The 13th International Workshop on Tau Lepton Physics
Aachen, Germany, 15-19 September, 2014

Results and prospects on hadronic cross section and $\gamma\gamma$ physics at KLOE/KLOE2

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Outline

- Hadronic contribution to $(g\text{-}2)_\mu$
- KLOE measurements of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$:
  - Small (photon) angle measurements (KLOE08) - Luminosity
  - Large (photon) angle measurement (KLOE10)- Luminosity
  - Small (photon) angle measurements (KLOE12) - $\pi\pi\gamma/\mu\mu\gamma$

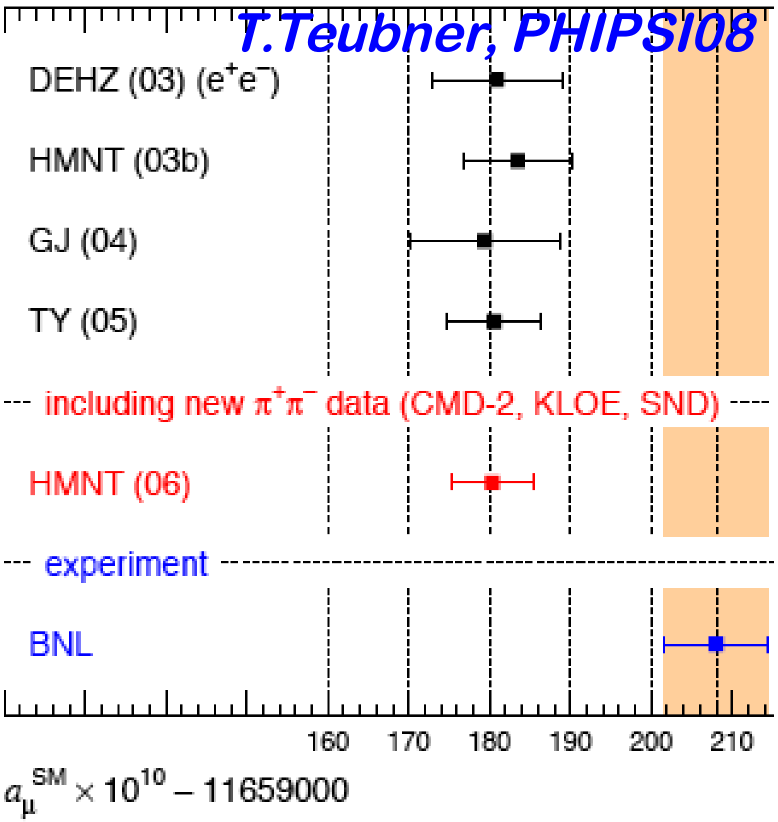
    PLB 720 (2013) 336–343
  - Evaluation of $a_\mu^{\pi\pi}$ and comparison with CMD-2/SND/BaBar
  - Preliminary combination of KLOE08, KLOE10, KLOE12 for $a_\mu^{\pi\pi}$ and the fit of F_π
- $\gamma\gamma$ Physics program at KLOE-2

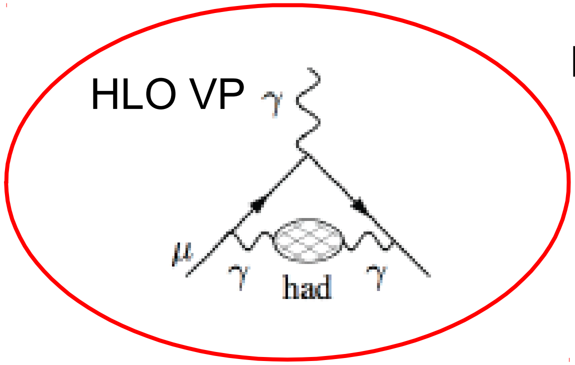
Muon anomaly

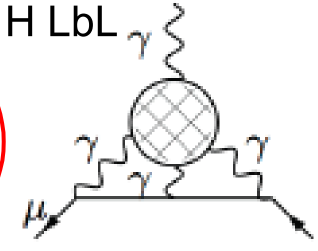
$$a_\mu = \frac{(g_\mu - 2)}{2}$$

- Long established discrepancy (>3σ) between SM prediction and BNL E821 exp.
- Theoretical error δa_μ^{SM} (~6x10^{-10}) dominated by HLO VP ([4–5]x10^{-10}) and HLbL ([2.5–4]x10^{-10}).
- Experimental error δa_μ^{EXP} ~6x10^{-10}(E821). Plan to reduce it to 1.6x10^{-10} by the new g-2 experiments at FNAL and J-PARC.

a_μ^{SM} compared to BNL world av.







a_μ^{HLO} = (690.9±**4.4**)x10^{-10} [Eidelman, TAU08]

a_μ^{HLbL} =(10.5±2.6)x10^{-10} [Prades, dR&V. 08] =(11 ±4)x10^{-10} (Jegerlehner, Nyffler)

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

δa_μ^{HLO} ~0.7%

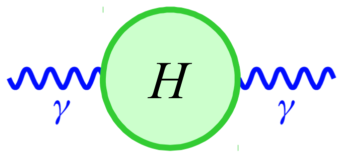
δa_μ^{HLbL} ~25-40%

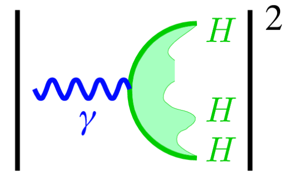
In 2001 a_μ^{EXP}-a_μ^{TH}=(23±16)•10^{-10}

a_μ^{HLO}:

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

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 region < 1 GeV contributes up to 70% !

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

Input:

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

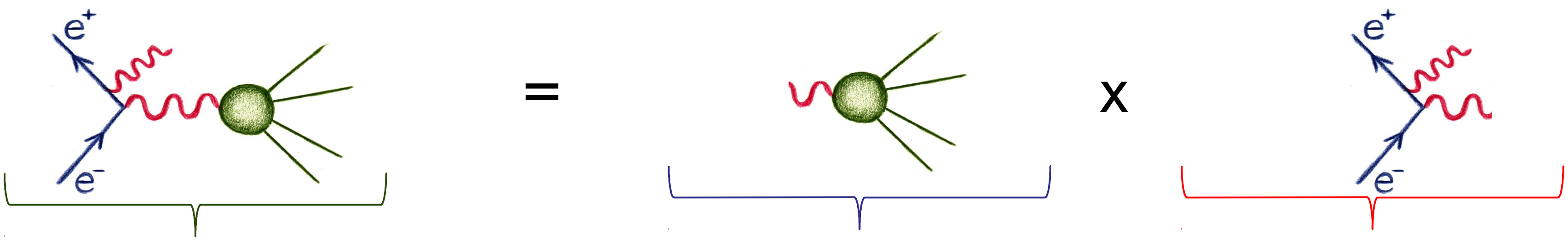
b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections)

(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 — 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

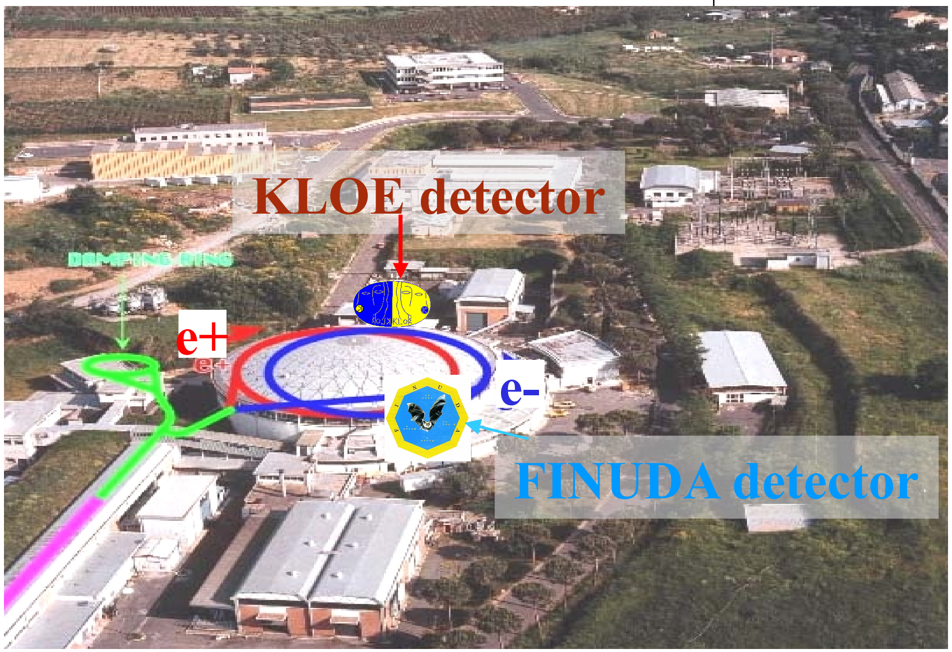
H. Czyż, A. Grzelińska, J.H. Kühn, G. Rodrigo, Eur. Phys. J. C 27, 2003

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

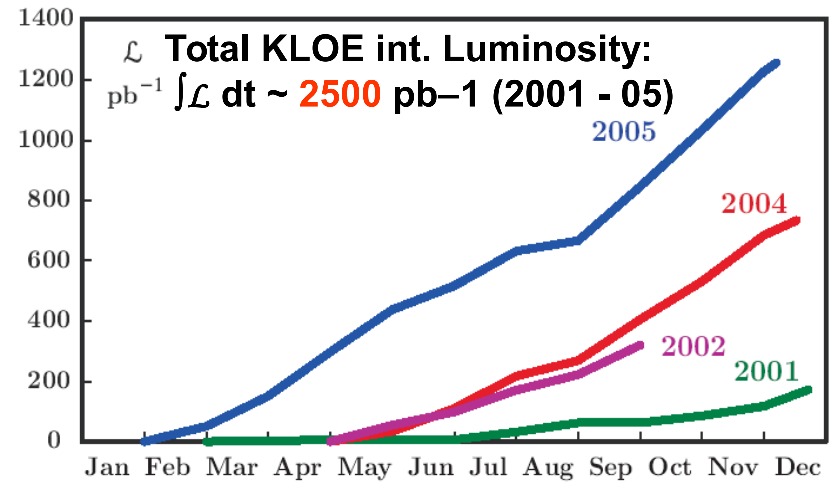
IN 2005 KLOE has published the first precision measurement of $\sigma(e^+e^-\to\pi^+\pi^-)$ with ISR using 2001 data (140pb^{-1}) PLB606(2005)12 ⇒ ~3σ discrepancy btw a_μ^{SM} and a_μ^{exp}

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

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



Integrated Luminosity

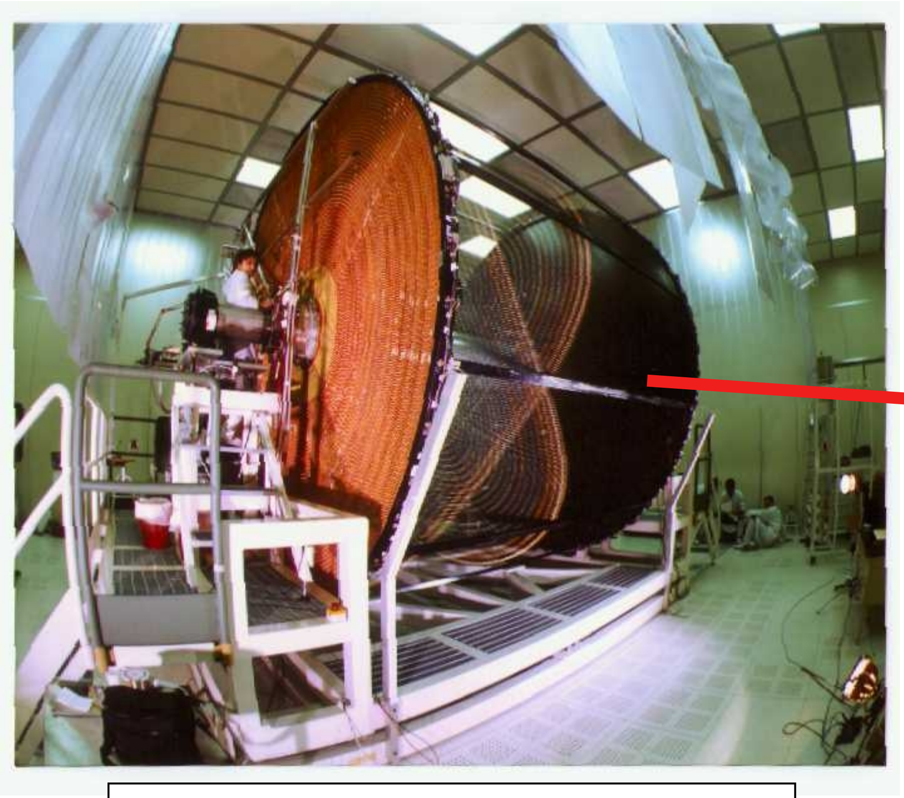


Peak Luminosity $L_{peak} = 1.5 \cdot 10^{32}\,cm^{-2}s^{-1}$

KLOE05 measurement (PLB606(2005)12) ***based on 140pb^{-1} of 2001 data*** **(Superseded by KLOE08)**	***KLOE10 measurement*** (PLB700 (2011)102) ***based on 233 pb^{-1} of 2006 data*** ***(at 1 GeV, different event selection)***
KLOE08 measurement (PLB670(2009)285) ***was based on 240pb^{-1} of 2002 data***	***KLOE12 measurement*** (PLB720(2013)336) ***based on 240 pb^{-1} of 2002 data*** ***(from ππγ/μμγ ratio)***

