Vertex Detector for the CEPC
— A Prospective Overview

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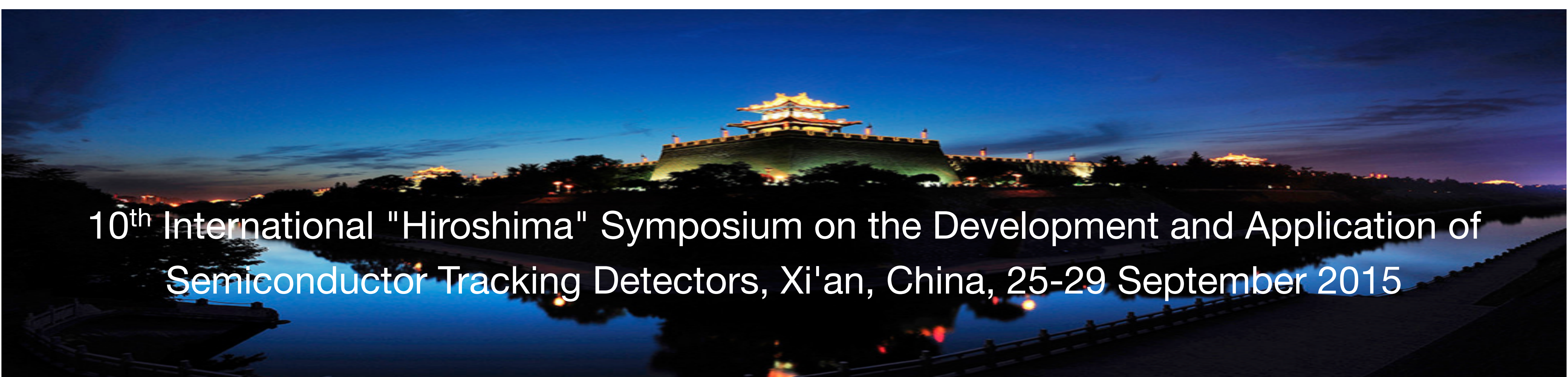


10th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Xi'an, China, 25-29 September 2015

Outline

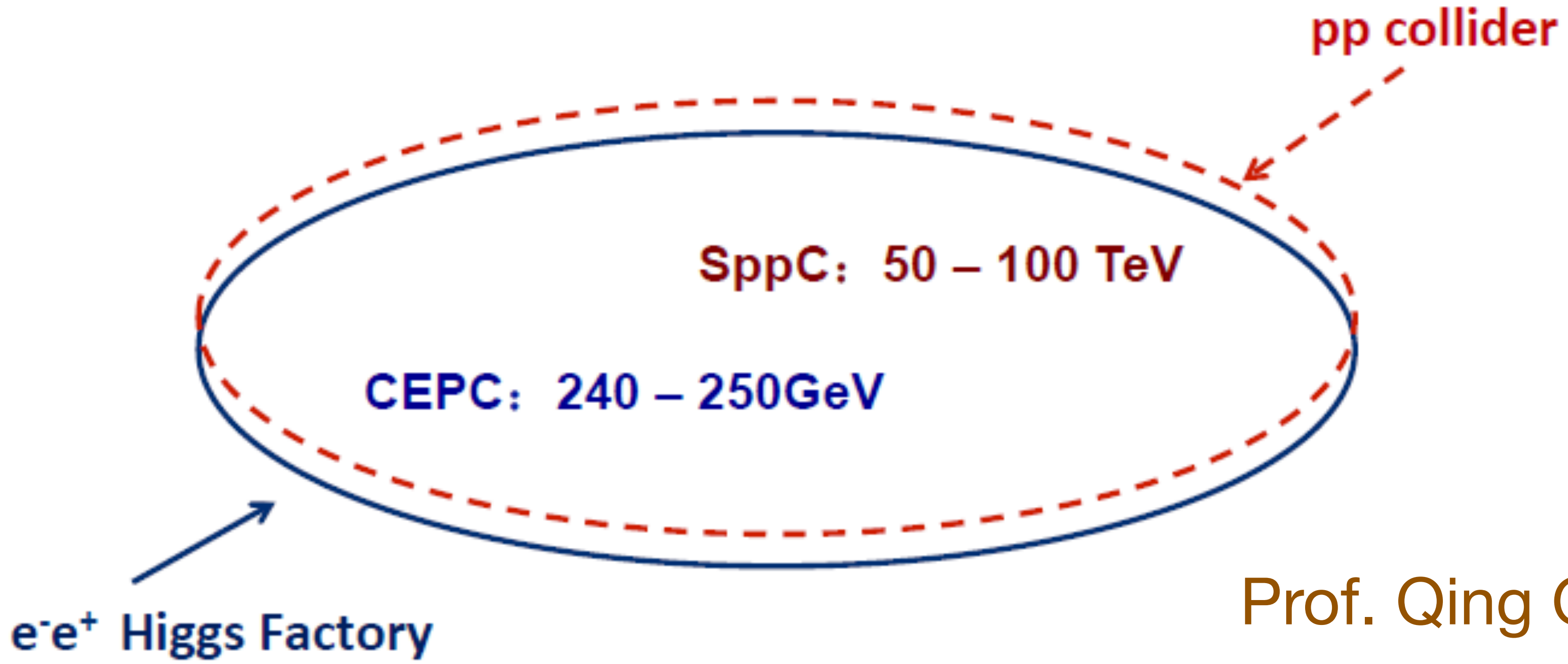
- Introduction to CEPC
- Performance requirements
- Candidate technologies
- R&D status
- Summary

Introduction

- The **Higgs Discovery** in 2012 witnessed the breakthrough in the history of particle physics and triggered wave of thoughts on **Higgs Factories** around the world …

A. Bondel and F. Zimmerman, *A High Luminosity e+e- Collider in the LHC tunnel to study the Higgs Boson*, arXiv:1112.2518, **even before the Higgs discovery!**

