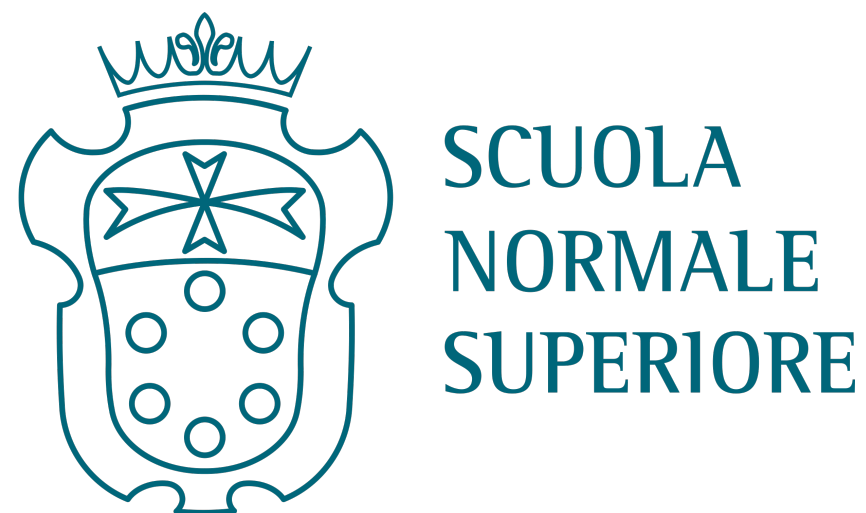


# *KLOE-NXT*: towards a new measurement of the two-pion contribution to the anomalous magnetic moment of the muon

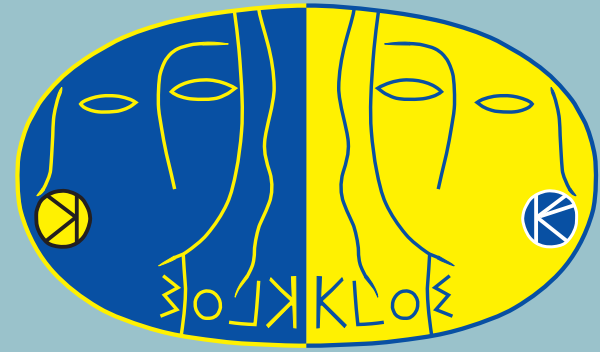
14th edition of the International Workshop on  $e^+e^-$  collisions from Phi to Psi

Lorenzo Punzi on behalf of the KLOE-2 Collaboration

June 8th 2026



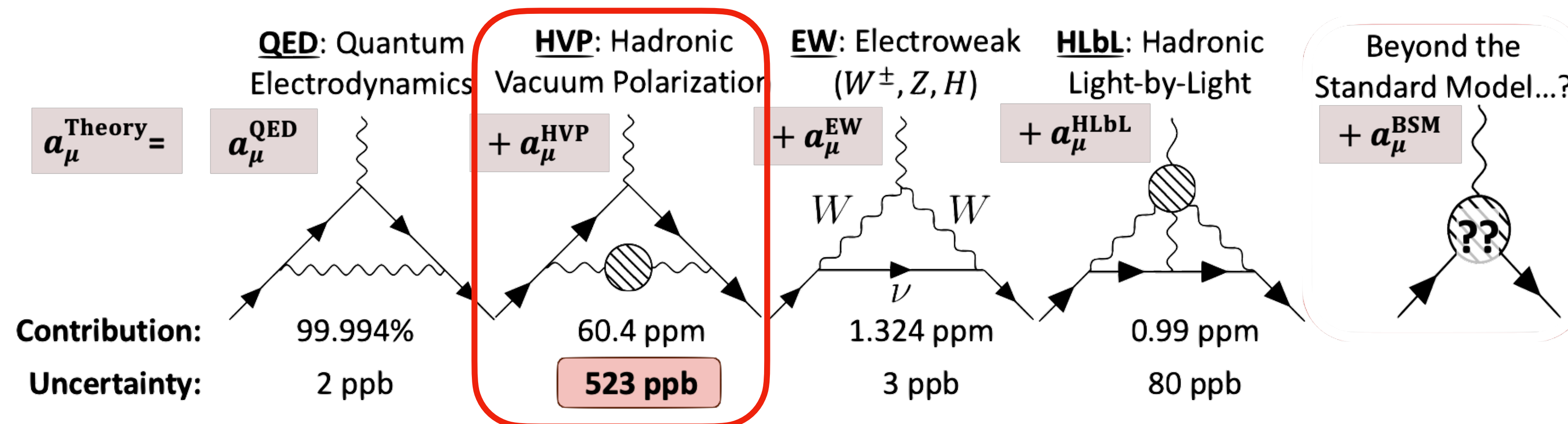
# The Muon Anomalous Magnetic Moment



- Intrinsic magnetic moment  $\vec{\mu}$  of the muon lepton is defined as

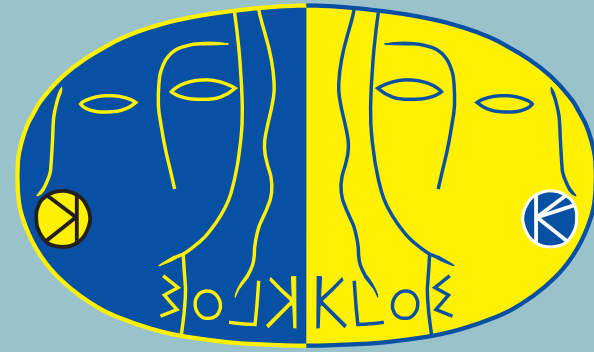
$$\vec{\mu} \equiv g_{\mu} \frac{e}{2m_{\mu}} \vec{S} \quad \text{where gyromagnetic ratio } g_{\mu} = 2 \text{ in Dirac relativistic QM theory}$$

- We define the **anomalous magnetic moment** of the muon  $a_{\mu}$  as  $a_{\mu} \equiv (g_{\mu} - 2)/2 \neq 0$
- Standard Model (SM) prediction consists of multiple contributions from different interactions

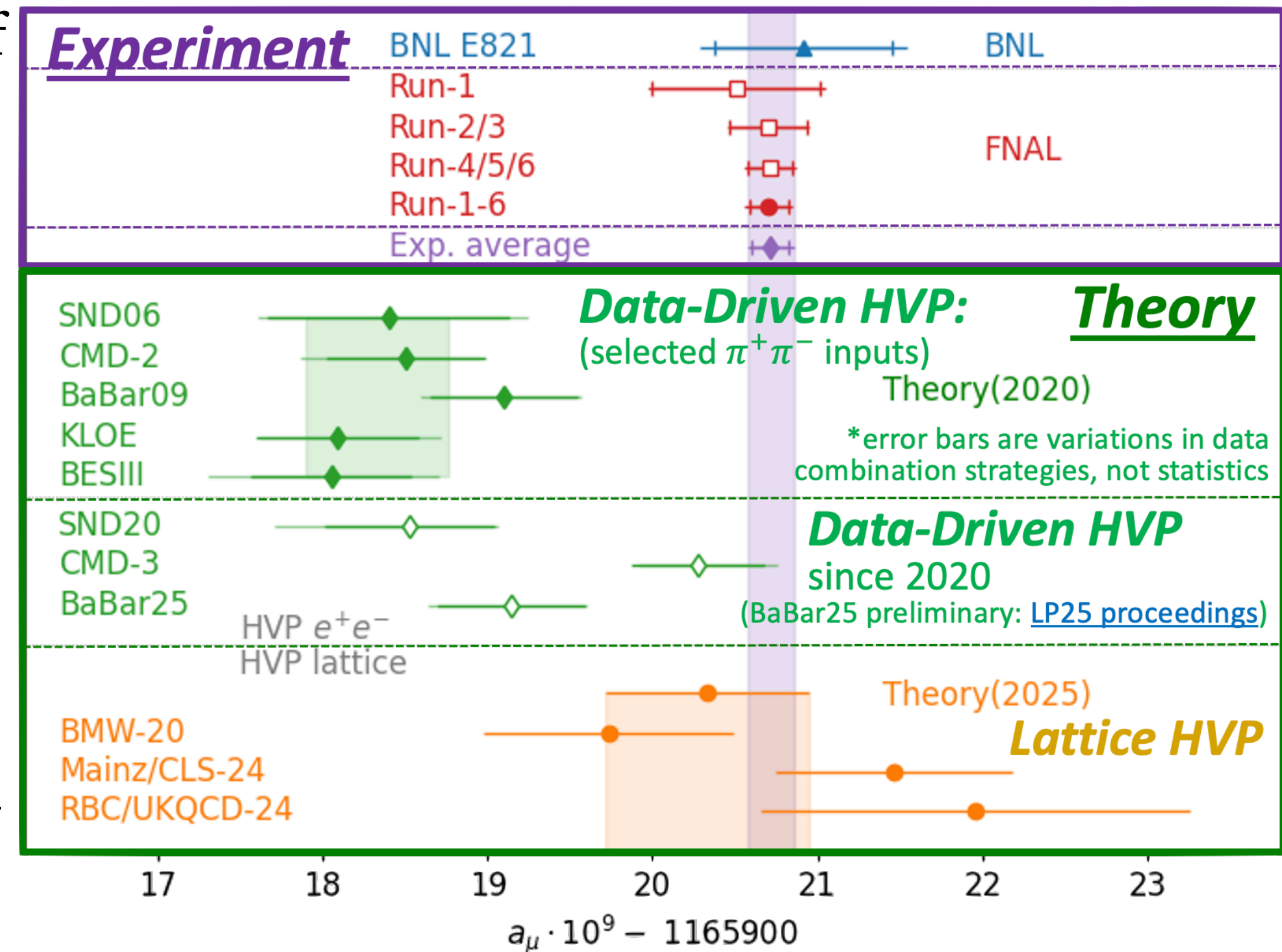


Leading order HVP term  $a_{\mu}^{\text{HLO}}$  dominates total uncertainty due to non perturbative nature of QCD at low energy scales!

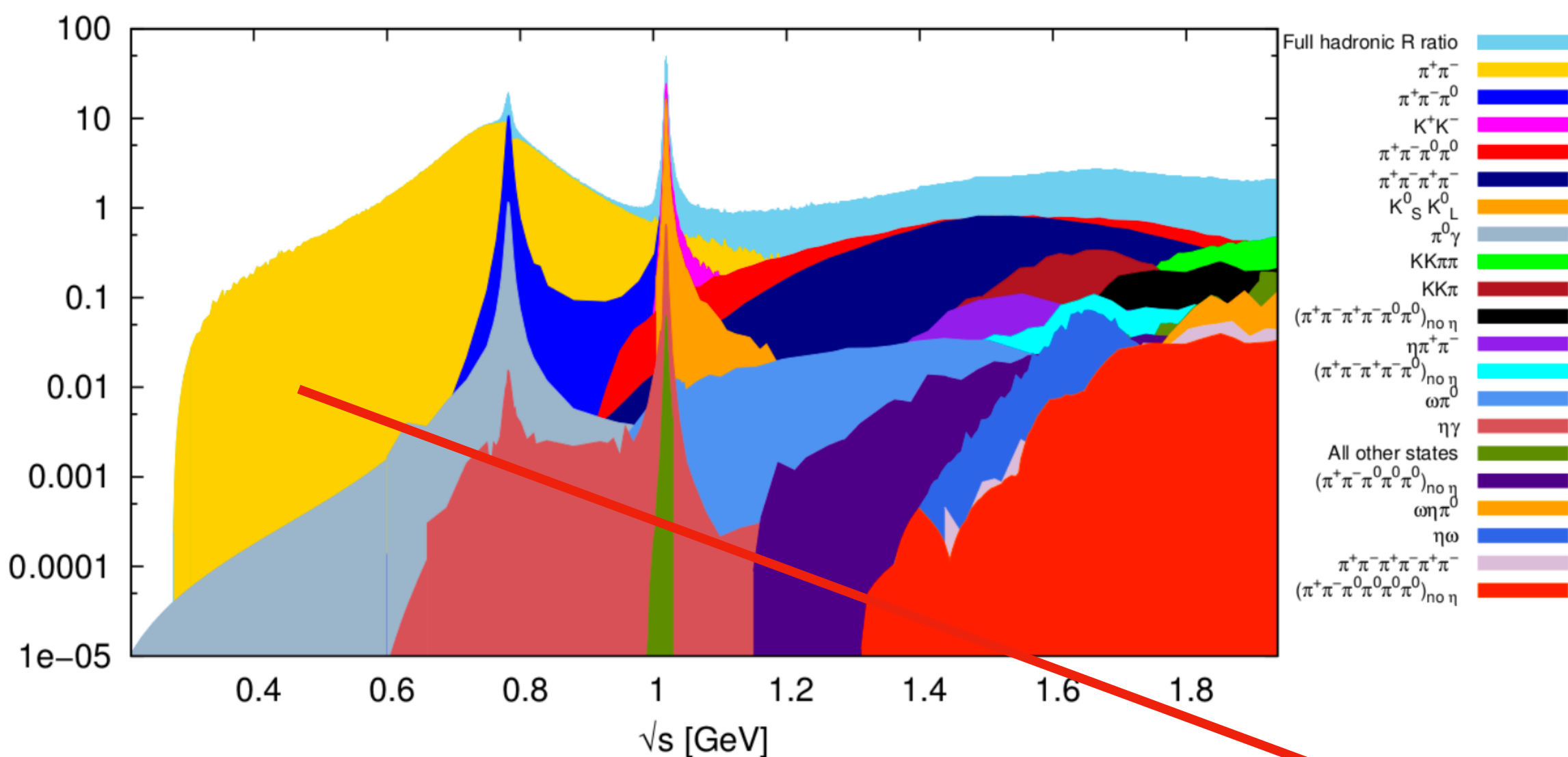
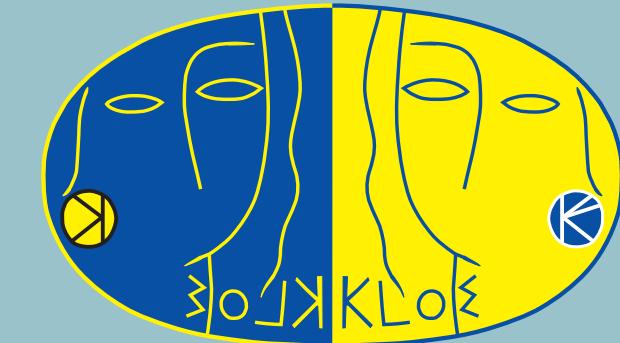
# The Current Muon $g - 2$ Puzzle



- Decades of measurements at CERN, BNL, and Fermilab culminate in the 2025 **experimental world average  $a_\mu^{Exp}$** , achieving an unprecedented precision of **124 ppb**
- Theoretical predictions  $a_\mu^{SM}$  based on a **data-driven dispersive approach to calculate  $a_\mu^{HVP}$**  present major discrepancies with  $a_\mu^{Exp}$ , some at the level of  $\sim 5\sigma$
- More recent **lattice calculations of  $a_\mu^{HVP}$**  are compatible with the measured  $a_\mu^{Exp}$
- Discrepancy between the two approaches to predicting  $a_\mu^{HVP}$  (**Dispersive vs Lattice**) **remains to be solved!**



# A Puzzle Within a Puzzle: Dispersive HVP

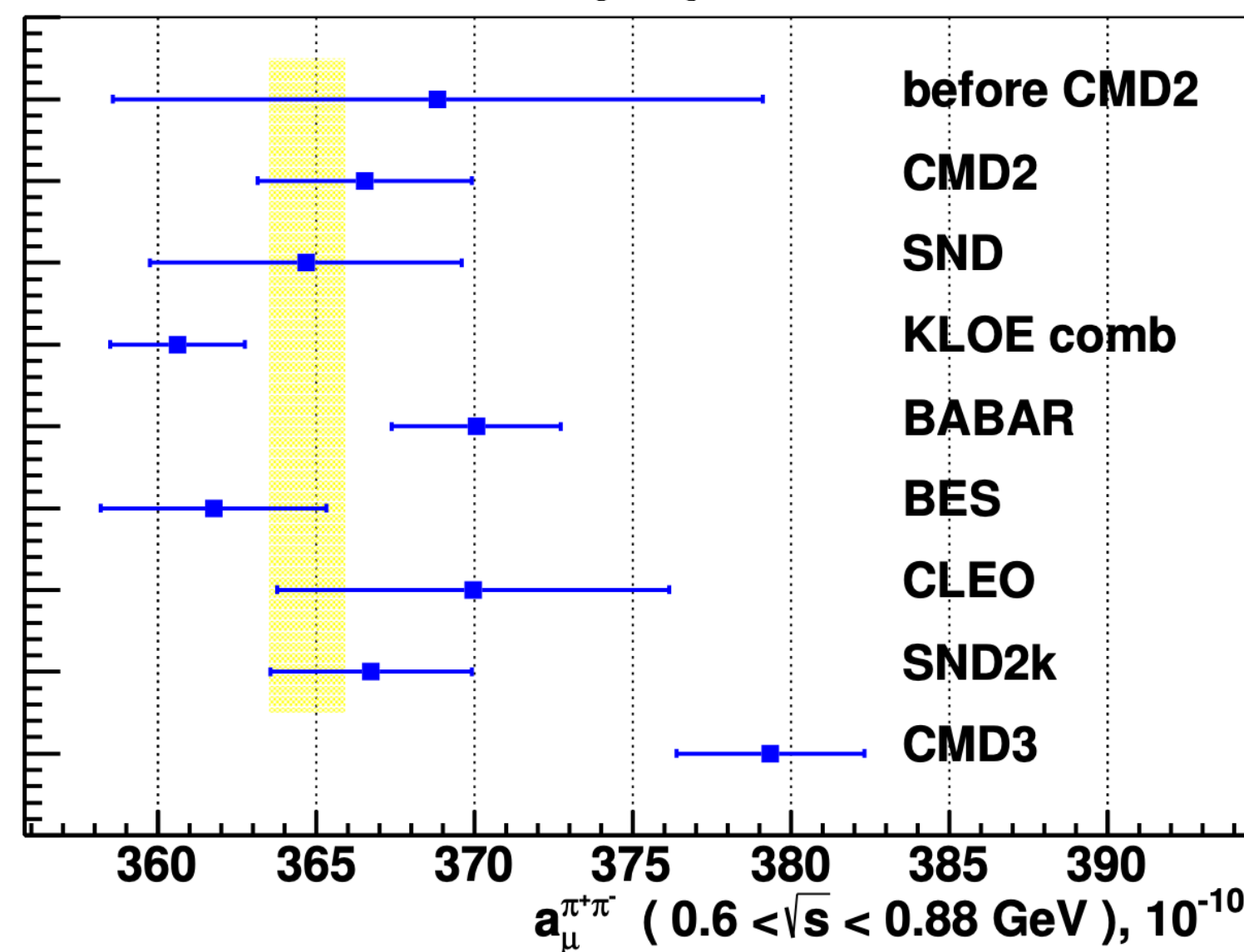


- Theoretical  $a_\mu^{SM}$  prediction is limited by non-perturbative  $a_\mu^{HVP,LO} \rightarrow$  dispersive data-driven approach exploits optical theorem to estimate  $a_\mu^{HVP,LO}$  from *hadronic cross section measurements*

$$a_\mu^{HVP,LO} = \frac{\alpha^2}{3\pi^2} \int_{m_{\pi^0}^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

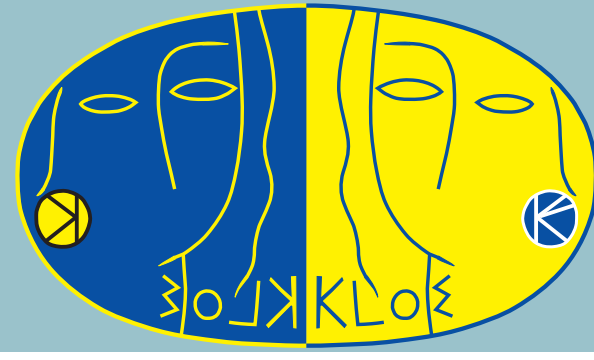
$$K(s) = \text{known Kernel function}$$

$$R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma_{\text{born}}(e^+e^- \rightarrow \mu^+\mu^-)}$$

