# CEPC Machine-Detector Interface

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Joint efforts between Detector and Accelerator Groups

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# Machine Detector Interface

- The CEPC Machine Detector Interface (MDI) shall cover all aspects that are of common concern to both detectors and the machine, including:
  - beam induced background
  - interaction region design
  - beam pipe design
  - forward calorimeters
  - shielding
  - experimental area layout, platforms
  - common assembly procedures
  - …

  } touched in this talk (beam induced background, interaction region design, beam pipe design, forward calorimeters)

- More detailed work shall follow …

Q. XIU

# Beam Induced Background

- Background from beam-beam interaction and beamstrahlung
  - electron-positron pair production
  - quark pairs → minijets

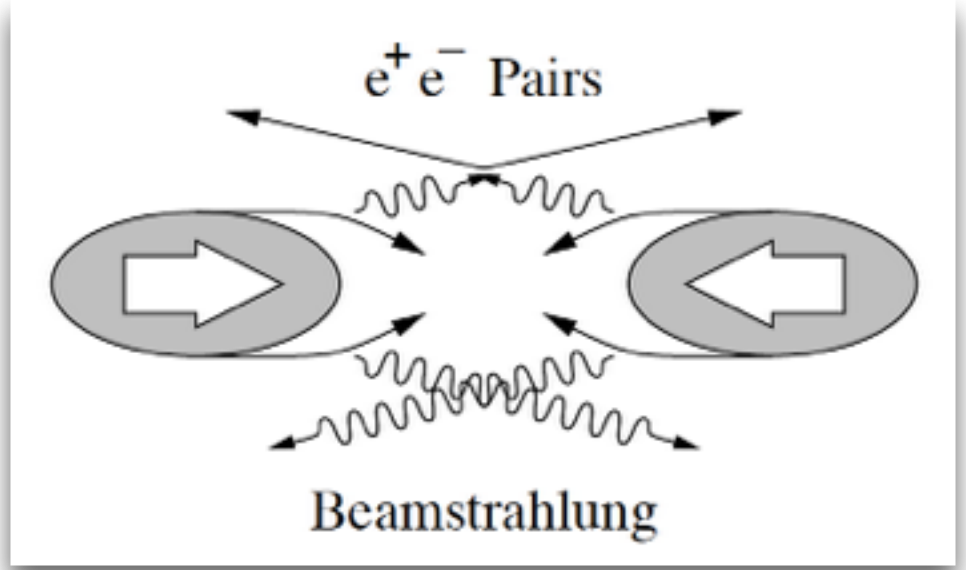



illustration of beam-beam interaction and beamstrahlung and pair-production

- Other background sources include:
  - radiative Bhabha scattering
  - beam halo muons
  - synchrotron radiation
  - beam-gas interaction
  - beam dumps

(beam halo muons, synchrotron radiation, beam-gas interaction, beam dumps:) shall be minimised by optimal machine design

# Simulation with Guinea-Pig

- **G**enerator of **U**nwanted **I**nteractions for **N**umerical **E**xperiment **A**nalysis—**P**rogram **I**nterfaced to **G**EANT → one of the standard tools for the simulation of beam-induced backgrounds

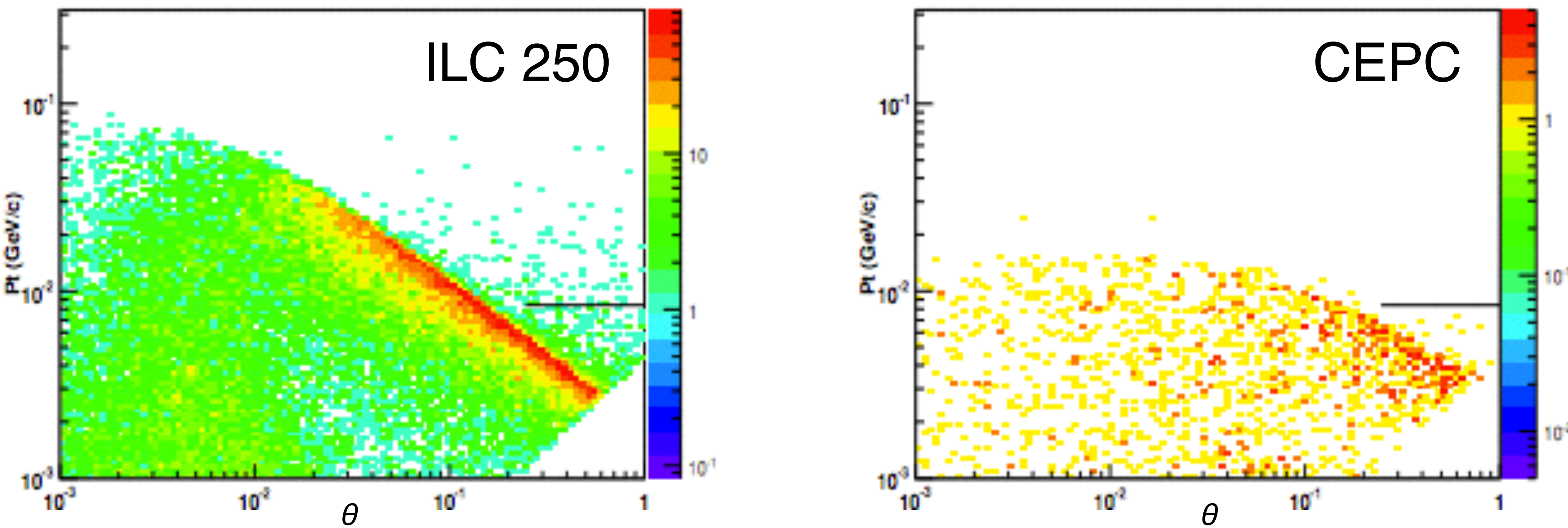
- Input machine parameters for CEPC and ILC (cross-checks with published results)

| Collider | E | N/bunch | σ | σ |
|---|---|---|---|---|
| ILC 250 | 250 | 2 × 10 | 729/7.7 | 300 |
| CEPC | 240 | 3.7 × 10 | 73700/160 | 2260 |

- Comparison with other generator programs in future studies

# Results with Pair-Production

particle density : $p_T$ vs polar angle; black lines indicate the vertex detector coverage in polar angle

