Status of Performance

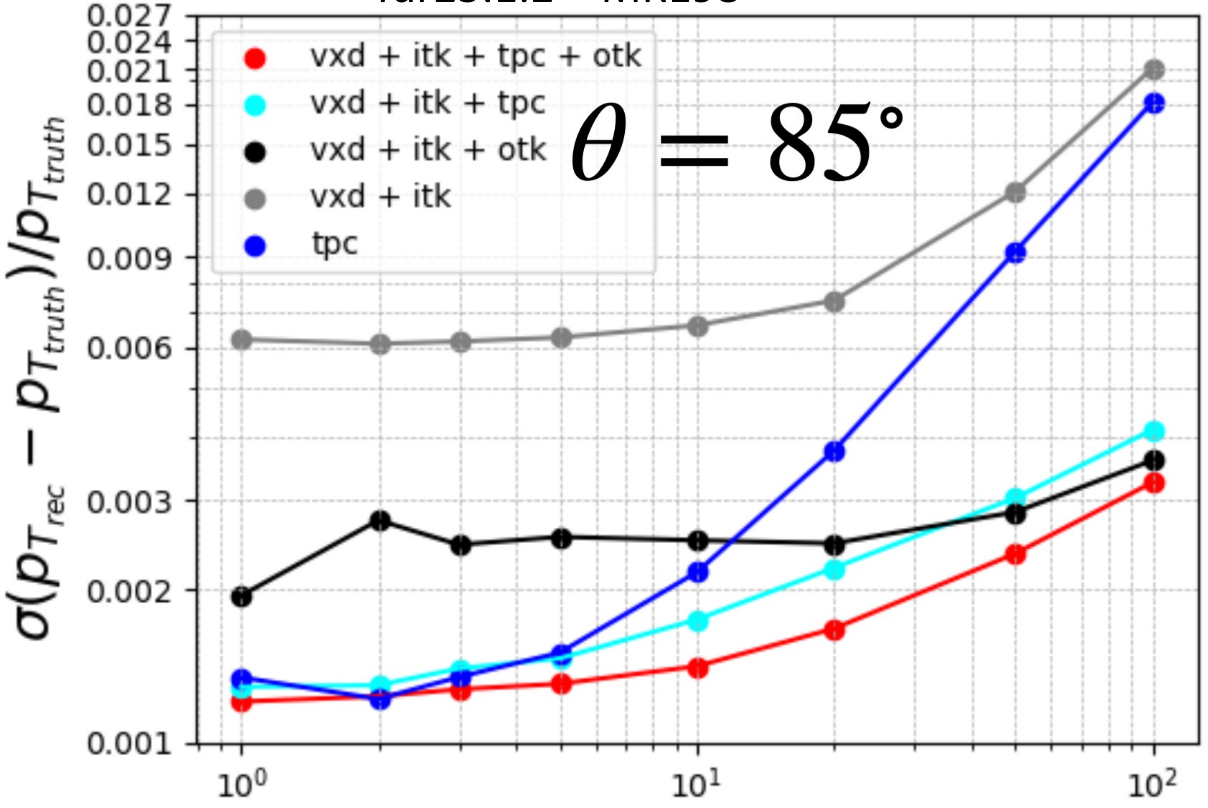
- CEPCSW TDR25.1.2 release:
  - Endcap calorimeter now available for studies
  - TPC dn/dx reconstruction algorithm improved
- Some updates since 25.1.0
  - Tracking
  - PID
    - Charged Hadron PID
    - Lepton ID
  - Photon performance
  - Jet Performance
  - Vertexing

Update 2025.02.11

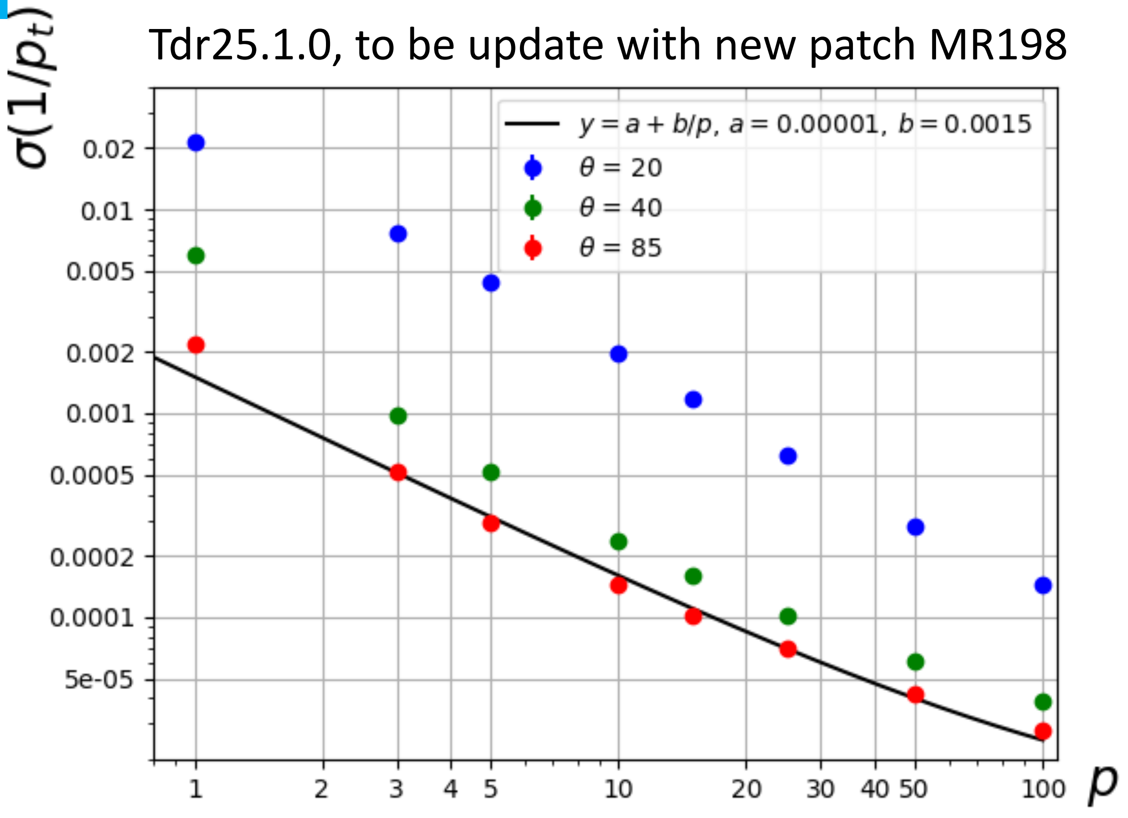
Tracking momentum resolution

Chenguan Zhang, Hao Zhu

Tdr25.1.2 + MR198



Tdr25.1.0, to be update with new patch MR198

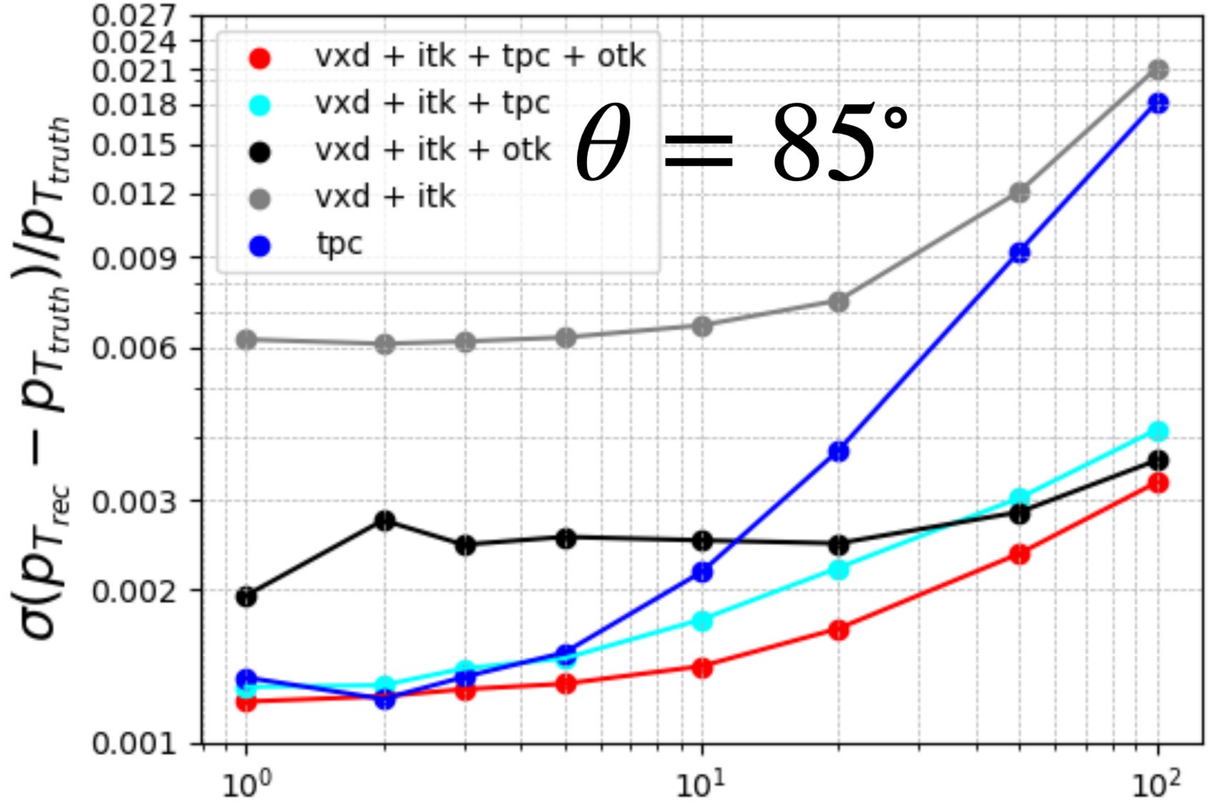


Curve of $10^{-5} \oplus 1.5 \times 10^{-3}/(p \cdot \sin\theta)$ shown for illustration

- **low pT issue resolved**
  - **Due to different material maps btw Geant4 simulation and reconstruction, now simplified and consistent btw sim and rec.**

Update 2025.02.11

Full simulation vs Delphes



Full simulation in CEPCSW

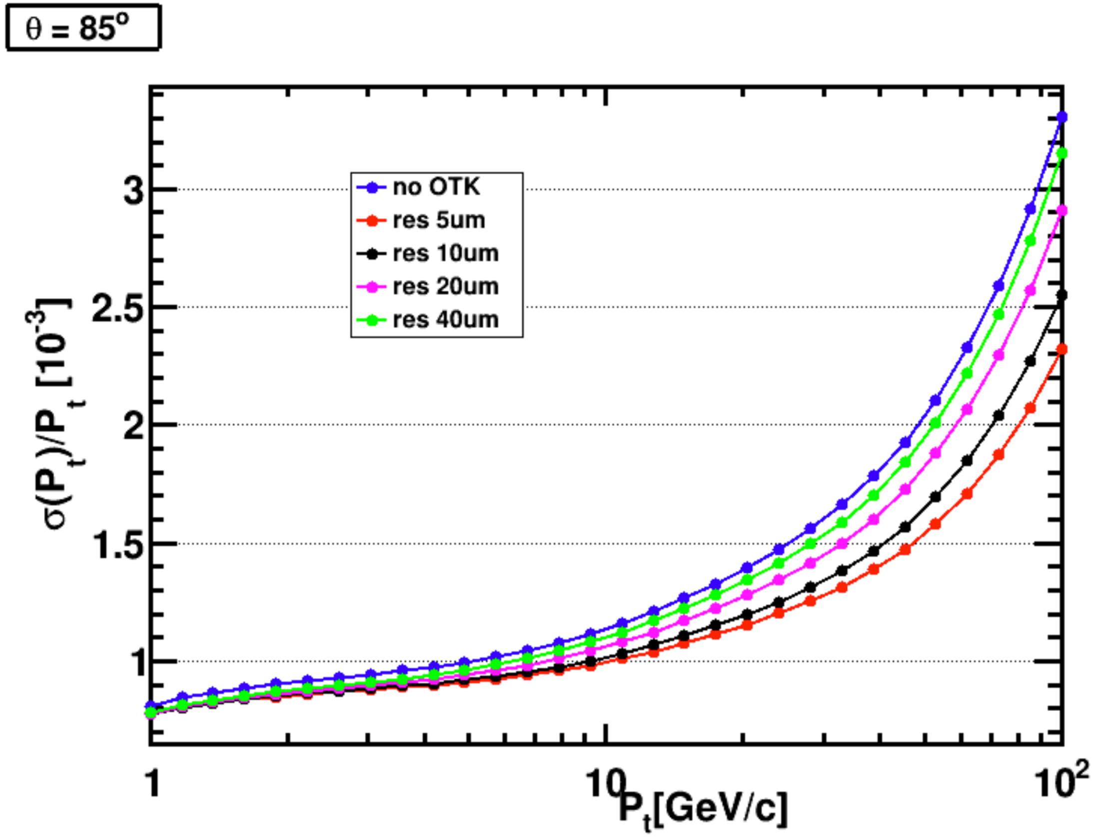


Figure 5.4: Options of OTK: different spatial resolution

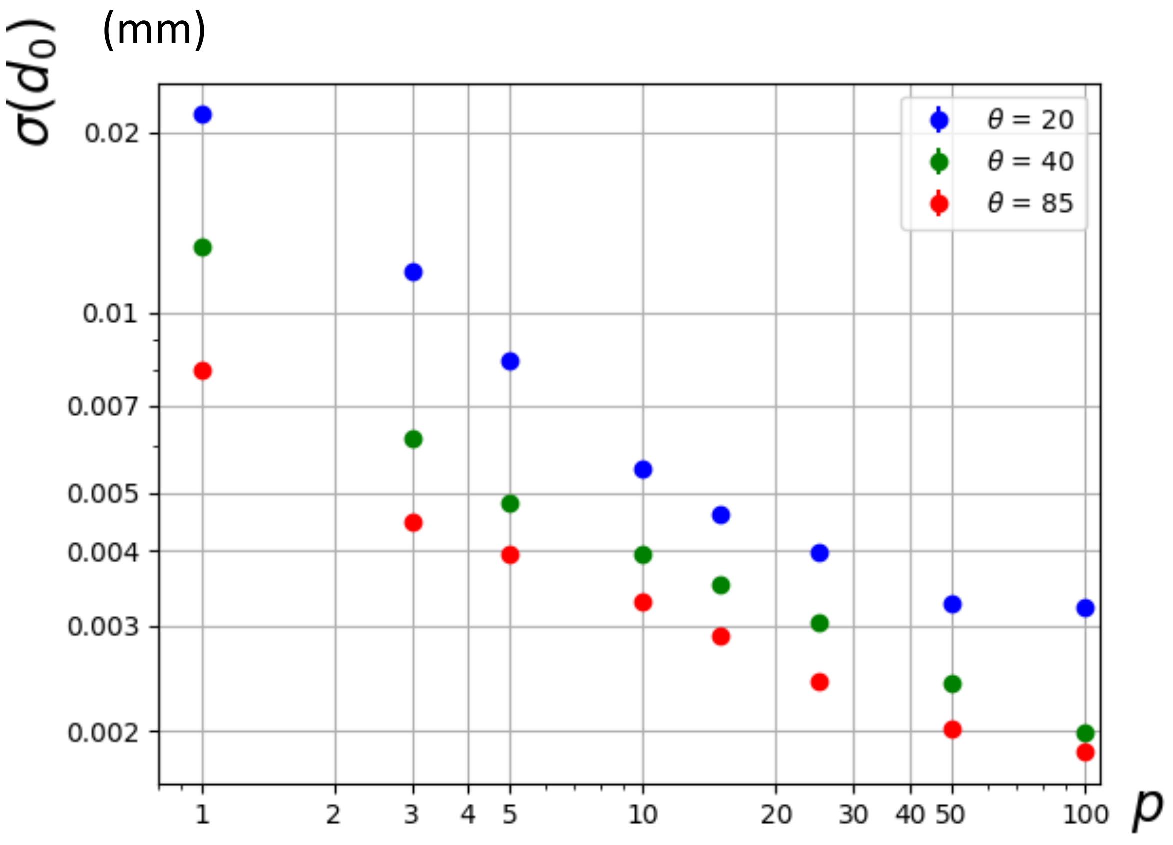
Delphes

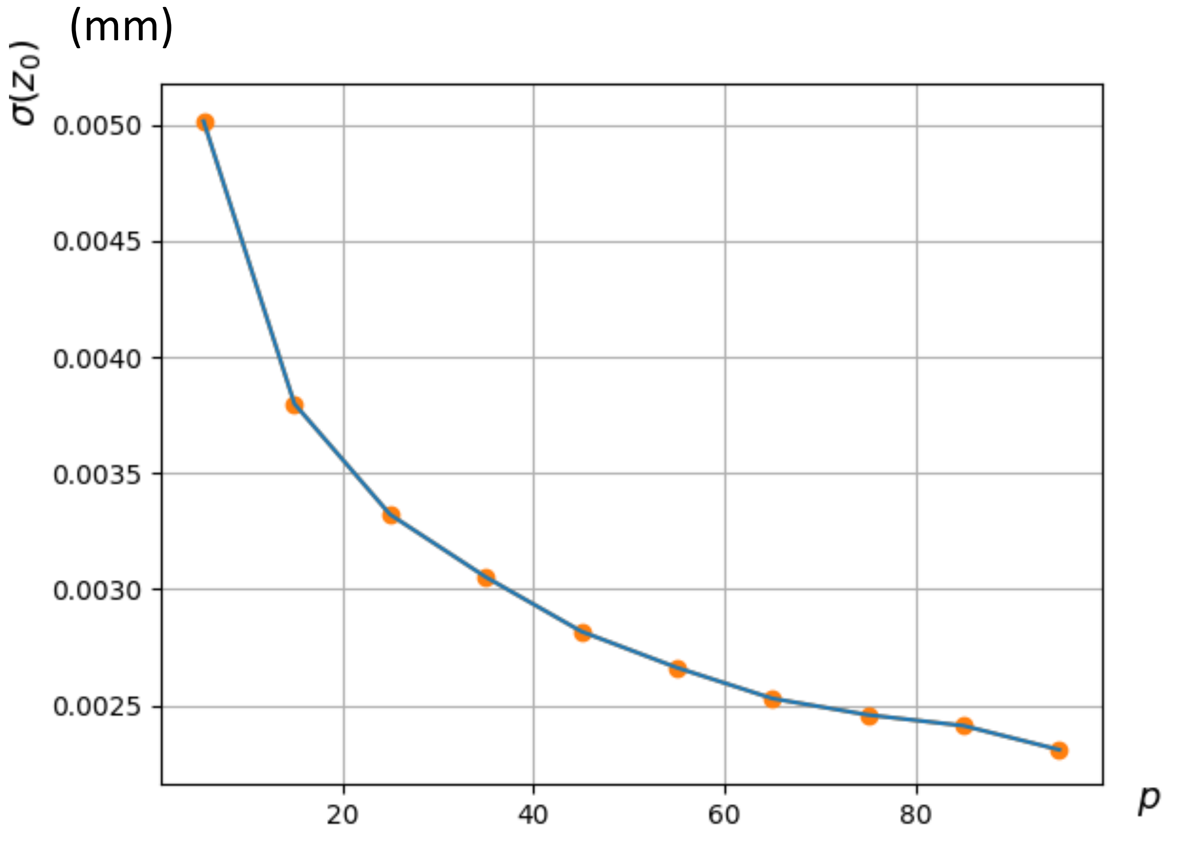
Slightly worse than Delphes, expected due to more realistic material