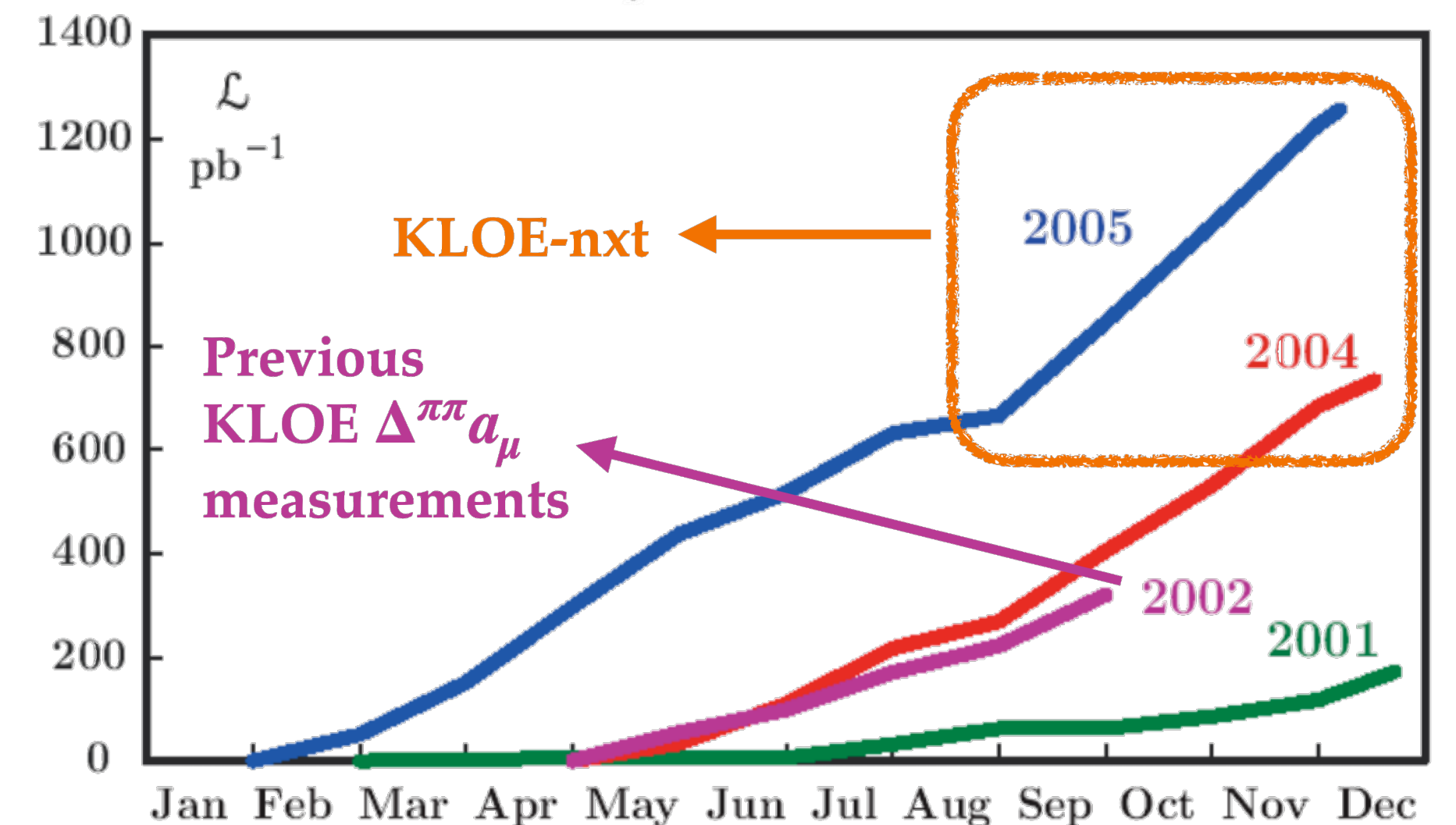
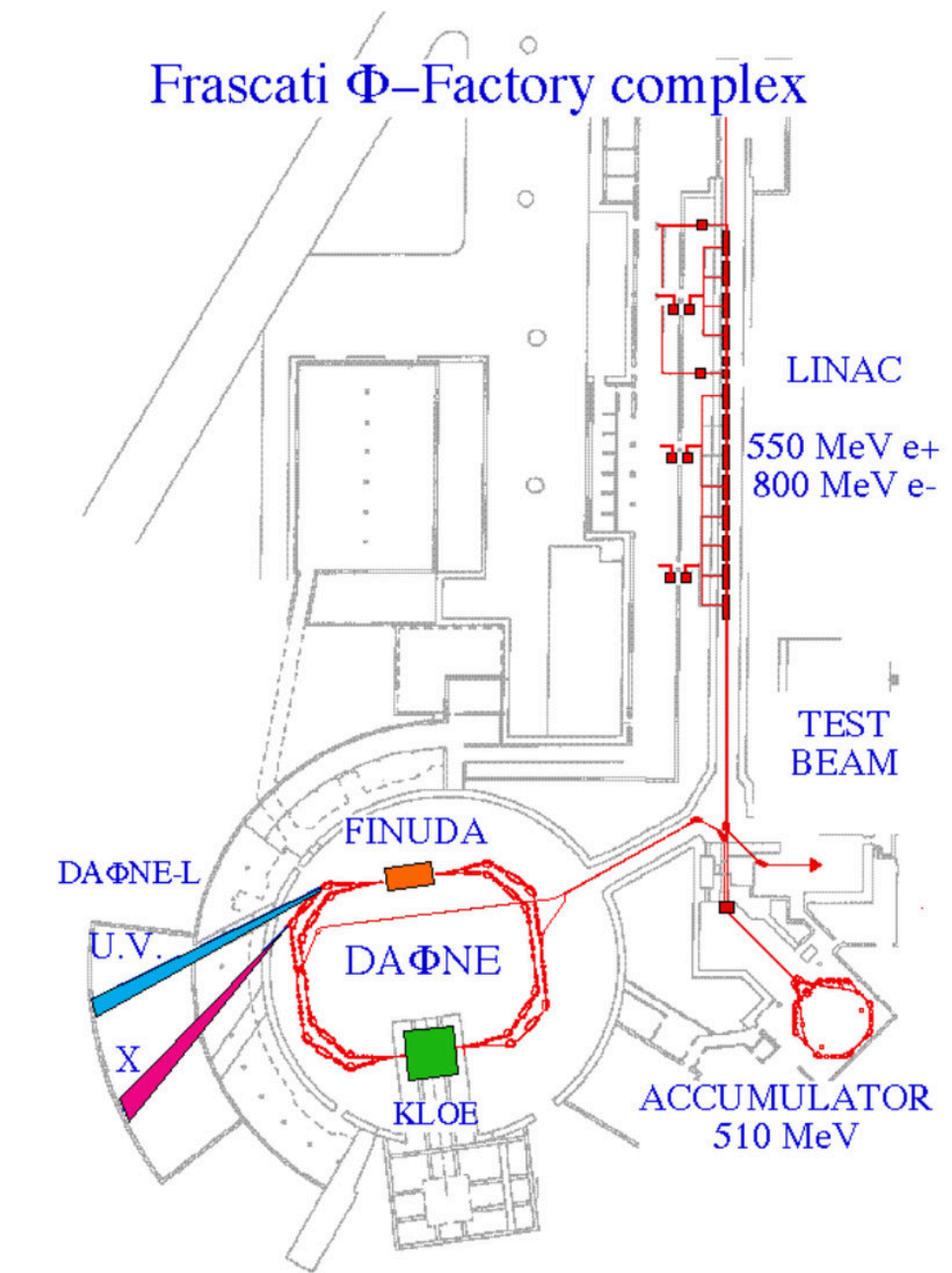


- In non-perturbative QCD energy range, hadronic contribution to  $a_\mu^{HVP,LO}$  is dominated by the  $e^+e^- \rightarrow \pi^+\pi^-$  channel ( $\sim 73\%$ )  $\rightarrow$  Cross section independently measured by KLOE, BABAR, CMD-2/3, BESIII, SND,...
- Resulting  $a_\mu^{SM}$  predictions are generally discrepant with world average  $a_\mu^{Exp}$  (some exceptions e.g. CMD-3) and also **discrepant between one another** at the level of  $\sim 3\sigma$  ( $\sim 5\sigma$  including CMD-3)
- New result from BABAR confirms their previous measurement (see I. Garzia's talk!)

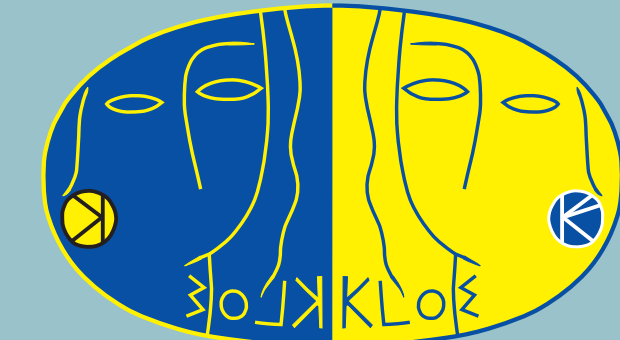
# The KLOE Experiment @ DAΦNE in LNF



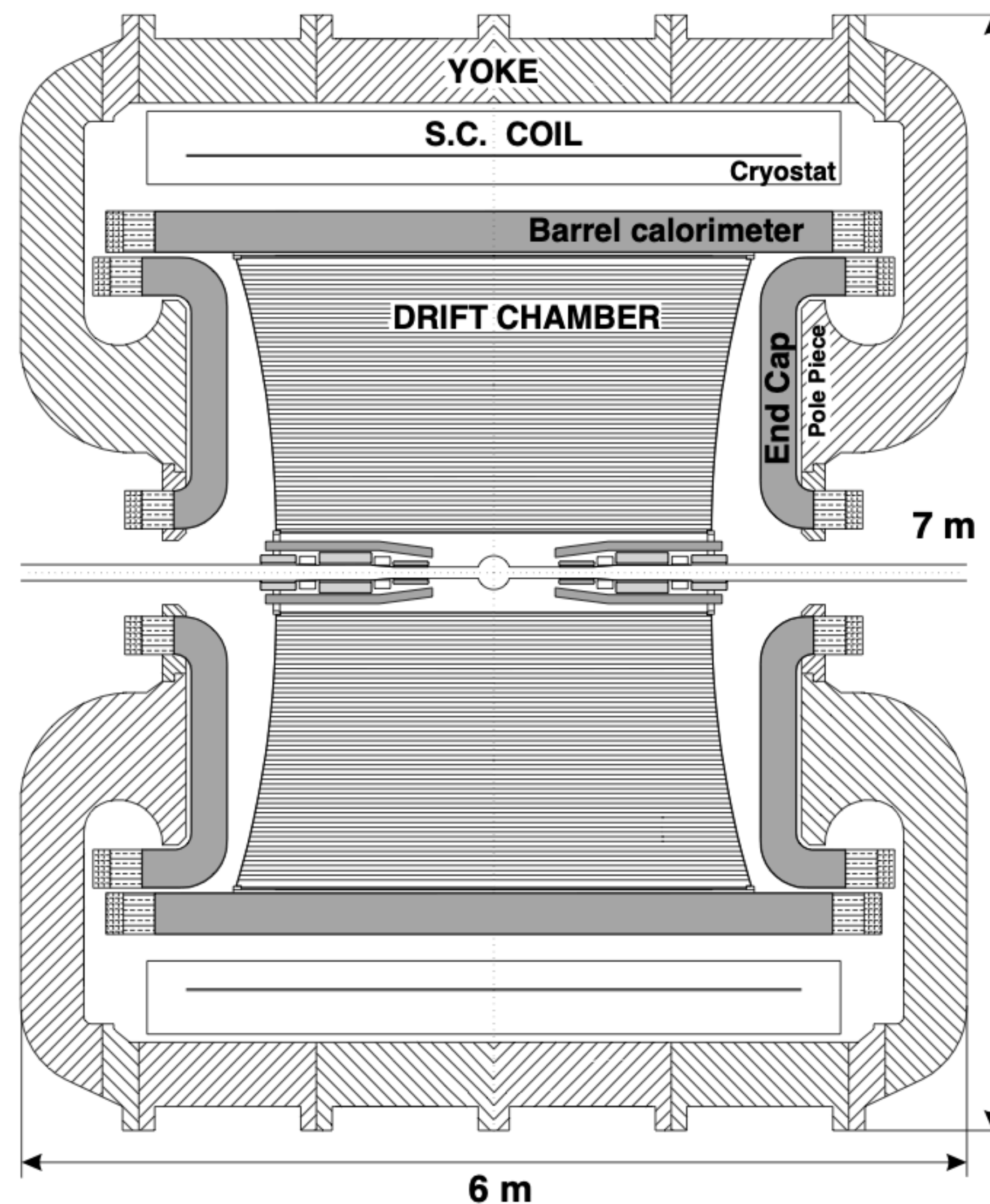
- KLOE-1 and KLOE-2 experiments located at the DAΦNE  $e^+e^-$  collider in Frascati, Italy  $\rightarrow$  fixed c.m.s. energy of  $m_\phi \simeq 1020$  MeV
- KLOE-1 data taking in 2002-2006, with  $2.5 \text{ fb}^{-1}$  on peak +  $250 \text{ pb}^{-1}$  off-peak ( $\sqrt{s} \simeq 1000$  MeV) in 2006
- Maximum luminosity of  $\sim 8.5 \text{ pb}^{-1}/\text{day}$  achieved in 2005
- Previous KLOE  $\Delta^{\pi\pi} a_\mu$  measurements only used  $240 \text{ pb}^{-1}$  from 2002 ( $\sim 3.5\text{M}$   $\pi\pi\gamma$  events) and  $250 \text{ pb}^{-1}$  from 2006
- There are still  $\sim 1.7 \text{ fb}^{-1}$  of 2004-2005 data ( $\sim 25\text{M}$   $\pi\pi\gamma$  events) to analyse **for a new  $\Delta^{\pi\pi} a_\mu$  measurement**



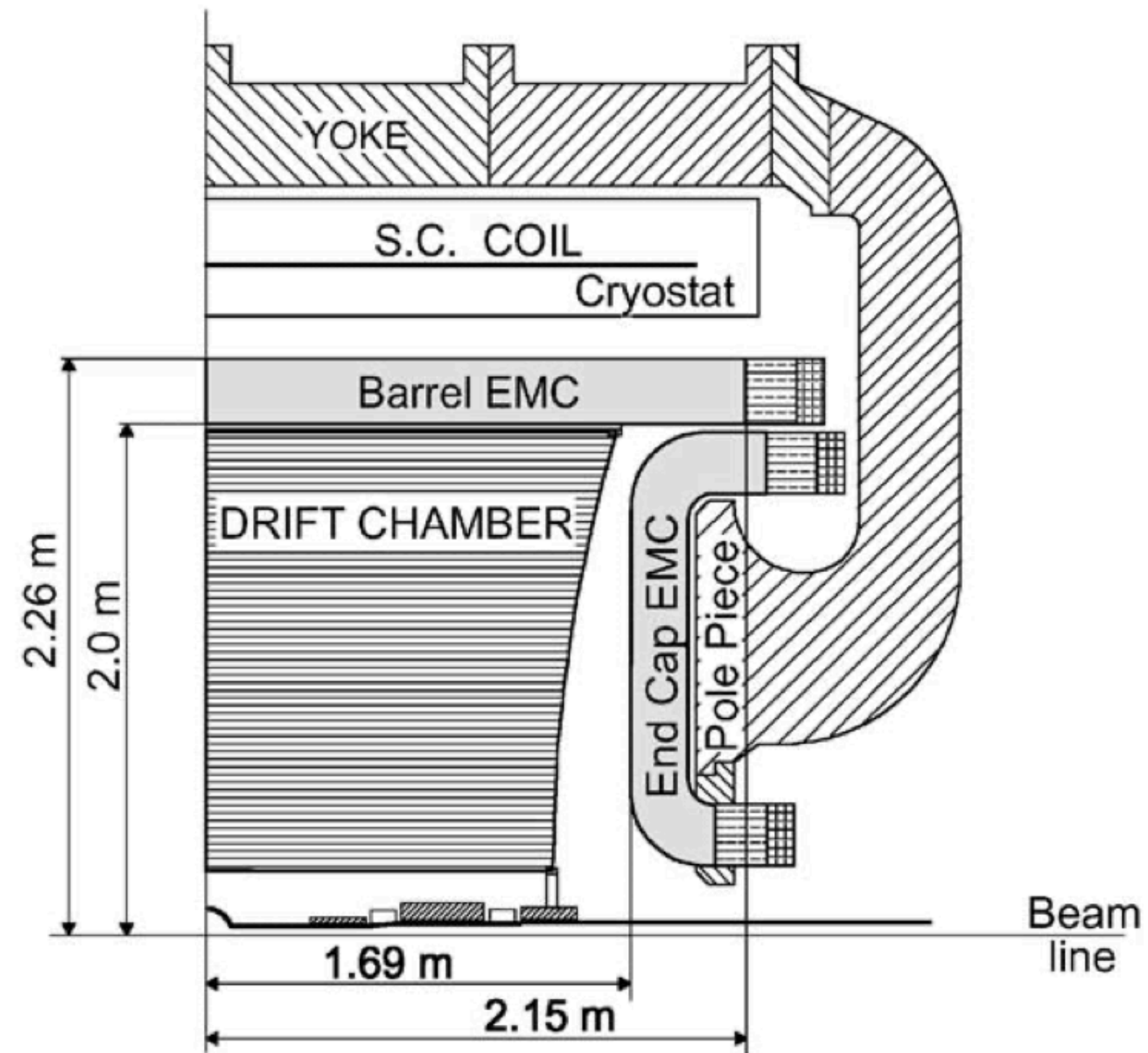
# The KLOE Detector : Drift Chamber



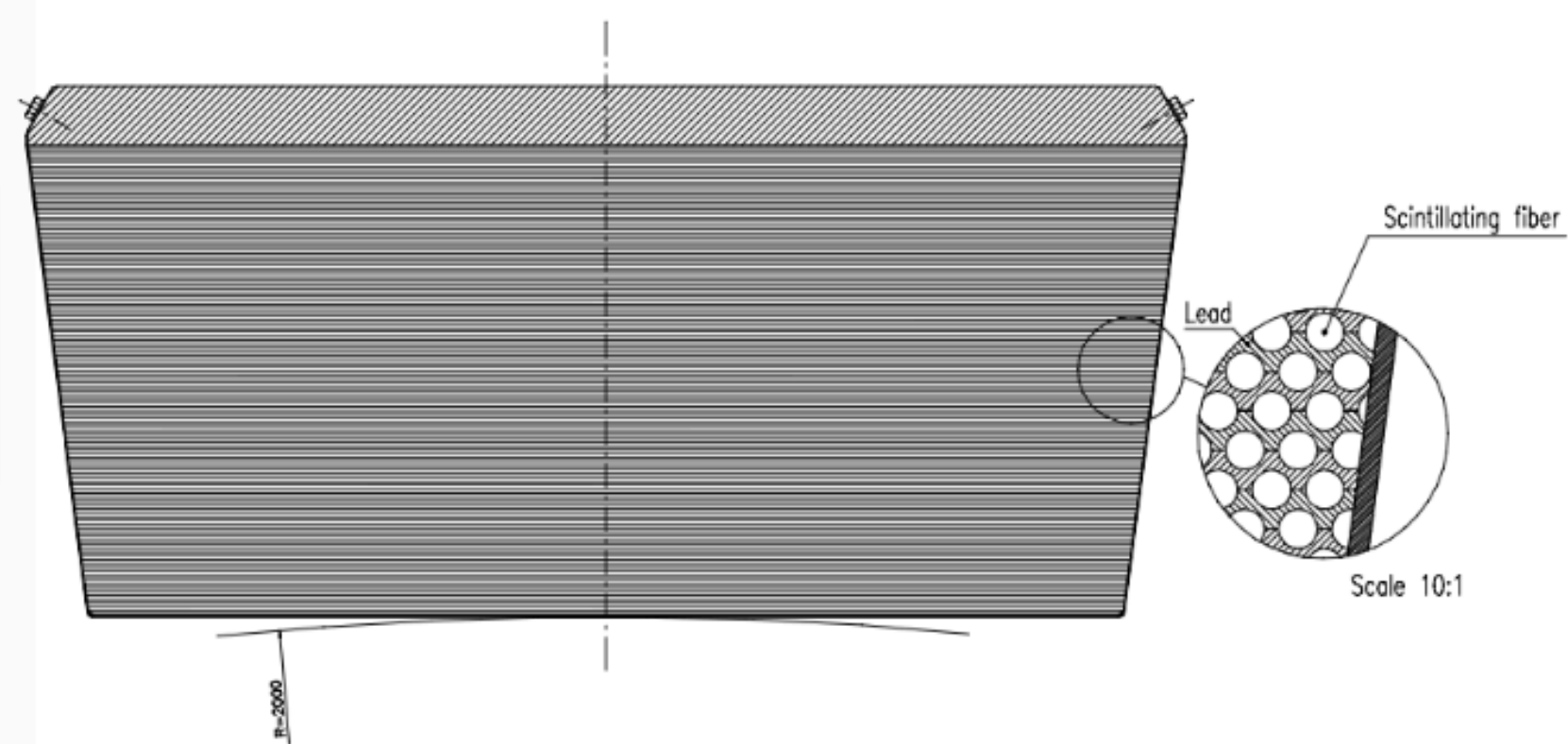
- Full stereo 3.3m x 2m (L x r) cylindrical drift chamber immersed in 0.52T solenoidal magnetic field
- Chamber filled with 90% Helium - 10% Isobutane to minimise MS
- Comprised of 50k+ wires (field:sense = 3:1) arranged in layers
- Wires in same layer are parallel to each other and have same stereo angle
- Stereo angle allows for reconstructing  $z$  coordinates and varies gradually from  $\pm 60$  mrad to  $\pm 150$  mrad
- Resolutions achieved:  $\sigma_{r\phi} \simeq 200\mu\text{m}$ ,  $\sigma_z \simeq 2\text{mm}$ ,  $\sigma_{vtx} \simeq 3\text{mm}$ ,  $\sigma(p_T)/p_T \simeq 0.4\%$   $\longrightarrow$  excellent momentum resolution



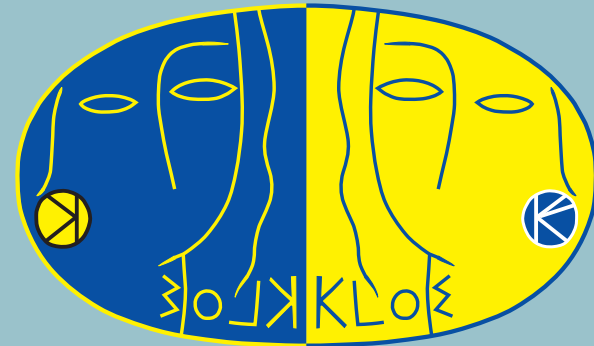
# The KLOE Detector : EM Calorimeter



- Sampling calorimeter (Barrel + Endcaps) comprised of Pb passive layers + scintillating fibre sensing layers
- Detects photons in 20 MeV - 500 MeV energy range with 98% of  $4\pi$  acceptance
- 24 (barrel) + 64 (endcap) calorimeter modules
- Modules organised in  $4.4 \times 4.4 \text{ cm}^2$  cells in 5 layers
- Readout using  $\sim 5\text{k}$  photomultipliers, which feed trigger, ADCs and TDCs (allow measurement of coordinate along fiber)
- Resolutions achieved:
  - $\sigma_E/E \simeq 5.7\% / \sqrt{E[\text{GeV}]}$
  - $\sigma_t = 5.4 / \sqrt{E[\text{GeV}]} \oplus 140 \text{ ps} \rightarrow \sigma_z \simeq 9 / \sqrt{E[\text{GeV}]} \text{ mm}$



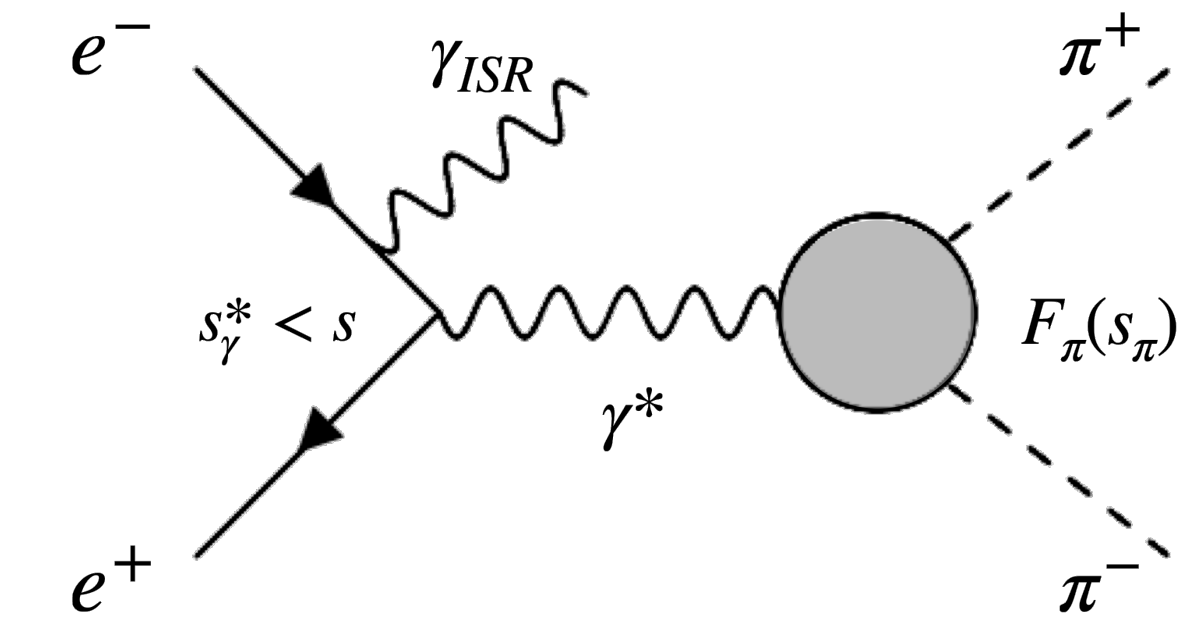
# Previous KLOE $\Delta^{\pi\pi} a_\mu$ Analyses: KLOE08



