CEPC Detector and Physics Studies

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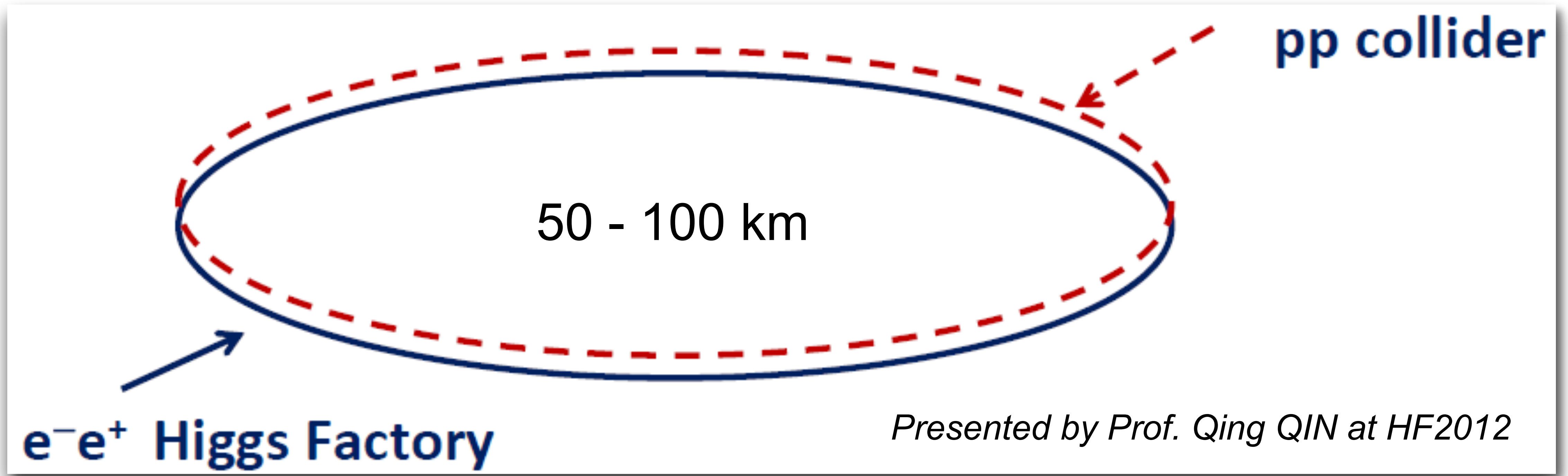
Outline

- Project overview
- Higgs Physics @ CEPC
- The CEPC detector
- Machine-Detector Interface
- Summary

Project Overview

- Circular Electron Positron Collider (CEPC) operating at $\sqrt{s}$~ 240 - 250 GeV (Higgs Factory) with luminosity of 2×10^{34} $cm^{-2}s^{-1}$, 2 interaction points (IP), over ~10 years
  - 10^6 clean Higgs allowing precision measurements of Higgs properties
  - Operation at Z-pole/WW threshold for electroweak and flavour physics
- Upgradable to Super proton-proton Collider (SppC) with $\sqrt{s}$~ 70 - 100 TeV
  - Direct search for New Physics



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)

SppC

2020 | 2030 | 2040

R&D (2014-2030)	Engineering Design (2030-2035)	Construction (3035-2042)	Data taking (2042-2055)

Preliminary Conceptual Design Report

Volume I: Physics & Detector

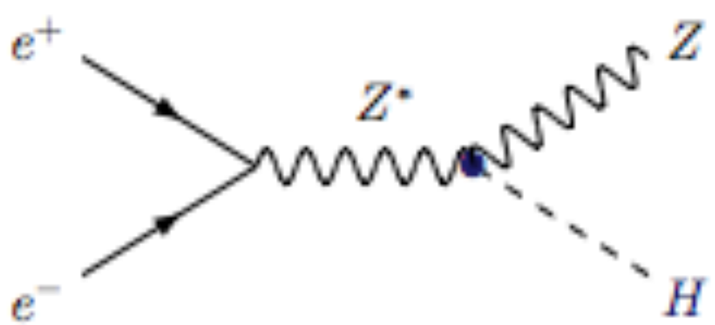
Volume II: Accelerator

To appear shortly at:

