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

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Outline

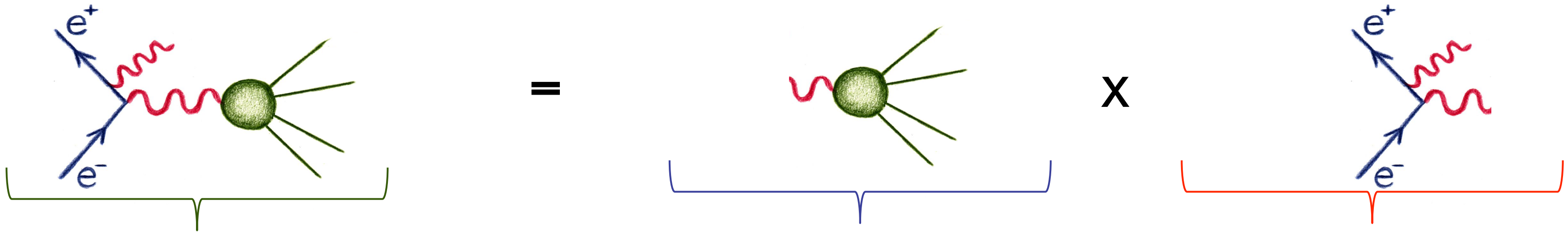
Normalized to luminosity ($e^+e^- \to e^+e^-(\gamma)$)

- 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 (KLOE11, *preliminary*)
  - Comparison with KLOE08, KLOE10 and evaluation of $a_\mu^{\pi\pi}$
- Outlook and conclusion

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 $H(s, M^2_{hadr})$

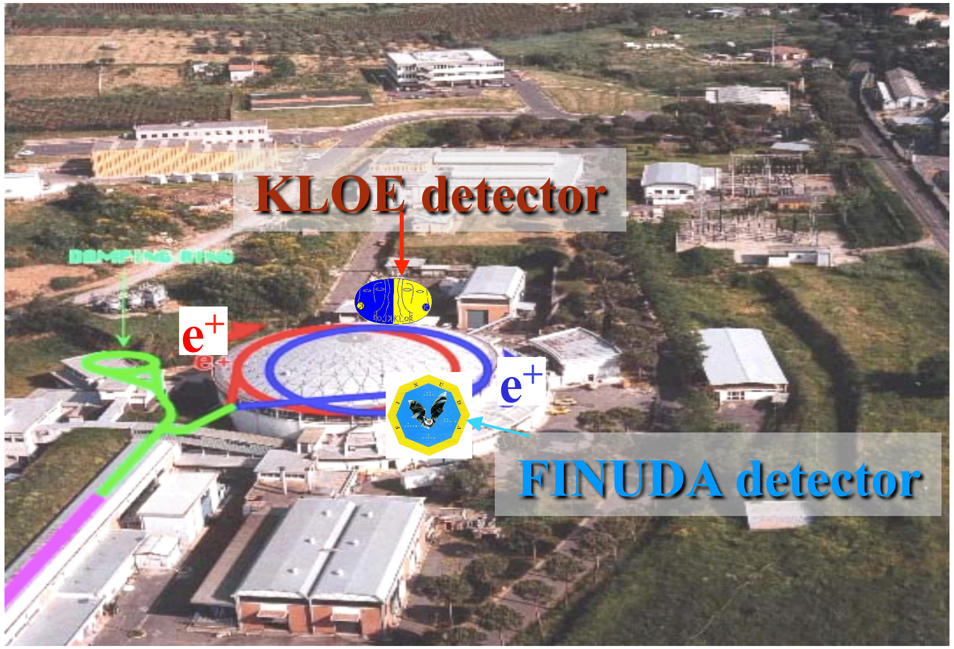
➔ **EVA + PHOKHARA MC Generator**

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)

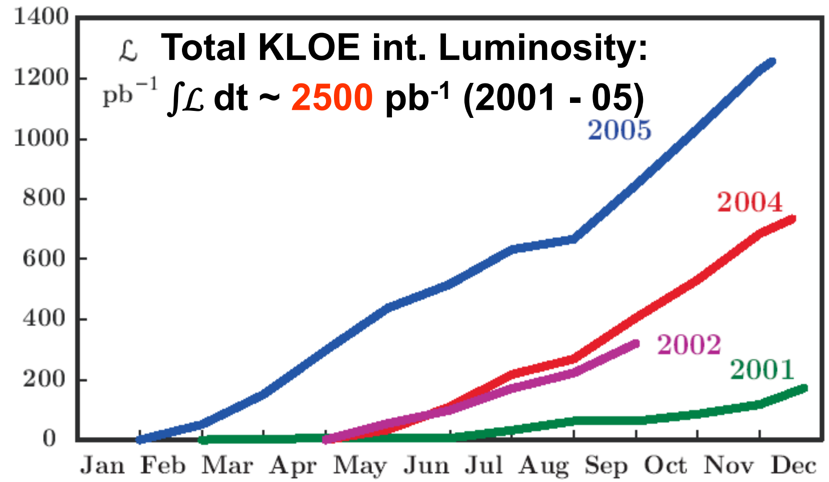
IN 2005 KLOE has published the first precision measurement of $\sigma(e^+e^- \to \pi^+\pi^-)$ with ISR using 2001 data (140pb^{-1}) PLB606(2005)12 $\Rightarrow$ ~3σ discrepancy btw a_μ^{SM} and a_μ^{exp}

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:

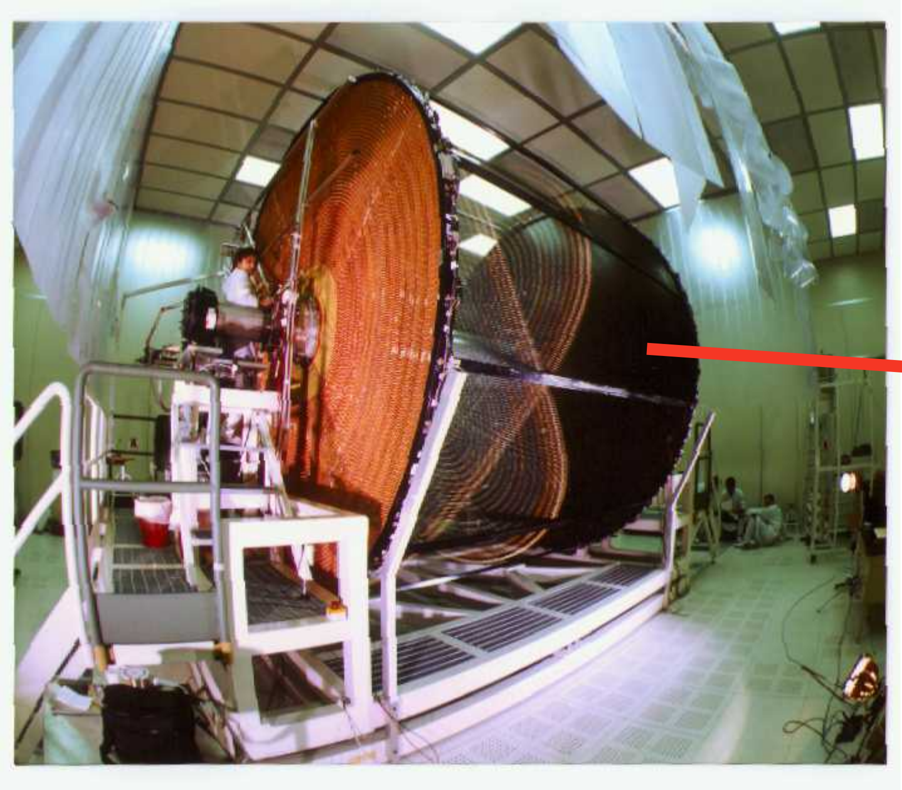
- **Energy scan (4 points around m_Φ-peak)**
- **240 pb^{-1} at $\sqrt{s}$ = 1000 MeV (off-peak data)**

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

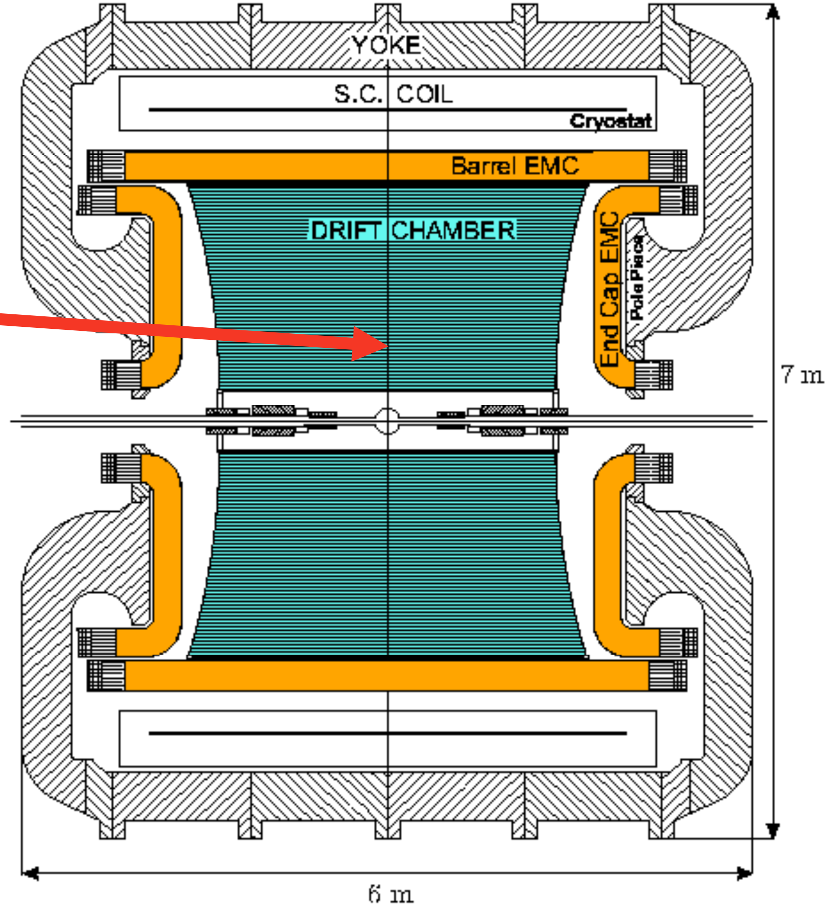
KLOE10 measurement (PLB700 (2011) 102) based on 233 pb^{-1} of 2006 data (at 1 GeV, different event selection)

KLOE Detector

Drift chamber



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



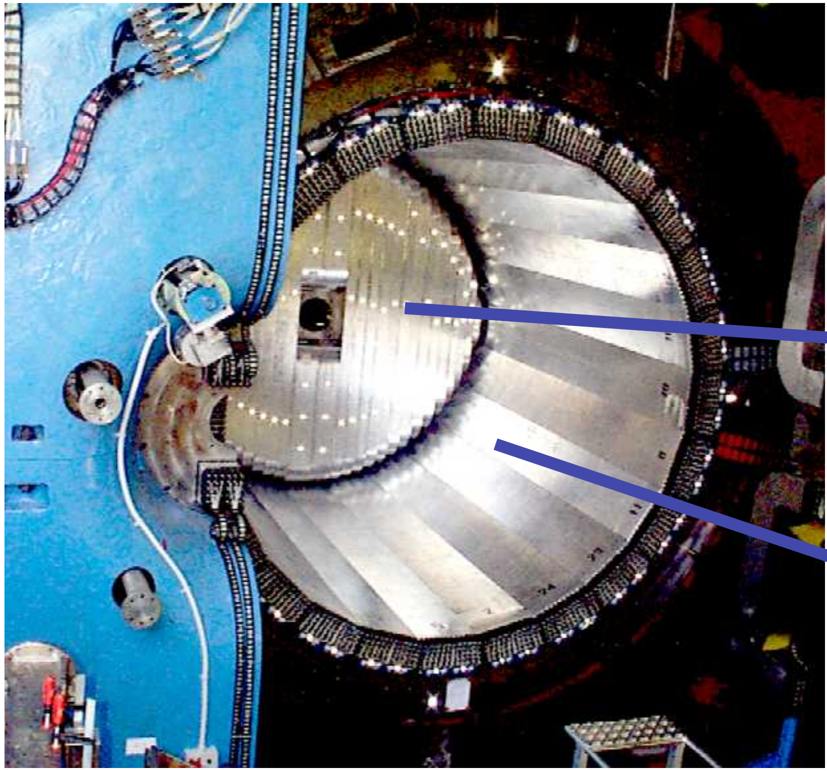
$\sigma_p/p = 0.4\%$ (for 90^0 tracks)

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

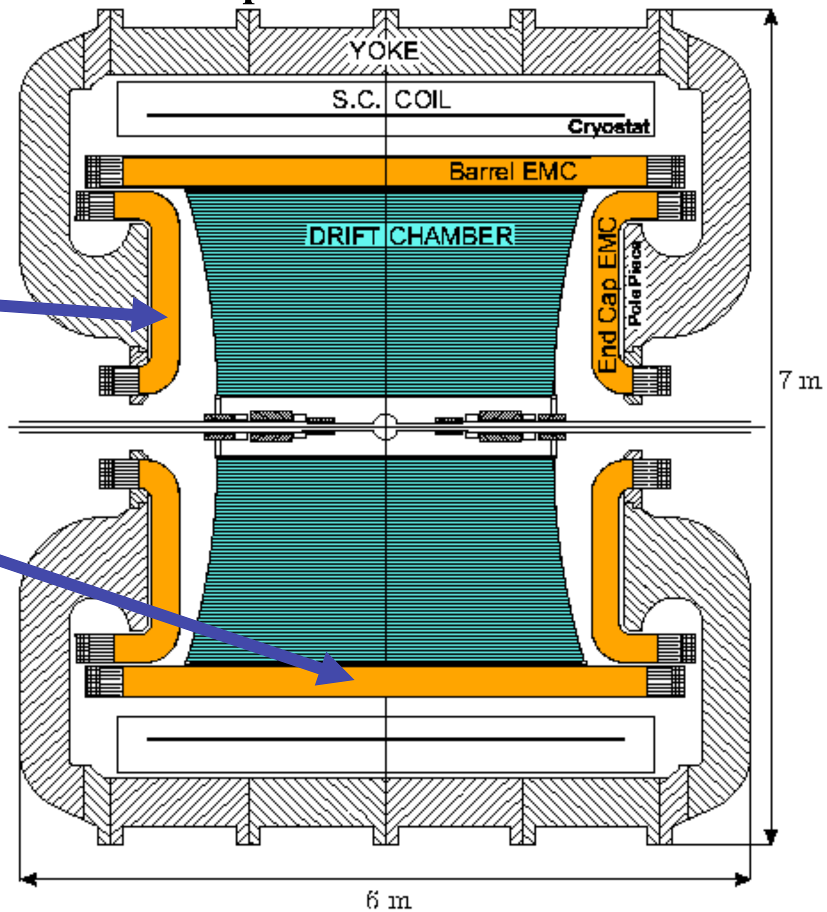
Excellent momentum resolution

KLOE Detector

Electromagnetic Calorimeter



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



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

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

(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

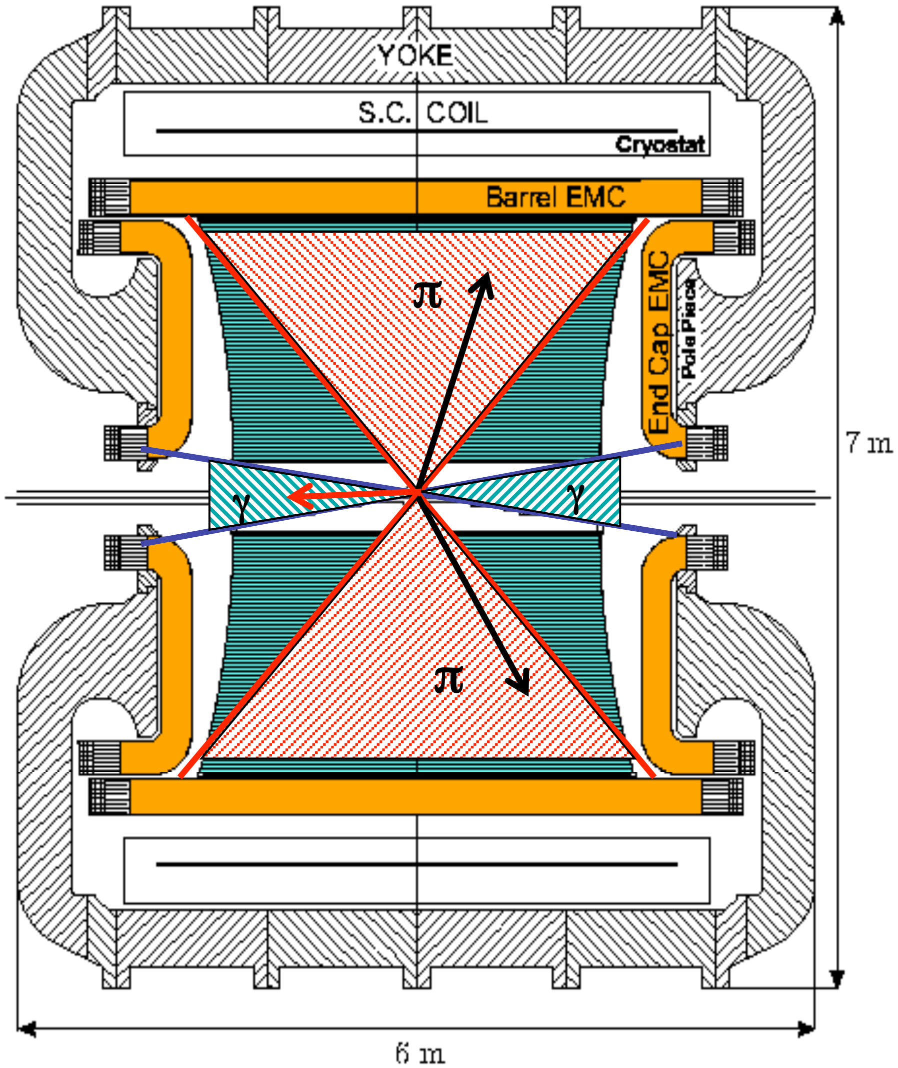
$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

