Hadronic cross section measurement at DAΦNE via radiative return

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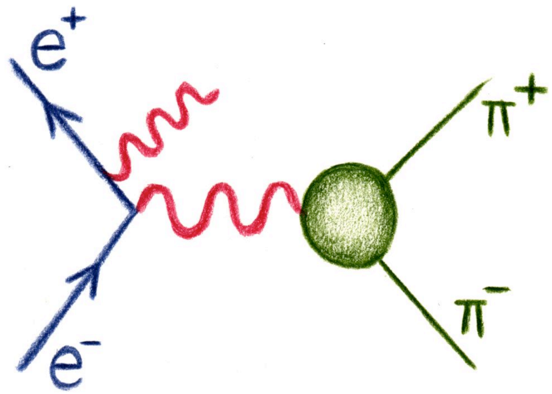
$\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ with ISR:

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)

Small angle analysis:

Pion tracks are measured at angles
$50^{o} < \theta_{\pi} < 130^{o}$

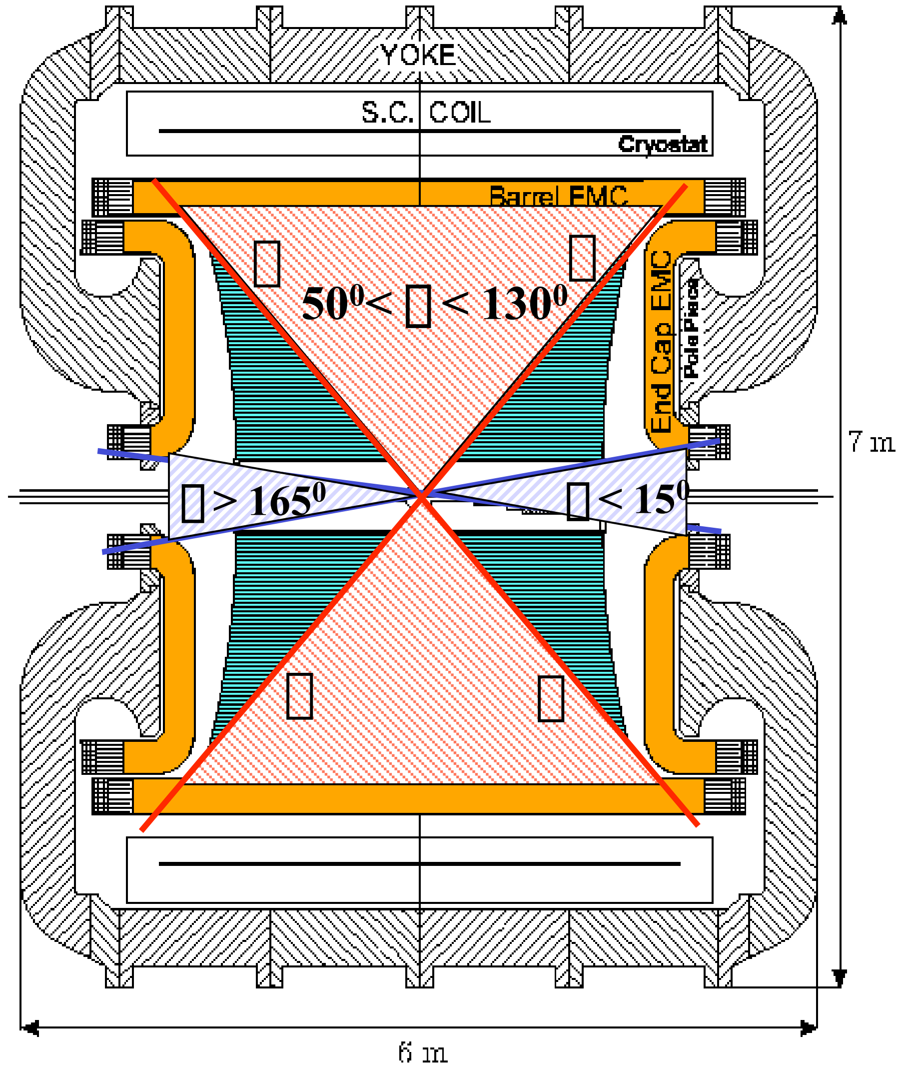
Photons are required to be within
$\theta_{\gamma} < 15^{o}$ or $\theta_{\gamma} > 165^{o}$

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

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

The choice of this kinematical region was motivated by:

- **small relative contribution of FSR**
- **reduced background contamination:**
  - $e^{+}e^{-} \rightarrow e^{+}e^{-}\gamma$
  - $e^{+}e^{-} \rightarrow \mu^{+}\mu^{-}\gamma$
  - $e^{+}e^{-} \rightarrow \phi \rightarrow \pi^{+}\pi^{-}\pi^{0}$



Background subtraction:

1) Pion-Electron-Separation

Rad. Bhabhas e⁺e□□ e⁺e□□ are separated by means of a Likelihood-Method (Signature of EmC-Clusters and TOF of particle tracks)