http://cepc.ihep.ac.cn/preCDR/volume.html

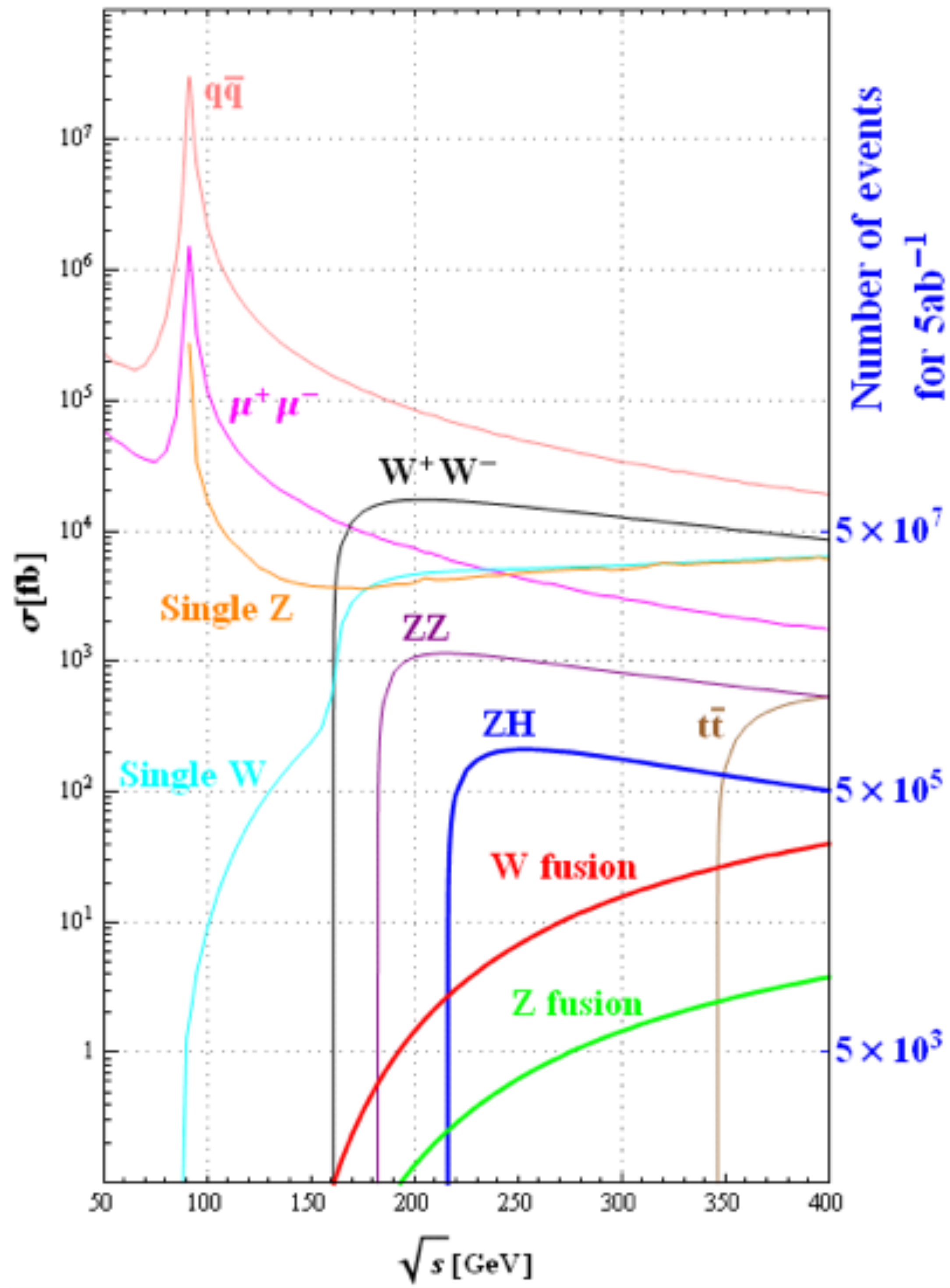
Higgs Physics @ CEPC

- Precision measurements of Higgs properties to percent or even sub-percent levels
- Dominant production process ZH, with additional contribution from vector boson fusions



$$m^2_{\text{recoil}} = (\sqrt{s} - E_{ff})^2 - p^2_{ff} = s - 2E_{ff}\sqrt{s} + m^2_{ff}$$

- Powerful recoil mass method allowing model-independent measurements of production cross sections and branching ratios, accurate determination of Higgs mass
- Stringent requirements on detector performance



