Belle II vertex detector commissioning and CO_2 cooling system

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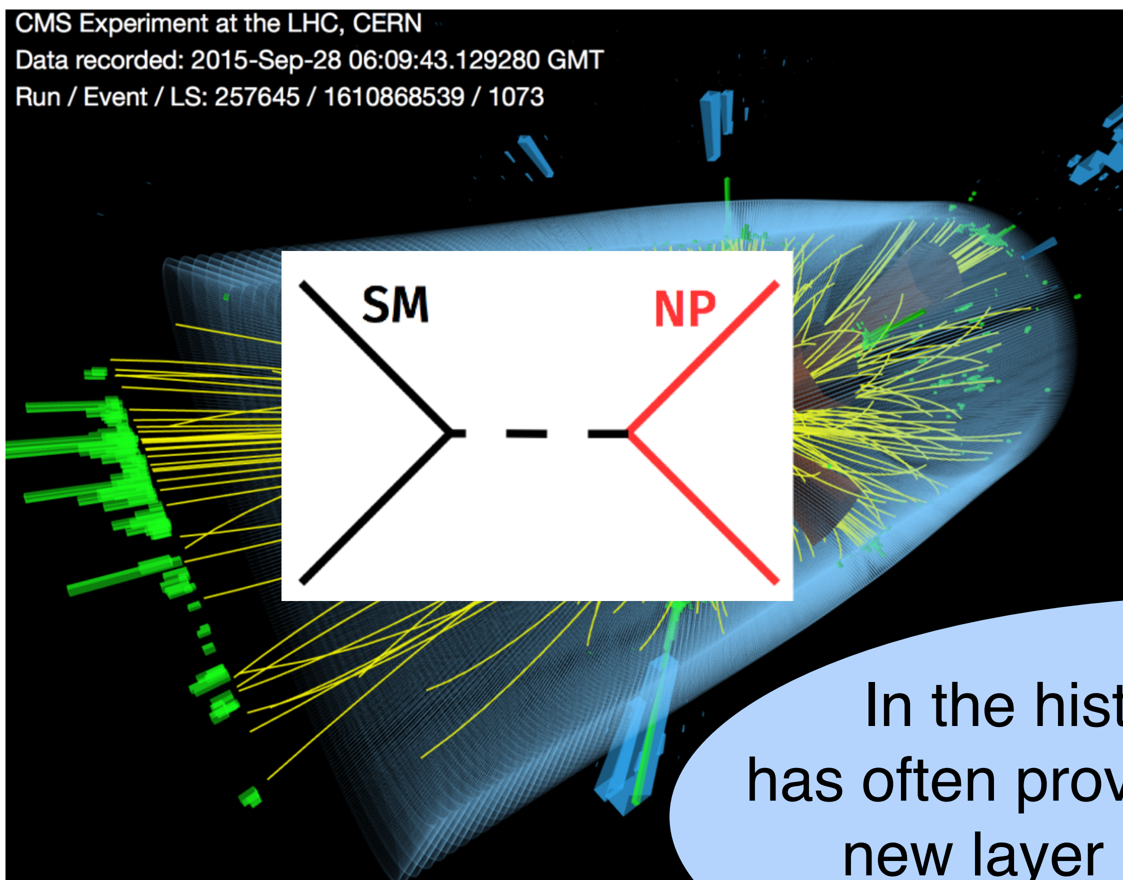
Outline

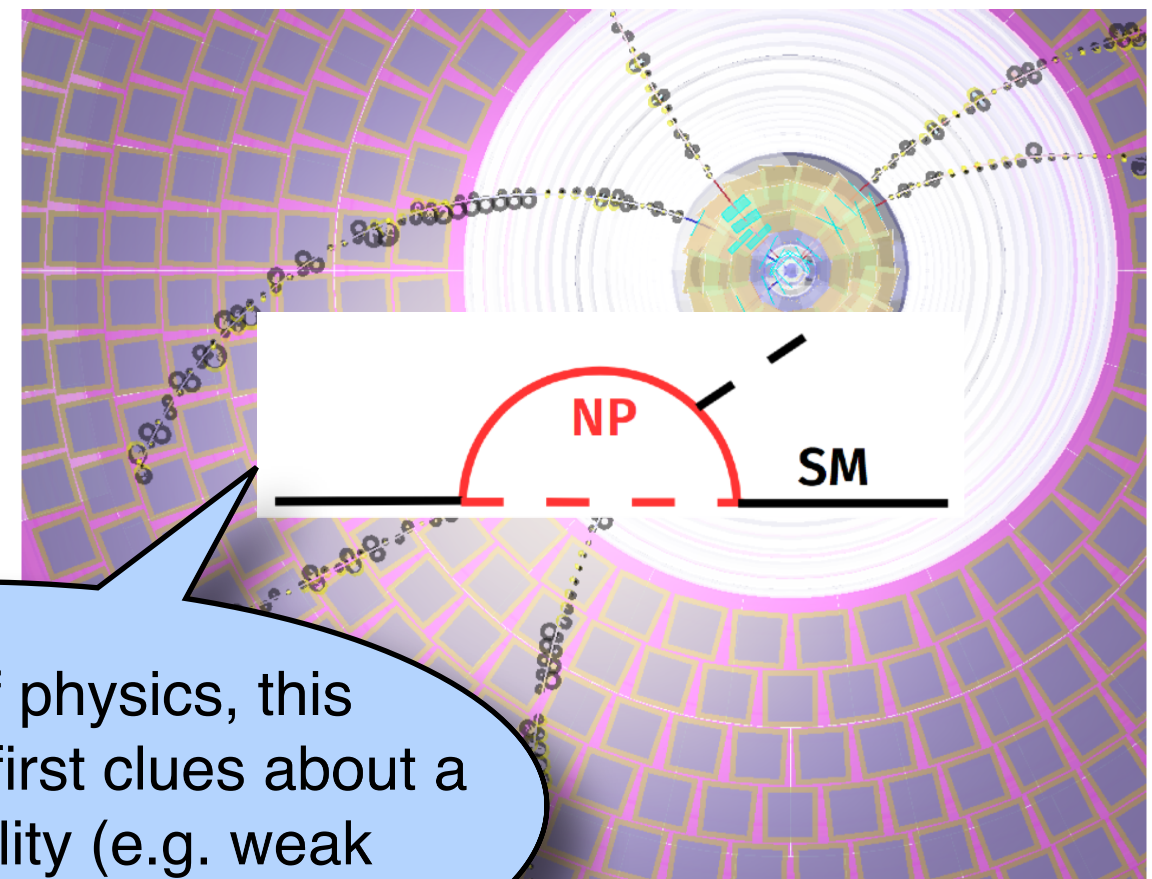
- 1. Introduction
  - 1.1 SuperKEKB/Belle II
  - 1.2 New Physics searches at Belle/Belle II
  - 1.3 Belle II vertex detector
- 2. VXD commissioning
  - 2.1 BEAST II
  - 2.2 Phase 2 integration test at DESY
  - 2.3 Beam tests at DESY
- 3. VXD mechanics
  - 3.1 Thermal mockup studies

Complementary Pathways to New Physics

Energy Frontier
- Allow for direct production of new particles
- New Physics (NP) reach limited by the beam energy scale $\mathcal{O}(10\text{TeV})$

Luminosity Frontier
- New “virtual” particles can occur in quantum loops
- Sensitivity to mass scale $\mathcal{O}(100\text{TeV})$



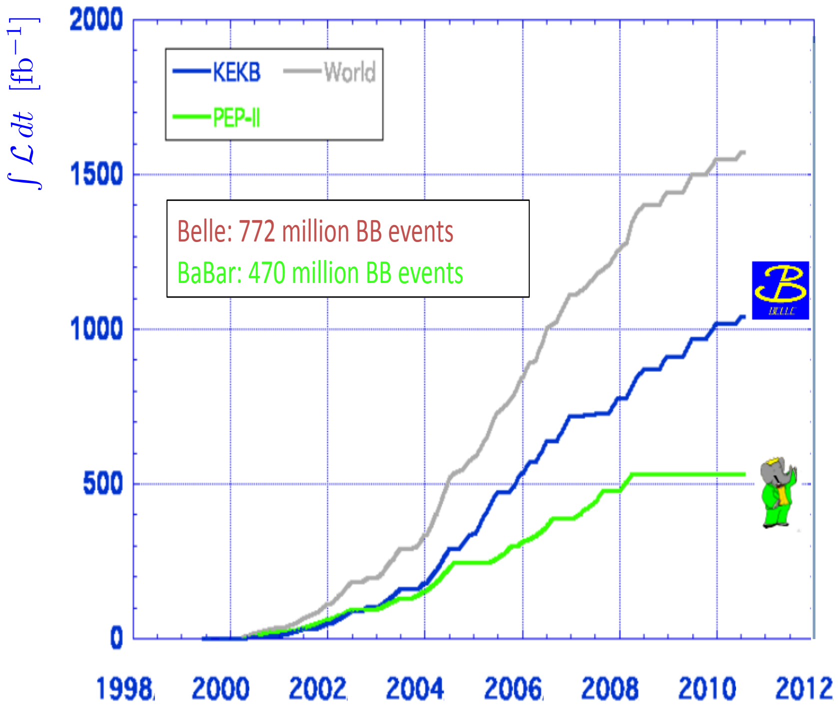


In the history of physics, this has often provided first clues about a new layer of reality (e.g. weak interactions, c, t, Higgs…)

Direct and indirect searches are complementary and must both be pursued!

Success of 1st Generation B-Factories

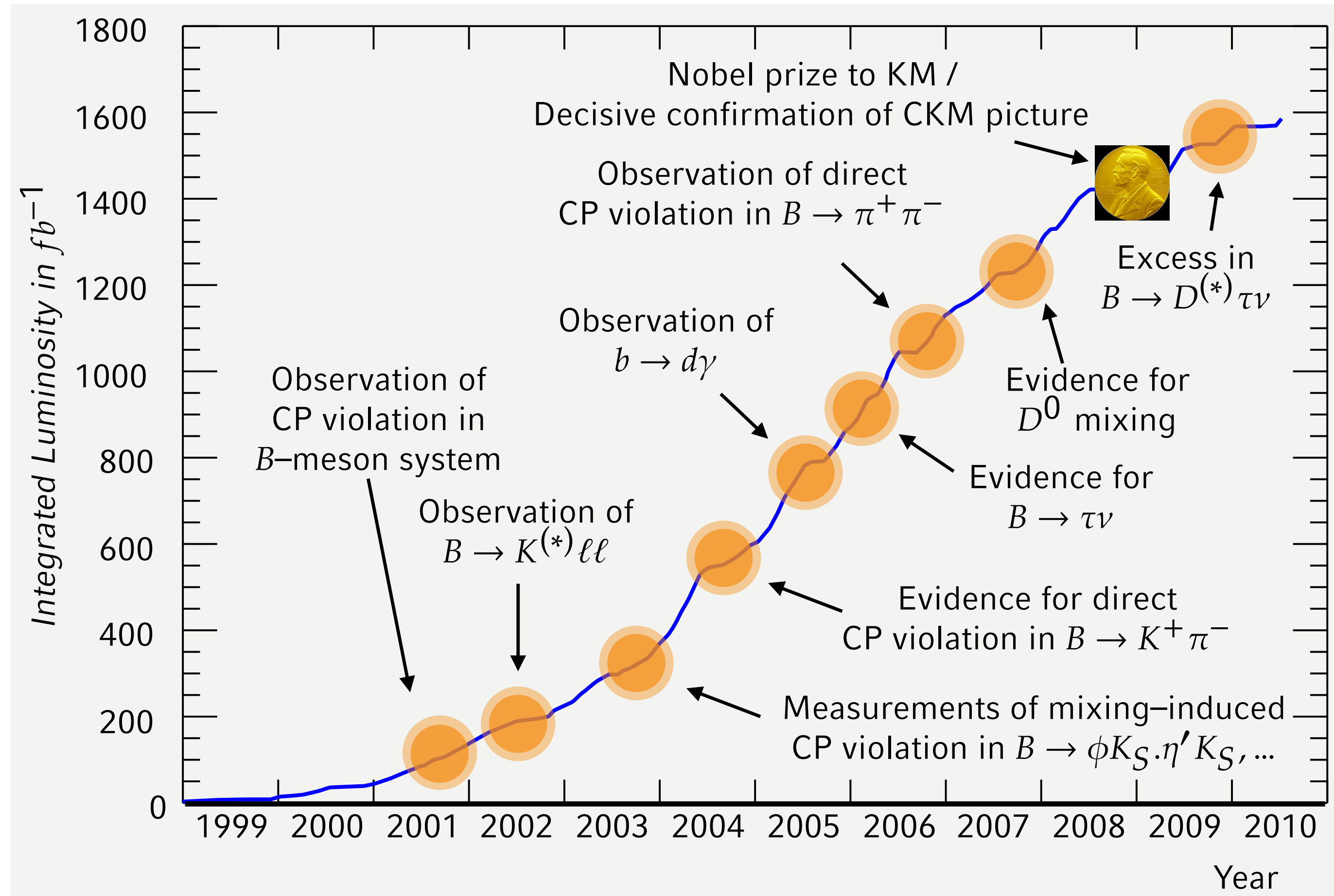
KEKB / PEP-II

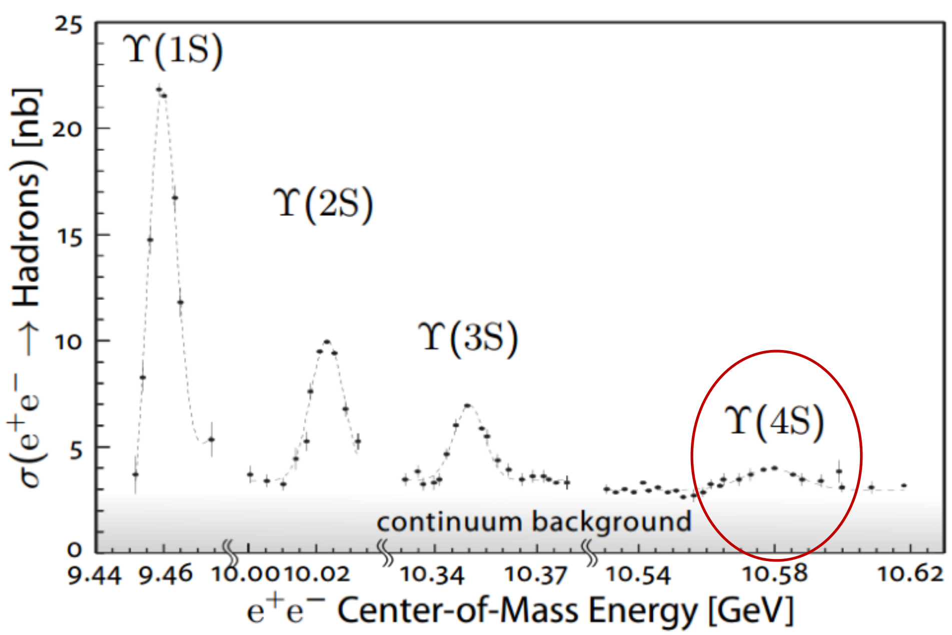


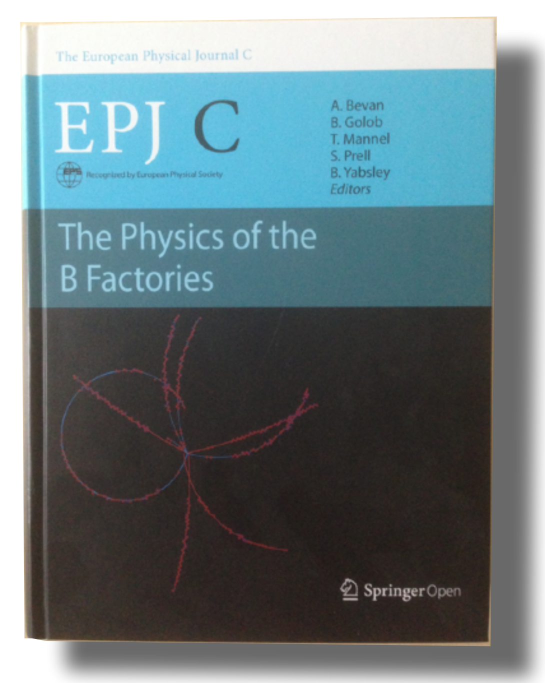
> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Belle Achievement

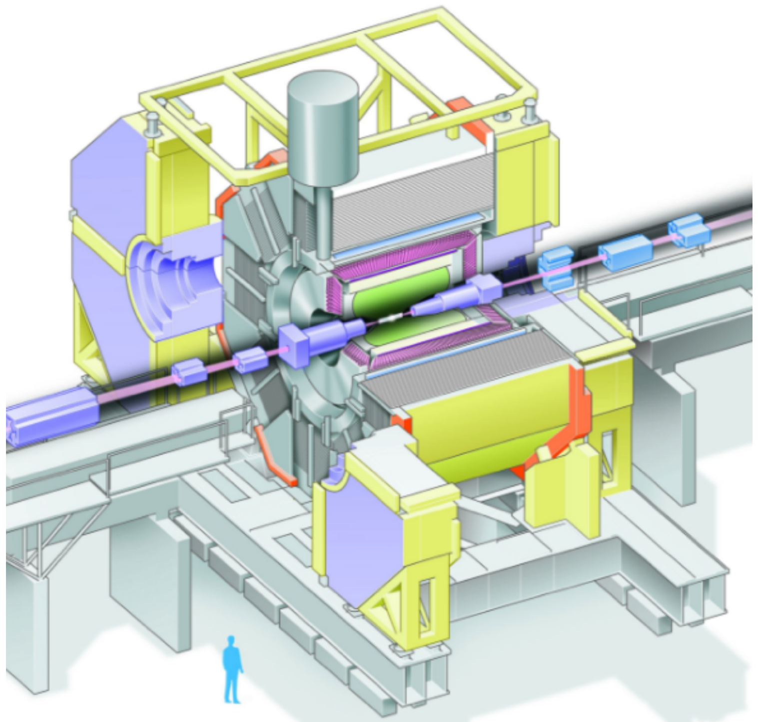


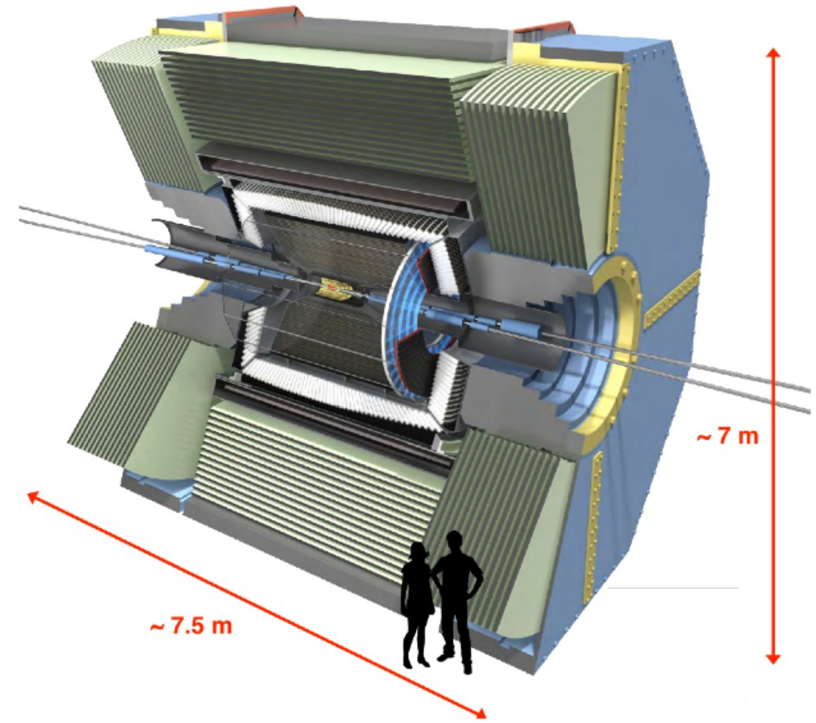




> 900 pages

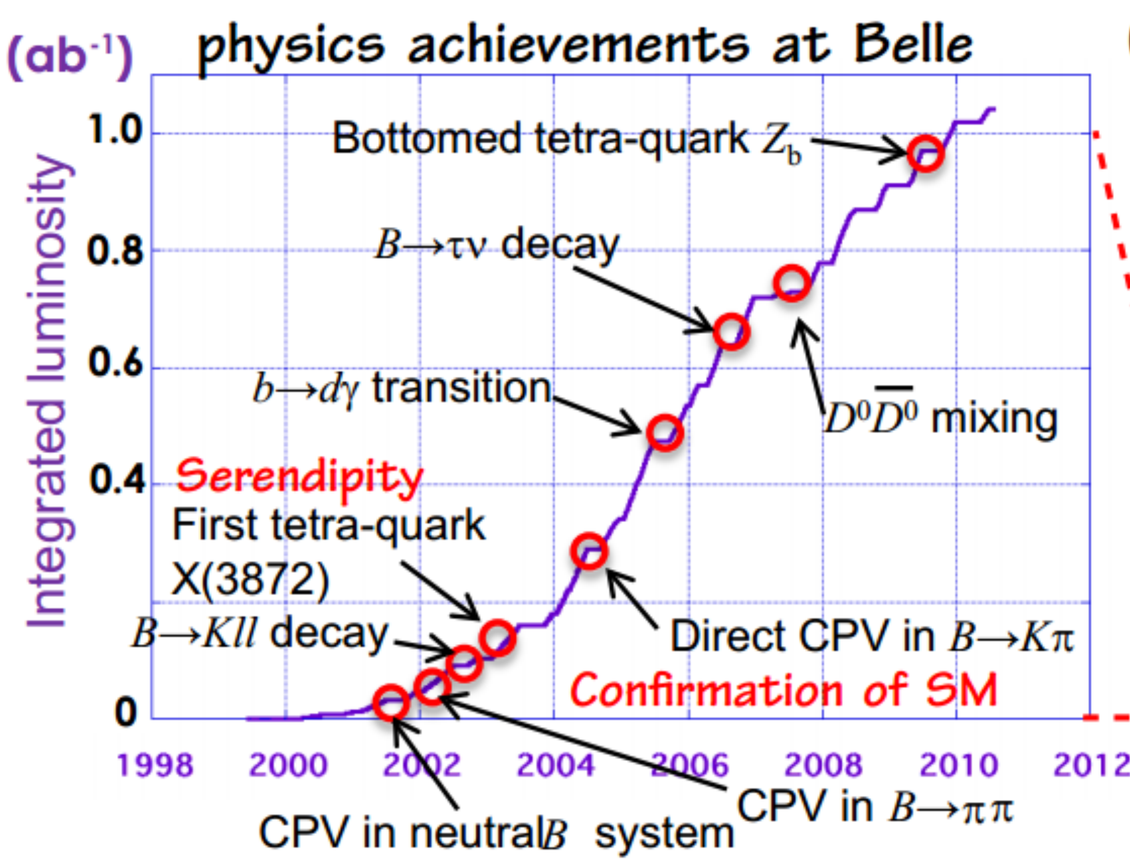
From Belle to Belle II

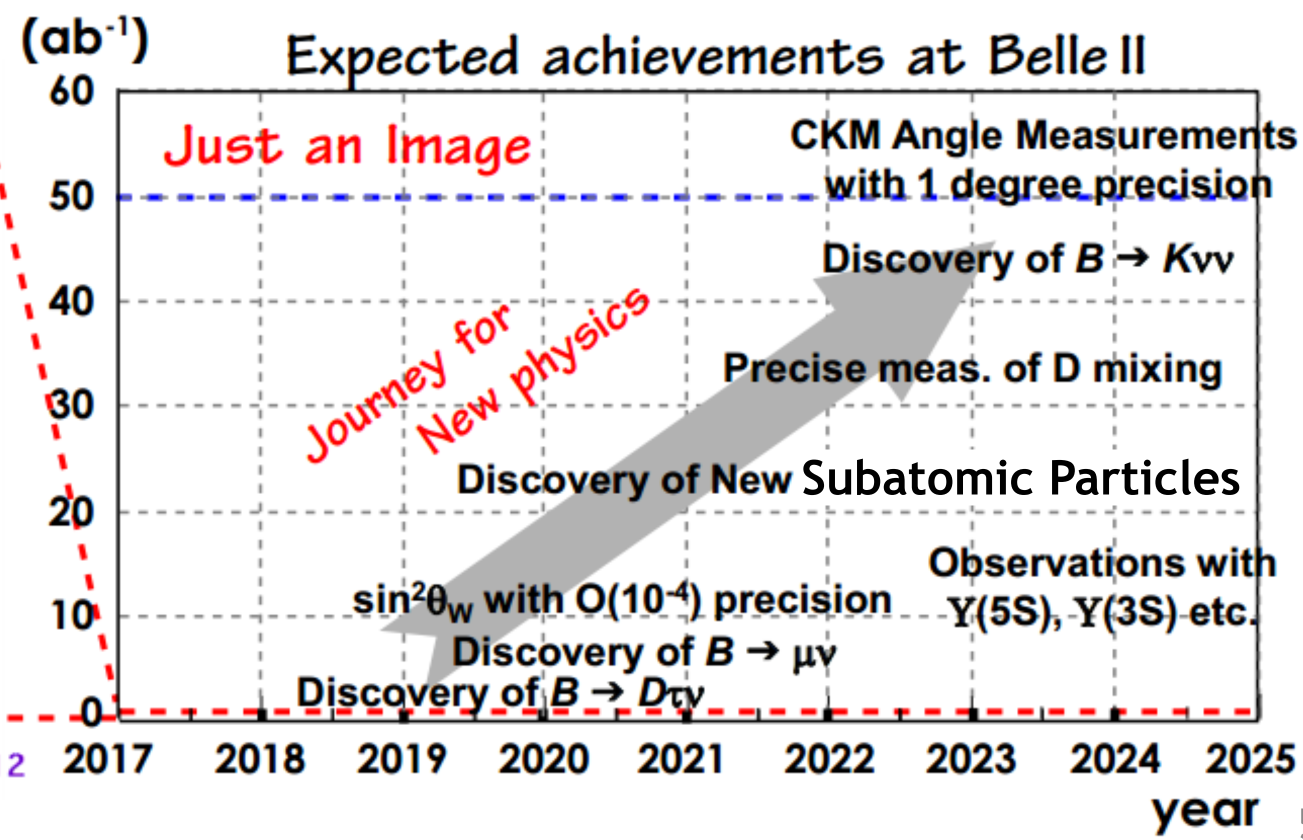




Belle achieves >450 Physics Journal Publications

Expected to gain 50ab^{-1} sample in next decade





B-factories vs LHC[b]

- Advantages of LHCb
  - O(mb) vs O(nb) b cross section
    - 10^6 times larger (10^5 in acceptance)
  - $O(10^4$mm) vs $O(10^2$mm) decay length
    - 10^2 times larger

	Babar /Belle	**ATLAS / CMS**	**LHCb**
$\sqrt{s}$ [GeV]	10.58 [y(4S)]	7000 / 8000	7000 / 8000
BB production	coherent BB state	incoherent BB state	
σ_{bb} [μb] in acceptance	0.0011	75	94
L [fb^{-1}]	550 / ~1000	~30	3
bb pairs in acceptance [10^{11}]	0.01	22	3

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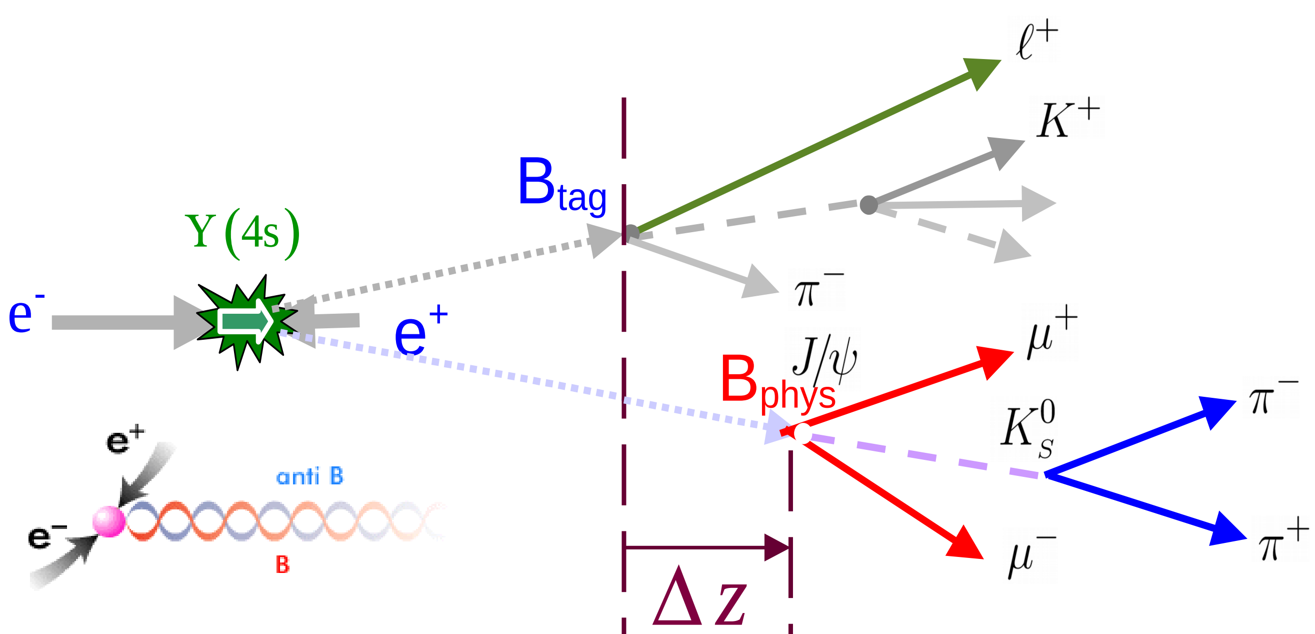


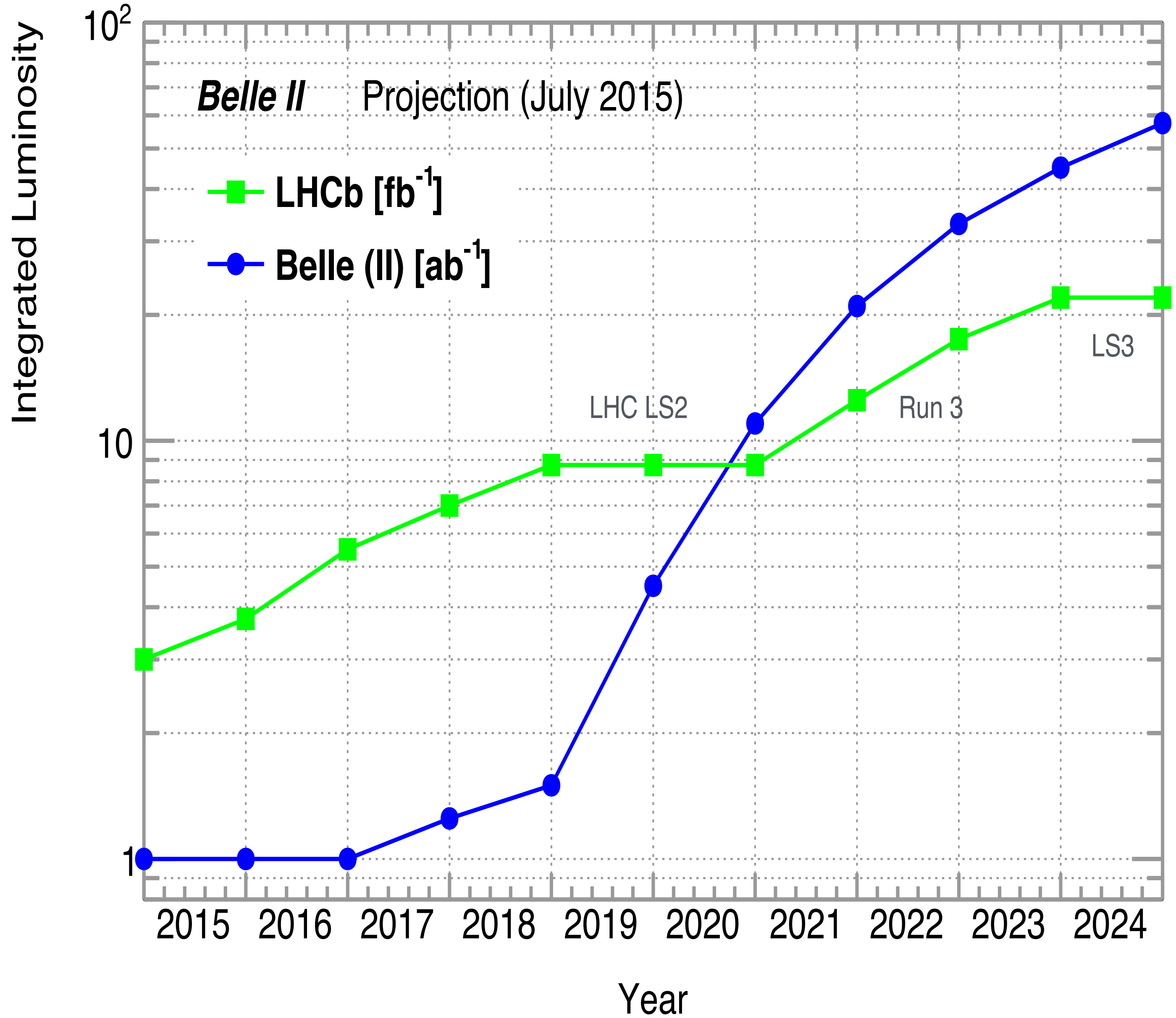
Quantum entangled neutral B meson pair production

Belle ~ 200 μm
Belle II ~ 130 μm

- Advantages of B factories
  - much higher luminosity (x10^3)
  - "**missing mass**" analyses can be performed to infer existence of **new particles** via energy/momentum conservation
  - **low background** allows for the reconstruction of final states containing **photons** from decays of π^0, $\rho^\pm$, η, η' etc. and K_L^0 reconstruction
  - detection of decay products of one B allows **flavour** of the other B to be **tagged** (time dependent CP violation)
  - large samples of τ leptons allowing for measurements of **rare** τ **decays** and searches for **lepton flavour and lepton number violating** τ decays

LHCb vs Belle II:Competition and Complementarily

Integrated Luminosity



- B_s System
  - CPV in $J/\psi\phi$, $\phi\phi$,
  - CPV in Mixing
- $B \to \mu\mu$
- CKM phase γ in $B \to DK$
- CPV in B_d
- $B \to X_s\, ll$ (exclusive)
- $B \to X\gamma$ (exclusive)
- Charm physics
- Semi-leptonic B decays
- τ - physics: LFV
- $B \to D, D^* \tau\nu$
- $B \to X_s\, ll$ (inclusive)
- $B \to X\gamma$ (inclusive)
- $B \to \tau\nu$, $\mu\nu$
- $B \to K^*\nu\nu$, $B \to \nu\nu$

B_s & charged tracks

Important cross checks

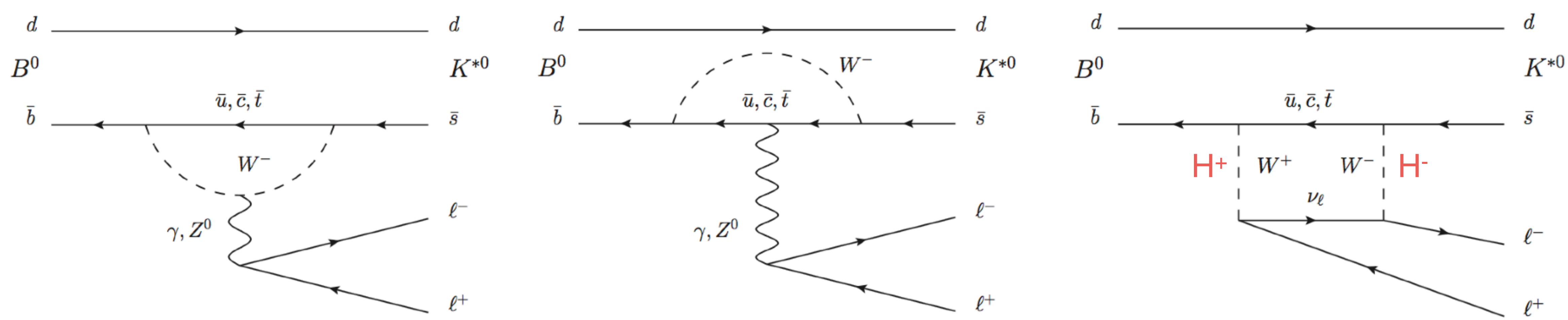
inclusive & neutrals

Slide adapted from J.Albrecht, DESY Seminar 25.10.16

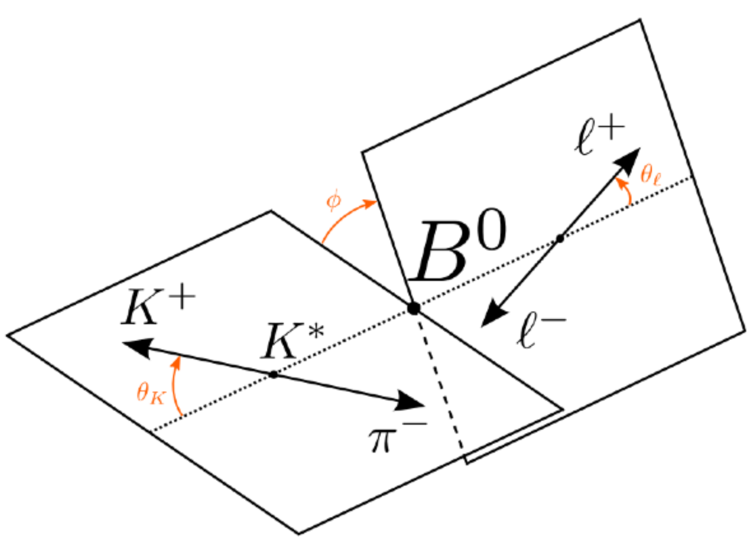
- Healthy competition between LHCb and Belle II
- Complementary approaches but physics programs have also significant overlap for cross checks in important areas

Rare decay: $B \to K^{*}ll$ ($l=\mu,e$)

- $b \to s$ flavor changing neutral current (FCNC) is suppressed within the SM, new physics can interfere with the SM amplitude can lead to the modified branching fraction or angular distribution.



