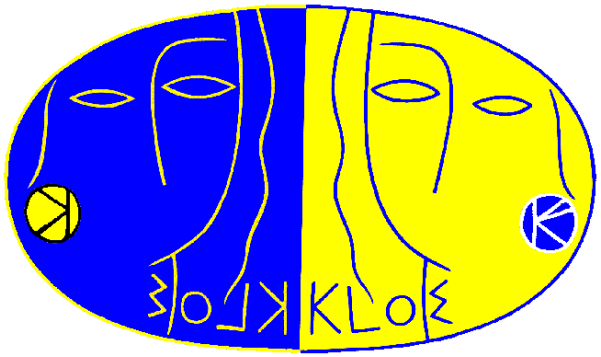
KLOE measurement of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$ with Initial State Radiation and the $\pi\pi$ contribution to the muon anomaly

Graziano Venanzoni

(for the KLOE/KLOE-2 collaboration)

Laboratori Nazionali di Frascati



EPS HEP 2013, Stockholm, 20 July 2013

Outline

- Hadronic contribution to $(g-2)_\mu$
- KLOE measurements of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$:
  - Small (photon) angle measurements (KLOE05, KLOE08)
  - Large (photon) angle measurement (KLOE10)
  - Evaluation of $a_\mu^{\pi\pi}$ and comparison with CMD-2/SND/BaBar
- New measurement of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$ by $\pi\pi\gamma/\mu\mu\gamma$ ratio (KLOE12) PLB 720 (2013) 336–343
  - Comparison with KLOE08, KLOE10 and evaluation of $a_\mu^{\pi\pi}$
- Outlook and conclusion

Normalized to luminosity $(e^+e^- \to e^+e^-(\gamma))$

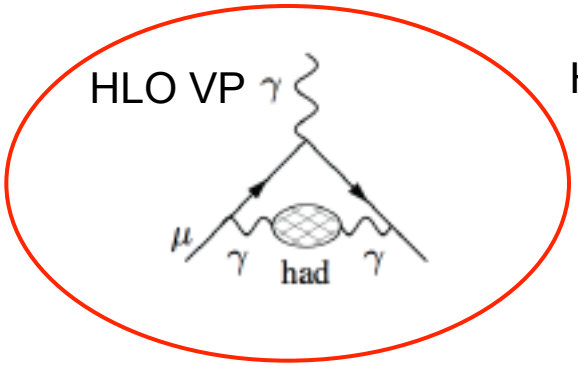
Muon anomaly

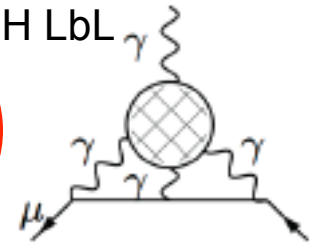
$$a_\mu = \frac{(g_\mu - 2)}{2}$$

- Long established discrepancy (>3σ) between SM prediction and BNL E821 exp.

- Theoretical error δa_μ^{SM} (~6×10^{-10}) dominated by HLO VP ($4\div5\times10^{-10}$) and HLbL ($[2.5\div4]\times10^{-10}$). A **twofold** improvement on δa_μ^{SM} from 2001 (thanks to new e^+e^- measurements)!

- Experimental error δa_μ^{EXP} ~6 $\times10^{-10}$(E821). Plan to reduce it to 1.6 10^{-10} by the new g-2 experiments at FNAL and J-PARC.





a_μ^{HLO} = (690.9±**4.4**)10^{-10} [Eidelman, TAU08]

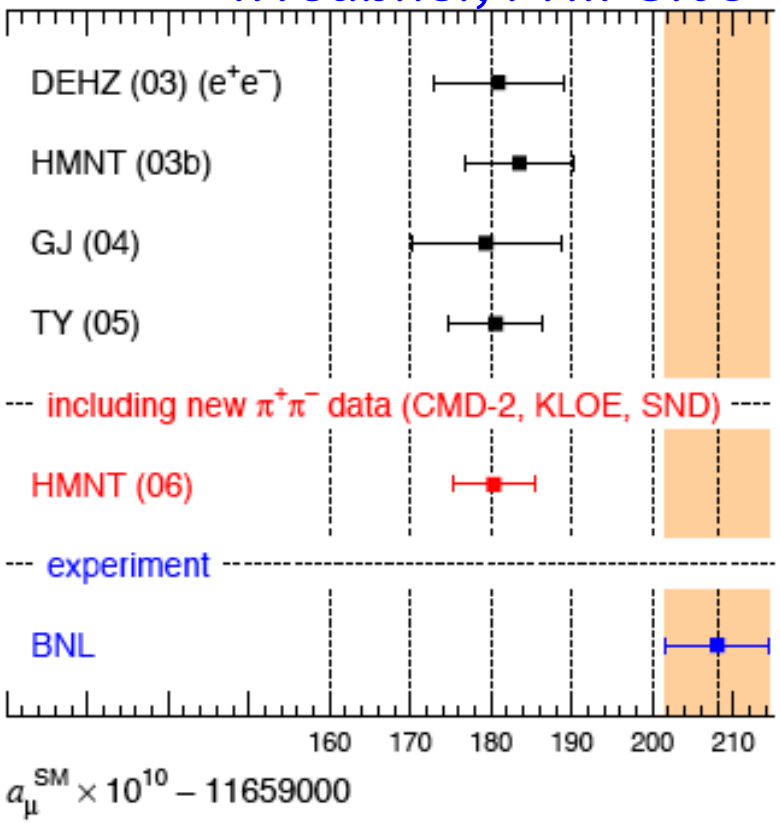
δa_μ^{HLO} **~0.7%**

a_μ^{HLbL} =(10.5±2.6)10^{-10} [Prades, dR&V. 08] =(11 ±4)10^{-10} (Jegerlehner, Nyffler)

δa_μ^{HLbL} **~25-40%**

a_μ^{SM} compared to BNL world av.

T.Teubner, PHIPSI08

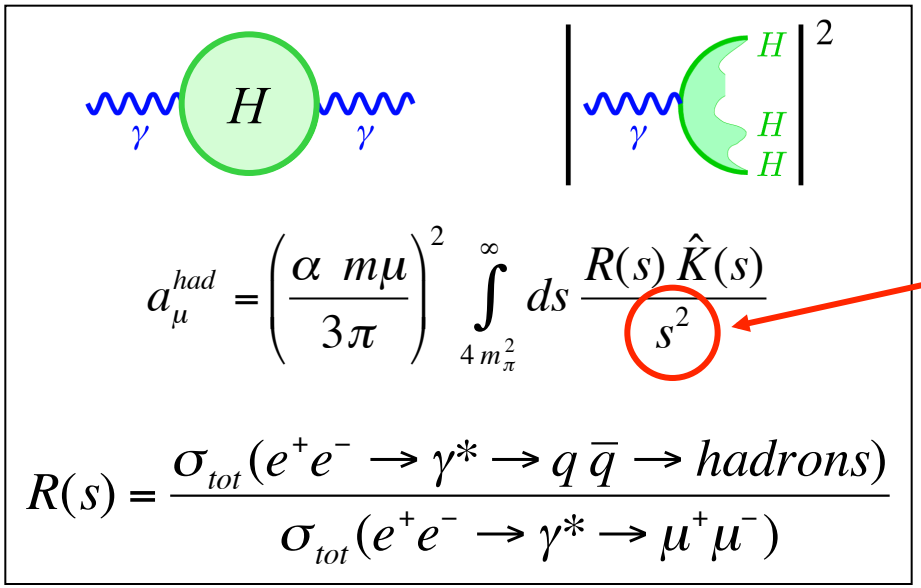


$$a_\mu^{EXP} - a_\mu^{TH} = (27.6 \pm 8.1) \cdot 10^{-10}, \sim 3.4\sigma$$

In 2001 a_μ^{EXP}-a_μ^{TH}=(23±16)•10^{-10}

a_μ^{HLO}:

L.O. Hadronic contribution to a_μ can be estimated by means of a dispersion integral:



$$a_\mu^{had} = \left(\frac{\alpha\ m\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds\ \frac{R(s)\,\hat{K}(s)}{s^2}$$

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to q\,\bar{q} \to hadrons)}{\sigma_{tot}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

$1 / s^2$ makes low energy contributions especially important:

$e^+e^- \to \pi^+\pi^-$

in the range < 1 GeV contributes to 70% !

- K(s) = analytic kernel-function
- above sufficiently high energy value, typically 2…5 GeV, use *pQCD*

Input:

a) hadronic electron-positron cross section data (G.dR 69, E.J.95, A.D.H.'97,….))

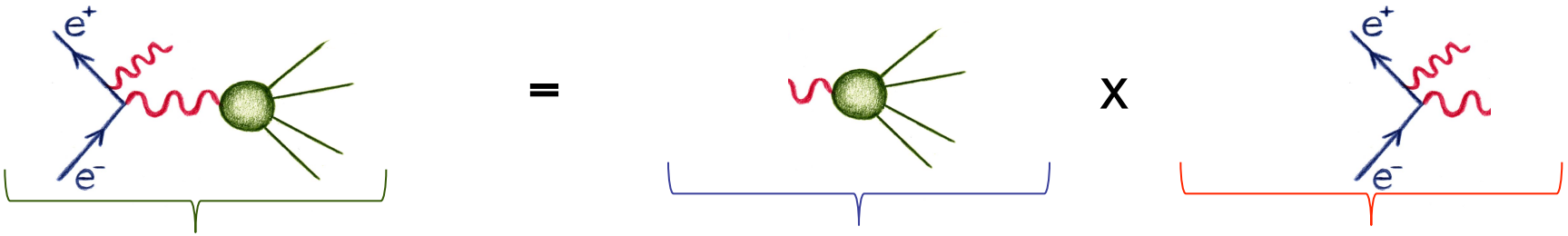
b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections)

Alemany, Davier, Hoecker '97

ISR: Initial State Radiation

Neglecting final state radiation (FSR):

$$\frac{d\sigma(e^+e^- \to hadrons + \gamma)}{dM^2_{hadr}} = \frac{\sigma(e^+e^- \to hadrons, M^2_{hadr})}{s} H(s, M^2_{hadr})$$



measured cross section = resulting cross section x radiator function

Theoretical input: precise calculation of the radiation function $H(s, M^2_{hadr})$

➔ **EVA + PHOKHARA MC Generator**

Binner, Kühn, Melnikov; Phys. Lett. B 459, 1999

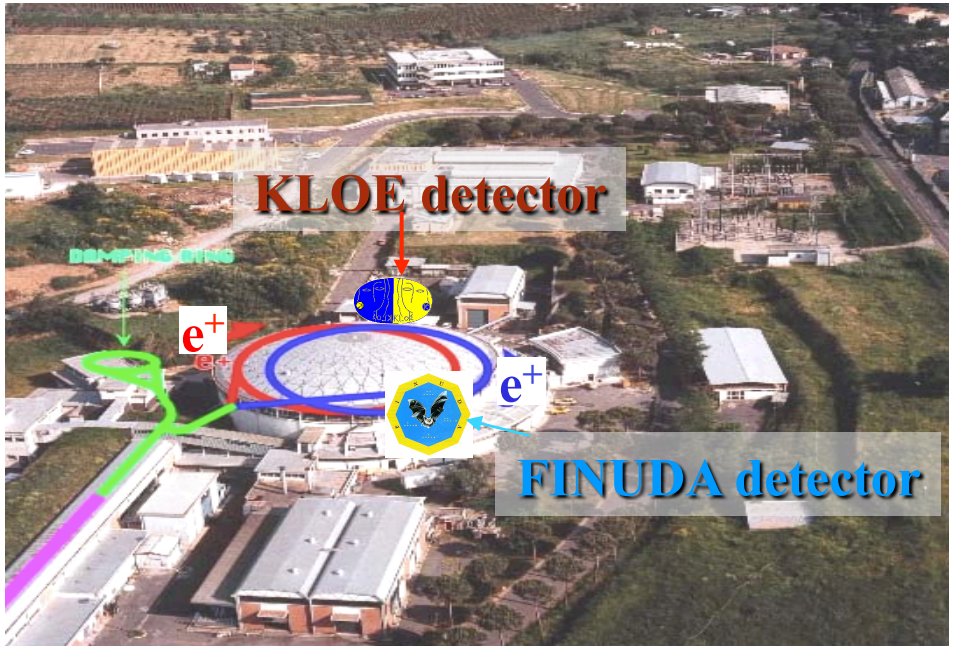
H. Czyż, A. Grzelińska, J.H. Kühn, G. Rodrigo, Eur. Phys. J. C 27, 2003

(exact next-to-leading order QED calculation of the radiator function)

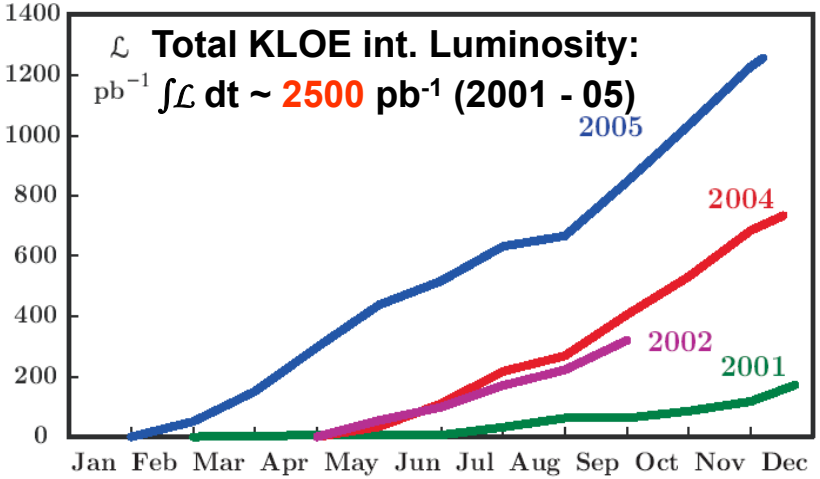
IN 2005 KLOE has published the first precision measurement of $\sigma(e^+e^- \to \pi^+\pi^-)$ with ISR using 2001 data ($140pb^{-1}$) PLB606(2005)12 $\Rightarrow$ ~3σ discrepancy btw a_μ^{SM} and a_μ^{exp}

DAΦNE: A Φ-Factory in Frascati (near Rome)

e^+e^- - collider with $\sqrt{s}=m_\Phi\approx 1.0195$ GeV



Integrated Luminosity



Peak Luminosity $L_{peak}= 1.5 \cdot 10^{32}cm^{-2}s^{-1}$

KLOE05 measurement (PLB606 (2005)12) was based on 140pb^{-1} of 2001 data!

2006:

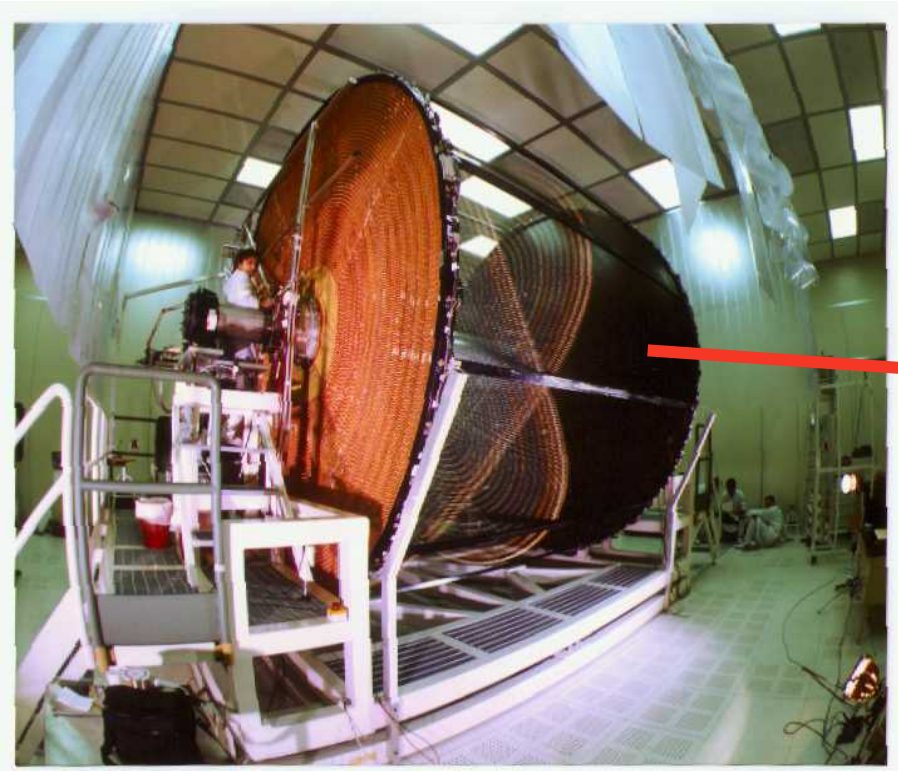
- **Energy scan (4 points around m_Φ-peak)**
- **240 pb^{-1} at $\sqrt{s}$ = 1000 MeV (off-peak data)**

KLOE08 measurement (PLB670 (2009)285) was based on 240pb^{-1} from 2002 data!