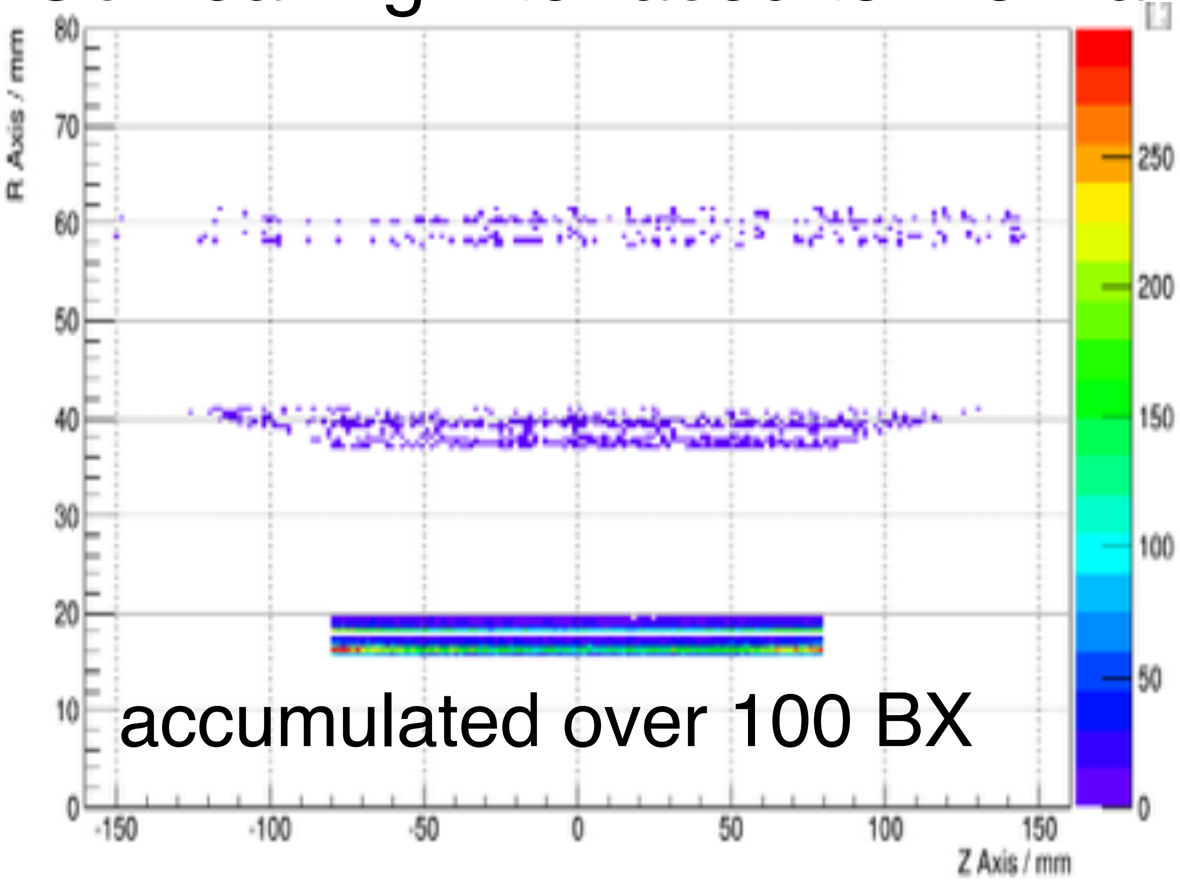



- Preliminary studies confirm much lower beam-induced background for CEPC compared to ILC ← much smaller beamstrahlung due to large bunch size

# Hit Density: Vertex Detector

- The vertex detector needs to be placed as close as possible to the interaction point (better IP resolution) → most vulnerable to radiation background
  - detector occupancy, double-hit probability, radiation tolerance …

Guinea-Pig interfaced to Mokka




hit density for 1st layer (r=16mm):

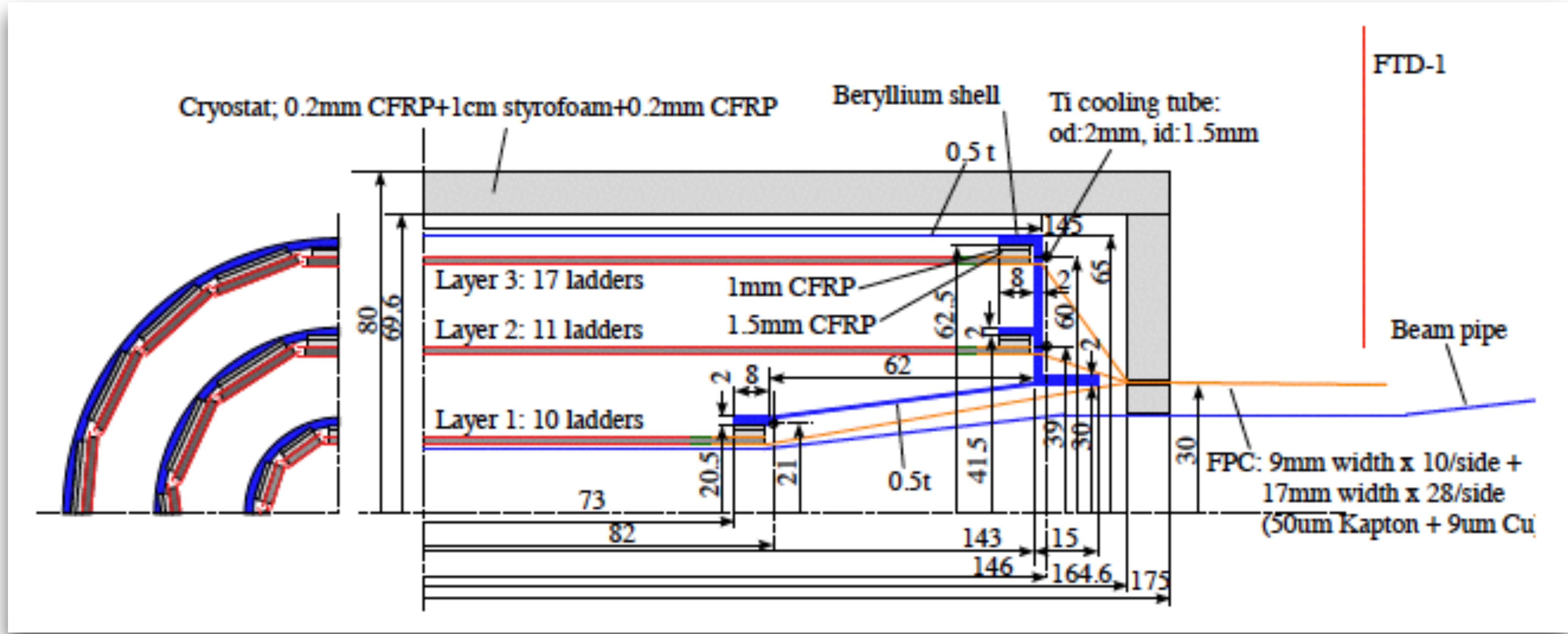
0.02/mm²/BX (CEPC)

0.08/mm²/BX (ILC 250)

lower detector occupy
less radiation damage

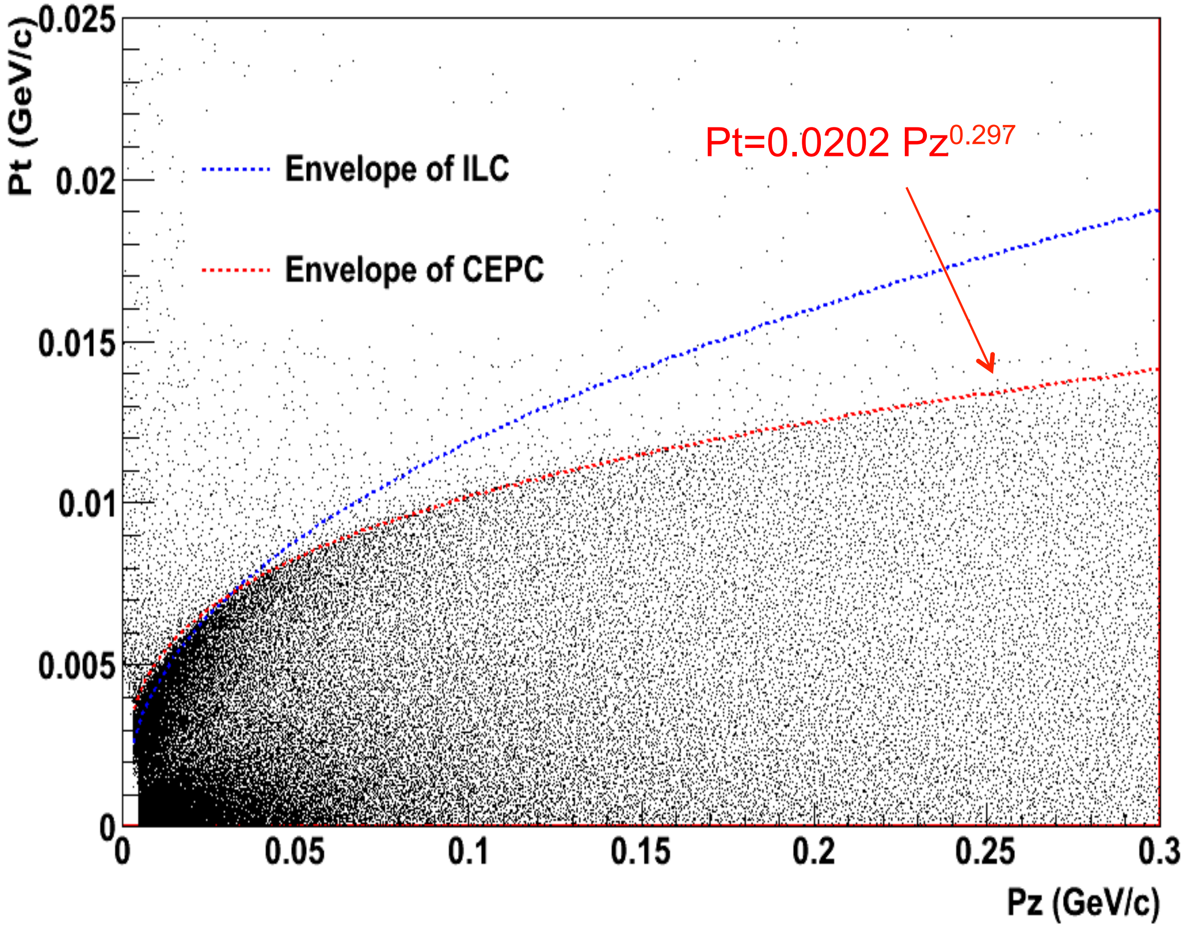
Can we place the vertex detector more closer to the IP ?