Impact parameter resolution

Chenguan Zhang, Hao Zhu

Tdr25.1.0

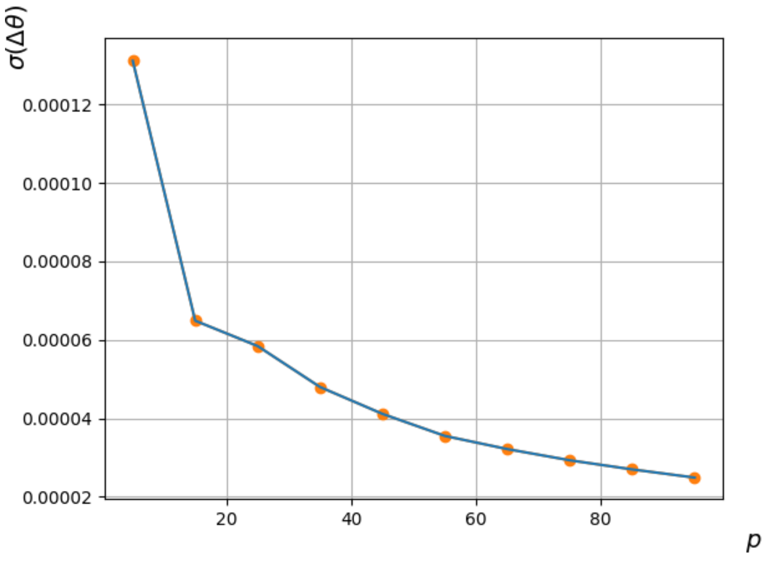


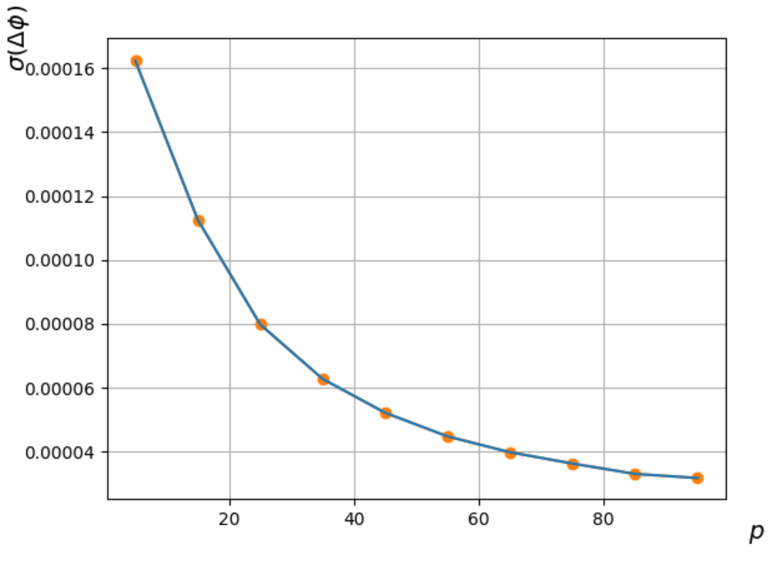


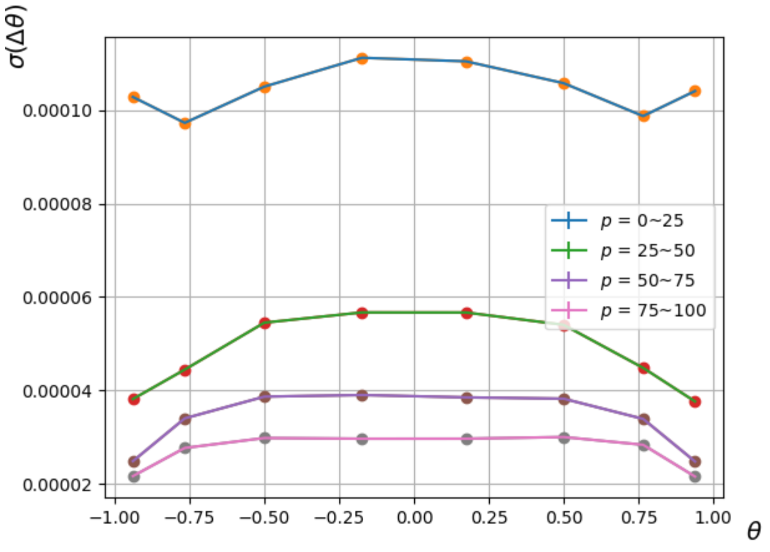
Tracking angular resolution

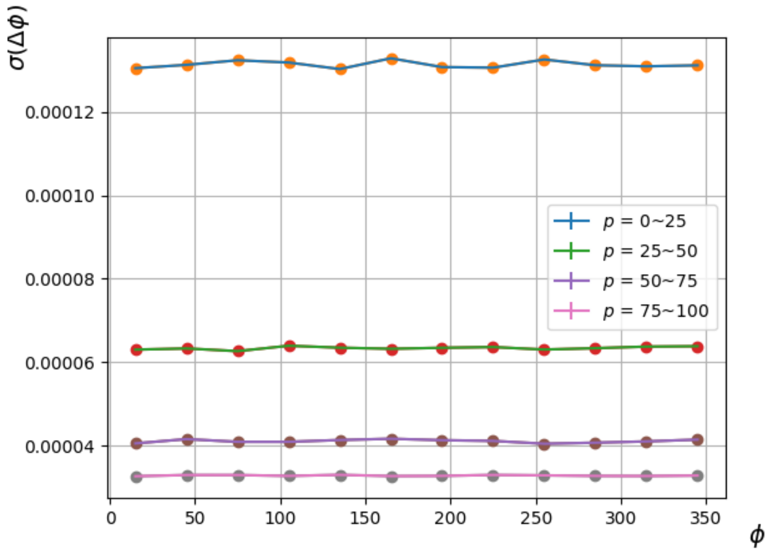
Tdr25.1.0

Chenguan Zhang, Hao Zhu







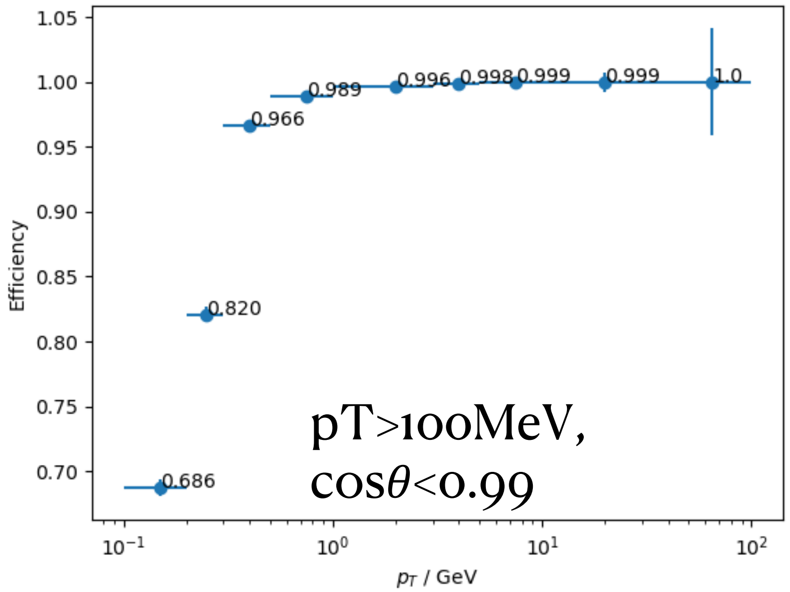


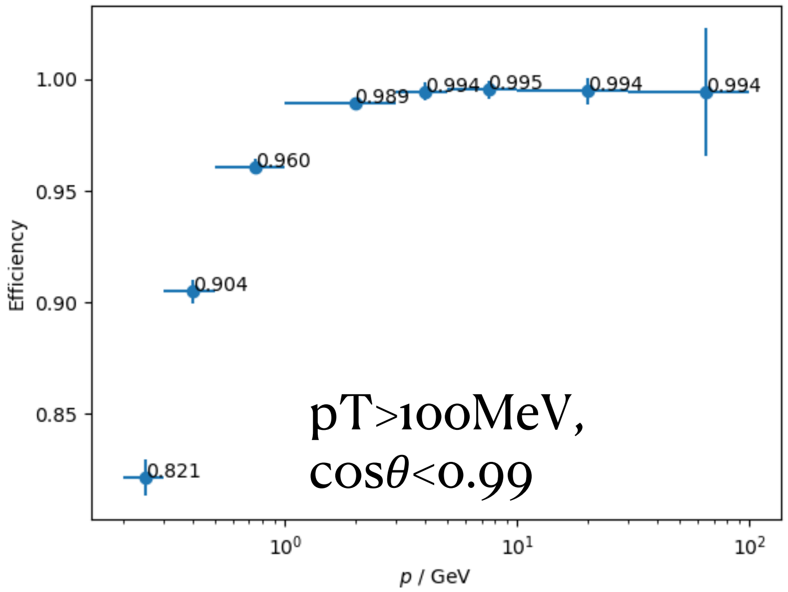
Tdr25.1.0

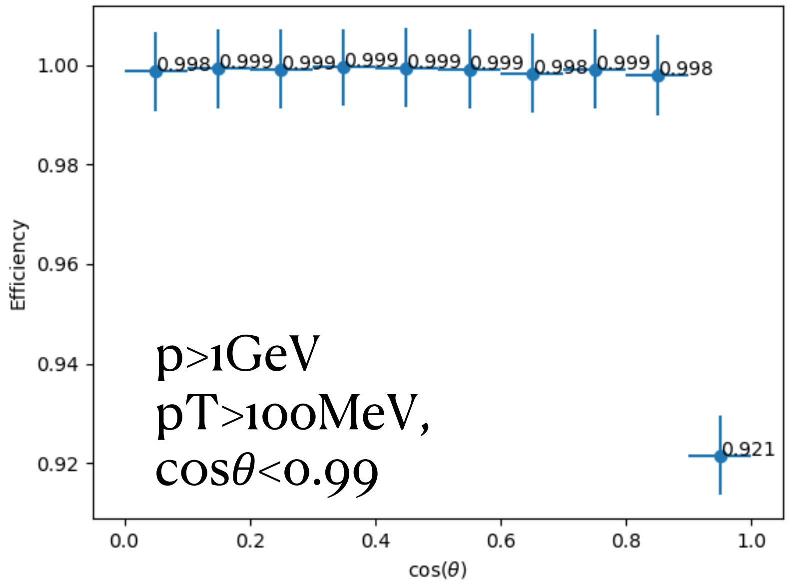
Tracking efficiencies

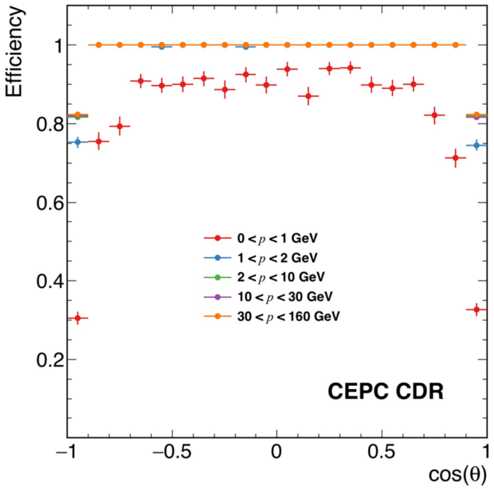
Chenguan Zhang

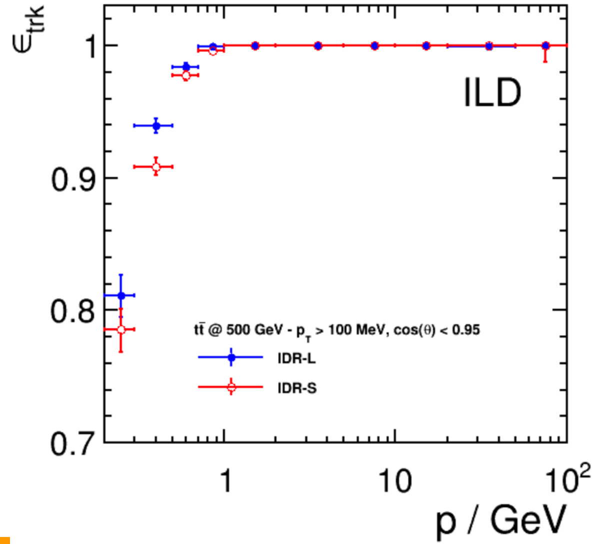
- **Sample: E124_nnHbb, no background mixing**

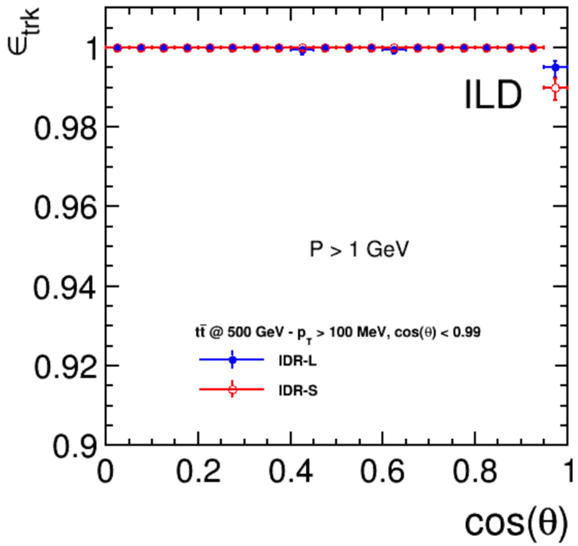










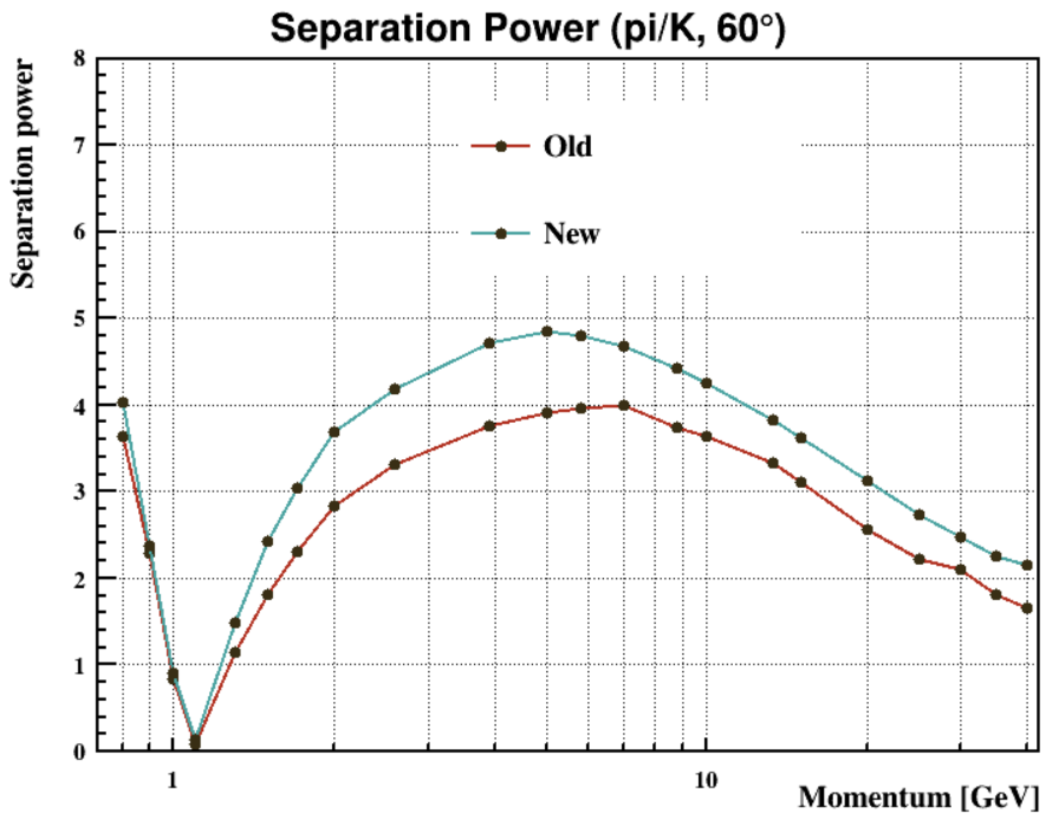


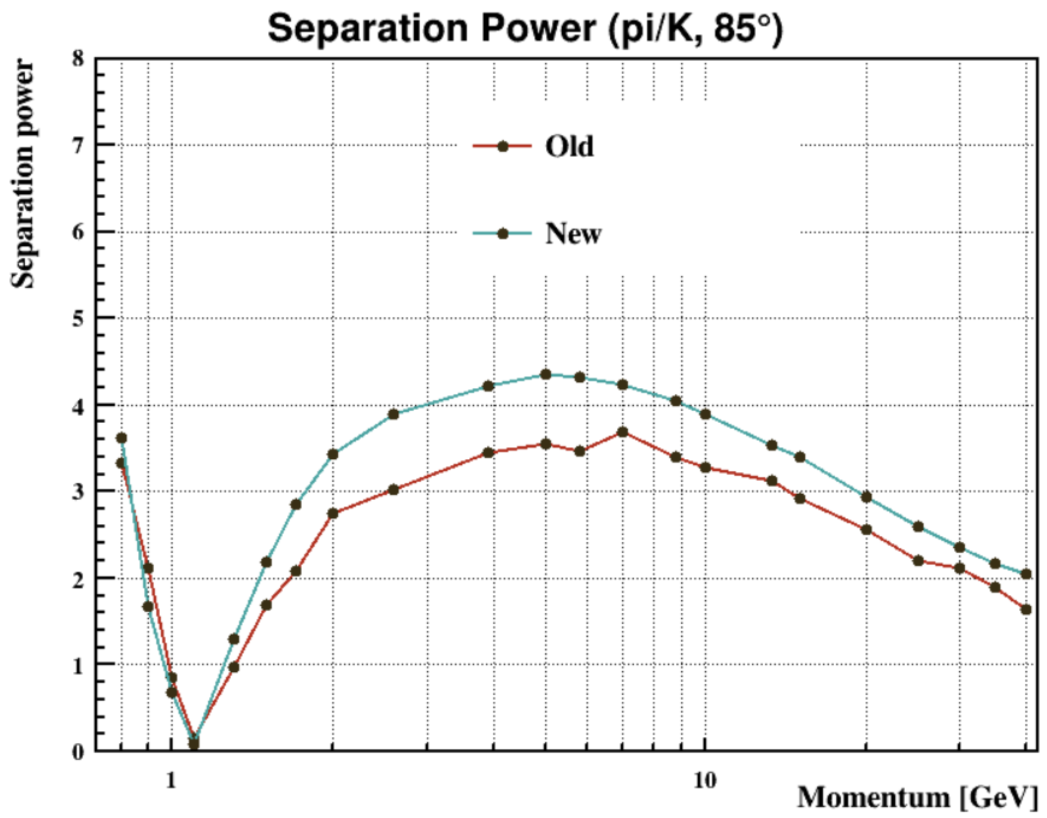
Similar performance as in CDR

PID

TPC PID update

Jingxian Zhang, Guang Zhao, Linhui Wu, et. al.