SM and NP processes

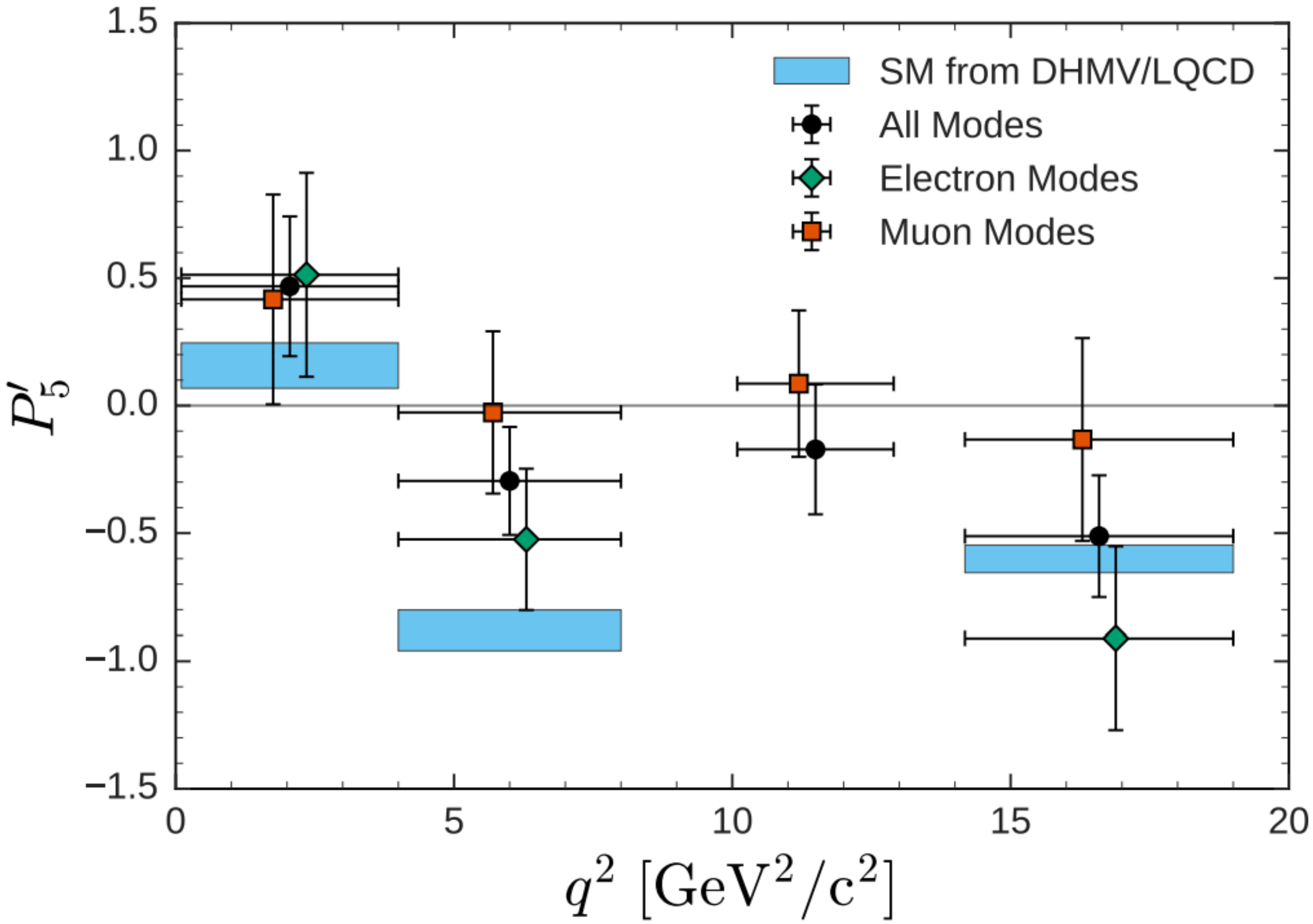


$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \right.$$
$$+\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$-F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$\left.+\sqrt{F_L(1-F_L)}P'_5\sin 2\theta_K\sin\theta_\ell\cos\phi\right].$$

3 free parameters: F_L, $A_T^{(2)}$, P'_5

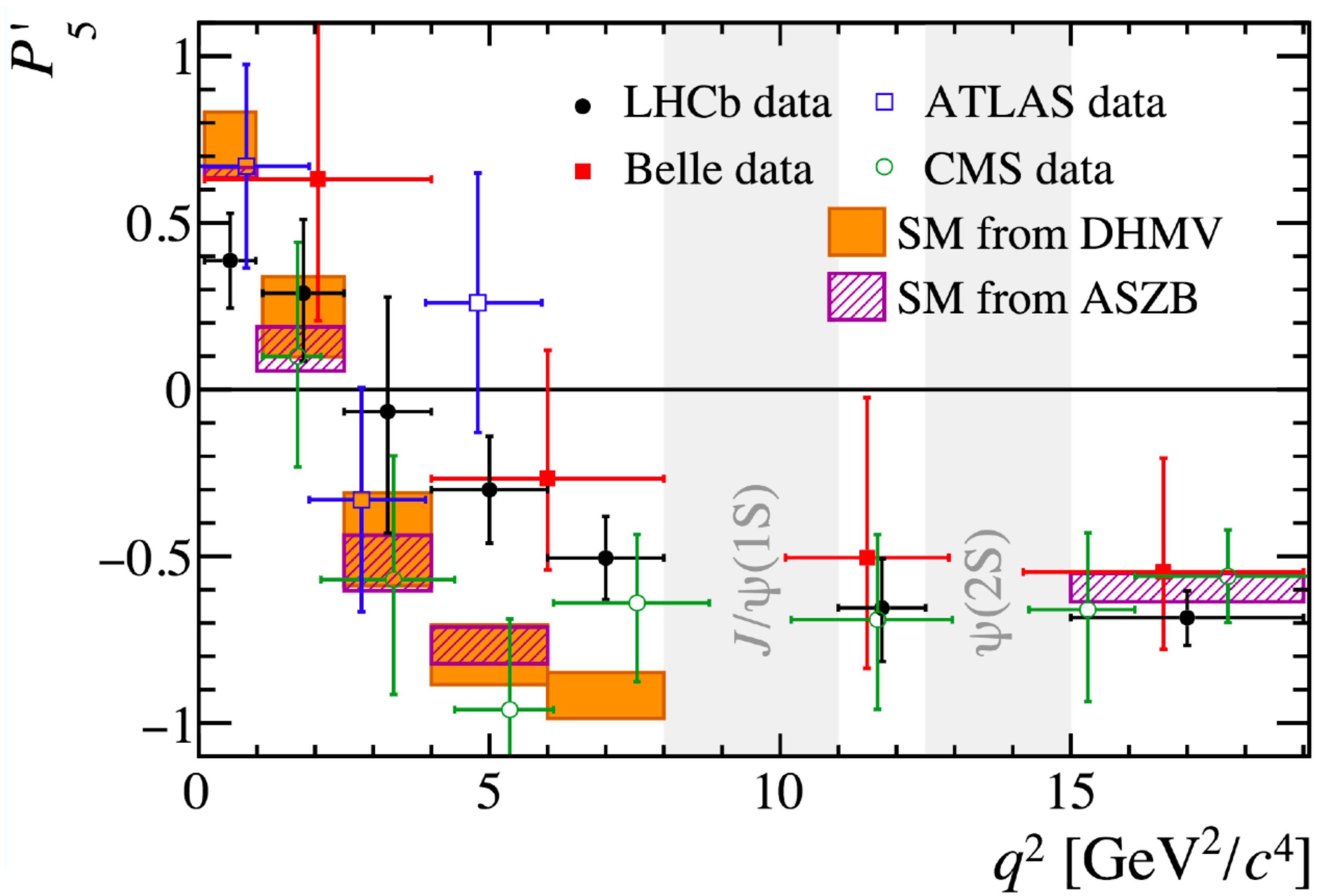
Lepton-Flavor-Dependent Angular Analysis of B →K*ll at Belle

The analysis is performed on a data sample corresponding to an integrated luminosity of 711fb^{-1} containing 772 ×10^{6} $B\bar{B}$ pairs, , collected at the Υ(4S) resonance with the Belle detector. The result is consistent with standard model (SM) expectations, where the largest discrepancy from a SM prediction is observed in the muon modes with a local significance of **2.6σ**.



PhysRevLett.118.111801

Angular Analysis of $B \to K^*ll$



ATLAS-CONF-2017-023

CMS PAS BPH-15-008

JHEP 02 (2016) 104

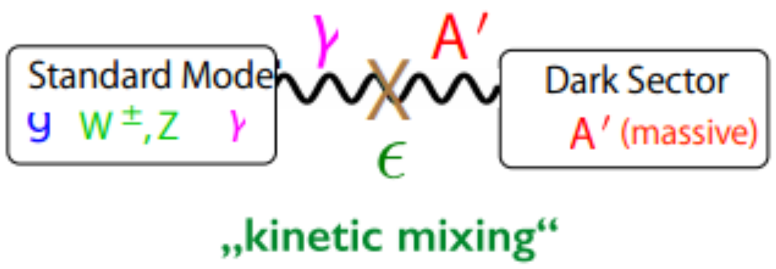
Belle Preprint 2016-15

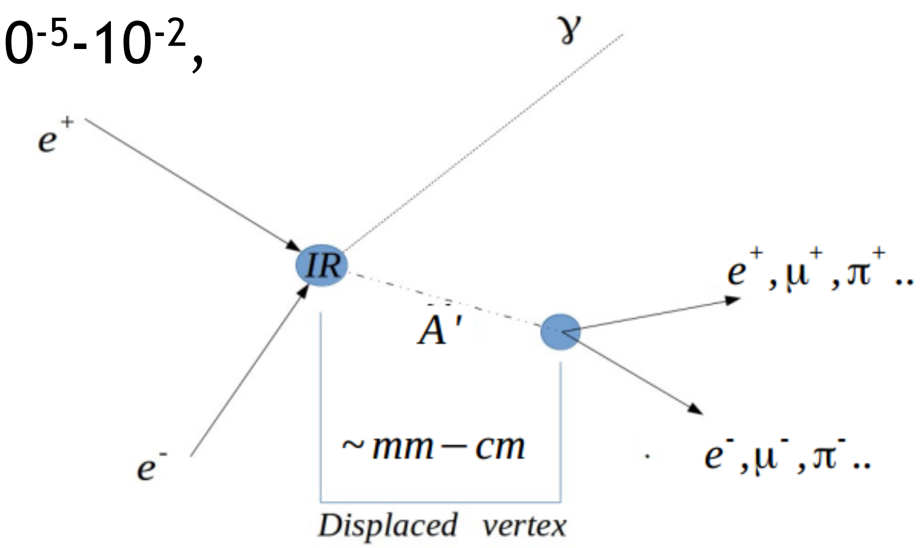
- Local discrepancy with SM prediction
  - LHCb (**3.7σ**)
  - ATLAS (**2.7σ**)
  - CMS (1397 signal events)

Dark Photon search

(Holdom, 1986) A new boson (dark photon, A') belonging to an additional U(1)' symmetry would mix kinetically with the photon.

The strength of the kinetic mixing is supposed to be small, 10^{-5}-10^{-2}, the smaller the value the longer A' lifetime (i.e. long lived).

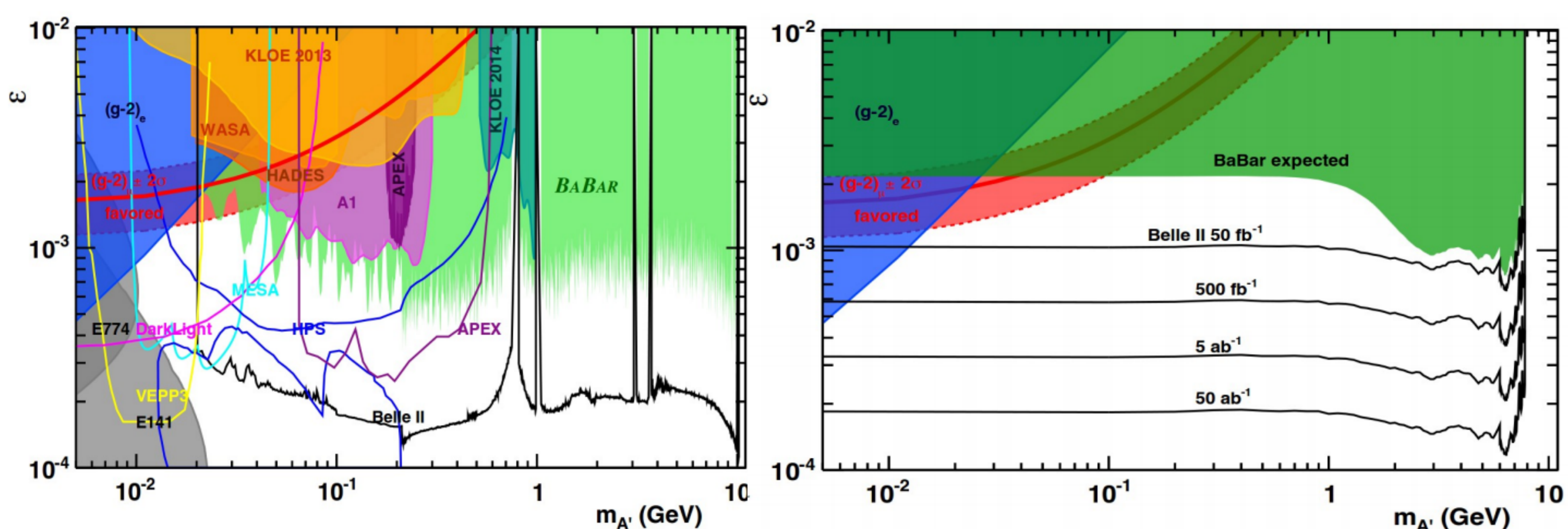




Expected limits at Belle II compared to other experiments

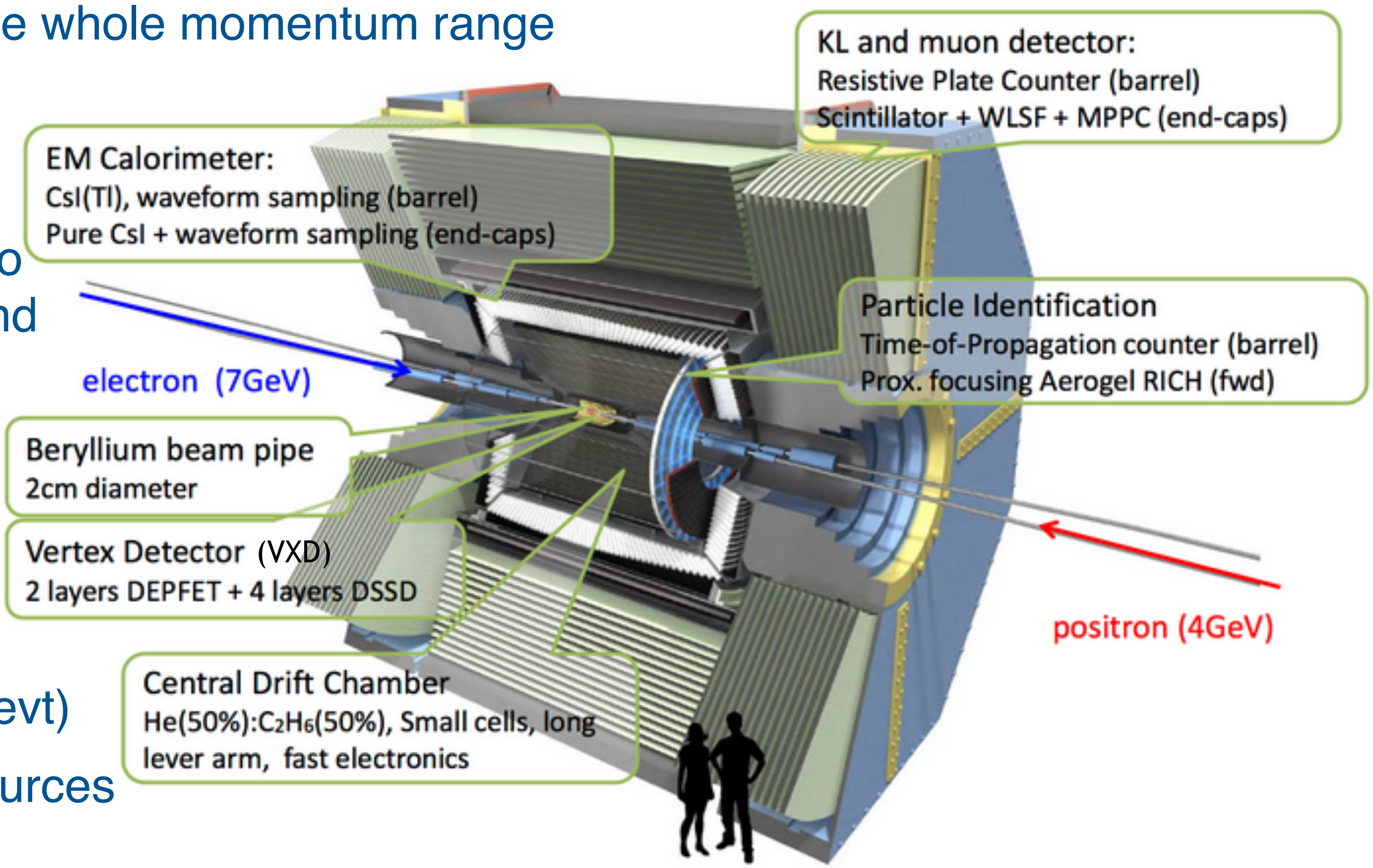
- Projection from BABAR results to Belle 2 luminosity assuming same trigger/detection/reconstruction efficiency

$e^+e^- \to \gamma A' \to \gamma e^+e^-, \gamma\mu^+\mu^-$, *prompt* $\qquad e^+e^- \to \gamma A' \to \gamma\chi\bar{\chi}$



Belle II Detector

- Smaller beam pipe radius allows to place the innermost PXD layer closer to the Interaction point (r = 1.4 cm)
  - significantly improved vertex resolution
- New PXD is part of the vertex detector with larger SVD
- PID: TOP and ARICH
  - better K/p separation covering the whole momentum range
  - fake rate reduced by factor 2-5
- ECL and KLM consolidation
  - improvements in ECL and KLM to compensate for larger background
- Improved hermeticity
  - geometry and reduced boost
- Improved trigger and DAQ
  - 30 kHz L1 rate
  - 10 kHz HLT output rate (300 kB/evt)
  - need substantial computing resources



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- Accelerator Review Committee (ARC) Report February 2015
  - The Interaction Region (IR) is by far the most complicated area of SuperKEKB
  - It consists of a remarkable number of highly sophisticated coupled systems with extremely demanding physical, mechanical, vacuum, and magnetic requirements and constraints
  - The IR vacuum chamber is extremely complex and fragile

  - geometry and reduced boost
- Improved trigger and DAQ
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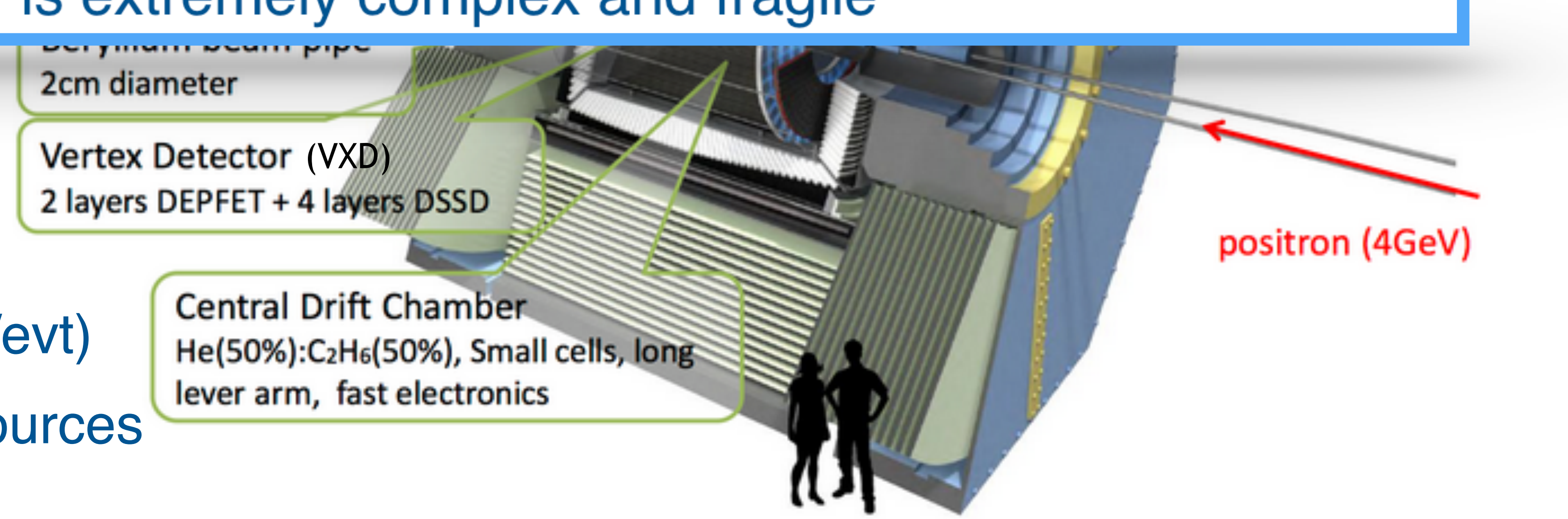
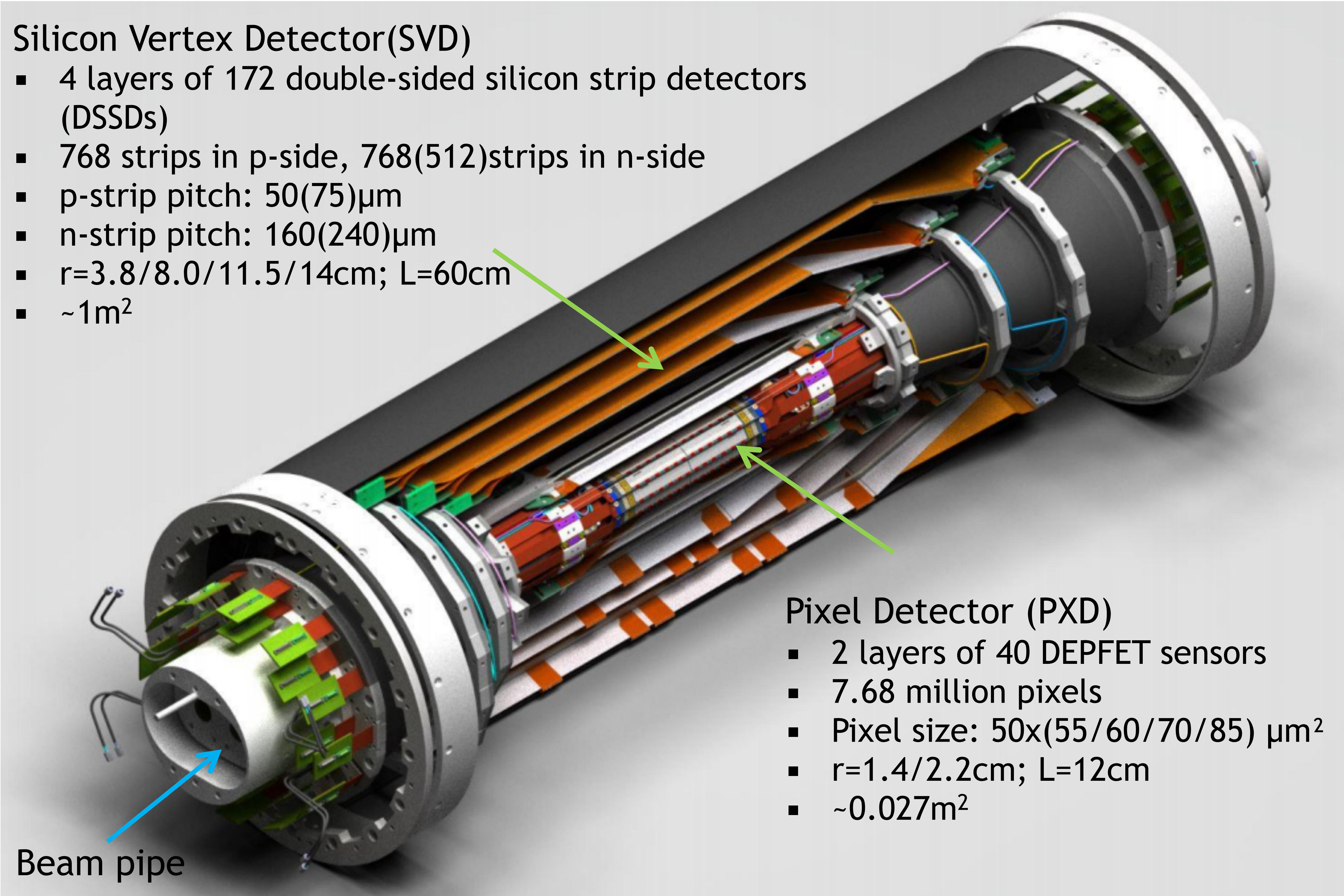
  - need substantial computing resources



Belle II Vertex Detector (VXD)



Silicon Vertex Detector(SVD)

- 4 layers of 172 double-sided silicon strip detectors (DSSDs)
- 768 strips in p-side, 768(512)strips in n-side
- p-strip pitch: 50(75)μm
- n-strip pitch: 160(240)μm
- r=3.8/8.0/11.5/14cm; L=60cm
- ~1m^2

Pixel Detector (PXD)

- 2 layers of 40 DEPFET sensors
- 7.68 million pixels
- Pixel size: 50x(55/60/70/85) μm^2
- r=1.4/2.2cm; L=12cm
- ~0.027m^2

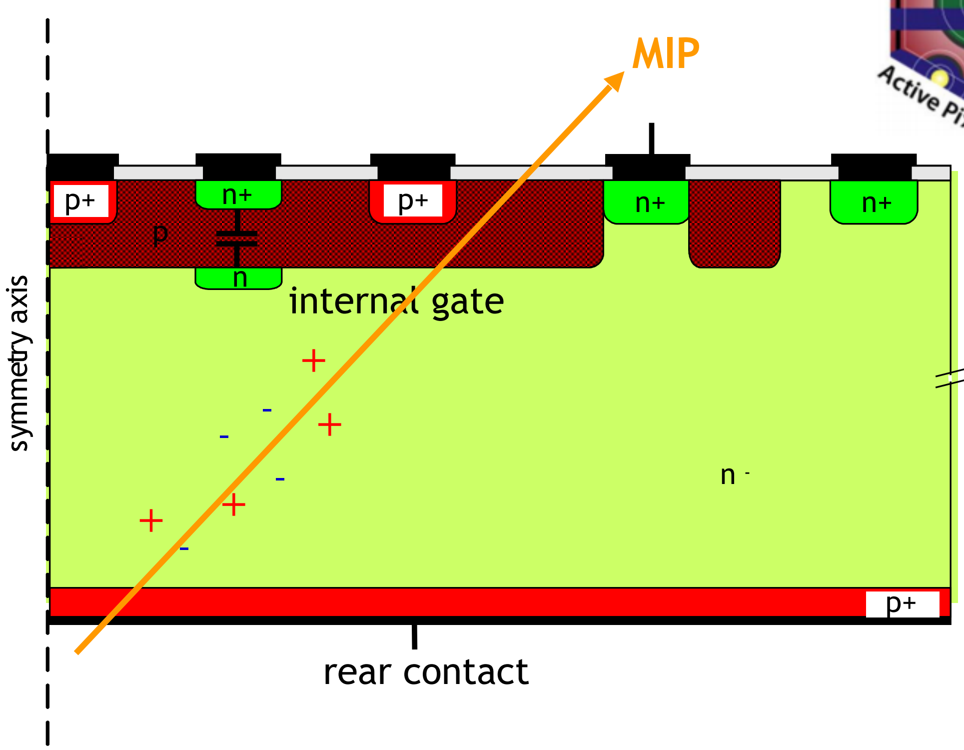
DEPFET Pixel

Pixel detectors can be divided into two categories:

a) Hybrid pixels, in which the sensor and the readout IC are separate entities, connected with bump-bond. e.g. ATLAS, CMS

b) (semi-)monolithic detectors. Two main streams are the so-called CMOS monolithic active pixels (**MAPS**) e.g. STAR, ALICE, and depleted p-channel field effect transistor (**DEPFET**) e.g. Belle II

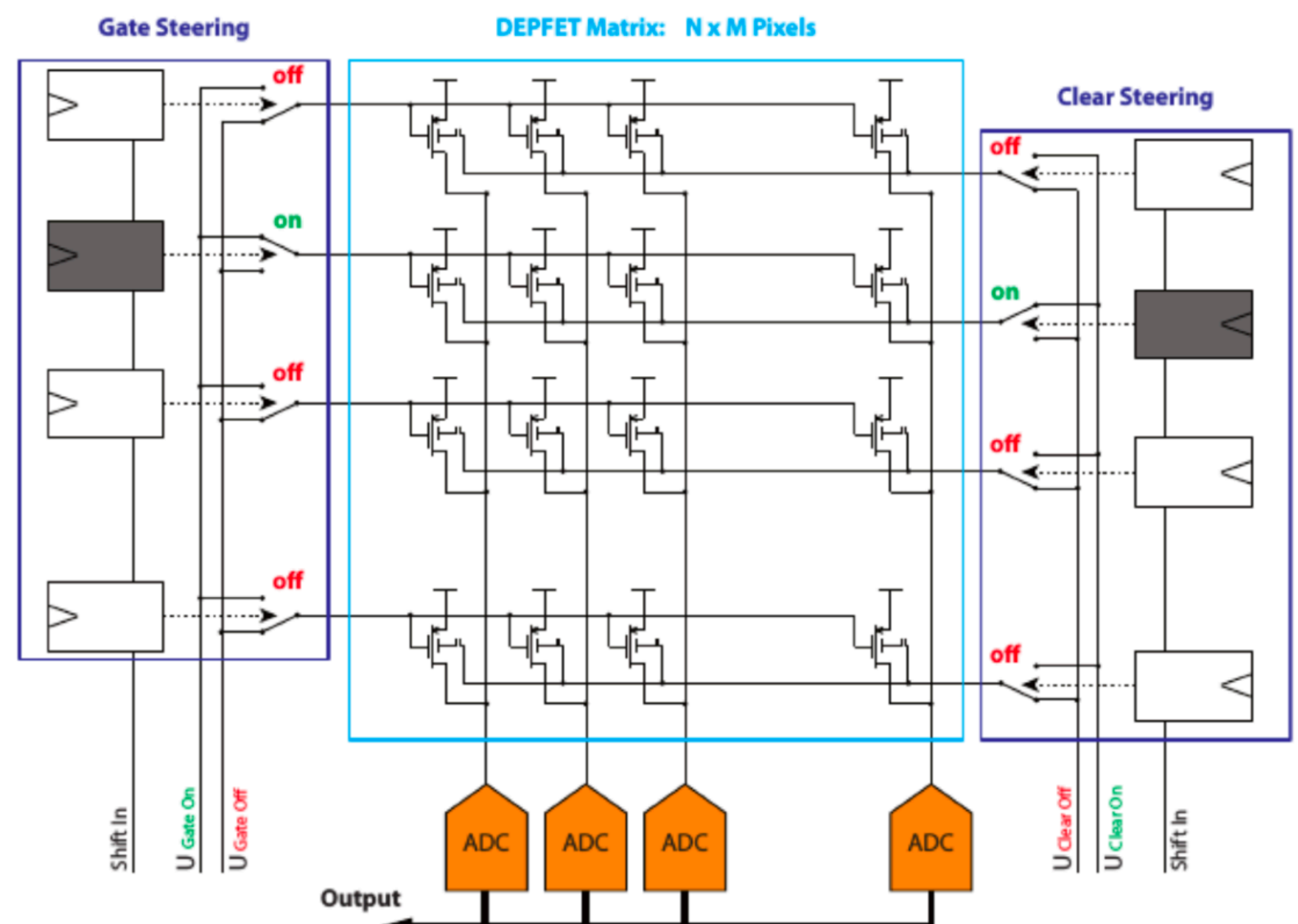
DEPFET Principle



The DEPFET amplifies the signal internally.

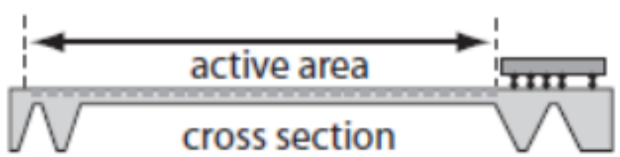
$$g_q = \frac{\partial I}{\partial q} \approx 700 \, \frac{\text{pA}}{\text{e}^-}$$

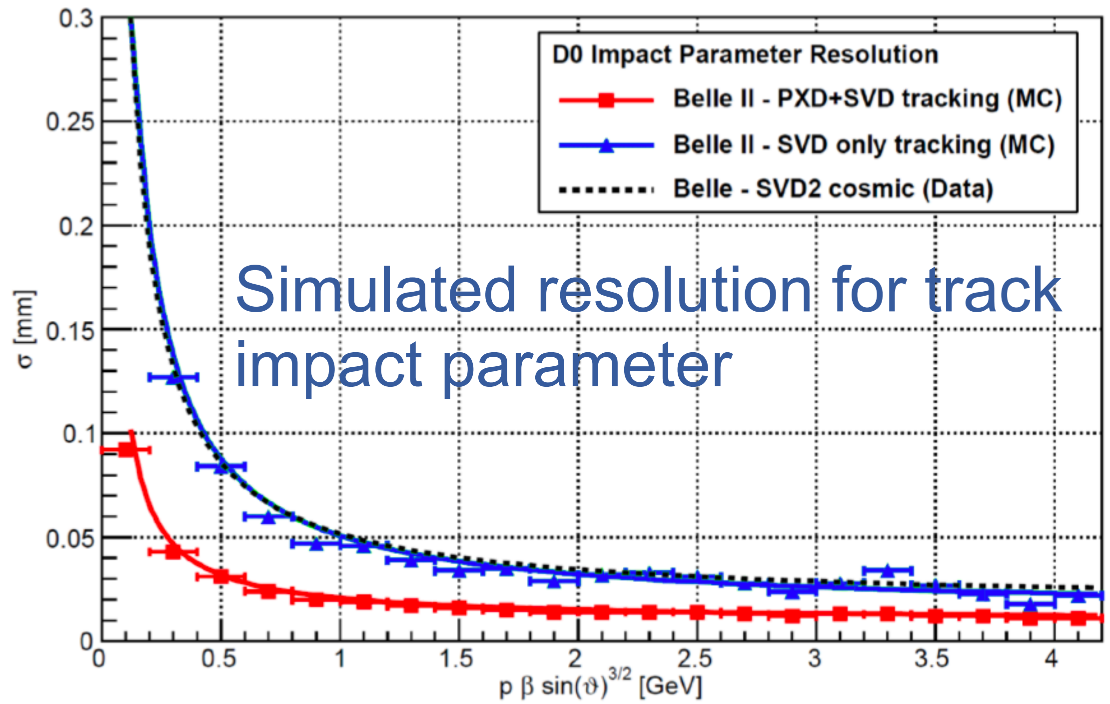
Rolling-shutter readout mode



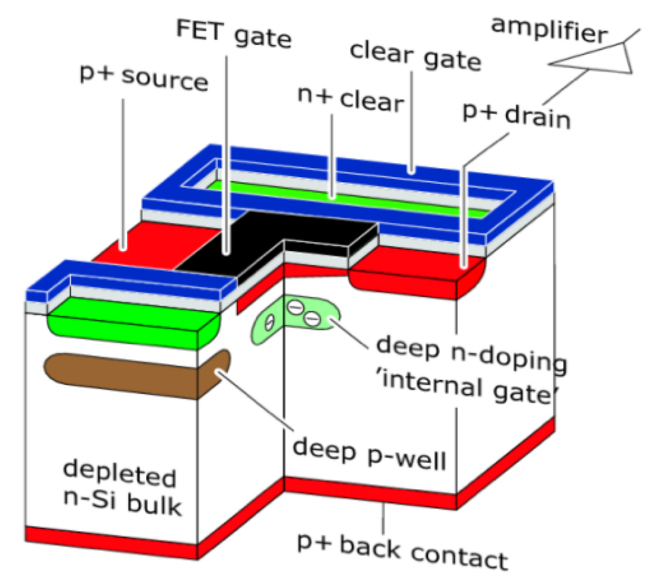
DEPFET Pixel Sensor

2 layers @14(22) mm
Pixel size: 50 x 55-85 μm^2
Occupancy: 0.4 hits/μm^2/s (3% max)
Integration time: 20 μs (rolling shutter)
Thickness: 75 μm, 0.21% X_0 per layer

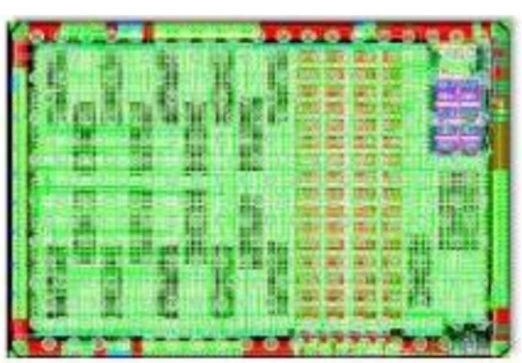




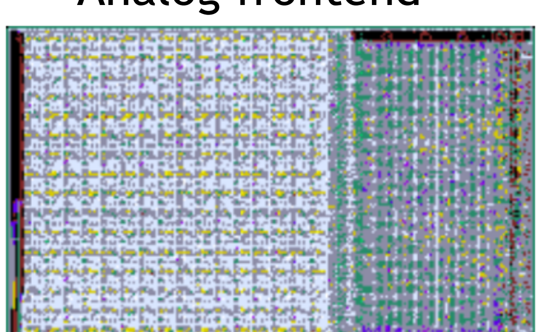
Depleted P-channel Field-Effect Transistor (DEPFET)

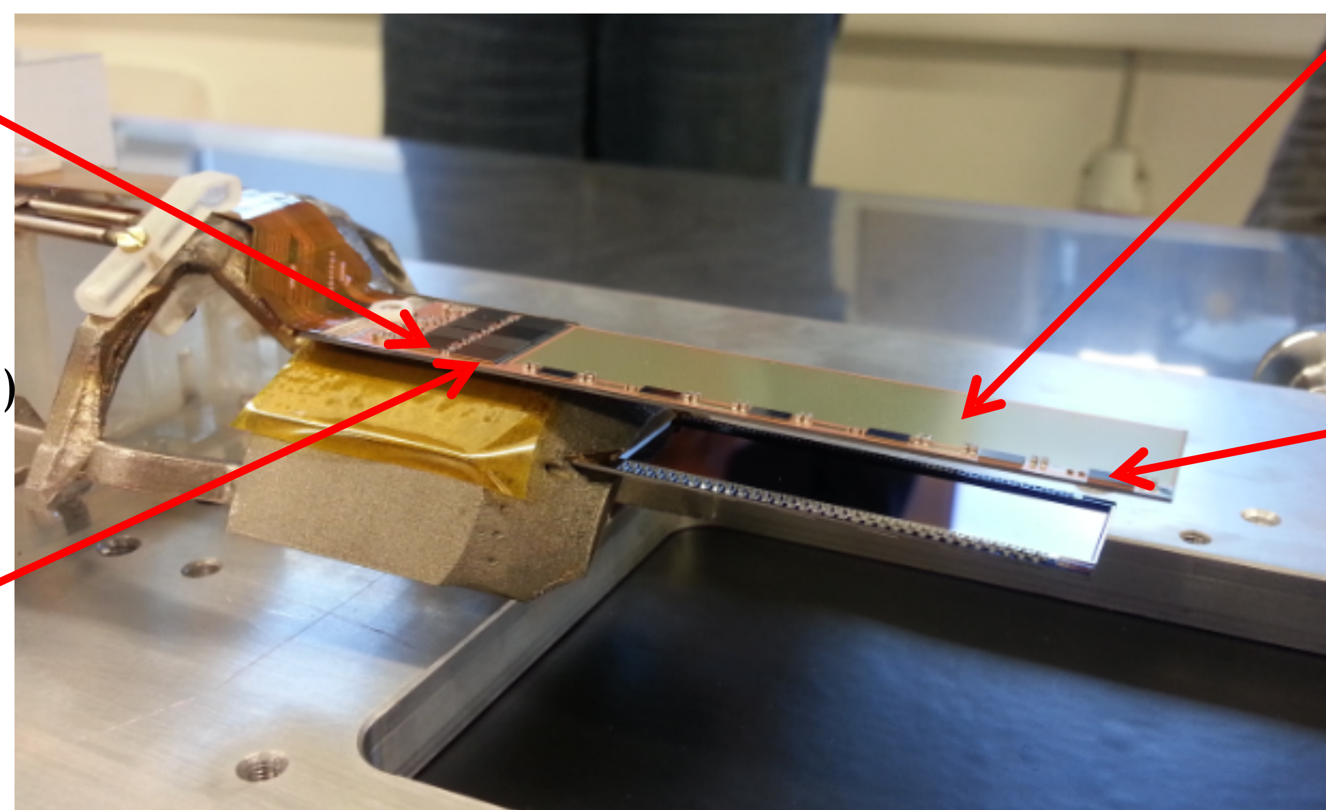


DHP (Data Handling Processor)
First data compression

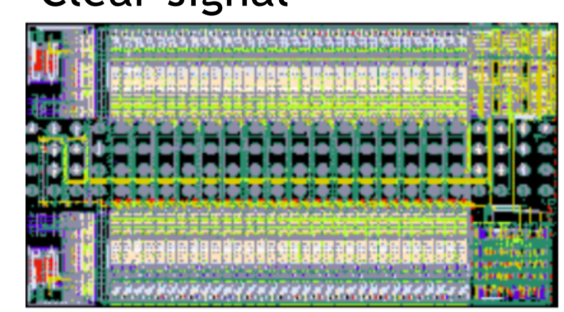


DCDB (Drain Current Digitizer)
Analog frontend





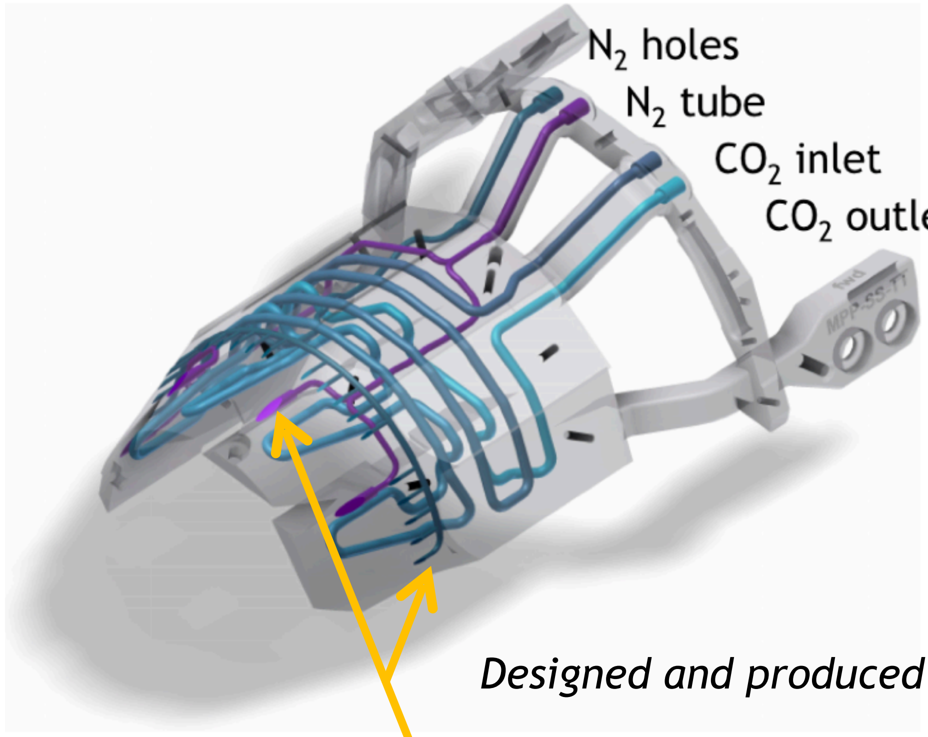
SwitcherB
Row control, Gate and Clear signal



