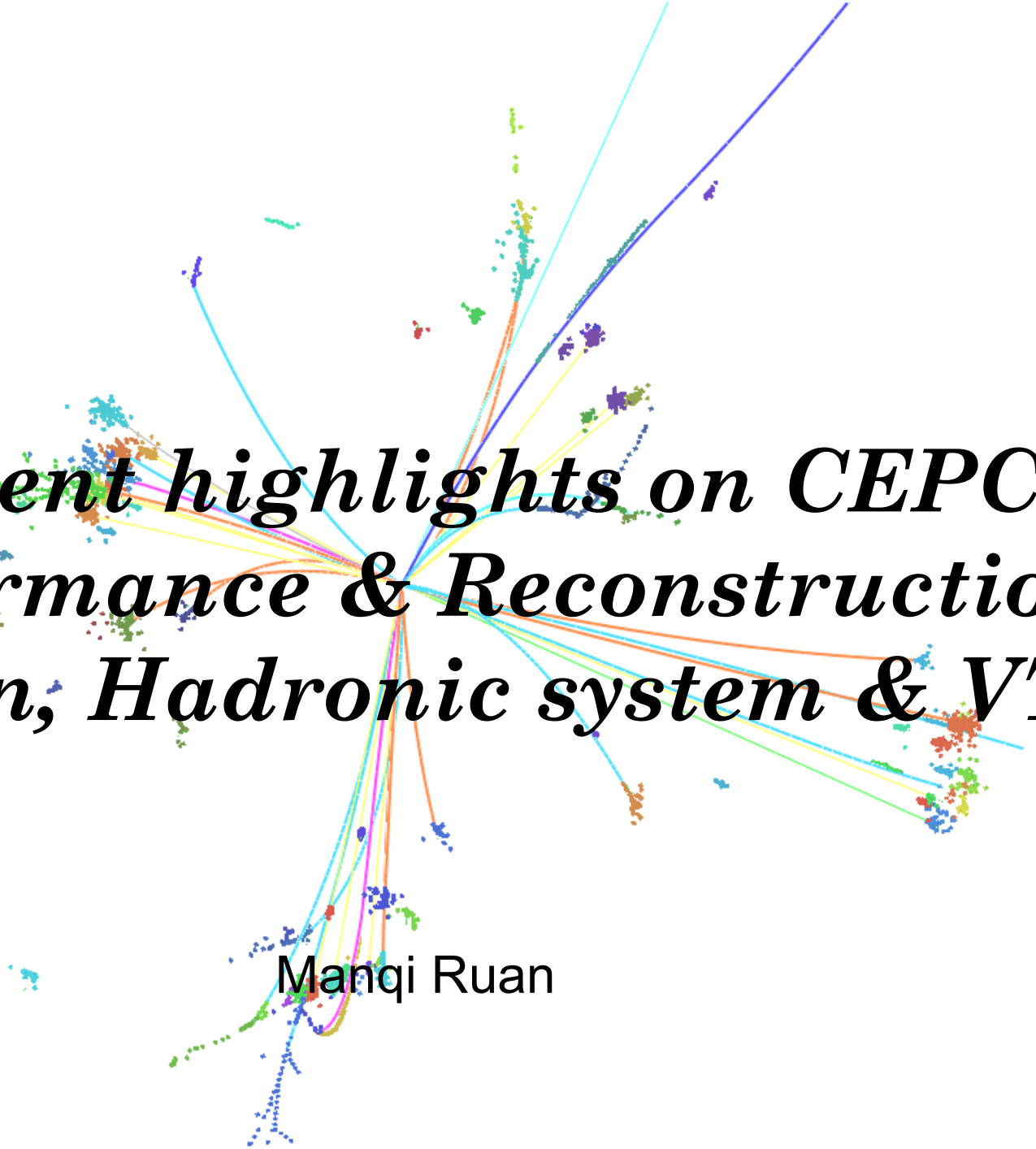


Recent highlights on CEPC Performance & Reconstruction: Lepton, Hadronic system & VTX

Manqi Ruan

...

Reconstruction: interpret the detector signal as Physics Objects

PFA reconstruction

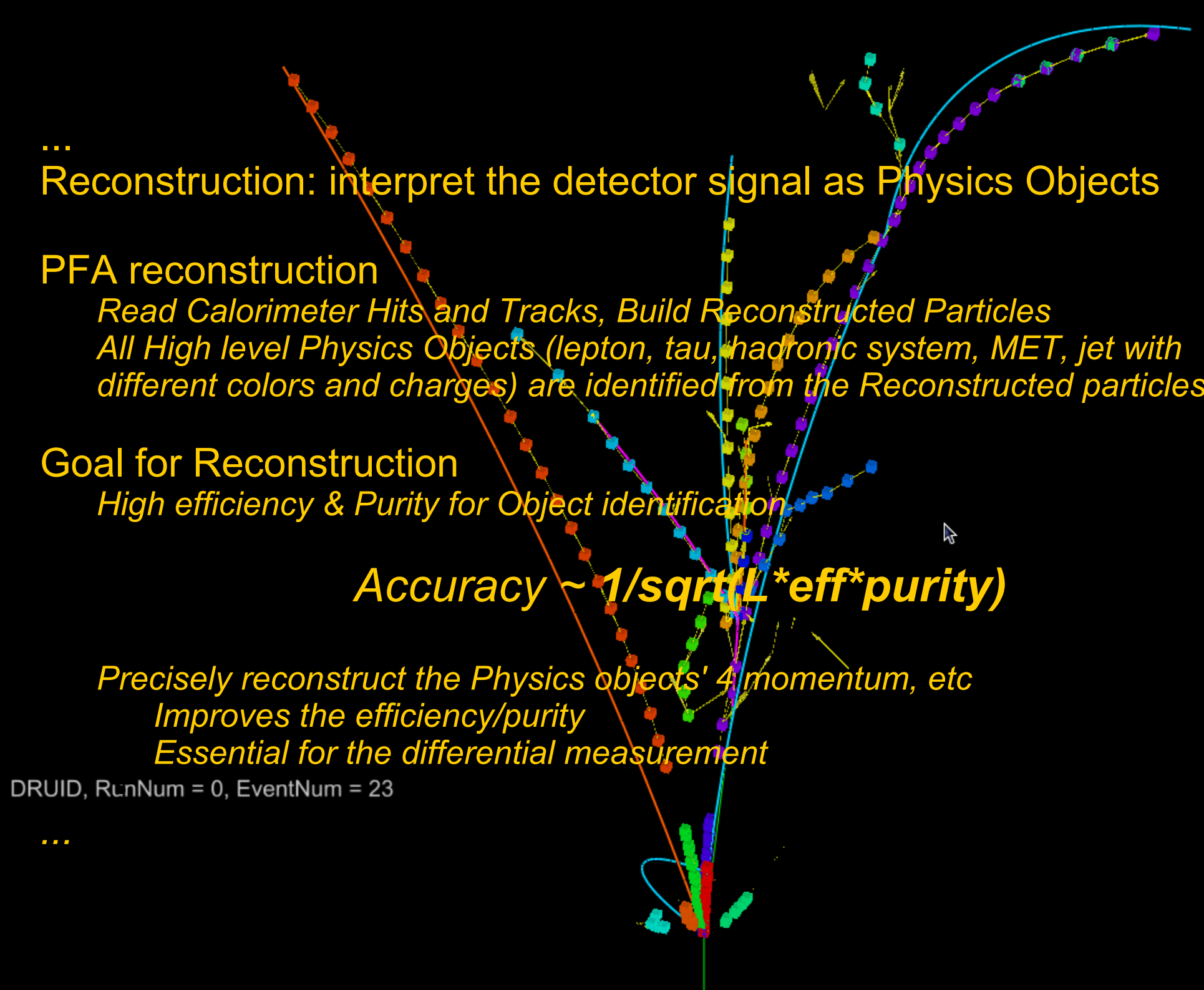
Read Calorimeter Hits and Tracks, Build Reconstructed Particles
All High level Physics Objects (lepton, tau, hadronic system, MET, jet with different colors and charges) are identified from the Reconstructed particles

Goal for Reconstruction

High efficiency & Purity for Object identification

Accuracy ~ 1/sqrt(L*eff*purity)

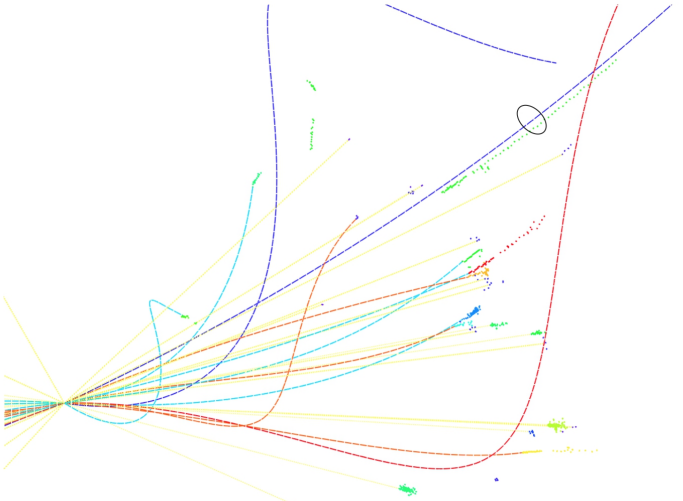
Precisely reconstruct the Physics objects' 4 momentum, etc
Improves the efficiency/purity
Essential for the differential measurement



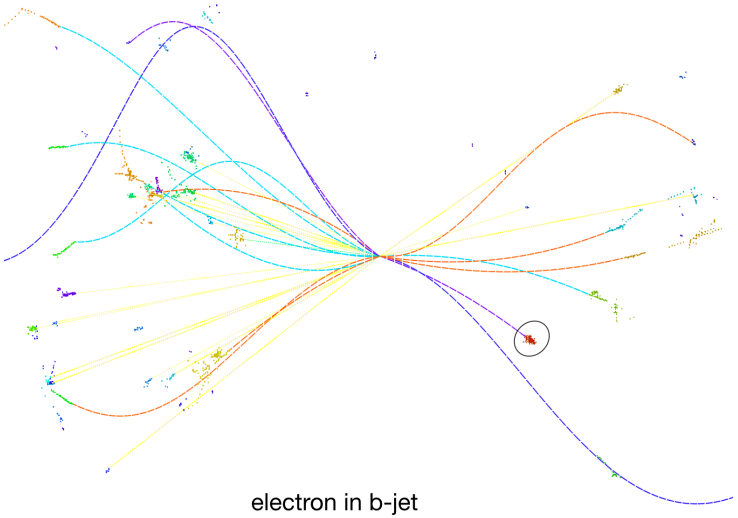
...

Lepton

- Electron & Muon
  - Isolated
  - Inside jet
- Tau
  - Leptonic event ($Z \rightarrow \tau\tau$; $\nu\nu H$, $H \rightarrow \tau\tau$)
  - Isolated τ in hadronic event
  - T in jet
- Dan Yu



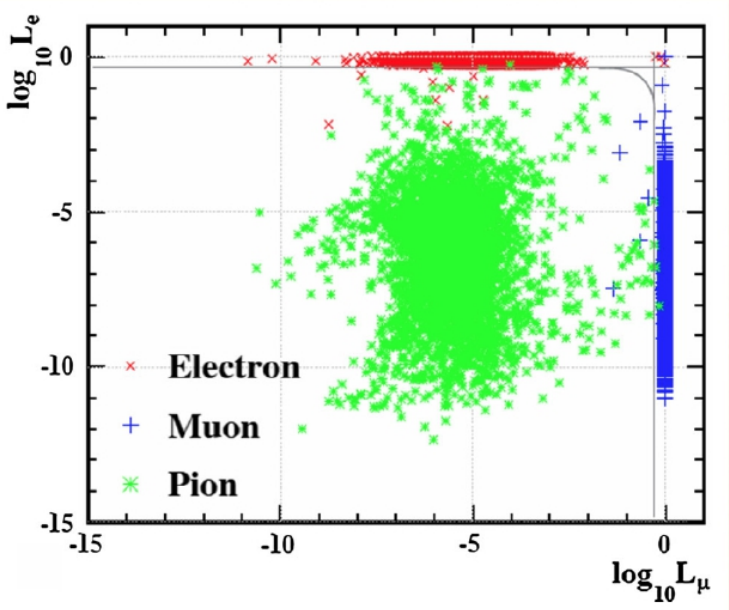
muon in b-jet

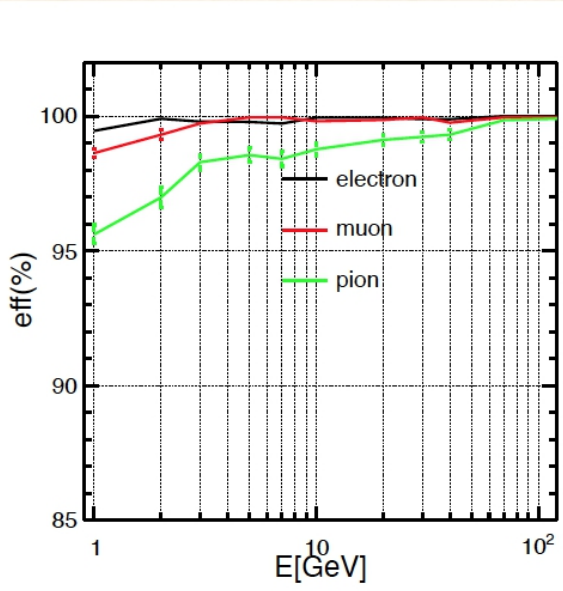


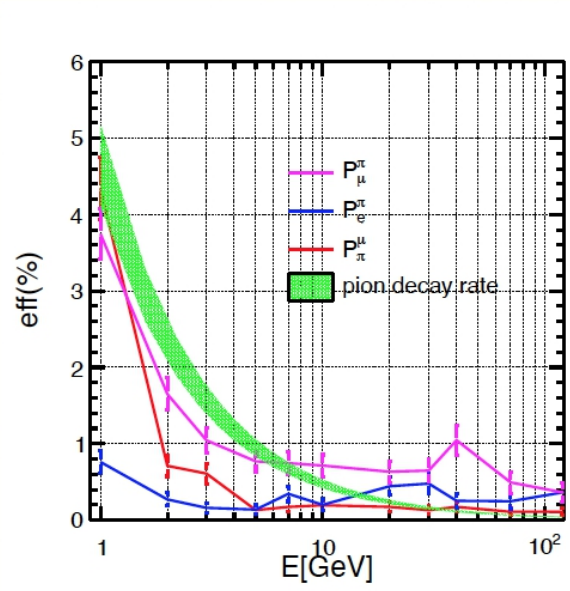
electron in b-jet

Light Lepton Identification

- LICH uses TMVA methods to summarize 24 input variables into two likelihoods, corresponding to electrons and muons.
- The efficiency for electron and muon is higher than 99.5% (E>2 GeV). Pion efficiency ~ 98%.







