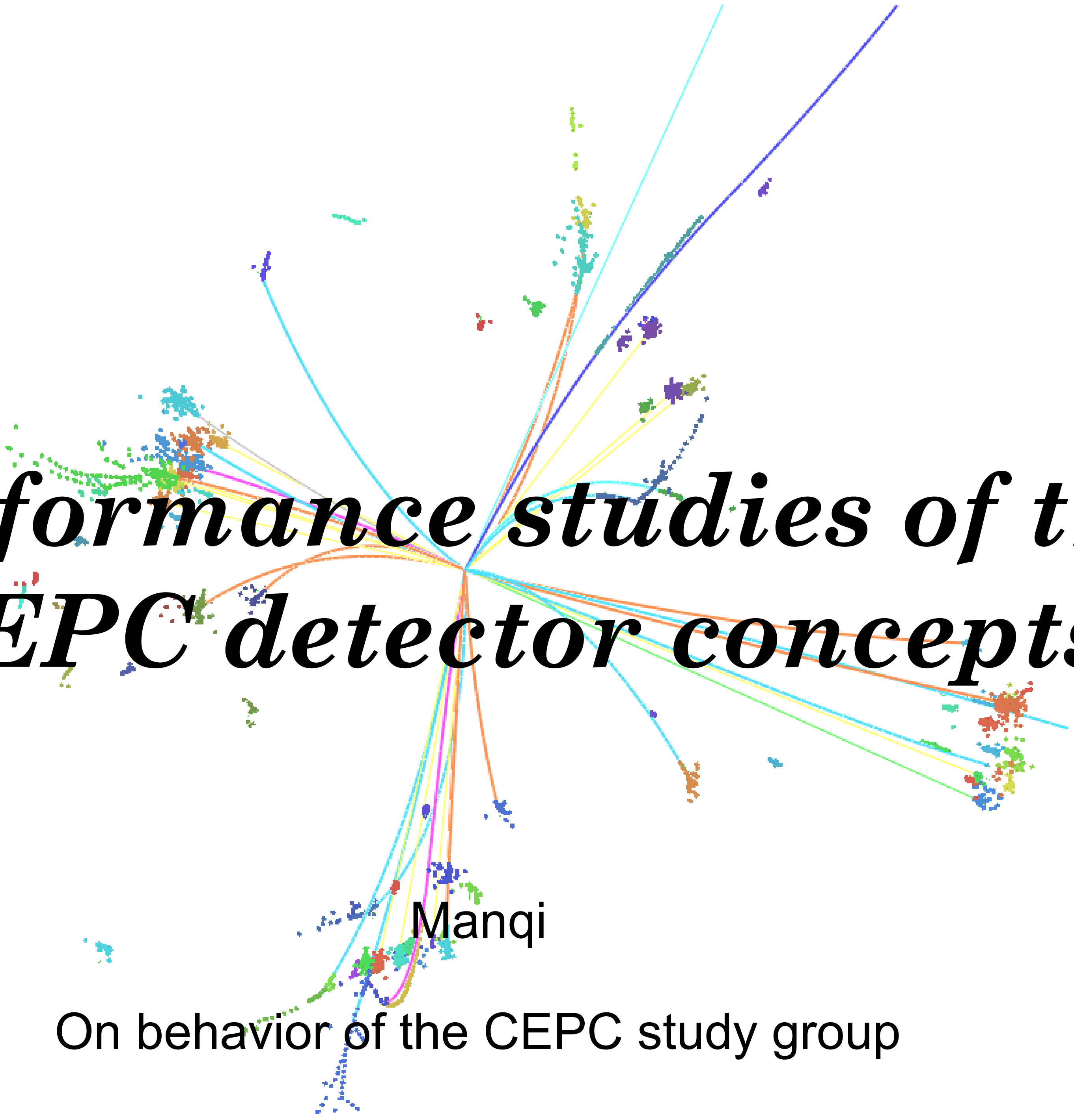


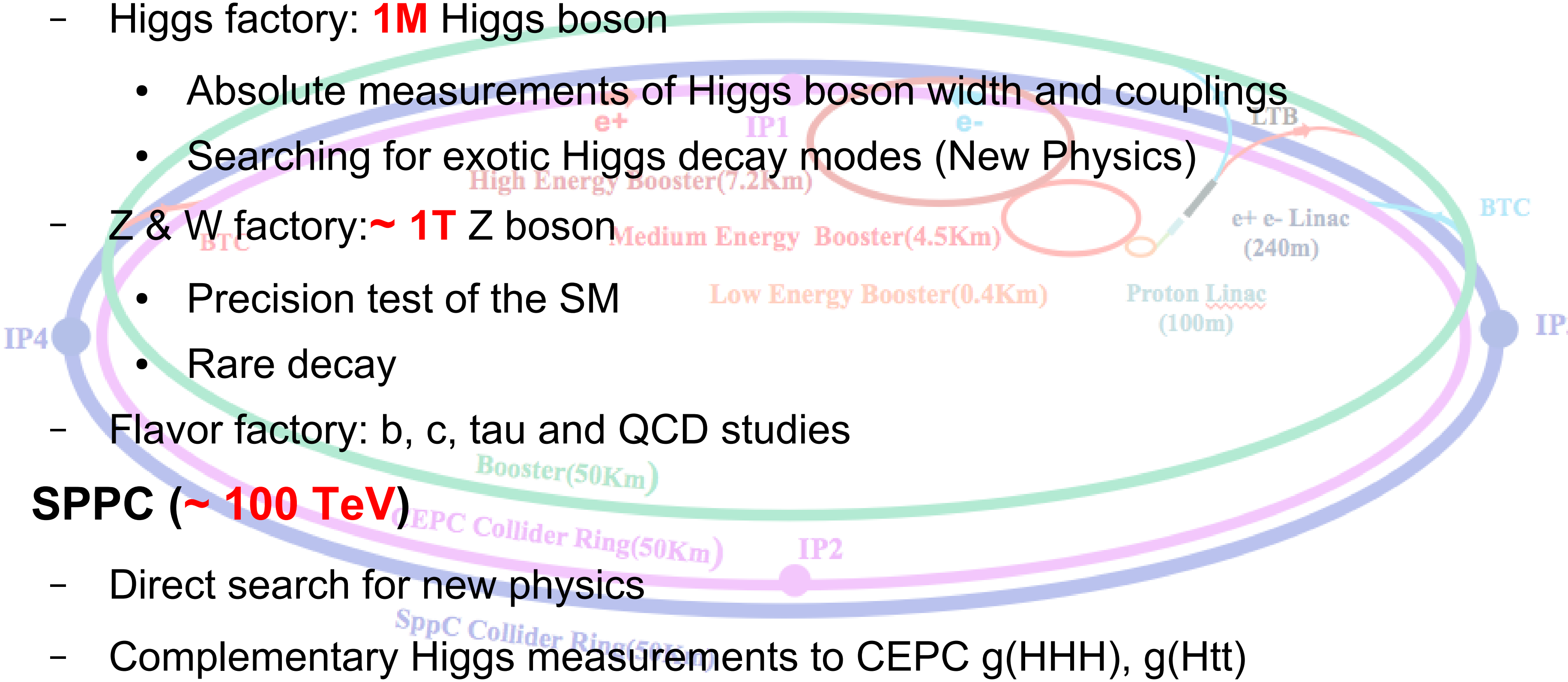
Performance studies of the CEPC detector concepts

Manqi

On behavior of the CEPC study group

Science at CEPC-SPPC

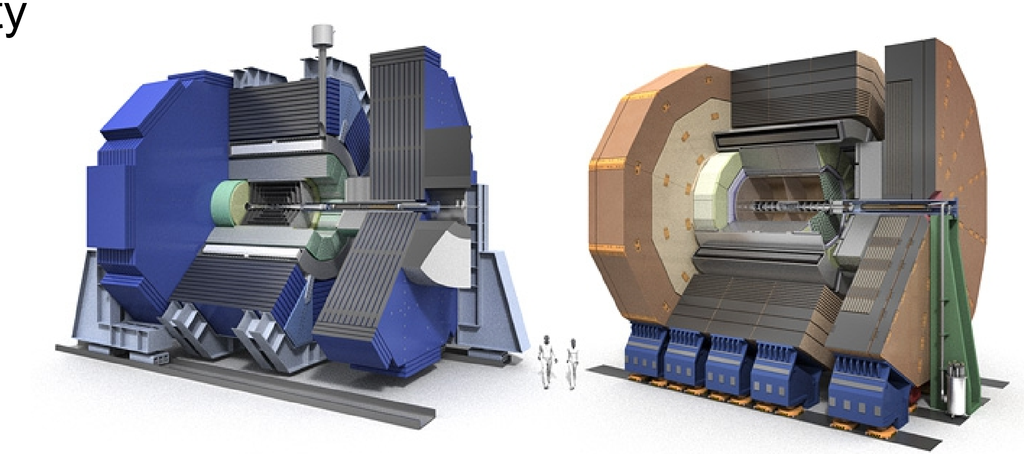
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 1T** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



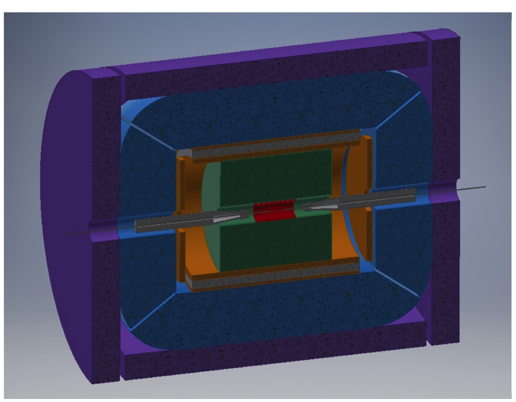
Complementary

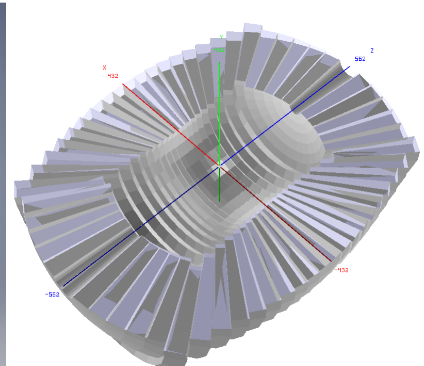
Two classes of Concepts at CDR

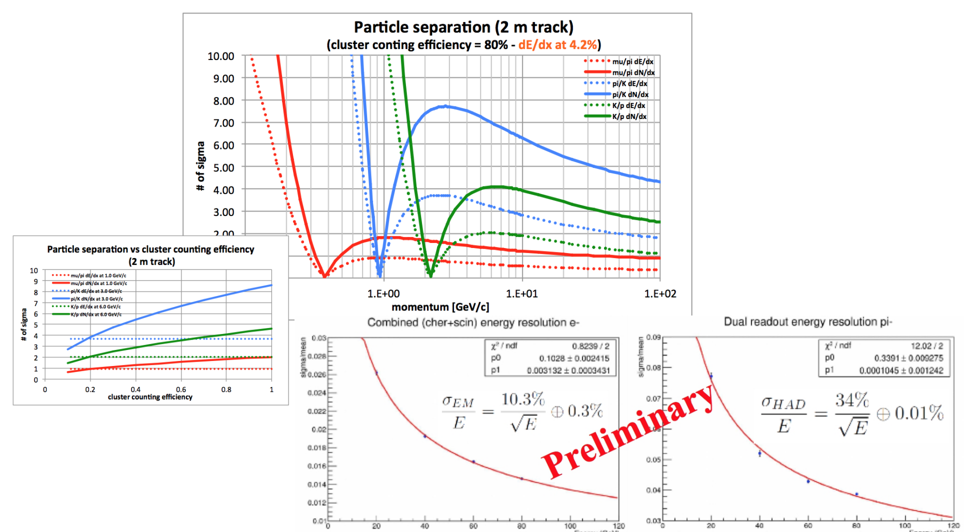
- PFA Oriented concept using High Granularity Calorimeter
  - \+ TPC (ILD-like, **Baseline**)
  - \+ Silicon tracking (SiD-like)



- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter



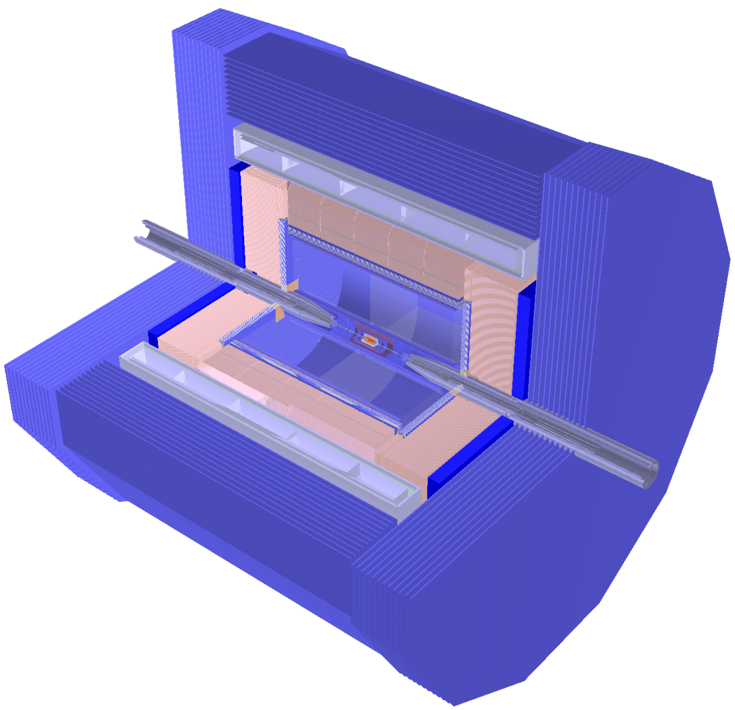


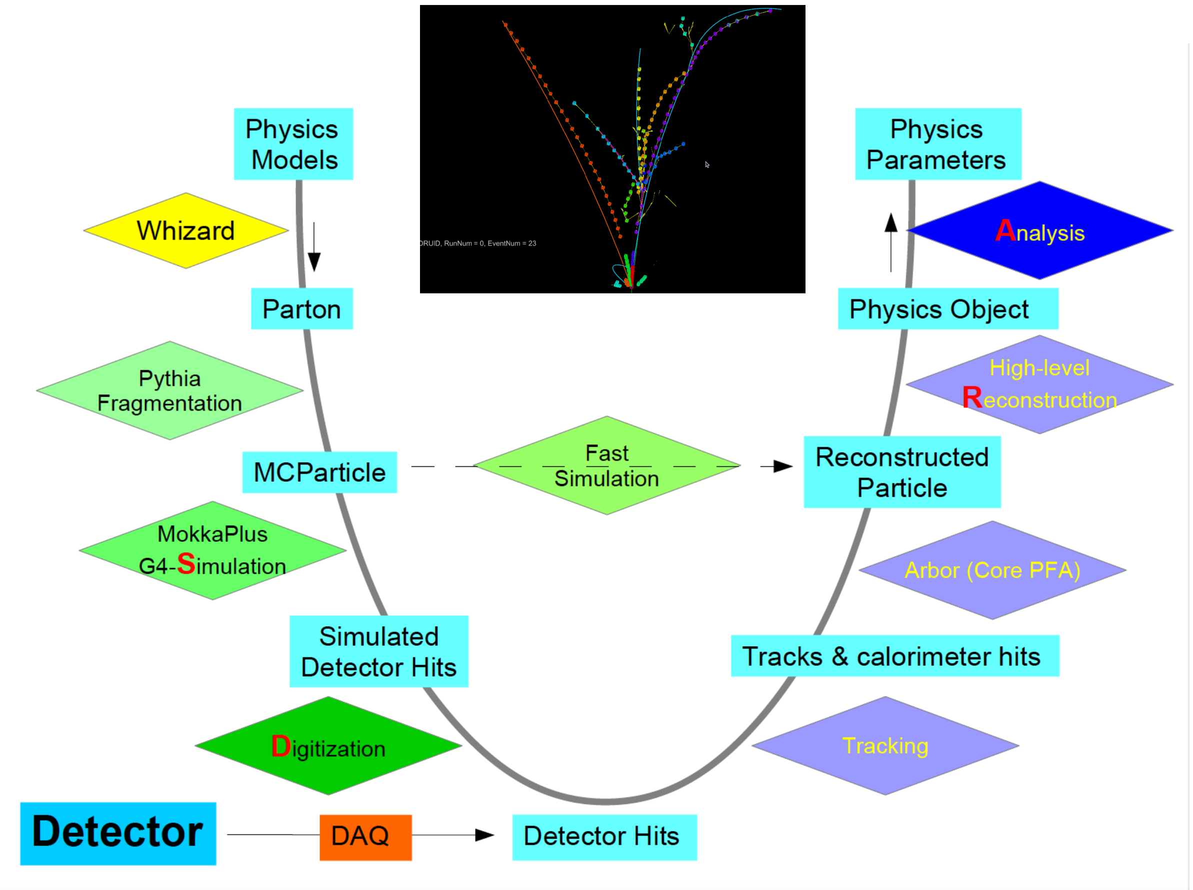


https://indico.ihep.ac.cn/event/6618/

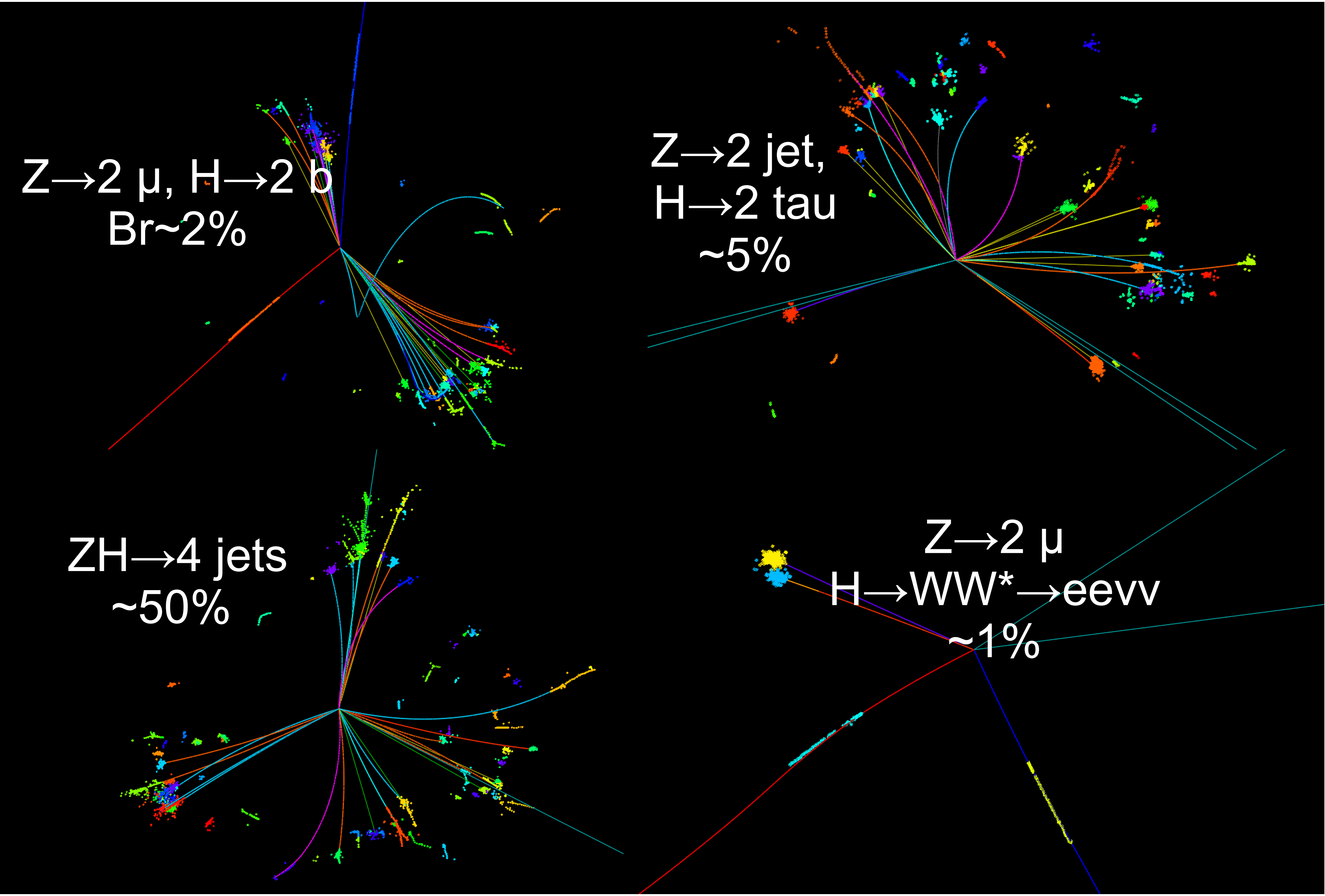
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

Baseline detector: Simu & Reco





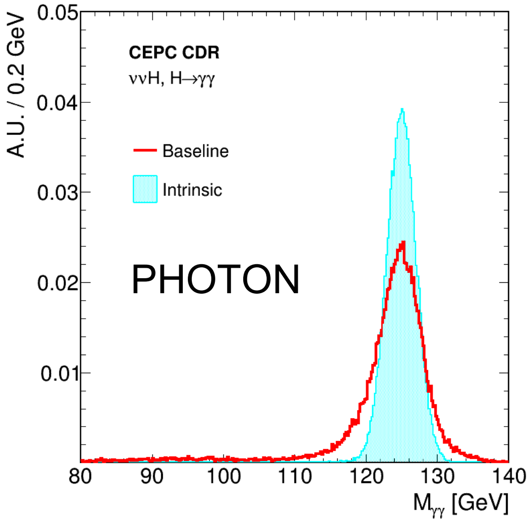
Starting from the ILD/ilcsoft, adjust-optimize the geometry, developing PFA (Arbor) & other high-level reconstruction algorithms.