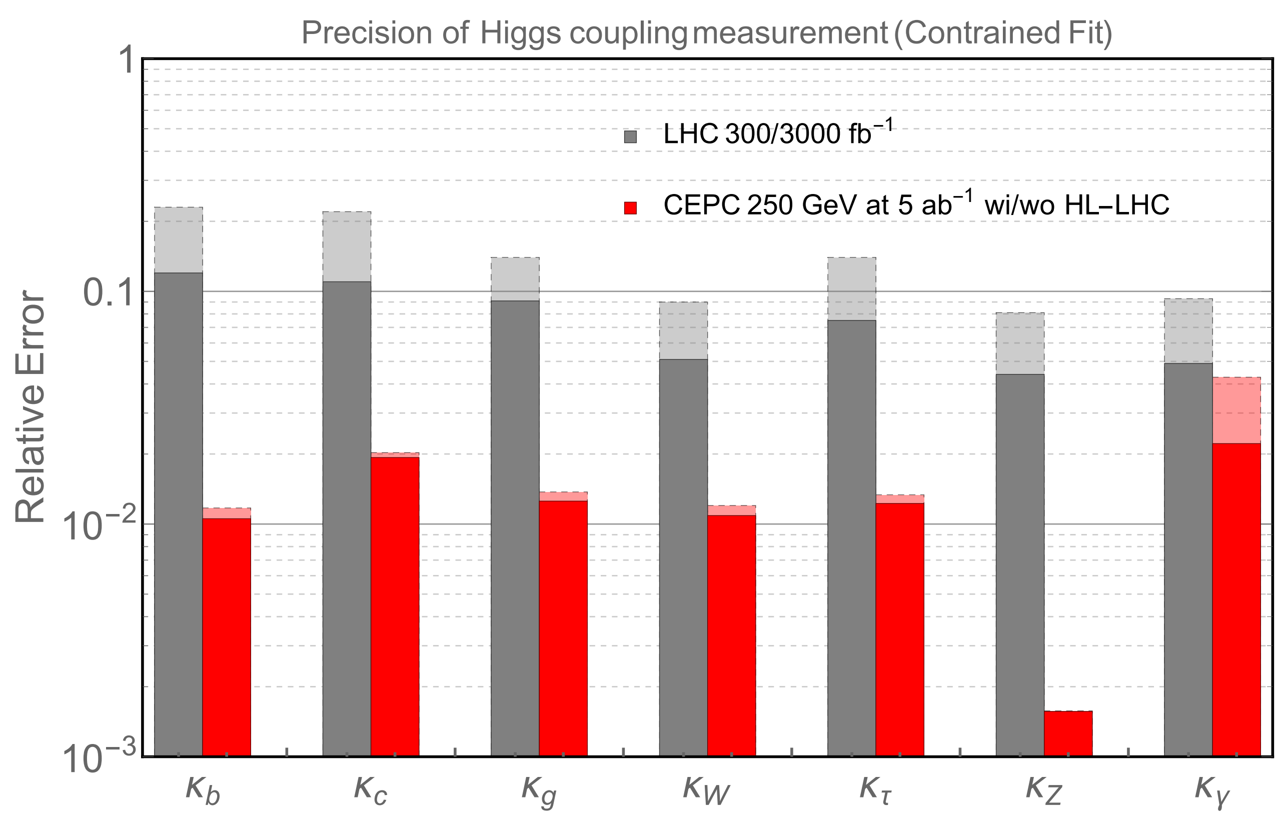
- Where the story began … presented by Prof. Qing Qin at the **Accelerators for a Higgs Factory: Linear vs. Circular (HF2012)**

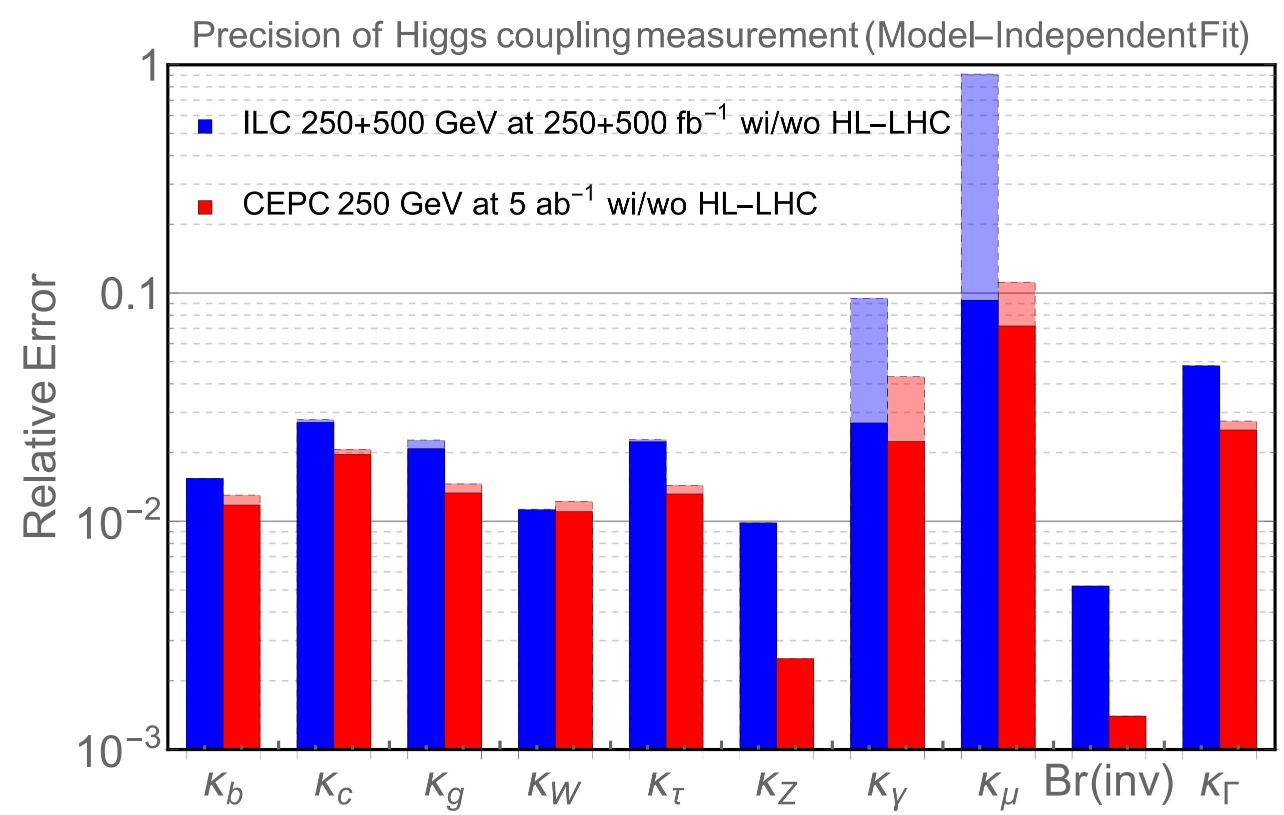


Prof. Qing Qin

Circular Electron Positron Collider

- **Circular Electron Positron Collider (CEPC)** to collide electron/positron beams at $\sqrt{s}$ ~240 GeV with a peak luminosity of 2×10^{34} $cm^{-2}s^{-1}$, and 2 IP to deliver ~1M clean ZH events over 10 years → **Higgs Factory**
  - *Higgs mass, cross section, branching ratios, couplings etc.*
- Operate at Z-pole/WW threshold → **EW precision measurements**





