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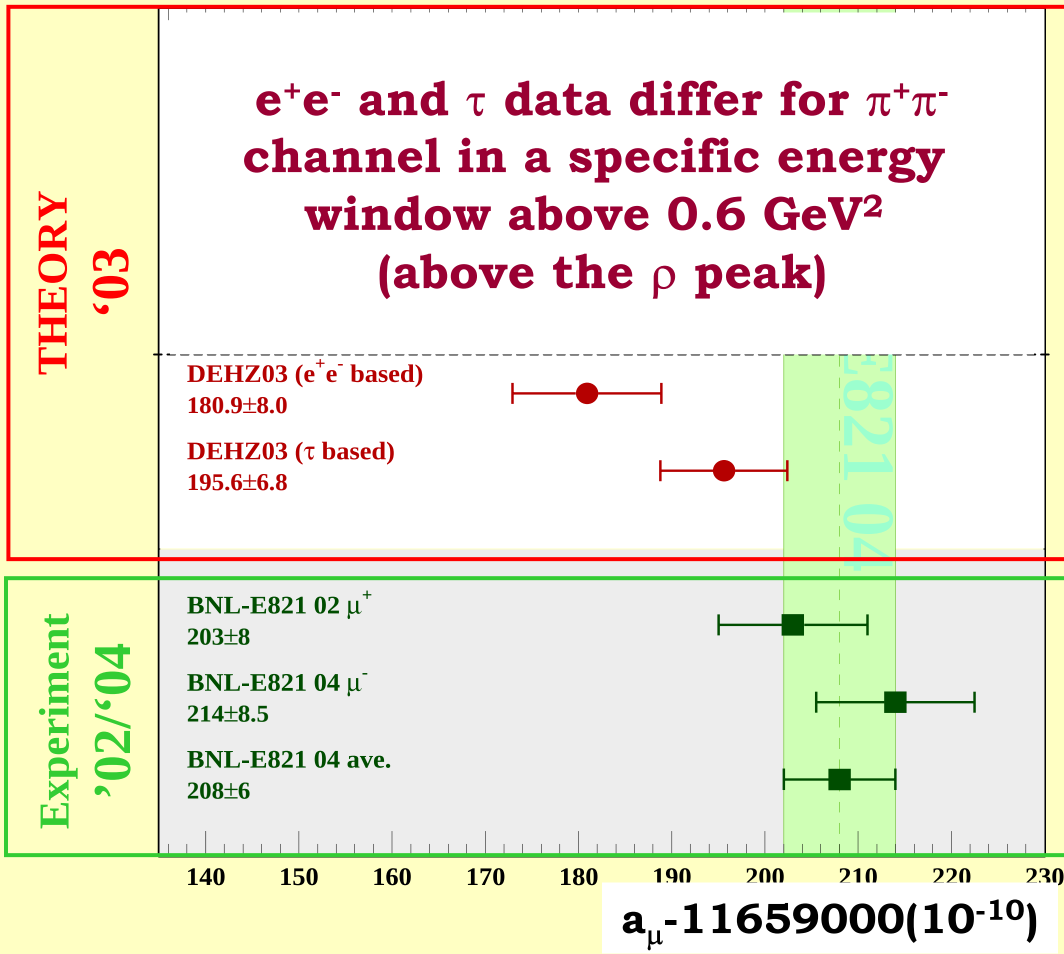
Tau04
Nara 14-17/09/2004

Measurement of the hadronic cross section at KLOE

a_μ theory vs. experiment

Status up to July ’04



Dispersion integral for hadronic contribution to a_μ evaluated for:

a) CMD-2 (Novosibirsk/VEPP-2M) $\pi^+ \pi^-$ channel with 0.6% precision < 1 GeV

b) τ-Data from ALEPH /OPAL/CLEO

$e^+ e^-$ - Data: 2.7 σ - Deviation

τ – Data: 1.4 σ - Deviation

Experiment BNL-E821

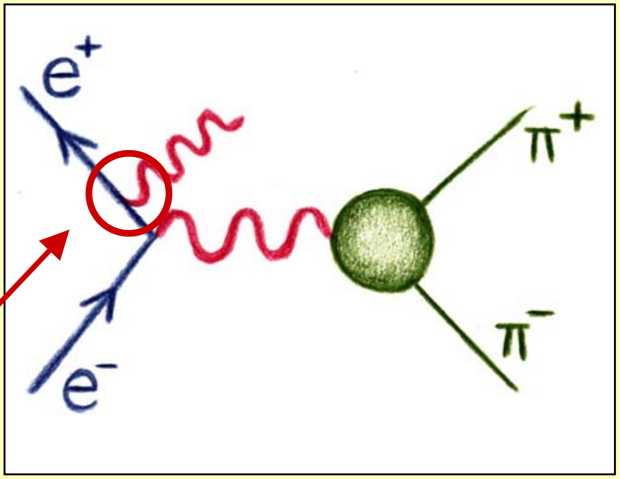
Values for μ^+(2002) and μ^-(2004) in agreement with each other.

Precision: 0.5ppm

The Radiative Return

The standard method to measure $\sigma(e^+e^- \to \text{hadrons})$ is the energy scan, i.e. the syst. variation of c.m. energy of the machine.
Since at DAΦNE the collision energy is fixed,
we use a **complementary** approach:
looking for $e^+e^- \to \pi^+\pi^-\gamma$ events, where the photon is emitted in the initial state (ISR), we have a continuous variation of s_π, the invariant mass of the hadronic system

$$4m_\pi^2 < s_\pi < m_\phi^2$$



Precise knowledge of ISR process
Radiator function $H(Q^2, \theta_\gamma, M^2_\Phi)$
MC generator: Phokhara
H. Czyz, A. Grzelinska, J.H. Kühn, G. Rodrigo

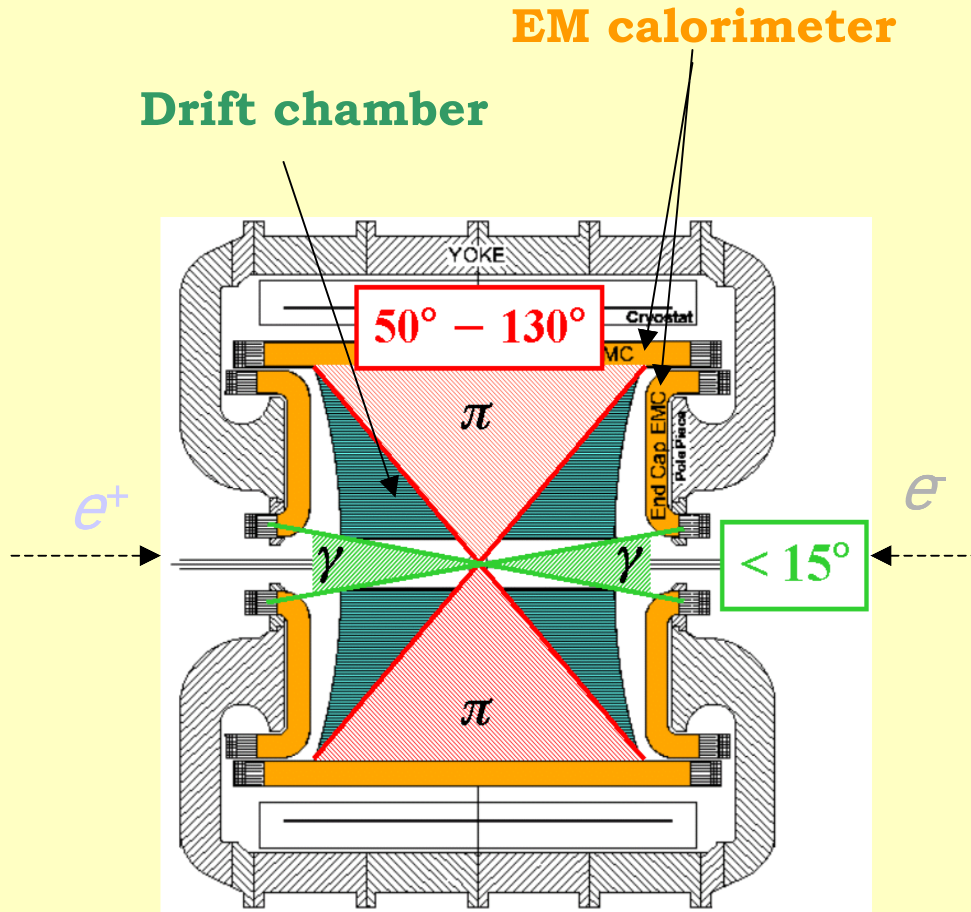
$$M^2_{hadr} \frac{d\sigma(e^+ e^- \to hadrons + \gamma)}{dM^2_{hadrons}} = \sigma(e^+ e^- \to hadrons)\, H(M^2_{hadr})$$

