Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

with the KLOE detector

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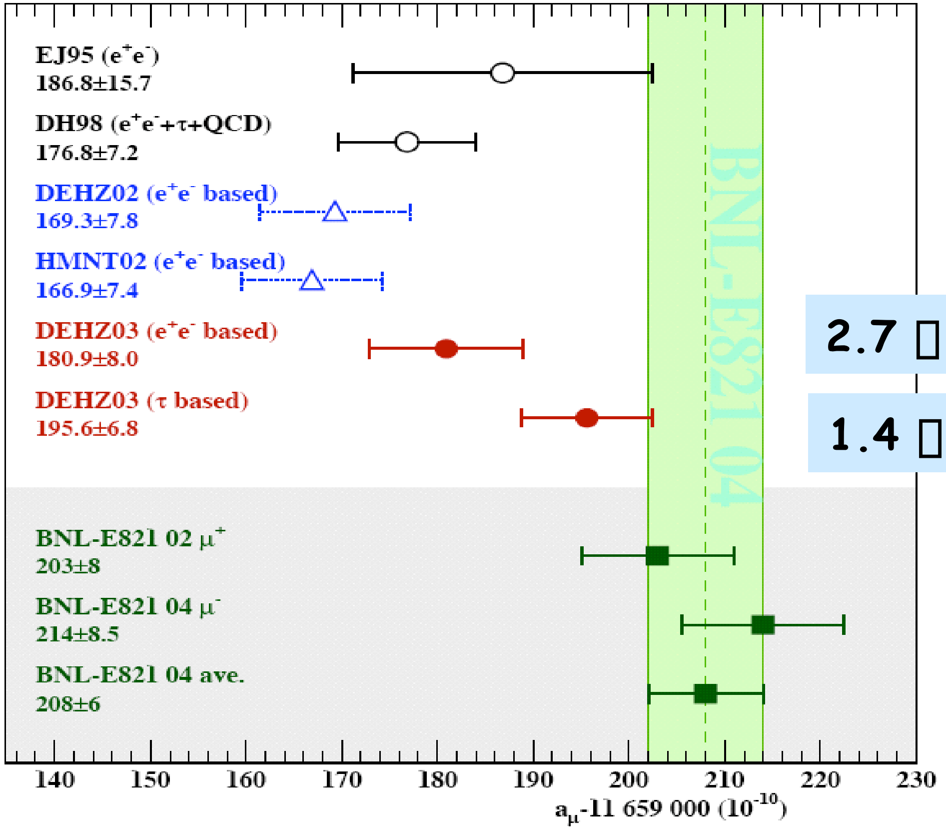
Status on $(g-2)_\mu$:

Davier, Eidelman, Höcker, Zhang: hep-ph/0308213,
E821: hep-ex/0401008



2.7 σ

1.4 σ

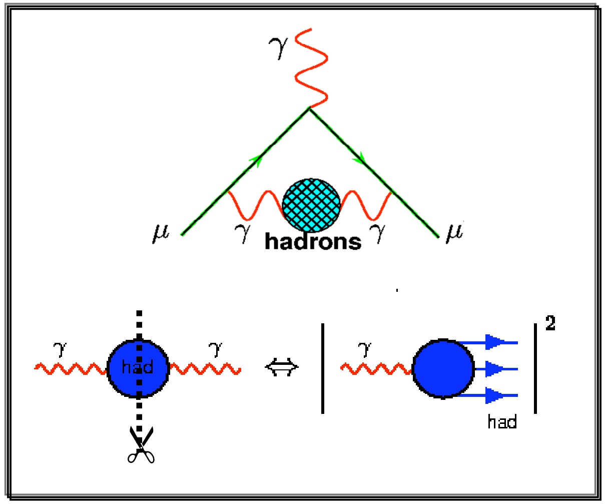
Disagreement between e^+e^- based and τ based evaluations

• The nature of the difference in the two theoretical evaluations of a_μ^{had} has to be understood in order to claim a discrepancy between (SM-)theory and experiment

• More and better information on the hadronic contribution to the SM calculation of a_μ could help to clarify this difference and (together with a further reduction of the experimental error) give the discrepancy between theory and experiment a higher significance

Dispersion integral:

a_μ^{hadr} can be expressed in terms of $\sigma(e^+e^- \rightarrow$ hadrons$)$ by the use of a dispersion integral:

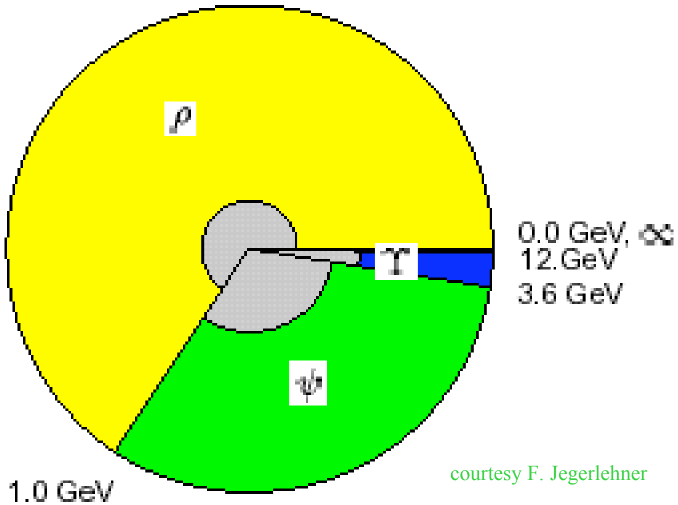


$$a_\mu^{hadr} = \frac{1}{4\pi^3}\left(\int_{4m_\pi^2}^{E_{Cut}^2} ds\, \sigma^{hadr,exp}(s) K(s) + \int_{E_{Cut}^2}^{\infty} ds\, \sigma^{hadr,pQCD}(s) K(s) \right)$$

- E_{cut} is the threshold energy above which pQCD is applicable
- s is the c.o.m.-energy squared of the hadronic system
- $K(s)$ is a steady function that goes with $1/s$, ***enhancing low energy contributions of $\sigma^{hadr}(s)$***

Low energy contribution:

The region around the energy of the ρ-meson adds with ca. 61% to the total value of a_μ^{hadr}. [Jegerlehner; hep-ph/0104304]

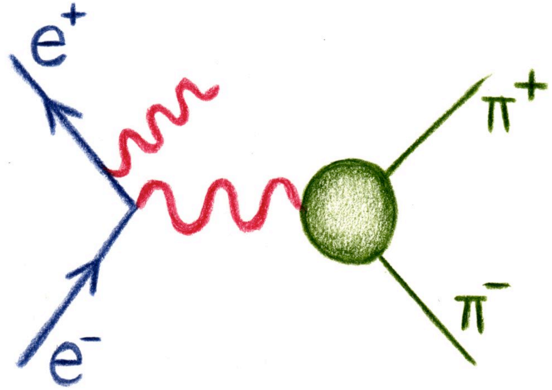


The ρ-meson decays to 100% in $\pi^+\pi^-$, so in this energy region the analysis efforts concentrate on the determination of

$$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$$

$\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ with ISR:

Particle factories have the opportunity to measure the cross section $\sigma(e^+ e^- \to hadrons)$ as a function of the hadronic c.m. energy $M^2_{hadrons}$ by using the **radiative return**.



$$M^2_{hadr} \frac{d\sigma(e^+ e^- \to hadrons + \gamma)}{dM^2_{hadrons}} = \sigma(e^+ e^- \to hadrons)\, H(M^2_{hadr})$$

This method is a **complementary approach** to the standard energy scan.

It requires precise calculations of the radiator ***H***.

