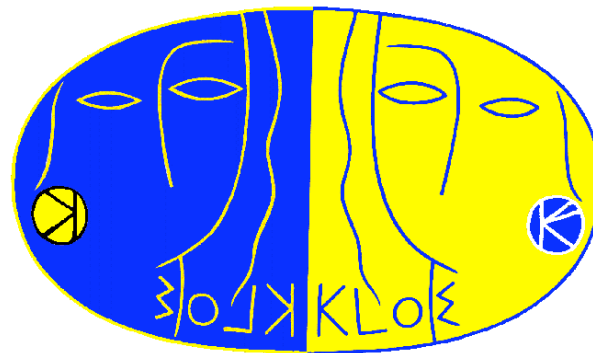


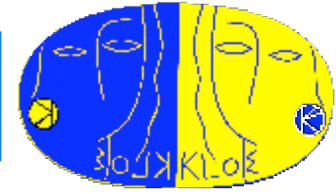
*Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$
at DAΦNE with the radiative return*

Stefan E. Müller
Institut für Exp. Kernphysik,
Universität Karlsruhe
(for the KLOE collaboration)

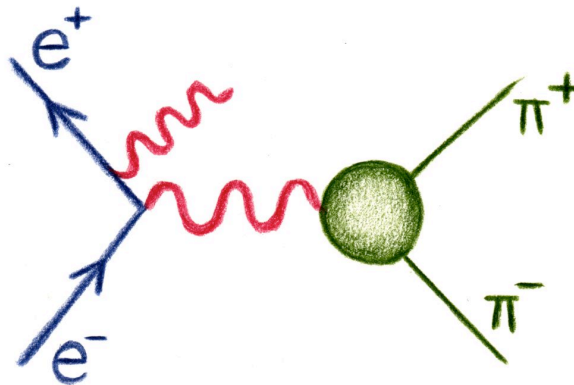


Workshop on
 e^+e^- in the 1-2 GeV range
Alghero, 10.-13. September 2003

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



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



$$\sigma_{\text{hadr}}^2 \frac{d\sigma(e^+e^- \rightarrow \text{hadrons} + \gamma)}{dM_{\text{hadrons}}^2} = \sigma(e^+e^- \rightarrow \text{hadrons}) H(M_{\text{hadr}}^2, \cos\theta_{\text{min}})$$

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

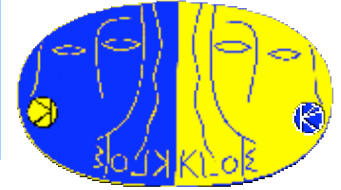
It requires precise calculations of the radiator H .

→ 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)

Signal selection:



Pion tracks are measured at angles
 $50^\circ < \theta < 130^\circ$

Photons are required to be within
 $\theta < 15^\circ$ or $\theta > 165^\circ$

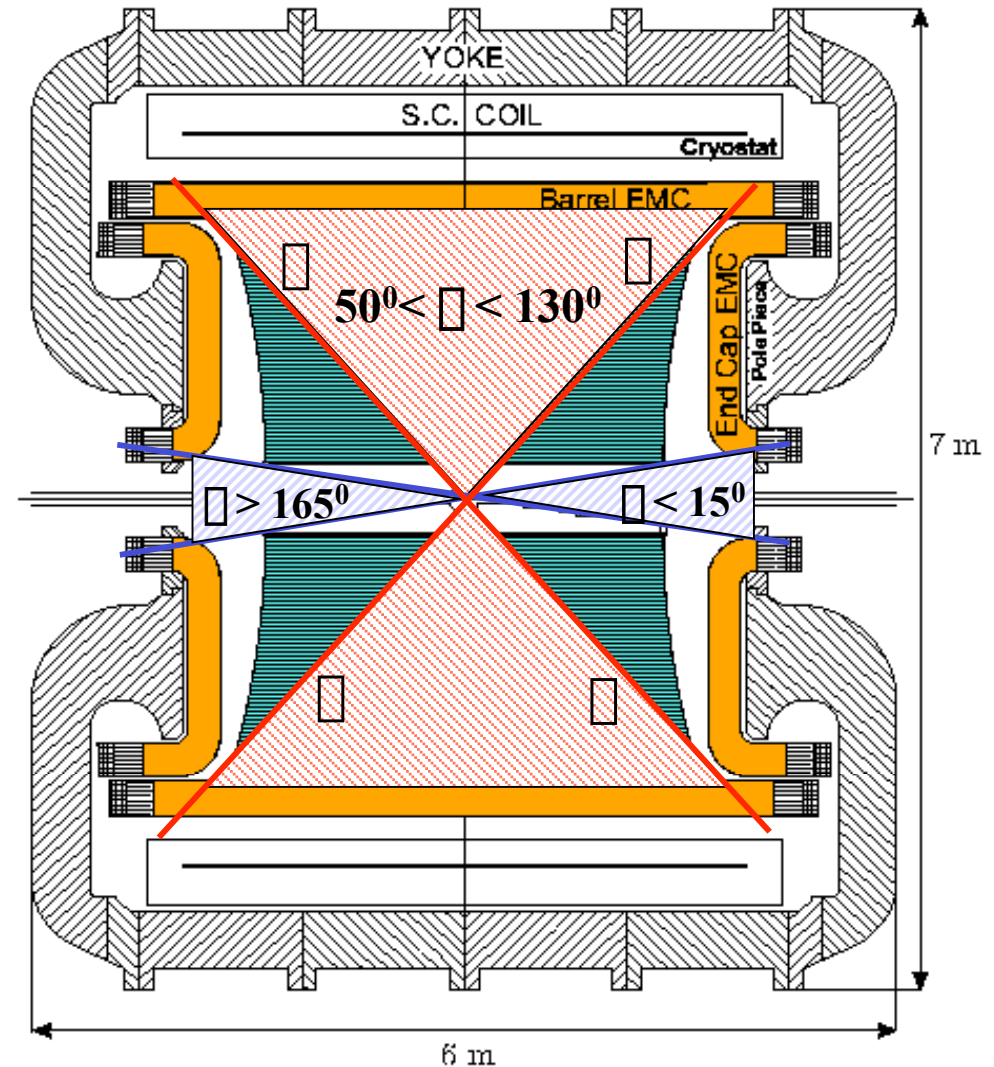
Untagged measurement in which we cut on
 the direction of the missing momentum