2) Kinematic Separation

□□ □⁺□□□⁰

e⁺e□□ □⁺□□□

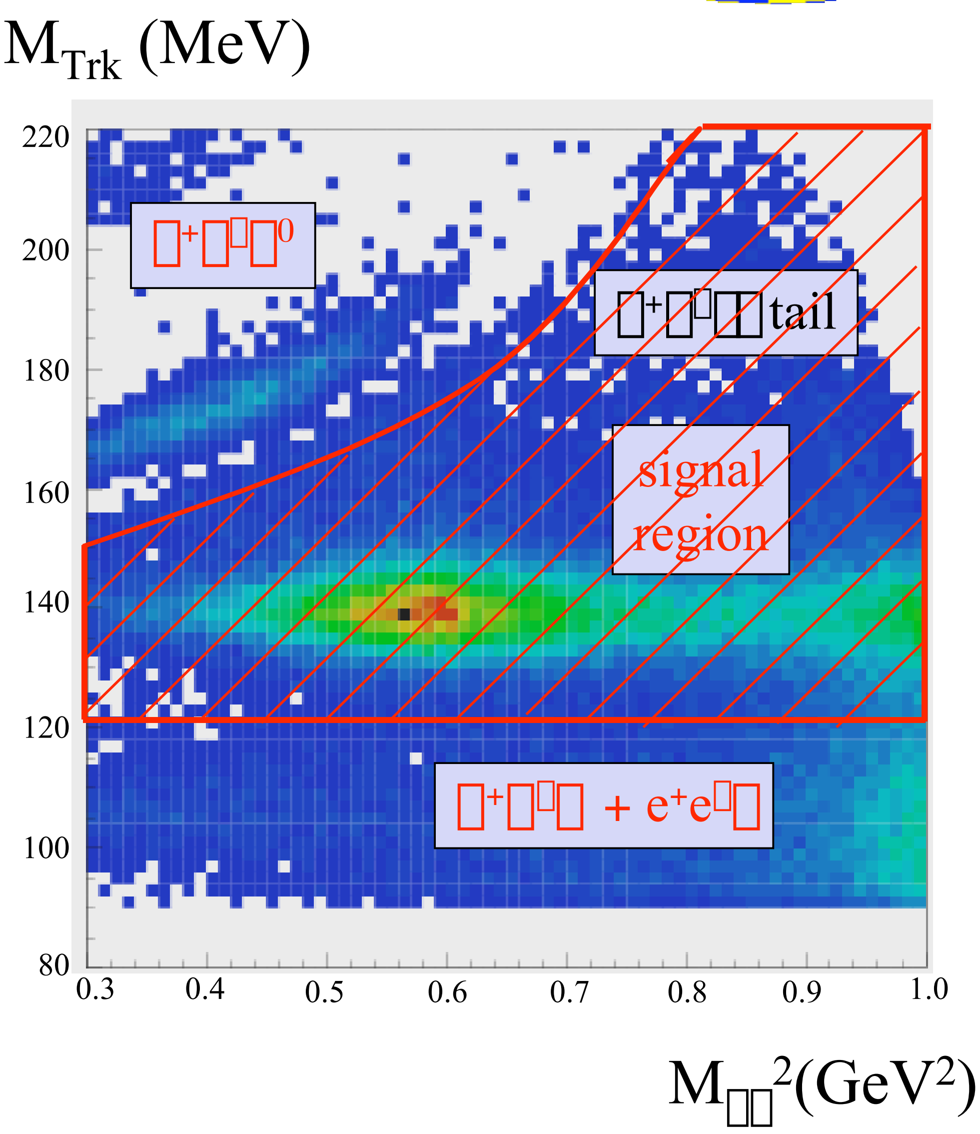
using „Trackmass“-variable

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

$M_{□□}$ – dependent M_{TRK}-Cut

3) Residual Background

Fit Trackmass-Spectra for signal and background with free normalization parameters (shape from MC)



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

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

Efficiencies:

- Trigger & Cosmic veto
- Tracking, Vertex
- π- e- separation
- Reconstruction filter
- Trackmass-cut
- Unfolding resolution
- Acceptance

Background:

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

Errors:

0.9%

Luminosity:

Bhabhas at large angles

> 55°, σ_{eff} = 430 nb

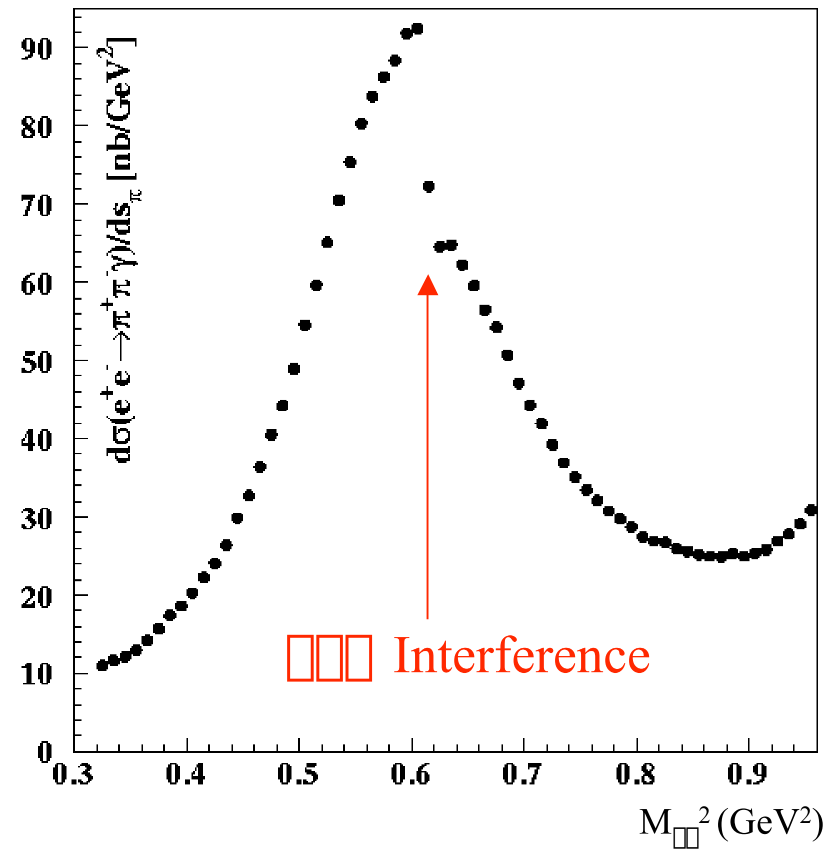
→ Talk of F. Nguyen

$0.3\%_{exp}$

$0.5\%_{theo}$

Statistics: **$141 pb^{-1}$ of 2001-Data**

1.5 Million Events



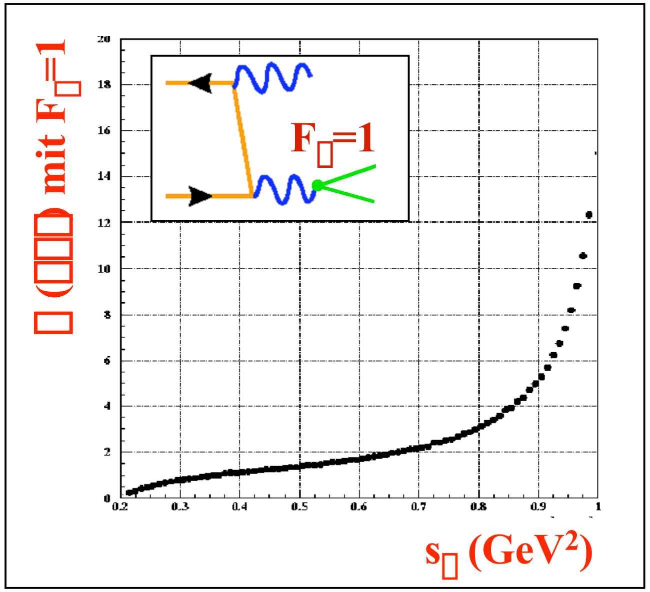
$\sigma(e^+e^- \to \pi^+\pi^-)$:

$$M_{\pi\pi}^2 \frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \sigma_{\pi\pi}(s) \cdot \mathbf{H(s)}$$