Possible Project Timeline

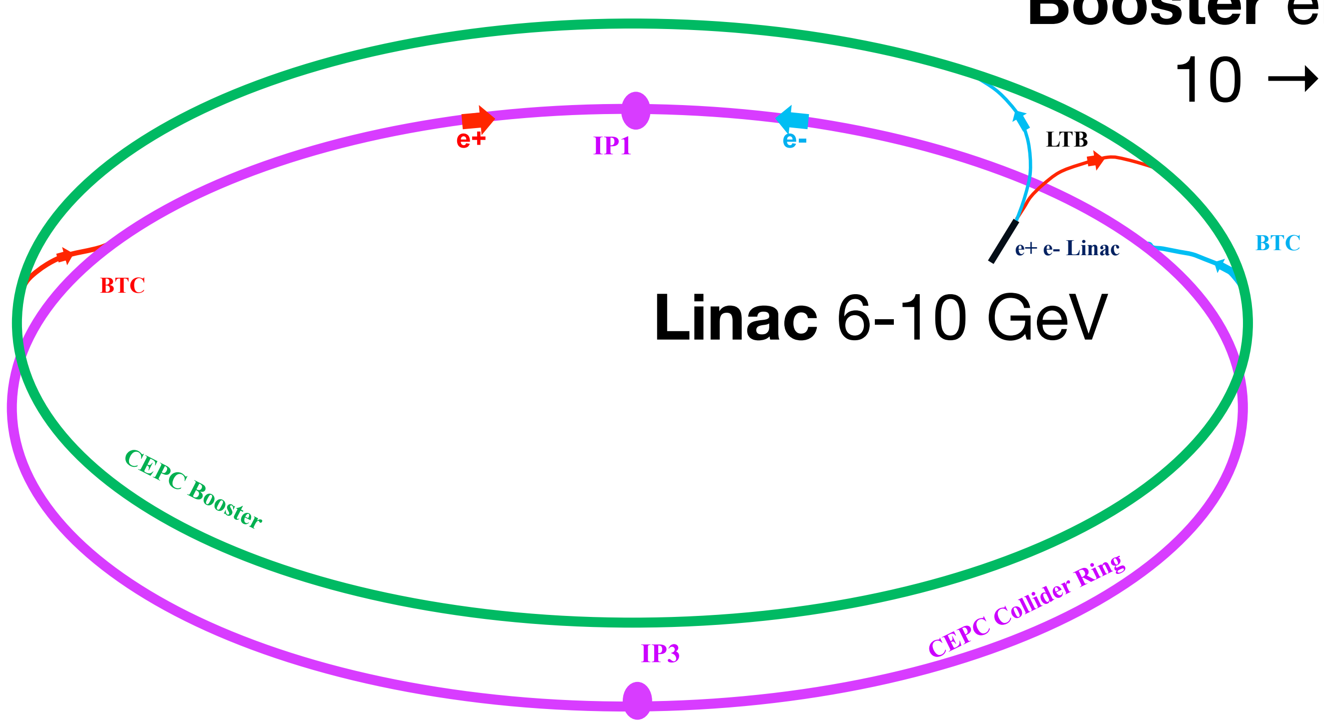
CEPC

2015	2020	2025	2030	2035

Pre-studies (2013-2015)	R&D Engineering Design (2016-2020)	Construction (2021-2027)	Data taking (2028-2035)

1st Milestone: pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

Booster energy ramp up
10 → 120 GeV



Linac 6-10 GeV

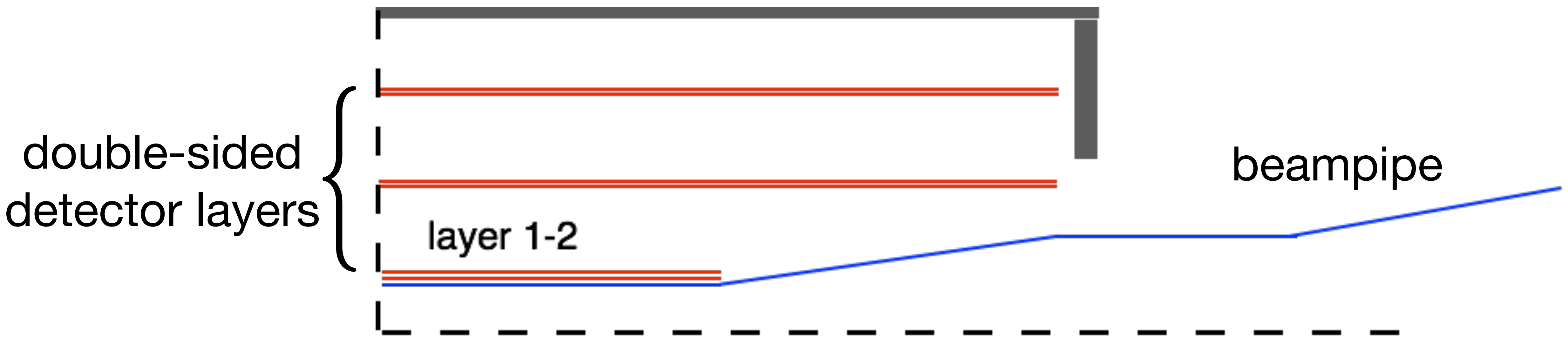
Collision Ring
$\sqrt{s}$ ~240 GeV

Vertex Detector

- Crucial to achieve high impact parameter resolution, which is required for heavy flavour (b/c) and τ-tagging:

$$\sigma_{r\phi} = 5 \oplus 10/p \cdot \sin^{3/2}\theta \ \mu\text{m}$$

- For the physics feasibility studies, the ILD vertex detector layout has been adopted, which features 3 double-sided layers ranging between 1.6 -6.0 cm



