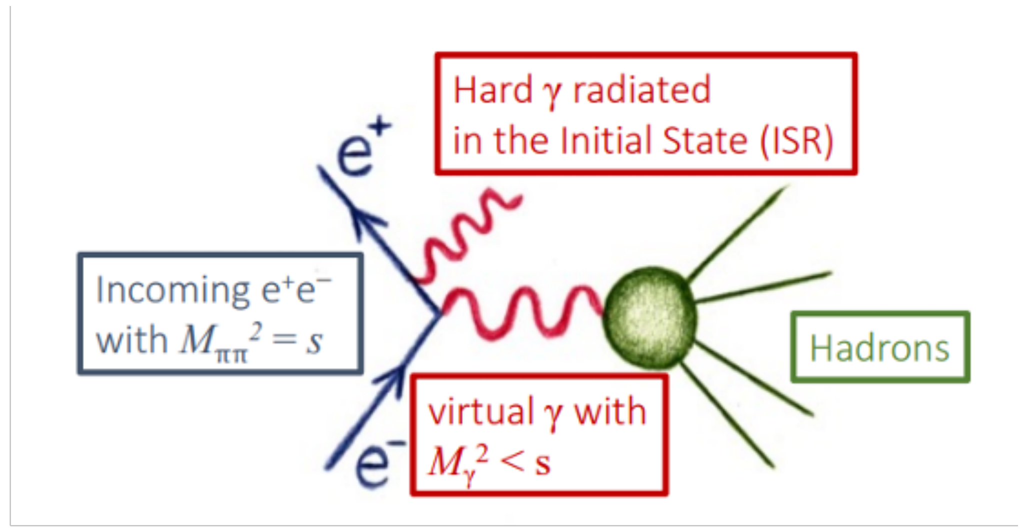
9 May 2024

Status Report on the $\pi\pi\gamma/\mu\mu\gamma$ Analysis

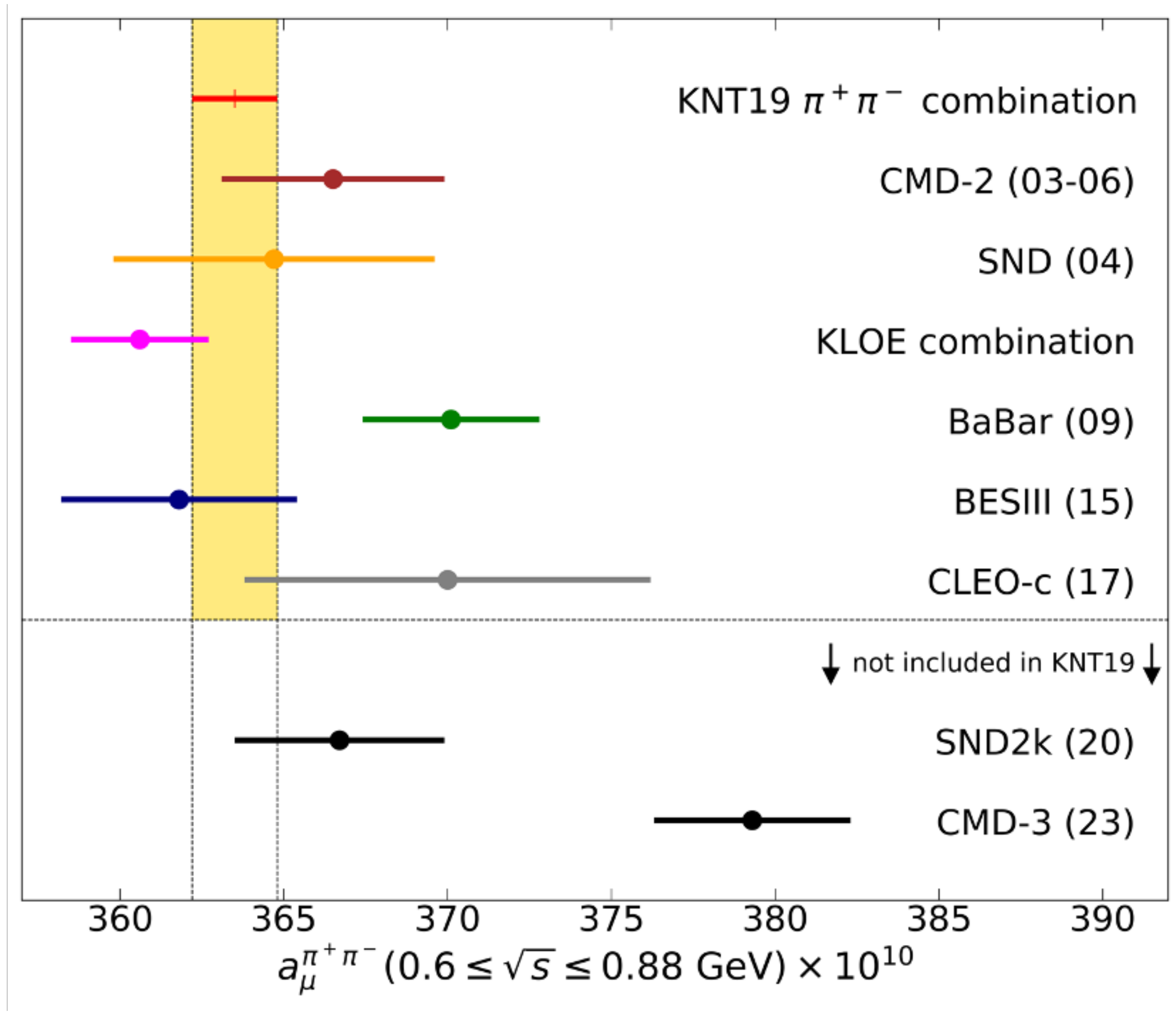
Estifa'a Zaid on behalf of KLOE HVP group

Overview

- Current experimental effort to discern tensions in the dispersive approach to determining muon g-2 prediction.
- The main contribution to the evaluation of the hadronic contribution to the muon anomaly (a_μ^{HLO}) is taken from the $e^+e^- \rightarrow$ hadron cross section



- A long standing tension ($\simeq 2.8\sigma$) exists between KLOE cross section measurements and BaBar.
- New CMD3 $e^+e^- \rightarrow \pi^+\pi^-$ cross section measurement is in tension with both Babar ($\simeq 2.3\sigma$) and KLOE ($\simeq 5.1\sigma$).
- Combined theoretical prediction for the dispersive approach is limited by tensions between KLOE and Babar measurements. Even without including CMD-3 measurement.
- This analysis aims to use **2004/2005 KLOE data** to carry out a new measurement. The $\sim 1.7 fb^{-1}$ includes ~ **25 million** $\pi\pi\gamma$ **events** which have **never been used** before in such an analysis.



Overview

- The **KLOE23 analysis** aims to use 2004/2005 KLOE data to carry out a new measurement.
- The $\sim 1.7fb^{-1}$ includes ~ 25 million $\pi\pi\gamma$ events which have never been used before in such an analysis.
- **Small angle analysis**
  - **photons** are required to be at small polar $\theta_\gamma < 15^\circ$ **or** $\theta_\gamma < 165^\circ$ wrt to the beam-line.
  - The two charged tracks are required to be within $50^\circ < \theta_\gamma < 165^\circ$
  - **Normalisation to muon ISR differential cross section (similar to KLOE12)**
- **The above will make the basis of the KLOE23 analysis however group is prepared to make modifications if desired.**
- Analysis group is tackling different aspects using new techniques with the intention of reducing the larger systematic uncertainties. **-KLOE23$_{\text{(goal)}}$: $0.1\%_{stat} \oplus 0.2\%_{th} \oplus 0.3\%_{syst} \Rightarrow \sim 0.4\%_{tot}$**

Blinding

Tracking

Detector Tuning

Background

This presentation will cover the latest developments in the analysis from the past 4 months. For previous work see Paolo Beltrame's and Lorenzo Punzi's slides from previous KlOE meetings

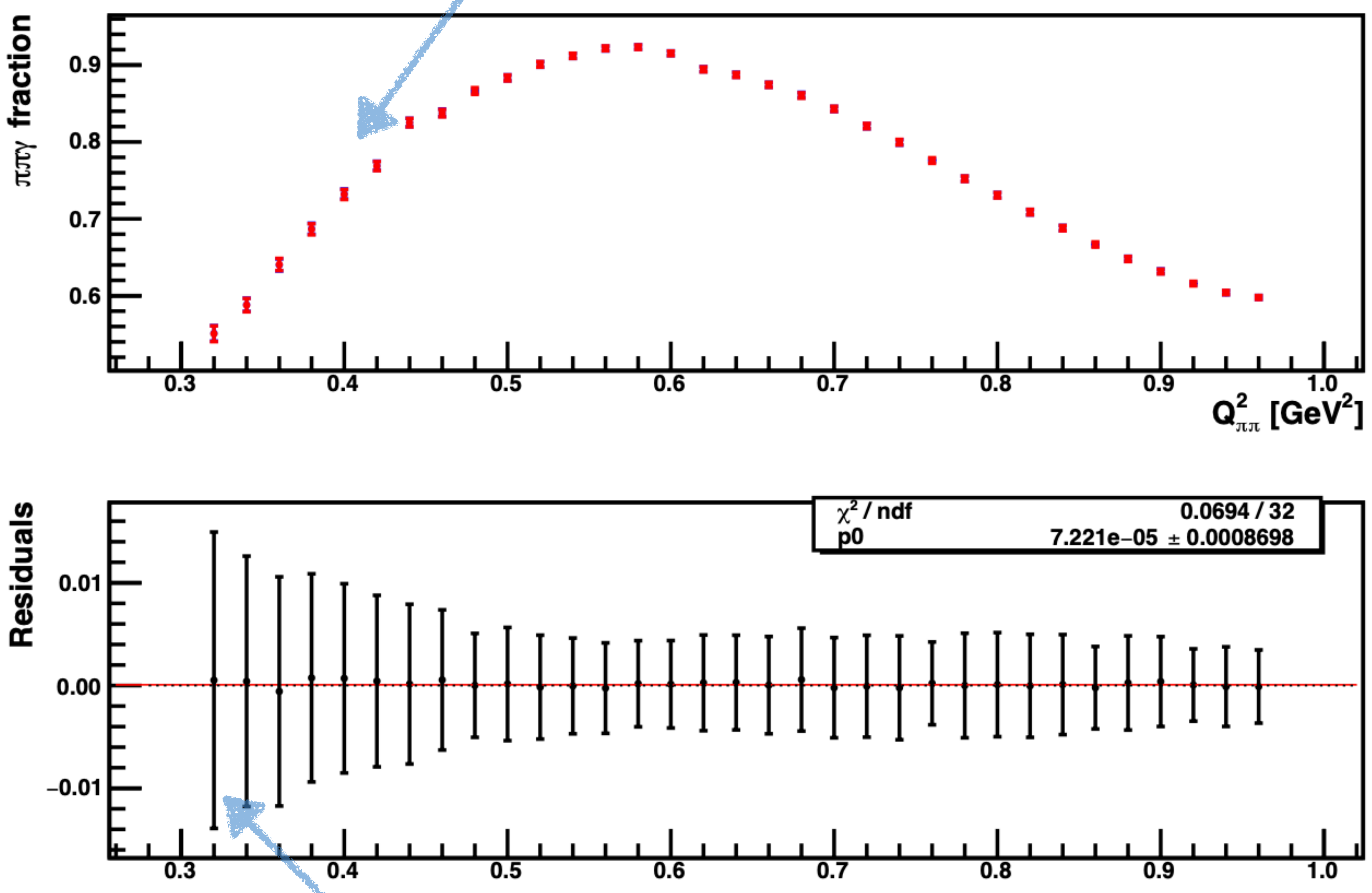
Areas to reduce systematic uncertainty from KLOE8 and KLOE12 analyses

Syst Errors (%)	$a_\mu^{\pi\pi}$ absolute	$a_\mu^{\pi\pi}$ ratio
Background Filter (FILFO)	negligible	negligible
Background Subtraction	0.3	0.6
Trackmass	0.2	0.2
Particle ID	negligible	negligible
Tracking	0.3	0.1
Trigger	0.1	0.1
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	0.2	negligible
Acceptance (θ_π)	negligible	negligible
Software Trigger (L3)	0.1	0.1
Luminosity	$0.3\,(0.1_{th} \oplus 0.3_{exp})$	-
$\sqrt{s}$ dep. of H	0.2	-
Total exp. systematics	0.6	0.7
Vacuum Polarisation	0.1	-
FSR treatment	0.3	0.2
Rad. function H	0.5	-
Total theory systematics	0.6	0.2
Total systematic error	0.9	0.7

Blinding

- The new KLOE analysis will be **conducted blindly** to ensure good practice and lack of bias throughout.
- This is not a trivial task and is the **first analysis KLOE a_μ^{HLO} analysis to be blinded.**
- The aim of blinding is shift the result of the analysis by a small amount without jeopardising the distributions of data and Monte Carlo.
- Two root-tuples will be used in this analysis; **blinded and working (unblinded) root-tuples**
- Root-tuples will be blinded by:
  - **Removing a small, unknown fraction of events from the data.**
  - This modifies the measured differential cross section by **removing a different fraction of events from each $Q^2_{\pi\pi}$ or $Q^2_{\mu\mu}$ slice** whilst leaving other distributions unchanged.
- Efficiencies are calculated on the working root-tuples but are applied to the blinded ones.
- **Extraction of $|F_\pi|^2$ is done only on blinded root-tuples.**

Fitted fractions of original data (blue) and blinded data (red)



Residual difference of the fractions

Blinding

Things to note

Blinded root-tuples will be available at the very end and will only be **provided when all analysis steps are signed off**. All corrections found with working root-tuples will then be applied to blinded ones.

Blinded root-tuples can have signal region cuts pre-applied.

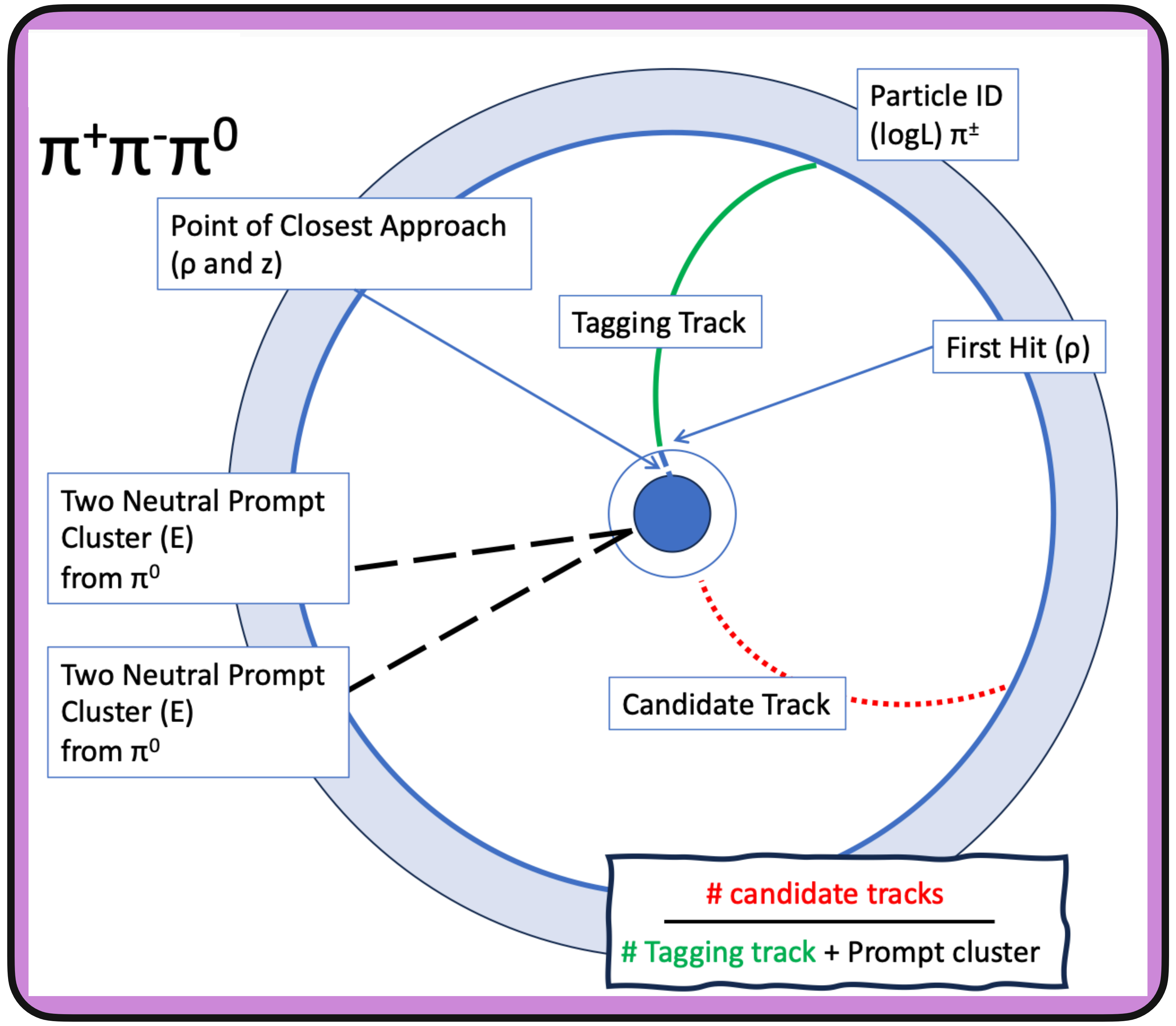
$\pi\pi\gamma$ **analysis will be performed on** $Q^2_{\pi\pi}$ **blinded root-tuples and** $\mu\mu\gamma$ **on** $Q^2_{\mu\mu}$

