Measuring hadronic cross section at KLOE

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Hadronic contributions to the anomalous magnetic moment of the muon

Marseille, March 14th- 16th, 2002

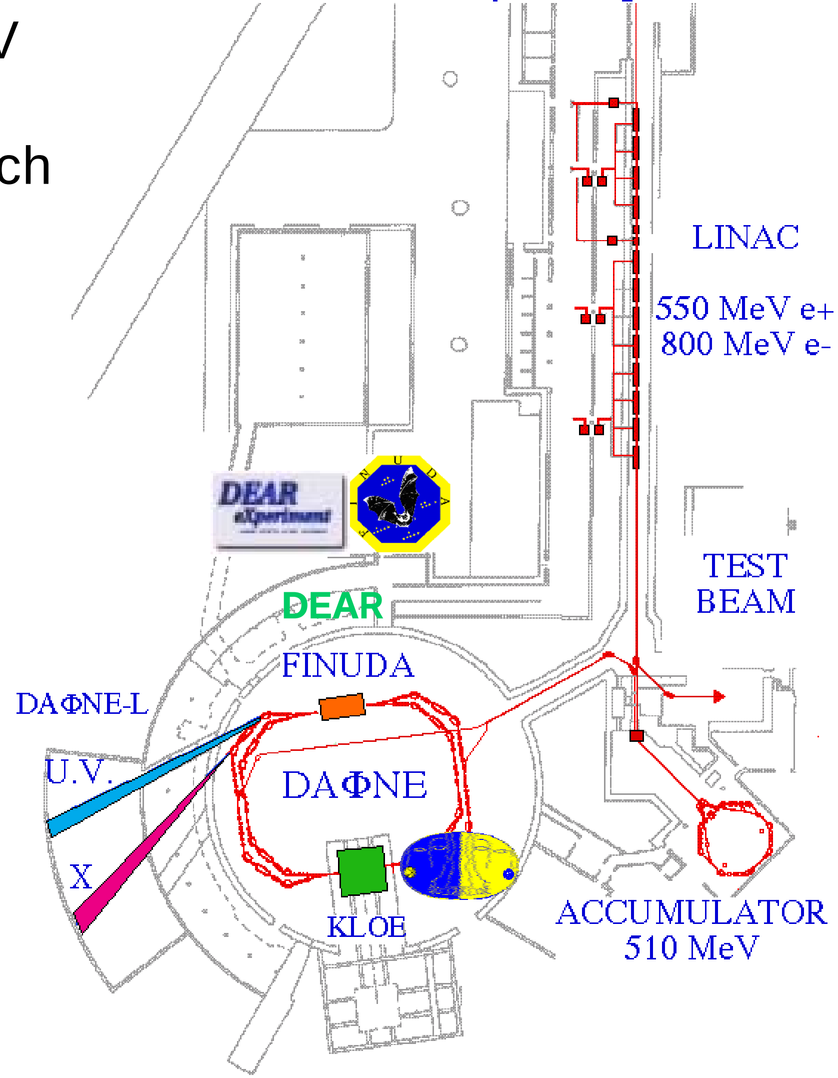
KLOE at DAϕNE

(**D**ouble **A**nnular ϕ-Factory for **N**ice **E**xperiments)

