LEVERHULME TRUST

Theory Initiative - September 2024

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

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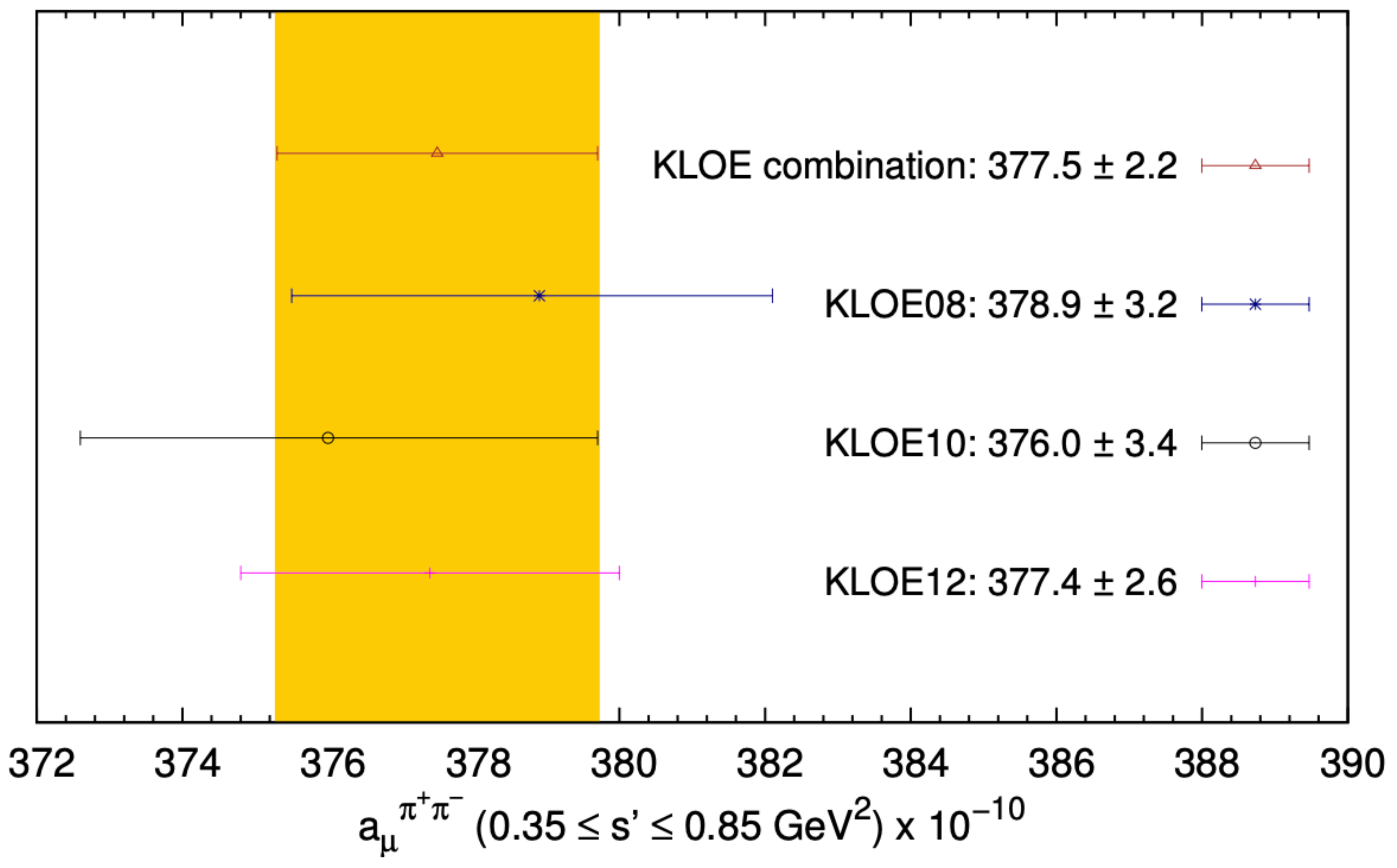
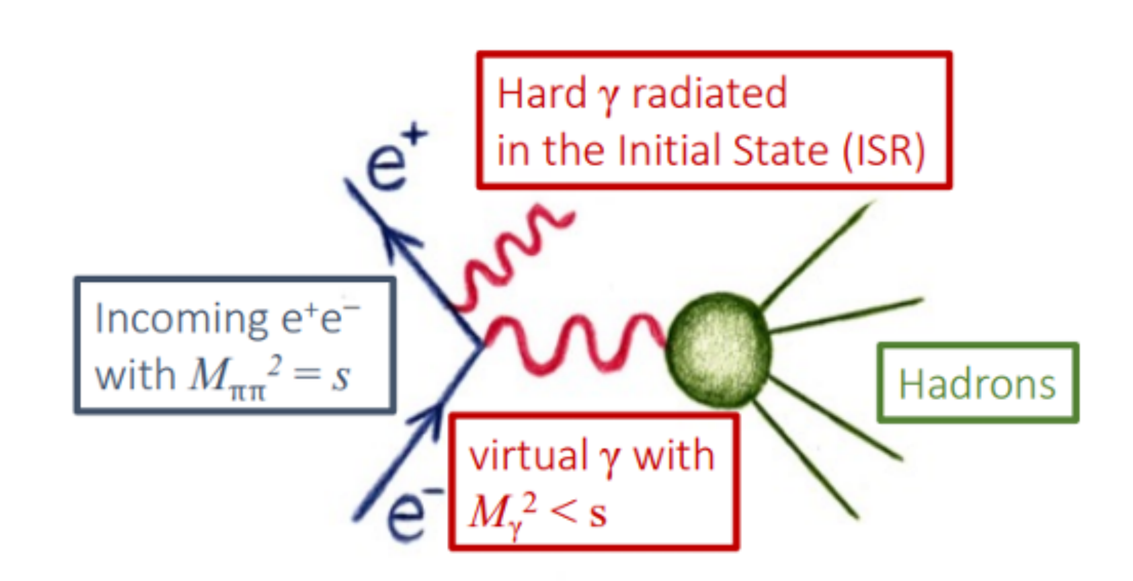
Overview

- **In this talk:**
  - Current landscape of muon anomaly a_μ
  - DAϕNE and the KLOE detector
  - KLOE08, KLOE10, KLOE12 analyses and results
  - New KLOE analysis (KLOE23) and its goals
  - Current work on:
    - Tracking
    - Blinding
    - Background Subtraction
    - Monte Carlo simulation
  - Look to future work to be done to produce an analysis result

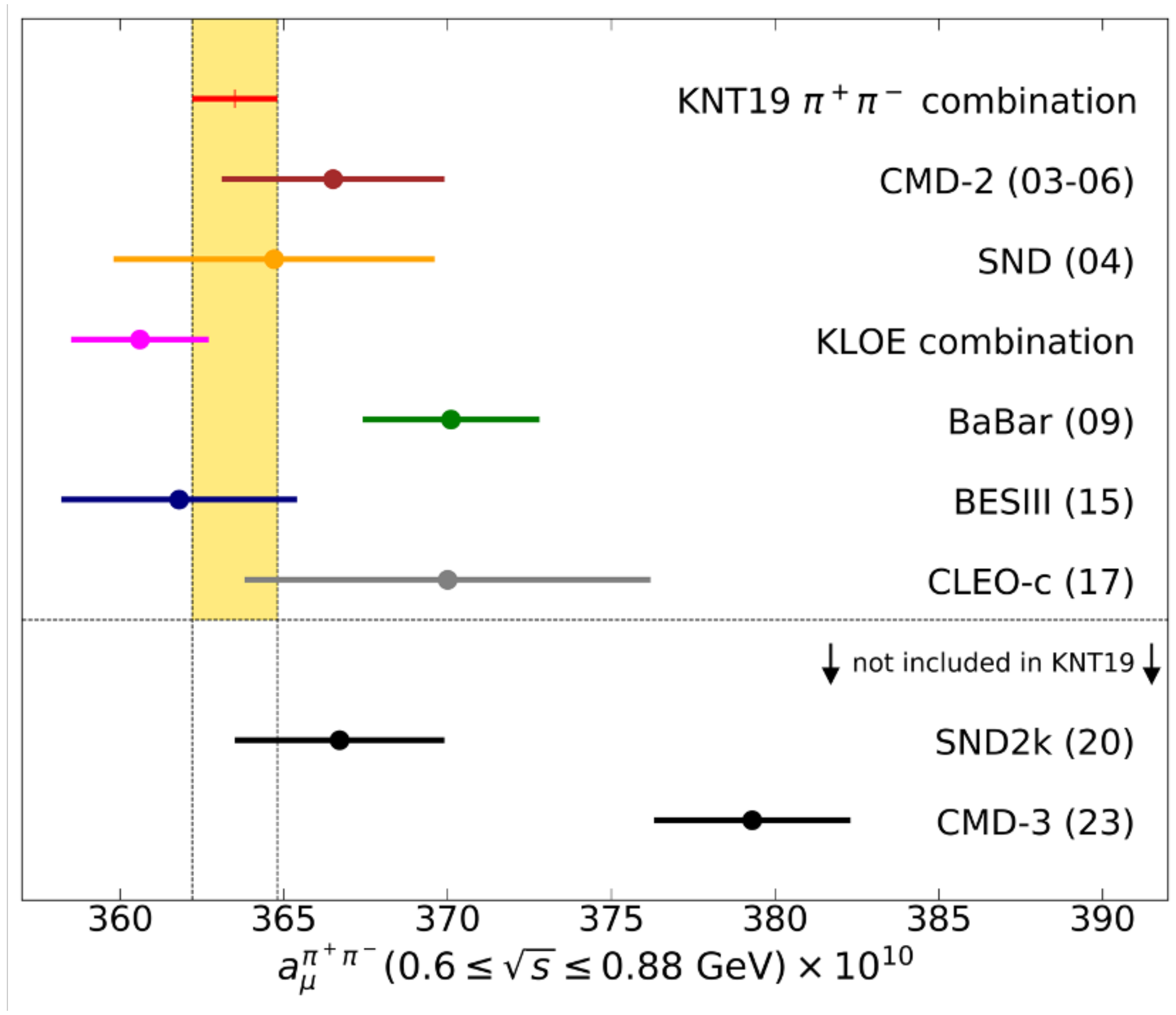


Measurement of a_μ

- 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

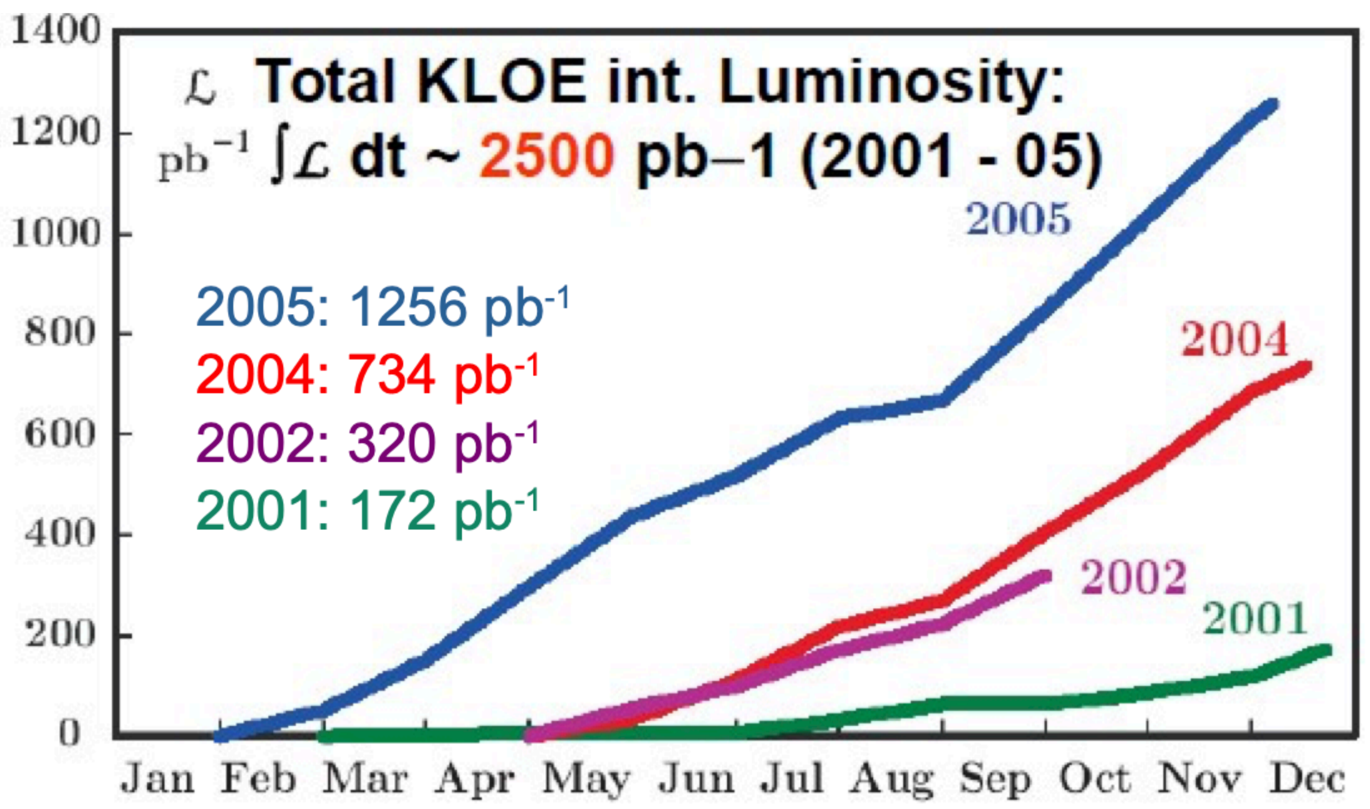


- A long standing tension ($\simeq 2.8\sigma$) exists between KLOE cross section measurements and BaBar
- New CMD-3 $e^+e^- \rightarrow \pi^+\pi^-$ cross section measurement is in tension with both BaBar ($\simeq 2.3\sigma$) and KLOE ($\simeq 5.1\sigma$)
- Combined theoretical prediction for the dispersive approach is limited by tensions between KLOE and BaBar measurements. Even without including CMD-3 measurement



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 $\sqrt{s} = 1\,\mathrm{GeV}$
- 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**

