# Summary of the MDI mini-workshop

**The aim of this mini-workshop is to invite experts of MDI from very different colliders to exchange and share their experiences and knowledge with many common interests, and to promote collaborations among them. 16 - 17 January 2020.**

T. Tauchi (KEK)

CEPC MDI workshop, IHEP, Beijing, 28-29 May 2020
The HEP conference, HKUST IAS, Hong Kong, 20 January 2020

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
HKUST JOCKEY CLUB INSTITUTE FOR ADVANCED STUDY

IAS PROGRAM

# High Energy Physics

January 6-24, 2020

## Mini-Workshop: Accelerator - Machine Detector Interface for Future Colliders (Jan 16-17, 2020)

# Agenda on 16 January 2020

**Opening Remarks** by Jie Gao 高 杰 (IHEP)

Talks with 25min + 5min Q/As

**Introduction :** Overview of Different Colliders, Jie Gao 高 杰 (IHEP)

**SuperKEKB :**

Background Status and Study at Belle II, SuperKEKB, Carsten Niebuhr (DESY)

Status of the Superconducting Final Focus Magnet at SuperKEKB, Norihito Ohuchi 大内 徳人 (KEK)

Stability of the final focus magnets at SuperKEKB, Hiroshi Yamaoka 山岡 広 (KEK)

**LEP - FCCee/CEPC :**

Lessons Learned from LEP and their Application to FCC/CEPC, Helmut Burkhardt (CERN)

**CEPC :**

CEPC MDI Accelerator Issues, Sha Bai 白莎 (IHEP)

CEPC RADIATION BACKGROUND STUDIES, Hongbo Zhu 朱 宏博 (IHEP)

CEPC MDI SC Magnet System, Yingshun Zhu et al. 朱应顺 (IHEP)

CEPC MDI Mechanics Issues, Haijing Wang 王 海靜 (IHEP)

CEPC MDI Detector Issues - In engineering design, Ji Quan 紀 全 (IHEP)

CEPC Detector Overall Facilities and Hall Issues, Zhu Zian 朱 自安 (IHEP)

# Agenda on 17 January 2020

**Circular Colliders :**

MDI issues of **BINP Super TauCharm factory**, Anton Bogomyagkov (BINP)

Overview of MDI at **FCC-ee**, Michael Koratzinos (CERN)

**ILC :**

(Selected) MDI Issues of ILD, Roman Pöschl (IJClab)

ILD Background Studies at ILC, Daniel Jeans (KEK)

The SiD Detector - Machine Backgrounds, Marcel Stanitzki (DESY)

**ILC and Future Colliders :**

Superconducting Final Focus Magnets at ILC and Future Colliders, Brett Parker (BNL)

**CLIC ( ILC, FCC ) :**

CLIC Machine Detector Interface, Philip Burrows (Oxford Univ.) , Lau Gatignon (CERN)

Stabilisation of Final Focus Magnets for CLIC and FCC, Maurizio Serluca, Laurent Brunetti (LAPP)

IP Fast Feedback Systems (FONT) at ILC and CLIC, Philip Burrows (Oxford Univ.)

**Discussion on possible future collaboration :**

All

# **Overview of Different Colliders, Jie Gao 高 杰 (IHEP)**

Review of some accelerator theories for colliders

Expressions of luminosity for circular and linear colliders

CC : the maximum beam beam tune shift $\xi_y$ and the dynamic apertures

LC : $N_{\mathrm{had}},\ n_{\gamma},\ \sigma_{\gamma\gamma\to\mathrm{had}}$

Historical review of e+e- circular coliders

The original idea by Rolf Wideöe in 1943

The first colliders : VEP-1 ($e^-e^-$) in 1963 (Novosibisk), AdA ($e^+e^-$) in 1963 (Orsay)

Higher energy and higher luminosity colliders in future, CEPC@China, FCCee@CERN

Historical review of e+e- linear colliders

The original idea by Maury Tigner in 1965

The first collider : SLC in 1989, born at the ICFA seminar, Fermilab, October 1978

TeV colliders in future, ILC@Japan (LCC/ICFA), CLIC@CERN

Historical review of hadron hadron circular colliders

The first colliders : ISR (pp) at CERN, 1970-1983, SPS ( $\bar{\mathrm{p}}\mathrm{p}$) at CERN, 1981-1990

Future colliders : SPPC@China, FCC@CERN

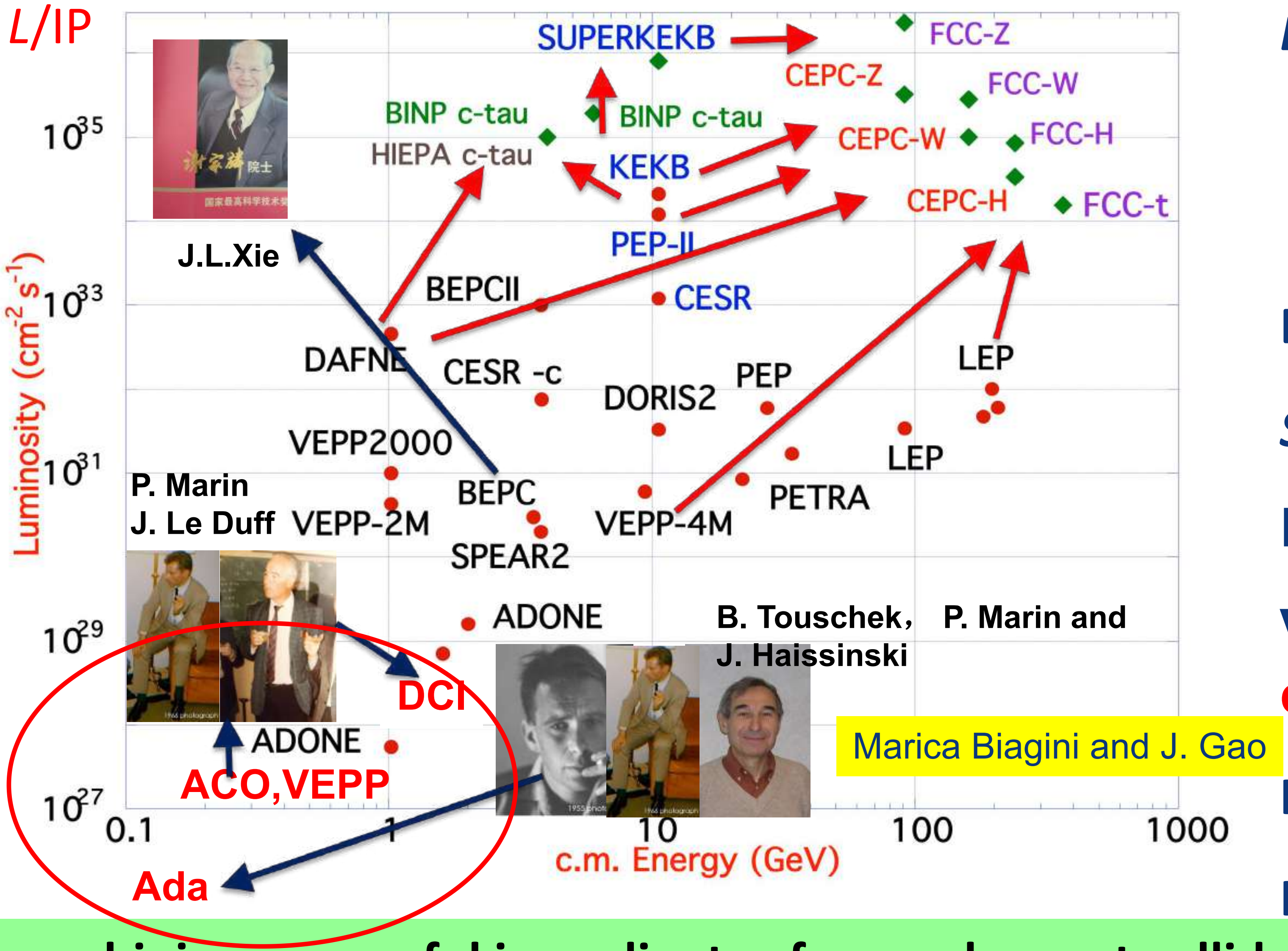
Historical review of electron proton circular colliders

The first collider : HERA at DESY for 1991-2007

DOE approved EIC at BNL (CD0) in Jan. 2020

References are appended

# Future circular lepton factories based on proven concepts and techniques from past colliders and light sources



***B-factories:*** **KEKB & PEP-II:**
double-ring lepton colliders,
high beam currents,
top-up injection

**DAFNE:** crab waist, double ring

***Super B-factories,*** **S-KEKB:** low $\beta_y$*

**LEP:** high energy, **SR effects**

**VEPP-4M, LEP:** precision E calibration

**KEKB:** *e*$^+$ source

**HERA, LEP, RHIC: spin gymnastics**

**combining successful ingredients of several recent colliders → highest luminosities & energies**

# CEPC CDR  Parameters

| | *Higgs* | *W* | *Z*（*3T*） | *Z*（*2T*） |
|---|---|---|---|---|
| Number of IPs | 2 | | | |
| Beam energy (GeV) | **120** | **80** | **45.5** | |
| Circumference (km) | 100 | | | |
| Synchrotron radiation loss/turn (GeV) | 1.73 | 0.34 | 0.036 | |
| Crossing angle at IP (mrad) | 16.5×2 | | | |
| Piwinski angle | 2.58 | 7.0 | 23.8 | |
| Number of particles/bunch $N_e$ ($10^{10}$) | 15.0 | 12.0 | 8.0 | |
| **Bunch number (bunch spacing)** | **242 (0.68μs)** | **1524 (0.21μs)** | **12000 (25ns+10%gap)** | |
| Beam current (mA) | 17.4 | 87.9 | 461.0 | |
| **Synchrotron radiation power /beam (MW)** | **30** | **30** | **16.5** | |
| Bending radius (km) | 10.7 | | | |
| Momentum compact ($10^{-5}$) | 1.11 | | | |
| **β function at IP $\beta_x^* / \beta_y^*$ (m)** | **0.36/0.0015** | **0.36/0.0015** | **0.2/0.0015** | **0.2/0.001** |
| Emittance $\varepsilon_x/\varepsilon_y$ (nm) | 1.21/0.0031 | 0.54/0.0016 | 0.18/0.004 | 0.18/0.0016 |
| Beam size at IP $\sigma_x/\sigma_y$ (μm) | 20.9/0.068 | 13.9/0.049 | 6.0/0.078 | 6.0/0.04 |
| Beam-beam parameters $\xi_x/\xi_y$ | 0.031/0.109 | 0.013/0.106 | 0.0041/0.056 | 0.0041/0.072 |
| RF voltage $V_{RF}$ (GV) | 2.17 | 0.47 | 0.10 | |
| RF frequency $f_{RF}$ (MHz)  (harmonic) | 650 (216816) | | | |
| Natural bunch length $\sigma_z$ (mm) | 2.72 | 2.98 | 2.42 | |
| Bunch length $\sigma_z$ (mm) | 3.26 | 5.9 | 8.5 | |
| HOM power/cavity (2 cell) (kw) | 0.54 | 0.75 | **1.94** | |
| Natural energy spread (%) | 0.1 | 0.066 | 0.038 | |
| Energy acceptance requirement (%) | **1.35** | **0.4** | **0.23** | |
| Energy acceptance by RF (%) | 2.06 | 1.47 | 1.7 | |
| Photon number due to beamstrahlung | 0.1 | 0.05 | 0.023 | |
| Lifetime _simulation (min) | 100 | | | |
| Lifetime (hour) | **0.67** | **1.4** | **4.0** | **2.1** |
| *F* (hour glass) | 0.89 | 0.94 | 0.99 | |
| **Luminosity/IP $L$ ($10^{34}$cm$^{-2}$s$^{-1}$)** | **2.93** | **10.1** | **16.6** | **32.1** |

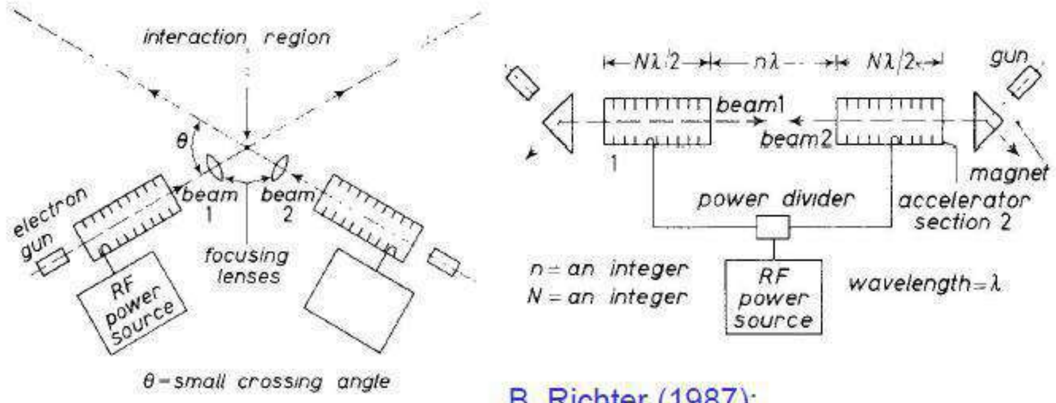
SInce 2013 Jan

# FCC-ee collider parameters

| parameter | Z | WW | H (ZH) | ttbar |
|---|---|---|---|---|
| beam energy [GeV] | 45 | 80 | 120 | 182.5 |
| beam current [mA] | 1390 | 147 | 29 | 5.4 |
| no. bunches/beam | 16640 | 2000 | 393 | 48 |
| bunch intensity [$10^{11}$] | 1.7 | 1.5 | 1.5 | 2.3 |
| SR energy loss / turn [GeV] | 0.036 | 0.34 | 1.72 | 9.21 |
| total RF voltage [GV] | 0.1 | 0.44 | 2.0 | 10.9 |
| long. damping time [turns] | 1281 | 235 | 70 | 20 |
| horizontal beta* [m] | 0.15 | 0.2 | 0.3 | 1 |
| vertical beta* [mm] | 0.8 | 1 | 1 | 1.6 |
| horiz. geometric emittance [nm] | 0.27 | 0.28 | 0.63 | 1.46 |
| vert. geom. emittance [pm] | 1.0 | 1.7 | 1.3 | 2.9 |
| bunch length with SR / BS [mm] | 3.5 / 12.1 | 3.0 / 6.0 | 3.3 / 5.3 | 2.0 / 2.5 |
| luminosity per IP [$10^{34}$ $cm^{-2}s^{-1}$] | 230 | 28 | 8.5 | 1.55 |
| beam lifetime rad Bhabha / BS [min] | 68 / >200 | 49 / >1000 | 38 / 18 | 40 / 18 |

**Valery TELNOV, “Linear colliders: history”, Budker INP, Novosibirsk**
**IHEP Seminar, Beijing, December 6, 2018, invited by Prof. Jie Gao**

M. Tigner, ``A possible apparatus for electron clashing-beam experiments,''
Nuovo Cim. 37, 1228 (1965).



M.Tigner (1965):

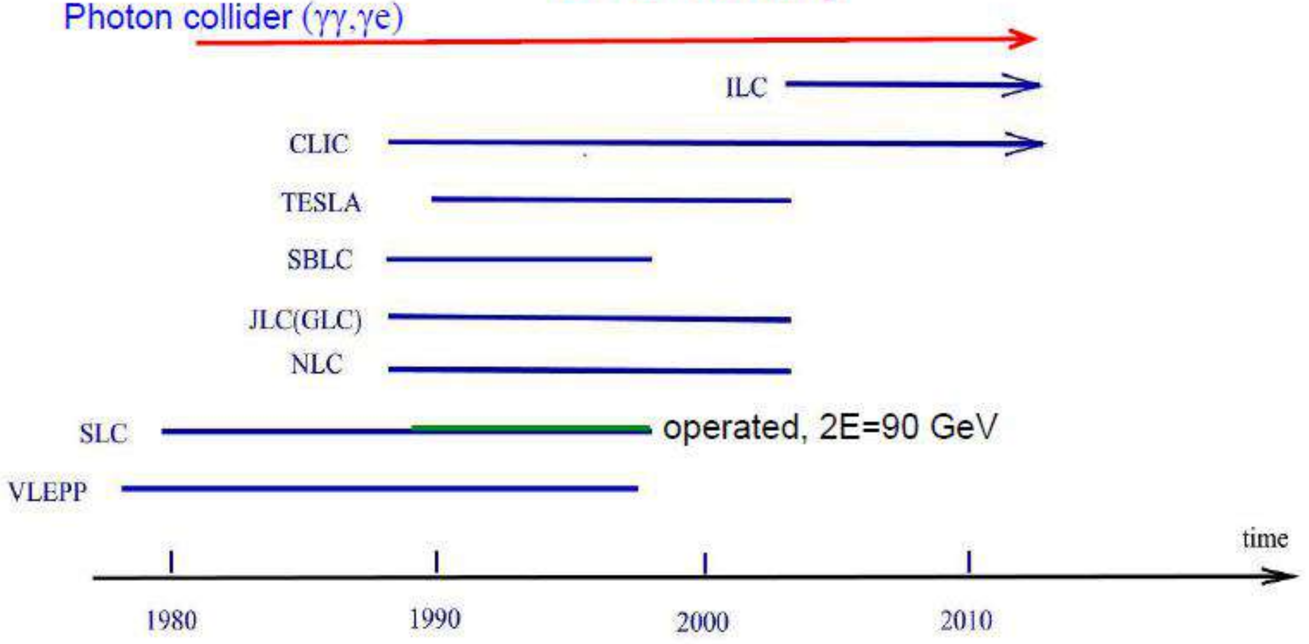
While the storage ring technique for performing clashing-beam experiments (1) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant or superficially more complex may prove more tractable.

B. Richter (1987):
In this paper, Tigner talks about a system using colliding linac beams as an alternative to storage rings for studying electron-electron collisions. He talks about the benefits of superconductivity and how to lower the operating power by using energy recovery. He lists the luminosity requirements for low energy machines in the few GeV energy range.

This paper did not attract attention, there were no citations until 1979, when U.Amaldi discovered this paper

## Linear e+e- colliders

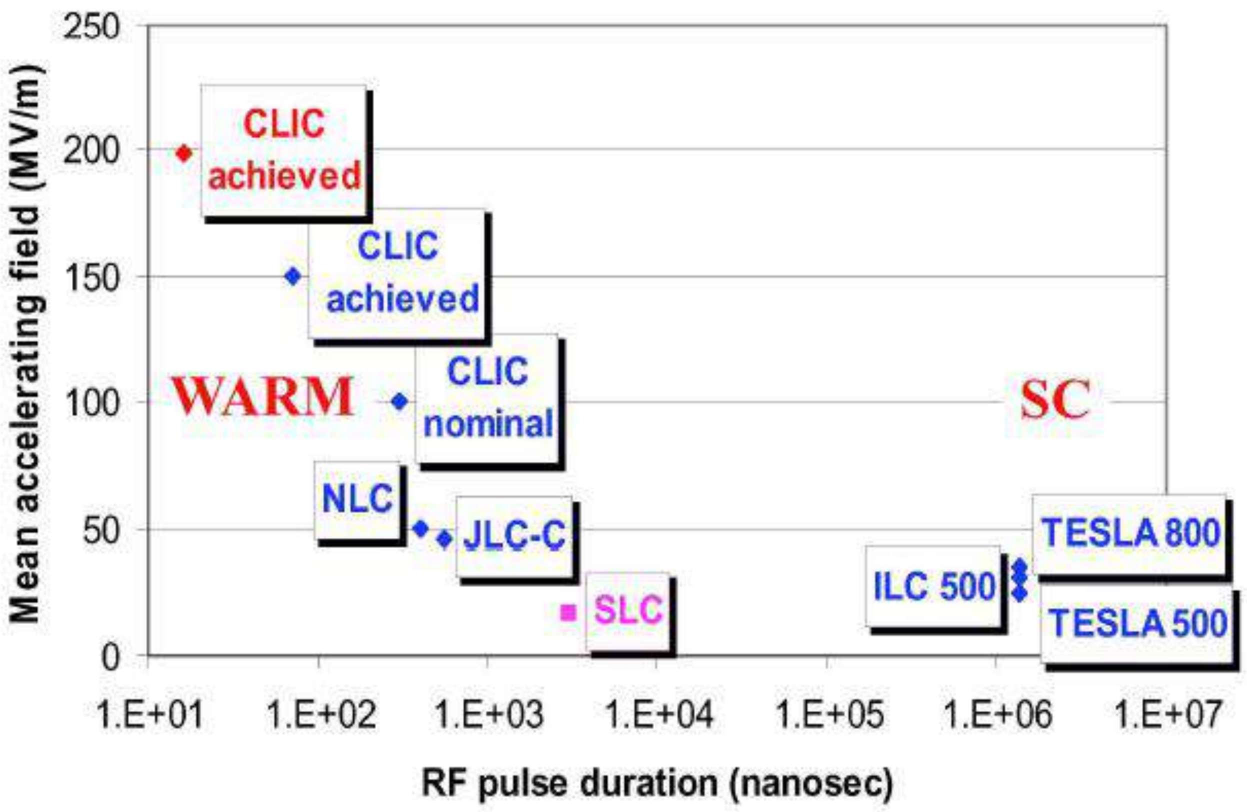
### Brief history



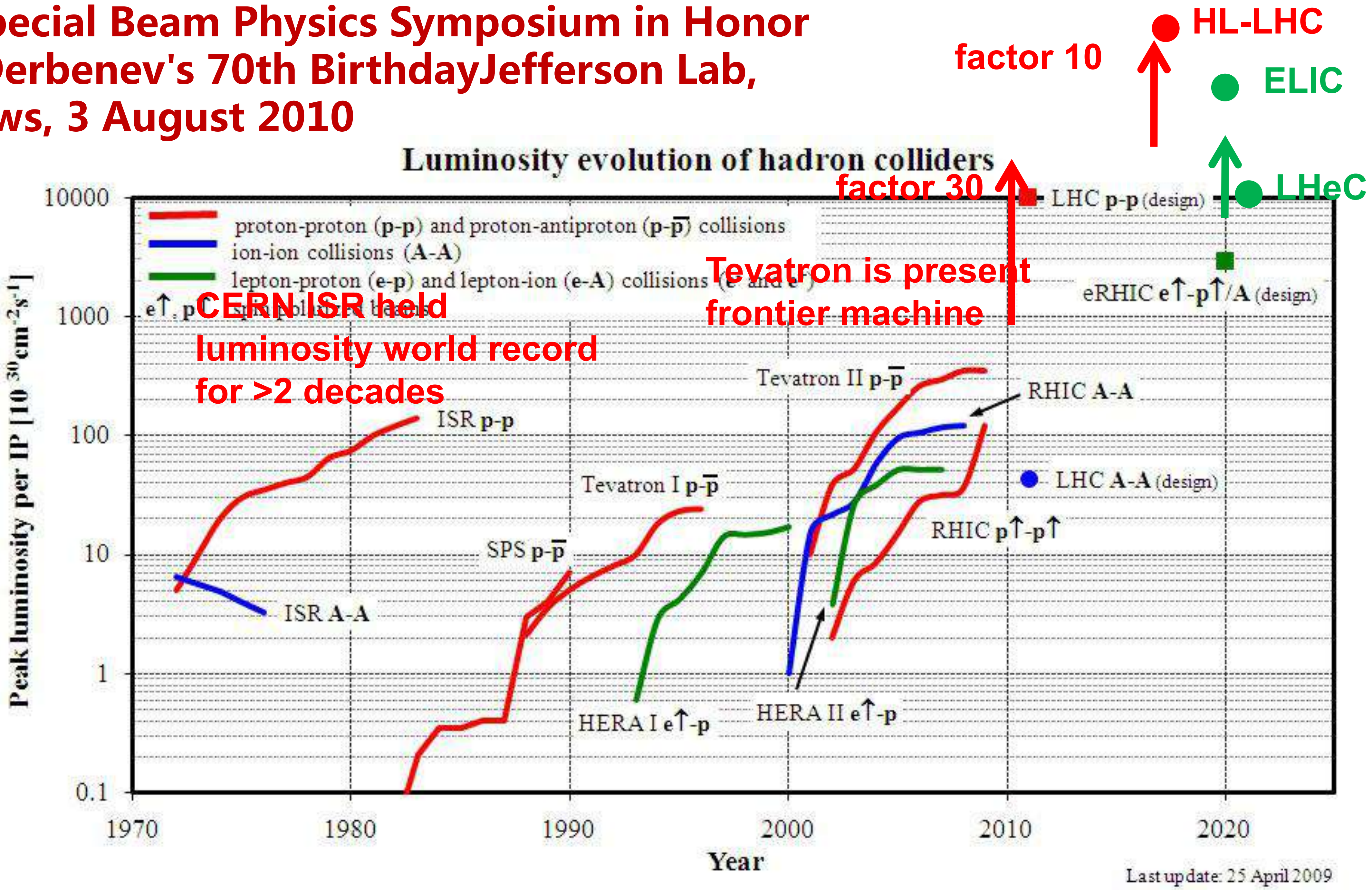
# ILC and CLIC parameters

upgrage to (3-4)1
is foreseen

| | unit | ILC | | | CLIC | | |
|---|---|---|---|---|---|---|---|
| $2E_0$ | GeV | 250 | 500 | 1000 | 250 | 500 | 3000 |
| $L_{\mathrm{tot}}$ | $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 0.75 | 1.8 | 4.9 | 1.37 | 2.3 | 5.9 |
| $L_{\mathrm{geom}}$ | $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 0.37 | 0.75 | 2.61 | 0.82 | 1.42 | 4.29 |
| No. Higgs/yr($10^7$s) | 1000 | 23 | 49 | – | 34 | 44 | 446 |
| Length | km | 21 | 31 | 48 | 13.2 | 13.2 | 48.3 |
| $P$ (wall) | MW | 128 | 162 | 301 | 225 | 272 | 589 |
| Pol. $e^-$/Pol. $e^+$ | % | 80/30 | 80/30 | 80/30 | 80/0 | 80/0 | 80/0 |
| Accel. gradient | MV/m | 31.5 | 31.5 | 31.5/45 | 40 | 80 | 100 |
| $N$ per bunch | $10^{10}$ | 2 | 2 | 1.74 | 0.34 | 0.68 | 0.372 |
| Bunches per pulse | | 1312 | 1312 | 2450 | 842 | 354 | 312 |
| Bunch distance | ns | 554 | 554 | 366 | 0.5 | 0.5 | 0.5 |
| Rep. rate | Hz | 5 | 5 | 4 | 50 | 50 | 50 |
| Norm. emit. $\varepsilon_{x,n}$ | mm-mrad | 10 | 10 | 10 | 0.66 | 2.4 | 0.66 |
| Norm. emit. $\varepsilon_{y,n}$ | mm-mrad | 0.035 | 0.035 | 0.03 | 0.025 | 0.025 | 0.02 |
| $\beta_x$ at IP | mm | 13 | 11 | 11 | 8 | 8 | 4 |
| $\beta_y$ at IP | mm | 0.41 | 0.48 | 0.23 | 0.1 | 0.1 | 0.07 |
| $\sigma_x$ at IP | nm | 729 | 474 | 335 | 150 | 200 | 40 |
| $\sigma_y$ at IP | nm | 7.66 | 5.9 | 2.7 | 3.2 | 2.3 | 1 |
| $\sigma_z$ at IP | mm | 0.3 | 0.3 | 0.225 | 0.072 | 0.072 | 0.044 |
| Ener. loss. $\delta E/E$ | % | 0.95 | 4.5 | 10.5 | 1.5 | 7 | 28 |


Accelerating fields in Linear Colliders

**Frank Zimmermann, “Hadron and Hadron-Lepton Colliders” Special Beam Physics Symposium in Honor of Yaroslav Derbenev's 70th BirthdayJefferson Lab, Newport News, 3 August 2010**



CERN ISR held luminosity world record for >2 decades

Tevatron is present frontier machine

Courtesy W. Fischer

# FCC-hh and SppC collider parameters

| parameter | FCC-hh | | SppC | HL-LHC | LHC |
|---|---|---|---|---|---|
| collision energy cms [TeV] | 100 | | 75 | 14 | 14 |
| dipole field [T] | 16 | | 12 | 8.33 | 8.33 |
| circumference [km] | 97.75 | | 100 | 26.7 | 26.7 |
| beam current [A] | 0.5 | | 0.73 | 1.1 | 0.58 |
| bunch intensity [$10^{11}$] | 1 | 1 | 1.5 | 2.2 | 1.15 |
| bunch spacing [ns] | 25 | 25 | 25 | 25 | 25 |
| synchr. rad. power / ring [kW] | 2400 | | 1100 | 7.3 | 3.6 |
| SR power / length [W/m/ap.] | 28.4 | | 12.8 | 0.33 | 0.17 |
| long. emit. damping time [h] | 0.54 | | 1.17 | 12.9 | 12.9 |
| beta* [m] | 1.1 | 0.3 | 0.75 | 0.15 (min.) | 0.55 |
| normalized emittance [μm] | 2.2 | | 2.4 | 2.5 | 3.75 |
| peak luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] | 5 | 30 | 10 | 5 (lev.) | 1 |
| events/bunch crossing | 170 | 1000 | ~300 | 132 | 27 |
| stored energy/beam [GJ] | 8.4 | | 9.1 | 0.7 | 0.36 |

# Future hadron-lepton colliders

| Parameters | ENC | ELIC | eRHIC | LHeC | |
|---|---|---|---|---|---|
| option | RR | RR | LR | RR | LR |
| P-A/e- energy [GeV] | 15/3.3 | 60/3 | 325/20 | 7000/60 | 7000/60 |
| √(s) [GeV] | 14 | 27 | 160-102 | 1296 | 1296 |
| luminosity [$10^{32}$ $cm^{-2}s^{-1}$] | 2 | 400 | 140 | 17 | 10 |
| P/e- polarization [%] | 80/80 | | 70/80 | /40 | /90 |
| P/e- bunch popul. [$10^9$] | 5.4/23 | 11/60 | 200/24 | 170/26 | 170/2.0 |
| P/e- bunch length [mm] | 0.3/0.1 | 5 | 49/20 | /10 | /0.3 |
| P/e- bunch interval [ns] | 19 | | 74 | 25-50 | 25-50 |
| P/e- tr. emit. $\gamma\varepsilon_{x,y}$ [μm] | | 0.8/75 | 1200/25000 | 3.75/580,290 | 3.75/50 |
| IP beam size $\sigma_{x,y}$ [μm] | | | | 30, 16 | 7 |
| full crossing angle [mrad] | | | | 0.93 | 0 |
| geometric reduction $H_{hg}$ | | | | 0.77 | 0.91 |
| Energy Recovery efficien. | - | - | 94? | - | 94% |
| average current [mA] | | 860/4800 | 420/50 | 131 | 6.6 |
| tot. wall plug power[MW] | | | | 100 | 100 |

J.-P. Delahaye, ICHEP'10

# Background Status and Study at Belle II, SuperKEKB, Carsten Niebuhr (DESY)

SuperKEKB / Belle II Commissioning since 2016

Phase 1 in 2016 w/o QCS, Belle II, Phase 2 in 2018 w/ QCS, BEAST II (background) w/o VTX

Phase 3 since 2019, Physics run w/ VTX , the peak luminosity of 1.88 x $10^{34}$ (design 8 x$10^{35}$ ) $cm^{-2}s^{-1}$

Major backgrounds

Single beam : “off-momentum acceptance” particles by internal scatterings in a bunch (**Touschek**, $T \cdot \frac{I_{\pm}^2}{n_b \sigma_y}$ ), **beam gas** ( $B \cdot I_{\pm} p Z_{eff}^2$ ), synchrotron radiation and injection background (2x 25Hz)

Beam-beam : radiative Bhabha and two photon process

In May 2019, dominant background source from LER beam-gas ( 5 times more than the HER)
Data/MC ratio : O(1) for LER Touschek, O(10) for Beam-gas and
$>10^3$ for HER Touschek due to (too) small MC estimate

**Collimators** protect QCS and Belle II against background bursts and mitigate Touschek/Beam-gas background

Horizontal and vertical ones for Touschek and the beam gas backgrouds, respectively.

Especially, LER vertical collimators are essential.

Mitigation of the damage : from tungsten to carbon head to reduce the deposite energy in the collimator

**IP Beam pipe :** Ta (Cu plated, water cool) - Be (Au plate, $1mm^t$ paraffin cool) - Ta (Cu plate, water cool)

**Beam background has major impact on further progress of SuperKEKB performance**

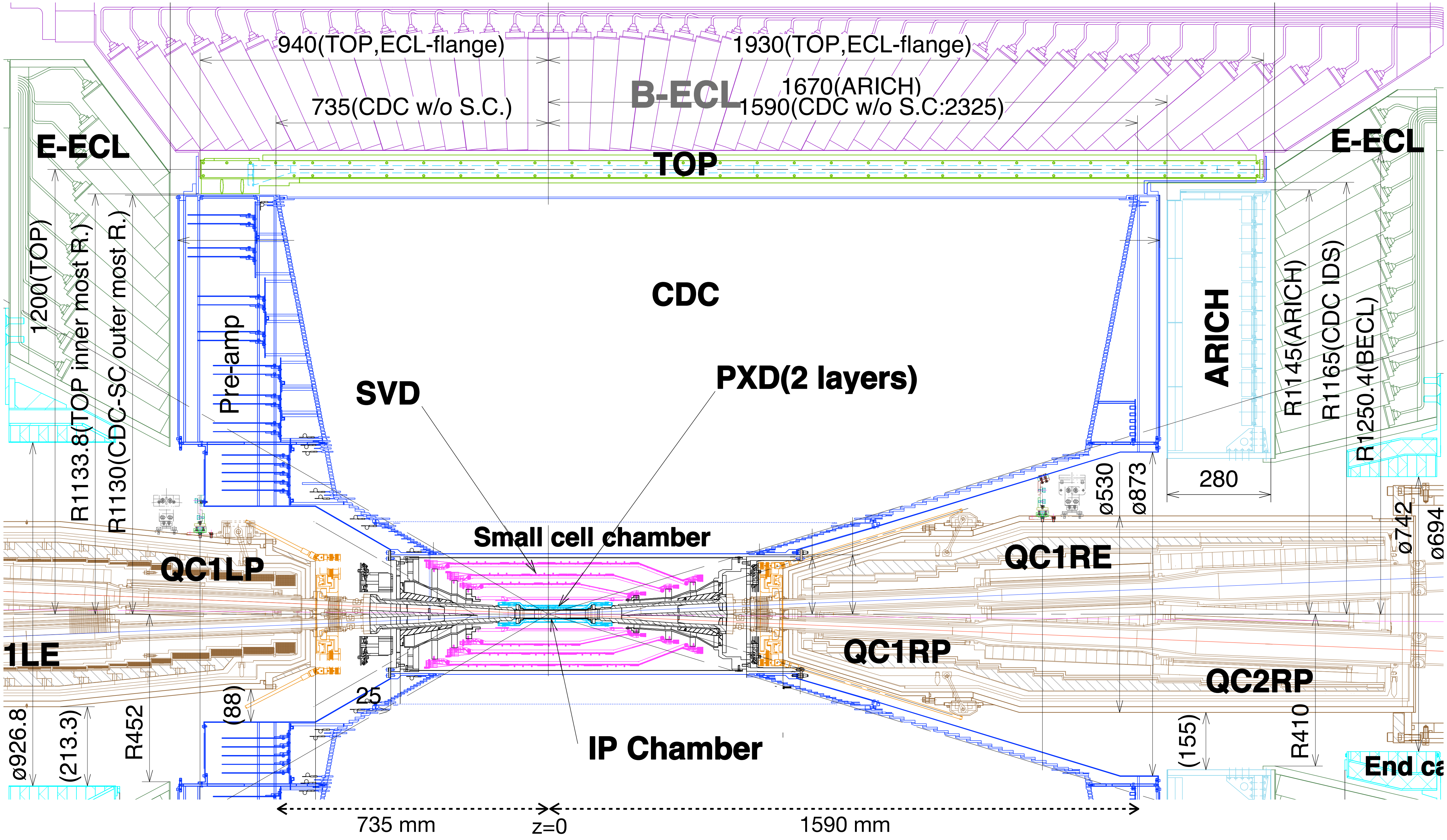
Background conditions strongly depend on optics parameters and vacuum level in the ring

**At future optics with smaller $\beta^*_y$, collimator optimization will get even more difficult**

$\beta^*_y$ =1mm (present) to 0.3mm (design)

Transverse mode coupling (TMC) instability, smaller equivalent width, etc.

# Belle II Subdetectors



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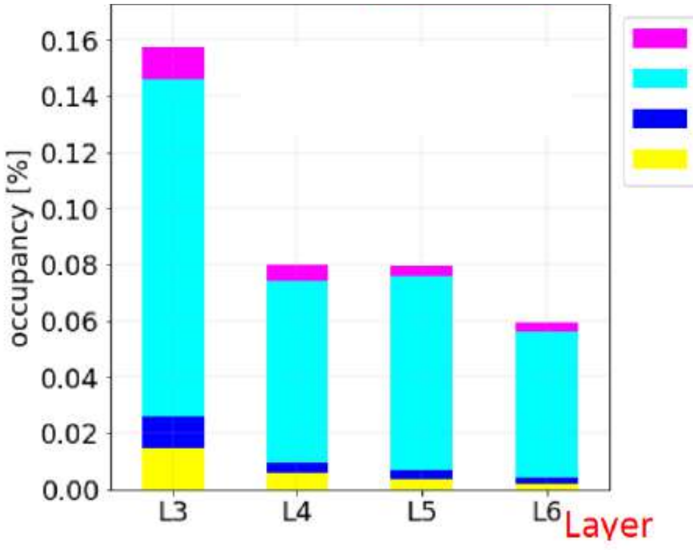
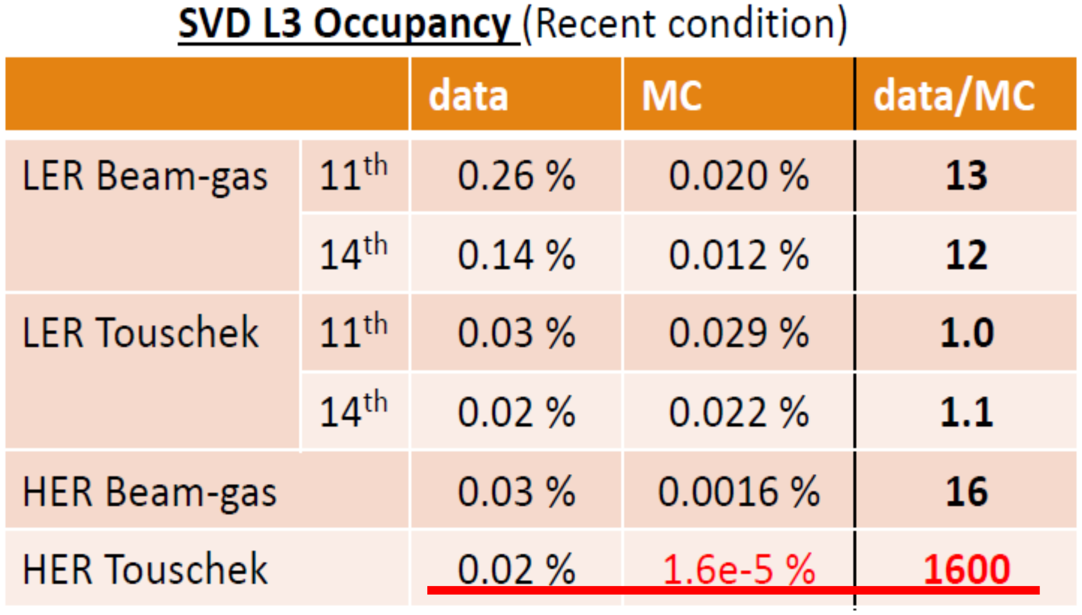
# Beam Background Situation in May

SVD

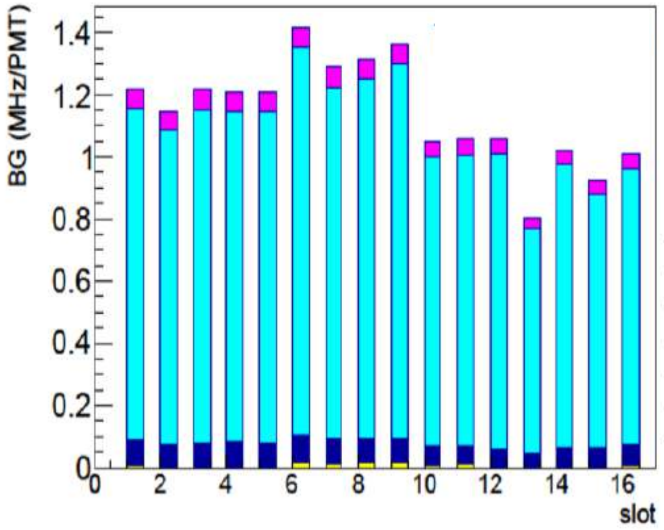




**SVD L3 Occupancy** (Recent condition)

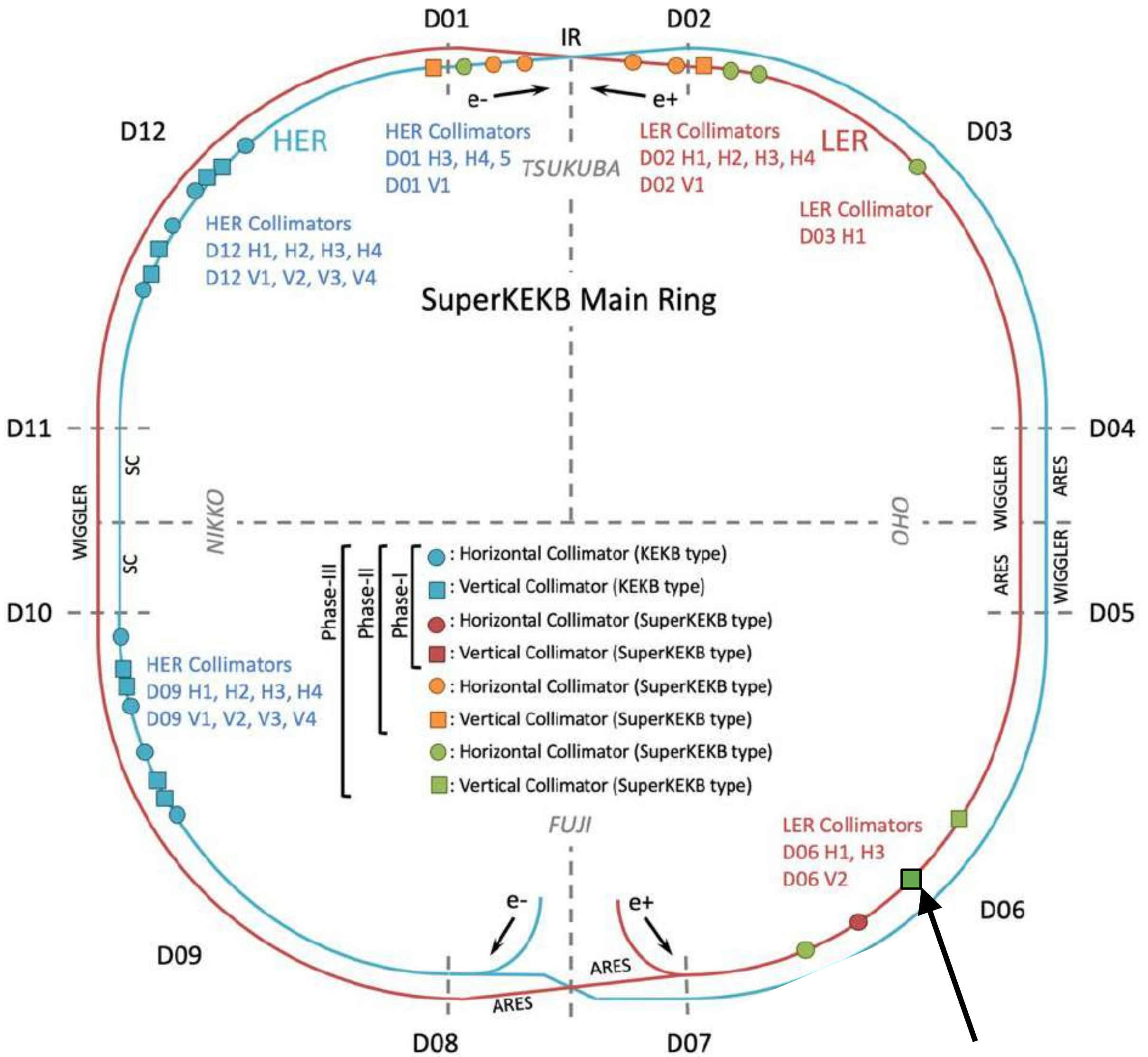
| | | **data** | **MC** | **data/MC** |
|---|---|---|---|---|
| LER Beam-gas | 11th | 0.26 % | 0.020 % | **13** |
| | 14th | 0.14 % | 0.012 % | **12** |
| LER Touschek | 11th | 0.03 % | 0.029 % | **1.0** |
| | 14th | 0.02 % | 0.022 % | **1.1** |
| HER Beam-gas | | 0.03 % | 0.0016 % | **16** |
| HER Touschek | | 0.02 % | 1.6e-5 % | **1600** |

TOP



- Although conditions change somewhat from day to day the general observations are:
  - LER storage background ≈ 5 x HER storage background
    - dominant background source from LER beam-gas
- Data/MC ratio
  - *O*(1) for LER Touschek, *O*(10) for Beam-gas
  - >$10^3$ for HER Touschek due to (too) small MC estimate

# SuperKEKB Collimators



New vertical collimator **D06V1** installed in winter shutdown: reduce loss rate at D02V1 & IP

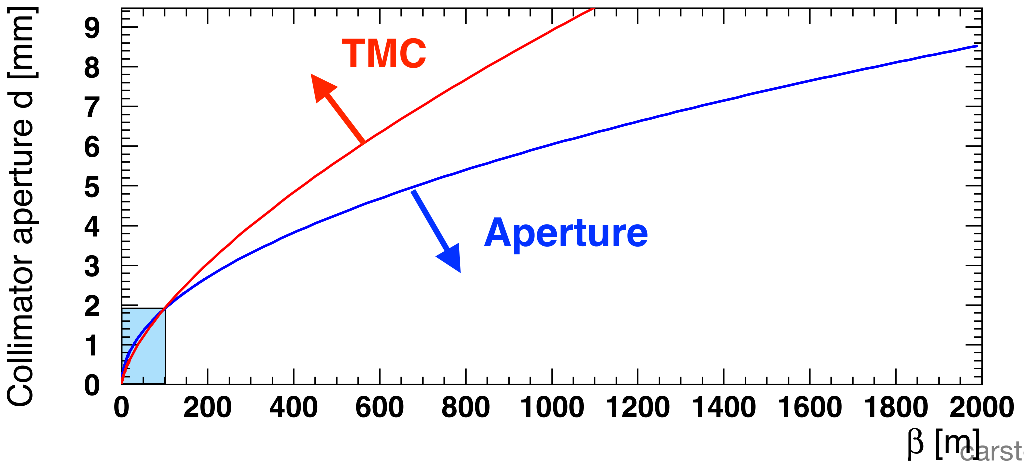
- Tasks
  - protect QCS and Belle II against background bursts
  - mitigate Touschek/Beam-gas background
- Horizontal collimators effectively reduce Touschek BG
- Vertical collimators are essential for reducing Coulomb BG
  - aperture should be narrower than QC1 aperture

$$d/\sqrt{\varepsilon\beta} < r_{QC1}/\sqrt{\varepsilon\beta_{QC1}} \Rightarrow d_{max} \propto \beta^{1/2}$$

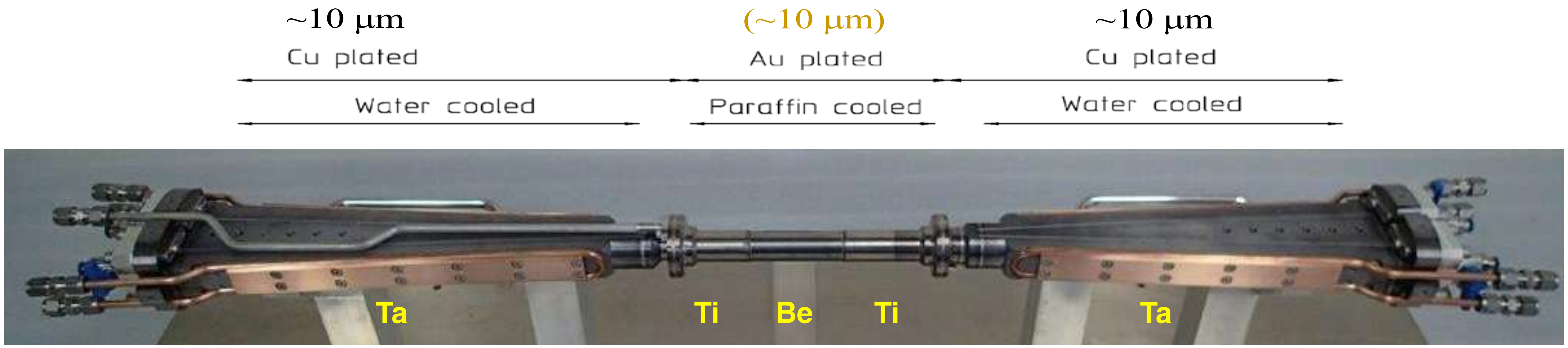
  - avoid Transverse Mode Coupling (TMC) instability

$$I_{thresh} \propto 1/k_{\perp} \text{ and } k_{\perp} \propto d^{-2/3} \Rightarrow d_{min} \propto \beta^{2/3}$$

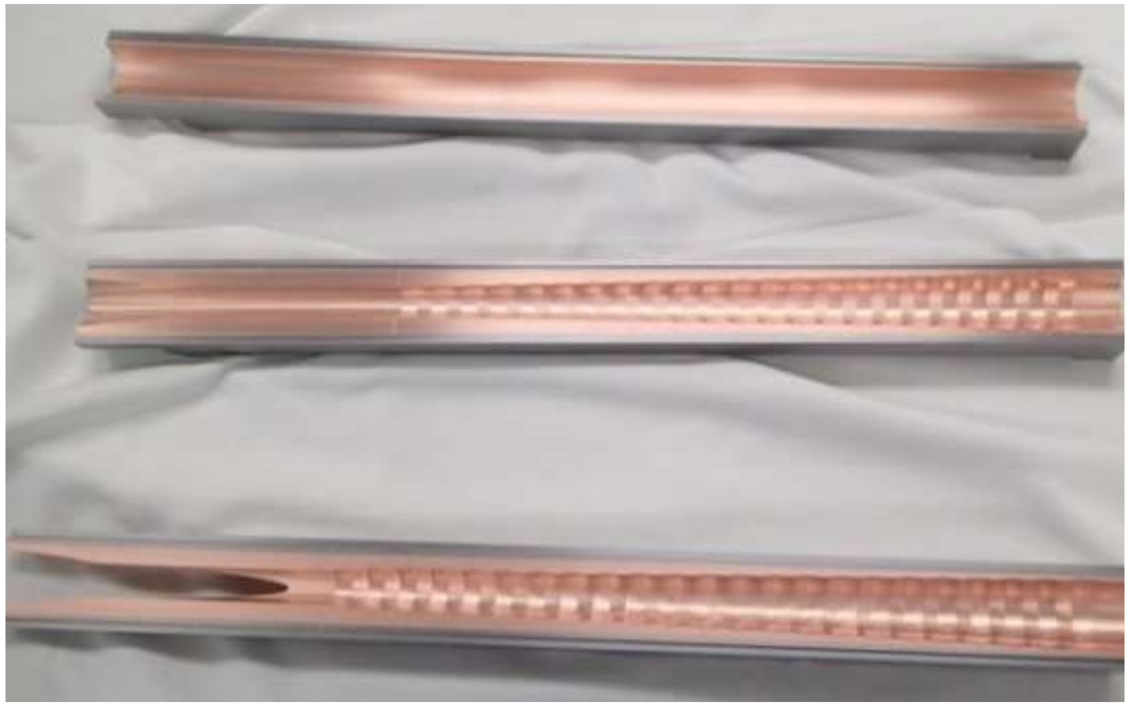
  - choose location where phase advance wrt QC1 is small
  - distribute loss rate budget over several collimators



# IR Beam Pipe Design



- Central part 20mm OD
  - Outer Be tube: 0.4 mm thick
  - Inner Be tube: 0.6 mm thick
  - Gap for paraffin: 1 mm
- Challenging connection technologies
  - Be-Ti brazing, Ti-Ta HIP, Ta-Ta EBW
- Crotch part (tantalum)
  - Only tapered parts exposed to direct synchrotron radiation from last bend
    - Taper: reduce the number of photons entering the central part
    - Ridges: keep the direction of scattered photons away from Be



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# Status of the Superconducting Final Focus Magnet at SuperKEKB,
# Norihito Ohuchi 大内 徳人 (KEK)

## Super KEKB Interaction region (IR) :

HER($e^-$ beam) QC2LE,QC1LE → QC1RE,QC2RE with the horizontal crossing angle of 83mrad

LER($e^+$ beam) QC2LP,QC1LP ← QC1RP,QC2RP

## IR superconducting magnets, 55 in total :

8 main quadrupoles, 35 correctors(direct winding@BNL), 4 compensatie solenoids, 8 leak field cancel coils

with different magnet types with “no”, permendur(50Fe-50Co) and iron yokes

## Operation of superconducting magnets in the Phase-2 and 3 commissioning :

$\beta^*_y$ =80 to 3mm in Phase-2, $\beta^*_y$ = 8 to 2mm in Phase-3(2019ab), $\beta^*_y$ = 2 to 1mm in Phase-3(2019c)

magnet quench events : 25 → 6 (3 by beams) → 3 (2 by beams)

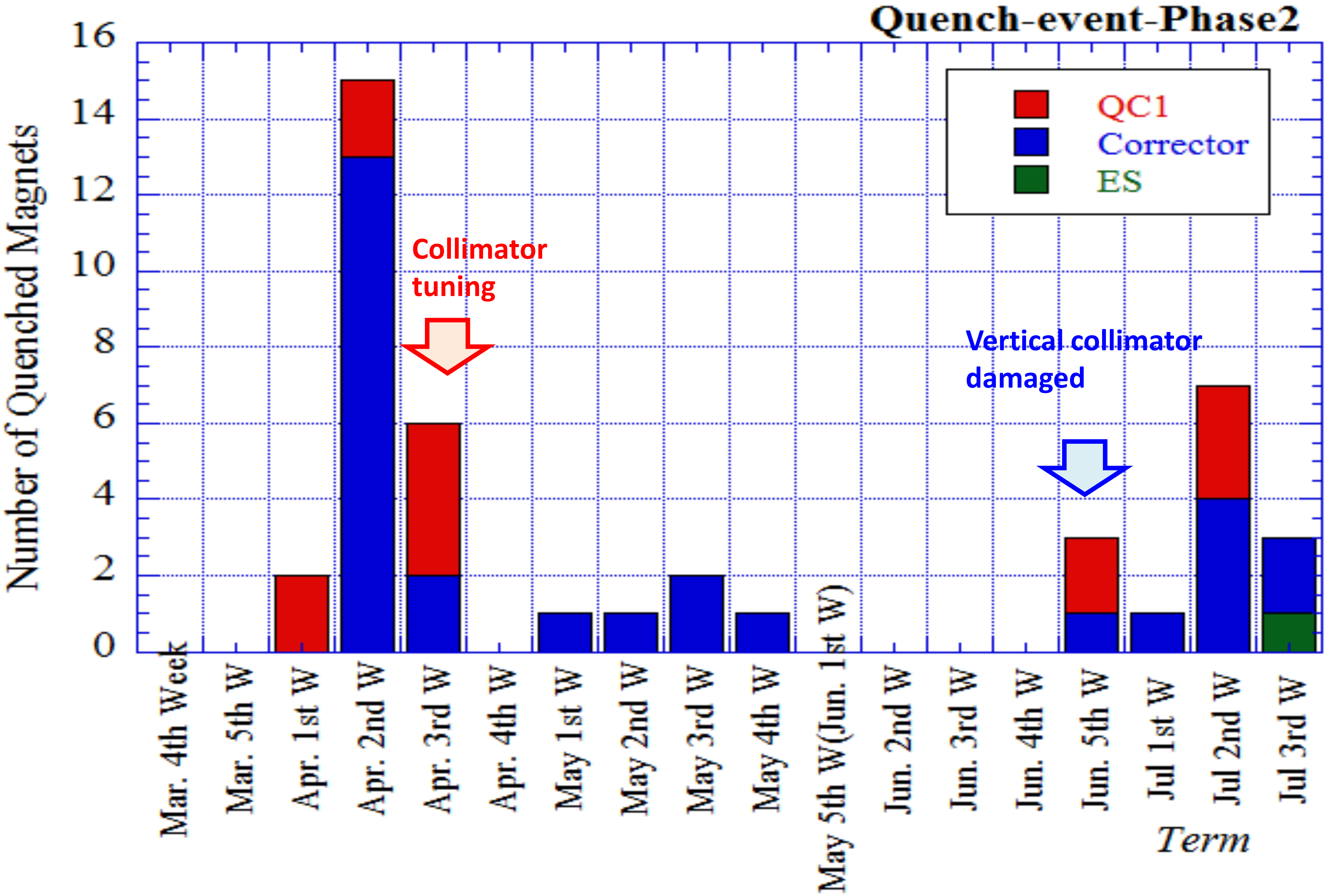
The quench of the superconducting magnets are reduced drastically.

