UNIVERSITY OF LIVERPOOL

LEVERHULME TRUST

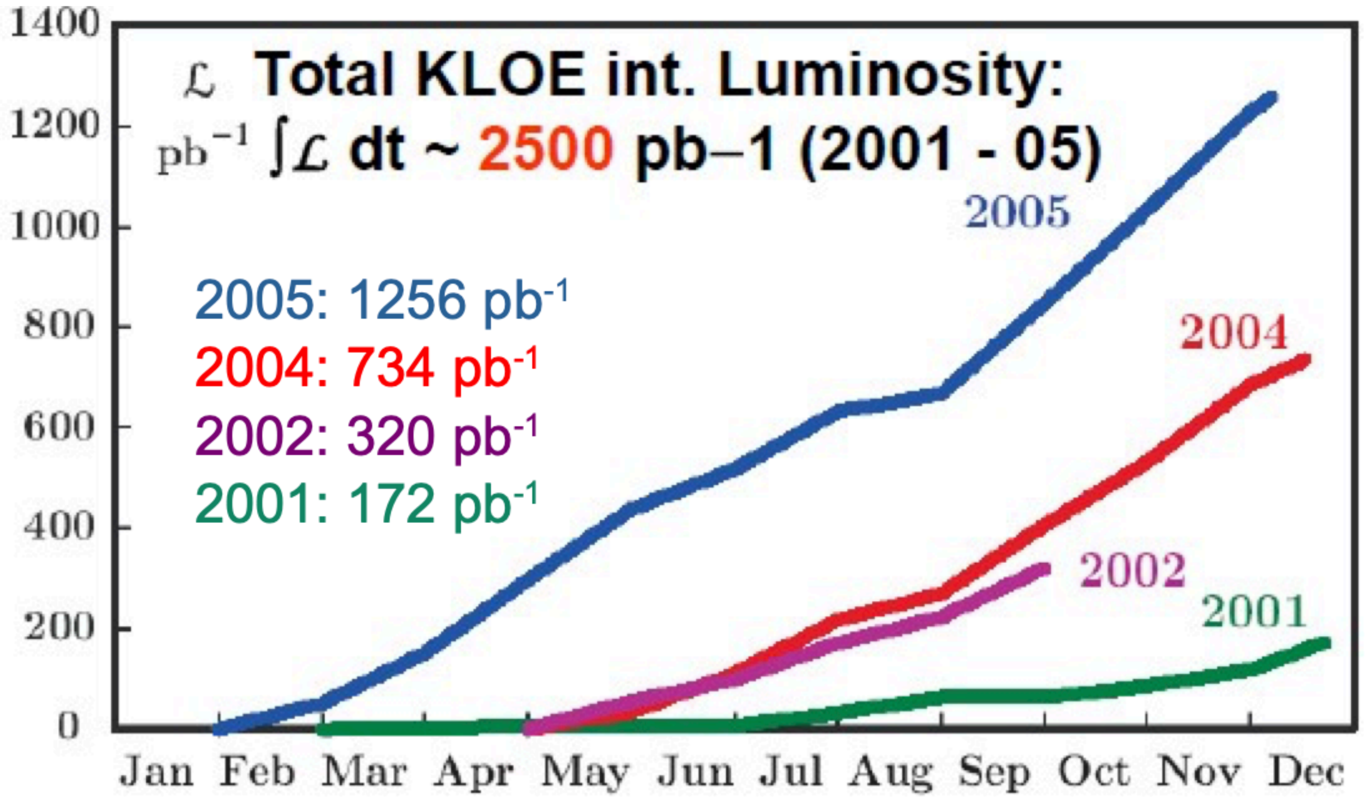
RadioMonteCarlow2 - June 2026

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

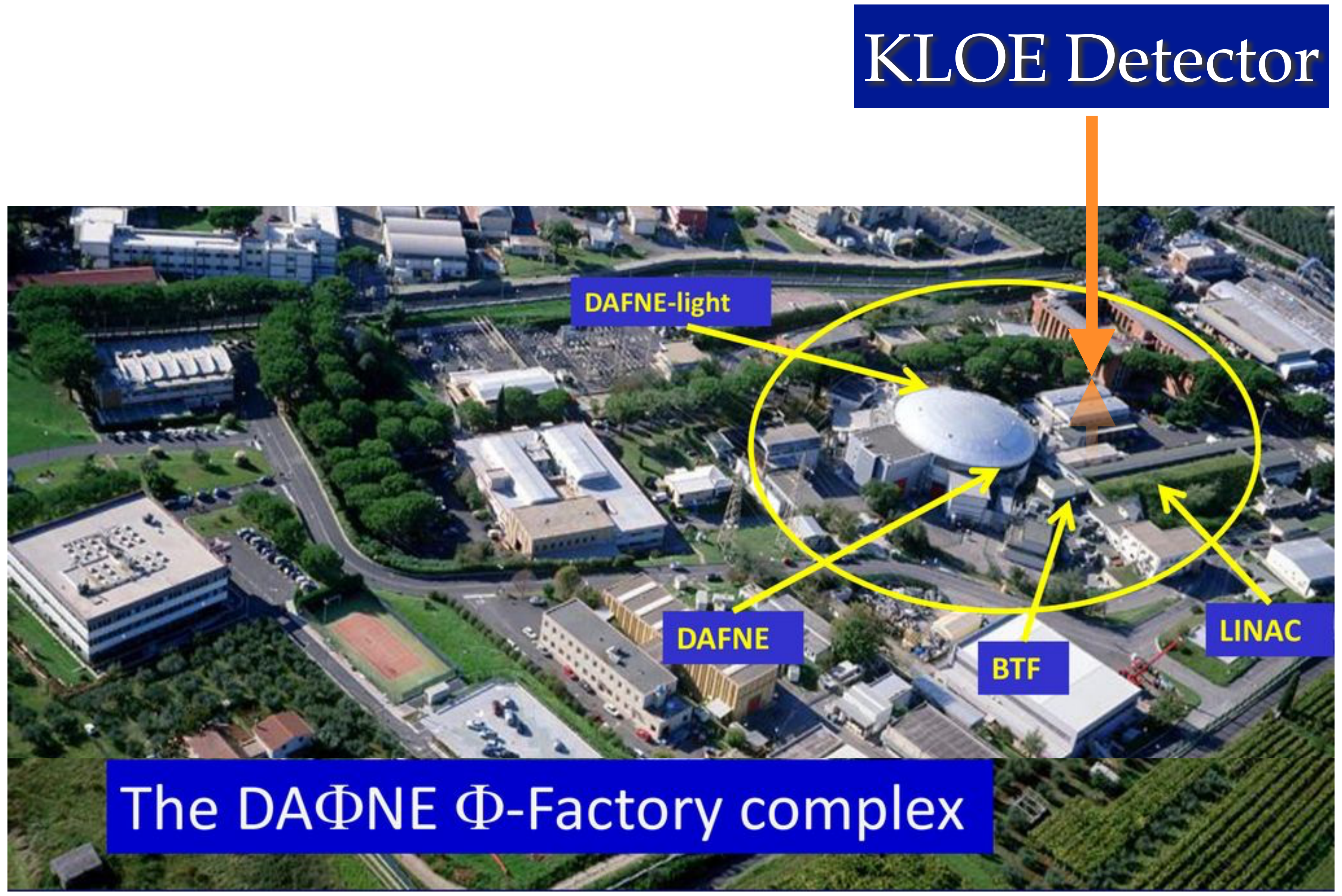
Estifa'a Zaid on behalf of KLOE-2 collaboration

KLOE at DAϕNE

- DAϕNE, located in Frascati is an e^+e^- collider running at a fixed **CoM energy (~1020 MeV)** equal to the mass of the ϕ-meson
- The e^+e^- particles collide in one of two interaction regions, where the KLOE detector is located
- KLOE **data-taking years were 2001-2006**, with a total integrated luminosity of 2.5 fb^{-1} + 250 pb^{-1} off-peak at $\sqrt{s} = 1\,\text{GeV}$
- Peak luminosity was reached during 2005 run with ~ 8.5 pb^{-1}/day
- **Previous KLOE analyses were done on 240 pb^{-1} (~ 3.5 million $\pi\pi\gamma$ events) of data taken in 2002 and 232 pb^{-1} from 2006**

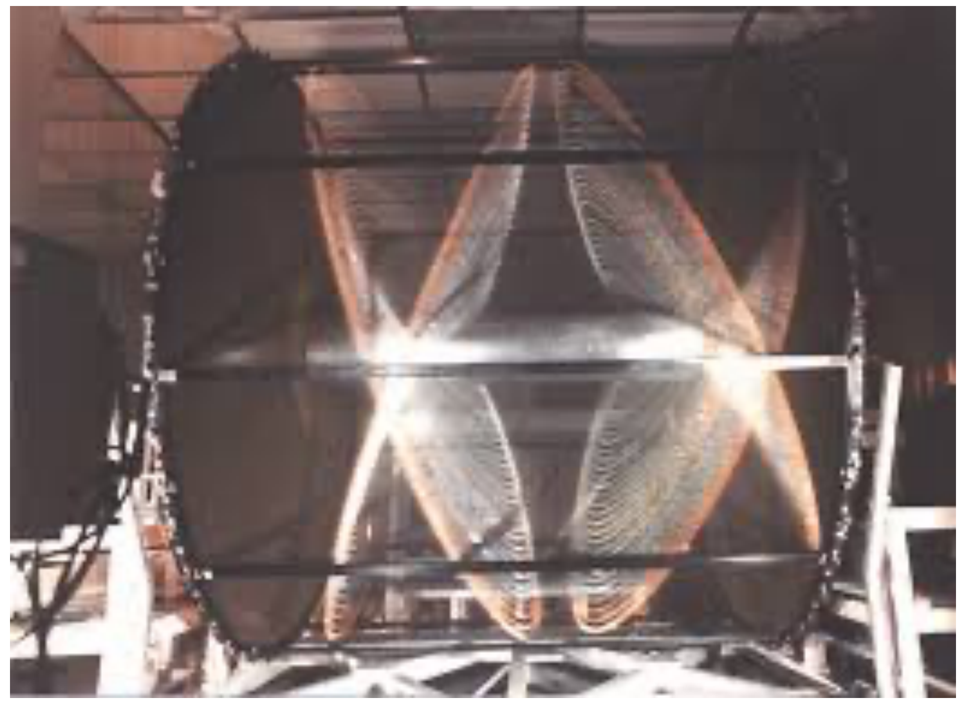


- This ongoing analysis aims to use **2004/2005 KLOE data** to carry out a new measurement. The ~1.7 fb^{-1} includes **~ 25 million $\pi\pi\gamma$ events** which have **never been used** before in such an analysis. 2006 off-peak data will be used for additional cross checks and systematic studies

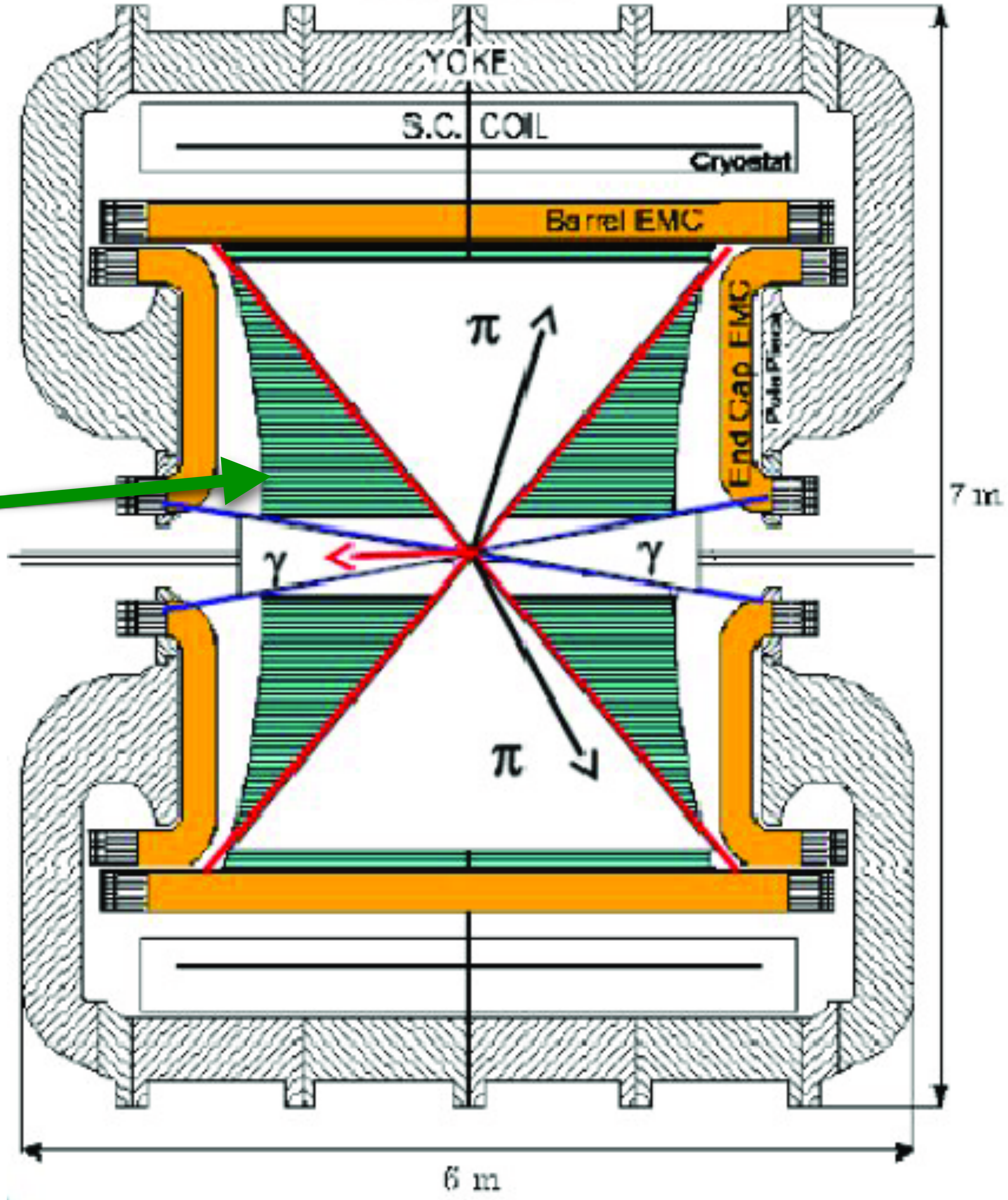


KLOE Detector - Drift Chamber[1]

- **Drift Chamber**
  - Drift chamber is a full stereo **3.3m long cylinder with a radius of 2m** outside the beam pipe hole that is 25 cm in radius
  - Chamber is filled with **90% helium and 10% isobutane**
  - DC is made up of over 50,000 wires with a **field:sense ratio of 3:1** to make drift cells arranged in layers



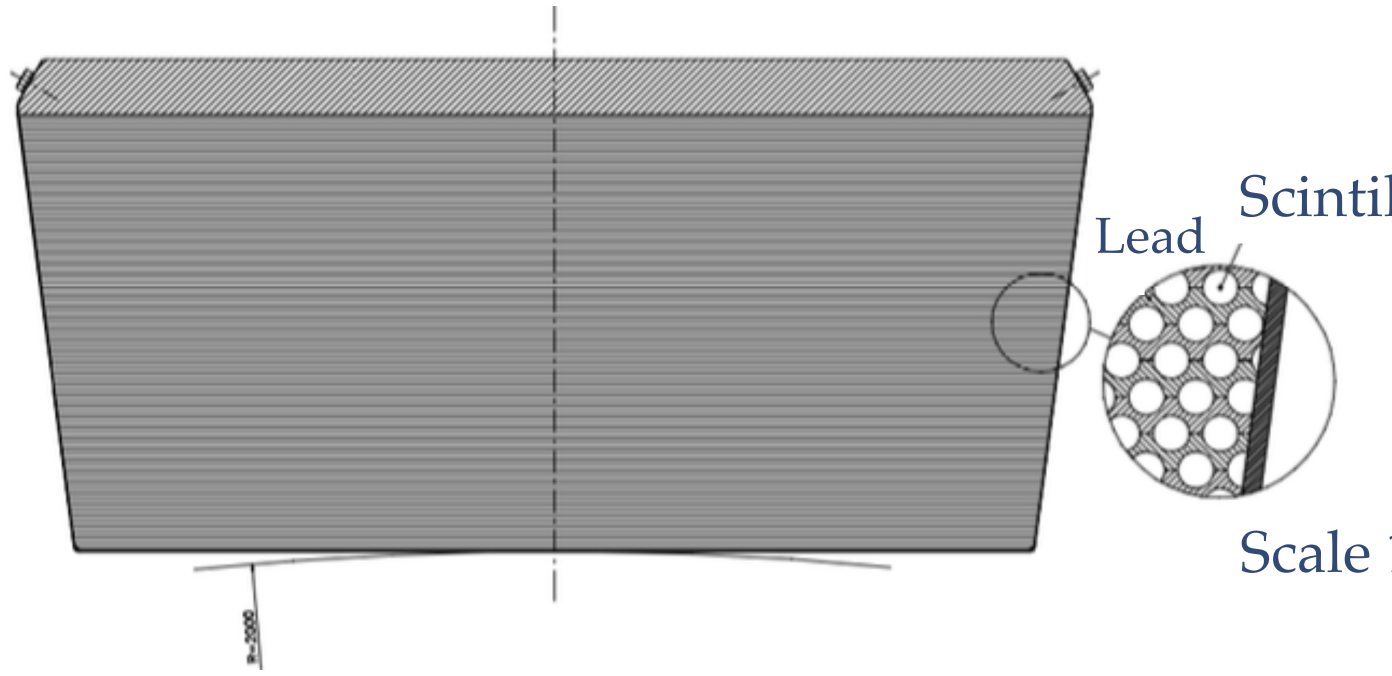
  - Wires in the same layer are parallel to each other and have the same stereo angle wrt to z-axis
  - Good resolution of the z-coordinate is achieved by varying the stereo angle of different layers
  - **Resolution:**
    - $\sigma_{xy} \approx 150\,\mu\text{m}$; $\sigma_z \approx 2\,\text{mm}$; $\sigma_{\text{vertex}} \approx 3\,\text{mm}$; $\delta p/p_T \approx 0.4\%$
    - Momentum resolution of the drift chamber is excellent (important for detector effects, mass unfolding, etc…)



[1] Adinolfi, M., Ambrosino, F., Andryakov, A., et al. (2002). The tracking detector of the KLOE experiment. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 488(1–2), 51-73. https://doi.org/10.1016/S0168-9002(02)00514-4.

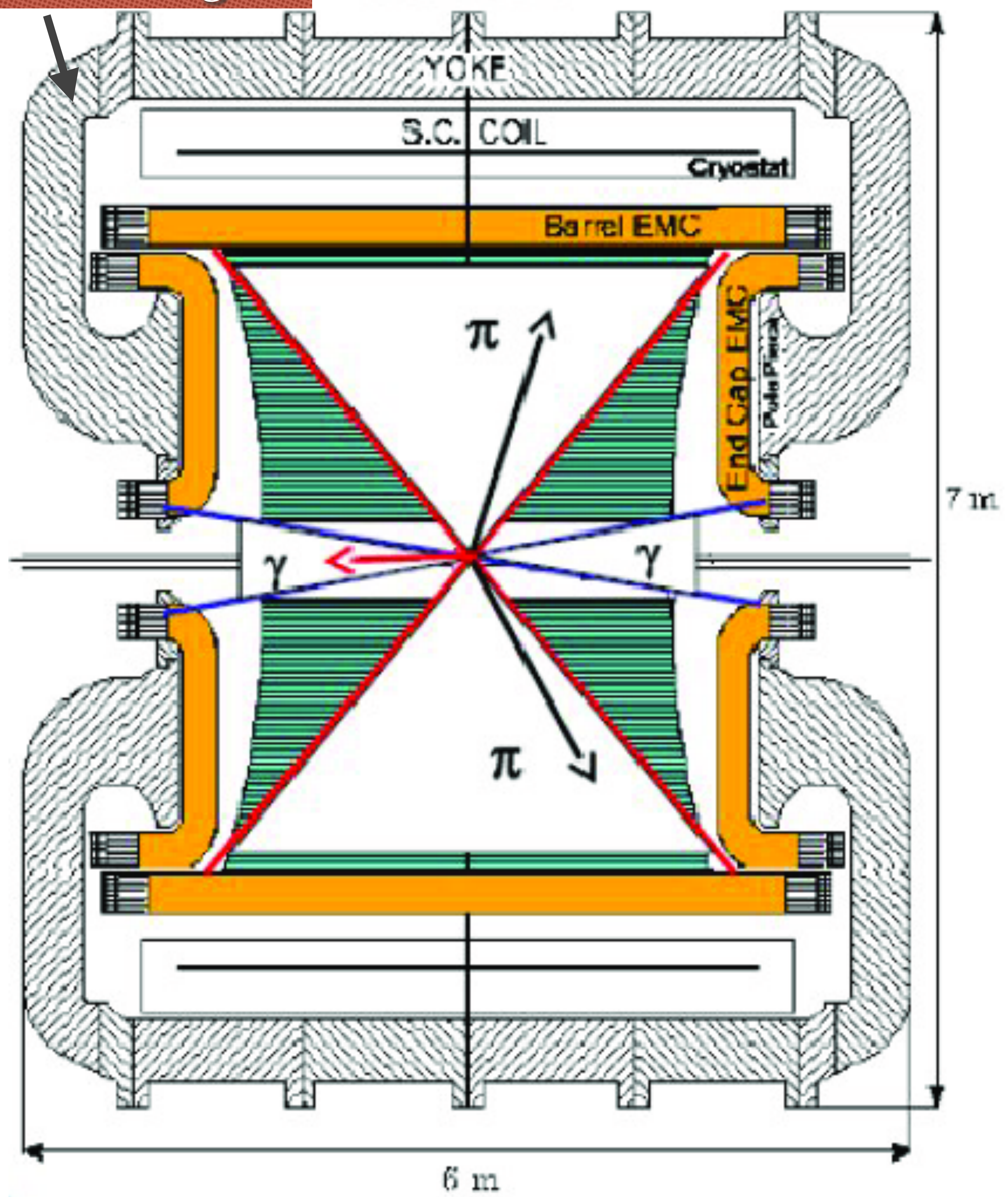
KLOE Detector - Calorimeter[2]

- EM Calorimeter
  - **Detects photons of 20 to 500 MeV** and has 98% 4π coverage
  - Sampling Calorimeter with **lead passive layers and scintillating fibre sensing layers**



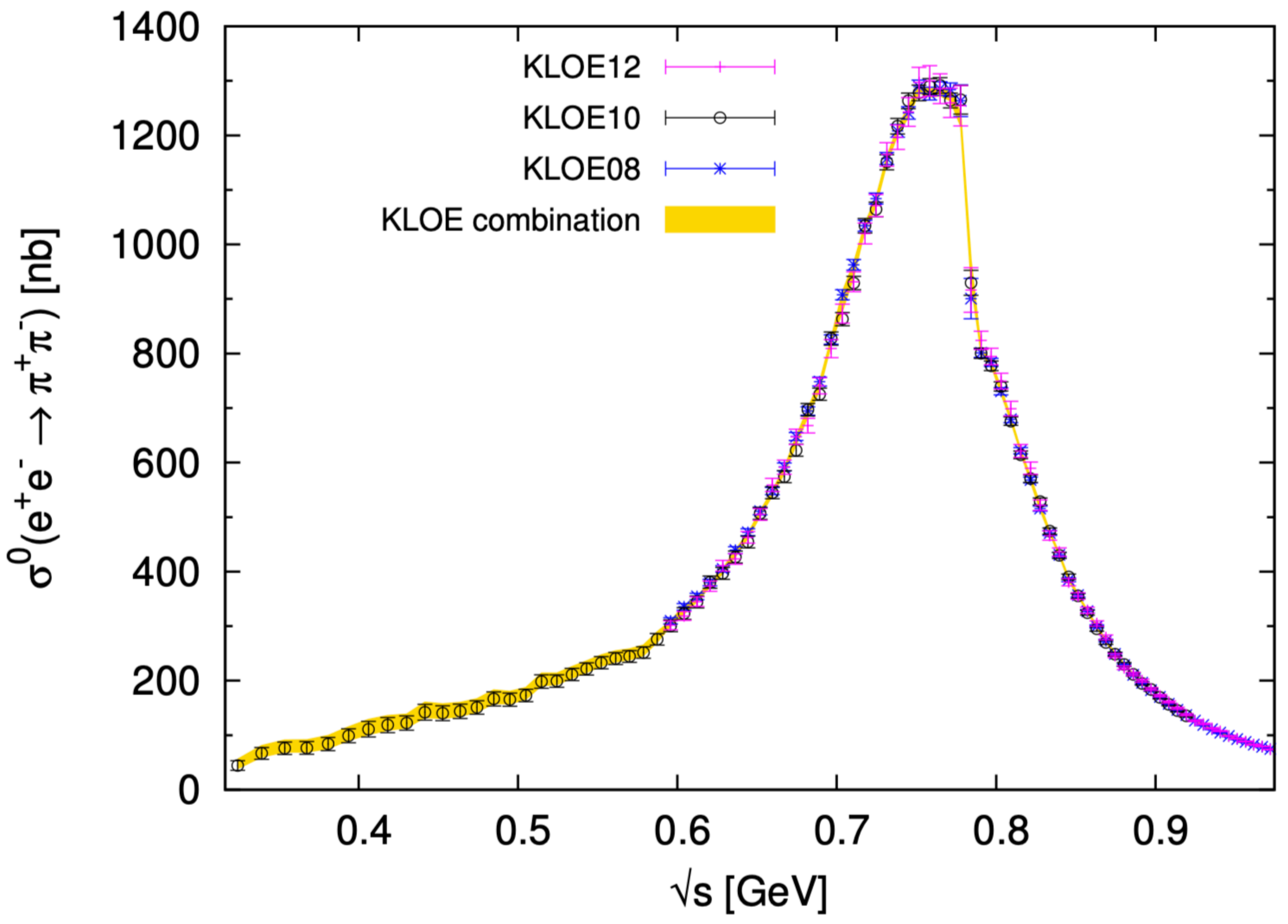
  - 24 calorimeter modules form the barrel
  - 32 calorimeter modules form the end-caps
  - The fibres are read out on both ends by light guides which then feed into photomultipliers.
  - Calorimeter modules are organised in **4.4 x 4.4** cm^2 **areas (cells) in five layers**
  - **Resolution:**
    - $\sigma_E/E = 5.7\,\%/\sqrt{E(GeV)};\quad \sigma_t(ps) = 5.4/\sqrt{E(GeV)} \oplus 140;$
  - **This calorimeter is now on the way to DUNE!**

0.52 T Magnet



[2] Adinolfi, M., Ambrosino, F., Antonelli, A., et al. (2002). The KLOE electromagnetic calorimeter. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 482(1–2), 364-386. https://doi.org/10.1016/S0168-9002(01)01502-9.