Performance Requirements

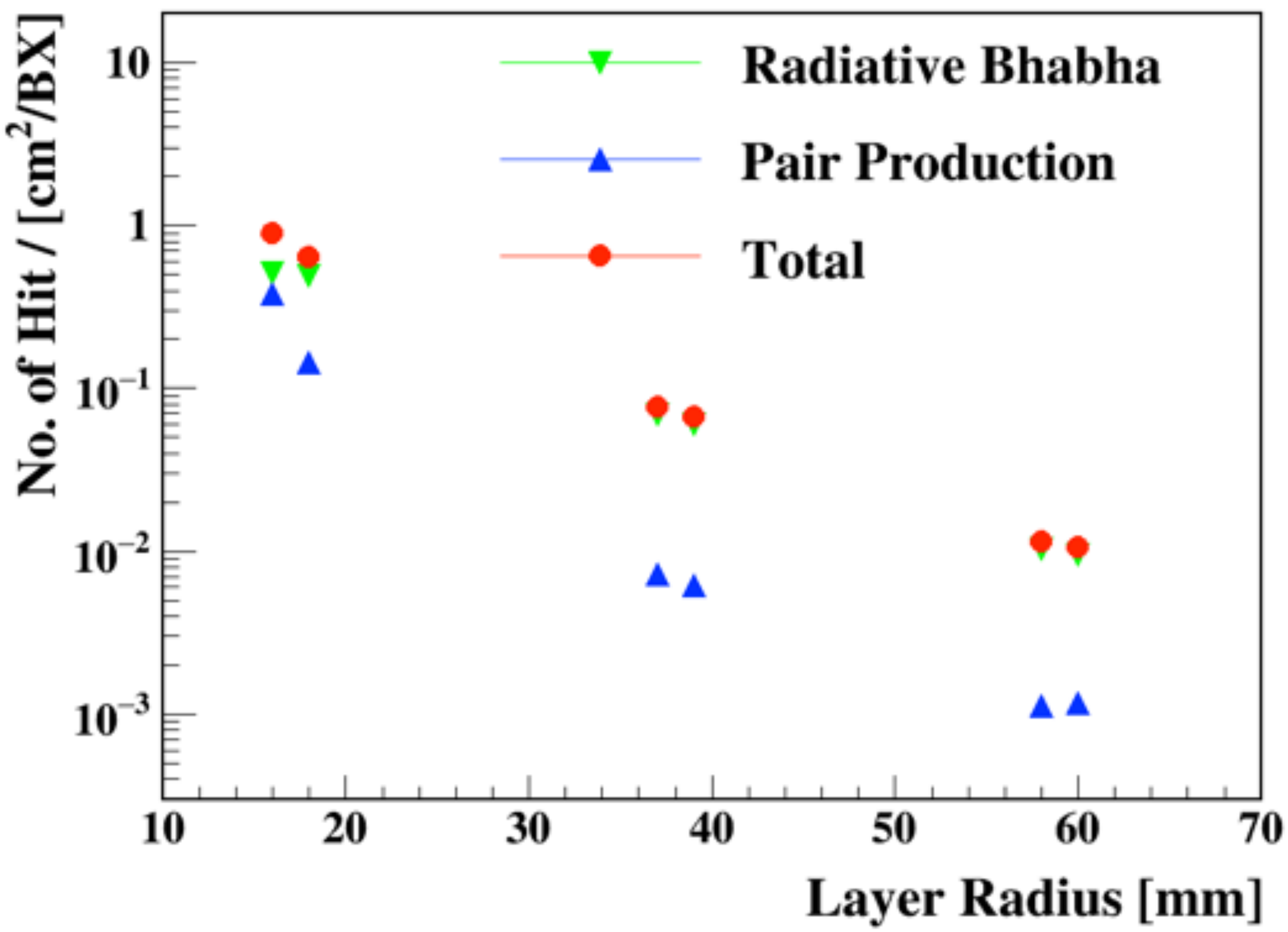
$$\sigma_{r\phi} = 5 \oplus 10/p \cdot \sin^{3/2}\theta \ \mu\mathrm{m}$$

- Imposing stringent requirements on the Vertex detector
  - **Spatial resolution near the interaction point $\sigma_{SP} \leq 3$ μm** → high granularity (small pixel size)
  - **Material budget ≤0.15%X_0/layer** → monolithic pixel sensor (sensor + embedded electronics, thinned down to e.g. 50 μm) + air cooling (power dissipation ≤50 mW/cm^2)
  - **Low detector occupancy below 0.5%** → high granularity and short integration time
  - **Radiation tolerance (pre.)**: ~1 MRad (TID) and 10^{12} n_{eq}/cm^2 (NIEL)

Similar to the ILC vertex detector requirements but **without power-pulsing**

Hit Density

- Critical parameter to determine the segmentation (+ physics requirements) and readout time of pixel sensors
- Mostly driven by background events originating from pair production, radiative Bhabha scattering, synchrotron radiation …

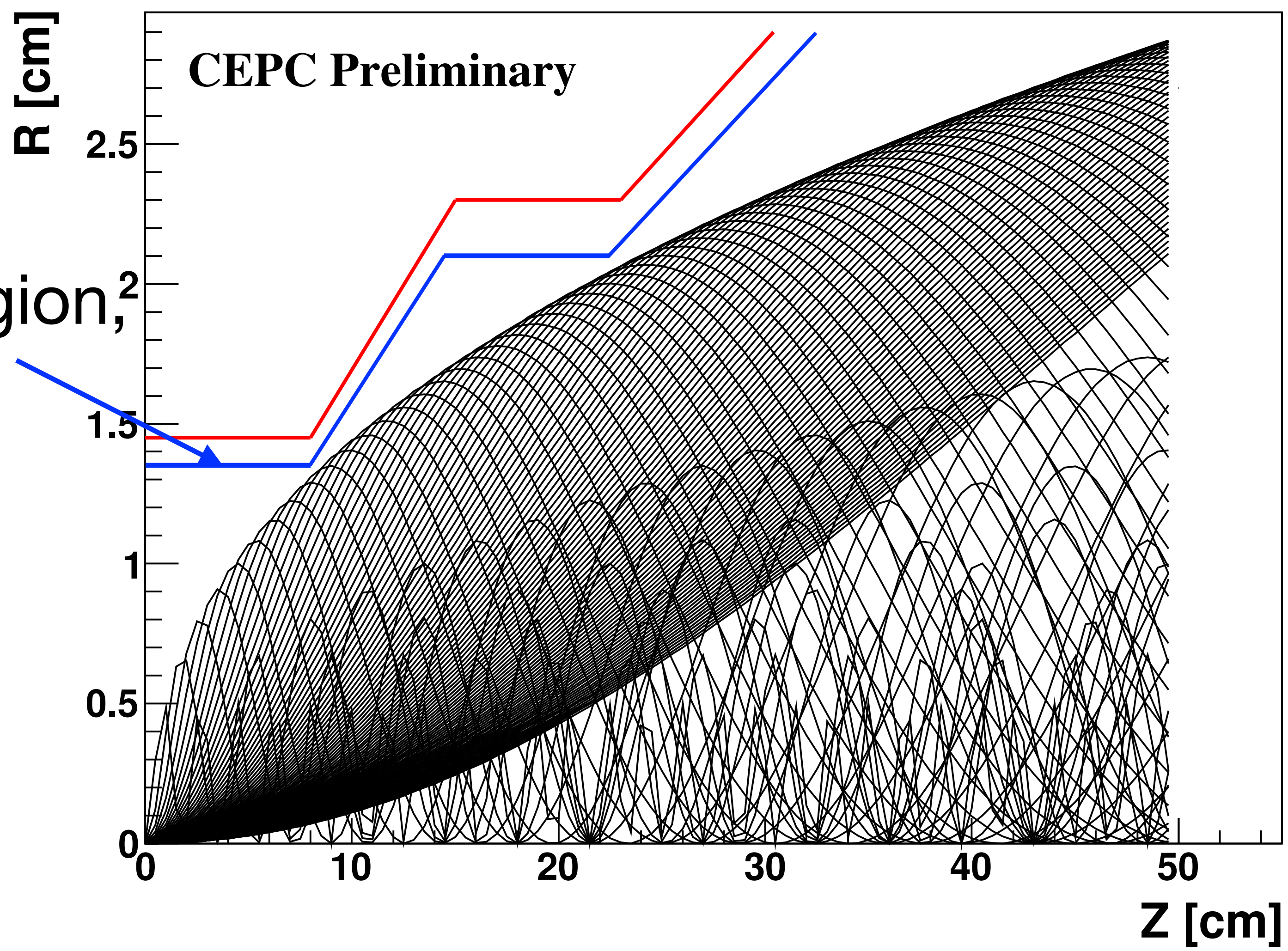


bunch spacing ~ 3.6 μs

Layout Optimisation

- The 1st vertex detector layer as close as possible to IP to minimise the extrapolation uncertainty and to improve the impact parameter resolution
- Electrons/positrons from pair production will develop a "kinematic edge" and detector components and beampipe should be kept sufficiently far away from this edge.