KLOE Detector

Drift chamber

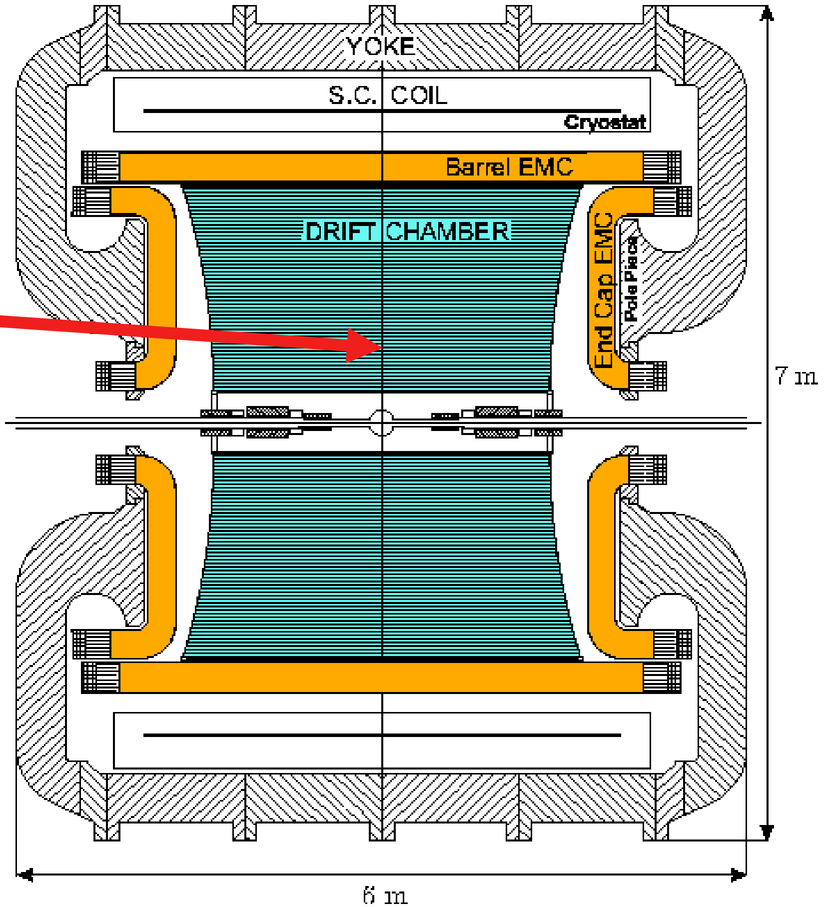


σ_p/p = 0.4% (for 90^0 tracks)

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

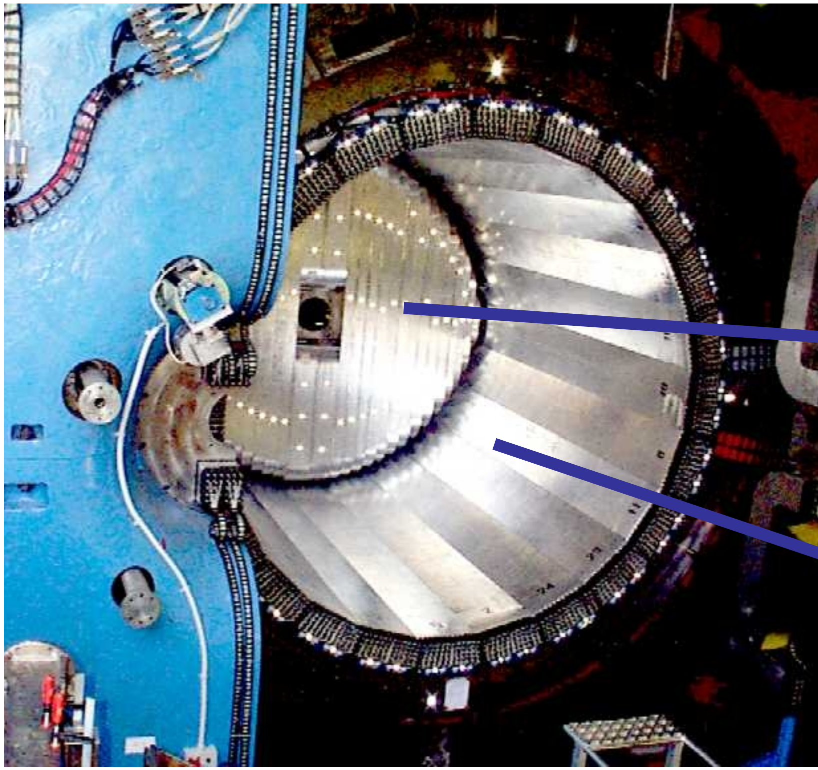
Excellent momentum resolution

Full stereo geometry, 4m diameter, 52140 wires 90% Helium, 10% iC_4H_{10}

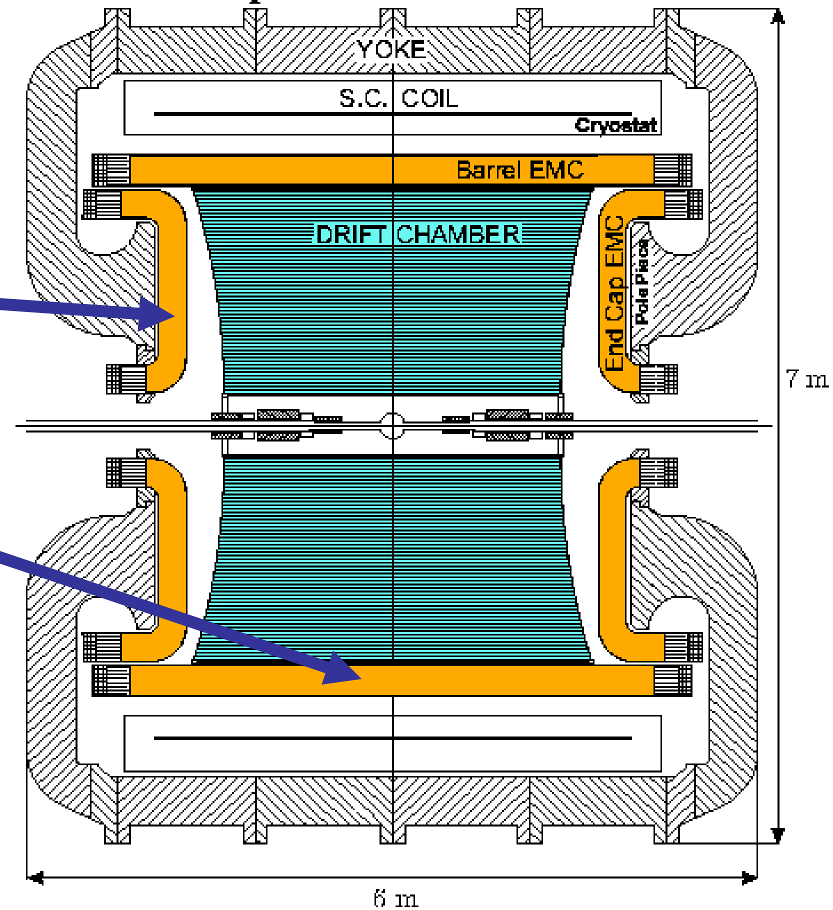


KLOE Detector

Electromagnetic Calorimeter



Pb / scintillating f bers (4880 PMTs)
Endcap - Barrel - Modules



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

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

(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

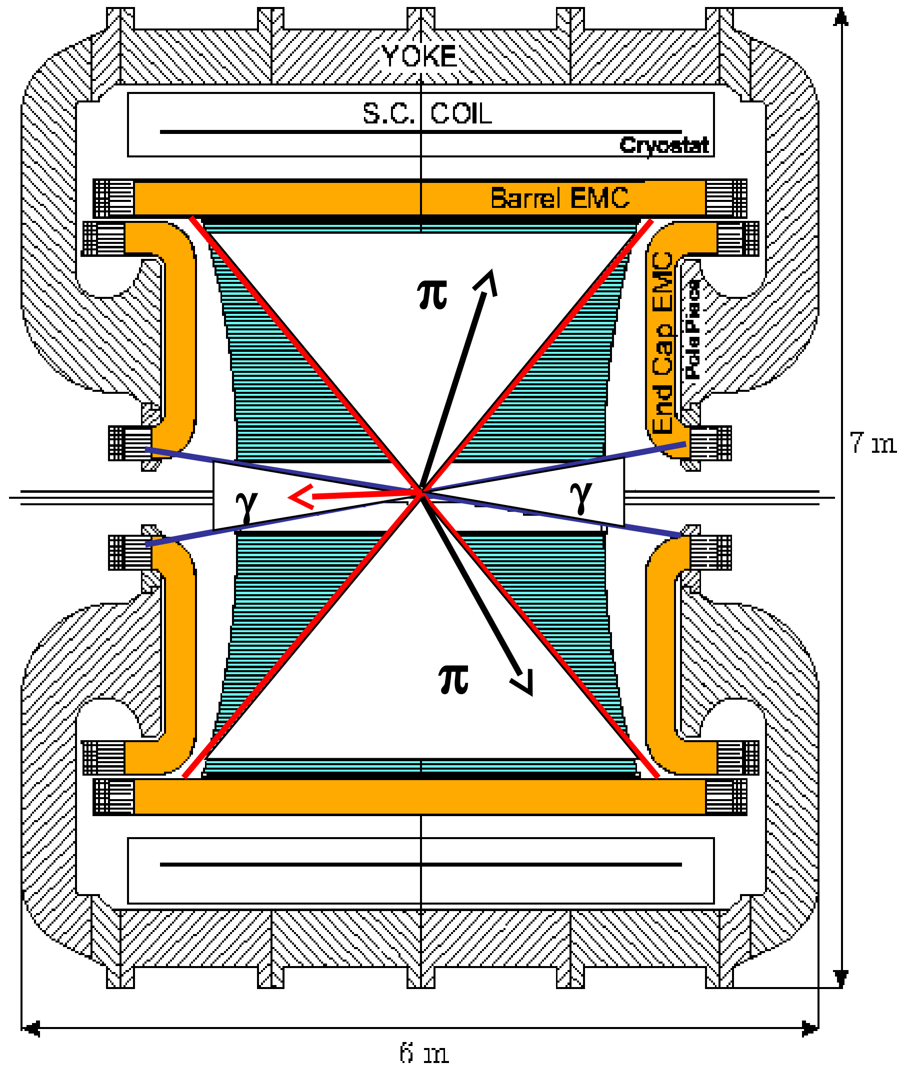
$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

→ 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

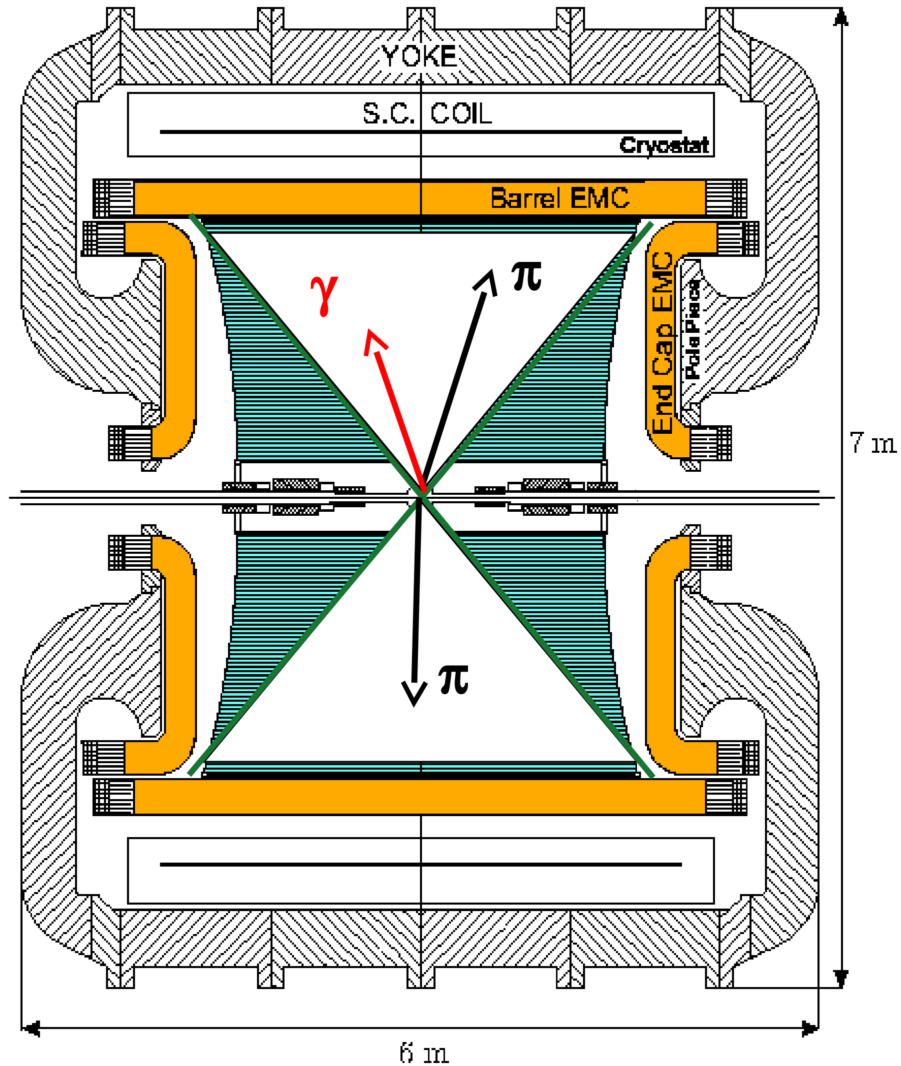
b) Photons at large angles

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

→Photon is explicitly measured in the detector!