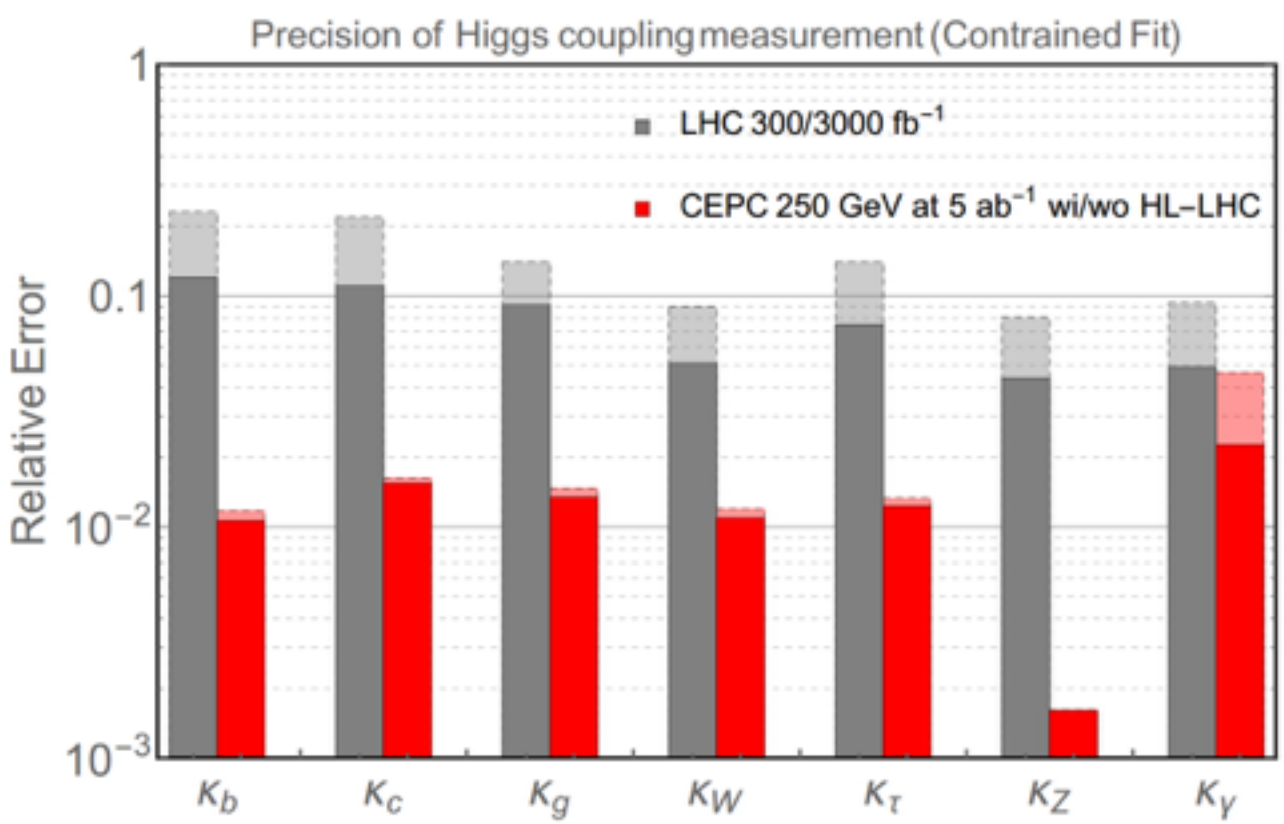
Higgs Precision Measurements

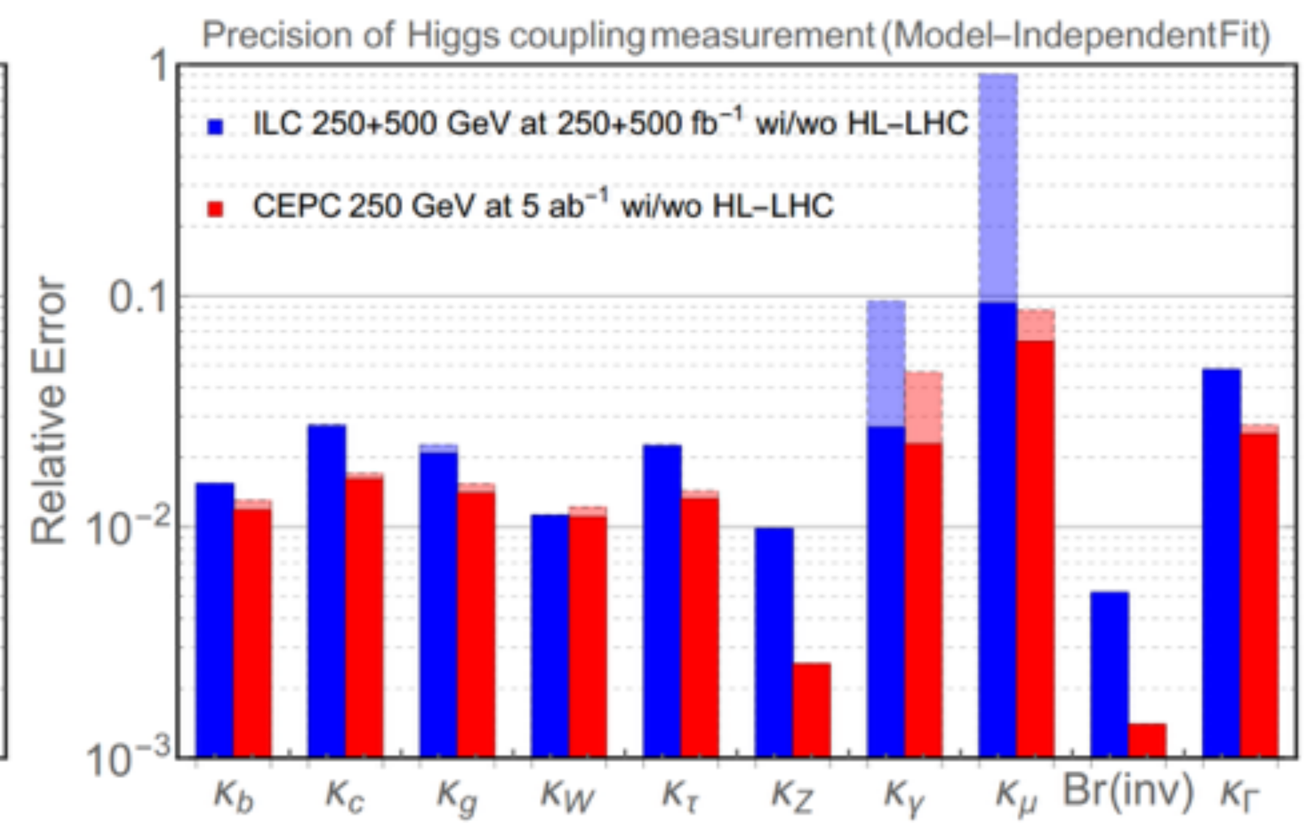
ΔM_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times \mathrm{BR}(H \to bb)$
5.5 MeV	2.8%	0.51%	2.8%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to bb$	0.28%	0.58%
$H \to cc$	2.2%	2.3%
$H \to gg$	1.6%	1.7%
$H \to \tau\tau$	1.2%	1.3%
$H \to WW$	1.5%	1.6%
$H \to ZZ$	4.3%	4.3%
$H \to \gamma\gamma$	9.0%	9.0%
$H \to \mu\mu$	17%	17%
$H \to \mathrm{inv}$	0.28%	0.28%

- Precision level to percent or even sub-percent (systematic uncertainties not yet taken into account) → *details in the upcoming preliminary conceptual design report*

Higgs Couplings



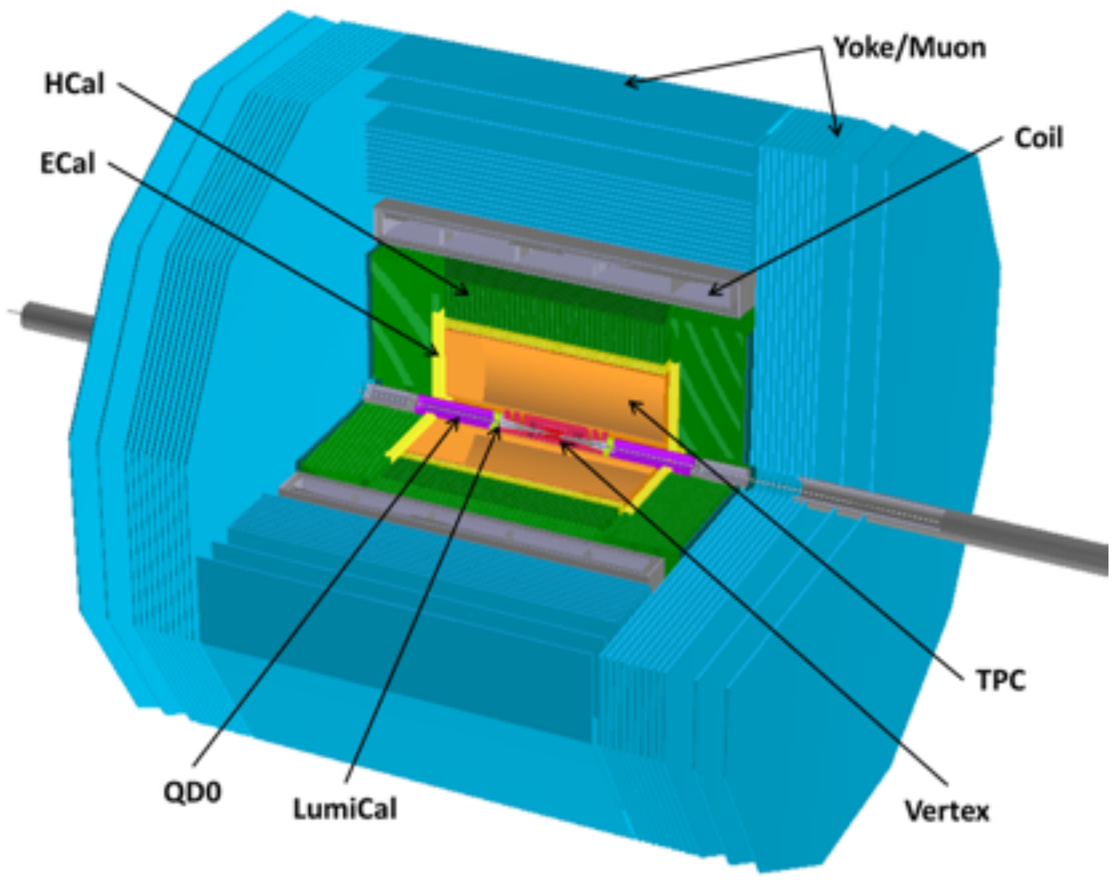


- Extraction of couplings based on different scenarios (n-parameters, model-independent or constrained fit …) → *keep in mind the assumptions*
- Significant precision improvements over the projected HL-LHC results; better than the ILC results (250+500 operation scenario) in most cases (*statistics matters*)

Detector Overview

- ILD detector as the starting point, but with special considerations:
  - CEPC operation in continuous working mode → no power pulsing
  - Less aggressive center-of-mass energy → more compact calorimeters
  - Machine-Detector Interface design
  - And more …
- Physics potential (Higgs precision) evaluated with the ILD-like detector and several critical R&D items identified in preCDR
- Detector requirements for Z-pole operation not yet fully taken into account
- Full silicon tracker as the "SiD" concept always kept in mind and to be explored

Detector concept based on the ILD



Vertex Detector

- Essential for heavy flavour (measurements with $H \to b\bar{b}$, $c\bar{c}$, gg) and tau-lepton tagging, requiring transverse impact parameter resolution:

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

- Vital to develop pixel detectors with low power electronics in the absence of power pulsing and efficient cooling without introducing much material (*performance evaluated for additional material with simulation, and layout optimisation*)
- **Possible R&D strategy:**
  - To improve existing sensor technologies: CMOS, SOI and DEPFET, and to investigate emerging technologies: 3D IC, etc.
  - Powering, cooling and light-weighted mechanics
  - Important to explore synergies with other experiments with similar requirements

Calorimeters

- Particle Flow Algorithm (PFA) oriented electromagnetic and hadronic calorimeters:
- Intensive R&D effort coordinated by the CALICE collaboration