➔ **EVA + PHOKHARA MC Generator**

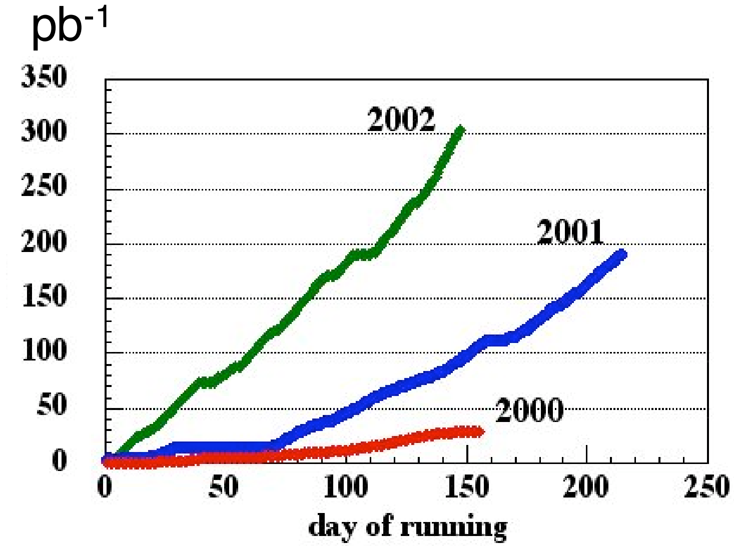
(S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999)

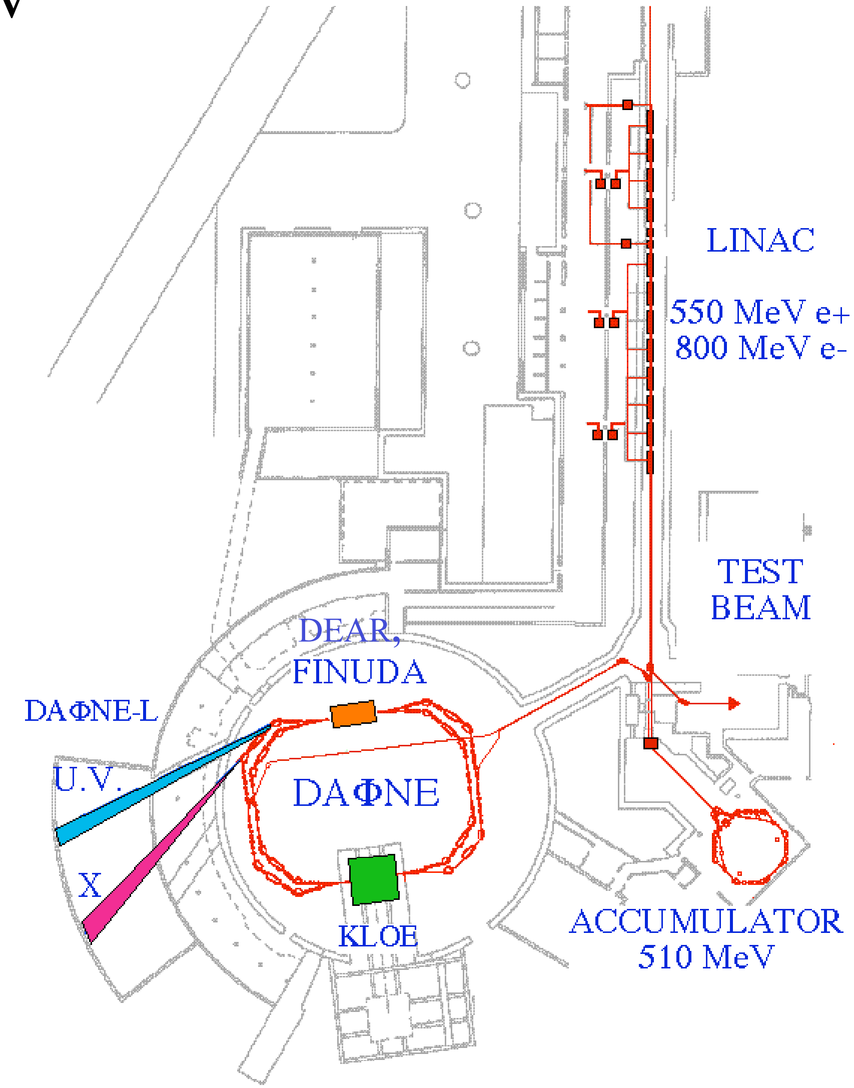
(H. Czyz, A. Grzelinska, J.H. Kühn, G. Rodrigo, hep-ph/0308312)

DAΦNE: A Φ-Factory

(**D**ouble **A**nnular Φ-Factory for **N**ice **E**xperiments)

e^+e^- - collider with $\sqrt{s} = m_\phi \simeq 1.020$ GeV





2000 run : 25 pb^{-1} 7.5 x 10^7 φ

2001 run: 190 pb^{-1} 5.7 x 10^8 φ

2002 run: 300 pb^{-1} 9.0 x 10^8 φ

DAΦNE Backgr. reduced

KLOE:

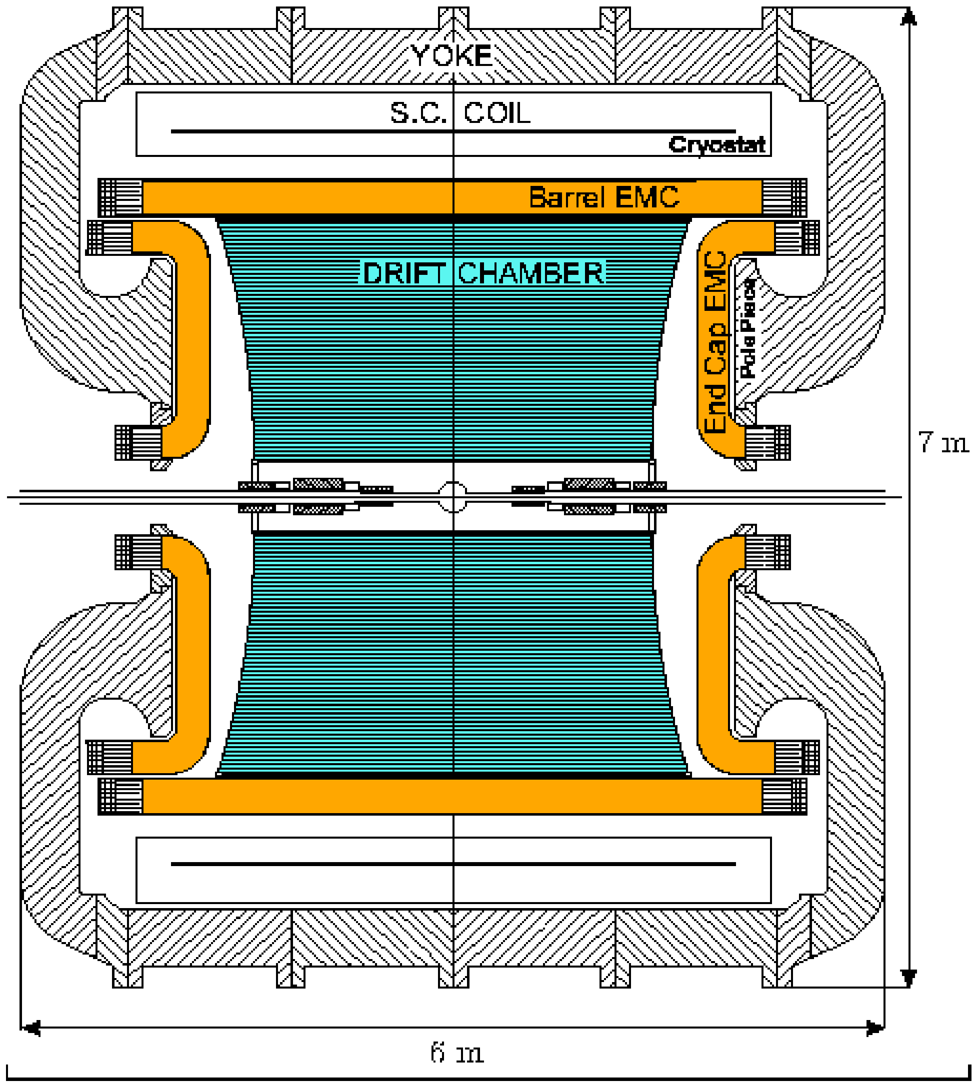
(KLOng Experiment)