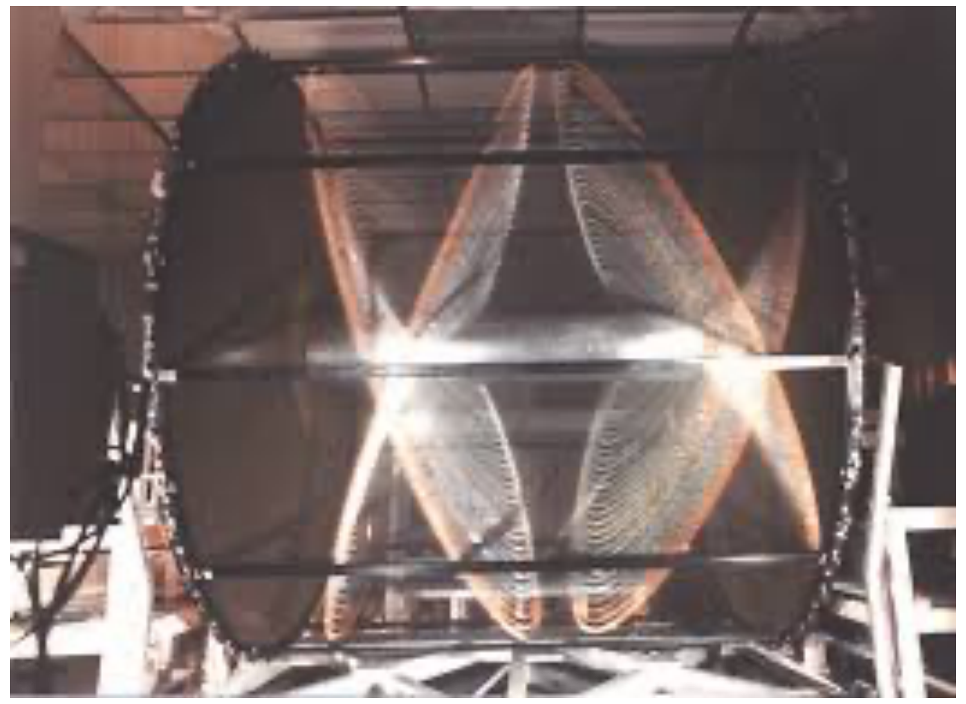


- This ongoing analysis aims to use **2004/2005 KLOE data** to carry out a new measurement. The ~1.7 fb^{-1} includes **~ 25 million $\pi\pi\gamma$ events** which have **never been used** before in such an analysis. 2006 off-peak data will be used for additional cross checks and systematic studies.

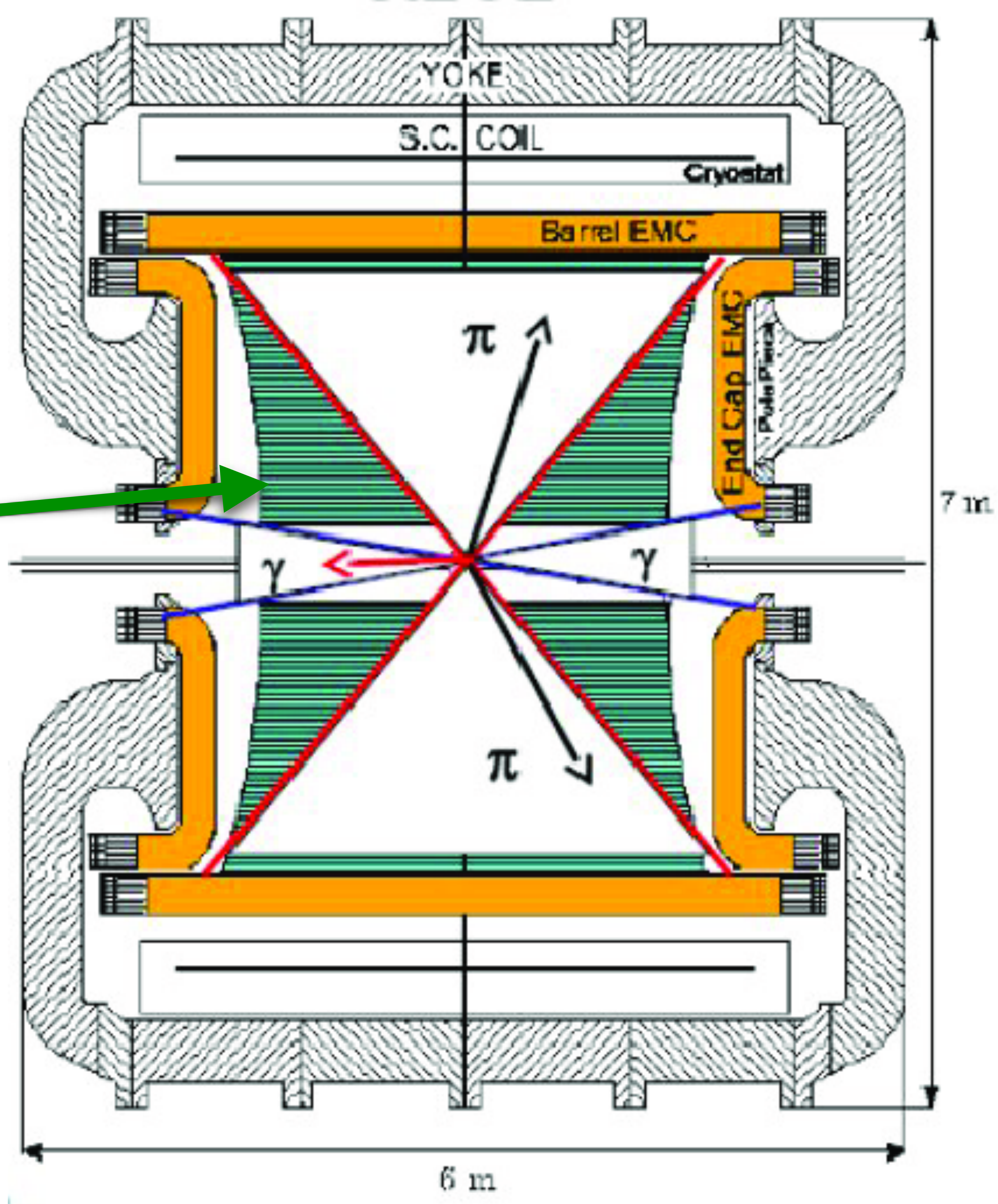
KLOE Detector

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 25cm in radius
  - Chamber is filled with **90% Helium and 10% isobutane**
  - DC is made up of over 50000 wires with a **field:sense ratio of 3:1** to make drift cells arranged in layers



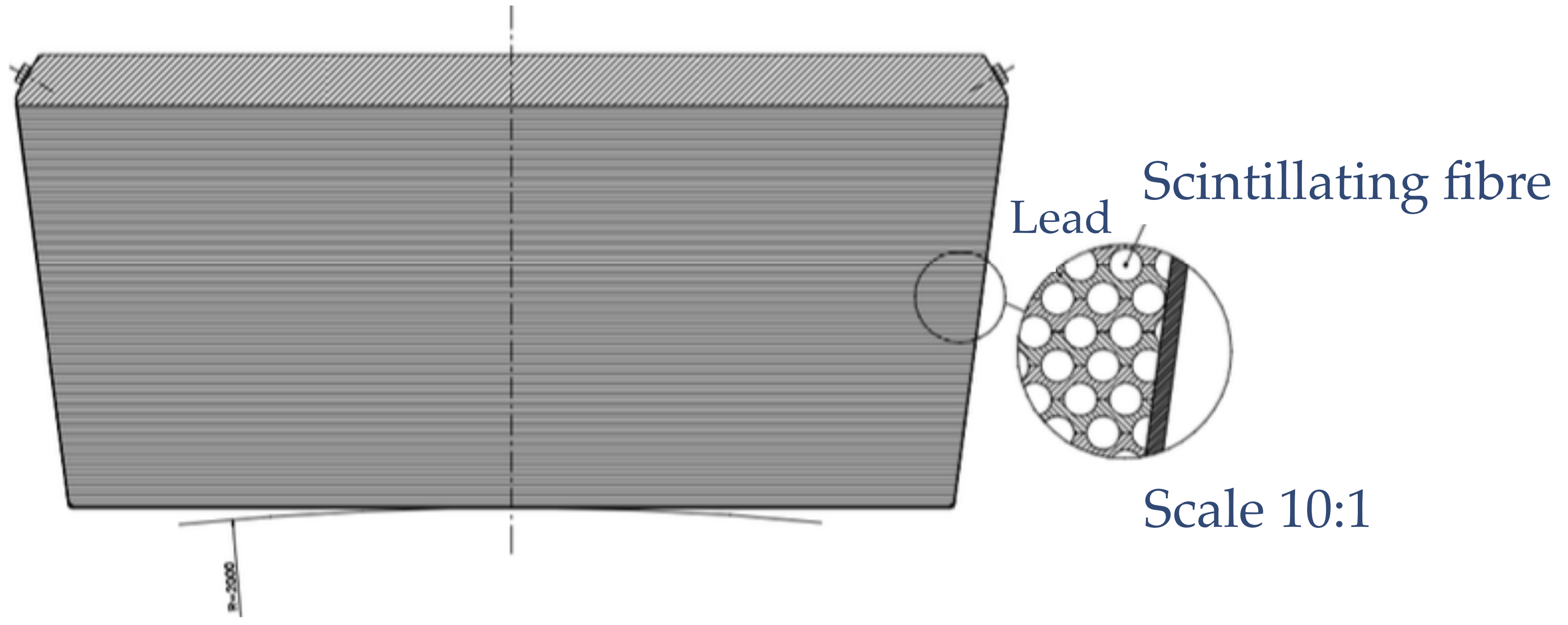
  - Wires in the same layer are parallel to each other and have the same stereo angle wrt to z-axis
  - Good resolution of the z-coordinate is achieved by varying the stereo angle of different layers
  - **Resolution:**
    - $\sigma_{xy} \approx 150\,\mu\text{m}$; $\sigma_z \approx 2\,\text{mm}$; $\sigma_{\text{vertex}} \approx 3\,\text{mm}$; $\delta p/p_T \approx 0.4\%$
    - 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.

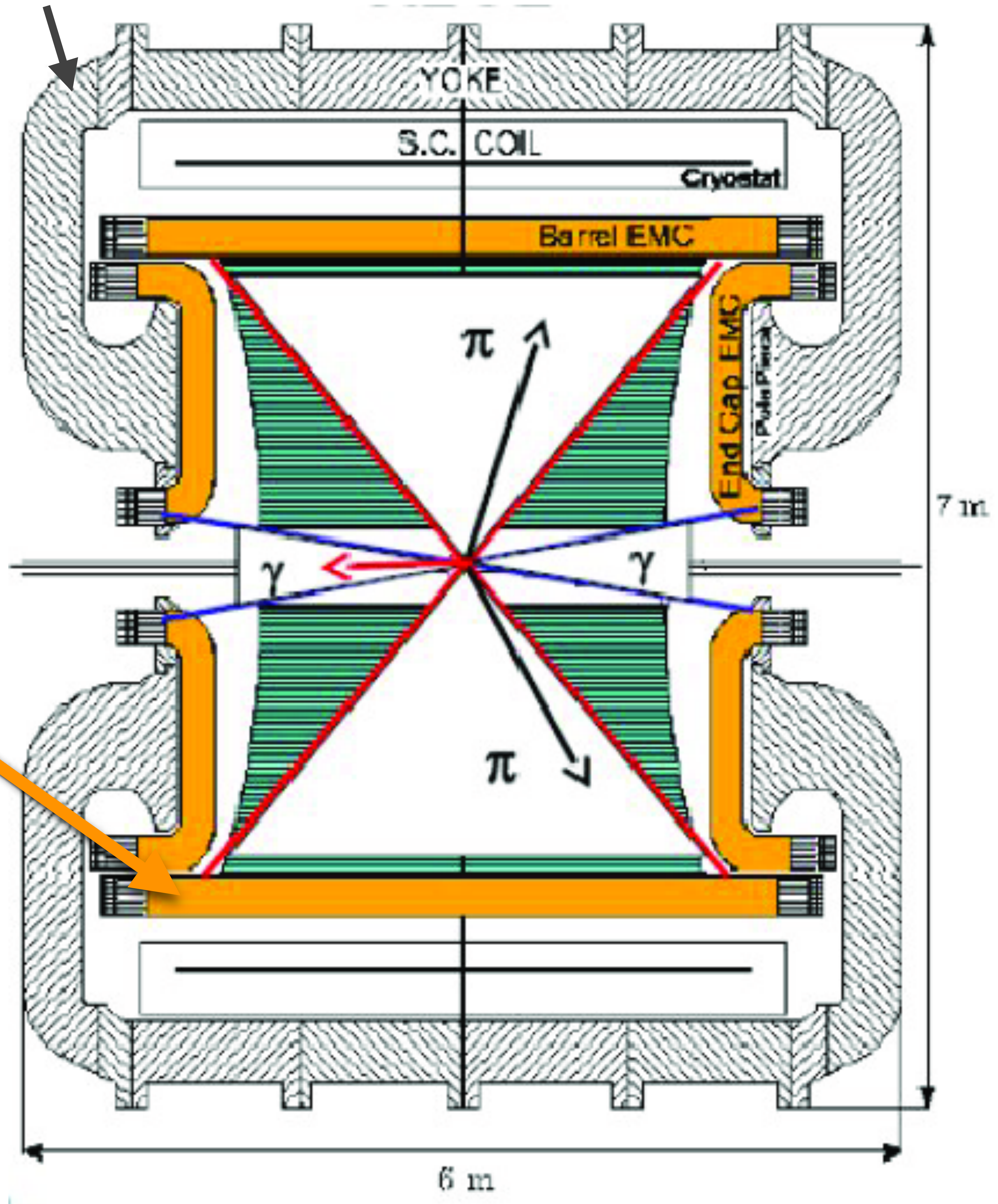
KLOE Detector - Calorimeter[2]

- **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.
  - Calorimeters are organised in **4.4 x 4.4** cm^2 **areas (cells) in five layers**
  - **Resolution:**
    - $\sigma_E/E = 5.7\,\%/\sqrt{E(GeV)}$; $\sigma_t(ps) = 5.4/\sqrt{E(GeV)} \oplus 140$;
  - **This calorimeter is now on the way to DUNE !**

