Light Meson Physics with KLOE

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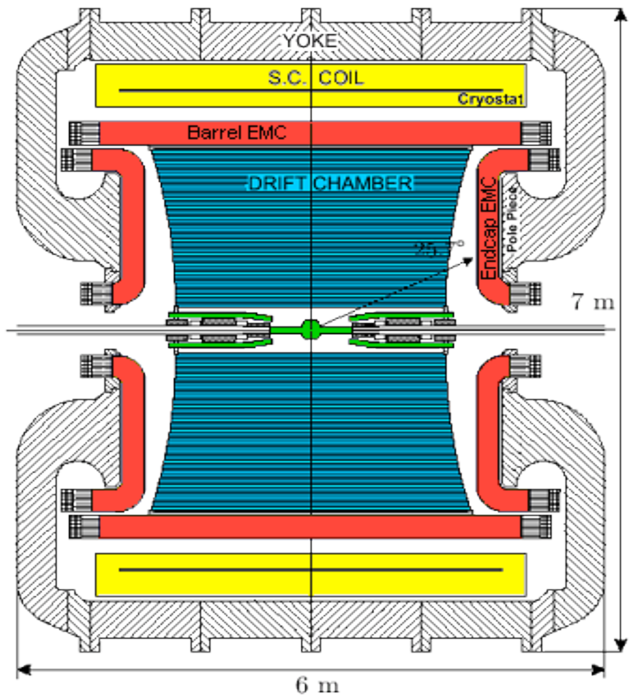
(LNF–INFN)
on behalf of the KLOE Collaboration

- Recent results on η decays
- First studies on $\gamma\gamma$ interactions
- New $\sigma(e^+e^-\rightarrow\pi^+\pi^-)$ measurement

XLVth Moriond QCD and High Energy Interactions – 13-20 March 2010

The KLOE experiment at DAΦNE

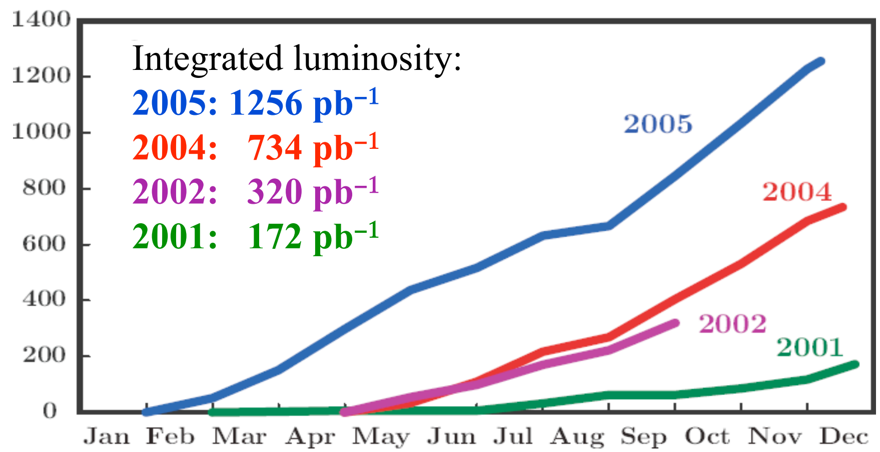


Drift chamber

- Gas mixture: **90% He + 10% C_4H_{10}**
- **$\delta p_t / p_t < 0.4\%$ (θ>45°)**
- **$\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm**

Electromagnetic calorimeter

- lead/scintillating fibers
- 98% solid angle coverage
- **$\sigma_E / E = 5.7\% / \sqrt{E(GeV)}$**
- **$\sigma_t = 57\ ps / \sqrt{E(GeV)} \oplus 100\ ps$**
- **PID capabilities**



Data taking ended on March 2006

- **2.5 fb^{-1} on tape @ $\sqrt{s} = M_\phi$ (8×10^9 ϕ)**
- **~10 pb^{-1} @ 1010, 1018, 1023 and 1030 MeV**
- **250 pb^{-1} @ 1000 MeV**

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

- ✓ Significant contribution from the chiral anomaly responsible of $\eta \to \gamma\gamma$ 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 $\Gamma(\eta \to \pi\pi\gamma)/\Gamma(\eta \to \pi\pi\pi)$ differs >3σ from old measurements

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

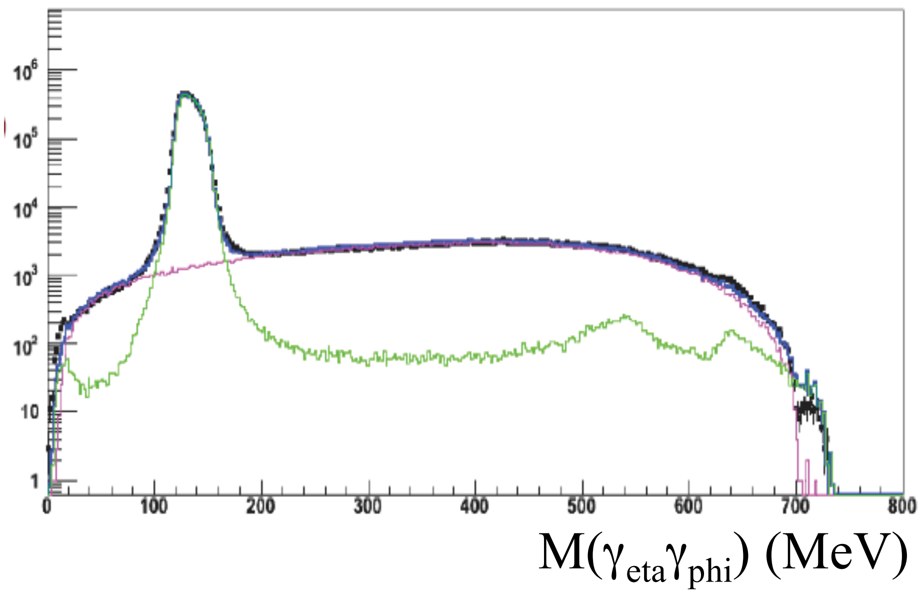
value	events	author	year
0.203 ± 0.008	PDG average		
0.175 ± 0.007 ± 0.006	859	Lopez	2007
0.209 ± 0.004	18 k	Thaler	1973
0.201 ± 0.006	7250	Gormley	1970

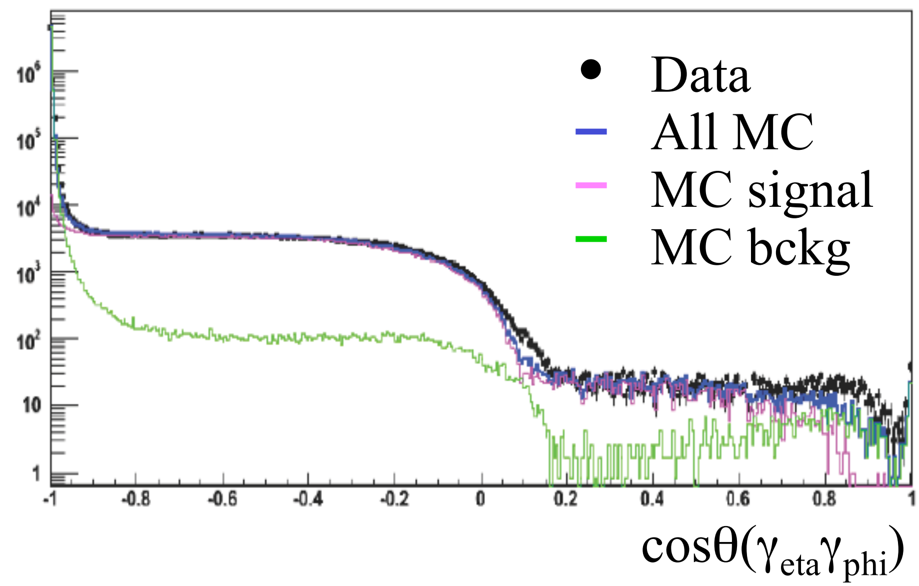
$\Gamma(\eta\rightarrow\pi^+\pi^-\gamma)/\Gamma(\eta\rightarrow\pi^+\pi^-\pi^0)$

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

  ε = 29%, BKG/SIG=10:1

- Different topology in $\gamma\gamma$ distributions for signal and background
- Simultaneous fit to both spectra to extract signal





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

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

PRELIMINARY

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

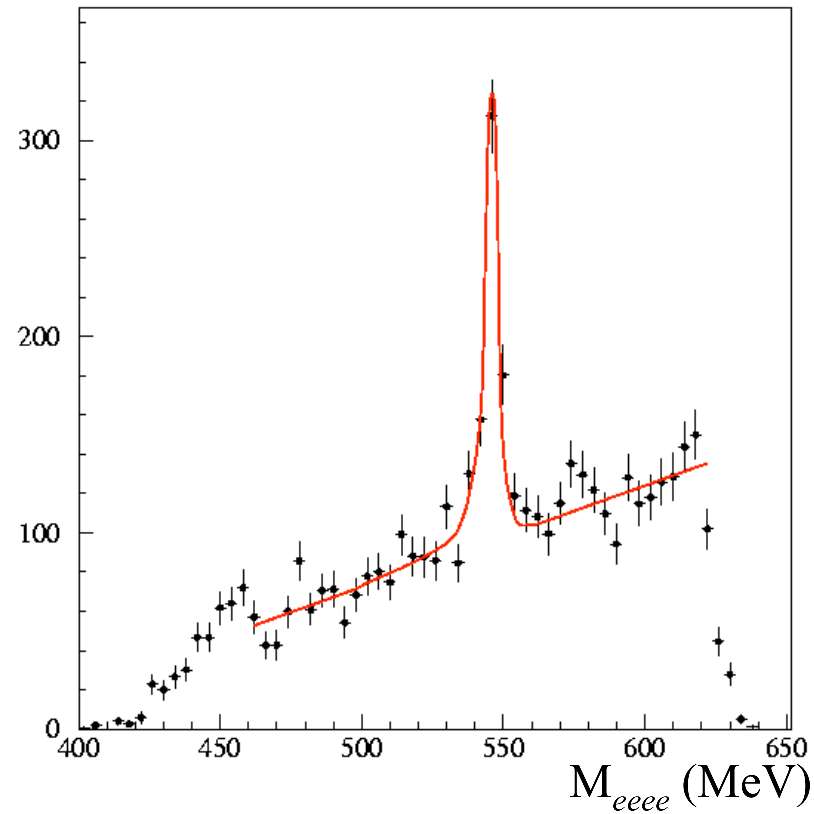
- **Preliminary result agrees with PDG average, confirming old results from 70s**
- We are evaluating systematics, aiming to reach ~ 1%
- Plan to use full KLOE data set to investigate the $\pi^+\pi^-$ invariant mass distribution: cuts on $M\gamma\gamma$ and $\cos\theta(\gamma\gamma)$ in the π^0 rest frame allow to reduce the background contribution to 2% with a signal efficiency of ~25%

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

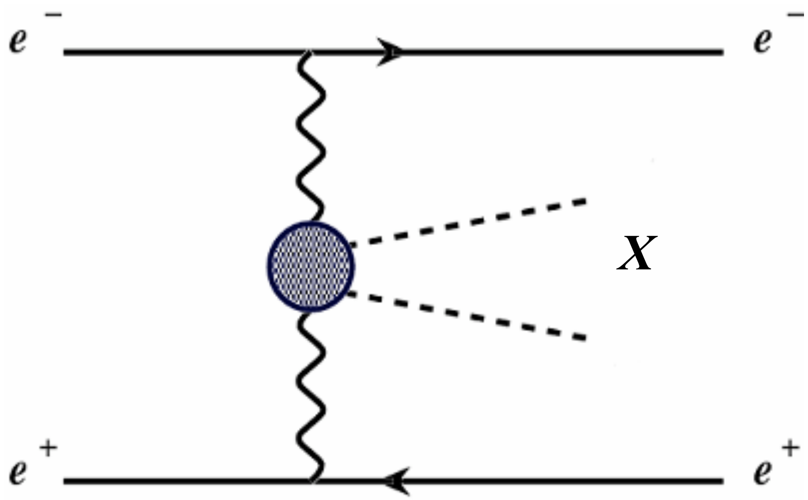
FIRST OBSERVATION!

