KLOE: New Analysis Results

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on behalf of the KLOE Collaboration

- Kaon physics
- Hadronic physics @ $\sqrt{s} = M_\phi$
- Hadronic physics @ $\sqrt{s} = 1$ GeV

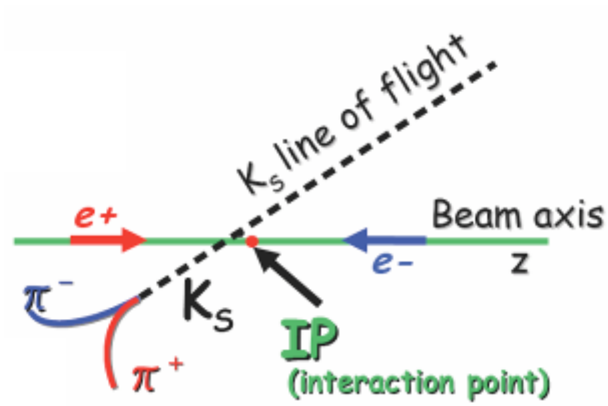
39th LNF Scientific Committee – LNF, 26 October 2009

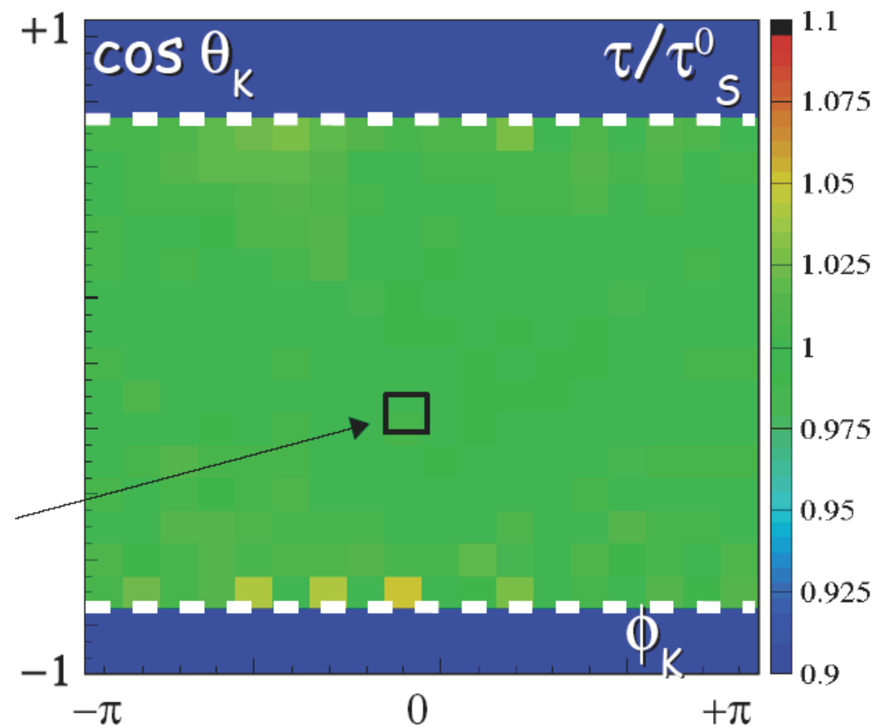
Kaon physics: progress since last SC

$\Gamma(K\rightarrow e\nu(\gamma))/\Gamma(K\rightarrow \mu\nu(\gamma))$	Accepted for publication (EPJC)
K_S lifetime	Preliminary
K_L lifetime	Preliminary
$K_S \rightarrow \pi^0\pi^0\pi^0$	Update with all statistics in progress
BR($K^\pm \rightarrow \pi^\pm\pi^+\pi^-$)	In progress

K_S lifetime: measurement technique

- Lifetime from fit to proper time, t_0, distribution of $K_S \to \pi^+\pi^-$ events
- ϕ position event by event from PCA of K_L flight direction to beamline ($\sigma(Z_{IP})= 0.2$ cm while beam spread ~ 3 cm)
- Redundant measurement of K_S momentum (from tracks / line of flight and $\sqrt{s}$)
- Factor 3.5 improvement on t_0 by means of geometrical fit (K_S direction fixed, IP position and decay distance free)





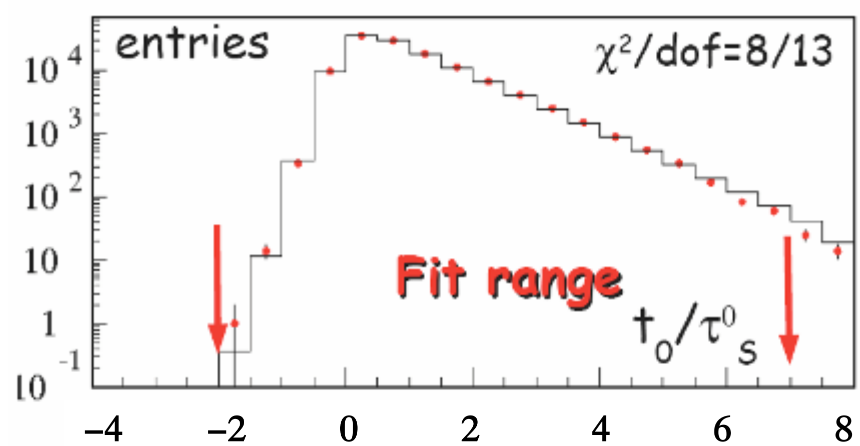
Lifetime obtained from a weighted average on 270 independent fits

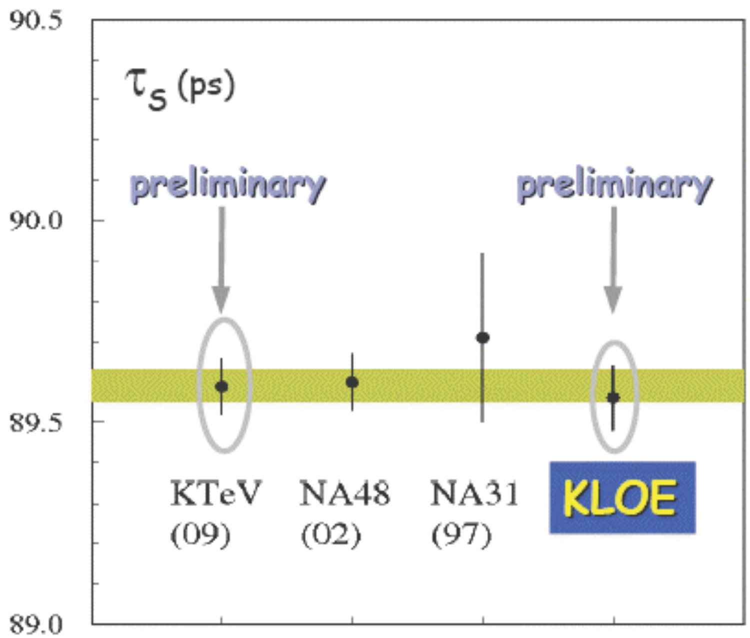
K_S lifetime: results

PRELIMINARY

730 pb^{-1} → 25 million events after all cuts

- Results as function of K_S direction (different resolution)
- Fit range: (–2 ,+7) τ^0_S
- Resolution described by two gaussians
- 5 parameters fit: τ_S + resolution





τ_S= (89.56 ± 0.03$_{stat}$ ± 0.07$_{syst}$) ps

New world average:

τ_S = (89.59 ±0.04) ps

[4.6×10^{-4} error w.r.t. PDG08 5.6×10^{-4}]

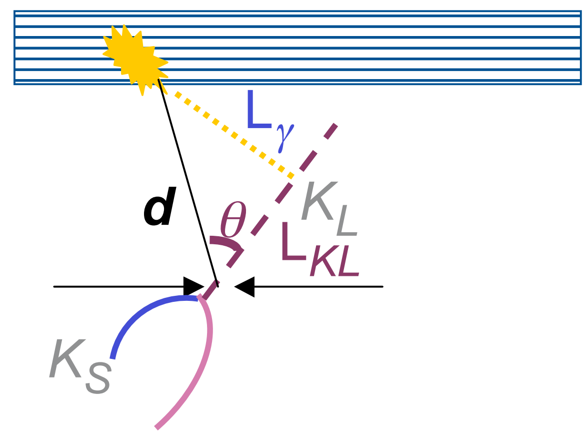
K_L lifetime

The error on τ_L is the main limiting factor on V_{US} accuracy from K_L decays

$\frac{\delta(V_{us}f_+(0))}{(V_{us}f_+(0))}$ =	0.1 %	$\oplus$	0.2 %	$\oplus$	0.1%	$\oplus$	0.1%
	BR		τ_L		phases space integral		radiative corrections

τ_L measurement can be improved (stat.+syst.) with whole KLOE data sample

- K_L tagged with $K_S \to \pi^+\pi^-$ vertex at IP
- K_L direction and momentum from DC measurements
- Unique to the KLOE calorimeter: L_{KL} and L_γ by time measurements t_γ



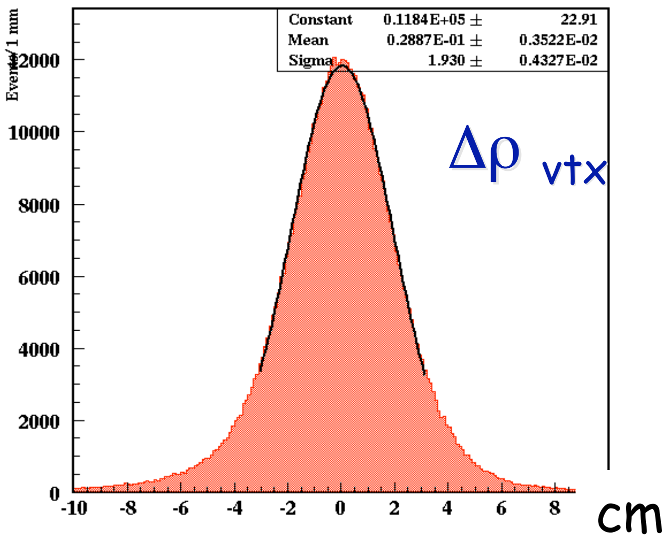
$$L_\gamma^2 = d^2 + L_{KL}^2 - 2d\, L_{KL} \cos\theta$$

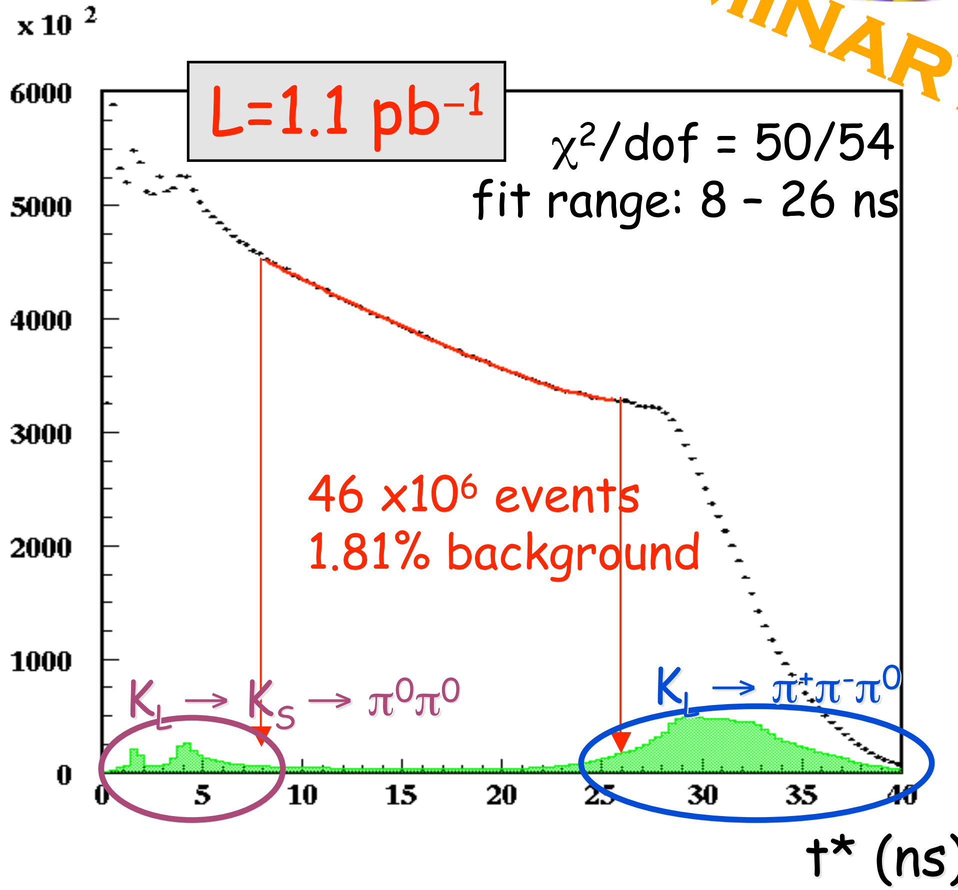
$$c\, t_\gamma = L_{KL} / \beta_L + L_\gamma$$

K_L lifetime: results

PRELIMINARY

- K_L "photon" vertex, built with at least 3 γ's from $3\pi^0$ decay
- Time scale, neutral vtx resolution, γ reconstruction efficiency surveyed with $K_L \to \pi^+\pi^-\pi^0$ events