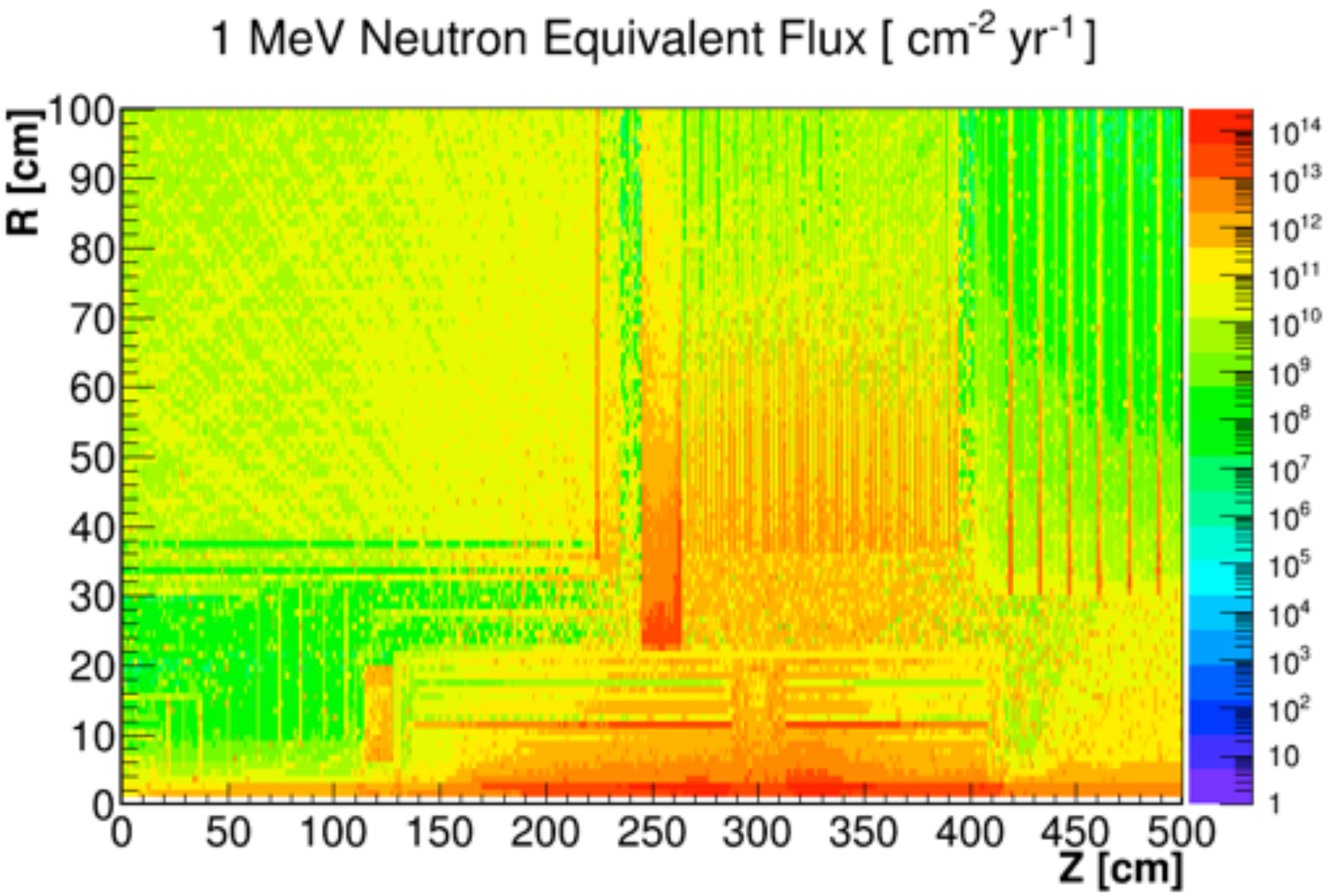
possible to push the beampipe closer by **1 mm** in the central region, and exact gain to be estimated

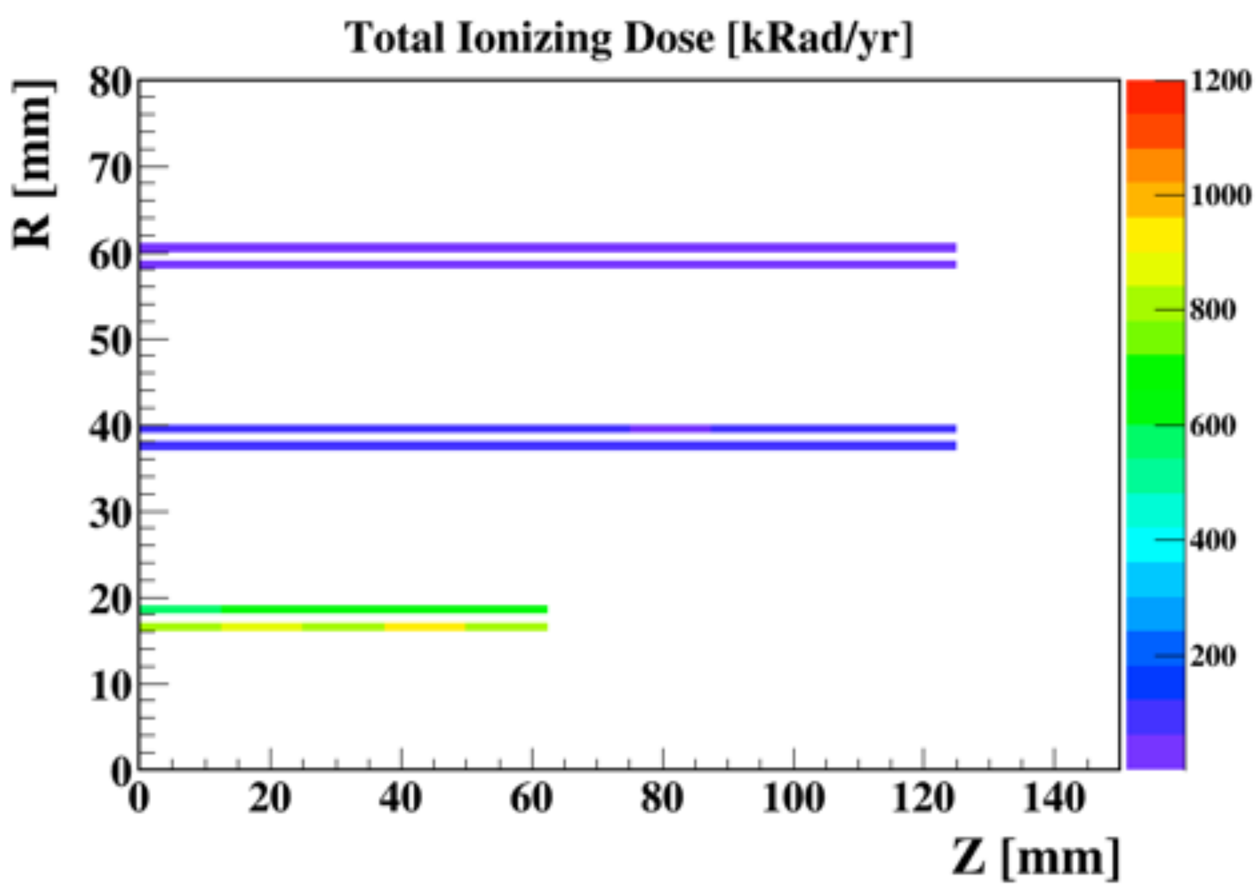


general strategy for layout optimisation being developed

Radiation Levels

- Benign radiation environment by the (HL-)LHC standard, but still considerable





Annual values (including safety factors of 5):