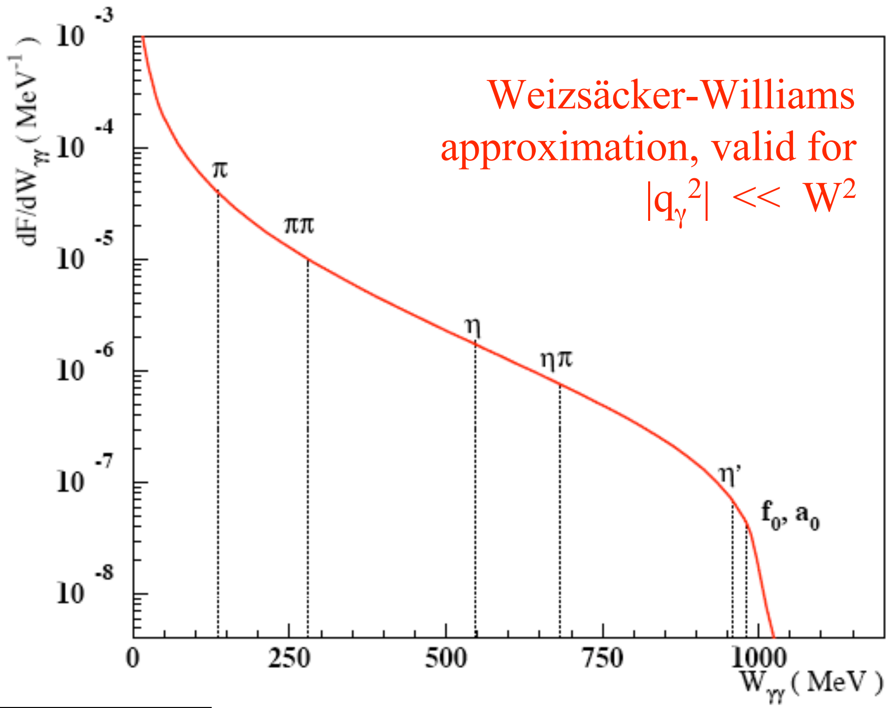
- Data sample: **1.7 fb^{-1}**
- MC simulation according to J.Bijnens and F. Persson, arXiv:0106130 (courtesy of J.Bijnens)
- FSR included
- e^+e^- pairs from photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from ϕ decays subtracted
- Fit to M_{eeee} distribution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

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



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





- **e^+e^- not tagged**

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

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

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

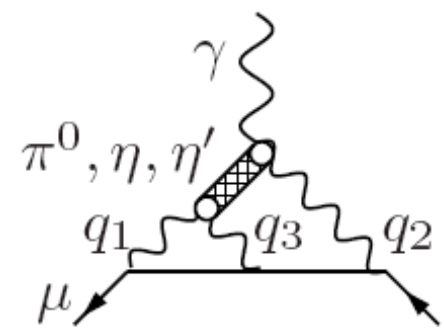
$\sqrt{s}$ (GeV)	1
$\sigma(e^+e^- \to e^+e^-\pi^0)$ (pb)	266
$\sigma(e^+e^- \to e^+e^-\eta)$ (pb)	43
$\sigma(e^+e^- \to e^+e^-\eta')$ (pb)	3.3

$e^+e^-\to e^+e^-\eta$: 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	$e^+e^-\to e^+e^-\eta$	**7.2-10.4**
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^-\to e^+e^-\eta$	**29**
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^-\to e^+e^-\eta$	**9.4-10.6**
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^-\to e^+e^-\eta$	**34.6**

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



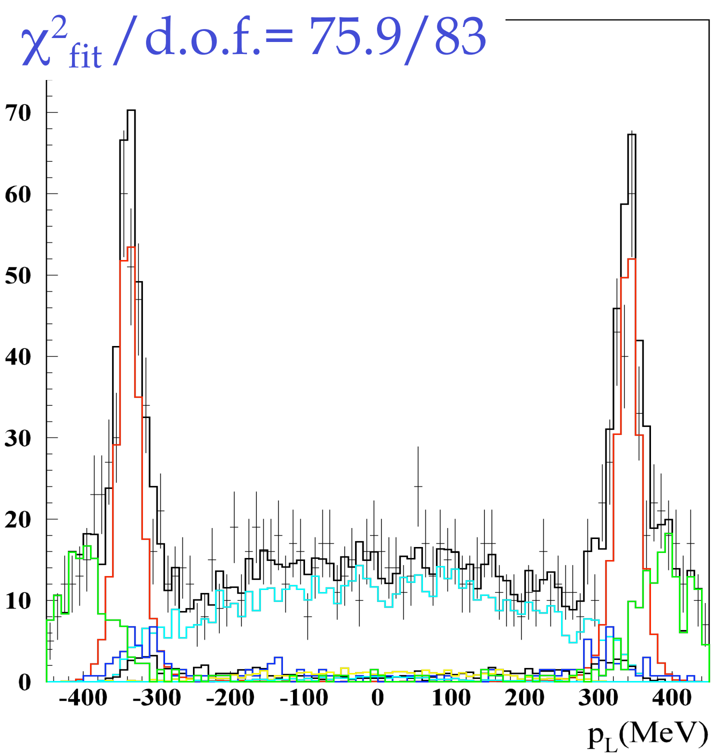
$$\sigma_{\gamma\gamma\to R}(q_1,q_2) \propto \Gamma_{R\to\gamma\gamma}\frac{8\pi^2}{M_R}\delta((q_1+q_2)^2 - M_R^2)\left|F(q_1^2,q_2^2)\right|^2$$

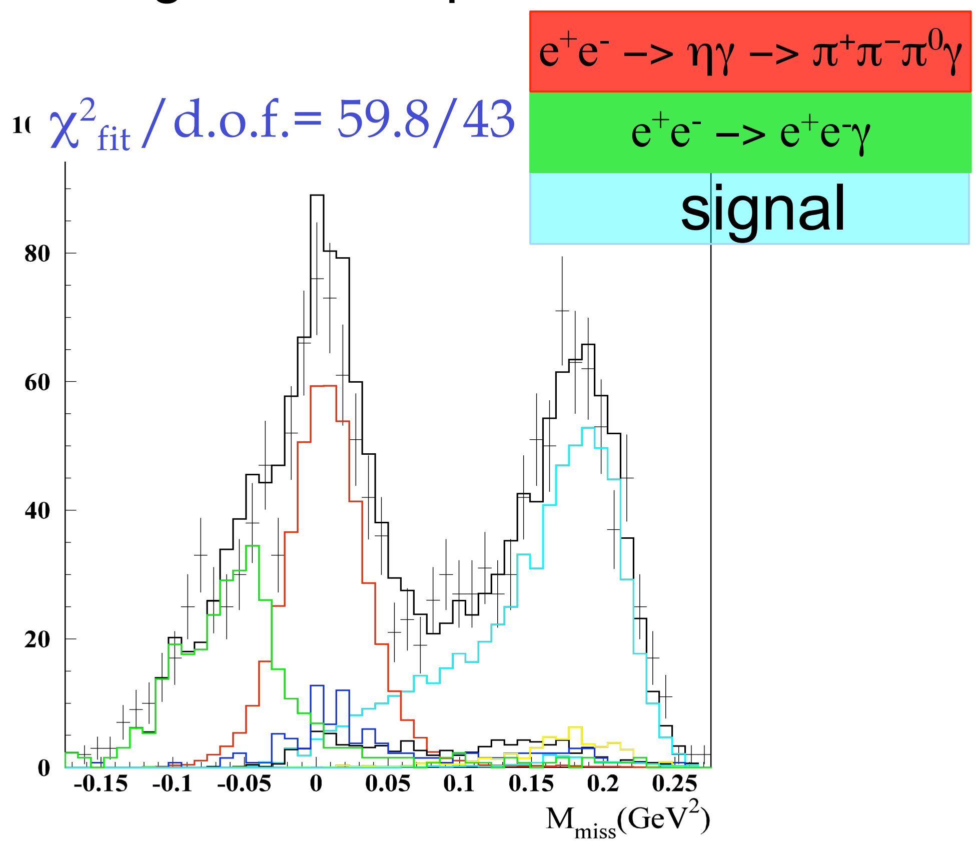
$e^+e^-\rightarrow e^+e^-\eta$: fit results

PRELIMINARY

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

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





~ 600 signal events. Extraction of $\sigma(e^+e^-\rightarrow e^+e^-\eta)$ and $\Gamma_{\gamma\gamma}$ in progress

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

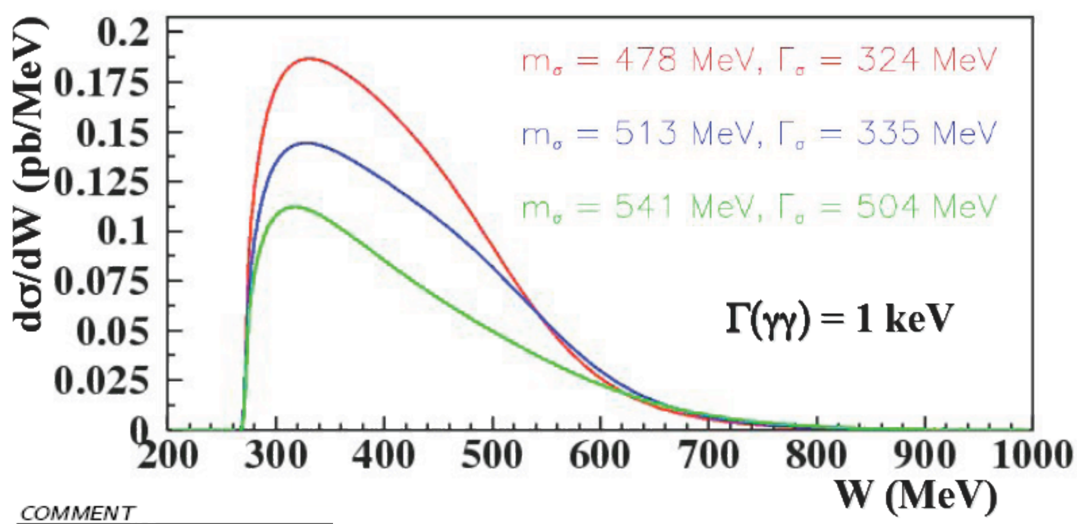
Search for $\gamma\gamma \to \sigma(600) \to \pi\pi$