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

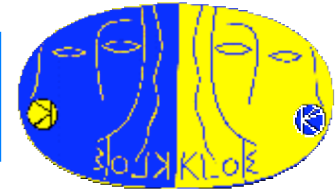
The choice of this kinematical region
 was motivated by:

- **small relative contribution of FSR**
- **reduced background contamination:**

- $e^+e^- \rightarrow e^+e^- \pi^0$
- $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
- $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$



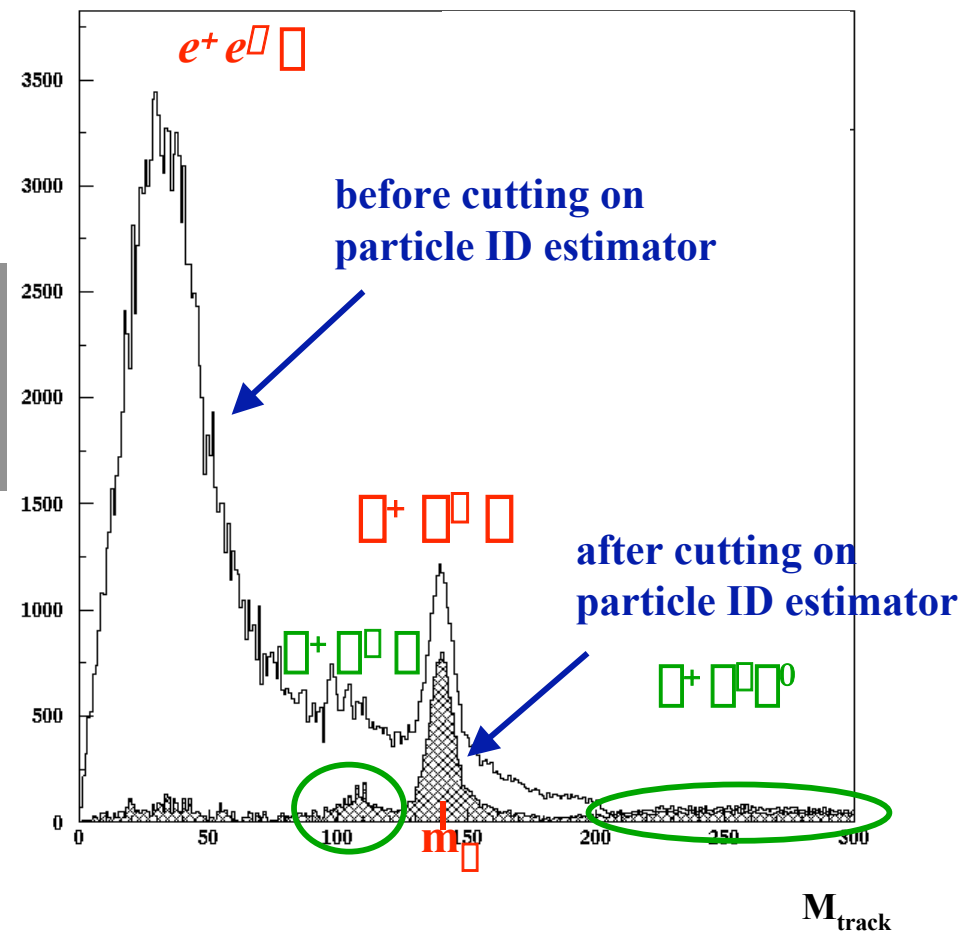
Background rejection:



To reduce Bhabha contamination, a π -e-separation is performed using a particle ID estimator based on:

- TOF of charged clusters
- Shape and energy deposition of the “charged” cluster

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



Background rejection:

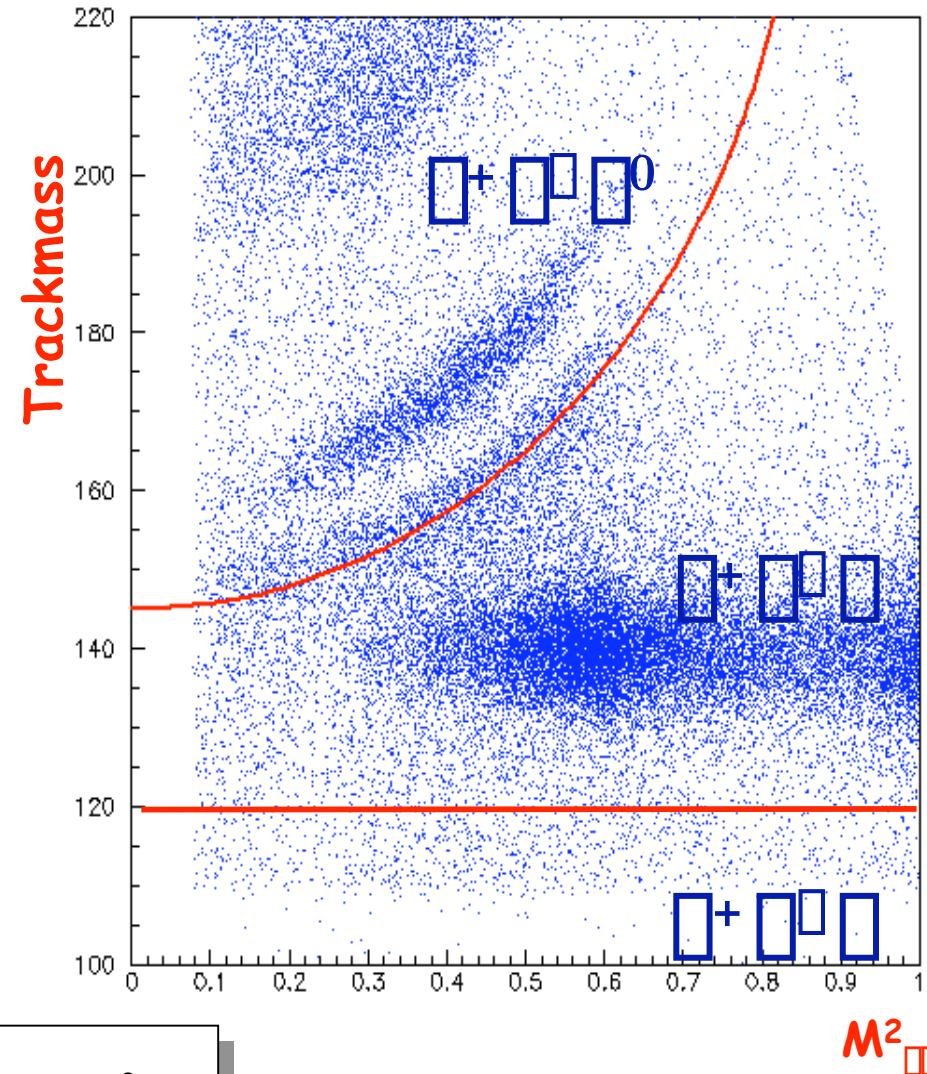


The signal is further selected by performing a cut in the kinetical variable **trackmass** in order to reduce $\pi^+ \pi^- \pi^0$ **background**

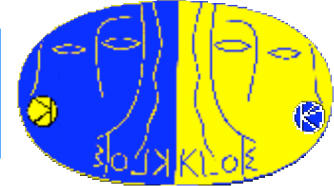
$\pi^+ \pi^- \pi^0$ background
($M_{\text{track}} \approx 105 \text{ MeV}$) is
rejected by a cut on $M_{\text{track}} = 120 \text{ MeV}$

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} :

$$q^2 = \left[M_{\pi}^2 + \sqrt{\vec{p}_1^2 + M_{\text{trk}}^2} \right]^2 - (\vec{p}_1 + \vec{p}_2)^2 = 0$$



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



140 pb⁻¹ of 2001 data were analyzed according to the items discussed.

After selection: **1 500 000 events**
(11000 evts/pb⁻¹)

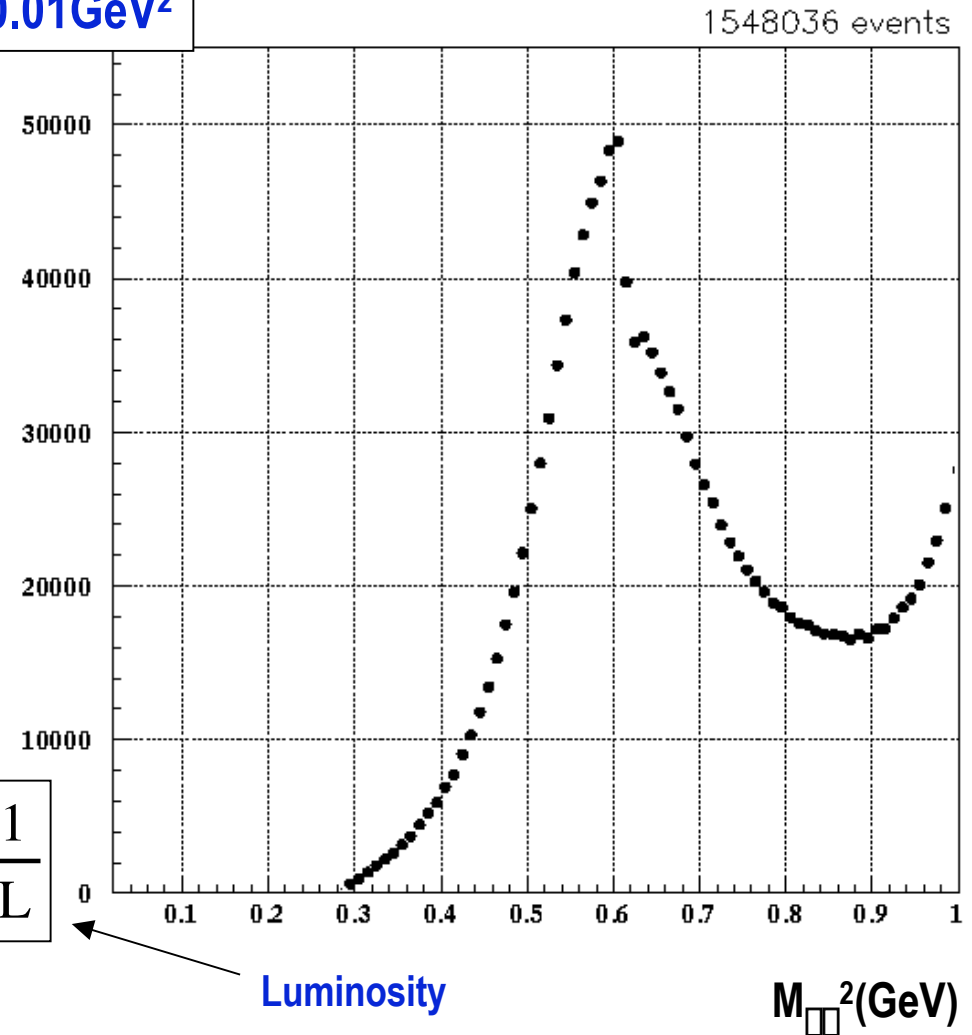
statistical error/bin < 1%
for $M_{\pi\pi}^2 > 0.45 \text{ GeV}^2$

$$\frac{dN_{\pi\pi}}{dM_{\pi\pi}^2} = \frac{N^{\text{obs}} - N^{\text{bkg}}}{\Delta M_{\pi\pi}^2} \times \frac{1}{\epsilon_{\text{Select.}}} \times \frac{1}{L}$$

Signal
Background

Selection efficiency

$N_i/0.01\text{GeV}^2$



Acceptance: $|\eta_{\pi\pi}| < 15^\circ$ ($|\eta_{\pi\pi}| > 165^\circ$), $50^\circ < \phi_{\pi\pi} < 130^\circ$, $E_{\pi\pi} > 10 \text{ MeV}$

