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

Graziano Venanzoni
(for the KLOE collaboration)
Laboratori Nazionali di Frascati

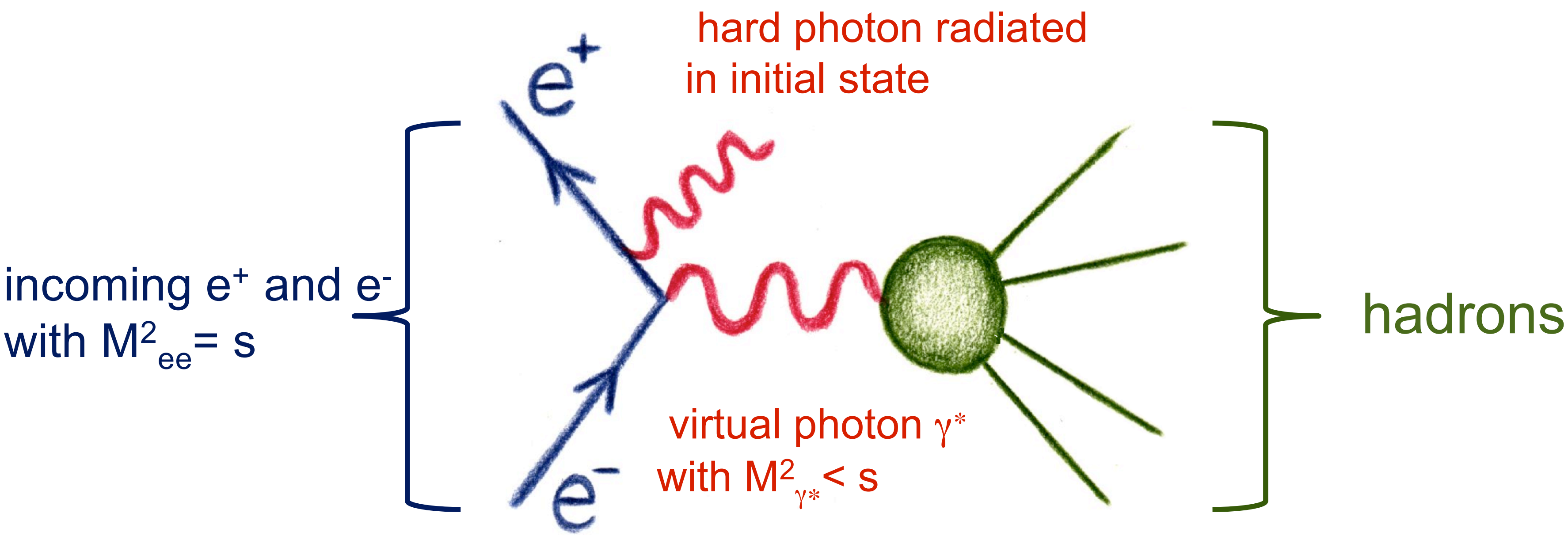
LNF, Scientific Committee, 24 June 2010

Outlook

- KLOE measurements of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$:
  - Small (photon) angle measurements (KLOE05, KLOE08)
  - Large (photon) angle measurement (KLOE09) New!
- Evaluation of $a_\mu^{\pi\pi}$ and comparison with CMD-2/SND/BaBar
- New measurement well advanced:
  - Extraction of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$ by $\mu\mu\gamma$ normalization
- Future prospects with KLOE-2
- Conclusions

ISR: Initial State Radiation

Particle factories (DAΦNE, 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 $\sqrt{s}$).

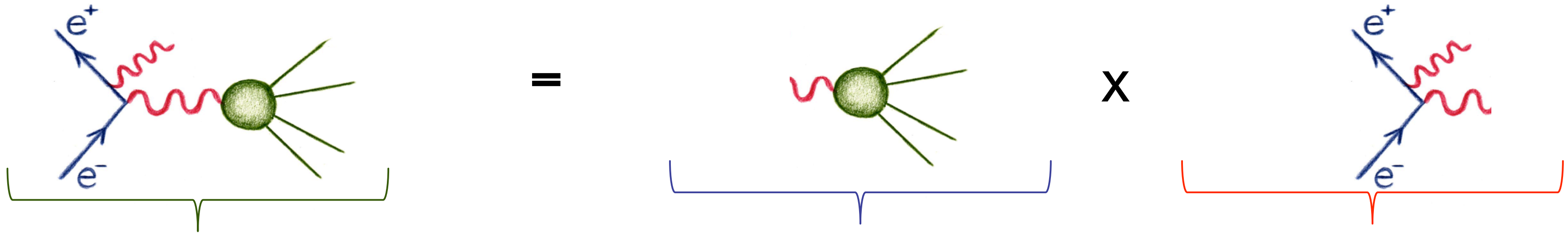


The emission of a hard γ in the bremsstrahlung process in the initial state reduces the energy available to produce the hadronic system in the e^+e^- collision.

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 ($140 pb^{-1}$) PLB606(2005)12 ⇒ ~3σ discrepancy btw a_μ^{SM} and a_μ^{exp}

Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-(\gamma))$ with photon emitted at Small Angle ("*SA Analysis*")

Phys. Lett. B 670 (2009) 285

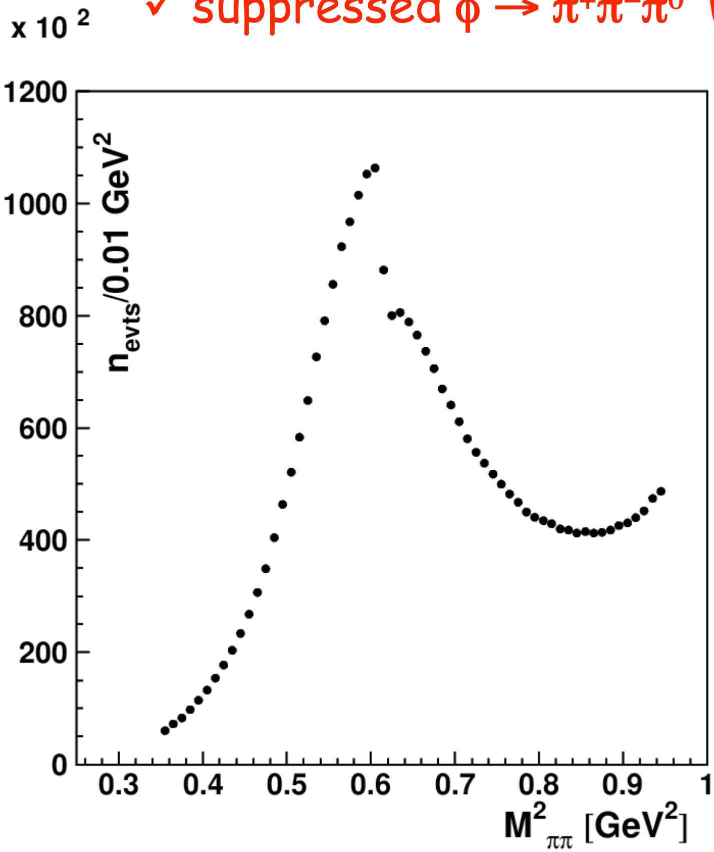
Event Selection (KLOE08)

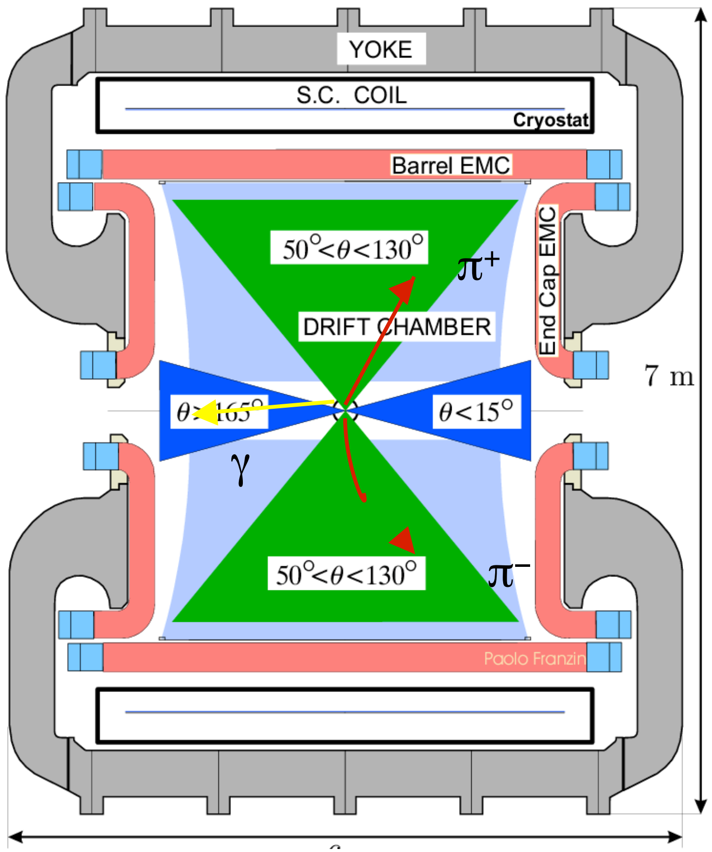
a) 2 tracks with $50^o < \theta_{track} < 130^o$

b) small angle (not detected) γ
($\theta_{\pi\pi} < 15^o$ or $> 165^o$)

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

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





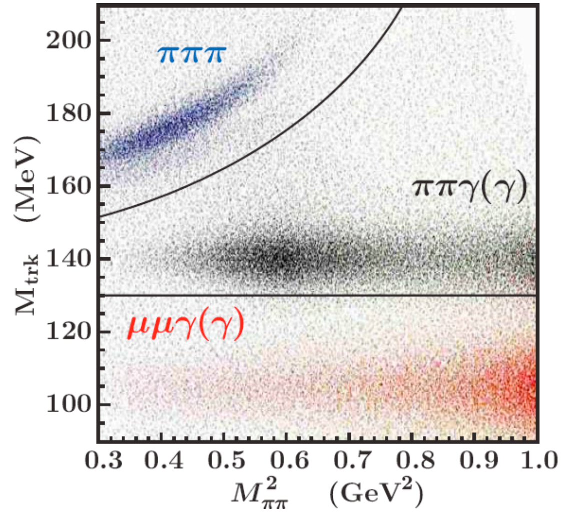
statistics: 240pb^{-1} of 2002 data

3.1 Mill. Events between 0.35 and 0.95 GeV^2

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

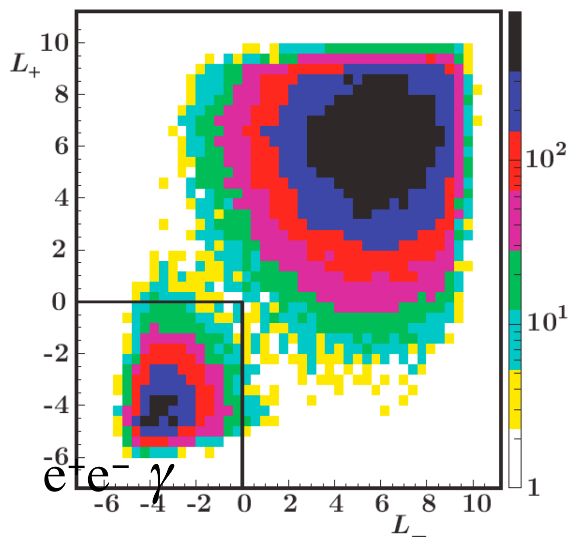


M_{Trk}: defined by 4-momentum conservation assuming 2 charged particle (of same mass) and one γ in the final state

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

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.

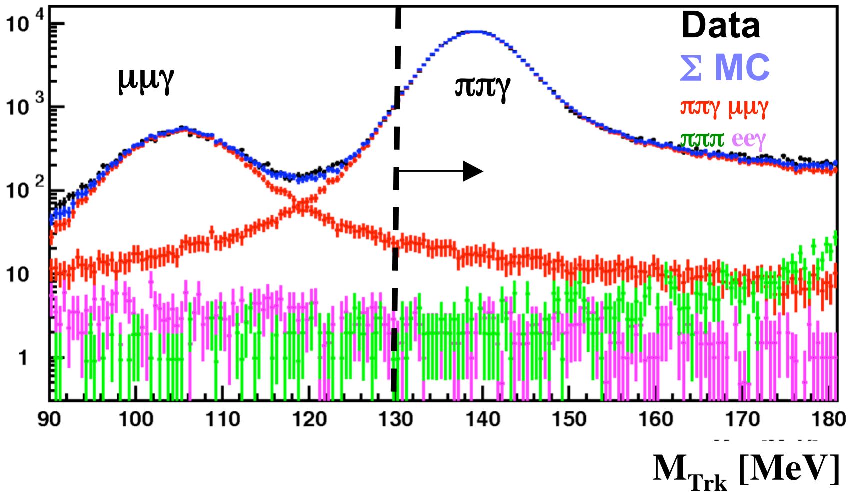
$\pi^+\pi^- \gamma$,



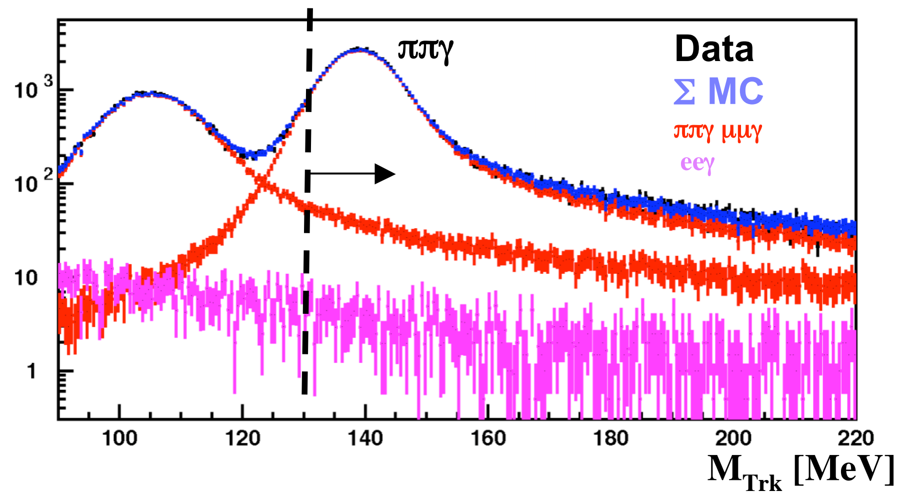
Background:

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

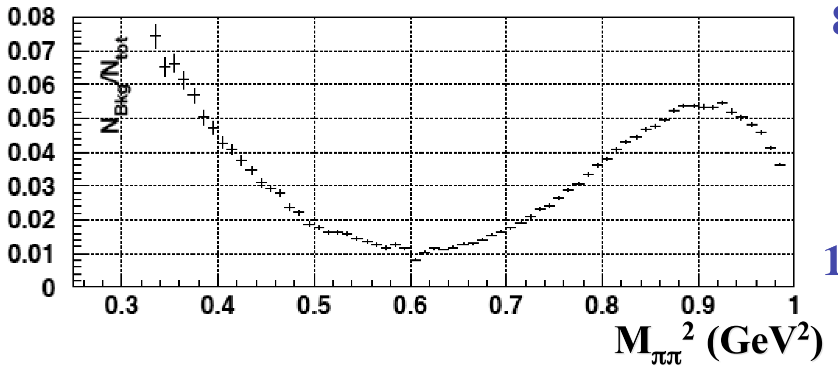
$0.60 < M_{\pi\pi}^2 < 0.62$ GeV^2, χ^2/ndof = 158/180



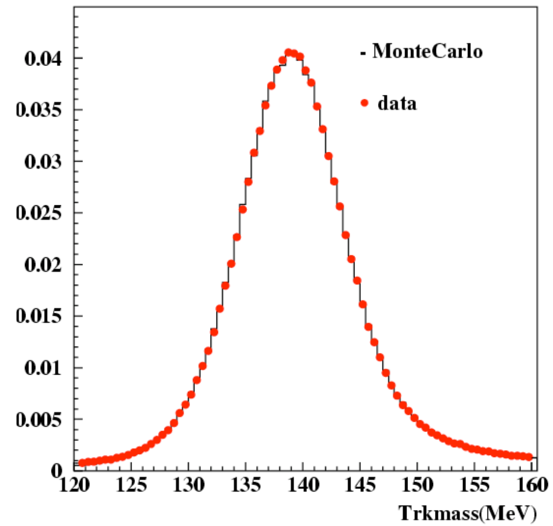
$0.84 < M_{\pi\pi}^2 < 0.86$ GeV^2 χ^2/ndof = 179/258