**HER and LER beams were well controlled to the QCS superconducting magnets by the collimator and the beam abort system.** Also,the quench detector system and the quench monitoring system are improved.

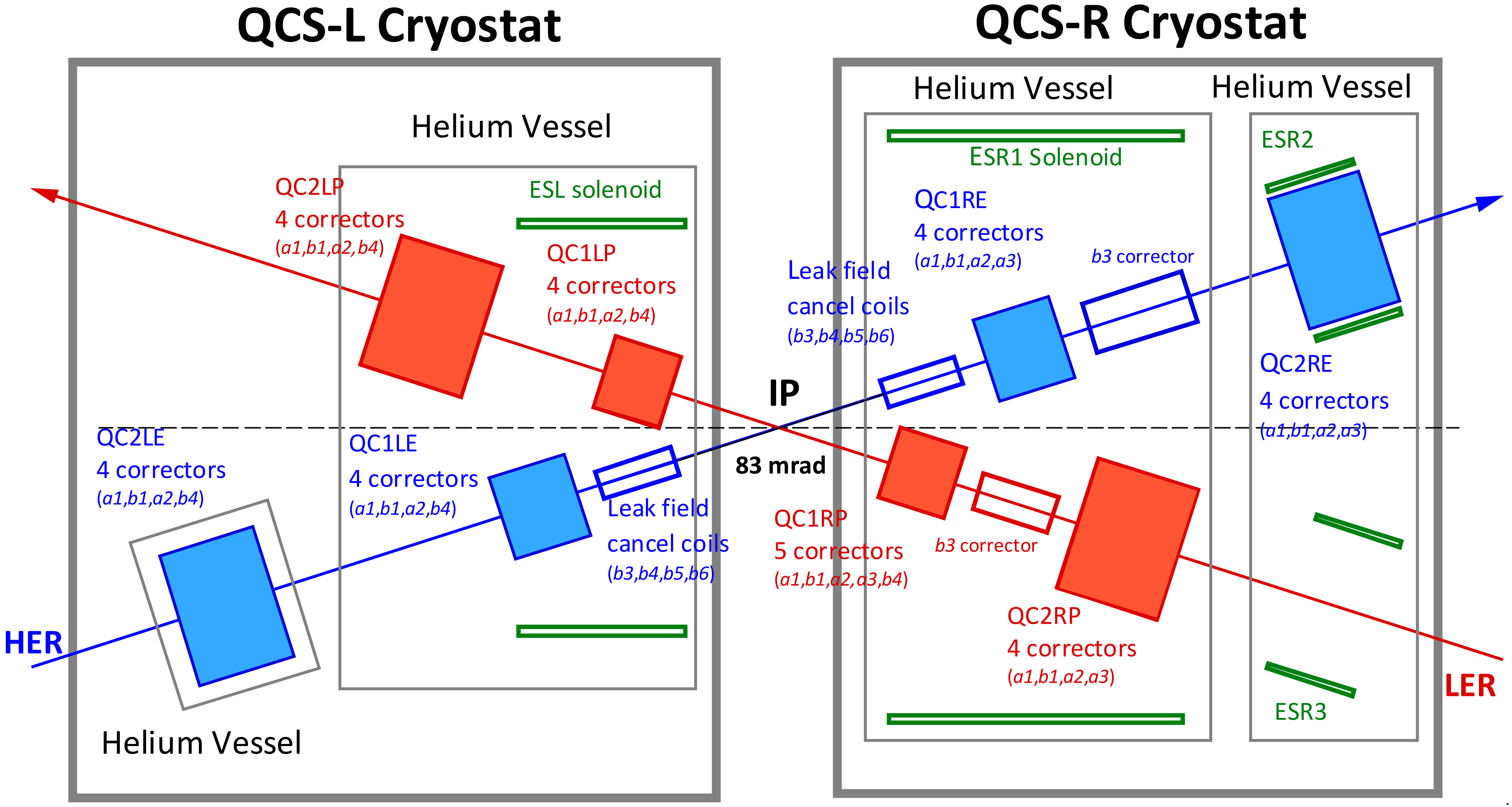
Brett’s comment :it is bad to have corrector coils inside the main coils and they should only be put on the outside where they would be better protected and/or one should consider using a conductor like Nb3Sn or HTS to gain more operating margin. …a thin (maybe 1 or 1.5 mm) layer of helium inside all the coils …

# QCS operation and quench in Phase-2

**Phase-2 (Mar. 16, 2018 ~ Jul. 17, 2018)**



# Configuration of IR magnets



## 25 SC magnets in QCSL

4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
16 SC correctors: a1, b1, a2, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
1 compensation solenoid

## 30 SC magnets in QCSR

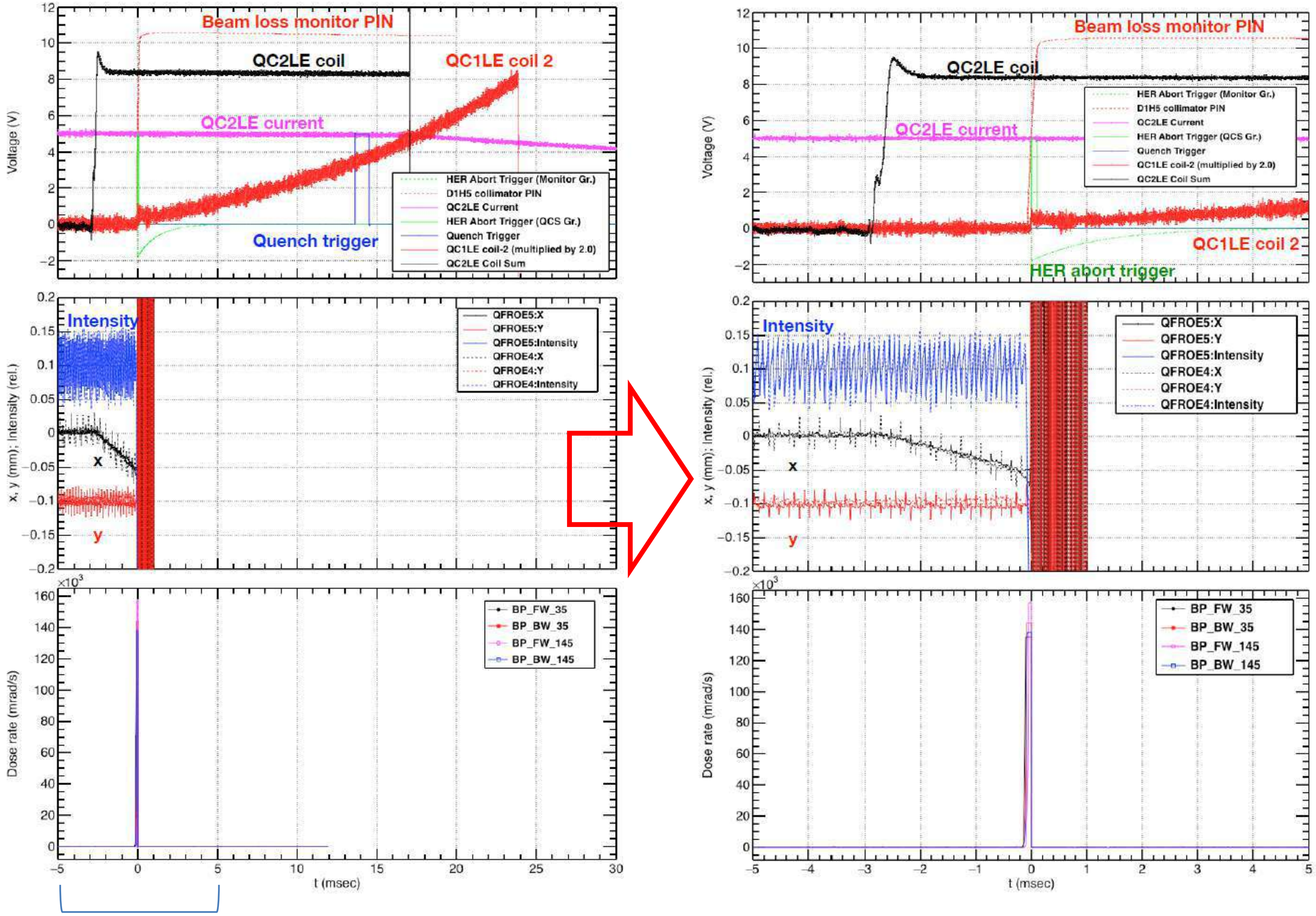
4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
19 SC correctors: a1, b1, a2, a3, b3, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
3 compensation solenoid

# QCS magnet quenches in Phase-3

QCS
&
Beam loss monitor

BPM (Libera)

Diamond detector



Expanded in the right plots

# Stability of the final focus magnets at SuperKEKB, Hiroshi Yamaoka 山岡 広 (KEK)

## To minimize vibration of the final focus magnets (QCS);

Design rigid structure → Increase resonant frequency

Apply high damping material (M2052), whose effect was estimated in the KEKB support system.

Apply active/passive isolation system

### Improvement of the QCS support system from KEKB to SuperKEKB

magnet boat/table → the moving stage on the precise flat floor by the self-leveling method
cantilever height 2.2m → 1.5m with epoxy resin
QCS weight 1.5t → 2.5t

### Development of the finite element modeling and the vibration analysis

maximum deformation 2mm → 0.4mm
resonant frequency (V) 14Hz → 29Hz (22Hz meas.) , (H) 20Hz → 35Hz (25Hz meas.)

### Measured results of the vertical vibration on the QCS cryostat

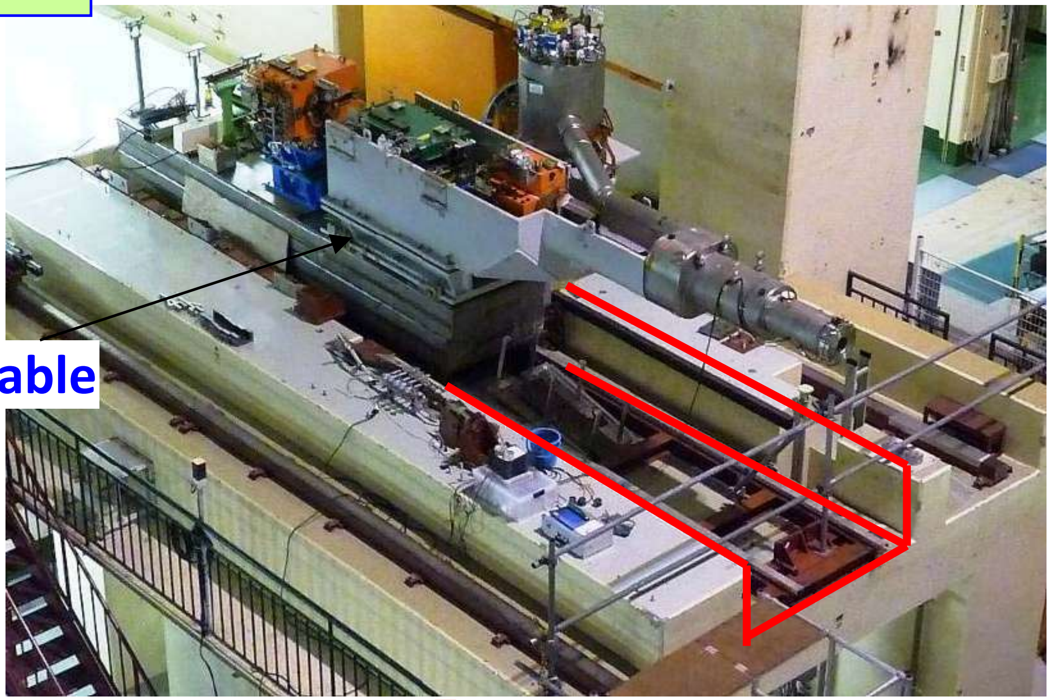
Integrated amplitude (f<10Hz) 300nm → 50nm ( 40nm calculated by the FEM)

### The FEM results of difference in the vertical vibrations between QC1RP and QC1RE

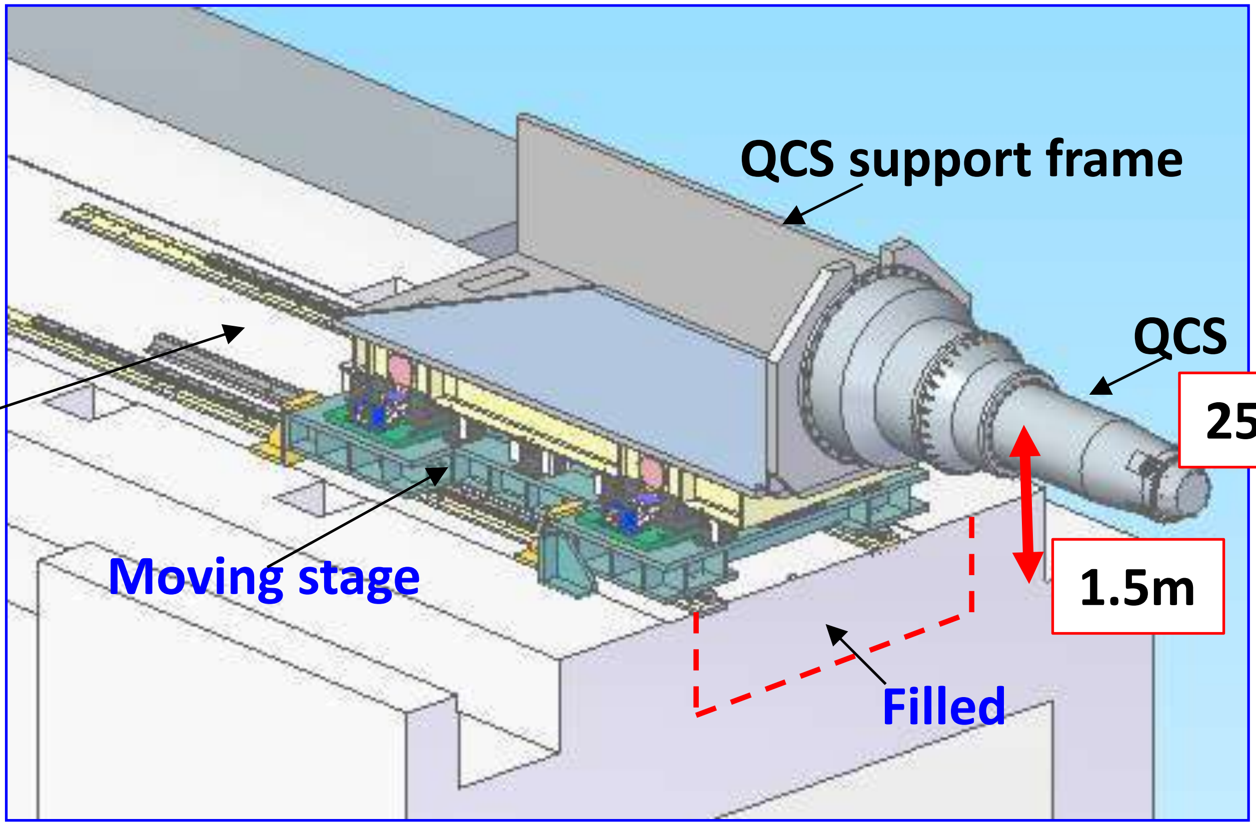
25nm@25Hz and 14nm@50Hz , these results show that the luminosity loss < 5% is expected.

**The QCS magnetic center vibrations** will be measured by a 2,500 turn pickup coil ( R&D of Japan-US collaboration).

## QCS support system for KEKB

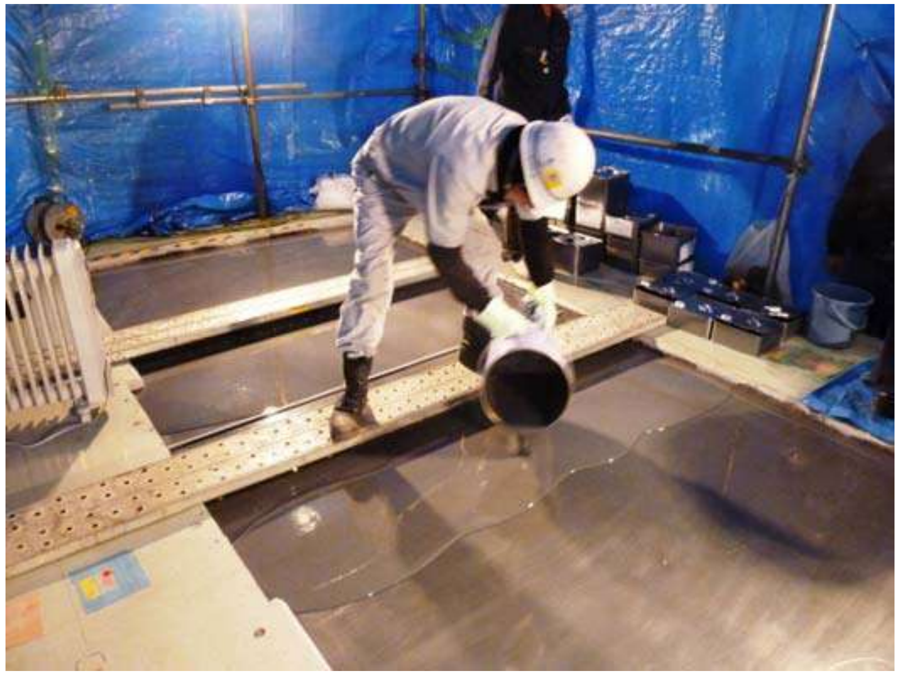


## QCS support system for SuperKEKB



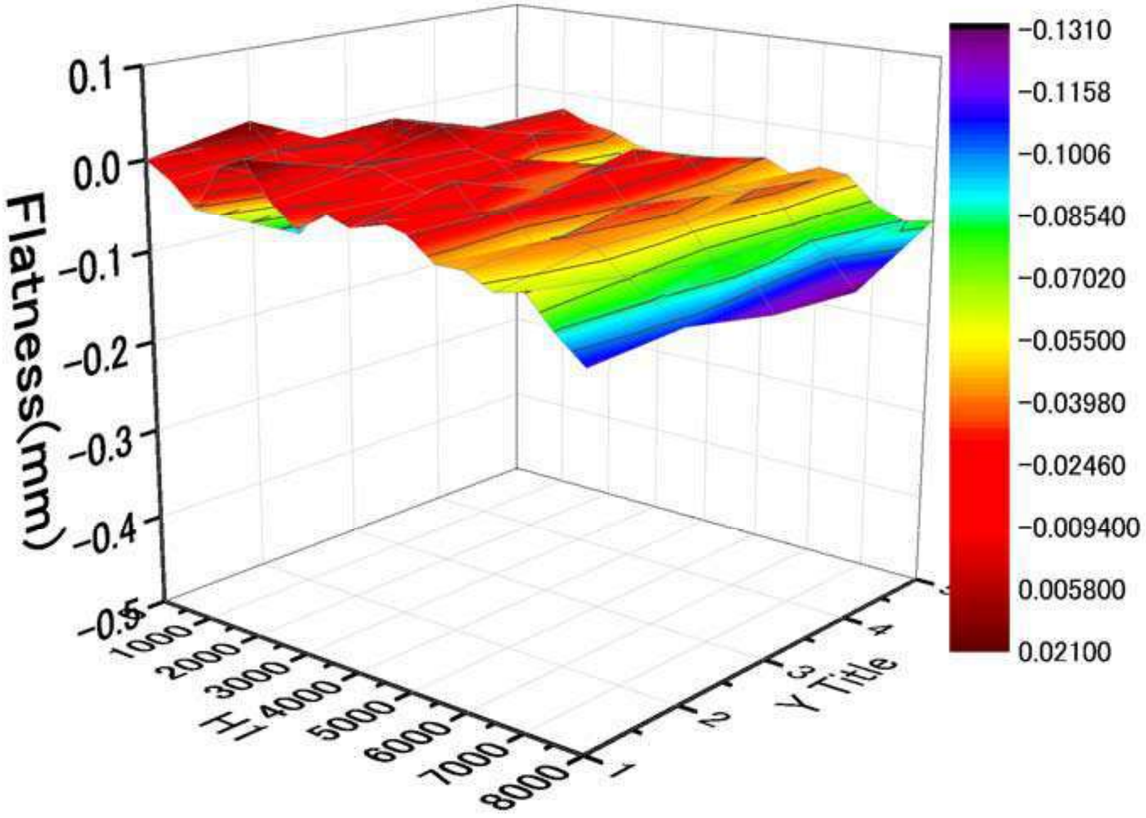
- **QCS;**
  1500kg → 2500kg
- **Height;**
  2.1m → 1.5m
- **No magnet table**

# Self-leveling method(Precise flat floor)



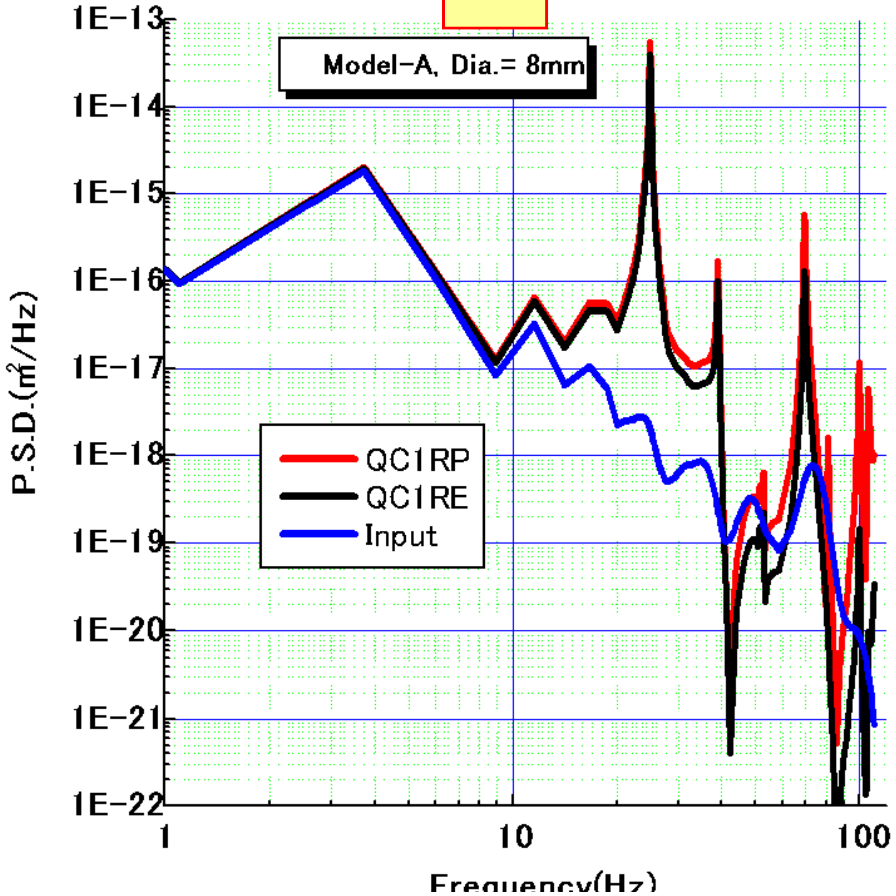
**Completion**

**Flatness of the floor**

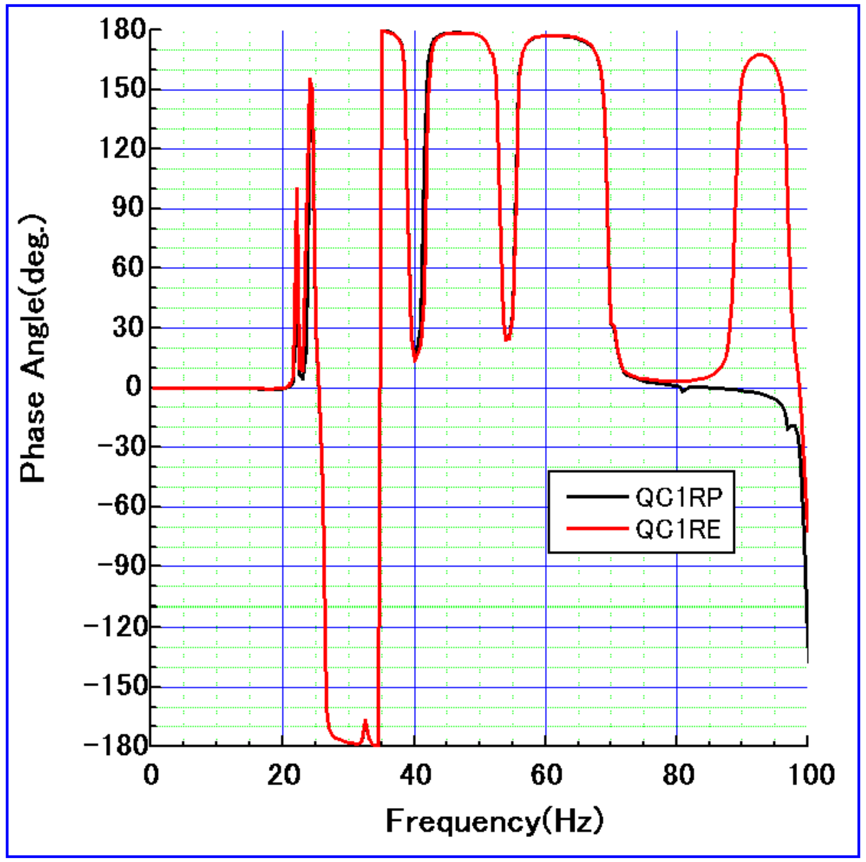


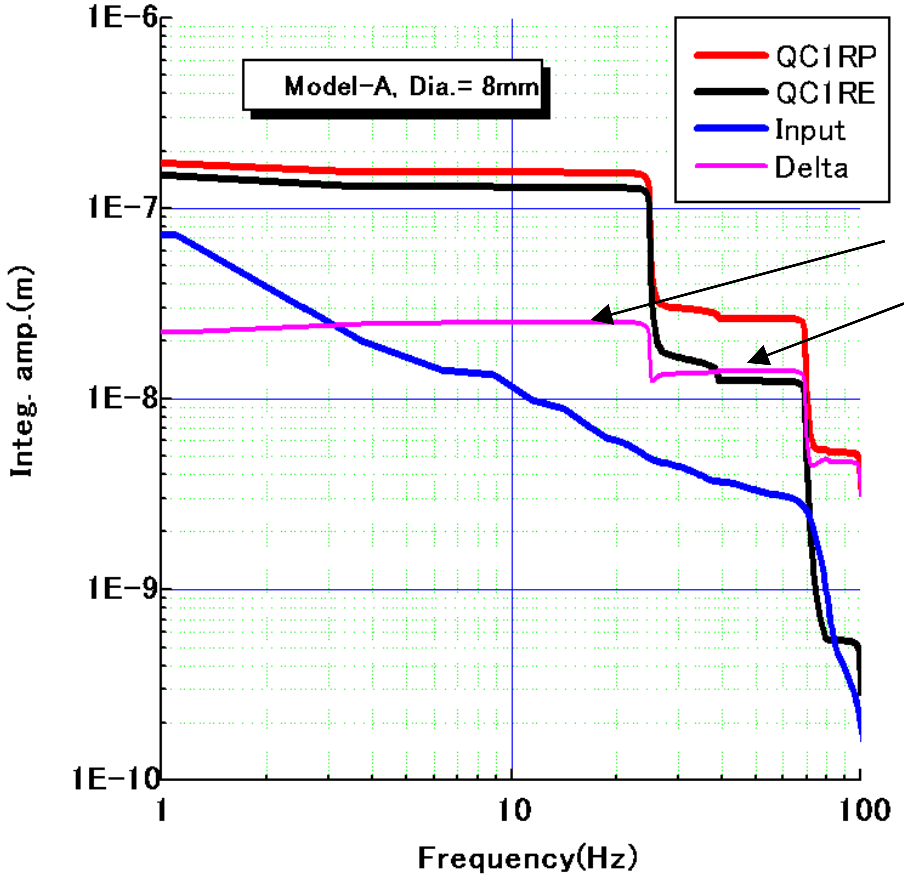
# FEM results

**R**



## Phase angle





**25nm@20Hz**

**14nm@50Hz**

# Lessons Learned from LEP and their Application to FCC/CEPC, Helmut Burkhardt (CERN)

## Bit of history of the CERN Large Electron-Positron Collider

tunneling 13/9/1983 - 8/2/1988; Operation($Z^0$@LEP1,104GeV@LEP2) for 1990-2000, dismantled for LHC

minimum $\beta^*$ and maximum tune shift were limited by the need for stable low background running condition

distance IP to 1st superconducting Quadrupole (centre) L* = 3.7 m for LEP, 2.8 m FCC-ee, 23 m for LHC

## Challenges for FCC, CEPC

2 rings : less evident to find collisions, need to frequently re-steer to centre collisions

Smaller beams, large crossing angle, Beamstrahlung, high power : risk of damage by heating and beam losses

Top-up injection : need for more aperture to efficiently capture beams, background spikes by losses
and lager amplitude (halo) from injection, continuously running at top maximum intensity and power

Background/Signal exchange, logging and status displays for good performance by the continuous tuning

Thermal photon scattering is the main single beam lifetime limitation in LEP, also creates off-momentum partcles

Muon backgrounds : with the beam lifetime of 200min (FCCee_Z), $2.4\times10^{11}$ $e^+$,$e^-$/sec are lost, which generate
millions of muons/sec → avoid collimation of $e^+$,$e^-$ in line of sight to experiments

Non-Gaussian tails measured by scraping with loss monitors at LEP

larger tail (>$10\sigma_y$) in the vertical plane than the horizontal tail which was reproduced by simulation

Tails from beam-beam, high chromaticity, particle scattering

Background spikes, enhanced synchrotron radiation from quadruples

Machine induced backgrounds (MIB) in LEP ~ 100 collimators to reduce MIB

Synchrotron radiation - no direct and single reflected radiation to experiments in IP region at LEP

the critical photon energies : 69, 725keV@LEP1, 2 and 1.3MeV@FCC-ee

Fluorescence, specular reflection etc. are well simulated by GEANT4, now.

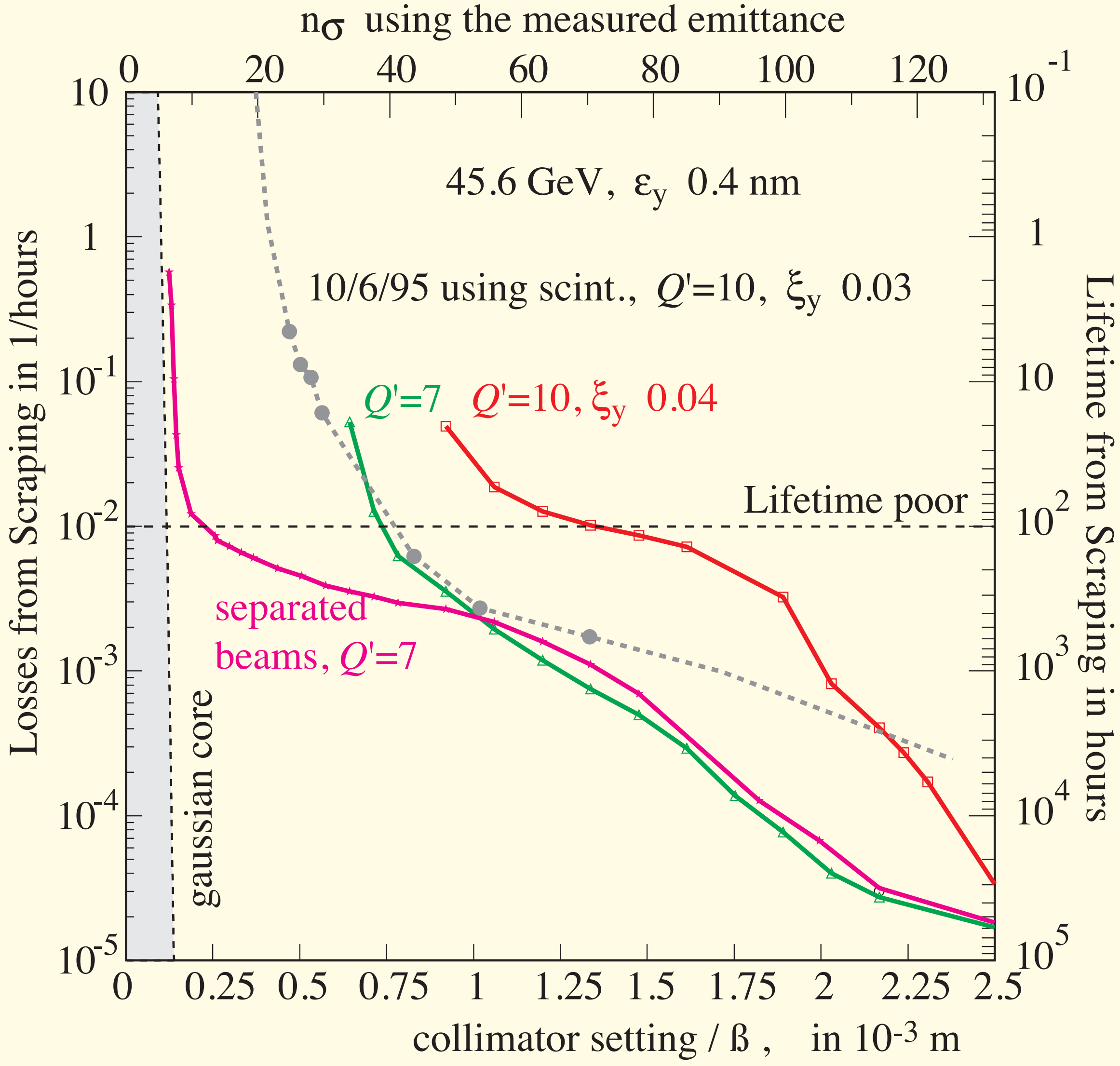
**Much of the work is on details, MDI - IR design particularly important,**

simulation, beam-dynamics, background — benchmarked with LEP and $e^+e^-$ factories, stimulating and profiting from further hardware / technology developments

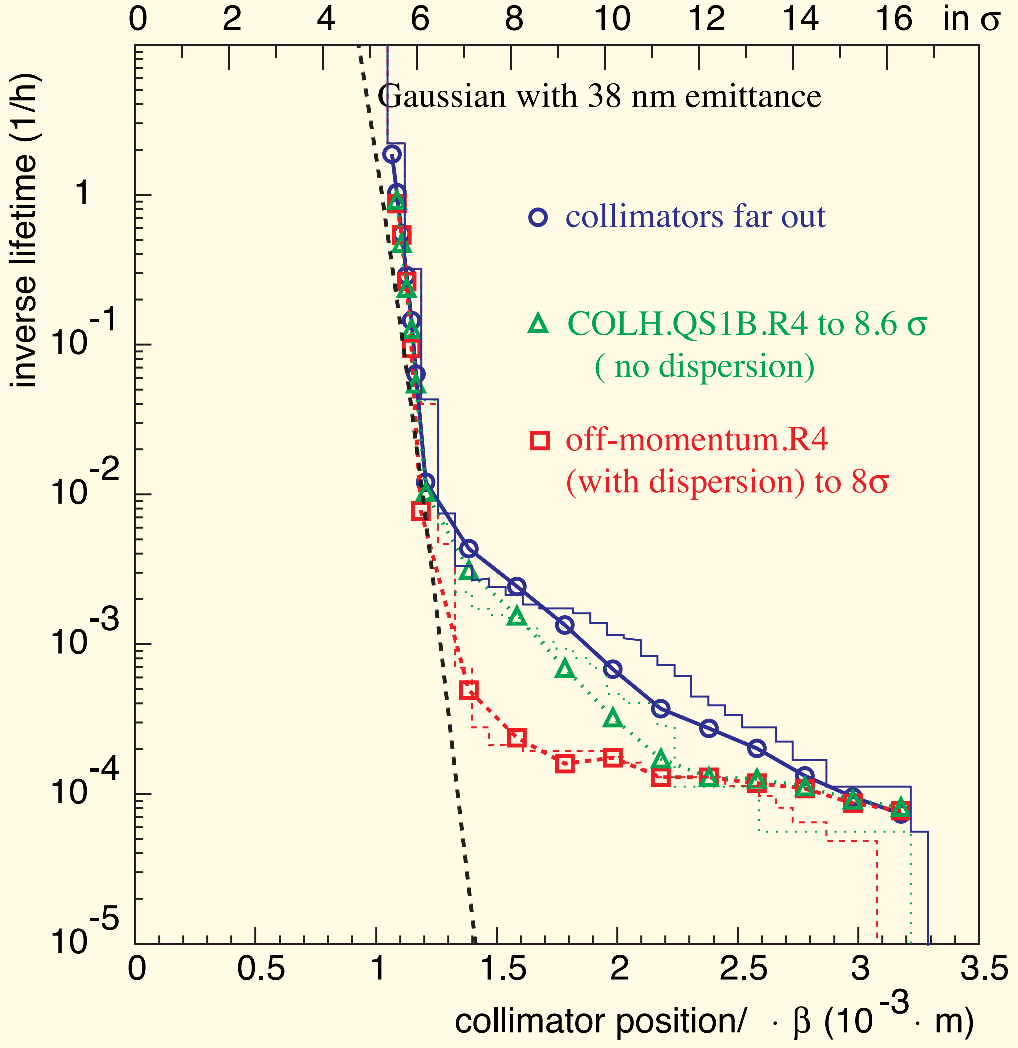
# non-Gaussian tails, LEP

measured by scraping with loss monitors

vertical plane, colliding beams



horizontal plane
reproduced by simulation

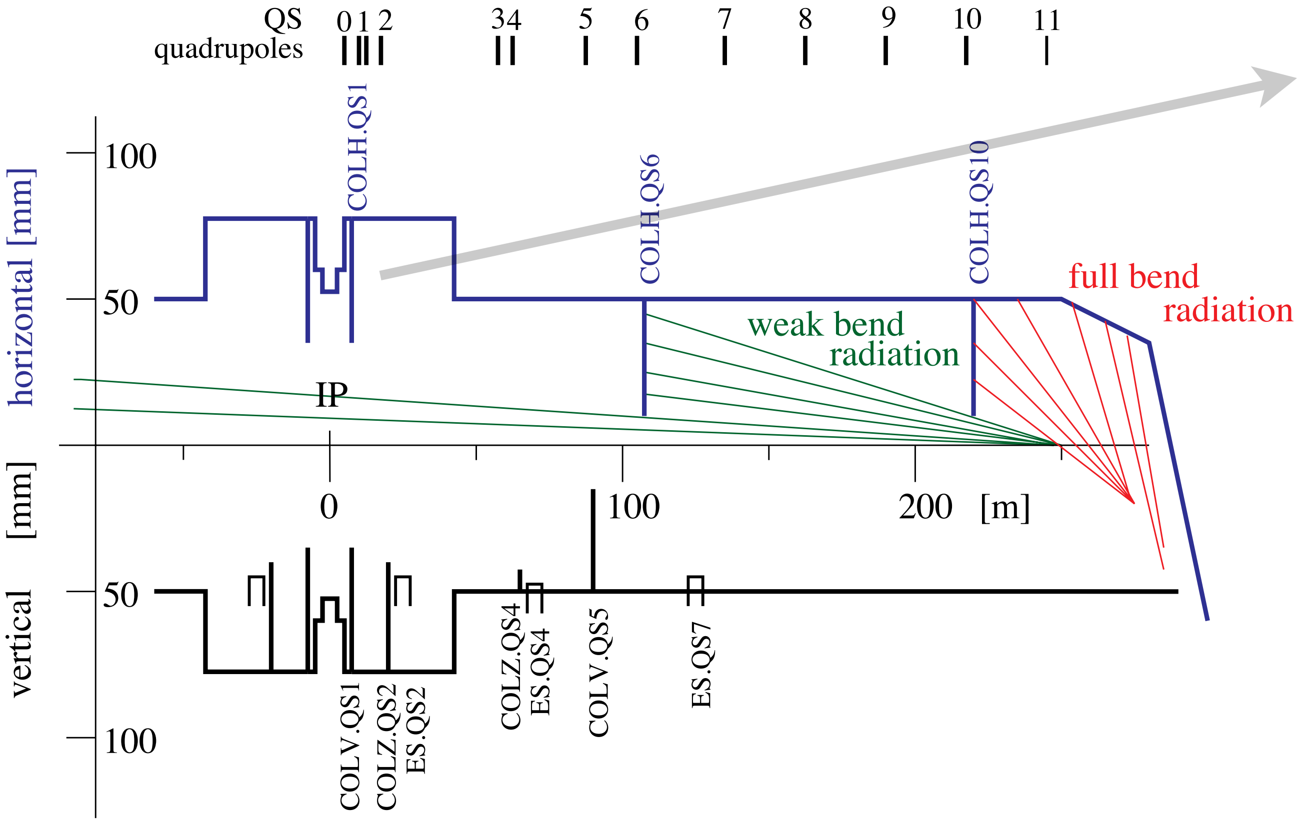


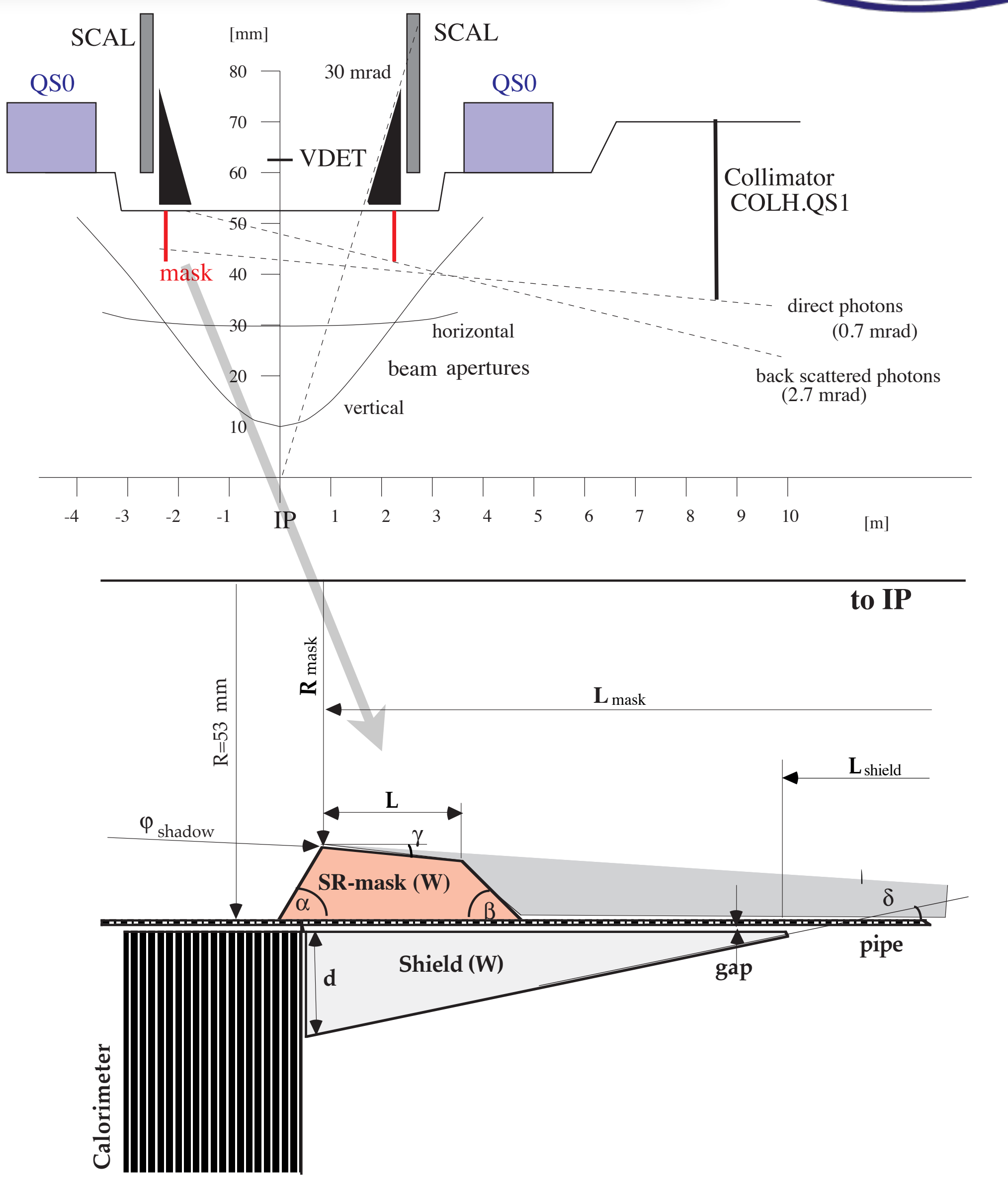
**Tails from : beam-beam, high chromaticity, particle scattering**

**Background spikes, enhanced synchrotron radiation from quadruples**

H.B. I. Reichel, G. Roy, Transverse beam tails due to inelastic scattering in LEP, PRSTAB, 3:091001, 2000; I. Reichel, CERN-Thesis-98-017
H.B. "Beam lifetime and beam tails in LEP." CERN-SL-99-061-AP and Proc. e+ e+ Factories 1999, KEK, Tsukuba 1999

# LEP, as example of an IR optimized for SR





**Georg von Holtey** et al., [Nucl.Instrum.Meth.A403:205-246, 1998]

**Eb = 45 GeV to 104 GeV** **the closest we got to FCC-ee**

**Machine induced backgrounds, MIB in LEP** **~ 100 collimators to reduce MIB**

**flat, symmetric machine, no crossing angle, few (4-12) bunches**

**Synchrotron radiation -** **no direct and single reflected radiation to experiments in IP region**

**Off-momentum beam-gas and thermal photon**

# CEPC MDI Accelerator Issues, Sha Bai 白莎 (IHEP)

**MDI layout ( about ±7m long from the IP ) and IR design :**

The detector solenoid magnet of 3T, 7.6m length. All accelerator components in $\cos\theta<0.993$ ( $\theta<0.118$ )

The horizontal crossing angle is 33mrad and L*= 2.2m.