NIEL: 10^{12} n_{eq}/cm^2 and **TID: 1 MRad**

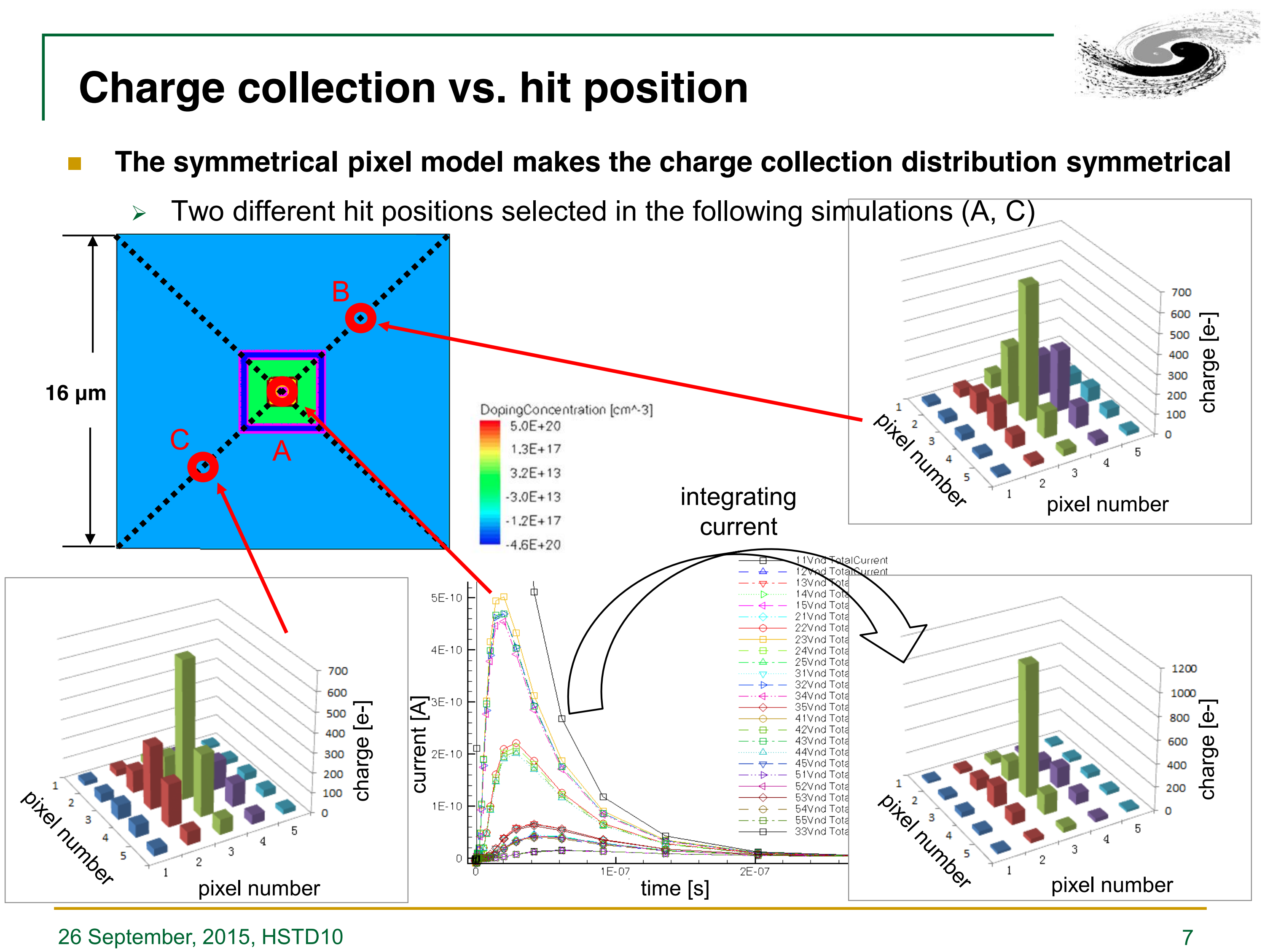
Candidate Technologies

- Monolithic pixel sensor technologies considered:
  - **CMOS**: Ultimate installed for STAR PXL, technology for ALICE ITS upgrade, pursued by ATLAS for Pixel Phase-II upgrade …
  - **DEPFET**: Belle-II pixel detector (attractive feature of self-supporting structure with low material budget in the active volume)
  - **SOI**: actively pursued for X-ray detection (existing design expertise, see Yunpeng Lu's talk), potential issue with radiation tolerance
  - **3D-IC**: trials within the 3D consortium, promising (ultimate detector) but technology not mature enough

- Given the technology maturity and accessibility, **CMOS technology (TJ CIS 0.18 μm)** has been chosen for initial sensor R&D.

Early Stage R&D

- Important to understand the charge collection efficiency with different diode geometries, epitaxial layer resistivity and thickness, radiation damage … , TCAD simulation followed by measurements → **sensor optimisation**