PXD Ladder Support

Both layers are mounted on the combined support and cooling blocks (SCBs)

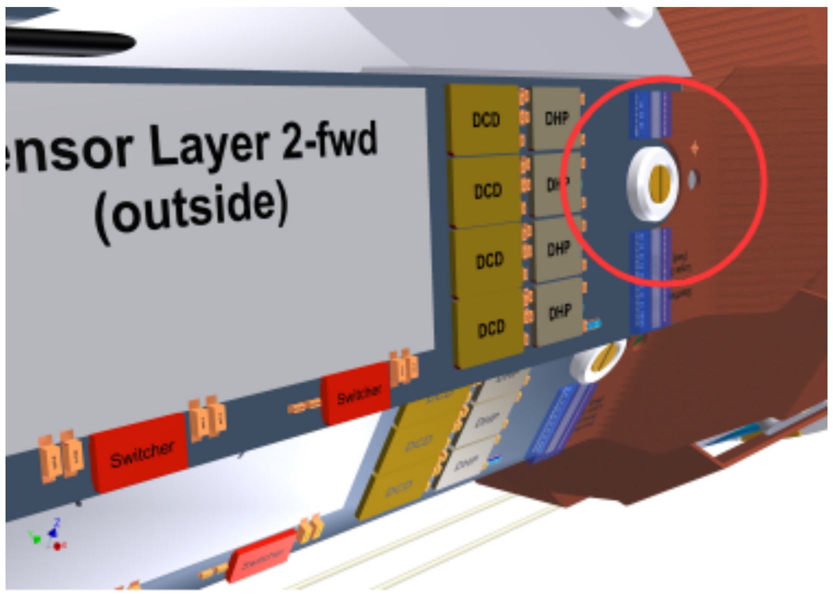
- connected by silver coated carbon fiber tubes for air cooling and grounding

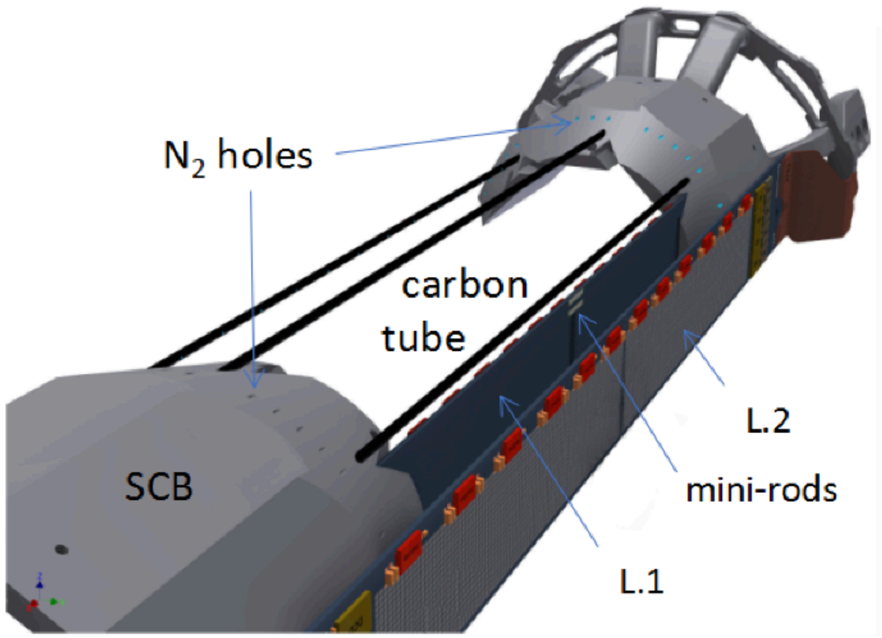


SCB, manufactured using 3D printing technology, with enclosed CO_2 and open N2 channels inside.

Ladders screwed on support

- elongated hole on the FWD side
- M1.2 screw with plastic washer o-ring to prevent electrical contact between screw and silicon.
- torque of 7mNm allows for compensating of thermal expansions.

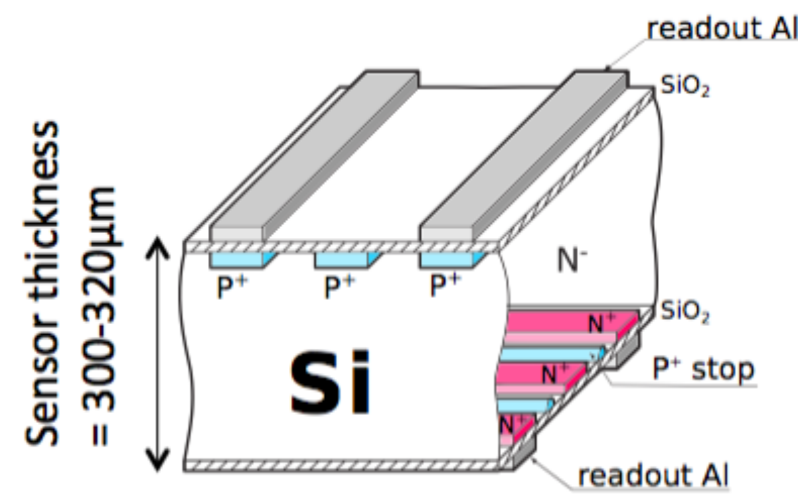


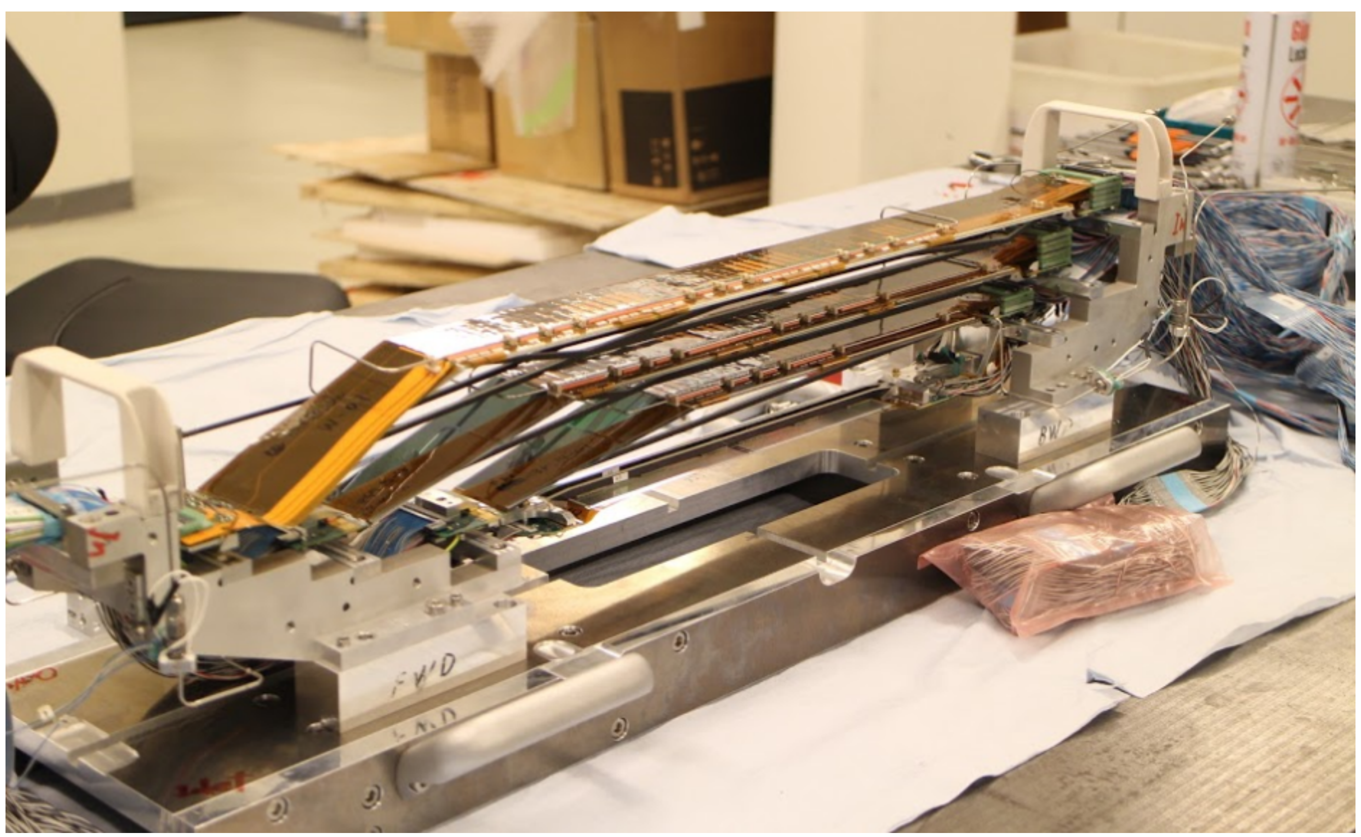


Belle II SVD

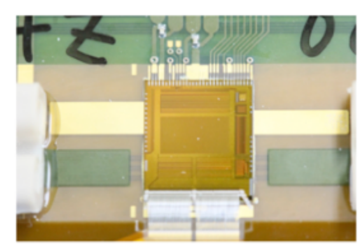
- Four-layer (numbered 3-6) of ladders with up to five DSSD sensors in a row.
- p-strip pitch: 50(75)μm
- n-strip pitch: 160(240)μm
- APV25 front end ASICs are thinned down to 100μm
- Slanted shapes in FWD region for the material budget reduction. Average 0.7% X_0 per layer.

DSSD (Double-sided Si strip detector)

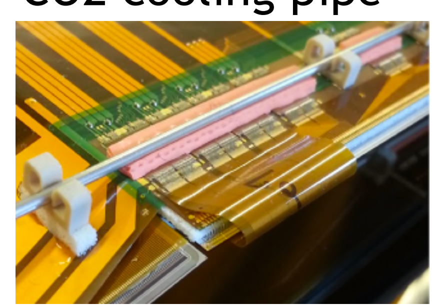




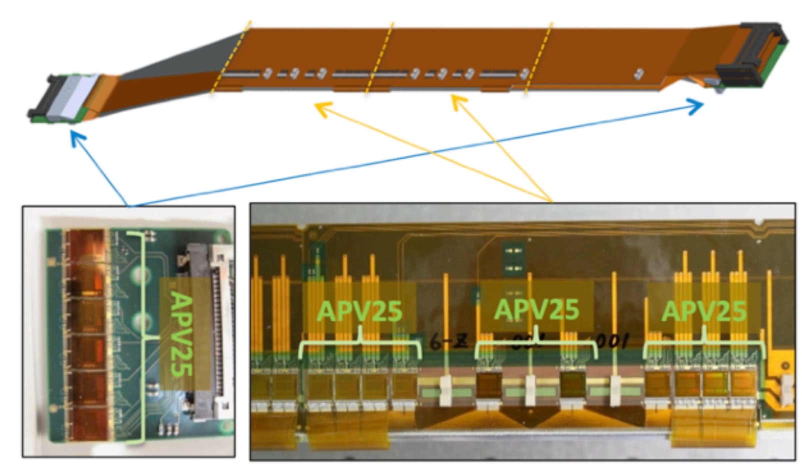
APV25 chips



Origami flex and CO2 cooling pipe



APV25s in ladder

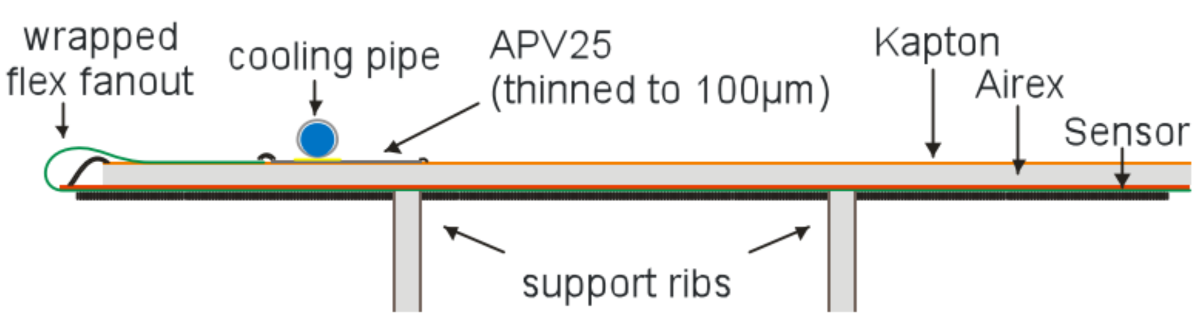


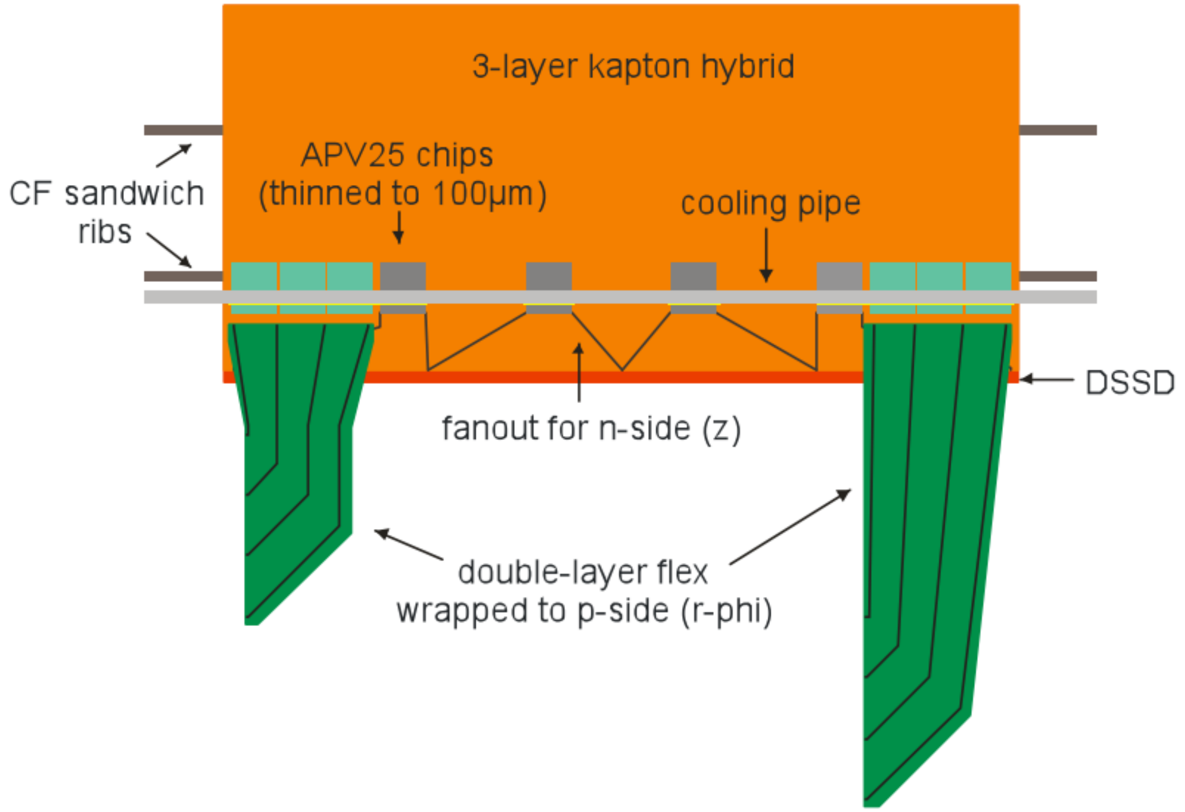
SVD Module Design

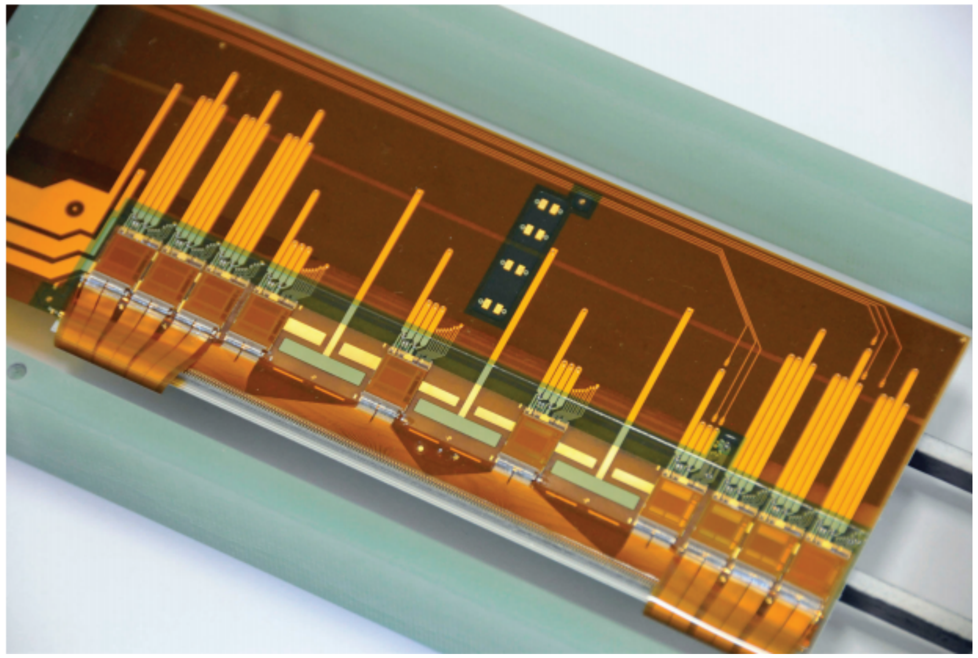
Silicon Vertex Detector

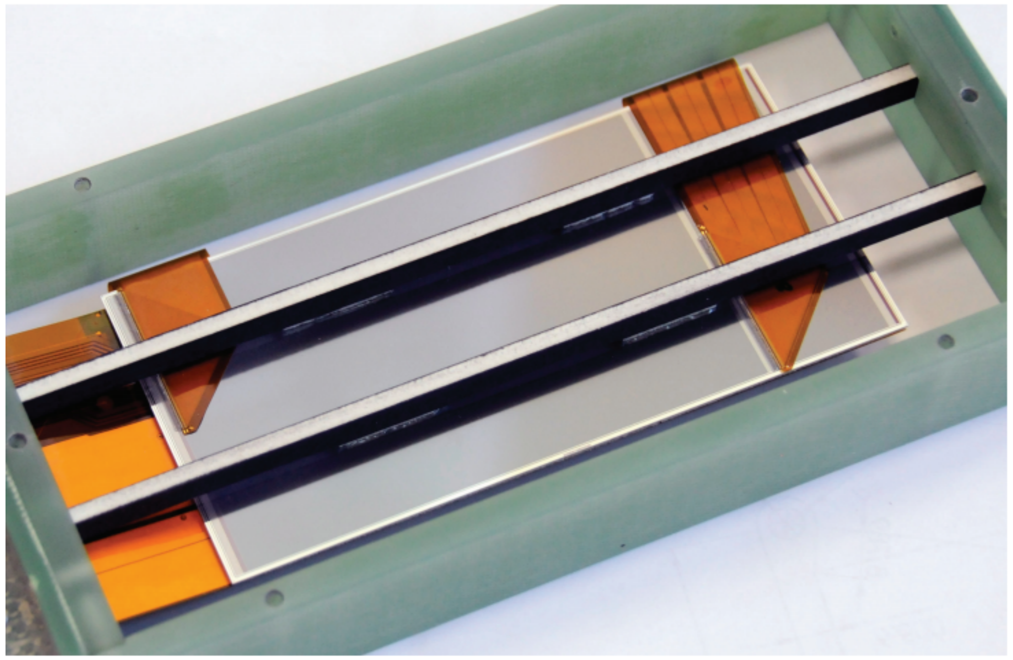
- Supported by two ribs and Airex foam core sandwich.
- the Origami concept, all APV25 are aligned in a row and cooled by a single cooling pipe per ladder.

Modules in the barrel

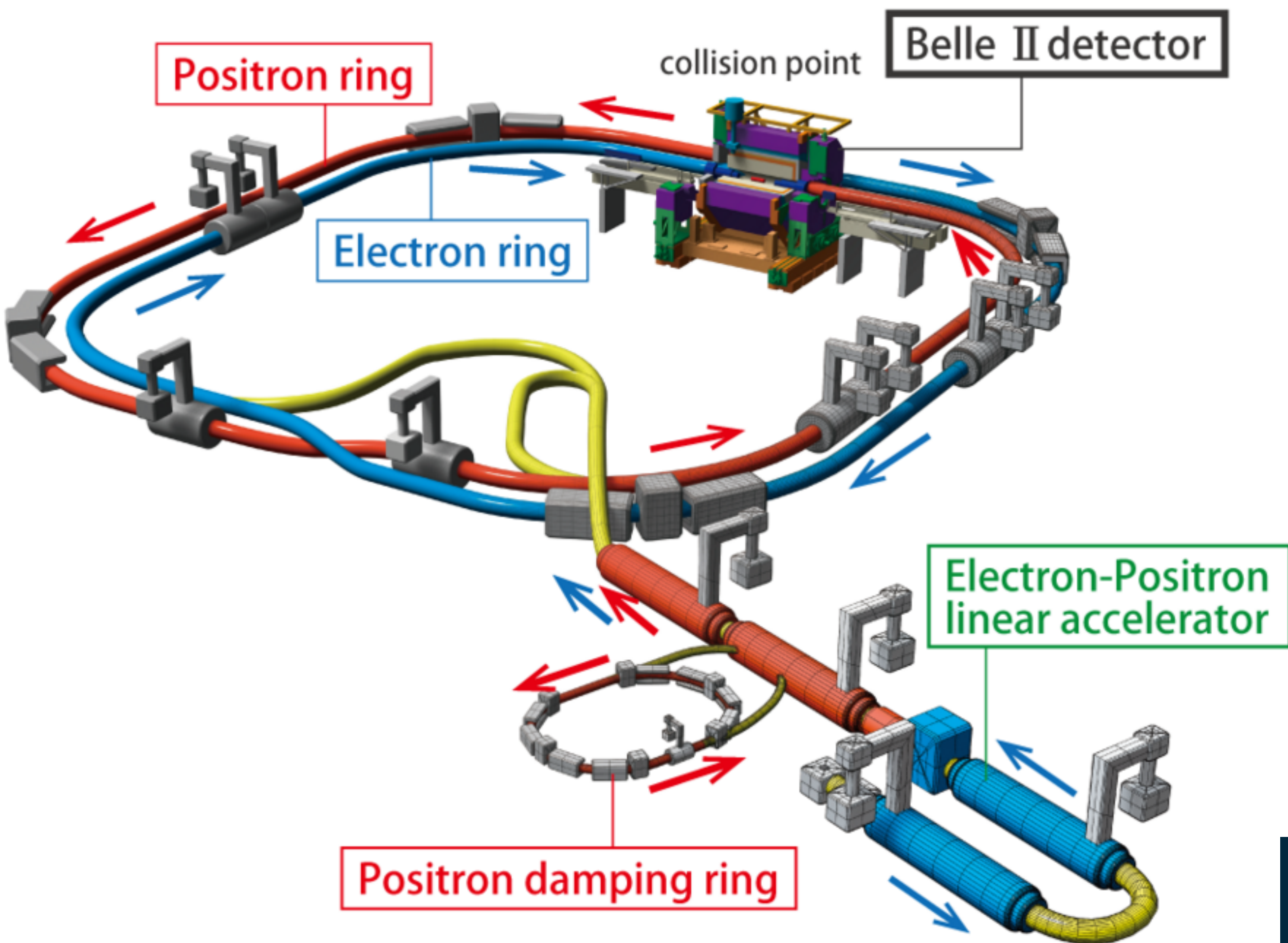


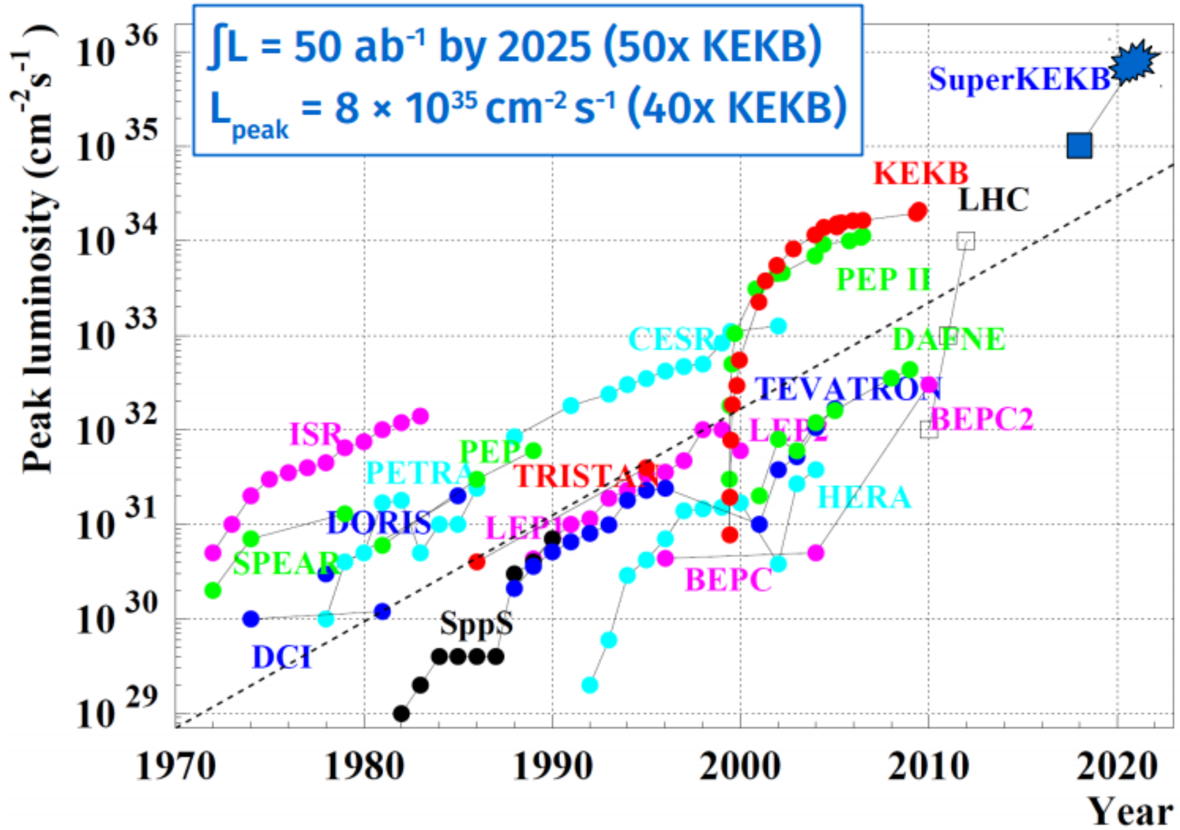






SuperKEKB Upgrade

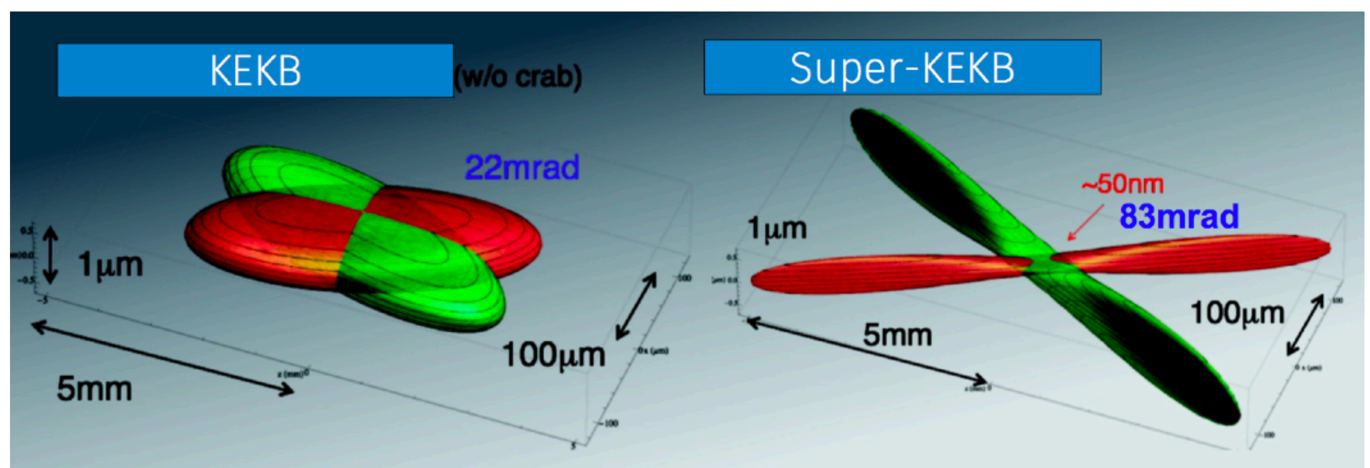




beam current

$$L = \frac{\gamma_{\pm}}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

vertical beta function at IP



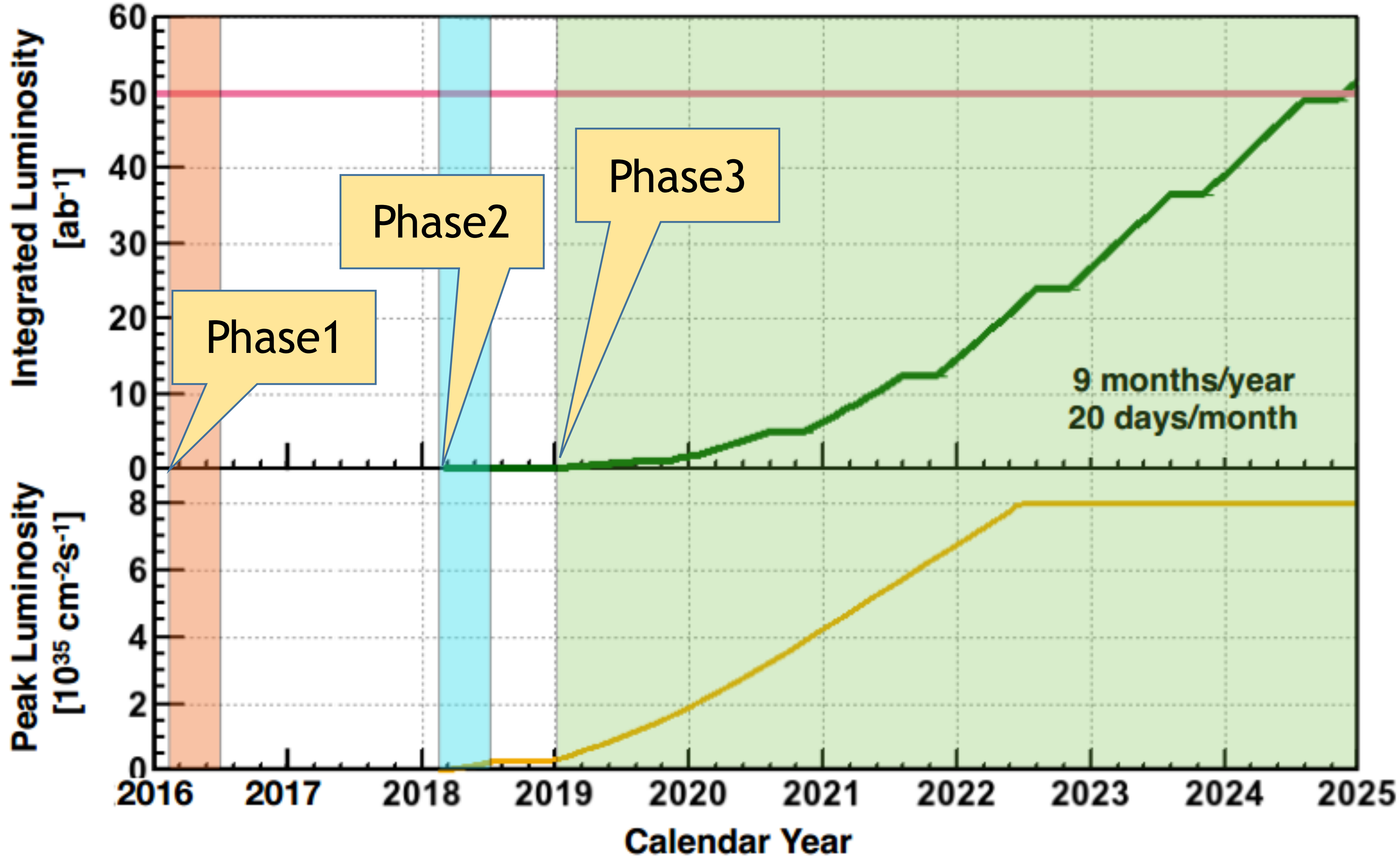
	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10³⁴
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10³⁴

factor 20

factor 2-3

SuperKEKB Commissioning Schedule

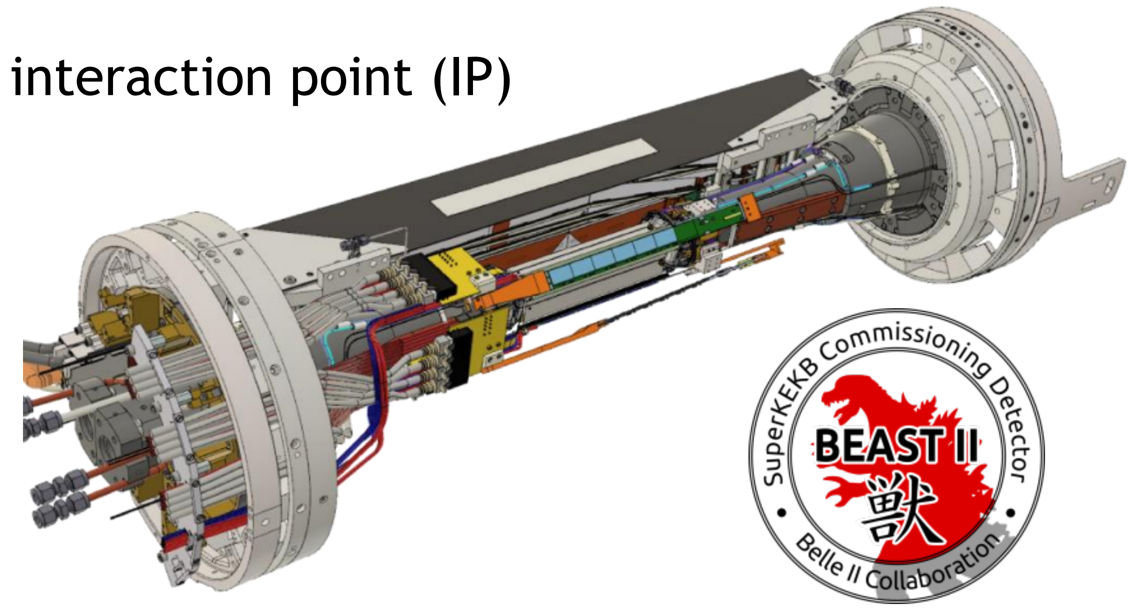
- Phase 1: Beam commissioning, without collisions & Belle II (Successfully finished in Jun. 2016)
- Phase 2: partial Belle II is rolled in (without full VXD) in Apr.2017, collision tuning will start.
- Phase 3 – Physics Run: Full Belle II with VXD



SuperKEKB Commissioning Phase 2

Beam Exorcism for A STable experiment (BEAST II) :

To characterise the beam-induced backgrounds near the interaction point (IP)



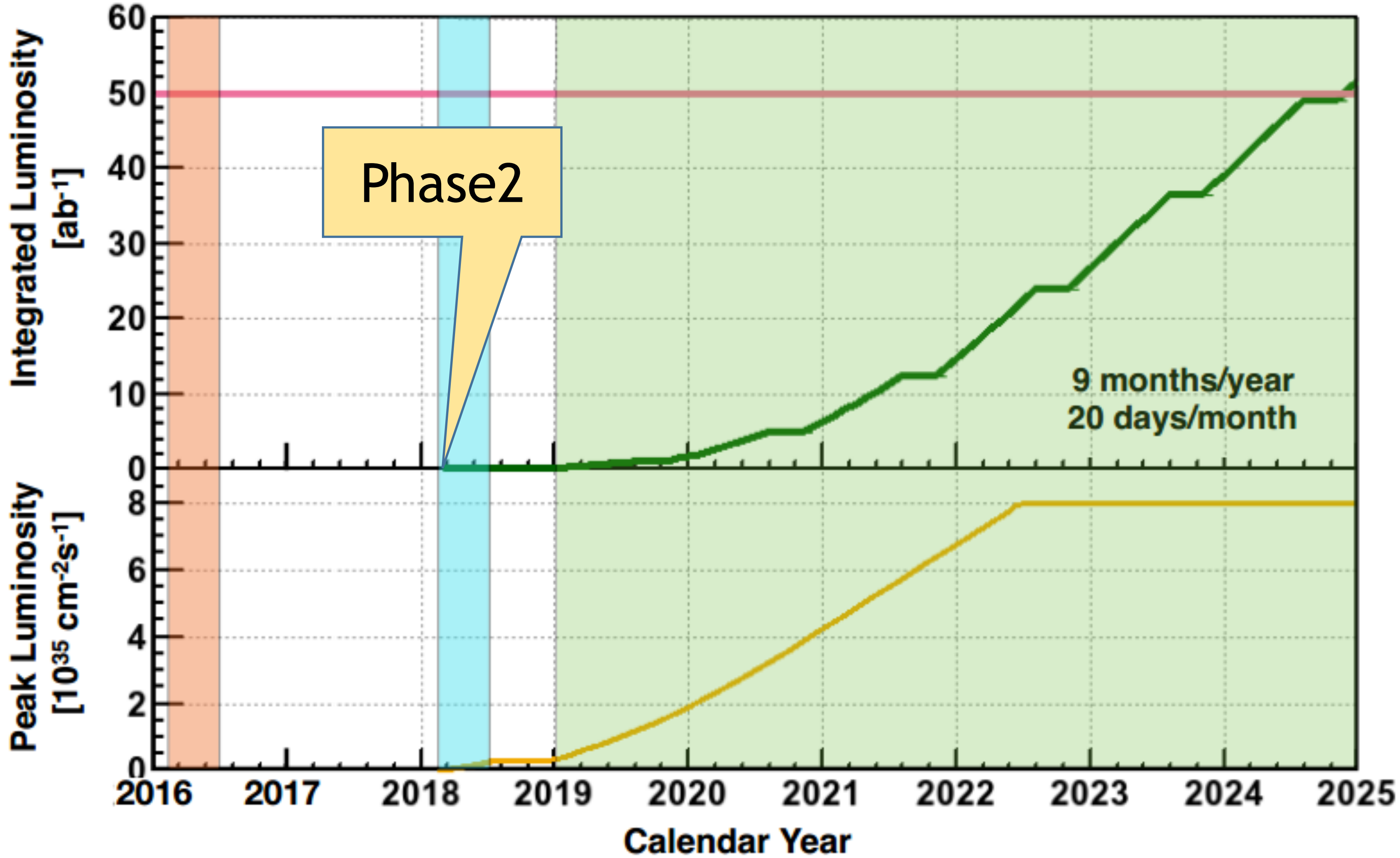
In Phase 2

Goal for accelerator

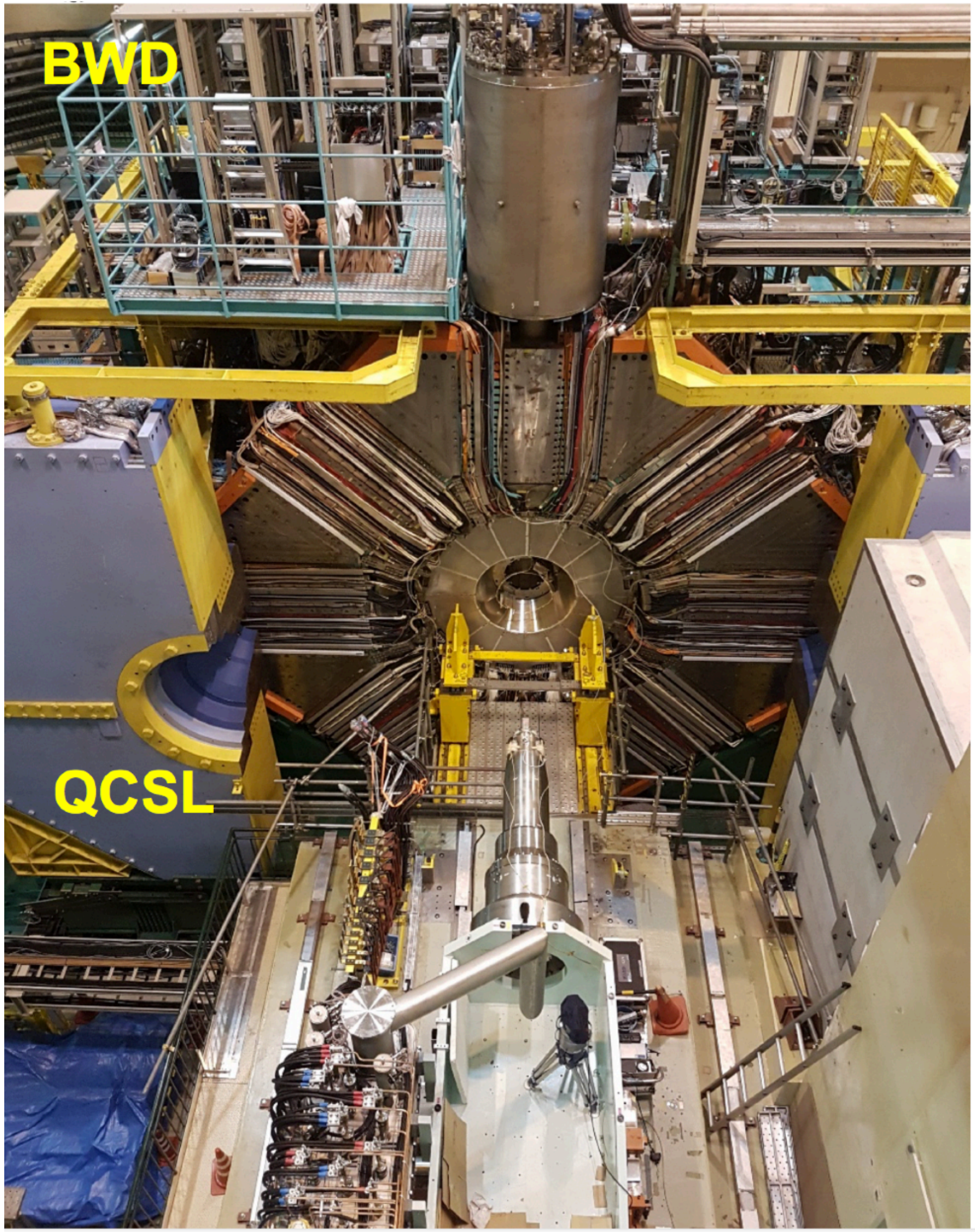
- Machine commissioning
- The target luminosity is $1 \times 10^{34} cm^{-2}s^{-1}$.