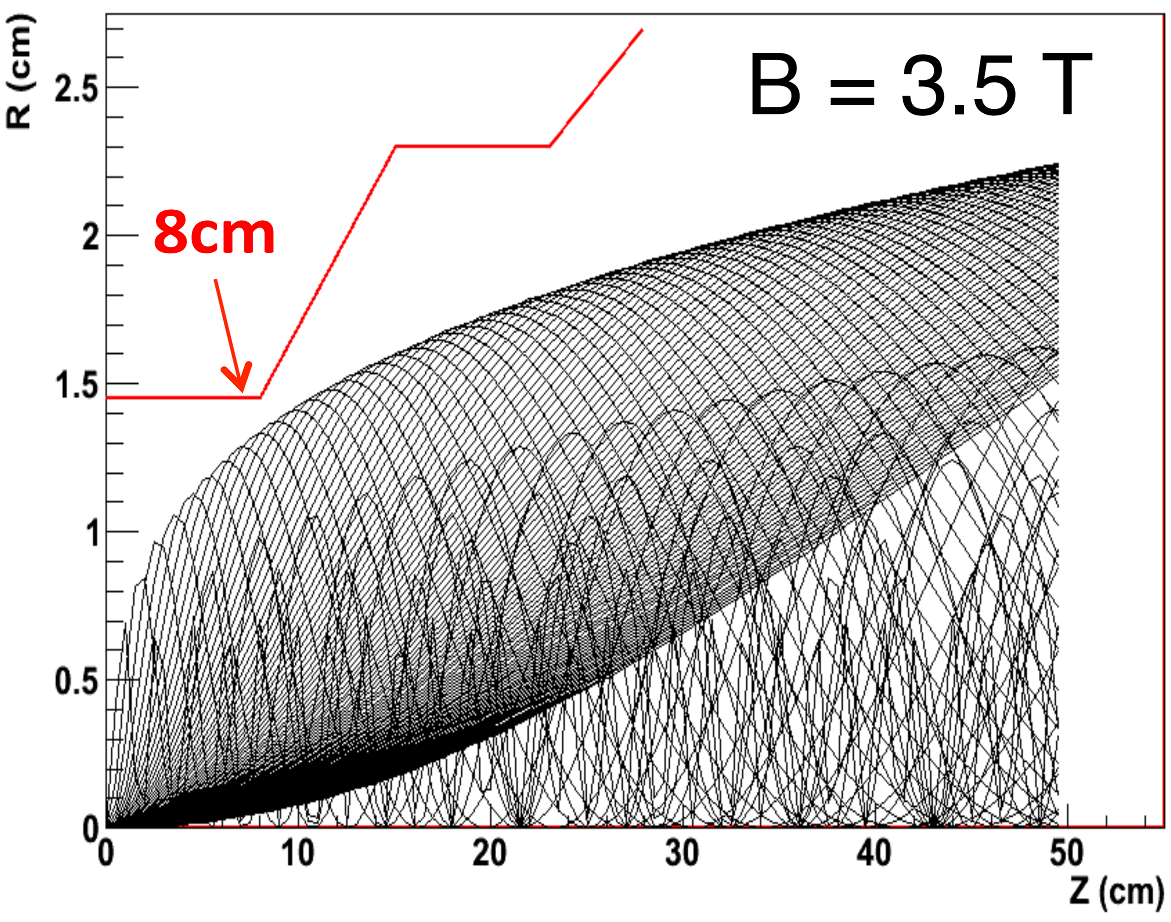
# Closer to IP




- The 1st layer of the layer of the vertex detector is nearly mounted on the beam pipe ($r$ =14.5 mm) ← what defines the position/radius of the beam pipe?
  - beam dynamic aperture → discussed in IR design
  - pair-edge of beam-induced background → next slide

# Pair Edge



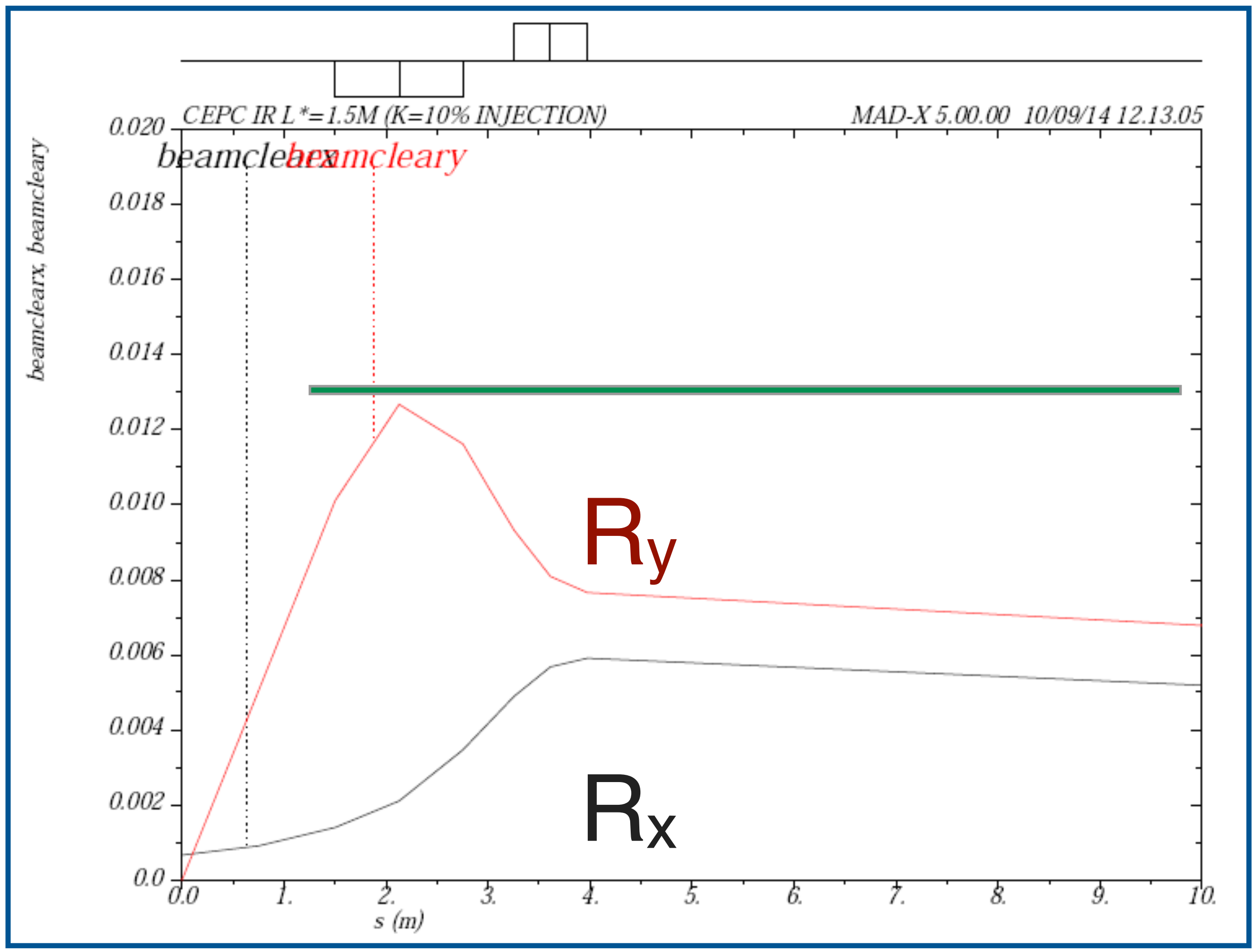

- Pairs develop a sharp edge and the beam pipe must be placed outside the edge
- Fit analytical function of the edge in $p_T$-$p_z$ and draw helices in r-z, taking into account the crossing angle and solenoid field