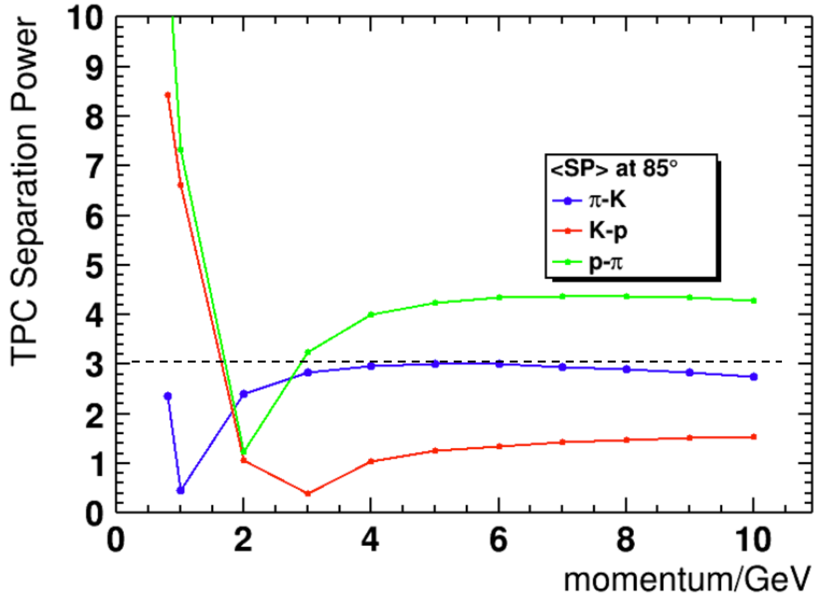


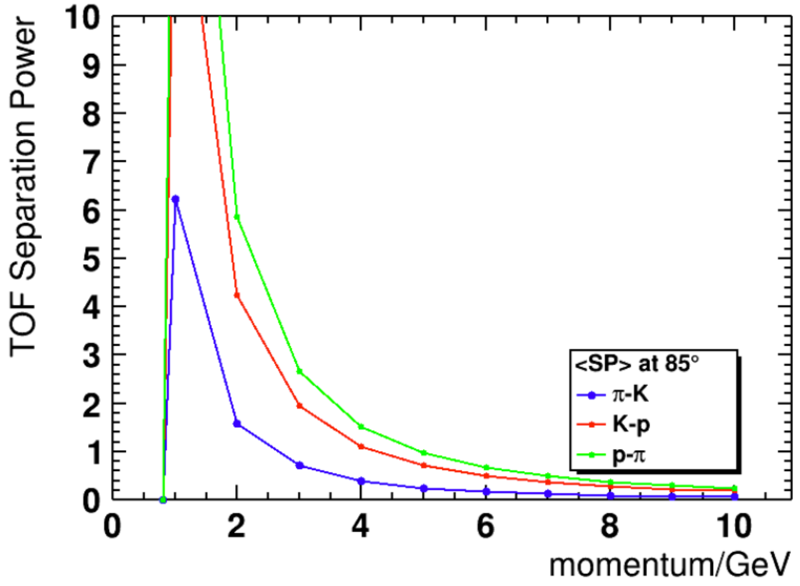
- 在1 ~ 10 GeV，新算法的鉴别区分度显著提升
- TPC组下一步工作：
  - 在更新的CEPCSW框架下实现击中级别全模拟
  - 结合TPC本底研究的结果，考察本底对粒子鉴别的影响

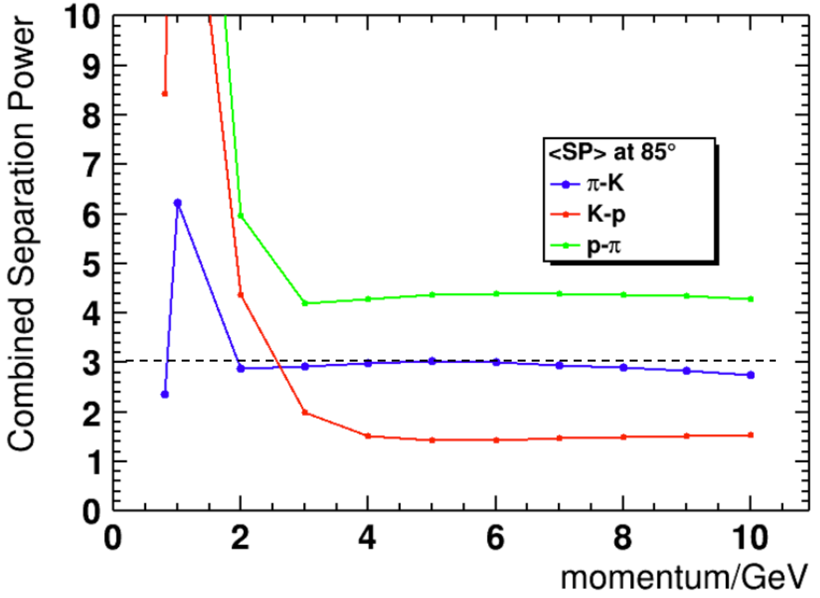
$$O_{AB}=2|A-B|/(\sigma_A+\sigma_B)$$

TPC PID in 25.1.0

Xiaotian Ma, Chenguang Zhang, et. al.



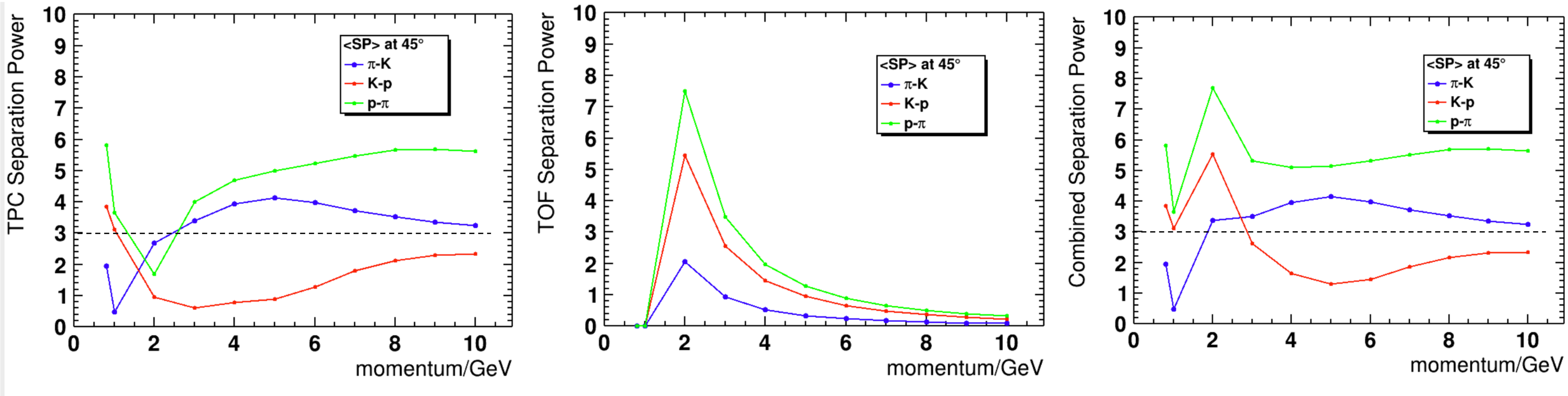




Separation power: $O_{AB} = \frac{|A - B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$

TPC PID in 25.1.0

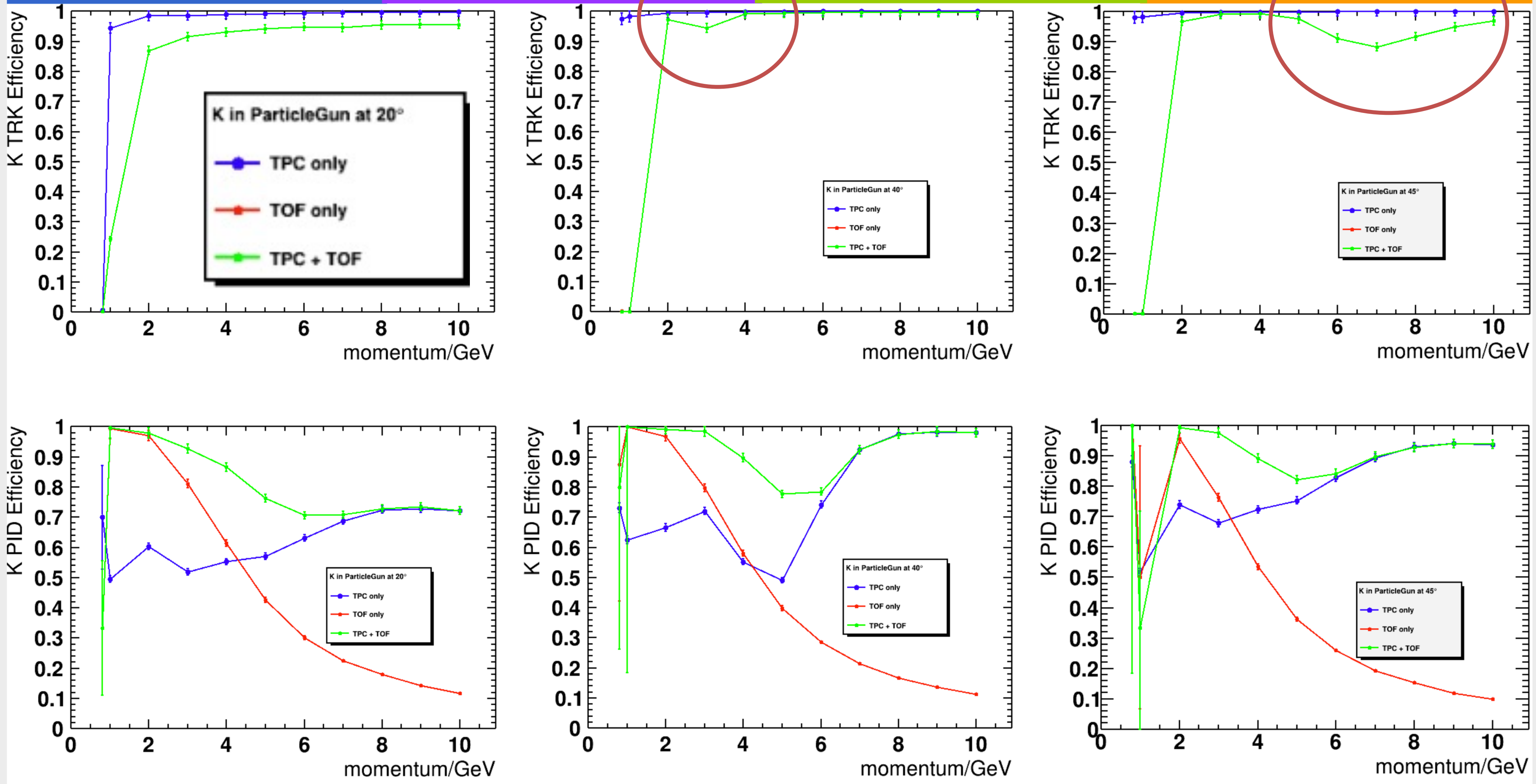
Xiaotian Ma, Chenguang Zhang, et. al.



- **PID SP @45° worse than that @85° for p<2 GeV**
  - could be due to imperfect parameterization of dN/dx implemented in 25.1.0
  - A patch was implemented yesterday -> 25.1.2
- **Study ongoing with the new patch**

TPC+TOF PID in 25.1.0

Xiaotian Ma, Chenguang Zhang, et. al.



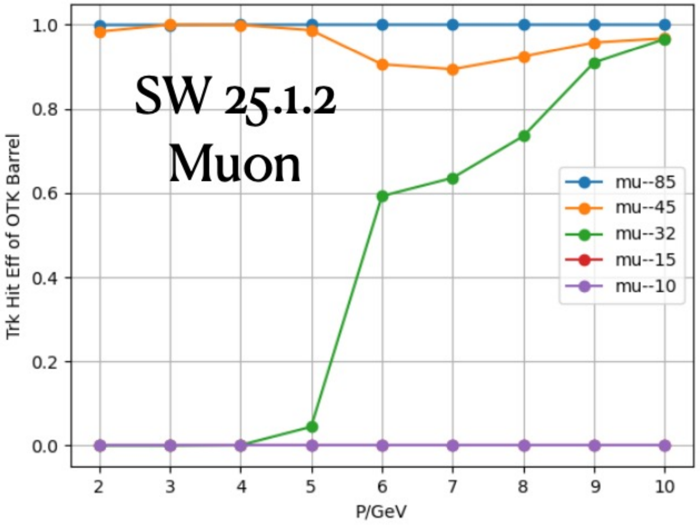
- **Investigation:**
  - **K track efficiency drop in the region of 6-8 GeV for 45°**
  - **3 GeV for 40°**
  - **ToF fired, but ToF hit not used in the track fitting**
  - **The issue does not appear in 60-89°**

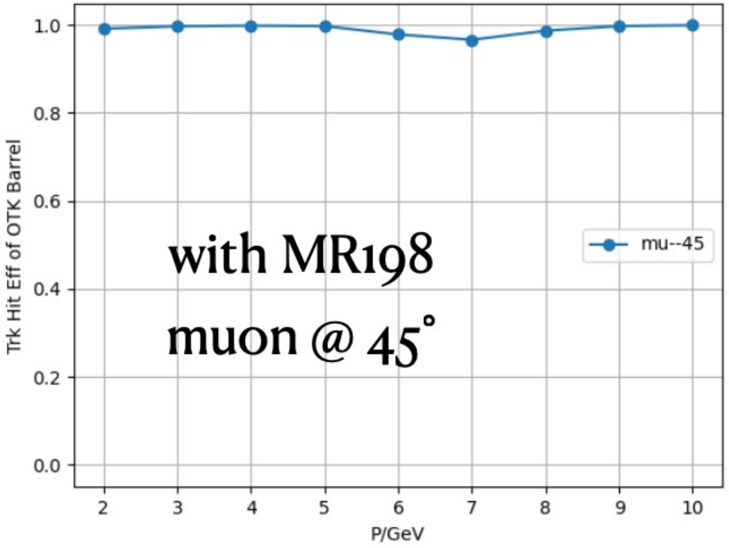
20 degree (left) VS 40 degree (middle) VS 45 degree (right)
ParticleGun K- TRK/PID efficiency

2

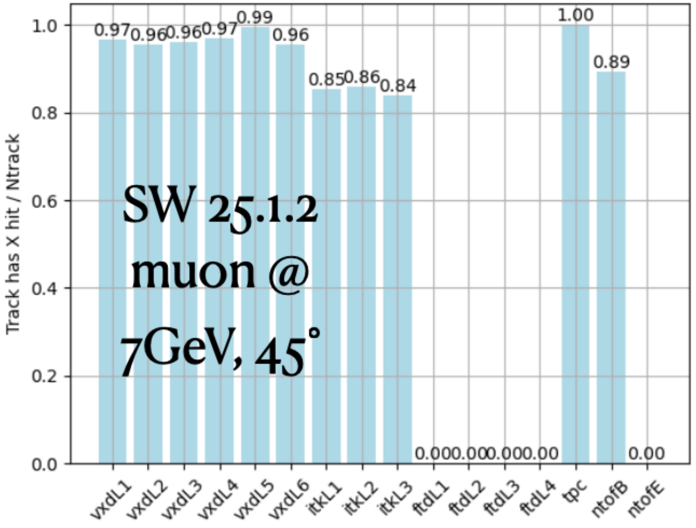
TPC+TOF PID in 25.1.2+MR198

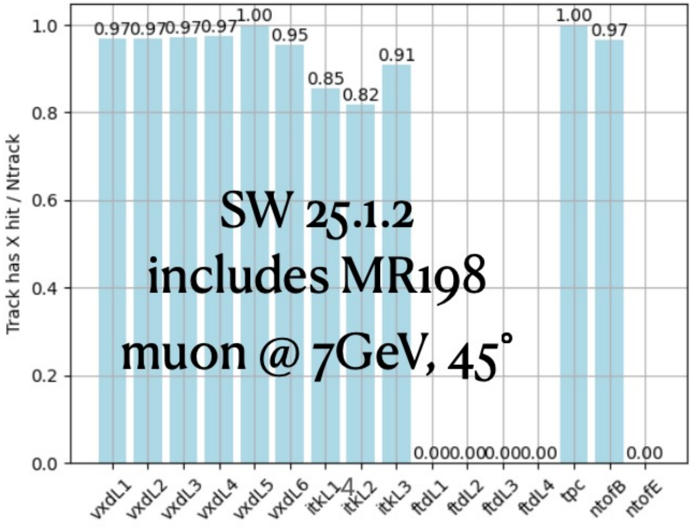
Xiaotian Ma, Chenguang Zhang, et. al.