$\pi^+\pi^-\gamma$ selection

Pion Tracks at large angles
$50^o < \theta_\pi < 130^o$

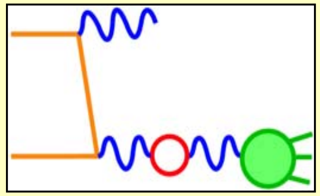
Photons at small angles
$\theta_\gamma < 15^o$ and $\theta_\gamma > 165^o$
are masked by
quadrupoles near the I.P.
(**no photon tagging**)

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



- High Statistics for **ISR** Photons
- Low relative contribution of **FSR**
- Reduced background contamination

$\pi^+\pi^-\gamma$ cross section



$dN(\pi^+\pi^-\gamma)/dM_{\pi\pi}^2$
after acceptance cuts

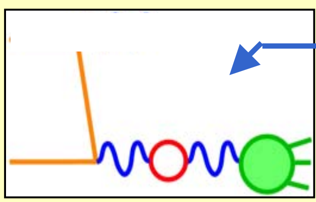
Event analysis:
Efficiencies and background

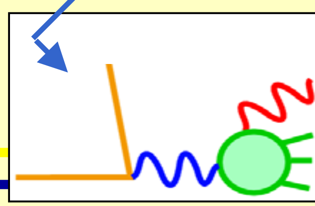
Normalize to **Luminosity**

Differential cross section
$d\sigma(\pi^+\pi^-\gamma)/dM_{\pi\pi}^2$

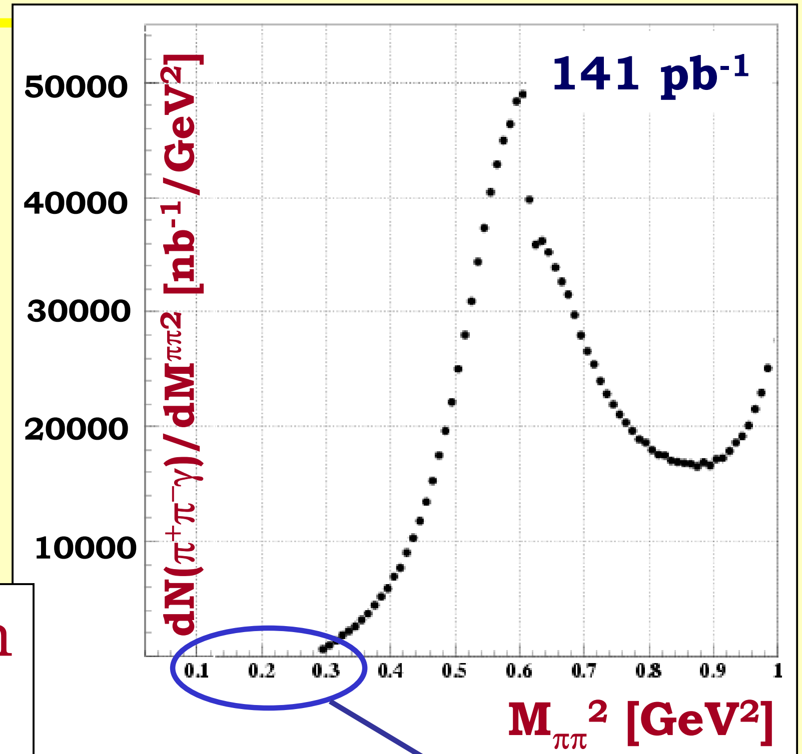
Divide by **Radiator Function**

Radiative Corrections

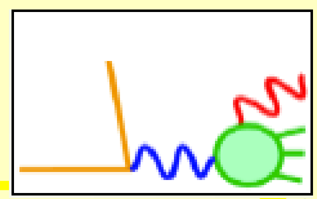




Cross section
$\sigma(e^+e^- \to \pi^+\pi^-)$

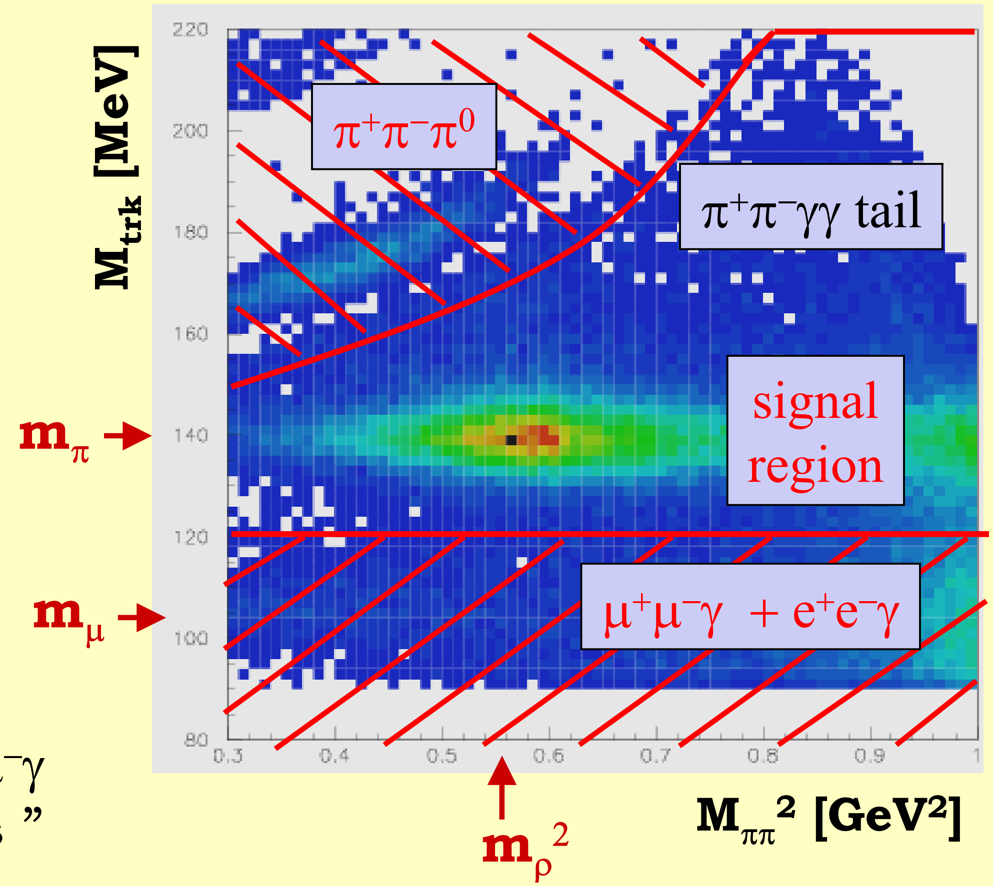


No acceptance at threshold region



Background Rejection 1/2

Step 1: $e^+e^-\gamma$ are separated from $\pi^+\pi^-\gamma$ by means of a Likelihood method (signature of EmC-clusters and TOF of particle tracks)