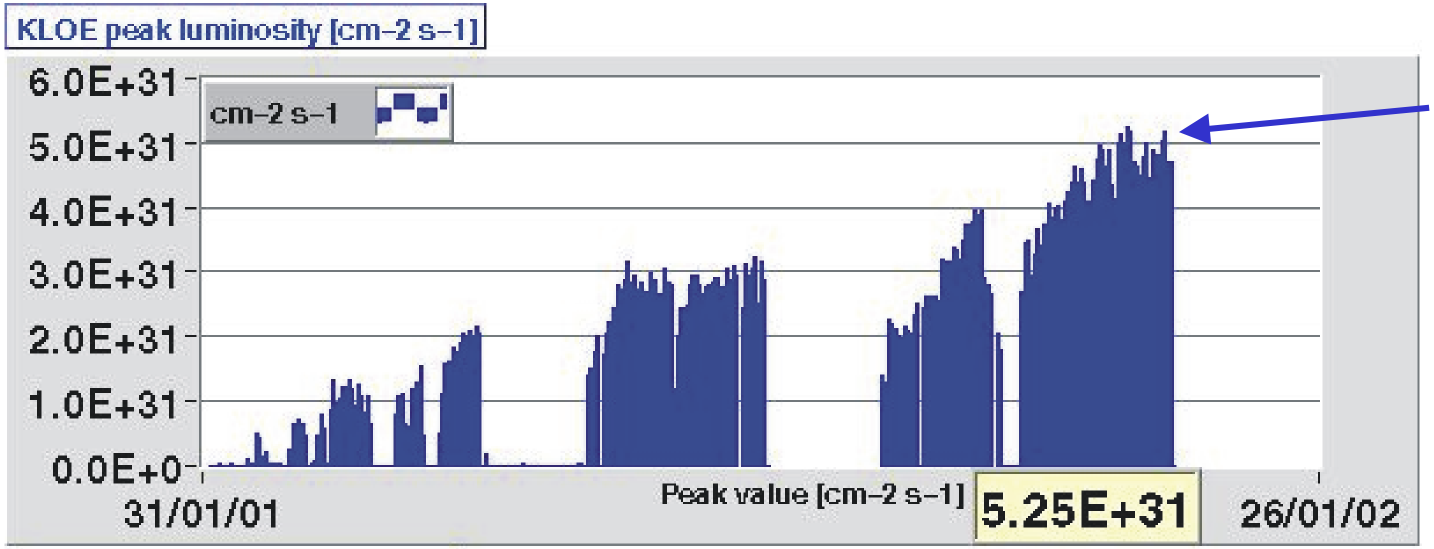
- e^+e^- - collider with $\sqrt{s}=m_\Phi\approx 1.020$ GeV
- two separate rings to minimize beam-beam-effects allowing multibunch
- accumulator for efficient injection into main rings
- two interaction points: KLOE and DEAR/FINUDA

BR's for selected ϕ decays	
K^+K^-	49.1%
K_SK_L	34.1%
$\rho\pi+\pi^+\pi^-\pi^0$	15.5%