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

KLOE



Luminosity:

KLOE measures L with Bhabha scattering

Eur.Phys.J.C47:589-596,2006

55° < θ < 125°; acollinearity< 9°; p ≥ 400 MeV

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

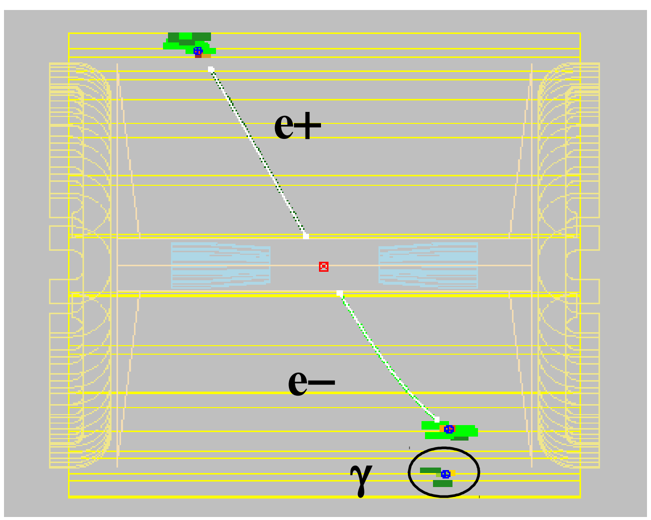
Generator used for σ_{eff}: **BABAYAGA** (Pavia)

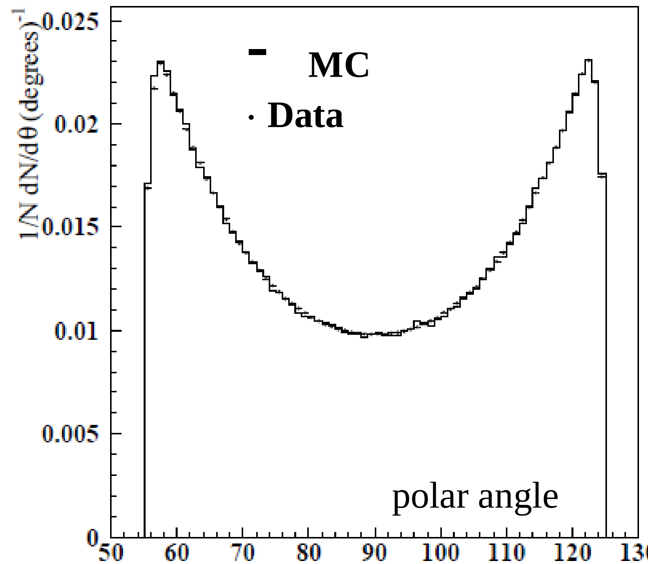
NPB758 (2006) 22

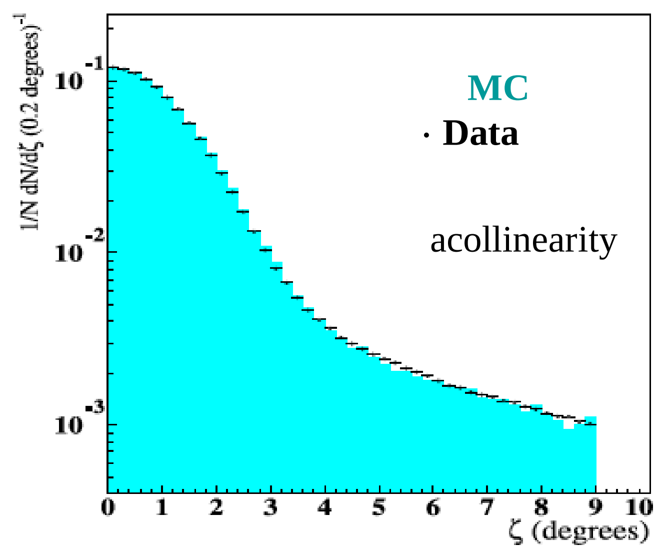
New version (**BABAYAGA@NLO**) gives 0.7% decrease in cros. sect., and better accuracy:0.1%

Systematics on Luminosity:

TOTAL 0.1 % th ⊕ 0.3% exp = 0.3%







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

Phys. Lett. B 670 (2009) 285

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

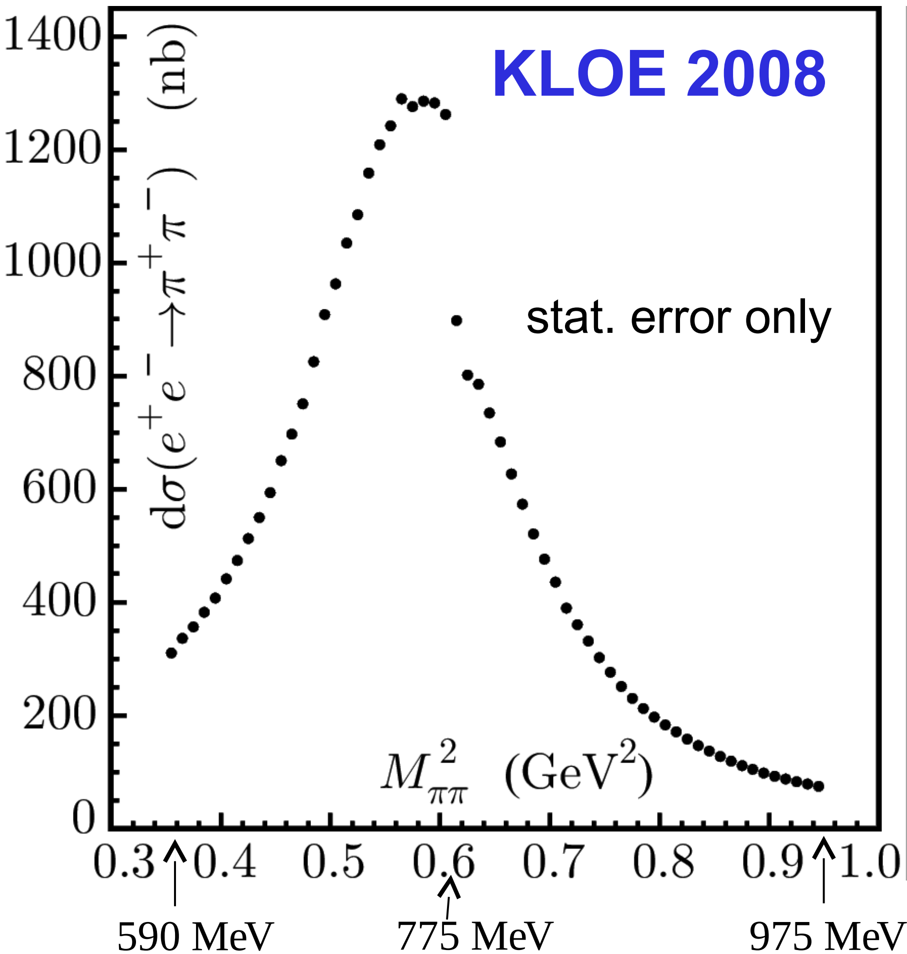
Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
p/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.2%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dep. Of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	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 of FSR as function of $(M^0_{\pi\pi})^2$



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

$a_\mu^{\pi\pi}$(0.35-0.95GeV^2) = (387.2 ± 0.5$_{stat}$ ±2.4$_{syst}$ ±2.3$_{theo}$) · 10^{-10}

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

Phys. Lett. B 700 (2011) 102

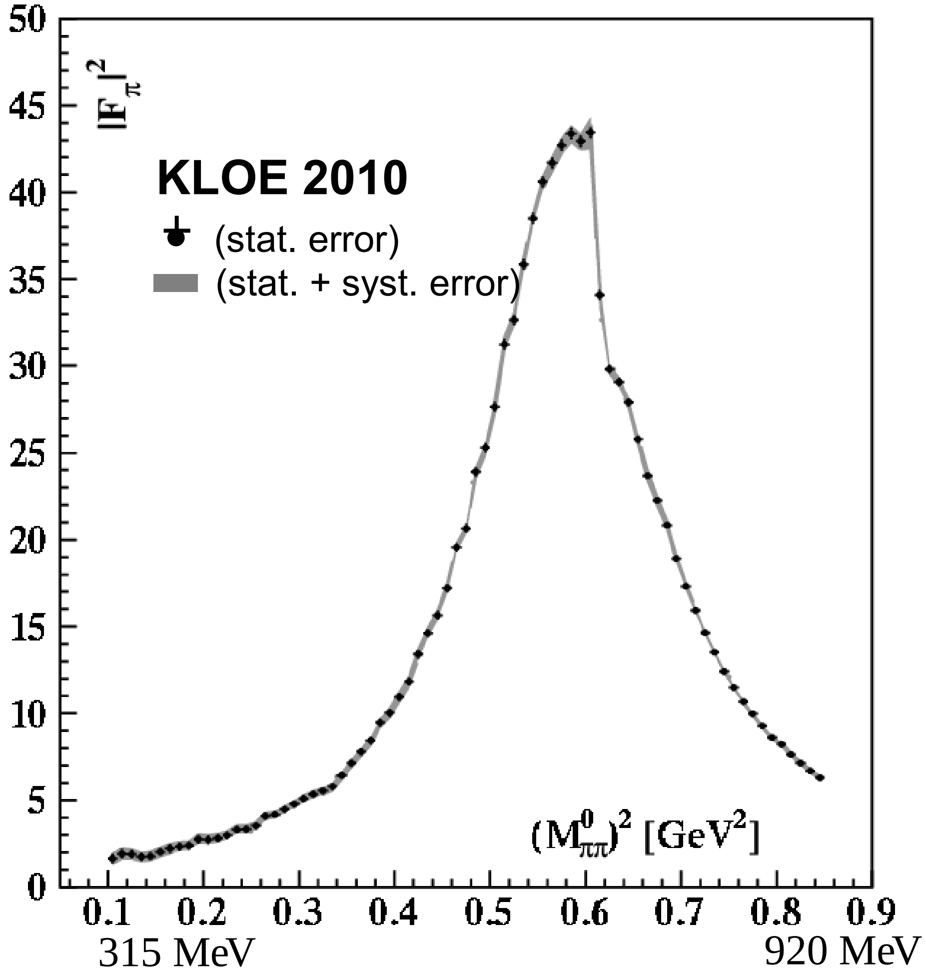


Table of systematic errors on $a_\mu^{\pi\pi}$(0.1-0.85 GeV²):

Reconstruction Filter	negligible
Background	0.5%
f0+ρπ	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 %

Dispersion Integral:

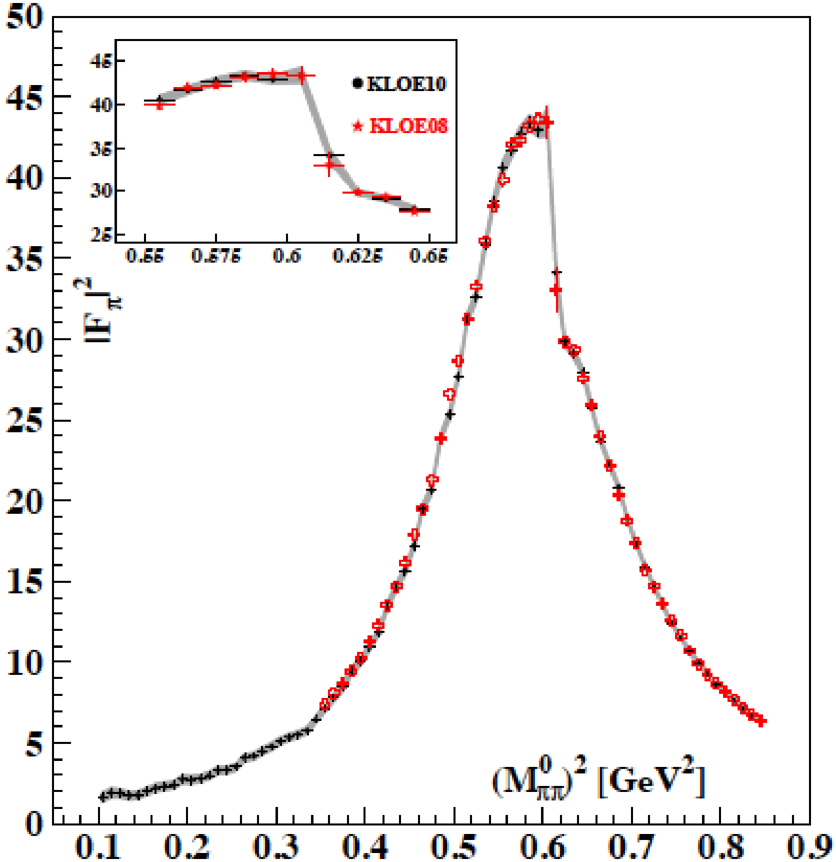
$$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s)K(s)ds$$

$a_\mu^{\pi\pi}$**(0.1-0.85 GeV²) = (478.5 ± 2.0$_{stat}$ ±5.0$_{syst}$ ±4.5$_{theo}$) · 10^{-10}**

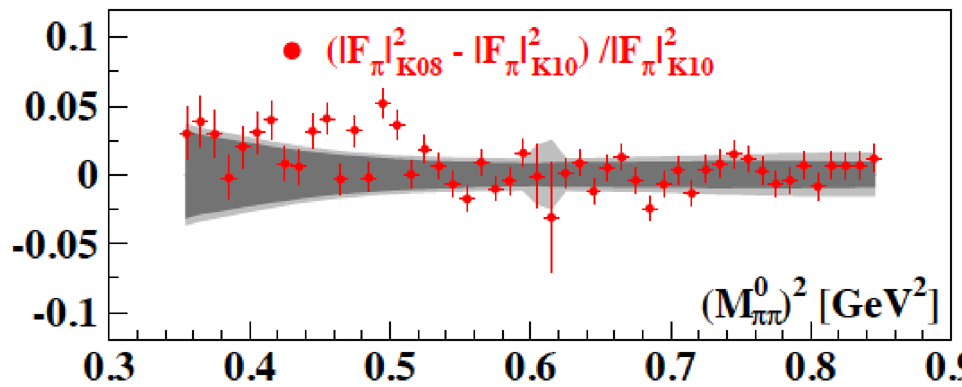
0.4% 1.0% 0.9%

Comparison of results: KLOE10 vs KLOE08

KLOE08 result compared to KLOE10:



Fractional difference:



Good agreement with KLOE08, especially above 0.5 GeV²

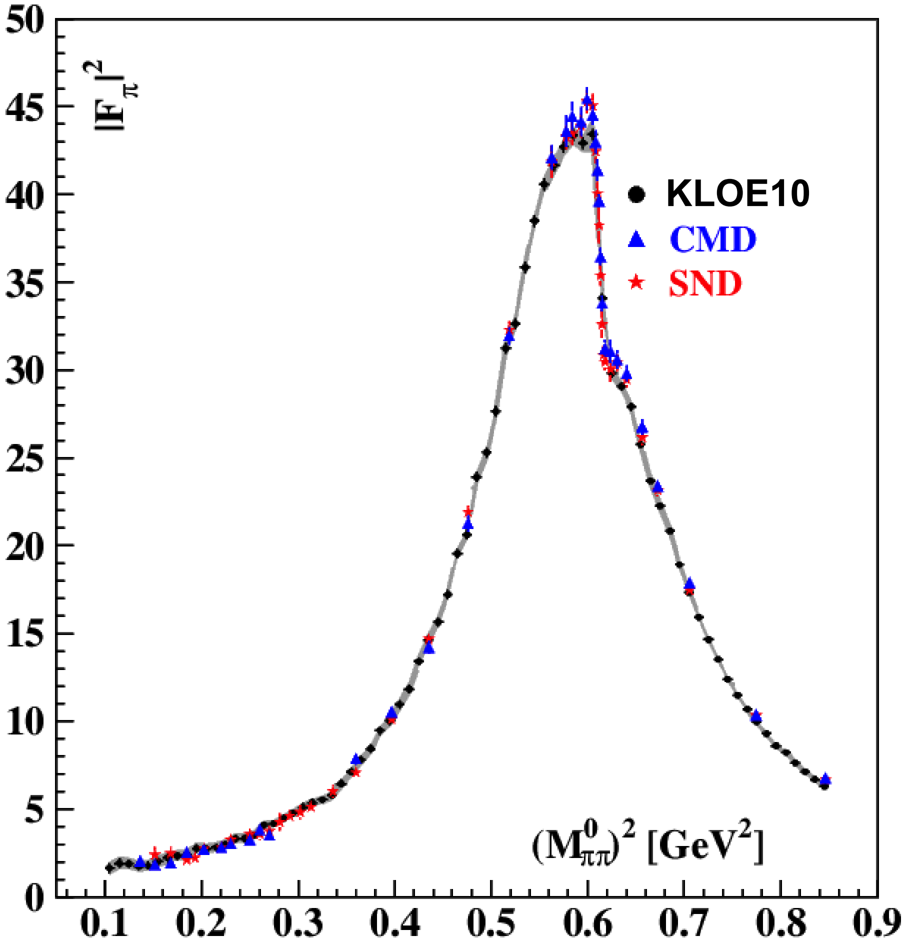
Combination of KLOE08 and KLOE10:

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

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

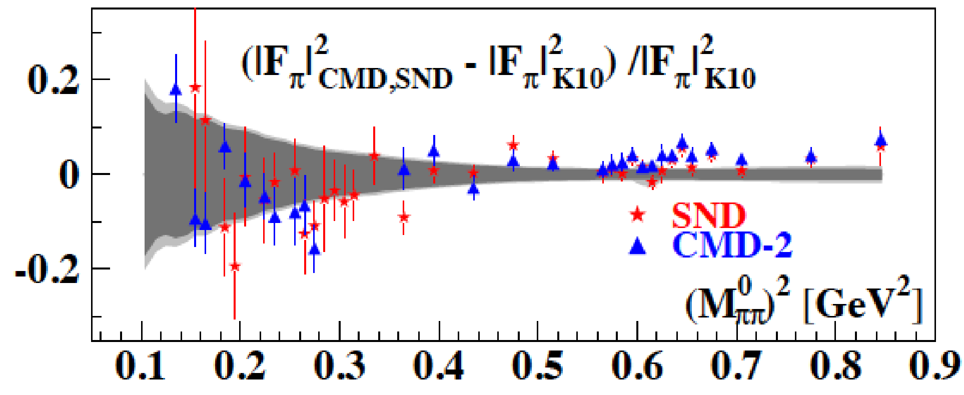
Comparison of results: KLOE10 vs CMD-2/SND

CMD and SND results compared to KLOE10: Fractional difference



SND: M.N. Achasov et al., J. Exp. Theor. Phys. 103, 480 (2006)

CMD-2: R.R. Akhmetshin et al., PLB648, 28 (2007)



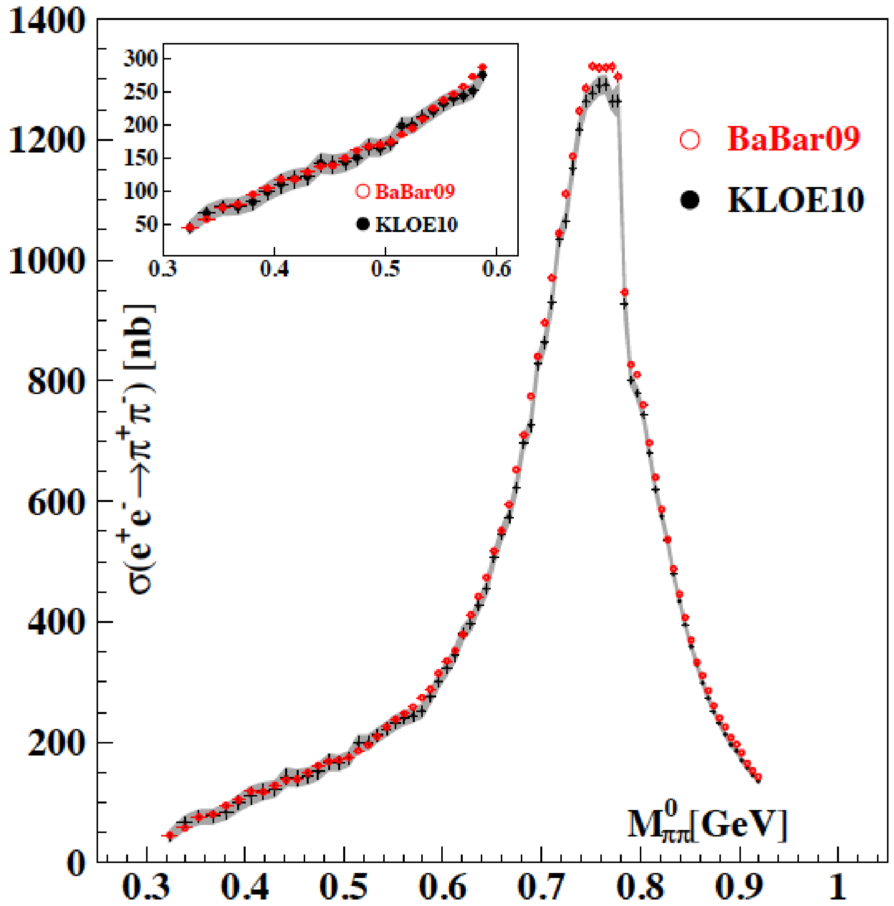
band: KLOE10 error

Below the ρ peak good agreement with CMD-2/SND.

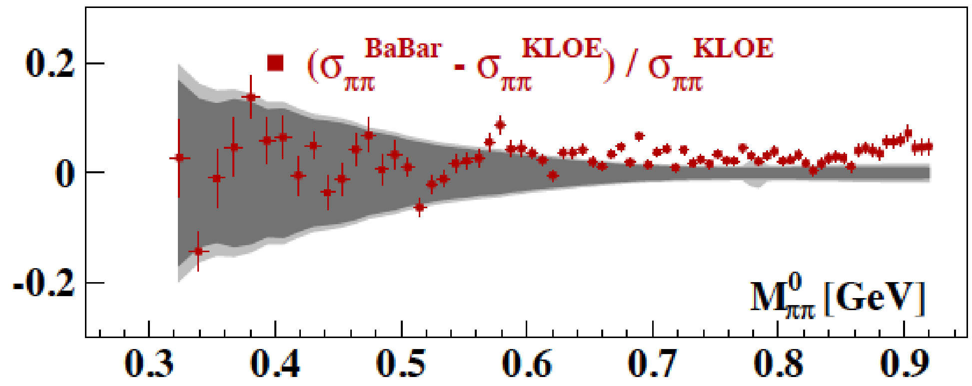
Above the ρ peak KLOE10 slightly lower

Comparison of results: KLOE10 vs BaBar

BaBar results compared to KLOE10: Fractional difference



BaBar: B. Aubert et al., Phys. Rev. Lett. 103, 231801 (2009)



band: KLOE10 error

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

KLOE12: New $\sigma_{\pi\pi}$ measurement from $\pi\pi\gamma/\mu\mu\gamma$

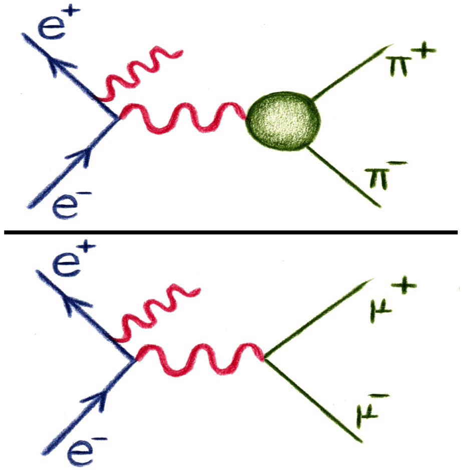
Phys. Lett. B 720 (2013) 336–343

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).

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

kinematical factor ($s_{\mu\mu}^{Born}$ / $s_{\pi\pi}^{Born}$)

meas. quantities



Many systematic effects drop out:

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

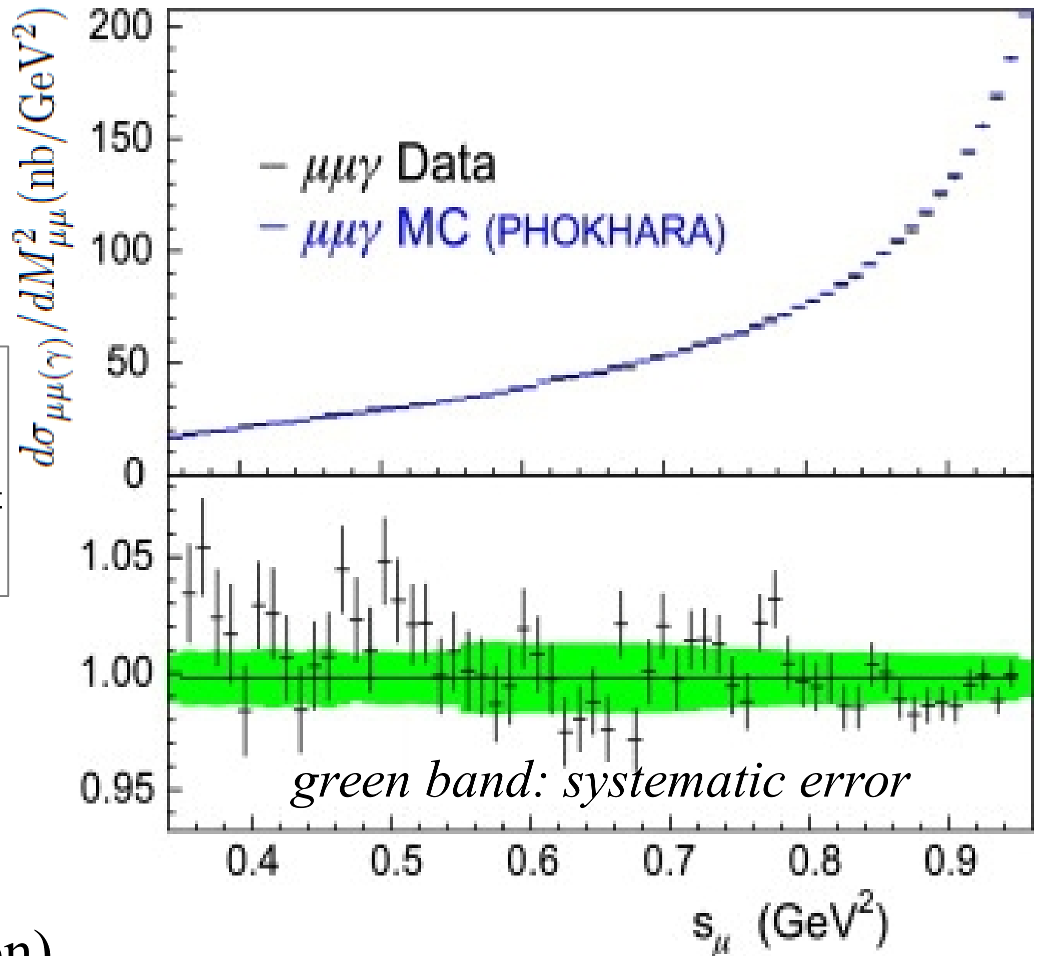
Data Sample:

- 239.2 pb^{-1} of 2002 data (the same used in KLOE08 analysis)
- photon at small angle
- 0.87 Million $\mu\mu\gamma$ events
- 3.4 Million $\pi\pi\gamma$ events

μμγ cross section: meas/simu comparison

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

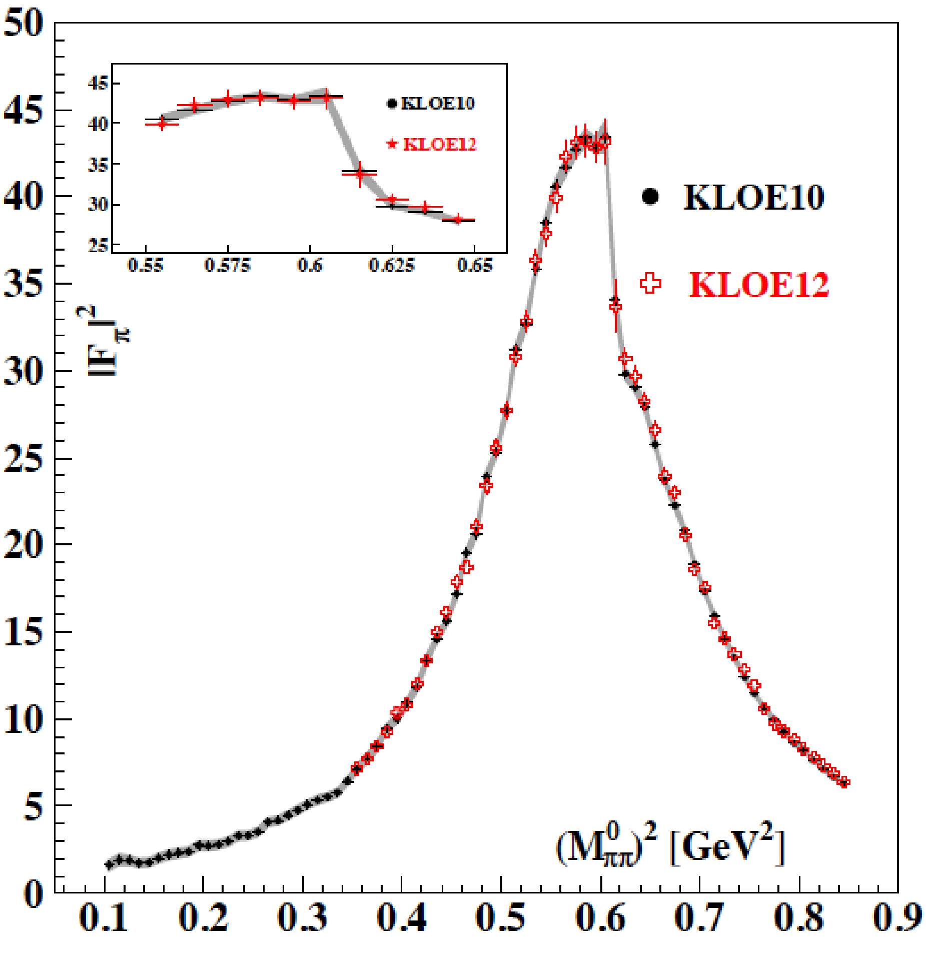
$$\frac{d\sigma^{DATA}_{\mu\mu\gamma(\gamma)}}{d\sigma^{MC}_{\mu\mu\gamma(\gamma)}} = 0.998 \pm 0.001_{stat} \pm 0.011_{syst}$$