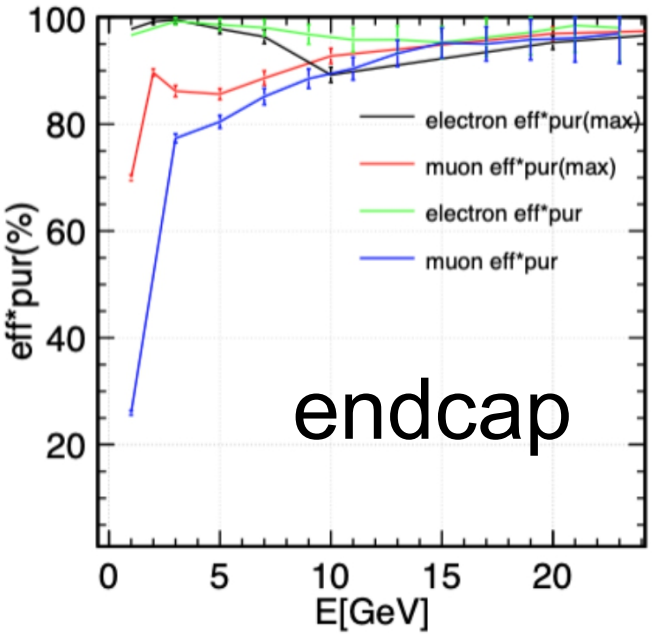
Migration Matrix at 40GeV (LICH)

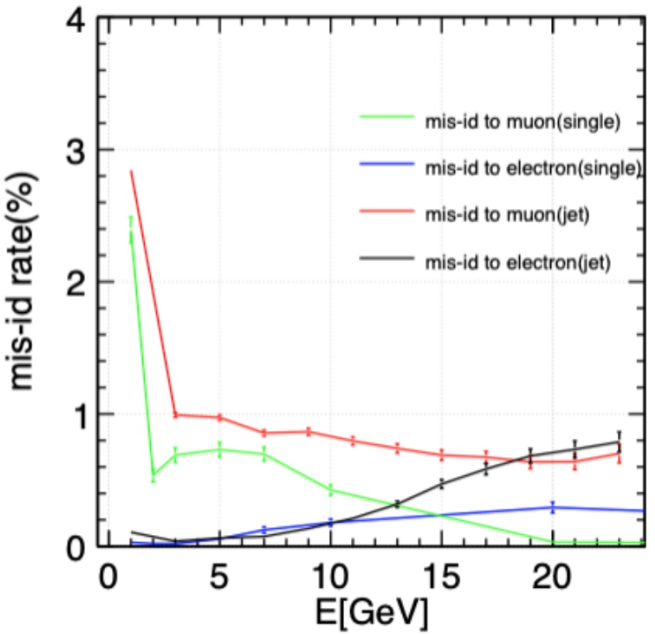
Type	e^- *like*	μ^- *like*	π^+ *like*
e^-	99.71 ± 0.08	< 0.07	0.21 ± 0.07
μ^-	< 0.07	99.87 ± 0.08	0.05 ± 0.05
π^+	0.14 ± 0.05	0.35 ± 0.08	99.26 ± 0.12

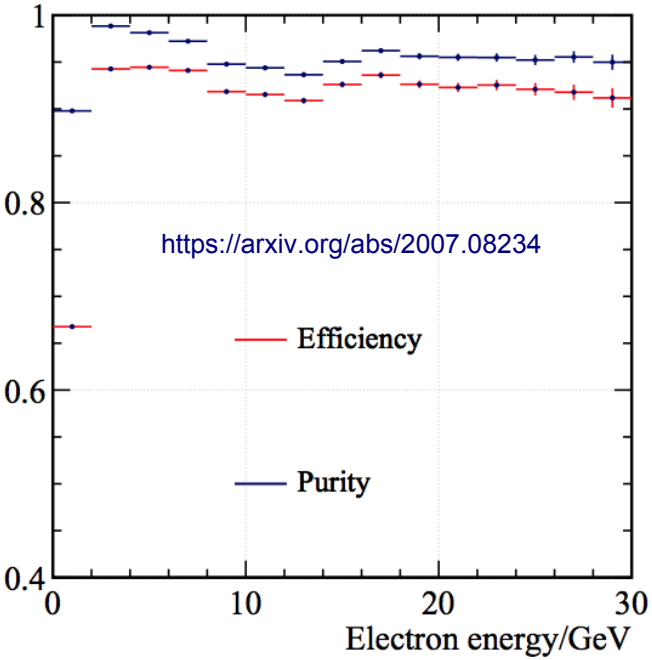
Migration Matrix for ALEPH PID ($> 2\,GeV$)(*Eur.Phys.J.C20:401-430,2001*)

Type	e^- *like*	μ^- *like*	π^+ *like*	undefined
e^-	99.57 ± 0.07	< 0.01	0.32 ± 0.0	0.09 ± 0.04
μ^-	< 0.01	99.11 ± 0.08	0.88 ± 0.08	0.01 ± 0.01
π^+	0.71 ± 0.04	0.72 ± 0.04	98.45 ± 0.06	0.12 ± 0.03

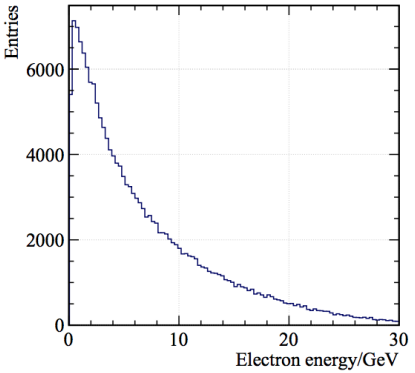
Leptons in jet: slightly degrading





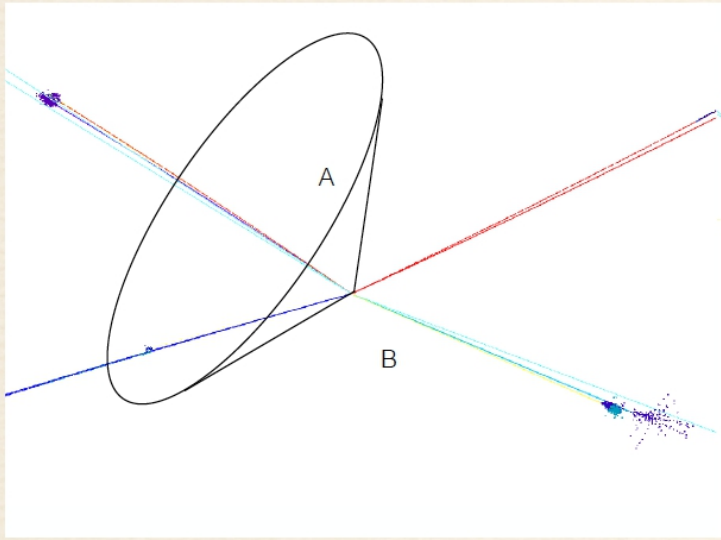


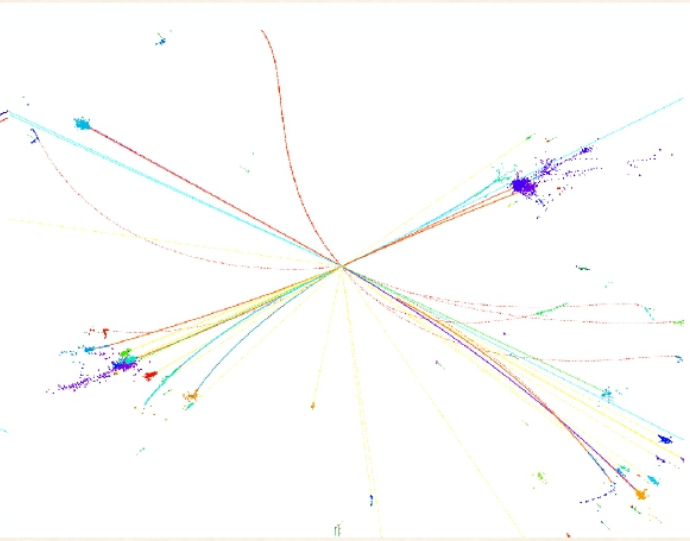
- Induced by the limited performance on PFA Clustering.
- Benchmark: electron finding in Bc⟶τν⟶eννν analysis
  - An ideal lepton id can improve ~ 10%, visible, **not significant.**

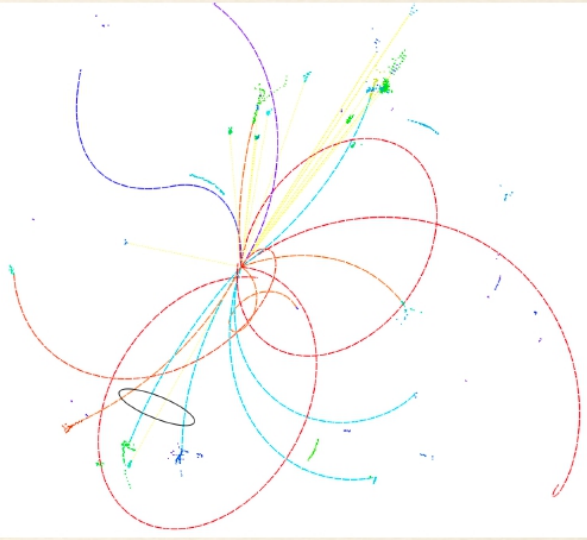


Event topology

- llH channel / $Z \rightarrow \tau\tau$
- qqH (isolate τ with jets)
- τ inside jets