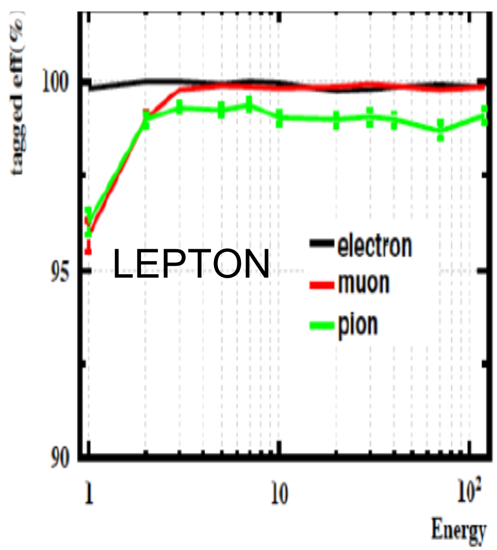

Z→2 μ, H→2 b
Br~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 μ
H→WW*→eevv
~1%

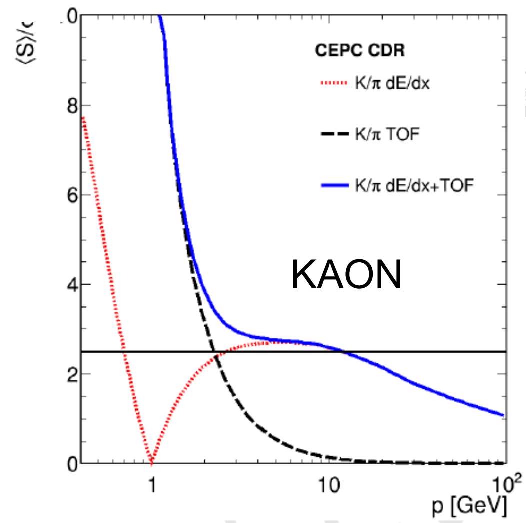
Reconstruction of Physics objects

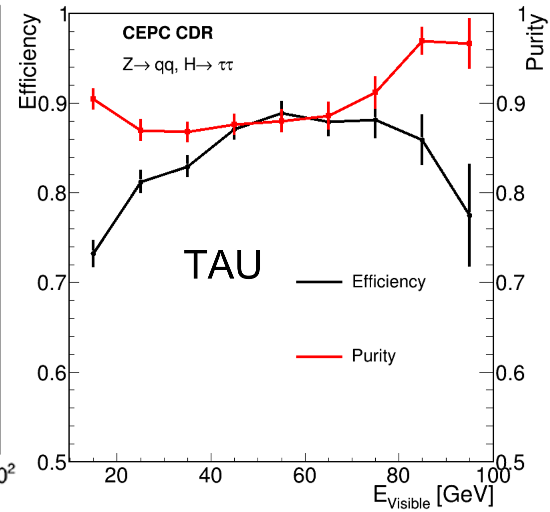
Eur. Phys. J. C (2017) 77: 591

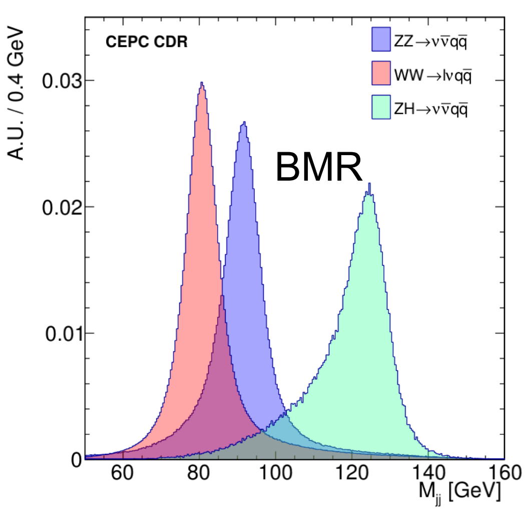
Eur. Phys. J. C (2018) 78:464

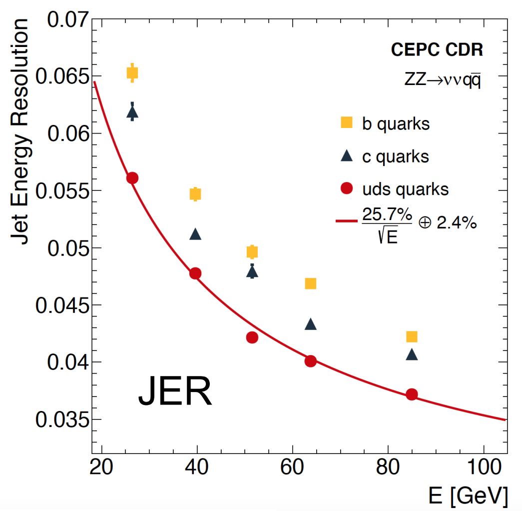


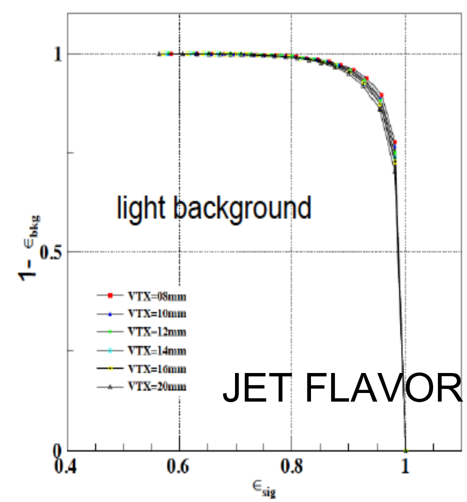


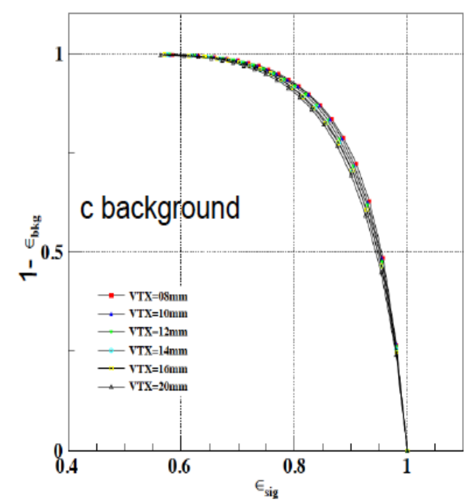






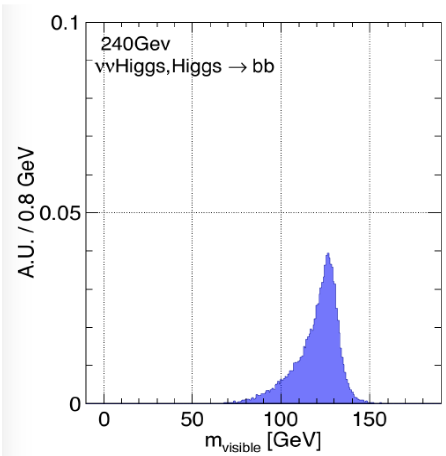


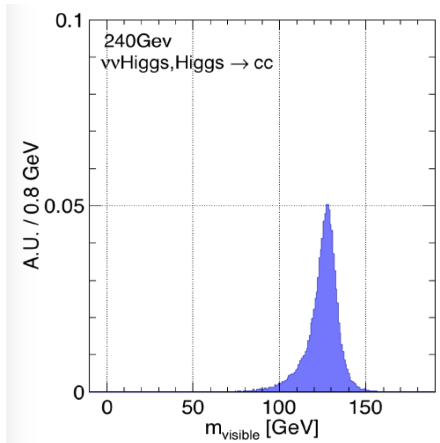


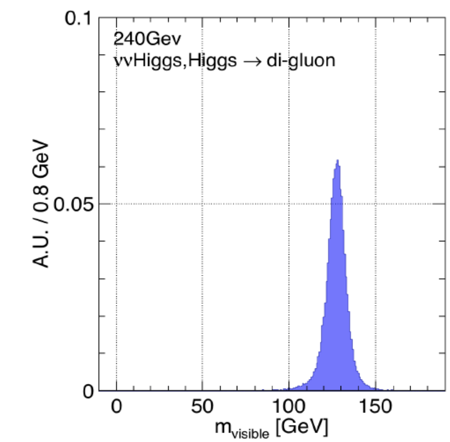


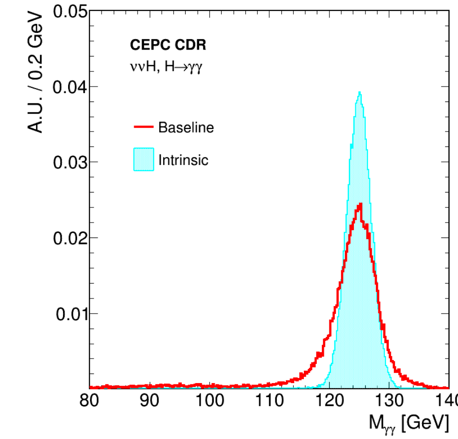
Eur. Phys. J. C (2018) 78: 426

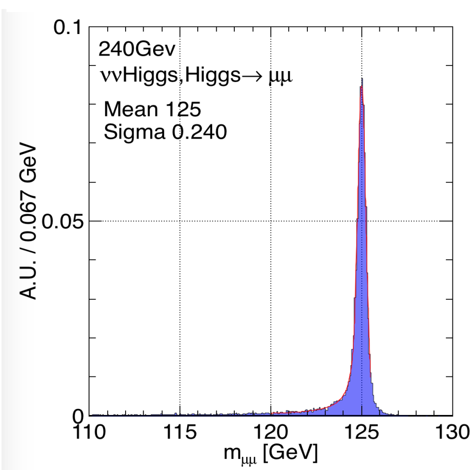
Higgs Signals

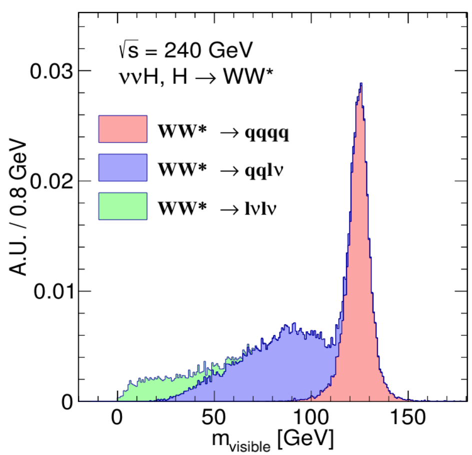


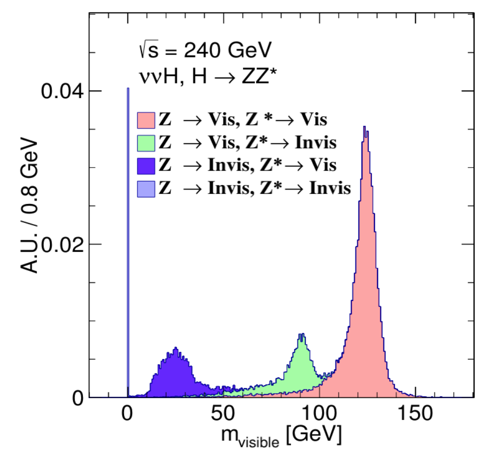


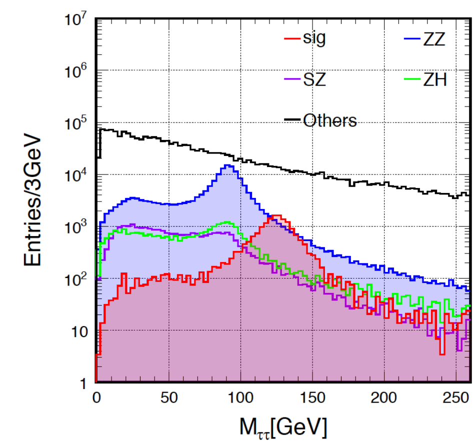










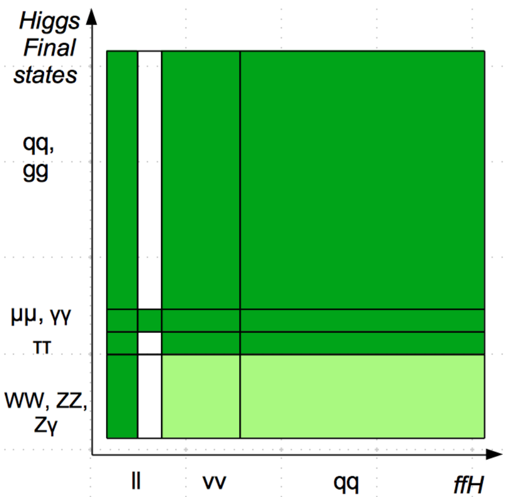


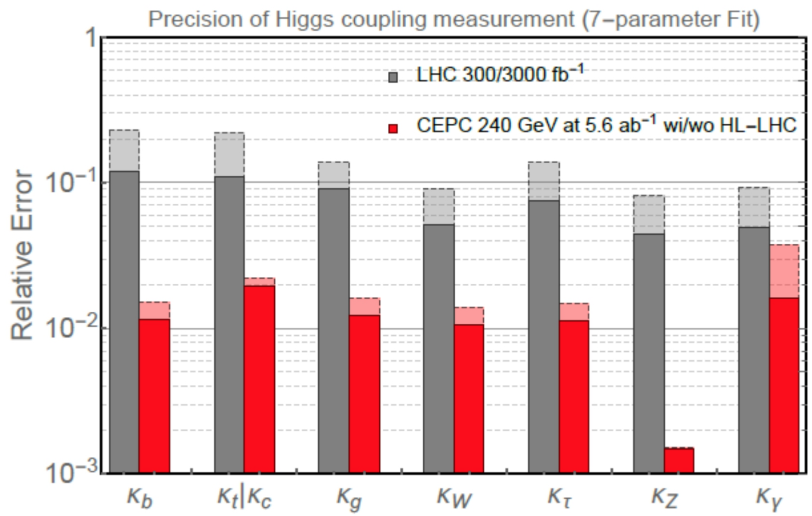
Clear Higgs Signature in all SM decay modes

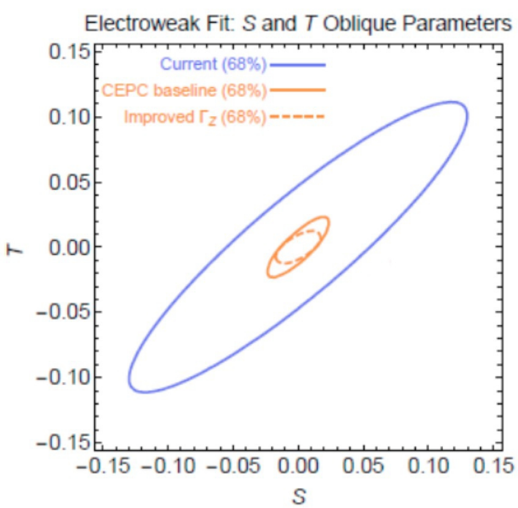
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

Right corner: di-tau mass distribution at qqH events using collinear approximation

