ZH jets mode study with realistic PFA

TILC09 Physics and Benchmark

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with ILC physics WG (Asia)

ZH mode study

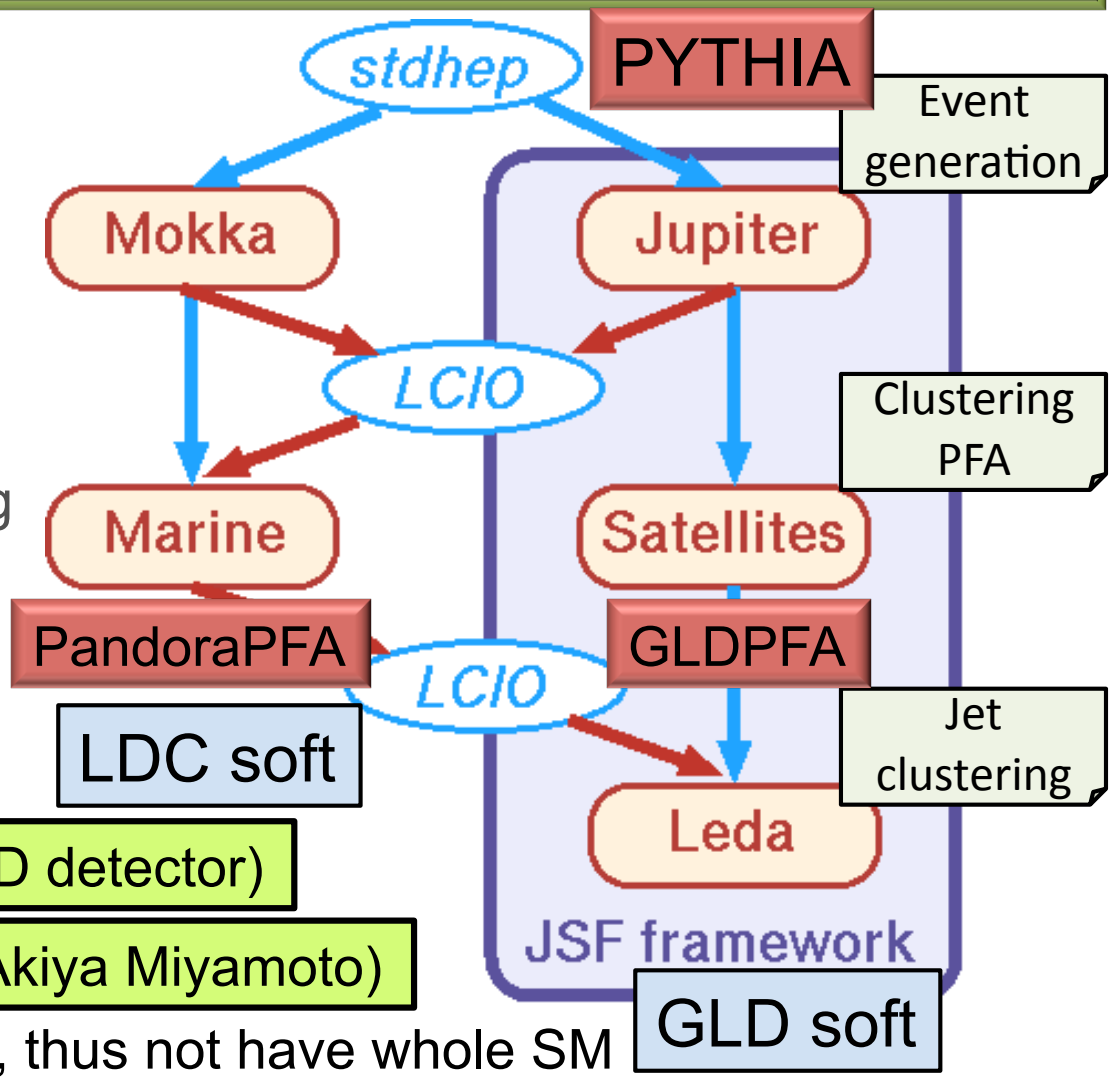
- Analysis of the Higgs mass direct reconstruction in ZH jet mode can be one of the performance tests of the realistic Particle Flow Algorithm (PFA), since their final state forms multi-jet.
- Compare performance of the realistic PFA with the perfect clustering PFA in ZH jet mode.
  - GLDPFA (GLD base) and PandoraPFA (LDC base)
    →Currently merged as **ILD** for LOI study

ZH recoil mass (tracker resolution)
ZH branching ratio (b/c tagging efficiency)
studies are shown in LOI benchmark analysis

Since this is my Ph.D thesis theme and a little old content compare to LOI physics.

Analysis tools in ILD (GLD/LDC)

- "GLDPFA" is prepared for GLD detector simulation
  - Jupiter (MC generation)
  - Satellites (reconstruction/PFA)
  - Leda (Jet clustering)
- Jupiter data can also analyze with PandoraPFA by converting LCIO format.
- We try to use these PFA for same MC data and compare with perfect PFA.



Detector : gldapr08_14m (3T GLD detector)

MC data : Produced in KEK (by Akiya Miyamoto)

