KLOE Measurement of the $\sigma_{\pi\pi(\gamma)}$ cross section and the $\pi^+\pi^-$ contribution to the muon anomaly

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Outline

- Introduction: DAΦNE and KLOE
- Measurement of the $\sigma_{\pi\pi(\gamma)}$ using ISR events with γ at small angle
- Determination of the $\pi^+\pi^-$ contribution to a_μ
- Comparisons with recent e^+e^- experiments
- Outlook: $\sigma_{\pi\pi(\gamma)}$ using ISR events with large angle γ
- Conclusions

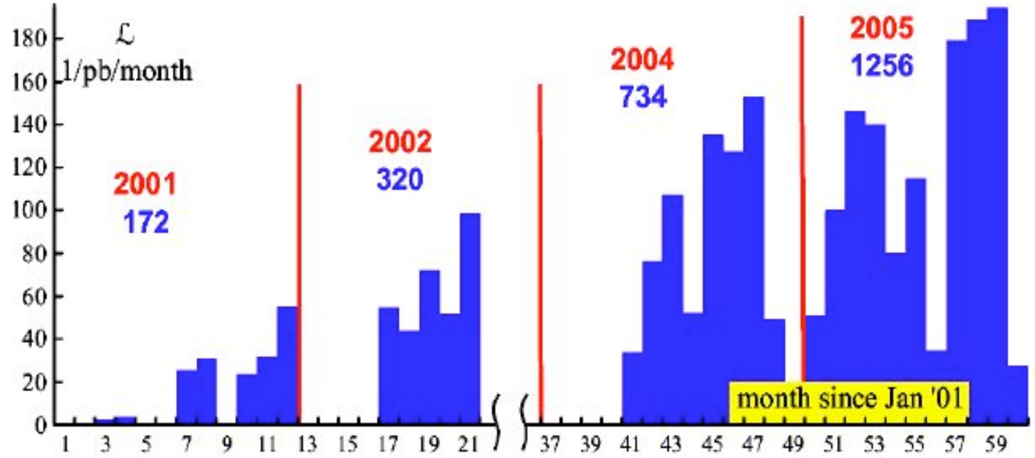
DAΦNE and KLOE

L_{peak} = 1.3 × 10^{32} cm^{-2} s^{-1}

- ✓ $e^+ e^-$ collide at M_Φ: $\sqrt{s} \sim 1.019$ GeV
- ✓ angle btw the beams @ IP ~ 2 × 12.5 mrad
- ✓ residual momentum in LAB ~ 13 MeV

2001-05: ~ 2.5 fb^{-1} at M_ϕ

2006: ~ 250 pb^{-1} at $\sqrt{s}$=1 GeV + $\sqrt{s}$ scan



Calorimeter, EmC:

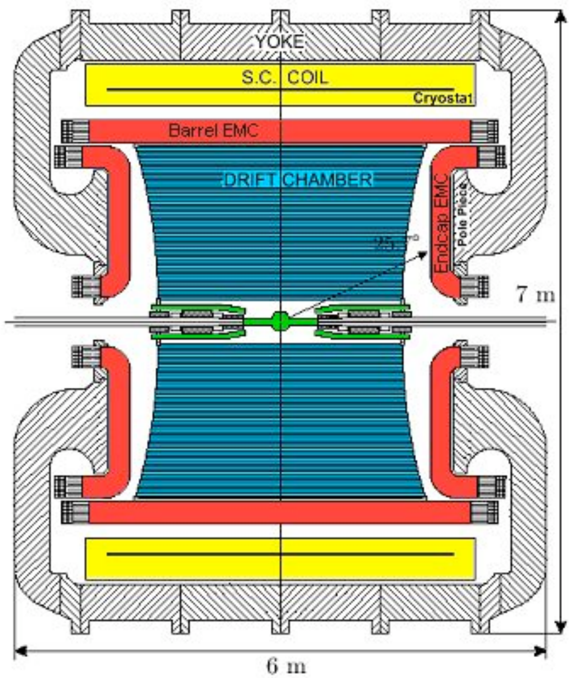
Pb/Scint. Fiber, 4880 PMTs

98% of solid angle

$\sigma_E / E = 0.057/\sqrt{E}$ (GeV)

$\sigma_t = 57$ ps / $\sqrt{E}$ (GeV) $\oplus$ 50 ps

$\sigma_\perp = 1.3$ cm



Drift Chamber, DC:

4 m Ø × 3.3 m length

90% He, 10% i-C_4H_{10}

12582 stereo sense wires

$\sigma_p / p = 0.4\%$ for $\theta > 45°$

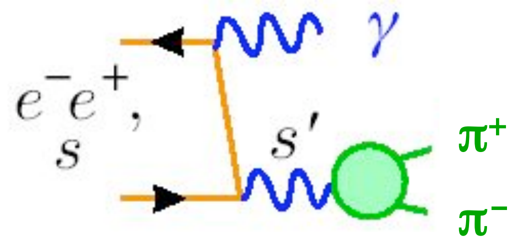
$\sigma_{r\varphi} = 0.150$ mm, $\sigma_z = 2$ mm

$\sigma(m_{\pi\pi}) \sim 1$ MeV

both detectors
w/ trigger decision

The cross section $\sigma_{e+e- \to \pi+\pi-}$ from ISR events

at a fixed $\sqrt{s}$, studying *Initial State Radiation* events, $\sigma_{e+e- \to \pi+\pi-}(s)$ is extracted



ISR only: $$M^2_{\pi\pi} \frac{d\sigma_{e^+e^- \to \pi^+\pi^-\gamma}}{dM^2_{\pi\pi}} = \sigma_{e^+e^- \to \pi^+\pi^-}(M^2_{\pi\pi}) \cdot H(M^2_{\pi\pi}, \theta_{\min})$$

➔ **EVA + PHOKHARA MC Generator**

(S. Binner, J.H. Kühn, K. Melnikov, PLB459,1999)

(H.Czyż, A.Grzelińska, J.H Kühn, G.Rodrigo, EPJC27,2003)

main advantage:

no point-to-point errors on beam energy and luminosity

main requirement:

precise knowledge of ISR radiative corrections

1st KLOE publication (based on 140 pb^{-1})

A. Aloisio et al., PLB606(2005)12 → KLOE05

$$\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \frac{N^{obs} - N^{bkg}}{\Delta M^2_{\pi\pi}} \cdot \frac{1}{\varepsilon_{sel}} \cdot \frac{1}{L}$$

Selection of $\pi\pi\gamma$ events at small angle

PUBLISHED: PLB670(2009)285

a) 2 tracks with $50^o < \theta_{track} < 130^o$

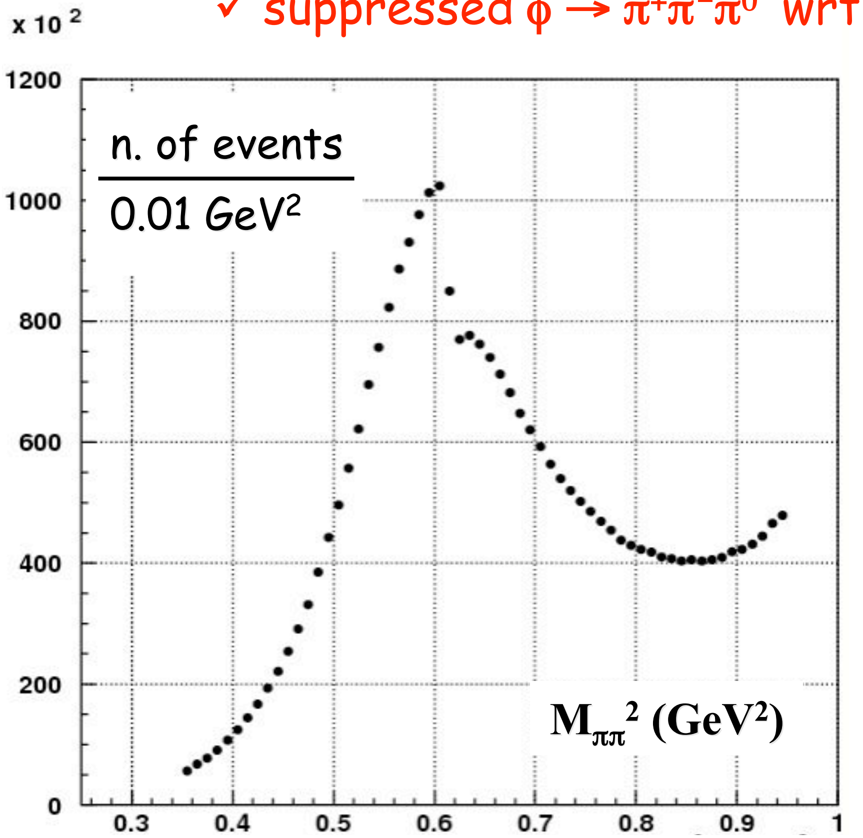
b) small angle γ ($\theta_{\pi\pi} < 15^o$)