0.52 T Magnet



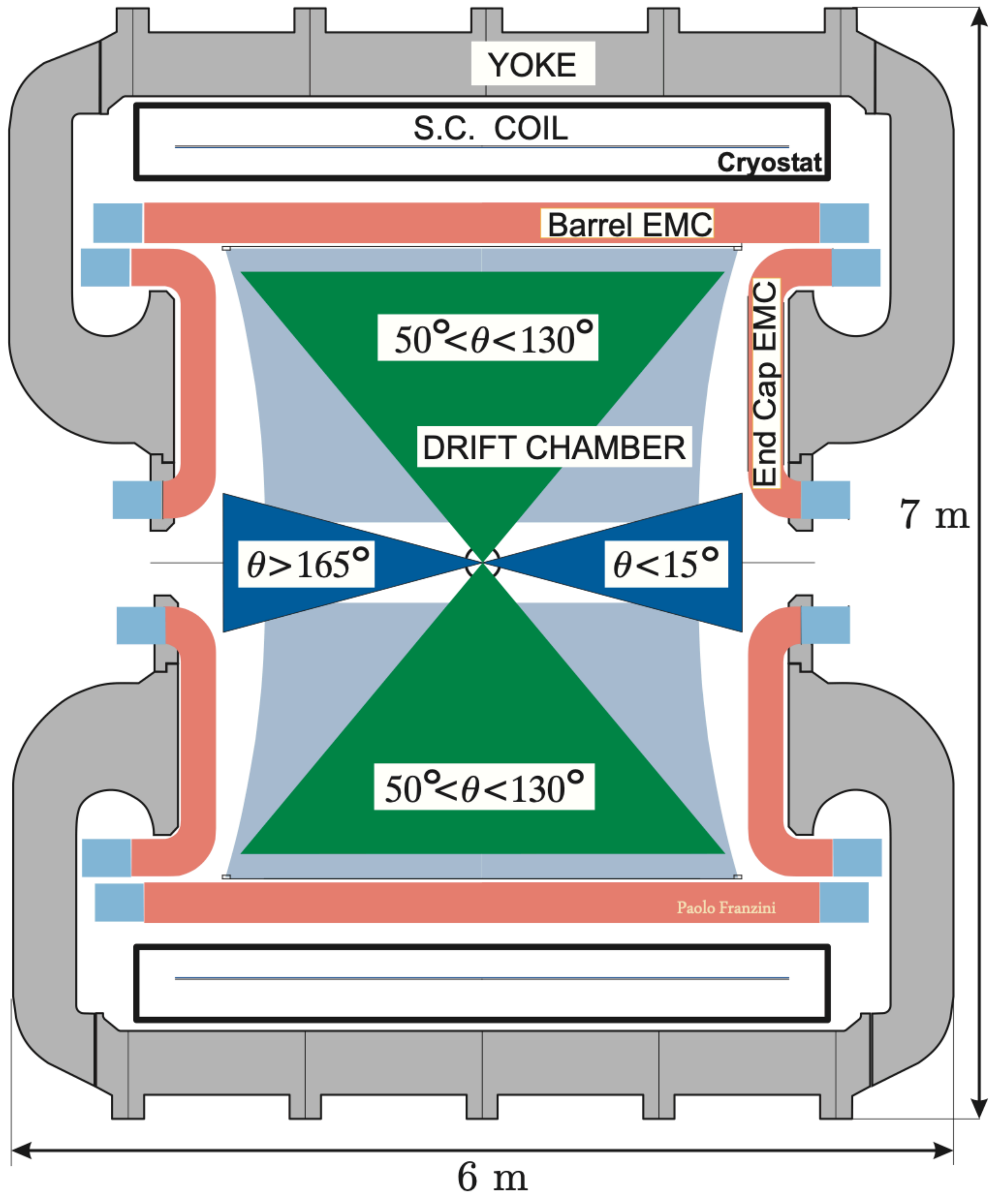
[2] Adinolfi, M., Ambrosino, F., Antonelli, A., et al. (2002). The KLOE electromagnetic calorimeter. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 482(1–2), 364-386. https://doi.org/10.1016/S0168-9002(01)01502-9.

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 suts:**
  - **2 pion tracks at large angles** $50° < \theta_\pi < 130°$
  - **small angle cuts:**
    - **photons at small angles** $\theta_{miss} < 15°$ **or** $\theta_{miss} > 165°$
    - photon momentum from kinematics: $\vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$
    - 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:

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

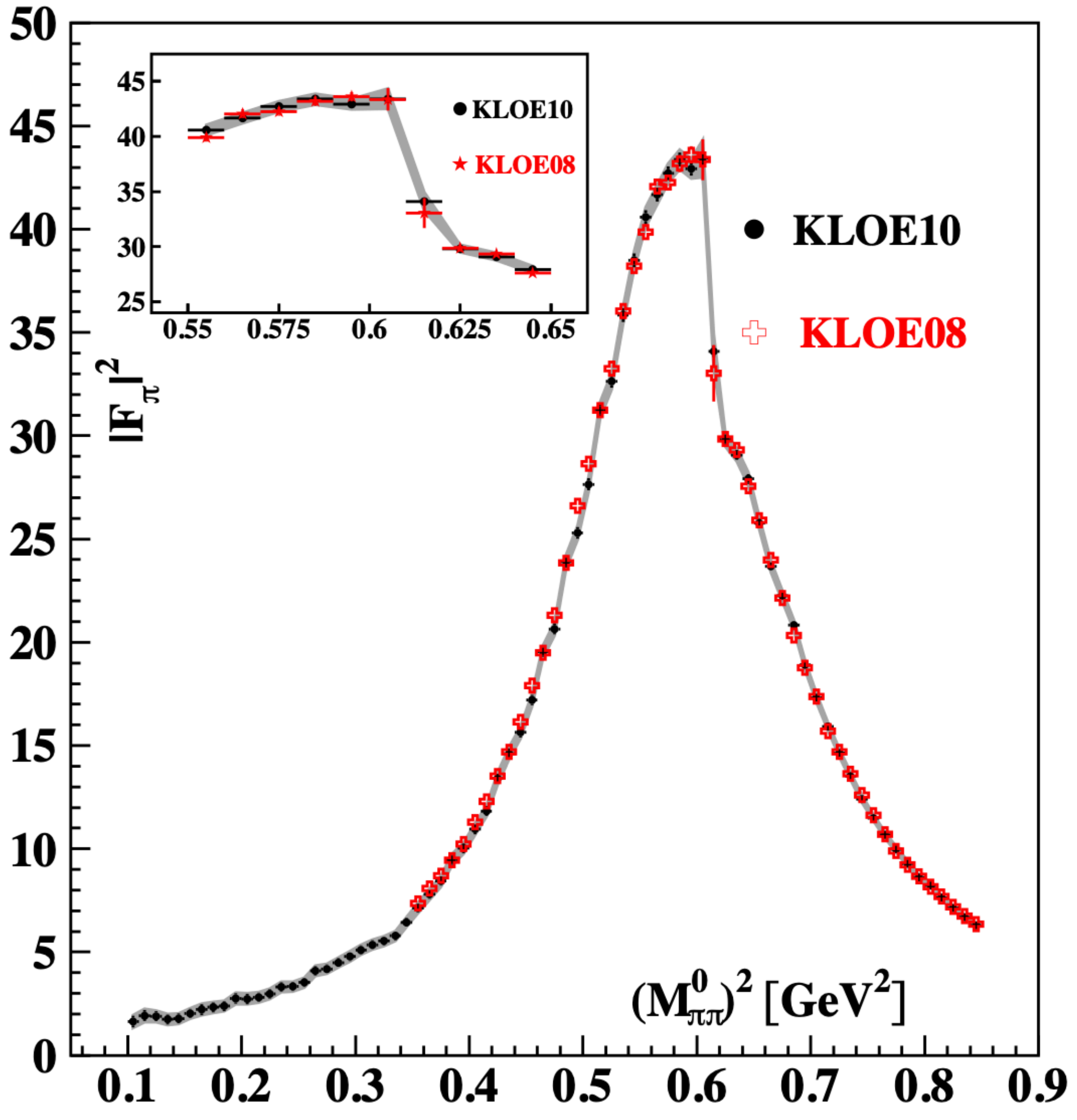
Radiator function

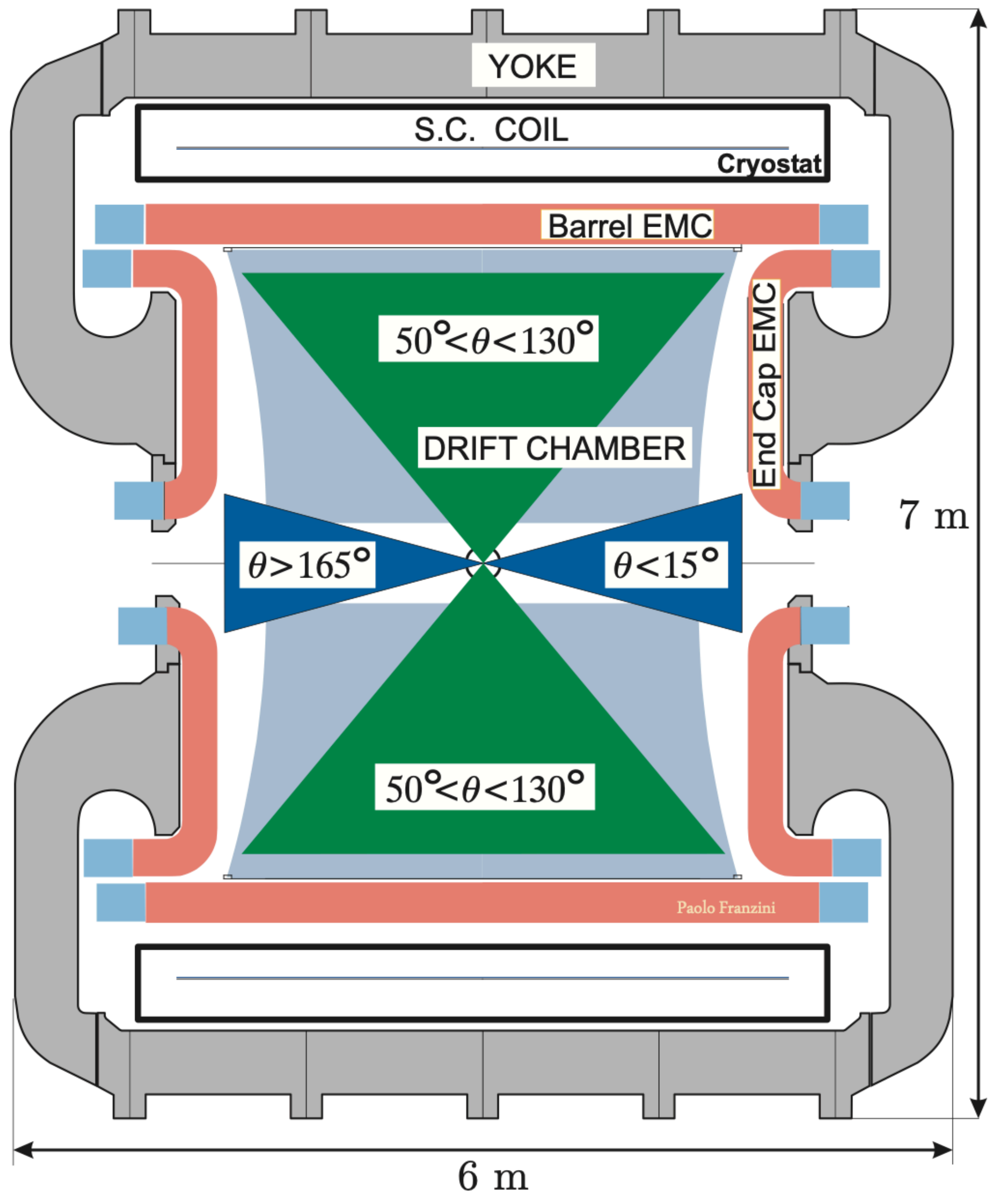
Observed Spectrum for $\pi\pi\gamma(\gamma)$ events
↓
(Level 3 Trigger)
↓
Offline filter corr.
↓
Background subtr.
↓
$M_{Trk} + \Delta E_{Miss}$ corr.
↓
Unfolding ($M^2_{Rec} \to M^2_{True}$)
↓
Corr. for border eff. in Acc.
↓
π/e likelihood + TCA corr.
↓
Tracking corr.
↓
Trigger corr.
↓
Unshifting ($M^2_{\pi\pi} \to M^2_{\gamma^*}$)
↓
Acceptance θ_π corr.
↓
Luminosity corr.
↓
Acceptance θ_Σ corr.
↓
Division by Radiator H
↓
Corr. for vac. pol.
↓
$\sigma_{\pi\pi}$ KLOE08

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**

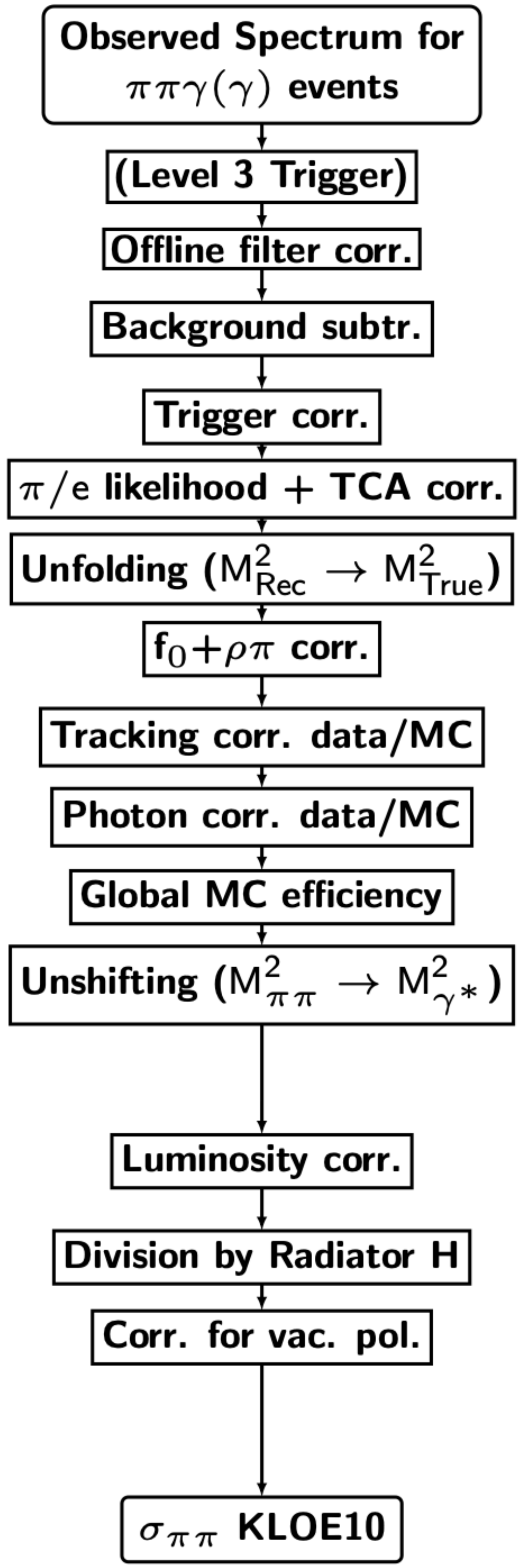




In order to measure $\sigma_{\pi\pi}(s_{\pi\pi})$ while operating at fixed $\sqrt{s}$ **Initial State Radiation** is used:

