Software, simulation, and performance of CEPC

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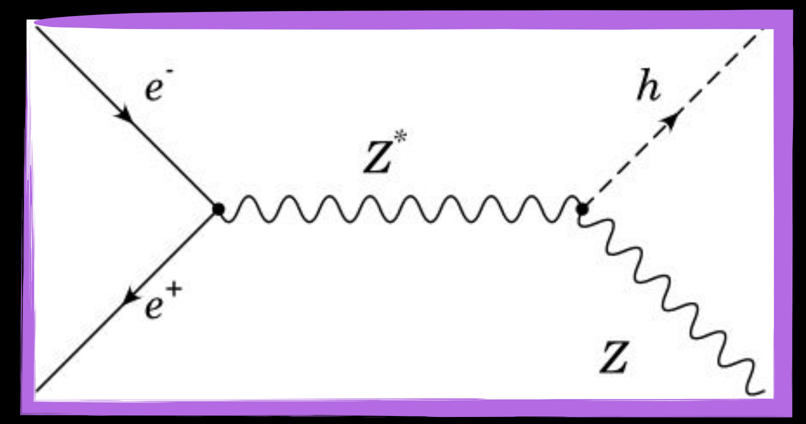
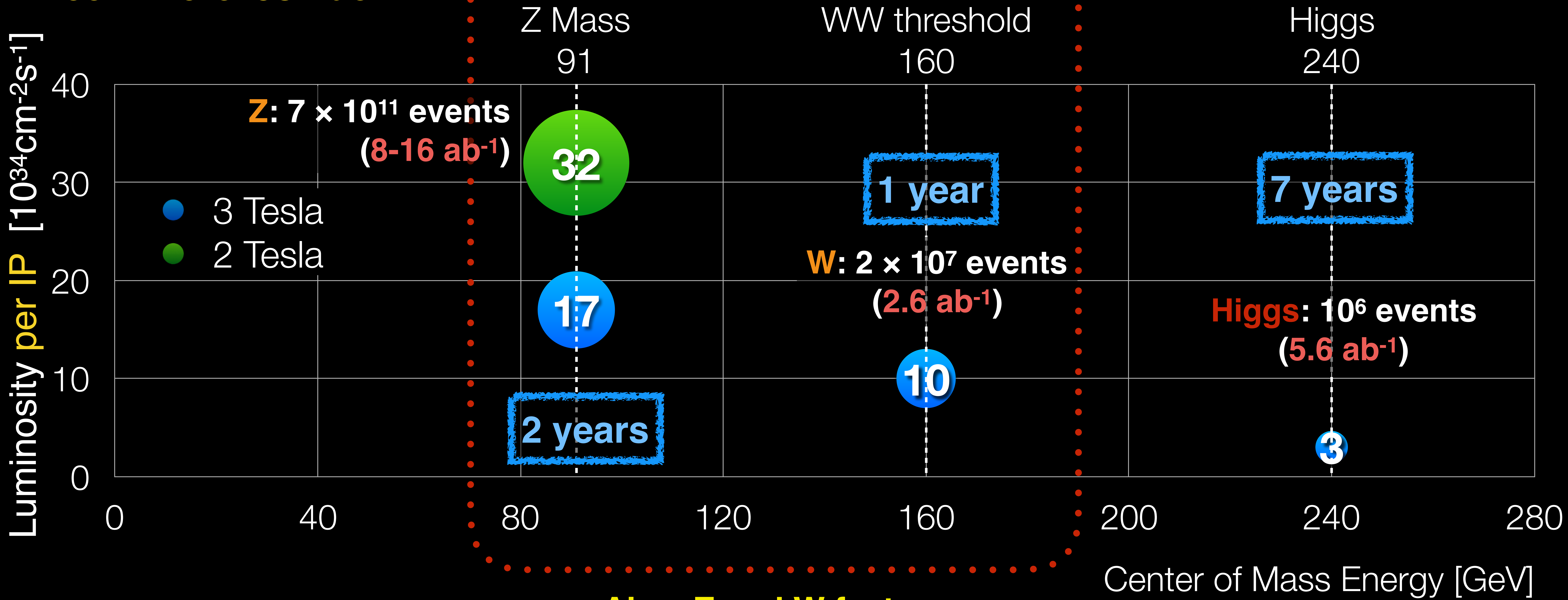
Outline

- Introduction
- What we had
- What we are going to have
- Summary

The CEPC Physics

100 km e+e- collider





Also, Z and W factory

Upgradable to 360 GeV for top study

2 IPs planned

What we already had?

CEPC baseline software

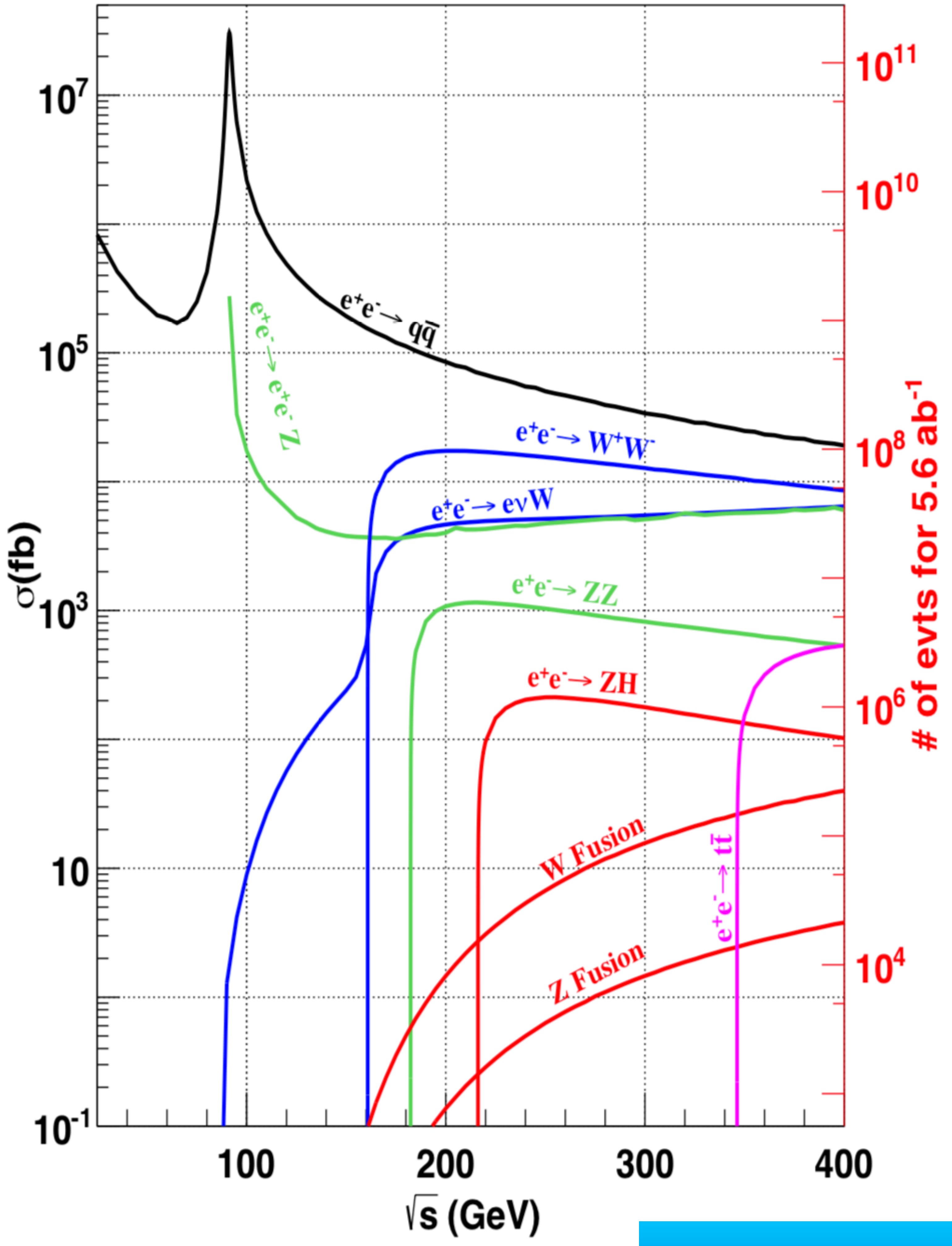
- full simulation
- reconstruction
- analysis

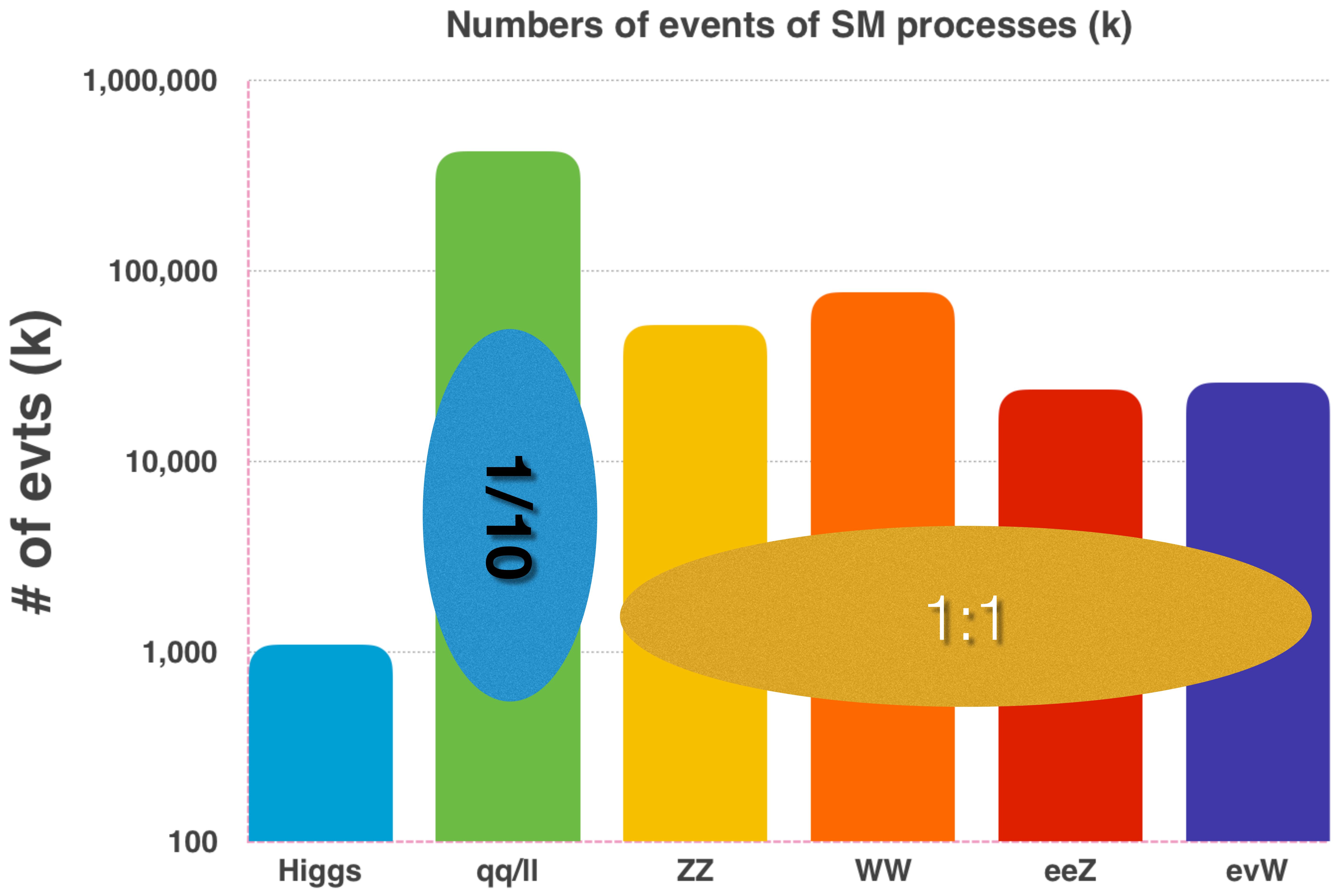
Generator samples @ 91, 160, 240 and 360 GeV

Complete full simulated samples @ 240 GeV

+ Selected full simulated samples at other energy points

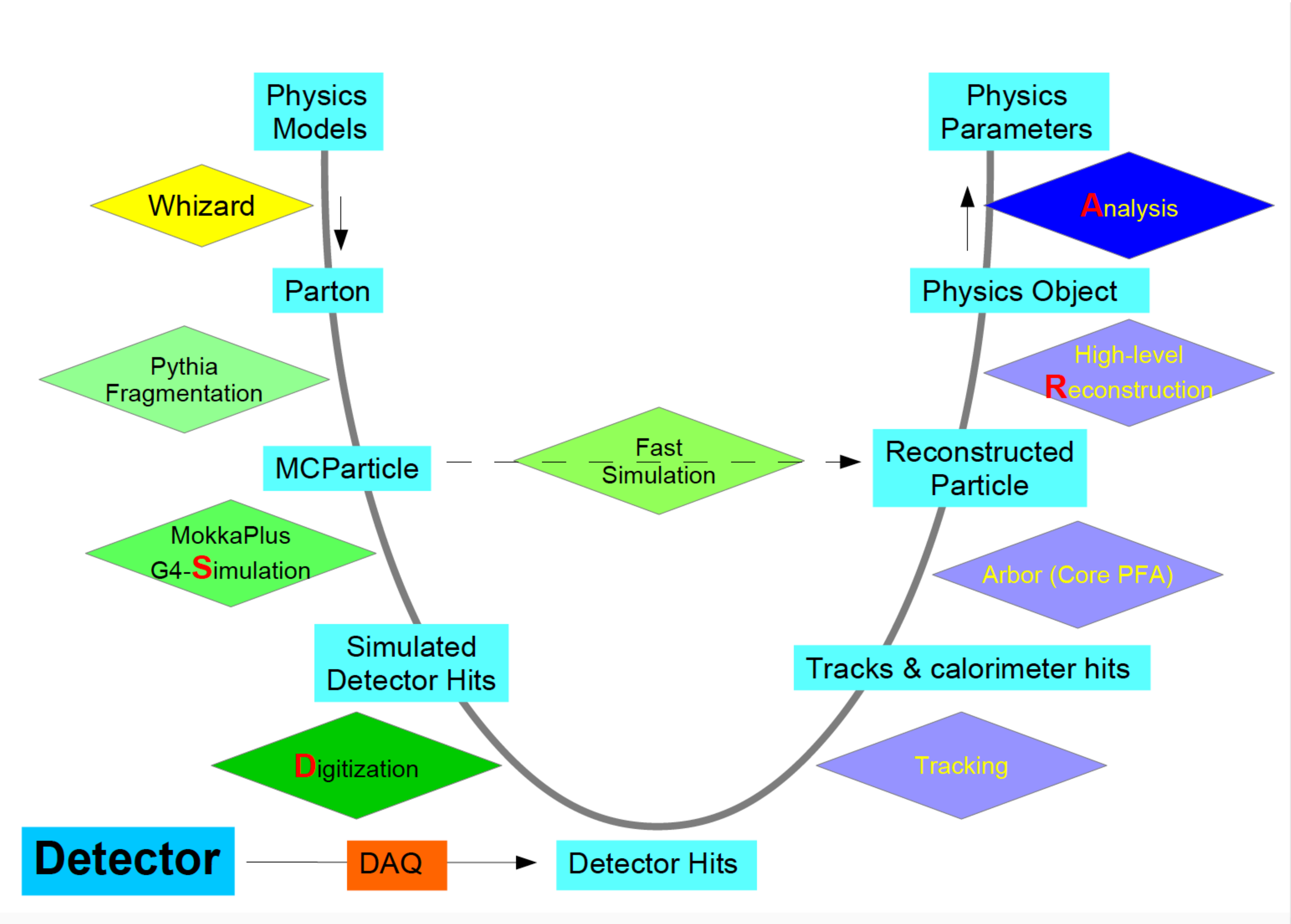
Complete MC samples of 240 GeV
+ some at 91, ~160, and 360 GeV





Sufficient to do various physics study

CEPC baseline software — http://cepcsoft.ihep.ac.cn/



- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder (Coral)
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display (Druid)
- General Analysis Framework (FSClasser)
- Fast Simulation (Delphes + FSClasser)