Applied on Higgs physics, et.al







Chinese Physics C

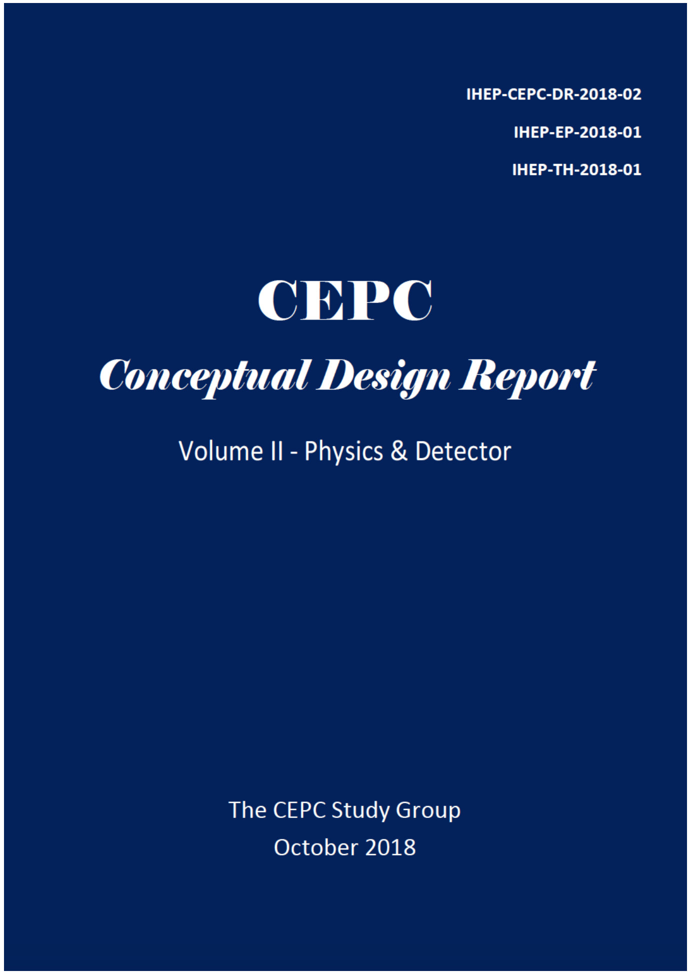
PAPER • **OPEN ACCESS**

Precision Higgs physics at the CEPC

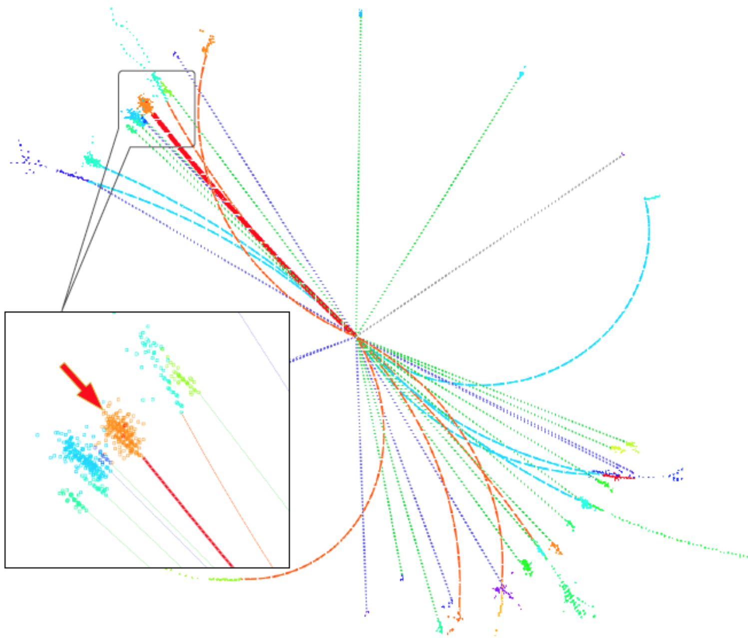
To cite this article: Fenfen An *et al* 2019 *Chinese Phys. C* **43** 043002

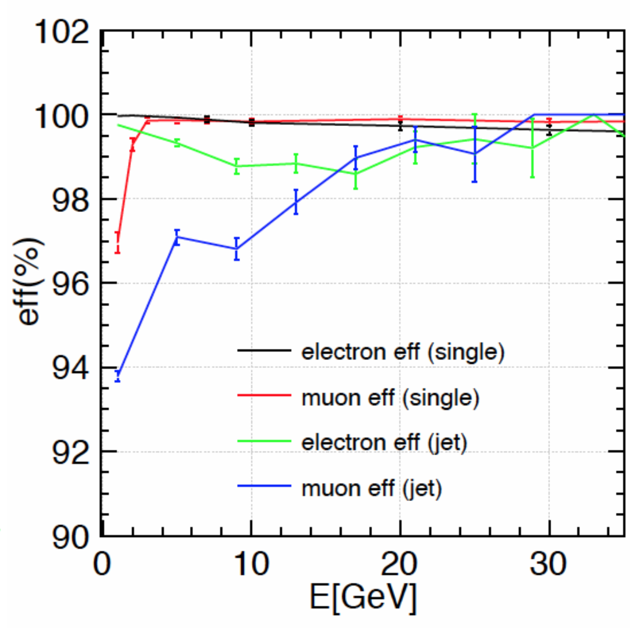
View the article online for updates and enhancements.

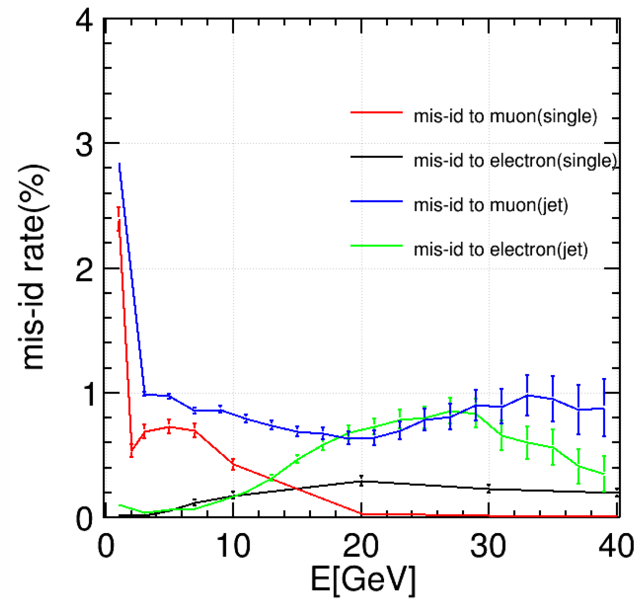
https://arxiv.org/pdf/1810.09037.pdf



Jet lepton





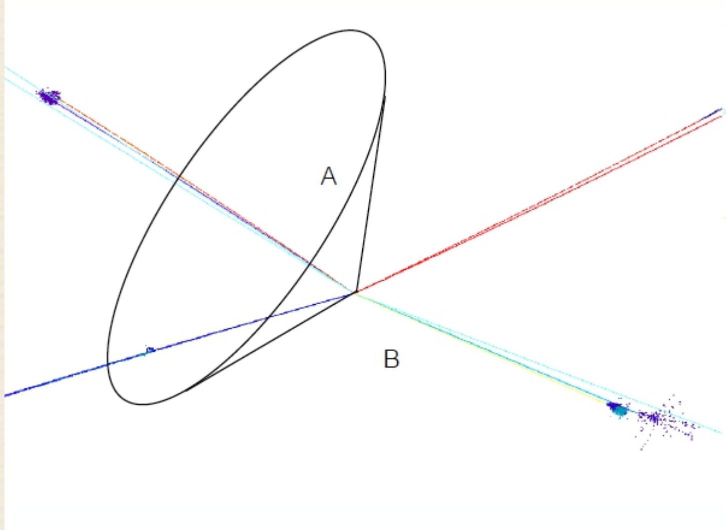


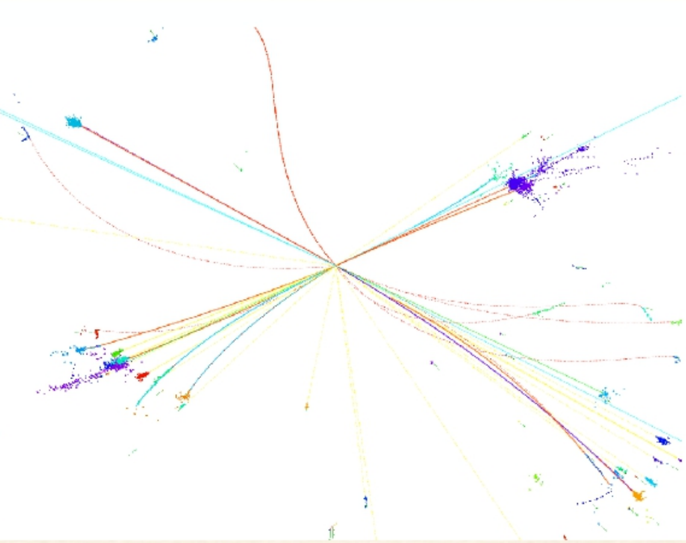
Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & contaimination).

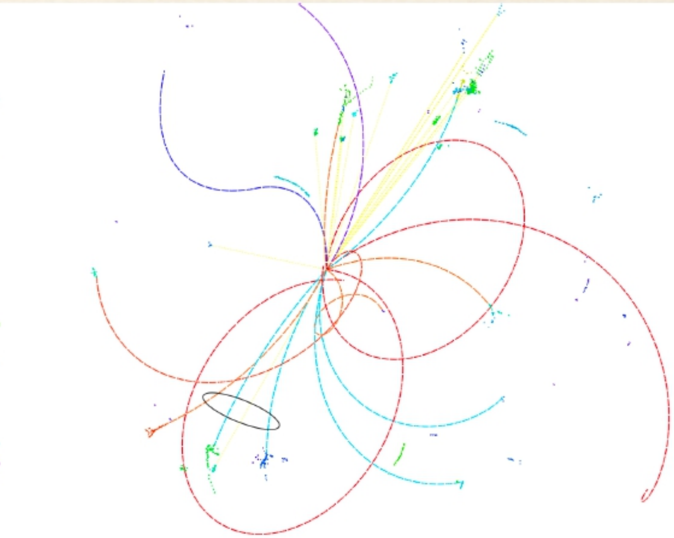
At the same working point, the efficiency can be reduced by up to 3%; while mis-id rate increases up to 1%. Marginal Impact on Flavor Physics measurements as Bc->tauv.

Event topology

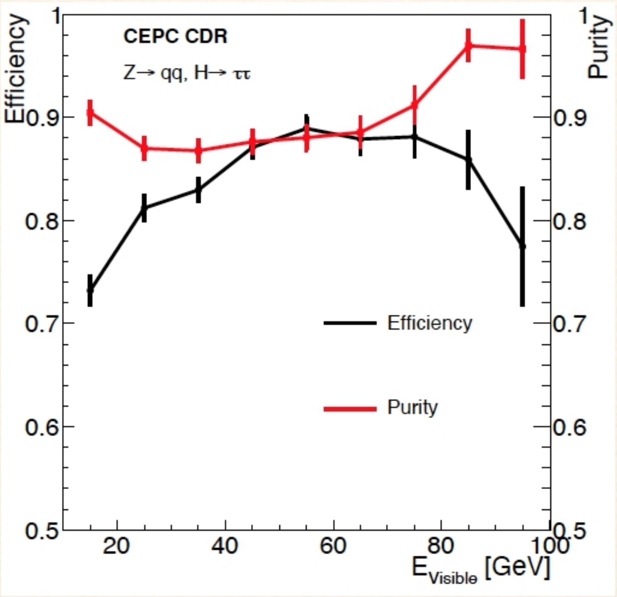
- llH channel / Z→ττ
- qqH (isolate τ with jets)
- τ inside jets

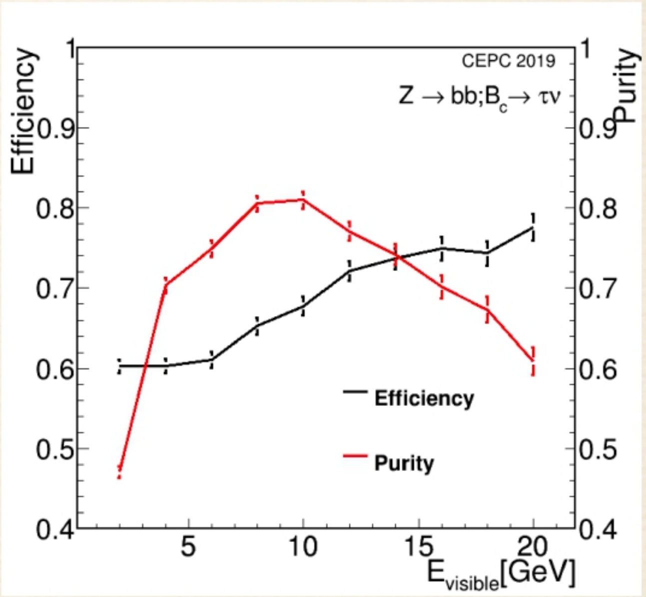




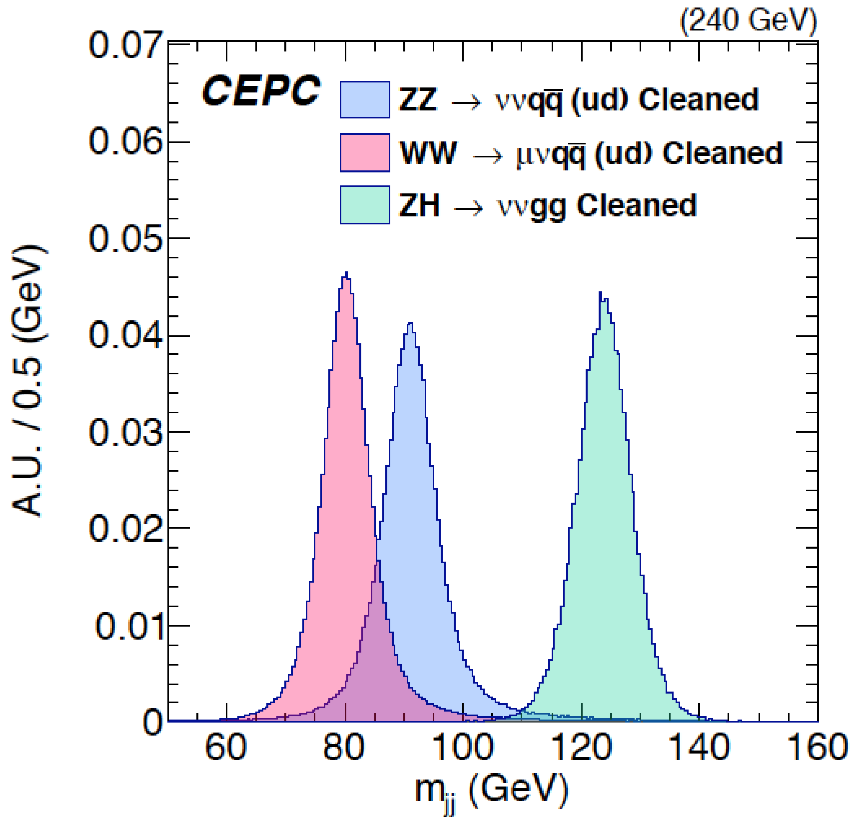


- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter
- Efficiency > 90%





CEPC Baseline: BMR = 3.8%



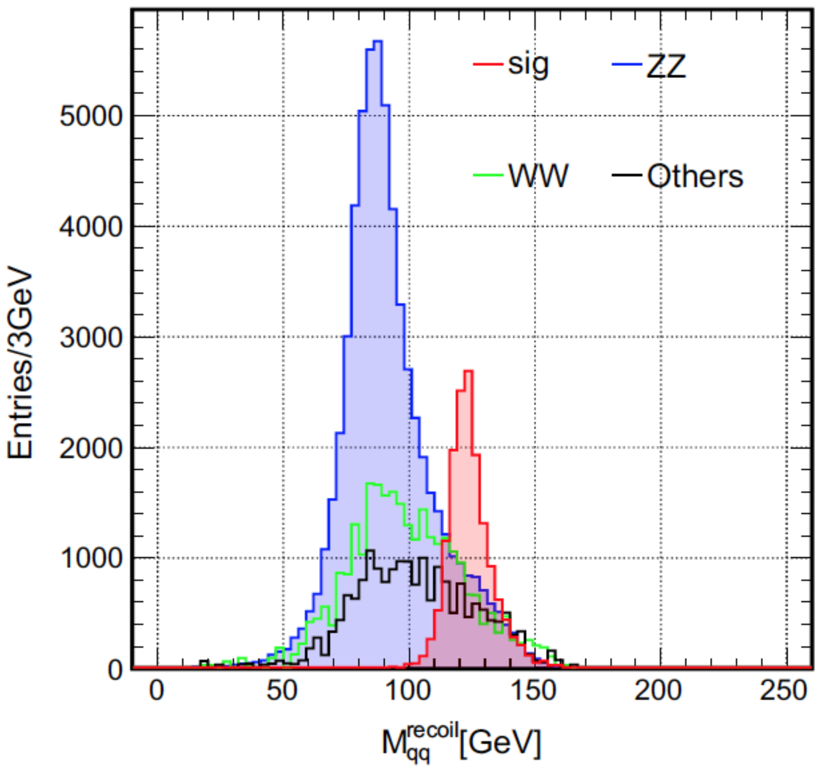
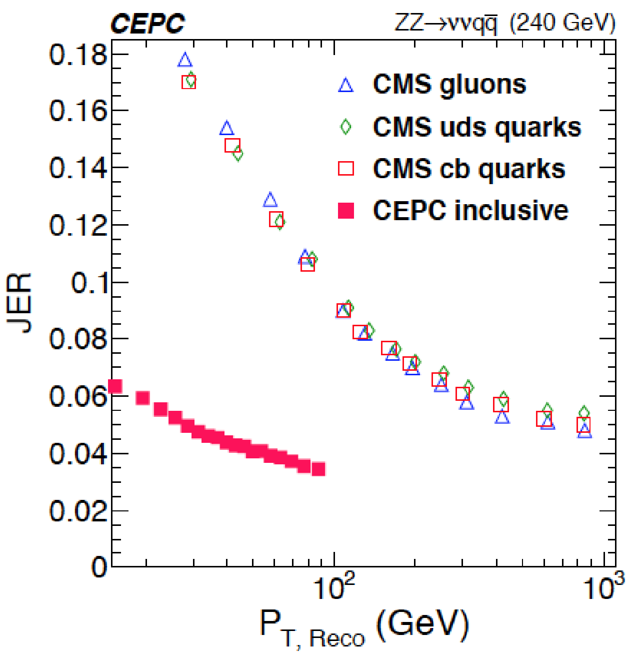
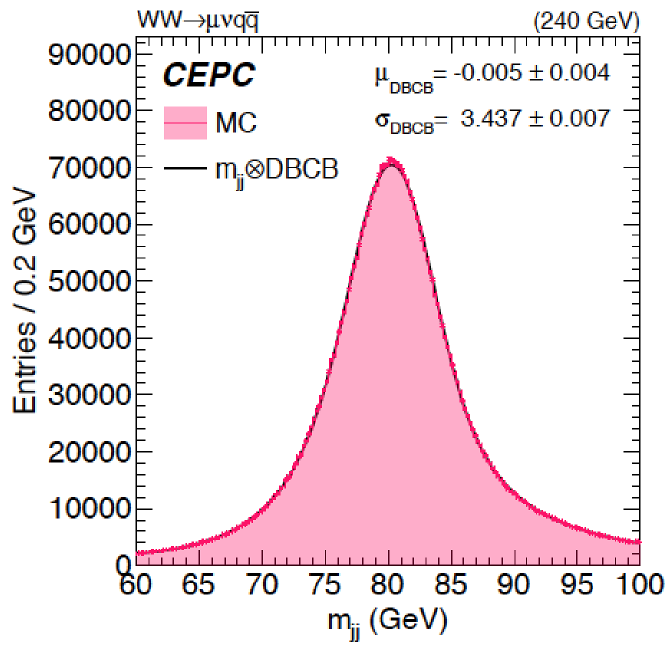


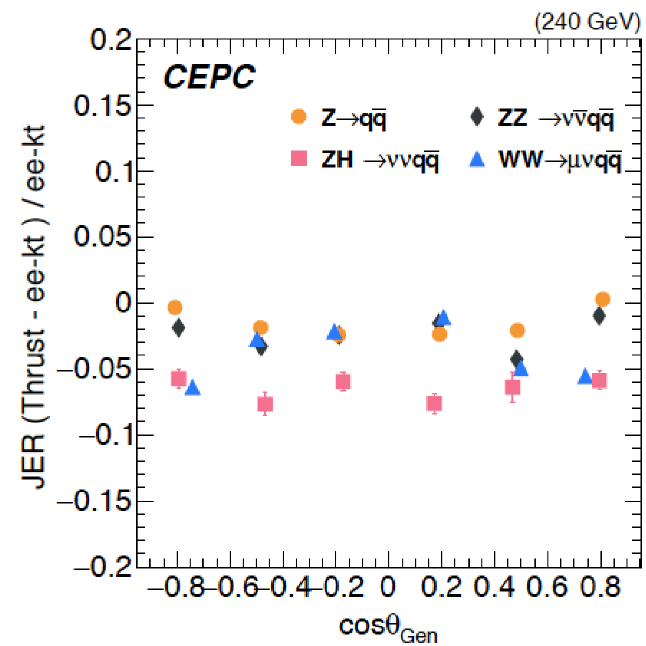
Fig. 7 Distribution of the recoil mass of the qq, M_{qq}^{recoil} for $Z \to qq$, $H \to \tau\tau$ and each background at $\sqrt{s} = 240$ GeV after the previous cuts

FulFill the requirement of BMR < 4%, to separate the W/Z/Higgs with hadronic system invaraint mass, and the qqH signal from qqX background with recoil mass spectrum.