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

Radiator function



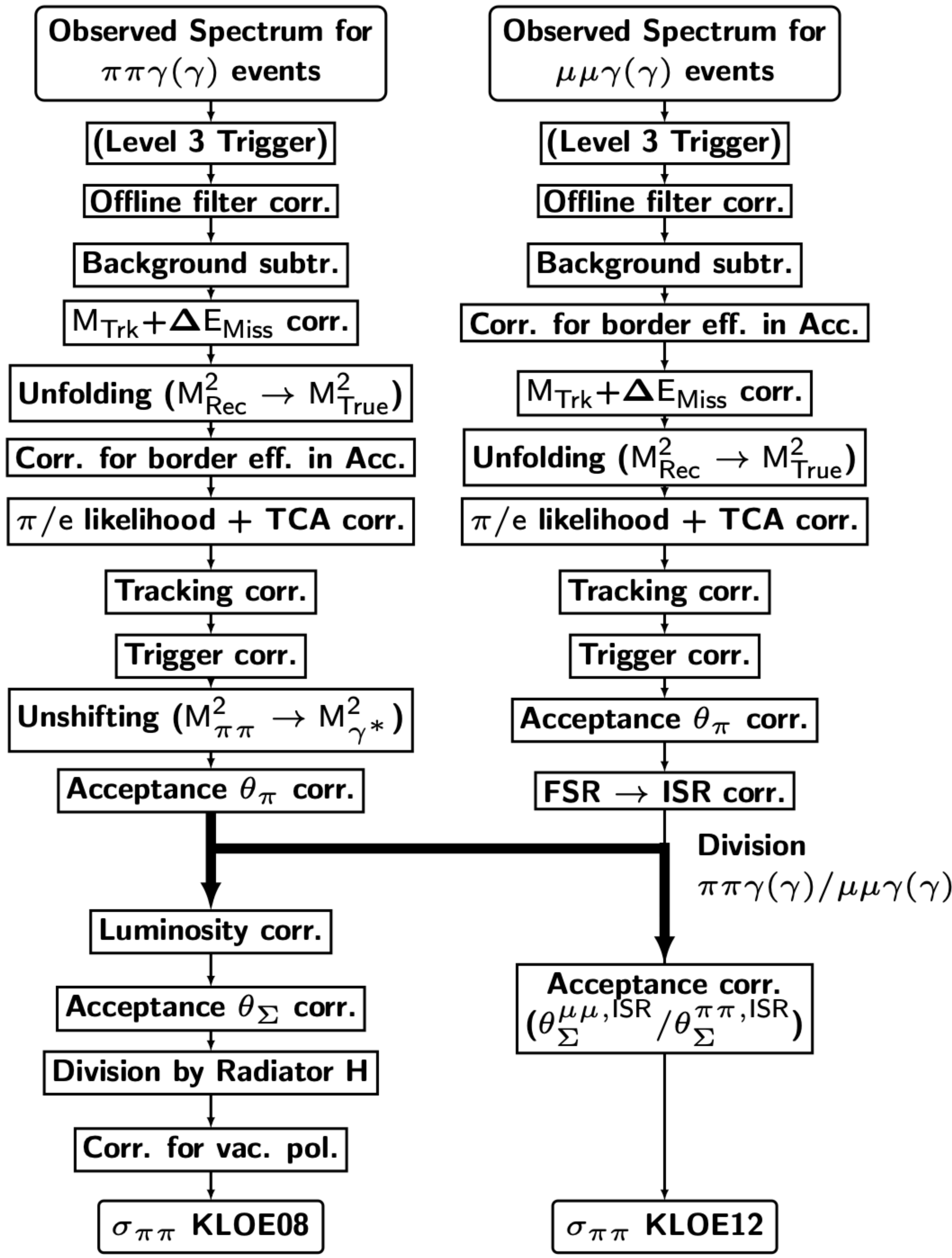
KLOE12 measurement

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

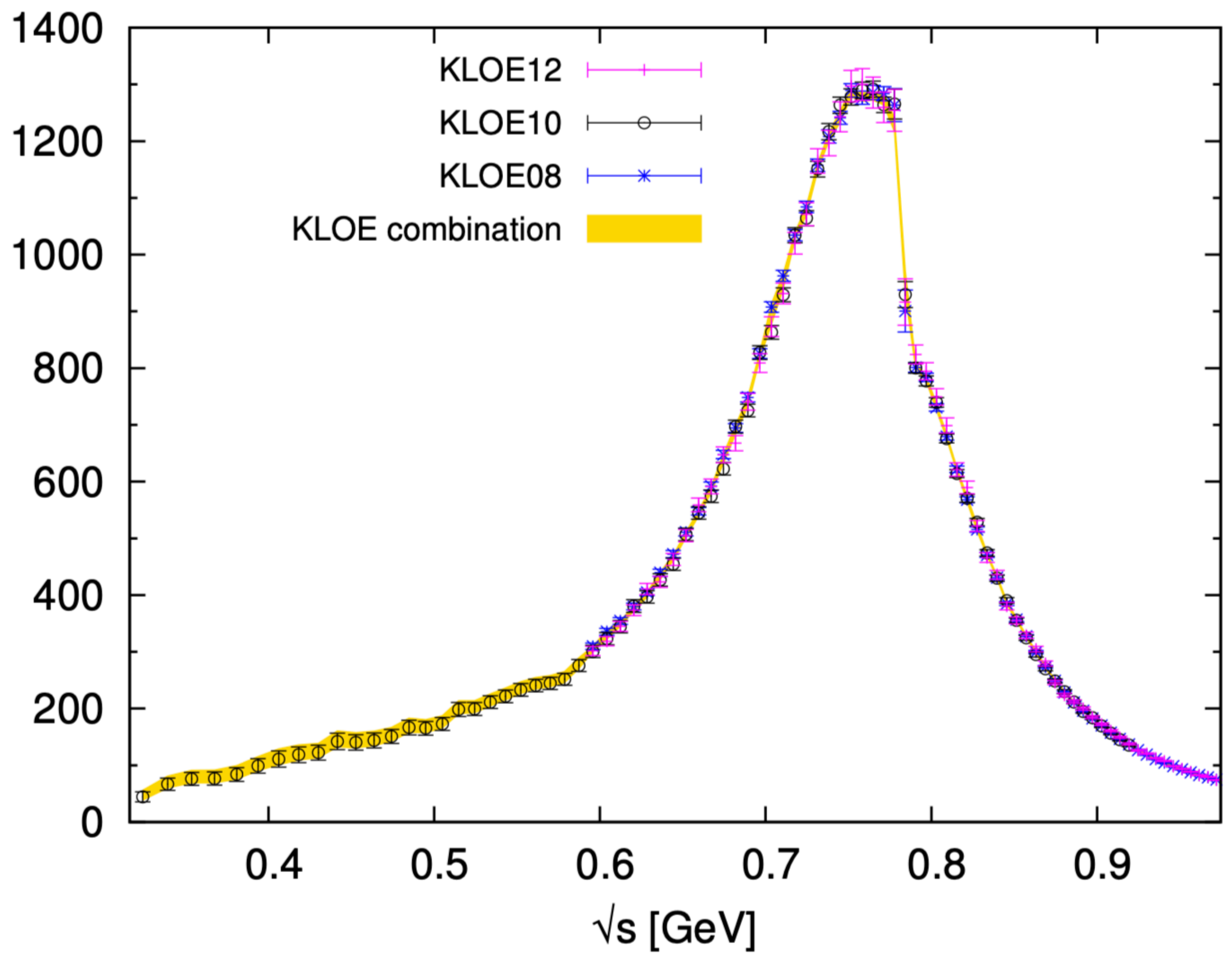
KLOE08 + different normalisation:

- **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



KLOE measurements



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.**

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

The new (KLOE23) measurement

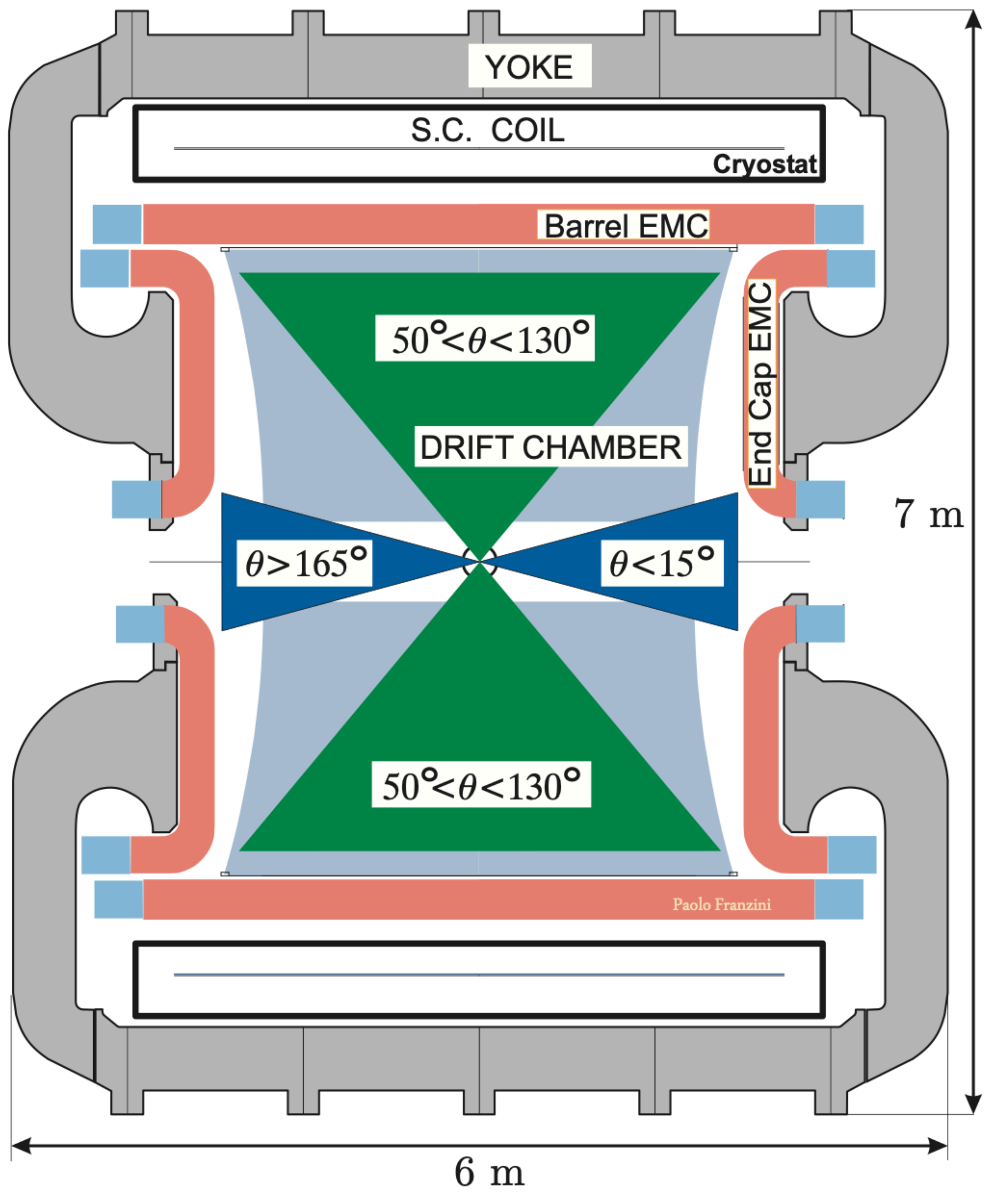
KLOE23 analysis

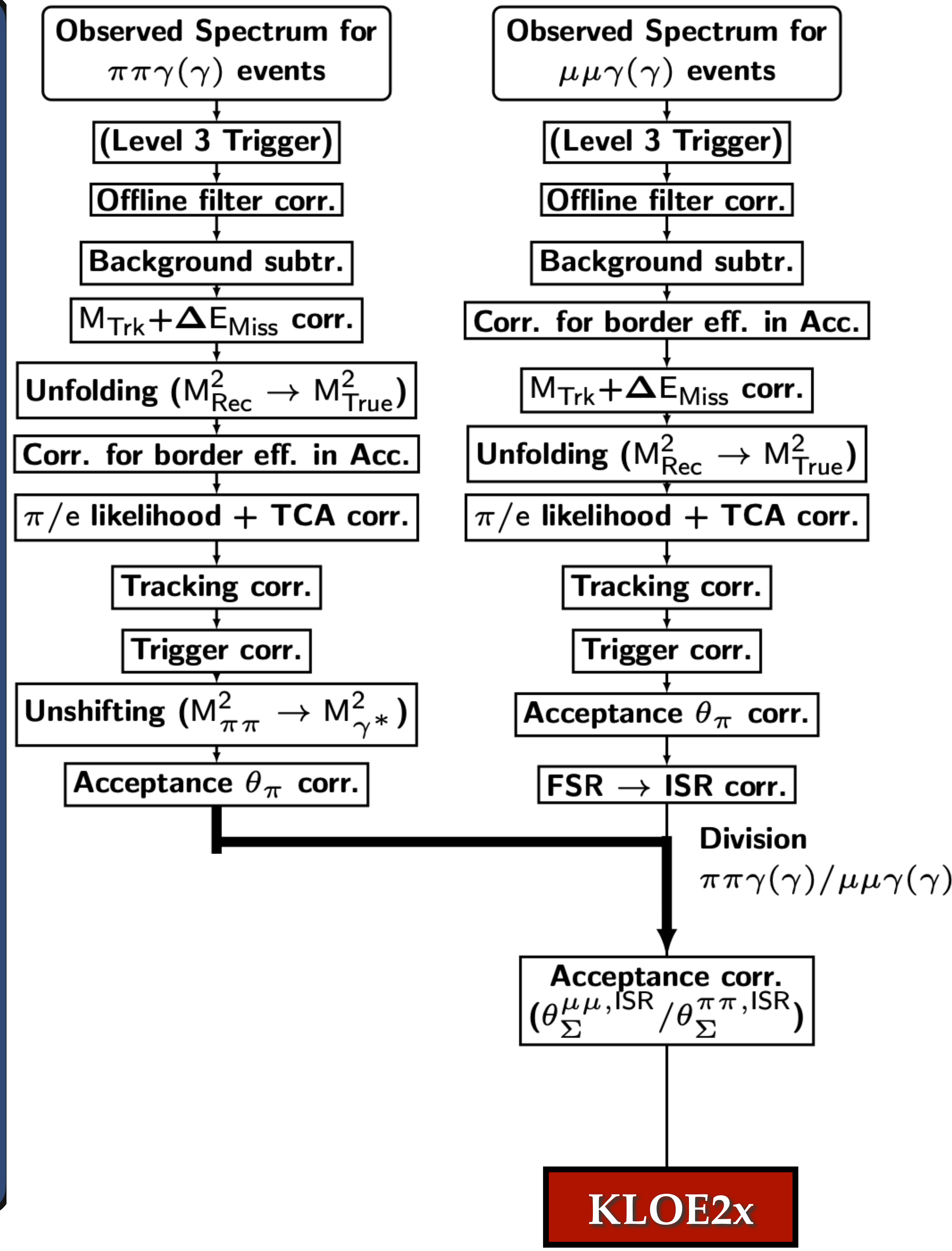
- 60 points between 0.35 and 0.95 GeV^2
- based on 1.7 fb^{-1}data taken in 2004/2005.
- **Selection cuts:**
  - **2 pion (muon) tracks at large angles**