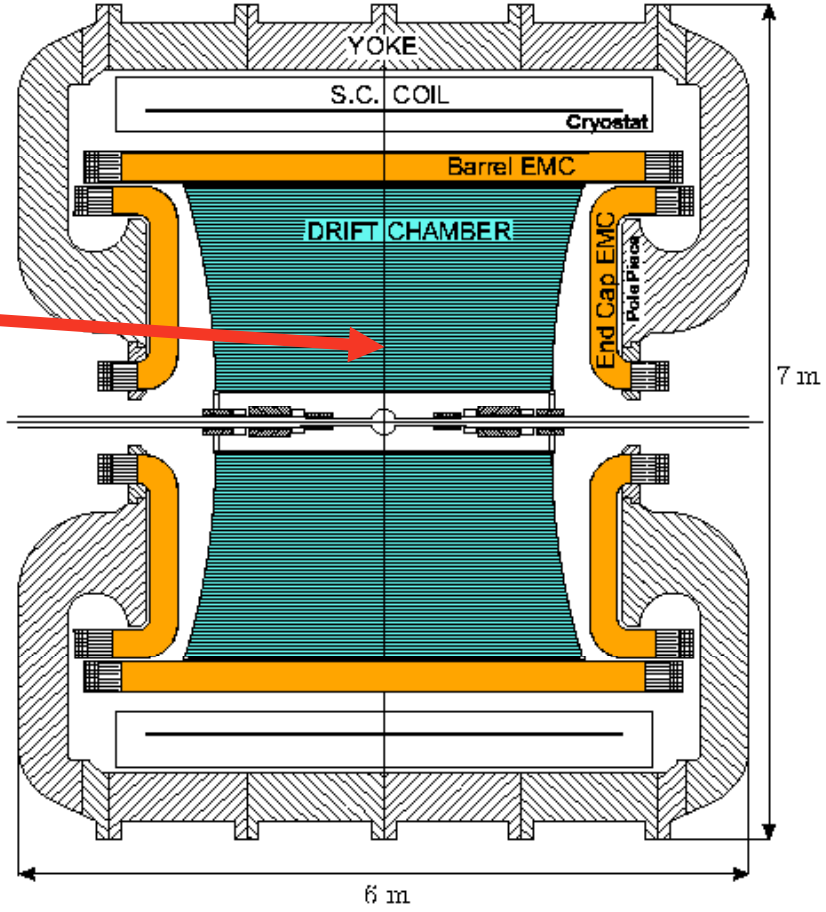
KLOE10 measurement (PLB700 (2011) 102) based on 233 pb^{-1} of 2006 data (at 1 GeV, different event selection)

KLOE Detector

Drift chamber



Full stereo geometry, 4m diameter,
52.140 wires 90% Helium, 10% iC_4H_{10}



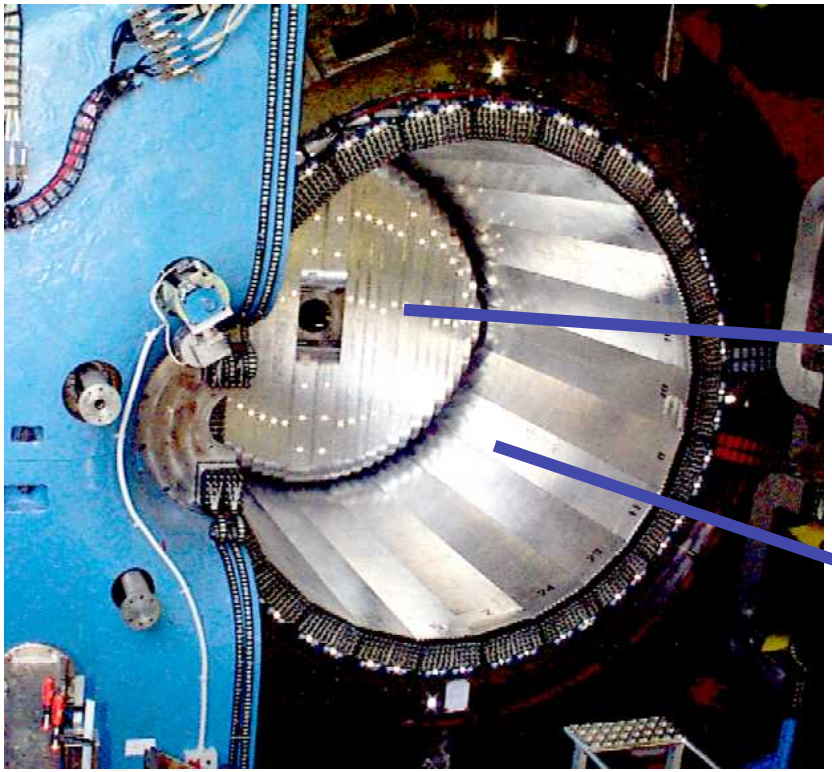
$\sigma_p/p = 0.4\%$ (for 90^0 tracks)

$\sigma_{xy} \approx 150$ mm, $\sigma_z \approx 2$ mm

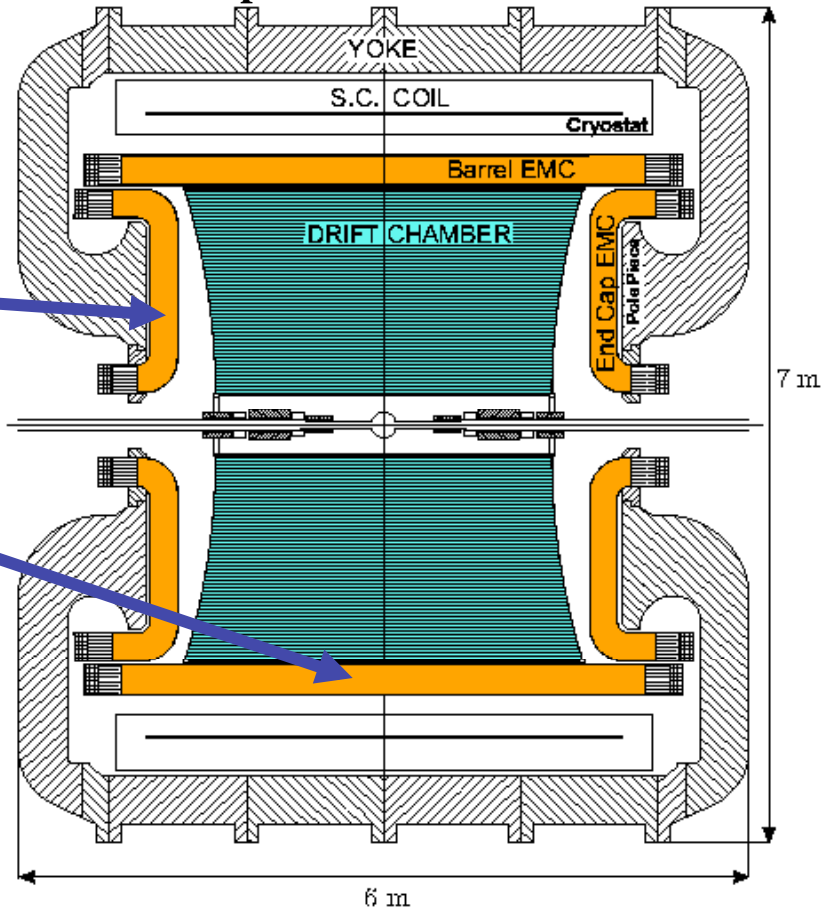
Excellent momentum resolution

KLOE Detector

Electromagnetic Calorimeter



Pb / scintillating fibres (4880 PMT)
Endcap - Barrel - Modules



$$\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$$

$$\sigma_T = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 100 \text{ ps}$$

(Bunch length contribution subtracted from constant term)

Excellent timing resolution

Event Selection: Small Angle (SA)

Pion tracks at large angles

$50^o < \theta_\pi < 130^o$

a) Photons at small angles

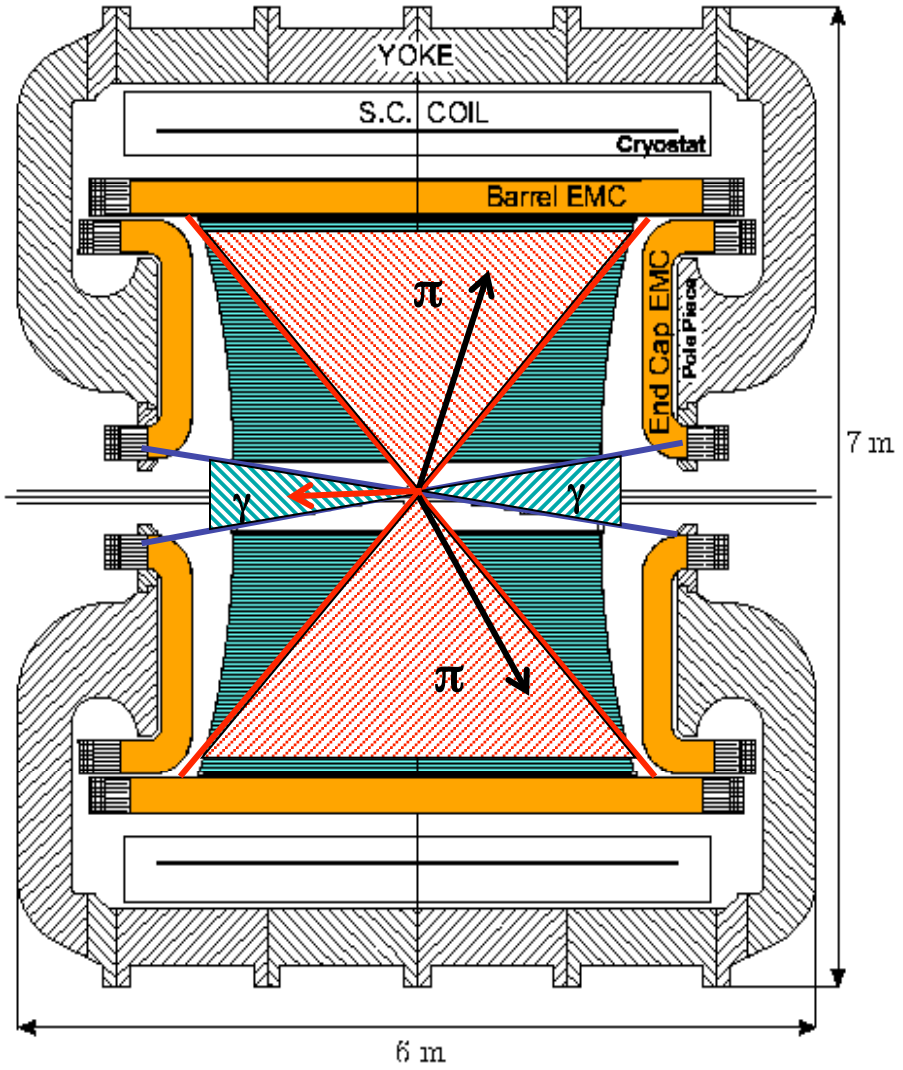
$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

➔ Photon momentum from kinematics:

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

- High statistics for ISR photons
- Very small contribution from FSR
- Reduced background contamination

KLOE



Event Selection: Large Angle (LA)

Pion tracks at large angles

$50^o < \theta_\pi < 130^o$

a) Photons at small angles

$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

➔ **Photon momentum from kinematics:**

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

- High statistics for ISR photons
- Very small contribution from FSR
- Reduced background contamination

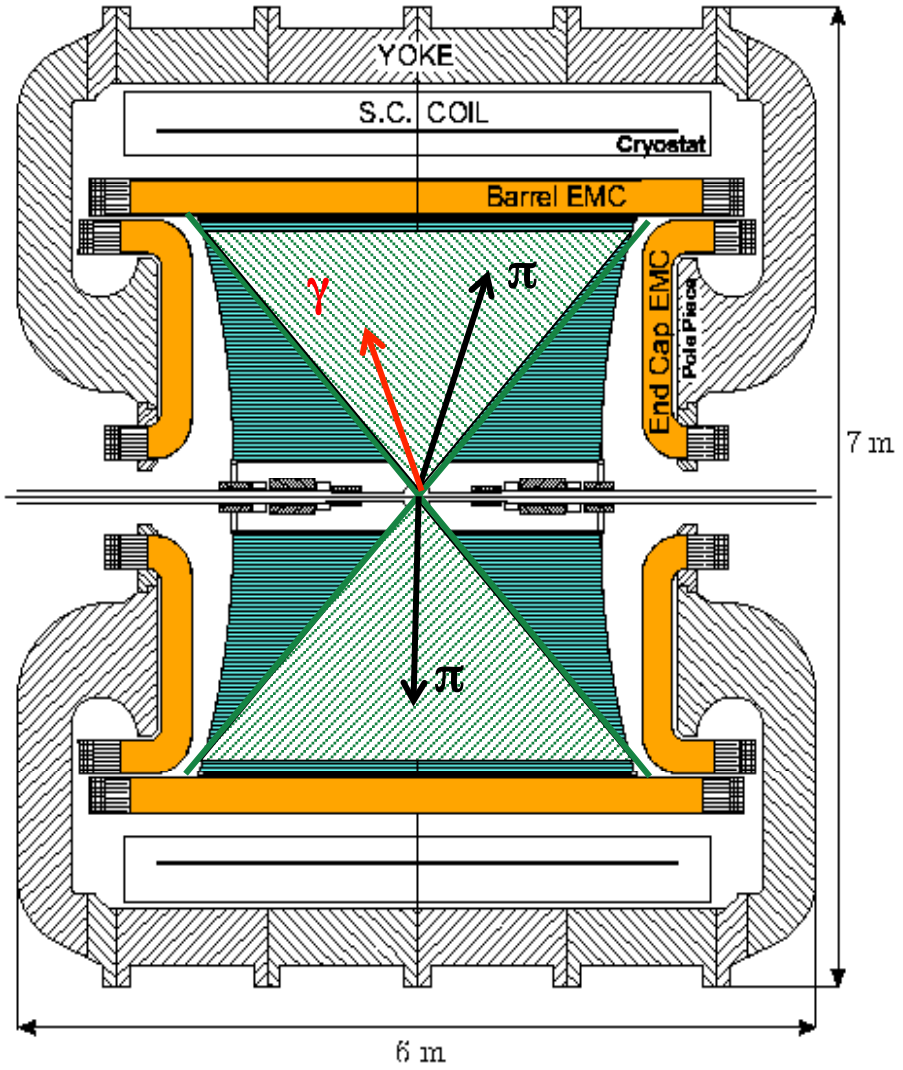
b) Photons at large angles

$50^o < \theta_\gamma < 130^o$

➔**Photon is explicitly measured in the detector!**

- Threshold region accessible
- Lower signal statistics
- Increased contribution from FSR and $\phi \rightarrow \pi^+\pi^-\pi^0$ (use off peak data)

KLOE



KLOE08: Small Angle ($\sqrt{s}$= 1020 MeV)