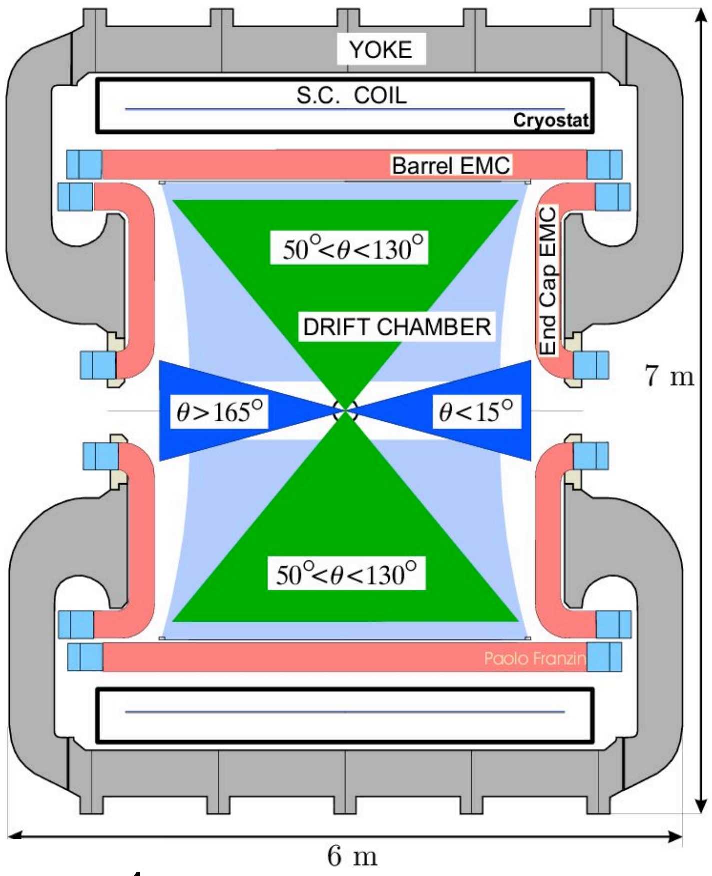
kinematics: $\vec{p}_\gamma = \vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$

✓ high statistics for ISR ($\sim \theta^{-2}$)

✓ low relative FSR contribution

✓ suppressed $\phi \to \pi^+\pi^-\pi^0$ wrt the signal





statistics: 242pb^{-1}

3.4 Million Events

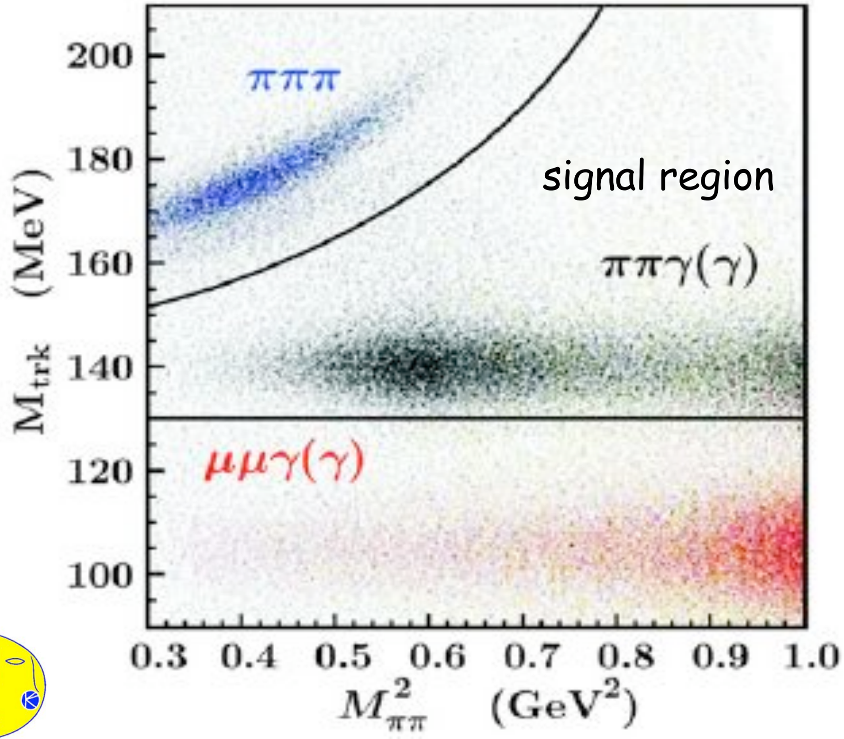
Selection of $\pi\pi\gamma$ events: suppress background

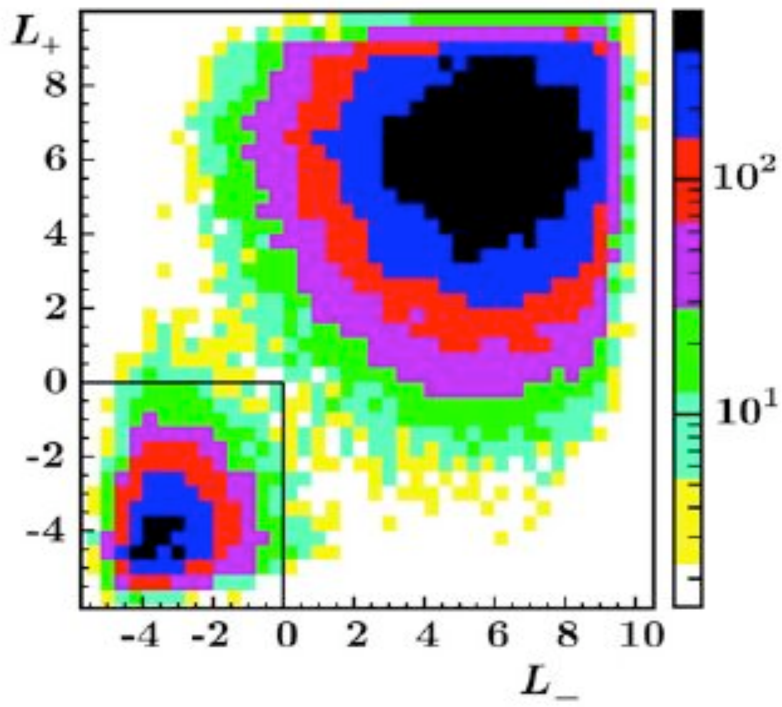
suppress
$e^+e^- \rightarrow e^+e^-\gamma$

π/e separation performed with particle ID based on the calorimeter

remnant
$e^+e^- \rightarrow \mu^+\mu^-\gamma$ & $\phi \rightarrow \pi^+\pi^-\pi^0$

cut and estimated as a function of $M_{\pi\pi}^2$

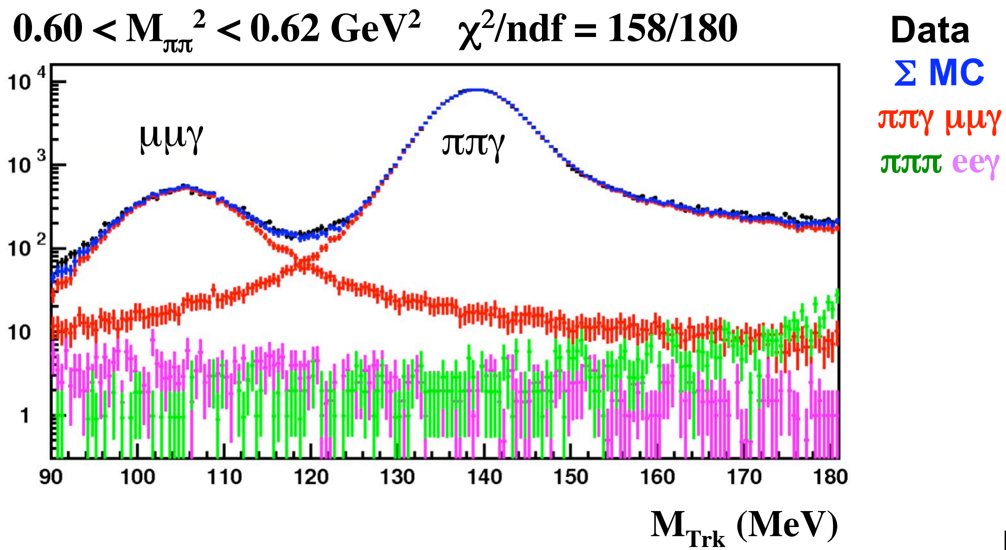


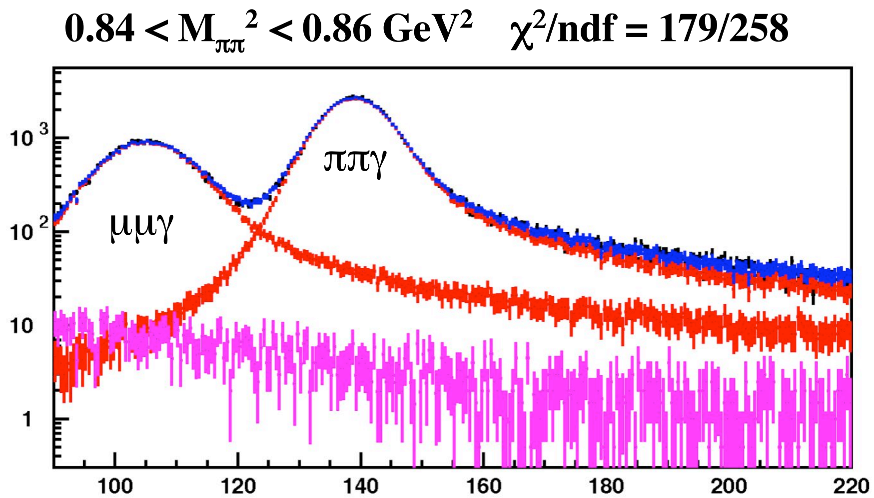


$\mathbf{m_{trk}}$, defined under the hypothesis of 2 equal mass particles and 1 γ in the final state

