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

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(for the KLOE collaboration)

Workshop on

e^+e^- in the 1-2 GeV range

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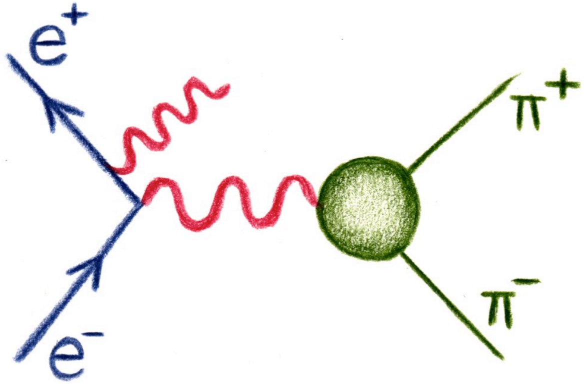
$\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ with ISR:

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



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

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

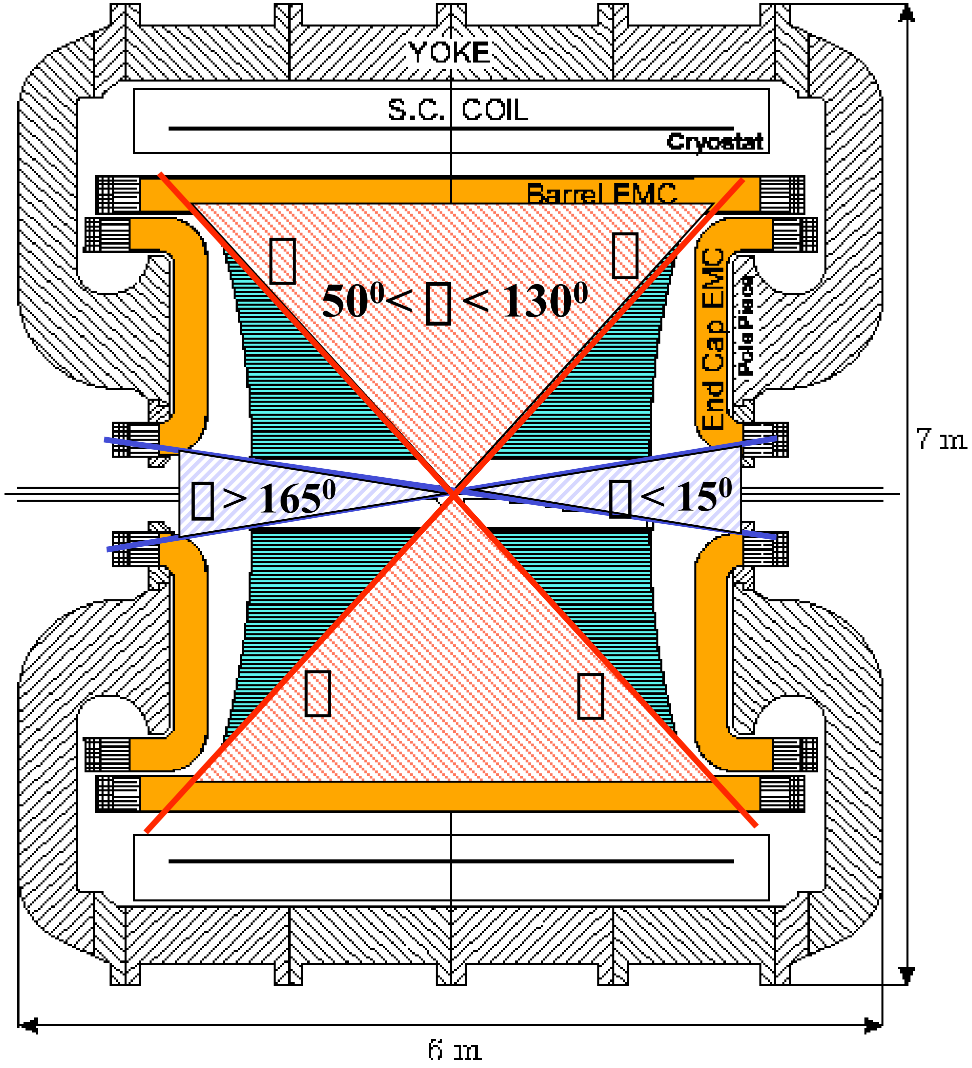
Photons are required to be within
$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