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

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

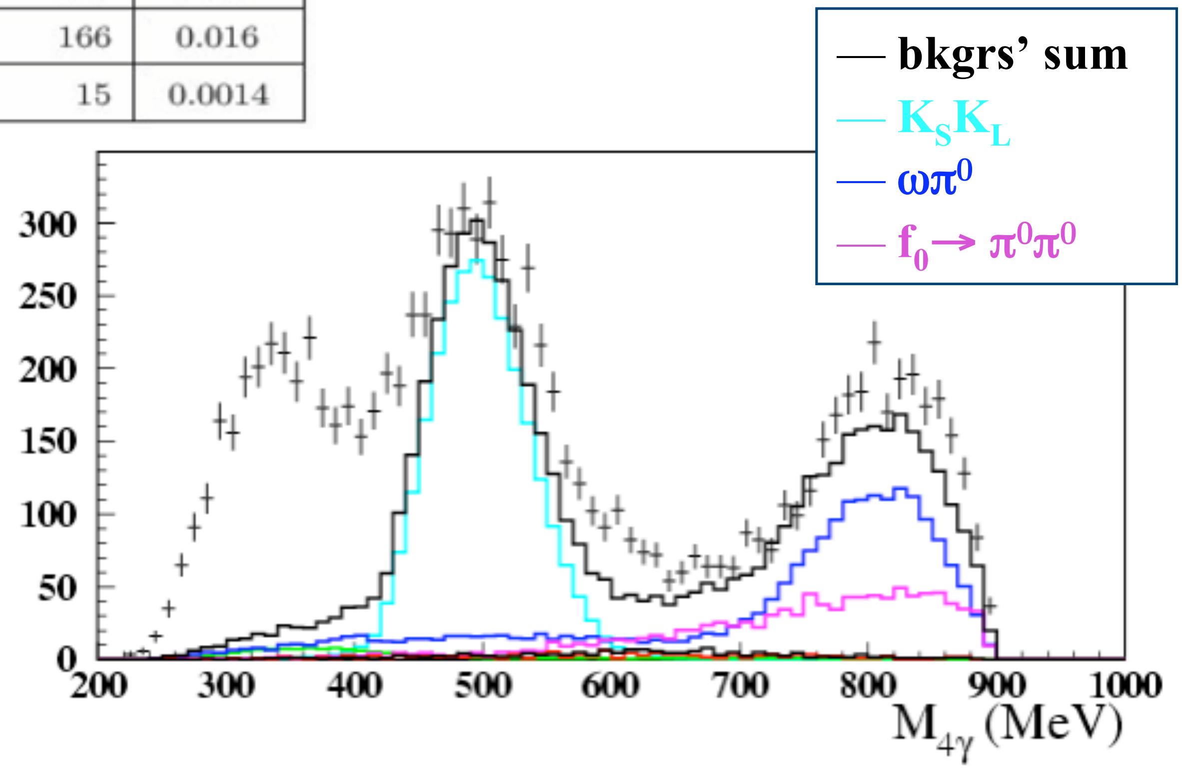
PRELIMINARY

Expected background yields:

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

Data sample: 239.6 pb^{-1}

10188 events after selection

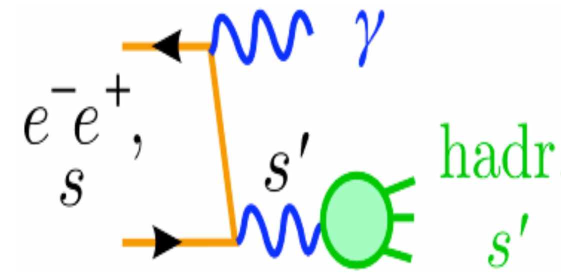


Excess of ~4000 events w.r.t. known backgrounds in the $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$ region

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

PLB 670 (2009) 285

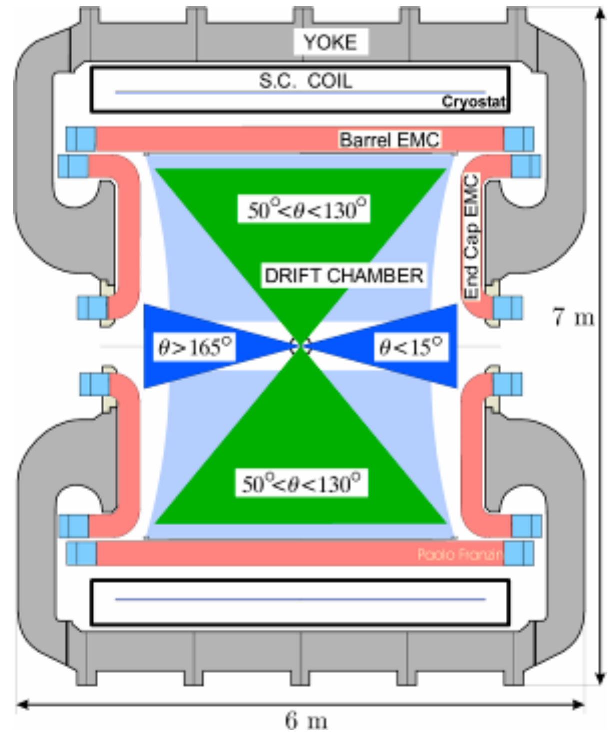
2) **Large angle: $50^o < \theta_\gamma < 130^o$**
- Higher background
- All $M_{\pi\pi}$ spectrum
- ISR Photon detected

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

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

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

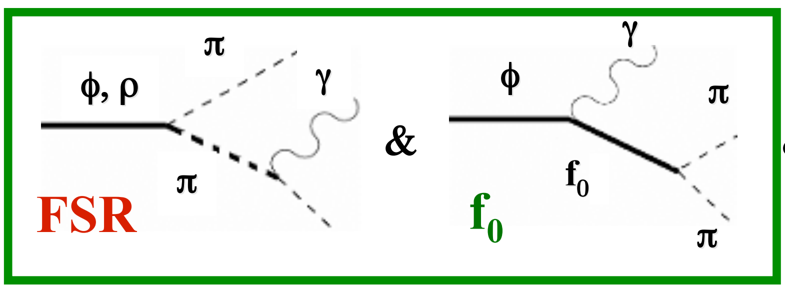
At least 1 photon with $50^o < \theta_\gamma < 130^o$ **and** $E_\gamma > 20$ **MeV** $\Rightarrow$ **photon detected**



- ❖ 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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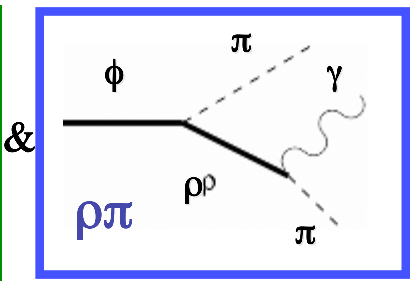

$\sigma(e^+e^-\to\pi^+\pi^-\gamma(\gamma))$: LA analysis

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

Photons at large angles
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- complementary analysis w.r.t. SA
- threshold region $(2m_\pi)^2$ accessible
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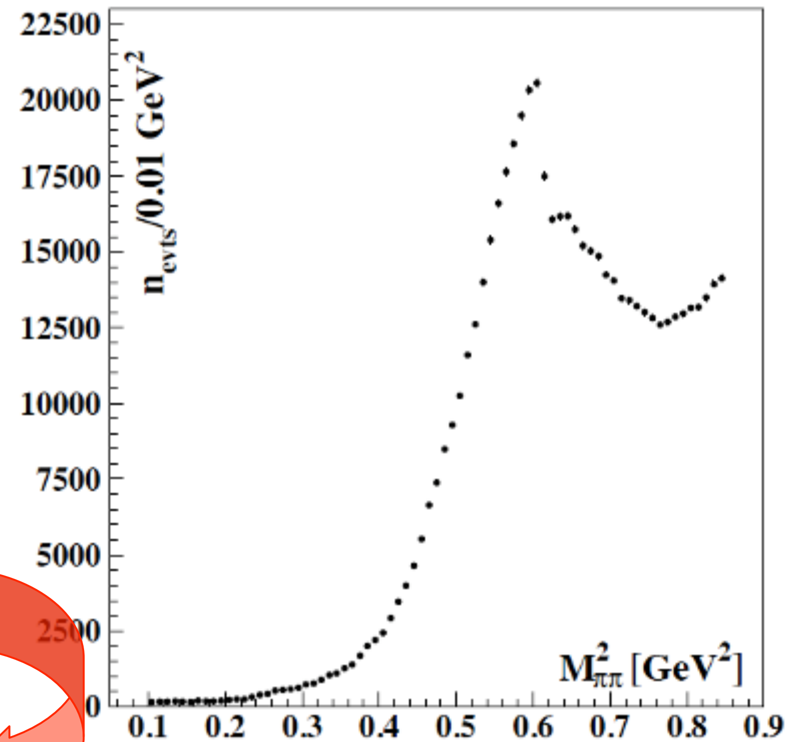
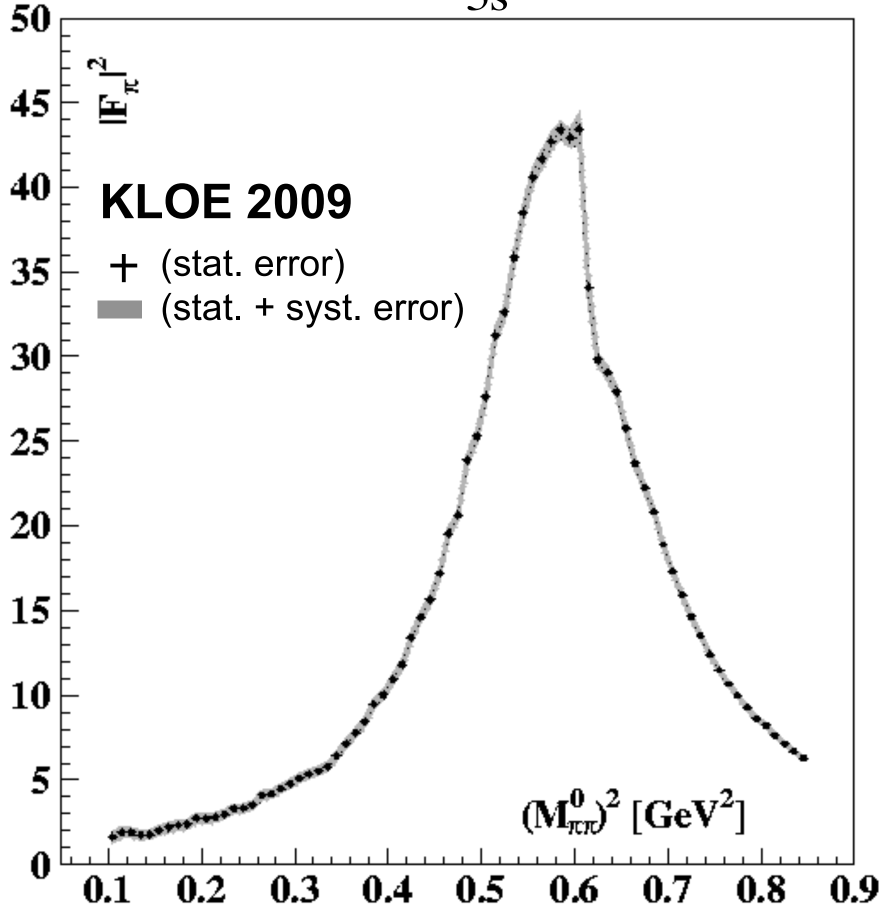
233 pb^{-1} of 2006 data
600 kEvents