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

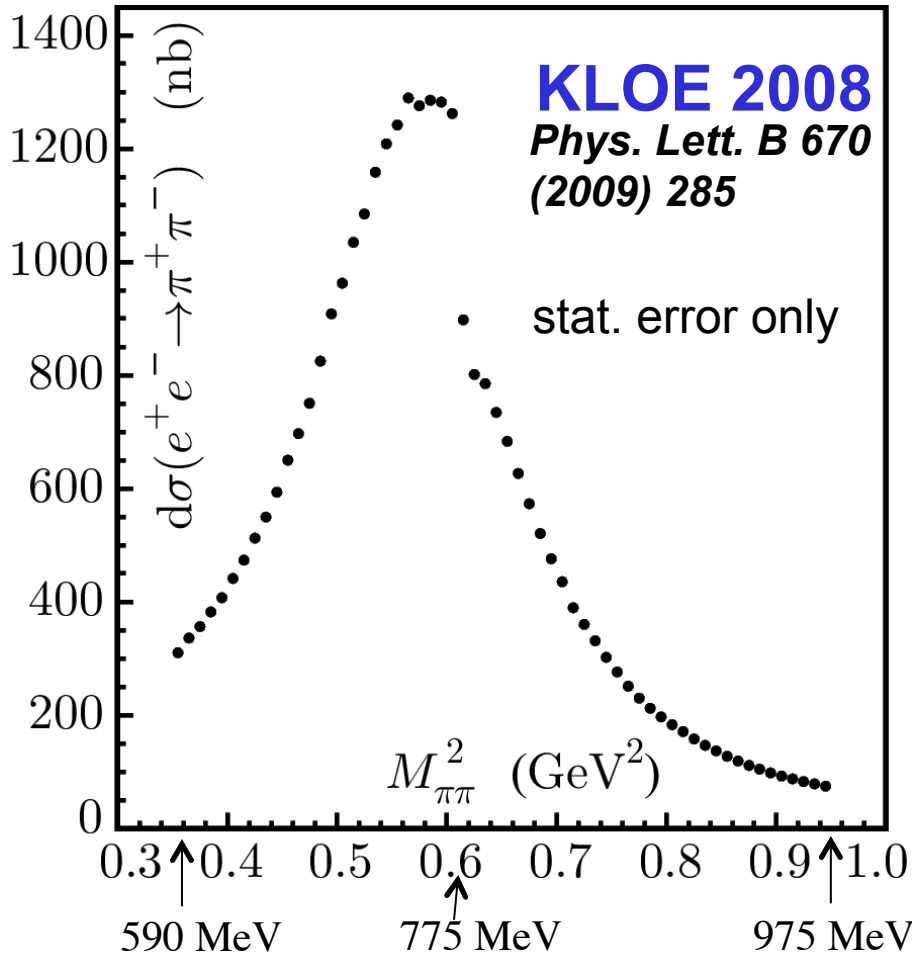
Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
p/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.2%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dep. Of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

experimental fractional error on a_μ = 0.6 %

FSR treatment	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 $(M^0_{\pi\pi})^2$



$$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s) K(s) ds$$

$a_\mu^{\pi\pi}(0.35\text{-}0.95\text{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$

KLOE10: Large Angle ($\sqrt{s}$= 1000 MeV)

Phys. Lett. B 700 (2011) 102

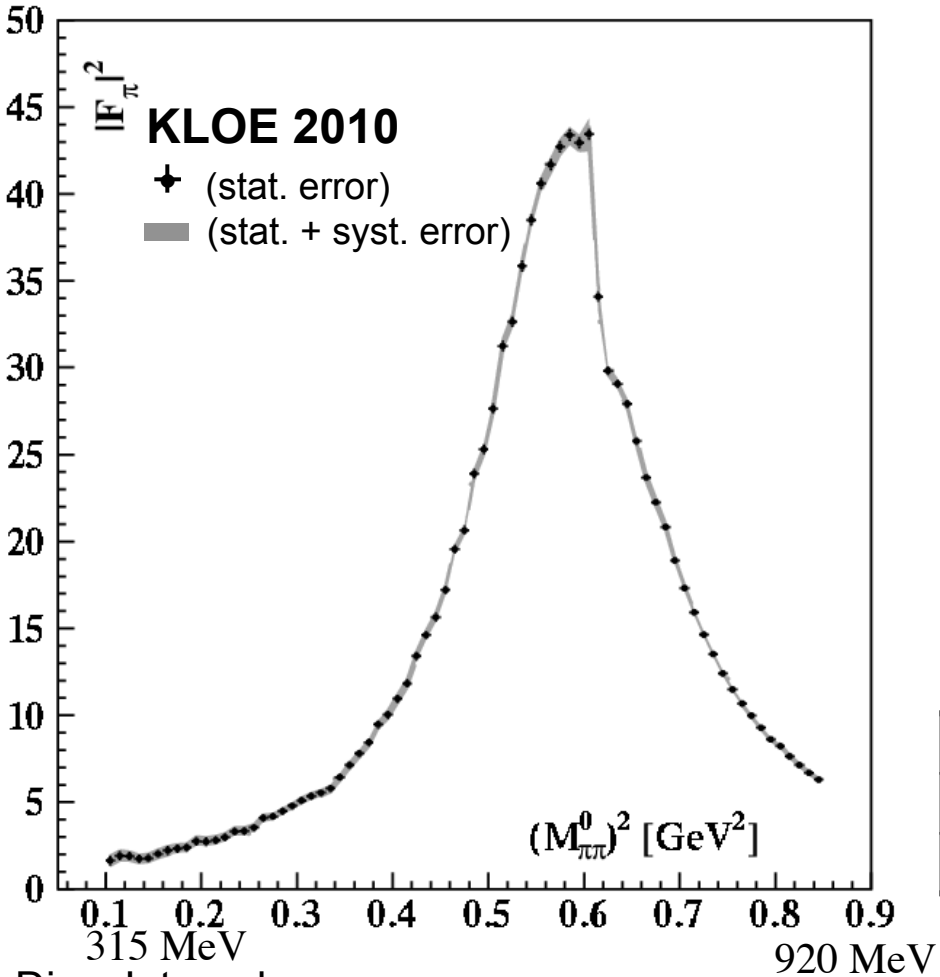


Table of systematic errors on $a_\mu^{\pi\pi}(0.1\text{-}0.85\ \text{GeV}^2)$:

Reconstruction Filter	negligible
Background	0.5%
$f_0+\rho\pi$	0.4%
Ω cut	0.2%
Trackmass	0.5%
p/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.2%
Acceptance	0.5%
Unfolding	negligible
Software Trigger	0.1%
Luminosity$(0.1_{th} \oplus 0.3_{exp})$%	0.3%

experimental fractional error on a_μ = 1.0 %

FSR treatment	0.8%
Radiator H	0.5%
Vacuum polarization	0.1%

theoretical fractional error on a_μ = 0.9 %

Disp. Integral:

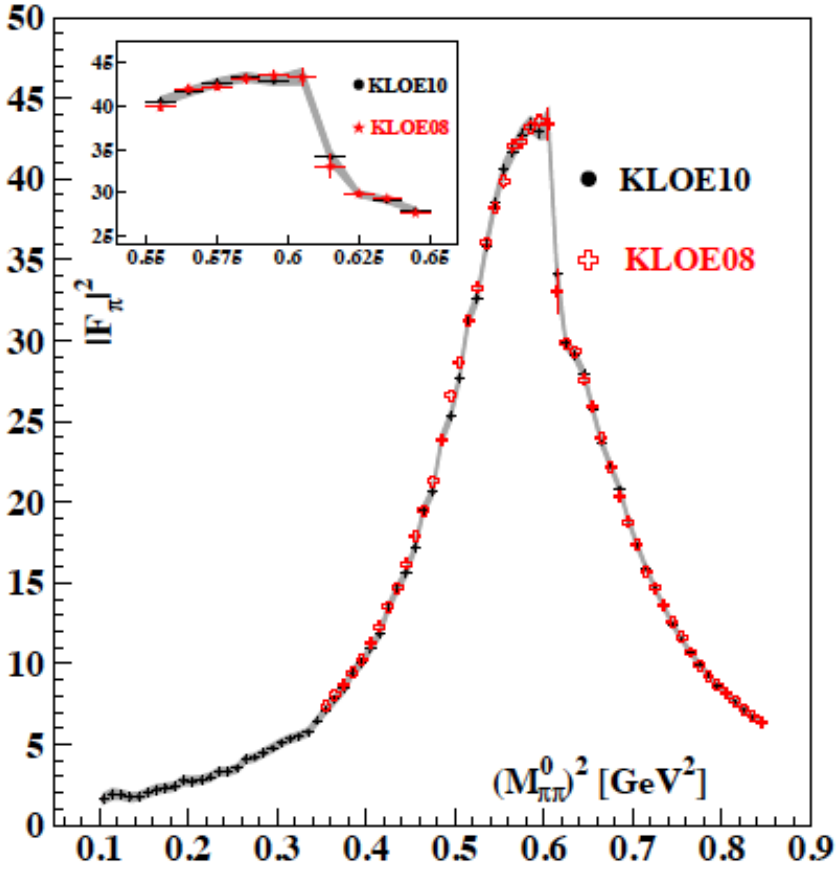
$$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s) K(s) ds$$

$$a_\mu^{\pi\pi}(0.1\text{-}0.85\ \text{GeV}^2) = (478.5 \pm 2.0_{stat} \pm 5.0_{sys} \pm 4.5_{theo}) \cdot 10^{-10}$$

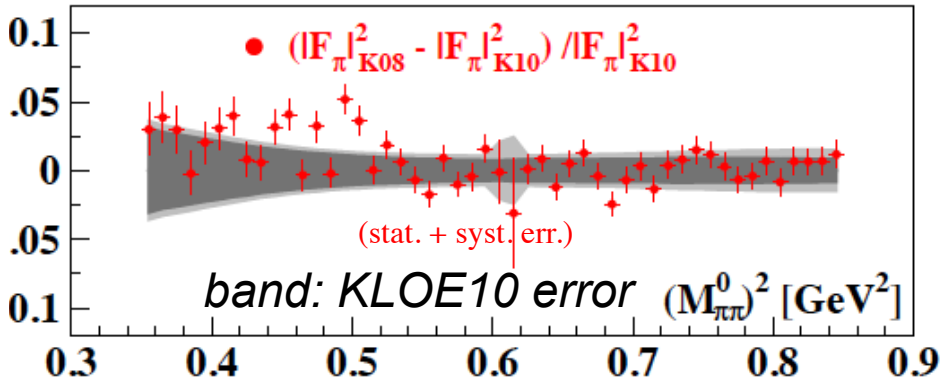
0.4% 1.0% 0.9%

Comparison of results: KLOE10 vs KLOE08

KLOE08 result compared to KLOE10:



Fractional difference:



Excellent agreement with KLOE08, expecially above 0.5 GeV^2

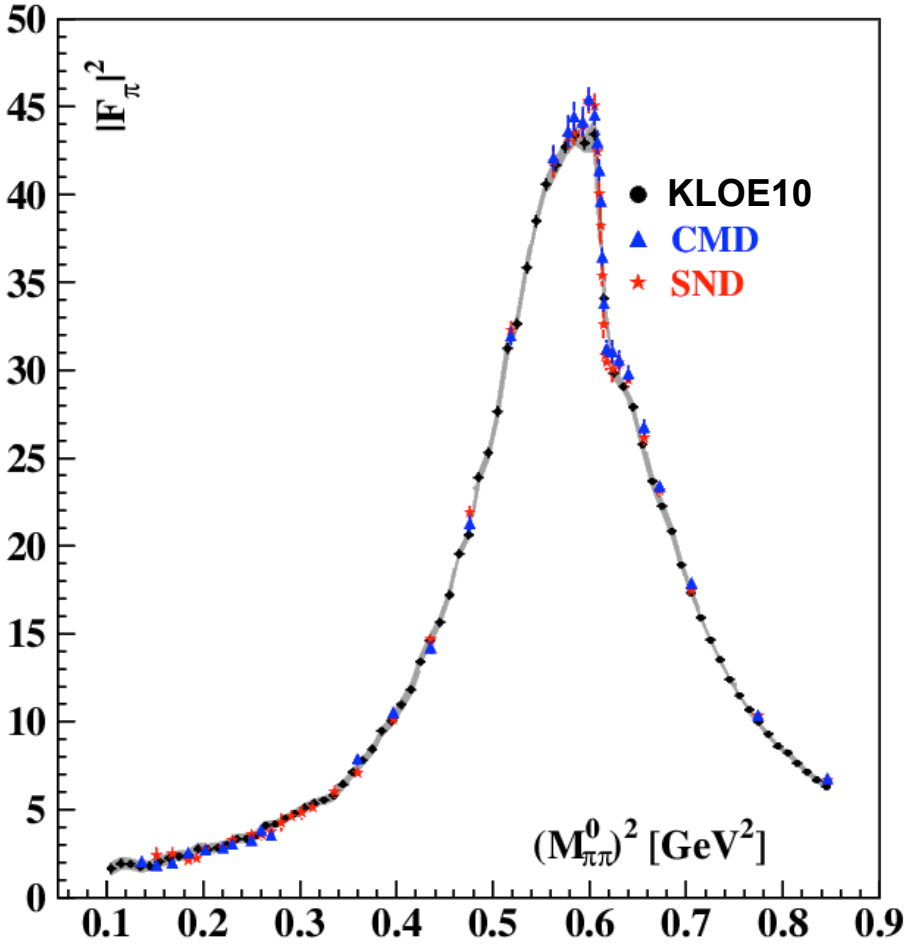
Combination of KLOE08 and KLOE10:

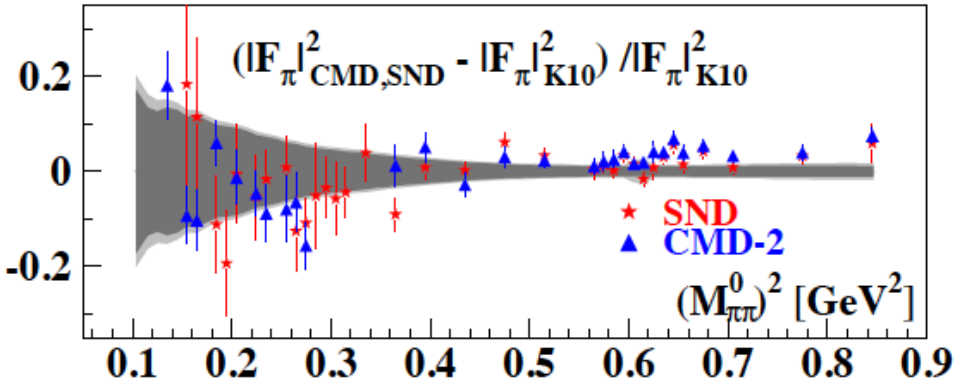
$a_\mu^{\pi\pi}(0.1\text{-}0.95\ \text{GeV}^2) = (488.6 \pm 6.0) \cdot 10^{-10}$

KLOE covers ~70% of total a_μ^{HLO} with a fractional total error of 1.2%

Comparison of results: KLOE10 vs CMD-2/SND

CMD and SND results compared to KLOE10: Fractional difference



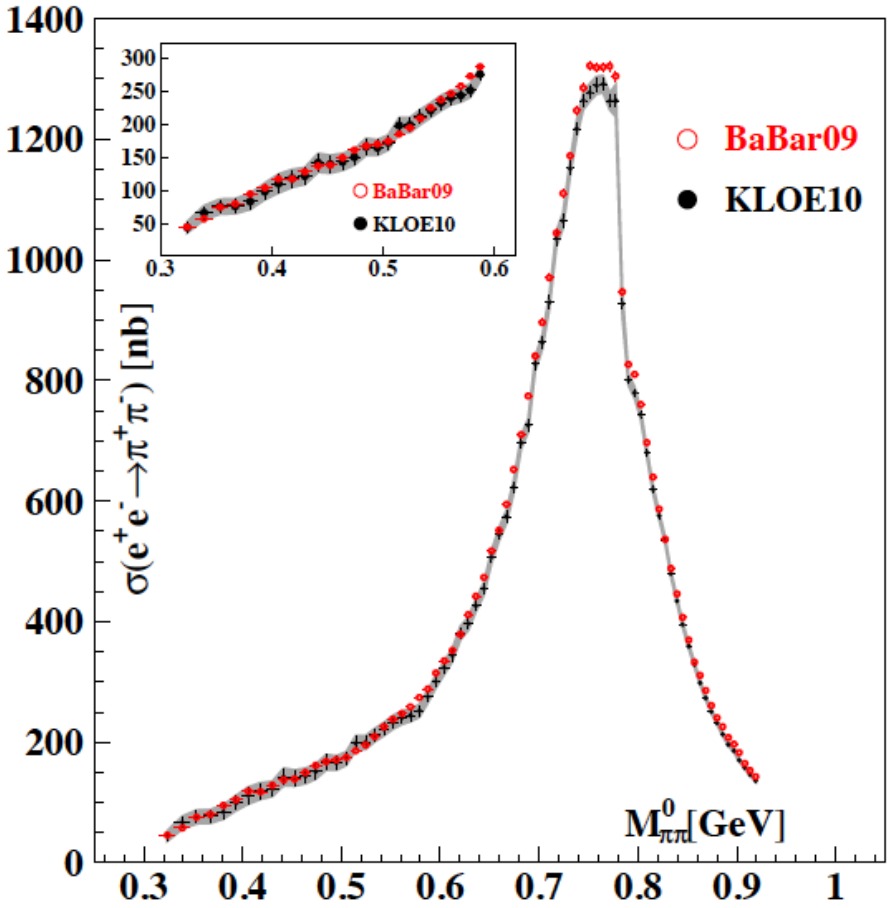


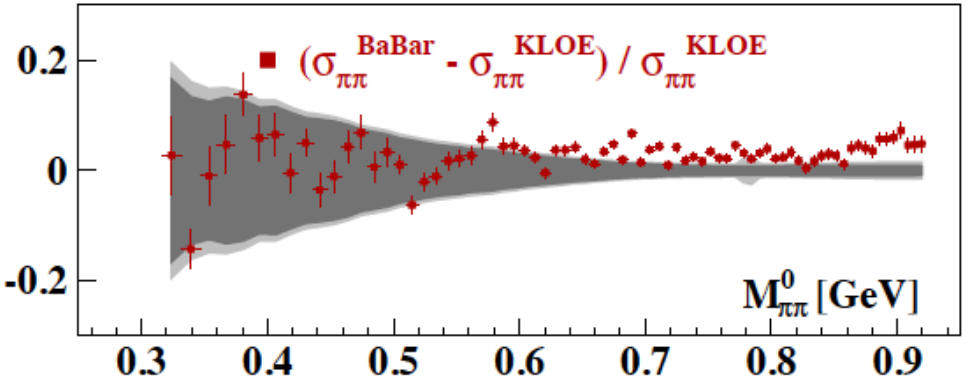
band: KLOE10 error

Below the ρ peak good agreement with CMD-2/SND.
Above the ρ peak KLOE10 slightly lower (as KLOE08)