    $50^\circ < \theta_{\pi,\mu} < 130^\circ$
  - **small angle cuts:**
    - **photons at small angles $\theta_{miss} < 15^\circ$ or**

      $\theta_{miss} > 165^\circ$
    - photon momentum from kinematics:

      $\vec{p}_{\text{miss}} = -(\vec{p}_+ + \vec{p}_-)$
  - normalisation to $\mu\mu\gamma$
- **the above will make the basis of the KLOE23 analysis however group is prepared to make modifications if desired.**





The new (KLOE23) measurement

KLOE23 analysis

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

KLOE12: $0.3\%_{stat} \oplus 0.2\%_{th} \oplus 0.7\%_{syst} \Rightarrow \sim 0.8\%_{tot}$

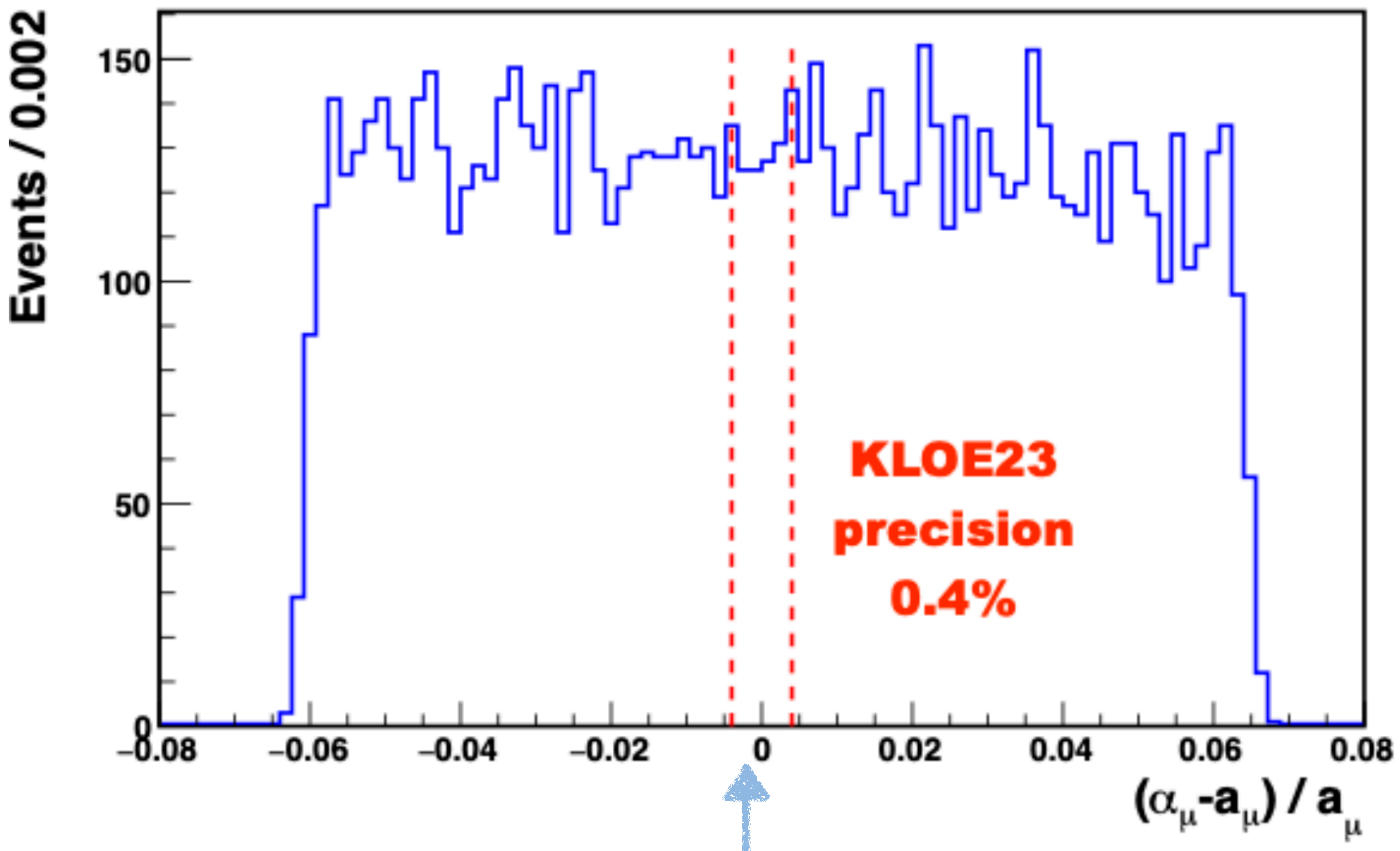
KLOE23(goal): $0.1\%_{stat} \oplus 0.2\%_{th} \oplus 0.3\%_{syst} \Rightarrow \sim 0.4\%_{tot}$

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

	KLOE12	KLOE23
Syst Errors (%)	$a_\mu^{\pi\pi}$ ratio	$a_\mu^{\pi\pi}$ 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

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 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**
- For the blinding 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 $a_{\pi\pi} \propto \int ds \ldots \sigma_{\pi\pi}(s)$ by 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 will be 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.

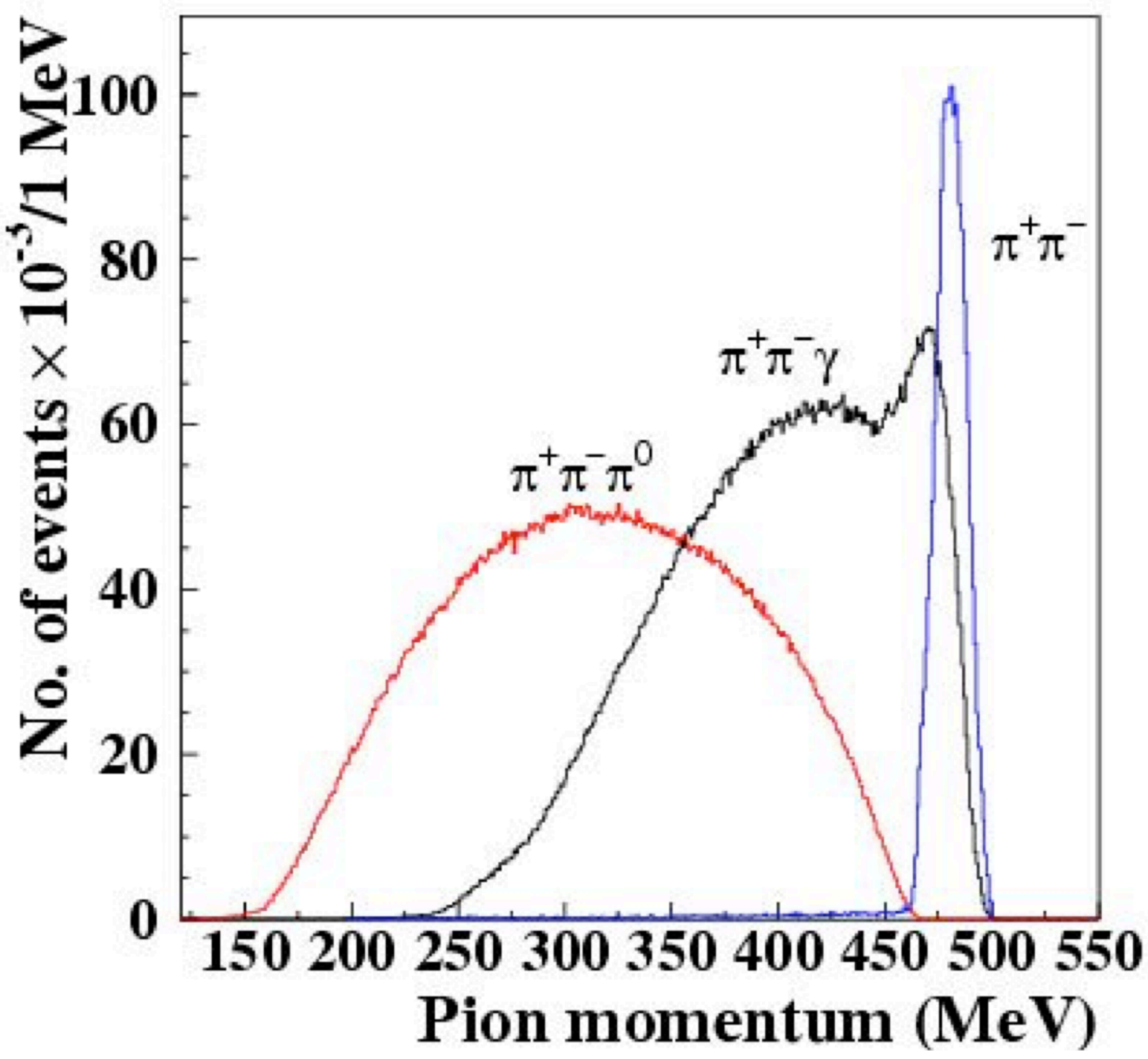
Unblinding will be performed only at the completion of the analysis and with the agreement of all the analysers involved.

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

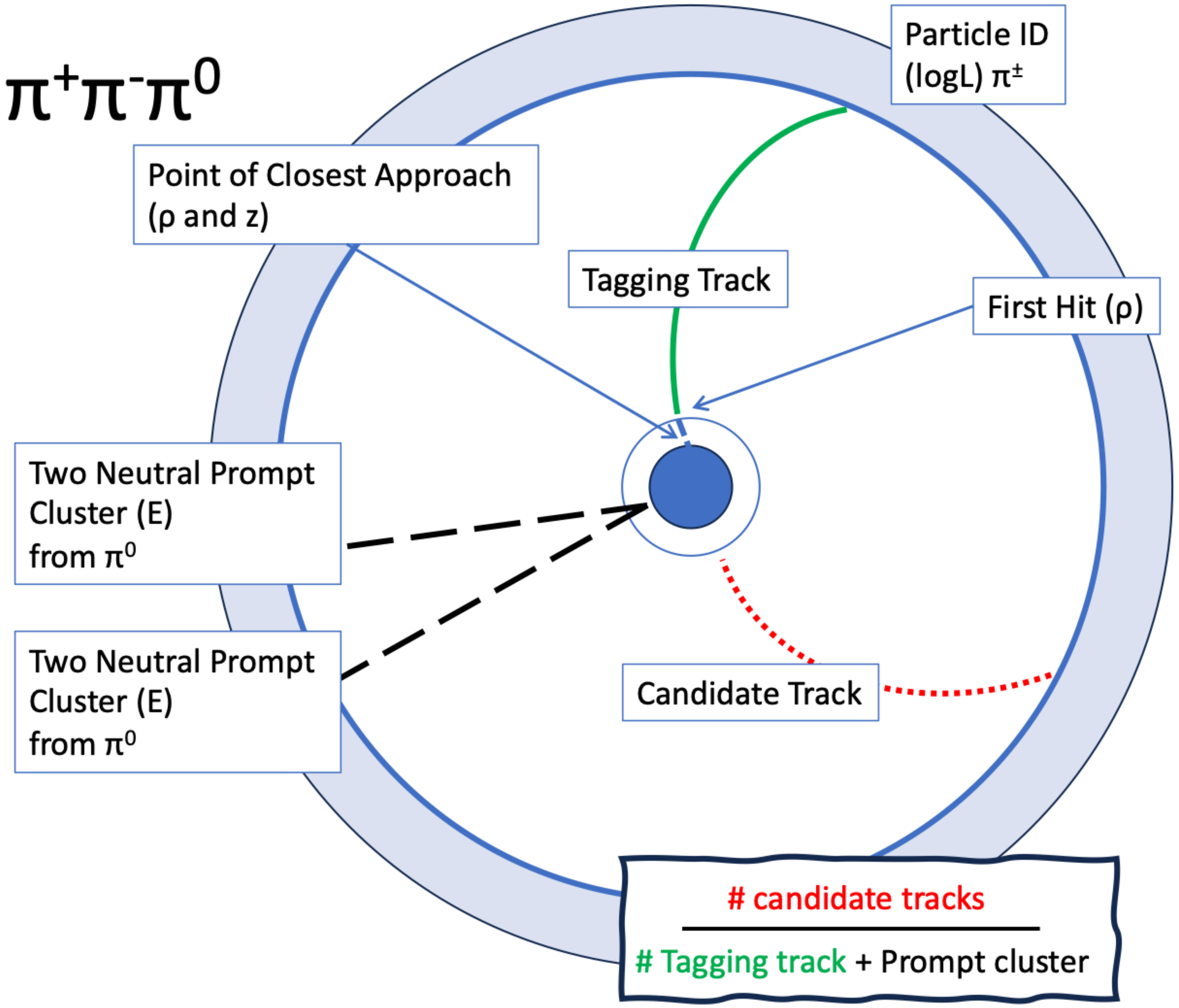
This blinding procedure like many others **assumes a level of honesty** from analysers. Analysers agree not to look at the pion form factor directly or indirectly before the unblinding.