Jet Response

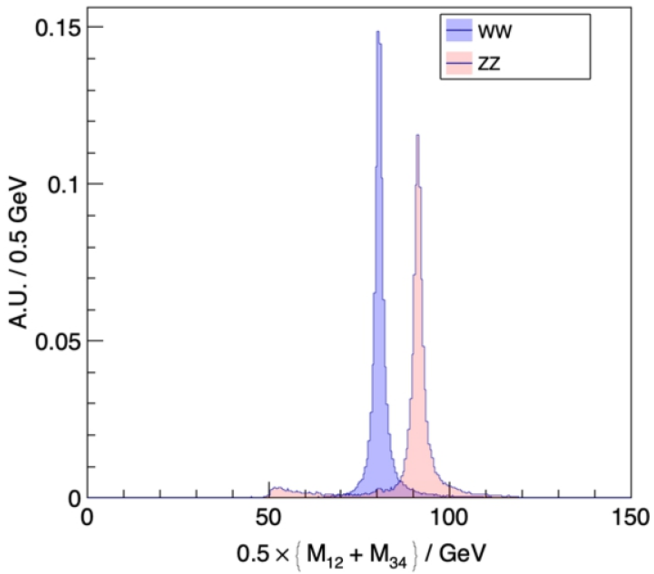


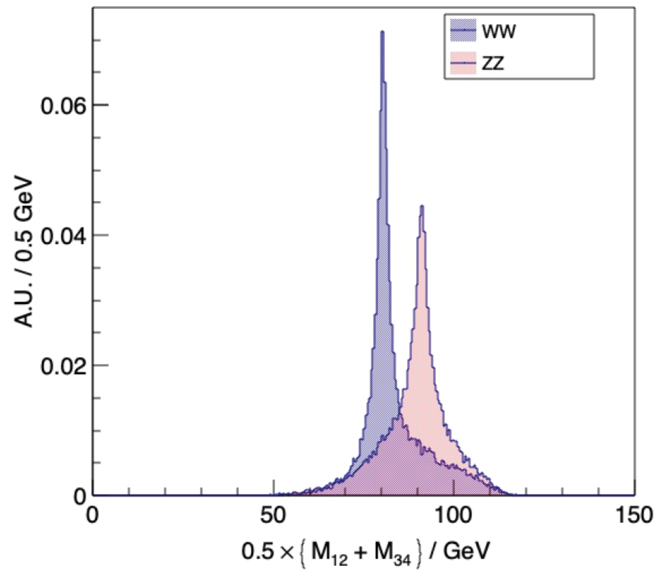


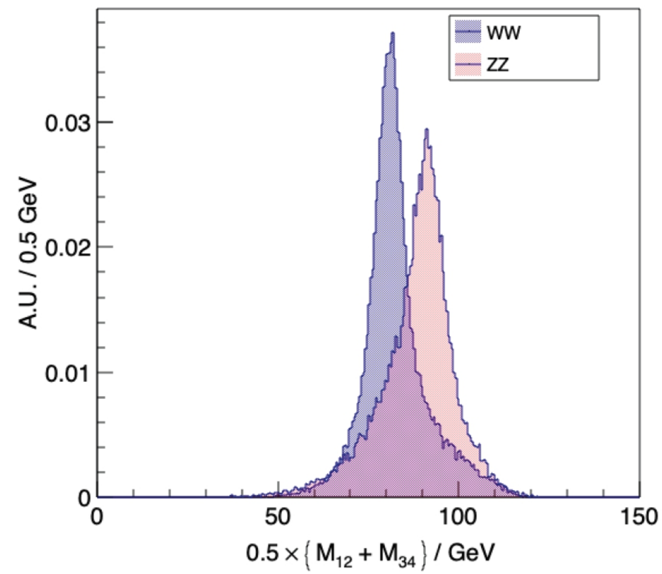


- Significantly better than LHC experiments (at 0 PU);
- Jet Calibration: control the W mass measurements at Higgs run ~ 10 MeV
- Thrust based JC could improve JER ~ 5-10% w.r.t baseline (ee-kt);

Color Singlet Identification in full hadronic multi boson events: critical







- Separation be characterized by
- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2

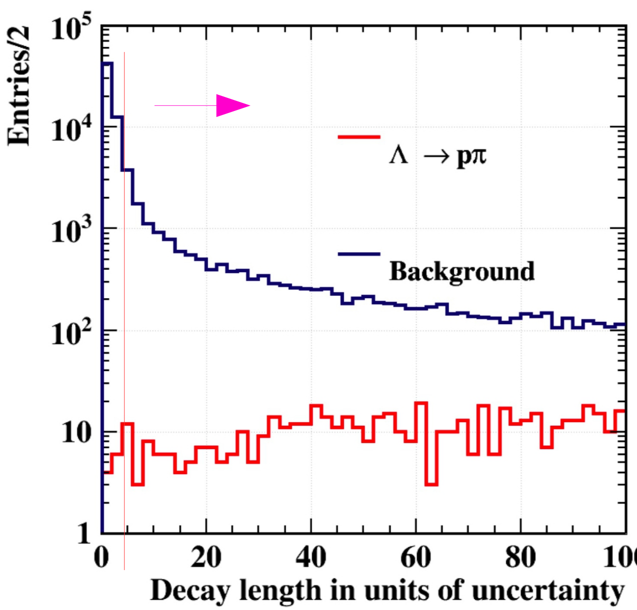
$$\textit{overlapping ratio} = \sum_{bins} min(a_i, b_i)$$

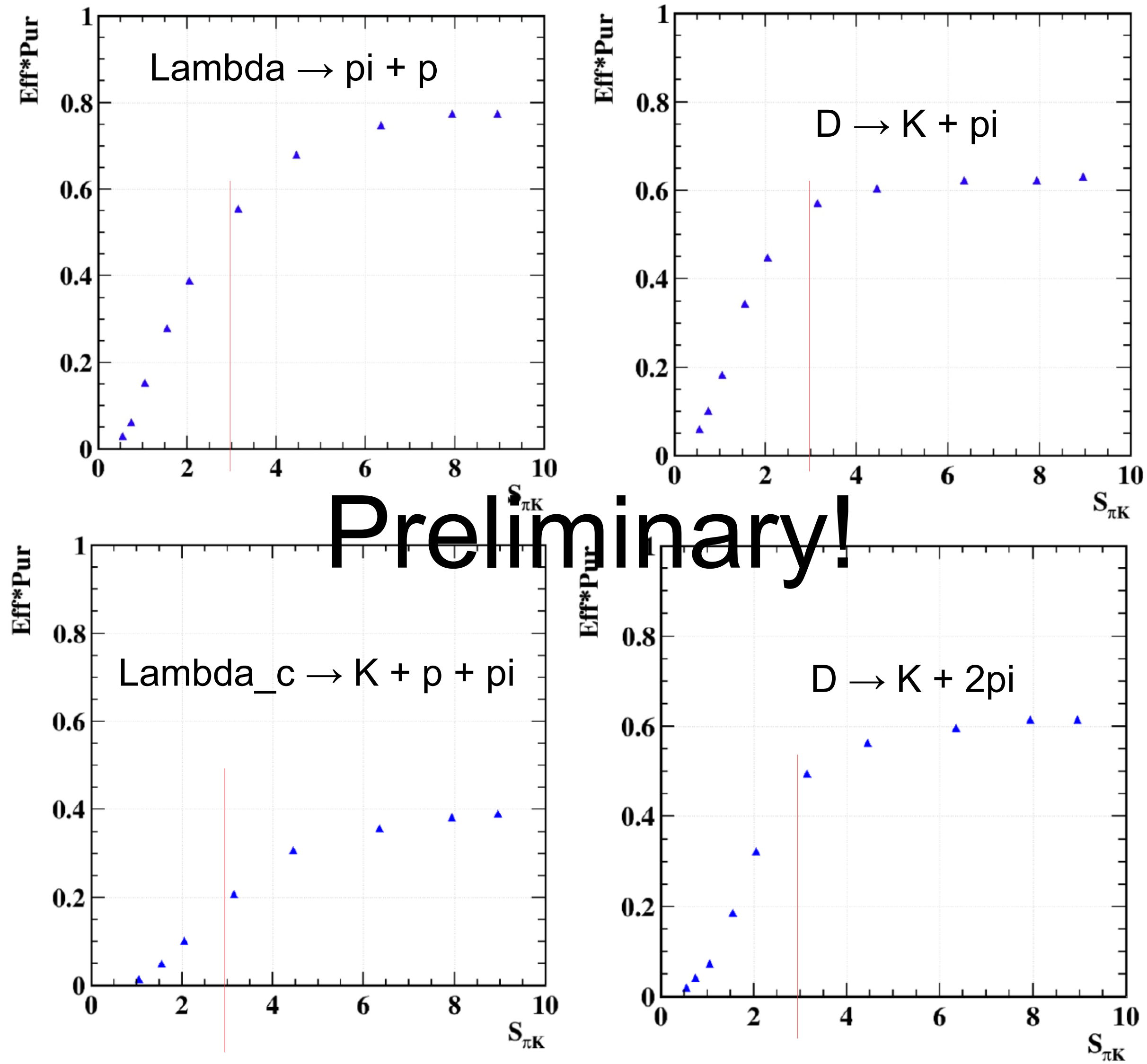
$$\chi^2 = \frac{(M_{12} - M_B)^2 + (M_{34} - M_B)^2}{\sigma_B^2}$$

- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - + Jet confusion – Genjet: Overlapping ratio of **53%**
  - + Detector response – Recojet: Overlapping ratio of 58%

Pid & Objective Hadron finding

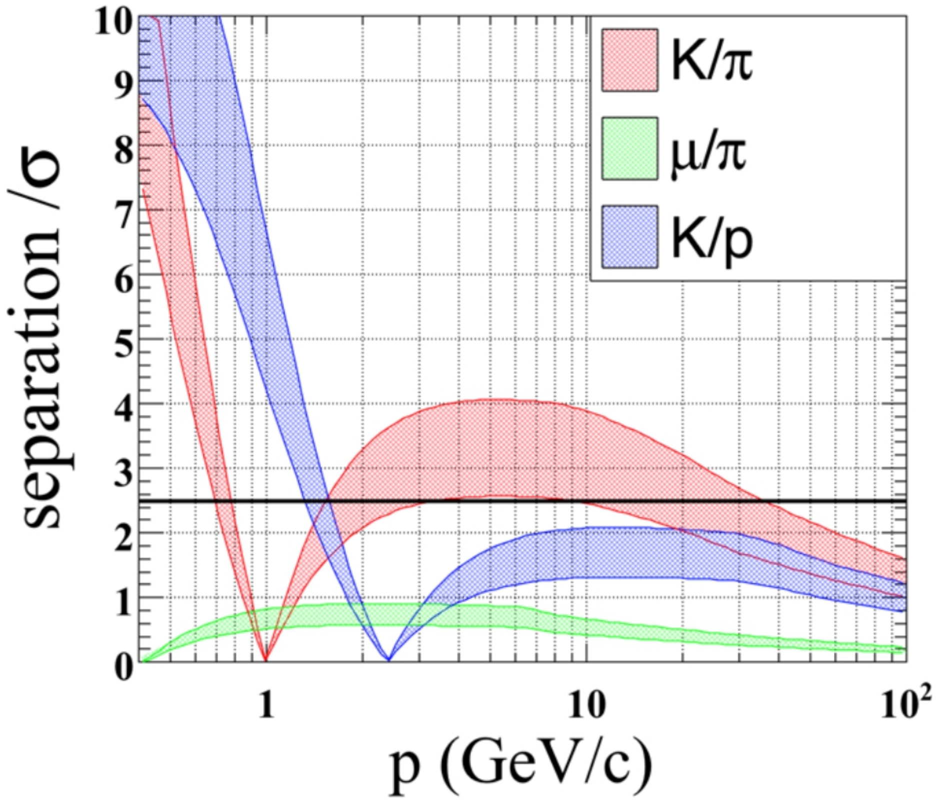
$$S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma_{I_A}^2 + \sigma_{I_B}^2}},$$

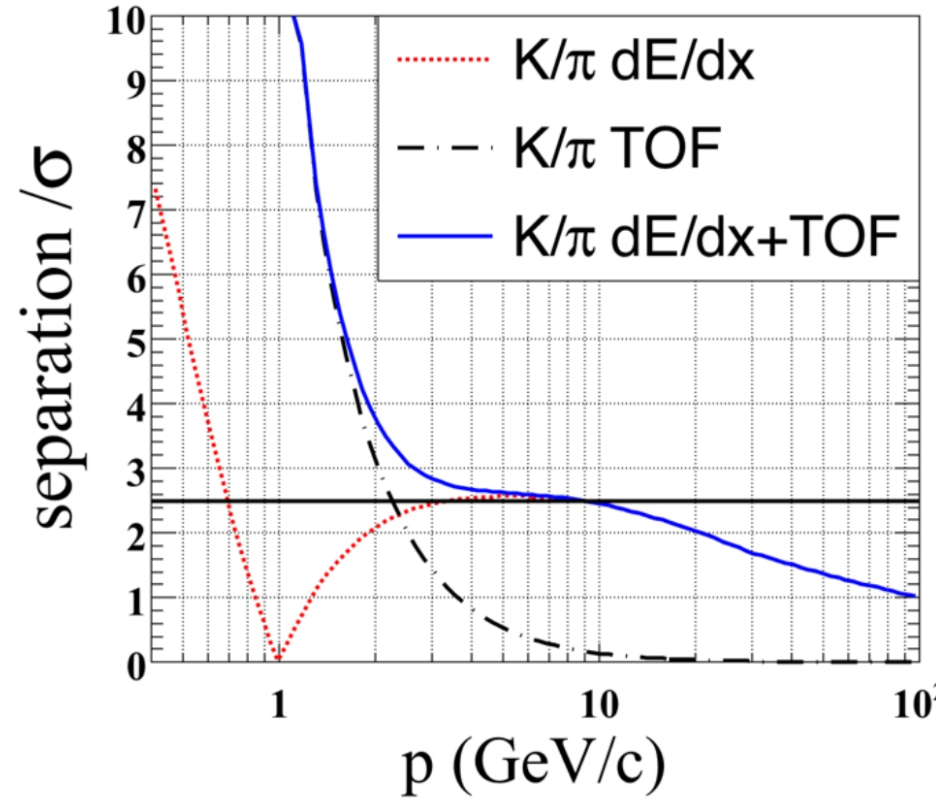




Preliminary!

Kaon





Highly appreciated in flavor physics @ CEPC Z pole
- TPC dEdx + ToF of 50 ps

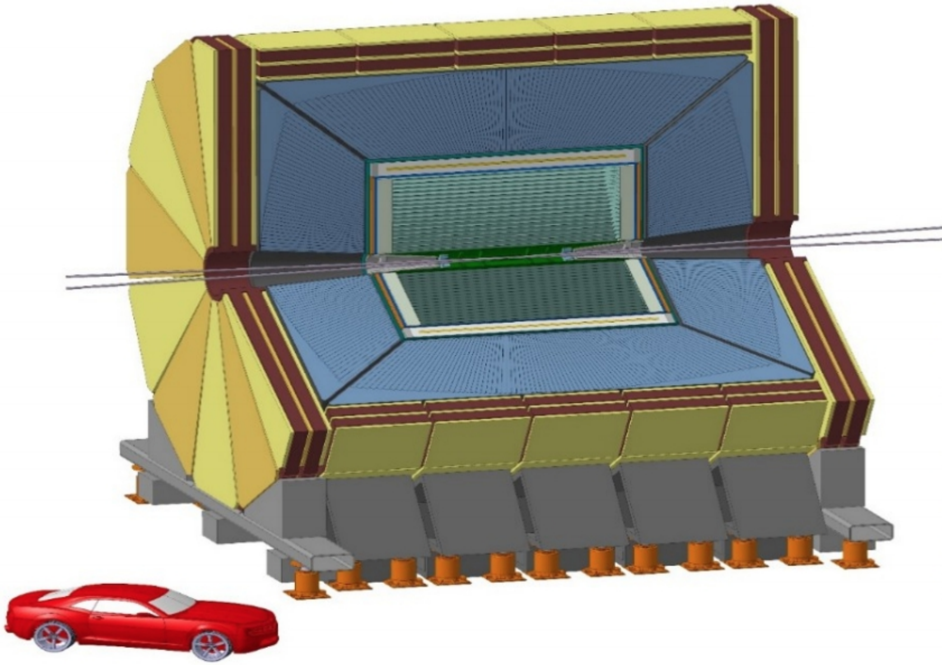
At inclusive Z pole sample:
- Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
- Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