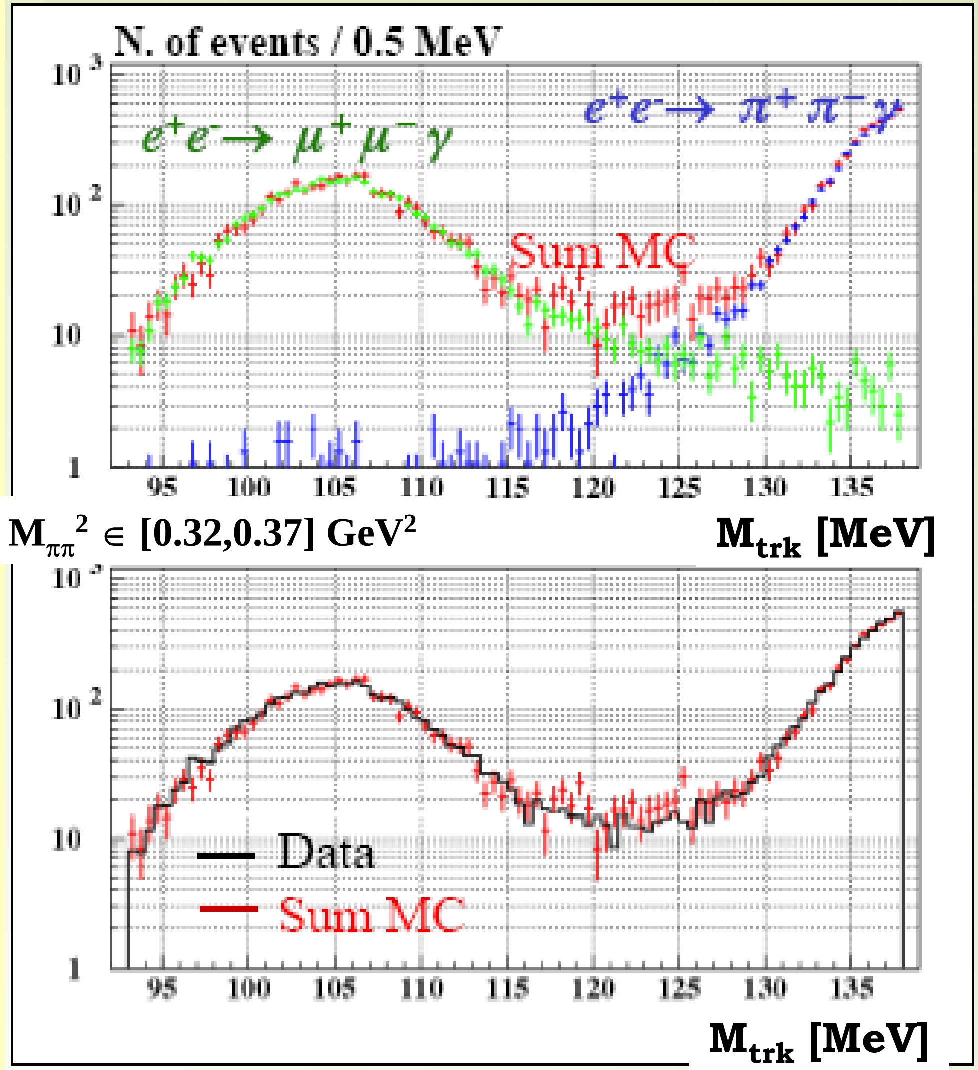


Step 2: $\phi\to\pi^+\pi^-\pi^0$ and $e^+e^-\to\mu^+\mu^-\gamma$ rejected by means "Trackmass "

$$(M_\phi - \sqrt{|\vec{p}_1|^2 + M_{trk}} - \sqrt{|\vec{p}_2|^2 + M_{trk}})^2 - |\vec{p}_1 + \vec{p}_2|^2 = |q_\gamma|^2 = 0$$

Background Rejection 2/2

Step 3: fit data trackmass distributions with MC ones (signal + background) with free normalization parameters



Luminosity Measurement

KLOE uses **large angle Bhabha events** for the luminosity evaluation:

$$\int L \; dt = \frac{N}{\sigma^{MC}} (1 - \delta_{Bkg})$$

N = events with 55°<θ<125°

Experimental precision

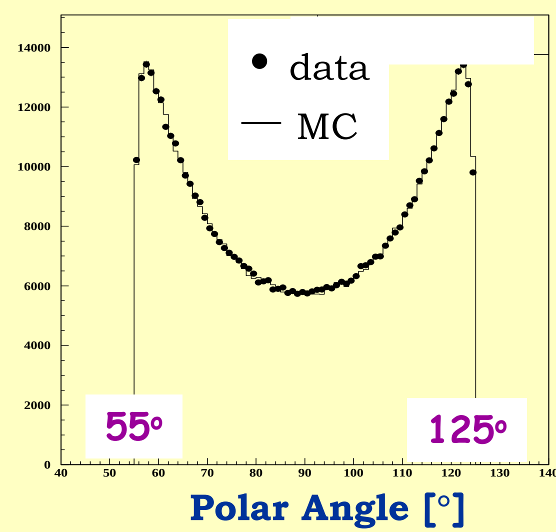
Excellent agreement data-MC

Theory precision (radiative corr.)

- BABAYAGA event generator (Pavia group)
- syst. comparison among other generators (Bhagenf, BHWIDE, VEPP-2M); max. Δ = 0.7 %

⇒**uncertainty 0.5%** =BABAYAGA error

Analysis items Luminosity	Correction	Uncertainty
Acceptance	-0.2%	0.2 %
Knowledge W		0.1 %
Background	+0.5%	0.1 %
Tracking Efficiency		0.1 %
EmC Cluster Efficiency	-0.2%	0.1 %
EmC Calibration Drifts		0.1 %
Cosmic-Ray Veto	+0.5%	0.1 %
Total exp systematics	+0.6%	0.3 %



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

EFFICIENCIES:

- Trigger + Cosmic Veto
- Tracking Vertex
- π/e separation
- Reconstruction filter
- Trackmass cut
- Unfolding procedure
- Acceptance