- **Magnet:**
  Superconducting coil (B=0.5 T)

- **EM Calorimeter:**
  Lead/Scintillating fibres
  4880 PM

- **Driftchamber:**
  12582 Sense Wires
  52140 wires in total

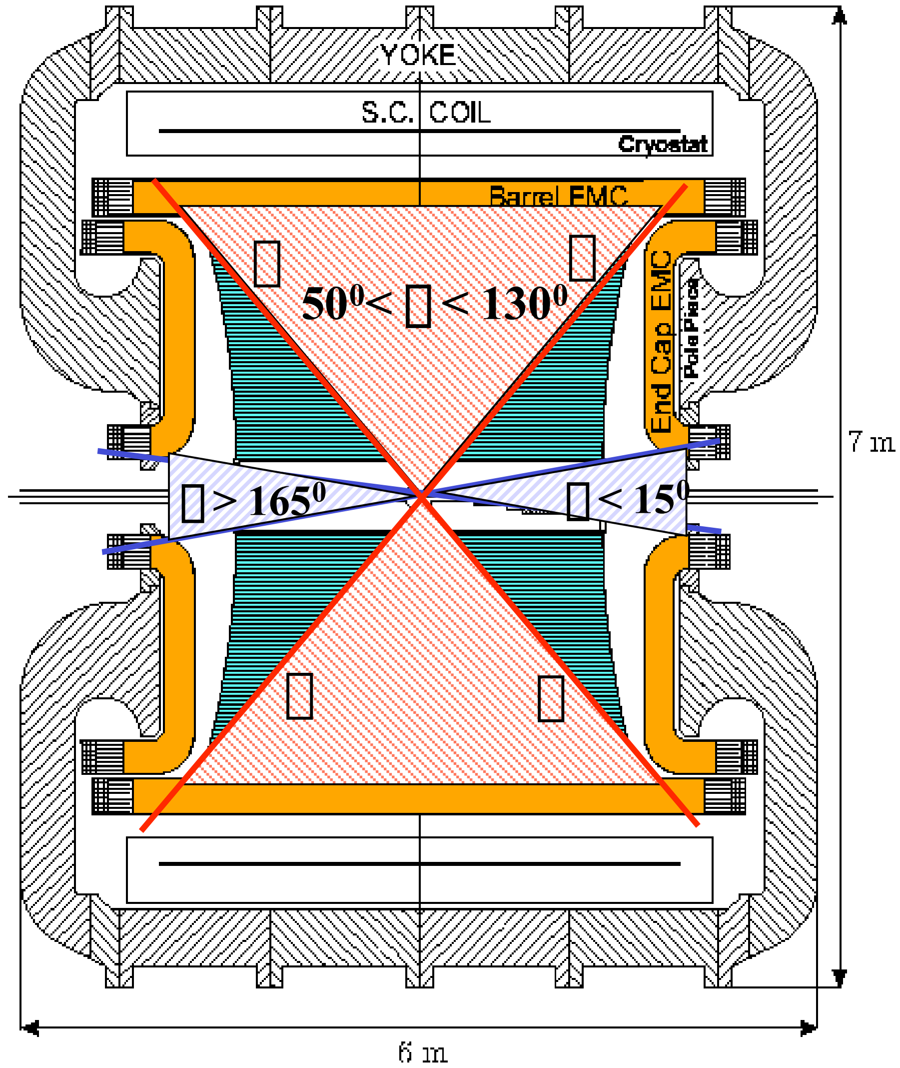
- **Beryllium Beampipe:**
  R=10 cm, 0.5 mm thick



Signal selection:

Pion tracks are measured at angles
$50^o < □_□ < 130^o$

Photons are required to be within
$□_□ < 15^o$ or $□_□ > 165^o$



Untagged measurement in which we cut on the direction of the missing momentum

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

The choice of this kinematical region was motivated by:

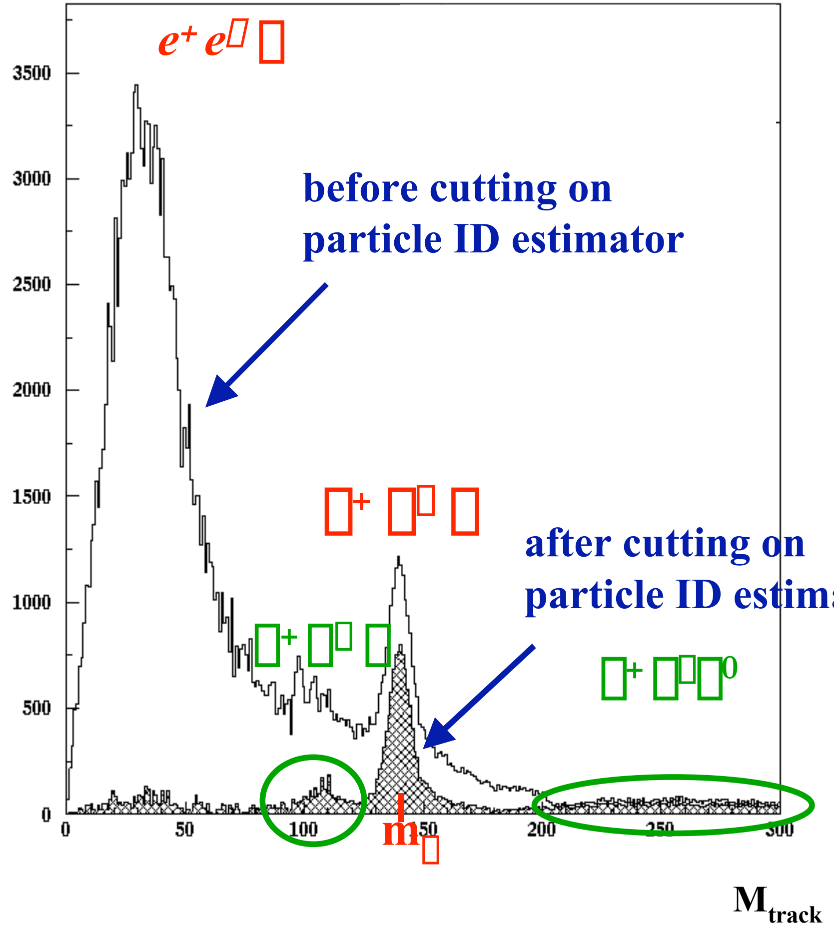
- **small relative contribution of FSR**
- **reduced background contamination:**
  - $e^+e^□ □ e^+e^□ □$
  - $e^+e^□ □ □^+□^□ □$
  - $e^+e^□ □ □ □ □^+□^□□^0$

Background rejection:

To reduce Bhabha contamination, a □-e-separation is performed using a particle ID estimator

- TOF of charged clusters in EMC
- Shape and energy deposition of the cluster

The event is selected if one of the charged tracks is identified to be a pion.