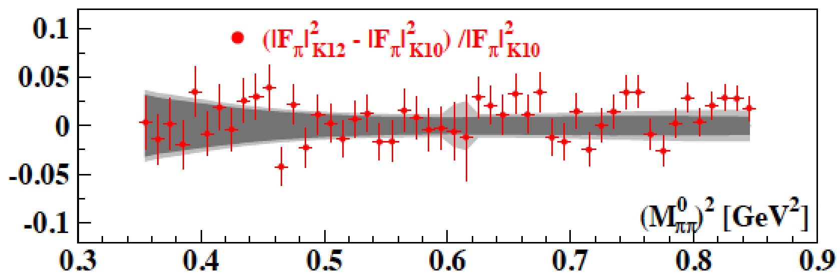
- The systematic error has been averaged on $M^2_{\mu\mu}$
- Good agreement with PHOKHARA MC (NLO Calculation)
- Consistency check of Radiator function, Luminosity, etc…

Comparison of results: KLOE12 vs KLOE10

KLOE12 result compared to KLOE10:



Fractional difference:



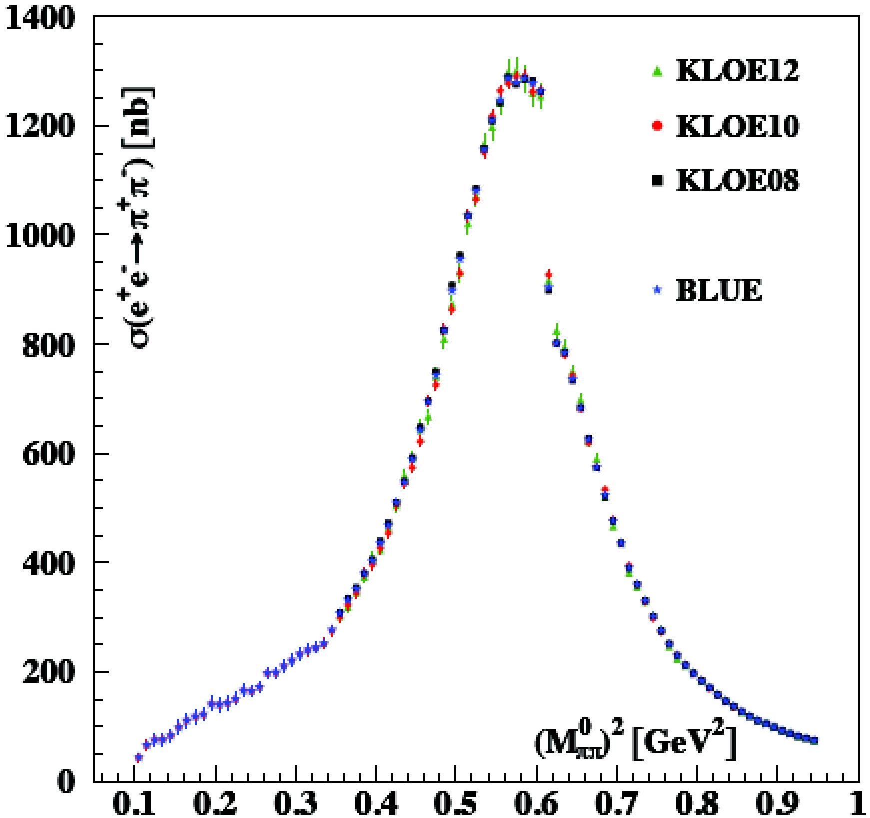
band: KLOE10 error

Excellent agreement between these 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	$376.6 \pm 0.9_{\mathrm{stat}} \pm 3.3_{\mathrm{sys+theo}}$

Preliminary combination of KLOE08,10,12

by Stefan E. Müller



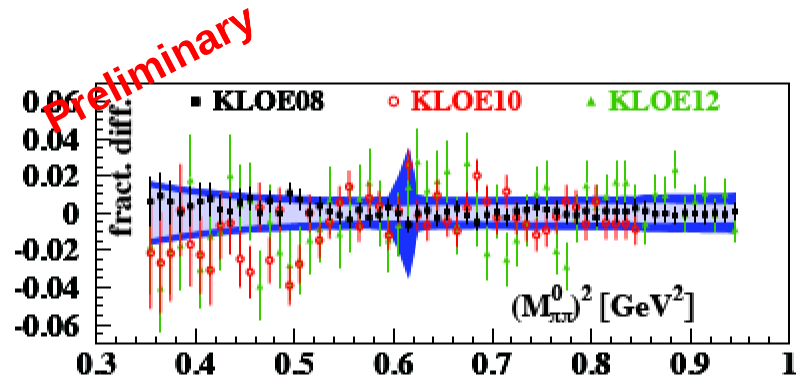
$a_\mu^{\pi\pi}$(0.1-0.95 GeV^2) = (487.8±5.7) · 10^{-10}

Covariance matrices (stat and syst) for combined analysis will be available at the web page: www.lnf.infn.it/kloe/ppg

Combination of KLOE08,KLOE10, and KLOE12 using the Best Linear Unbiased Estimate (BLUE) based on:

A. Valassi, NIM A500 (2003) 391

G. D'Agostini, NIM A346 (1994) 306

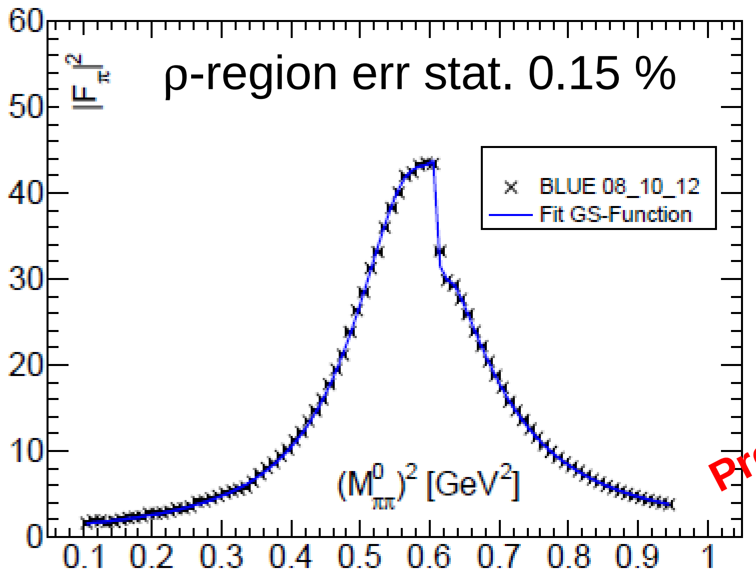


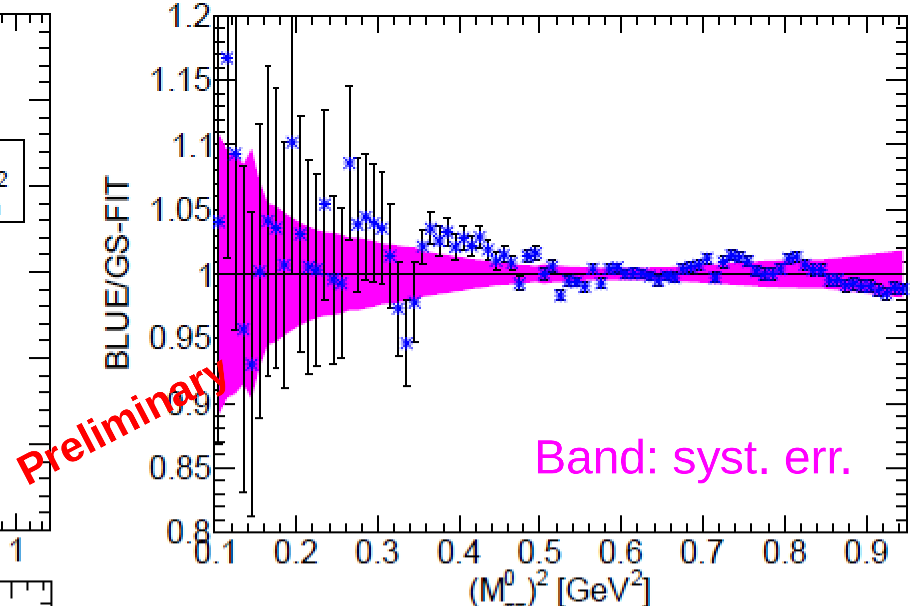
$$\frac{|F_{\mathrm{KLOEXX}}|^2 - |F_{\mathrm{BLUE}}|^2}{|F_{\mathrm{BLUE}}|^2}$$

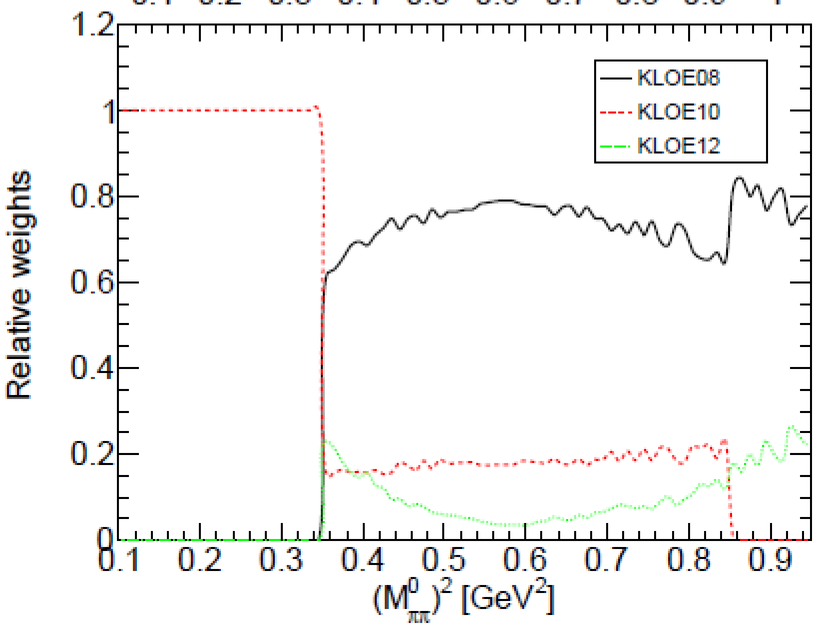
Grey band: Stat. errors

Blue band: Stat. + Syst. errors

Preliminary fit with Gounaris-Sakurai parametrization of KLOE08,10,12







Only statistical error are included in the fit!

Parameters (GS)	KLOE (PDG)
M_ρ(MeV)	774.3±0.1$_{stat}$ (775.49±0.34)
Γ_ρ(MeV)	146.9±0.2$_{stat}$ (149.1±0.8)
M_ω(MeV)	782.7±0.2$_{stat}$ (782.65±0.12)
Γ_ω(MeV)	7.0±0.4$_{stat}$ (8.49±0.08)
$\alpha(10^{-3})$	1.45±0.04$_{stat}$
$\beta(10^{-3})$	-83.1±0.6$_{stat}$
δ(deg.)	10.2±1.7$_{stat}$
$(\chi^2/\text{n.d.f})$	221.4/82 (2.7)

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

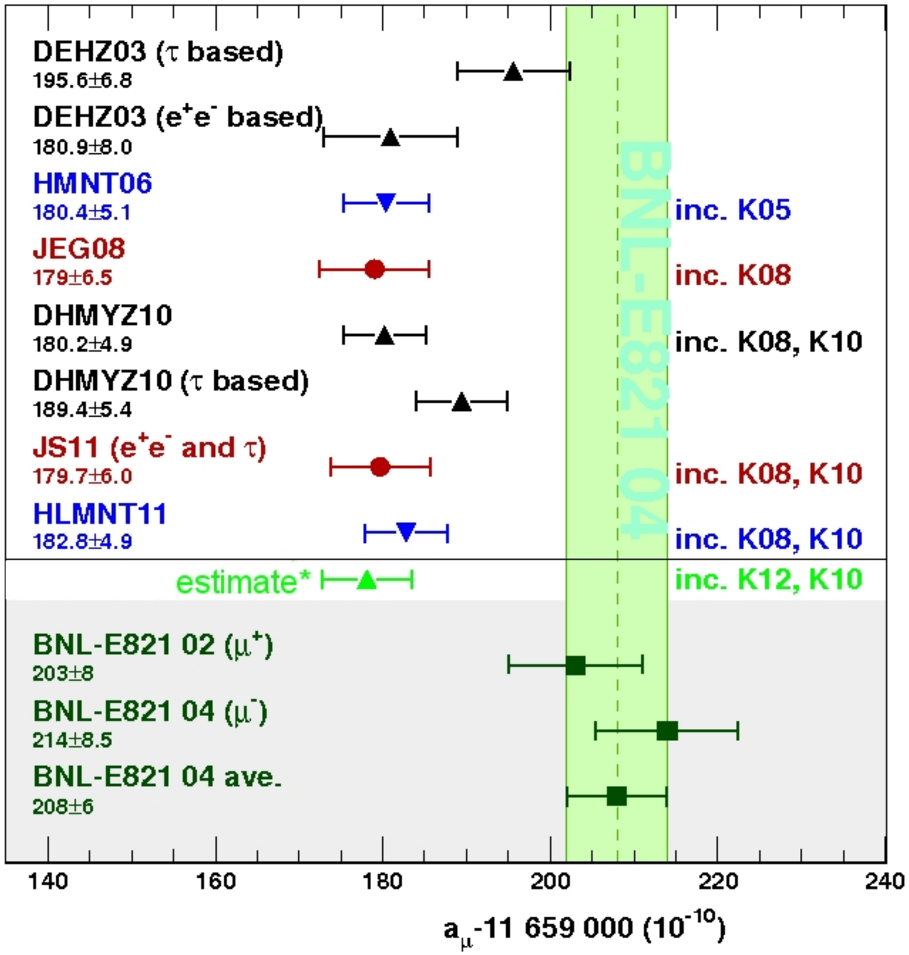
Theoretical predictions compared to the BNL result

- **Discrepancy between a_μ^{SM} and a_μ^{EXP} at the 3.5σ level is confirmed by the KLOE measurement of the ratio of cross sections $\pi\pi\gamma/\mu\mu\gamma$**

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

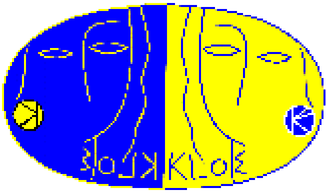
- **Previous tension between e^+e^- and τ data is reduced by 1σ [F. Jegerlehner et al., Eur.Phys.J. C71 (2011) 1632, ρ-γ treatment]**

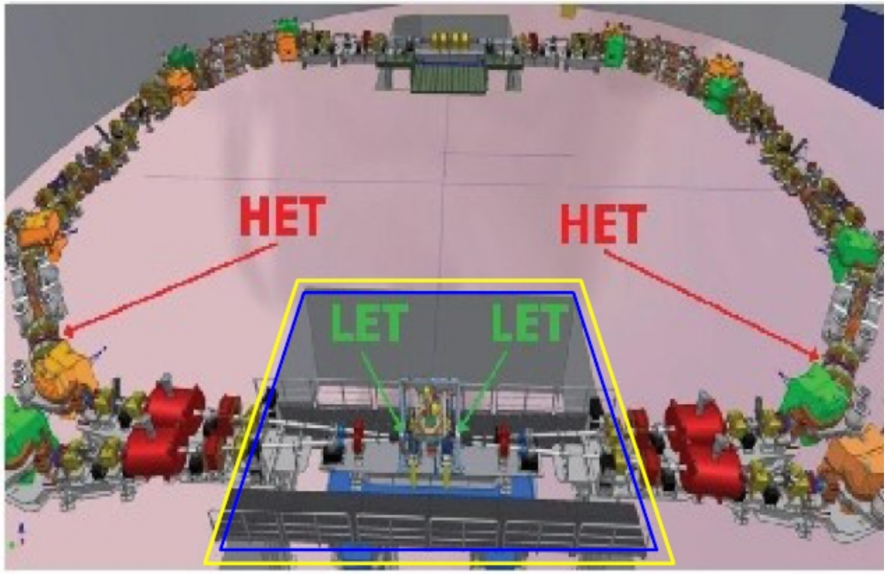
Results from new g-2 experiments (at FNAL and JPARC) will be very important!