0.9 %

BACKGROUND

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

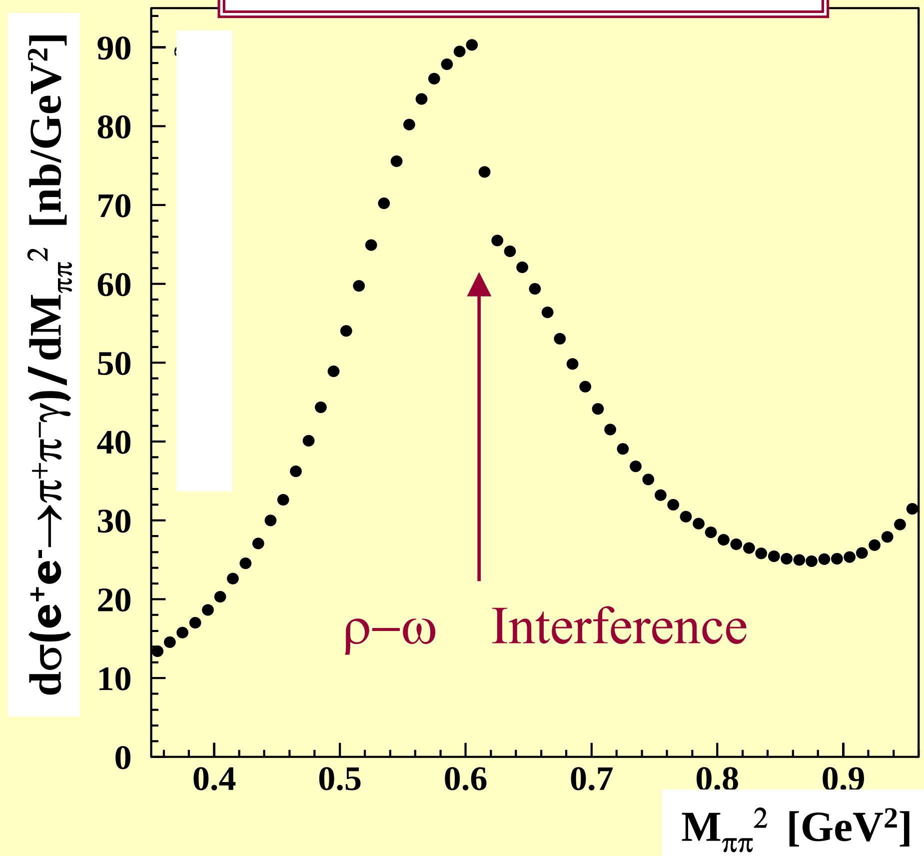
0.3 %

LUMINOSITY

- Bhabha at large angles

0.6 %

140 pb^{-1} of 2001 data
1.5 millions events

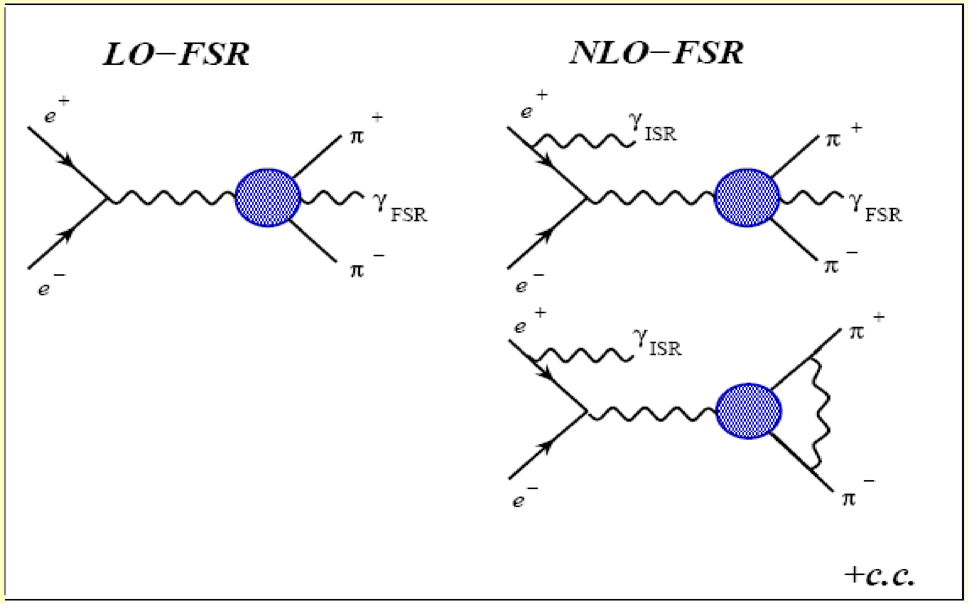


FSR Contribution

There is no initial state radiation and the e^+ and the e^- collide at the energy $M_\phi \Rightarrow$ the virtual γ has $Q^2 = M_\phi{}^2$

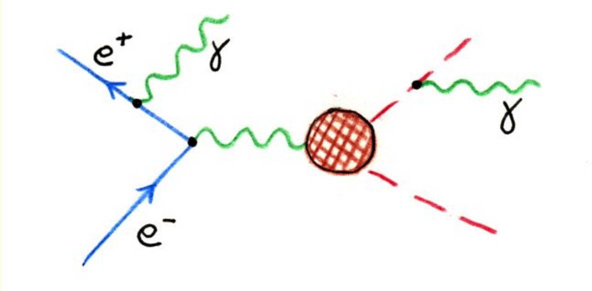
Background

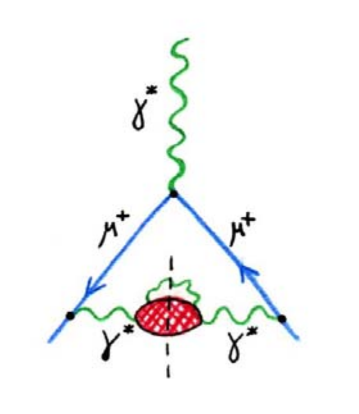
Two kinds of FSR



Simultaneous presence of a initial and final photon

The cross section $e^+e^- \to \pi^+\pi^-$ has to be inclusive with respect to **NLO FSR** events:



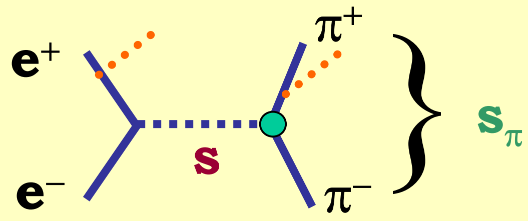


FSR Treatment

"**FSR Inclusive**" **approach**

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

add back missing FSR



Invariant mass of the system $\pi^+\pi^-$, s_π $\neq$ invariant mass of the virtual photon **s**

Event analysis
Phokhara ISR+FSR
Luminosity

$\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}\gamma_{FSR})$ (with γ_{ISR} crossed out)

Correction for unshifting

Radiator H

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

FSR uncertainty

"FSR Exclusive" approach

$N(e^+e^- \to \pi^+\pi^-\gamma_{ISR}\ \ \gamma_{FSR})$ (with γ_{FSR} crossed out)

subtract FSR contribution
estimated by MC

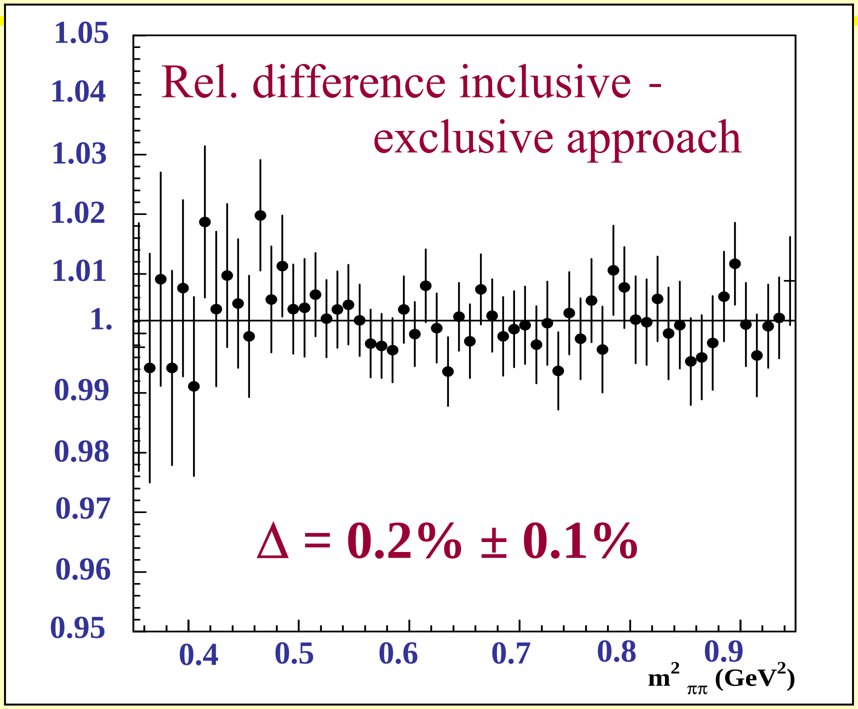
Event analysis
Phokhara ISR
Luminosity

$\sigma(e^+e^- \to \pi^+\pi^-\gamma_{ISR})$ (with γ_{ISR} crossed out)

Radiator H

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

0.8 .. 0.9% Schwinger '90



The 2 methods are in excellent agreement

- Higher order FSR corrections negligible
- Proof of Factorization Ansatz

FSR systematic = 0.3%, coming from 2 contributions

- 0.2% difference **incl-excl correction**
- upper limit of 20% for **scalar QED model** (point-like pions): $20\% \times 1\% = 0.2\%$

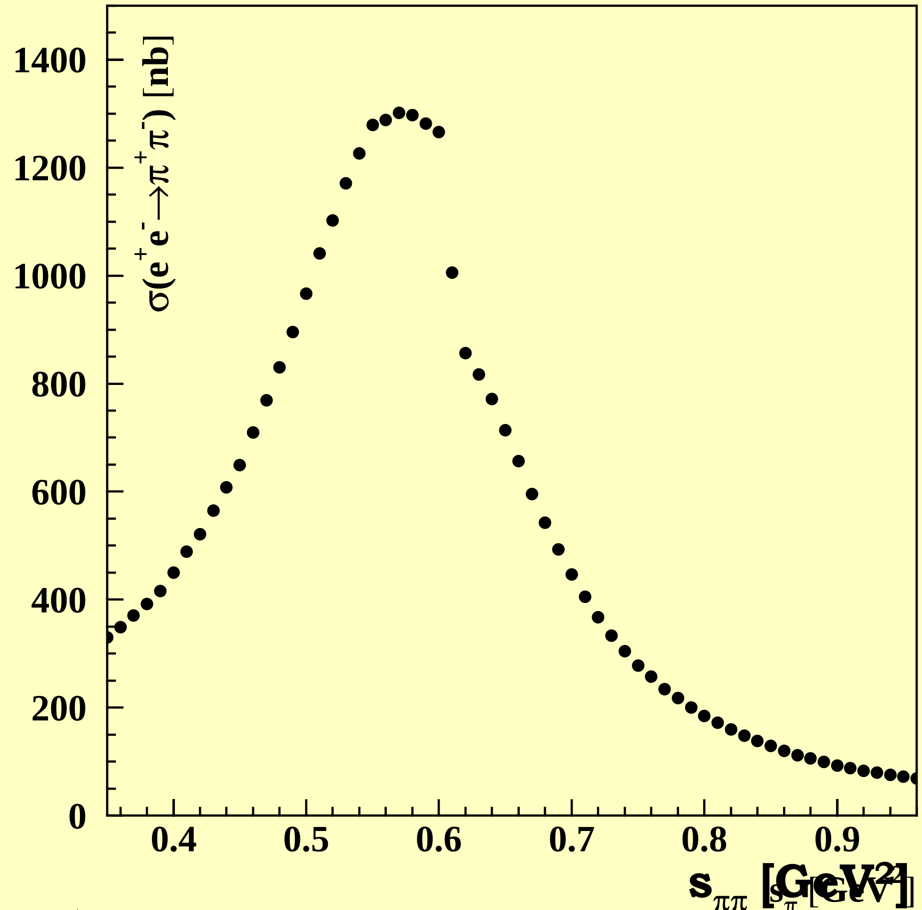
Cross Section $\sigma(e^+e^- \to \pi^+\pi^-)$