- **Bug fixed in 25.1.2+MR198 by Chengdong Fu**
  - **Tracking in the gap region between nearby sensors**



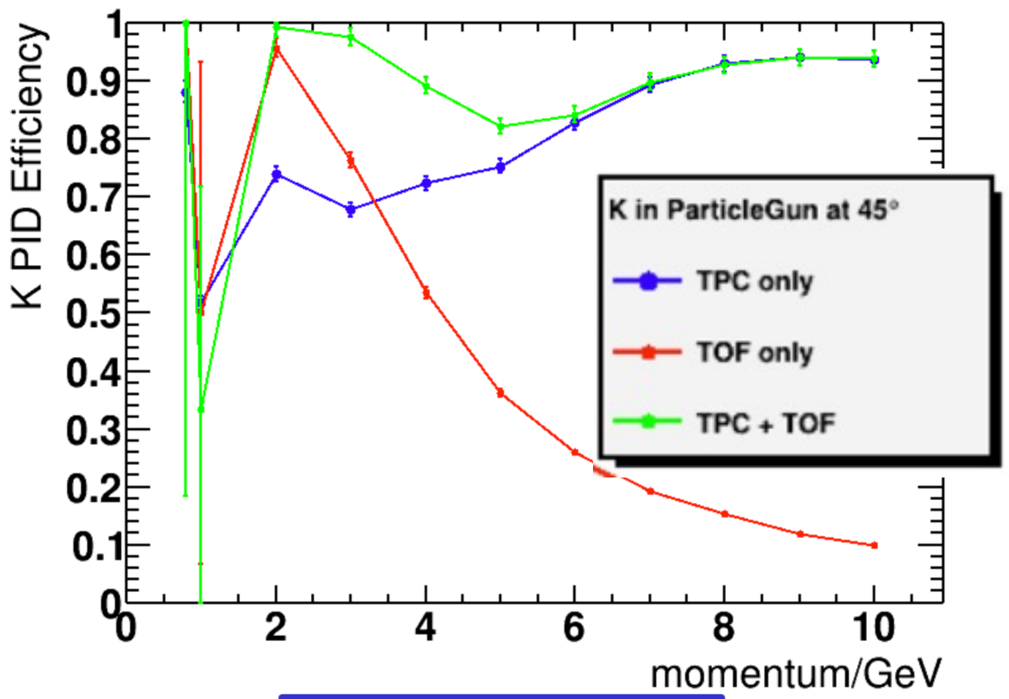


OTK hit usage eff for this particular case improved from 89% to 97%

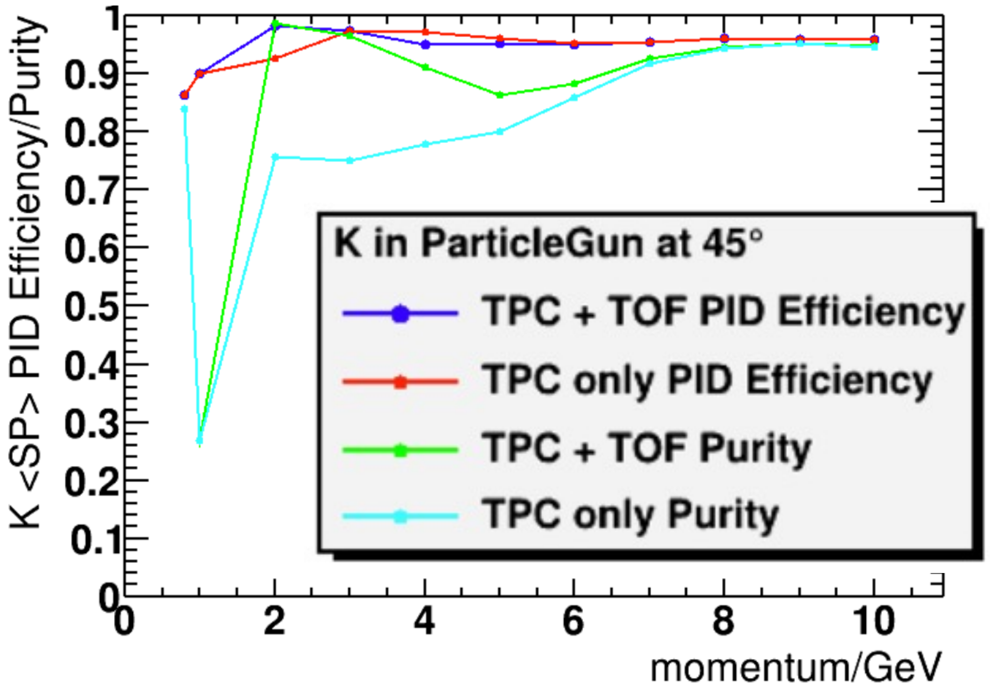
A side observation:
Low hit eff in ITK, due to old geometry
→ ITK geometry to be updated in CEPCSW in one week

Kaon PID efficiency/purity

Xiaotian Ma, Chenguang Zhang, et. al.



PID Efficiency



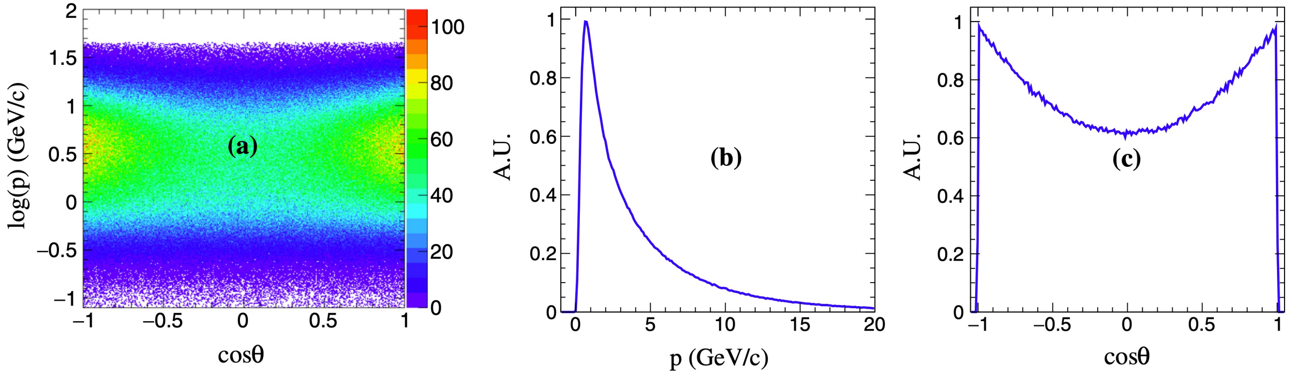
PID Efficiency / Purity after optimization

- @45°, 2-10GeV, combined kaon PID efficiency/purity could reach 95%/90% level
- **to-do: kaon eff/purity in Z events**

TOF for ITK

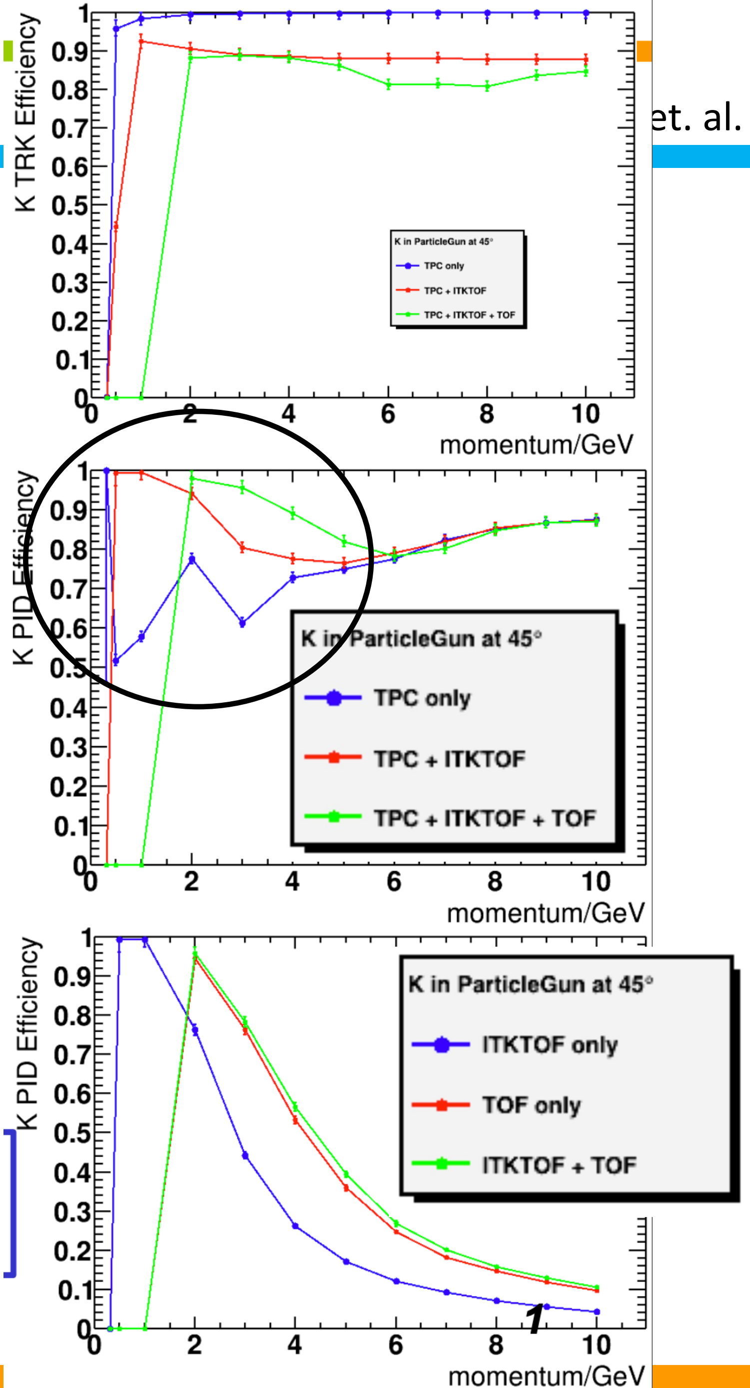
Kinematic distribution of kaons in Z→ qq MC events as a function of log(p) and cosϑ (a), p (b), and cosϑ (c)

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



- Plenty of tracks with p<2GeV won't reach OTK
- Add ToF in outer layer of ITK (ITKTOF)
  - No additional layer, and keeping space position resolution unchanged
  - Improve significantly Kaon PID efficiency in low momentum (<3GeV)
- To-do:
  - More points below 2 GeV
  - also performance for endcap region (polar angle < 32º)

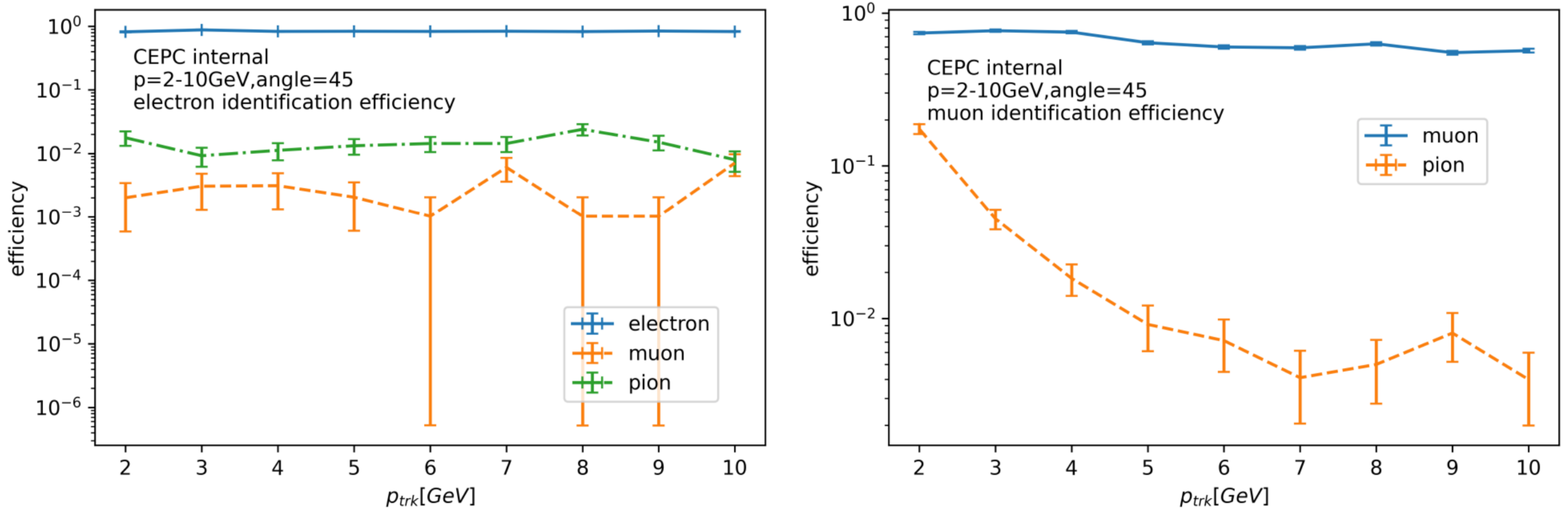
tdr24.12.0



et. al.

Lepton PID

Ligang Xia, Changhua Hao (NJU)



- Electron working point: E(ecal)/p(trk) > 0.9
- Muon working point: $\chi^2_{ECAL} < 3$ & $\chi^2_{HCAL} < 3$
  - $\chi^2_{\mathrm{HCAL}}(2\mathrm{GeV}) = (\frac{\mathrm{E_{HCAL}} - 0.348}{0.066})^2, \chi^2_{\mathrm{ECAL}}(2\mathrm{GeV}) = (\frac{\mathrm{E_{ECAL}} - 0.05}{0.0083})^2$
- To-do: More info./tech. can be used for further improvement; Combination with TPC&TOF

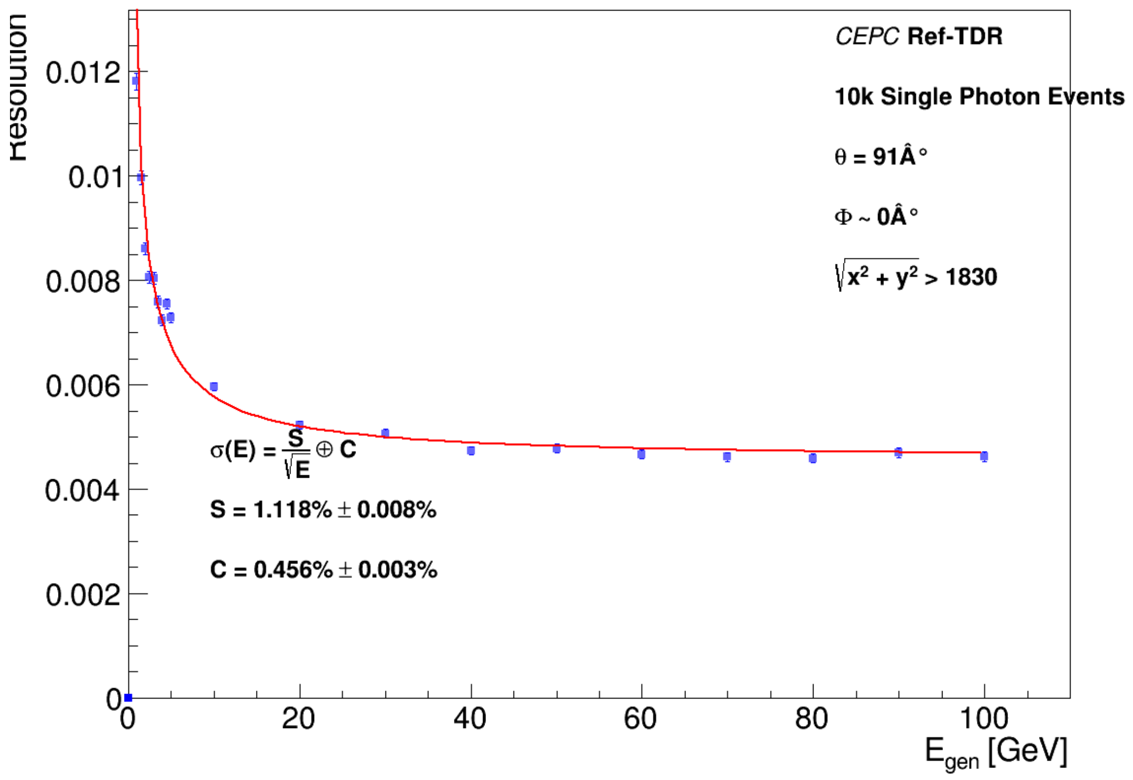
- **Muon reconstruction in muon chambers are still ongoing**

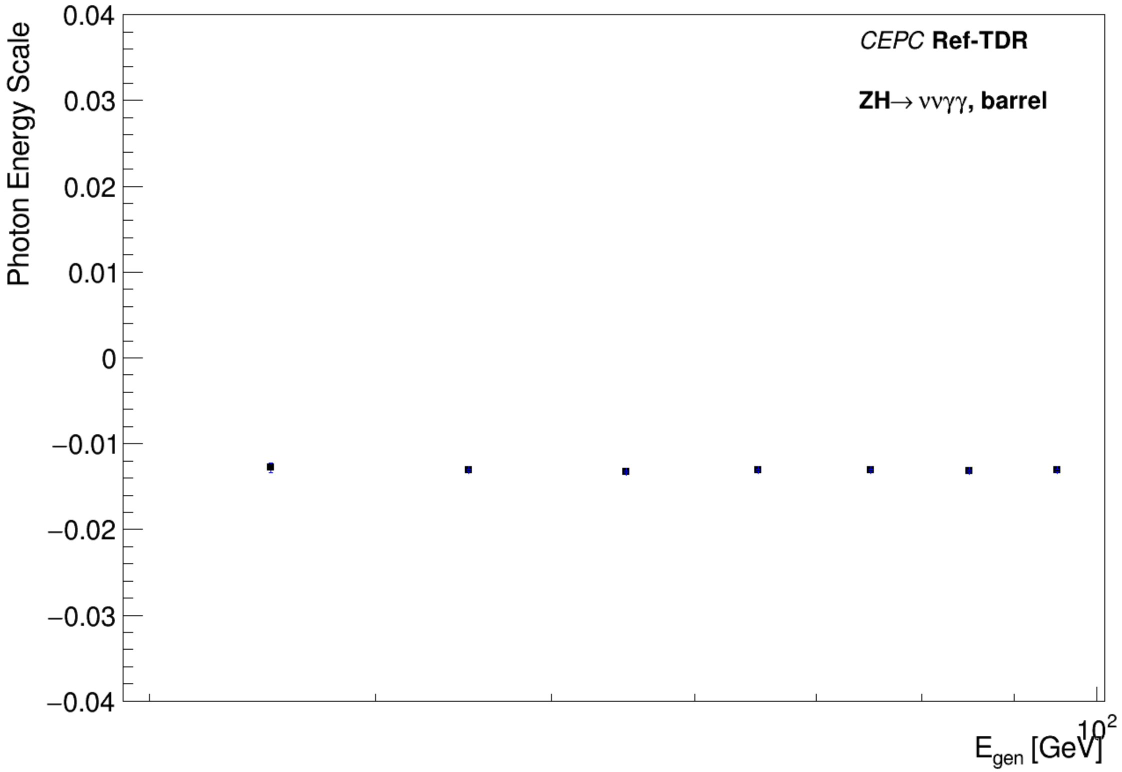
Photon

Single photon performance

tdr24.12.0

Reda, Kaili Zhang, et. al.