$\tau_L = (50.56 \pm 0.14_{stat} \pm 0.21_{syst})$ ns

Whole data sample: $\sigma_{stat} \to 0.11$ ns

Work in progress to reduce systematics

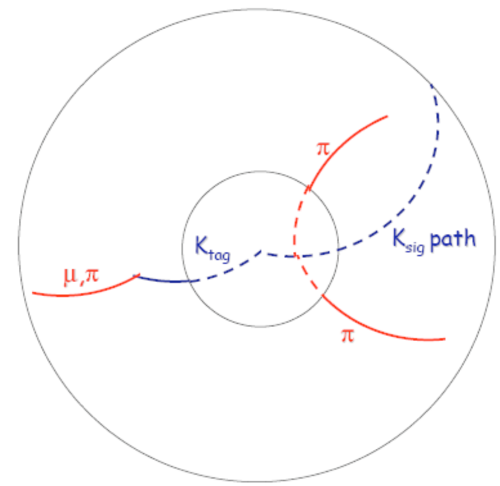
KLOE

τ_L = 50.92(30) ns	PLB 626 (2005)
τ_L = 50.72(36) ns	PLB 632 (2006)

BR($K^+ \rightarrow \pi^+\pi^-\pi^+(\gamma)$)

- ❖ Completes the KLOE program of precise and fully inclusive $K^\pm$ dominant BRs
- ❖ Available measurement from 70s, with no information on rad. cut-off:

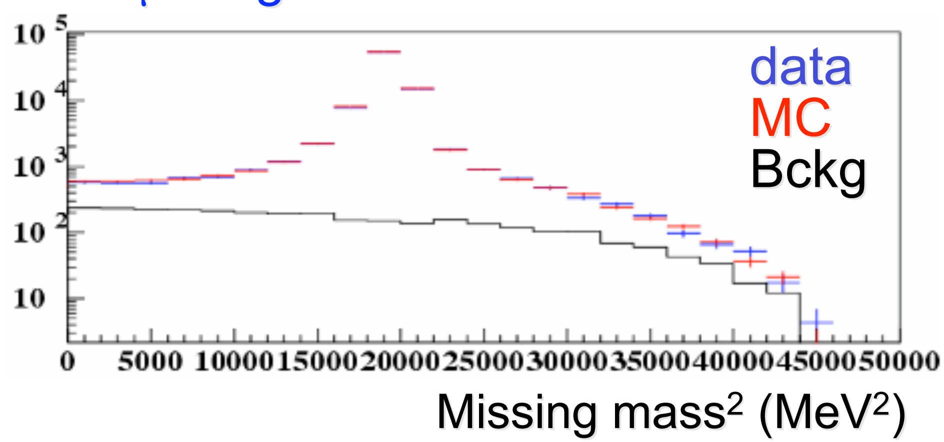
CHIANG $_{(2330\ evts)}$: BR($K \rightarrow \pi^+\pi^-\pi^+$) = (5.56 ± 0.20)%
ΔBR/BR = 3.6×10^{-2}



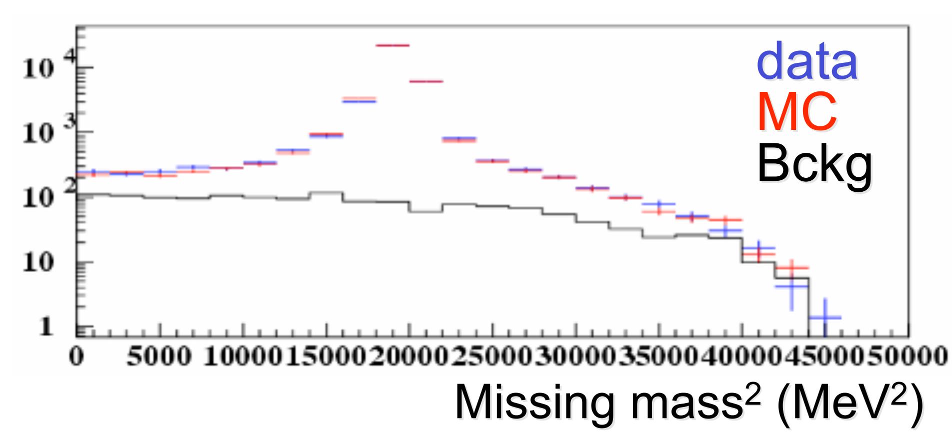
Signal selection

- ➢ 2-tracks vertex before DC inner wall and along the K path obtained from backward extrapolation of the tagging kaon track to the I.P.
- ➢ Signal peak in the missing mass spectrum (~m_π^2)

$K \rightarrow \mu\nu$ tag: ≈ 60000 $K^+ \rightarrow 3\pi$ events



$K \rightarrow \pi\pi^0$ tag: ≈ 25000 $K^+ \rightarrow 3\pi$ events



$BR(K^+ \to \pi^+\pi^-\pi^+(\gamma))$

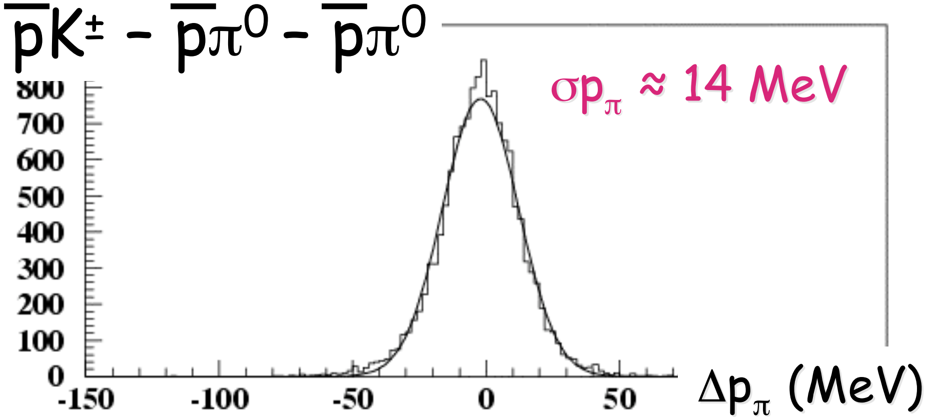
Signal selection efficiency from MC and folded with $\frac{\varepsilon_{\text{single trk}}(\text{data})}{\varepsilon_{\text{single trk}}(\text{MC})}$

$K \to \pi\,\pi^0\pi^0$ control sample to measure $\varepsilon_{\text{single trk}}$

Control sample selection

- K path from the tagged K track and ϕ kinematics
- Reconstruct neutral vertex $K \to \pi^0\pi^0 X$ decays looking for 4 γ's with time measurements consistent with the Kaon ToF

$\overline{p}_{\pi^\pm} = \overline{p}_{K^\pm} - \overline{p}_{\pi^0} - \overline{p}_{\pi^0}$



The purity of the sample is ≅ 99%

Hadronic physics: progress since last SC

$\phi \to K_S K_S \gamma$	PLB 679 (2009) 10
$\phi \to a_0(980)\ \gamma$	PLB 681 (2009) 5
Gluonium content in η'	JHEP 07 (2009) 105
$\eta \to \pi^0\pi^0\pi^0$	Final, paper in preparation
$\eta \to \pi^+\pi^-\gamma$	Prel. BR evaluation, $M_{\pi\pi}$ study in progress
$\eta \to \pi^+\pi^- e^+ e^-$	PLB 675 (2009) 283
$\eta \to e^+ e^- e^+ e^-$	First observation
$\eta \to \mu^+\mu^-$	Analysis tuning
$\gamma\gamma \to \pi^0\pi^0$	Analysis refined with all off-peak data
$\gamma\gamma \to \eta$	New search
$\sigma(\pi\pi\gamma)$ large angle, off-peak data	Final, paper in preparation
$\sigma(\pi\pi\gamma)/\sigma(\mu\mu\gamma)$	In progress

$\eta\rightarrow\pi^+\pi^-\gamma$: motivations

- ✓ Significant contribution from the chiral anomaly responsible of $\eta\rightarrow\gamma\gamma$ decay is expected. Study of the two pion system allows for test of ChPT and its unitarized extensions (e.g. VMD or chiral unitarity approach) → **$M_{\pi\pi}$ shape needed**

- ✓ Existing data, low in statistics and not acceptance corrected, not sufficient for unambiguous theoretical interpretation

- ✓ Latest result from CLEO on $\Gamma(\eta\rightarrow\pi\pi\gamma)/\Gamma(\eta\rightarrow\pi\pi\pi)$ differs >3σ from old measurements

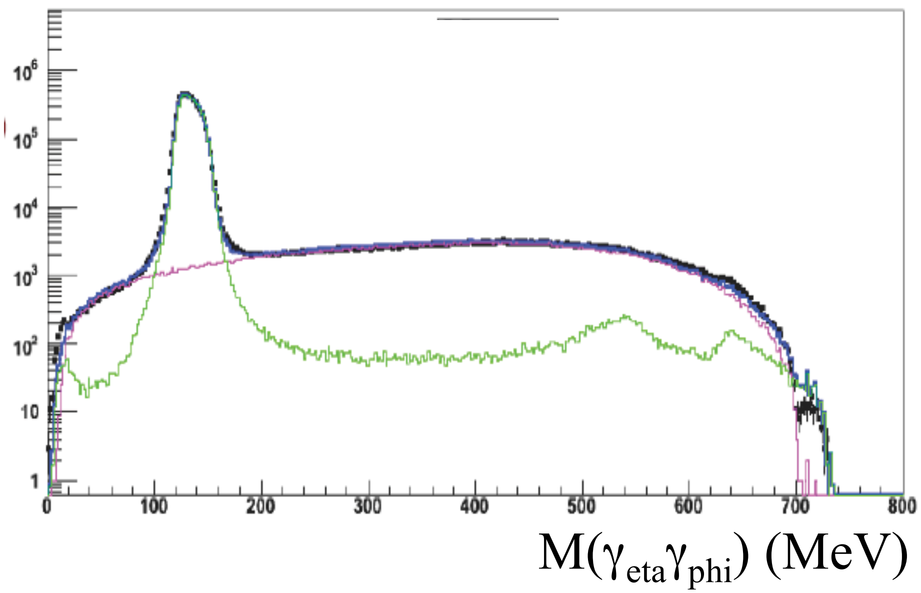
$\Gamma(\eta\rightarrow\pi^+\pi^-\gamma)\,/\,\Gamma(\eta\rightarrow\pi^+\pi^-\pi^0)$

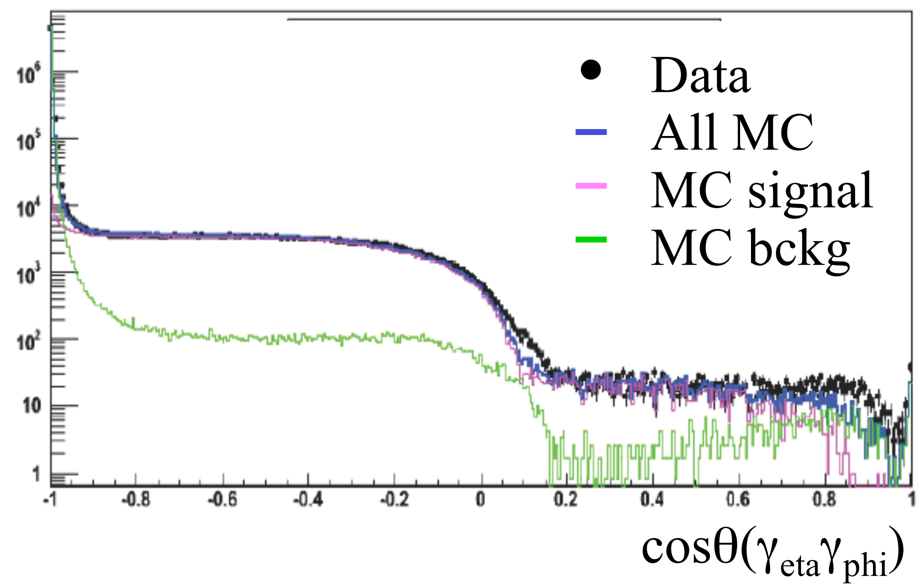
value	events	author	year
0.203 ± 0.008	PDG average		
0.175 ± 0.007 ± 0.006	859	Lopez	2007
0.209 ± 0.004	18 k	Thaler	1973
0.201 ± 0.006	7250	Gormley	1970

$\Gamma(\eta\to\pi^+\pi^-\gamma)/\Gamma(\eta\to\pi^+\pi^-\pi^0)$

- DATA SAMPLE: **1.2 fb^{-1}**
- Kinematical cuts to remove all bckg but $\phi\to\pi^+\pi^-\pi^0$:

  ε = 29%, BKG/SIG=10:1
- Different topology in $\gamma\gamma$ distributions for signal and background
- Simultaneous fit to both spectra to extract signal





$\eta\to\pi^+\pi^-\pi^0$ selected with high efficiency (40%) and BKG/SIG=0.5%

$\Gamma(\eta\to\pi^+\pi^-\gamma)/\Gamma(\eta\to\pi^+\pi^-\pi^0)$

PRELIMINARY

$$\frac{\Gamma(\eta\to\pi^+\pi^-\gamma)}{\Gamma(\eta\to\pi^+\pi^-\pi^0)} = 0.2014 \pm 0.0004_{stat}$$