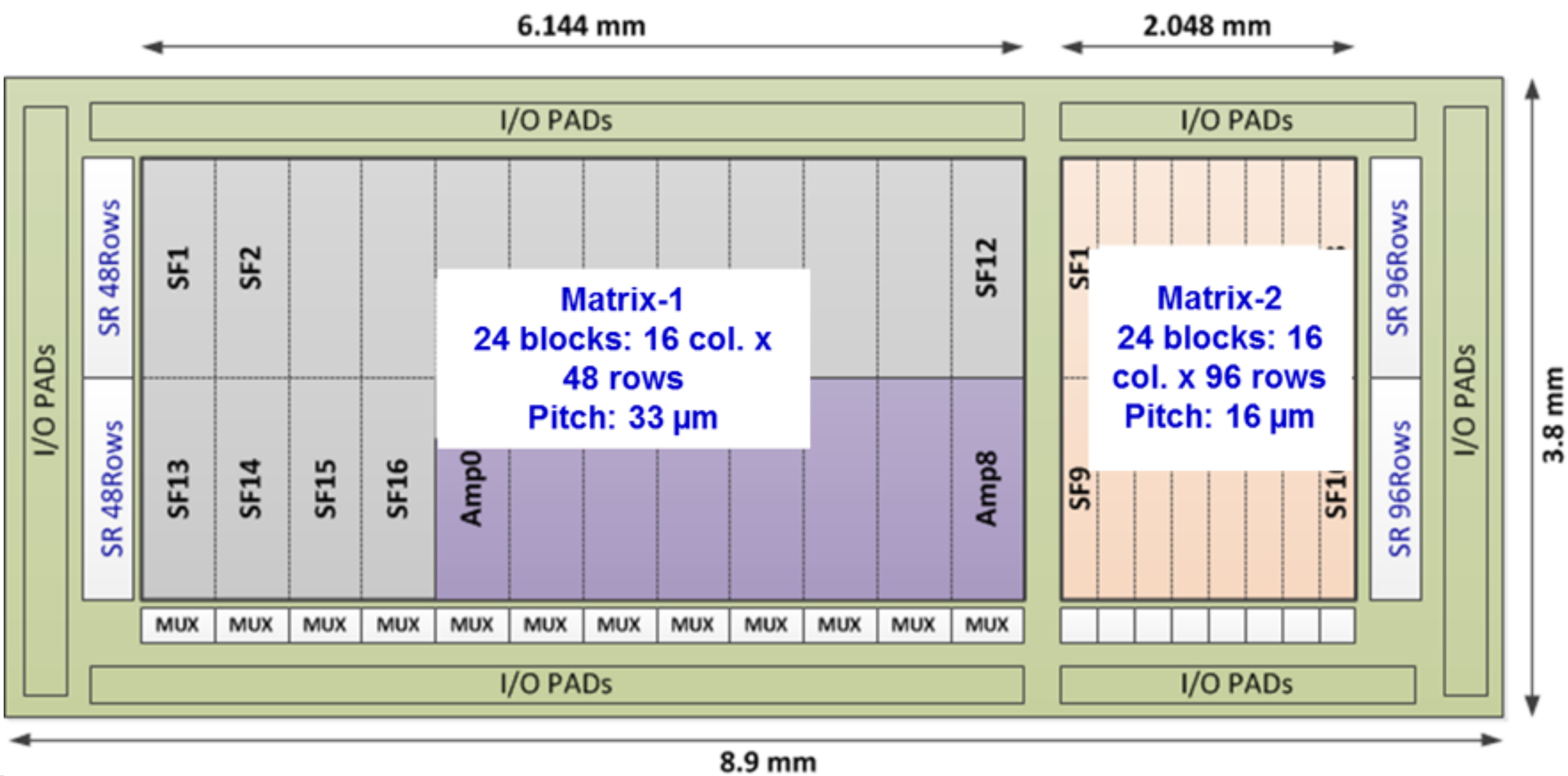


Sector	Diode area	Footprint	Structure
SFB1	3 μm²	20 μm²	2T_nmos
SFB2	4 μm²	20 μm²	2T_nmos
SFB3	8 μm²	20 μm²	2T_nmos
SFB4	3 μm²	15 μm²	2T_nmos
SFB5	4 μm²	15 μm²	2T_nmos
SFB6	8 μm²	15 μm²	2T_nmos
SFB7	3 μm²	11 μm²	2T_nmos
SFB8	4 μm²	11 μm²	2T_nmos
SFB9	8 μm²	11 μm²	2T_nmos
SFB10	3 μm²	8 μm²	2T_nmos
SFB11	4 μm²	8 μm²	2T_nmos
SFB12	8 μm²	8 μm²	2T_nmos
SFB13	8 μm²	20 μm²	2T_pmos
SFB14	4 μm²	8 μm²	2T_pmos
SFB15	8 μm²	20 μm²	3T_nmos
SFB16	4 μm²	8 μm²	3T_nmos

See Ying Zhang's talk

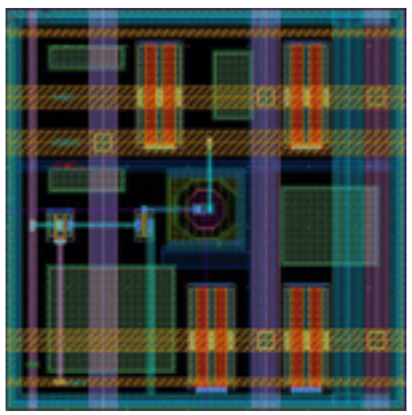
First Submission

- Submission mainly for charge collection optimisation, but with several blocks reserved for analog circuit studies (e.g. amplifiers)



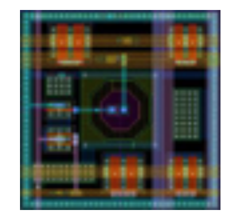
Considerations

- **Pixel sizes** of 16 × 16 μm² (binary readout) and 33 × 33 μm² (multi-bit ADC) to achieve 3μm resolution with conmtratints: 1. power consumption, 2.) effective area → possible alleviation with **extension in z** (z resolution loss to be studied with physics simulation) or **3D-IC** (analog/digital tiers)



33 × 33 μm²

areas filled up with capacitors possible for implanting more transistors



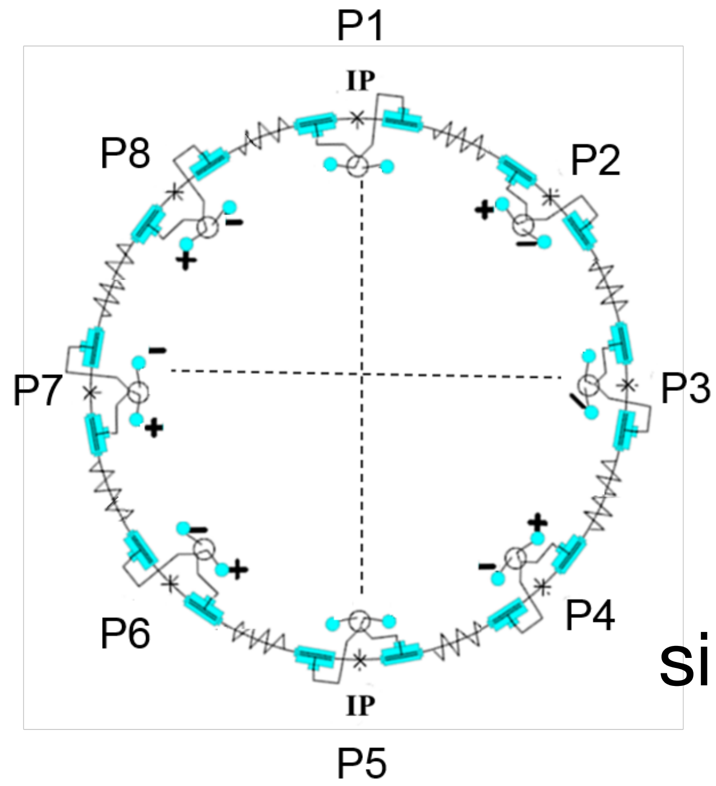
16 × 16 μm²

completely filled up

- **Readout architecture**: digitisation in pixel (to minimise power dissipation to drive analog signal) and sparsified readout → e.g. ALPIDE for the ALICE ITS
- **Cooling technique**: force-air cooling demonstrated for STAR PXL and thermal simulation for CLIC vertex detector, or more aggressive with micro channel cooling (LHCb)