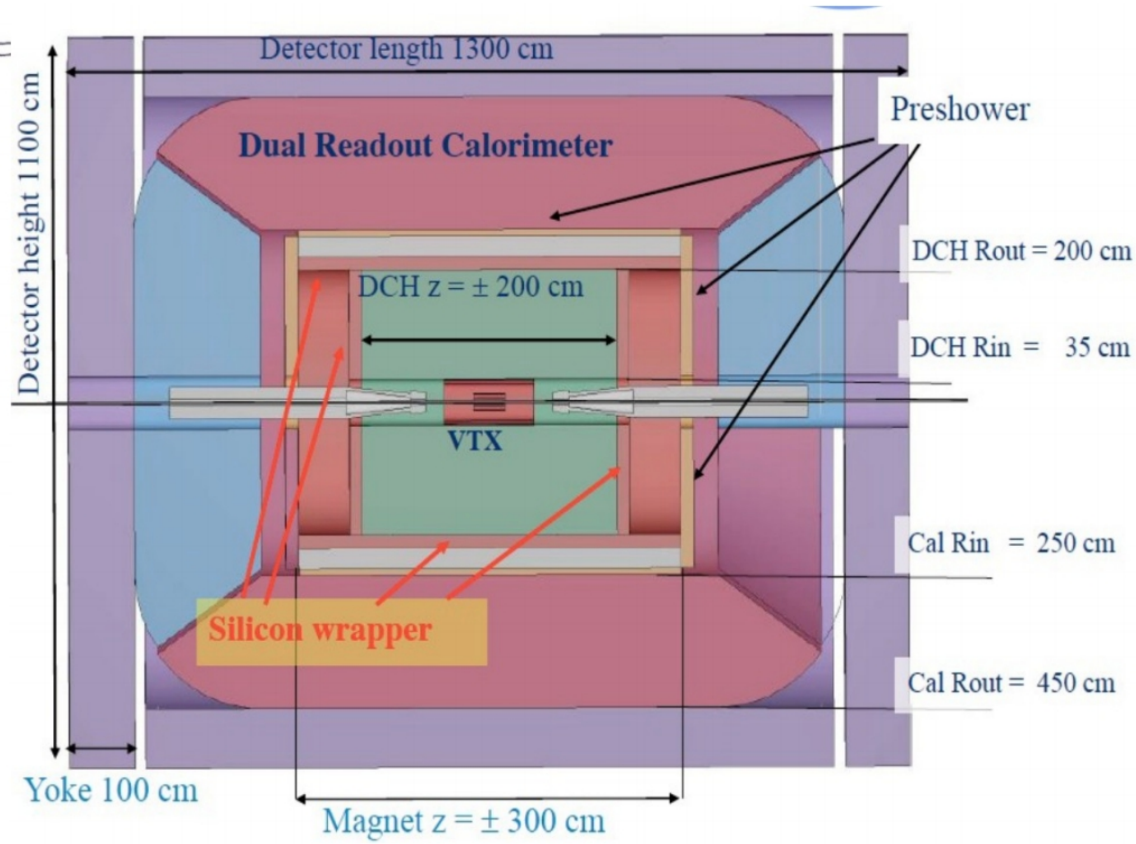
CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464

Performance Update from IDEA

G Mezzadri (INFN – IHEP) – gmezzadr@fe.infn.it
On behalf of the IDEA detector concept group

HK IAS program on High Energy Physics – Hong Kong

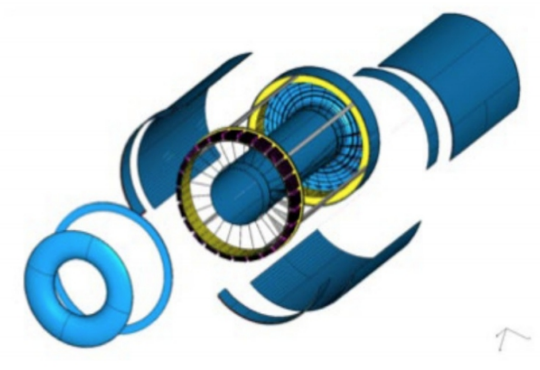


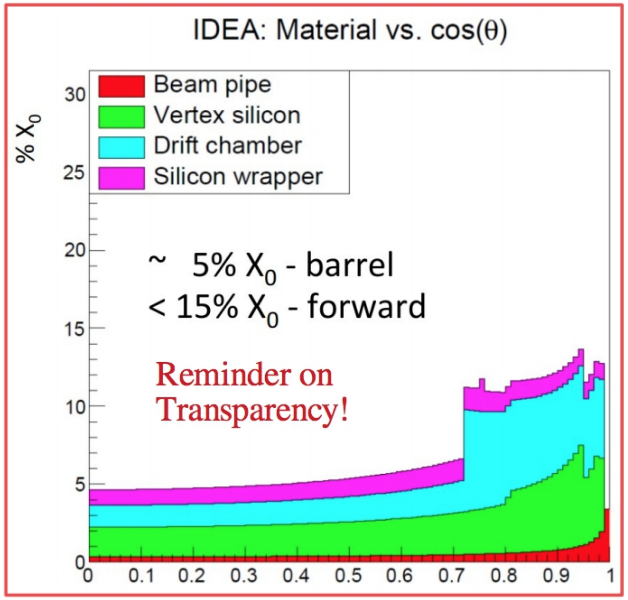


Tracker

Proposed tracking with Drift Chamber (evolution of KLOE and MEG-II DC)

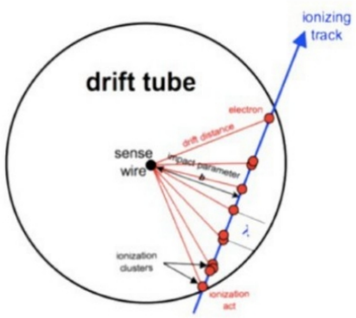
- Minimize multiple scattering, X_0 ~ 2% in tracking volume
- He-iC_4H_{10} gas mixture → Max drift time 360 ns
- Maximum stereo angle ~ 30°
- Cluster counting readout (more in the next slides)

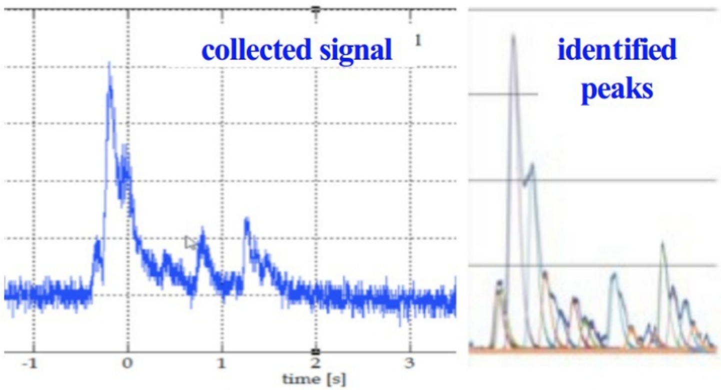




Cluster Counting

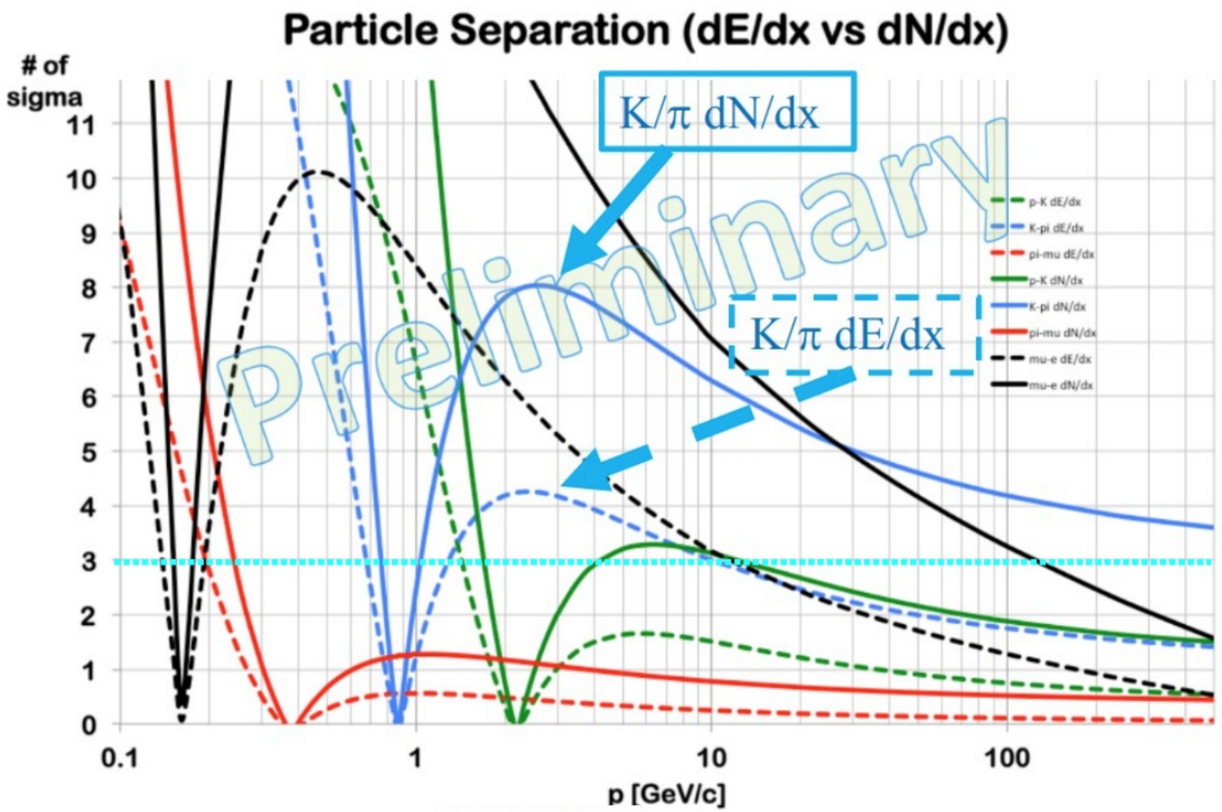
Count the number of primary ionization per unit length (dN/dx).
Since the interval between two ionization acts can be as long as few ns, a GHz sampling electronics is needed





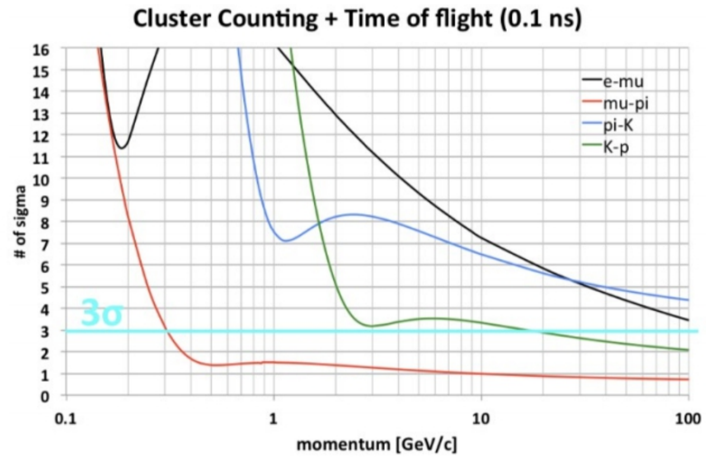
Digital information (dN/dx) to improve particle identification and spatial resolution replacing **analog information** (dE/dx)

Cluster Counting – Role in particle identification



Analytic calculations show an excellent performance for a 2 m track (solid line)

3σ K/π separation can be found by adding a 100 ps timing layer



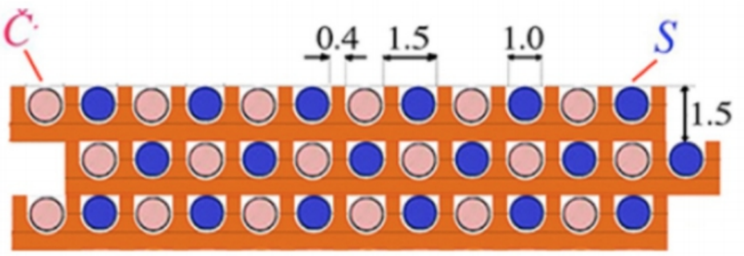
HK IAS on HEP - IDEA - MEZZADRI 17

Calorimetry

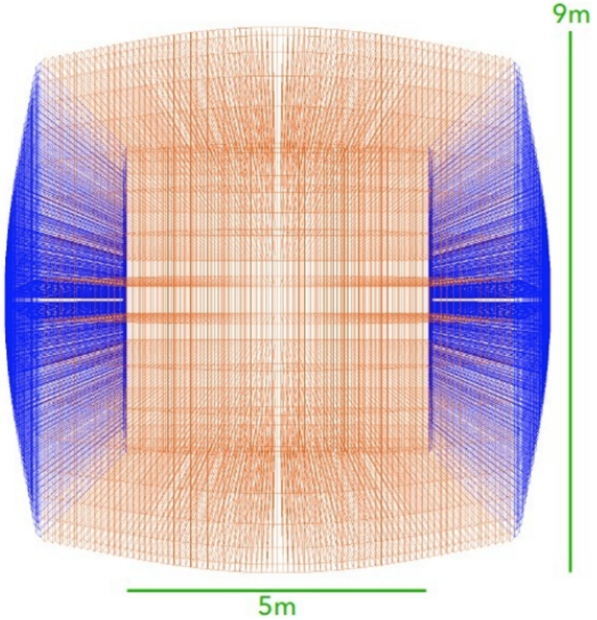
Aim: good energy resolution and boson reconstruction in two jets

Dual readout calorimeter – EM & Hadronic in one single sampling detector
- 1.5 mm fiber pitch
- Cherenkov/Scintillation

Working principle demonstrated by DREAM/RD-52

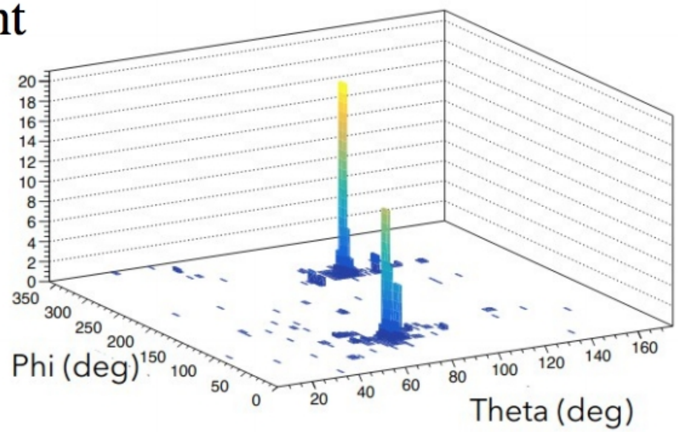


Each of the 130 10^6 fibers is connected to a SiPM

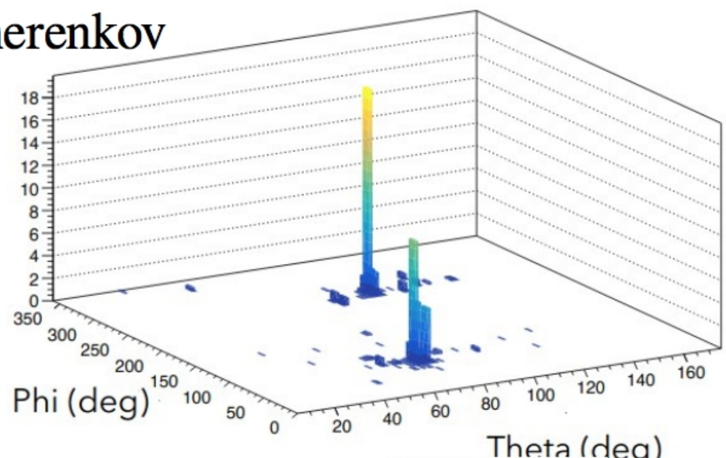


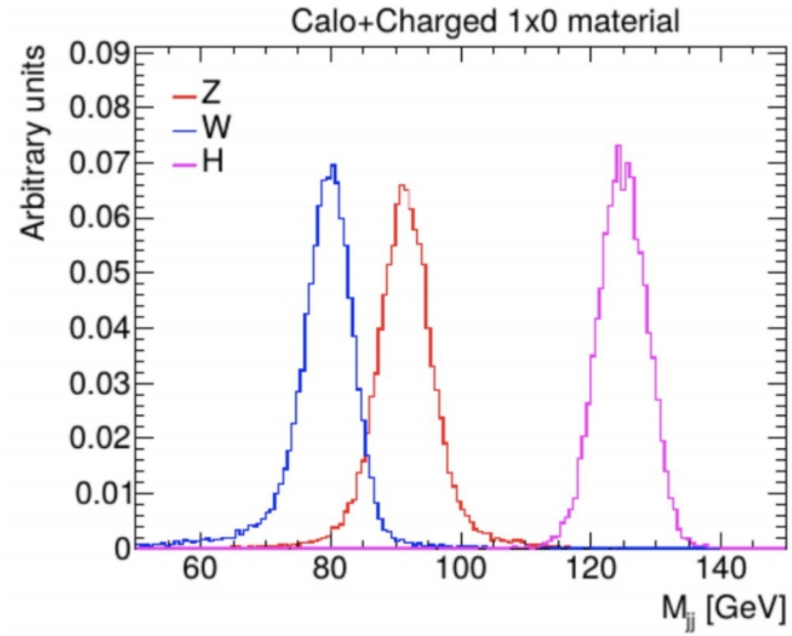
Jets reconstruction – Boson→ jj

Scint



Cherenkov





First the individual Scintillation and Cherenkov showers are reconstructed.

The results are then combined with “track aided” calibration

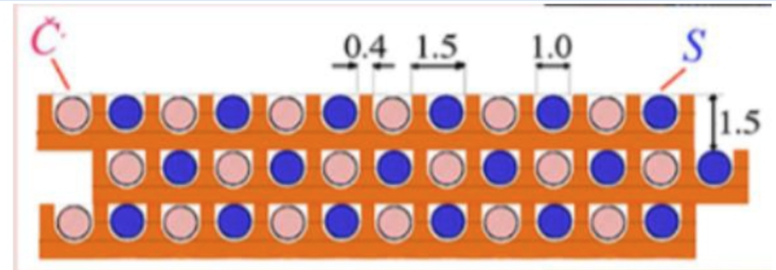
Istituto Nazionale di Fisica Nucleare

HK IAS on HEP - IDEA - MEZZADRI

中国科学院高能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences

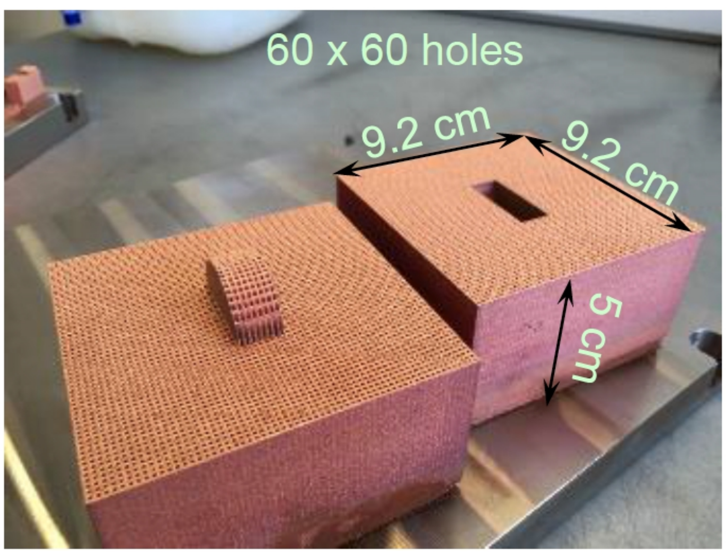
Dual Readout Calorimeter

- The calorimeter in the IDEA design is a DR CAL, for both EM & hadronic showers.



Cu absorber, 1 mm fibers

3-D printing of a Cu absorber by Korean colleagues

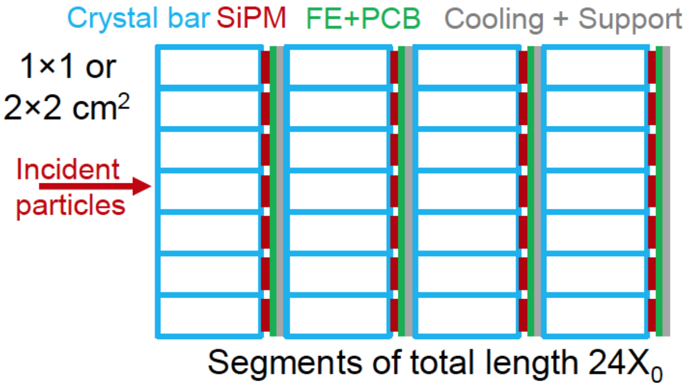


- Detector performance has been studied in simulation.
- Physics performance of benchmark channels, both standard approach & deep learning algorithm.
- Prototype modules are to be built, first an EM prototype by early 2021, then the hadronic size module.
- A 60×60–hole Cu absorber from 3-D printing looks promising.