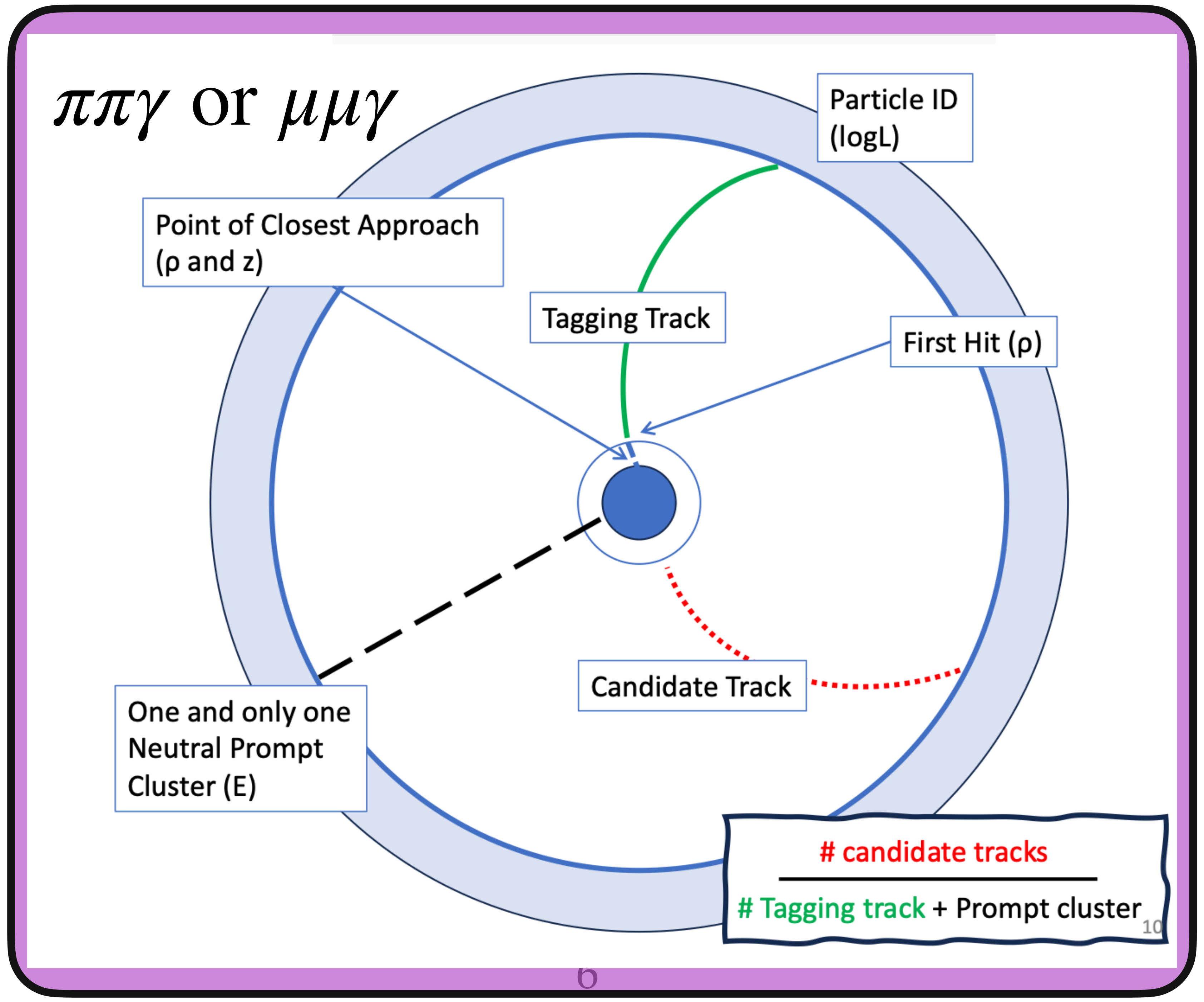
This blinding is still undergoing checks to ensure procedure is sound.

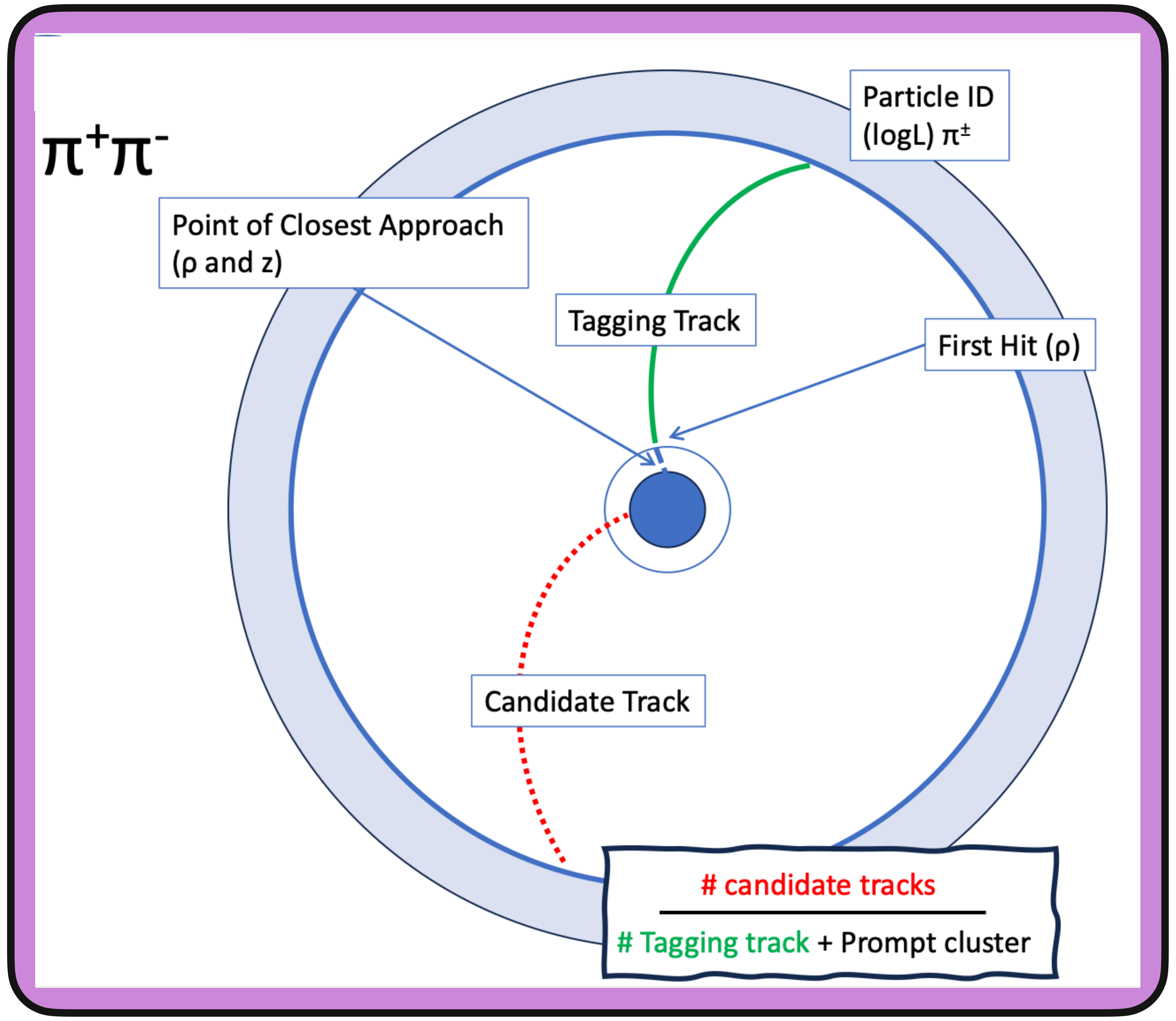
This blinding procedure like many others **assumes a level of honesty** from analysers. Analysers agree to not study the pion form factor using the working root-tuples.

Tracking

- The group's aim is to **study the tracking efficiency and reproduce previous analyses selections** and results.
- Selections will be made for : $\pi^+\pi^-\pi^0$, $\pi^+\pi^-$, and $\mu^+\mu^-\gamma$

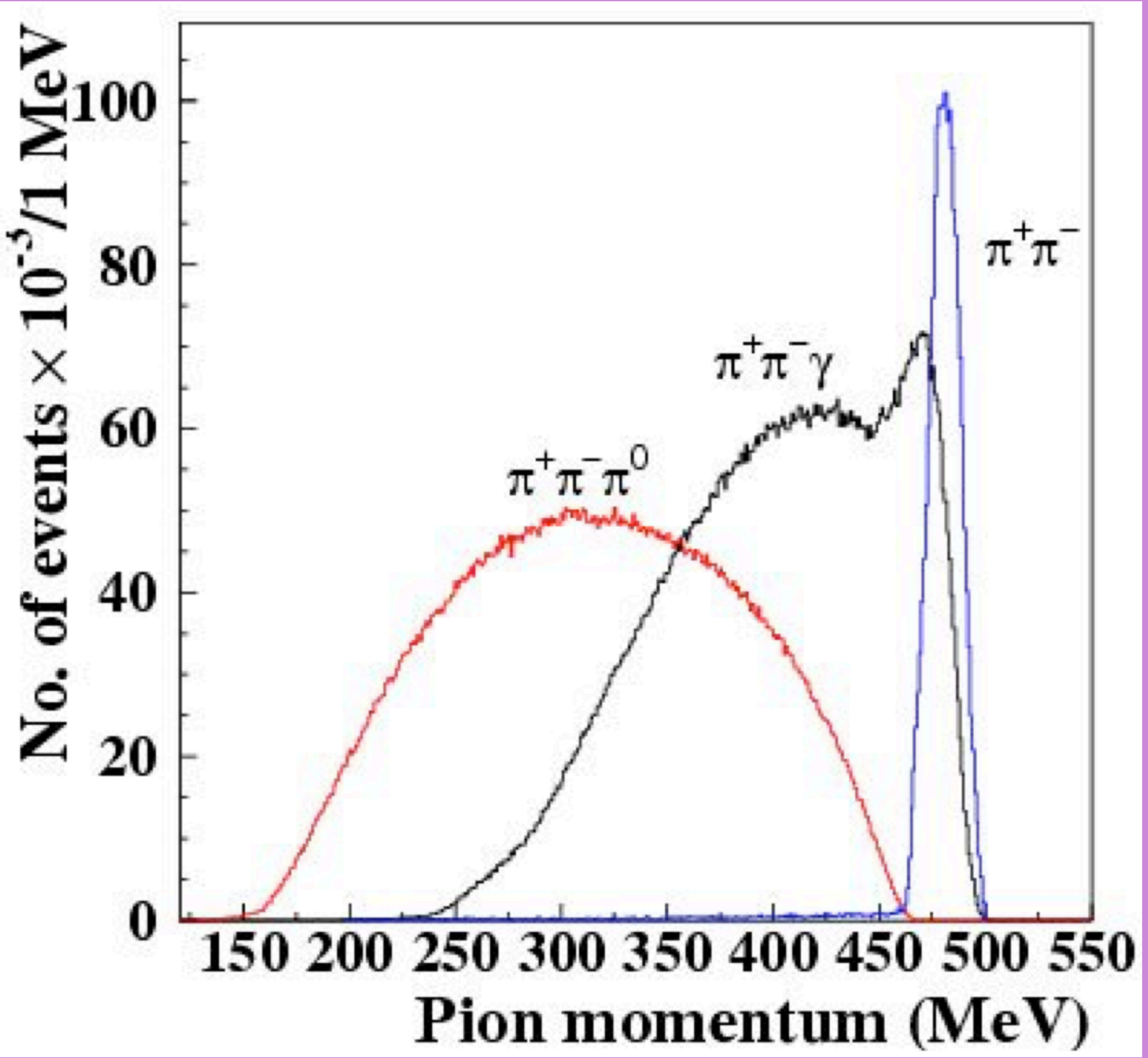




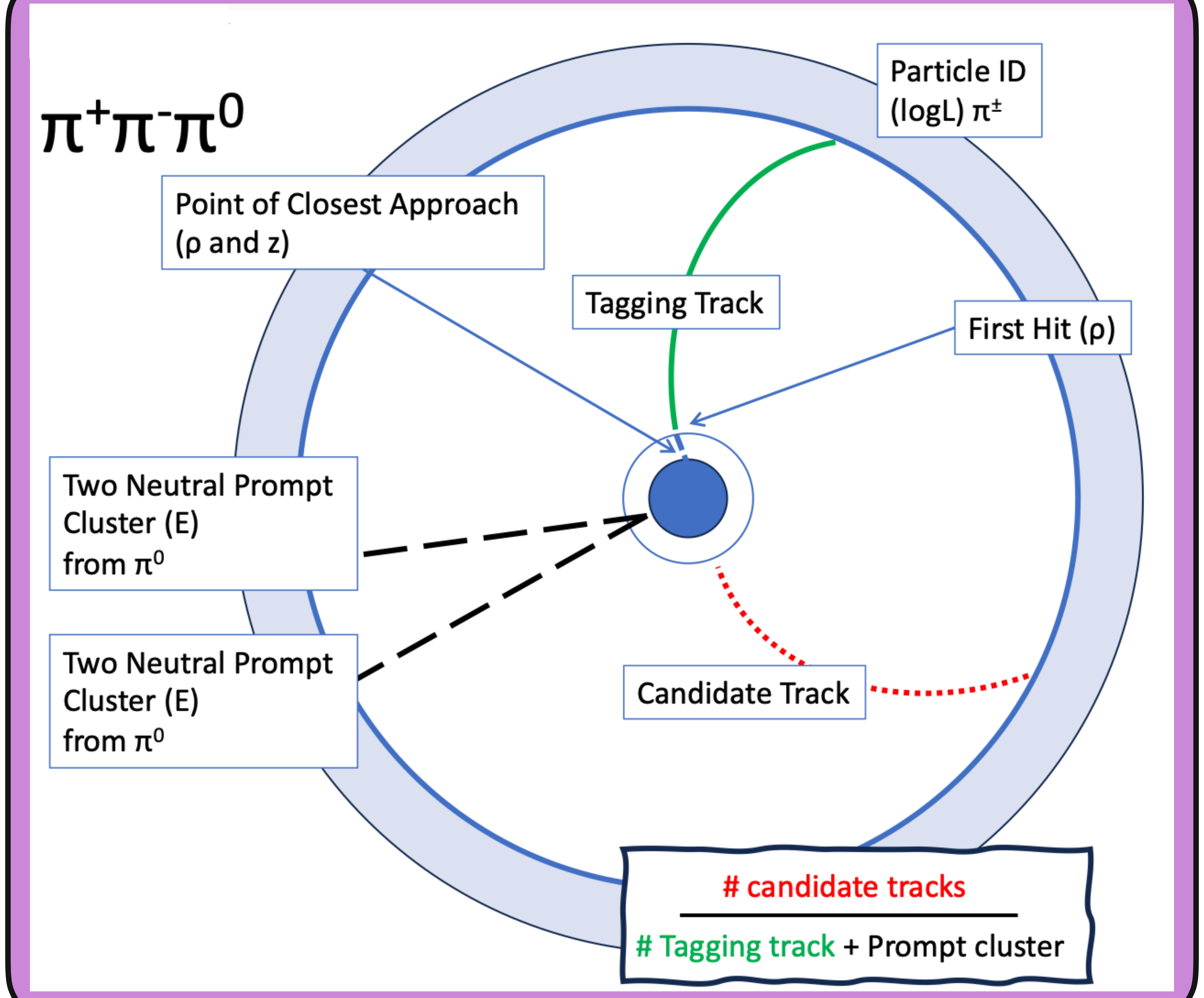


Tracking

- $\pi^+\pi^-\pi^0$ selections
- $\pi^+\pi^-$ selections
- $\pi\pi\gamma$ or $\mu\mu\gamma$ selections
- These selections result in different momentum regions being covered.
- The old selection procedure will be subsequently detailed, these may change in the future.