* Our extrapolation based on DHMYZ10

$\gamma\gamma$ physics at KLOE2





$$e^+ e^- \rightarrow e^+ e^- \gamma^* \gamma^* \rightarrow e^+ e^- X$$

to taggers (HET or LET)

in KLOE

LET (Low Energy Tagger)

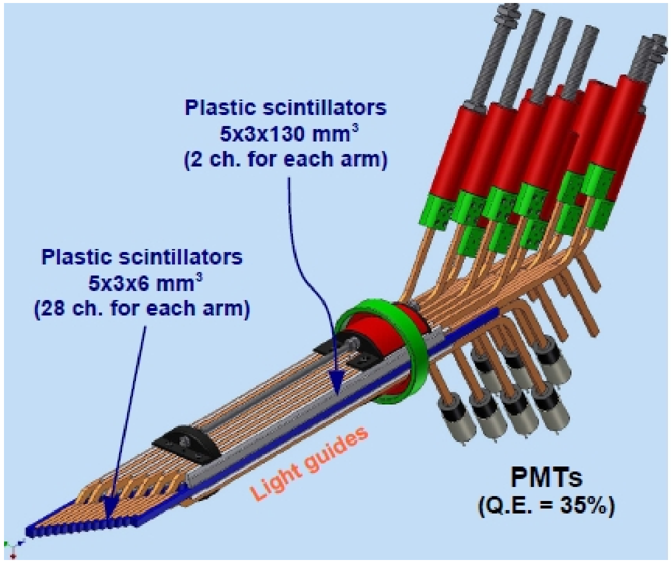
→ Inside KLOE detector (1m from IP)

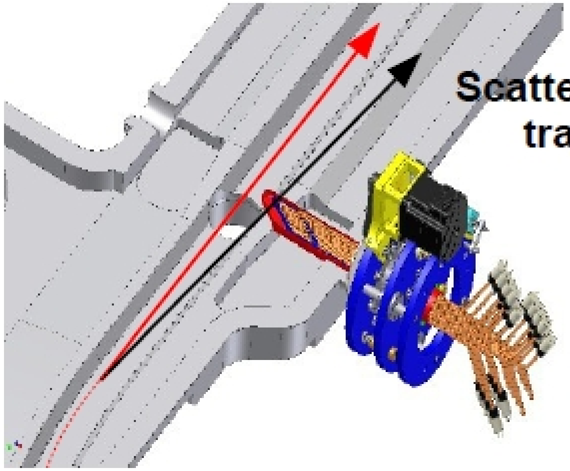
→ energy acceptance (160-400) MeV

HET (High Energy Tagger)

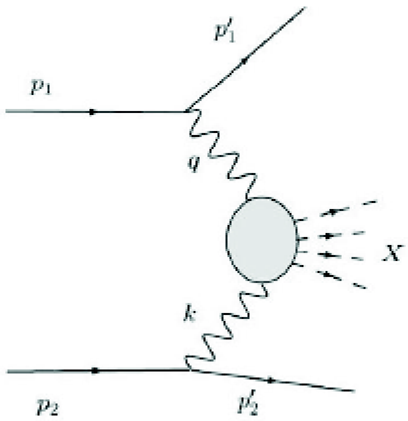
→ After bending dipole (11m from IP)

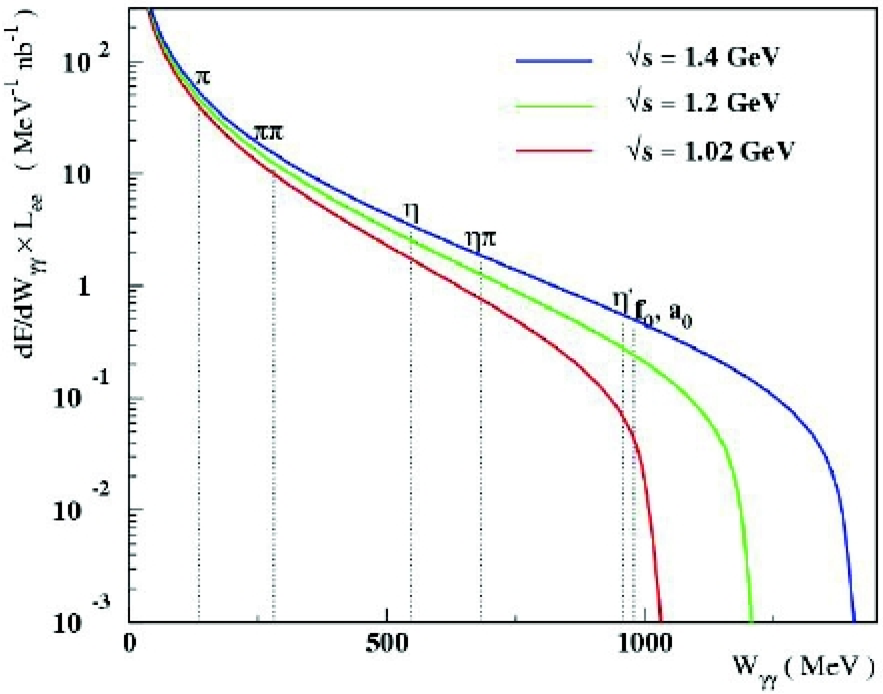
→ energy acceptance (420-495) MeV





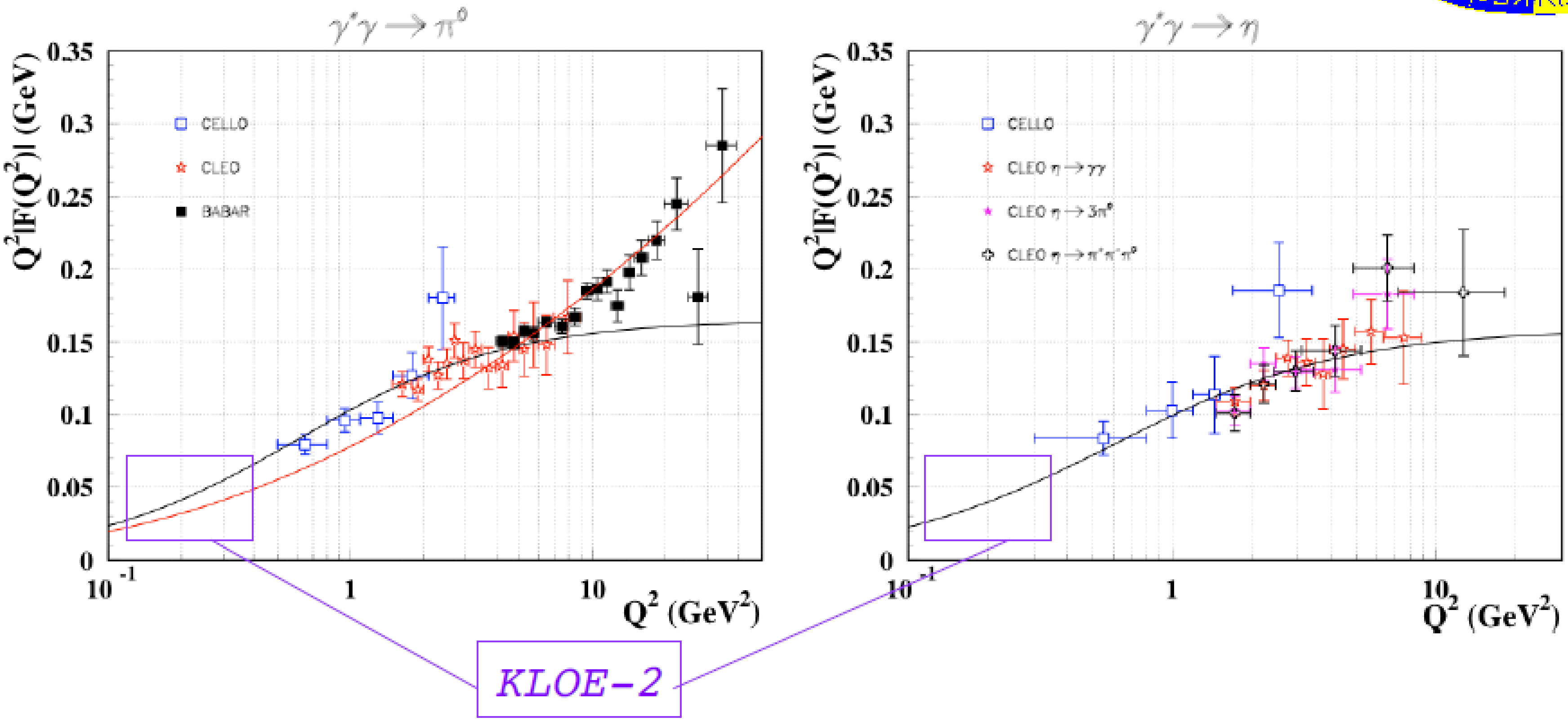
γγ physics



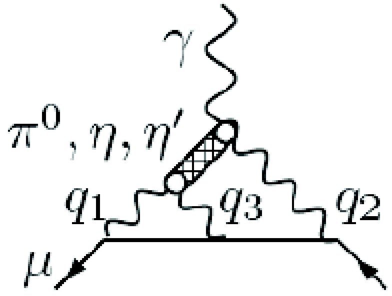


- $X = \pi\pi \Rightarrow$ search for $\sigma(600)$
- $X = \pi^0, \eta, (\eta')$
  - $\Gamma(X \rightarrow \gamma\gamma)$
  - Transition form factors $F_{X\gamma^*\gamma^*}(q_1^2, q_2^2)$

KLOE-2 contribution to a_μ^{LbL}

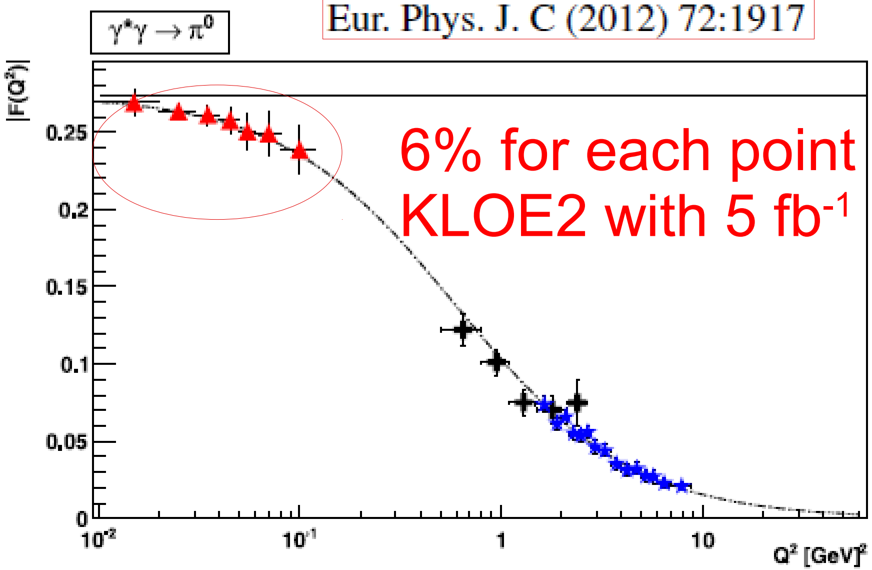


- **Measurement of $\Gamma(P \rightarrow \gamma\gamma)$**
- **Transition form factors $F_{P\gamma^*\gamma^*}(q_1^2, q_2^2)$:**
  - **input for the calculation of the Light-by-Light contribution to g-2 of the muon**



KLOE-2 contribution to a_μ^{LbL}

Eur. Phys. J. C (2012) 72:1917



By including KLOE-2→a reduction of a factor 2 in the error of $a_\mu^{\pi 0}$!

