ProtoDUNE-SP Neutral Pion Reconstruction

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DUNE-UK Project Meeting

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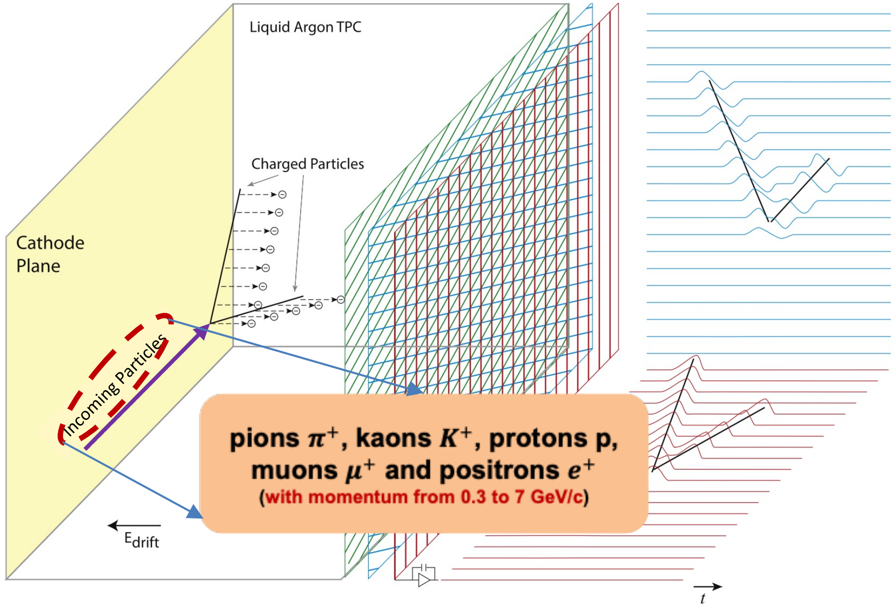
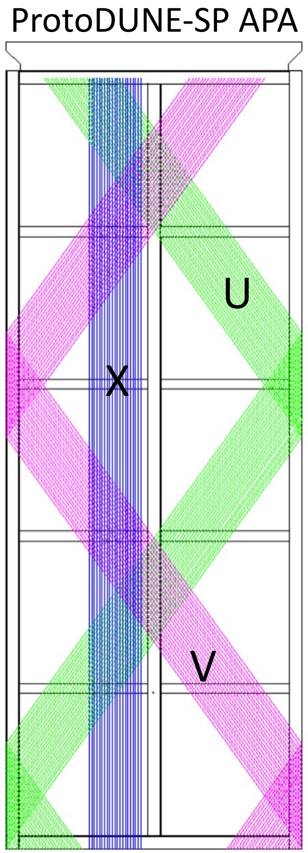
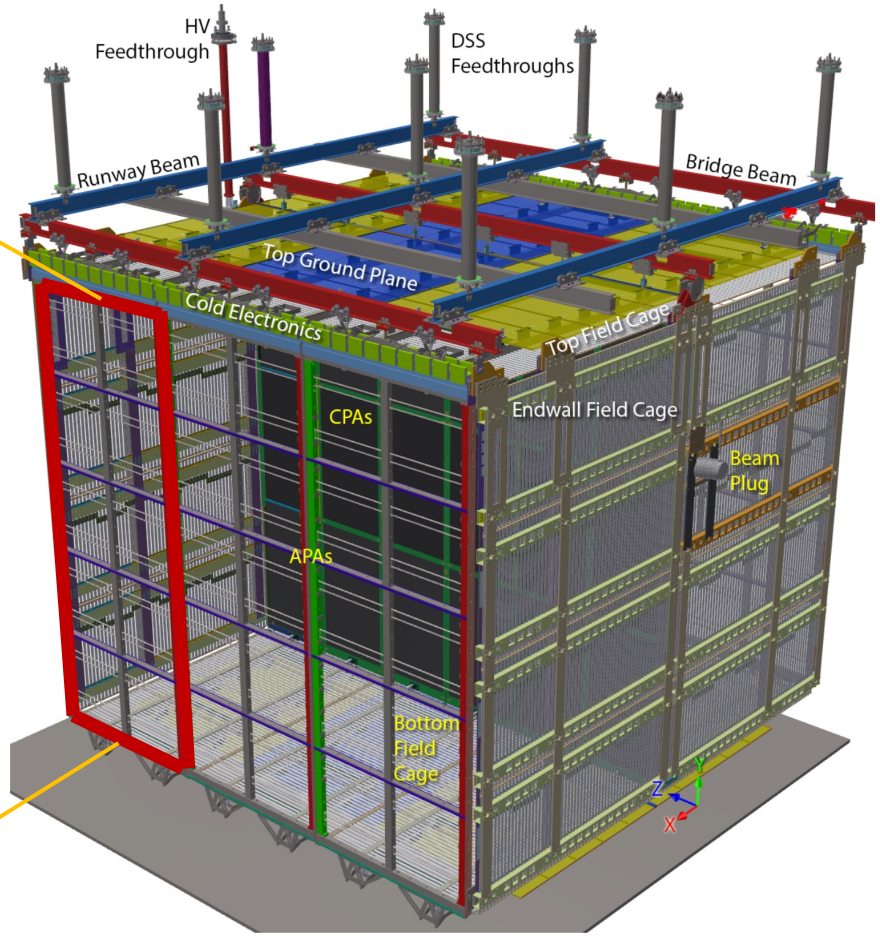
ProtoDUNE-Single Phase

The protoDUNE single-phase apparatus is one of the two large scale prototypes of the far detector module of DUNE.

- Several goals:
  - Cryostat design validation (electronics, high voltage, LAr purity)
  - Data acquisition and storage
  - Detector performance characterisation
  - Event reconstruction and analysis





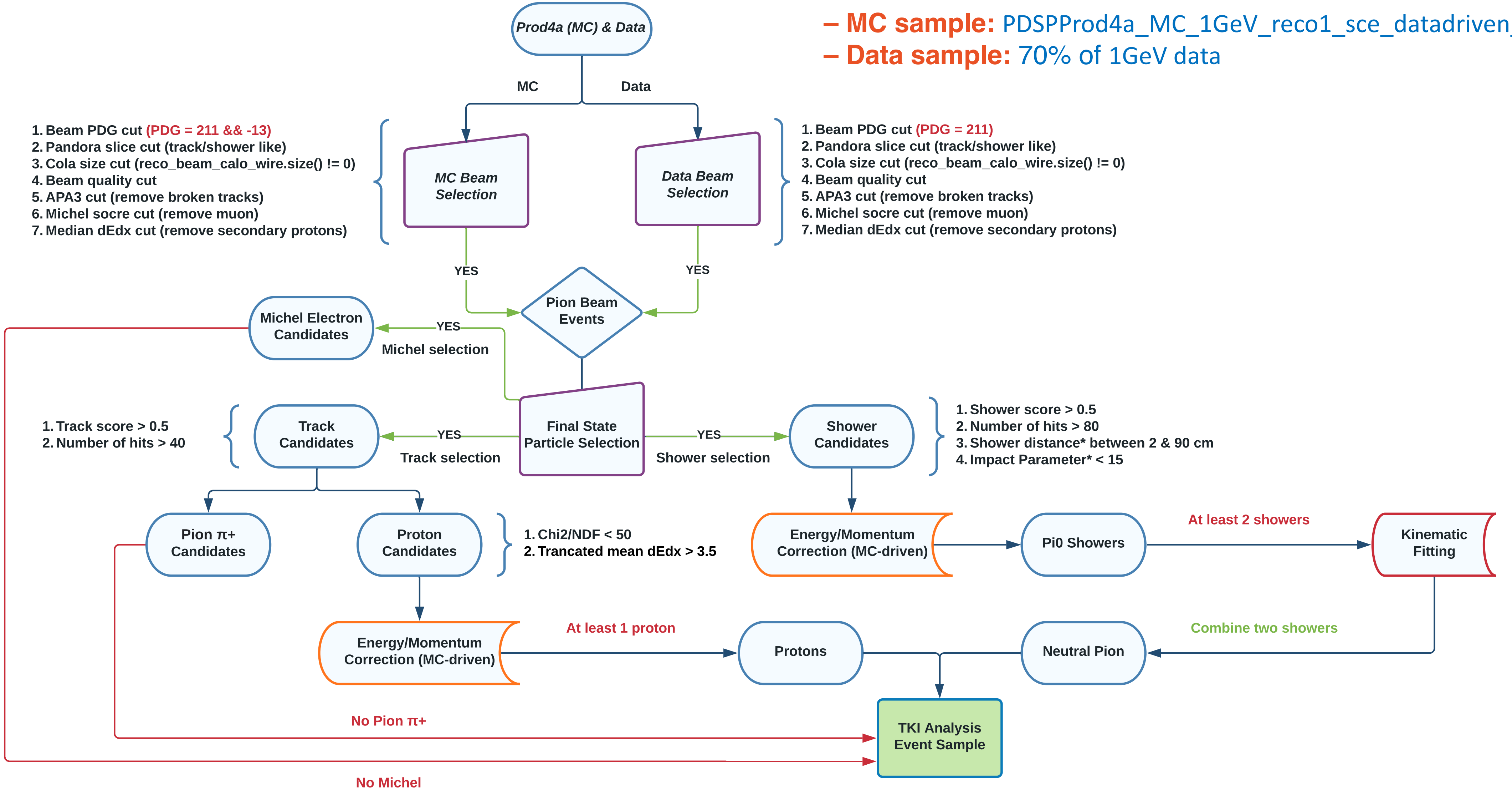


Analysis Flowchart

$\pi^+ n(^{40}Ar) \rightarrow \pi^0 p$

[Previous talk]

– **MC sample:** PDSPProd4a_MC_1GeV_reco1_sce_datadriven_v1_00 – 09
– **Data sample:** 70% of 1GeV data



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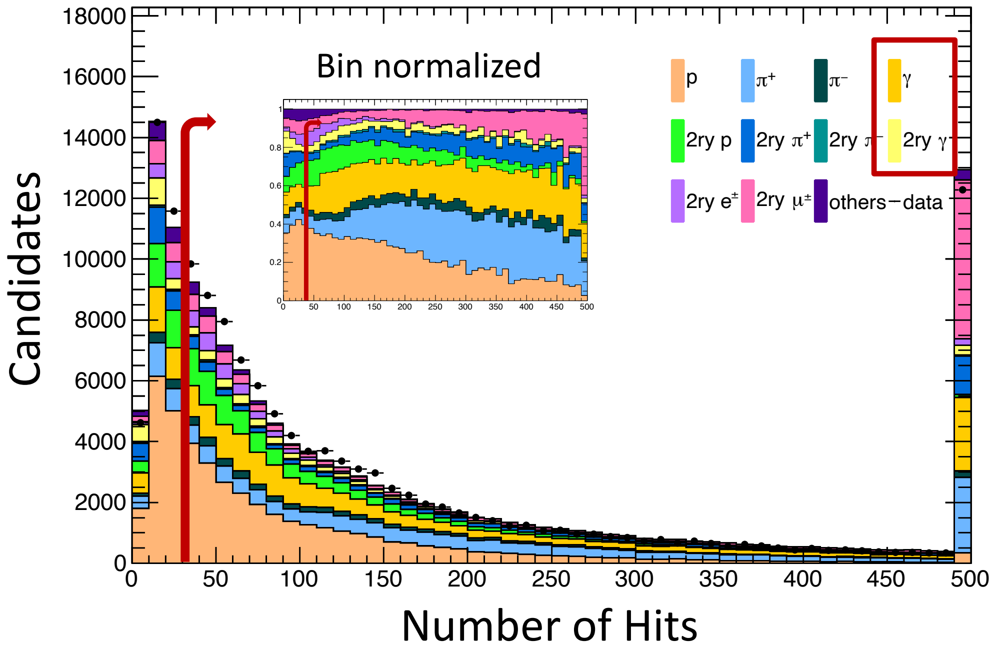
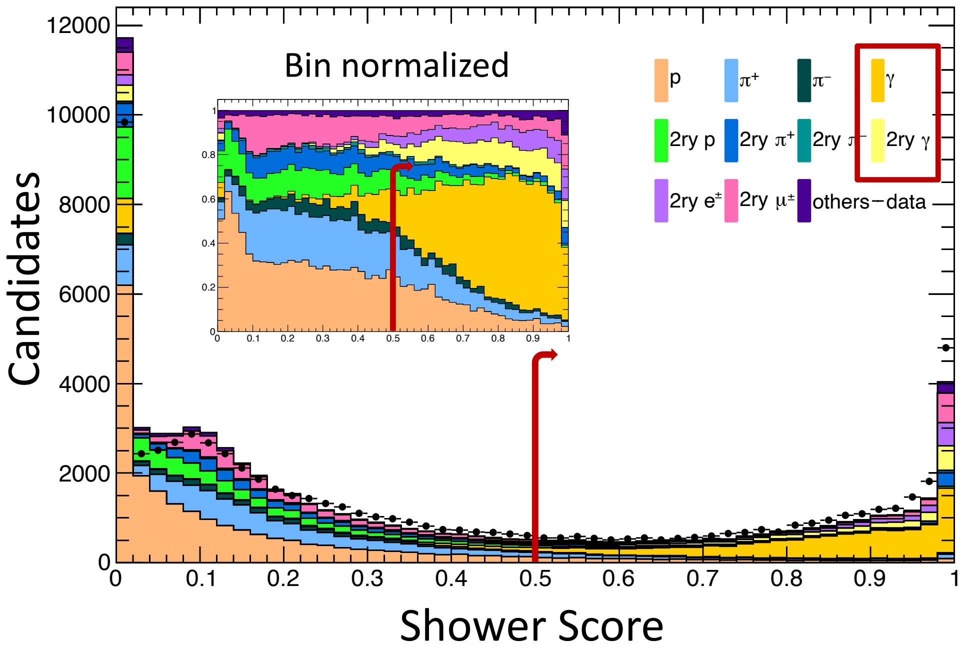
Shower Selection & Reconstruction