The beam stay clear (BSC) : $BSC_x=\pm18\sigma_x+3$mm for injection and $BSC_y=\pm22\sigma_y+3$mm for beam lifetime

**IR SC magnets physics design parameters :**

QD0a/QD0b : 1.5m length, 77.5T/m, apertures 10.16 - 22.03 mm(H), 15.13-17.46mm(V)

QF1 : 2m length, 63.4T/m, apertures 23.64-30.91mm(H), 16.79-14.01(V), L*(QF1)=5.51m

**Solenoid compensation :**

$\int B_z\,ds$ ( z<2.12m) ～0， $B_z$ <300 Gauss at z > 2.12m with skew quadrupole coils

**Synchrotron radiation :**

Last bend :12.5W@Lumical-QDa, 0.75W@QDa,0.9W@QDb,6.3W@QDa-QDb,1.78W@QF1,19.6W@QDb-QF1

also estimated under the extreme conditions of offsets of -2mrad,+0.115mrad(angle), ± 5mm (position).

Critical energy (H/V in keV) : 458.7/271.2@QDa, 657.9/361.5@QDb, 428.3/613.5@QF1

From the solenoid combined field, no SR hit on the Be IP pipe and hit on the beam pipe at 213.5m from IP.

**Beam loss in IR :** 218 bunches at 2997Hz, $1.5\times10^{11}$/bunch, L=5.2 x $10^{34}$cm$^{-2}$s$^{-1}$

Thermal photon scattering, beam gas scattering, beamstrahlung(BS), radiative Bhabha scattering(RBB)

Beam loss reduced to very low level with collimators for RBB and BS. IR vacuum of 3 x $10^{-10}$ torr

**Collimator design :**

Beam stay clear, impedence control, phase between the pair collimators, put in large dispersion region

SR from the upstream bending magnet in the ARC can contribute to the heat load of the collimators.

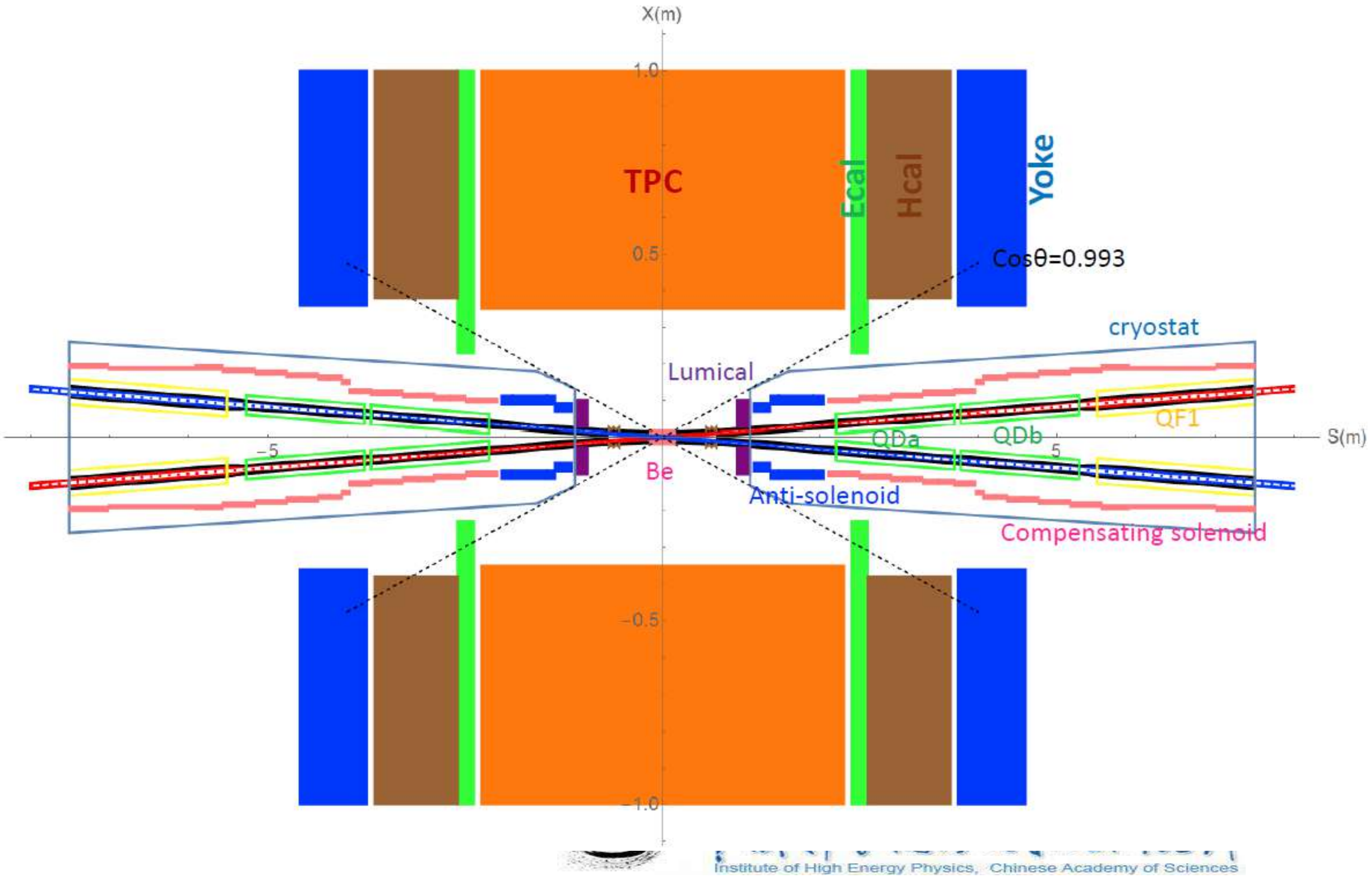
**HOM absorber :**

HOM, 10GHz, ~3kW, trapped mode at the crotch point (z~±700mm)

HOM absorber: inner surface of the beam pipe is grooved and coated with absorbing material,
and the outer surface of the beam pipe is water cooled.

**IP BPM :** two 4 button electrodes BPM at ± 80cm from the IP in the double pipe part, in front of Lumcal.

# MDI layout and IR design



- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m.

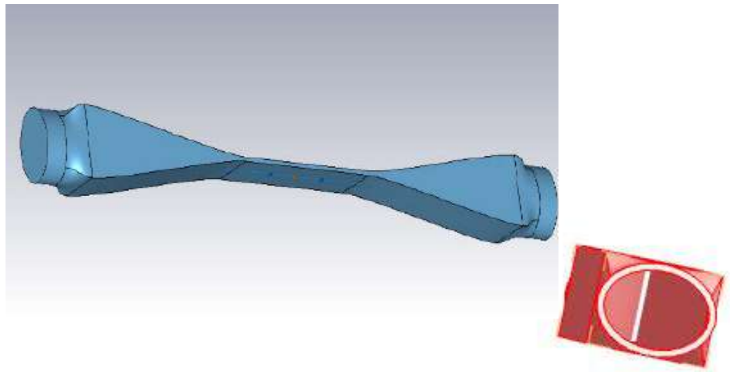
# CEPC beam lifetime

| | Beam lifetime | others |
|---|---|---|
| Quantum effect | >1000 h | |
| Touscheck effect | >1000 h | |
| Beam-Gas（Coulomb scattering） | >400 h | Residual gas CO，$10^{-7}$Pa |
| Beam-Gas（bremsstralung） | 63.8 h | |
| Beam-Thermal photon scattering | 50.7 h | |
| Radiative Bhabha scattering | 74 min | |
| Beamstrahlung | 80 min | |

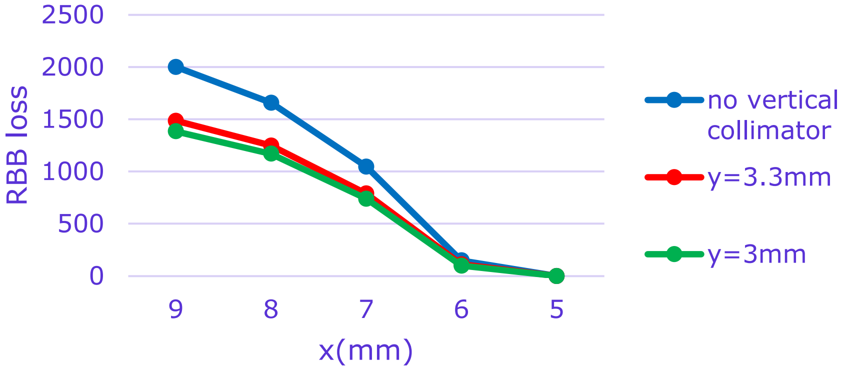
# Collimator design

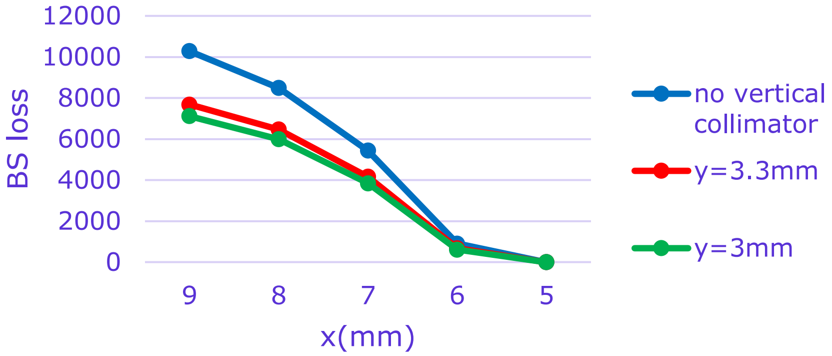
- Beam stay clear region: 18 $\sigma_x$+3mm, 22 $\sigma_y$+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta+(D_x\sigma_e)^2}$

| name | Position | Distance to IP/m | Beta function/m | Horizontal Dispersion/m | Phase | BSC/2/m | Range of half width allowed/m m |
|---|---|---|---|---|---|---|---|
| APTX1 | D1I.1897 | 2139.06 | 113.83 | 0.24 | 356.87 | 0.00968 | 2.2~9.68 |
| APTX2 | D1I.1894 | 2207.63 | 113.83 | 0.24 | 356.62 | 0.00968 | 2.2~9.68 |
| APTX3 | D1O.10 | 1832.52 | 113.83 | 0.24 | 6.65 | 0.00968 | 2.2~9.68 |
| APTX4 | D1O.14 | 1901.09 | 113.83 | 0.24 | 6.90 | 0.00968 | 2.2~9.68 |
| APTX5 | DMBV01IRU0.492 | 31 | 196.59 | 0 | 362.86 | 0.01178 | 2.9~11.78 |



- horizontal collimator half width 5mm(13$\sigma_x$)
- The collimators will not have effect on the beam quantum lifetime.


RBB loss upstream vs horizontal collimator half width


BS loss upstream vs horizontal collimator half width

# CEPC RADIATION BACKGROUND STUDIES, Hongbo Zhu 朱 宏博 (IHEP)

**Interaction Region Layout ：**

Based on the CDR design (to be optimized) , e.g. a single QD0 (2m long, 136T/m)

**Radiation Backgrounds,** important inputs to the detector (+machine) designs ：

beam-induced or luminosity related radiation backgrounds

**Synchrotron radiation :** BDSim to transport beam (core + halo) from the last dipole to the interaction region and record the particles hitting the central beryllium beam pipe (± 7cm from IP).

Careful mask design, the tip shape and high Z material(Au chosen, 0.6mm$^t$) for SR from the last bend

3 locations at |Z|= 1.51,1.93 and 4.2m → Photons/bunch hitting the central beam pipe from 80, 000 to 250.

**Beamstrahlung/pair production :** generated with GuineaPig

Background expressed by hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL)

With a safety factor of 10;

pairs: 2.26 hits cm$^{-2}$ BX$^{-1}$, 591.14 KRad yr$^{-1}$, 1.11x10$^{12}$ n$_{eq}$cm$^{-2}$yr$^{-1}$@VTX 1st layer , Higgs factory (E$_{cm}$=240GeV)

Off-Energy beam particles (radiative Bhabha, beam gas, thermal photon scattering etc.) :

**2 sets of collimators placed, but not sufficient yet, optimaization is needed**

RB and beam gas, thermal photon backgrounds generated by BBBrem and a costomized code, respectively, then particles were tracked with SAD, hit map in the vertex detector ( with the collimators) is calculated.

The beam gas backgrounds dominates 368.37 cm$^{-2}$ BX$^{-1}$ at the VTX 1st layer, at 10$^{-7}$ Pa vacuum pressure

**VERIFICATION WITH BEPC II/BES III for simulation tools and analysis procedures :**

Decomposition of background components as the SuperKEKB (C. Niebuhr's talk), the experimental steps were proposed as well as the vacuum pressure degradation test in the beam pipe at the BSRF end station.

From experiences at LEP and SuperKEKB, 10-20 collimaters may be needed per IP.

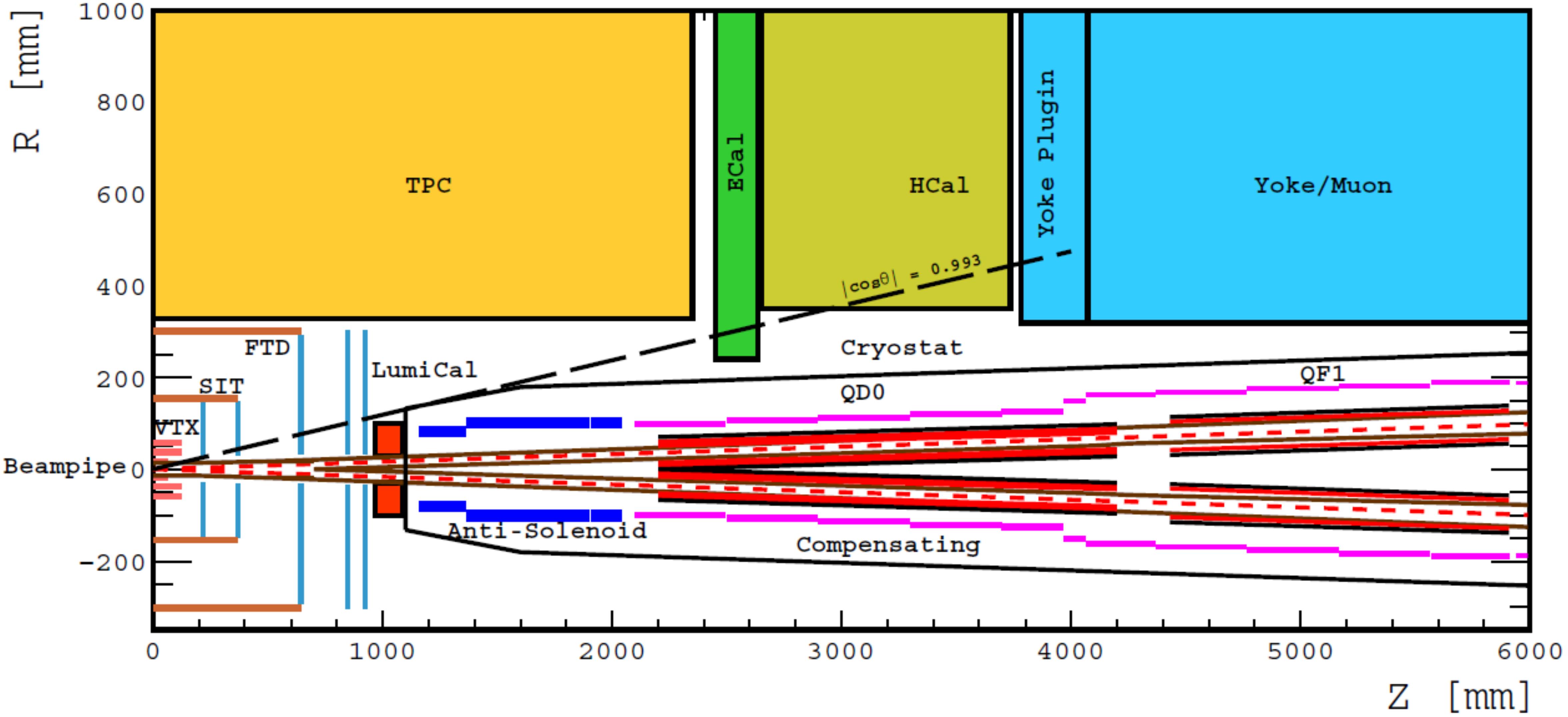
**Suggestions in discussion :**

Backgroud study is also needed for the quench protection.

More frequent communication with accelerator MDI group is needed for the accelerator design is advanced.

# INTERACTION REGION LAYOUT

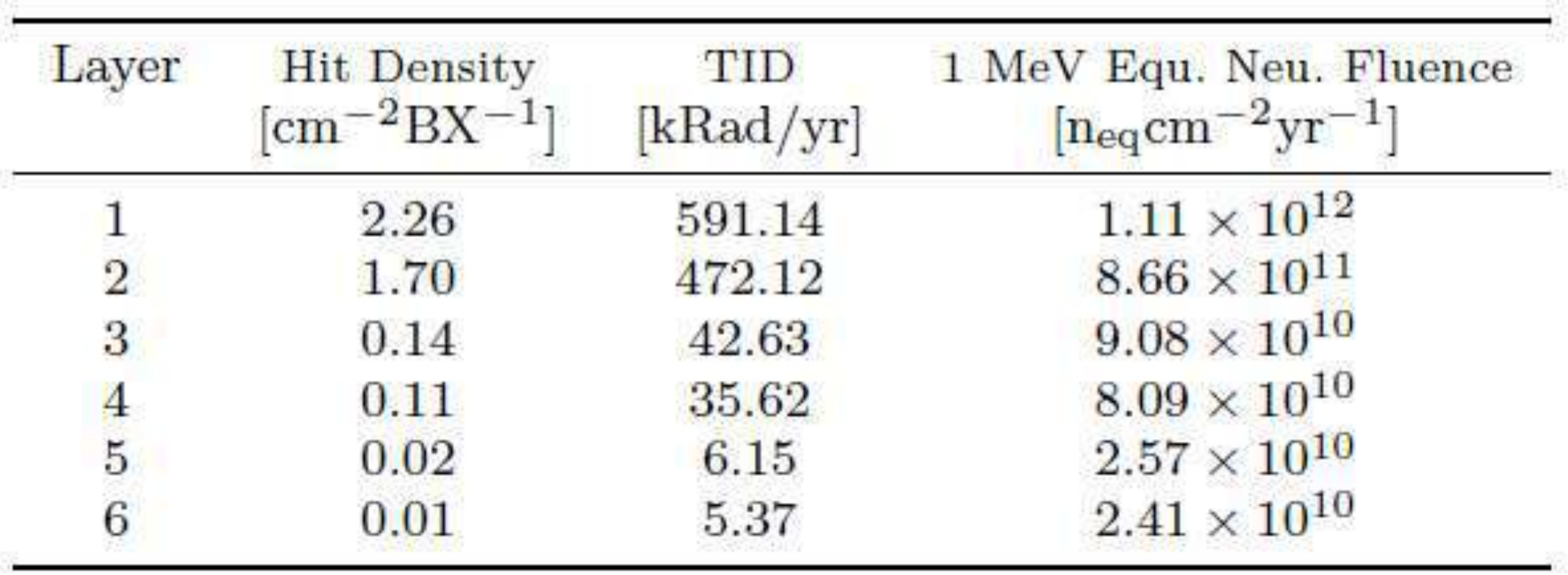
- Interaction region layout in CDR (*to be optimized*)



# PAIR PRODUCTION (UPDATED)

- Estimated backgrounds in the vertex detector (still using the CEPC CDR machine parameters)

Higgs ($\sqrt{s} = 240$ GeV)



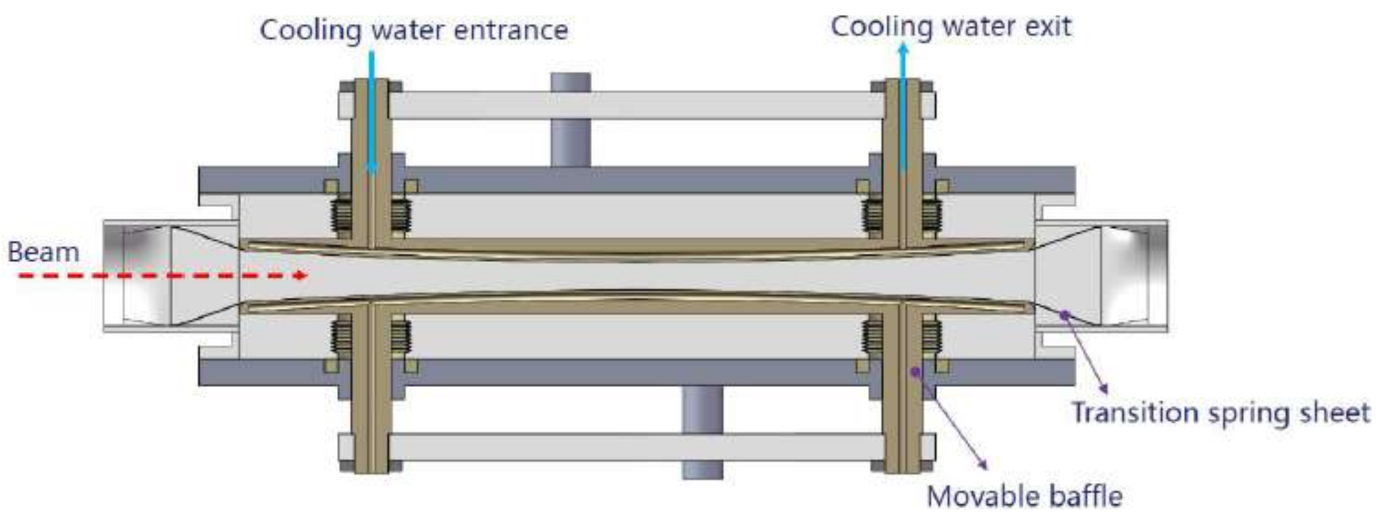
| Layer | Hit Density $[\mathrm{cm}^{-2}\mathrm{BX}^{-1}]$ | TID [kRad/yr] | 1 MeV Equ. Neu. Fluence $[\mathrm{n_{eq}cm^{-2}yr^{-1}}]$ |
|---|---|---|---|
| 1 | 2.26 | 591.14 | $1.11 \times 10^{12}$ |
| 2 | 1.70 | 472.12 | $8.66 \times 10^{11}$ |
| 3 | 0.14 | 42.63 | $9.08 \times 10^{10}$ |
| 4 | 0.11 | 35.62 | $8.09 \times 10^{10}$ |
| 5 | 0.02 | 6.15 | $2.57 \times 10^{10}$ |
| 6 | 0.01 | 5.37 | $2.41 \times 10^{10}$ |

Z ($\sqrt{s} = 91$ GeV)

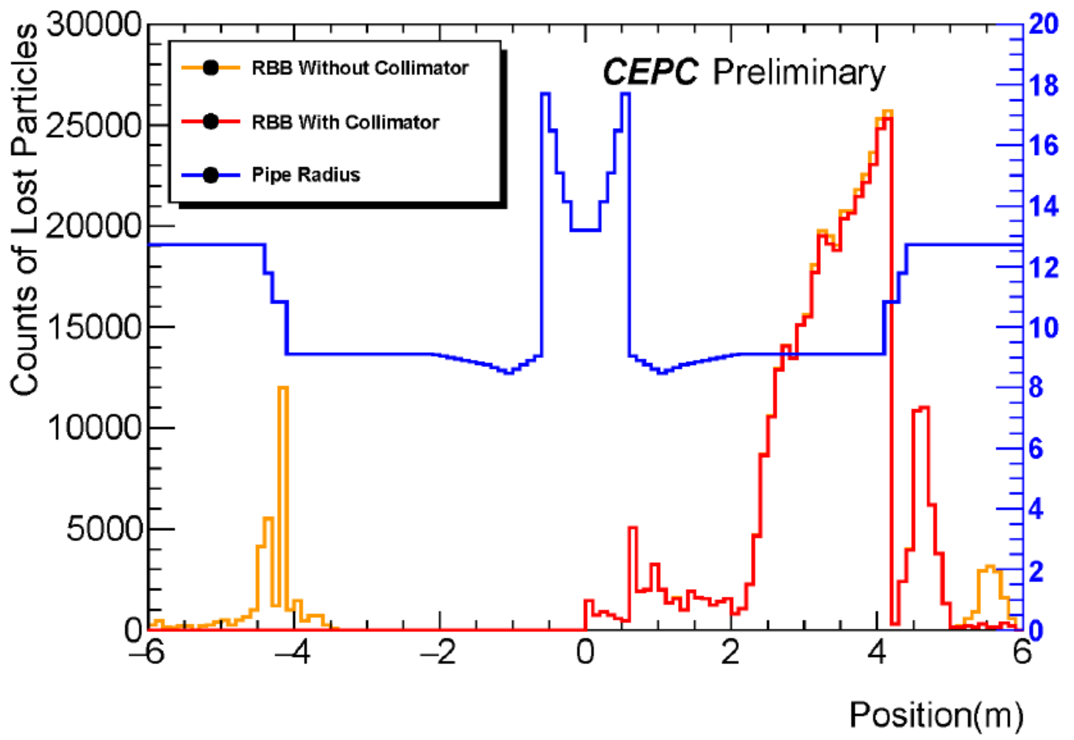
|  | Hit Density [hits/cm$^2$·BX] | TID [kRad/year] | NIEL [$10^{12}$ 1 MeV $\mathrm{n_{eq}}$/cm$^2$·year] |
|---|---|---|---|
| B = 2 T |  |  |  |
| B = 3 T | 0.019 | 274.09 | 0.51 |

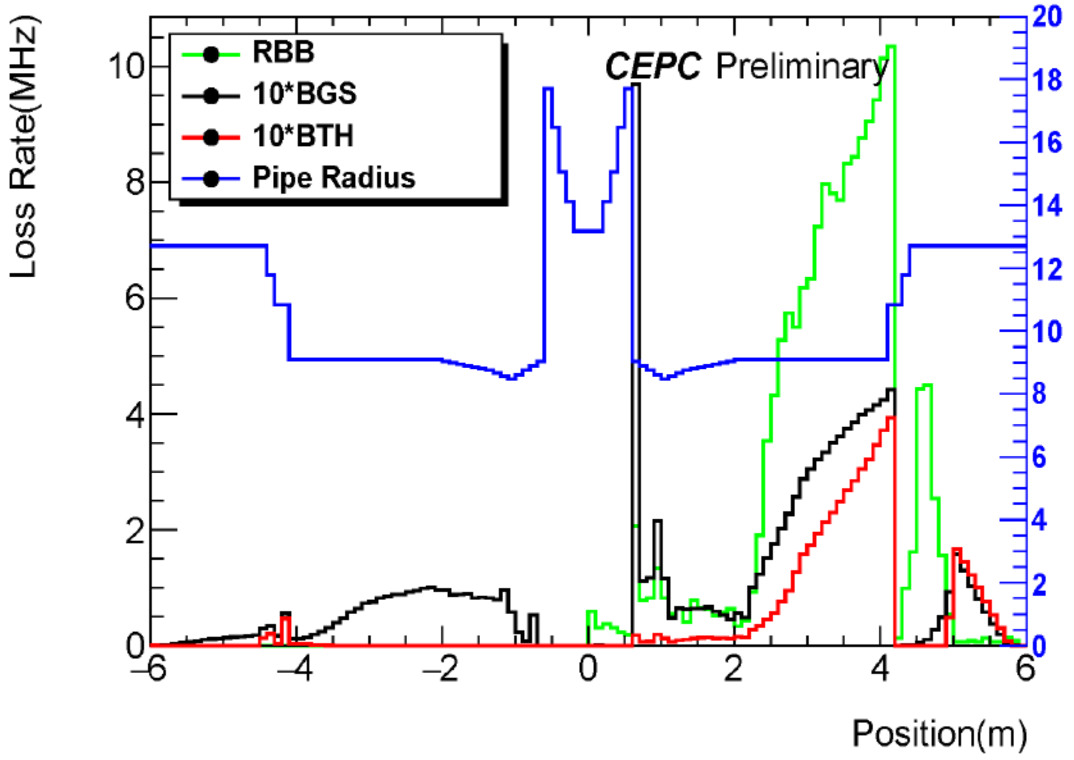
# COLLIMATORS

- Two sets of collimators (**NOT Sufficient!)** placed upstream to stop off-energy beam particles, far away from the beam clearance area (exact aperture size subject to optimization)



Inspired by the BEPCII collimator design





# Off-Energy Beam Particles

- Estimated backgrounds at the first vertex detector layer (still using the CEPC CDR machine parameters)

| | Hit Density [hits/cm$^2$·BX] | TID [MRad/year] | NIEL [$10^{12}$ 1 MeV $n_{eq}$/cm$^2$·year] |
|---|---|---|---|
| Radiative Bhabha | 0.93 | 1.2 | 4.08 |
| Beam Thermal Photons | 2.31 | 2.3 | 5.48 |
| Beam-Gas Interaction | 368.37 | 39.90 | 965 |

Vacuum pressure assumed to be $10^{-7}$ Pa

Beam-gas interaction backgrounds reduce linearly to the vacuum pressure level → better vacuum, e.g. $10^{-8}$ Pa

# CEPC MDI SC Magnet System, Yingshun Zhu et al. 朱应顺 (IHEP)

**Overview of CEPC MDI SC magnets :** L*=2.2m and the horizontal crossing angle of 33mrad

CDR designs of QD0/QF1, 136/110 T/m, 2/1.48m length, located in the 3T solenoid field

anti-solenoids before QD0, outside QD0 and QF1 are needed.

QD0 w/ or w/o iron yokes and QF1 with iron yokes and anti-solenoid coils are in the same cryostat.

**Iron-free design of final focus QD0 :**

two layers cos2$\theta$ quadrupole coil using NbTi Rutherford cable without iron yoke, 2510A @4.2K

Two layers of shield coil is introduced outside the quadrupole coil to improve the field quality

Integrated field harmonics with shield coil $< 3\times10^{-4}$.

Coil inner/outer radius = 20/26.5mm, beam pipe inner/outer radius = 10/13mm

Collar outer radius = 31.5mm, shield coil outer radius =33.5mm

**QD0 design with iron core :**

Iron core in the middle part is shared by the two apertures (**novel design**)

The field harmonics w/ field crosstalk between the two apertures is smaller than $0.5\times10^{-4}$

The excitation current can be reduced to, i.e. 2060A @4.2K

**Design of QD0 short model magnet with 0.5m length (near IP side) : First trial in China**

Verification of the design with two apertures w/ iron yoke, mastering the cryogenic testing technique and for the development of long QD0 model

FEM stress analysis was completed and no influence of the 3T solenoid with anti-solenoid was calculated.

The physical design of QD0 short model magnet passed the experts review in July 2019.

**Design of superconducting quadrupole magnet QF1 :**

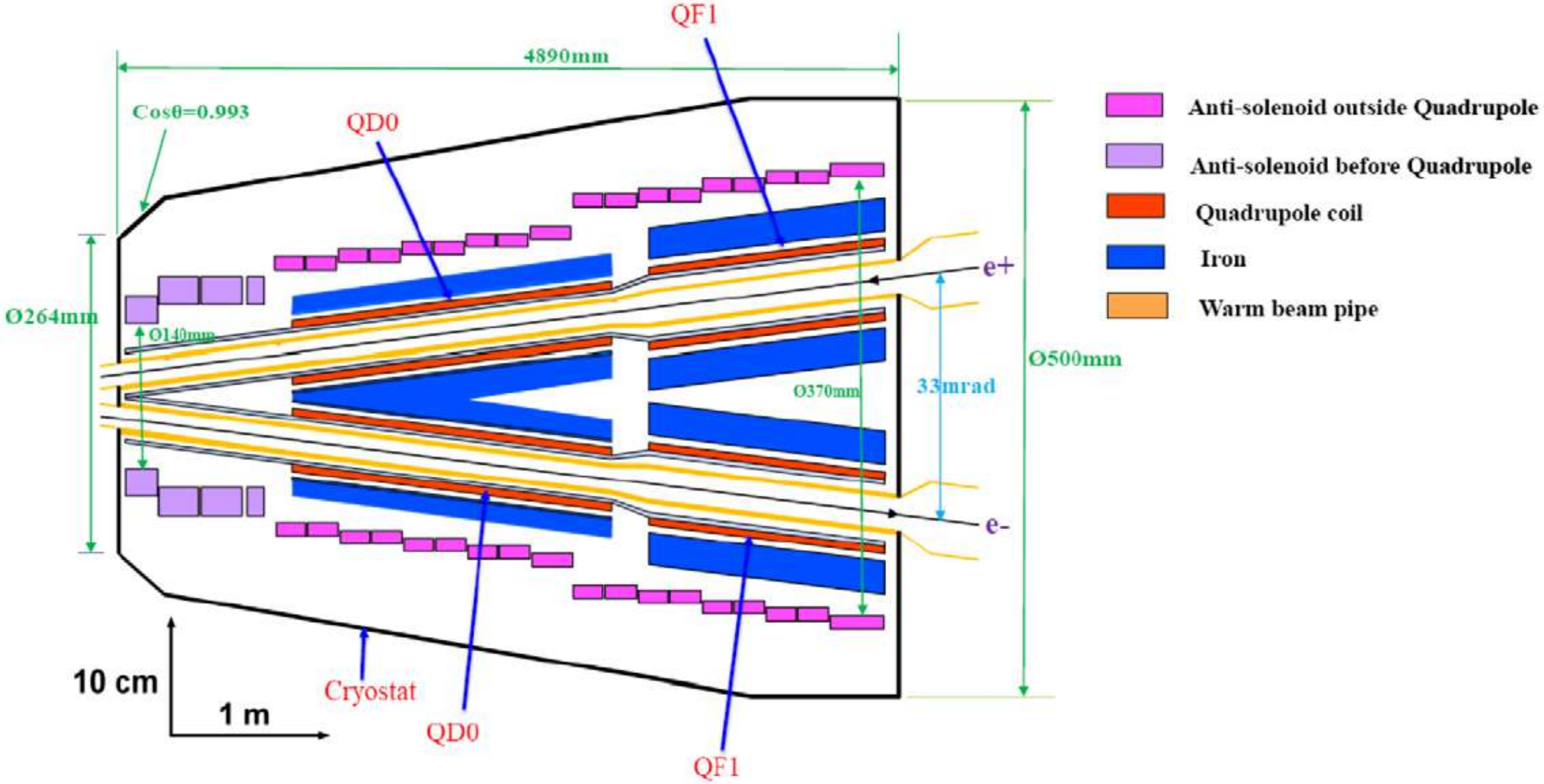
The design is similar to the QD0 with iron yoke with the negligibly small effect of the cross talk.

**Design of superconducting anti-solenoid :**

The anti-solenoid is divided into a total of 29 sections with different inner coil diameters ($B_{max}$=7T).

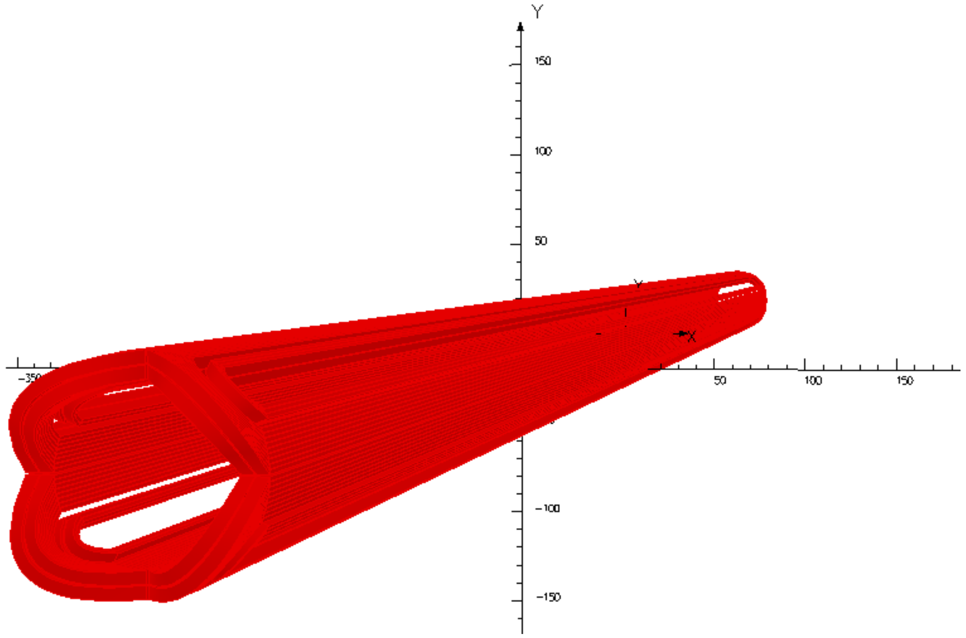
To reduce the length of the cryostat, the sections after QF1region will be operated at room-temperature.

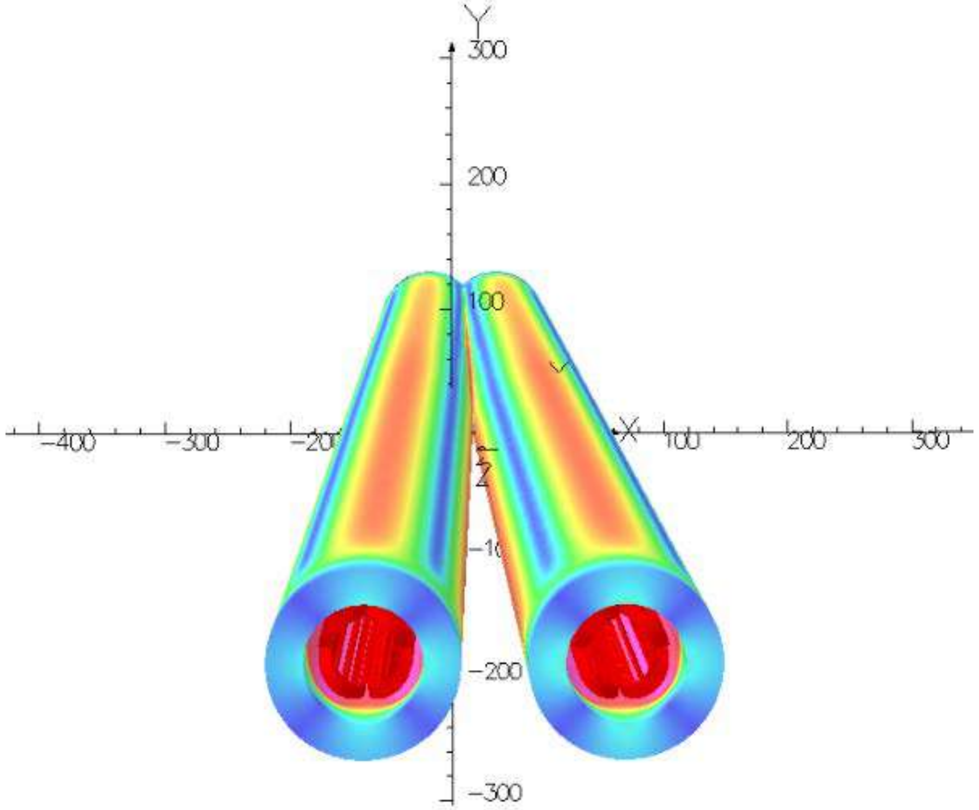
- CEPC MDI SC Magnets including: superconducting QD0,QF1, anti-solenoid on each side of the IP point.
- QD0, QF1, and anti-solenoid coils are in the same cryostat.

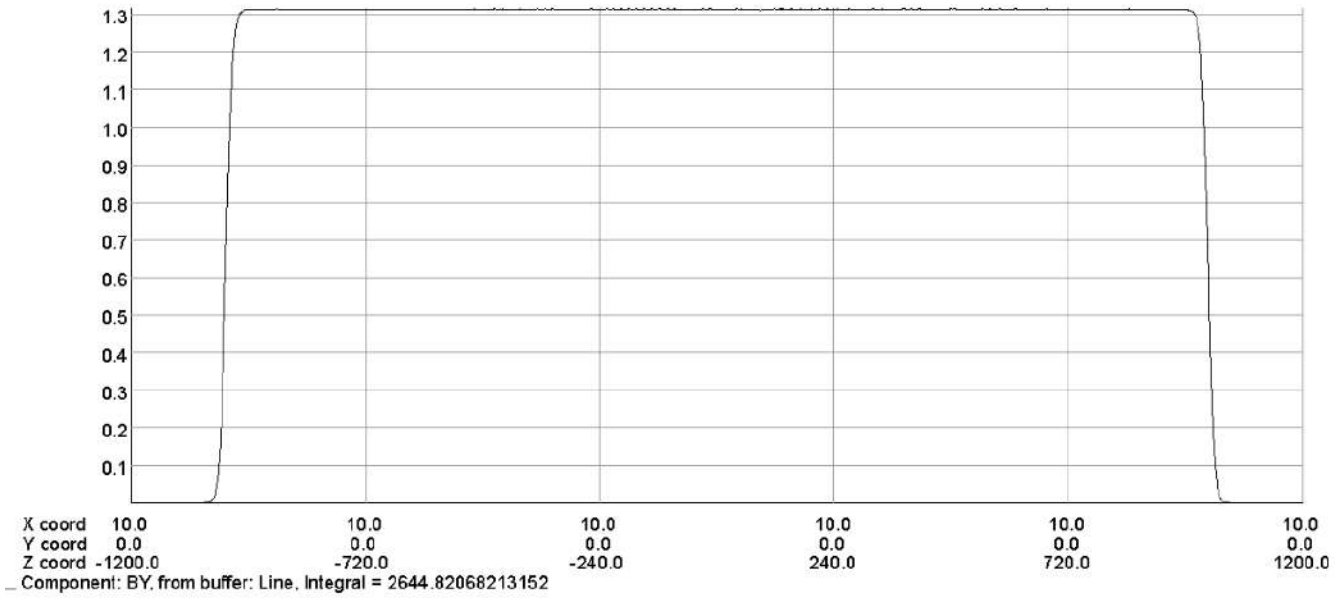


Schematic layout of QD0, QF1, and anti-solenoid

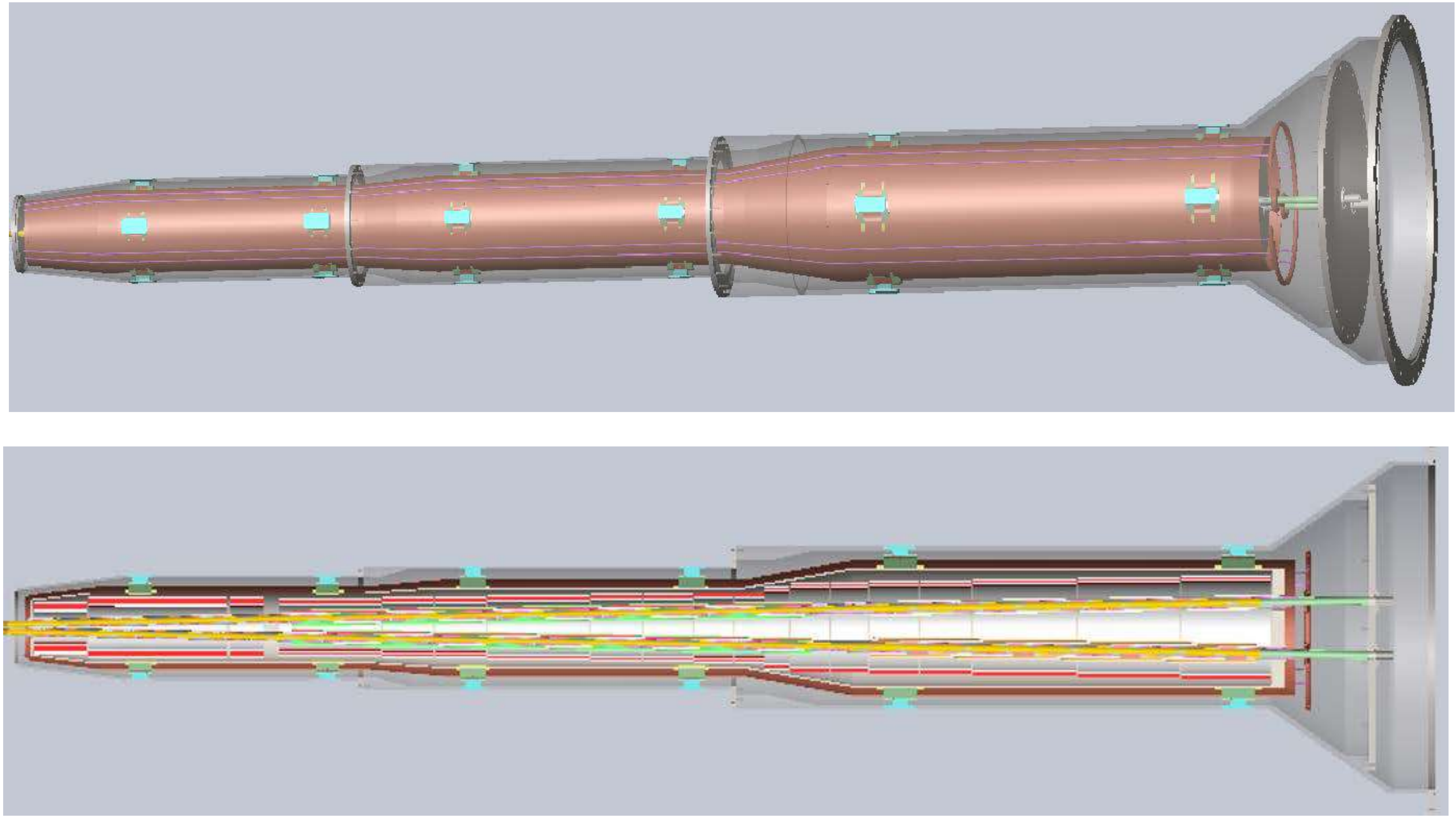
- ◆ QD0: Quadrupole magnet using cos2θ coil with iron yoke, with crossing angle between two apertures.
- ● Novel design, the first such magnet in the world.







- Design status of MDI SC magnet cryostat:



- ✓ **Cost inquiry for QD0 short model magnet fabrication has been completed.**
- ● The basic hardware necessary for prototype magnet was investigated.
- ● Winding machine for 0.5m QD0 quadrupole coil is available in IHEP Magnet Group (need some tooling).

IHEP winding machine

Review meeting

- ■ The physical design of QD0 short model magnet passed the experts review in July 2019.

# CEPC MDI Mechanics Issues, Haijing Wang 王 海靜 (IHEP)

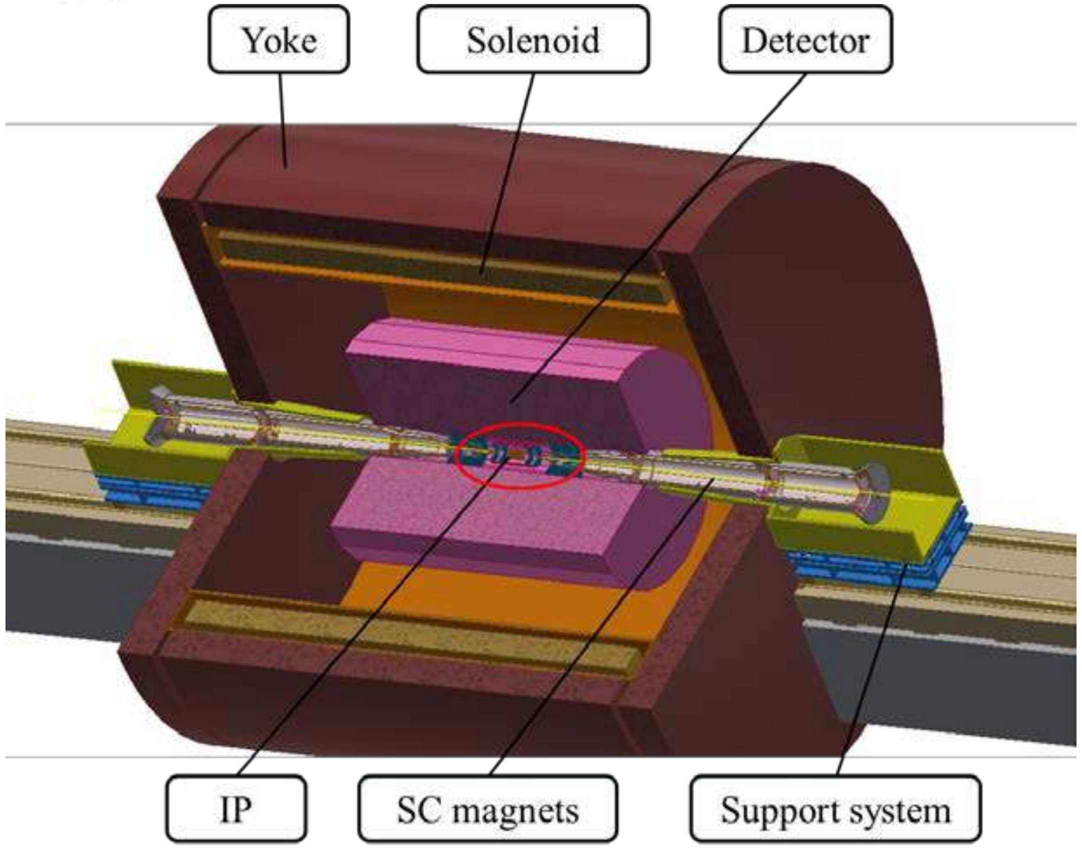
**Overview :** Detector layout of CDR design, where the iron yoke length = 9.6m
First vacuum pump@±6.5m and the remote vacuum connection@70cm

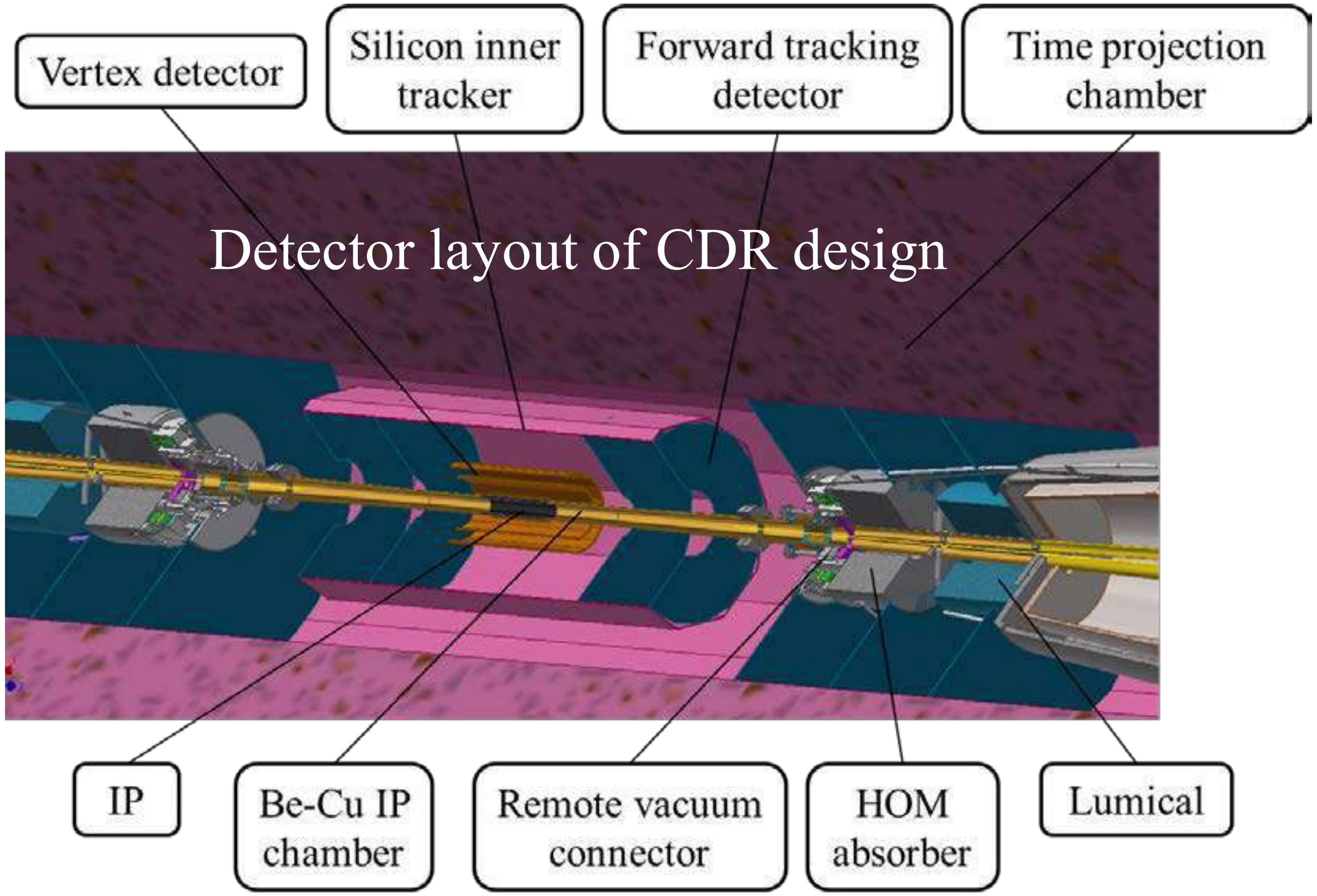
**Preliminary installation scenario :**
The IP chamber and detectors(VTX,SIT,FTD) are assembled and aligned.
Pre-alignment of SC(FF) magnets with the cryostat in working condition, then install BPM, HOM absorber,RVC.
Move the SC magnets to working location, then connect the flanges following the alignment
Finish the connection and alignment for both sides, install the yoke walls
**Two key issues:** the vacuum leak rate < 2.7x $10^{-11}$Pa $m^3$/s and the alignment error: ≤30μm
**One concern issue :** the distance from yoke boundary to connection location (m) = 6.1m → 3.8m
The current design is based on the shortest version (3.8m), while needs to be discussed further.