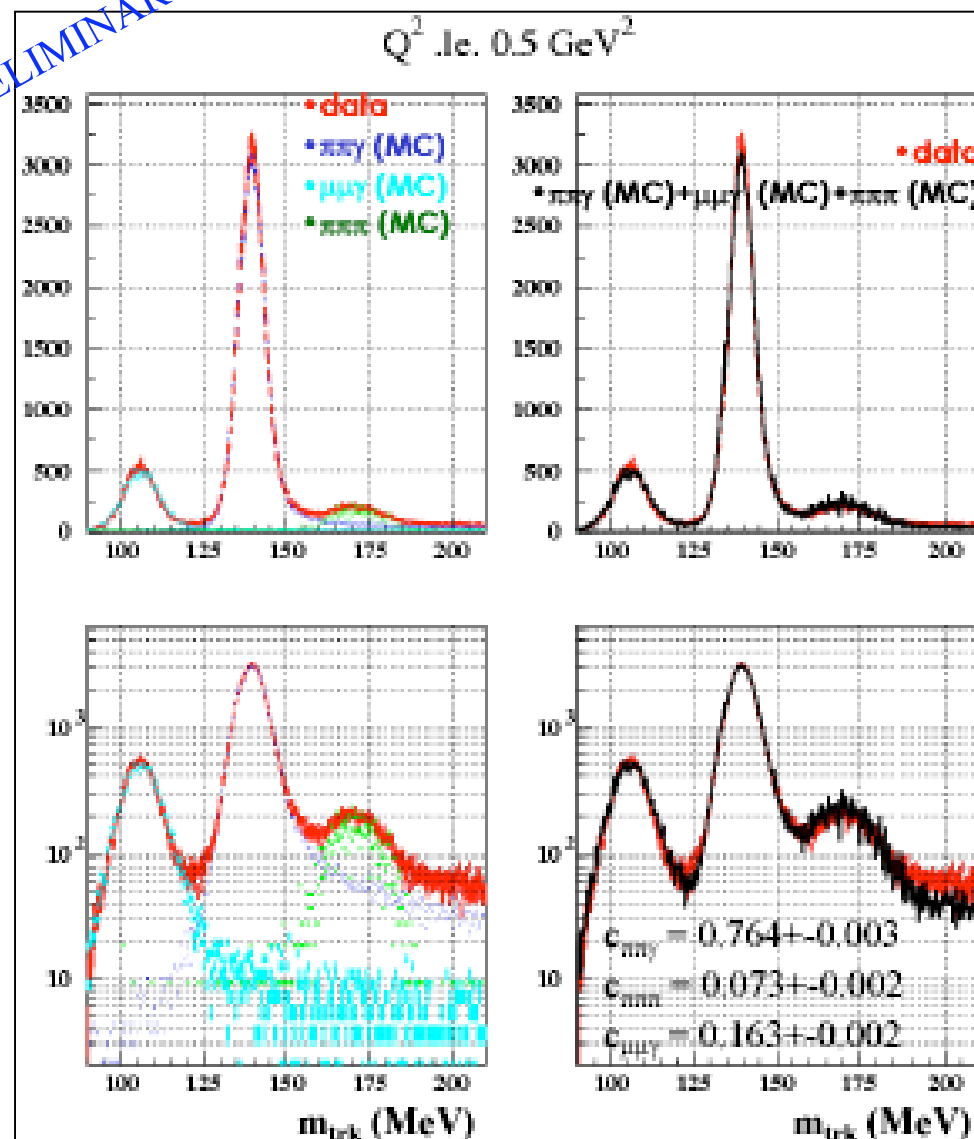
Background subtraction:



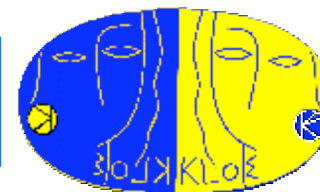
Remaining contaminations from $\pi^+\pi^-\pi^0$ and $\pi\pi\pi$ are measured by fitting the shape of signal and background in the trackmass distribution for different bins of $M_{\pi\pi}^2$.

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

PRELIMINARY



Luminosity:



- Luminosity measured with Large Angle Bhabhas: $55^\circ < \theta_e < 135^\circ$
- 2 independent generators used for radiative corrections:
 - BABAYAGA (Pavia group): $\sigma_{\text{eff}} = (428.8 \pm 0.3_{\text{stat}}) \text{ nb}$
 - BHAGENF (Berends modified): $\sigma_{\text{eff}} = (428.5 \pm 0.3_{\text{stat}}) \text{ nb}$

◆ 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	0.3 %
Background ($\pi\pi + \pi\pi\pi$)	0.1 %
Trigger+Track+Clustering	0.2 %
Knowledge of s run-by-run	0.1 %
TOTAL 0.5 % theory \oplus 0.4% exp = 0.6 %	

Efficiencies:



Trigger

including Cosmic Veto Eff.