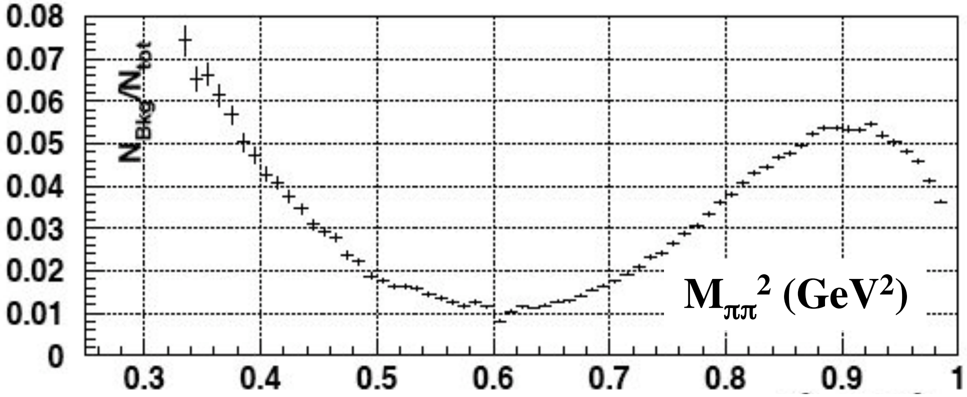
Background estimates

Main backgrounds obtained from MC shapes fitted to data distribution in M_{Trk}





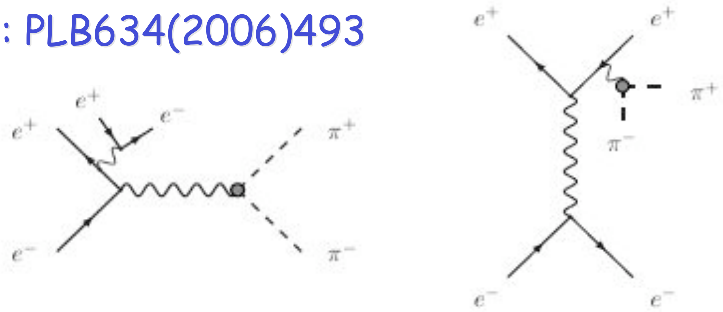
Bkg (μμγ, πππ and eeγ) fraction



Bkg errors are due to :

- Uncertainty on e+e- → e+e-$\pi^+\pi^-$ contribution

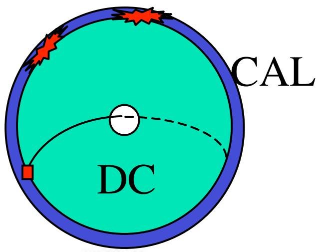
EKHARA: PLB634(2006)493

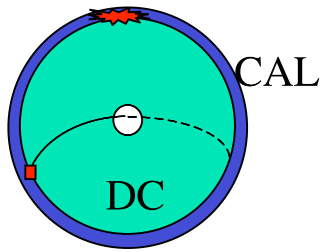


- Error on normalization parameters obtained from the fit

Data/MC corrections for the π track

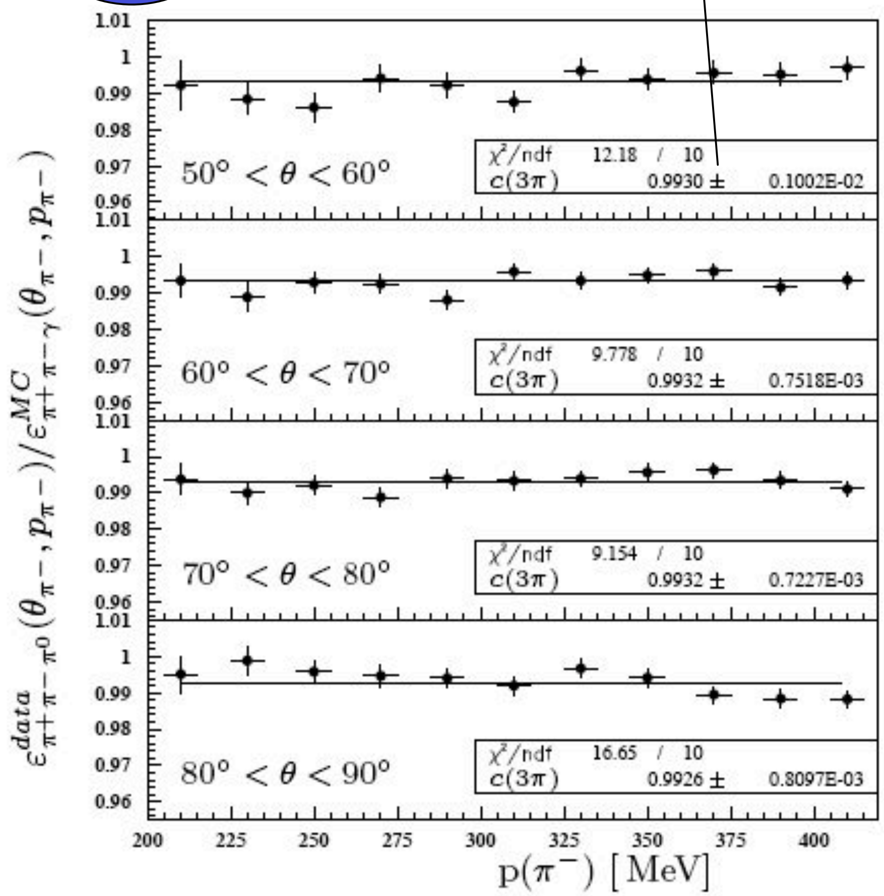
corrections obtained from $\pi^+\pi^-\pi^0$ (large statistics, momentum limited) and $\pi\pi\gamma$ data samples (after kin. χ^2) compatible within 0.3% → syst. error

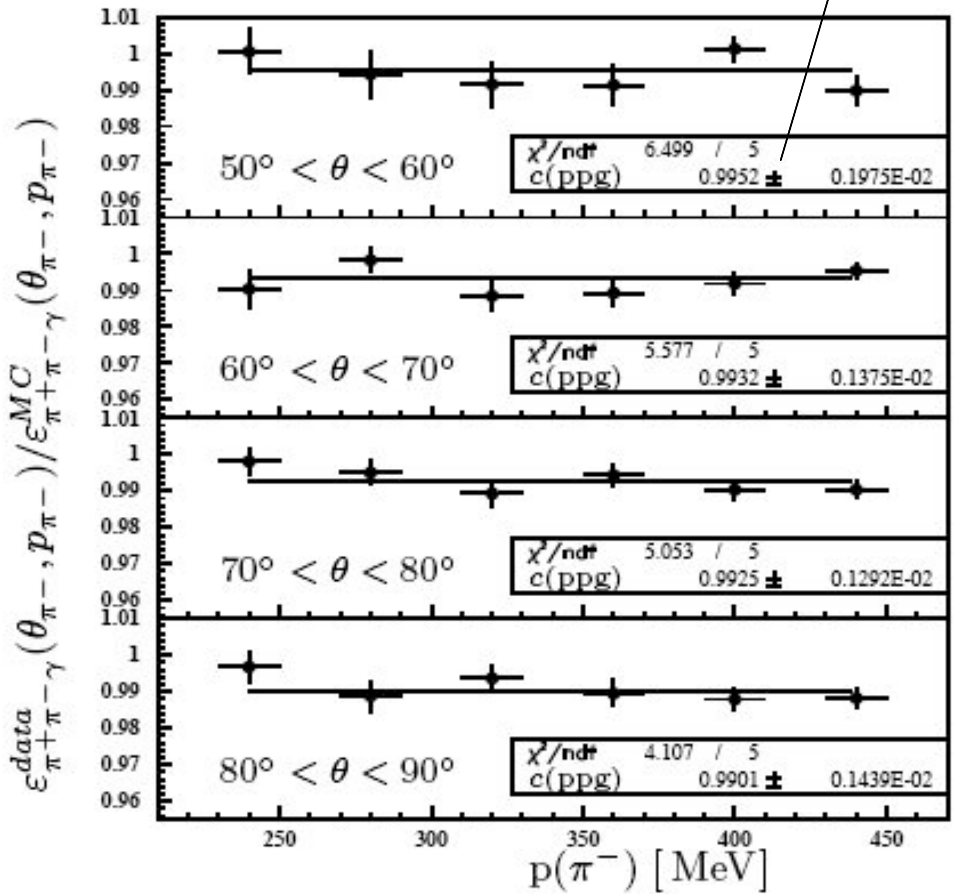




$C_{3\pi} = 0.993 \pm 0.001$

$C_{\pi\pi\gamma} = 0.995 \pm 0.002$





Luminosity

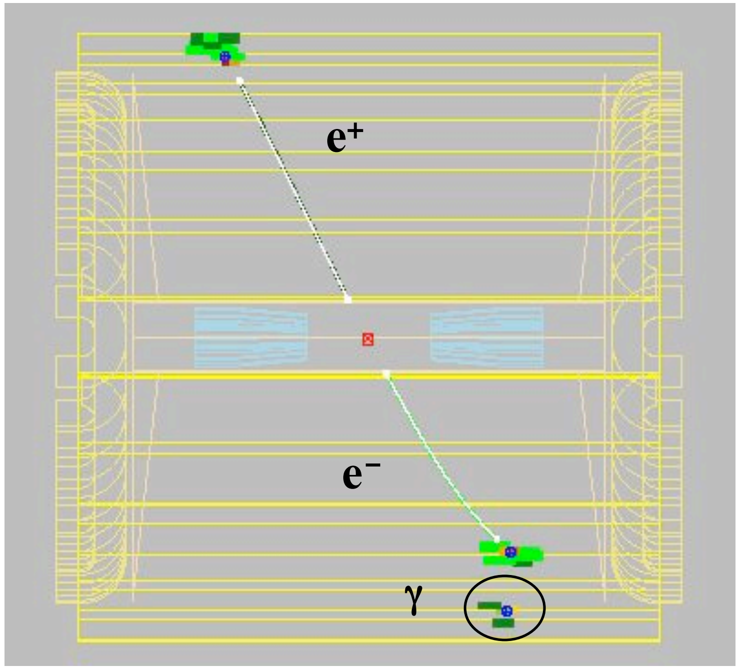
KLOE measures $\mathcal{L}$ with Bhabha scattering

$55° < \theta < 125°$

acollinearity $< 9°$

$p \geq 400$ MeV

$$\int \mathcal{L}\,\mathrm{dt} = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}$$



F. Ambrosino et al. (KLOE Coll.)
Eur.Phys.J.C47:589-596,2006

generator used for σ_{eff}
BABAYAGA (Pavia group)
C. M.C. Calame et al., NPB758 (2006) 22