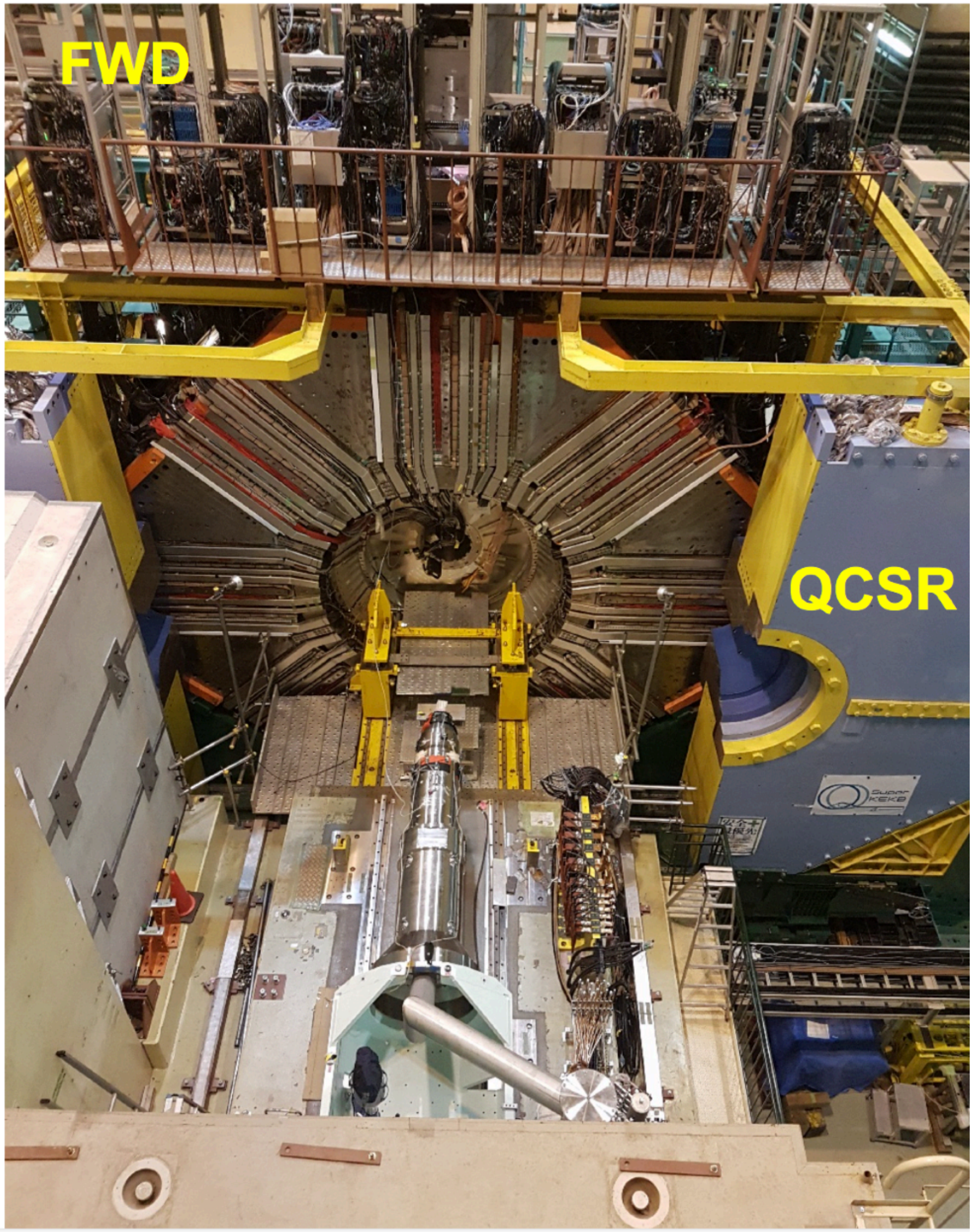
Goal for detector

- To ensure radiation safe environment for the full VXD.



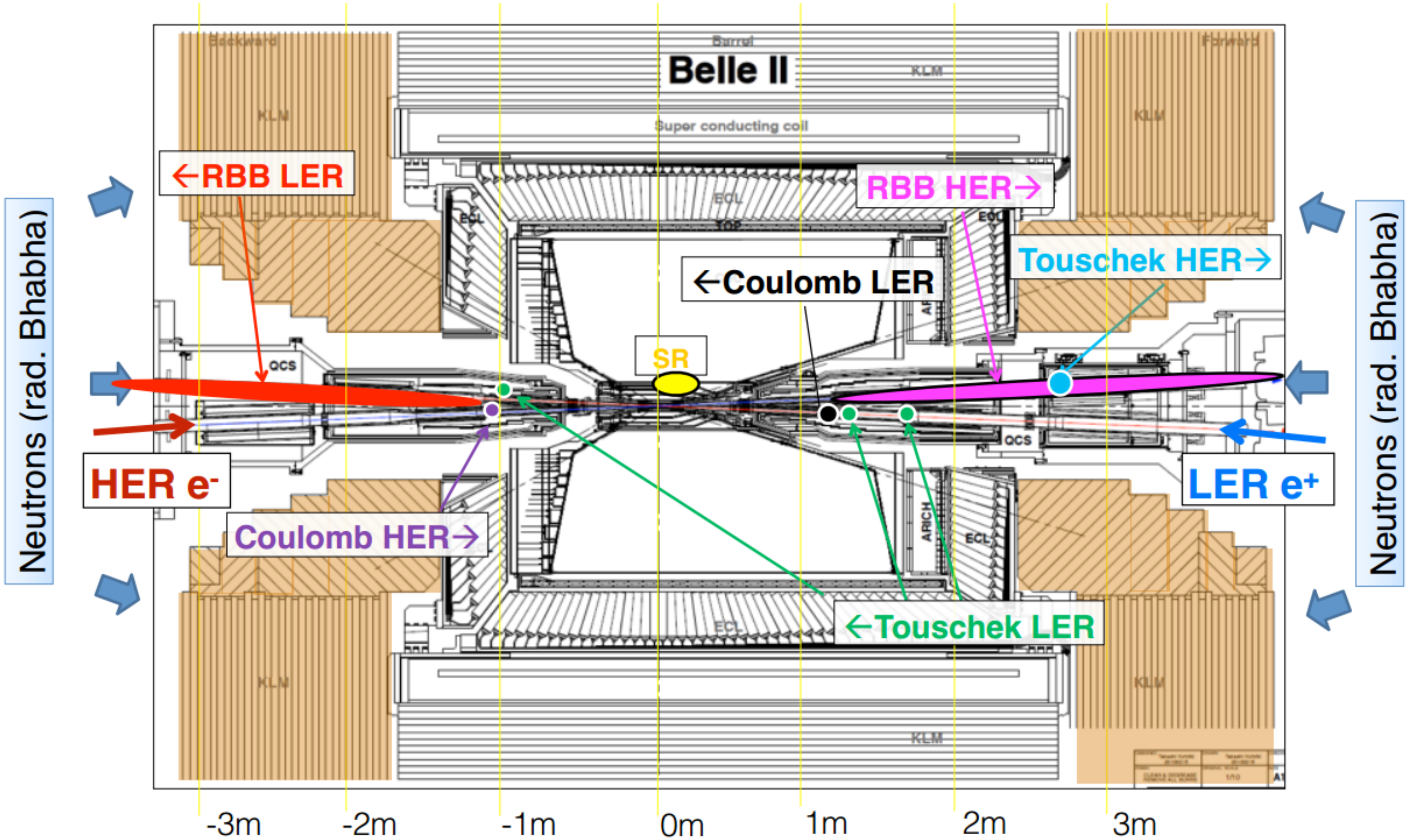
Belle II detector occupies its place





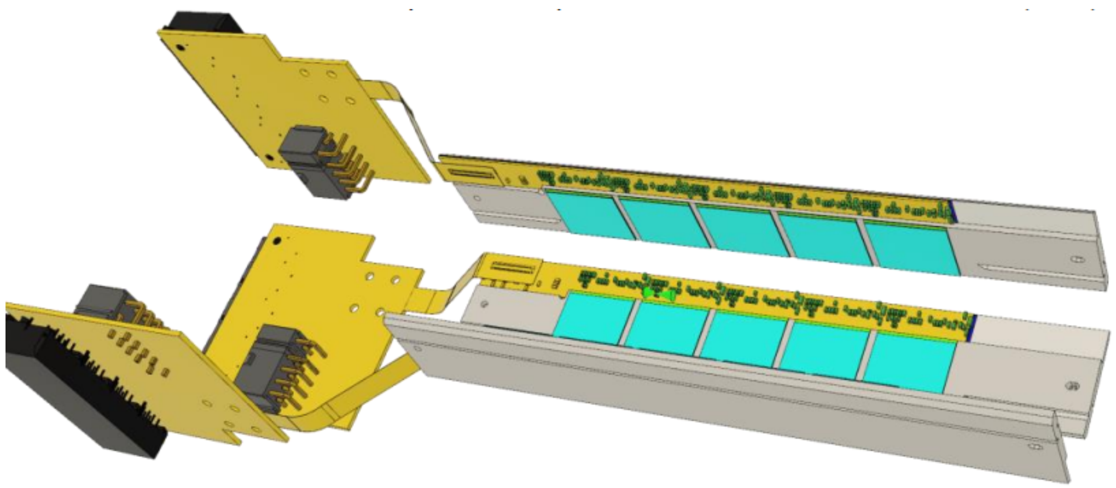
Beam Induced Background

40X instantaneous luminosity is expected to lead to significantly higher background levels in all Belle II subdetectors.

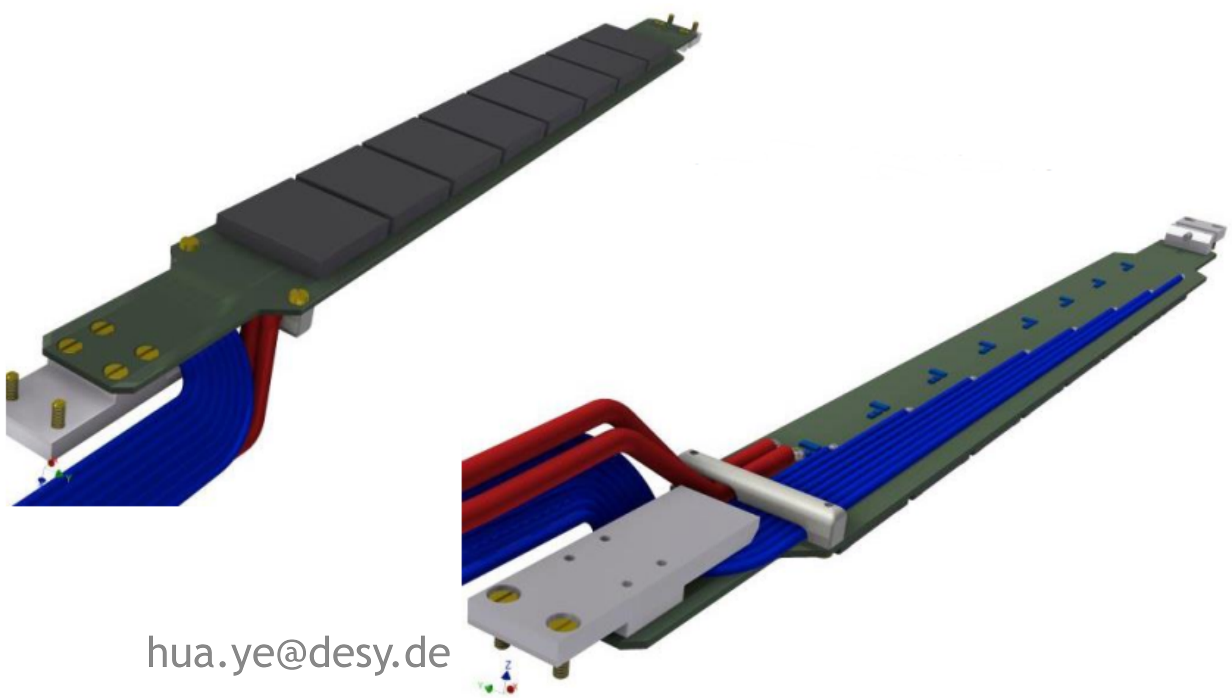


FANGS, CLAWS and PLUME

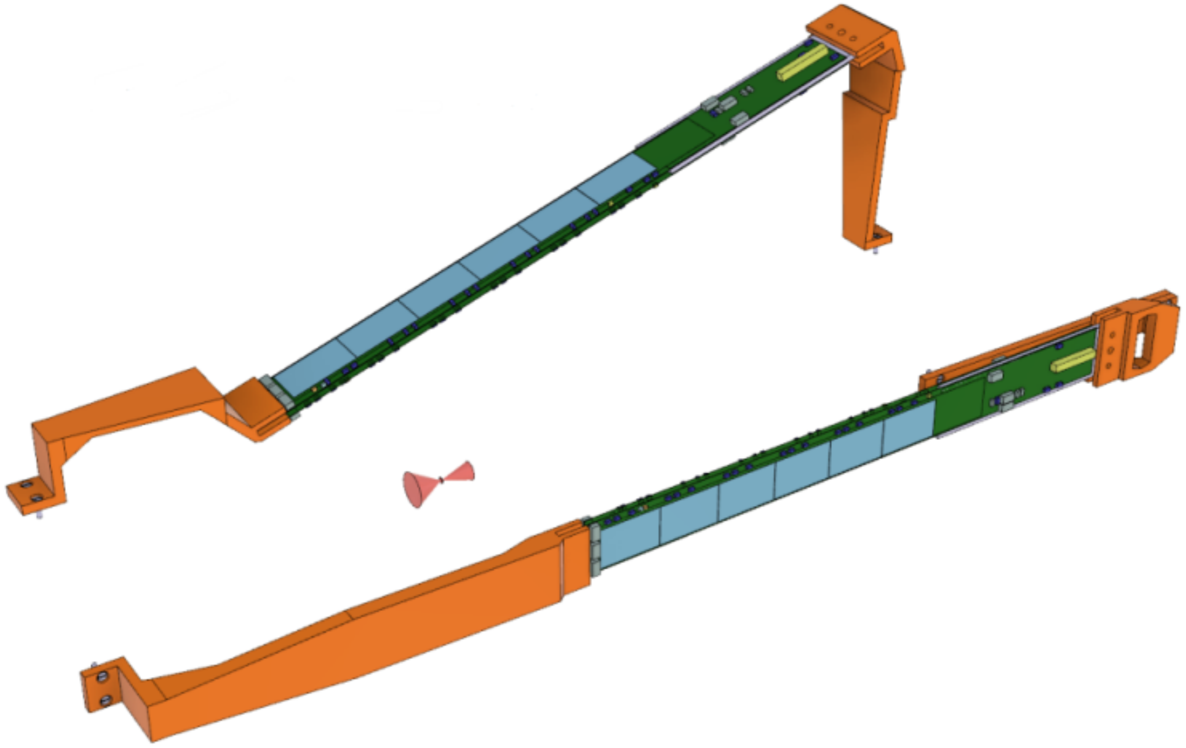
FANGS: planar pixel with ATLAS IBL readout (FE-I4)
To investigate the Synchrotron Radiation (SR) and deposited energy spectrum of background.



CLAWS: Plastic scintillators with SiPM readout
To study the time evolution of beam injected background and its decay constant



PLUME: double-layer MIMOSA pixels
To study the spatial distribution and direction information of the beam injected background.



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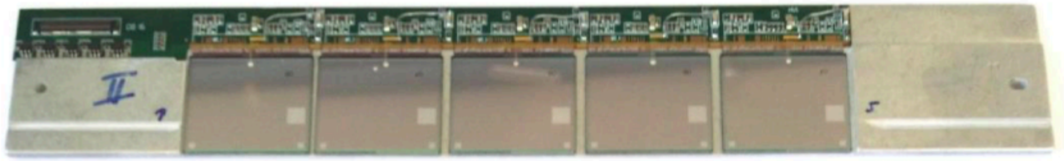

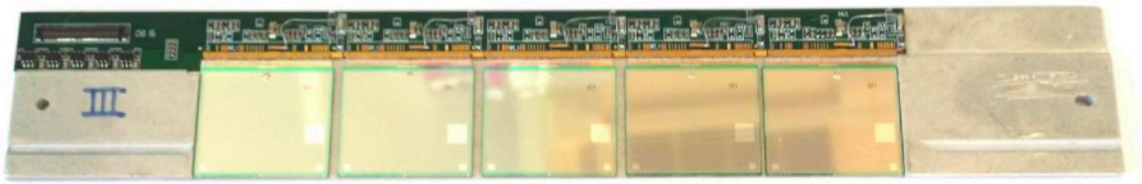

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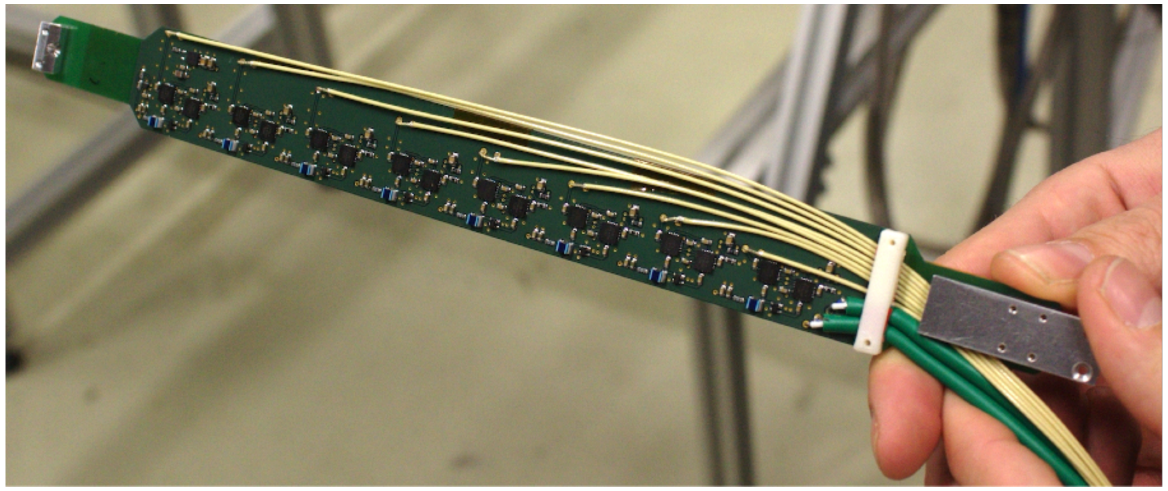
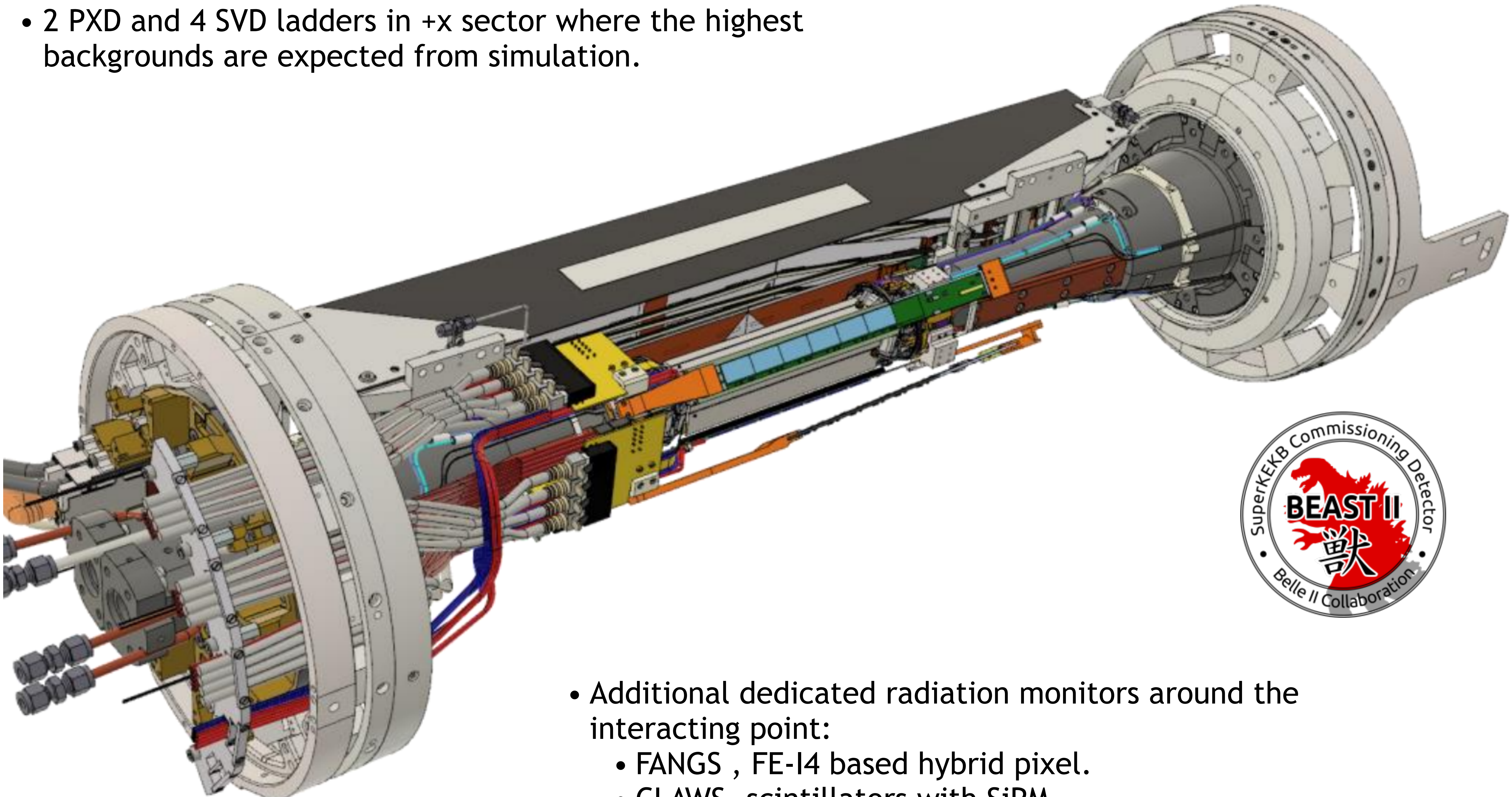


Vertex Detector in Phase II

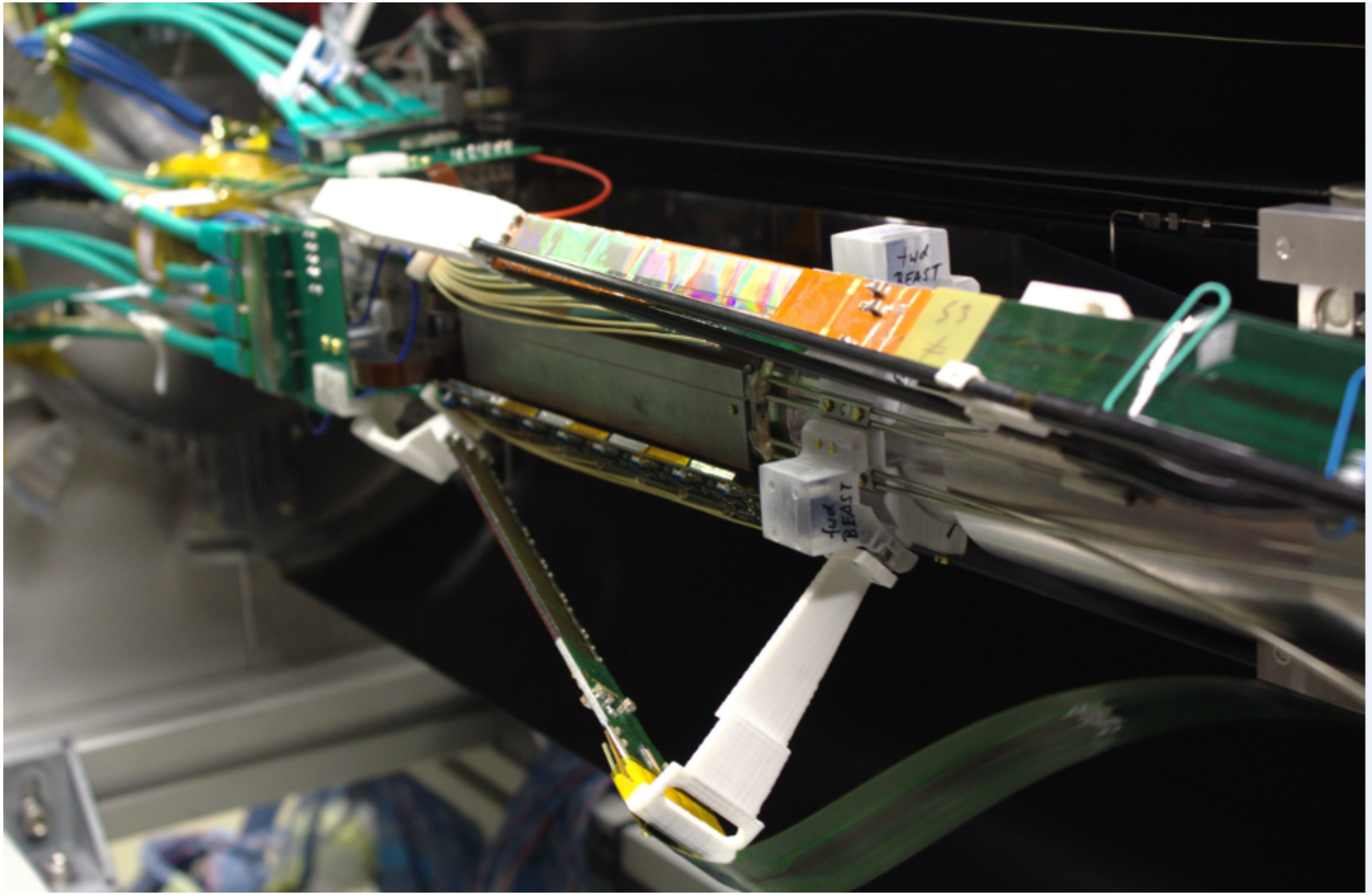
To ensure radiation safe environment for the full VXD.

- 2 PXD and 4 SVD ladders in +x sector where the highest backgrounds are expected from simulation.



- Additional dedicated radiation monitors around the interacting point:
  - FANGS , FE-I4 based hybrid pixel.
  - CLAWS, scintillators with SiPM.
  - PLUME, double-sided high granularity MIMOSA pixels

BEAST II Integration test at DESY



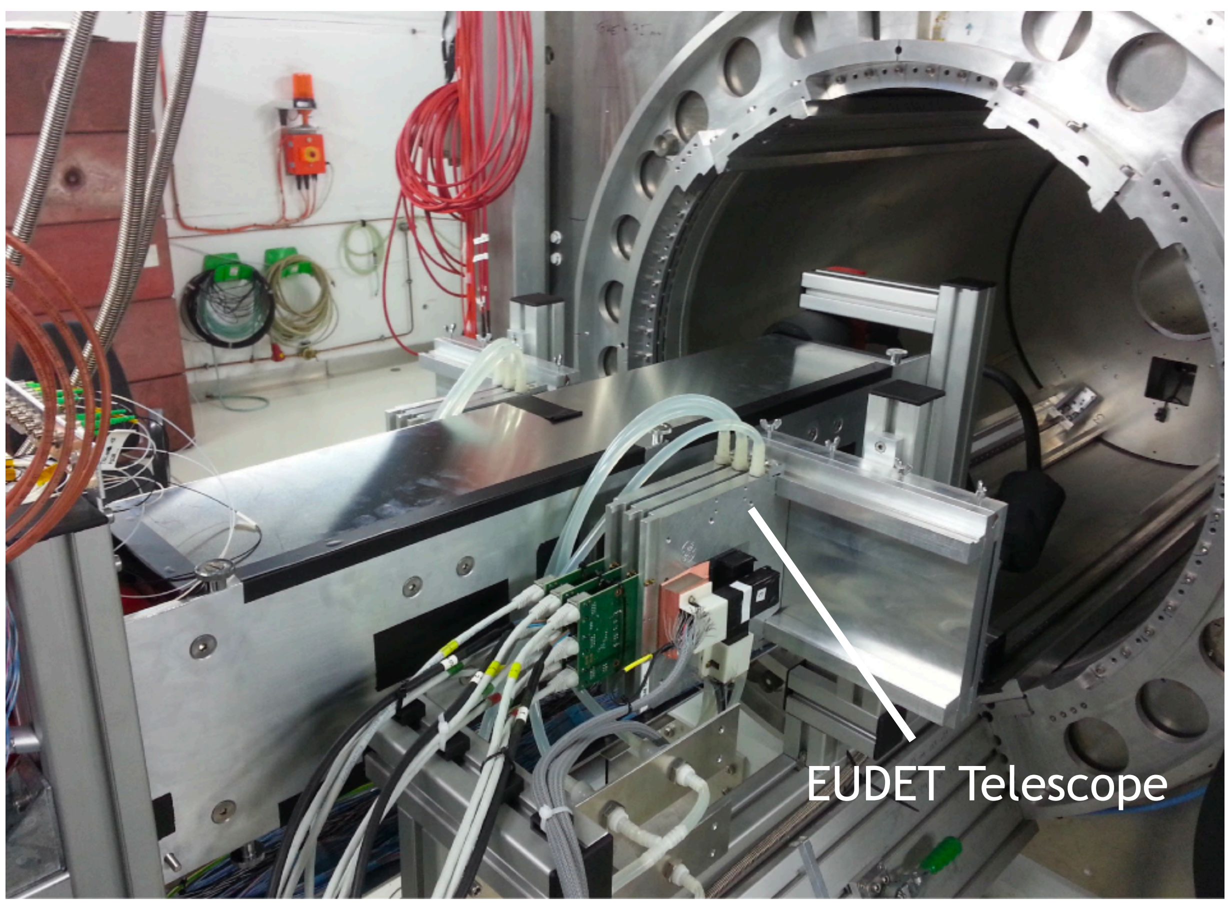
Belle II VXD beam tests at DESY

DESY provides the infrastructure and facilities for these critical beam tests

- Complete VXD readout chain: HLT, ROI, monitoring, event building, pocketDAQ, CO2 cooling, slow control, environmental sensors.
- FANGS and CLAWS joined in 2017.
- Illumination with (up to) 6 GeV e^- in solenoid magnetic field up to 1T (PCMAG)

Test beam in Apr.2016
PXD and SVD were tested

Test beam in Feb.2017
Up to 4 PXD modules were tested with beam, FANGS and CLAWS were involved.