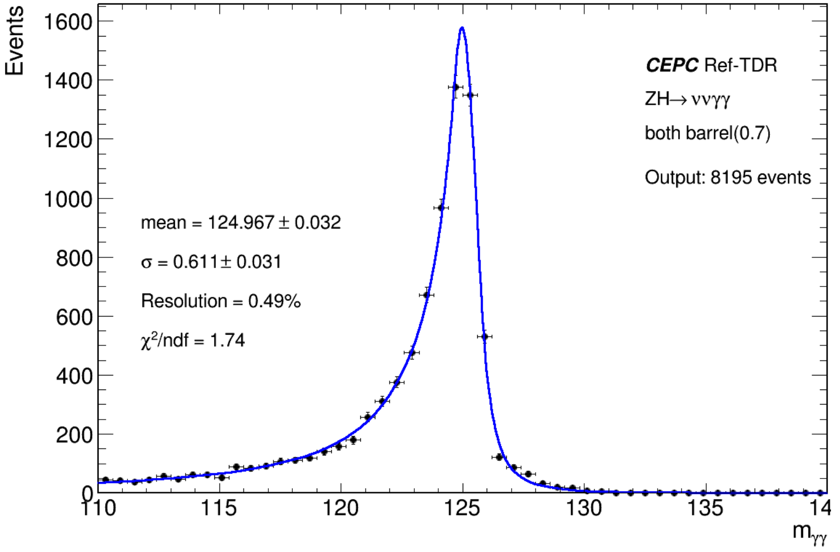


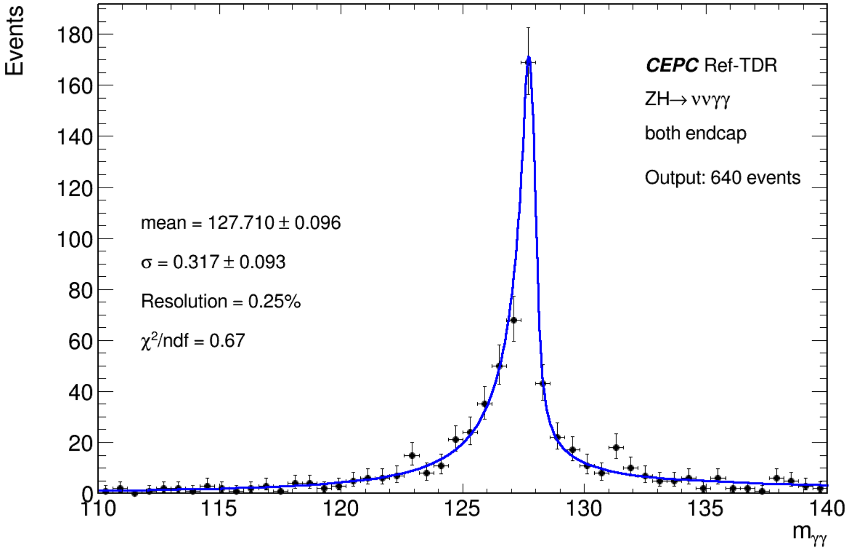
- Studies ongoing with new release
  - single photon E resolution scan over E vs. θ

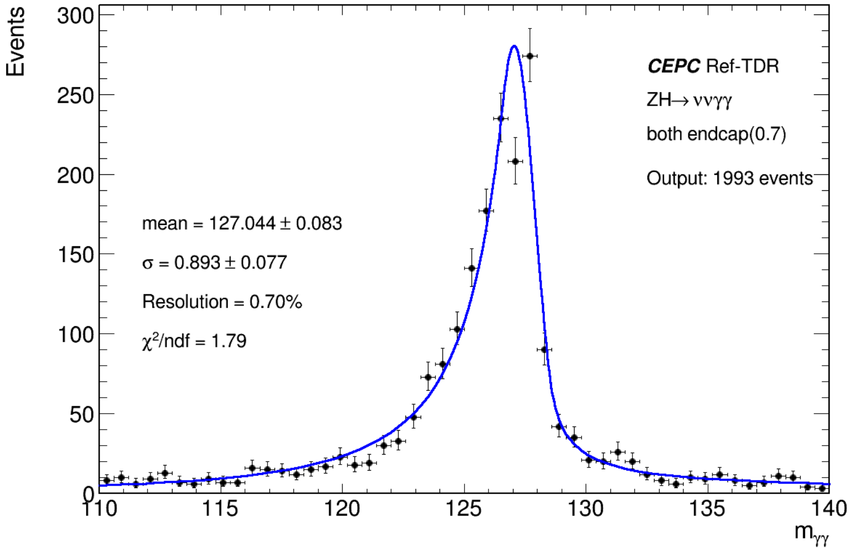
H->γγ performance

tdr25.1.0

Reda, Kaili Zhang, et. al.







Both photons in barrel with cos**θ** < 0.7
resolution ~ 0.49%

Both photons in endcap with cos**θ** > 0.85
resolution ~ 0.25%

Both photons in endcap+crack
(with cos**θ** > 0.7)
resolution ~ 0.7%

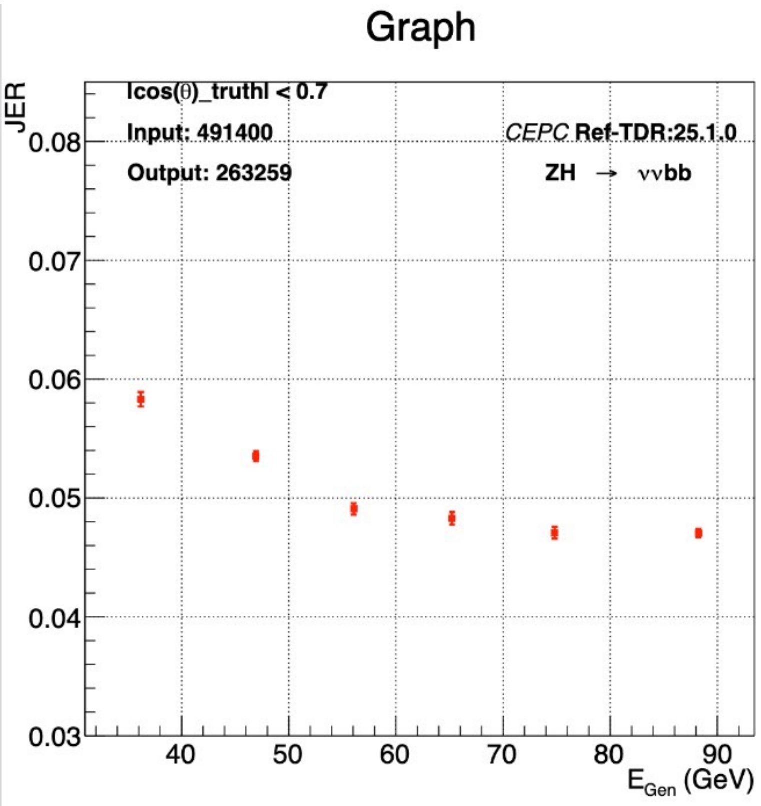
- Barrel resolution worse than endcap, due to dead materials missed in endcap
  - **Bug found and fixed by software group, will be integrated into next releases**

Jets

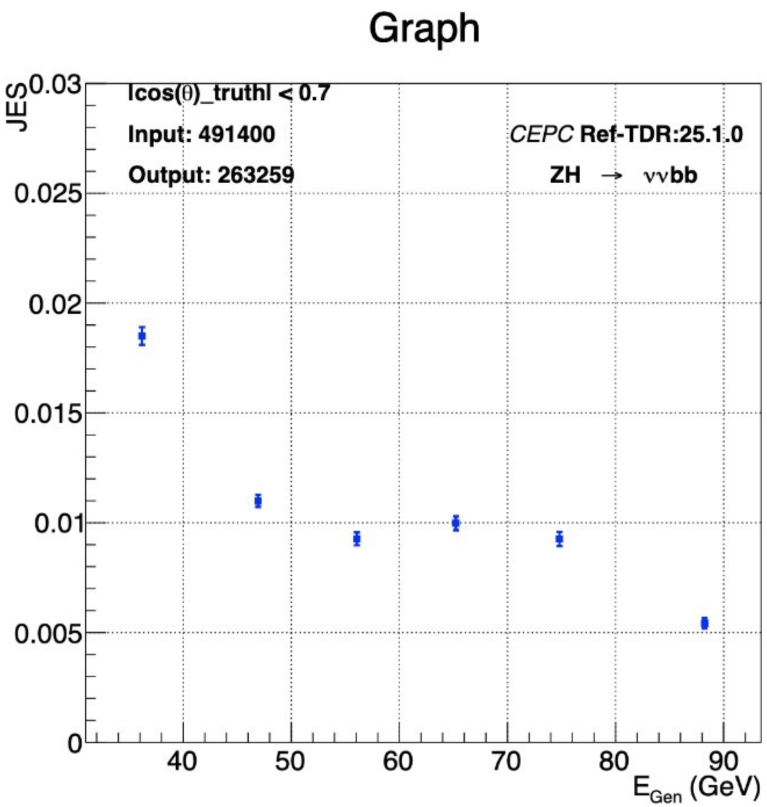
JER

Yingqi Hou, Kaili Zhang, et. al.

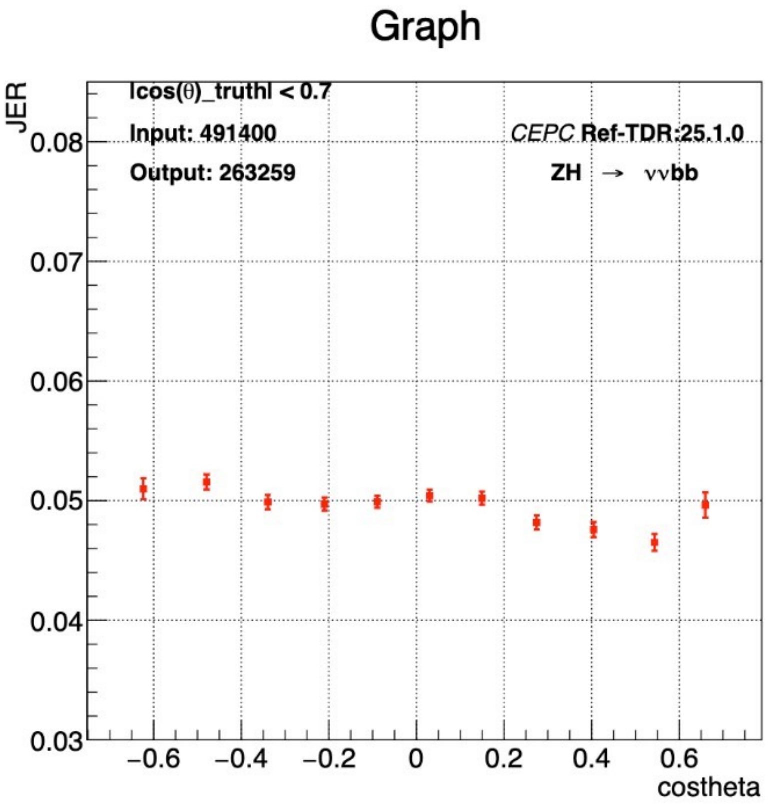
- ZH->ννbb sample



JER vs E



JES vs E

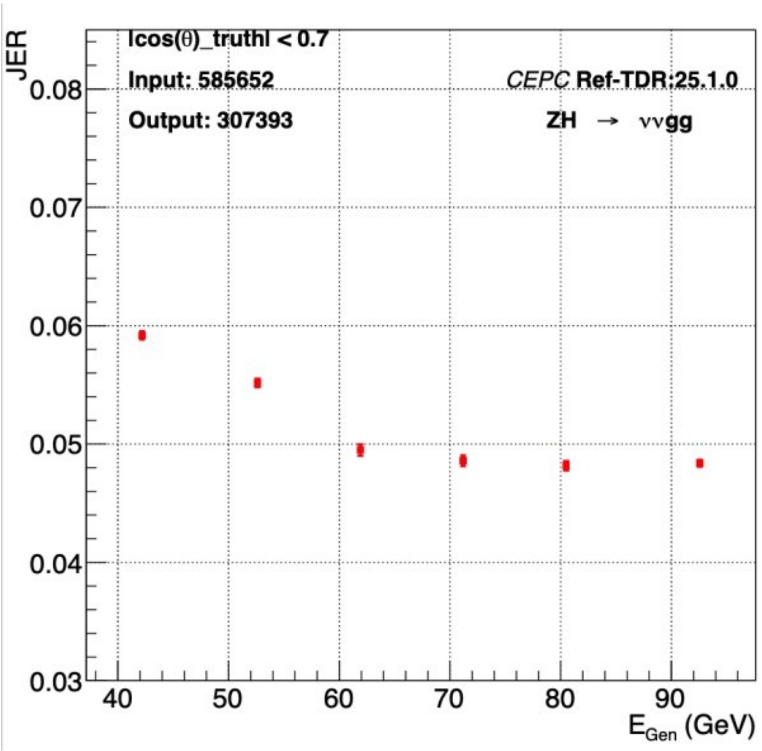


JER vs cos $\boldsymbol{\theta}$

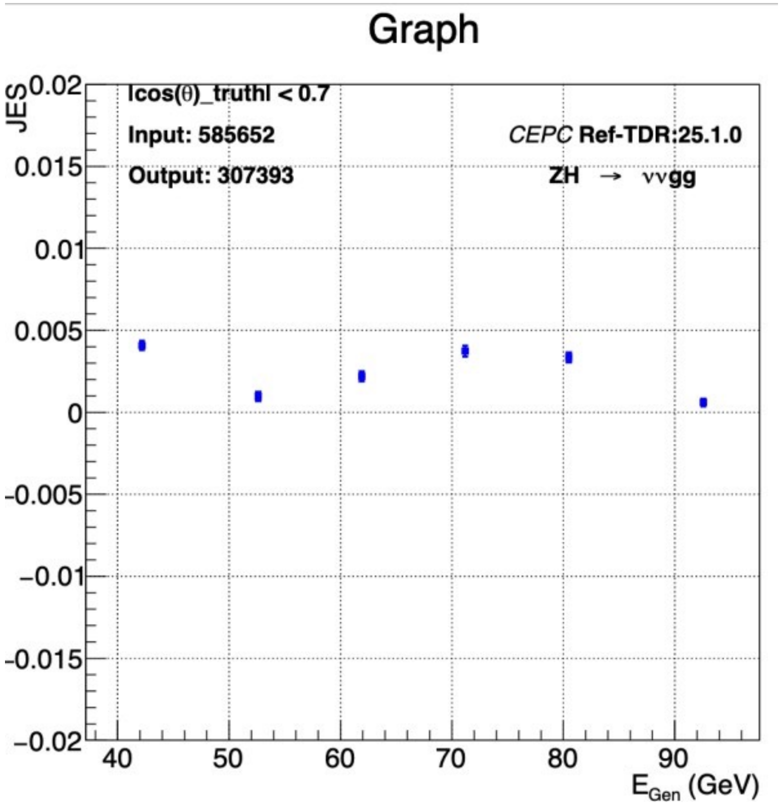
JER

Yingqi Hou, Kaili Zhang, et. al.

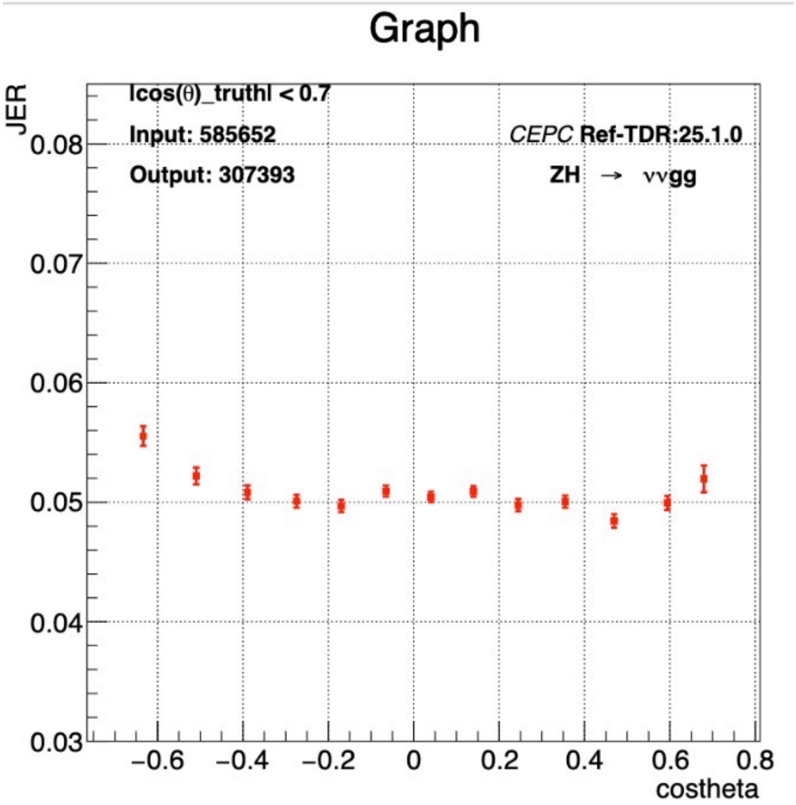
- ZH->*vv*gg sample



JER vs E



JES vs E



JER vs cos $\boldsymbol{\theta}$

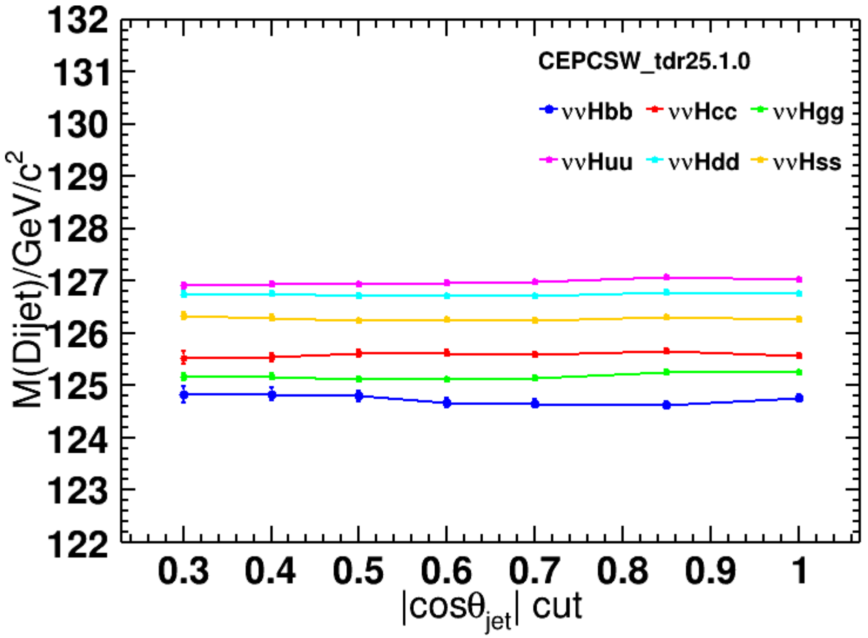
Physics level: without event cleaning
Detector level: with event cleaning |Pt_isr|,|Pt_v|<1GeV.
|cos_theta|<0.85 in the table.