- **Preliminary result agrees with PDG average, confirming old results from 70s**

- We are evaluating systematics, aiming to reach ~ 1%

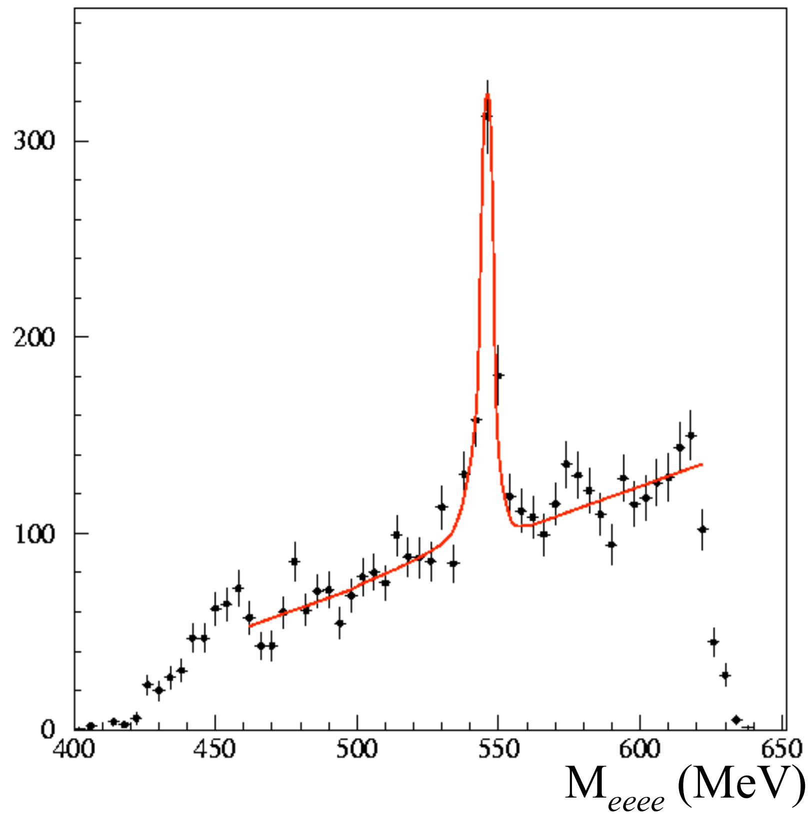
- Plan to use full KLOE data set to investigate the $\pi^+\pi^-$ invariant mass distribution: cuts on $M\gamma\gamma$ and $\cos\theta(\gamma\gamma)$ in the π^0 rest frame allow to reduce the background contribution to 2% with a signal efficiency of ~25%

$\eta \rightarrow e^+e^-e^+e^-$ analysis

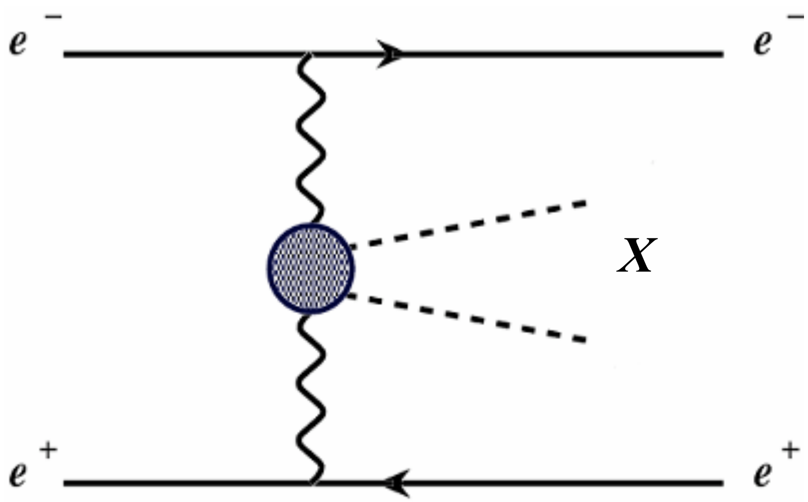
FIRST OBSERVATION!

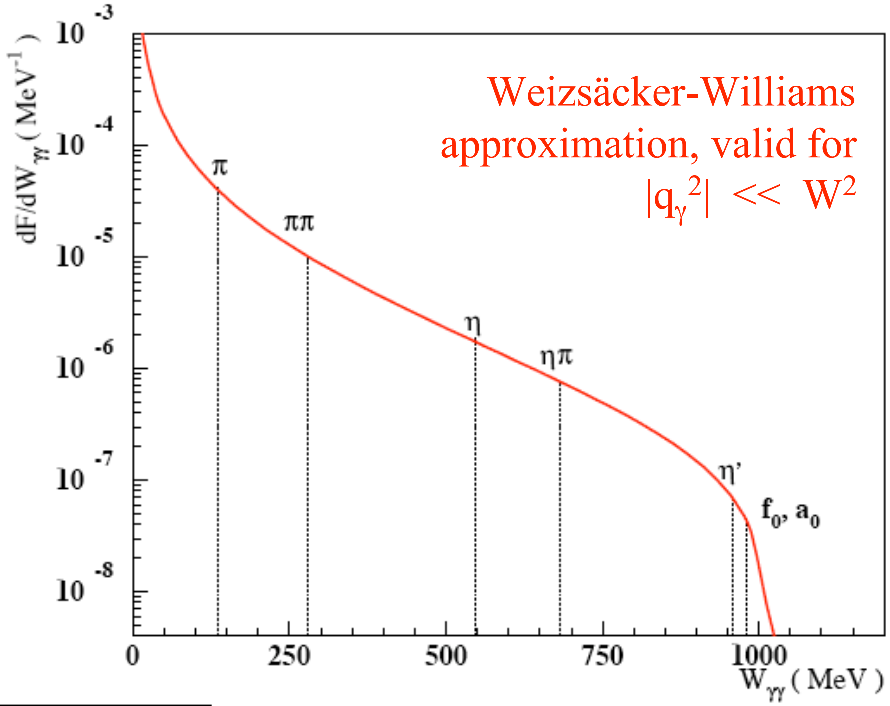
- Data sample: **1.7 fb^{-1}**
- MC simulation according to J.Bijnens and F. Persson, arXiv:0106130 (courtesy of J.Bijnens)
- FSR included
- e^+e^- pairs from photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from ϕ decays subtracted
- Fit to M_{eeee} distribution with MC signal + continuum background shapes yields:

$$N_{eeee} = 413 \pm 31$$



The $e^+e^- \to e^+e^-X$ process





$$N_{e^+e^-\to e^+e^-X} = L_{ee}\int \frac{dF_{\gamma\gamma}}{dW_{\gamma\gamma}}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})\,dW_{\gamma\gamma}$$

$$\sigma_{e^+e^-\to e^+e^-X} = \frac{16\alpha^2\Gamma_{X\gamma\gamma}}{m_X^3}\left(\ln\frac{E_b}{m_e}\right)^2\left((y^2+2)^2\ \ln\frac{1}{y} - (1-y^2)\ (3+y^2)\right)$$

$$y = m_X/(2E_b)$$

√s (GeV)	1
σ (e⁺e⁻ → e⁺e⁻ π⁰) (pb)	266
σ (e⁺e⁻ → e⁺e⁻ η) (pb)	43
σ (e⁺e⁻ → e⁺e⁻ η') (pb)	3.3

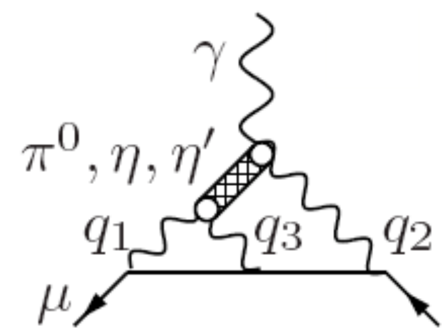
$e^+e^- \rightarrow e^+e^-\eta$: motivations

★ $\Gamma(\gamma\gamma)$ measurement

VALUE (keV)	EVTS	DOCUMENT ID		TECN	COMMENT	√s (GeV)
0.510±0.026 OUR FIT						
0.510±0.026 OUR AVERAGE						
0.51 ±0.12 ±0.05	36	BARU	90	MD1	$e^+e^- \rightarrow e^+e^-\eta$	7.2-10.4
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^- \rightarrow e^+e^-\eta$	29
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^- \rightarrow e^+e^-\eta$	9.4-10.6
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^- \rightarrow e^+e^-\eta$	34.6

★ **Transition form factors for light-by-light contributions (A. Nyffeler, J.Prades) to g-2…**

→ **KLOE-2 needed**



$$\sigma_{\gamma\gamma\rightarrow R}(q_1,q_2) \propto \Gamma_{R\rightarrow\gamma\gamma}\frac{8\pi^2}{M_R}\delta((q_1+q_2)^2 - M_R^2)\left|F(q_1^2,q_2^2)\right|^2$$

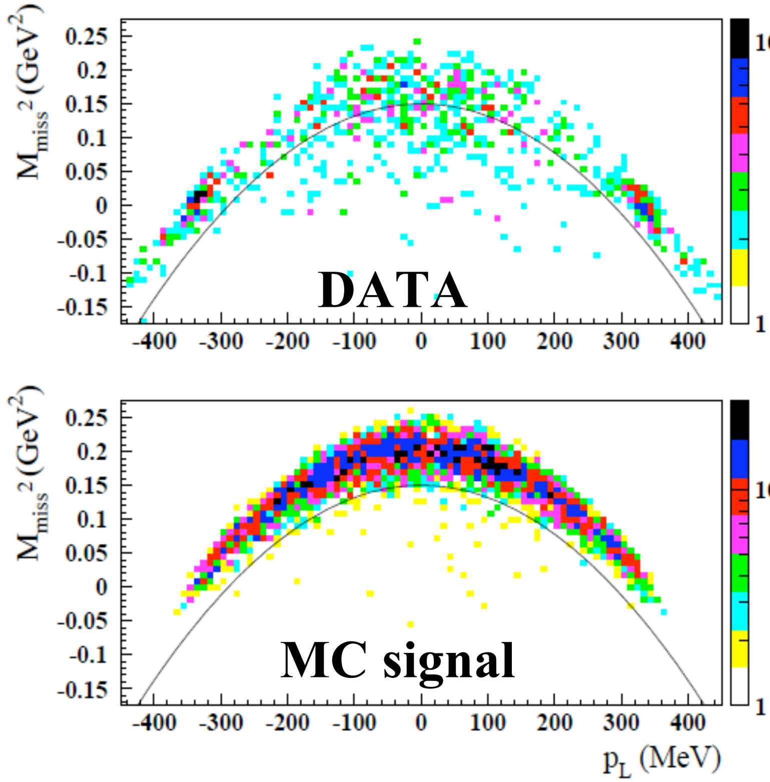
Selection of $e^+e^- \to e^+e^-\eta$ events

Data sample: 240 pb^{-1} @ $\sqrt{s}$ = 1 GeV

Selected channel: $\eta \to \pi^+\pi^-\pi^0$

- Two prompt neutral clusters
- Two tracks
- Photon pairing: $\chi^2_{\pi 0} < 8$
- Kinematic fit: $\chi^2_{\eta} < 16$
- Parabolic cut on:

$$M^2_{miss} \approx s + M^2_{\eta} - 2E_T\sqrt{s} - \frac{p^2_L}{E_T}\sqrt{s}$$



Signal: $\sigma = 0.043$ nb $\quad \varepsilon_{tot} = 20\%$

Backgrounds:

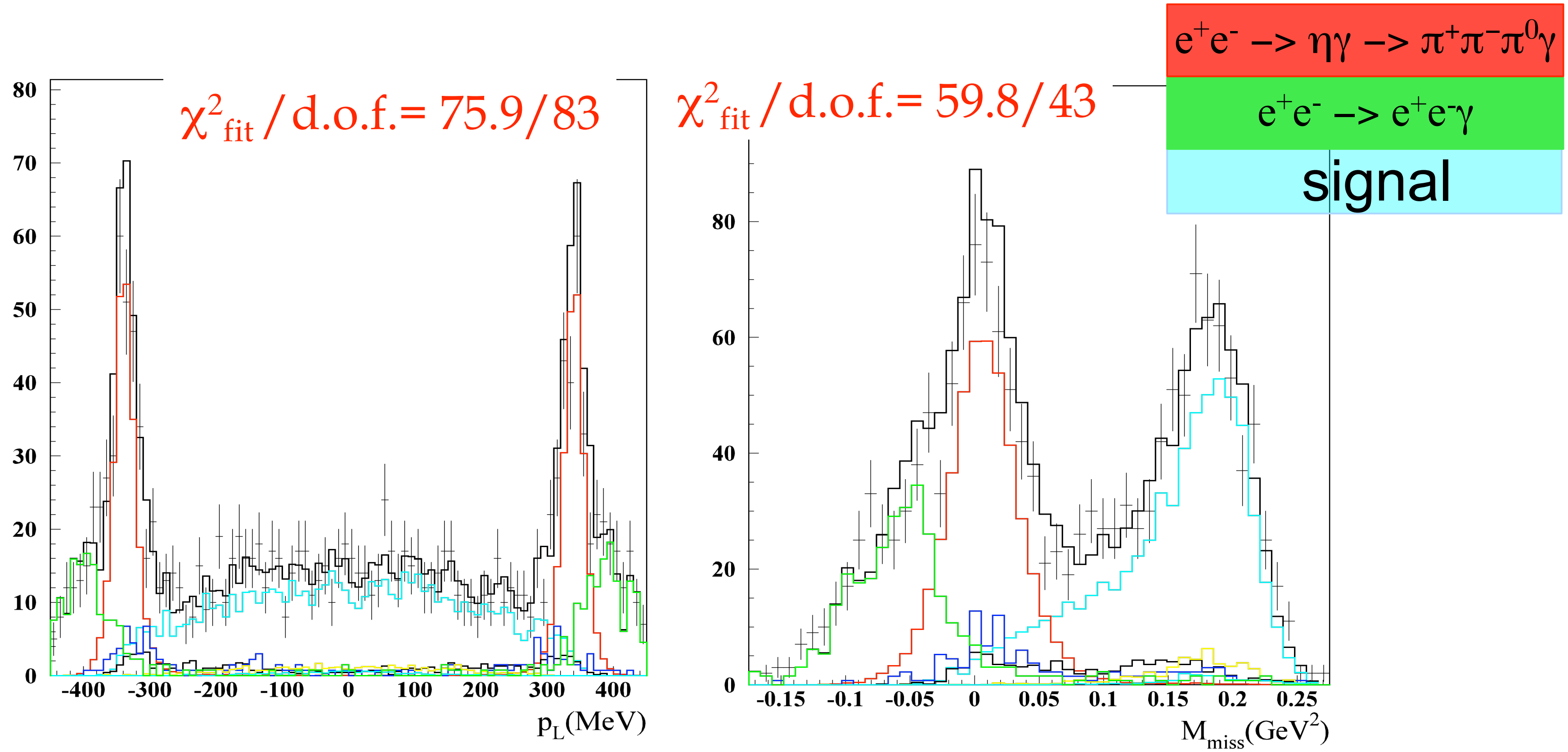
	$\eta\gamma$ $\eta \to \pi^+\pi^-\pi^0$	$\omega\pi^0$ $\omega \to \pi^+\pi^-\pi^0$	$\pi^+\pi^-\pi^0$	K^+K^- $\mu\nu,\ \pi^\pm\pi^0$	K_SK_L	$e^+e^-\gamma$
σ (nb)	0.23	5.7	30	8.6	2.0	400
ε	9.2×10^{-3}	6.3×10^{-5}	1.5×10^{-5}	1.9×10^{-5}	1.7×10^{-5}	$\mathcal{O}(10^{-7})$

$e^+e^-\to e^+e^-\eta$: fit results

PRELIMINARY

Fit to p_L and M_{miss}^2 with signal and background shapes

Background yields constrained by present knowledge of x-sections



Extraction of $\sigma(e^+e^-\to e^+e^-\eta)$ and $\Gamma_{\gamma\gamma}$ in progress

Statistical accuracy on $\Gamma_{\gamma\gamma}$ comparable with existing measurements

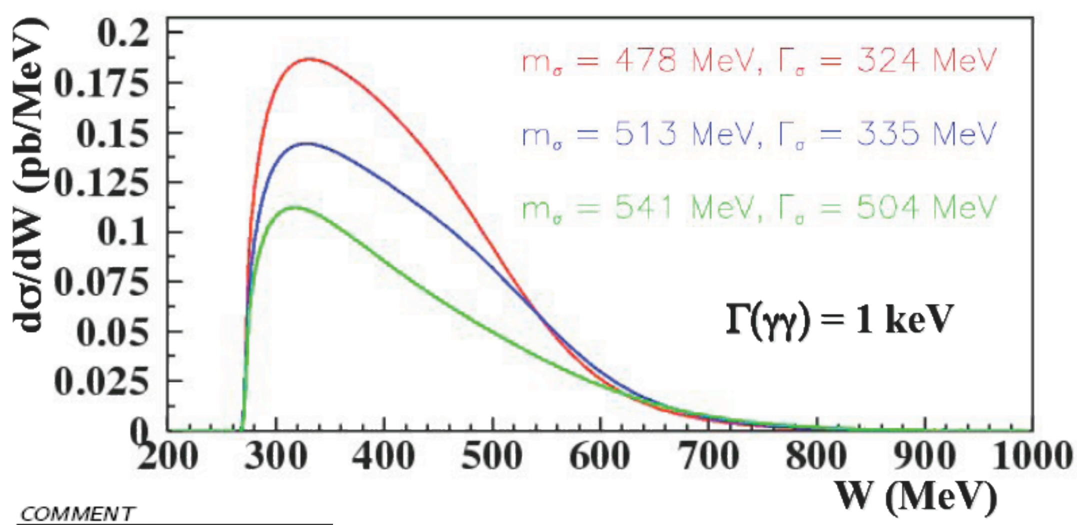
Search for $\gamma\gamma \to \sigma(600) \to \pi\pi$

- Long debate about the experimental evidence of the $\sigma(600)$ meson
- Evidence for $\pi^+\pi^-$ bound state (E791, CLEO, BES) from Dalitz plot analyses
- Values of mass and width with large uncertainties
- **Indirect evidence in the $e^+e^- \to \pi^0\pi^0\gamma$ Dalitz plot analysis @ KLOE**

Only process to measure directly the $\sigma\gamma\gamma$ coupling → infer structure

$\pi^0\pi^0$ preferred w.r.t. $\pi^+\pi^-$ due to smaller background contamination

BW shape folded with γγ flux function



$f_0(600)$ PARTIAL WIDTHS

$\Gamma(\gamma\gamma)$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.2 ± 0.4	[48] BERNABEU	08	RVUE	
3.9 ± 0.6	[49] MENNESSIER	08	RVUE	$\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0$
4.1 ± 0.3	[50] PENNINGTON	06	RVUE	$\gamma\gamma \to \pi^0\pi^0$
3.8 ± 1.5	[51,52] BOGLIONE	99	RVUE	$\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0$
5.4 ± 2.3	[51] MORGAN	90	RVUE	$\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0$
10 ± 6	COURAU	86	DM1	$e^+e^- \to \pi^+\pi^-e^+e^-$

Selection of $e^+e^-\rightarrow e^+e^-\pi^0\pi^0$ events

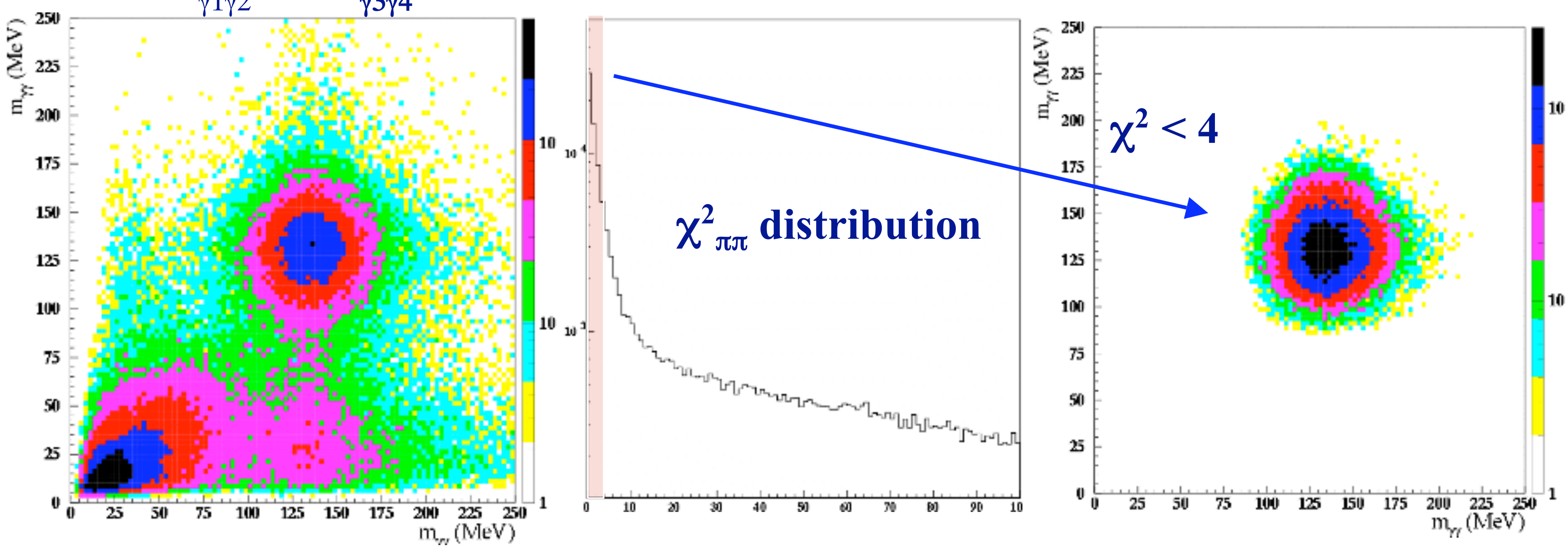
- Four prompt neutral clusters
- No tracks
- Photon pairing: $\chi^2_{\pi\pi} < 4$
- $\Sigma_{2Emin} > 60$ MeV
- $p_T < 80$ MeV

$$\chi^2_{\pi\pi} = \left(\frac{M_{ij} - m_{\pi 0}}{\sigma(E_i, E_j)}\right)^2 + \left(\frac{M_{lk} - m_{\pi 0}}{\sigma(E_l, E_k)}\right)^2$$

$$\frac{\sigma(E_i, E_j)}{M_{ij}} = \frac{1}{2}\left(\frac{\sigma_{E_i}}{E_i} \oplus \frac{\sigma_{E_j}}{E_j}\right)$$

$$M_{ij}^2 = 2E_iE_j(1-\cos\theta_{ij})$$

$m_{\gamma 1\gamma 2}$ vs. $m_{\gamma 3\gamma 4}$



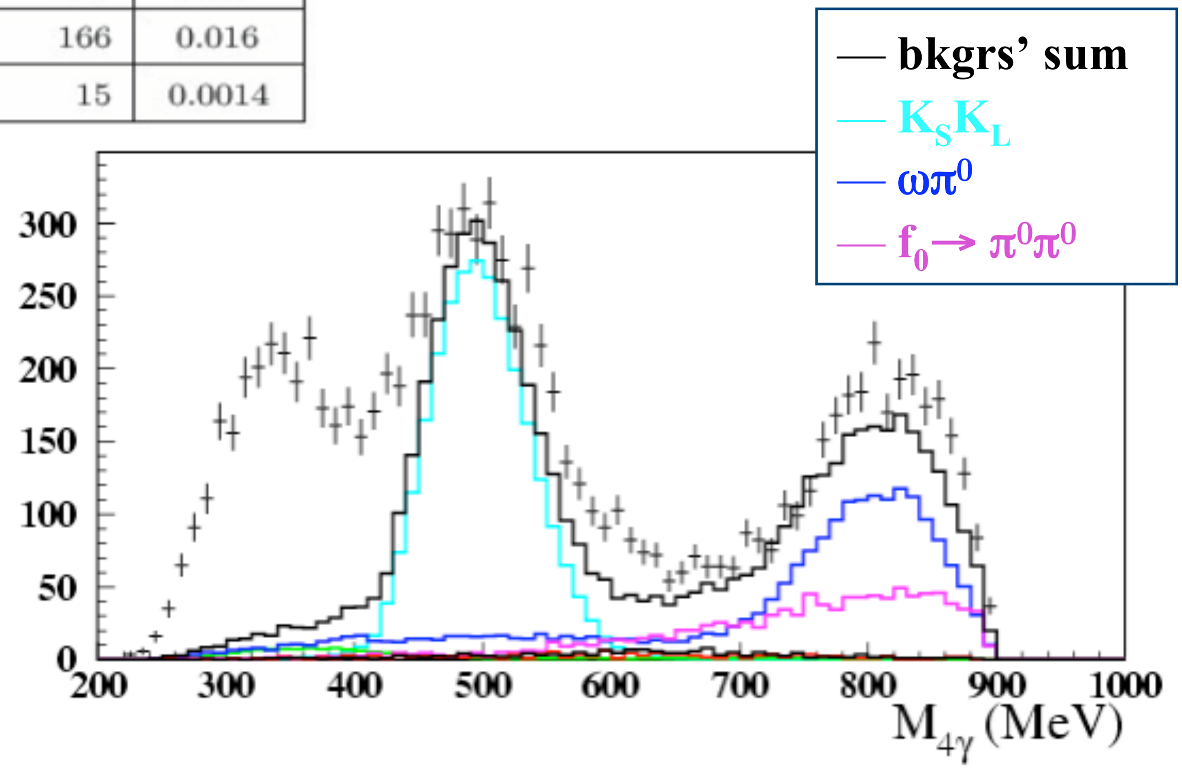
$e^+e^- \to e^+e^-\pi^0\pi^0$: $M_{4\gamma}$

PRELIMINARY

Expected background yields:

	ϵ	σ (nb)	$n = \epsilon L \sigma$	$n/10188$
$K_S K_L$	5.60×10^{-3}	2.0	2 682	0.26 ★
$\eta \to 3\pi^0$	1.79×10^{-3}	0.33	142	0.014
$\omega\pi^0$	1.55×10^{-2}	0.55	2 045	0.2 ★
$f_0 \to 2\pi^0$	2.58×10^{-2}	0.17	1 052	0.10 ★
$a_0 \to \eta\pi^0$	4.55×10^{-3}	0.11	120	0.012
$e^+e^- \to \gamma\gamma$	1.92×10^{-5}	360	166	0.016
$\eta \to \gamma\gamma$	1.57×10^{-4}	0.39	15	0.0014

From 239.6 pb^{-1}
10188 events after selection

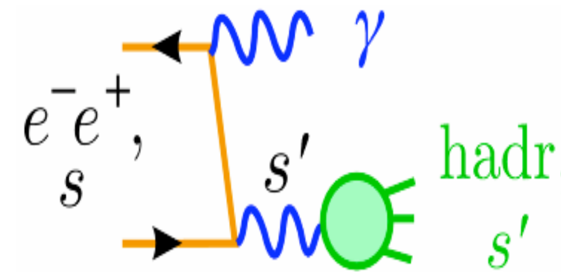


Excess of ~4000 events w.r.t. known backgrounds in the $\gamma\gamma \to \sigma(600) \to \pi^0\pi^0$ region

$\sigma(e^+e^-\to\pi^+\pi^-\gamma(\gamma))$ measurement

$\sigma(e^+e^-\to\pi^+\pi^-\gamma)$ measured at fixed $\sqrt{s}$ with high accuracy

ISR used to extract $\sigma(e^+e^-\to\pi^+\pi^-)$ for $\sqrt{s'}$ from $2M_\pi$ to $\sqrt{s}$



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

FSR neglected

Requires precise calculations of the radiator function H(s)
PHOKHARA MC NLO generator [EPJC27(2003)]

$\sigma(e^+e^-\to\pi^+\pi^-\gamma)$ measured via absolute normalization with Bhabhas:

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

- Background rejection with PID using EMC info ($ee\gamma/\mu\mu\gamma$) and kin. cuts ($\phi\to\pi\pi\pi$)
- Efficiencies evaluated on data with independent methods
- Luminosity from large angle Bhabha scattering evts

Two samples used:

1) **Small angle: $\theta_{\pi\pi} < 15^o$ or $\theta_{\pi\pi} > 165^o$**
   - Higher cross s[illegible]
   - Kinematically limited

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2) **Large angle: $50^o < \theta_\gamma < 130^o$**
   - Higher background
   - All $M_{\pi\pi}$ spectrum
   - ISR Photon detected

$\sigma(e^+e^-\to\pi^+\pi^-\gamma(\gamma))$: LA analysis

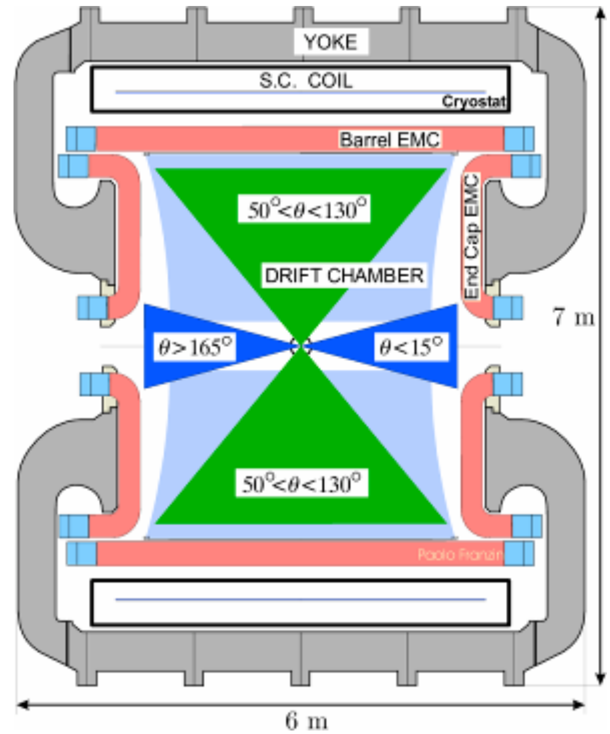
2 pion tracks at large angles

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

Photons at large angles

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

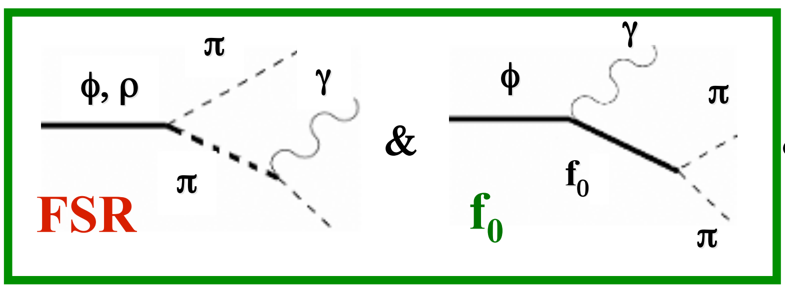
At least 1 photon with $50^o < \theta_\gamma < 130^o$ **and** $E_\gamma > 20$ **MeV** $\Rightarrow$ **photon detected**



- ❖ complementary analysis w.r.t. SA
- ❖ threshold region $(2m_\pi)^2$ accessible
- ❖ γ_{ISR} photon detected (4-mom. constraints)

- ❖ lower signal statistics
- ❖ larger contribution from FSR events
- ❖ larger $\phi\to\pi^+\pi^-\pi^0$ background contamination
- ❖ irreducible background from ϕ decays

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



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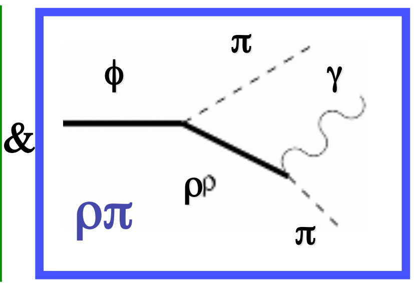

$\sigma(e^+e^- \to \pi^+\pi^-\gamma(\gamma))$: LA analysis

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

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

- complementary analysis w.r.t. SA
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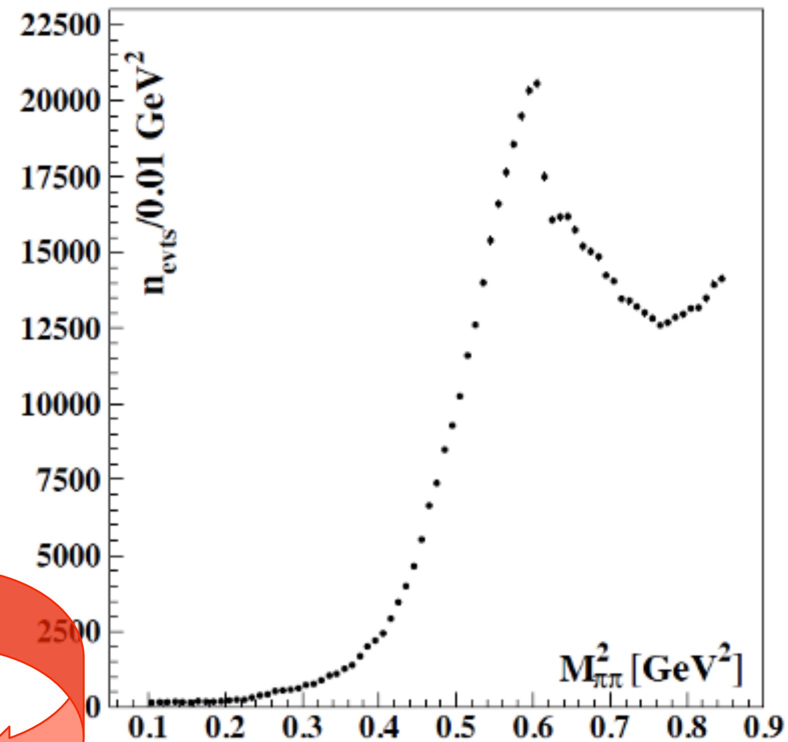
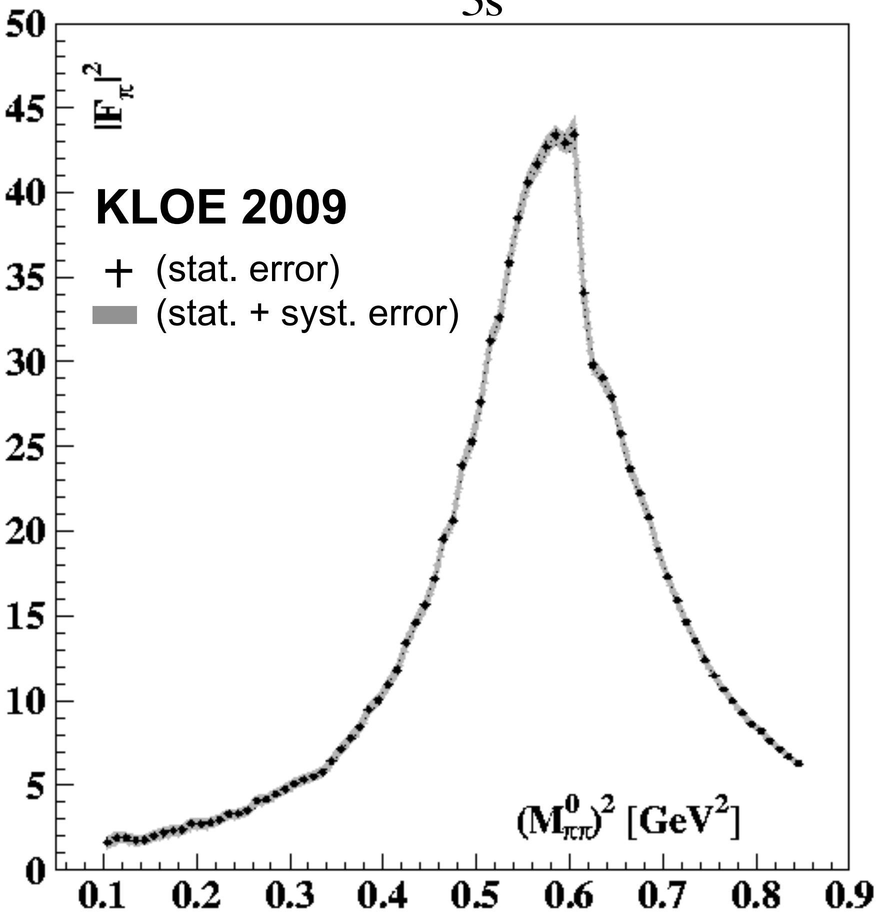
233 pb^{-1} of 2006 data
600 kEvents



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

KLOE result on Large Angle analysis

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



Disp. Integral:

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

Systematic errors on $a_\mu^{\pi\pi}$(0.1-0.85 GeV^2):

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%

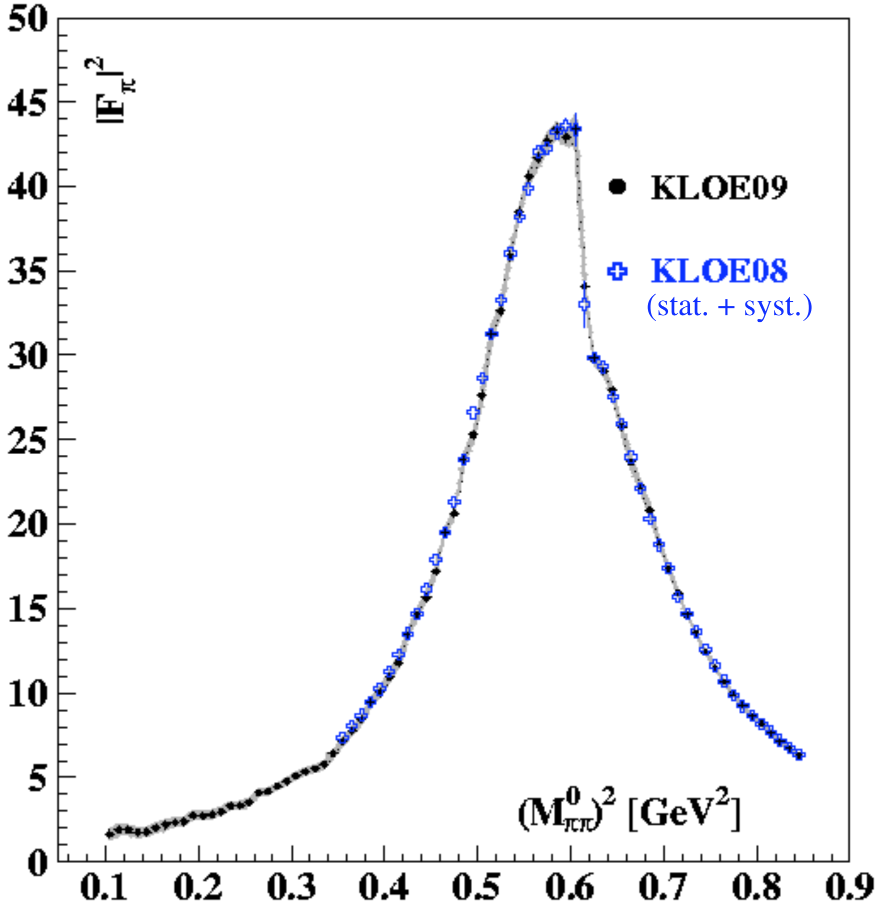
Theoretical fractional error on a_μ = 0.6 %