# A Few Thoughts

- It is possible to place the beam pipe closer to the IP, and so the 1st layer of the vertex detector
  - beam-induced background: detector occupancy, radiation level and pair edge ← less crucial compared to ILC
  - shorter layer preferred ← as demonstrated by SiD design
- To fully benefit from the shorter distance to IP, the following issues (and more) need to be addressed:
  - higher spacial resolution of pixel sensors: current $\sigma_{SP}$ ~ 2.8 µm (*previous study shows negligible improvement after placing the 1st layer possibly due to the limited resolving capability*) → even more challenging for sensor design
  - Beryllium beam pipe with small radius and thin wall → challenging for machining and resistance to vacuum pressure

# Final Doublet

- Beam stay-clear region
  - $R_x=5*\sigma_{x\_inj}$, $R_y=5*\sigma_{y\_inj}$
  - $\sigma_{x\_inj}$=21.8nm, $\sigma_{y\_inj}$=2.2nm (assuming 10% coupling for injection beam)
  - Inner radius of vacuum chamber at QD0 and QF1: 1.3 cm




L* = 1.5 m ← new baseline design

QD0: L=1.25 m, R=1.3 cm, G=-300 T/m

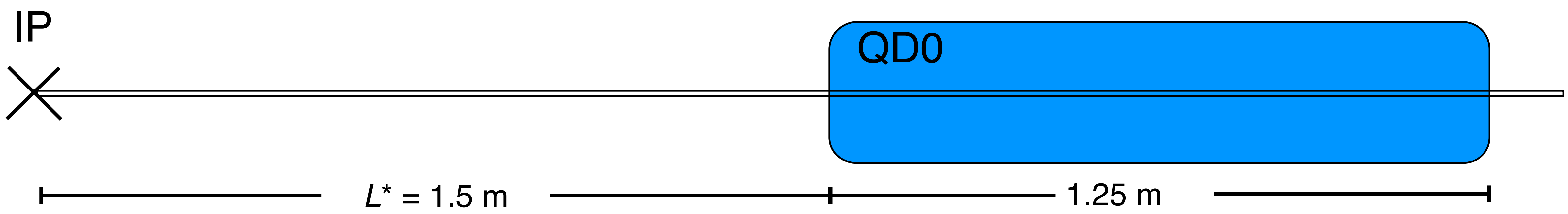
D2 = 0.5 m

QF1: L = 0.72 m, R=1.3 cm, G=300 T/m

Impacts on detector design

# Why Small L*?

- $L^*$ defines the distance between first quadruple (QD0) to the interaction point



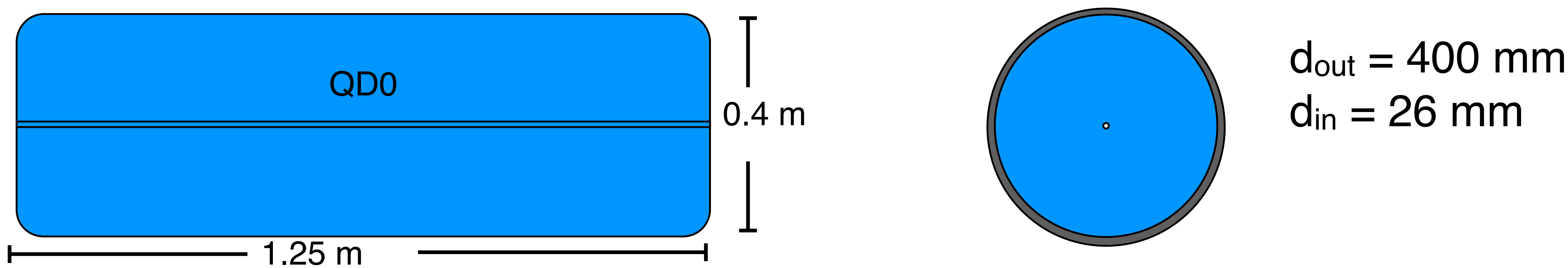

- Pros: small $\beta_y^{max}$ and $\xi_y$ → to realise the design luminosity

$$\beta_y^{max} \propto \frac{L^{*2}}{\beta_y^*} \qquad \xi_y \propto \frac{L^*}{\beta_y^*}$$

- Cons: degraded detector performance (more challenges and difficulties in detector design, and more …)

# QD0 Design

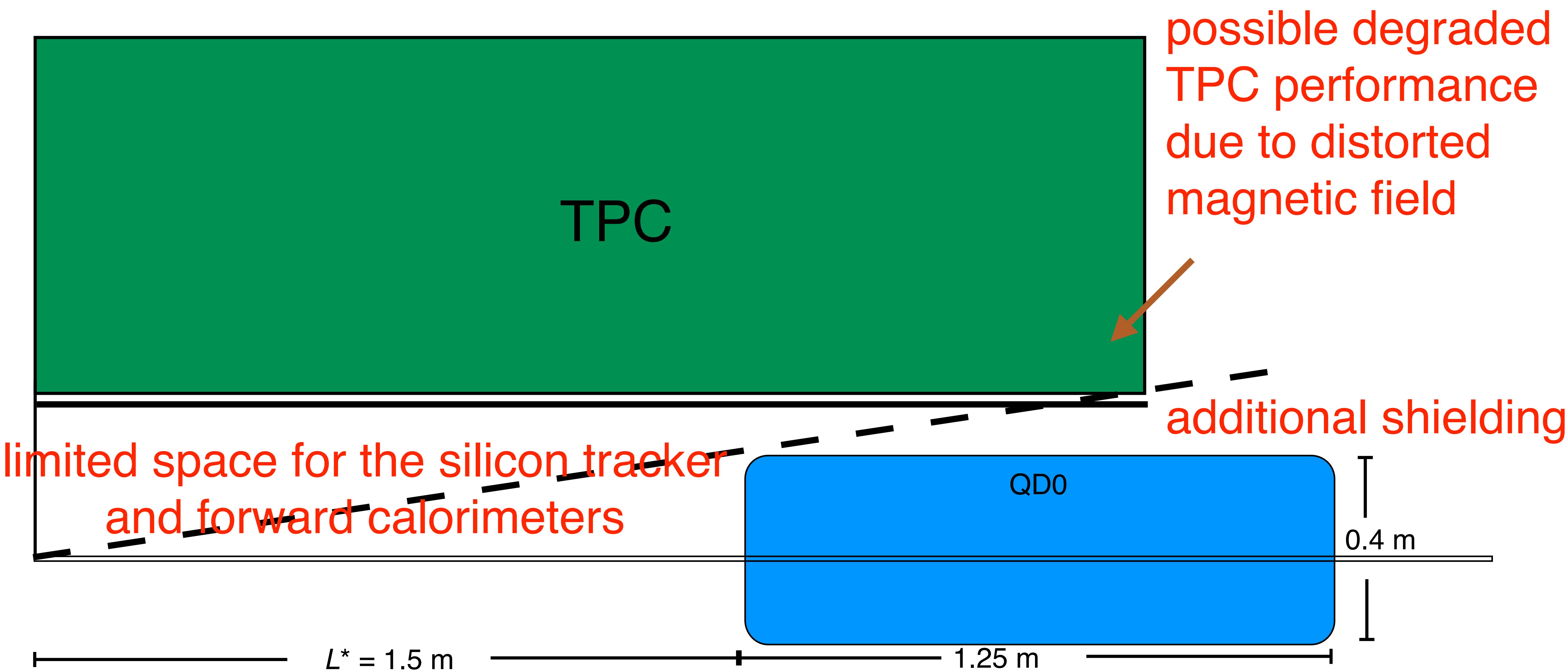
*Y. ZHU*




- The latest final doublet configuration requires magnetic field strength of ~4 T + additional compensation for the detector solenoid field 3-4 T → superconducting magnets
- Difficult to achieve the desired magnetic field with matured NbTi technology (heat load induced by synchrotron radiation?) but less cost-effective with advanced $Nb_3Sn$
- More realistic and detailed design, including cooling and shielding, need to get started…