Tracking

- Tracking will be **conducted on the working root-tuples**
- Previous analyses have provided a foundation for selections and tracking efficiency. **In KLOE23 these will be studied and updated with improvements made**
- Selections:
  - $\pi^+\pi^-\pi^0$
  - $\pi^+\pi^-$
  - $\pi\pi\gamma$ or $\mu\mu\gamma$
- These selections result in different momentum regions being covered.
- The *old* selection procedure will be subsequently detailed …

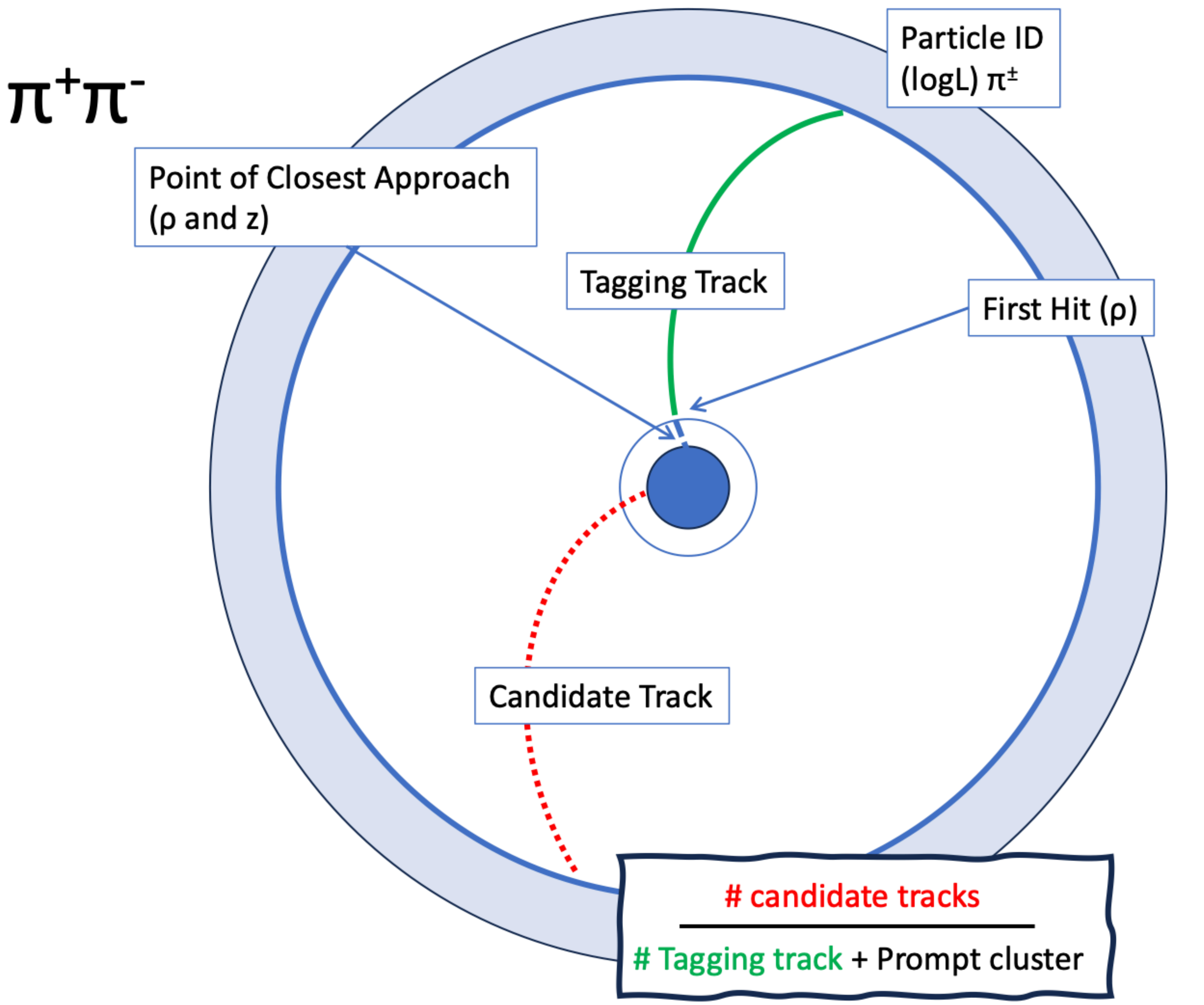


Tracking



- **$\pi^+\pi^-\pi^0$ 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:**
  - 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)*

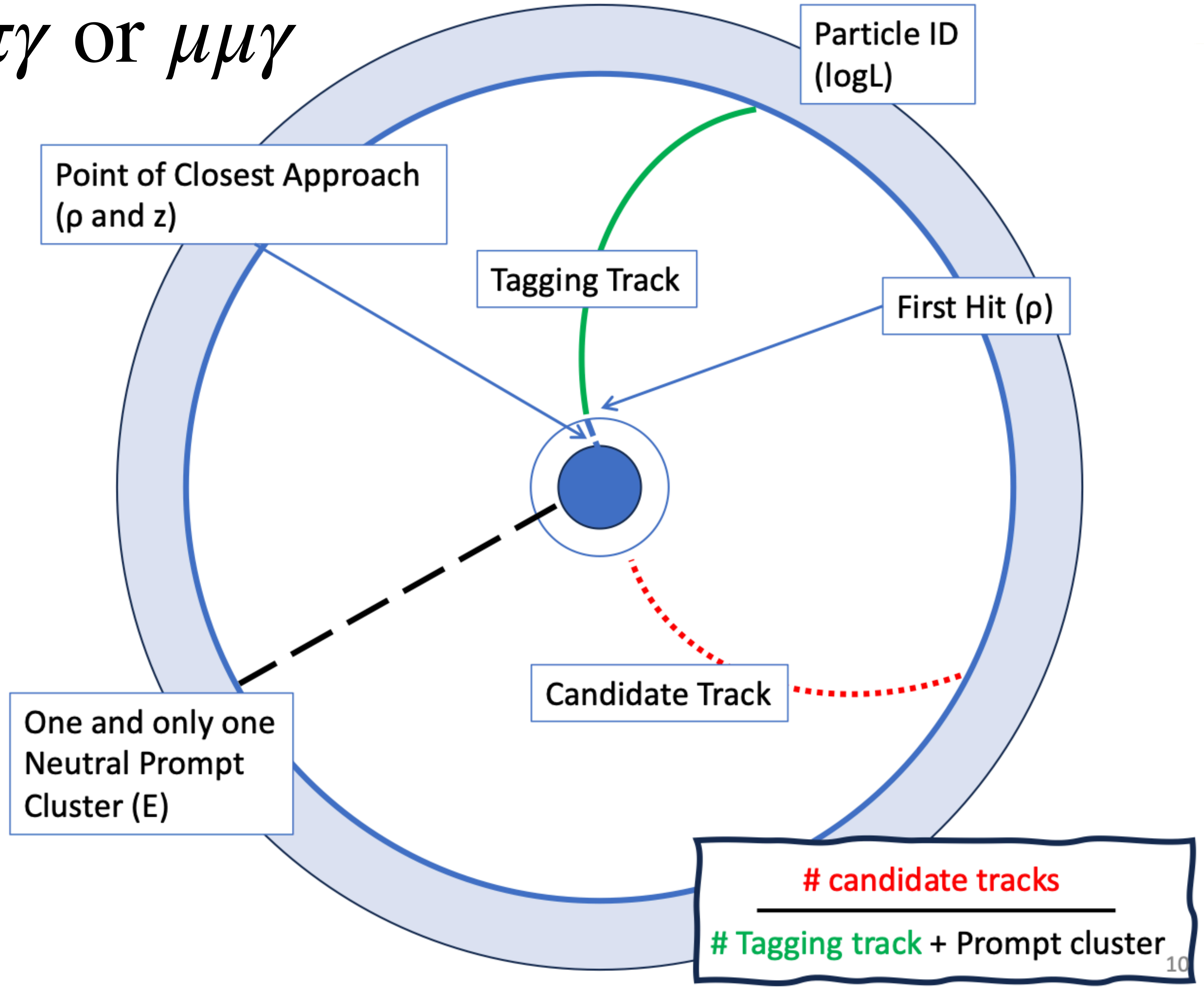
Tracking



- **$\pi^+\pi^-$ 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:**
  - 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

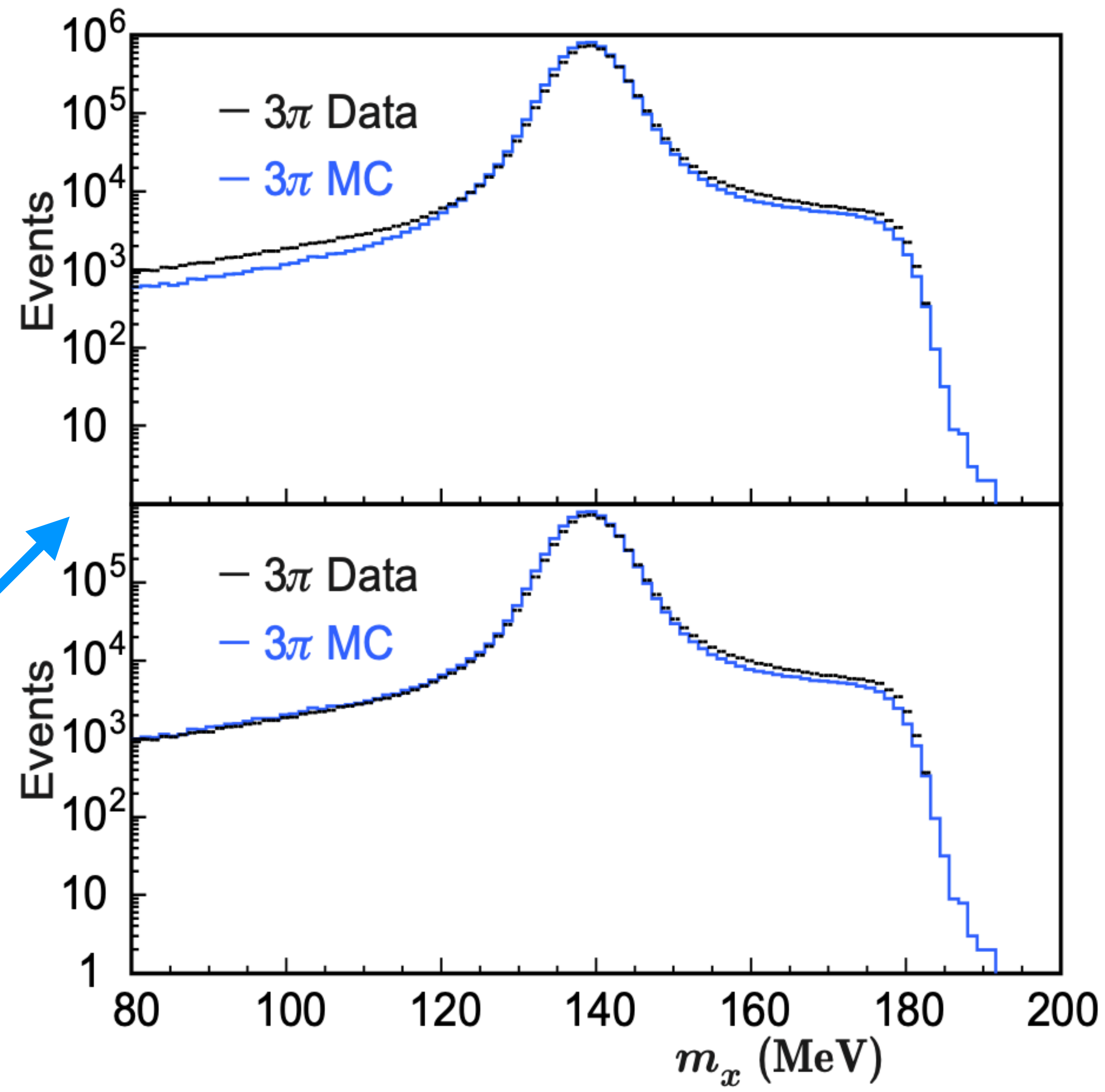
$\pi\pi\gamma$ or $\mu\mu\gamma$



- $\pi\pi\gamma$ 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:**
  - 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 $\mu^-(\mu^+)$