An overview of KLOE measurements



KLOE08 analysis

- 60 points between 0.35 and 0.95 GeV^2
- based on 240.0 pb^{-1} data taken in 2002
- **Selection cuts:**
  - **2 pion (muon) tracks at large angles**
    $50^\circ < \theta_{\pi,\mu} < 130^\circ$
  - **small angle cuts:**
    - **photons at small angles $\theta_{miss} < 15^\circ$ or $\theta_{miss} > 165^\circ$**
    - photon momentum from kinematics: $\vec{p}_{\text{miss}} = -(\vec{p}_+ + \vec{p}_-)$
    - high statistics for ISR events
    - low FSR contribution
    - suppression of $\phi \to \pi^+\pi^-\pi^0$ background
    - threshold region not accessible
- normalisation to Bhabha and PHOKHARA radiator

KLOE10 analysis

- 75 points between 0.1 and 0.85 GeV^2
- based on 232.6 pb^{-1} data taken in 2006 with $\sqrt{s} = 1\,GeV$
- **Selection cuts:**
  - **2 pion (muon) tracks at large angles**
    $50^\circ < \theta_{\pi,\mu} < 130^\circ$
  - **large angle cuts:**
    - **at least 1 photon at large angles**
      $50^\circ < \theta_\gamma < 130^\circ$
    - photon detection possible
    - disadvantages of Large angle cuts e.g. more $\phi \to \pi^+\pi^-\pi^0$ background and higher FSR contribution overcome by use of 2006 dataset.
- normalisation to Bhabha and PHOKHARA radiator

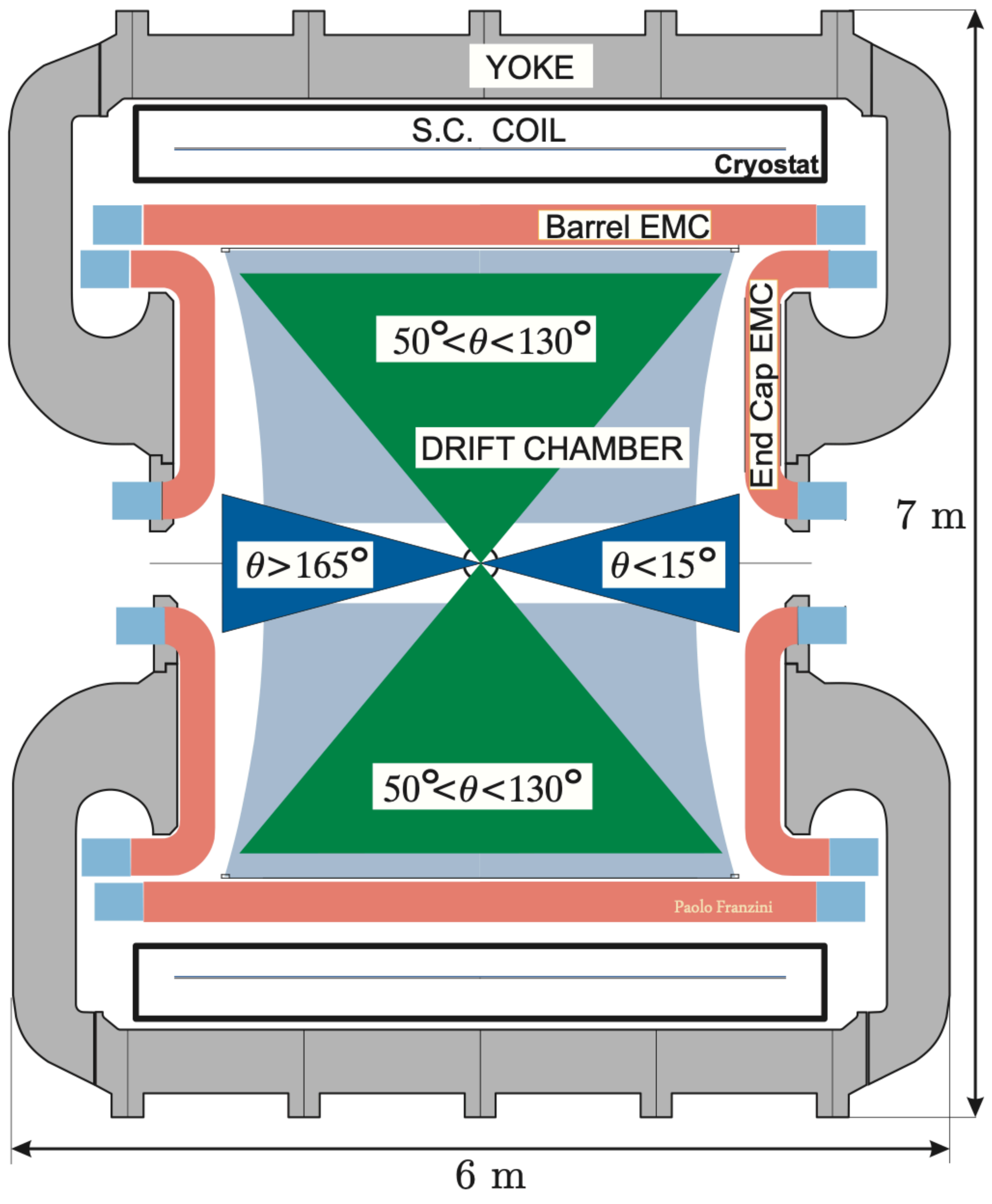
KLOE12 analysis

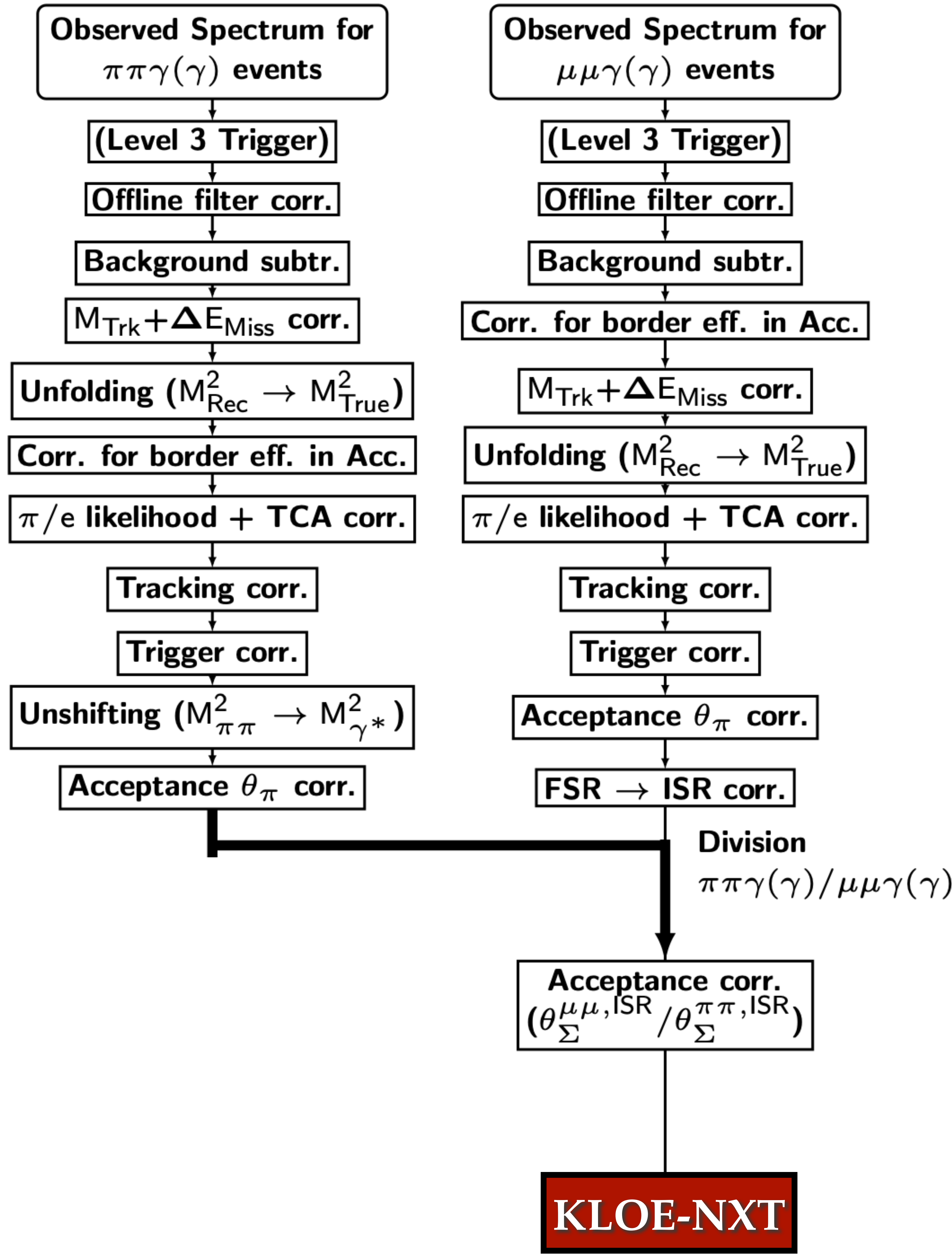
- 60 points between 0.35 and 0.95 GeV^2
- based on 240.0 pb^{-1} data taken in 2002
- **selection match KLOE08 small angle analysis**
- **normalisation to $\mu\mu\gamma$ events**

The new (KLOE-NXT) measurement

KLOE-NXT analysis

- 60 points between $0.35 < M^2_{\pi\pi} < 0.95\ GeV^2$
- based on $1.7\ fb^{-1}$ data taken in 2004/2005
- **Selection cuts:**
  - **2 pion (muon) tracks at large angles $50^\circ < \theta_{\pi,\mu} < 130^\circ$**
  - **small angle cuts:**
    - **photons at small angles $\theta_{miss} < 15^\circ$ or $\theta_{miss} > 165^\circ$**
    - photon momentum from kinematics: $\vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$
- normalisation to $\mu\mu\gamma$
- **The above will make the basis of the KLOE-NXT analysis however the group is prepared to make modifications if desired**





The new (KLOE-NXT) measurement

KLOE-NXT analysis

- Analysis group is tackling different aspects using new techniques with the intention of reducing the larger systematic uncertainties.

KLOE12: **0.3**$\%_{stat}$ ⊕ **0.2**$\%_{th}$ ⊕ **0.7**$\%_{syst}$ ⇒ ~ **0.8**$\%_{tot}$

KLOE-NXT$_{\mathbf{(goal)}}$: **0.1**$\%_{stat}$ ⊕ **0.2**$\%_{th}$ ⊕ **0.3**$\%_{syst}$ ⇒ ~ **0.4**$\%_{tot}$

- There will be a factor 7 statistical improvement making the statistical uncertainty negligible wrt systematics.
- There is dedicated work on the background. subtraction procedure to achieve a **x3 reduction of the background subtraction uncertainty**.

Syst Errors (%)	KLOE12 $a_\mu^{\pi\pi}$ ratio	KLOE-NXT (expected) $a_\mu^{\pi\pi}$ ratio
Background Filter (FILFO)	negligible	negligible
Background Subtraction	0.6	0.2
Trackmass	0.2	0.2
Particle ID	negligible	negligible
Tracking	0.1	0.1
Trigger	0.1	0.1
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	negligible	negligible
Acceptance (θ_π)	negligible	negligible
Software Trigger (L3)	0.1	0.1
Luminosity	-	-
$\sqrt{s}$ dep. of H	-	-
Total exp. systematics	0.7	0.3
Vacuum Polarisation	-	-
FSR treatment	0.2	0.2
Rad. function H	-	-
Total theory systematics	0.2	0.2
Total systematic error	0.7	0.4

The Current Effort

Background subtraction
Applying tuning and improving background subtraction by using multiple variables and comparing different MC generators after background subtraction

Luminosity
Studying Very Large Angle Bhabha events and applying data MC corrections. Systematic studies also ongoing

Collinear events analysis
Studying Collinear data sample to extract form factor and asymmetry measurements.

Data-MC tuning
Working on new methods to improve data MC agreement

Normalised QED check
Studying $\mu\mu\gamma$ sample and reproducing analysis workflow chain

Tracking efficiency
Extracting MC and data tracking efficiencies and studying different momentum ranges using $\pi^+\pi^-\pi^0$, , $\pi\pi\gamma$ or $\mu\mu\gamma$

Overcoming computing challenges

Problems

- The analysis was heavily slowed down due to computing issues in the INFN-LNF laboratories. We were delayed for over a year recovering access to KLOE 2004/5/6 data
- KLOE computing relied on outdated IBM infrastructure including and especially the tape library which we depended on to access KLOE data.
- We needed to restore two partitions of the IBM tape library and other machines/subsystems
- Solutions were limited due to low personnel numbers and irreplaceable hardware.

Problems solved

- As of a few months the ago :
  - KLOE-1 data has been migrated to CNAF (only missing ~10% of KLOE-1)
  - One partition of the tape library has been fully restored
  - Code has been ported over to git
  - Working environment set up in both CNAF and Liverpool
  - First pass of KLOE-1 data re-processing and MC production on linux machines is complete

Luminosity

- In order to do a QED closure test we require an accurate knowledge of the integrated luminosity and associated systematic uncertainties
- Luminosity is measured with the KLOE detector using Very Large Angle Bhabha (VLAB) events, $e^+e^- \rightarrow e^+e^-$

$$\int L dt = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}},$$ where σ_{eff} is taken from Monte Carlo simulation

- **Advantages of Bhabha events:**
  - Very high statistics (σ ~ 430 nb) for $55^\circ < \theta < 125^\circ$
  - Excellent theoretical precision of the process
  - Clean and well-defined event topology

Taken from 2006 publication of KLOE measurement of DAϕNE luminosity

	correction (%)	systematic error (%)
angular acceptance	+0.25	0.25
tracking	–	0.06
clustering	+0.14	0.11
background	-0.62	0.13
cosmic veto	+0.40	–
energy calibration	–	0.10
center of mass energy	+0.10	0.10
	+0.34	0.32

Dominant systematics arise from Data/Monte Carlo differences, which must be carefully evaluated and accounted for.

Luminosity

- **We intend to:**
  - **Analyse 2002, 2004, 2005 and 2006 KLOE datasets individually**
  - **Use the updated BABAYAGA@NLO generator**
  - **Perform an independent cross check using $e^+e^- \to \gamma\gamma$**
- The effective VLAB cross section is obtained from Monte Carlo, therefore the resolution of the variables and the efficiency of the selection must be corrected for any mismatch between data and Monte Carlo.
- Differences in the resolution of the kinematic variables can give rise to systematic effects at the borders of the chosen phase space.

- **Very Large Angle Bhabha Selections**

Pre-selection: at least two energy clusters with $800\ \text{MeV} > E_{clu} > 240\ \text{MeV}$, within 4 ns, and separated by d > 200 cm

LAB selection (calorimeter only): two energy clusters with $800\ \text{MeV} > E_{clu} > 300\ \text{MeV}$ in the barrel region.

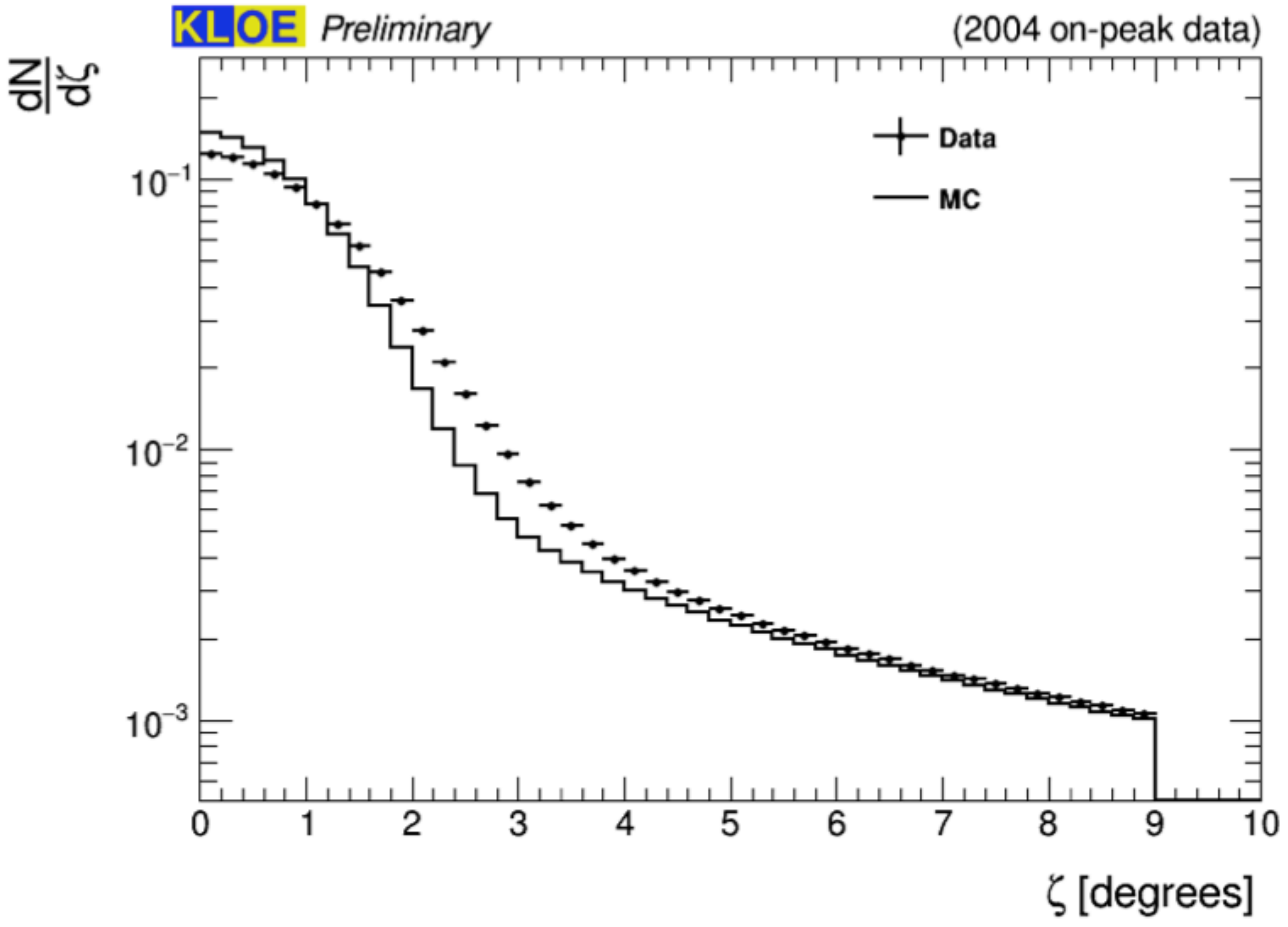
The pair minimising the acollinearity $\zeta = |\theta_{clu1} + \theta_{clu2} - 180^\circ|$ is selected, with $\zeta < 10^\circ$

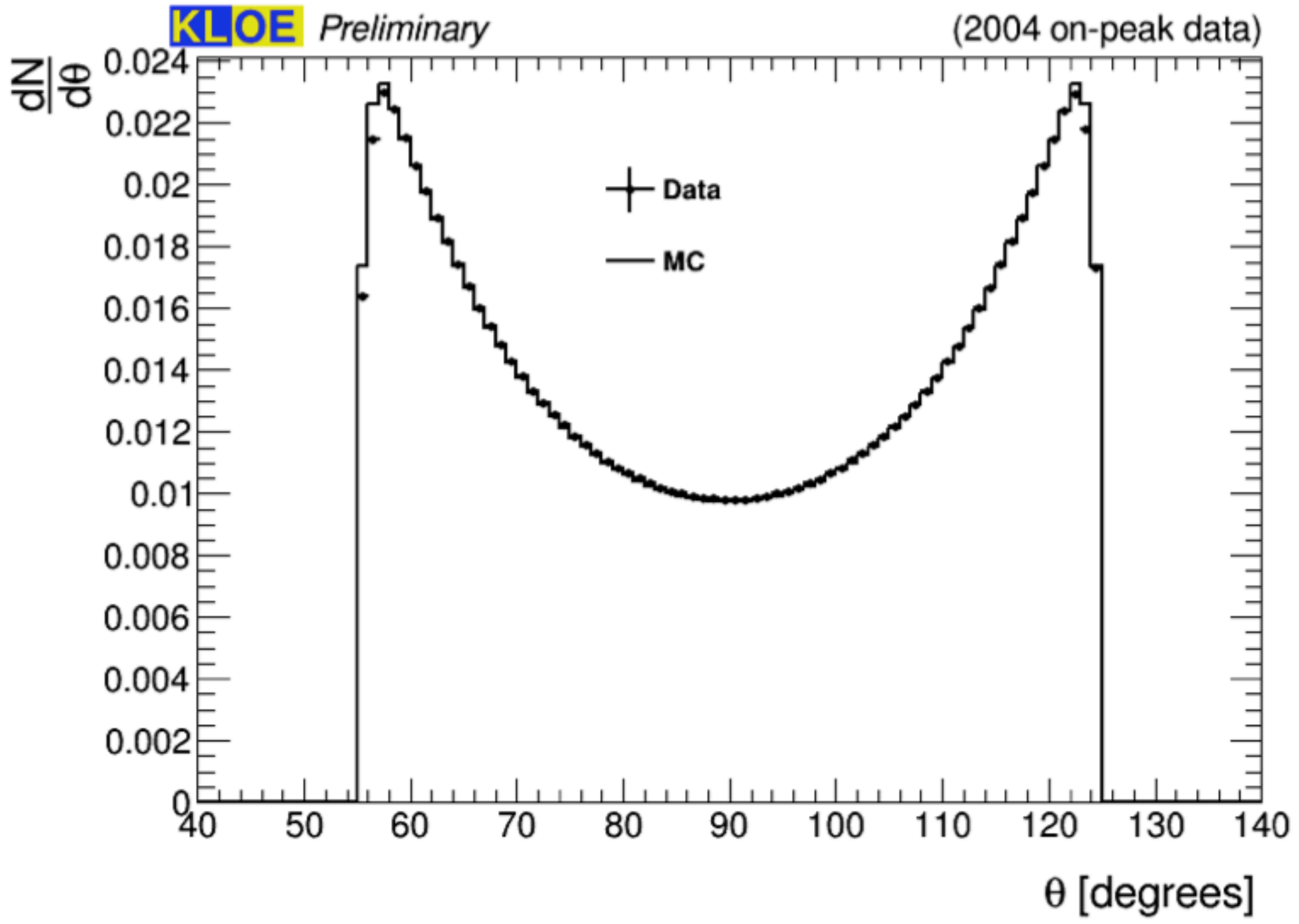
Final VLAB selection: inclusion of drift chamber information to improve selection and suppress background.