Reconstr. Filter

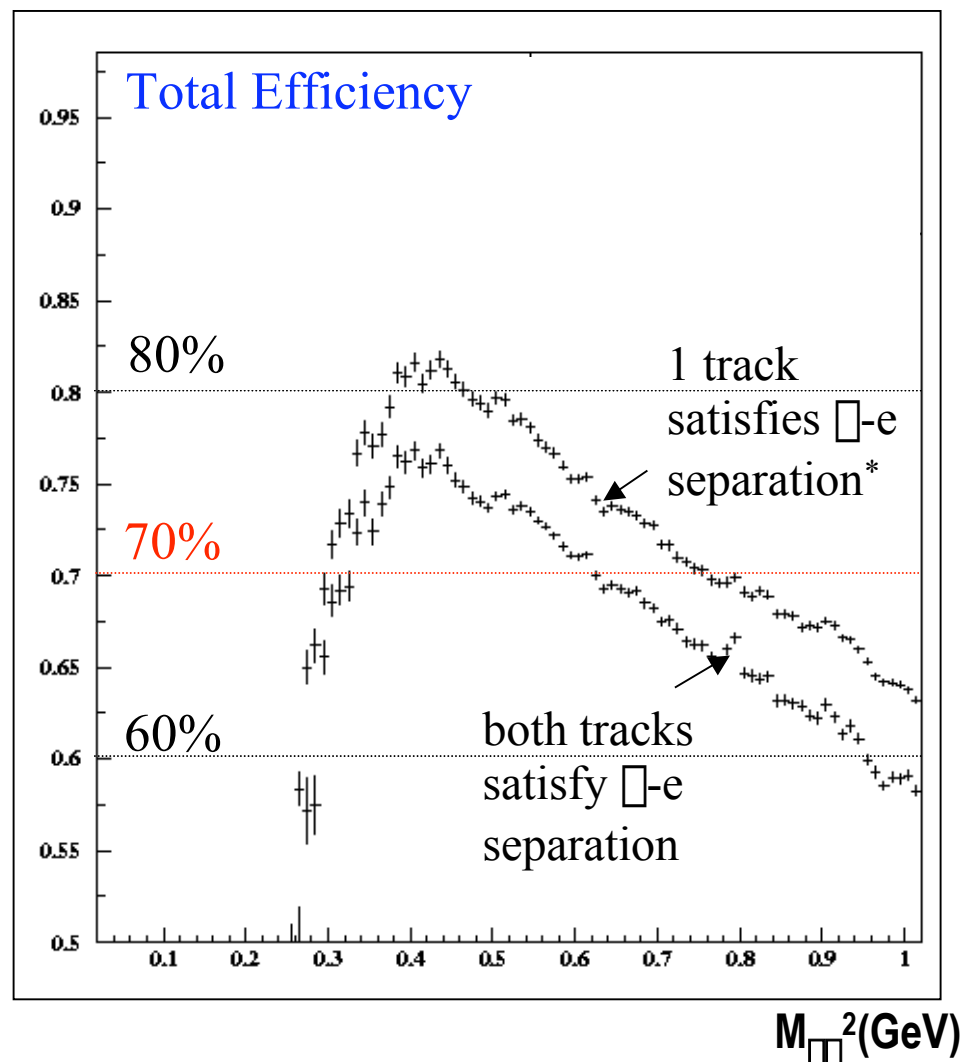
Tracking / Vertex

μ -e separation

Trackmass

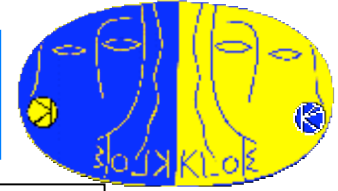
blue = estimated from data and/or
indep. control samples $\mu^+\mu^-\mu^0$, $\mu^+\mu^-$
Kinematics simulated by MC

red = estimated from MC and
compared with data



* used in this analysis

$$\sigma(e^+e^- \rightarrow \pi^+\pi^0\pi^-):$$



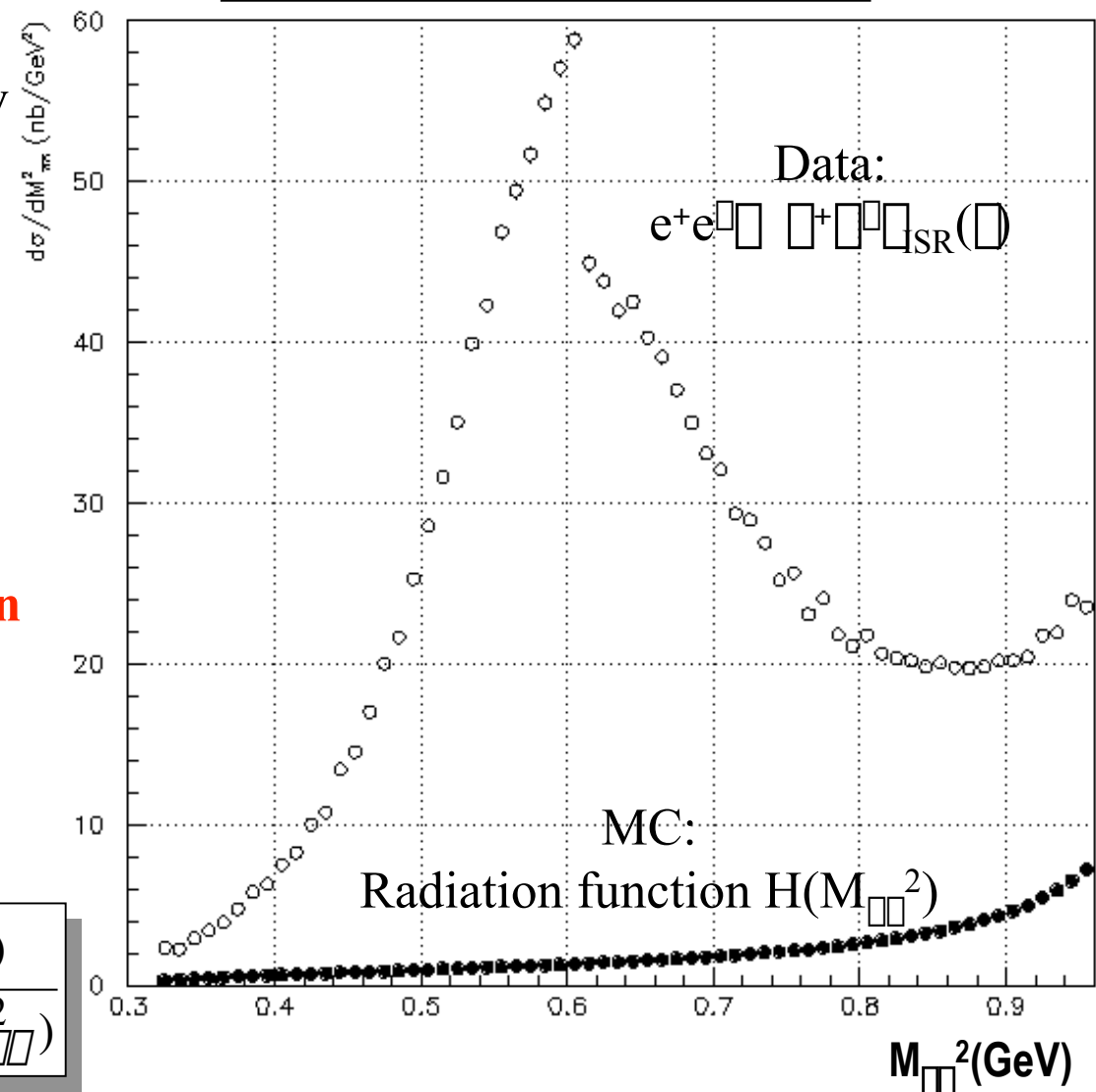
After subtracting the residual background, correcting for efficiencies, dividing for luminosity and unfolding the detector resolution, we arrive to