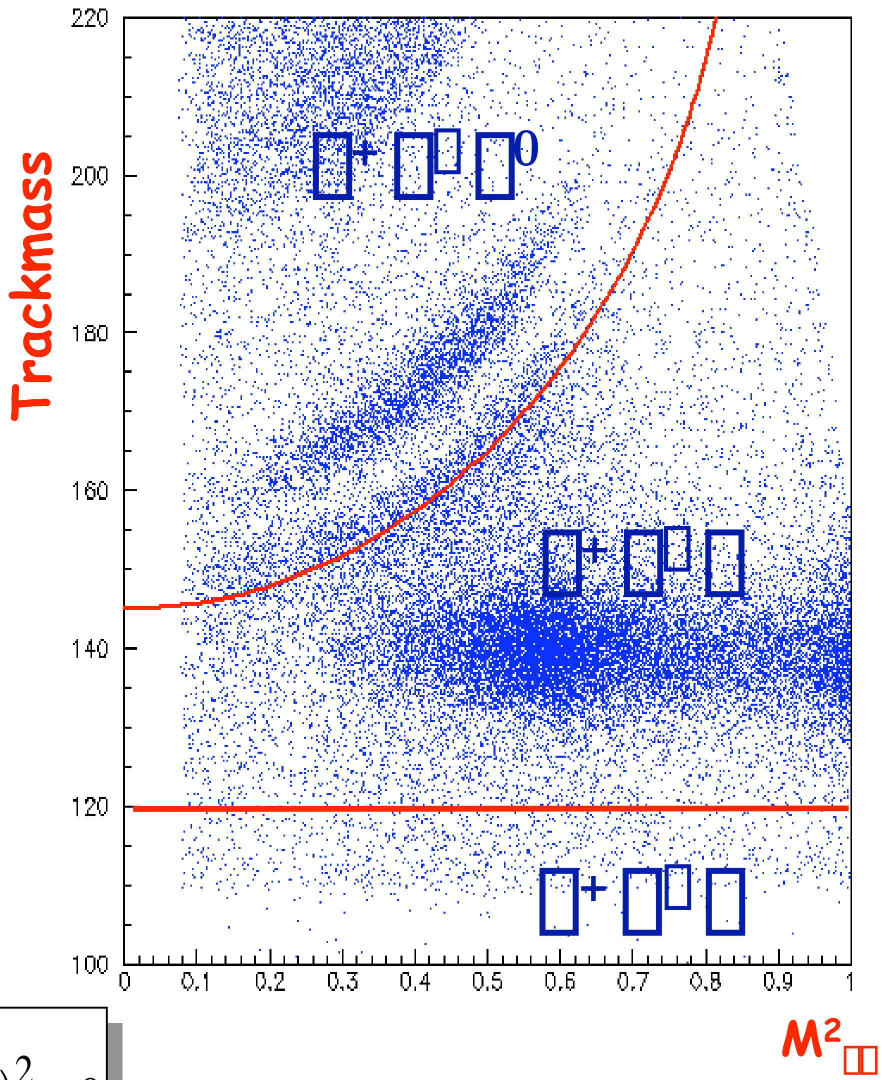
Background rejection:

The signal is further selected by performing a cut in the kinetical variable **trackmass** in order to reduce **□+ □□ □0 background**

□+ □□ □background (M_{track}□105 MeV) is rejected by a cut on M_{track} =120 MeV

The trackmass is the particle mass for the two tracks obtained by using the 4-momentum-conservation and the assumption that both particles have the same mass M_{trk}:

$$q_{\square}^2 = \left(M_{\square} - \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} - \sqrt{\vec{p}_2^{\,2} + M_{trk}^2} \right)^2 - \left(\vec{p}_1 + \vec{p}_2\right)^2 = 0$$



$M_{\pi\pi}^2$- Spectrum:

140 pb^{-1} of 2001 data were analyzed according to the items discussed.

After selection: **1 500 000 events**

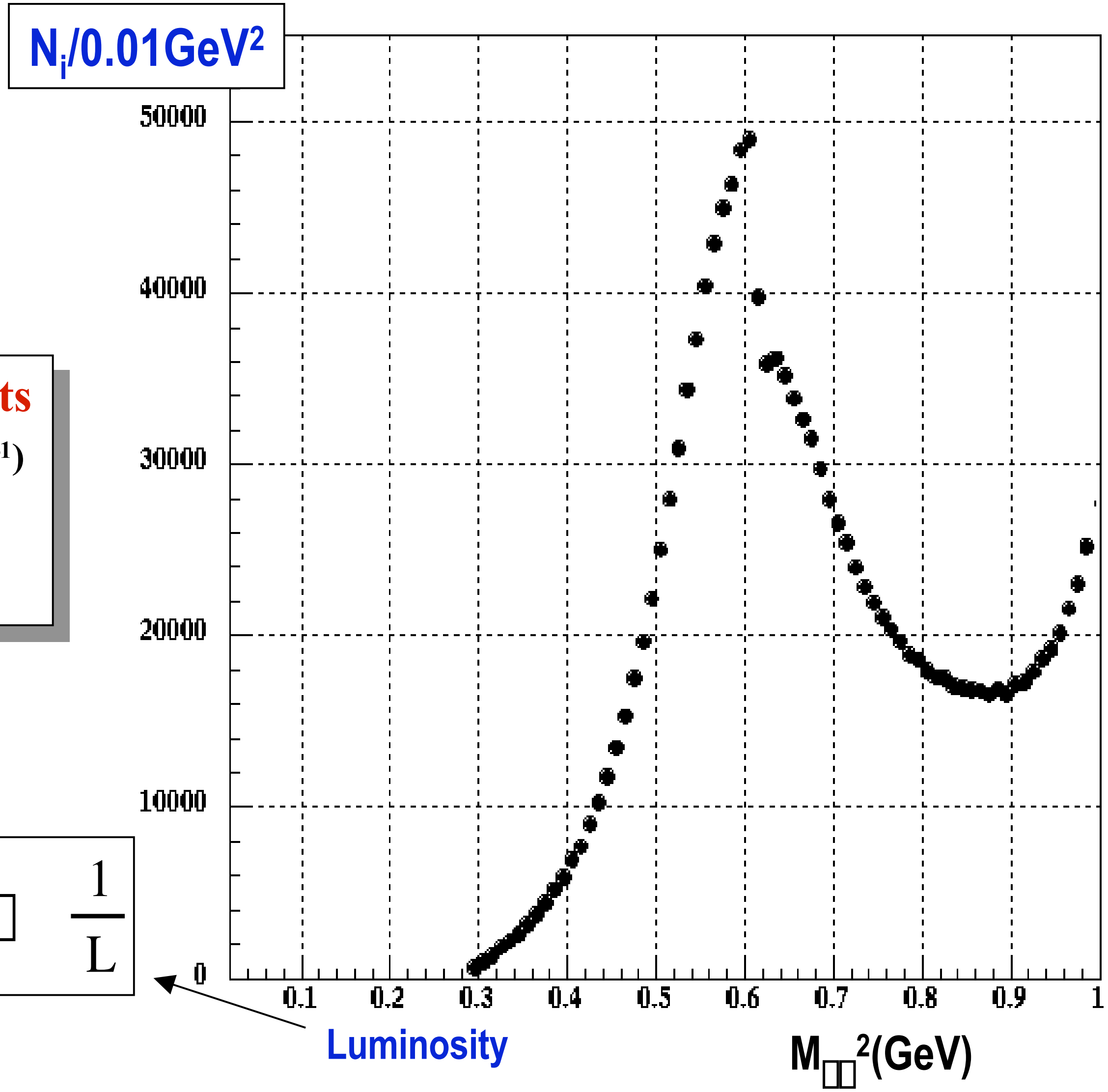
(11000 evts/pb^{-1})