Two oppositely charged tracks are required with $|p| > 400$ MeV, satisfying track quality cuts, as well as tighter angular requirements on the clusters

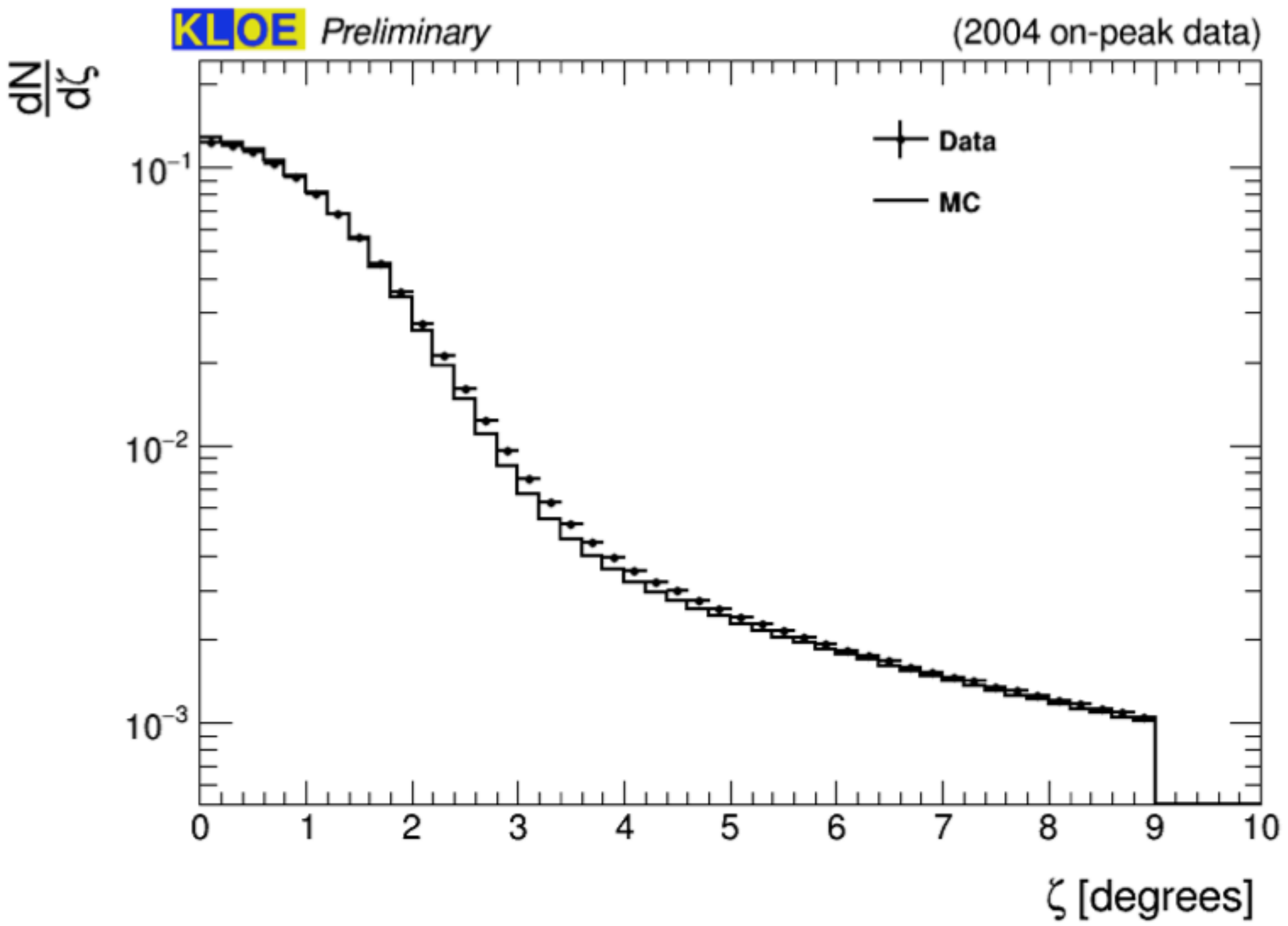
Luminosity

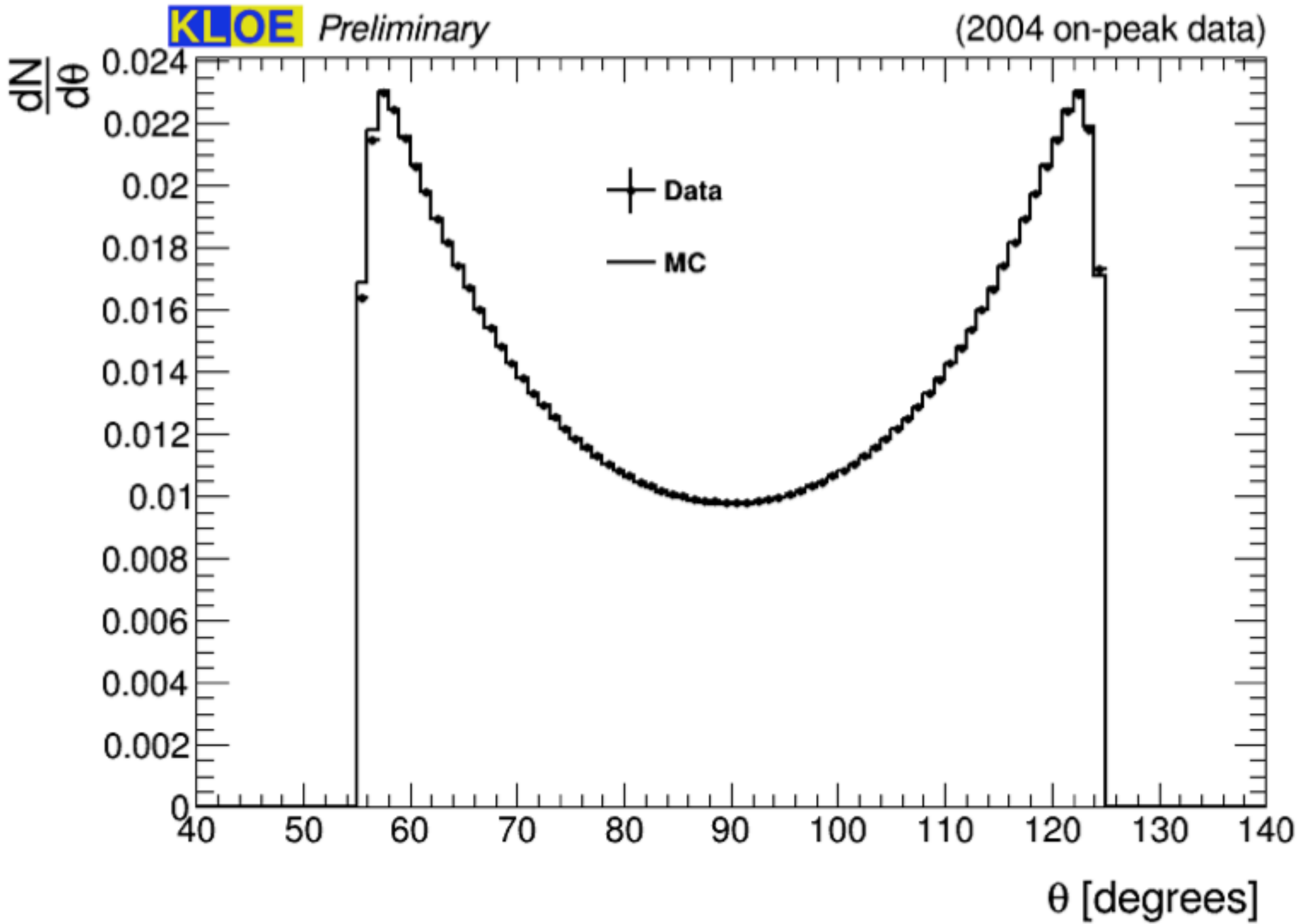
Before Correction





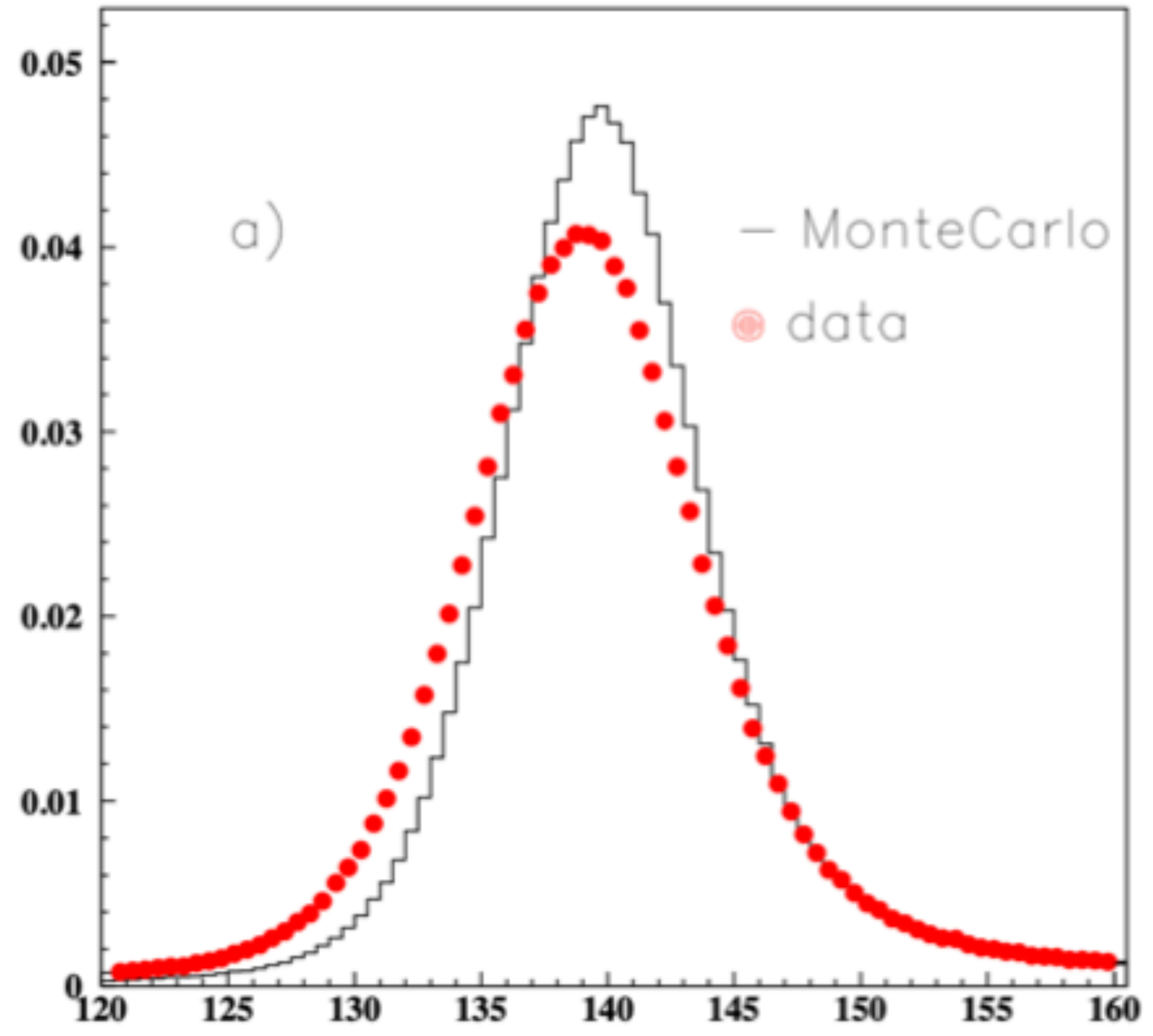
After Correction





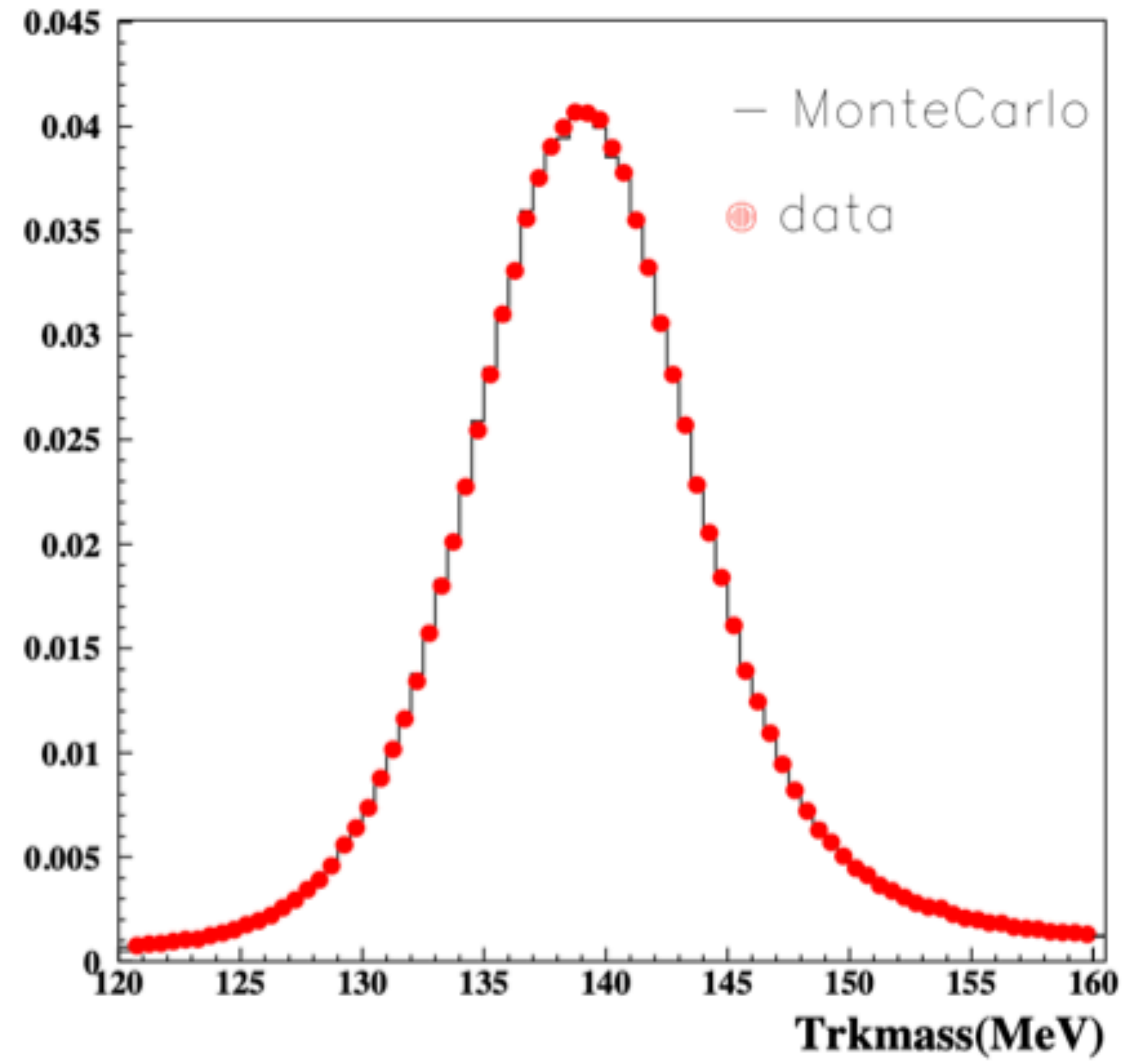
Data MC Tuning

- **Why we need MC tuning:**
  - Targeted precision of the KLOE-NXT analysis requires faithful MC description of real data
  - Raw KLOE simulation presents discrepancies with respect to data
- In previous analyses (KLOE08) discrepancies were studied using distribution of trackmass (M_{trk}) in the $\pi\pi\gamma$ signal channel.
- Tuning of Monte Carlo to improve consistency with data was achieved through shifting and smearing charged tracks' momenta components $p^{\pm}_{x,y,z}$
- Work done to reproduce and validate KLOE08 tuning method



Taken from KLOE08 internal note

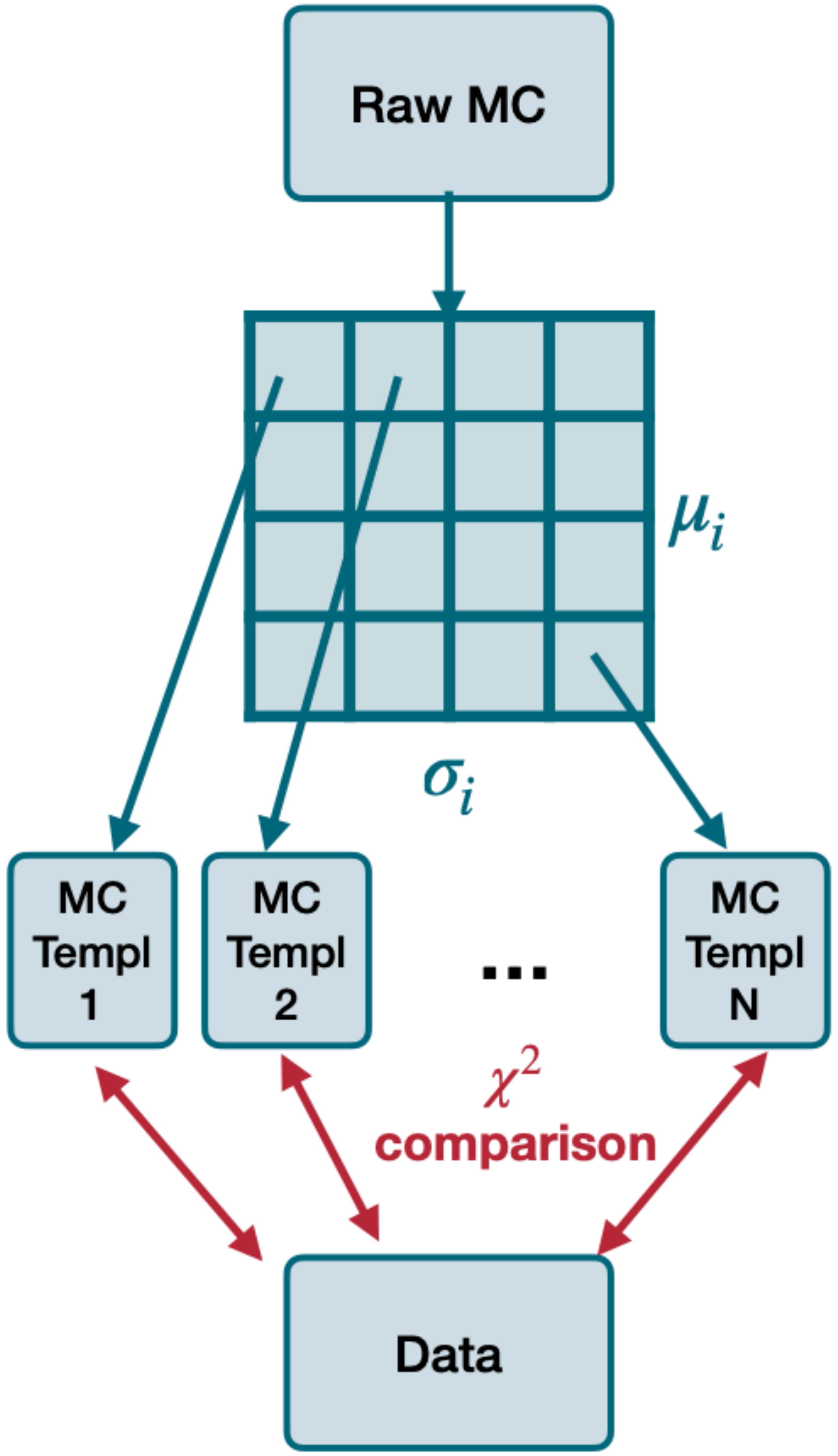
Before Correction



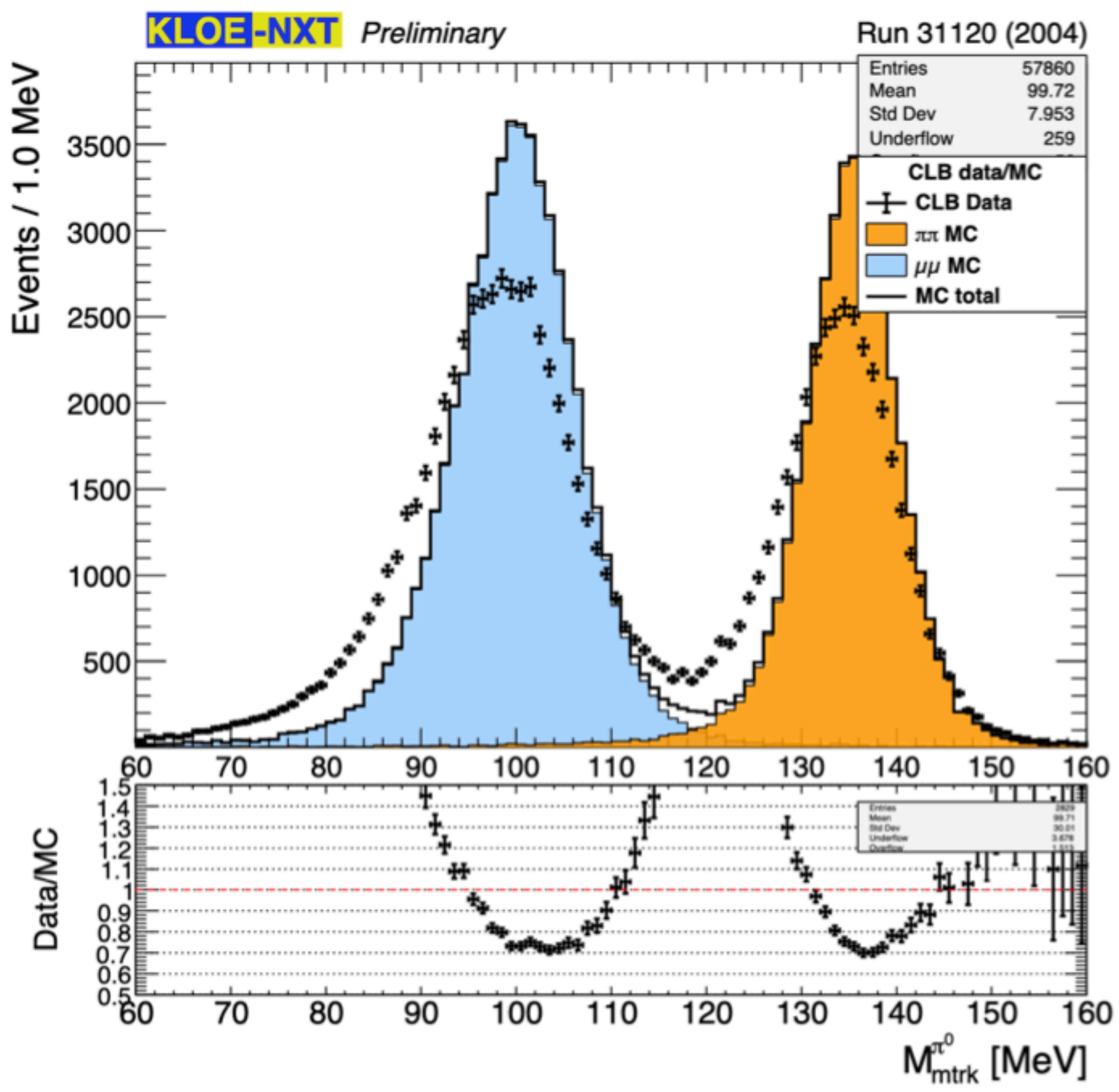
After Correction

A novel method for Data MC Tuning

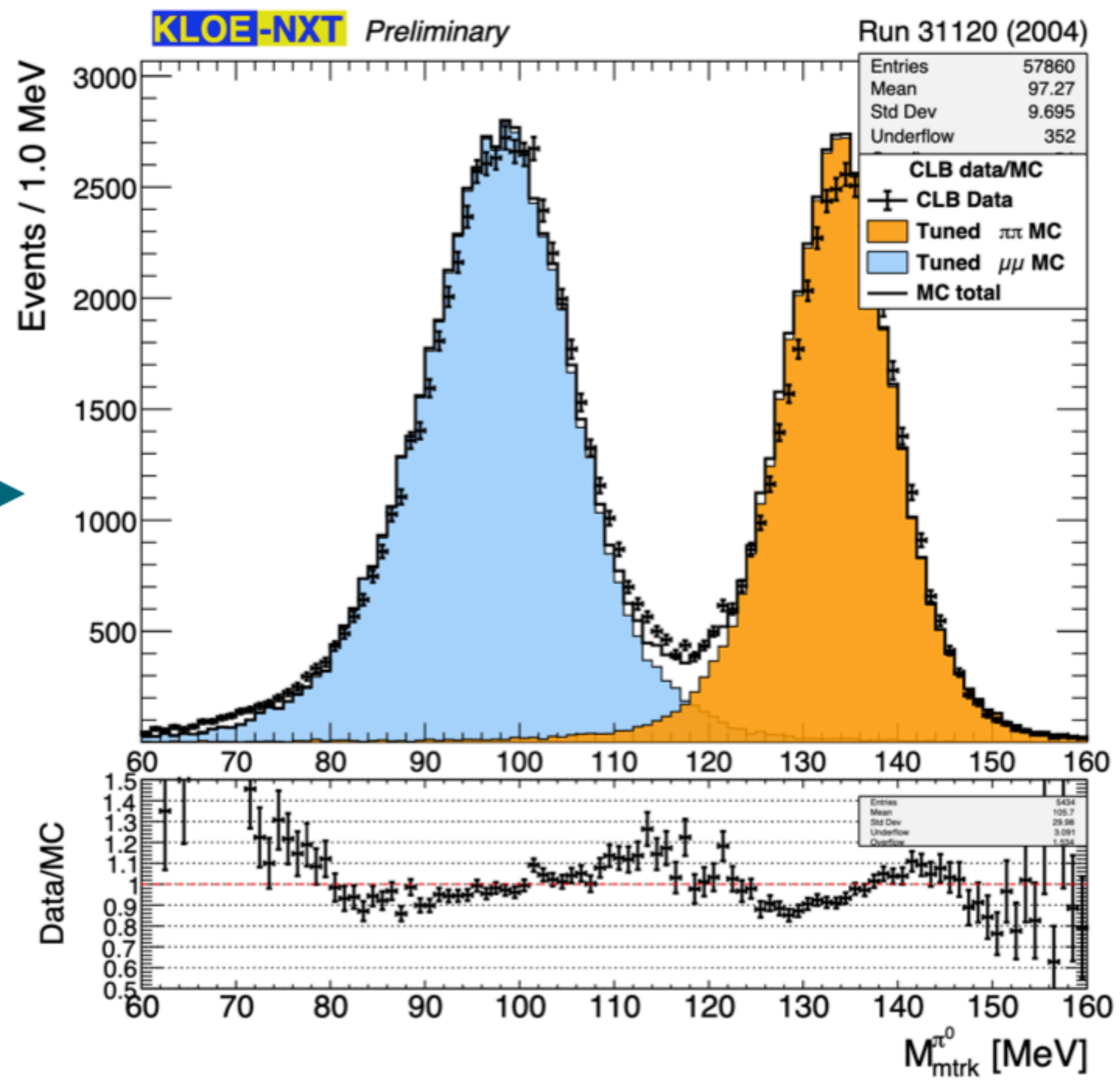
- **Template fit method :**
  - Tune Monte Carlo on *control* **channels**, namely $\pi^0\pi^+\pi^-$ and CLB ($\pi^+\pi^-$ and $\mu^+\mu^-$)
  - Tune on **lower level variables** that are more independent: {κ, θ, φ} instead of $\{p_x, p_y, p_z\}$
  - Tune by simply adding **Gaussian noise term** x ∈ {κ, θ, φ}   x → x + Gaus (μ(κ, θ), σ(κ, θ)) or $x \rightarrow x \times (1 + Gaus(\mu(k,\theta)), \sigma(k,\theta)))$.
- **Steps:**
  - Start from a common Monte Carlo production, choose a grid of N values for the parameters $\{\mu_x^i, \sigma_x^i\}$
  - For each point in the grid tune the MC sample with gaussian noise according to the parameters values at that grid point with different coefficient values. We therefore have N different tuned MC samples.
  - Choose the best tuned sample based on lowest discrepancy with data. Discrepancy is measured with a χ^2 comparison between data and MC histograms of different variables (e.g. M_{trk})