# Constraints on Detector Design

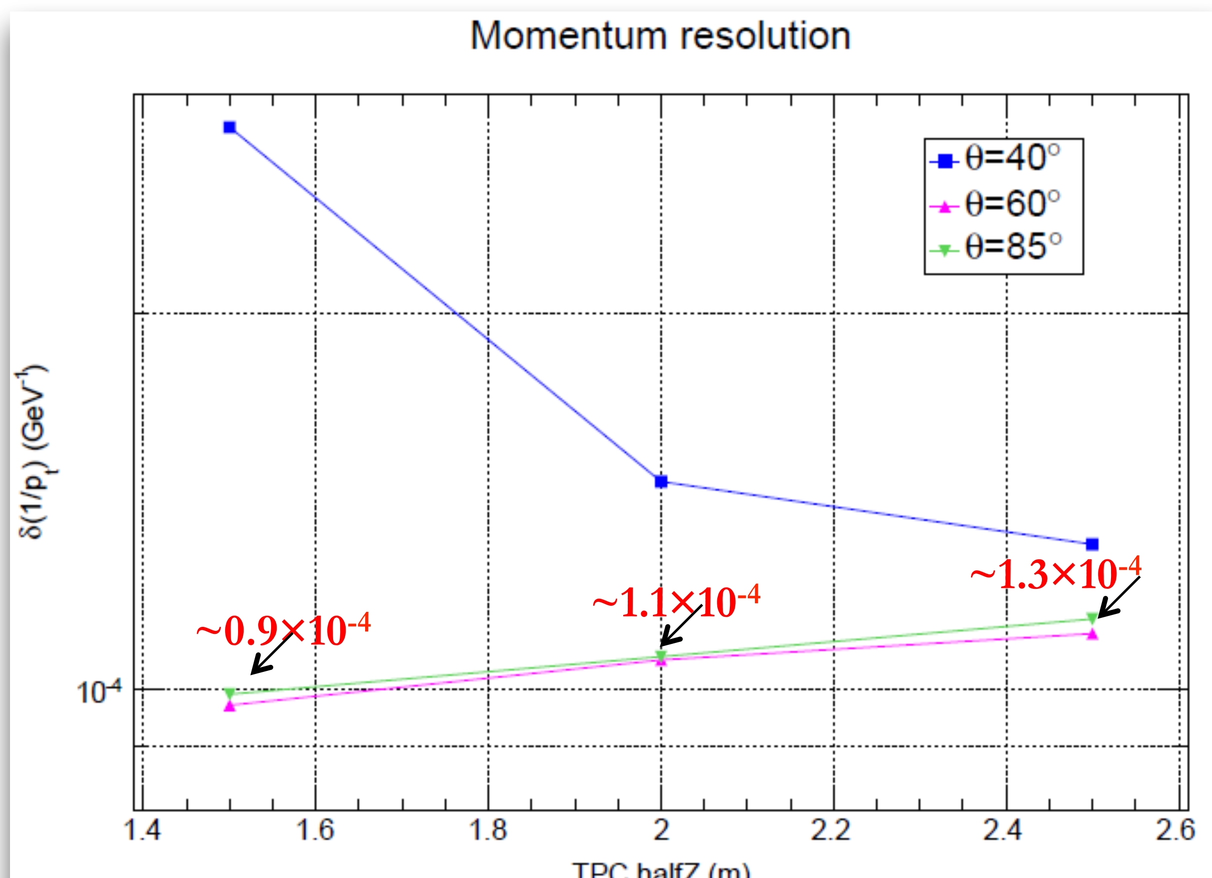
- The shorter L* imposes several challenges on the detector design (layout) and might result in degraded performance.



# Impacts on TPC

*H. Qi*

- With the assumed diameter of QD0, *i.e. d*=400mm, there seems to be minor loss in polar angle coverage
- TPC performance might degrade due to distorted magnetic field (partially recoverable in reconstruction software, but only if the magnetic field can be precisely determined).



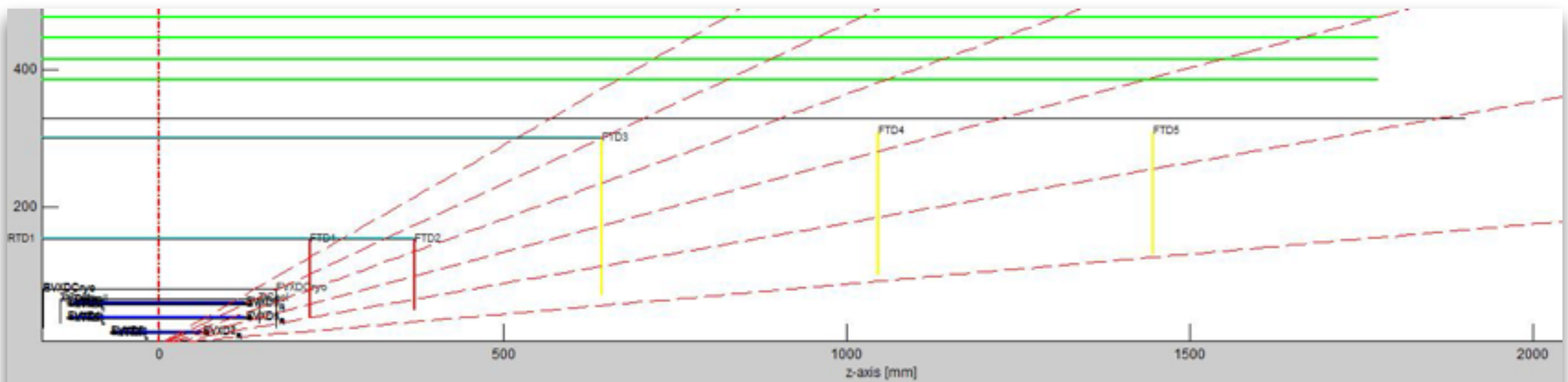

**additional concerns:**

- magnetic field design
- support structure
- particle showering
- shielding (scattering particle)
- …

# Impacts on the Silicon Tracker

*B. Liu*

- The vertex detector, given its current position, can be left untouched (improved performance if closer to IP).
- The silicon tracker needs to be redesigned given limited space after insertion of QD0, e.g. dropping the last two disks.