Radiator-Function H(s) (ISR):

- **ISR-Process calculated at NLO-level**
  Generator ***PHOKHARA*** *(Kühn et.al)*
- Comparison with *KKMC (Jadach et.al.)*

Precision: *0.5%*



Radiative Corrections:

i) Bare Cross Section
divide by Vacuum Polarisation

ii) FSR - Corrections
Cross section $\sigma_{\pi\pi}$ must be incl. for FSR

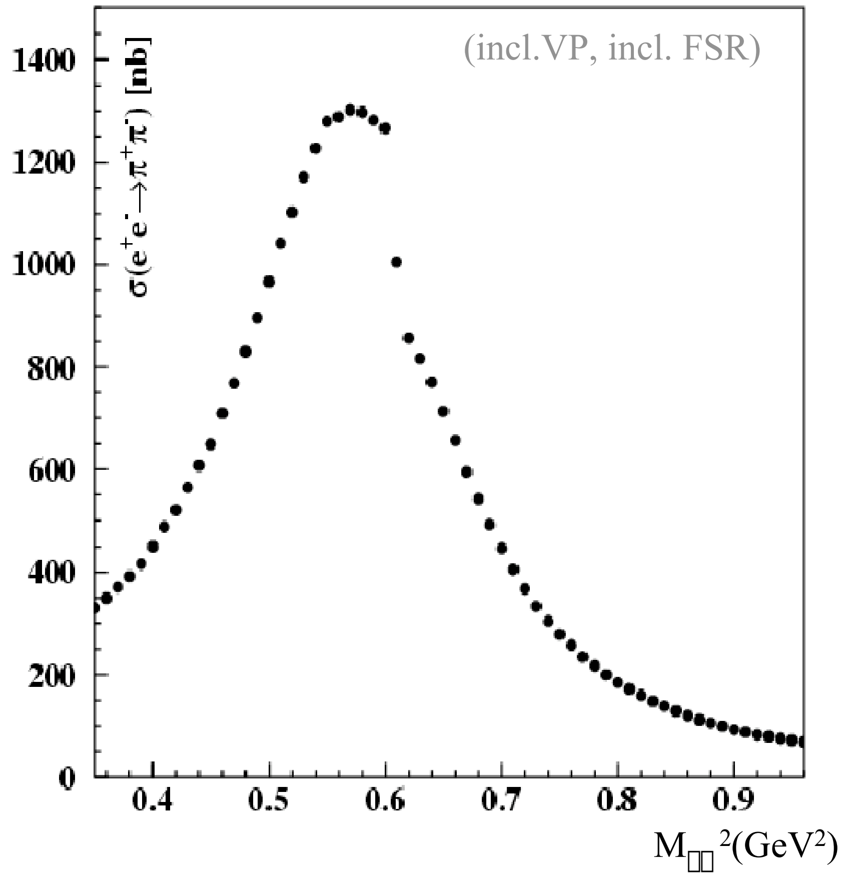
Radiative Return requires ISR photon ➔ be inclusive for ISR-FSR-events

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

Error of 0.3% assigned to FSR-corrections

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

Result: Cross Section $e^+e^- \rightarrow \pi^+\pi^-$



Published in Phys. Lett. B606, 12 (2005)

Exp. syst. uncertainties:

- Efficiencies
- Background Subtraction

TOTAL 0.9%

Theory syst. uncertainties:

- Radiator Function H 0.5%
- Vacuum Polarization 0.2%
- Luminosity 0.6%
- FSR resummation 0.3%

TOTAL 0.9%

TOTAL syst. ERROR 1.3%

Pion form factor:

Comparison with results from CMD-2 experiment (pion form factor)

$$\sigma_{\pi\pi}(M^2_{\pi\pi}) = \frac{\pi\alpha^2}{3M^2_{\pi\pi}}\beta^3_\pi\left|F_\pi\left(M^2_{\pi\pi}\right)\right|^2$$

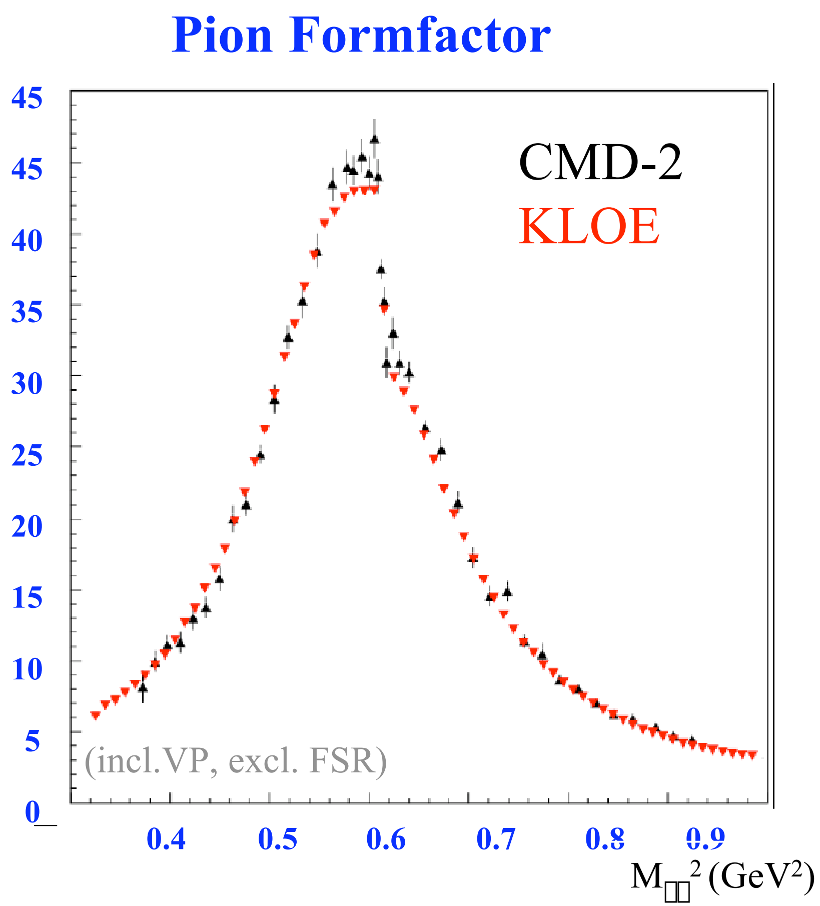
Evaluating the dispersion integral

$$\frac{1}{4\pi^3}\int\sigma^{\pi\pi}(s)K(s)ds$$

between $0.37 < M_{\pi\pi}^2 < 0.93$ GeV^2:

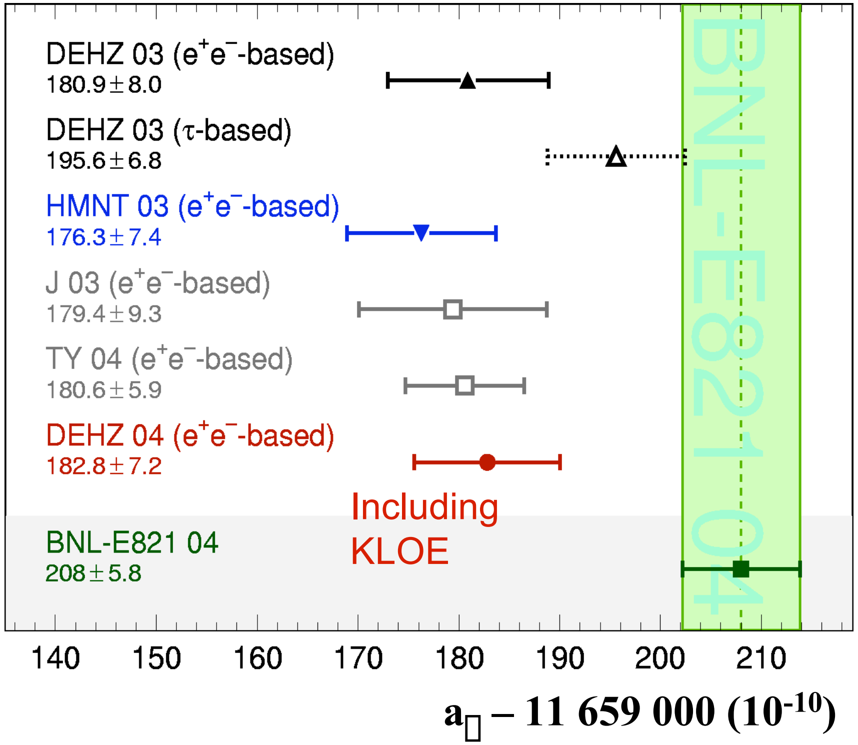
KLOE: $(375.6 \pm 0.8_{stat} \pm 4.9_{syst+theo})\ 10^{-10}$

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

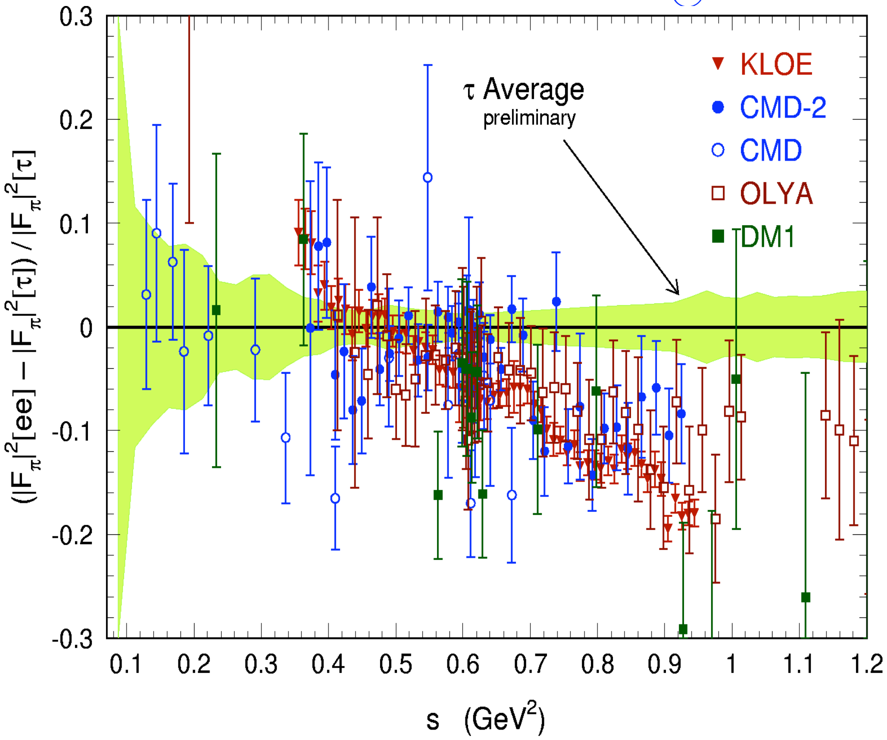


- KLOE data points are not in excellent but in a fair agreement with CMD-2: KLOE higher at low s_π and lower at large s_π
- Apparently effects compensate in the evaluation of the dispersion integral

Muon anomaly@ICHEP04:



A. Höcker @ ICHEP04



KLOE Data included!

- New 4th order QED contribution
- New Light-by-light contribution

□– data excluded!

$a_{□}^{exp} - a_{□}^{theo} = (25.2 \pm 9.2) \cdot 10^{-10}$

2.7 "standard deviations"

Analysis with 2002 data:

A next step is to "replay" the analysis with 2002 data:

- much more stable data taking conditions (less fluctuations in machine background)
- inefficiency of *trigger veto for cosmics* on $\pi^+\pi^-\gamma$ cured
- Offline reconstruction filter has been improved
- New event classification routine for $\pi^+\pi^-\gamma$ selection