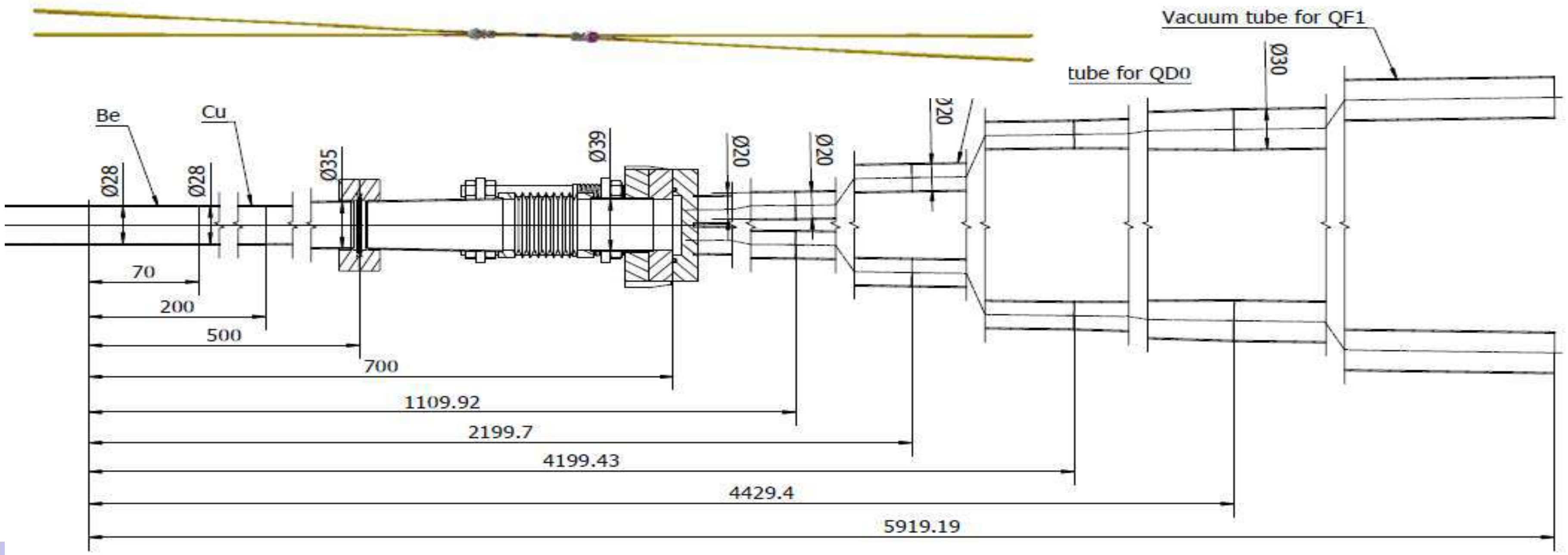
**Remote vacuum connection (RVC) methods :**
RVC similar to SuperKEKB as baseline, and studying other schemes in parallel.
Option-1 : Long tools of spline flange, spline gear (ϕ264mm x 223mm) and bellows, locking gear,
pneumatic annular, limit pin, long tools and support
Option-2 : Inlatable seal design (ϕ112mm x 120mm) @CSNS but limited leak rate < $10^{-7}$Pa $m^3$/s
with improvements of precise maching of sealing membrane and flange, different material of
sealing membrane and flange, using edge sealing instead of membrane sealing
**Common issue :** all exceeds the requirement of cos$\theta$<0.993, **so Lumical move to IP assembly ?**

**Support system of SC magnets :**
The current design of cryostat is 5 m long with18 mm thick stainless walls, about 2 tons in total.
The FEM analysis results: 190μm maximum deformation in downward for the about 3.6m cantilever support
, also 48μm / ℃ of the environmental temperature. So, **No clear solution right now !**

# Overview

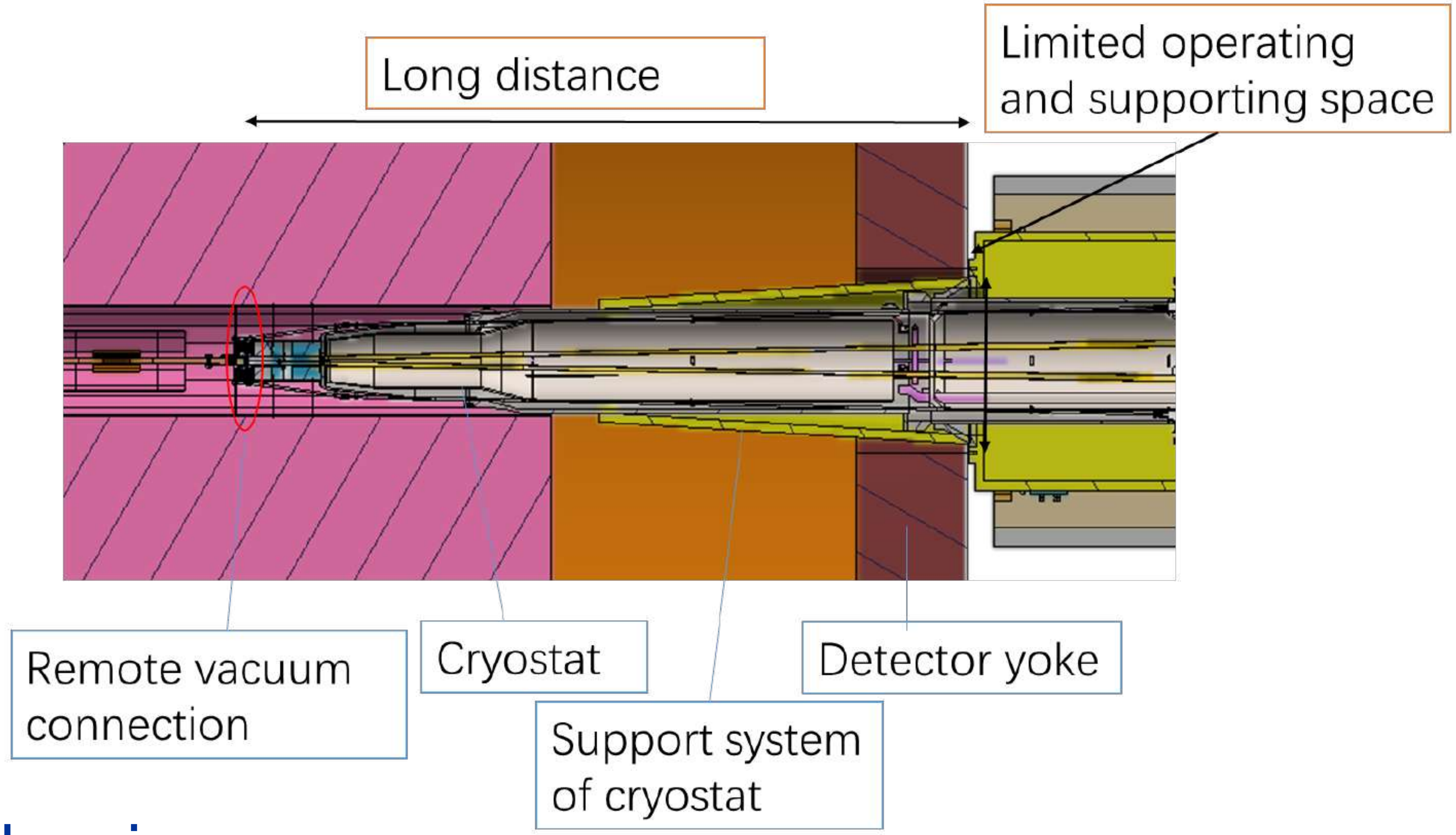



Detector layout of CDR design



For the layout above, the length of yoke is 9.2 meters. The length of yoke should be discussed further.

# Preliminary installation scenario

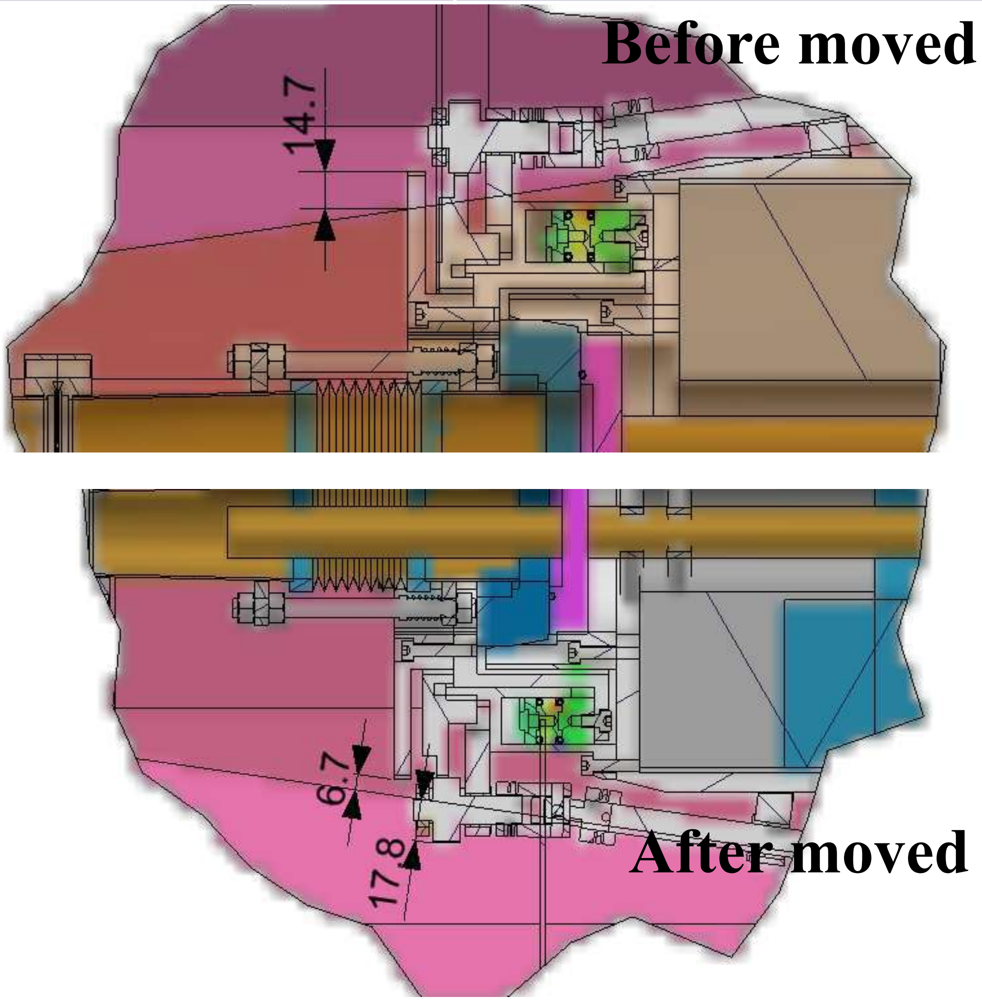


- Two key issues:
  - Vacuum connection method at MDI to fulfill the vacuum requirement. Leak rate: ≤2.7e-11Pa.m3/s
  - Support system of cryostat to fulfill the alignment requirement. Alignment error: ≤30 μm, at least ≤50 μm.

# Remote vacuum connection methods

| | RVC | Inflatable seal | Long tools |
|---|---|---|---|
| Sealing methods | Pneumatic clamping with auxiliary locking | Pneumatic clamping | Screws clamping using long tools |
| Advantages | Successful experience from SuperKEKB | Successful experience from CSNS; Small and simple; Bellows at accelerator side | Simple and small |
| Disadvantages | Big and complex; Bellows at IP chamber side | Difficult for leak rate requirement | Difficult in operation |

- The bellows of all methods have RF fingers.
- Physics requirements: all accelerator devices are within acos0.99.
- RVC design exceeds the boundary.
- New consideration is that main body of Lumical move to IP assembly, thus the space is better.



# CEPC MDI Detector Issues - In engineering design, Ji Quan 紀 全 (IHEP)

## General introduction :

Detector of CDR design, where the iron yoke length = 12.02m ← 9.6m

The connection part between spectrometer and accelerator is accelerator vacuum tube

Accelerator components must access through 5310 - 1400(beam pipe@detector) - 5310mm from both sides within $\cos\theta < 0.993$

## Interface requirements and structural design :

Barrel yoke (dodecagon) with helical arrangement with 3180t and the FEM result of 0.6mm deformation

End yoke with strengthening ribs with 1165t has the max. deformation of 2.08mm due to the magnetic force

It is small so that the design parameters of yoke for the magnetic field requirements, can meet the strength and the stiffness requirements for the detector design

Beampipe of 1400mm length equiped with the veterx detector and Lumcal($<\phi$153mm)

Carbon fiber cylinder (a, support) , Gas enlarge channel (b, air cooling),

The central Be pipe (c, paraffin cooling), The extending Al pipe (d, water cooling)

**An optional choice:** pillow seal for RVC, It consists of two flanges connected by inflatable dual bellows.

e.g. A leak-rate of $1.3 \times 10^{-11}$Pa $m^3$/s@JPARC,RIKEN meets the vacuum design requirements of beam pipe.

Can thin-walled beryllium pipe support the inflation pressure of pillow seal?

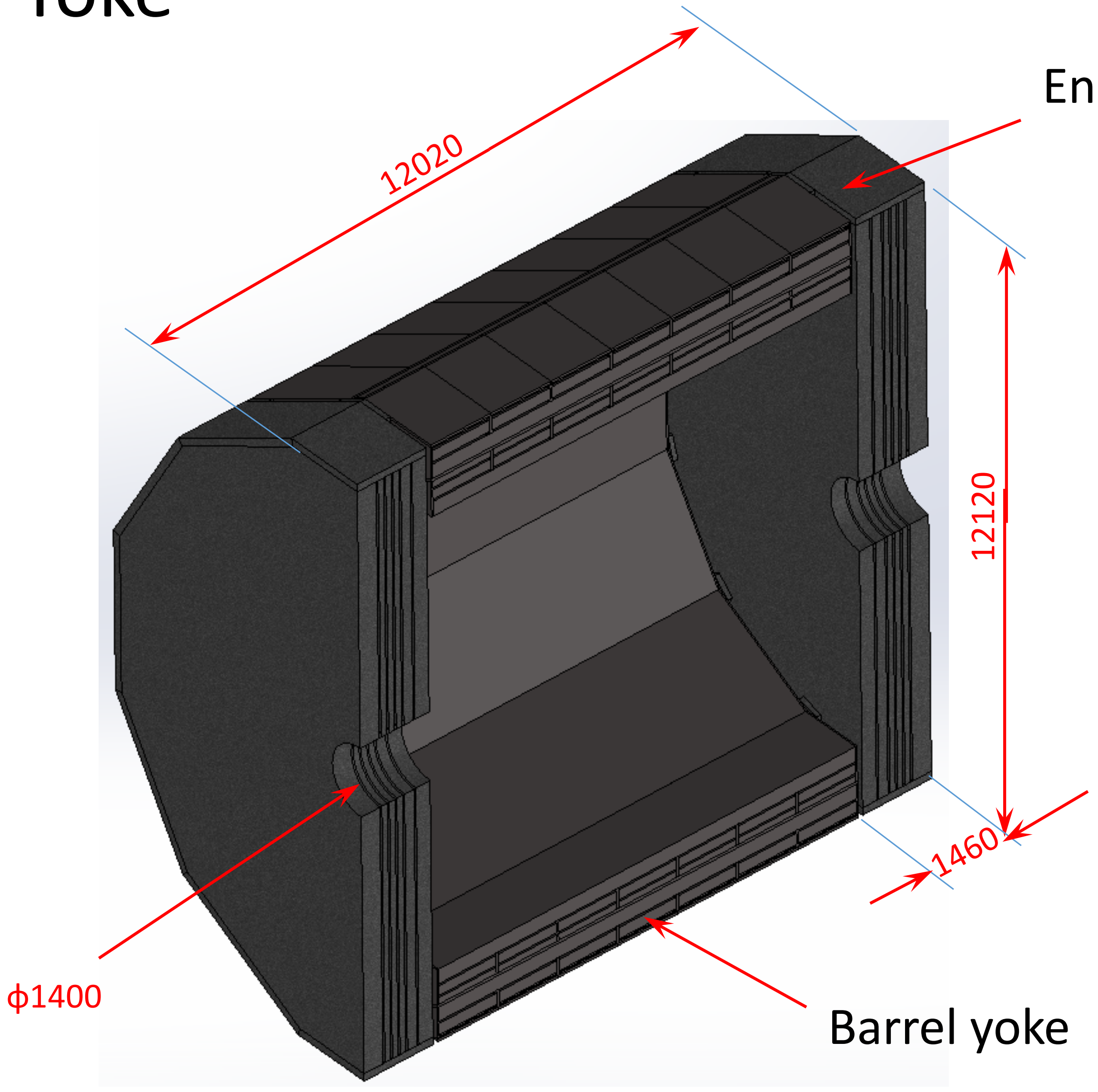
The FEM results show that In general, the beam pipe is safe under pressure of 0.3MPa at both ends.

## Next step :

Determine the vacuum connection structure of the accelerator vacuum tube and the beam pipe as soon as possible. (It affects the progress of follow-up work)

# 2. Interface requirements and structural design

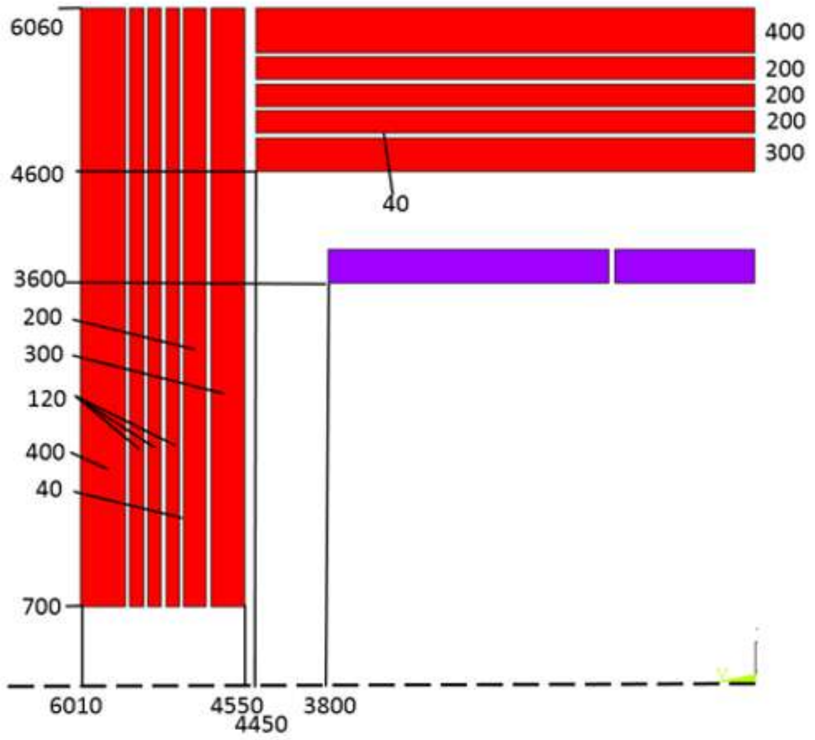
## 1) Yoke



End yoke

Barrel yoke

Structural drawing



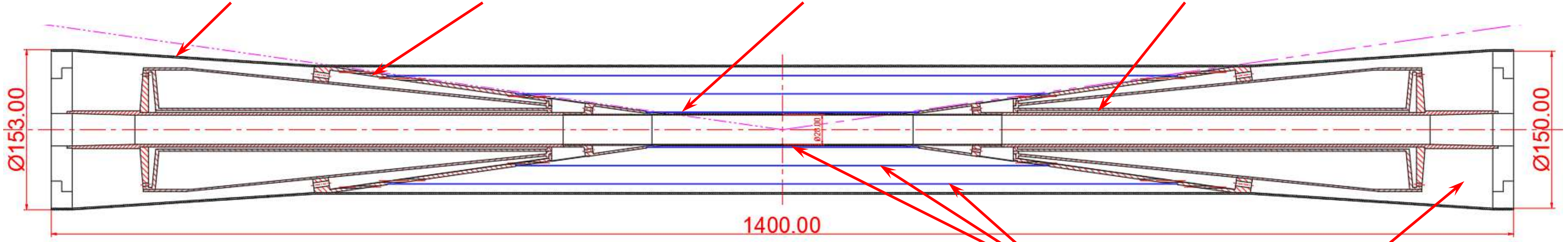
Yoke iron dimensions
(Zhu zian and Ning feipeng)

Weight:5500 tons

# 2) Beampipe

General design idea：

Optimized space, independent sub-cavity cooling



a.Carbon fiber cylinder

b.Gas enlarge channel

c.The central Be pipe

d.The extending Al pipe

**vertex**

**LumiCal space**

Note:

1.The beam tube consists of four components： a, b, c and d

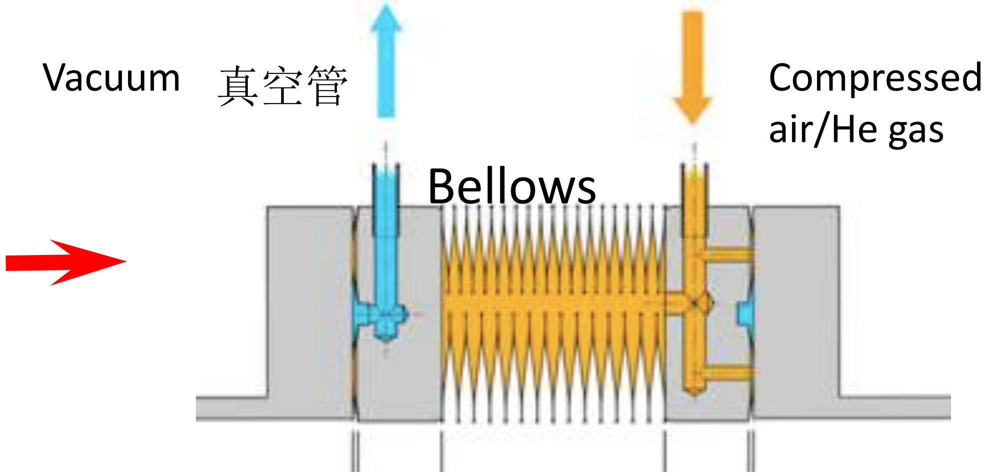
2.On the beampipe, two detectors are installed --- Vertex and Lumical

# An optional choice: Pillow seal

**Pillow seal can be remotely operated by compressed air.**

--It consists of two flanges connected by inflatable dual bellows.

--Each flange has a vacuum sealing surface consisting of a thin and Inflatable metal foil, which is polished to a mirror-like one.



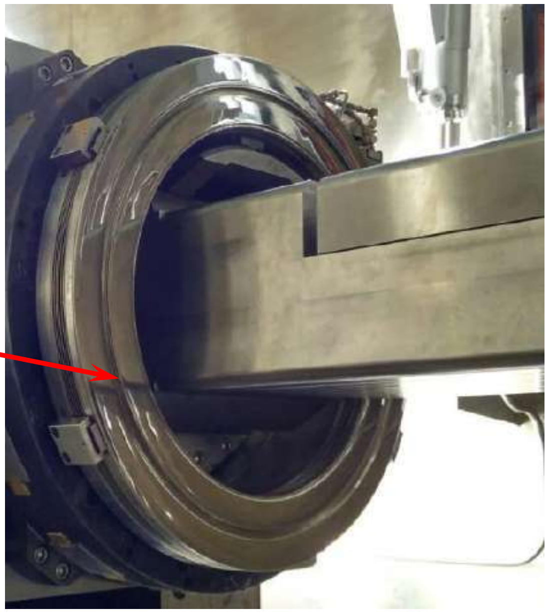
Structure of Pillow seal

**Pillow seal has been successfully applied in CSNS.**

--in Target system: leak-rate 2.5×$10^{-7}$Pa.m$^3$/s.

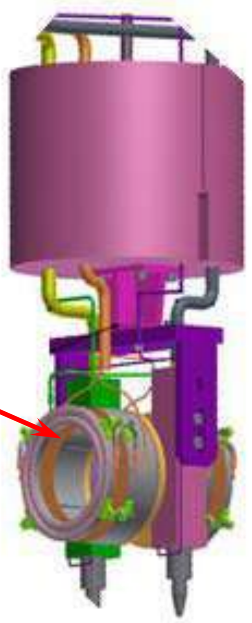
--in Proton Beam Window(PBW): leak-rate 1.0×$10^{-9}$Pa.m$^3$/s

Pillow seal



Pillow seal in Target system

Pillow seal



Pillow seal in PBW

## CEPC Detector Overall Facilities and Hall Issues, Zhu Zian 朱 自安 (IHEP)

**Design points :**

Undergroud experimental hall, surface facilities, detector assembly, utilities, magnetic field leakage, radiations, scheduling, cost performance etc.

**Two IPs/detectors of CEPC :**

Baseline detector : LTS solenoid (3T,$\phi$7.2m x 7.4m,NbTi,4K) outside the calorimeters, TPC

IDEA detector : HTS solenoid (2T,$\phi$4m x 6m,YBCO,4K) inside the dual-readout calorimeters, drift chamber

**Stray magnetic field distribution :**

Magnetic stray field of the baseline(CDR) detector, 50Gaus@20.6m(R),25.5m(Z),
and 28Gauss@the booster ring (R=25m) where the accelerator magnets must be shielded.

**Cavern & Shaft :**

Main cavern (30Hx30Wx40Lm$^3$) experimental hall, 20 and 300t cranes, a $\phi$16m shaft ,1,000t gantry crane

Auxiliary cavern (18Hx18Wx80Lm$^3$) detector service, electronics, power supplies, cryogenics system etc. with a $\phi$9m service shaft and a $\phi$6m personnel access shaft.

**Procedure of large piece down to cavern :**

Biggest and heavy part, the fully assembled and tested solenoid, to be lowered. After landing, only moving longitudinally. A temporarily/middle yoke ring pre-assembled together with the solenoid, weight about 800 tons. To be optimized and improved with yoke assembly procedure

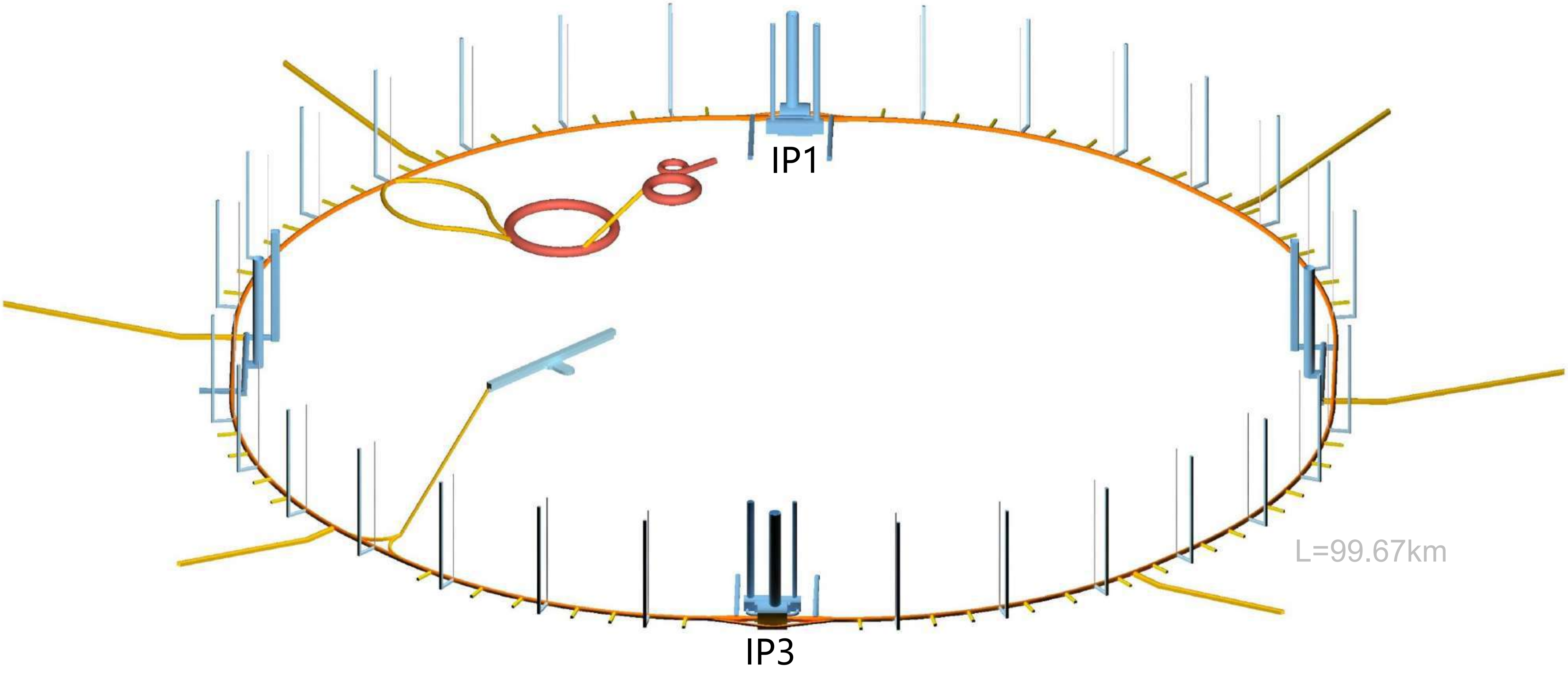
**Ground building (for the surface assembling):**

Magnet assembly hall, cryogenics hall with helium gas tank, gantry crane, sub-detectors assembling and testing hall providing additional advantage of rehearsing the risky operations, water cooling station, gas station and power supply

**Next steps :**

Detailled procedures of piping, cabling, connection between underground and ground facilities and many together with progress of the detector design.

# CEPC layout



本图为华东设计院提供

**Two detectors in IP1/IP3**

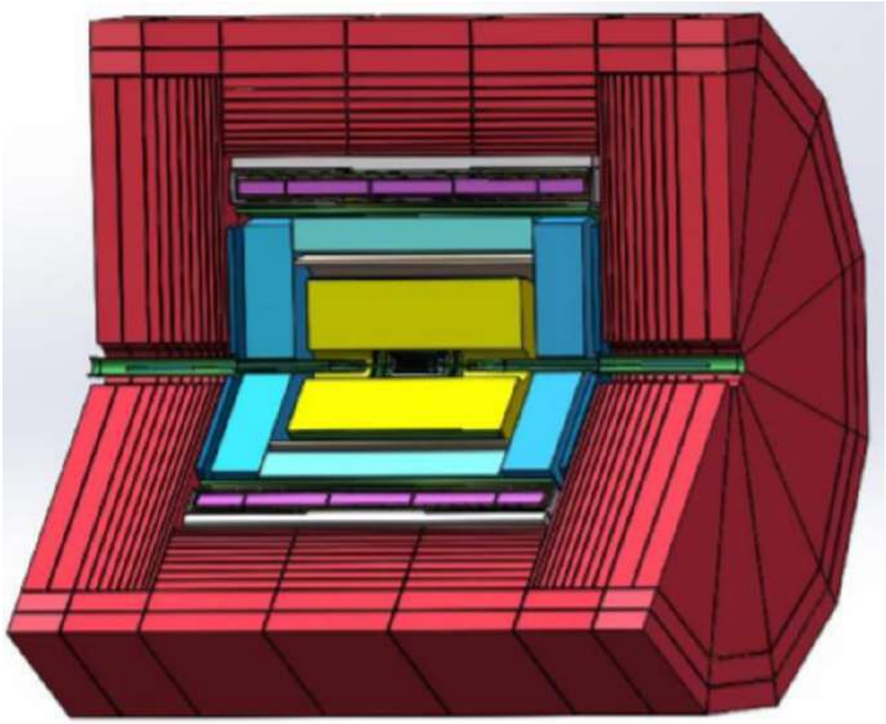
# Two Detectors for CEPC

**LTS Solenoid：**

- Solenoid located outside calorimeter
- Inner diameter 7.2 m, length 7.4 m
- Central field：3 T
- Superconductor：NbTi
- Operation temperature：4.2 K

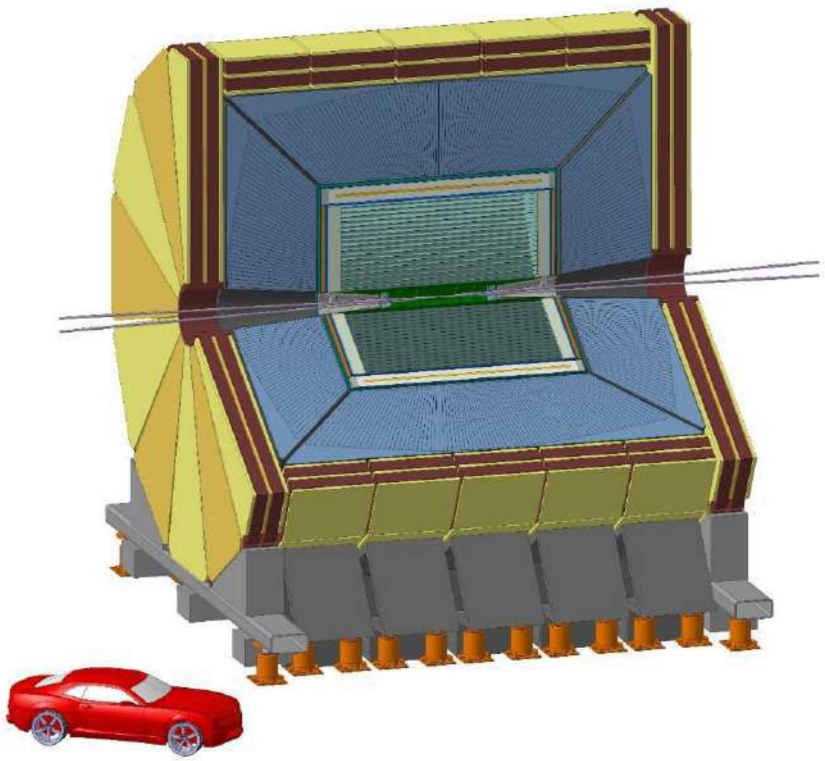
**HTS Solenoid：**

- Solenoid located outside calorimeter/less material
- Inner diameter 4 m, length 6 m
- Central field：2 T
- Superconductor：YBCO
- Operation temperature：20 K



Baseline detector

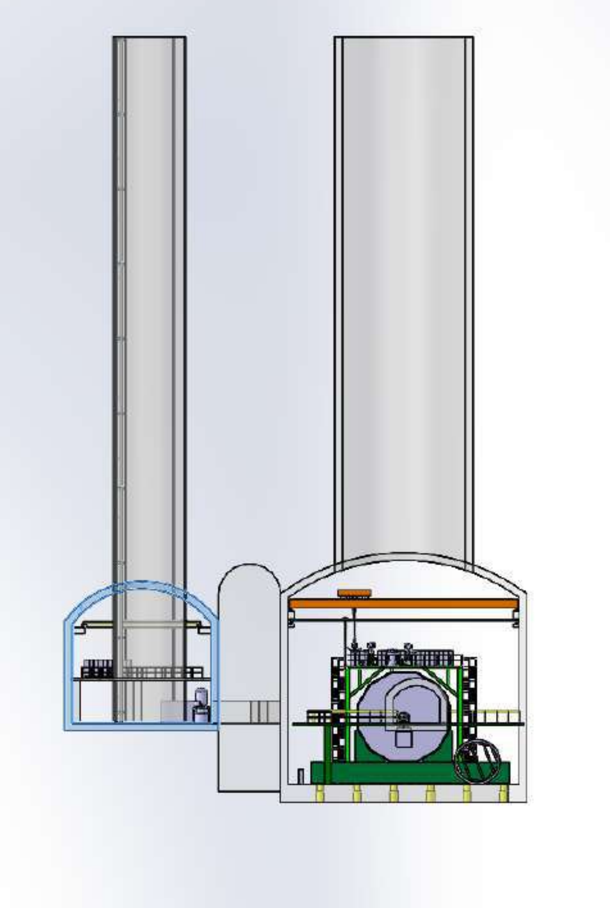
IDEA detector



# Cavern and Shafts

**Main cavern**

- 30*30*40 m(H*W*L)
- Host the detector and front-end electronics
- Host machine devices near colliding point
- Allow detector opening and maintenance
- equipped with two crane, 20 and 300 tons
- One main access shaft, Ø16 m, equipped with a 1000 tons gantry crane, permitting successive installation of the large detector pieces from ground



**Auxiliary cavern**

- 18*18*80 m(H*W*L)
- Parallel to the main cavern, accessible for maintenance during data taking
- One service shaft Ø9 m provides equipment access
- One personnel access shaft Ø6 m
- Electronics and power supply sub-detectors
- Detector working gas buffer and distribution
- Detector magnet power supply and quench protection device
- Cryogenic refrigerator and distribution for superconducting magnet
- Power supply and control cabinet of the machine colliding devices

# Ground building

**Detector assembly and testing Hall:**

- Most of sub-detector assemble and test here in series
- To avoid too many personal crowded in underground cavern
- Provides additional advantage of rehearsing the risky operations
- More convenience for hardware working groups

Layout of ground building around colliding area

**Latest design**

本图为华东设计院提供

## MDI issues of BINP Super TauCharm factory, Anton Bogomyagkov (BINP)

**Parameters :** The beam energy from 1 to 3GeV, circumference 478.092m

$E_{beam}$=3GeV, I=7 x$10^{10}$/bunch, $\beta^*_x$=50mm, $\beta^*_y$=0.5mm, $\varepsilon_x$=10.9nm, $\kappa$=0.5%, $\sigma_z$=10mm, 290bunches

**$2\theta$=60mrad,** single IP, luminosity=1.1 x$10^{35}$cm$^{-2}$s$^{-1}$ , ($\sigma^*_x$ =20$\mu$m, $\sigma^*_y$=165nm), L*=0.905m

**MDI area :** All accelerator equipment should be **inside 175 mrad cone**

Region 1: FF quadrupoles, solenoids, correctors, flanges, bellows, RVC, HOM absorbers...

Region 2: solenoid nonlinear fringe fields, a need for screening and correction

FF vacuum chamber: Be-tube(±150mm, $\phi$30mm, cooled), Y-chamber(cooled), BPMs)

Cryostat with FF magnets : Compensating coil, QD0 100T/m, 200mm length, correction coils,
QF1 45T/m, 300mm length with screening solenoid

**FF quadrupole : iron yoke double aperture SC :**

No field cross-talk between apertures but no additional coils for symmetry required

prototype made

**Vacuum chamber : design and testing for the thermal load of 100W/m**

From room temperature beam chamber to cryogenic temperature magnet

Minimizes the number of bellows, high-frequency contacts, cold-warm transitions,
simplifies removal of the heat

**Remote vacuum connector (RVC) :** R&D with successful result, leak rate < 1 x$10^{-10}$ mbar($10^{-8}$Pa) L/s

Assembling with and without RVC as SuperKEKB/Belle II and DAΦNE/KLOE, respectively

**DAΦNE/KLOE like assembling w/o RVC is proposed**

**Two type of compensation coils, i.e. cylindrical and elliptical shapes :**

Cylindrical layout provides insufficient vertical emittance blow up (23 pm)

Elliptical layout has no emittance blow up

Both schemes fit inside the 175 mrad cone

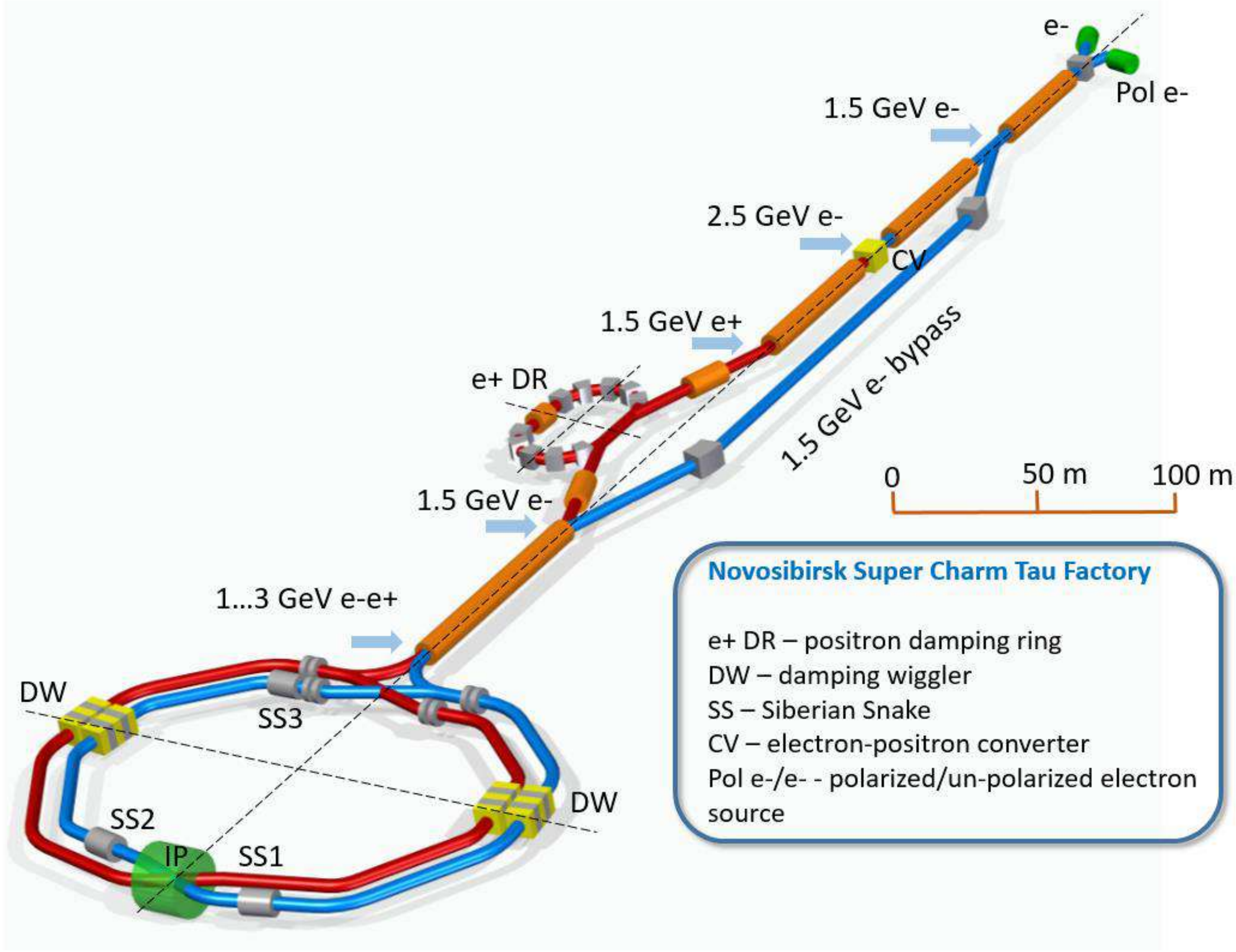
Elliptical schemes has smaller fields in the quadrupoles area and more compact but more complicated

# Parameters

*) Two superconducting wigglers with 3.5 T and 1.5 m long to reduce damping time from $\tau_x$ = 300 ms to $\tau_x$ = 100 ms

| **E(MeV)** | **1000*** | **1000** | **1500** | **2000** | **3000** |
|---|---|---|---|---|---|
| **$\Pi$(m)** | 478.092 | | | | |
| **$F_{RF}$(MHz)** | 349.9 | | | | |
| **q** | 558 | | | | |
| **$2\theta$(mrad)** | 60 | | | | |
| **$\kappa$ (%)** | 0.5 | | | | |
| **$\beta_x^*$(mm)** | 50 | | | | |
| **$\beta_y^*$(mm)** | 0.5 | | | | |
| **$\alpha \times 10^4$** | 9.77 | | | | |
| **I(A)** | 1 | 1 | 2.2 | 2.2 | 2 |
| **$N_{e/bunch} \times 10^{-10}$** | 2.1 | 2.1 | 4.5 | 5.2 | 7 |
| **$N_b$** | 500 | 500 | 490 | 420 | 290 |
| **$U_0$(keV)** | 11.7 | 11.7 | 59.3 | 187.4 | 948 |
| **$V_{RF}$(kV)** | 1000 | 1000 | 600 | 1000 | 2000 |
| **$\nu_s$** | 0.0093 | 0.0093 | 0.0059 | 0.0065 | 0.0072 |
| **$\delta_{RF}$(%)** | 3.4 | 3.4 | 2 | 2 | 1.7 |
| **$\sigma_e \times 10^3$** | 1 | 1.2 | 0.9 | 0.8 | 9.6 |
| **$\sigma_s$(mm)** | 7.9 | 9.5 | 11 | 8.8 | 10 |
| **$\varepsilon_x$(nm)** | 11.3 | 16.3 | 8.8 | 7 | 10.9 |
| **$L_{HG} \times 10^{-35}\left(cm^{-2}s^{-1}\right)$** | 0.21 | 0.14 | 0.8 | 1.3 | 1.1 |
| **HG (%)** | 76 | 72 | 79 | 82 | 77 |
| **$\xi_x$** | 0.0042 | 0.0029 | 0.0031 | 0.0042 | 0.003 |
| **$\xi_y$** | 0.06 | 0.04 | 0.07 | 0.085 | 0.054 |
| **$\varphi$** | 10 | 10 | 16 | 14 | 13 |
| **$\tau_L$ (s)** | 3245 | 4968 | 1803 | 1080 | 1197 |

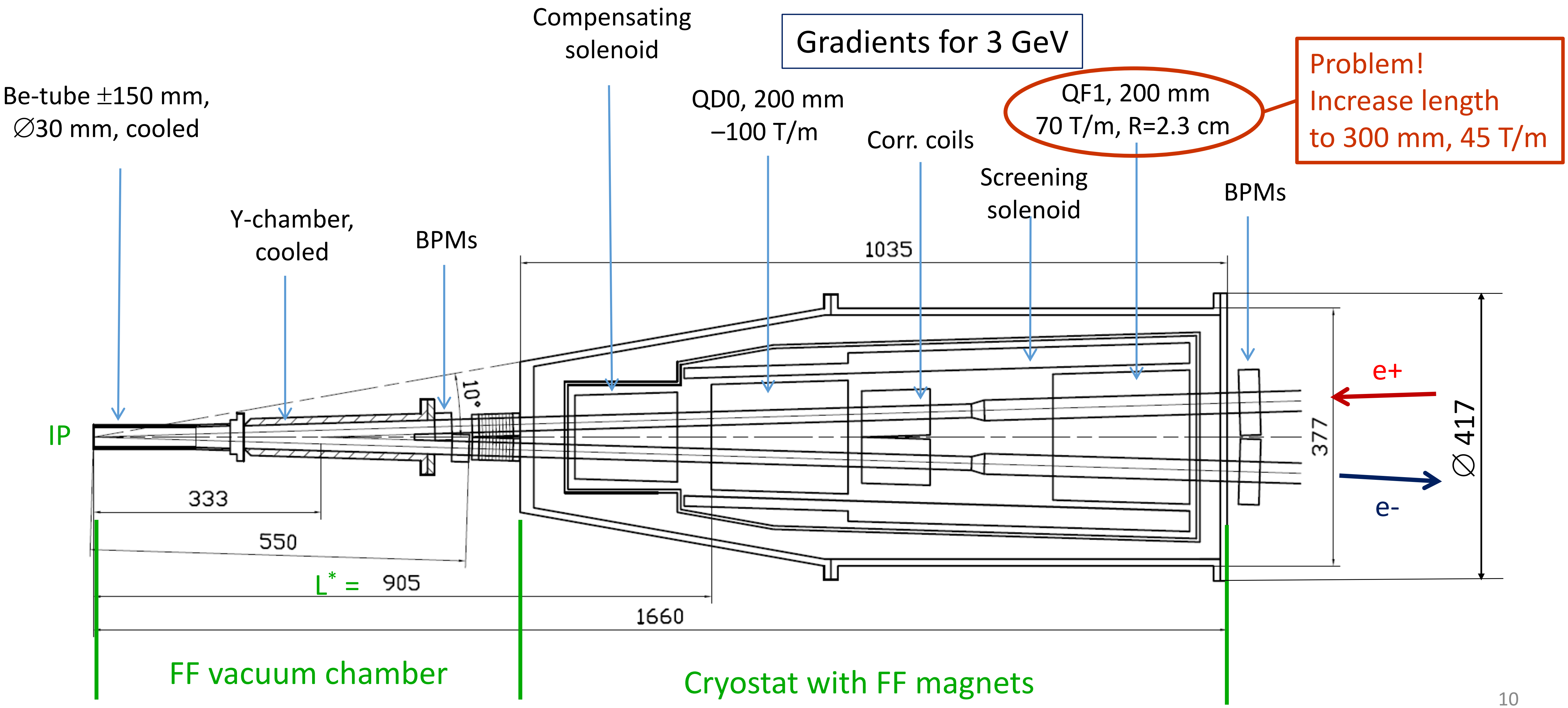
# The whole facility



**Novosibirsk Super Charm Tau Factory**

e+ DR – positron damping ring
DW – damping wiggler
SS – Siberian Snake
CV – electron-positron converter
Pol e-/e- - polarized/un-polarized electron source