A novel method for Data MC Tuning

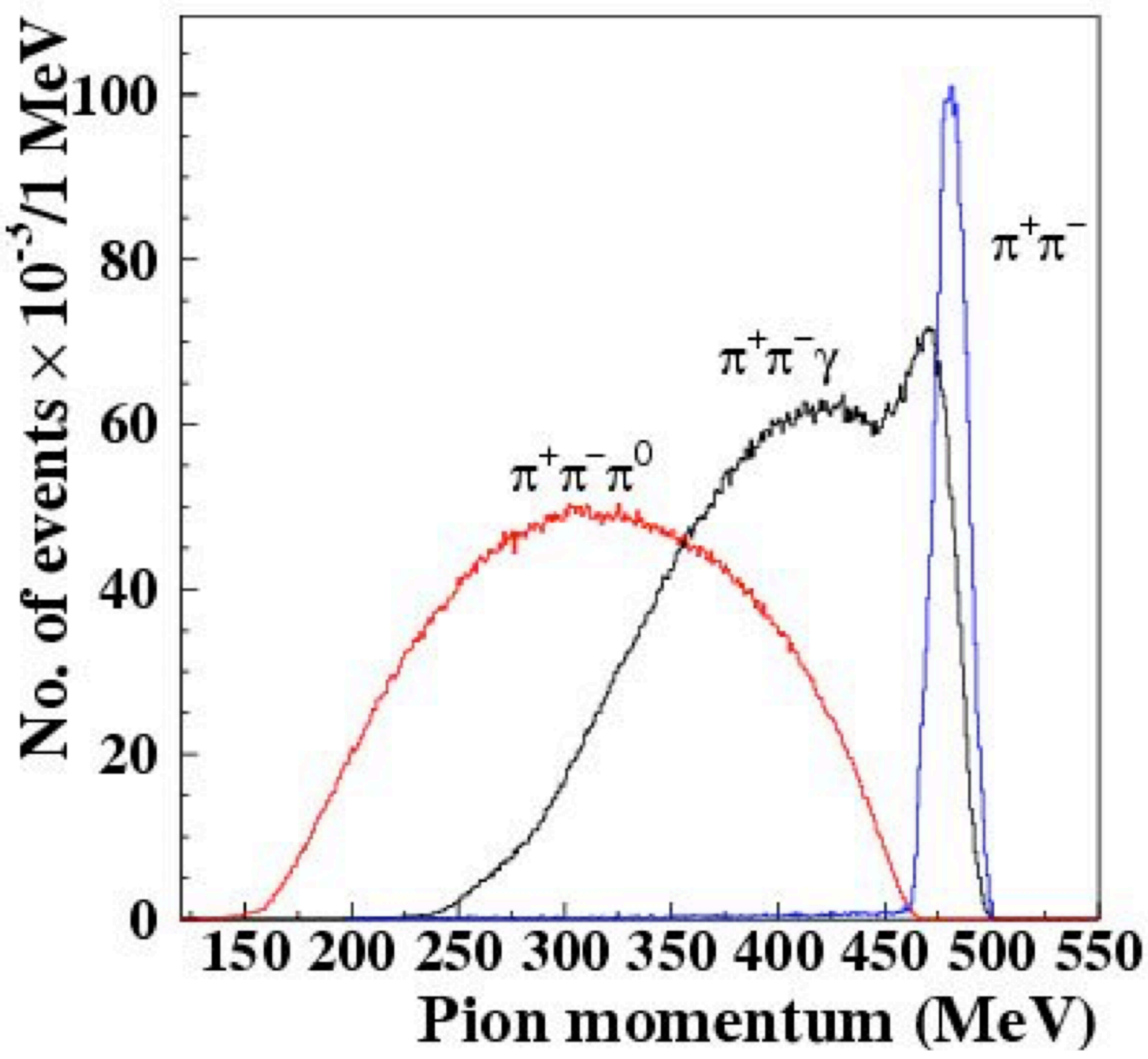


After applying tuning found with template fit on 3π stream

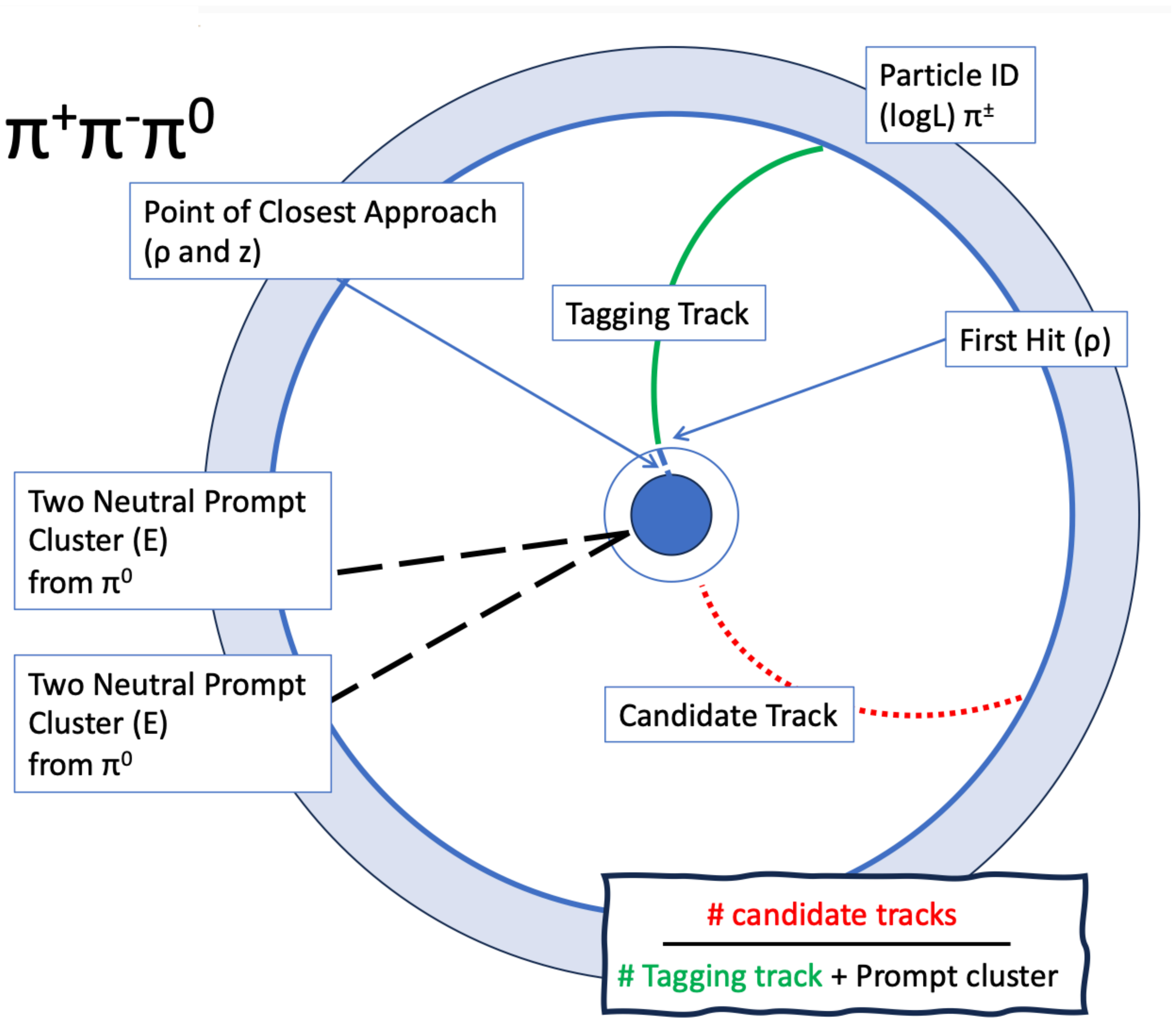


Tracking

- Aim:
  - Extract tracking efficiencies for both MC and data
  - Selections being used:
  - $\pi^+\pi^-\pi^0$
  - $\pi^+\pi^-$
  - $\pi\pi\gamma$ or $\mu\mu\gamma$
- These selections result in different momentum regions being covered



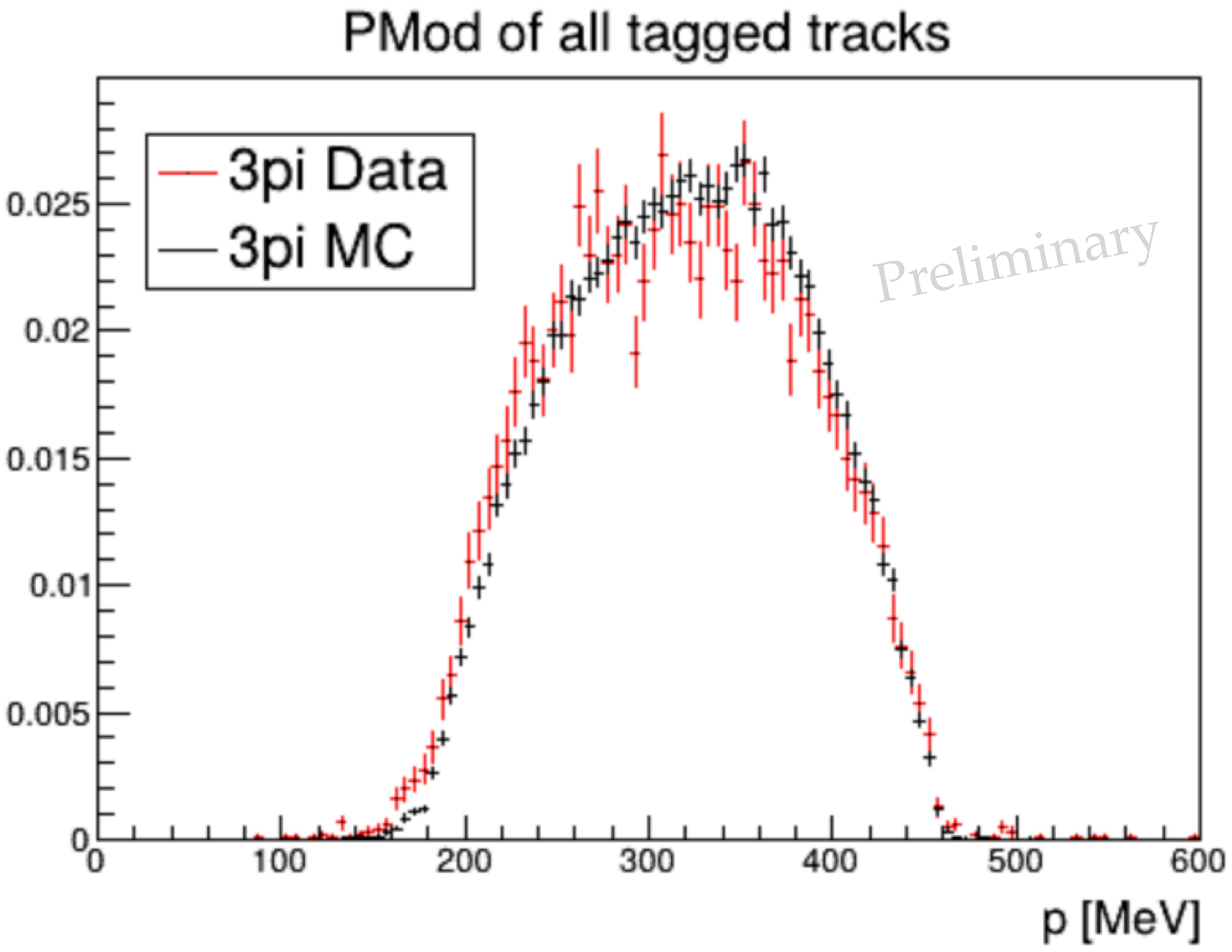
Tracking



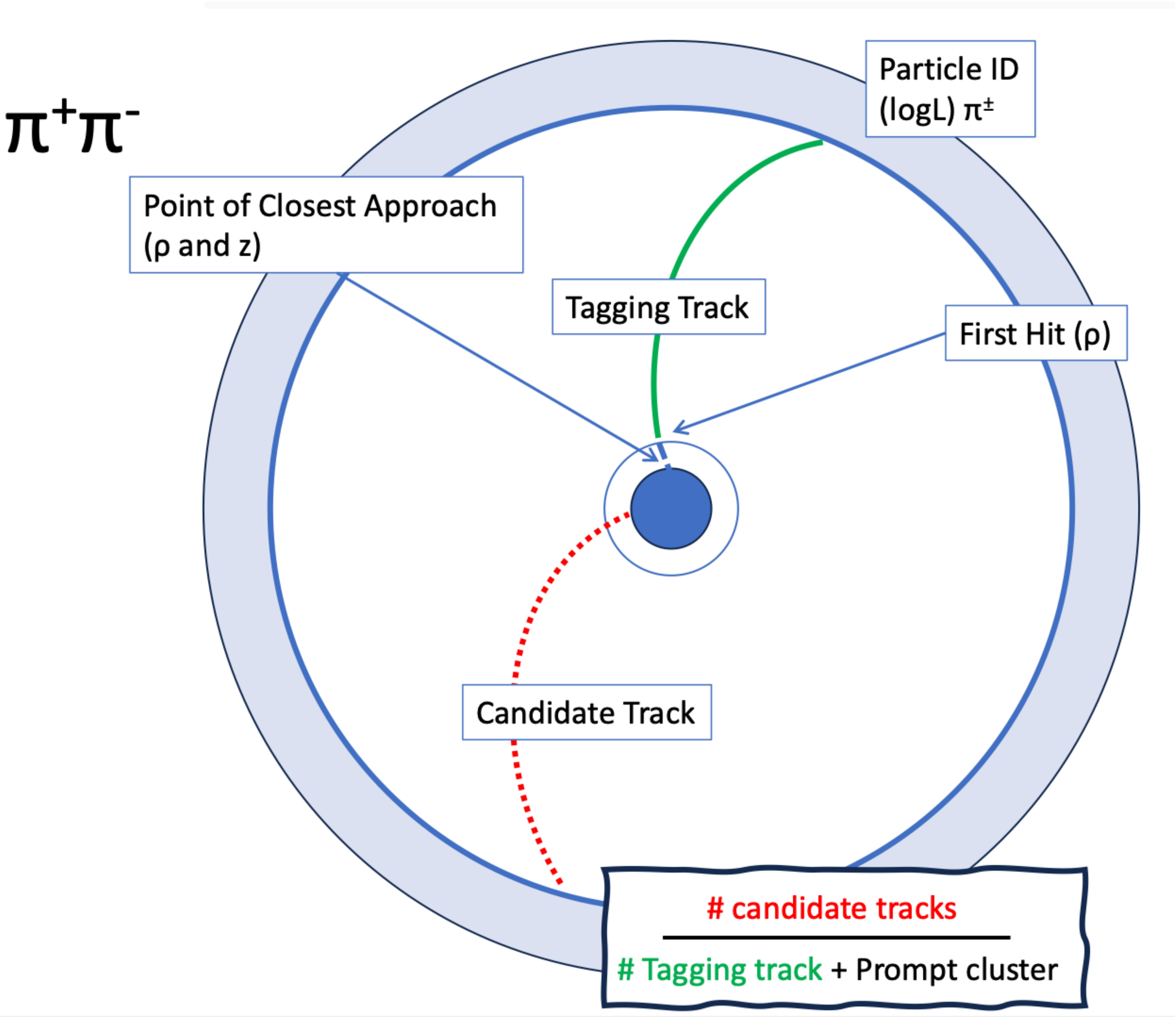
- $\pi^+\pi^-\pi^0$ **selections:**
  - $\sqrt{x_{fh}^2 + y_{fh}^2} < 50\text{cm}$
  - $\sqrt{x_{pca}^2 + y_{pca}^2} < 8\text{cm}$
  - $|Z_{pca}| < 7\text{cm}$
  - Must have associated cluster with particle identification LogLikelihood>1
- **Associated clusters to pions:**
  - Clusters with $E > 30\text{MeV}$
  - $R > 60\text{cm}$
  - $|m_{\gamma\gamma} - m_{\pi^0}| < 20\text{MeV}$
  - Neutral, i.e. not associated to any tracks
- **Tag and probe:**
  - Given the tagging track, $\pi^+(\pi^-)$, and two photons search for candidate track $\pi^-(\pi^+)$
- *Care is taken to not bias the sample through tracking selection (for example the tagging track is expected to satisfy the trigger)*

Tracking

- Current work:
  - Starting with $\pi^+\pi^-\pi^0$ the *old* selection procedure is being reproduced with distributions being studied e.g. track momenta.
  - Plot shows momentum distribution after all selections are applied on data and MC.

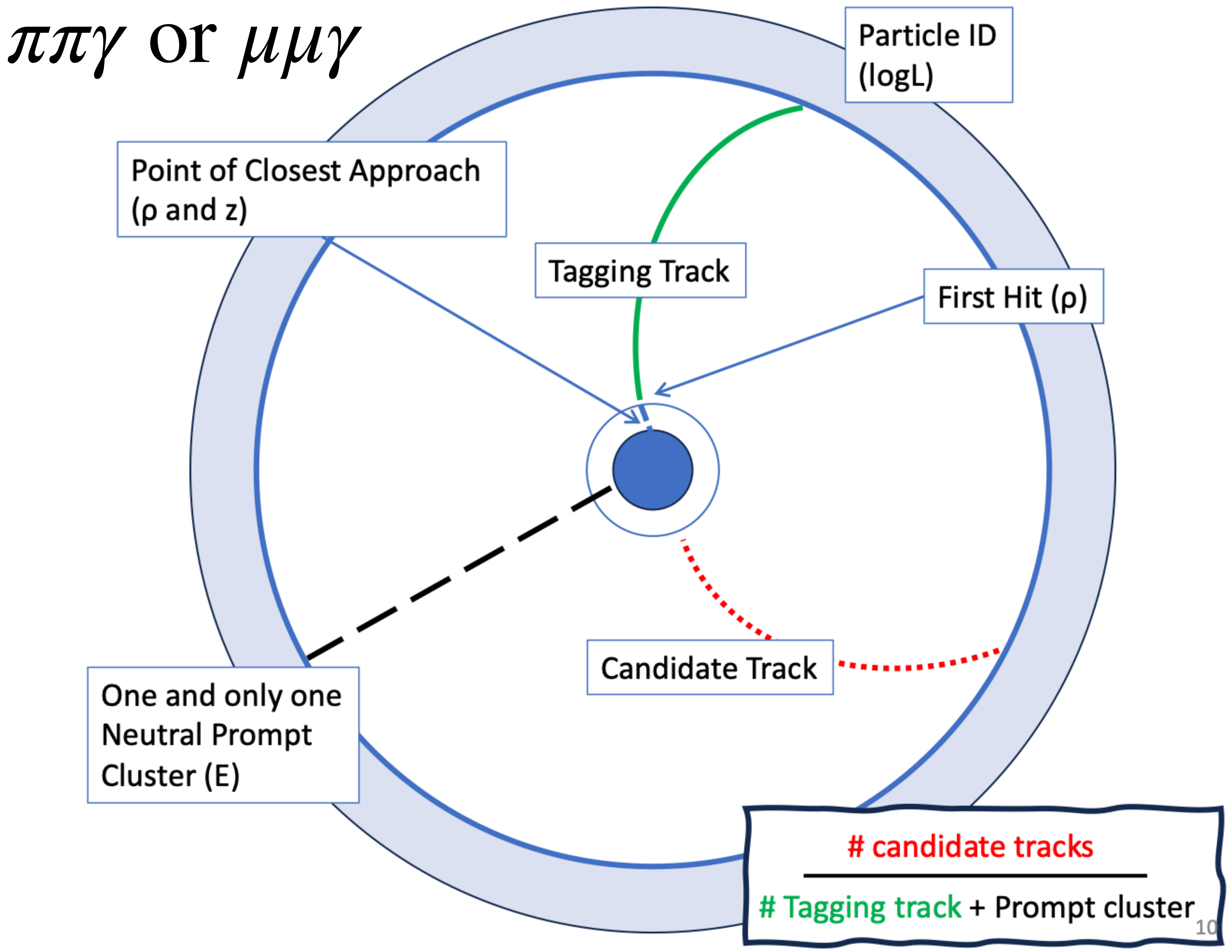


Tracking



- **$\pi^+\pi^-$ 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 particle identification LogLikelihood>1
- **Associated clusters to pions:**
  - 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 $\pi^-(\pi^+)$