➔ Photon momentum from kinematics:

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

- 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:

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

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

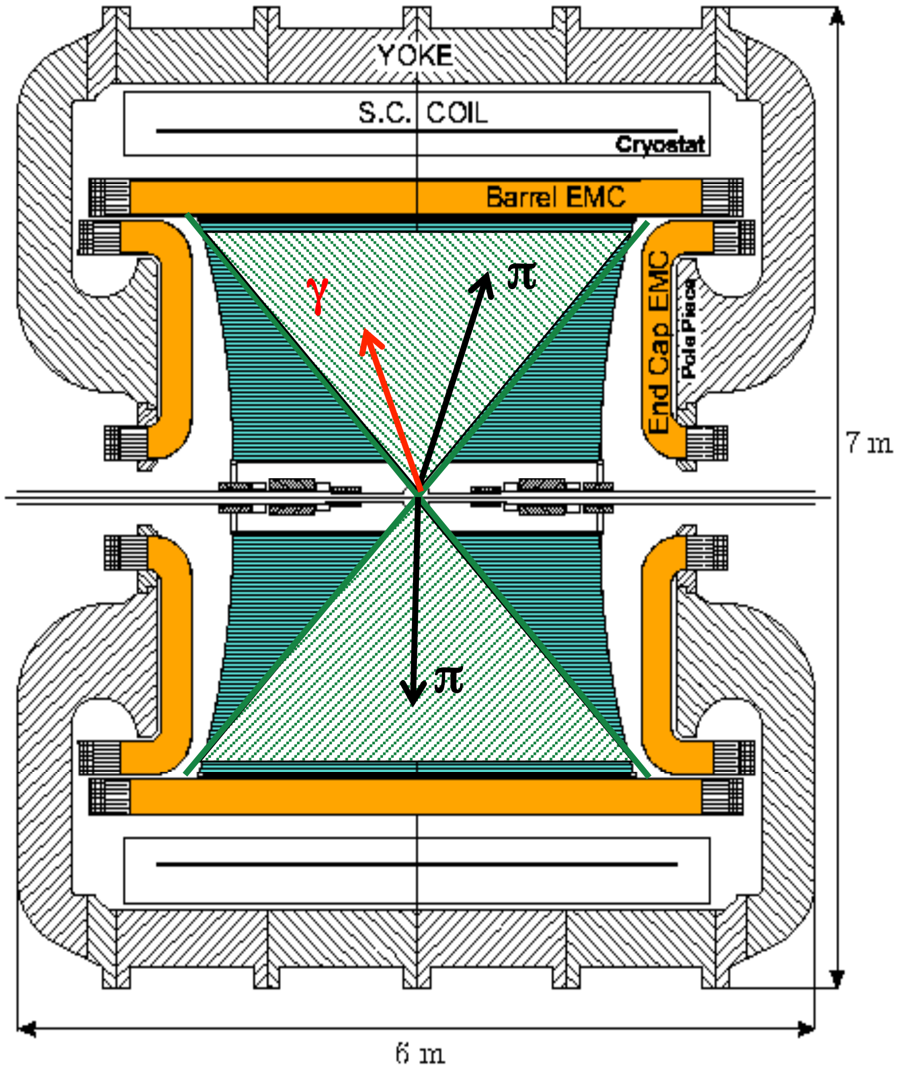
b) Photons at large angles

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

➔ 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%

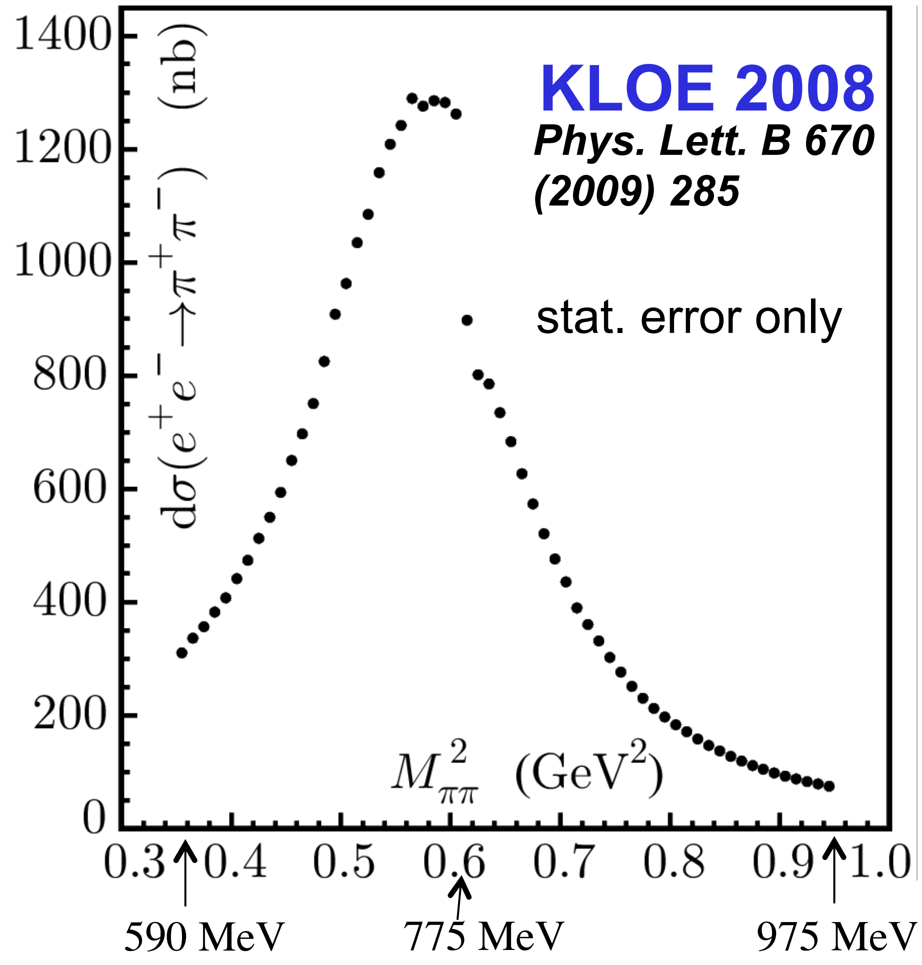
experimental fractional error on a_μ = 0.6 %

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

theoretical fractional error on a_μ = 0.6 %

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

$\sigma_{\pi\pi}$, undressed from VP, inclusive for FSR as function of $(M^0_{\pi\pi})^2$



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

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

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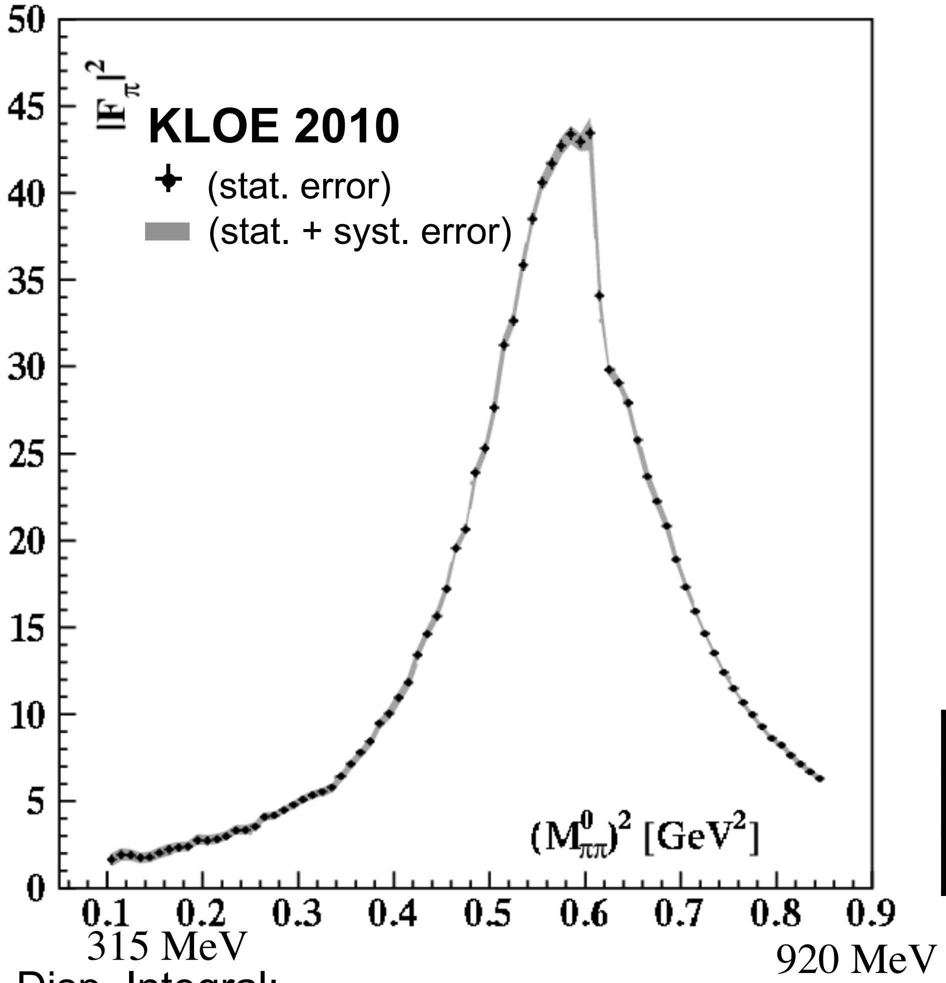


Disp. Integral:

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

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

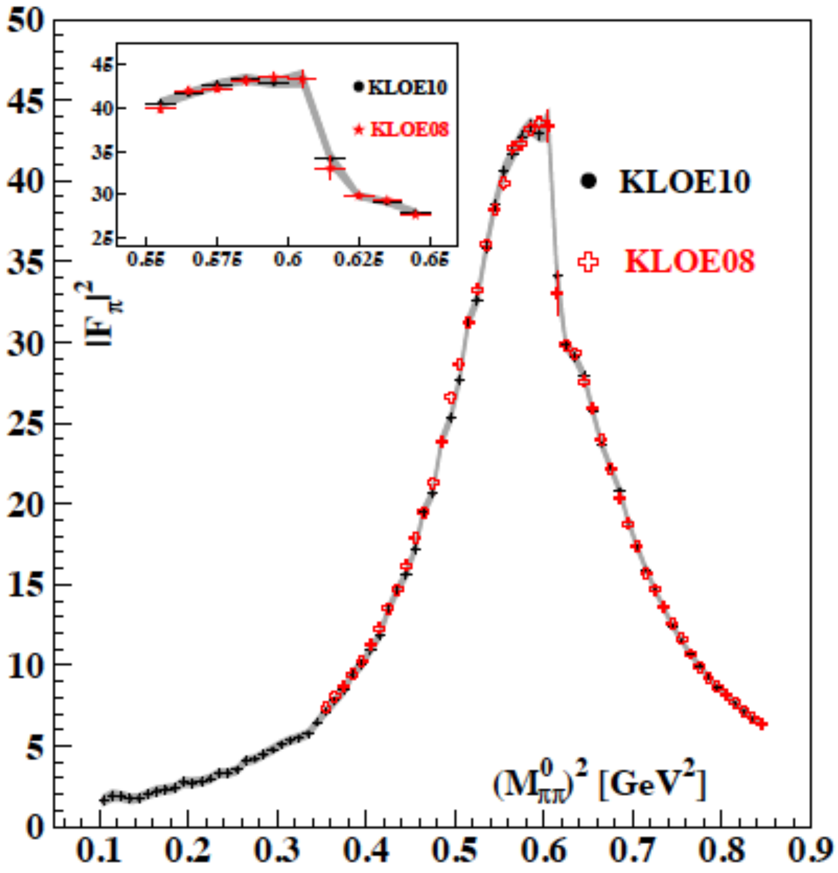
theoretical fractional error on a_μ = 0.9 %

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

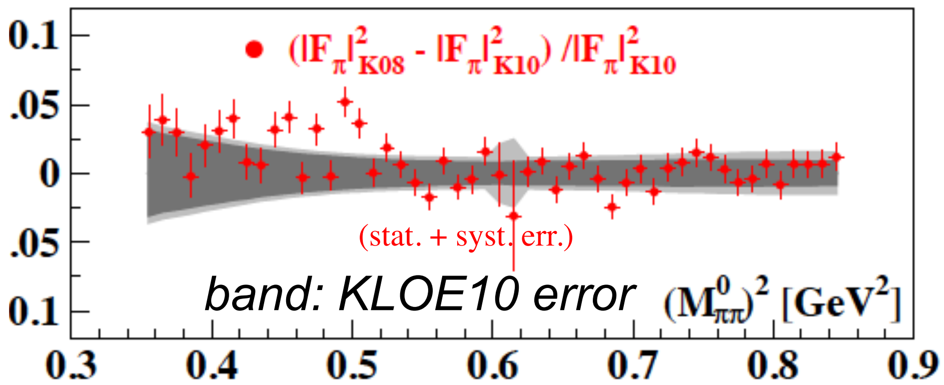
0.4% 1.0% 0.9%

Comparison of results: KLOE10 vs KLOE08

KLOE08 result compared to KLOE10:



Fractional difference:



Excellent agreement with KLOE08, expecially above 0.5 GeV^2

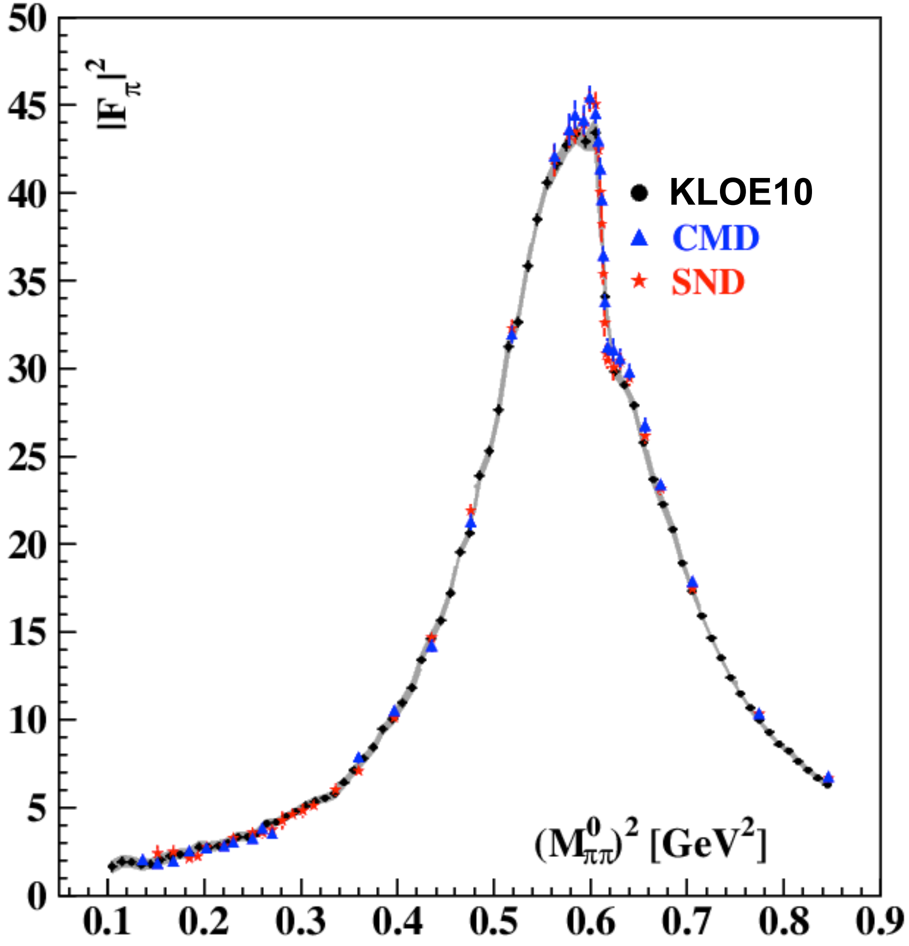
Combination of KLOE08 and KLOE10:

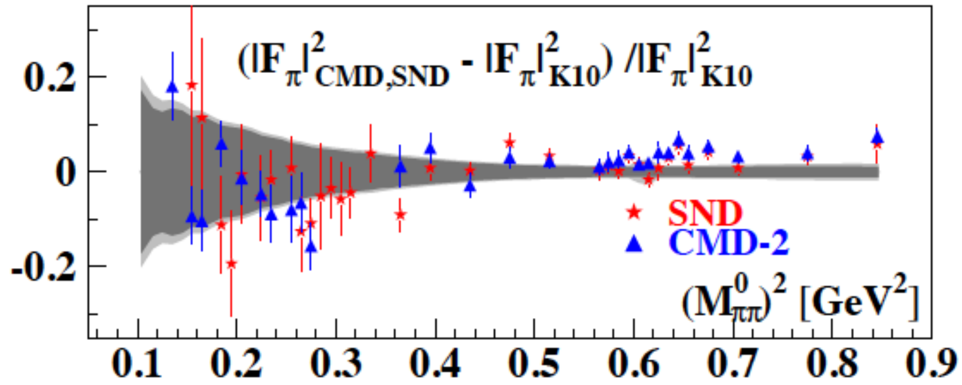
$a_\mu^{\pi\pi}$**(0.1-0.95 GeV^2) = (488.6±6.0) · 10^{-10}**

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



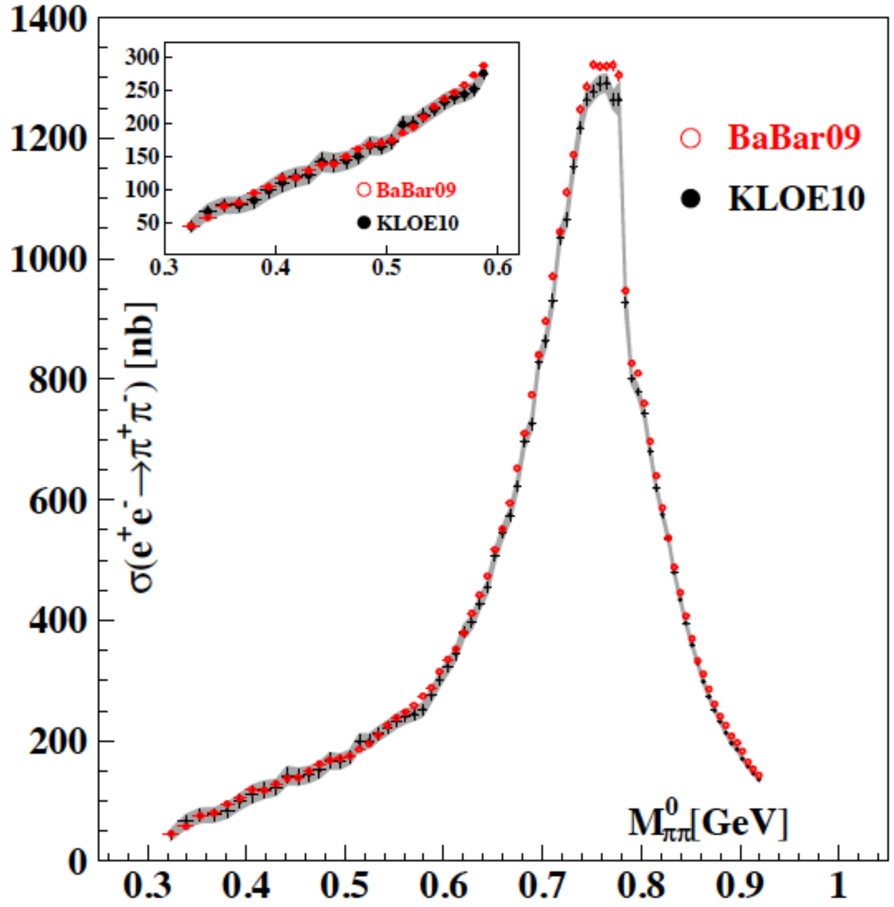


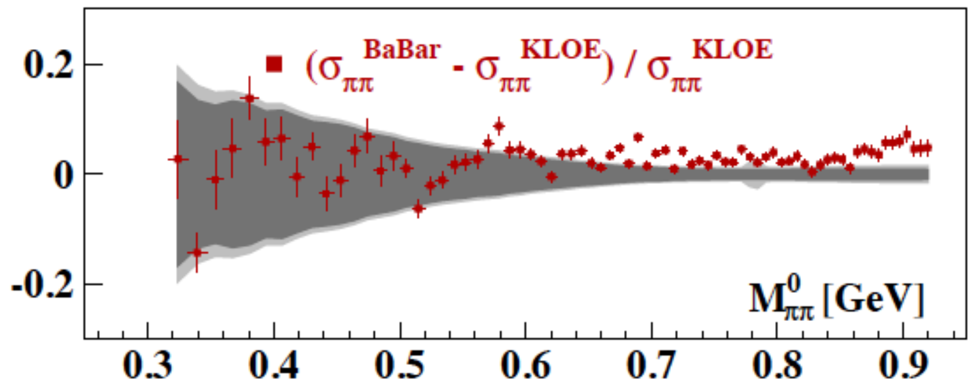
band: KLOE10 error

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





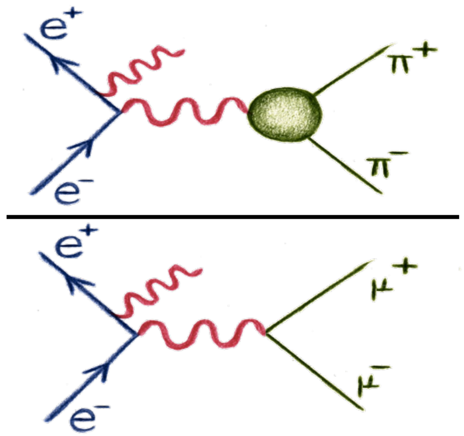
band: KLOE10 error

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).

$$\boxed{|F_\pi(s')|^2 \approx \underbrace{\frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3}}_{\substack{\text{kinematical factor}\\ (s_{mm}^{Born}\,/\,s_{pp}^{Born})}} \underbrace{\frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}}_{\substack{\text{meas.}\\ \text{quantities}}}}$$



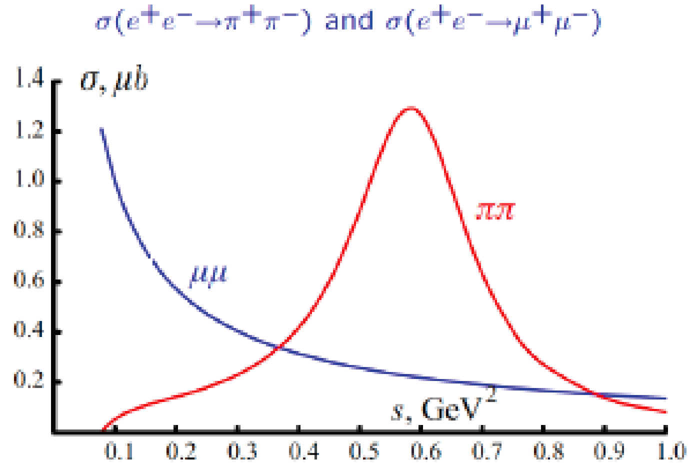
Many radiative corrections drop out:

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

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

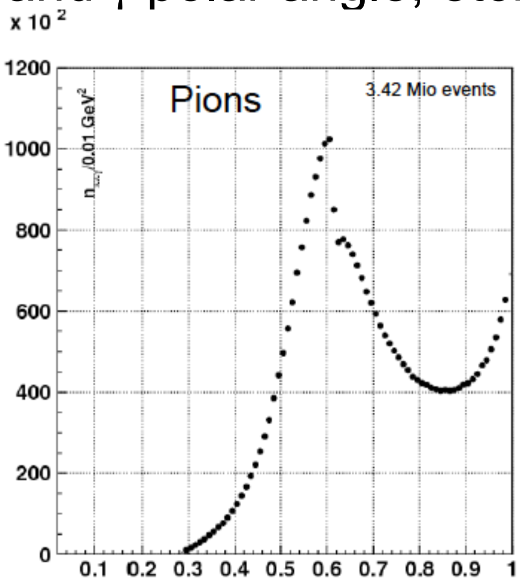
- *muons:* $M_{Trk} < 115$ *MeV*
- *pions :* $M_{Trk} > 130$ *MeV*

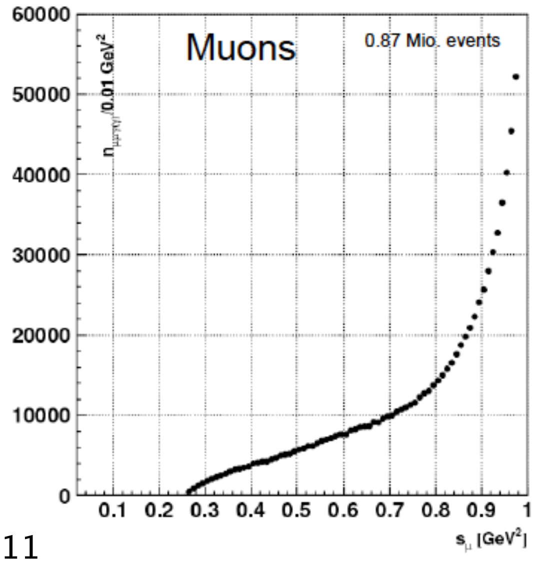
Very important control of π/μ *separation in the* ρ *region!* $(\sigma_{\pi\pi} >> \sigma_{\mu\mu})$

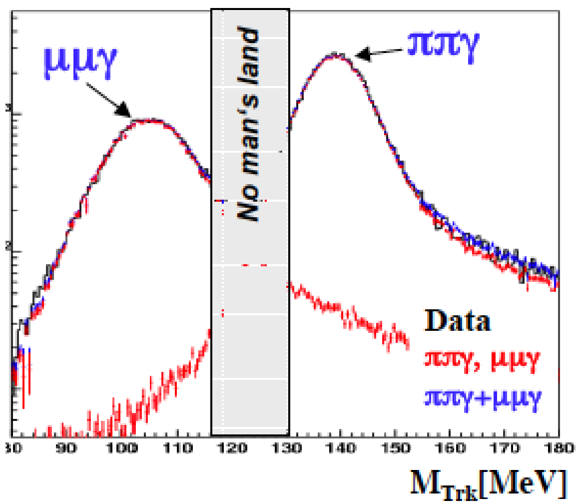


KLOE11: analysis of $\pi\pi\gamma/\mu\mu\gamma$

- 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...





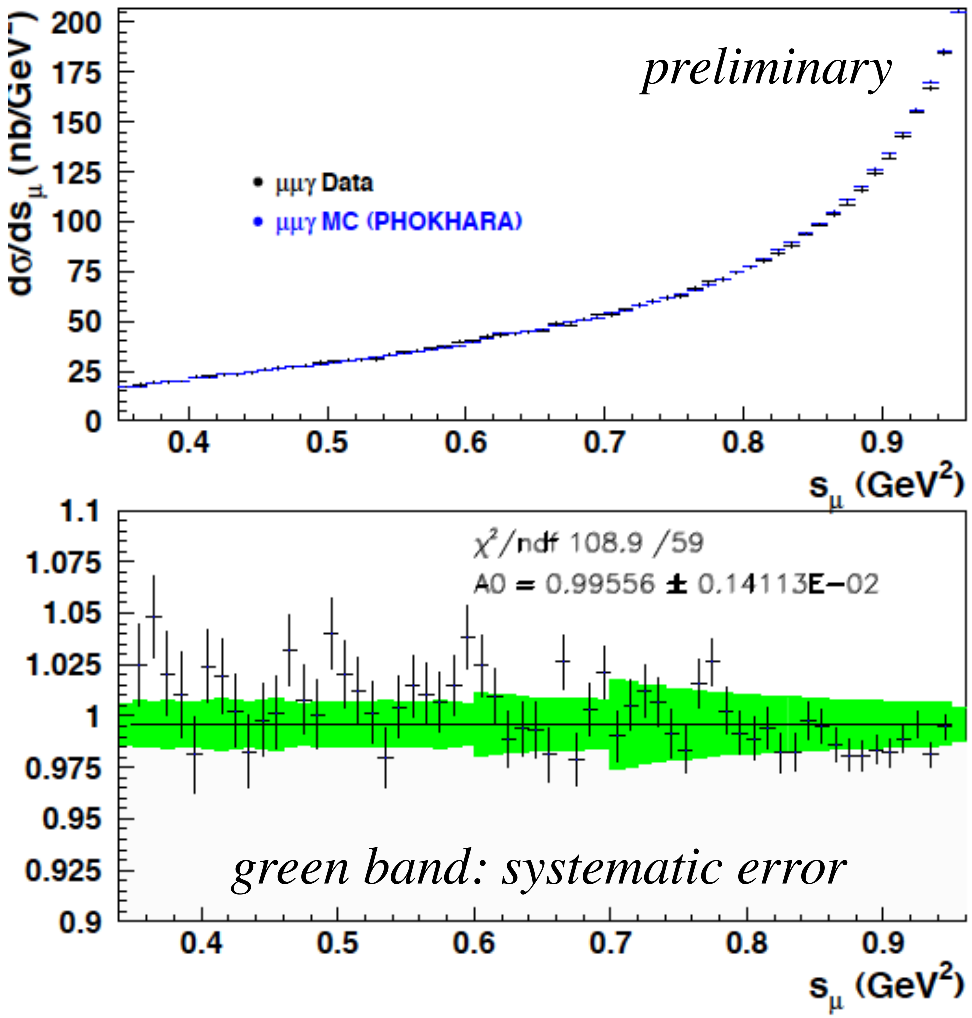


$\mu\mu\gamma$ cross section: data/MC comparison

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

$$\frac{d\sigma^{DATA}_{\mu\mu\gamma(\gamma)}}{d\sigma^{MC}_{\mu\mu\gamma(\gamma)}} = 0.996 \pm 0.001_{stat} \pm 0.011_{syst}$$