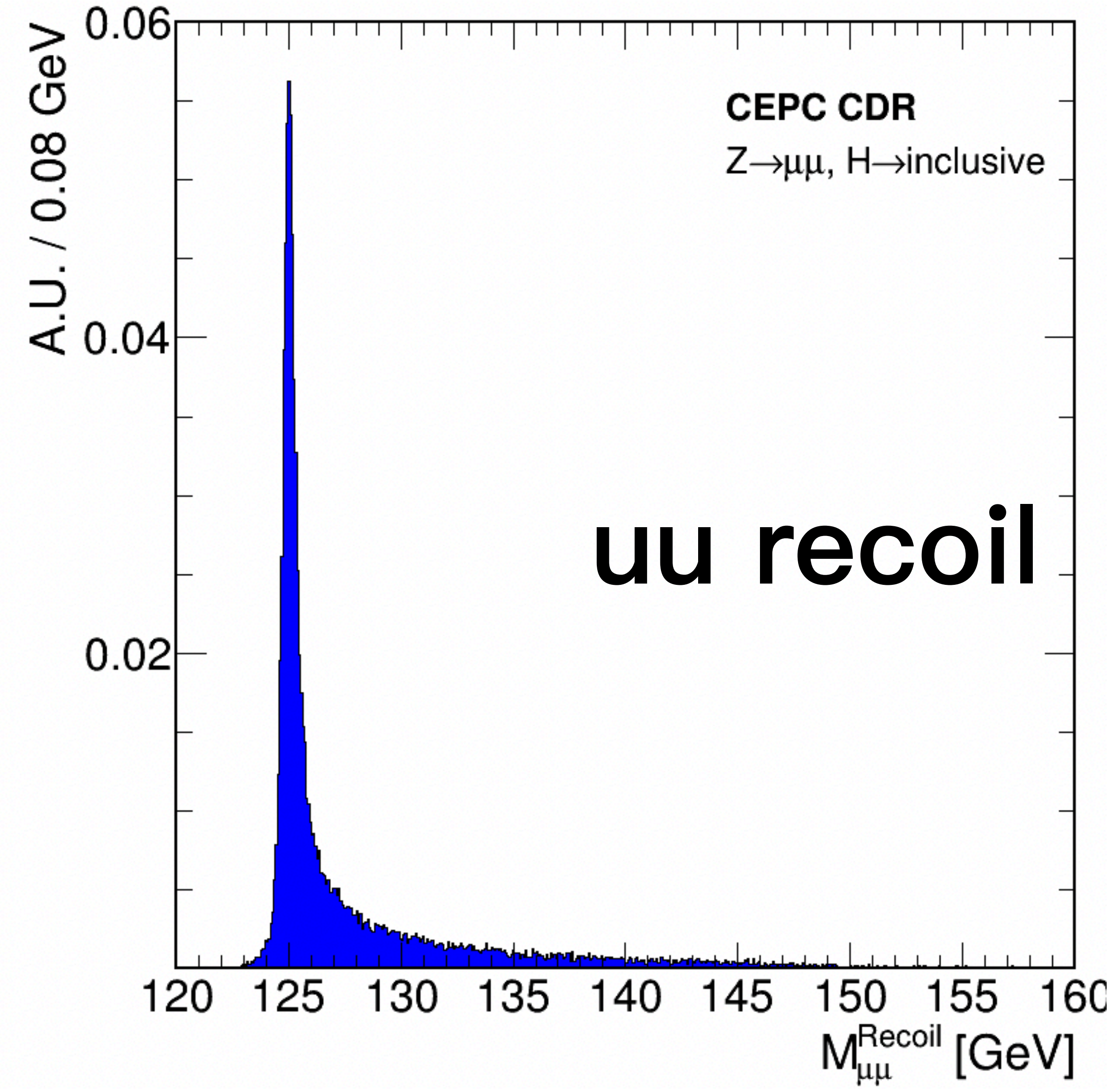
CEPC software team efforts

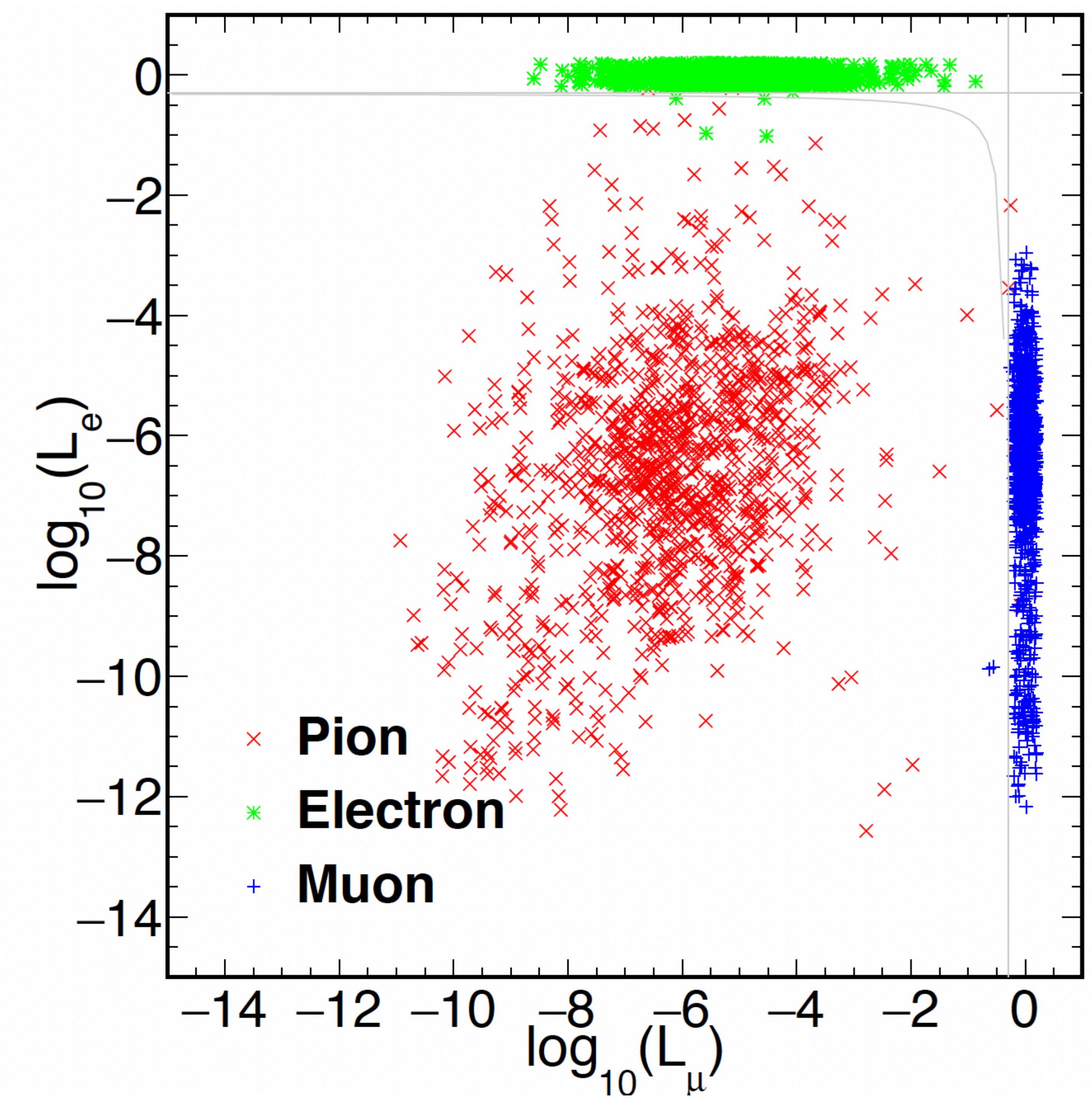
CEPC baseline detector
Particle flow philosophy

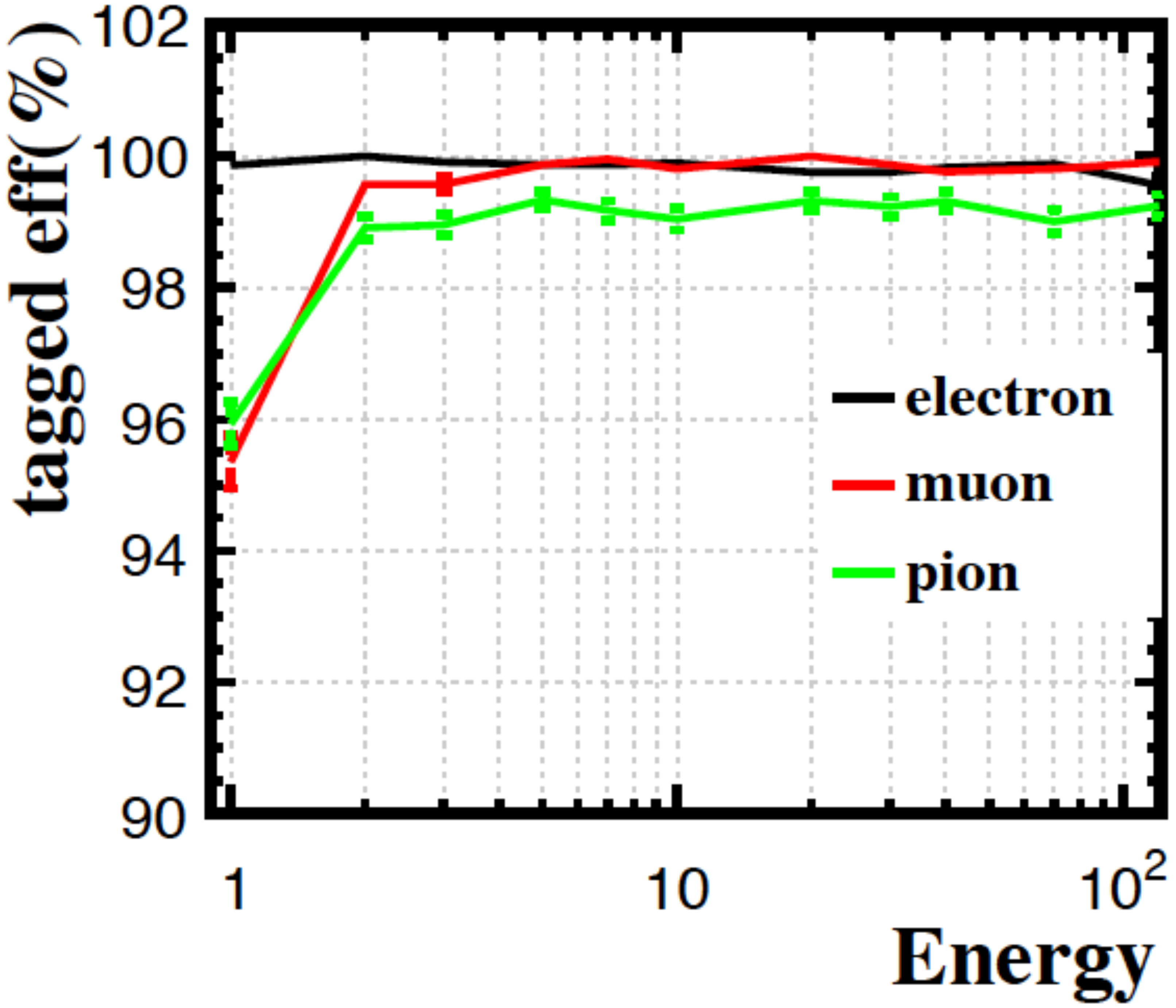
Particle flow: make use of the optimal sub-detector information in reconstruction and a high granularity calorimetry system required

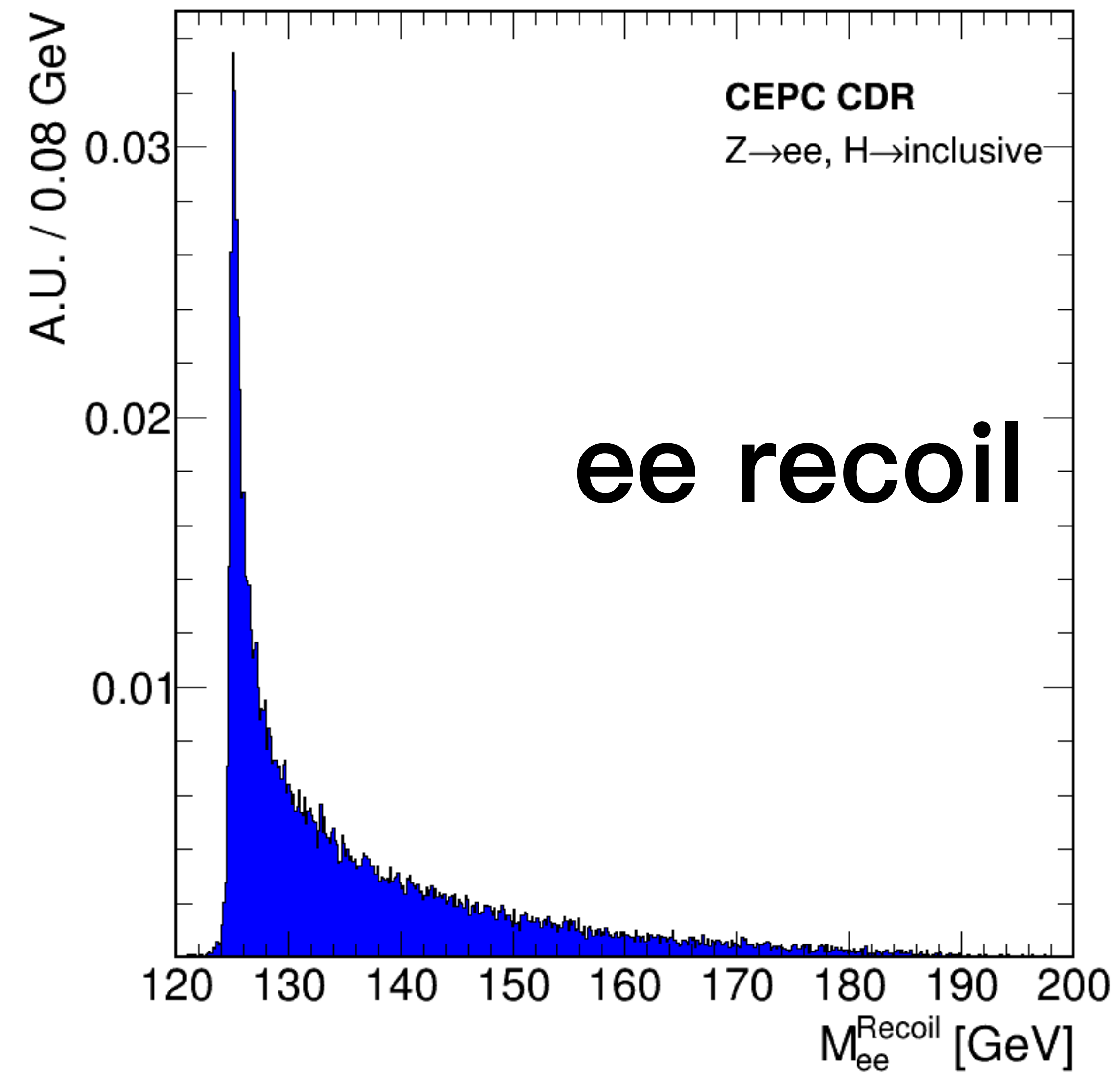
Particles in jet	Fraction of E	Measured by	Resolutions (σ^2)
Charged tracks	~60%	Tracker	Negligible
Photons	~30%	Ecal	0.20^2E_{jet}
Neutral hadron	~10%	Ecal+Hcal	0.50^2E_{jet}
Conclusion	Required for 30%/sqrt(E)		0.20^2E_{jet}