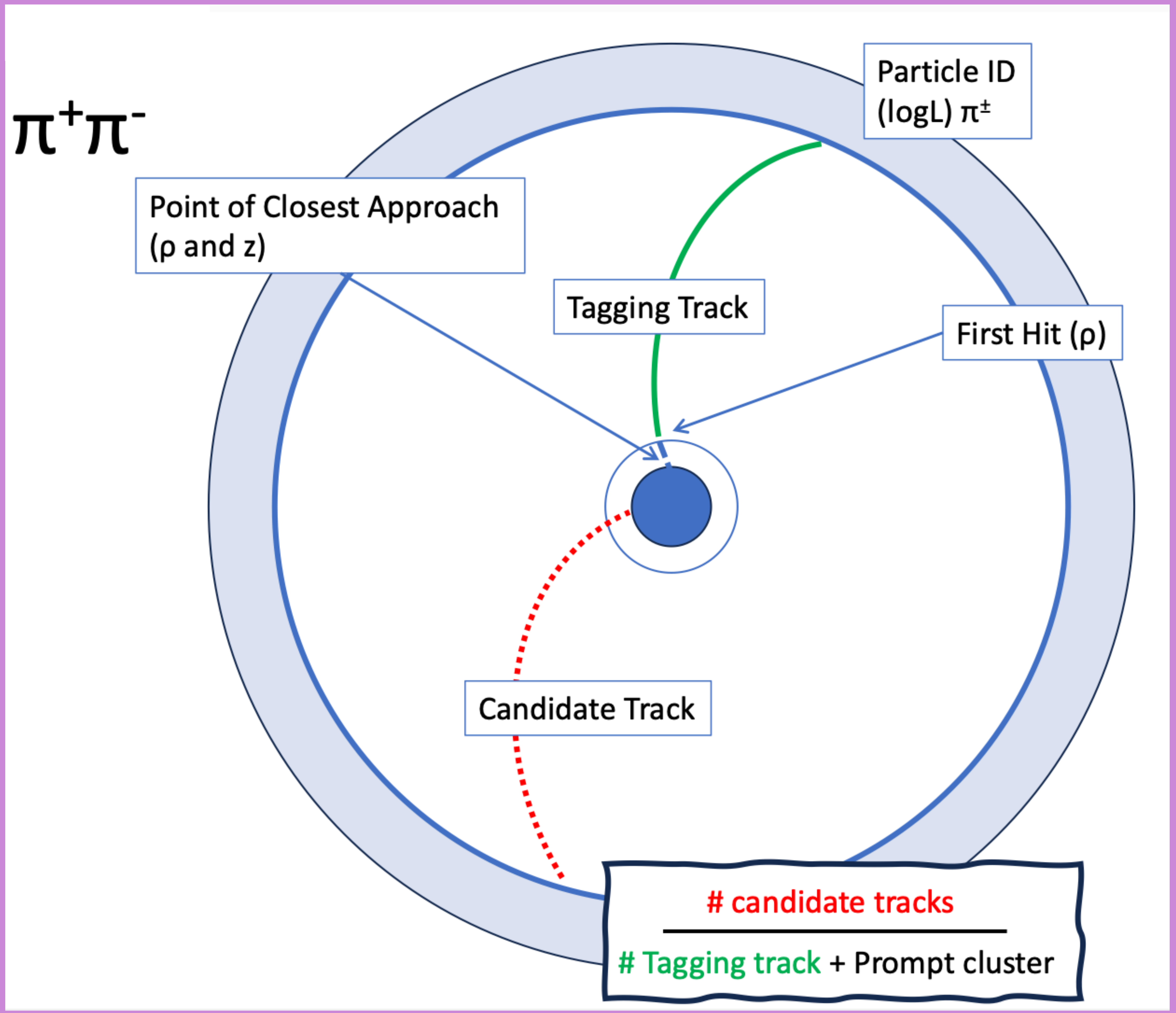


Tracking



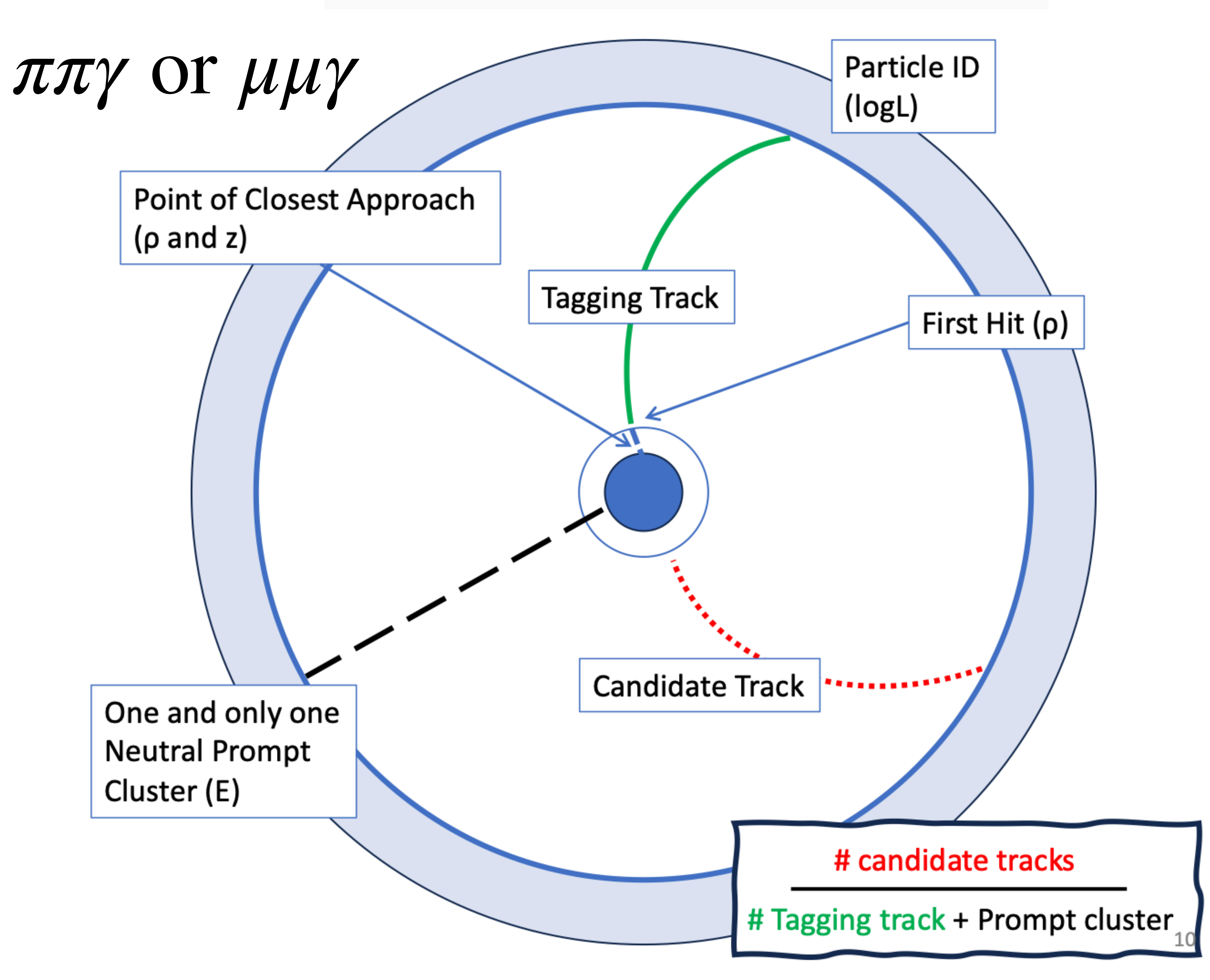
- $\pi^+\pi^-\pi^0$ selections:
  - $\sqrt{x_{fh}^2 + y_{fh}^2} < 50\text{cm}$
  - $\sqrt{x_{pca}^2 + y_{pca}^2} < 8\text{cm}$
  - $|Z_{pca}| < 7\text{cm}$
  - Must have associated cluster with LogL>1
- Associated clusters to pions:
  - 2 and only 2 clusters with $E > 30\text{MeV}$
  - $R > 60\text{cm}$
  - $|m_{\gamma\gamma} - m_{\pi^0}| < 20\text{MeV}$
  - Neutral. i.e. not associated to any tracks.
- Tag and probe:
  - Given the tagging track, $\pi^+(\pi^-)$, and two photons search for candidate track $\pi^-(\pi^+)$

Tracking



- $\pi^+\pi^-$ selections:
  - $\sqrt{x_{fh}^2 + y_{fh}^2} < 50\text{cm}$
  - $\sqrt{x_{pca}^2 + y_{pca}^2} < 8\text{cm}$
  - $|Z_{pca}| < 7\text{cm}$
  - Must have associated cluster with LogL>1
- Associated clusters to pions:
  - 1 or 2 clusters with $E > 50\text{MeV}$
  - Clusters are in the barrel and within $5ns < t > 8ns$
- Tag and probe:
  - Given the tagging track, $\pi^+(\pi^-)$, search for candidate track $\pi^-(\pi^+)$

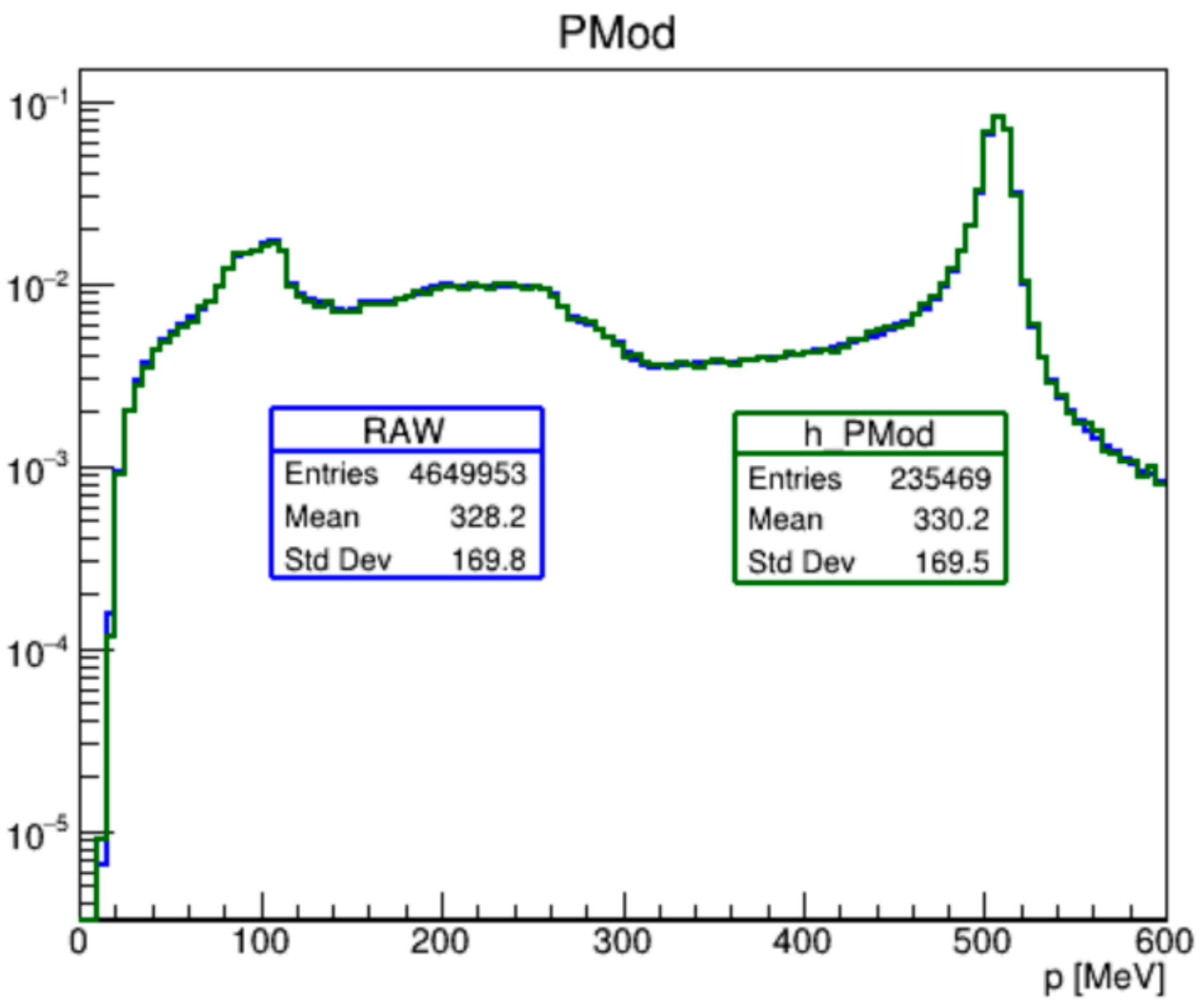
Tracking

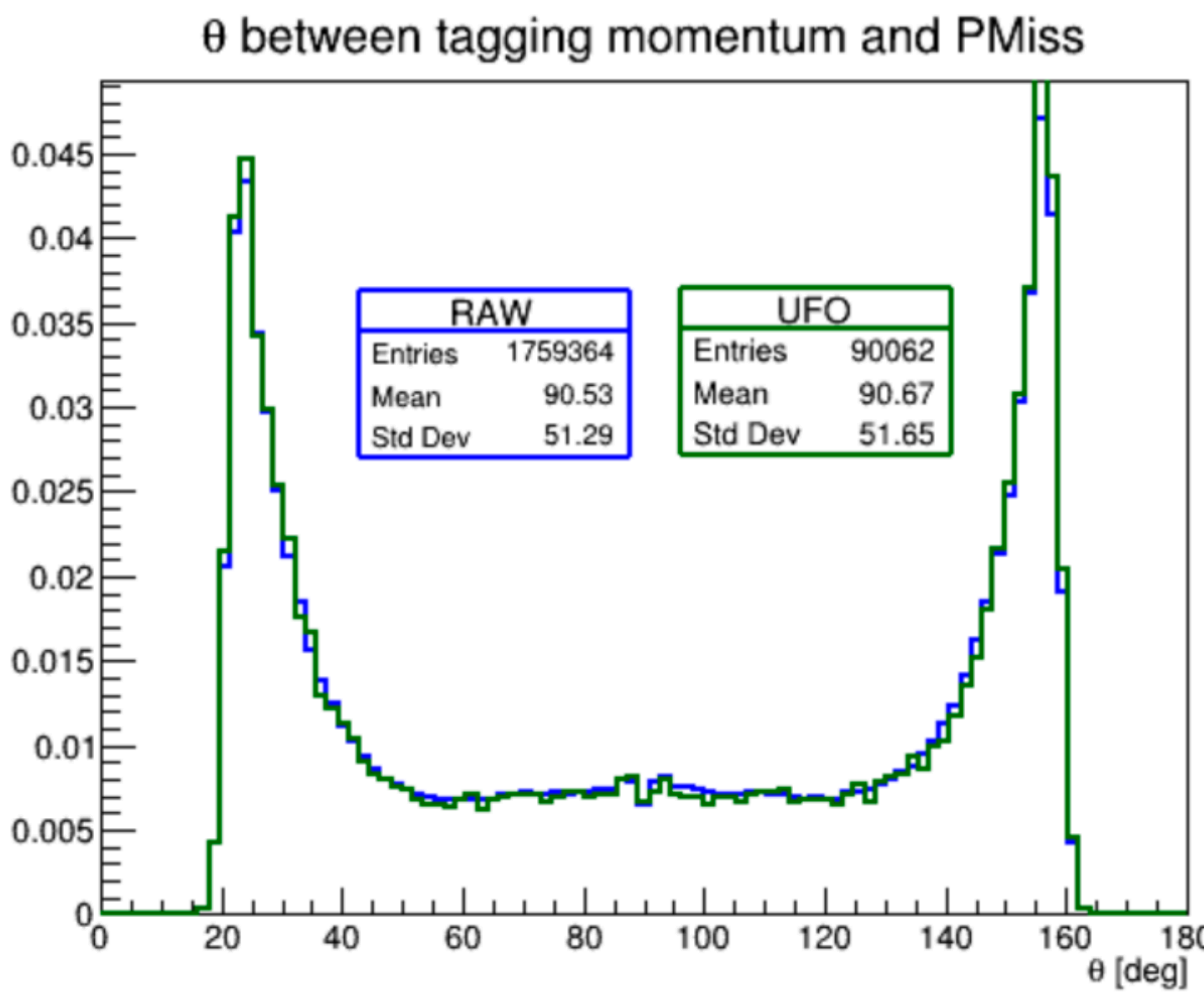


- $\pi\pi\gamma$ or $\mu\mu\gamma$ selections:
  - $\sqrt{x_{fh}^2 + y_{fh}^2} < 50\text{cm}$
  - $\sqrt{x_{pca}^2 + y_{pca}^2} < 8\text{cm}$
  - $|Z_{pca}| < 7\text{cm}$
  - Must have associated cluster with LogL>1
- Associated clusters to pions:
  - 1 and only 1 prompt (according to ECL_NEURAD) cluster with $E > 50\text{MeV}$
  - Neutral. i.e. not associated to any tracks.
- Tag and probe:
  - Given the tagging track, $\mu^+(\mu^-)$, search for candidate track $\mu^-(\mu^+)$

Tracking

- Studies have been thus far been done using reconstructed **UFO root-tuples** from 2004 data.
- **Checks** have been conducted to ensure that UFO data is consistent with RAW data.
- Why UFO ?
  - DSTs are already on tape and can be recalled from the library and root-tuples produced quickly.
- Comparison studies were done on events with a tagged $\pi^{\pm}$.
- More comparisons are being done using more variables whilst implementing identical reconstruction.