The syst error has been averaged on s_μ



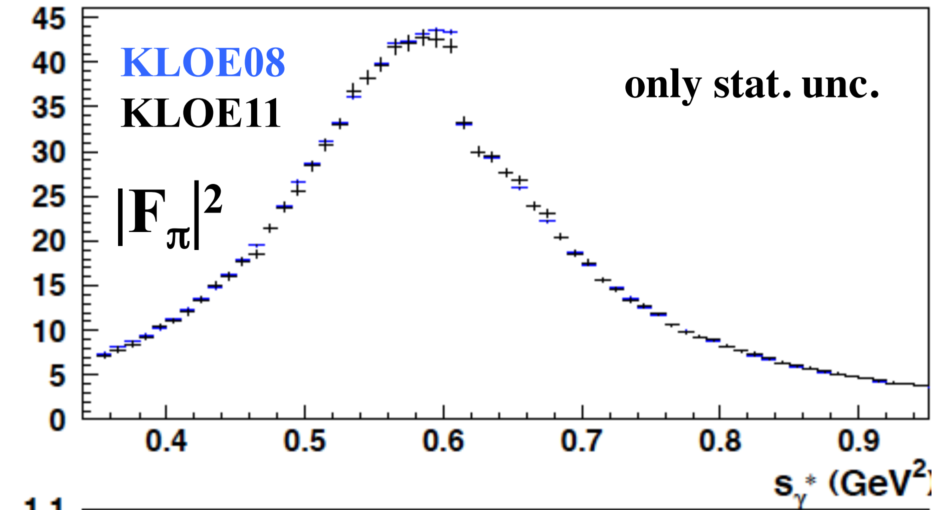
Good agreement of $\sigma_{\mu\mu\gamma}$ from data with PHOKHARA (NLO QED) MC

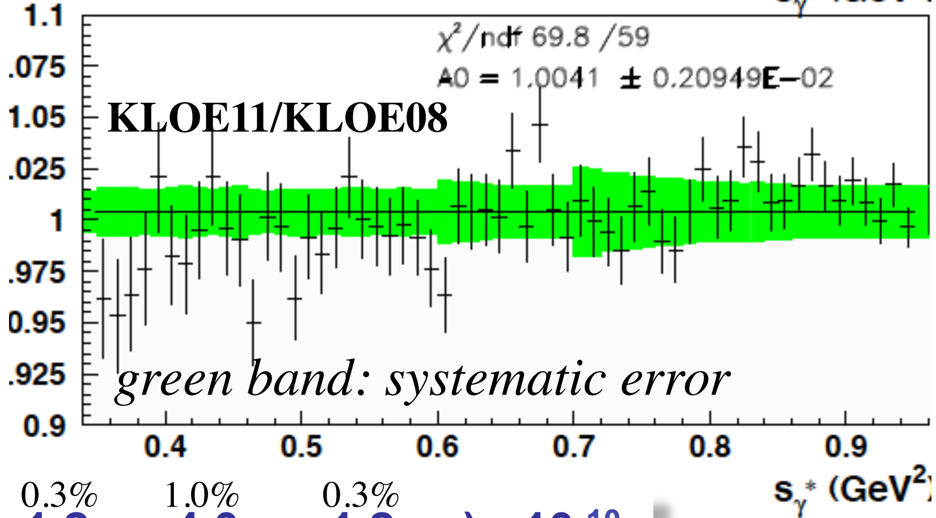
Consistency check of Radiator function, Luminosity, etc…

KLOE11 result on $|F_\pi|^2$ and comp. with KLOE08

Syst. errors (%)	KLOE08 $\Delta^{\pi\pi} a_\mu$ abs	KLOE11 $\Delta^{\pi\pi} a_\mu$ ratio
Reconstruction Filter	negligible	negligible
Background subtraction	0.3	$0.8\ (0.3_{\pi\pi\gamma} \oplus 0.7_{\mu\mu\gamma})$
Trackmass	0.2	$0.4\ (0.2_{\pi\pi\gamma} \oplus 0.4_{\mu\mu\gamma})$
Particle ID	negligible	negligible
Tracking	0.3	$0.6\ (0.3_{\pi\pi\gamma} \oplus 0.5_{\mu\mu\gamma})$
Trigger	0.1	$0.1\ (0.1_{\pi\pi\gamma})$
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	0.2	negligible
Acceptance (θ_π)	negligible	negligible
Software Trigger (L3)	0.1	$0.1\ (0.1_{\pi\pi\gamma} \oplus 0.1_{\mu\mu\gamma})$
Luminosity	$0.3\ (0.1_{th} \oplus 0.3_{exp})$	-
$\sqrt{s}$ dep. of H	0.2	-
Total exp systematics	0.6	1.0
Vacuum Polarization	0.1	-
FSR treatment	0.3	0.3
Rad. function H	0.5	-
Total theory systematics	0.6	0.3
Total systematic error	0.9	1.1

preliminary





KLOE11 halves the theoretical error

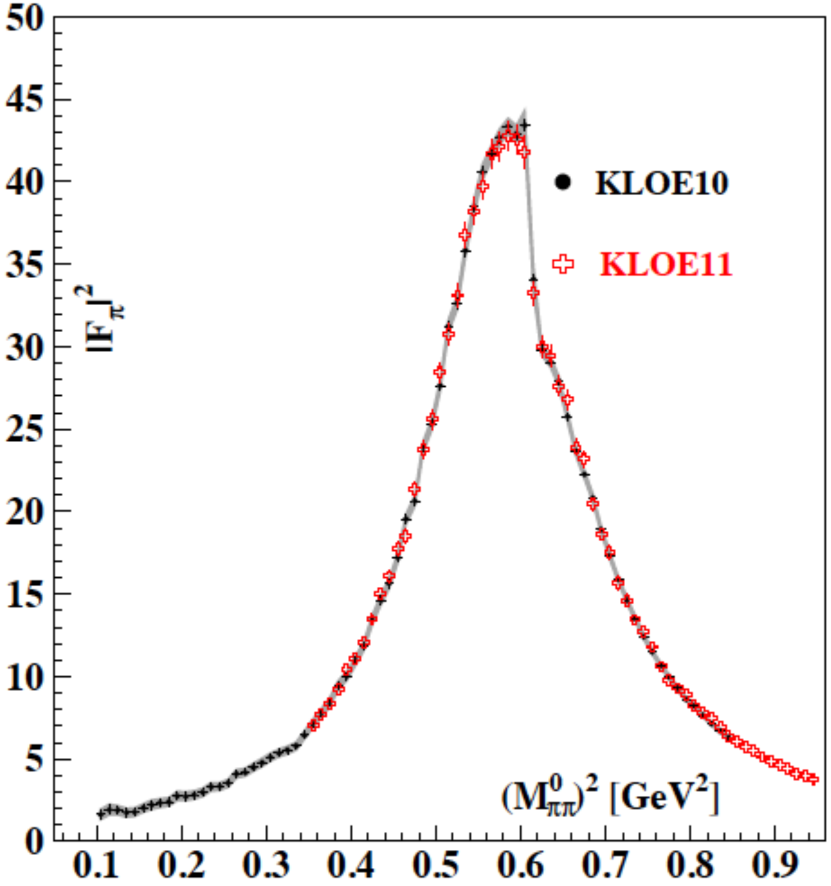
KLOE11: $a_\mu^{\pi\pi}(0.35\text{-}0.95\,\mathrm{GeV}^2) = (384.1 \pm \underset{}{\overset{0.3\%}{1.2}}_{stat} \pm \overset{1.0\%}{4.0}_{sys} \pm \overset{0.3\%}{1.2}_{theo}) \cdot 10^{-10}$

KLOE08: $a_\mu^{\pi\pi}(0.35\text{-}0.95\,\mathrm{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$

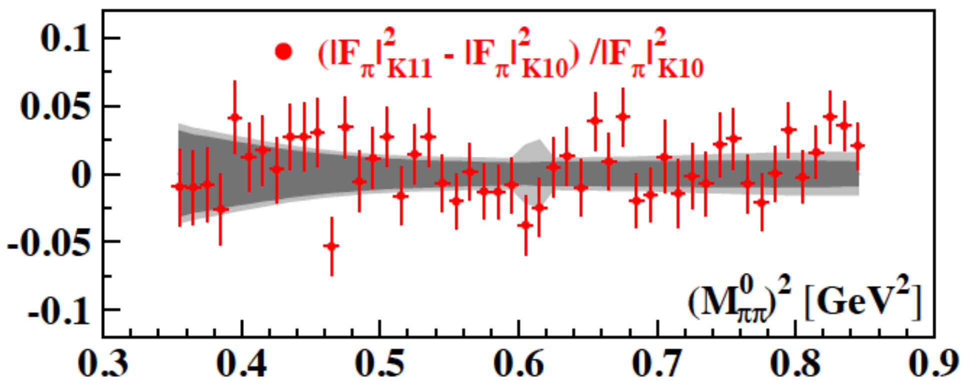
Comparison of results: KLOE11 vs KLOE10

KLOE11 result compared to KLOE10:

preliminary



Fractional difference:



band: KLOE10 error

Excellent agreement between the two measurements!

Comparison with other exp. in progress

KLOE11: $a_\mu^{\pi\pi}(0.35\text{-}0.85\,\mathrm{GeV}^2) = (376.4 \pm 1.2_{stat} \pm 4.1_{sys\ tot}) \cdot 10^{-10}$

KLOE10: $a_\mu^{\pi\pi}(0.35\text{-}0.85\,\mathrm{GeV}^2) = (376.6 \pm 0.9_{stat} \pm 3.3_{sys\ tot}) \cdot 10^{-10}$

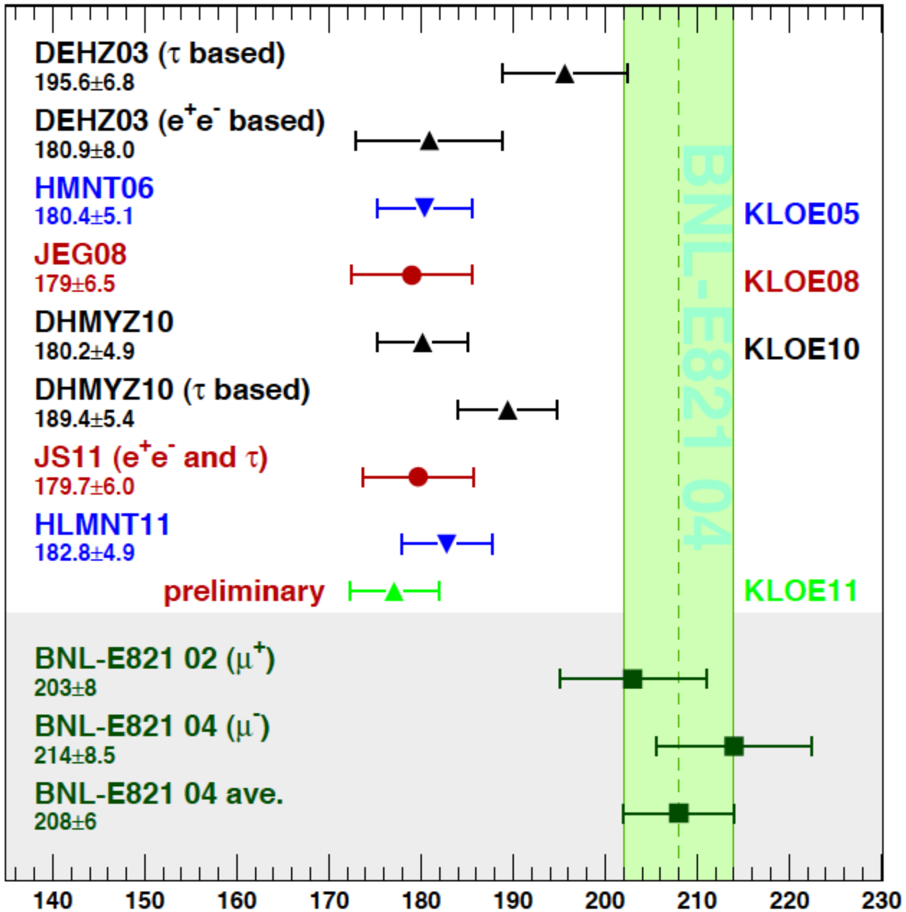
$a_\mu=(g_\mu-2)/2$:

Theoretical predictions compared to the BNL result (2009)

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

- Remaining differences on $\sigma_{\pi\pi}$ btw different experiments (mainly KLOE/BaBar) to be clarified [Δa_μ^{EXP-SM} =2.4÷3.7σ]

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



Preliminary KLOE11 in agreement with previous KLOE measurements and confirms the 3σ discrepancy!

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

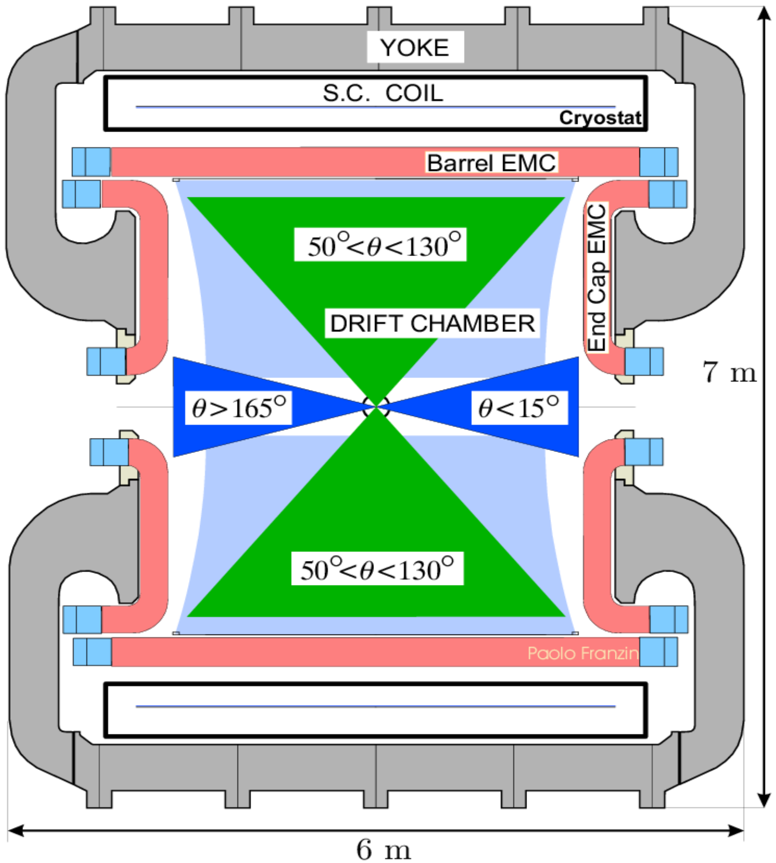
Conclusion

- 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 0.1-0.95 GeV^2 (70% of a_μ^{HLO}) with 1.2% total error
- A new (*preliminary*) measurement of $|F_\pi|^2$ from the $\pi\pi\gamma/\mu\mu\gamma$ ratio (based on 240 pb^{-1}) with 1.1% systematic error has been presented
- 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
- Preliminary results show good agreement for $\mu\mu\gamma$ cross section with NLO QED calculation (PHOKHARA MC) and for $|F_\pi|^2$ with previous KLOE measurements
- $a_\mu^{\pi\pi}$ from $\pi\pi\gamma/\mu\mu\gamma$ ratio is in agreement with previous KLOE measurements and confirms the 3σ discrepancy

Outlook

- We plan to publish the new measurement from the $\pi\pi\gamma/\mu\mu\gamma$ soon
- Still more than 1.5 fb^{-1} of KLOE data on tape. This would represent a ~4 improvement in statistics. We plan to analyse these data to improve $\sigma_{\pi\pi}$ (and maybe other channels) measurement.

Stay tuned!

