Status of the Interaction Region Design

Hongbo Zhu

On behalf of the MDI group

23 September 2020

The CEPC MDI Group (Incomplete)

- Coordination team
  - Hongbo Zhu, Jie Gao, Jianchun Wang, Xinchou Lou
- Accelerator
  - Sha Bai (Liaison, general), Dou Wang (physics), Yudong Liu (HOM), Haijing Wang (mechanics), Yingshun Zhu (SC magnets), Tongxian Zhao (cryogenics), …
- Detector
  - Quan Ji (Overall mechanics, beam pipe), Suen Hou (LumiCal), Peilian Liu (LumiCal), Haoyu Shi (backgrounds), Wei Xu (backgrounds), Chengdong Fu (G4 geometry), Joao Costa, Zhijun Liang, Jinyu Fu (vertex), Gang Li (physics performance) + *mechanics team from Dongguan branch + …*

TASKFORCE

SHORT TERM DELIVERABLES -- TO BE DISCUSSED

- A consistent design of the interaction region based on the CDR machine parameters in about two months
  - Head loads from HOM, synchrotron radiation, particle loss
  - Beampipe (central + forward) with cooing structures and interface to Vertex and LumiCal
  - Background levels (hit density, TID, NIEL) in sub-detectors (Vertex, Tracker, Calorimeter and LumiCal) + basic mitigation measures (collimators, masks, shielding, Au coating)
  - Superconducting magnets (compensating solenoid and quadrupoles) with optimized aperture size and protection
  - Detector solenoid and Yoke design
  - Supporting structure and install scheme
  - ...

6/10/20 CEPC MDI WG Meeting 16

(Bi-)Weekly Meetings & Workshops

September 2020

- 16 Sep MDI Regular Group Meeting
- 09 Sep MDI Regular Group Meeting

July 2020

- 29 Jul MDI Regular Group Meeting
- 15 Jul MDI Regular Group Meeting
- 08 Jul MDI Regular Group Meeting (CANCELLED)
- 07 Jul CEPC LumiCal Discussion
- 01 Jul MDI Regular Group Meeting

June 2020

- 24 Jun MDI Regular Group Meeting
- 10 Jun MDI Regular Group Meeting

CEPC MDI Workshop

from Thursday, 28 May 2020 at **08:00** to Friday, 29 May 2020 at **18:00** (Asia/Shanghai)
at **IHEP (C305)**

Manage

Description We will use Tencent Meeting for remote participation. If this is your first time to use this video meeting program, you may download the client below:

https://meeting.tencent.com/download-center.html?from=1002 (Chinese) or
https://meeting.tencent.com/sg/en/index.html (English)

CEPC Workshop MDI Day 1

https://meeting.tencent.com/s/i4hwYnUWjcqq

Meeting ID: 280 290 019

CEPC MDI Workshop Day 2

https://meeting.tencent.com/s/RVXAEt5YsIaY

Meeting ID: 168 252 533

Workshop on Detector & Accelerator Mechanics

28-29 August 2020
Dongguan
Asia/Shanghai timezone

Search

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- Author List
- My Conference
  - My Contributions
- Participant List

vidyo Link:https://vidyo.ihep.ac.cn/flex.html?roomdirect.html&key=QH53ERTgAS
Room Extension:002020081800
Room PIN:20200828

Starts 28 Aug 2020 08:00
Ends 29 Aug 2020 20:10
Asia/Shanghai

Dongguan
A1-102

No material yet

+ frequent offline discussions

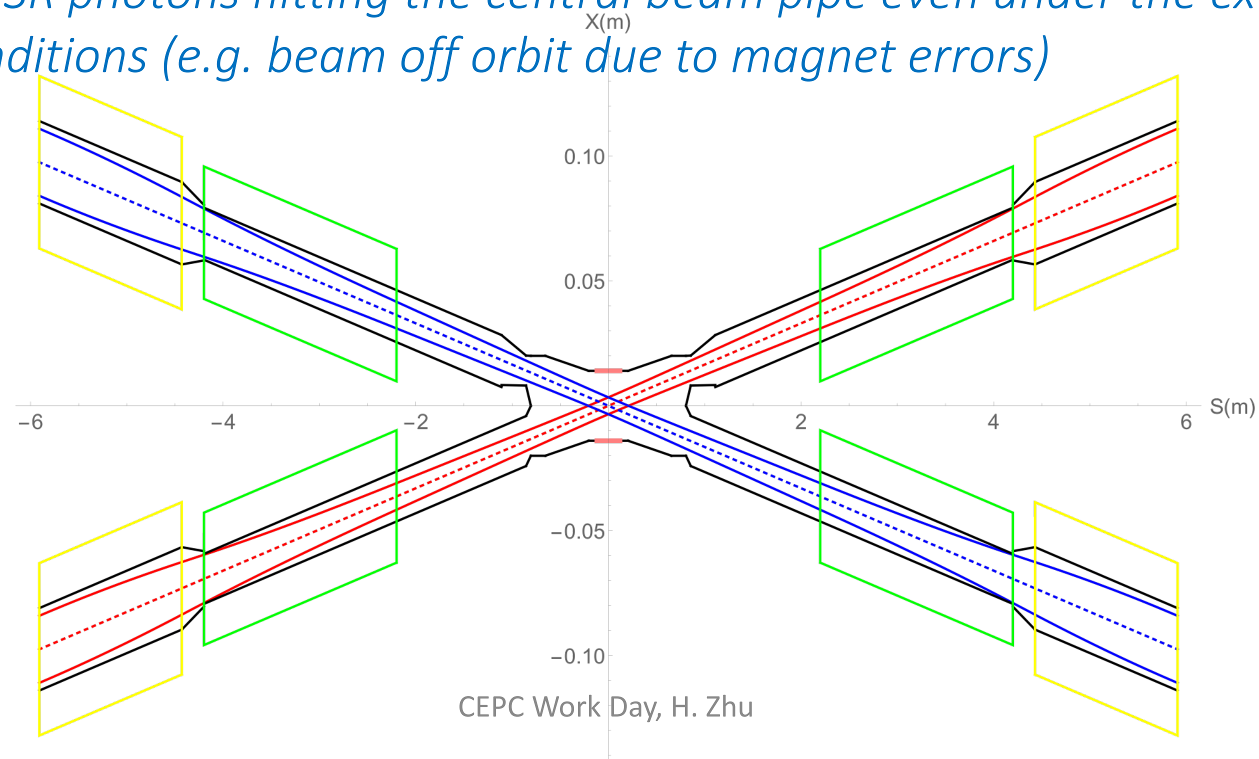
S. Bai

STARTING WITH SYNCHROTRON RADIATION

- Synchrotron radiation should be dealt with high priority at circular machines when designing the interaction region;
  - Sextuple magnets to lower the critical energy of SR photons