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

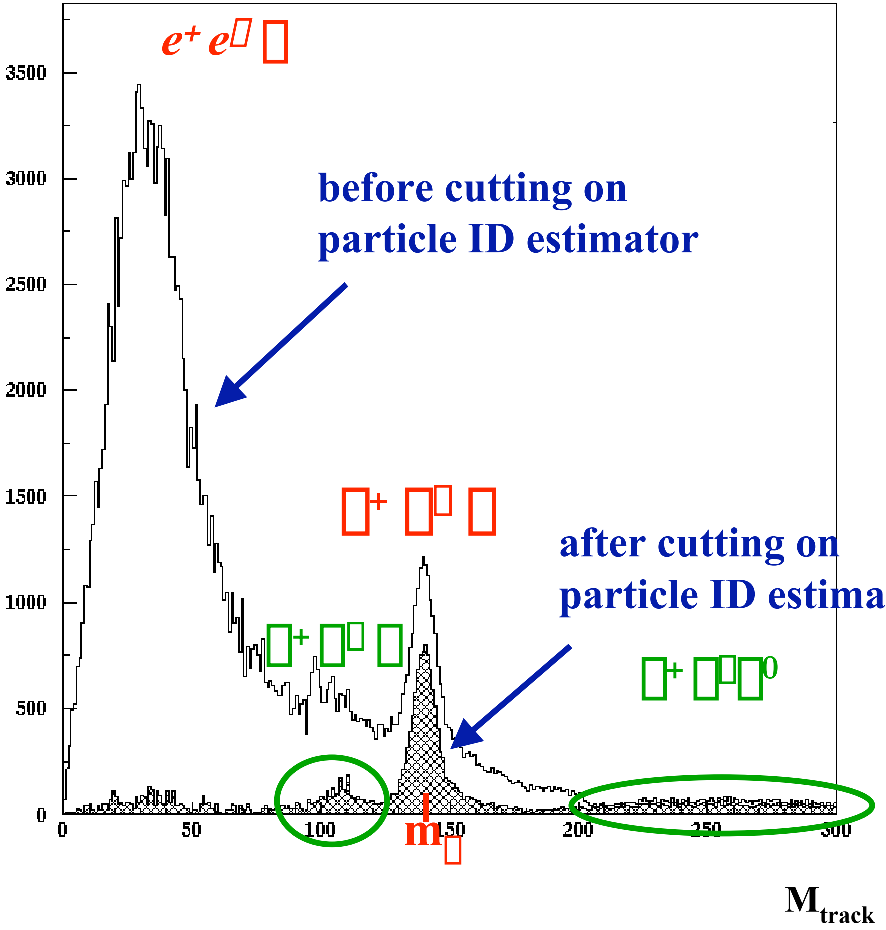


Background rejection:

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

- 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.



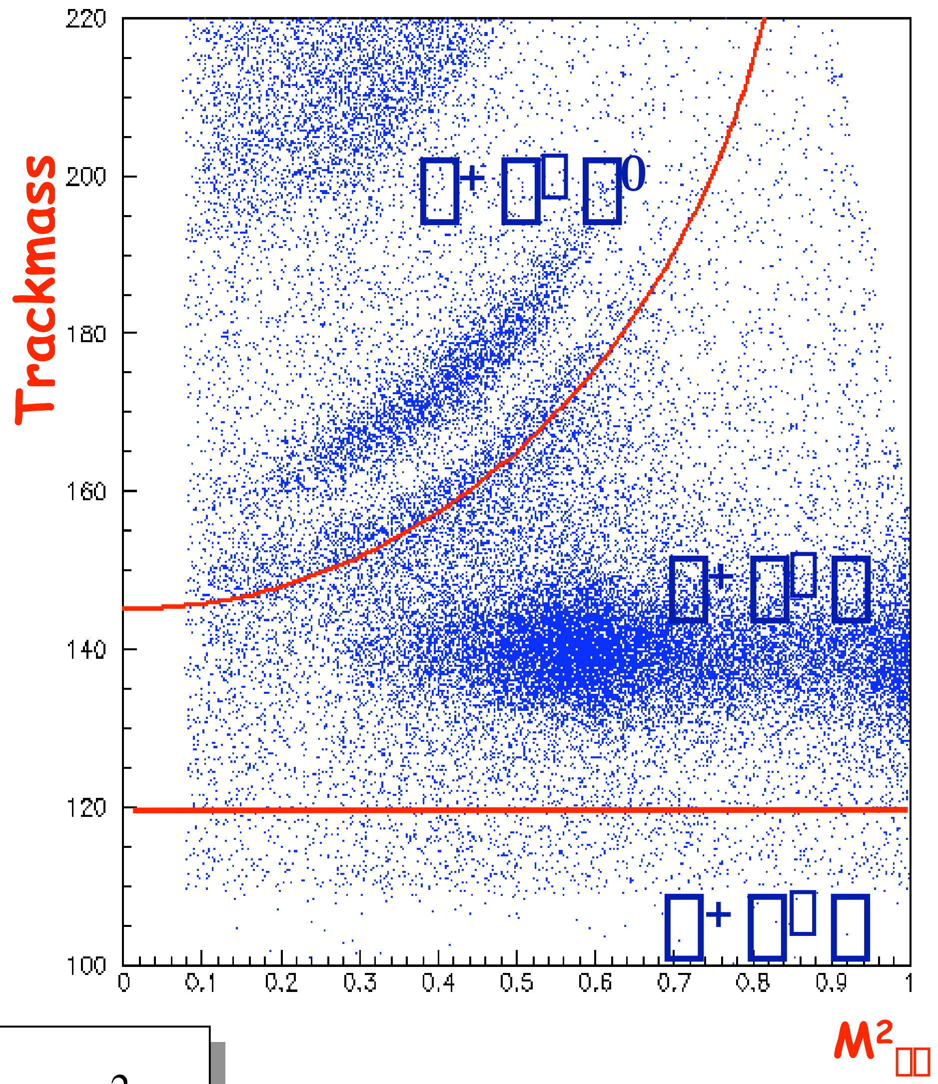
before cutting on particle ID estimator

after cutting on particle ID estimator

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**

$\mu^+\mu^-\gamma$ background ($M_{track} \approx 105$ 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}:

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

$M_{\pi\pi}^2$- 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 GeV²

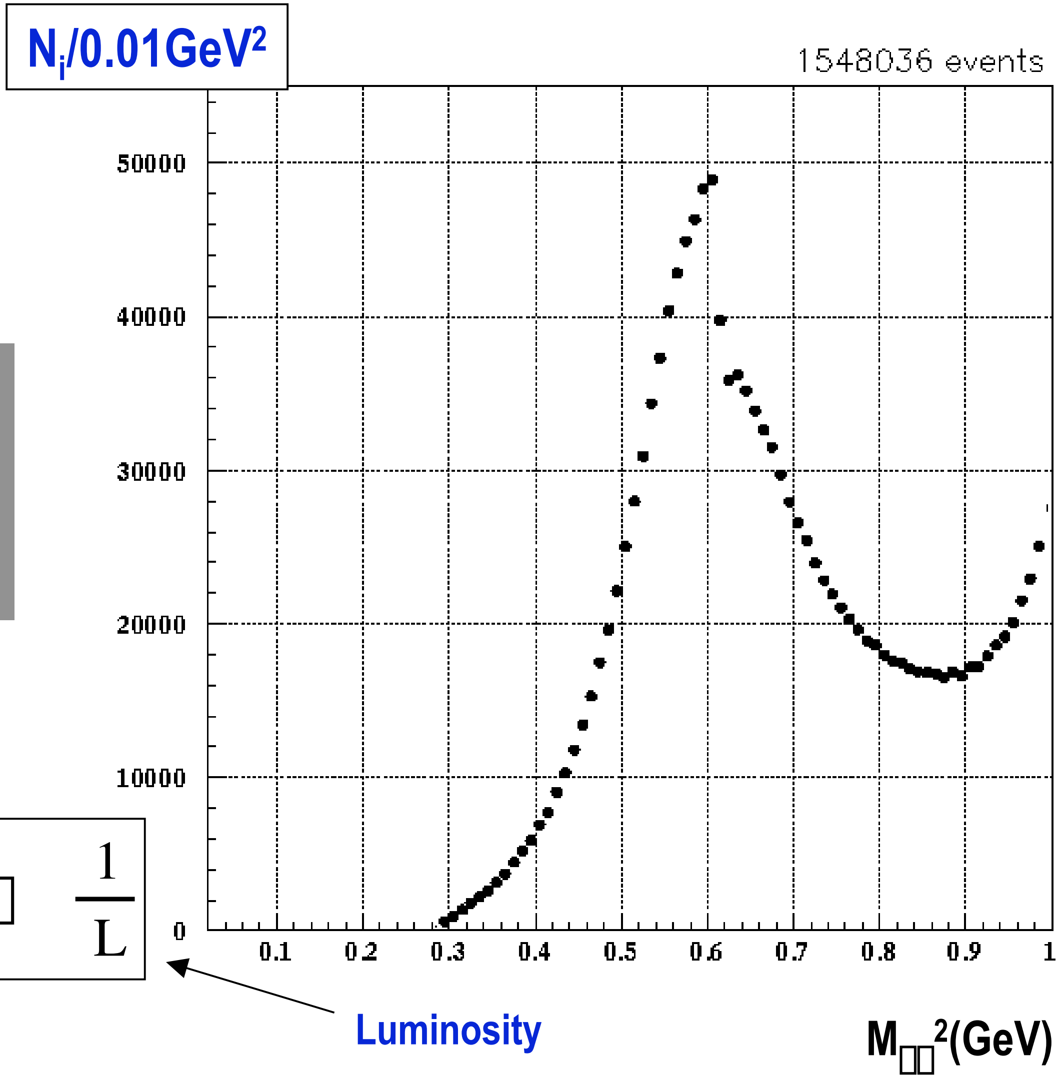
Signal

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

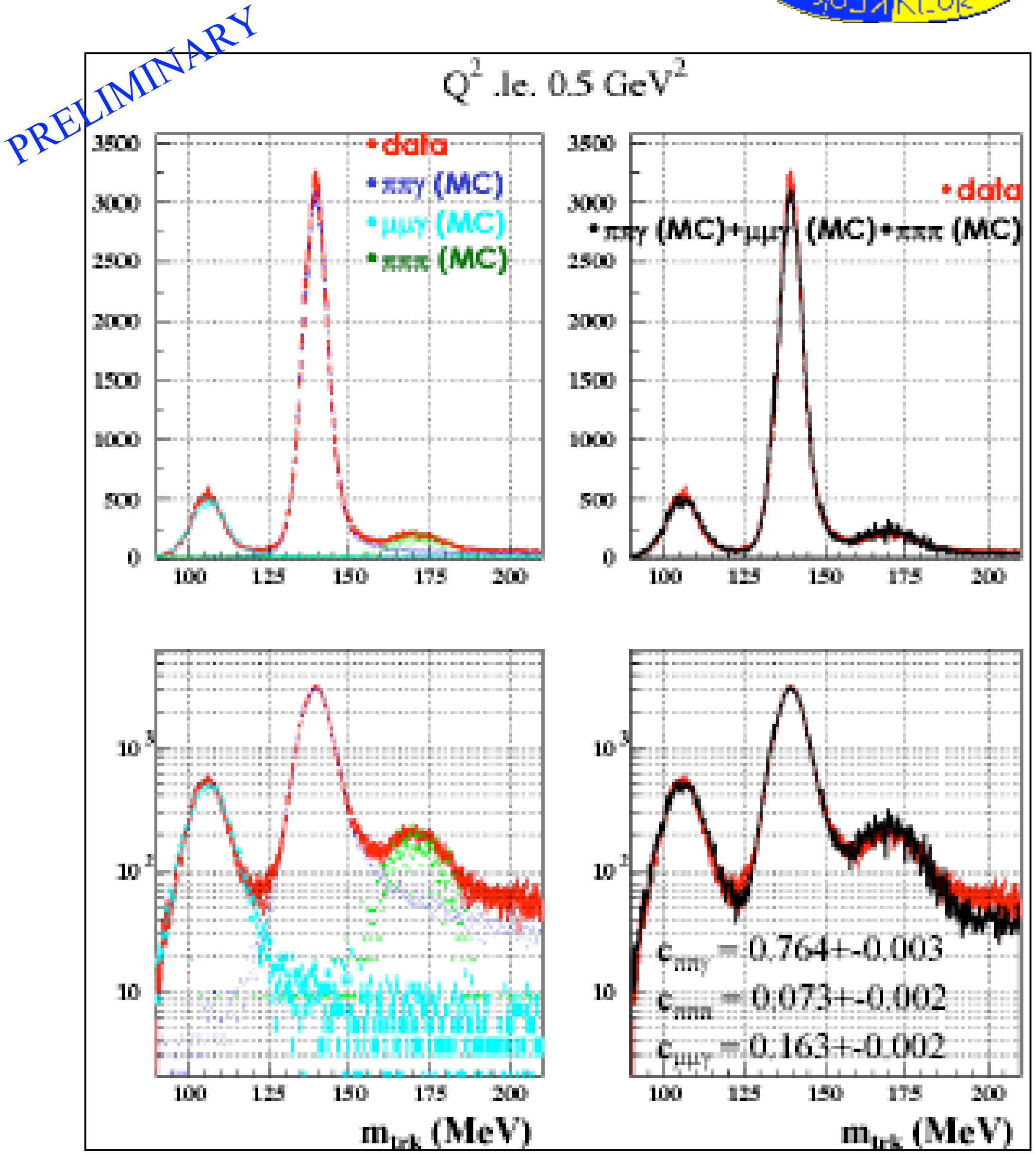


Acceptance: $\theta_{\pi\pi}$<15° ($\theta_{\pi\pi}$ >165°), 50°<θ_{π}<130°, $E_{□}$>10 MeV

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: $55^o<\theta_e<135^o$
- 2 independent generators used for radiative corrections:
  - BABAYAGA (Pavia group): $\sigma_{eff} = (428.8\pm0.3_{stat})$ nb
  - BHAGENF (Berends modified): $\sigma_{eff} = (428.5\pm0.3_{stat})$ 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	0.3 %
Background ($\mu\mu\gamma+\pi\pi\gamma$)	0.1 %
Trigger+Track+Clustering	0.2 %
Knowledge of $\sqrt{s}$ run-by-run	0.1 %
TOTAL 0.5 % theory $\oplus$ 0.4% exp = 0.6 %	

Efficiencies:

Trigger

including Cosmic Veto Eff.