Final spectrum: after the correction for vacuum polarization

$$\sigma_{bare}(s) = \sigma(s) \cdot \left(\frac{\alpha(0)}{\alpha(M^2_{\pi\pi})} \right)^2$$

$\Delta\alpha_{had}(s)$ from F. Jegerlehner, July 2003

Acceptance	0.3 %
Trigger	0.3 %
Reconstruction Filter	0.6 %
Tracking	0.3 %
Vertex	0.3 %
Particle ID	0.1 %
Trackmass	0.2 %
Background subtraction	0.3 %
Unfolding	0.2 %
Total exp systematics	0.9 %
Luminosity	0.6 %
Vacuum Polarization	0.2 %
FSR resummation	0.3 %
Radiation function ($H(s_\pi)$)	0.5 %
Total theory systematics	0.9 %



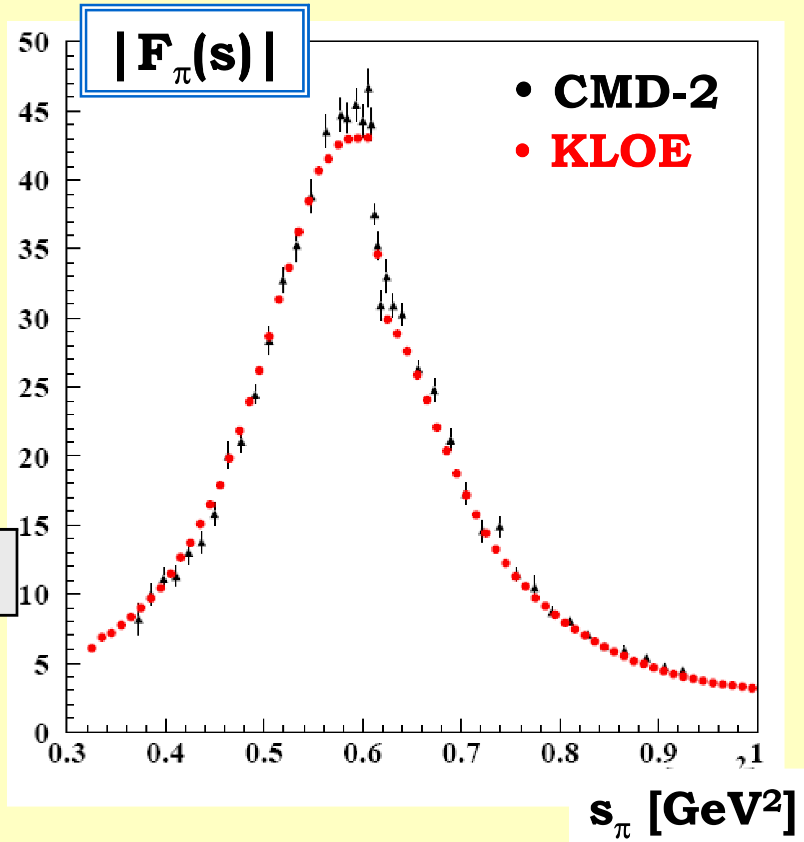
Total error = 1.3 %

2π contribution to a_μ^{hadr}

- We have evaluated the dispersion integral for 2π channel in the energy range $0.35 < s_{\pi\pi} < 0.95$ GeV^2

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\mathrm{GeV}^2}^{0.95\mathrm{GeV}^2} \mathrm{ds}\, \sigma(e^+e^- \to \pi^+\pi^-)\, \mathrm{K(s)}$$

$a_\mu^{\pi\pi} = (388.7 \pm 0.8_{stat} \pm 3.5_{syst} \pm 3.5_{theo})\ 10^{-10}$



- Comparison with CMD-2 in the energy range $0.37 < s_{\pi\pi} < 0.97$ GeV^2

KLOE	$(375.6 \pm 0.8_{stat} \pm 4.8_{syst+theo})$	**1.3% Error**
CMD-2	$(378.6 \pm 2.7_{stat} \pm 2.3_{syst+theo})$	**0.9% Error**

At large values of s_π ($>m_\rho^2$) we are consistent with CMD-2 and we confirm the deviation from τ-data.

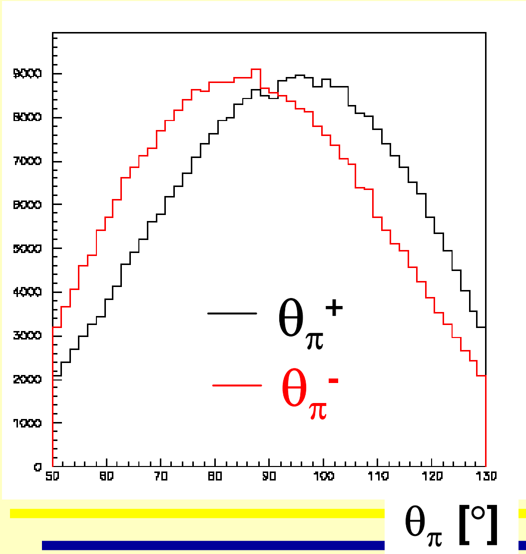
Conclusion

- KLOE has proven the feasibility to use initial state radiation to measure hadronic cross section (hep-ex 0407048)
- We expect to reduce the systematic error below 1% by repeating the analysis with 2002 data. Improvements from theory are also expected.
- The analysis at large photon angle to study the region near the threshold is going on.
- Evaluation of ratio R – the analysis has already begun

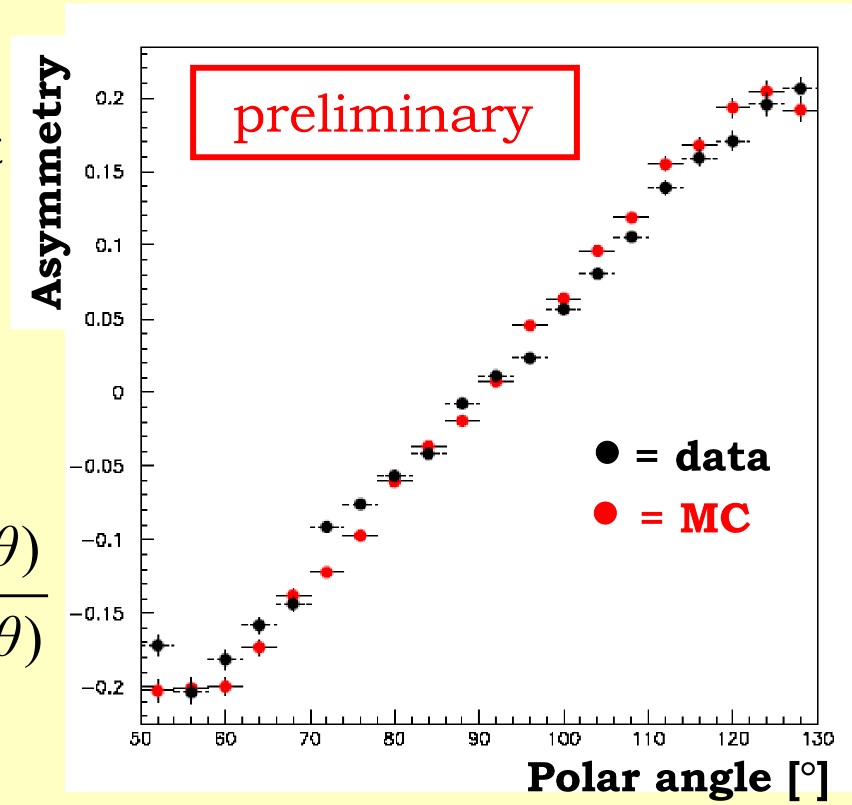
Outlook

- Large angle photon analysis to explore the threshold region
  ➔ **tagged measurement**