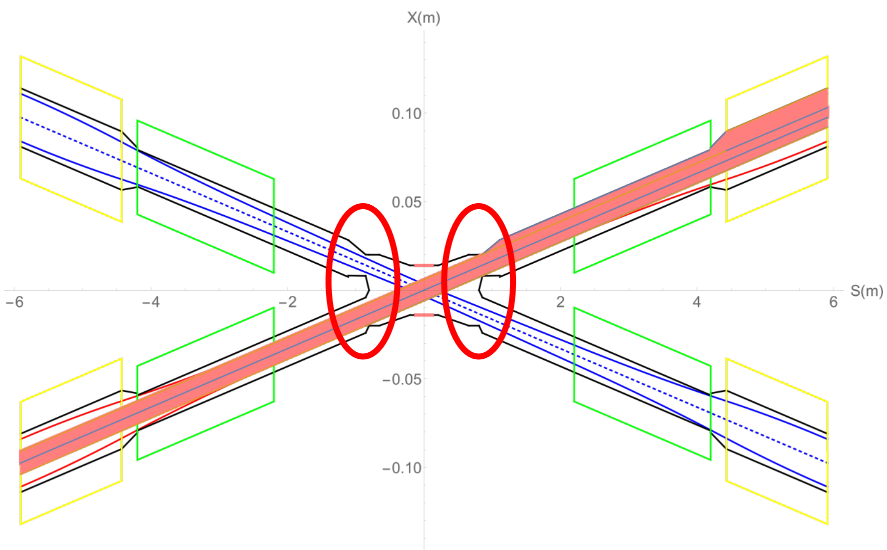
Revised beam pipe design to achieve:

No direct SR photons hitting the central beam pipe even under the extreme beam conditions (e.g. beam off orbit due to magnet errors)



S. Bai

Revised Beam Pipe & Vacuum Chamber Design



- **Most important update:** asymmetric up & down stream beampipe apertures

Feasibility confirmed by accelerator physics and mechanics design

↓

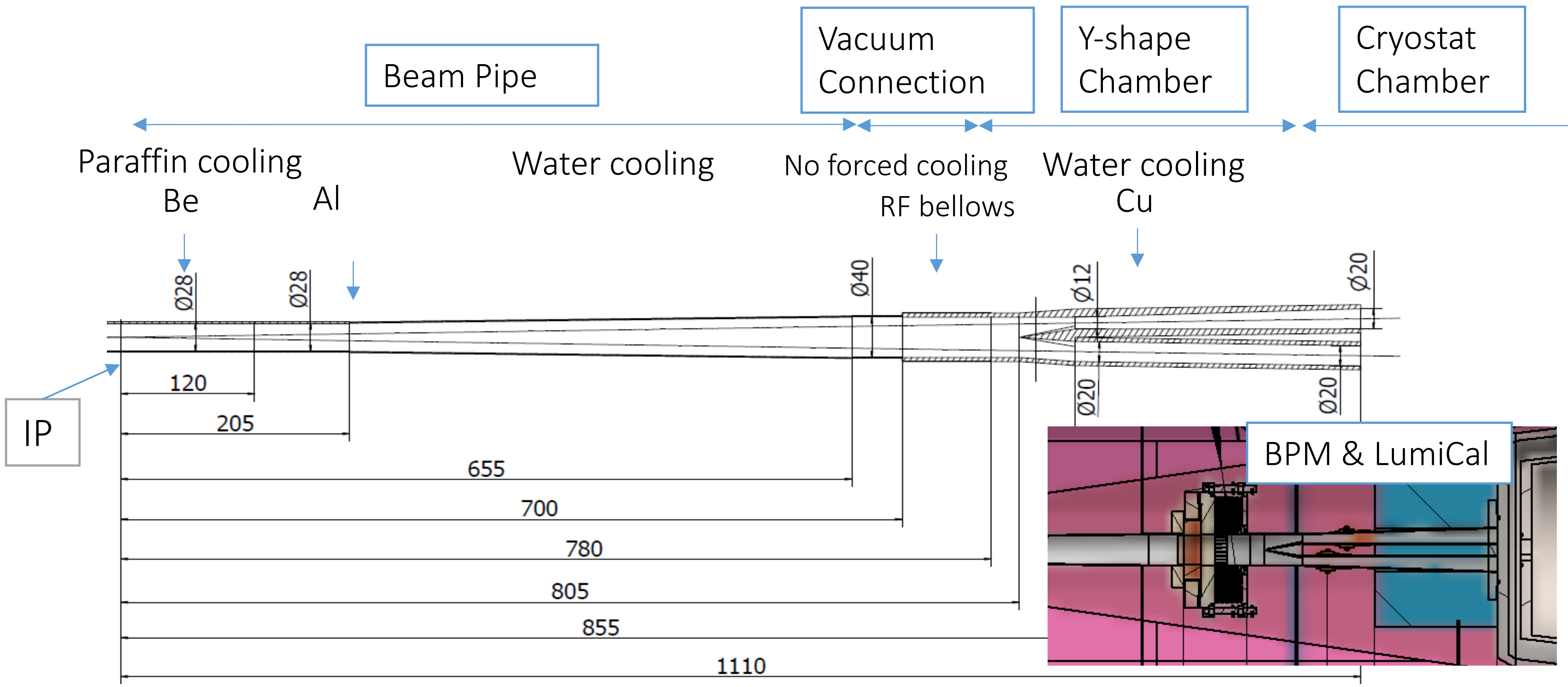
Guaranteed: no SR power deposition between ±0.855 m

	Power Deposition	Average Power Density
0.855m~1.11m	36.53 W	39.79 W/cm^2
1.11m~2.2m	2.24 W	0.57 W/cm^2
QD0	4.34 W	0.6 W/cm^2
QD0~QF1	48.04 W	58.02 W/cm^2
QF1	4.56 W	0.86 W/cm^2

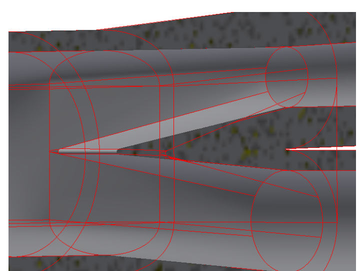
Nearly 20 versions discussed & tried out

BEAM PIPE & VACUUM CHAMBERS

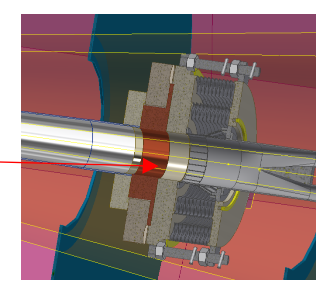
H. Wang



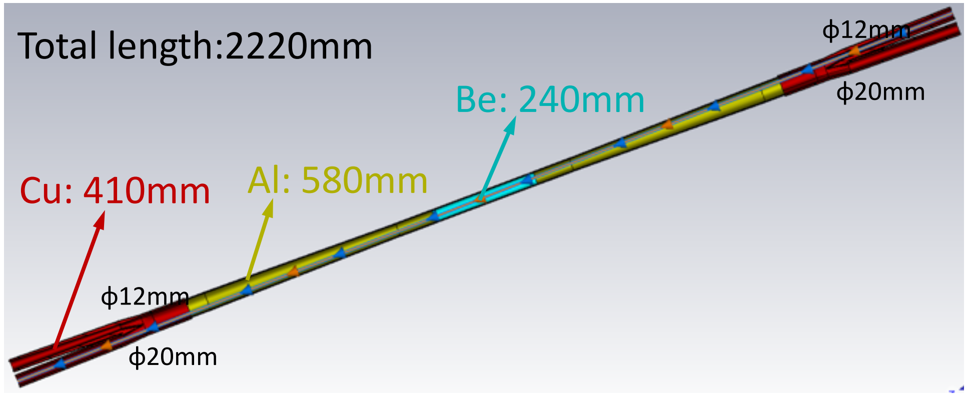
Asymmetric design to prevent direct hitting of synchrotron radiation photons