Shower Selection

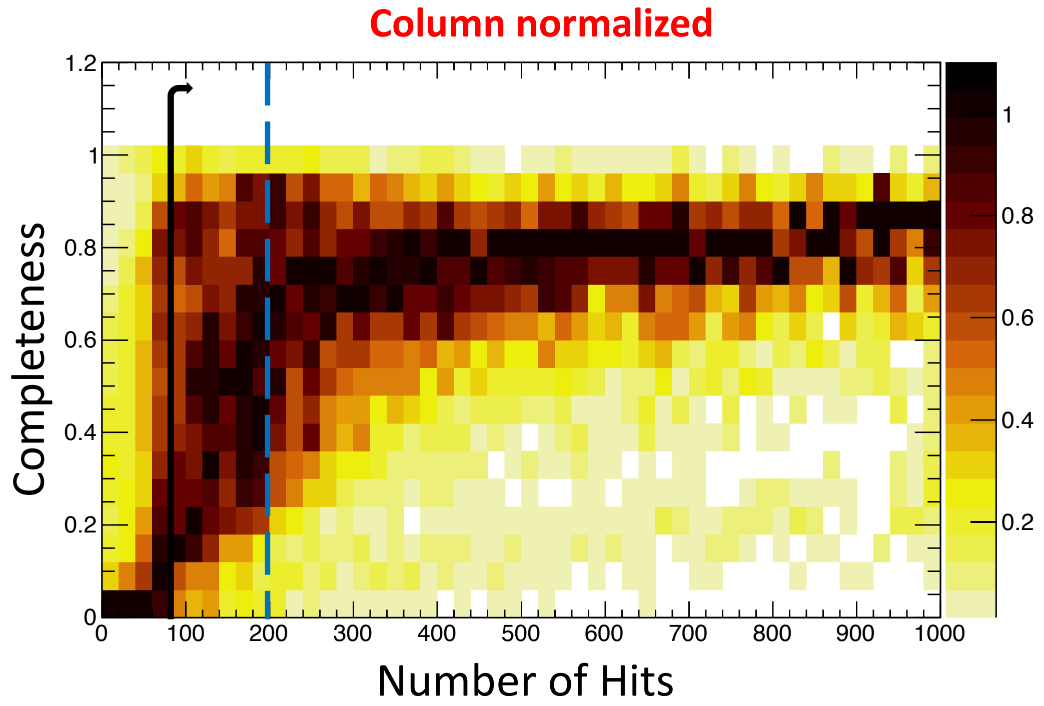




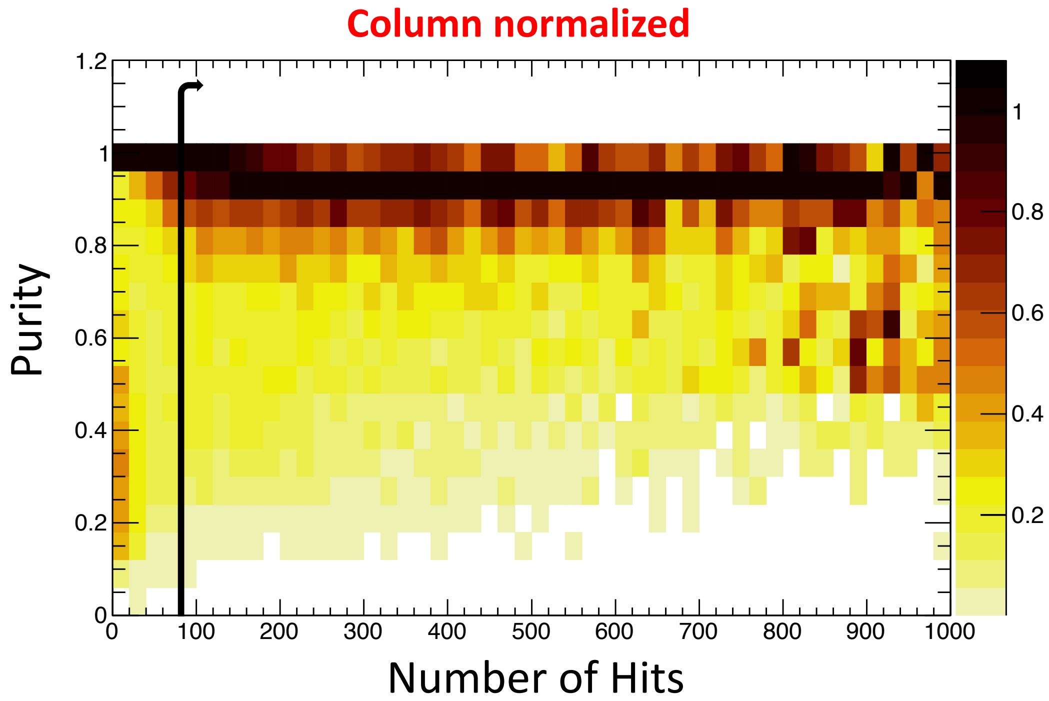
- **Shower score** can be used to select shower like particles.
- Most protons and pions have shower score less than 0.5

- Rec. particles are counted as a **shower** if :
  1. Number of hits > 80
  2. Shower Score > 0.5

Why nHits > 80 (Shower Selection)

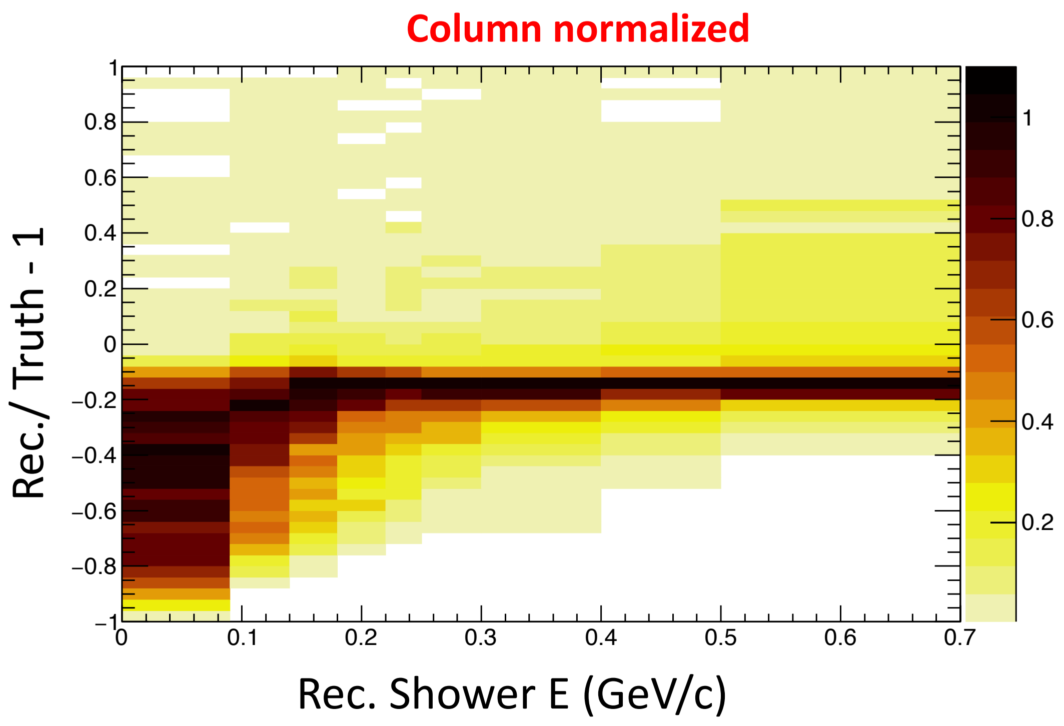


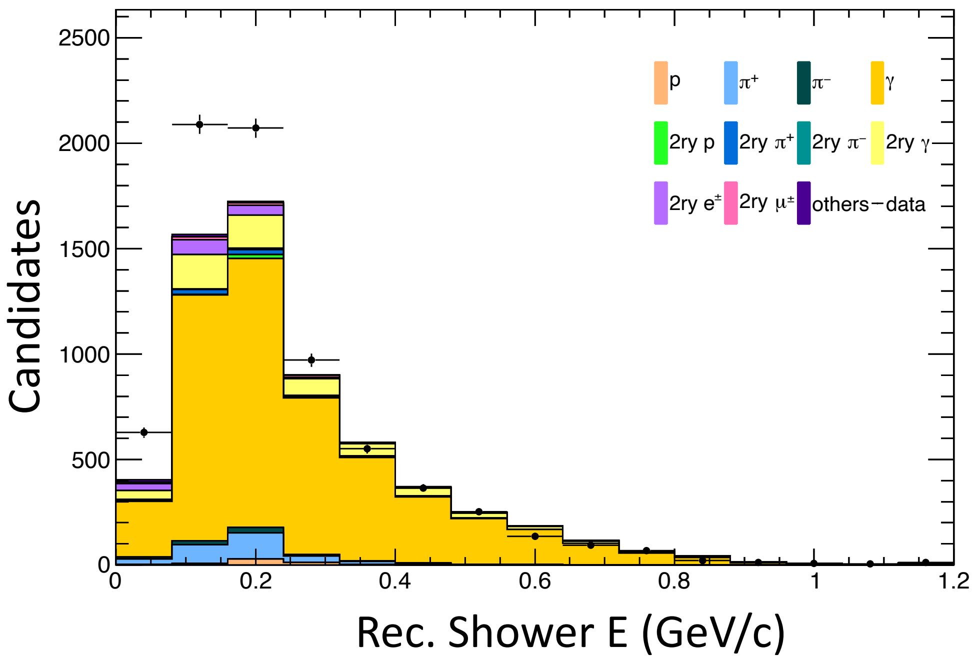
- This is the Completeness VS nHits after select particle with **shower score** > 0.5
- Select nHits > 80 will reject those very low completeness rec. particle.



- The max. completeness is about **0.8**.
- Best cut would be nHits > 200, but will reduce the sample size dramatically.
- We can see that the rec. showers are not completed, 20% of hits are missing.

