Key Updates on the MDI: Summary of MDI/Int Session of the Workshop

Haoyu SHI

CEPC Physics and Detector Plenary Meeting

2022.06.01

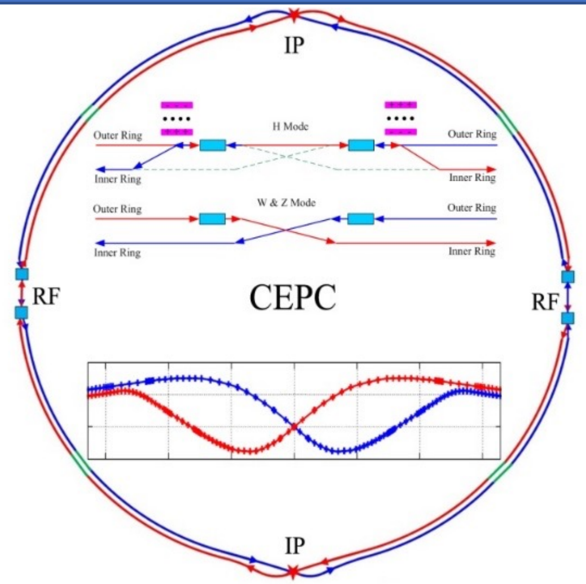
Basic Information

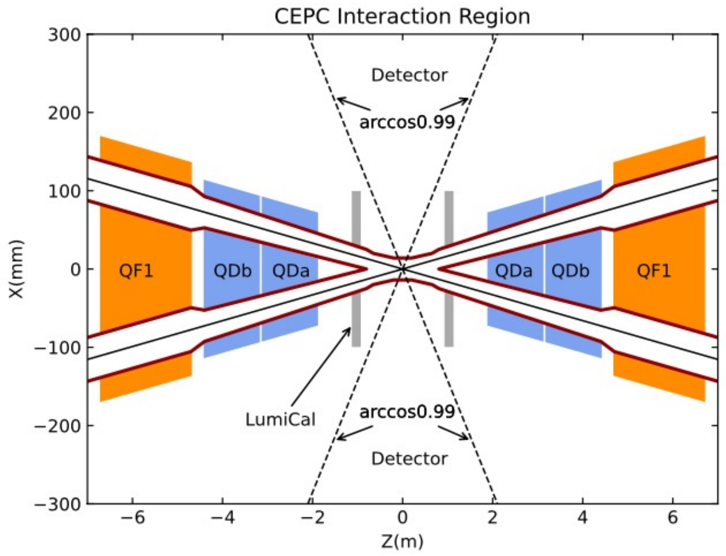
- 2 Sessions, 8 talks (6 CEPC + 1 FCC-ee + 1 CEPC/FCC-ee)
- Covering Topics:
  - MDI(Design/Beam Backgrounds/etc)
  - LumiCal
  - Magnets
  - Mechanics
  - Installation & Integration

CEPC

Introduction of the MDI

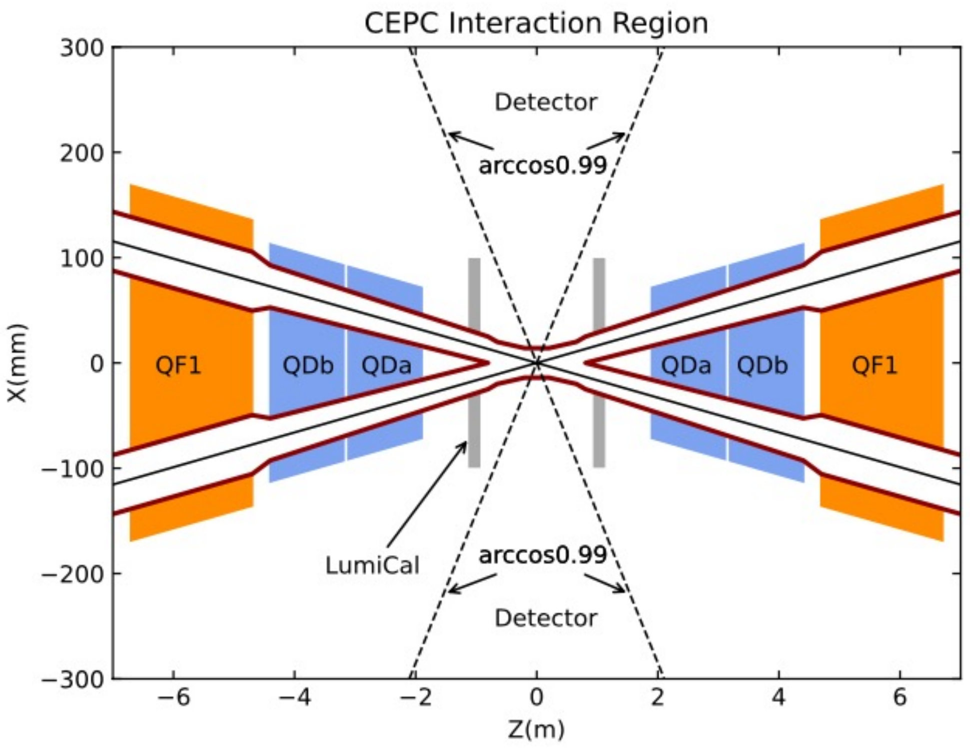
- MDI stands for "Machine Detector Interface"
  - Interaction Region and other components
  - 2 IPs
  - 33mrad Crossing angle
- Flexible optics design
  - Common Layout in IR for all energies
  - High Luminosity, low background impact, low error
  - Stable and easy to install, replace/repair
- For CEPC TDR, the interaction region is ± 7 m from the IP