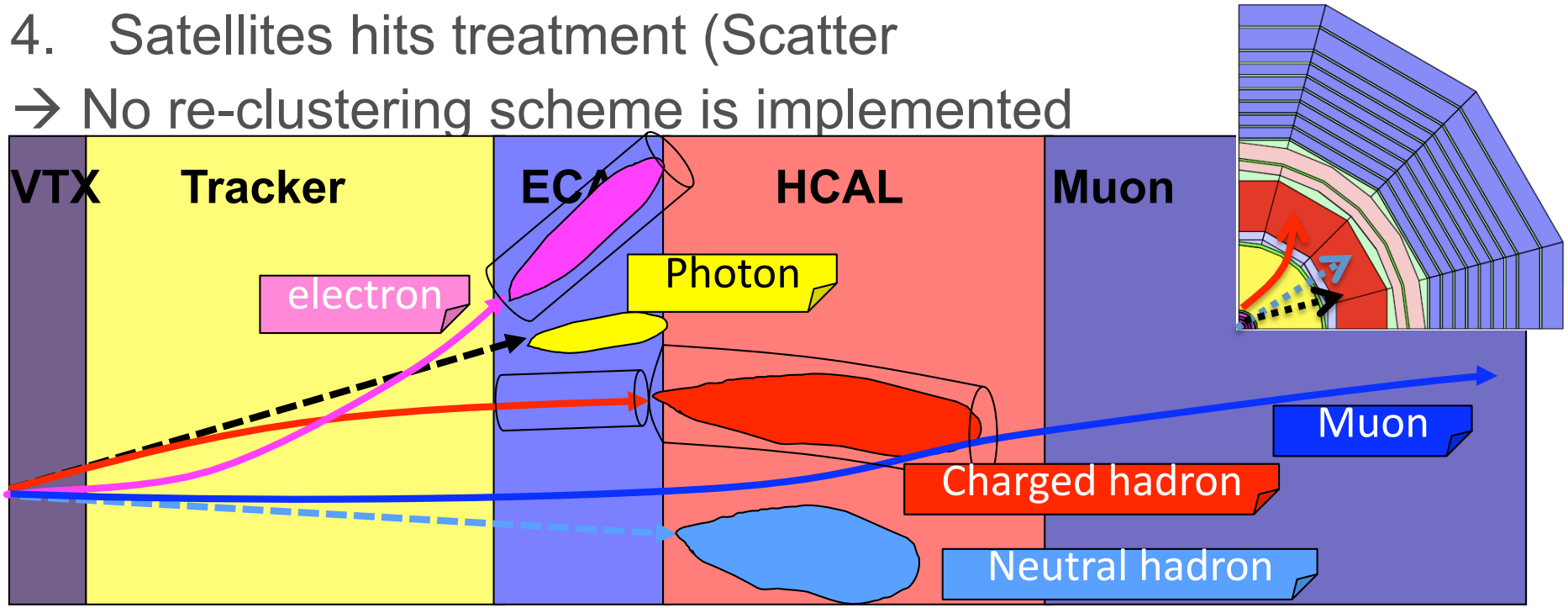
Not use standard stdhep samples, thus not have whole SM background processes (ZZ background is only considered)

Realistic GLDPFA scheme

After applying nearest neighboring clustering, process following scheme

1. Photon finding (Calculate photon likelihood)
2. Charged hadron clustering (track cluster matching)
3. Neutral hadron finding (Calculate NHD likelihood)
4. Satellites hits treatment (Scatter

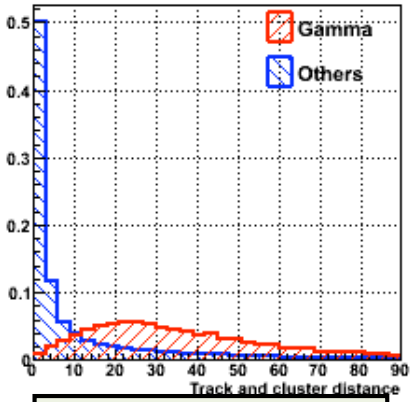
→ No re-clustering scheme is implemented



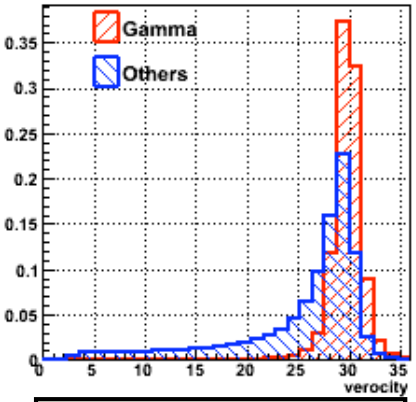
Detail of GLDPFA reconstruction

Photon finding (with Likelihood method)