Reconstr. Filter

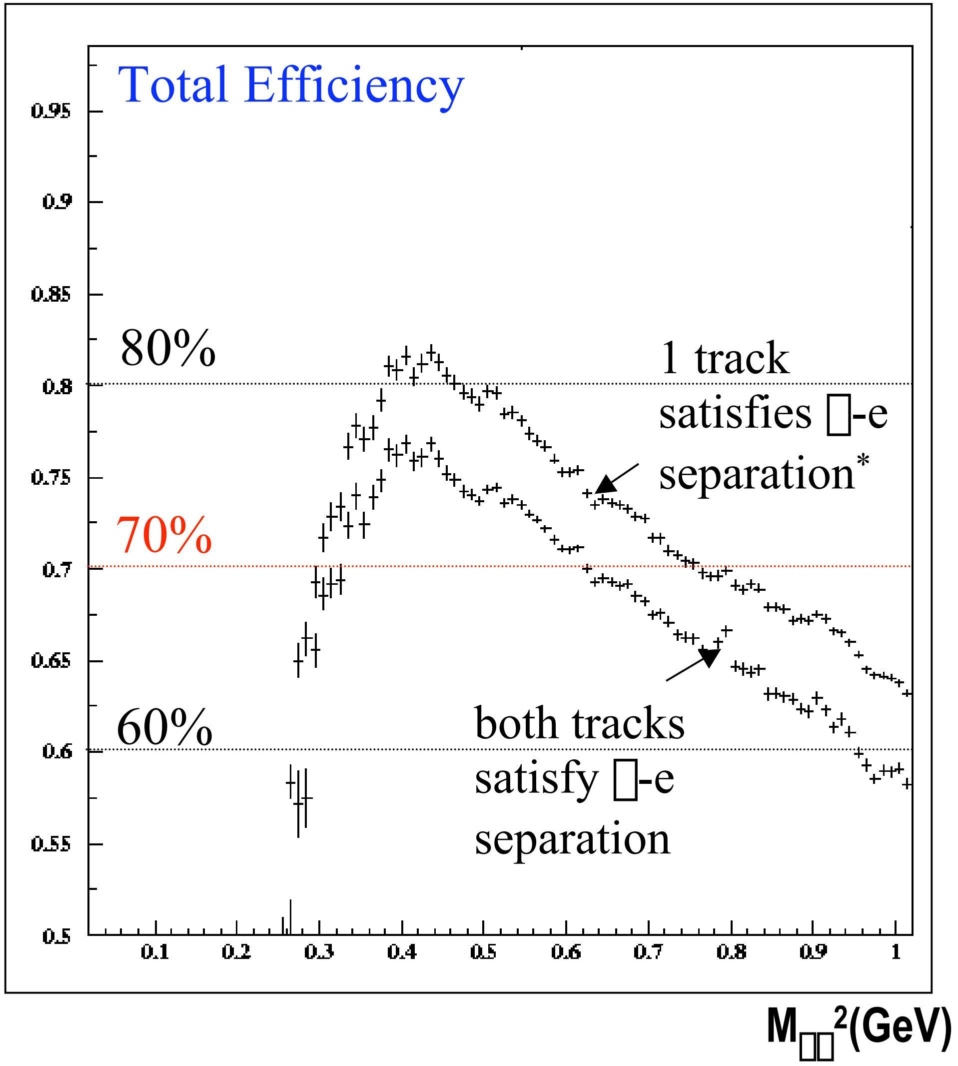
Tracking / Vertex

π-e separation

Trackmass

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

red = estimated from MC and compared with data



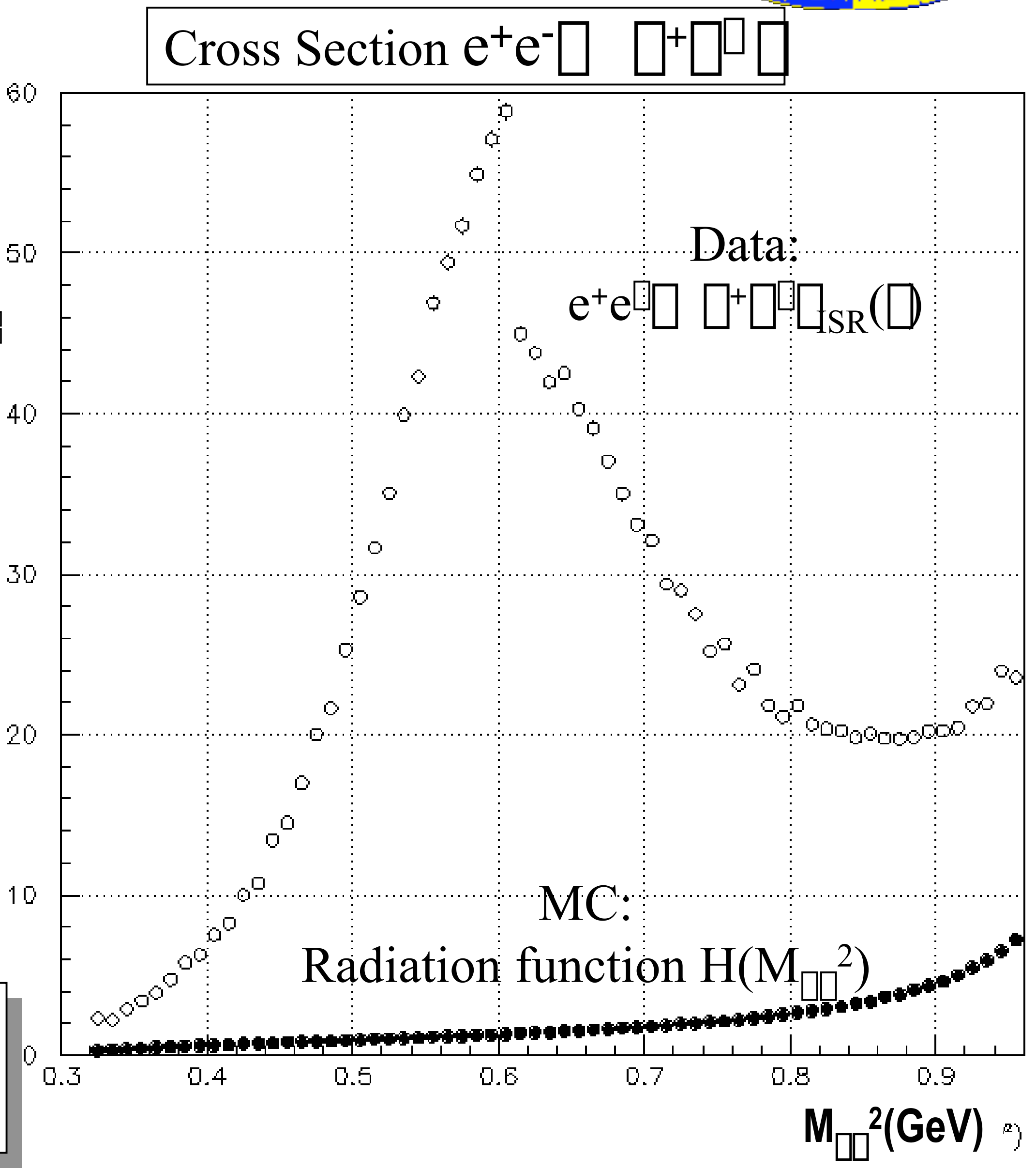
* used in this analysis

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

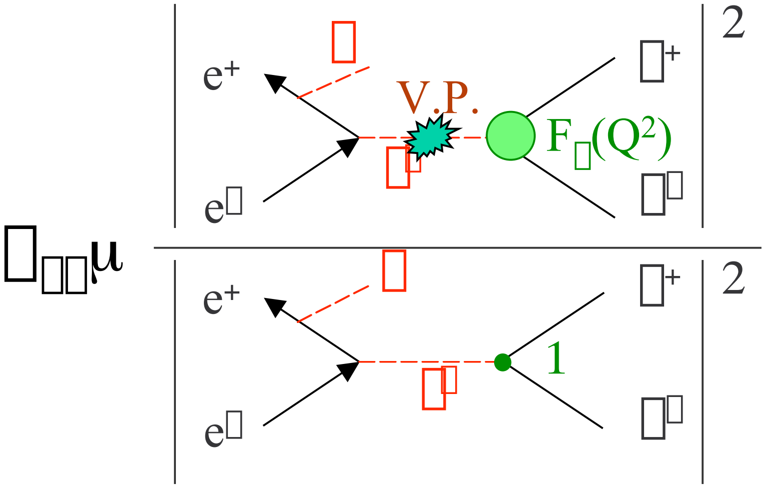
After subtracting the residual background, correcting for efficiencies, dividing for luminsity