KLOE needs to reach permil accuracy on $\Box_{\Box\Box}$ with ISR

Stefan E. Müller
Laboratori Nazionali di Frascati

(for the KLOE collaboration)

Working Group on Rad. Corr. and MC Generators for Low Energy

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KLOE analysis: Small angle

Pion tracks at large angles

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

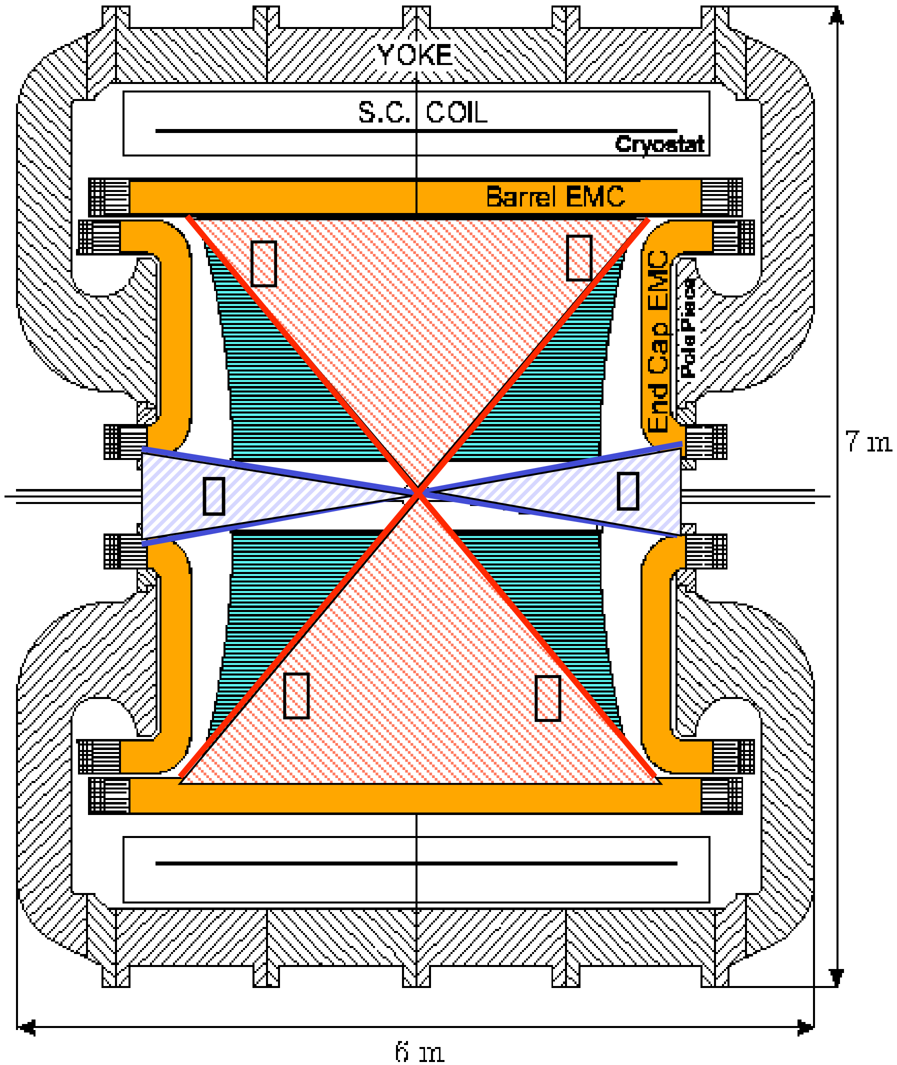
a) Photons at small angles

$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

➔ No photon tagging!

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

- High statistics for ISR photons
- Very small contribution from FSR
- Reduced Backgr. contamination