# Machine-detector interface



Gradients for 3 GeV

Be-tube ±150 mm, ∅30 mm, cooled

Y-chamber, cooled

BPMs

Compensating solenoid

QD0, 200 mm –100 T/m

Corr. coils

Screening solenoid

QF1, 200 mm 70 T/m, R=2.3 cm

Problem! Increase length to 300 mm, 45 T/m

BPMs

IP

e+

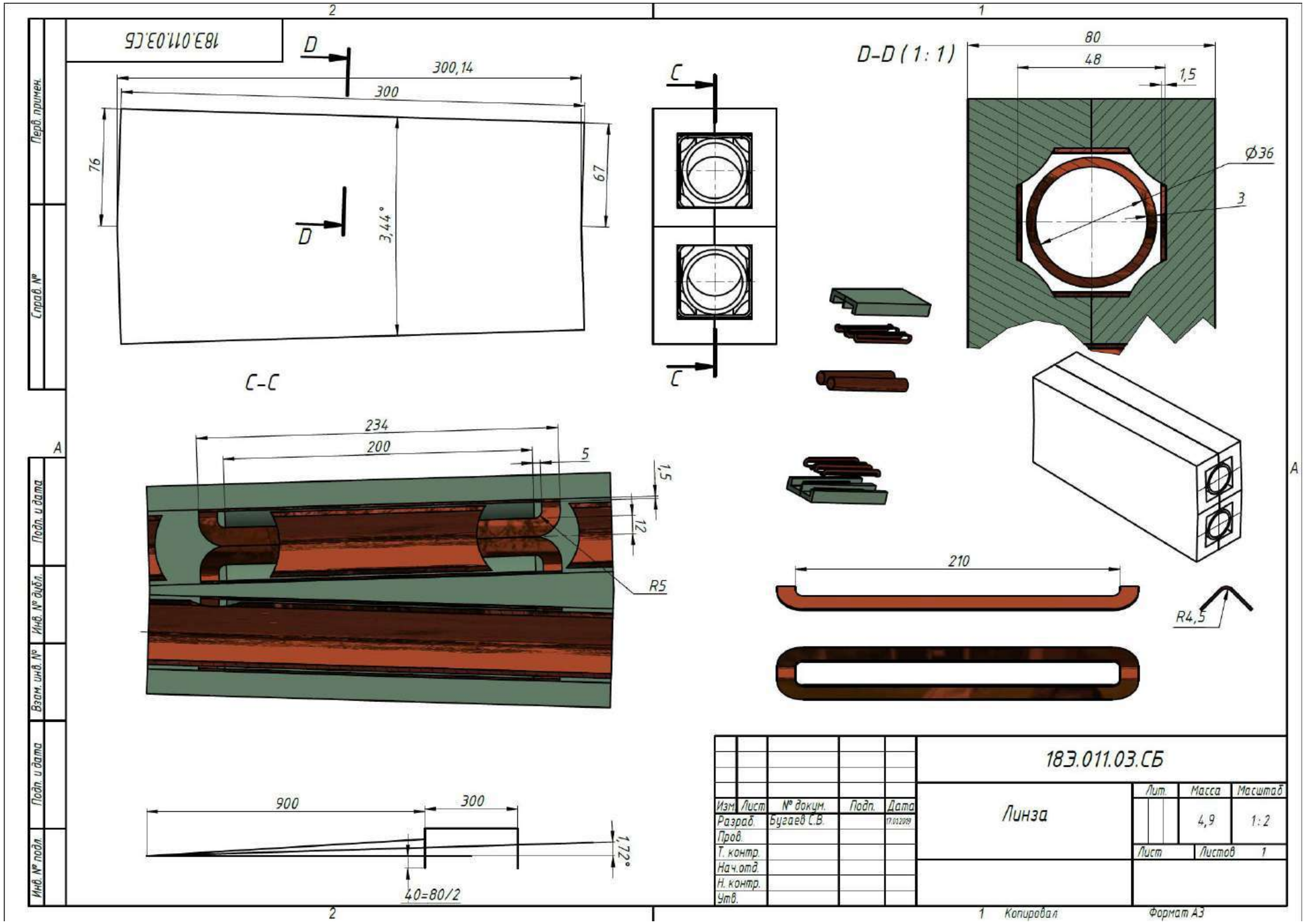
e-

$L^* =$ 905

FF vacuum chamber

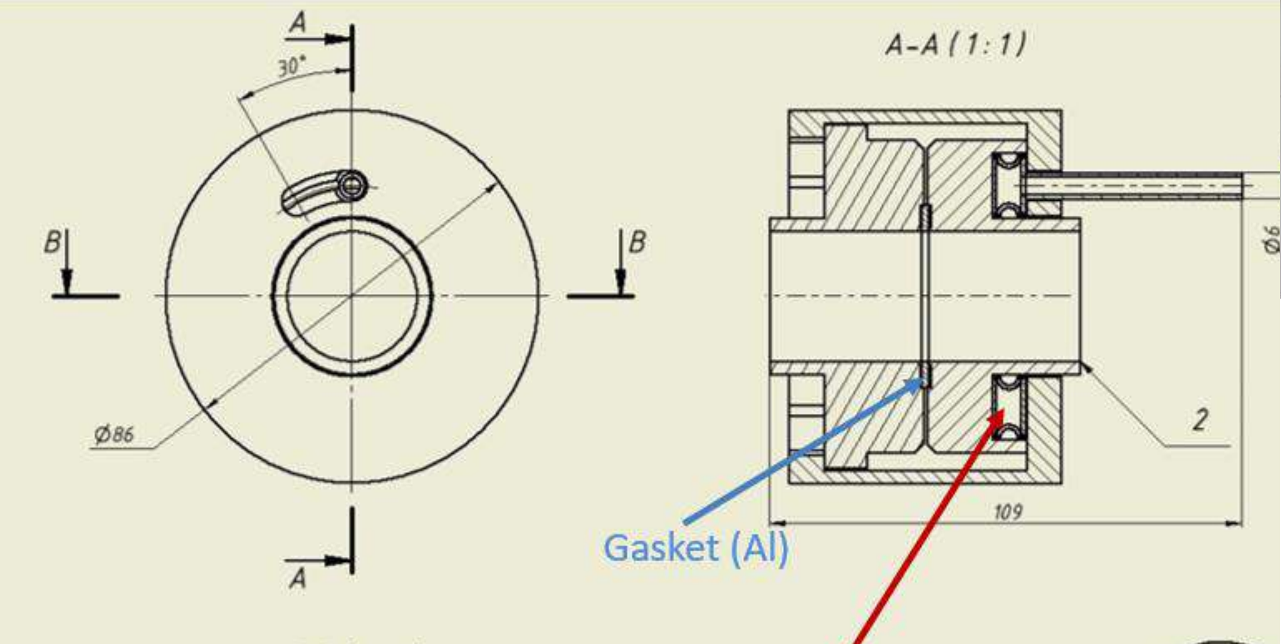
Cryostat with FF magnets

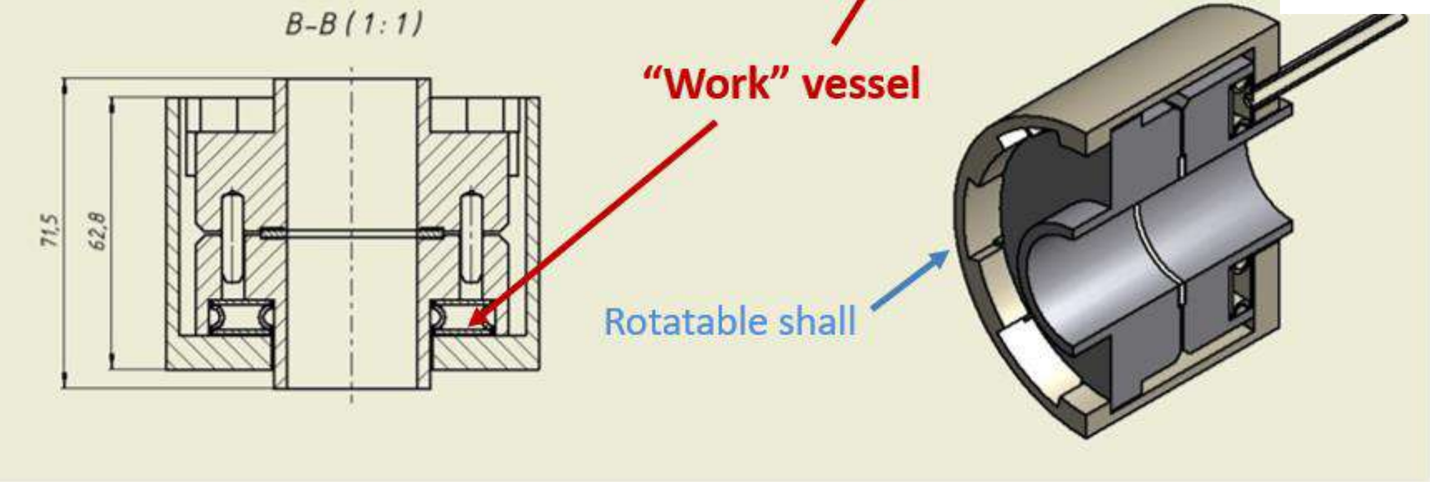
# FF quadrupole prototyping



Dual aperture superconducting quadrupole: G=100 T/m, L=200 mm, R=45 mm

# Remote vacuum connector (RVC)





**Parts of the flange connection**

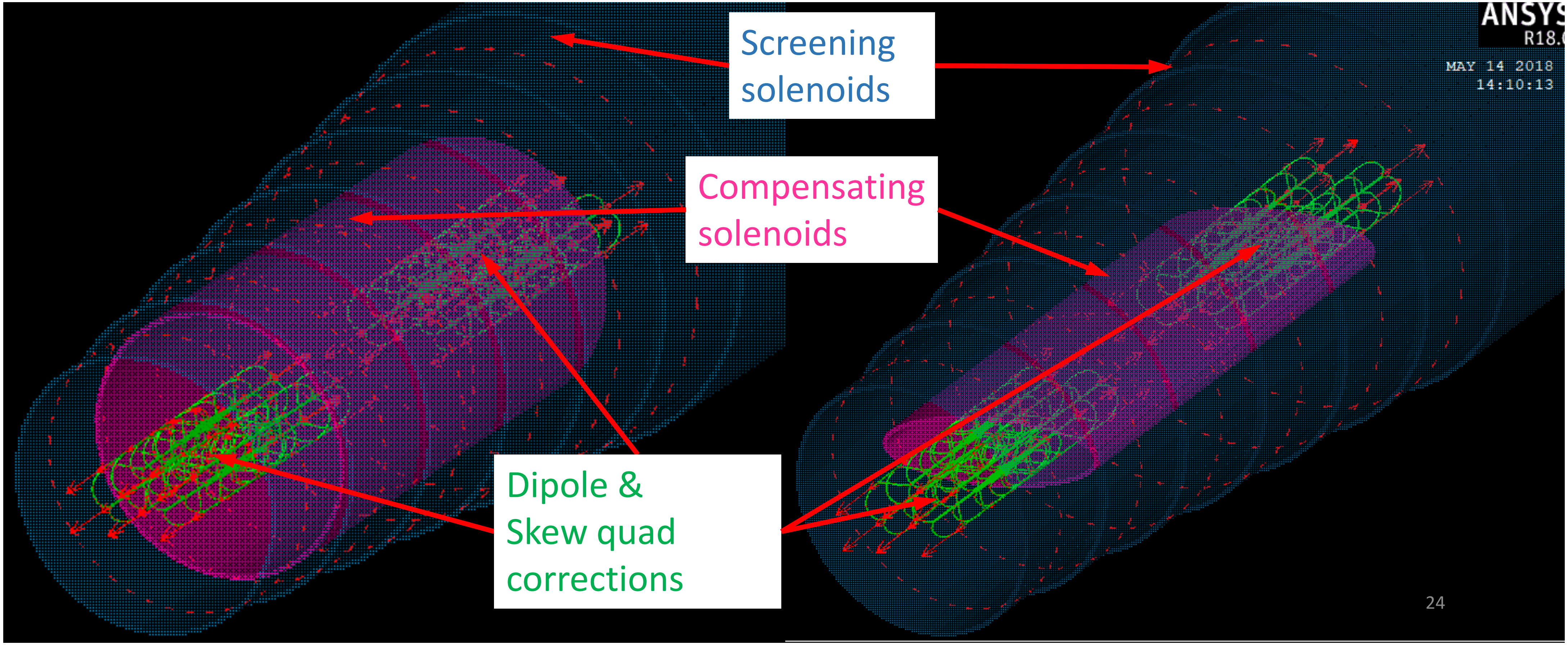
**Assembled connection**

- We've got successful result with Cu and Al gaskets at pressure 150 atmosphere. Leak rate is less than 1E-10 mbar*L/s.
- Note, the connection keeps smoothness of internal surface along beam propagation

# Detector field compensation: elliptical

-Cylindrical for a both beams

-Elliptical for a both beams



Screening solenoids

Compensating solenoids

Dipole & Skew quad corrections

# Overview of MDI at FCC-ee, Michael Koratzinos (CERN)

**Introduction :** Definition of MDI and its importance with some specifics for the circular colliders

**Requirements at the IP, FCCee, which should be realized with technical solutions :**

1. Accelerator magnetic elements **< 110mrad**; 2. Integrated field seen by the beam = 0

3. Small vertical emmittance growth due to fringe fields; 4. FFQ in a zero-field; 5. Field errors of FFQ < $1\times10^{-4}$

**Solutions :** 4. Screening solenoids; 3. Compensating solenoid; 5. Two **CCT**-FFQs; 2. OK by tuning

**Baseline solutions/designs, L*=2.2m and the horizontal crossing angle of 30mrad:**

Luminometer in front of the magnetic elements, i.e. the compensating solenoid at 2m form IP

FFQ located in the integrated solenoid field < 50mTm surrounded by the screening solenoid

**The detector solenoid field, 2T or 3T with respect to the emittance blow up $\Delta\varepsilon_y \propto B_{det}^5$ :**

The emittance blow up from 2IPs is 0.4pm at 2T, it is 3pm at 3T (the budget 1pm). Luminosity→ 1/1.7

**Final focus quadrupole with a canted-cosine theta (CCT,double helix) design, iron-free also :**

All the requrement are satisfied ! CCT consists of two layers of helical coils to cancel out the solenoid fields "the multipole mix is a local property of the magnet, which can vary along its length. This is not possible with a traditional design. "

**QC1L** 100T/m,1.2m length, 40mm aperture (fits the warm water-cooled beam pipe of inner diameter 30mm) the integrated multipoles of < 0.1 units of $10^{-4}$. The edge effects can be compensated by the first two turns.

**FF prototype :**

CCT is a relatively new idea in magnet design, and never one has been built with compensation.

→ the FCC FF quad prototype project, the first prototype was made and just in time for Chistmas 2019!

There was **a warning message from SuperKEKB ( K.Oide, 26/6/2019)**;

"The final quads and solenoids must be robust enough against beam losses. Esp. thin corrector windings. …"

**LumiCal :** W+Si sandwich: 3.5 mm W + Si sensors in 1 mm gaps, 25 layers ($25X_0$), 1074 < z < 1190 mm

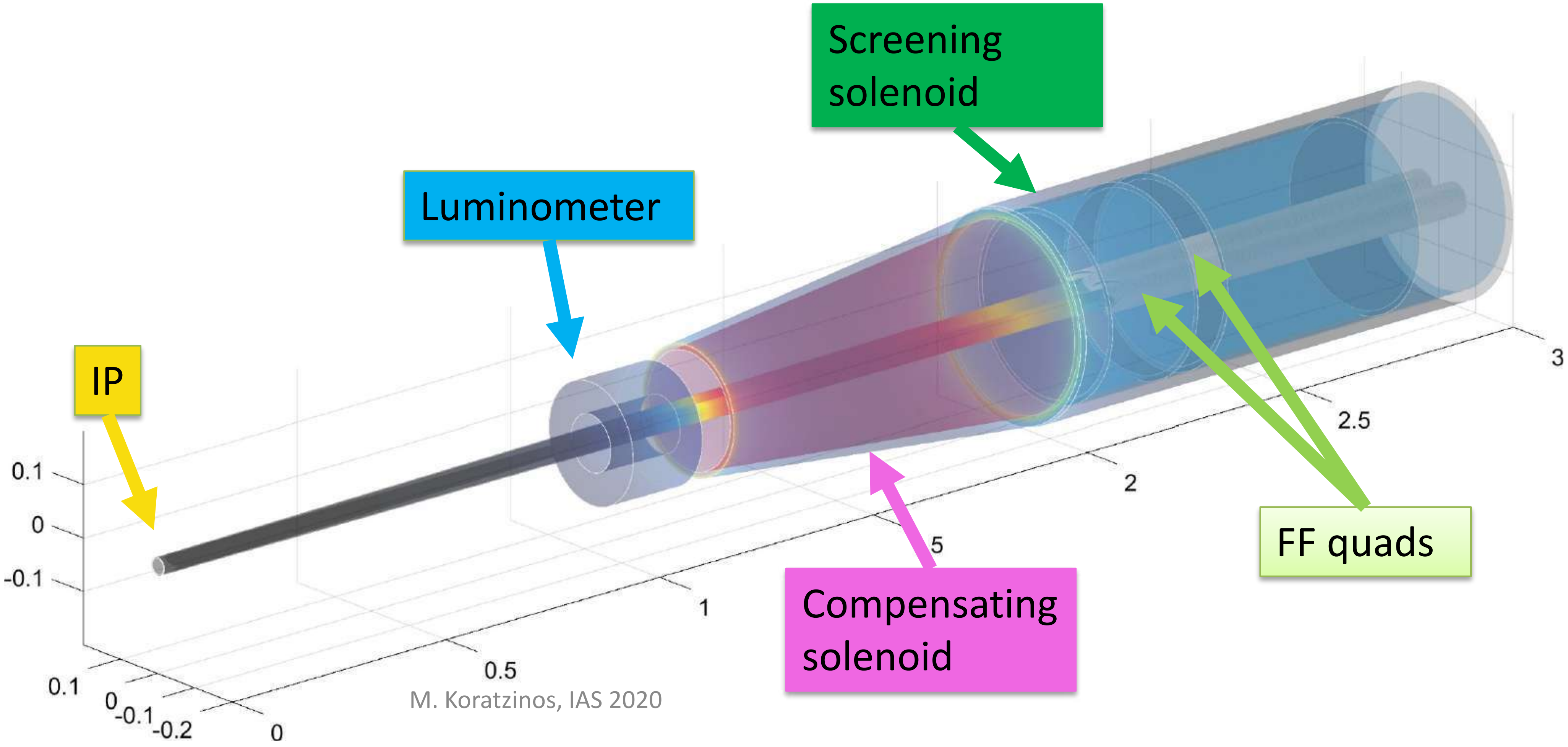
**Beampipe**, HOM absorbers, BPM, remote flange, bellows :

**FF quads assembly** in thin cryostat using a stiff skelton for $\theta$<110mrad,and the cantilever support (4.37m)

# The FCC-ee baseline solution

- L* = 2.2m; 30mrad opening angle between beamlines
- Luminometer needs to fit in front of magnetic elements and as far back as possible to have a decent rate
- FF quads sit in a zero longitudinal field region (integral of solenoid field <50mTm ) encompassed by a screening solenoid which needs to extend to L* of 2.0m
- A compensating solenoid must sit between the screening solenoid and luminometer to ensure an integral field of zero

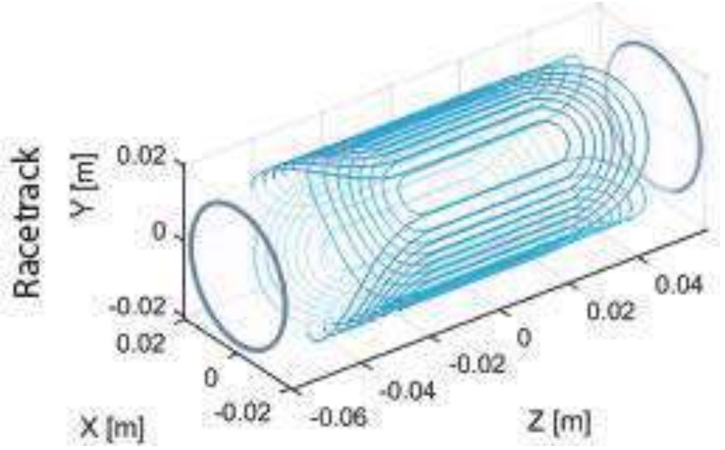
This is the design with the minimum number of magnetic elements.



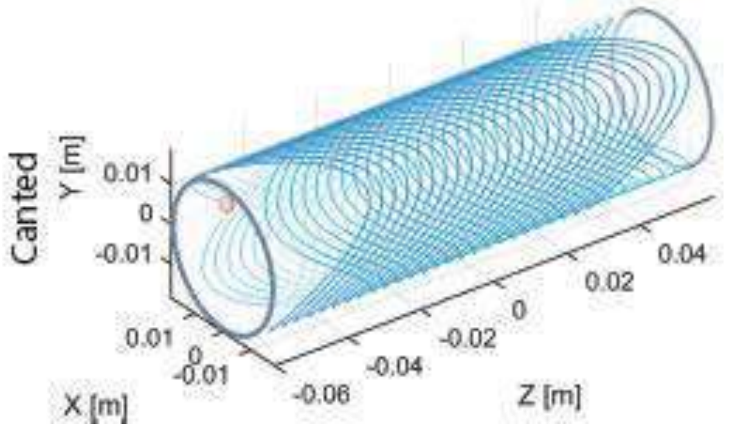
Unlike linear colliders, we are facing the challenge of FF quads inside the detector!

# What is a CCT magnet (a.k.a. “double Helix”)?

**Conventional**



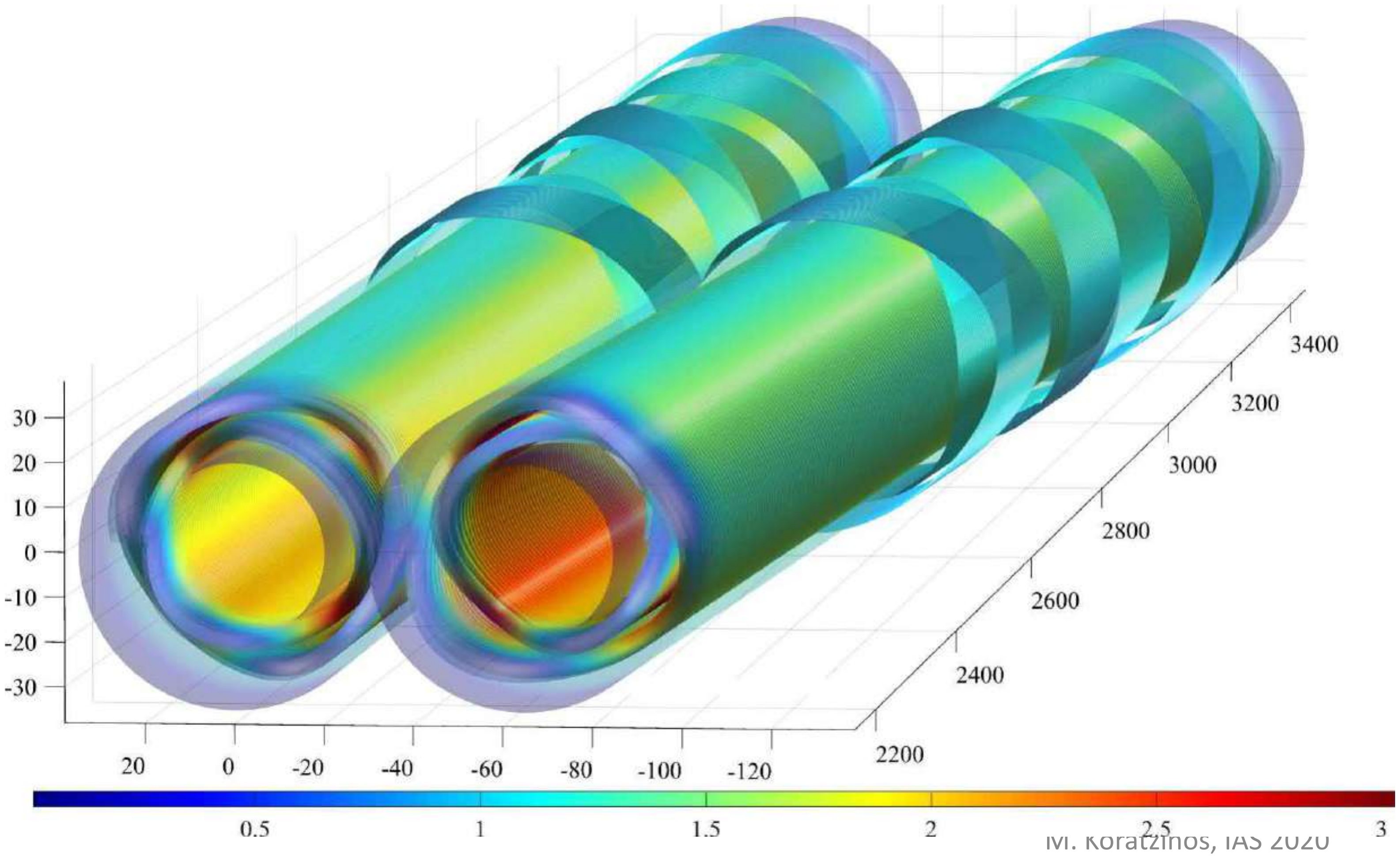
**CCT (Double Helix)**

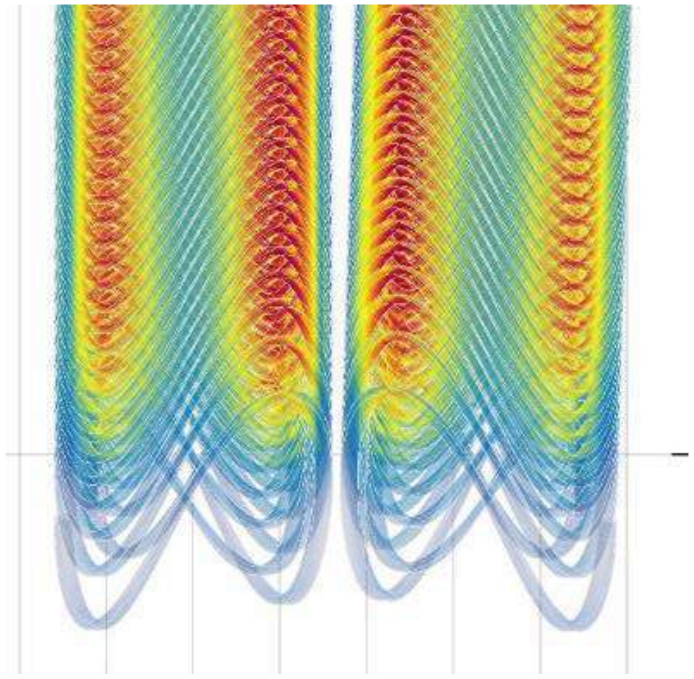


- Novel idea (discovered in the 70ies, but gained momentum recently with the advent of CNC manufacturing and 3D printing)
  - Excellent field quality
  - Engineering simplicity: no pre-stress; fast prototyping
  - Simpler and cheaper than conventional designs
  - But: more conductor for same field compared to conventional design

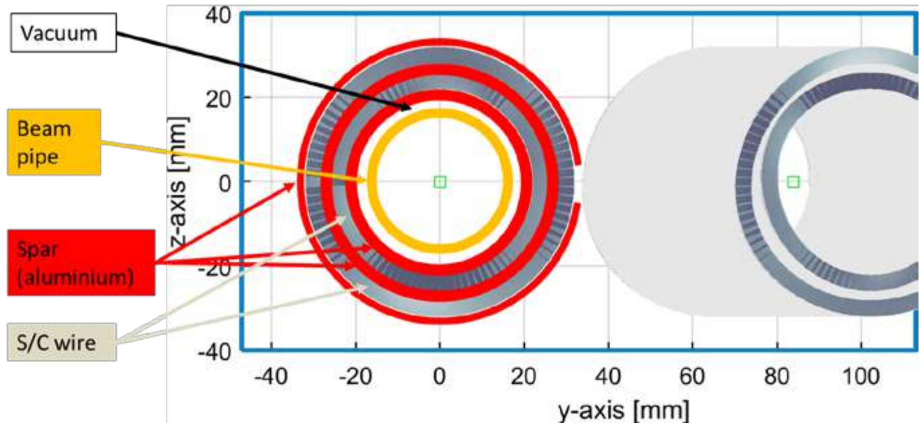
# QC1L1

QC1L1 is the first and most demanding pair of quadrupoles of the final focus system of FCC-ee





Inner bore: 40mm (diameter)
Fits outside the warm water-cooled beam pipe of inner diameter 30mm



# …just in time for Christmas!

# (Selected) MDI Issues of ILD, Roman Pöschl (IJClab)

**Introduction :** ILC project, Physics program(Z to 1TeV), Detector requrements, ILC250 status

**Requirements at the IP for the pushpull operation of two detectors:**

Self-shielding against radiations and the stray magnetic field of < 50Gauss at the garage position (15m apart)

The detector is very hermetic covering down to $\theta$=5mrad ( BeamCal is the most forward detector ).

**Beams :** Train of ~1msec at 5Hz, 1 train=1312 x 554ns, 2 x$10^{10}$/bunch, $\sigma_Z$=300$\mu$m, Pol.$e^-/e^+$=80/30%

The horizontal crossing angle of 14mrad, L*=4.1m common for the two detectors, QD0 inside of the detector with QD0EX1(extraction) and SD0(sextupole) for the local chromaticity correction scheme

**QD0 :** Superconducting, actively shielded so no compensating solenoid by Brett's design

**Study of development of vacuum since the TDR, especially L*= 4.4m → 4.1m :**

Effects of the vacuum pumps(120L/s) removal were studied; 20 times worse but recovered by NEG coating

Beam gas background much smaller than pair induced background, so even 100nTorr can be tolerable.

**ILD solenoid magnet, iron yoke :** 3.5T and can be up to 4.5T

Thinner yoke for the cost reduction, -20%@60cm iron off, -50%@2m iron off , but the radiation ?

increasing stray fields 93Gauss@15m 1,000Gauss@15m→ 50Gauss w/ shielding wall

**Anti-DID ( max. 360 Gauss dipole field ) integrated in the solenoid to reduce backgrounds :**

The magnetic fields are aligned to the out-going/extracting beam together with low-energy pair particles

**Power pulsing operation for the detector electronics :**

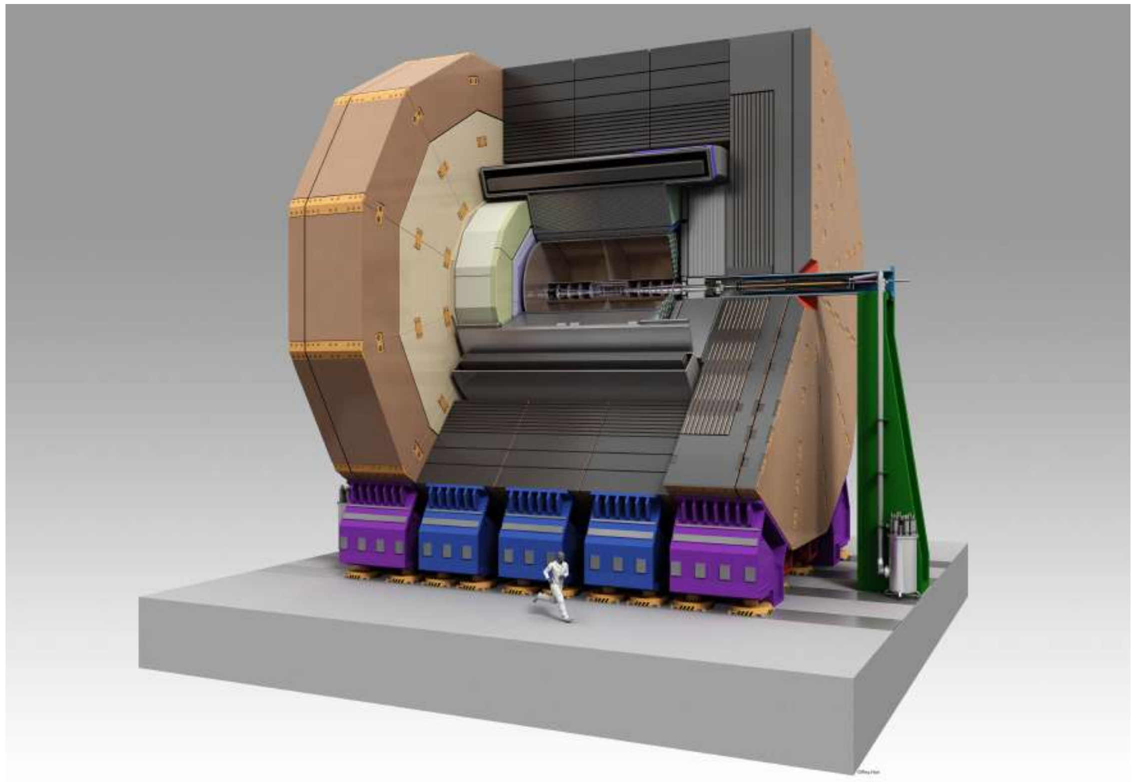
Electronics switched on during > ~1ms of ILC bunch train and data acquisition while bias currents shut down between bunch trains. Mastering of technology is essential for operation of ILC detectors

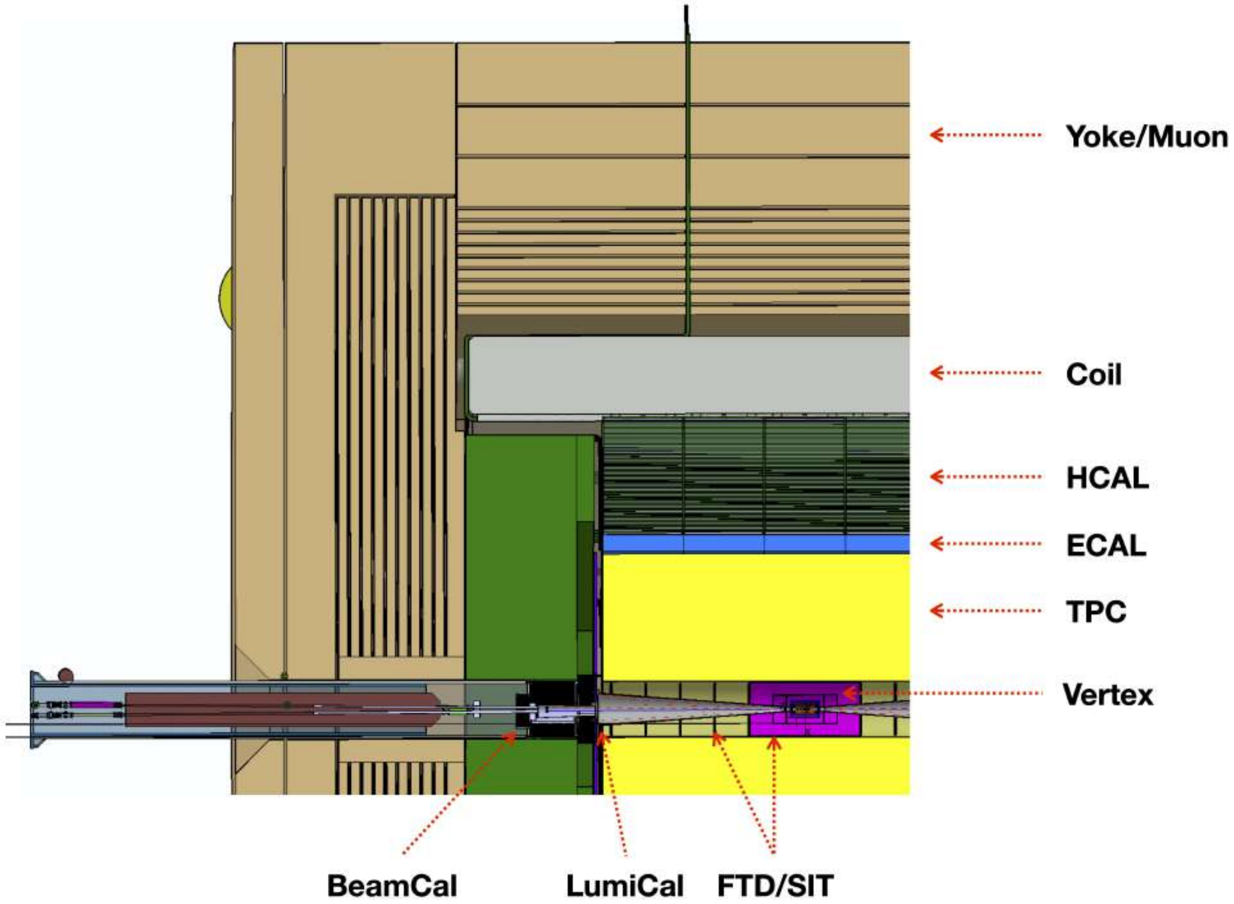
Total power consumptions are 982kW underground and 2450kW on surface ( current estimations )

**Cabling scheme :**

Extraction of cables from the inner detectors with minimum gaps and for opening endcaps without disconneting the cables , the locations of patchpanels are important in very limited spaces.

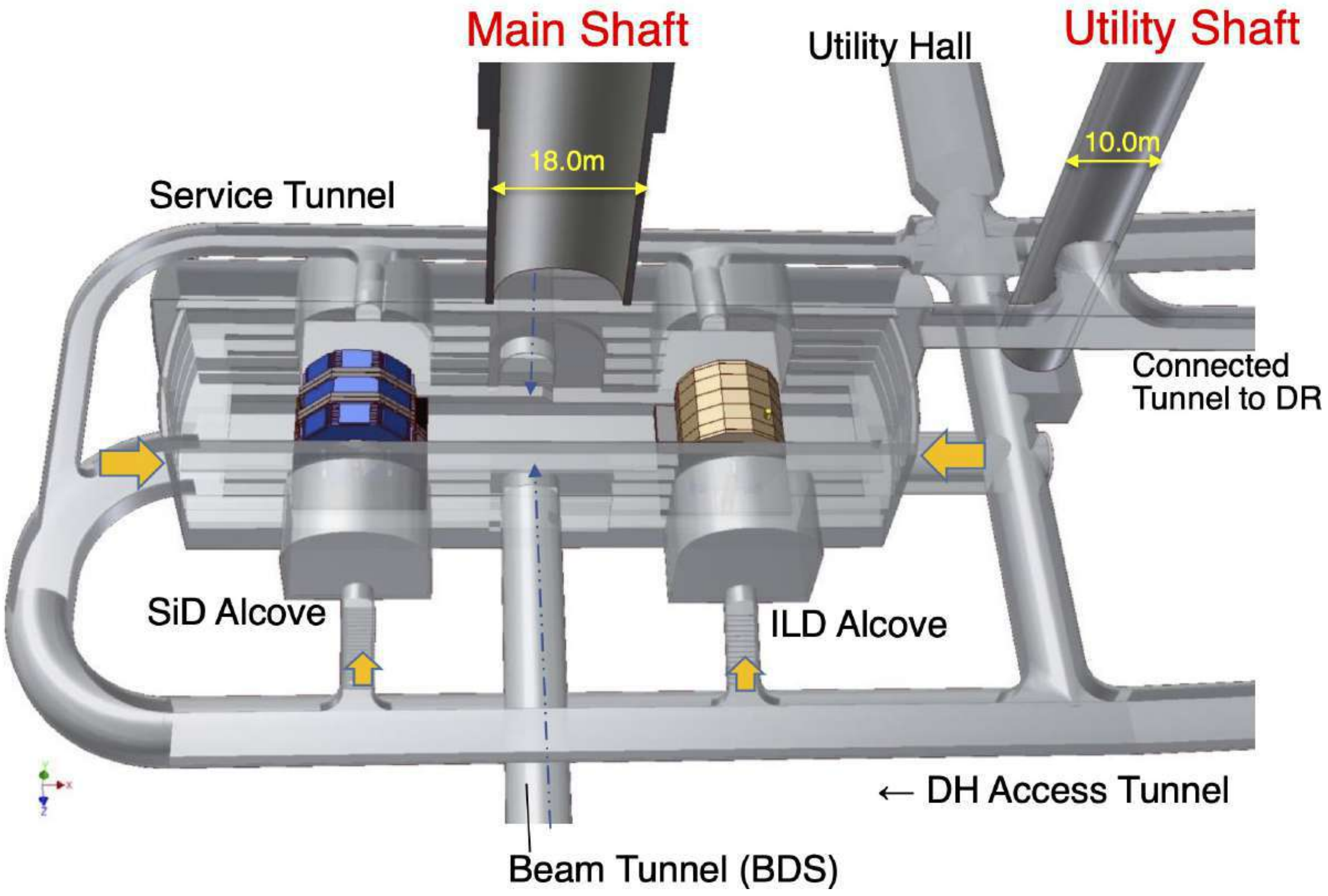
# The ILD Detector



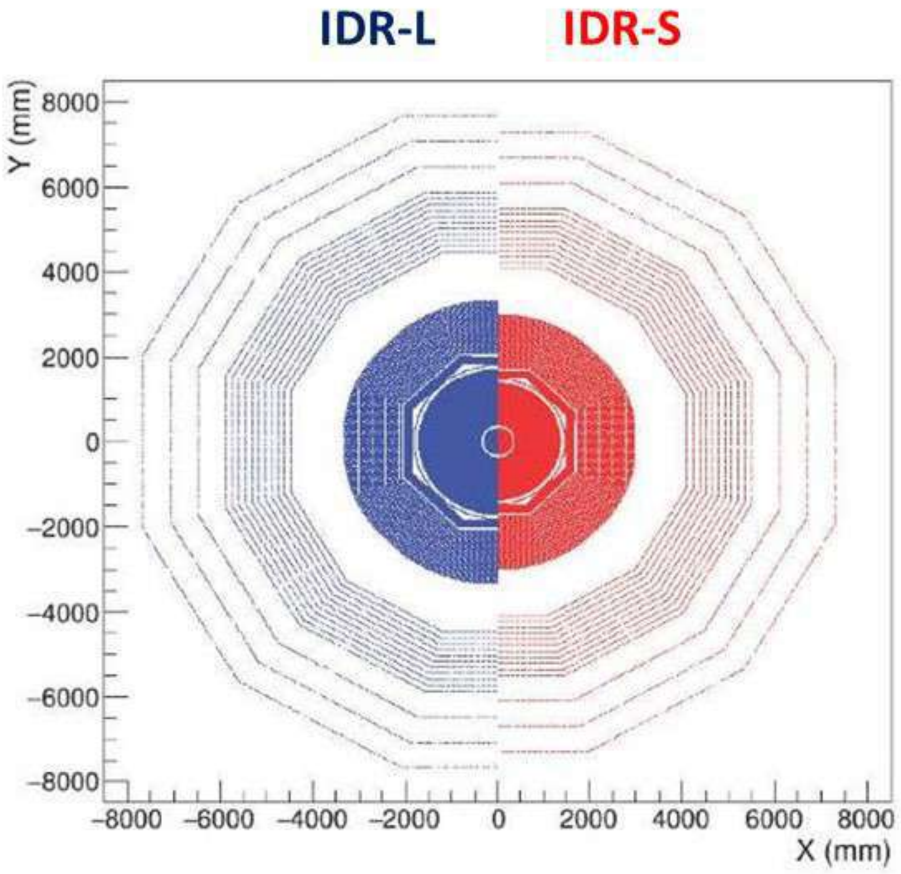


- Relevant for MDI: B-Field of 3.5-4 T and integrated dipole QD0
  - Integrated dipole moves with detector
  - More details in following slides

# Push Pull and site related infrastructure



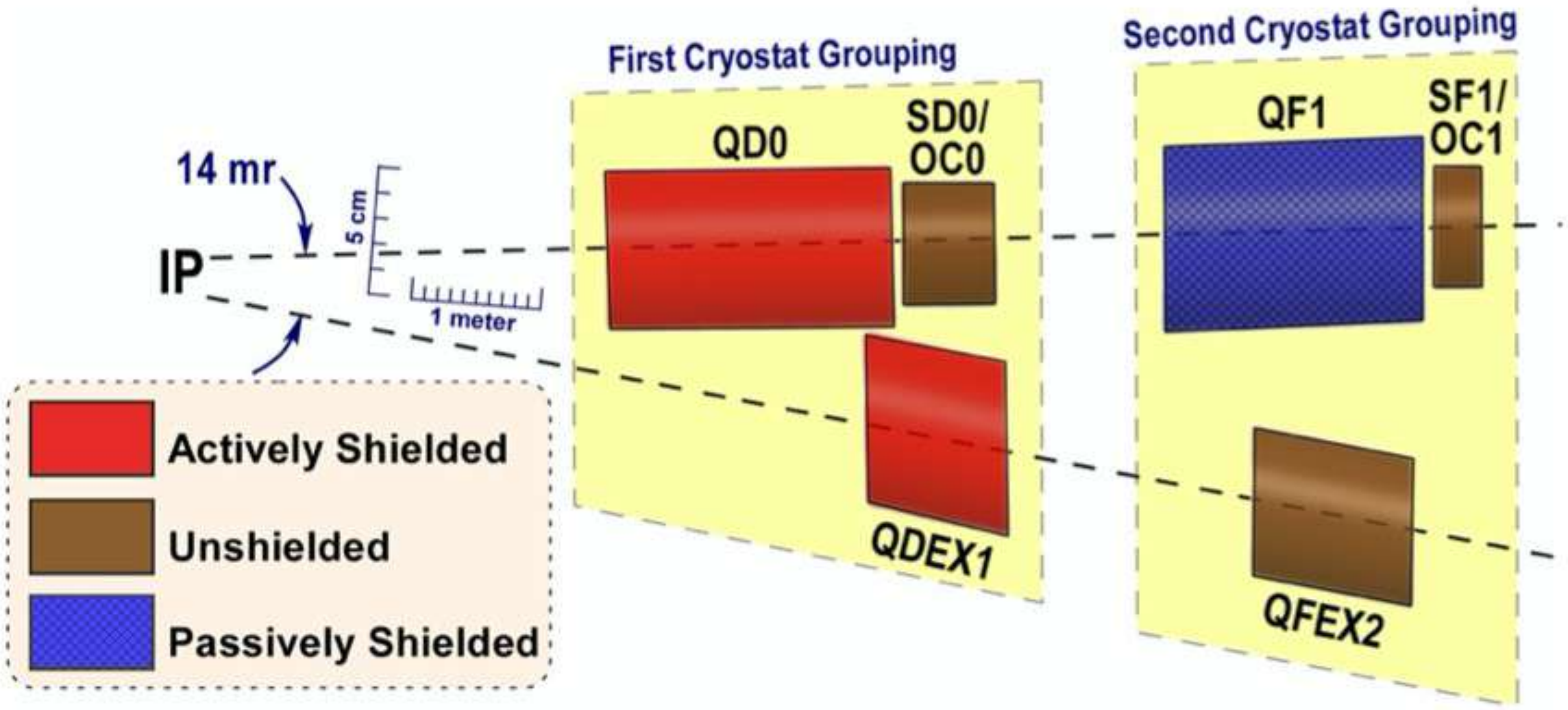
# “Large” and “Small” ILD Detector



| Detector | IDR-L | IDR-S |
|---|---|---|
| B-field | 3.5 T | 4 T |
| VTX inner radius | 1.6 cm | 1.6 cm |
| TPC inner radius | 33 cm | 33 cm |
| TPC outer radius | 177 cm | 143 cm |
| TPC length (z/2) | 235 cm | 235 cm |
| ECAL inner radius | 180 cm | 146 cm |
| ECAL outer radius | 203 cm | 169 cm |
| HCAL inner radius | 206 cm | 172 cm |
| HCAL outer radius | 335 cm | 300 cm |
| Coil inner radius | 342 cm | 308 cm |

Different outer TPC radii – Different magnetic field values

# From machine to detector – The “last step”



- Beams collide under 14mrad crossing angle
- Focusing into the interaction region with final doublet QD0 and QF1
  - QD0 is part of detector (ILD) and QF1 is part of the machine
  - See more details on final focus magnets in talk by B. Parker

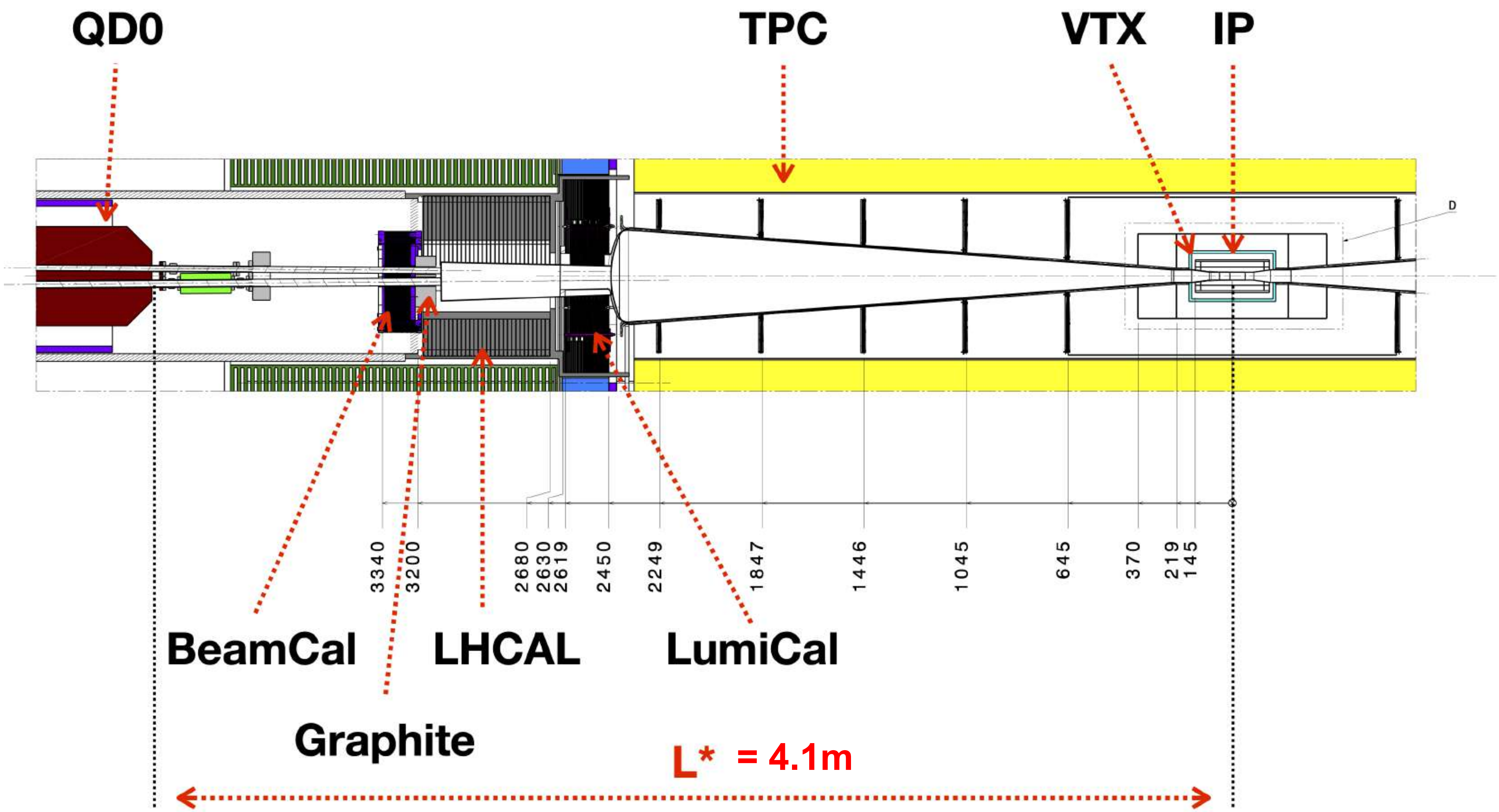
# Vaccum in IP region for different configurations

| | | | | | |
|---|---|---|---|---|---|
| DP0 + IP | Pumps IP 120 l/s | Without baking | 5,6 nTorr | $H_2O$ | initial |
| DP0 + IP | No pumps IP | Without baking | 120 nTorr | $H_2O$ | DP0 and IP volume not separated / Length reduction |
| DP0 + IP | Neg coating | Baking IP | 0,23 nTorr | $H_2$/ $H_2O$ | Length reduction |
| DP0 + IP | Neg satured | Baking IP | 1,4 nTorr | $H_2O$ / $H_2$ | Length reduction |

- Without pump vacuum in IP region around ~20 times worse than with pump
  - Excellent vacuum could be recovered with NEG coating
  - ... at the expense of the need for baking of the beam pipe to activate the NEG ~100h at 180° C

*IJCLab*

# Current design of ILD Forward Region



# ILD Background Studies at ILC, Daniel Jeans (KEK)

**Introduction of ILD detector :** large (TDR baseline) and Small option

TPC, the vertex detector of silicon pixels surrounded by silicon strips, calorimeters (FCAL, ECAL, HCAL)

**Beamstrahlung :** Low energy incoherent pairs are generated by the beam beam interactions.

The high $p_T$ tail can directly reach the inner detectors, and the vast majority have low $p_T$ and “follow” the B-field lines. Some of them hit the BeamCal then generate the seconday backgrounds

The anti-DID field (field in x-direction) is rather complex system.