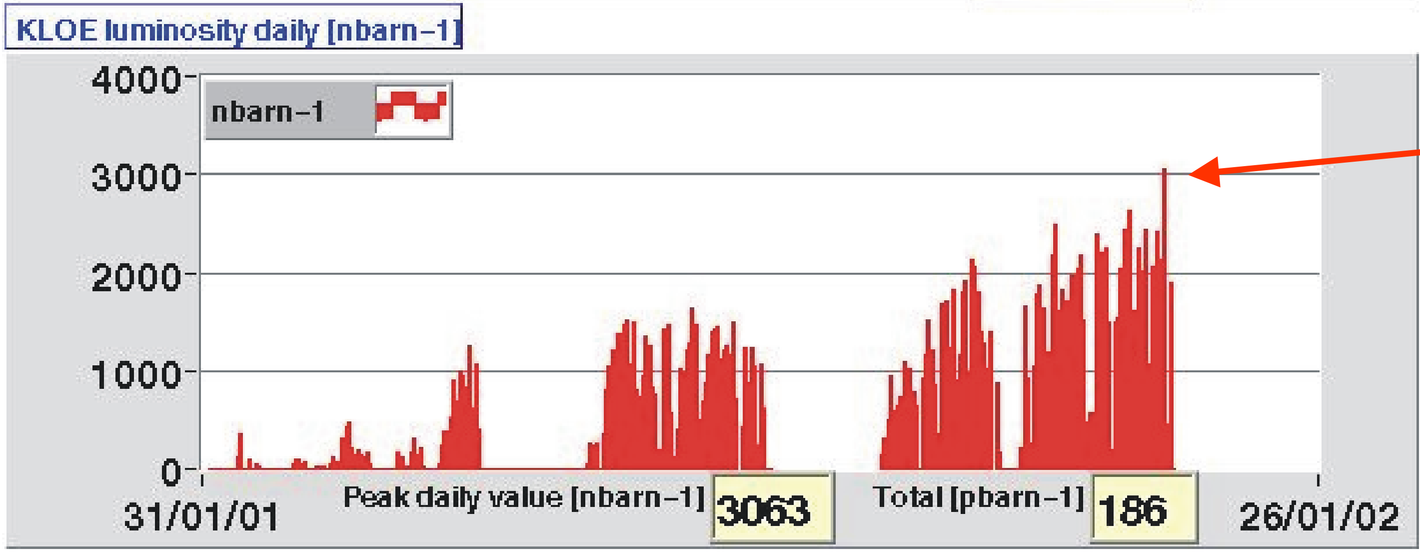
Frascati Φ–Factory complex



DAΦNE achievements

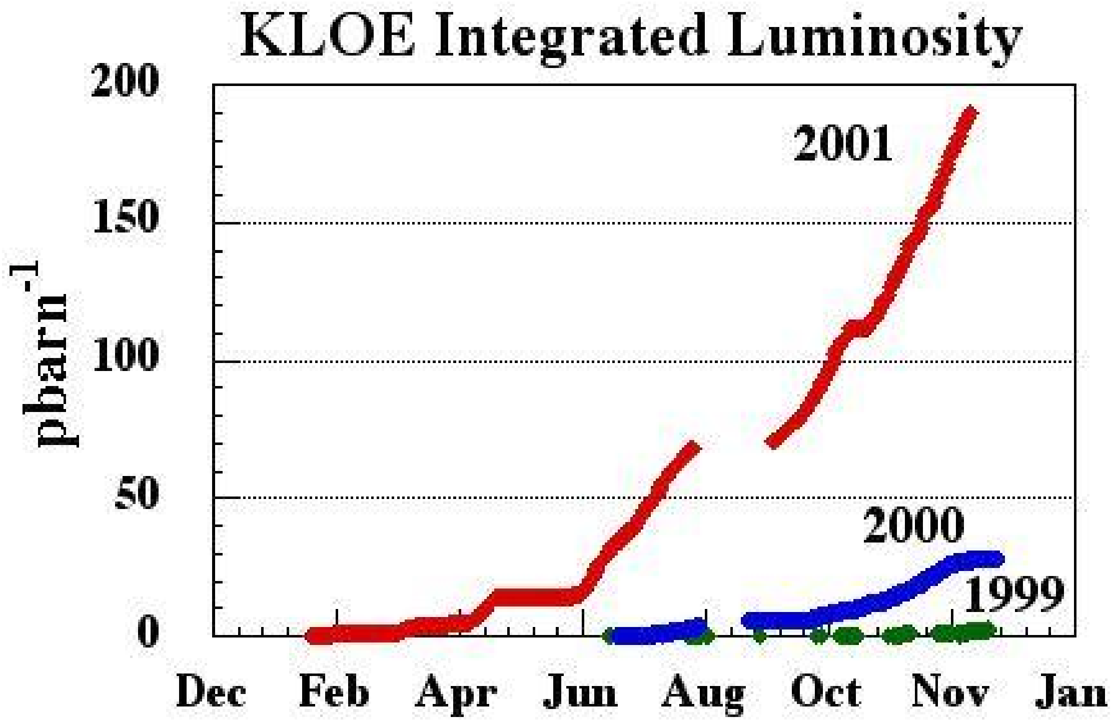


Max Instantaneous Luminosity:
5.25·10^{31} cm^{-2}s^{-1}



Best Daily average Luminosity:
~3 pb^{-1}/day

DAΦNE achievements

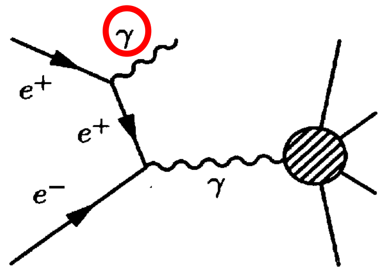


1999: 3 pb^{-1}
2000: 25 pb^{-1} ***preliminary analysis***
2001: 175 pb^{-1}
2002: …from April to August

But no energy scan foreseen…

The radiative return method*

☺Initial state radiation (ISR) can reduce the energy of the e^+e^- system (E_{CM}):