Comparison of results: KLOE10 vs BaBar

BaBar results compared to KLOE10: Fractional difference





band: KLOE10 error

Agreement within errors below 0.6 GeV; BaBar higher by 2-3% above

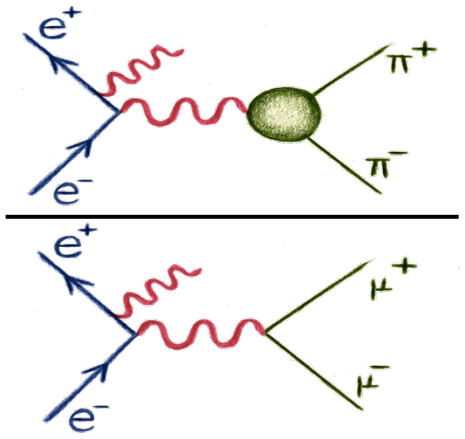
New $\sigma_{\pi\pi}$ measurement from π/μ

An alternative way to obtain $|F_\pi|^2$ is the bin-by-bin ratio of pion over muon yields (instead of using absolute normalization with Bhabhas).

$$|F_\pi(s')|^2 \approx \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \quad \frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}$$

kinematical factor (s_{mm}^{Born} / s_{pp}^{Born})

meas. quantities



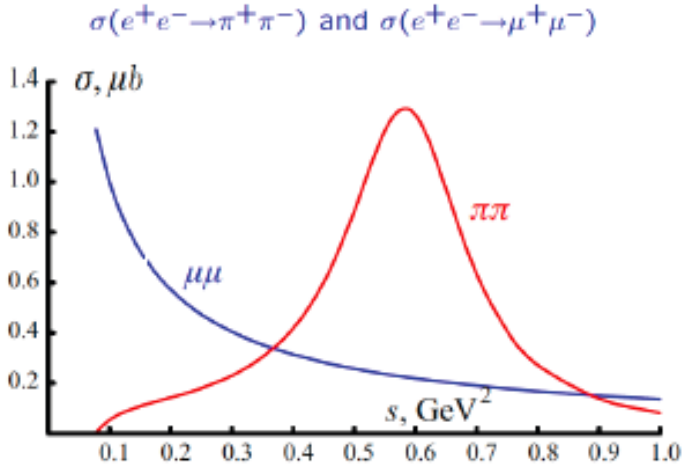
Many radiative corrections drop out:

- *radiator function*
- *int. luminosity from Bhabhas*
- *Vacuum polarization*

Separation btw $\pi\pi\gamma$ and $\mu\mu\gamma$ using M_{TRK}

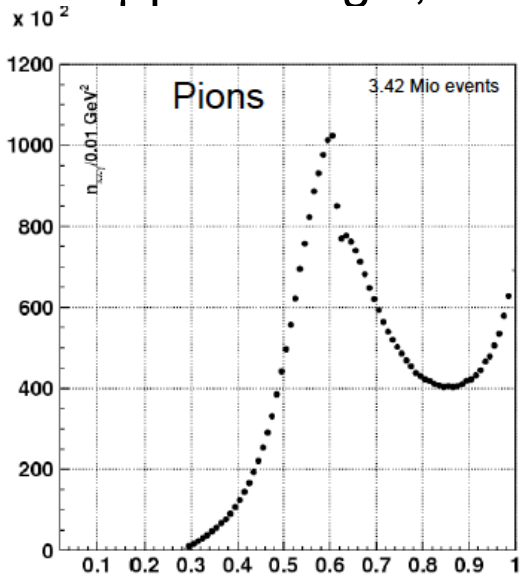
- *muons:* $M_{Trk} < 115$ *MeV*
- *pions :* $M_{Trk} > 130$ *MeV*

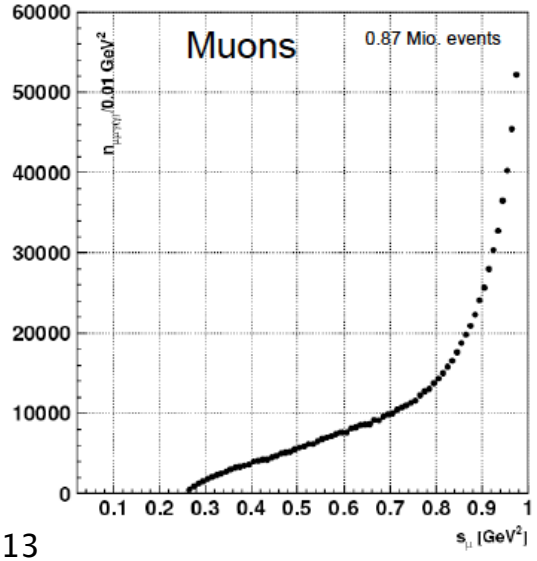
Very important control of π/μ *separation in the* ρ *region!* ($\sigma_{\pi\pi} >> \sigma_{\mu\mu}$)

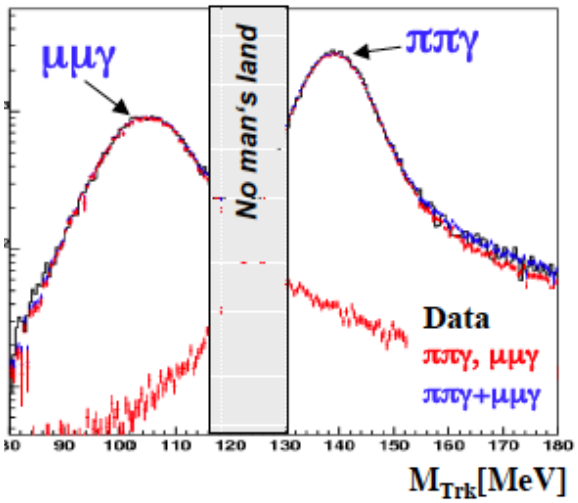


KLOE12: analysis of $\pi\pi\gamma/\mu\mu\gamma$

- 239.2 pb^{-1} of 2002 data sample (the same used in KLOE08 analysis), with photon at small angle : 0.87 Million $\mu\mu\gamma$ events (compared to 3.4 Million for $\pi\pi\gamma$)
- Careful work to achieve a control of ~1% in the muon selection, especially in the ρ region where $\pi\pi\gamma/\mu\mu\gamma \sim 10$. π/μ separation crosschecked in three different methods (M_{TRK} fit, Kinematic fit, cut on σ_{MTRK})
- $\mu\mu\gamma$ (and $\pi\pi\gamma$) Efficiencies (Trk,Trg,PID) done on data
- Excellent data/MC agreement for many kinematic variables: M_{TRK}, track and γ polar angle, etc...



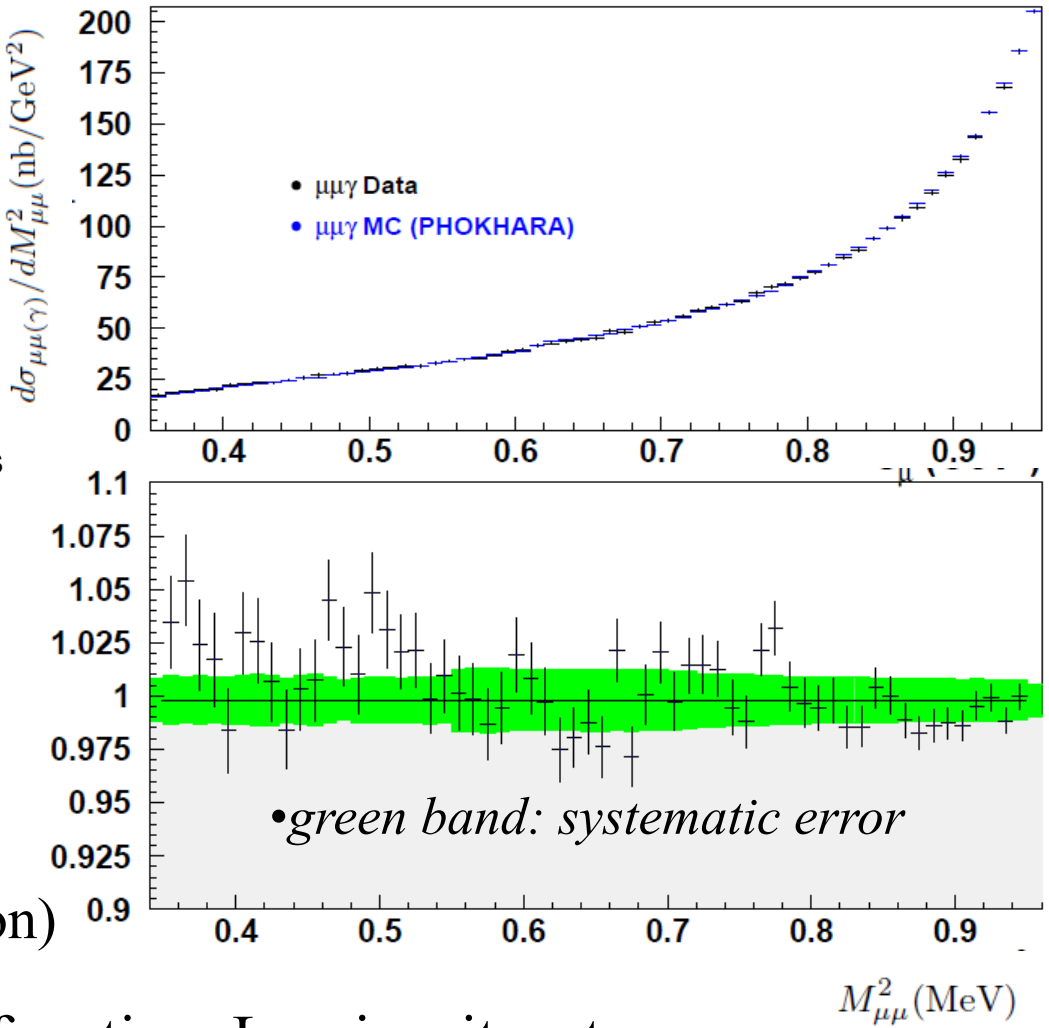




μμγ cross section: data/MC comparison

$$\frac{d\sigma^{obs}_{\mu\mu\gamma(\gamma)}}{dM^2_{\mu\mu}} = \frac{\Delta N_{Obs} - \Delta N_{Bkg}}{\Delta M^2_{\mu\mu}} \cdot \frac{1}{\varepsilon_{Sel}} \cdot \frac{1}{\int L dt}$$

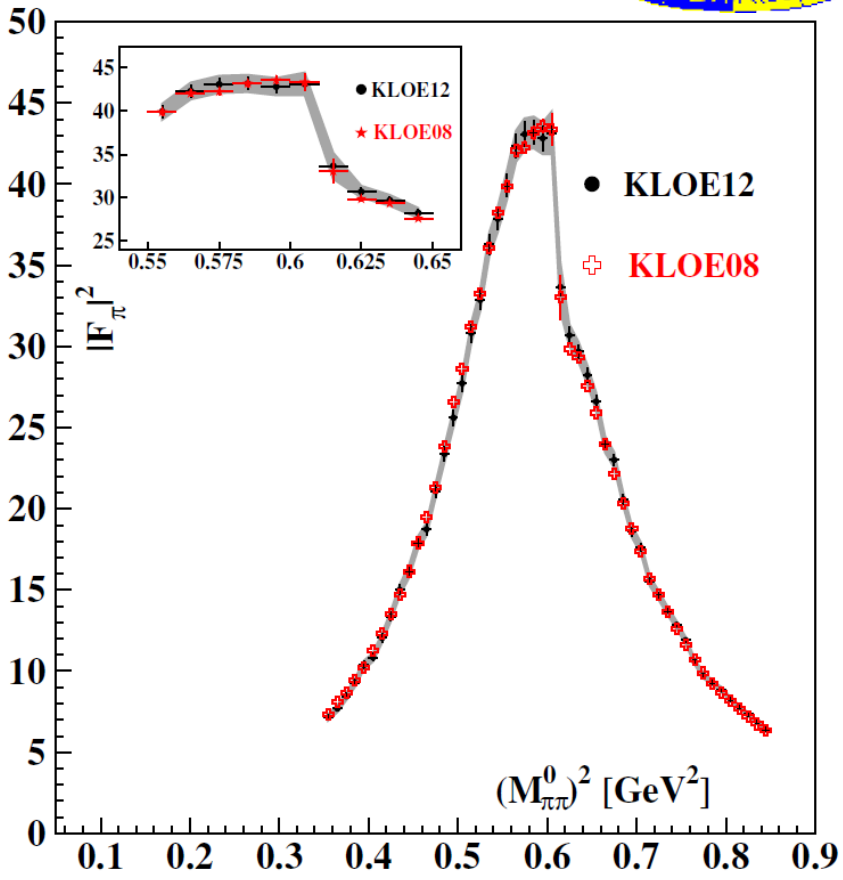
$$\frac{d\sigma^{DATA}_{\mu\mu\gamma(\gamma)}}{d\sigma^{MC}_{\mu\mu\gamma(\gamma)}} = 0.998 \pm 0.001_{stat} \pm 0.011_{sys}$$



- The systematic error has been averaged on $M^2_{\mu\mu}$
- Good agreement with PHOKHARA MC (NLO Calculation)
- Consistency check of Radiator function, Luminosity, etc…

KLOE12 result on $|F_\pi|^2$ and comp. with KLOE08

	KLOE08	KLOE12
Syst. errors (%)	$\Delta^{\pi\pi} a_\mu$ abs	$\Delta^{\pi\pi} a_\mu$ ratio
Reconstruction Filter	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 Polarization	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

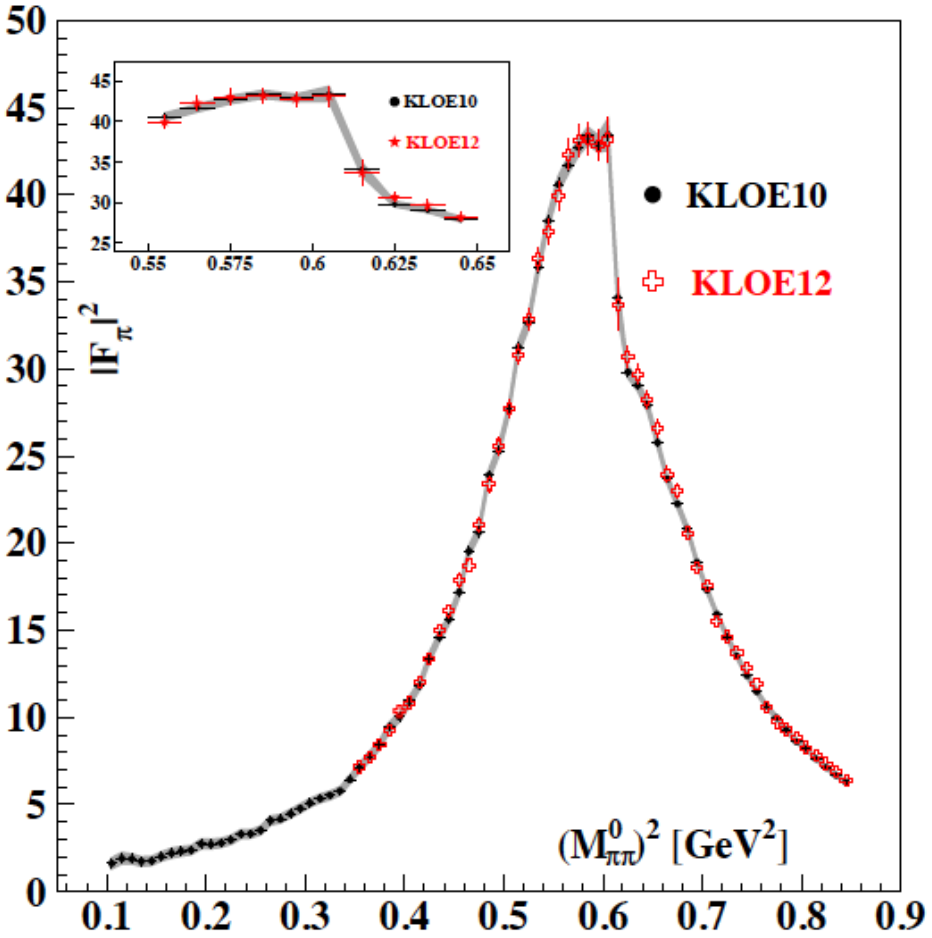


	$a_\mu^{\pi\pi}(0.35 - 0.95\ \mathrm{GeV}^2) \times 10^{10}$
KLOE12	$385.1 \pm 1.1_{\mathrm{stat}} \pm 2.7_{\mathrm{sys+theo}}$
KLOE08	$387.2 \pm 0.5_{\mathrm{stat}} \pm 3.3_{\mathrm{sys+theo}}$

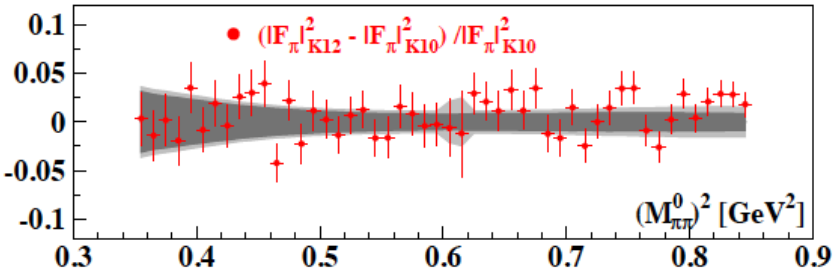
- Good agreement btw the two measurements, especially in the ρ region.
- Improved syst. error in KLOE12. Theoretical error strongly reduced
- The two measurements are not independent ($\pi\pi\gamma$ sample is the same)…

Comparison of results: KLOE12 vs KLOE10

KLOE12 result compared to KLOE10:



Fractional difference:



band: KLOE10 error

Excellent agreement between the two independent measurements!