Is it needed？ How big is its effect on detector backgrounds？

**Simulate beamstrahlung pairs at ILC-250 with ILD Geant4-based simulation :**

Using the detailed field maps of the 3T solenoid/yoke, with and without anti-DID field, where the use of anti-DID better centres distribution on outgoing beampipe and reduces total energy deposit

“Direct” hits by particles directly coming from IP and the seconday particles, which are distingushed by the hit time in the simulation, “early” and “late” for the direct and the seconday backgrounds

The VTX hits : the anti-DID reduces “late” hits by 1/3 ~ 1/4 in all the layers, 40% reduction in total hits

THe TPC hits : according to TPC experts, it looks manageable.

( TPC is sensitive to the back-scattered Xrays also. )

we have not yet concluded if we need anti-DID, but we have information with which to decide...

**Beamline muons :** Muon production and transportation are simulated by L. Keller, G. White @ SLAC.

Muons are produced at the upstream collimators by hitting the **halo** particles in the beam of **0.1%** assumed.

They are reduced by 5 toroidal spolilers (ϕ1.4m x 5m) w/ or w/o a muon wall ($5.2 x 5 x 5 m^3$).

Question: is the muon wall needed？

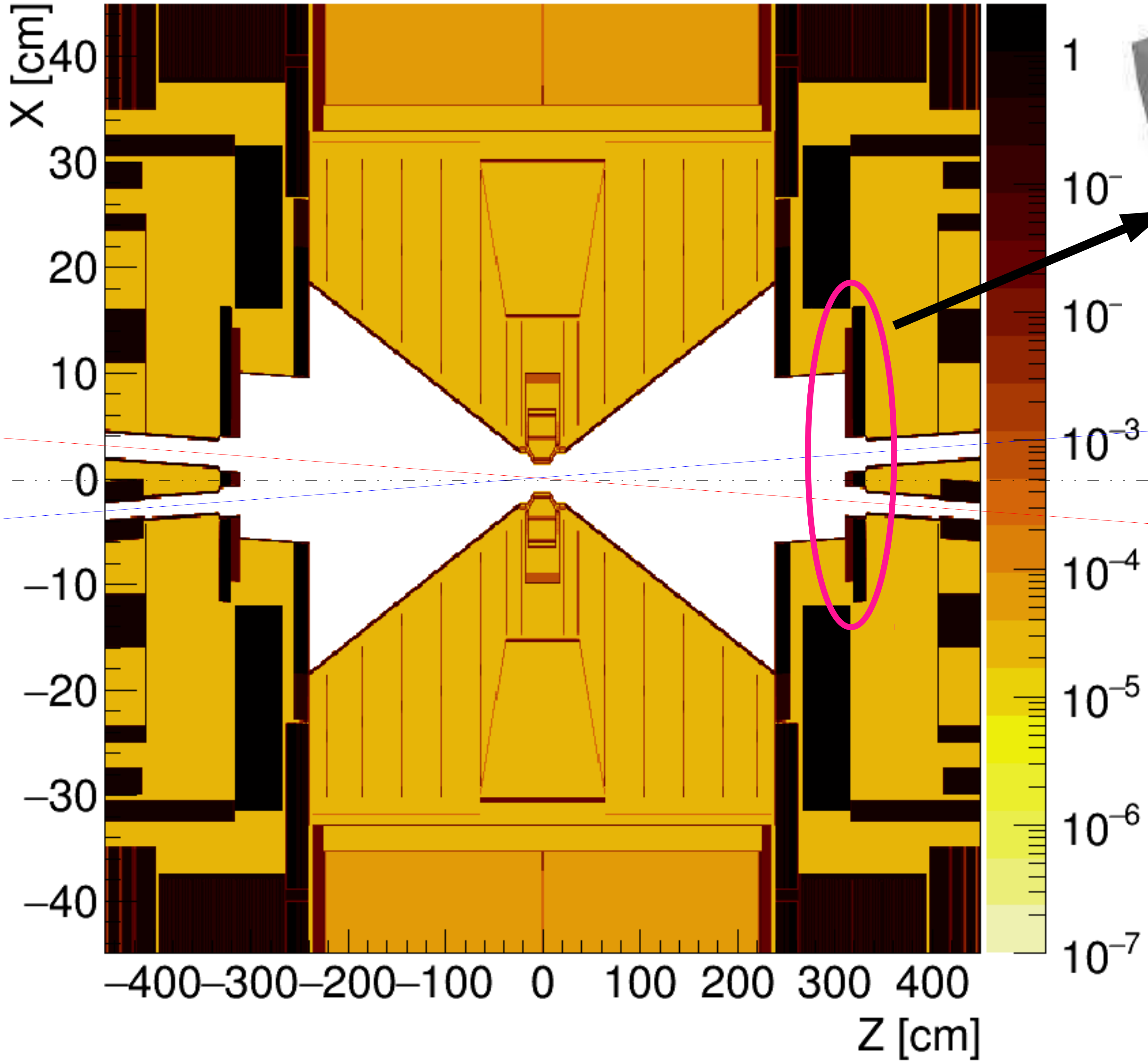
Results : a few muons per bunch crossing seems manageable, ~ 4/BX w/ 5 donut spoilers (no muon wall)

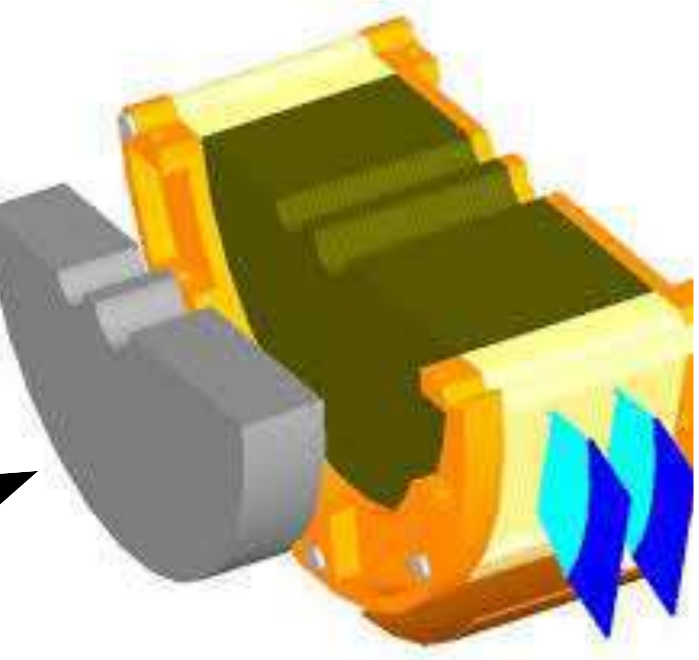
**The muon wall probably not needed from an event reconstruction standpoint.**

→ probably good idea to reserve space for it in case of future need (e.g. unexpectedly large backgrounds...)

→ should be taken into account for estimating detector data rates

# beamcal, crossing angle



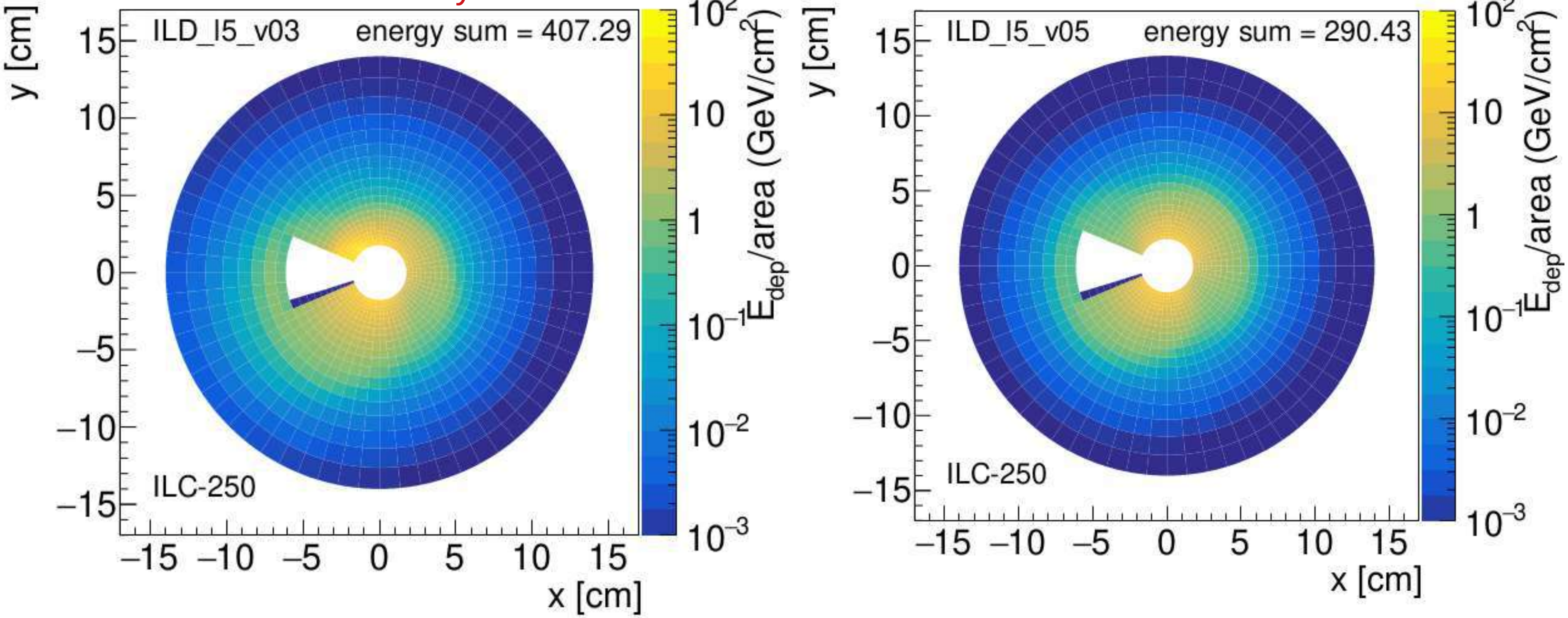


# simulate beamstrahlung pairs at ILC-250

ILD Geant4-based simulation

detailed field maps of solenoid/yoke, with and without anti-DID field

energy deposit in BeamCal sensors



solenoid only

solenoid + anti-DID

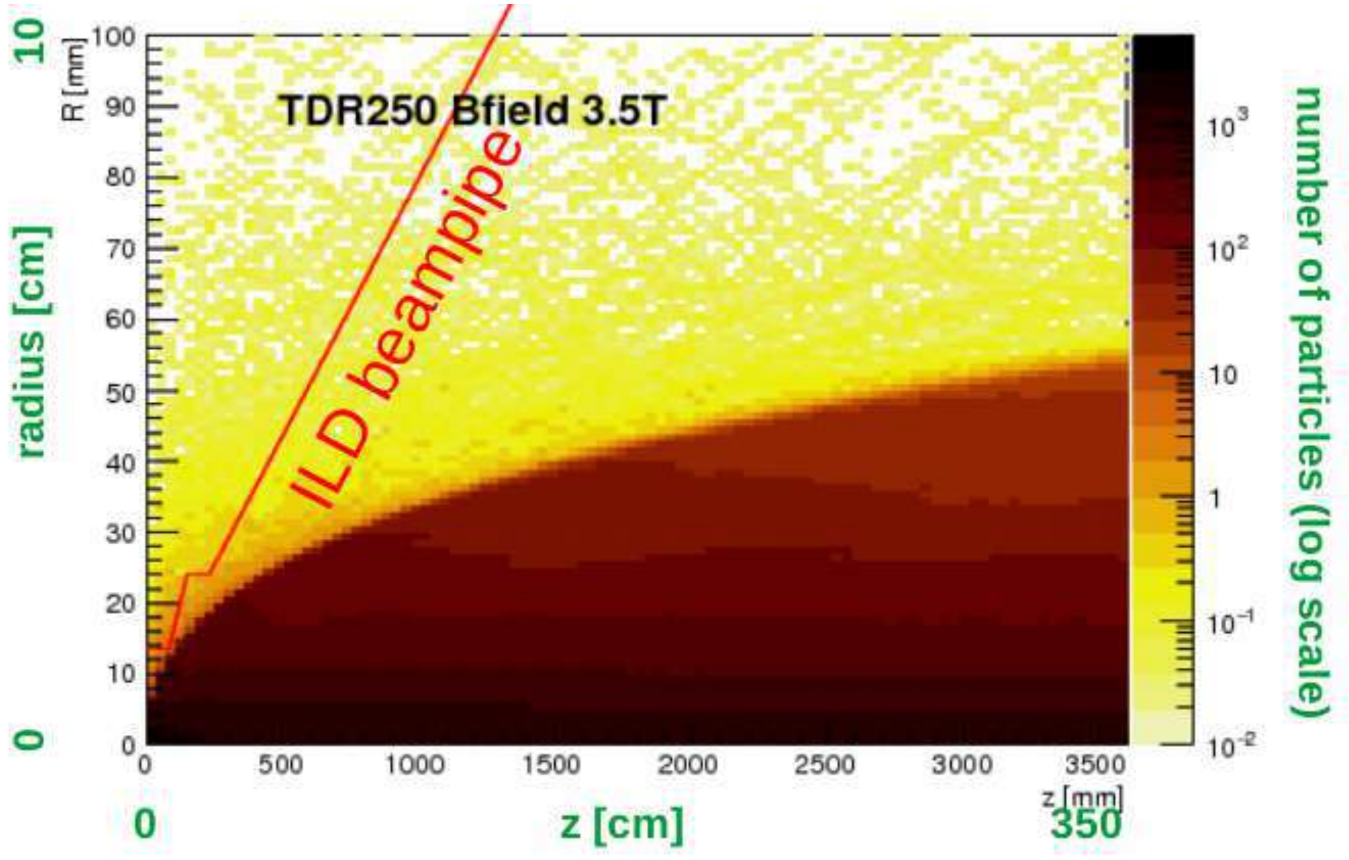
use of anti-DID better centres distribution on outgoing beampipe, reduces total energy deposit

# beamstrahlung: hits in vertex detector

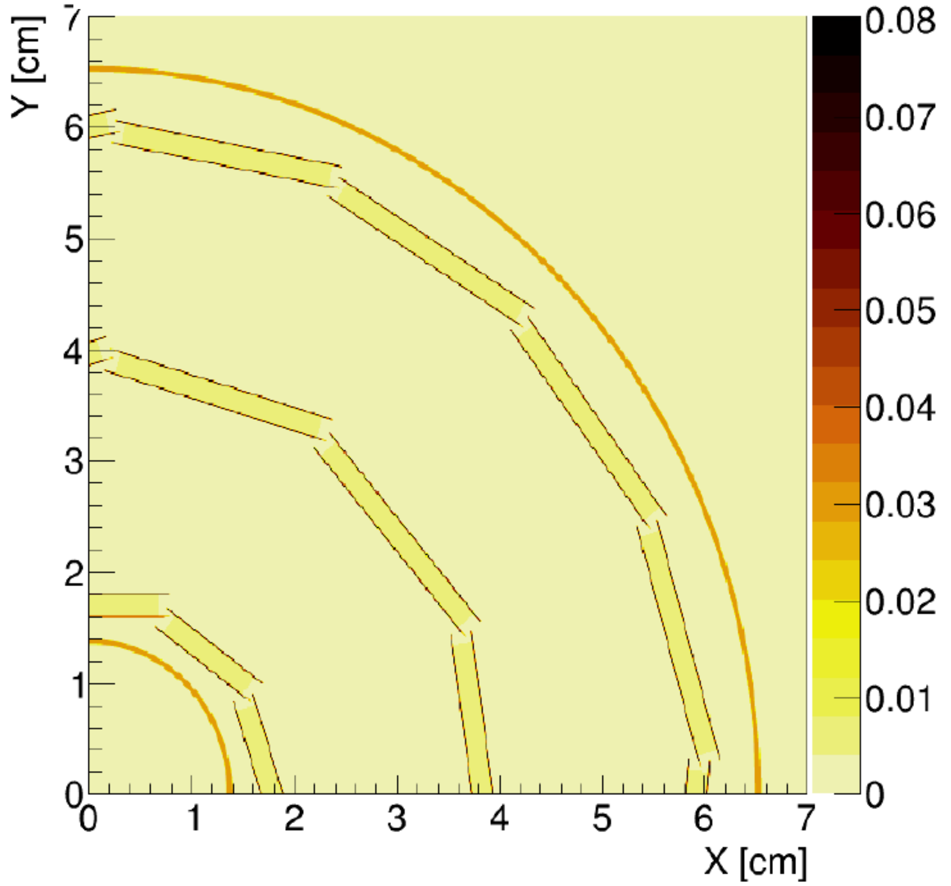
“direct” hits → particles directly coming from IP

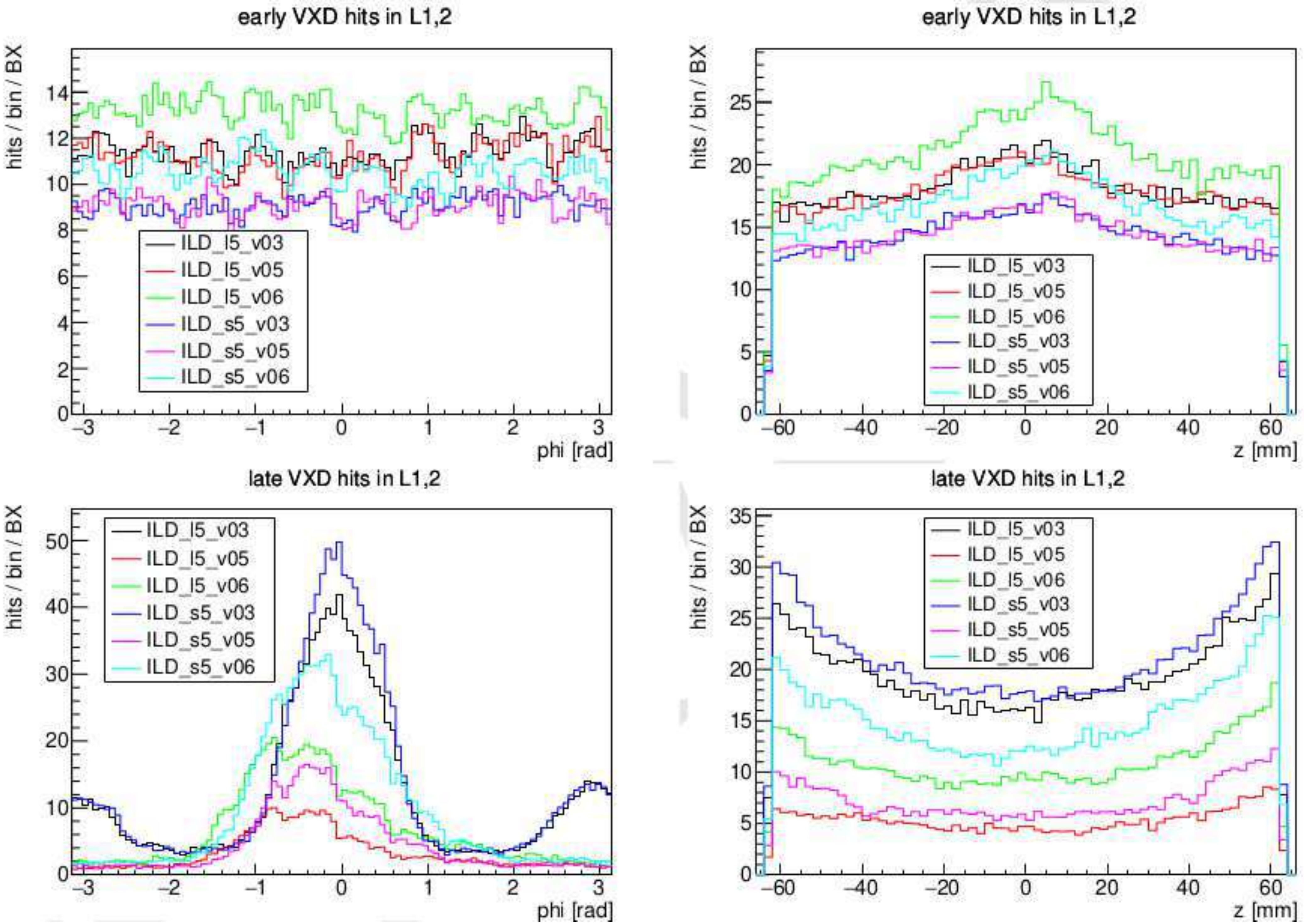
“back-scattered” hits → secondaries produced
when e+ e- interact with forward calorimeters

in simulation, distinguish based on hit time:
“direct” = early / “back-scattered” = late



vertex detector geometry

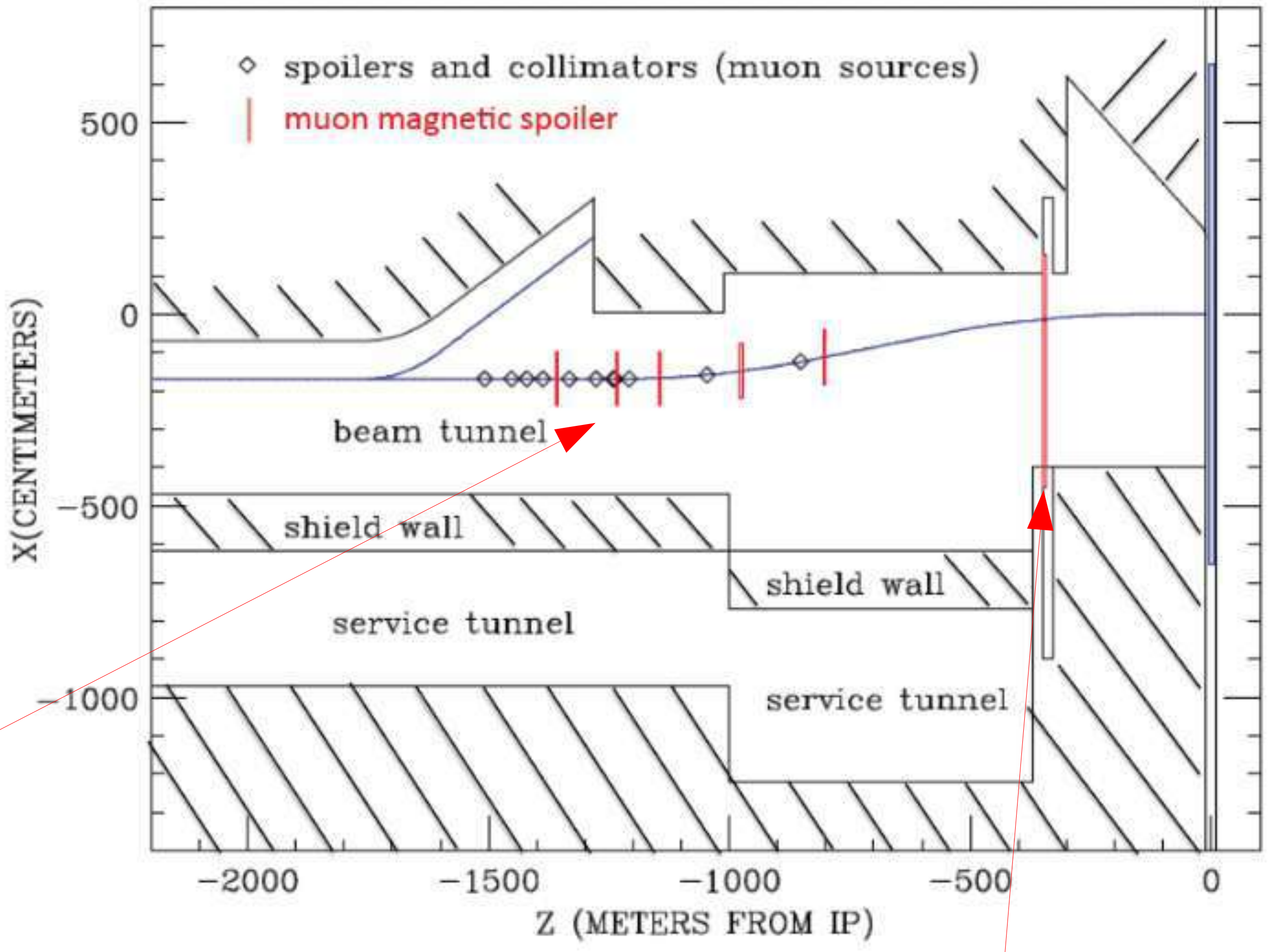




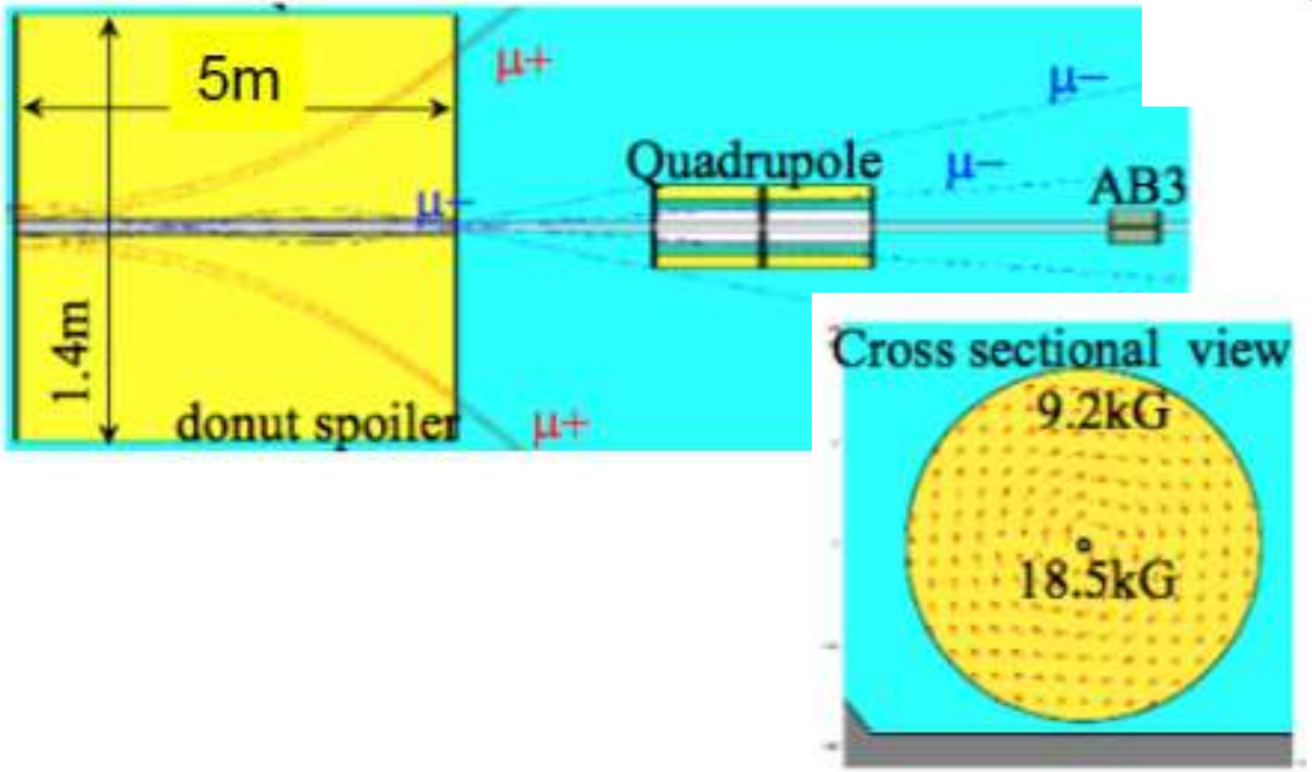
| | | |
|---|---|---|
| **250 GeV** | **3.0 T** | **solenoid only** |
| **250 GeV** | **3.0 T** | **solenoid + anti-DID** |
| **500 GeV** | **3.0 T** | **solenoid + anti-DID** |
| **250 GeV** | **3.5 T** | **solenoid only** |
| **250 GeV** | **3.5 T** | **solenoid + anti-DID** |
| **500 GeV** | **3.0 T** | **solenoid only** |

# beamline muon spoiling

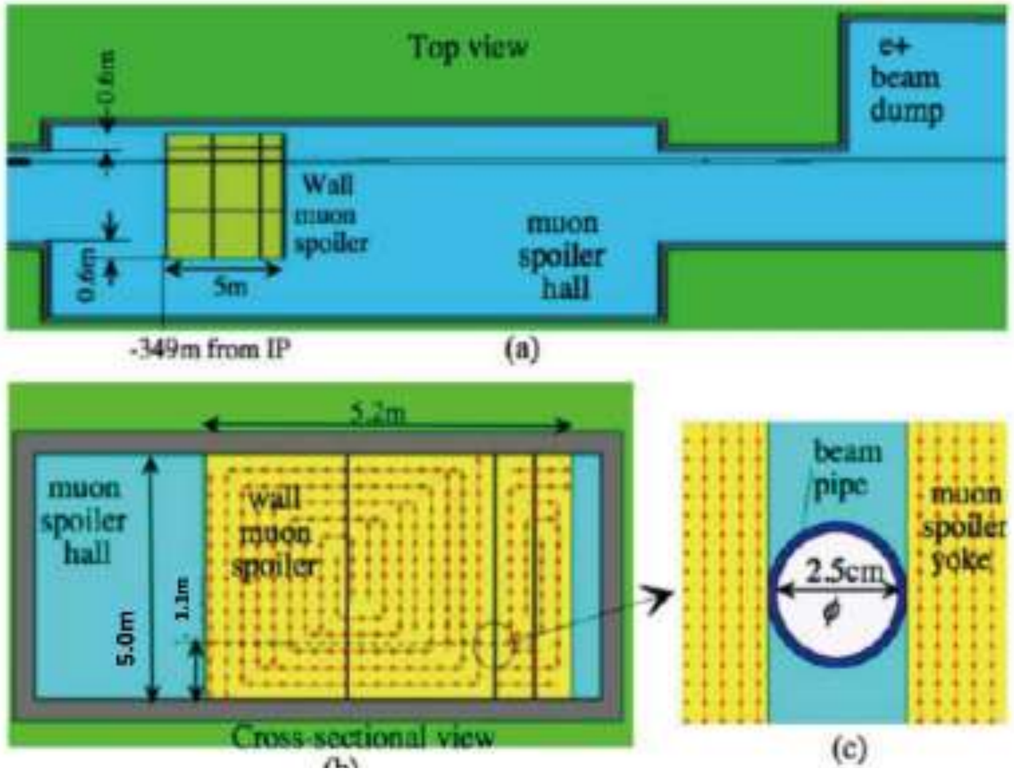
from Keller, White
arXiv:1901.06449



toroidal spoilers



muon wall



question: is the muon wall needed ?

## The SiD Detector - Machine Backgrounds, Marcel Stanitzki (DESY)

**Introduction of ILC Accelerator and SiD detector :** ILC250, the double the bunch number option ILC Bunch Train Structure has huge Impact on the Detector design, triggerless readout, buffering on front-end&Readout after the last bunch and the power pulsing, saving of a factor 100→No Active cooling

**SiD :** Compact high-field design (5T solenoid), All-Silicon tracking for robustness against backgrounds based on SLD experiences, at a linear collider every bunch train is like the first turn in a synchrotron (J.Brau)

**SiD MDI :** The proximitry of the vertex detector to the IP is constrained by the beam parameters. beam pipe, LumiCal, PolyC mask, BeamCal, BPMs, QD0, IP feedback kicker and the support tube

**Sources of backgrounds : From beamstrahlung to neutrons**

$e^+e^-$ pairs (GuineaPig), muons from the collimators(MuCarlo), neutrons from the main beam dump(FLUKA) All studies have used full detector simulation of SiD with Geant4-based.

**Pair Background :**

IP beam pipe designed for the envelope which changes with the beam energy, 250GeV is much more relaxed than 500GeV. It is good time to think about vertex detector upgrade, different beam pipe at enegy upgrade.

**Results :** SiD Default “4 hits per cell per train”(buffer) was considered a good compromise between performance and complexity . Doubling the bunch number (luminosity upgrade), it has impact on detector design, mainly electronics increasing the buffer depth to fulfill the fraction of dead cells < $10^{-4}$.

**Muon Halo : first observed in SLD and unavoidable at a linac → shielding, timing**

Number of hits are calculated for cases of “5 spoilers” and “5 spoilers + wall” at ILC250, ILC500. Muons traverse SiD from left to right ( $\Delta t \sim 40$ns ), many muons are “slow” spiraling in the magnetic field creating hits, but **overall occupany due to muons is never even getting close to $10^{-4}$.**

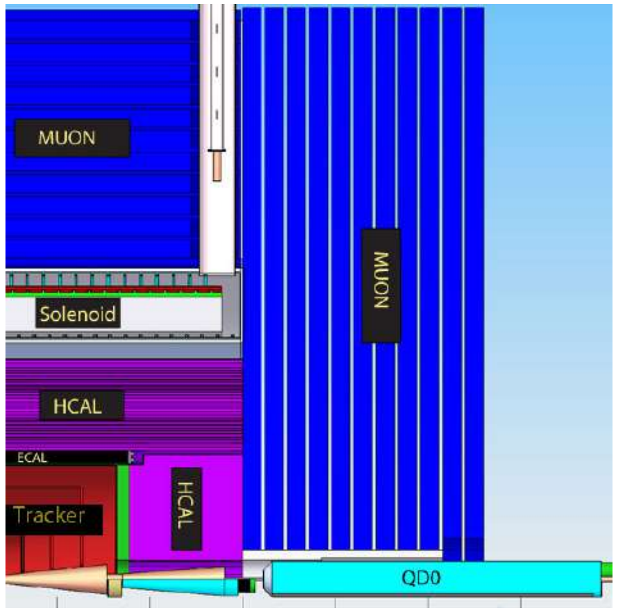
**Neutrons from the Beam Dump :** The “hottest spot” of the ILC at ± 350m from IP Results of timing and occupancy , the fraction of dead cells < $10^{-4}$ with the buffer depth of 4.

**The way forward :**

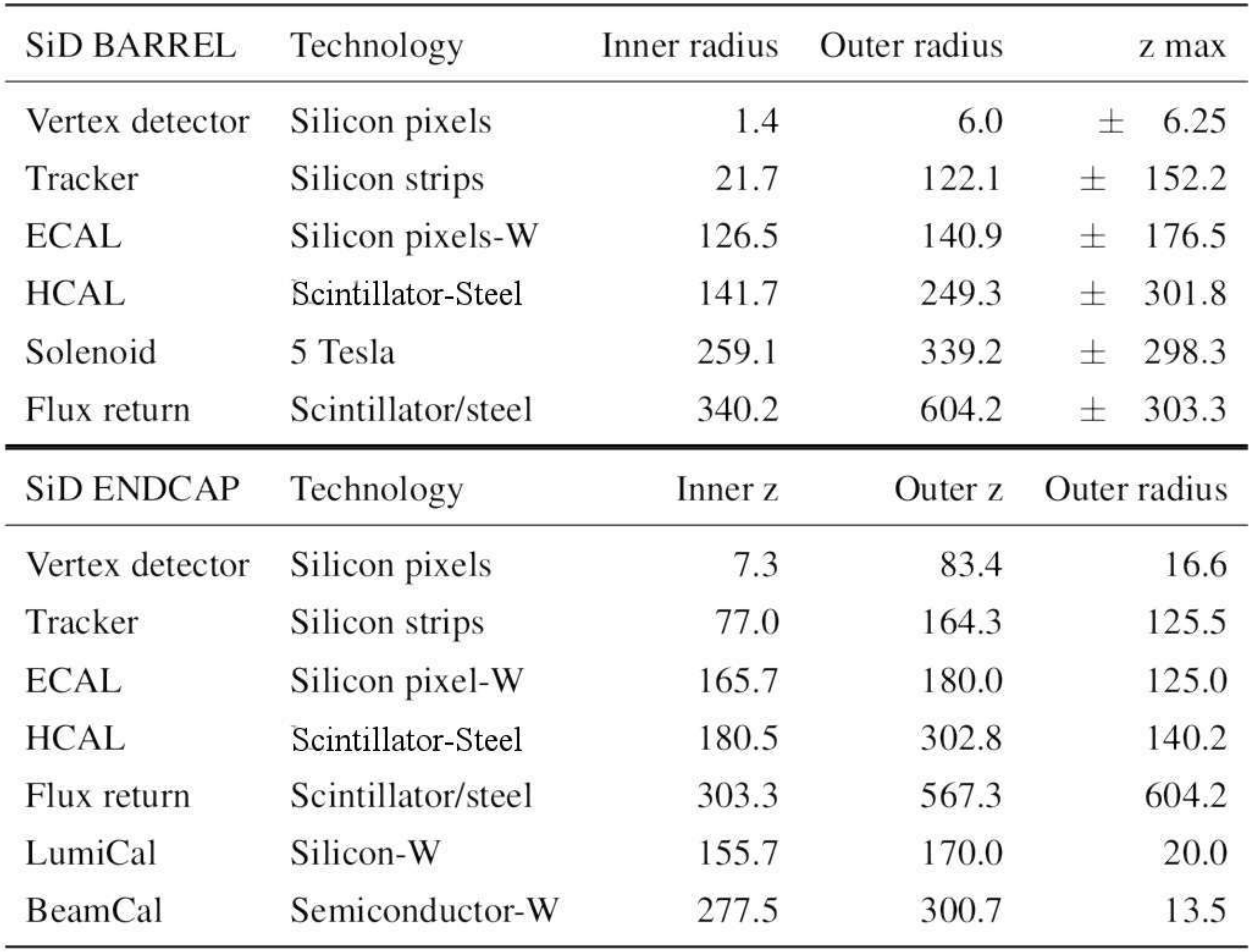
After a green light, repeat the studies with a close-to-final MDI design incl. shielding, pacman, vibration …

# SiD – Compact Silicon Detector

## Baseline Parameters



- Compact high-field design
- All-Silicon tracking
- B Field 5 T, $r_{ECAL}$=1.25 m
- Robustness against backgrounds
- Integrated Design

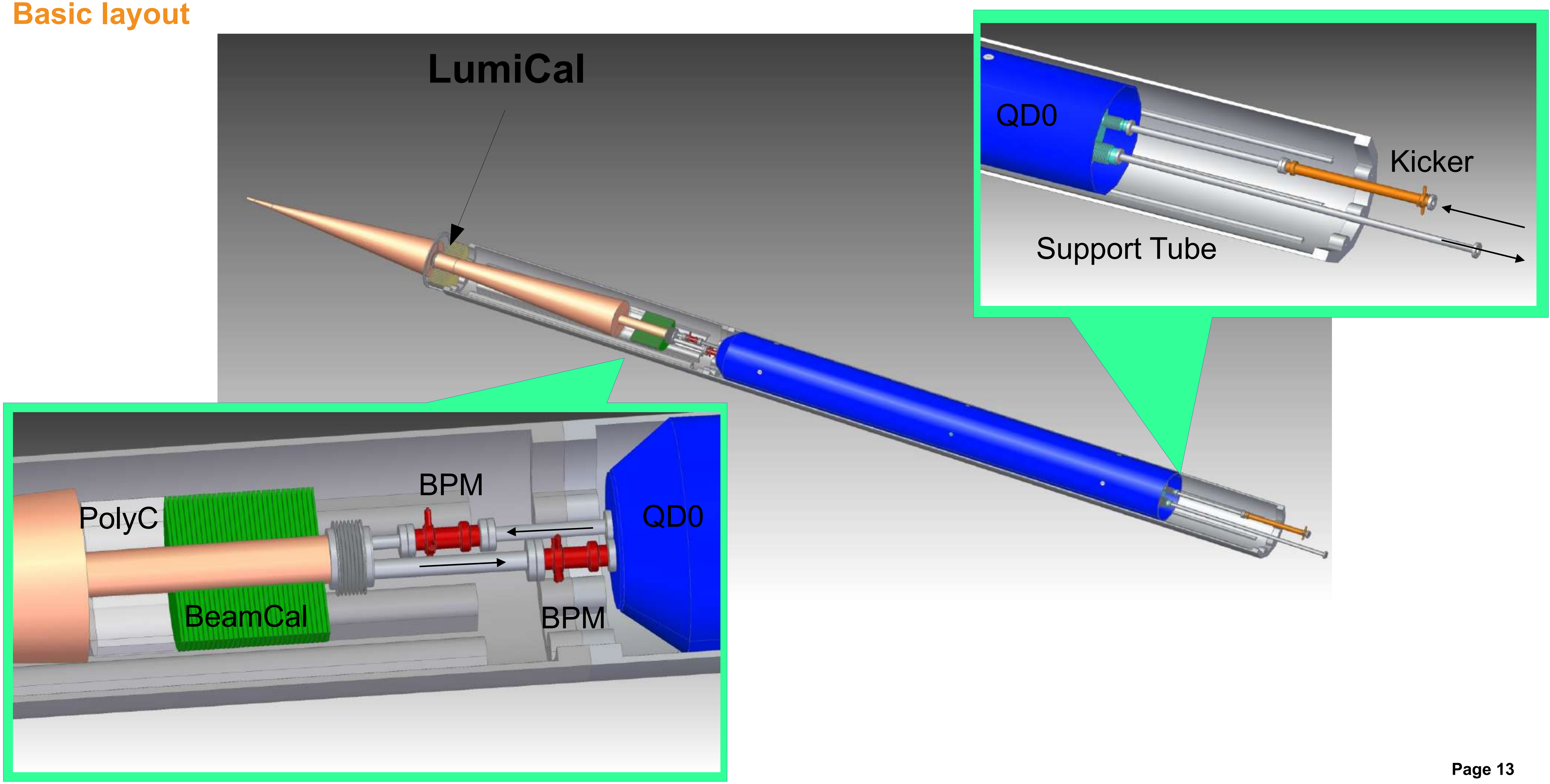


| SiD BARREL | Technology | Inner radius | Outer radius | z max |
|---|---|---|---|---|
| Vertex detector | Silicon pixels | 1.4 | 6.0 | ± 6.25 |
| Tracker | Silicon strips | 21.7 | 122.1 | ± 152.2 |
| ECAL | Silicon pixels-W | 126.5 | 140.9 | ± 176.5 |
| HCAL | Scintillator-Steel | 141.7 | 249.3 | ± 301.8 |
| Solenoid | 5 Tesla | 259.1 | 339.2 | ± 298.3 |
| Flux return | Scintillator/steel | 340.2 | 604.2 | ± 303.3 |

| SiD ENDCAP | Technology | Inner z | Outer z | Outer radius |
|---|---|---|---|---|
| Vertex detector | Silicon pixels | 7.3 | 83.4 | 16.6 |
| Tracker | Silicon strips | 77.0 | 164.3 | 125.5 |
| ECAL | Silicon pixel-W | 165.7 | 180.0 | 125.0 |
| HCAL | Scintillator-Steel | 180.5 | 302.8 | 140.2 |
| Flux return | Scintillator/steel | 303.3 | 567.3 | 604.2 |
| LumiCal | Silicon-W | 155.7 | 170.0 | 20.0 |
| BeamCal | Semiconductor-W | 277.5 | 300.7 | 13.5 |

# The SiD MDI

## Basic layout

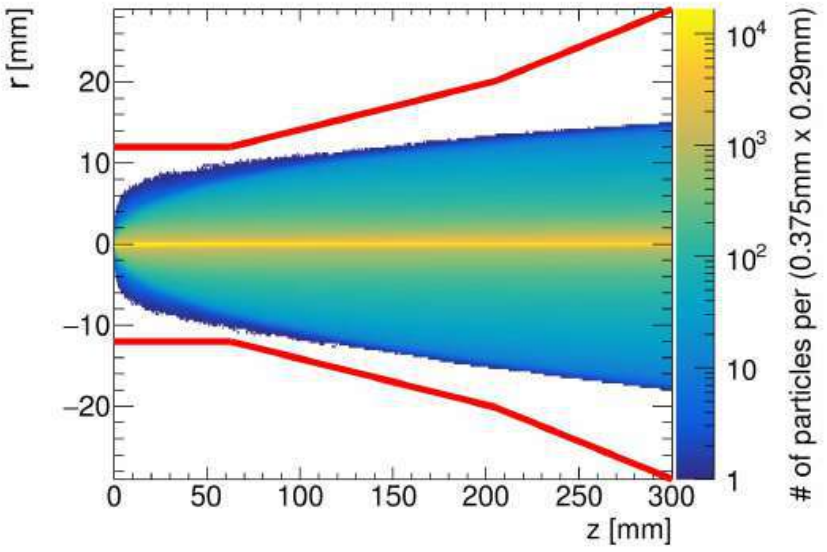


# Pair Background

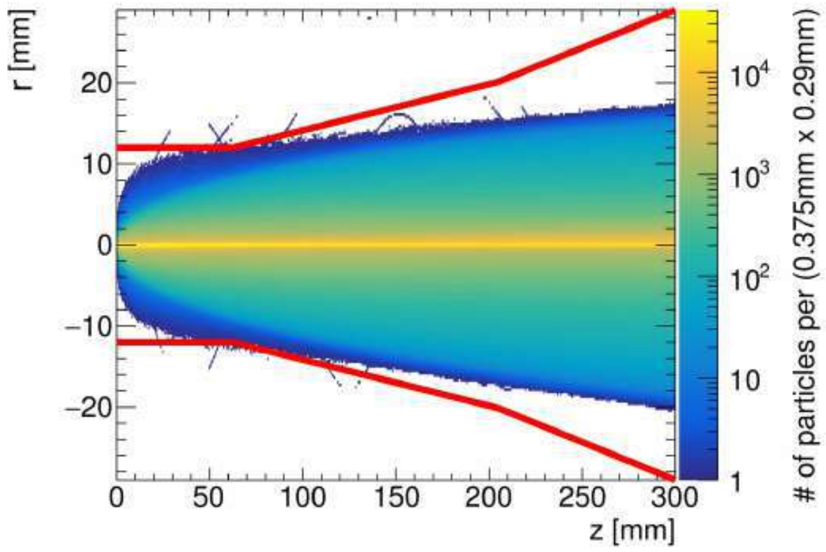
## Machine parameter dependence

- More aggressive optics come with a price

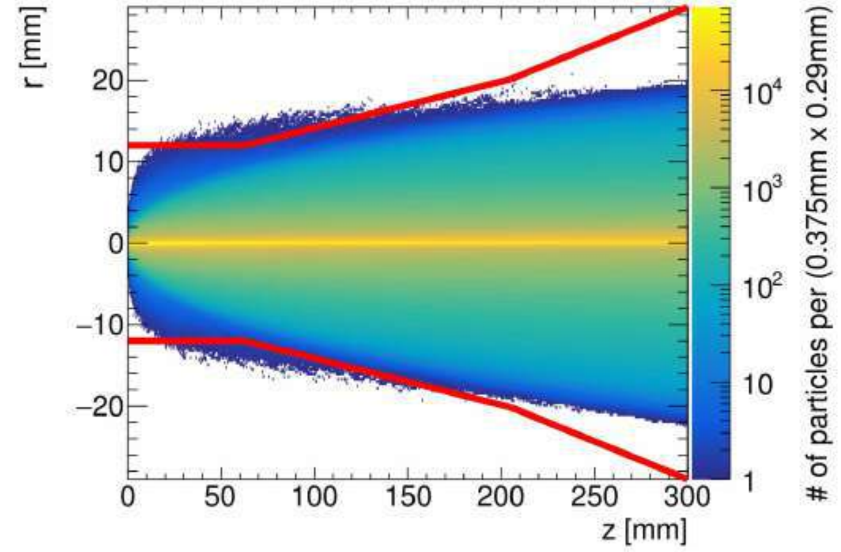
| ILC250 sets | $\epsilon_x$ (µm) | $\beta_x^*$ (mm) | $\beta_y^*$ (mm) |
|---|---|---|---|
| Baseline | 10.0 | 13.0 | 0.41 |
| (A) | 5.0 | 13.0 | 0.41 |
| (B) | 5.0 | 9.19 | 0.41 |
| (C) | 5.0 | 9.19 | 0.58 |