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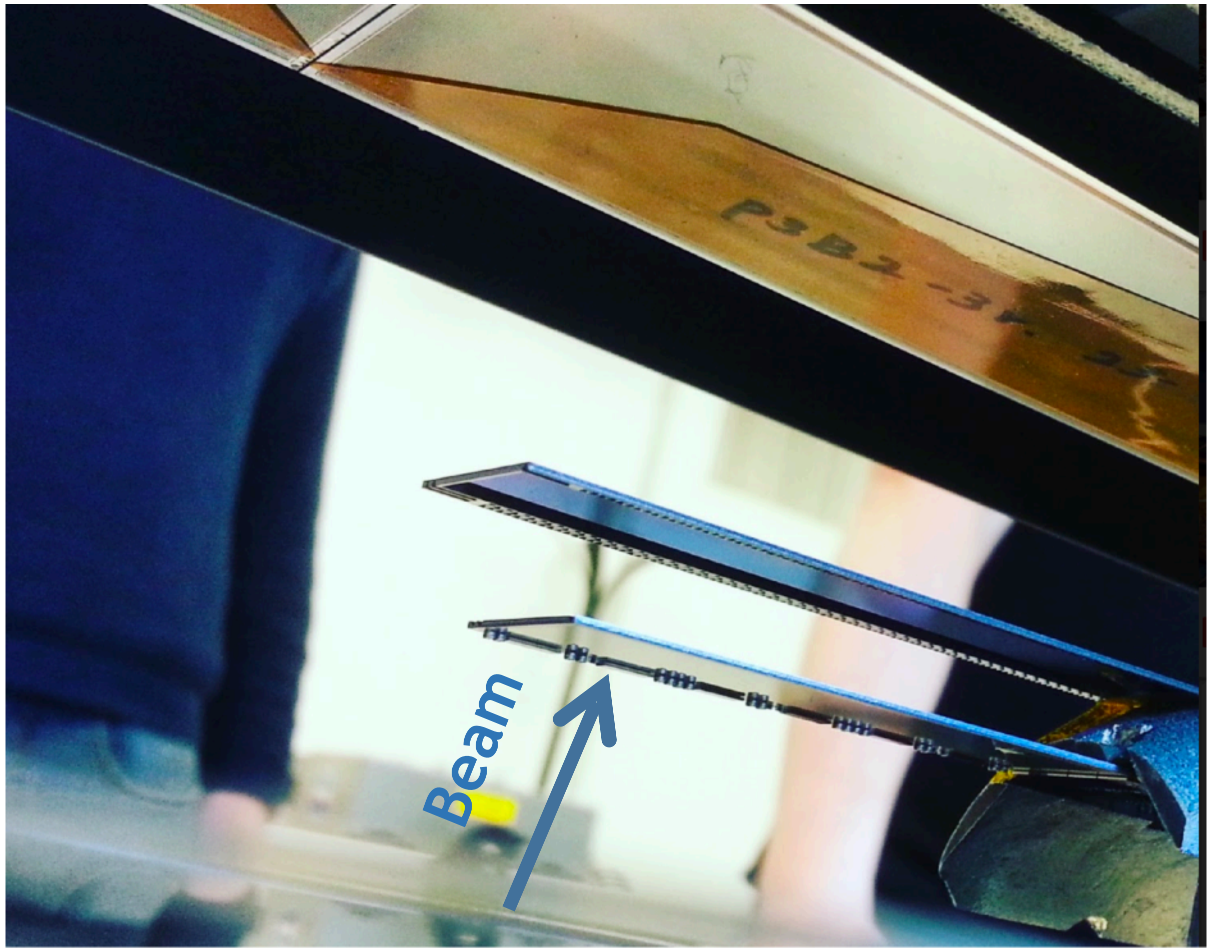

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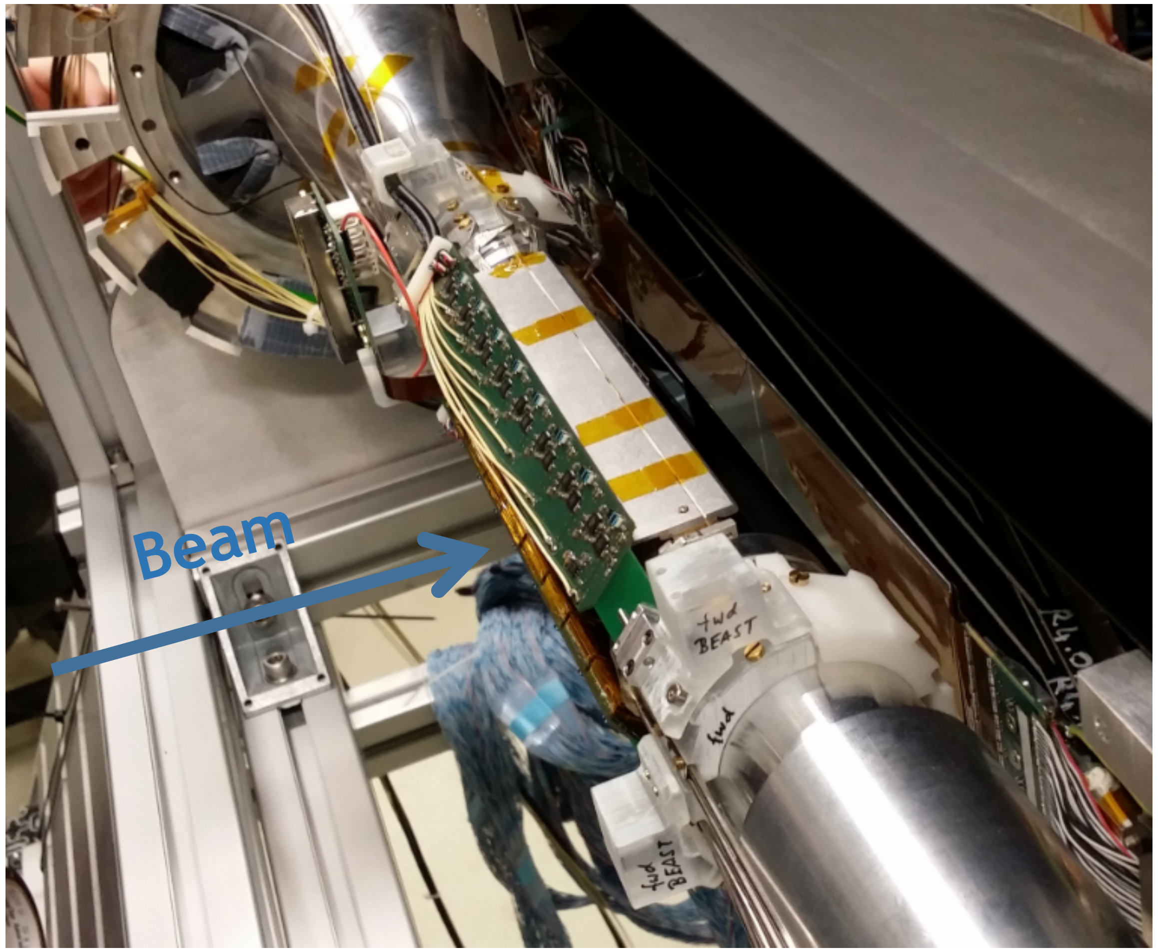
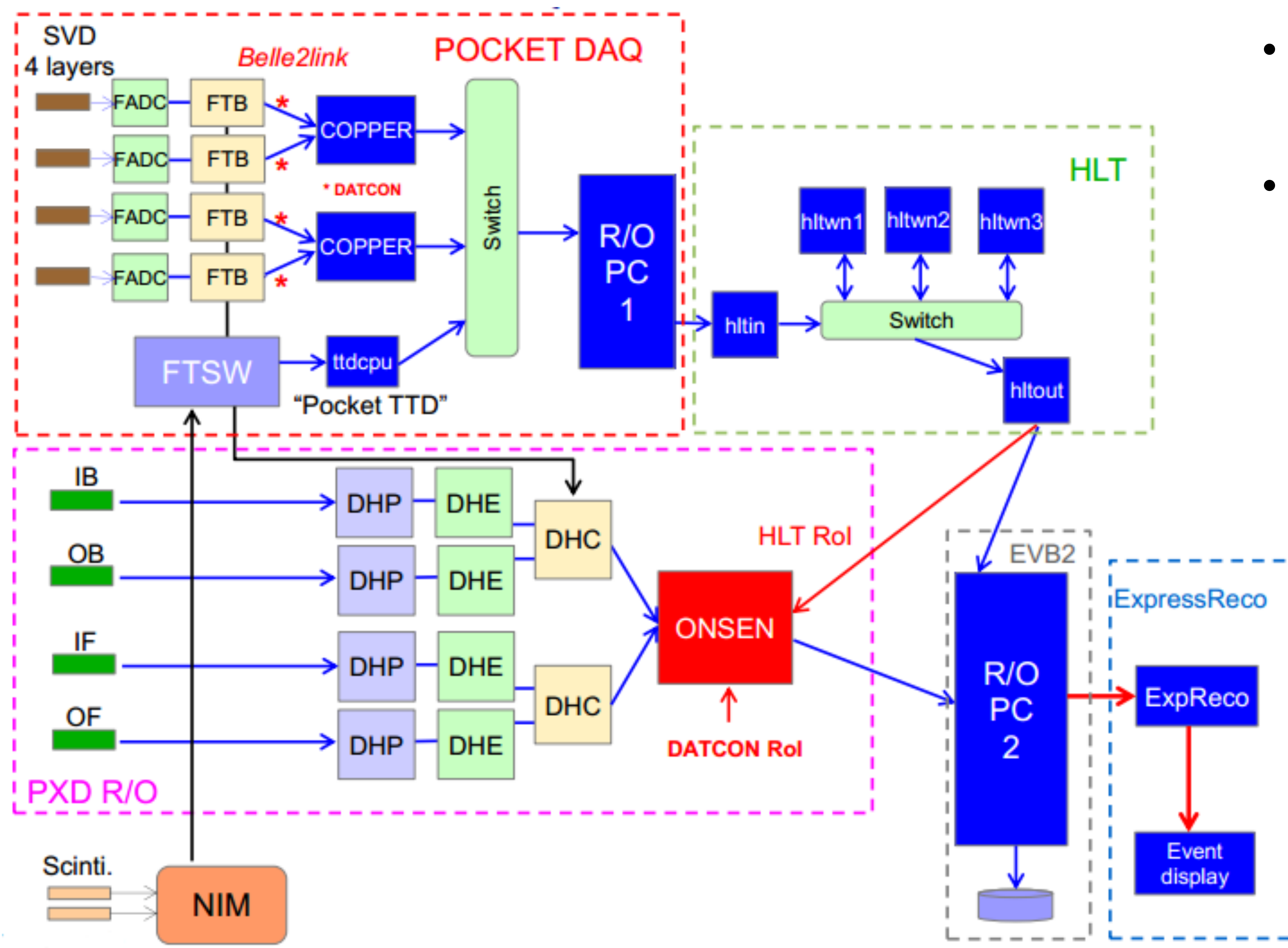


VXD Test Beam DAQ Structure

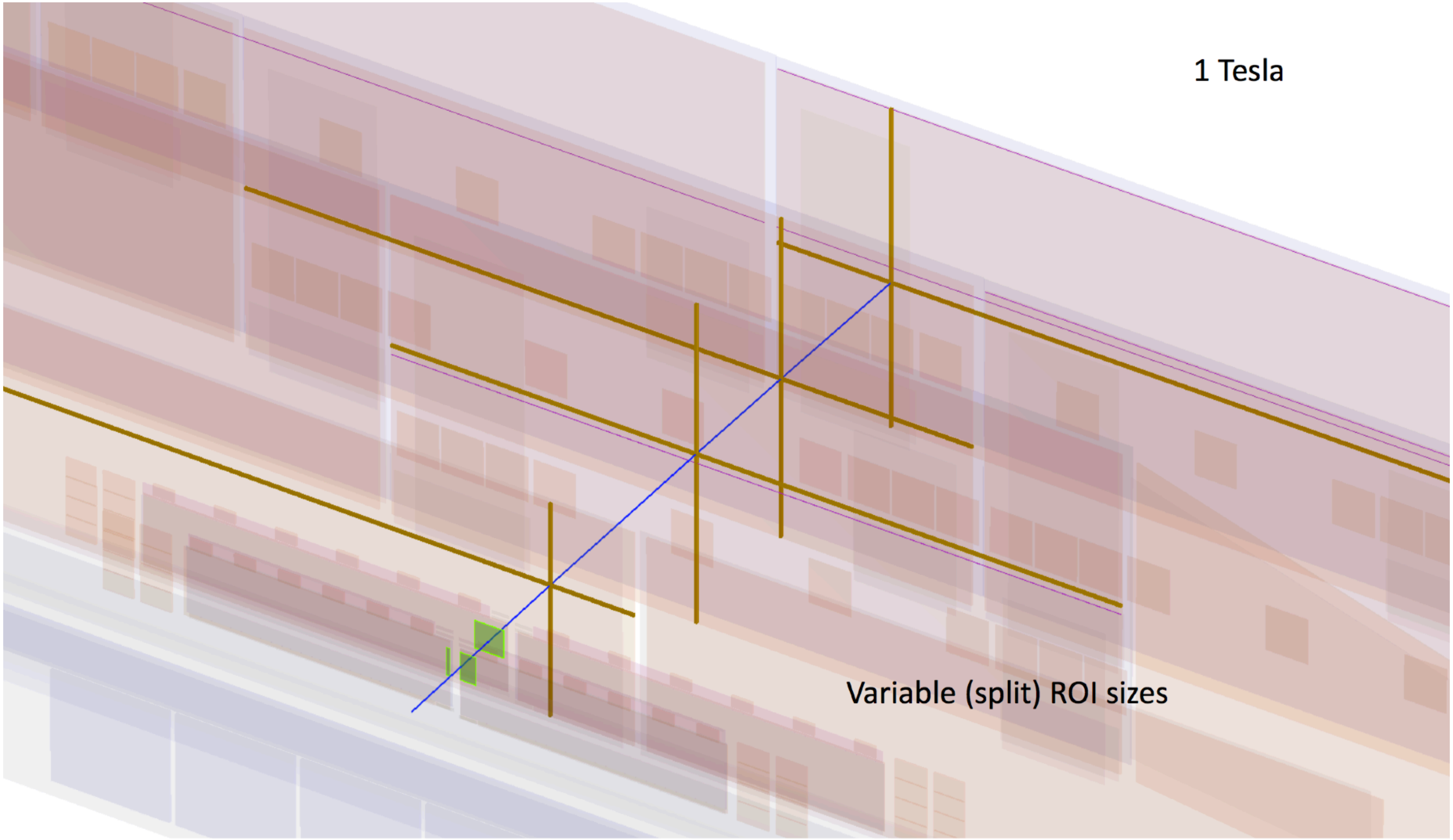
- PXD data output rate of about 30 GB/s after zero suppression.
- DAQ system aims to reduce the background data by a factor of 30.
- A set of ROIs on PXD sensors are determined, Onsen buffers the output data and records just the data from the pixels inside the ROIs.



- HLT defines ROIs using the information of SVD and central drift chamber (CDC)
- DATCON defines ROIs using only SVD hits

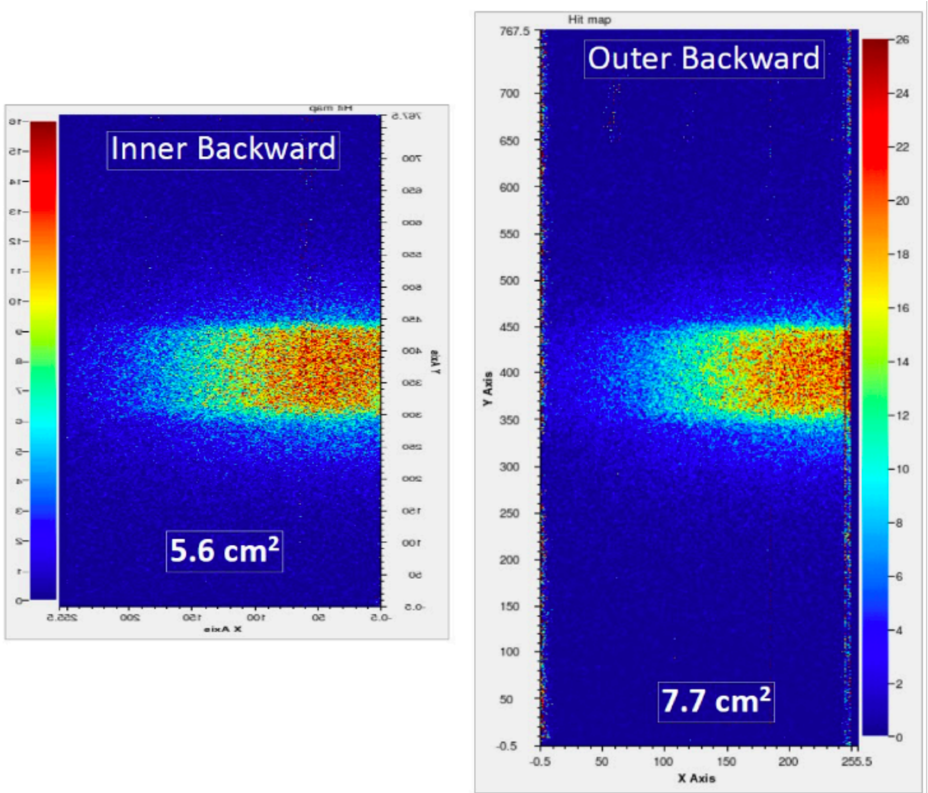
ROI: region of interest
HLT: High level trigger
DATCON: Data concentrator
ONSEN: Online Selection Nodes
EVB: Event builder
DHE: Data handling engine
DHH: Data handling hub
…

ROI selection

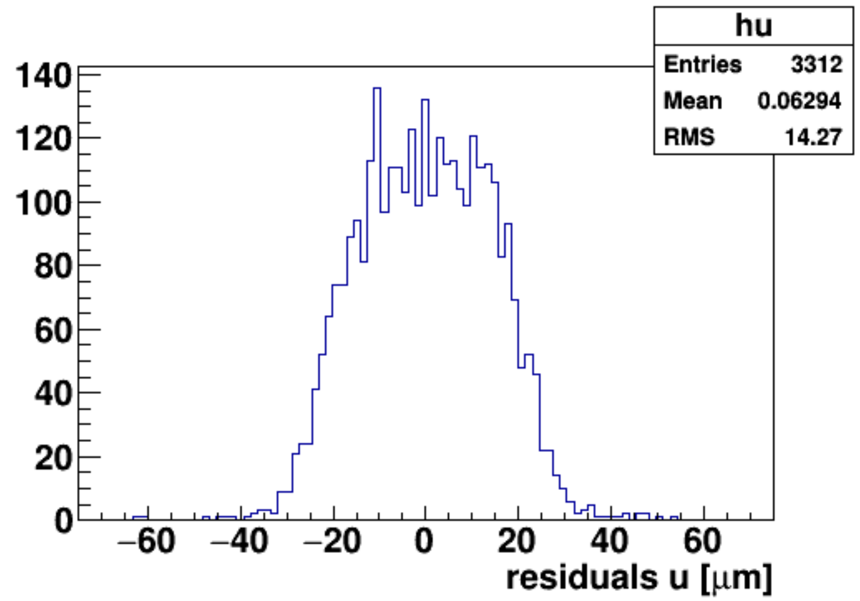


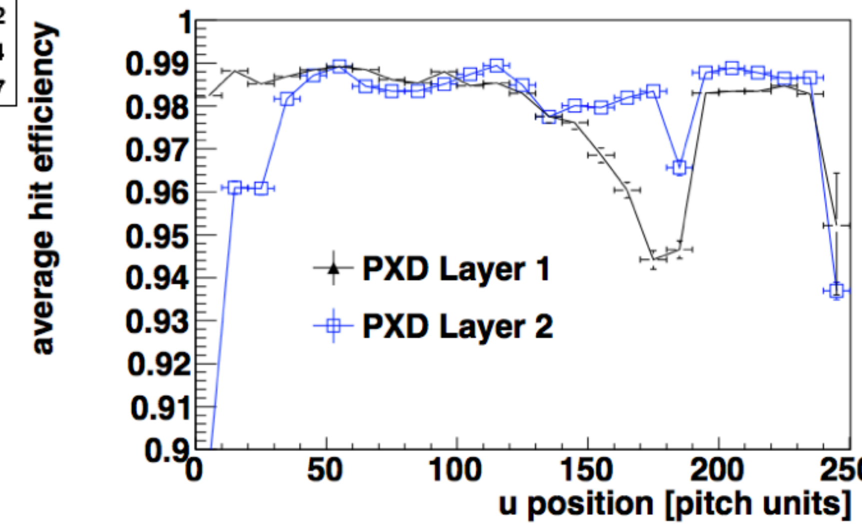
VXD performance

PXD hit map



Residuals and hit efficiency of PXD sensors



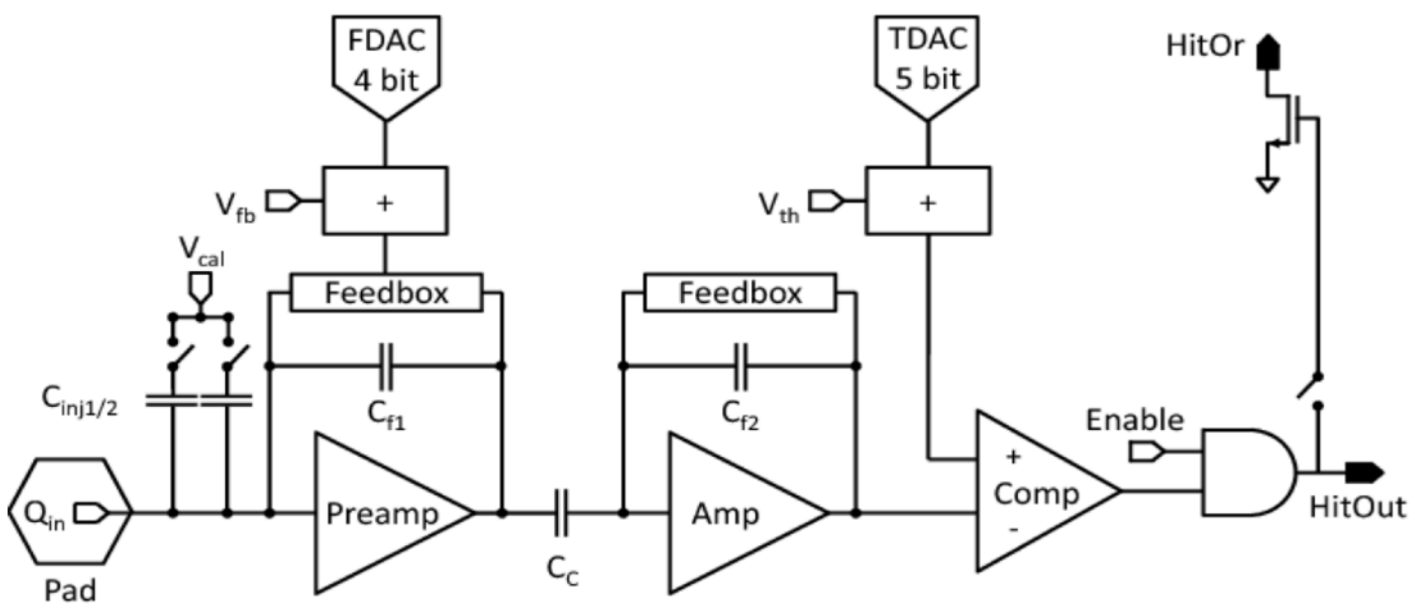


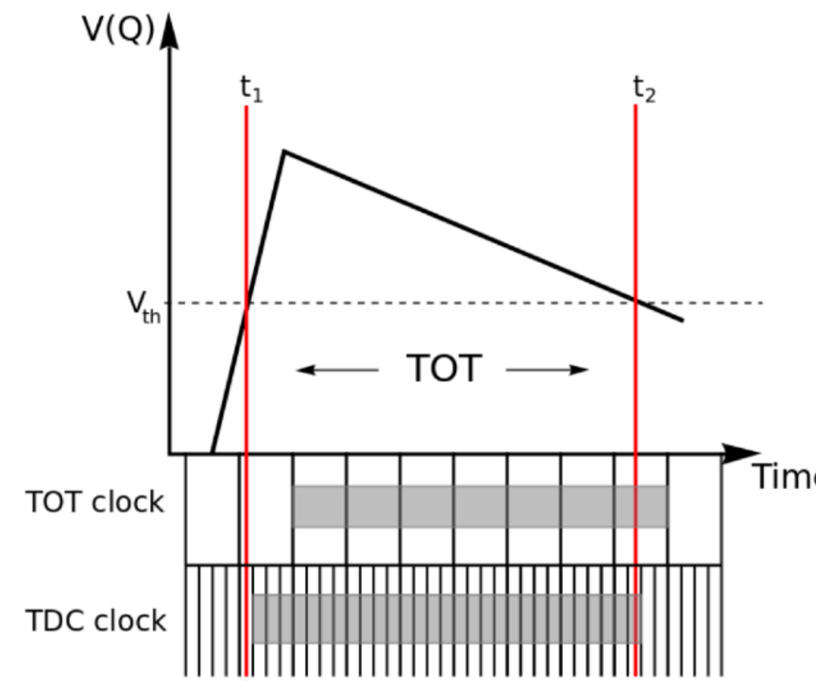
Residuals of SVD sensors

	$r-\phi$ - direction				z - direction		
ladder	σ [μm]	$\sqrt{\sigma^2-\sigma^2_{track}}$ [μm]	$p/2\sqrt{12}$ [μm]	ladder	σ [μm]	$\sqrt{\sigma^2-\sigma^2_{track}}$ [μm]	$p/2\sqrt{12}$ [μm]
L3	10.4 ± 0.1	8.2	7.2	L3	24.9 ± 0.3	23.6	23.1
L4	11.7 ± 0.1	9.8	10.8	L4	35.5 ± 0.4	34.6	34.6
L5	11.9 ± 0.1	10.0	10.8	L5	33.7 ± 0.3	32.7	34.6
L6	11.4 ± 0.1	9.3	10.8	L6	31.4 ± 0.3	30.4	34.6

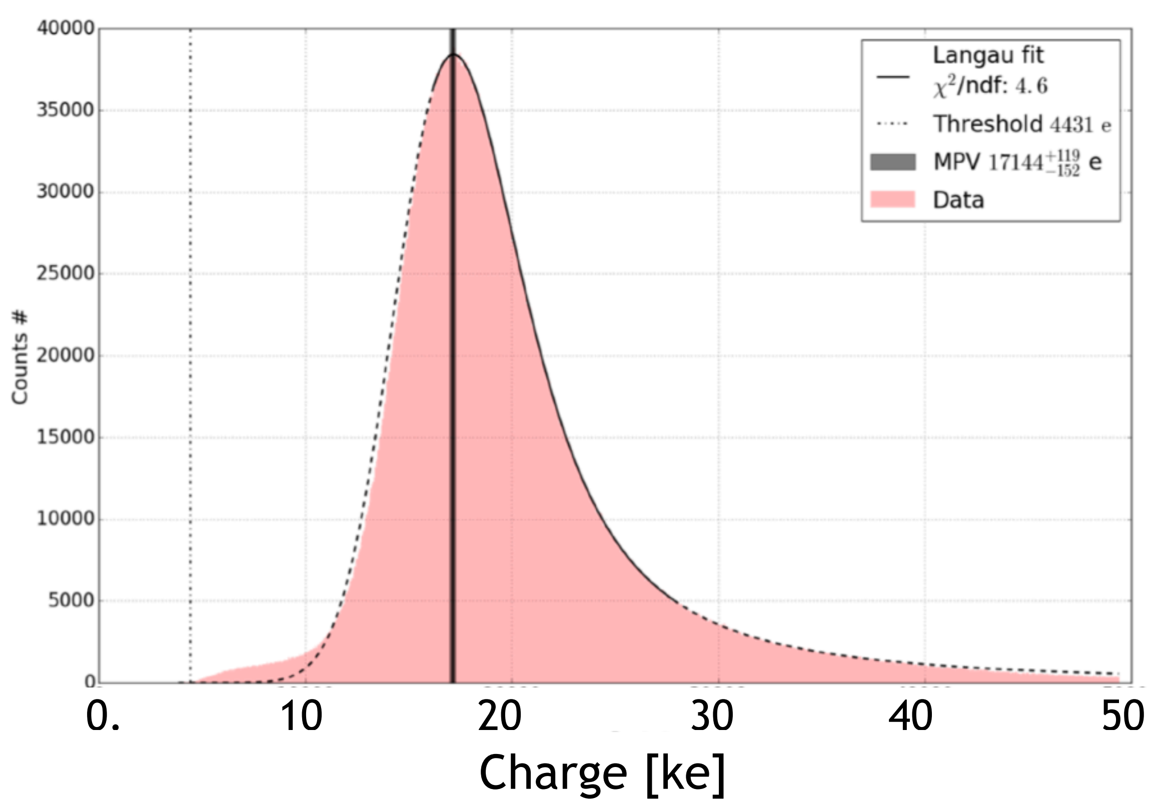
FANGS performance

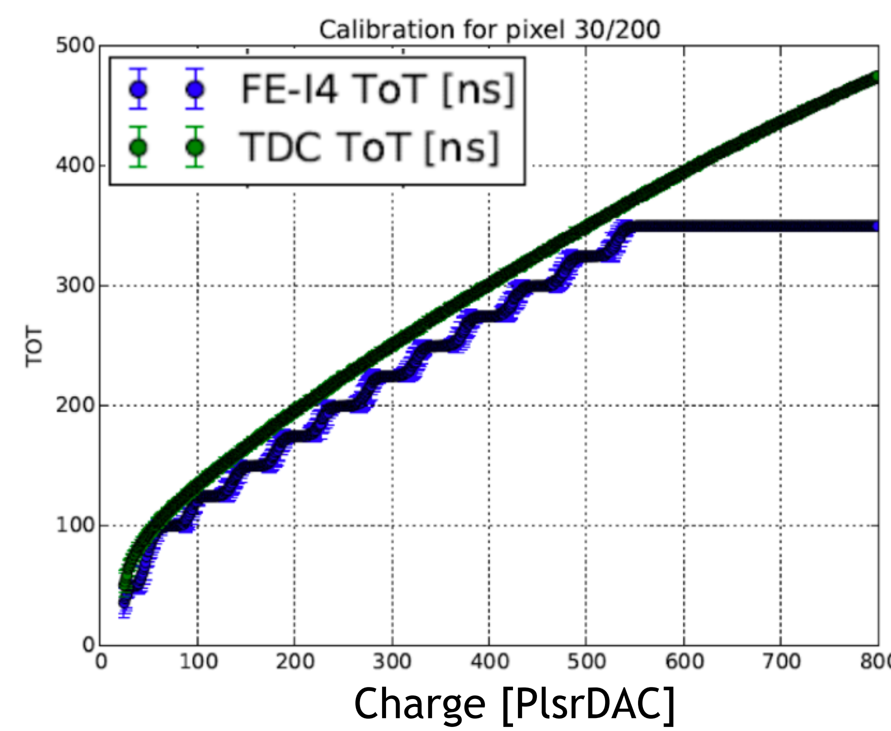
FE-I4 analog pixel cell





Time over threshold (TOT) with 40 MHz clock.
Time to digital converter (TDC) uses 640 MHz FPGA clock.

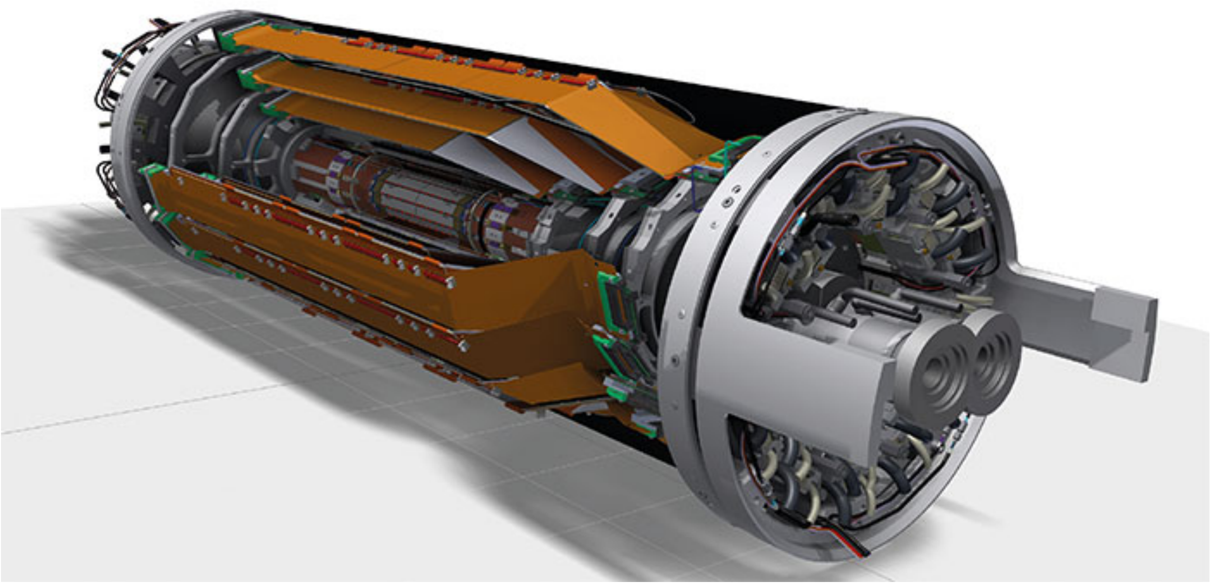


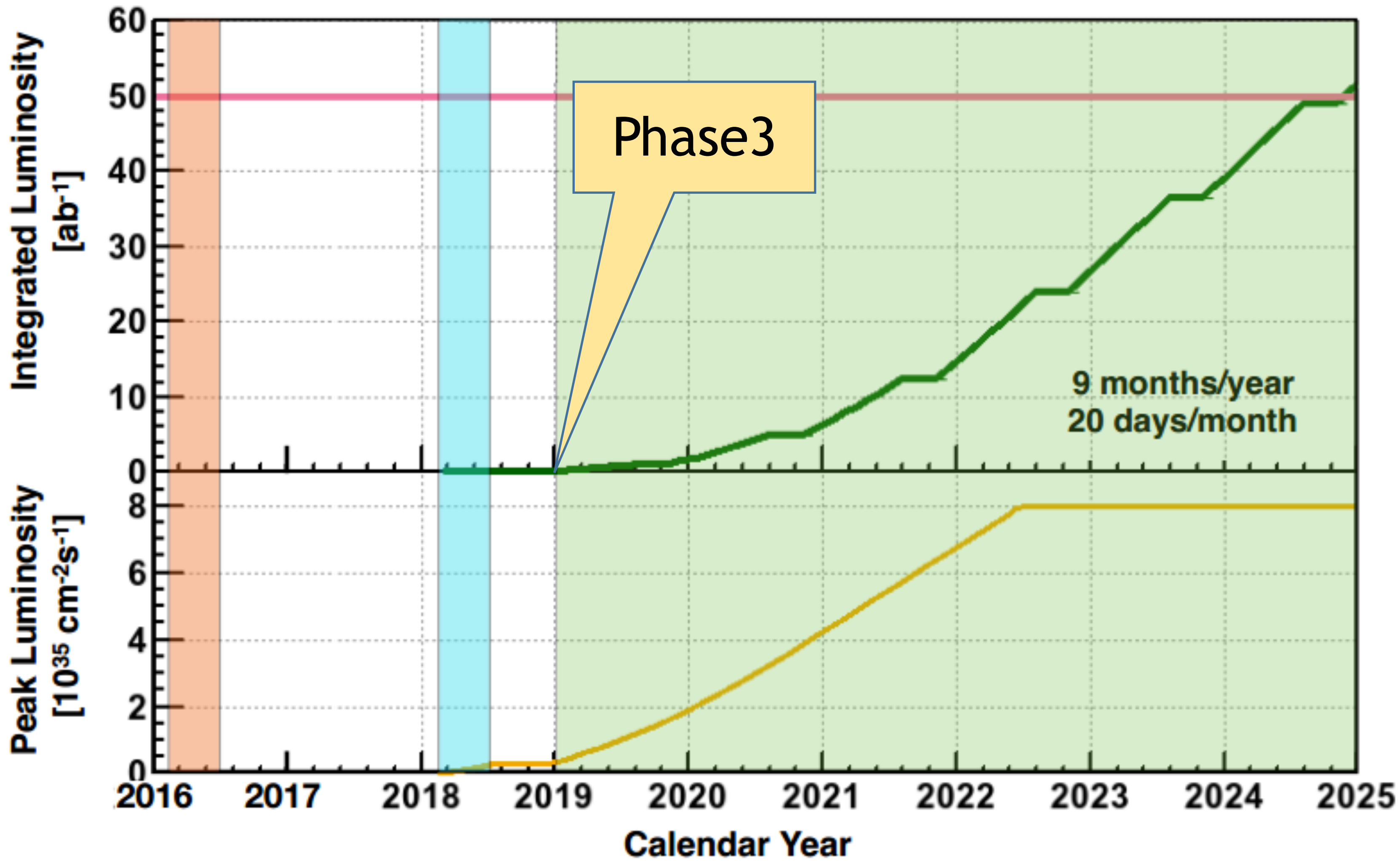


Calibrated charge deposition with TDC method, the fitted mean value (17.1ke) is consistent with the expected value, 18ke.

SuperKEKB Commissioning Phase 3

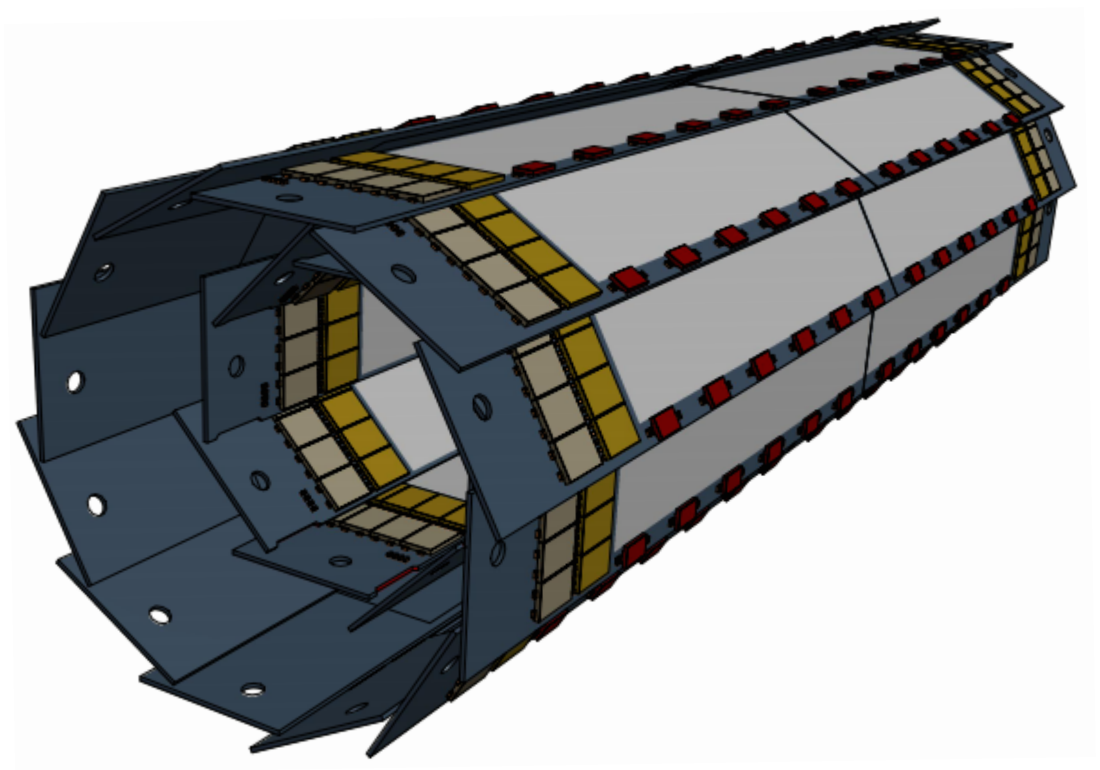
Detector
- Full Belle II detector
- PXD production is underway, integration is under preparation at DESY



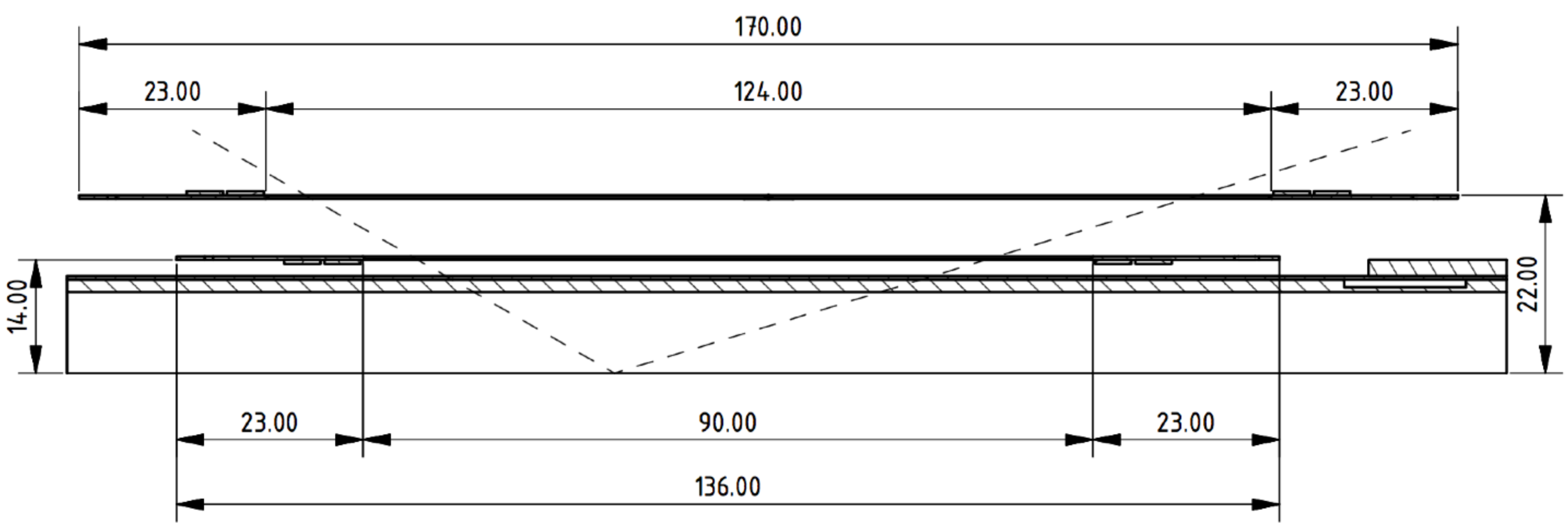


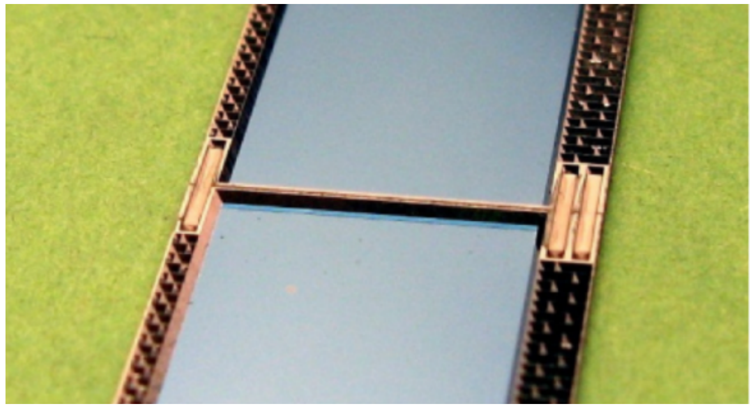
PXD Layout

- 2 layers pixel detector with 40 DEPFET sensors
- 2 layers @14(22) mm
- 7.68 million pixels with the pitch size: 50x55-85 μm^2
- sensitive area size:
  - 12.50 X 44.80 mm^2 (layer.1)
  - 12.50 X 61.44 mm^2 (layer.2)
  - will be thinned down to 75 µm.