- Dual readout in crystal ECAL is also being explored.

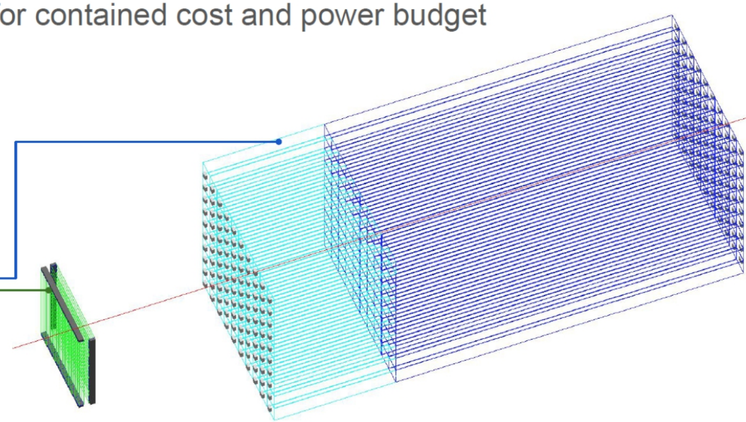
Crystal ECAL: several new ideas

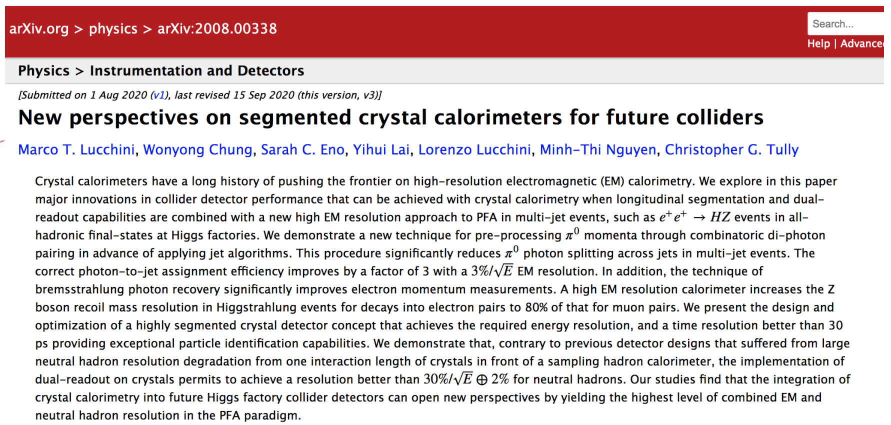
- Single end readout; potentials with PFA
- Study γ/π^0 separation & energy resolution to optimize transverse and longitudinal segmentation.



- ***SCEPCAL:*** a **S**egmented **C**rystal **E**lectromagnetic **P**recision **C**alorimeter
- **Transverse and longitudinal segmentations** optimized for particle identification, shower separation and performance/cost
- Exploiting **SiPM readout** for contained cost and power budget

- **Timing layer** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x54 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layer** — $\sigma_E/E \sim 3\%/\sqrt{E}$
  - PbWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)





arXiv.org > physics > arXiv:2008.00338

Search...
Help | Advance

Physics > Instrumentation and Detectors

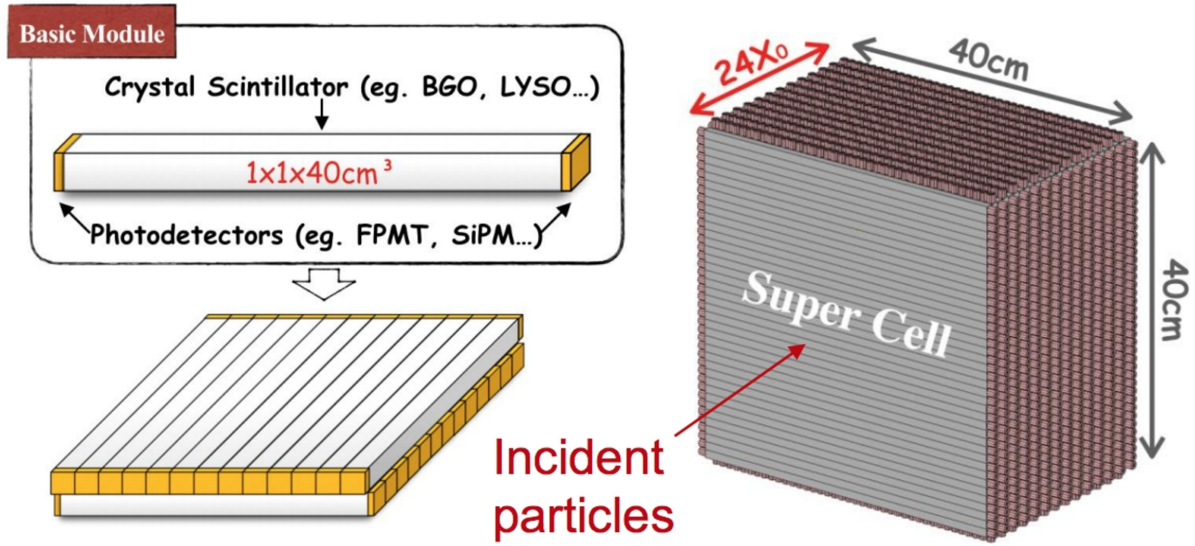
[Submitted on 1 Aug 2020 (v1), last revised 15 Sep 2020 (this version, v3)]

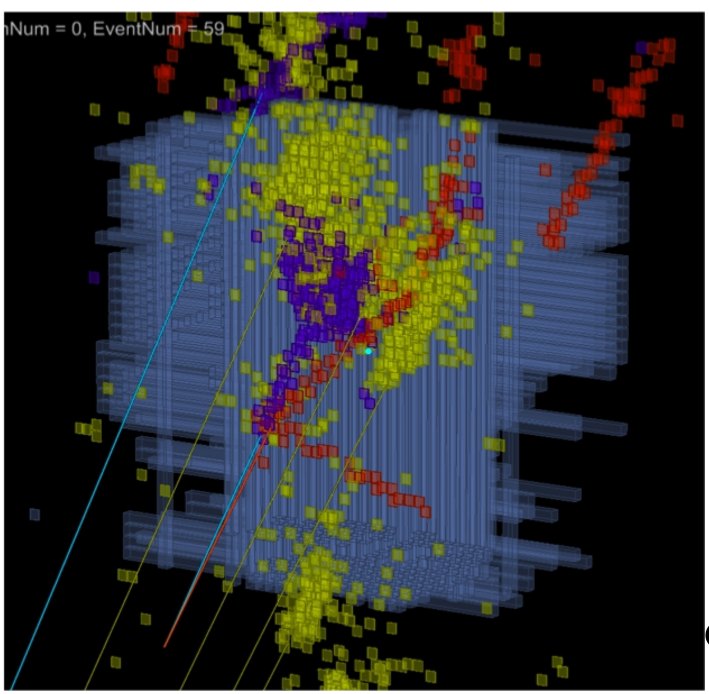
New perspectives on segmented crystal calorimeters for future colliders

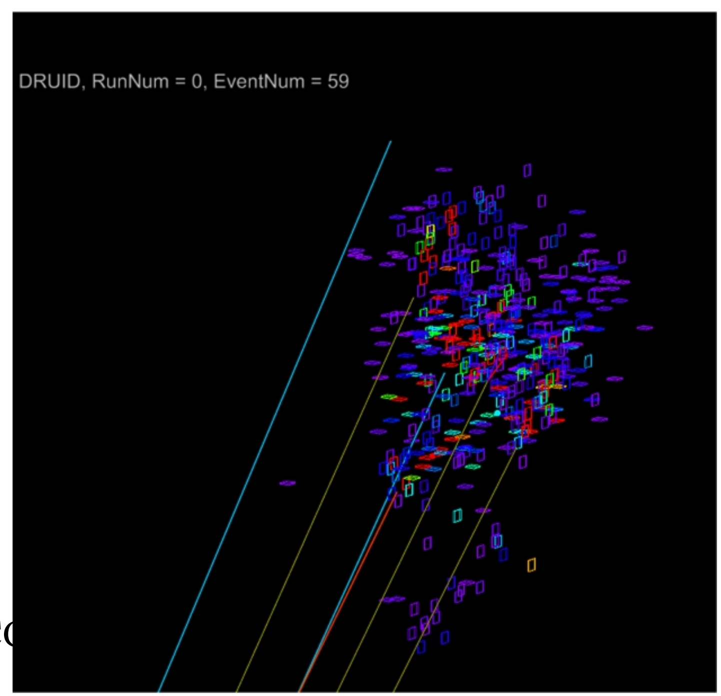
Marco T. Lucchini, Wonyong Chung, Sarah C. Eno, Yihui Lai, Lorenzo Lucchini, Minh-Thi Nguyen, Christopher G. Tully

Crystal calorimeters have a long history of pushing the frontier on high-resolution electromagnetic (EM) calorimetry. We explore in this paper major innovations in collider detector performance that can be achieved with crystal calorimetry when longitudinal segmentation and dual-readout capabilities are combined with a new high EM resolution approach to PFA in multi-jet events, such as $e^+e^+ \to HZ$ events in all-hadronic final-states at Higgs factories. We demonstrate a new technique for pre-processing π^0 momenta through combinatoric di-photon pairing in advance of applying jet algorithms. This procedure significantly reduces π^0 photon splitting across jets in multi-jet events. The correct photon-to-jet assignment efficiency improves by a factor of 3 with a $3\%/\sqrt{E}$ EM resolution. In addition, the technique of bremsstrahlung photon recovery significantly improves electron momentum measurements. A high EM resolution calorimeter increases the Z boson recoil mass resolution in Higgstrahlung events for decays into electron pairs to 80% of that for muon pairs. We present the design and optimization of a highly segmented crystal detector concept that achieves the required energy resolution, and a time resolution better than 30 ps providing exceptional particle identification capabilities. We demonstrate that, contrary to previous detector designs that suffered from large neutral hadron resolution degradation from one interaction length of crystals in front of a sampling hadron calorimeter, the implementation of dual-readout on crystals permits to achieve a resolution better than $30\%/\sqrt{E} \oplus 2\%$ for neutral hadrons. Our studies find that the integration of crystal calorimetry into future Higgs factory collider detectors can open new perspectives by yielding the highest level of combined EM and neutral hadron resolution in the PFA paradigm.

Crystal ECAL

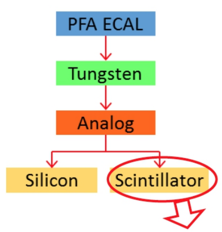




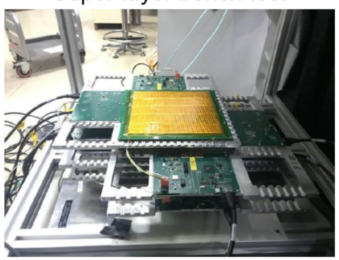


Prototypes

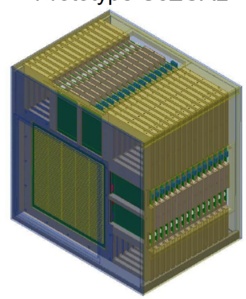
PFA ECAL



Super-layer bench test

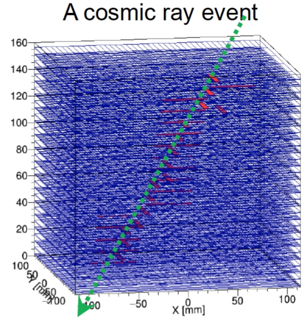


Prototype ScECAL

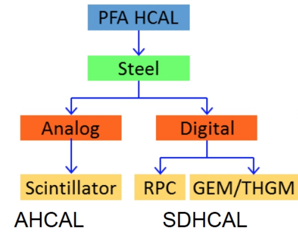


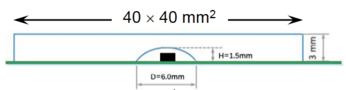
- An alternative PFA ECAL in CDR: scintillator + SiPM as the sensitive detector, tungsten as absorber, totals $24X_0$ radiation length.
- A 32-layer prototype has been constructed (Sept 2020): 3.2 mm thick W-Cu plate, scintillator bar size 5×45 mm^2, 1 SiPM/bar.
- It has been tested with cosmic rays, and an electron beams at IHEP (Nov 2020). When possible the prototype will be tested in the beam at DESY.

A cosmic ray event

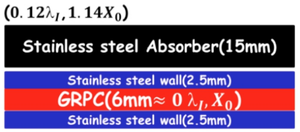


PFA HCAL





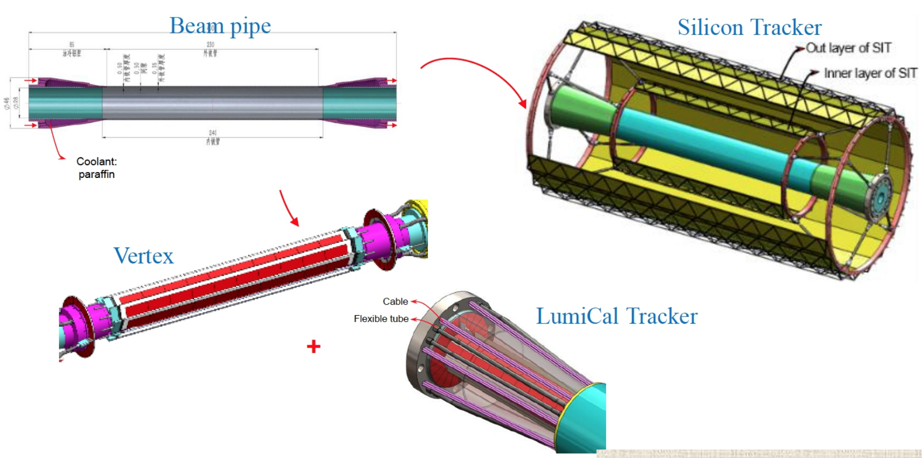
- AHCAL of Steel+Scint+SiPM:
  - Prototype size 72×72×100 cm^3, 40 layers, 2cm steel plates, 4×4 cm^2 detector cell.
  - Readout electronics & DAQ are developed.
  - Preparing for production.
- SDHCAL based on GRPC:
  - Prototype size 1×1×1.4 m^3, 48 layers, 1×1 cm^2 detector cell, 2 cm steel absorber.
  - Construct a 35×50 cm^2 GRPC before a full size.
- SDHCAL based on MPGD
  - Constructed a 25×25 cm^2 detector, and studied its performance.



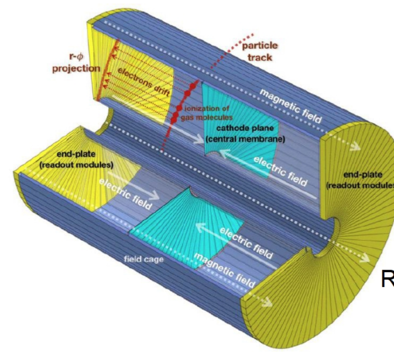
Prototypes & Integration

Interaction Region Design

- **Completed:** Synchrotron radiation & high order mode heat load calculation → beam pipe thermal analysis → detector radiation backgrounds evaluation
- **On-going:** Assess physics gains, design risks and difficulties to shrink the central Be beam pipe: **ϕ28mm → ϕ20mm**, wall thickness: **0.5+0.35 mm → 0.2+0.15 mm**.
- **On-going:** Engineering design of sub-detectors including interfacing, integration installation scheme (focused but not limited to the interaction region).



Time Projection Chamber

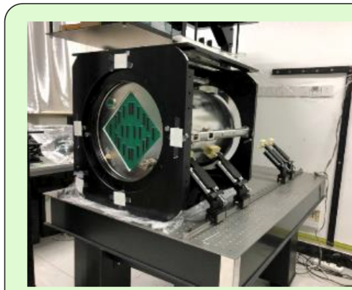


The main tracker

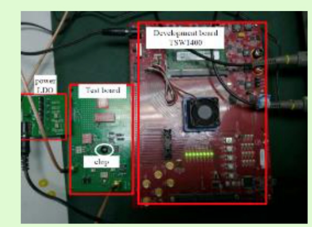
Resol in r-Φ~100 μm

- Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by laser calibration at low lumin, difficult @ Z-pole.
- Potential solutions to suppress IBF, e.g. Pixel TPC with double meshes, or micromegas.
- When Gain×IBF=1, distortion <16 μm @ L= 32 $\times 10^{34}$ $cm^{-2}s^{-1}$, <49 μm @10^{36} $cm^{-2}s^{-1}$.