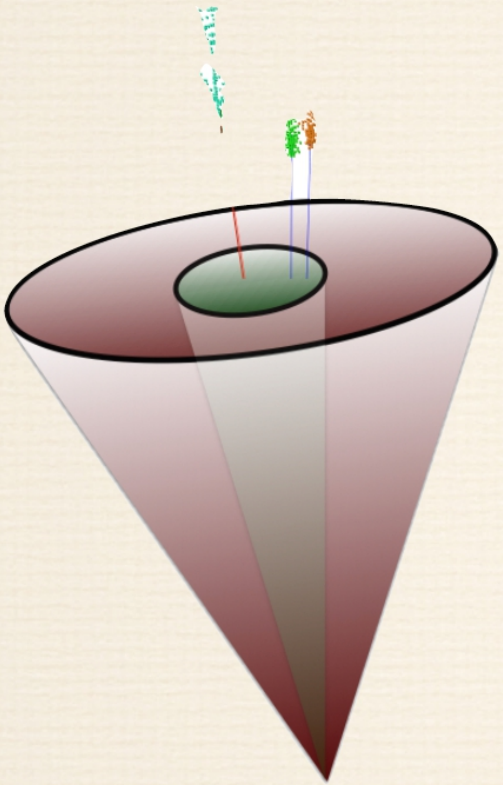


- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter

- Tau jet reconstruction package: TAURUS

- TAURUS with different parameters

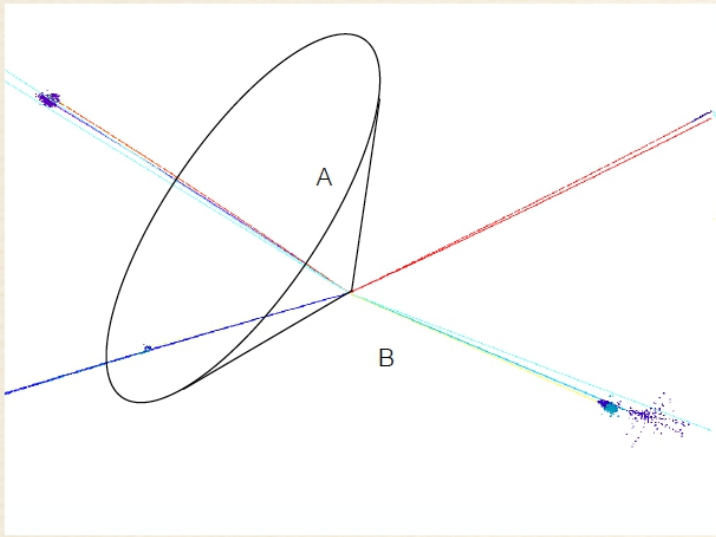
Taurus

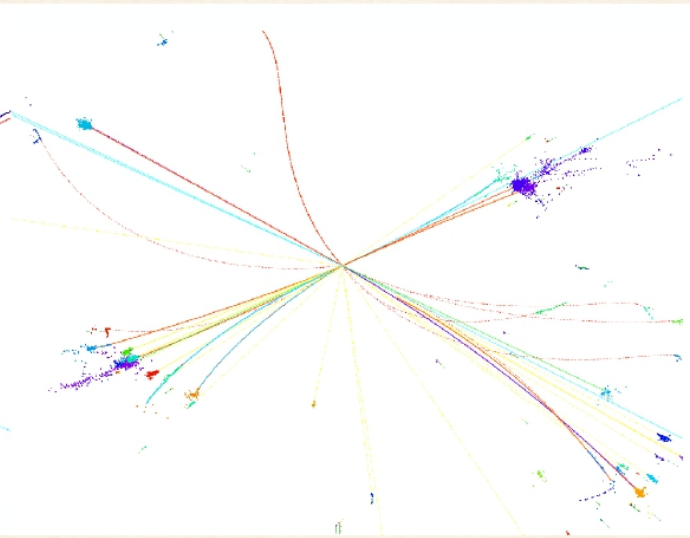


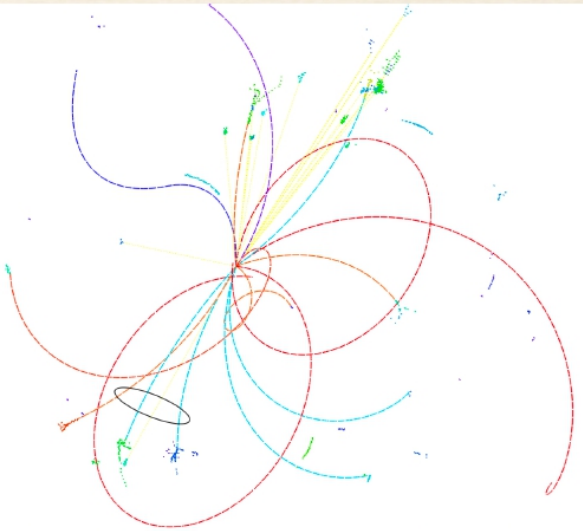
- Double cone based algorithm
  - Find seeds(Tracks with enough energy)
  - Collect particle in two cones
  - Use the multiplicity, energy ratio between two cones, invariant mass for τ tagging

Event topology

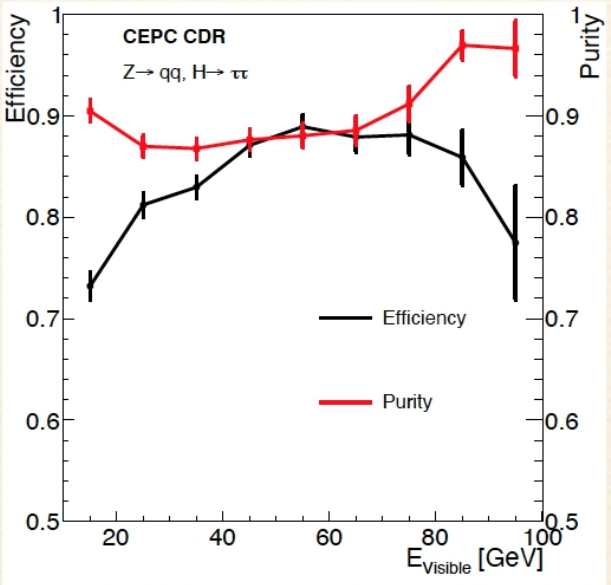
- llH channel / Z→ττ
- qqH (isolate τ with jets)
- τ inside jets

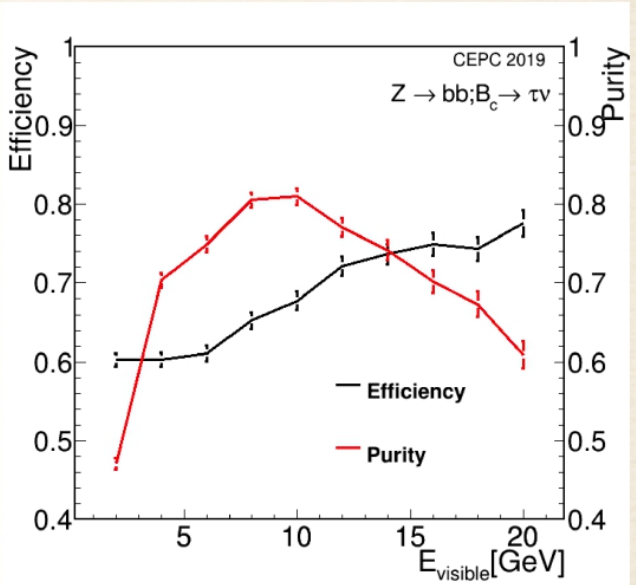






- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter
- Efficiency > 90%





Hadronic System

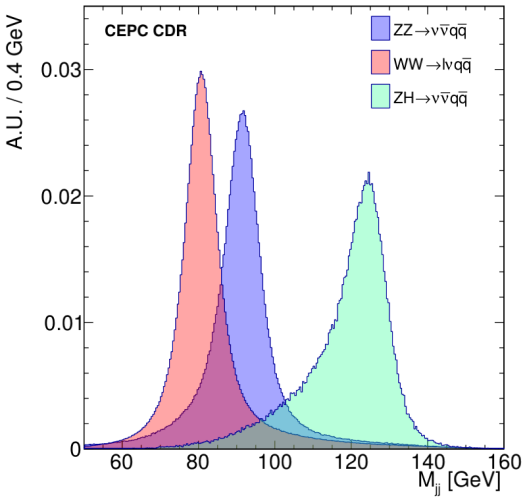
- Identify the hadronic system, and measure its 4-momentum
  - Identification: solved as leptons are well identified...
  - 4-momentum measurement: BMR(Boson mass resolution)
  - Identification of ISR photon, Bremstrahlung/FSR from lepton, converted Photon (EM objects), etc, still needs more development (Not urgent, we know it works)

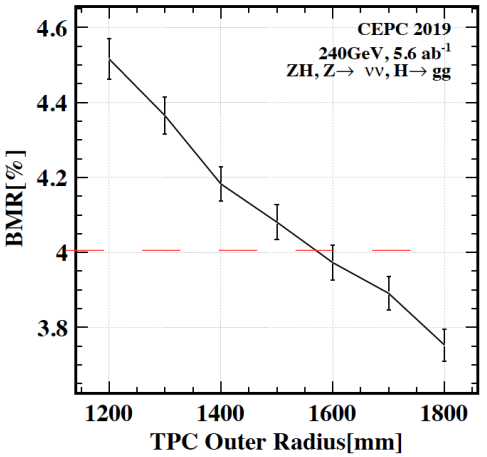
- Identify Jet: Differential measurements + Flavor/Charge identification...
  - Current criteria: Jet Clustering and Matching
  - Jet is strongly entangled with QCD... Go beyond?

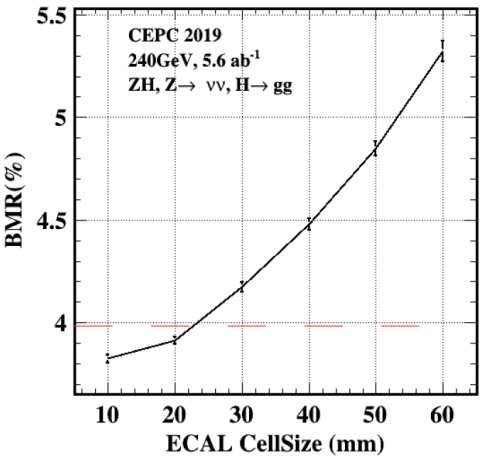
- CSI (Color Singlet Identification), i.e., identify single Boson in full hadronic ZZ, ZH, WW events.
  - Challenge, Important & Interesting

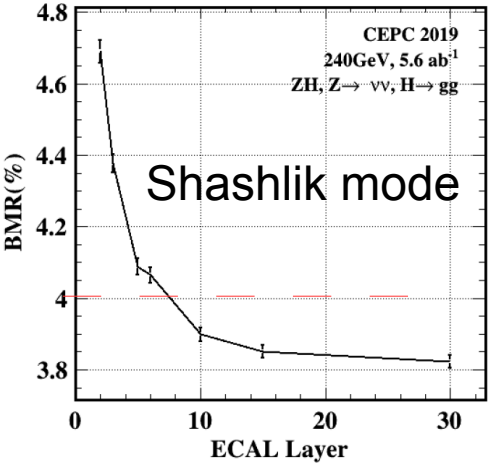
BMR oriented Optimization

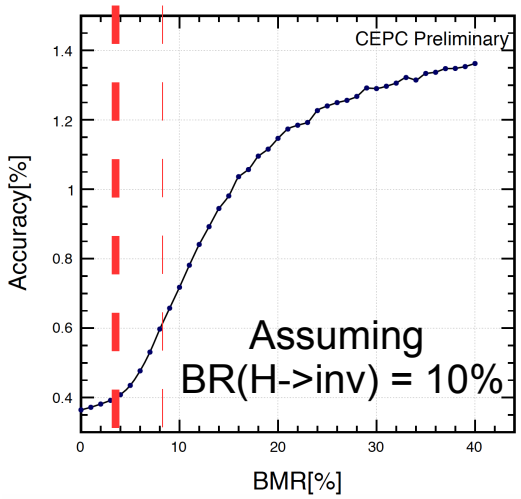
Yukun, Dan, Jiechen, Hanhua, etc

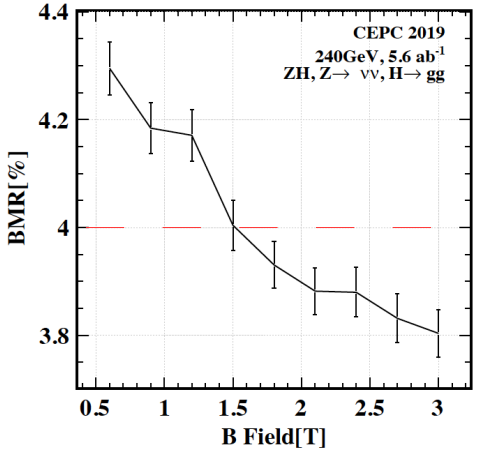


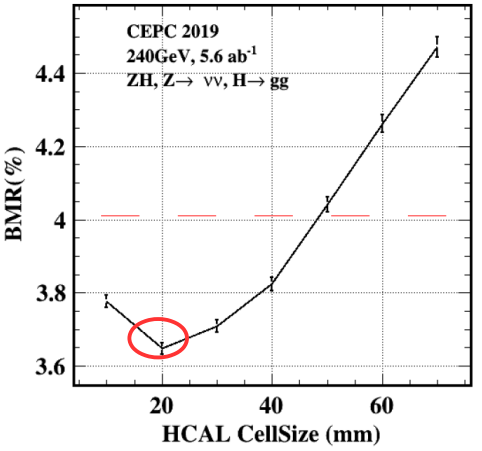


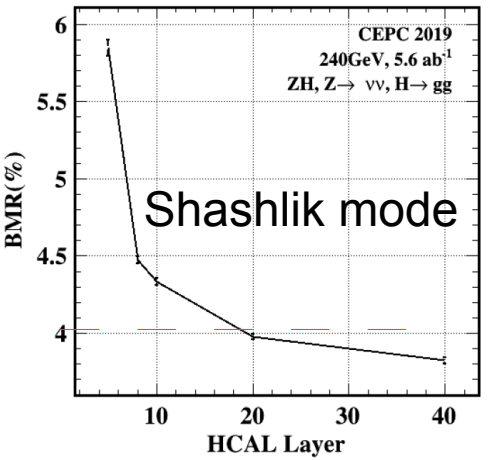












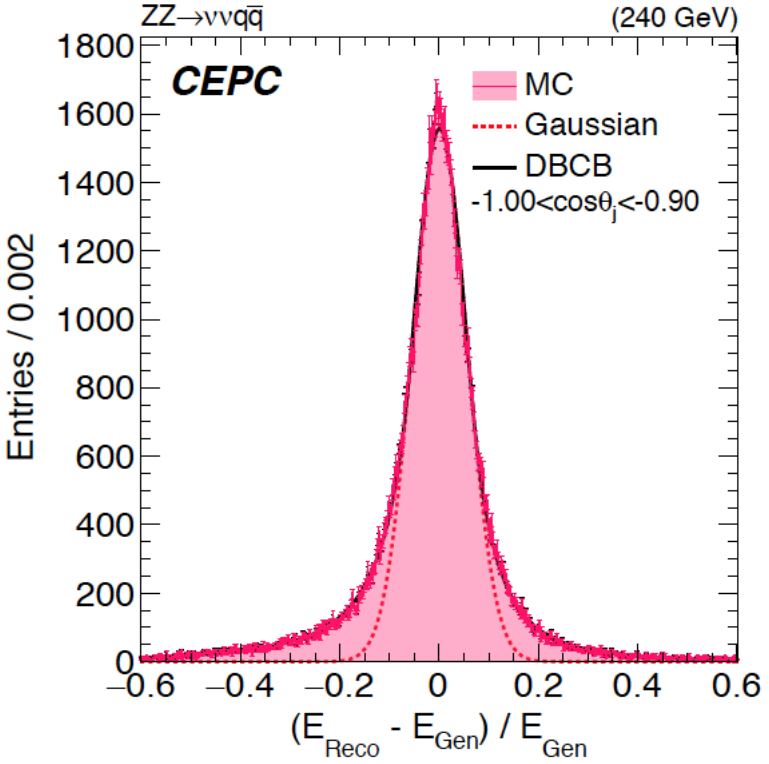
CEPC requirements: BMR < 4% (3.8% achieved at CDR baseline)