- Test of **sQED model**:
  at large photons angles the amount of FSR is large. Here it is possible to study the charge asymmetry.
  It comes out from the interference between ISR (C-odd) and FSR (C-even)



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

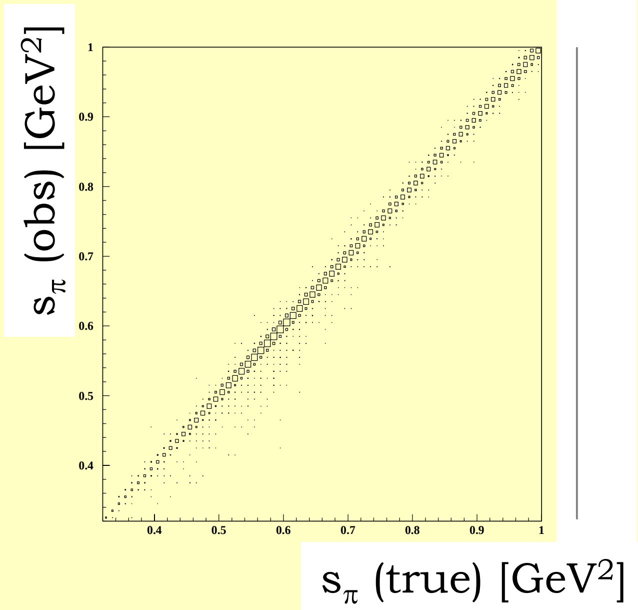


Integrating asymmetry we get a difference data-MC of (8.5 ± 1.2)%

Backup slices

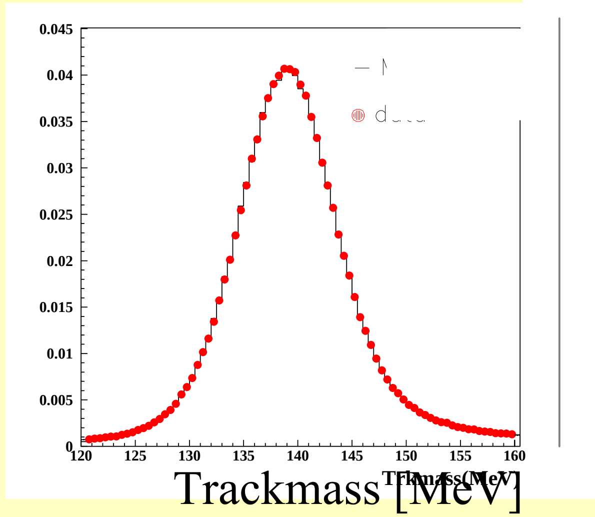
Unfolding the Mass Revolution

The **smearing matrix "almost" diagonal**
Inversion of smearing matrix possible
A more sophisticated unfolding technique is obtained by means of the **unfolding package GURU** (A. Höcker et.al./ALEPH).

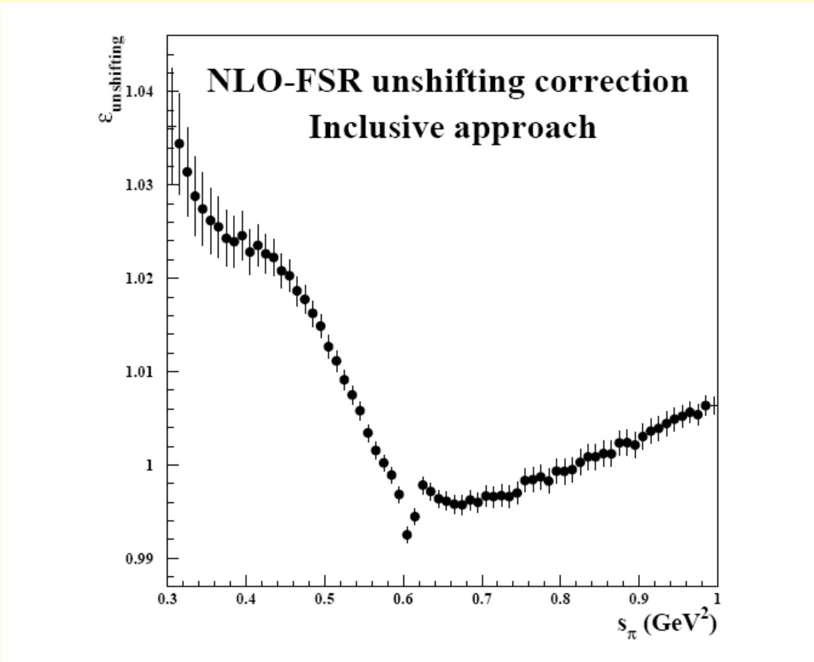


Issues: - Reliability of MC simulation ✓
- Correct choice of the regularization parameter

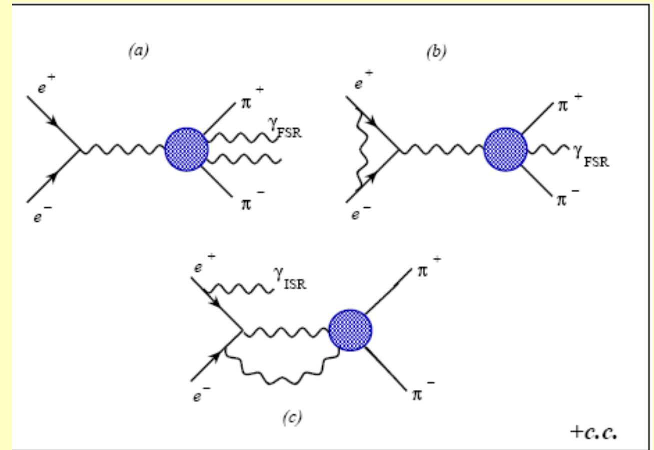
Systematics studied by varying meaningful values of the regularization parameter:



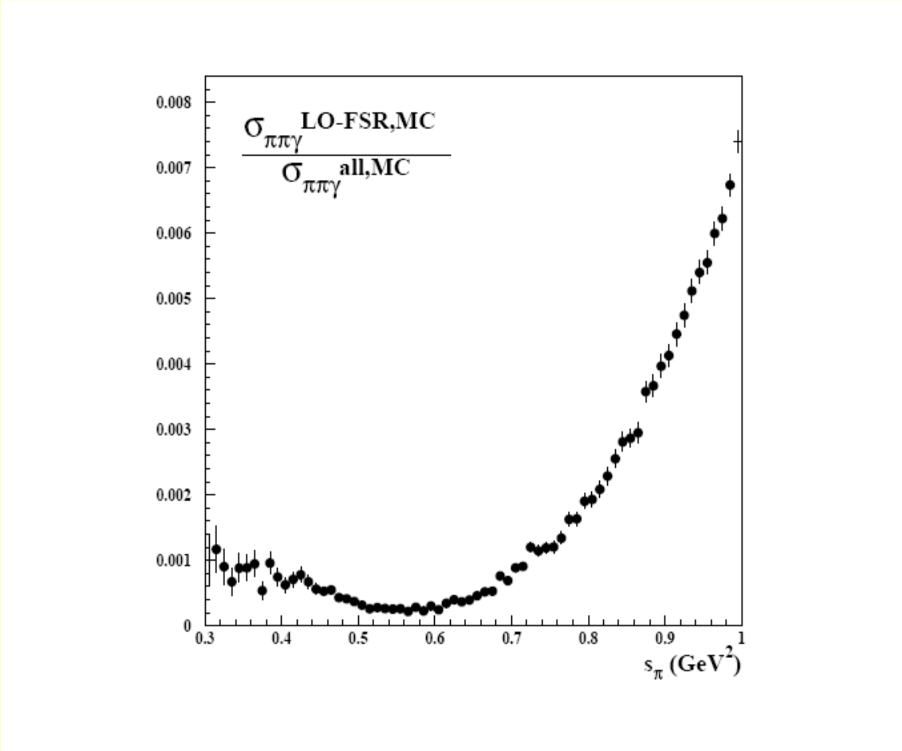
Due to nature of the dispersion integral the effect on a_μ is almost negligible