Look at the process $e^+e^- \to \pi^+\pi^- + n\gamma\ (+\ e^+e^-)$:

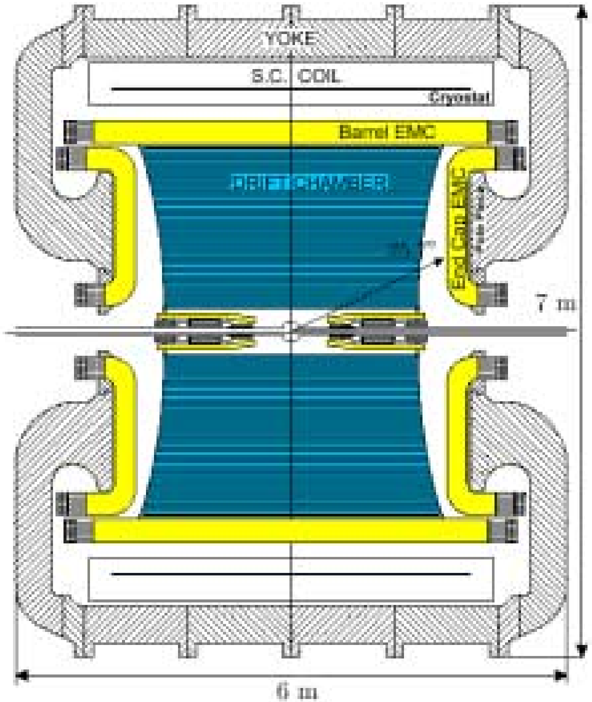
- The energy of the e^+e^- system changes continuously in the range $2m_\pi < E_{CM} < M_\phi$
- $d\sigma(e^+e^- \to \pi\pi + ?)\ /dM^2_{\pi\pi}$ is related to $d\sigma(e^+e^- \to \pi^+\pi^-, E_{CM})/d\,E_{CM}$

  ($M_{\pi\pi}^2$ invariant mass of the hadronic system)
- stat. error: ISR lower cross section, Daϕne high luminosity, KLOE excellent eff.
- systematical error: mostly different from energy scan measurements, FSR?

***S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999**

The KLOE detector

Lead/scintillating fiber
4880 PMTs
98% coverage of solid angle



4 m diameter × 3.3 m length
90% helium, 10% isobutane
12582/52140 sense/total wires
All-stereo geometry

σ_E/E 5.7% / $\sqrt{E(\mathrm{GeV})}$

σ_t 54 ps / $\sqrt{E(\mathrm{GeV})} \oplus$ 50 ps

(finite bunch-length contribution subtracted)

σ_p/p 0.4 %

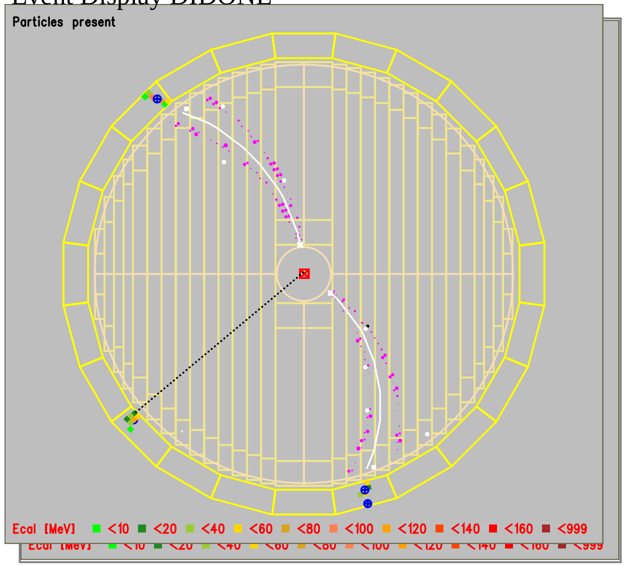
σ_{xy} 150 μm

σ_z 2 mm

$e^+ e^- \rightarrow \pi^+ \pi^- (+n\gamma)$ in KLOE

Look for events with two tracks coming from a vertex in the interaction region.