Leptons: momentum resolution & Pid







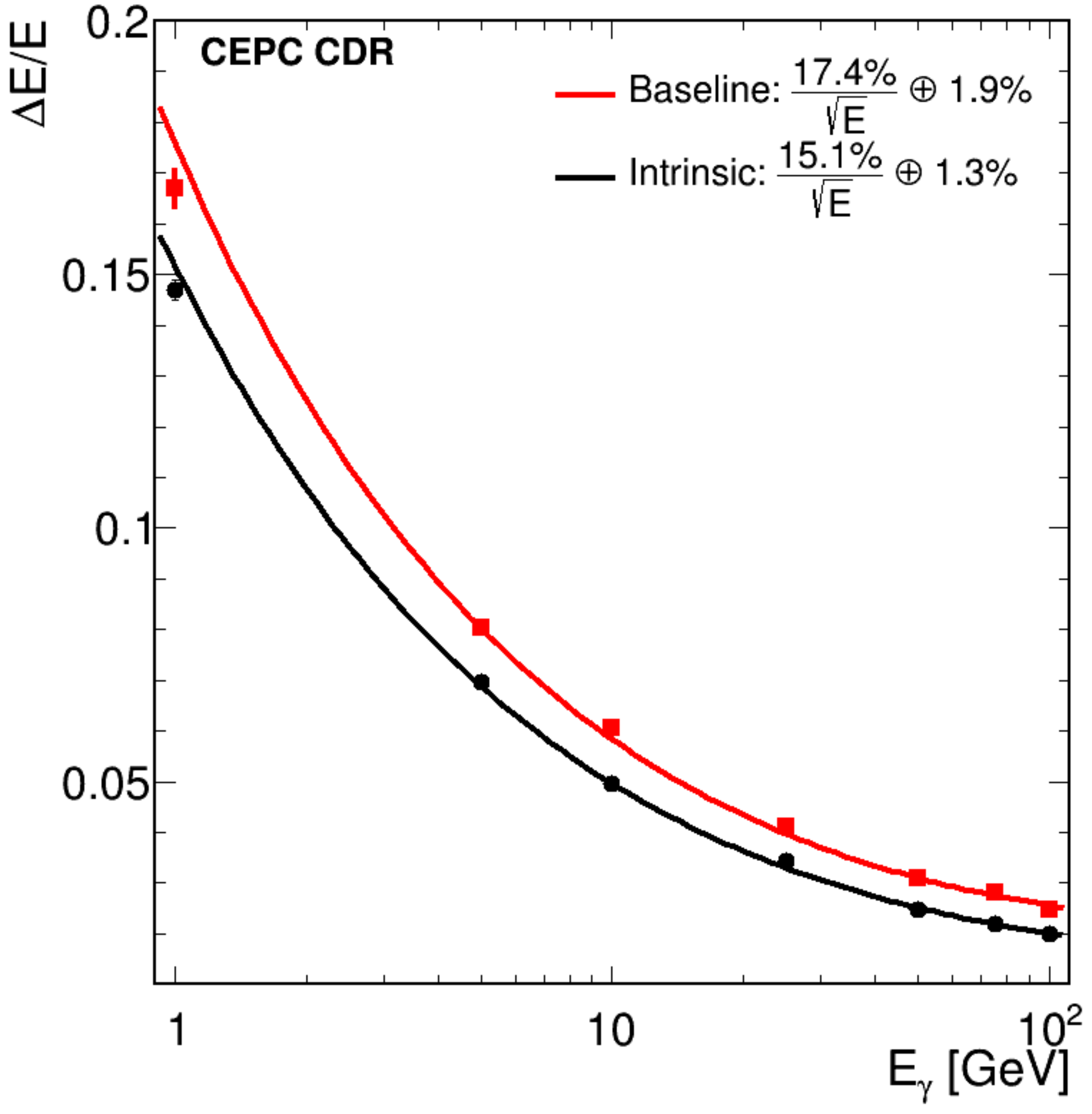


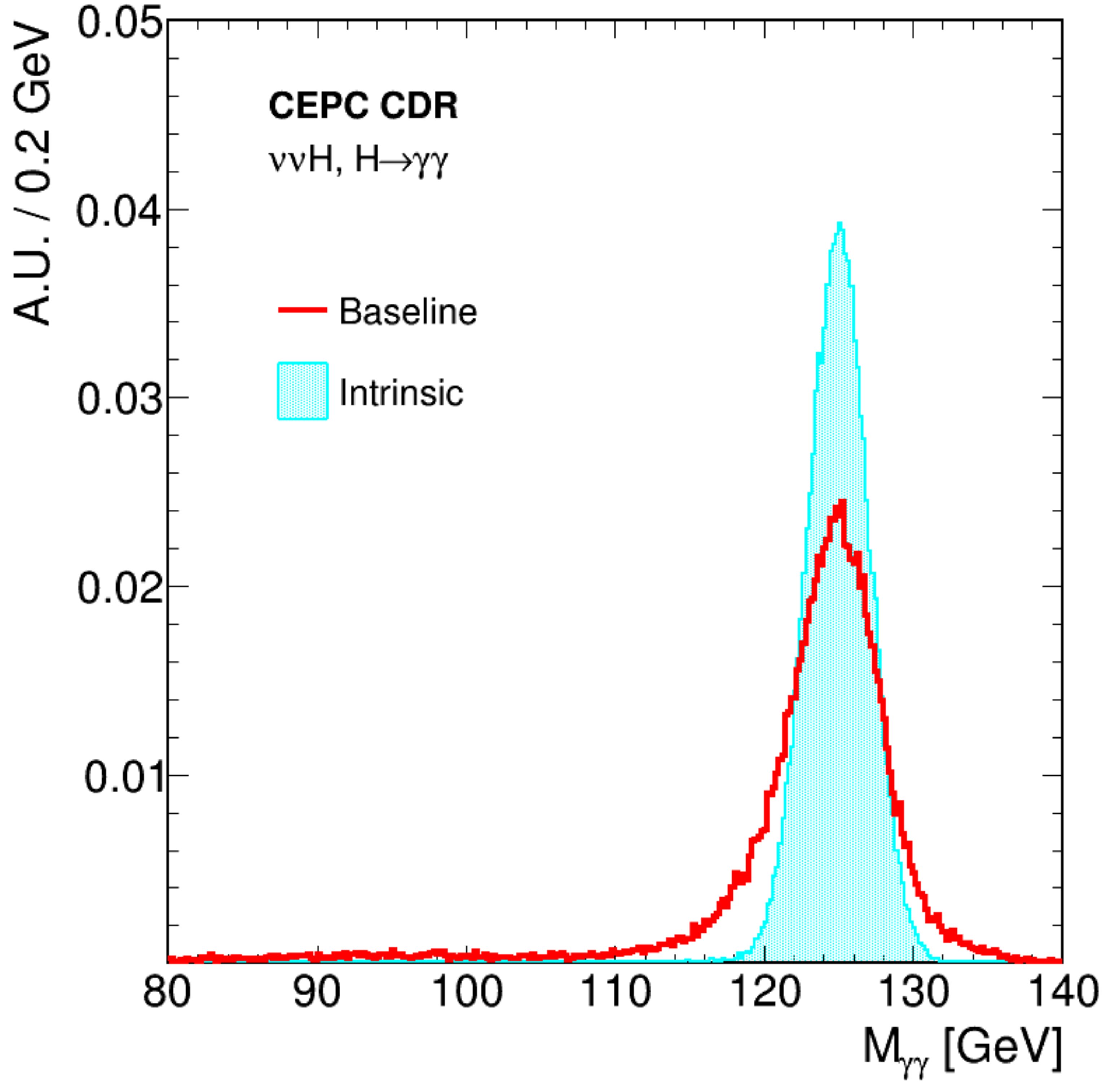
BDT method using 4 classes of 24 input discrimination variables.

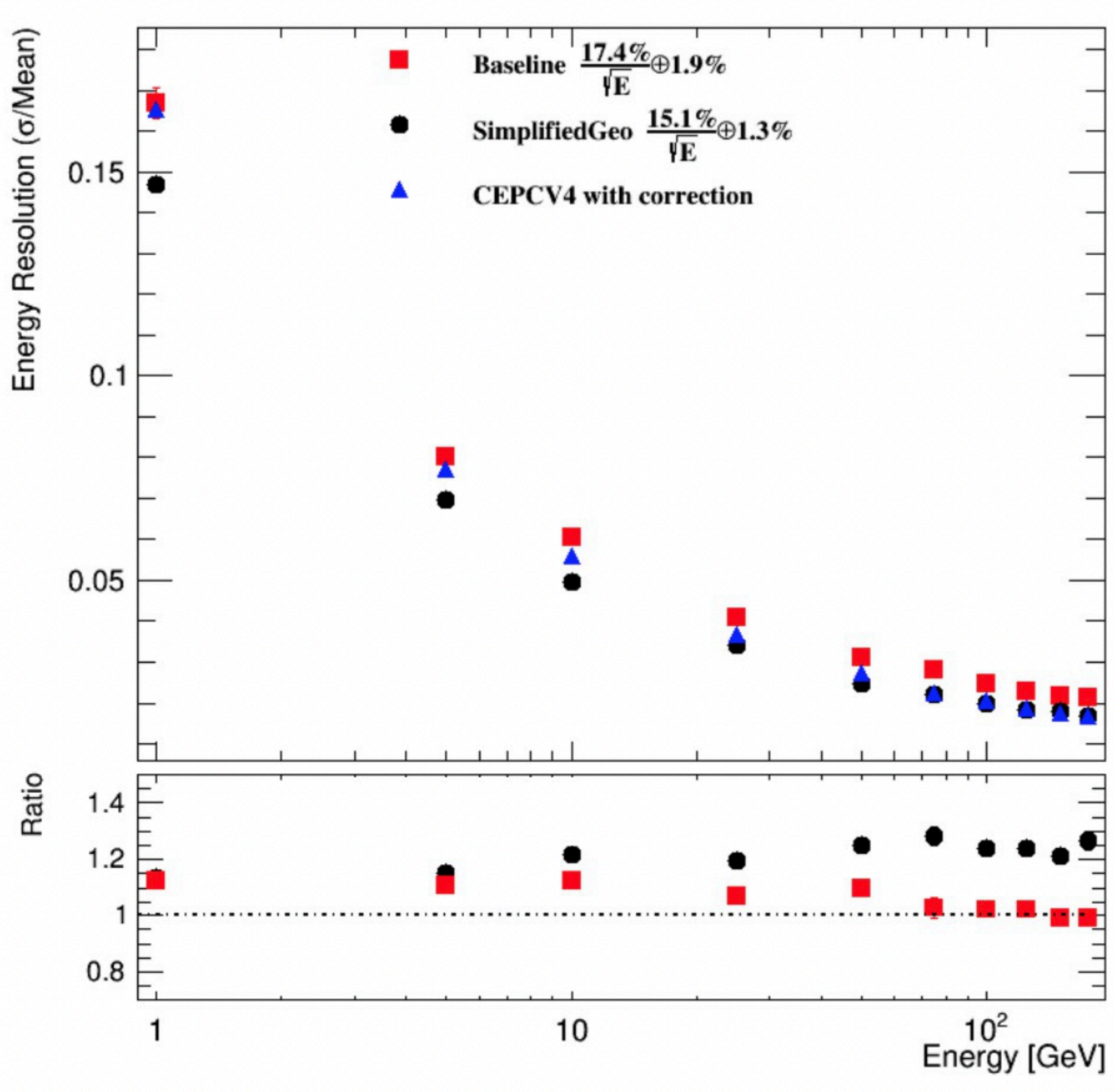
Test performance at: Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5

Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% & Pion mis id rate ~ 1%

Photons: energy resolution

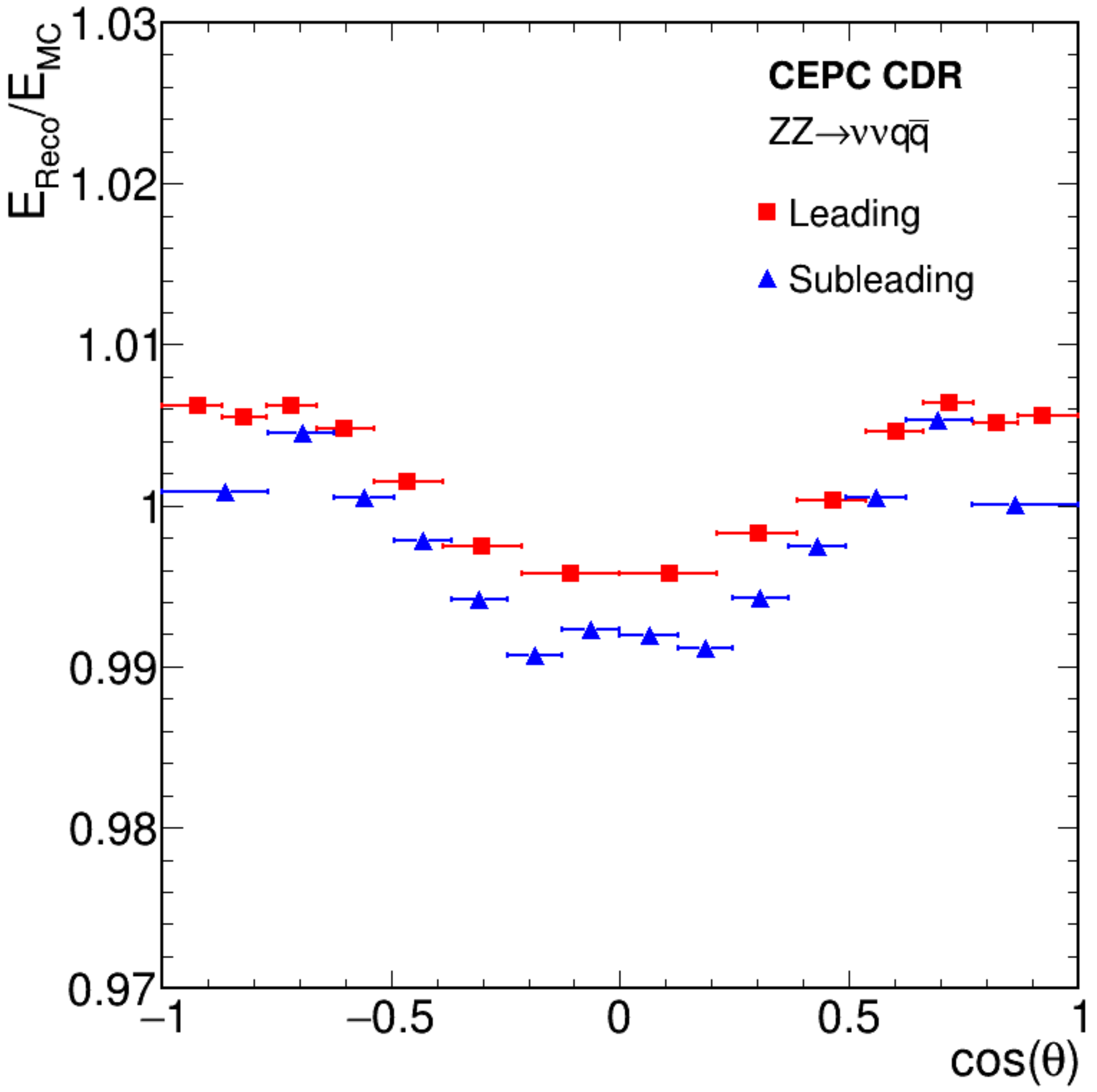


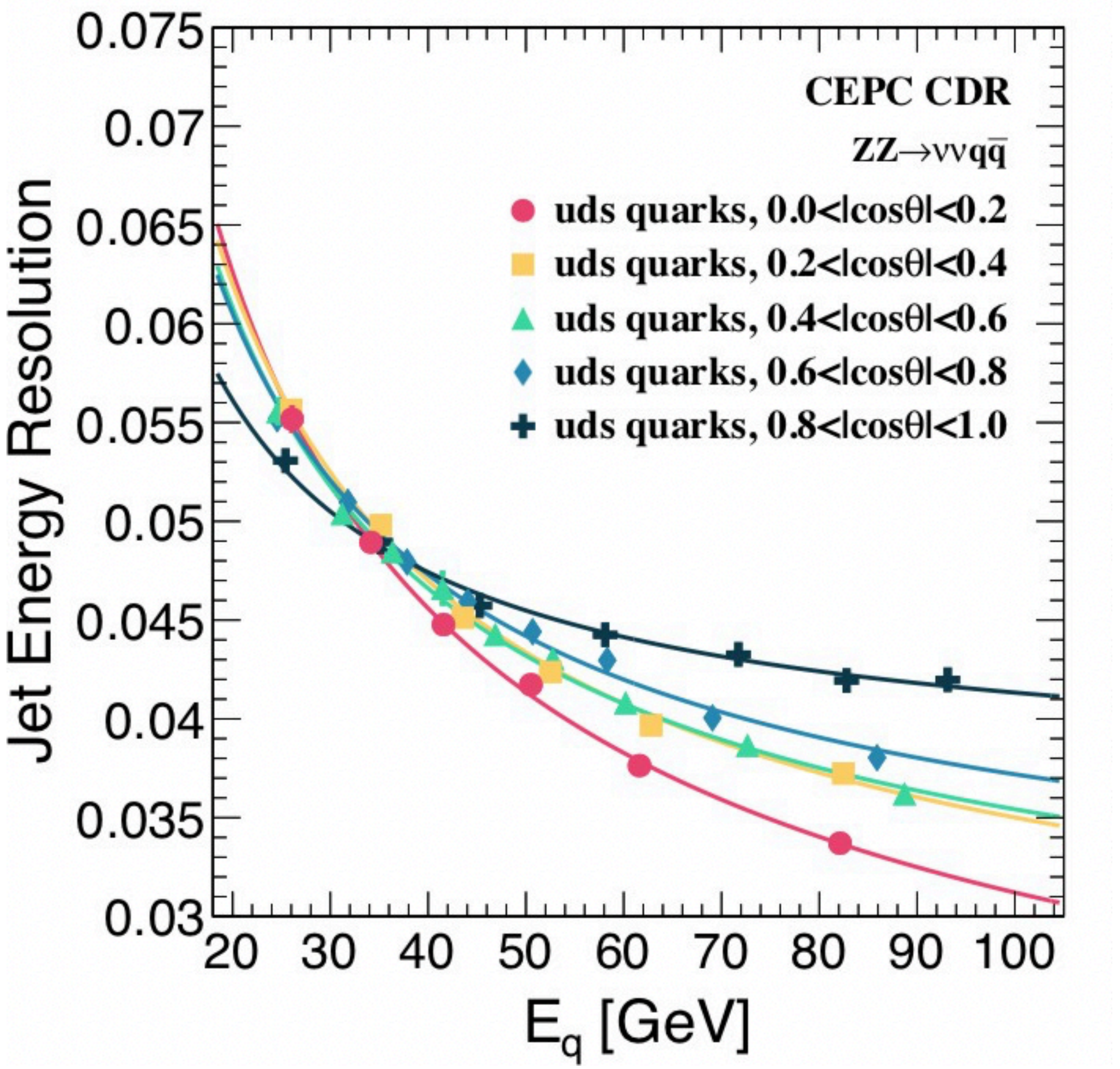




- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/baseline geometry
- The geometry defects correction could be efficiently corrected