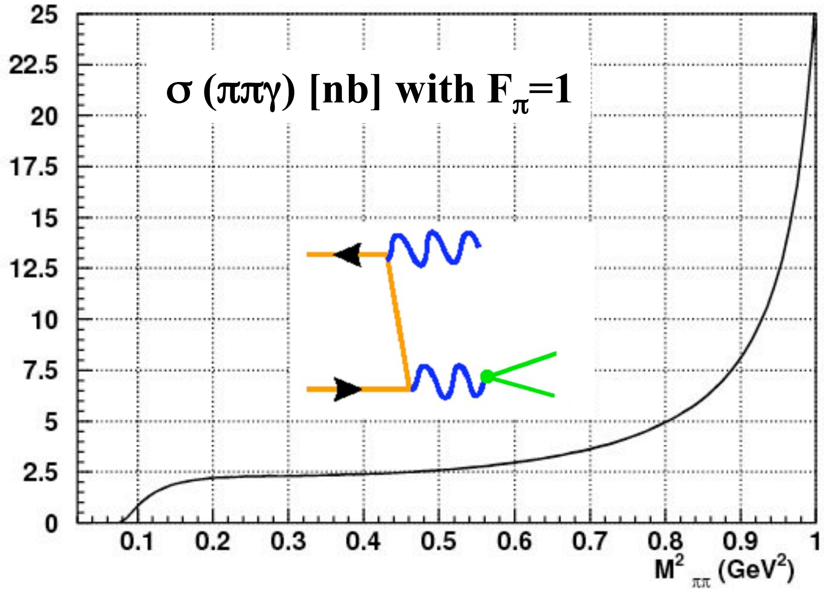
new version (**BABAYAGA@NLO**) gives much better accuracy: 0.1%

Systematics on Luminosity	
Theory	0.1 %
Experiment	0.3 %
TOTAL 0.1 % th ⊕ 0.3% exp = 0.3%	

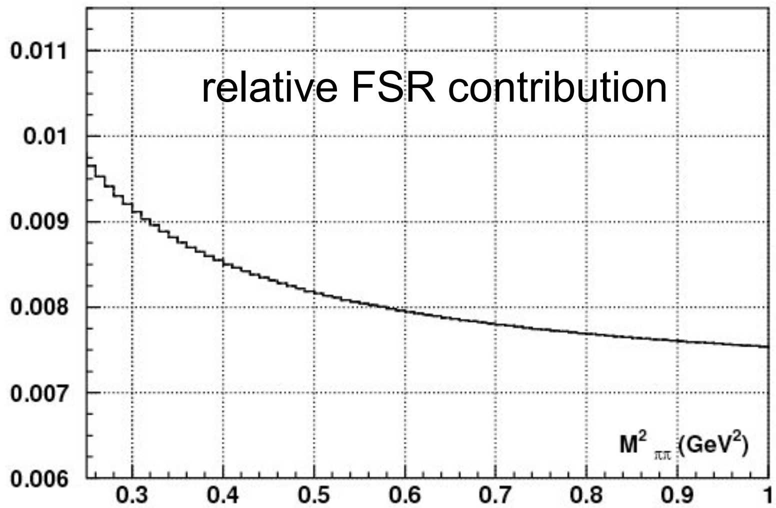
Radiative corrections

- **ISR-Process calculated at NLO-level**
  PHOKHARA generator (Czyż, Kühn et.al)
  Precision: 0.5%

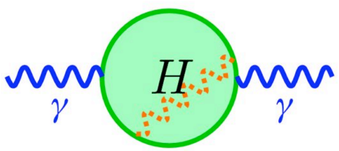
$$M^2_{\pi\pi}\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s)\times \mathbf{H(s)}$$

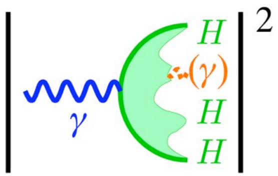


i) Bare Cross Section
divide by Vacuum Polarisation
➔ from F. Jegerlehner

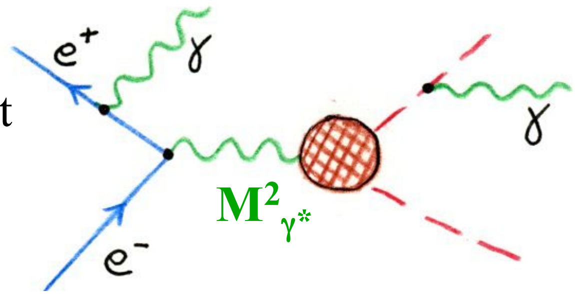


ii) FSR - Corrections
cross section $\sigma_{\pi\pi}$ must be inclusive for FSR





FSR corrections taken into account in the efficiency evaluation and in $M^2_{\pi\pi} \rightarrow M^2_{\gamma^*}$



Systematic uncertainties

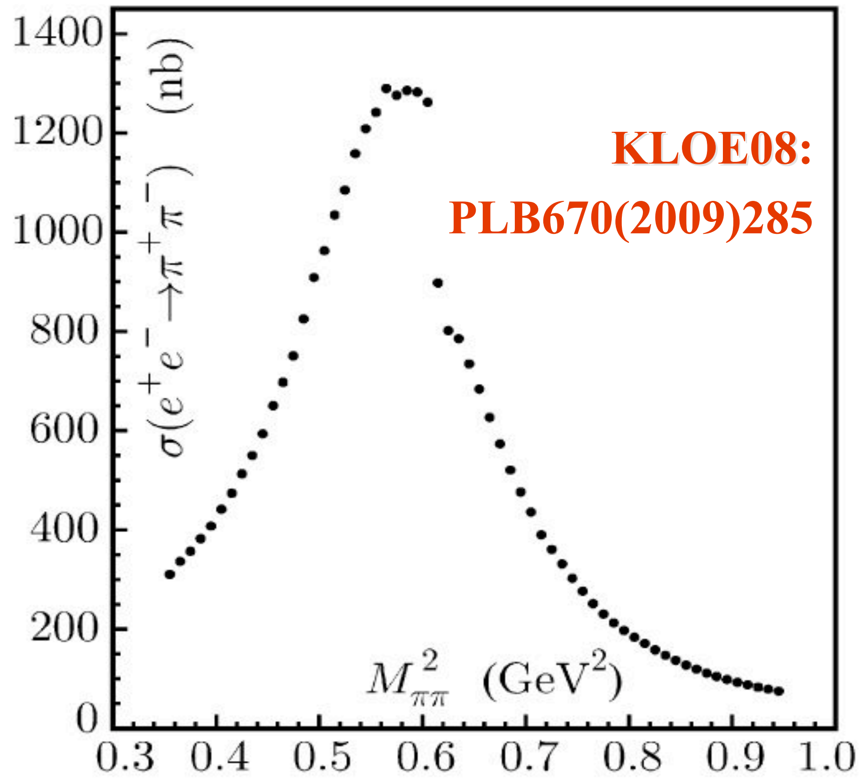
Systematic errors on $a_\mu^{\pi\pi}$:

Reconstruction Filter	negligible
Background	0.3%
M_{trk} cuts	0.2%
π/e ID and TCA	negligible
Tracking	0.3%
Hardware Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.1%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dependence of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

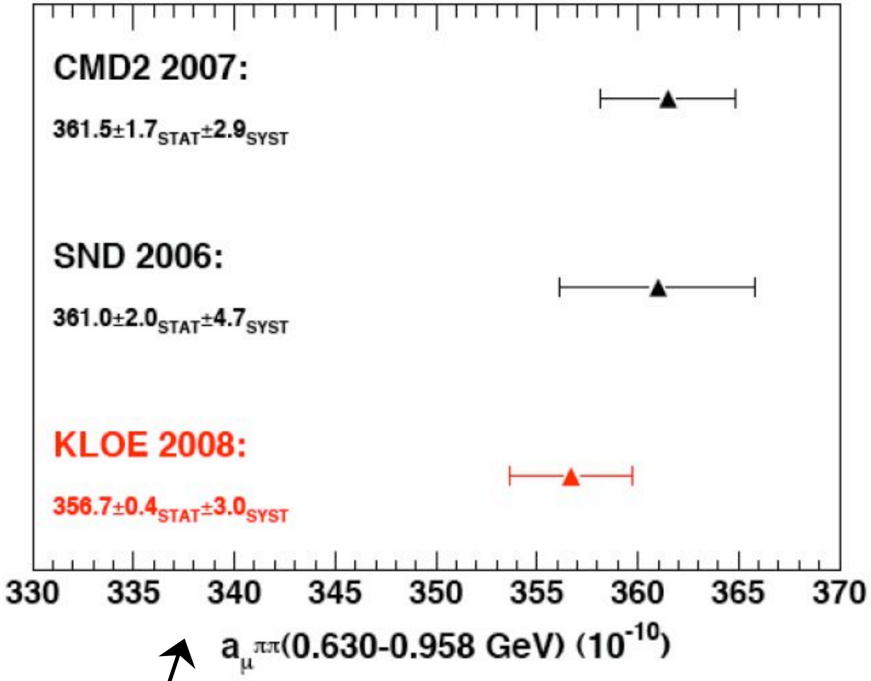
experimental fractional error on a_μ = 0.6 %

FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	0.1%

theoretical fractional error on a_μ = 0.6 %



$\sigma_{\pi\pi}$, undressed from VP, inclusive for FSR as function of $(M_{\gamma*})^2$



