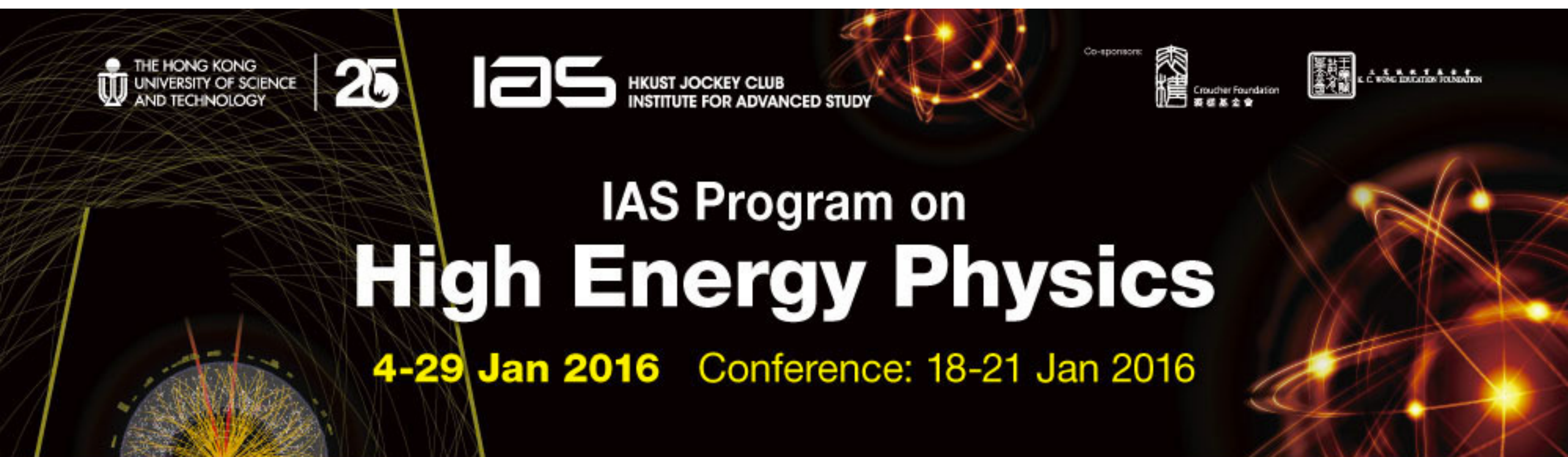
Machine Detector Interface at Electron Colliders

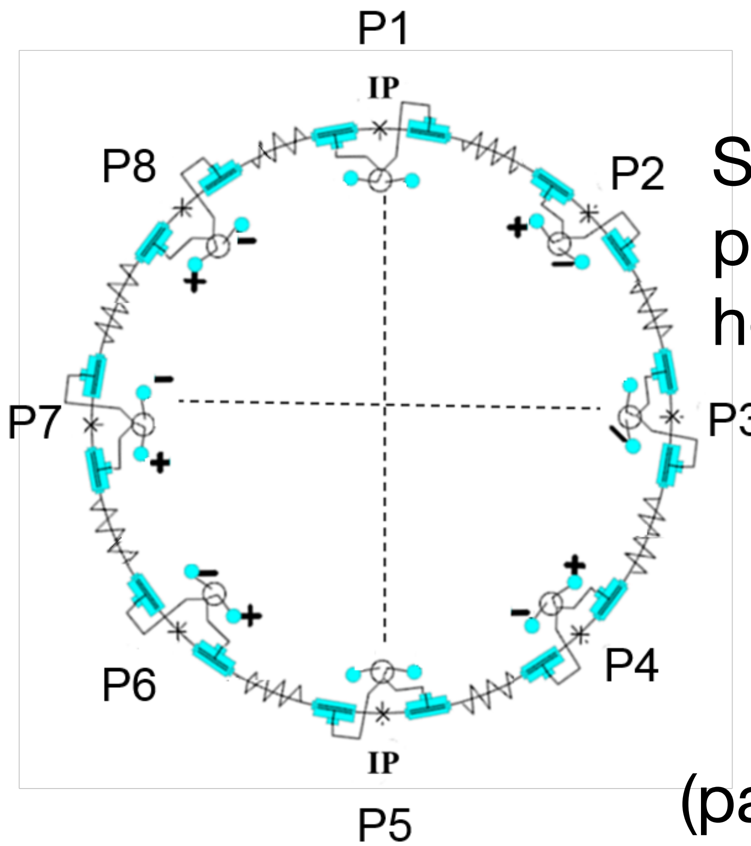
Hongbo Zhu (IHEP, Beijing)



Outline

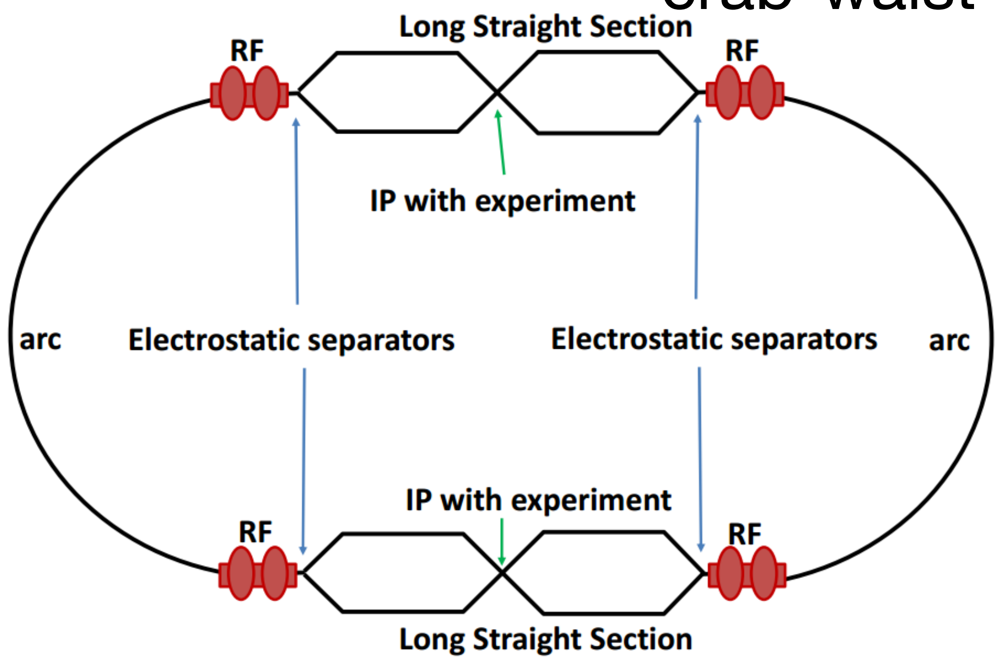
- Introduction
- Interaction Regions
- Radiation Backgrounds
- Final Focusing Magnets
- Luminosity Measurement
- Beam Energy Measurement
- Summary

Disclaimer: Not possible to cover all the MDI aspects or the machines

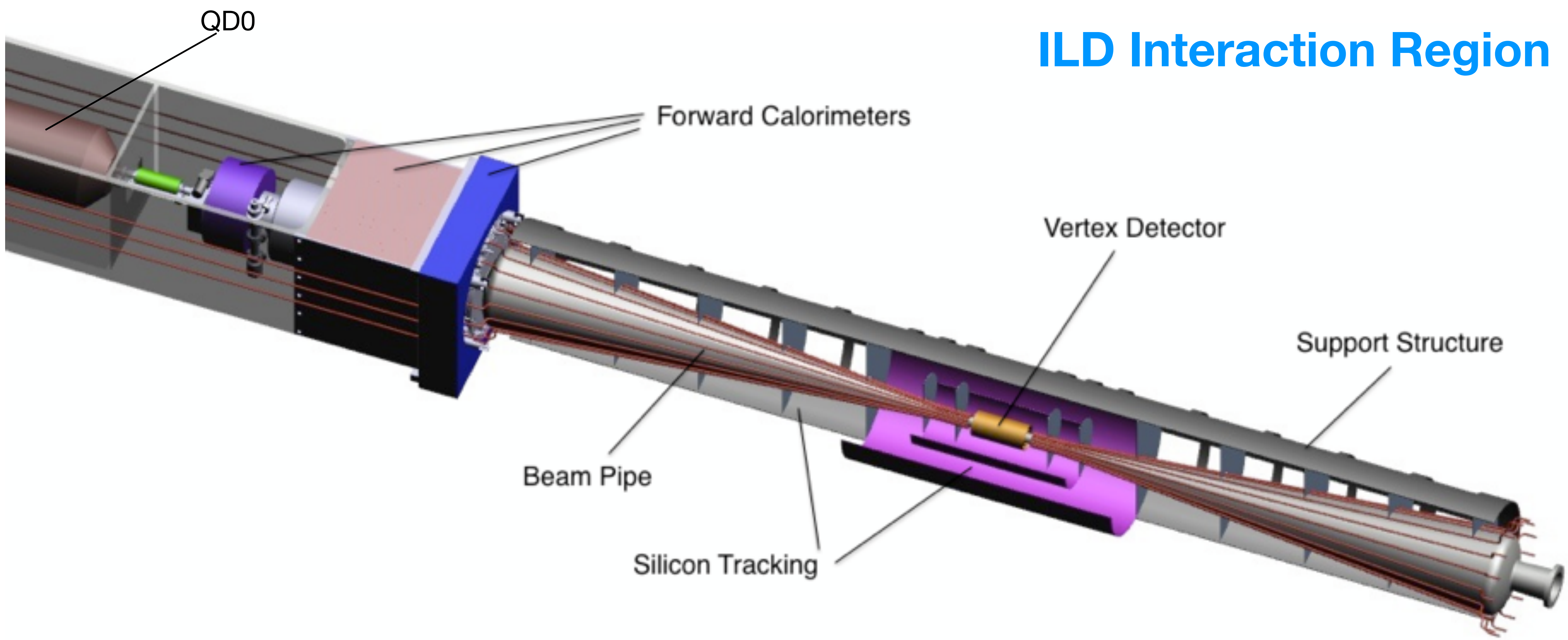


Single ring, pretzel scheme, head-on collision

(partial) double ring, crab-waist



Interaction Region

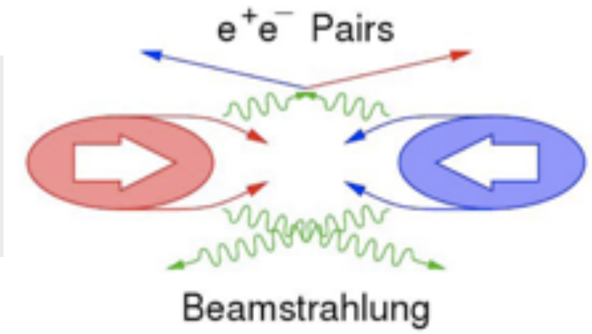


- Extremely complicated! Requiring profound understanding of both machine and detector performance, **and more …**
- Necessary to optimise both machine and detector designs → **trade-offs**
- Started CEPC physics feasibility studies with the modified ILD design