and unfolding the detector resolution, we arrive to **$\sigma(e^+e^- \to \pi^+\pi^-\gamma)$** in bins of **$M_{\pi\pi}^2$**

To get the cross section for **$e^+e^- \to \pi^+\pi^-$** 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 $F_\pi = 1$:**

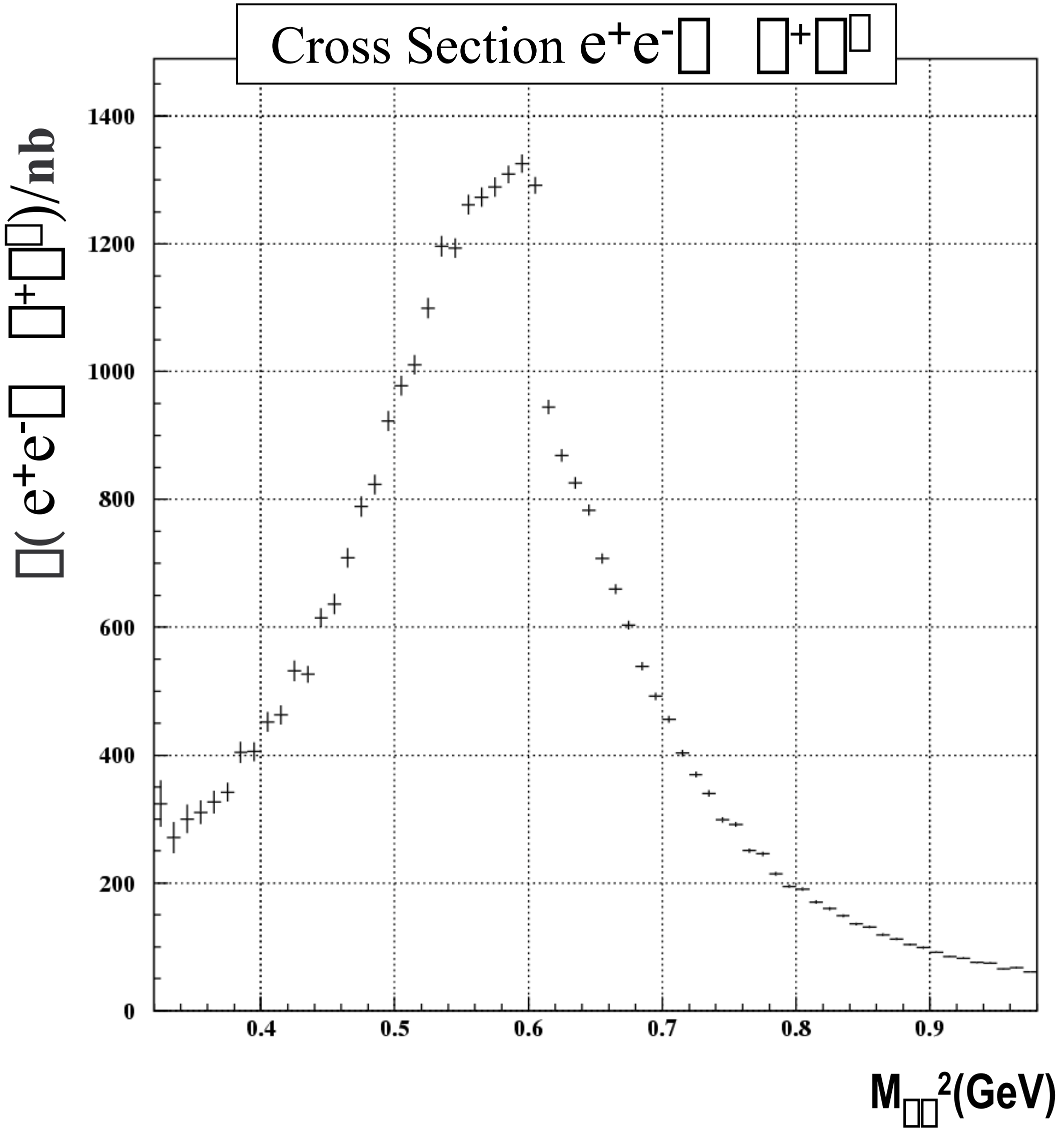
$$\sigma_{\pi\pi} \quad \left|F_\pi(M^2_{\pi\pi})\right|^2 = \frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{d\sigma_{\pi\pi\gamma,F_\pi=1}(M^2_{\pi\pi})}$$