Shower Energy Reconstruction



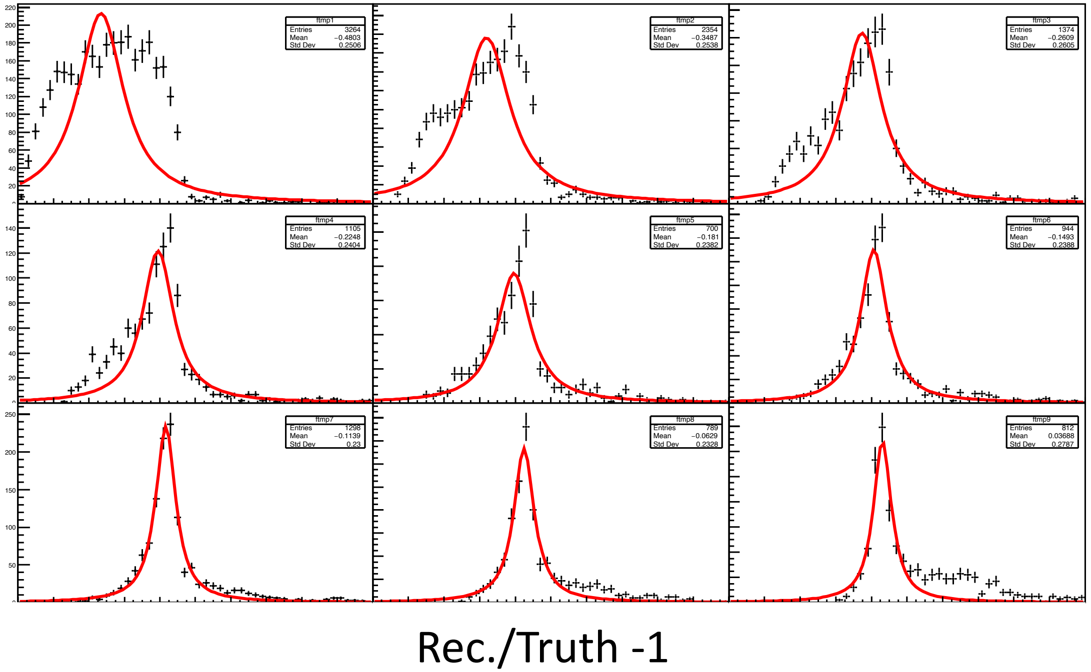


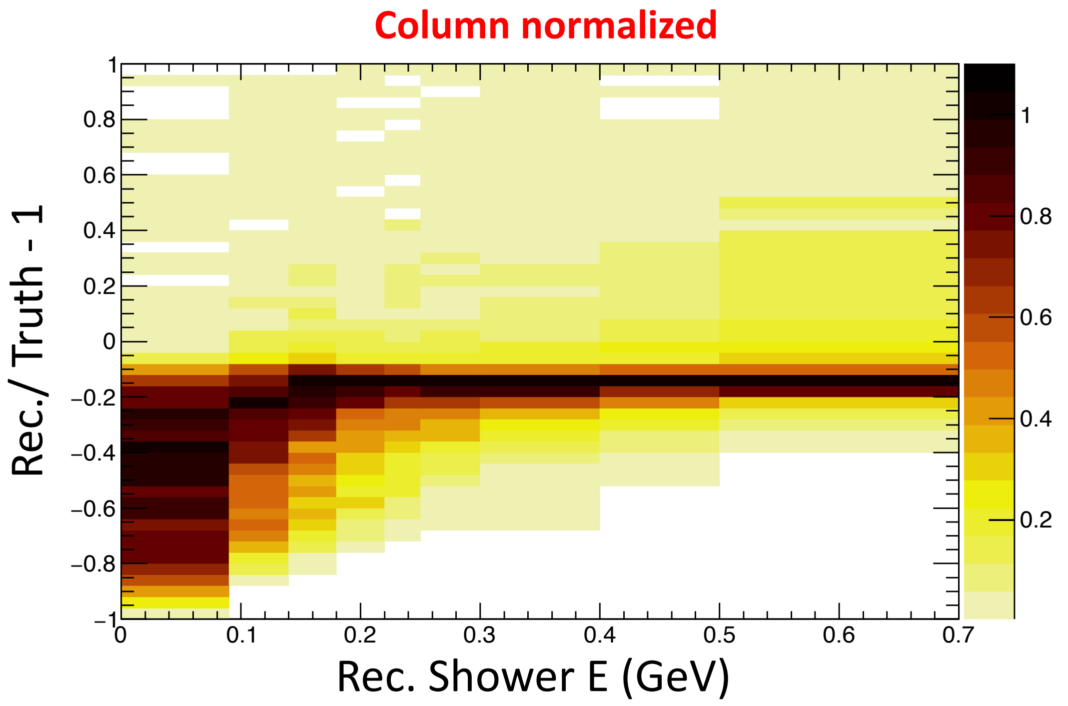
- A very large rec. bias is found in shower energy (- 15%) in 0.2 – 0.7 GeV.
- Lower energy region has even larger bias.

- We have a MC-data discrepancy for energy below 0.2 GeV.
- Can apply the energy correction

Shower Energy Correction

- ❖ A MC-driven method can be used to correct the bias in the reconstruction.



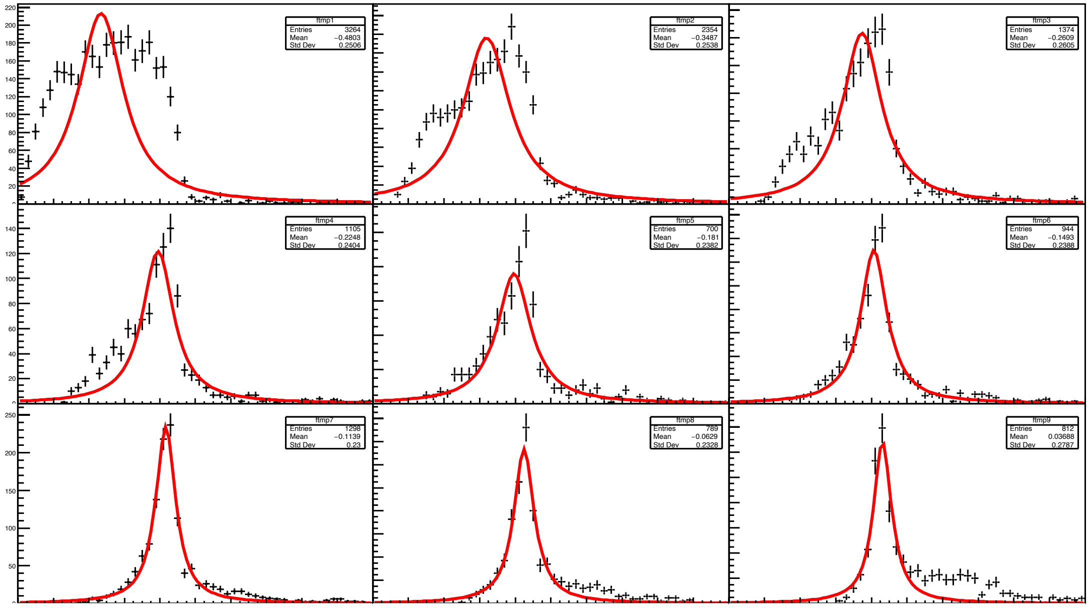


0.0–0.7 GeV in 9 unequal bins

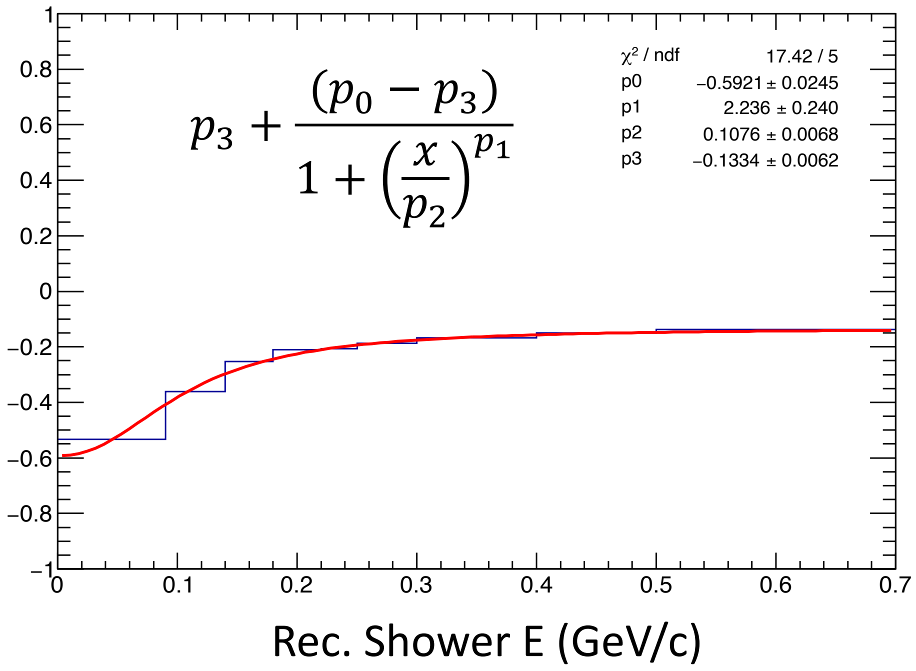
- ❖ For the energy < 0.18 GeV, the fractional bias distribution cannot be fitted by a Cauchy function
- ❖ Still have very poor resolution in low energy region

Shower Energy Correction

❖ A MC-driven method can be used to correct the bias in the reconstruction.



Rec./Truth -1



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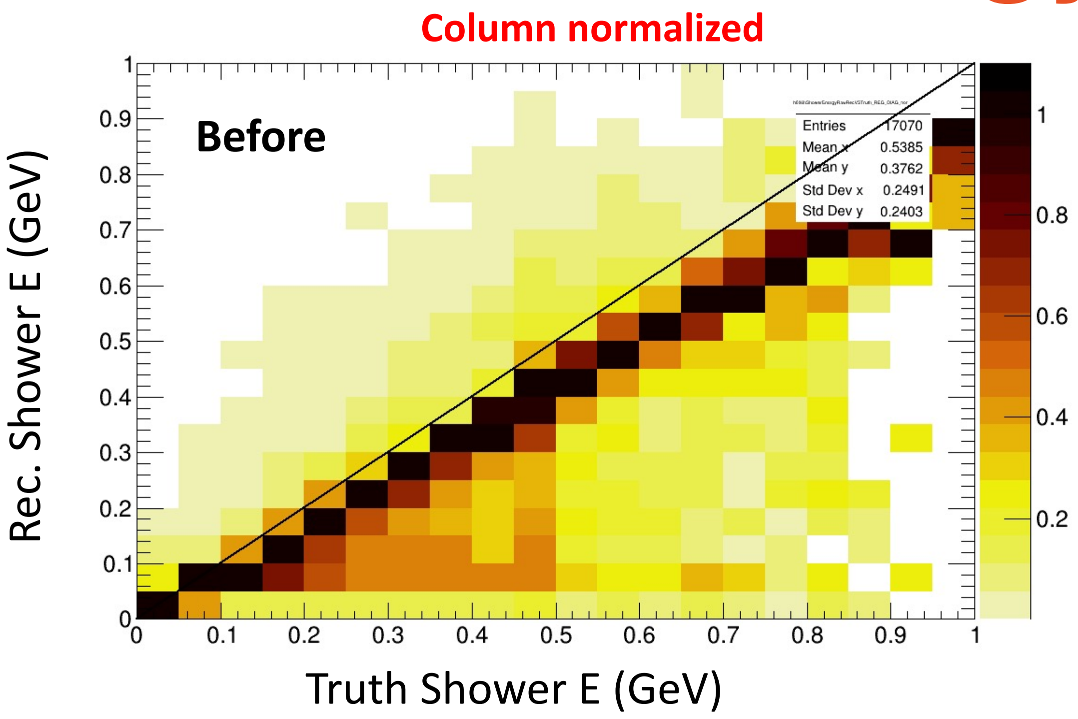
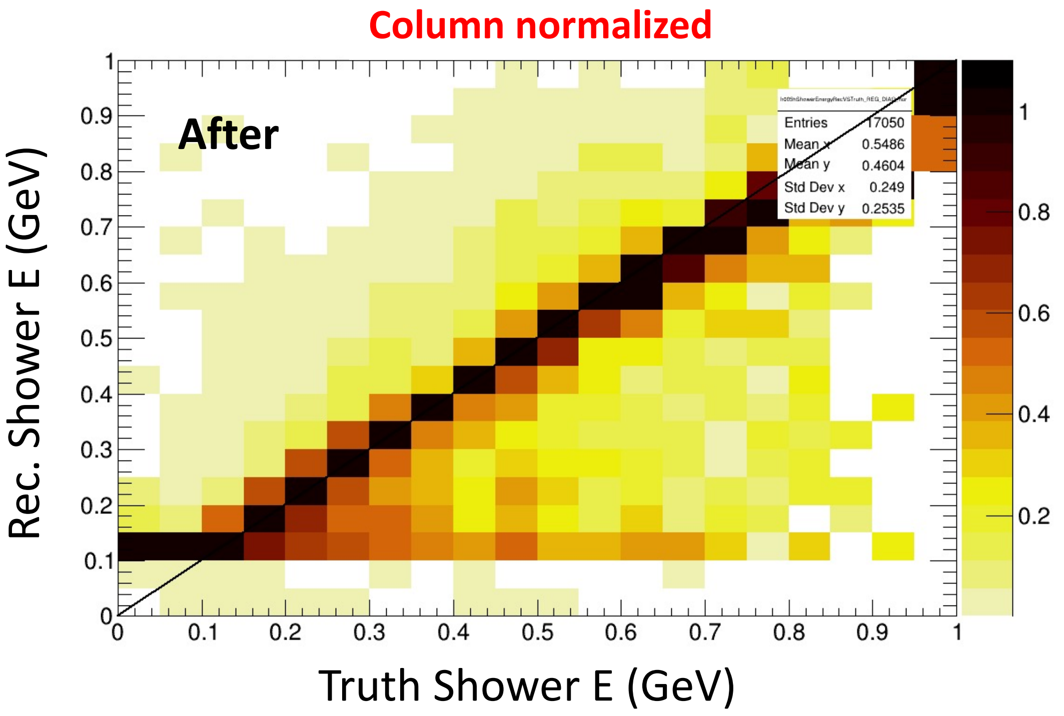
Before/After Energy Correction