In addition the measurement of $\Gamma(\pi_0 \to \gamma\gamma)$ will constrain $F_{\pi 0}(q^2=0)$ (which is now obtained by WZW model $1/4\pi f_\pi$ w/o error)

A0 : CELLO, CLEO, PDG;

A1 : CELLO, CLEO, PrimEx;

A2 : CELLO, CLEO, PrimEx, KLOE-2;

B1 : CELLO, CLEO, BaBar, PrimEx;

B2 : CELLO, CLEO, BaBar, PrimEx, KLOE-2;

Model	Data	χ^2/d.o.f.	Parameters			$a_\mu^{\mathrm{LbyL};\pi^0} \times 10^{11}$
VMD	A0	6.6/19	$M_V = 0.778(18)$ GeV	$F_\pi = 0.0924(28)$ GeV		$(57.2 \pm 4.0)_{JN}$
VMD	A1	6.6/19	$M_V = 0.776(13)$ GeV	$F_\pi = 0.0919(13)$ GeV		$(57.7 \pm 2.1)_{JN}$
VMD	A2	7.5/27	$M_V = 0.778(11)$ GeV	$F_\pi = 0.0923(4)$ GeV		$(57.3 \pm 1.1)_{JN}$
LMD+V, $h_1 \neq 0$	B1	18/35	$\bar{h}_5 = 6.44(22)$ GeV^4	$\bar{h}_7 = -14.92(21)$ GeV^6	$h_1 = -0.17(2)$ GeV^2	$(72.4 \pm 1.6)^*_{JN}$
LMD+V, $h_1 \neq 0$	B2	19/43	$\bar{h}_5 = 6.47(21)$ GeV^4	$\bar{h}_7 = -14.84(7)$ GeV^6	$h_1 = -0.17(2)$ GeV^2	$(71.8 \pm 0.7)^*_{JN}$

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 value measured at BNL

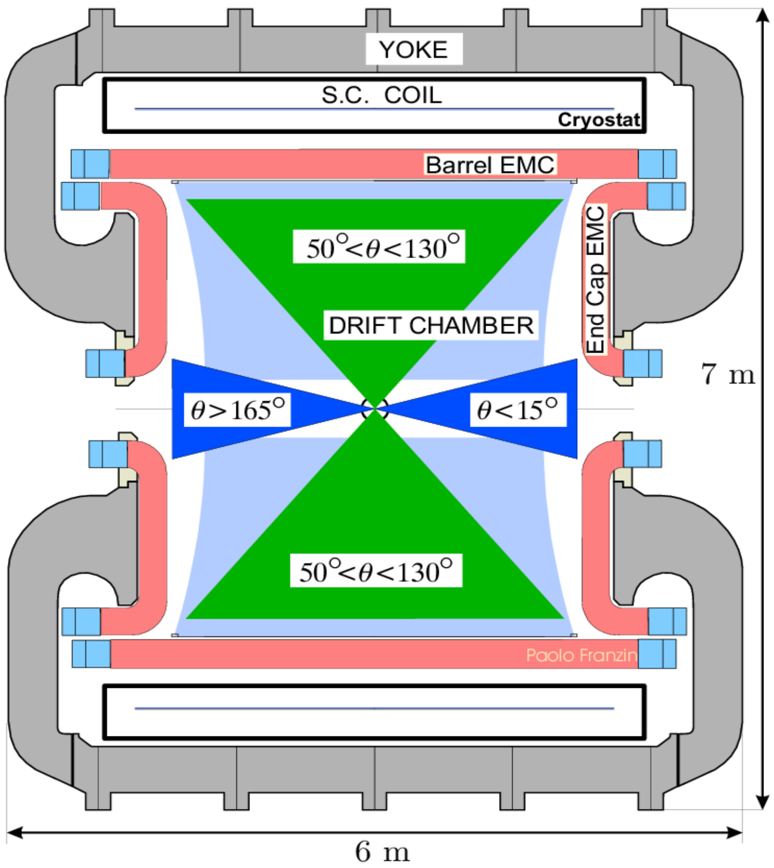
- The published measurements (KLOE05, KLOE08, KLOE10), normalized to Bhabha events, have allowed us to measure $a_\mu^{\pi\pi}$ in the region below 1 GeV with **~1%** total error

- A new measurement (KLOE12) of $|F_\pi|^2$ from the ππγ/μμγ 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 μμγ cross section with NLO QED calculation (PHOKHARA MC) and for $|F_\pi|^2$ with previous KLOE measurements (confirming 3σ discrepancy on a_μ)

Conclusion

- KLOE-2 can give an important contribution to the evaluation of HLBL scattering to the muon g-2, via the $\gamma\gamma$ physics. We found that with 5 fb^{-1} KLOE-2 can reduce the error of a factor 2 on the on-shell related a_μ π_0 by measuring:
  - $\Gamma(\pi_0 \rightarrow \gamma\gamma)$ at 1%
  - $F\pi_0(Q^2)$ <0.1 GeV2 with 6% stat. uncertainty for each point.
- Still more than 1.5 fb^{-1} of KLOE data on tape. This would represent a factor ~4 improvement in statistics. We plan to analyze these data to improve $\sigma_{\pi\pi}$
- A new round of data taking with KLOE-2 upgraded detector is expected to begin Fall 2014.

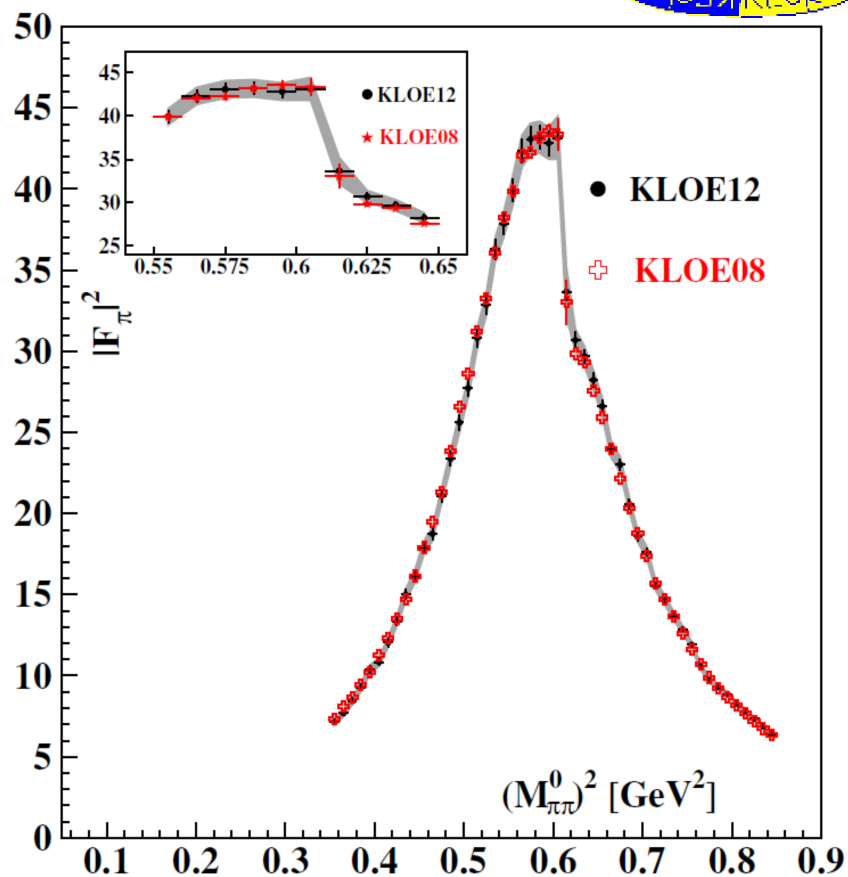


SPARE SLIDES

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

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

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



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

Luminosity:

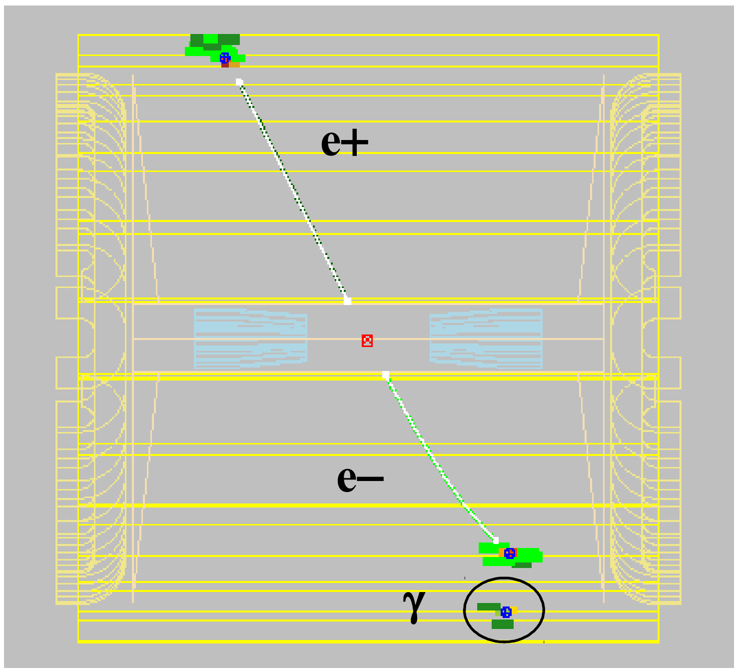
KLOE measures $\mathcal{L}$ with Bhabha scattering

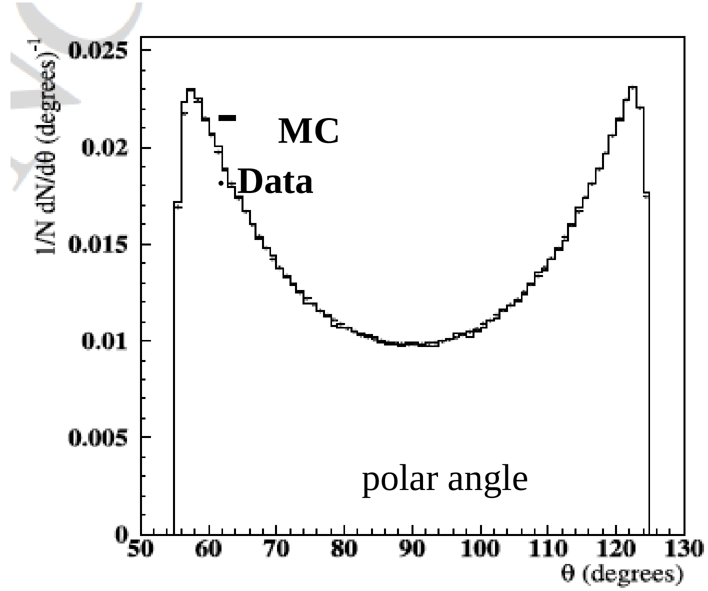
$55° < \theta < 125°$

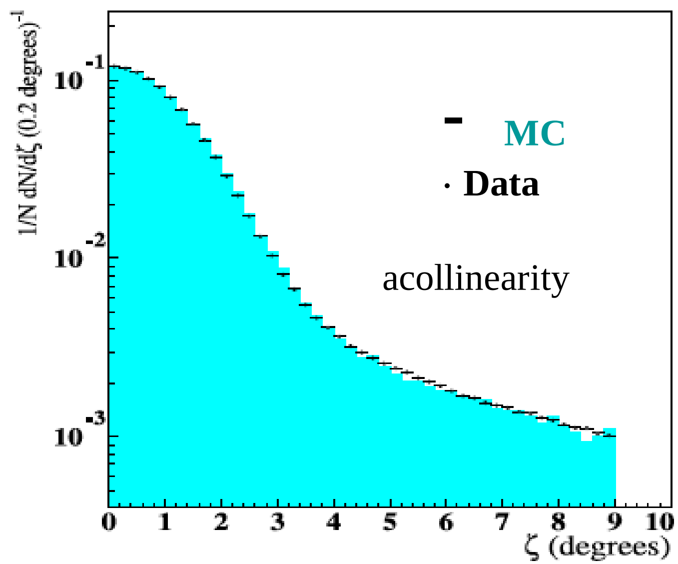
acollinearity < 9°

$p \geq 400$ MeV

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



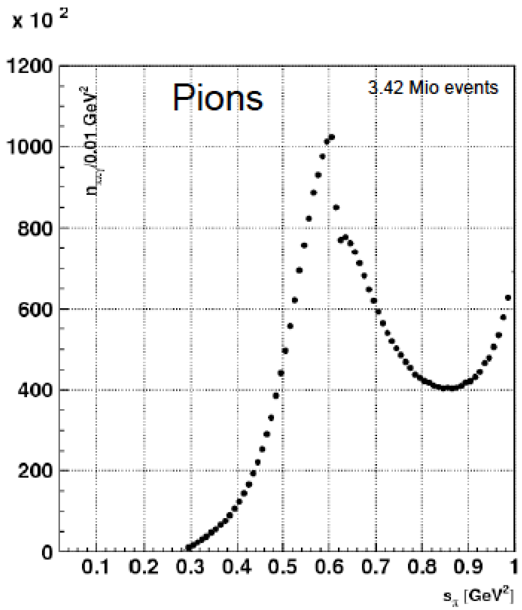


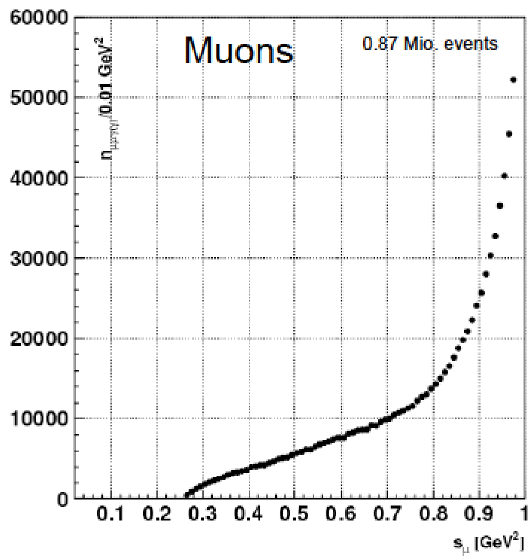


KLOE12: New $\sigma_{\pi\pi}$ measurement from $\pi\pi\gamma/\mu\mu\gamma$

- *Important to get a good π/μ separation, especially in the ρ region where $\sigma_{\pi\pi}/\sigma_{\mu\mu} \sim 10$*
  - Obtained ~1% uncertainty in the muon selection
  - π/μ separation cross-checked with three different methods (*M_{Track}* fit, Kinematic fit, cut on σ_{MTrack})
- μμγ (and ππγ) efficiencies (Tracking,Triggering,PID) done on measurement data
- Excellent measurement/simulation agreement for many kinematic variables: M_{Track}, tracks, and γ polar angle, etc...