Tot bckg ($\mu\mu\gamma$, $\pi\pi\pi$ and $ee\gamma$) **contribution**



- Excellent agreement on M_{TRK} distribution between data and MC



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 $< 9°$

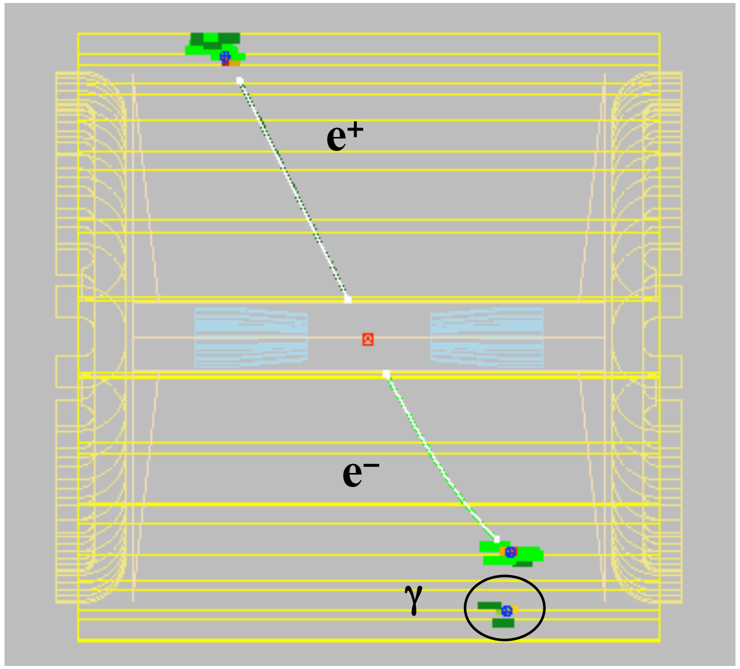
$p \geq 400$ MeV

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

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:

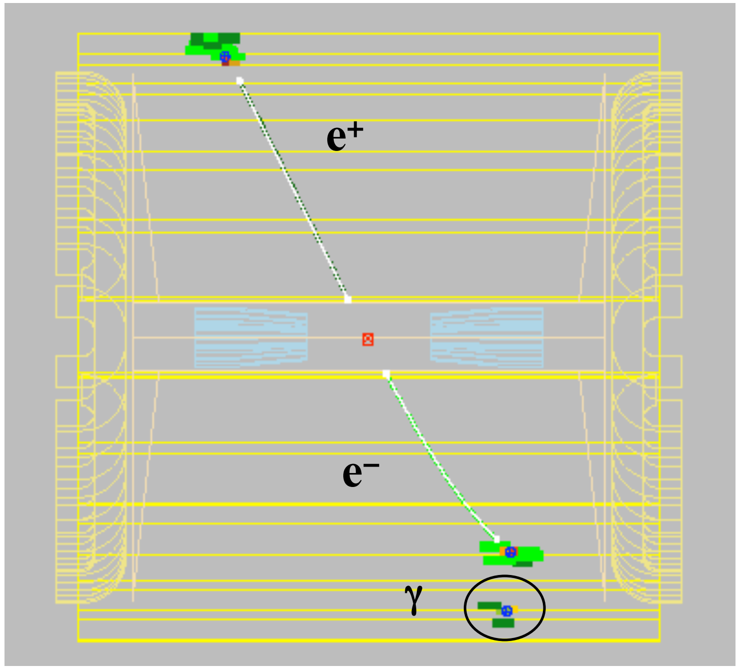
KLOE measures $\mathcal{L}$ with Bhabha scattering

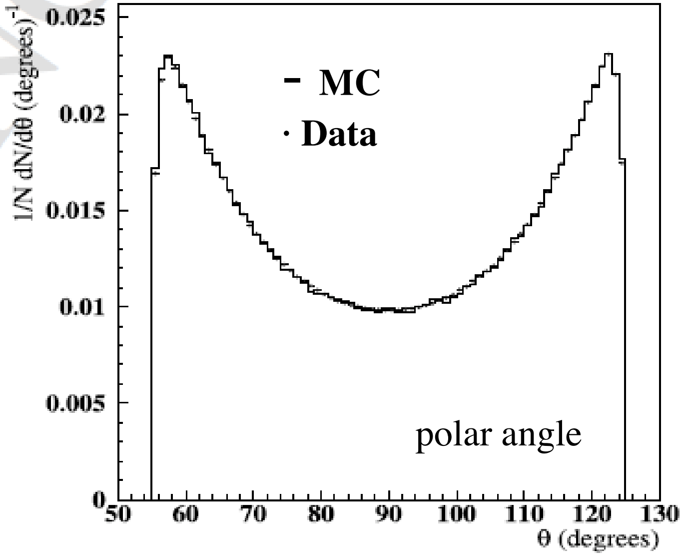
$55° < \theta < 125°$

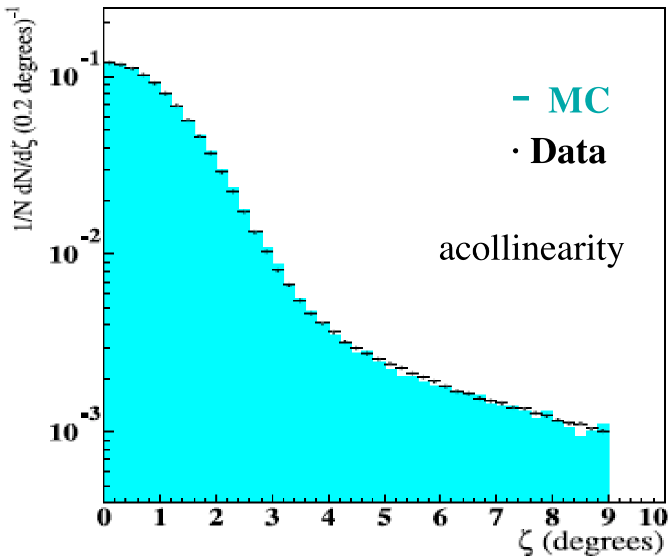
acollinearity < 9°

p ≥ 400 MeV

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







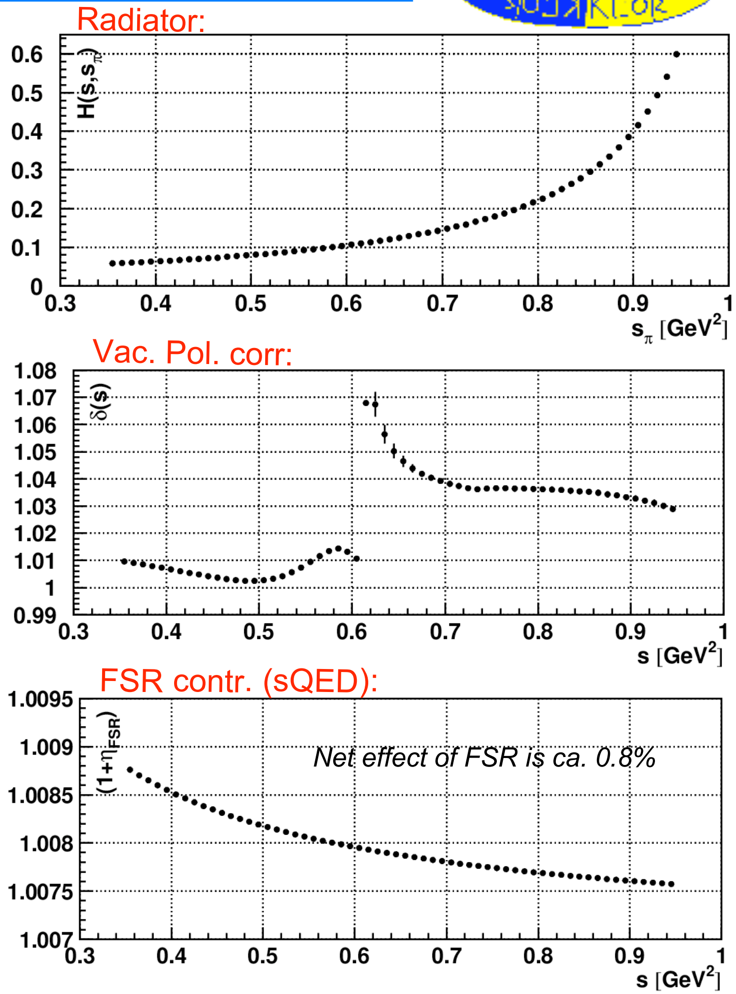
Radiative Corrections

Radiator-Function $H(s,s_\pi)$ (ISR):

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

Precision: 0.5%

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



Radiative Corrections:

i) Bare Cross Section

divide by Vacuum Polarisation $\delta(s)=(\alpha(s)/\alpha(0))^2$

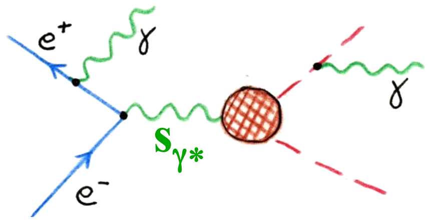
➔ from F. Jegerlehner

ii) FSR

Cross section $\sigma_{\pi\pi}$ must be incl. for FSR for use in the dispersion integral of a_μ

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)



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

KLOE result (KLOE08)

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

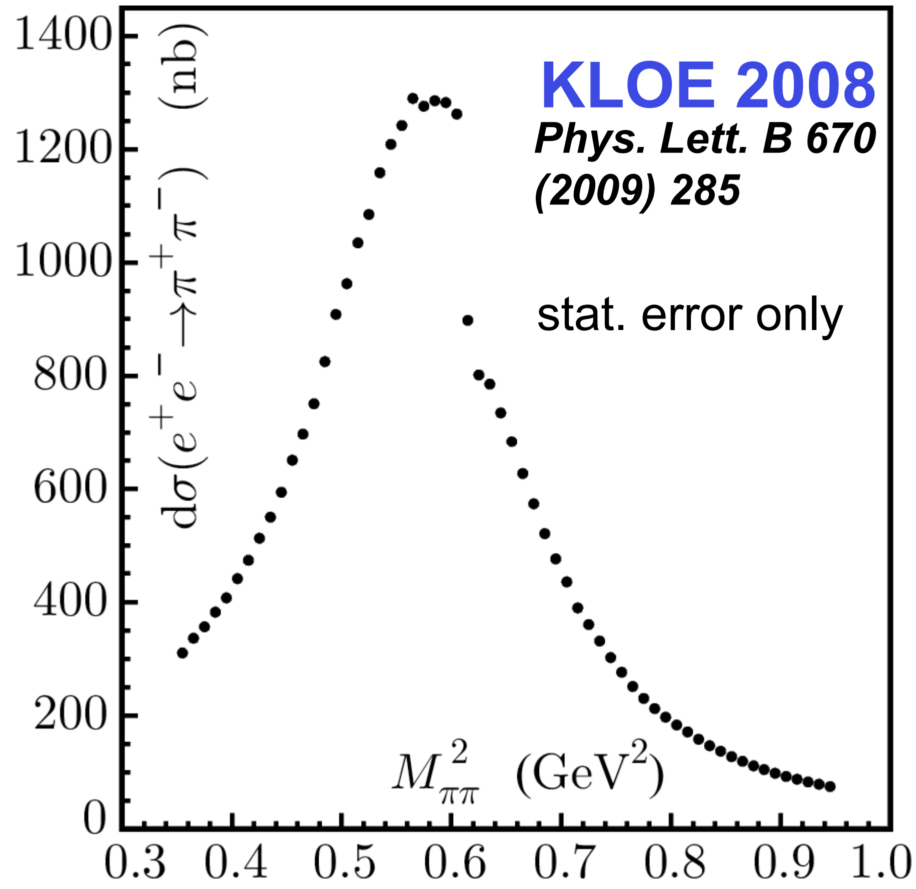
Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
π/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.1%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dep. Of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%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

experimental fractional error on a_μ = 0.6 %

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

theoretical fractional error on a_μ = 0.6 %

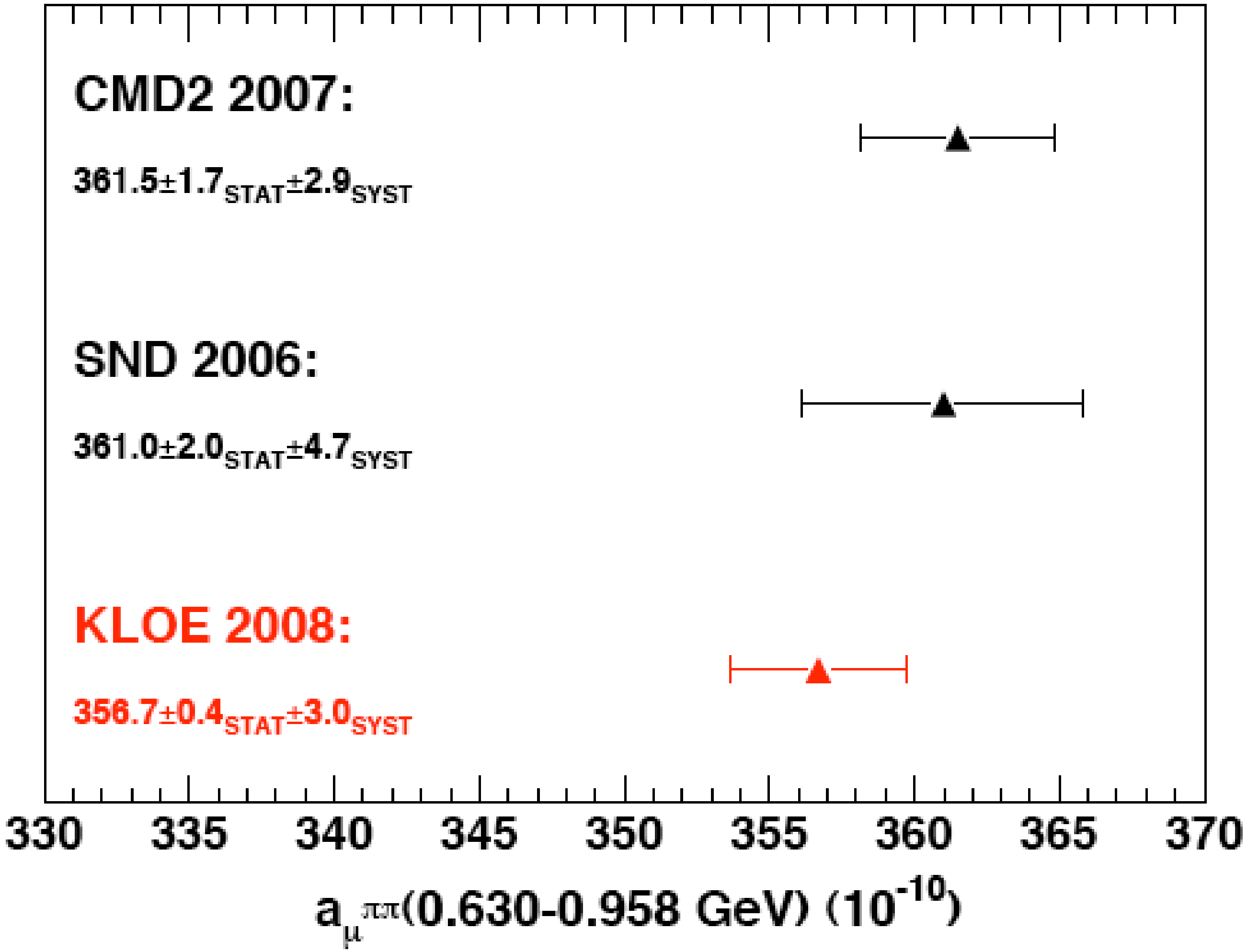
$\sigma_{\pi\pi}$, undressed from VP, inclusive for FSR as function of $(M^0_{\pi\pi})^2$



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

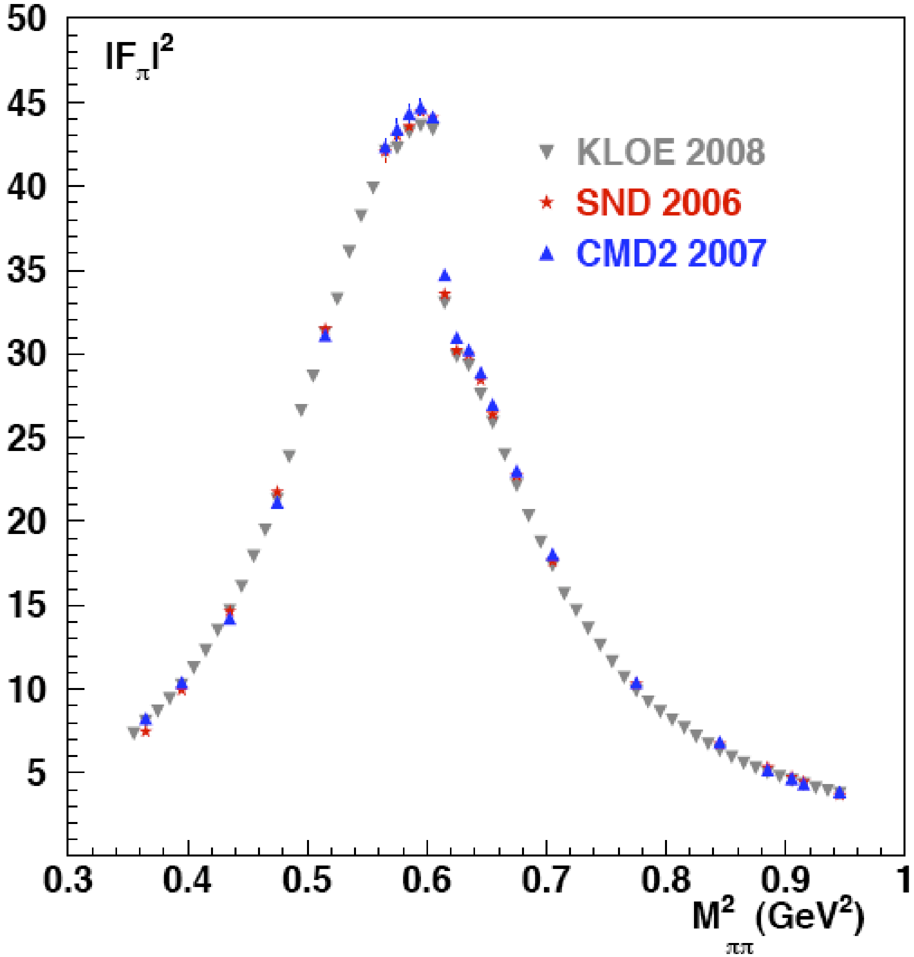
$a_\mu^{\pi\pi}(0.35\text{-}0.95\text{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$