- ❖ After applying the energy correction for showers, the bias in the shower reconstruction is reduced.
- ❖ Correction function works well.

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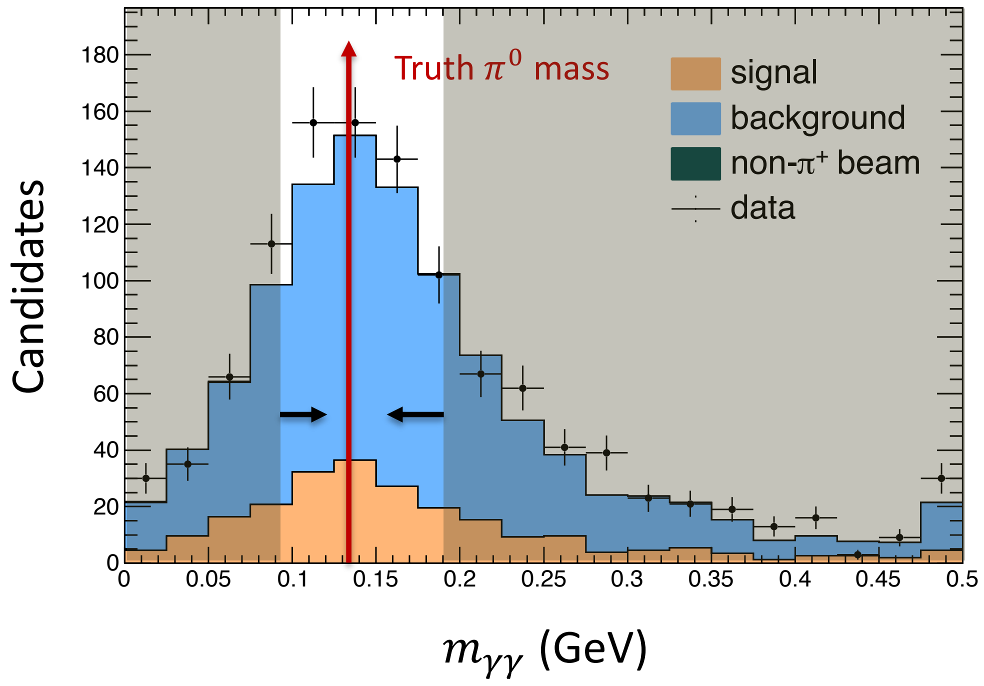
Reconstructed Neutral Pion

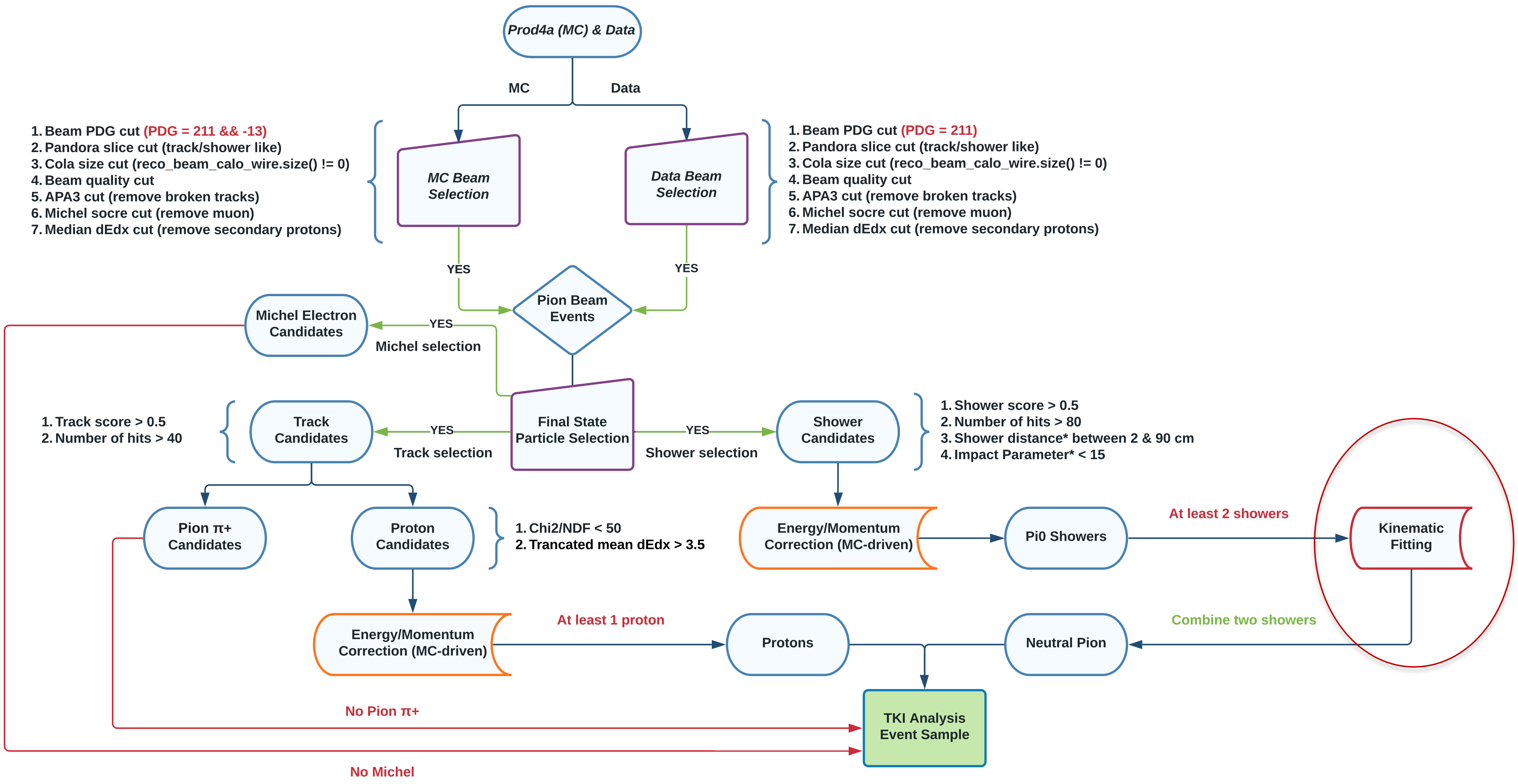


- The two photon invariant mass looks great after the energy correction.
- The spread in the mass distribution is quite large in signal
- Apply the kinematic fitting to further improve the shower energy or opening angles
- KF is used to improve the rec. π^0 momentum and energy

*See back-up slides (page 27) for signal definition

Analysis Flowchart

$\pi^+ n(^{40}Ar) \rightarrow \pi^0 p$



π^0 Kinematic Fitting

TMinuit Double Minimisation

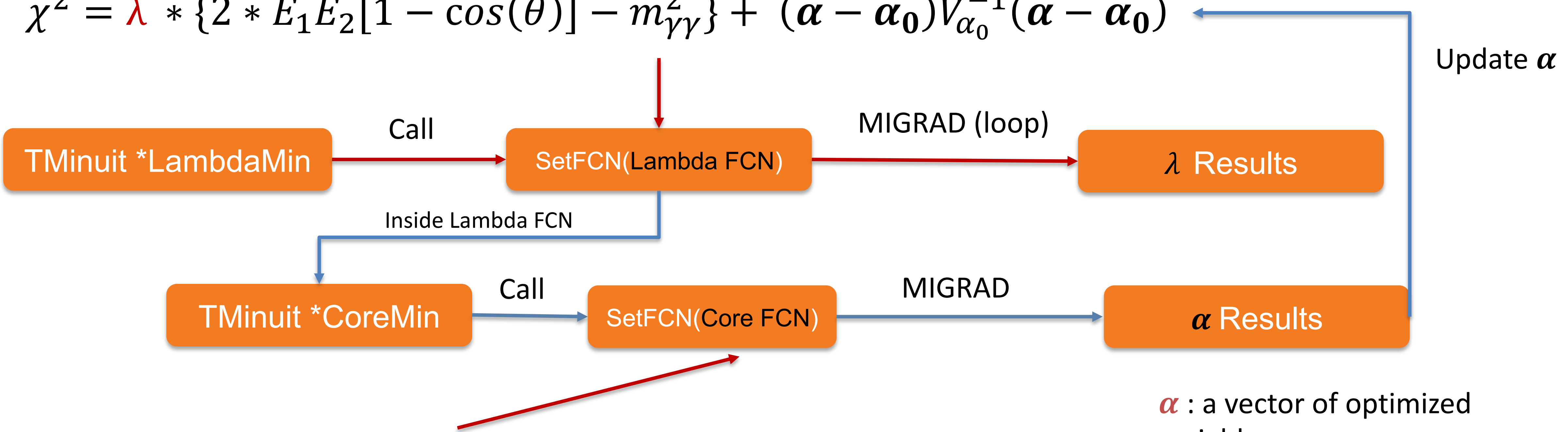
[Previous talk]

❖ $m_{\gamma\gamma}^2 = 2E_1E_2(1-cos(\theta))$

- We could use two TMinuit object to achieve the minimisation.
- We are using the "MIGRAD" algorithm.