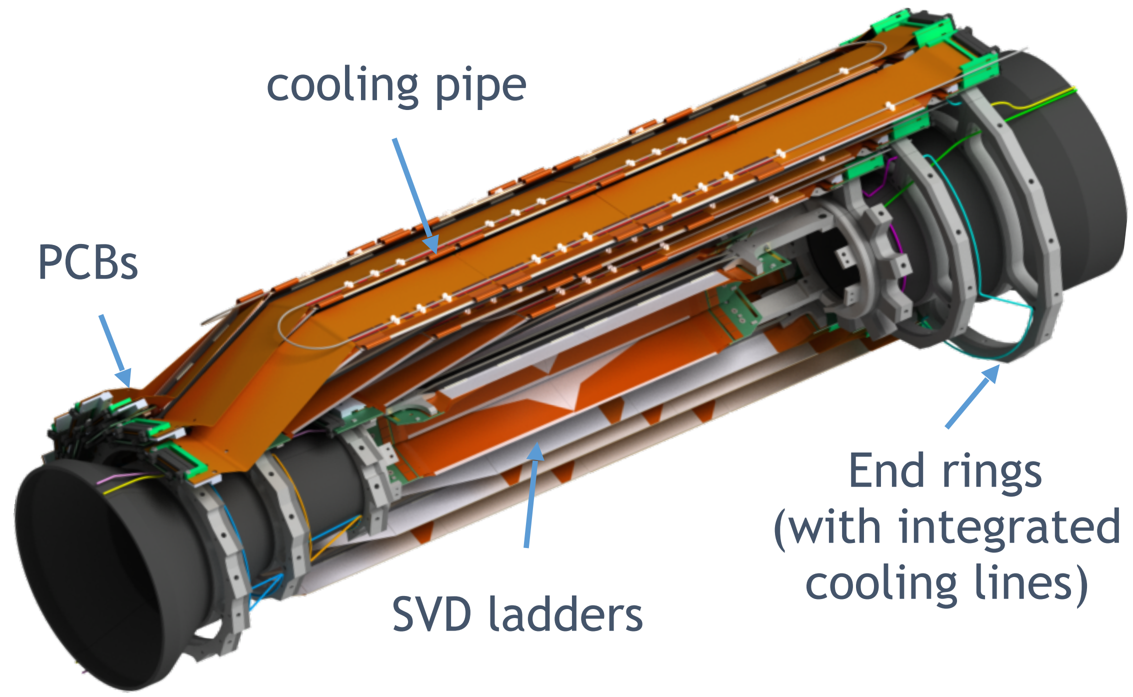
Ladder formed from 2 sensors
- butt-face joint glueing
- ceramic mini-rods embedded in the thick rim of sensor

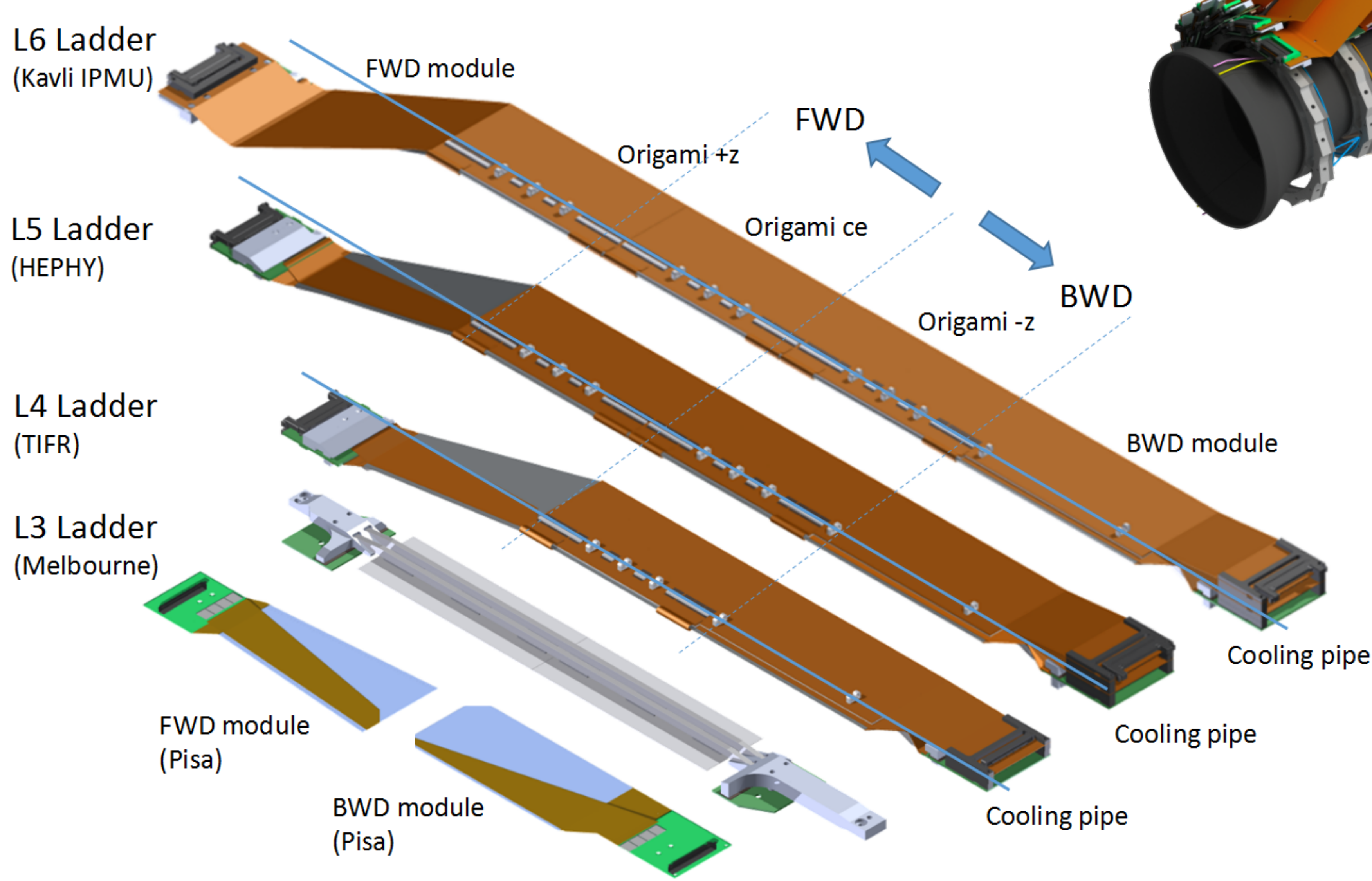




SVD Layout

- For layers.4-6, a slant angle with trapezoidal sensors is implemented in the forward part.
- For Lay.3 and forward/backward DSSDs of Layers.4-6, the APV25s are mounted in the end of the ladder and get support and cooling with the endrings.
- The barrel DSSDs of Layers.4-6 are cooled by pipes.





Layer	Ladders(DSSDs)
6	16 (5)
5	12 (4)
4	10 (3)
3	7 (2)

Cooling Requirement

Powder Consumption

CO_2 Circuit	Detector	Half	Layer	Type	Side	Power [W]
1	PXD	up	1&2	endring	bwd	90
2			1&2	endring	fwd	90
3		down	1&2	endring	bwd	90
4			1&2	endring	fwd	90
					sum PXD	360
5	SVD	left	3-6	endring	bwd	93
6		right	3-6	endring	bwd	93
7		left	3-6	endring	fwd	93
8		right	3-6	endring	fwd	93
9		left	4&5	origami	bwd	68
10		right	4&5	origami	bwd	68
11		left	6	origami	bwd	96
12		right	6	origami	bwd	96
					sum SVD	700
					sum VXD	1060

Requirements

- PXD: Sensor < 25ºC to minimize shot noise due to leakage current; ASICs < 50ºC to avoid risk of electro-migration.
- SVD: APV25 readout chips surface@~0ºC for SNR improvement.
- Power consumption: PXD 360W; SVD 700W, together with the heat load through 9m of vacuum isolated flex lines; required cooling capacity of 2-3kW.
- VXD needs to be thermally isolated against CDC and beam pipe. Room temperature at the inner surface of CDC is required for stable calibration and dE/dx performance

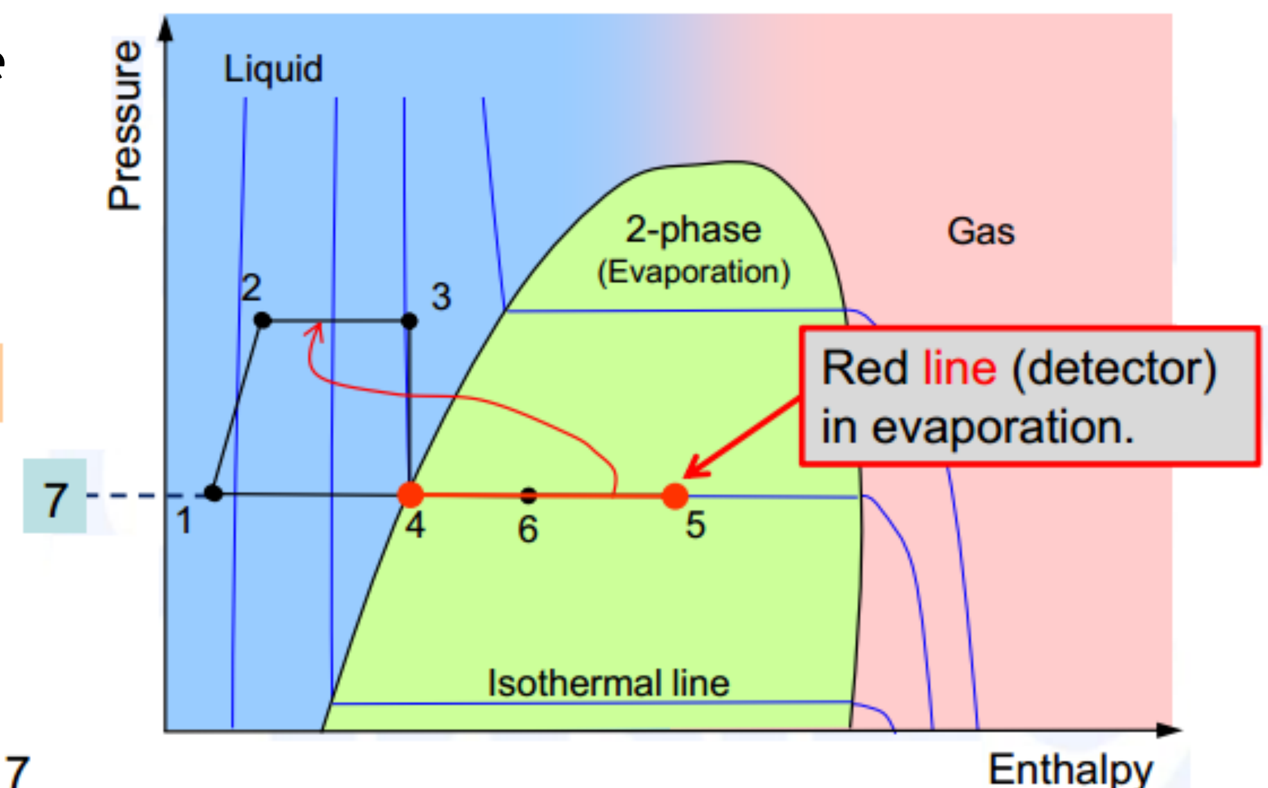
2-phase CO_2 Cooling

New cycle for particle detectors: 2PACL
(The 2-Phase Accumulator Controlled Loop)

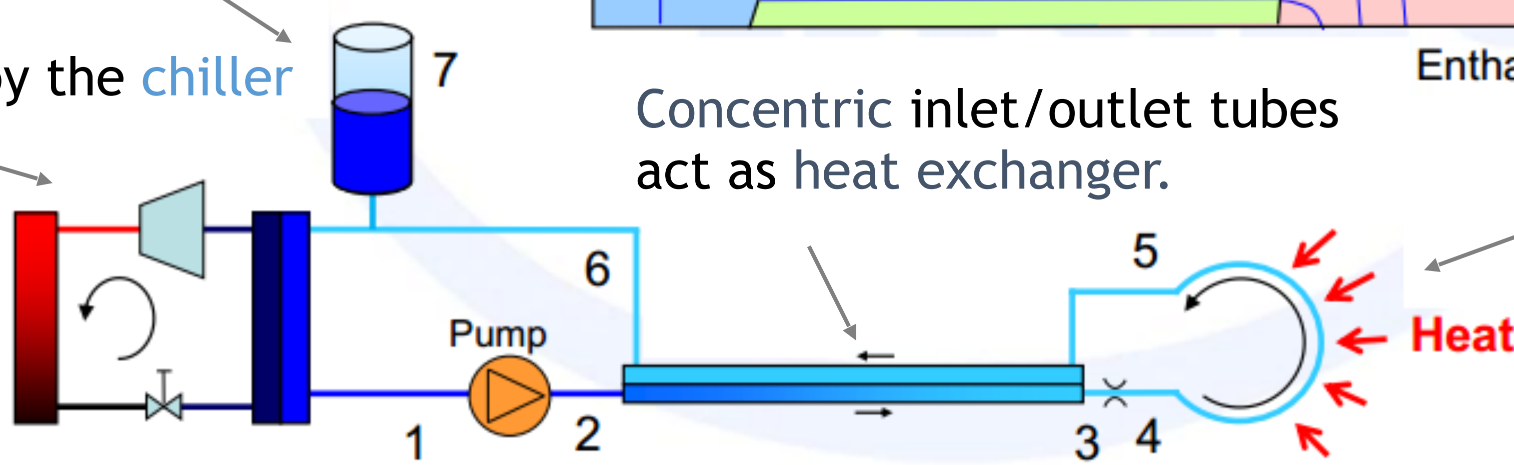
The pressure drop in (4-5) should be small, therefore the accumulator directly controls the pressure in the detector.

Detector is on

Controlling the **accumulator** pressure hence the condenser and evaporator pressure.



Vapor is condensed by the chiller



Concentric inlet/outlet tubes act as heat exchanger.

The detector acts as evaporator

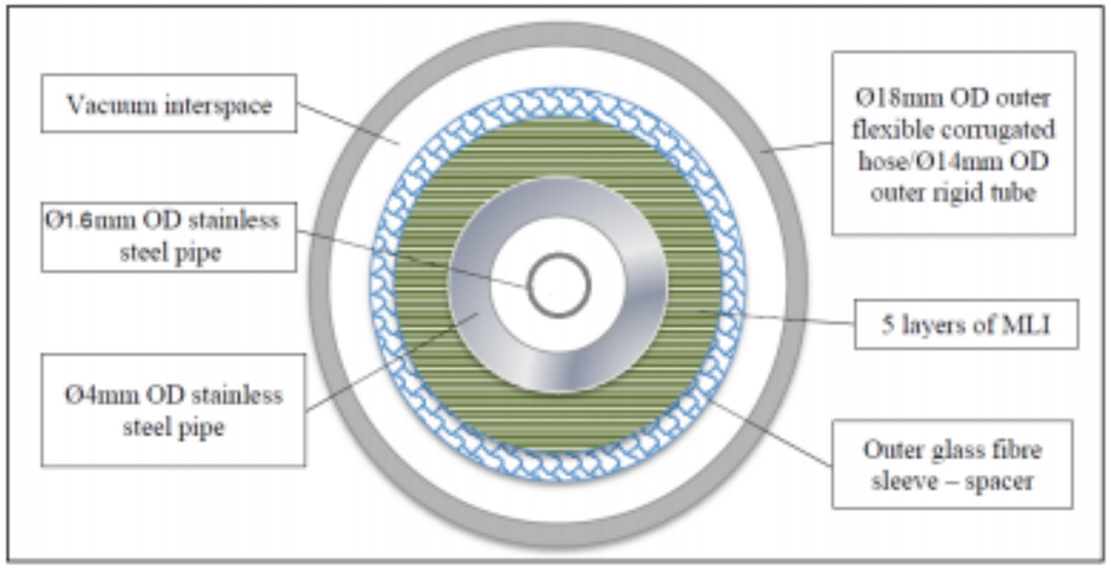
The sub-cooled CO_2 will prevent the pump from cavitation.

2-Phase CO_2 Cooling System: MARCO

The 2-phase CO_2 cooling is an efficient concept for low-mass detector.

- ➢ Heat removal by evaporating liquid CO_2 at the constant temperature and pressure.
- ➢ The temperature can be controlled by the pressure in the 2-phase vessel (accumulator) away from the experiment, no local control or monitor is necessary.
- ➢ Challenges: need to guarantee the 2-phase state, otherwise "dry-out".

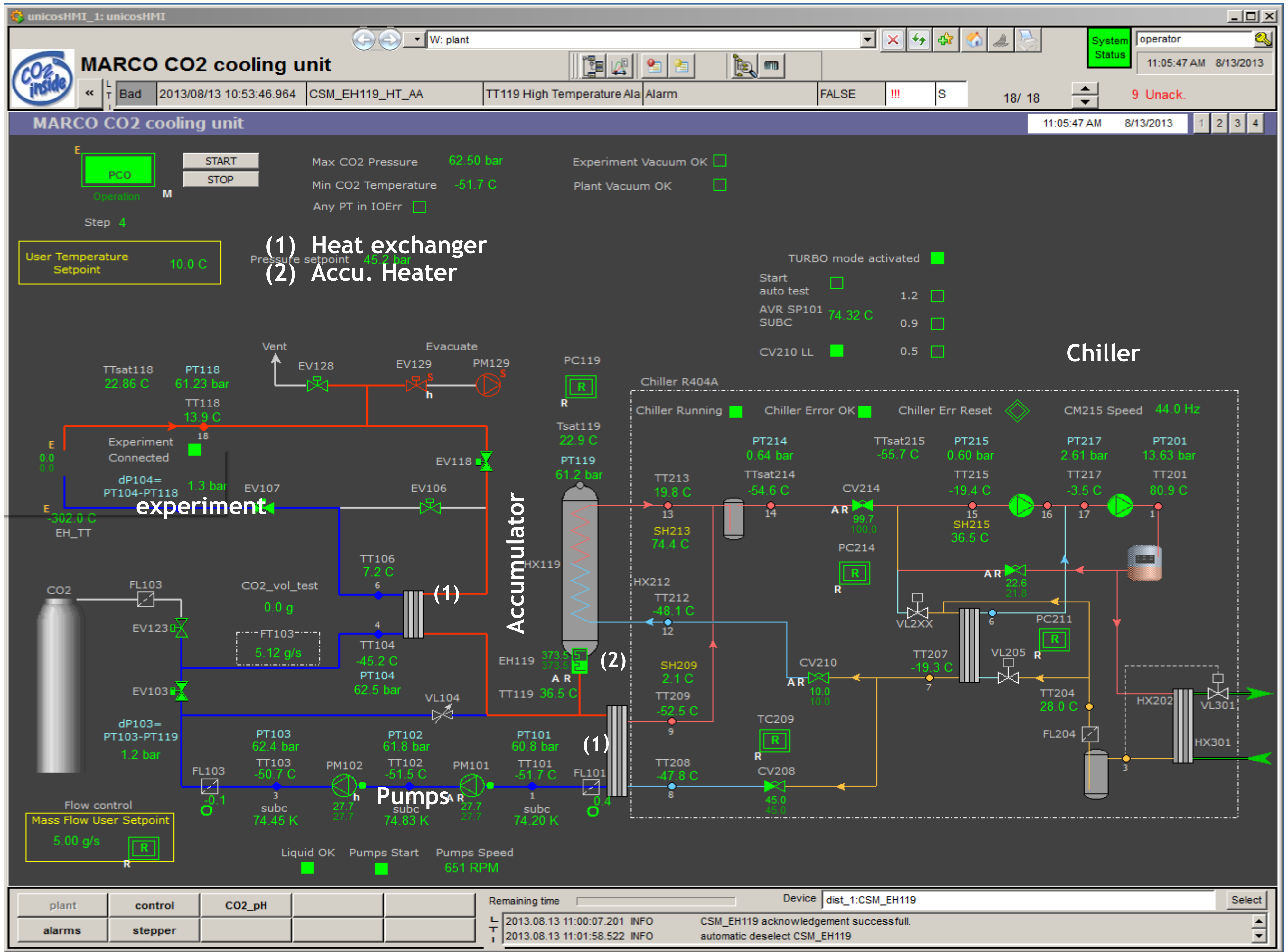
Concentric transfer flex line



MARCO : ***M***ultipurpose ***A***pparatus for ***R***esearch on ***CO***$_2$

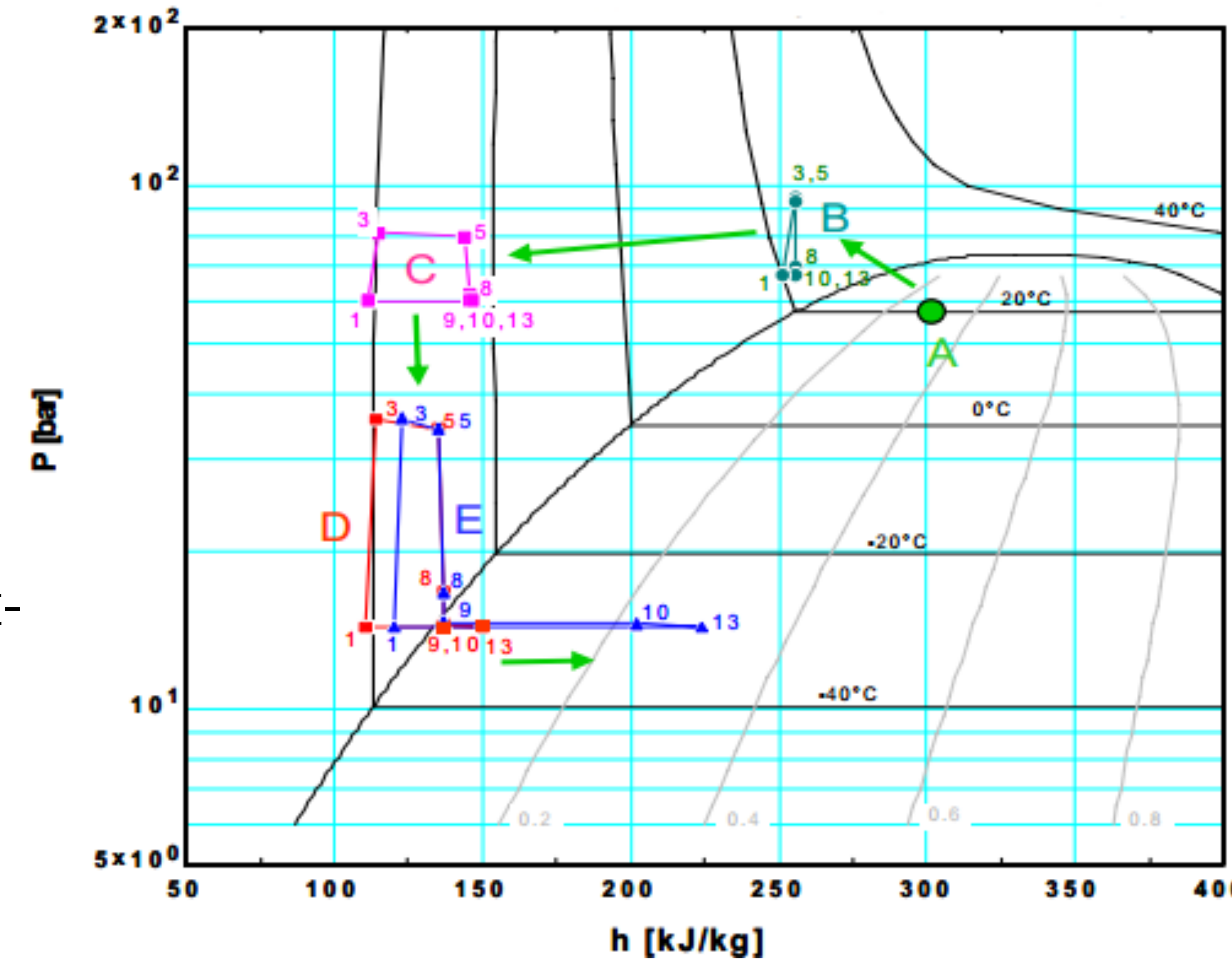
- ❑ Fully automatic (User friendly) CO_2 system for general use.
- ❑ Base design on detector cooling plants (Atlas IBL, BelleII)

2-Phase CO_2 Cooling System: MARCO



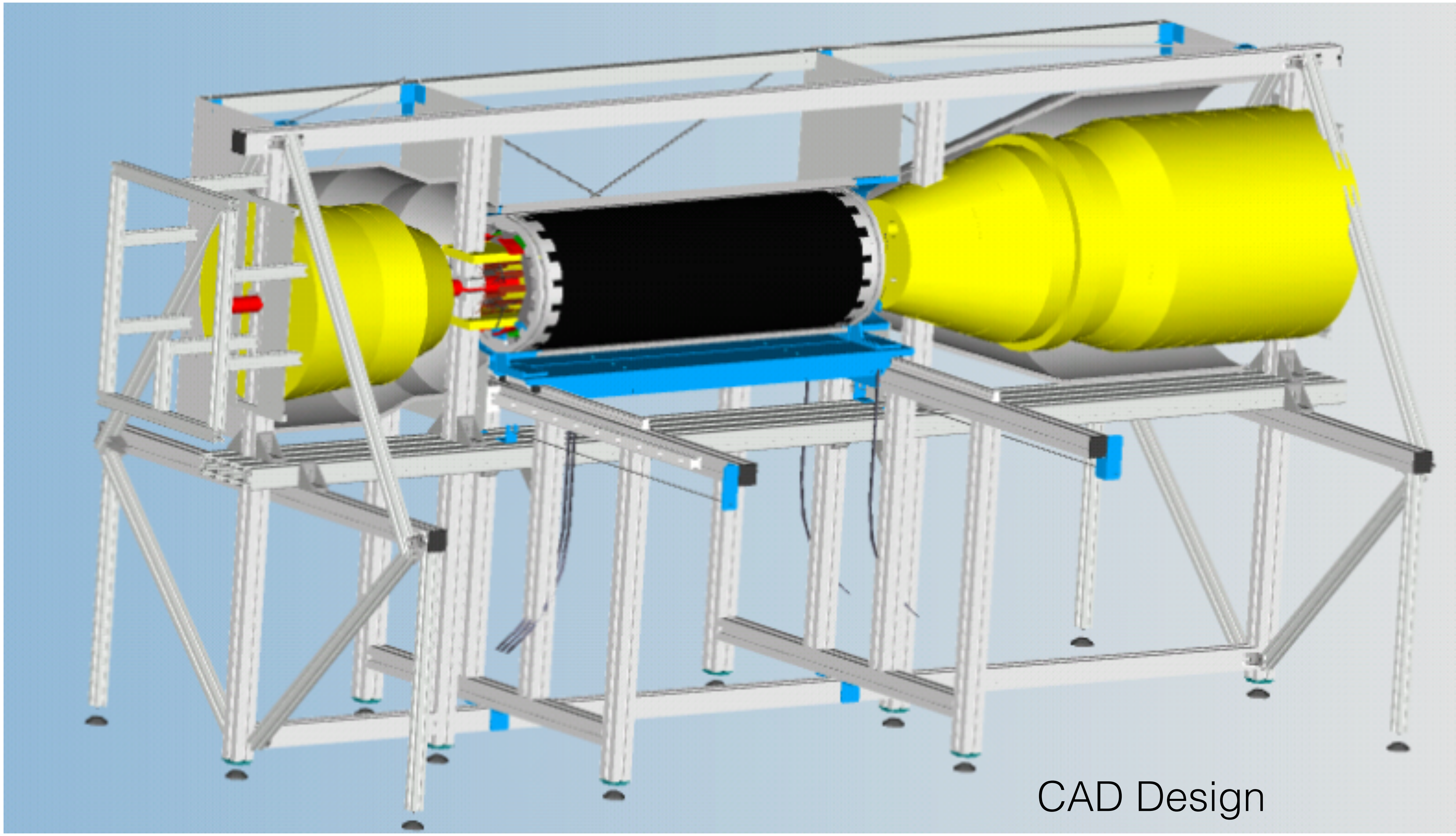
MARCO operation

A. Prime the system, the accumulator is heated. The increasing pressure causes the loop full with liquid.
B. Switch on the pump.
C. Chiller cools down the CO2 to liquid.
D. Accumulator reaches the desired set-point temperature
E. Detector is on.



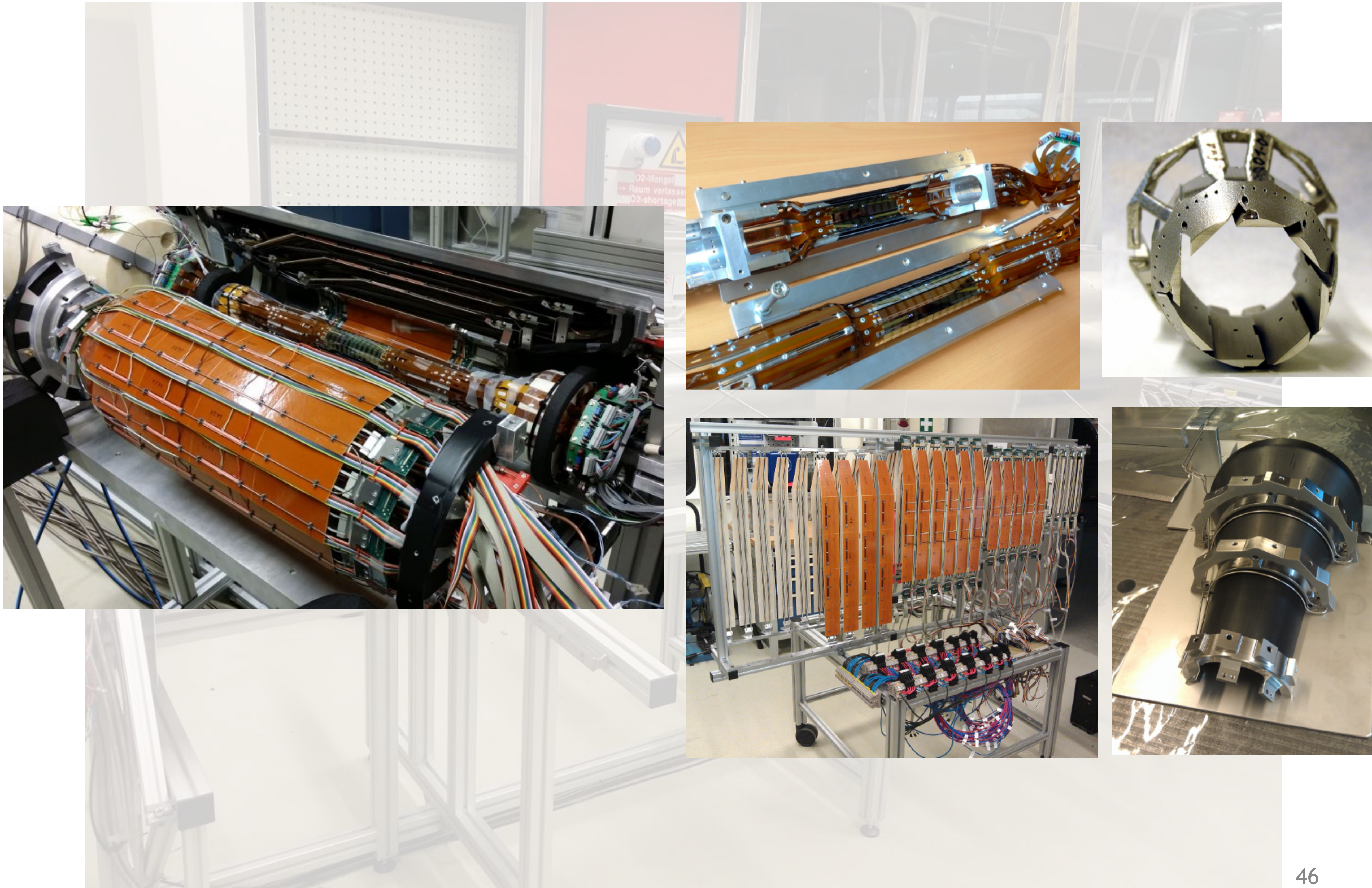
VXD Thermal Mockup

A full-size thermal mock-up is built at DESY, to verify and optimise the cooling concept of Belle II VXD.



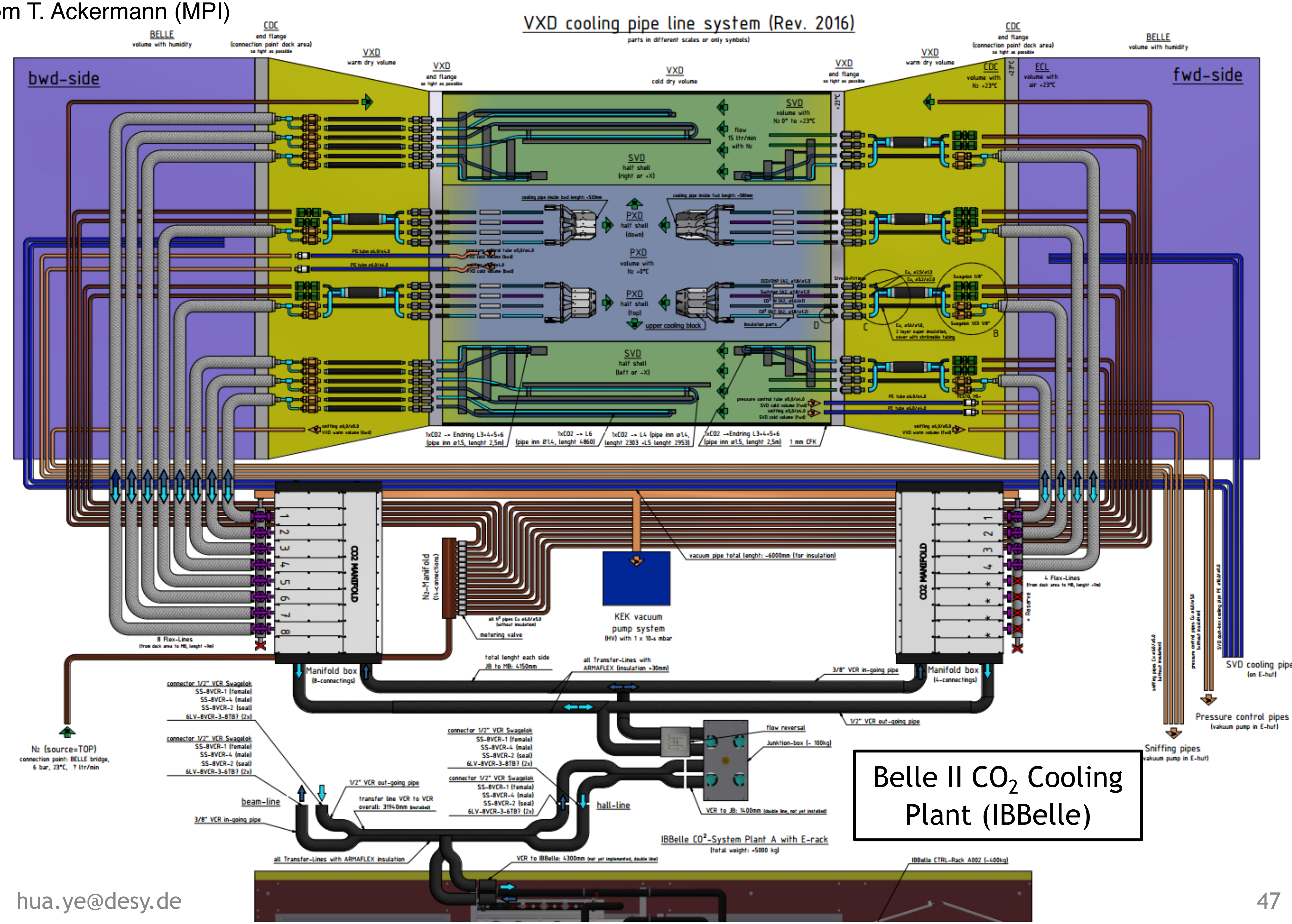
VXD Thermal Mockup

VXD Thermal Mockup



VXD Cooling System

From T. Ackermann (MPI)

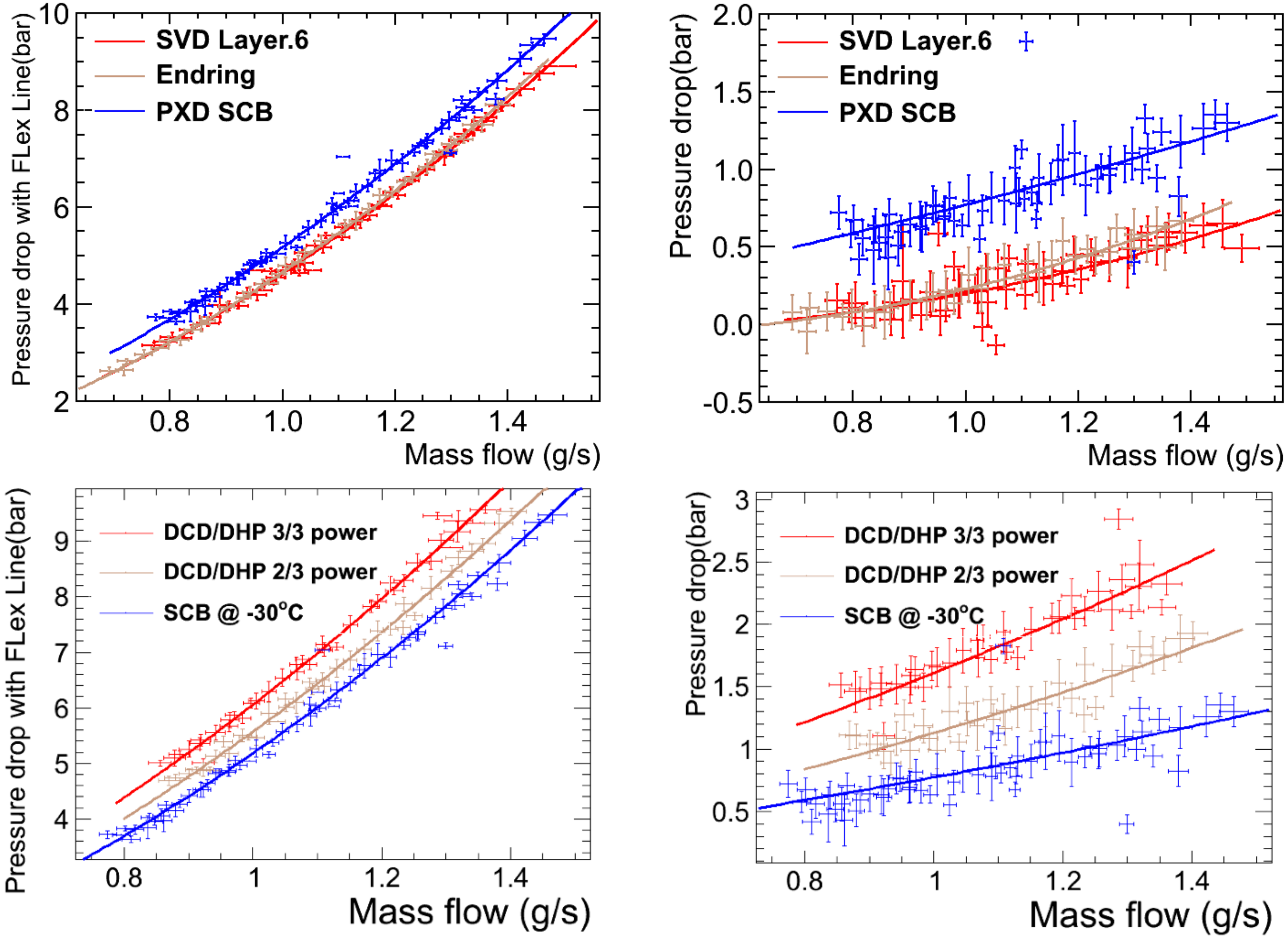


Belle II CO_2 Cooling Plant (IBBelle)

Pressure drop in Cooling Circuit

Belle II

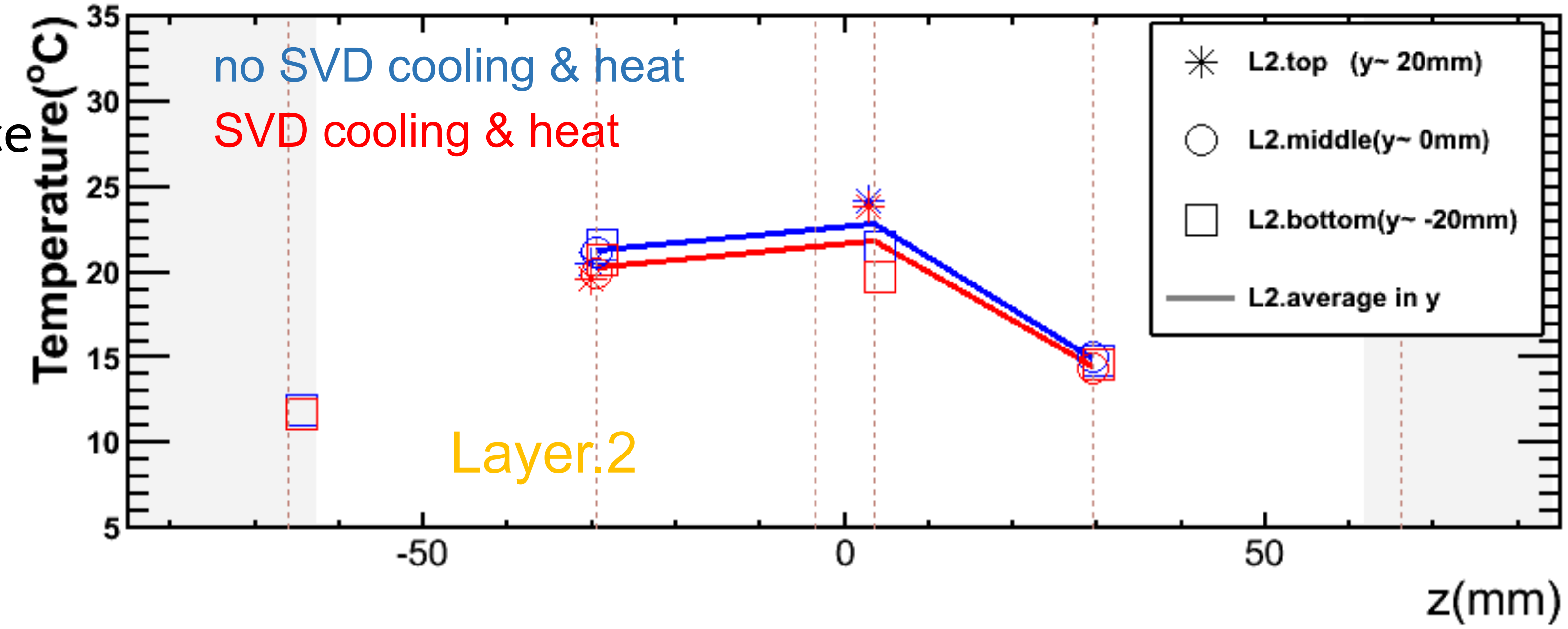
- The long and thin cooling lines cause pressure drops, which result in temperature gradients.
- Relatively big contribution of pressure drop in transfer flex line, to ensure balanced CO_2 mass flow in each circuit.