$$\sigma(e^+e^- \rightarrow \pi^+\pi^0\pi^-) \text{ in bins of } M_{\pi\pi}^2$$

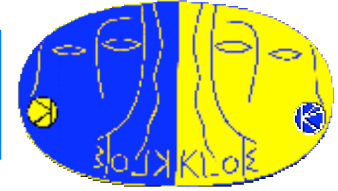
To get the cross section for $e^+e^- \rightarrow \pi^+\pi^-$ we divide the $\pi^+\pi^0\pi^-$ cross section by the cross section $\pi^+\pi^0\pi^-$ for “pointlike” pions which is obtained technically from the MC generator by setting $F_\pi = 1$:

$$\sigma_{\pi\pi} = \frac{|F_\pi(M_{\pi\pi}^2)|^2}{d\sigma_{\pi\pi\pi, F_\pi=1}(M_{\pi\pi}^2)} = \frac{d\sigma_{\pi\pi\pi}(M_{\pi\pi}^2)}{d\sigma_{\pi\pi\pi, F_\pi=1}(M_{\pi\pi}^2)}$$

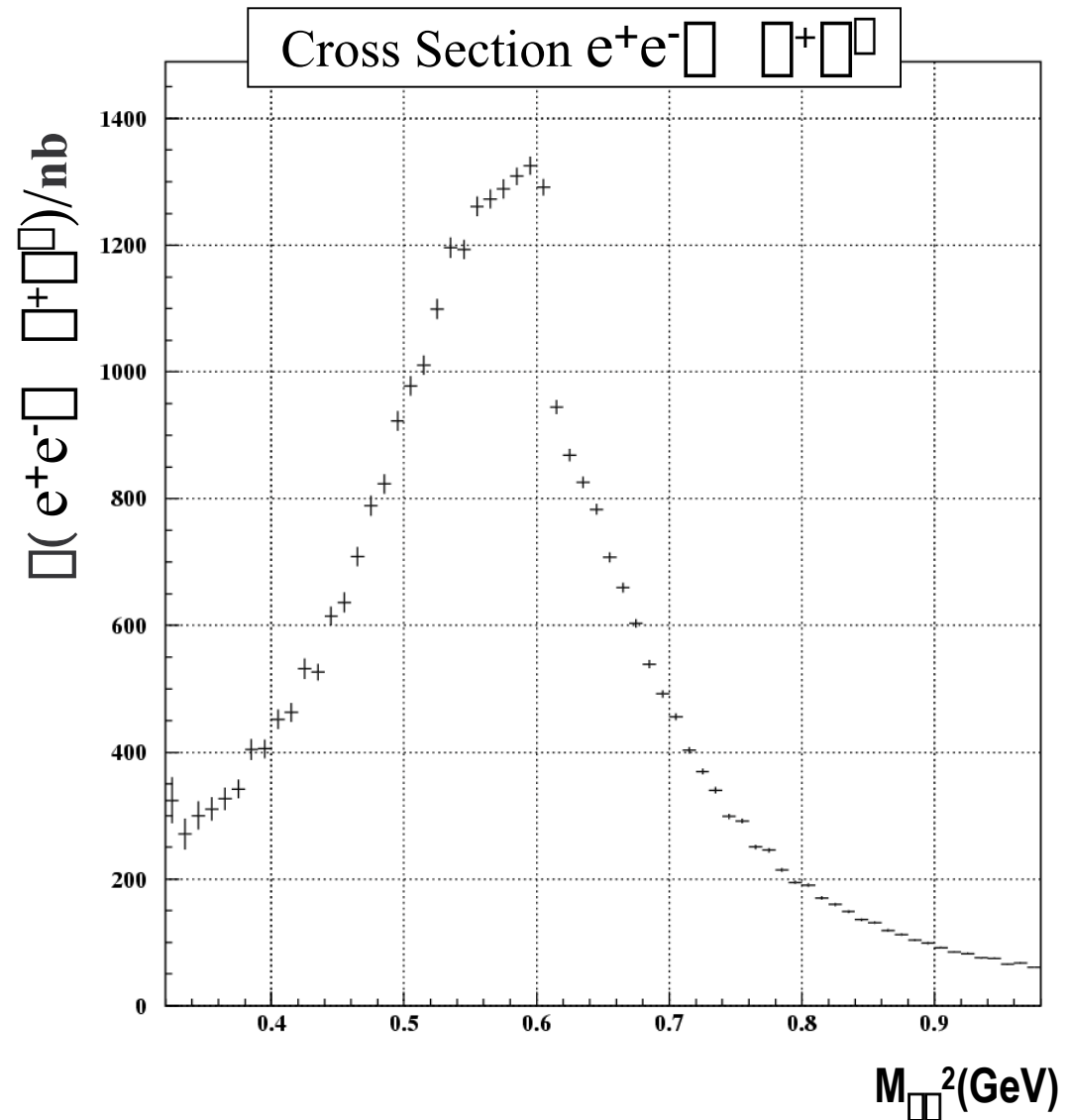
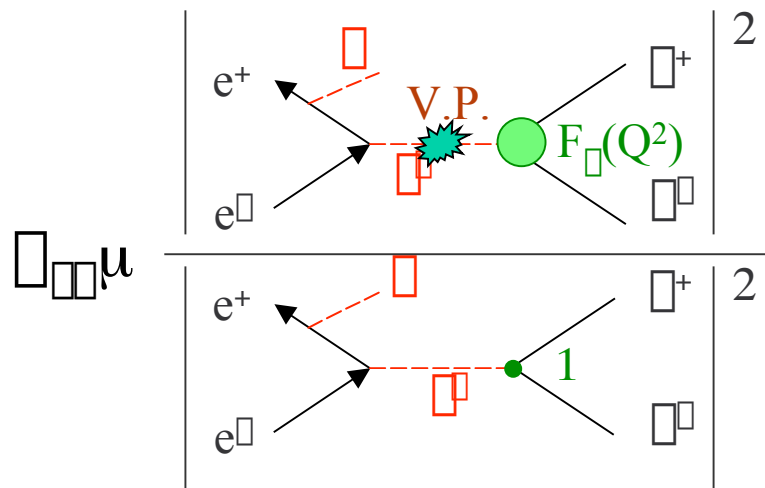
Cross Section $e^+e^- \rightarrow \pi^+\pi^0\pi^-$