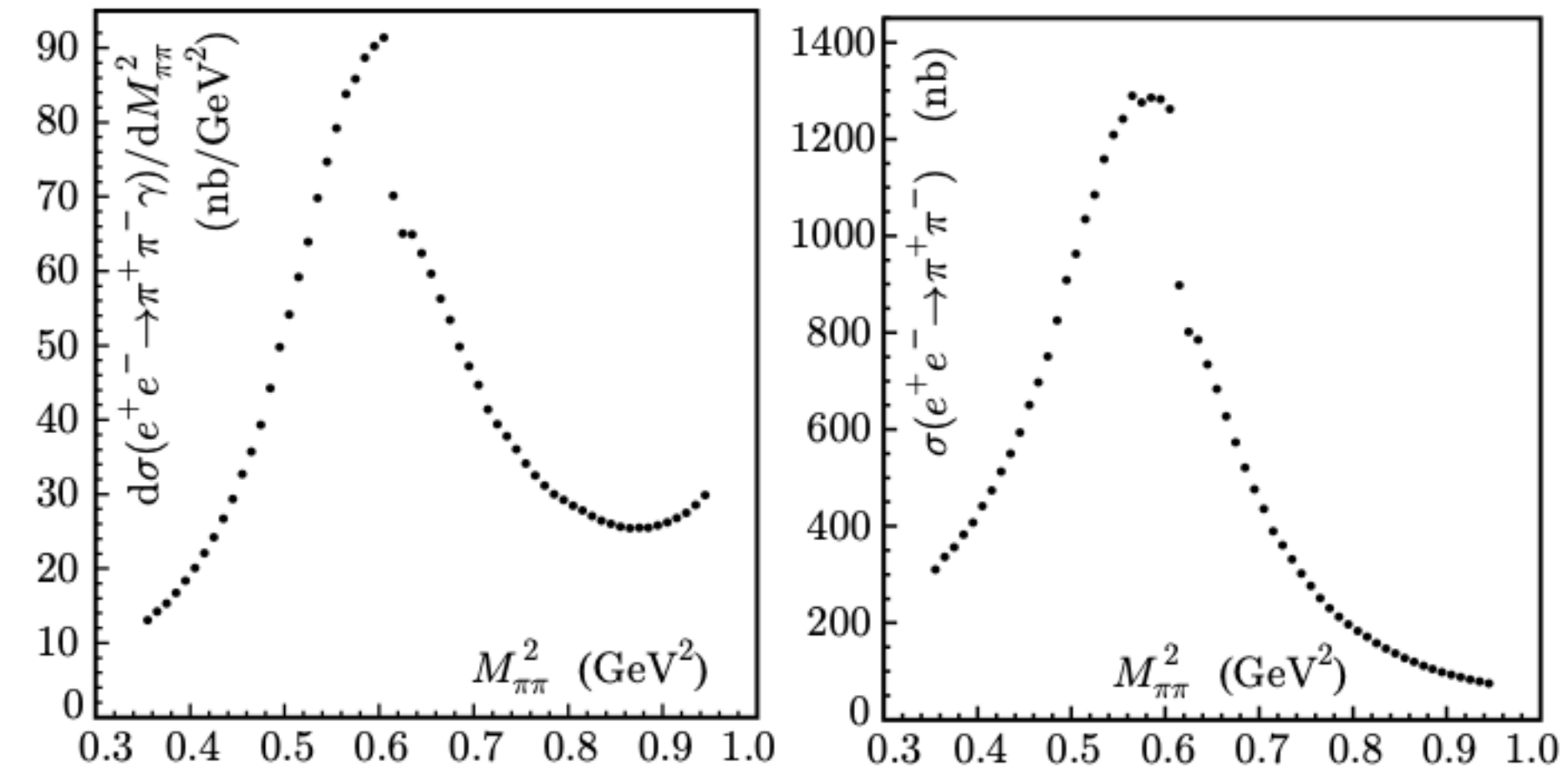
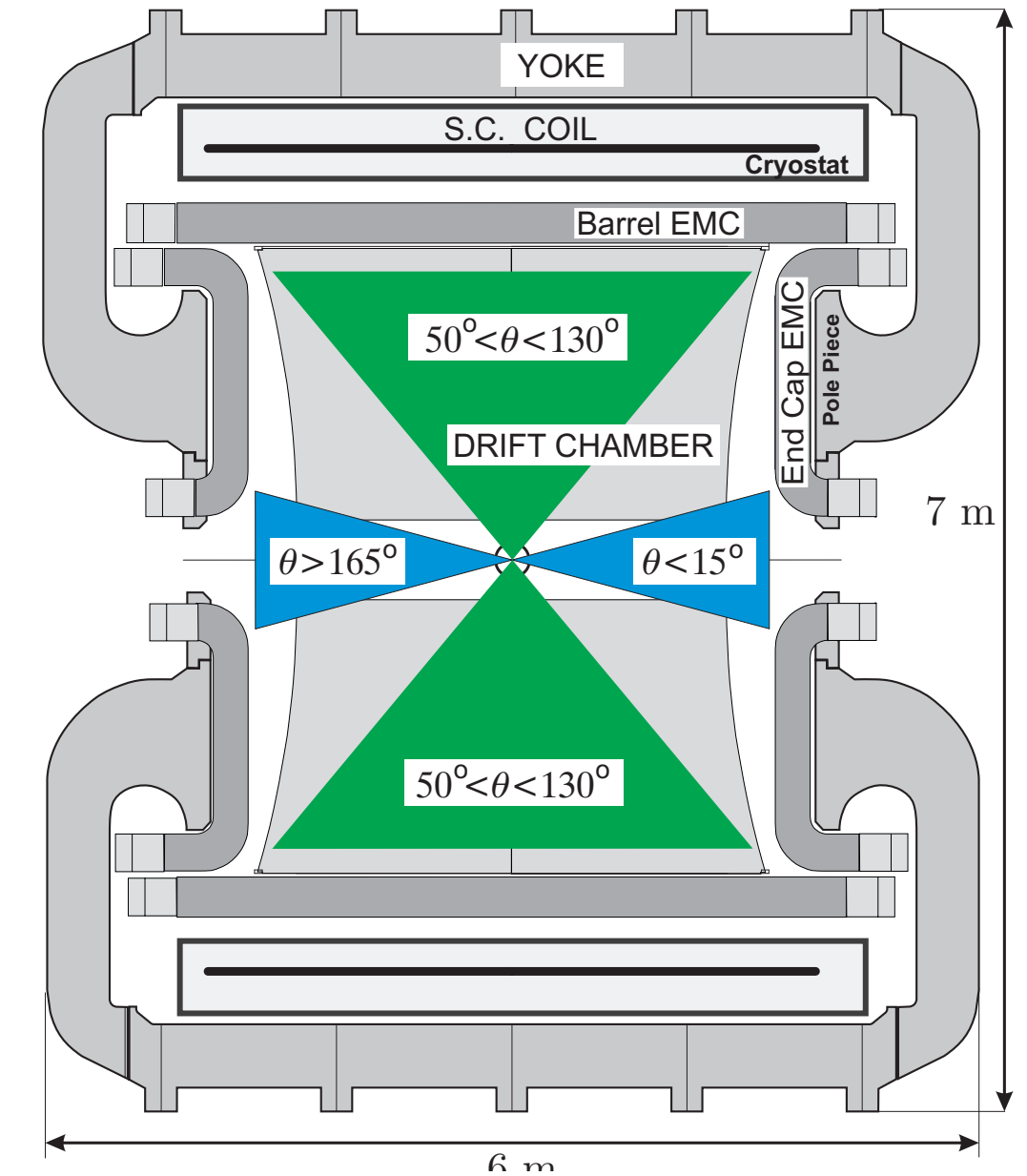
## KLOE08

- Measure 60 points of  $s$  between 0.35 and 0.95  $\text{GeV}^2$
- 240.0  $\text{pb}^{-1}$  from 2002 run
- 2 charged tracks (pions) at large angles  $50^\circ < \theta_\pm < 130^\circ$
- *Untagged* photon at small angle using kinematics  
 $\vec{p}_{miss} \equiv -(\vec{p}_+ + \vec{p}_-) \rightarrow \theta_{miss} < 15^\circ \vee \theta_{miss} > 165^\circ$
- Topology enhances ISR and suppresses FSR and  $\phi \rightarrow \pi^+\pi^-\pi^0$  background
- Topology cannot reach dipion threshold  $s = 4m_\pi$
- Cross section from normalisation to luminosity (Bhabha) and correction with radiator (PHOKHARA v5)

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



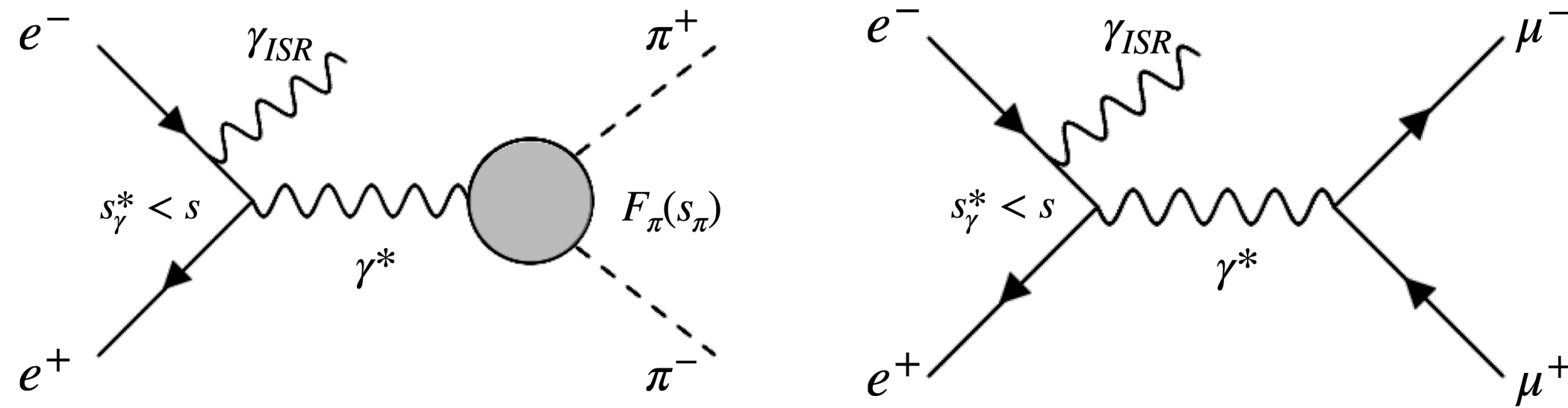
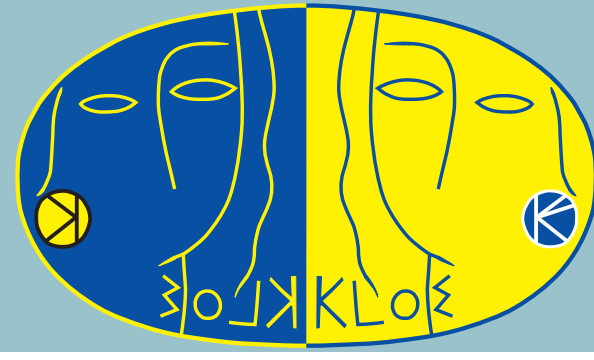
$$\Delta^{\pi\pi} a_\mu = \frac{1}{4\pi^3} \int_{s_{min}}^{s_{max}} ds \sigma_{\pi\pi}^0(s) K(s)$$



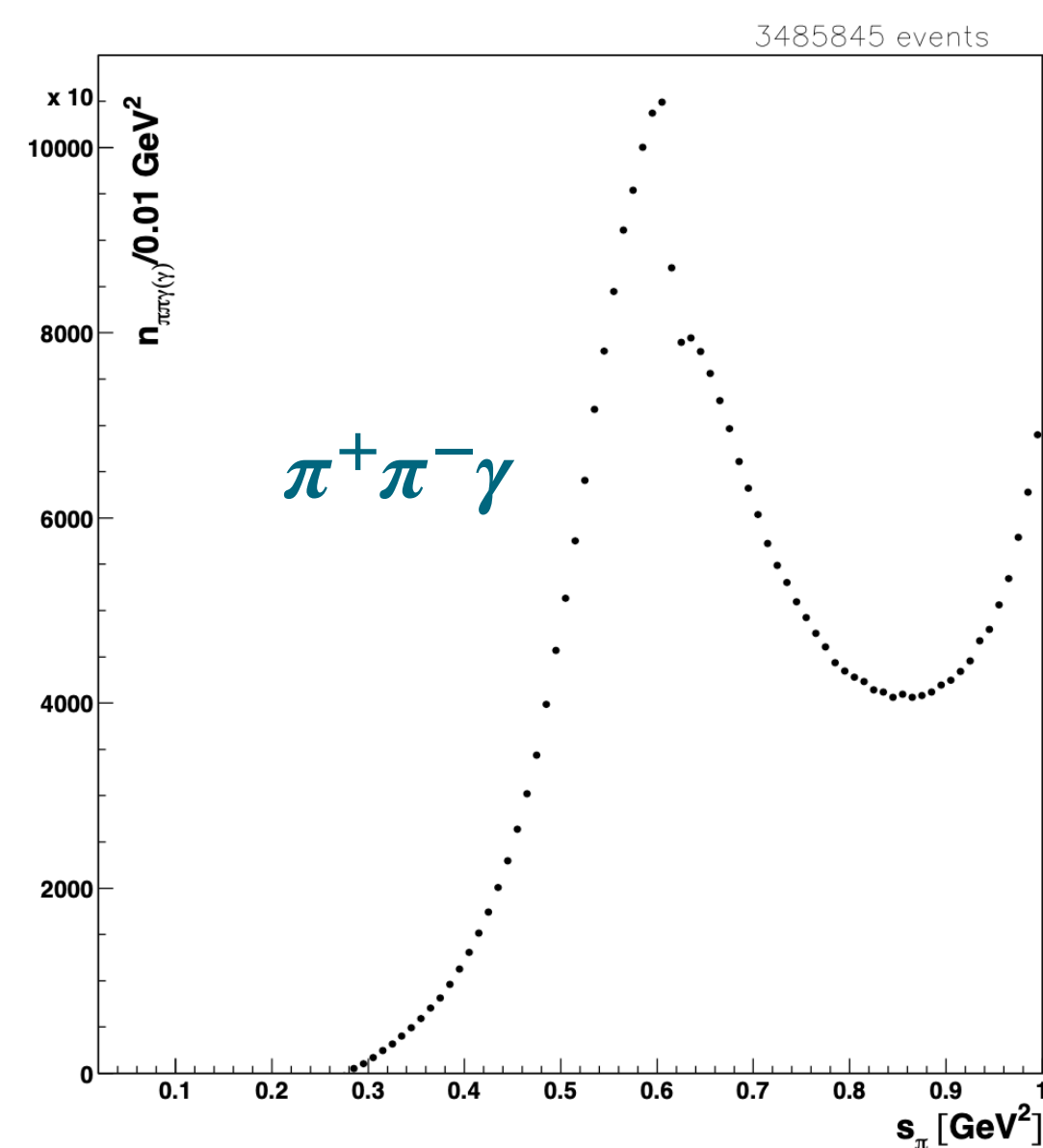
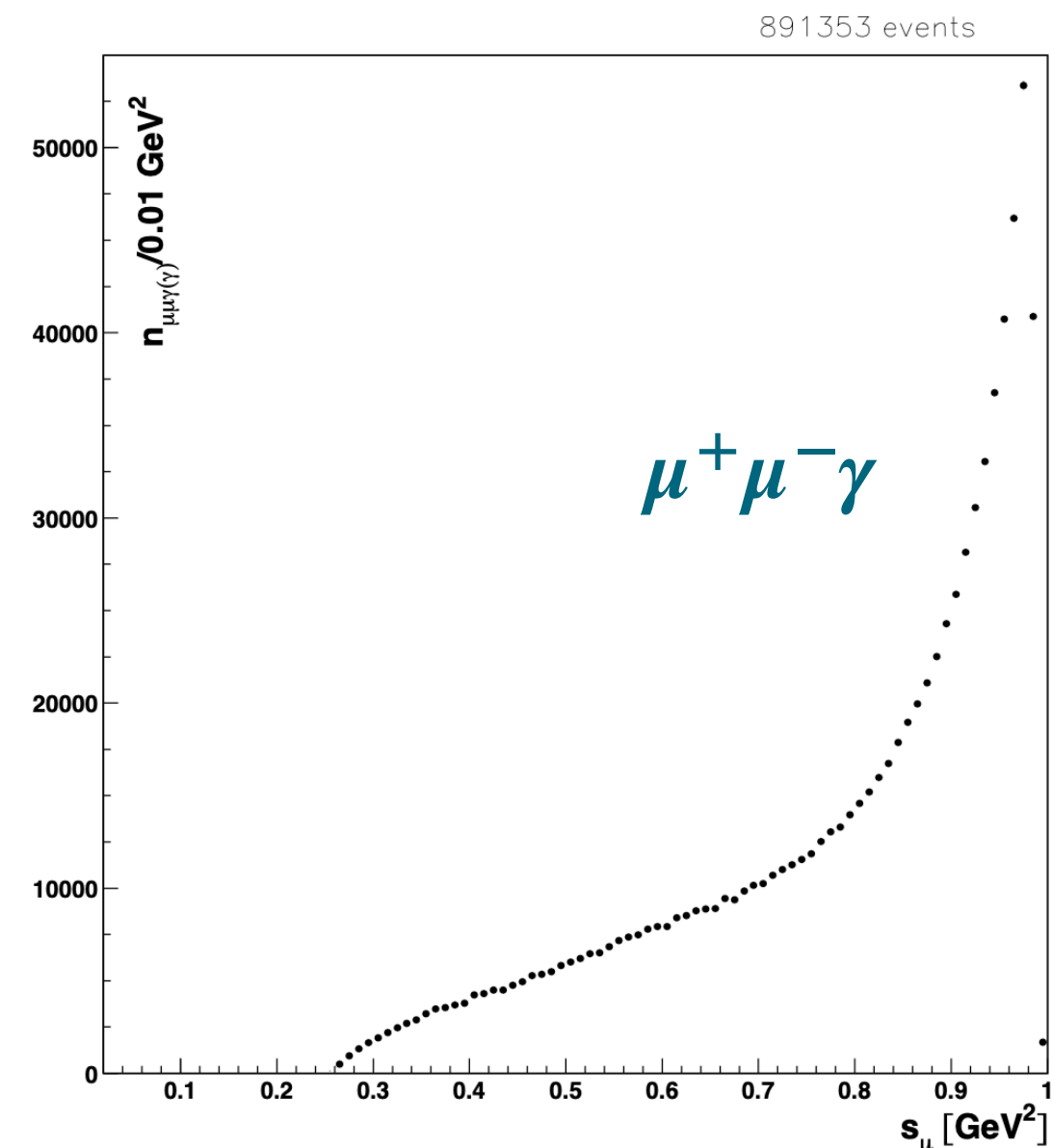
From KLOE08

Figure 42: Left: Cross section for the  $e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma)$  process, inclusive in  $\theta_\pi$  and with  $0^\circ < \theta_{\pi\pi} < 15^\circ$  or  $165^\circ < \theta_{\pi\pi} < 180^\circ$ . Right: *Bare* cross section for  $e^+e^- \rightarrow \pi^+\pi^-$ .