Cross Section $e^+e^- \to \pi^+\pi^-\gamma$

$\square(e^+e^-\square\ \square^+\square^\square)$:



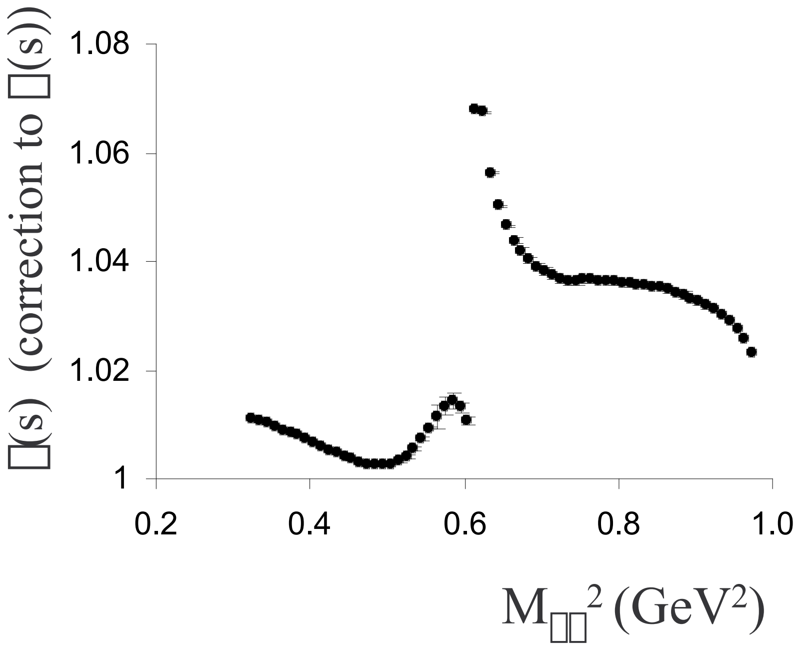
After dividing by the radiation function $H(M_{\square\square}^2)$, one gets the cross section $\square(e^+e^-\square\ \square^+\square^\square)$.



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

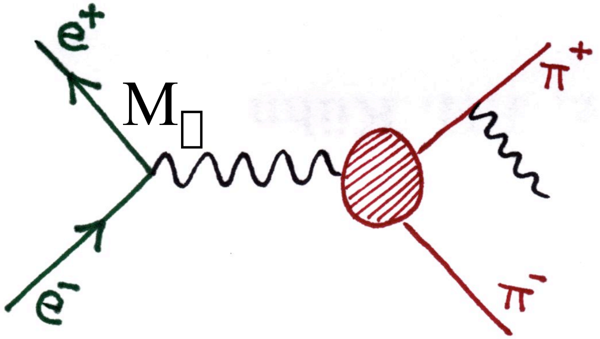
$$\delta(s) \quad \alpha^2(s) = \left[\frac{\alpha_0}{1 - \Delta\alpha_{lep}(s) - \Delta\alpha_{had}(s)}\right]^2 \equiv \delta(s)\cdot\alpha_0^2 \qquad \sigma_{bare}(s)$$