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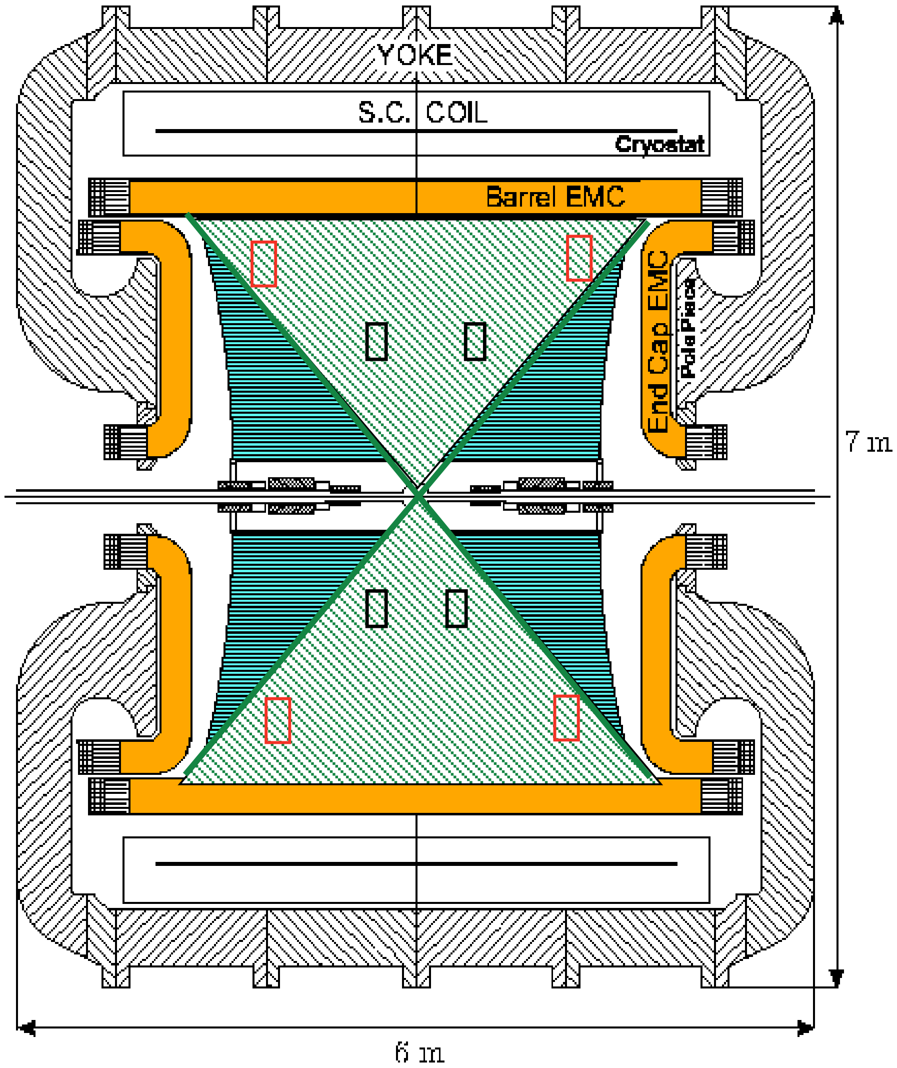
b) Photons at large angles

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

➔ **Photon tagging possible!**

- Threshold region accessible
- Increased contribution from FSR
- Contribution from $\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$



KLOE analysis: The Ratio

perform normalization with $\mu\mu\gamma$ events

$$\sigma_{\pi\pi}^{Born}(s) = \frac{d\sigma_{\pi\pi\gamma}^{obs}/ds}{d\sigma_{\mu\mu\gamma}^{obs}/ds}\,\sigma_{\mu\mu}^{Born}(s)$$

- Some Effects will cancel out in the ratio:

~~Luminosity (LA Bhabhas)~~	~~0.6%~~
~~Vacuum polarization~~	~~0.2%~~
FSR corrections	0.3%
~~Radiator function~~	~~0.5%~~
Total theoretical Error	**0.~~9~~%**

0.3%

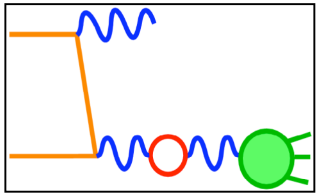
- Also some cancelllations in experimental selection efficiencies are expected
- Needs to select $\mu\mu\gamma$ events with similar precision as $\pi\pi\gamma$

- Compare $\mu\mu\gamma$-yield in data with Monte-Carlo simulation (PHOKHARA generator), which is using identical radiative ISR-corrections as for the F_π analysis (radiator function)

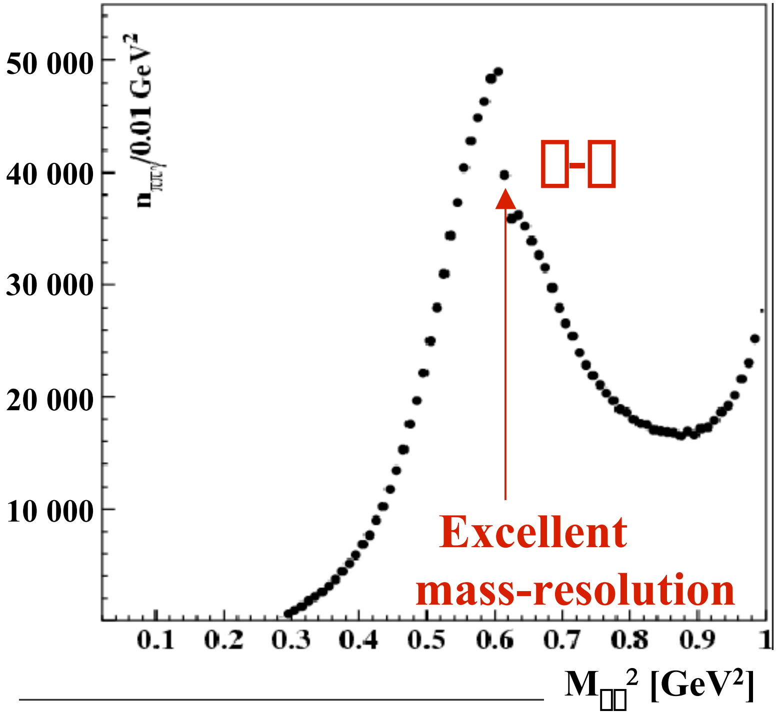
Important cross check of radiative corrections in MC!