Variables in red are varying in the process

$$\chi^2 = \lambda * \{2 * E_1E_2[1-cos(\theta)] - m_{\gamma\gamma}^2\} + (\boldsymbol{\alpha}-\boldsymbol{\alpha_0})V_{\alpha_0}^{-1}(\boldsymbol{\alpha}-\boldsymbol{\alpha_0})$$



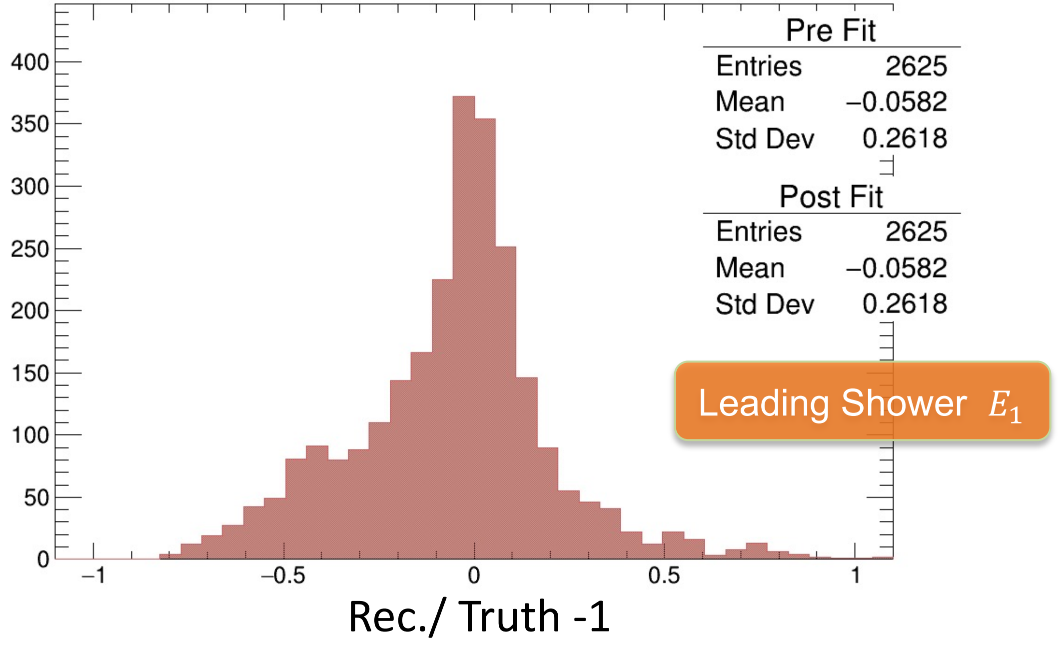
$$\chi^2 = \lambda * \{2 * E_1E_2[1-cos(\theta)] - m_{\gamma\gamma}^2\} + (\alpha-\boldsymbol{\alpha_0})V_{\alpha_0}^{-1}(\alpha-\boldsymbol{\alpha_0})$$

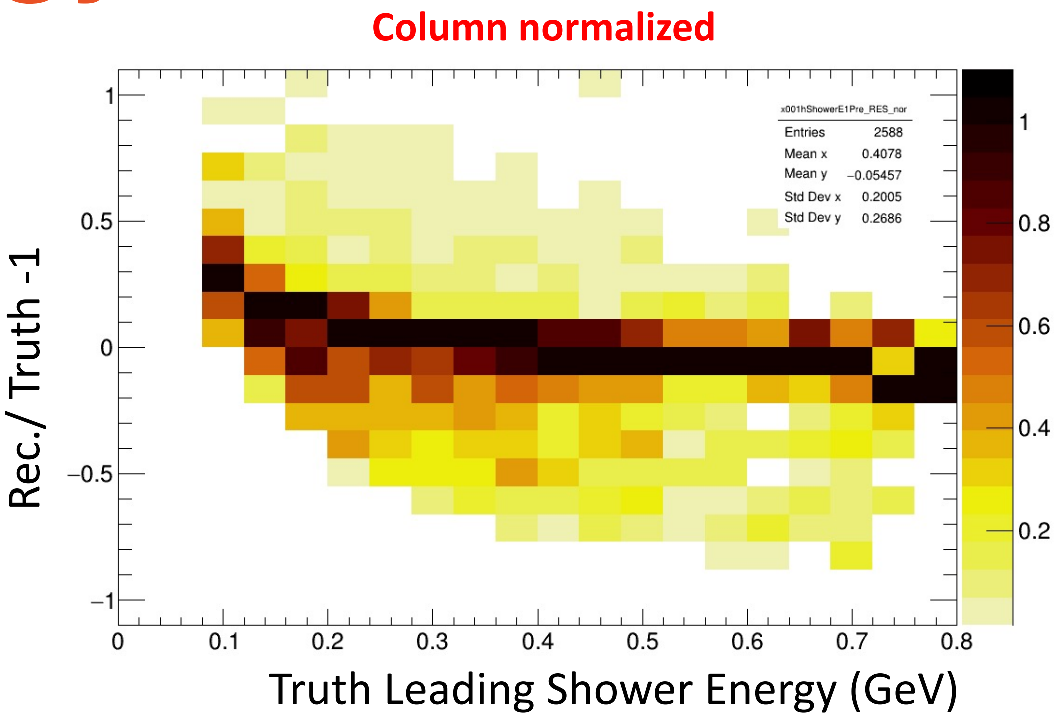
$\boldsymbol{\alpha}$: $[E_1, E_2, \boldsymbol{\theta}]$

α : a vector of optimized variables

$\boldsymbol{\alpha_0}$: a vector of the expected value of the measurements

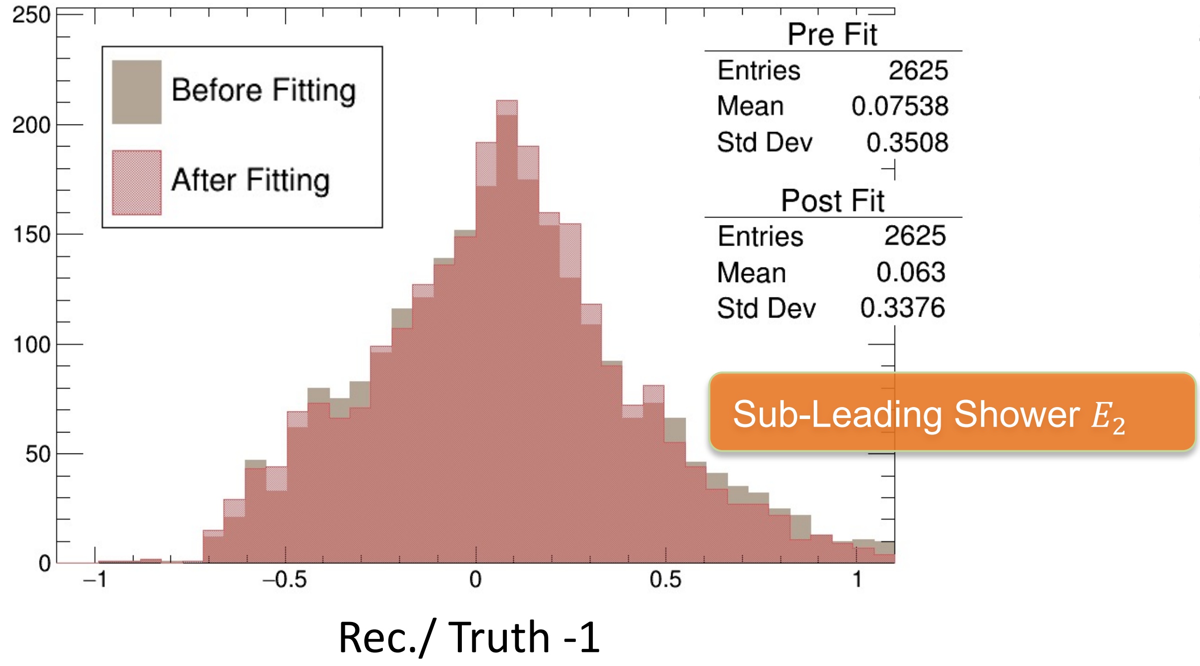
Leading Shower Energy

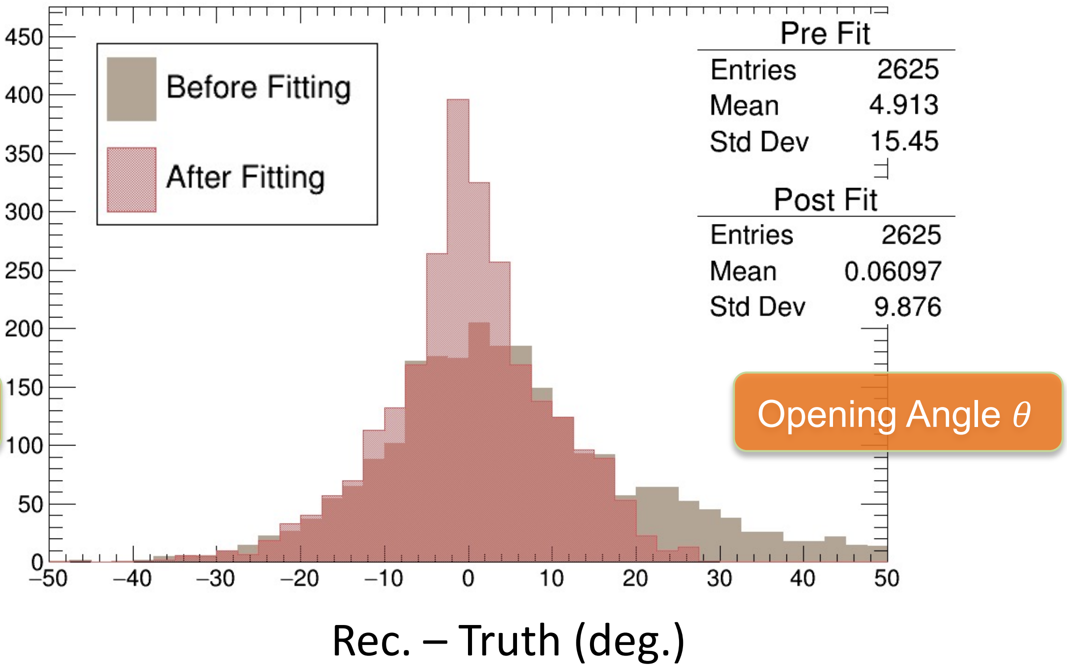




- ❖ The reconstructed leading shower energy is pretty good.
- ❖ Fix it in the process of kinematic fitting