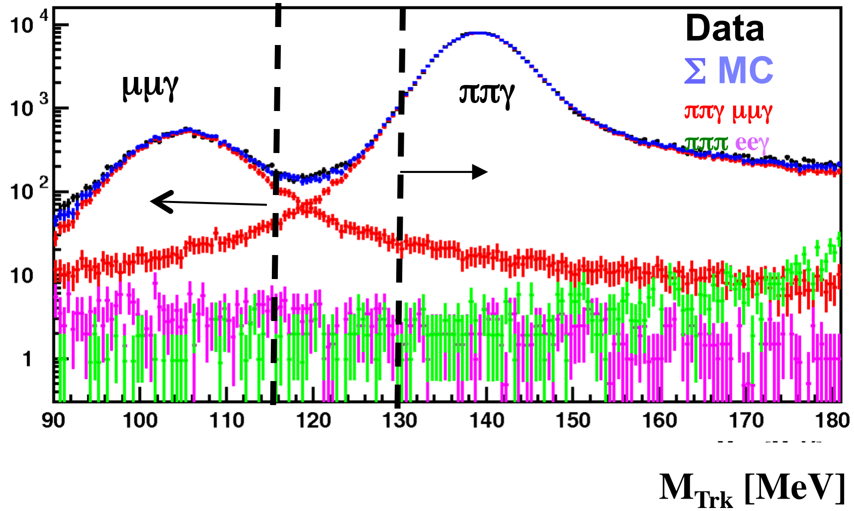


SPARE SLIDES

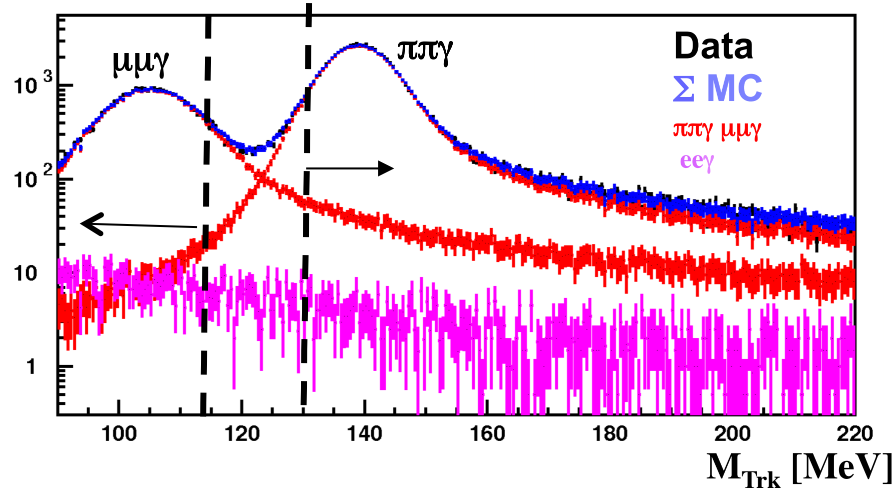
Background:

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

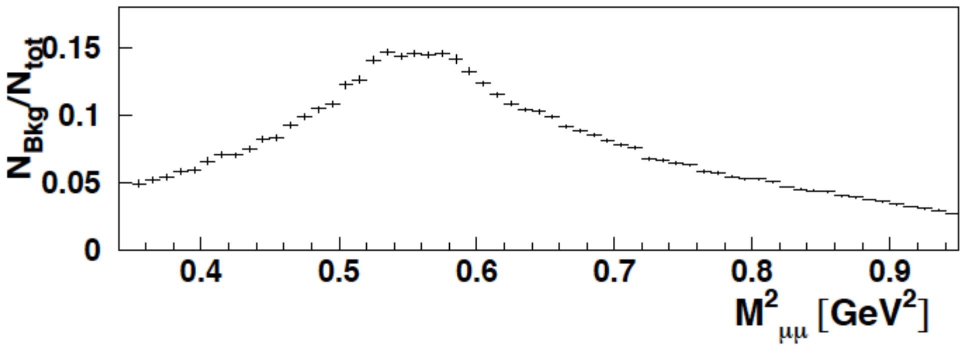
$0.60 < M_{\pi\pi}^2 < 0.62$ GeV^2, $\chi^2/ndof = 158/180$



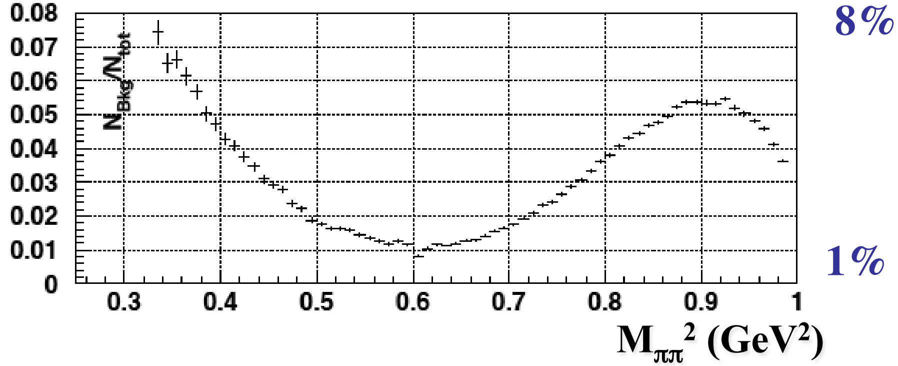
$0.84 < M_{\pi\pi}^2 < 0.86$ GeV^2 $\chi^2/ndof = 179/258$



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



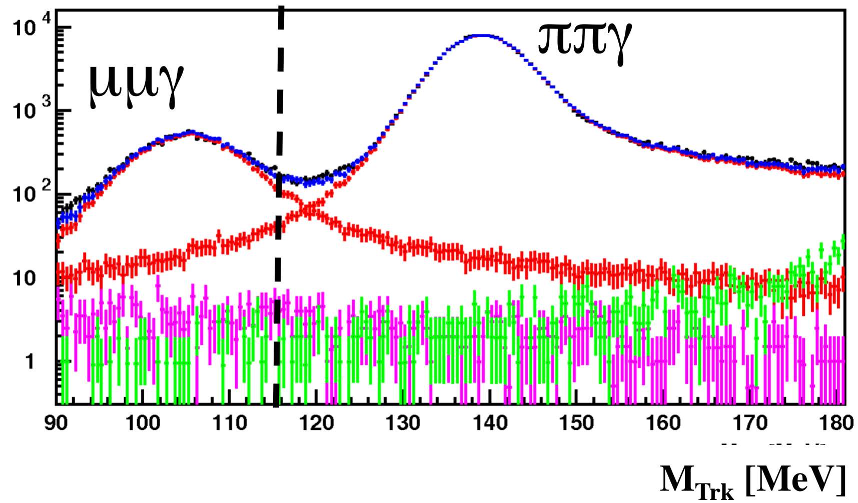
Tot % bckg to $\pi\pi\gamma$

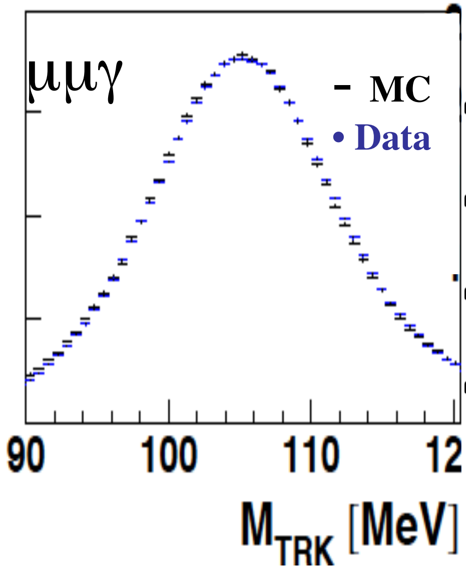


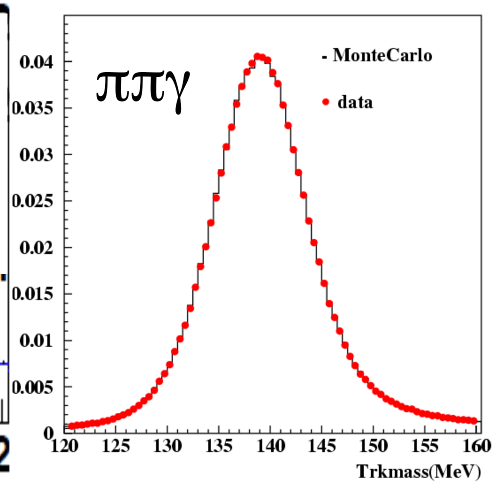
- Systematic error on $\mu\mu\gamma$ due to background~1% in the ρ peak

π/μ separation: control of $\pi\pi\gamma$ M_{TRK} tail

- A careful work has been done to achieve a control of ~1% in the muon selection, especially ~0.6 GeV^2 (ρ peak) where $\pi/\mu \sim 10$.
- $\pi\pi\gamma$ % background to $\mu\mu\gamma$ signal (M_{TRK}<115 MeV) is ~10% ➔ $\pi\pi\gamma$ M_{TRK} tail in the $\mu\mu\gamma$ region must be well under control.
- $\pi\pi\gamma$ M_{TRK} tail tuned using $\phi \to \pi^+\pi^-\pi^0$ control sample.
- Excellent agreement on M_{TRK} ($\pi\pi\gamma$ and $\mu\mu\gamma$) distributions







π/μ separation: control of $\pi\pi\gamma$ M_{TRK} tail

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- $\pi\pi\gamma$ M_{TRK} tail tuned using $\phi \to \pi^+\pi^-\pi^0$ control sample.
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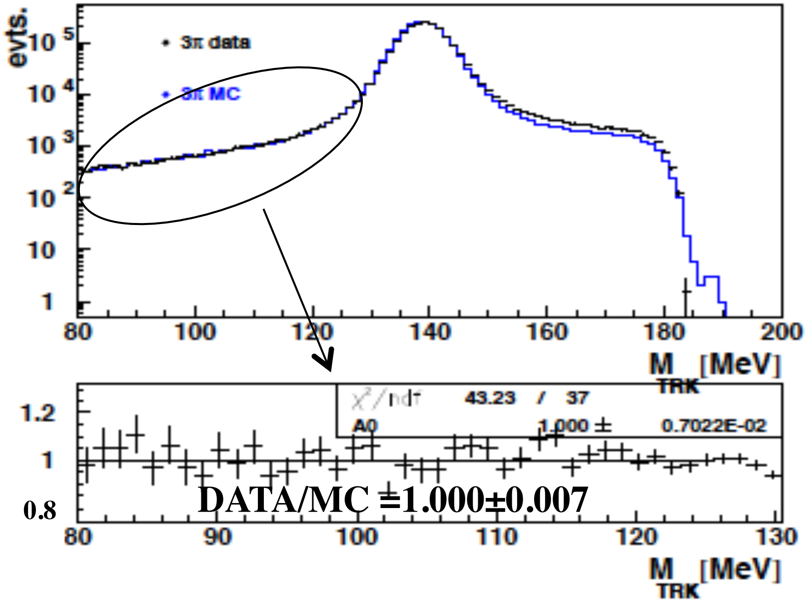
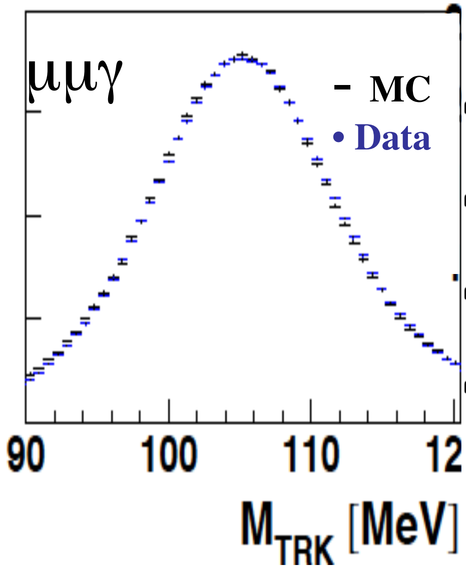
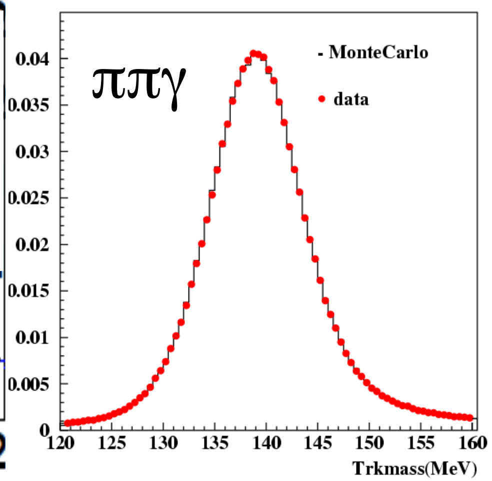
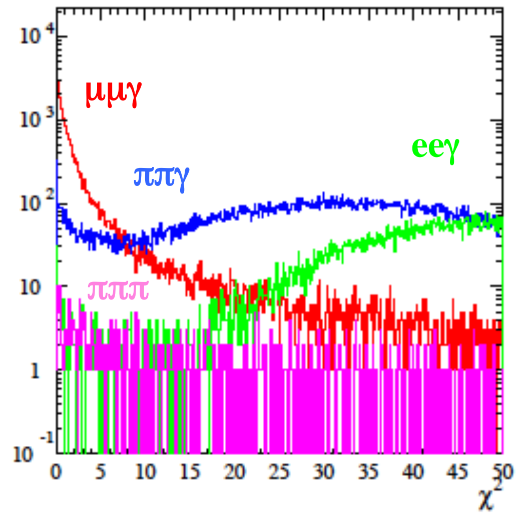




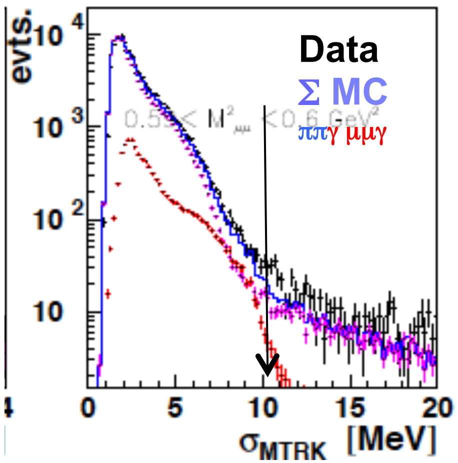


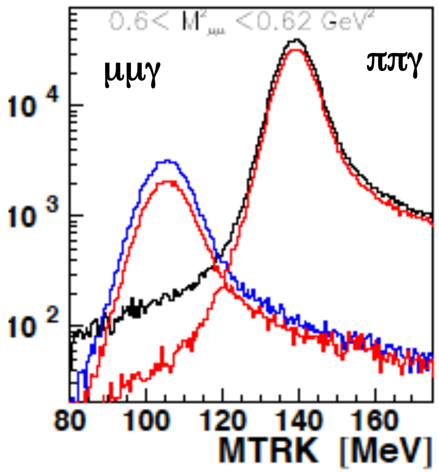
Cross check of π/μ separation

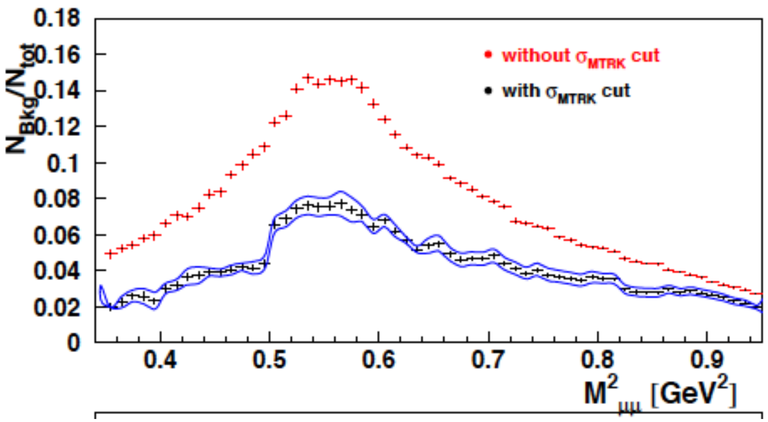
- The π/μ separation has been crosschecked with two different (and independent) methods:



- 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}





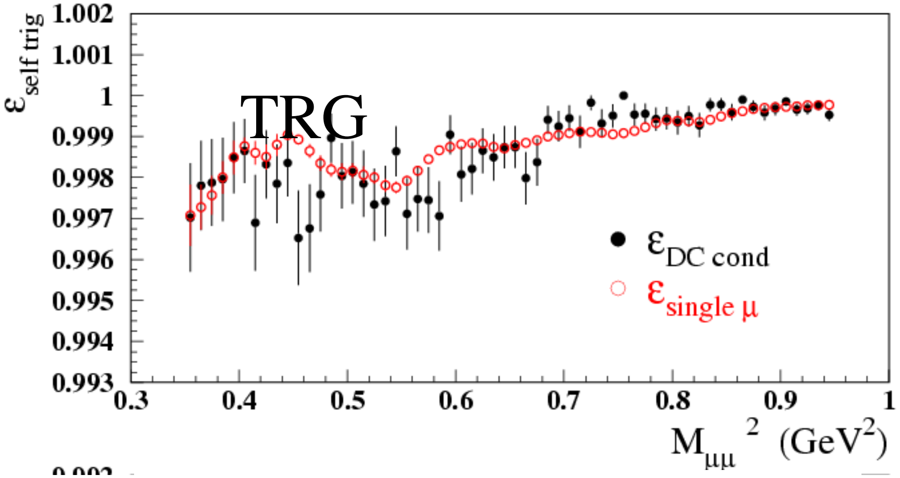


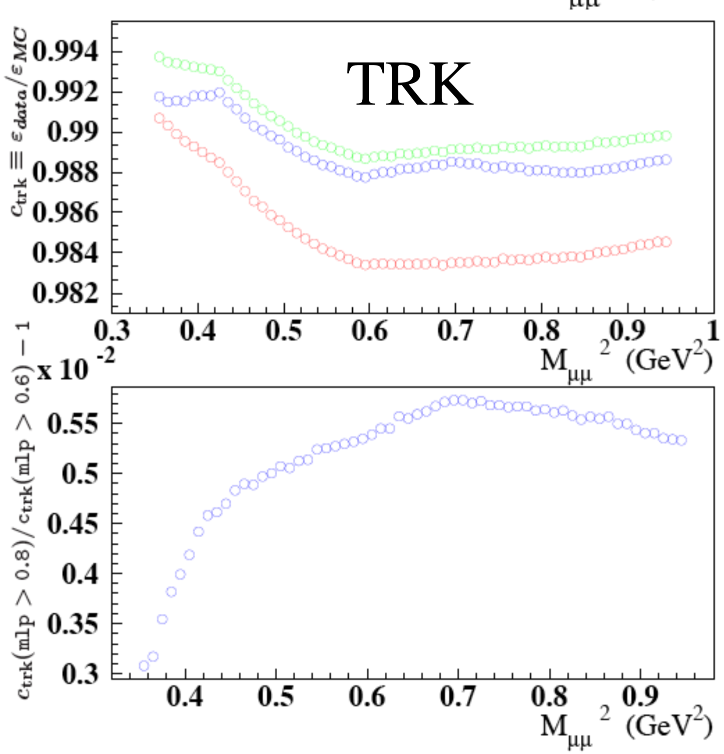
- π/μ separation obtained with these methods well in agreement with the standard one.