Less demanding for the CEPC given the lower jet energy (√s ~ 240-250 GeV)

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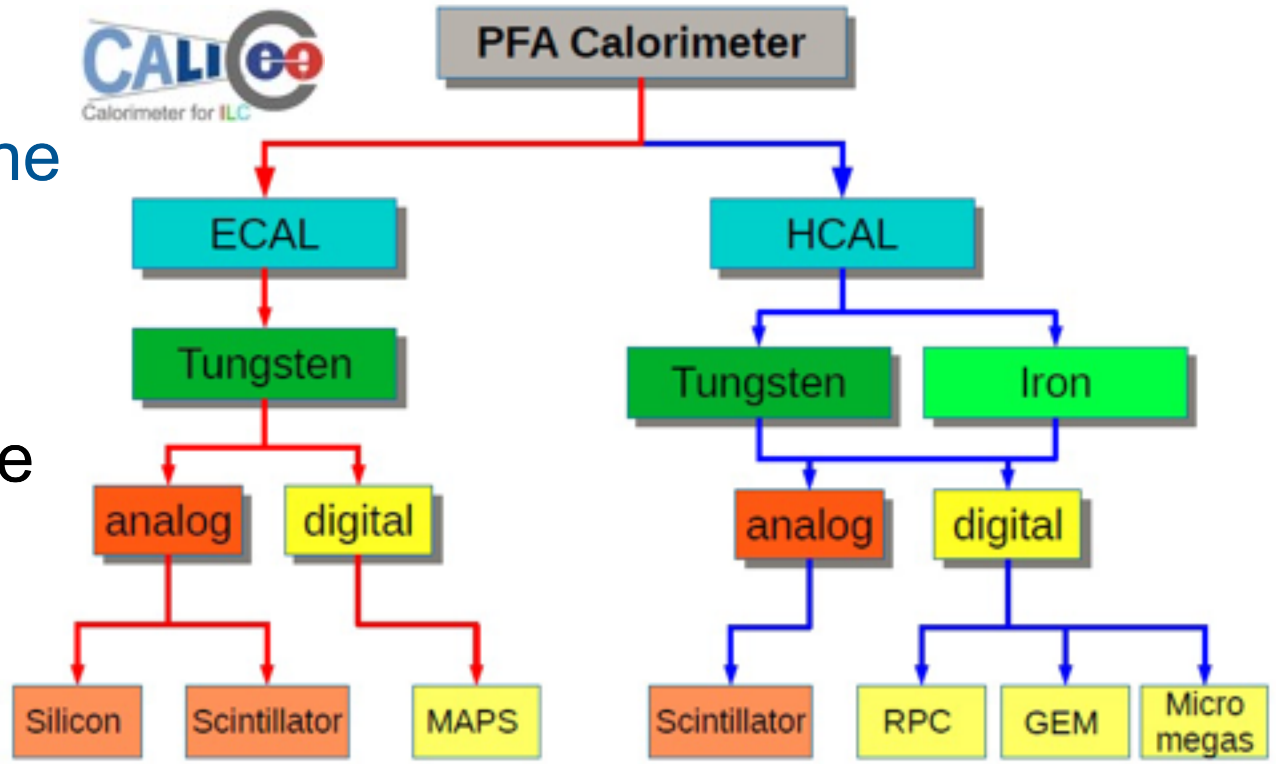
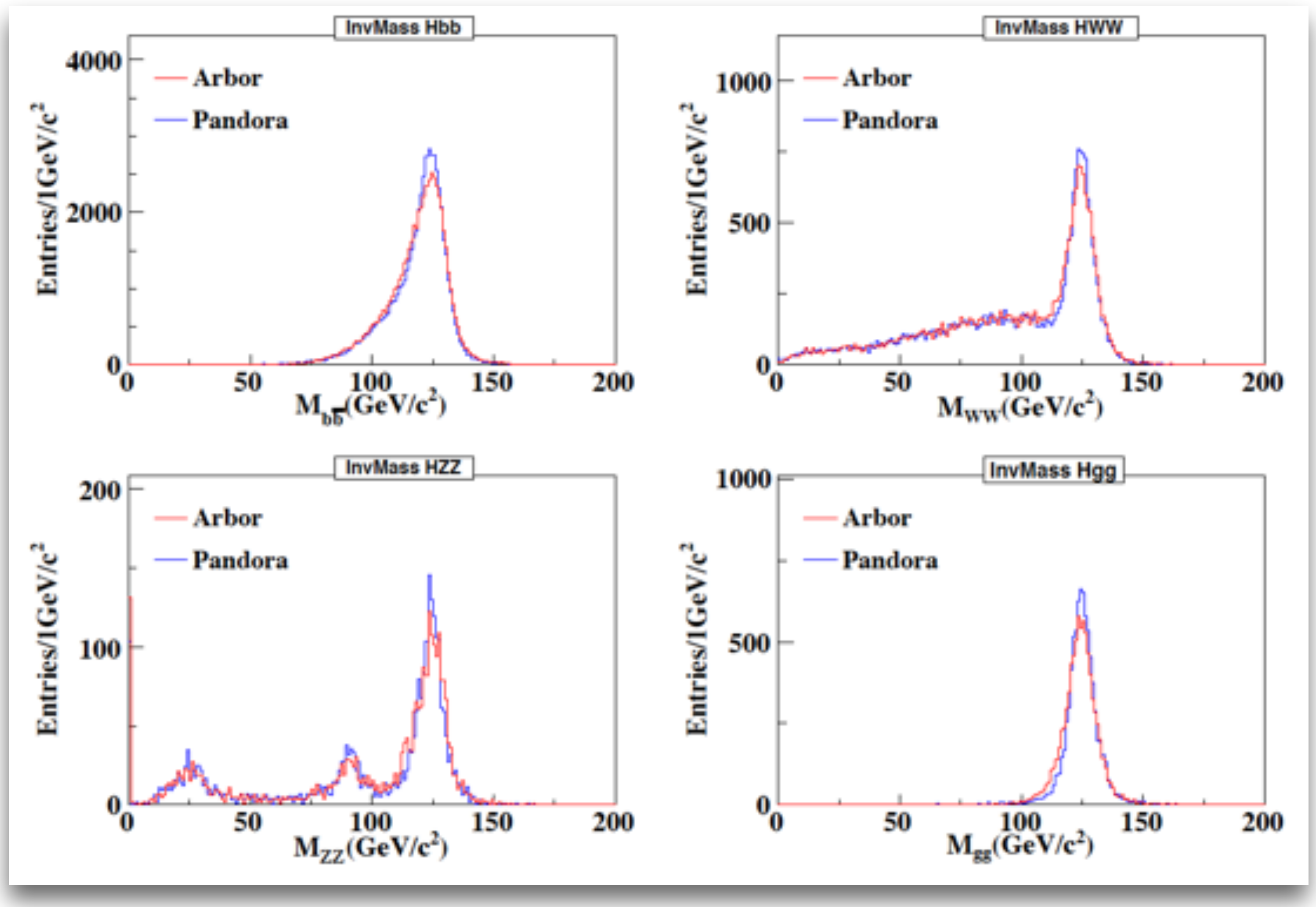
Balance between detector performance and power dissipation/cooling



- **Possible R&D strategy:**
  - Selective on detector technologies (analog ECAL read out with silicon/scintillator, digital HCAL read out with RPC/GEM) and prototyping
  - Joining the CALICE collaboration (?)