# Previous KLOE $\Delta^{\pi\pi} a_\mu$ Analyses: KLOE12



$$\sigma_{\pi\pi(\gamma)}(s) = \sigma_{\mu\mu(\gamma)}(s) \frac{d\sigma_{\pi\pi\gamma}^{ISR}/ds}{d\sigma_{\mu\mu\gamma}^{ISR}/ds}$$

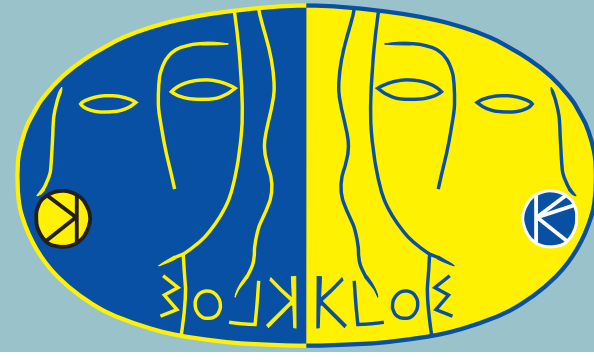


From KLOE12

## KLOE12

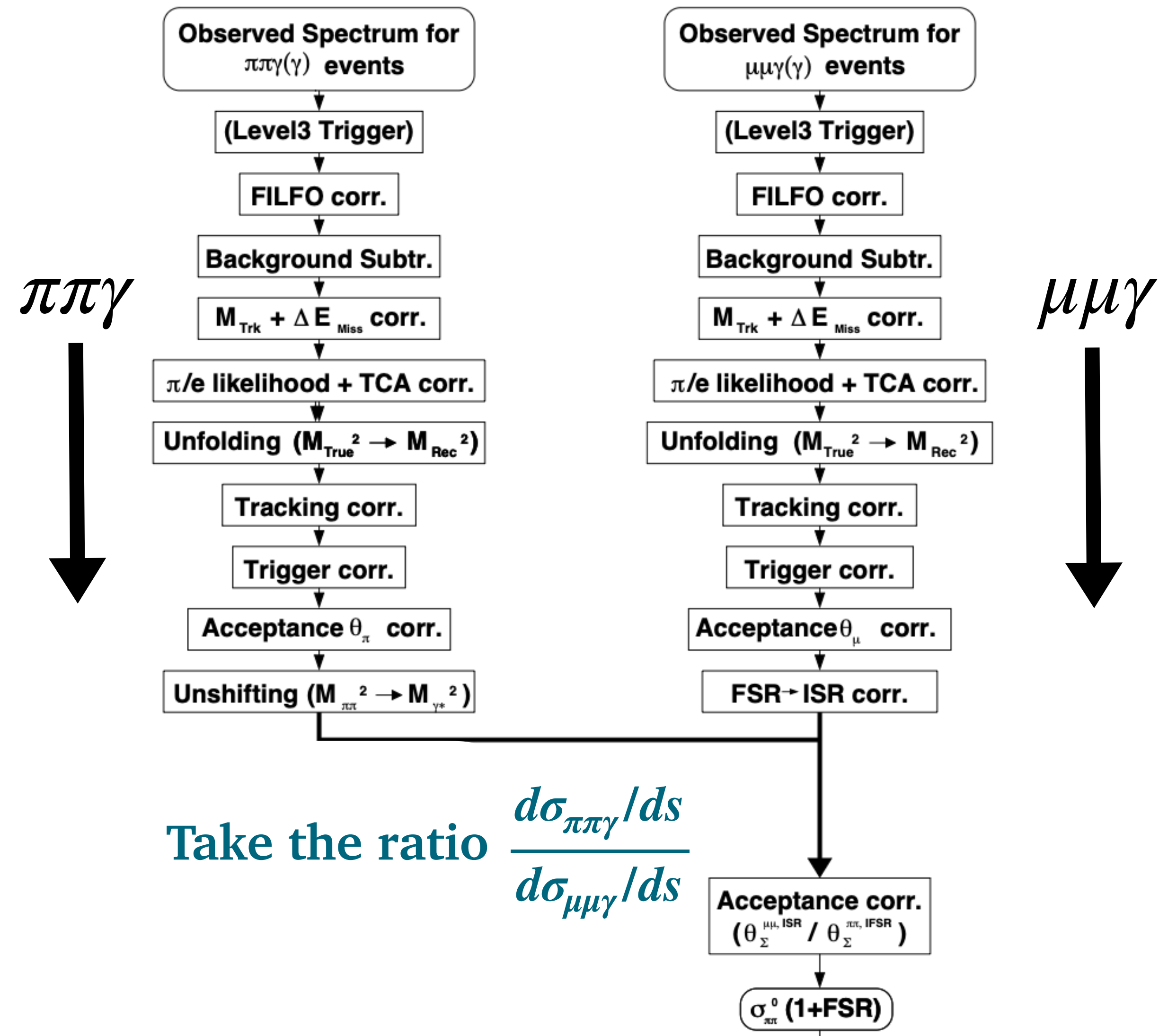
- Measure 60 points of  $s$  between 0.35 and 0.95  $\text{GeV}^2$
- 240.0  $\text{pb}^{-1}$  from 2002 run
- 2 charged tracks (pions) at large angles  $50^\circ < \theta_\pm < 130^\circ$
- *Untagged* photon at Small Angle using kinematics  $\vec{p}_{miss} \equiv -(\vec{p}_+ + \vec{p}_-) \rightarrow \theta_{miss} < 15^\circ \vee \theta_{miss} > 165^\circ$
- Topology enhances ISR and suppresses FSR and  $\phi \rightarrow \pi^+ \pi^- \pi^0$  background
- Topology cannot reach dipion threshold  $s = 4m_\pi$
- **Normalise to  $\mu\mu\gamma$  cross section**  $\rightarrow$  “ratio approach”
- Compatible with KLOE08 and KLOE10 despite different systematics

# A New Measurement: *KLOE-NXT*

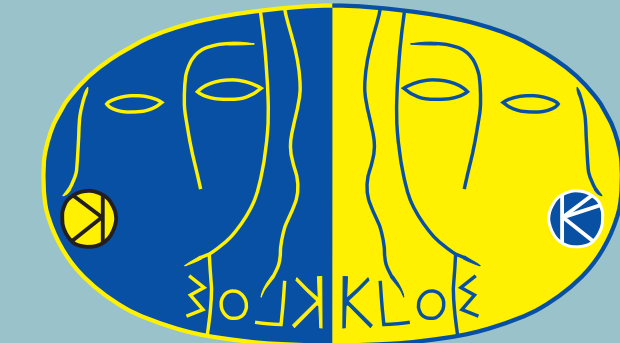


## KLOE-NXT (objective)

- Measure 60 points of  $s$  between 0.35 and 0.95 GeV<sup>2</sup>
- Same selections as KLOE08 and KLOE12
- Normalise to  $\mu\mu\gamma$  cross section as in KLOE12
- Use  $\sim 1.7\text{fb}^{-1}$  from 2004-2005 runs (7x statistics)
- Use 2006 dataset for cross-checks
- *Blind* the final result during analysis
- Use much newer MC generators, e.g. PHOKHARA v10, BABAYAGA@NLO, etc (see tomorrow's talks!)
- Use new updated reconstruction simulation
- Make use of higher statistics to improve on systematics

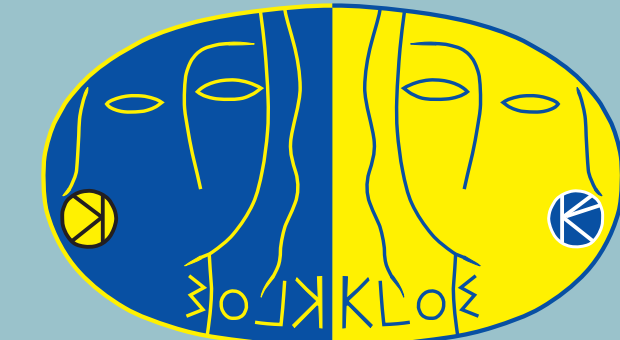


# Precision Goal of *KLOE-NXT*



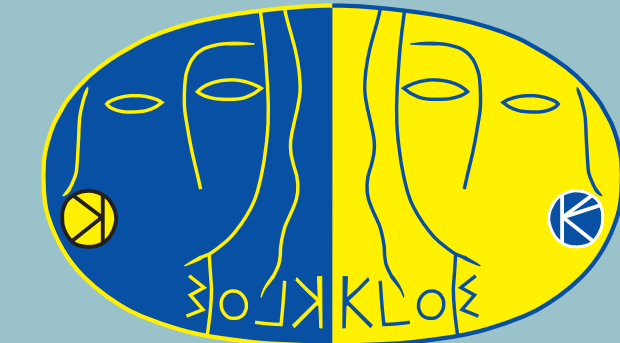
Syst Errors (%)	$a_{\mu\pi\pi}$ absolute (KLOE08)	$a_{\mu\pi\pi}$ ratio (KLOE12)	Expected <b>KLOE-NXT</b>
Background Filter (FILF0)	negligible	negligible	negligible
Background Subtraction	0.3	0.6	<b>0.2</b>
Trackmass	0.2	0.2	0.2
Particle ID	negligible	negligible	negligible
Tracking	0.3	0.1	0.1
Trigger	0.1	0.1	0.1
Unfolding	negligible	negligible	negligible
Acceptance ( $\theta_{\pi\pi}$ )	0.2	negligible	negligible
Acceptance ( $\theta_{\pi}$ )	negligible	negligible	negligible
Software Trigger (L3)	0.1	0.1	0.1
Luminosity	0.3 (0.1 <sub>th</sub> $\oplus$ 0.3 <sub>exp</sub> )	-	-
$\sqrt{s}$ dep. of $H$	0.2	-	-
Total exp. systematics	0.6	0.7	<b>0.3</b>
Vacuum Polarisation	0.1	-	-
FSR treatment	0.3	0.2	0.2
Rad. function $H$	0.5	-	-
Total theory systematics	0.6	0.2	0.2
Total systematic error	0.9	0.7	<b>0.4</b>

- With 7x statistics the final precision will be limited by systematics
- Substantial increase in statistics should allow for improvement of systematics and additional cross checks
- Main systematic comes from **background subtraction** → final goal is to reduce it by 3x leveraging increased statistics and new methods
- Final uncertainty goal:
  - KLOE12 :  $0.7\%_{syst} \oplus 0.2\%_{th} \oplus 0.3\%_{stat} = 0.8\%_{tot}$
  - KLOE-NXT goal :  $0.3\%_{syst} \oplus 0.2\%_{th} \oplus 0.1\%_{stat} = 0.4\%_{tot}$



- KLOE computing in LNF heavily relied on outdated IBM infrastructure, including the old tape library storing KLOE-1 data
- Two partitions of the tape library failed and other machines/subsystems failed in early 2024 , halting progress on the ongoing KLOE-NXT analysis
- Solutions were limited due to low personnel numbers and irreplaceable hardware
- **Good news!** Thanks to the effort of our group and the KLOE-2 computing personnel:
  - 90% of KLOE-1 data has been migrated to CNAF
  - One partition of the tape library has been fully restored (other is WiP)
  - Working environments have been setup both in CNAF computing center (Bologna) and Liverpool
  - Code has been ported to git and KLOE software moved to Linux infrastructure
  - **First KLOE-1 data re-processing and Monte Carlo production on Linux machines now complete!**

# Tuning of Monte Carlo Simulation

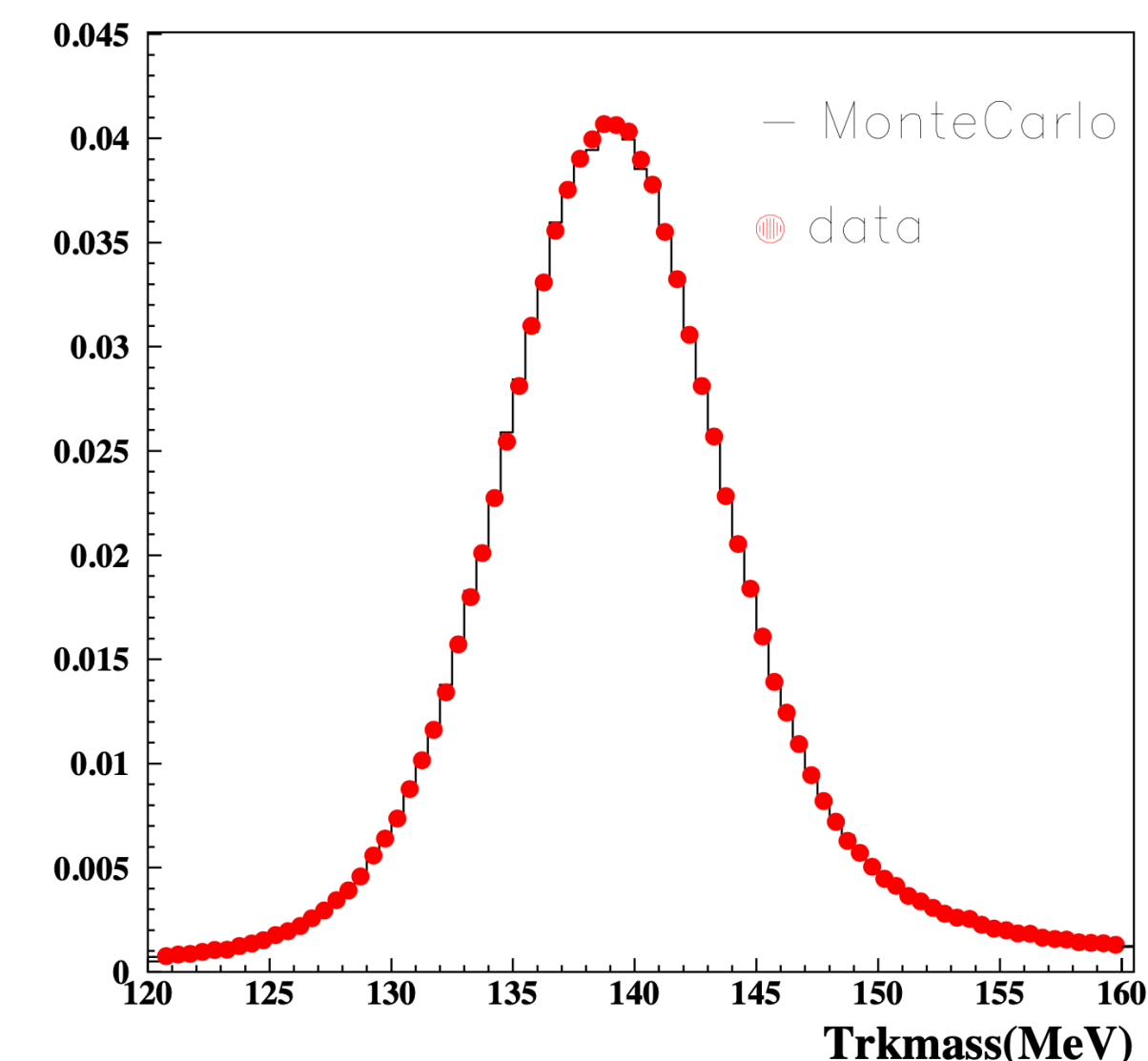
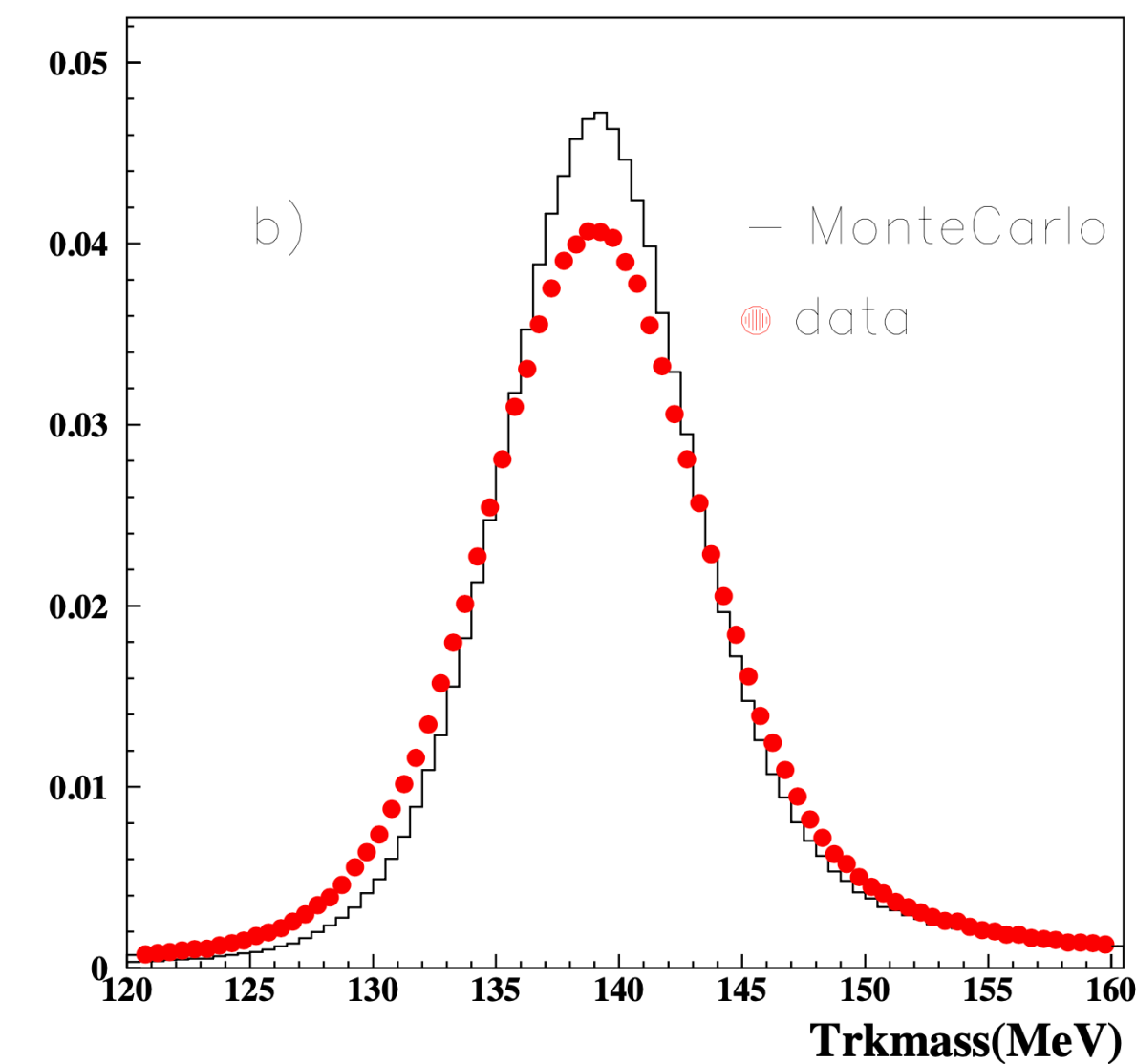


- Monte Carlo simulations are a cornerstone of the KLOE-NXT analysis (e.g. background subtraction, tracking efficiency, ...) → data-MC consistency is crucial for an accurate measurement
- Raw MC simulation is clearly discrepant w.r.t. data in observables frequently used in the analysis, such as *trackmass*  $M_{trk}^*$
- Previous KLOE08/KLOE12 analyses corrected the MC by shifting/smearing the charged tracks' momenta  $p_{x,y,z}^\pm$
- Corrections tuned by comparing  $M_{trk}$  distributions between data and Monte Carlo in the  $\pi^+\pi^-\gamma$  signal channel

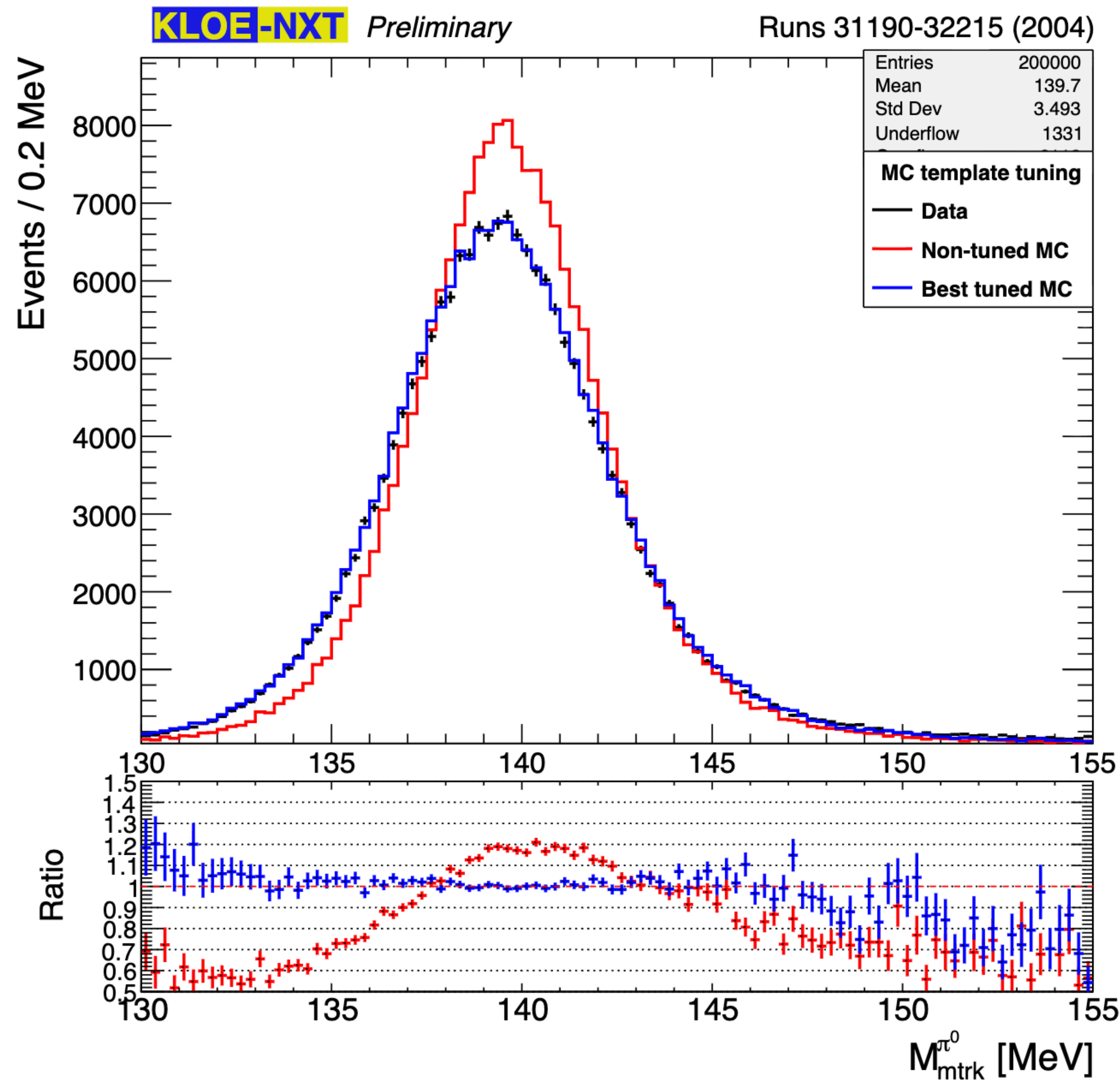
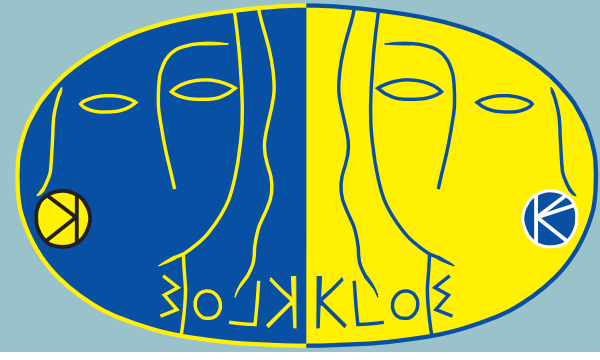
\*Estimates mass of  $X^\pm$  particle in events  $e^+e^- \rightarrow X^+X^-(\gamma)$

$$\left( E_\phi - \sqrt{p_+^2 + M_{trk}^2} - \sqrt{p_-^2 + M_{trk}^2} \right)^2 - \left| \vec{p}_\phi - \vec{p}_+ - \vec{p}_- \right|^2 \equiv 0$$