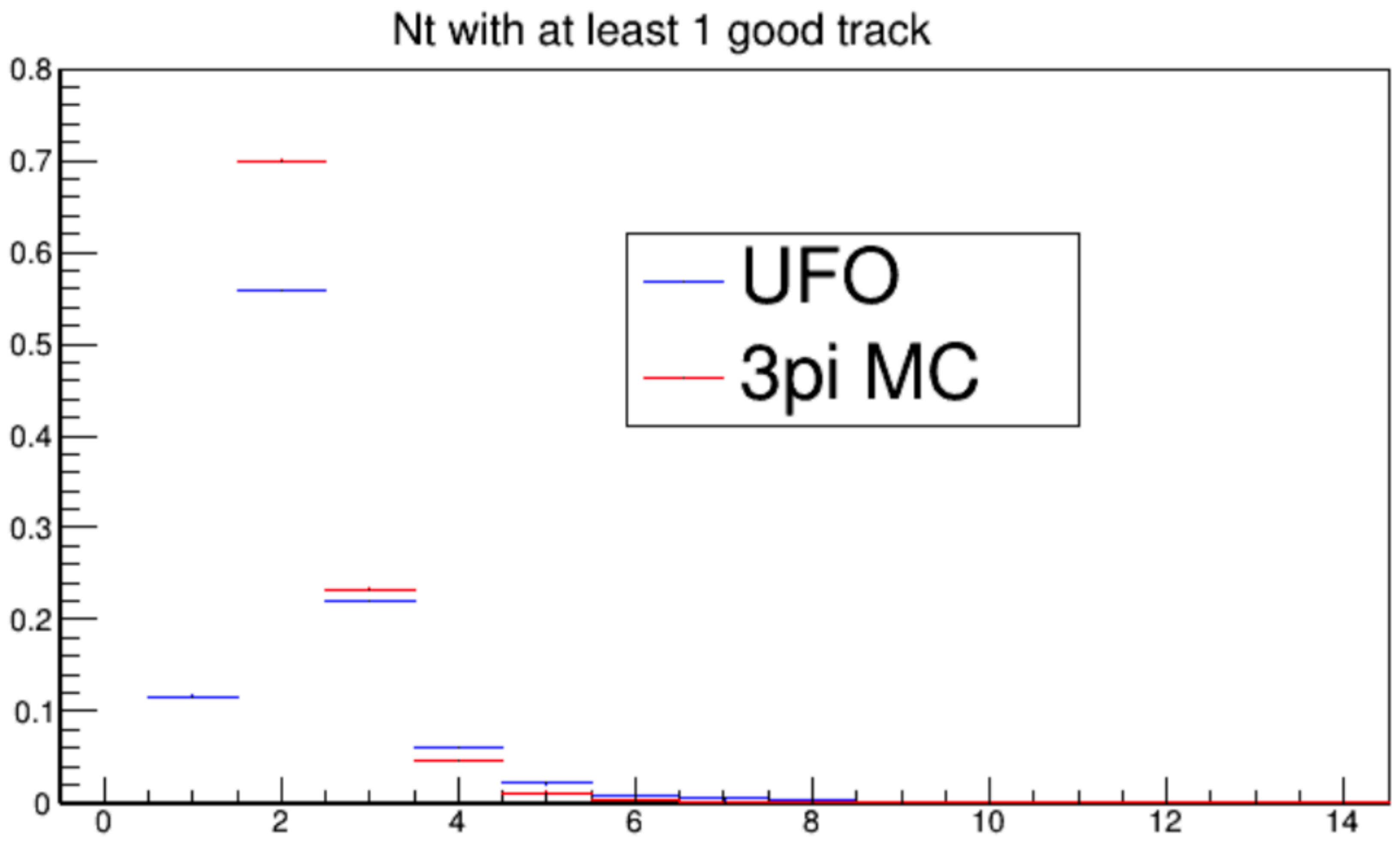


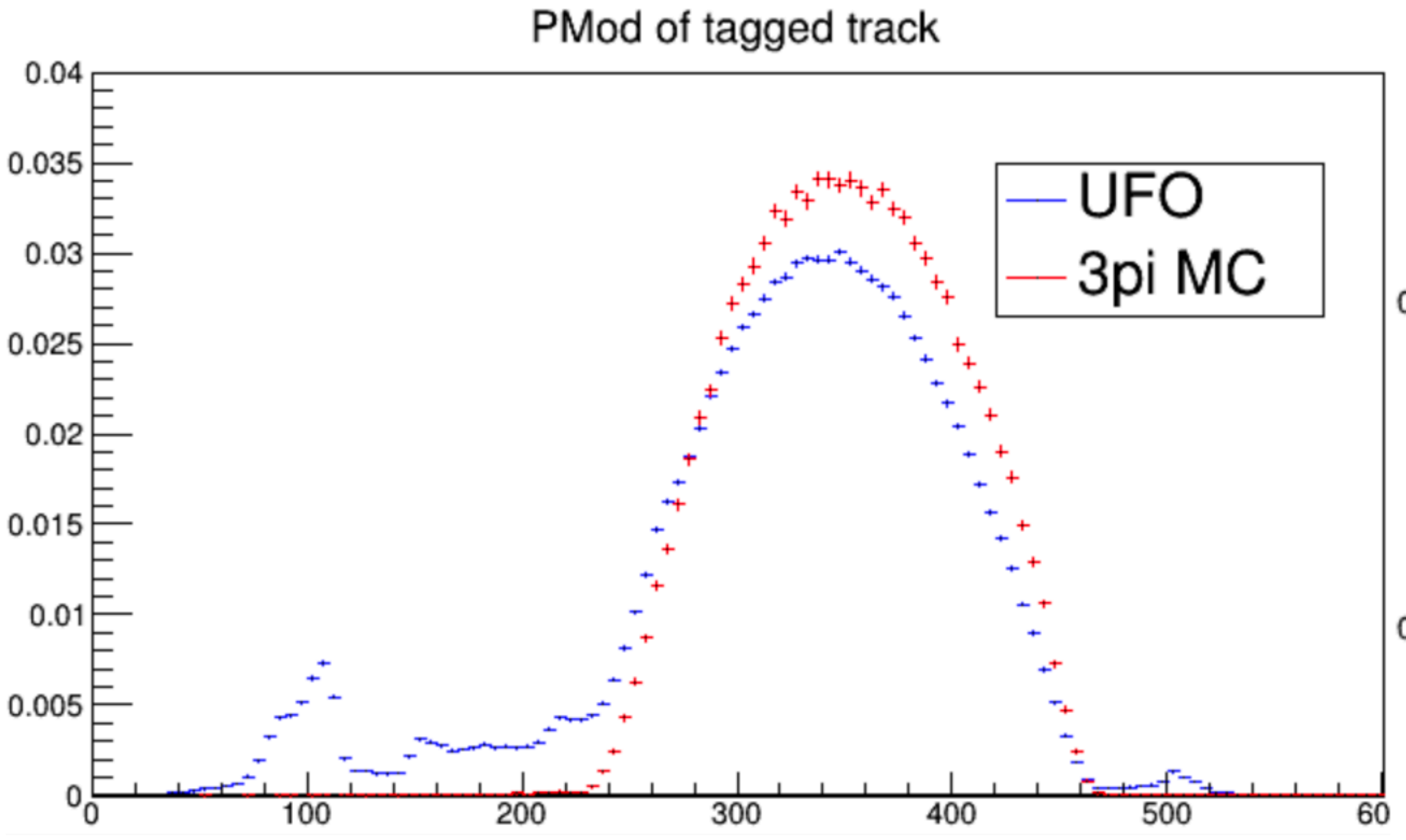


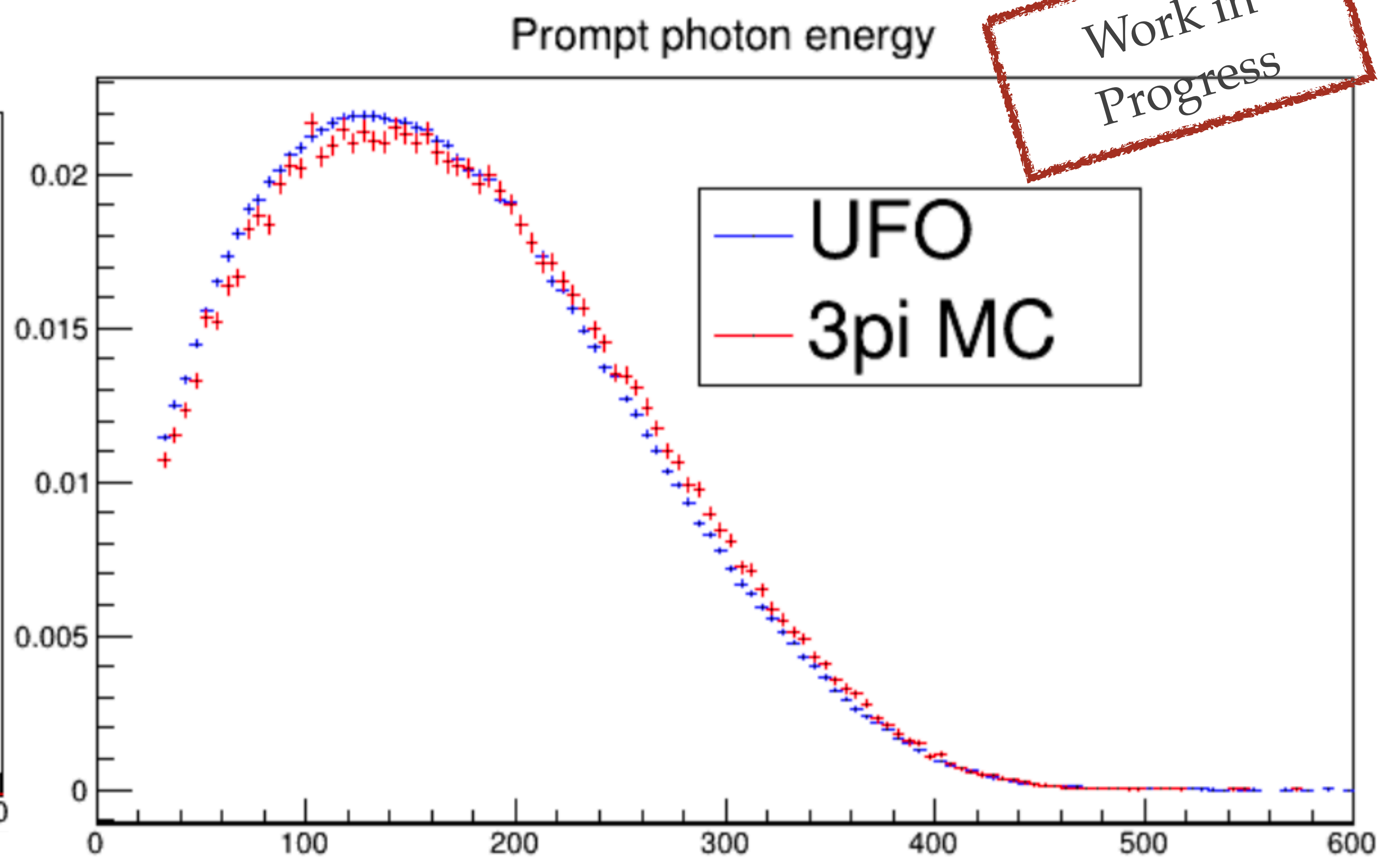
preliminary distributions are compatible within statistical errors

Tracking

- There are ongoing efforts to reproduce selection and tracking efficiencies using STENTU root-tuples from RAW data.
- Selected samples of $\pi^+\pi^-\pi^0$ from UFO files are compared to PROD2NTU MC.
- MC data comparison plots produced for different variables, selections still need to be finalised and matched between data and MC.