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 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%

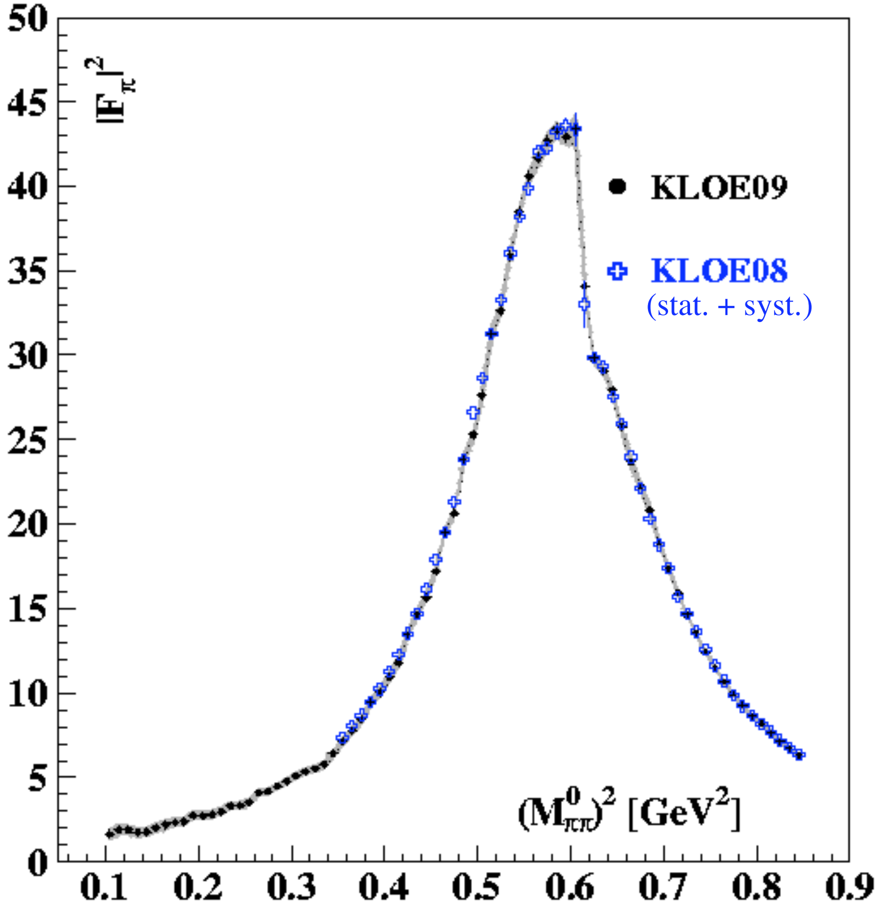
Theoretical fractional error on a_μ = 0.6 %

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

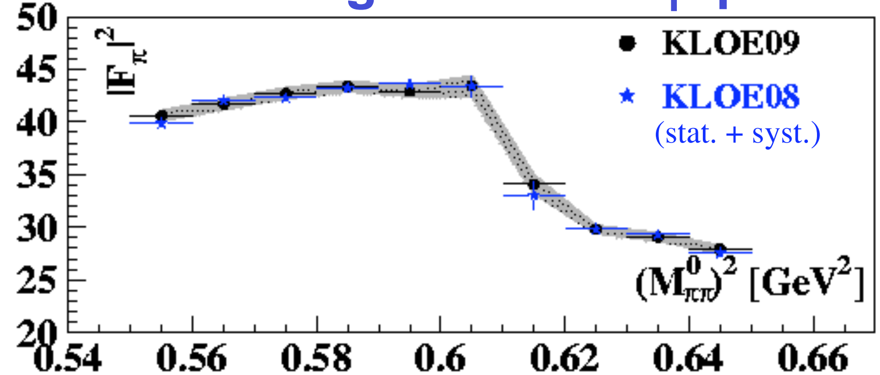
0.4% 1.0% 0.6%

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

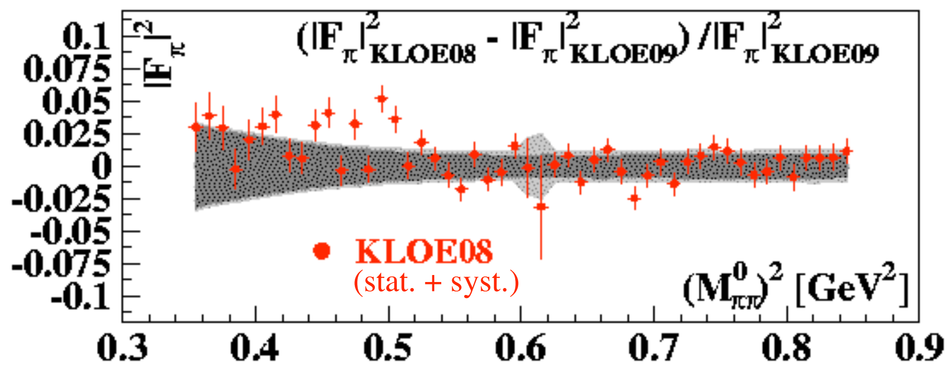
KLOE08: small angle analysis
KLOE09: large angle analysis



Zoomed region around ρ-peak:

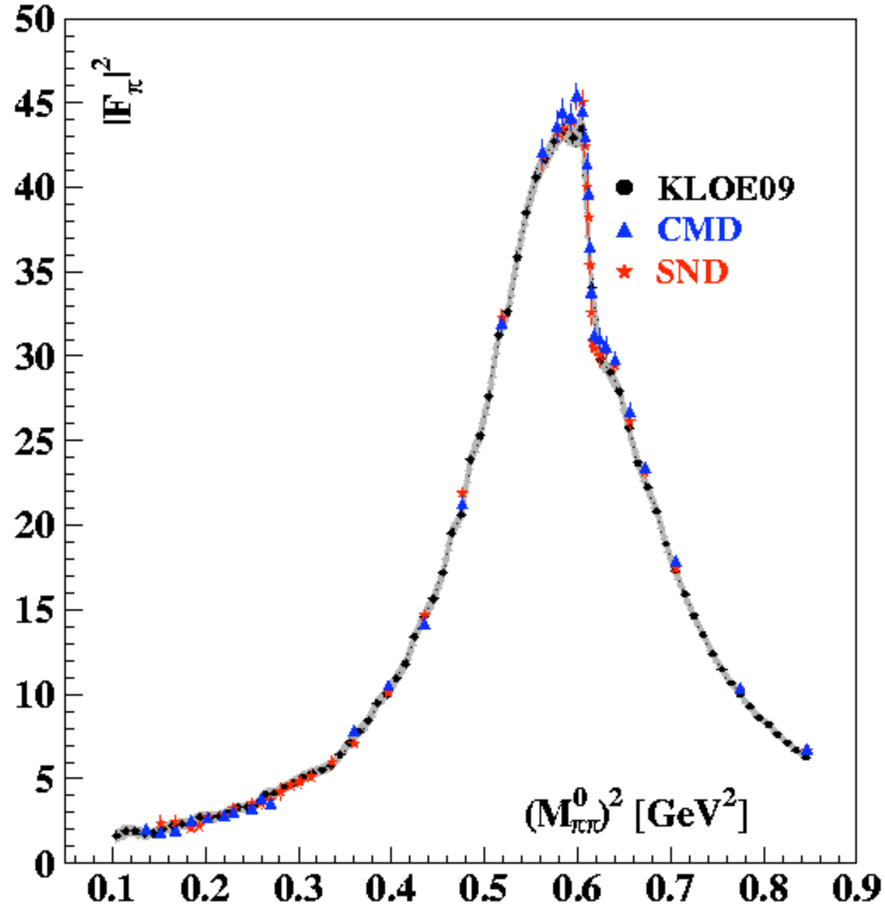


Fractional difference:



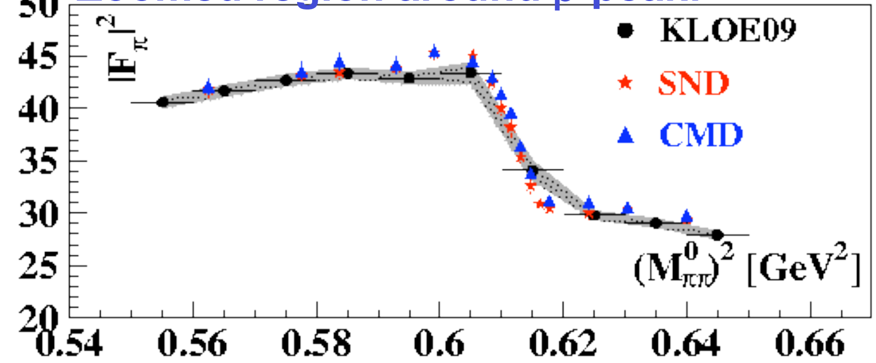
Grey band: KLOE09 error

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

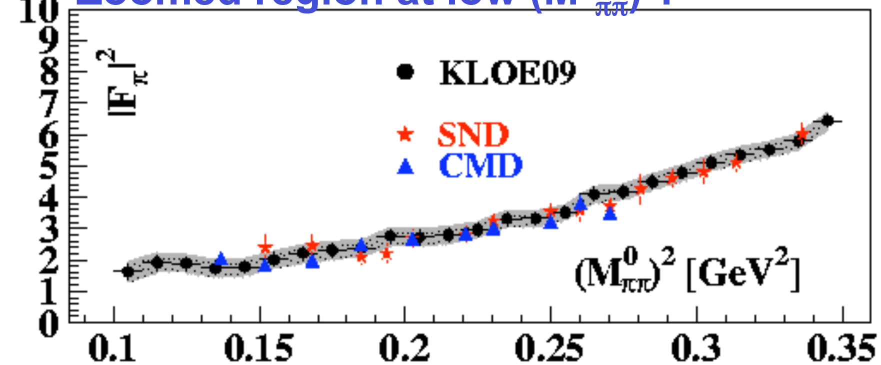


Grey band: KLOE09 error

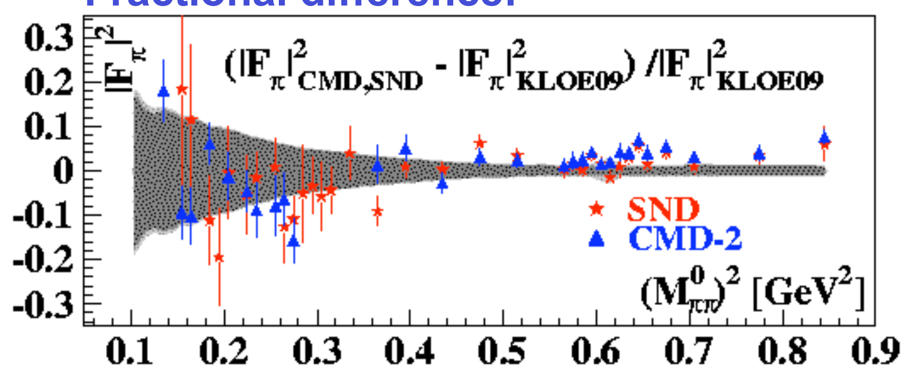
Zoomed region around ρ-peak:



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



Fractional difference:



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

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

$a_\mu^{\pi\pi}$(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%

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

The 3σ discrepancy between SM and BNL measurement on a_μ is confirmed

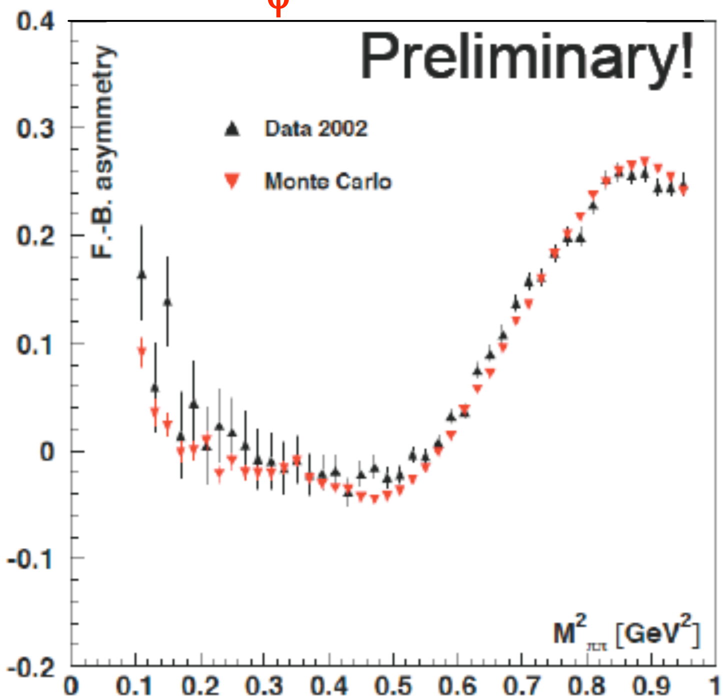
Forward-backward asymmetry

PRELIMINARY

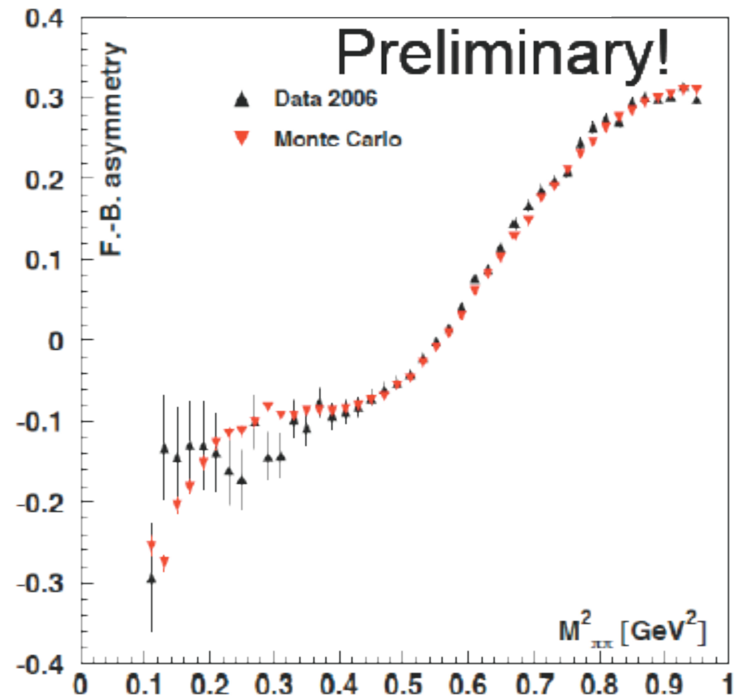
Different C parity of $\pi^+\pi^-$ for ISR and FSR+$\phi\rightarrow S\gamma$ gives rise to a non-vanishing

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

$\sqrt{s}=M_\phi \sim 1.0195$ 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**)

Conclusions

- **High statistics samples of light mesons produced at KLOE allow to perform precision measurement and to look for very rare decays**

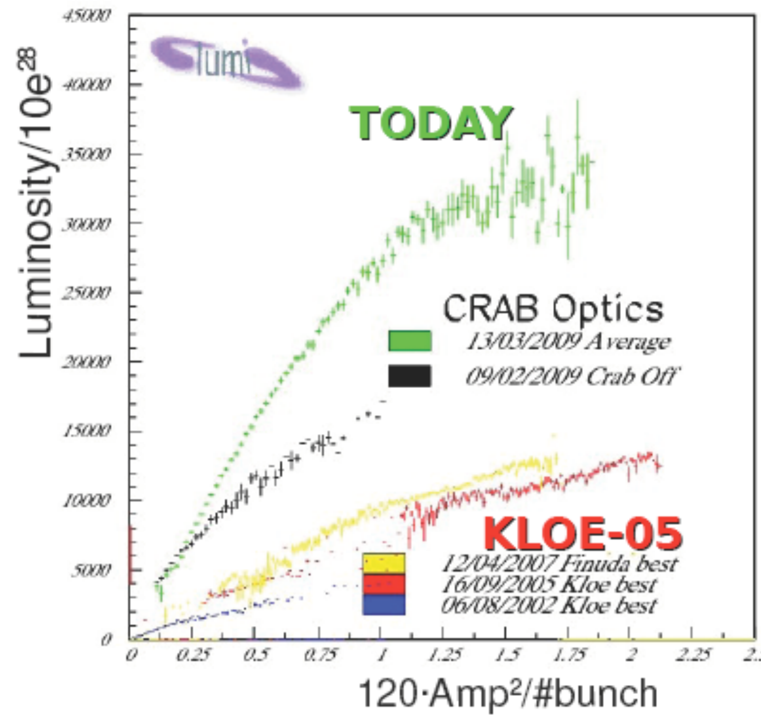
- **Unambiguous signature of η and $\pi^0\pi^0$ events produced through $\gamma\gamma$ interactions at $\sqrt{s}$ = 1GeV established**

- **New independent measurement of $\sigma_{\pi\pi}$ in agreement with KLOE published one confirms the 3σ discrepancy between SM and BNL measurement on a_μ**
  - **Measurement of pion FF with muon normalization in progress**

From KLOE to KLOE-2

New scheme to increase DAΦNE luminosity by a factor *O*(5) is being implemented (large crossing angle + "crabbed waist")

1. **KLOE-2 data-taking will start on May**, with the present detector + **tagger for γγ physics** ⇒ **~ 5 fb^{-1}**
2. **Detector upgrade**: inner tracker, new small angle calorimeters…
3. **Long data taking ⇒ 50 fb^{-1} in 3 – 4 years**



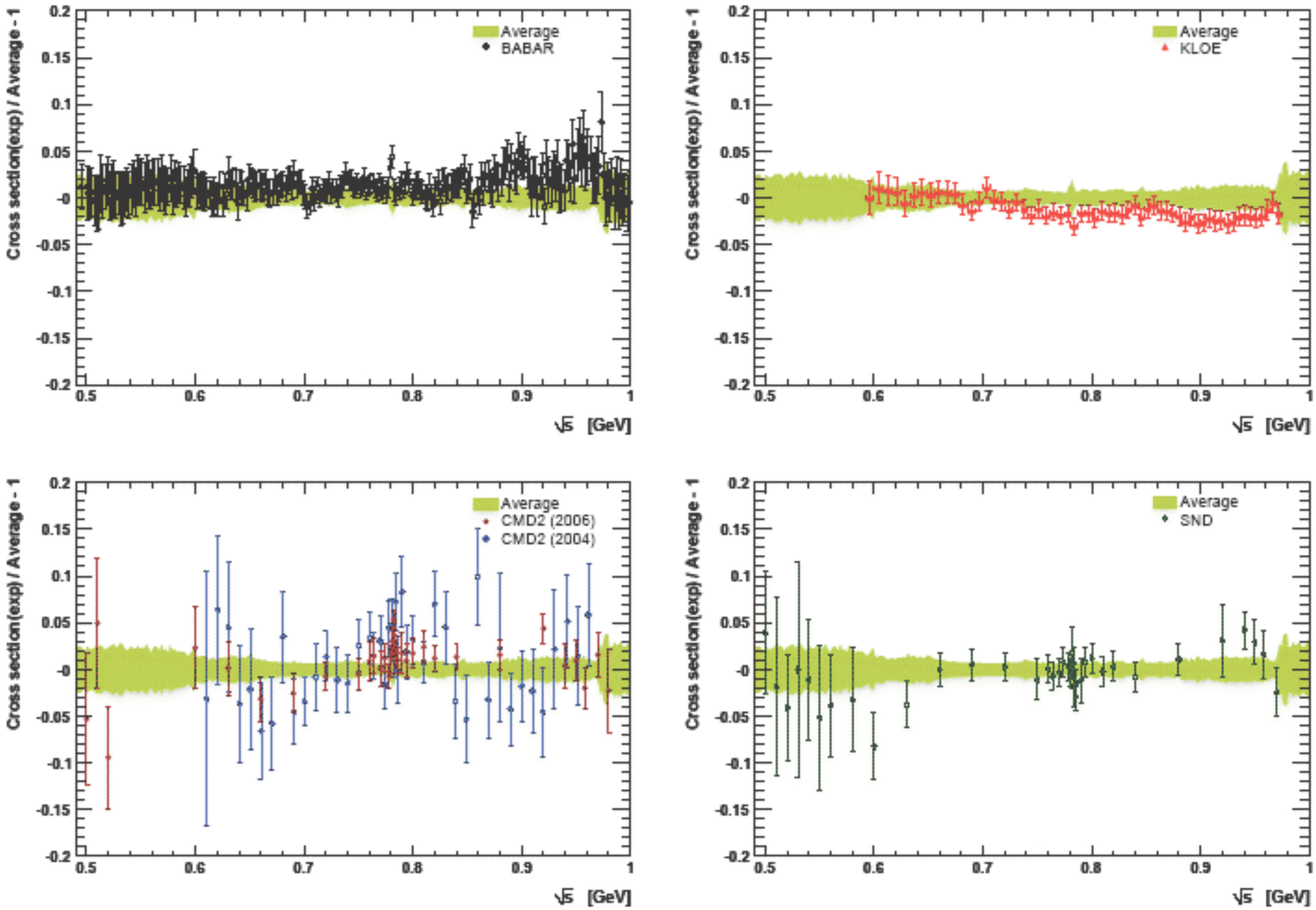
KLOE-2 physics program:

- **Kaon physics: CKM unitarity, Quantum Mechanics tests, lepton universality ($K^\pm \to e^\pm\nu$ / $K^\pm \to \mu^\pm\nu$), K_S rare decays**
- **Light hadrons: search for σ(600) in $\gamma\gamma \to \sigma \to \pi^0\pi^0$, $\phi \to (f_0/a_0)\gamma \to KK\gamma$ rare η decays, η' physics**

Backup slides

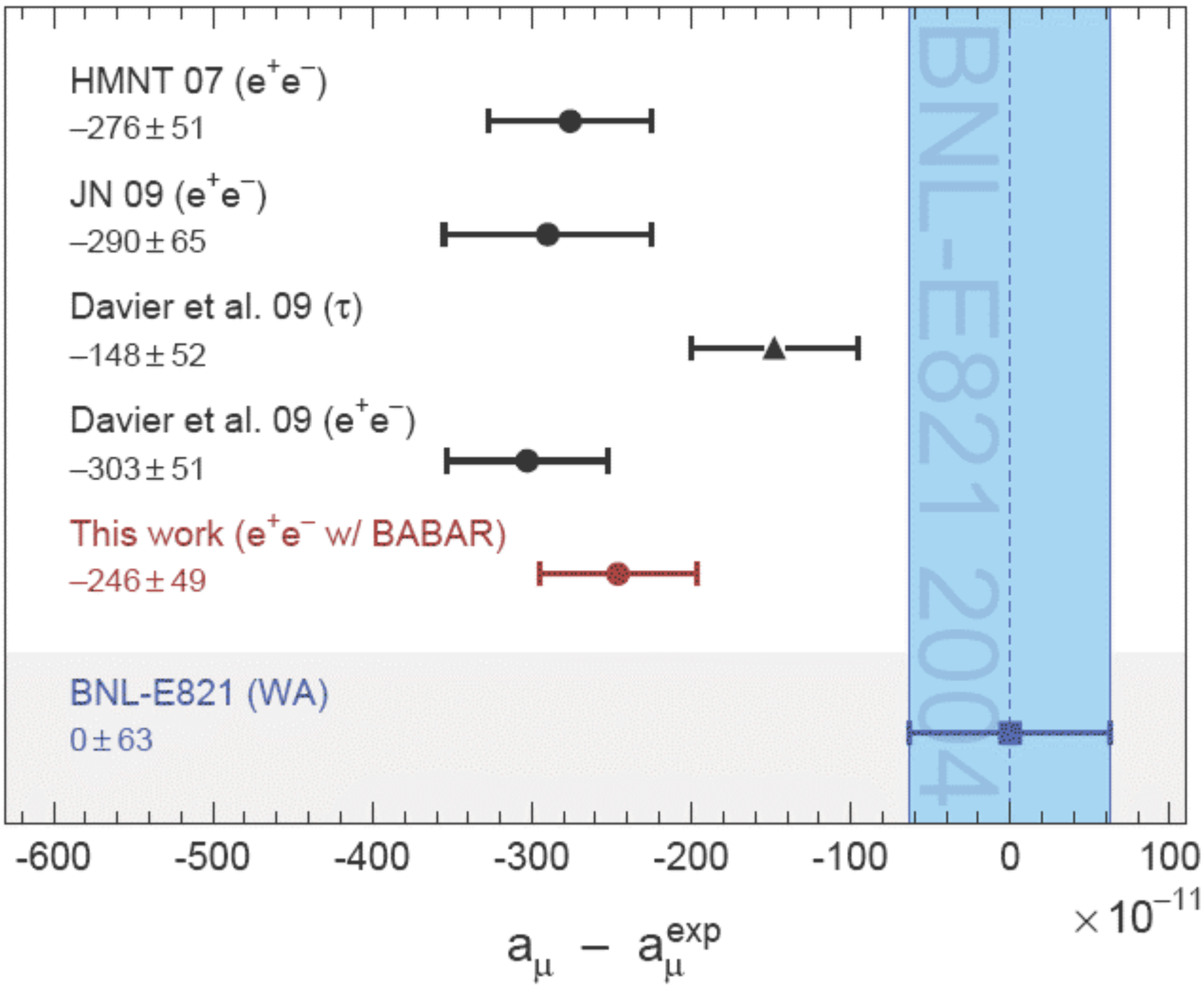
$|F_\pi|^2$: KLOE08 *vs* SND/CMD2/BABAR

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

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

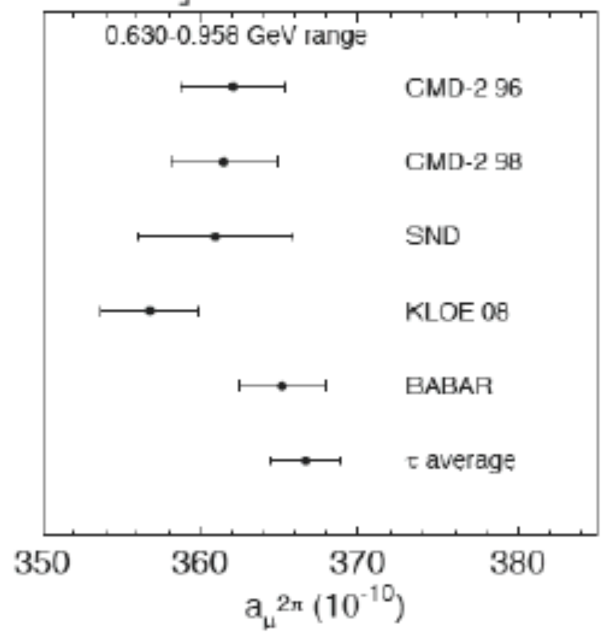
where $K(s)$ is the QED kernel,

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

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 *

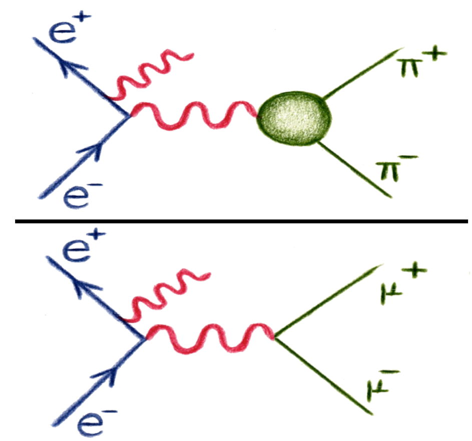
* arXiv:0906-5443 MD et al.

Wenfeng Wang PhiPsi09 14/10/2009 20

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)

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

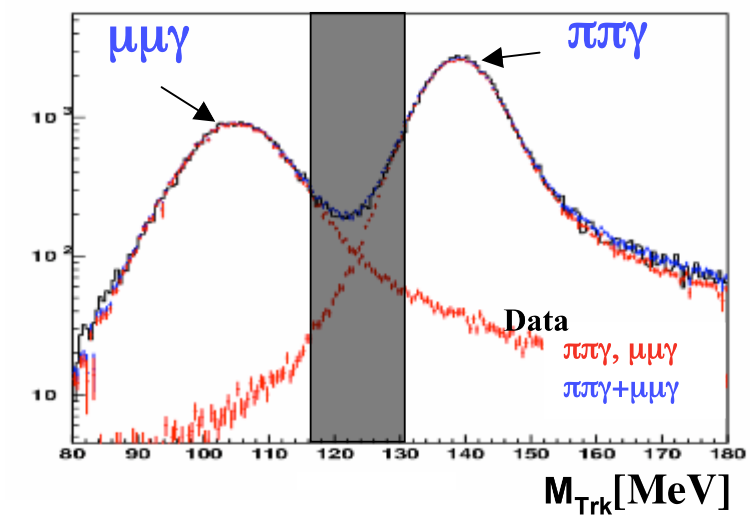


Many radiative corrections drop out:

- *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*



Luminosity measurement

KLOE measures *L* with Bhabha scattering

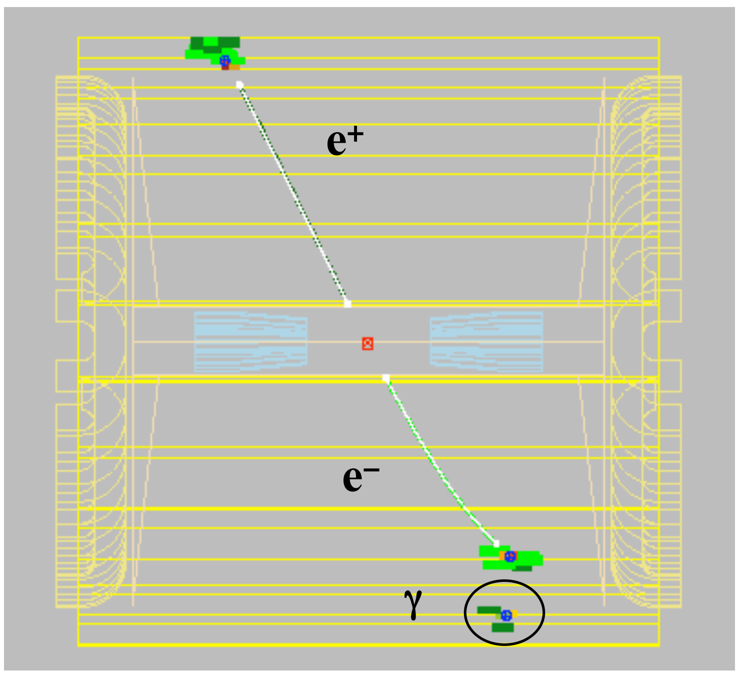
F. Ambrosino et al. (KLOE Coll.)
Eur.Phys.J.C47:589-596,2006