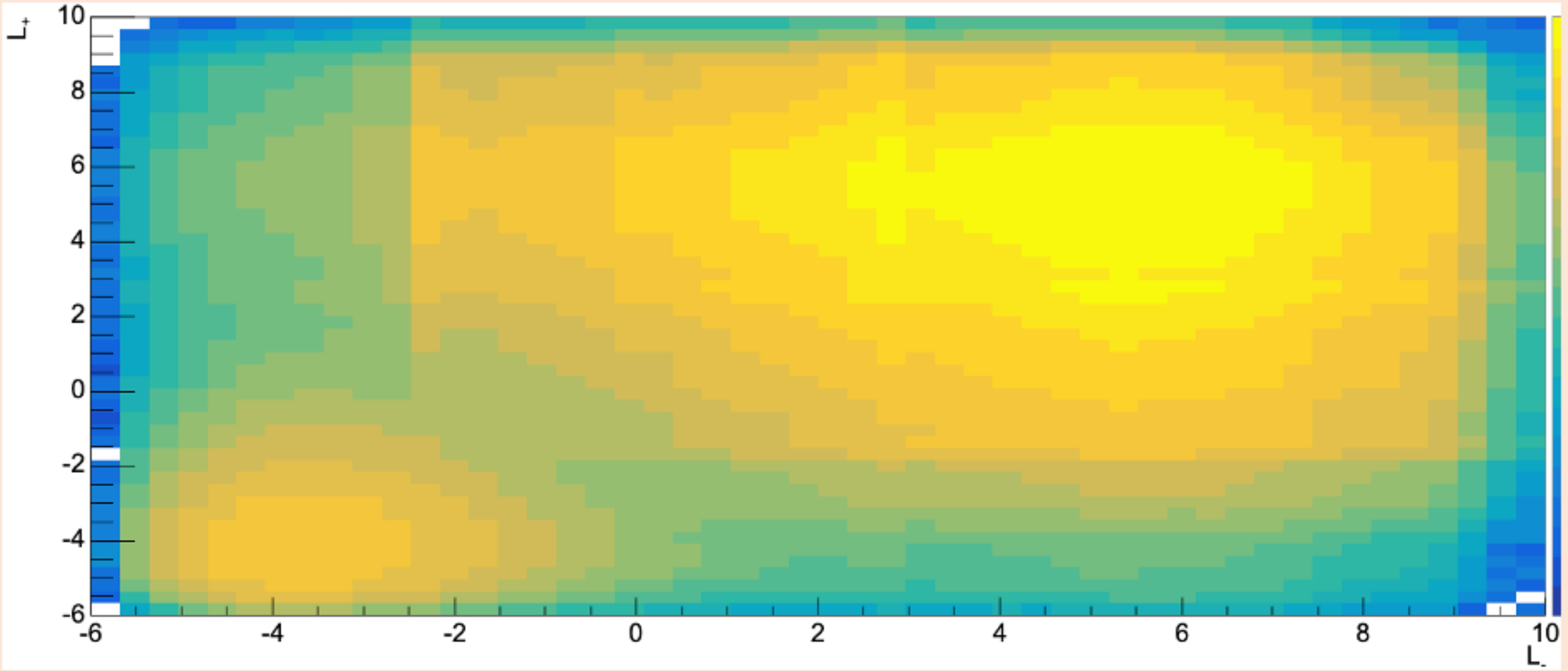
Tracking



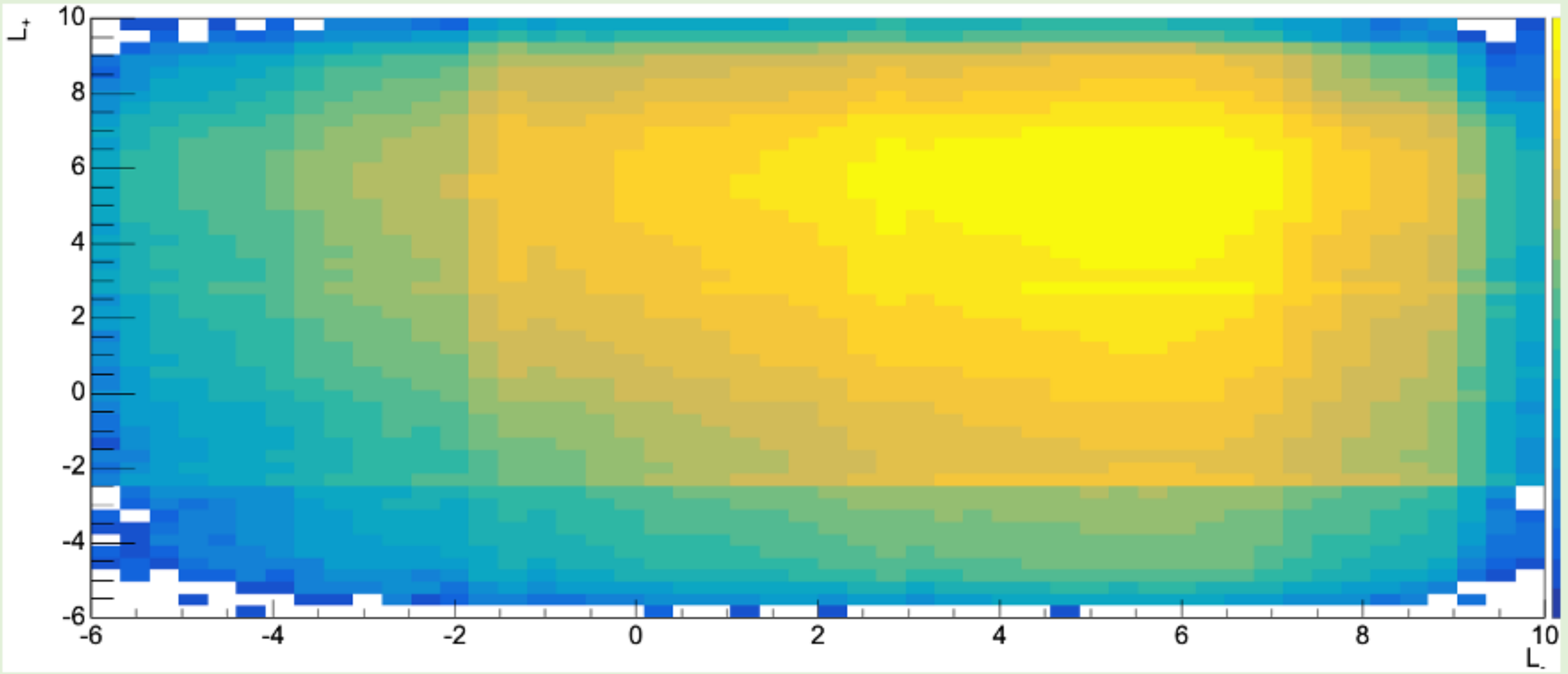
- **$\pi\pi\gamma$ or $\mu\mu\gamma$ selections:**
  - $\sqrt{x_{fh}^2 + y_{fh}^2} < 50\text{cm}$
  - $\sqrt{x_{pca}^2 + y_{pca}^2} < 8\text{cm}$
  - $|Z_{pca}| < 7\text{cm}$
  - Must have associated cluster with particle identification LogLikelihood>1
- **Associated clusters to pions:**
  - Prompt cluster 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 $\mu^-(\mu^+)$

Bhabha in $\pi^+\pi^-\pi^0$ samples and LogL

- **Data**
- Data 3pi stentu files



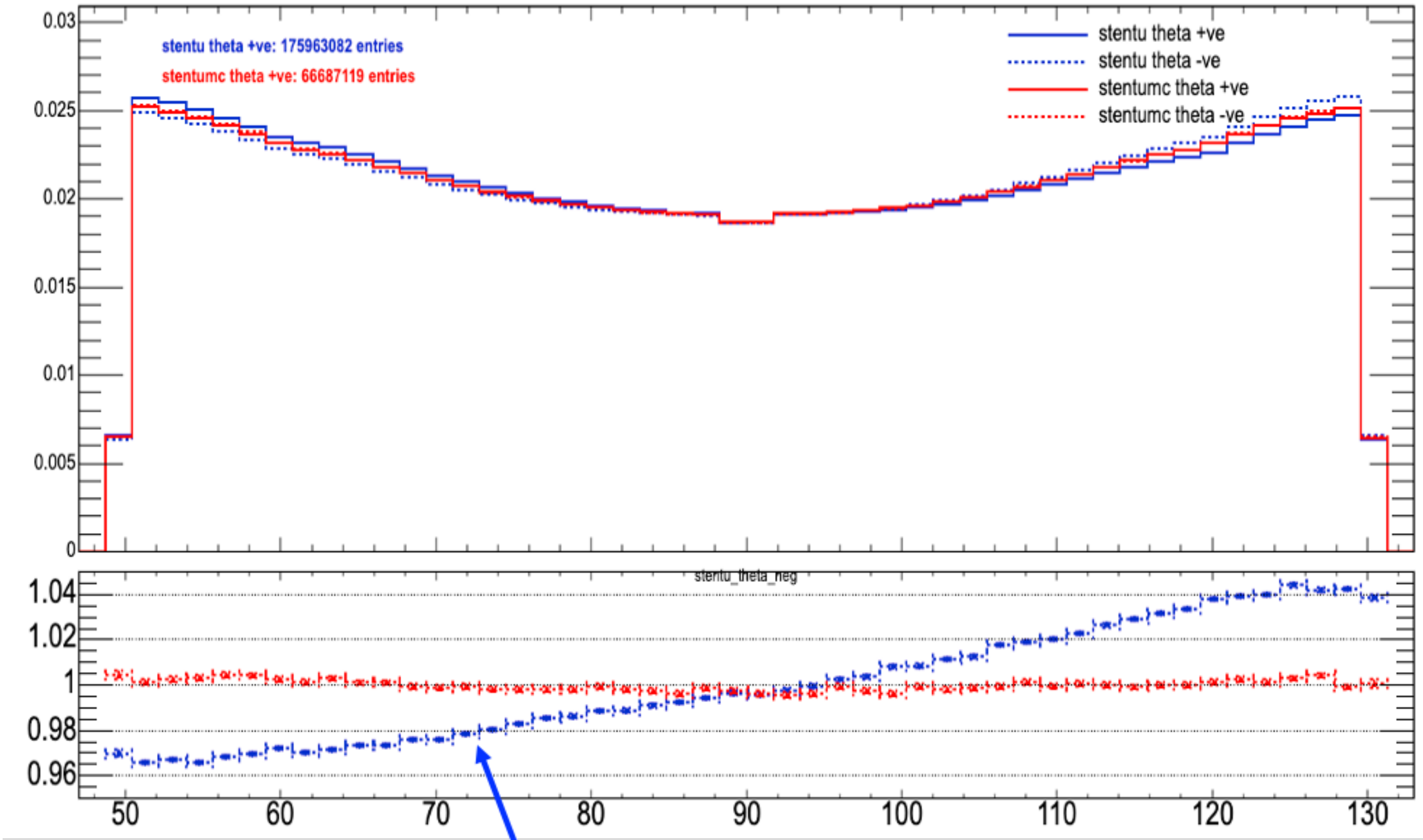
- **MC**
- MC 3pi stentu files – phirp

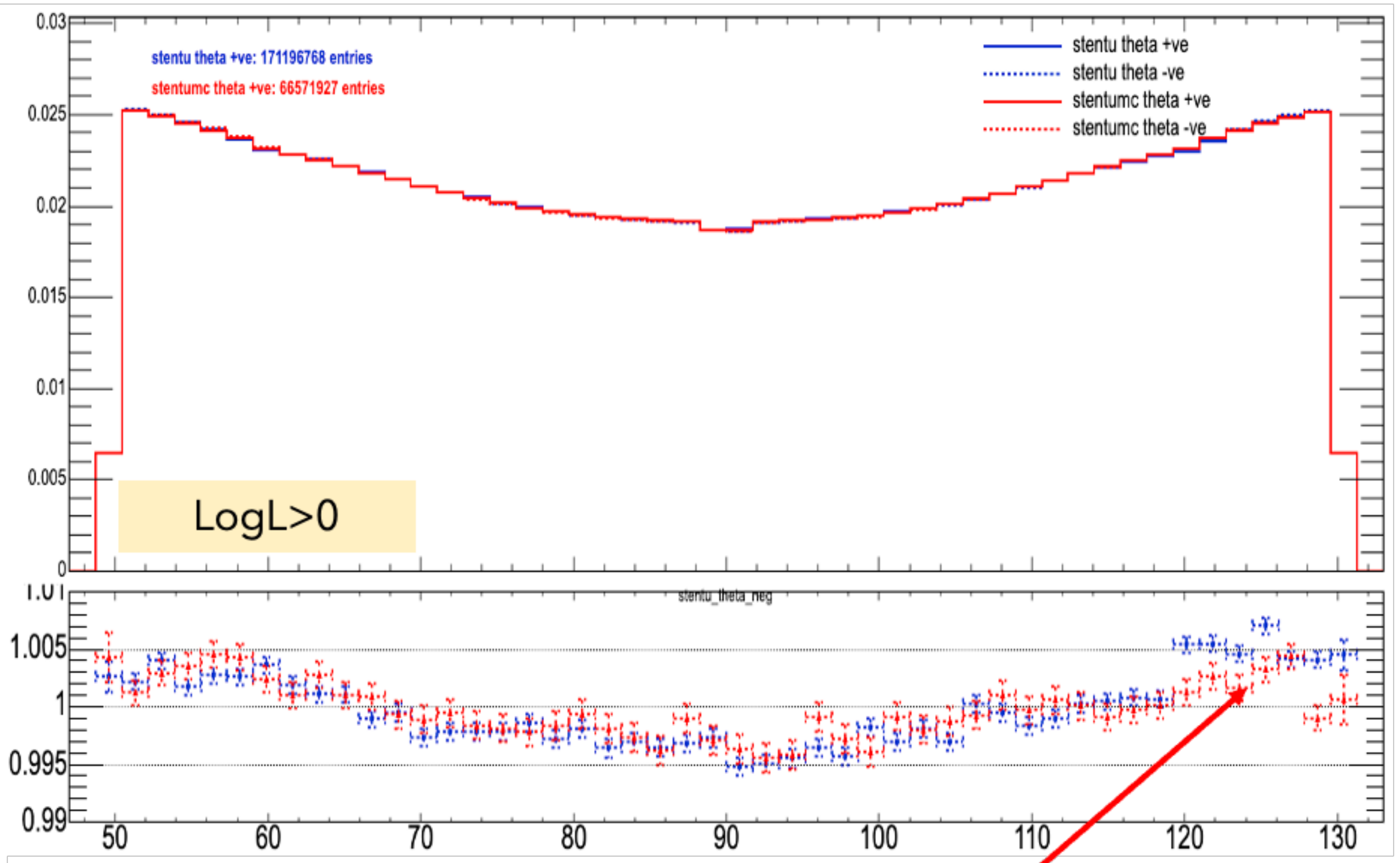


- Contamination in 3pi data of Bhabha necessitates a LogL cut above 0

Bhabha in $\pi^+\pi^-\pi^0$ samples and LogL

- θ
- Log L cut proves agreement between data and MC at the level of ~0.2%. This is improvement from +/-4% differences
- There are some differences between charged tracks in both MC and data $70 < \theta < 100$





Ratio – Data negative track/ Data positive track

Ratio – MC negative track/ MC positive track

Radiative corrections

- KLOE provided input to the theory initiative white paper 2025.
- Tested the effect of radiative corrections (RCs) in tuned comparisons between available MC generators w.r.t. Phokhara v10 @NLO.
- Tested different selection cuts, where RCs have different impacts: small angle (SA) acceptance (undetected photons); large angle (LA) acceptance (detected photons) with or without additional M_{trk} cut
- Compared $\mu\mu\gamma(\gamma)$ with ISR+FSR; $\pi\pi\gamma(\gamma)$ in ISR only due to limitations of other generators
- The results on simplified scenarios (i.e. no detector effects) do not suggest that there are issues in the implementation of Phokhara NLO.
- Current work:
  - Updating previously done studies to compare the new version of BABAYAGA@NLO.
  - Phokhara now has GVMD, which is major upgrade for pion scenario, *see Pau's talk* for the latest GVMD studies in the KLOE scenario.
  - Doing MC comparisons after the M_{trk} cut and also after background subtraction.
  - MC comparisons with detector effects this includes interfacing Phokhara10 with Geanfi, currently KLOE is using Phokhara5
  - Ongoing work on resummation of soft photon effects in Phokhara, *see Jeremy's talk*.
  - Ongoing work on NNLO accuracy *see William and Tom's talks.*

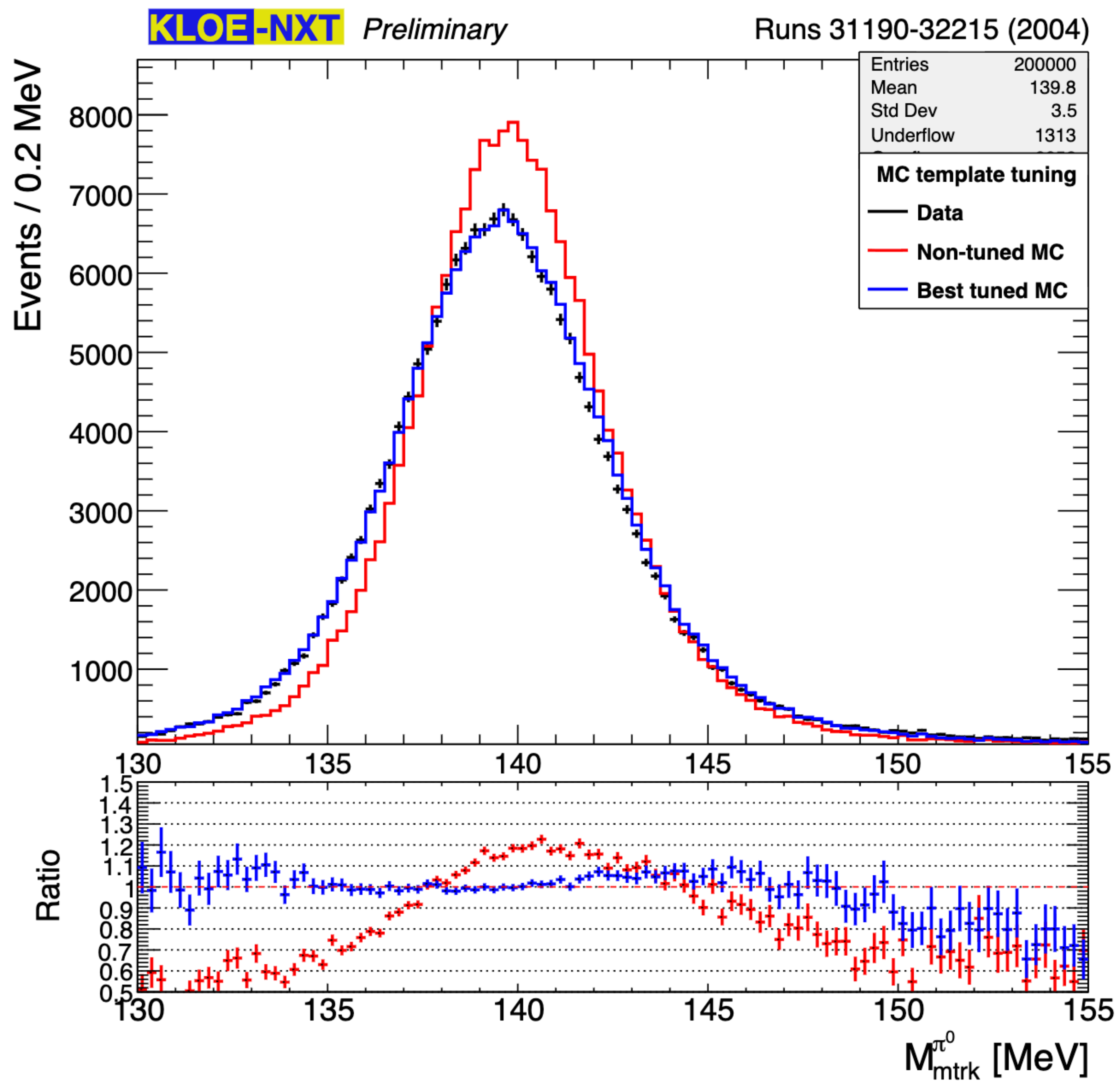
Summary

- 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
- This will be a factor 7 statistical improvement making the statistical uncertainty negligible wrt systematics
- The aim is a ~ threefold reduction on the statistical error and twofold reduction on the systematic one, resulting in a twofold reduction of the total error to ~0.4% on on $a_\mu^{HLO,2\pi}$
- The analysis will be conducted **blindly**
- Work is in progress on tracking efficiency, luminosity, normalised QED test, MC data tuning, background subtraction and collinear dataset analysis.
- Combined effort with theory members of the group to cross check RC for published analyses, calculate higher order radiative corrections and develop NNLO MC generators for the new analysis

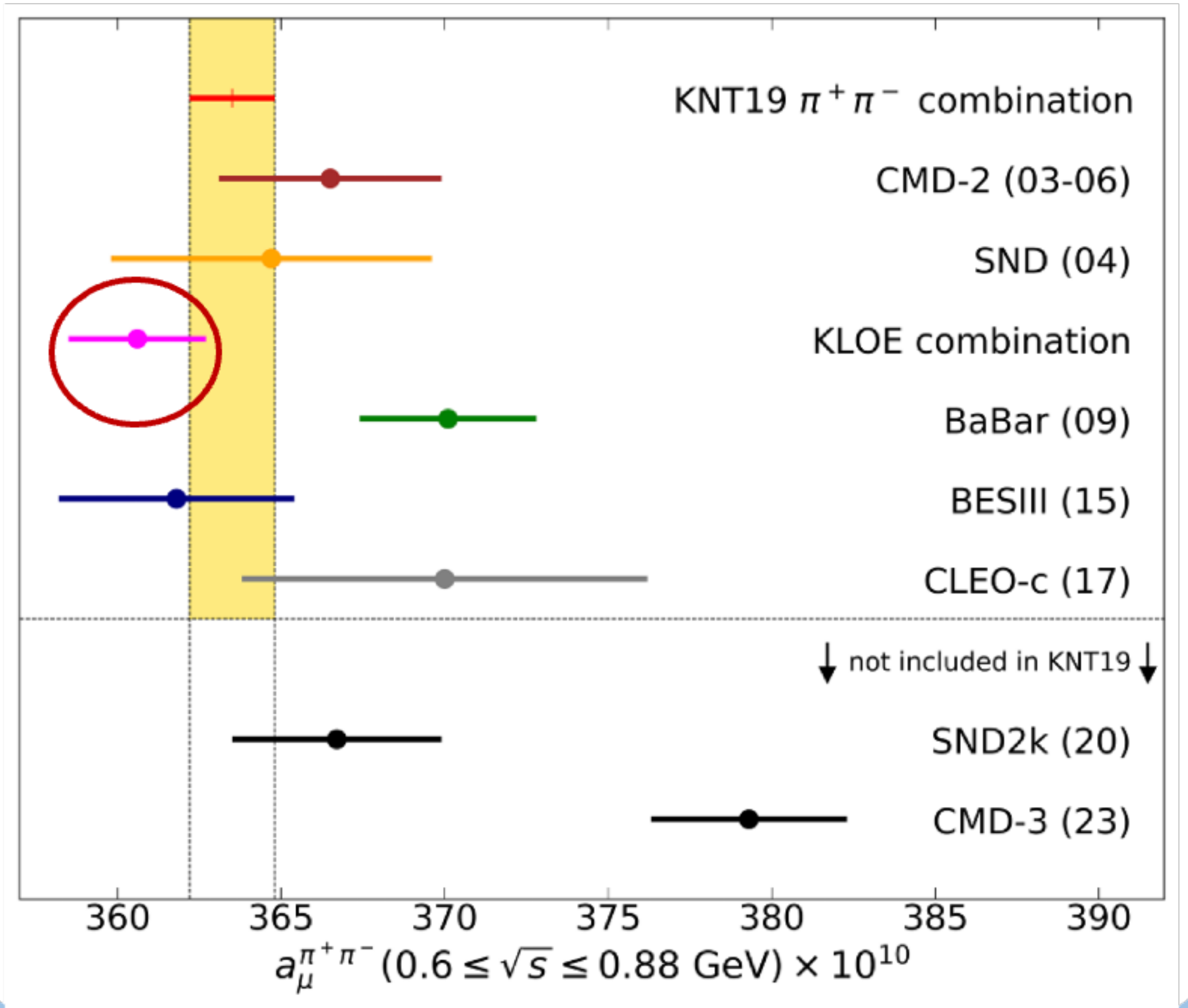
Thank you

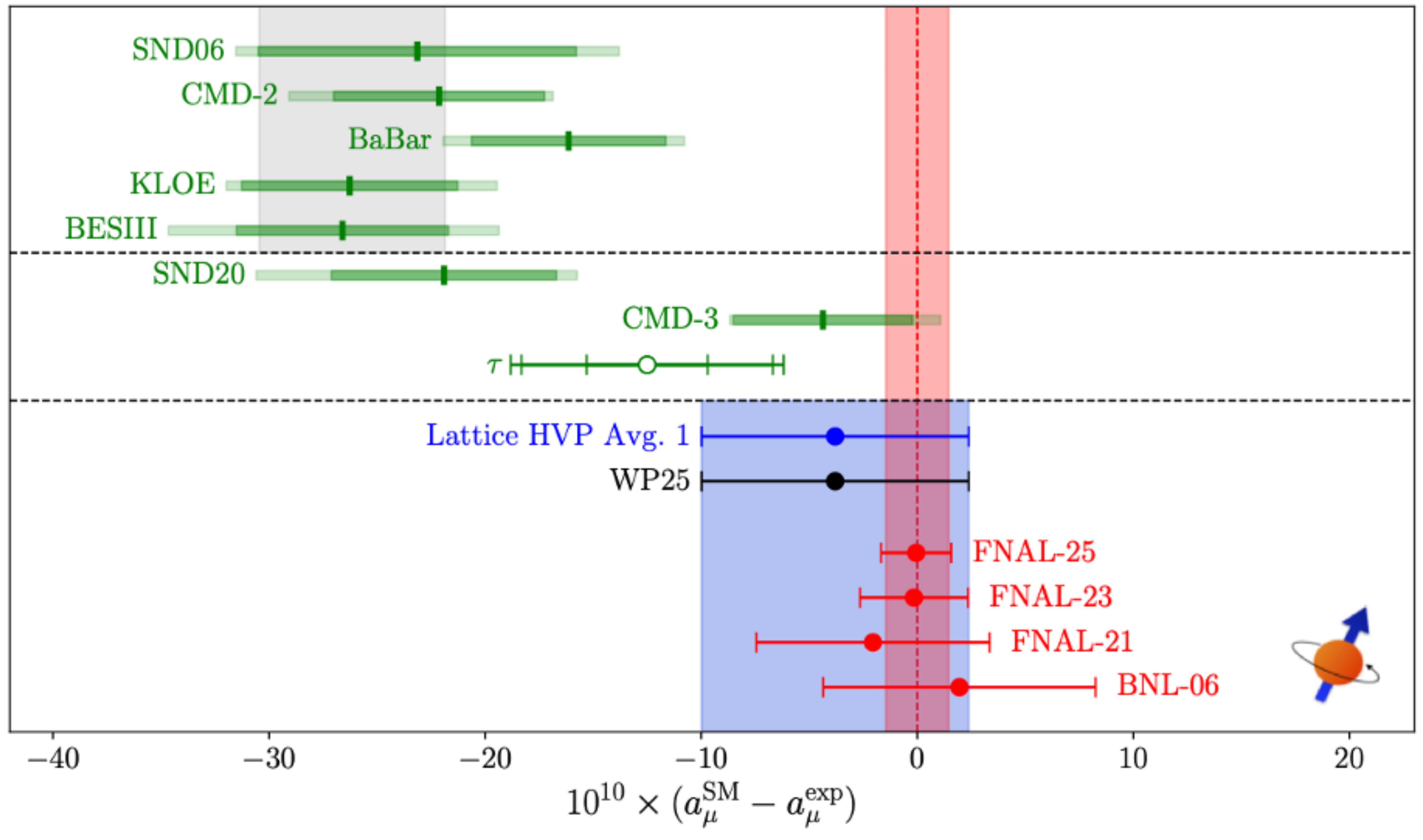
A novel method for Data MC Tuning

$$x \to x \times (1 + Gaus(\mu(k, \theta)), \sigma(k, \theta)))$$



The Muon g-2 landscape





The KLOE measurements have been instrumental in shaping the current landscape of muon g-2.