$a_\mu^{\pi\pi}$: KLOE vs CMD-2/SND

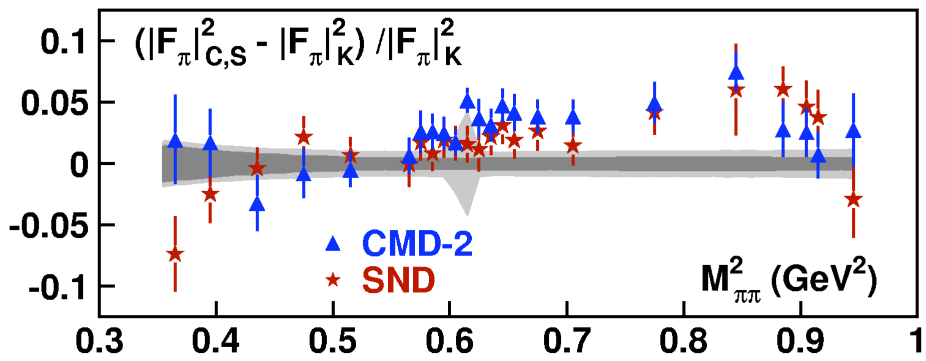


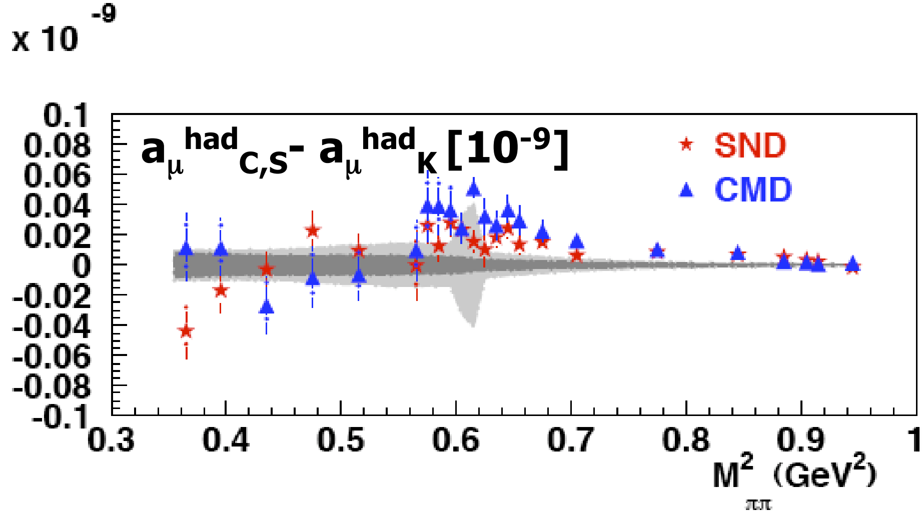
KLOE result in agreement with CMD2 and SND

Comparison with CMD2/SND



only statistical errors are shown



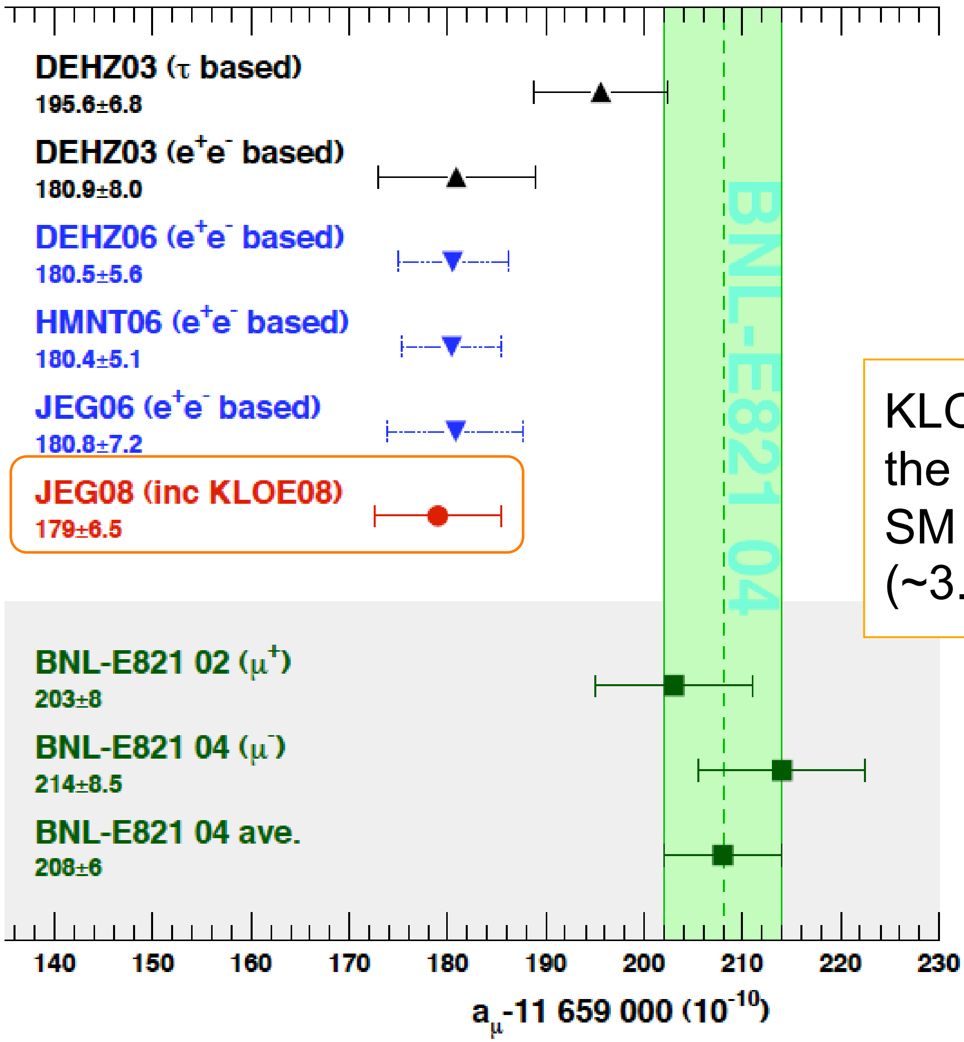


band: KLOE error
data points: CMD2/SND experiments

CMD-2 and SND data have been averaged over width of KLOE bin (0.01 GeV^2)

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

Theoretical predictions compared to the BNL result (in 2008):



KLOE08 confirms the discrepancy between SM and BNL experiment (~3.4σ)

Measurement of $\sigma(e^+e^-\rightarrow\pi^+\pi^-(\gamma))$ with photon emitted at Large Angle ("*LA Analysis*,,)

New measurement based on 2006 data taken at $\sqrt{s}$=1.0 GeV, 20 MeV below the ϕ-peak (different selection!)

Paper ready to be submitted for publication

Event Selection

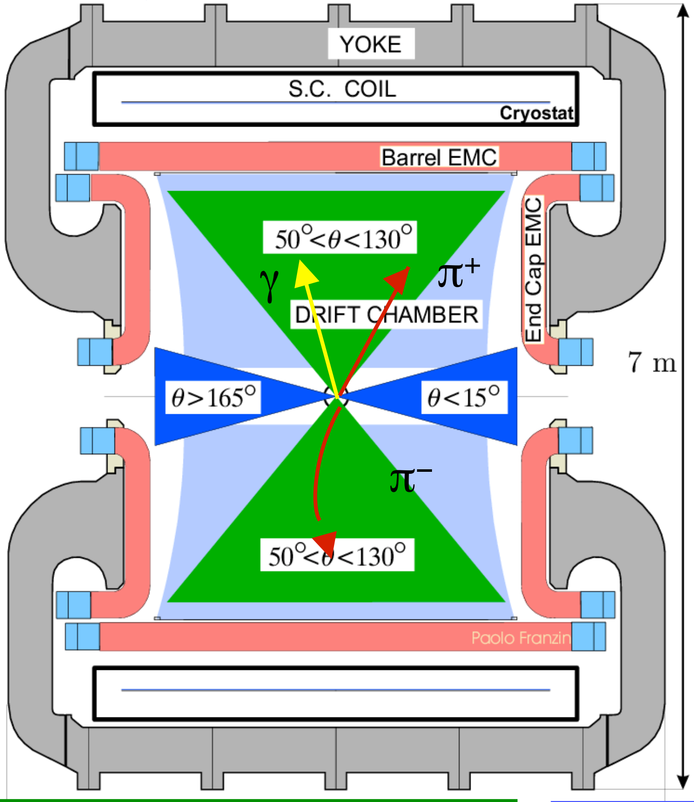
2 pion tracks at large angles
$50^o < \theta_\pi < 130^o$

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

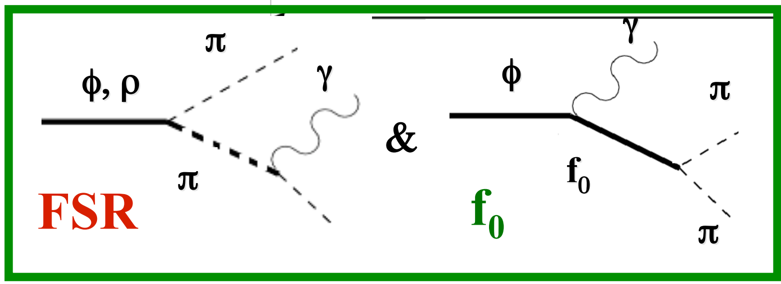
- ✓ **independent complementary analysis**
- ✓ **threshold region $(2m_\pi)^2$ accessible**
- ✓ **γ_{ISR} photon detected (4-momentum constraints)**

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

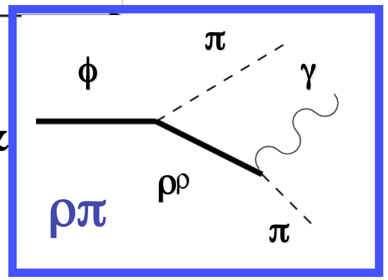
At least 1 photon with $50^o < \theta_\gamma < 130^o$ and $E_\gamma > 20$ MeV ➔ photon detected



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



&

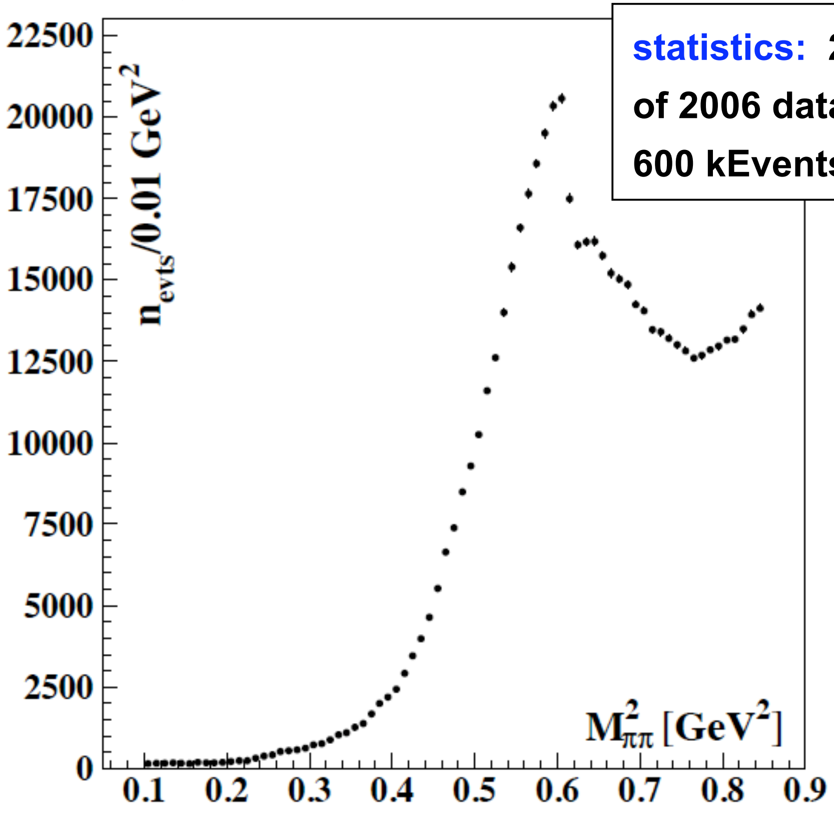


Event Selection

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

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

At least 1 photon with $50^o < \theta_\gamma < 130^o$
and $E_\gamma > 20$ **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 ($\phi \to f_0\,\gamma \to \pi\pi\,\gamma$)

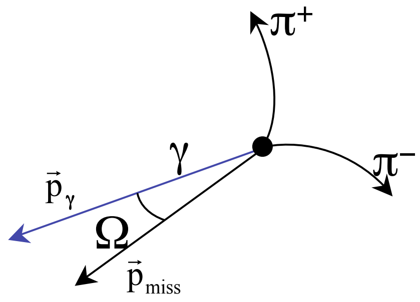
Use data sample taken at $\sqrt{s} \cong$ **1000 MeV**,
20 MeV below the ϕ–peak

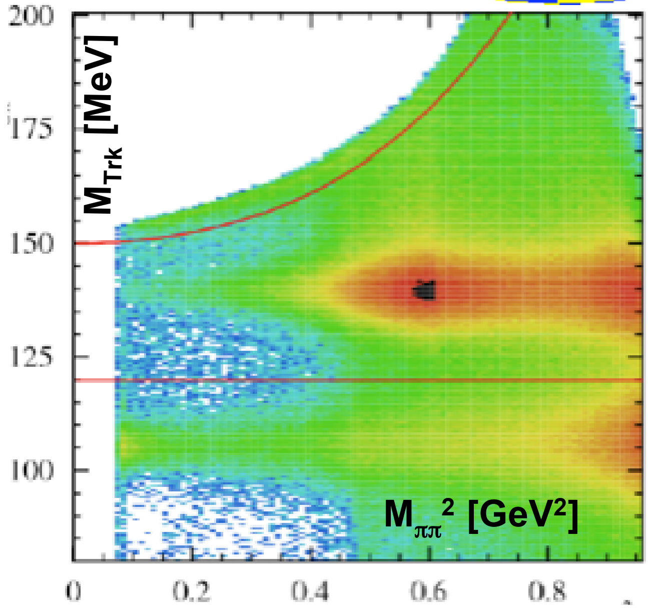
Event selection

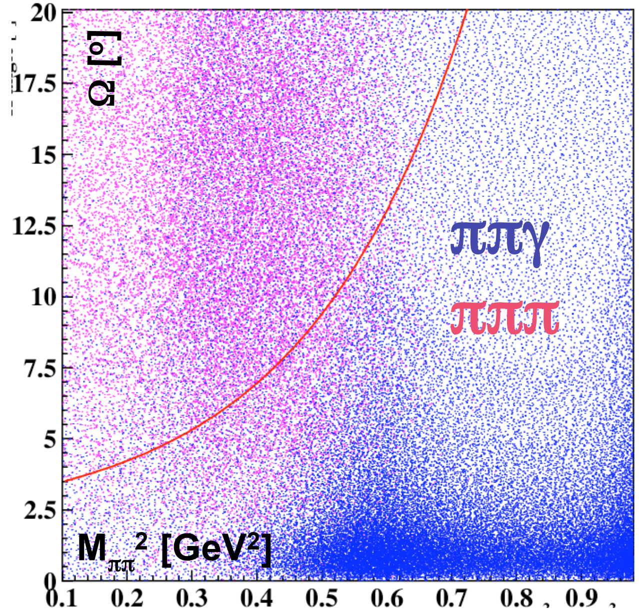
- Experimental challenge: Fight background from
  - $e^+e^- \rightarrow \mu^+\mu^- \gamma$,
  - $e^+e^- \rightarrow e^+e^- \gamma$
  - $\phi \rightarrow \pi^+\pi^-\pi^0$

  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.