Dependence between BMR & Detector Geometry quantified

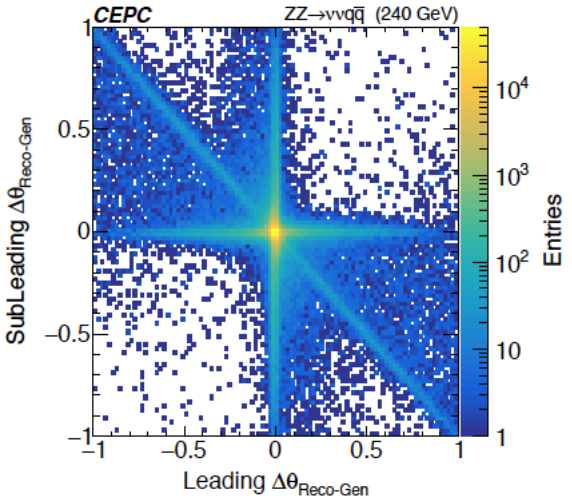
BMR oriented Optimization

- BMR = 3.8%, 3.6% seems reachable without fundamental change..
  - Preliminary... HCAL optimal size ~ 2 cm → reduce the HCAL # Channel to a quarter (digital read mode at AHCAL...)
- Allowance of 4%, BMR = 3.6/3.8% means:
  - *Reduce the tracker R&Z by 24/12%*
  - *Reduce the ECAL #Channels to a quarter or more: either by double Cell size, or reduce the #Layer*
  - *Reduce the B-Field from 3T to 1T/1.5T*
  - *Increase the HCAL Cell size ~ 5 cm or even larger! HCAL #Cell reduced to 4%...*
  - *Reduce the HCAL #Layer by 50%*
  - Optimal geometry can be determined once cost dependence on above parameters is clear.
- Improving BMR... is the key objective for reconstruction.

Differential Jet Response

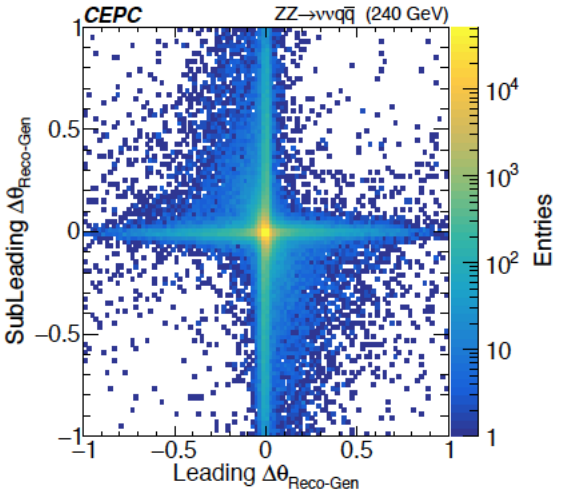


Matching with energy



(a)

Matching with angle

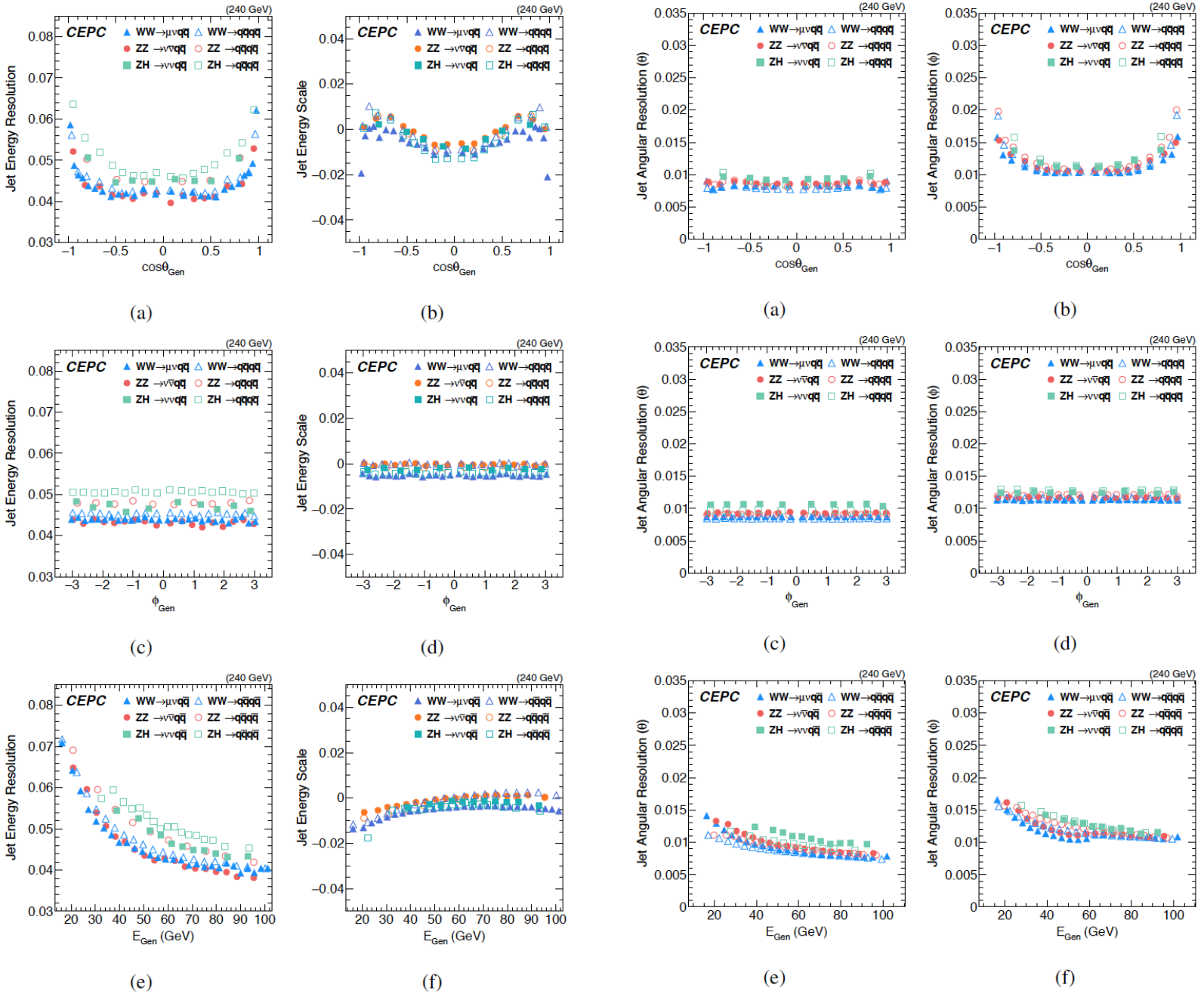


(b)

Peizhu LAI

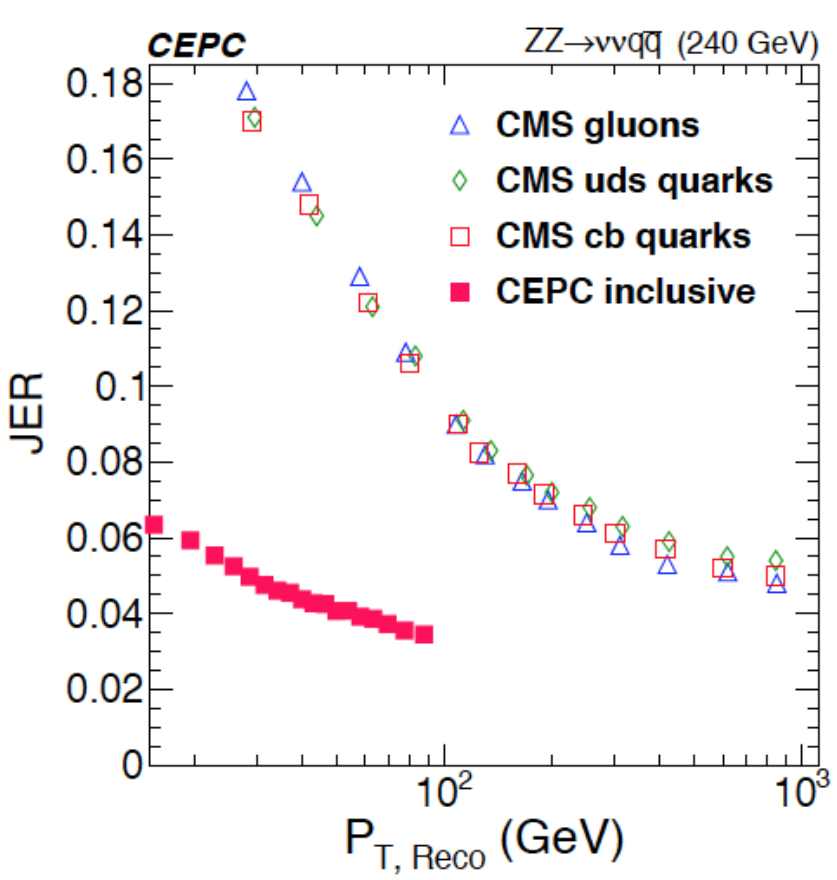
- Parton → Genjet → Recojet
- Matching between Genjet & Recojet using direction information
- Relative difference between Gen/Recojet: Jet Energy Resolution/Scale, Jet Angular Resolution/Scale

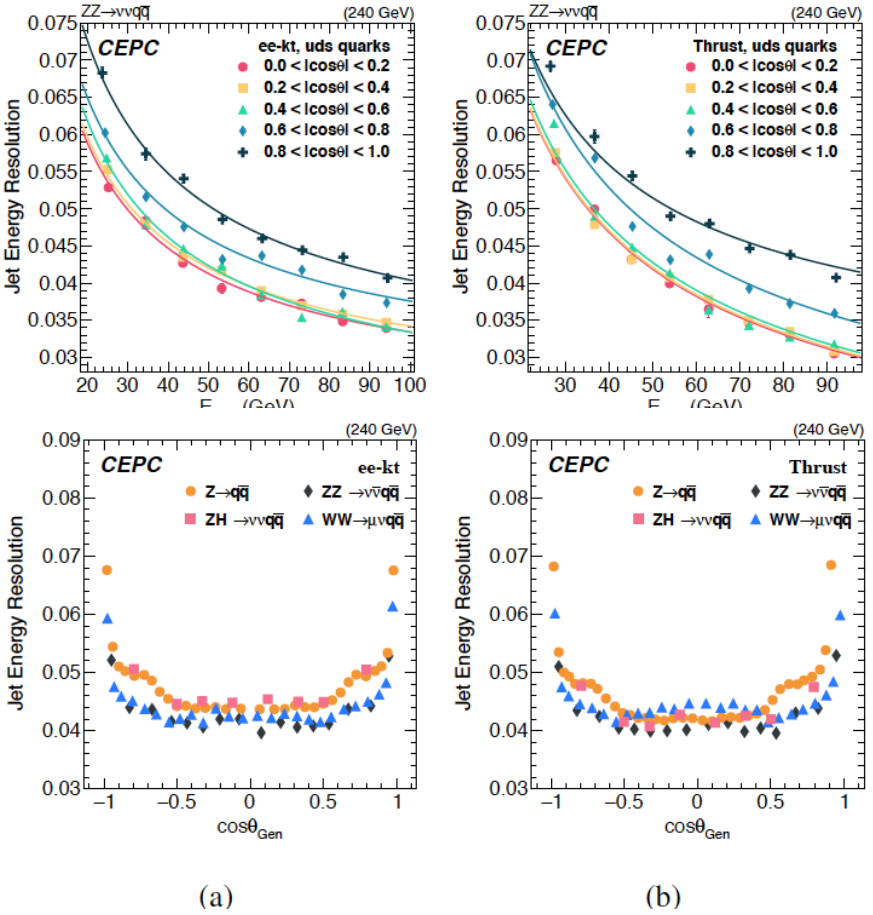
Differential jet response



Angular Scale: 1E-4!