The Current Effort

New KLOE hadronic cross section measurement

RadioMonteCarLow 2

Leading updated comparisons of Monte Carlo generators for low-energy physics.

Combined effort with theory members at Liverpool University to cross check Radiative Corrections for published analyses, calculate higher order radiative corrections and develop NNLO MC generators for the new analysis.

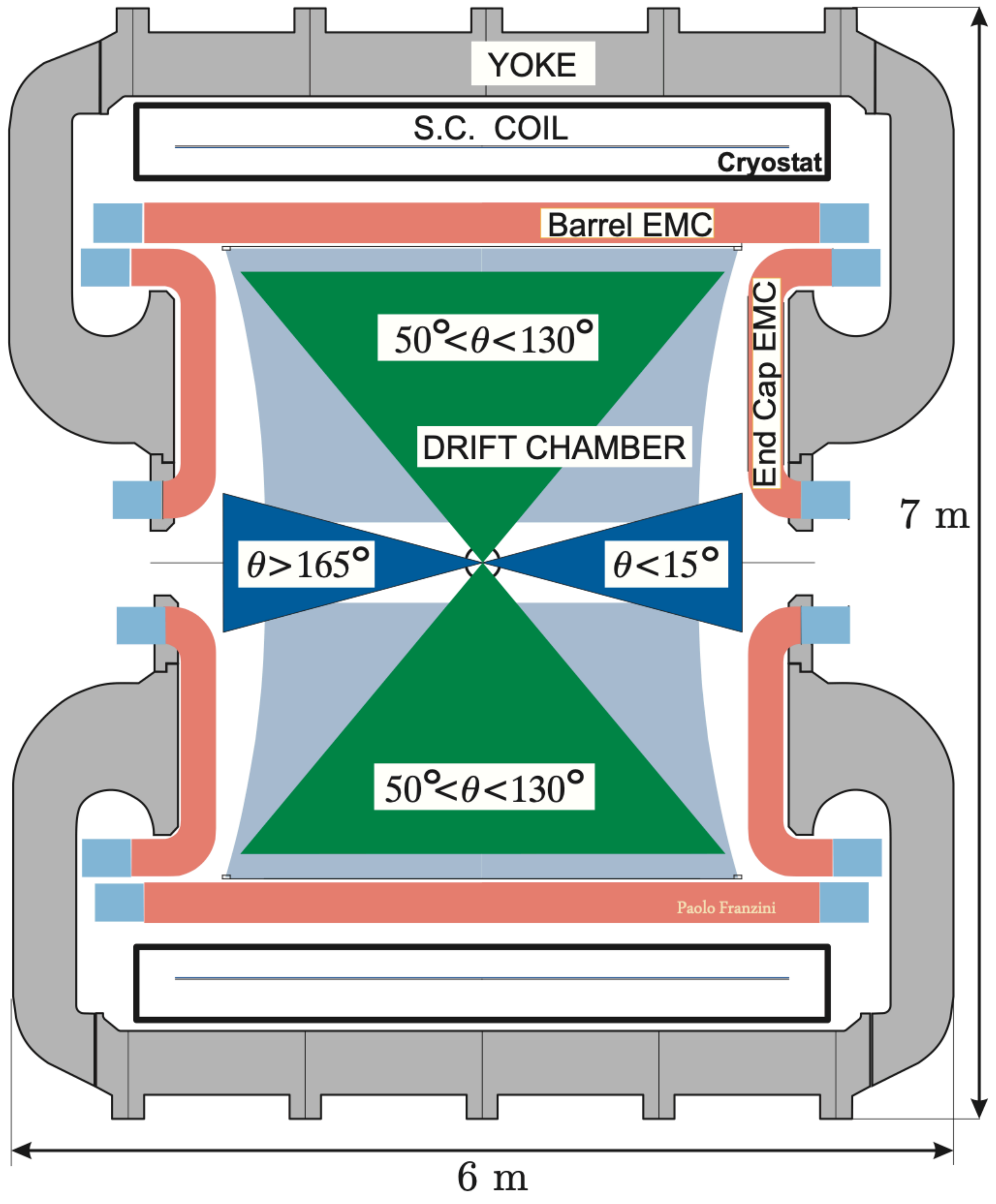
Large experimental group of 15 members at Liverpool University working on the KLOE analysis as well as collaborators from Pisa, Dresden and Krakow institutes.

Small Angle (KLOE08) measurement

Small Angle KLOE08 analysis - arXiv:0809.3950 [hep-ex]

60 points between 0.35 < $M^2_{\pi\pi}$ < 0.95 GeV^2

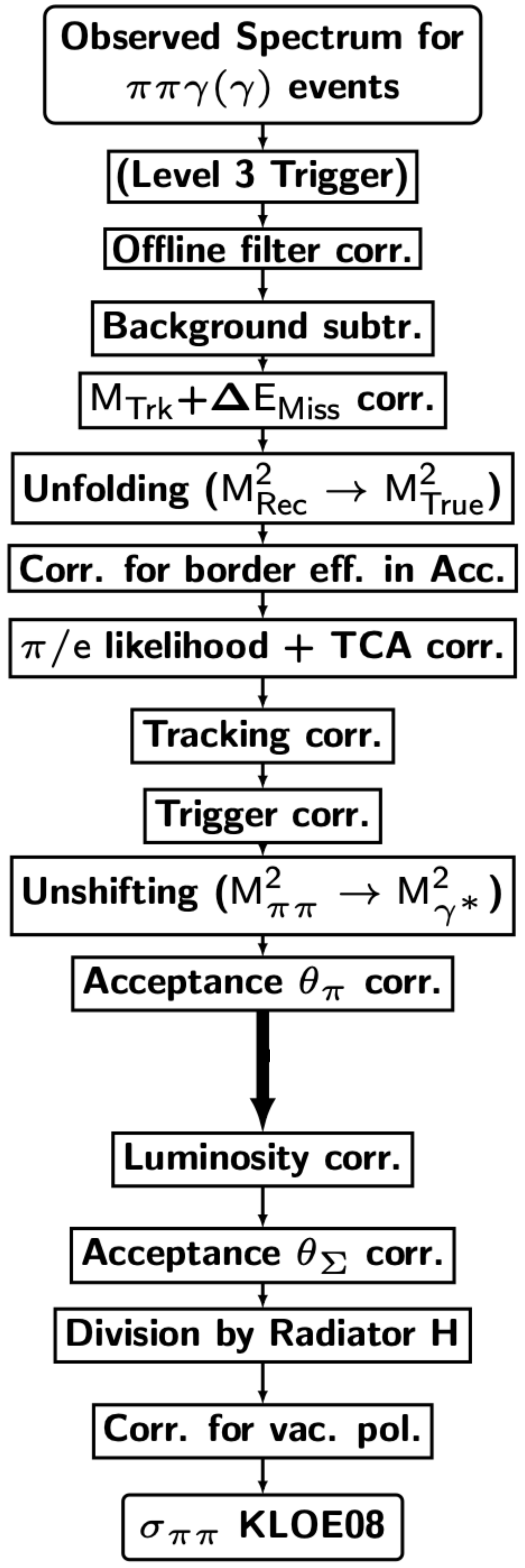
- based on 240.0 pb^{-1} data taken in 2002
- **selection cuts:**
  - **2 pion tracks at large angles** $50^\circ < \theta_\pi < 130^\circ$
  - **small angle cuts:**
    - **photons at small angles** $\theta_{miss} < 15^\circ$ **or** $\theta_{miss} > 165^\circ$
    - photon momentum from kinematics: $\vec{p}_{\text{miss}} = -(\vec{p}_+ + \vec{p}_-)$
    - high statistics for ISR events
    - low FSR contribution
    - suppression of $\phi \to \pi^+\pi^-\pi^0$ background
    - threshold region not accessible
- **normalisation to Bhabha and PHOKHARA radiator**



In order to measure $\sigma_{\pi\pi}(s_{\pi\pi})$ while operating at fixed $\sqrt{s}$ **Initial State Radiation** is used:

$$s\frac{d\sigma(e^+e^- \to \pi\pi\gamma)}{ds_{\pi\pi}}\Bigg|_{ISR} = \sigma_{\pi\pi}(s_{\pi\pi})H(s_{\pi\pi}, s)$$

Radiator function



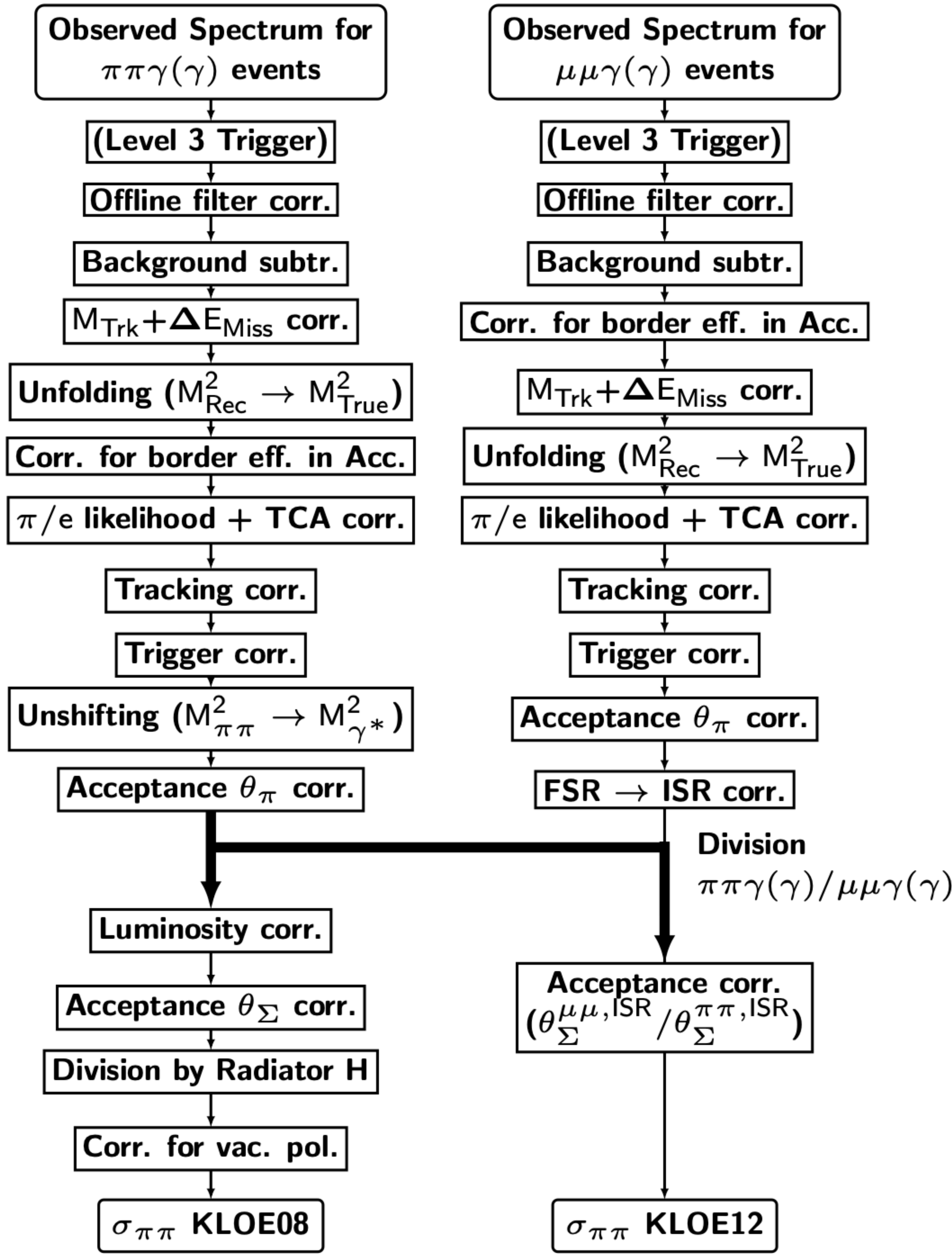
Small Angle (KLOE12) measurement

Small Angle KLOE12 analysis - arXiv:1212.4524 [hep-ex]

KLOE08 + different normalisation:

- **normalisation to $\mu\mu\gamma$ events**
- this is another method of extracting the cross section:
- $$\sigma_{\pi\pi(\gamma)}(s_{\pi\pi}) = \sigma_{\mu\mu(\gamma)}(s_{\mu\mu})\frac{d\sigma_{\pi\pi\gamma}/ds^*_\gamma}{d\sigma_{\mu\mu\gamma}/ds^*_\gamma}$$
- it is possible to **cancel out the luminosity dependence and radiator function** by normalising to $\mu\mu\gamma$
- this significantly **decreased the theoretical systematics but increased the background subtraction systematics**

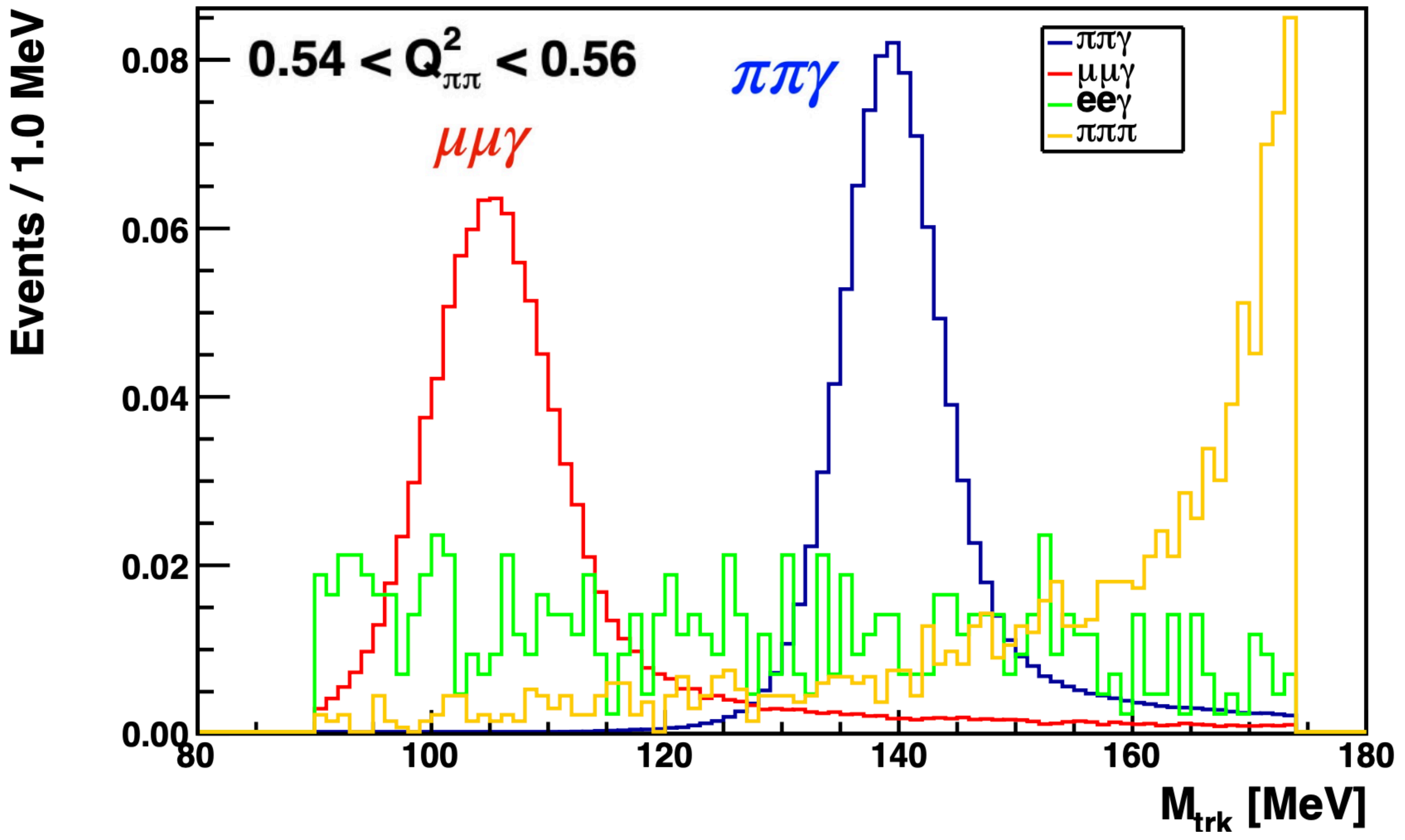
Syst Errors (%)	$a_\mu^{\pi\pi}$ absolute	$a_\mu^{\pi\pi}$ ratio
Background Filter (FILFO)	negligible	negligible
Background Subtraction	0.3	0.6
Trackmass	0.2	0.2
Particle ID	negligible	negligible
Tracking	0.3	0.1
Trigger	0.1	0.1
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	0.2	negligible
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

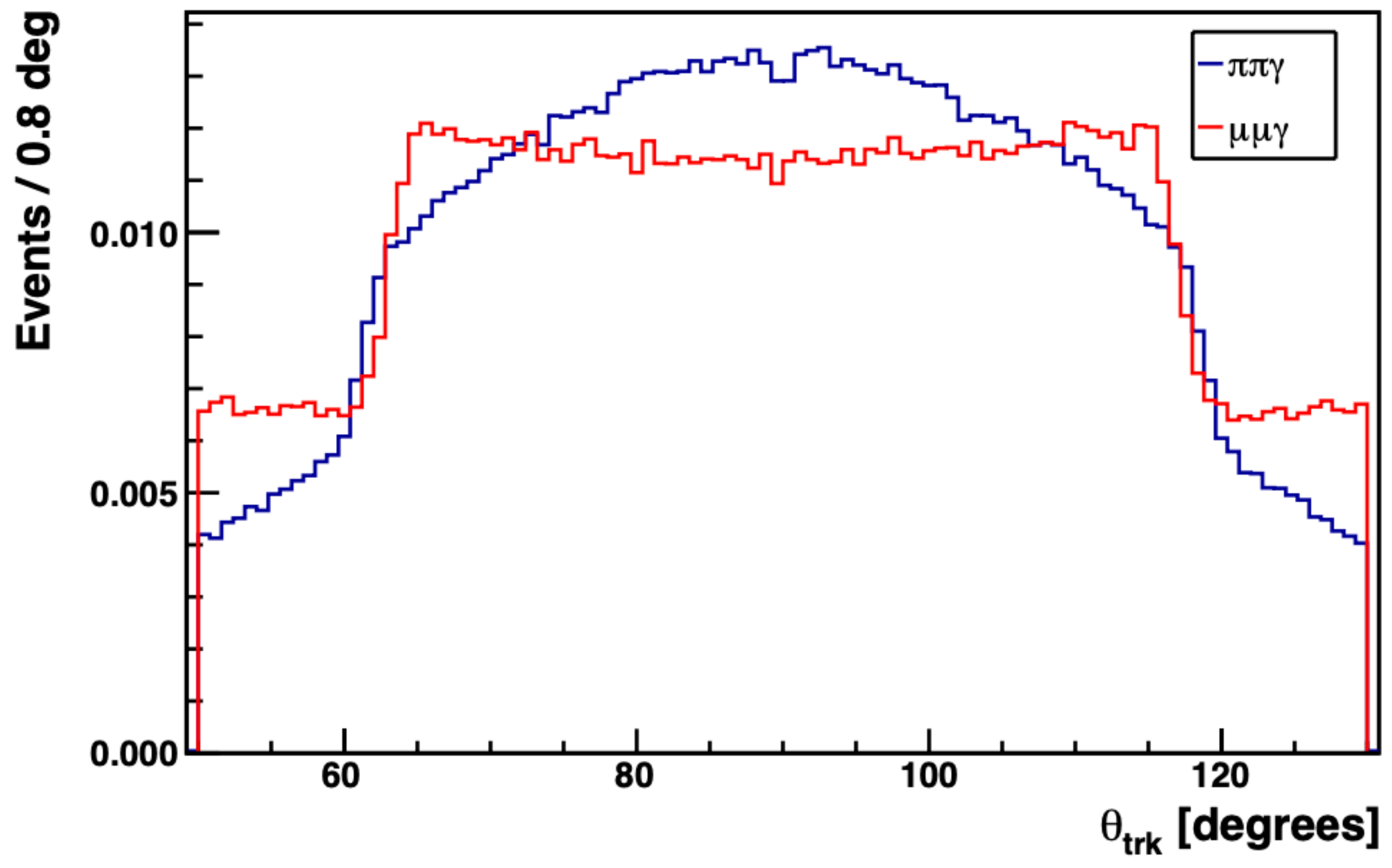


Backup

Background Subtraction

- Background sources
  - $e^+e^- \to \pi^+\pi^-\pi^0$, $e^+e^- \to \mu^+\mu^-\gamma$, $e^+e^- \to e^+e^-\gamma$
  - The objective is to estimate 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 in each $Q^2_{\pi\pi}$ slice is scaled by $(1 - f^i_B)$
  - **Background subtraction procedure is the dominant of the KLOE12 systematics (accounting for ~85% of the total error)**
- Progress
  - Implementation and correctness of old procedure checked by reproducing result from previous analysis using new code
  - Previous analyses use M_{trk} as the main discriminating variable for background subtraction
  - **Background fit results should be independent of variable chosen to fit on**
  - In order to improve the procedure other variables are being investigated as alternative or in addition to M_{trk} e.g. polar angle wrt the beam axis θ_{trk}
  - This will provide additional consistency and reduce the systematic uncertainties of the background subtraction