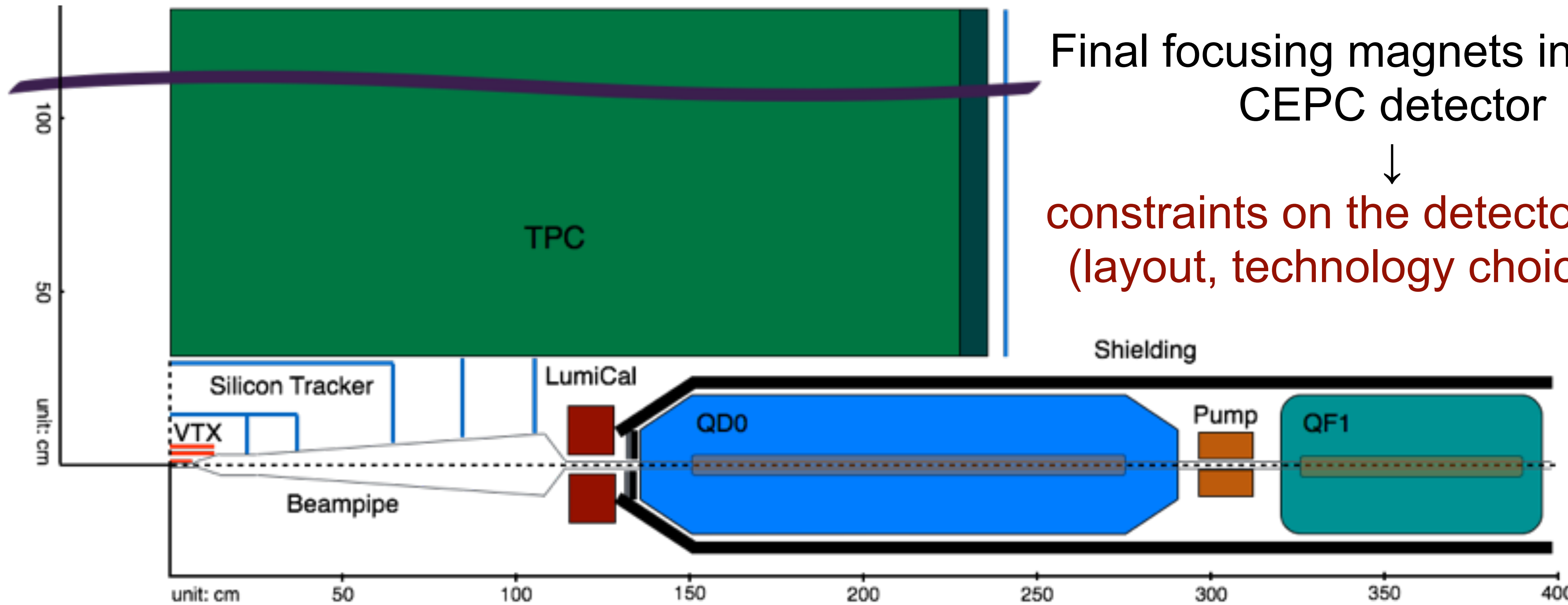
Design Principle — PFA

- Particle Flow Algorithm (PFA) to achieve excellent jet energy resolution and optimise the particle identification
- Continuing development on Arbor, an alternative algorithm to the popular PandoraPFA; results already comparable yet requiring further tunings



Machine-Detector Interface

- Interaction Region Layout



Final focusing magnets inside the CEPC detector
↓
constraints on the detector design (layout, technology choice, etc.)

- Beampipe, surrounding silicon detectors, luminosity calorimeter, final focusing quadrupoles (QD0 and QF1), etc.
- **Short focal length of L* = 1.5 m** → realisation of the design machine luminosity without exploding the chromaticity corrections
- Joint effort between detector and accelerator group to achieve optimal performance

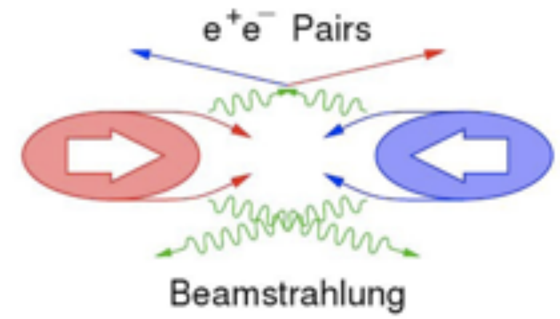
Background Estimation

- One of the most important and challenging topic at the CEPC
- Backgrounds originating from beam-beam interactions
  - Beamstrahlung
  - electron-positron pair production
  - hadronic background
  - Radiative Bhabha scattering
- Other important background sources
  - Synchrotron radiation
  - Beam-gas interactions
  - Beam-halo muons
  - Beam dumps
  - …

Preliminary results presented in this talk; but all of the backgrounds and their impacts on physics performance need to be carefully studied

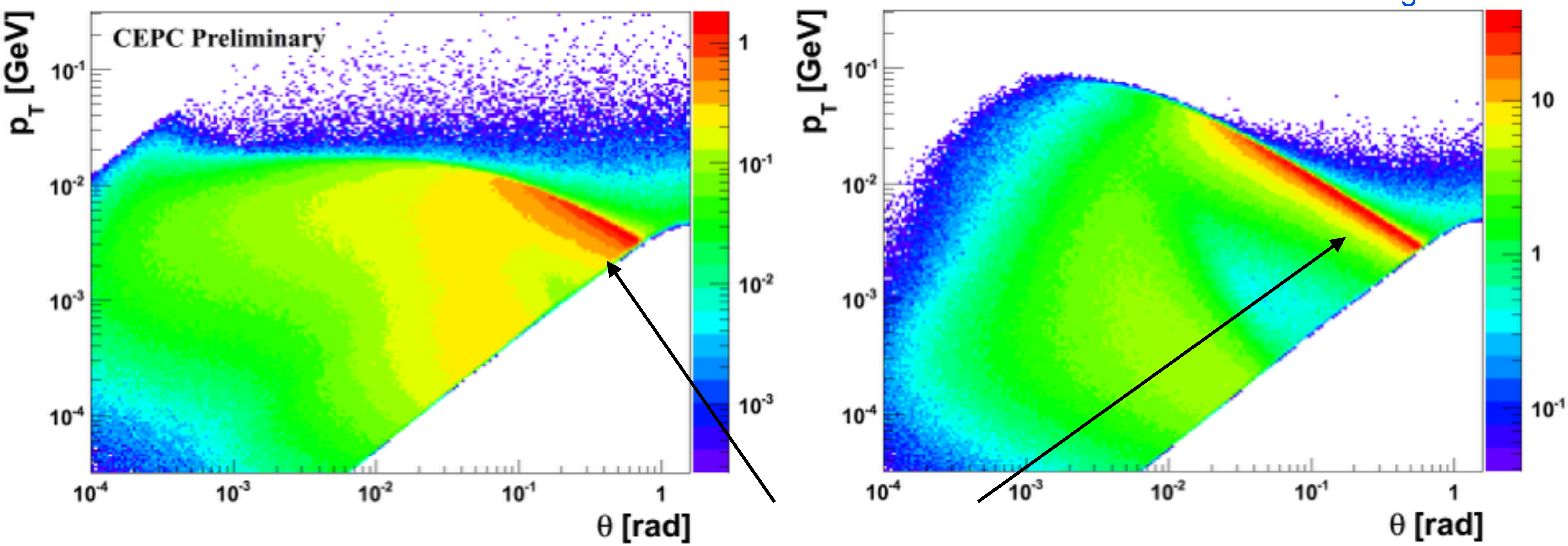
Careful machine design to minimise the contributions