Analysis	$a_\mu^{\pi\pi}(0.35-0.85\ \mathrm{GeV}^2)\times 10^{10}$
KLOE12	$377.4 \pm 1.1_{\mathrm{stat}} \pm 2.7_{\mathrm{sys+theo}}$
KLOE10	$376.6 \pm 0.9_{\mathrm{stat}} \pm 3.3_{\mathrm{sys+theo}}$

$a_\mu=(g_\mu-2)/2$:

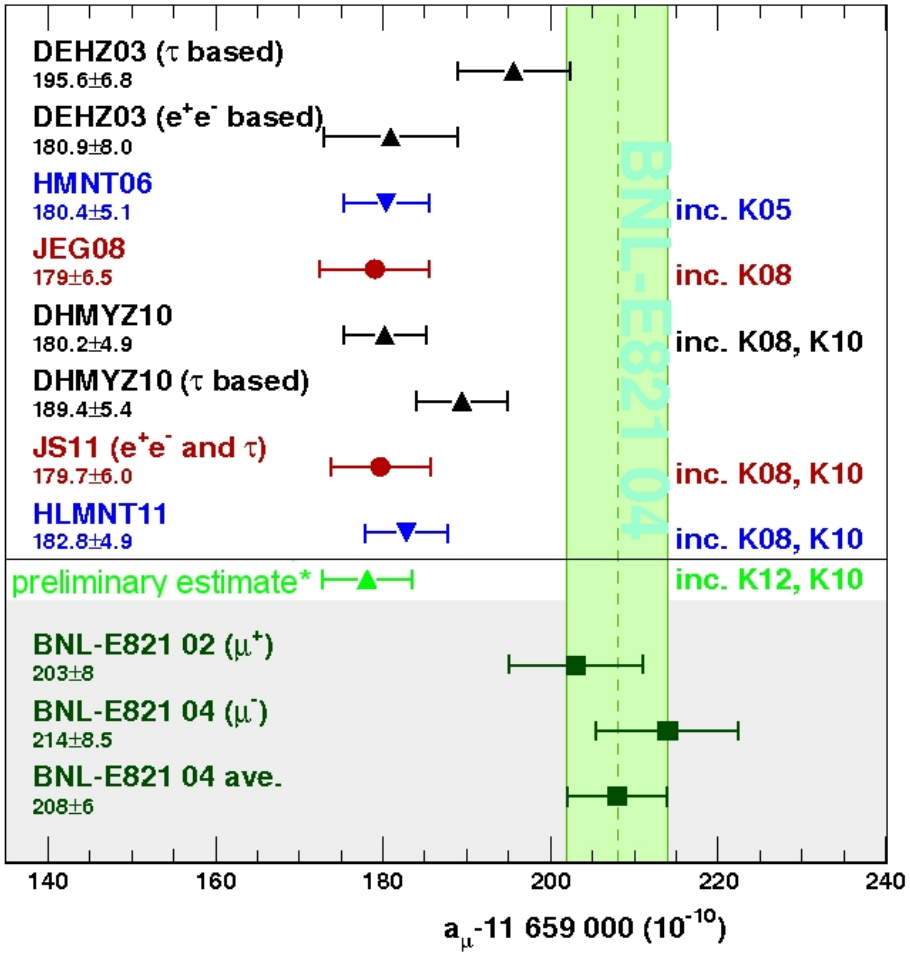
Theoretical predictions compared to the BNL result

- **The latest inclusion of all e^+e^- data gives a discrepancy btw a_μ^{SM} and a_μ^{EXP} of 3 to 4σ**

- KLOE12 in agreement with previous KLOE measurements confirms this discrepancy.

- **(Reduced) discrepancy btw ee and τ data (new I. corr.,ee,τ data). JS11 claims to have solved it**

Very important the new g-2 experiments (at FNAL and JPARC)!



* Our extrapolation based on DHMYZ10

Conclusion

- During the last 10 years KLOE has performed a series of precision measurements with ISR which confirmed a 3σ discrepancy between a_μ^{SM} and the BNL measured value

- The published measurements (KLOE05, KLOE08, KLOE10) normalized to Bhabha events, have allowed to measure $a_\mu^{\pi\pi}$ in the region below 1 GeV with **~1%** total error

- A new measurement of $|F_\pi|^2$ from the $\pi\pi\gamma/\mu\mu\gamma$ ratio (based on 240 pb^{-1}) with **0.7%** systematic error has been published (**PLB720 (2013) 336–343**)

- It doesn't rely on specific theoretical input (like luminosity and radiator function) and allows a stringent cross check of the published measurements with comparable systematic error

- Good agreement for $\mu\mu\gamma$ cross section with NLO QED calculation (PHOKHARA MC) and for $|F_\pi|^2$ with previous KLOE measurements (confirming 3σ discrepancy on a_μ)

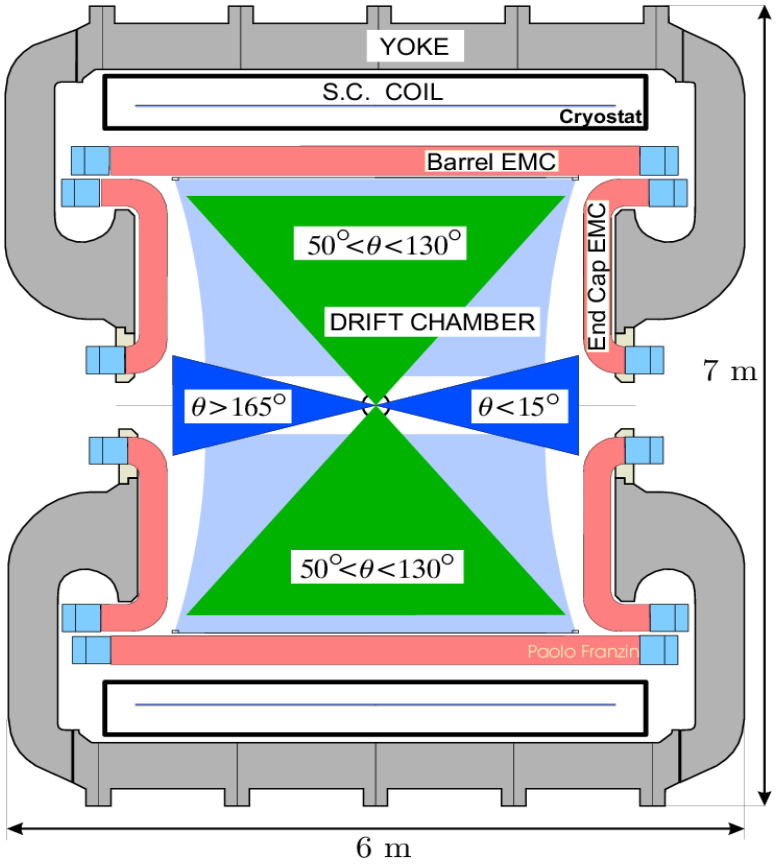
Outlook

- Still more than 1.5 fb^{-1} of KLOE data on tape. This would represent a ~4 improvement in statistics.

- A new round of data taking with KLOE-2 upgraded detector is expected from Fall 2013. For details see the following talks at EPS:

  - ***D. Domenici "The new detectors of the KLOE-2 experiment"***
  - ***E. De Lucia "Study of CP and CPT symmetries violation in kaon decays with KLOE"***
  - ***C. Bloise "Hadron physics studies at KLOE"***

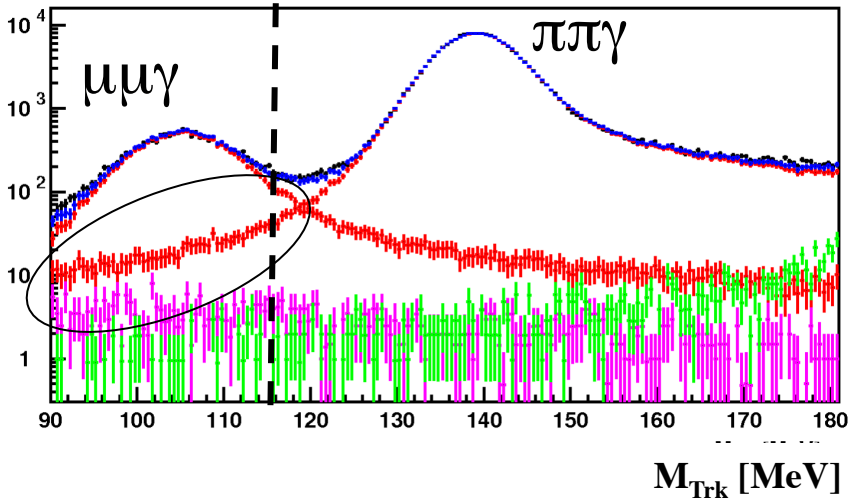
Stay tuned!

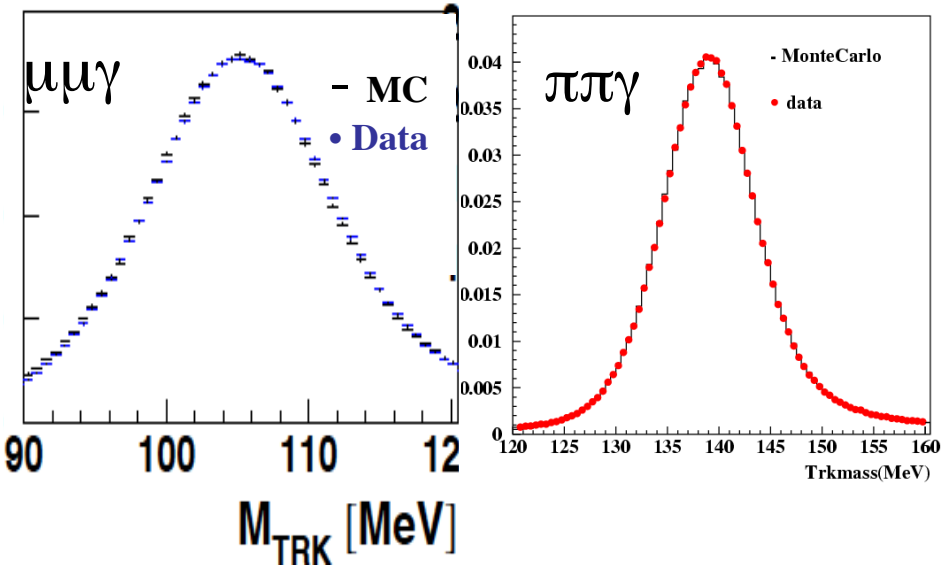


SPARE SLIDES

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

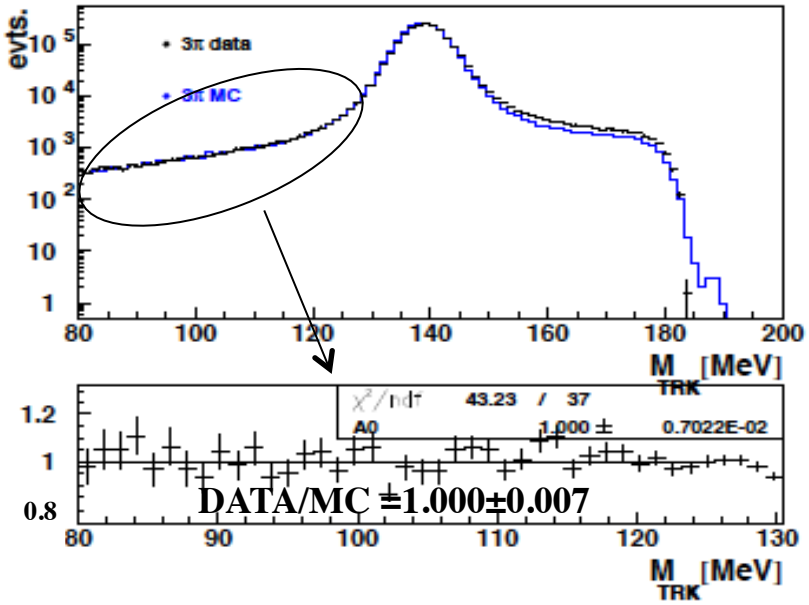
- A careful work has been done to achieve a control of ~1% in the muon selection, especially ~0.6 GeV² (ρ peak) where π/μ ~10.
- ππγ % background to μμγ signal (M_{TRK}<115 MeV) is ~15% at ρ peak
- ➔ ππγ M_{TRK} tail in the μμγ region must be well under control.
- ππγ M_{TRK} tail tuned using $\phi \rightarrow \pi^+\pi^-\pi^0$ control sample.
- Excellent agreement on M_{TRK} (ππγ and μμγ) distributions

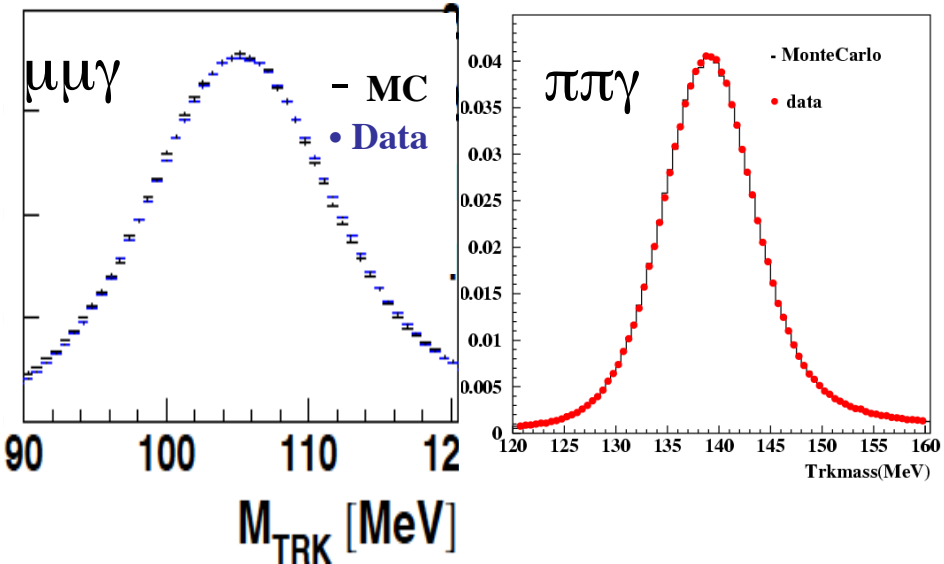




π/μ separation: control of ππγ M_{TRK} tail

- A careful work has been done to achieve a control of ~1% in the muon selection, especially ~0.6 GeV² (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 $\phi \rightarrow \pi^+\pi^-\pi^0$ control sample.
- Excellent agreement on M_{TRK} (ππγ and μμγ) distributions