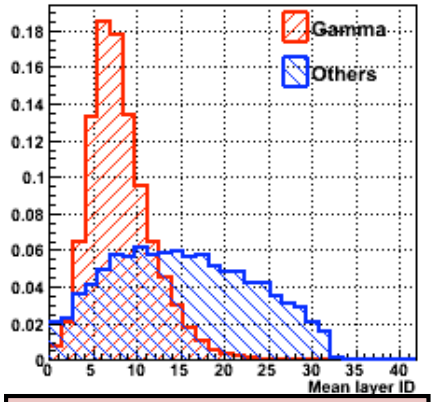
Track distance



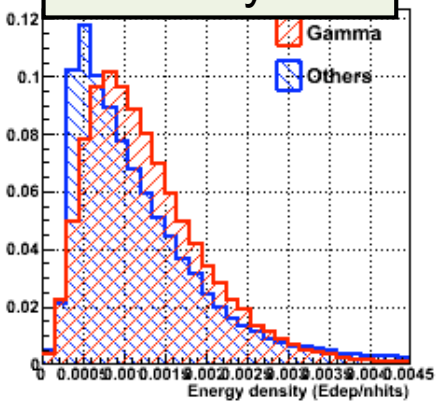
velocity



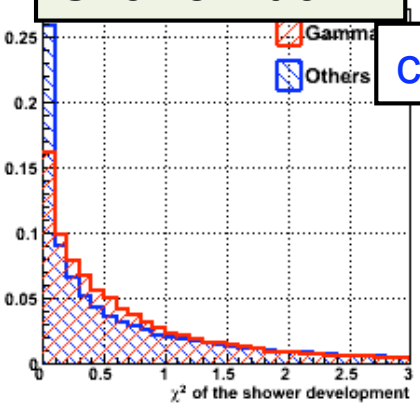
Edep/nhits



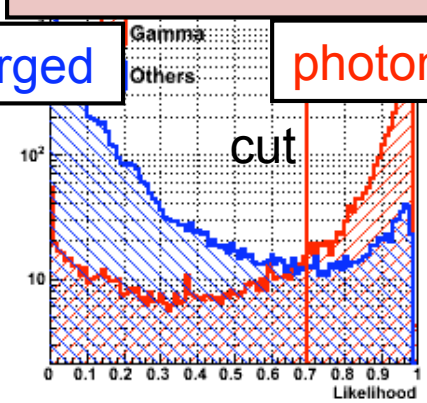
Mean layer ID



Shower fit chi2



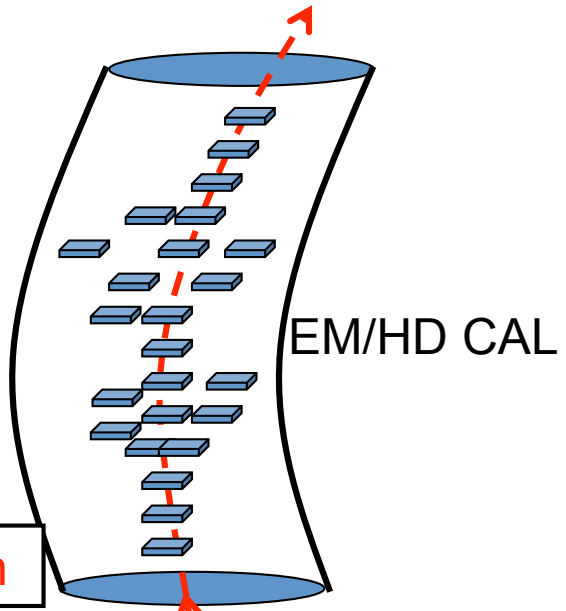
Photon likelihood



charged

photon

Charged hadron finding

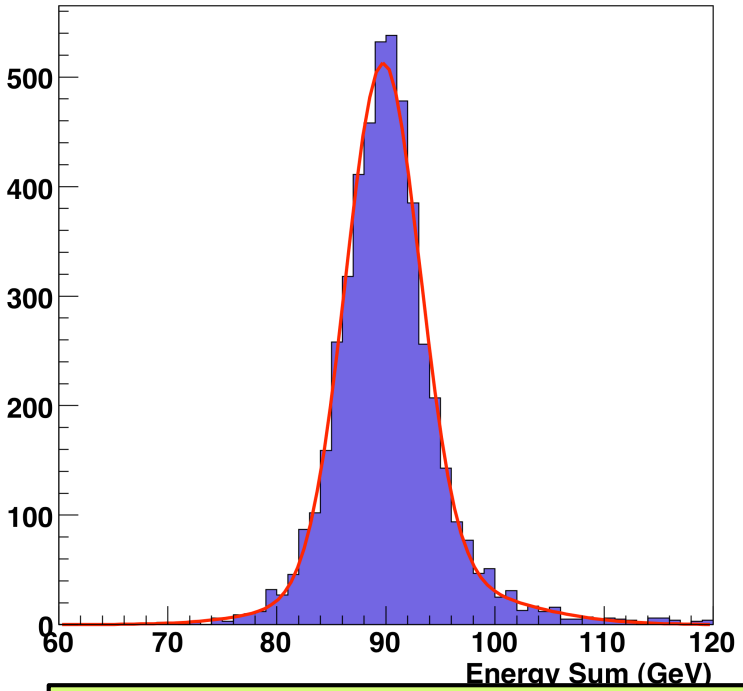


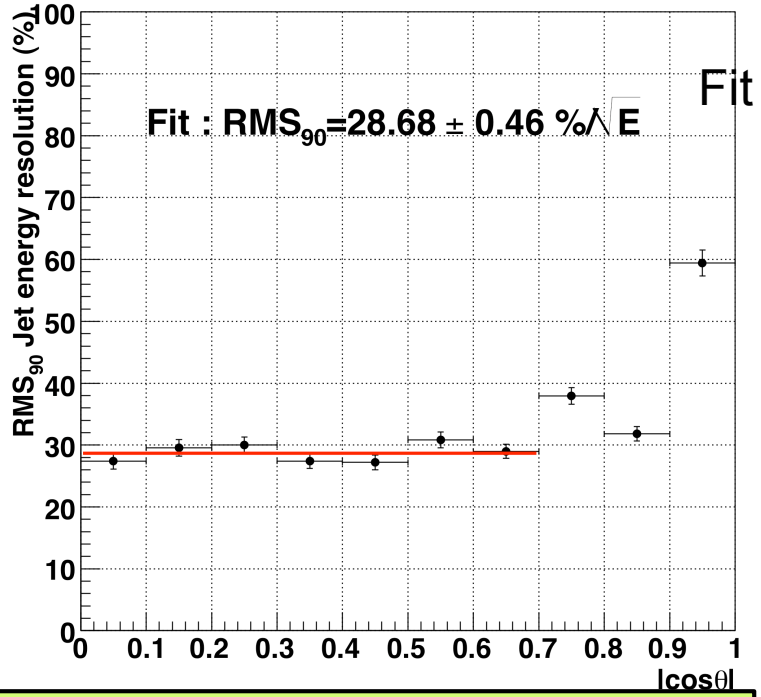
Tube based
track-cluster matching

Neutral hadrons finding also use same likelihood method

PFA tools cont.d
Jet energy resolution in Z-pole

GLDPFA performance with Z pole event (Z→qq @91.2 GeV)





Fit : |cosθ|<0.7

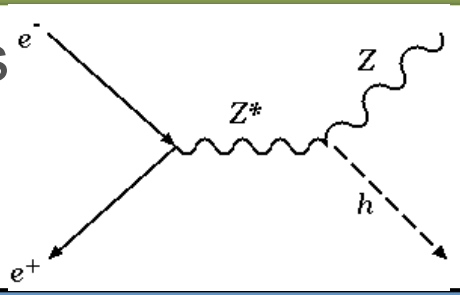
RMS_{90} = 28.7±0.46% /sqrt(E) in the fit region of |cosθ|<0.7

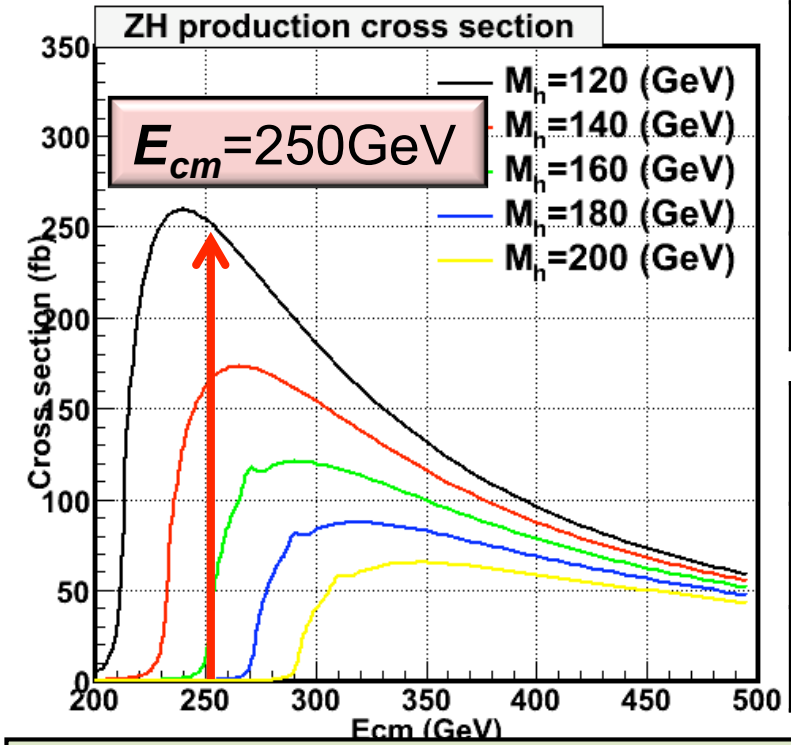
PandoraPFA can achieve the RMS_{90}~25% listed in LOI at 45GeV jet

In GLDPFA, re-clustering, photon recovers etc are not implemented.
But we shift to the “Physics study ” in jet mode analysis with this PFA.