Remaining issue: difficult to dissipate the heat around the RF finger

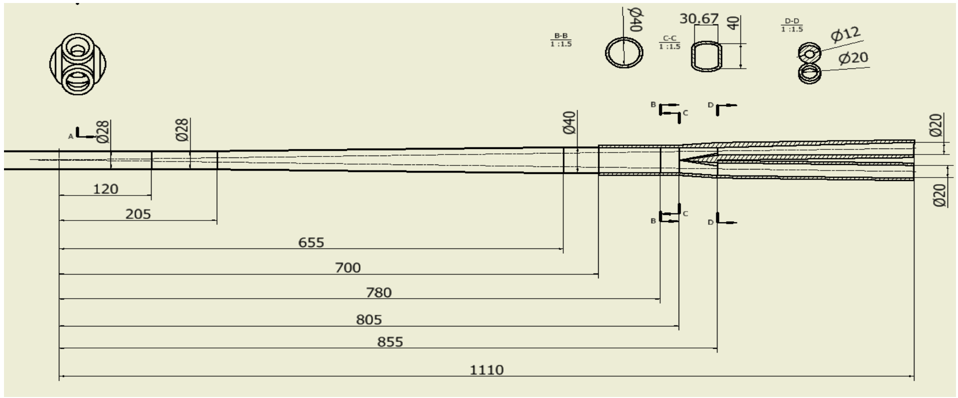


HOM SIMULATION



- CST used to simulate the impedance distribution and the trapped HOM heat deposition

Aperture in different region

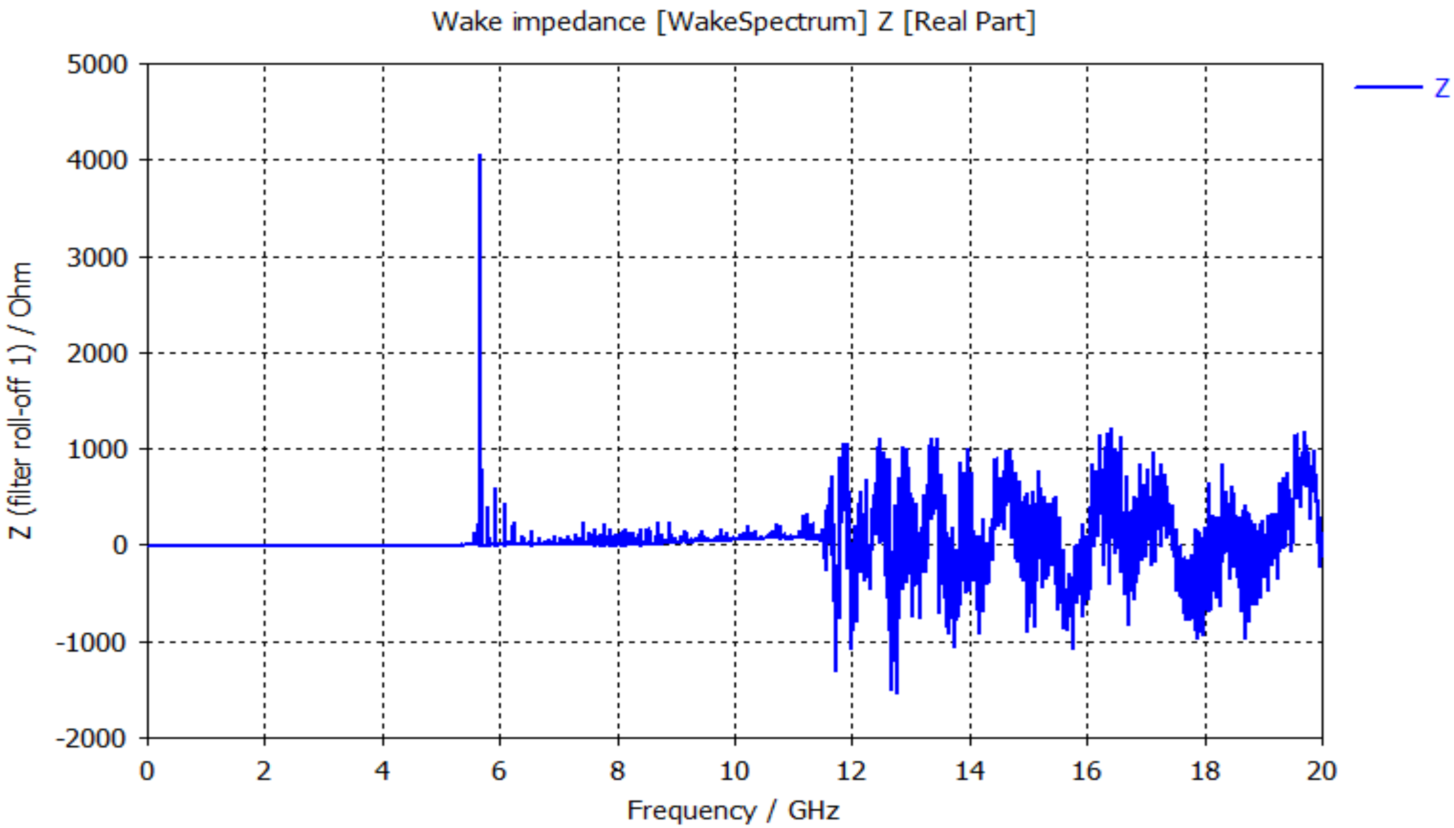


Total heat power in IR beam pipe:

1. HOM Power trapped in IR pipe
2. HOM from other part of the ring

Y. Liu

HOM SIMULATION



- CDR beam parameters, with loss factor trap@k_trap: 0. 085v/pc
  - P_{trap}(H/W/Z): 71w/288w/1007kw
  - P_{prop}(H/W/Z): 65w/264w/923w