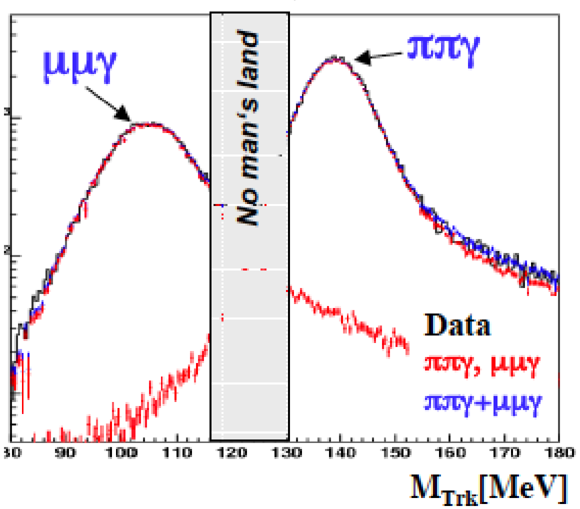
$$\left(\sqrt{s}-\sqrt{|\vec{p}_+|^2+M^2_{Track}}-\sqrt{|\vec{p}_-|^2+M^2_{Track}}\right)^2-\left(\vec{p}_++\vec{p}_-\right)^2=M^2_\gamma=0$$





Separation btw ππγ and μμγ using M_{Track}

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

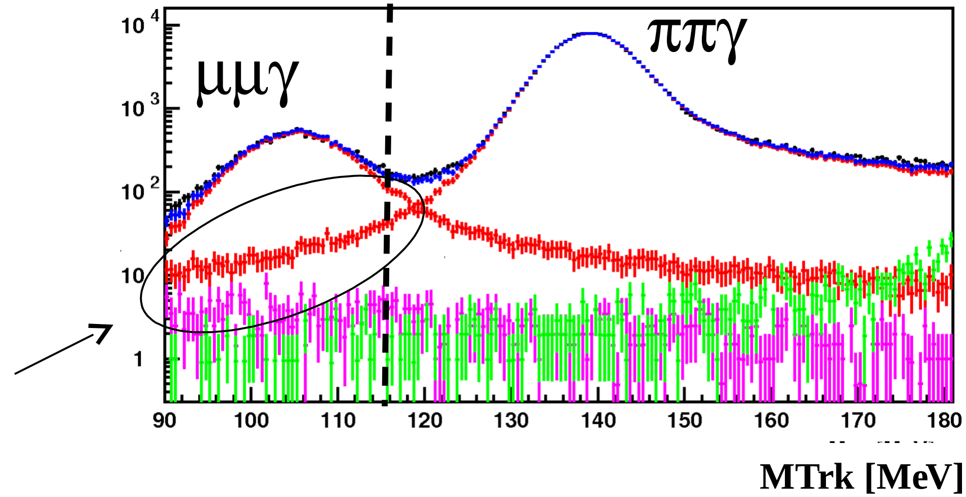


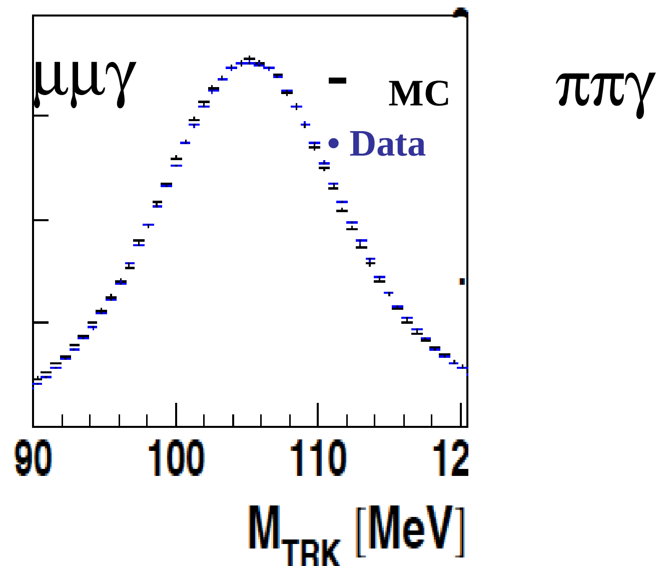
π/μ separation: control of ππγ M_{TRK} tail

- 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 (MTRK<115 MeV) is ~15% at ρ peak

➔ ππγ MTRK tail in the μμγ region must be well under control.

- ππγ MTRK tail tuned using φ→π+π−π0 control sample.
- Excellent agreement on MTRK (ππγ and μμγ) distributions





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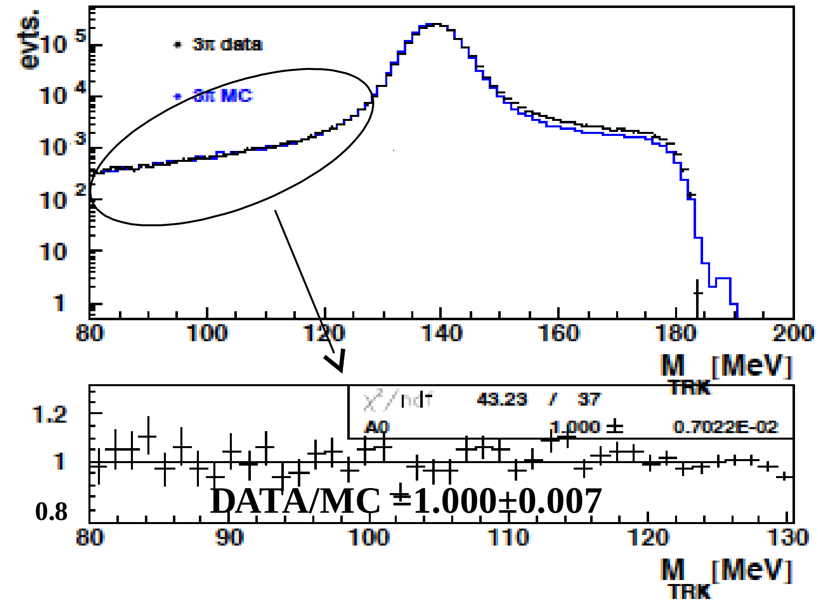
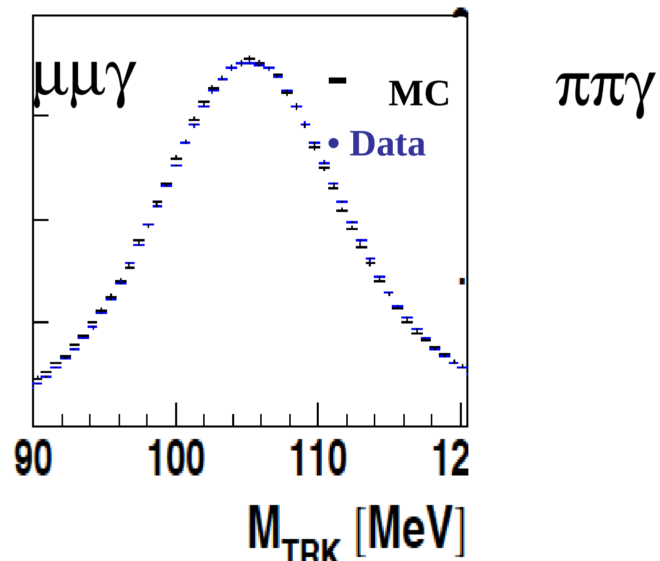
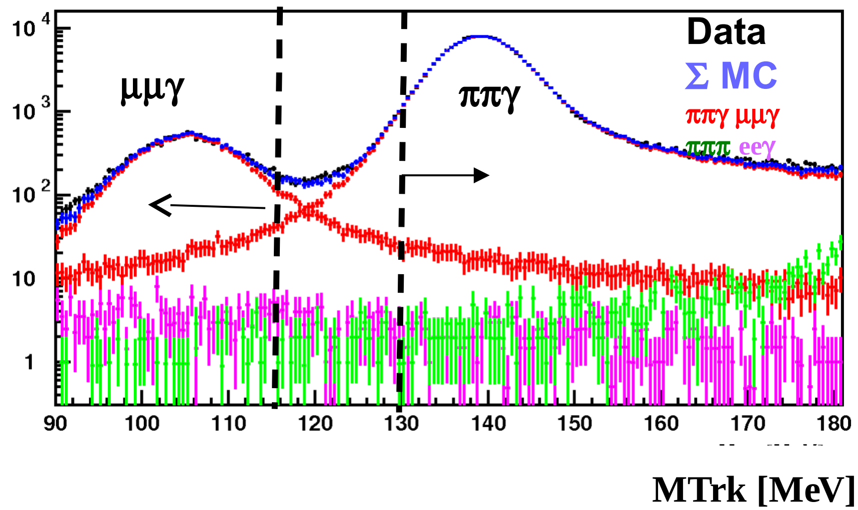




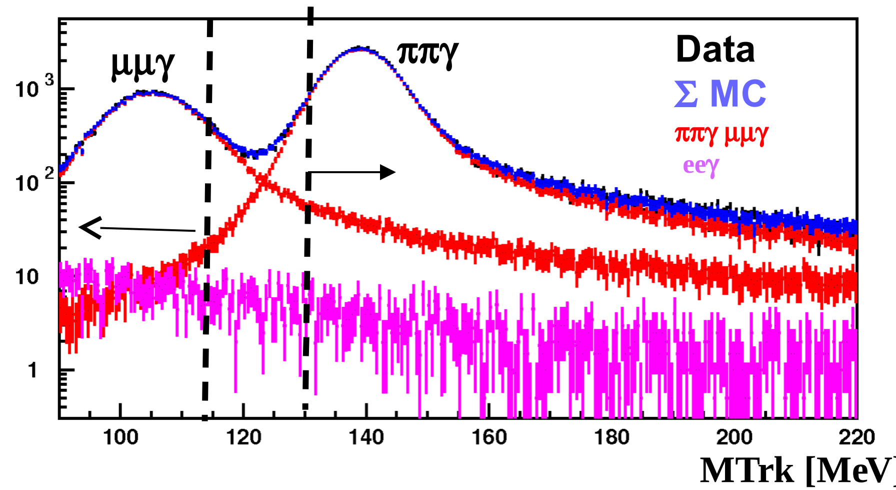
Background:

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

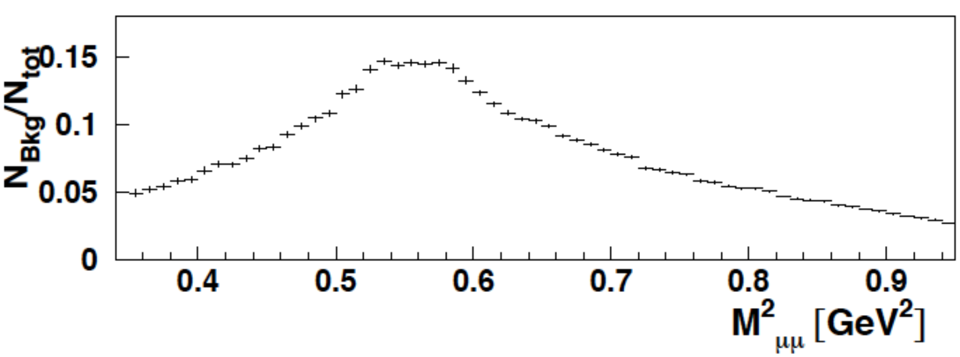
$0.60 < M_{\pi\pi}^2 < 0.62$ GeV², $\chi^2/ndof = 158/180$



$0.84 < M_{\pi\pi}^2 < 0.86$ GeV² $\chi^2/ndof = 179/258$



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



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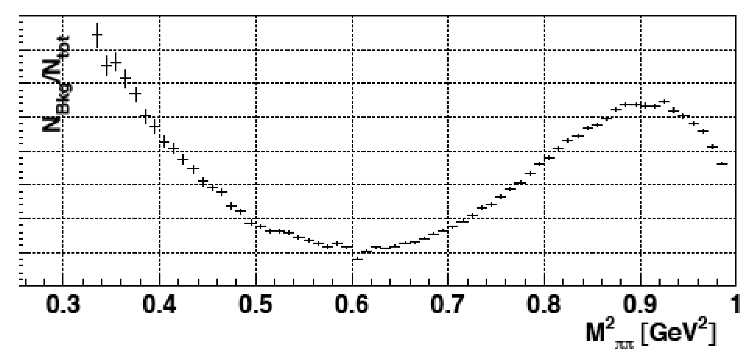
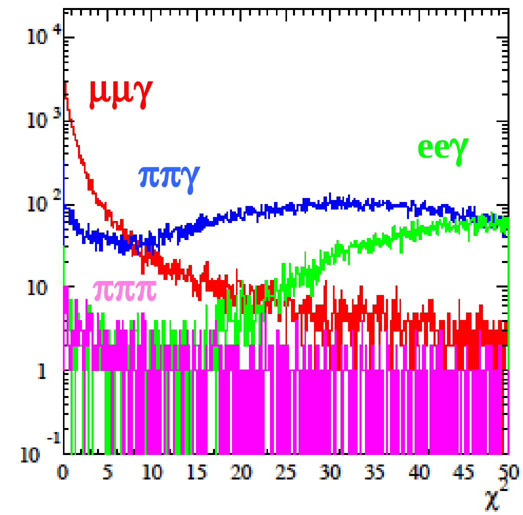


1%

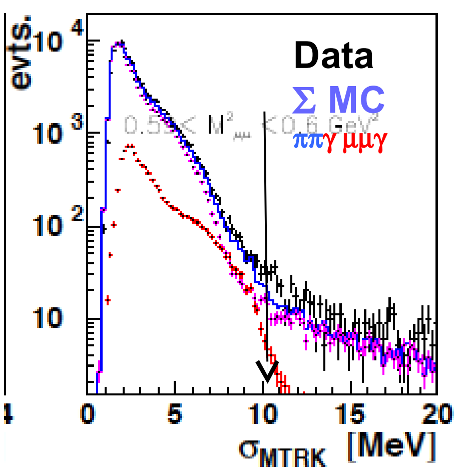
- Systematic error on $\mu\mu\gamma$ due to background ~1% in the ρ peak

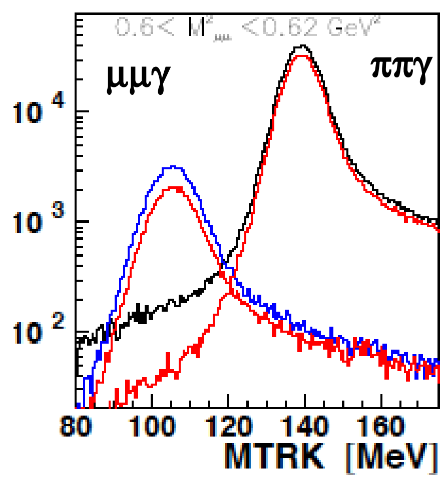
Cross check of π/μ separation

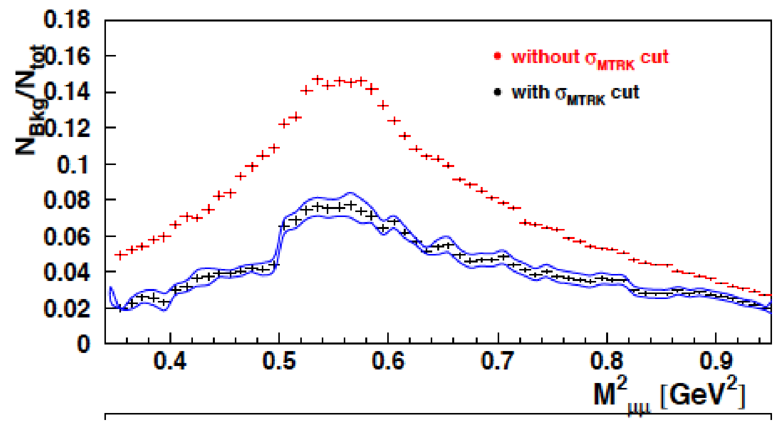
- The π/μ separation has been crosschecked with two different (and independent) methods:



- A kinematic fit, in the hypothesis of 2 body+1γ (ISR) events.
- A cut on the quality of the fitted tracks, parametrized by σMTRK







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(1γISR+1γFSR) 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(1γISR+1γFSR)
- 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)