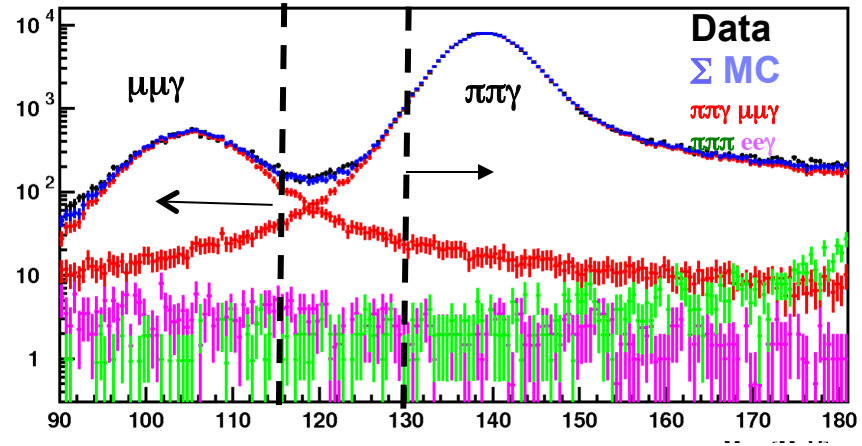




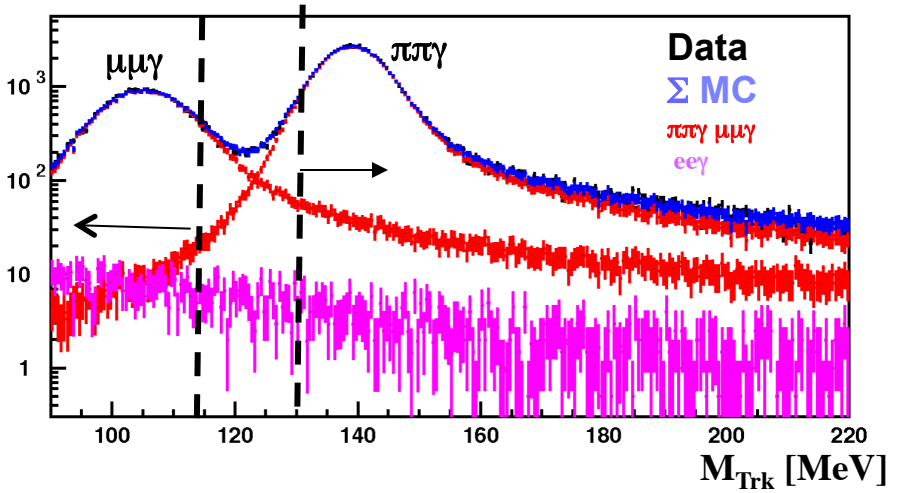
Background:

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

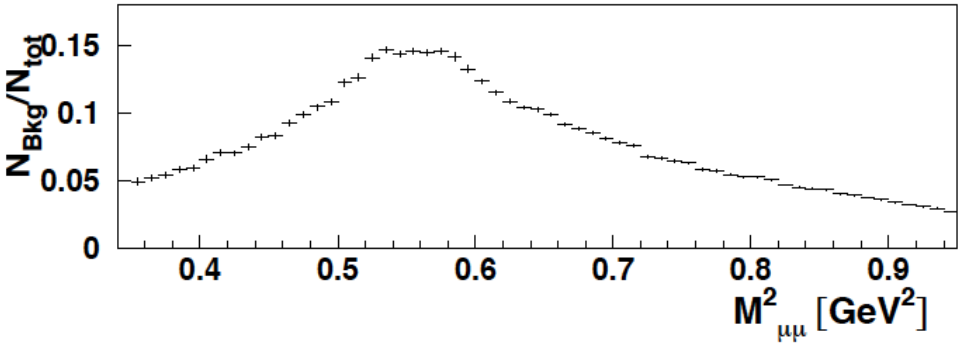
$0.60 < M_{\pi\pi}^2 < 0.62$ GeV^2, χ^2/ndof = 158/180



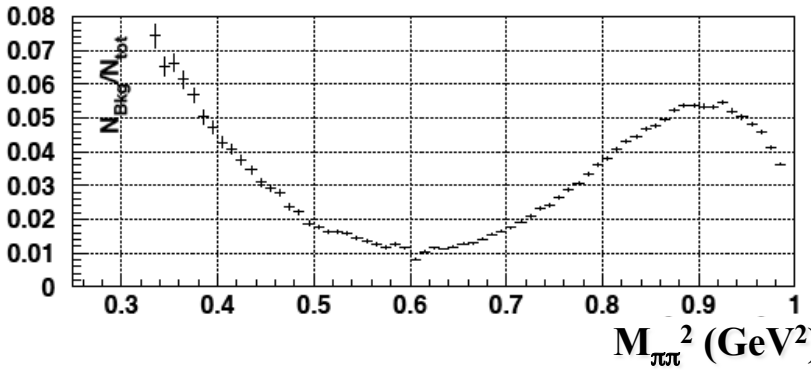
$0.84 < M_{\pi\pi}^2 < 0.86$ GeV^2 χ^2/ndof = 179/258



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



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



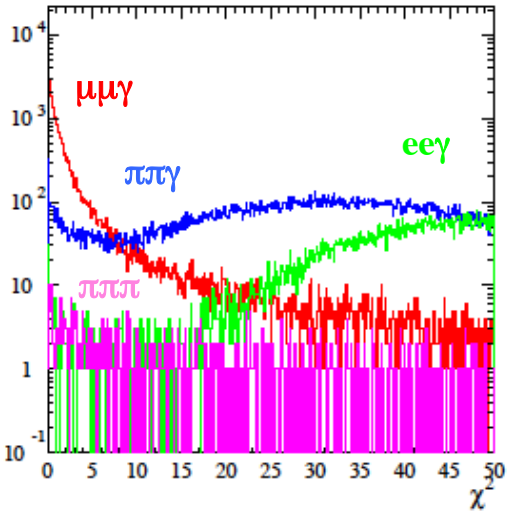
8%

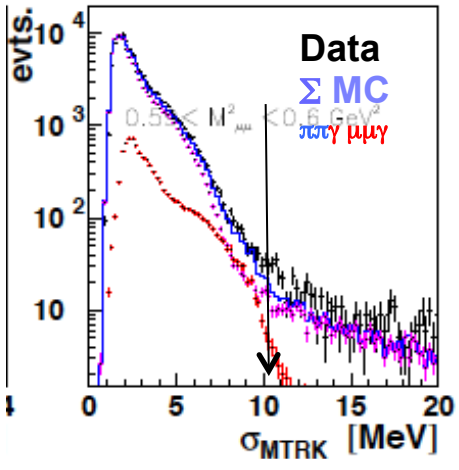
1%

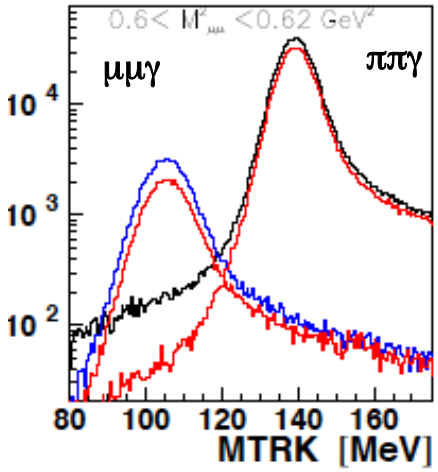
- Systematic error on $\mu\mu\gamma$ due to background~1% in the ρ peak

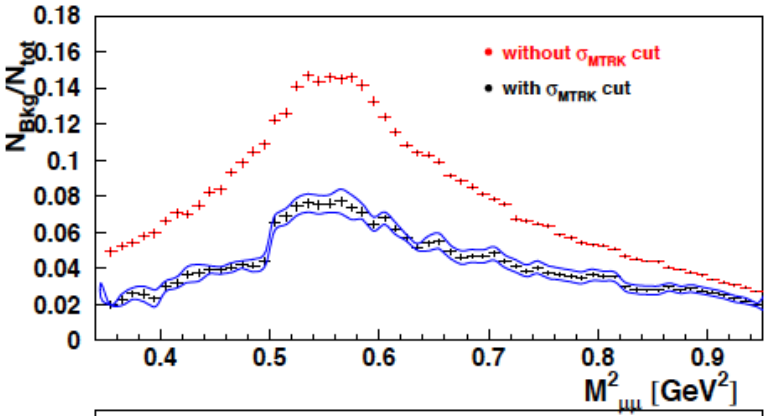
Cross check of π/μ separation

- The π/μ separation has been crosschecked with two different (and independent) methods:
- A kinematic fit, in the hypothesis of 2 body+1γ (ISR) events.
- A cut on the quality of the fitted tracks, parametrized by σ_{MTRK}



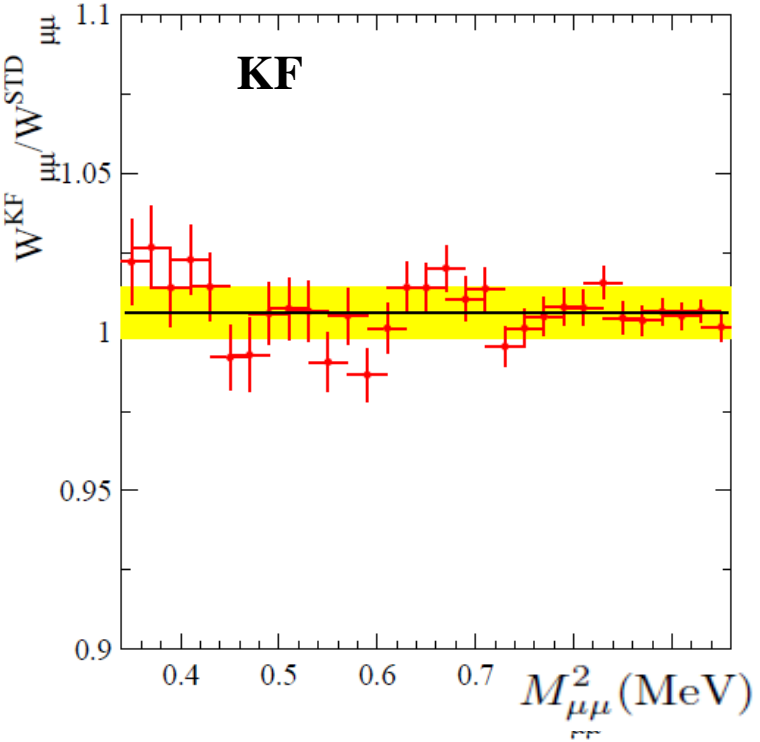






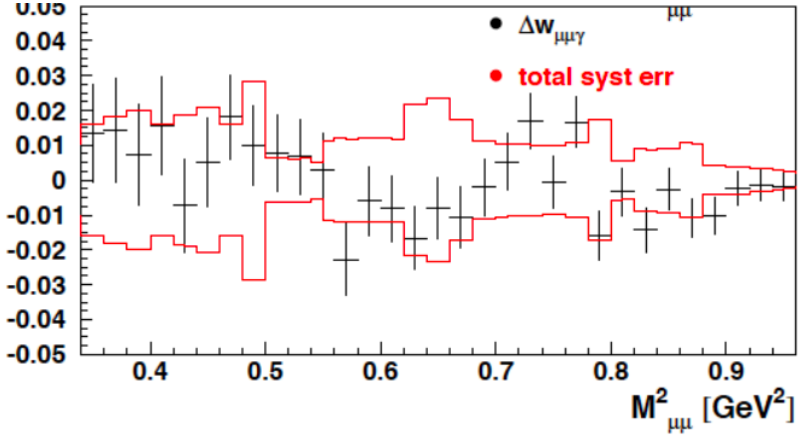
Results of σ_{MTRK} and KF cross checks

π/μ separation obtained with these methods well in agreement with the standard one



•The ratio of the muon yields from kinematic fit method with $\chi 2_{\mu\mu} < 10$ to the muon yields from standard method, fitted with the constant. Yellow bar is the systematic error of the kinematic fit method

σ_{MTRK}

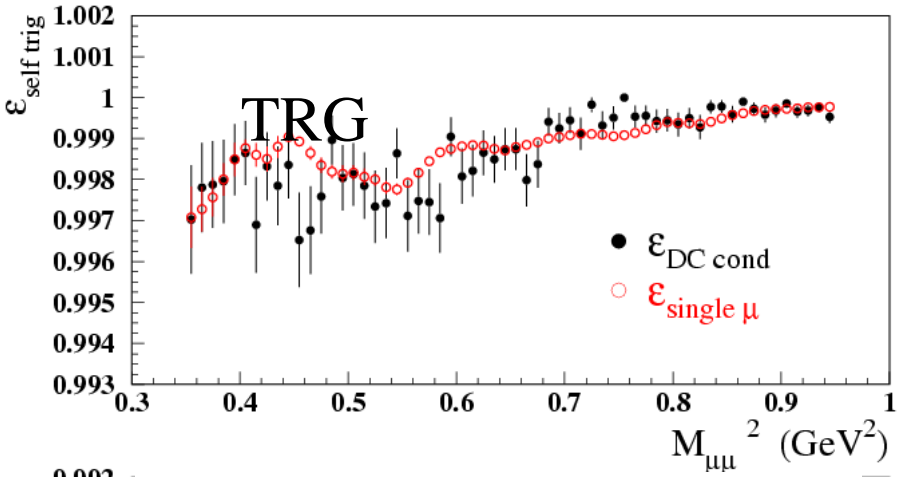


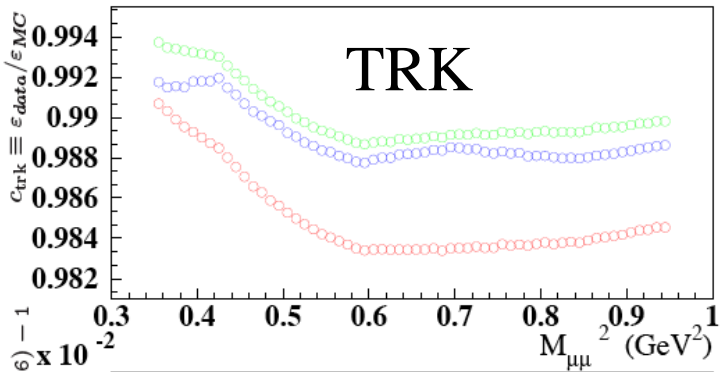
• Black dots are the differences of $\mu\mu\gamma$ yields obtained with std and σ_{MTRK} methods; Red line is the total systematic error of the difference.

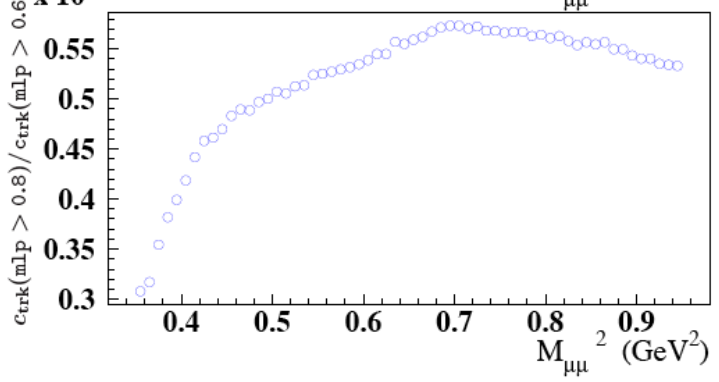
Efficiencies for μμγ

- The efficiencies of μμγ (and ππγ) for trigger,tracking, and PID have been carefully studied with data, using the single particle method and taking into account the kinematics by MC.
- Differently from ππγ, where the 3π sample was used to get the data/MC corrections, for μμγ there is no a direct control sample and we had used mmg itslef with lose selection criteria.

- All the efficiencies has been found to be above 96% with ~1% data/MC correction as maximum.







Extracting $\sigma_{\pi\pi}$ and $|F_\pi|^2$ from $\pi\pi\gamma$ events

a) Via absolute Normalisation to Bhabha events (KLOE05,08,10):

1)

$$\frac{d\sigma^{obs}_{\pi\pi\gamma(\gamma)}}{dM^2_{\pi\pi}} = \frac{\Delta N_{\mathrm{Obs}} - \Delta N_{\mathrm{Bkg}}}{\Delta M^2_{\pi\pi}} \cdot \frac{1}{\varepsilon_{\mathrm{Sel}}} \cdot \frac{1}{\int L dt}$$

$d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ is obtained by subtracting background from observed event spectrum, divide by selection efficiencies, and ***int. luminosity***:

2)

$$\sigma_{\pi\pi}(s) \approx s \frac{d\sigma^{obs}_{\pi\pi\gamma(\gamma)}}{dM^2_{\pi\pi}} \cdot \frac{1}{H(s)}$$

Obtain $\sigma_{\pi\pi}$ from (ISR) - radiative cross section $ds_{\pi\pi\gamma(\gamma)}/dM^2$ via theoretical radiator function H(s):

3)

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

Relation between $|F_\pi|^2$ and the cross section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

b) Via bin-by-bin Normalisation to rad. Muon events (New measurement!)