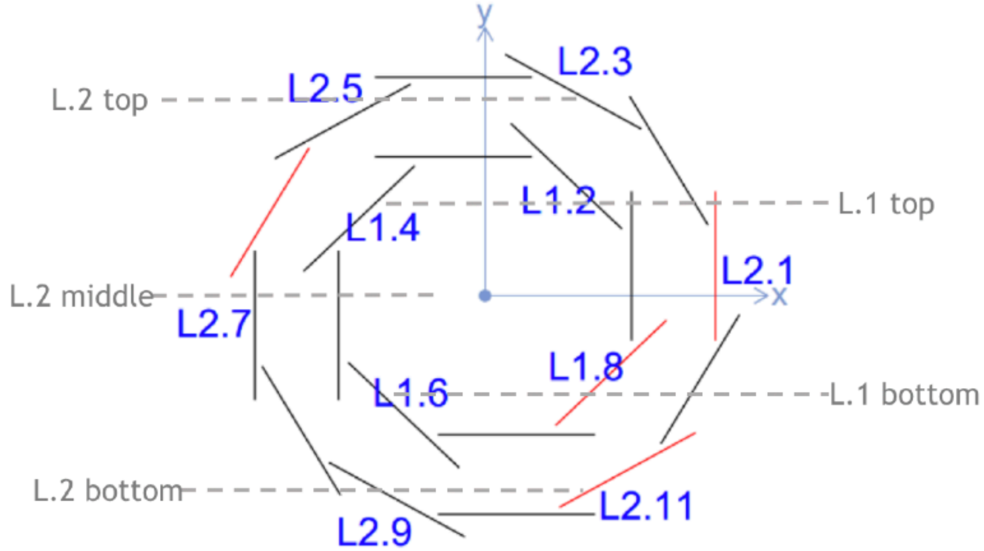


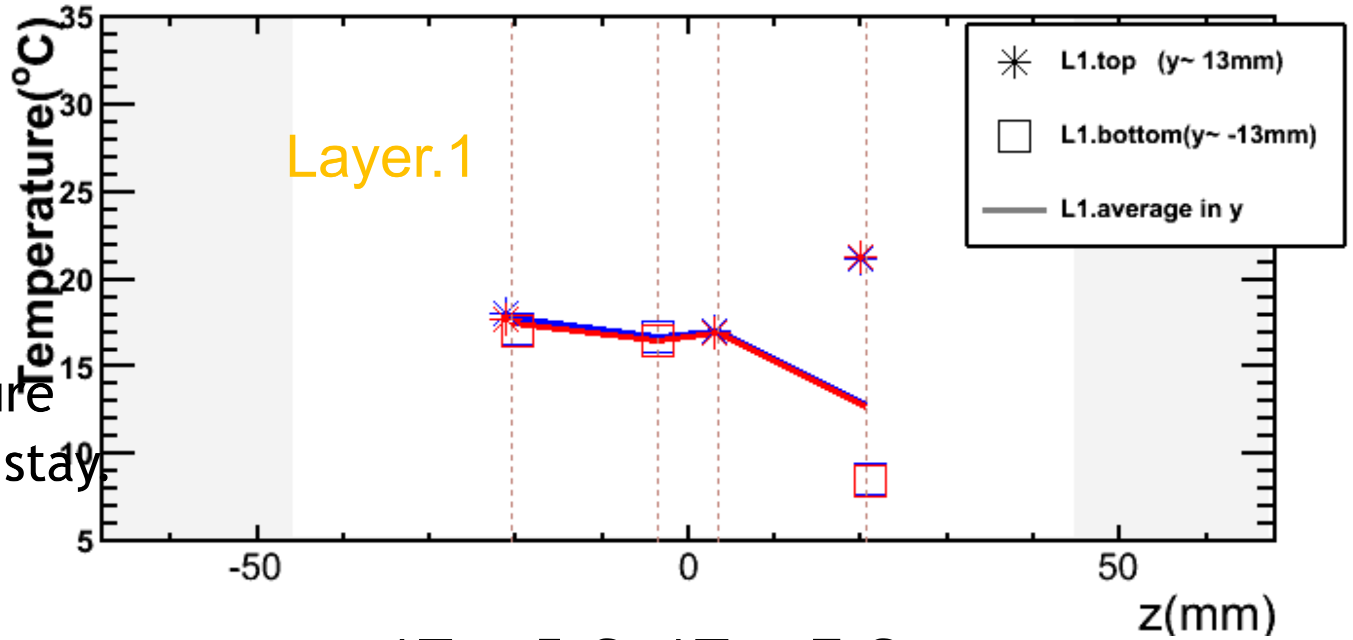
- Additional pressure drop of about 1 bar results from the heat load in PXD ASICs.

Temperature Distribution on PXD

- CO_2@-25°C; N_2 20L/min
- Power consumption*:
  - DCD/DHP 8W, Switcher 0.5W,
  - matrix 0.5W
- Temperature is monitored by resistance thermometers.
- With SVD cooling and power on, temperature on PXD changes ~2°C.





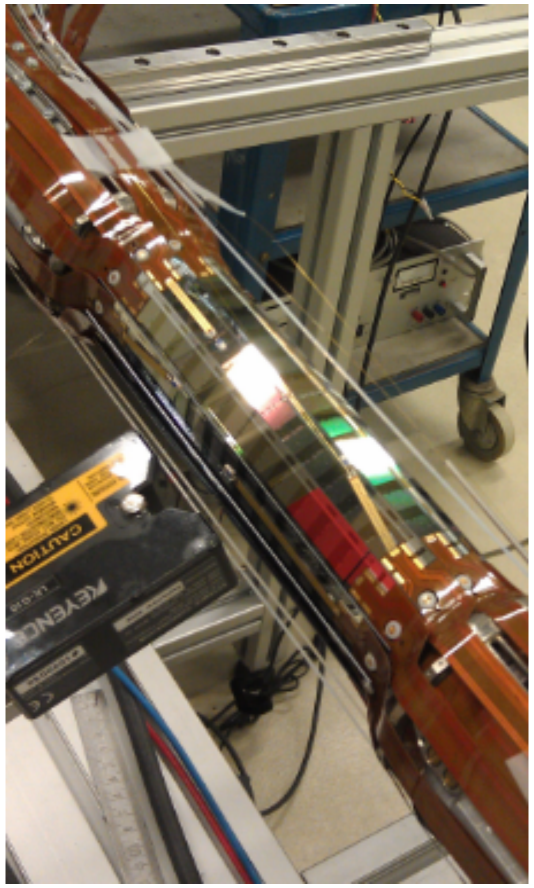


- By changing the CO_2 set point, the temperature distribution gets shifted, while the gradients stay.
- By increasing the N_2 flow, the gradient gets improved.

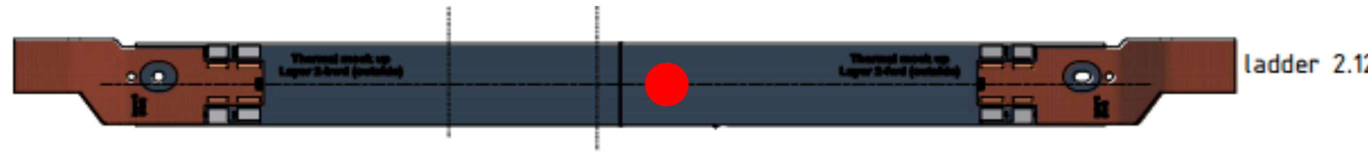
$\Delta T_Y \sim 5°C$, $\Delta T_Z \sim 7°C$

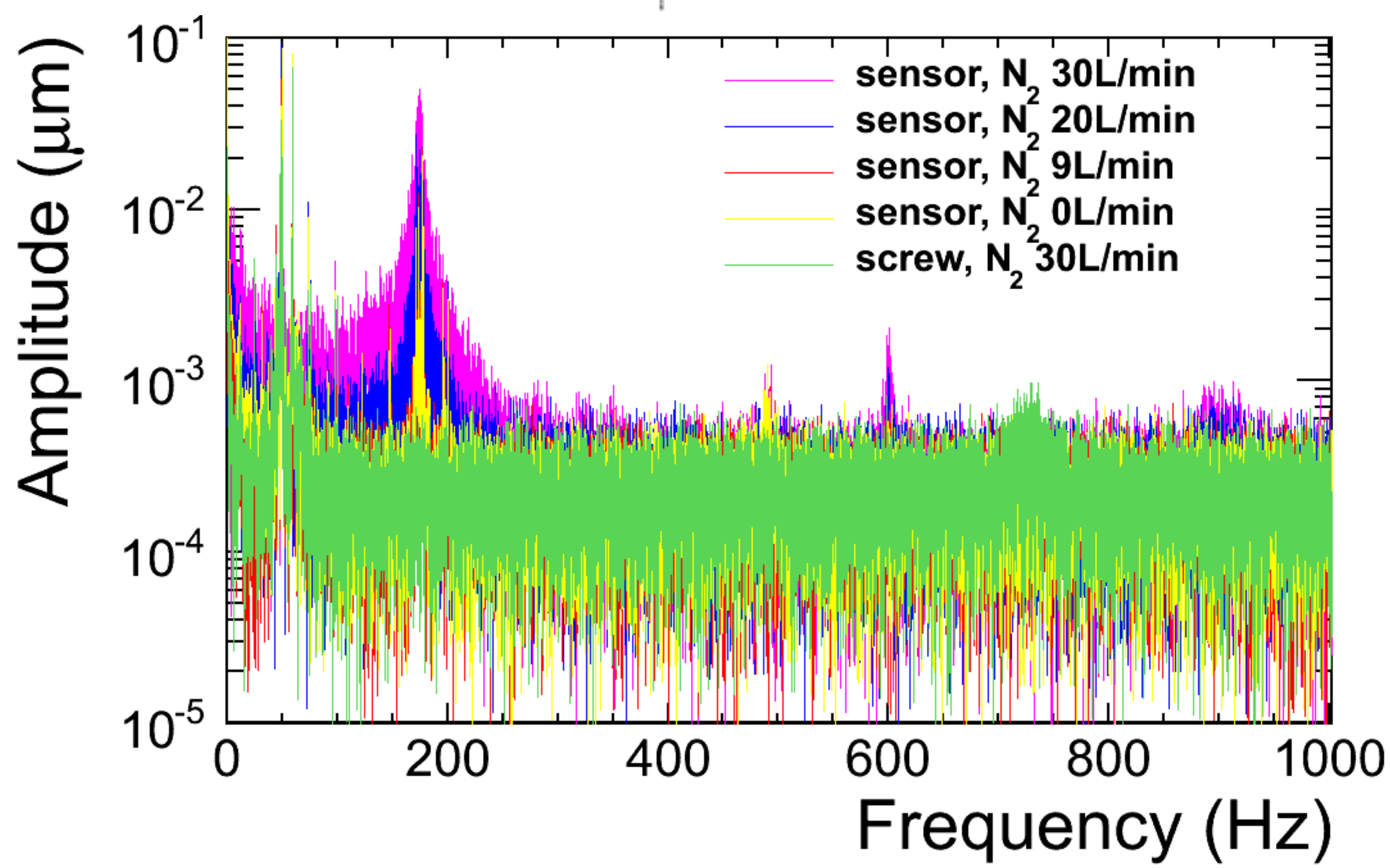
** Based on the initial numbers for the first versions of chips for DEPFET, the final numbers need to be confirmed in future.*

Vibration vs N_2 flow

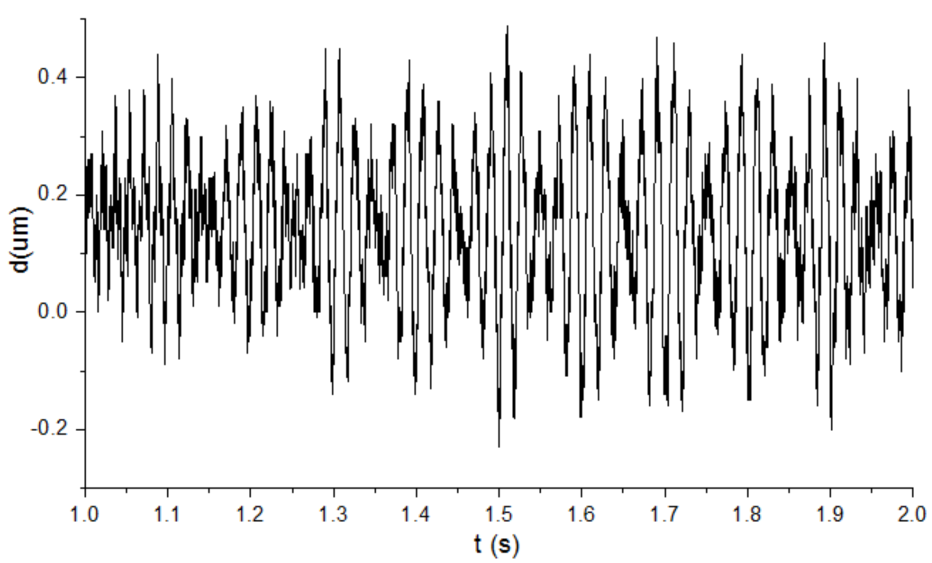


Using non-contact laser displacement sensor



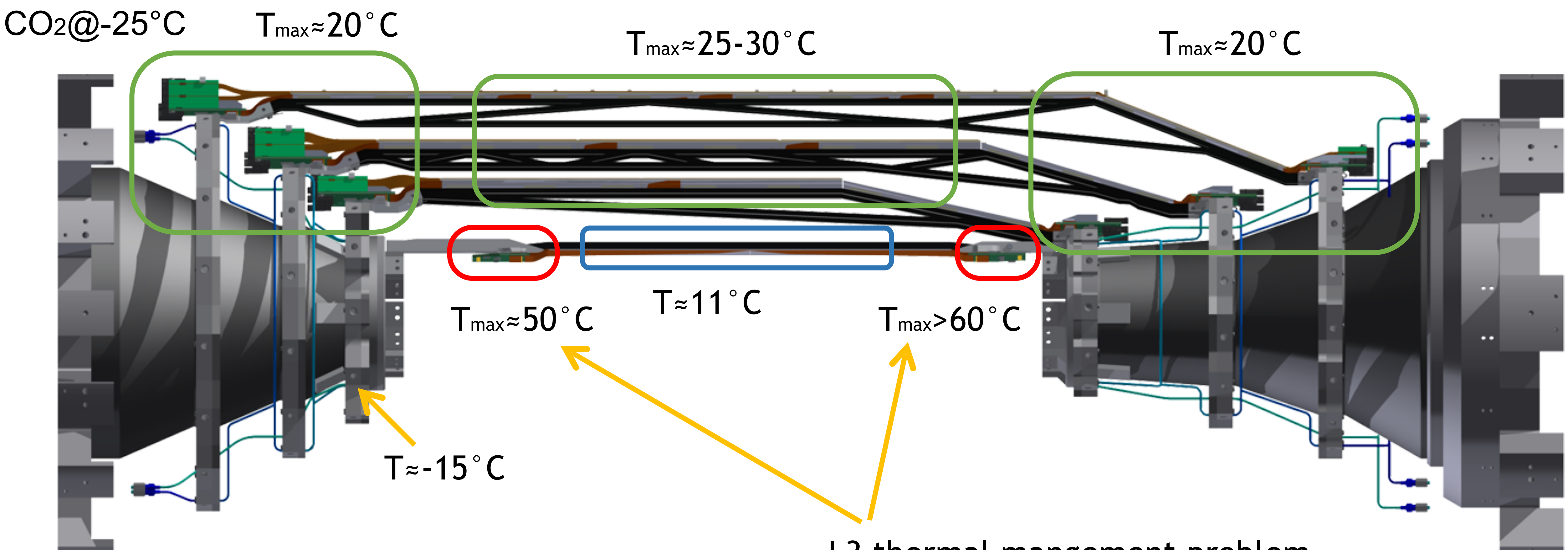


Vibration with RMS amplitude about 0.2um.



- A peak at about 175 Hz is observed, amplitude increases with the flow rate reaching about 0.02μm when 20L/min of N2 is injected.
- Flat background indicated by the measurements at the fixation screws on the SCB.

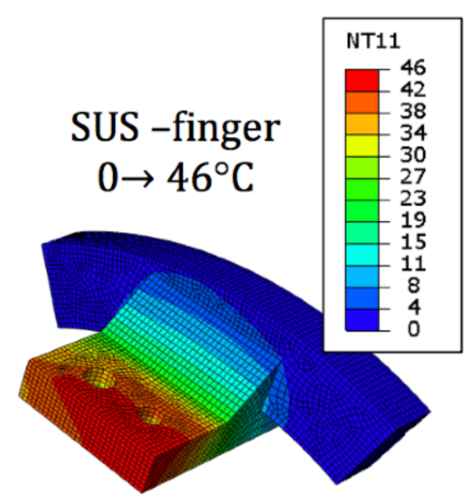
Temperature Distribution in SVD



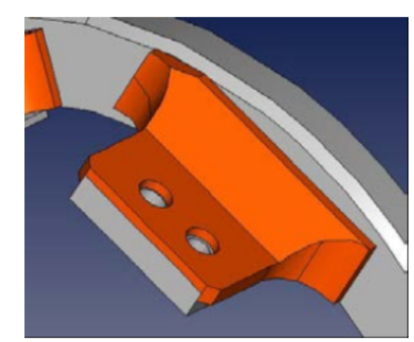
L3 thermal mangement problem

- Finite Element (FE) Simulation indicates most of the gradient (~45°C in FW) is in the endring finger, made of stainless steel.

- Temperature in the middle of L.3 sensors is strongly influenced by PXD, therefore relies on the injected N2 flow.
- For L4/5/6, with nominal load, the maximum temperature on FW/BW edges reaches about 20°C, and module ASICs reach about 25-30°C.

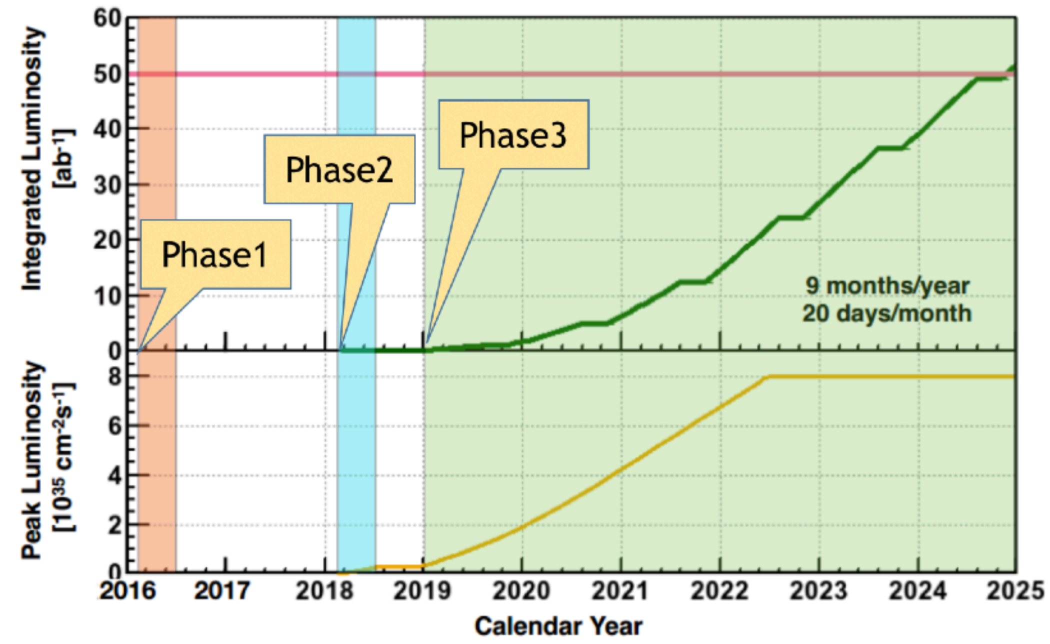


Update with copper insert, under testing in Melbourne.

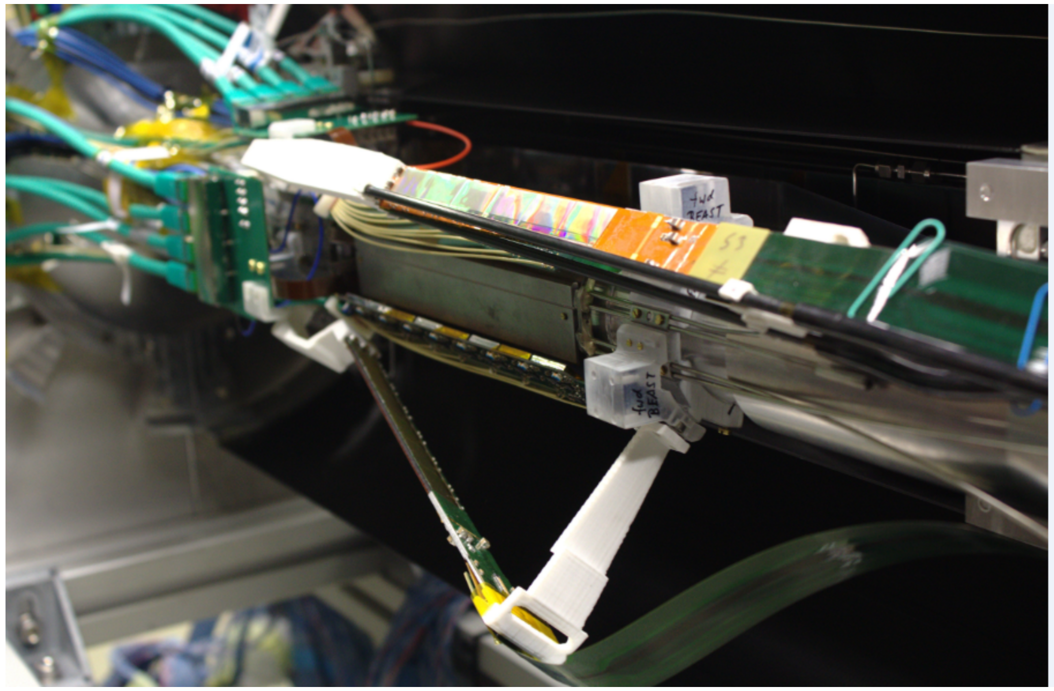


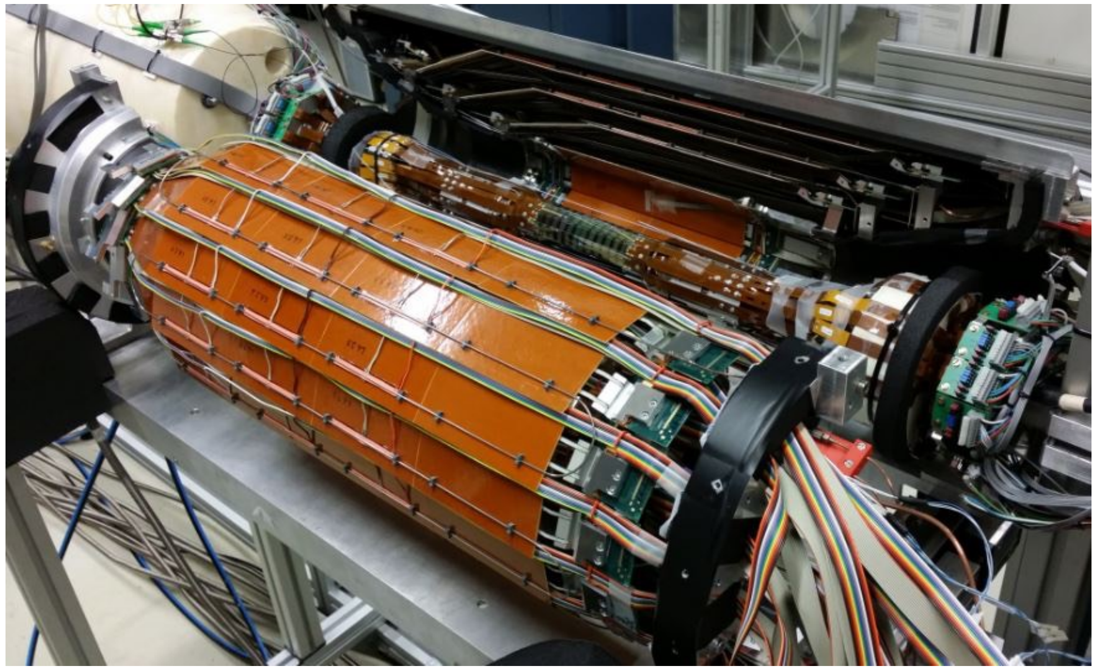
Summary

- SuperKEKB commissioning phase 2 will start in Feb.2018, partial Belle II detector has been rolled in.
- The Phase 2 vertex detector includes a sector of PXD and SVD, as well as additional dedicated radiation monitors - FANGS, CLAWS, PLUME etc.
- Integration of the Phase 2 vertex detector is tested at DESY.
- The detector is characterized at DESY test beam. Full VXD read out chain was involved for the fist time in the test.



- Operating environment of Belle II PXD and SVD are strongly coupled, meanwhile, it will influence the surrounding drift-chamber (CDC). Evaporative 2-phase CO2 and airflow injection perform VXD cooling.
- A full-size thermal mock-up is built at DESY, to verify and optimize the cooling concept of Belle II VXD.





Backup

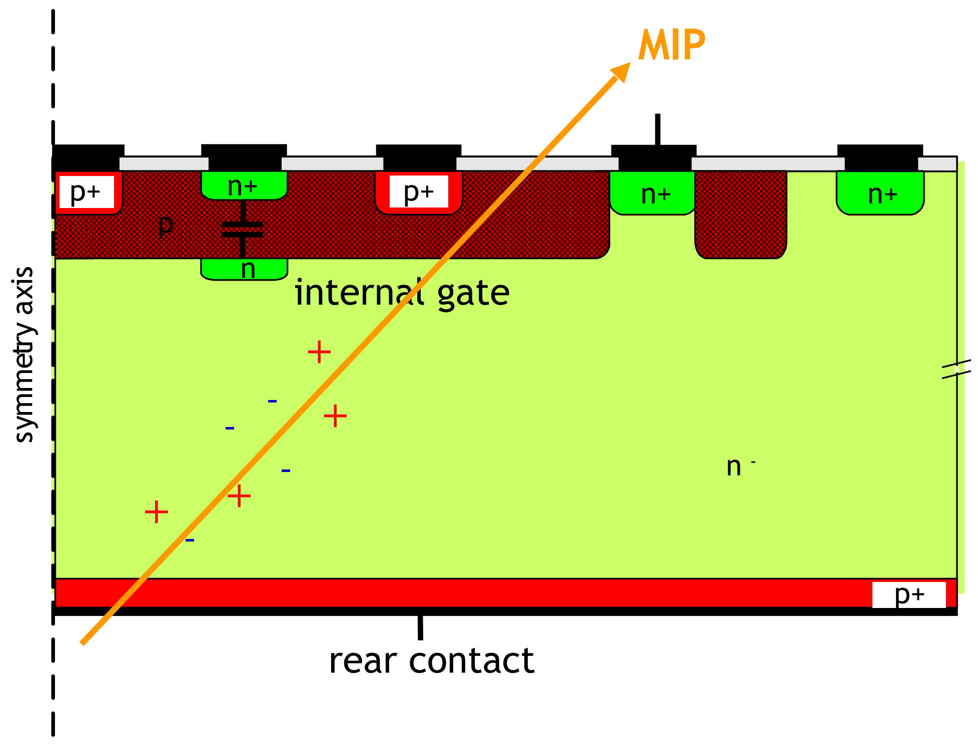
DEPFET

- Charge collected in the internal gate modulates the current between source and drain

- The DEPFET amplifies the signal internally.

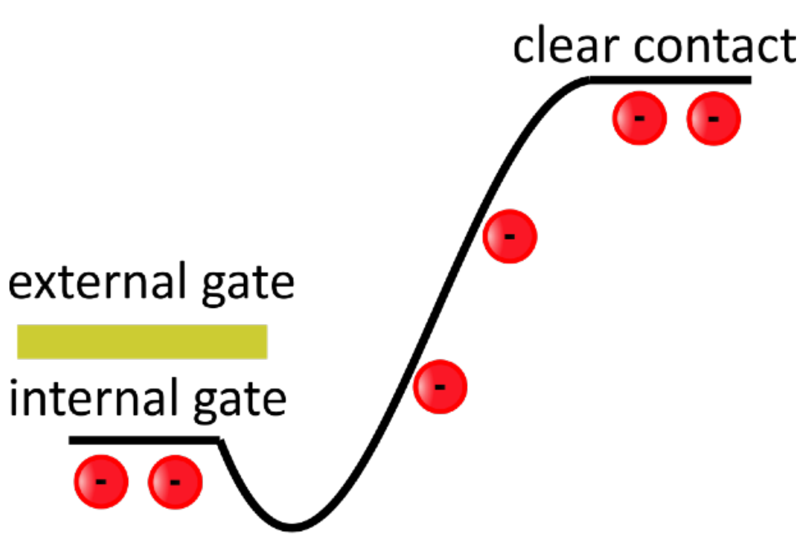
$$g_q = \frac{\partial I}{\partial q} \approx 700\,\frac{\mathrm{pA}}{\mathrm{e^-}}$$

To remove charge from the internal gate an additional clear contact is added.

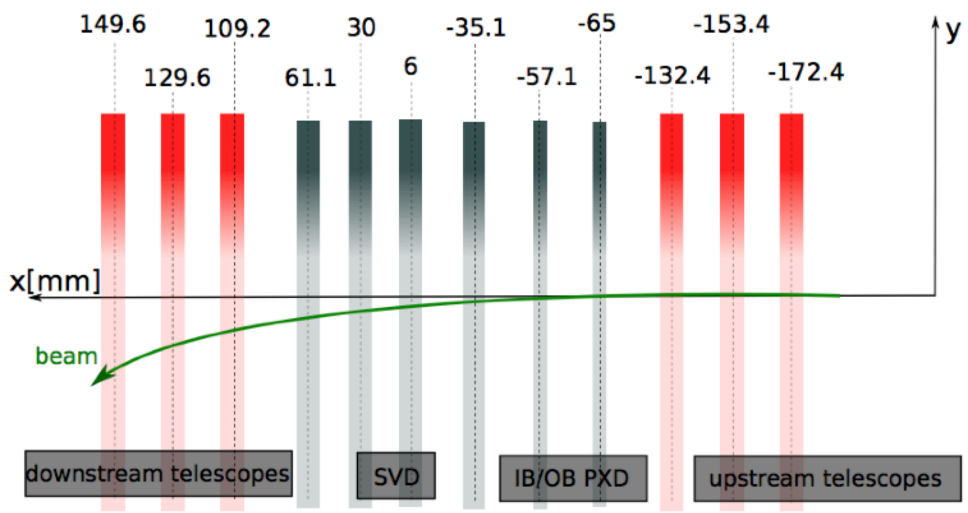


real clear

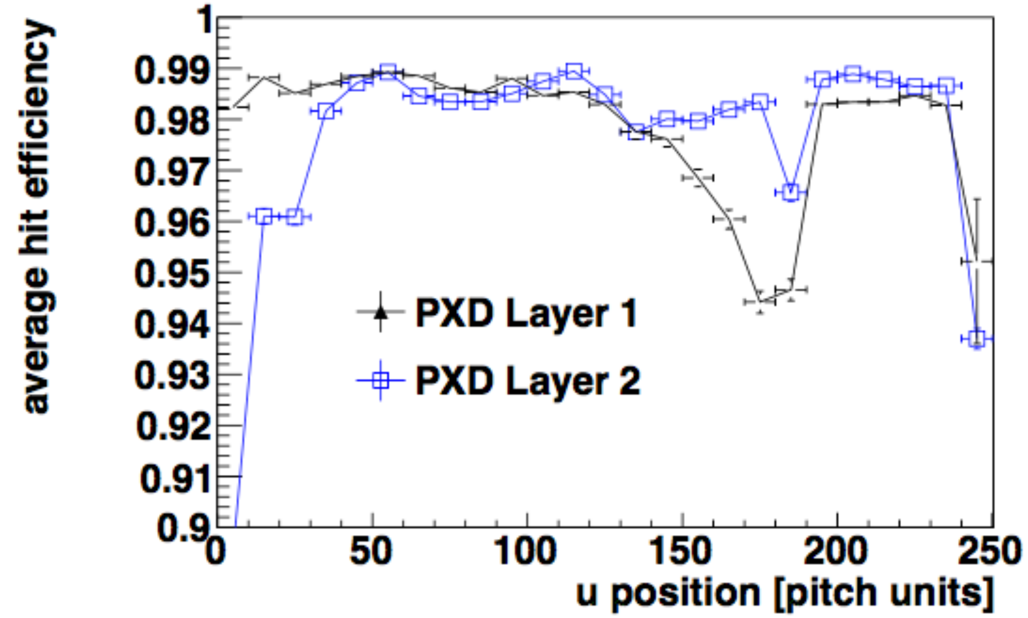
clear voltage high
gate voltage low



PXD resolution and hit efficiency

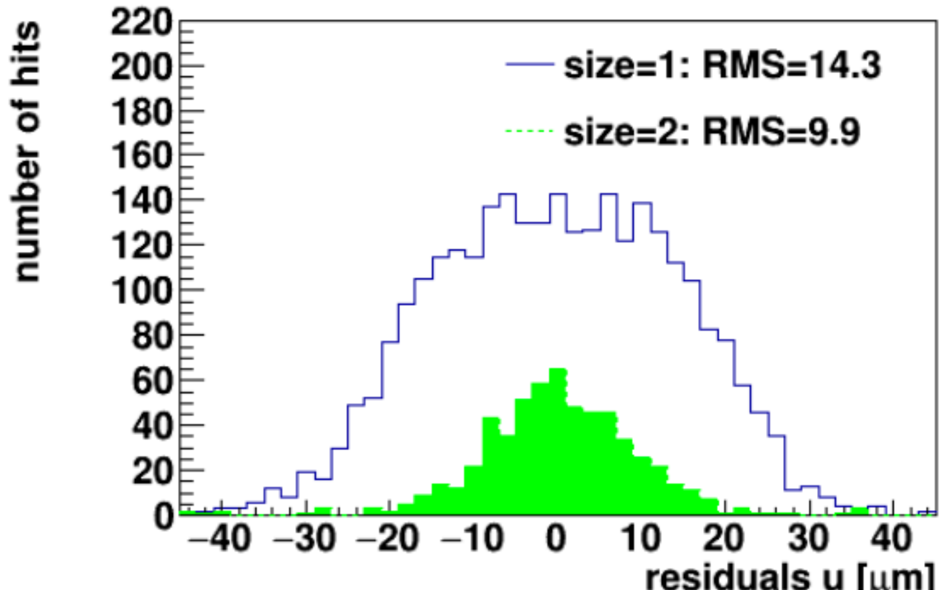


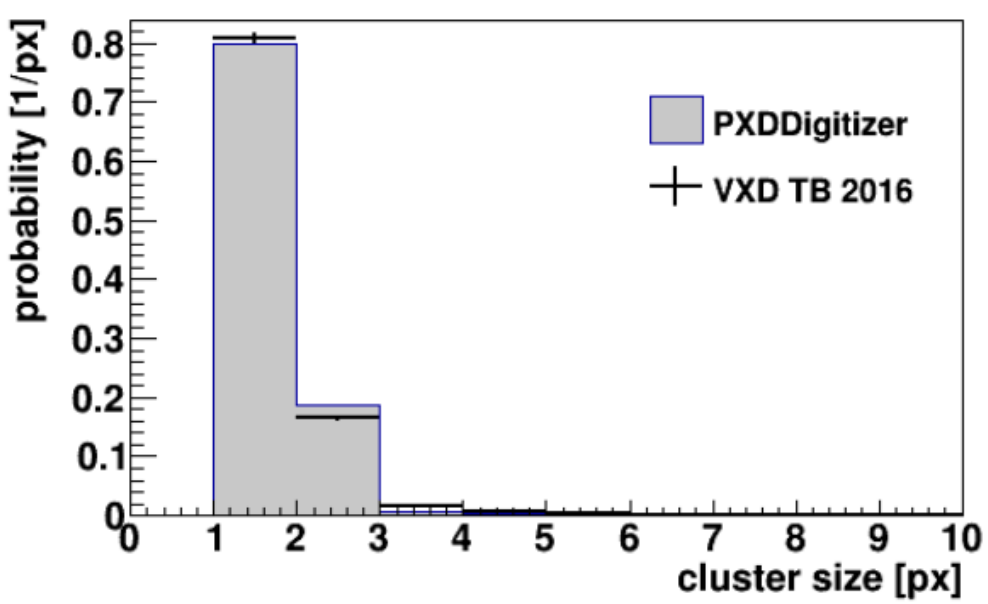
A track was counted as a pass when a PXD cluster was found in the ROI on the same sensor.