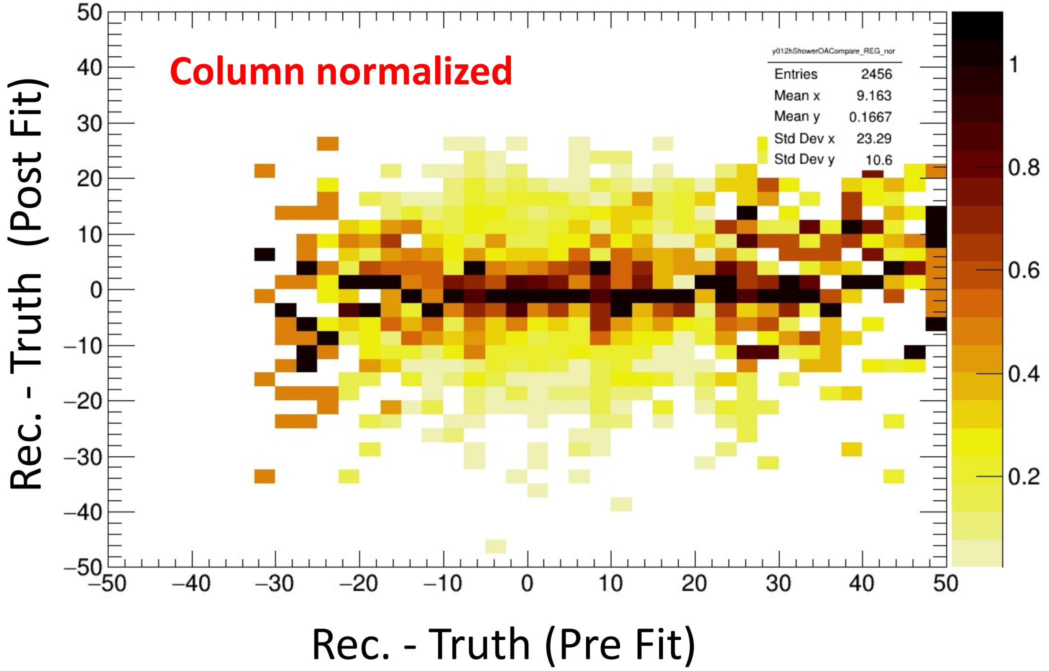
Kinematic Fitting Results

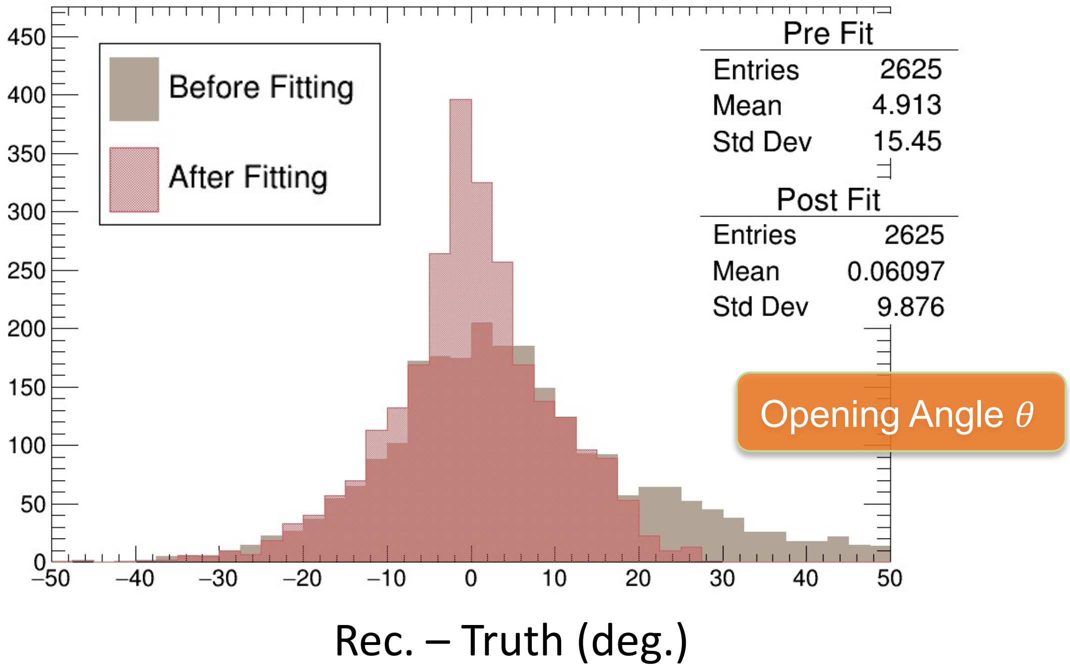




- ❖ After the kinematic fitting, the opening angle between two shower vectors is improved a lot.
- ❖ Reconstruct π^0 using leading shower E and opening angle

Kinematic Fitting Results

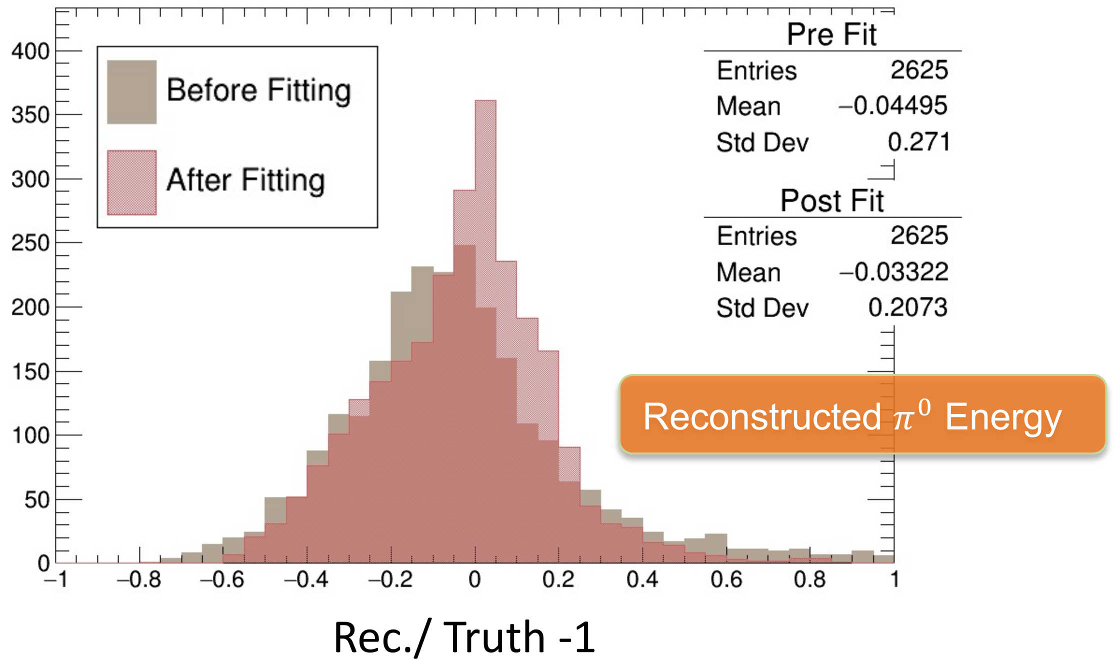


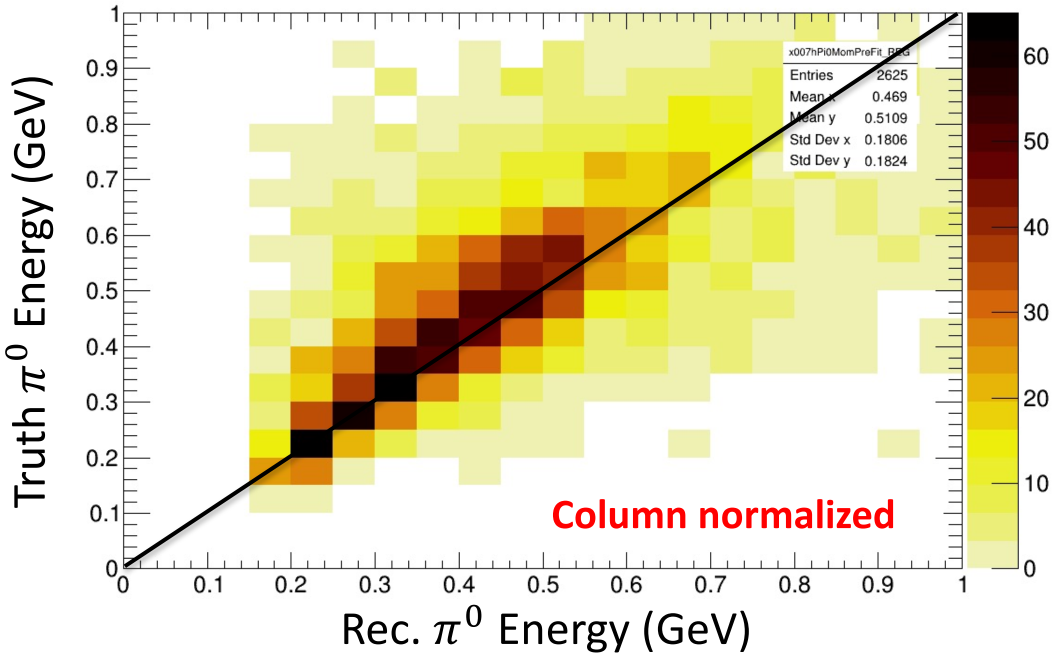


- After the kinematic fitting, the opening angle between two shower vectors is improved a lot.
- Reconstruct π^0 using leading shower E and opening angle

Reconstructed π^0 Energy

$$E_\pi = E_1 + \frac{m_{\pi^0}^2}{2E_1(1-cos\theta)}$$





- The reconstructed π^0 energy looks pretty good after the fitting
- The spread of the distribution is reduced and we have a sharper peak around 0.

Reconstructed π^0 Energy

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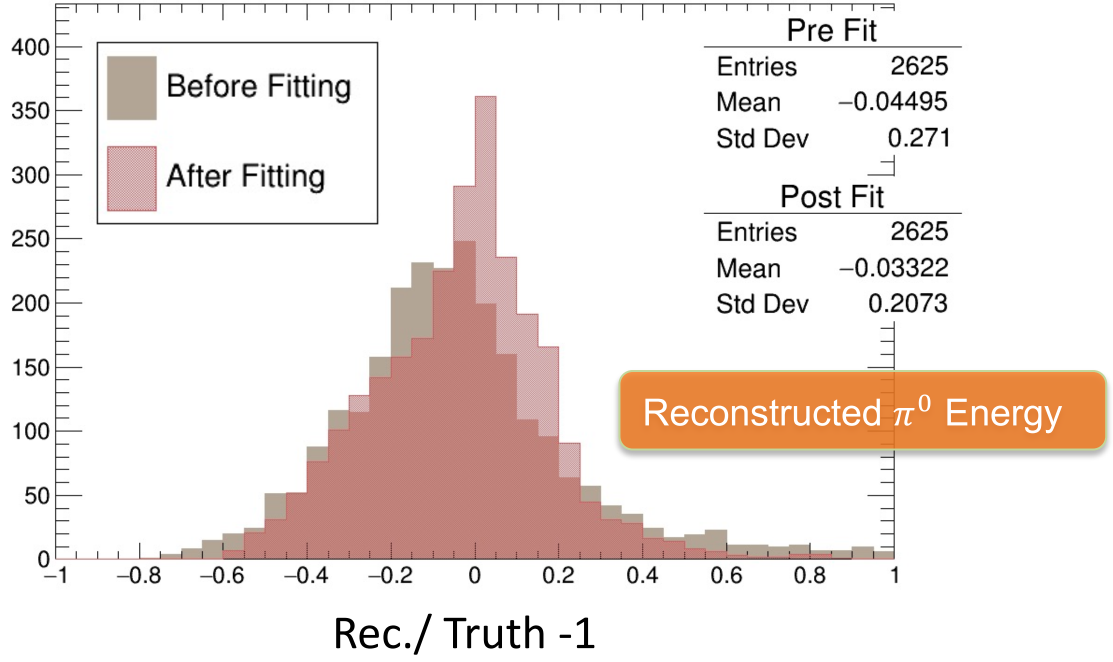