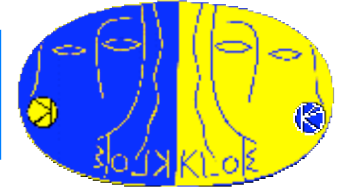
$$\sigma(e^+e^- \rightarrow \pi^+\pi^-):$$



After dividing by the radiation function $H(M_{\pi\pi}^2)$, one gets the cross section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ in bins of $M_{\pi\pi}^2$

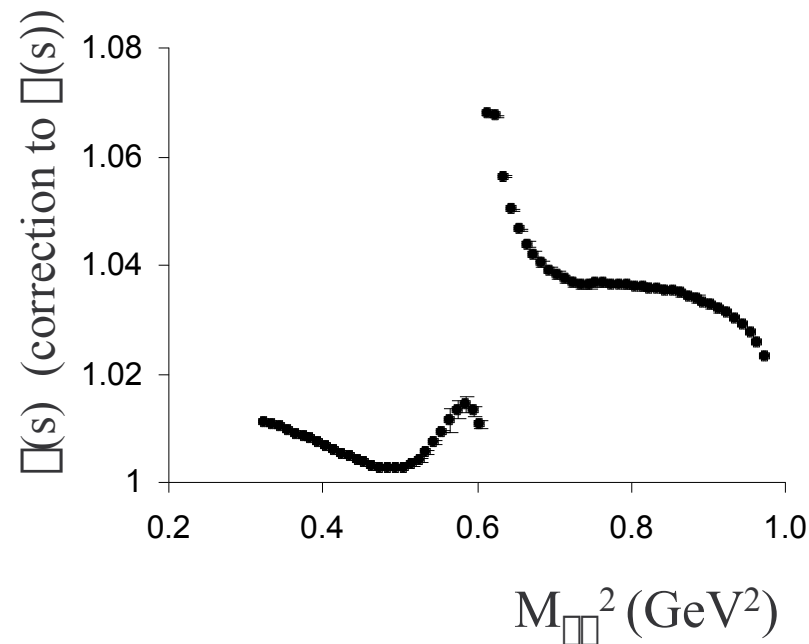


Rad. corrections: Vac. pol.

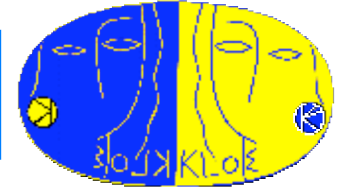


The “bare cross section” has to be used for the evaluation of the hadronic contribution to a_μ in the dispersion integral, i.e. the cross section has to be divided for the running of the fine structure constant α

$$\alpha(s) \cdot \alpha^2(s) = \left[\frac{\alpha_0}{1 + \alpha_0 \Pi_{lep}(s) + \alpha_0 \Pi_{had}(s)} \right]^2 \equiv \alpha(s) \cdot \alpha_0^2 \quad \alpha_{bare}(s)$$

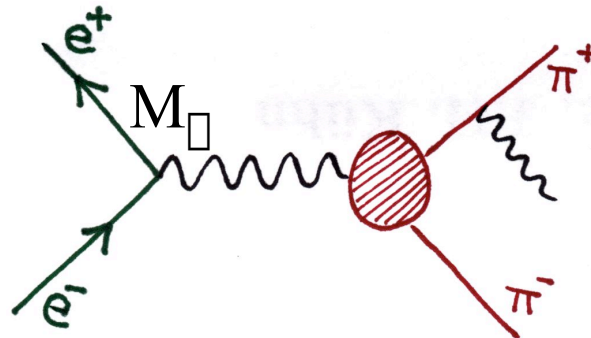


Rad. corrections: FSR (LO)

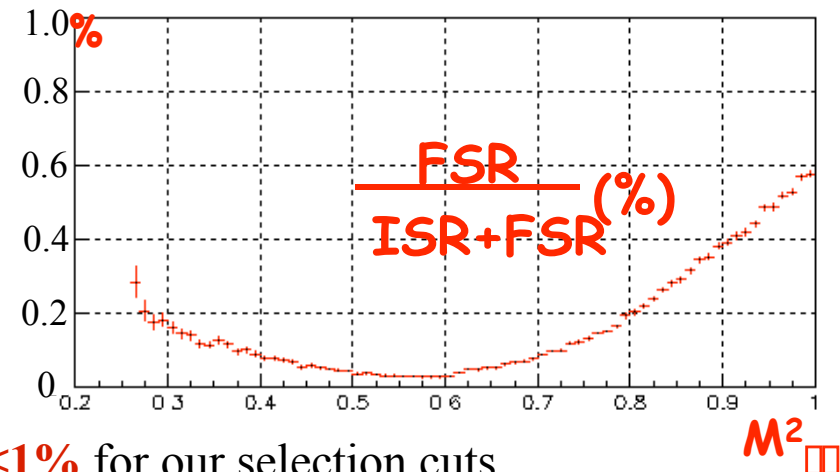
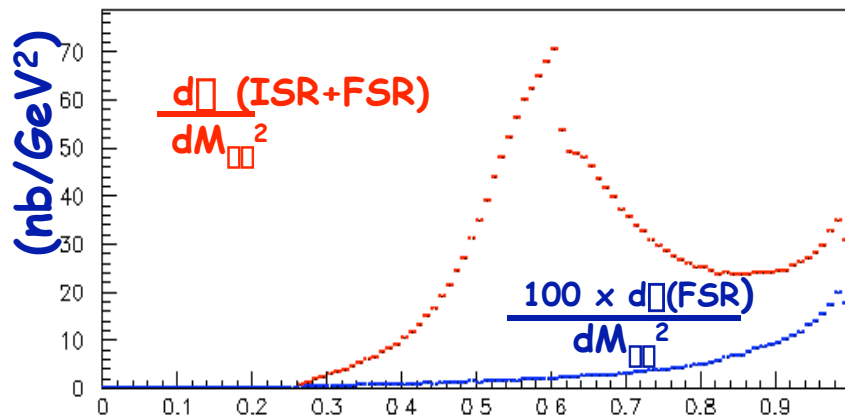


The cross section has to be corrected with respect to **Final State Radiation** (FSR).