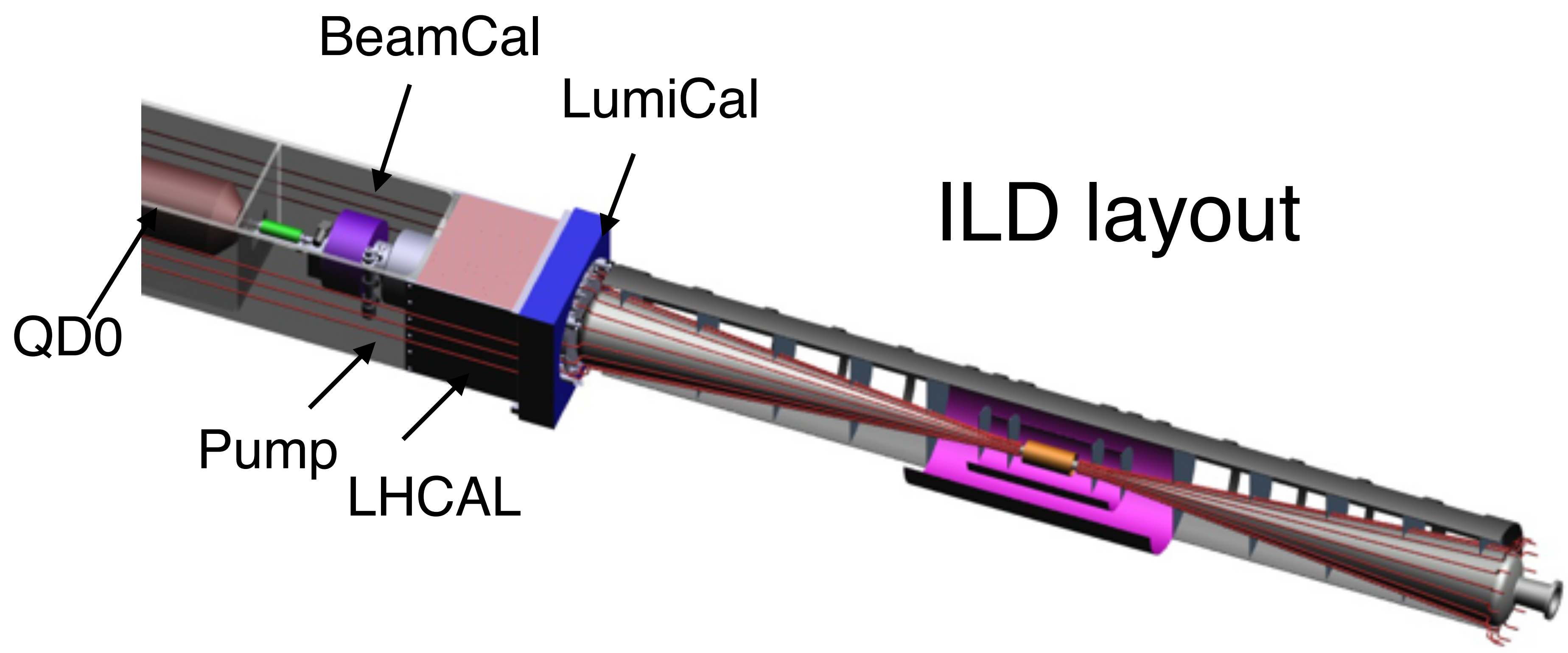



- Preliminary study shows worse IP resolution after removing the last two disks, but can be saved by adding one more pixel disk → challenges on mechanical design/cable routing

# Impacts on Calorimeters

- ~~Extension in polar angle coverage by LHCal~~
- Insertion of QD0 should not affect much the performance of calorimeters (larger inner radius of end-cap calorimeter to allow QD0 to get through)
- Any mechanical concerns?

# Impacts on the Forward Calorimeters




- LumiCal: precise luminosity measurement ($10^{-3}$)
- BeamCal: online luminosity monitor (10% accuracy)
- LHCAL: extension in coverage of HCAL

$L^* = 1.5$ m

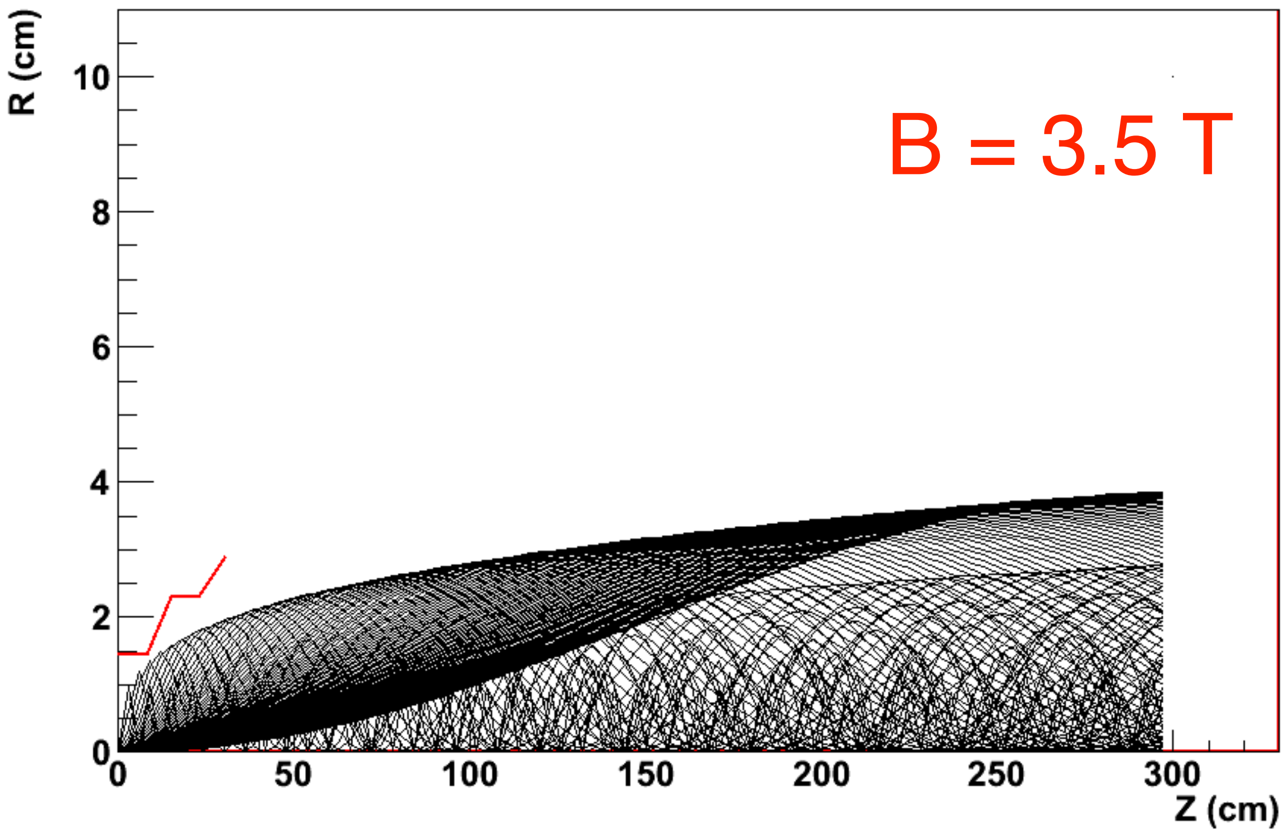
Impossible to accommodate all these forward calorimeters!