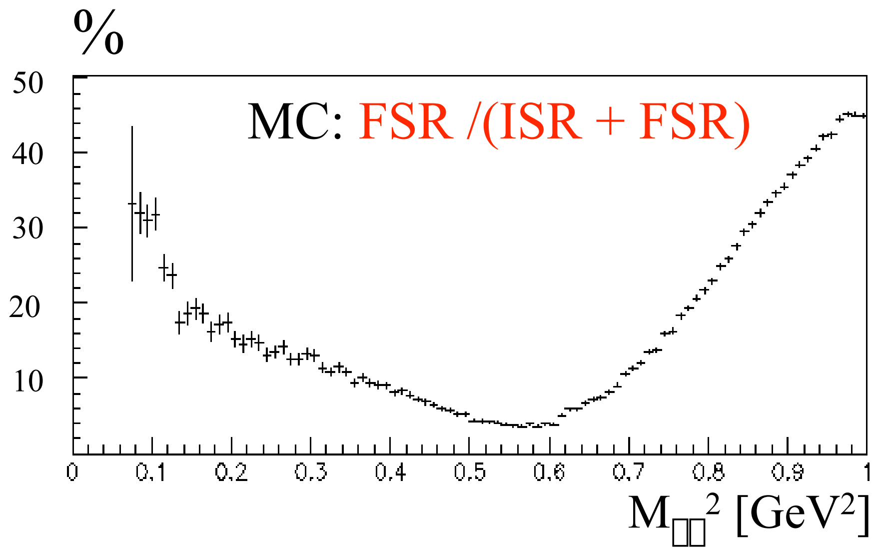
Last-minute-implementations in KLOE offline software still to be done before reprocessing of 2002 data can start

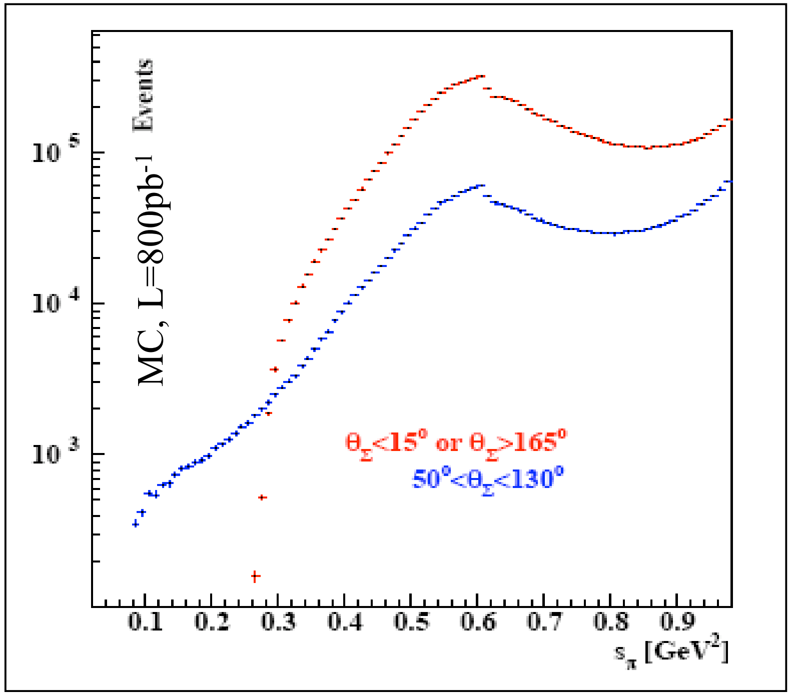
Together with improvements on theory side (luminosity, radiator function) will push down total syst. error **below 1%**

Large angle analysis:

Motivation:

- Only at large photon angles can the threshold mass region be reached
- Statistics become an issue (differently from small angle analysis)
- Relative amount of FSR is very large, also □+□□□0-bkg.





Strategy:

- Measure charge asymmetry and set a limit on validity of scalar QED model for description of FSR
- Study new structures (f_0, □) ?

Large angle analysis:

Pion tracks are measured at angles
$50^{o} < \square_{\square} < 130^{o}$

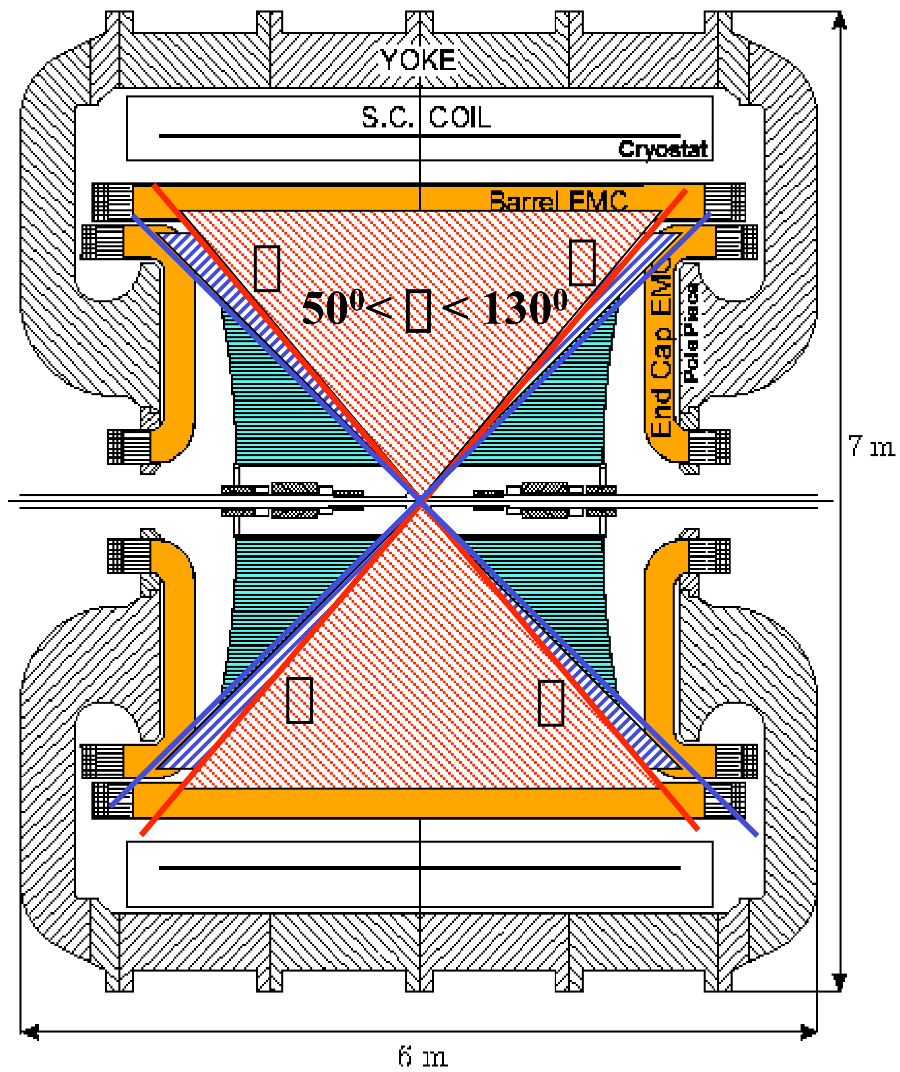
Missing momentum direction is required to be within
$45^{o} < \square_{miss} < 135^{o}$

In this region, the photons can be detected → <u>tagged</u> measurement!