Recent comparisons on $a_\mu^{\pi\pi}$

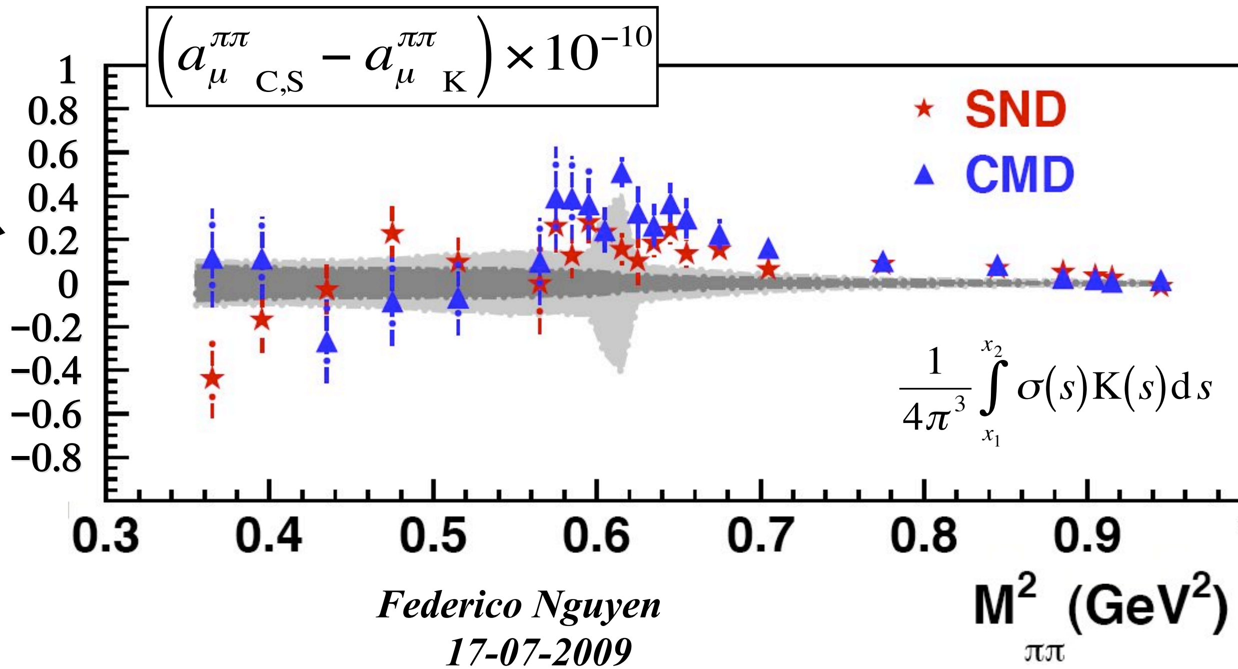
$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\mathrm{GeV}^2}^{0.95\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

average value in 10^{-10} units:

359.2 ± 2.1 with $\chi^2/\mathrm{dof} = 1.24/2$

confidence level of 54%

even at the largest difference, minor impact on $a_\mu^{\pi\pi}$



e^+e^- experiments are consistent

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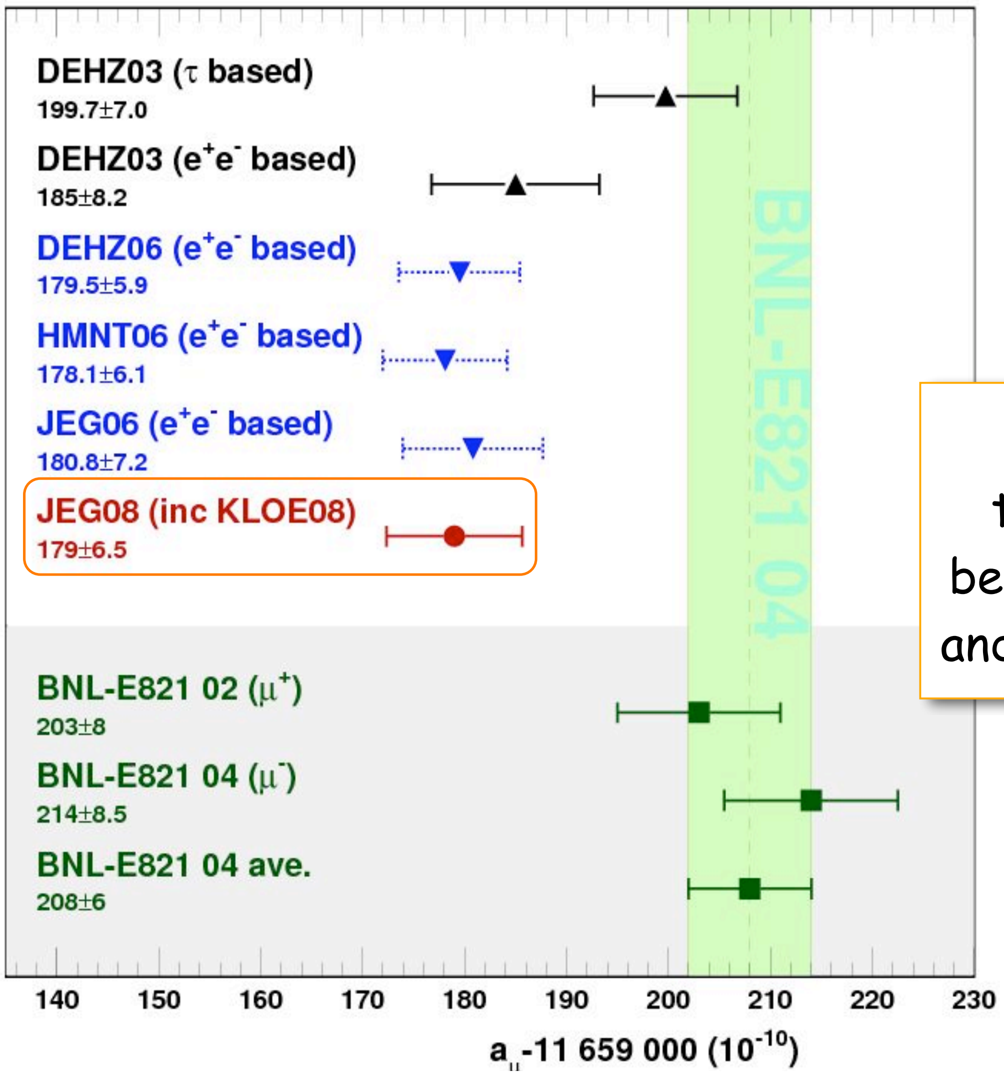
17-07-2009

Present situation on a_μ



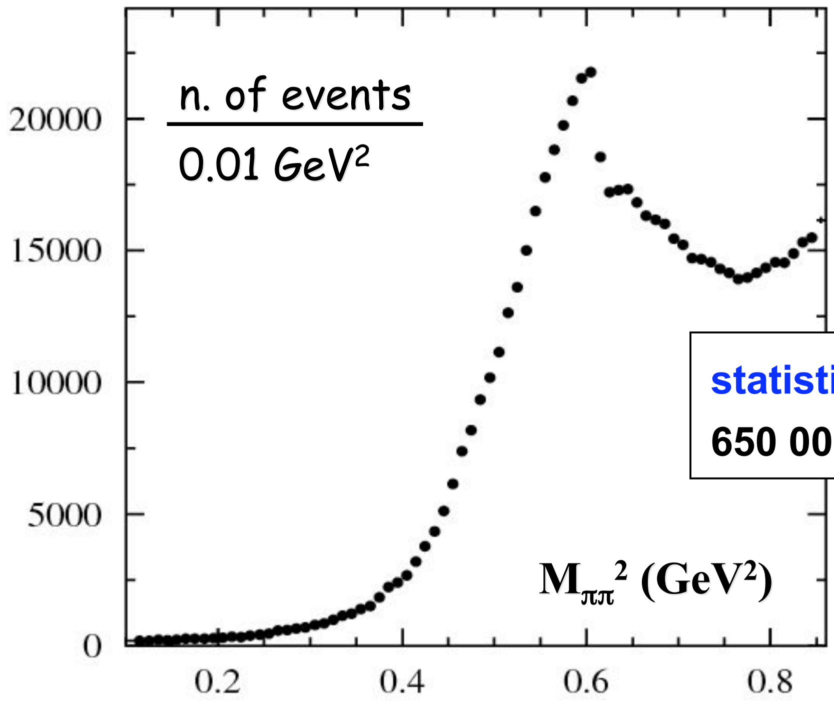
KLOE strengthens the discrepancy ~ 3.4 σ between the SM prediction and the BNL measurements

NEW: selection of ISR γ at large angle

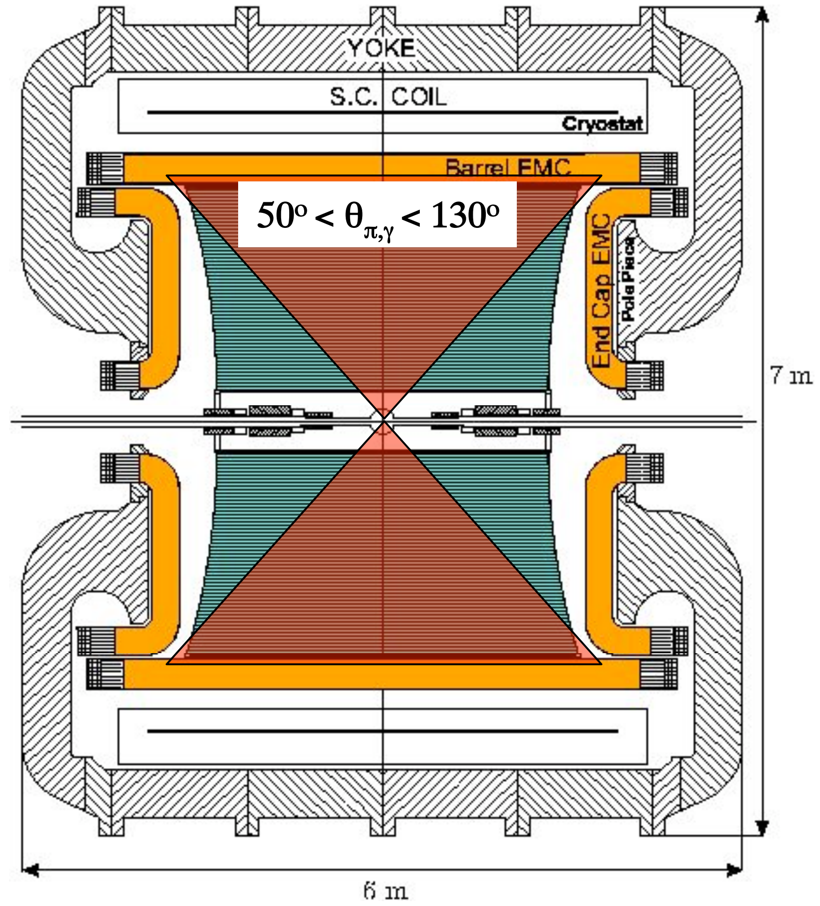
- ✓ **independent complementary analysis**
- ✓ **threshold region $(2m_\pi)^2$ accessible**
- ✓ **γ_{ISR} photon detected (4-momentum constraints)**

detection of 2 tracks and at least 1 γ (E > 50 MeV)