Cross section of ZH production

At the E_{cm}~250GeV, ZH Higgs-strahlung process has largest production cross section at the Higgs mass M_h=120GeV





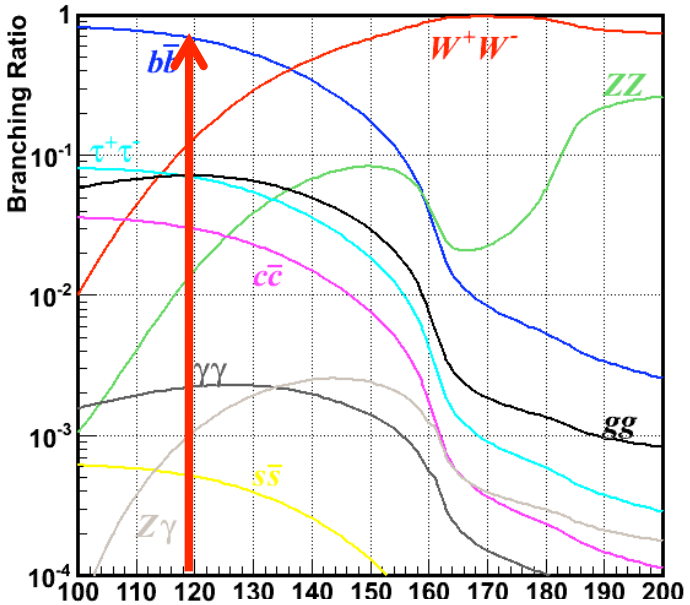
Z→invisible	E_{cm}=250GeV $\mathcal{L}$=250fb^{-1}
$ZH \rightarrow \nu\nu H$	σ=44.79 fb (11198)
$ZZ \rightarrow \nu\nu qq(BG)$	σ=307.4 fb (76850)

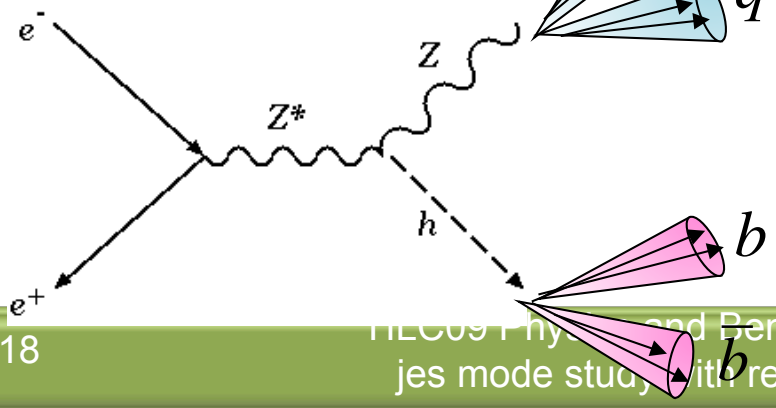
Z→hadronic	E_{cm}=250GeV $\mathcal{L}$=100fb^{-1}
$ZH \rightarrow qqH$	σ=157.5 fb (15750)
$ZZ \rightarrow qqqq(BG)$	σ=586.0 fb (58600)

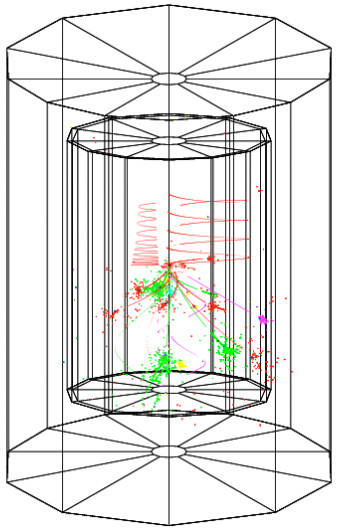
Higgs direct reconstruction with ZH production at E_{cm}=250GeV, M_h=120GeV