Efficiencies for $\mu\mu\gamma$

- The efficiencies of $\mu\mu\gamma$ (and $\pi\pi\gamma$) 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 $\pi\pi\gamma$, where the 3π sample was used to get the data/MC corrections, for $\mu\mu\gamma$ there is no a direct control sample and we had used mmg itslef with lose selection criteria.

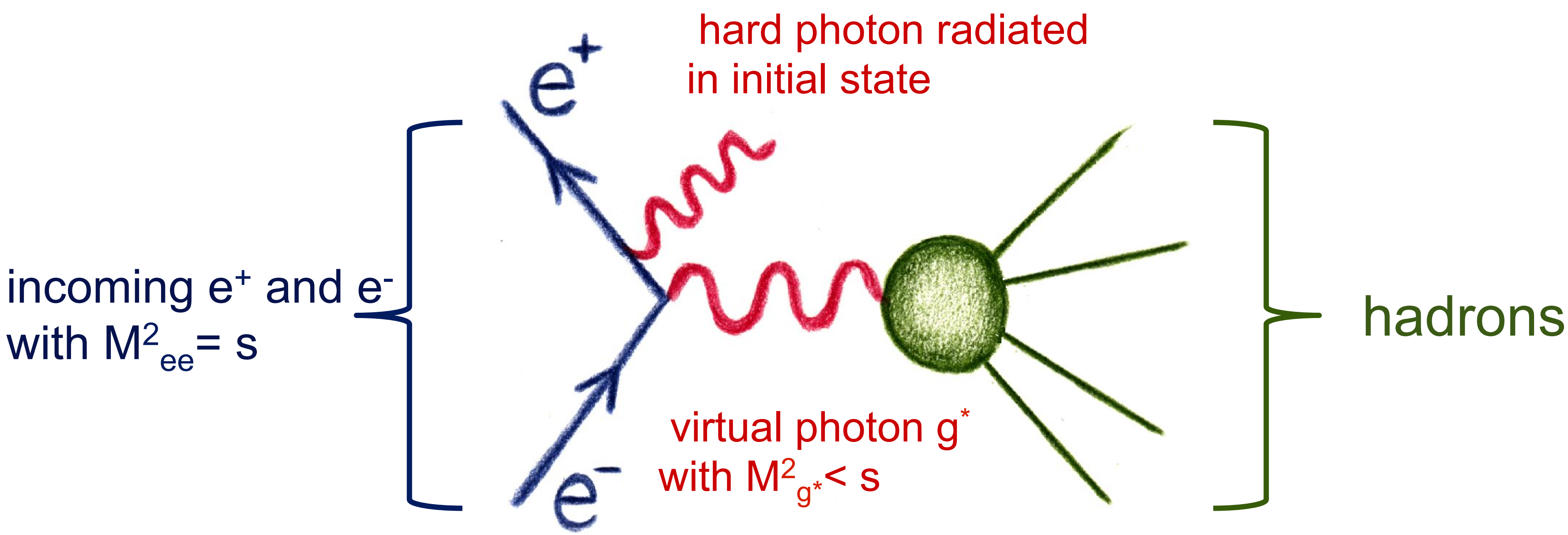
- All the efficiencies has been found to be above 96% with ~1% data/MC correction as maximum.





ISR: Initial State Radiation

Particle factories (DAFNE, PEP-II, KEK-B) can measure hadronic cross sections as a function of the hadronic c.m. energy using initial state radiation (**radiative return** to energies below the collider energy $\sqrt{s}$).



The emission of a hard g in the bremsstrahlung process in the initial state reduces the energy available to produce the hadronic system in the e^+e^- collision.

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

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

3)
$$|\mathrm{F}_\pi|^2 = \frac{3s}{\pi\alpha^2\beta^3_\pi}\sigma_{\pi\pi}(\mathrm{s})$$

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

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

Radiative Corrections

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

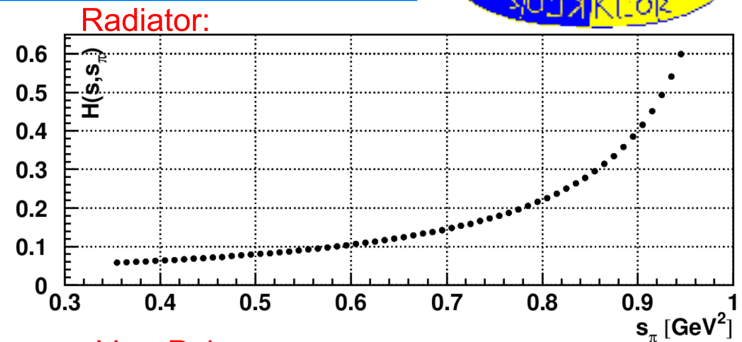
- **ISR-Process calculated at NLO-level**

PHOKHARA generator

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

Precision: 0.5%

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

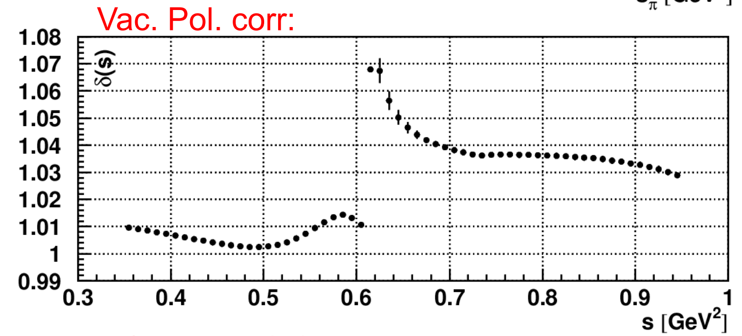


Radiative Corrections:

i) Bare Cross Section

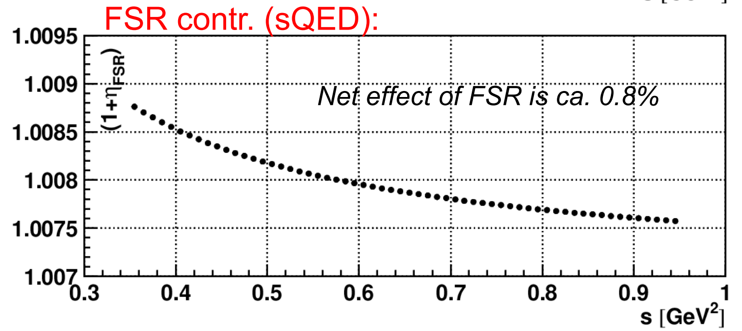
divide by Vacuum Polarisation d(*s*)=(a(*s*)/a(*0*))²

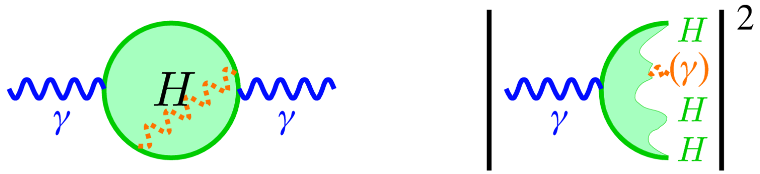
➔ from F. Jegerlehner



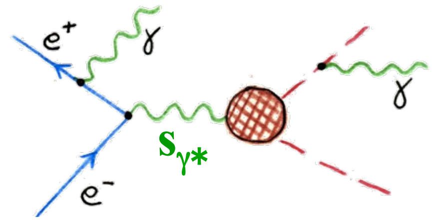
ii) FSR

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



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

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

SA Event Selection (KLOE08)

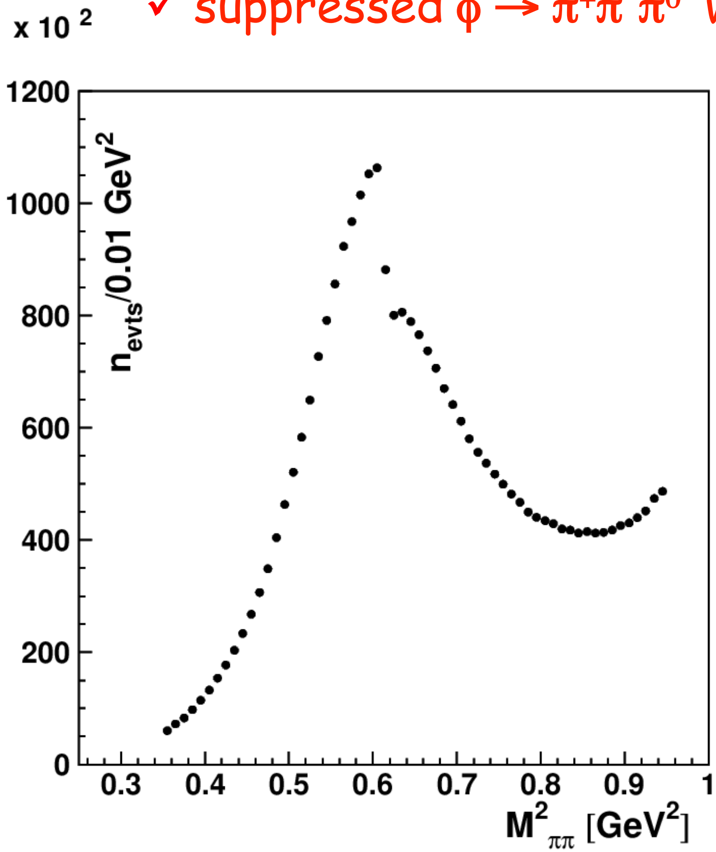
a) 2 tracks with $50^o < \theta_{track} < 130^o$

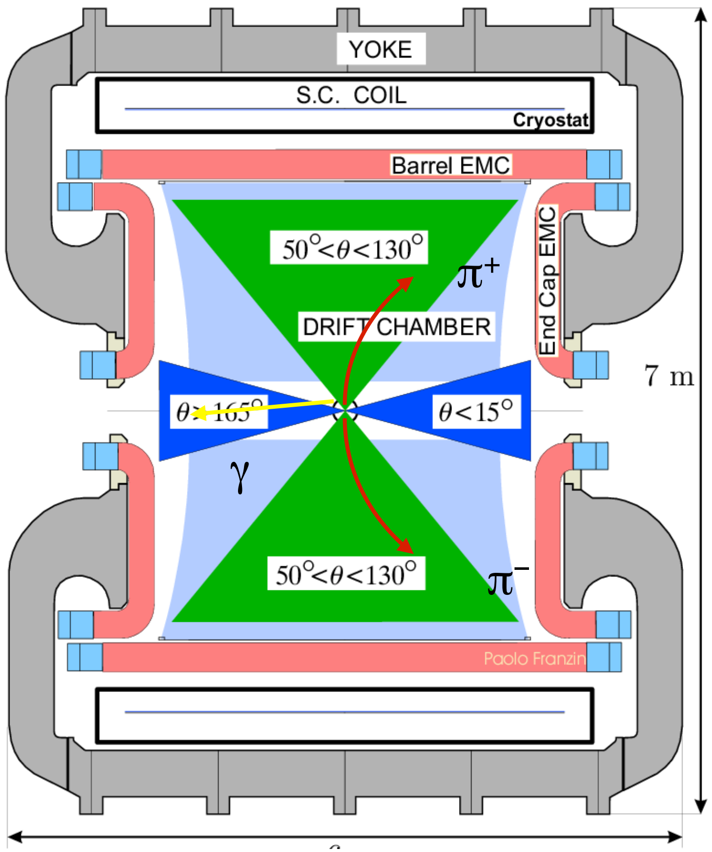
b) small angle (not detected) γ

($\theta_{\pi\pi} < 15^o$ or $> 165^o$)

- ✓ high statistics for ISR
- ✓ low relative FSR contribution
- ✓ suppressed $\phi \rightarrow \pi^+\pi^-\pi^0$ wrt the signal

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





statistics: **240pb^{-1} of 2002 data**

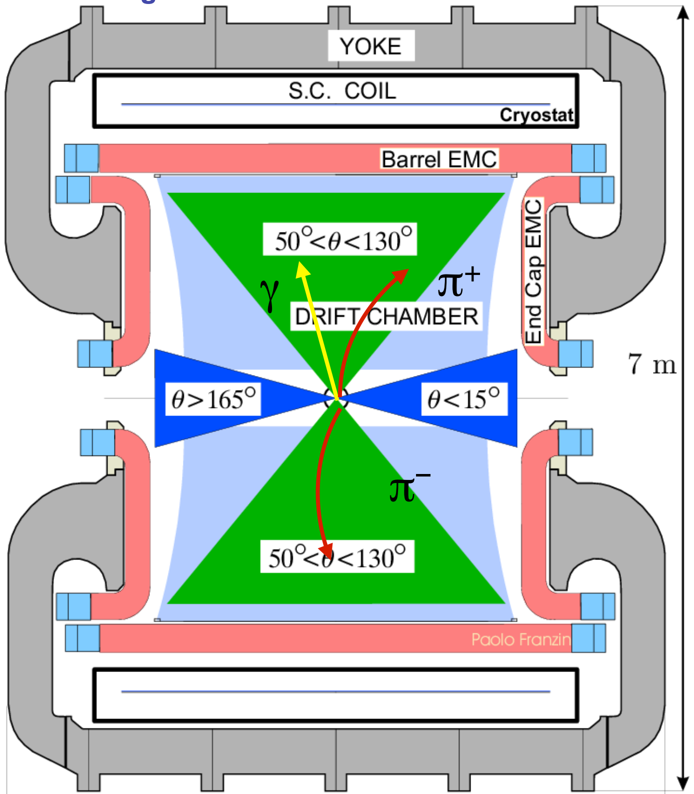
3.1 Mill. Events between 0.35 and 0.95 GeV^2

LA Event Selection (KLOE10)

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

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

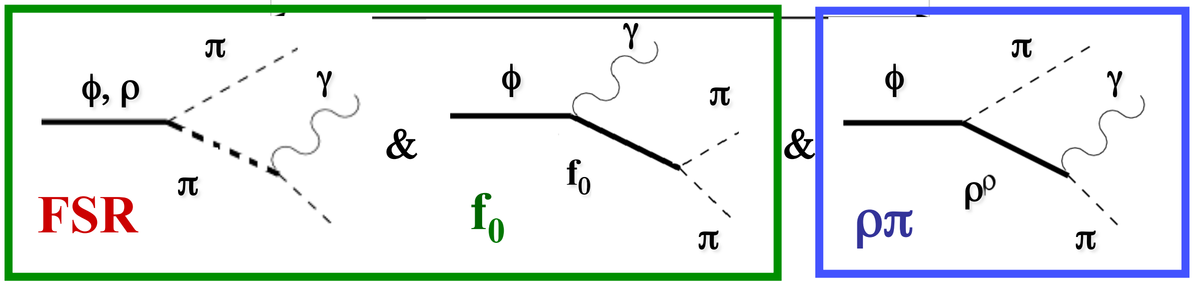
At least 1 photon with $50^o < \theta_g < 130^o$ and E_g > 20 MeV → photon detected