New KLOE result (KLOE09)

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

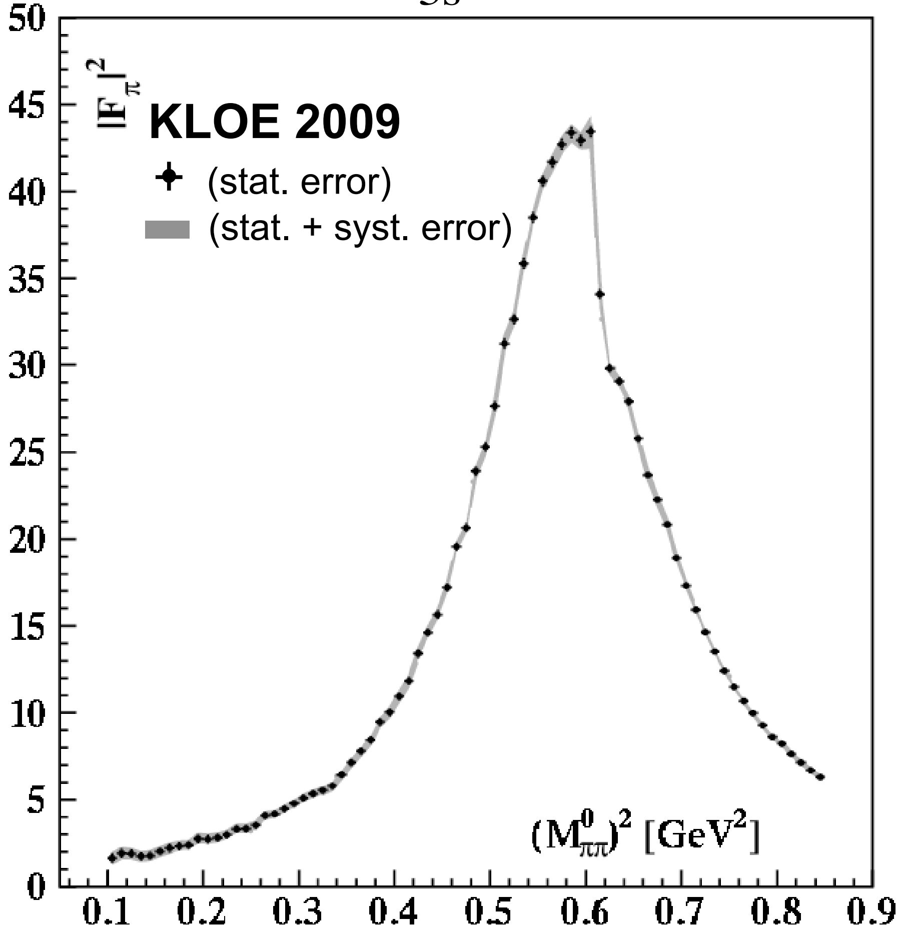


Table of systematic errors on $a_\mu^{\pi\pi}$(0.1-0.85 GeV²):

Reconstruction Filter	< 0.1%
Background	0.5%
$f_0+\rho\pi$	0.4%
Omega	0.2%
Trackmass	0.5%
π/e-ID and TCA	< 0.1%
Tracking	0.3%
Trigger	0.2%
Acceptance	0.4%
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 resummation	0.3%
Radiator H	0.5%
Vacuum polarization	< 0.1%

theoretical fractional error on a_μ = 0.6 %

Disp. Integral:

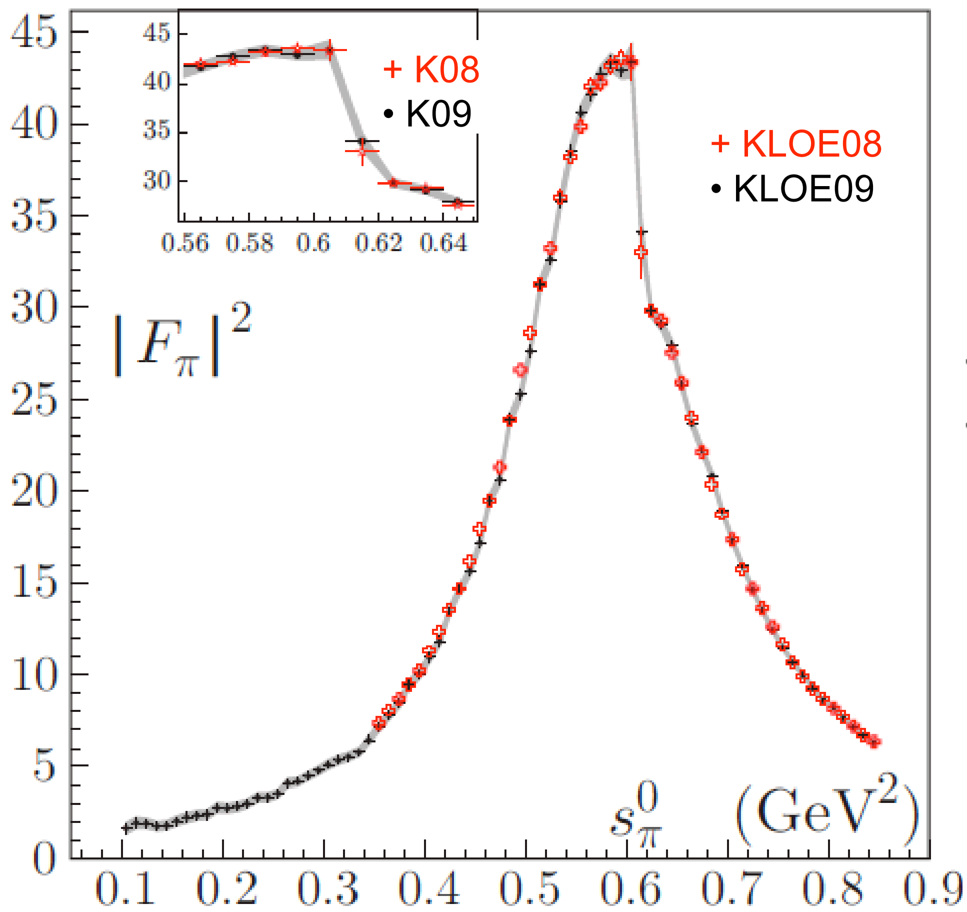
$$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s)K(s)ds$$

$a_\mu^{\pi\pi}$(0.1-0.85 GeV²) = $(478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \cdot 10^{-10}$

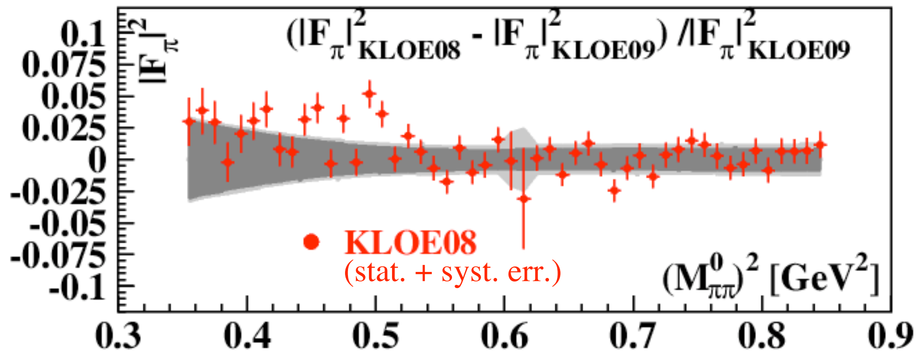
0.4% 1.0% 0.6%

Comparison of results: KLOE09 vs KLOE08

KLOE08 result compared to KLOE09:



Fractional difference:



band: KLOE09 error

Excellent agreement with KLOE08, expecially above 0.5 GeV^2

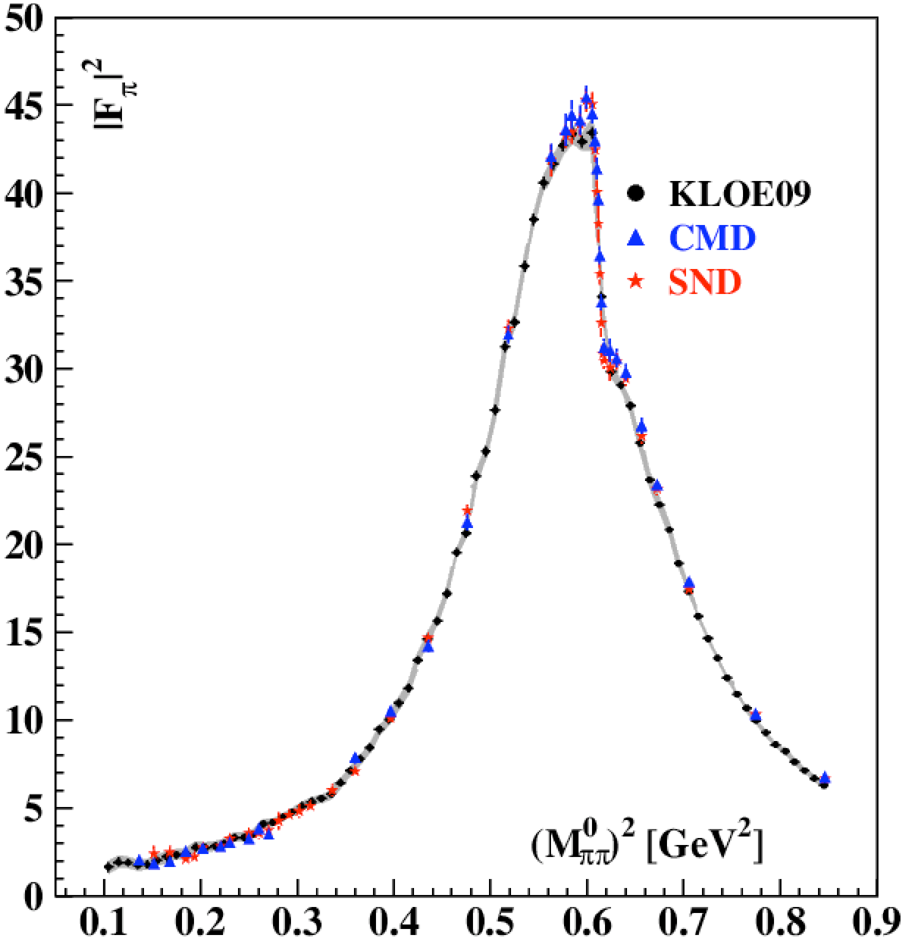
Combination of KLOE08 and KLOE09:

$a_\mu^{\pi\pi}(0.1\text{-}0.95\ \text{GeV}^2) = (488.6 \pm 5.0) \cdot 10^{-10}$

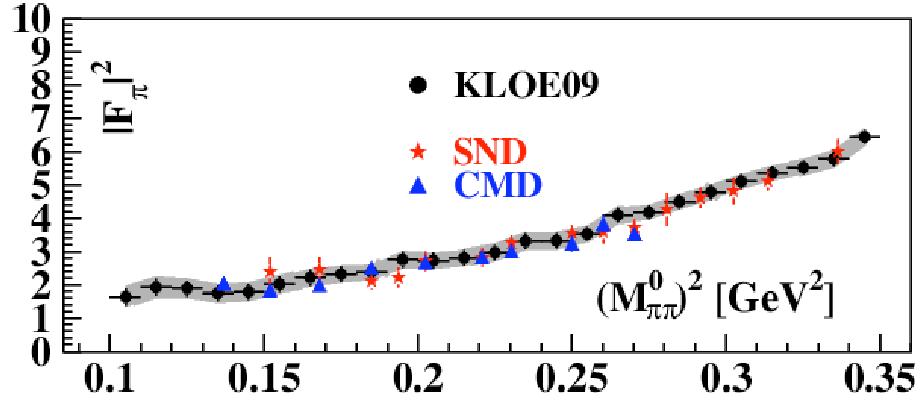
KLOE covers ~70% of total a_μ^{had} with an error of 1.0%

Comparison of results: KLOE09 vs CMD-2/SND

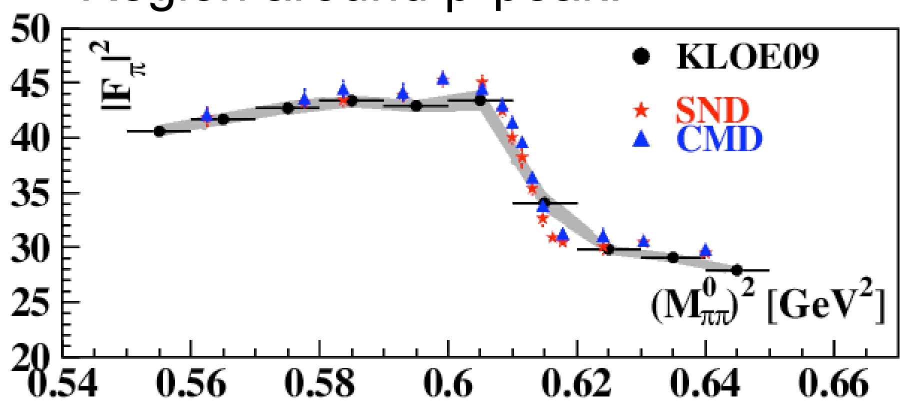
CMD and SND results compared to KLOE09:



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



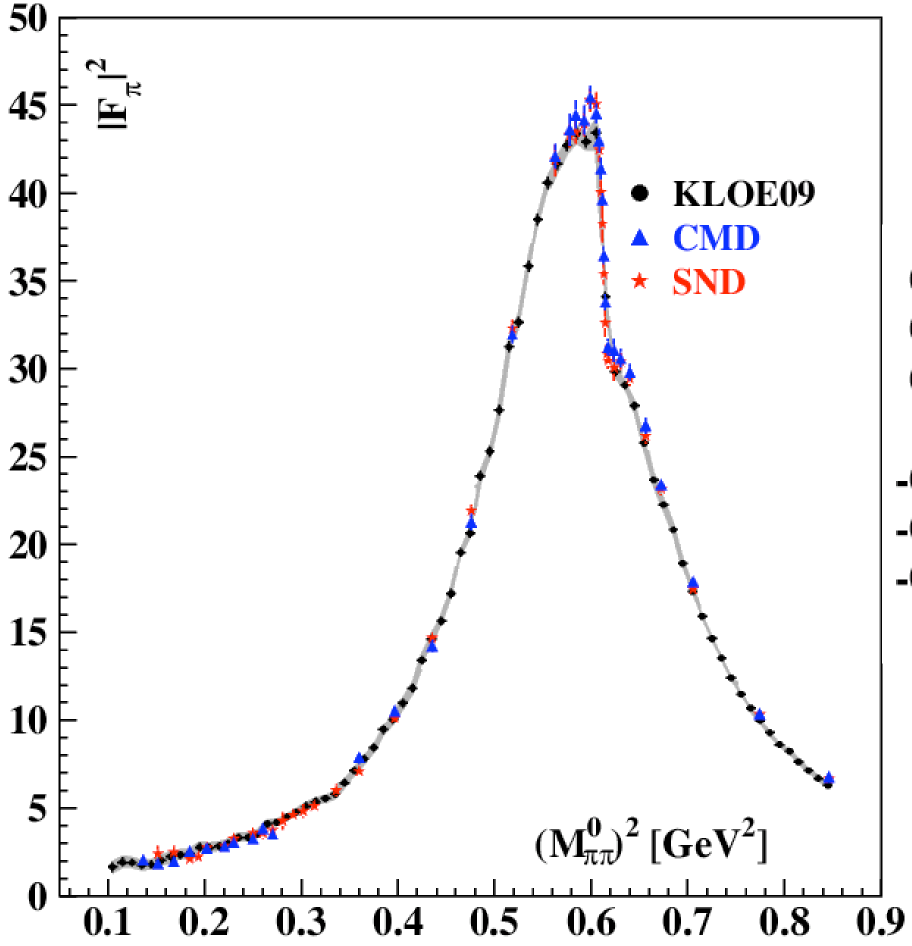
Region around ρ-peak:

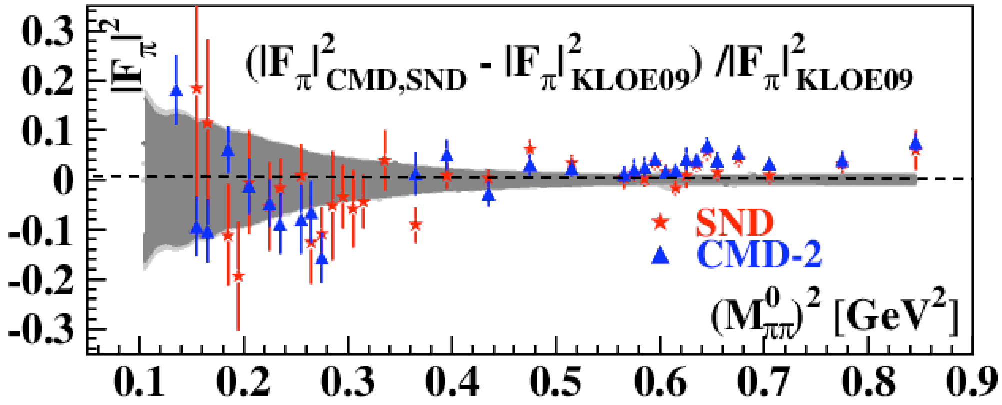


band: KLOE09 error

Comparison of results: KLOE09 vs CMD-2/SND

CMD and SND results compared to KLOE09: Fractional difference



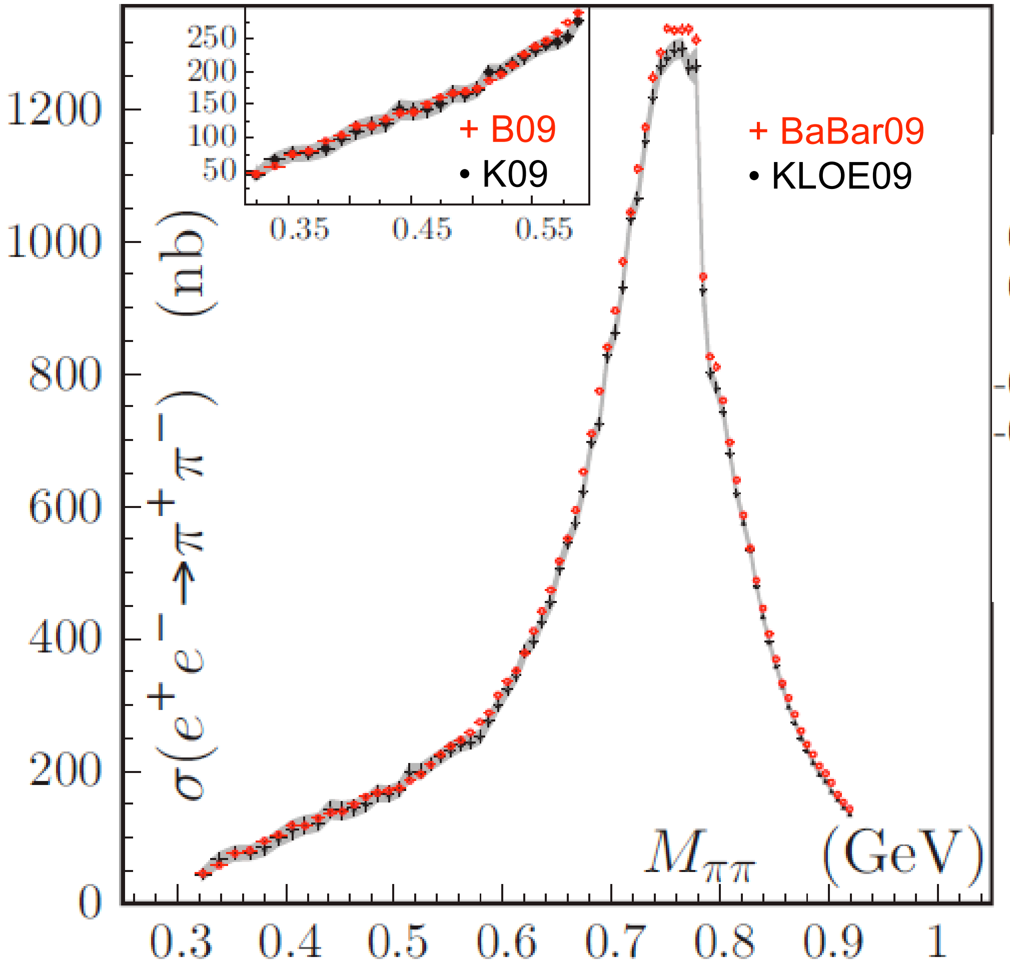


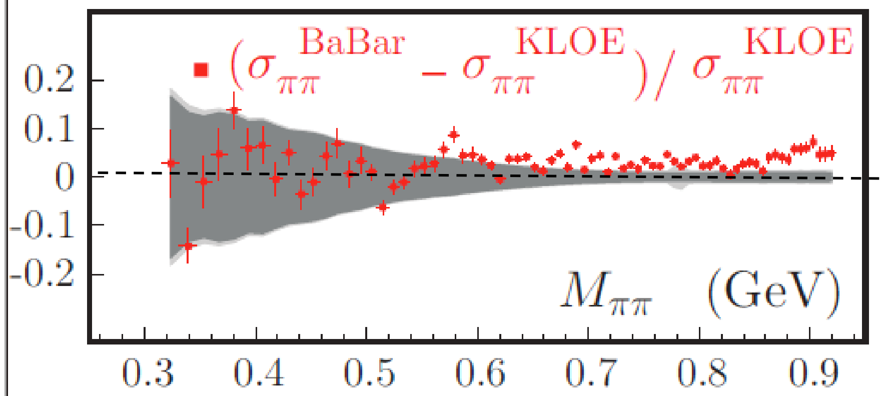
band: KLOE09 error

Below the ρ peak good agreement with CMD-2/SND.
Above the ρ peak KLOE09 slightly lower (as KLOE08)

Comparison of results: KLOE09 vs BaBar

BaBar results compared to KLOE09: Fractional difference





band: KLOE09 error

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

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

Theoretical predictions compared to the BNL result (2009)

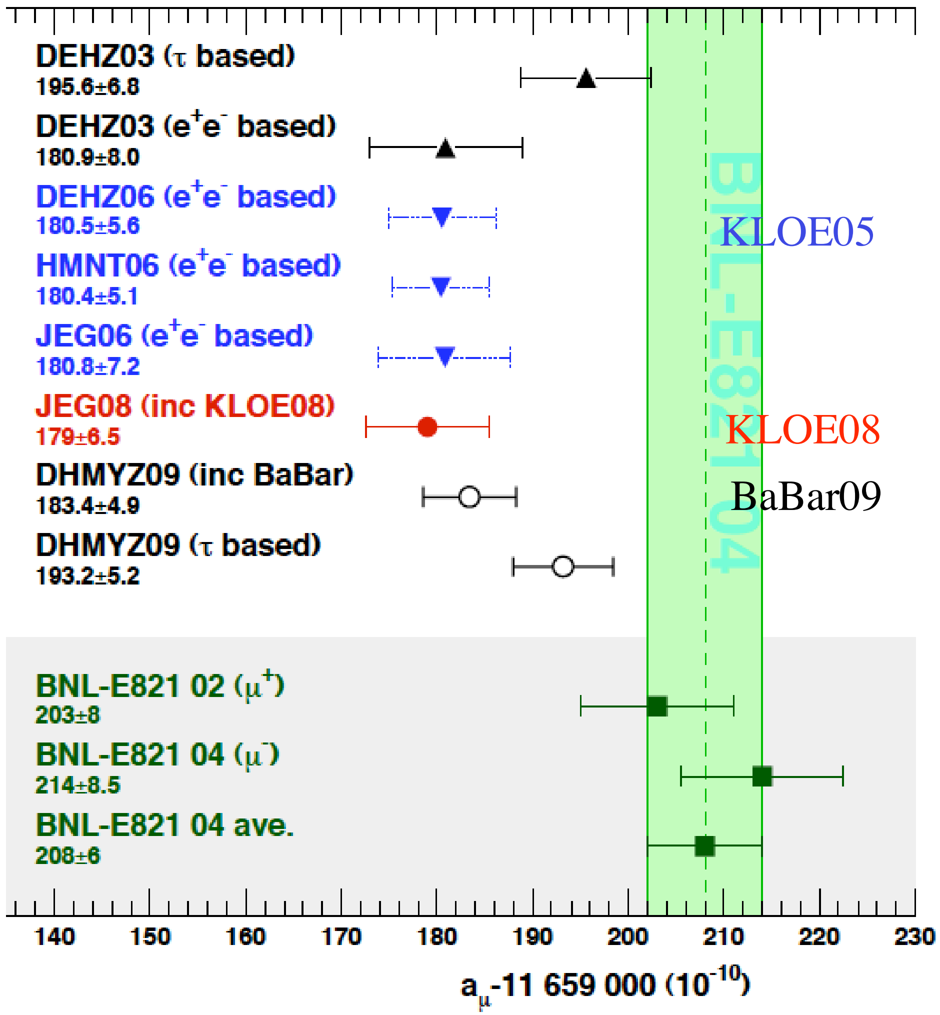
- The latest inclusion of all e^+e^- data (DHMYZ09) gives a discrepancy btw a_μ^{SM} and a_μ^{EXP} of 3.2σ

- Remaining differences on $\sigma_{\pi\pi}$ btw different experiments (mainly KLOE/BaBar) to be clarified [$\Delta a_\mu^{EXP\text{-}SM}=2.4\div3.7\sigma$]

Davier

- (Reduced) discrepancy with τ data (new I. corr.,ee,τ data) [$a_\mu^{ee} - \Delta a_\mu^{\tau}=1.4\sigma$]

KLOE09 is not yet in.



KLOE Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-(\gamma))$ by $\pi\pi\gamma/\mu\mu\gamma$ ratio

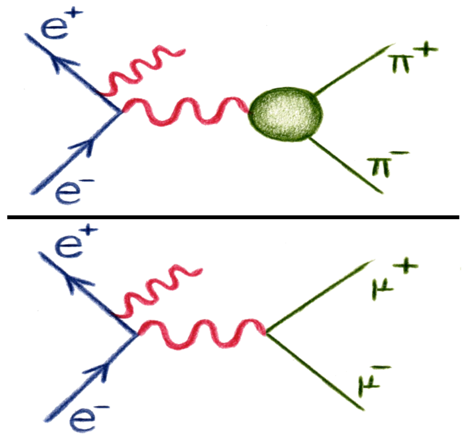
Analysis in a well advanced phase

$\sigma_{\pi\pi}$ 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).

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

kinematical factor ($\sigma_{\mu\mu}^{Born} / \sigma_{\pi\pi}^{Born}$) — meas. quantities



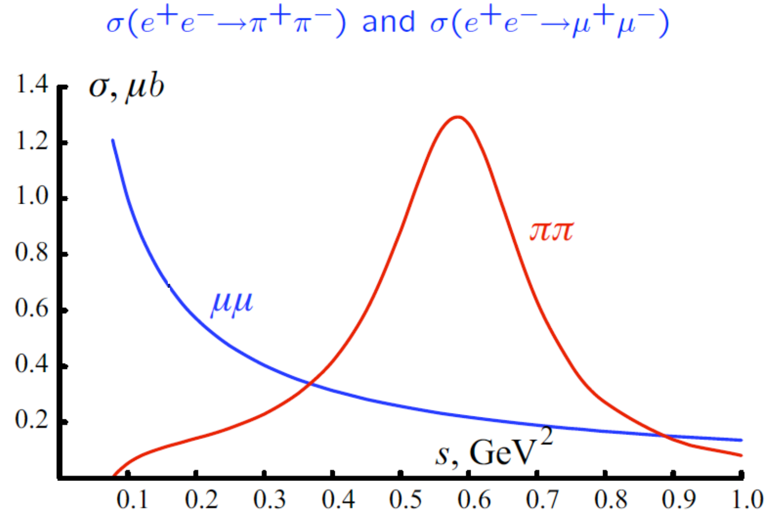
Many radiative corrections drop out:

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

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

- *muons:* $M_{Trk} < 120$ *MeV*
- *pions :* $M_{Trk} > 130$ *MeV*

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

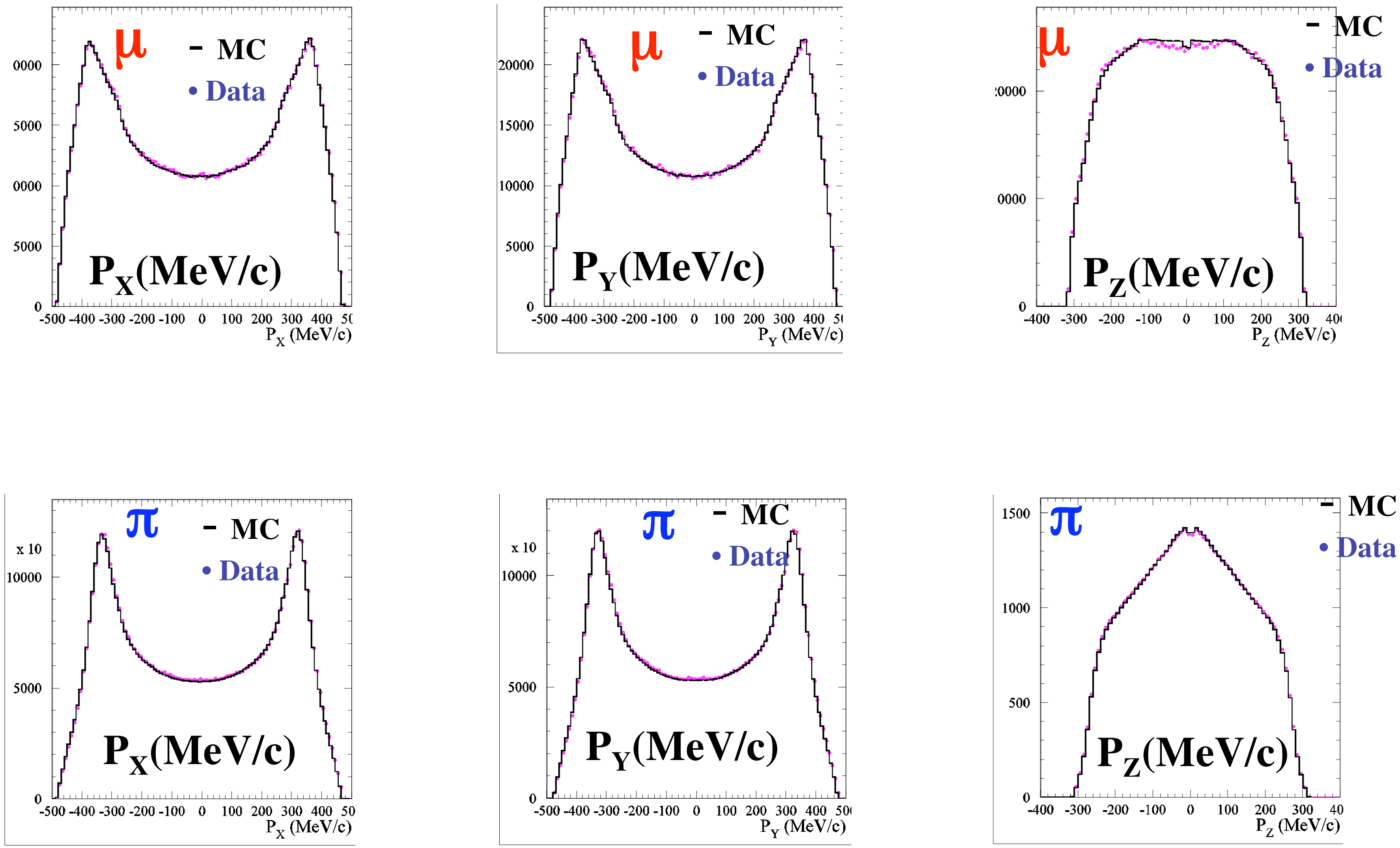


π/μ: Status of the Analysis

- 240 pb^{-1} of 2002 data sample (the same used in KLOE08 analysis): 0.87 Million $\mu\mu\gamma$ events expected (compared to 3.1 Million for $\pi\pi\gamma$)
- A lot of work has been done to achieve a control of ~1% in the muon selection, especially in the ρ region where $\pi/\mu \sim 10$ (see later)
- We have achieved an excellent Data/MC agreement for muons in many kinematic variables (as we did for pions)
- Most of efficiencies for muons have been done and are ~100%
- We have not yet performed the absolute ratio $\mu\mu\gamma_{DATA}/\mu\mu\gamma_{MC}$ (test of QED) to check Radiator, Luminosity, FSR, etc…