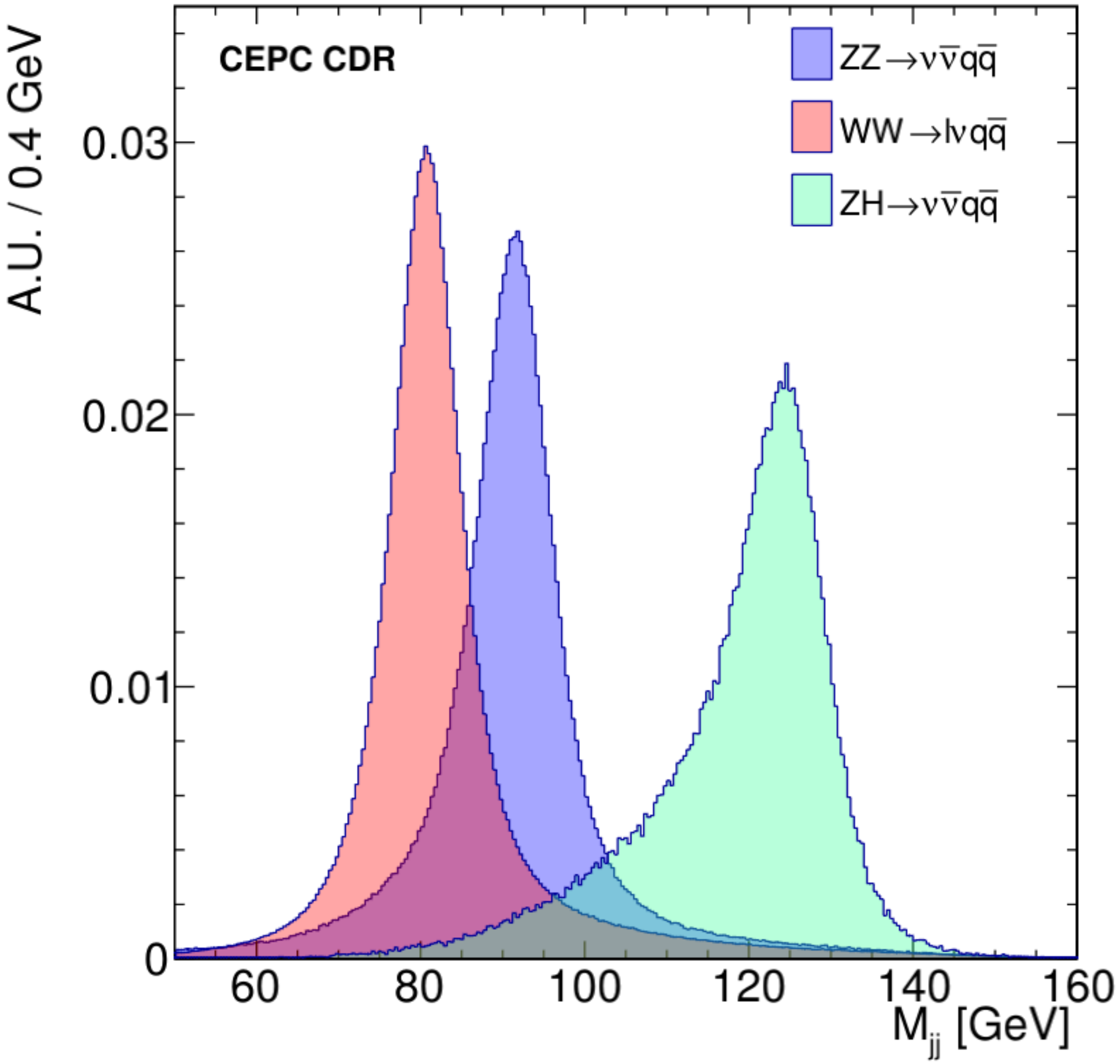
Jet energy scale & resolution

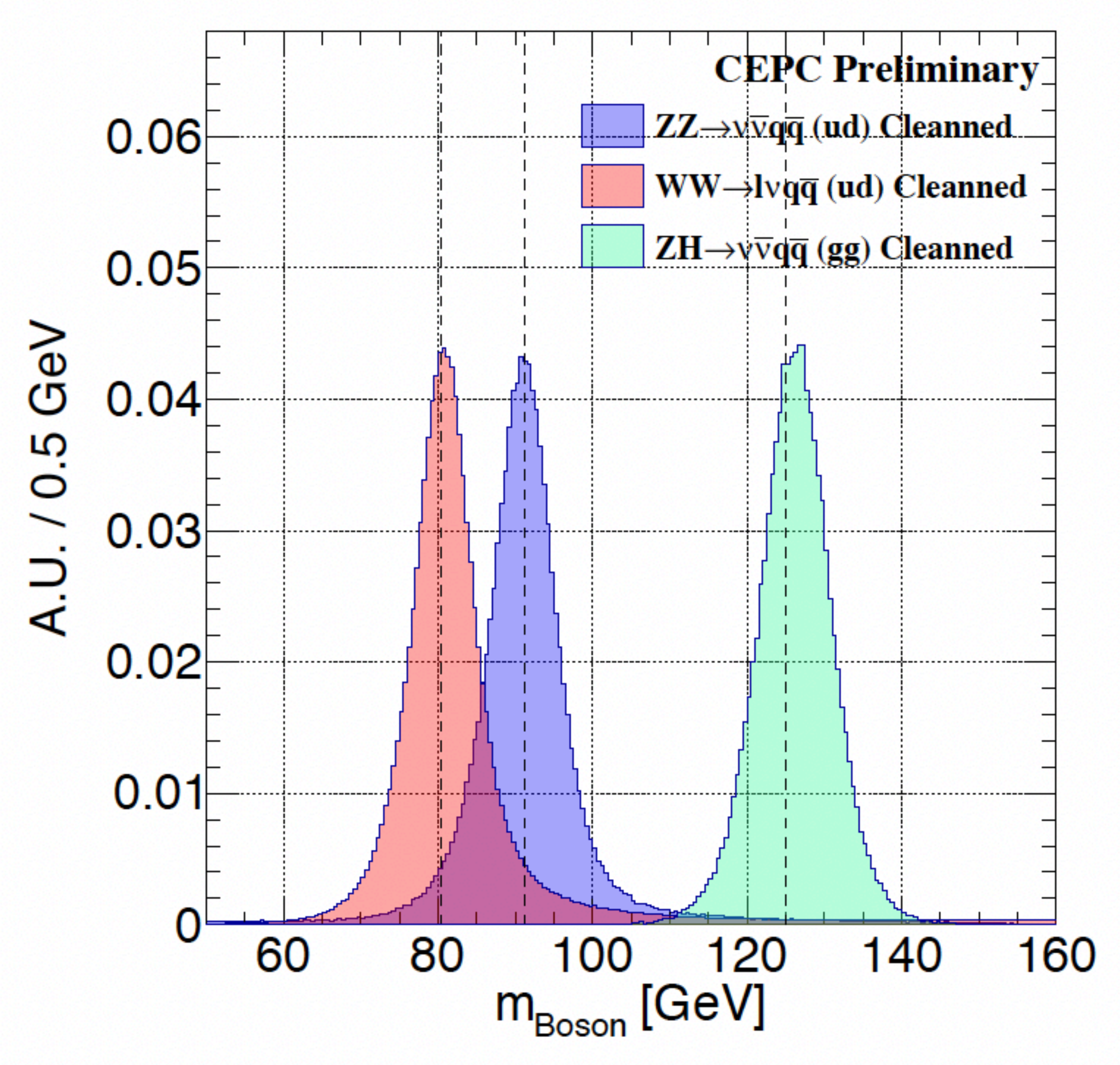




- ⭐JES ~ with 1% of the unity (without correction)
- ⭐JER ~ 3.5% – 5.5% for E ~ 20 — 100 GeV Jets
- ⭐Both significantly improved with respect to LHC experiments

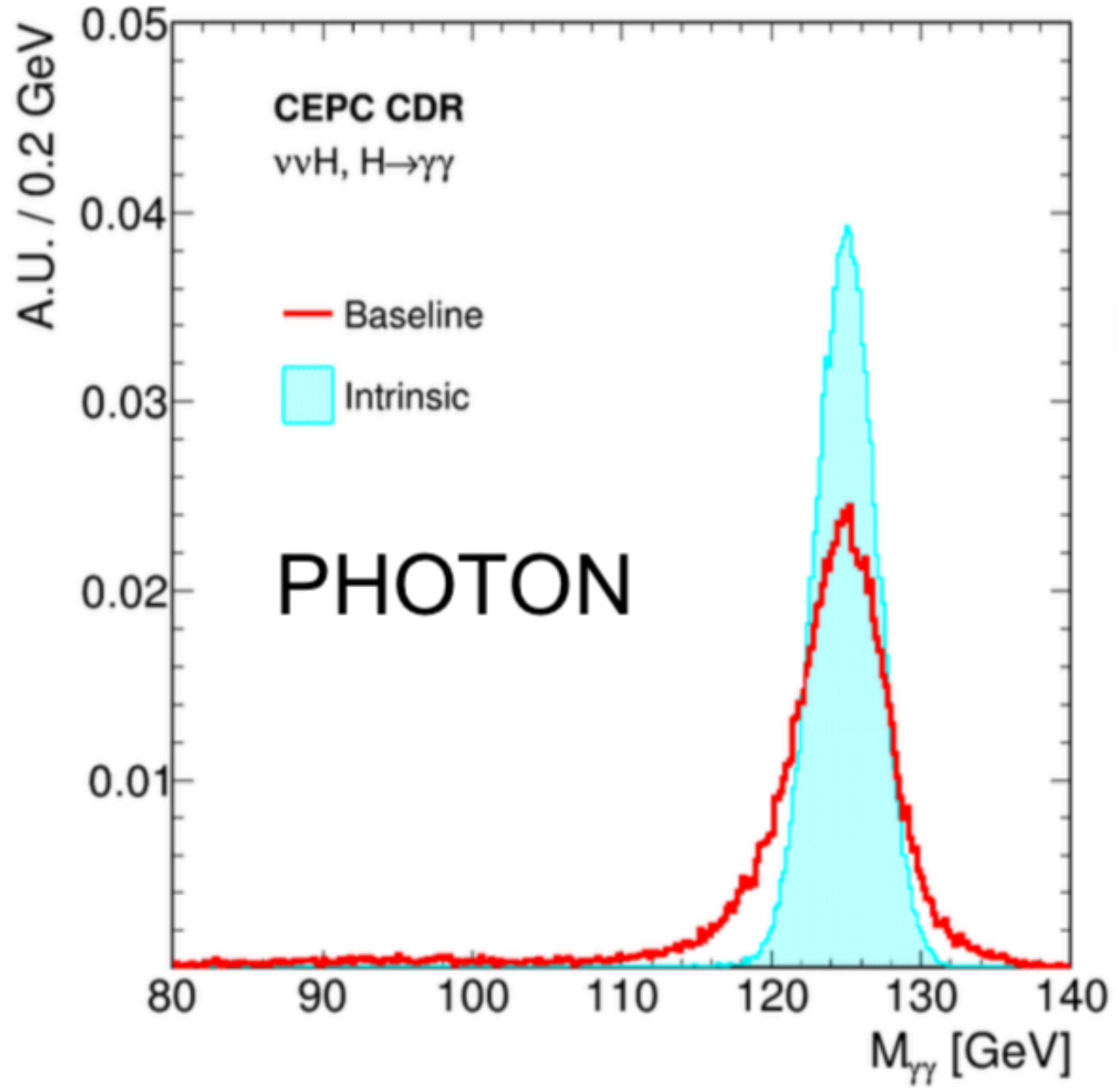
Jets: MBR of 3.8% reached, enables Massive Boson Separation