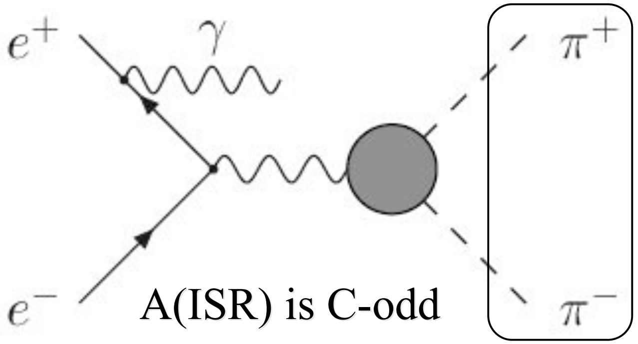
✓ **background from ϕ decays, $\phi \rightarrow \pi^+\pi^-\pi^0$ & $\phi \rightarrow f_0(980)\gamma \rightarrow \pi\pi\gamma$ suppressed using data taken at $\sqrt{s}$ = 1 GeV, off the ϕ peak**



statistics: 233 pb^{-1}
650 000 Events

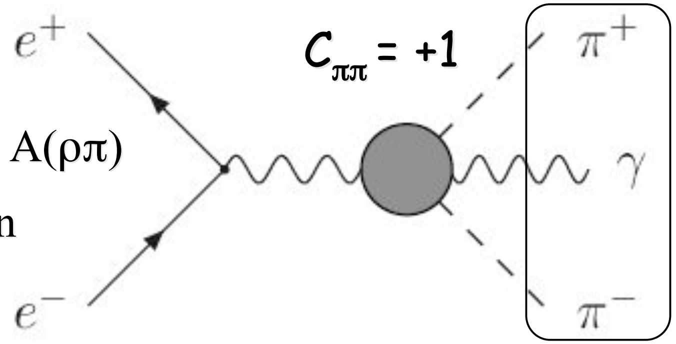


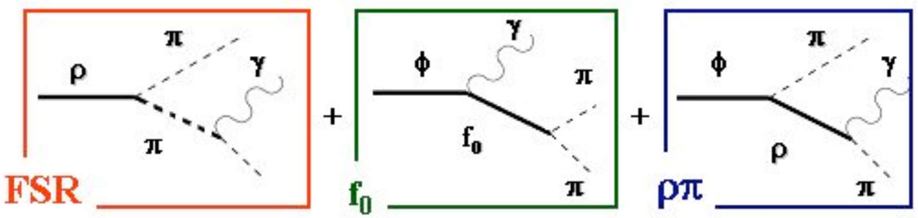
Control of backgrounds: A_{FB}



$C_{\pi\pi}$ = -1

A(FSR), A(Sγ), A(ρπ) are C-even





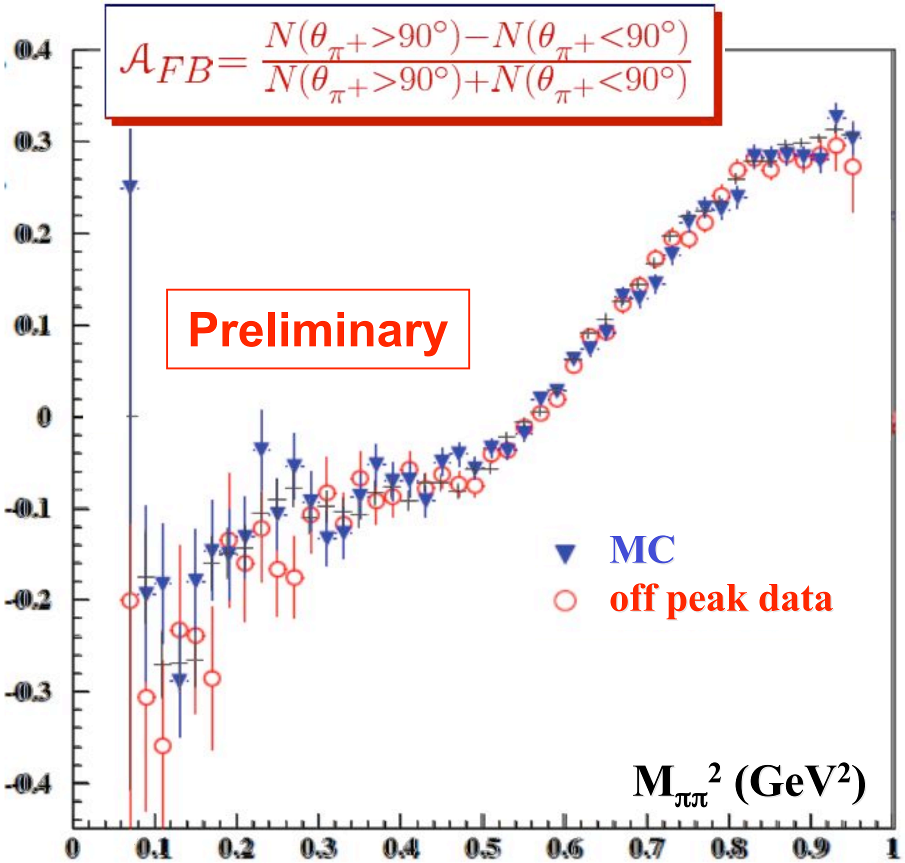
A_{FB} more sensitive than dσ/dM

MC based on

PHOKHARA: Phys.Lett.B611(2005)116

FASTERD: arXiv:0901.4440 [hep-ph]

accurate control of same final state interfering backgrounds



Conclusions

✓ we presented a new measurement of $\sigma_{\pi\pi(\gamma)}$ and of the $\pi^+\pi^-$ contribution to $a_\mu^{\pi\pi}$ in the range [0.35, 0.95] GeV^2 with 0.9% accuracy [PLB670 (2009) 285]

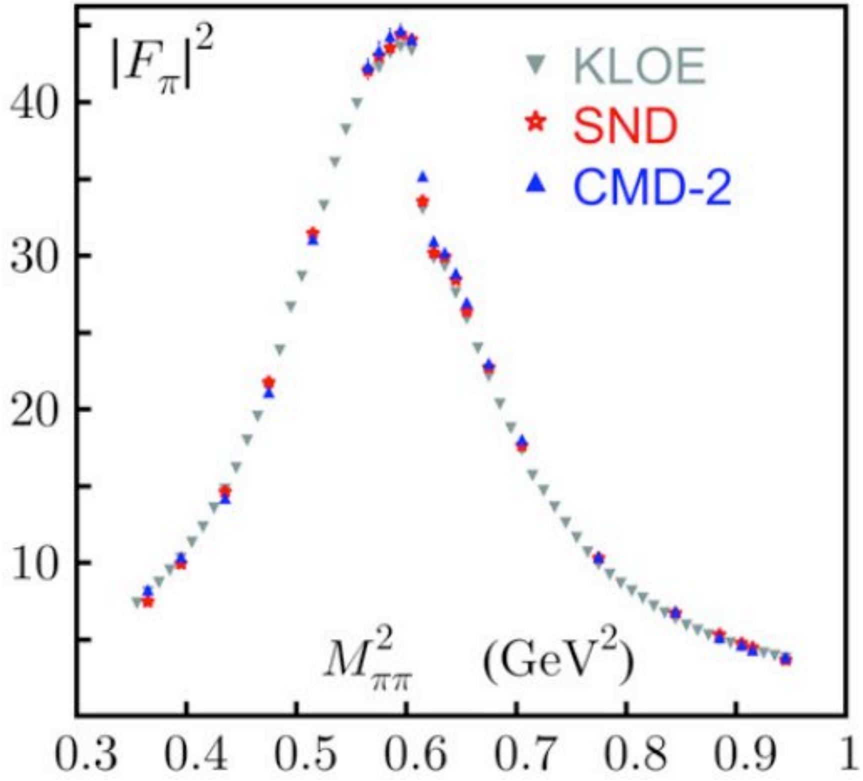
✓ this result is in good agreement with the CMD-2 and SND recent results, and it strengthens the difference between BNL measurement and SM prediction

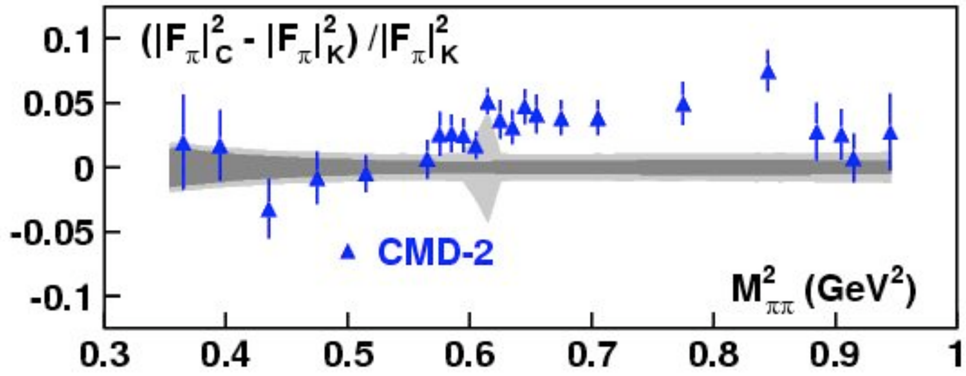
✓ an independent analysis with γ detected at large angle is very close to be finalized (selection cuts established and main corrections evaluated), preliminary data-MC comparison shows excellent agreement