Event gets selected if at least one photon is detected with

$E_{\square} > 50$ MeV
$50^{o} < \square_{\square} < 130^{o}$

In case of more than 1 photon, choose the one with smallest angle □ between the directions of $\square_{miss}$ and $\square_{\square}$



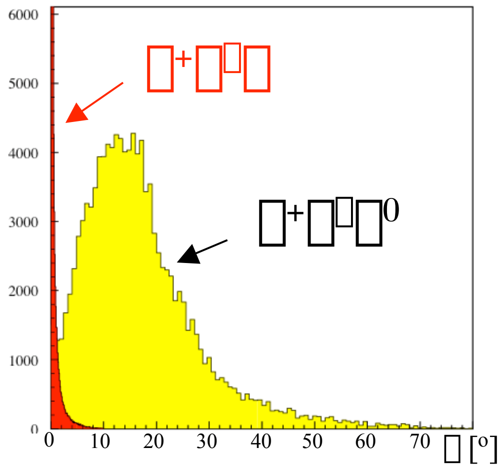
$\pi^+\pi^-\pi^0$ background:

- In a first step, $\pi^+\pi^-\pi^0$ events are rejected by a cut in the plane of $M_{\pi\pi}^2$ and M_{Trk} (similar as in the small angle analysis).

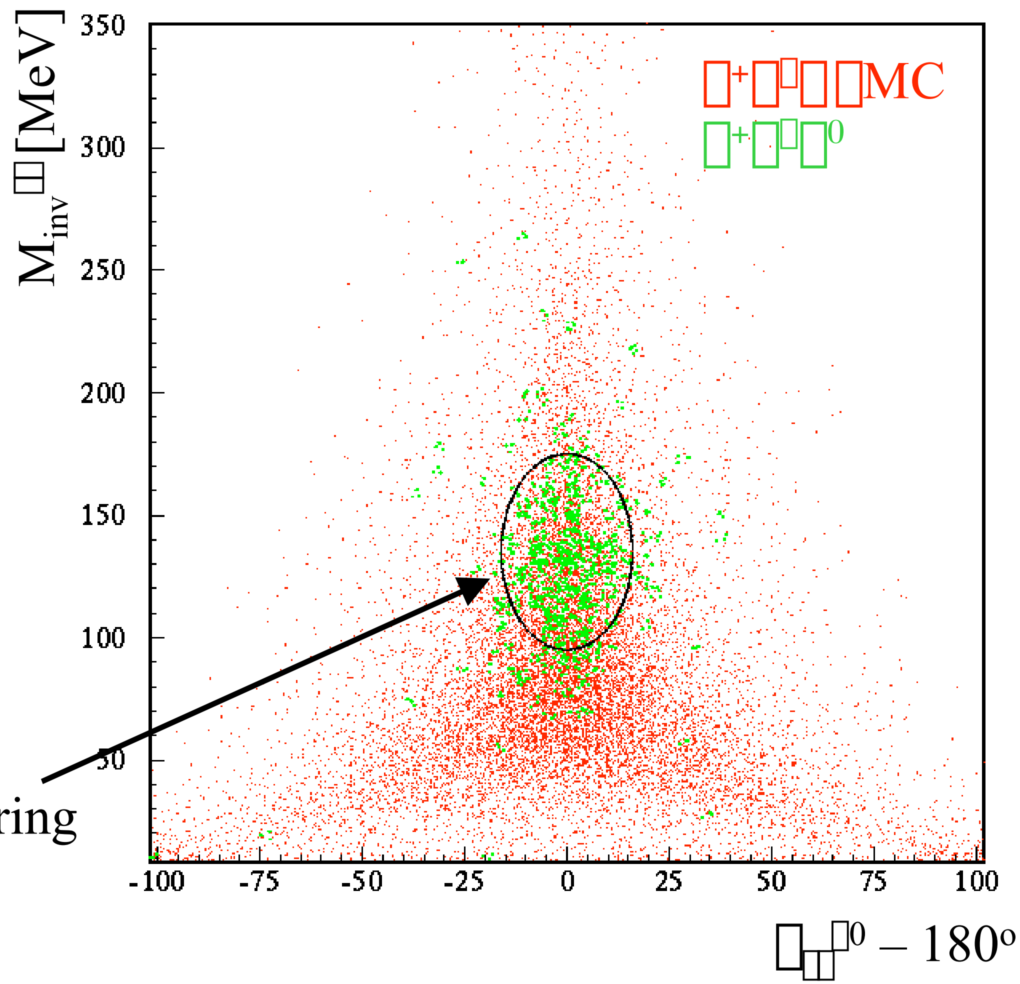
- Additionally, one can use the angle

$$\Omega = a\cos\left(\frac{\vec{p}_{\gamma}\cdot\vec{p}_{miss}}{|\vec{p}_{\gamma}||\vec{p}_{miss}|}\right)$$

to distinguish between $\pi^+\pi^-\gamma$ and $\pi^+\pi^-\pi^0$:



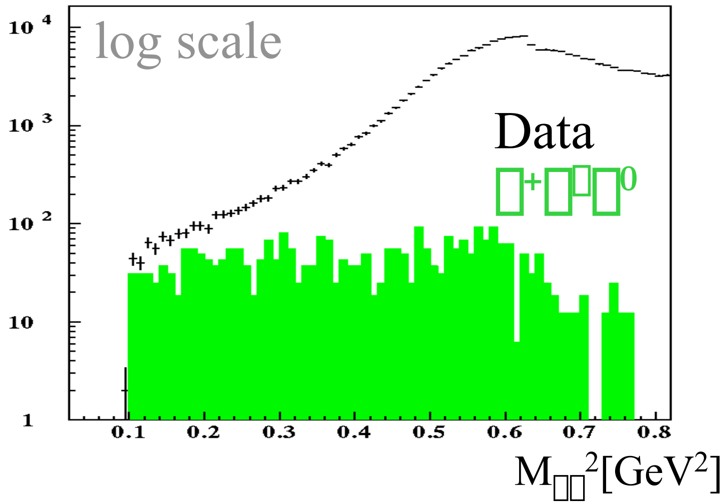
- In the case of more than one photon, $\pi^+\pi^-\pi^0$ events can be rejected by pairing two photons and cutting in the plane $M_{inv}^{\gamma\gamma}$ and $\theta_{\gamma\gamma}$ (in π^0 mass frame)