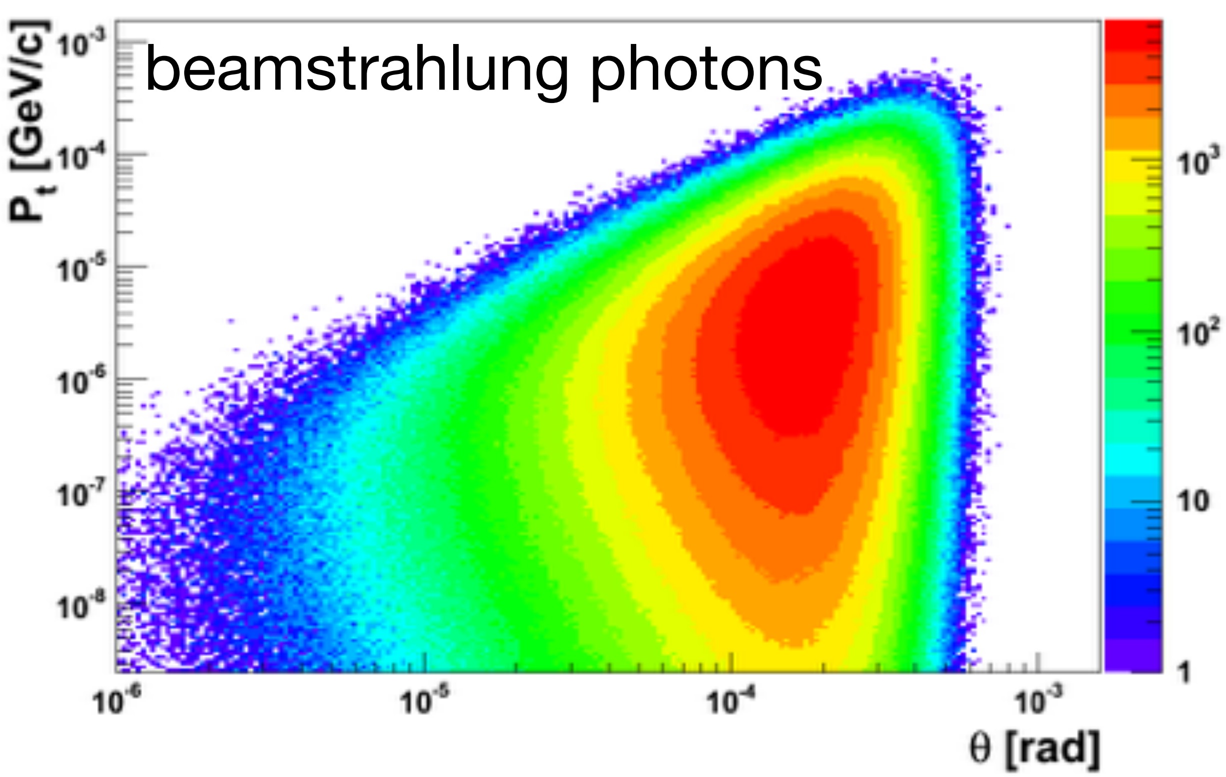
Radiation Backgrounds

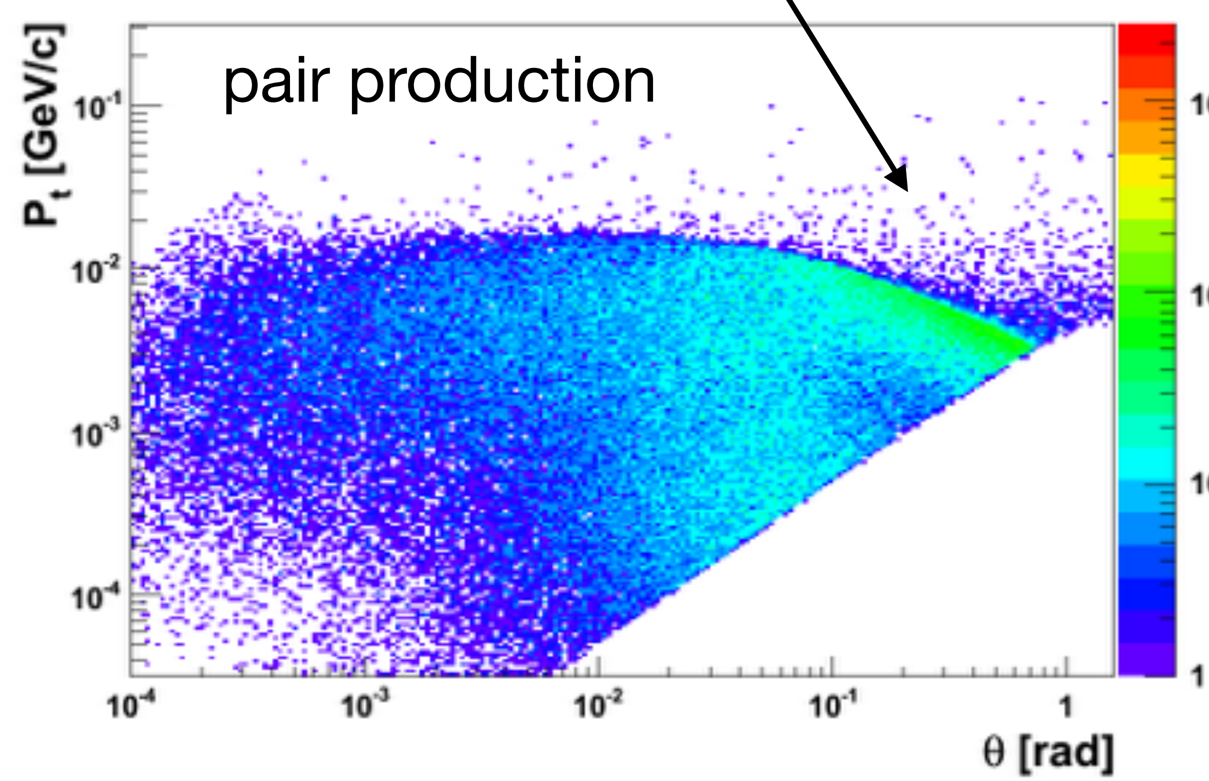
- Critical for detector and machine design, originating from various sources:
  - **Collision induced backgrounds:**
    - Beamstrahlung, (+consequent pair production, hadronic events …)
    - Radiative Bhabha scattering
  - **Machine induced backgrounds:**
    - Synchrotron radiation
    - Beam-gas interaction
    - Touschek
    - Beam halo
    - …
- Always have to carefully evaluate each background, **importance of which might differ from machine to machine**

Beamstrahlung



- Charged particles deflected by the strong field of the opposite bunch will emit radiation ("beamstrahlung") → potential issue of beam energy spread
- Important to keep machine/detector components sufficiently far away from the "kinematic-edge" created by the consequent pair production





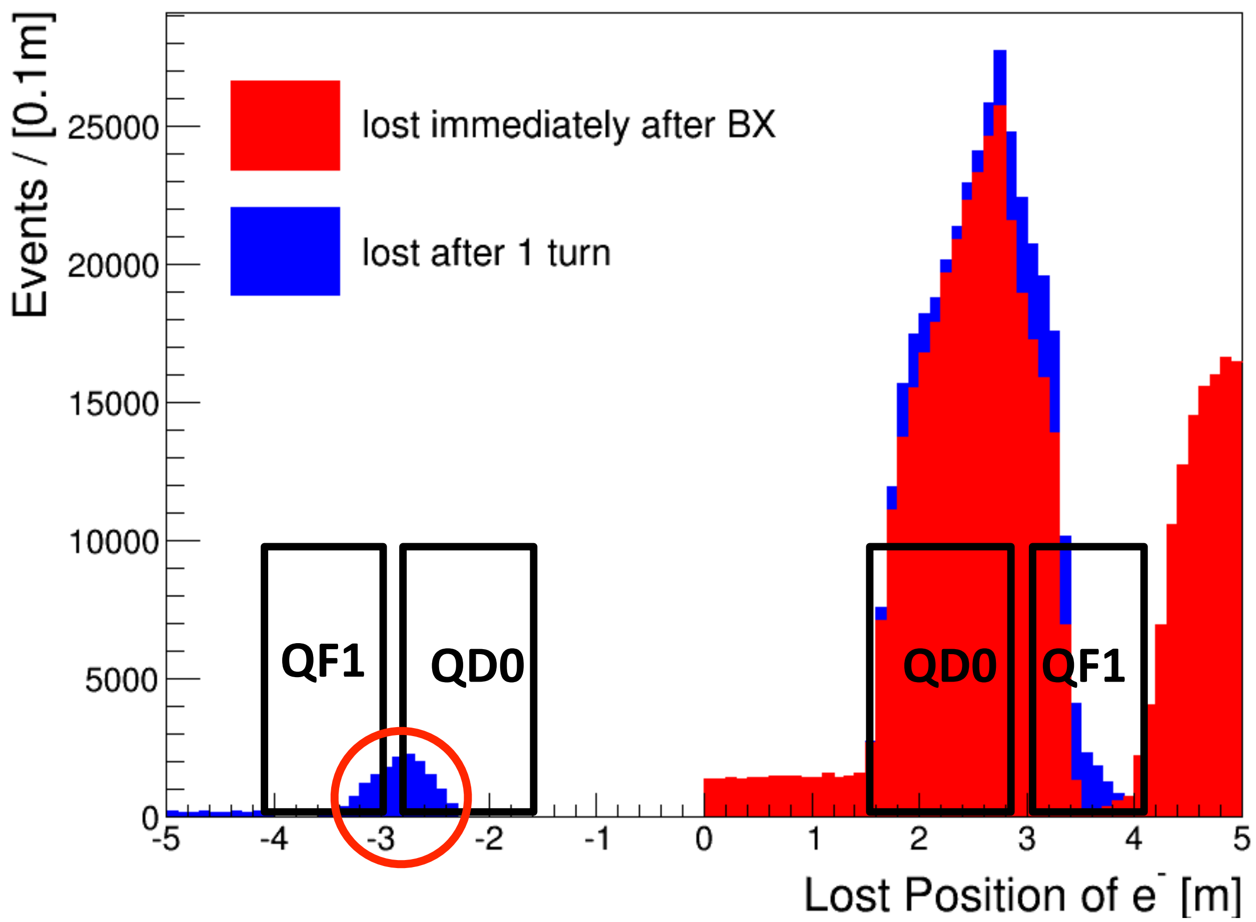
Beamstrahlung cont.