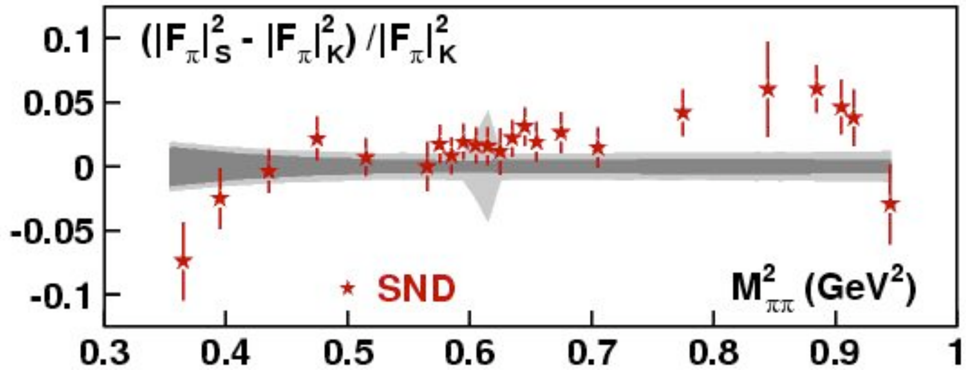
✓ we plan to determine the $\pi^+\pi^-$ contribution to $a_\mu^{\pi\pi}$, from ratio of $\pi\pi\gamma$ to $\mu\mu\gamma$ events, that allows an independent check of the radiator function and cancellation of some systematic effects

Comparisons on F_π

$$\sigma_{\pi\pi} = \frac{\pi\alpha^2\beta_\pi^3}{3s}\left|F_\pi\right|^2$$

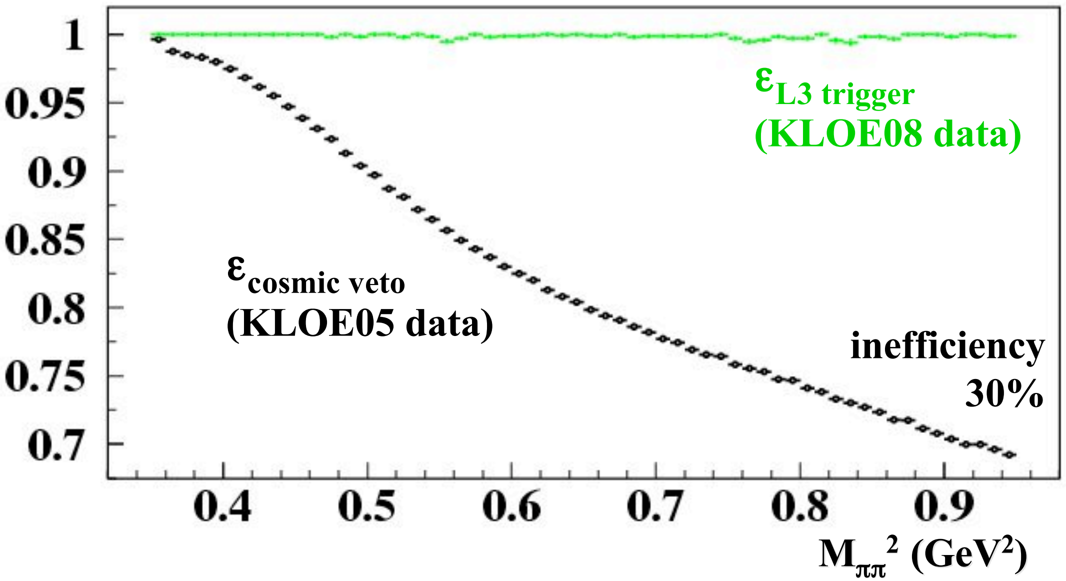






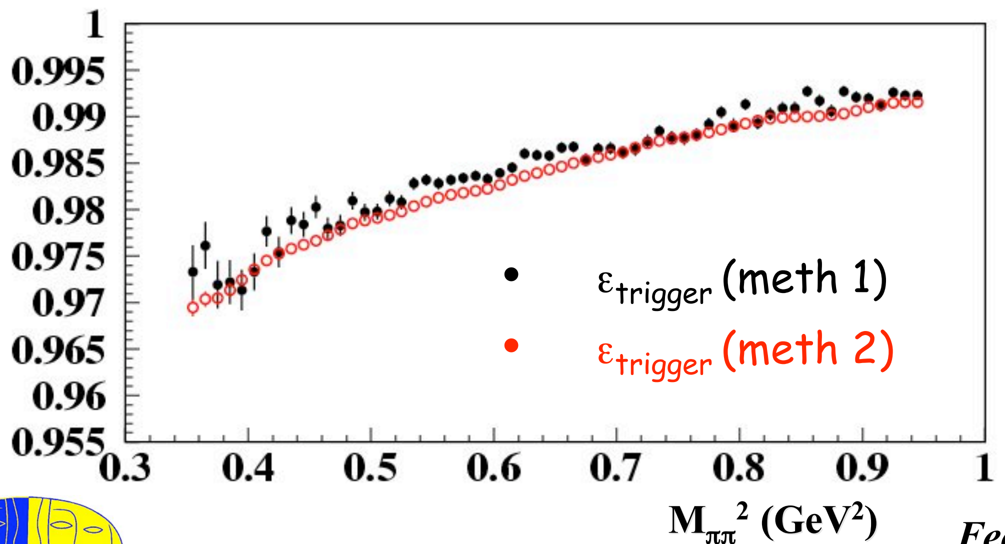
good agreement below and on the ρ peak among different e^+e^- experiments

Trigger corrections



average value = 0.9987±0.0002

the main source (hardware veto of cosmic rays) of inefficiency in the 2005 result has been removed



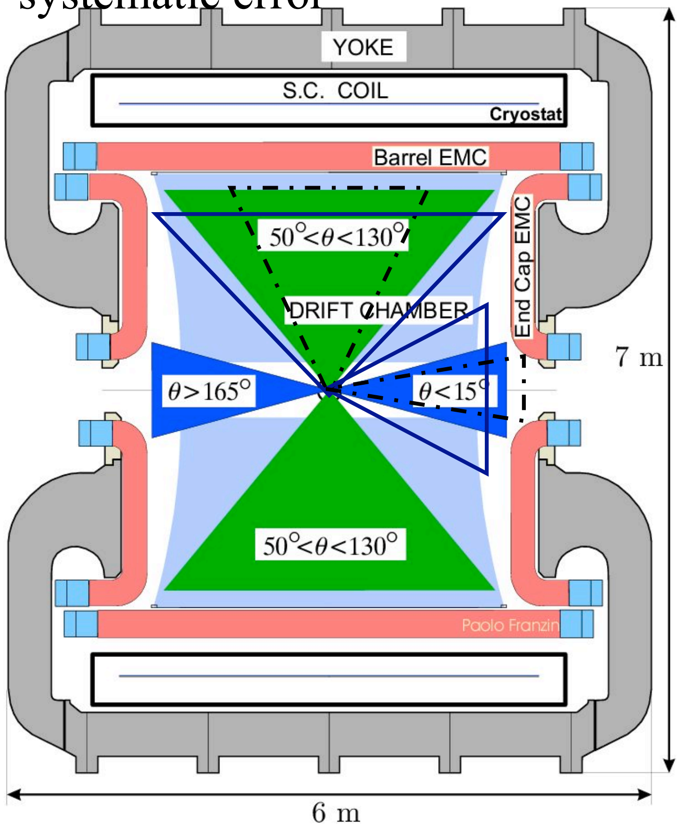
trigger efficiency: fractional error given by relative difference of 2 independent methods