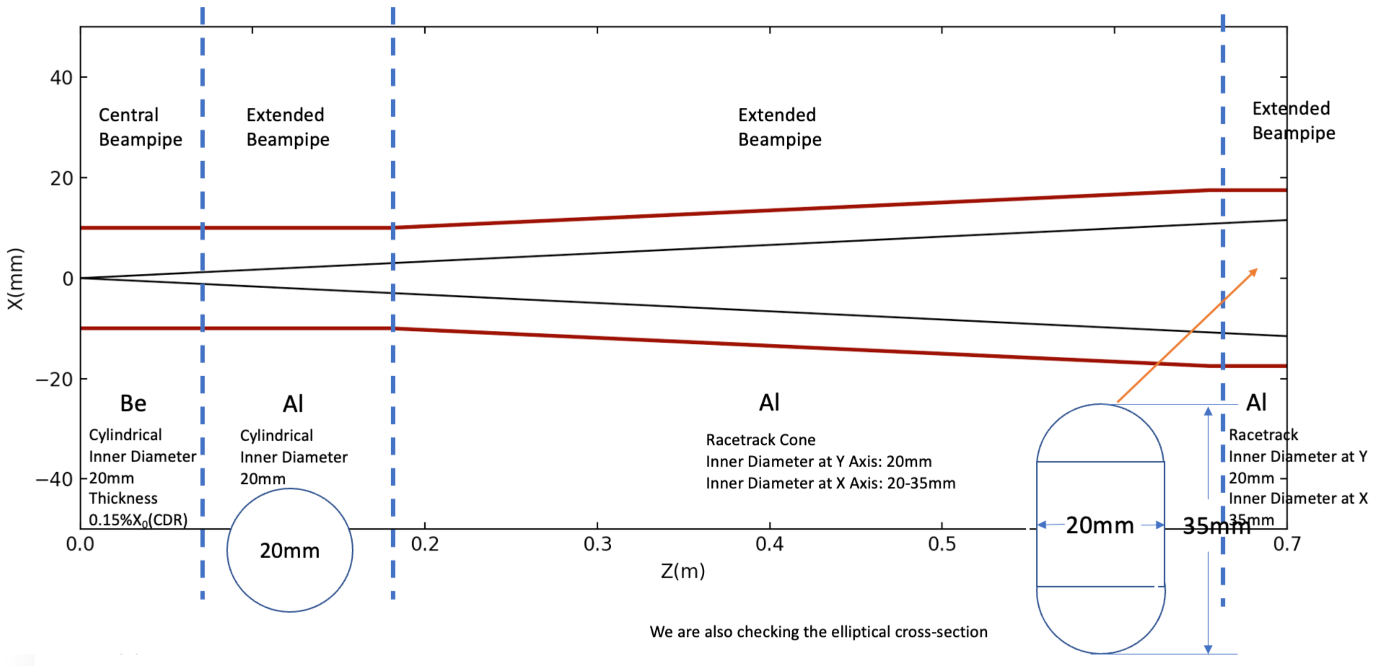




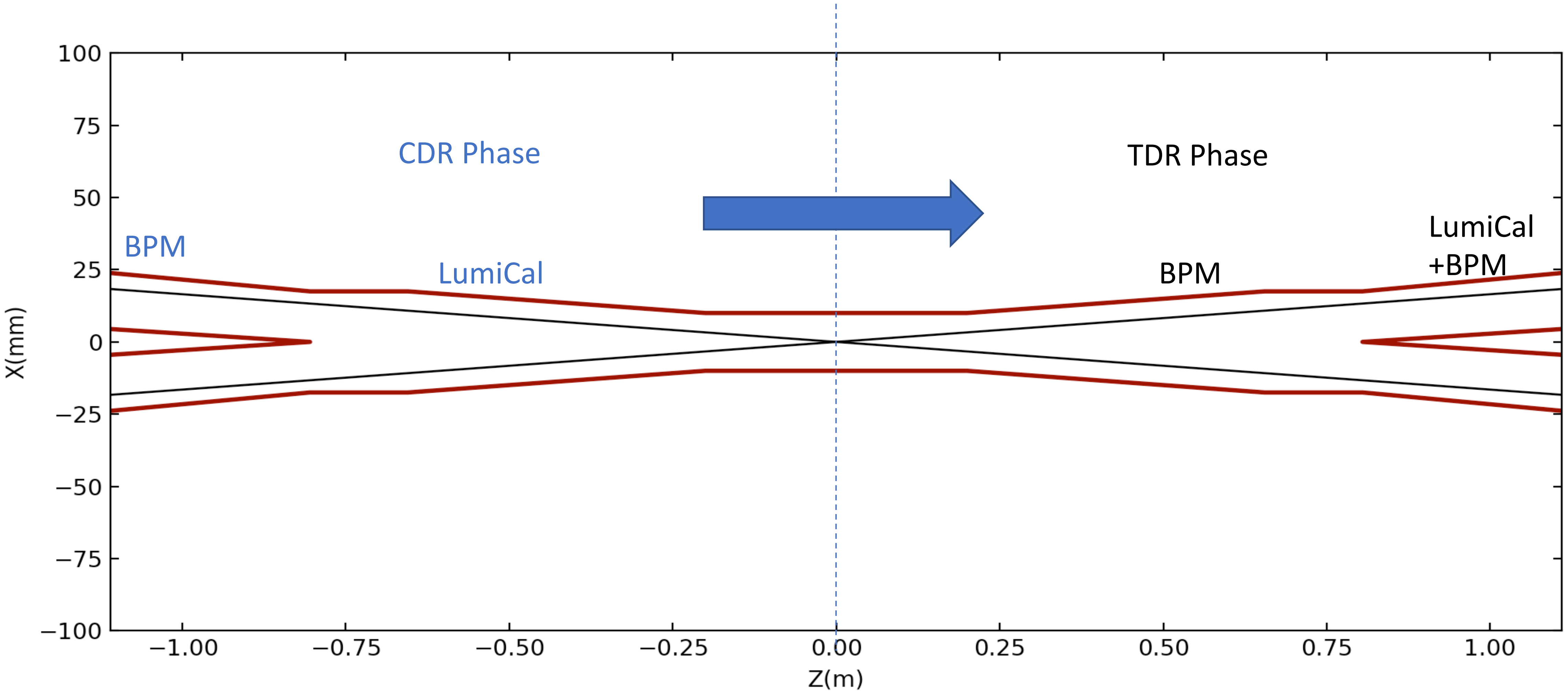
Physical Design

- Interaction Region Layout/Parameters
  - L* = 1.9m / Detector Acceptance = 0.99
- Central Diameter 20mm, “Racetrack” design starts at ± 180 mm.