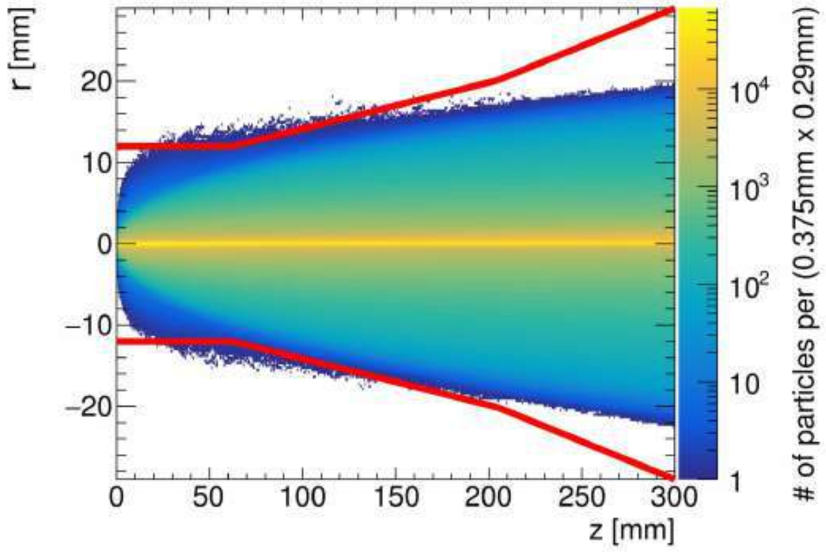
**(a)** *ILC250 set (TDR)*



**(b)** *ILC250 set (A)*



**(c)** *ILC250 set (B)*

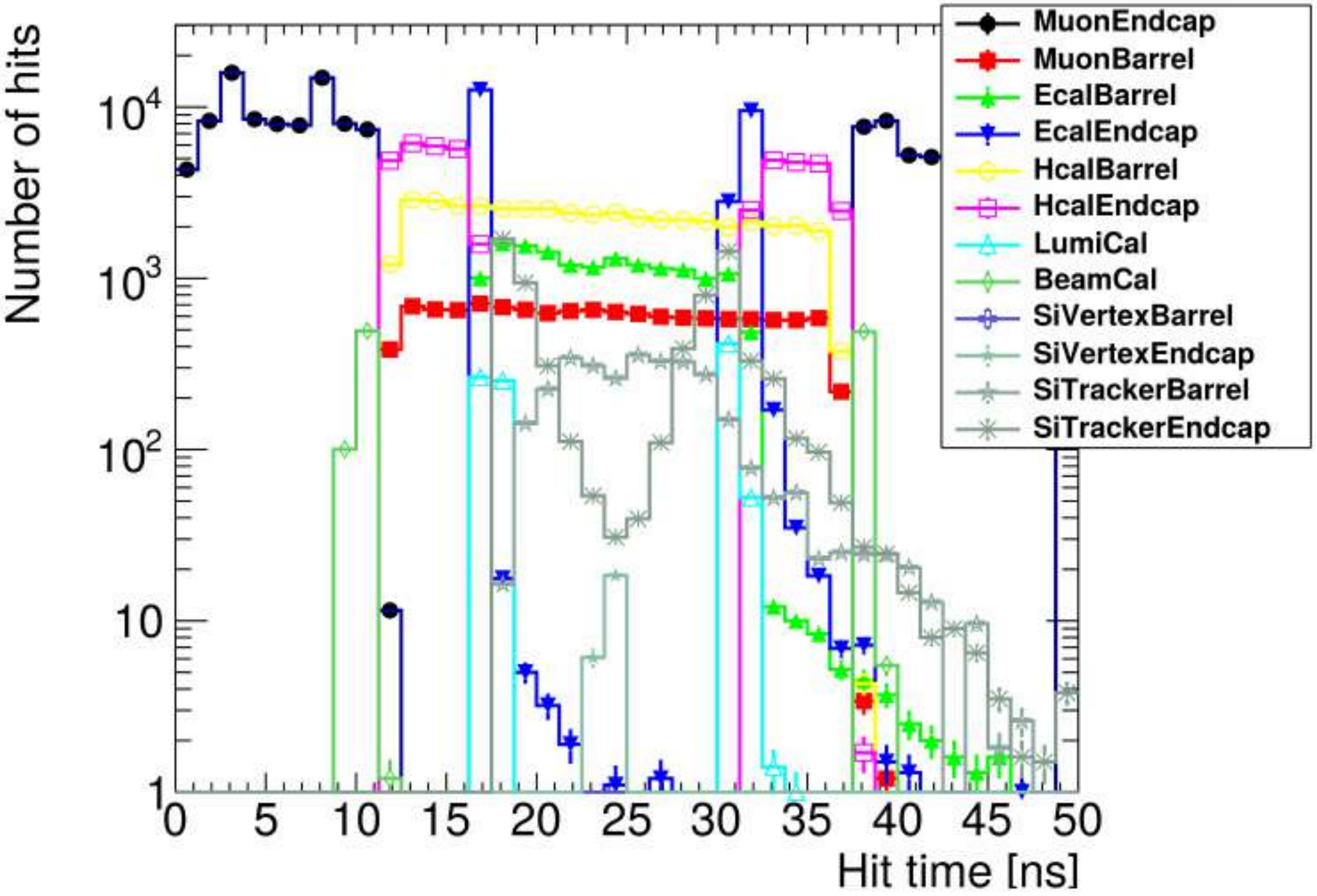


**(d)** *ILC250 set (C)*

# Muon Halo

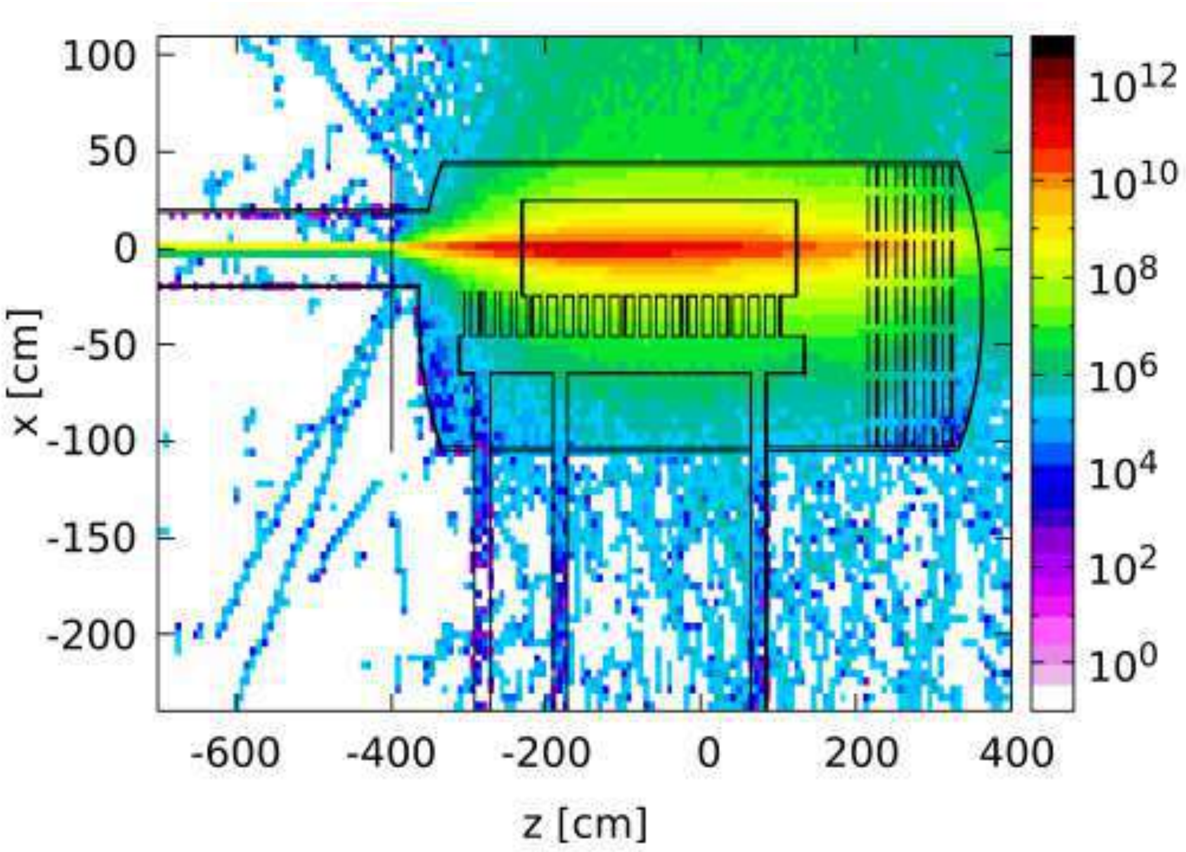
## Timing

- Muons traverse SiD from left to right
  - Easy to pick up with some timing
  - Time difference in the muon end cap ~ 40 ns
- Many muons are “slow”
  - Start spiraling in the magnetic field
  - Significant increase of hits ..
- Overall occupancy due to Muons
  - Never even getting close to $10^{-4}$

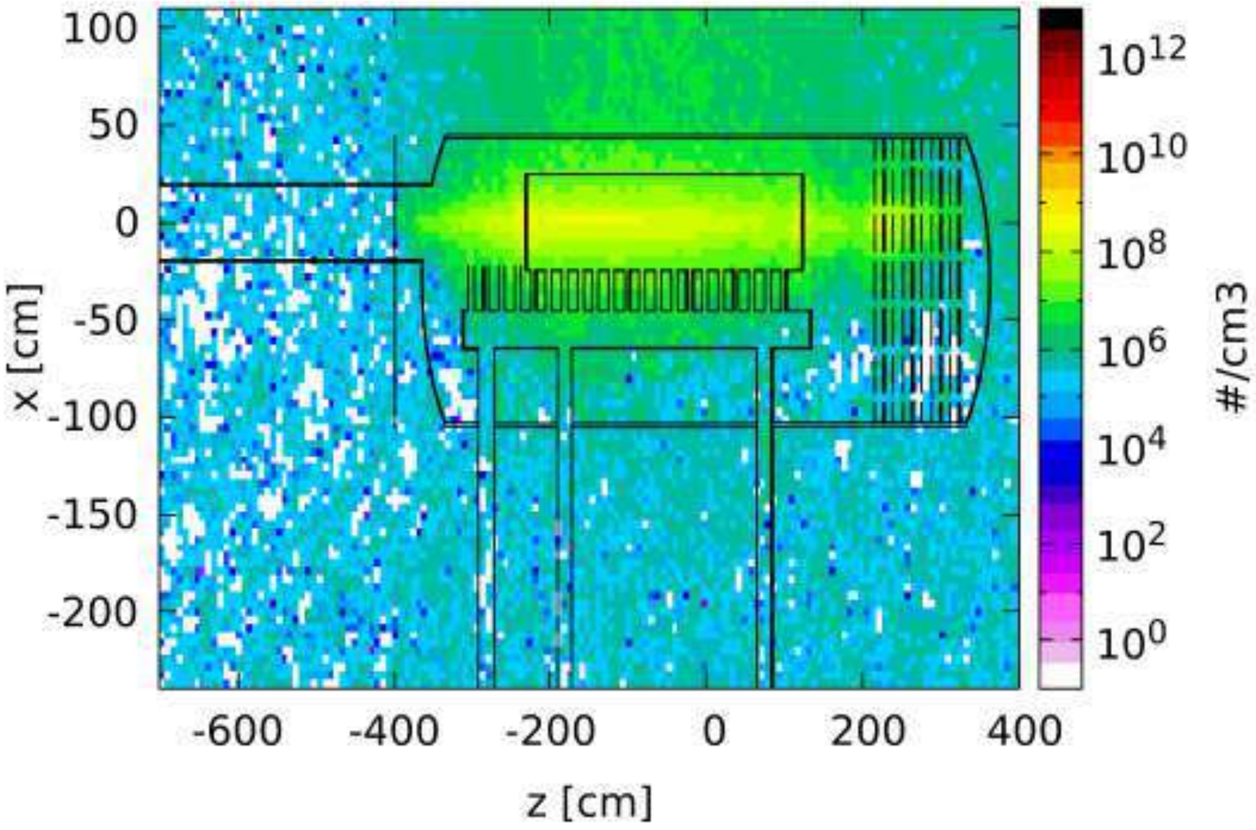


# Neutrons from the Beam Dump

## Particle Fluxes



Electrons



Neutrons

# Superconducting Final Focus Magnets at ILC and Future Colliders, Brett Parker (BNL)

## IR Magnet and MDI Lessons from Previous Work :

"IR Magnets" includes Final Focus quadrupoles, Beam Separation Dipoles, Solenoids/Anti-solenoids, Corrector Magnets and External Field Cancel Coils.

### HERA-II / BEPC-II IR Magnets and MDI:

The design of interface between the cold mass and the warm part is very important, rigid support v.s. heat load, movement of the magnetic center etc. in cooling and enegetic operations. (e.g. passing forces and torques from cold-to-warm supports )

### ILC Final Focus Magnets and MDI :

Because the present ILC QD0 assumes 1.9K superfluid cooling (for the least vibration, but never tested), the QD0 cryostat has an additional 4K conduction cooled heat shield; the extra radial space this requires is not wasted as it allows a larger outer solenoid coil to balance the axial force generated by the inner anti-solenoid coil. a force neutral anti-solenoid coil is added. also, (anti) DID concept come out.

### SuperKEKB IR Corrector Magnets and Cancel Coils :

With 35 correction coils and 8 cancel coils we sometimes hear this referred to as a "complicated system" . But having to dead reckon multiple, stringent, magnetic field magnet production requirements can itself be quite costly (i.e. require a lot of contingency to guarantee performance and no errors... the known unknowns) and brings its own risk (... the unknown unknowns). "It is bad to have corrector coils inside the main coils."

### Future : BNL Electron-Ion Collider (EIC) IR Magnets :

We are half way in a BNL funded (LDRD) project to wind and test a dual helical tapered quadrupole coil (**CCT**) to locally adjust the quadrupole strength which could also be used to add local admixtures of other field harmonic components.

### Future : CERN FCC-ee IR Magnets :

**Dual helical coil winding** is now a key IR magnet technology. We will continue to find synergies between future IR design work: ILC, CLIC, EIC, FCC-ee, FCC-eh/LHeC, CEPC and more!

# HERA-II / BEPC-II IR Magnets and MDI: Lessons

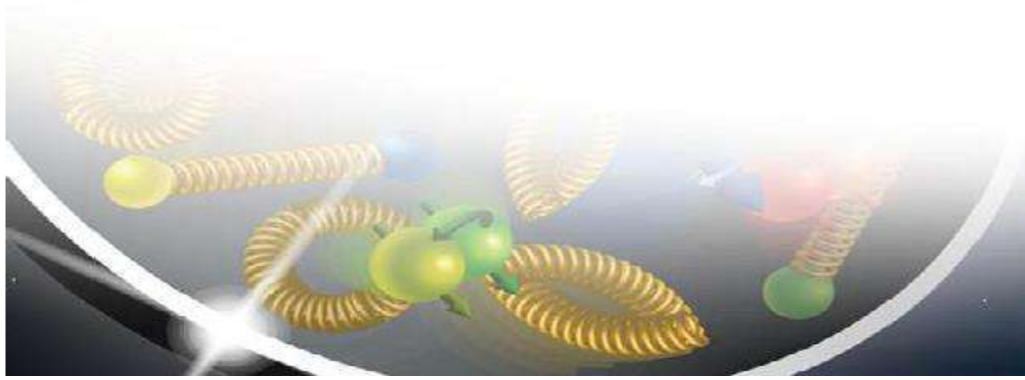
- The cryogenic/power lead connection interface and the physical mounting point (for HERA-II and BEPC-II the “endcans”) needs to be well defined and may require dedicated space outside/inside the experimental detector itself.
- Within the warm cryostat shell the cold mass components will shrink and move during cool down; need to define one fixed point where cold mass is fixed and allow other parts to move (bellows, keys in slots etc.)
- Any net forces or torques generated in the cold mass eventually have to be brought out to warm supports; the optimization to handle forces without generating large heat loads is not trivial and may require a surprising amount of radial and/or longitudinal real-estate.

# ILC Final Focus Magnets and MDI: Lessons

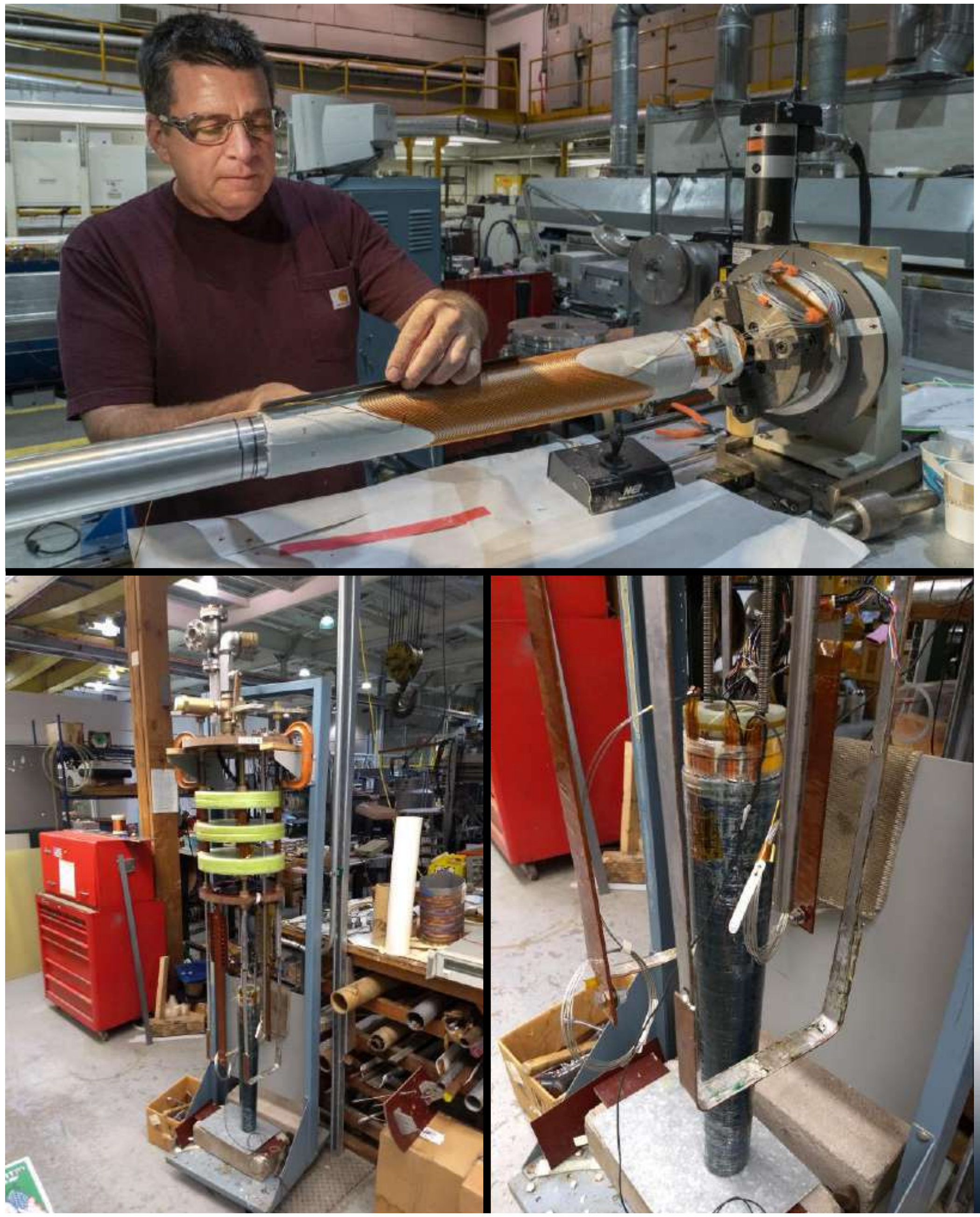
- The ILC QD0 shows how some of the complexity of the cryogenic interface can be moved further from the experiment (e.g. the Service Cryostat) in order to keep to a minimum diameter cryostat insertion (smaller impact on detector).
- Because the present ILC QD0 assumes 1.9K superfluid cooling, the QD0 cryostat has an additional 4K conduction cooled heat shield; the extra radial space this requires is not wasted as it allows a larger outer solenoid coil to balance the axial force generated by the inner anti-solenoid coil.
- Unfortunately while the QD0 R&D Prototype parts exist, the idea that 1.9K cooling avoids a significant driving term for vibration has never been tested.
- For the FCC-ee, if we use 4.5K in place of ILC 1.9K cooling and don't (and probably cannot) use a force neutral anti-solenoid coil configuration, the radial space between the cold mass and outer cryostat shell would be reduced… but then we need to deal with large forces and should carefully evaluate possible vibration modes.
- MDI for a push-pull IR layout is quite painful!

# SuperKEKB IR Correctors and Cancel Coils: Lessons

- Yes, building in the design flexibility (e.g. knobs for operators or IR opticians) to make beam orbit/optics changes can yield a design that seems "complicated."
- But having to dead reckon multiple, stringent, magnetic field magnet production requirements can itself be quite costly (i.e. require a lot of contingency to guarantee performance and no errors… the known unknowns) and brings its own risk (… the unknown unknowns).
- The good news is that we still continue to come up with new ideas to make progress on MDI challenges.



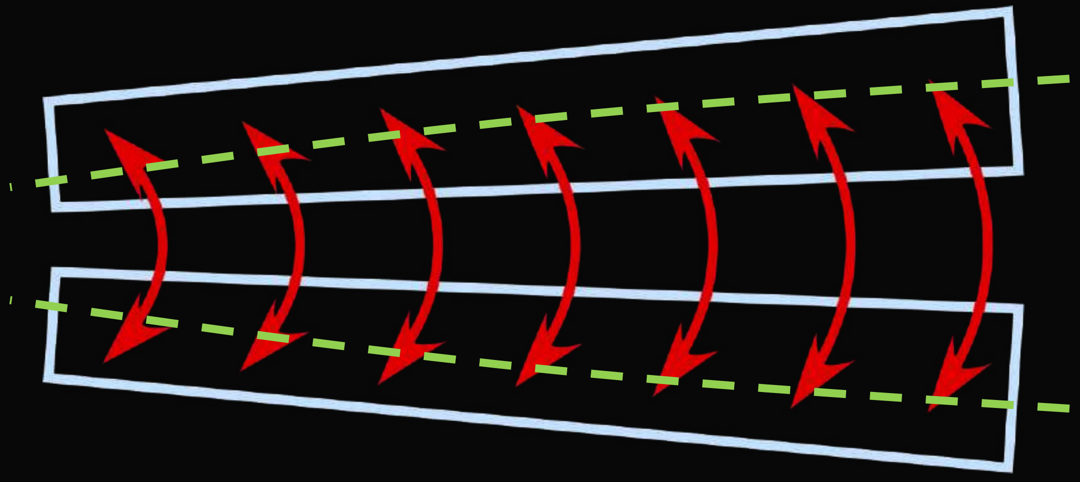
# BNL Electron-Ion Collider IR Magnets: Designs

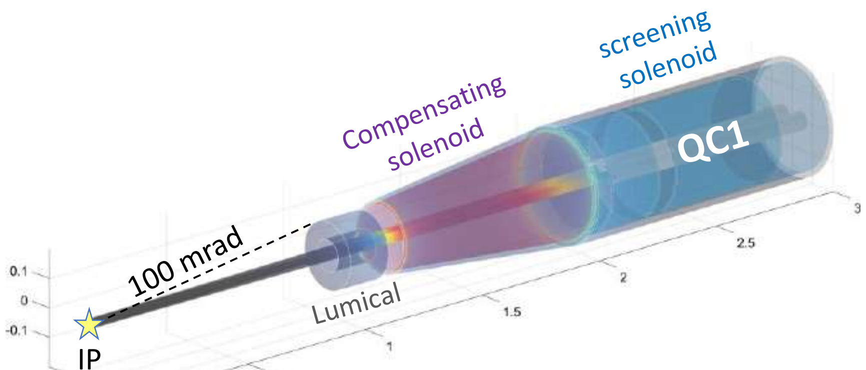


- For the EIC IR design we use tapered coil quadrupoles.
- Thanks to design flexibility of dual helical coil windings we can modify the local field components so as to keep the local quadrupole gradient constant.
- We are half way in a BNL funded (LDRD) project to wind and test a dual helical tapered quadrupole coil.
- Warm measurements show expected field quality and the target constant gradient.
- Preparations for cold testing are in progress.
- The same dual helical design flexibility that we use to locally adjust the quadrupole strength could also be used to add local admixtures of other field harmonic components (e.g. to buck out magnetic crosstalk between two side-by-side quadrupoles).

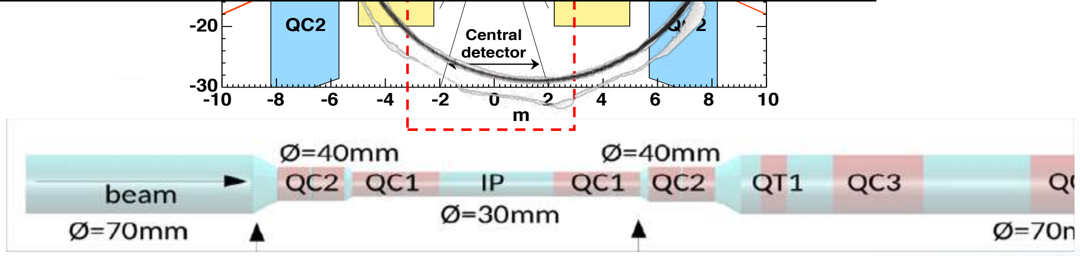
# CERN FCC-ee IR Magnets: Discussion

Challenge: Deal with magnetic crosstalk between the QC1 IR quadrupoles.





Unlike with SuperKEKB, we must also buck out the $B_1$ term or the zero field path in the quadrupole will be curved! [e.g. then cannot find an orbit path that avoids at least some dipole field]



Answer: Use flexible Double Helical coil design to locally adjust QC1 field much like we are doing for the BNL EIC IR.

1.5 cm radius z ± 12.5 cm

**Smaller central pipe: 1.0 cm for z ± 9 cm (with taper starting at z ± 40 cm from IP)**

**We could use BNL Direct Wind technology to make double helical coils that by design eliminate magnetic cross talk.**

## CLIC Machine Detector Interface, Philip Burrows (Oxford Univ.) , Lau Gatignon (CERN)

**Quick reminder: what is MDI :**

The Machine Detector Interface must ensure optimum luminosity for the experiment(s) with minimal backgrounds and includes the local environment and infrastructure. It integrates the post-collision line.

CDR : L*=3.5m, 2 detectors with push pull operation, the experimental hall accomodates them.

**Changes to detector model :**

Single detector, i.e. no push-pull of two detectors, but this does remain an option

L*=6m QD0 in the tunnel, which has the major implications for MDI , the same crossing angle of 20mrad

**Changes to MDI :**

Cavern layout : Detector opening not on IP

**Luminosity and tuning :**

Both beam optics with L*=3.5m and 6m were studied including the beam tuning, the latter luminosity is about 15% less than the former. However, it is better for the stabilization of FFQ (QD0).

**Stabilisation :** CLIC specification (displacement of the QD0 final focus) : 0.20 nm RMS@4Hz

Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0.25 nm RMS@4Hz

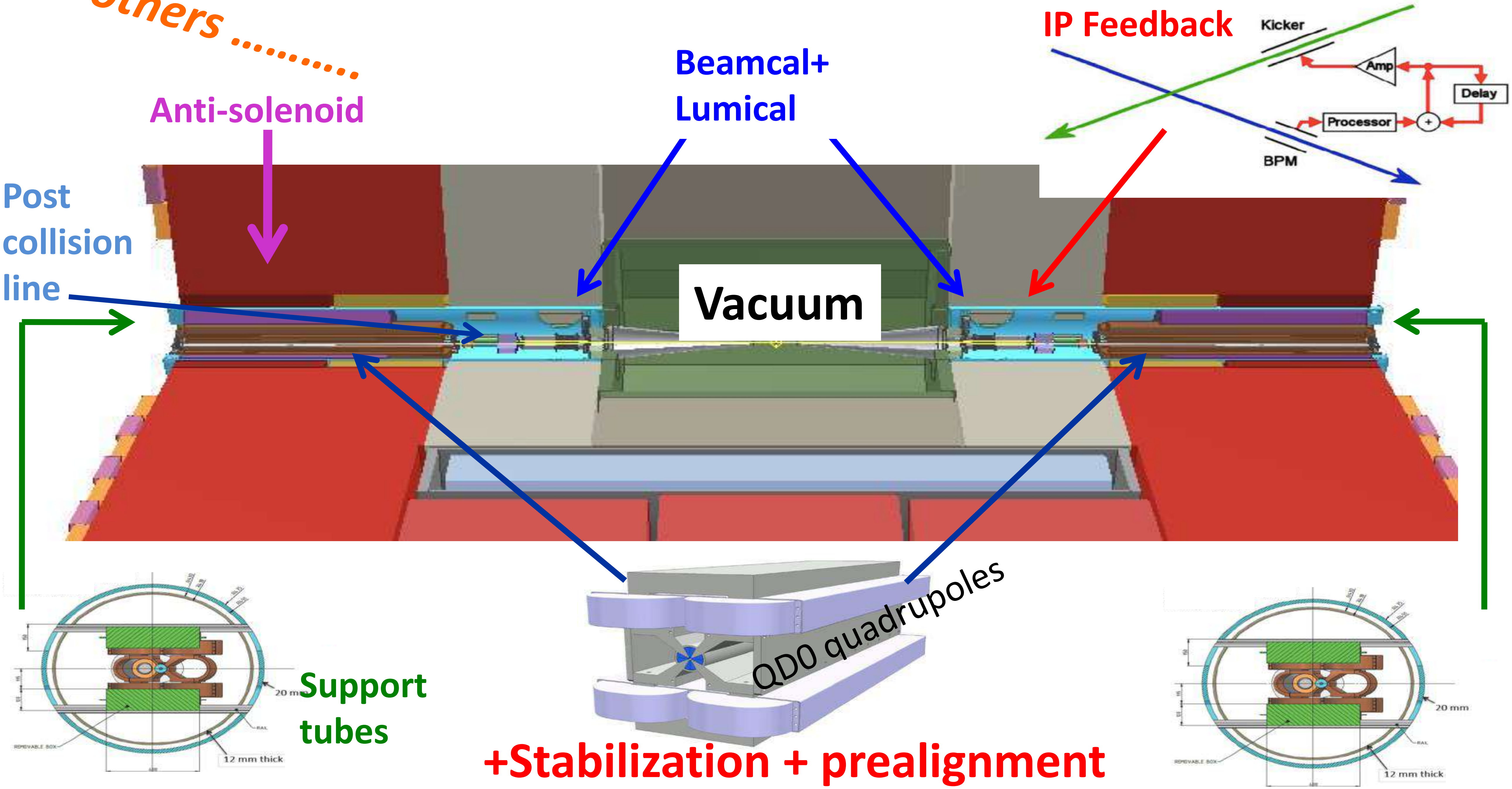
IP feedback system demonstrated

**Some other implications :**

Beam line sectorisation scheme (L*=6m) was proposed, which looks simpler and well separated between the detector and the accelerator elements.

**A new detector model with L* = 6 m has been evaluated and this is now the new baseline for CLIC.**

# MACHINE DETECTOR INTERFACE



Plus others ………

Anti-solenoid

Beamcal+
Lumical

IP Feedback

Post
collision
line

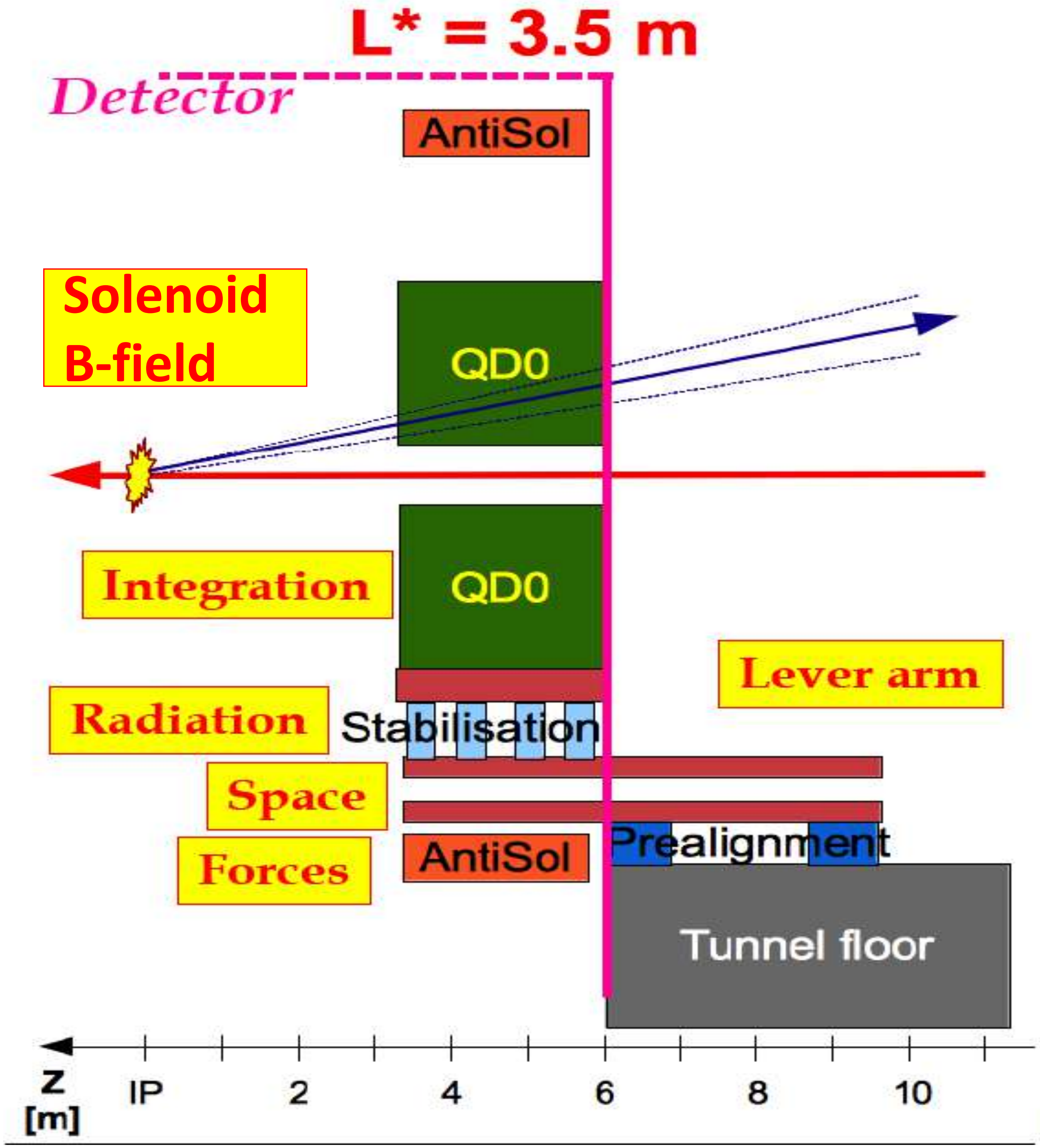
Vacuum

QD0 quadrupoles

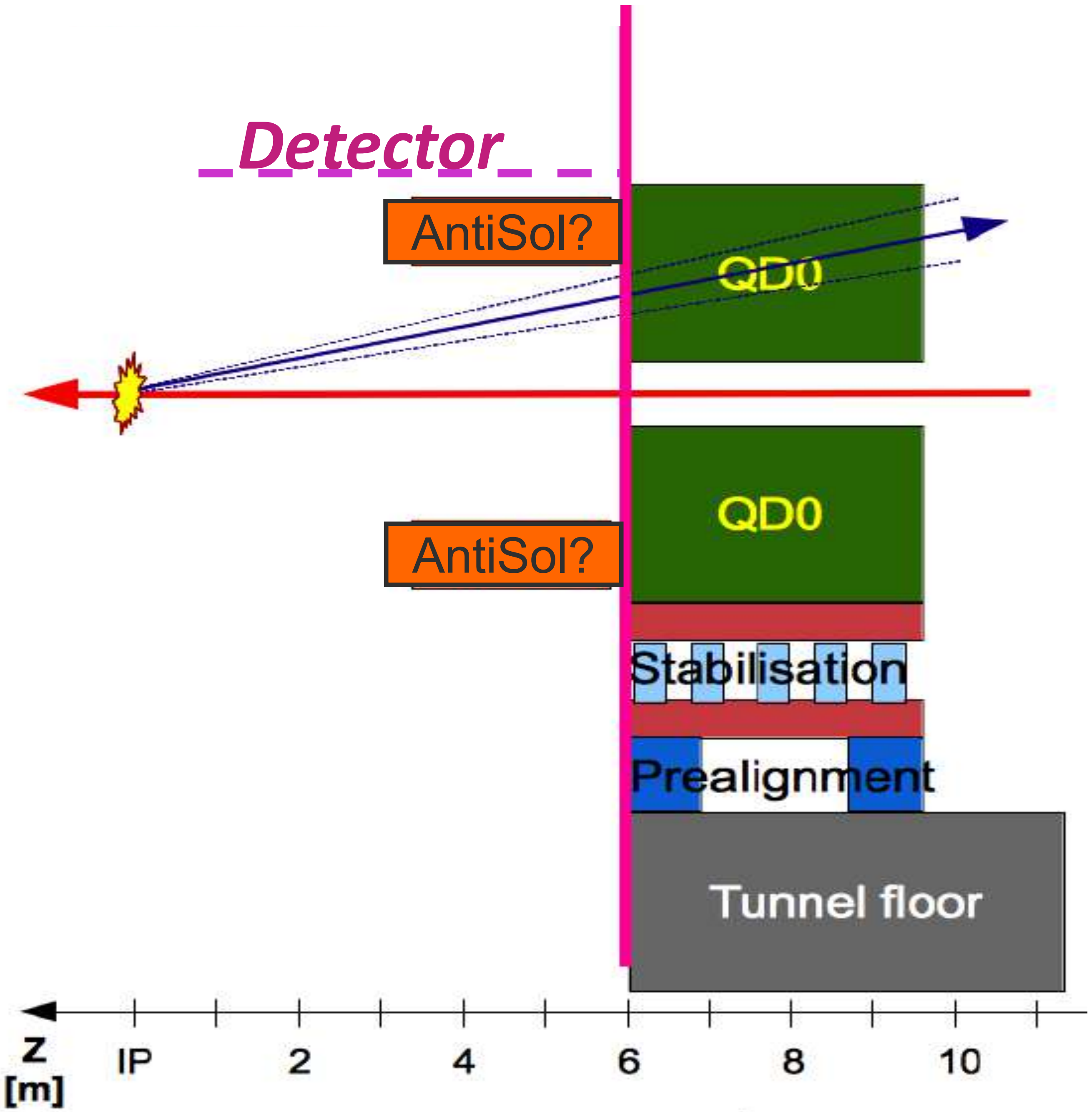
Support
tubes

+Stabilization + prealignment

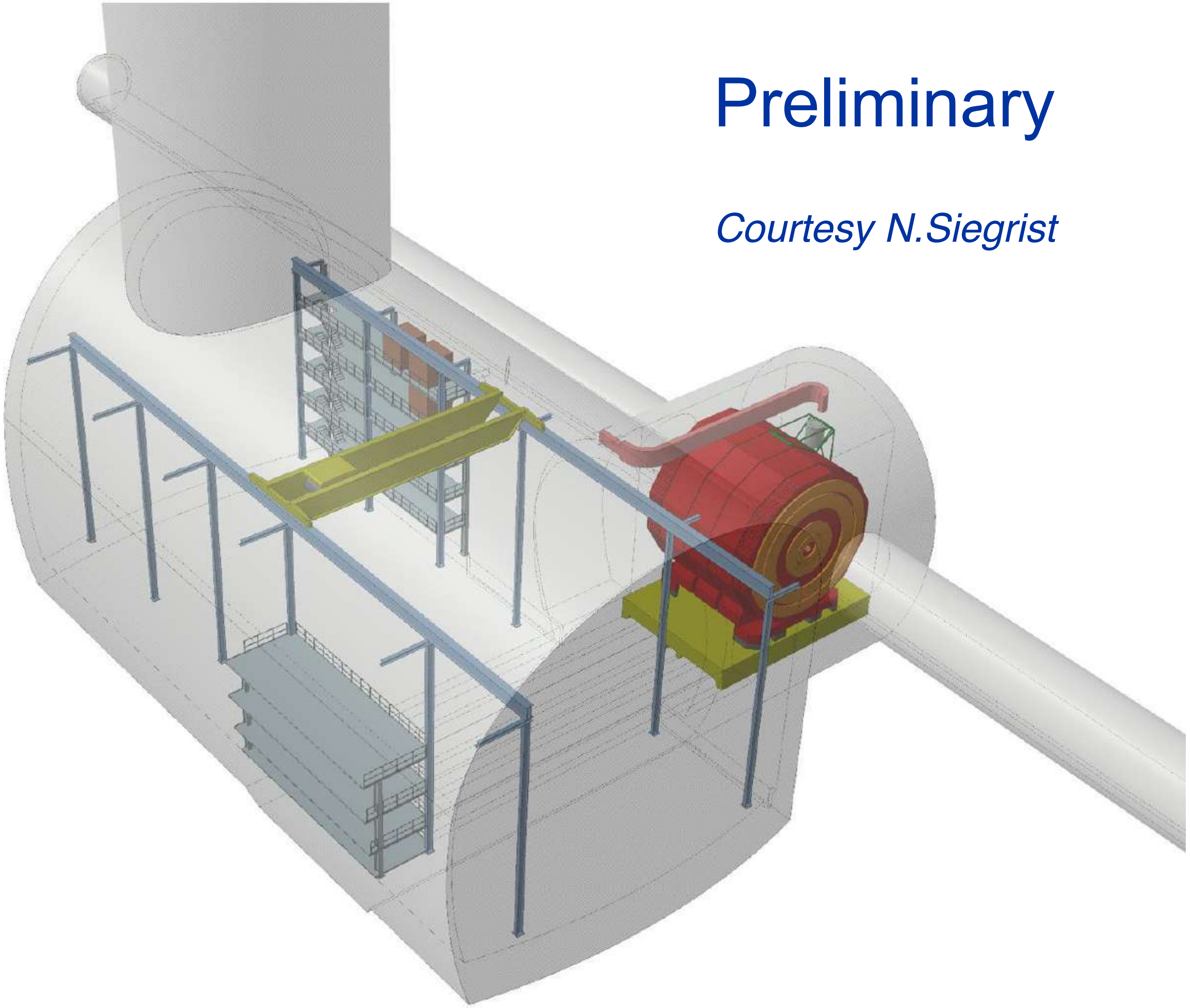
L* = 3.5 m


Detector
AntiSol
Solenoid
B-field
QD0
QD0
Integration
Lever arm
Radiation
Stabilisation
Space
Forces
AntiSol
Prealignment
Tunnel floor
Z
[m]
IP
2
4
6
8
10

L* = 6.5 m


Detector
AntiSol?
QD0
QD0
AntiSol?
Stabilisation
Prealignment
Tunnel floor
Z
[m]
IP
2
4
6
8
10

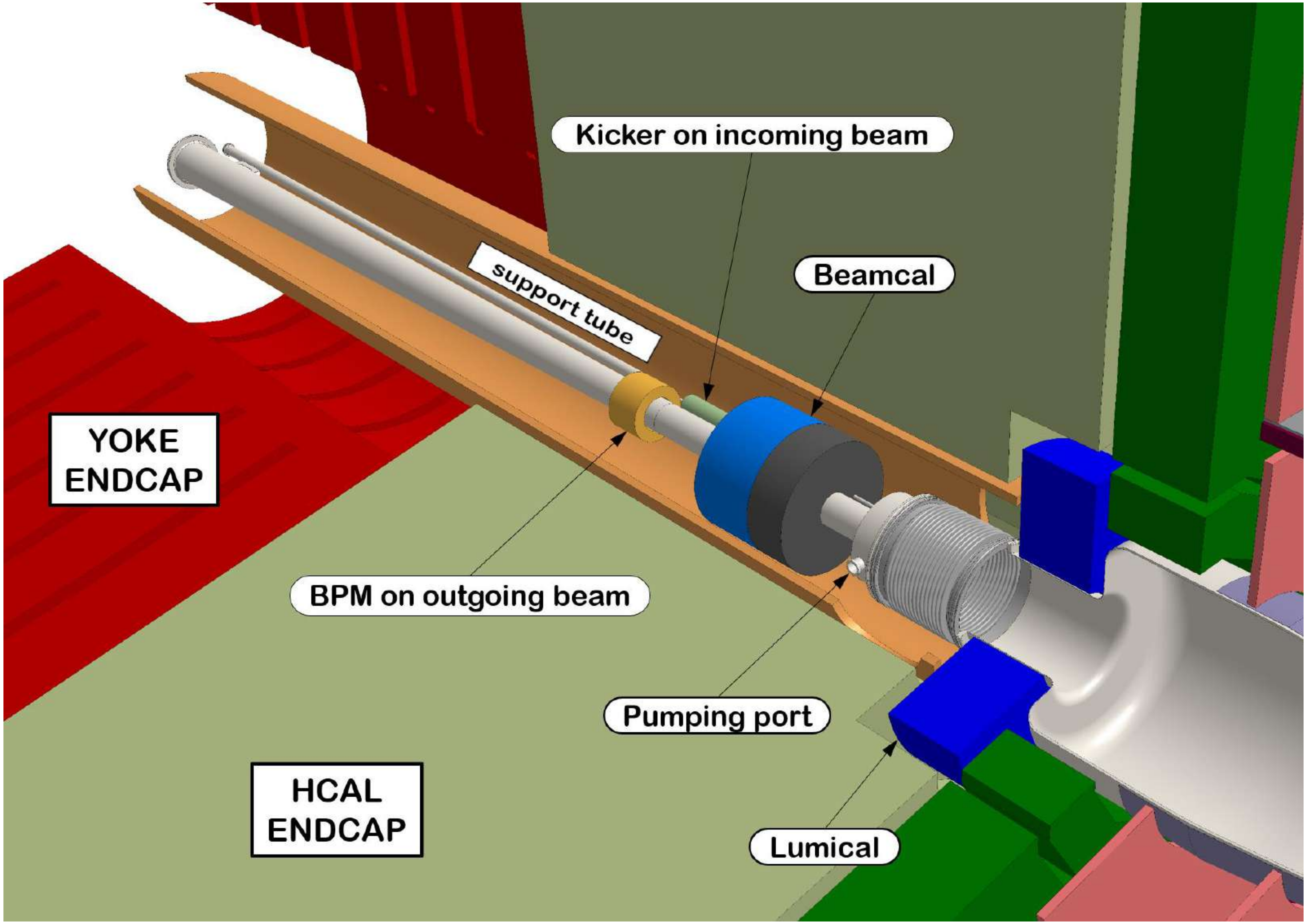
# Cavern layout



Preliminary

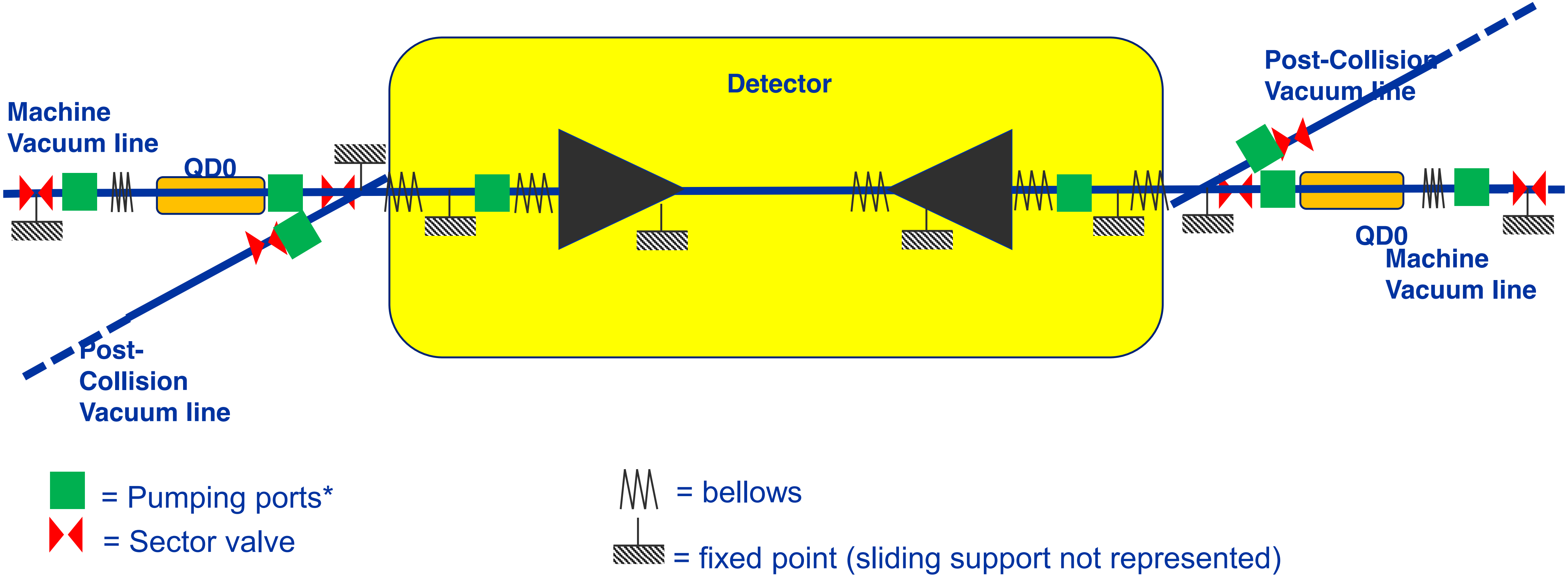
*Courtesy N.Siegrist*

- Proposal by detector group
- Detector opening not on IP
- Mechanical and civil engineering stability to be verified


Kicker on incoming beam
Beamcal
support tube
YOKE ENDCAP
BPM on outgoing beam
Pumping port
HCAL ENDCAP
Lumical

**C.Garion**

# Beam Line Sectorisation Scheme



*Pumping port number and position could change depending on pressure requirements or space constraints…

# Stabilisation of Final Focus Magnets for CLIC and FCC, Maurizio Serluca, Laurent Brunetti (LAPP)

**INTRODUCTION :** Successful operation of future colliders requires advanced vibration analysis and control, e.g. preserve the very low emittance along the beamline at LC and minimize emittance dilution both for the nano-meter beams.

**Vibration control for CLIC :** Spec. : Beam offset < 0.2 nm RMS at IP

Active control with the developed sensors : Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0.25 nm RMS@4Hz, where only 1 sensor in feedback.

From the demonstration to a large scale experiment, a large actuator must be developed for CLIC.

**Accelerator Test Facility: ATF2 :** 1.3GeV electron beam, $\sigma_z$=37nm (design), 40nm achieved

The passive stabiization of the final doublet magnets on the stiff table was demonstrated, i.e. the relative motion between shintake monitor and final doublets of [4 – 6] nm RMS @ 0.1Hz (vertical axis) .