From B. Valeriani's PhD thesis

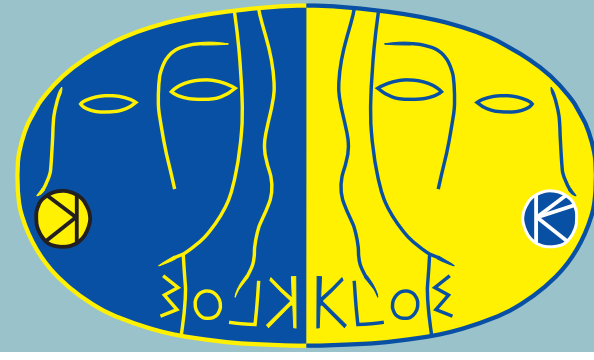


# Tuning of Monte Carlo Simulation

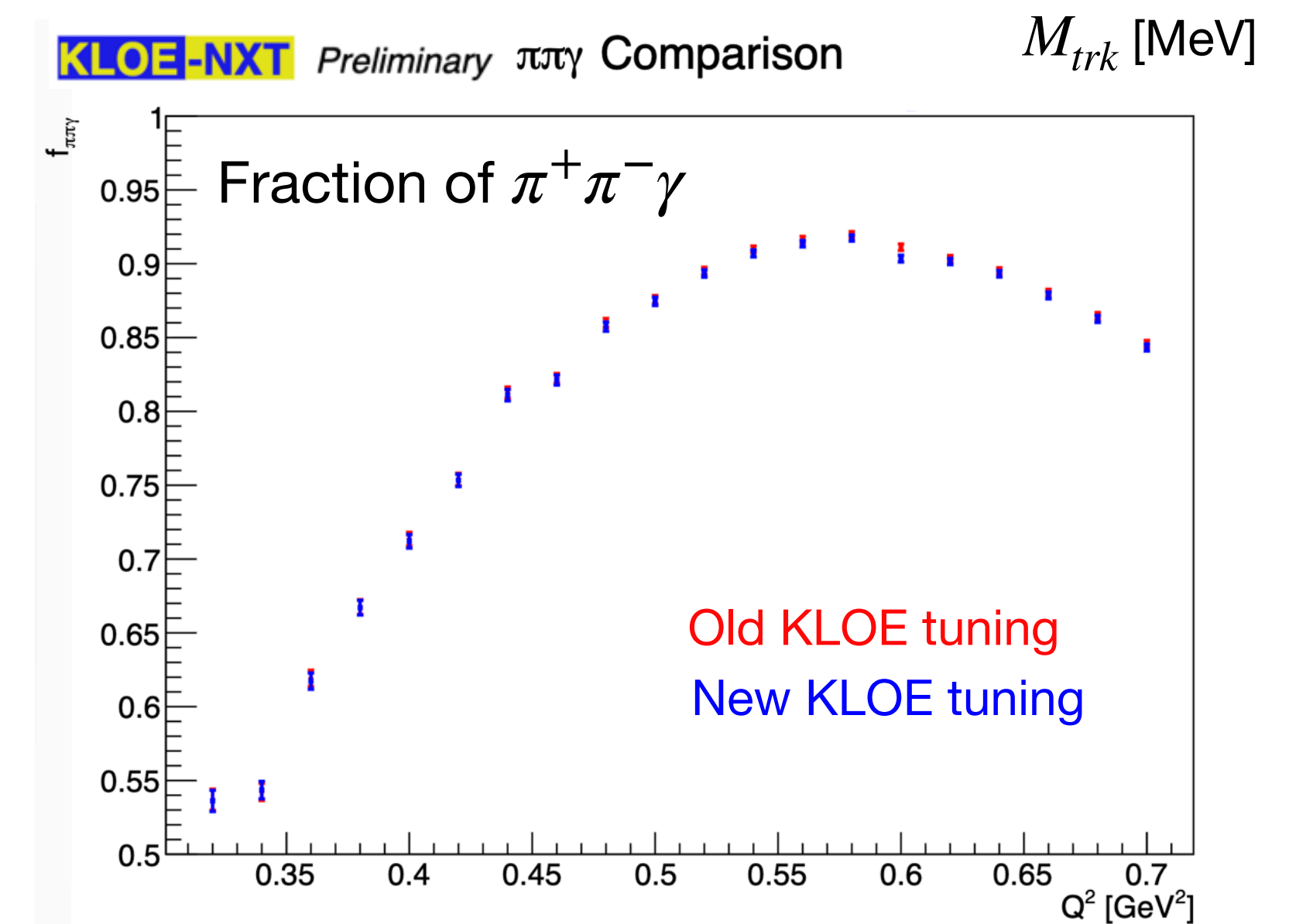
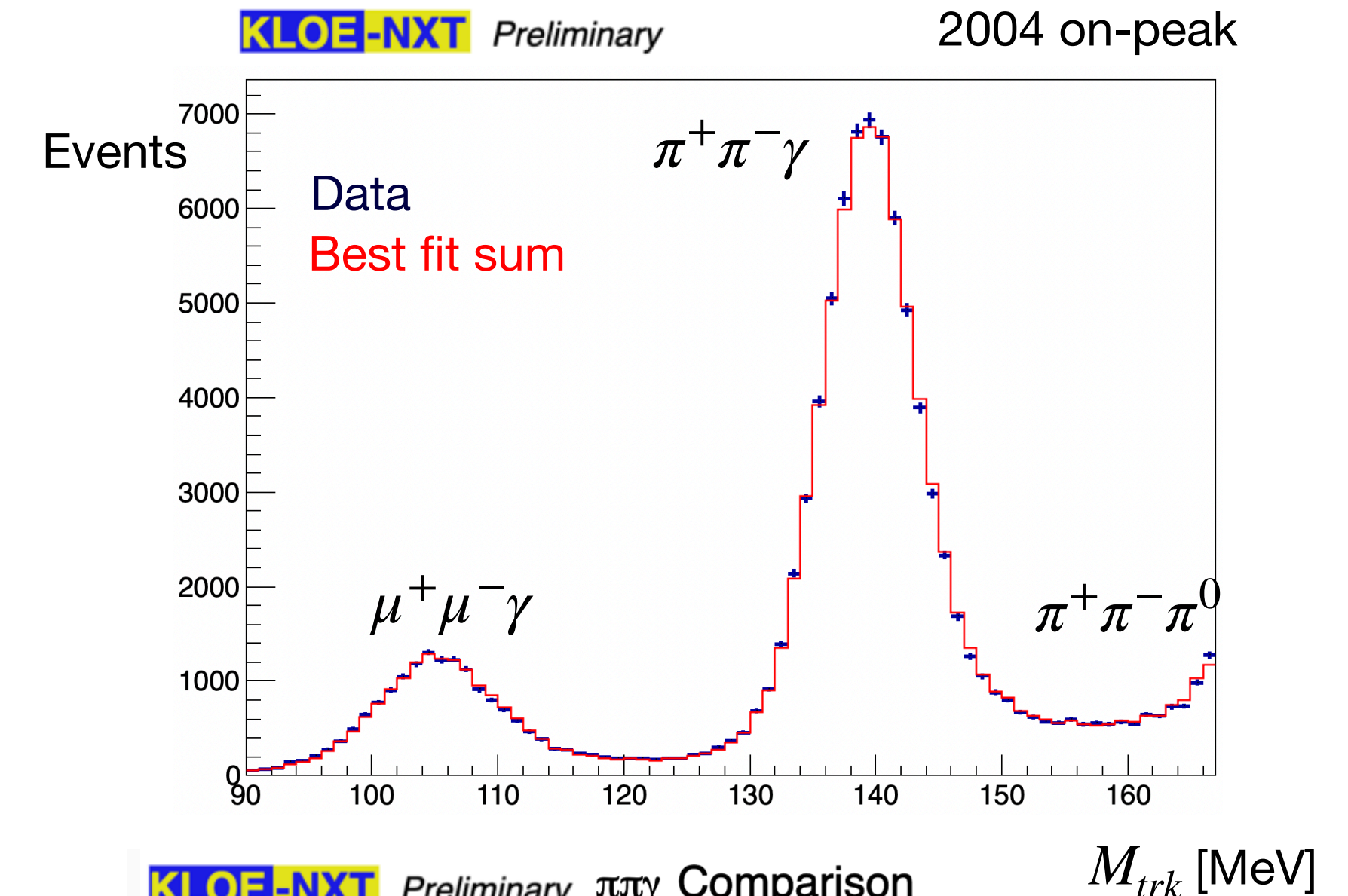


- **New tuning method currently being tested:**
  - Uses independent control channels such as  $\pi^+\pi^-\pi^0$  and  $\pi^+\pi^-$  instead of signal channel
  - Corrections applied to lower level track variables  $\{\kappa, \theta, \varphi\}$  instead of  $\{p_x, p_y, p_z\}$
- Correction takes the form of additive or multiplicative Gaussian terms applied to Monte Carlo events
- Gaussian parameters  $\{\mu, \sigma\}$  define the correction, found via template fit by  $\chi^2$  comparison of  $M_{\text{trk}}$  distributions with data
- Still many issues to tackle but promising results achieved so far

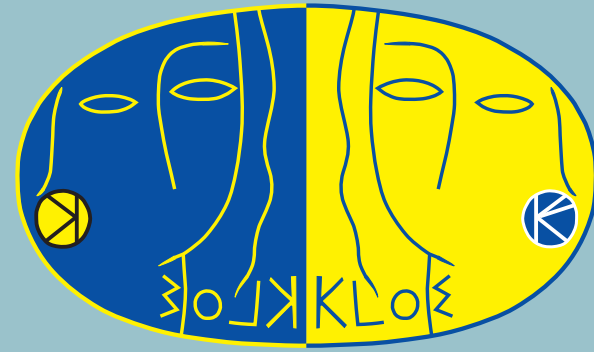
# Background Subtraction



- Despite signal selection cuts, residual background events survive from
  - $e^+e^- \rightarrow \mu^+\mu^-\gamma$
  - $e^+e^- \rightarrow e^+e^-\gamma$
  - $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
- Fraction of signal events estimated from a maximum likelihood template fit using the shapes of  $M_{trk}$  distributions coming from MC simulation of the channels  $\rightarrow$  *requires tuning the MC simulation beforehand*
- Fit performed separately in bins of  $M_{\pi\pi}^2 \rightarrow$  scale each bin by  $(1 - f_{bkg})$
- Replicated results of old KLOE08 fit procedure. Now working on:
  - Fitting other variables simultaneously to reduce error on fractions
  - Using new tuning for MC instead of the old one
  - Using new MC generators (e.g. BABAYAGAGA@NLO) for the distributions used in the fit

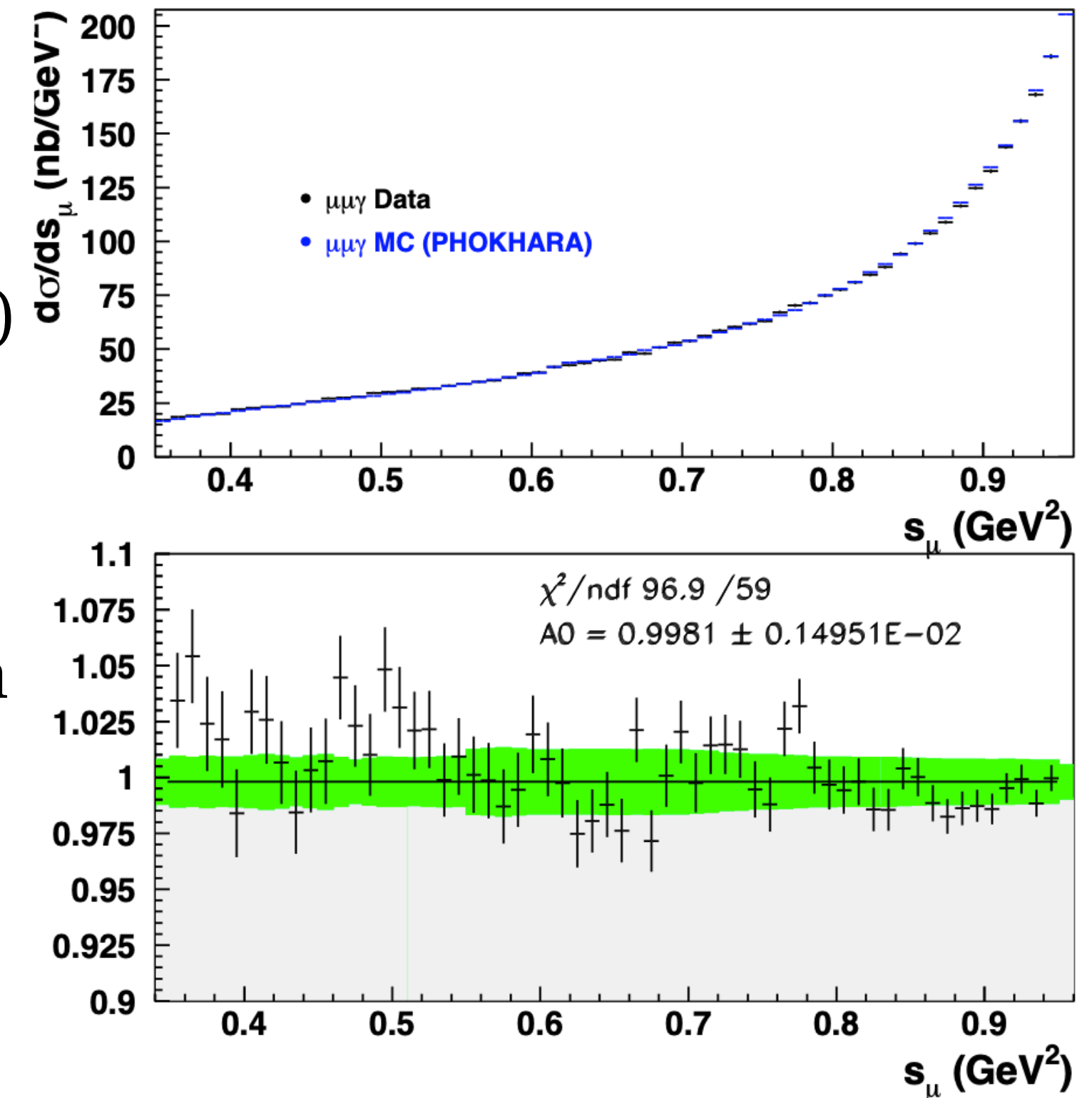


# Luminosity Studies: Why Luminosity?



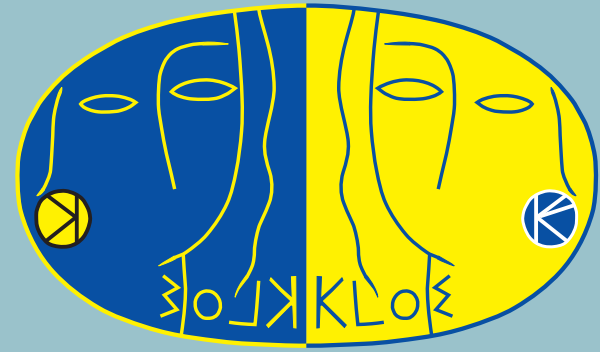
- Even in the *ratio approach* an important analysis cross check is the comparison between measured  $\mu\mu\gamma$  cross section and expectation from QED
- This test requires **measuring luminosity**  $\rightarrow$  Very Large Angle Bhabha (VLAB) events  $e^+e^- \rightarrow e^+e^-$  used due to high statistics and excellent theoretical precision of the process ( $\sigma_{eff}^{VLAB}$ )
- Previous luminosity measurement based on a 2006 KLOE study on 2001 data  $\rightarrow$  we intend to:
  - Analyse 2002, 2004, 2005, and 2006 datasets separately
  - Use the latest version of the BABAYAGA@NLO MC generator
  - Perform an independent cross check using the  $e^+e^- \rightarrow \gamma\gamma$  process
- Dedicated MC corrections to improve EMC cluster data/MC consistency are being studied

From KLOE12

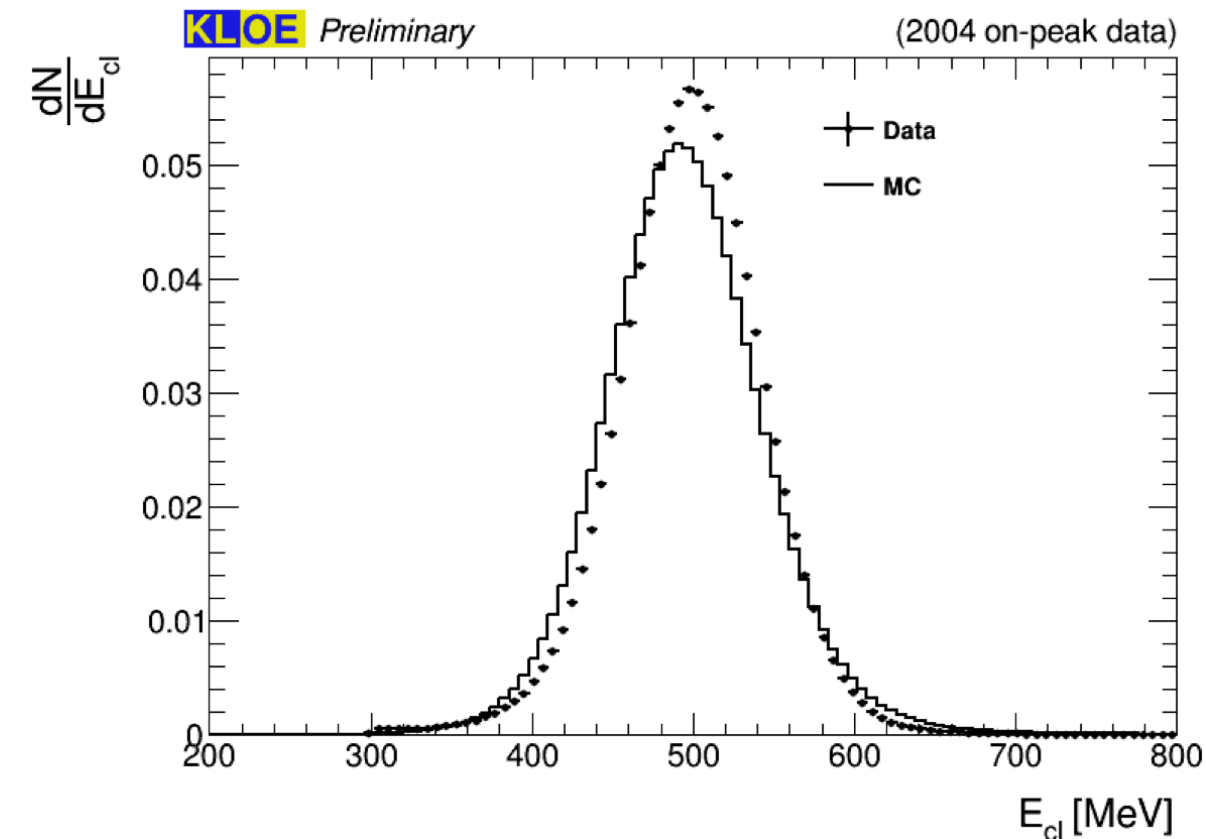


$$\int \mathcal{L} dt = \frac{N_{OBS}^{VLAB} - N_{bkg}^{VLAB}}{\sigma_{eff}^{VLAB}}$$