Y. Liu

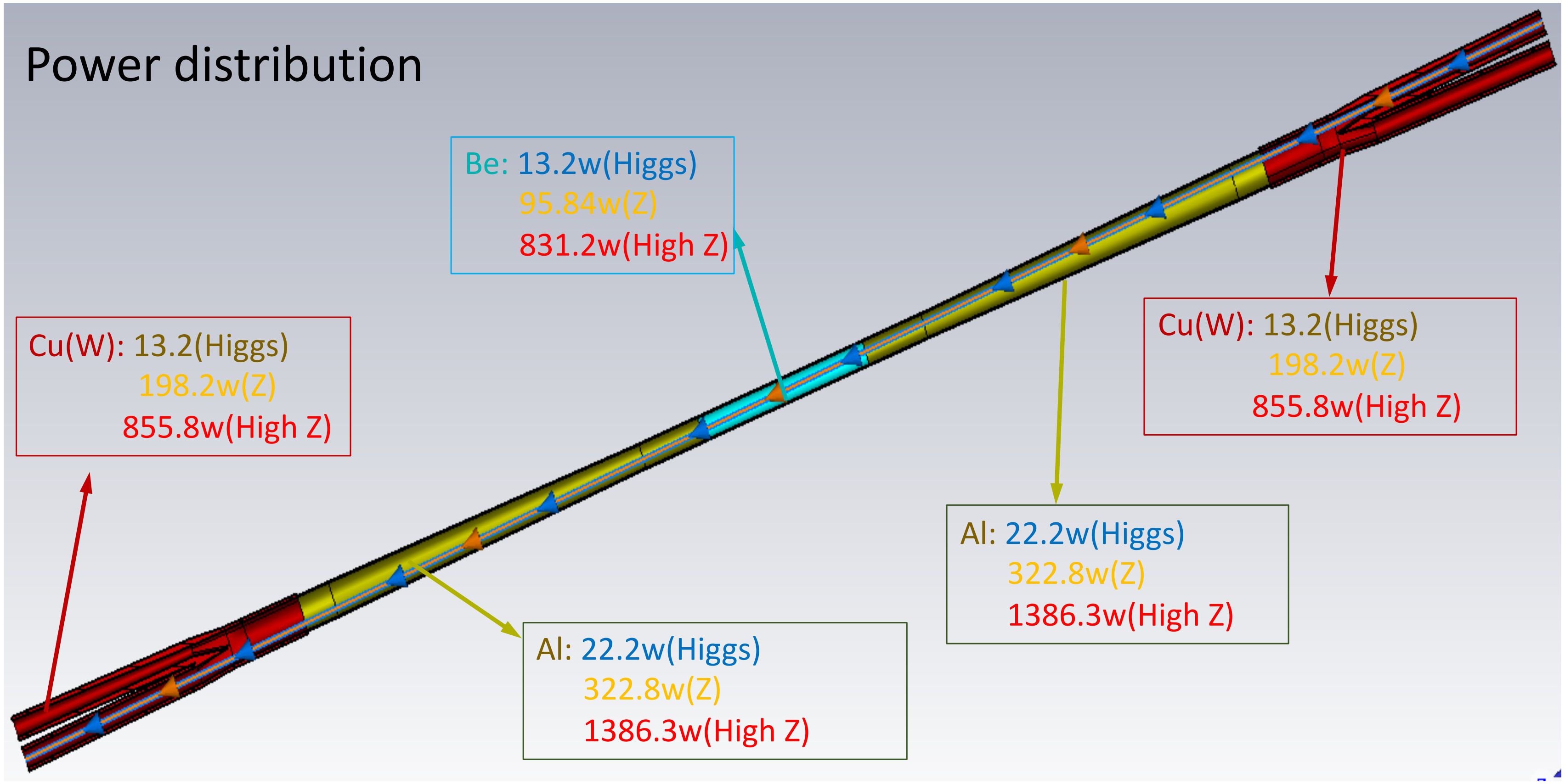
HOM Heat Load Results

- Maximum total HOM heat load at High-luminosity Z (CDR)
  - 415.6 W (Beryllium) + 1386.3 (Al) + 855.85 (Cu)

距 IP 距离（mm）	形状	内径(mm)	材料	内表面积 (mm^2)	备注	总功率&Higgs (W)	功率密度&Higgs (W/cm^2)	功率分布&Higgs (W)	总功率&Z (W)	功率密度&Z (W/cm^2)	功率分布&Z (W)	总功率&H Z (W)	功率密度&H Z (W/cm^2)	功率分布&H Z (W)
0 – 120	圆直管	直径28	Be	10556		6.6	0. 06	6. 60	47.92	0. 45	47. 92	415.6	3. 94	415. 60
120-205	圆直管	直径28	Al	7477		22.2	0. 04	2. 71	322.8	0. 53	39. 44	1386.3	2. 27	169. 36
205-655	圆锥管	直径28过渡到直径40	Al	48071	taper:1.75			17. 44			253. 54			1088. 85
655-700	圆直管	直径40	Al	5655				2. 05			29. 83			128. 09
700-780	圆直管	直径40	Cu	10052	远程连接装置预留	13.2	0. 03	2. 60	198.2	0. 39	39. 05	855.85	1. 68	168. 64
780-805	圆面过渡到跑道型	水平方向直径40-40，垂直方向直径40-30.7	Cu	3124				0. 81			12. 14			52. 41
805-855	跑道型过渡到两个圆面	上游直径12 下游直径20	Cu	6932				1. 79			26. 93			116. 30
855-1110	上游圆锥管 下游圆直管	上游直径12过渡到20，下游直径20	Cu	30906				8. 00			120. 08			518. 50