Extracting □$_{□□}$ from □□□ events:

dN(□$^+$□$^□$□) / dM$_{□□}^2$
after acceptance cuts



Event-analysis:
efficiencies, background
as a function of M$_{□□}$



Normalization with **Luminosity**

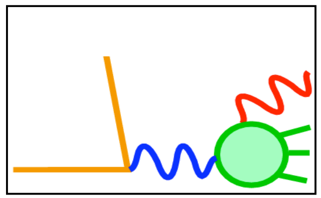
Differential cross section
d□(□$^+$□$^□$□)/dM$_{□□}^2$

Divide by **Radiator-function**

Radiative correction (FSR,VP,…)

Event-Analysis

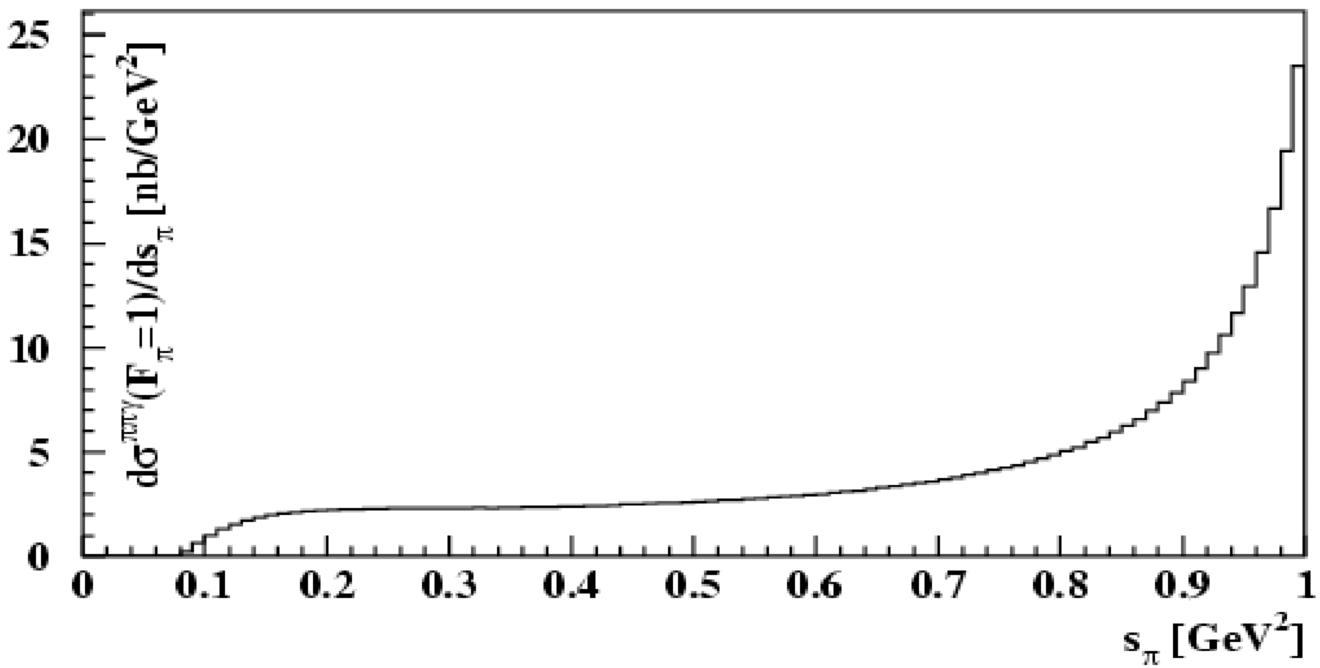
Cross section
□(e^+e^-□ □$^+$□$^□$)



Initial state radiation:

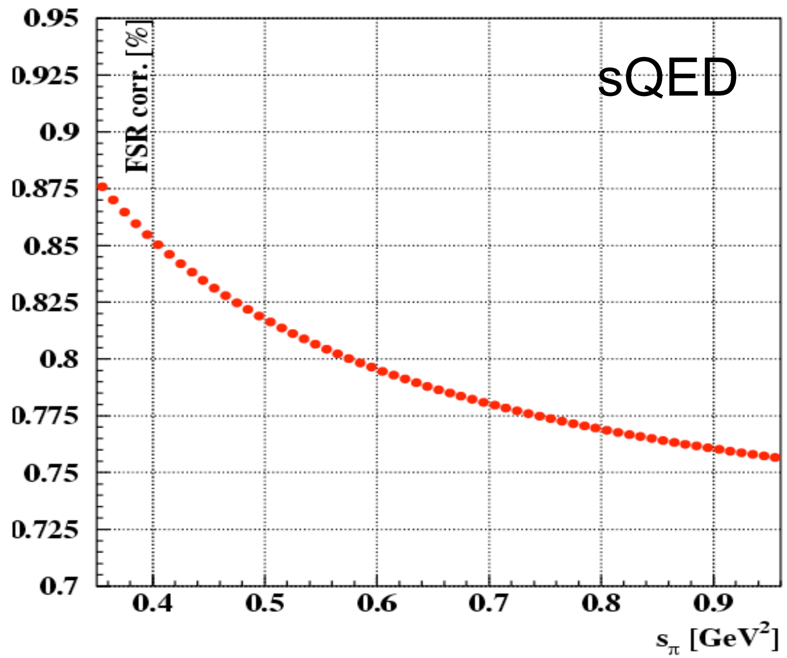
- Important ingredient for any radiative return measurement
- Universal correction, independent from Final State
- Used at KLOE analysis:
    - PHOKHARA with NLO-ISR [Eur. Phys. J. C24 (2002) 71]
        - claimed precision 0.5% translates directly into error of $a_{\mu}^{had,lo}$

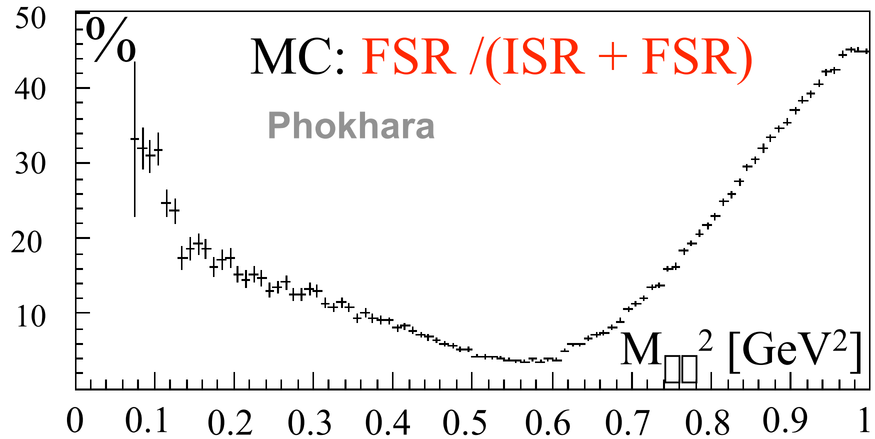
used in the analysis in the form of a differential cross section with $F_{\pi}=1$



Final state radiation:

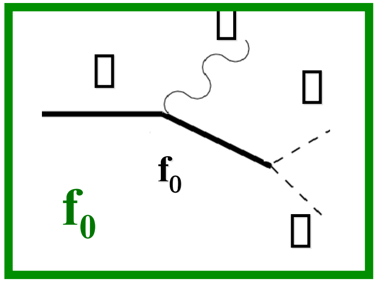
- cross section measurement has to be incl. in FSR for Dispersion Integral
- Model dependence for pions
  - scalar QED (sQED)
  - Resonance Perturbation Theory (RPT)
- Used in KLOE analysis:
  - PHOKHARA with FSR (sQED)
    - FSR at NLO for pions, muons, kaons
    - contains also simultaneous emission of ISR and FSR photon
- partly suppressed in small-photon-angle analysis
- Enters Determination of Eff. of kinematical variables (M_{Trk},…) and transition from $M^2_{\pi\pi}$ to s'
- Good Understanding of FSR is crucial for measuring threshold region <0.35 GeV²





Additional final states:

a) $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$



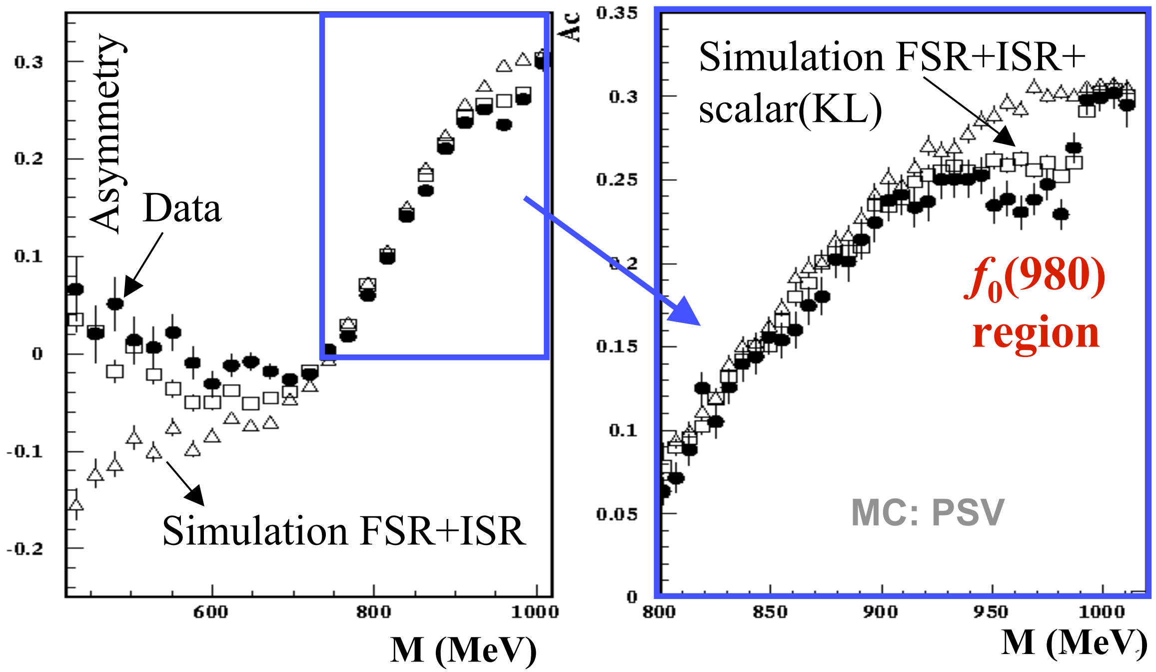
- process interferes with FSR amplitude
- main limitation at threshold due to model dependence in amplitudes
- Used in KLOE analysis:
  - hep-ph/0605244 Pancheri ,Shekhovtsova , Venanzoni (Achasov 4q)
  - PHOKHARA (KaonLoop, NoStructure, KLOE Fit)

Effect not only visible in Spectrum, but also in Forward-Backward Asymmetry

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

due to different C-Parity of $\pi^+\pi^-$ for ISR- and FSR-amplitude

● Data
△ Simulation FSR+ISR
□ Simulation FSR+ISR+ scalar(KL)



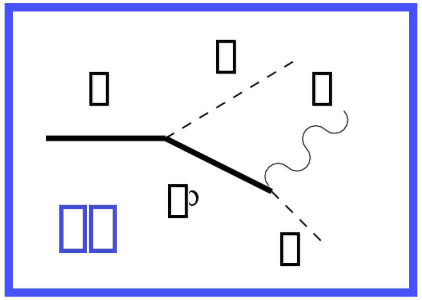
Additional Final States:

b) □□ □□□ □$^+$□$^□$□ (VMD)

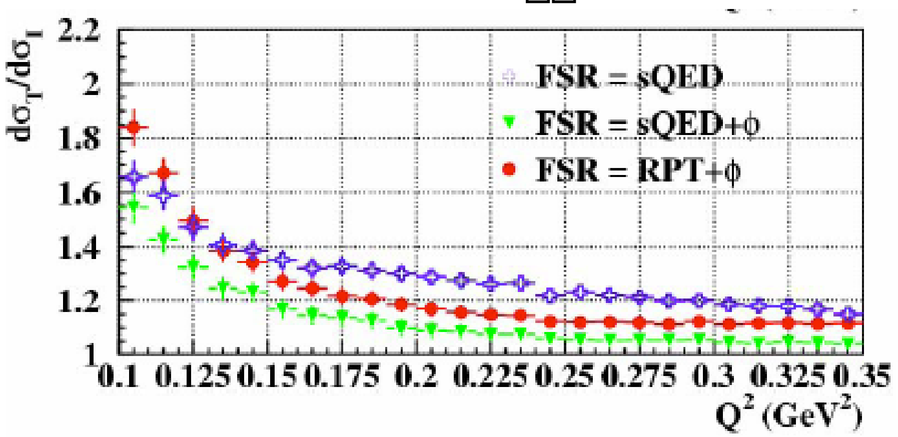
- Contribution is small:

  BR(□□ □□)=4.5·10^{-4}
- Again affects threshold region!
- Used in KLOE □$_{□□}$ analysis:
  - Pancheri ,Shekhovtsova , Venanzoni

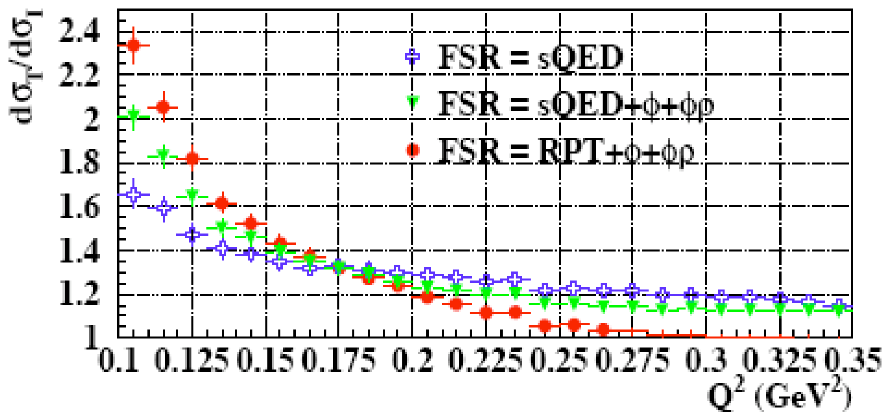
    (work in progress)



without □□



with □□



Shekhovtsova@Kazimierz06

Vacuum Polarisation:

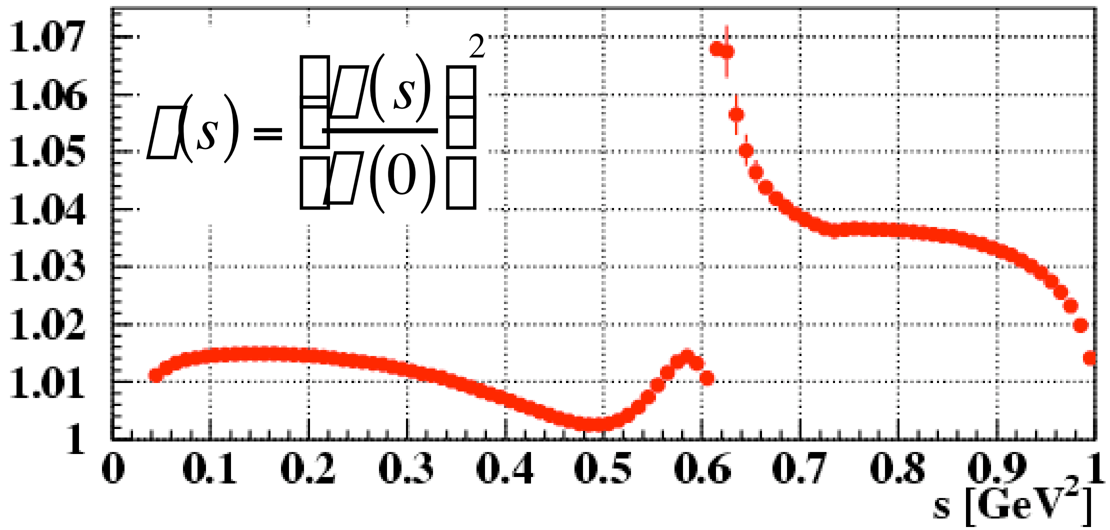
- cross section measurement has to be excl. in Vac. Pol. for Dispersion Integral
- divide for $\delta(s) = (\alpha(s)/\alpha(0))^2$

- Used in KLOE analysis:
  - Vacuum Polarisation function by F. Jegerlehner
    (now available at http://www-com.physik.hu-berlin.de/~fjeger/alphaQEDn.uu)

- In principle one should apply an *iterative* procedure by calculating the Vac. Pol. using the cross section data to which it is then reapplied etc.

  $\Rightarrow$ up to now not done in KLOE analysis

- Contributes about 0.2% to the error on the evaluation of $a_\mu^{had,lo}$ in the published KLOE analysis



Luminosity:

Luminosity is measured using „Large angle Bhabha“ events ($55^o<\theta_e<125^o$)

see dedicated talk by F. Nguyen tomorrow!

2 independent generators used at KLOE for radiative corrections:

–BABAYAGA (Pavia group): $\sigma_{eff} = (431.0 \pm 0.3_{stat})$ nb

C. M. Carloni Calame et al., Nucl. Phys., B584, 459, 2000

–BHAGENF (Berends modified): $\sigma_{eff} = (430.7 \pm 0.3_{stat})$ nb

F. Berends and R. Kleiss, Nucl. Phys., B228, 537, 1983

E. Drago and G. Venanzoni, Report INFN-AE-97-48, 1997

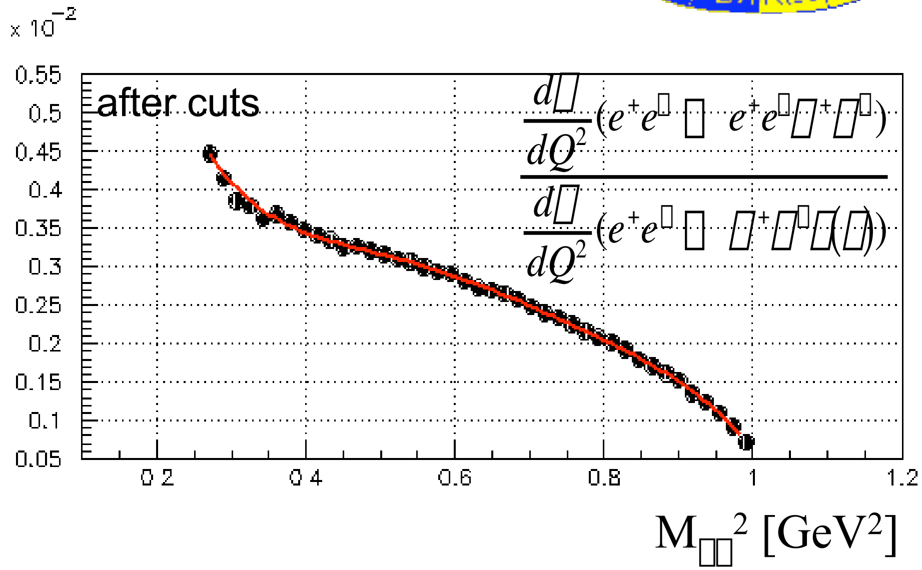
Both groups of authors quote a systematic uncertainty of 0.5%