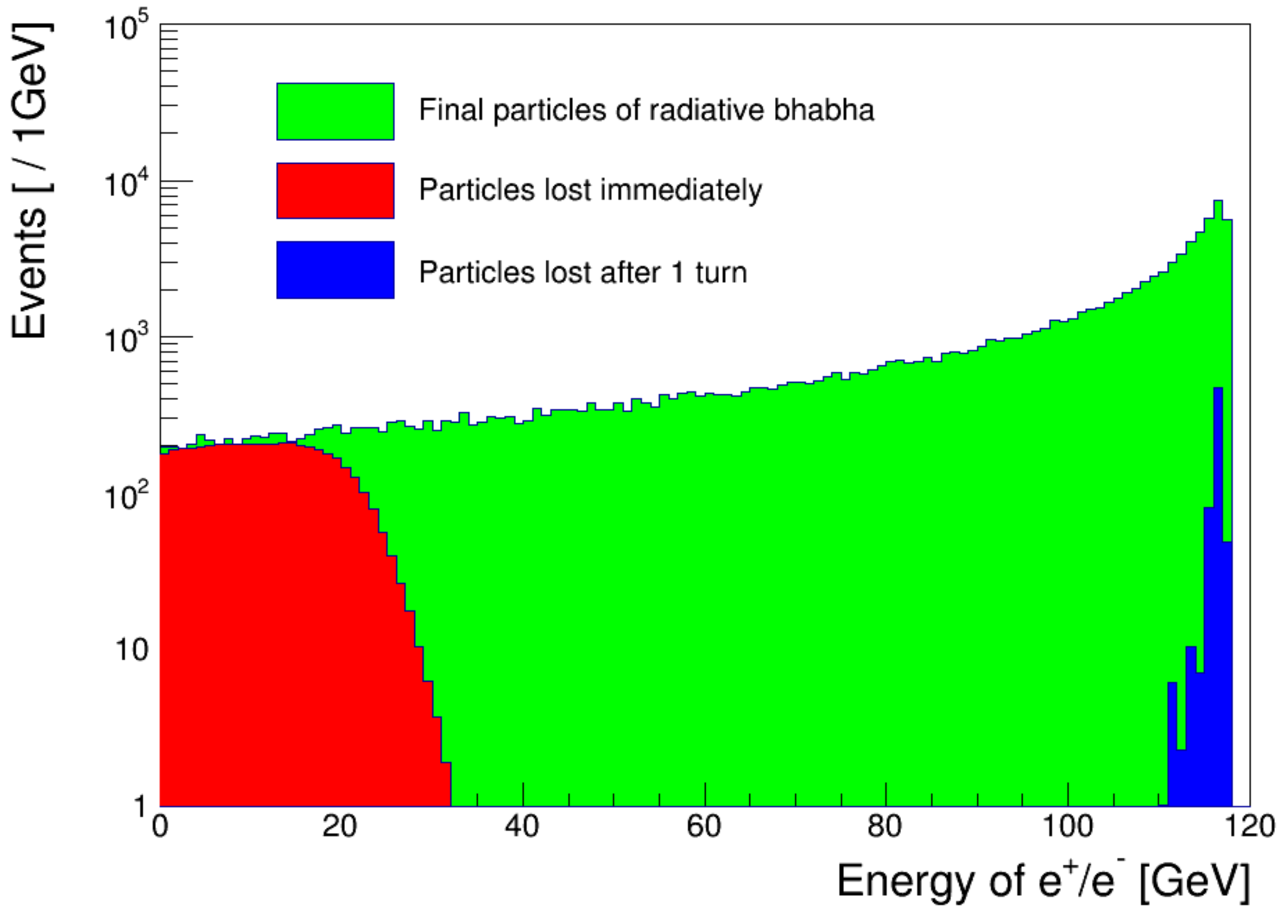
Parameters	Symbol	LEP2	CEPC	FCC-ee	ILC250
Center of mass energy	E_{cm} [GeV]	209	240	240	250
Bunch population	N [$\times 10^{10}$]	58	37.1	37	2
Horizontal beam size at IP	σ_x [nm]	270000	73700	61000	729
Vertical beam size at IP	σ_y [nm]	3500	160	120	7.7
Bunch length	σ_z [μm]	16000	2260	2110	300
Horizontal beta function at IP	β_x [mm]	1500	800	500	13
Vertical beta function at IP	β_y [mm]	50	1.2	1	0.41
Normalized horizontal emittance at IP	$\gamma\epsilon_x$ [mm · mrad]	9.81	1594.5	1761.3	10
Normalized vertical emittance at IP	$\gamma\epsilon_y$ [mm · mrad]	0.051	4.79	3.52	0.035
Luminosity	L [10^{34} cm^{-2}s^{-1}]	0.013	1.8	5.08	0.75
Beamstrahlung parameter	Υ_{av} [$\times 10^{-4}$]	**0.25**	**4.7**	**6.1**	**200**
Relative averaged energy loss per BX due to Beamstrahlung	δ_{av} [%]	**0.0001**	**0.005**	**0.0075**	**1.0**

Beamstrahlung effects not concerned for low energy machines, dominant backgrounds for ILC but less critical for CEPC

Radiative Bhabha Scattering

- Backgrounds from the original process ($e^+e^- \rightarrow e^+e^-\gamma$) not prominent
- **Dedicated to circular machines**: beam particles loosing energy (larger than the machine acceptance 2%) can be kicked off their orbits when returning to the IR and hit machine/detector elements (e.g. the final focusing magnets) → → → **particle shower**

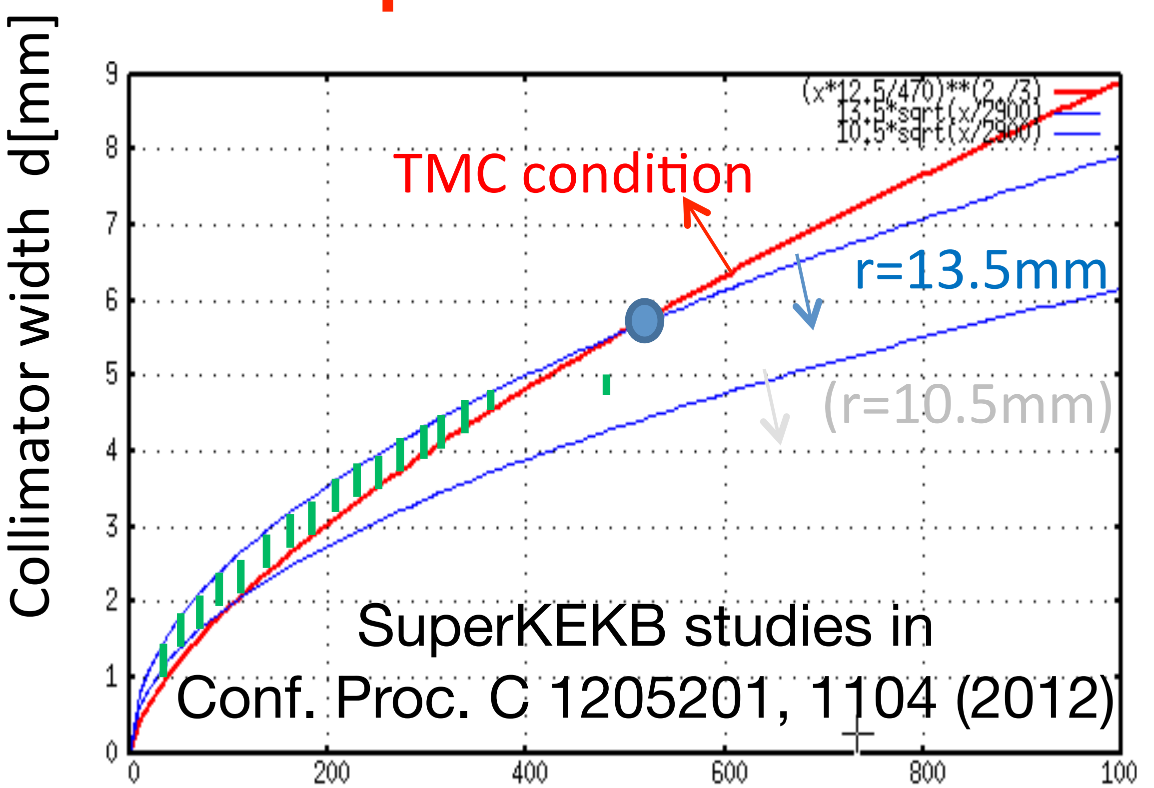




Radiative Bhabha Scattering cont.