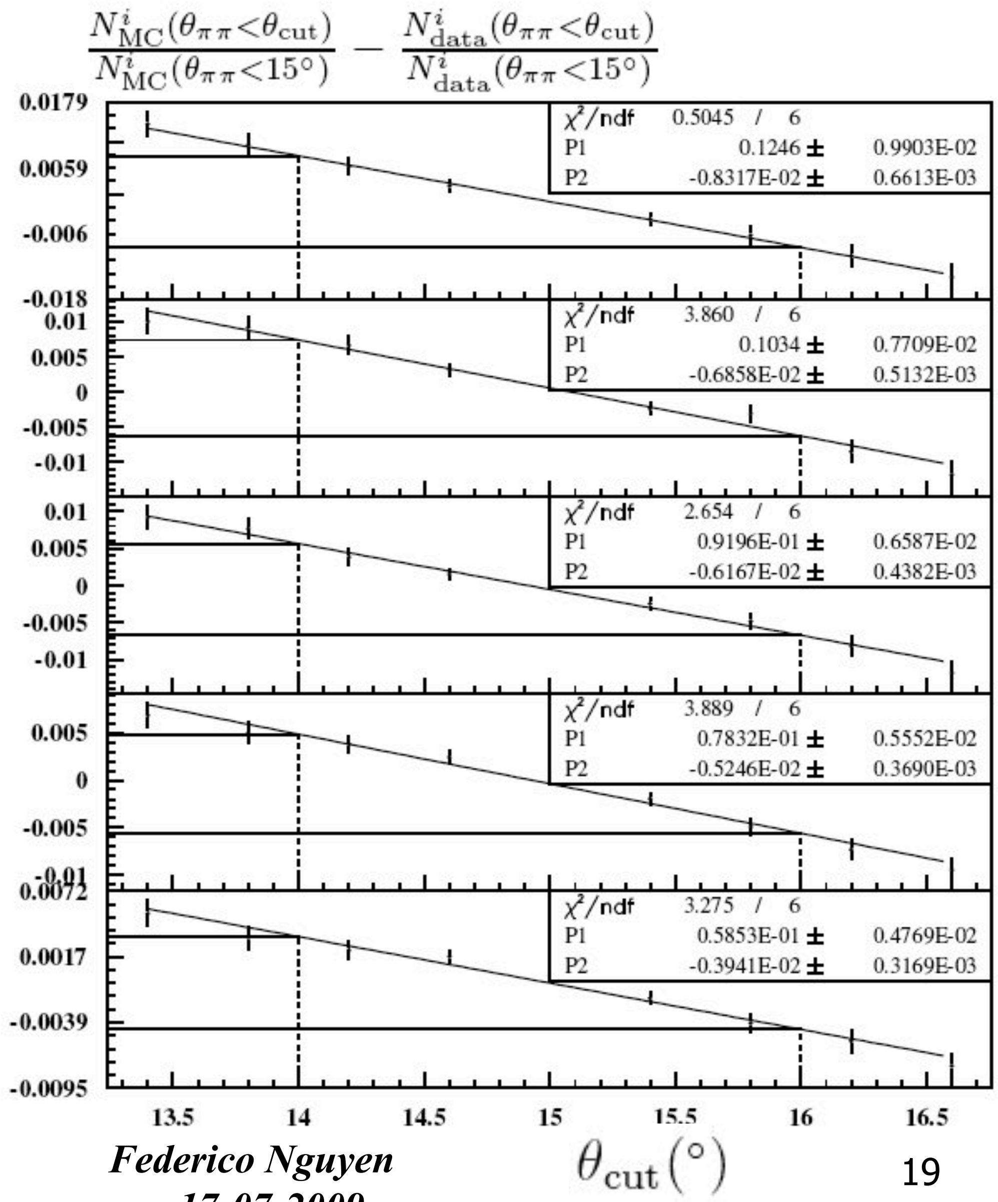
from data → *0.1%*

Geometrical acceptance for the γ

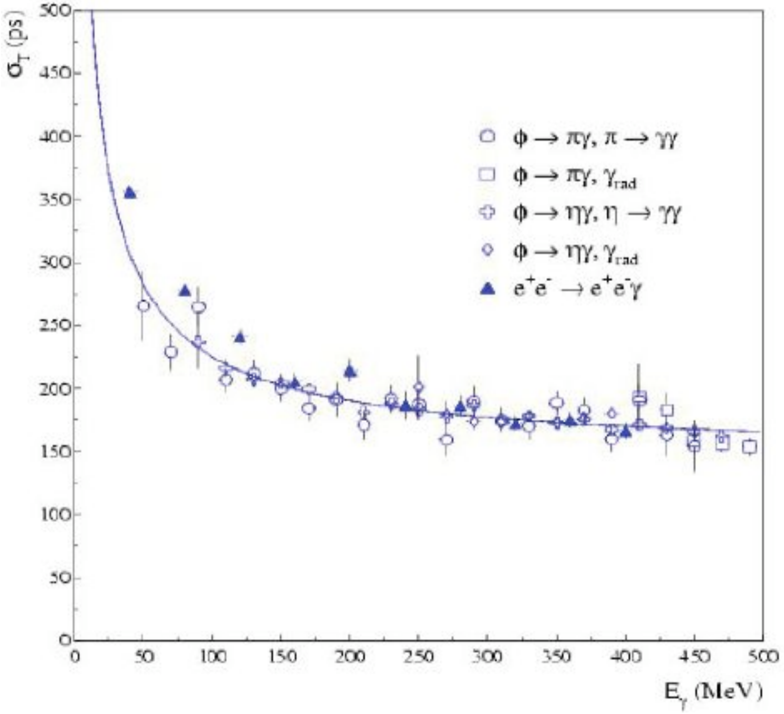
we study the impact of varying the 15° cut on $\theta_{\pi\pi}$ in slices of $M^2_{\pi\pi}$

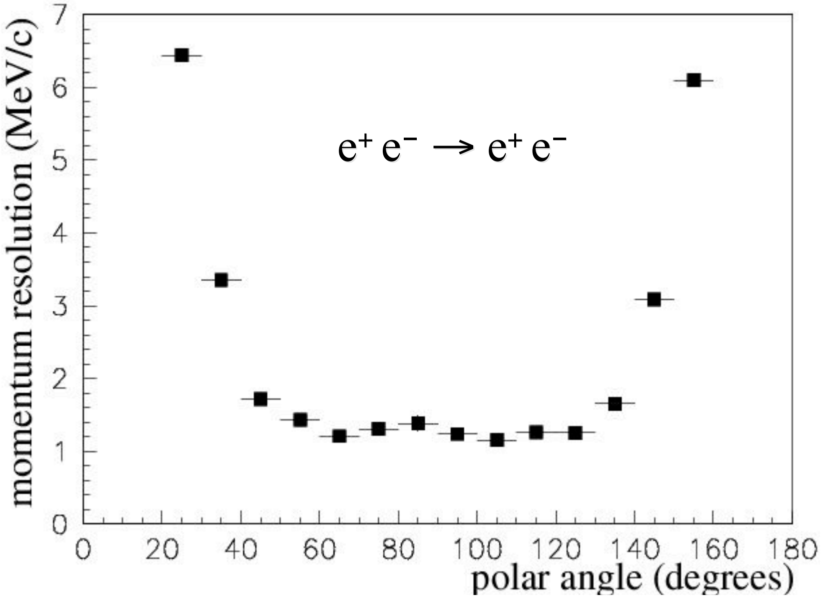
the data/MC spectrum variation is linear as a function of the cut, so the excursion at ± 1 degree is taken as systematic error

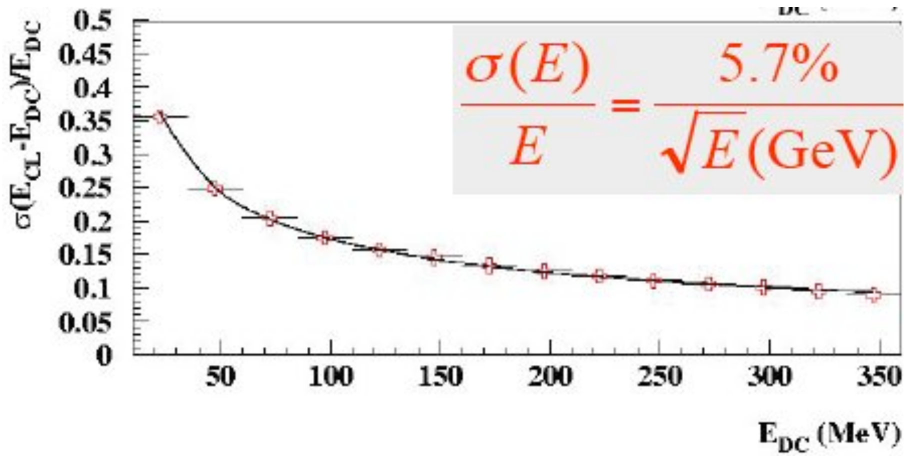


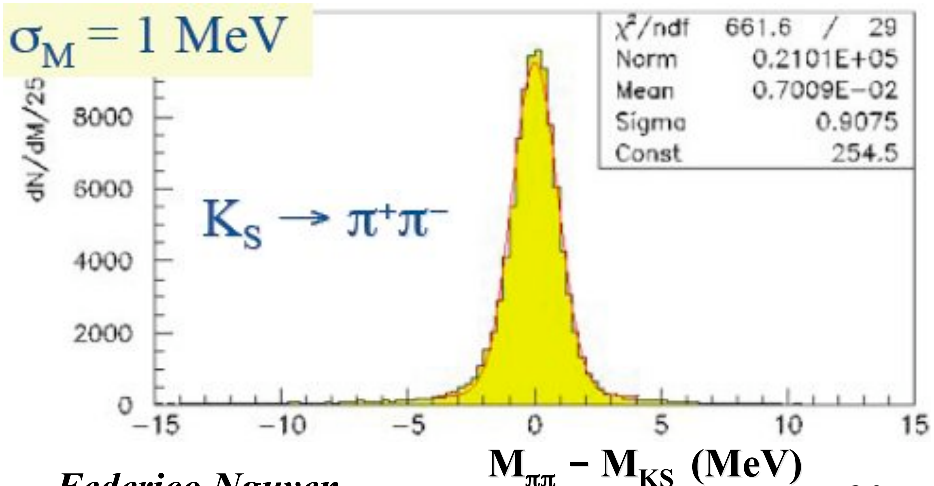


K LOng Experiment: resolutions









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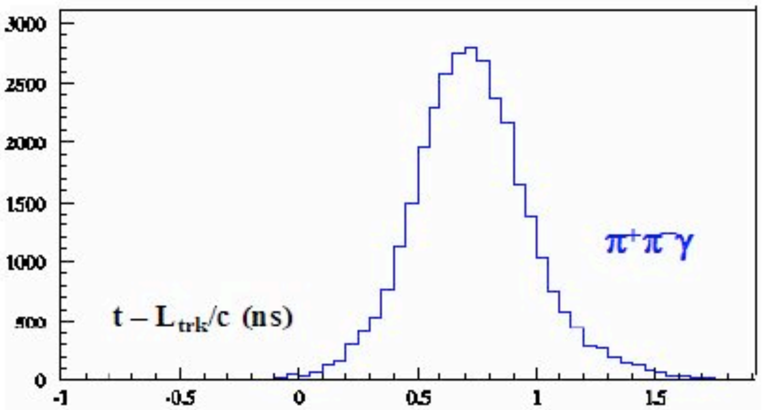
Electron/pion identification

π/e separation is performed using a particle ID function based on time and quantity and shape of the energy released in the calorimeter



time of flight: for low p values $\beta_\pi \neq \beta_e \sim 1$