Together with an exp. syst. uncertainty of 0.3%, this gives 0.6% uncertainty on $a_\mu^{had,lo}$

Other background channels:

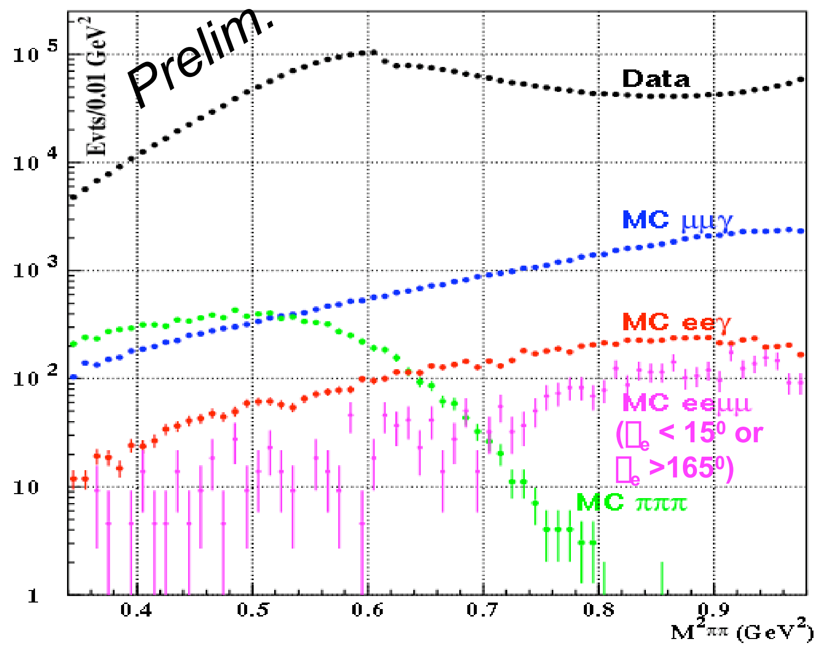
a) $e^+ e^- \to e^+ e^- \pi^+ \pi^-$

- contribution only in case when photon is NOT tagged
- Used in publ. KLOE analysis
  - Result from EKHARA generator (**hep-ph/0310335, Czyz, Nowak**)
  - added as syst. uncertainty to background contribution