- Sensitive to the **lattice design/final focusing magnets**, requiring optimised design of **collimation** and **shielding**

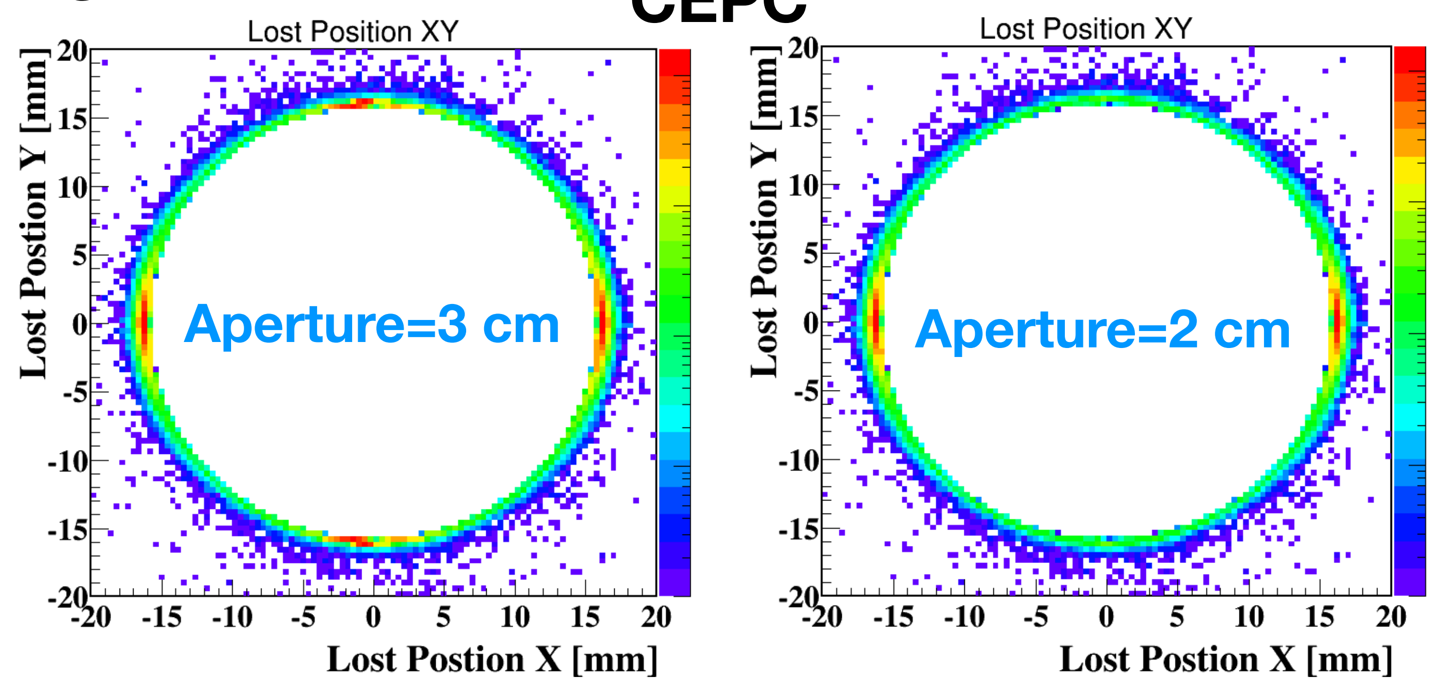
Where to place the collimators?



← small β

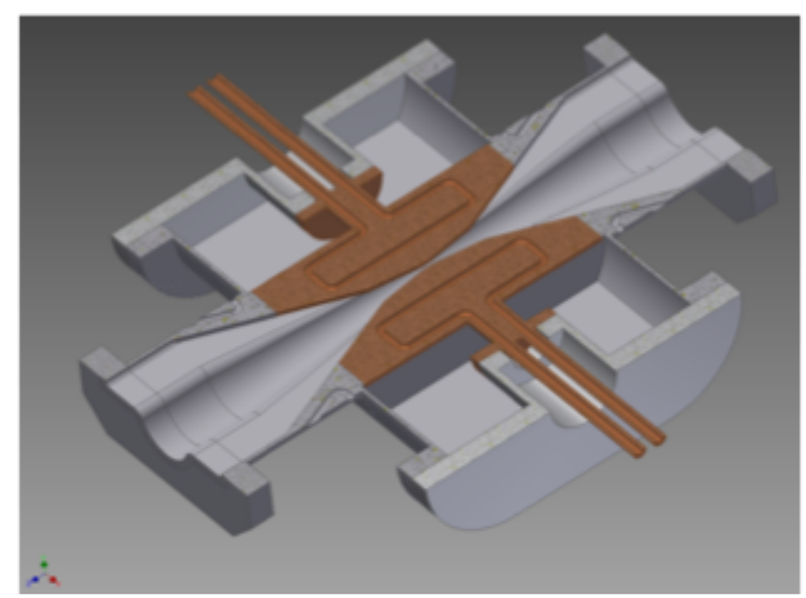
CEPC collimation system

CEPC



What shape?

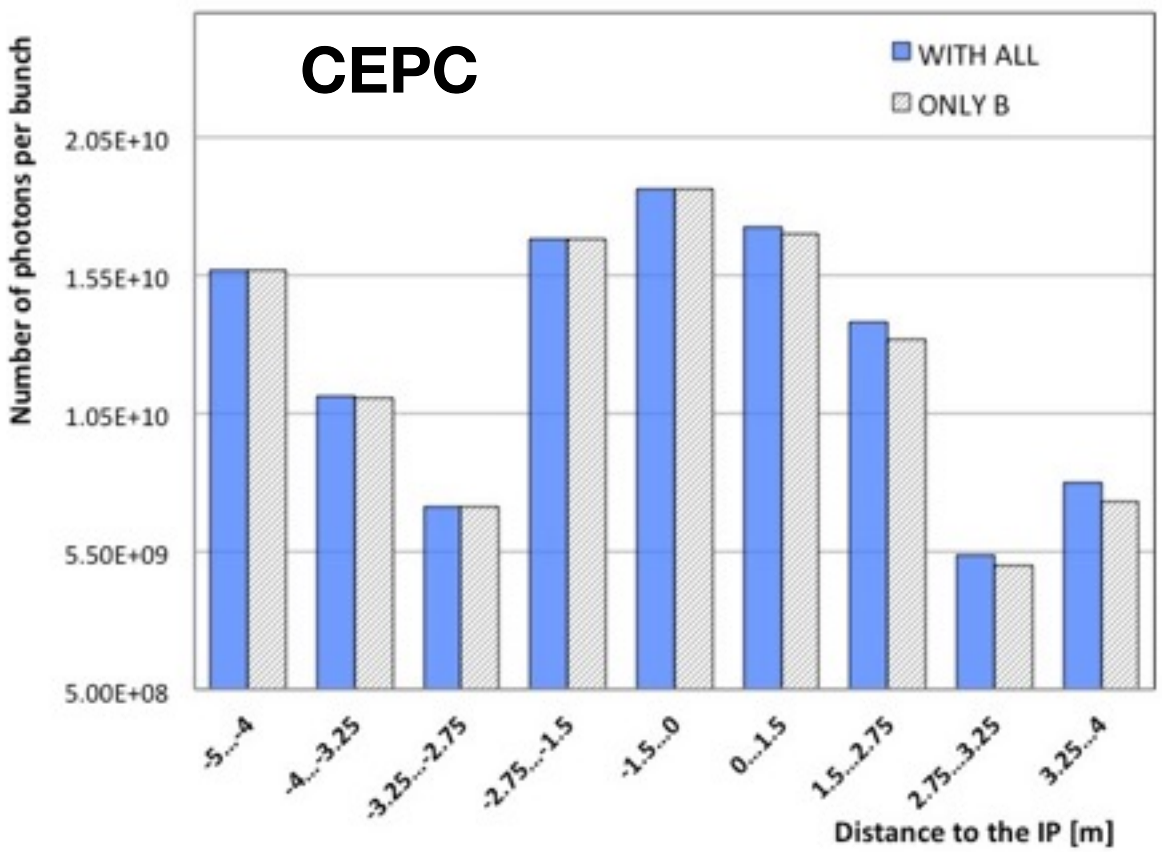
SuperKEKB Type
(PEP-II as reference)



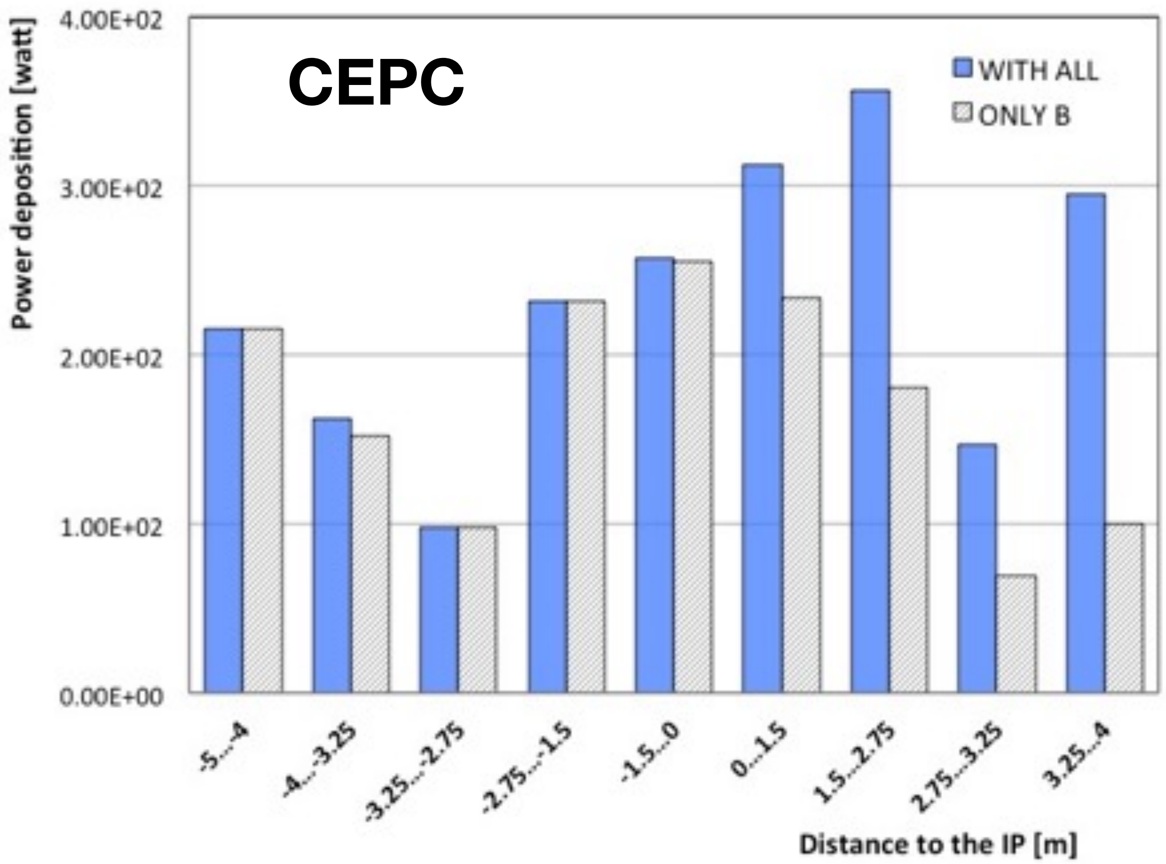
Synchrotron Radiation

- Beam particles bended by magnets emit Synchrotron Radiation photons, which are **non-negligible backgrounds at circular machines and requiring special consideration on protection of machine/detector**