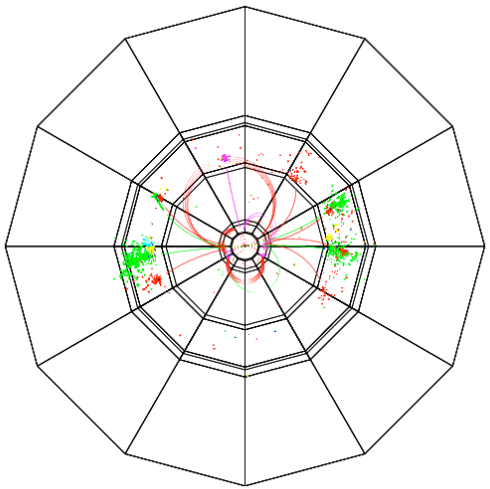
Event display of ZH jets mode

Higgs mainly decay to $b\bar{b}$ (di-jet) at M_h=120GeV

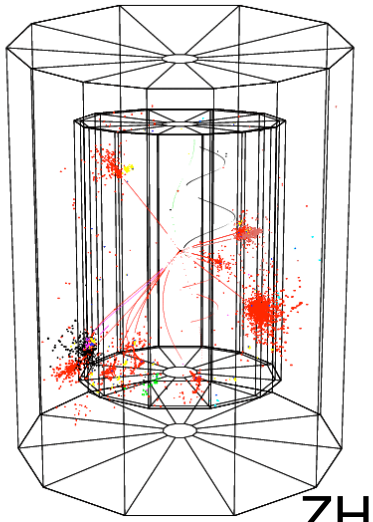


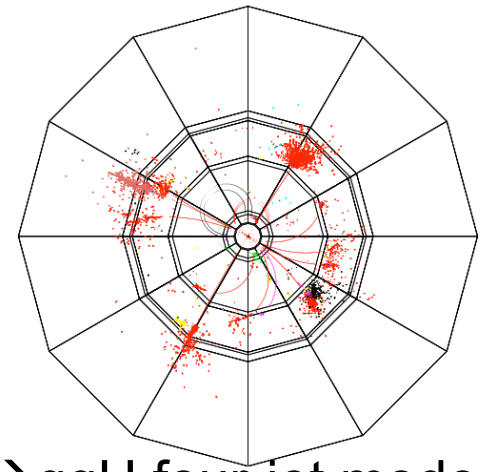






ZH→ννH two-jet mode



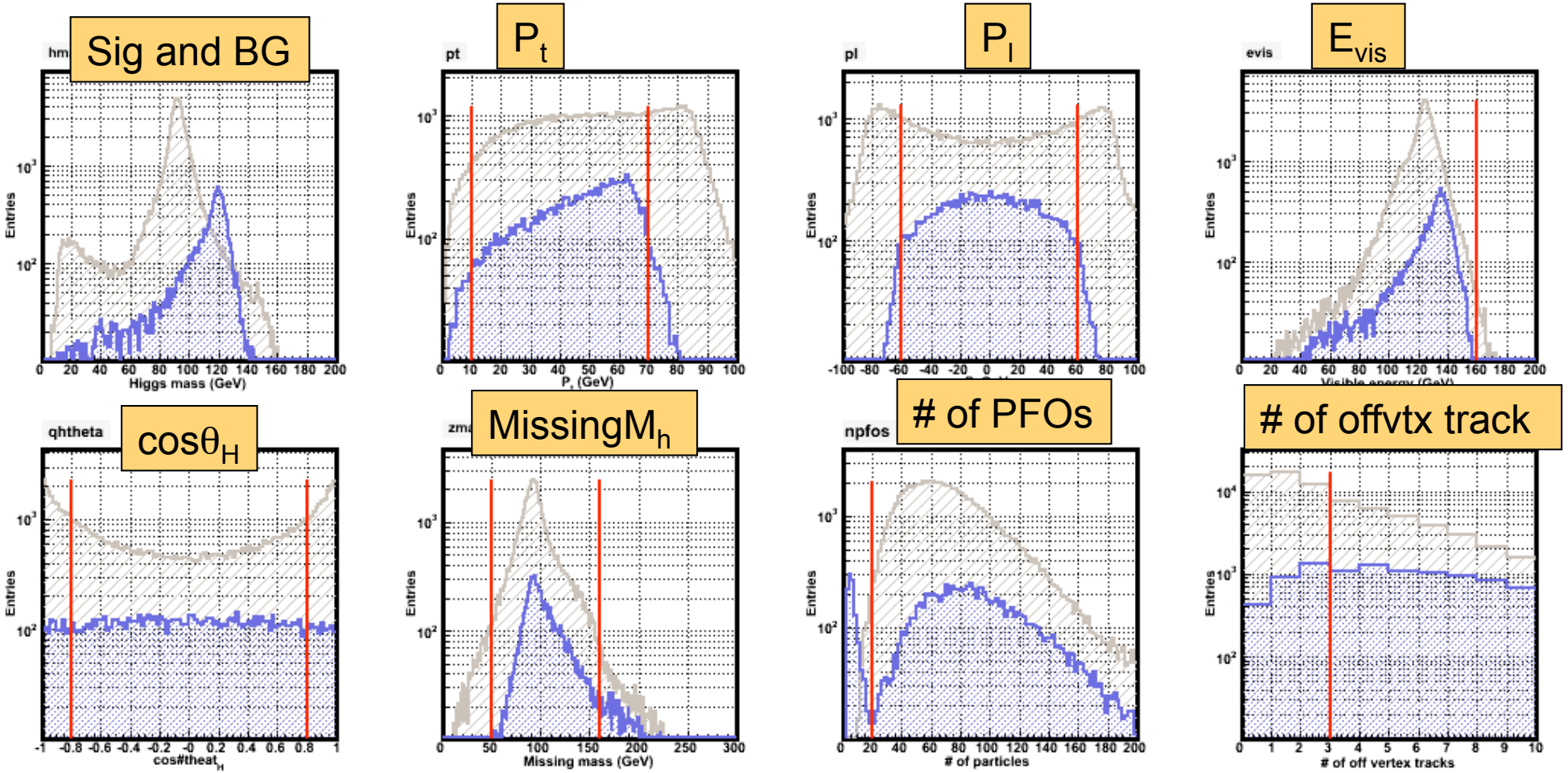


ZH→qqH four-jet mode

Event reconstruction of $ZH \rightarrow \nu\nu H$

- $ZH \rightarrow \nu\nu H$ (two-jet) case
  - just merge all the PFOs and get invariant mass as Higgs mass (Z is invisible)
- Background : $ZZ \rightarrow \nu\nu qq$ two-jet ($\mathcal{L}$=250fb^{-1})
- Selection criteria for background rejection
  - Visible energy : $E_{vis} < 160$ GeV
  - $|P_l| < 60$ GeV
  - P_t : $10 < P_t < 70$ GeV
  - Missing mass : $MissM \sim M_Z$
  - B tag probability (LCFI vertex) : Btagging prob > 0.8
    - # of off vertex tracks cut for GLD tools : offvtx3 > 3
  - Production angle of Higgs : $|\cos\theta_h| < 0.8$
- Kinematic 4C (E, P) fit has applied for missing energy correction