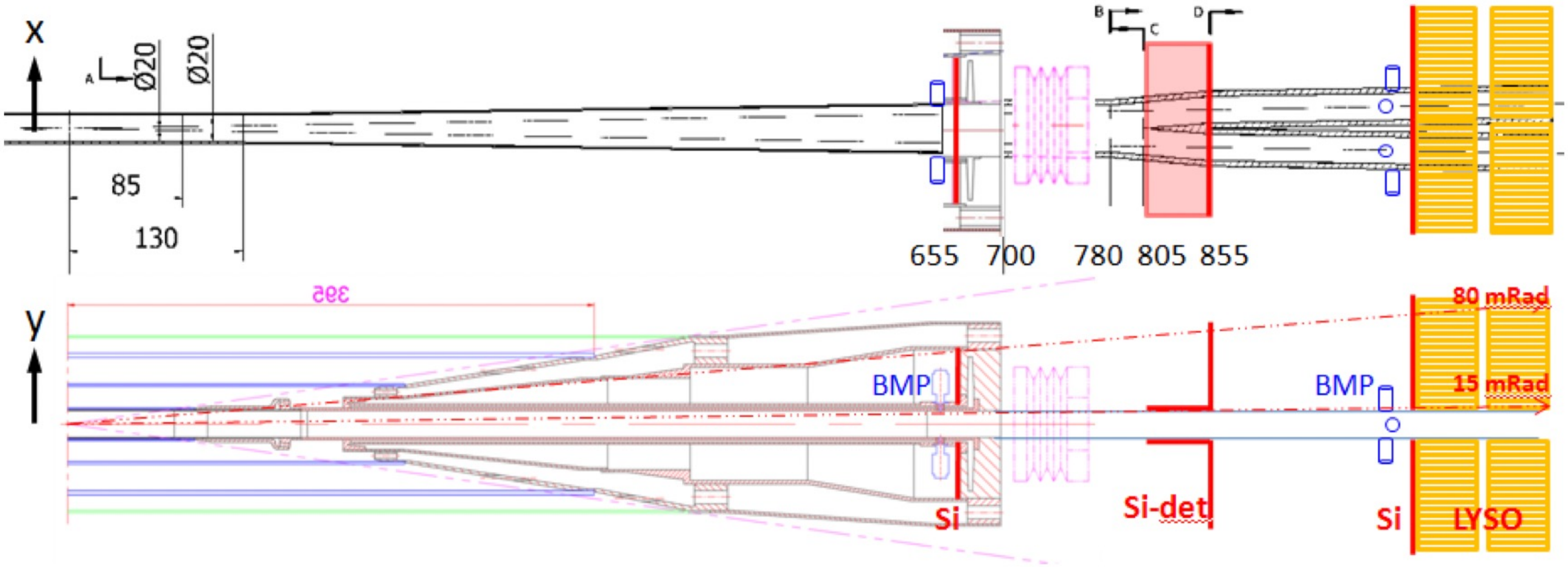
New Beampipe Design – Cryo to Cryo



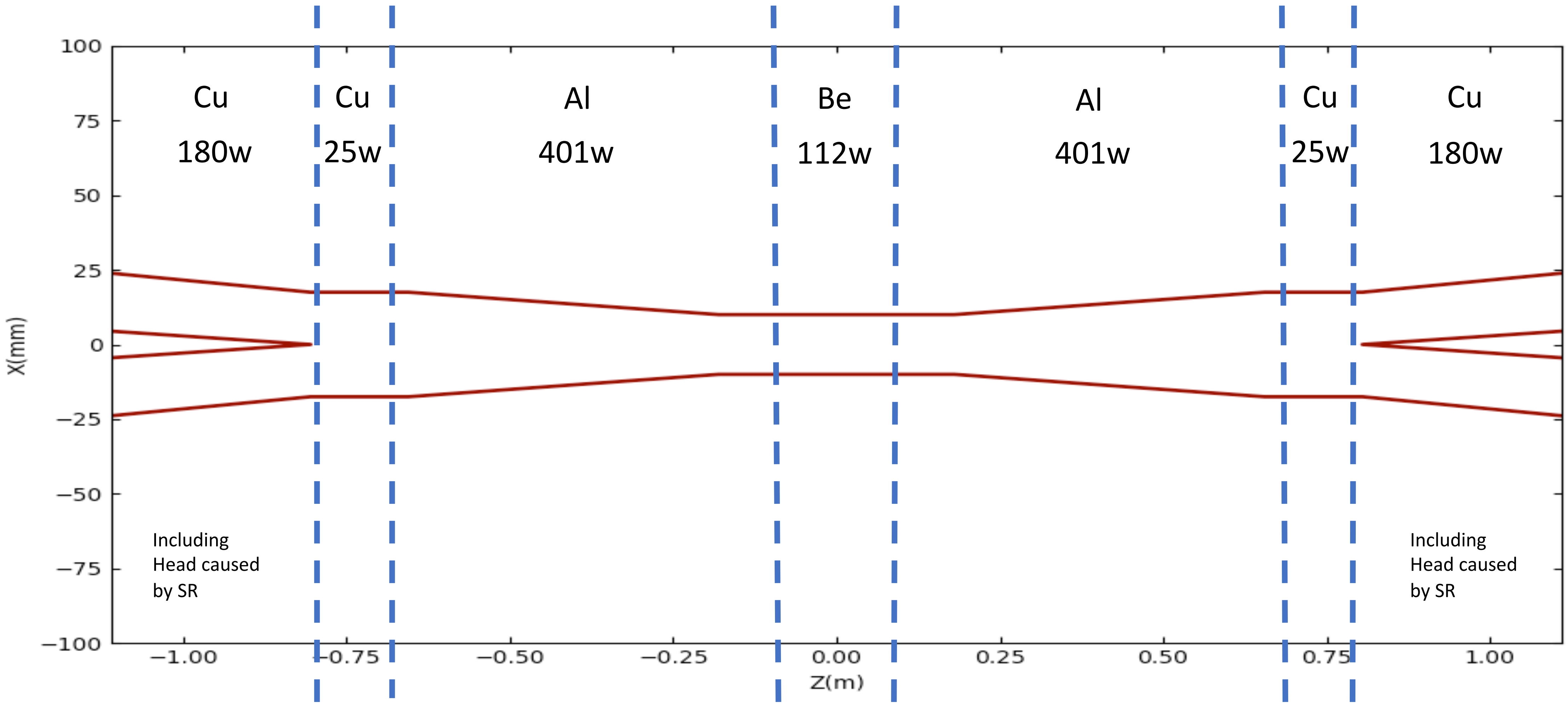
Updates of the LumiCal

- Si wafer + LYSO
- Detecting Angle: 15~80 mRad

S. Hou

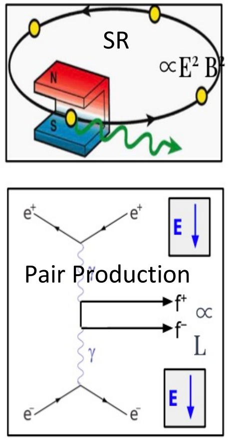


Heat Deposition



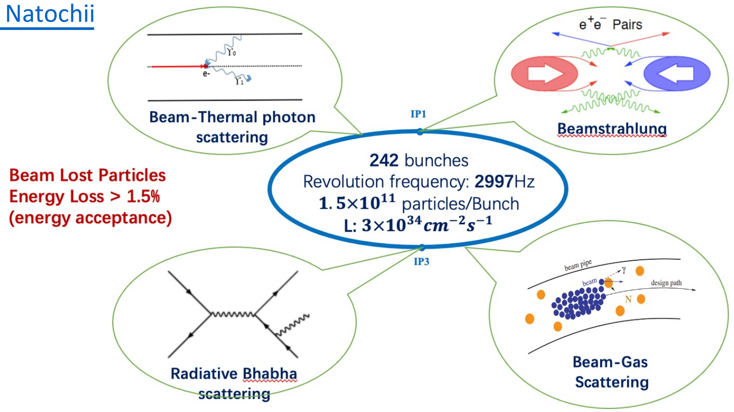
Background Estimation

- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(50 turns)
  - Using built-in LOSSMAP with one step ahead output
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered
- We are also updating our toolkit to latest version.
- Plan to study the photon bgs generated during BGB/BTH/RBB…