Electron-Positron Pair Production



- Most important background for the ILC detectors, less problematic for the CEPC
- Beam-beam interaction simulated with Guinea-Pig and cross-checked with CAIN

Simulation result with the ILC250 configurations



Detector components and the beampipe to be placed away from the kinematic edge

Hit density of 0.2 hits/cm^2/BX at the 1st vertex detector layer (0.8 hits/cm^2/BX for ILC250)

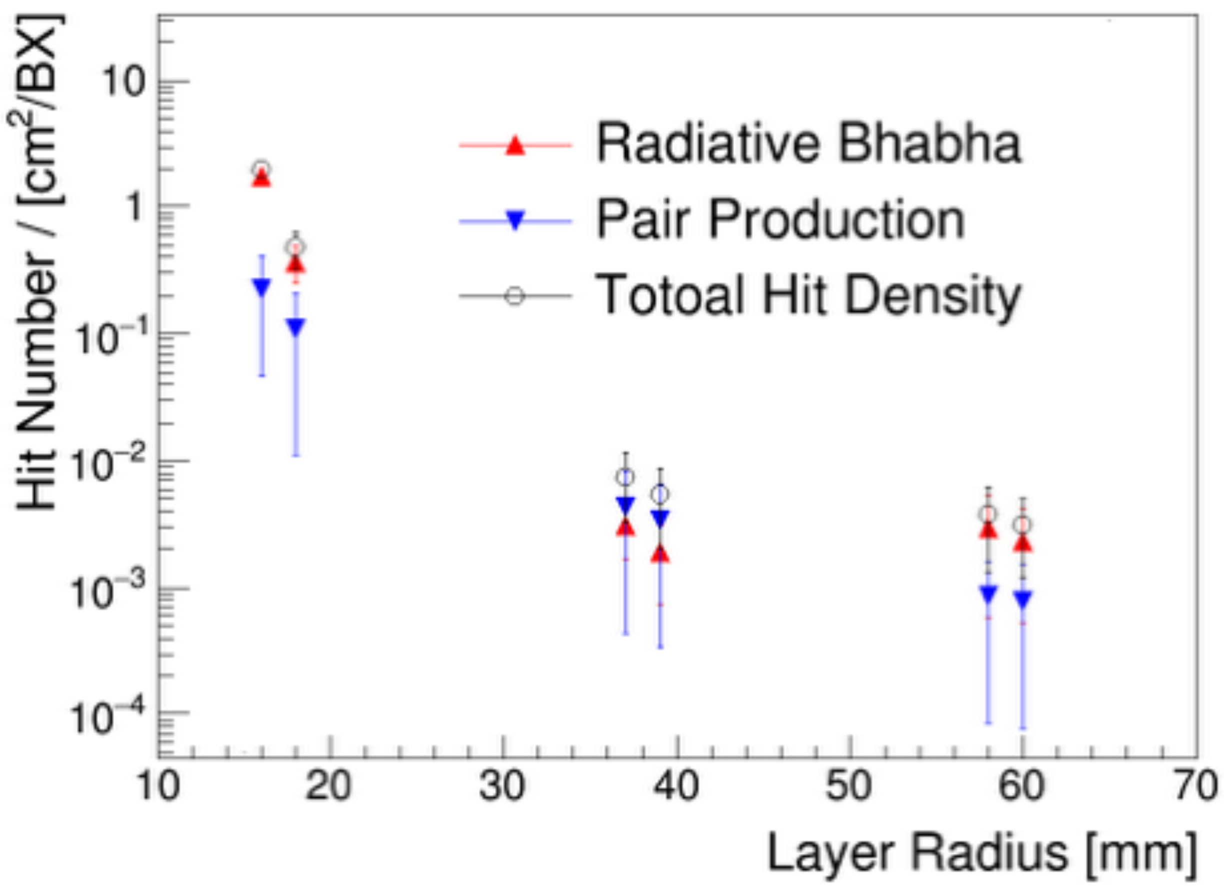
Radiative Bhabha Scattering

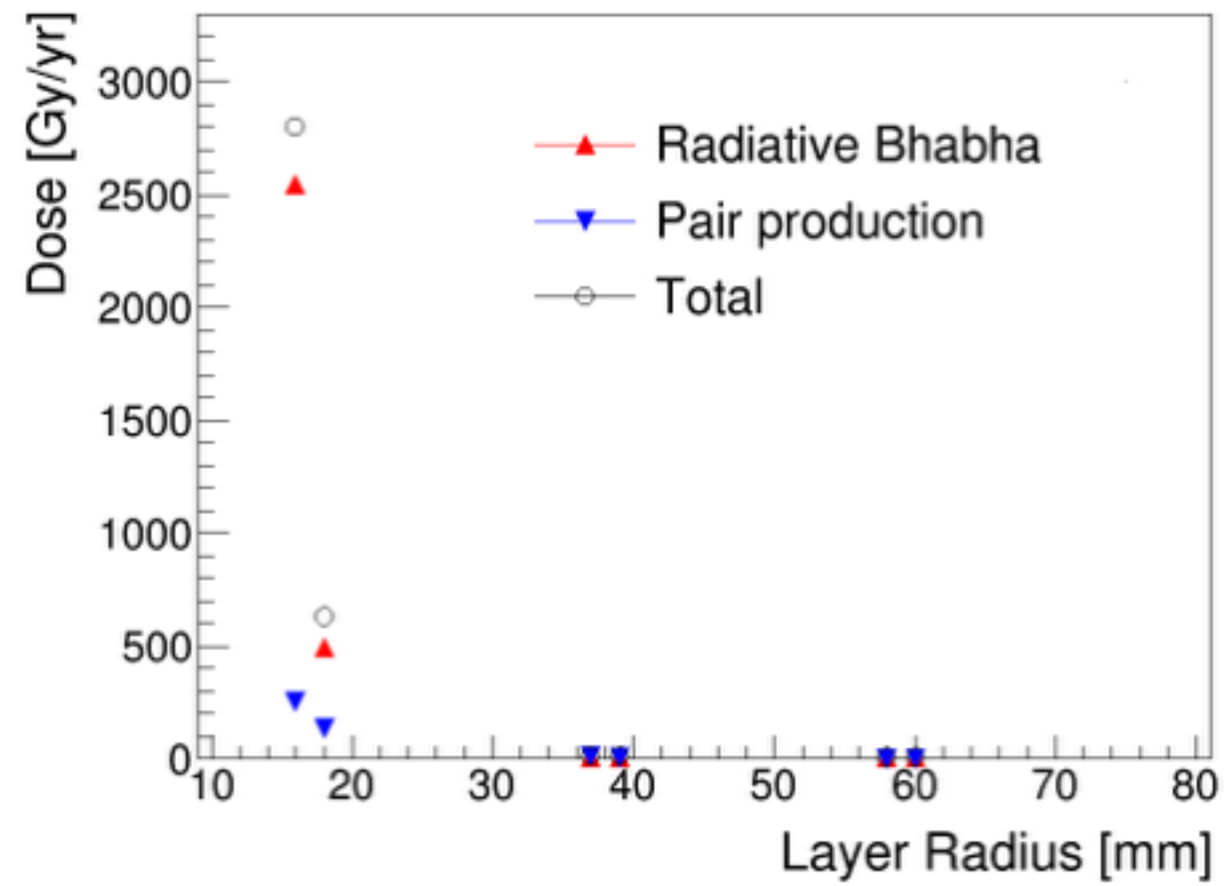
- Dominant background at SuperKEKB/Belle II; potentially the most important background at CEPC → shielding (*experience to be learnt from SuperKEKB*)