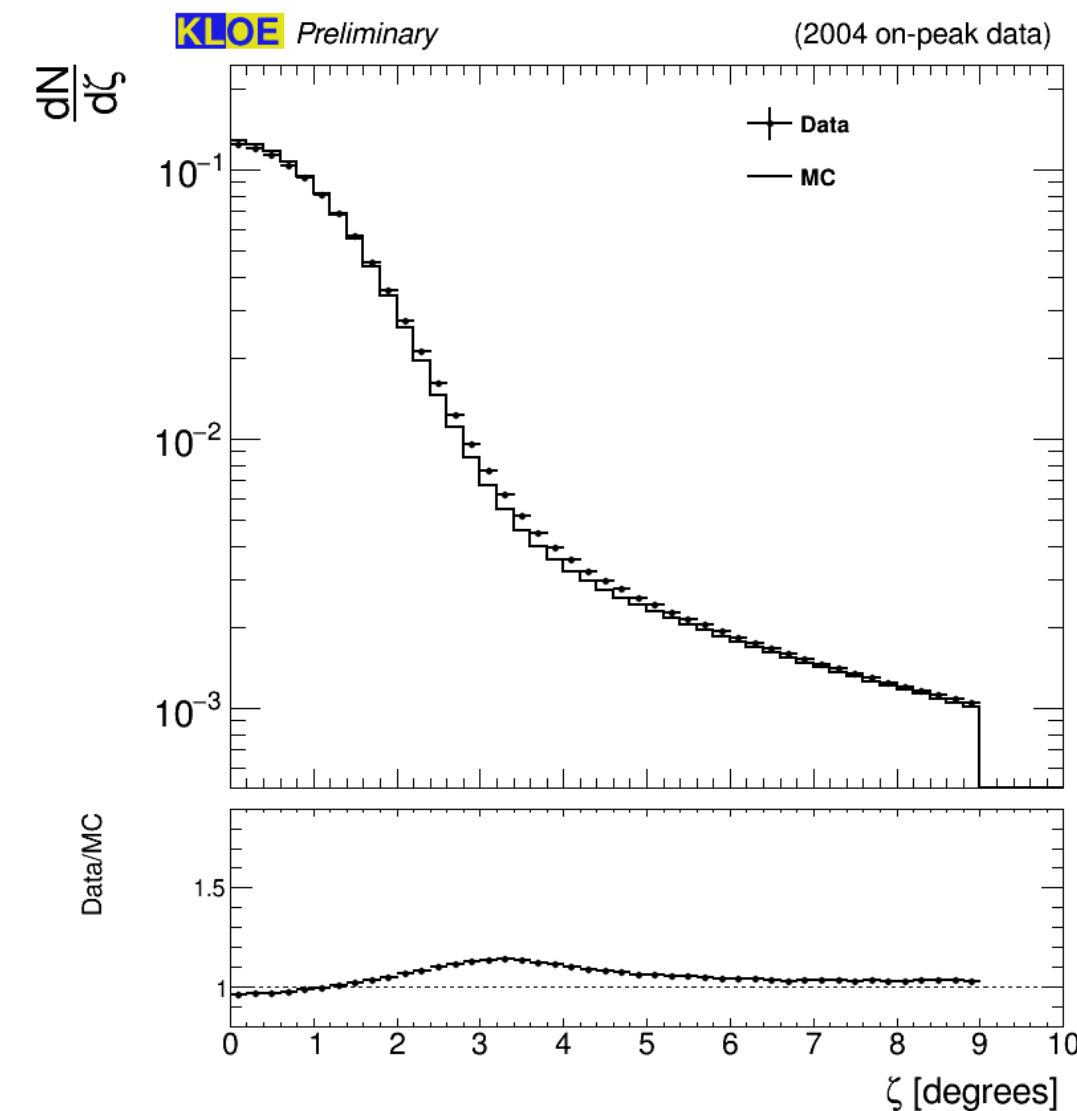
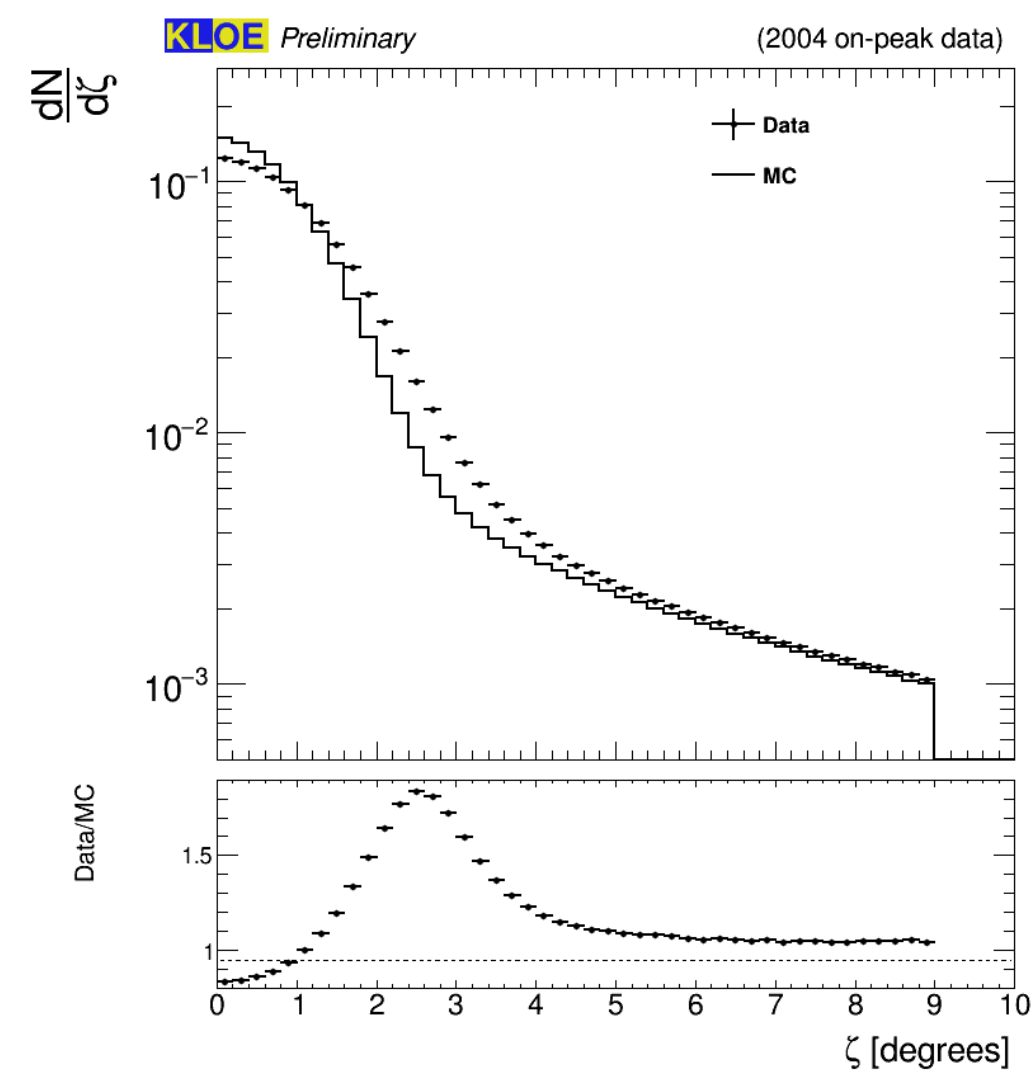
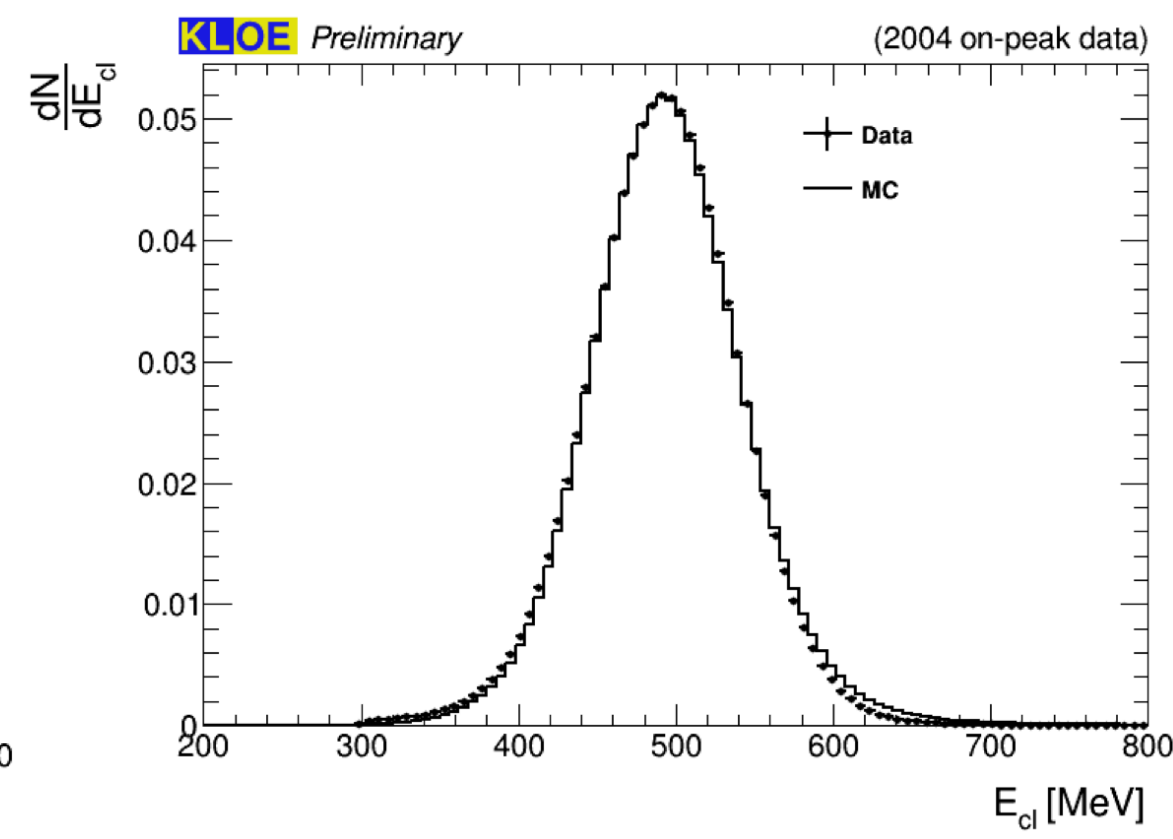
# Luminosity Studies: Cluster Corrections



## Before Corrections



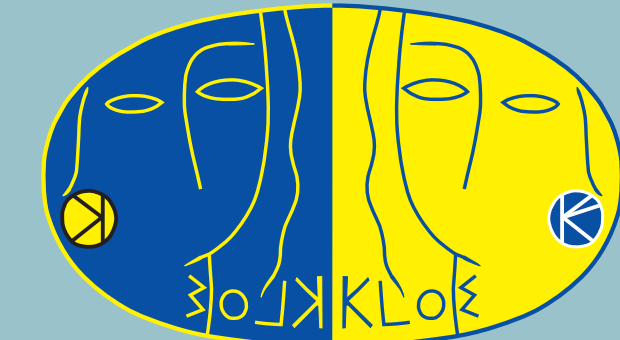
## After Corrections



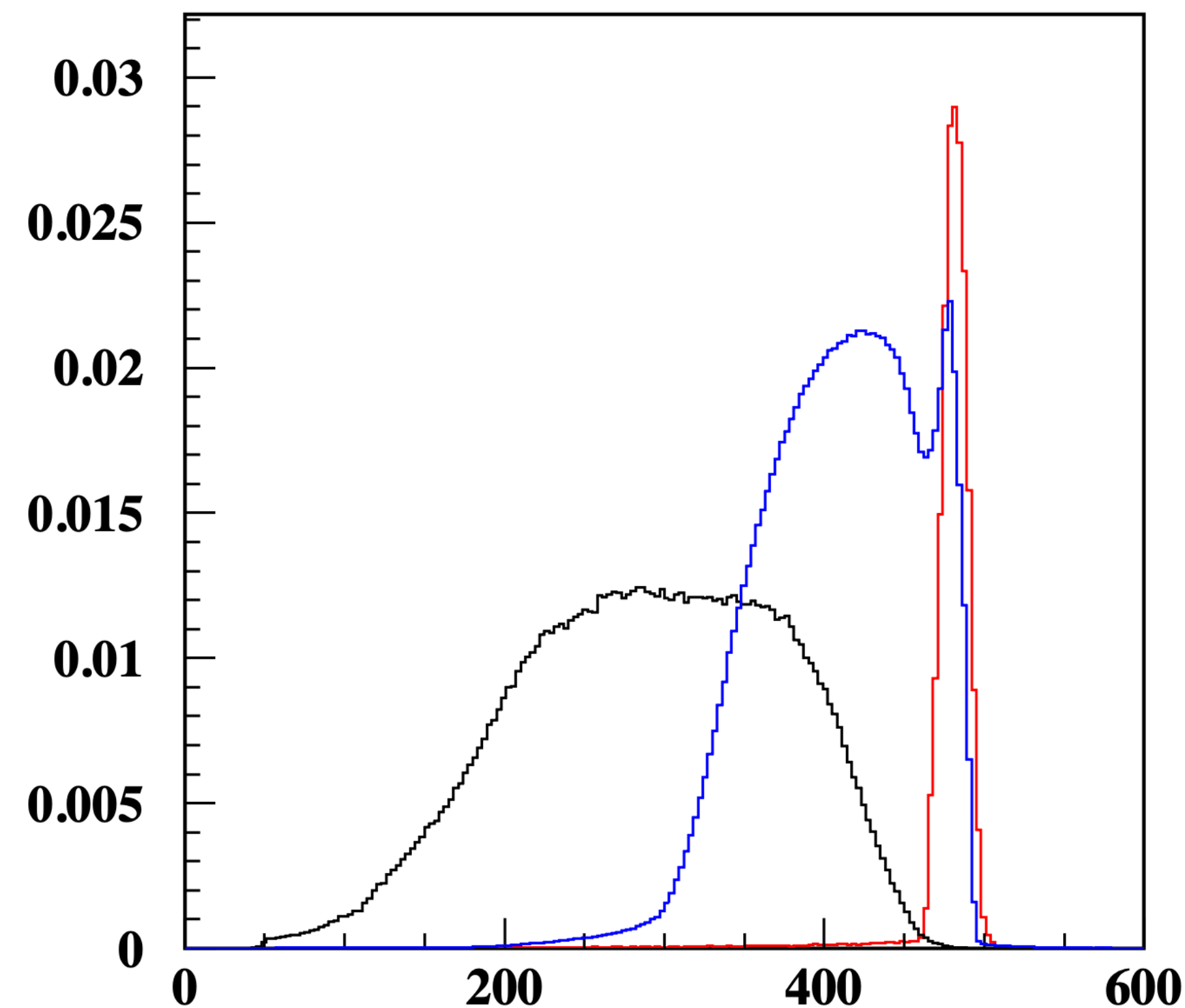
Acollinearity between clusters

- Corrections to Monte Carlo simulation of cluster position and energy are being developed
- For cluster energy a simple single Gaussian smearing is applied to data, obtained directly from a fit of both data and MC
- For cluster position, angles are corrected based on the data/MC discrepancy in resolution
- Cluster angles are compared with the extrapolated angle from the drift chamber track fit
- Discrepant data/MC  $\theta$  resolutions are corrected with a double gaussian fit
- Working on evaluating the respective systematics

# Tracking Efficiency

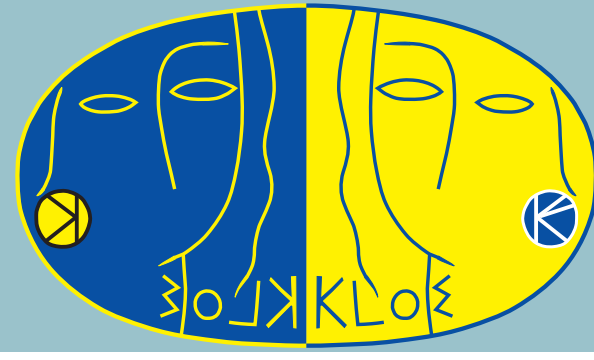


- An important systematic is related to tracking efficiency
- In order to span a wide range of momenta and evaluate systematic error, multiple channels are used
  - $\pi^+\pi^-\gamma$  and  $\mu^+\mu^-\gamma$  (signal)
  - $\pi^+\pi^-\pi^0$
  - $\pi^+\pi^-$  (**new!**)
- Efficiency is evaluated both on data (with ad hoc selections) and on Monte Carlo simulation as a function of  $M_{\pi\pi}^2$  and  $M_{\mu\mu}^2$  respectively
- Efficiency studies currently underway to:
  - Optimise selections
  - Use newer Monte Carlo generators
  - Exploit collinear  $\pi^+\pi^-$  events



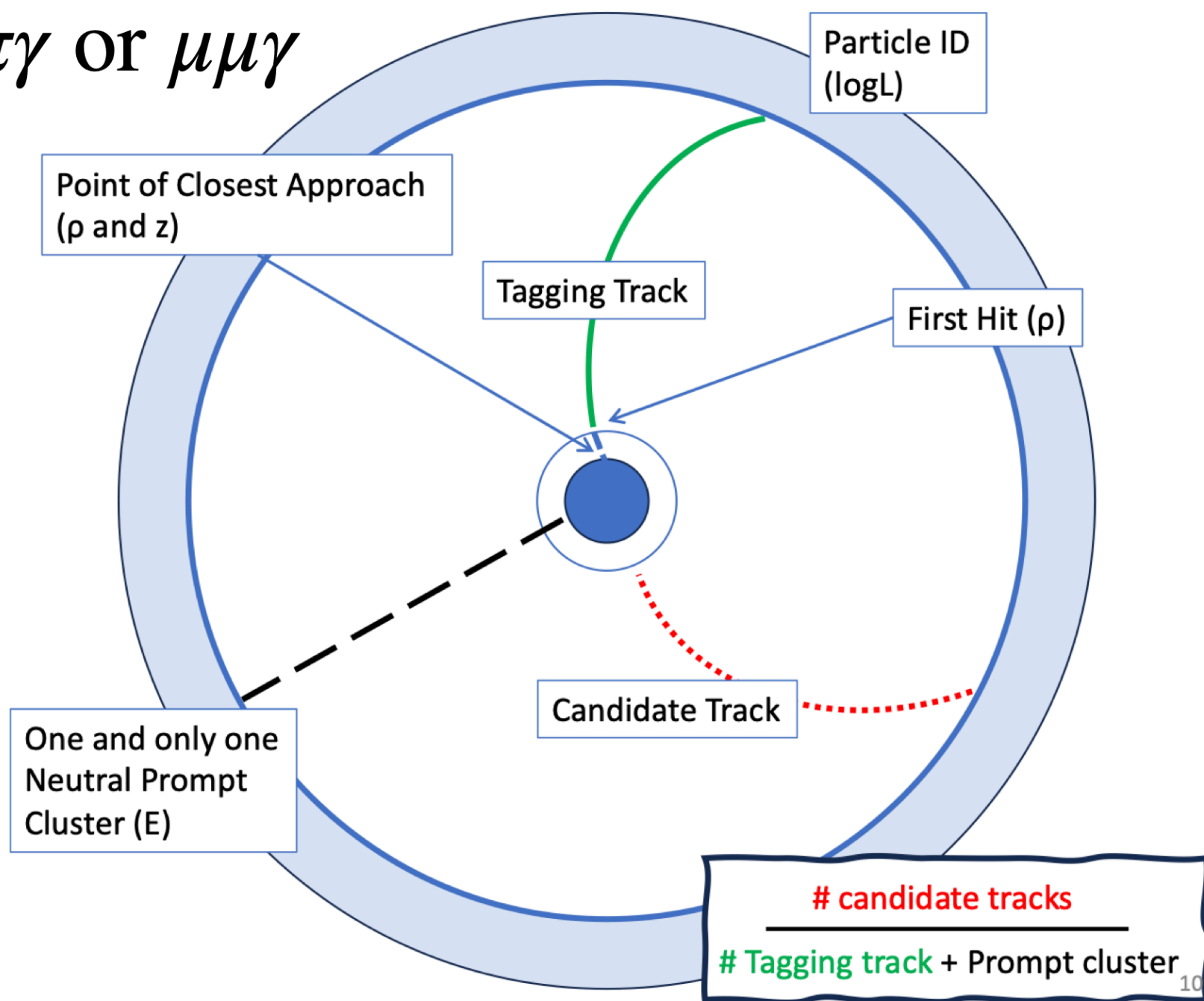
b)  $\pi^+, \pi^-$  momentum

# Tracking Efficiency

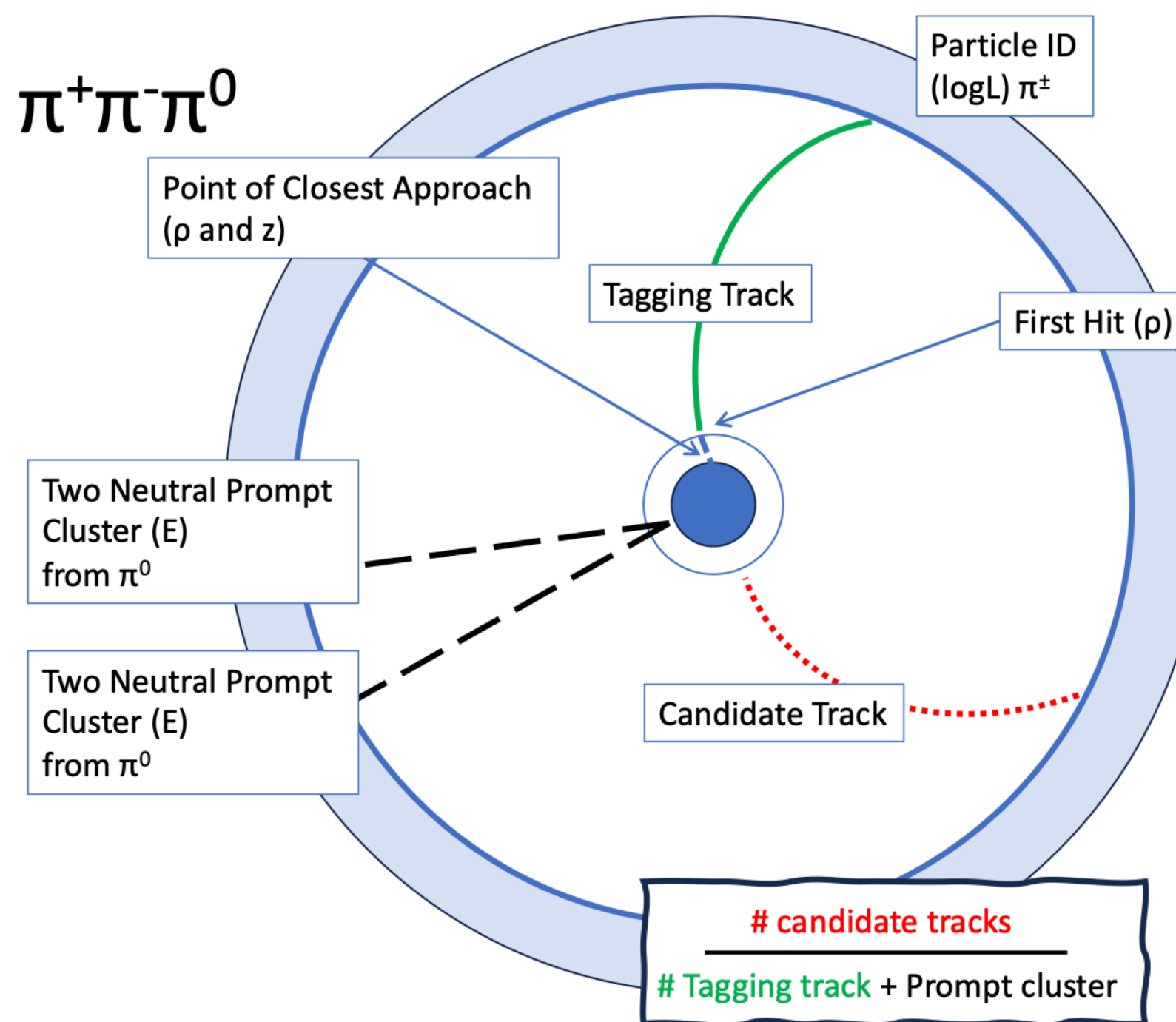


- Different selections for different topologies:

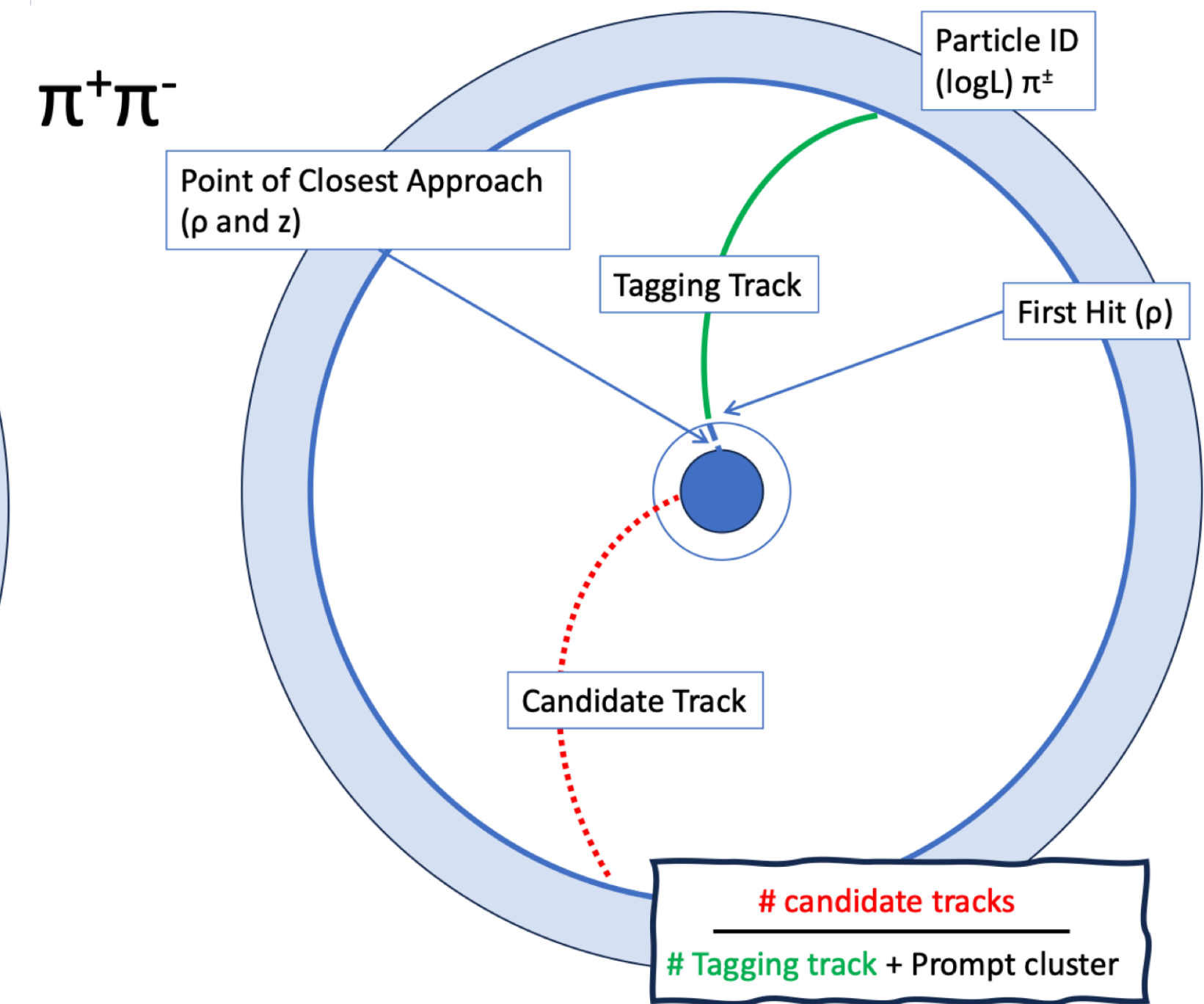
$\pi\pi\gamma$  or  $\mu\mu\gamma$

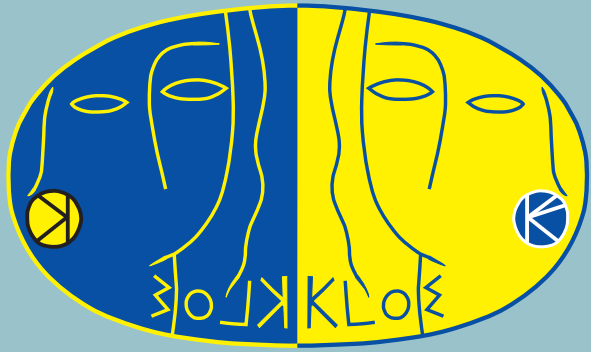


$\pi^+\pi^-\pi^0$



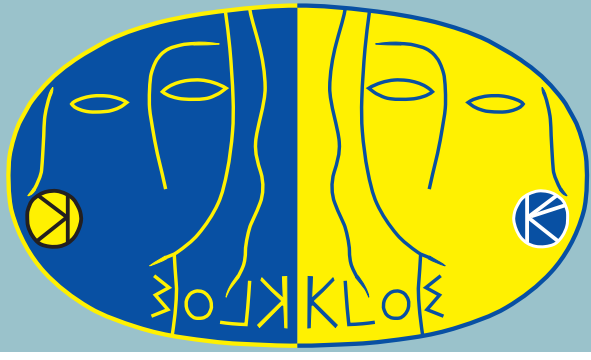
$\pi^+\pi^-$





- KLOE provided input to the 2025 Muon  $g - 2$  Theory Initiative White Paper
- Tested the effect of **Radiative Corrections** (RCs) by comparing available generators with PHOKHARA v10 @NLO in the channels  $\mu^+\mu^-\gamma(\gamma)$  (ISR+FSR) and  $\pi^+\pi^-\gamma(\gamma)$  (ISR only)
- Multiple selection cuts tested, small angle undetected photons (KLOE08/KLOE12) and large angle detected photons (KLOE10) with and without signal cut on  $M_{trk}$
- Results on simplified scenarios (i.e. no detector effects simulation) **do not suggest that PHOKHARA precision can explain HVP discrepancies** in the pion case
- Current work on RCs:
  - Update previous studies to compare with newest version of BABAYAGA@NLO
  - MC comparisons with detector effects **included**, interfacing new generators with KLOE's GEANFI
  - Ongoing work on resummation of soft photon effects in Phokhara *(see Pau's talk!)*
  - Phokhara now includes GVMD, important in pion scenario comparisons

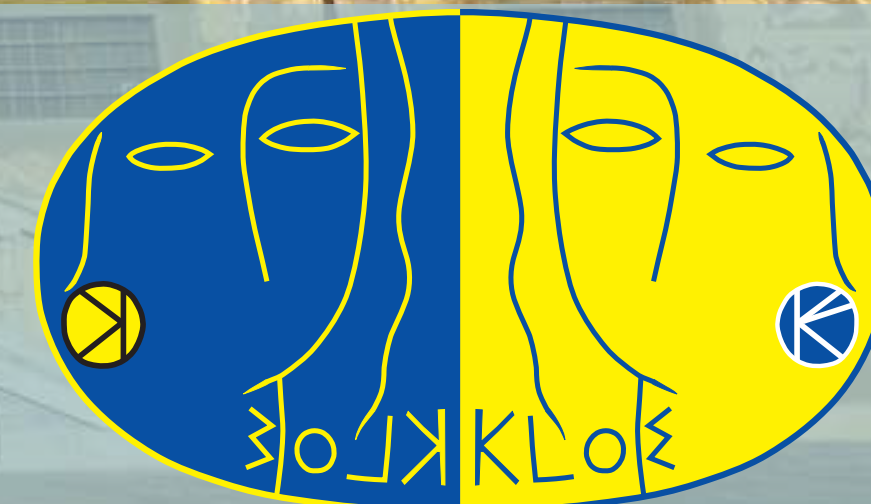
# Conclusions and Outlook



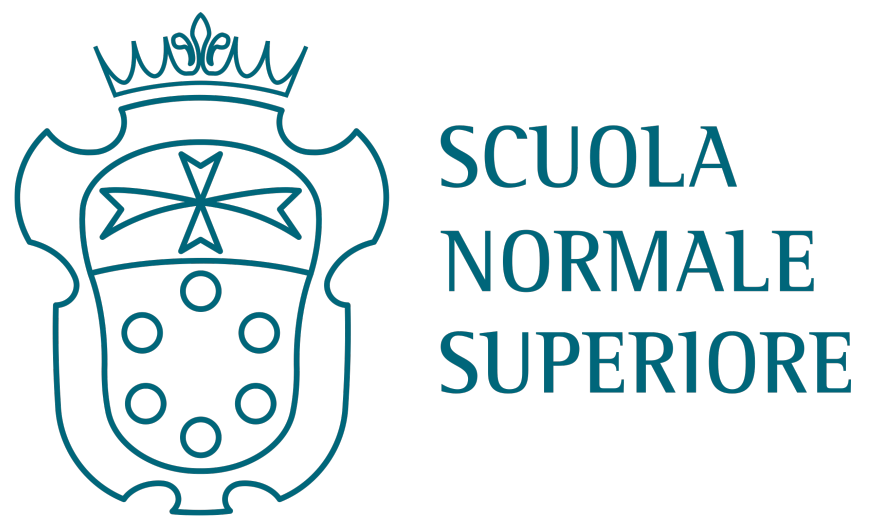
- KLOE-NXT is the new  $\Delta^{\pi\pi}a_\mu$  analysis by KLOE, using  $1.7 \text{ fb}^{-1}$  ( $\sim 25\text{M } \pi^+\pi^-\gamma$  events) of 2004-2005 data never used before for such purpose
- The 7x increase in statistics will make statistical uncertainty negligible and allow for improvement on the systematics
- **Final precision goal**: 3x reduction on the statistical uncertainty and 2x reduction on the systematic one, resulting in a total error of 0.4% on  $\Delta^{\pi\pi}a_\mu$
- The analysis will be conducted *blindly*, unlike previous KLOE  $\Delta^{\pi\pi}a_\mu$  analyses
- New Monte Carlo generators will be used, including (but not limited to) BABAYAGA@NLO and PHOKHARA v10 (see talks tomorrow!)
- Work is currently progressing on luminosity, tracking efficiency, MC tuning, background subtraction and collinear dataset studies
- There is also a 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



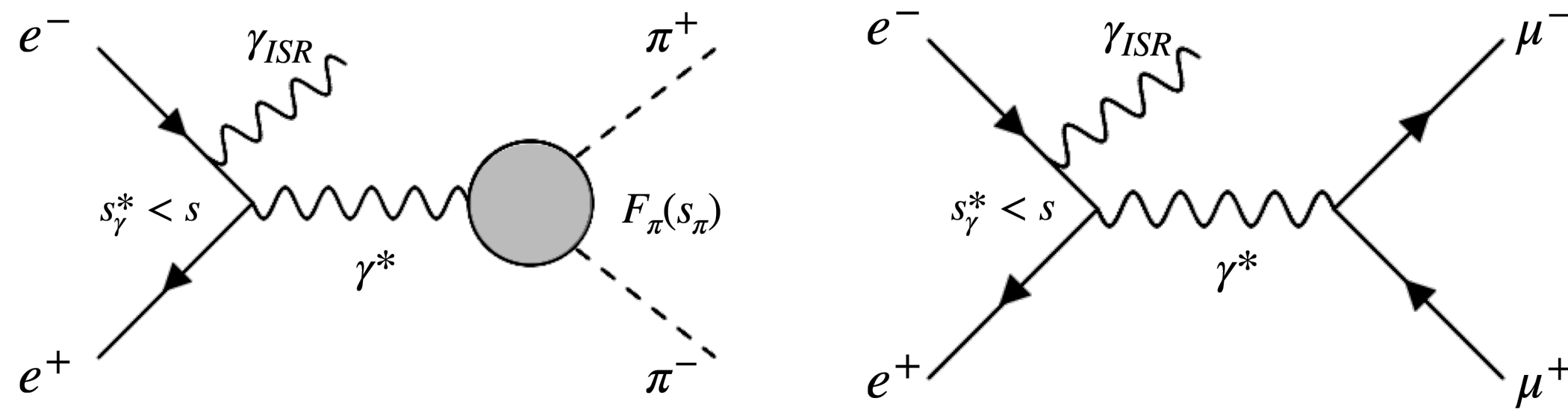
**Thank You!**



# Backup



# Previous KLOE $\Delta^{\pi\pi} a_\mu$ Analyses: KLOE12



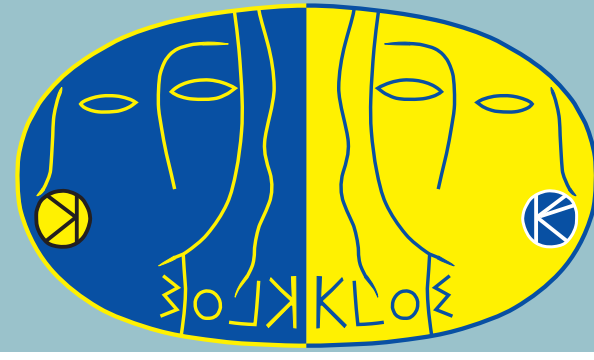
$$\sigma_{\pi\pi(\gamma)}(s) = \sigma_{\mu\mu(\gamma)}(s) \frac{d\sigma_{\pi\pi\gamma}^{ISR}/ds}{d\sigma_{\mu\mu\gamma}^{ISR}/ds}$$

$$\sigma_{\pi\pi}^0(s^*) = \frac{4\pi\alpha^2}{3s^*} \left( 1 + \frac{2m_\mu^2}{s^*} \right) \beta_\mu \frac{d\sigma_{\pi\pi\gamma}^{ISR}/ds^*}{d\sigma_{\mu\mu\gamma}^{ISR}/ds_\mu (1 - \eta_\mu(s_\mu))}$$

## KLOE12

- Measure 60 points of  $s$  between 0.35 and 0.95 GeV<sup>2</sup>
- 240.0 pb<sup>-1</sup> from 2002 run
- 2 charged tracks (pions) at large angles  $50^\circ < \theta_\pm < 130^\circ$
- Untagged photon at Small Angle using kinematics  $\vec{p}_{miss} \equiv -(\vec{p}_+ + \vec{p}_-) \rightarrow \theta_{miss} < 15^\circ \wedge \theta_{miss} > 165^\circ$
- Topology enhances ISR and suppresses FSR and  $\phi \rightarrow \pi^+\pi^-\pi^0$  background
- Cannot reach dipion threshold  $s = 4m_\pi$
- Normalise to  $\mu\mu\gamma$  cross section  $\rightarrow$  “ratio approach”
- Compatible with KLOE08 and KLOE10 despite different systematics

# Previous KLOE $a_{\mu}^{\pi\pi}$ Analyses: KLOE10



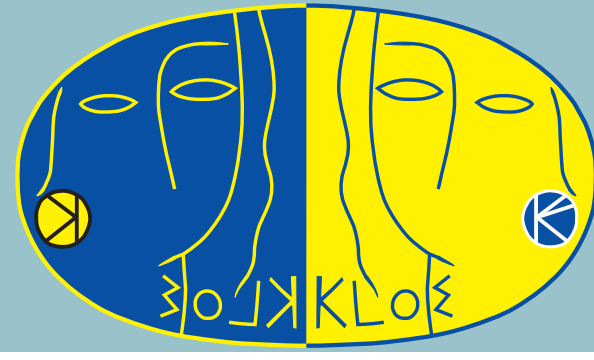
## KLOE08

- Measure 60 points of  $s$  between 0.35 and 0.95 GeV<sup>2</sup>
- 240.0 pb<sup>-1</sup> from 2002 run
- 2 charged tracks (pions) at large angles  $50^\circ < \theta_{\pm} < 130^\circ$
- Untagged photon at Small Angle using kinematics  
 $\vec{p}_{miss} \equiv -(\vec{p}_+ + \vec{p}_-) \rightarrow \theta_{miss} < 15^\circ \wedge \theta_{miss} > 165^\circ$
- Topology enhances ISR and suppresses FSR and  $\phi \rightarrow \pi^+\pi^-\pi^0$  background
- Cannot reach dipion threshold  $s = 4m_{\pi}$
- Cross section from normalisation to luminosity (Bhabha) and correction with radiator (PHOKHARA)

## KLOE10

- Measure 75 points of  $s$  between 0.10 and 0.85 GeV<sup>2</sup>
- 232.6 pb<sup>-1</sup> from 2006 off-peak data ( $\sqrt{s} \sim 1000$  MeV)
- 2 charged tracks (pions) at large angles  $50^\circ < \theta_{\pm} < 130^\circ$
- **Tagged photon** detected at large angle using EMC  $\rightarrow$   
 $50^\circ < \theta_{\gamma} < 130^\circ$
- Topology reaches much lower  $s$  at the cost of higher FSR and  $\phi \rightarrow \pi^+\pi^-\pi^0$  background
- $\phi \rightarrow \pi^+\pi^-\pi^0$  background mitigated by being off the  $\phi$  peak
- Cross section from normalisation to luminosity (Bhabha) and correction with radiator (PHOKHARA)

# Calorimeter Cluster Corrections



## Correction of $Z_{clu}$ in MC

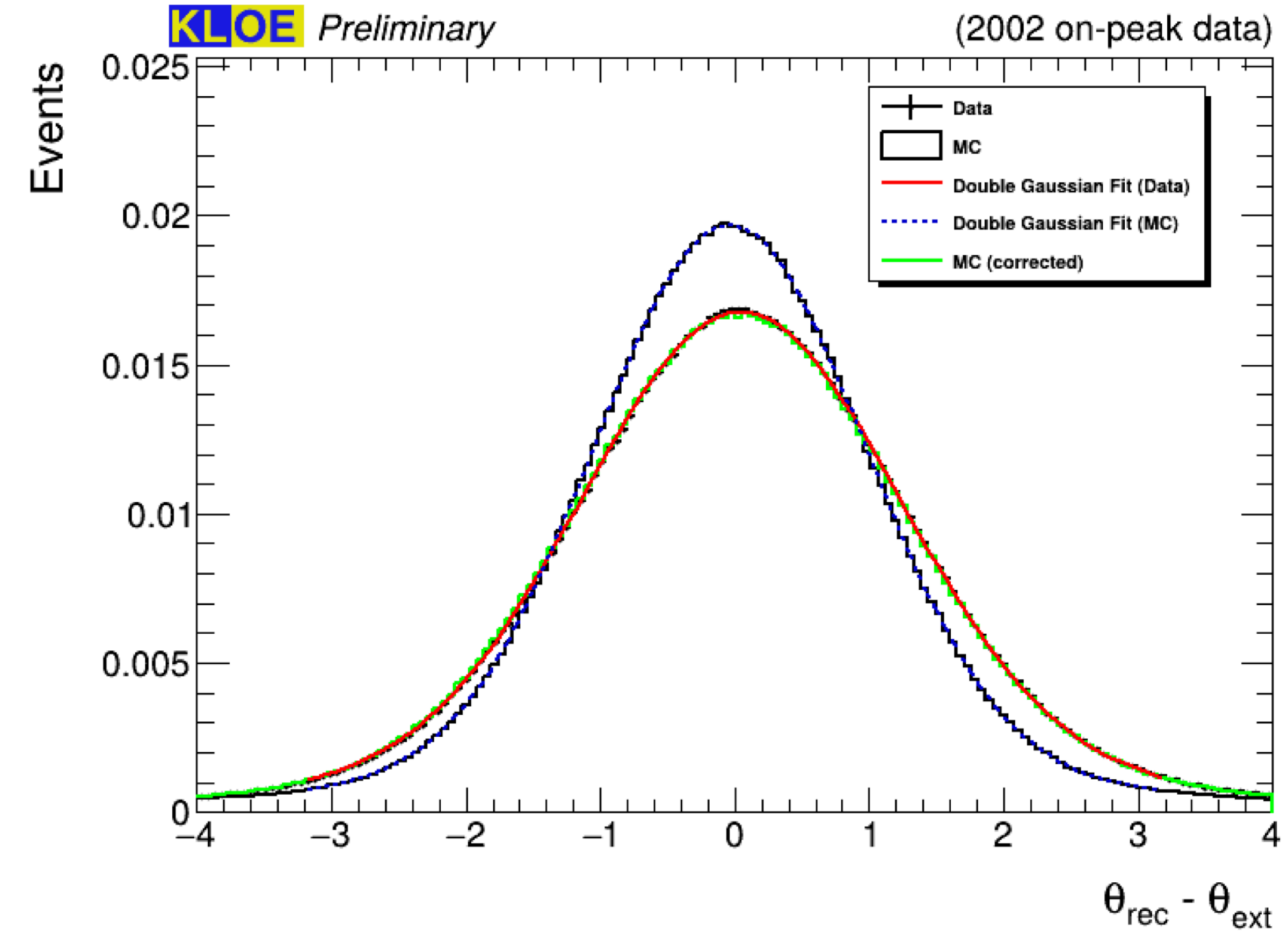
1: Define resolution by  $\theta_{rec} - \theta_{ext}$  for data and MC VLAB clusters, where  $\theta_{rec} = \cos^{-1}(Z_{clu,1}/r_{clu,1})$  and  $\theta_{extrapolated} = -\cos^{-1}(Z_{clu,2}/r_{clu,2})$ , i.e. the extrapolated cluster angle is antiparallel with respect to the reconstructed

2: Fit the resulting distributions from data and Monte Carlo separately with a double Gaussian, corresponding to a core plus a tail

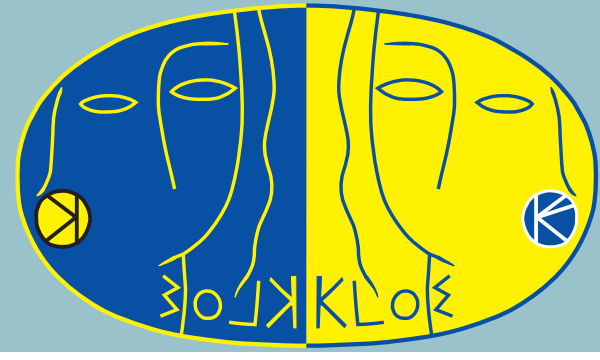
3: Calculate the fraction of the distribution corresponding to the core by  $A_{core} = \frac{A_{core} \cdot \sigma_{core}}{A_{core} \cdot A_{core} + A_{tail} \cdot A_{tail}}$

4: Draw a random number,  $x$ , between 0 and 1, if  $x < A_{core}$ , correct by  $\theta_{corrected} = \theta + \mathcal{N}(0, \sigma_{cor})$  where  $\sigma_{cor} = \sqrt{(\sigma_{data,core}^2 - \sigma_{MC,core}^2)}$ , else if  $x > A_{core}$ ,  $\sigma_{cor} = \sqrt{(\sigma_{data,tail}^2 - \sigma_{MC,tail}^2)}$ , and standard deviations and amplitudes are all extracted from the double Gaussian fit

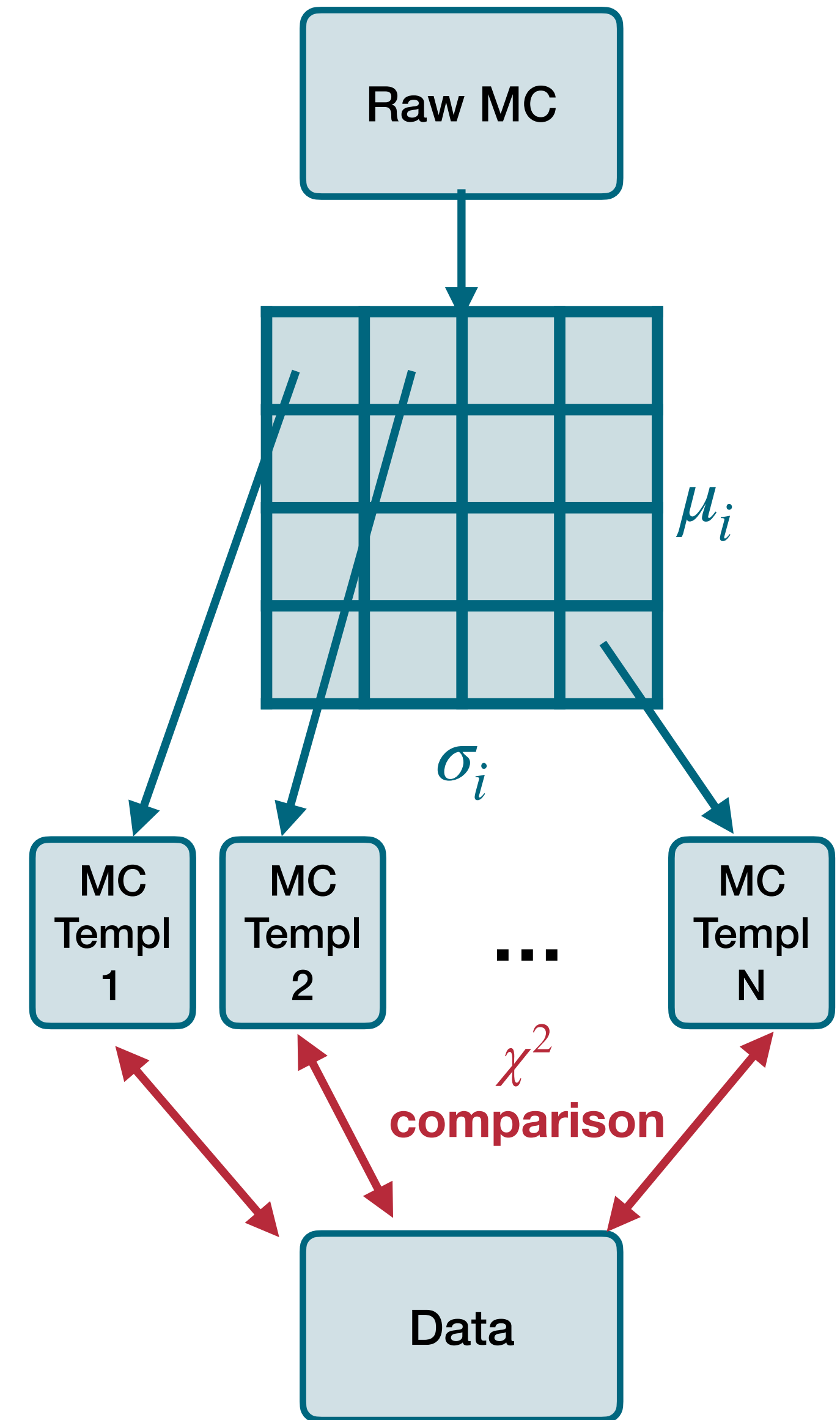
5: Apply correction on all clusters by  $Z_{clu,corrected} = r_{clu} \cdot \cos(\theta_{corrected})$