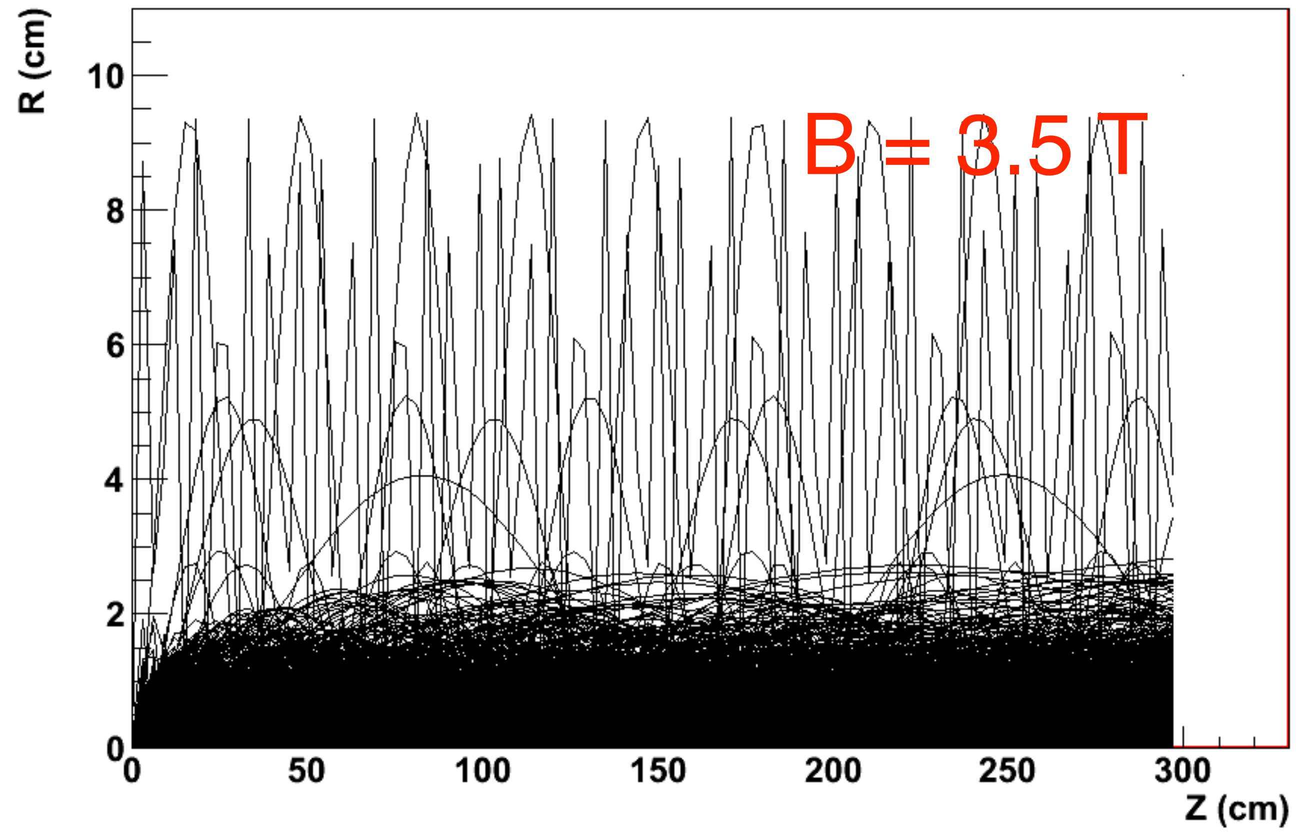
# LumiCal

- Essential to precise luminosity measurement $\Delta L/L \sim 10^{-3}$
  - mainly required by W/Z precision measurements
- Determine luminosity by counting Bhabha scattering events in the small angle region but should avoid beamstrahlung photons → preferred coverage: 30 - 90 mrad

- The insertion of QD0 forces LumiCal to move toward IP and reduce both inner and outer radii (compared to ILD/SiD) to reserved the required polar angle coverage. But by how much?

# Constraints on the LumiCal




- Starting position at $z$ =135 cm and longitudinal length of $l$ = 13 cm ← layers to contain the shower (only 2 cm before QD0 ?)
- Inner radius: 4~8 cm ($z$ = 135 cm) ← away from pair-edge
- Outer radius: 17.5 cm ← no further loss in polar angle coverage after inserting QD0

# Counting Bhabha Events

- Bhabha cross-section:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2E_{cm}^2}\left[\frac{1+\cos^4\frac{\theta}{2}}{\sin^4\frac{\theta}{2}} - \frac{2\cos^4\frac{\theta}{2}}{\sin^2\frac{\theta}{2}} + \frac{1+\cos^2\theta}{2}\right]$$

- Number of Bhabha events:

$$N = L\int d\sigma = L\frac{\pi\alpha^2}{E_{cm}^2}\int_{\theta_{min}}^{\theta_{max}}\left[\frac{1+\cos^4\frac{\theta}{2}}{\sin^4\frac{\theta}{2}} - \frac{2\cos^4\frac{\theta}{2}}{\sin^2\frac{\theta}{2}} + \frac{1+\cos^2\theta}{2}\right]\sin\theta d\theta$$

| Inner Radius (cm) | r=4 | r=5 | r=6 | r=7 |
|---|---|---|---|---|
| Fiducial θ (mrad) | 43~80.6 | 50.5~80.6 | 57.9~80.6 | 65.3~80.6 |
| Bhabha events/s | 124.9 | 77.3 | 46.9 | 26.2 |
| SiD: E | | | | |

Statistical precision can be preserved!

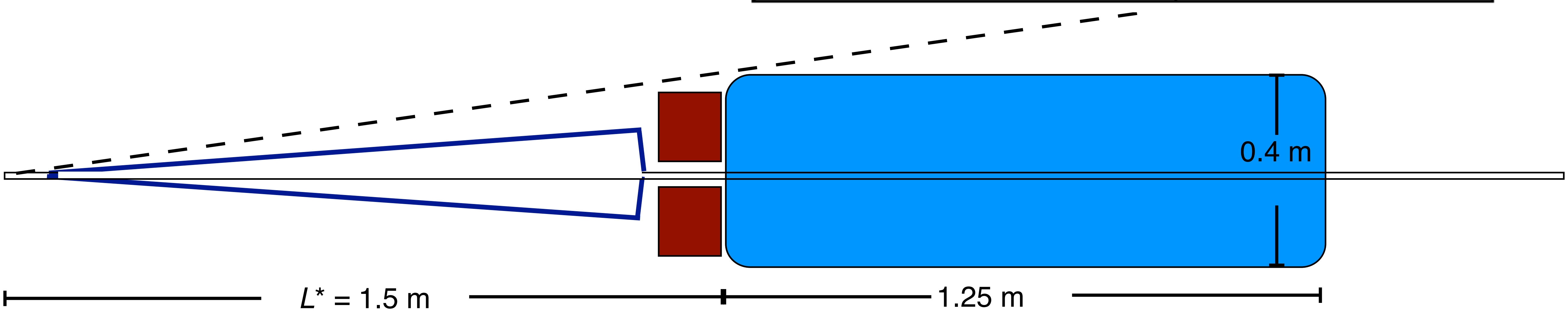
# LumiCal Location

- The polar angle coverage together with the CEPC beam conditions allow even smaller statistical uncertainty. But how about the total uncertainty?

Statistical uncertainty is only one of the many sources!

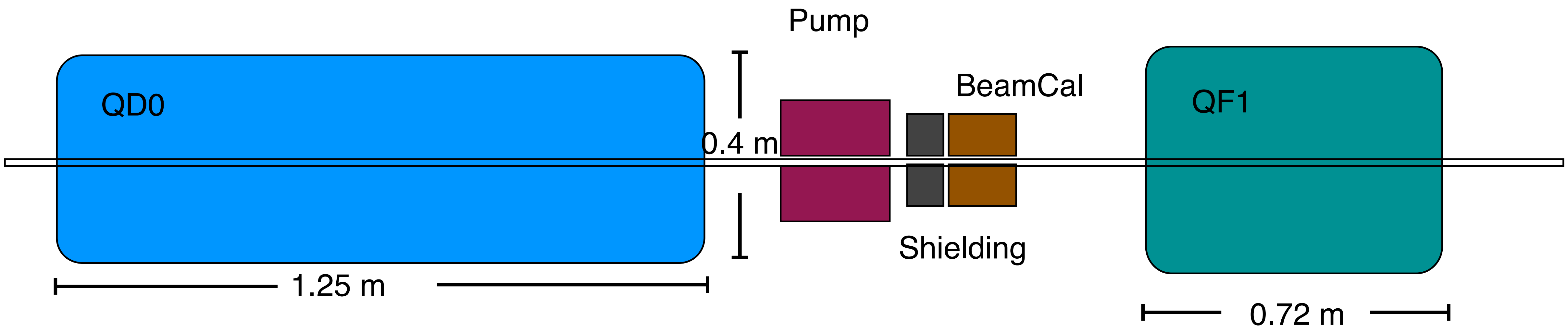
**arXiv:1006.2539**

| Source of uncertainty | $\Delta L/L$ |
|---|---|
| Bhabha cross-section $\sigma_B$ | $5.4\ 10^{-4}$ |
| Polar angle resolution $\sigma_\theta$ | $1.6\ 10^{-4}$ |
| Bias of polar angle $\Delta\theta$ | $1.6\ 10^{-4}$ |
| Energy resolution $\alpha_{res}$ | $1.0\ 10^{-4}$ |
| Energy scale | $1.0\ 10^{-4}$ |
| Physics background B/S | $2.3\ 10^{-3}$ |
| BHSE | $1.5\ 10^{-3}$ |
| Beam polarization | $1.9\cdot10^{-4}$ |
| **$\Sigma$** | **$3.0\ 10^{-3}$** |