JER: much better than LHC at same Pt

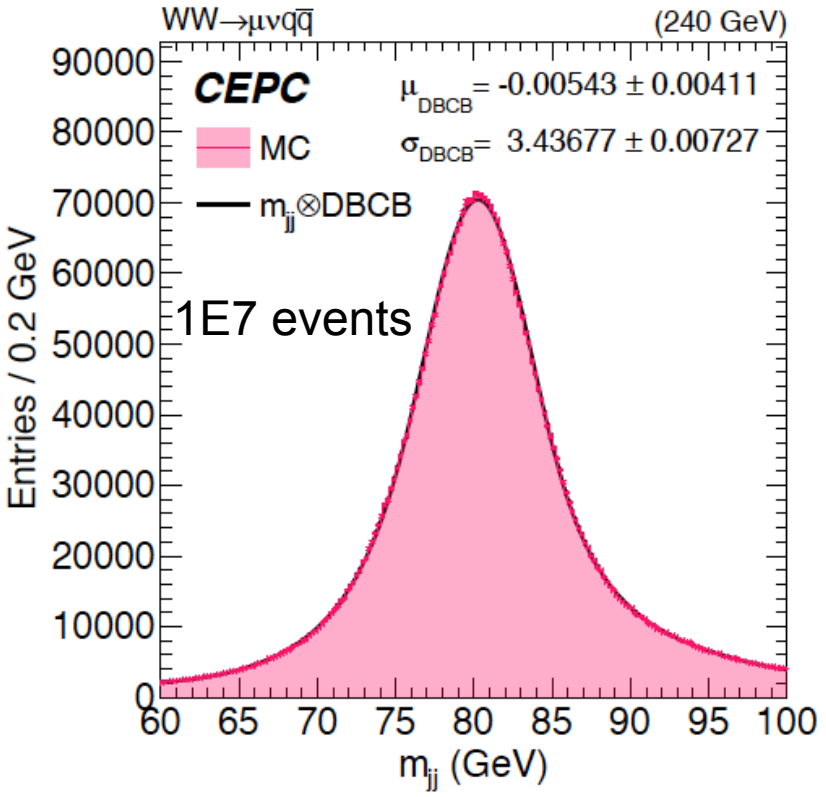




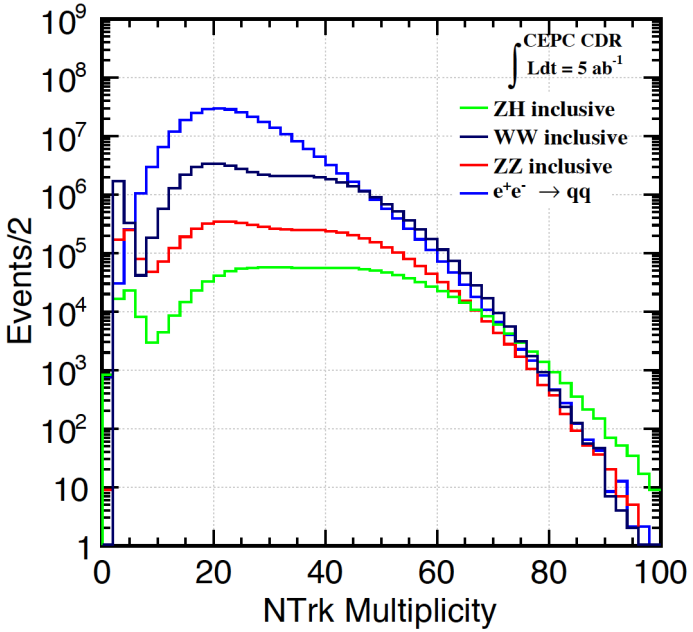
- Dependence on the Jet Clustering Algorithm: ~10%!...
- *What's the optimal choice of Jet clustering/matching for a given measurement? Why?...*

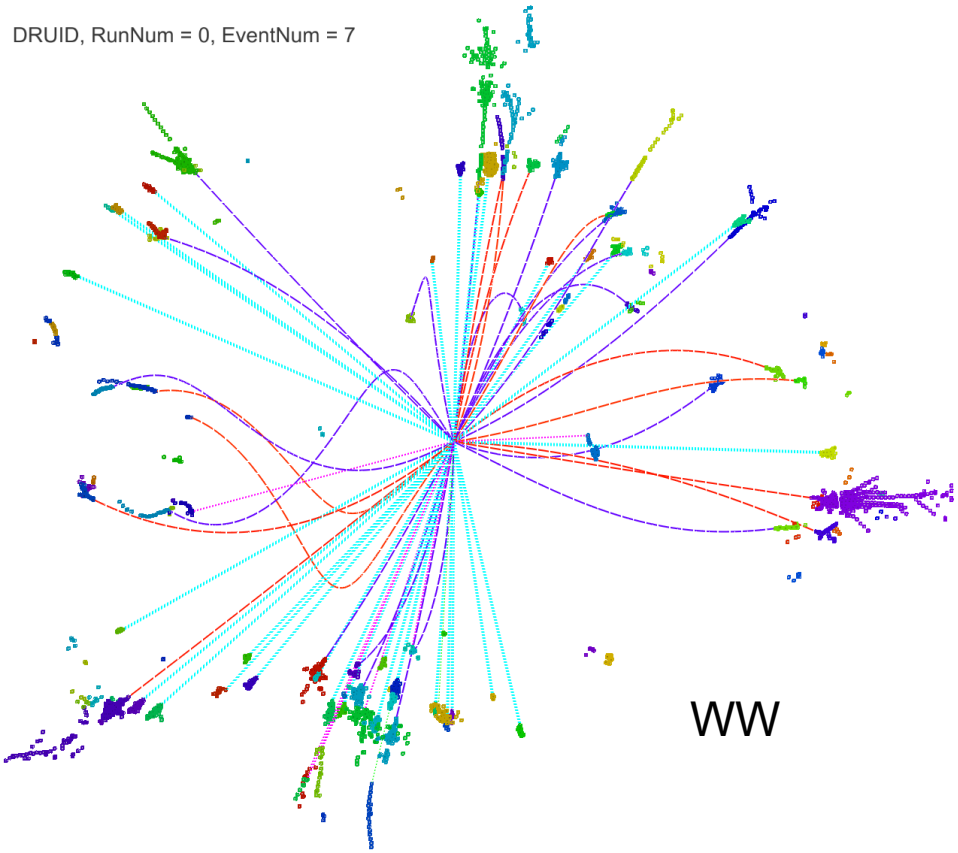
A very challenge & interesting topic

- W mass measurement at 240 GeV:
  - Statistic uncertainty ~
    - *1 MeV using only μνqq final state*
    - *Bias ~ 5 MeV once Z mass calibrated to known value*
  - Ultimate accuracy?
    - *Can we better control the systematic using the differential information?*
    - *Control the jet confusion?...*
    - *Identify & tame ISR?*
    - *Better calibrate?*
    - *Can we maintain sufficient stability over 7/10 years? ...*



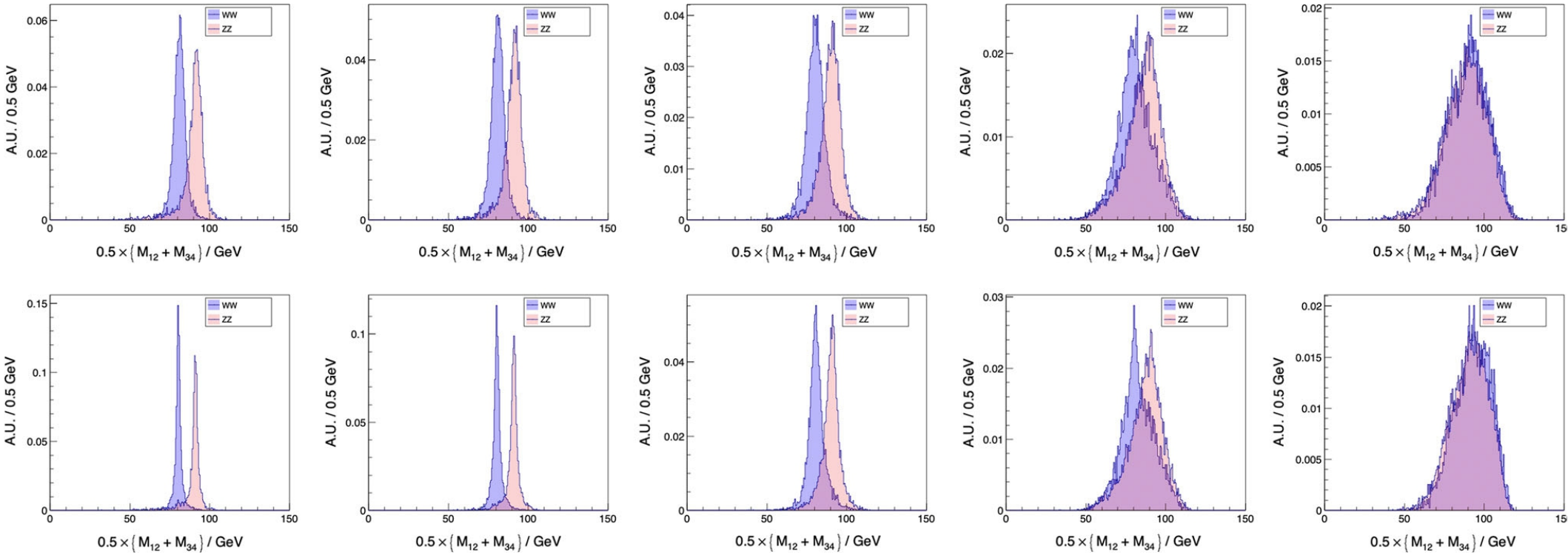
Color Singlet identification: Full hadronic WW-ZZ separation, an example

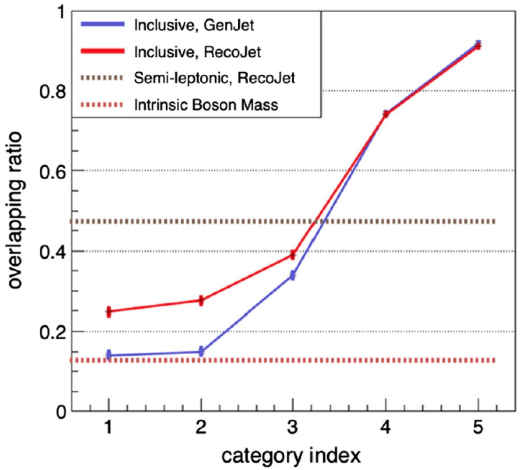




- Low energy jets! (20 – 120 GeV)
- Typical multiplicity ~ o(100)
- WW-ZZ Separation: determined by
  - Intrinsic boson mass/width
  - Jet confusion from color single reconstruction – jet clustering & pairing
  - Detector response

Jet confusion (wrong grouping) dominant the Separation performance

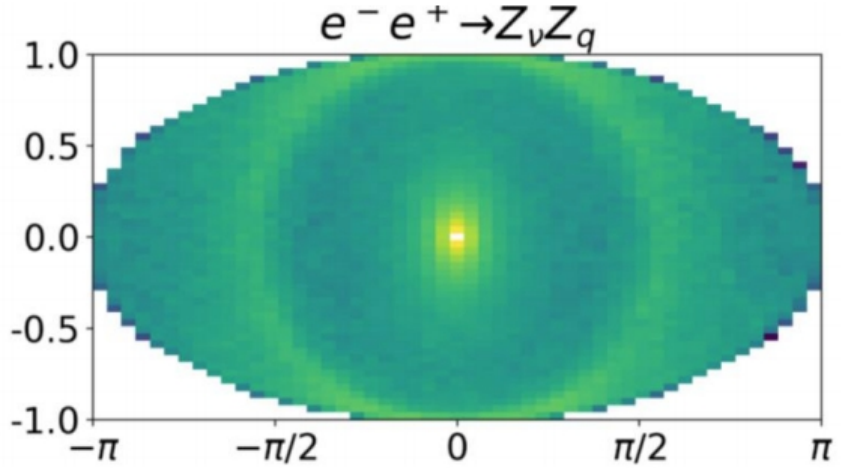


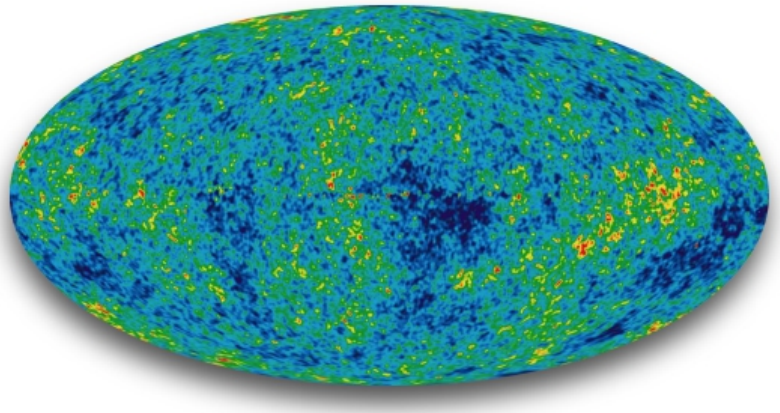


Need clever CSI, with respect to conventional Jet Clustering Matching Criteria...