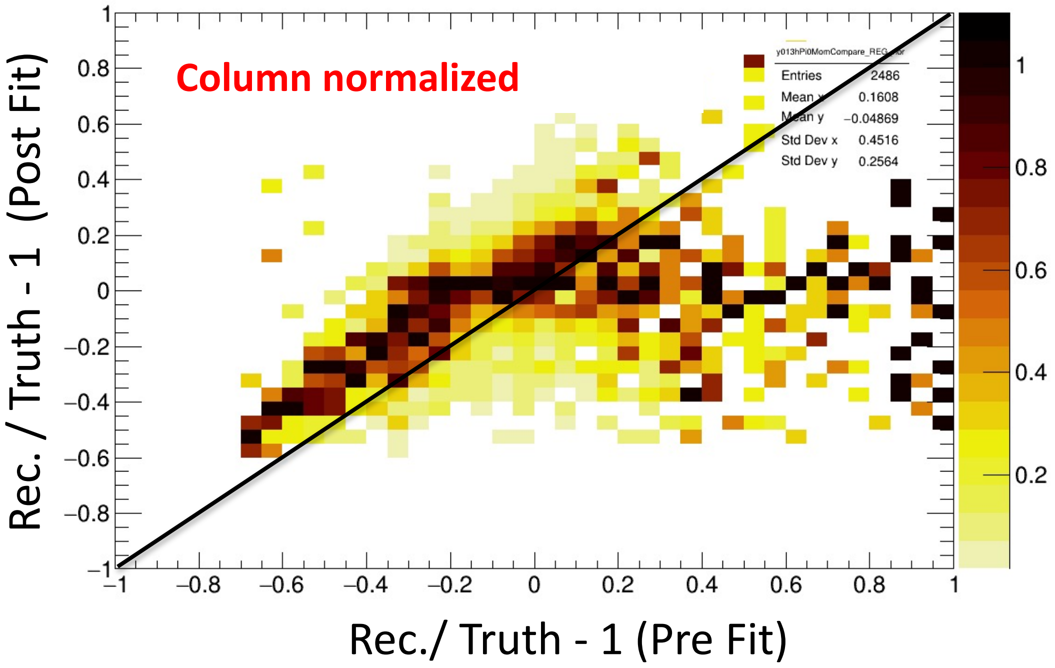

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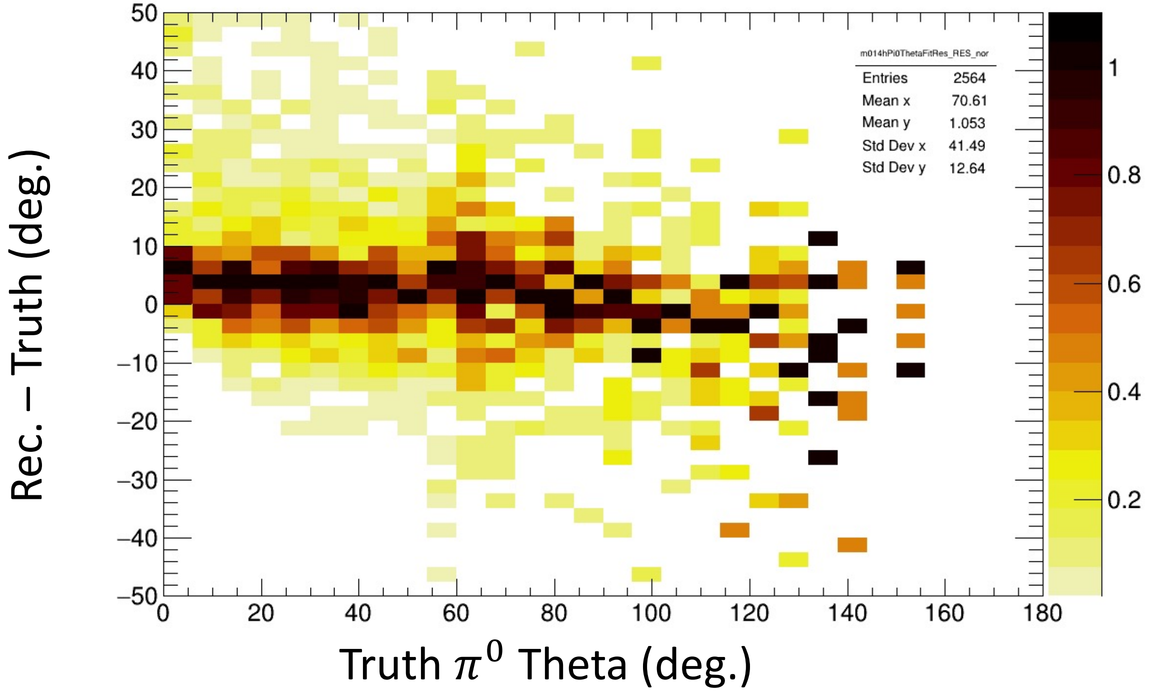
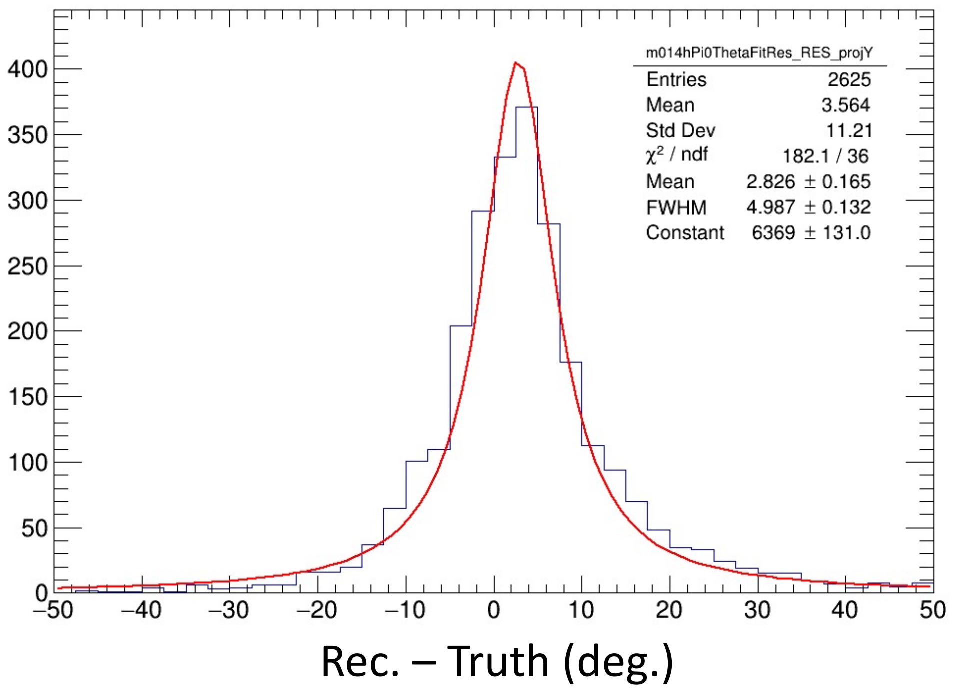
Rec. π^0 Theta θ (Detector coordinates)

Column normalized

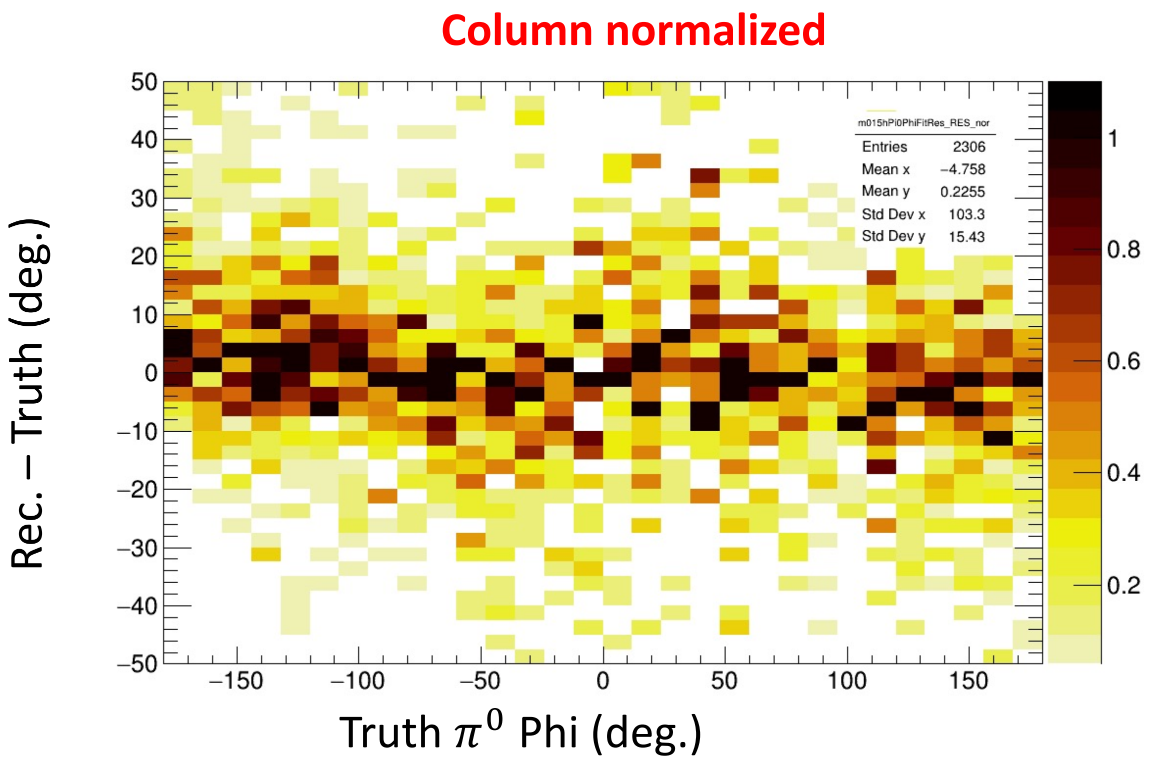


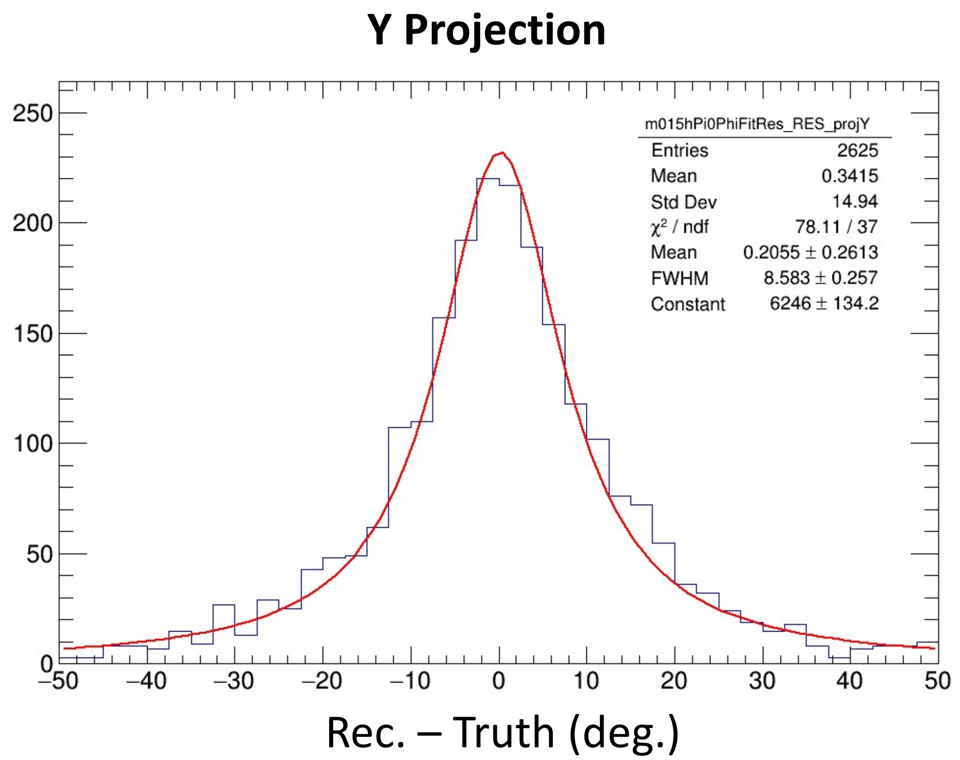
Y Projection



- The reconstructed π^0 theta θ (detector coordinates) has a ~ 3 ° bias
- Need to think about how to use the improved opening angle values to corrected the π^0 momentum vector (i.e. it's direction)

Rec. π^0 Phi ϕ (Detector coordinates)





- The reconstructed π^0 phi ϕ (detector coordinates) has a < 1° bias
- Need to think about how to use the improved opening angle values to corrected the π^0 momentum vector (i.e. it's direction)

Summary and Outlook

- A MC based energy correction is applied for reconstructed shower candidates.
- π^0 mass reconstruction was improved after selecting good shower candidates and applying the energy correction.
- The opening angle between two shower vectors was improved by the kinematic fitting
- π^0 energy reconstruction was also improved if we calculating it using E_1 and θ.
- Can correct the rec. π^0 momentum vector from the improved opening angle θ
- Plan to apply all the presented procedures for all energy beams and make inclusive pi0 measurement (π^++ Ar $\rightarrow \pi^0$ +X)

Thank you for your attention !