Y. Liu

HOM Power Distribution

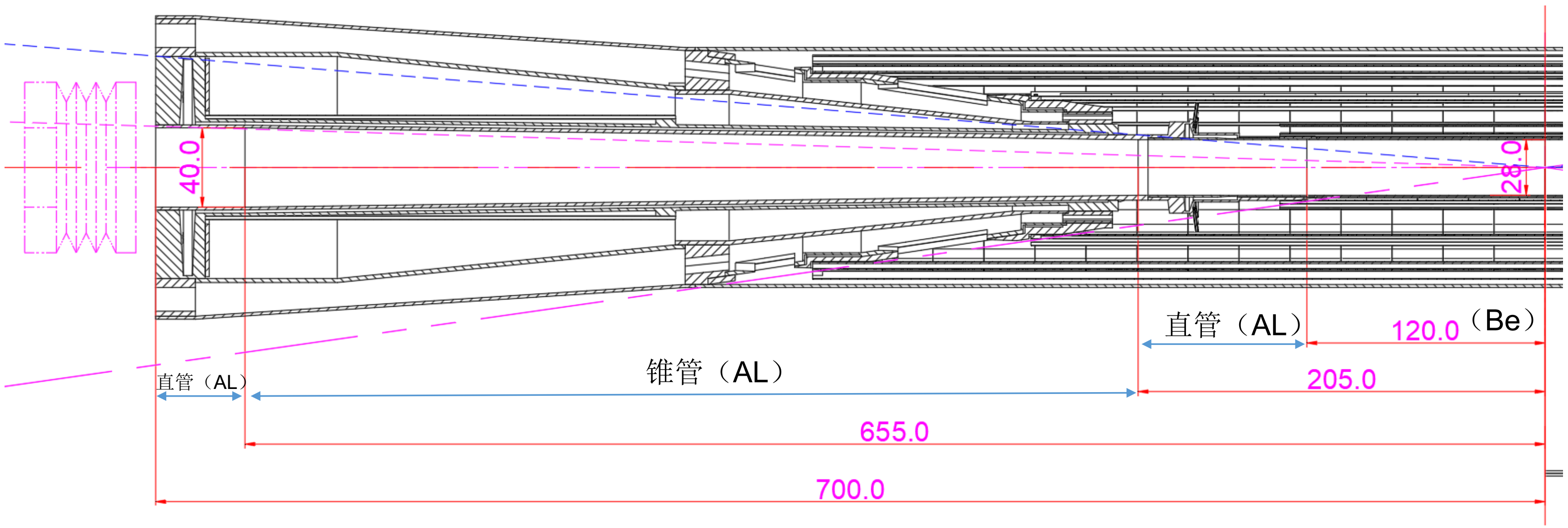


Q. Ji, et al.

Beam Pipe Structure

- Beryllium (central) and Aluminum (forward) beam pipes

束流管内部尺寸（加速器提供 ）					
距 IP 距离 (mm)	形状	内径(mm)	材料	内表面积(mm^2)	备注
0 – 120	圆直管	直径28	Be	10556	
120-205	圆直管	直径28	Al	7477	
205-655	圆锥管	直径28过渡到直径40	Al	48071	taper:1.75
655-700	圆直管	直径40	Al	5655	



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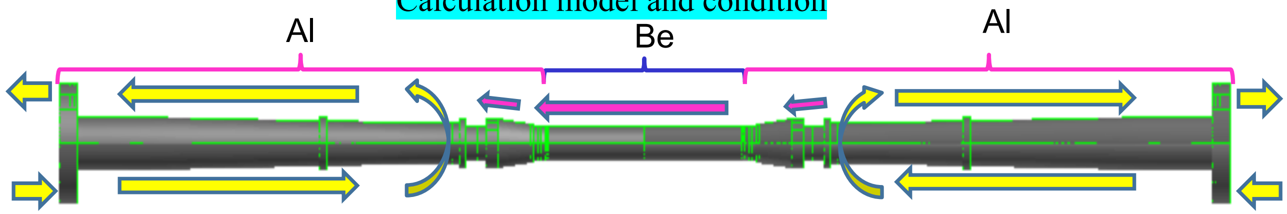
BEAM PIPE THERMAL ANALYSIS I

CDR Z parameters

Calculation model and condition



- Coolant: water
- Inlet temperature: 23℃
- Flow rate: 3.4L/min

- Coolant: paraffin
- Inlet temperature: 23℃
- Flow rate: 2.2L/min

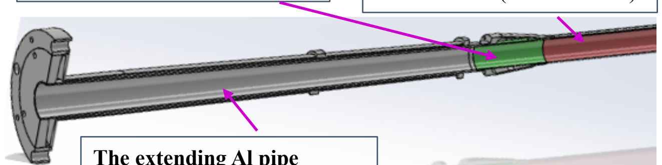
- Coolant: water
- Inlet temperature: 23℃
- Flow rate: 3.4L/min

Viscous model: Laminar

Heat in each part of calculation model

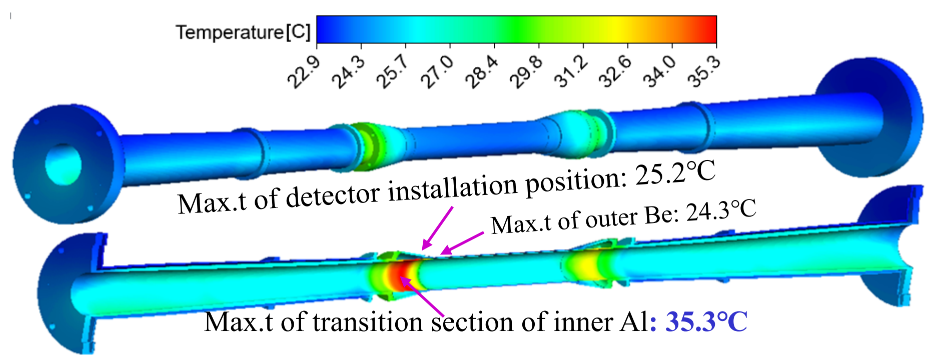
The enlarge cavity of Be pipe:
Z: 77.3W(5492.7W/m^2)
HZ: 332.0W(23589.0W/m^2)

Be pipe:
Z: 47.92W(4539.7W/m^2)
HZ: 415.6W(39371.9W/m^2)



The extending Al pipe
Z: 284.2W(5492.7W/m^2)
HZ: 1220.3W(23589.0W/m^2)

Temperature distribution in Z model



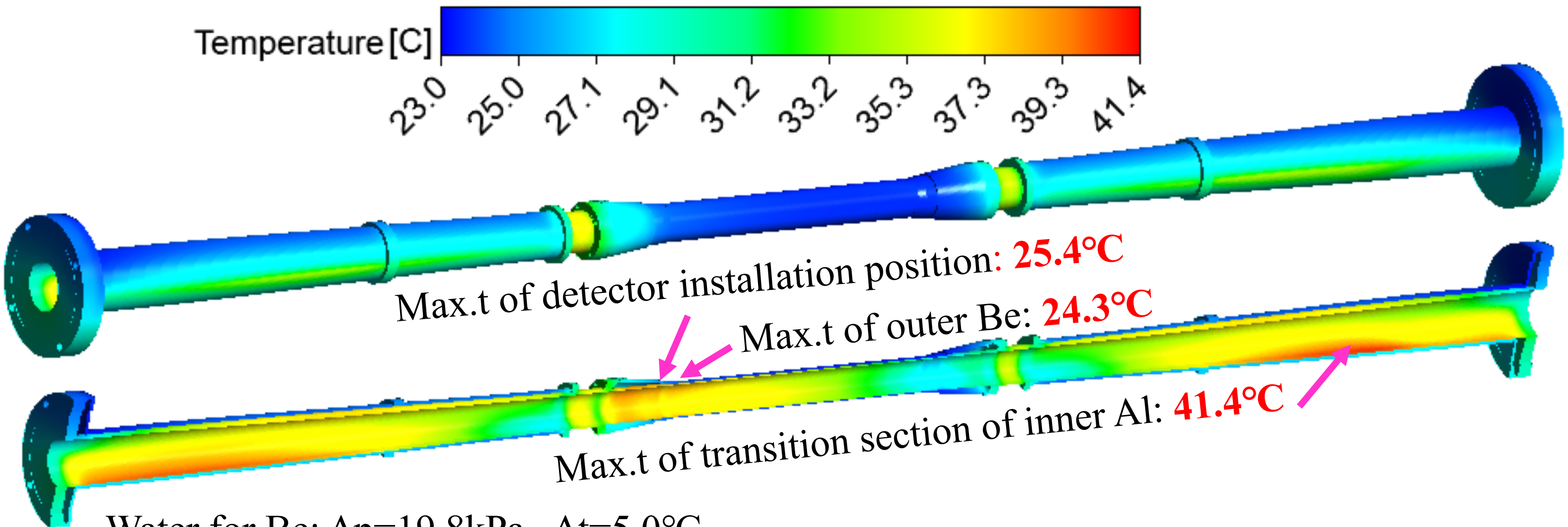
paraffin: Δp=19.8kPa, Δt=3.1℃
water: Δp=14.8kPa, Δt= 1.2℃

Beam Pipe Thermal Analysis II

With the heat deposition in the High Luminosity Z mode, it becomes impossible to cool the Be beam pipe with oil. Water is chosen as the coolant for the demonstration purpose.