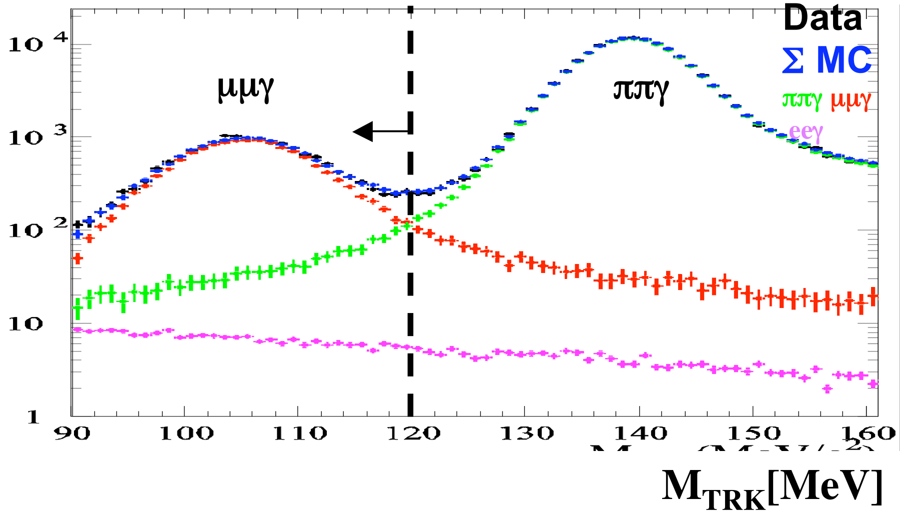
Results are expected soon…

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

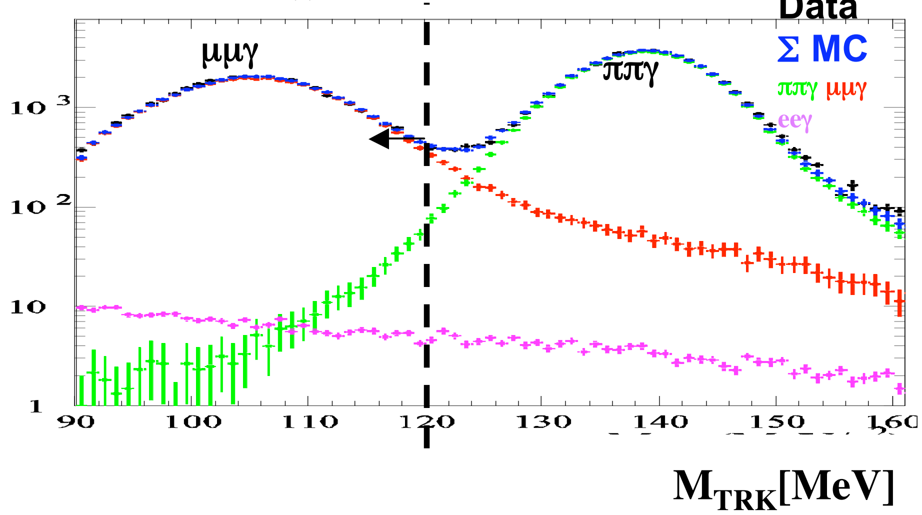


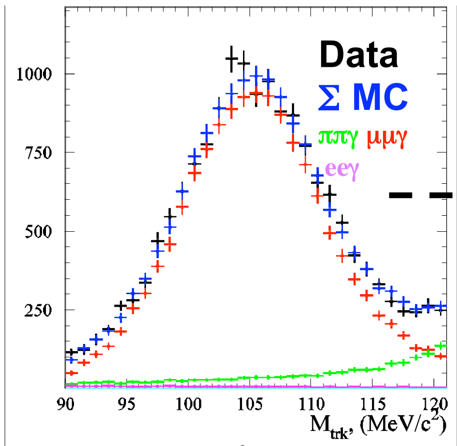
Example of μμγ selection via M_{TRK}

$0.59 < M_{\mu\mu}^2 < 0.61$ GeV²

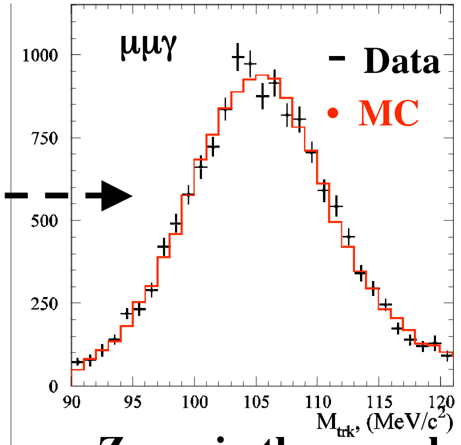


$0.93 < M_{\mu\mu}^2 < 0.95$ GeV²

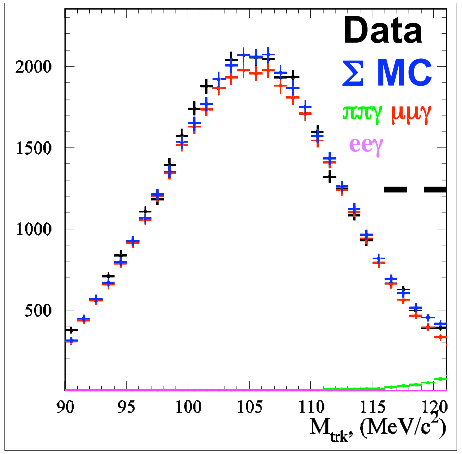




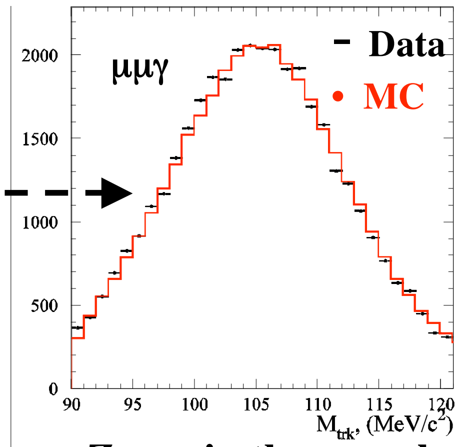
Zoom in the μ peak



Zoom in the μ peak, after background subtraction



Zoom in the μ peak

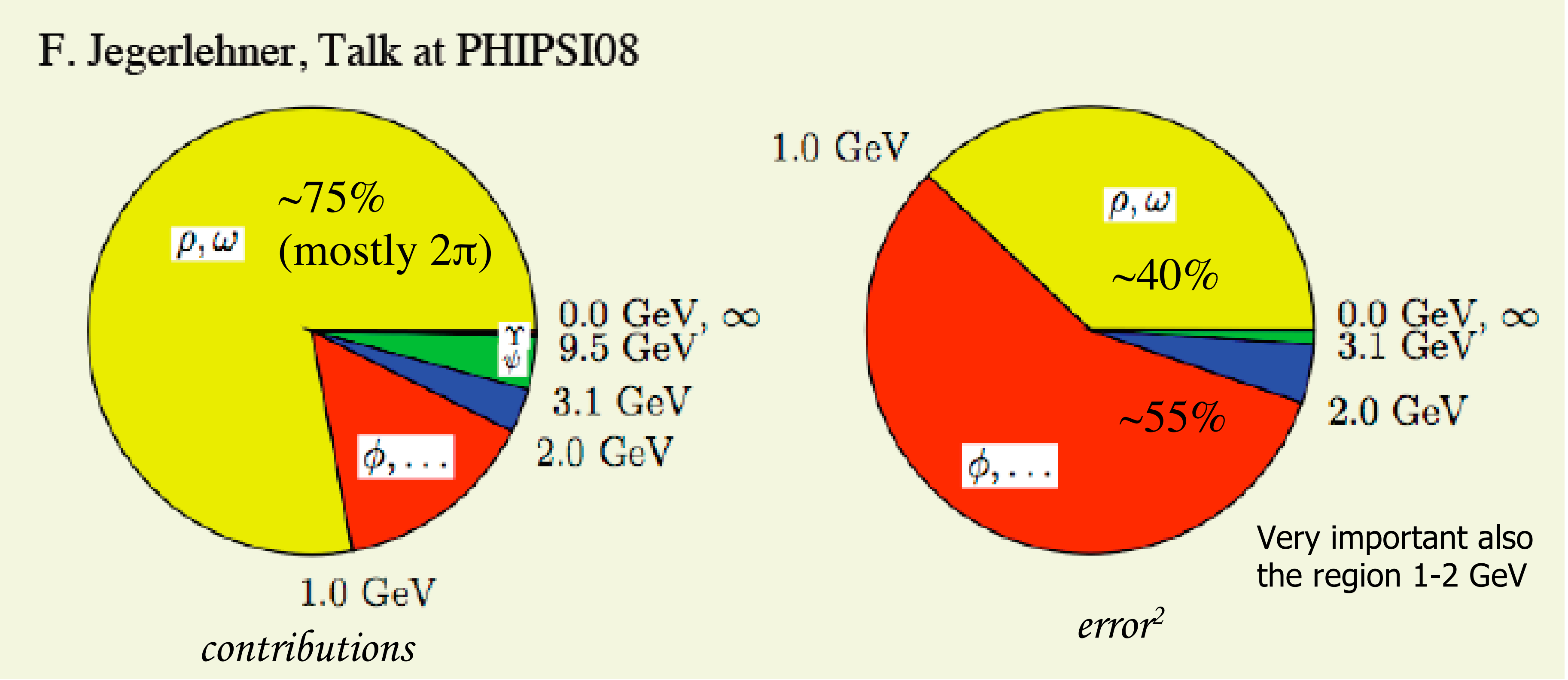


Zoom in the μ peak, after background subtraction

Prospects on σ_{HAD} with KLOE-2

Dispersion Integral:

Contribution of different energy regions to the dispersion integral and the error to a_μ^{had}



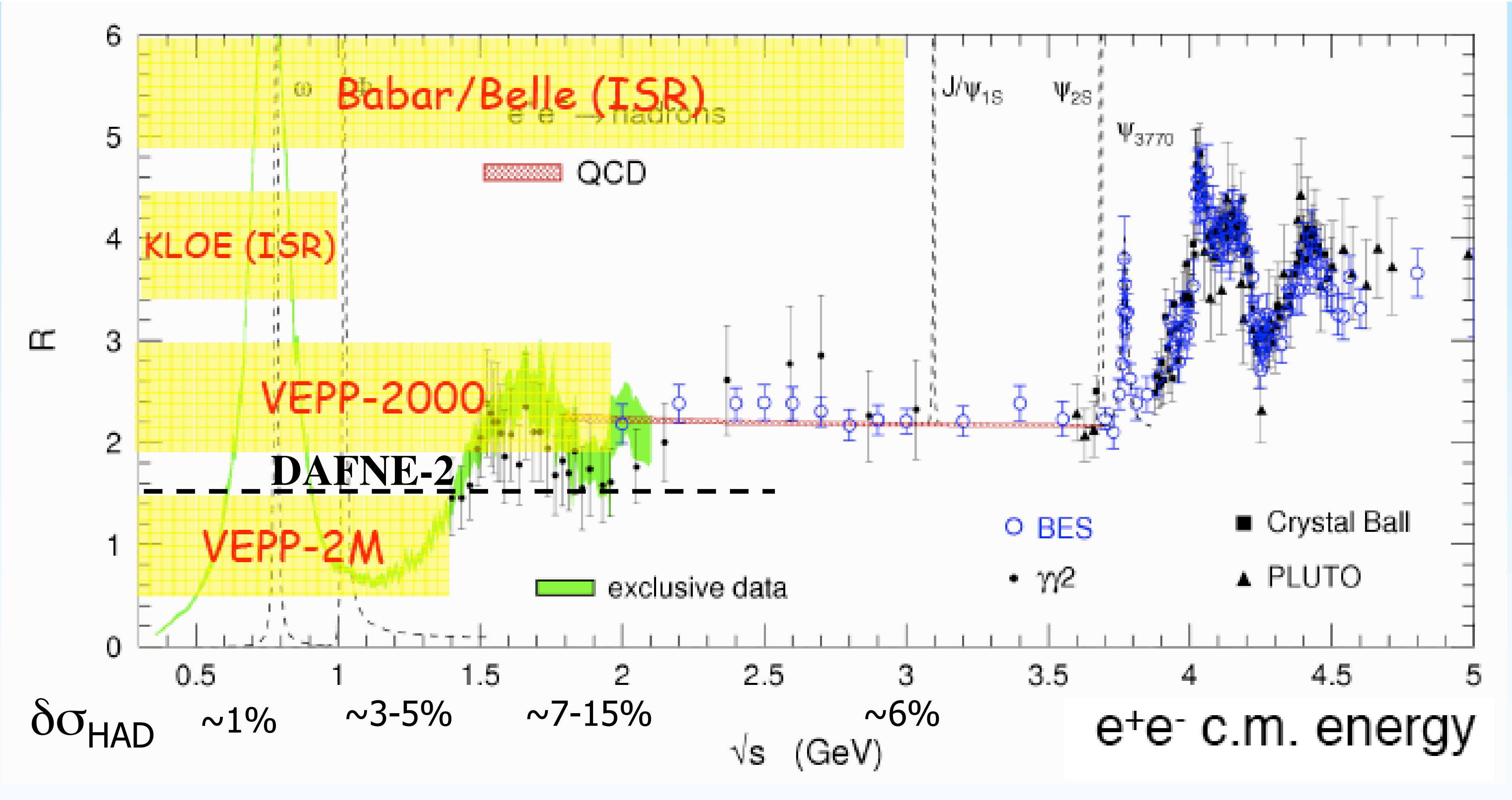
Experimental errors on σ^{had} translate into theoretical uncertainty of a_μ^{had}!

→ Needs precision measurements!

$\delta a_\mu^{exp} \rightarrow 1.5\ 10^{-10} = 0.2\%$ on a_μ^{HLO}

New g-2 exp.

e^+e^- data: current and future/activities



DAFNE-2: DAFNE upgraded in energy (up to 2-2.5 GeV) with a luminosity $\sim 10^{32}$ cm^{-2}s^{-1} ($\sim$5 pb^{-1} per day $\Leftrightarrow \sim$1 fb^{-1}/year)

Impact of DAFNE-2 on $(g-2)_\mu$

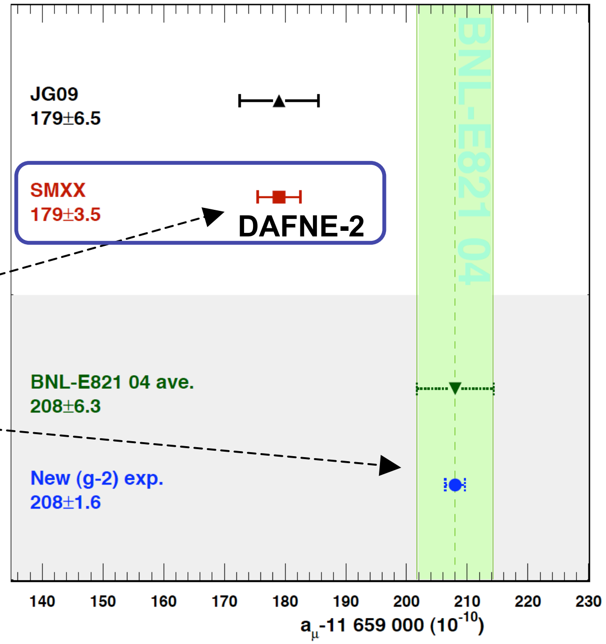
$a_\mu^{exp} - a_\mu^{theo,SM} = (27.7 \pm 8.4)10^{-10}$ (3.3σ) [Eidelman, TAU08]

$8.4 = \sim 5_{HLO} \oplus \sim 3_{HLbL} \oplus 6_{BNL}$

$\downarrow$ 4 $\quad$ $2.6_{DAFNE-2}$ $\quad$ 2.5 $\quad$ $1.6_{NEW\ G-2}$

7-8σ

(if 27.7 will remain the same)



$\delta a_\mu^{HLO} = 5.3 = 3.3(\sqrt{s}<1GeV) \oplus 3.9(1<\sqrt{s}<2GeV) \oplus 1.2(\sqrt{s}>2GeV)$

$\delta a_\mu^{HLO} \rightarrow$ **2.6**$=1.9\ (\sqrt{s}<1GeV) \oplus$ **1.3 ($\sqrt{s}<1GeV$)** $\oplus 1.2(\sqrt{s}>2GeV)$

This means:

$\delta\sigma_{HAD} \sim 0.4\%$ $\sqrt{s}<1GeV$ (instead of 0.7% as now) *With ISR at 1 GeV*

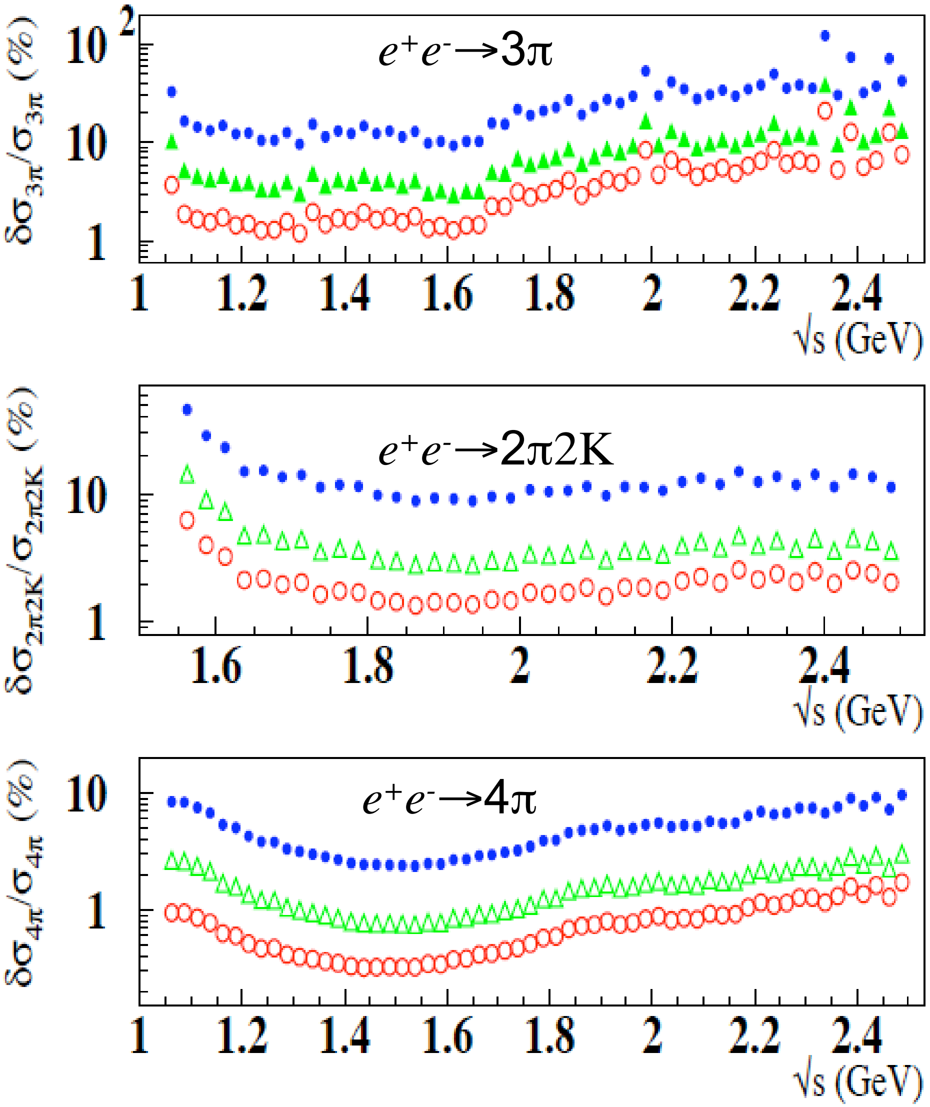
$\delta\sigma_{HAD} \sim 2\%$ $1<\sqrt{s}<2GeV$ (instead of 6% as now) *With Energy Scan 1-2 GeV*