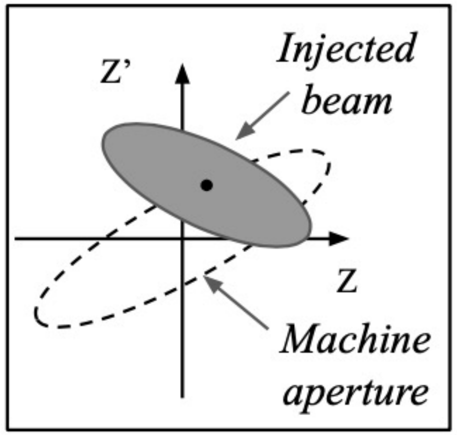
A. Natochii

Photon BG



Beam Loss BG

A. Natochii

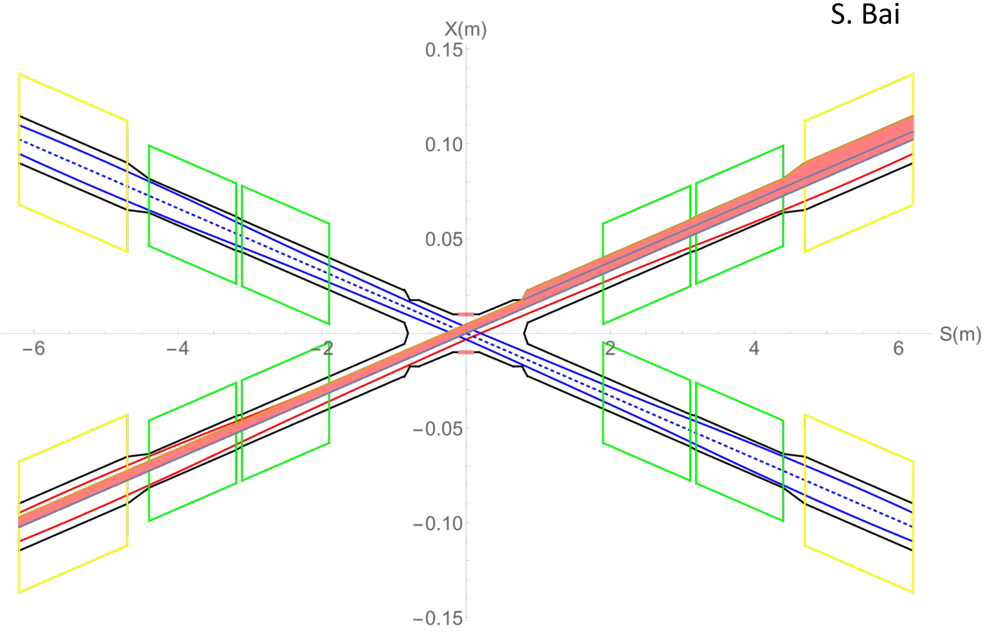


Injection BG

Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka/CEPCSW
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		

SR BG & Mitigation

- The SR must be dealt with high priority when designing the circular machine. At CEPC, there would be no SR photons hitting the central beam pipe directly in normal conditions
- However, some secondaries generated within QD would hit the detector beampipe, even the beryllium part. Therefore, the mitigation methods must be studied. We compared several methods based on CDR, and we believe the results can also be used on TDR with optimization.



Y. Sun

option	photon number of hit Be(N)	Deposition power(W)
1.21-mask-Cu	1736.0	1.45*e-5
1.21-mask-W	1698.0	1.36*e-5
2.2-mask-Cu	1147.0	0.94*e-5
cons-no mask-Cu	257364.0	206*e-5
cons-no mask-W	148030.0	99.7*e-5
1.21-mask-Cu-5μmAu	216.0	0.273*e-5
nomask	39400.0	30.57*e-5

TDR Estimation – with safety factor of 10

- For fast estimation, we try to perform some scaling based on CDR results according to Luminosity.
- We also performing the full-TDR simulation. Just started, acc. tracking waiting for collimators.
- We plan to have double check on detector simulation(Mokka/CEPCSW/FLUKA)
  - We learn that the background impact on LumiCal must be studied.

Scaling Results on 1st layer of vertex detector

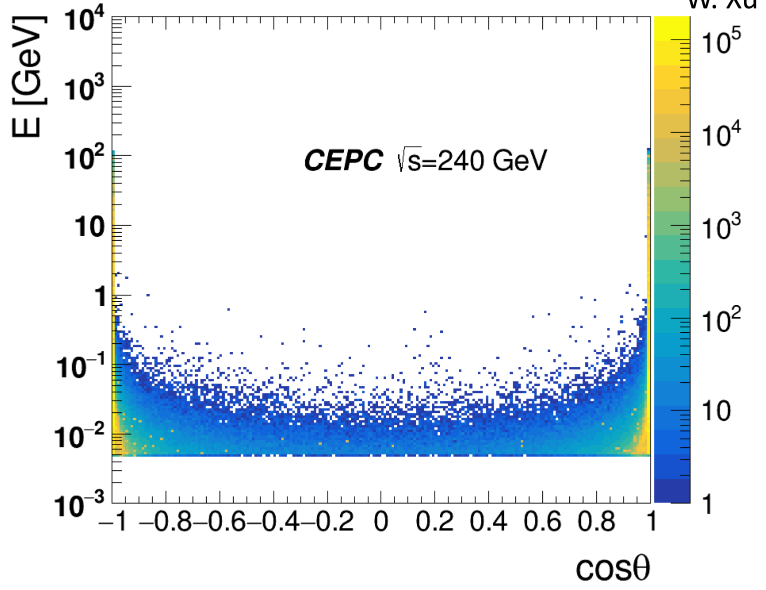
W. Xu

	CDR	TDR(30MW)	TDR(50MW)
Higgs (3T)	2.93	5.00	8.00
Z (2T)	32.1	115.0	184.0

	Hit Density($cm^{-2}\cdot BX^{-1}$)	TID($krad\cdot yr^{-1}$)	NIEL($n_{eq}\times 10^{12}\cdot cm^{-2}\cdot yr^{-1}$)
Vertex	2.3	5360	120.4
TPC	2.59e-2	387.09	42.503
Ecal Barrel	1.16e-3	31.56	8.002
Ecal EndCup	1.36e-3	14.175	6.128
Hcal Barrel	2.78e-5	1.450	0.9326
Hcal EndCup	1.32e-3	26.31	6.351