At LO final state radiation, there is no initial state radiation and the e^+ and the e^- collide at the energy M_\square :



This process has been studied with the **EVA** MC program:

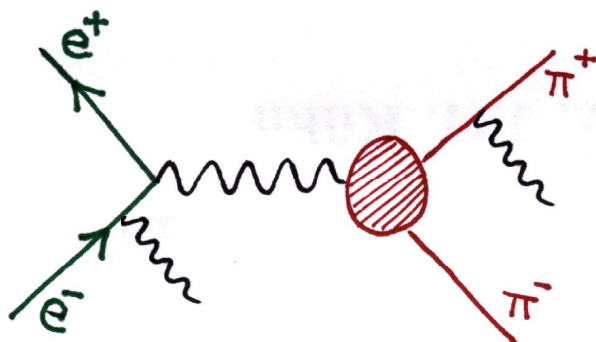


Contribution of **FSR(lo)** <1% for our selection cuts

Rad. corr.: FSR (LO+NLO)

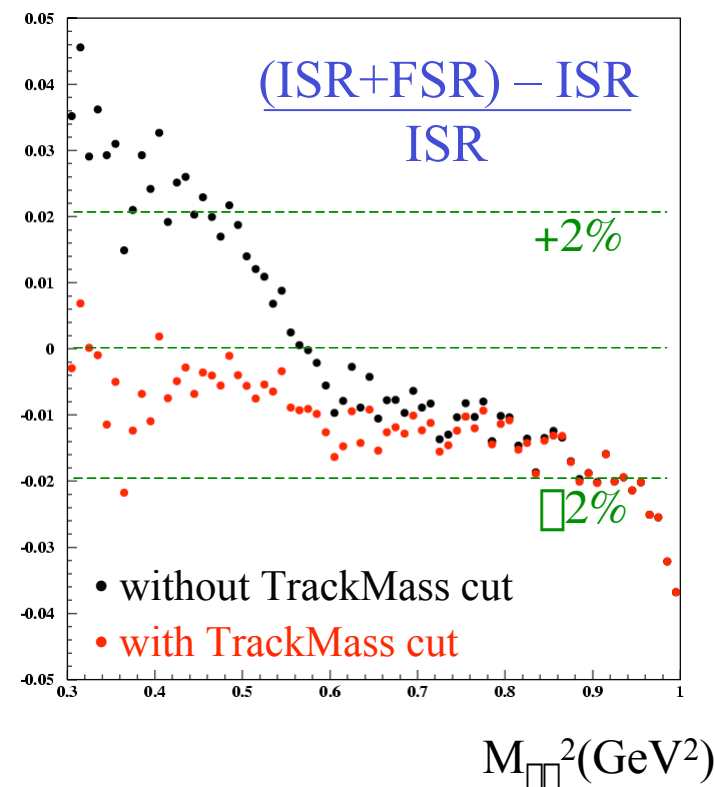


Just recently we got a **new version of Phokhara** which also simulates events with the **presence of 1 ISR- and 1 FSR-photon**:

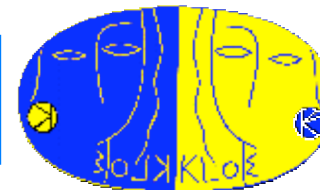


A preliminary check shows that **the FSR contribution is at most 1-2%**.

As of now, we *do not* apply any correction for FSR and add a **contribution of 2% to the systematic error**



Systematic error:



The **systematic error** is under **final evaluation!**
Contributions from:

Theory

– Radiator Function H	0.5%
– Vacuum Polarization	0.1%
– Luminosity	0.6%
TOTAL	0.8%

Experiment

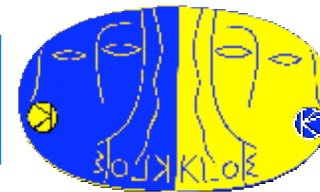
– Acceptance	0.3%
– Trigger	0.2%
– Tracking	0.3%
– Vertex	0.8%
– Rec. Filter	0.6%
– Likelihood	0.1%
– Track Mass	0.2%
– BKG subtr.	0.5%
– Unfolding	0.6%
TOTAL	1.4%

FSR 2.0%
□ < 1%

□ 1%

Systematic error can be reduced to • in a short time scale

Evaluation of a_μ :



We have integrated the bare cross section according to the dispersion integral in the energy range

$$0.37 < M_{\pi\pi}^2 < 0.92 \text{ GeV}^2$$

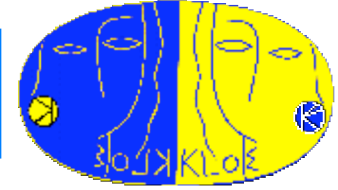
$$a_\mu^{\pi\pi} = \frac{1}{\pi} \int_{0.37}^{0.92} ds \cdot \sigma(e^+e^- \rightarrow \pi^+\pi^-) \cdot K(s)$$

KLOE Result:

$$a_\mu^{\pi\pi} / 10^{-10} = 374.1 \pm 1.1_{\text{stat}} \pm 5.2_{\text{syst}} \pm 3.0_{\text{theo}} (+7.5_{-0.})_{\text{FSR}}$$

FSR corrections for KLOE must be refined with the [new version of Phokhara MC](#)

Conclusions:



- Using **initial state radiation** as a means to measure the cross section for $e^+e^- \rightarrow \mu^+\mu^-$ from threshold to the full collider energy has been proven very effective
- **Analysis almost finished:**
Final checks, especially on **Final State Radiation Correction**
- **Next Steps:**
 - publish final results
 - study events at large photon angles to access lower $M_{\mu\mu}^2$ regions
 - use $\mu\mu\mu$ events for cross checking vacuum polarisation, FSR and additional ISR effects