- Generator BBBREM to simulate the small angle radiative Bhabha scattering and particles traced in the accelerator with SAD (Strategic Accelerator Design)
  - Scattered particles into the detector right after the collision → small
  - Electrons/positrons after emitting energetic photons (>2% of the beam energy as defined by the accelerator acceptance) kicked off their orbit and re-entering the IR and interacting with the beampipe/magnets (particle showering) → large

- Depending on the accelerator acceptance and the lattice design
- Multi-turn loss with small energy loss stopped by horizontal collimators in the accelerator ring (*but not in the design yet*)

Radiative Bhabha Scattering cont.

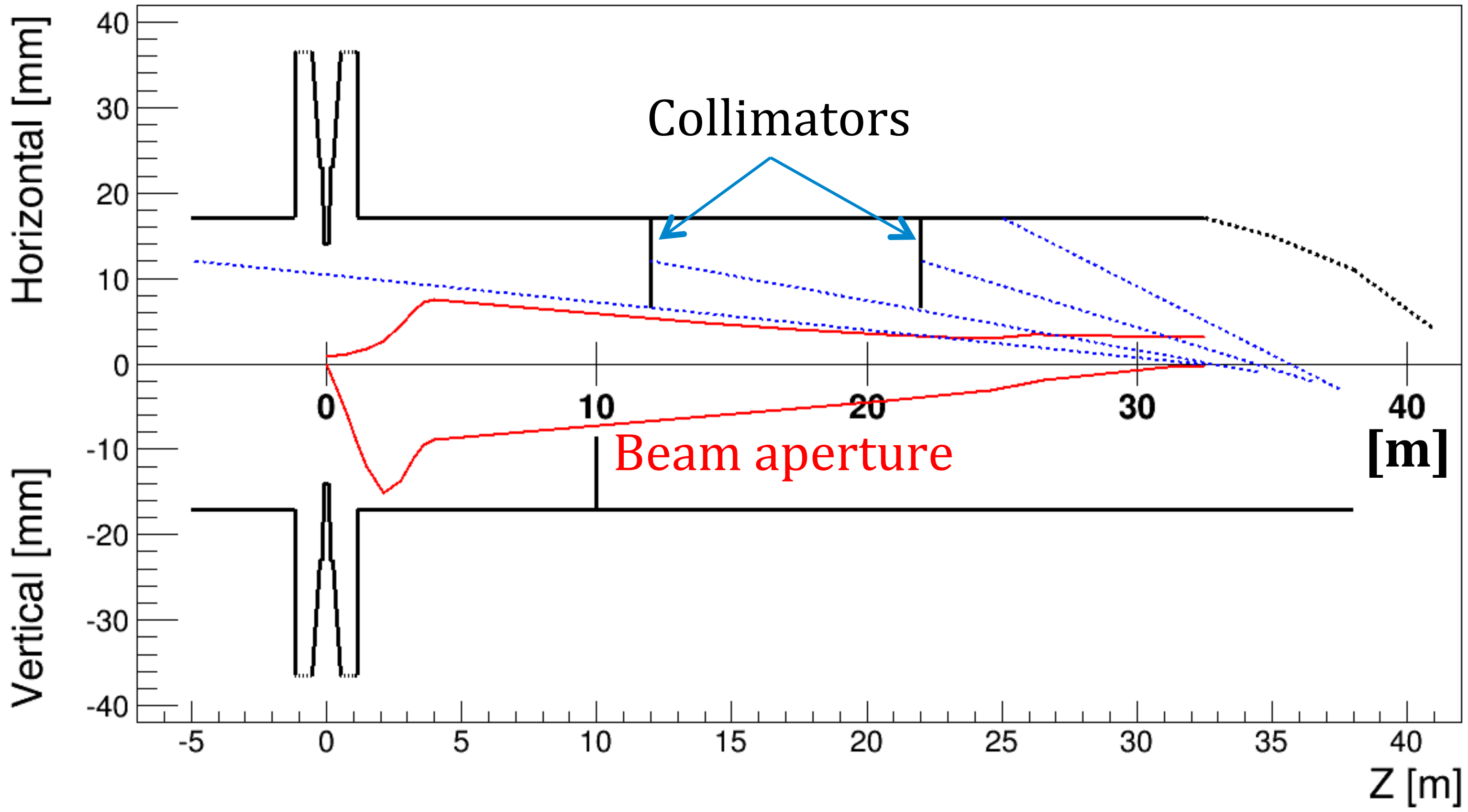




- Hit density increased to 2.2 hits/cm^2/BX (*2 from the radiative Bhabha scattering*)
- Very preliminary radiation tolerance on the inner most detector layer (safety factor of 5), *and detector shielding not included yet*:
  - Total Ionising Dose (TID) ~ 1.5 Mrad/year
  - Non-Ionising Energy Loss (NIEL) ~ 10^{12} 1MeV n_{eq}/cm^2/year

Synchrotron Radiation

- Another important background for circular machines; studied the particle fluence and energy deposition with the private code from Mike Sullivan (SLAC)
  - Preliminary conclusion: main contribution from the last bending dipole; detector and accelerator components safe.
- Ongoing studies with full detector simulation and together with design of the collimator system along the straight-line section → experience from LEP/ SuperKEKB