- ✓ 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 ($\phi \to f_0\,\gamma \to \pi\pi\,\gamma$)

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)

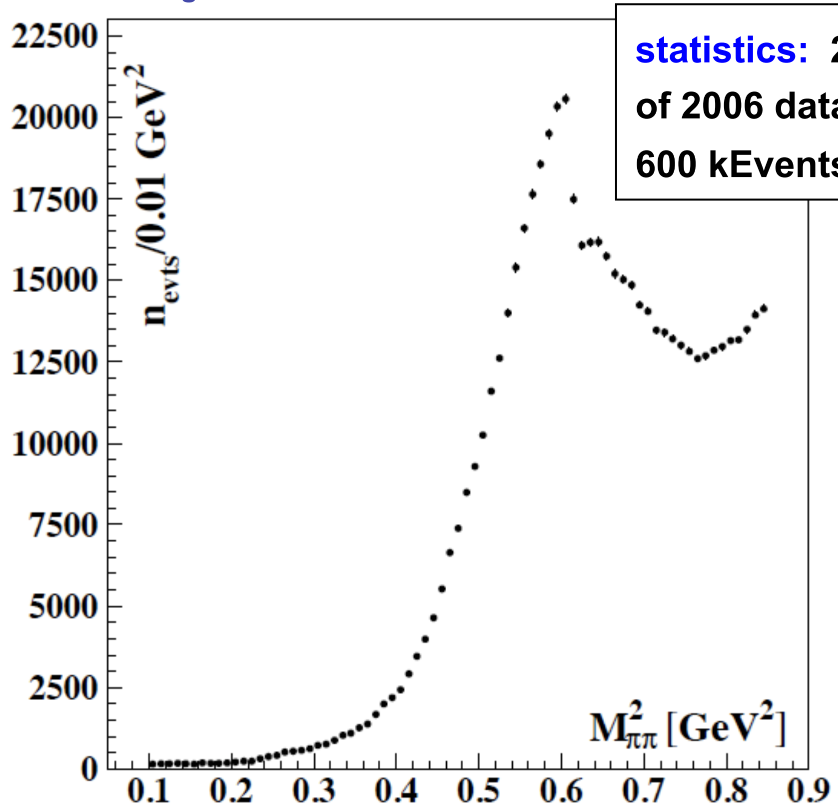
2 pion tracks at large angles
$50^o < \theta_p < 130^o$

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**

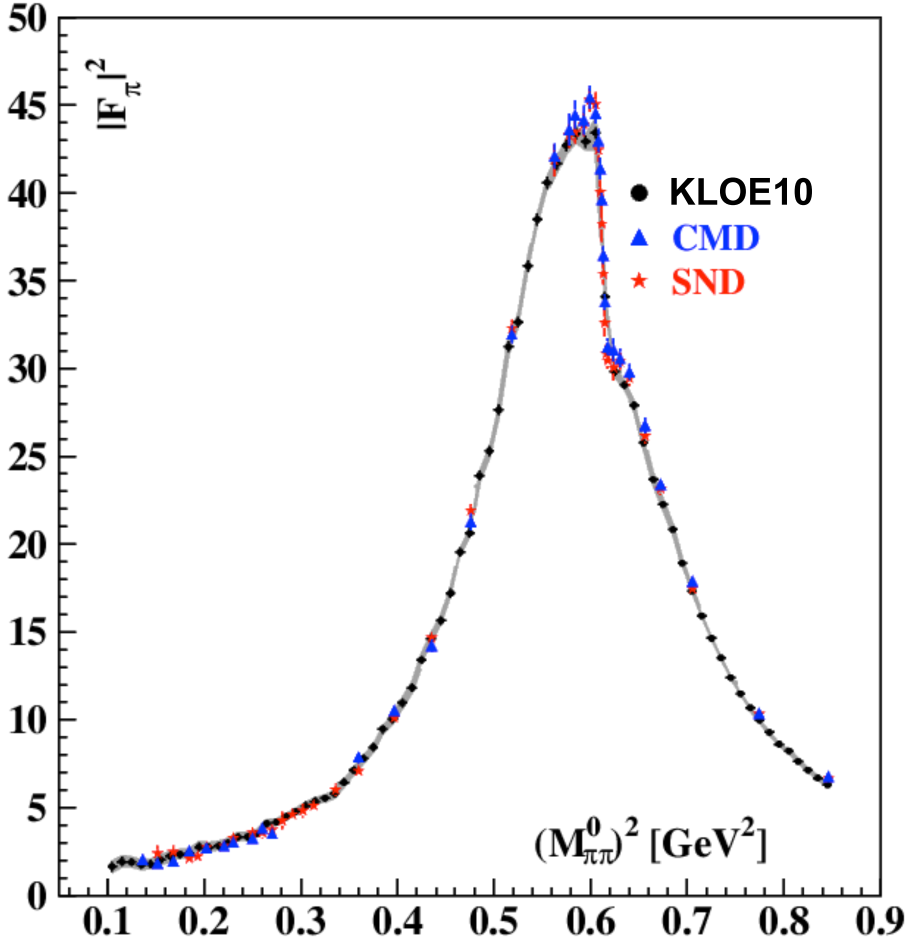


statistics: **233pb**$^{-1}$
of 2006 data
600 kEvents

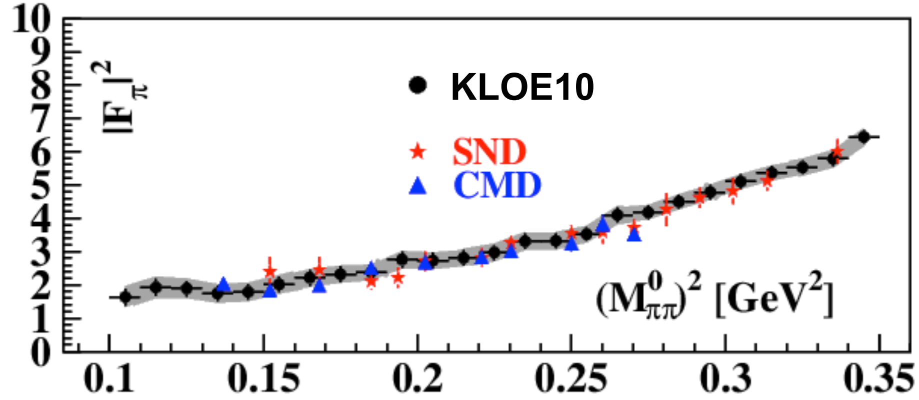
Use data sample taken at **$\sqrt{s} \cong 1000$ MeV**,
20 MeV below the f-peak

Comparison of results: KLOE10 vs CMD-2/SND

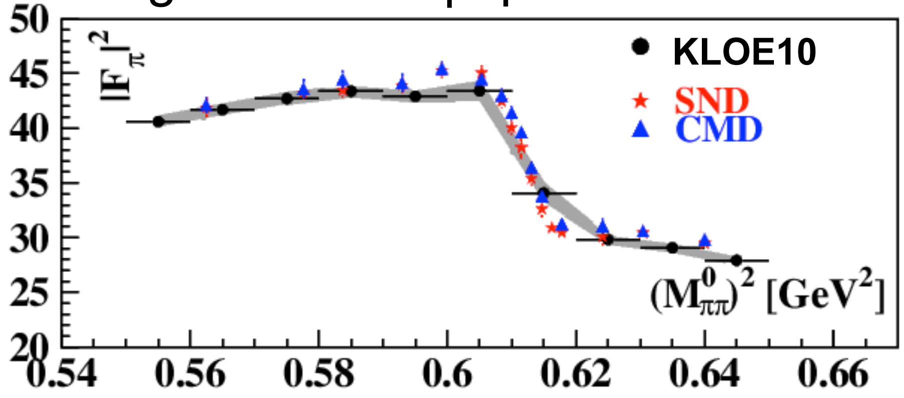
CMD and SND results compared to KLOE10:



Low $(\mathbf{M^0}_{\pi\pi})^2$: :



Region around ρ−peak:

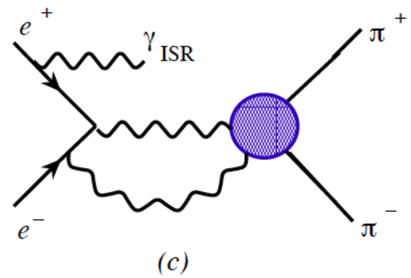


band: KLOE10 error

Final State Radiation (FSR)

The presence of not factorizable diagrams (like the 2 photon exchange) not present in Phokhara could lead to deviaton respect to:

$$\sigma^0_{\pi\pi} = \frac{4\pi\alpha^2}{3s'}(1+2m_\mu^2/s')\beta_\mu \frac{\left(d\sigma^{ISR+FSR}_{\pi\pi\gamma}(\theta^{\pi\pi}_\Sigma < 15^o)/ds'\right)}{\left(d\sigma^{ISR}_{\mu\mu\gamma}(\theta^{\mu\mu}_\Sigma < 15^o)/ds'\right)} \cdot Corr(\theta^{I+FSR}_\Sigma / \theta^{ISR}_\Sigma)$$



- For the $\pi\pi\gamma$ this has been tested *in our previous publication and a validity within 0.2% was found (for pointlike pions)*
- For $\mu\mu\gamma$, we can assume the same 0.2% as conservative estimate of this missing contribution in the passage from I+FSR to ISR (in our small angle region)

We take the combined error of 0.3% for the uncertainty on the rel. FSR contribution

List of systematic errors

SA

<table>
<tr><th></th><th>$\sigma_{\mu\mu\gamma}$</th><th>$\sigma_{\pi\pi\gamma}$ (Ref. [4])</th><th>$\sigma_{\pi\pi}^{bare}$ ratio</th><th>$|F_\pi|^2$ ratio</th></tr>
<tr><td>L3</td><td colspan="4">0.1 %</td></tr>
<tr><td>FILFO</td><td colspan="4">negligible</td></tr>
<tr><td>Bckg subtr.</td><td>M^2 dep. (Tab. 2)</td><td>M^2 dep. (Tab. 3)</td><td colspan="2">M^2 dep. (Tab. 4)</td></tr>
<tr><td>$M_{\rm TRK}$</td><td>0.4 %</td><td>0.2%</td><td colspan="2">0.4 %</td></tr>
<tr><td>PID</td><td colspan="4">negligible</td></tr>
<tr><td>Tracking</td><td>M^2 dep. (Tab. 8)</td><td>0.3%</td><td colspan="2">Tab. 9</td></tr>
<tr><td>Trigger</td><td>negligible</td><td colspan="3">0.1%</td></tr>
<tr><td>Unfolding</td><td>negligible</td><td colspan="3">M^2 dep. (Tab. 3 of [4])</td></tr>
<tr><td>Acceptance</td><td>M^2 dep. (Tab. 10)</td><td>M^2 dep. (Tab. 2 of [4])</td><td colspan="2">M^2 dep. (Tab. 11)</td></tr>
<tr><td>Luminosity</td><td colspan="2">0.3%</td><td colspan="2">-</td></tr>
<tr><td>FSR</td><td colspan="2">negligible</td><td>0.3%</td><td>0.3%</td></tr>
<tr><td>Rad. H</td><td colspan="4">-</td></tr>
<tr><td>$\sqrt{s}$ dep. of H</td><td colspan="4">-</td></tr>
<tr><td>Vac. Pol.</td><td colspan="3">-</td><td>0.1% ([25])</td></tr>
</table>

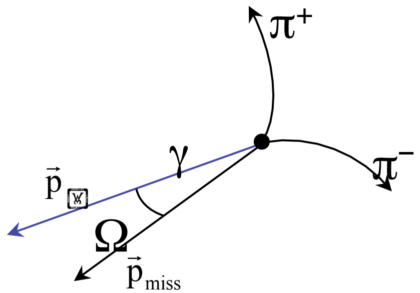
Table 12: List of systematic uncertainties for $\sigma_{\mu\mu\gamma}$, $\sigma_{\pi\pi\gamma}$ from SA analysis [4], $\sigma_{\pi\pi}$ (*bare*) and $|F_\pi|^2$ from the ratio.

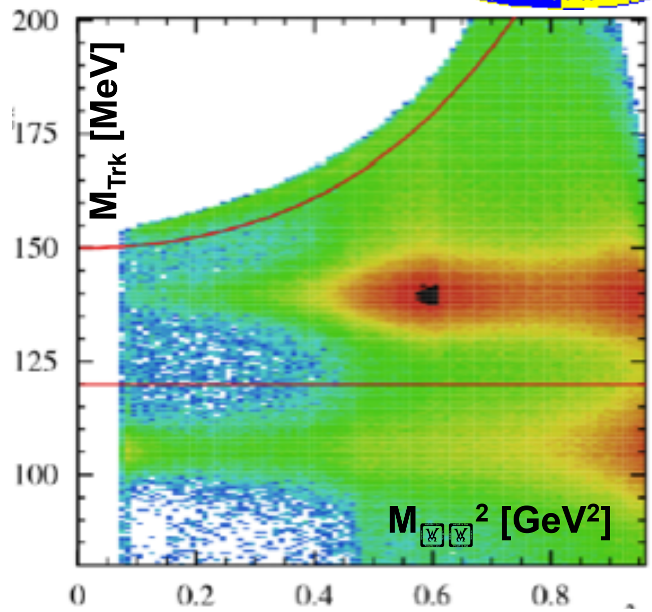
Event selection

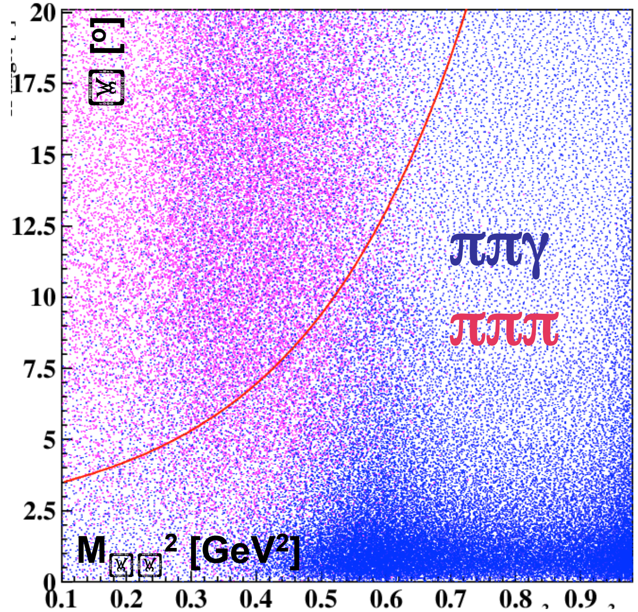
- Experimental challenge: Fight background from
  - $e^+e^- \rightarrow \mu^+\mu^- \gamma$,
  - $e^+e^- \rightarrow e^+e^- \gamma$
  - $\phi \rightarrow \pi^+\pi^-\pi^0$

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

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





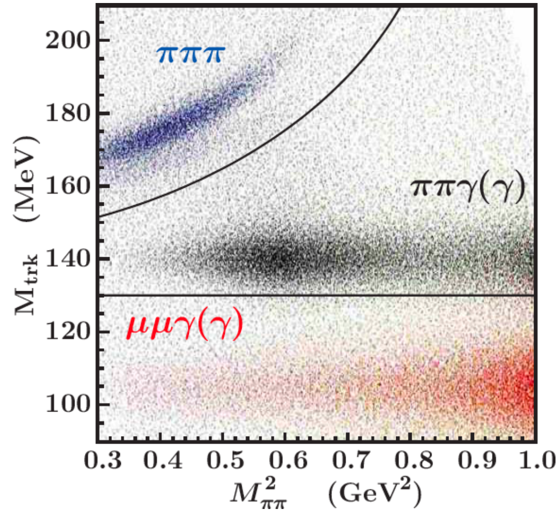


To further clean the samples from radiative Bhabha events, a particle ID estimator for each charged track based on Calorimeter Information and Time-of-Flight is used.