- Water flow rate for Be: 3.4L/min
- Water inlet temperature: 23℃
- Other calculation condition is the same as before

Temperature distribution in High Luminosity Z model



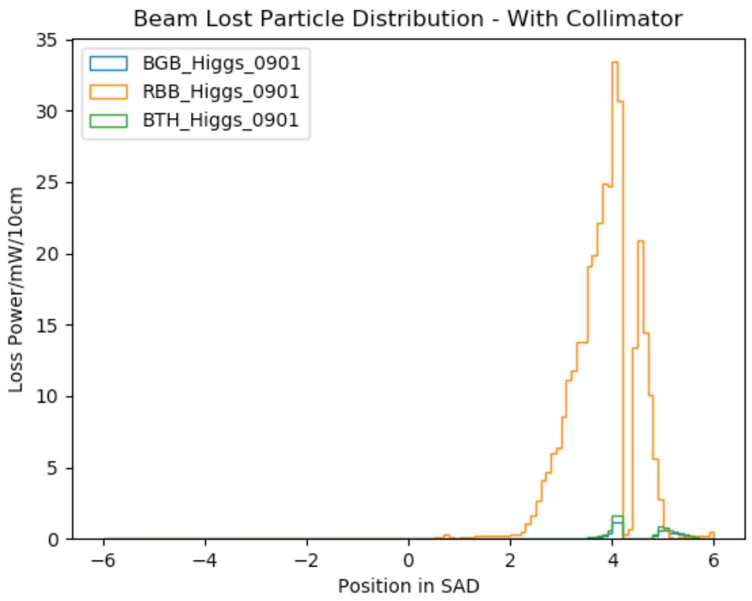
Water for Be: Δp=19.8kPa, Δt=5.0°C

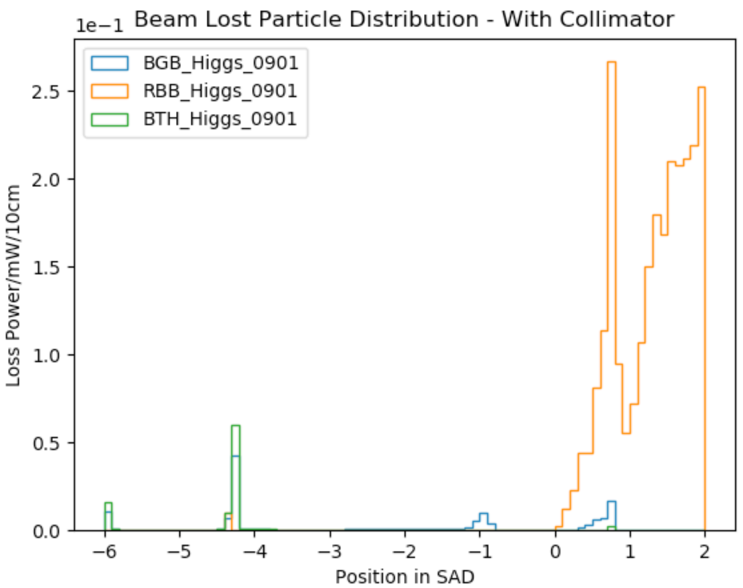
Water for extending Al pipe: Δp=14.9kPa, Δt= 5.1°C

W. Xu, H. Shi

Radiation Backgrounds

- Revisited (several times) the detector backgrounds caused by the beam loss particles, in particular beam-gas interactions and beam thermal photon interactions





- Extended the simulation (tracking) of particles over the ring and corrected for the normalization factors

W. Xu, H. Shi

UPDATED BACKGROUND LEVELS

- Higgs results updated, Z results coming soon

Safety factors of $\times$10 always applied

Background Type	Hit Density ($\mathrm{hits/cm^2 \cdot BX}$)	TID (kRad/year)	NIEL (1 MeV $\mathrm{n_{eq} \cdot cm^{-2}}$/year)
Pair production	1.8	491	0.9×10^{12}
Radiative Bhabha	0.34	590	1.5×10^{12}
Beam Gas	0.96	1,200	3.4×10^{12}
Beam Thermal Photon	0.016	21	5.7×10^{10}
Total	3.1	2,400	5.8×10^{12}

Remaining Issues

- LumiCal coverage reduced from [30,90 mrad] to [38, 90 mrad]
  - Space occupied by the double-layer Al beam pipe with cooling structure →
- Tight space in the crotch area for BPM and LumiCal
  - More critical if including a HOM absorber
- Thermal analysis of the vacuum chambers
  - Power trapped around the RF finger
  - Potential temperature rise and impacts on the vacuum level and position precision of vacuum chambers

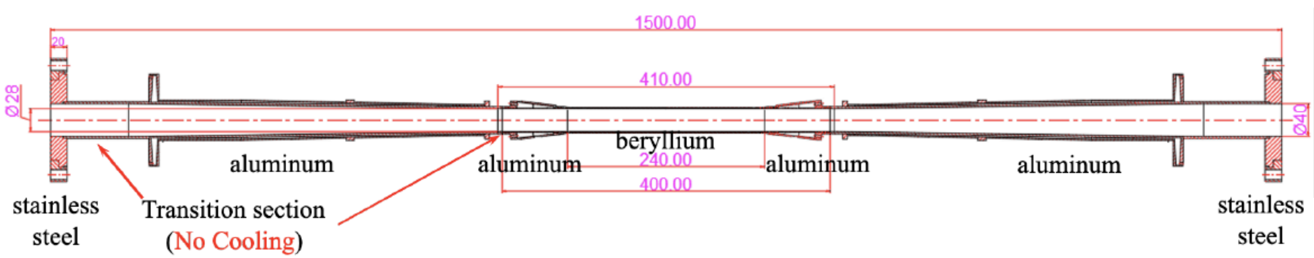
No intention to resolve these issues for the CDR machine/detector designs

SHRINKING THE BE BEAM PIPE: Φ28 → Φ20

HOW TO CONVERGE ON BEAMPIPE RADIUS

- Quantify the impacts of smaller beampipe radius on HOM heat load, radiation backgrounds and tracking/vertexing performance → caveat: studies based on the CDR machine parameters, conclusion might have to change with the involving machine design