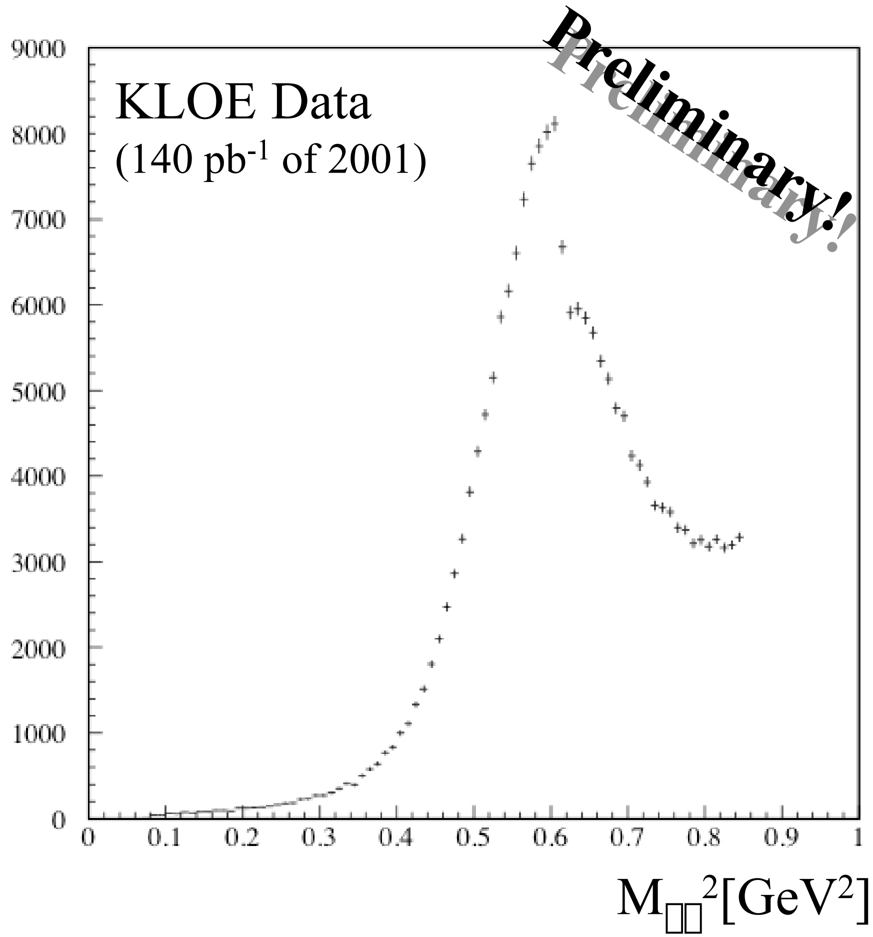


Spectrum (preliminary):

First (preliminary!) spectrum obtained:

- spectrum extends down to threshold region
- still a sizeable contribution of $\pi^+\pi^-\pi^0$!





- FSR? Additional backgrounds/contributions?

Charge 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 ***charge asymmetry***:

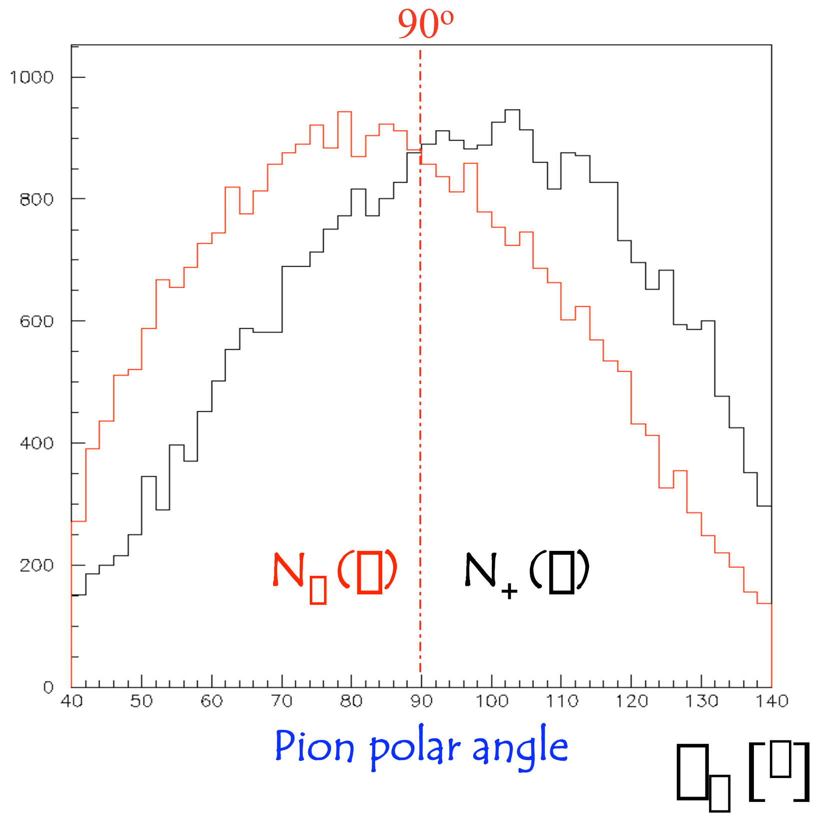
Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999

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

➔ check the validity of the FSR model used in the MonteCarlo comparing the charge asymmetry between data and MonteCarlo in the presence of FSR.