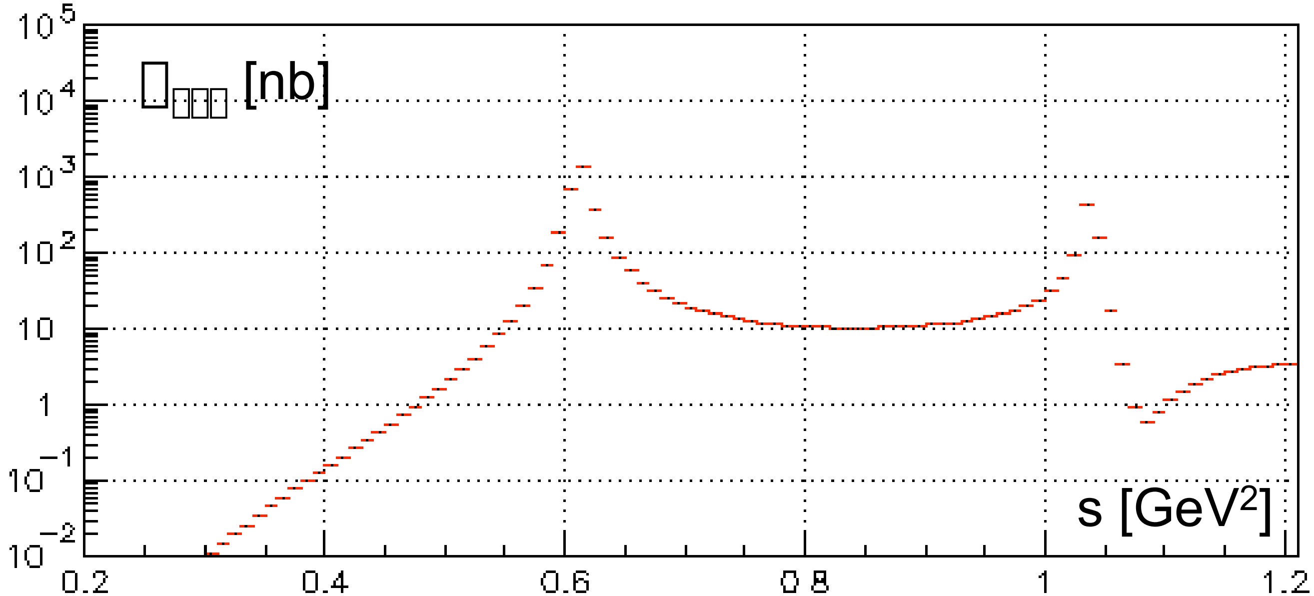
b) $e^+ e^- \to e^+ e^- \mu^+ \mu^-$

- only in case when photon is NOT tagged
- Used for prelim. checks:
  - NEXTCALIBUR (hep-ph/0011031) (Berends, Papadopoulos, Pittau)
- negligigible for e+e- □ □□□analysis
- small for e+e- □ □□□analysis when e^+,e^- escape along beampipe
- otherwise one needs to implement generator in detector simulation to understand detector response for e^+,e^- tracks.



$\sigma_{\pi\pi\pi}$ via ISR:

- contribution to $a_{\mu}^{had,lo}$ 10 times smaller than for $\pi\pi$-channel
- not yet studied at KLOE, but is on our list

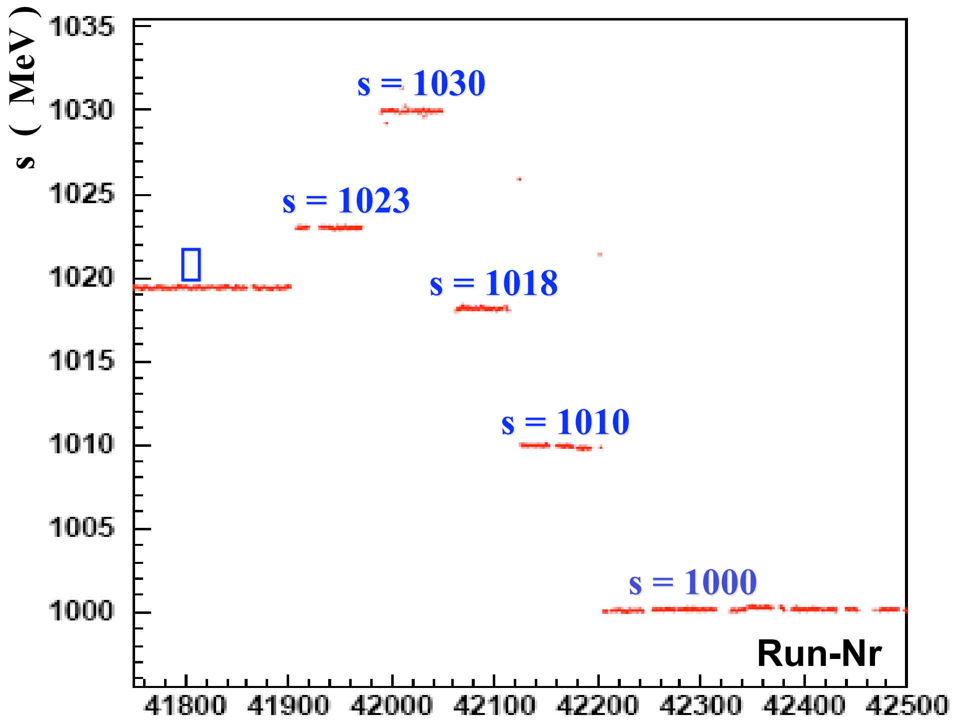


- contained inPHOKHARA (ISR only)
- possible background for $\pi\pi$-analysis when not vetoing π^0
- FSR will change the $M^2_{\pi\pi}$ of the charged pions

DAΦNE Off-peak runs: :

- Run at √s=1000 MeV between Dec. 2005 and March 2006
  → ~225pb^{-1} on tape

- Energy scan around φ-peak
  → 4 scan points, 10pb^{-1} each



Very interesting data! Will allow to attack many problems:

- Final state radiation (see talk of G. Venanzoni)
- Determination of Scalar parameters
- etc.

Analysis has started…

Summary:

"KLOE MC and Rad. Corr. Shopping List":

- FSR: *Model dependent for pions…needs different parametrizations implemented in MC. For muons, can in principle be checked by comparing data yield with MC expectation.* *
- Scalars:
- □□:

  } MC crucial to disentangle the individual contributions present in data, especially at low M^2. *
- ISR: *Basic ingredient to Radiative Return measurements. Current precision of 0.5% gives 0.5% error on $a_\mu^{had,lo}$. Any improvement and independent cross checks are welcome.*
- Vac. Pol.: Error dominated by exp. input, introduces 0.2% error on $a_\mu^{had,lo}$
- $e^+e^- \to \pi^+\pi^-\pi^0\gamma$ *Addition of FSR in PHOKHARA important for background studies for $\pi\pi\gamma$ analysis.*
- $e^+e^- \to e^+e^-\pi^+\pi^-$
- $e^+e^- \to e^+e^-\mu^+\mu^-$

  } Generators exist for these channels, and contributions are small.
- Luminosity → *see Talk of F. Nguyen*

* Off-Resonance data will help to settle these issues