- Beampipe shape (central + forward) to be (re-)defined



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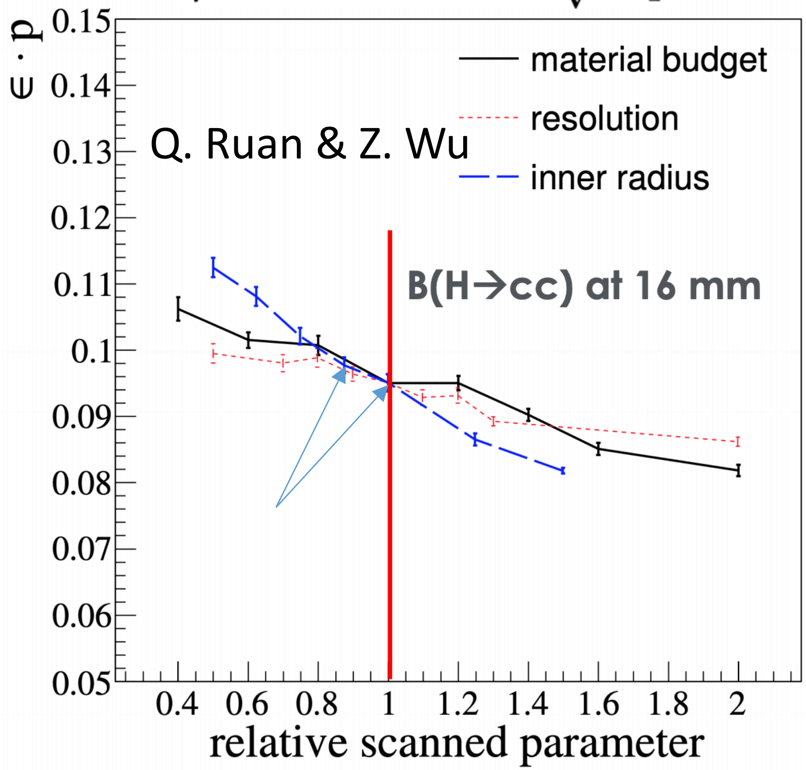
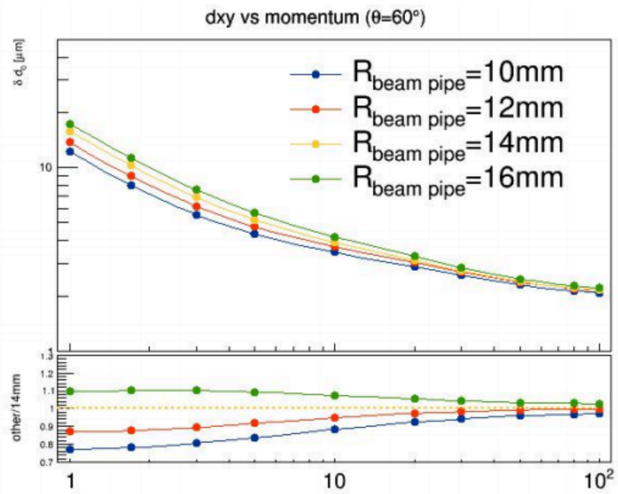
Physics Gains

- First estimates made with fast simulation and scaling

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



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



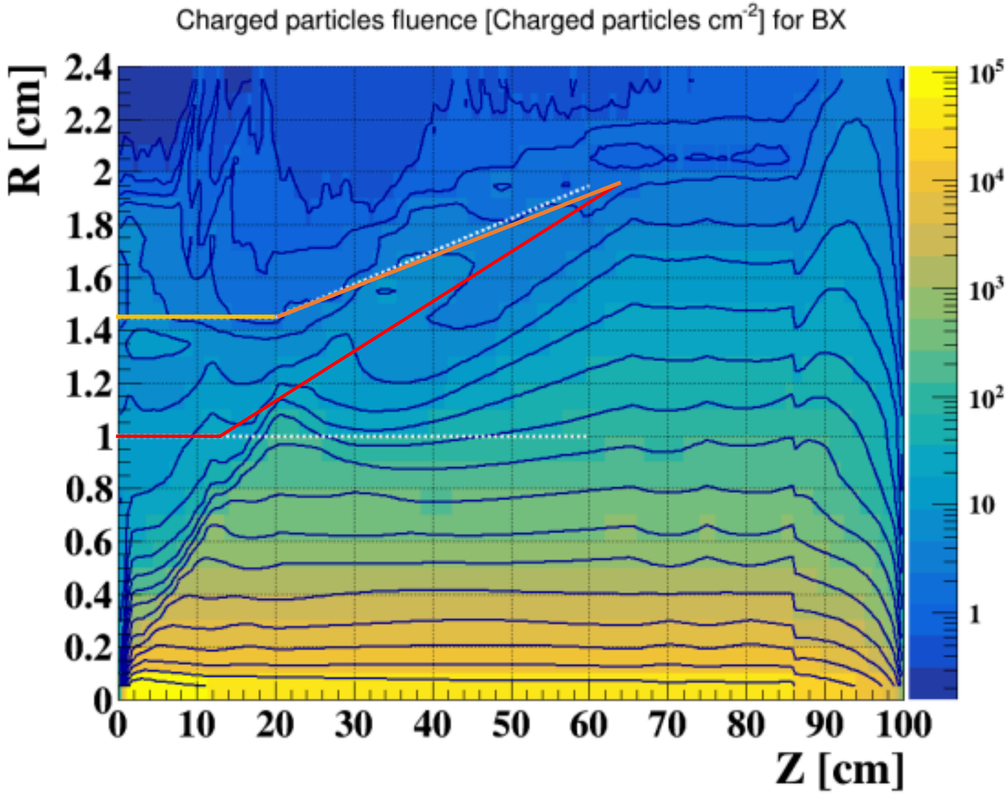
H. Zeng

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

G. Li

BEAM PIPE SHAPE

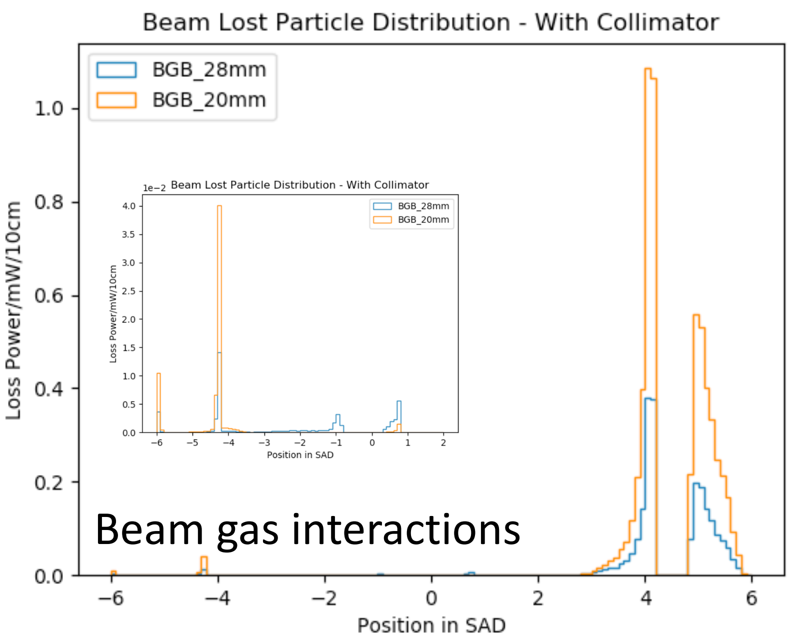
- To stay away from the too high background level area
- Cone starting from 130 mm (0~85 Be, 85~130 Al) , with the end position unchanged (655mm)