Power deposition along the orbit

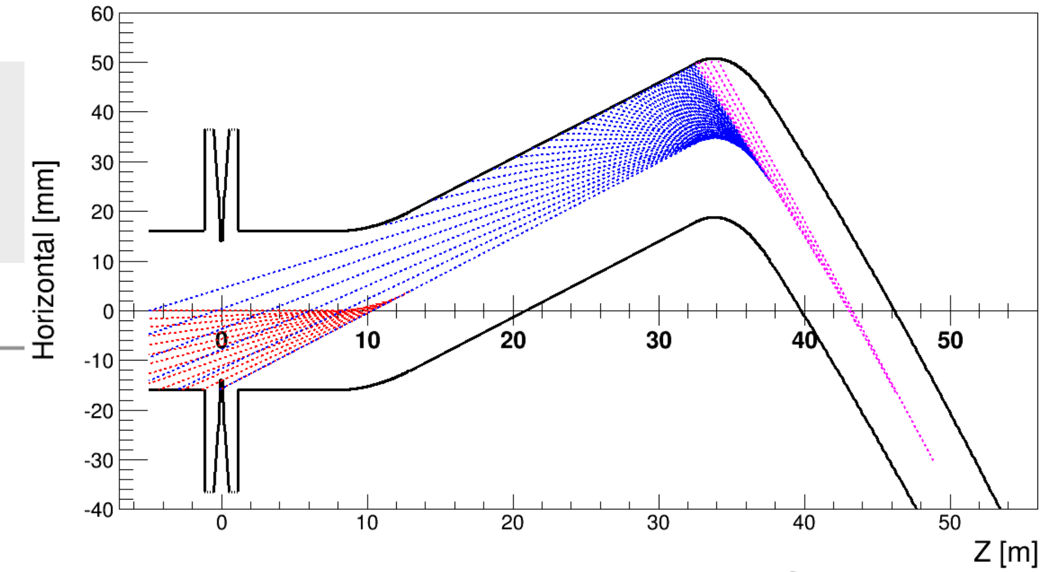


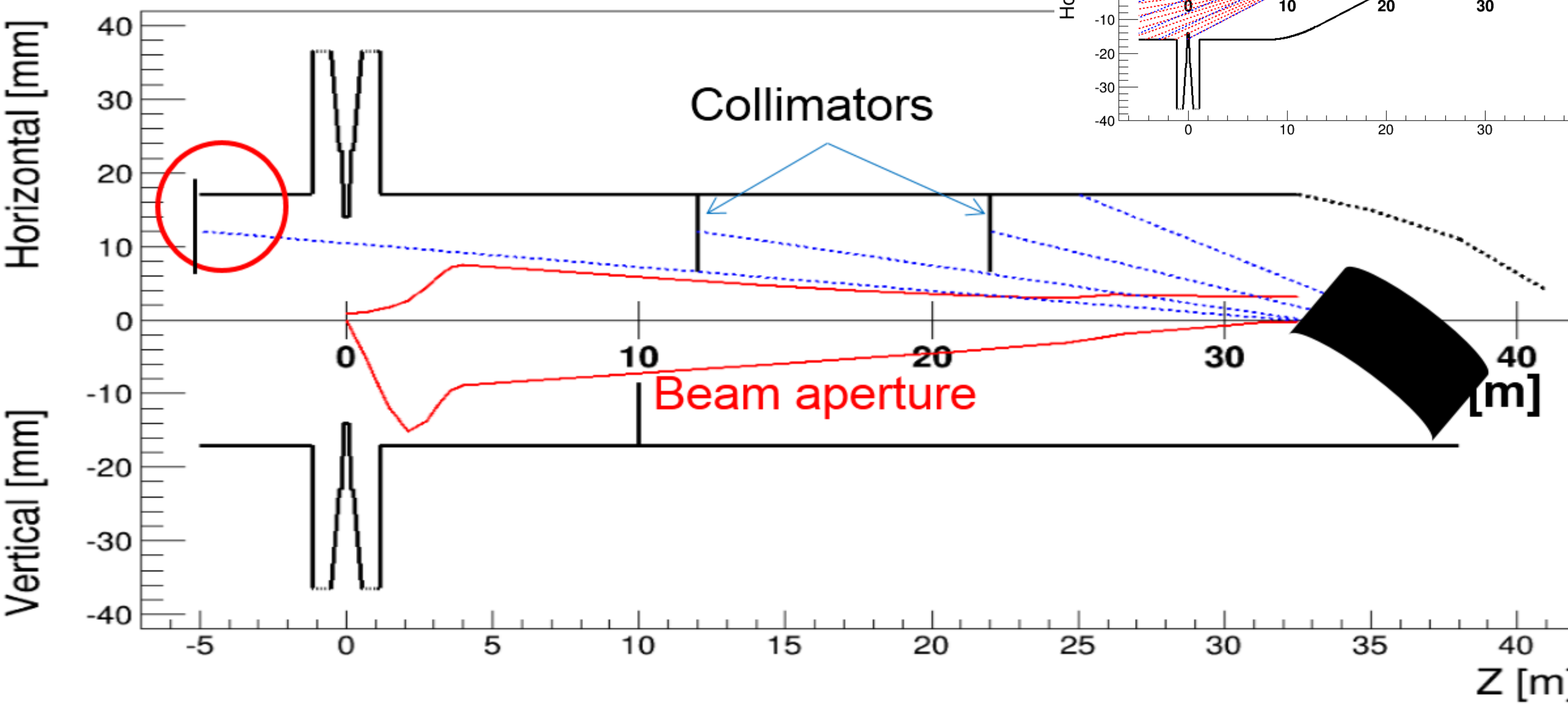
#SR photons along the orbit



Dominant contribution caused by the bending of the last dipole

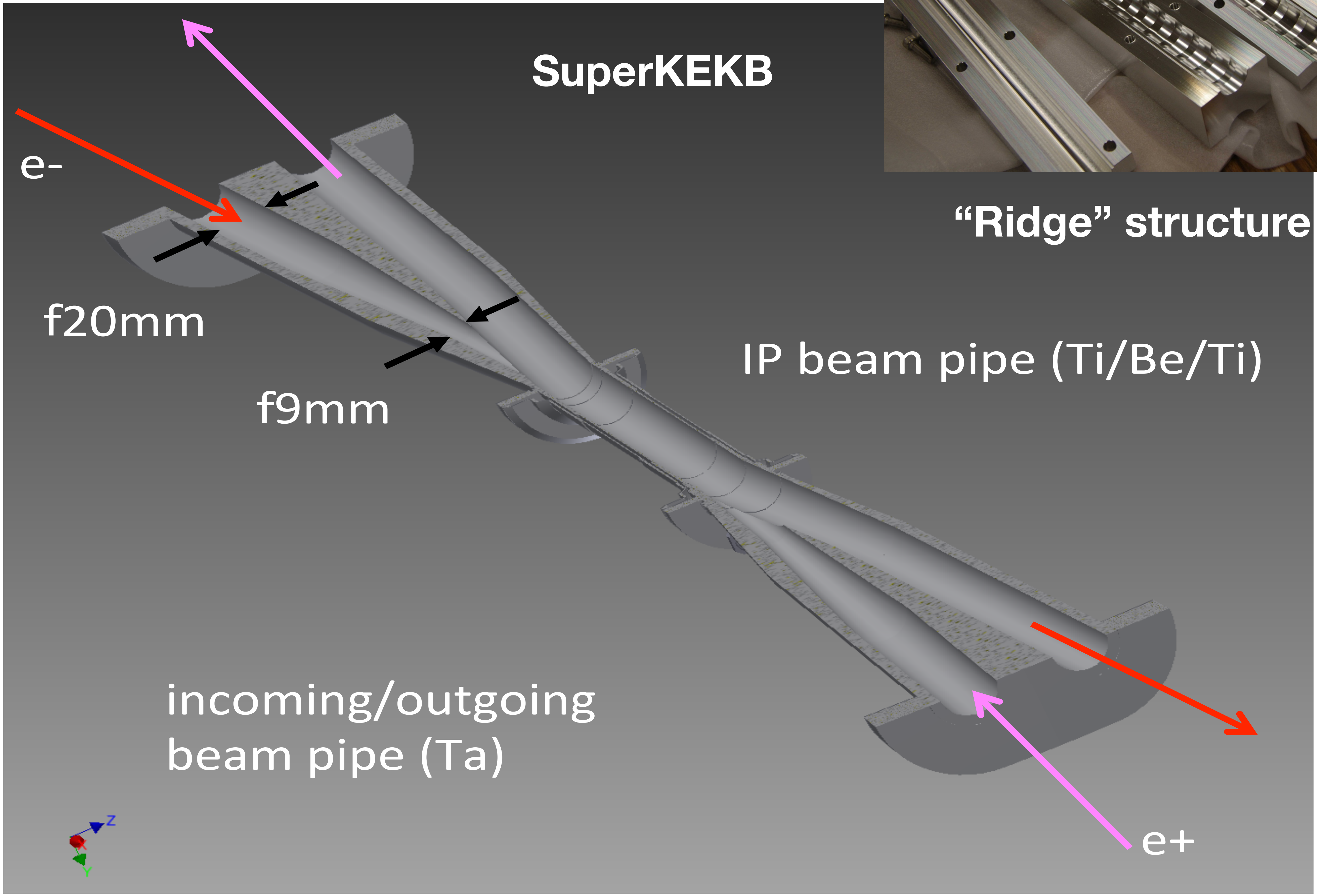
Synchrotron Radiation cont.