TDR Pair-Production Distribution

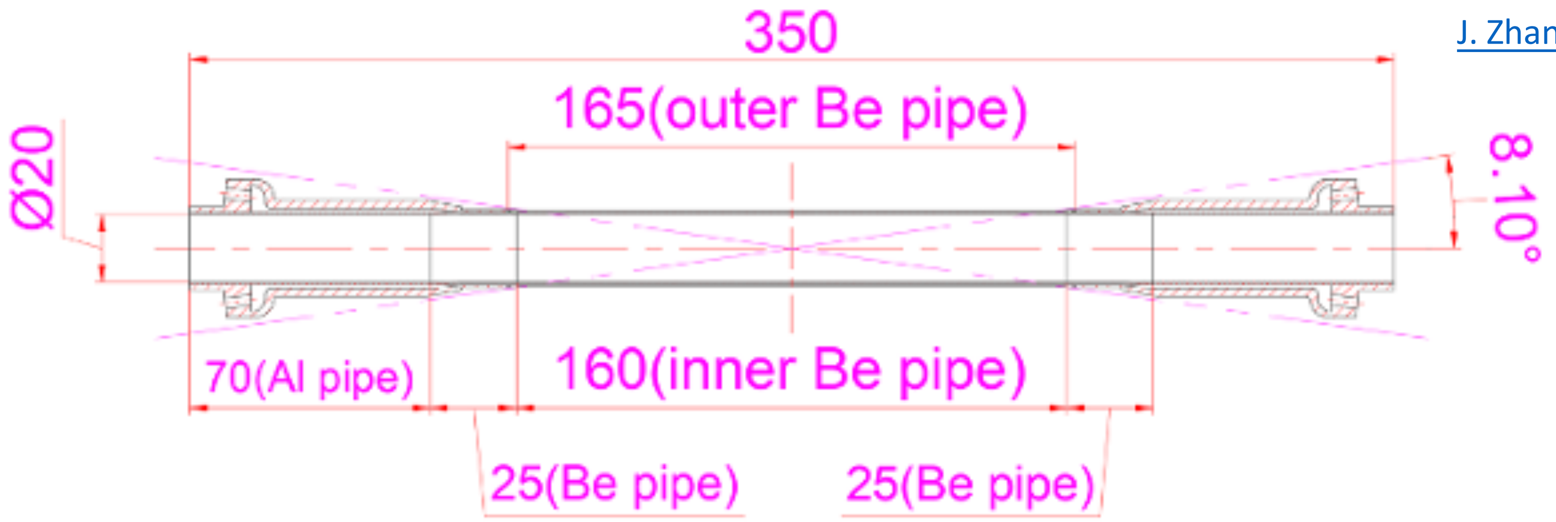
W. Xu



Updates on Mechanical Design

J. Zhang

Outer Be Layer: 0.15mm
Gap: 0.35mm
Inner Be Layer: 0.2mm
Thickness: ~0.2%X_0



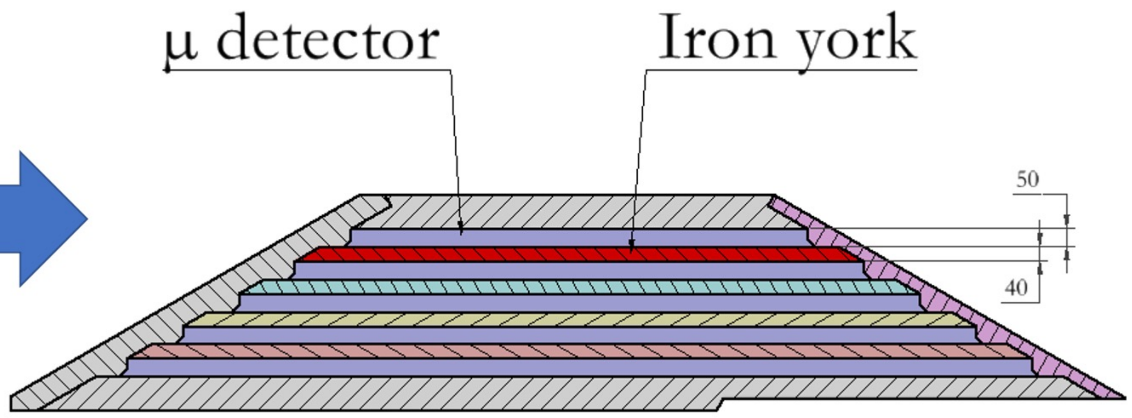
- The design of iron yoke/central beampipe has been updated.
- The structure analysis has been performed.

The 2021 version：

Iron Yoke thinkness：50mm
μ derctor thinkness：40mm

The 2022 version：

Iron Yoke thinkness：40mm
μ derctor thinkness：50mm

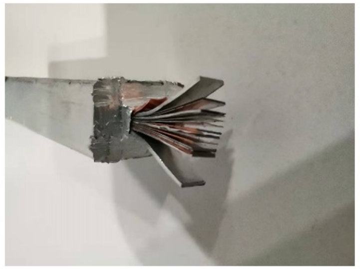


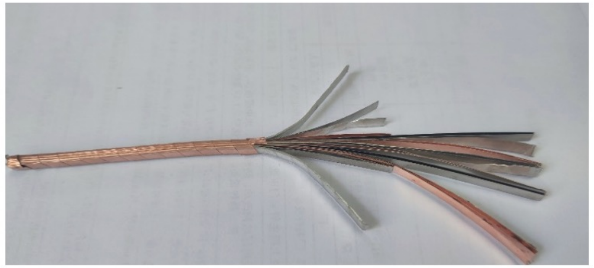
Progress of the Detector Solenoid

- The HTS prototype cable used for CEPC successfully developed and tested.
- Conceptual design of ultra-thin and transparent cryostat is performing.

F. Ning

After optimization and improvement：
Test cable: **tape layer: 7**, Expected critical current: 550A@77K

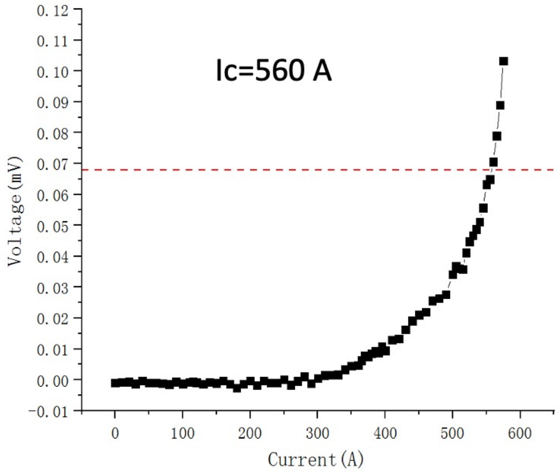




Big progress:
Test result: Ic = 560 A@77K

The cable performance is not degraded.
Next is the production of the full HTS tape cable (16 layers HTS tapes).

The prototype cable will be developed soon.