Completed



TPC Prototype + UV laser beams



FEE ASIC (65nm CMOS)

Status of the CEPC Project

Jianchun Wang

IHEP, CAS

XXVII Cracow Epiphany Conference

on Future of Particle Physics

Summary

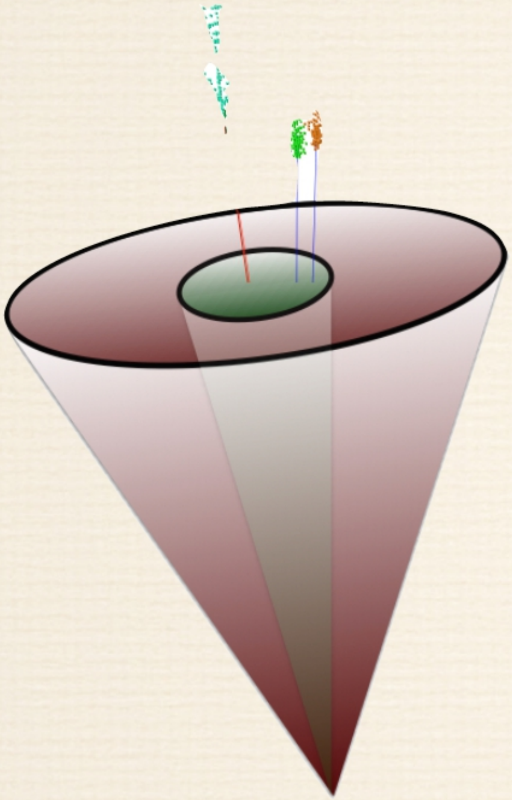
- Multiple detector concept for a multiple IP machine & iterations with prototype construction/test, integration study
- The baseline detector with precision tracker and high granularity calorimeter:
  - Fulfills the core physics requirement on Higgs/EW measurements.
    - Reconstruct elegantly all physics objects from Higgs events...
    - Clearly identify and separate different Higgs signals from the SM bkg
- Provides a reasonable starting point for the flavor physics (Tera Z)
    - Jet lepton, Kaons (eff & purity of 95% at Z pole), Neutral pion (up-to 30 GeV)...
- IDEA concept:
  - Different approach to purses good hadronic system reconstruction
  - DN/dx provides intriguing capability for the Pid/flavor physics
- New ideas: in exploration

Back up

Summary

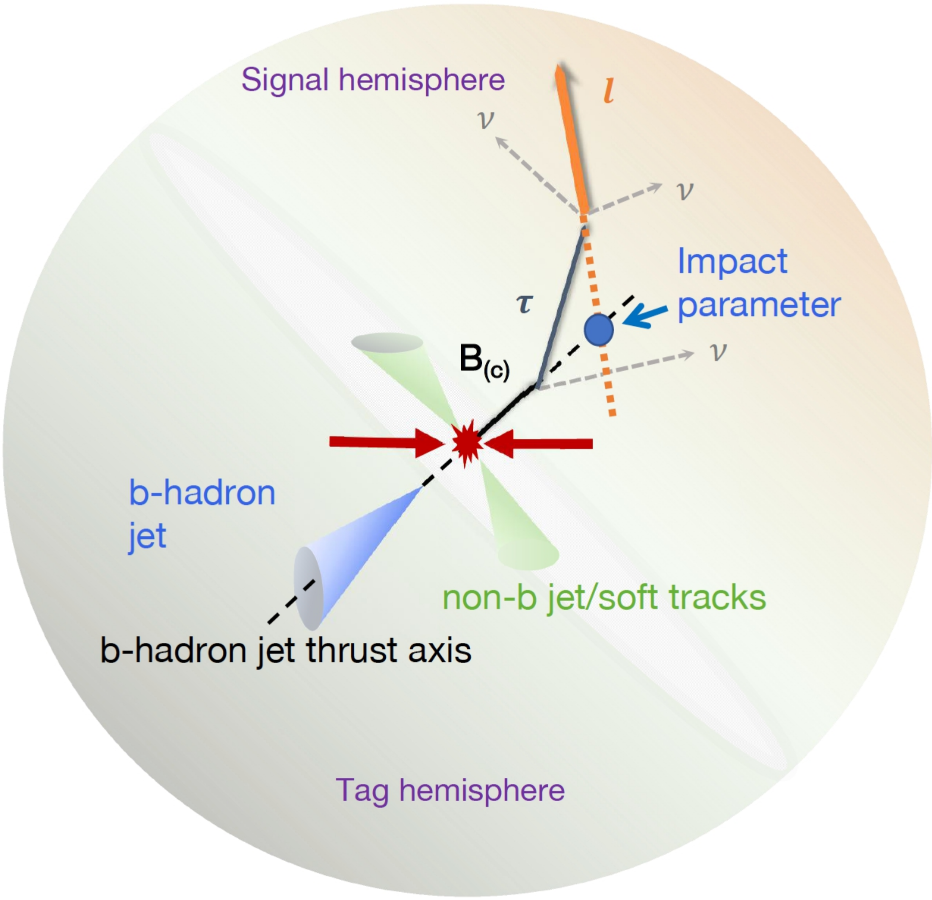
- Lots of interesting questions ahead:
  - Dependence between VTX geometry & 2nd vertex, jet flavor/charge reconstruction
  - Jet clustering & color singlet identification: optimization & systematic control
  - Quantification of the physics requirement, especially on flavor physics
  - Detector optimization-integration study
- Detailed validation...

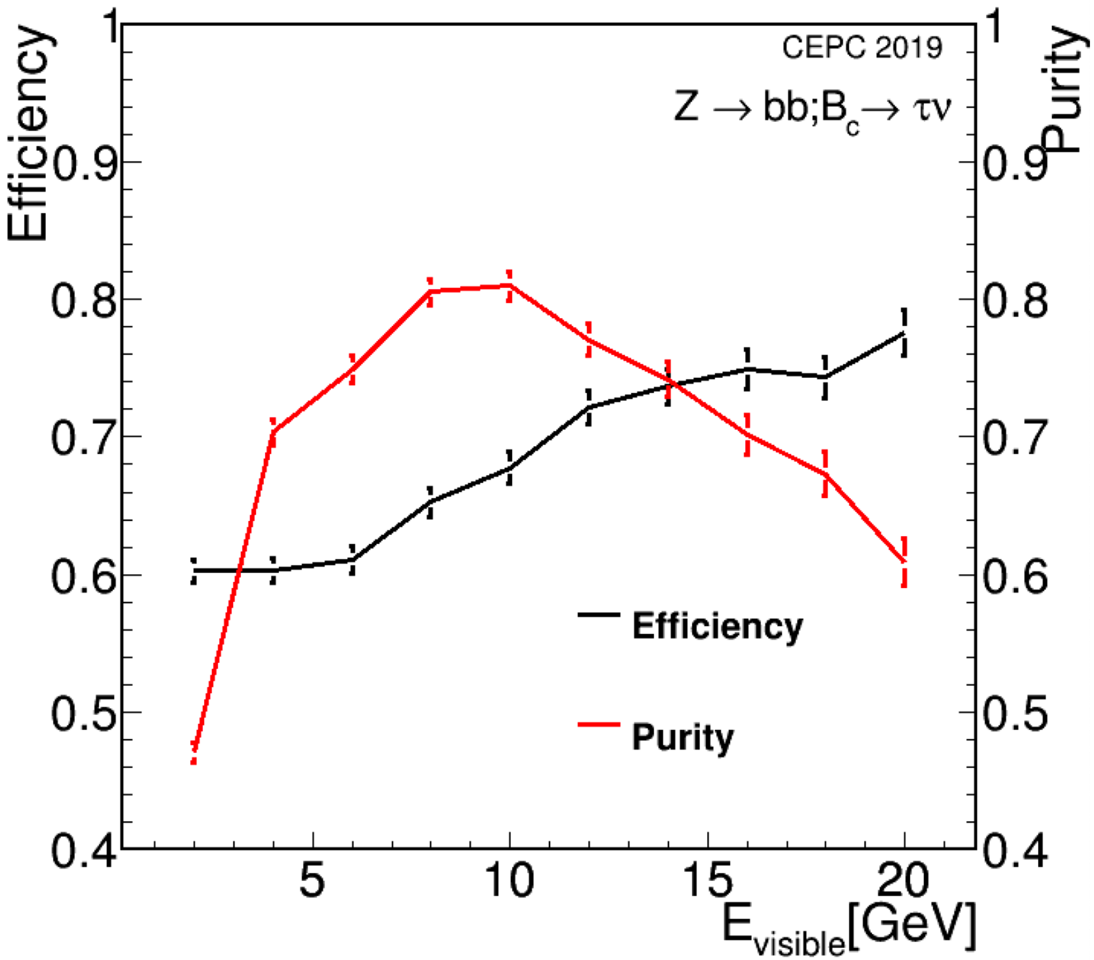
Taurus



- Double cone based algorithm
  - Find seeds(Tracks with enough energy)
  - Collect particle in two cones
  - Use the multiplicity, energy ratio between two cones, invariant mass for τ tagging

Tau finding inside jet





Eur. Phys. J. C (2020) 80:7
https://doi.org/10.1140/epjc/s10052-019-7557-y

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

The measurement of the $H \rightarrow \tau\tau$ signal strength in the future e^+e^- Higgs factories

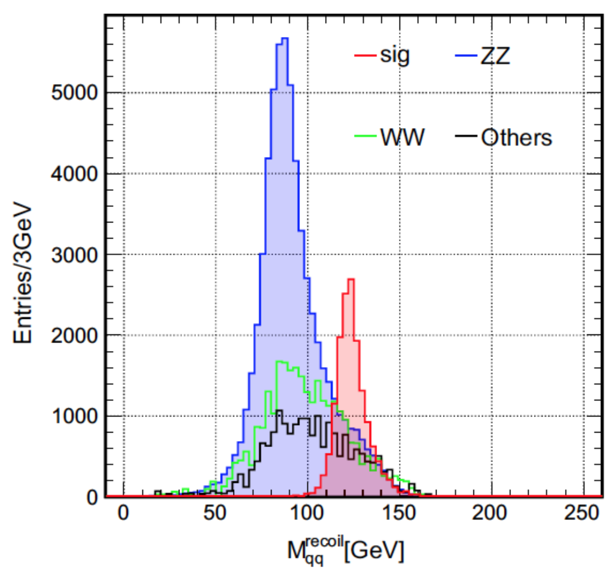
Dan Yu[1], **Manqi Ruan**[1,a], **Vincent Boudry**[2], **Henri Videau**[2], **Jean-Claude Brient**[2], **Zhigang Wu**[1], **Qun Ouyang**[1], **Yue Xu**[3], **Xin Chen**[3]

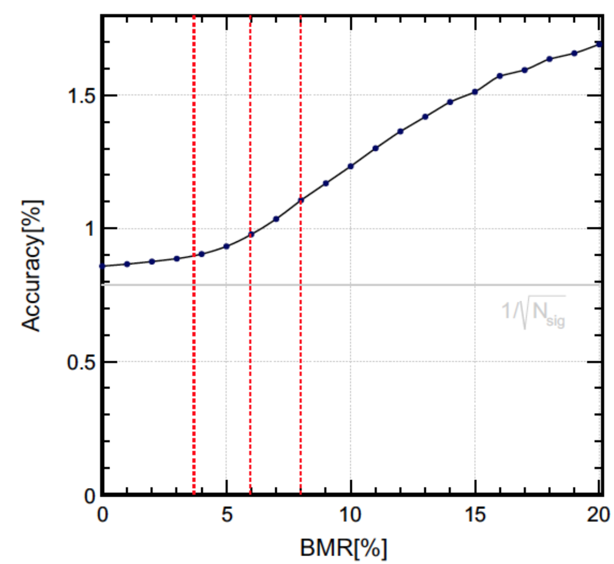
[1] IHEP, Beijing, China
[2] LLR, Ecole Polytechnique, Palaiseau, France
[3] Tsinghua University, Beijing, China

Received: 22 July 2019 / Accepted: 12 December

Table 9 Extrapolated accuracy $\delta(\sigma \times BR)/(\sigma \times BR)$ in the ILC 250 GeV (2000 fb^{-1})

	CEPC	ILC(L)	ILC(R)
Luminosity (ab^{-1})	5.6	2	2
Polarization (e^-, e^+)	–	(0.8, −0.3)	(−0.8, 0.3)
Total Higgs	1.18 M	0.60 M	0.40 M
Accuracy (%)	0.8	1.09	1.21



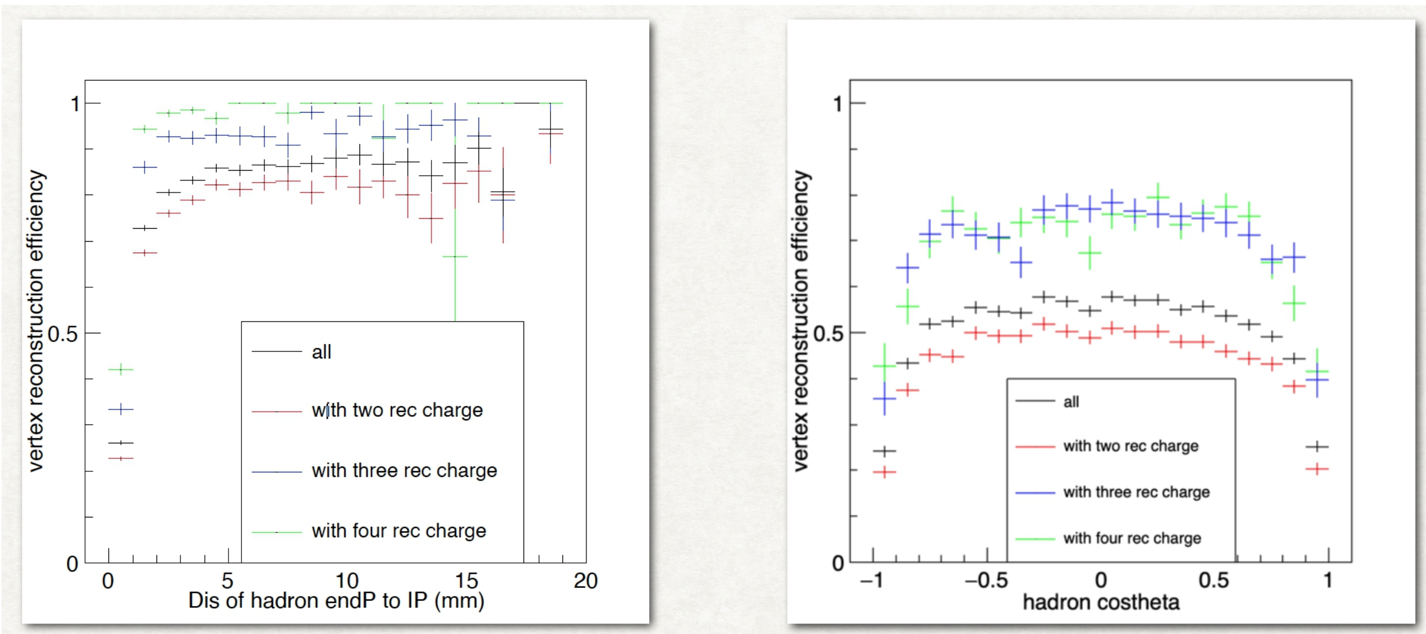


VTX reconstruction: Diagnosis

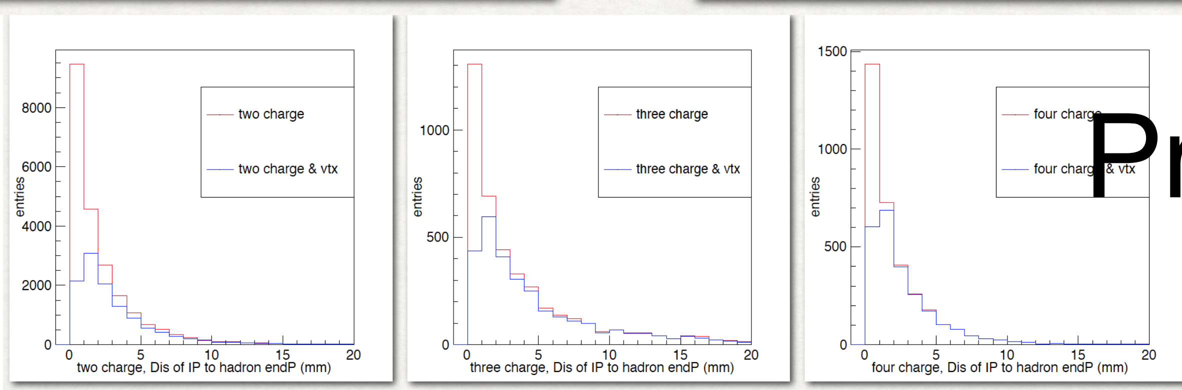
$$\frac{\textit{should been reconstructed vertex}\ \&\&\ \textit{have been reconstructed vertex}}{\textit{should been reconstructed vertex}}$$

C-hadron with given charge multiplicity && corresponding tracks reconstructed

- At vvH, H→cc events.



Yongfeng

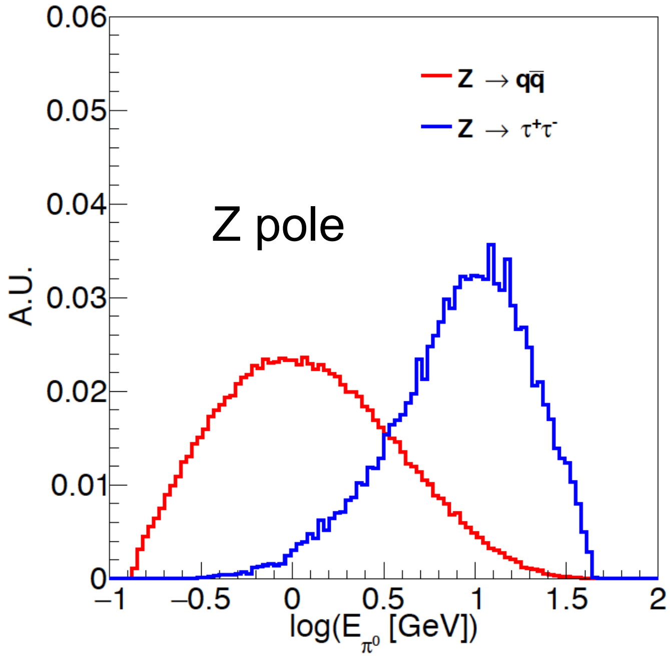


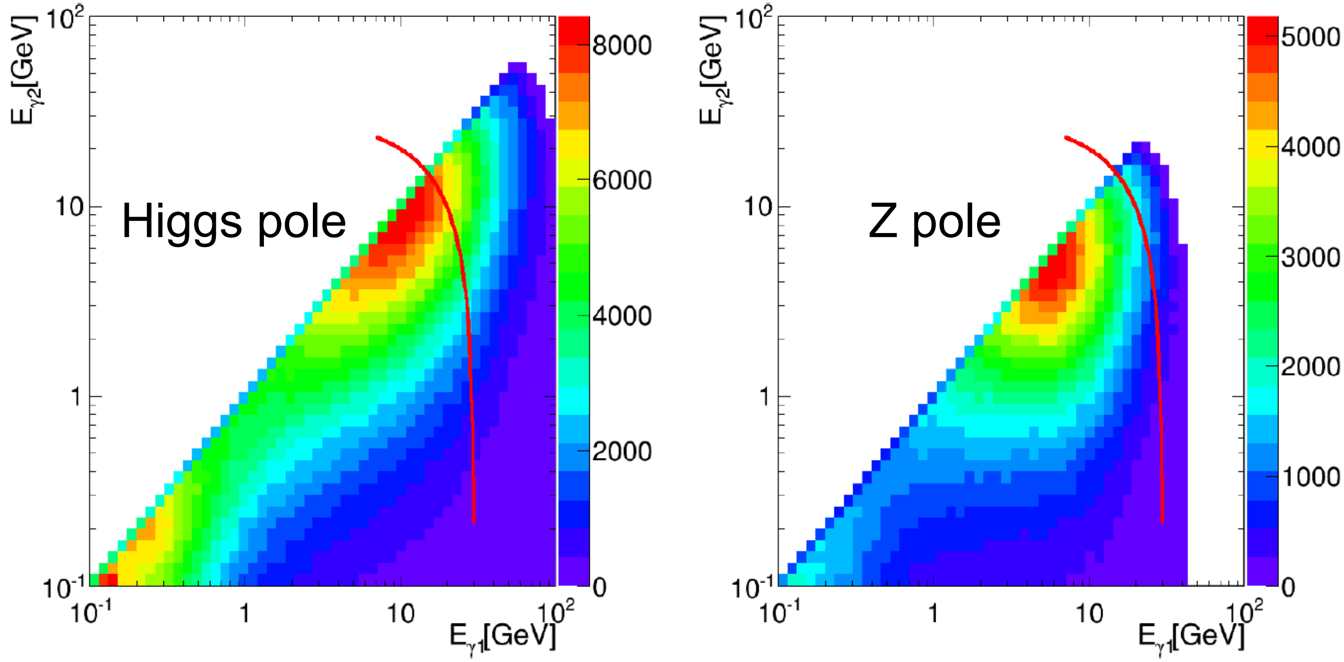
Preliminary

Photon & π^0

- Larger acceptance: for ISR photon tagging (Need further quantification) as well as luminosity measurement
- Threshold: ~o(100) MeV;
- Low energy photons < 20 GeV, mostly from π^0 decay
  - Flavor physics: narrow resonances
  - Exotic
- High energy photons: 20 – 100 GeV
  - $H \rightarrow \gamma\gamma$
  - Measurements with $Z\gamma$ events (ISR),
    - Neutrino generation measurements
    - Jet calibration, etc
- Good linearity for 3 orders of magnitude (100 MeV – 100 GeV)