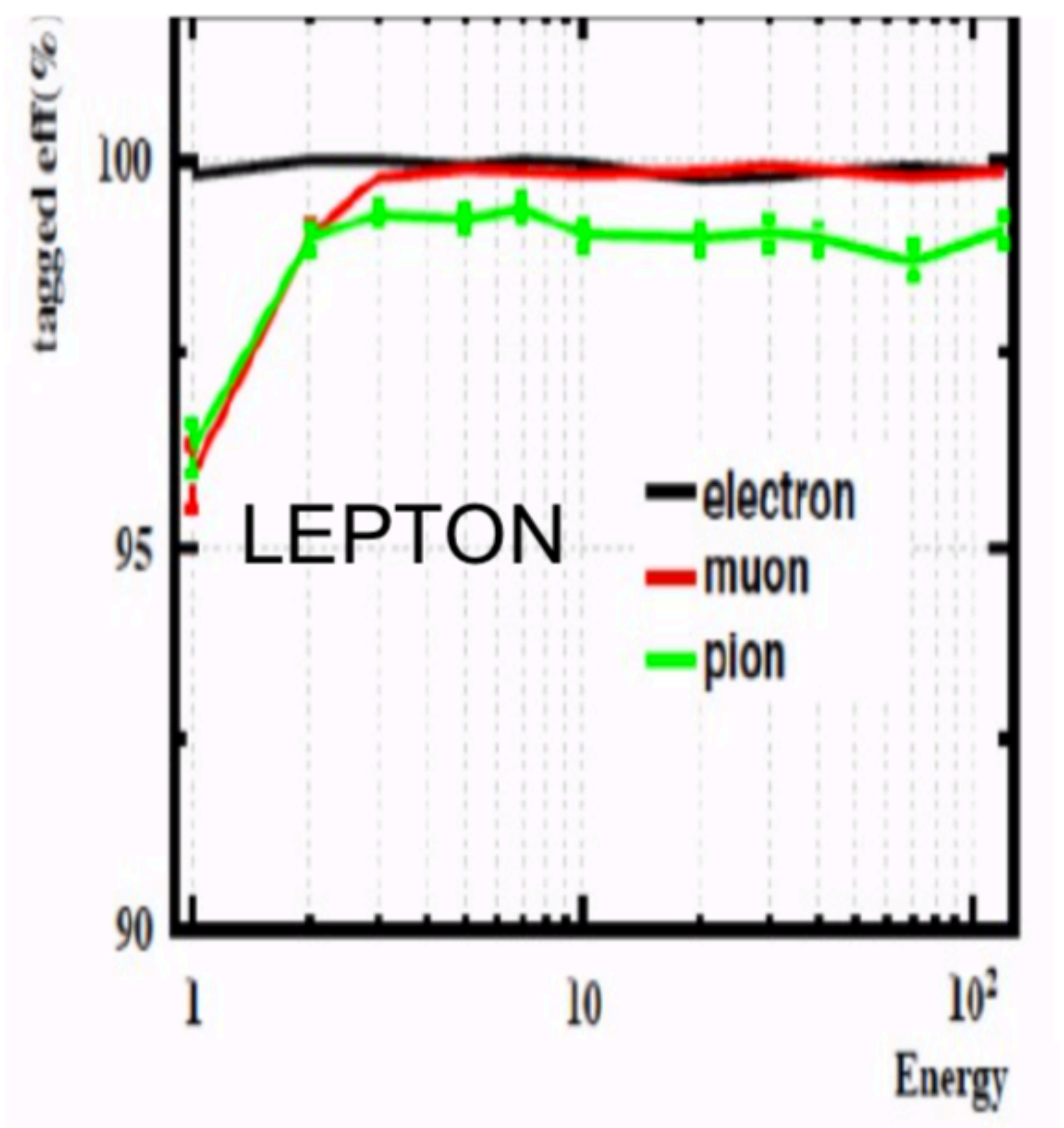


More work on Jet clustering and jet pairing to improve MBR

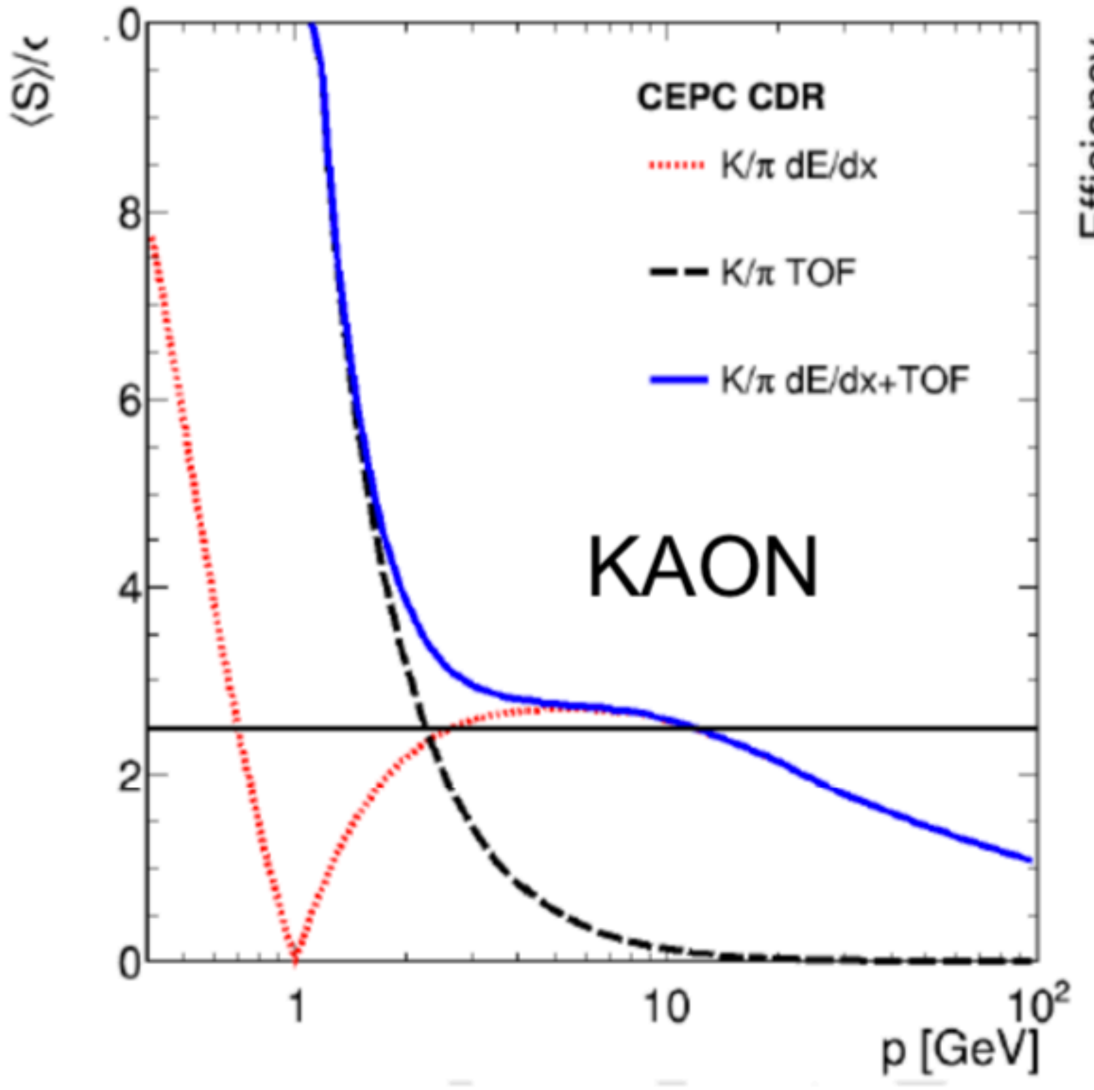
All physics objects ready serve for detector and physics performance evaluation