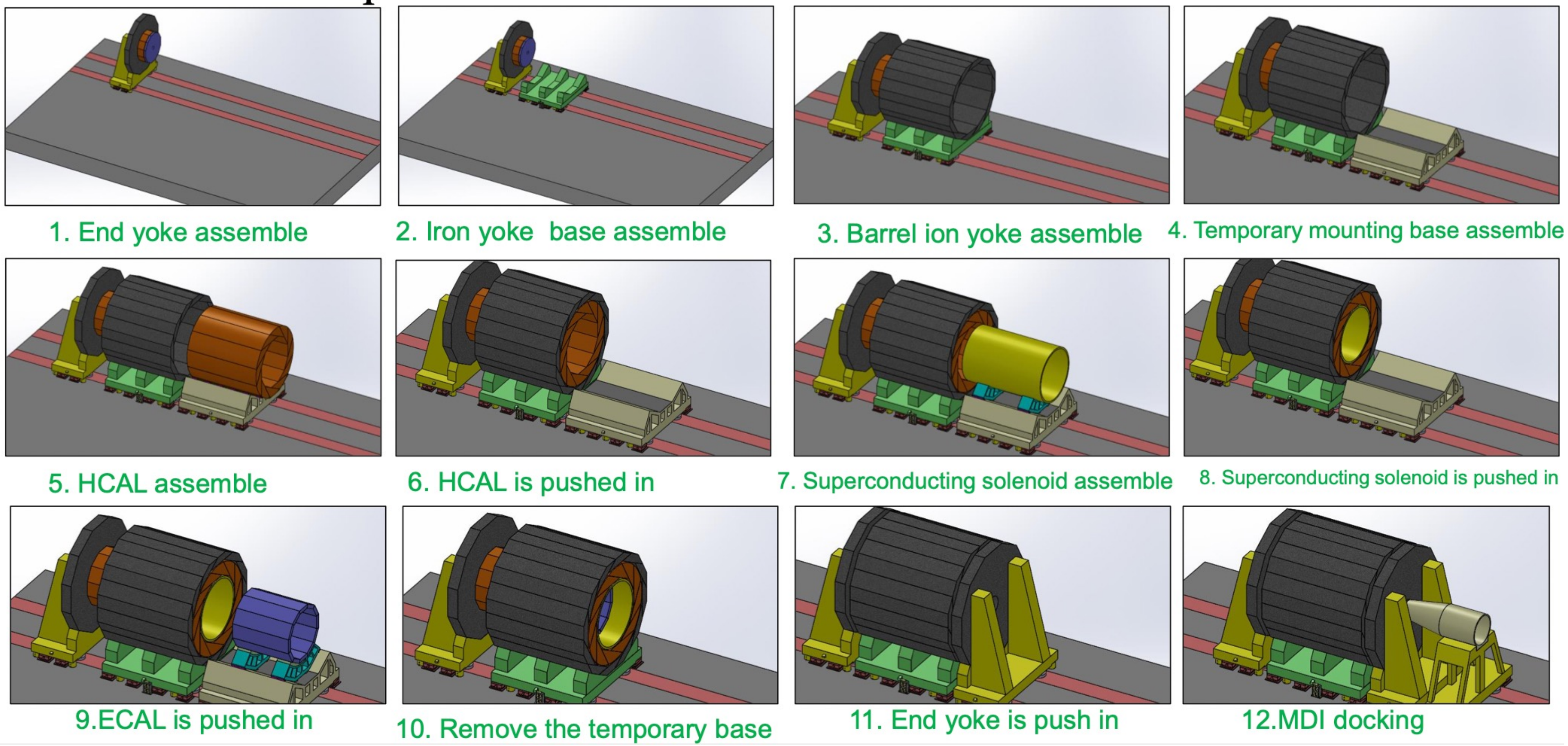
Cable test at 77 K

Preliminary Scheme of Detector Installation

- All sub-detectors will be installed one by one using several guide rails

S. Xiao

3.3 Installation process



FCC-ee

Design Requirements

FCC-ee Interaction Region

Similar to CEPC

- Requirement for the CDR: **Flexible design, one common IR for all energies**, from 45 to 182.5 GeV
- IR magnets will be superconducting
- At 45.6 GeV it will be a high intensity run (issues related on residual gas, collective effects)
- At 182.5 GeV it will be high energy run (issues related to synchrotron radiation)
- First circular collider dominated by Beamstrahlung
  - at the Z-pole bunch length is increased by 2.5 times, forcing top-up injection with few percent of current drop
  - above the ttbar threshold lifetime is dominated by BS
- Synchrotron radiation is a driver of the design

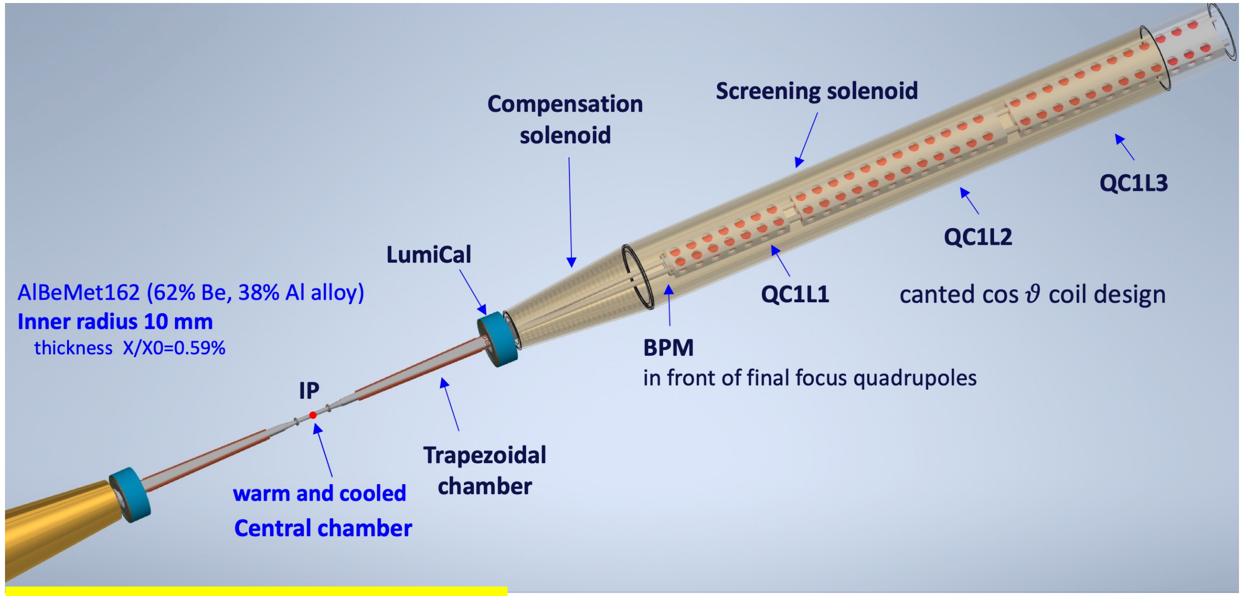
Comparison of the parameters

- Key parameter comparison of the CEPC and the FCC-ee, at both CDR phase and post-CDR phase

	CEPC-CDR	FCCee-CDR	CEPC-TDR	FCCee-PostCDR
Circumference	100km	99km	100km	91km
No. of IP	2	2	2	2/4
SR Power	30MW	50MW	30MW/50MW	50MW
L*	2.2m	2.2m	1.9m	2.2m
Detector Acceptance	0.993	0.99	0.99	0.99
B(detector)	3T/2T	2T	3T/2T	2T

Updates of the Central Chamber

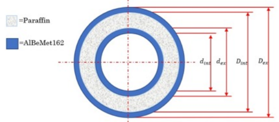
- Shrinking of the central diameter: 30mm(CDR)->20mm(Now)
- Double layer AlBeMet162(used at DAFNE) + Coolant: Thickness ~0.59% X_0
- Low impedance Design: Trapezoidal outside, racetrack inside.
  - No HOM absorber needed(Diameter of outer pipe: 30mm).