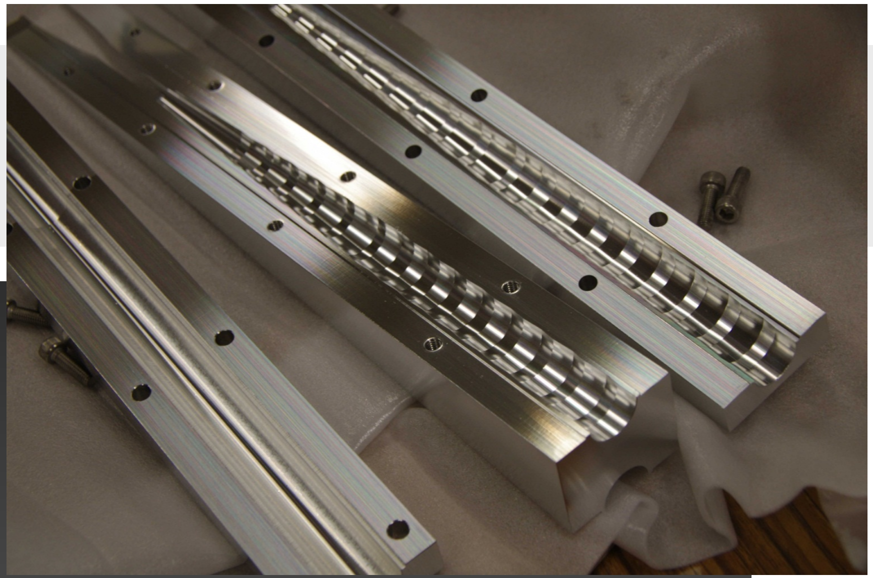




- Preliminary design of the CEPC collimation system inspired by the **LEP design** → suppress significantly the backgrounds
- Early thoughts of the collimator design (**shape, thickness …**)
- Difficult to prevent forward SR photons → **machine design optimisation**