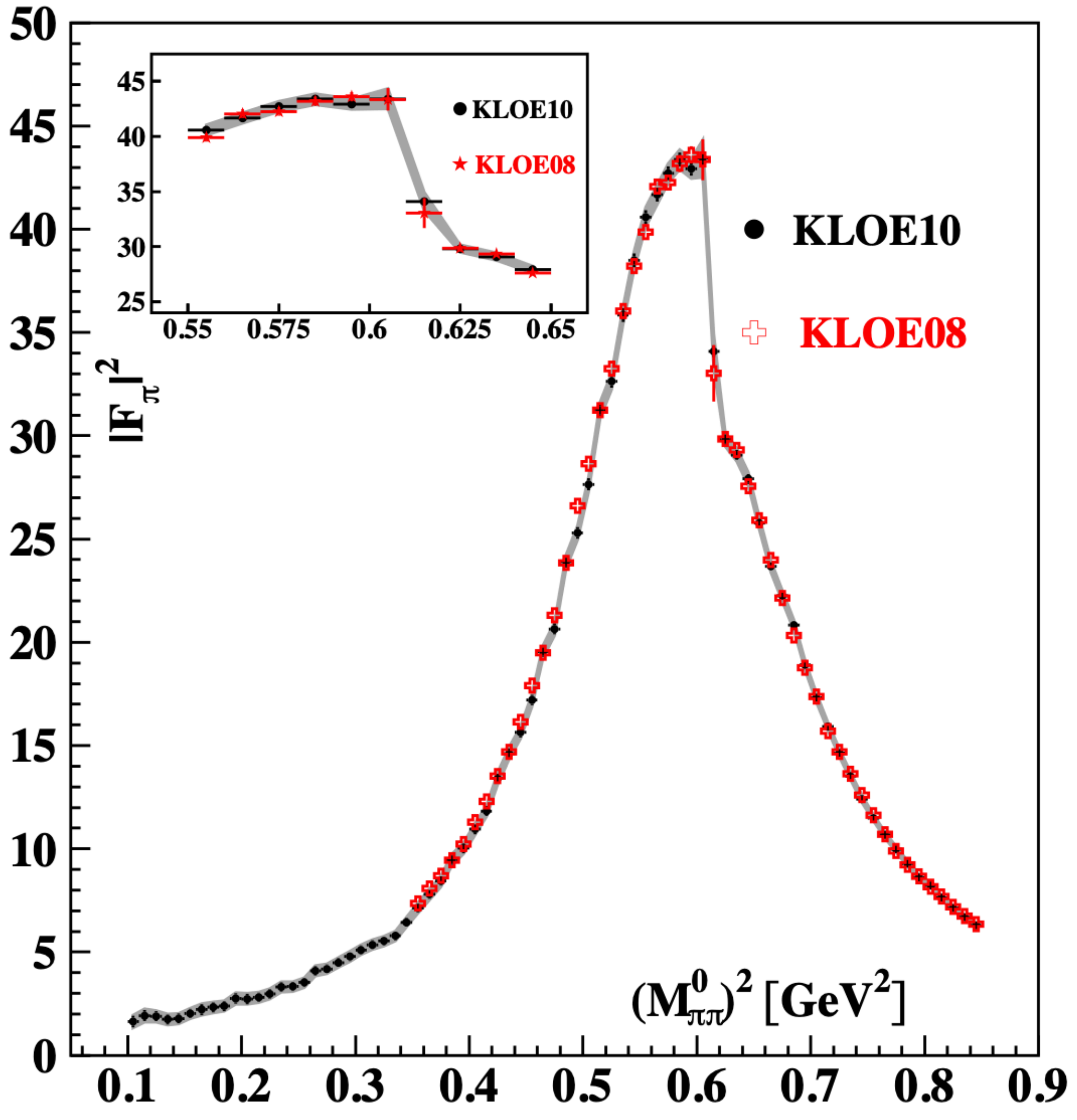


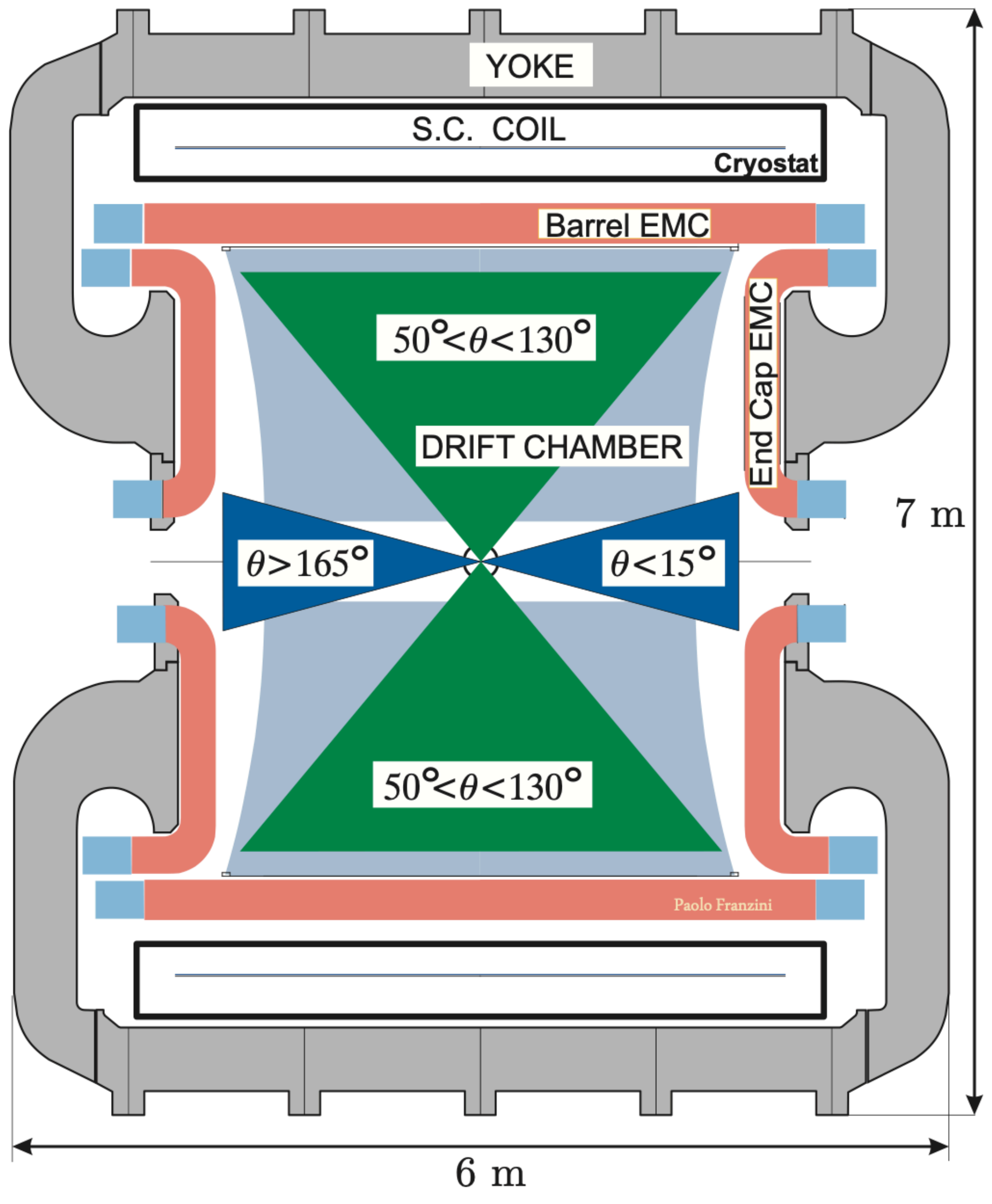


Large Angle (KLOE10) measurement

Large Angle KLOE10 analysis - arXiv:1006.5313 [hep-ex]

- This analysis allows us to extend the $M^2_{\pi\pi}$ region down towards the threshold for the dipion production
  - 75 points between $0.1 < M^2_{\pi\pi} < 0.85\ GeV^2$
  - based on 232.6 pb^{-1} data taken in 2006 with $\sqrt{s} = 1\ GeV$
  - **selection cuts:**
    - **2 pion tracks at large angles** $50^\circ < \theta_\pi < 130^\circ$
    - **large angle cuts:**
      - **at least 1 photon at large angles** $50^\circ < \theta_\gamma < 130^\circ$
      - photon detection possible
      - disadvantages of large angle cuts e.g. more $\phi \to \pi^+\pi^-\pi^0$ background and higher FSR contribution overcome by use of 2006 dataset
  - **normalisation to Bhabha and PHOKHARA radiator**

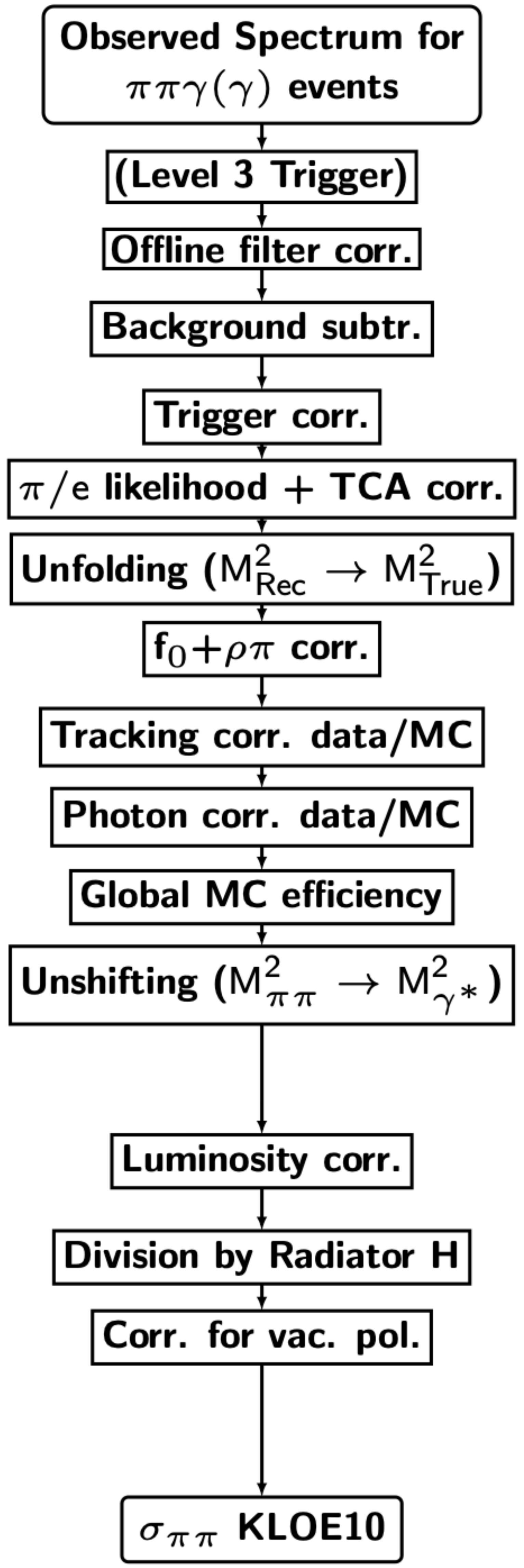




In order to measure $\sigma_{\pi\pi}(s_{\pi\pi})$ while operating at fixed $\sqrt{s}$ **Initial State Radiation** is used:

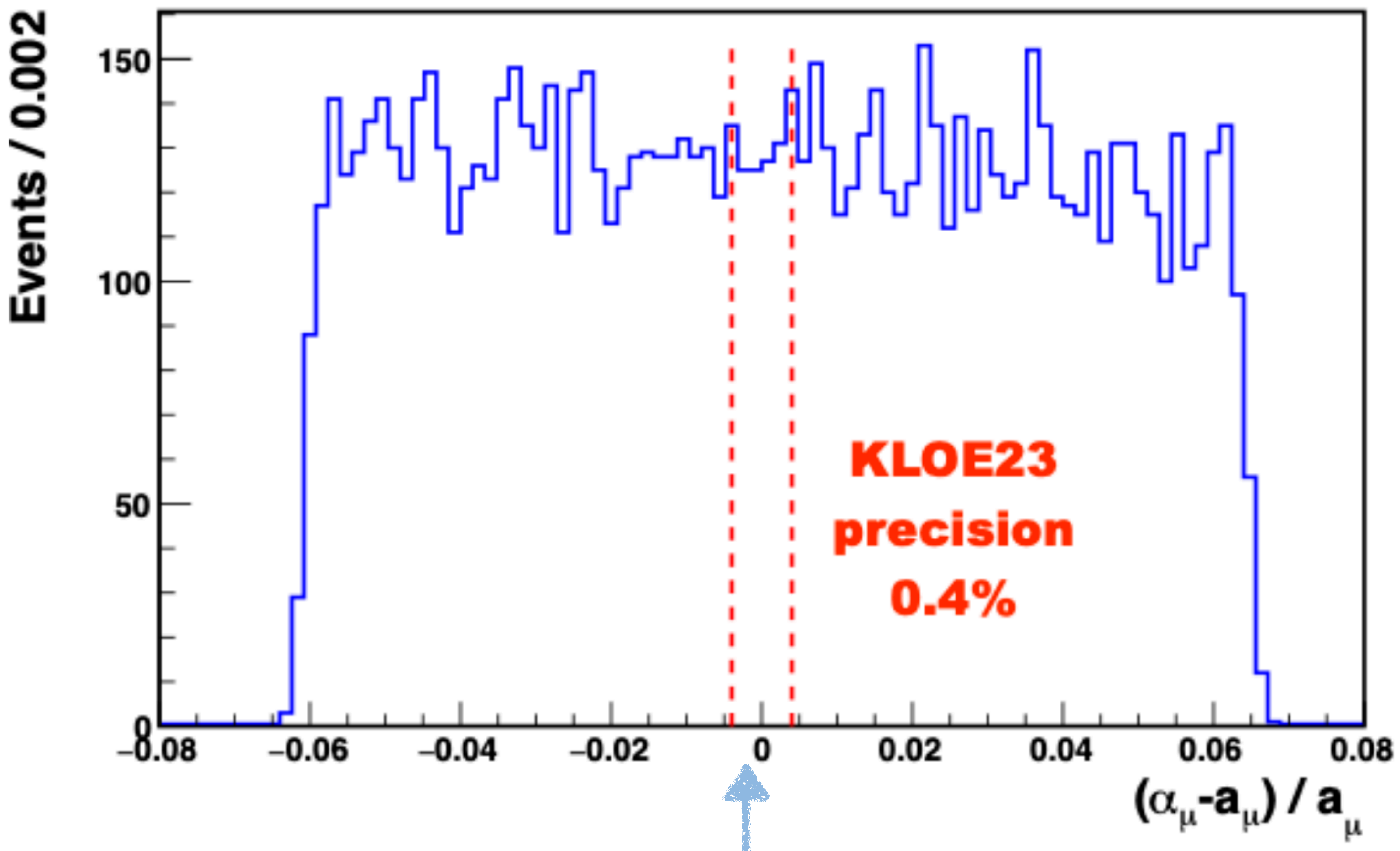
$$s\frac{d\sigma(e^+e^- \to \pi\pi\gamma)}{ds_{\pi\pi}}\Bigg|_{ISR} = \sigma_{\pi\pi}(s_{\pi\pi})H(s_{\pi\pi}, s)$$

Radiator function



Blinding

- The new KLOE analysis will be **conducted blindly** to ensure good practice and avoid bias throughout.
- This is not a trivial task and is the **first KLOE a_μ^{HLO} analysis to be blinded.**
- The aim of blinding is to shift the result of the analysis by a small amount without jeopardising the distributions of data and Monte Carlo.
- Two sets of root-tuples will be used in this analysis; **blinded and working (unblinded) root-tuples.**
- For the blinded root-tuples, proposed procedure is as follows:
  - **Removing a small, unknown (to the analysers) fraction of events from each $Q^2_{\pi\pi}$ or $Q^2_{\mu\mu}$ slice in data.**
  - This modifies the measured differential cross section and thus $a_{\pi\pi} \propto \int ds \ldots \sigma_{\pi\pi}(s)$ whilst having no affect on distributions at fixed Q^2 bins.
- Efficiencies are calculated on the working root-tuples ($|F_\pi|^2$ not accessible here).
- **Extraction of $|F_\pi|^2$ is done only on blinded root-tuples.**



Blinded value of a_μ is ±6% with respect to true value in simulations. Blinding offset **much larger than target KLOE23 precision**!

Blinding

Things to note

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

The blinding procedure will be done by a member of the collaboration that is external to the analysis.

Unblinding will be performed only at the completion of the analysis and with the agreement of all the analysers involved.

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

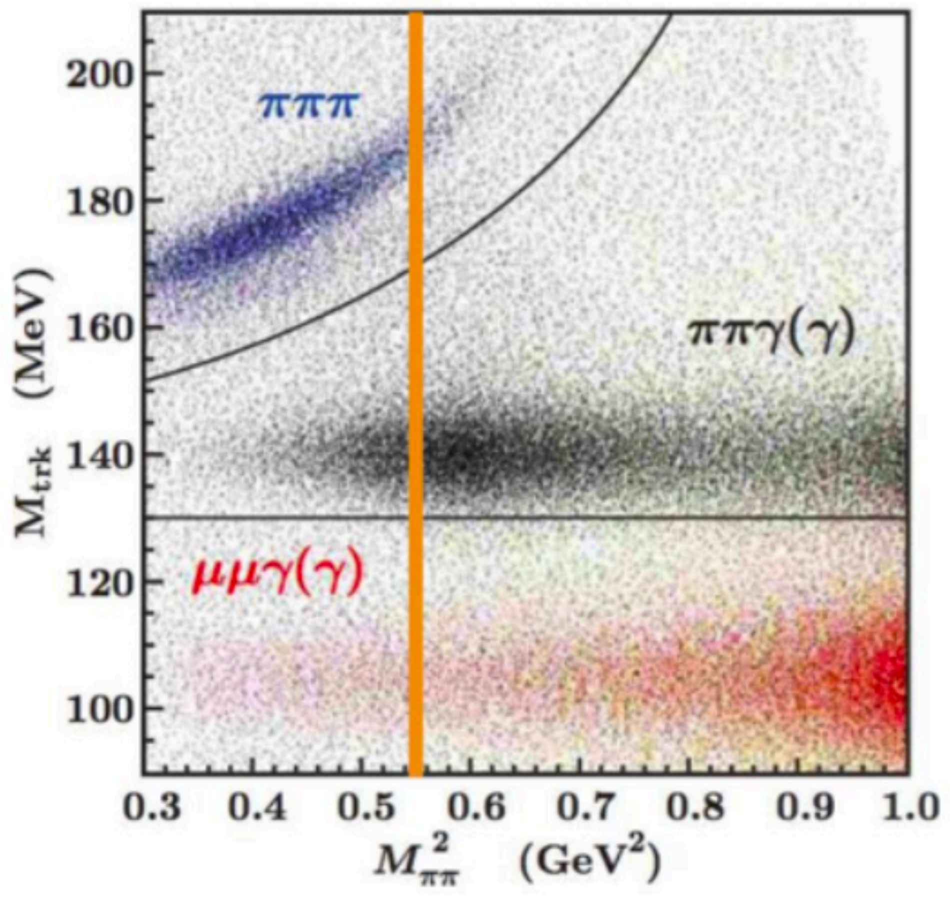
This blinding procedure like many others **assumes a level of honesty** from analysers. Analysers agree not to look at the pion form factor directly or indirectly before the unblinding.

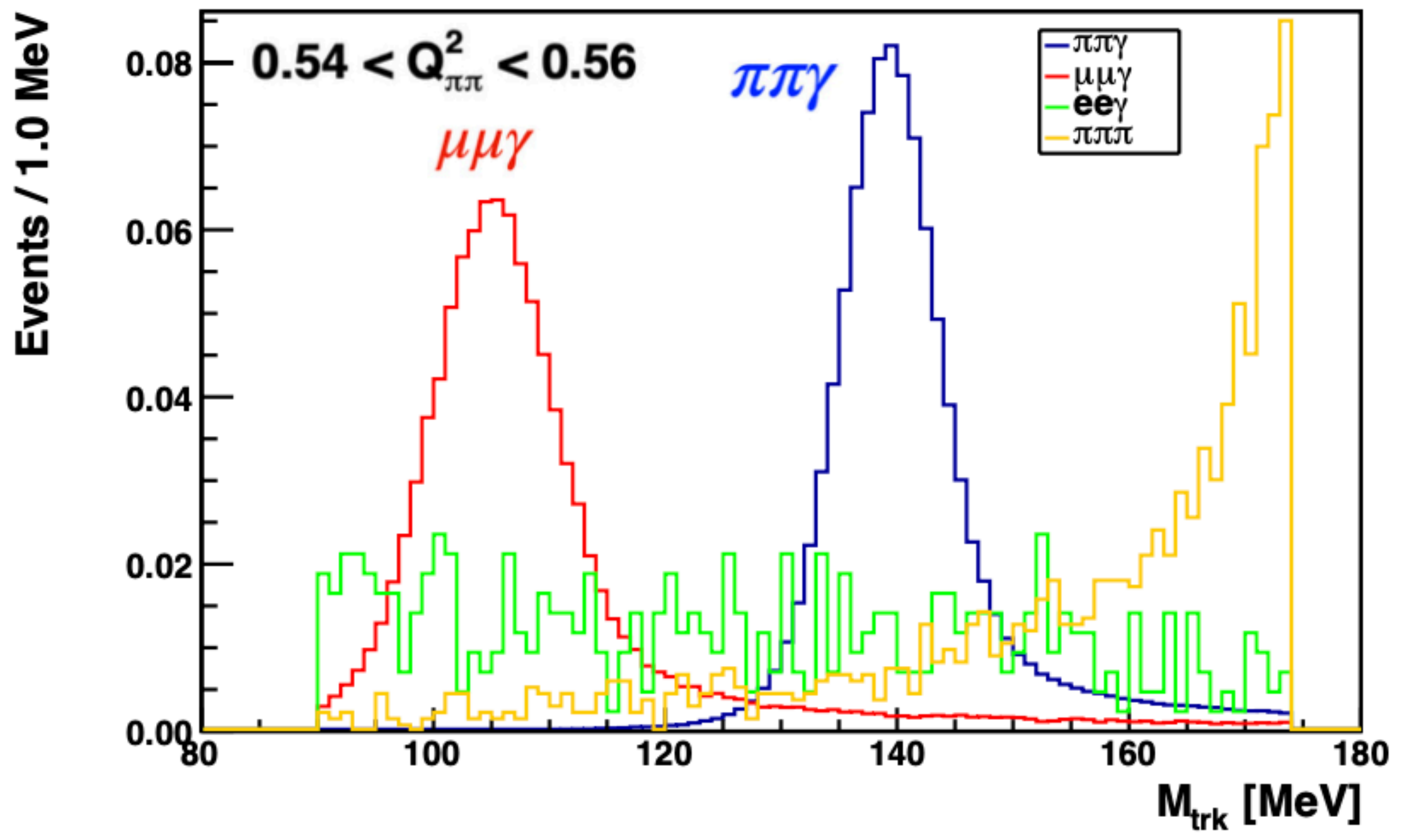
Background Subtraction

In the KLOE $\sigma(e^+e^- \to \pi^+\pi^-)$ analyses after the angular cuts a final selection ("signal cut") is performed on the **trackmass** variable $M_{trk} \longrightarrow$ used to define the signal region for $\pi^+\pi^-\gamma$ and $\mu^+\mu^-\gamma$.

$$M_{trk} \;:\quad \left(\sqrt{s} - \sqrt{|\vec{p}_+|^2 + M_{trk}^2} - \sqrt{|\vec{p}_-|^2 + M_{trk}^2}\right)^2 - (\vec{p}_+ + \vec{p}_-)^2 \equiv 0$$

$$e^+e^- \to X^+X^-\gamma \Longrightarrow M_{trk} = \hat{m}_X$$





- $80 < M_{trk} < 115$ MeV to select $\mu^+\mu^-\gamma$
- $M_{trk} > 130$ MeV to select $\pi^+\pi^-\gamma$

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Background Subtraction for $\pi^+\pi^-\gamma$ Analysis

Three main backgrounds survive the cuts in addition to the signal ($\pi^+\pi^-\gamma$) :

$$e^+e^- \to \mu^+\mu^-\gamma(\gamma) \qquad e^+e^- \to e^+e^-\gamma(\gamma) \qquad e^+e^- \to \pi^+\pi^-\pi^0$$

The objective is estimating the total fraction f_B^i of background events in each bin i of $Q^2_{\pi\pi}$:

$$f_B^i = f^i_{\mu\mu\gamma} + f^i_{ee\gamma} + f^i_{\pi\pi\pi}$$

- Data M_{trk} distribution is fitted in each bin i with MC M_{trk} distributions to find the fractions F^i_α of each channel α.
- Fits are performed on the **entire range** of M_{trk} (no signal cut) to increase sensitivity.
- Fractions in the **signal region** of M_{trk} (f^i_α) are calculated using the weights w^i_α:

$$w^i_\alpha \equiv F^i_\alpha \frac{N^i_{dat}}{N^i_{mc,\alpha}} \quad \Longrightarrow \quad f^i_\alpha = w^i_\alpha \frac{n^i_{mc,\alpha}}{n^i_{dat}} = F^i_\alpha \frac{N^i_{dat}}{N^i_{mc,\alpha}} \frac{n^i_{mc,\alpha}}{n^i_{dat}}$$