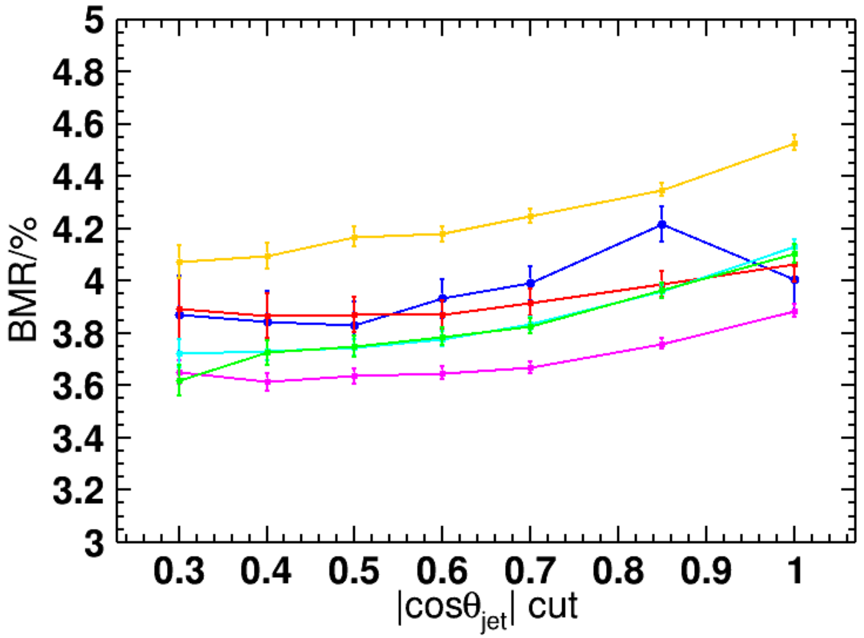
BMR

Tdr25.1.0

Xiaotian Ma, Kaili Zhang, et. al.

Case	process	$ZH \to \nu\nu gg$	$ZH \to \nu\nu bb$	$ZH \to \nu\nu cc$	$ZH \to \nu\nu uu$	$ZH \to \nu\nu dd$	$ZH \to \nu\nu ss$
Physical level	BMR/%	3.96 ± 0.03	4.22 ± 0.07	3.99 ± 0.05	3.76 ± 0.02	3.96 ± 0.02	4.35 ± 0.02
	Efficiency/%	73.1	73.7	73.7	73.8	73.8	73.7
Detector level	BMR/%	3.93 ± 0.03	3.70 ± 0.04	3.91 ± 0.03	3.76 ± 0.02	3.95 ± 0.02	4.34 ± 0.02
	Efficiency/%	68.9	29.4	50.9	73.4	73.4	73.3





To be understood

- Worse BMR in H->ss, could be due to more neutral hadrons in s-jets ?
- Jump in hbb case – ww fusion?

To-Do's for Jets

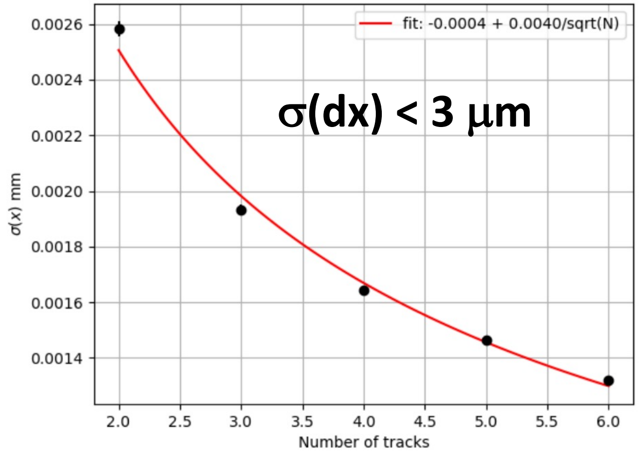
- **More studies in ee->Z->qq for different COMs**
  - Without the effects from jet finding or background
  - JER in terms of rms90/mean, to be compared with ILD、FCCee
- **Flavor tagging through ParticleNet – JOI**
- **Further studies in multiple-jets events**

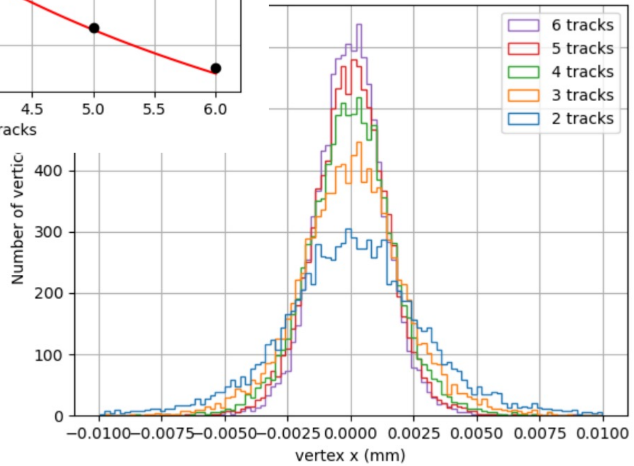
Vertex Performance

Chenguang, et al.

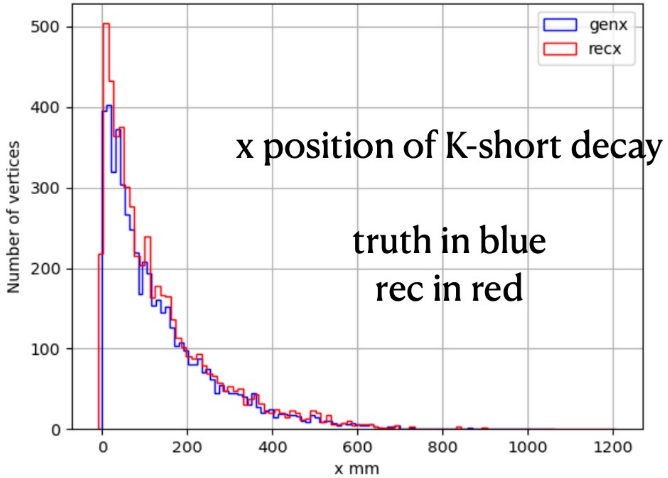
Package for vertex fit migrated, good performance seen in preliminary studies

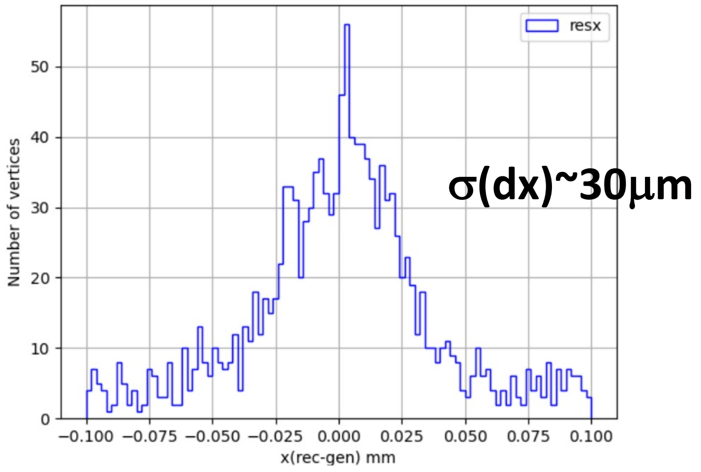
- Primary vertex resolution vs. number of tracks



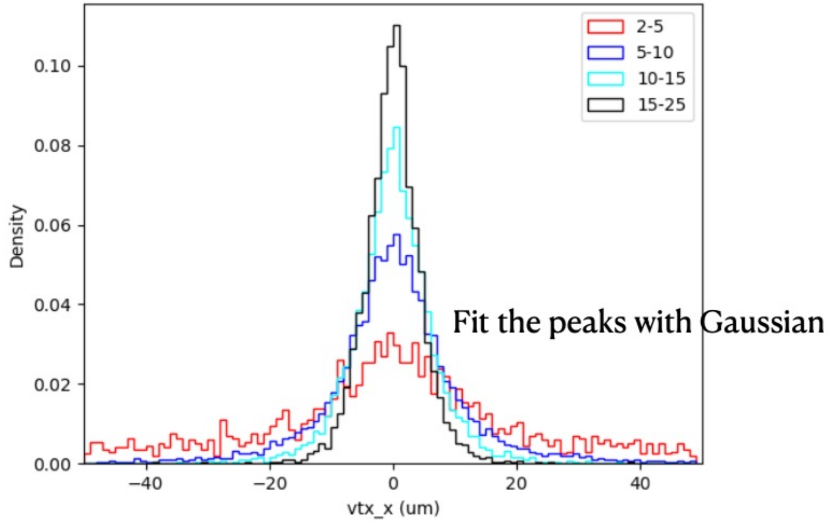


- For secondary vertex
  - 10k particle-gun K-short, pT=2GeV, $\theta = 85^\circ, \phi = 0^\circ$
    - 70% $K_s^0 \rightarrow \pi^+\pi^-$ events
    - Displaced vertices were reconstructed

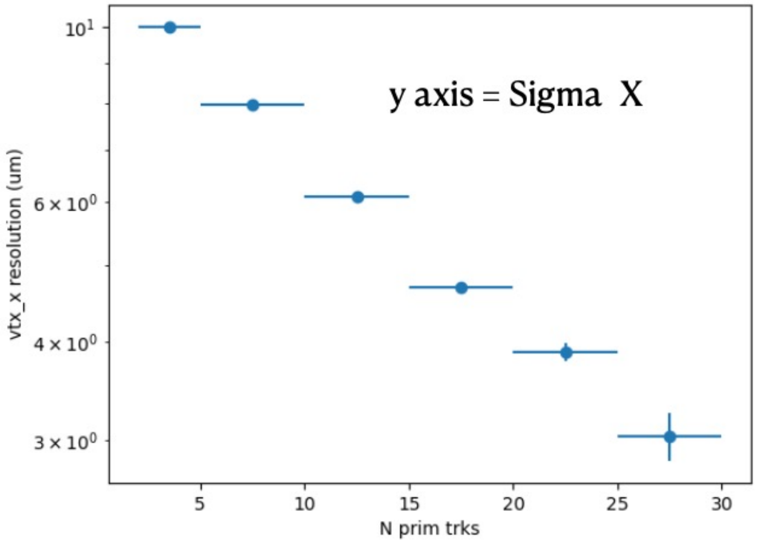


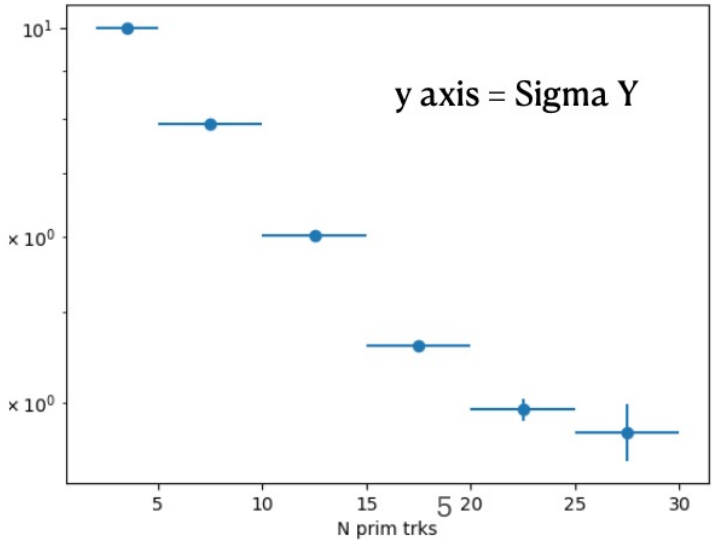


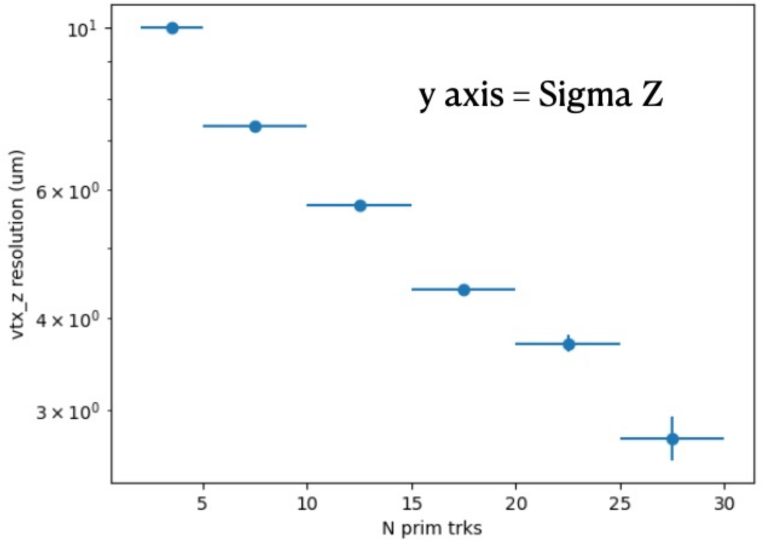
Primary vertex (E91_eebb events)



- Expected excellent performance 3~10 um of resolution



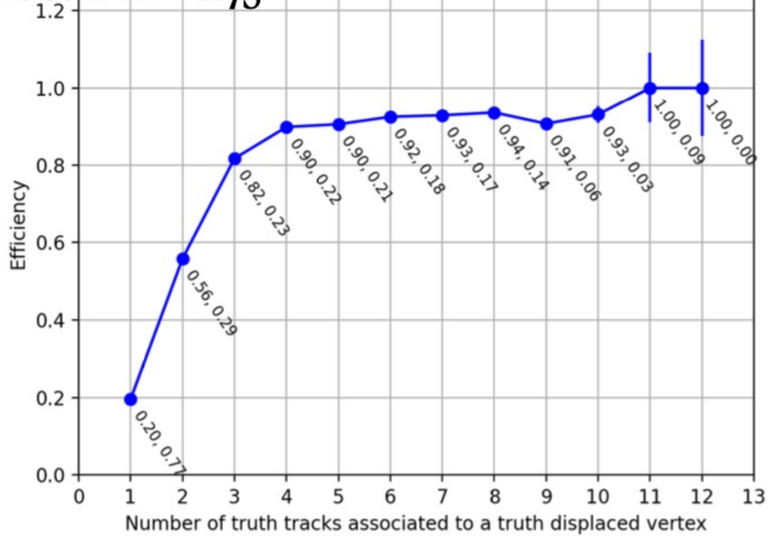


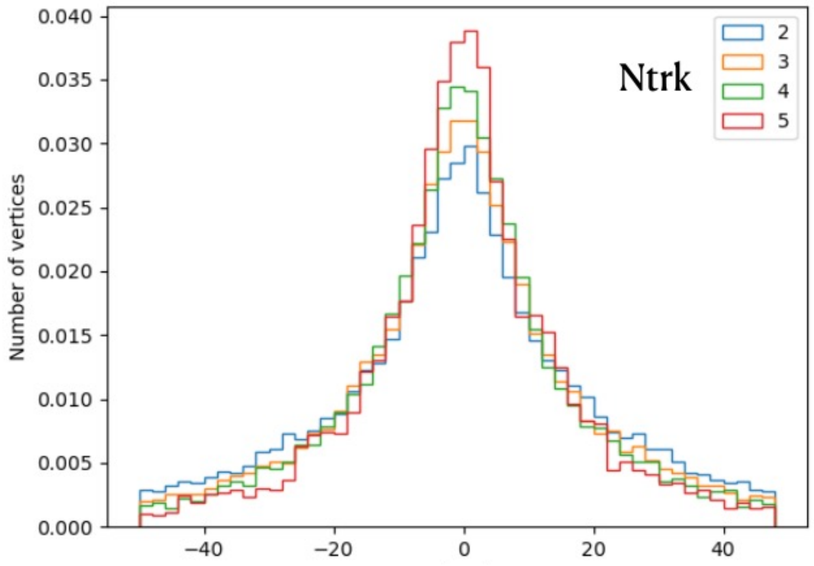


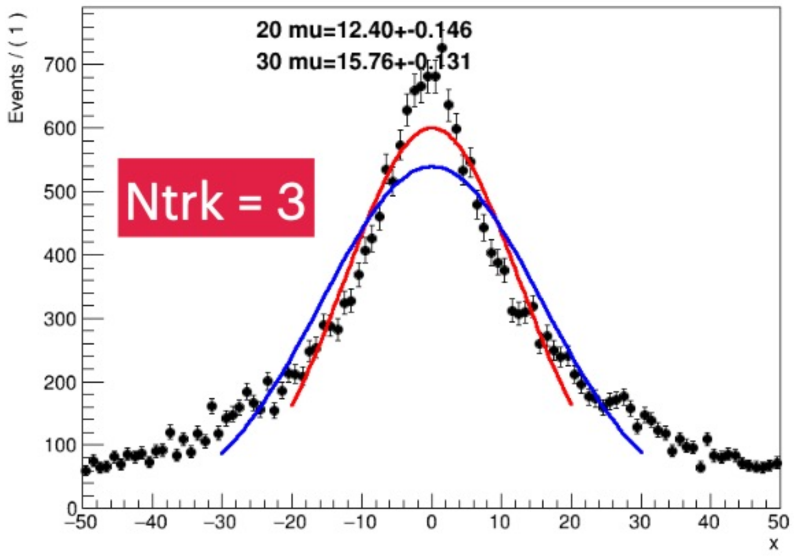
Update 2025.02.11

Secondary vertex (E91_eebb events)

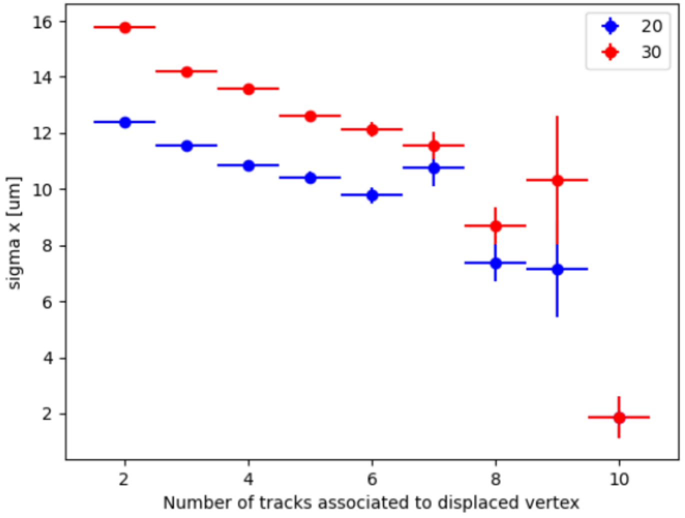
- Global Eff.= 0.75

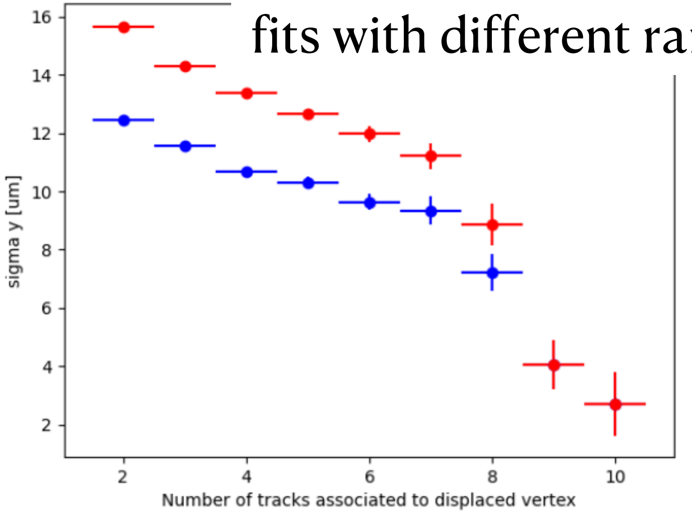


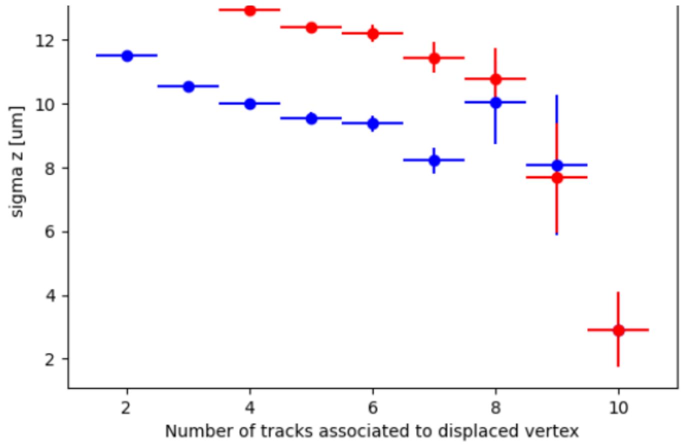




Non-Gaussian distributions, results shown for Gaussian fits with different ranges of 20 and 30 um