Radiative Corrections

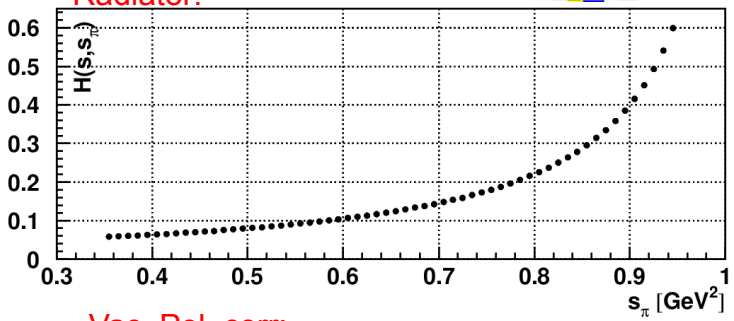
Radiator-Function $H(s,s_p)$ (ISR):

- **ISR-Process calculated at NLO-level**
  PHOKHARA generator
  (H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC27,2003)

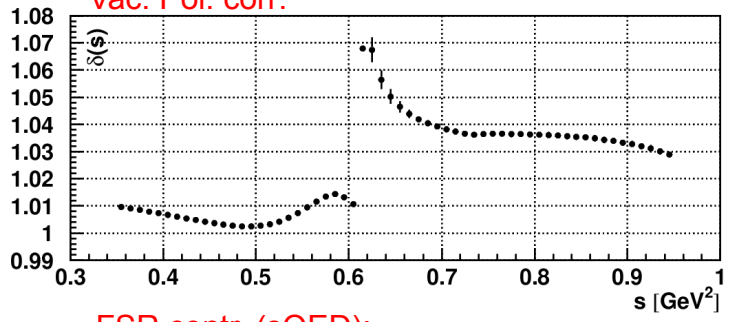
Precision: 0.5%

$$s \cdot \frac{d\sigma_{\pi\pi\gamma}}{ds_\pi} = \sigma_{\pi\pi}(s_\pi) \times H(s,s_\pi)$$

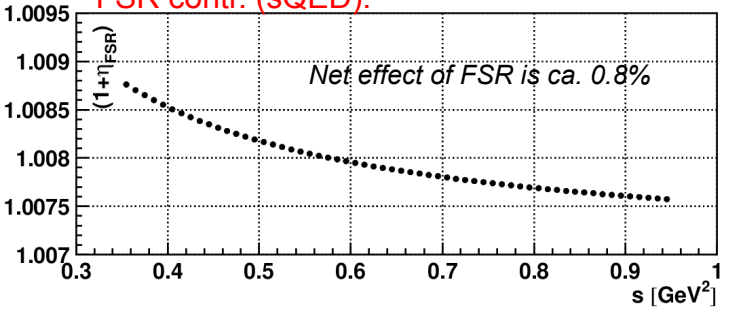
Radiator:



Vac. Pol. corr:



FSR contr. (sQED):



Radiative Corrections:

i) Bare Cross Section

divide by Vacuum Polarisation $d(s)=(a(s)/a(0))^2$

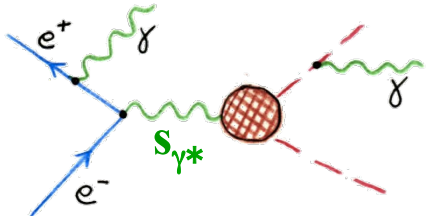
➔ from F. Jegerlehner

ii) FSR

Cross section s_{pp} must be incl. for FSR
for use in the dispersion integral of a_m

FSR corrections have to be taken into account in the efficiency eval. (Acceptance, M_{Trk}) and in the mapping $s_\pi \rightarrow s_{\gamma*}$

(H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC33,2004)



$s_{\gamma*} > s_\pi$

LA Event Selection (KLOE10)

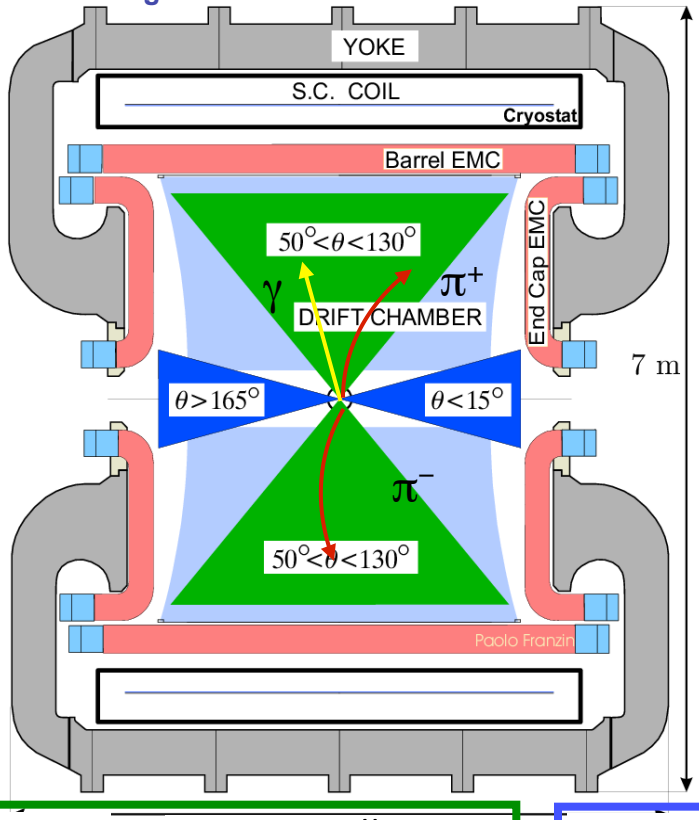
2 pion tracks at large angles
$50^o < \theta_p < 130^o$

Photons at large angles
$50^o < \theta_\gamma < 130^o$

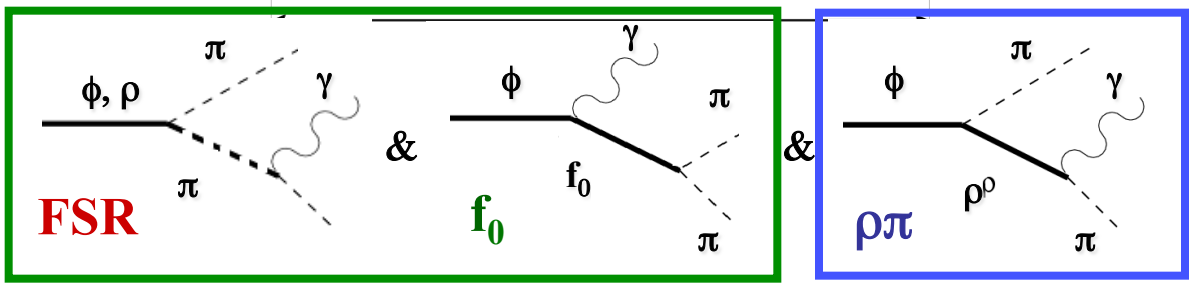
- ✓ independent complementary analysis
- ✓ threshold region $(2m_\pi)^2$ accessible
- ✓ γ_{ISR} photon detected (4-momentum constraints)

- ✓ lower signal statistics
- ✓ larger contribution from FSR events
- ✓ larger $\phi \to \pi^+\pi^-\pi^0$ background contamination
- ✓ irreducible background from ϕ decays ($\phi \to f_0\,\gamma \to \pi\pi\,\gamma$)

At least 1 photon with $50^o < \theta_g < 130^o$ and $E_g > 20$ MeV ➔ photon detected



Threshold region non-trivial
due to irreducible FSR-effects, which have to be estimated from MC using phenomenological models (interference effects unknown)



LA Event Selection (KLOE10)

2 pion tracks at large angles
$50^o < \theta_p < 130^o$

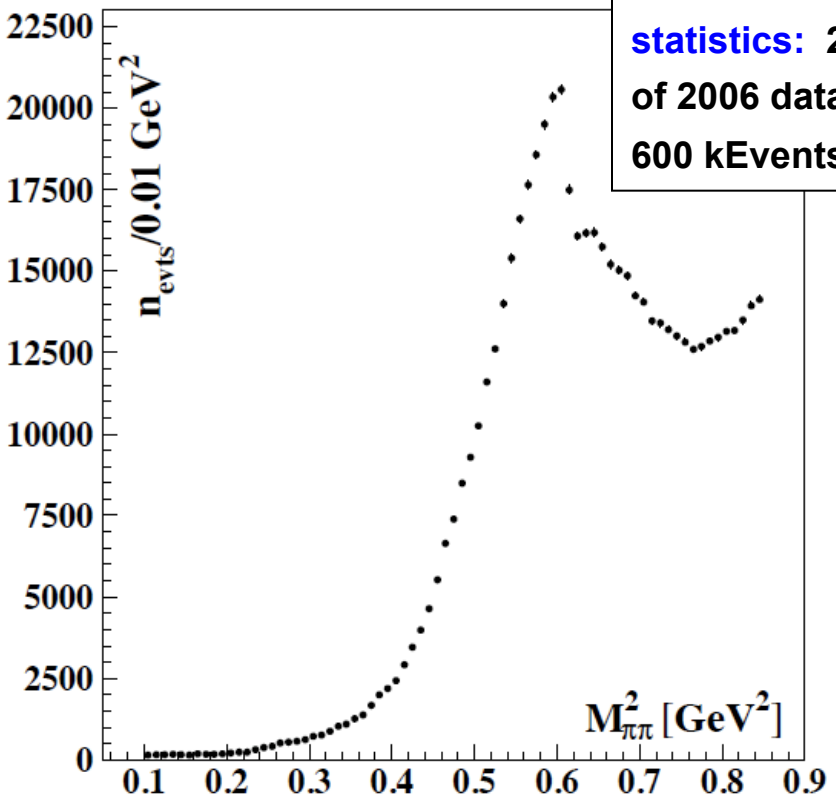
Photons at large angles
$50^o < \theta_\gamma < 130^o$

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

- ✓ lower signal statistics
- ✓ larger contribution from FSR events
- ✓ larger $\phi \to \pi^+\pi^-\pi^0$ background contamination
- ✓ irreducible background from ϕ decays ($\phi \to f_0\,\gamma \to \pi\pi\,\gamma$)

At least 1 photon with $50^o < \theta_g < 130^o$ and $E_g > 20$ MeV ➔ photon detected

statistics: 233pb^{-1}
of 2006 data
600 kEvents



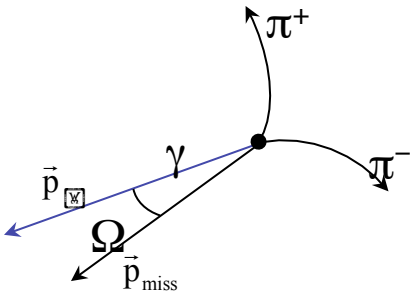
Use data sample taken at $\sqrt{s} \cong 1000$ **MeV**, 20 MeV below the f-peak

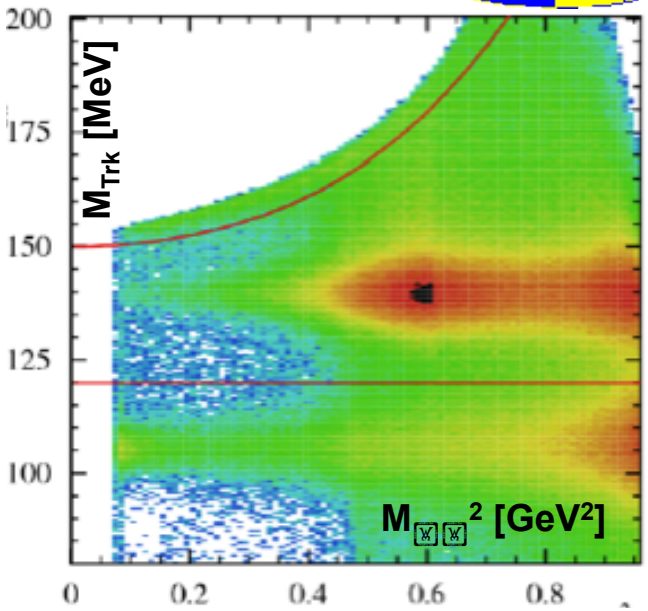
Event selection

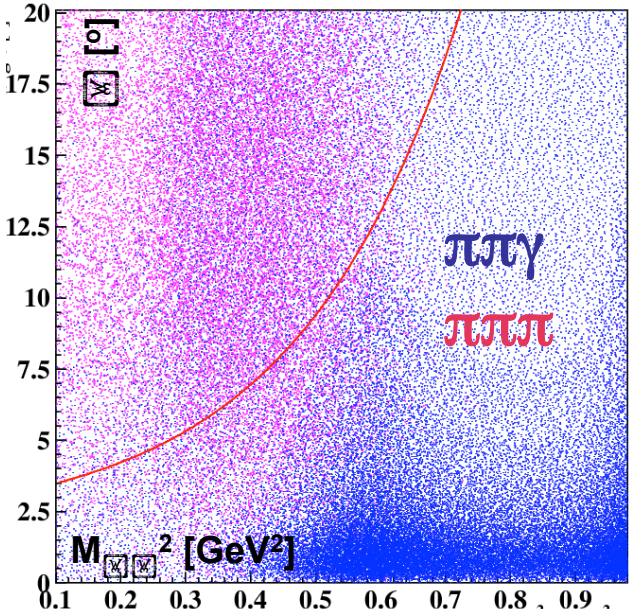
- **Experimental challenge: Fight background from**
  - $e^+e^- \to \mu^+\mu^- \gamma$,
  - $e^+e^- \to e^+e^- \gamma$
  - $\phi \to \pi^+\pi^-\pi^0$

  separated by means of kinematical cuts in *trackmass* M_{Trk} and the angle Ω between the photon and the missing momentum

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





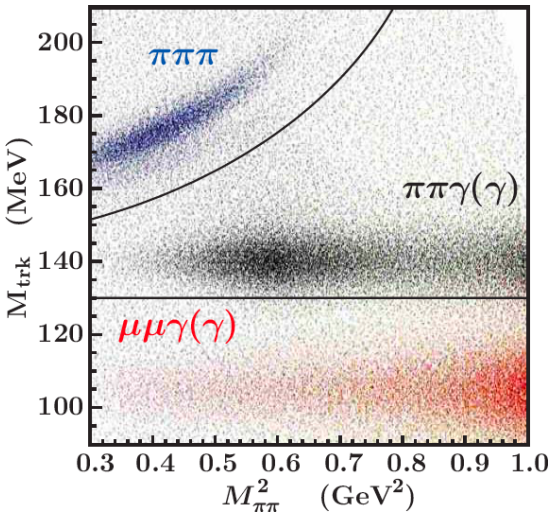


To further clean the samples from radiative Bhabha events, a particle ID estimator for each charged track based on Calorimeter Information and Time-of-Flight is used.

Event Selection

- Experimental challenge: control backgrounds from
  - $\phi \rightarrow \pi^+\pi^-\pi^0$
  - $e^+e^- \rightarrow e^+e^-\ \gamma$
  - $e^+e^- \rightarrow \mu^+\mu^-\ \gamma$,

  removed using kinematical cuts in *trackmass* M_{Trk} - $M_{\pi\pi}^2$ plane

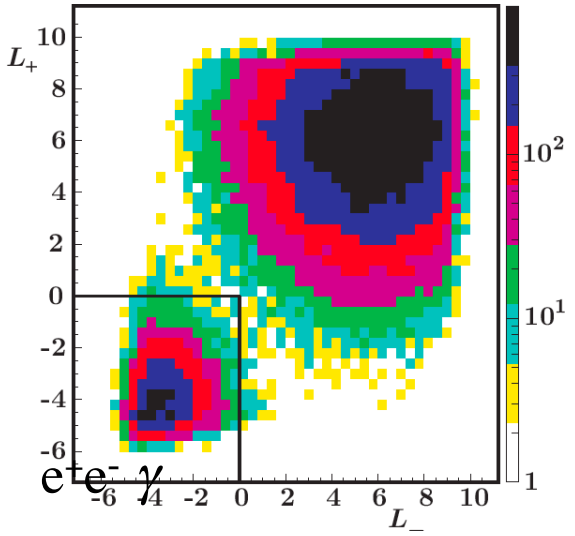


M_{Trk}: defined by 4-momentum conservation assuming 2 charged particle (of same mass) and one γ in the final state

$$\left(\sqrt{s} - \sqrt{p_1^2 + M_{trk}^2} - \sqrt{p_2^2 + M_{trk}^2}\right)^2 - (p_1 + p_2)^2 = 0$$

To further clean the samples from radiative Bhabha events, we use a particle ID estimator (PID) for each charged track based on Calorimeter Information and Time-of-Flight.