statistical error/bin < 1%
for $M_{\pi\pi}^2 > 0.45$ GeV^2

Signal — Background

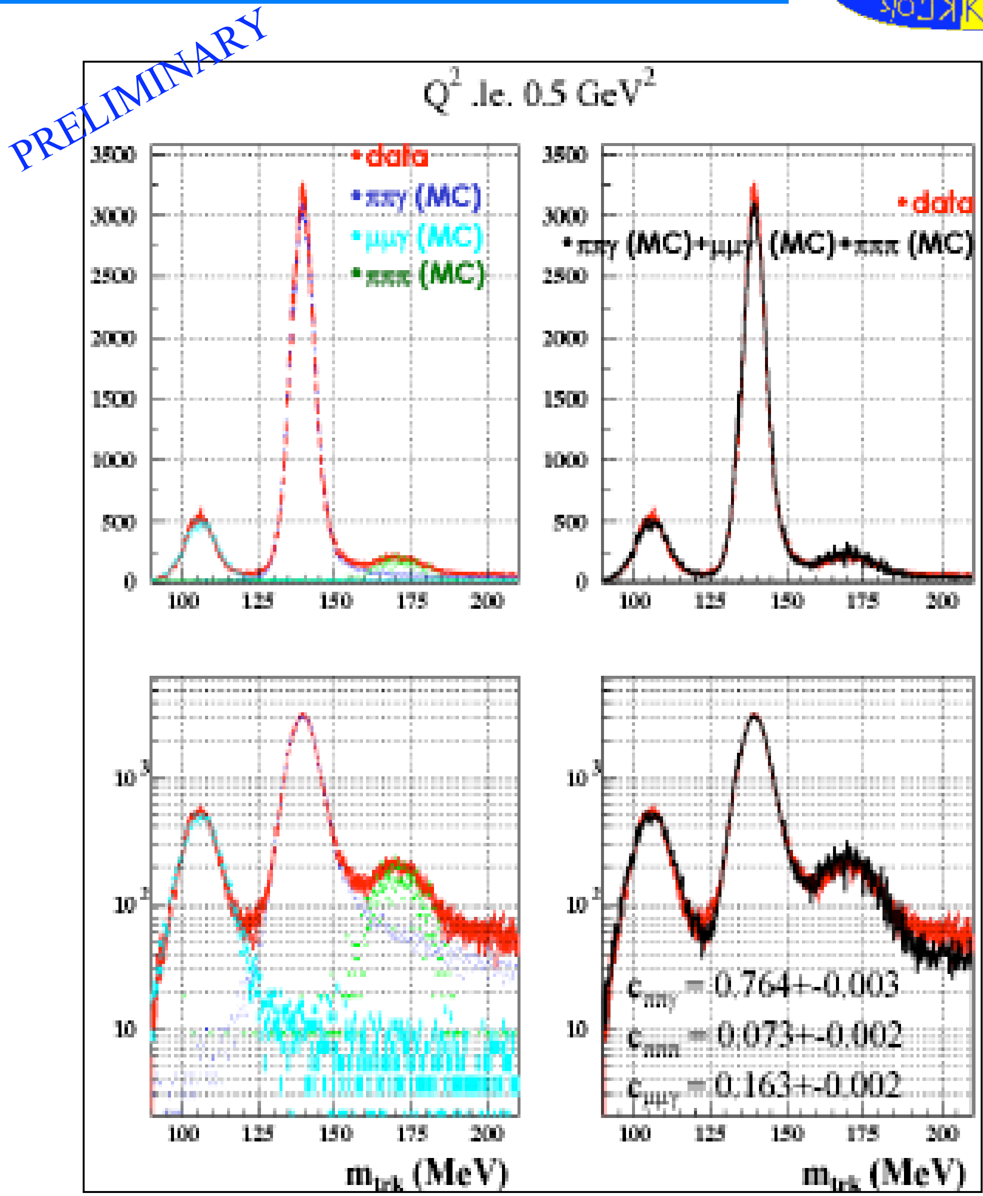
$$\frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \frac{N^{obs} - N^{bkg}}{\Delta M_{\pi\pi}^2} \cdot \frac{1}{\varepsilon_{Select.}} \cdot \frac{1}{L}$$

Selection efficiency — Luminosity



Acceptance: **□$_{□□}$<15° (□$_{□□}$ >165°), 50°<□$_{□}$<130°, E$_{□}$>10 MeV**

Background subtraction:



Remaining contaminations from $\pi^+\pi^-\pi^0$ and $\mu\mu\gamma$ are measured by fitting the shape of signal and background in the trackmass distribution for different bins of $M_{\pi\pi}^2$.

The estimated number of background events is then subtracted from the spectrum.

Luminosity:

- Luminosity measured with Large Angle Bhabhas: $55^o < \theta_e < 125^o$
- 2 independent generators used for radiative corrections:
  - BABAYAGA (Pavia group): $\sigma_{eff} = (428.8 \pm 0.3_{stat})$ nb
  - BHAGENF (Berends modified): $\sigma_{eff} = (428.5 \pm 0.3_{stat})$ nb

- Systematics from generator claimed to be 0.5%
- Experimental systematic error determined by comparing data and MC angular and momentum distributions

Systematics on Luminosity	
Theory	0.5 %
Acceptance	0.2 %
Background (□□□+□□□)	0.1 %
Trigger+Track+Clustering	0.2 %
Knowledge of s run-by-run	0.1 %
TOTAL	0.5 % theory ⊕ 0.3% exp = 0.6 %

Efficiencies:

Trigger

including Cosmic-ray Veto Eff.

Reconstr. Filter

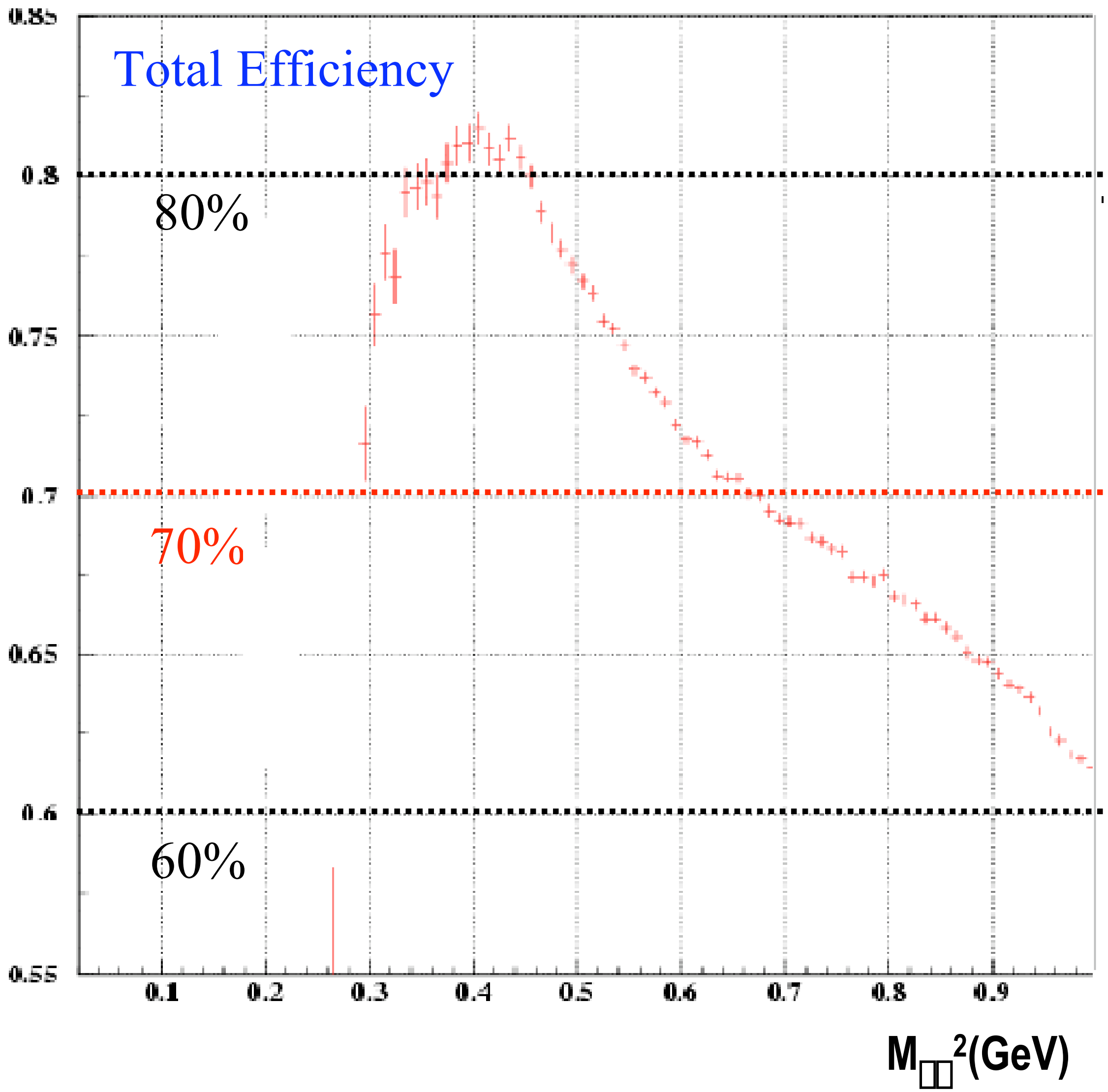
Tracking / Vertex

□-e separation

Trackmass

blue = estimated from data and/or indep. control samples □+□□□0, □+□□
Kinematics simulated by MC