Work in Progress

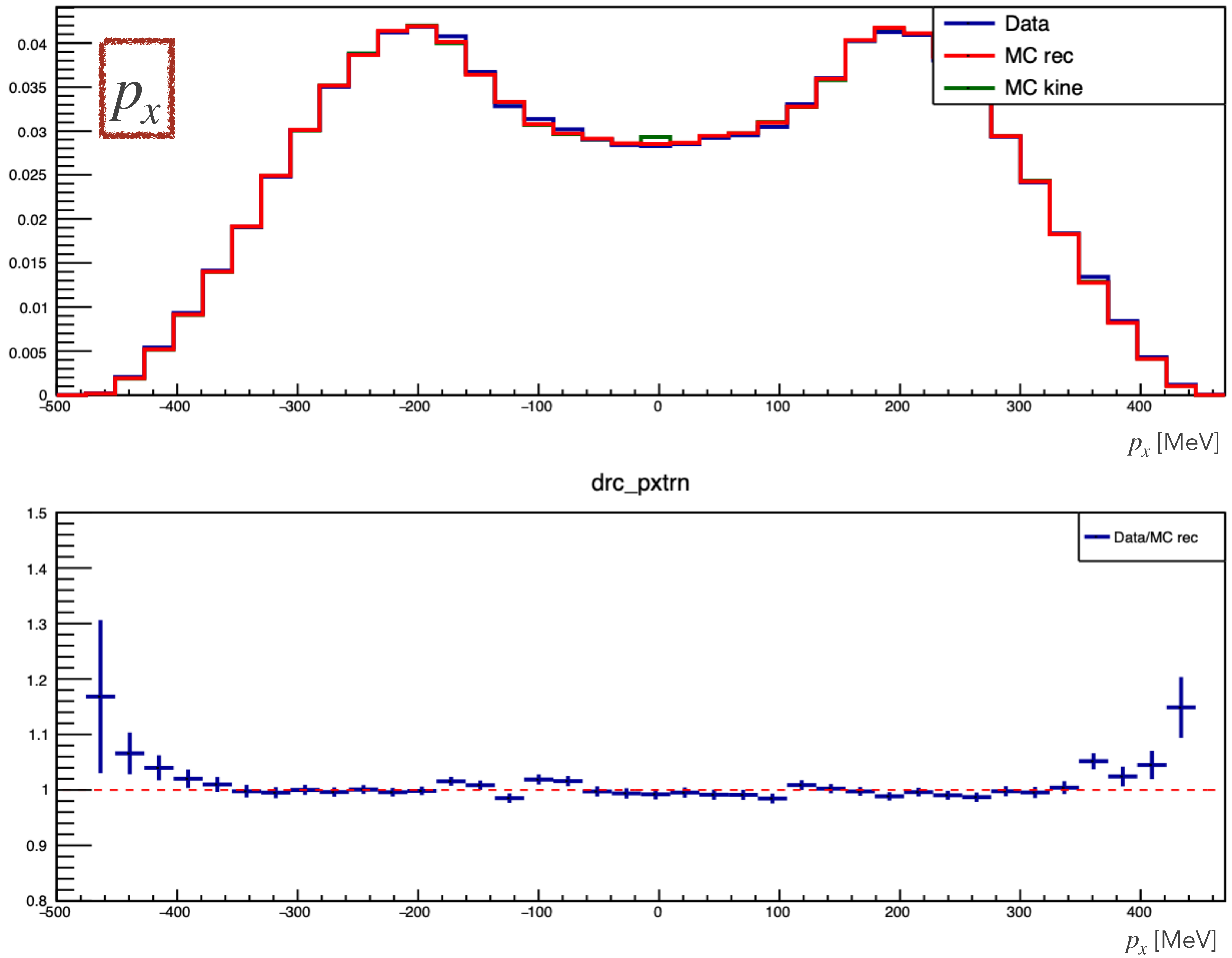
Tuning

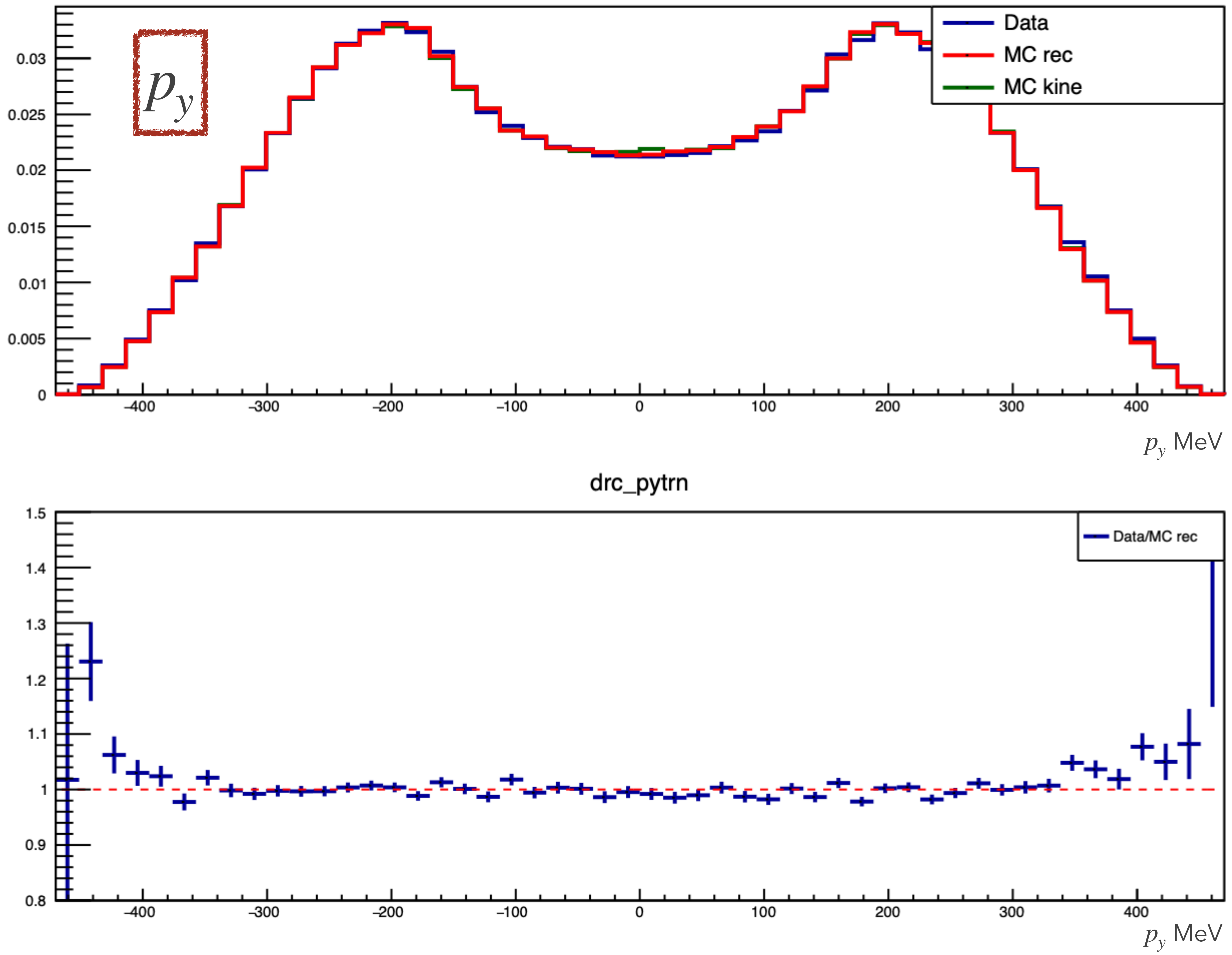
- Aim:
  - Produce a comprehensive set of distributions from variables in PROD2NTU and STENTU
  - **Investigate and quantify possible discrepancies between Data and Monte Carlo.**
- Studies have so far been **conducted on $\pi^+\pi^-\pi^0$ using STENTU** root-tuples.
- The root-tuples use the last ~ 5-7 pb^{-1} of 2005 data.
- Distribution comparisons have been done for momentum and position variables as well as other track and cluster variables.
- Data and MC agree to varying degrees depending on the variables. **Investigations are underway on discrepancies found.**

STENTU Variables Overview			
Variable	Consistent	Inconsistent	V.Inconsistent
Momentum			
p_x	•		
p_y	•		
p_z		•	
$p_t = \sqrt{p_x^2 + p_y^2}$:		•	
$p_{tot} = \lvert \mathbf{p}_+ \rvert + \lvert \mathbf{p}_- \rvert$:		•	
Position			
x_{first}		•	
y_{first}	•		
z_{first}		•	
x_{last}		•	
y_{last}	•		
z_{last}	•		
x_{pca}			•
y_{pca}			•
z_{pca}		•	
θ (polar)		•	
ϕ (azimuth)	•		
x_{clu}	•		
y_{clu}	•		
z_{clu}		•	
Tracks			
M_{trk}			•
n_{hits}			•
n_{vtx}	•		
Clusters			
n_{prompt}		•	
E_{clu}			•
T_{clu}		•	
$E_{\text{total,clu}}$			•
$Q^2_{\pi\pi}$		•	
Trgtype	•		

Tuning

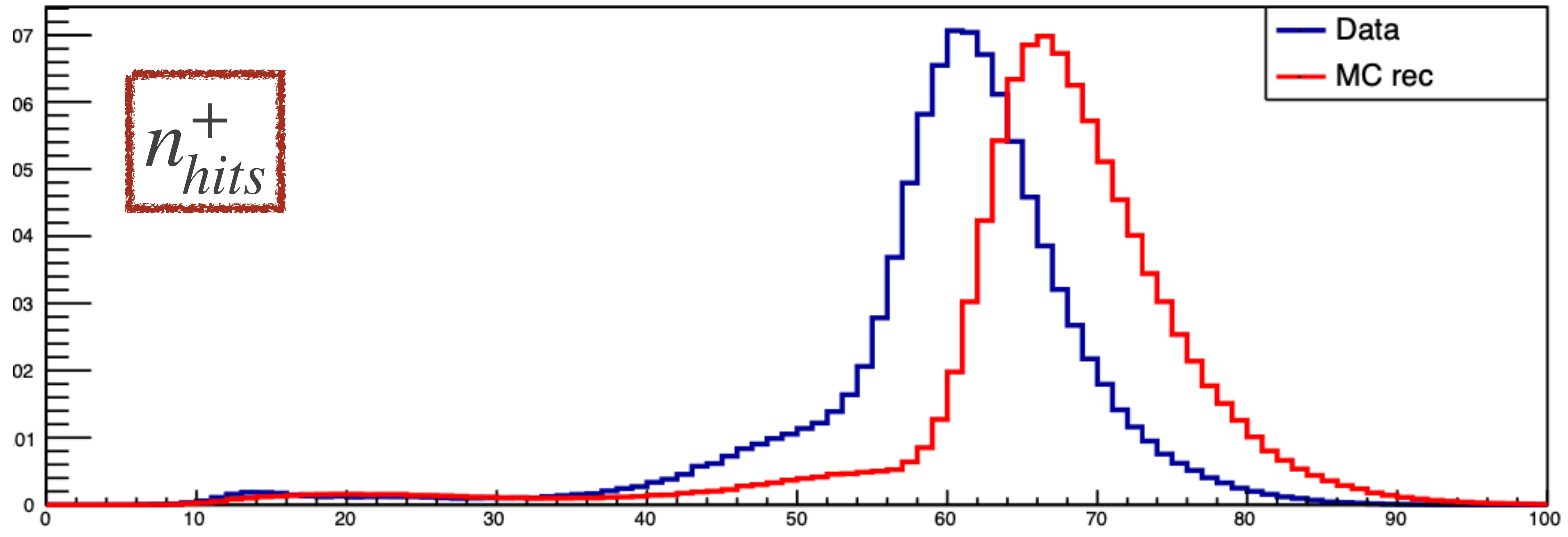
- Approximately **50% of the variables investigated are very consistent.** For example: transverse momentum variables of the tracks are consistent between data and MC.

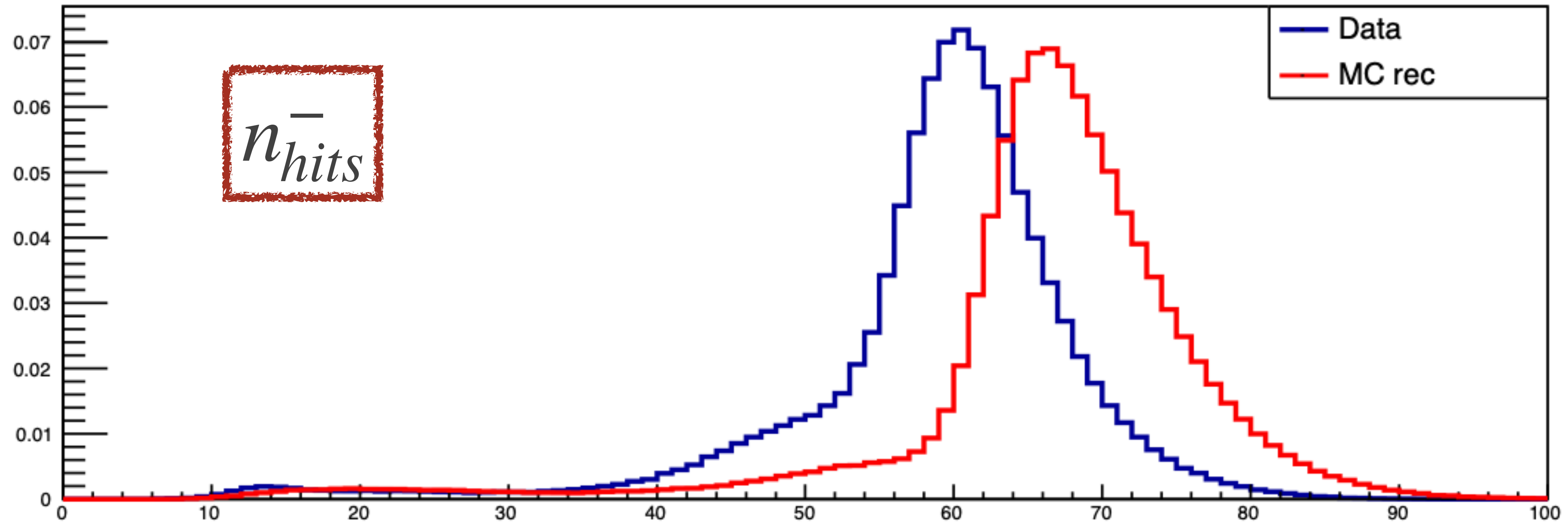


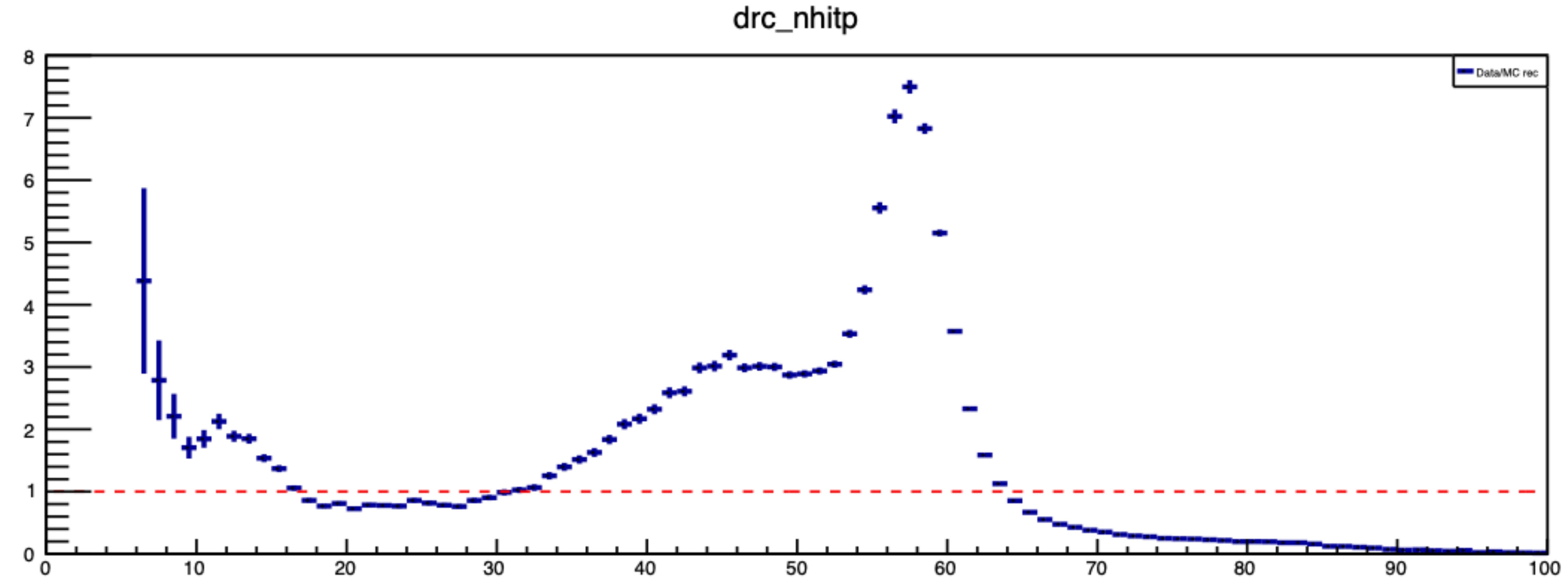


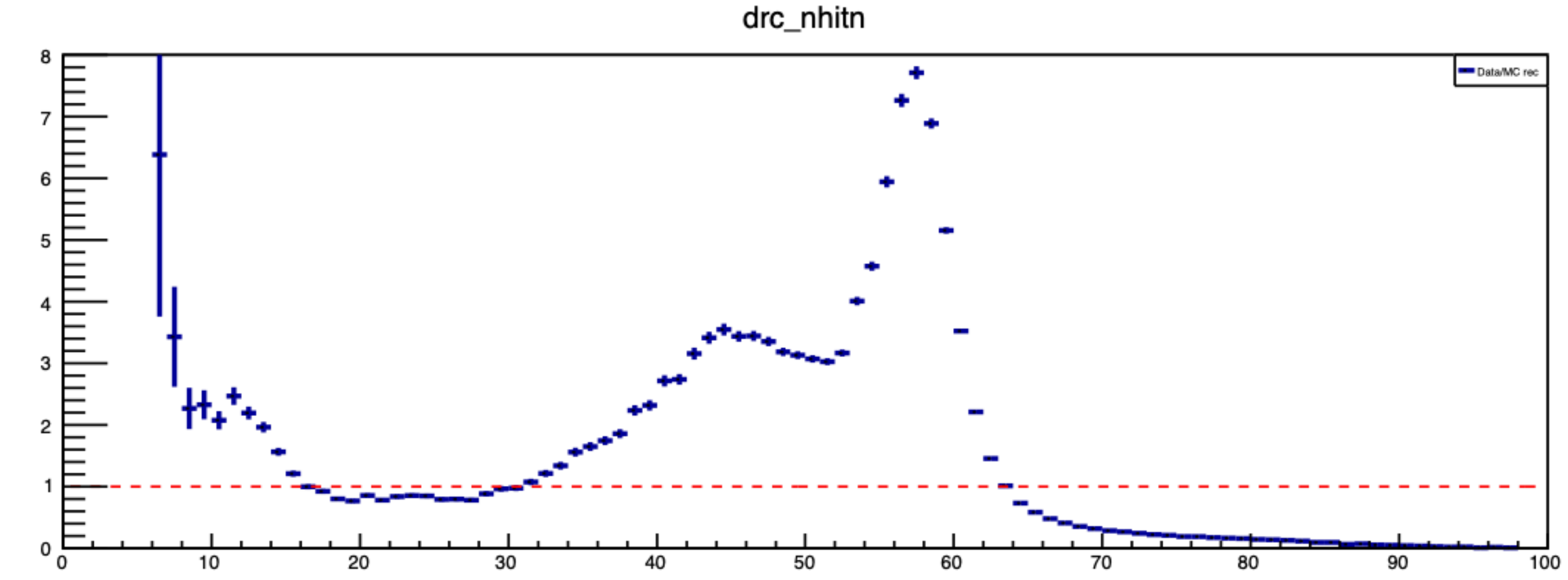
Tuning

- More interestingly some variables show clear discrepancy and are being investigated starting with the track variables.
- Note: the reason for the discrepancy in n_{hits} is yet to be determined, any conclusions should be drawn after further investigation
- **Distributions are presented separately for positive and negative tracks.** Below are examples of variables which are different between data and MC but are consistent for negative and positive tracks (as to be expected).