$55° < \theta < 125°$

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%	

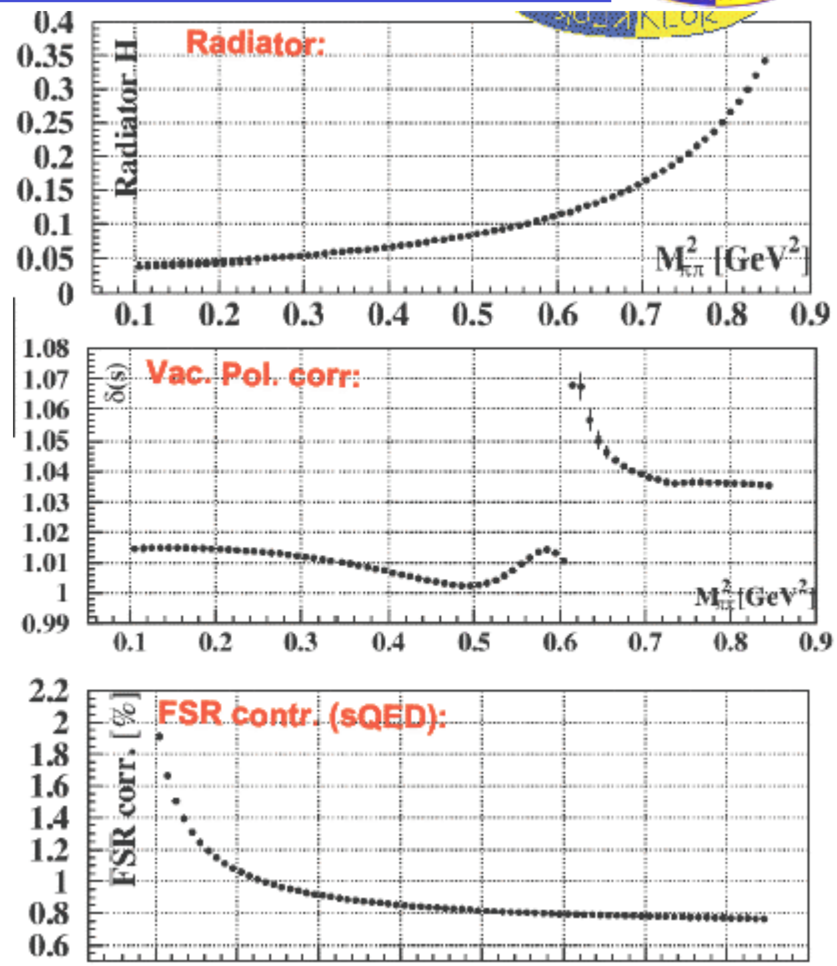
Radiative corrections

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

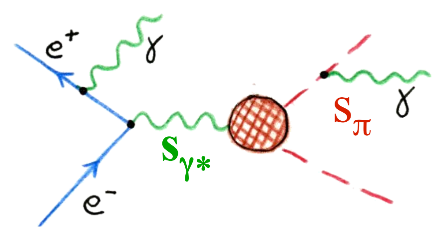
→ from F. Jegerlehner

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)



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

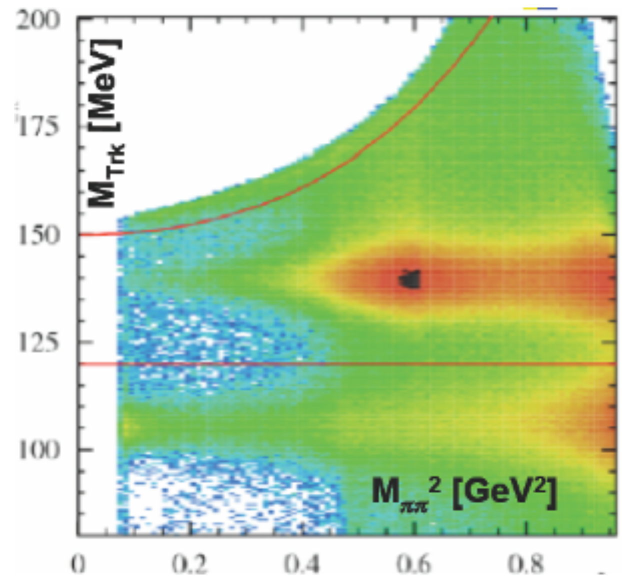
Event selection

Experimental challenge: background from

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

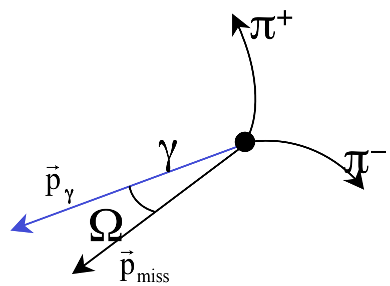
1. kinematical cuts in trackmass M_{Trk}
(defined by 4-momentum conservation under the hypothesis of 2 tracks with equal mass and a γ)

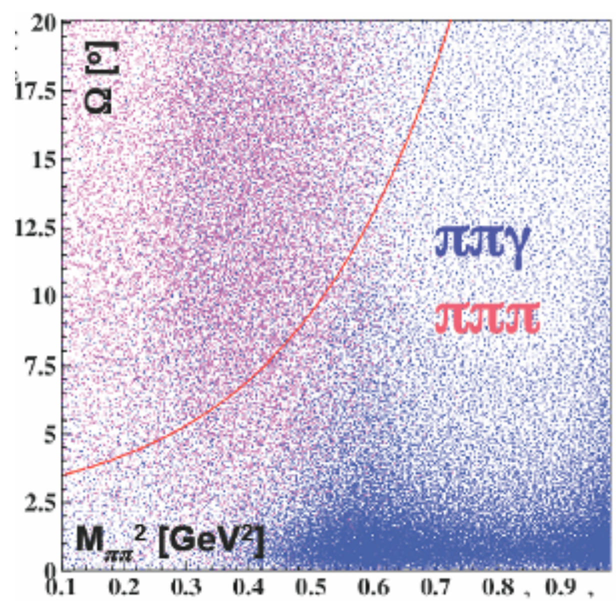
$$\left(\sqrt{s}-\sqrt{p_1^2+M_{trk}^2}-\sqrt{p_2^2+M_{trk}^2}\right)^2-(p_1+p_2)^2=0$$



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

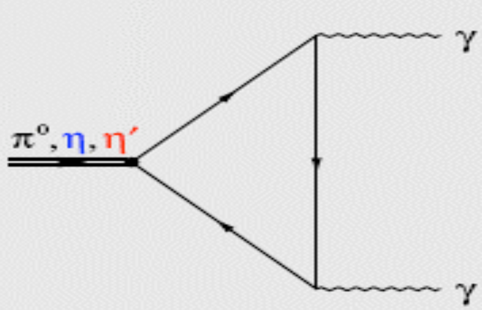
$\eta\to\pi^+\pi^-\gamma$: contributions

Anomalies in QCD

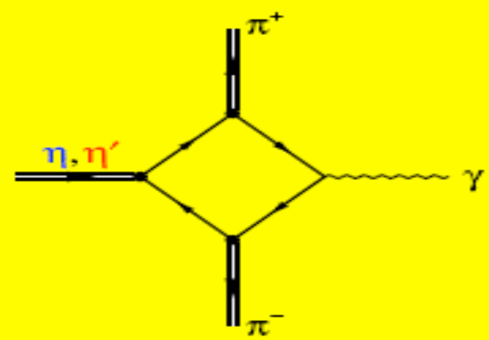
Wess-Zumino-Witten Lagrangian

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

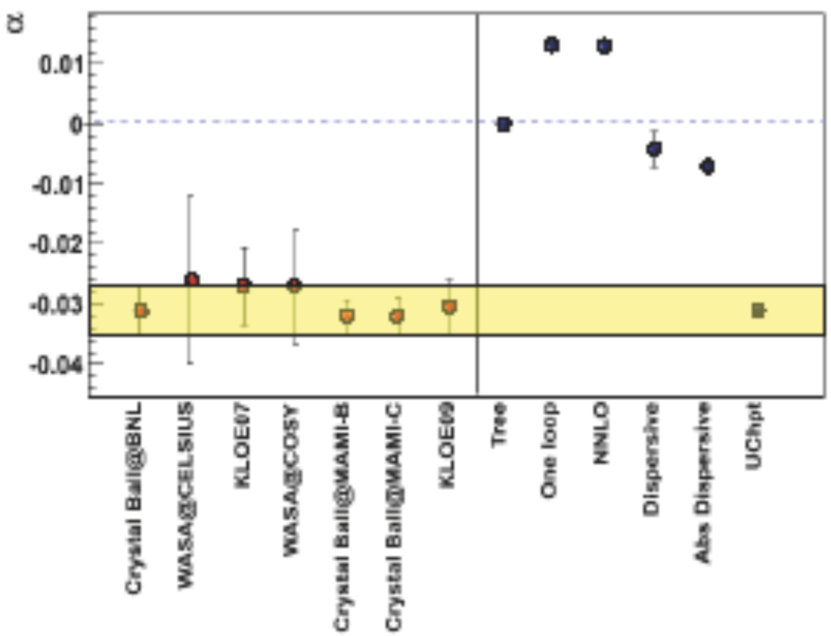
- Resonant contribution:
  1. ρ production with its subsequent decay to a pion pair (VDM)
  2. existence of a small non-VDM contribution
- Anomalous contribution:
  box anomaly (similar to the classical triangle anomaly), responsible for $\eta/\eta' \to\pi^+\pi^-\gamma$ decays predicted by PCAC and by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

$\eta \rightarrow \pi^0\pi^0\pi^0$

At the lowest order $\eta \rightarrow \pi^0\pi^0\pi^0$ decay amplitude can be parametrize by

$$|A|^2 \propto 1 + 2\,\alpha\,z \qquad \text{where} \qquad z = \frac{2}{3}\sum_{i=1}^{3}\frac{(3E_i - M_\eta)^2}{(M_\eta - 3M_\pi)^2}$$

The slope α was measured to be negative and small in disagreement with CA ($\alpha = 0$)
The explanation of this effect poses a challenge for **ChPT**
LO calculations in ChPT coincide with CA
NLO calculations significantly improve the agreement for the partial decay width but predict a small positive value ($\alpha > 0$).



KLOE final:
615000 events
Fit Z in the range [0 ÷ 0.7]:

$$\alpha = -0.0301 \pm 0.0035_{stat}\,{}^{+0.0022}_{-0.0036}{}_{syst}$$

paper in writing ...

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

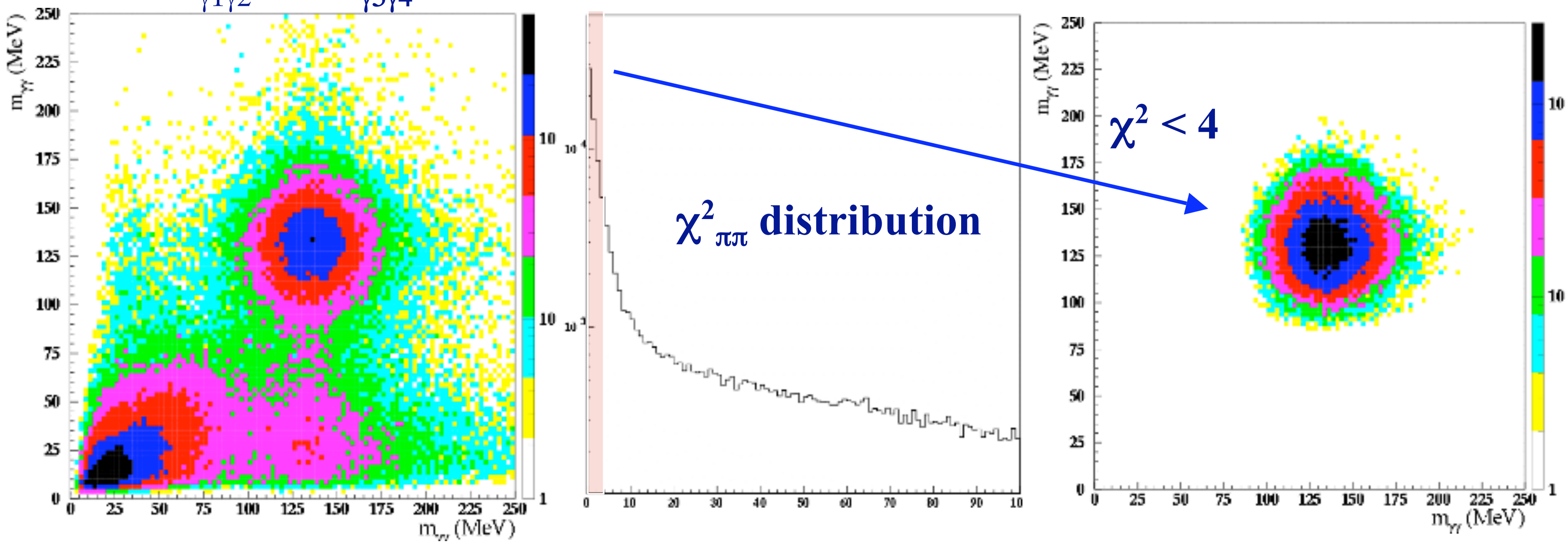
- Four prompt neutral clusters
- No tracks
- Photon pairing: $\chi^2_{\pi\pi} < 4$
- $\Sigma_{2Emin} > 60$ MeV
- $p_T < 80$ MeV