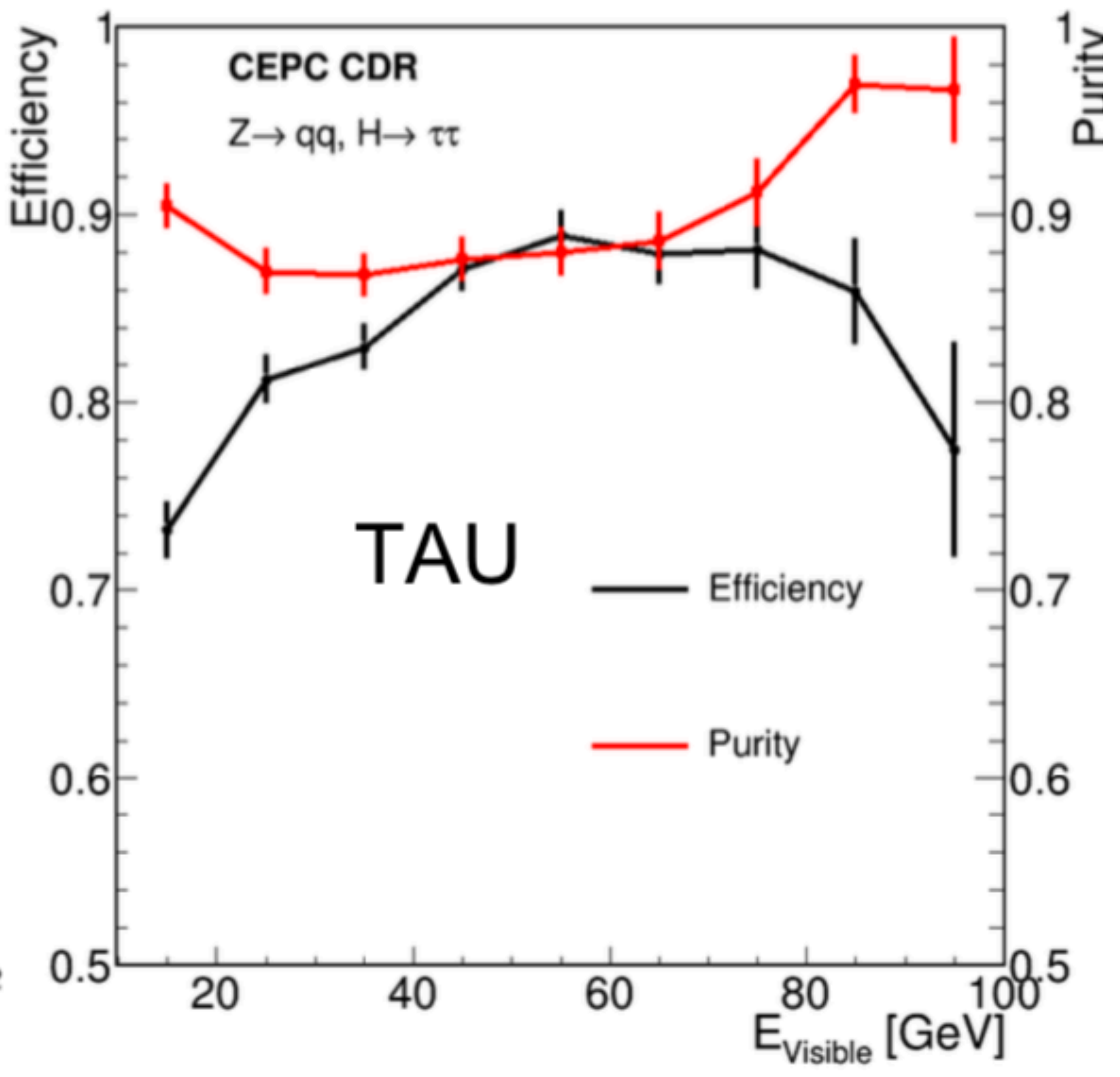


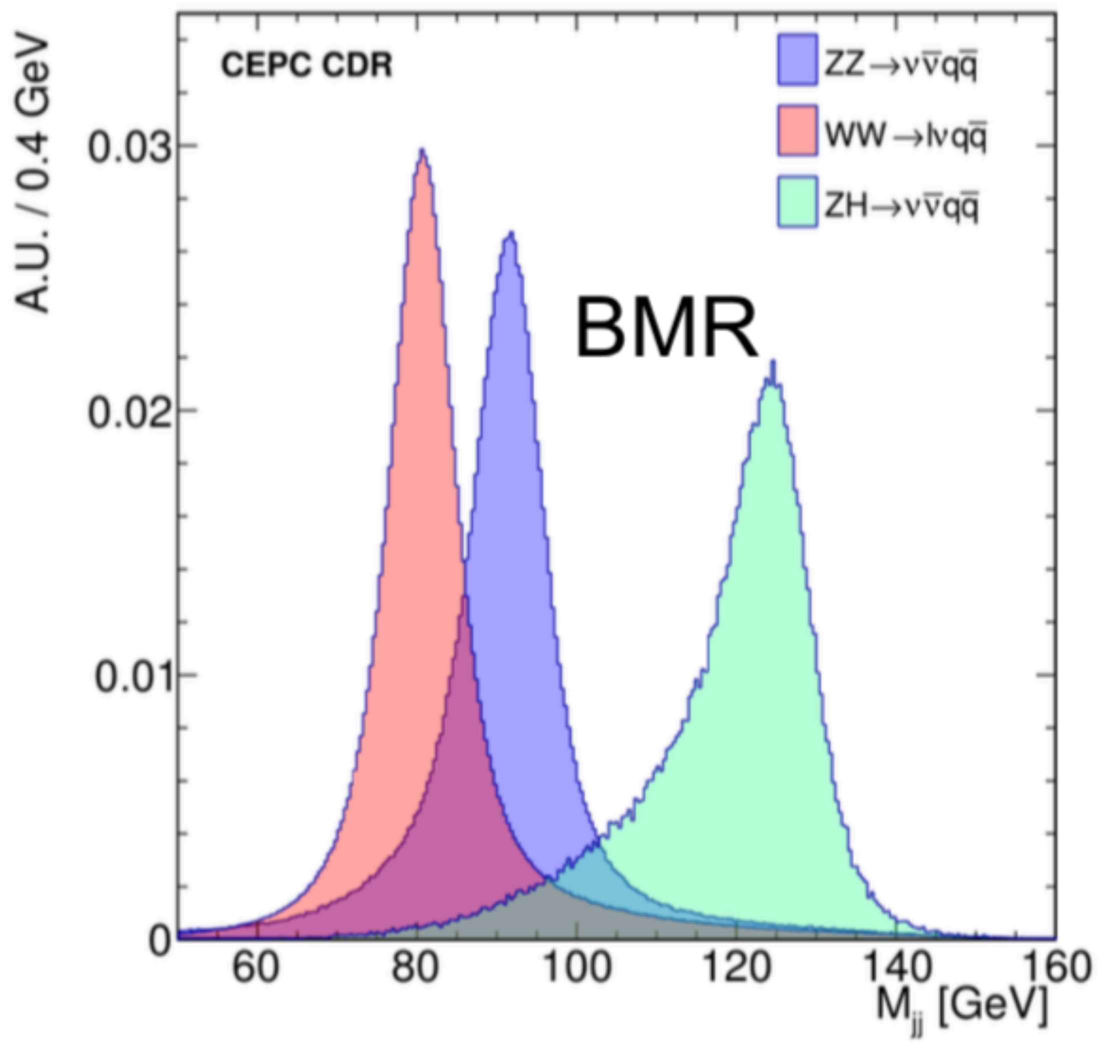
Eur. Phys. J. C (2017) 77: 591

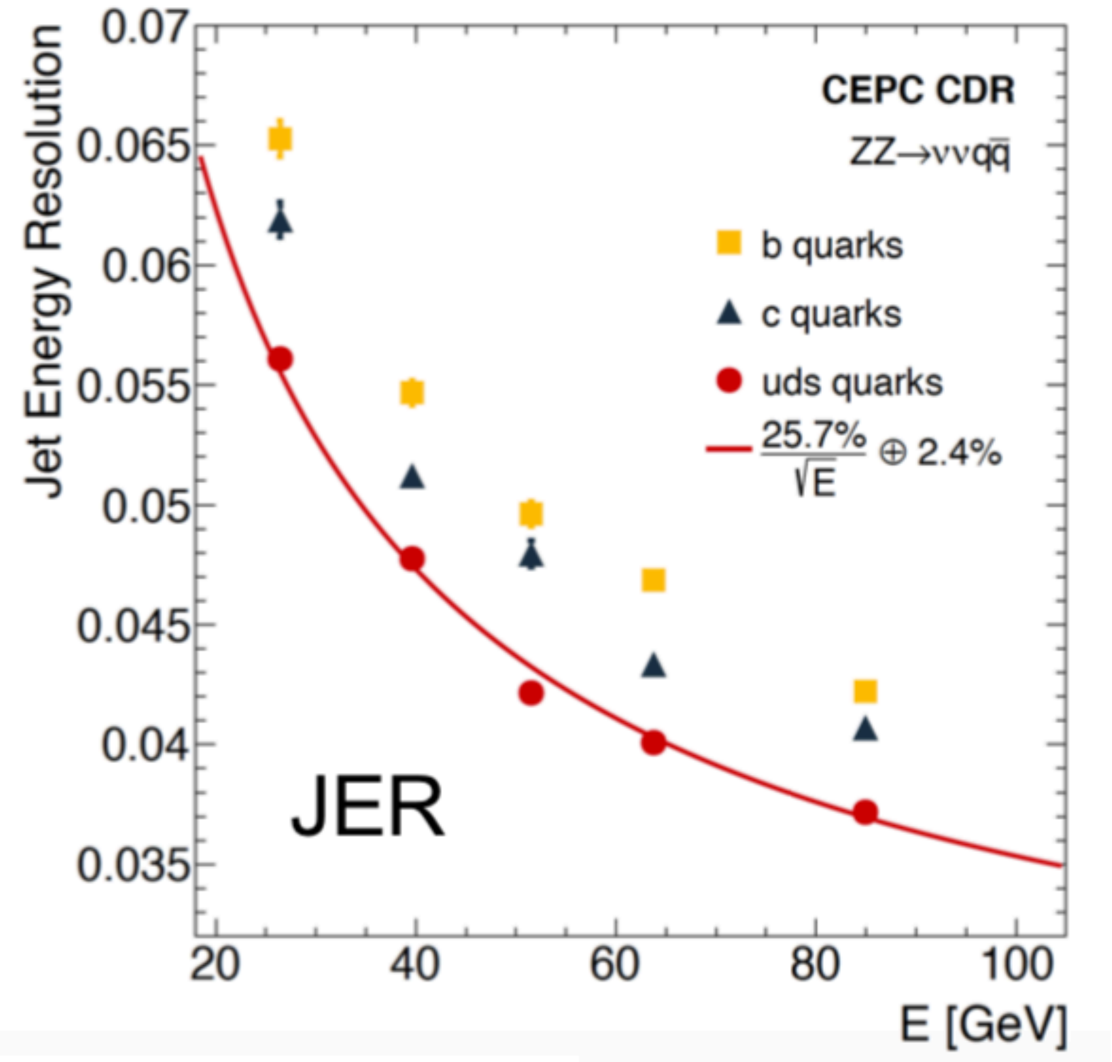


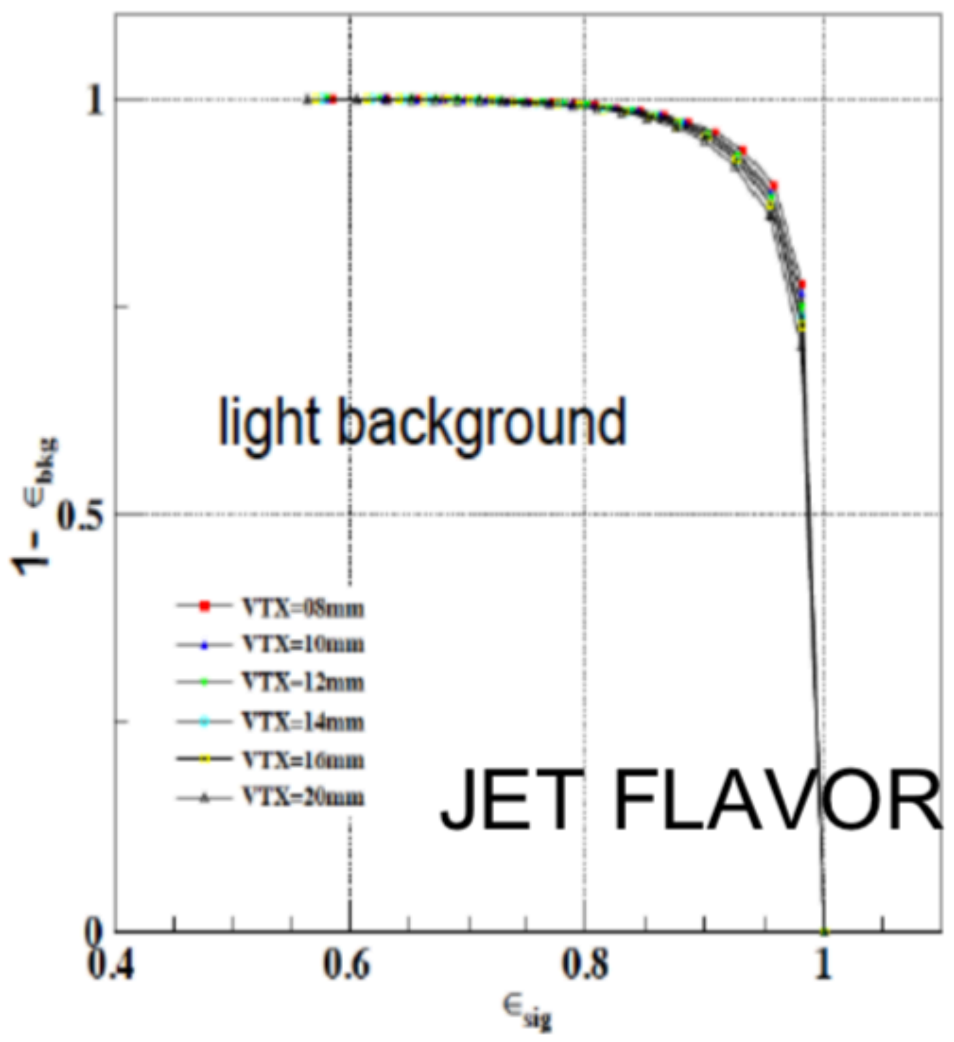
Eur. Phys. J. C (2018) 78:464

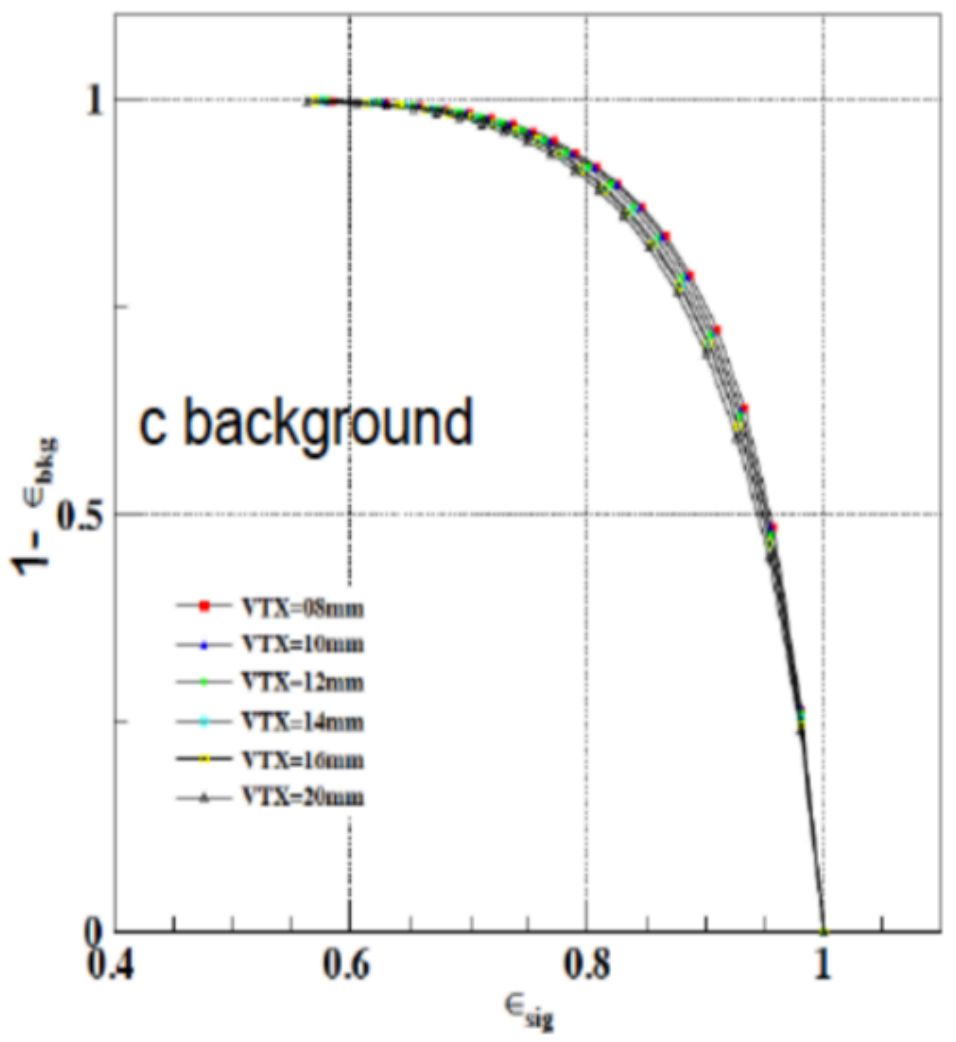












Eur. Phys. J. C (2018) 78: 426

Conceptual Design Report

IHEP-CEPC-DR-2015-01
IHEP-EP-2015-01
IHEP-TH-2015-01

2015

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

The CEPC-SPPC Study Group
March 2015

IHEP-CEPC-DR-2015-01
IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

The CEPC-SPPC Study Group

March 2015

Public release: November 2018

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

arXiv: 1809.00285

The CEPC Study Group
August 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

arXiv: 1811.10545

The CEPC Study Group
October 2018

What we are going to have?

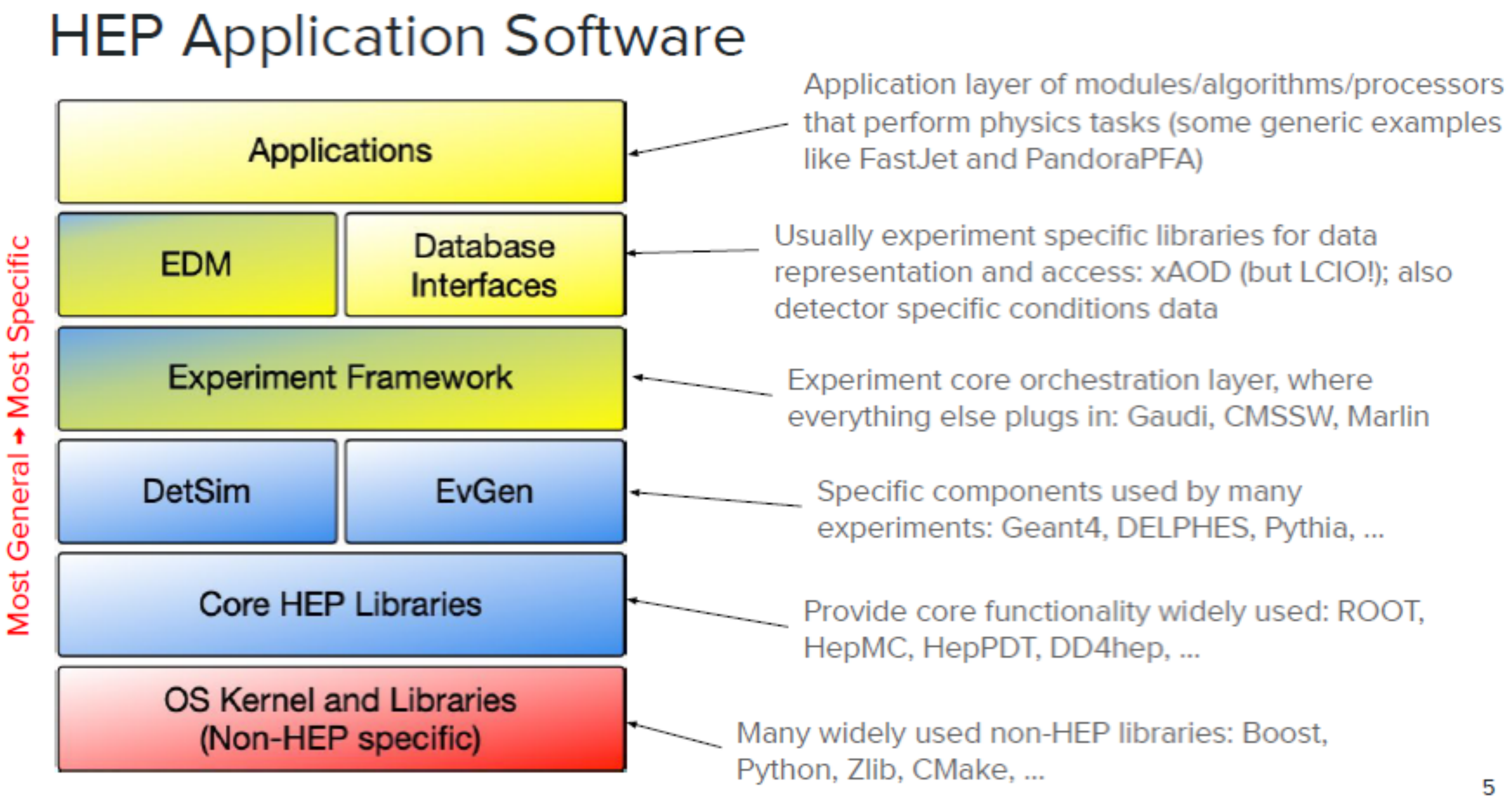
A set of new software
Morden, easy to maintain and use, interacts with other experiments, even with industry…

CEPCSW should

- Handle huge data volume
  - O(~EB) for CEPC running at Z pole
  - Large and complex database
- Support parallelization
  - Levels: algorithm, intra–event and inter–event
  - Technologies: OpenCL, CUDA, TBB, MPI…
  - Re–use of existing and successful algorithms
- Support heterogeneous computing
  - CPU,GPU, FPGA, HPC, Cloud…
  - Portable and flexible
- Have interface to novel tools and software
  - Application of Machine learning, Deep Learning, and Big Data, …
- Have friendly user interfaces
  - Hiding new techniques from physicists
  - Support flexible analysis
- International collaboration from very beginning …

Common Software Stack (CSS)

A common solution for future collider experiments: CLIC, FCC, CEPC

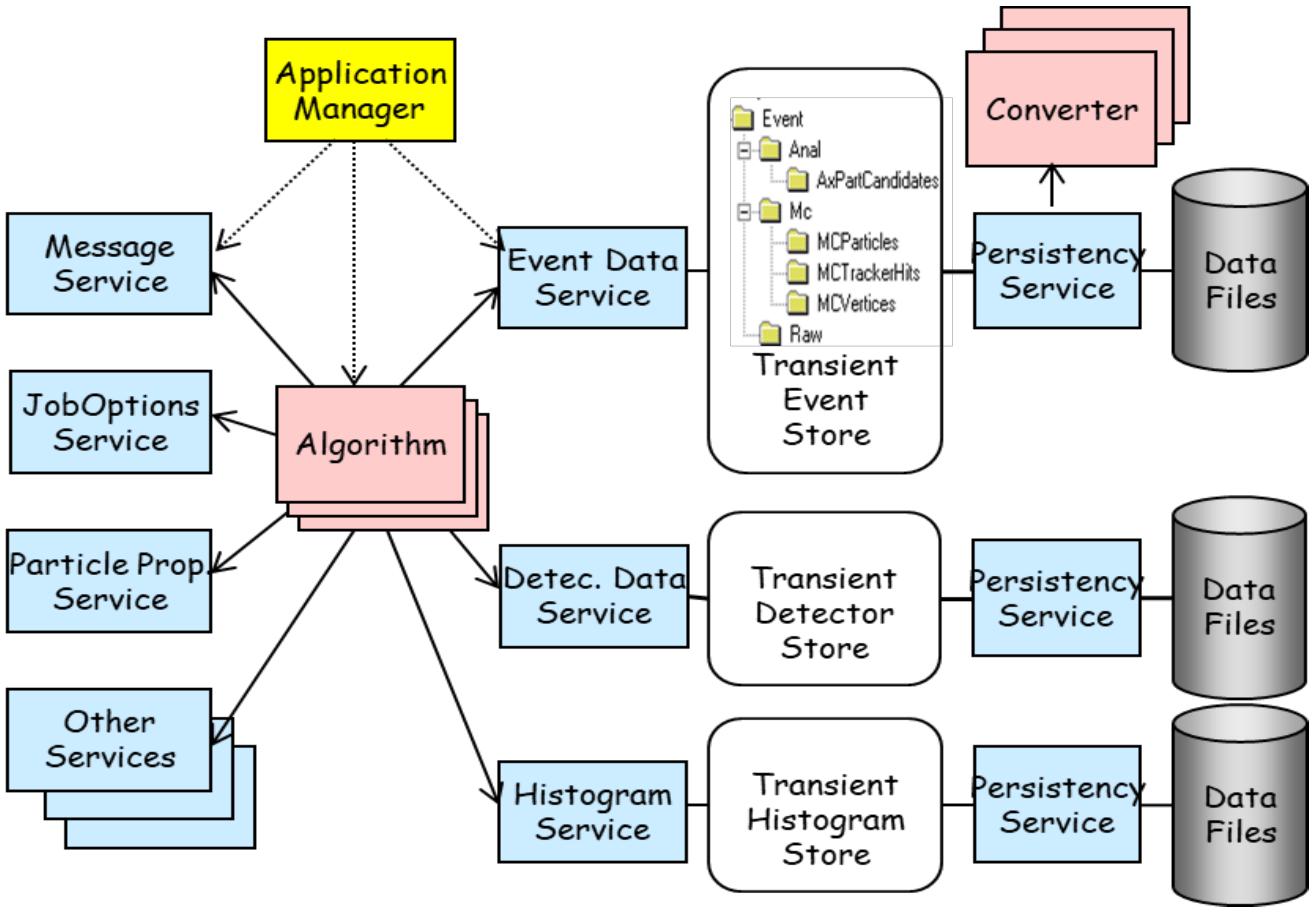


The CEPCSW prototype based on CSS

- The goal is the development of a software prototype
  - to integrate some existing software components
  - to demonstrate the capabilities to meet future requirements from detector design and optimization, testbeam, and to understand both detector performances and physics sensitivities.
  - to be able to follow the main trends of computing development of HEP experiments e.g. support of multithreading, GPU, FPGA, HPC etc.
  - to support continuous integrations of new software components, leading towards the final production system.
- Major components of the prototype
  - Underlying framework: a software skeleton with well defined interfaces for various types of software components
  - Event Data Model (EDM): management of data related to a physics event
  - Detector description: management of detector geometry and material information
  - Infrastructure: tools for version control, compiling, testing and deployment etc.