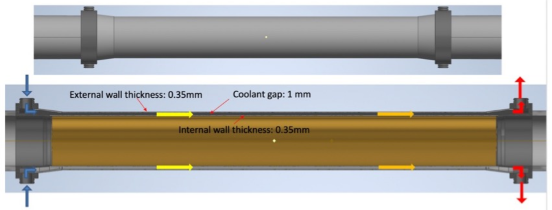


Similar to CEPC

Low impedance central chamber

warm and cooled
central beam pipe





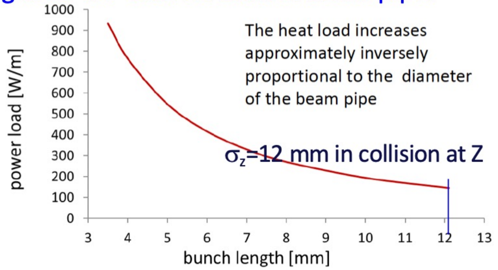
Inner radius 10 mm

Material	thickness
AlBeMet162 (62% Be and 38% Al alloy)	0.35 mm
Paraffin (PF200)	1 mm
AlBeMet162	0.3 mm
Au	5 μm

Thickness 1.7mm (X/X0=0.59%)

CDR: inner radius 15 mm for X/X0=0.47%

Heat load due to resistive wakefields vs bunch length for a r=1cm Be central beam pipe.



Beamstrahlung Photons

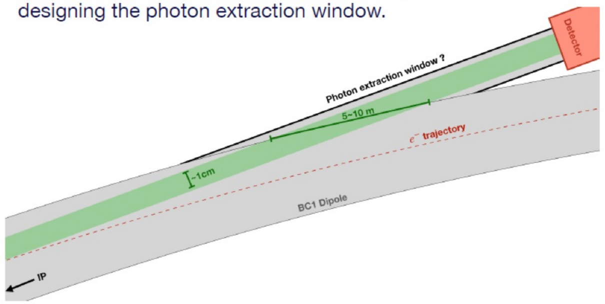
- The photons generated through beamstrahlung process would be huge.
- Despite pair-production, a mount of photons would be backgrounds, but will deposit heats downstream.

Should also be important at CEPC
Needs to be studied

Beamstrahlung monitor

-radiation from the colliding beams is intense (380 kW over cm^2 section!)
- potentially very precise monitoring of collision offsets in both x and y.
  -- operations
  -- centre-of-mass energy control
- basically un instrumented beam dump.   proposed by A. Blondel

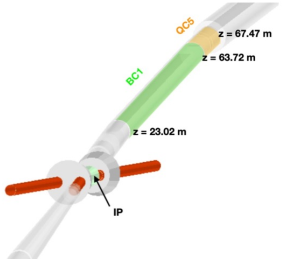
While the spot size is ~1x1cm^2, due to the very small impinging angle on the beam pipe wall (~1mrad) the region hit by the photons is **several meters long** on the longitudinal dimension, so this should be taken in consideration when designing the photon extraction window.

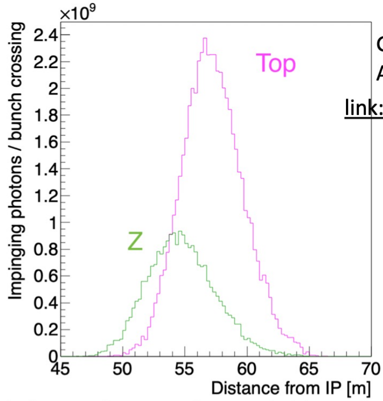


Beamstrahlung Radiation generated at the IP

A significant flux of photons is generated at the IP in the very forward direction by Beamstrahlung, radiative Bhabha, and solenoidal and quadrupolar magnetic fields.
Beamstrahlung interactions produce an **intense source of locally lost beam power**
The impinging angle of the **Beamstrahlung** photons with the pipe is about 1 mrad for both beam energies.

	Beam energy	Beamstrahlung Radiation power
$E\gamma$> = 2 MeV	45.6 GeV	387 kW
$E\gamma$>=67 MeV	182.5 GeV	89 kW





GuineaPig++
A. Ciarma
link: IPAC21 MDI

Beamstrahlung photons tracked up to their loss points, at about 50-60 m after the IP

Requires special beam pipe extraction line and alcove: Beamstrahlung instrumented photon dump

Summary & Outlook

	CEPC-CDR	FCCee-CDR	CEPC-TDR	FCCee-PostCDR
Circumference	100km	99km	100km	91km
No. of IP	2	2	2	2/4
SR Power	30MW	50MW	30MW/50MW	50MW
L*	2.2m	2.2m	1.9m	2.2m
Detector Acceptance	0.993	0.99	0.99	0.99
B(detector)	3T/2T	2T	3T/2T	2T
Diameter of Central pipe	28mm	30mm	20mm	20mm
Thickness of Central pipe	0.15% X_0	0.47% X_0	0.2% X_0	0.59% X_0

- We have started our TDR work, together with validation and optimization.
- FCC-ee might be another benchmark of our study.

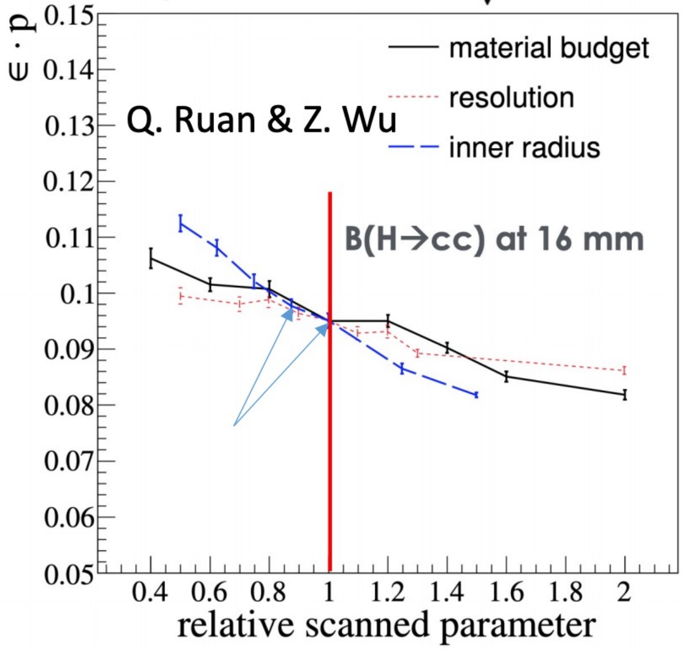
Thank You

Backup

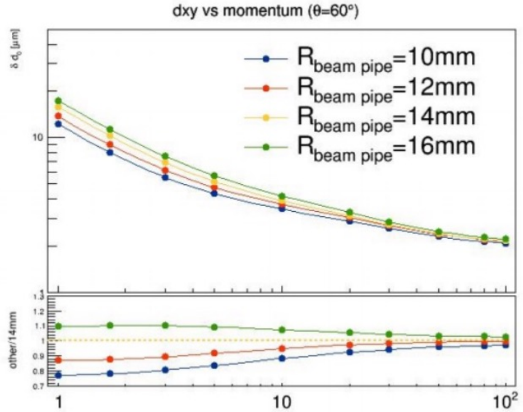
Physics Gains for 20mm Be

- First estimates made with fast simulation and scaling

$$\frac{\delta_\mu}{\mu} \propto \frac{\sqrt{S+B}}{S} \propto \frac{1}{\sqrt{\epsilon \cdot p}}$$