Also, the feedforward system was tested with14 GM sensors on the magnets at the beamline. Jitter reduction around 10-20% due to very unstable run conditions and strong jitter at the injection of the extraction line

**SuperKEKB :** Real-time vibration measurements system installed on both sides of BELLE II with LAL,KEK

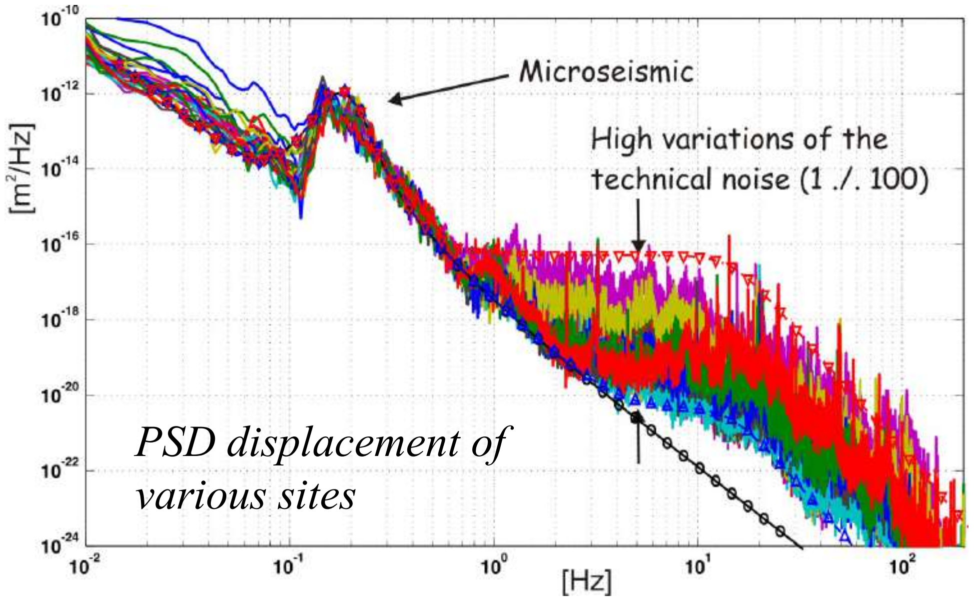
To study the correlation between measured luminosity and vibrations : 24 hour monitoring gives indications about time and frequency of disturbances that helps in the research of the vibration sources (Dec. 2019)

**Analysis of the common aspects with FCC-ee :** FFQ support by the 4.37m long cantilever

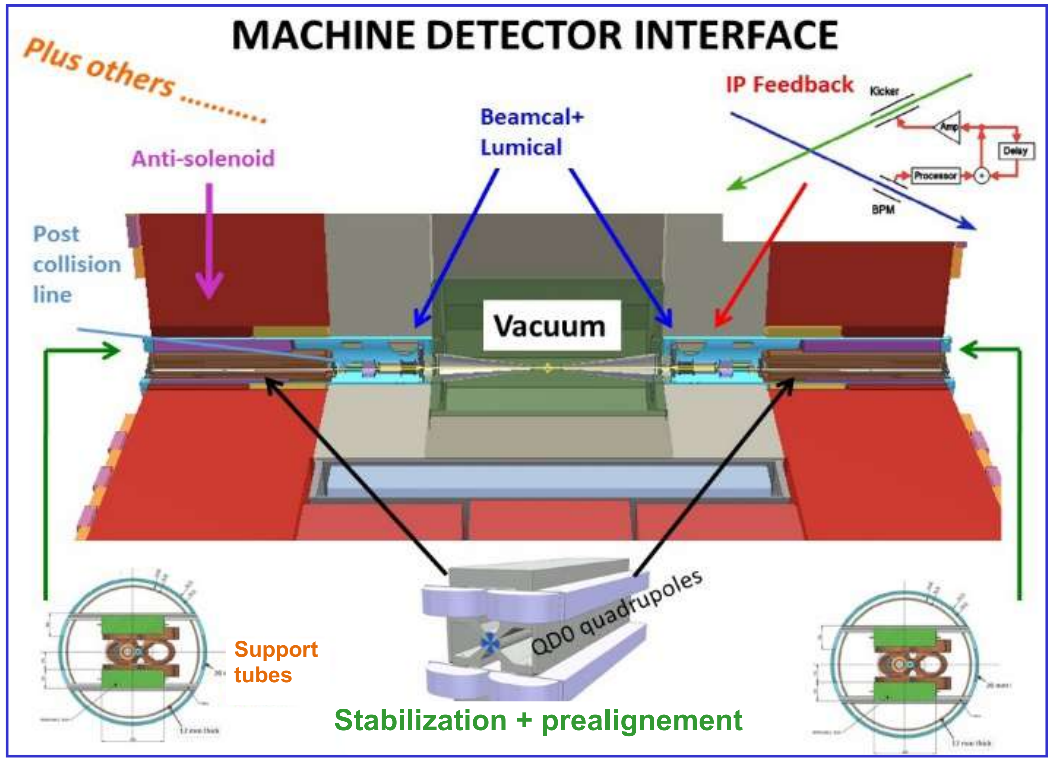
Within the FCC-ee MDI collaboration we are reviewing the main steps towards the study of vibrations and stabilisation for FCC-ee, including active and/or passive control, IP feedback with respect to the interest frequency range and global (beam) tracking simulation to identify the specifications.

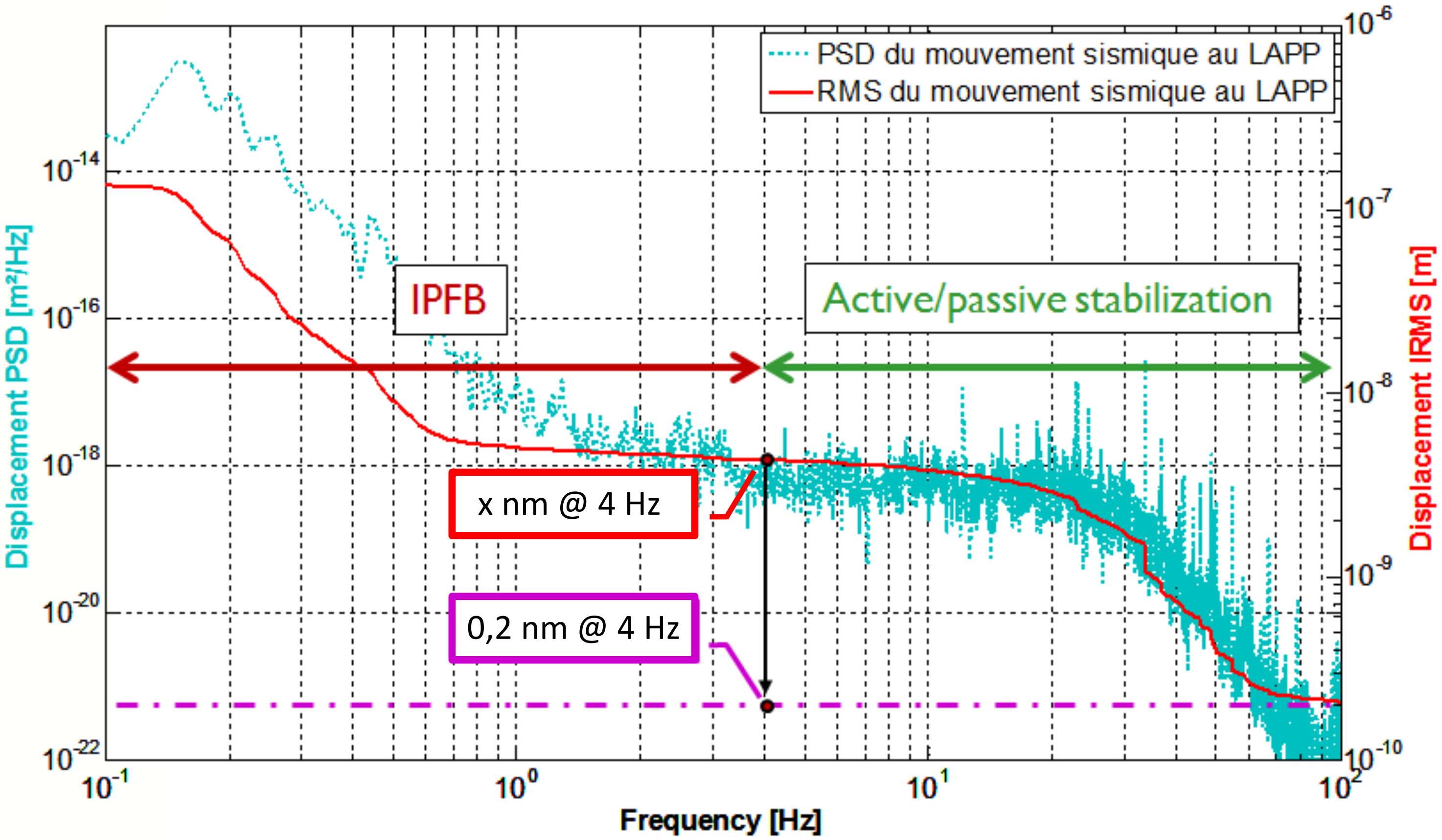
# Strategy of Control

- ***Seismic motion:***
  - *Seismic activities (starting in low frequencies)*
  - *Technical noise (human activities, cooling…)*



- ***Beam trajectory control & mechanical stabilization:***





- ➢ At the Interaction Point (beam feedback: IPFB + mechanical stabilization),
- ➢ We aim at **0,2 nm RMS at 0,1 Hz**

# Active Control with the Developed Sensors

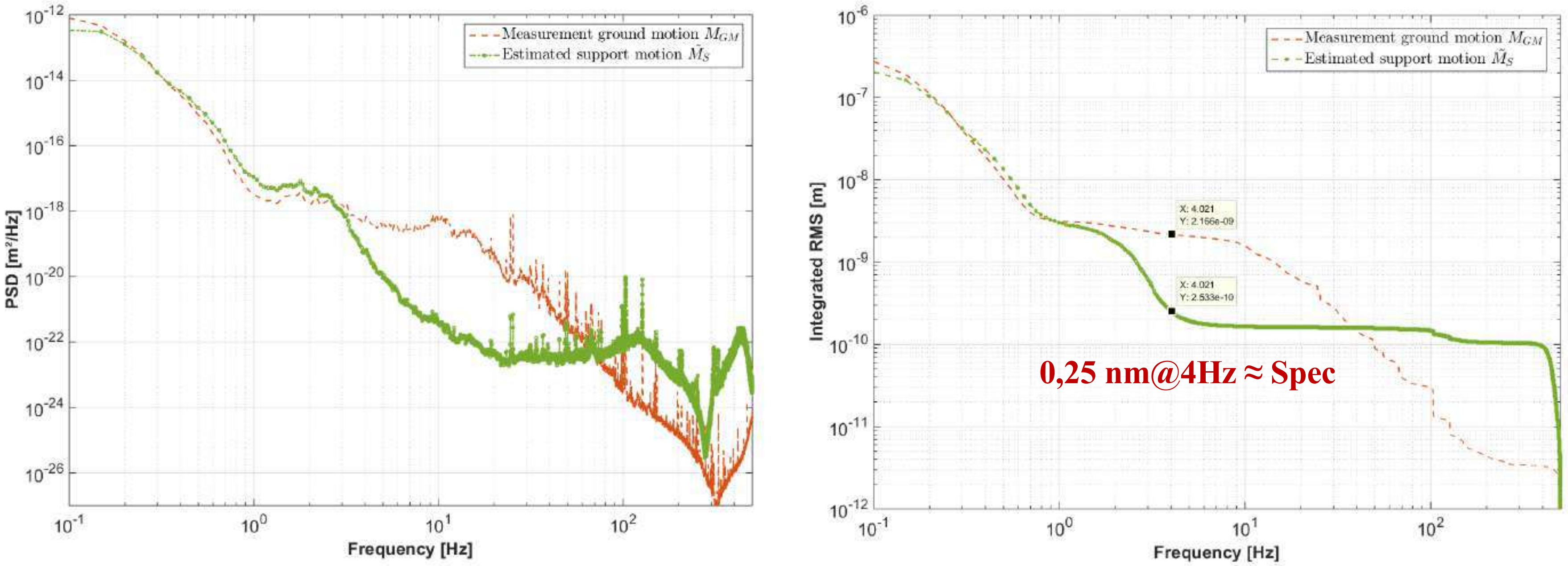
- ***CLIC Demonstration of feasibility at reduced scale***
  - CLIC specification (displacement of the QD0 final focus) : 0,20 nm RMS@4Hz
  - Previous results with LAPP active foot + 4 commercial sensors : 0,60 nm RMS@4Hz

➢ **Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0,25 nm RMS@4Hz**

- *Only 1 sensor in feedback -> control less complex and more efficient*

*- LAPP active foot + LAPP sensors (one on ground used to monitor ground motion and 1 on top used in feedback) -*

➢ *Collider environment*
➢ *Large scale*

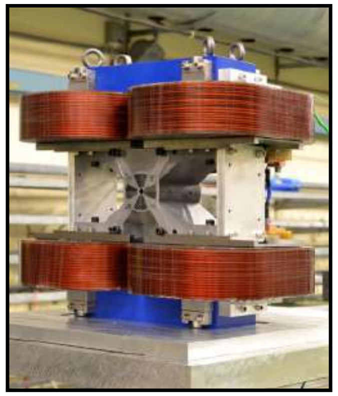


**0,25 nm@4Hz ≈ Spec**

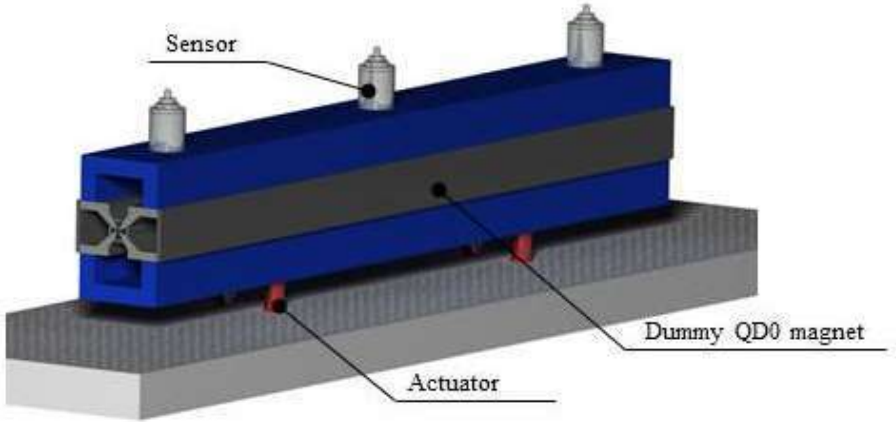
*- Displacement **without control** / **with control at LAPP** -*

G. Balik, et al., "Vibration control using a dedicated inertial sensor“, IEEE Sensors Journal, 2018

# From the Demonstration to a Large Scale Experiment

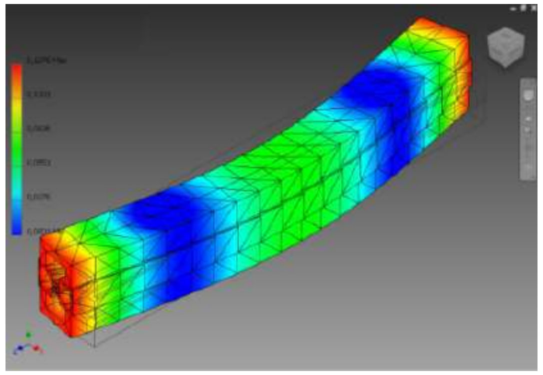


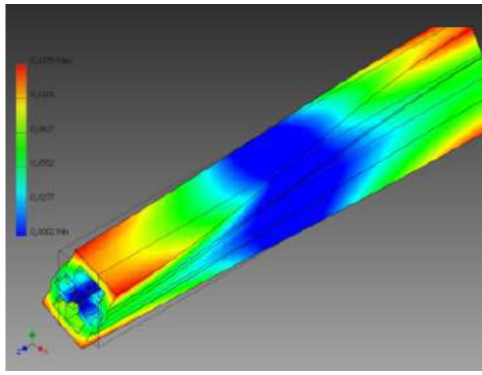
*Slide of QD0*

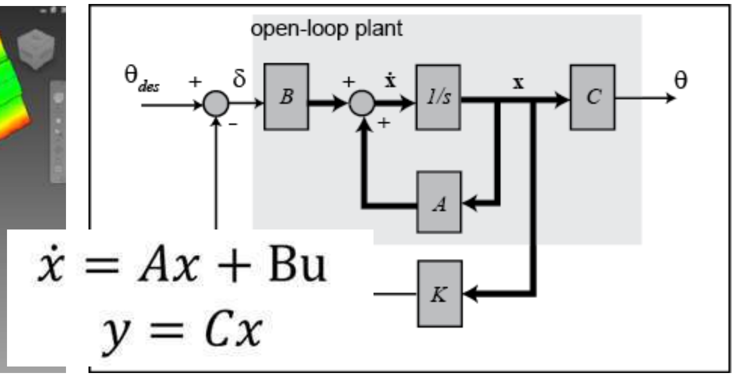


***QD0 : 2,7m – 1,5 tons***

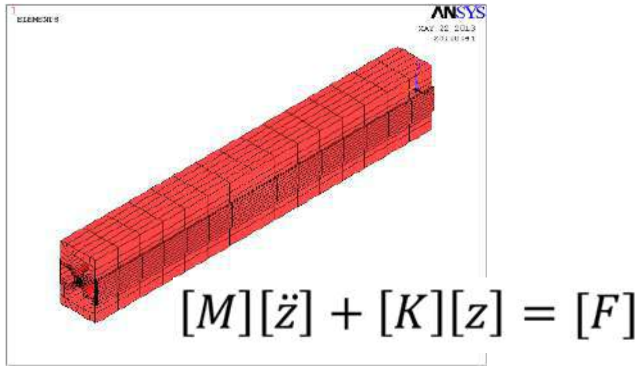
- ***Simulation***







$$\dot{x} = Ax + Bu$$
$$y = Cx$$



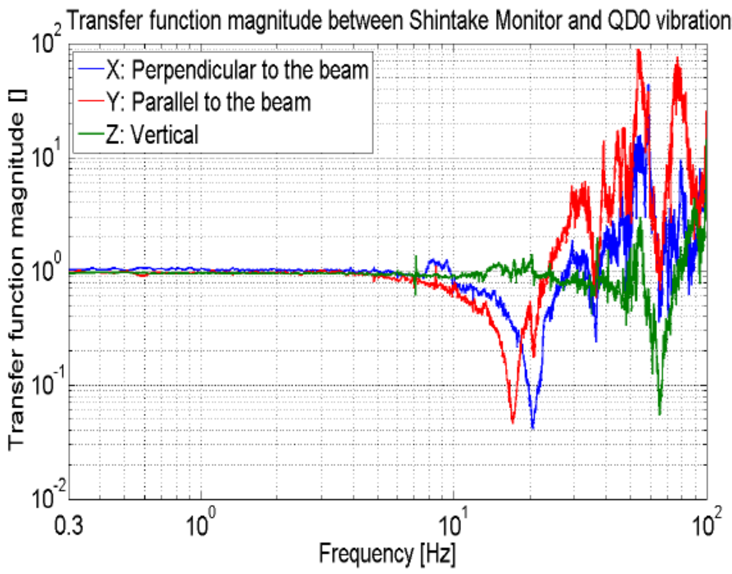
$$[M][\ddot{z}] + [K][z] = [F]$$

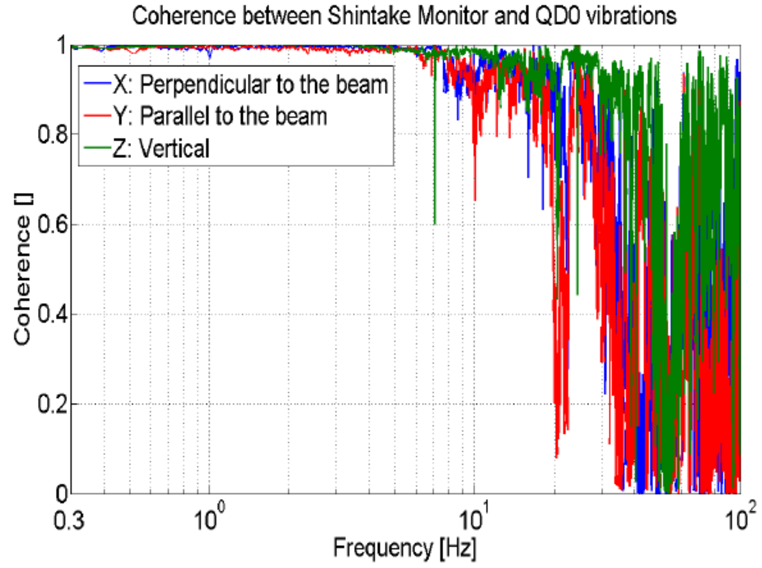
- FEM : Modal analysis using finite elements - Determination of the most significant modes (frequency response characteristics)
- Expression in the form of a state space model and study of the control strategy
- Integration in a control loop (using Simulink for example) with a global simulation (sensor, actuators, ADC, DAC, Data processing…. and seismic motion model and its coherence)
- Control in simulation (location and number of active feet, type of active feet, degrees of freedom, type of control (SISO, MIMO))

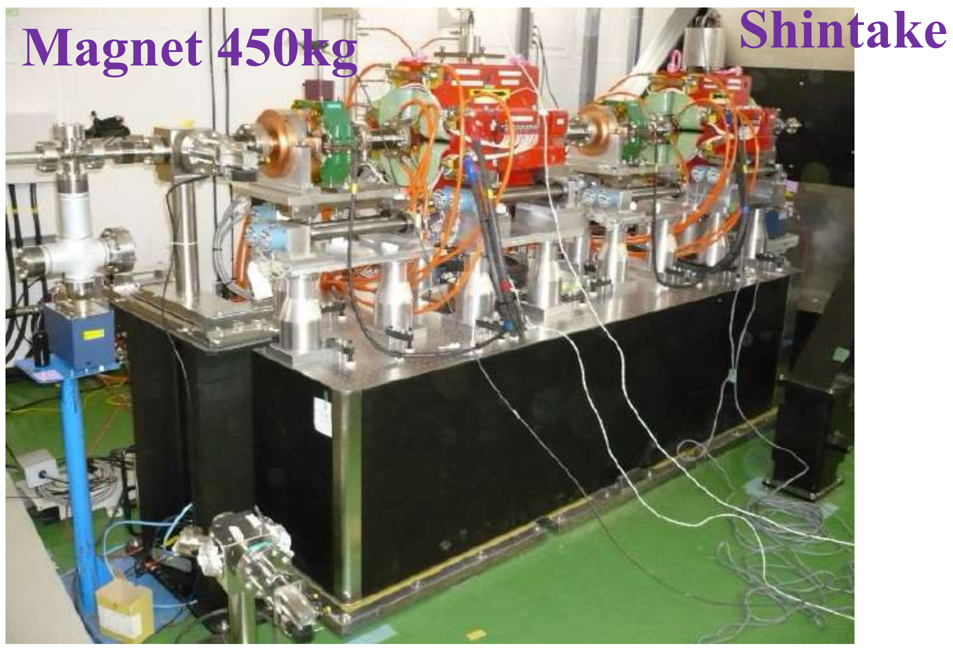
**Simulation of active control with all the elements (electronics, mechanics, instrumentation, feedback, disturbances…) could be adapted to FCC**

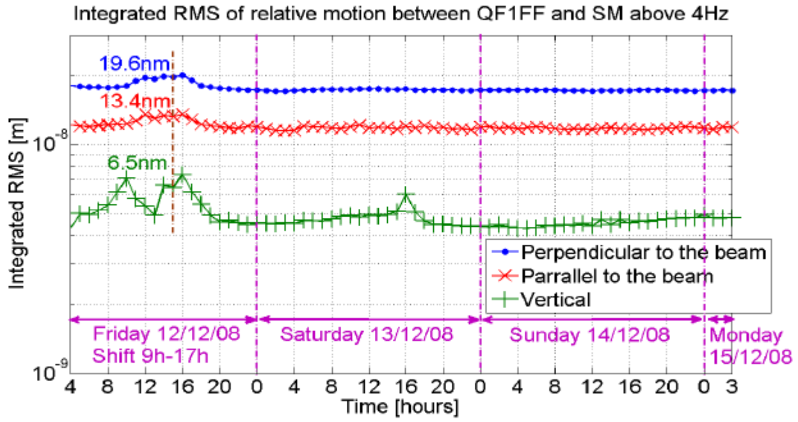
# ATF2: Optimization of the Relative Motion

- ***Final setup of the final focus:***









- ➢ Very stiff in z direction (first eigenfrequency at 70Hz induced by the final doblets supports) - beeswax

- ➢ ***Relative motion between shintake monitor and final doublets of [4 – 6] nm RMS @ 0,1 Hz (vertical axis):***

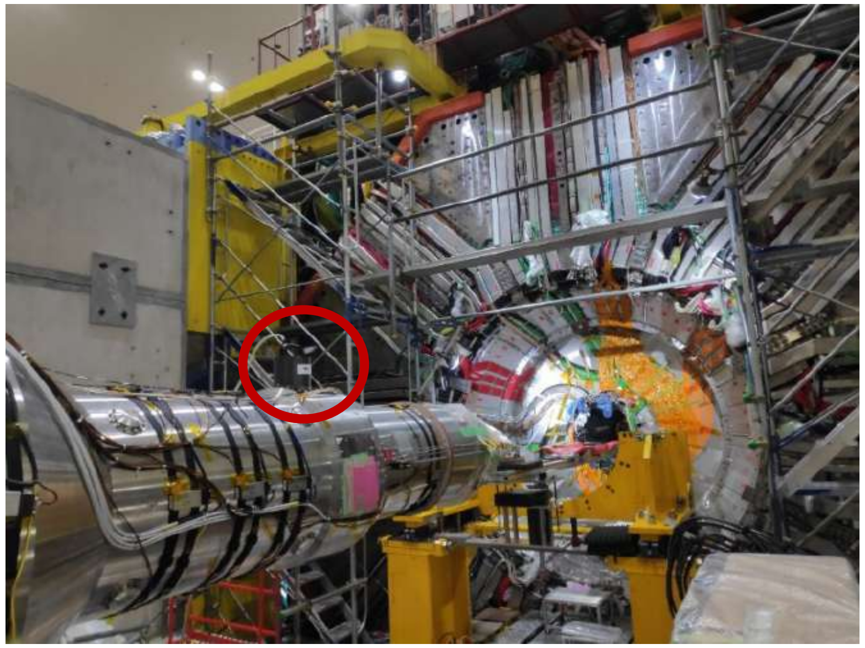
| | Tolerance | Measurement [SM-QD0] | Measurement [SM-QF1] |
|---|---|---|---|
| Vertical | 7 nm (for QD0)<br>20 nm (for QF1) | 4.8 nm | 6.3 nm |
| Perpendicular to the beam | ~ 500 nm | 30.7 nm | 30.6 nm |
| Parallel to the beam | ~ 10,000 nm | 36.5 nm | 27.1 nm |

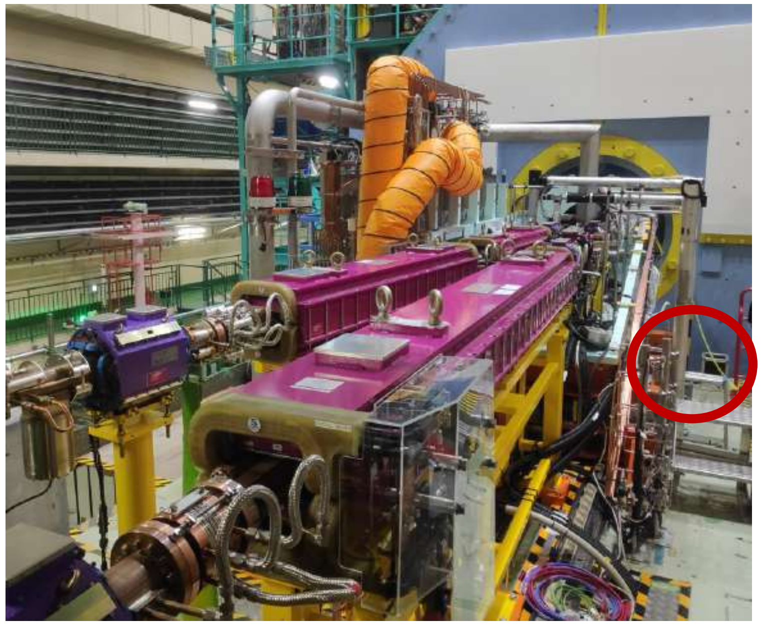
**For FCC: strategy of control (CLIC vs ATF2)**

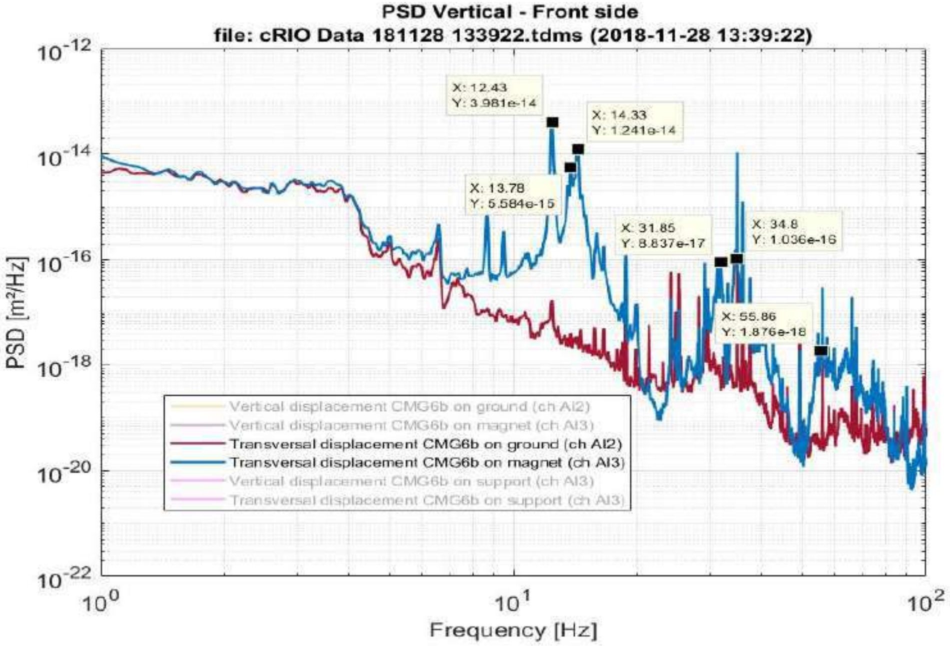
# SuperKEKB: Experimental Activities on Site

- **Vibration measurements June 2018**

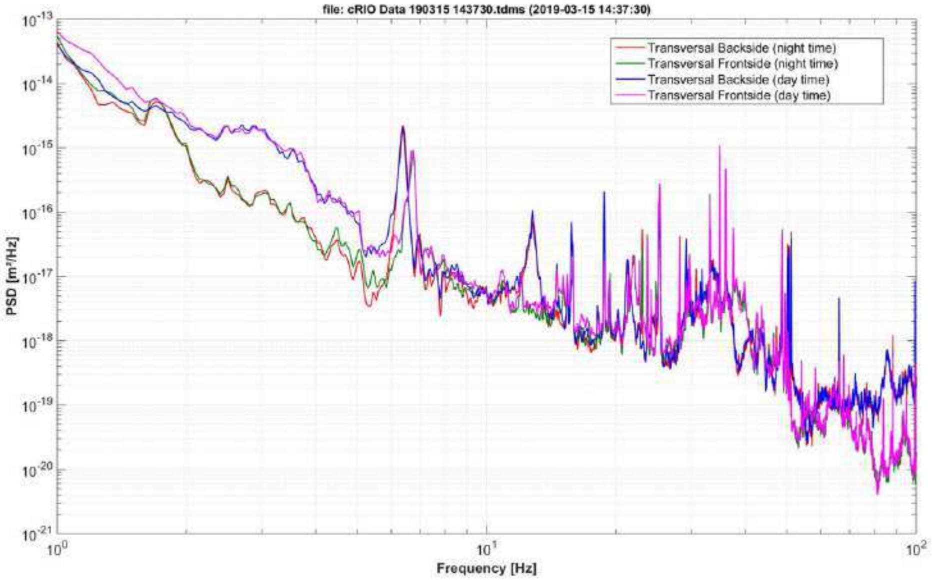
*- Preliminary measurements of the cryostat dynamics-*







*Comparative measurements ground vs cryostat*



*Comparative measurements day / night on the both sides of the detector*

# IP Fast Feedback Systems (FONT) at ILC and CLIC, Philip Burrows (Oxford Univ.)

## Introduction and IP FB system concept :

IP feedback system has been optimized for the beam parameters, especially the time structure of bunch train of ILC and CLIC, which are 1,300bunches/500ns-sepration and 300bunches/0.5ns-sep., respectively.

The feedback latency, current technology must be O(100ns), digital@ILC and O(10ns), analog@CLIC.

FB hardware should be close to IP (especially for CLIC ! ) for the speed of light of 30cm/ns.

Two systems, one on each side of IP, allow for redundancy.

## ILC IP FB design status : ILC TDR (2013)

IP beam position feedback: beam position correction up to ± 300 nm vertical at IP

IP beam angle feedback: hardware located few 100 metres upstream, very similar to position FB, less critical

Bunch-by-bunch luminosity signal (from ‘BEAMCAL’)

FB BPM in front of QD0 and FB kicker just behind of QD0/SD0

## CLIC IP FB design status : CLIC CDR (2012)

NB : primary method for control of beam collision overlap is via vibration isolation of the FF magnets, and dynamic correction of residual component motions

IP beam position feedback: beam position correction up to ± 50 nm vertical at IP within a train (157ns)

More realistic engineering design in development

FB BPM and kicker are located just behind the BeamCal

**FONT prototype systems performance :** Stripline BPM resolution of 0.3μm ( latency, drive power )

ILC prototype: FONT4 at KEK/ATF was verified the basic performance satisfication (150ns, < 300 nm)

CLIC prototype: FONT3 at KEK/ATF was verified the basic performance satisfication ( 13ns, < 50nm )

## Outstanding technical issues :

Component designs need to be optimised for tight spatial environments, cabling, operation in large, spatially-varying B-field , further studies of radiation environment, electronics location, rad hardness, shielding and RF interference between beam and FB electronics and also between kicker and detector etc. .

# Beam parameters

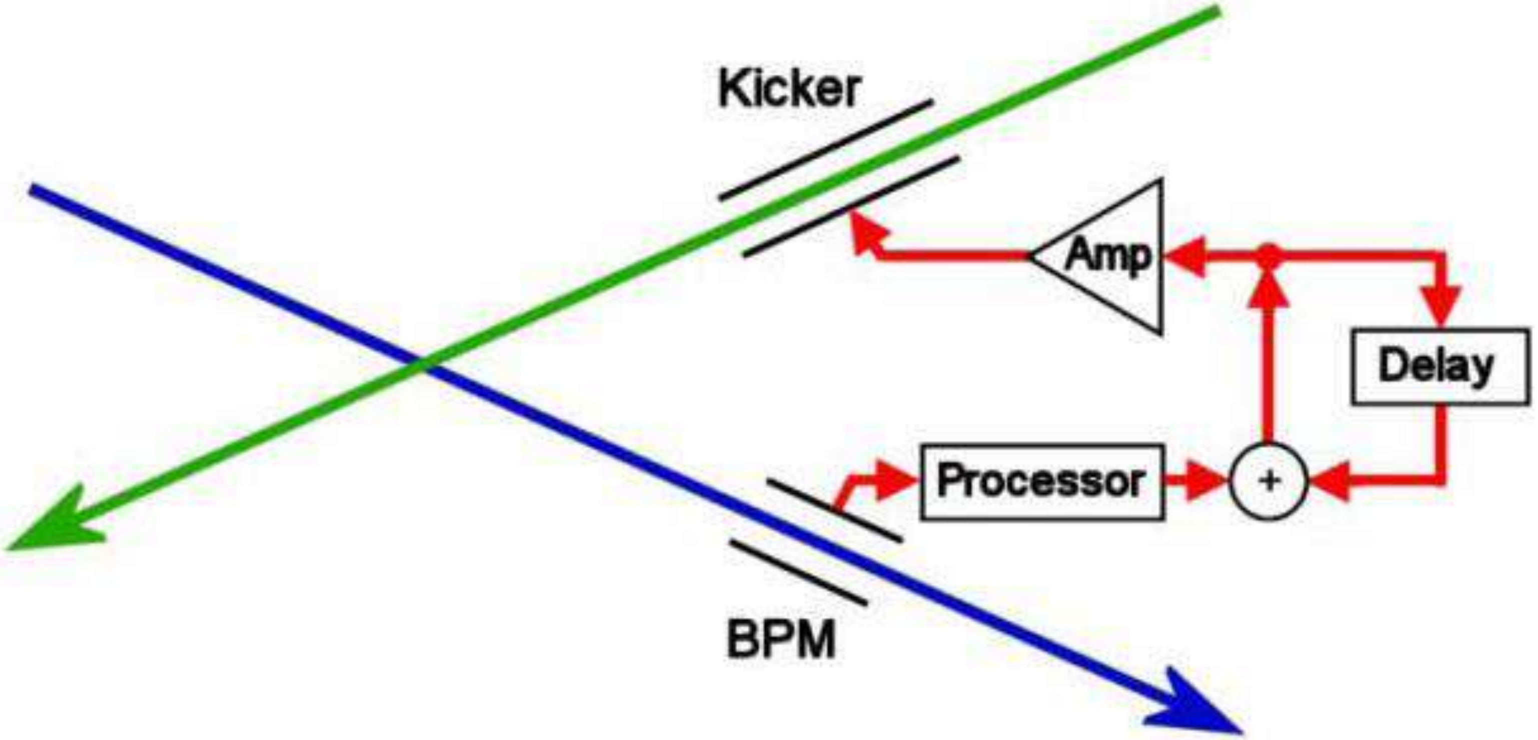
| | ILC 250 | 500 | CLIC 3 TeV | |
|---|---|---|---|---|
| Electrons/bunch | 2 | 2 | 0.37 | 10**10 |
| Bunches/train | 1312 | 1312 | 312 | |
| Bunch separation | 554 | 544 | 0.5 | ns |
| Train length | 727 | 727 | 0.156 | us |
| Train repetition rate | 5 | 5 | 50 | Hz |
| Horizontal IP beam size | 516 | 474 | 40 | nm |
| Vertical IP beam size | 8 | 6 | 1 | nm |
| Luminosity | 1.4 | 1.8 | 6 | 10**34 |

# IP beam feedback concept

Last line of defence against relative beam misalignment

Measure vertical position of outgoing beam and hence beam-beam kick angle

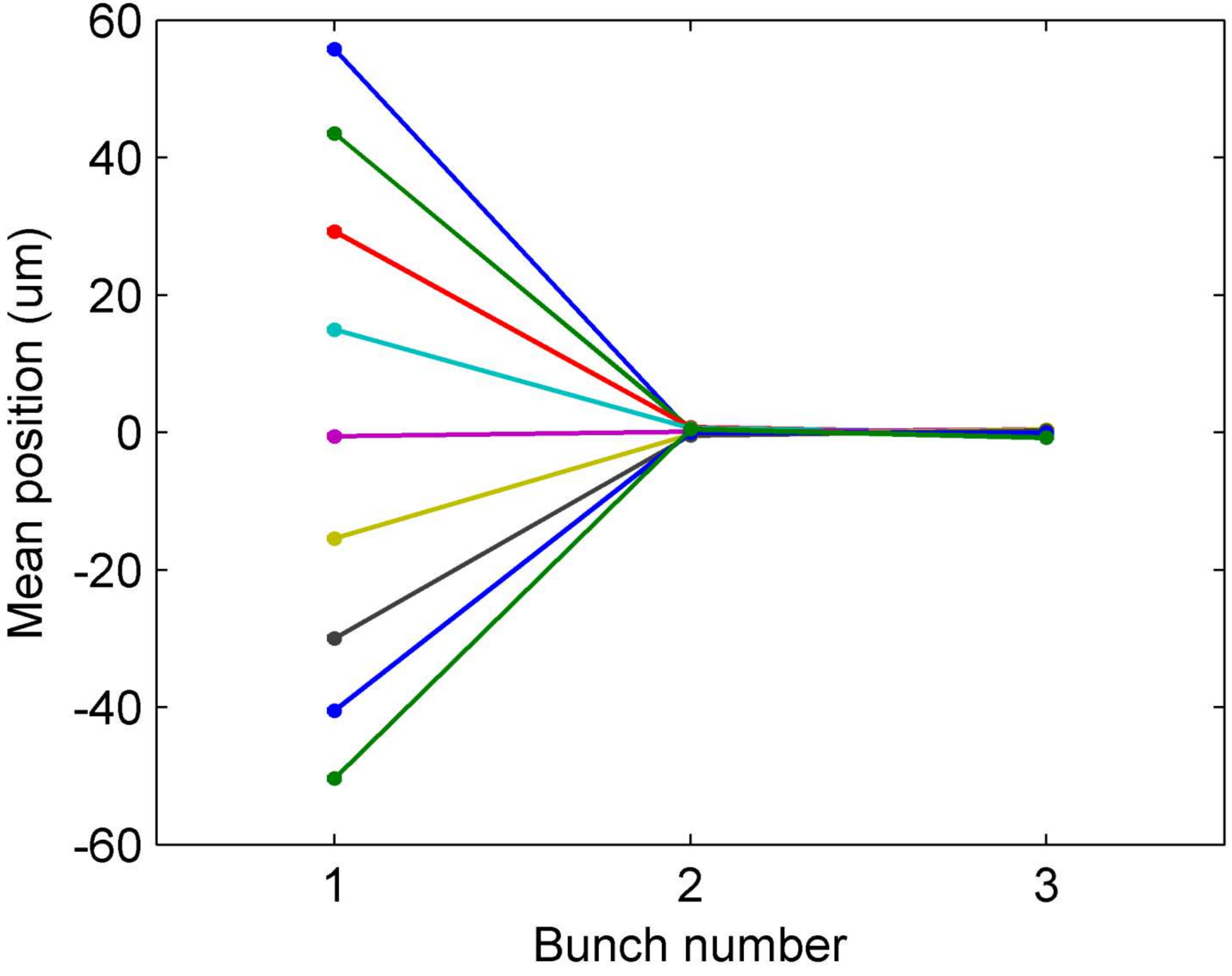
Use fast amplifier and kicker to correct vertical position of beam incoming to IR



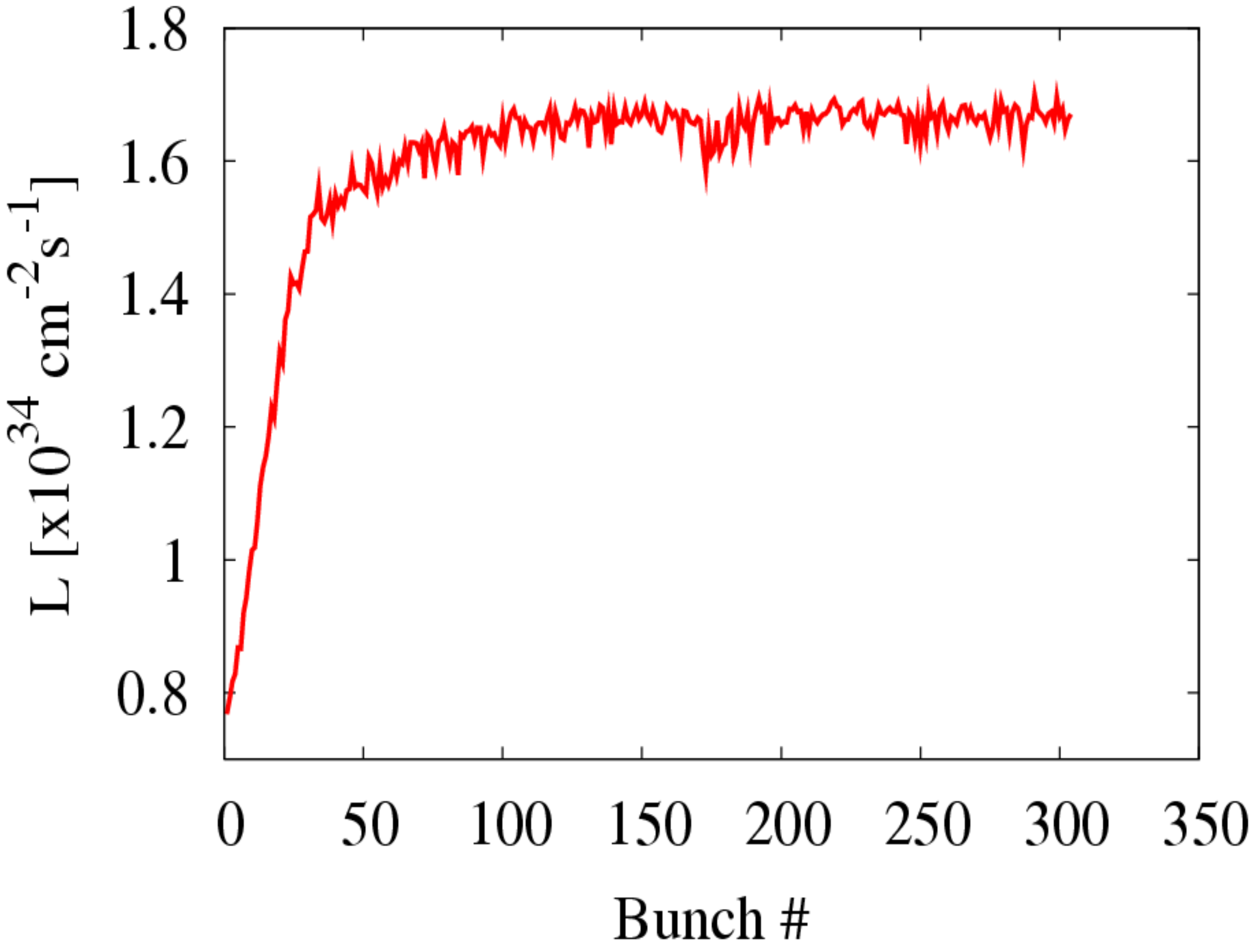
## FONT – Feedback On Nanosecond Timescales:

Robert Apsimon, Neven Blaskovic Kraljevic, Douglas Bett, Ryan Bodenstein, Talitha Bromwich
Philip Burrows, Glenn Christian, Christine Clarke, Ben Constance, Michael Davis, Tony Hartin,
Young Im Kim, Simon Jolly, Steve Molloy, Gavin Neson, Colin Perry, Rebecca Ramjiawan,
Javier Resta Lopez, Jack Roberts, Christina Swinson

# FONT ILC prototype performance

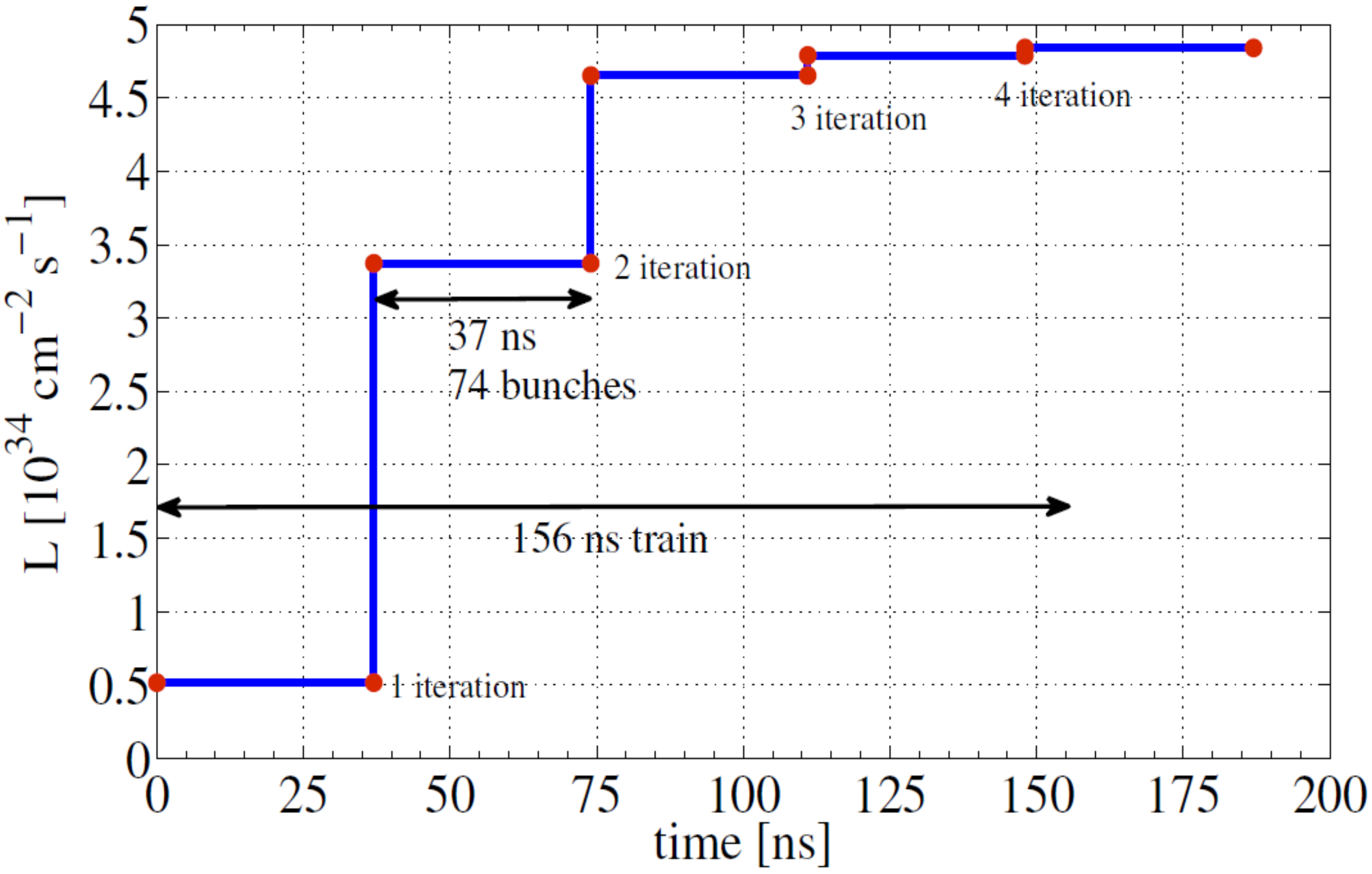


# Simulated ILC IP FB performance



# CLIC IP FB performance

**Single random seed of GM C**



# Discussion on possible future collaboration :

We could successfully exchange MDI issues of SuperKEKB, CEPC, SuperTauCharm factory, FCCee, ILC, CLIC and BNL-EIC. We found a lot of common issues such as superconducting final focus magnets, beam induced backgrouds, mechanical integration, solenoid compensation schemes, beam pipe design, forces and torques management . It is very nice to know current issues at various colliders. Also, we could communicate with experimentalists and accelerator physicists, although they work separately on a daily basis. This workshop place is rather good since many of us leave from their own universities, institutes and we could concentrate in the mini-workshop.

The MDI is a meeting place for experimentalists and accelerator physicists to discuss on realization of future colliders in the energy and luminosity frontiers. Since investment of future collider is huge, all of them can not be realized, even a single collider is difficult to be realized. It is very important to have an international collaboration through common issues such as MDI for us to participate in such a collider with actual contributions as much as possible in future.

There is a suggestion to continue this kind of activity, i.e. MDI mini-workshop by inviting young generations from experimental and accelerator fields. The HKUST IAS seems to be a good place if finantial support is available at least for local expenses to students.