Underlying Framework : Gaudi

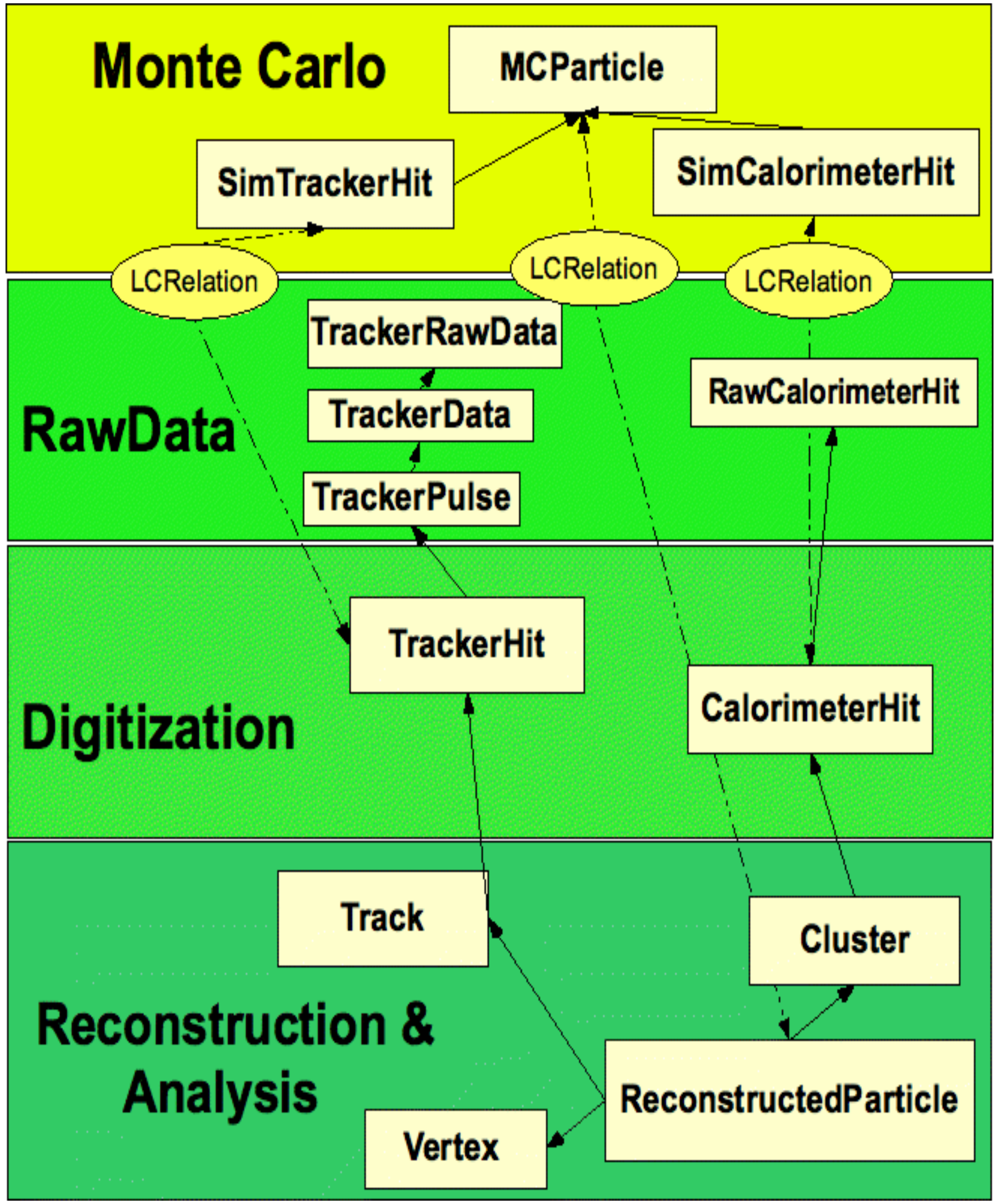
- The core part of the framework is light-weighted
- key components:
  - Application Manager
  - Services
  - Algorithms
  - Tools



- Data is separated from algorithms – physicists can concentrate on the algorithms
- Originally developed for LHCb, also used by BESIII and DYB in China

Event Data Model : EDM4HEP

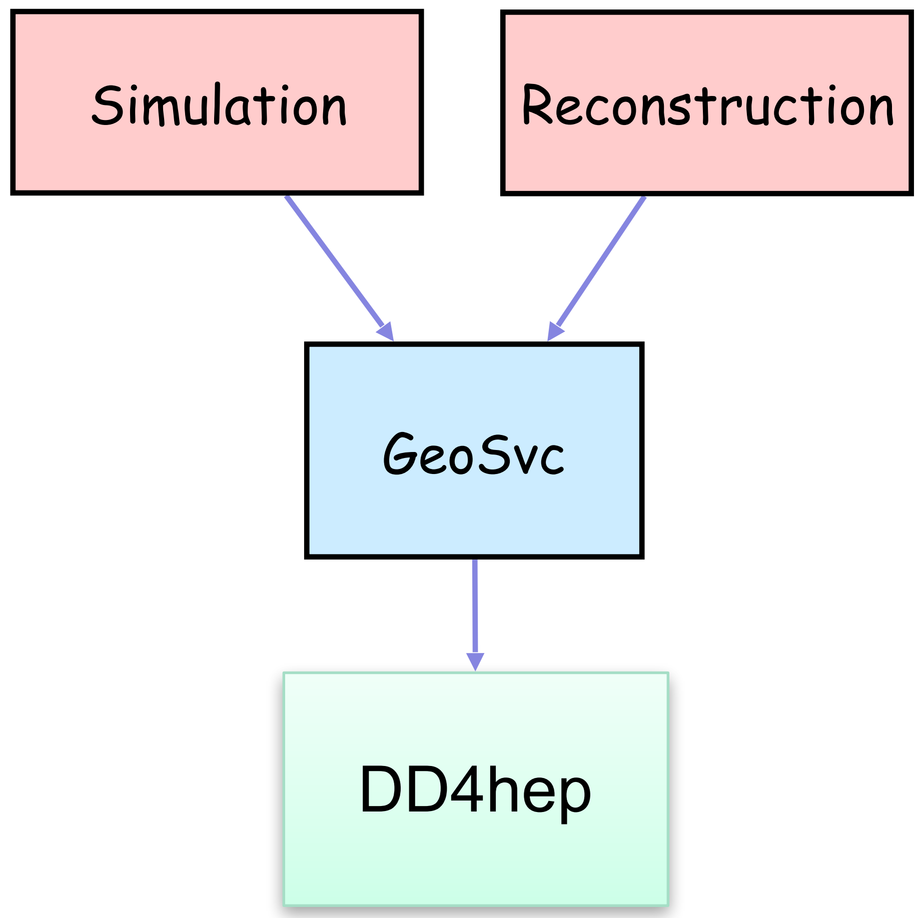
- The EDM4HEP project is being constructed in the context of CSS
- PLCIO: a mixture of LCIO and PODIO
  - the candidate of EDM4HEP
  - LCIO defines a common Event Data Model for Collider Experiments
    - MC Data, Raw Data
    - Digitization, Reconstruction and Analysis Data
    - Relations between different data objects
  - PODIO is developed for FCC studies
    - creates all C++ and Python code based on a description of the EDM structures in a YAML file
    - Plan Old Data (flat TTree in ROOT)

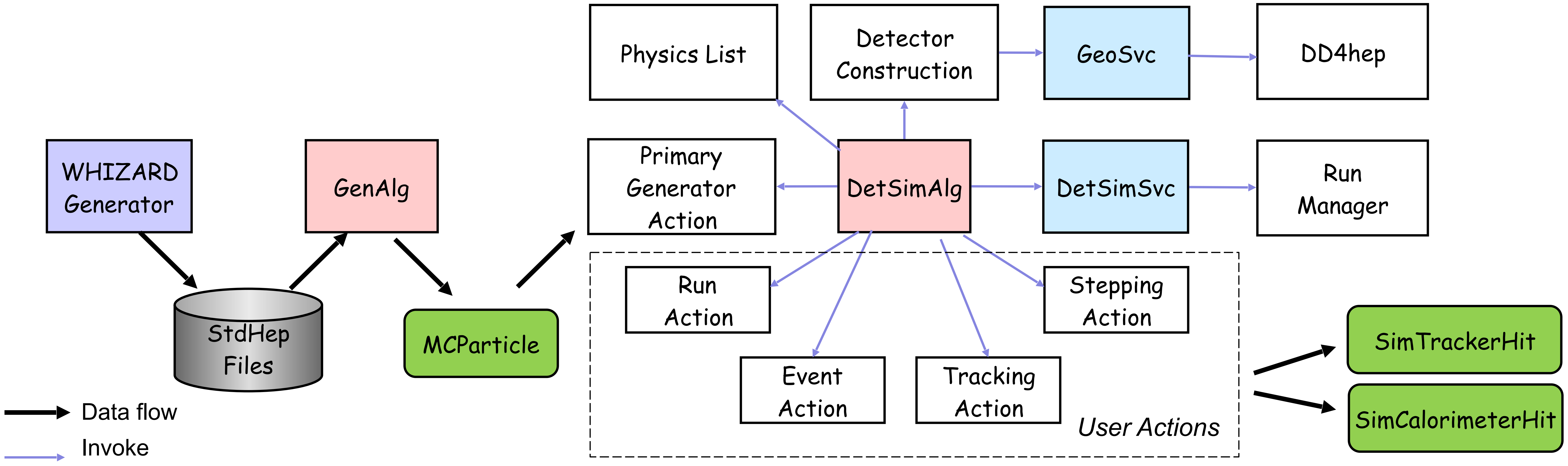


- CEPCSW uses a customized PLCIO before EDM4HEP is ready

Detector Description and Simulation

- Unified Geometry Service
  - Interfaced to DD4HEP
  - Used by simulation and reconstruction
- Simulation tool
  - Integrated with physics generator & Geant4

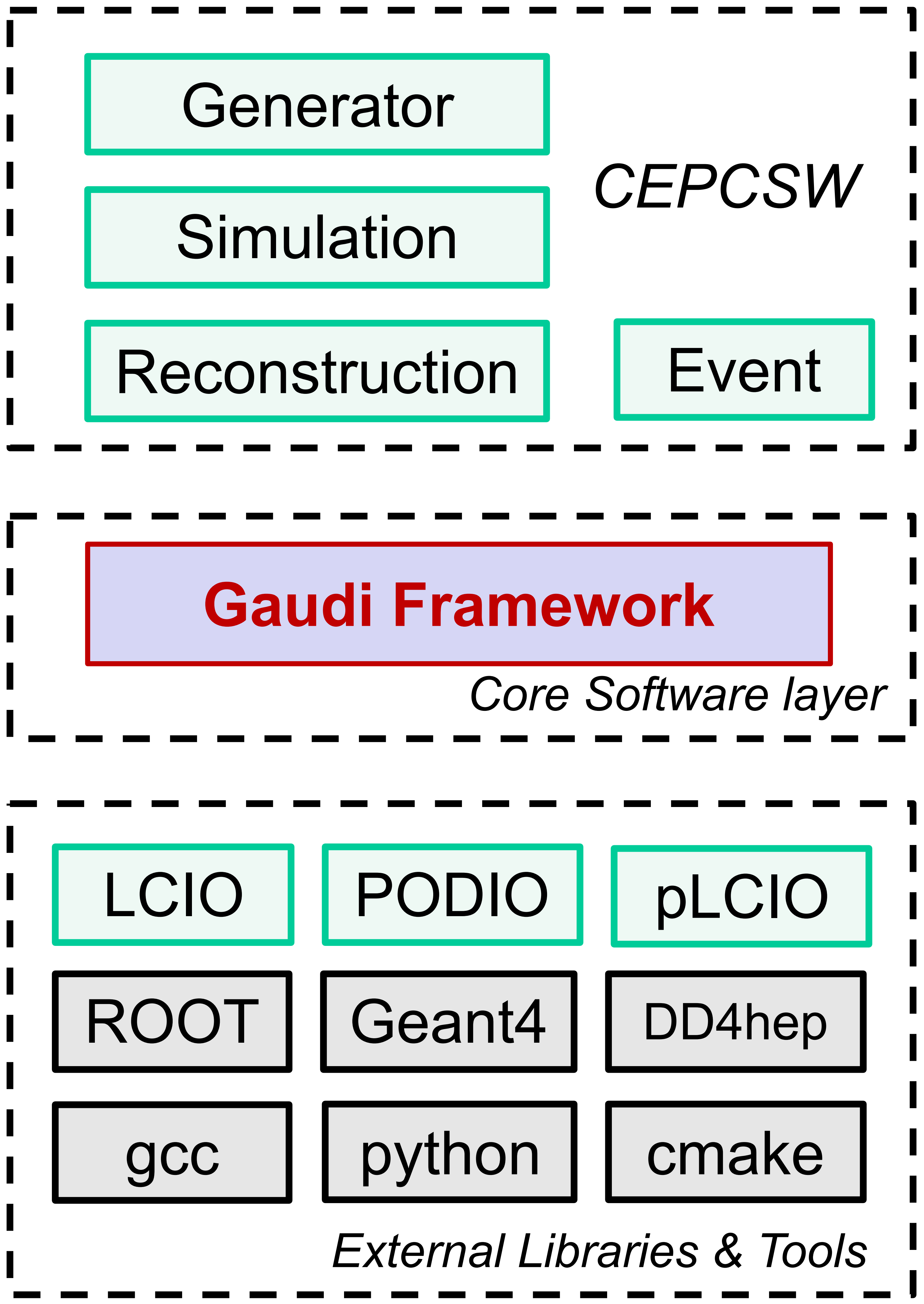




Software Infrastructure and Building

- Common tools
  - CMake: Build & deployment
    - Gaudi cmake macros
  - Git: version control
    - http://cepcgit.ihep.ac.cn/cepc-prototype
  - CVMFS: software distribution
    - CEPC specific:

    /cvmfs/cepcsw.ihep.ac.cn/prototype
- Software building
  - Key4HEP in the context of CSS
  - Software organization, compiling, installing and configuration



Status and Plans

- A well designed data processing chain is important in short term (R&D) and long term (Operation).
- To fulfill the requirements, a CEPCSW prototype is being developed based on CSS (Common Software Stack)
  - Gaudi, EDM4HEP (currently PLCIO), DD4HEP and Key4HEP
  - Easy to migrate and reuse existing algorithms
- CEPCSW prototype tasks
  - Data model, I/O and other common services
  - Unified geometry system for Sim/Rec/Ana
  - Integrate and migrate existing Sim/Rec/Ana algorithms
- Joined the international collaboration on CSS for future HEP experiments
- To release the first workable demo with simulation and track reconstruction in next month.

Summary

- CEPC has rich physics program
- CEPC did lots of excellent work with CEPC software based on ILCsoft — preCDR, CDR, many publications
- CEPC is developing a modern software can meet the requirement of data-taking, processing, and physics study in a background of wide international cooperation
  - A prototype of CEPCSW is going to be release next month during the workshop
- Welcome to join us, your experiences are valuable

Extras

Workshop Agenda

- https://agenda.infn.it/event/19047/
  - Introduction and motivation (Paolo Giacomelli, INFN Bologna)
  - Software status of the LHC experiments (Tommaso Boccalli, CERN)
  - ILC software (Frank Gaede, DESY)
  - FCC software (Gerardo Ganis, CERN)
  - CEPC software framework (Xingtao Huang, SDU)
  - Common software tools (Graeme Stewart, CERN)
  - Turkey software stack vision (Andre Sailer, CERN)
- Round table discussions
  - General discussion on a common software framework
  - Towards a common software stack

Organized by Weidong Li (IHEP), Dario Menasce (INFN), Pere Mato Vila (CERN)

Workshop Outcome

- Development of a Common Turnkey Software Stack (Key4HEP), containing:
  - HEP standard and new libraries / packages, such as ROOT, Geant4, HepMC, VecCore, VecMath, VecGeom, …
  - Externals, such as Boost, GSL, Eigen, …
  - EDM and Geo libraries, such as DD4Hep, PODIO
  - Rec/Tracking libraries, such as ACTS, PandoraPFA, …
  - One framework
- MARLIN framework will continue to be used by the LC community while the Key4HEP is commissioned.