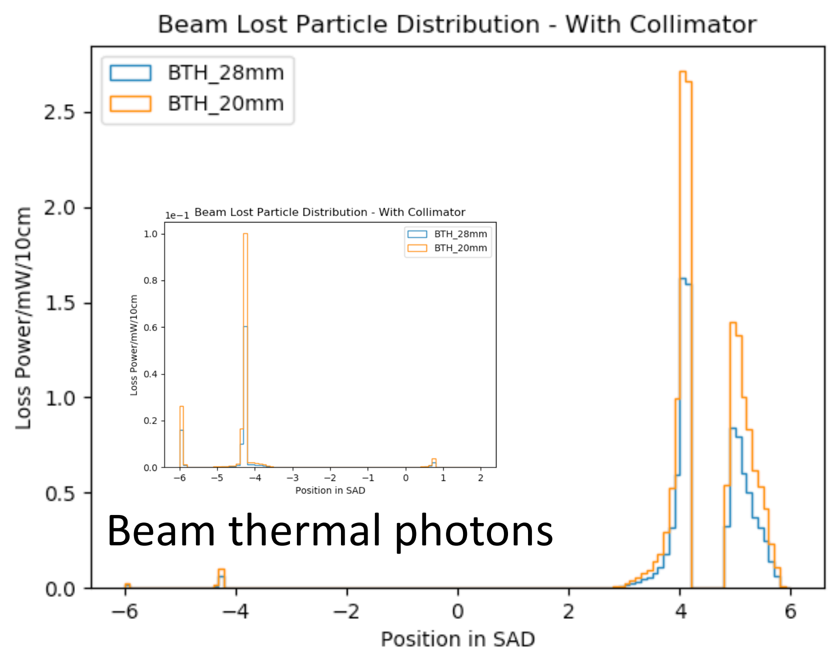


BACKGROUNDS

- Inventible increase in radiation backgrounds
  - Pair Production (×5-10)
  - Beam-gas Interaction (× 3)
  - Beam thermal photons (×1.5)

Detector simulation on-going





What Next

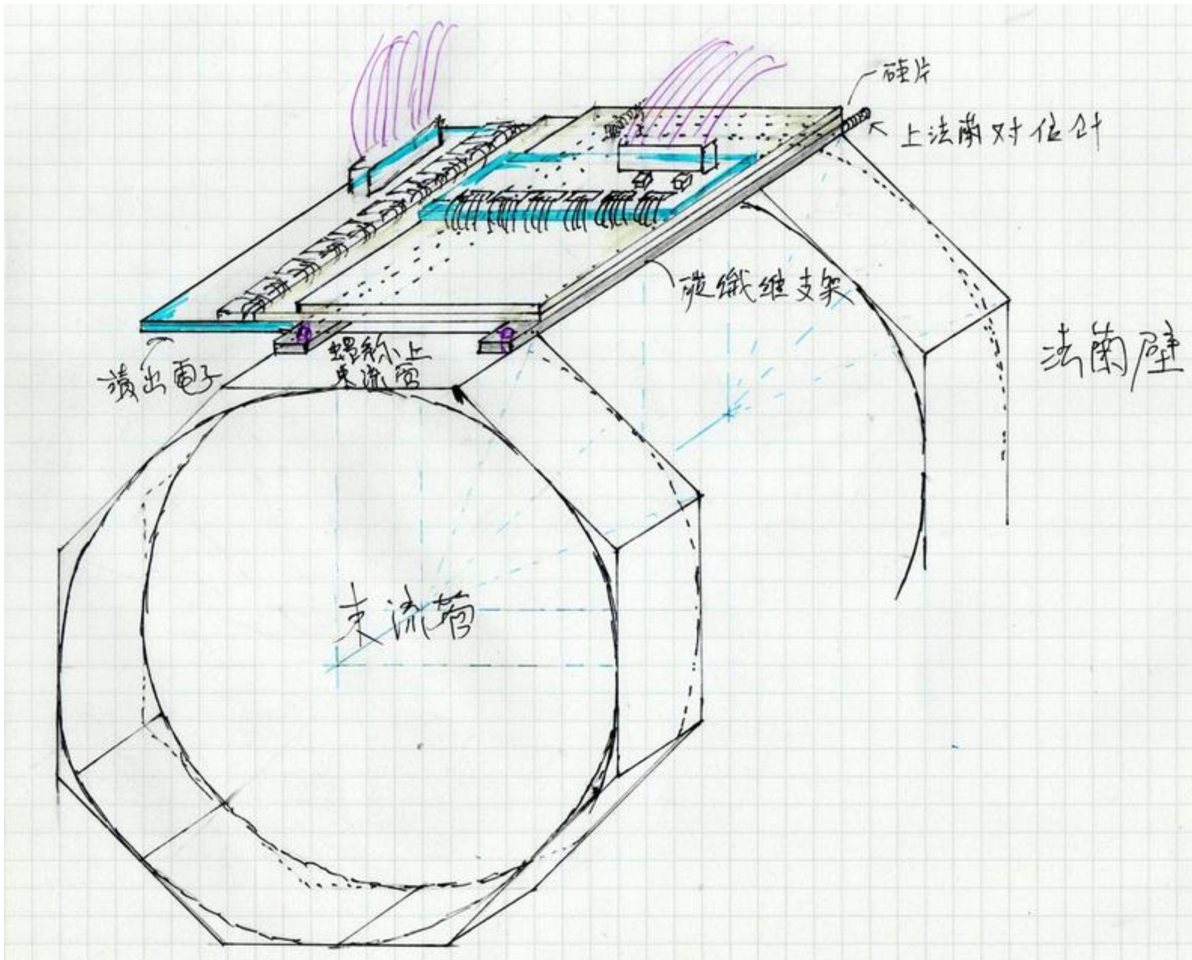
- Complete the interaction region design with the central beam pipe radius of Φ28 mm (in one week) and conclude on the gains and risks of Φ20 mm (before the CEPC workshop) → journal paper in preparation *(another paper on backgrounds to be submitted shortly)*

- Prepare for re-designing the interaction region for the high luminosity Z design (Synchrotron radiation → HOM heat load/LumiCal coverage → central beam pipe with (new) cooling/radiation backgrounds → SC magnets → (joint) supporting structure/installation scheme)

What Next

- Alternative cooling techniques for the Beryllium beam pipe
  - Low ambient temperature with cold gas → increase the thermal conductivity & reduce the temperature gradient
  - Cooling with a thin layer of water to be reconsidered → Beryllium corrosion after irradiation (reported in literature) to be confirmed experimentally at CSNS
  - Different beam pipes for Higgs and Z, given the huge difference in HOM heat load → change together the 1st vertex layer (upgrade)
- A

LumiCal Design



SUPPORTING STRUCTURE & INSTALLATION SCHEME

- Beryllium (central) and Aluminum (forward) beam pipes