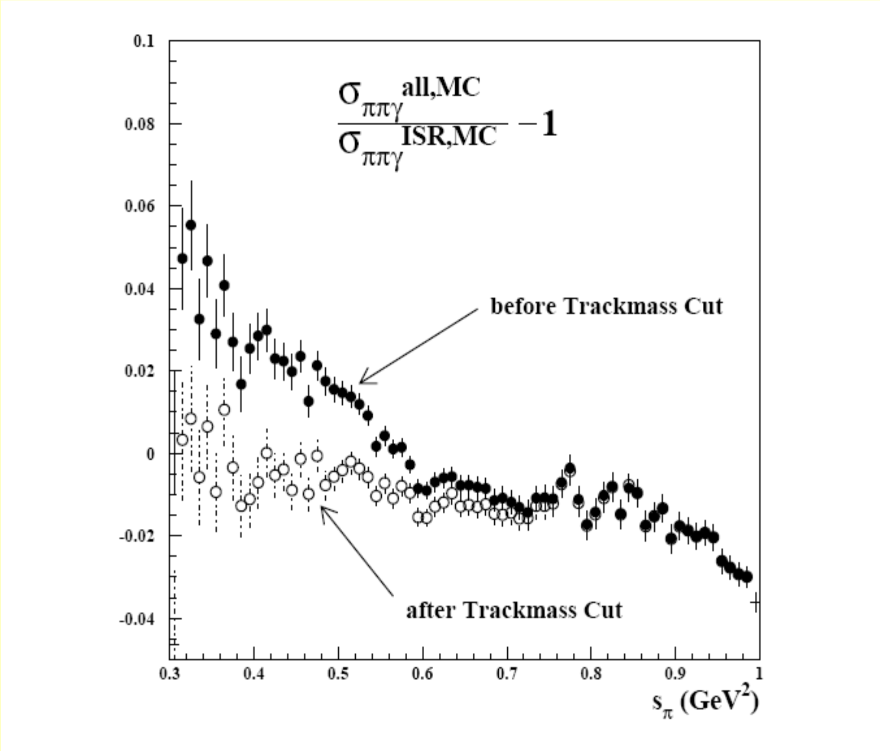


Unshifting correction



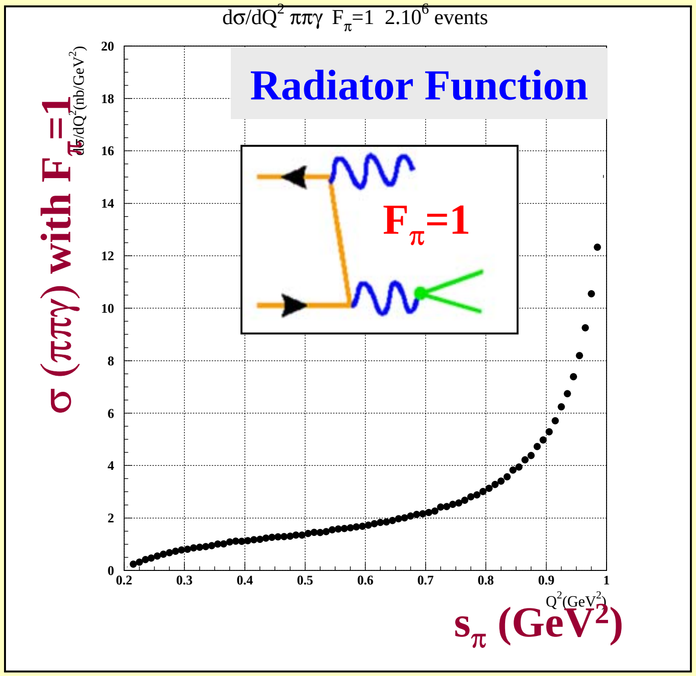
Terms not included in Phokhara

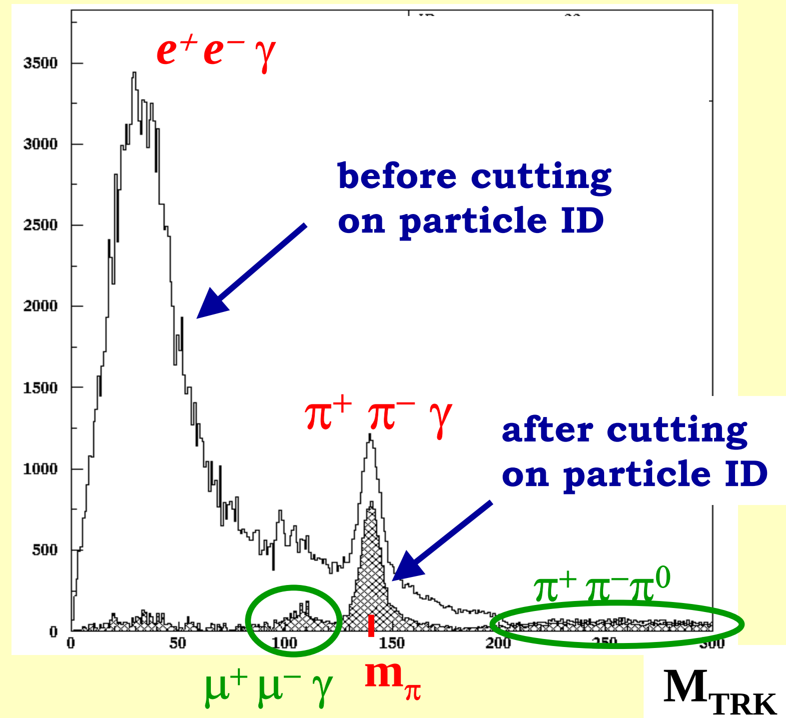




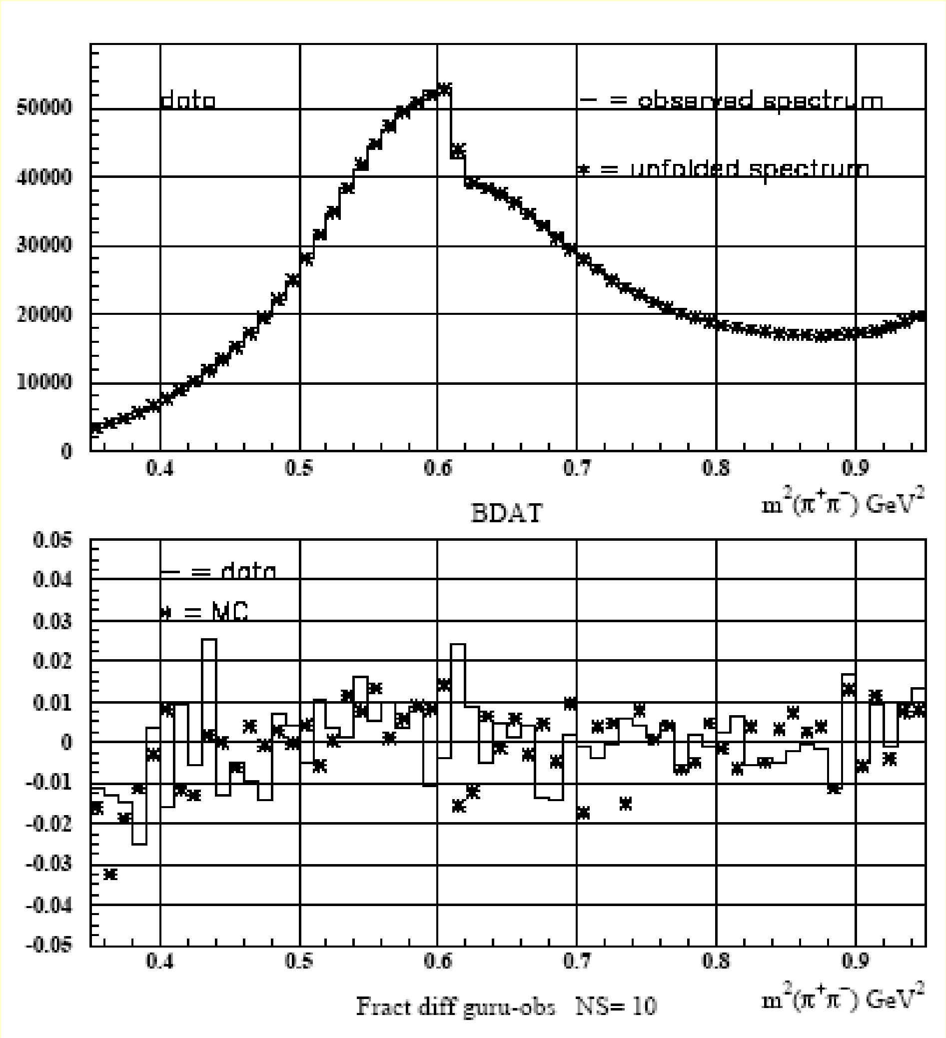
Relative contribution of LO-FSR

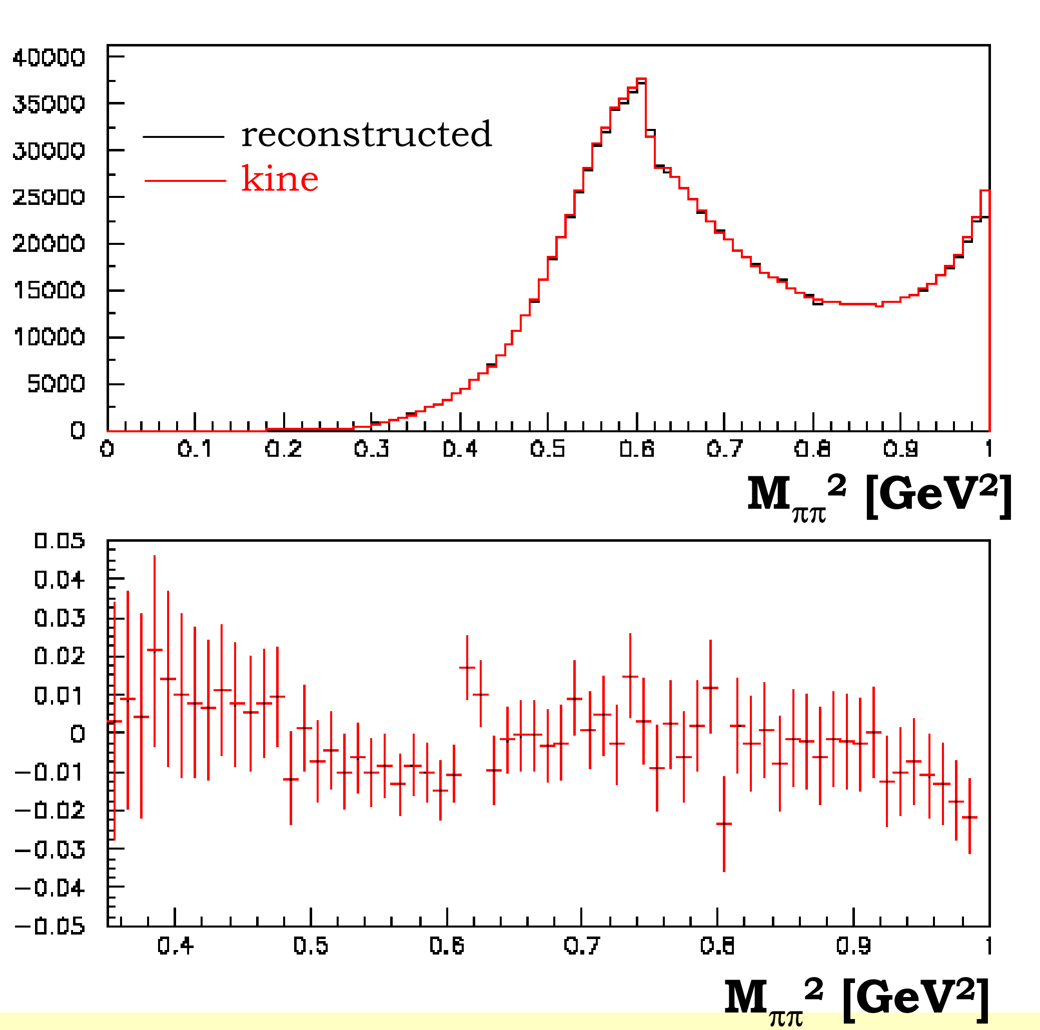
Relative contribution of NLO-FSR





Likelihood effect on M_{trk} distribution


data
— = observed spectrum
* = unfolded spectrum
50000
40000
30000
20000
10000
0
0.4
0.5
0.6
0.7
0.8
0.9
m^2(π^+π^-) GeV^2
BDAT
— = data
* = MC
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Fract diff guru-obs NS= 10
m^2(π^+π^-) GeV^2


40000
35000
30000
25000
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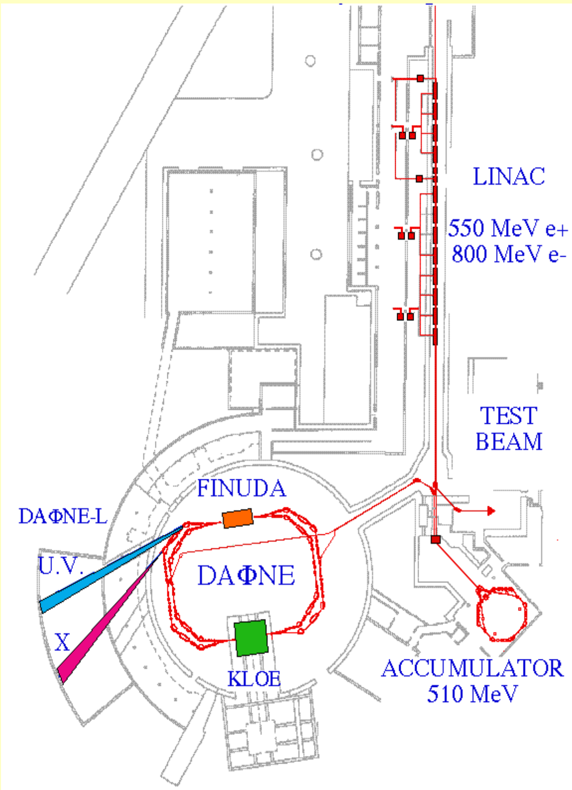