$a_\mu^{\pi\pi}$(0.1-0.85 GeV^2) = $(478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \cdot 10^{-10}$

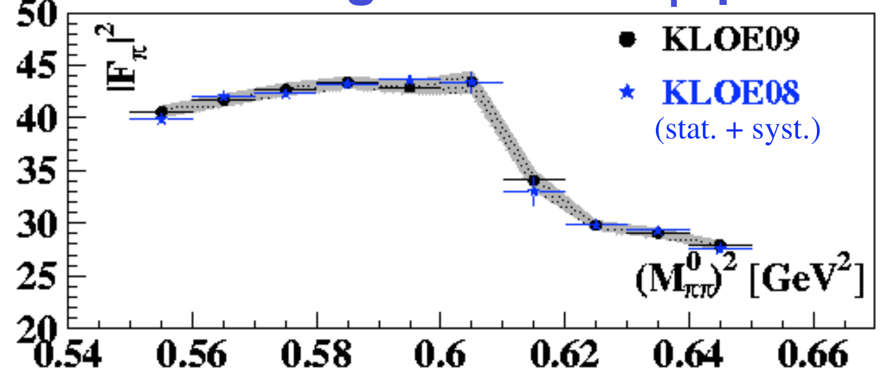
0.4% 1.0% 0.6%

$|F_\pi|^2$: KLOE09 *vs* KLOE08

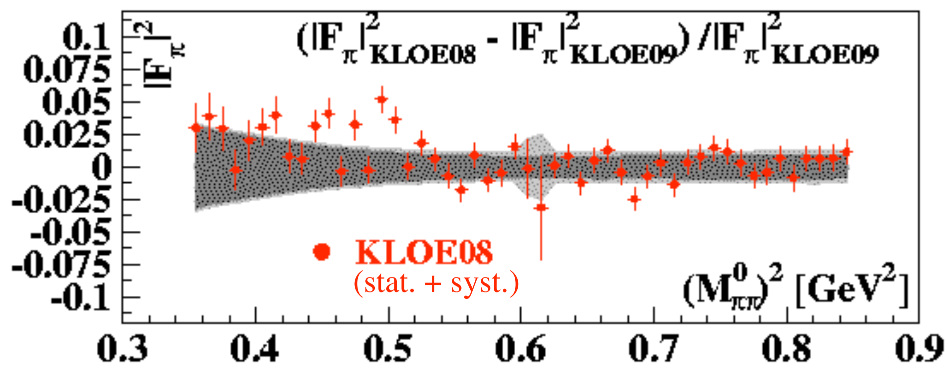
KLOE08: small angle analysis
KLOE09: large angle analysis



Zoomed region around ρ-peak:

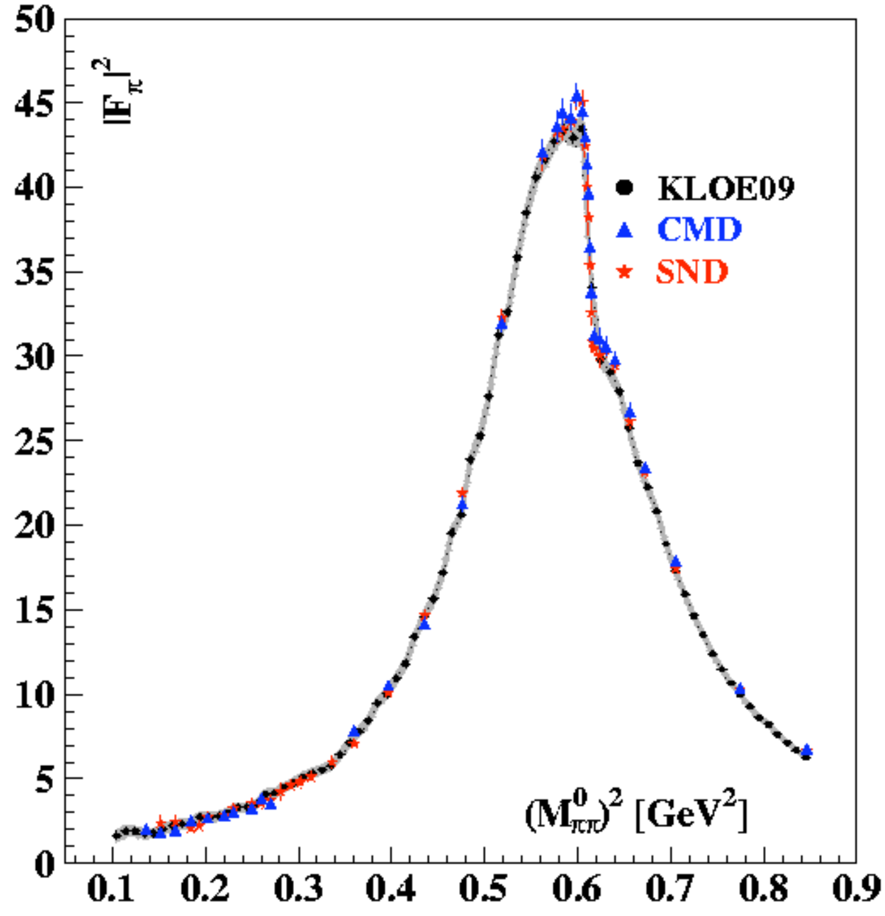


Fractional difference:



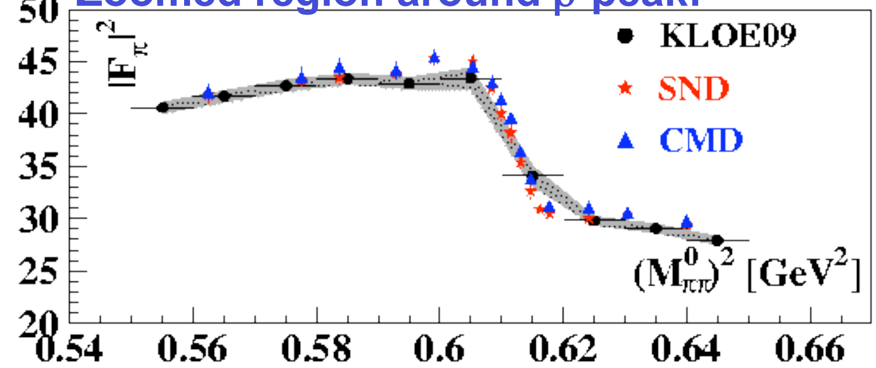
Grey band: KLOE09 error

$|F_\pi|^2$: KLOE09 *vs* SND/CMD2

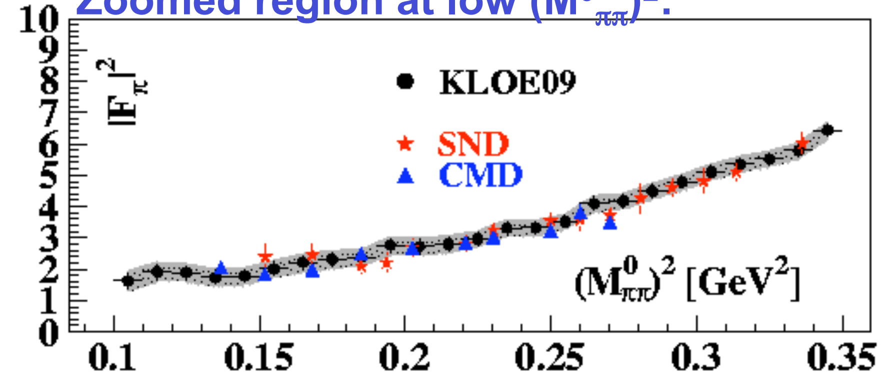


Grey band: KLOE09 error

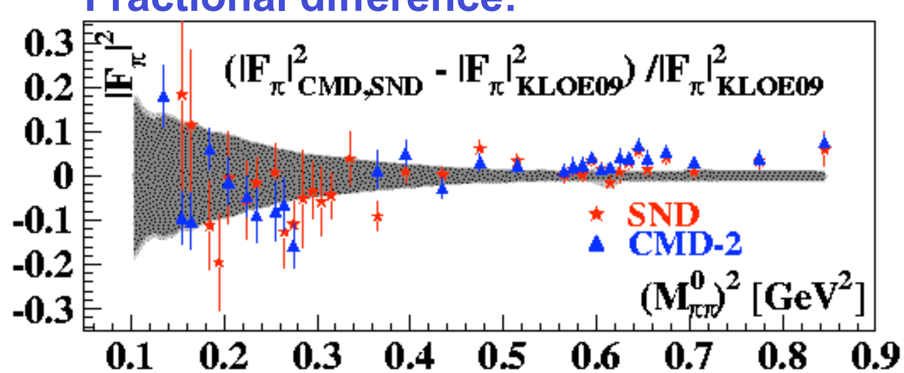
Zoomed region around ρ-peak:



Zoomed region at low $(M^0_{\pi\pi})^2$:



Fractional difference:



Comparison on $a_\mu^{\pi\pi}$

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

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

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%

$a_\mu^{\pi\pi}$(0.152-0.270 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

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

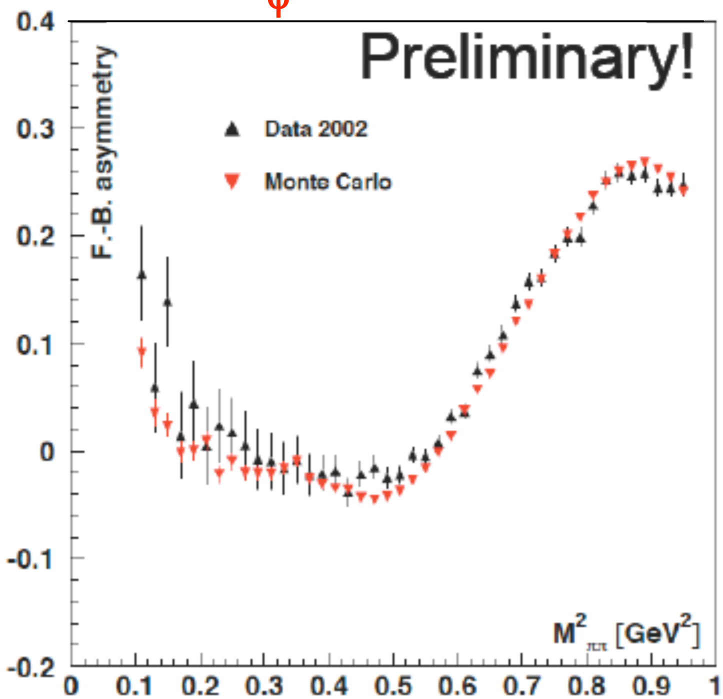
Forward-backward asymmetry

PRELIMINARY

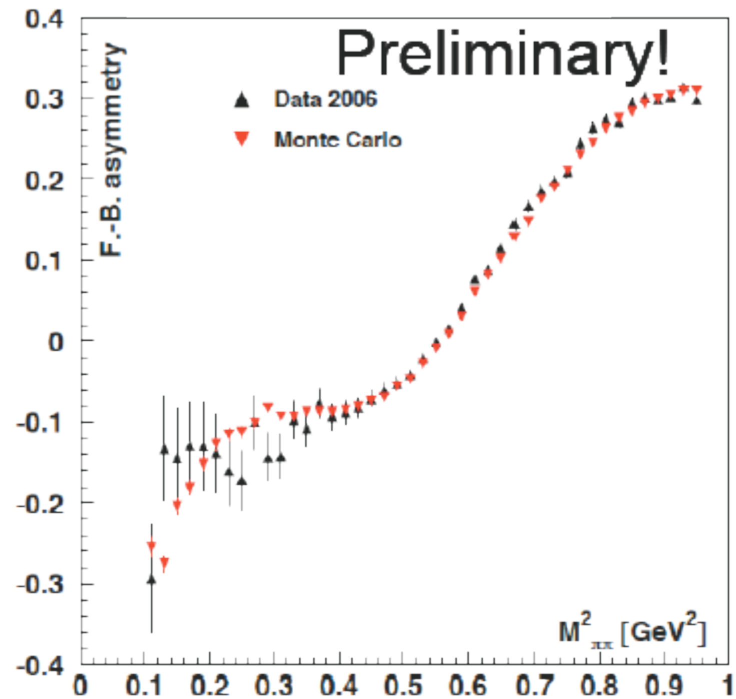
Different C parity of $\pi^+\pi^-$ for ISR and FSR+$\phi\to S\gamma$ gives rise to a non-vanishing

$$A_{FB}(M_{\pi\pi}) = \frac{N(\vartheta > 90^\circ) - N(\vartheta < 90^\circ)}{N(\vartheta > 90^\circ) + N(\vartheta < 90^\circ)}(M_{\pi\pi})$$

$\sqrt{s}=M_\phi \sim 1.0195$ GeV



$\sqrt{s} \sim 1.000$ GeV



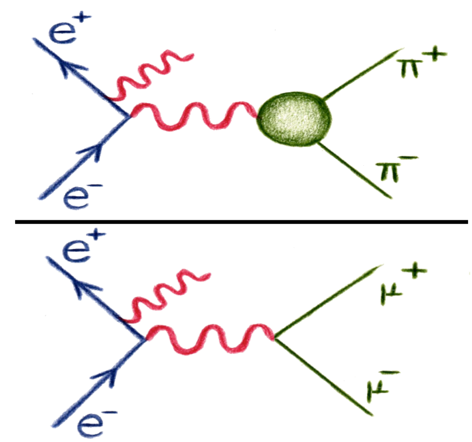
PHOKHARA-MC modified by O. Shekhovtsova using scalar+VMD contribution extracted from KLOE $\pi^0\pi^0\gamma$ analysis (**EPJC49(2007)473**)

Next $\sigma_{\pi\pi}$ measurement: π/μ ratio

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)

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

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

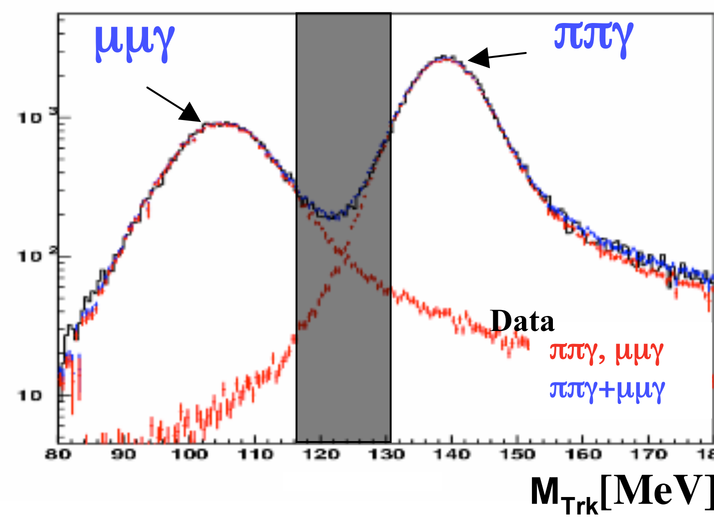


Many radiative corrections drop out:

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

Separation between pions and muons done experimentally using kinematical cuts:

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



Conclusions

❖ Still a lot of relevant physics results from the analysis of the KLOE data set, both at M_ϕ and at 1 GeV !!!