red = estimated from MC and compared with data

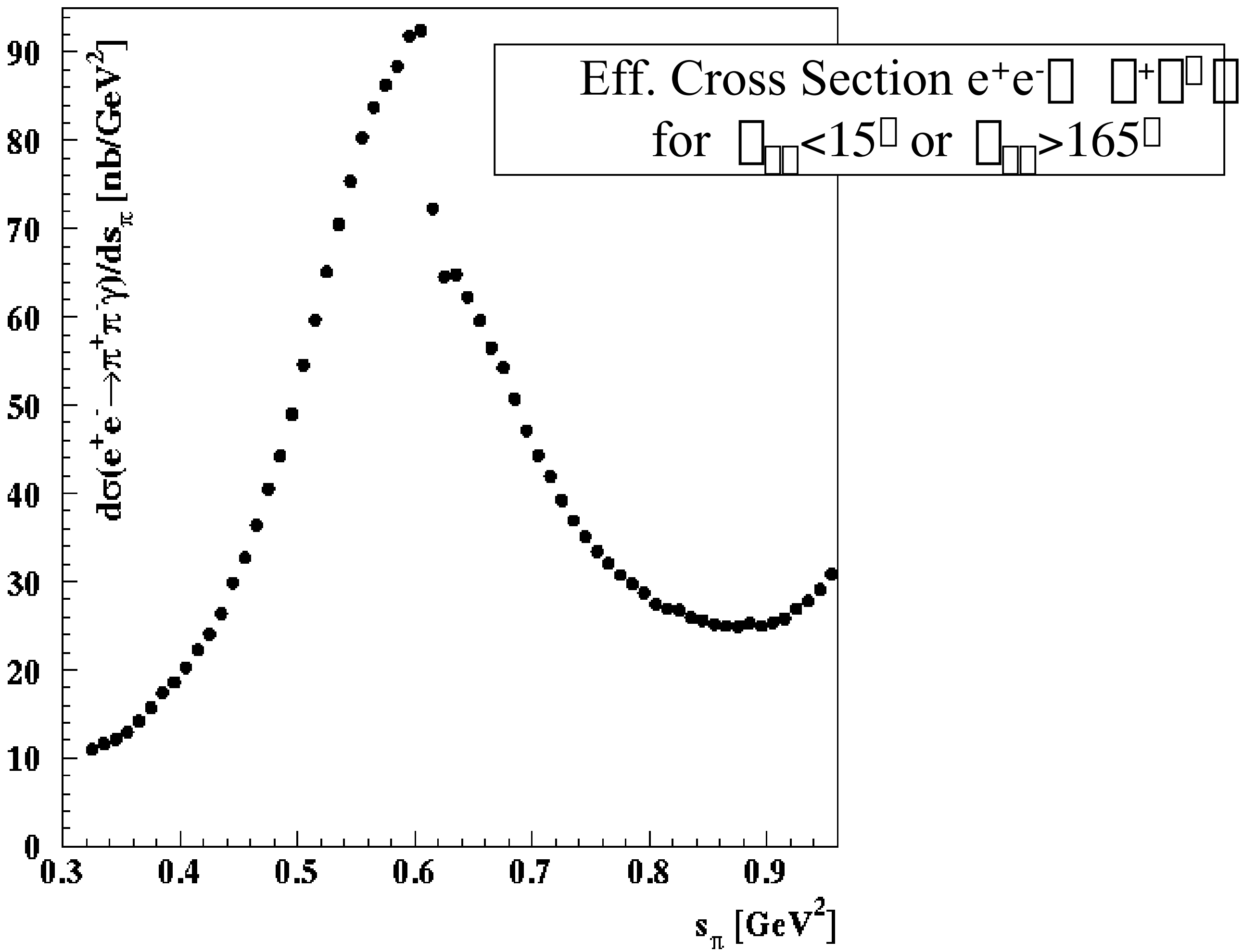


$\sigma(e^+e^- \to \pi^+\pi^-\gamma)$:

After subtracting the residual background, correcting for the FSR contribution, dividing for luminosity and efficiencies and unfolding the detector resolution, we arrive to

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

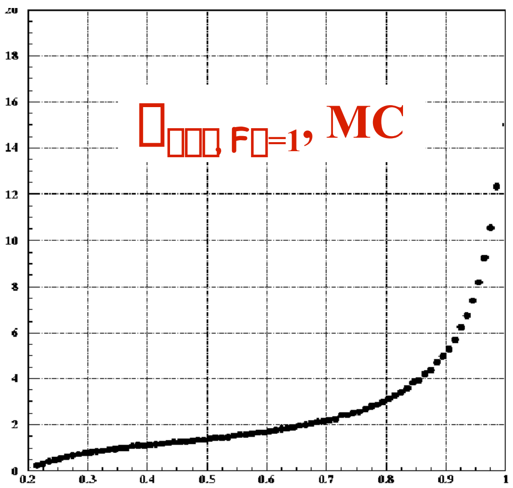
in bins of $M_{\pi\pi}^2$:

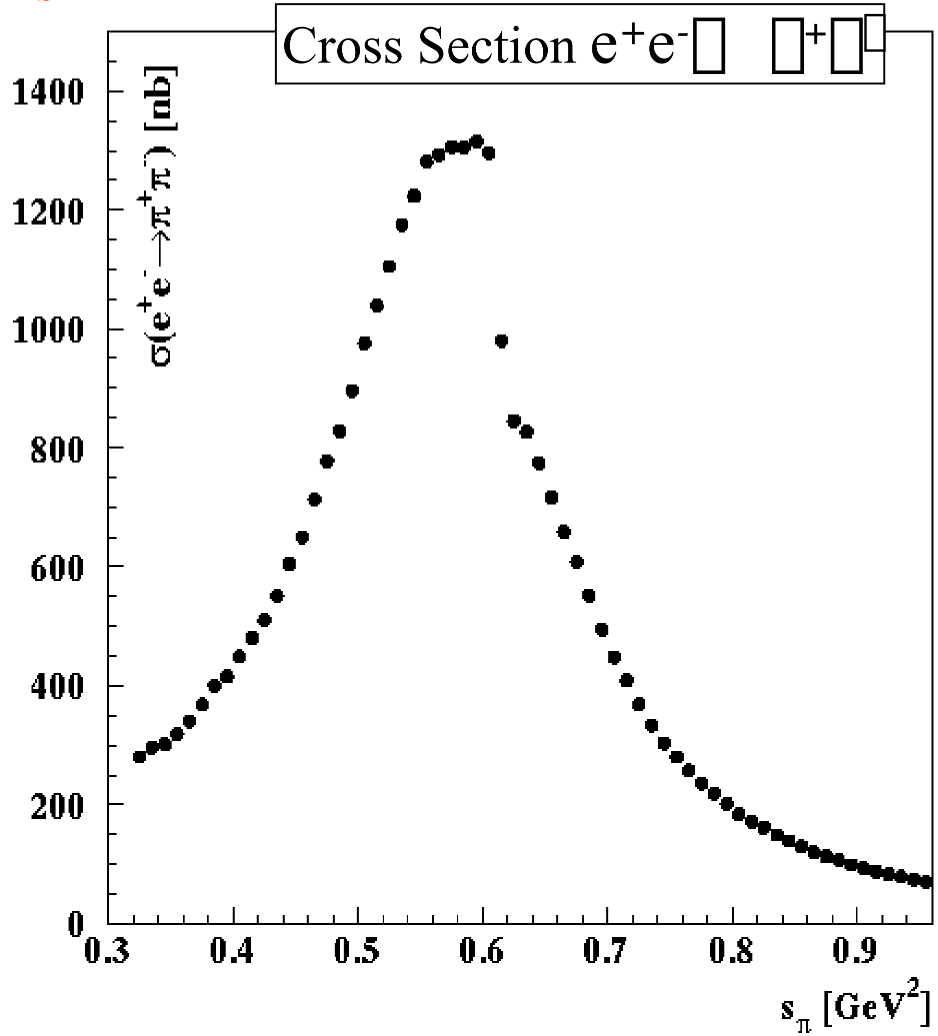


$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$:

To get the cross section for $e^+e^- \rightarrow \pi^+\pi^-$ we divide the **$\pi^+\pi^-\gamma$ cross section** by the **cross section $\pi^+\pi^-\gamma$ for "pointlike" pions** which is obtained technically from the **MC generator** by **setting $F_\pi = 1$:**

$$\sigma_{\pi\pi} \propto \left|F_\pi(M^2_{\pi\pi})\right|^2 = \frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{d\sigma_{\pi\pi\gamma, F_\pi=1}(M^2_{\pi\pi})}$$

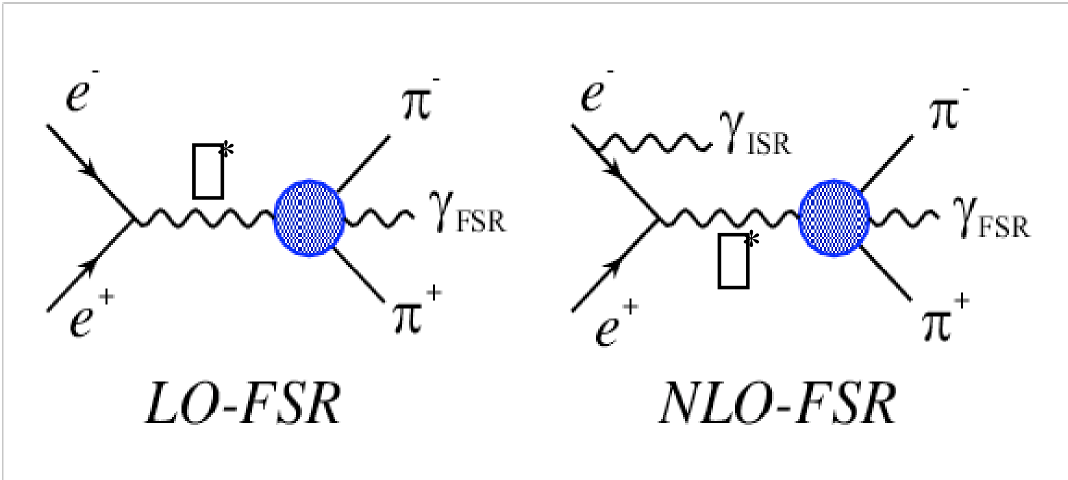




Final State Rad.:

The cross section for $e^+e^- \to \pi^+\pi^-$ has to be inclusive with respect to final state radiation events in order to evaluate a_μ

We distinguish between two kinds of FSR contributions:

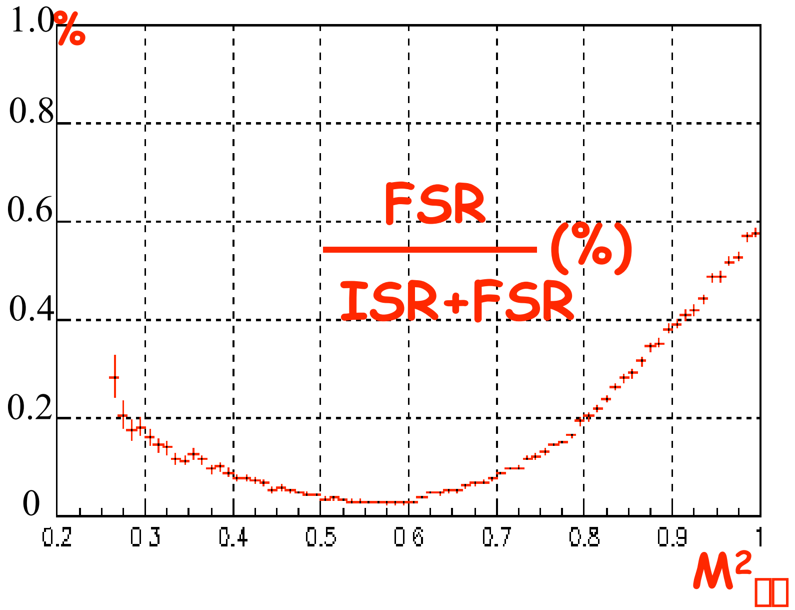


LO-FSR: No initial state radiation, e^+ and e^- collide at the energy M_ϕ=1.02 GeV

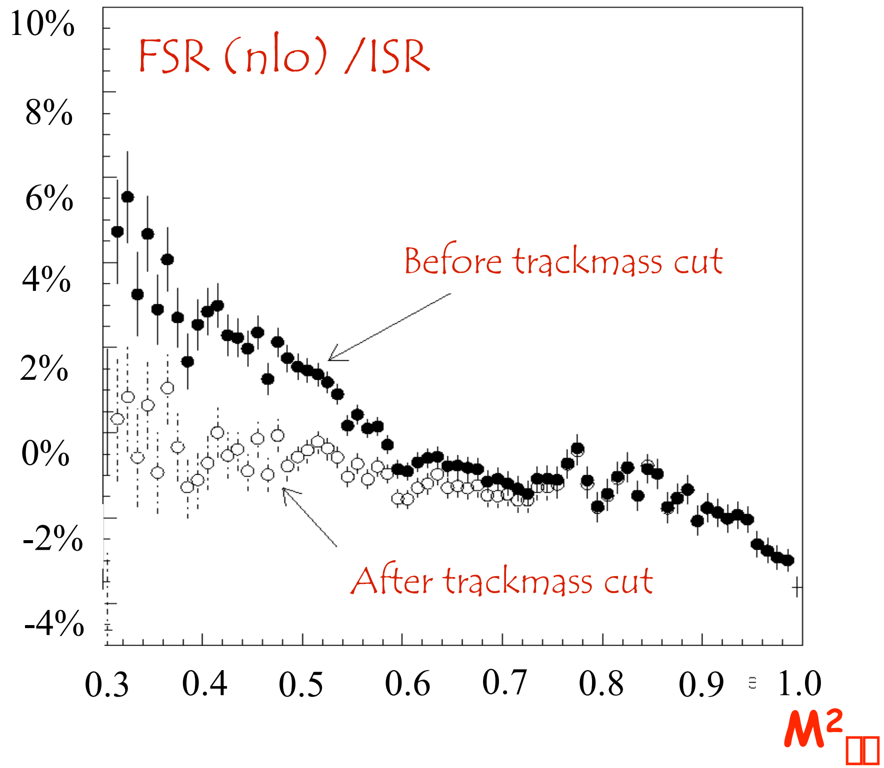
NLO-FSR: Simultaneous presence of one photon from initial state radiaition and one photon from final state radiation

Final State Rad.:

LO-FSR is a background in our analysis - fiducial volume cuts reduce relative contribution well below 1%:



NLO-FSR should be included in thespectrum - however the cut in *trackmass* removes this contribution at low $M_{□□}^2$:



Final State Rad.:

Two complementary procedures to correct for Final State Radiation:

FSR-exclusive approach:	FSR-inclusive approach:

$N(e^+e^- \to \pi^+\pi^-\gamma_{ISR}\,(\gamma_{FSR}))$

subtract remaining FSR contr. | add back missing FSR contr.

using PHOKHARA MonteCarlo (sQED)

FSR-exclusive	FSR-inclusive
$\sigma(e^+e^- \to \pi^+\pi^-\gamma_{ISR})$	$\sigma(e^+e^- \to \pi^+\pi^-\gamma_{ISR}\gamma_{FSR})$