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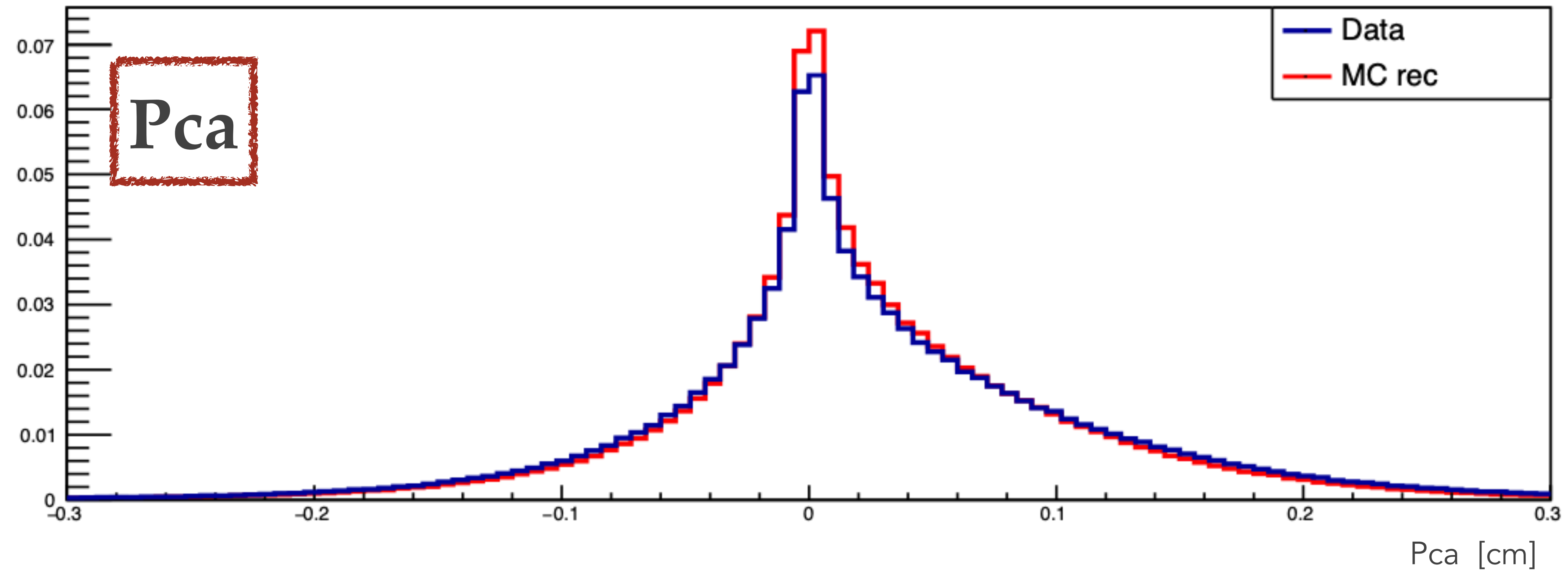
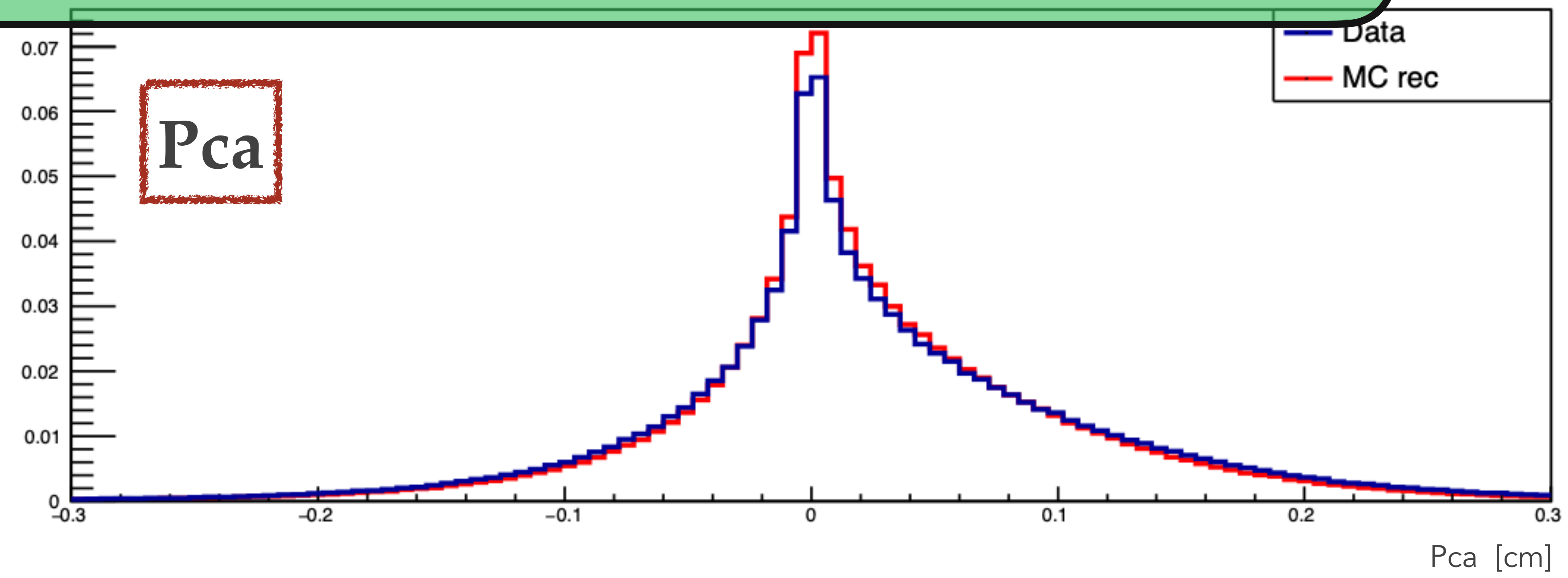
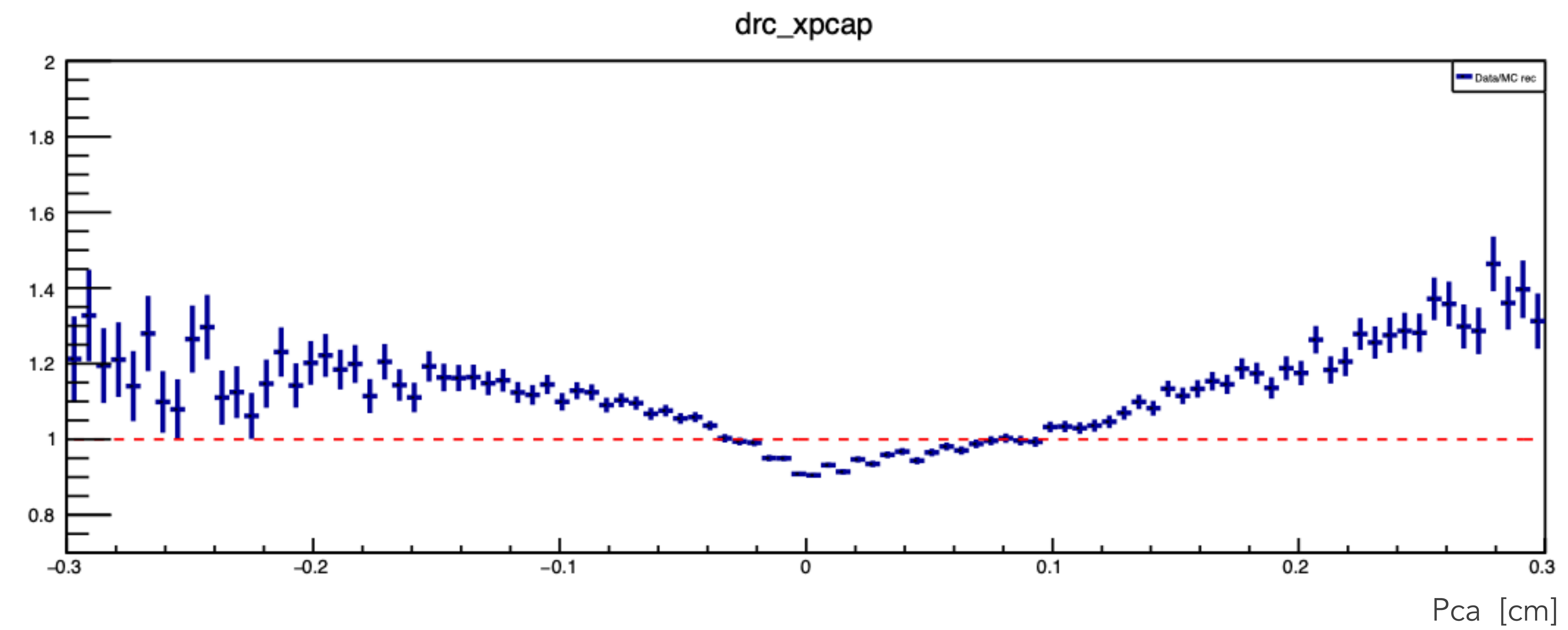
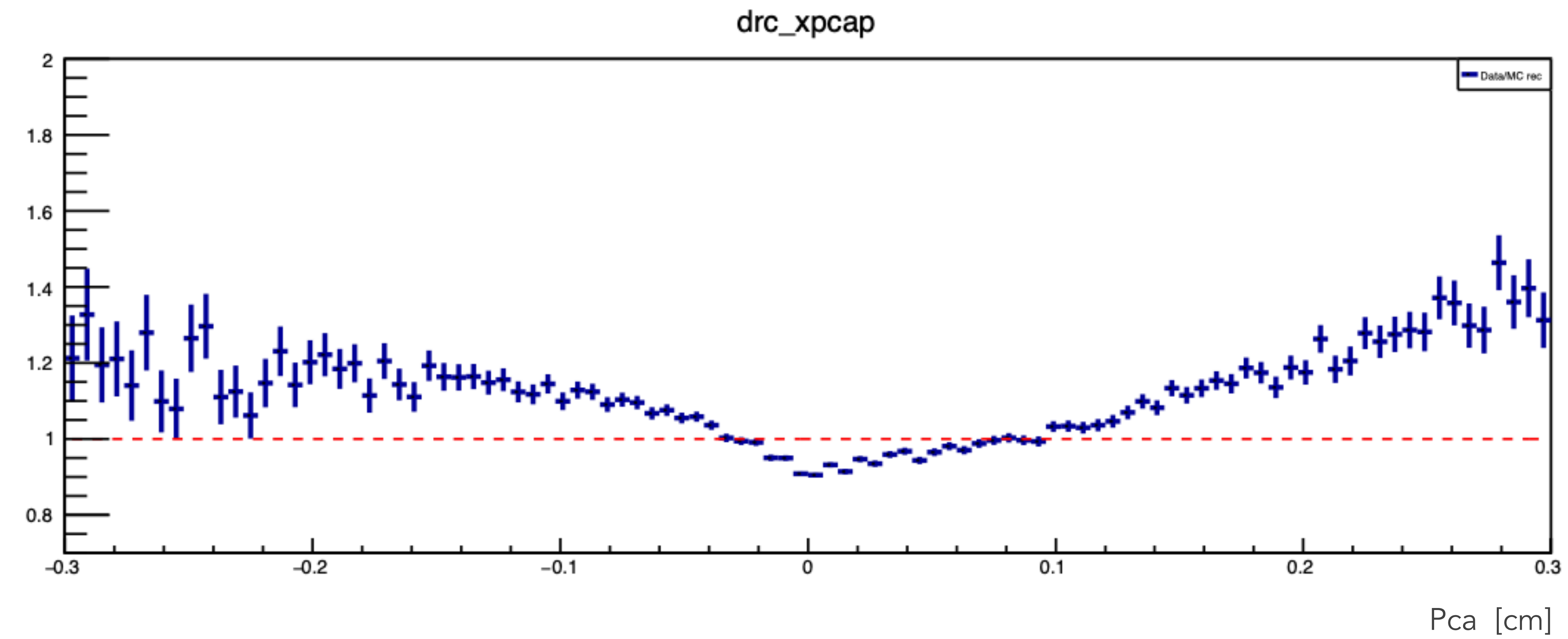