$$\sigma_{d_0}^2 = \sigma_{geom}^2 + \sigma_{MS}^2$$
$$= \left(\frac{\sigma_1 r_2}{r_2 - r_1}\right)^2 + \left(\frac{\sigma_2 r_1}{r_2 - r_1}\right)^2 + \sum_{j=1}^{n_{scatt}} \left(R_j \Delta\Theta_j\right)^2$$



H. Zeng

- Implement the geometry in simulation and run a full analysis to estimate the physics gains

G. Li

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, Vertex : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($cm^{-2} \cdot BX^{-1}$)	2.3	2.3	2.3	0.63	0.63	0.63
TID($krad \cdot yr^{-1}$)	930	1490	2540	10.5	3150	5360
NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)	2.2	3,5	6.0	23.6	70.8	120.4

  - Detector Impacts, TPC : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($cm^{-2} \cdot BX^{-1}$)	2.59e-2	2.59e-2	2.59e-2	6.365e-3	6.365e-3	6.365e-3
TID($krad \cdot yr^{-1}$)	4.385	7.483	11.973	67.53	241.93	387.09
NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)	0.4519	0.7712	1.234	7.415	26.565	42.503

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, Ecal Barrel : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	1.162e-3	1.162e-3	1.162e-3	2.714e-4	2.714e-4	2.714e-4
TID($\boldsymbol{krad \cdot yr^{-1}}$)	0.319	0.544	0.871	5.505	19.722	31.555
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	0.1285	0.2193	0.3509	1.396	5.001	8.002

  - Detector Impacts, Ecal Endcup: CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	1.356e-3	1.356e-3	1.356e-3	2.335e-4	2.335e-4	2.335e-4
TID($\boldsymbol{krad \cdot yr^{-1}}$)	0.2841	0.4848	0.7757	2.473	8.860	14.175
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	0.1248	0.2130	0.3408	1.069	3.830	6.128

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, HCal Barrel : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	2.778e-5	2.778e-5	2.778e-5	1.1e-5	1.1e-5	1.1e-5
TID($\boldsymbol{krad \cdot yr^{-1}}$)	7.603e-3	12.974e-3	20.76e-3	0.2529	0.906	1.450
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	0.0116	0.198	0.317	0.1627	0.5829	0.9326

  - Detector Impacts, HCal Endcup: CDR→TDR(Scale)

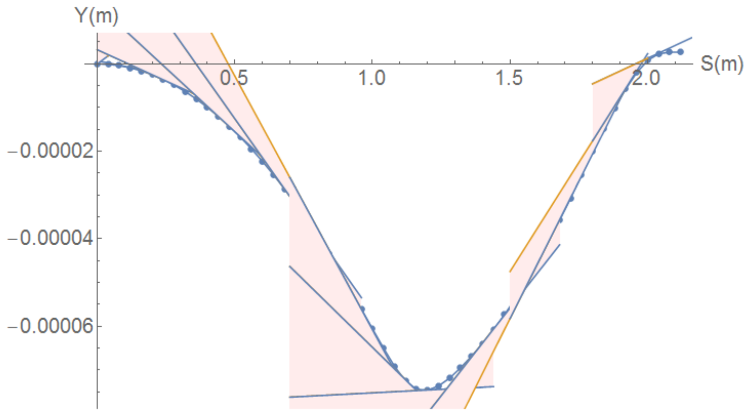
Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	1.321e-3	1.321e-3	1.321e-3	2.732e-4	2.732e-4	2.732e-4
TID($\boldsymbol{krad \cdot yr^{-1}}$)	0.284	0.485	0.775	4.589	16.44	26.31
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	0.159	0.271	0.434	1.108	3.97	6.351

SR from solenoid combined field

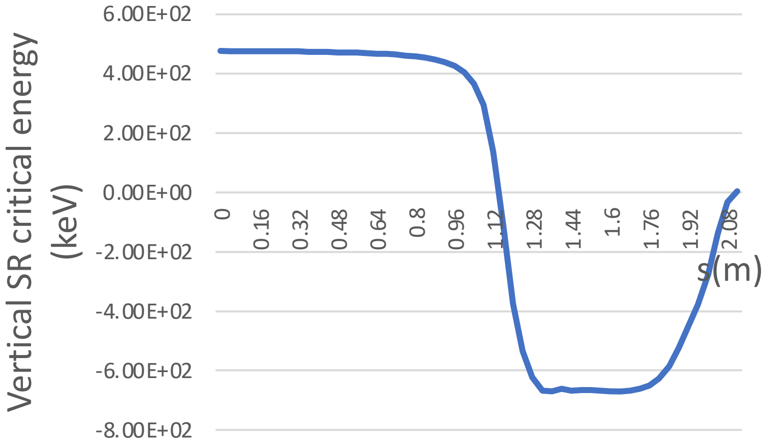
S. Bai

- Horizontal trajectory will couple to the vertical
- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.



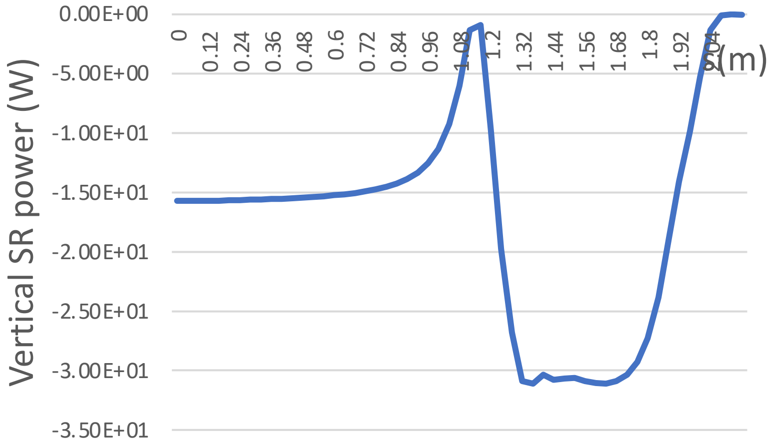
- SR fan is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and no background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.

Vertical SR critical energy distribution



Maximum: 670keV

Vertical SR power distribution



Maximum: 31W