❖ Summary of achievements in 2009:

- 6 published papers
- 1 accepted paper
- 3 drafts in preparation

❖ Our goal is to complete all the analyses mentioned today and start addressing other selected items before the start of the upcoming KLOE-2 run

Planned analysis (2010)

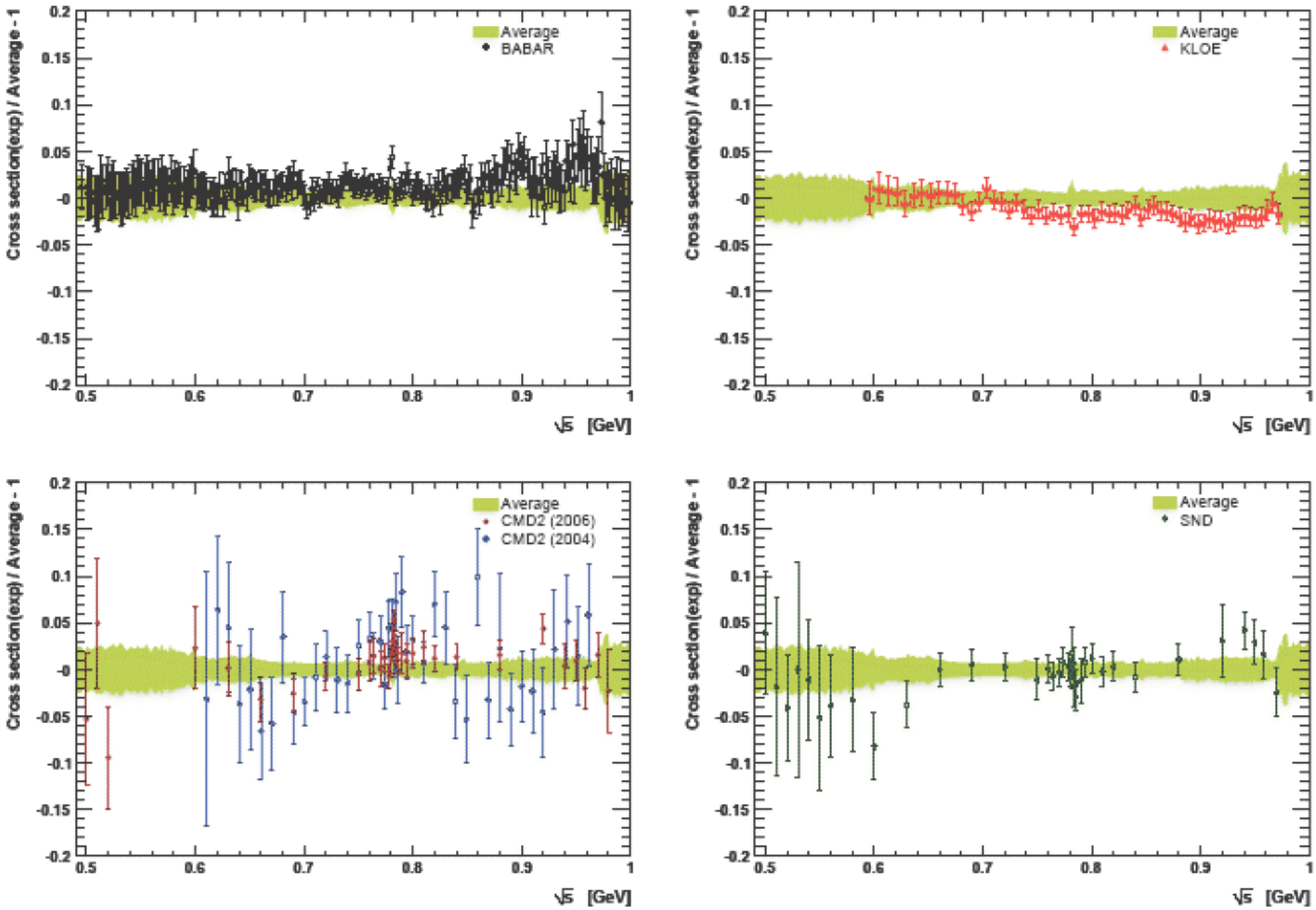
- $K_S \to \pi l \nu$ / $K_S \to \pi\pi ee$
- FF slopes from K_{l3} decays
- Parameters of CPT violation and Lorentz symmetry

- $K^{\pm}$ lifetime
- $K^{\pm}$ semileptonic decays

- $\eta \to \pi^0 \gamma\gamma$
- $\eta' \to \eta\pi\pi$

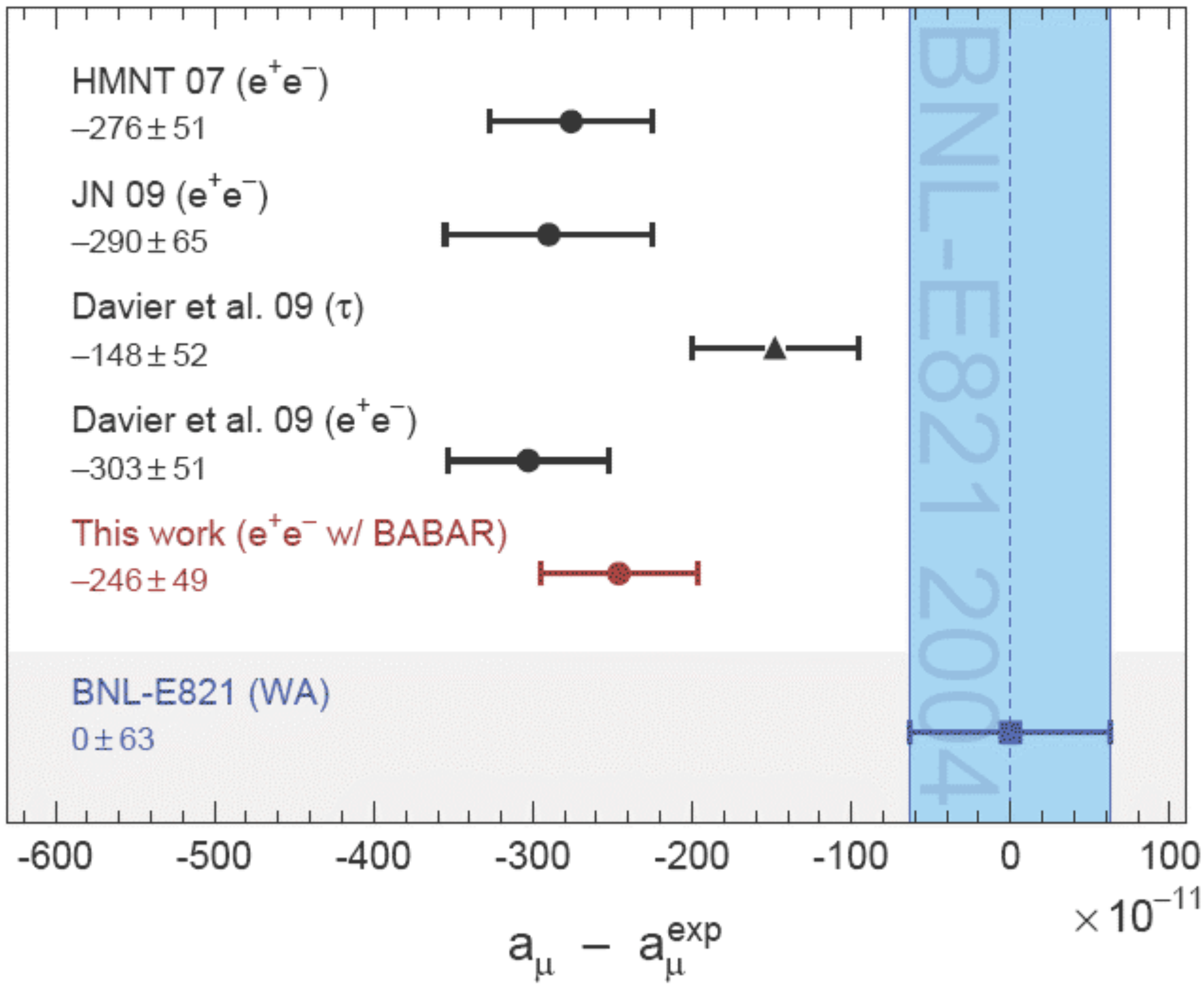
$|F_\pi|^2$: KLOE08 *vs* SND/CMD2/BABAR

From M. Davier at al, arXiv:0908:4300



Comparison on a_μ

From M. Davier at al, arXiv:0908:4300



***τ* deviation: 1.8 σ**

***e⁺e⁻* deviation: 3.1 σ**

- 2.8 σ excluding KLOE
- 2.3 σ BABAR only

From BABAR talk @ PHIPSI09

Computing $a_\mu^{\pi\pi}$

$$a_\mu^{\pi\pi(\gamma),LO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\, \sigma^0_{\pi\pi(\gamma)}(s) \,,$$

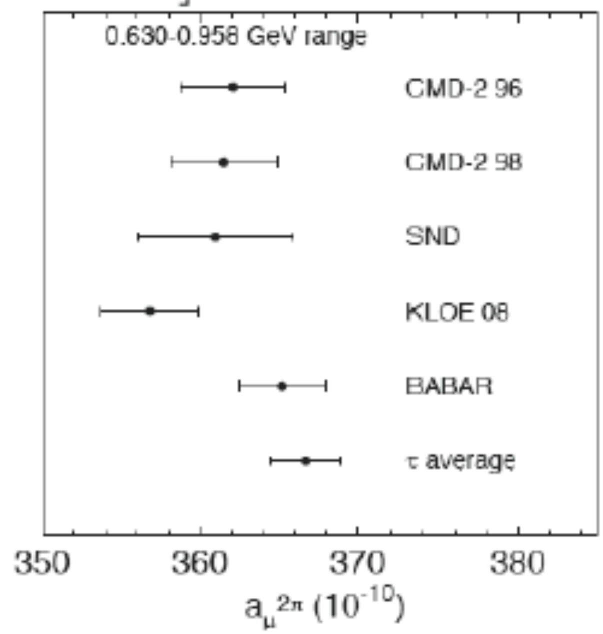
where $K(s)$ is the QED kernel,

$$K(s) = x^2\left(1-\frac{x^2}{2}\right) + (1+x)^2\left(1+\frac{1}{x^2}\right)\left[\ln(1+x) - x + \frac{x^2}{2}\right] + x^2\,\frac{1+x}{1-x}\ln x \,,$$

with $x = (1-\beta_\mu)/(1+\beta_\mu)$ and $\beta_\mu = (1-4m_\mu^2/s)^{1/2}$.

$m_{\pi\pi}$ range (GeV)	$a_\mu^{\pi\pi(\gamma),LO}$ BABAR
0.28–0.30	$0.55 \pm 0.01 \pm 0.01$
0.30–0.50	$55.62 \pm 0.63 \pm 0.55$
0.50–1.00	$445.94 \pm 2.10 \pm 2.51$
1.00–1.80	$9.97 \pm 0.10 \pm 0.09$
0.28–1.80	$514.09 \pm 2.22 \pm 3.11$

($\times 10^{-10}$)



0.28-1.8 (GeV)

BABAR	514.1 ± 3.8
previous e^+e^- combined	503.5 ± 3.5 *
τ combined	515.2 ± 3.5 *

* arXiv:0906-5443 MD et al.