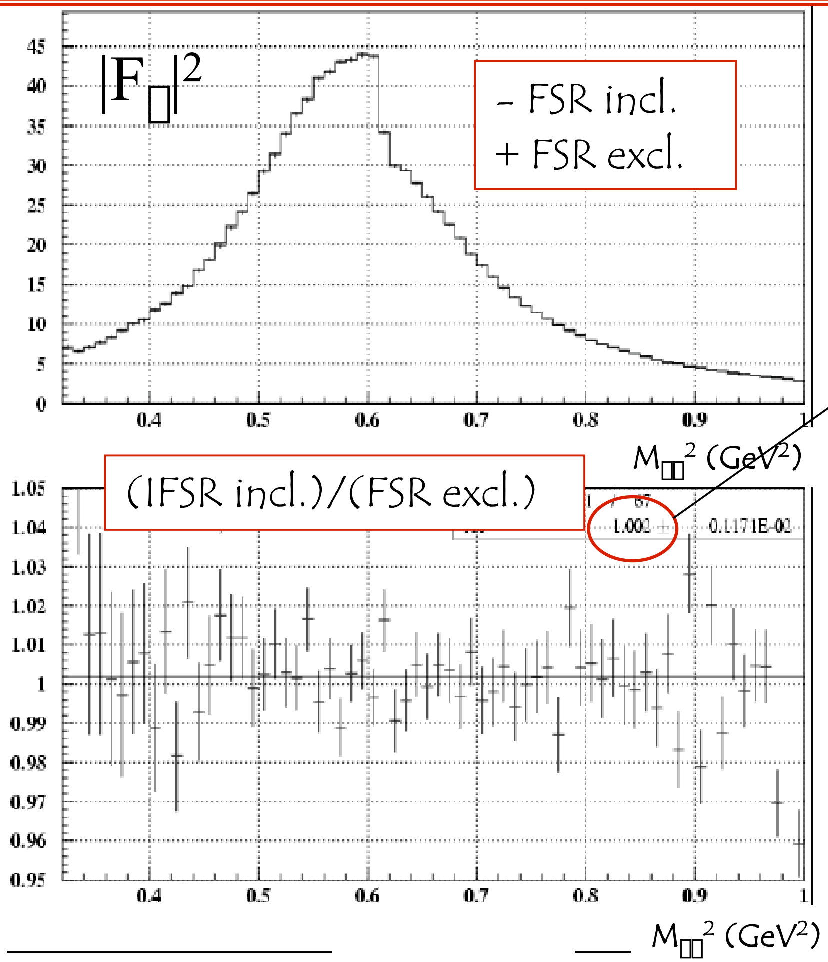
Division by radiator function H (obtained from MC for pure ISR)

FSR-exclusive	FSR-inclusive
$\sigma(e^+e^- \to \pi^+\pi^-)$	Map $M^2_{\pi\pi\gamma(FSR)}$ to $M^2_{\pi\pi}$ using MonteCarlo
add back FSR by hand (sQED, Schwinger 1990)	

$\sigma(e^+e^- \to \pi^+\pi^-\gamma_{FSR})$

Final State Rad.:

Comparison between FSR incl. approach vs FSR excl. approach:



The difference between the two methods is < 0.2%

Higher order FSR diagrams and NLO interference terms between ISR and FSR amplitudes (not simulated by MC) are negligible

Systematic error:

The systematic error has contributions from:

Experiment

– Acceptance	0.3%
– Trigger	0.3%
– Tracking	0.3%
– Vertex	0.7%
– Rec. Filter	0.6%
– Particle ID	0.1%
– Track Mass	0.2%
– BKG subtr.	0.5%
– Unfolding	0.3%
TOTAL	**1.2%**

Theory

– Radiator Function H	0.5%
– Vacuum Polarization	0.2%
– Luminosity	0.6%
– FSR resummation	0.5%
TOTAL	**1.0%**

a_μ - preliminary results:

Calculating the dispersion integral $\frac{1}{4\pi^3}\int \sigma^{\pi\pi}(s)K(s)\,ds$ gives:

$a_\mu^{had-\pi\pi}(0.35< s=M_{\pi\pi}^2<0.95\ \mathrm{GeV}^2) = (389.2 \pm 0.8_{stat} \pm 4.7_{syst} \pm 3.9_{theo})\ 10^{-10}$

Comparison with CMD2:

$a_\mu^{had-\pi\pi}(0.37< M_{\pi\pi}< 0.93\mathrm{GeV}^2)$

=

KLOE:	$(376.5 \pm 0.8_{stat} \pm 5.9_{syst+theo})\ 10^{-10}$
CMD2:	$(378.6 \pm 2.7_{stat} \pm 2.3_{syst+theo})\ 10^{-10}$

- Both measurement are in agreement within the errors
- **e^+e^- – τ discrepancy for a_μ is confirmed**

Conclusions:

- For the first time initial state radiation has been used to measure the precise cross section for $e^+e^- \rightarrow \pi^+\pi^-$

- Analysis finished:
  Result currently circulated within collaboration for approval, will be published in the next weeks

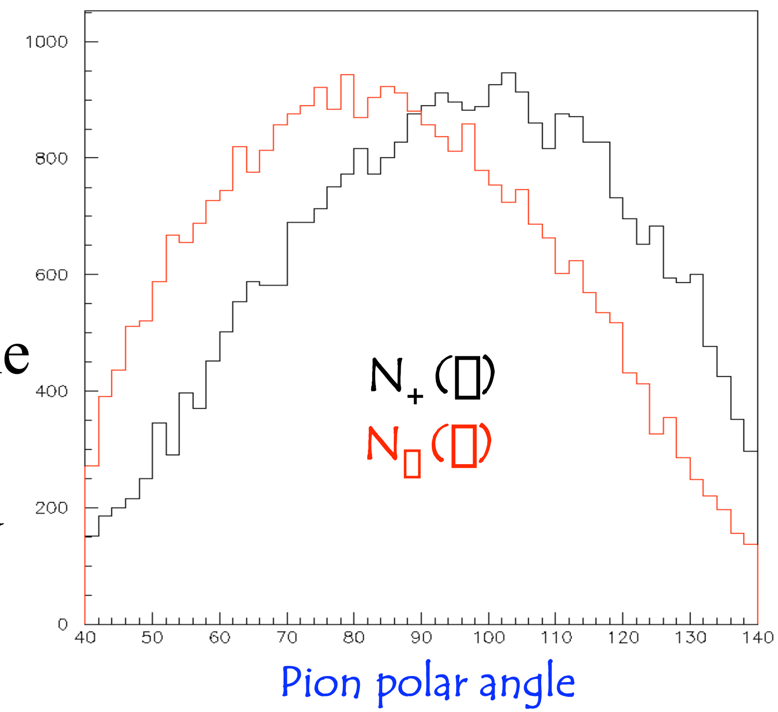
- Next Steps:
  - replay the analysis with 2002 data (hope for better systematics due to more clean and stable machine conditions)
  - study events at large photon angles to access lower $M_{\pi\pi}^2$ regions and check FSR parametrization (scalar QED)
    ➔ charge Asymmetry
  - use $\mu\mu\gamma$ events for cross checking vacuum polarisation, FSR and additional ISR effects

Charge asymmetry:

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

$$A(\theta) = \frac{N_{\pi^+}(\theta) - N_{\pi^-}(\theta)}{N_{\pi^+}(\theta) + N_{\pi^-}(\theta)}$$

This is an ideal means to check the validity of the FSR model used in the MonteCarlo - just compare the charge asymmetry between data and MonteCarlo in the presence of FSR.



Charge asymmetry:

Relative FSR contribution is high if both pions and photons are emitted at large angles:

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

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

In this case, the photon can be detected, which helps in suppressing $\pi^+\pi^-\pi^0$ background.

This is a completely new analysis (currently going on).