ZH→ννH with ZZ background



P_l, cosθ, b-tagging works efficiently for ZZ background rejection

Higgs signal

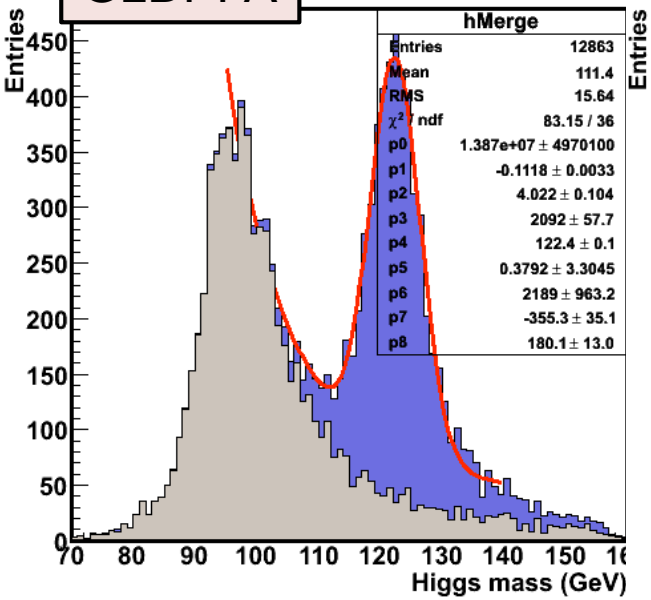
ZZ BG

Two-jet mass reconstruction

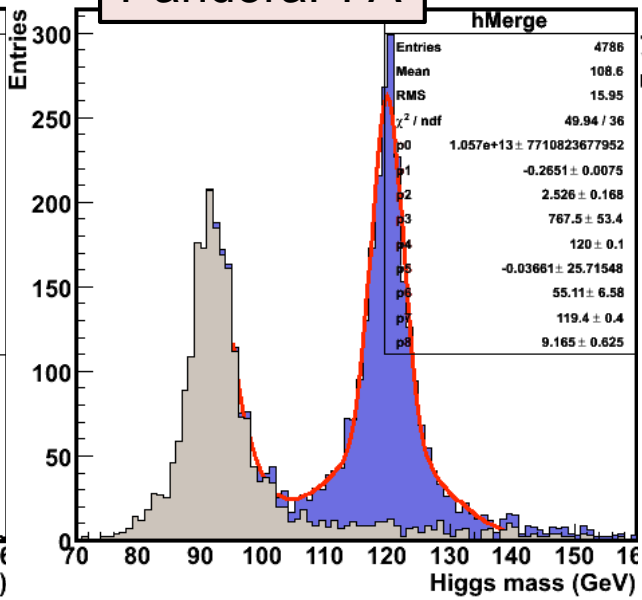
4C fit for $ZH \rightarrow \nu\nu H$ 2 jet

Measured variables : jet energy and angle

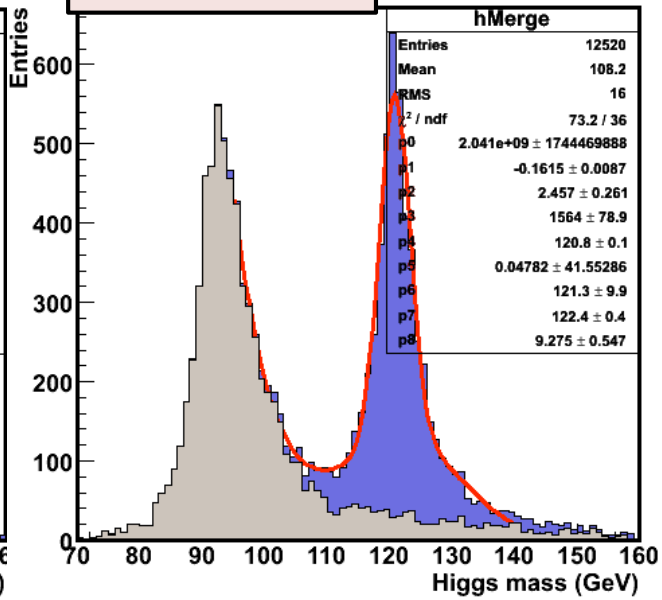
GLDPFA



PandoraPFA



Perfect PFA



M_h=122.43 ± 0.09GeV
σ=4.02± 0.10 GeV

M_h=119.59 ± 0.13GeV
σ=2.53± 0.16 GeV

M_h=120.82 ± 0.07GeV
σ=2.46 ± 0.26 GeV

Pandora PFA achieve the almost same level as perfect PFA

Fitted with Gaussian convoluted Gaussian function with Expo BG

LCFIVertex makes better background rejection in PandoraPFA

Event reconstruction for $ZH \rightarrow qqH$

- $ZH \rightarrow qqH$ (four-jet) case
  - Forced 4 jet clustering has applied with Durham jet finder.
  - GLDPFA cannot reconstruct well for four-jet mode because of particles multiplicity and worse jets combination.
- Selection variables
  - χ^2 of jet combination : $\chi^2 < 5$
  - P_t < 20 GeV
  - Visible energy : E_{vis} > 220 GeV
  - Higgs production angle : $|\cos\theta_h|<0.8$
  - thrust < 0.9
  - Missing Mass of Higgs candidate jets : $MissM_{34} \sim M_Z$
  - B tagging probability : Btag prob > 0.8 or # of offvtx > 3
  - Energy of jets : E_j > 20 GeV