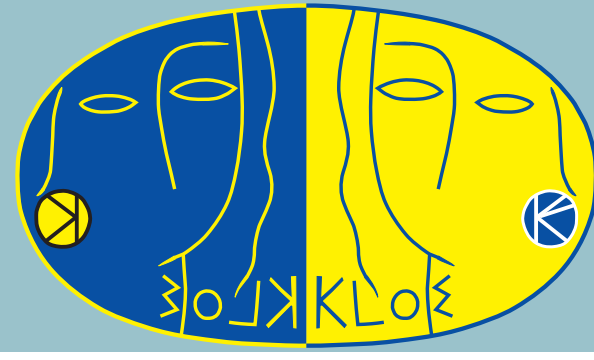


# Tuning with Template Fit

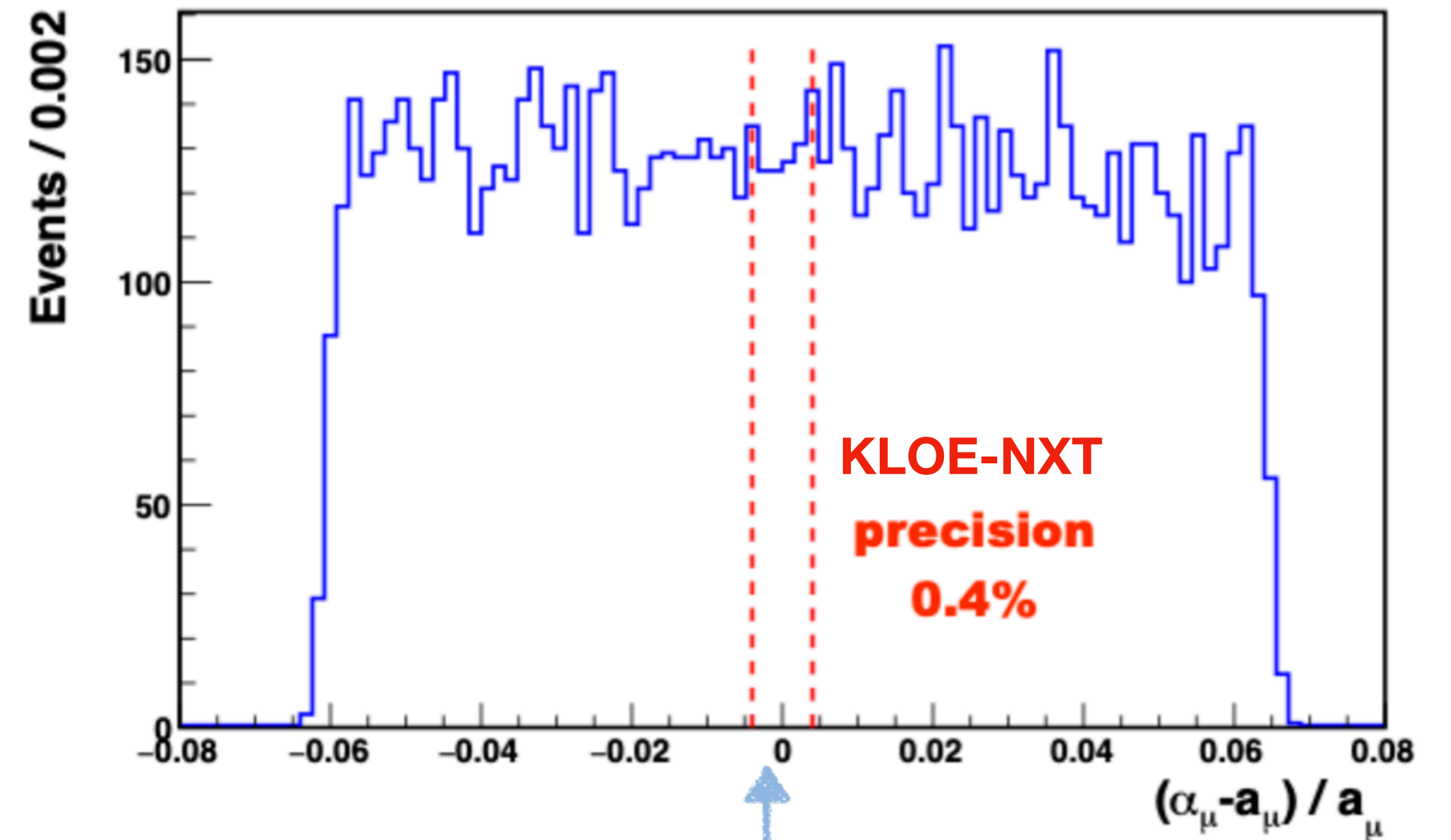


- The parameters that fix the tuning are the coefficients  $\{\mu_i^x, \sigma_i^x\} \rightarrow$  we want to find the parameters that best improve data/MC empirical agreement
- Can be done through a **template fit**:
  - Start from a common Monte Carlo production that should simulate a data set and choose a grid of  $N$  values for the parameters  $\{\mu_i^x, \sigma_i^x\}$ .
  - 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  $\rightarrow N$  different tuned MC samples
  - Choose the best tuned sample based on lowest discrepancy with data. Discrepancy is measured with a  $\chi^2$  comparison between data and MC histograms of variable (e.g.  $M_{trk}, M_{trk}^{\pi^0}, \dots$ )



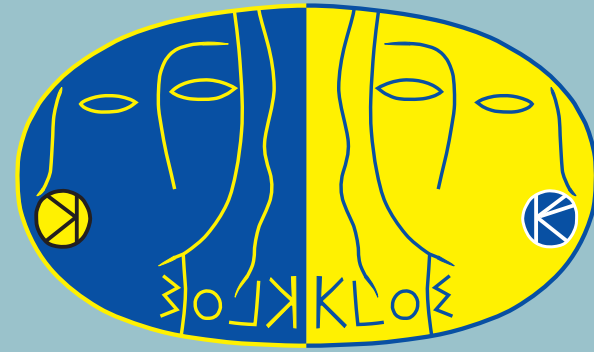


- ❖ The new KLOE analysis will be **conducted blindly** to ensure good practice and avoid bias throughout.
- ❖ This is not a trivial task and is the **first KLOE  $a_\mu^{HLO}$  analysis to be blinded**.
- ❖ The aim of blinding is to shift the result of the analysis by a small amount without jeopardising 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  $Q_{\pi\pi}^2$  or  $Q_{\mu\mu}^2$  slice in data.**
  - ❖ This modifies the measured differential cross section and thus
$$a_{\pi\pi} \propto \int ds \dots \sigma_{\pi\pi}(s)$$
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  $a_\mu$  is  $\pm 6\%$  with respect to true value in simulations. Blinding offset **much larger than target KLOE-NXT precision!**

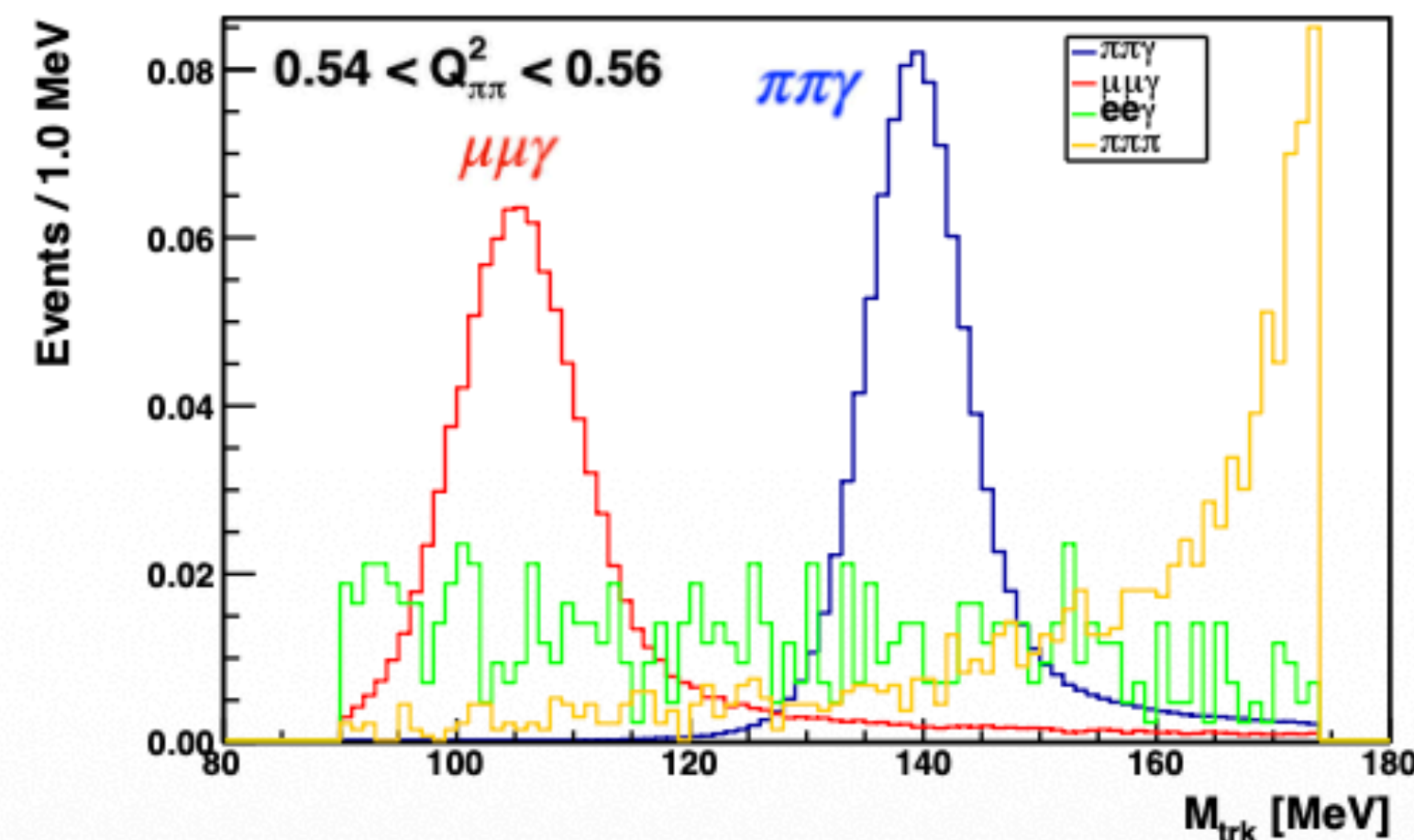
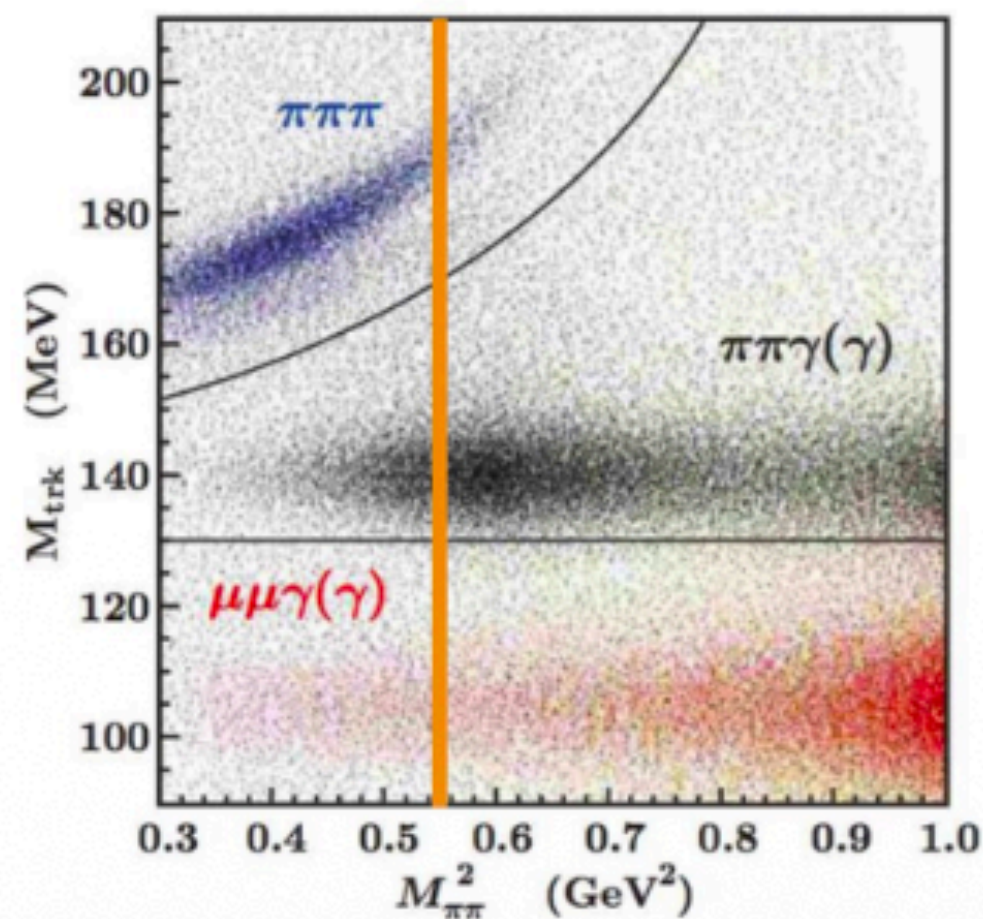
# Background Subtraction



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

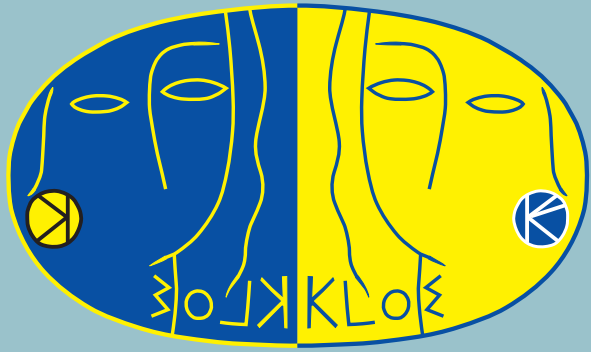
$$M_{trk} : \left( \sqrt{s} - \sqrt{|\vec{p}_+|^2 + M_{trk}^2} - \sqrt{|\vec{p}_-|^2 + M_{trk}^2} \right)^2 - (\vec{p}_+ + \vec{p}_-)^2 \equiv 0$$

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



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

# Background Subtraction



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

$$e^+e^- \rightarrow \mu^+\mu^-\gamma(\gamma) \quad e^+e^- \rightarrow e^+e^-\gamma(\gamma) \quad e^+e^- \rightarrow \pi^+\pi^-\pi^0$$

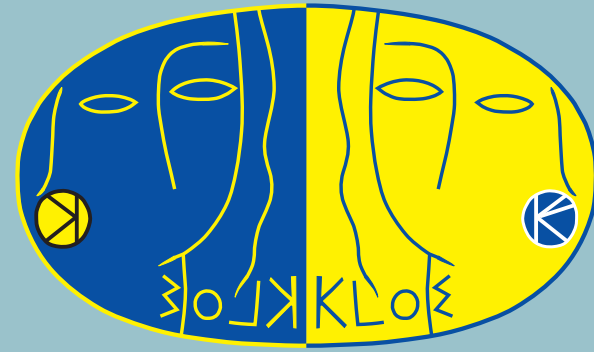
The objective is estimating the total fraction  $f_B^i$  of background events in each bin  $i$  of  $Q_{\pi\pi}^2$ :

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

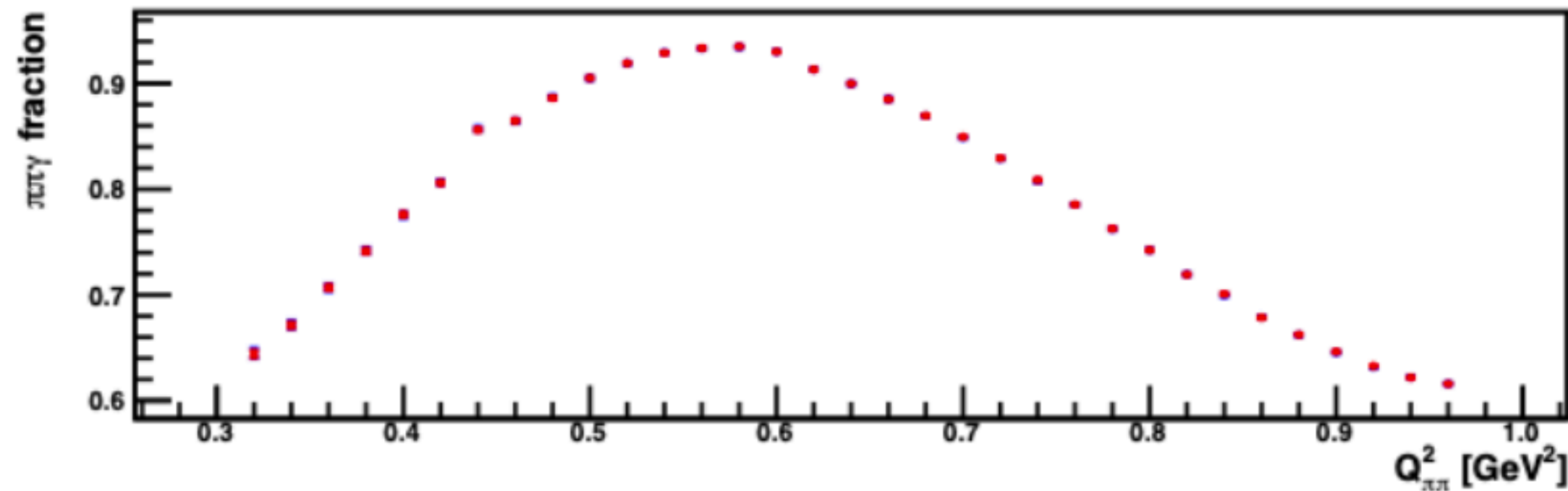
- Data  $M_{trk}$  distribution is fitted in each bin  $i$  with MC  $M_{trk}$  distributions to find the fractions  $F_\alpha^i$  of each channel  $\alpha$ .
- Fits are performed on the **entire range** of  $M_{trk}$  (no signal cut) to increase sensitivity.
- Fractions in the **signal region** of 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

$$w_\alpha^i \equiv F_\alpha^i \frac{N_{dat}^i}{N_{mc,\alpha}^i} \quad \Rightarrow \quad f_\alpha^i = w_\alpha^i \frac{n_{mc,\alpha}^i}{n_{dat}^i} = F_\alpha^i \frac{N_{dat}^i}{N_{mc,\alpha}^i} \frac{n_{mc,\alpha}^i}{n_{dat}^i}$$

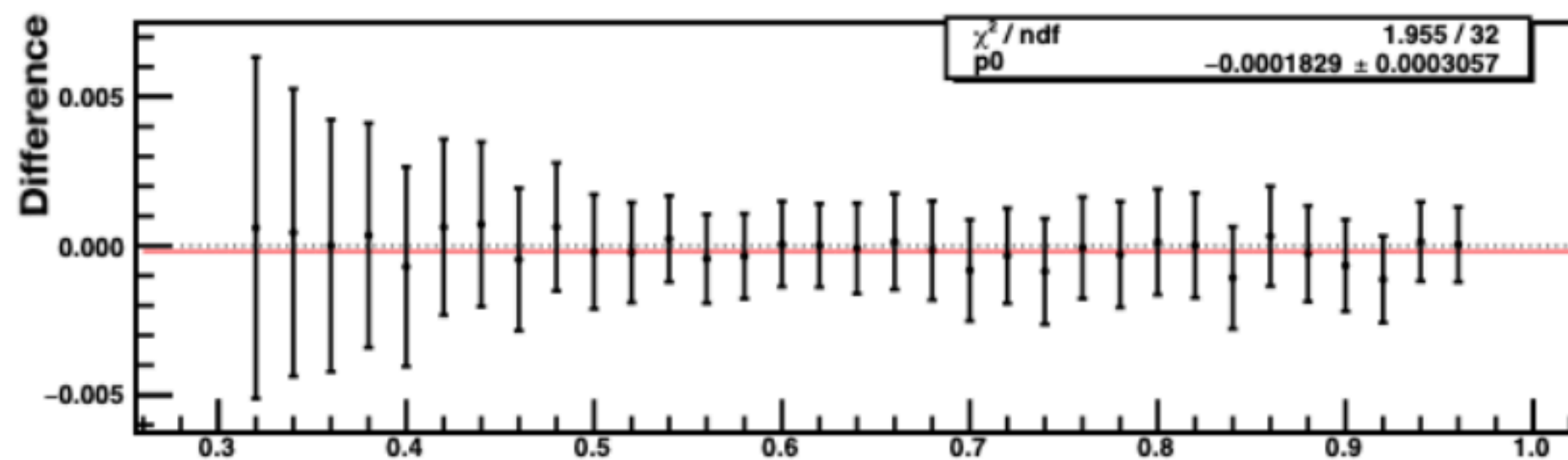
# Background Subtraction



- $\theta_{trk}$  can be used to perform a 2D fit with  $M_{trk}$   $\longrightarrow$  greater **consistency** constraining and better **precision** on the best fit fractions.
- The test yields promising results  $\longrightarrow$  **fraction error decreased by  $\sim 30\%$ !**



$(M_{trk}, \theta_{trk})$  and  $M_{trk}$  fitted  $\pi\pi\gamma$  fractions ( $F_{\pi\pi\gamma}$ ) as a function of  $Q_{\pi\pi}^2$  on toy data.



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