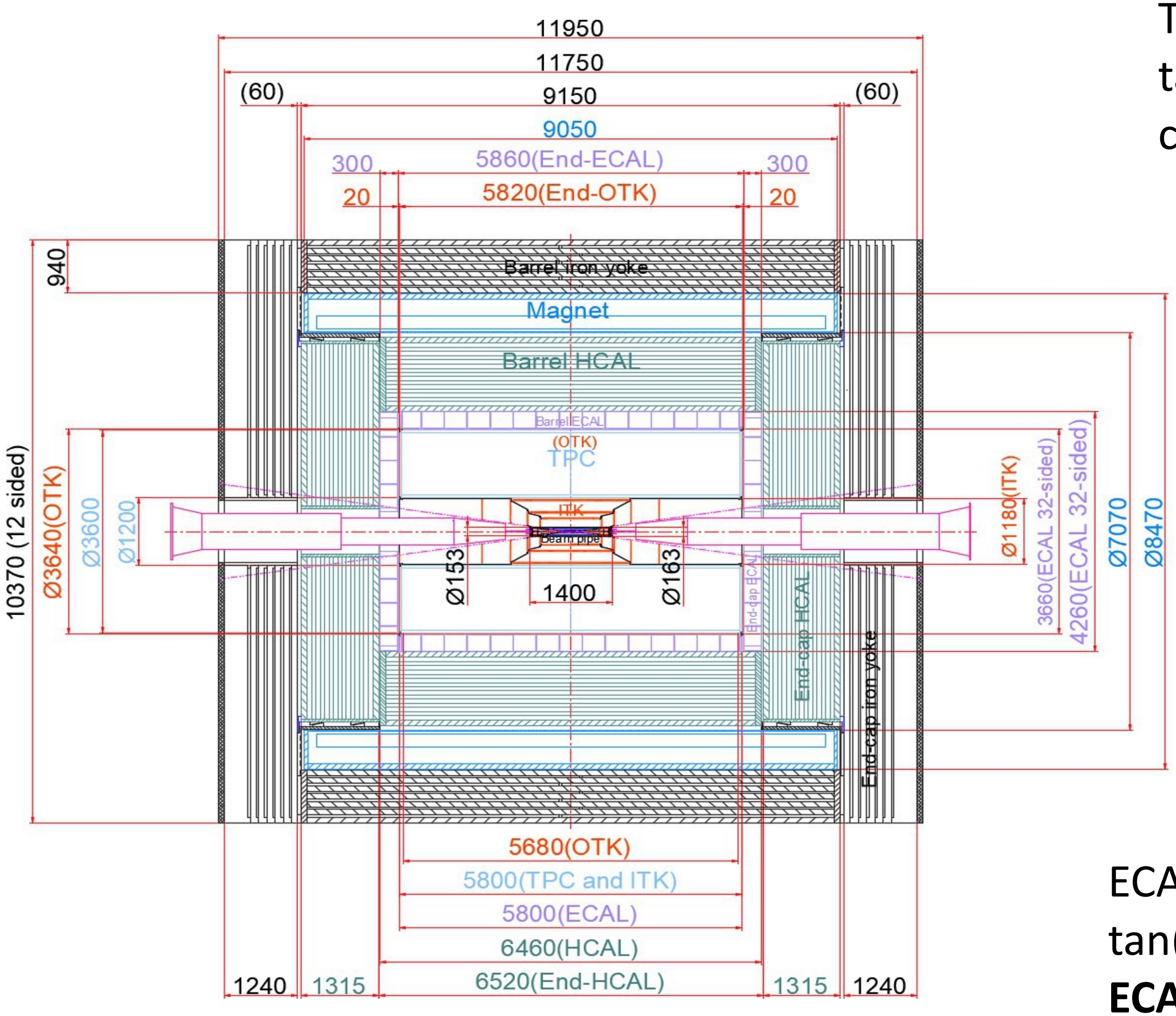
Summary

- Studies on physics object performance through full simulation shown
  - Tracking pT resolution $10^{-5} \oplus 1.5\times10^{-3}/(p\cdot\sin\theta)$ for polar angle at 85^{o}
  - PID (TPC+TOF)~ 3$\boldsymbol{\sigma}$ separation power for 3-10 GeV pi-K
  - BMR reaches the design goal 4% overall
  - Excellent vertex performance as expected
- Moving to physics benchmark studies while waiting for updates from SW
  - Simplifying material map of Geant4 simulation, to be consistent with the map used for reconstruction – done
  - Event mixing for including beam background – only for object performance evaluation, not for benchmark studies
  - Final granularity of the long crystal bars – moving to 15mmX15mm
  - Muon reconstruction in muon chambers
- Agreed with SW: final release by the end of February

Backup

CEPC ref-det Geometry

- From Q. Ji, 20241217



Angle for the transition btw barrel and endcap:
TPC radius 0.6m - 1.8m, length 5.8m
tan(theta) = 1.8/2.9 = 0.6207 -> theta~ 31.8 degree
cos(theta) ~ 0.85

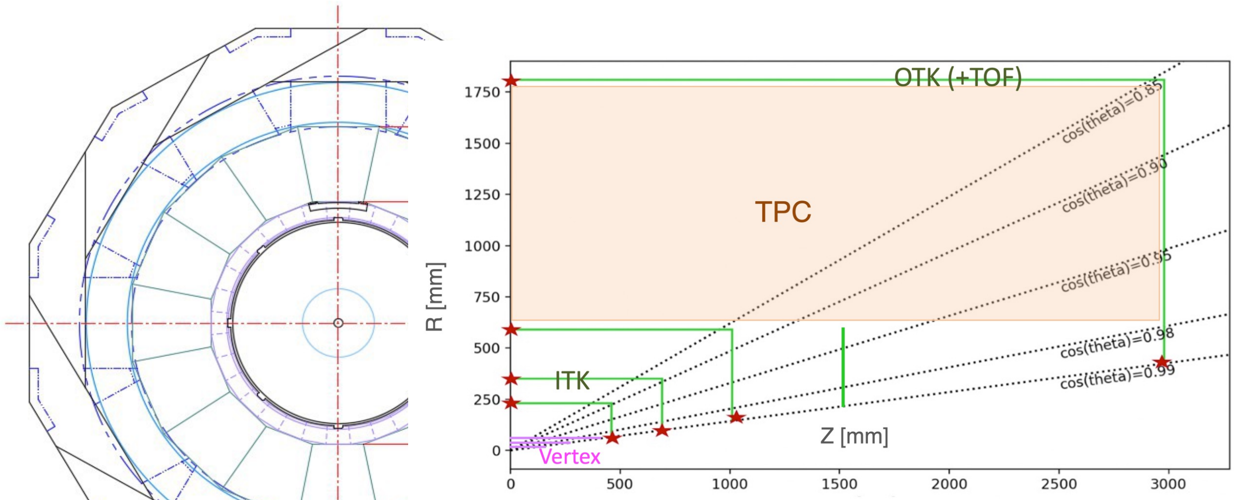
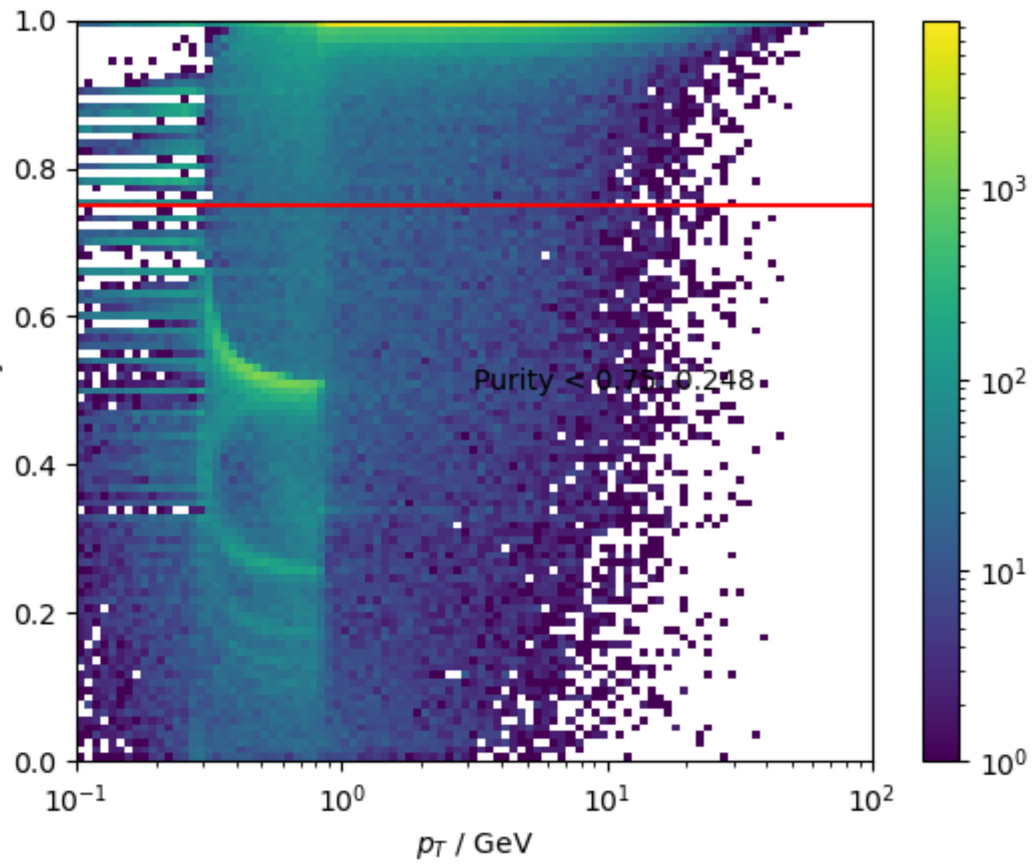


Figure 5.2: The layout of the CEPC tracker system.

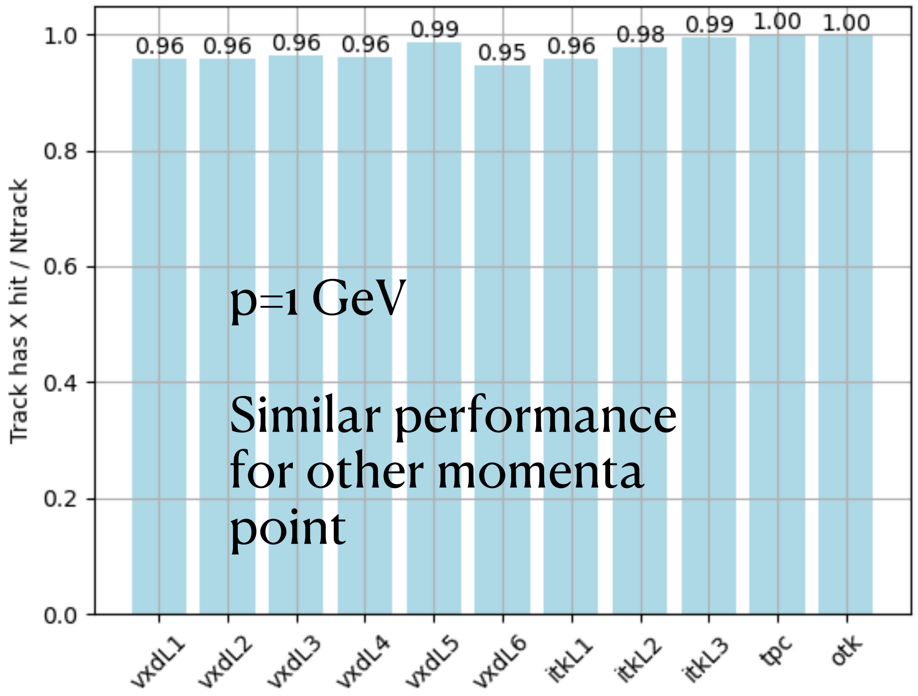
ECAL overlap region:
tan(theta) from 2.13/2.9 to 1.83/2.9 -> cos(theta): 0.806 to 0.846
ECAL coverage 0.99 – tan(theta) 0.3/2.9 -> cos(theta) ~ 0.995

Track hit purity/efficiency



- need the plot in log scale (for Z axis)
- purity/eff. definition: with and without TPC
- purity def: rec trk hits (truth) / rec trk hits
- efficiency def: rec trk hits (truth) / mc trk hits

Tracking hit efficiencies (used in trk fit)



theta ?

需要不同theta 角度的图， endcap ITK 有4层

PID eff, separation power

$$\chi_{\mathrm{TPC}}(i) = \frac{(dN/dx)_{\mathrm{meas}} - (dN/dx)^{i}_{\mathrm{exp}}}{\sigma_{(dN/dx)_{\mathrm{meas}}}}, i = \pi/K/p$$

$$\chi_{\mathrm{ToF}}(i) = \frac{t_{\mathrm{meas}} - t^{i}_{\mathrm{exp}}}{\sigma_{t_{\mathrm{meas}}}}, \sigma_{t_{\mathrm{meas}}} = \sqrt{0.05^2 + 0.02^2}$$

$$\chi^2(i) = \chi^2_{\mathrm{TOF}}(i) + \chi^2_{\mathrm{TPC}}(i)$$

$$\mathrm{Efficiency}_{\mathrm{trk}}(\mathrm{TPC}) = \frac{N^{\mathrm{TPC}}_{\mathrm{trk}}}{N^{\mathrm{reco}}_{\mathrm{trk}}}$$

$$\mathrm{Efficiency}_{\mathrm{PID}}(i) = \frac{N^{\mathrm{TPC}}_{\mathrm{trk}(i)}\left(\chi^2(i) < \chi^2(j)\right)}{N^{\mathrm{TPC}}_{\mathrm{trk}(i)}} (j \neq i)$$

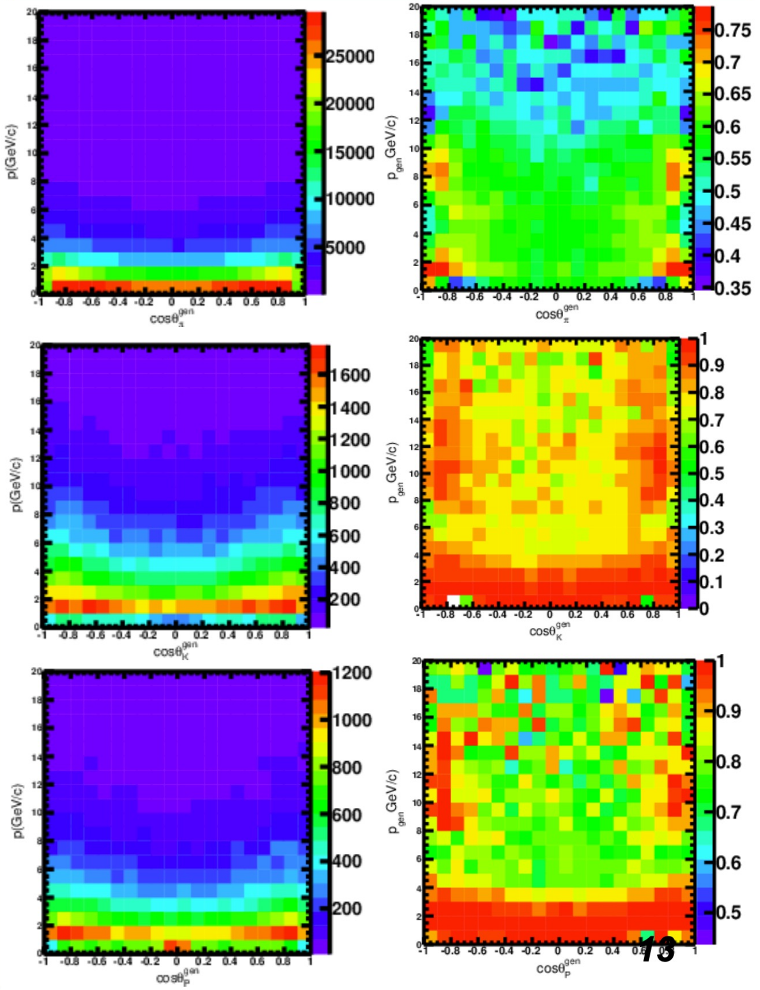
$$\mathrm{purity}(K) = \frac{N_{K\to K}}{N_{K\to K} + N_{\pi\to K} + N_{p\to K}}$$