The spatial resolution

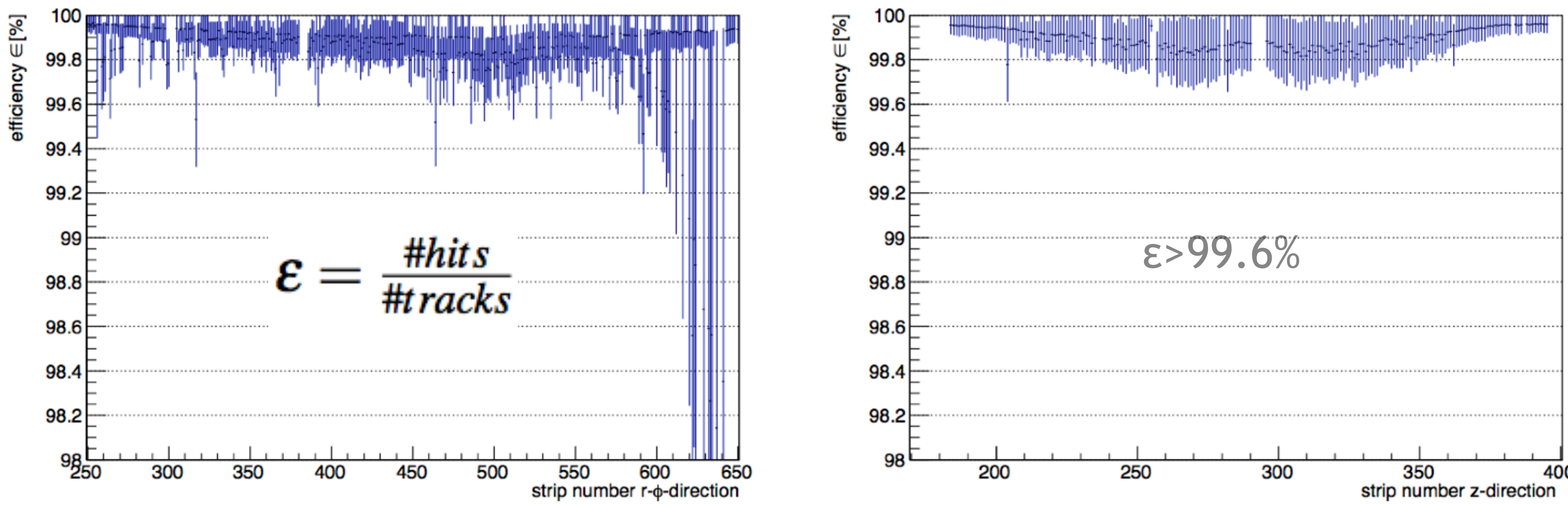
- The expected coordinate is estimated using the hits from at least 3 SVD planes and from the EUDET telescope.
- The residual RMS for single hit clusters agree with the digital resolution of Pitch.





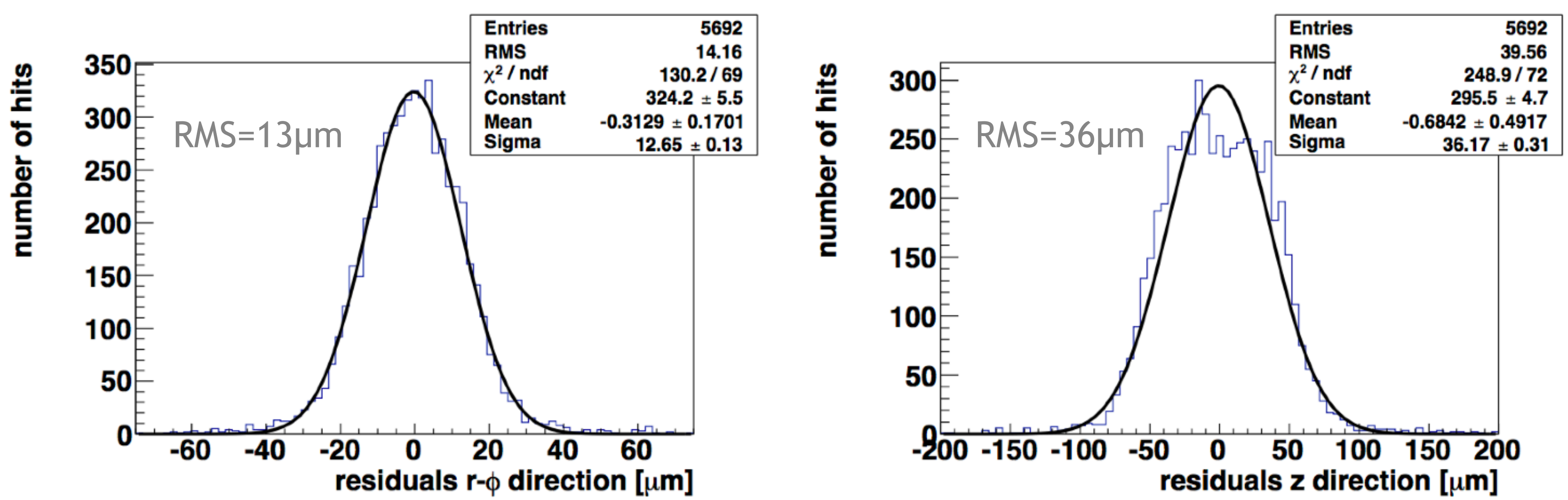
SVD efficiency and resolution

Hit efficiency is measured only using three out of the four SVD layers. The hits are counted when a signal is found within 300µm of the predicted track position.



Efficiency as function of the strip number for SVD layer.5

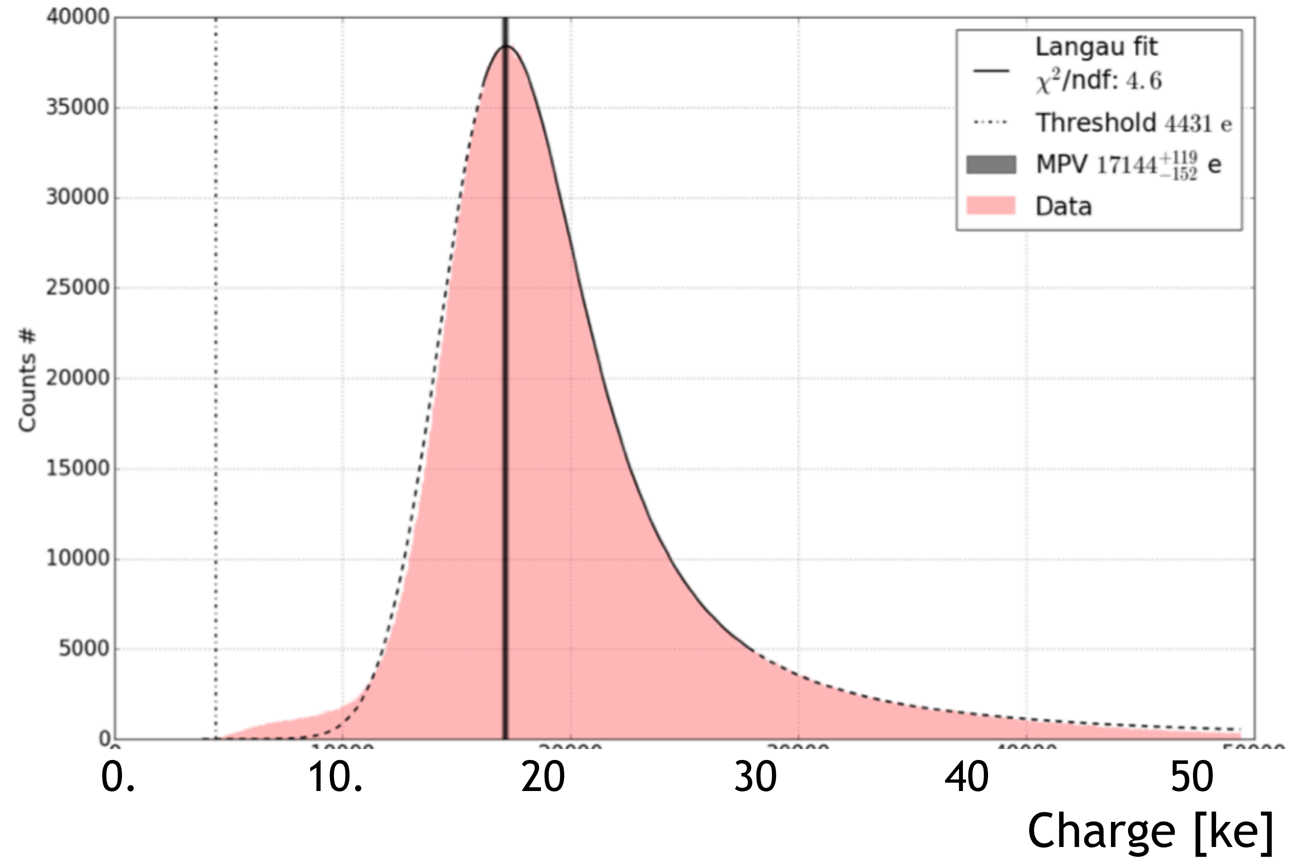
Telescope planes were used in the analysis to reduce the track extrapolation uncertainty.



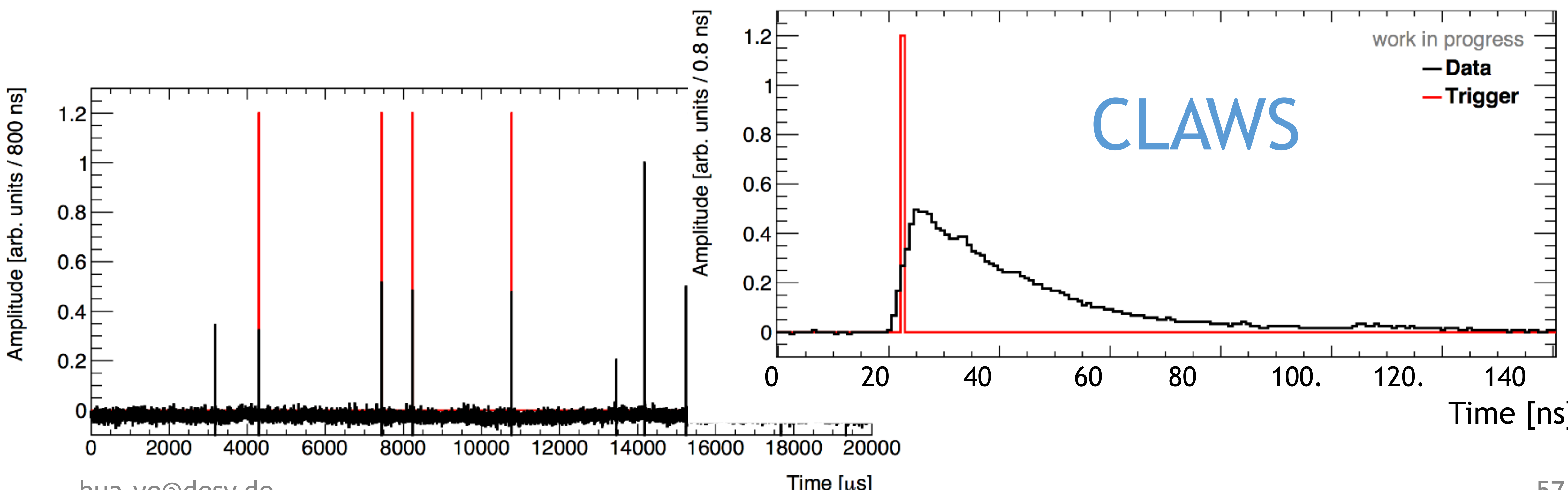
Residuals for the SVD layer.5

FANGS, CLAWS in Beam Tests

Calibrated charge deposition with TDC method, the fitted mean value (17.1ke) is consistent with the expected value, 18ke.



Typical CLAWS wave form in test beam



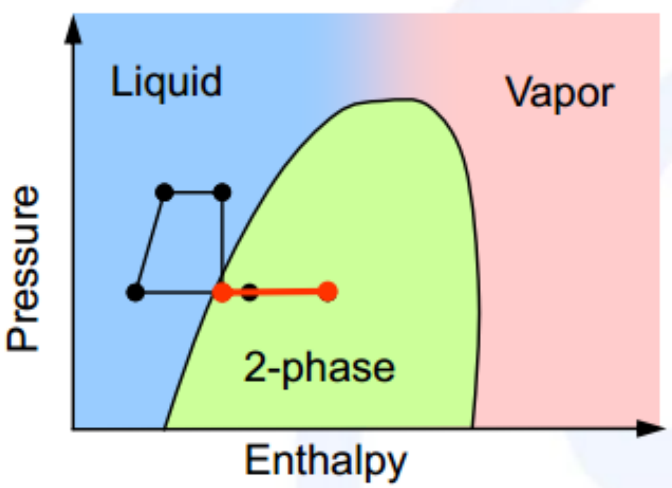
2-phase CO_2 Cooling

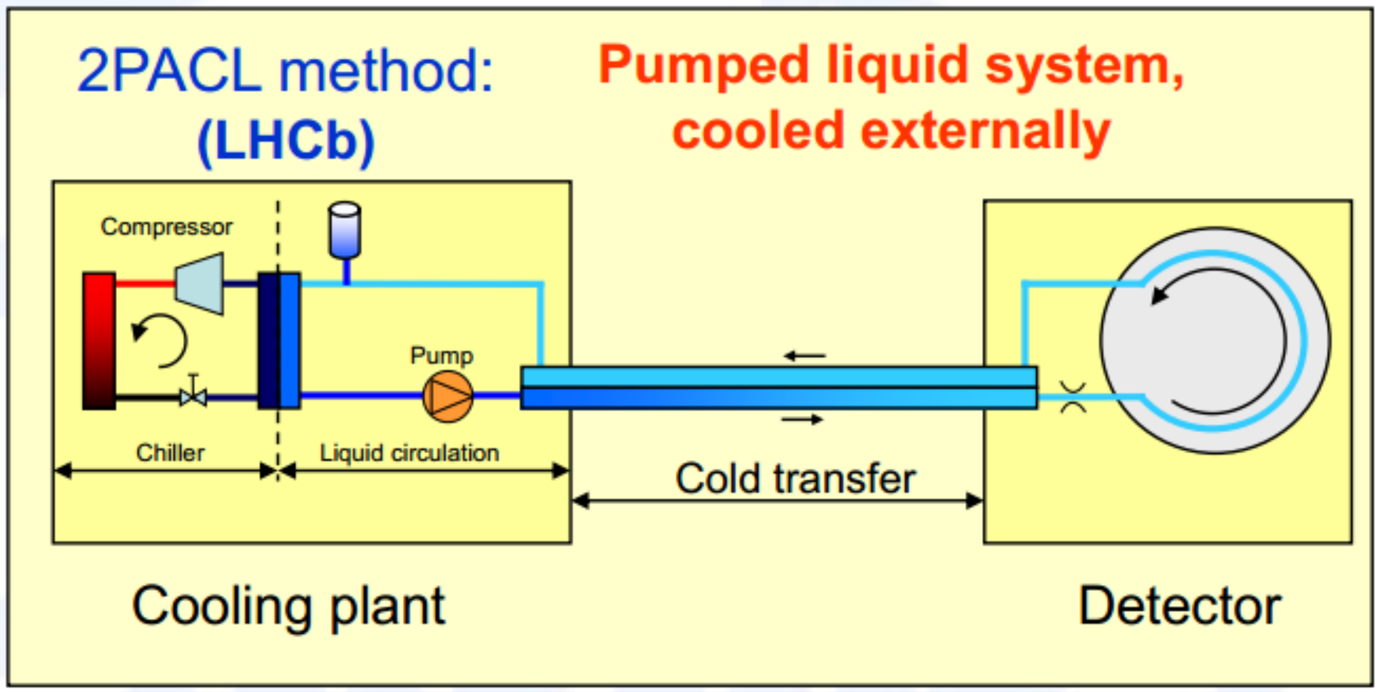
Belle II

bverlaat@nikhef.nl

New cycle for particle detectors: 2PACL

(The **2**-**P**hase **A**ccumulator **C**ontrolled **L**oop)

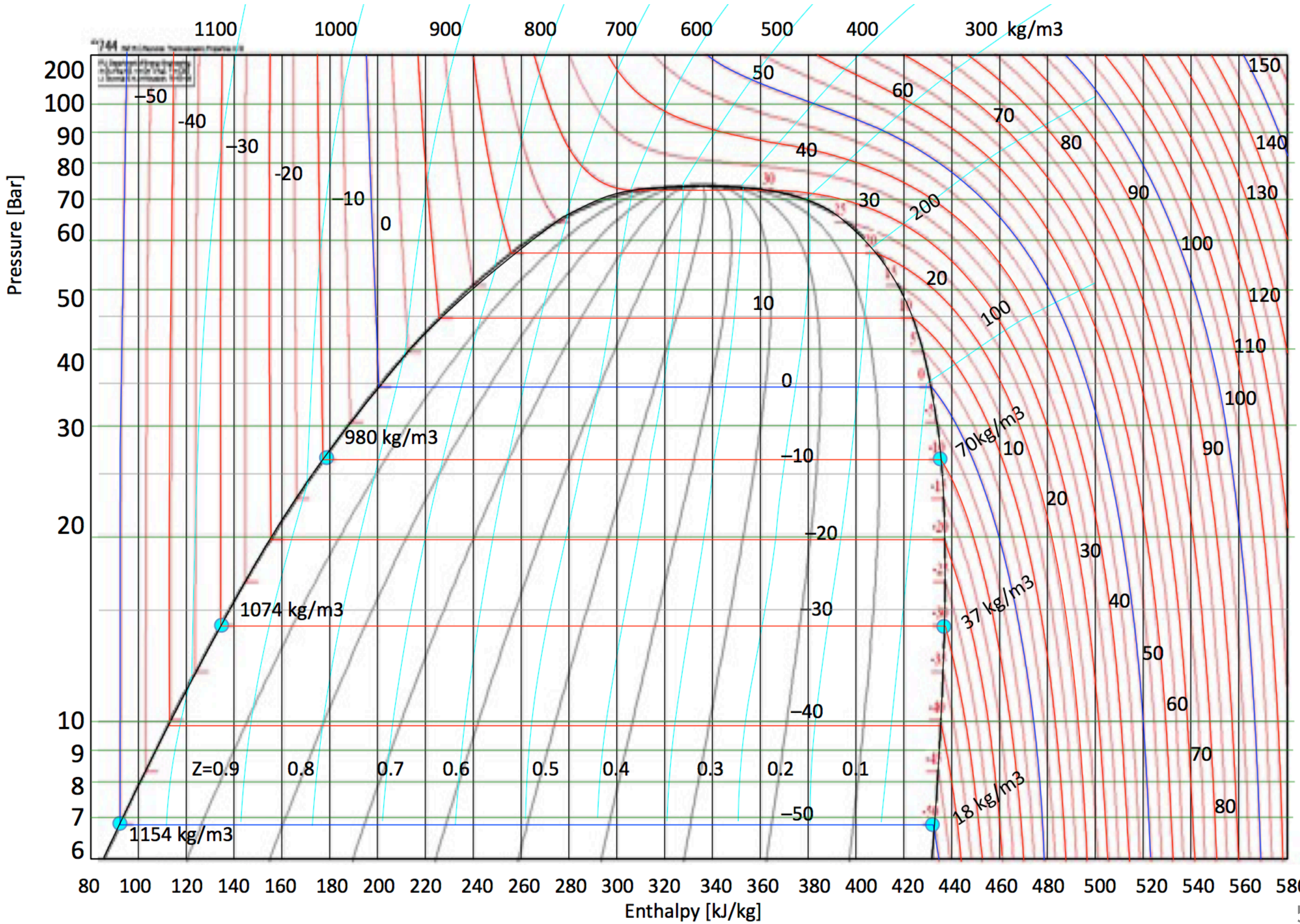




- The 2PACL has the following advantages:
  - Cycle stays on the liquid side, no heat required (experiment can be cooled unpowered and no control heaters required)
  - Evaporator pressure=(temperature) controlled with a 2-phase vessel away from the experiment. No local control nor sensing needed!
  - All control hardware in a distant accessible cooling plant
  - Primary cooling can be anything, no accurate temperature control needed as long as it is colder than the 2PACL 2-phase temperature.
  - Inlet fluid state defined by physics => saturated liquid.
  - Large temperature range (typical from room temperature down to -40°C)

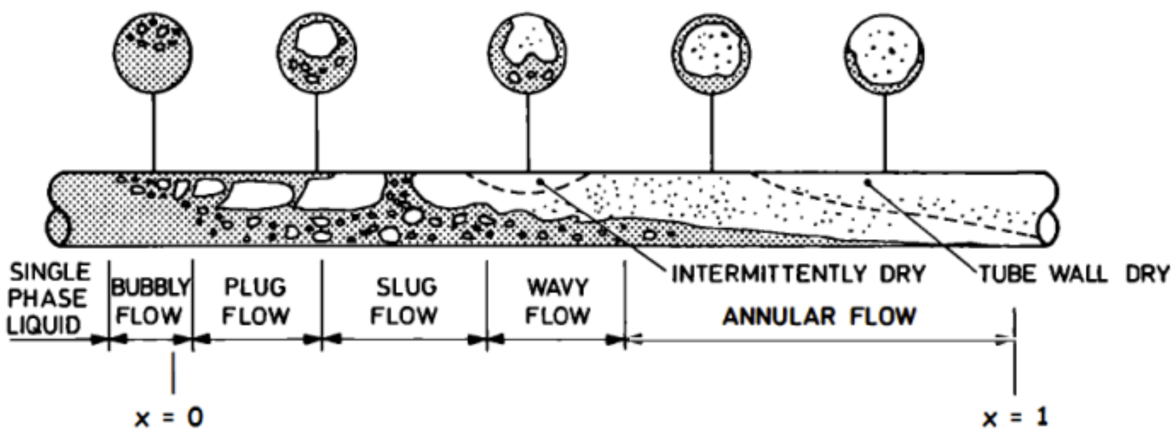
17

CO_2 Pressure-Enthalpy

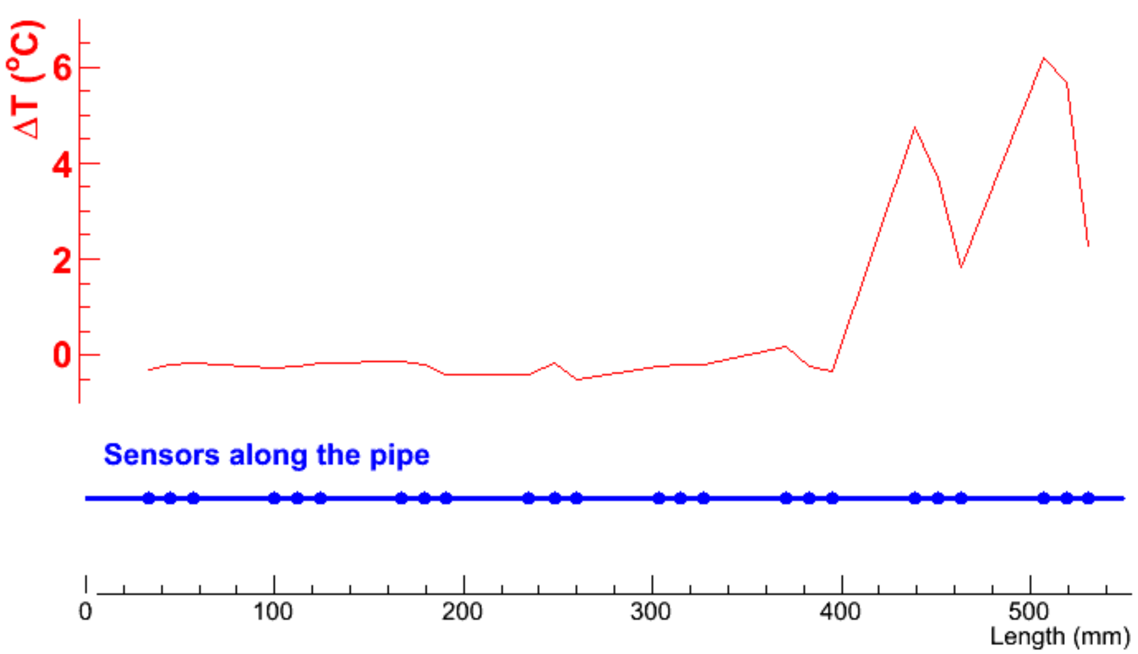


Study Onset of Dry-out

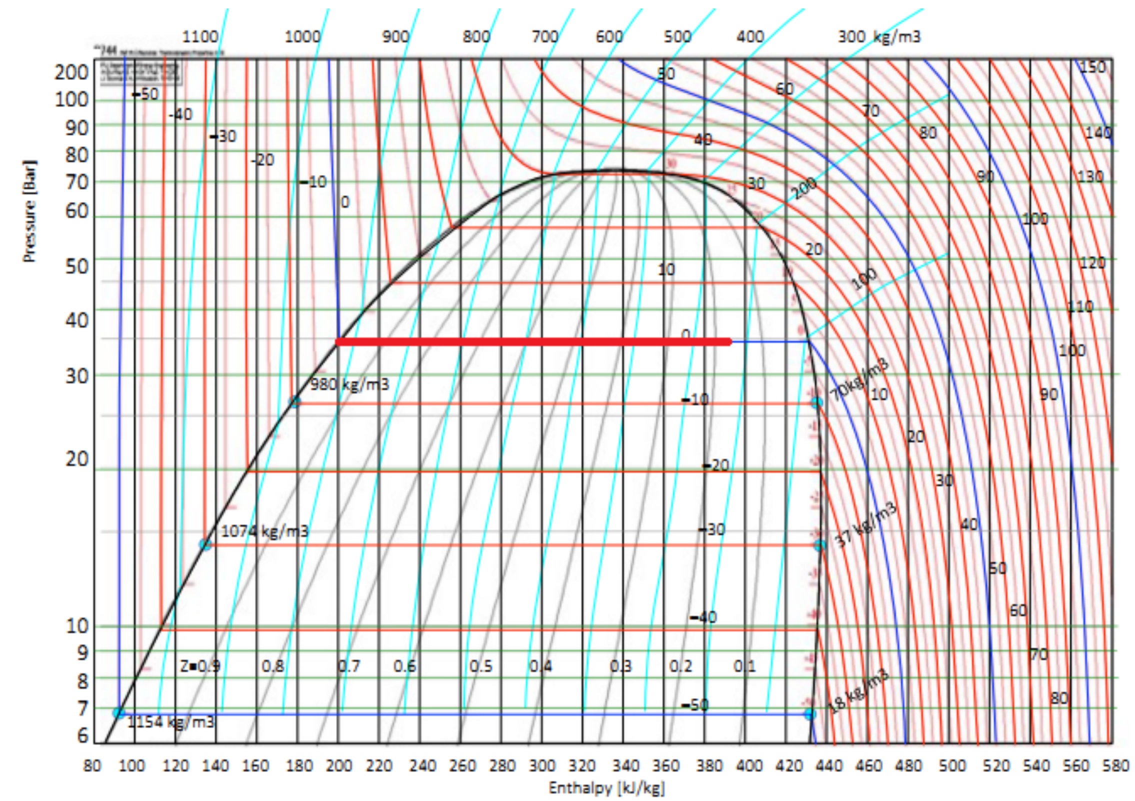
When the vapor quality gets too high, there will be no liquid film on the capillary walls, then result in a shape increase of the cooling block temperature.



Dry out



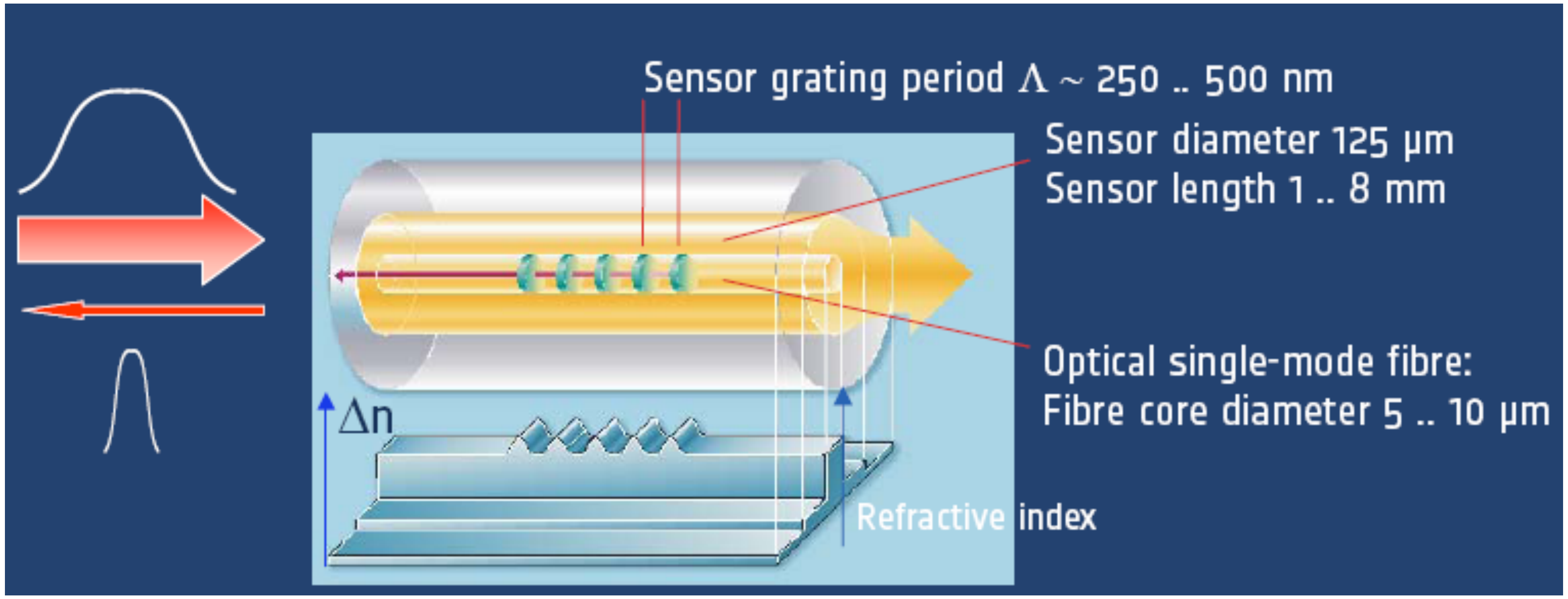
The dry out happens in the last 6 sensors



Estimated mass flow to get rid of 'dry out'

- CO_2@-30ºC, mass flow in the mockup should not be lower than 5.4 g/s, giving the pressure drop of about 1.7 bar in the cooling circuit.

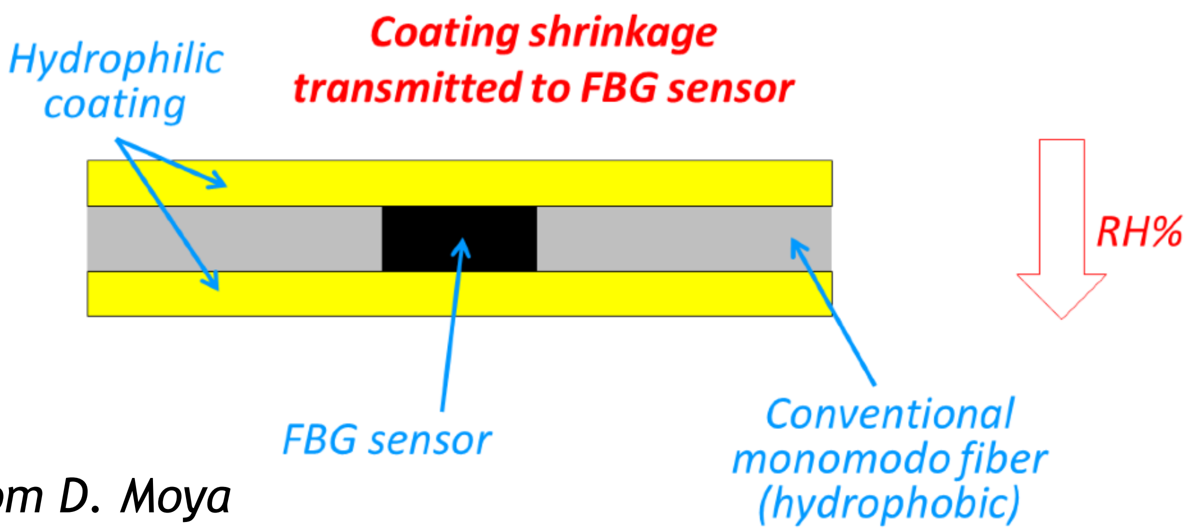
Humidity monitor: Sensitivity mechanism



4 Fiber Optical Sensors (FOSs) are mounted to monitor temperature and humidity in the dry volume

– The Sensitivity of the FBG sensors is a mechanical effect induced by the coating. FO is hydrophobic, but becomes sensitive to humidity when is protected with a hydrophilic coating. The coating swell under high relative humidity environment (due to water molecules absorption) and shrinkage with lower relative humidity. This deformation is transmitted to the fiber.

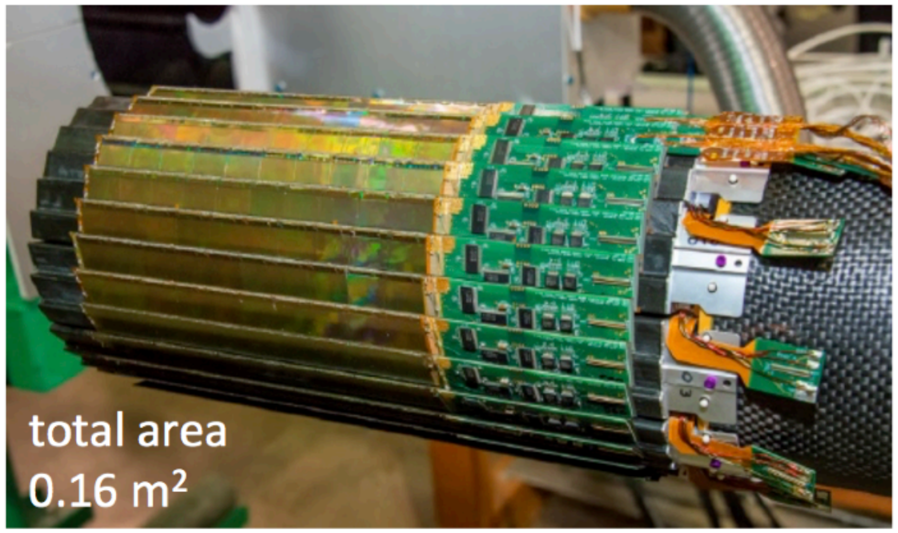
Advantages
• very low material budget
• radiation hardness
• all active electronics accessible



From D. Moya

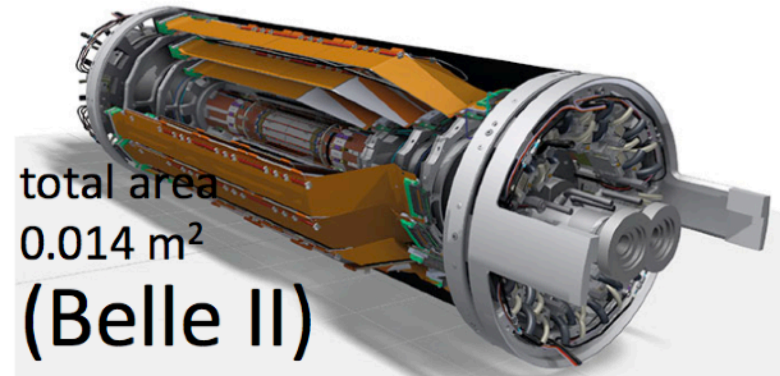
(Semi-)Monolithic Pixel Detector

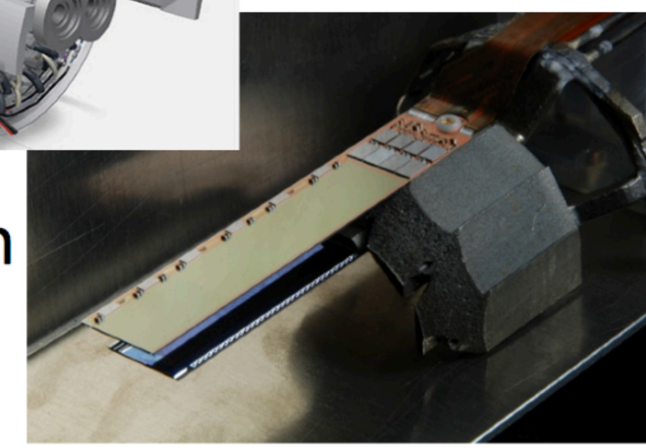
STAR / RHIC MAPS



operated 2014-2015

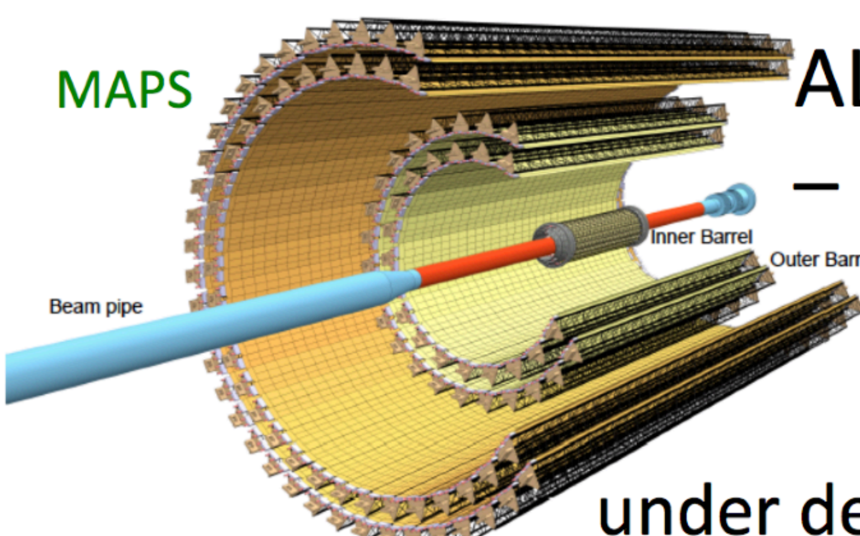
DEPFET pixels





in production
for 2017

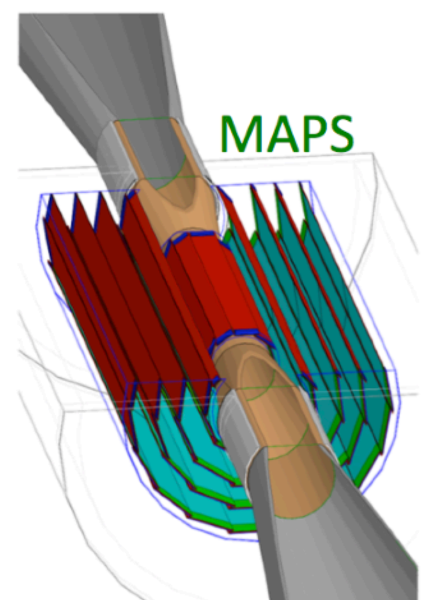
MAPS



ALICE
– Upgrade

total area
$\sim 10\ m^2$

under development
target: 2018



ILC

total area
$?\ m^2$

current
baseline

N. Wermes, Desy Kolloquium 2016

32