Back-up

MC Selections Efficiency

Cuts	All	Selected	Fraction	Total Fraction
Pion Beam Selection				
Beam PDG	358929	205219	57.2%	57.2%
Pandora Beam Type	205219	174724	85.1%	48.7%
Calo Size	174724	171519	98.2%	47.8%
Beam Quality	171519	123403	71.9%	34.3%
APA 3	123403	100303	81.3%	28.0%
Michel Score	100303	98272	98.0%	27.4%
Mean dEdx	98272	93871	95.5%	26.1%
Event Topology Selection				
Protons (≥ 1)	93871	28712	30.6%	8.00%
Showers (≥ 2)	28712	947	3.3%	**0.26%**
No Pion π^+	947	770	81.3%	0.21%
No Michel electron	770	710	92.2%	0.20%

Data Selections Efficiency

Cuts	All	Selected	Fraction	Total Fraction
Pion Beam Selection				
Beam PDG	1192336	164415	13.8%	13.8%
Pandora Beam Type	164415	123906	75.4%	10.4%
Calo Size	123906	120507	97.3%	10.1%
Beam Quality	120507	82984	68.9%	6.96%
APA 3	82984	63209	76.2%	5.30%
Michel Score	63209	61606	97.5%	5.17%
Mean dEdx	61606	57941	94.1%	4.86%
Event Topology Selection				
Protons (≥ 1)	57941	16211	28.0%	1.36%
Showers (≥ 2)	16211	680	4.2%	**0.06%**
No Pion π^+	680	563	82.8%	0.05%
No Michel electron	563	516	91.7%	0.04%

Truth Signal Definition

- Phase space cuts on protons and pions:

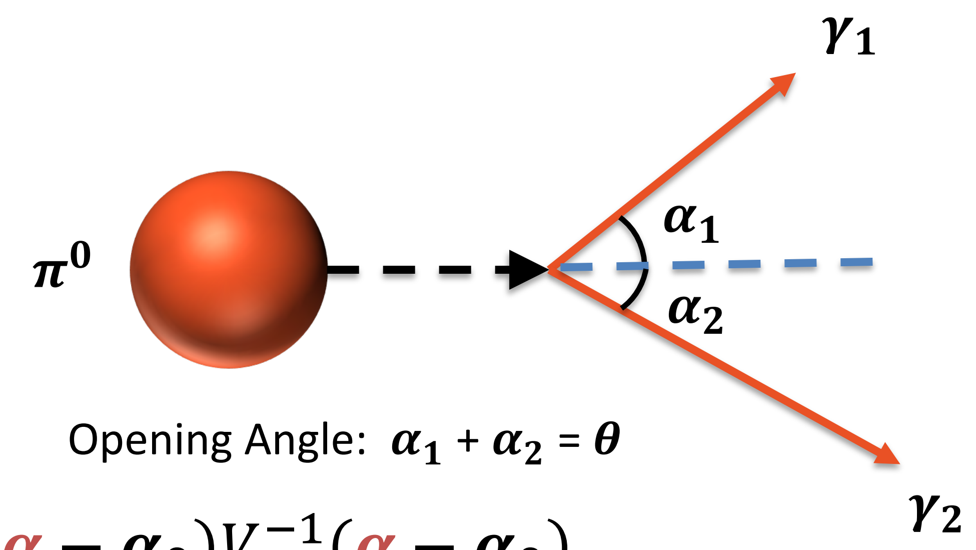
1. Leading proton momentum 0.45 - 1 GeV/c
2. Sub-leading proton momentum < 0.45 GeV/c
3. No cuts on pions

0.45 GeV/c is the reconstruction threshold, 1 GeV/c is limit where momentum by range is reliable

- Beam type and Event topology cuts:

1. Incoming π^+ beam
2. At least one proton
3. At least one π^0
4. No π^+
5. No background particles ($\pi^-$and kaons, doesn't care about neutrons and nucleus)

π^0 Decay Kinematics



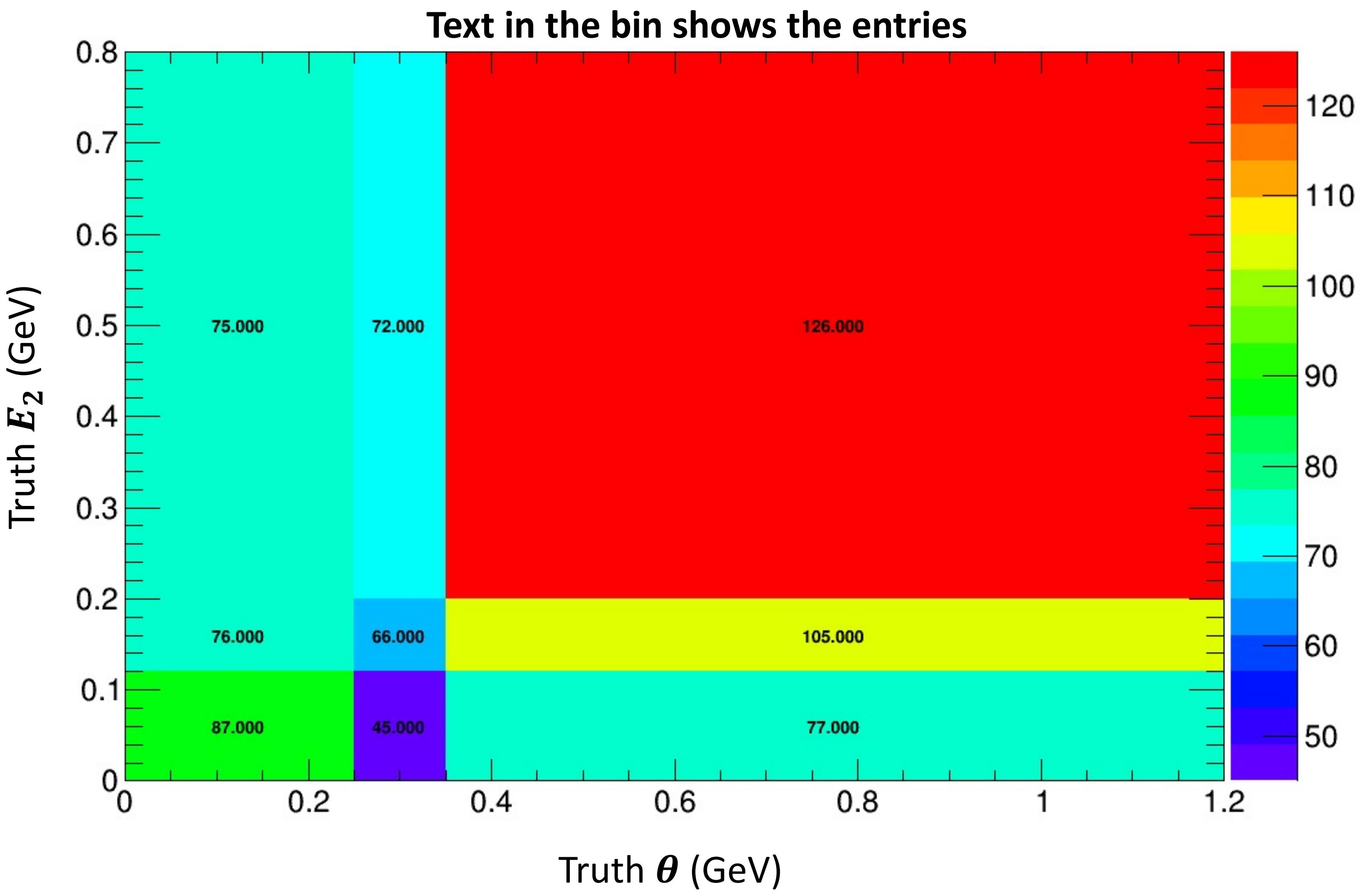
Opening Angle: $\alpha_1 + \alpha_2 = \theta$

- Invariant mass of two photons:
  - $m_{\gamma\gamma}^2 = 2E_1E_2(1 - cos(\theta))$
- Minimizing (Full CVM):
  - $\chi^2 = \lambda * \{2 * E_1E_2[1 - cos(\theta)] - m_{\gamma\gamma}^2\} + (\boldsymbol{\alpha} - \boldsymbol{\alpha_0})V_{\alpha_0}^{-1}(\boldsymbol{\alpha} - \boldsymbol{\alpha_0})$
  - where $\boldsymbol{\alpha} = (E_1 \quad E_2 \quad \theta)$
  - $V_{\alpha_0}^{-1}$ is the inverse of the full CVM matrix

$\boldsymbol{\alpha}$: $[\mathrm{E}_1, \mathrm{E}_2, \boldsymbol{\theta}]$

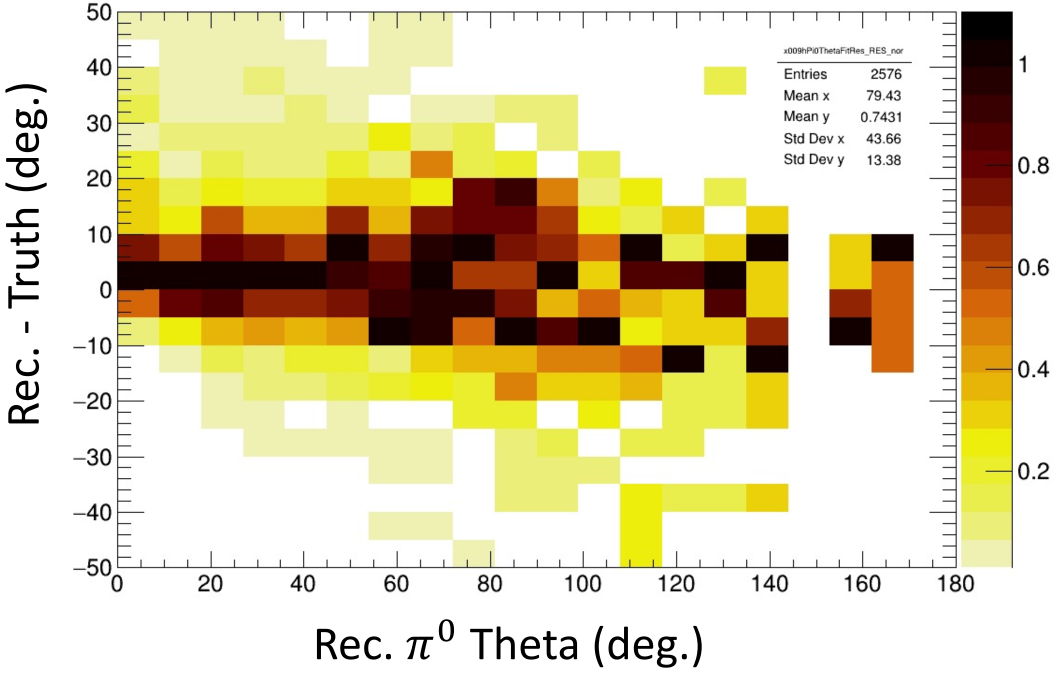
- More familiar form (diagonal only CVM)
  - $\chi^2 = \lambda * \{2 * E_1E_2[1 - cos(\theta)] - m_{\gamma\gamma}^2\} + \Sigma_i\left(\alpha_i - \alpha_{0_i}\right)^2/\sigma_i^2$
  - we set the off diagonal elements to be 0

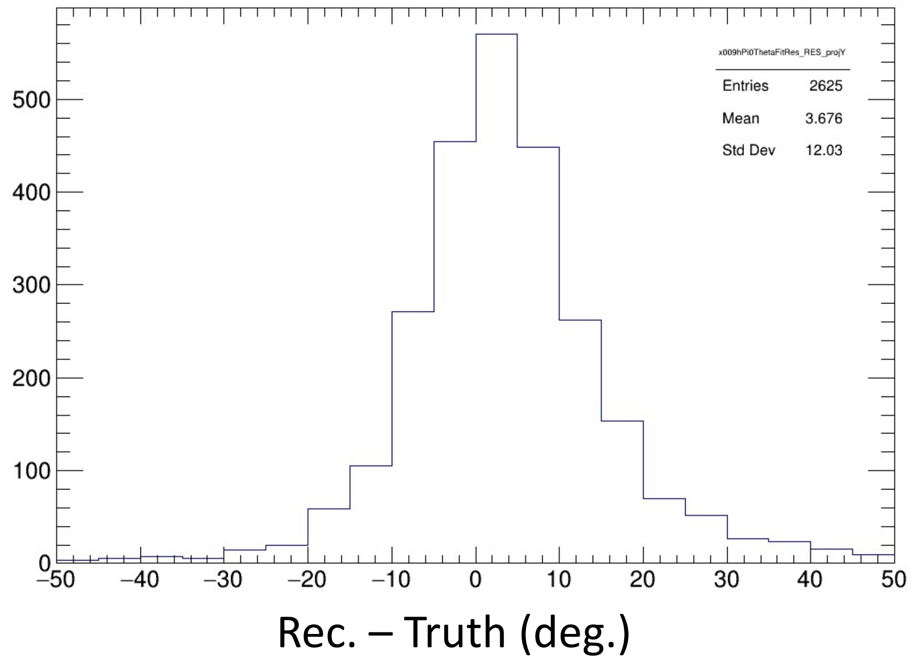
Covariance Matrix



- Need to make sure the entries in each bin are similar.
- Each bin will have a set of rec. quantities and a set of truth quantities.
- The expected value of the measurements is the mean value of the truth distribution in that bin.
- For each bin, one can calculate the CVM.

Reconstructed π^0 Theta





- The reconstructed π^0 theta (relative to the beam) has a 3 - 4° bias
- Need to think about how to use the improved opening angle values to corrected the π^0 momentum vector (i.e. it's direction)