SR Collimation

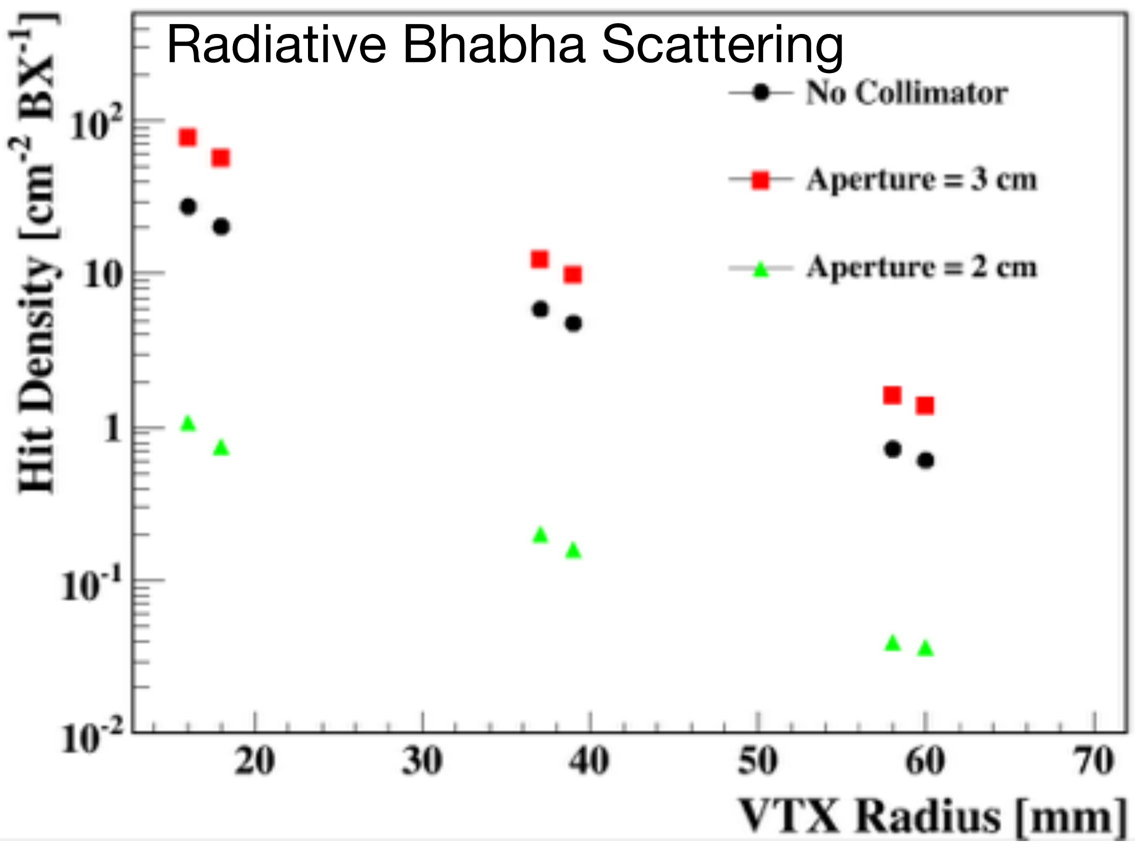


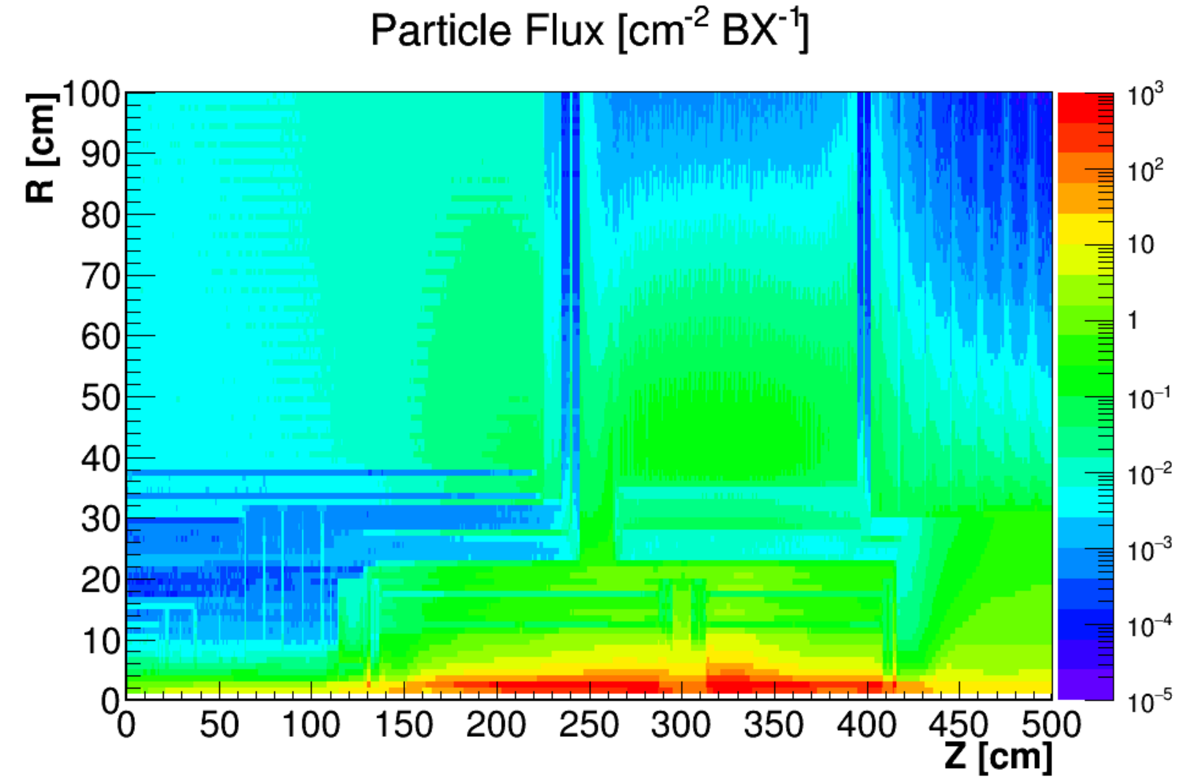


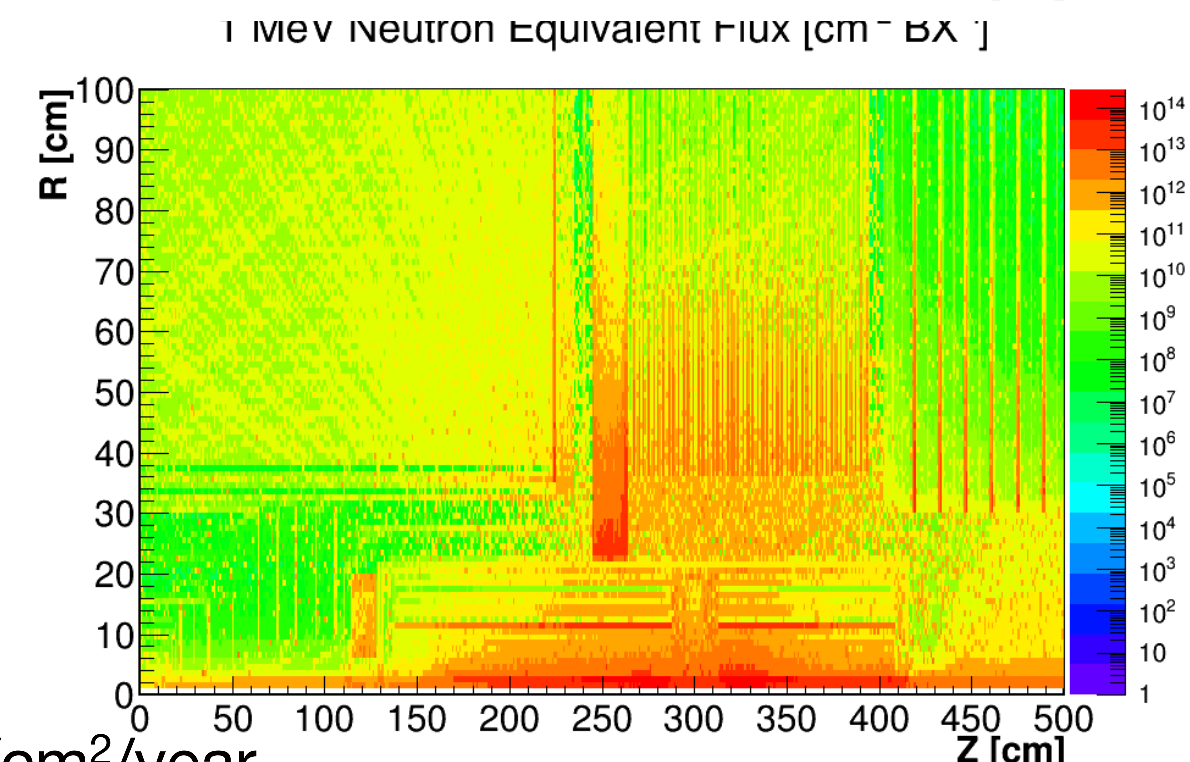
“Ridge” structure

Radiation Levels

- CEPC/ILC at the same level, benign compared to the (HL-)LHC standard







1st vertex detector layer r=1.6 cm (prel.):

- **Hit density** ~ 1 hits/cm^2/BX
- **Total ionisation dose (TID)**: 1 MRad/year
- **Non-ionisation energy loss (NIEL)**: 10^{12} neq/cm^2/year

Final Focusing Magnets

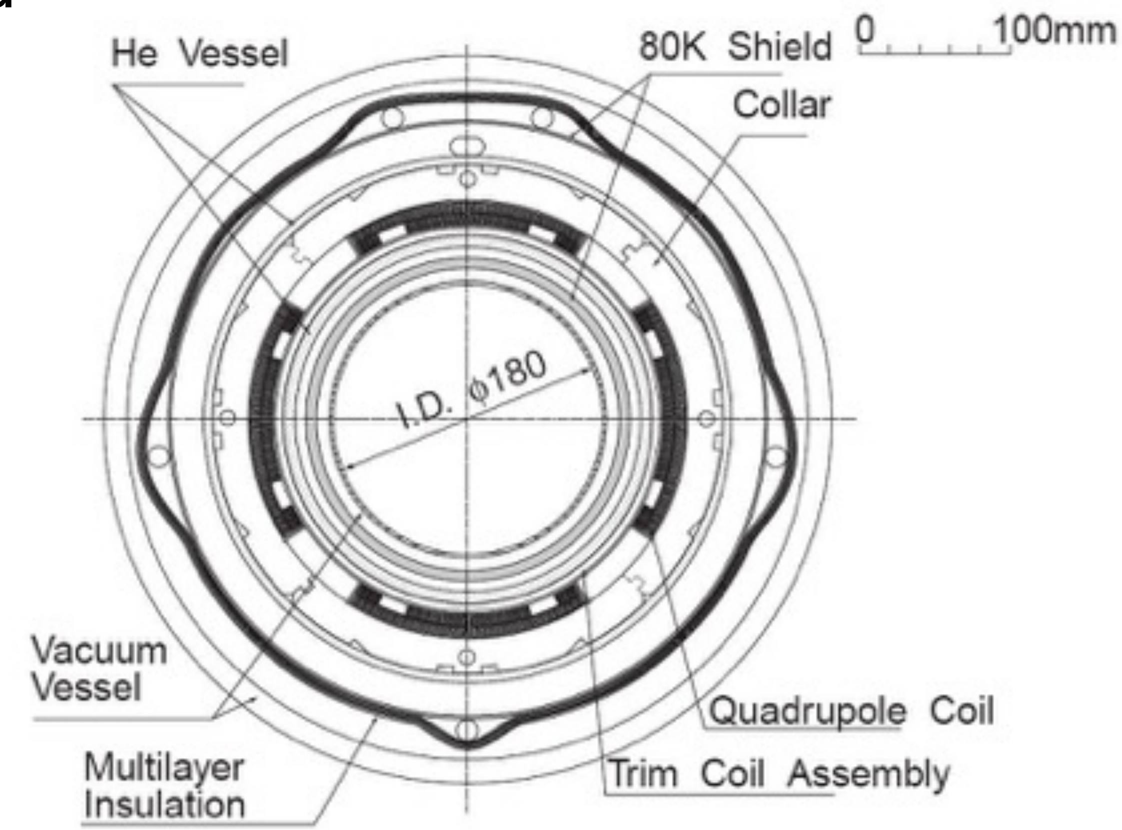
- **Final focusing magnets inside the CEPC detector due to short L***

Magnet	Length (m)	Field gradient (T/m)	Coil inner radius (mm)
QD0	1.25	304	20
QF1	0.72	309	20

- The magnetic fields at the pole region exceed 7T, and the two quadruple magnets are embedded inside the detector solenoid magnet of 3.5T → preferably with the **Nb_3Sn** technology
  - Coils in Rutherford type Nb3Sn cables clamped by stainless steel collar
  - Conceptual design performed based on typical quadrupole block coil; magnetic field calculated with OPERA from Cobham Technical Services.

Quadruple and Anti-Solenoid

- To minimise the impact of detector solenoid on beam stability, necessary to introduce anti-solenoid outside the quadruple
- Total integral longitudinal fields generated by the detector solenoid and anti-solenoid cancels out completely.



ILC prototype

- **Mechanical structure (superKEKB type)**
- CEPC of similar structure but higher magnetic fields, crossing-angle to be dealt with in the double partial ring design

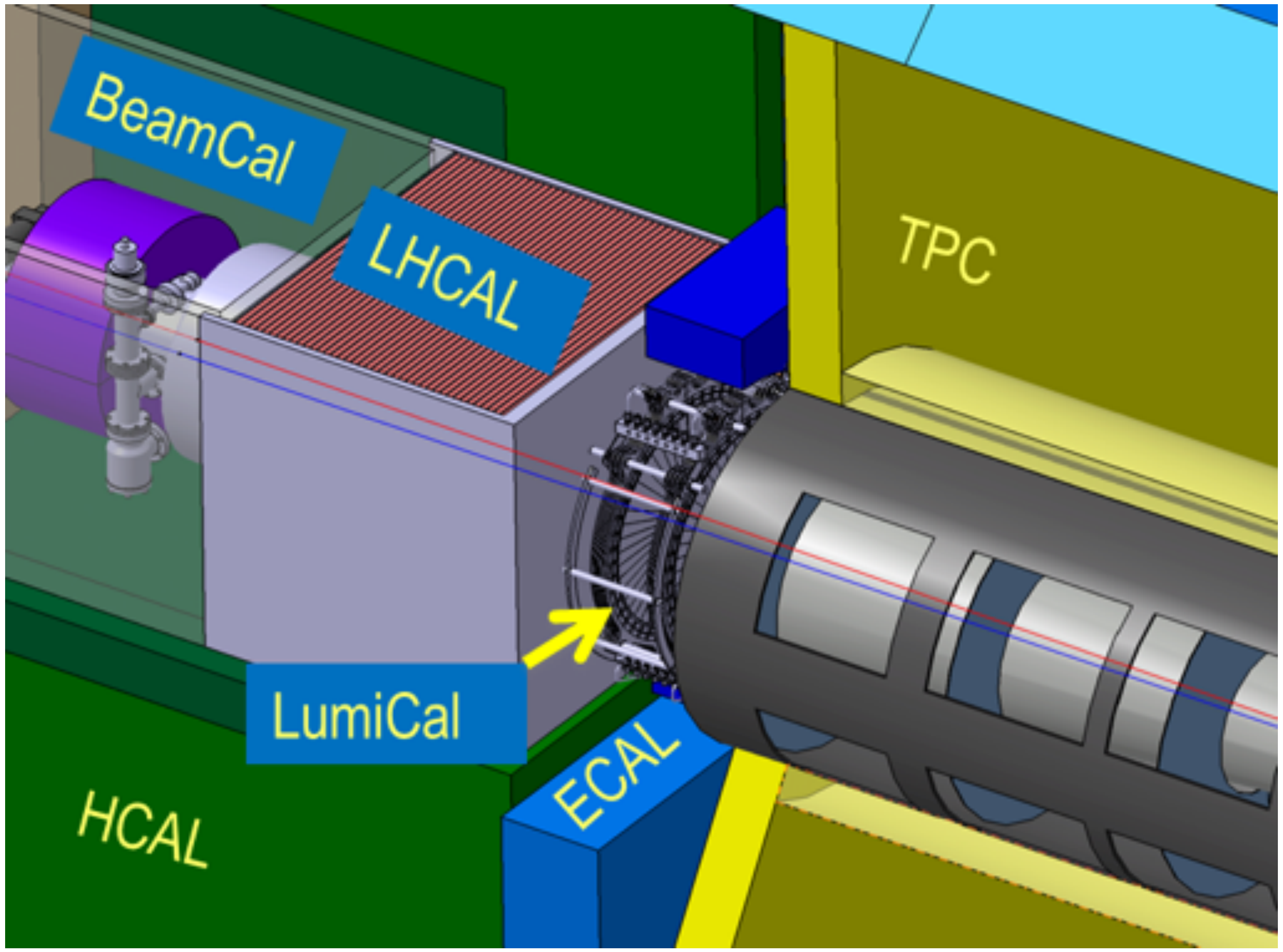
Luminosity Measurement

- Desired luminosity uncertainty of **~1‰** (achieved for LEP experiments!) as required by Higgs/Z precision measurements at CEPC/ILC
  - **LumiCal**: Calorimeter with silicon-tungsten sandwich structure to measure small angle radiative Bhabha scattering events
  - **Limited space before QD0 (CEPC)**: $z \in [115, 128$ cm$]$ and $\theta \in [60, 90$ mrad$]$ requiring angular precision of $\Delta\theta/\theta_{min} < 5\times10^{-4}$
  - **Other sources of uncertainties**: theoretical calculation of cross-section, polar angle bias, physics background subtraction, etc.