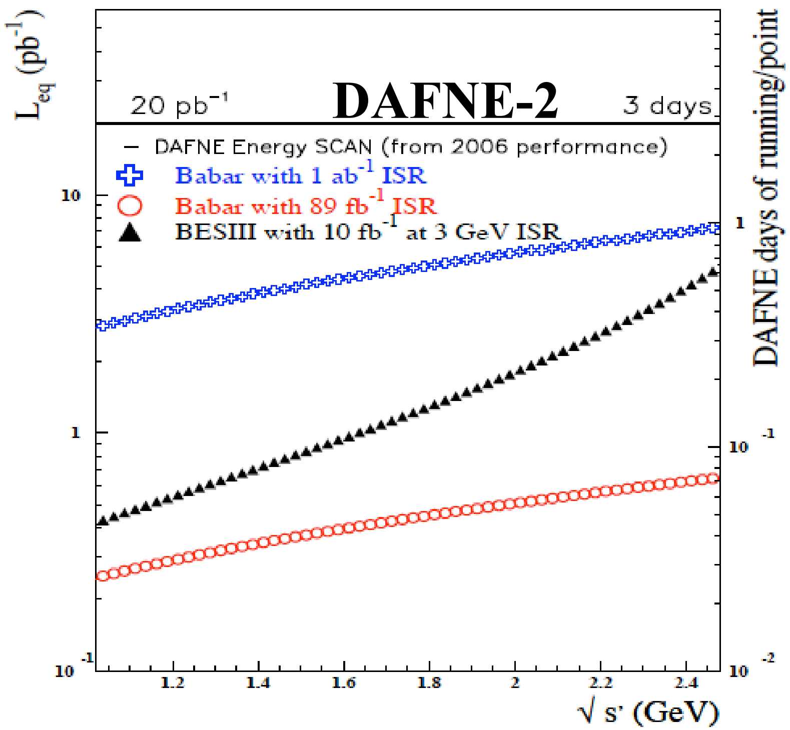
Possible at DAFNE-2!

Precise measurement of σ_{HAD} at low energies very important also for $\alpha_{em}(M_Z)$ (necessary for ILC) !!!

Impact of DAFNE-2 on exclusive channels in the range [1-2.5] GeV with a scan (Statistics only)

- **Published BaBar results:89 fb^{-1}(ISR)**
- ▲ **"BaBar" × 10 (890 fb^{-1})**
- o **KLOE-2 energy scan: 20 pb^{-1}/point @ L= 10^{32} cm^{-2} s^{-1}, 25 MeV bin ⇒ 1 year data-taking**





DAFNE-2 is **statistically** equivalent to 5÷10 ab^{-1} B-factories

Proposal for taking data with the KLOE-2 Detector at the DAΦNE collider upgraded in energy

LNF Note 10/17(P)
June 2010

Abstract

This document reviews the physics program of the KLOE-2 detector at DAΦNE upgraded in energy and provides a simple solution to run the collider above the ϕ-peak (up to $\sim$ 2, possibly 2.5 GeV). It is shown how a precise measurement of the multihadronic cross section in the energy region up to 2 (possibly 2.5) GeV will have a major impact on the tests of the Standard Model through a precise determination of the anomalous magnetic moment of the muon and the effective fine-structure constant at the M_Z scale. With a luminosity of $\sim 10^{32}\text{cm}^{-2}\text{s}^{-1}$, DAΦNE upgraded in energy can perform a scan in the region from 1 to 2.5 GeV in one year, by collecting an integrated luminosity of 20 pb^{-1} for single point (corresponding to few days of data taking), assuming an energy step of 25 MeV. A few years of data taking in this region would provide important tests of QCD and effective theories by $\gamma\gamma$ physics with open thresholds for pseudo-scalar (like the η'), scalar (f_0, f_0', etc...) and axial-vector (a_1, etc...) mesons; vector-mesons spectroscopy and baryon form factors, tests of CVC, and searches for exotics. In the final part of the document a technical solution for the energy upgrade of DAΦNE is proposed.

Proposal supported by LNF (Research and Accelerator Division) together with national and foreign institutes

Conclusions

❑ KLOE has performed the first precision measurement of $\sigma_{\pi\pi}$ in the region 0.35 - 0.95 GeV^2 with ISR → 1.3% systematic error (KLOE05, ***PLB 606, 12 (2005)***)

- ***discrepancy*** *between a_μ^{SM} and BNL experiment (~3σ)*

❑KLOE has presented a new measurement in 2008 (KLOE08, ***Phys. Lett. B 670, 285 (2009)***) with a different data sample using the same selection of KLOE05 (photon at small angle) →0.9% systematic error

- *KLOE08 confirms the **discrepancy** of ~3σ between a_μ^{SM} and a_μ^{EXP}*
- *KLOE08 **$a_\mu^{\pi\pi}$** agrees with recent results from CMD2 and SND experiments. Reasonable agreement on $\sigma_{\pi\pi}$ shapes*

❑KLOE has presented a new measurement of $\sigma_{\pi\pi}$ in 2009 (KLOE09) in the range 0.1- 0.85 GeV^2 using data taken at 1.0 GeV (20 MeV below the ϕ–peak), with a different selection of KLOE08 → 1.0% systematic error

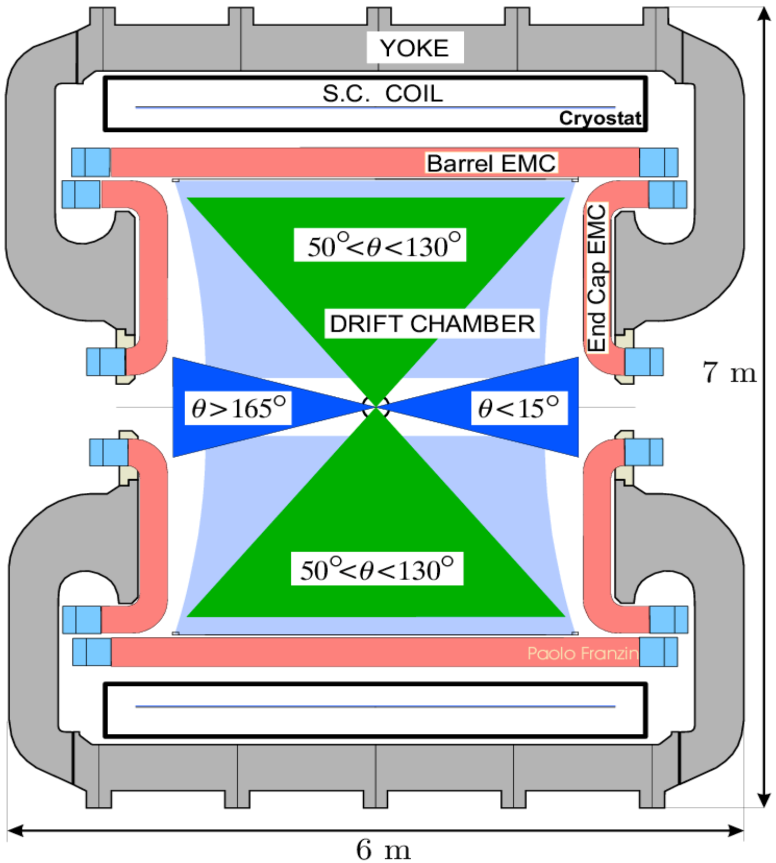
- *Very good agreement with KLOE08 in the overlapping region (0.35-0.85 GeV^2). Combination of the two measurements done*
- *Agreement within errors with BaBar below 0.6 GeV; BaBar lies higher (2-3%) above*

Outlook

- Measurement of $\sigma_{\pi\pi}$ from $\pi\pi\gamma/\mu\mu\gamma$ ratio well advanced.
  - Comparison of $\mu\mu\gamma_{DATA}/\mu\mu\gamma_{MC}$ will provide a consistency test for Radiatior, Luminosity, FSR etc…
  - Results are expected soon

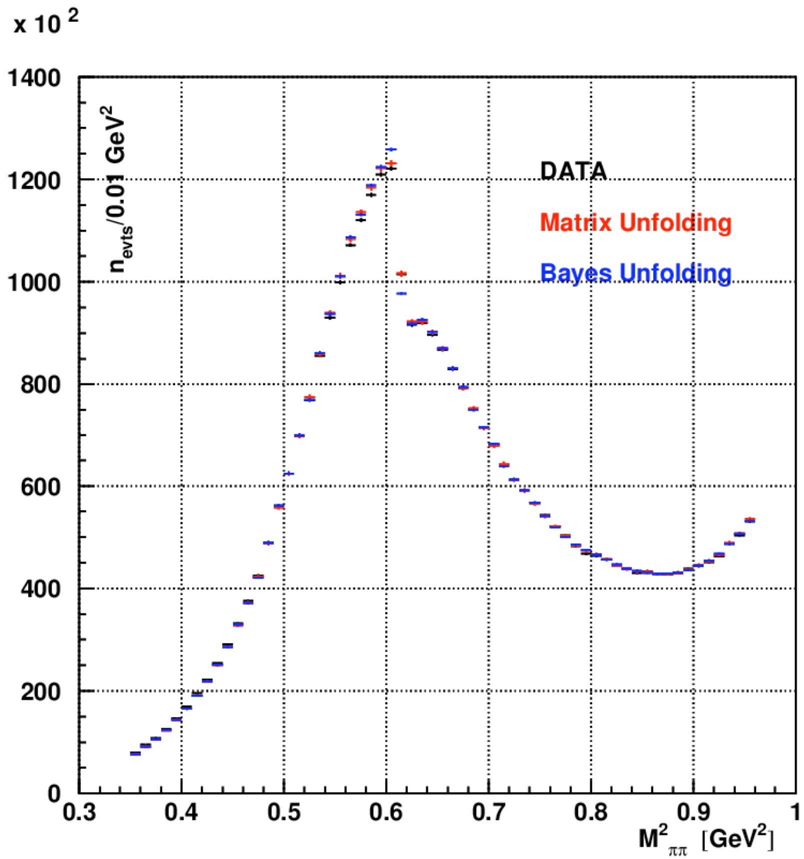
- Still about 1.5 fb^{-1} of KLOE from 2004/2005 data to be analyzed (3 times the statistics used up to now)

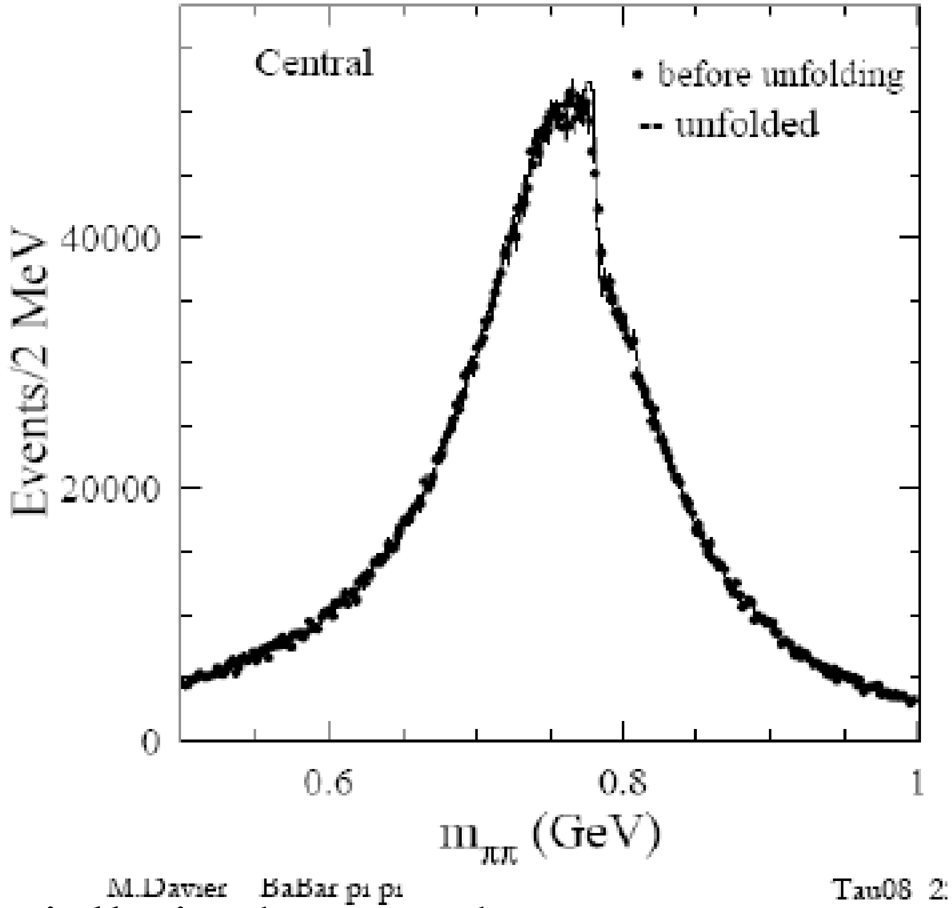
- Very important for a_μ also the region between 1 and 2 GeV. Already a lot has been done from BaBar and Belle with ISR, and more will come also from BES-III. To reach the ultimate precision of 1-2% projects like KLOE-2 at DAFNE-2 (DAFNE upgraded in energy) will be essential.



SPARE SLIDES

Unfolding: KLOE vs BaBar 2π





Large effect for BaBar especially in the ρ peak.

Essentially no effect for KLOE

Cross section data:

At low energies (< 2 GeV) only measurements of exclusive channels, two approaches:

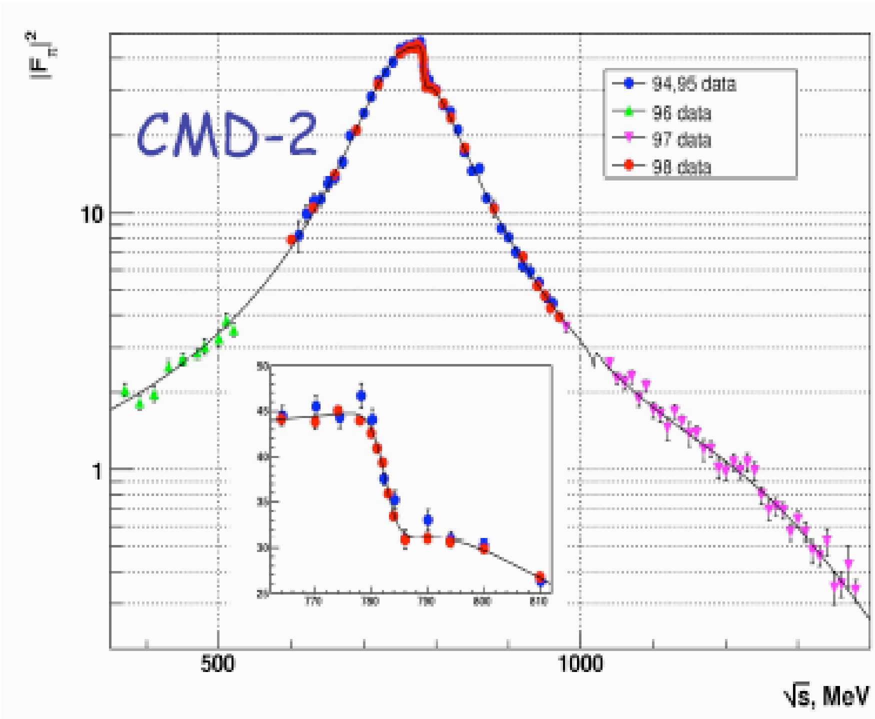
Energy scan (CMD2, SND):

- energy of colliding beams is changed to the desired value
- "direct" measurement of cross sections
- needs dedicated accelerator/physics program
- needs to measure luminosity and beam energy for every data point

Radiative return (KLOE, BABAR, BELLE):

- runs at fixed-energy machines (meson factories)
- use initial state radiation process to access lower lying energies or resonances
- data come as by-product of standard physics program
- requires precise theoretical calculation of the radiator function
- luminosity and beam energy enter only once for all energy points
- needs larger integrated luminosity

Pion form factor @ Novosibirsk (with energy scan)

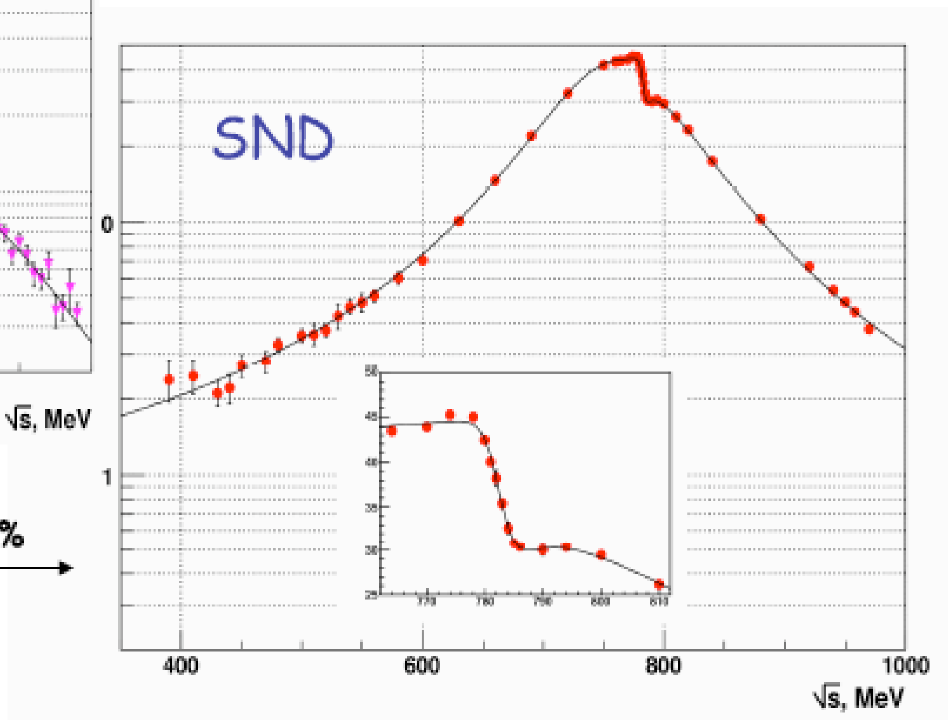


Systematic error

0.7% 0.6% / 0.8% 1.2-4.2%

CMD-2 ~ $9 \cdot 10^5$ ev.