Eur. Phys. J. C (2019) 79:274

“Dictionary” between Event Projection and CMB



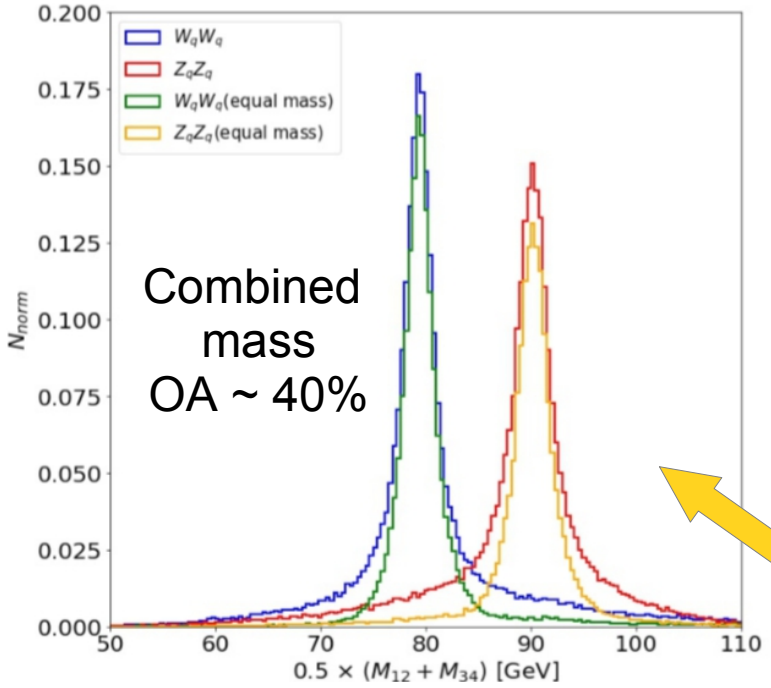


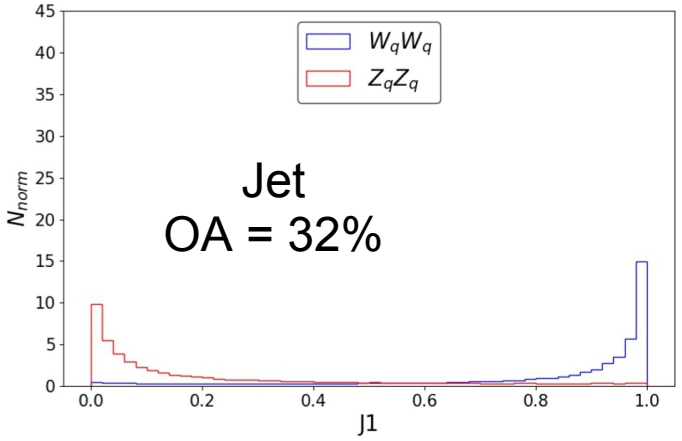
Mollweide projection at e^-e^+ colliders	All-sky CMB map
Projection sphere	Celestial sphere
Equatorial plane	Galactic plane
Energy (p_T, timing, charge, d_0, etc.) projection	Temperature (polarization) map
Event-level kinematics	Anisotropy
Fox-Wolfram moments	Power spectrum (TT, TB, BB, etc.)
Multi-spectra	Bispectrum, trispectrum, etc.
... ...	... ...

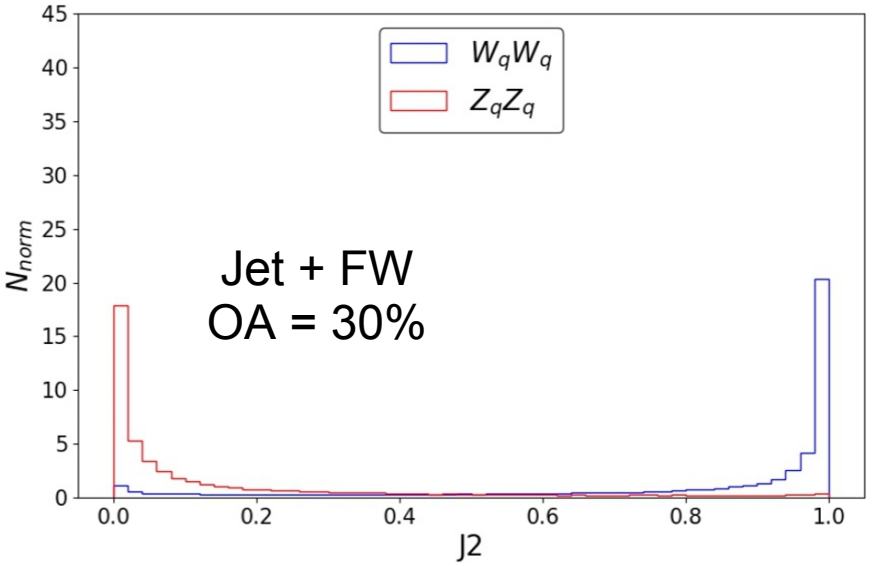
In such CMB-like information scheme, the event-level information is encoded as the FW moments at leading order and multi-spectra at higher orders.

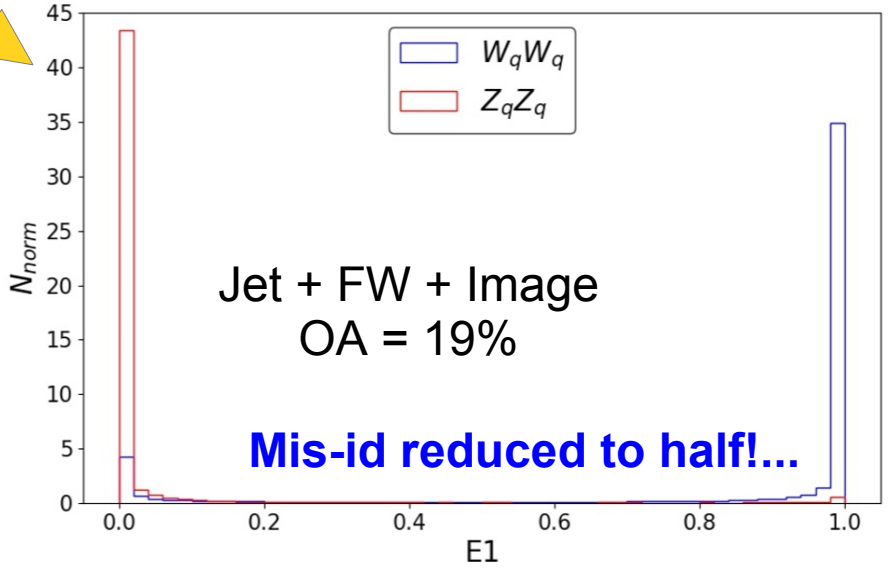
https://arxiv.org/abs/2004.15013

Separation with Jet, image & Machine L...









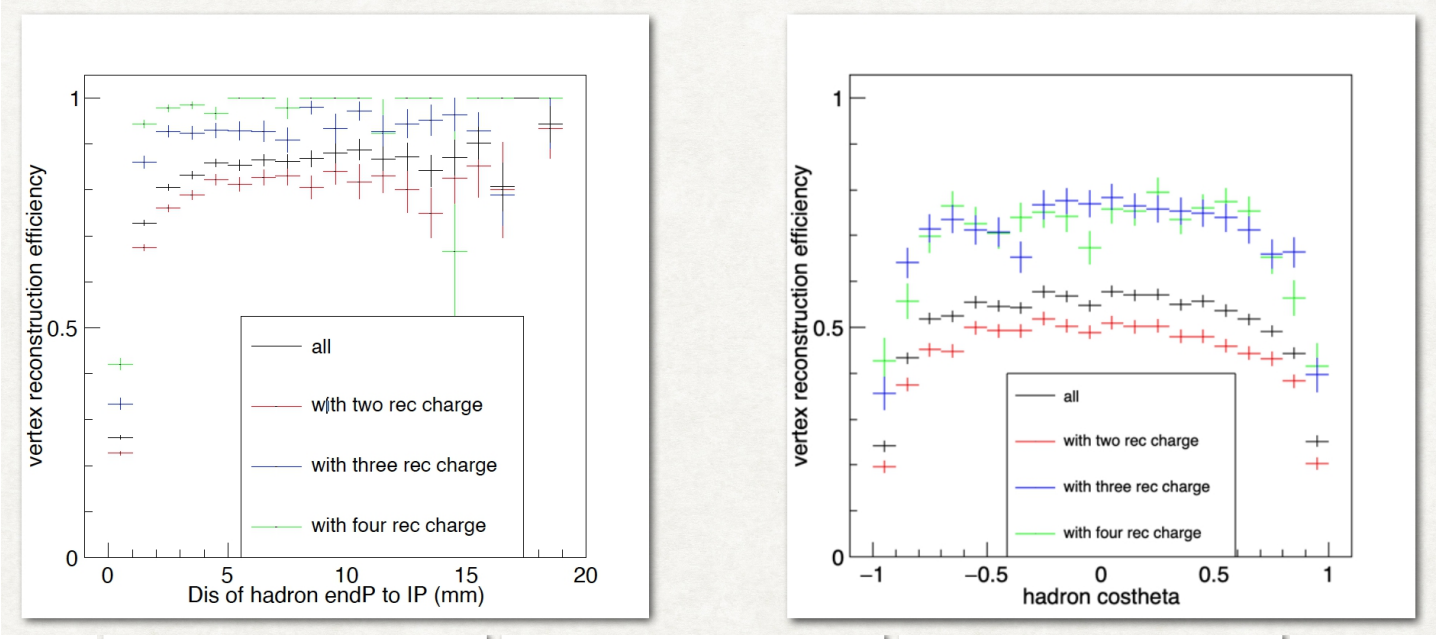
Truth level info. ~ ideal detector

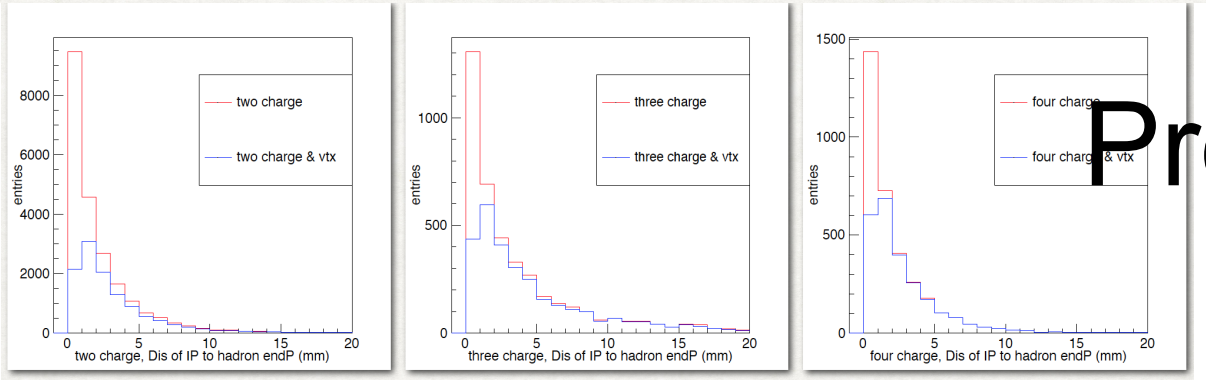
VTX reconstruction: Diagnosis

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

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

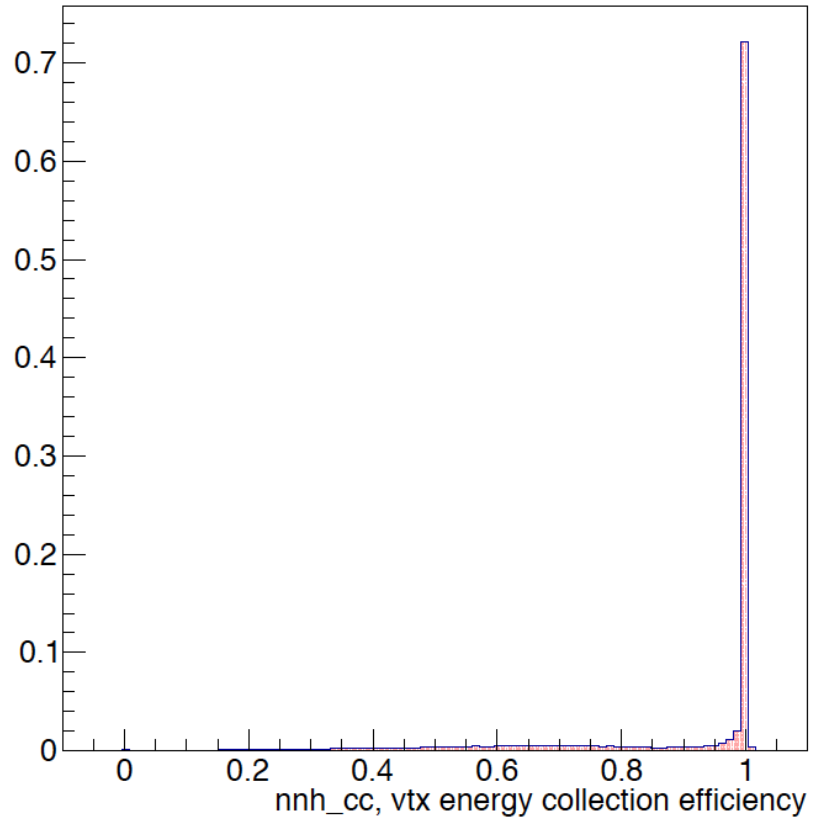
- At vvH, H→cc events.