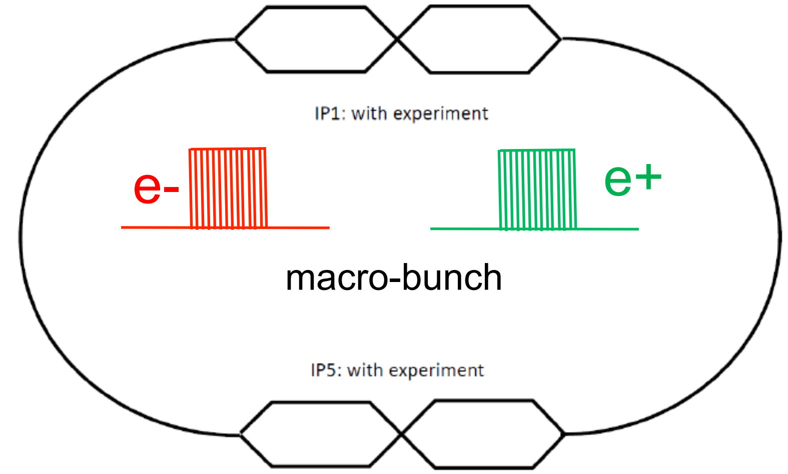
Moving Target

- As the accelerator design evolves, the requirements on the vertex detector might have to change.
- Increased backgrounds would lead to in higher radiation tolerance requirement and time-stamping capability (O(10ns)) to distinguish bunch crossings.
- Necessary to revise the sensor specifications and readout requirements in near future.



single bunch

macro-bunch train

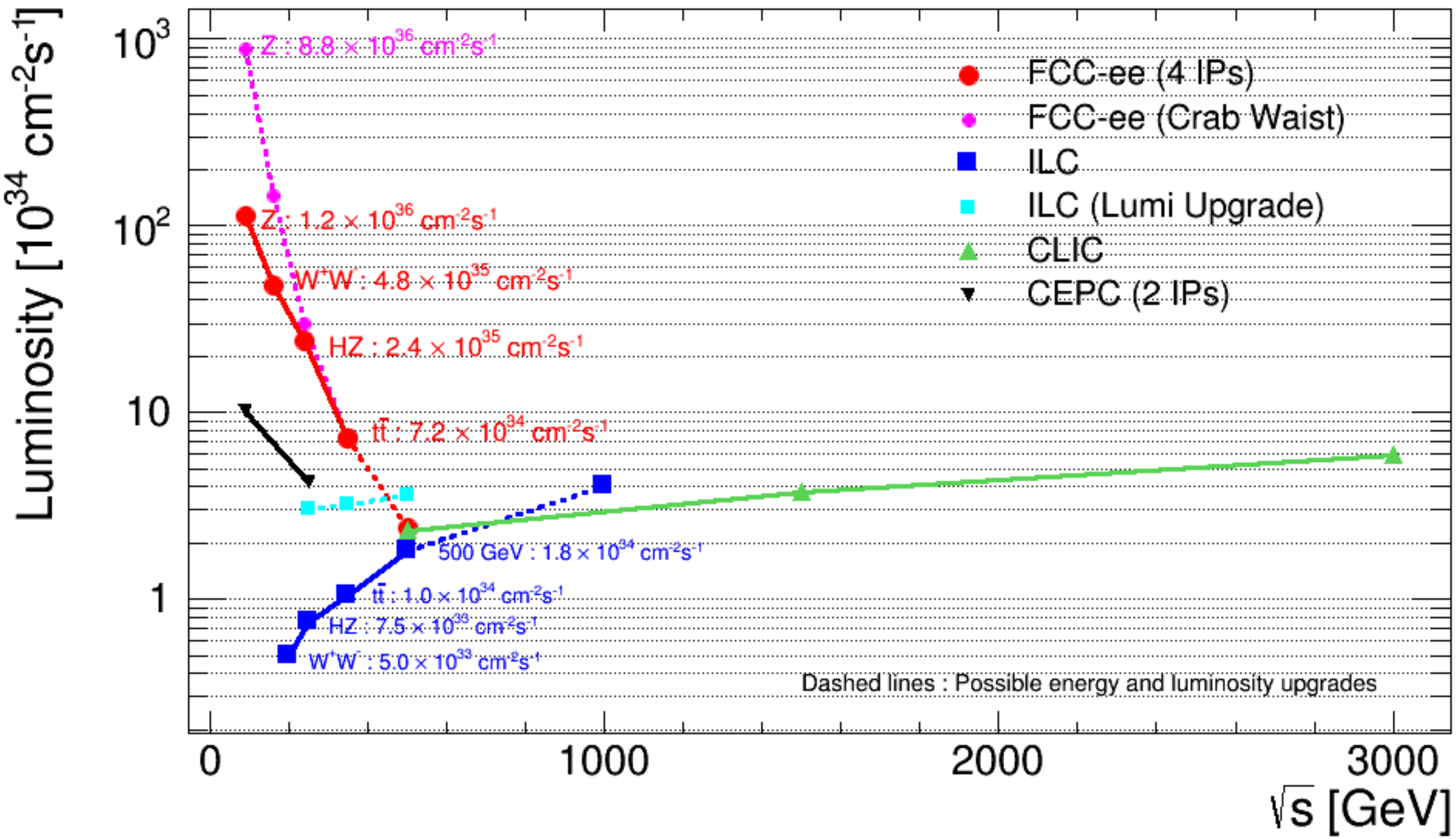


Summary

- Circular Electron Positron Collider (CEPC) as a Higgs Factory → **precision Higgs measurements**
- Performance requirements on the vertex detector similar to that of the ILD but with special considerations on power consumption and backgrounds → **might have to be revised**
- Pixel sensor R&D based on CMOS technology has just started with sensor charge collection optimisation

Thank you for your attention!

Luminosity



Luminosity [10^{34} $cm^{-2}s^{-1}$]
10^3
10^2
10
1
0
1000
2000
3000
$\sqrt{s}$ [GeV]
Z : 8.8×10^{36} $cm^{-2}s^{-1}$
Z : 1.2×10^{36} $cm^{-2}s^{-1}$
W^+W^- : 4.8×10^{35} $cm^{-2}s^{-1}$
HZ : 2.4×10^{35} $cm^{-2}s^{-1}$
$t\bar{t}$: 7.2×10^{34} $cm^{-2}s^{-1}$
500 GeV : 1.8×10^{34} $cm^{-2}s^{-1}$
$t\bar{t}$: 1.0×10^{34} $cm^{-2}s^{-1}$
HZ : 7.5×10^{33} $cm^{-2}s^{-1}$
W^+W^- : 5.0×10^{33} $cm^{-2}s^{-1}$
FCC-ee (4 IPs)
FCC-ee (Crab Waist)
ILC
ILC (Lumi Upgrade)
CLIC
CEPC (2 IPs)
Dashed lines : Possible energy and luminosity upgrades