# BeamCal

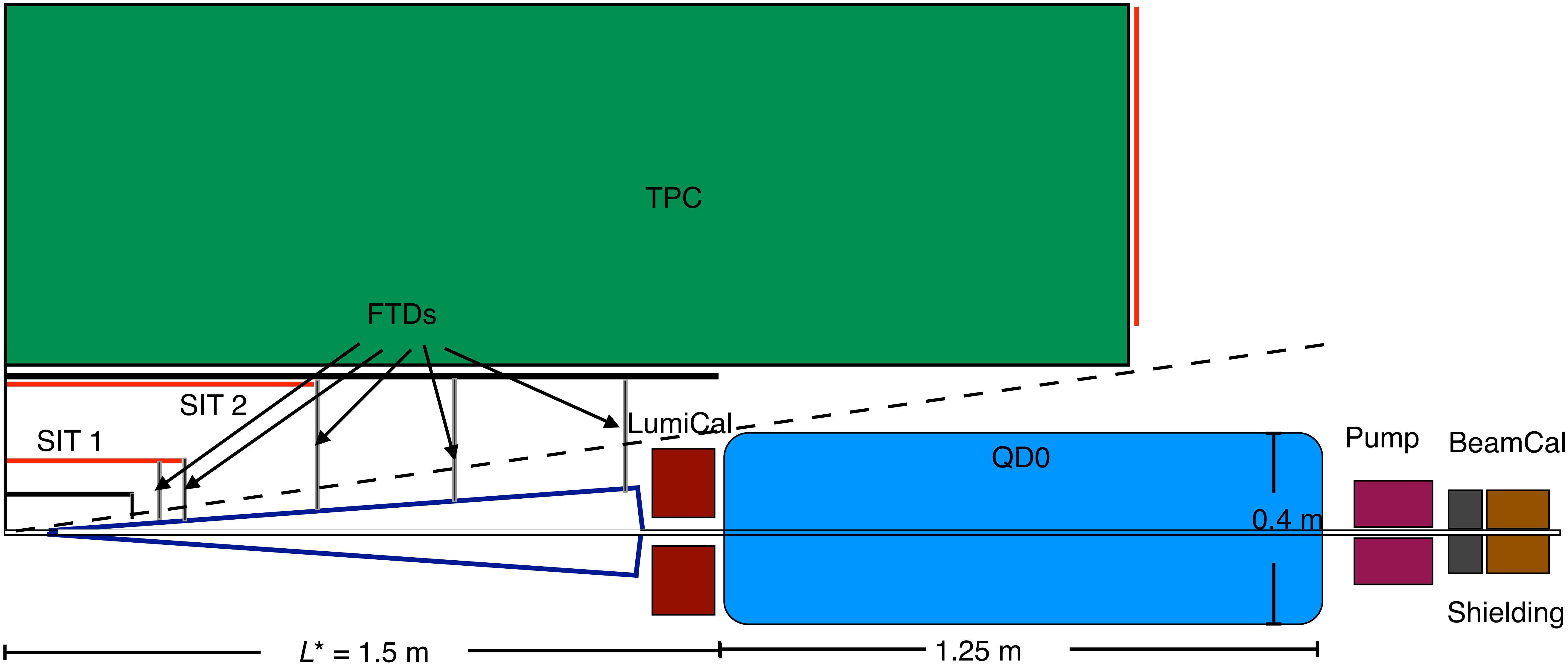
- BeamCal provides online luminosity estimation by measuring beamstrahlung photon in small angle, e.g. 5~30 mrad
- BeamCal will be moved to after QD0 (similar design as BESIII) and maybe even after the vacuum pump (reminder: 0.5m between QD0 and QF1).




- Can BeamCal collect enough beamstrahlung photons? (less beamstrahlung for CEPC and outside of QD0)

# Imaginary Layout

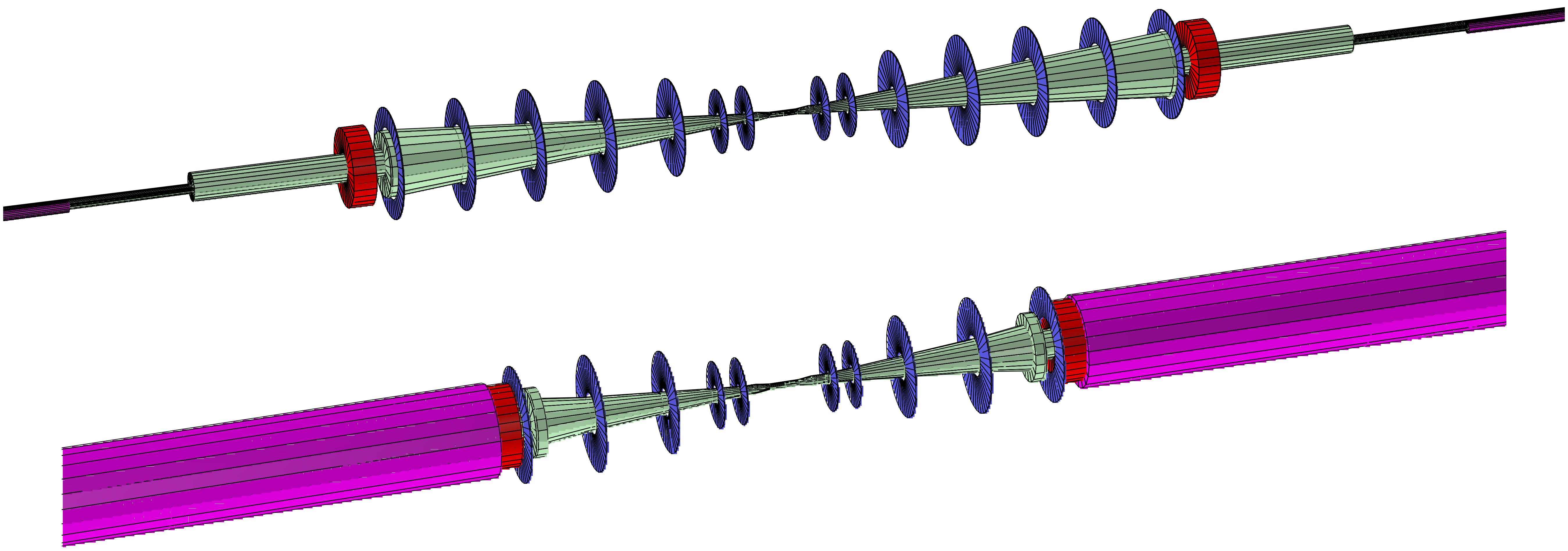
- Imaginary layout without any mechanical considerations (support structure, installation feasibility, system stability …)



# Detector Simulation

*Y. XU*

- Detector layout in simulation to study the impacts on physics



# Summary

- Initial efforts to study the Machine-Detector Interface issues
- The new baseline design of L*=1.5 certainly imposes many known and unknown challenges in detector design, most of which require detailed studies. → joint efforts
- We need to come up with a “baseline” detector design soon!