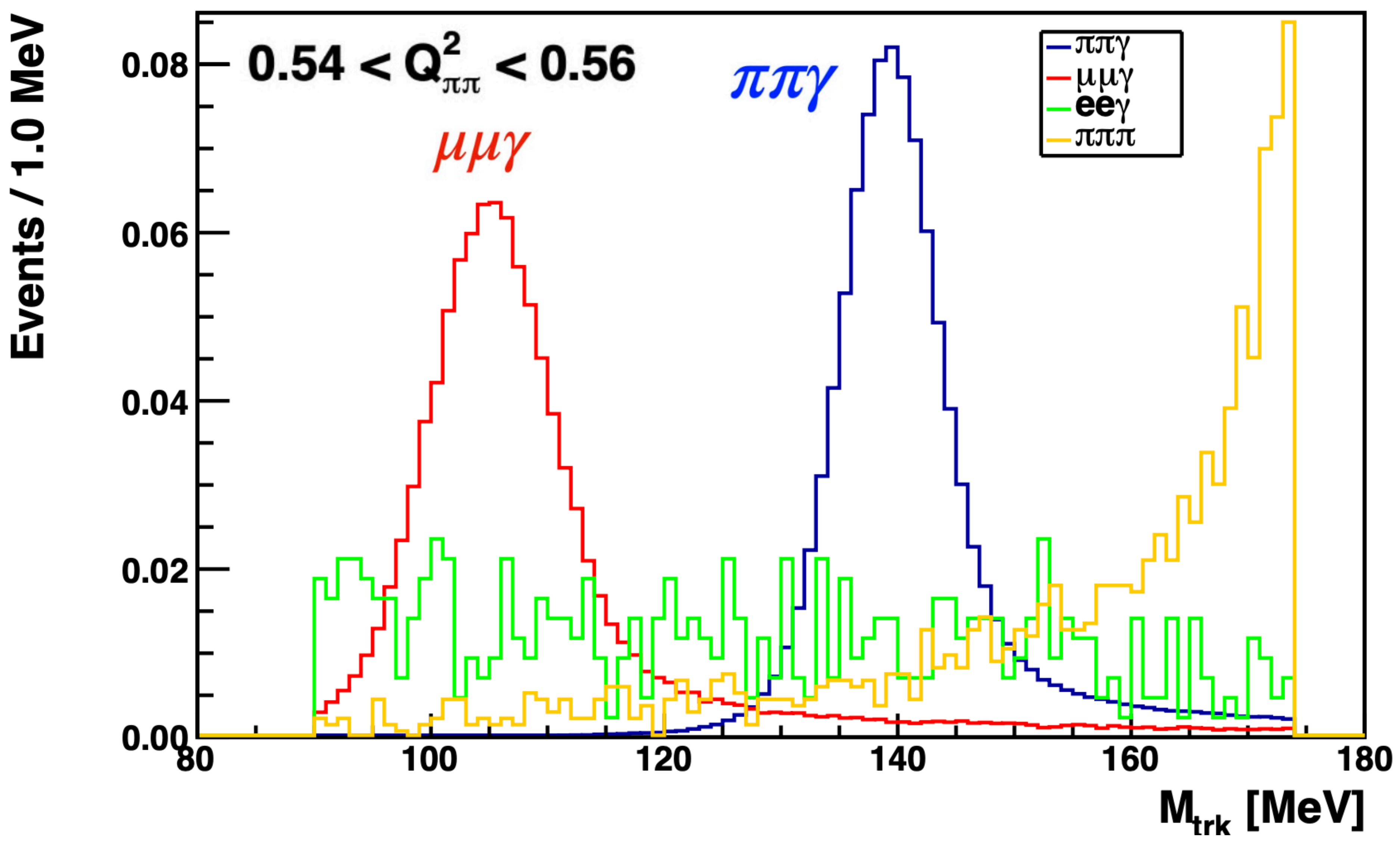
Data MC Comparisons

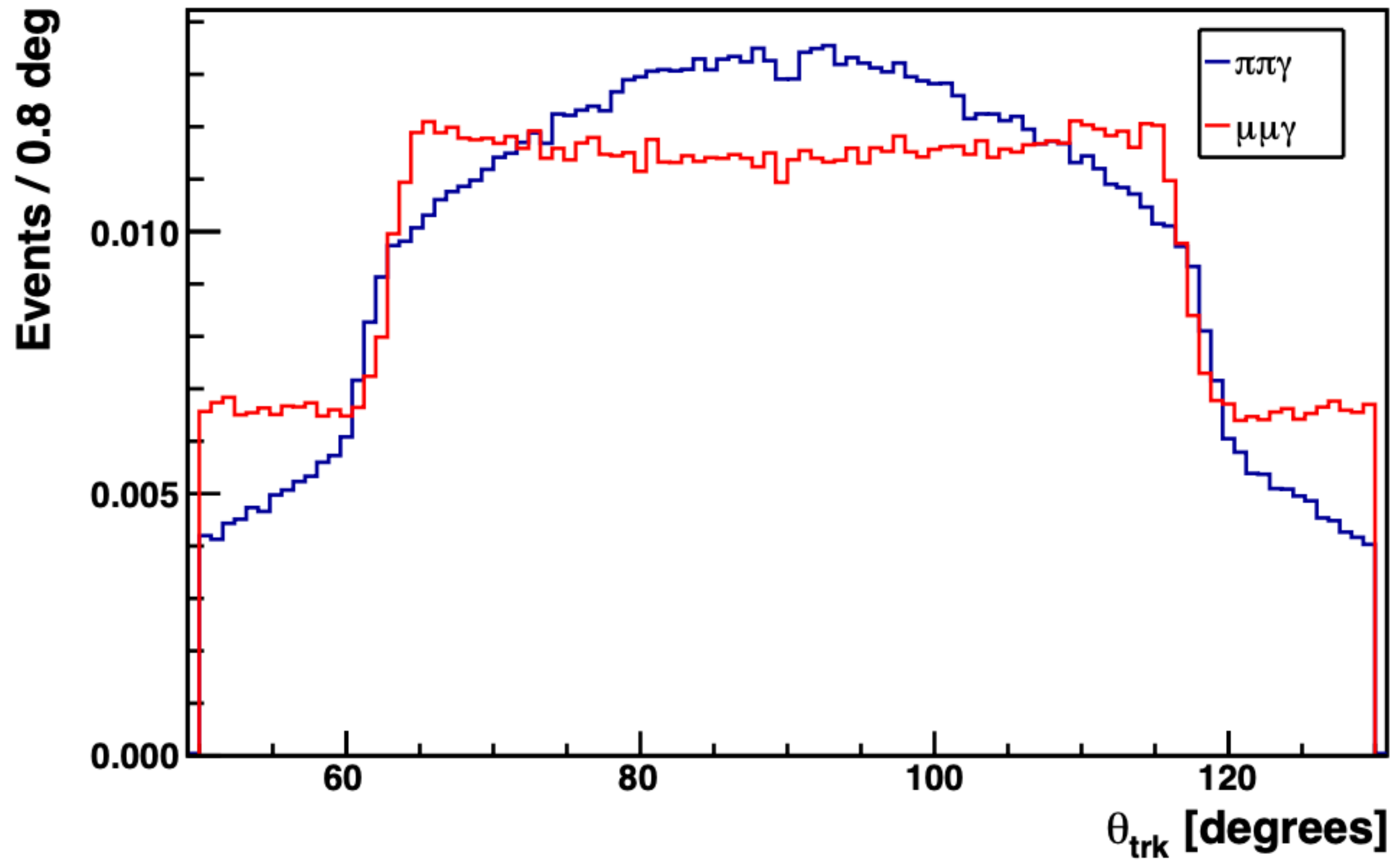
- **Aim:**
  - Comprehensively **improve Monte Carlo simulation** of data
  - Ongoing work uses $\pi^+\pi^-\pi^0$, $\pi\pi\gamma$, $\mu\mu\gamma$, $\pi^+\pi^-$
- **Distribution comparisons** will be done for momentum and position variables as well as other track and cluster variables
- *Data and MC m_x distributions for the $\pi\pi\pi$ control sample, before (upper) and after (lower) the resolution correction.*



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 of 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 checked by reproducing result from previous analysis using new code.
  - Previous analyses uses 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 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.

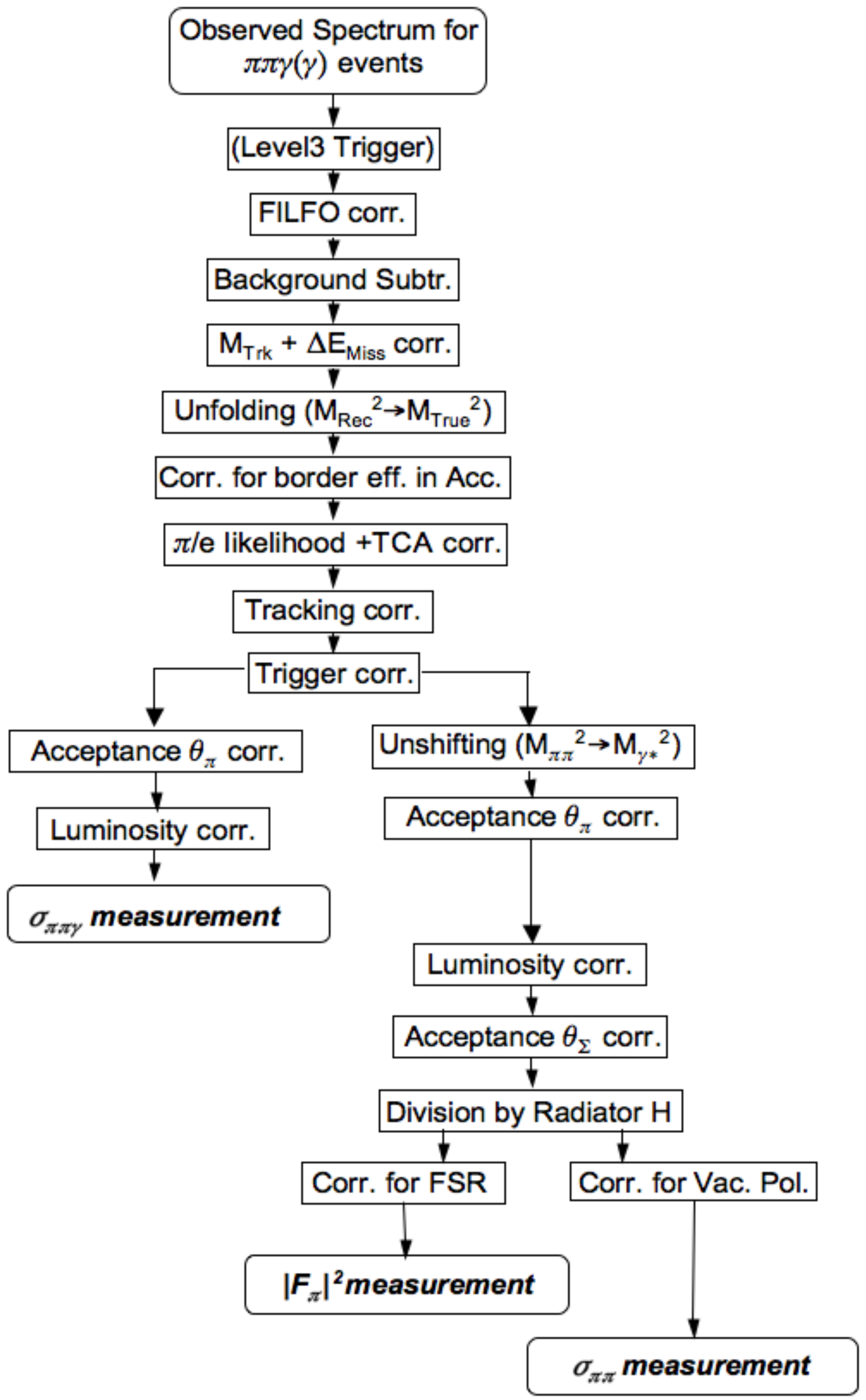




Look to the future

Planned future work:

- **Work is ongoing in great detail on all aspects of the analysis** (e.g. Trigger efficiencies, luminosity …) with the aim to improve systematic uncertainties and possibly simplify the procedure
- Parallel work is being done on the **computing infrastructure** in Frascati to improve accessibility to the data
- **Theory efforts**
- A significant effort is ongoing on radiative corrections with the ultimate goal of producing NNLO MC generators
    - See Graziano, William, Yannick talks
    - STRONG2020
- **Study hadron-photon model**
- **Produce the blinded root-tuples.**



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 in the background systematic uncertainty and a twofold reduction in the remaining systematic uncertainty resulting in a ~0.3% systematic error
- The analysis will be conducted **blindly**
- Work is in progress on working root-tuples, for efficiency estimates, improving MC simulation and background studies.
- Combined effort with theory members of the group to calculate higher order radiative corrections and develop NNLO MC generators
- Timeline for completion not earlier than 2026.