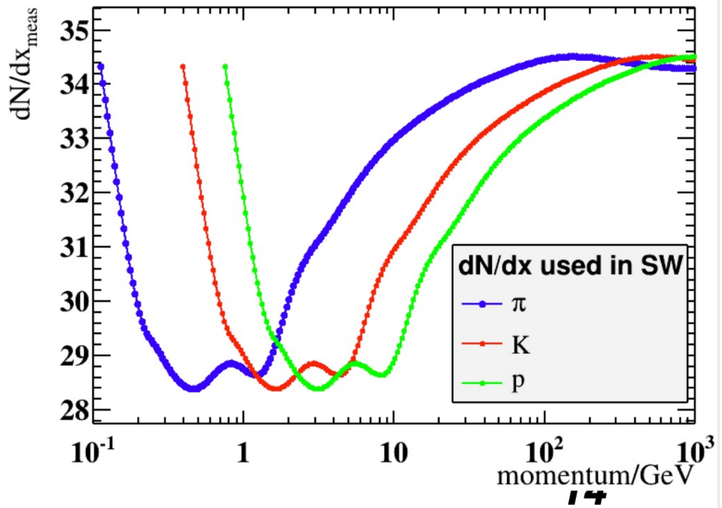
$$\mathrm{Efficiency}_{\mathrm{opti.\ PID}}(i) = \frac{N^{\mathrm{TPC}}_{\mathrm{trk}(i)}\left(a < \chi(i \to i) < b\right)}{N^{\mathrm{TPC}}_{\mathrm{trk}(i)}}$$

$$\text{Separation power: } O_{AB} = \frac{|\mathrm{A} - \mathrm{B}|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

$$\sqrt{O^2_{AB,\,\mathrm{TPC}} + O^2_{AB,\,\mathrm{TOF}}}$$

Track phase space and combined PID efficiency in $Z \to qq$ in tdr24.12.0





LUT at cosθ = 0.766 (40o) to understand

软件组分母 算数平均值(σ_A+σ_B)/2，这里是几何平均值，差sqrt(2)倍左右

PFA Jet resolution

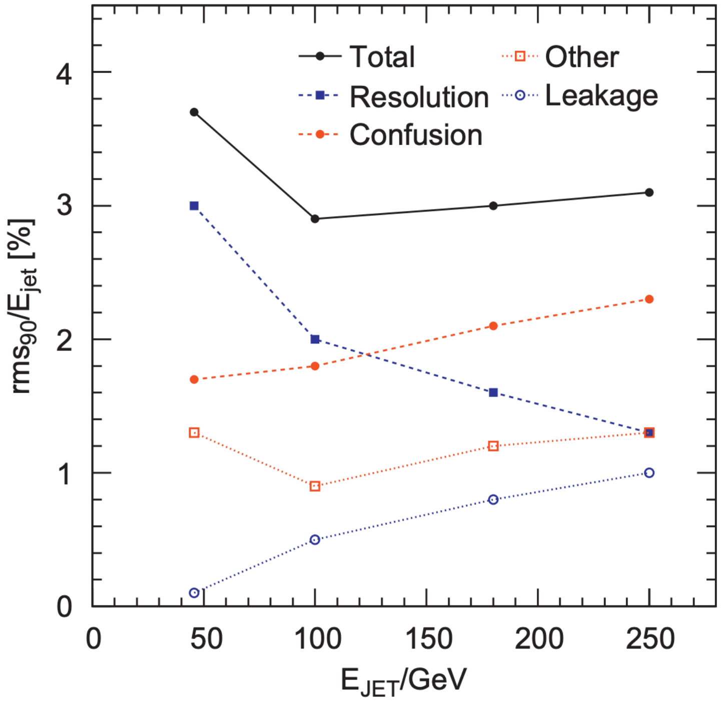


Fig. 9. The contributions to the PFlow jet energy resolution obtained with PandoraPFA as a function of energy. The total is (approximately) the quadrature sum of the components.

neutral hadrons being lost within charged hadron showers. For all jet energies considered, fragments from charged hadrons, which

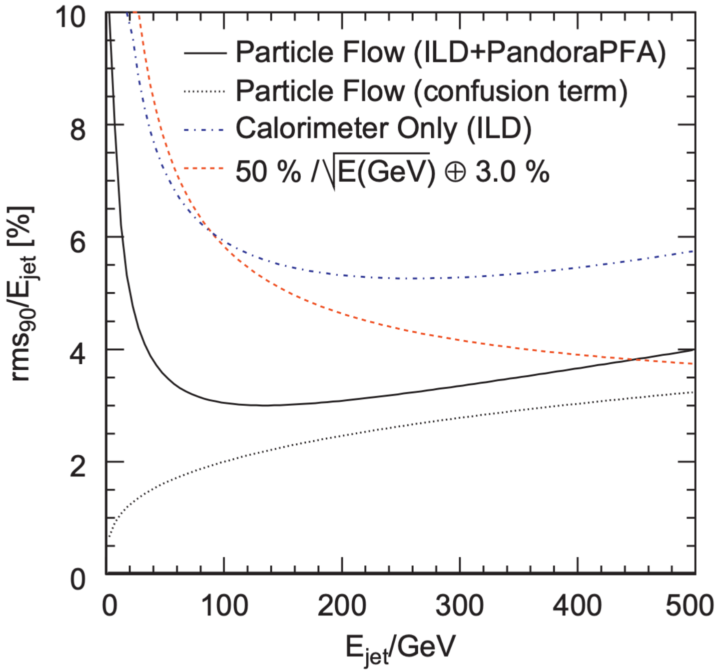
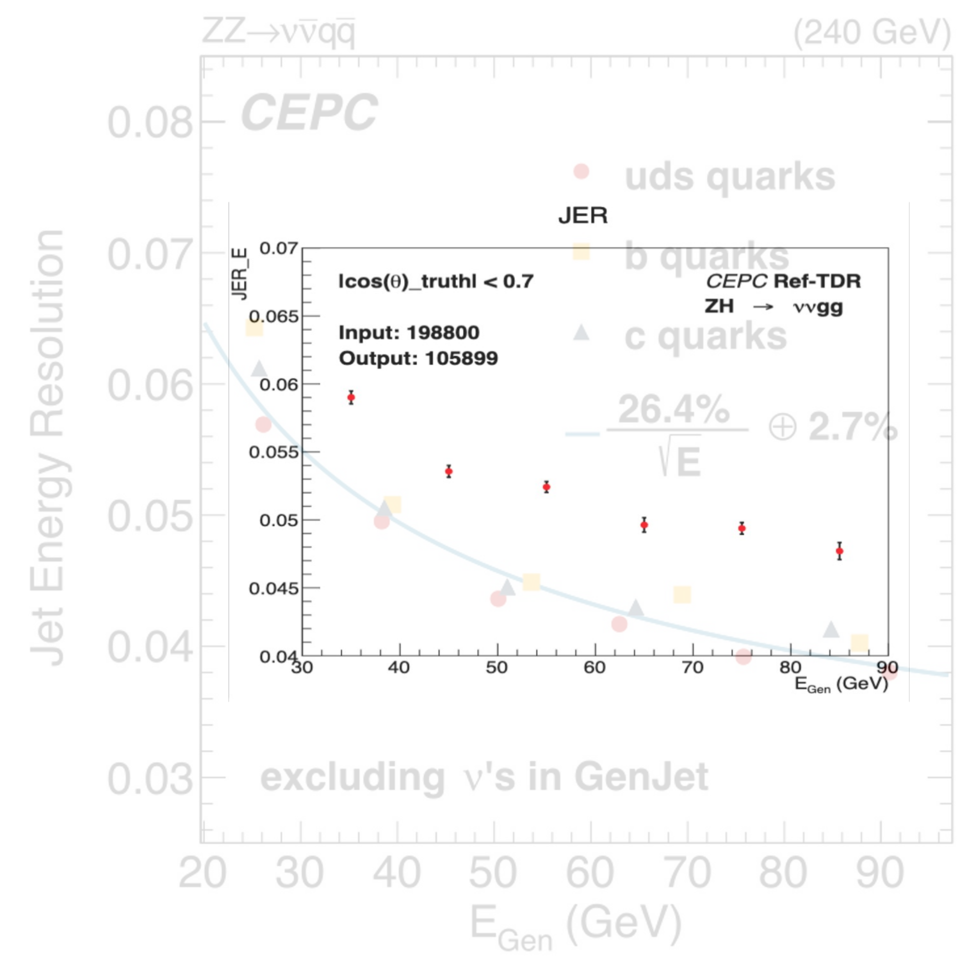


Fig. 10. The empirical functional form of the jet energy resolution obtained from PFlow calorimetry (PandoraPFA and the ILD concept). The estimated contribution from the confusion term only is shown (dotted). The dot-dashed curve shows a parameterisation of the jet energy resolution obtained from the total calorimetric energy deposition in the ILD detector. In addition, the dashed curve, $50\%/\sqrt{E(\mathrm{GeV})} \oplus 3.0\%$, is shown to give an indication of the resolution achievable using a traditional calorimetric approach.

Jet Performance

Yingqi, Xiaotian, Kaili, et al.

- Significantly improved w.r.t. previous version, BMR now reaches ~3.8%, though Barrel only



24.12.0

Process		$ZH \to \nu\nu gg$	$ZH \to \nu\nu bb$	$ZH \to \nu\nu cc$
Cumulative efficiency /%	$\Sigma\lvert Pt_{ISR}\rvert < 1\text{GeV}/c$	95.3	95.3	95.4
	$\Sigma\lvert Pt_{\nu}\rvert < 1\text{GeV}/c$	89.8	39.5	66.5
	$\lvert\cos\theta_{jet}\rvert < 0.7$	53.1	22.0	38.0
DSCB BMR/%		3.99 ± 0.02	3.84 ± 0.04	4.04 ± 0.03

CDR

Table 3. Higgs boson mass resolution (sigma/Mean) for different decay modes with jets as final state particles, after event cleaning.

$H \to bb$	$H \to cc$	$H \to gg$	$H \to WW^*$	$H \to ZZ^*$
3.63%	3.82%	3.75%	3.81%	3.74%

Comments/Recommendations on Performance

- The planned list of channels looks a bit too high for a few months of work, better to focus on demonstrating that the reference detector reaches adequate performance for physics
  - **Select fewer channels, aimed at demonstrating that the reference detector reaches adequate performance for physics. Include some simple topology (e.g. Z→mumu). Encompass H, Z, W and top physics.**
  - **Foresee in the TDR results and figures about performance on basic objects (leptons, photons, jets) as a function of energy and polar angle**
  - A measurement of V_cs during the WW run is probably a more relevant benchmark than V_cb ;
  - The channel to be used for the electroweak mixing angle measurement should be clarified

Plans:

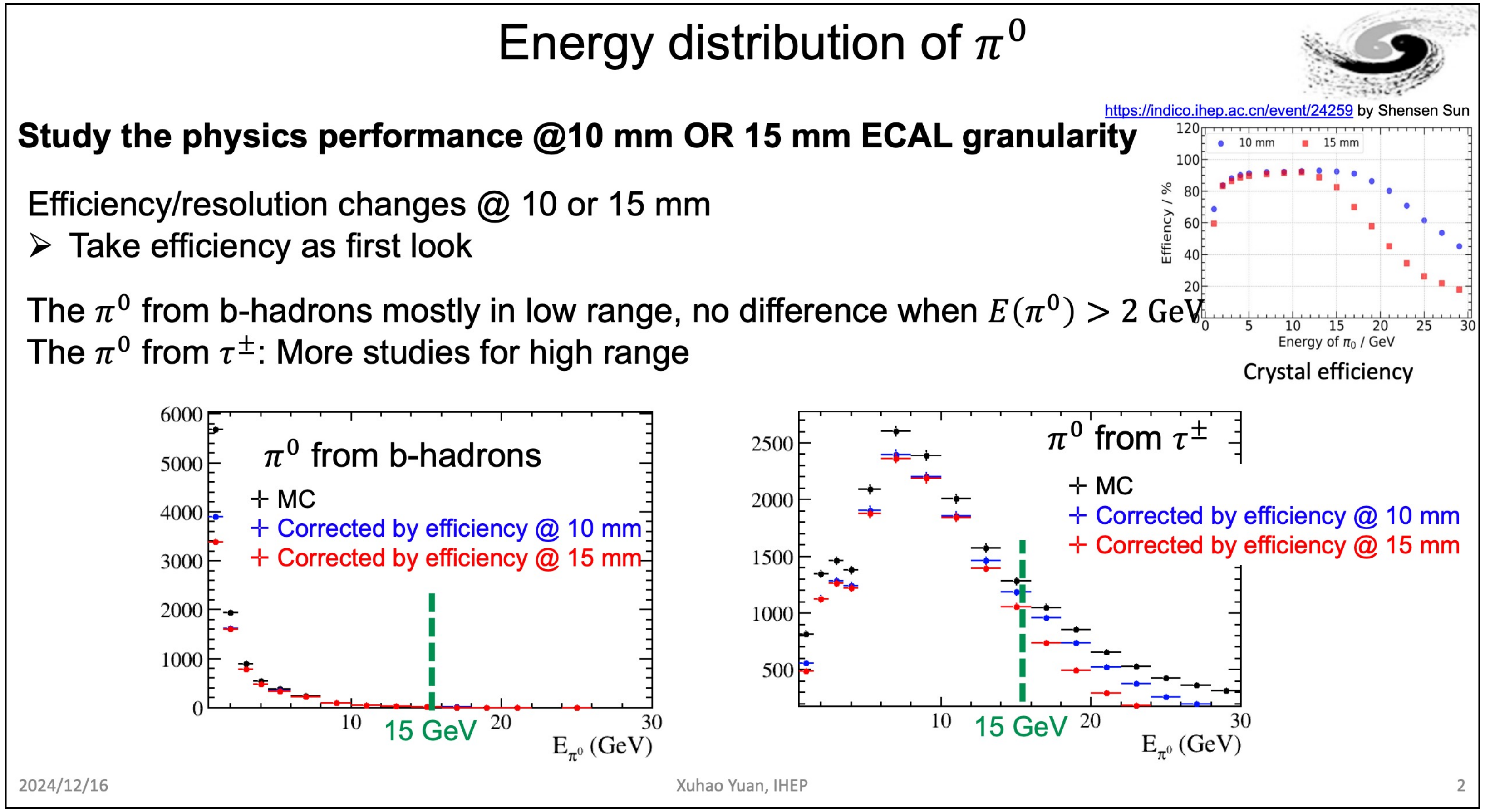
Priority: working closely with software team for the development and performance studies of basic objects

H→ss/cc/sb
H→inv
Vcb
W fusion Xsec
α_s
CKM angle $\gamma-2\beta$
Weak mixing angle
Higgs recoil
H→bb, gg
H→μμ
H→γγ
W mass & width
Top mass & width
Bs→$\nu\nu\phi$
Bc→$\tau\nu$
B0→2π^0
H→LLP
H→aa→4γ

→

	Process @ c.m.e	Domain	Relevant Det. Performance
Z→μμ	Z@ 91.2 GeV	Z	lepton ID, tracking
H→γγ	qqH	Higgs	photon ID, EM resolution
Higgs recoil	$\ell\ell$H	Higgs	Lepton ID, track dP/P
H→ss	ννH @ 240 GeV	Higgs	PID, Vertexing, PFA + JOI
H→inv	qqH	Higgs/NP	PFA, MET
Vcs/Vcb	WW→$\ell\nu$qq @ 240/160 GeV	Flavor	PFA, JOI + PID (lepton, tau)
H→LLP	$\ell\ell$H	NP	TPC, TOF, calo, muon detectors
H→μμ	qqH	Higgs	lepton ID, tracking, OTK
Top mass & width	Threshold scan @ 360 GeV	EW	Beam energy
Weak mixing angle	Z→bb @ 91.2 GeV	EW	JOI

Studies towards ECAL granularity



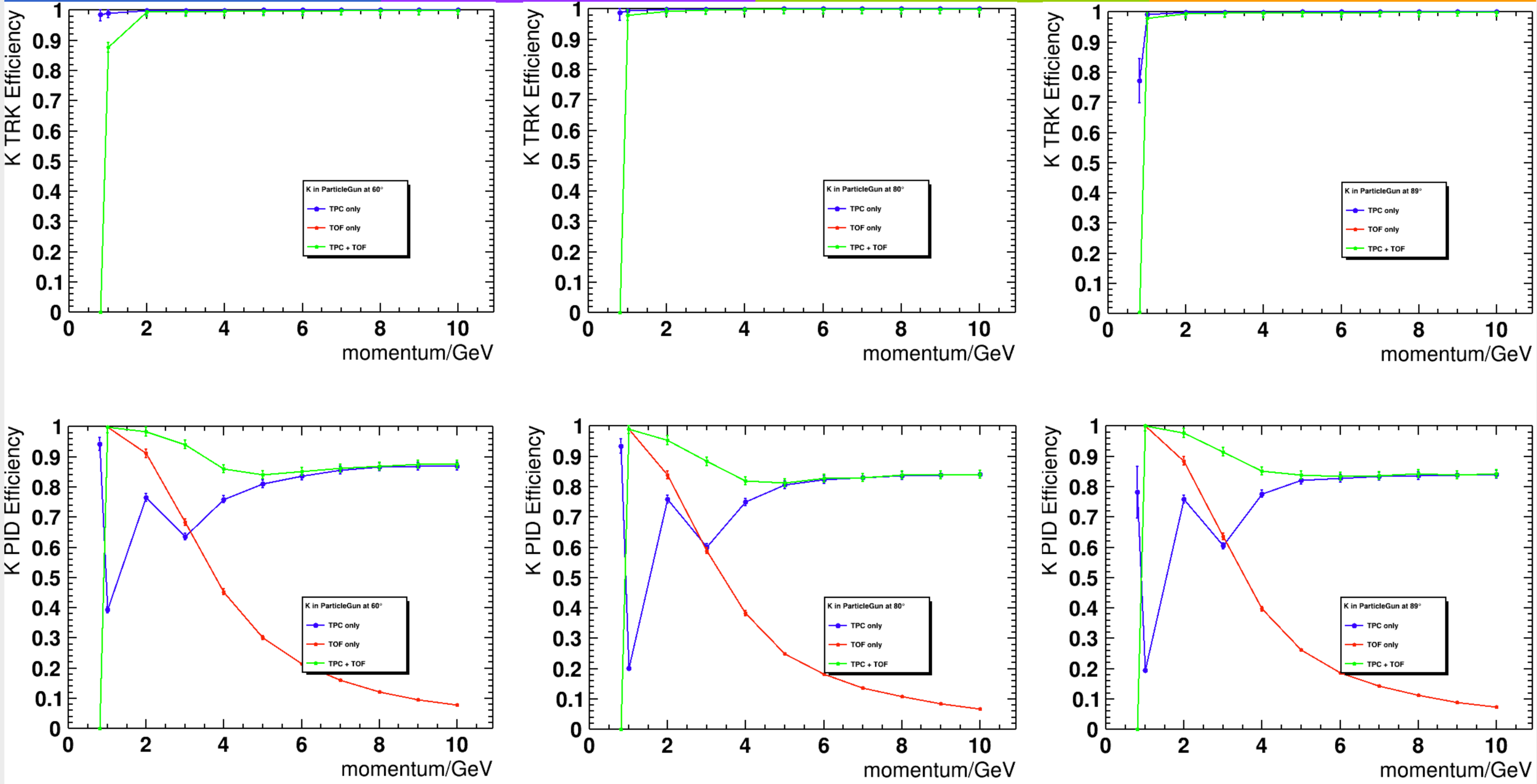
- Inclusive π^0 from b-hadron all similar with 10 or 15 mm
  - Not easy to find the "golden channel" related to B-hadron decays with p^0
  - Seems no need for b-hadron benchmark studies
  - Higher momentum for π^0 from B's two body decays, more studies ongoing
- αS studies with tau dominated by systematics uncertainties
  - Difficult to evaluate quantitatively,
  - Not clear if 1x1 cm would be better
- CP in H->$\tau\tau$, statistical uncertainty dominated
  - To be followed up
- There are confidence on good separation between large pT π^0 and single photon by shower shapes, etc.

π^0 with E > 15 GeV from ee->Z->qq: ~ 1%

π^0 with E > 15 GeV from ee->Z->$\tau\tau$: ~25%

TPC+TOF PID in 25.1.0

Xiaotian Ma, Chenguang Zhang, et. al.



60 degree (left) VS 80 degree (middle) VS 89 degree (right)

ParticleGun K- TRK/PID efficiency

- **The issue does not appear in 60-89°**

3