π^0: energy range





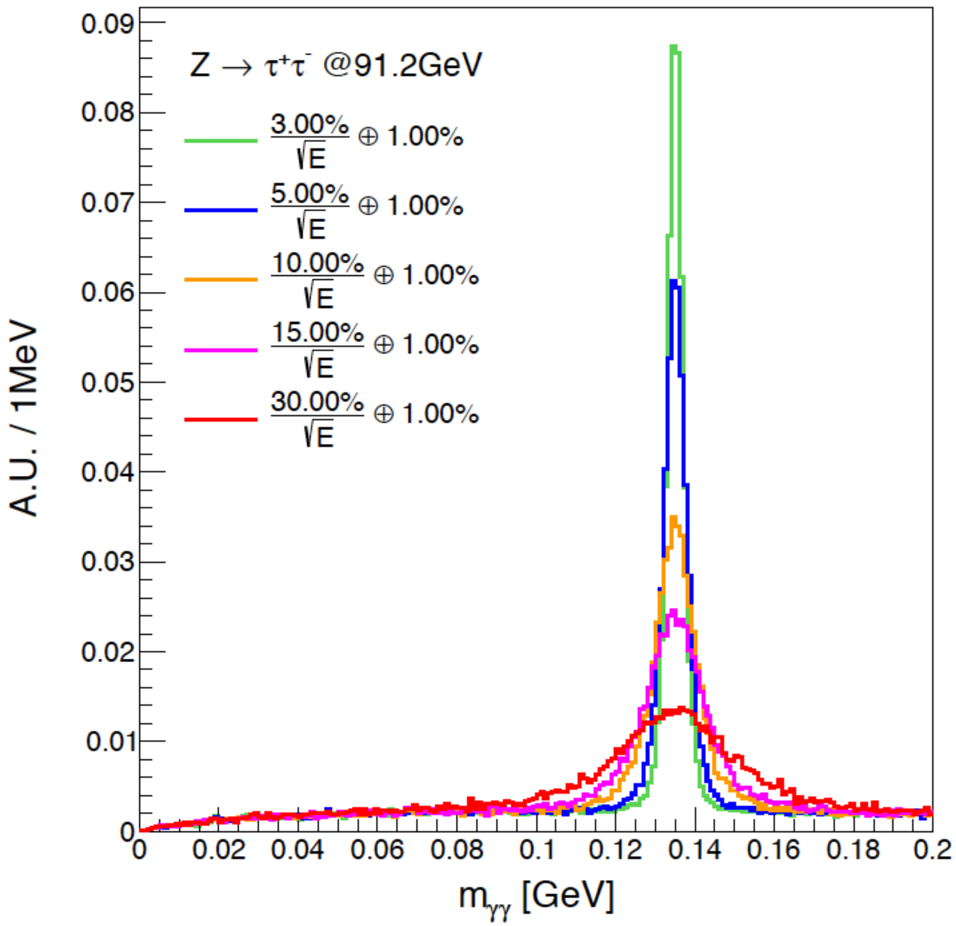
(a) (b)

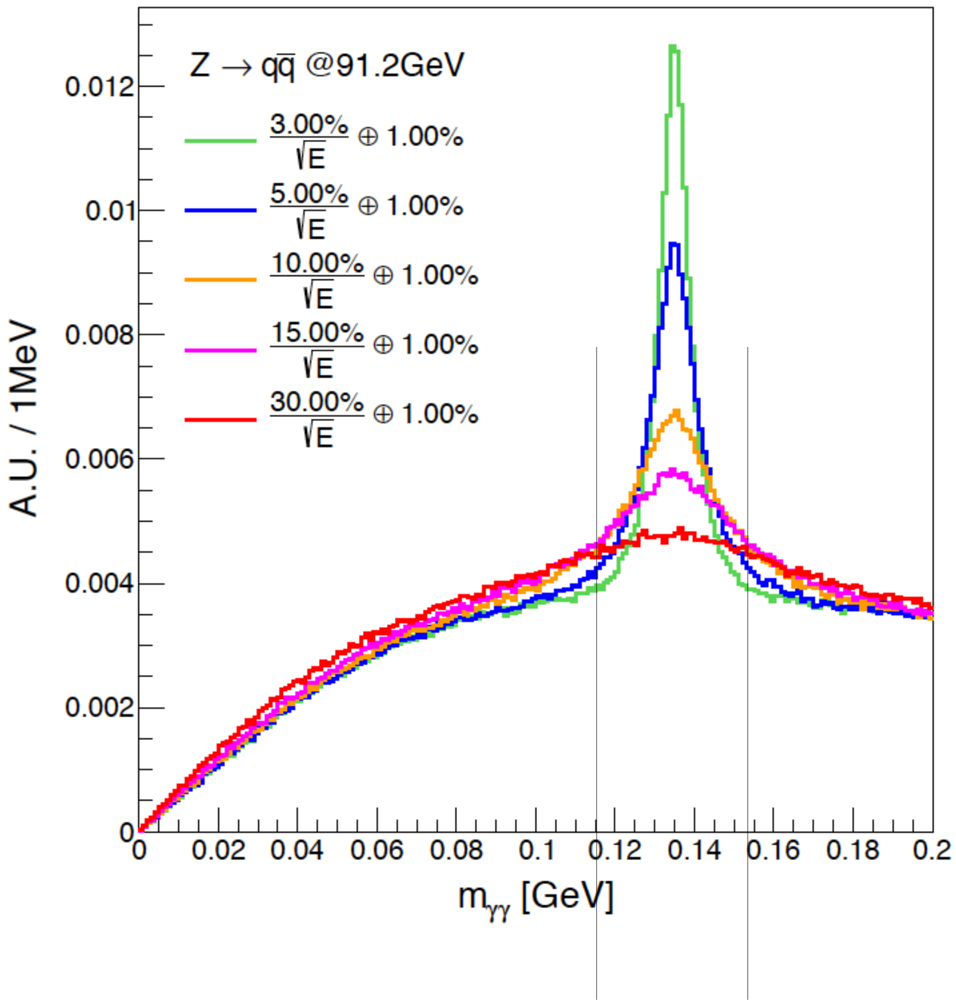
Fig. 14: The generated π^0 distribution as a function of the energies of di-photons from $\pi^0 \to \gamma\gamma$ in inclusive Higgs (a) and $Z \to \tau\tau$ samples (b). $E_{\gamma 1}$ is the energy of the leading photon. $E_{\gamma 2}$ is the energy of the sub-leading photon. The red line is the function of $E_{\gamma 1} + E_{\gamma 2} = 30$ GeV.

- π^0 energy (rest-mass, 30 GeV – 60 GeV): photon threshold ~ o(100) MeV
- At Z pole: be able to separate photons from Pi-0 decay, up to 30 GeV

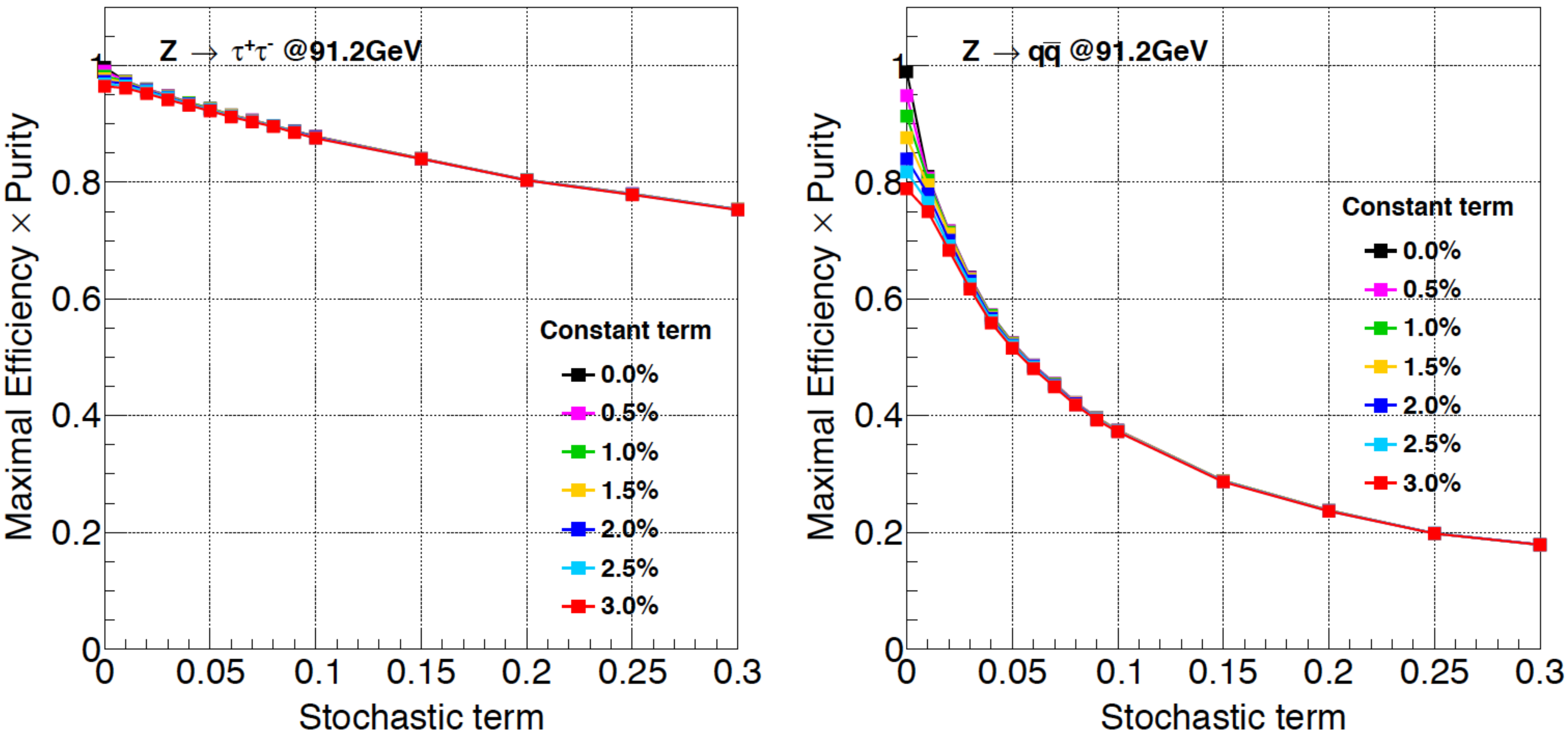
π⁰: truth level analysis

Yuexin





Impact of EM resolution on π^0 finding



Dependency on π^0 energy

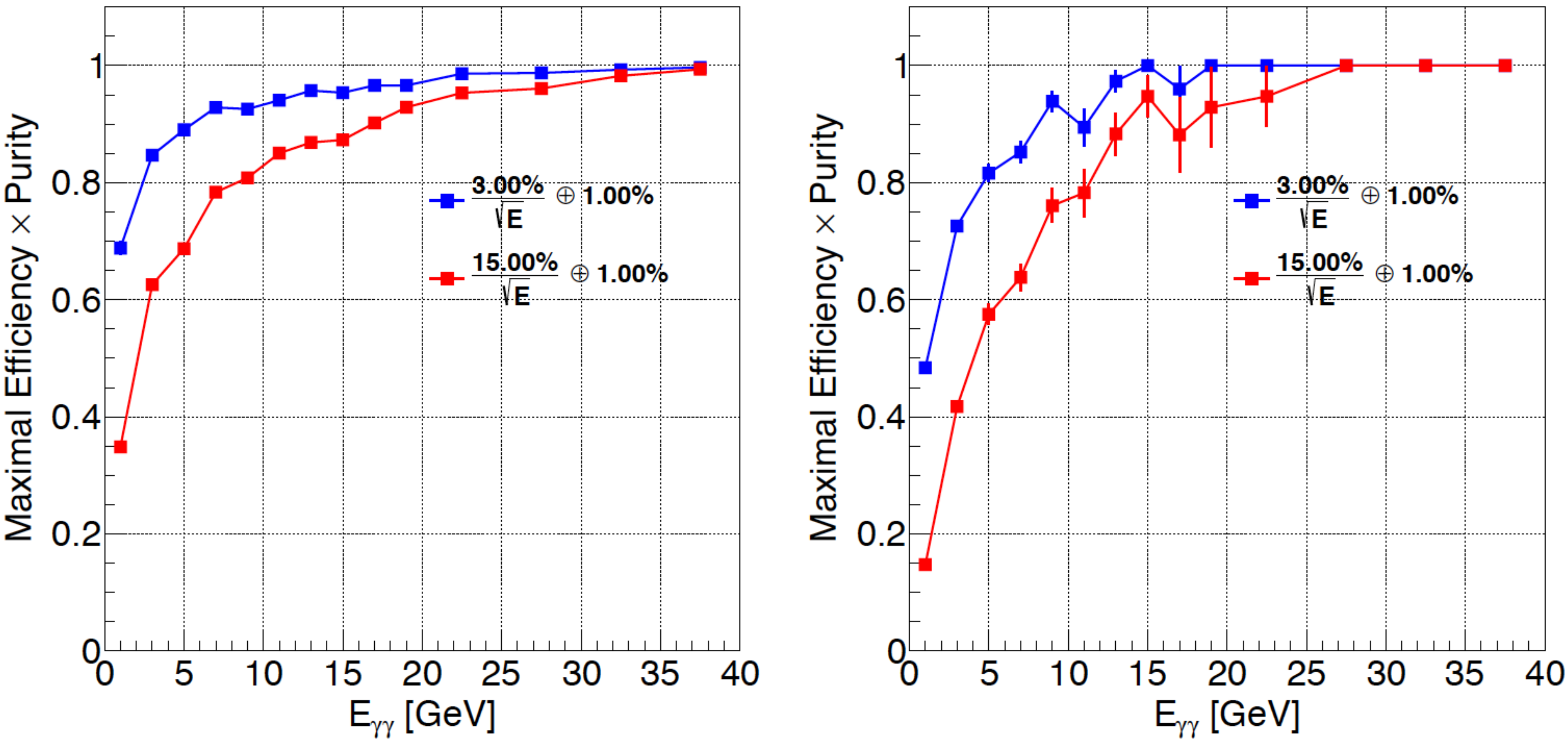


Figure 13: Energy differential maximal $\epsilon \times p$ for $Z \to \tau^+\tau^-$ (left) and $Z \to q\bar{q}$ (right).

...Surely the low energy pi-0 reconstruction benefit more from a better EM resolution...

π⁰: energy spectrum decomposition

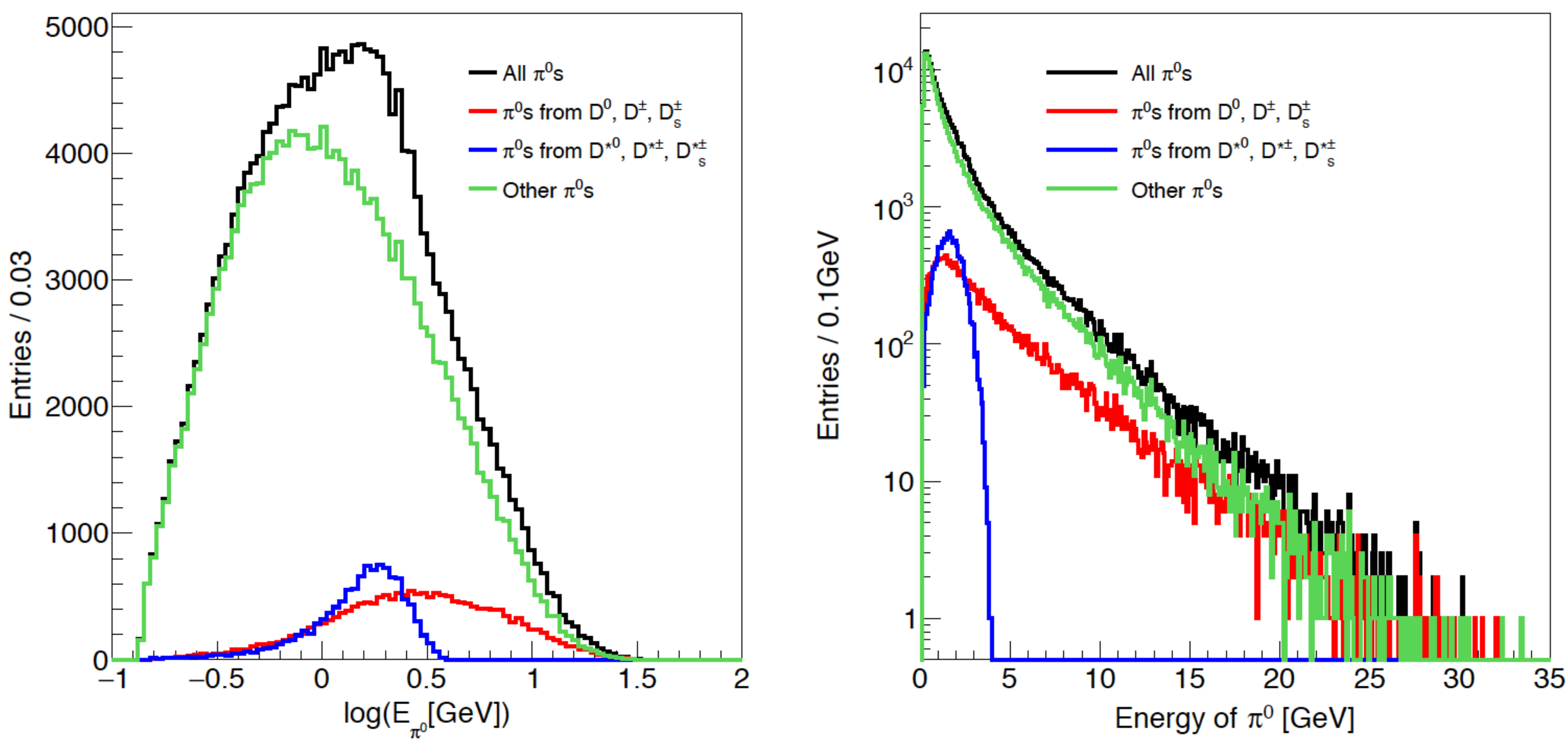


Figure 13: Energy spectrum of π^0 from different origins in $Z \to c\bar{c}$.

π^0 reco

- ECAL resolution is critical: improving the ECAL resolution from 15%/sqrt(E) to 5%/sqrt(E) (with 1% constant term) significantly improve the inclusive π^0 reconstruction efficiency
  - From 85% to 92% at $Z \to$tautau
  - From 30% to 50% at $Z \to$qq

- Low energy π^0 is more sensitive to ECAL energy resolution.

- Further quantification needs physics benchmarks
  - Narrow States $\to$ n*π^0 + X, X are a set of charged Particle. For example Bs $\to 2\pi^0$

π0 Reconstruction Rate

by Yuqiao Shen

- The probability of successfully reconstructing π0 in the barrel region and in the endcap region
- In the barrel region, 50% can be reconstructed when π0 energy lower than 22 GeV.
- In the endcap region, 50% can be reconstructed when π0 energy lower than 34 GeV.
- The lower energy degrading caused by photon identification and reconstruction.
- Most within the region with above 50% reconstruction rate