Wenfeng Wang PhiPsi09 14/10/2009 20

K_S lifetime: results

Systematic errors

Source	fractional value $\times 10^4$
- selection cuts :	3.3
- $\cos\theta_K$ FV cut	5.7
- Kaon mass :	0.4
- fit range :	5.0

$$\tau_{K_S} = (\,89.56 \pm 0.03_{stat} \pm 0.07_{syst})\ \text{ps}$$

preliminary

K_L lifetime: results

preliminary

$$\tau_L = 50.56 \pm 0.14_{stat} \pm 0.21_{syst}\ \text{ns}$$

table of systematic

source	$\Delta\tau/\tau$ %	$\Delta\tau$ (ns)
ε_{tag}	0.34	0.17
ε_{Kl}	0.16	0.08
time scale	0.12	0.06
nuclear interactions	0.16	0.08

comparison with previous KLOE measurements

$\tau_L = 50.92 \pm 0.17_{stat} \pm 0.13_{syst\ uncorr} \pm 0.27_{syst\ corr}$ ns — *PLB 626 (2005)*

$\Delta = 1.4\ \sigma$, taking into account the correlation between syst.

$\tau_L = 50.72 \pm 0.11_{stat} \pm 0.21_{syst}$ ns — *PLB 635 (2006)*

$\Delta = 0.4\ \sigma$

Absolute BR($K^+ \to \pi^+\pi^-\pi^+(\gamma)$)

lifetime and absolute BRs by KLOE
(dBR/d$\tau^\pm$ and correlations available)

$K^+ \to \mu\nu$	0.6366(18)	0.3%	*PLB 632(2006)*
$K^+ \to \pi^+\pi^0$	0.2065(9)	0.5%	*PLB 666(2008)*
$K^\pm \to \pi^0 e^\pm \nu$	0.0497(5)	1.0%	*JHEP 02(2008)*
$K^\pm \to \pi^0 \mu^\pm \nu$	0.0324(4)	1.2%	*JHEP 02(2008)*
$K^\pm \to \pi^\pm\pi^0\pi^0$	0.0176(3)	1.7%	*PLB 597(2004)*
$\tau^\pm$	12.347(30) ns	0.24%	*JHEP 01 (2008)*

PLB 666 (2008)

BR($K^\pm \to \pi^\pm\pi^+\pi^-$)= 0.0568(22)   measured using $(1 - \Sigma BR_{KLOE})$

- *this measurement completes the KLOE program of precise and fully inclusive $K^\pm$ dominant BR's*
- needed to perform a global fit to $K^\pm$ BR's
- available measurement dates back to '72 (no information on radiation cut-off)

CHIANG (2330 evts) BR($K \to \pi^+\pi^-\pi^+$) = $(5.56 \pm 0.20)\%$ $\Delta BR/BR = 3.6 \times 10^{-2}$

~ 180 pb^{-1} enough to reach *statistical relative error at few permil level*

Luminosity measurement

KLOE measures *L* with Bhabha scattering

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

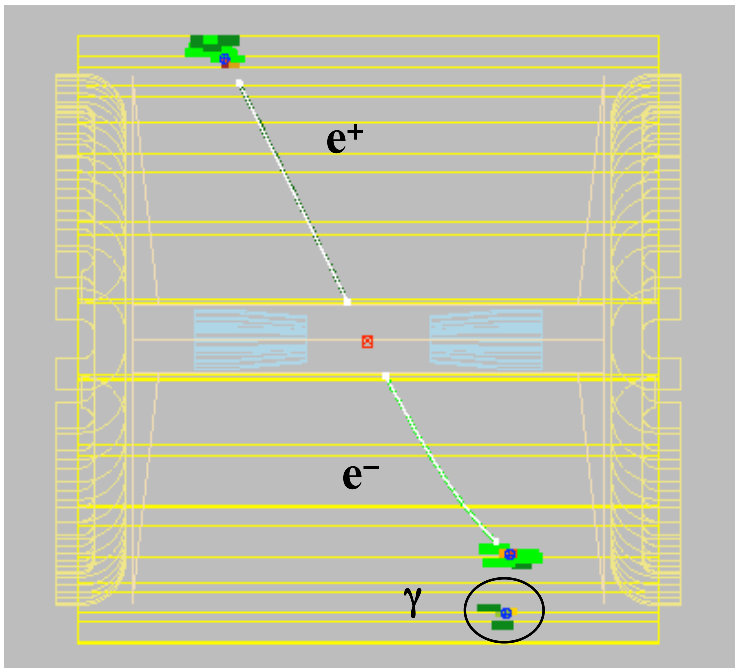
$55° < \theta < 125°$

acollinearity < 9°

p ≥ 400 MeV

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

generator used for σ_{eff}
BABAYAGA (Pavia group):
C. M.C. Calame et al., NPB584 (2000) 459
Now: *C. M.C. Calame et al., NPB758 (2006) 22*



newer 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%	

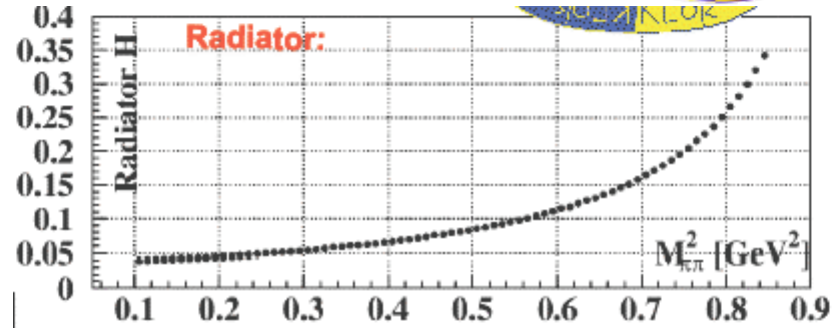
Radiative corrections

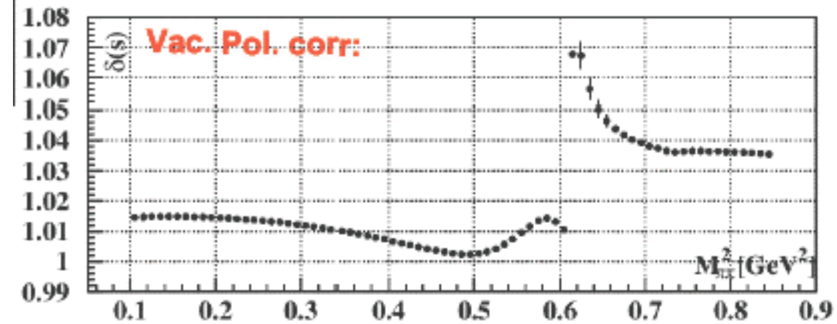
Radiator-Function $H(s,s_\pi)$ (ISR):

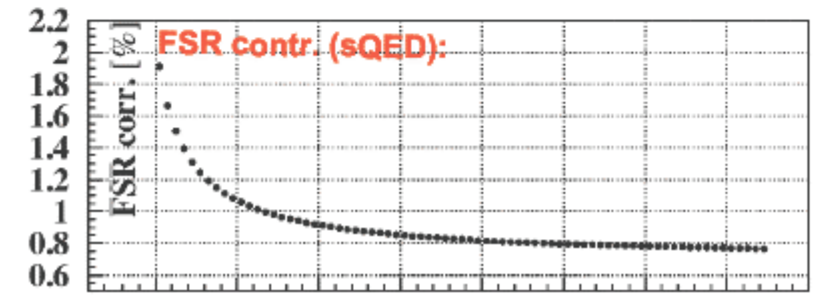
- **ISR-Process calculated at NLO-level**
  PHOKHARA generator
  (H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC27,2003)

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 $\delta(s)=(\alpha(s)/\alpha(0))^2$

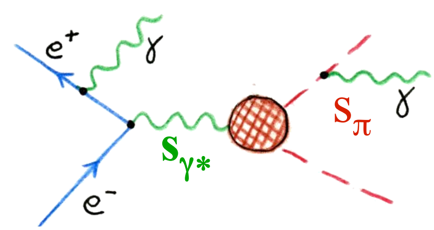
➔ from F. Jegerlehner

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 passage $s_\pi = M^2_{\pi\pi} \rightarrow (M^0_{\pi\pi})^2 = s_{\gamma*}$

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

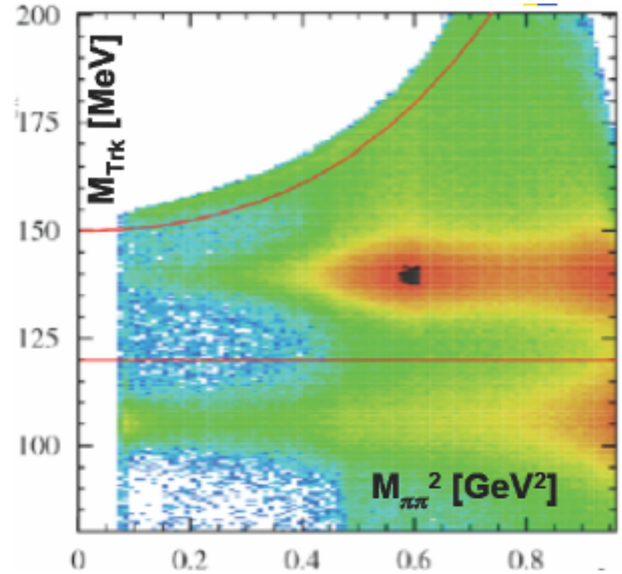


$s_{\gamma*} > s_\pi$

Event selection

Experimental challenge: background from

- $e^+e^- \to \mu^+\mu^- \gamma$
- $e^+e^- \to e^+e^- \gamma$
- $\phi \to \pi^+\pi^-\pi^0$

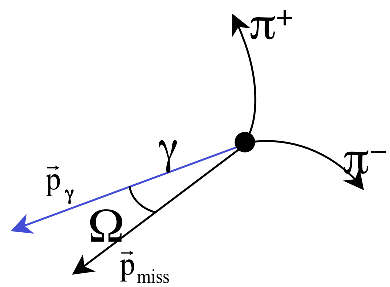


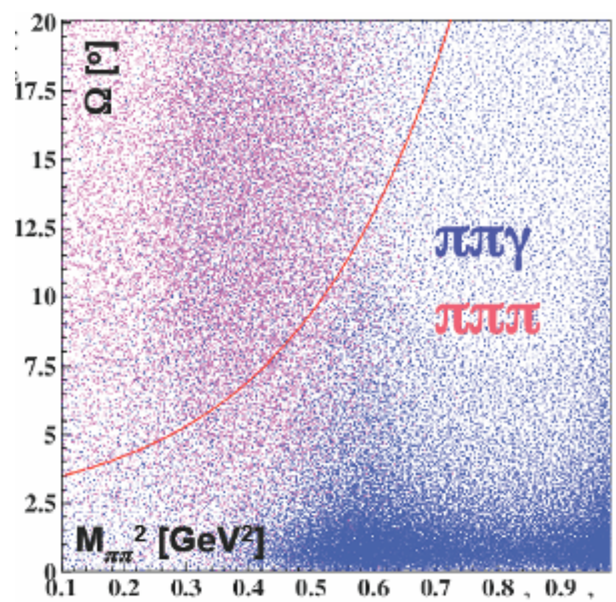
1. kinematical cuts in trackmass M_{Trk}
(defined by 4-momentum conservation under the hypothesis of 2 tracks with equal mass and a γ)

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

2. angle Ω between the photon and missing momentum

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





3. 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

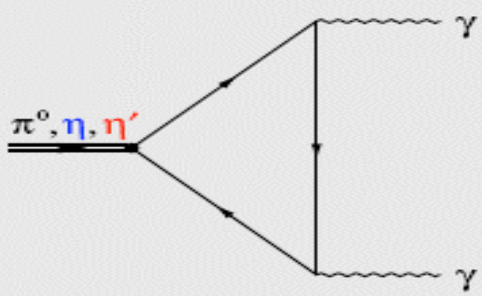
$\eta \to \pi^+\pi^-\gamma$: contributions

Anomalies in QCD

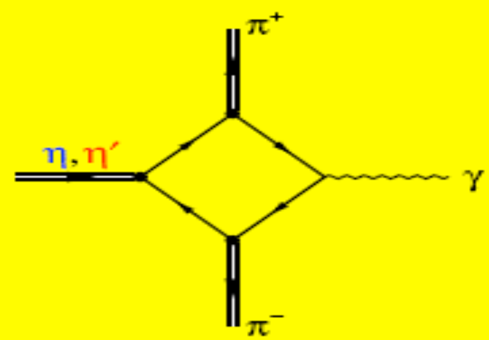
Wess-Zumino-Witten Lagrangian

J. Wess, B. Zumino, Phys. Lett. B 37 (1971) 95
E. Witten, Nucl. Phys. B 223 (1983) 422

$$L_{WZW} = L_{AVV} + L_{AAAV} + \ldots$$



triangle anomaly



box anomaly

- Resonant contribution:
  1. ρ production with its subsequent decay to a pion pair (VDM)
  2. existence of a small non-VDM contribution
- Anomalous contribution:
  box anomaly (similar to the classical triangle anomaly), responsible for $\eta/\eta' \to \pi^+\pi^-\gamma$ decays predicted by PCAC and by the Wess-Zumino-Witten chiral lagrangian