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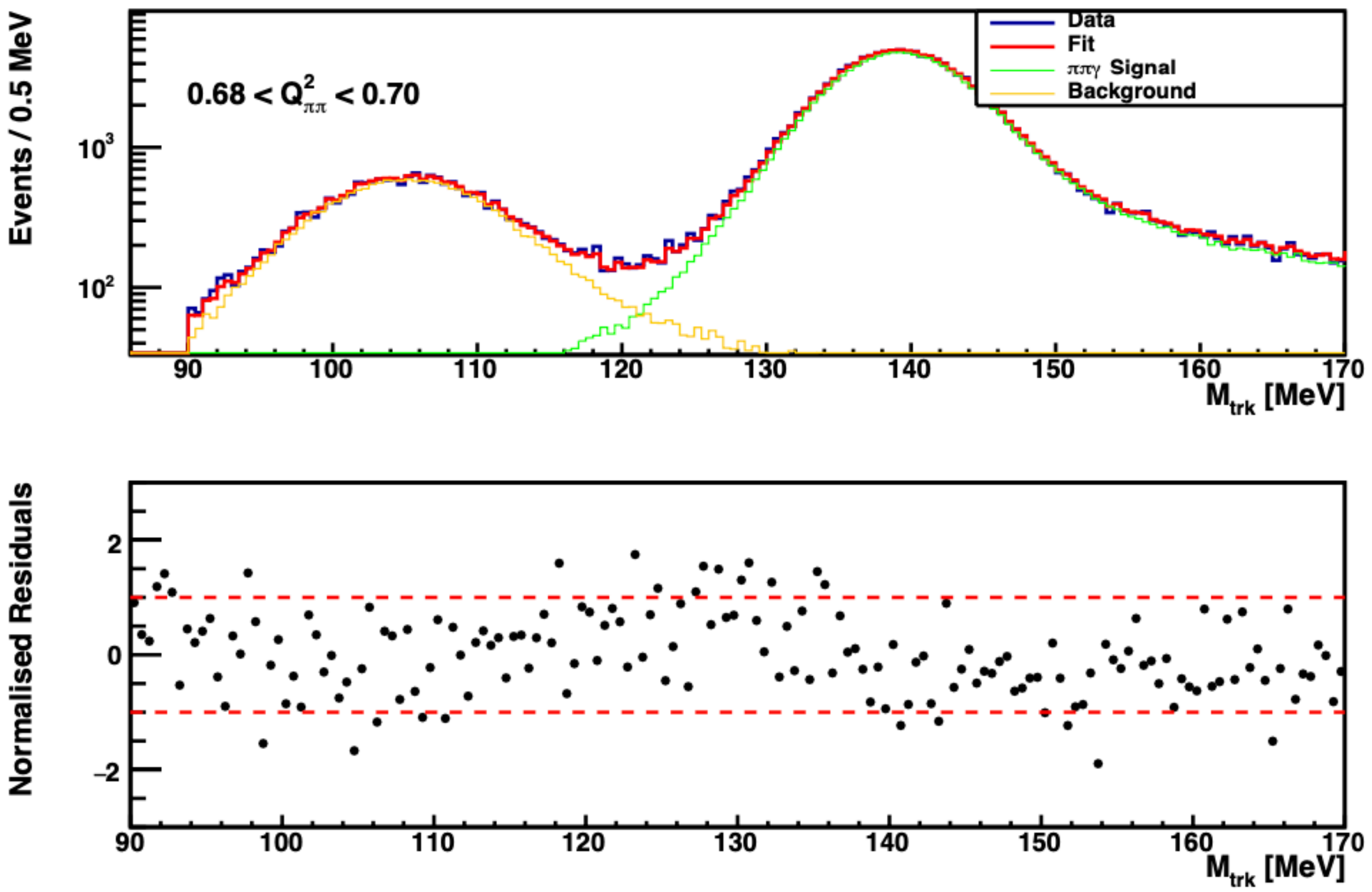
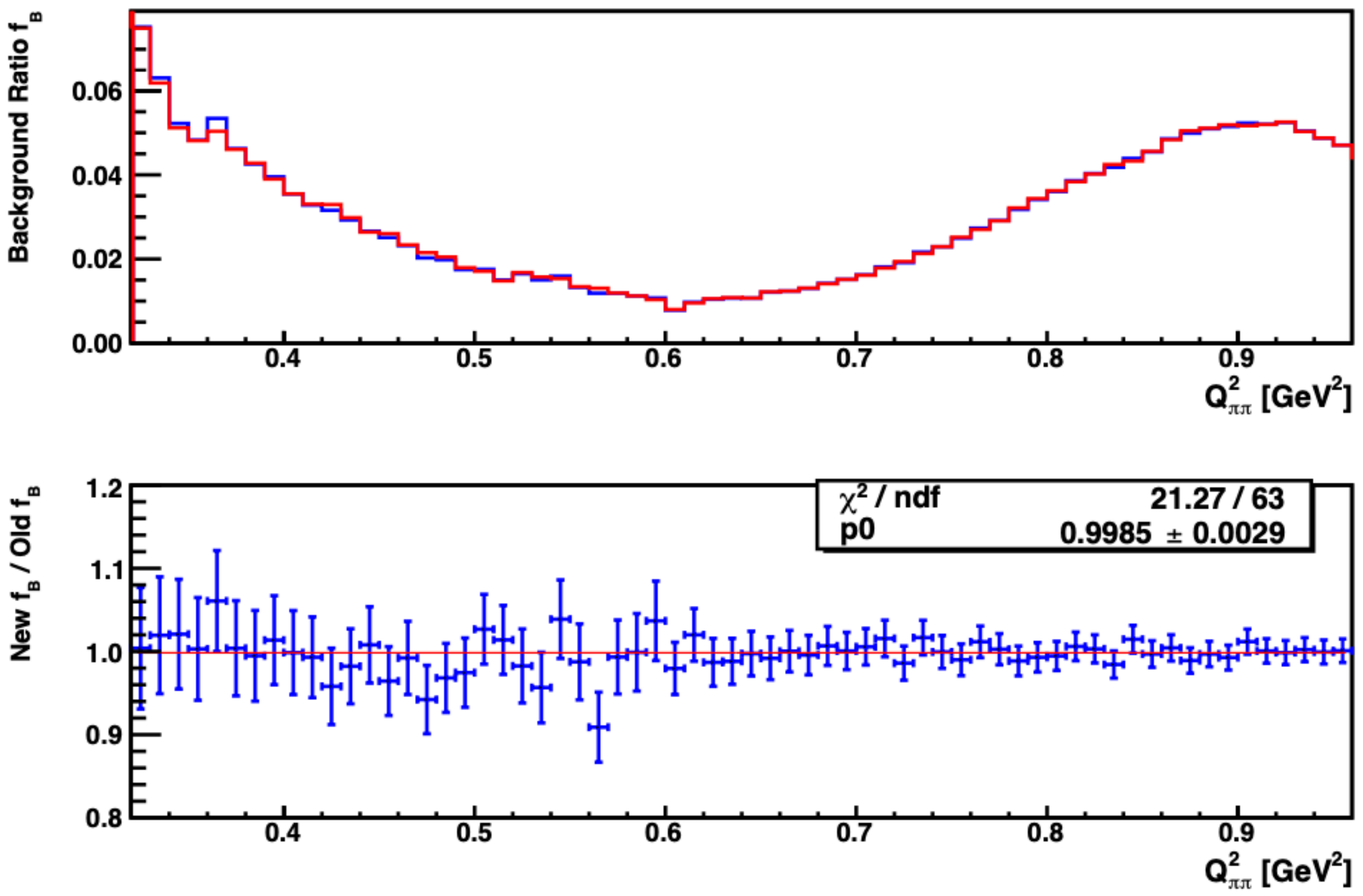
Reproducing the KLOE08 Background Fit on M_{trk}

The KLOE08 background fit using M_{trk} ($\pi^+\pi^-\gamma$ analysis) was successfully **reproduced using newer software** (`C++` instead of `Fortran+Perl`).



Fit on M_{trk} in a bin of $Q^2_{\pi\pi}$.



Comparison of old and new results for f^i_B.

$$f^i_B = f^i_{\mu\mu\gamma} + f^i_{ee\gamma} + f^i_{\pi\pi\pi} \text{ in bin } i \text{ of } Q^2_{\pi\pi}.$$

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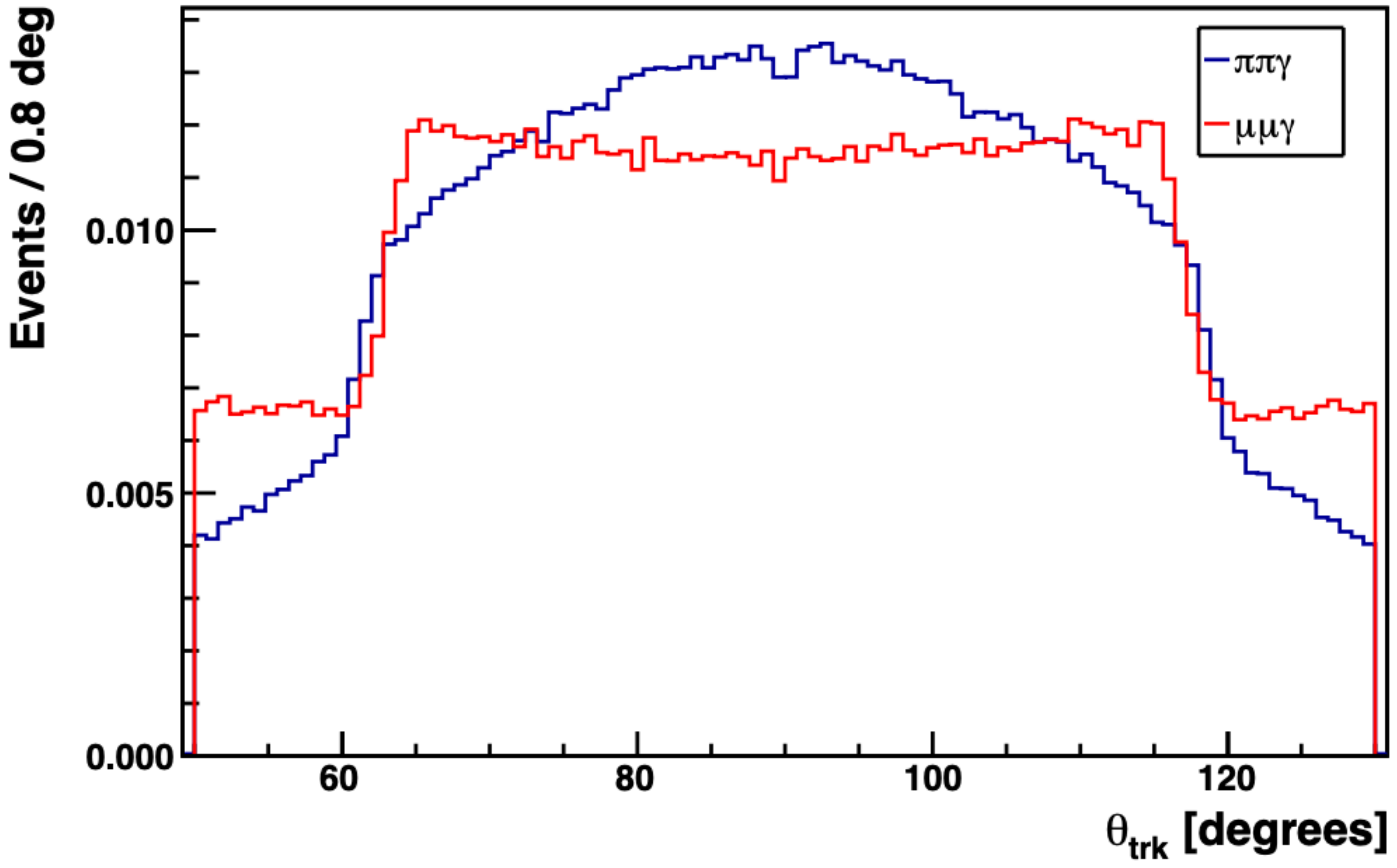
New Fit Variable : θ_{trk}

- Background fit can in principle be performed on **any variable** $\longrightarrow$ M_{trk} was chosen for its good separation between $\pi^+\pi^-\gamma$ and $\mu^+\mu^-\gamma$.
- Considering new fit variables can increase **confidence** in result and possibly increase **precision**.
- New variable: polar angle of charged particles θ_{trk} has been studied as a fit variable.



- Different distribution due to different spin of π and μ.
- Less separation compared to M_{trk}.

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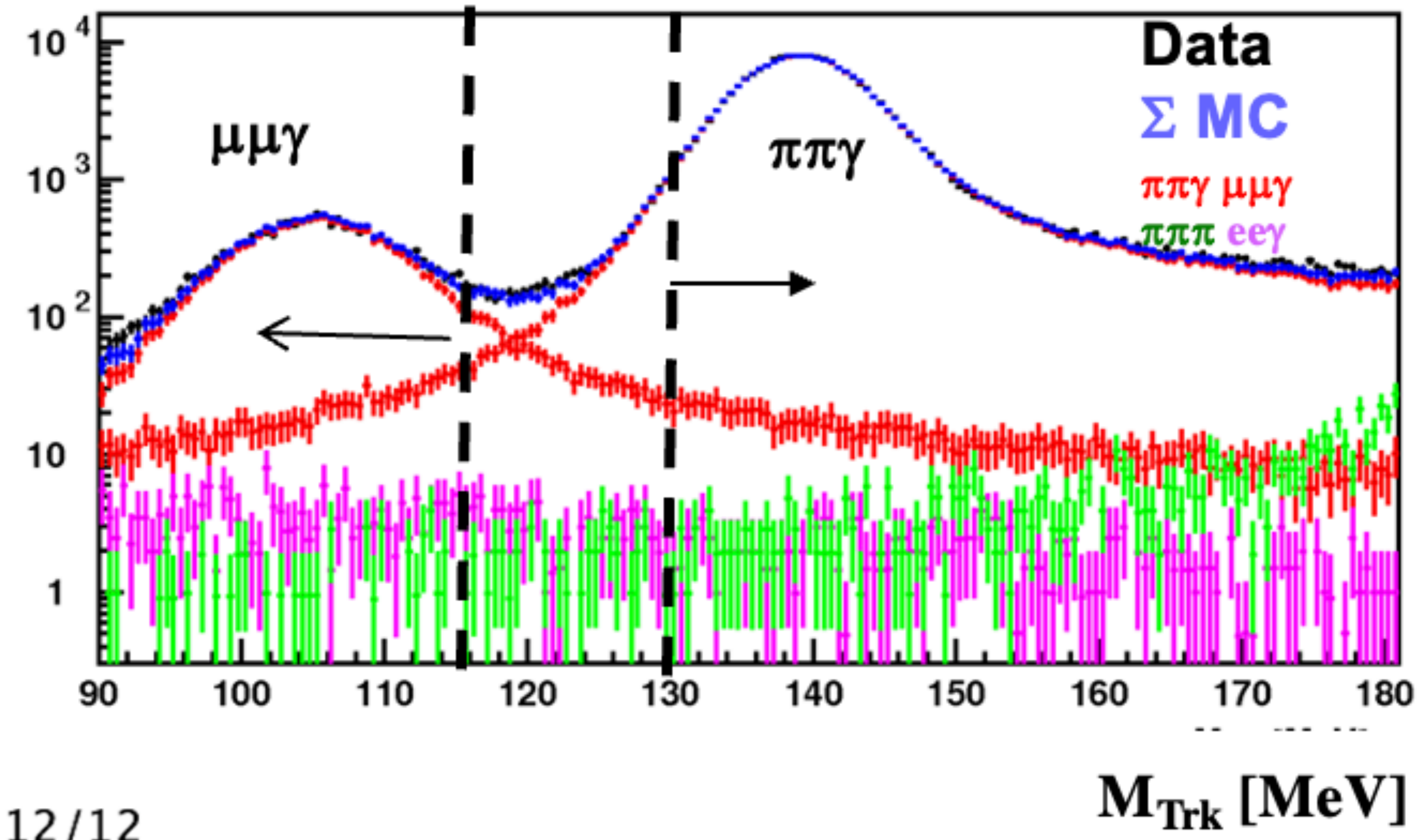
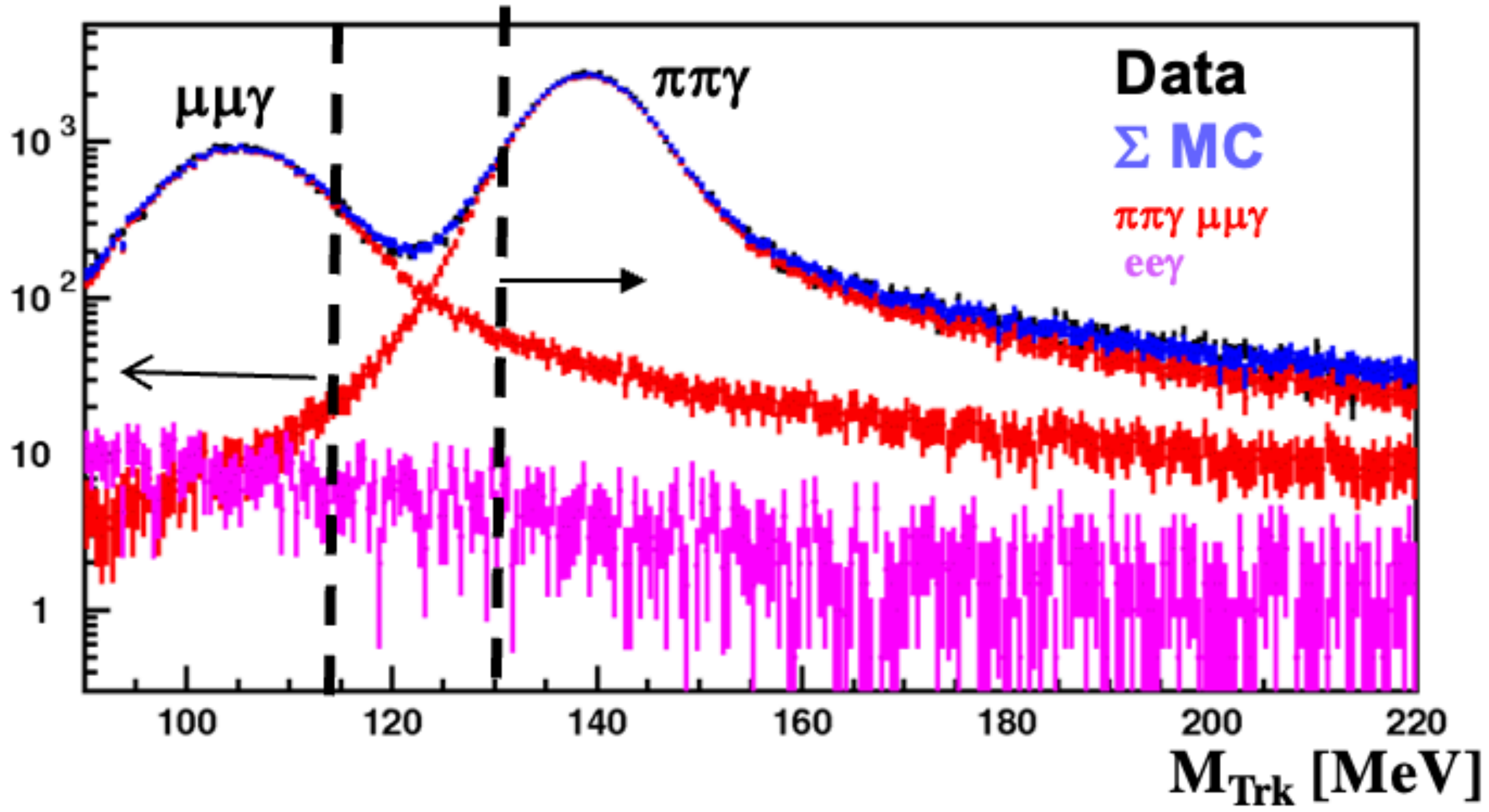
Background:

Main backgrounds estimated from MC shapes fitted to data distribution in M_{Trk} ($\pi\pi\gamma/\mu\mu\gamma$, $\pi\pi\pi$, $ee\gamma$)

$0.60 < M_{\pi\pi}^2 < 0.62$ GeV^2, χ^2/ndof = 158/180

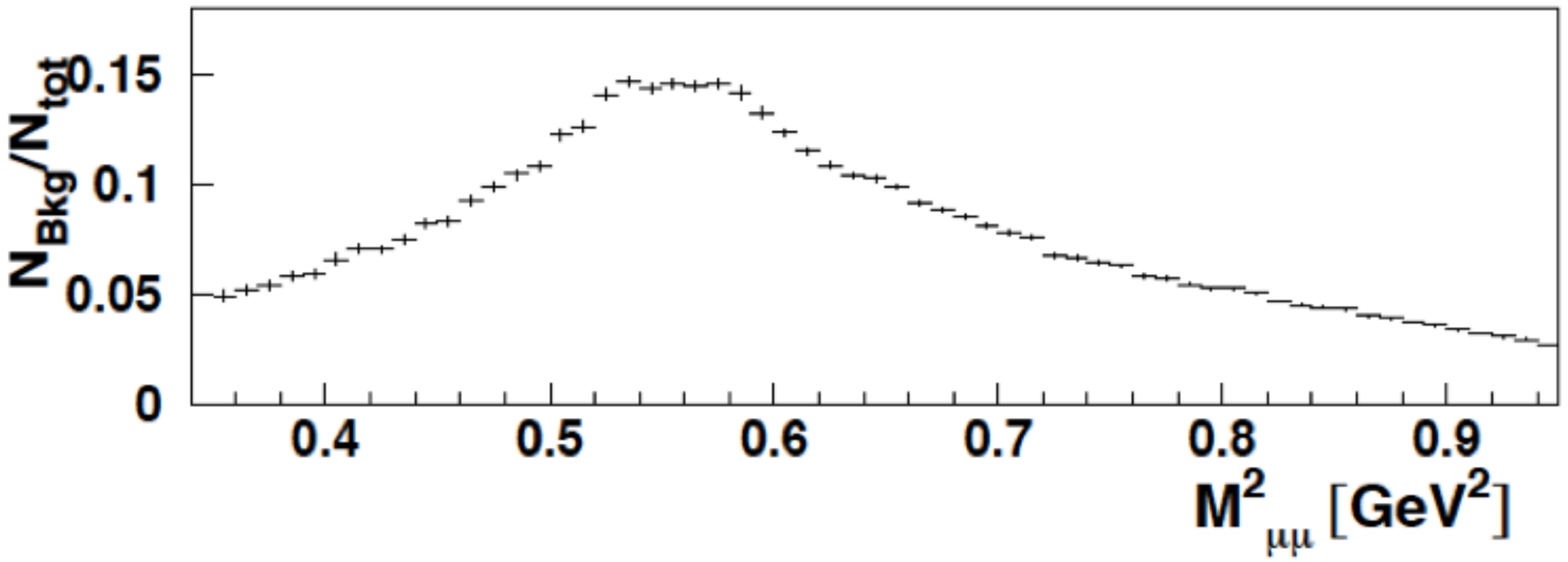


$0.84 < M_{\pi\pi}^2 < 0.86$ GeV^2 χ^2/ndof = 179/258

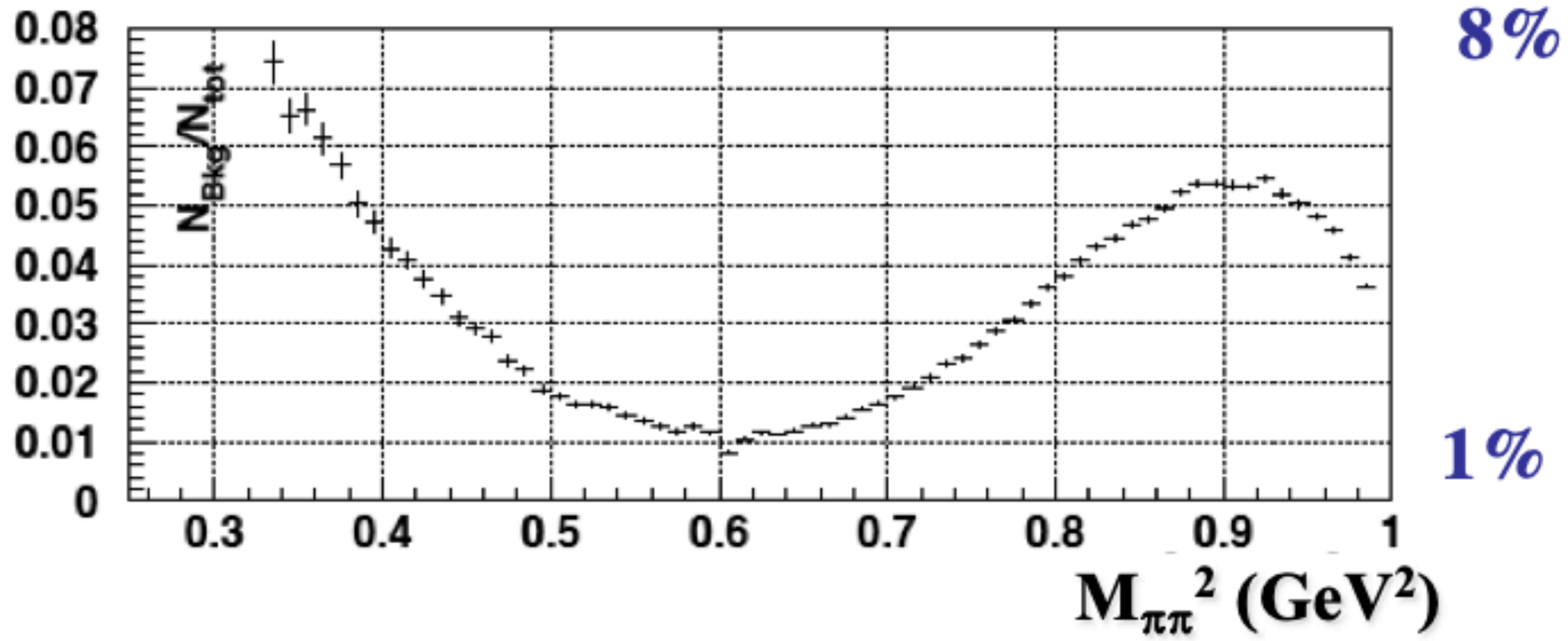


G. Venanzoni – CSN1– 4/12/12

Tot % bckg to $\mu\mu\gamma$



Tot % bckg to $\pi\pi\gamma$



- Systematic error on $\mu\mu\gamma$ due to background~1% in the ρ peak

π/μ separation: control of ππγ M_{TRK} tail

- A careful work has been done to achieve a control of ~1% in the muon selection, especially ~0.6 GeV^2 (ρ peak) where π/μ ~10.
- ππγ % background to μμγ signal (M_{TRK}<115 MeV) is ~15% at ρ peak
- ➔ ππγ M_{TRK} tail in the μμγ region must be well under control.
- ππγ M_{TRK} tail tuned using $\phi\to\pi^+\pi^-\pi^0$ control sample.
- Excellent agreement on M_{TRK} (ππγ and μμγ) distributions