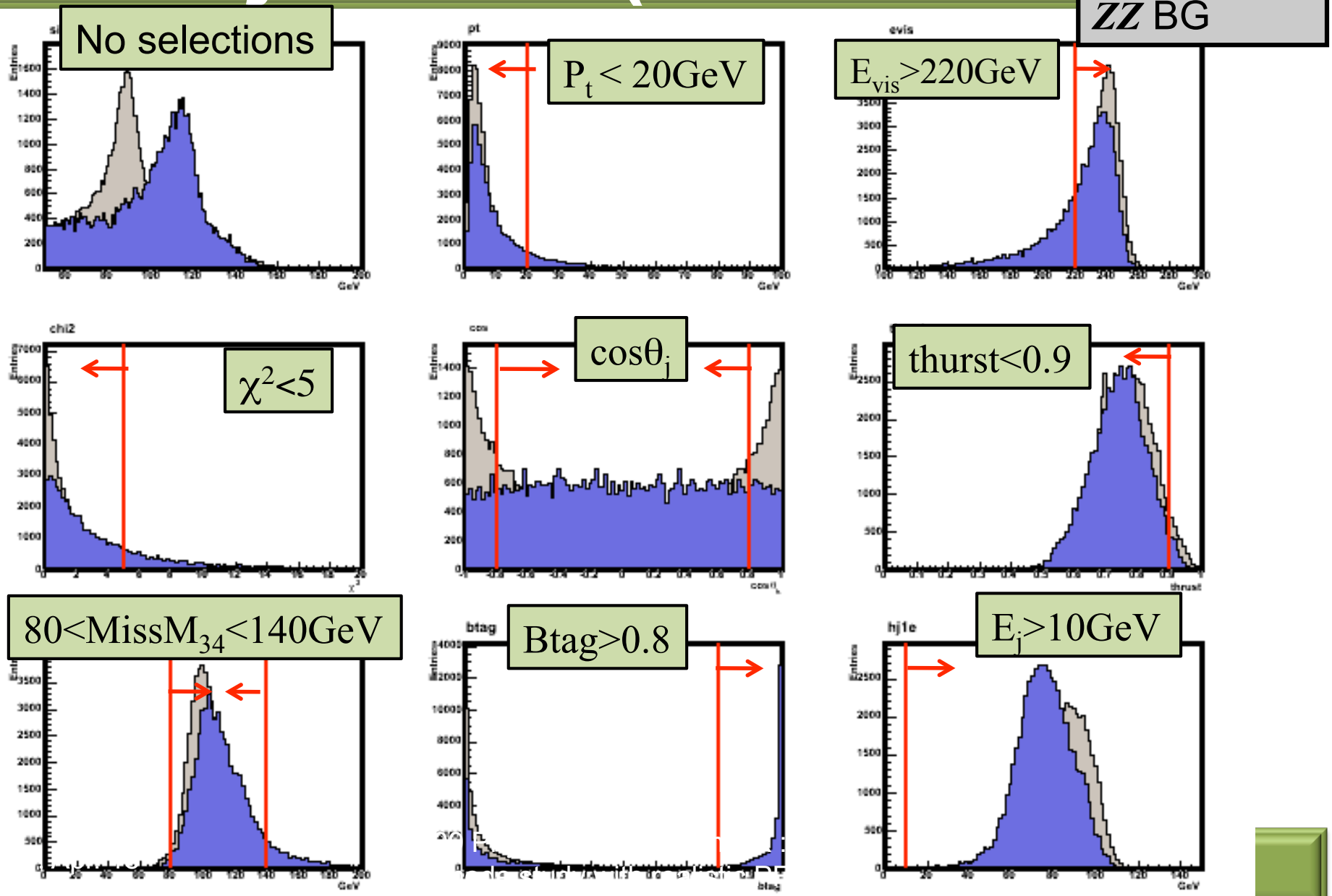
Select better jet pair combination

$$\chi^2 = \left(\frac{M_{12} - M_Z}{\sigma_Z}\right)^2 + \left(\frac{MissM_{34} - M_Z}{\sigma_Z}\right)^2$$