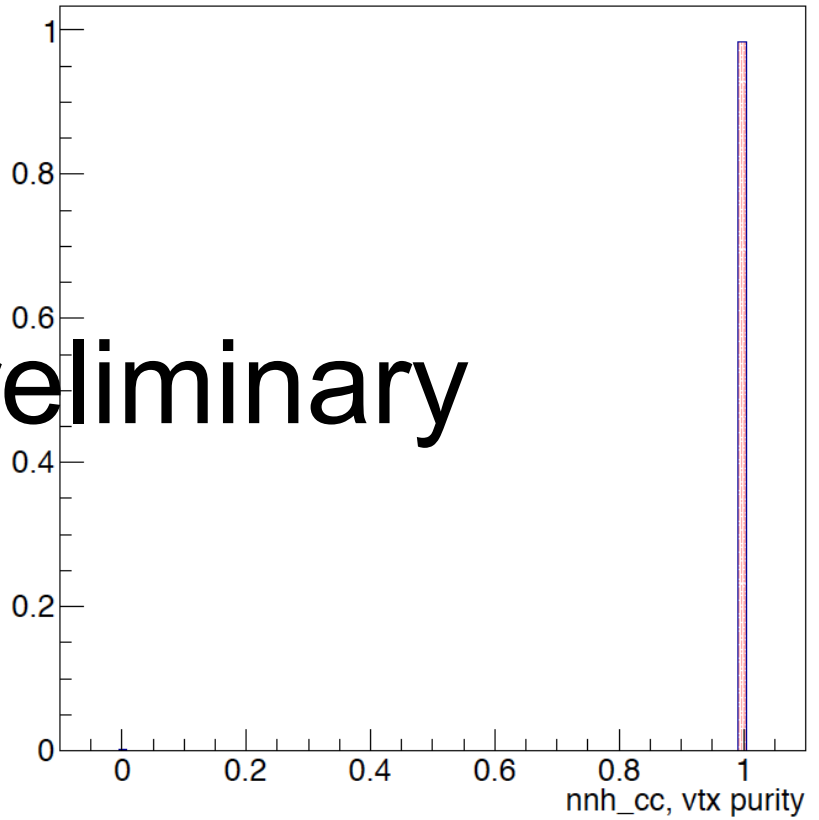
Preliminary

VTX reconstruction: Diagnosis



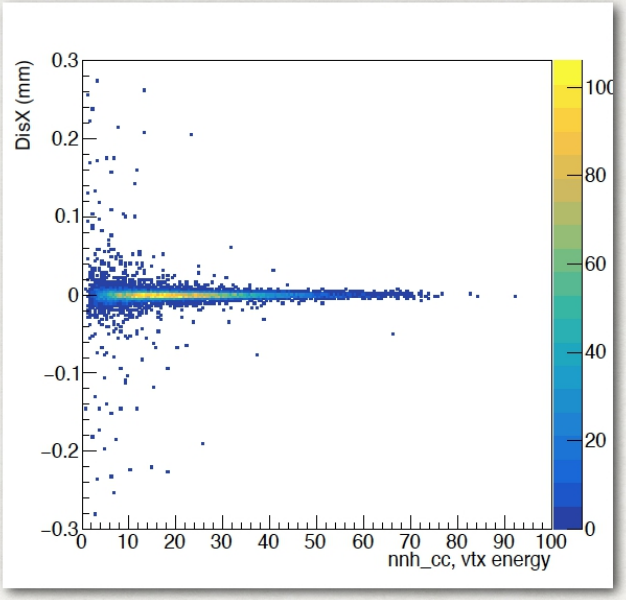
$$\frac{the\ \ vertex\ \ energy\ \ comes\ \ from\ \ hadron\ \ (RC)}{the\ \ energy\ \ of\ \ hadron\ \ charge\ \ particles\ \ (MC)},$$

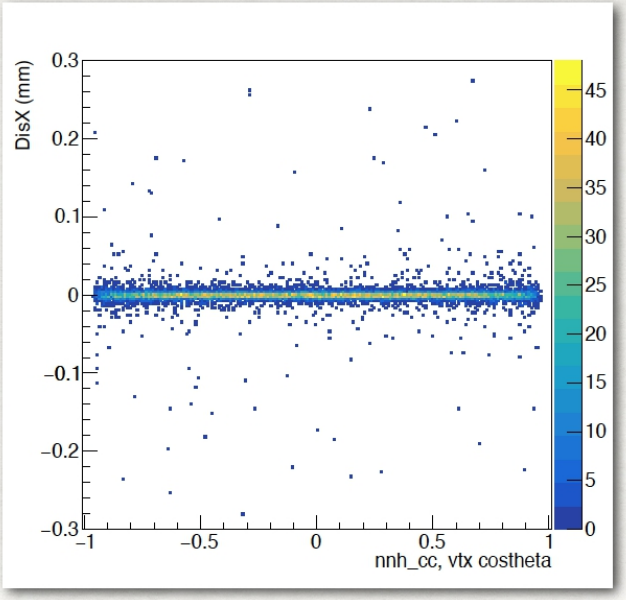
Preliminary

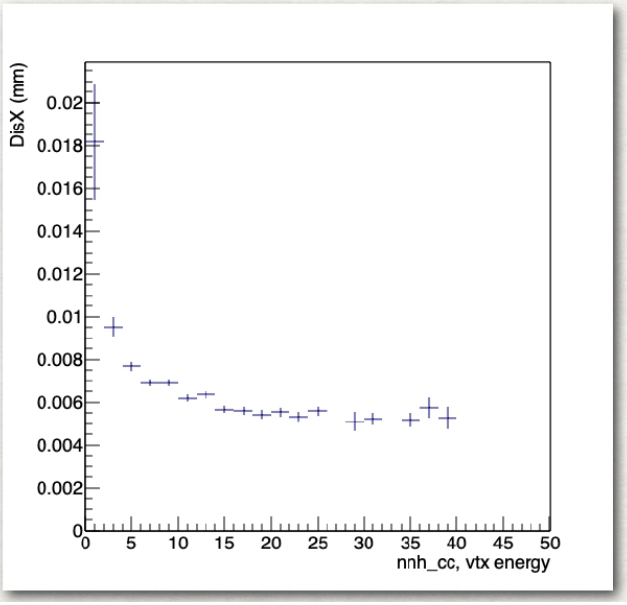


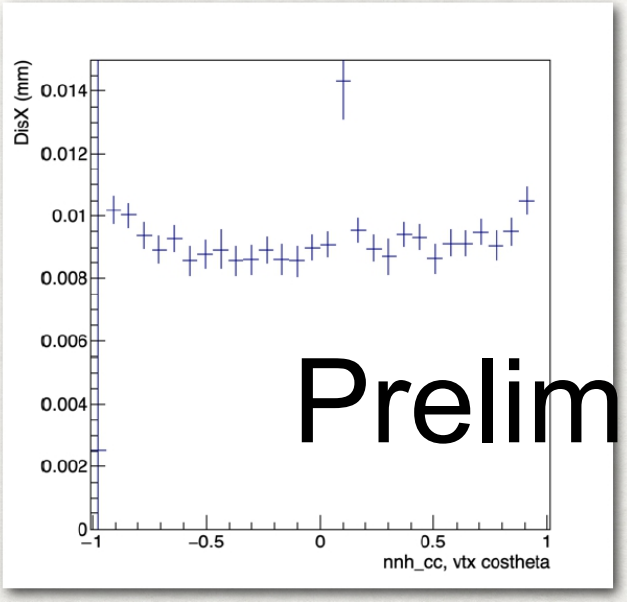
$$\frac{the\ \ vertex\ \ energy\ \ comes\ \ from\ \ hadron}{the\ \ energy\ \ of\ \ vertex}.$$

VTX Position resolution (transverse): 5-10 μm









Preliminary

For more detail

- Talks at Crystal Calorimeter WS
  https://indico.ihep.ac.cn/event/11938/other-view?view=standard
  - Jet lepton (Dan)
  - Optimization: BMR at different geometries (Yukun, Dan, Jiechen, Hanhua, etc)
  - Differential jet response (Peizhu)
  - Test of Principle: Reconstruction at crystal ECAL with long bars (Yuexin): 2 particle incident on super cell is solvable.

- CEPC General Detector meeting
  - Going beyond the jet (Lingfeng LI):
    https://indico.ihep.ac.cn/event/12201/contribution/7/material/slides/0.pdf

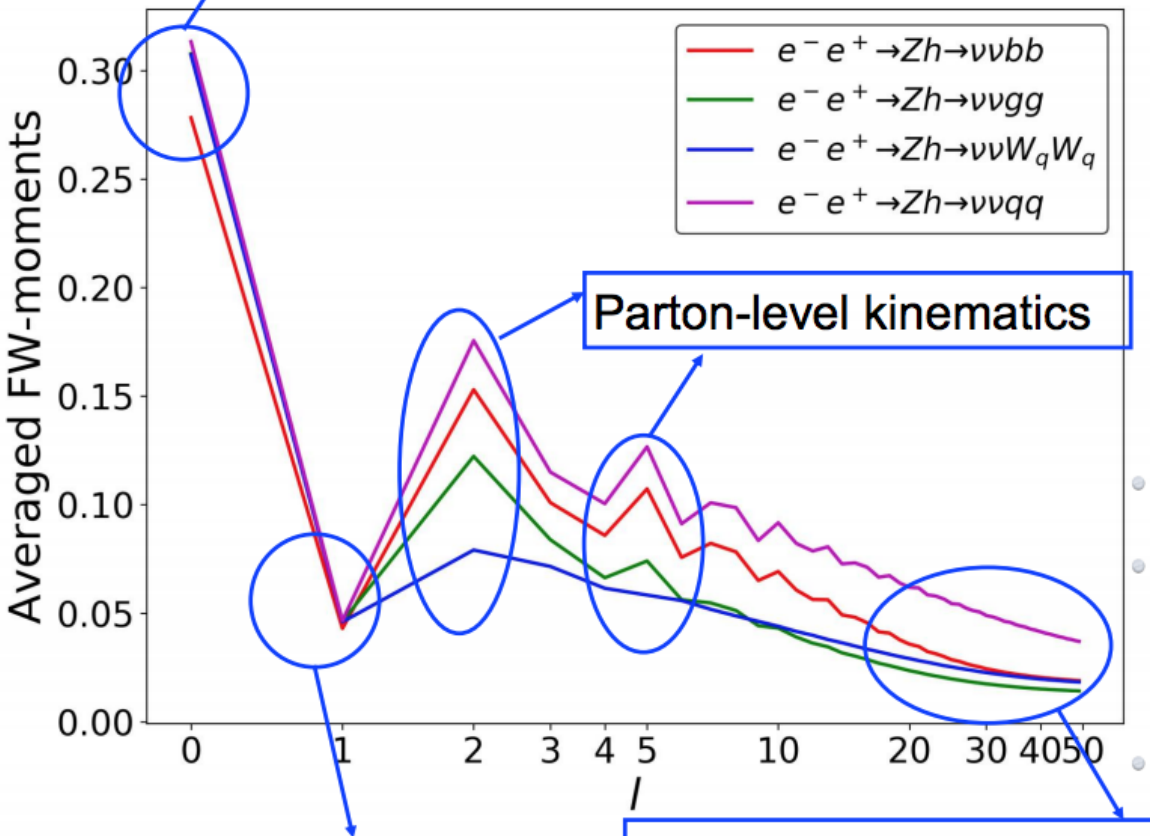
Summary

- Leptons:
  - Electron & Muon: improvement is always possible, but not significant
    - Maximally ~10% improvement in total eff & purity for electron in b-jet
  - Tau: eff*purity~70%/50% for isolated/jet tau – reasonable/improvement might be significant
  - Summarize into publication
- Hadronic System:
  - BMR, standard & guidance the optimization:
    - BMR→3.6%. Allowance of 4% means cost can be significantly reduced w.r.t baseline.
    - Better BMR is an important: goal for Reco-Algorithm development.
  - Differential: Promising - Superb to LHC experiments (2-4 times in JER, 4-10 times in JES...) benchmark analyses, i.e., TGC is needed to understand the requirement
  - CSI (Color Singlet Identification): be innovative!...
- VTX: at H→cc event
  - Looks good except **VERY LOW** efficiency for VTX with Charge Multiplicity of 2: **Diagnosis!**
  - Typical position resolution of 5-10 μm:
    - Is it good enough?
    - Relation with Tracker/VTX geometry?