Thank you

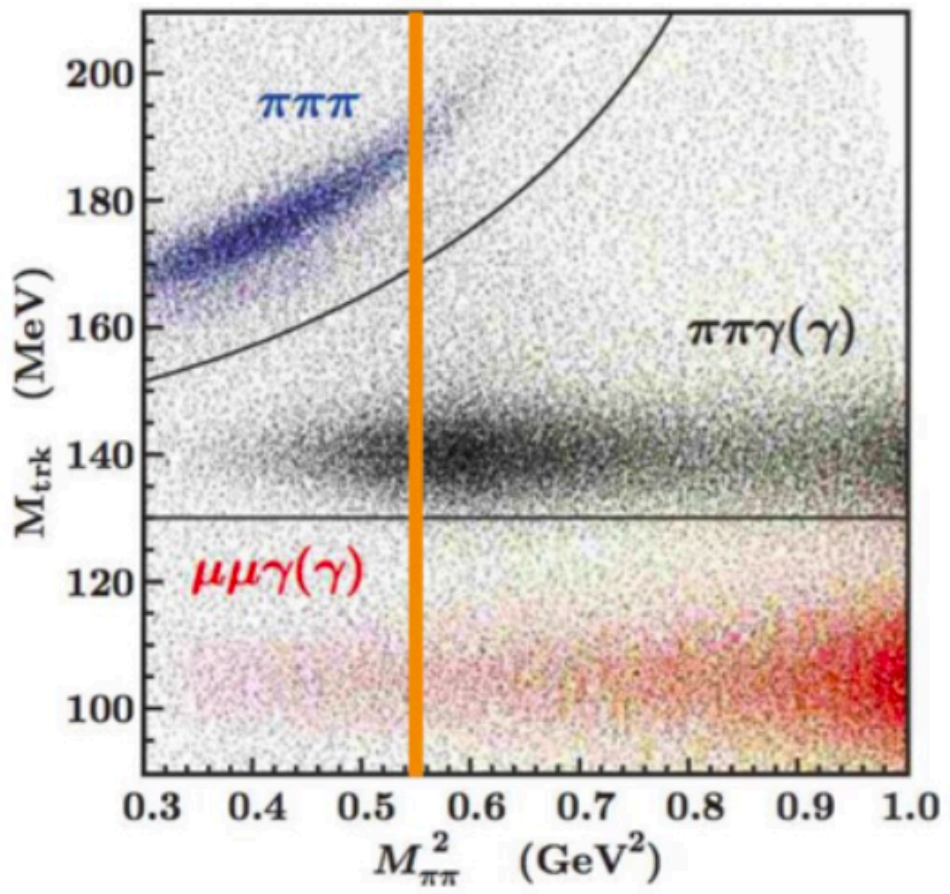
Backup

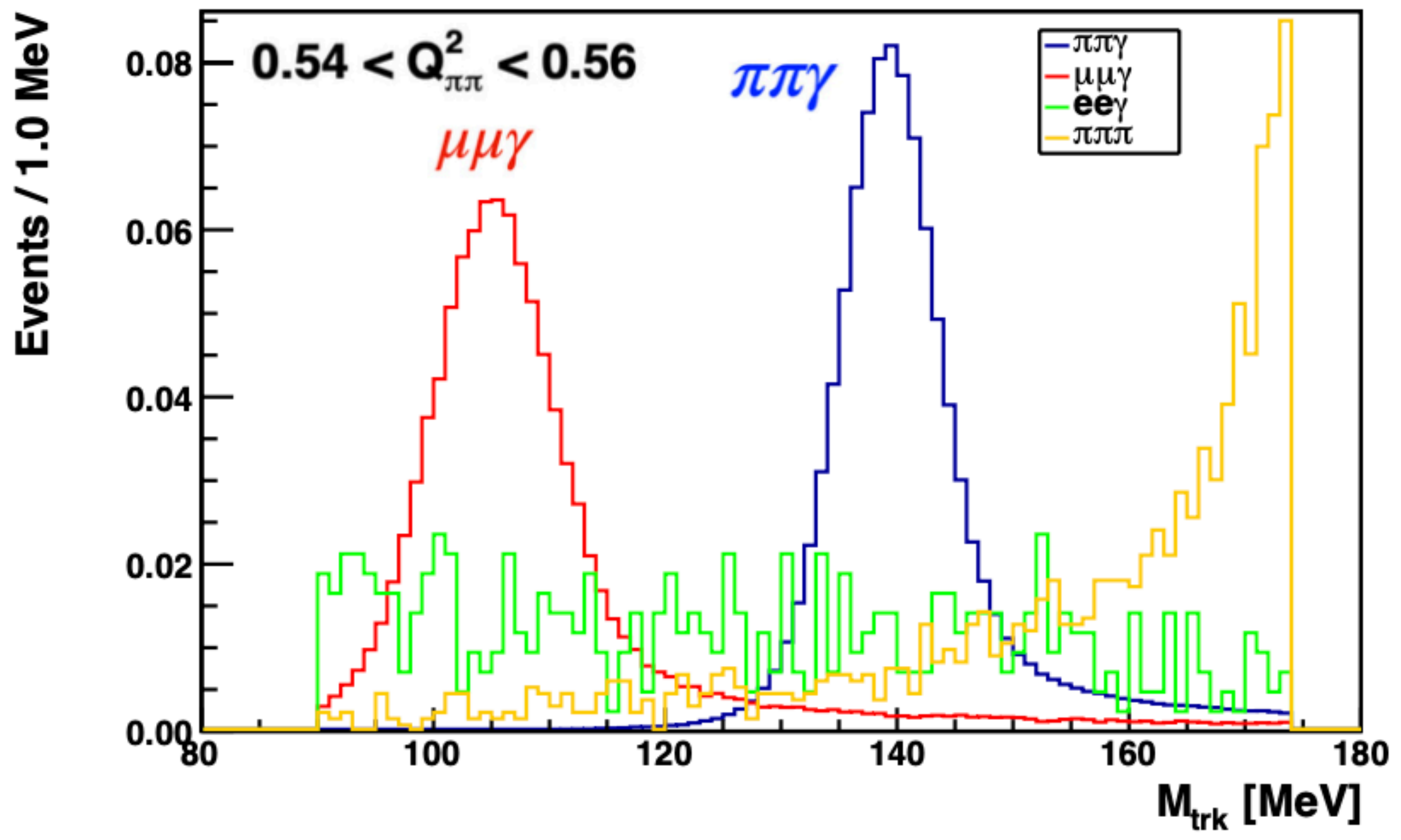
Background Subtraction

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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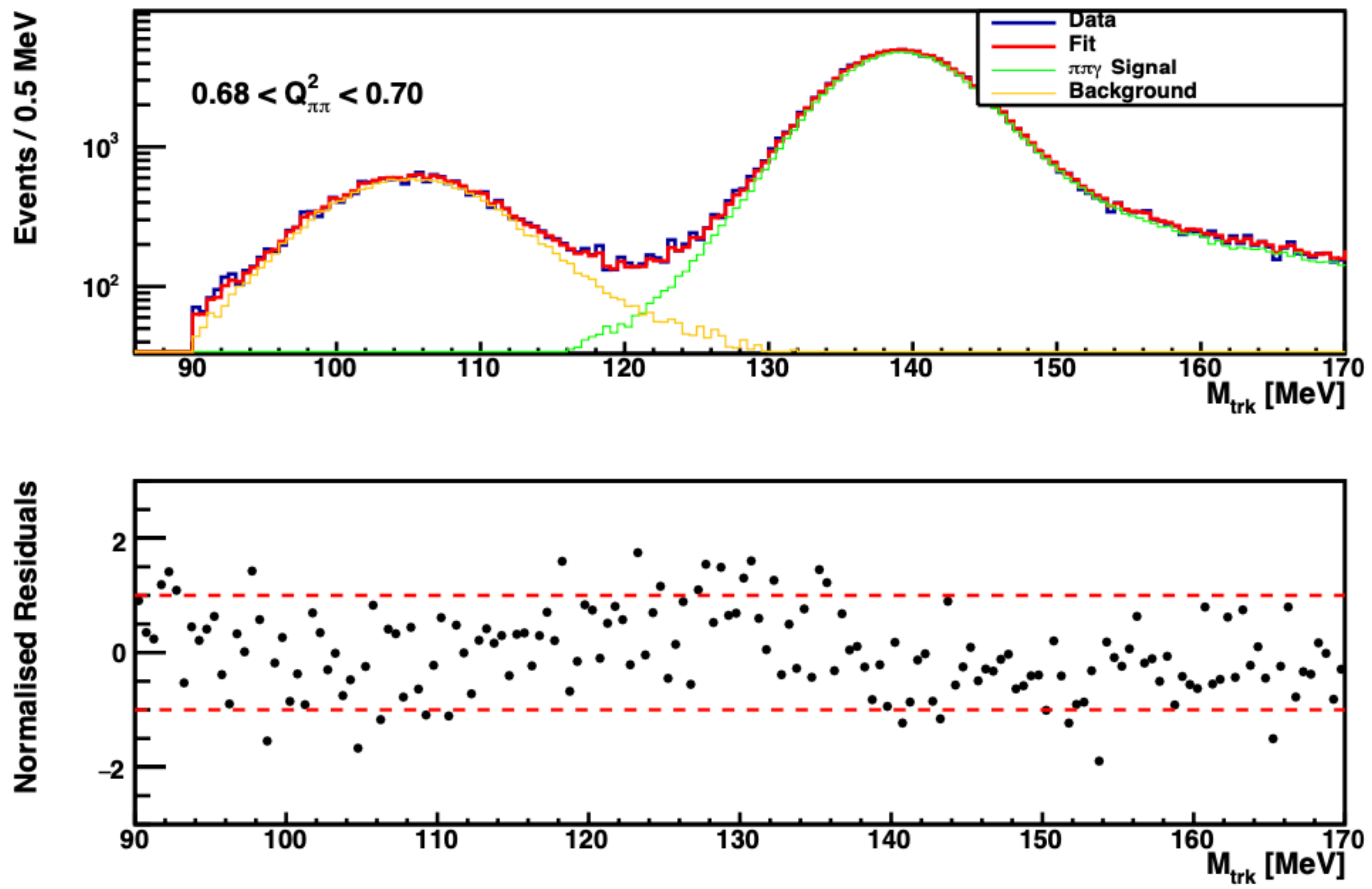
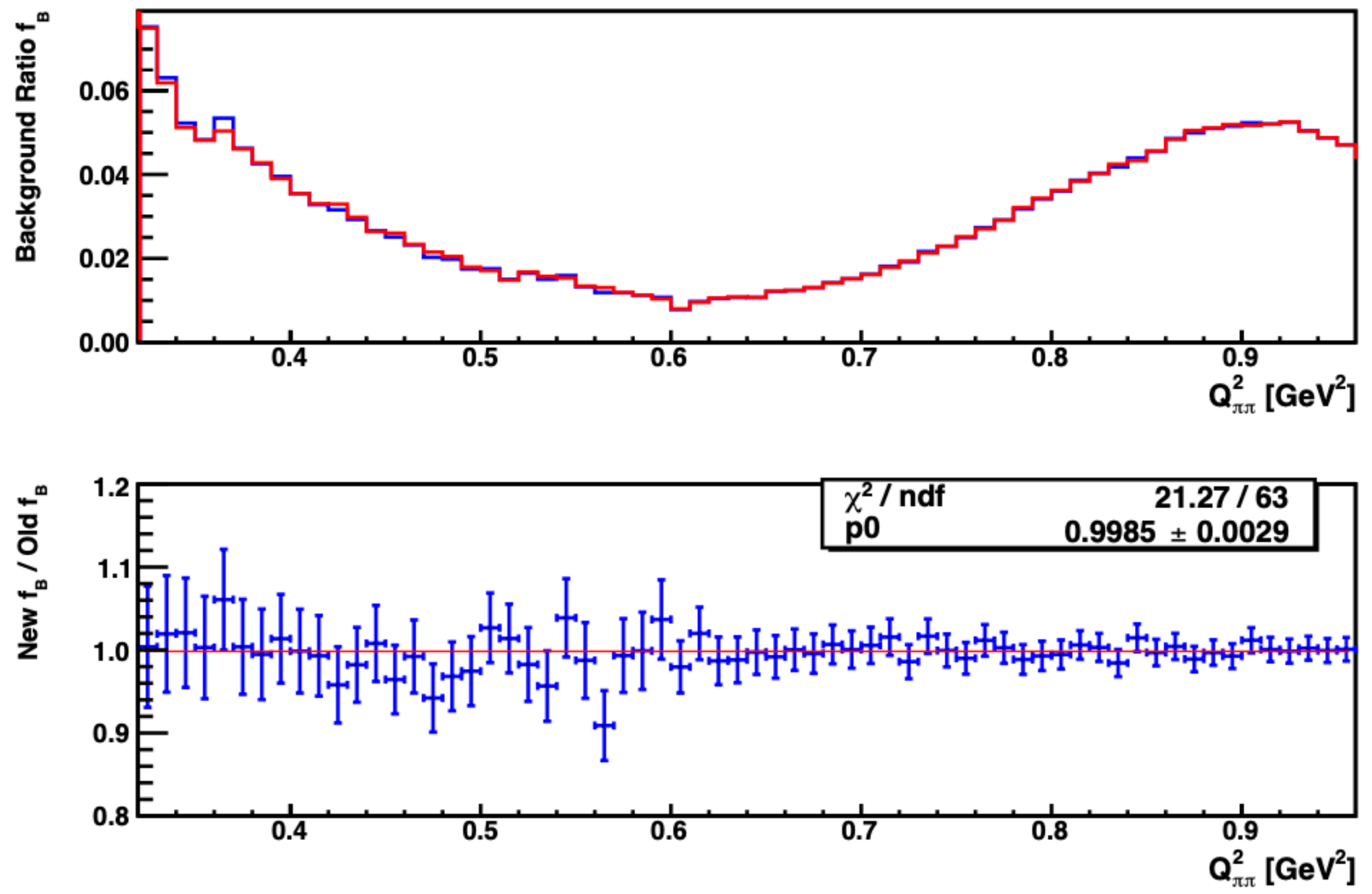
Reproducing the KLOE08 Background Fit on M_{trk}

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_B^i.

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

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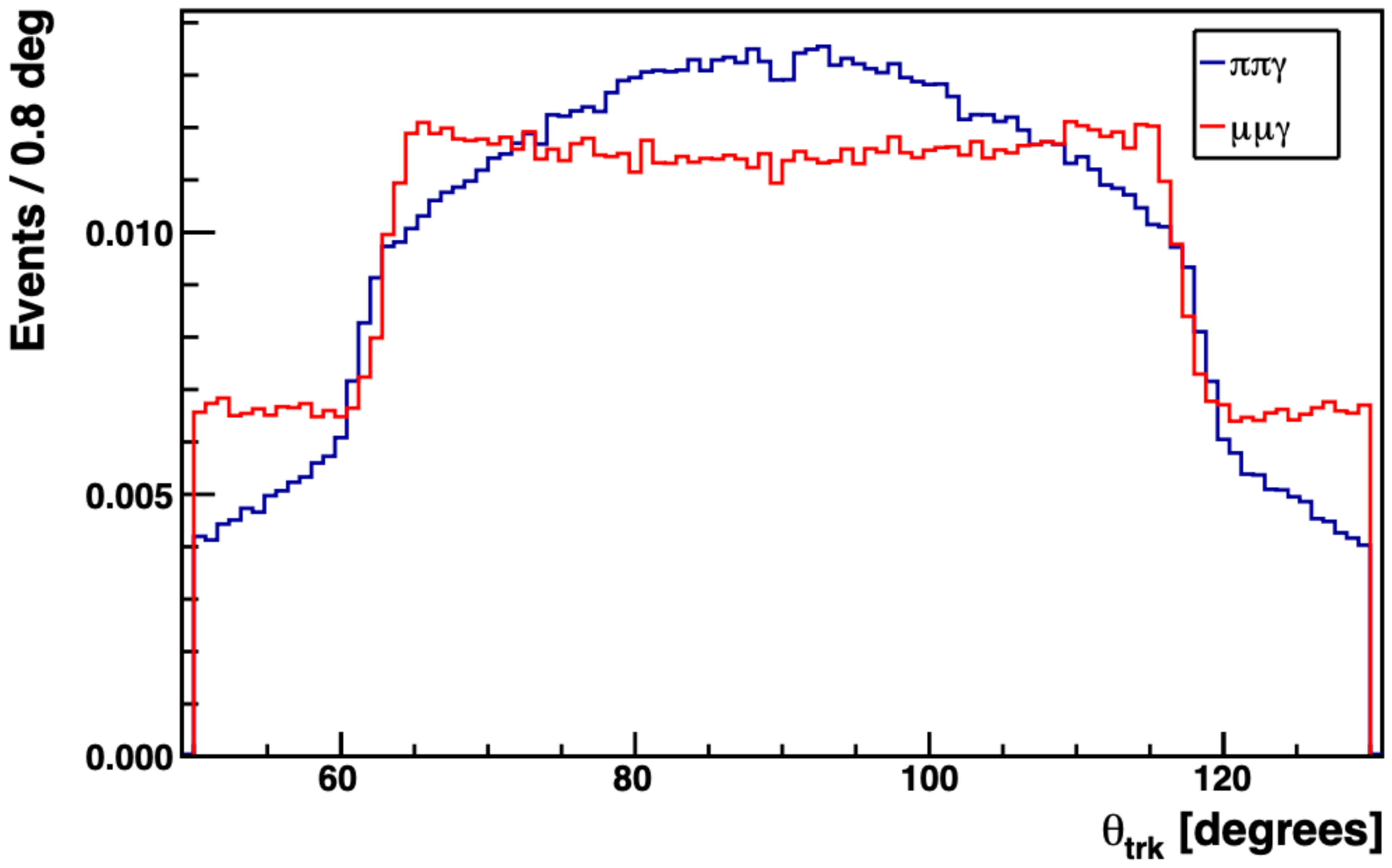
New Fit Variable : θ_{trk}

- 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}.