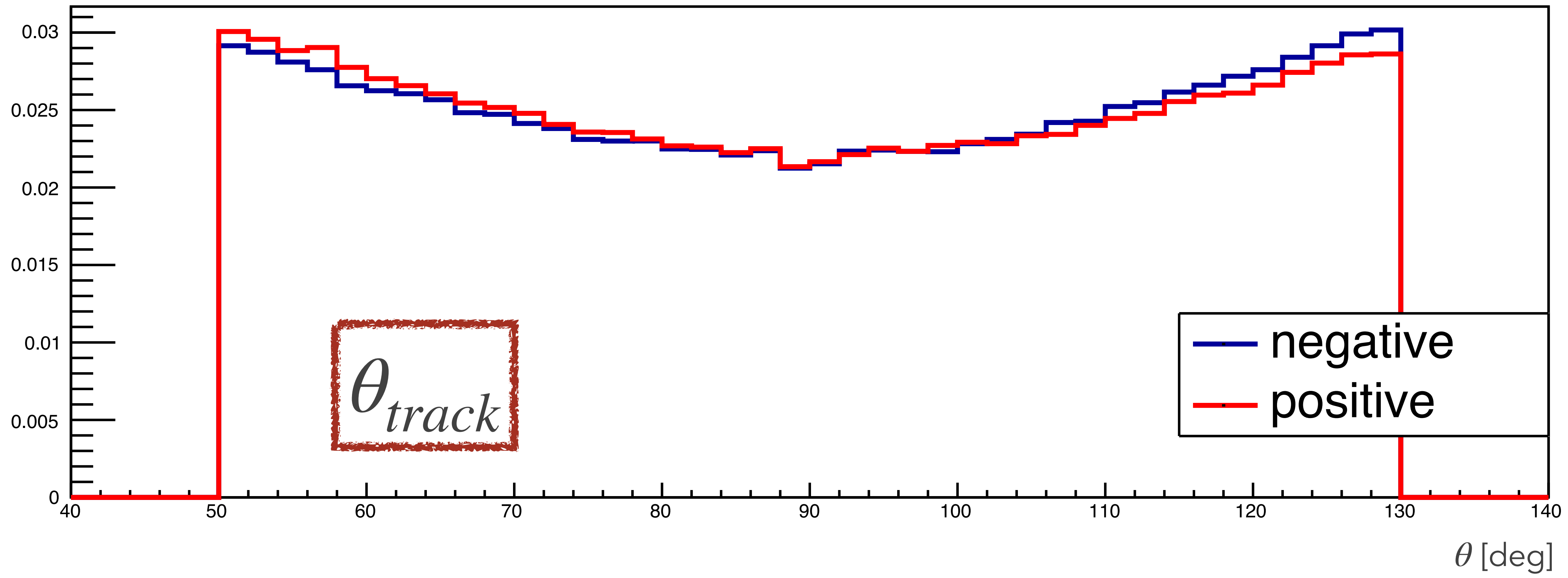


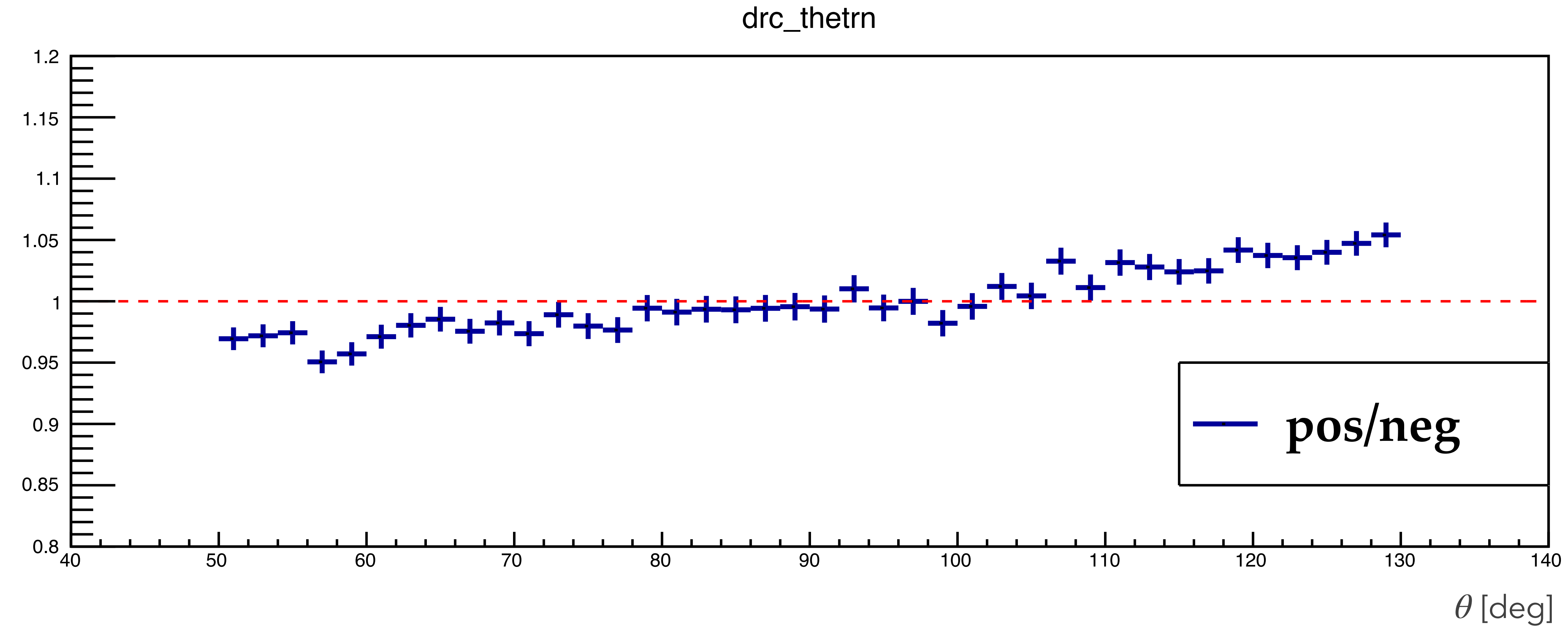


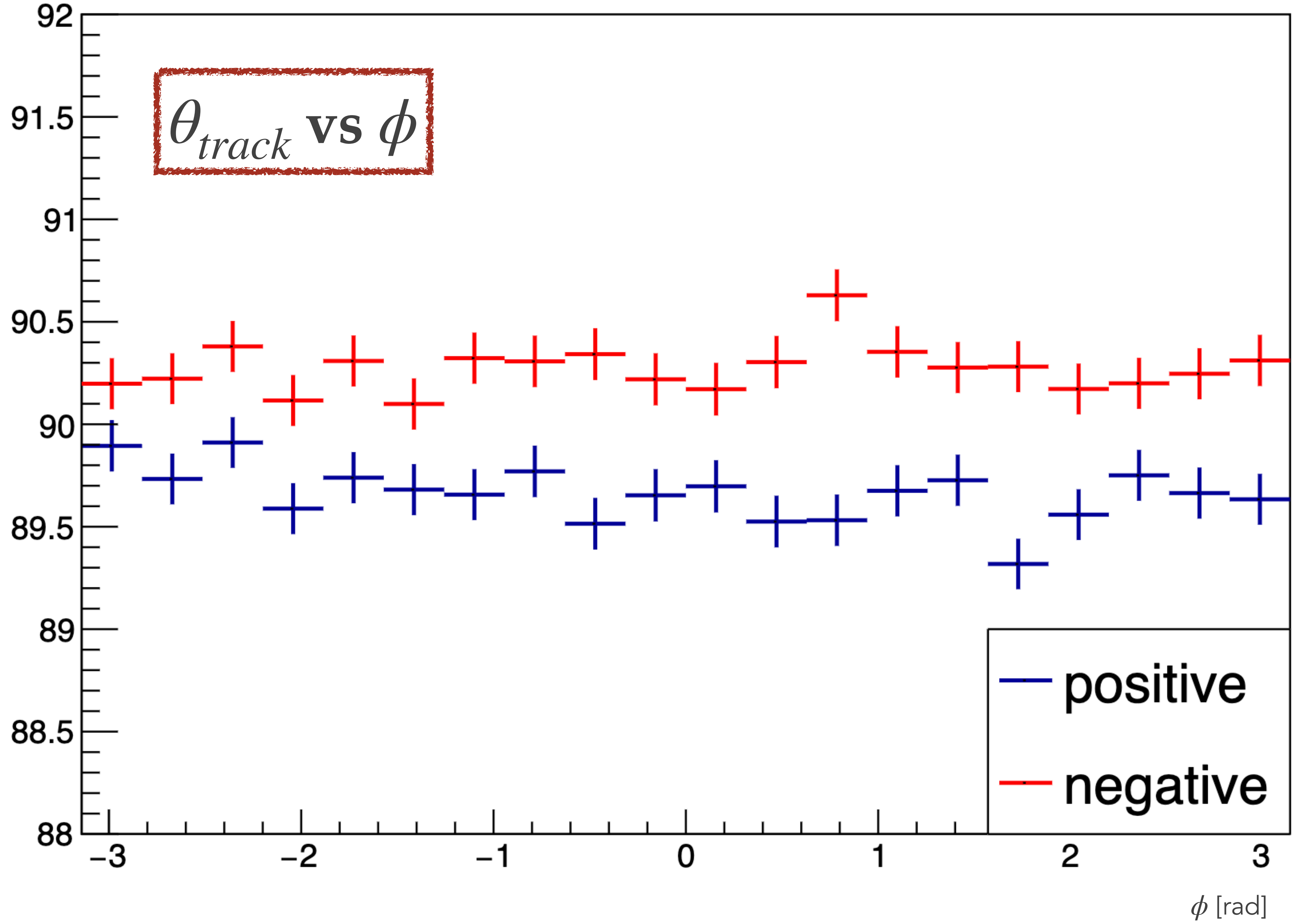


Tuning

- Distributions for θ variable show an interesting **discrepancy between positive and negative tracks in Data.** MC doesn't exhibit the same feature.
- This has a clear effect on **distributions calculated along the z axis ($p_z = p_T cot(\theta)$),** this is both for tracks (first hit, last hit, position, momentum)and calorimeter clusters.







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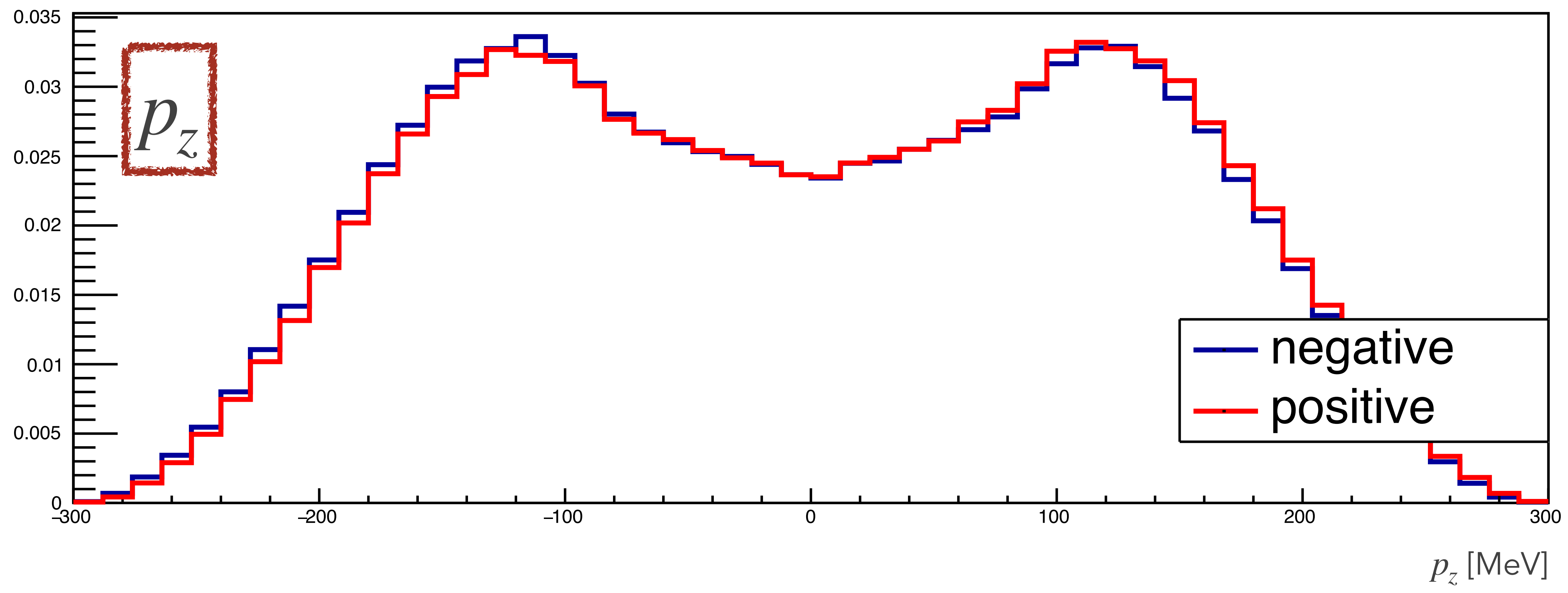
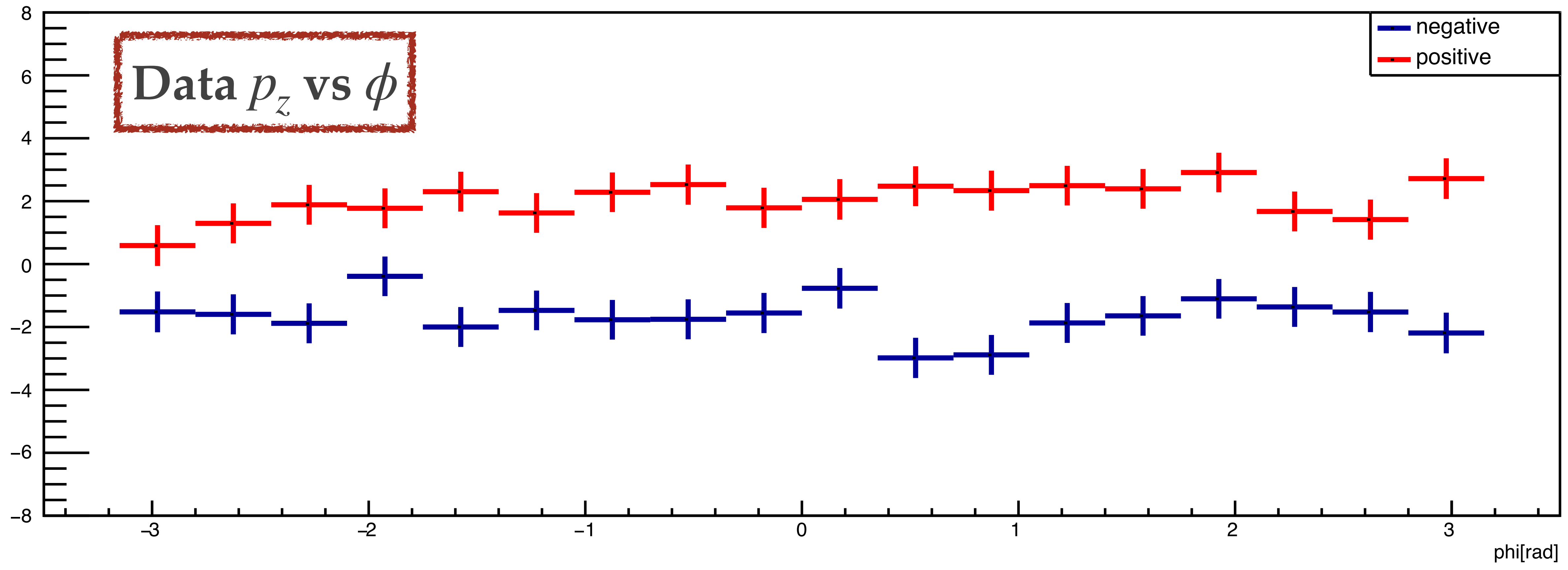
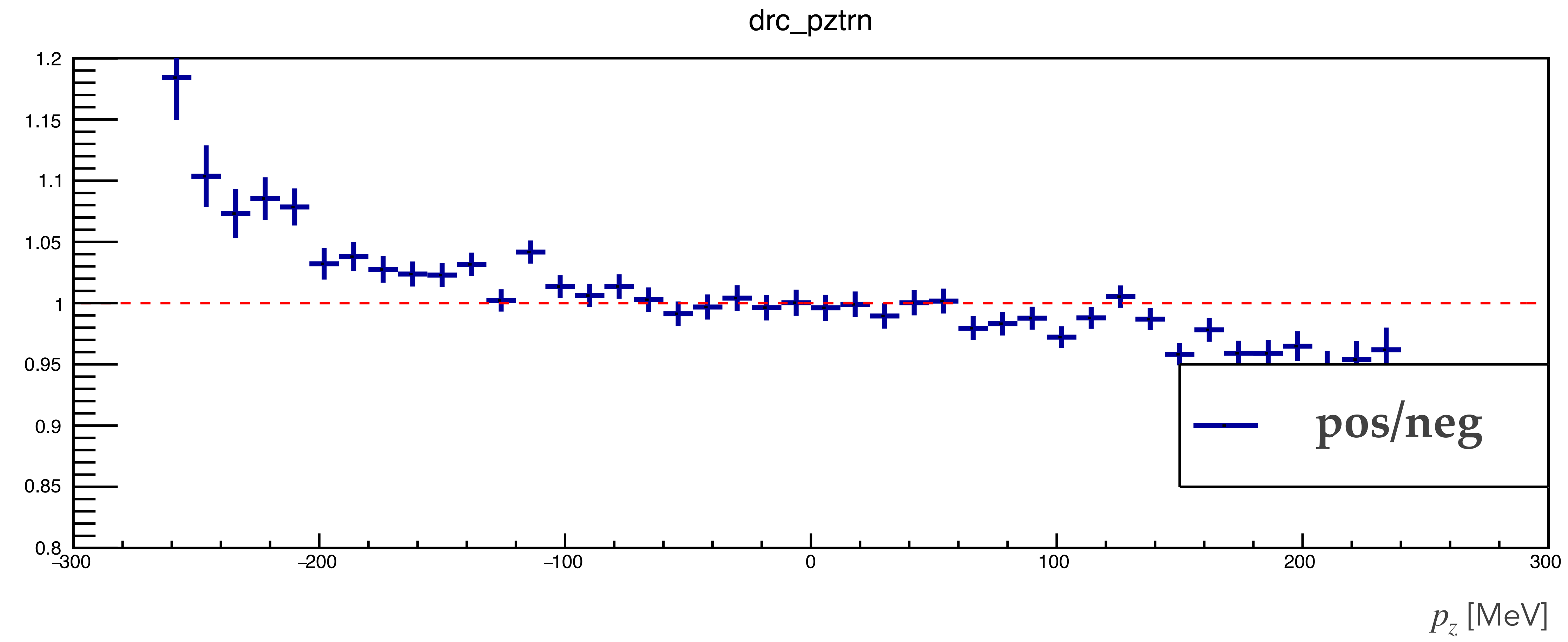
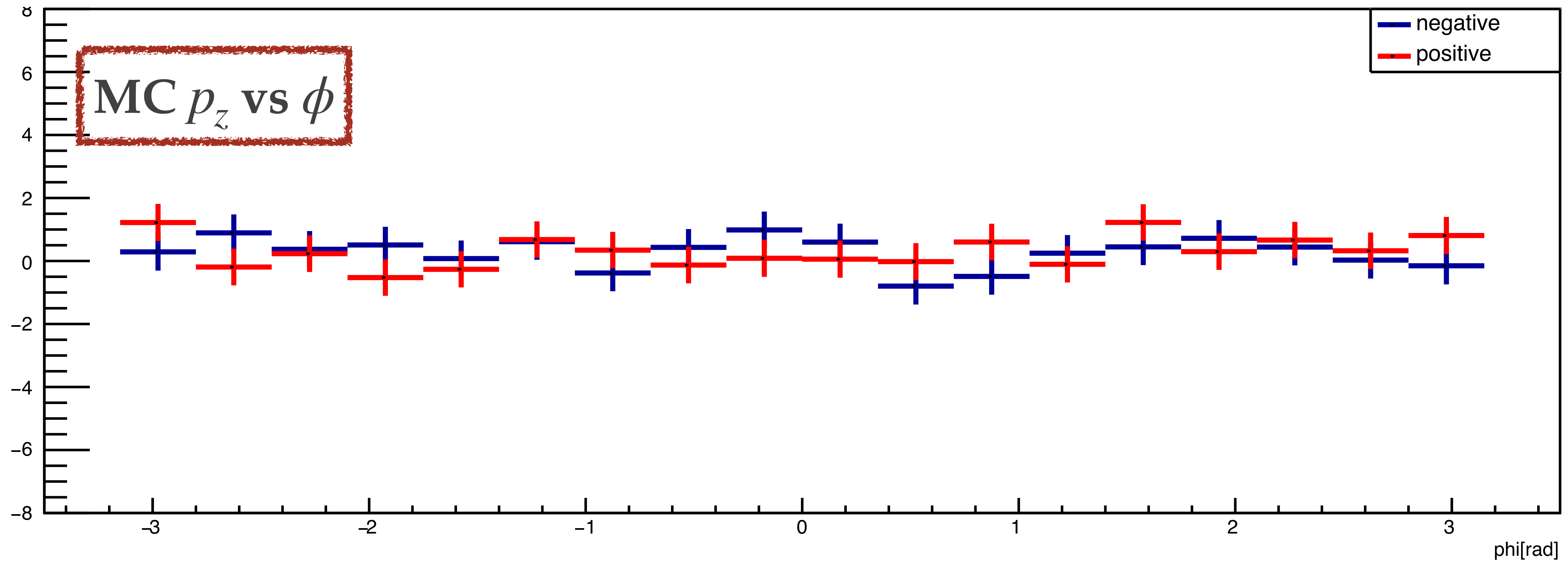