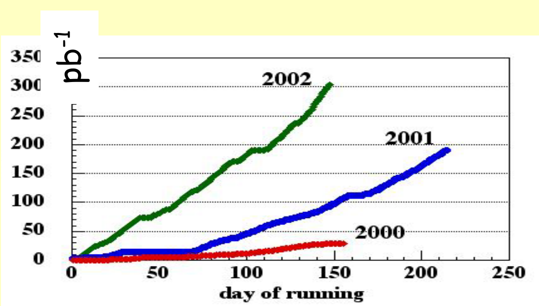
5000
0
reconstructed
kine
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$M_{\pi\pi}^2$ [GeV^2]
0.05
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
−0.05
0.4
0.5
0.6
0.7
0.8
0.9
1
$M_{\pi\pi}^2$ [GeV^2]

KLOE & DAΦNE



- e^+e^- collider @ $\sqrt{S} = M_\Phi$ = 1019.4 MeV
- achieved peak Luminosity: **8 × 10^{31}cm^{-2} s^{-1}**
- 2000-2002 data set: ~ **500 pb^{-1}**



KLOE detector designed
for CP violation studies ⇒
good time resolution
σ_t= 57 ps /√E(GeV) ⊕ 54 ps
in calorimeter and
high resolution drift chamber
(***σ_p/p is 0.4% for θ > 45°***),
ideal for the measurement
of $M_{\pi\pi}$.