Event Selection

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

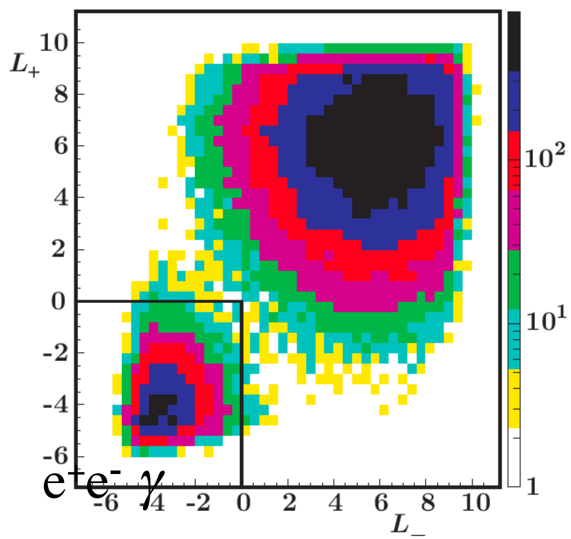
  removed using kinematical cuts in *trackmass* M_{Trk} - $M_{\pi\pi}^2$ plane



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

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

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

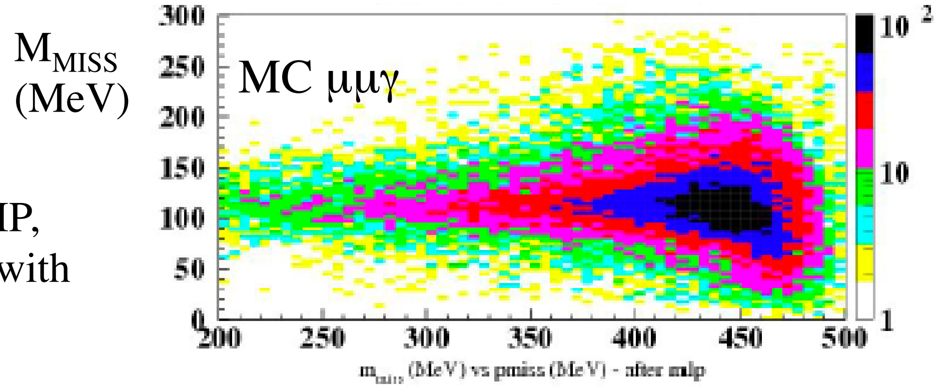


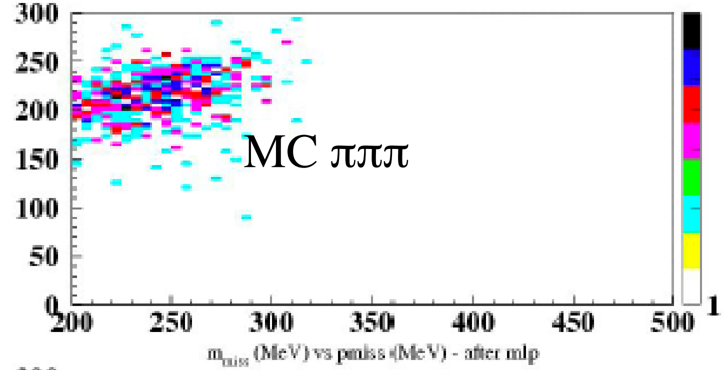
To further clean the samples from radiative Bhabha events, we use a particle ID estimator (PID) for each charged track based on Calorimeter Information and Time-of-Flight.

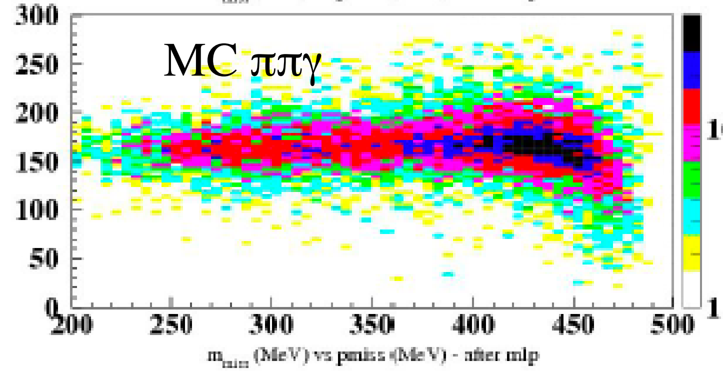
μ Tracking efficiency

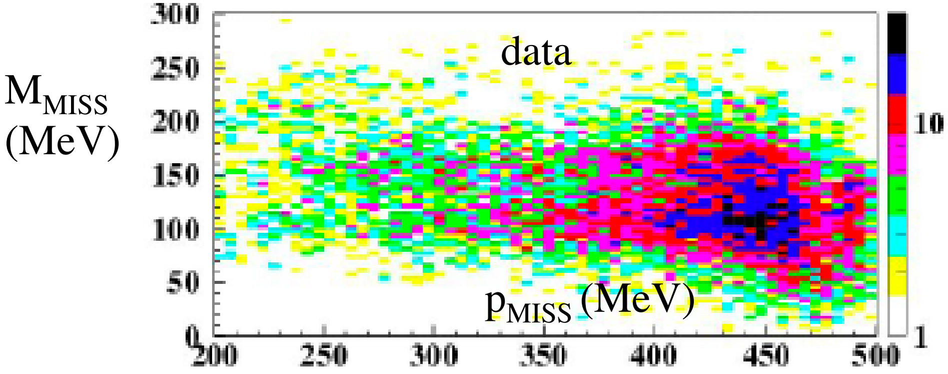
Since for muons we don't have an control sample (like 3π for pions), we have refiltered all 2002 data set (240 pb^{-1}) according to:

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









Luminosity:

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

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

$55° < \theta < 125°$

acollinearity $< 9°$

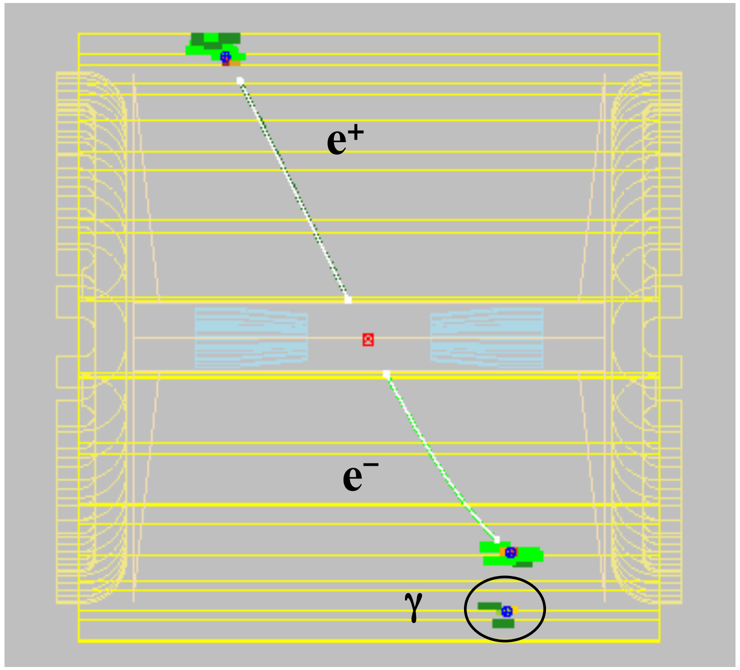
$p \geq 400$ MeV

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

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:

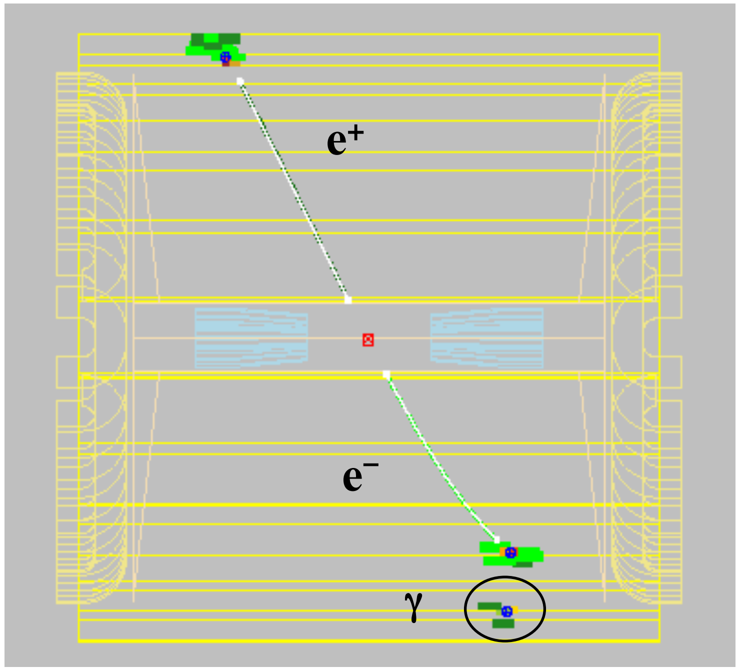
KLOE measures $\mathcal{L}$ with Bhabha scattering

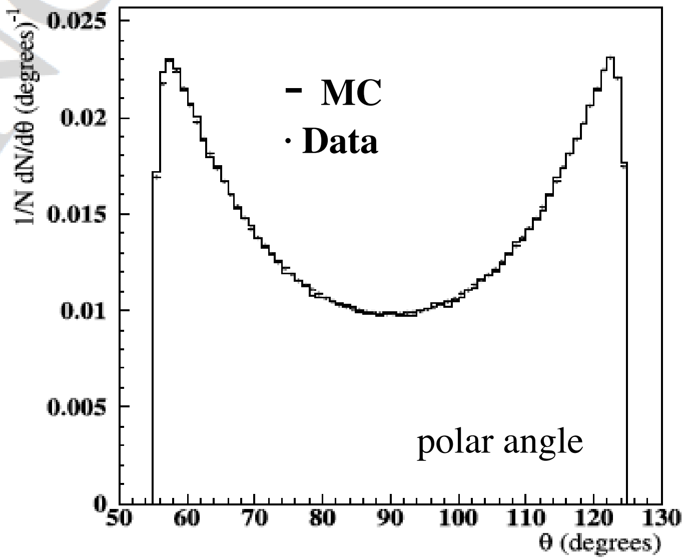
55° < θ < 125°

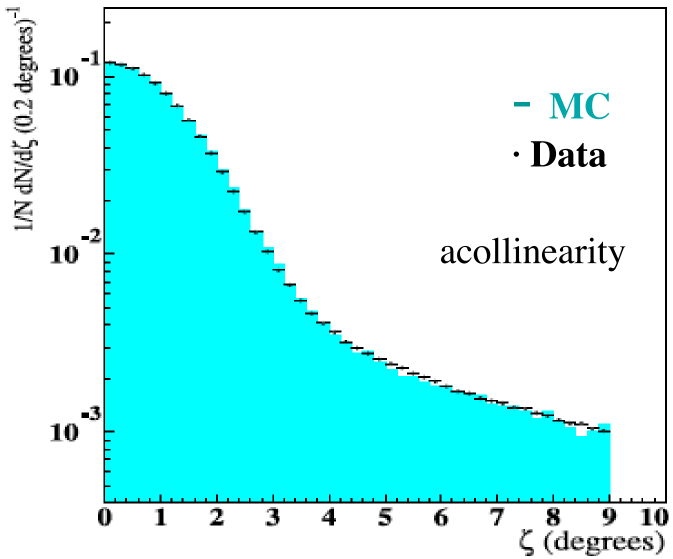
acollinearity < 9°

p ≥ 400 MeV

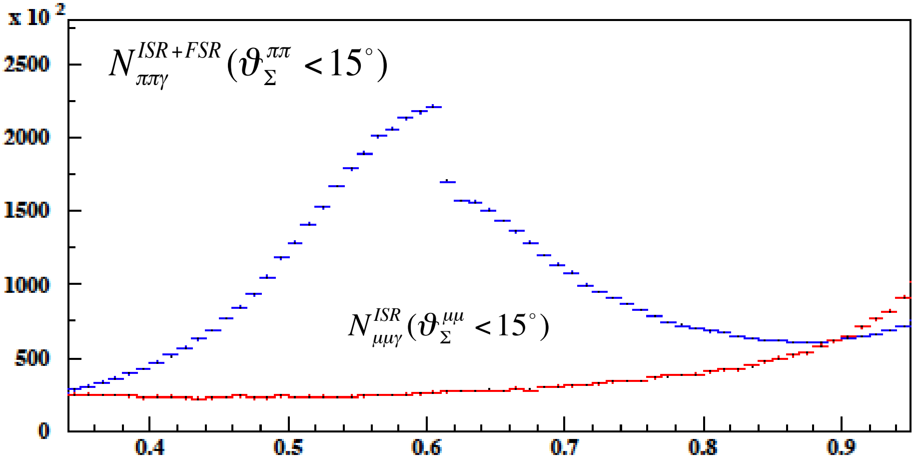
$$\int \mathcal{L}\, dt = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}$$

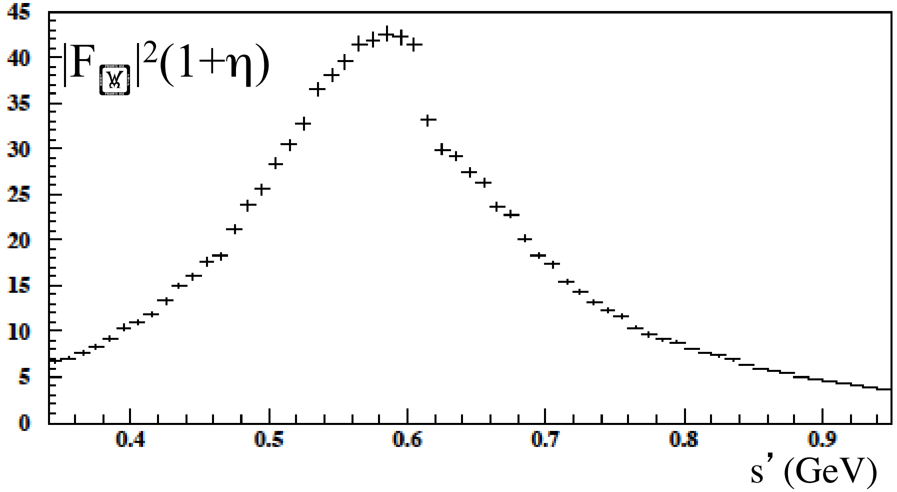




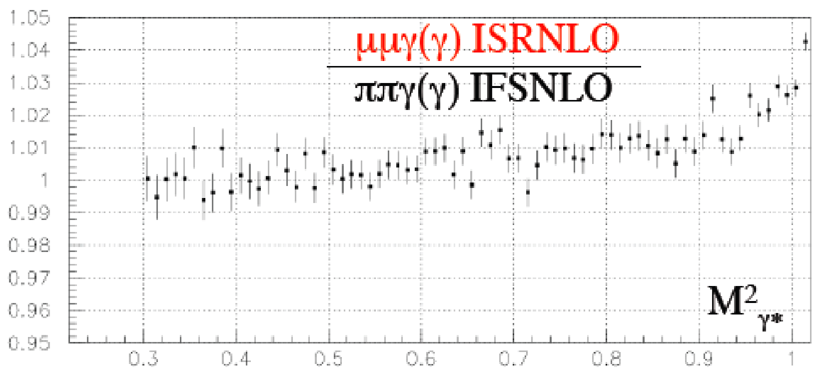


Extracting $|F_\pi|^2$ by π/μ ratio:





In the ratio the correction for acceptance is ~1% (instead of 30% for the absolute measurement)



$$|F_\pi(s')|^2 \cdot (1+\eta(s')) = \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \cdot \frac{\left(d\sigma^{ISR+FSR}_{\pi\pi\gamma}(\theta^{\pi\pi}_{\Sigma} < 15^{o})/ds'\right)}{\left(d\sigma^{ISR}_{\mu\mu\gamma}(\theta^{\mu\mu}_{\Sigma} < 15^{o})/ds'\right)} \cdot Corr(\theta^{I+FSR}_{\Sigma}/\theta^{ISR}_{\Sigma})$$

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