SND ~ $8 \cdot 10^5$ ev.



Systematic error

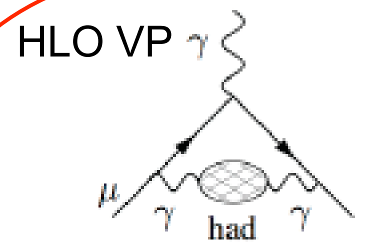
3.2% 1.3% 8

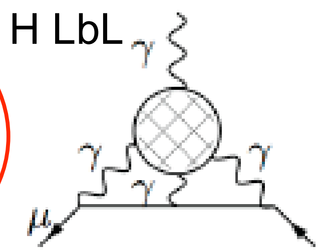
Good agreement between the two spectra

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 ($4 \div 5 \times 10^{-10}$) and HLbL ($[2.5 \div 4] \times 10^{-10}$)
•Experimental error δa_μ^{EXP} ~6×10^{-10}(E821). Plan to reduce it to $1.5\ 10^{-10}$ by the new g-2 experiment @FNAL (and also by new project @ J-PARC)





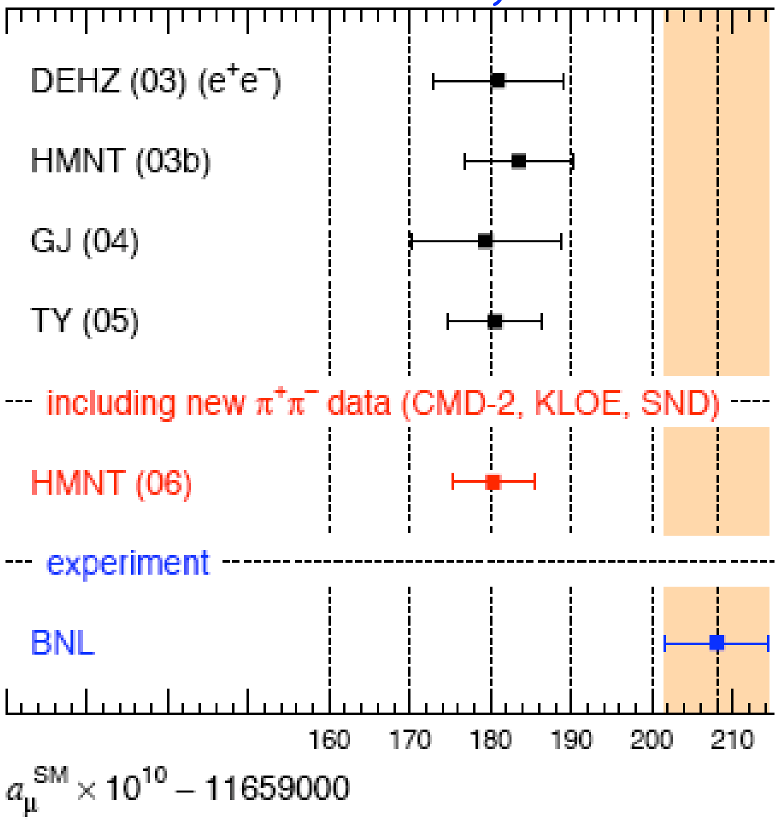
a_μ^{HLO} = (690.9±**4.4**)10^{-10}
[Eidelman, TAU08]

δa_μ^{HLO} ~0.7%

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

a_μ^{SM} compared to BNL world av.

T.Teubner, PHIPSI08



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

a_μ^{HLO}:

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

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

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

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

$e^+e^- \rightarrow \pi^+\pi^-$

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

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

a) Via absolute Normalisation to VLAB Luminosity (as in 2005 analysis):

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 $d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ via theoretical radiator function H(s):

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

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 *(analysis is in a well advanced phase, see later)*

Test of Final State Radiation model by measurement of the Forward-Backward asymmetry in $e^+e^- \to \pi^+\pi^-\gamma$ process

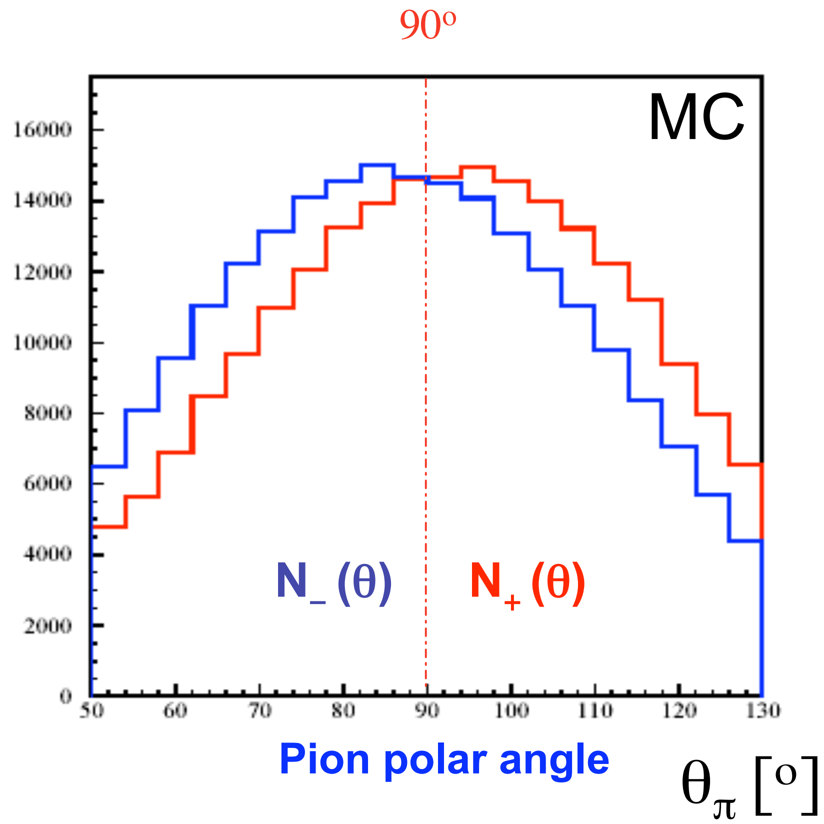
Forward-backward asymmetry:

In the case of a non-vanishing FSR contribution, the interference term between ISR and FSR is odd under exchange $\pi^+ \leftrightarrow \pi^-$ .This gives rise to a non-vanishing ***asymmetry***:

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

Forward-backward asymmetry:

$$A = \frac{N(\theta^+ > 90^o) - N(\theta^+ < 90^o)}{N(\theta^+ > 90^o) + N(\theta^+ < 90^o)}$$



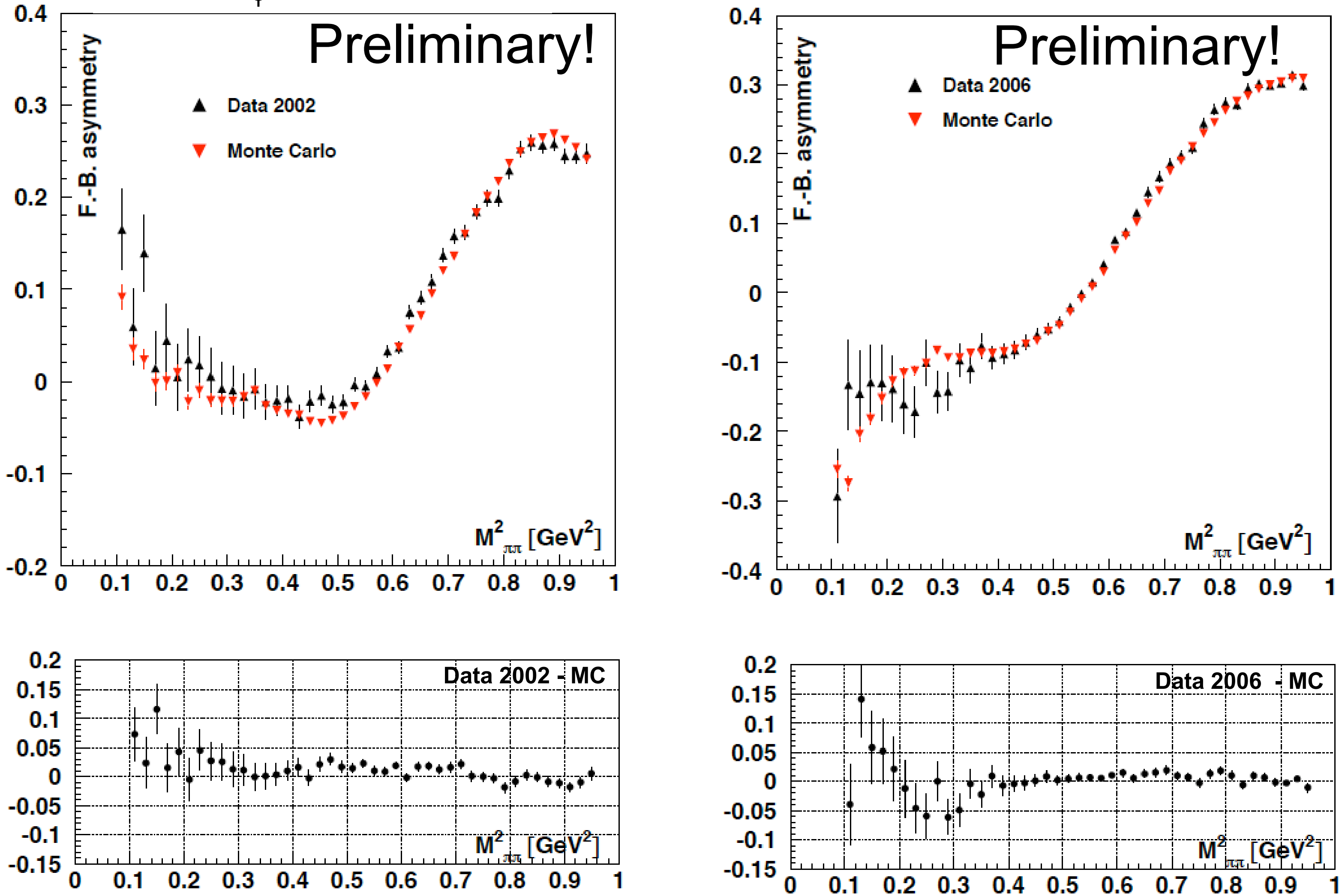
Ideal tool to test the validity of models used in Monte Carlo to describe the pionic final state radiation (point-like pion assumption, RχT, etc.)

In a similar way like FSR, radiative decays of the ϕ into scalar mesons decaying to $\pi^+\pi^-$ also contribute to the asymmetry.

Czyz, Grzelinska, Kühn, hep-ph/0412239

Forward-backward asymmetry:

$\sqrt{s} = m_\phi \approx 1.0195$ GeV $\sqrt{s} \approx 1.000$ GeV



PHOKHARA-MC modified by O. Shekhovtsova using Kaon-Loop-Model used in KLOE analysis of $\pi^0\pi^0\gamma$ final state (reference)

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) >> $\delta M_{\pi\pi}^2 \sim 2\ 10^{-3}\ GeV^2$

$\Rightarrow$ Unfolding only relevant at low $M_{\pi\pi}^2$ (up to 4%) and at $\rho-\omega$ 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)
- 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

$\Rightarrow$ Larger effects on the unfolding

- Negligible contribution of LO FSR, % contribution of NLO FSR($1\gamma_{ISR}+1\gamma_{FSR}$)
- Normalize to $\mu\mu\gamma$
- 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)

DAFNE Energy upgrade scheme (P. Raimondi)

- Dafne injection scheme limits the beam energy to 540 MeV. An increase of this energy requires major changes, and seems not feasible.

  ⇒ The most reasonable solution is to inject in Dafne at the "nominal" energy of about 510MeV and then ramp the energy up to desired one

  The Quad's around the interaction region must be replaced by superconductive ones (now they are permanent)

  ⇒ In this way 1.4 GeV total energy can be reached.
- In order to achieve higher energy (2 GeV) the dipoles in the main rings must be replaced.
- Assuming $L \sim 10^{32}$ cm^{-2} s^{-1} and 50% duty cicle (due to ramping time) →5pb^{-1}/day can be reached (1fb^{-1}/year).
- Cost estimate: O(10) Meur (up to ~2 GeV)

  Needs a detailed work

$\Delta a_\mu^{\pi\pi}$ for different exp.:

$\Delta a_\mu^{\pi\pi}$(0.35-0.85GeV²):

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int_{x_1}^{x_2} \sigma^{had}(s) K(s)\, ds$$

KLOE08 (small angle)

$a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (large angle)

$a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

0.2% 0.6% 0.6%

$\Delta a_\mu^{\pi\pi}$ for different exp.:

$\Delta a_\mu^{\pi\pi}(0.35\text{-}0.85 GeV^2)$:

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int_{x_1}^{x_2} \sigma^{had}(s) K(s)\, ds$$

KLOE08 (small angle) — $a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (large angle) — $a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

0.2% 0.6% 0.6%

$\Delta a_\mu^{\pi\pi}(0.152\text{-}0.270 GeV^2)$:

KLOE09 (large angle) — $a_\mu^{\pi\pi} = (48.1 \pm 1.2_{stat} \pm 1.2_{sys} \pm 0.4_{theo}) \cdot 10^{-10}$

CMD-2 — $a_\mu^{\pi\pi} = (46.2 \pm 1.0_{stat} \pm 0.3_{sys}) \cdot 10^{-10}$

$\Delta a_\mu^{\pi\pi}$ for different exp.:

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int_{x_1}^{x_2} \sigma^{\text{had}}(s)\,K(s)\,ds$$

$\Delta a_\mu^{\pi\pi}$(0.35-0.85GeV²):

KLOE08 (small angle) — $a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (large angle) — $a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

0.2% 0.6% 0.6%

$\Delta a_\mu^{\pi\pi}$(0.152-0.270 GeV²):

KLOE09 (large angle) — $a_\mu^{\pi\pi} = (48.1 \pm 1.2_{stat} \pm 1.2_{sys} \pm 0.4_{theo}) \cdot 10^{-10}$

CMD-2 — $a_\mu^{\pi\pi} = (46.2 \pm 1.0_{stat} \pm 0.3_{sys}) \cdot 10^{-10}$

$\Delta a_\mu^{\pi\pi}$(0.397-0.918 GeV²):

KLOE08 (small angle) — $a_\mu^{\pi\pi} = (356.7 \pm 0.4_{stat} \pm 3.1_{sys}) \cdot 10^{-10}$

CMD-2 — $a_\mu^{\pi\pi} = (361.5 \pm 1.7_{stat} \pm 2.9_{sys}) \cdot 10^{-10}$

SND — $a_\mu^{\pi\pi} = (361.0 \pm 2.0_{stat} \pm 4.7_{sys}) \cdot 10^{-10}$

BaBar — $a_\mu^{\pi\pi} = (365.2 \pm 1.9_{stat} \pm 1.9_{sys}) \cdot 10^{-10}$