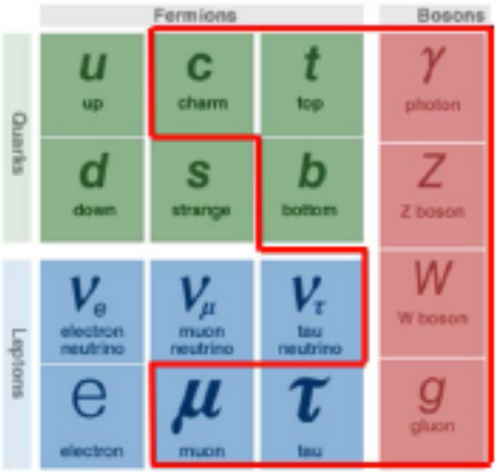


Summary

- High energy circular electron positron collider (CEPC) as a Higgs factory and upgradable to proton-proton collider → LEP/LHC style, similar to FCC but with different priorities
- Precision measurements performed based on the ILD-like detector concept, pushing the precision to (sub-)percent levels
- Detector R&D items identified and to be carried out toward the CDR/TDR → international collaboration expected
- Machine-detector interface issues, in particular detector backgrounds evaluated (partially), and to be further studied → much to learn from LEP/SuperKEKB, and possible collaborative studies with FCC-ee

Backup

Higgs coupling measurement

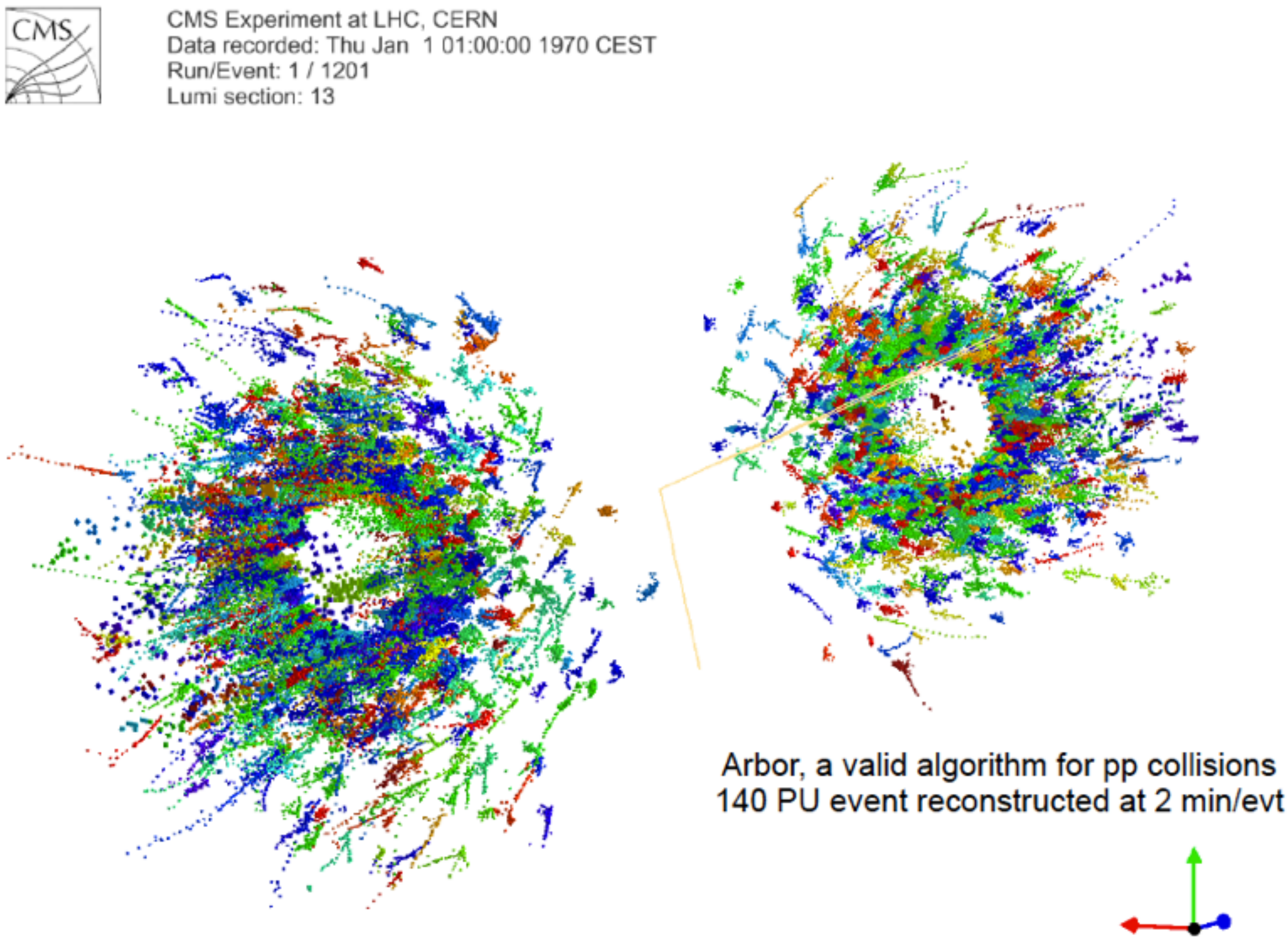


- The output of previous table can be used as the input to make a fit to extract the coupling parameters.
- The deviation of the parameters from SM can be parameterized as : $\kappa_f = \frac{g(h_{ff})}{g(h_{ff},SM)}$, $\kappa_V = \frac{g(h_{VV})}{g(h_{VV},SM)}$
  - for a small deviation, new physics is not very sensitive to the deviation of κ_u, κ_d, κ_s, κ_e .
  - κ_t κ_c, κ_b, κ_τ, κ_μ κ_z, κ_w, κ_γ, κ_g, κ_{inv}, Γ_{tot} are 11 model independent parameters for the fit.

Adding assumptions:

- K_t can be separated since it determines only ttH production and it is not CEPC's job (10 parameters): κ_c, κ_b, κ_τ, κ_μ κ_z, κ_w, κ_γ, κ_g, κ_{inv}, Γ_{tot}
- $\kappa_\tau = \kappa_\mu$ 9 parameters (lepton university)
- No invisible decay : 8 parameters.
- No exotics 7 parameters : κ_c, κ_b, $\kappa_\tau = \kappa_\mu$, κ_z , κ_w, κ_γ, κ_g

Arbor @ CMS


CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Jan 1 01:00:00 1970 CEST
Run/Event: 1 / 1201
Lumi section: 13
Arbor, a valid algorithm for pp collisions
140 PU event reconstructed at 2 min/evt

Input Machine Parameters

- **G**enerator of **U**nwanted **I**nteractions for **N**umerical **E**xperiment **A**nalysis—**P**rogram **I**nterfaced to **G**EANT → GUINEA-PIG
- Input machine parameters for CEPC (*compared to ILC250*)

Machine Parameters	CEPC	ILC250
E_{cm} [GeV]	240	250
Particles per bunch	3.7×10^{11}	2.0×10^{10}
Beam size σ_x/σ_y [nm]	73700/160	729/7.7
Beam size σ_z [μm]	2260	300
Norm. Emittance $\varepsilon_x/\varepsilon_y$ [mm · mrad]	1595/4.8	10/0.035

- Results being cross-checked with CAIN