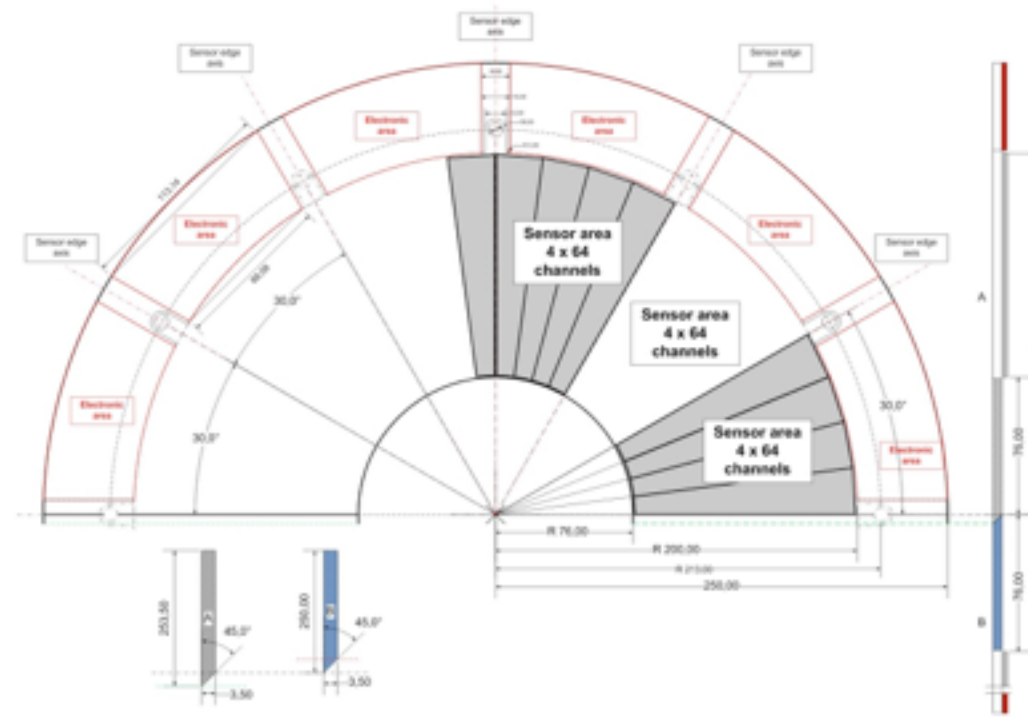
  → **Nontrivial to achieve the target luminosity uncertainty**
- Online luminosity monitor allowing fast tuning of beam parameters
  - Even smaller angle Radiative Bhabha scattering events: → **ILC (BeamCal)**
  - Radiation-hard sensors (e.g. CVD diamond) to measure radiative Bhabha events at zero photon scattering angle → **CEPC/SuperKEKB**

LumiCal

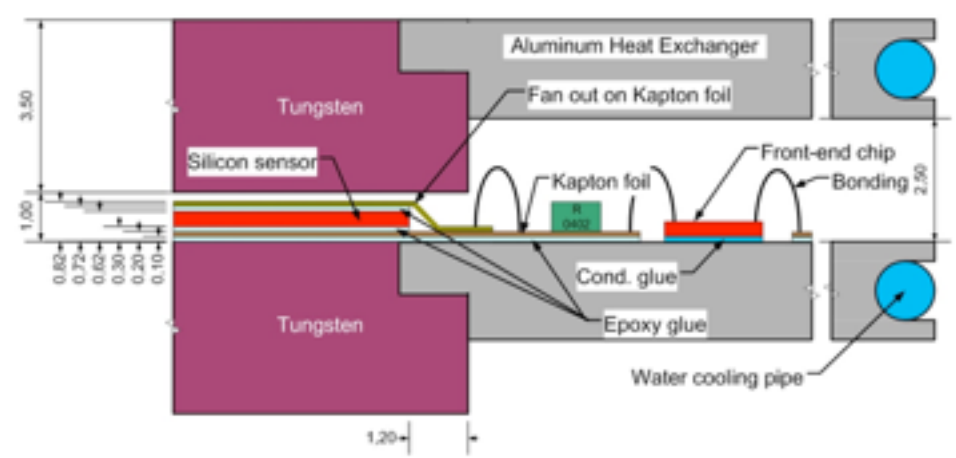
LumiCal for ILD



Layout of half plane



Sensor and electronics

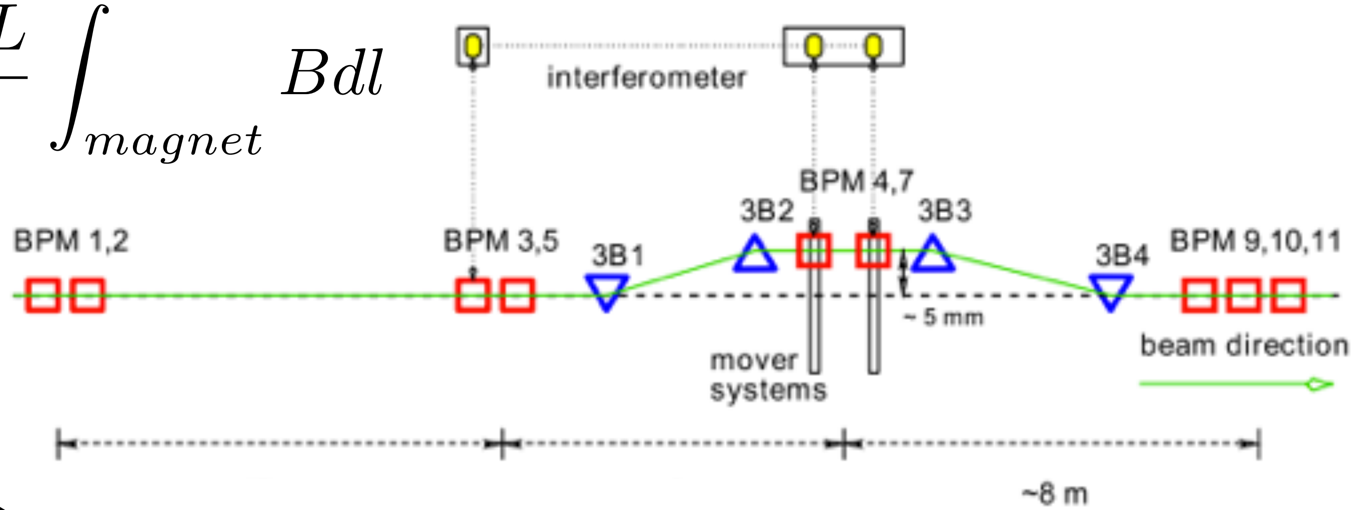


- Reference design for the CEPC LumiCal but even more challenging due to limited space in front of the final focusing magnets (**N.B.: no space at all for BeamCal**)

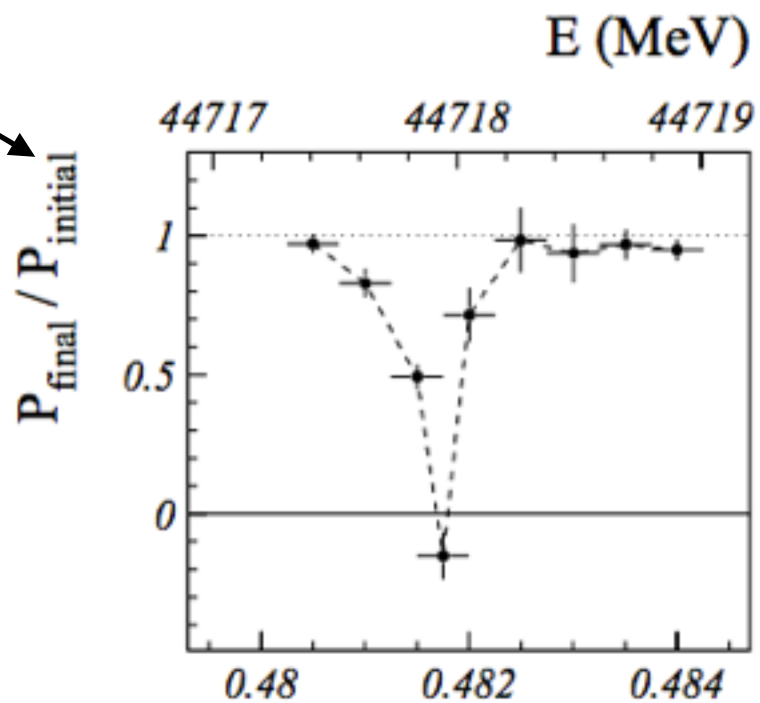
Beam Energy Measurement

- Important to determine precisely e.g. the Higgs mass
- **Which method?**

$$E_b = \frac{c \cdot e \cdot L}{x} \int_{magnet} Bdl$$



  - **Spectrometers** (LEP-II, ILC)
  - **Resonance depolarisation** (LEP)
  - **Laser Compton scattering** (ILC)
  - **Physics reference process** (LEP, ILC)
  - **…**



More discussion at this conference

- "***Energy Calibration Issues***" - Ivan Koop
- "***Polarization Free Methods for Beam Energy Calibration***" - Nikolay Muchnoi

- **Not yet clear how to measure the CEPC beam energy precisely (10^{-4})**

Summary and Outlook

- Necessary to **re-design the interaction region** ← partial double ring (large crossing-angle) and new detector layout
- Performed the first round of **radiation background estimation** and started to repeating the studies for partial double ring (workable lattice), together with **conceptual design of the collimation system**
- To achieve **complete magnetic field (detector solenoid and anti-solenoid) cancellation** and conceptual design of QD0 (likely even more complicated for double partial ring)
- More practical thoughts on **forward detectors (e.g. LumiCal)** and initiate early R&D efforts on detector/electronics
- To find an appropriate way to **measure the beam energy precisely**

- **Adding more to the long to-do list**: Beampipe, mechanics …