Selection criteria for $ZH \rightarrow qqH$ four-jet mode (PandoraPF

Higgs signal

ZZ BG

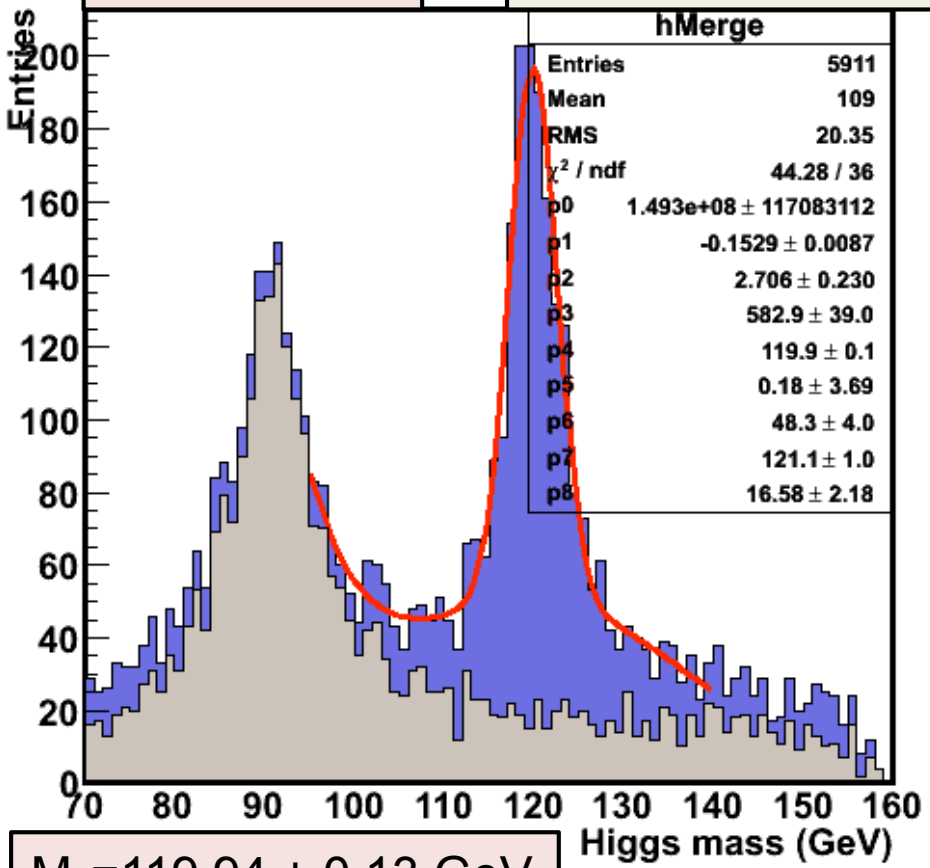


Mass reconstruction of ZH→qqH four-jet mode

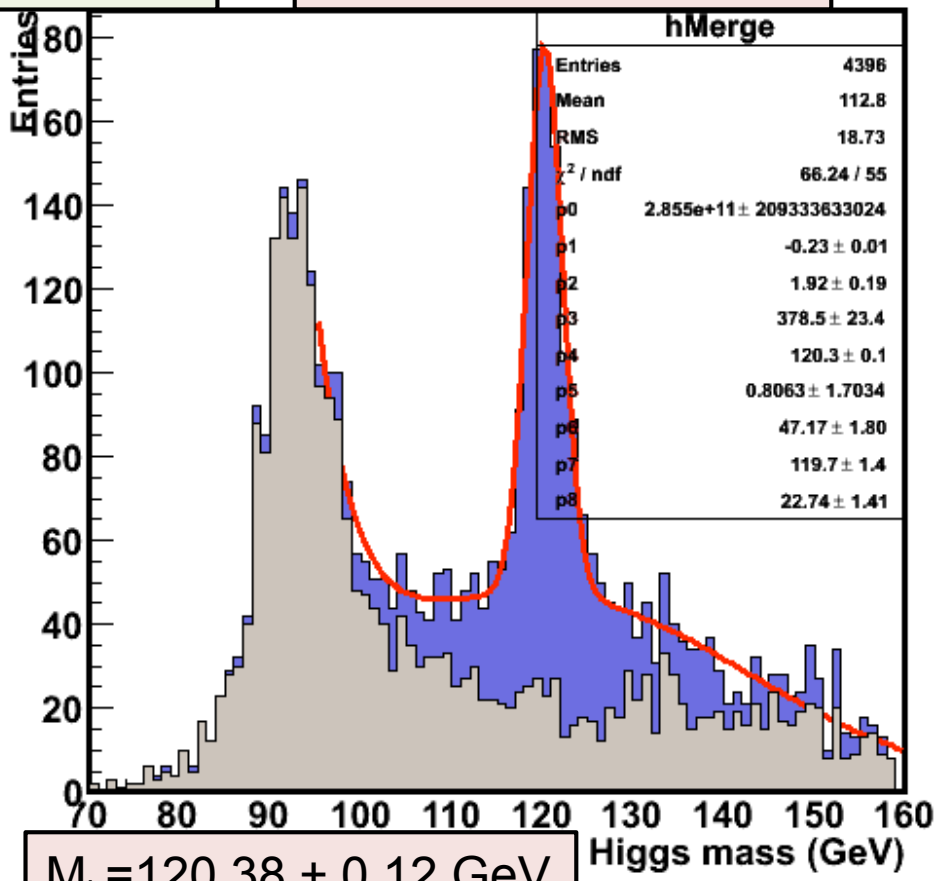
Pandora PFA

5C fit for $ZH \rightarrow qqH$ four-jet

Perfect clustering PFA



M_h=119.94 ± 0.13 GeV
σ=2.71 ± 0.23 GeV



M_h=120.38 ± 0.12 GeV
σ=1.98 ± 0.11 GeV

Kinematic 5C fit with energy, momentum + Mz constraint

Summary of Higgs analysis

- Pandora PFA can be useable for the ZH jets mode analysis and well separate ZZ background.
- PandoraPFA can be achieved the almost same level as the perfect clustering PFA performance at the E_{cm}=250GeV for the Higgs mass of 120GeV for two/four jet mode.
- GLDPFA had possibility to improve the performance even it will not maintain any more.
  →Shift to **ILD** geometry with common stdhep samples for full SM background study.

BACKUP

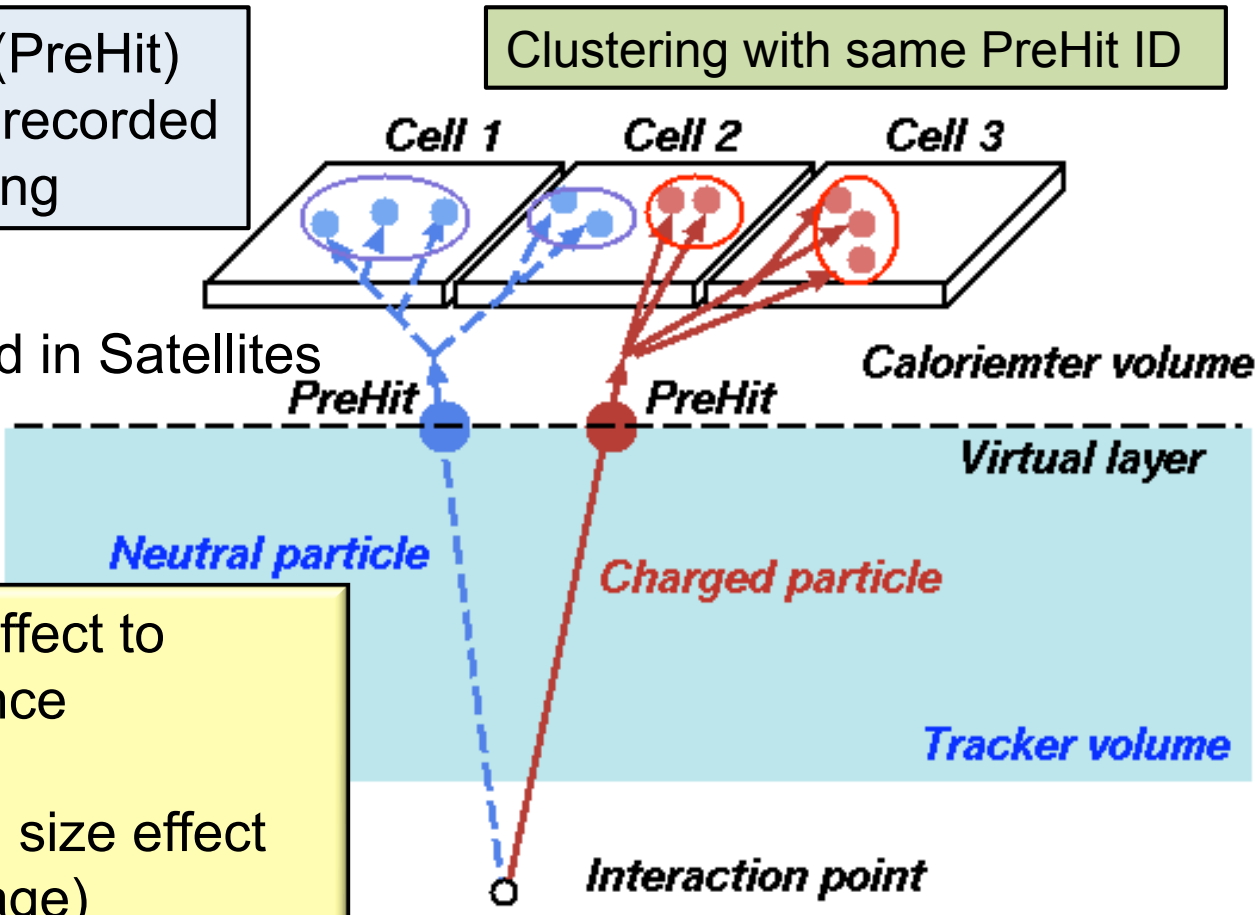
Perfect clustering PFA

Perfect clustering method (Cheated PFA) is used for the reference of the PFA performance comparison.

Mother particle information (PreHit) in front of the calorimeter is recorded for the no-confusion clustering

Implemented in Satellites

- Remove cluster overlap effect to evaluate the PFA performance
- Disappear the realistic cell size effect from the PFA (extended usage)



Kinematic constraint fit

- Measured variables
  - Jet Energy (E) and jet angle (θ,ϕ)
  - 12 variables for 4 jets
  - 6 variables for 2 jets with 3 unmeasured variables (Z)
- Constraints
  - $\boldsymbol{\Sigma E - E_{cm} = 0,\ \Sigma Px = 0,\ \Sigma Py = 0,\ \Sigma Pz = 0}$ (4C)
  - Add Z mass (M_Z) constraint for 4 jets mode (5C)
  - Fit : $p_{fit}=\sqrt{\{E_{fit}^2-(E_{meas}^2-p_{meas}^2)\}}$
- 4C fit for 2 jets mode and 5C fit for 4 jets mode has applied to correct the unmeasured neutrino decay.
  - Reason of the lower tail of Higgs signal