➔ in a similar way, radiative decays of the ϕ into scalar mesons decaying to $\pi^+\pi^-$ contribute to the charge asymmetry

Czyz, Grzelinska, Kühn, hep-ph/0412239

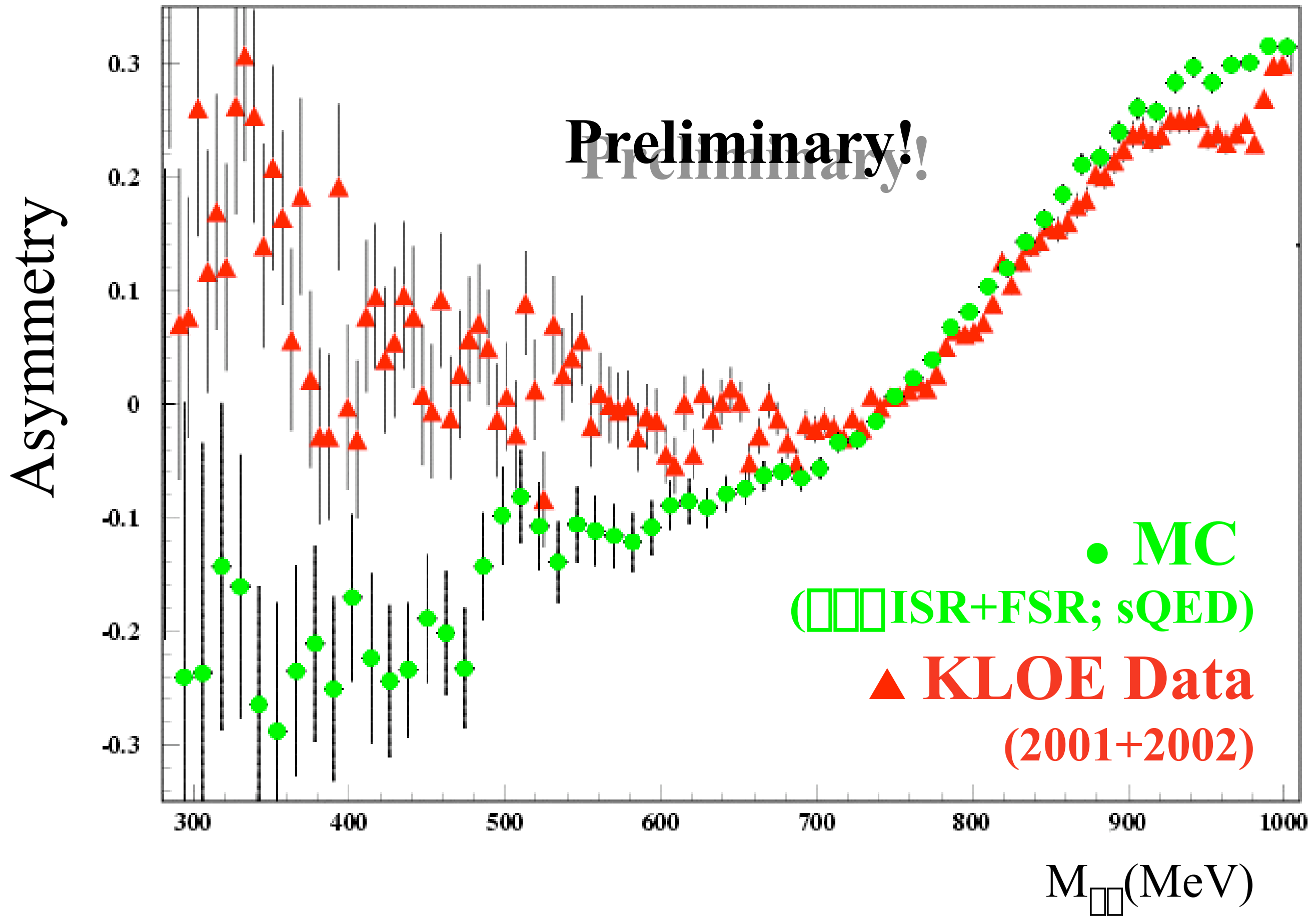


<u>Possibility to study the properties of scalar mesons with charge asymmetry</u>

Charge Asymmetry:

Asymmetry as function of M□□
(from KLOE □□ f₀□□ □⁺□⁻□analysis)

(see also Talk of P. Gauzzi)



Conclusions:

- KLOE has published the first measurement of the $e^+e^- \to \pi^+\pi^-$ cross section between 0.35 GeV^2 and 0.95 GeV^2 using the radiative return with a negligible statistical error and 1.3% total syst. uncertainty

- Complementary analysis requiring the photon to be emitted at large angles has been started, which allows to access the region for $M_{\pi\pi}^2 < 0.3$ GeV^2
  - o selection cuts are defined
  - o Next step: Determination of efficiencies and background
  - o *Validity of FSR model?*
  - o *Contribution from scalars?*

  } **Charge asymmetry**

- In addition, an upgrade of the small photon angle analysis is being done using 2002 data

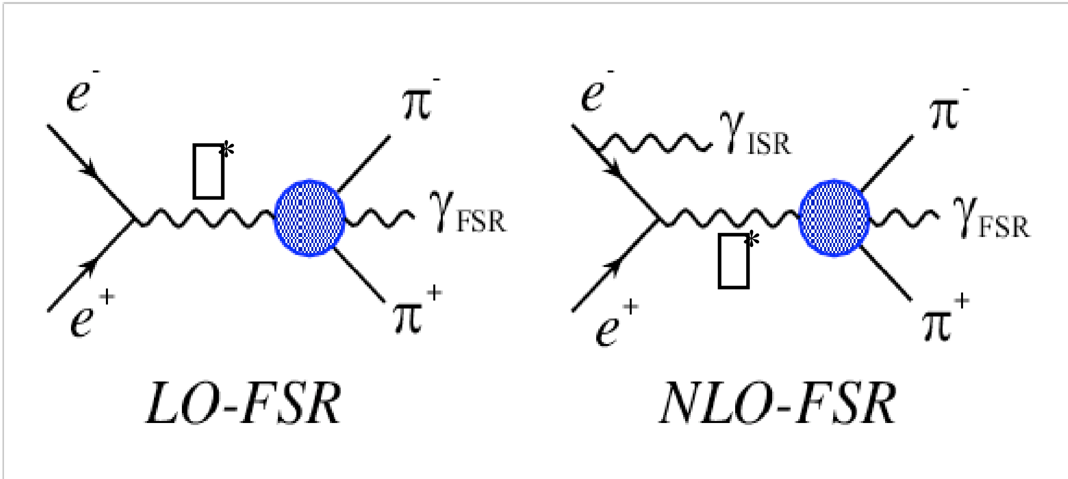
- Measurement of $\sigma(e^+e^- \to \pi^+\pi^-\gamma)/\sigma(e^+e^- \to \mu^+\mu^-\gamma)$ (normalization to muons) $\to$ direct measurement of R

Backup Slides

Final State Rad.:

The cross section for $e^+e^- \rightarrow \pi^+\pi^-$ 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 radiation and one photon from final state radiation

Charge Asymmetry:

Preliminary comparison of charge asymmetry for data (after large angle selection cuts) and MonteCarlo simulation:

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

Possible effects of scalar mesons or FSR (beyond sQED) are not visible when including full range of $M_{\pi\pi}^2$