$\pi^+\pi^-\ \gamma$,

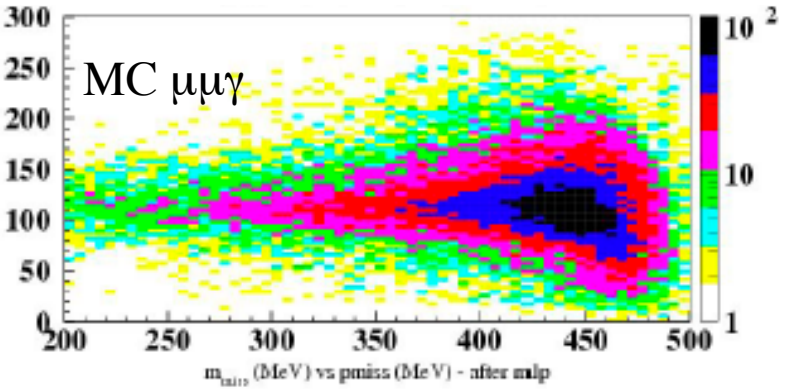


μ Tracking efficiency

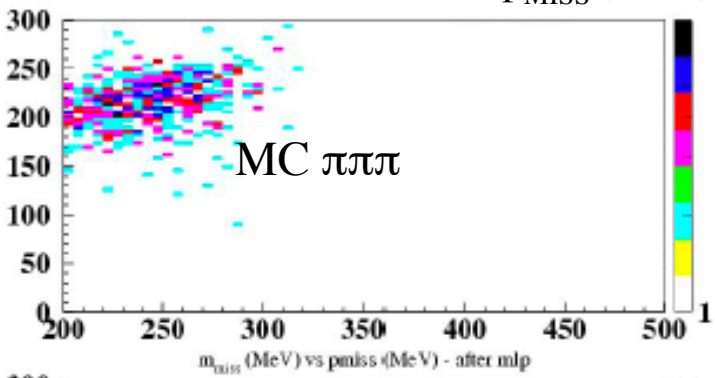
Since for muons we don't have an control sample (like 3π for pions), we have refiltered all 2002 data set (240 pb^{-1}) according to:

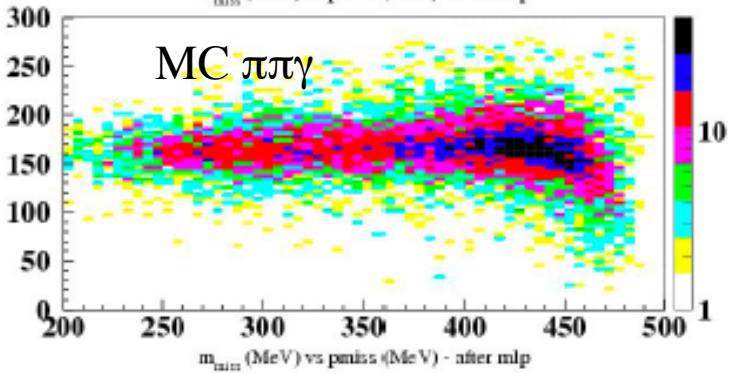
1) a "good" tagging track extrapolating back to the IP, which satisfies the trigger associated to a cluster with LogrL>0, 1 and MLP>0.7
2) 1 neutral prompt clusters not associated to the tagging track with E>50 MeV. A constraint on the photon energy and time to further clean the sample, and improve missing momentum and energy
3) The tagging track must have p > 450 MeV (to reject $\pi^+\pi^-\pi^0$ events), the *candidate* track must have mass (built from 4 momentum conservation) 50 <M_{miss} < 130 MeV

M_{MISS} (MeV)

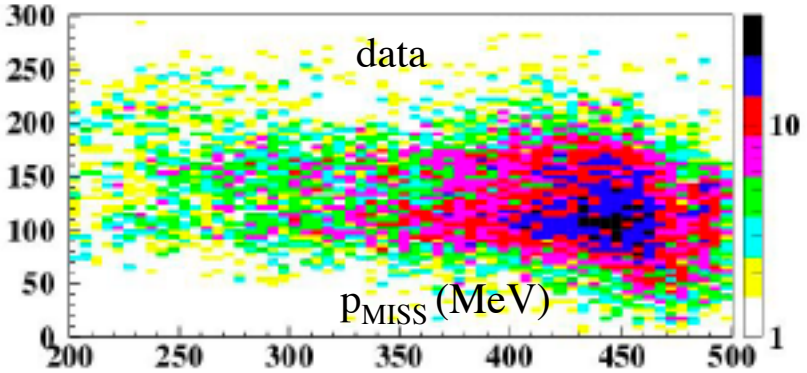


p_{MISS} (MeV)





M_{MISS} (MeV)



Luminosity:

KLOE measures *L* with Bhabha scattering

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

$55° < \theta < 125°$

acollinearity < 9°

p ≥ 400 MeV

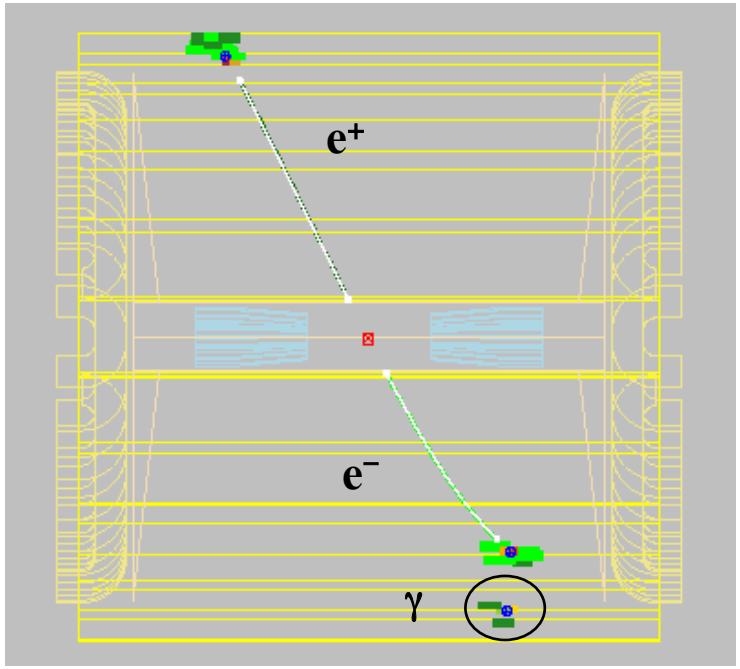
$$\int \mathcal{L}\,dt = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}$$

generator used for σ_{eff}

BABAYAGA (Pavia group):

C. M.C. Calame et al., NPB758 (2006) 22

new version (**BABAYAGA@NLO**) gives
0.7% decrease in cross section,
and better accuracy: 0.1%



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

Luminosity:

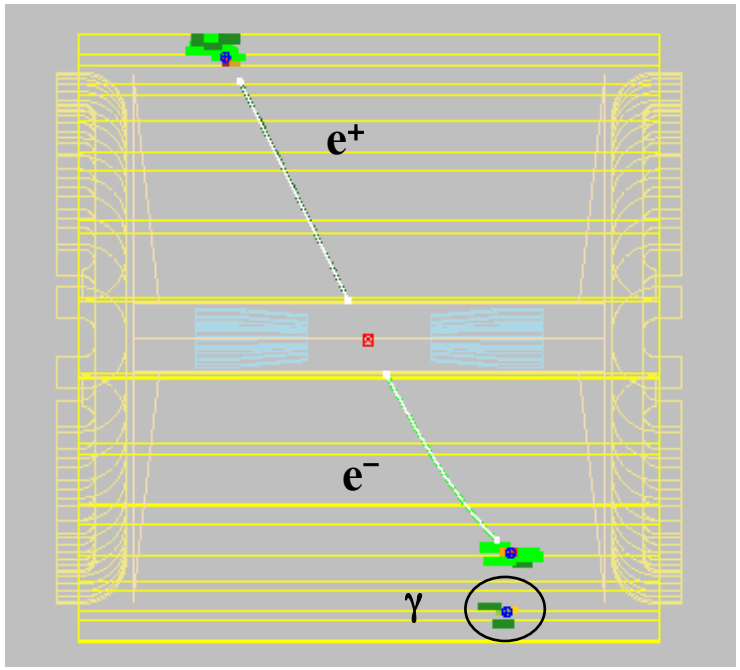
KLOE measures *L* with Bhabha scattering

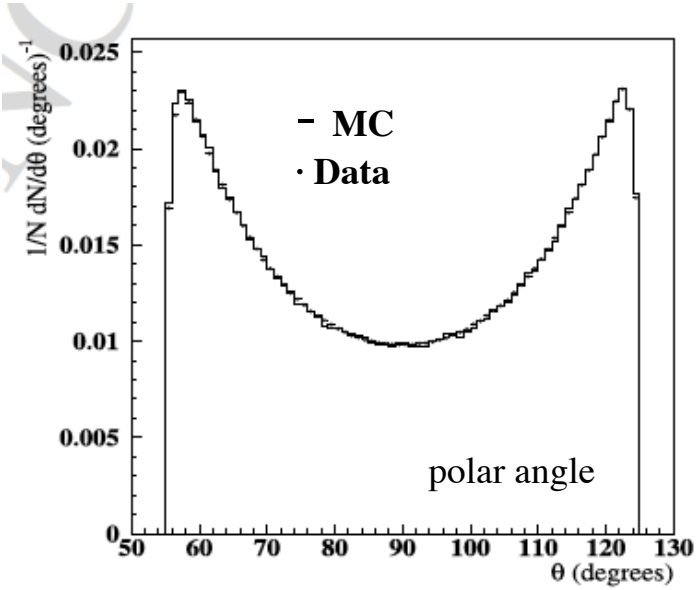
55° < θ < 125°

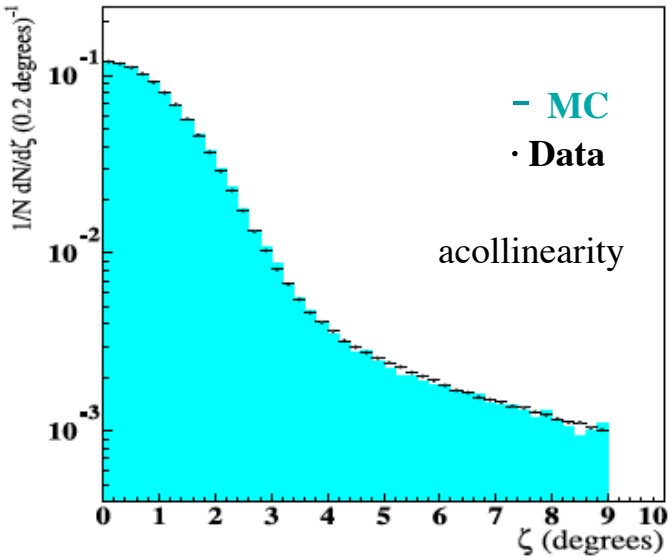
acollinearity < 9°

p ≥ 400 MeV

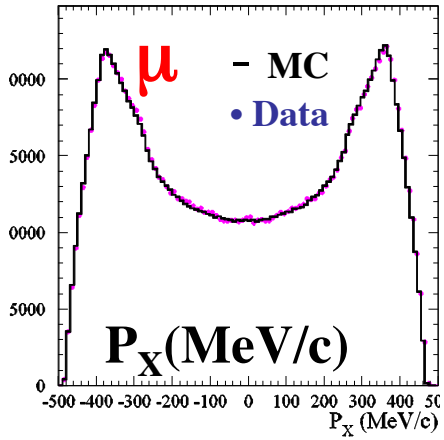
$$\int \mathcal{L}\,dt = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}$$

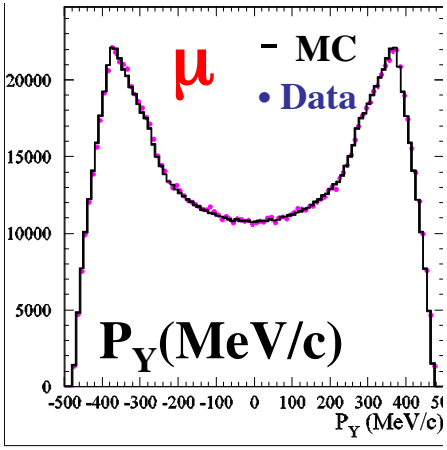


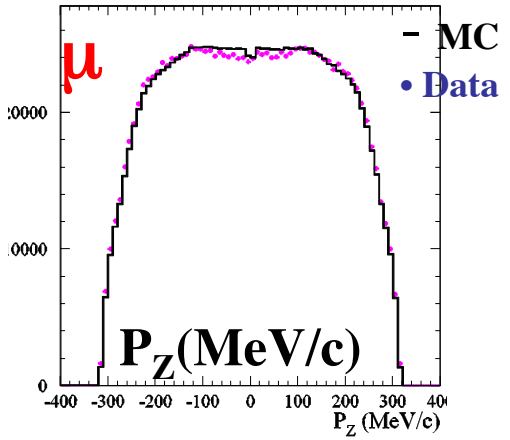


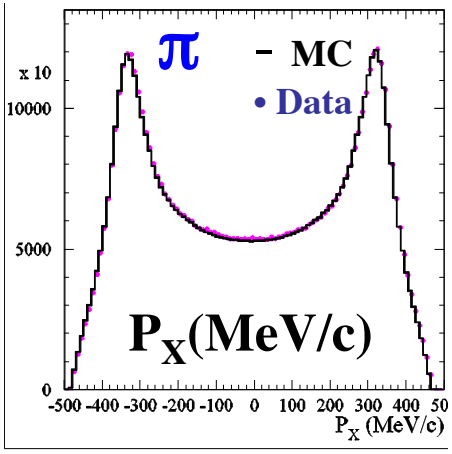


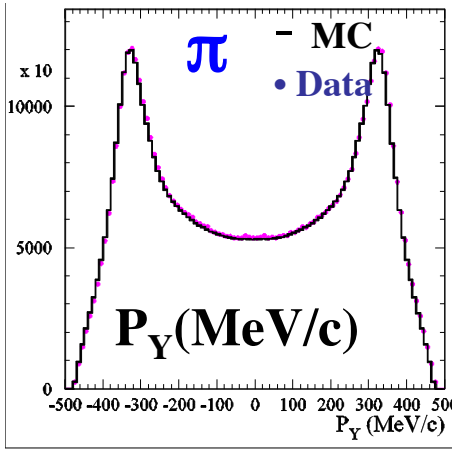
Example of data/MC comparison for μμγ and ππγ: momentum components of μ and π

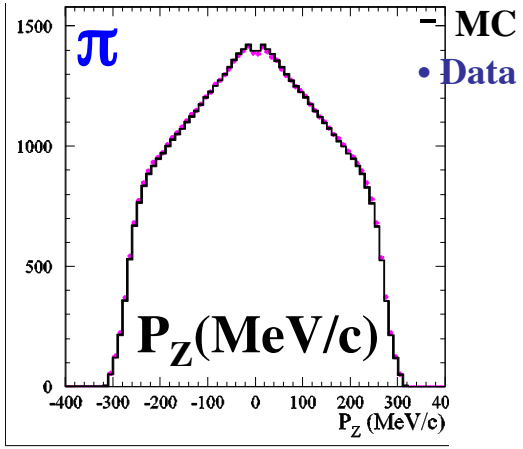












ISR: KLOE vs BaBar 2π

KLOE:

- The photon is "soft" (detected or not)
- No Kinematic fit
- Bin of 0.01 GeV^2 (~8 MeV at ρ peak) >> $\delta M_{\pi\pi}^2 \sim 2\ 10^{-3}$ GeV^2

⇒ Unfolding only relevant at low $M_{\pi\pi}^2$ (up to 4%) and at ρ−ω cusp,

- Negligible contribution of LO FSR, and <2% contribution of NLO FSR($1\gamma_{ISR}+1\gamma_{FSR}$) only at low $M_{\pi\pi}^2$
- Normalize to **Luminosity** (=Bhabha), but also to μμγ (K12)
- Use **Phokhara** for acceptance, radiator and additional-photon effects

BaBar:

- The photon is "hard" and detected
- Kinematic fit to improve resolution
- Bin of 2 MeV in the region 0.5-1 GeV

⇒ Larger effects on the unfolding

- Negligible contribution of LO FSR, % contribution of NLO FSR($1\gamma_{ISR}+1\gamma_{FSR}$)
- Normalize to μμγ
- Interplay btw **Phokhara** and **AfkQED** to estimate additional-photon effects

Different selections and use of theoretical ingredients (R.C., Luminosity, Radiator). Additional cross checks are possible (and needed)