The Physics Goals

Precision tests of Standard Model (Higgs, W and Z) → Potential to find new physics

Higgs boson and electroweak symmetry breaking

Directly exploring new physics

- Exotic Higgs boson decays
- Exotics Z boson decays
- Dark matter and hidden sectors
- Extended Higgs sector

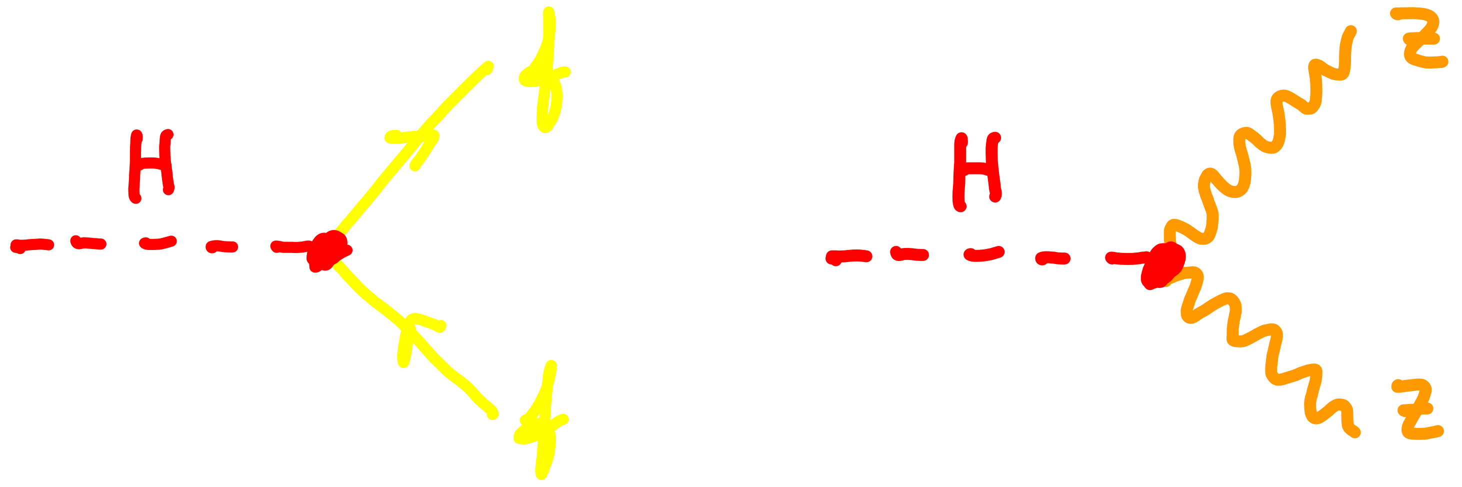
QCD precision study

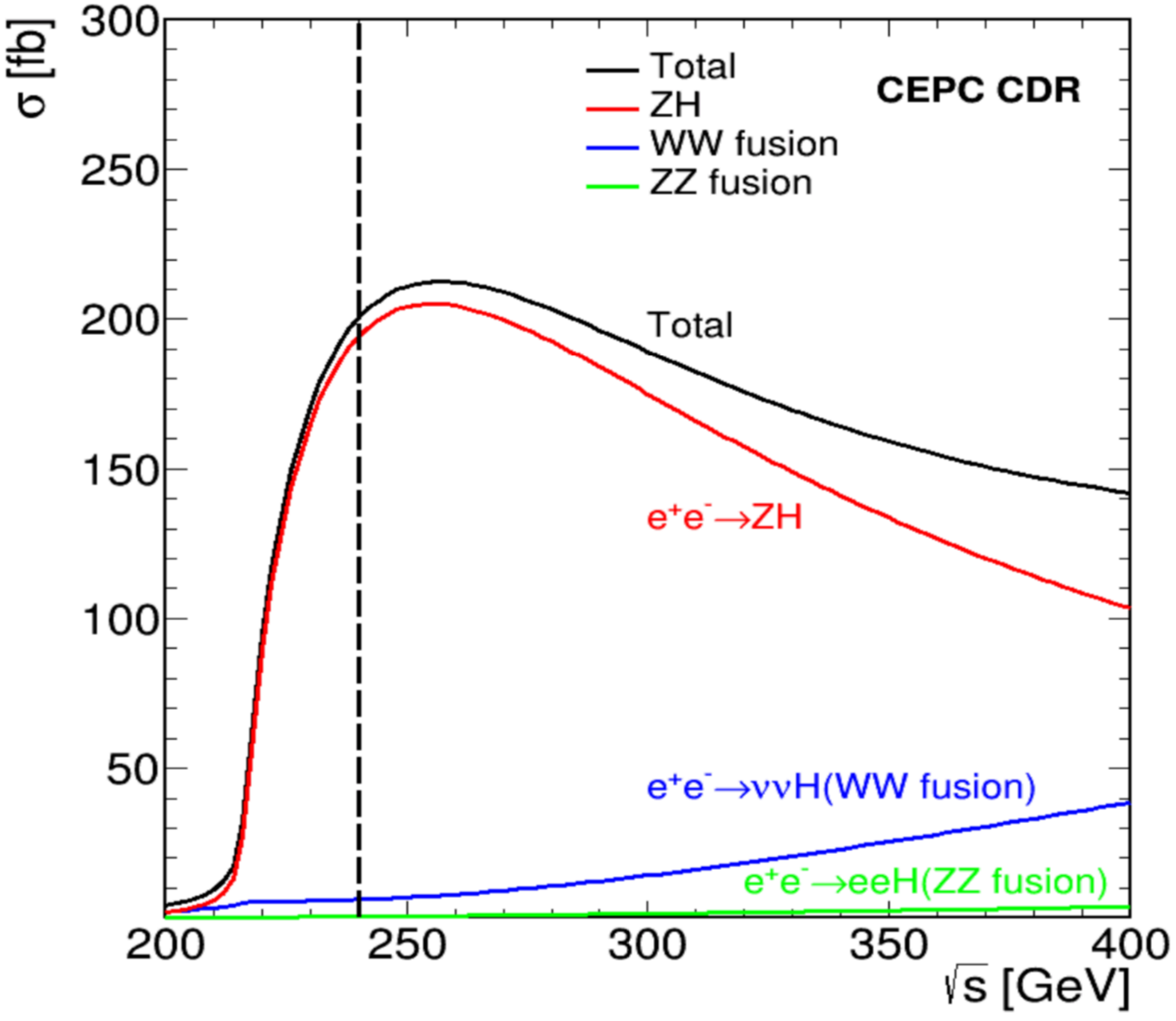
- Precision α_S determination
- Jet rates at CEPC
- QCD dynamics, soft QCD effects
- QCD event shapes and light-quark Yukawa couplings

Flavor physics at the *Z* pole

- Rare B decays
- Tau lepton decays
- Flavor violating *Z* decays

Higgs production in e^+e^- collisions





Events at 5.6 ab^{-1}

ZH: 10^6 events

ννH: 10^4 events

e^+e^-H: 10^3 events

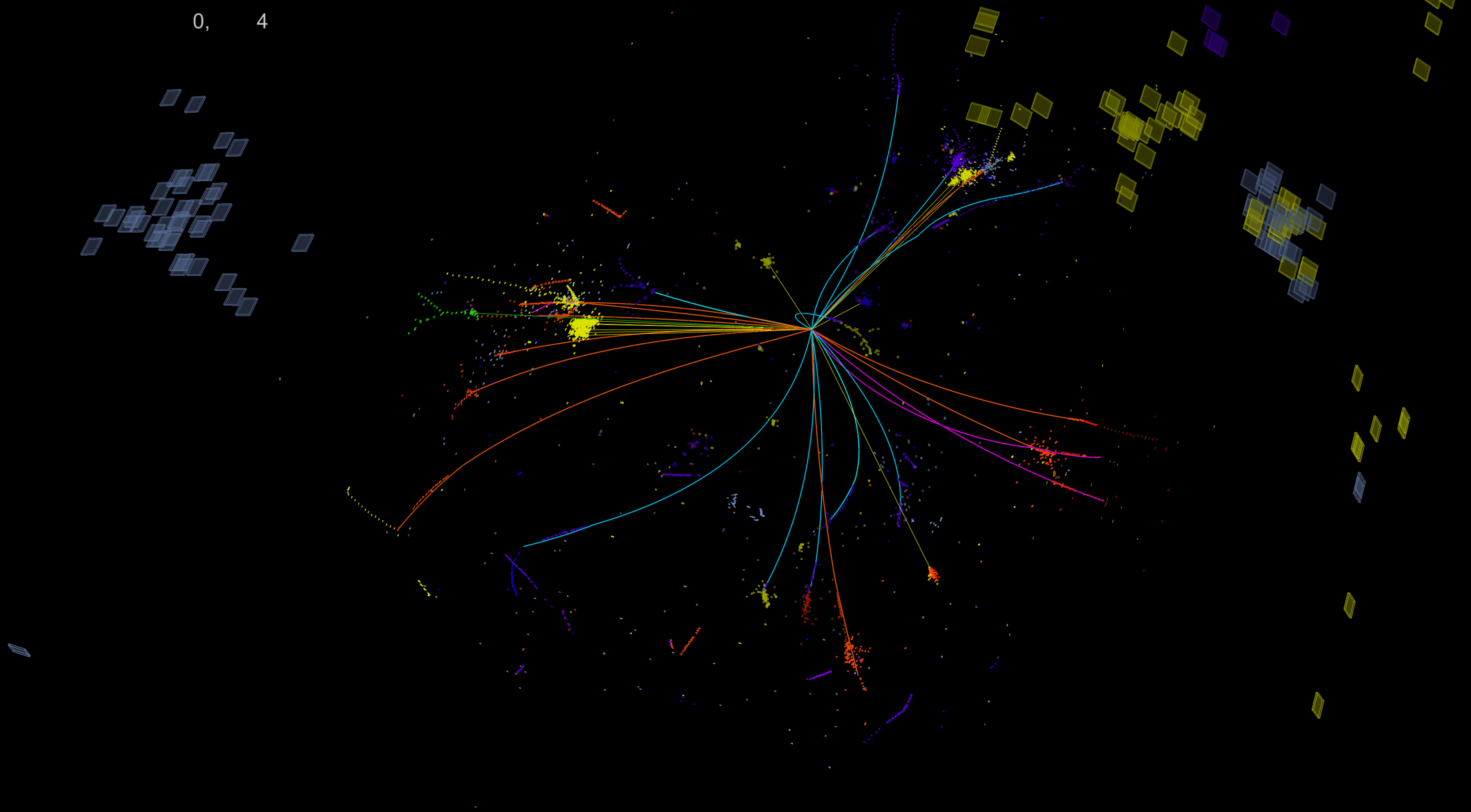
S/B
1:500–1000

Observables:
Higgs mass, CP, σ(ZH),
event rates (σ(ZH, ννH)*Br(H→X)),
differential distributions

Extract:
Absolute Higgs width, couplings

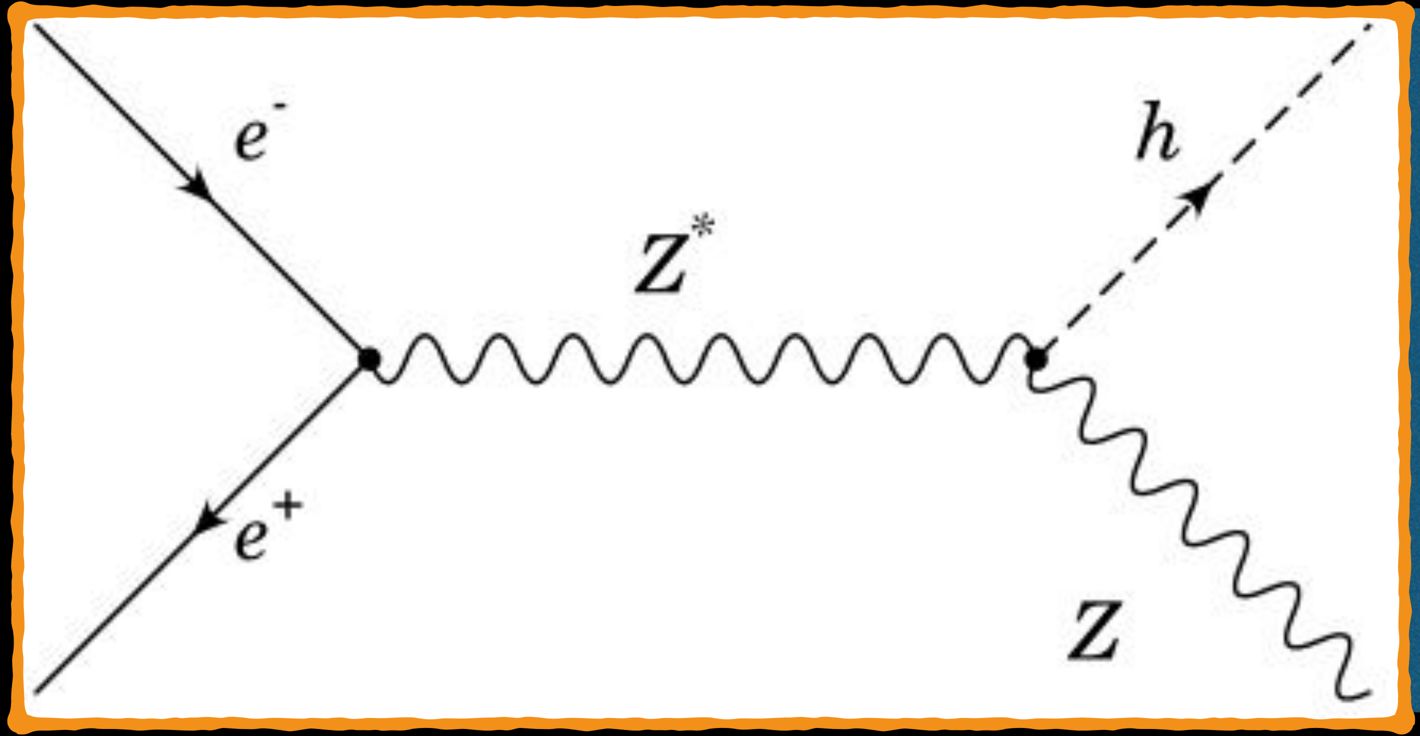
Typical hadronic events: tracks, photons, neutral hadrons

0, 4



Revival of e^+e^- Circular Colliders

Relatively low Higgs mass:
m_H = 125 GeV



$\sqrt{s}$ = ~240 GeV

LEP stopped in 2000, limited by synchrotron energy loss, at $\sqrt{s}$ = 209 GeV

$$\frac{240\ \text{GeV}}{209\ \text{GeV}} \sim 1.14$$

Radius	50 km	70 km	100 km
Synchrotron energy loss relative to LEP $\frac{E_b^4}{r}$	~0.9	~0.65	~0.5

2012
Scientists in China proposed

Circular Electron-Positron Collider (CEPC)
— precision Higgs studies

Benchmarks for performance

Physics process	Measurands	Critical detector	Required performance
$ZH \to l^+l^-X$	m_H, σ_{ZH}	Tracker	$\Delta(1/P_T) = 2 \times 10^{-5} \oplus \frac{10^{-3}}{P(\text{GeV})\sin^{\frac{3}{2}}\theta}$
$H \to \mu^+\mu^-$	$B(H \to \mu^+\mu^-)$		
$H \to b\bar{b}, c\bar{c}, gg$	$B(H \to b\bar{b}, c\bar{c}, gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\text{GeV})\sin^{\frac{3}{2}}\theta}(\mu\text{m})$
$H \to q\bar{q}, W^+W^-, ZZ$	$B(H \to q\bar{q}, W^+W^-, ZZ)$	ECAL, HCAL	$\sigma_E^{jet} = 3 \sim 4\,\%$ at 100GeV
$H \to \gamma\gamma$	$B(H \to \gamma\gamma)$	ECAL	$\frac{\Delta E}{E} = \frac{0.20}{\sqrt{E(\text{GeV})}} \oplus 0.01$