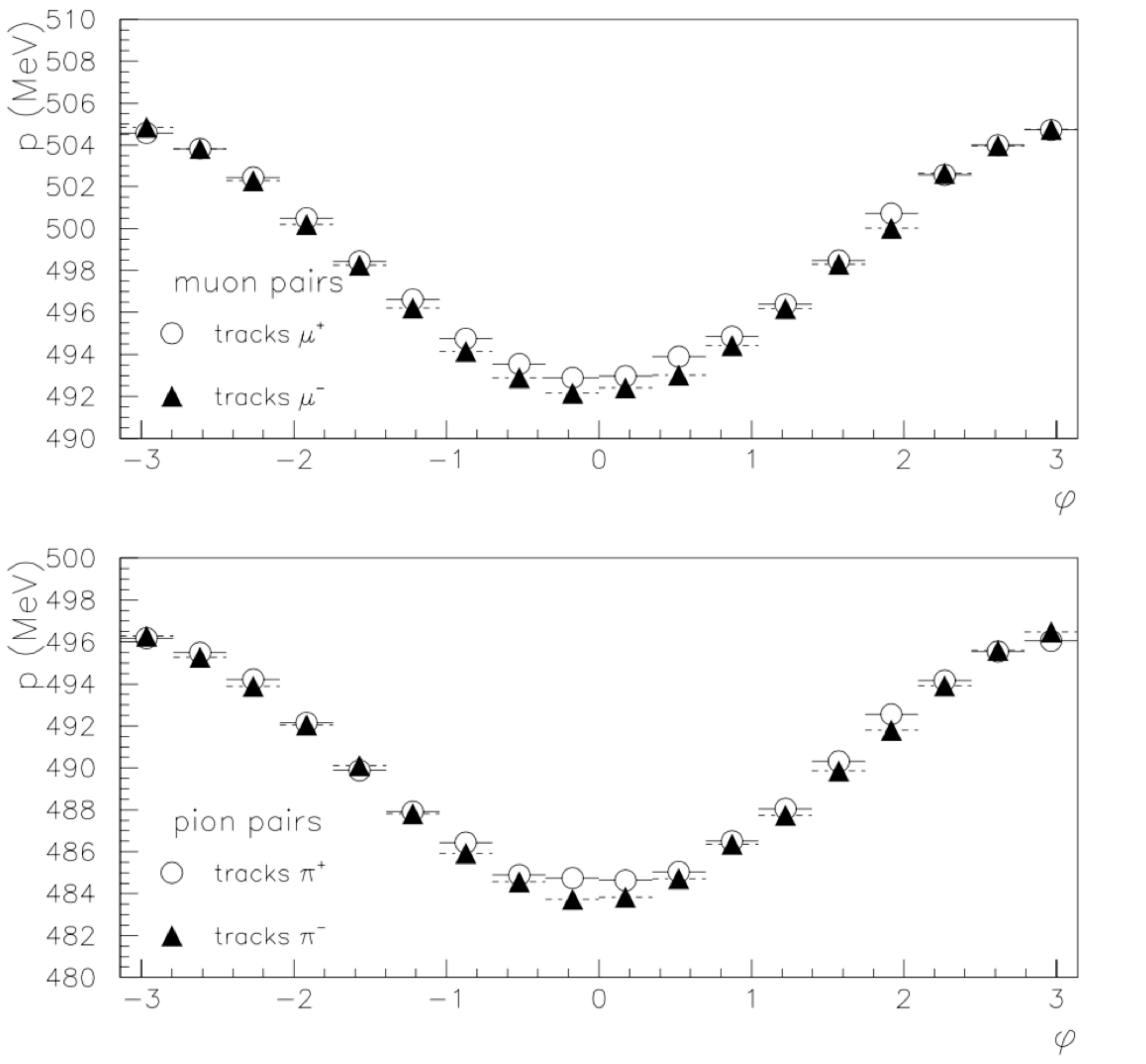




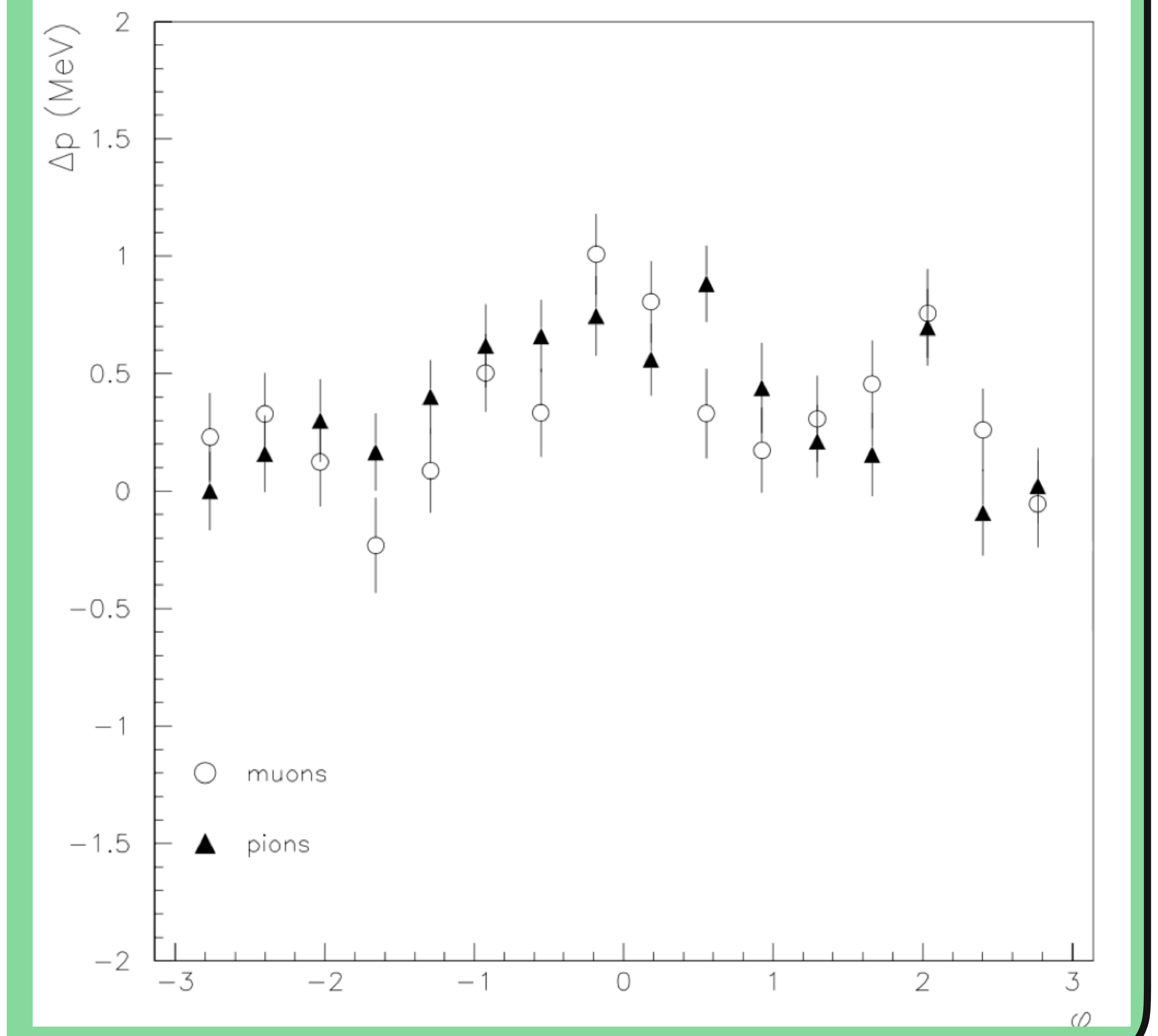
Tuning

- A difference between positive and negative tracks was observed in previous analyses.
- A heuristic correction was applied by Cesare Bini et al.
- We can take a similar approach but are trying to :
  - Determine if the discrepancy is the same as what was previously seen
  - Understand the source

$\pi^+\pi^-$ and $\mu^+\mu^-$ events (2000 data)



Discrepancy in momentum as a function of azimuthal angle



Background Subtraction

Background subtraction procedure

- **Background sources**
  - $e^+e^- \to \pi^+\pi^-\pi^0$, $e^+e^- \to \mu^+\mu^-\gamma$,
  - The objective is estimating the total fraction f of background events in individual slices of $Q^2_{\pi\pi}$: $f^i_B = f^i_{\mu\mu\gamma} + f^i_{ee\gamma} + f^i_{\pi\pi\pi}$
  - The number of events of in each $Q^2_{\pi\pi}$ slice is scaled by $(1 - f^i_B)$
- **Strategy**
  - **Divide the M_{trk} distribution of each of the background sources into slices of $Q^2_{\pi\pi}$**
    - M_{trk} is the mass of the charged tracks under the hypothesis of two particles with the same mass and one photon in the final state.
  - The **data distribution of M_{trk} is fit to a weighted sum of MC distributions from different sources** in order to estimate the proportions of each source in the recorded data
  - **Fits are performed on the full range of M_{trk}** to extract the fractions of each channel, F^i_α.
  - **Weights are calculated using the fractions, weights are then used to calculate the fractions in the signal region.**

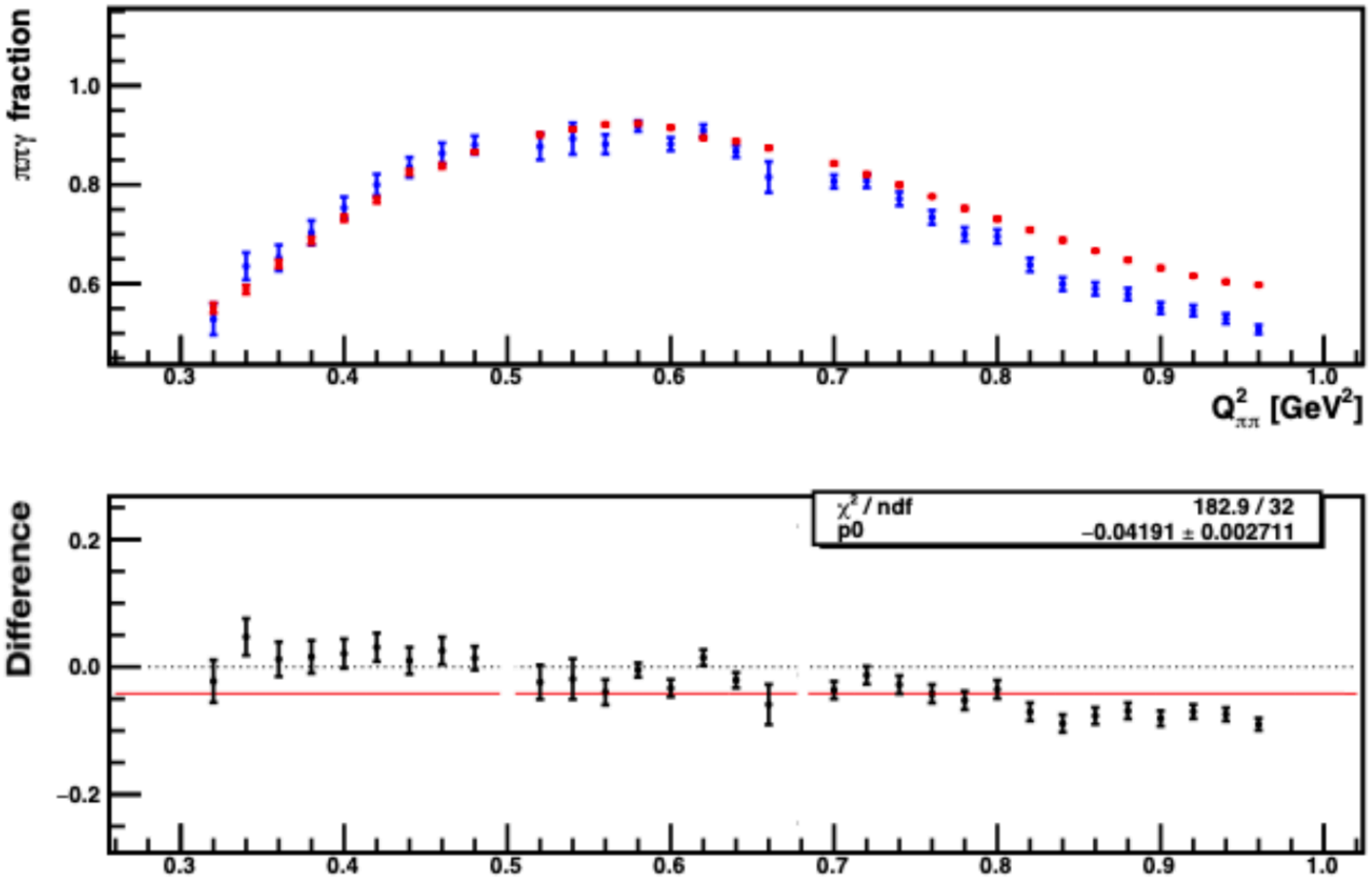
- $$w^i_\alpha = F^i_\alpha \frac{N^i_{data}}{N^i_{mc,\alpha}}$$
- $$f^i_\alpha = w^i_\alpha \frac{n^i_{mc,\alpha}}{n^i_{data}}$$

$$f^i_B = \frac{w^i_{\mu\mu\gamma} n^i_{mc,\mu\mu\gamma} + w^i_{ee} n^i_{mc,ee\gamma} + w^i_{\pi\pi\pi} n^i_{mc,\pi\pi\pi}}{n^i_{data}}$$

Background Subtraction

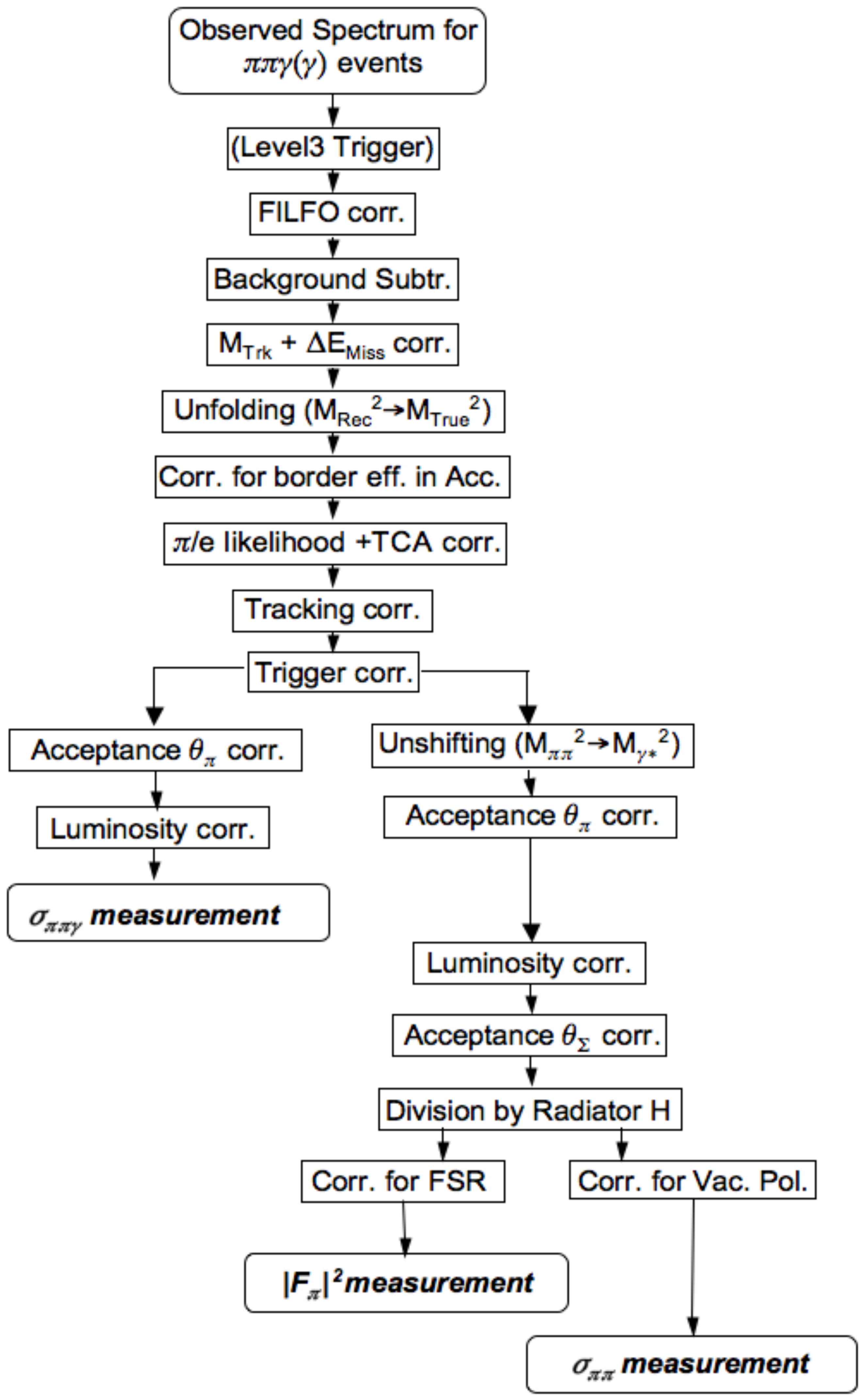
Background subtraction procedure

- **Progress**
  - Implementation and correctness checked by reproducing result from previous analysis.
  - **Background fit results should be independent of variable chosen to fit on.**
  - Other variables being investigated as alternative or addition to M_{trk} e.g. polar angle wrt to the beam axis θ_{trk}.
  - **Discrepancies between variables found in fractions when using 2002 data.**
  - **Detector tuning studies on MC and data** are instrumental to improving background fitting procedure and understanding such discrepancies.
- Lorenzo Punzi's Thesis provides a detailed overview of the background subtraction procedure currently being worked on.



Look to the future

- **Other work currently in progress**
  - **Luminosity**
    - Re-do measurement of integrated luminosity using large angle Bhabha scattering events and normalising them to the effective cross section
  - **FILFO**
    - Proposal to switch of FILFO filtration but include the FILFO module decision flags for further study if needed.
  - **Theory radiative correction**
    - See upcoming talk for more details on MC development and radiative correction studies.
- **Areas the group will begin work on:**
  - Trigger efficiencies
  - Particle Identification
  - Unshifting



Summary

- This analysis aims to use **2004/2005 KLOE data** to carry out a new measurement. The $\sim 1.7 fb^{-1}$ **includes ~ 25 million** $\pi\pi\gamma$ **events** which have never been used before in such an analysis.
- The analysis will be conducted **blindly with blinded and unblinded root-tuples**
- We have presented a few preliminary results and found some inconsistencies, which we have to understand and it's work in progress
- Once that more work has been done, we would need to reprocess the data and we will let you know

Thank you

Backup