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

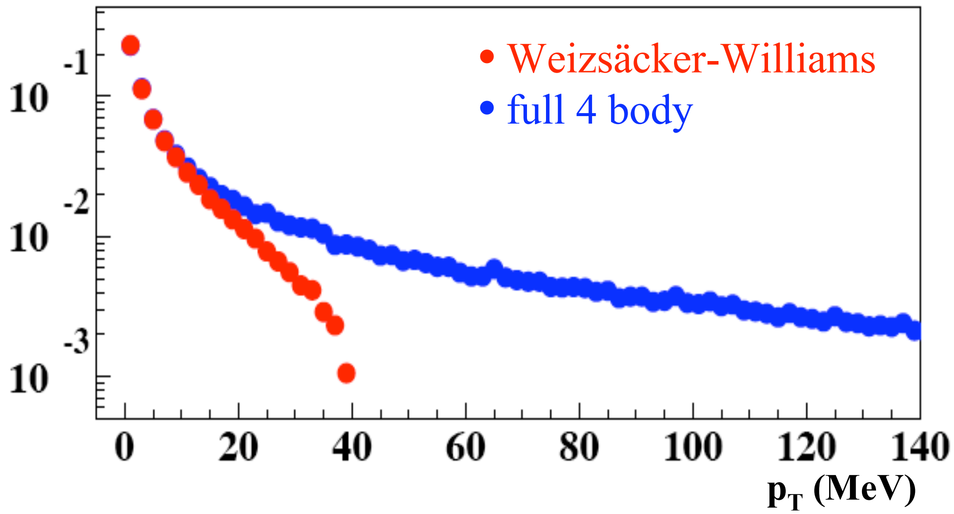
$$\frac{\sigma(E_i, E_j)}{M_{ij}} = \frac{1}{2}\left(\frac{\sigma_{E_i}}{E_i} \oplus \frac{\sigma_{E_j}}{E_j}\right)$$

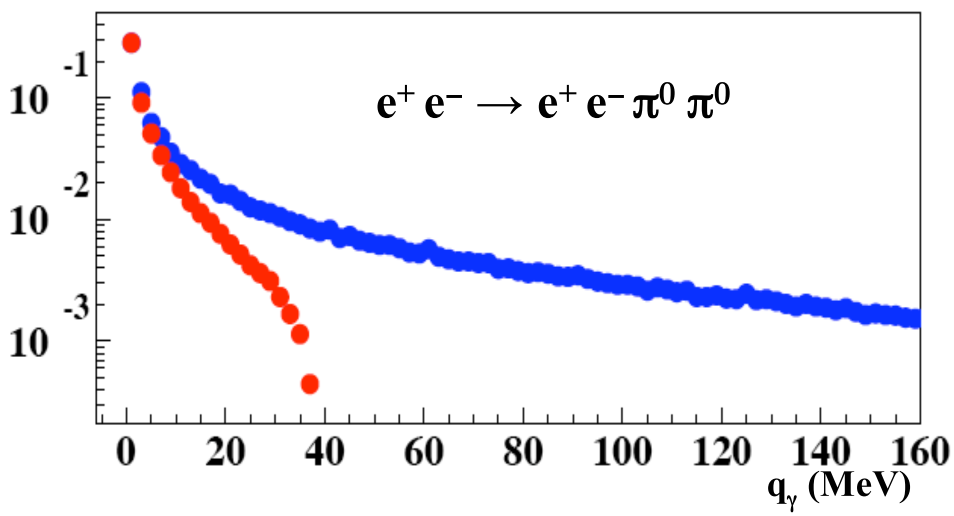
$$M_{ij}^2 = 2E_iE_j(1 - \cos\theta_{ij})$$

$m_{\gamma1\gamma2}$ vs. $m_{\gamma3\gamma4}$



Comparison btw W.W. and phase space

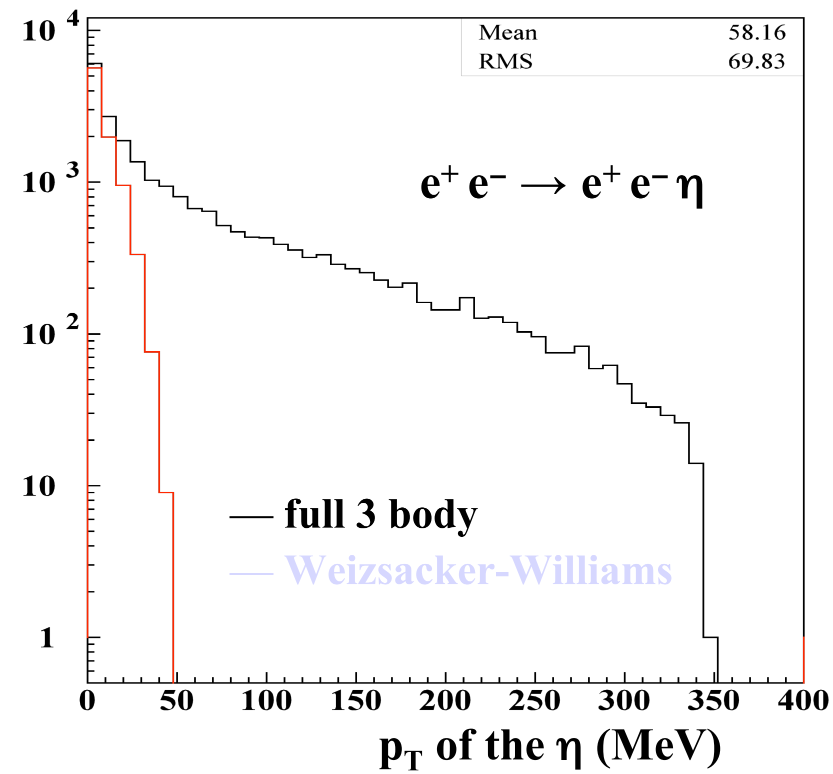




F.Nguyen, F. Piccinini & A. Polosa
Eur.Phys.J.C47(2006)65

1) W.W. is reproduced with a cut $\theta < 5^o$ for final state e^+e^-

2) impact at the % level within cuts (p_T < 80 MeV)

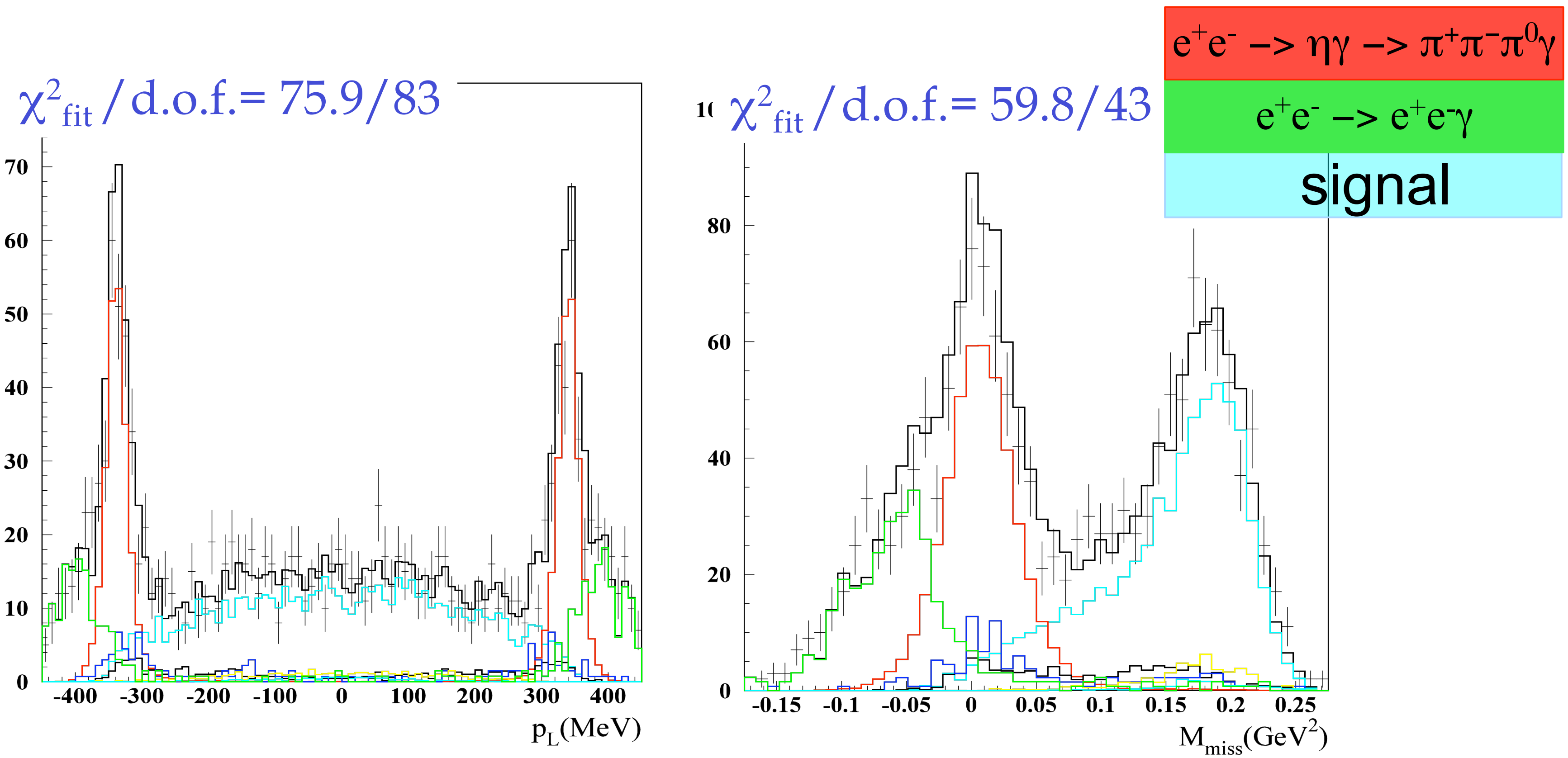


$e^+e^-\to e^+e^-\eta$: fit results

PRELIMINARY

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

Background yields constrained by present knowledge of x-sections



~ 600 signal events. 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