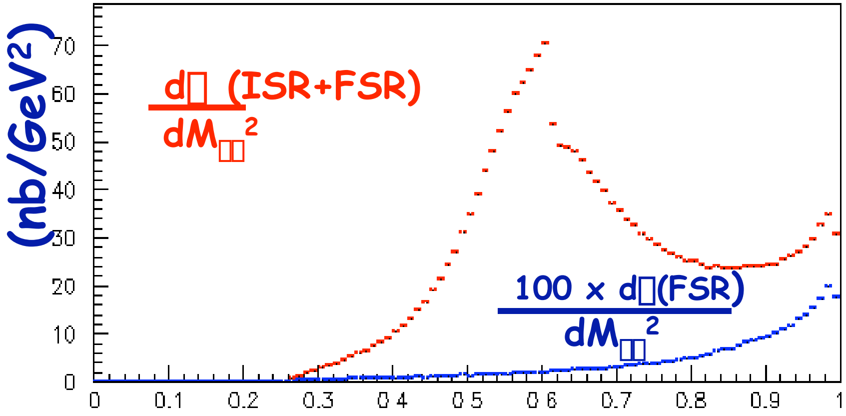
Rad. corrections: FSR (LO)

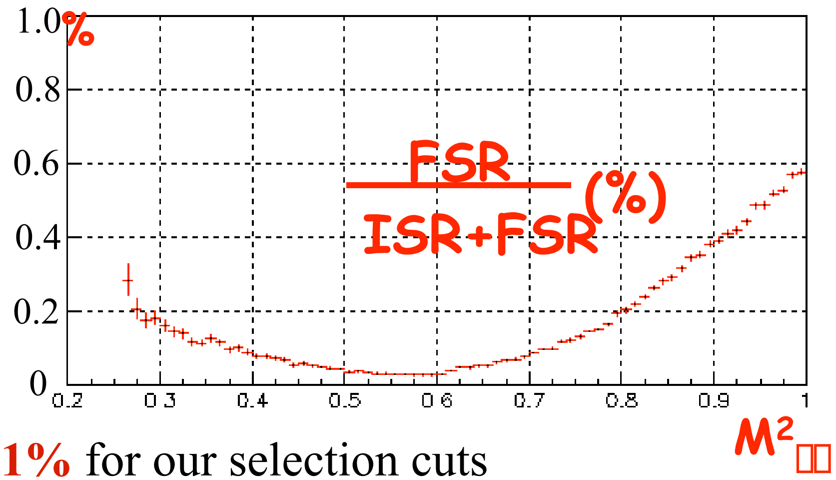
The cross section has to be corrected with respect to Final State Radiation (FSR).

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



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

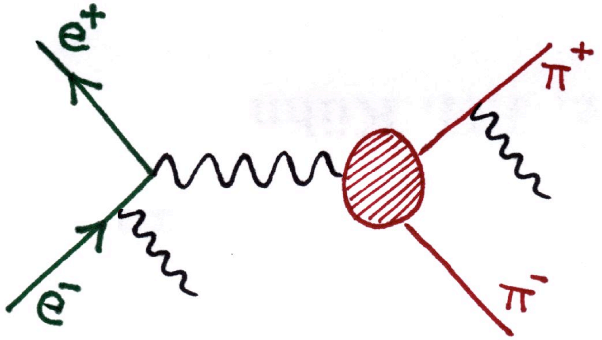


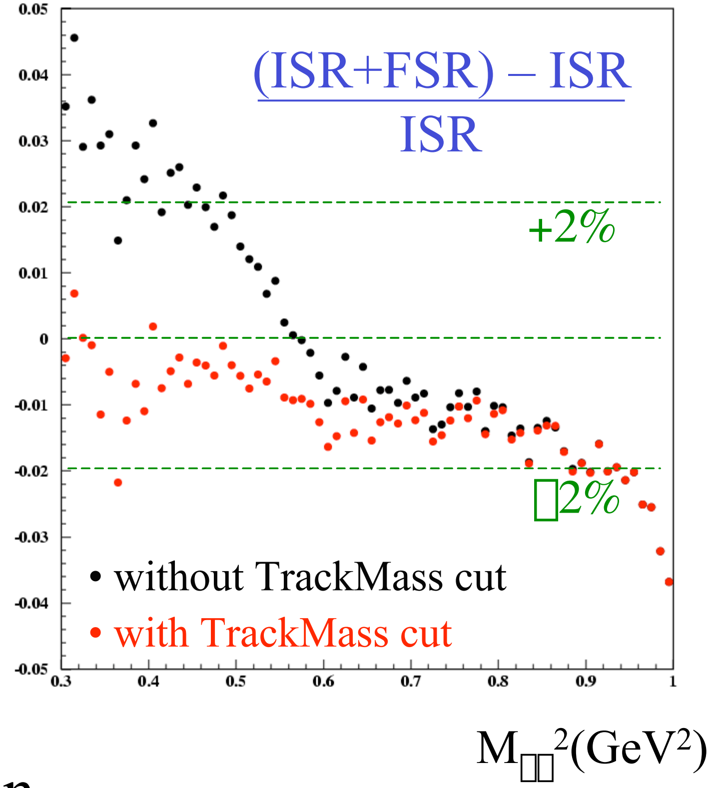


Contribution of **FSR(lo) <1%** for our selection cuts

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%**

FSR 2.0%

□ < 1%

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%**

□ 1%

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

Conclusions:

- Using initial state radiation as a means to measure the cross section for e^+e^-□ □$^+$□$^{□}$ 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 $M_{□□}^2$ regions
  - use □□□events for cross checking vacuum polarisation, FSR and additional ISR effects