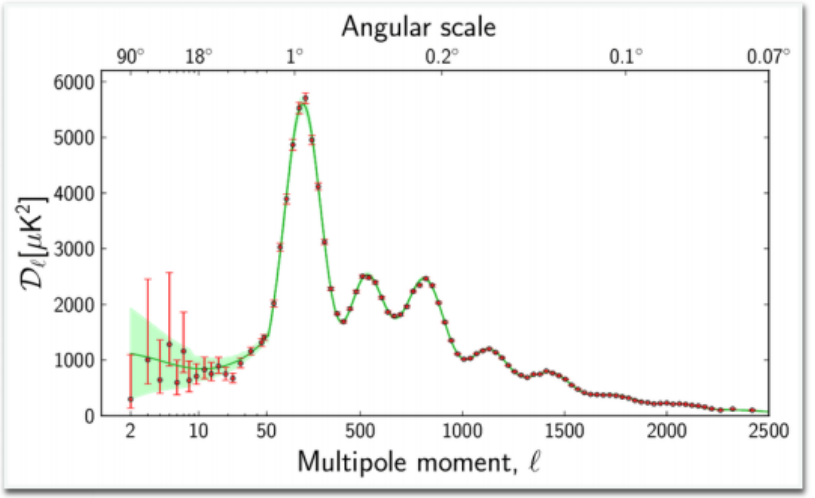
Backup

FW Moments of Energy Distribution

$$H_{EE;0} = \frac{(\sum_i E_i)^2}{s}$$



$$H_{EE;1} = \frac{|\sum_i \vec{p}_i|^2}{s}$$

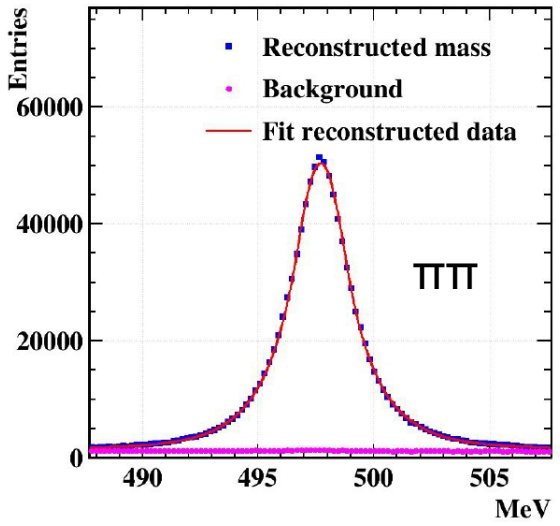


Analogue to CMB power spectrum

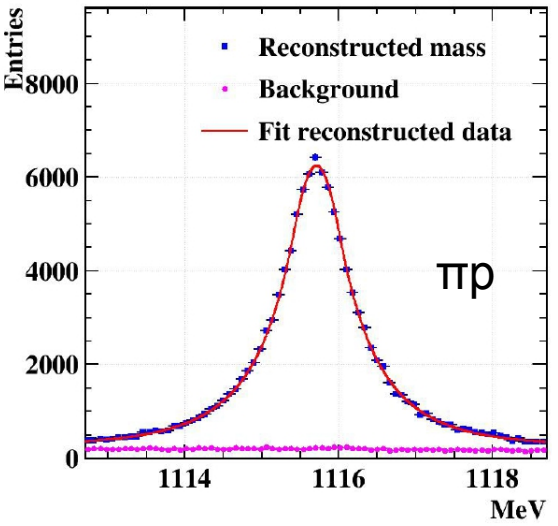
Difference: suppressed sample (``cosmic'') variance, due to large size of data sample

Similarity: physics at characteristic sales may result in ``acoustic peaks''

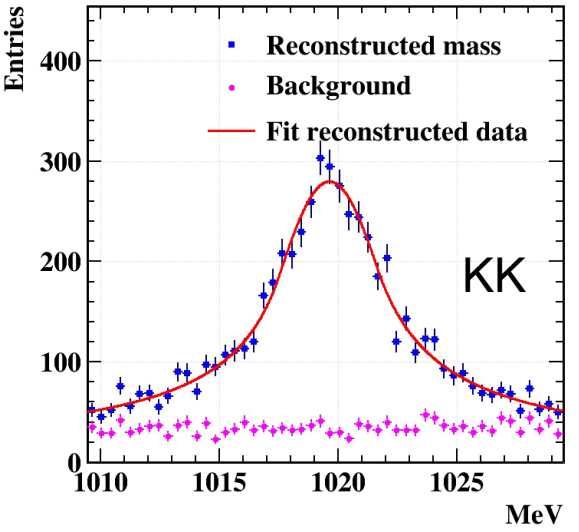
K_s, Λ, ϕ...

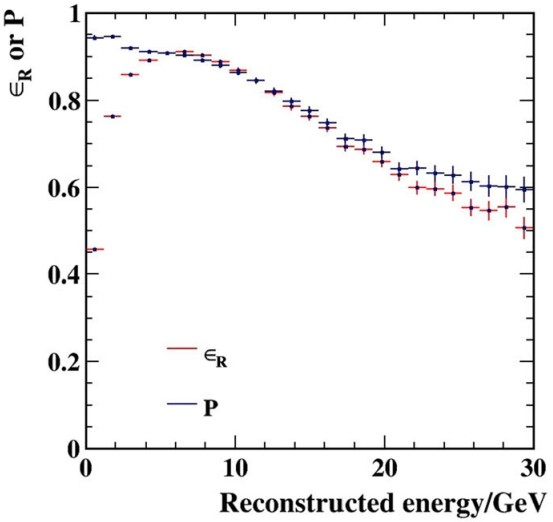


(a) K_S^0

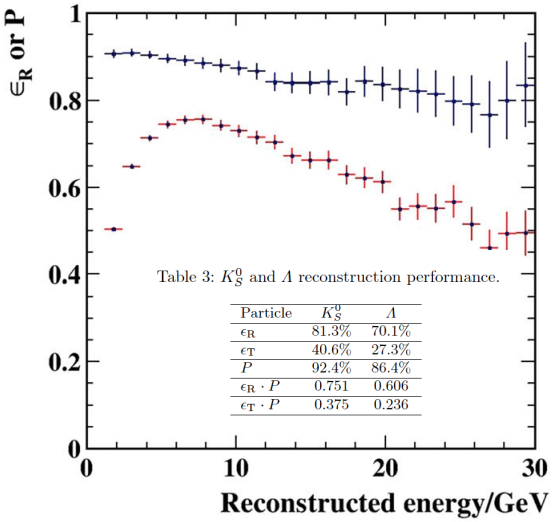


(b) Λ

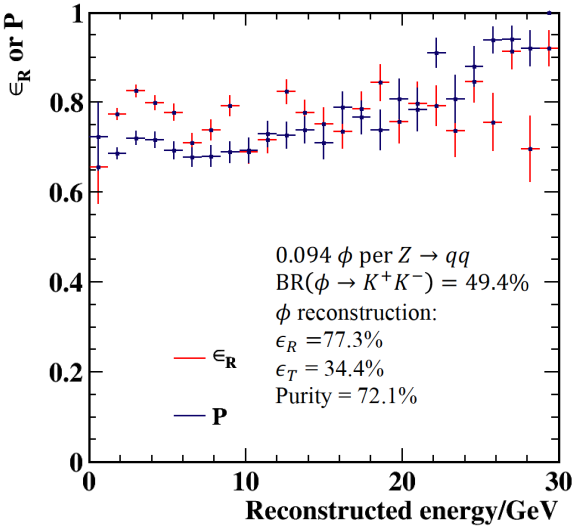




(a) K_S^0



(b) Λ



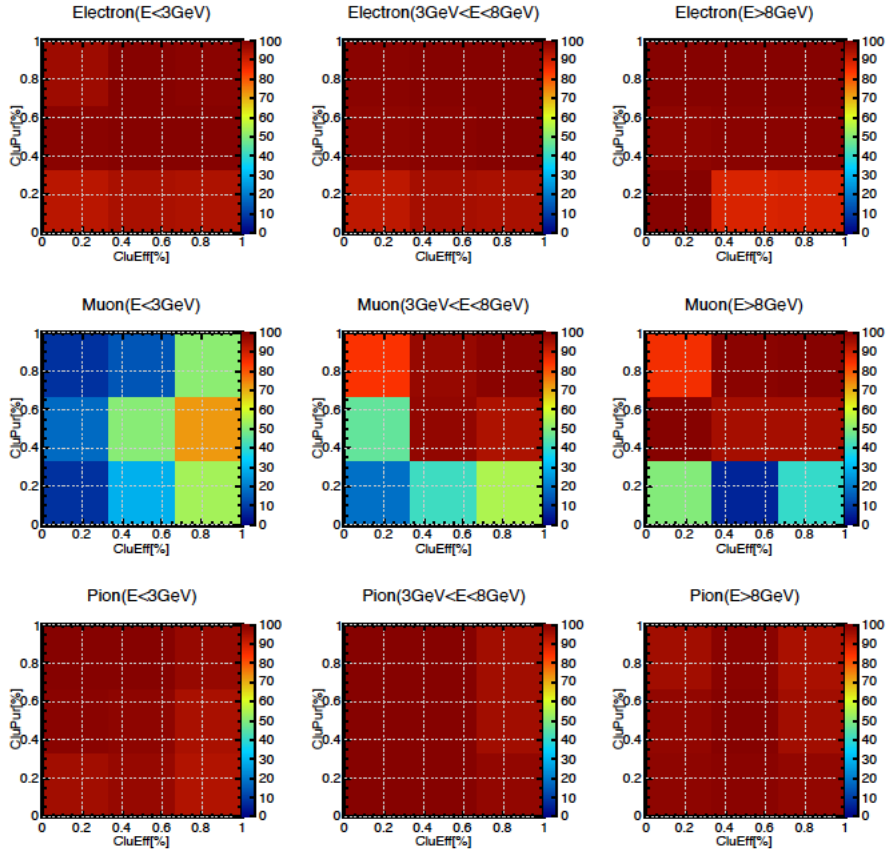


Fig. 8 The lepton identification efficiency in jets depending on clustering efficiency and purity.

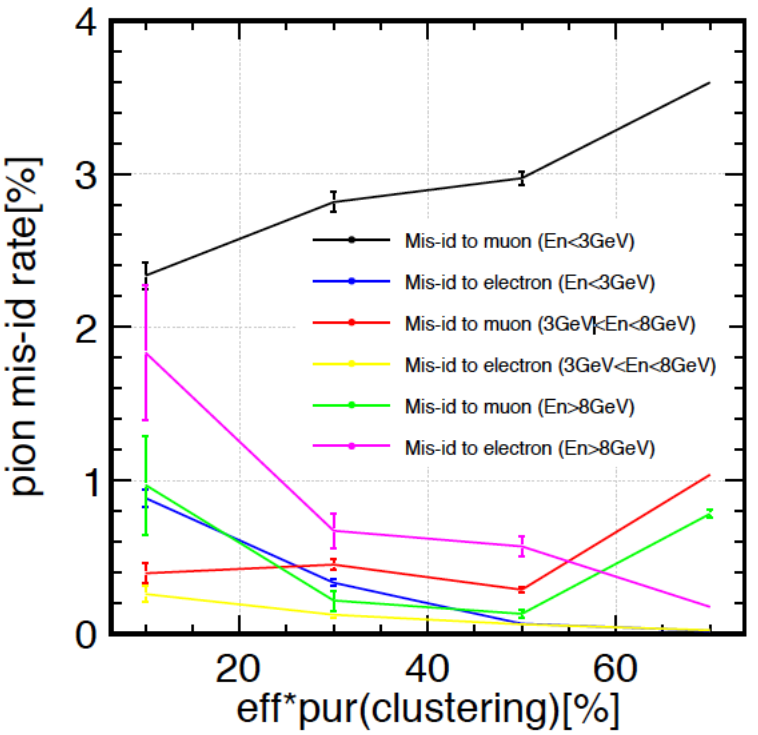


Fig. 9 The mis-id rate of pions to electrons or muons in jets, depending on clustering efficiency times purity.