Event Display DIDONE



From pion momenta:

- $M^2_{\pi\pi}$
- $\vartheta_{\pi\pi}$ ($\equiv \vartheta_\gamma$ in case of only 1 γ but DC resolution is better than EMC one)

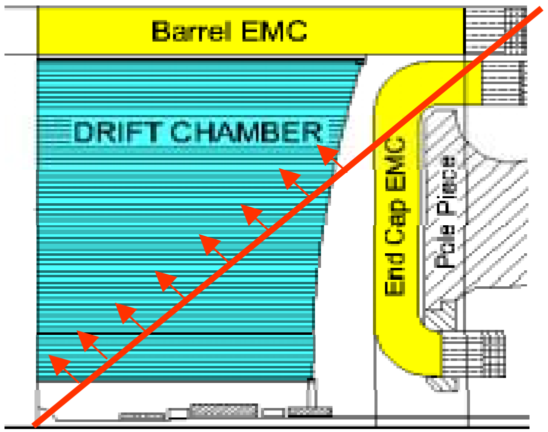
The photon(s) is not used!

(but can modify trigger efficiency)

To improve tracking efficiency, the two tracks are required to be in the central part of the detector:

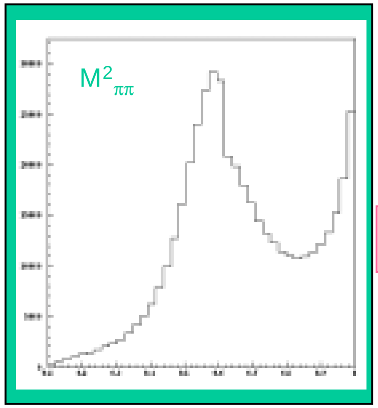
$40^o < \theta_{TRACK} < 140^o$

+condition on P_T



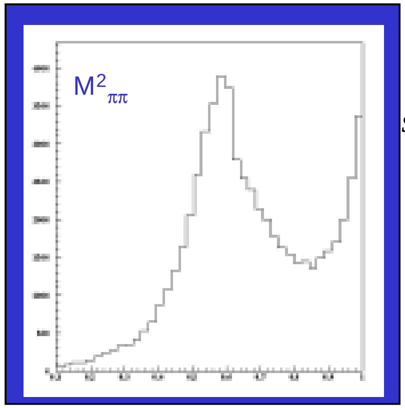
Tighter cuts are applied on one of the two tracks to make sure it reachs the calorimeter in the barrel. This **golden track** will be used for particle identification.

How to extract F_π from $\sigma_{e^+e^-\to\pi^+\pi^-+n\gamma}$?



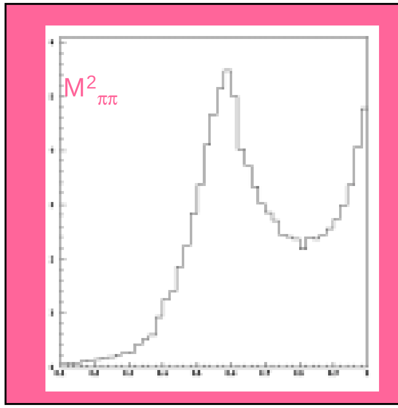
*1) MC generators**
(ISR, FSR, f_0,...):
π momenta ,
other detectable particles
(trigger eff. studies)

SMEARING matrix → *way I*



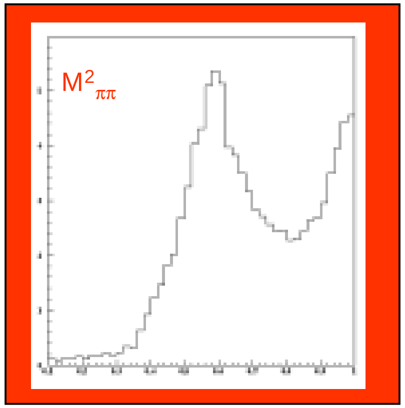
2) Detector simulation:
smearing due to the resolution
(Eva and Aφρωdite $O(\alpha)$ impemented)

SELECTION efficiencies →



3) Analysis cuts:
S/B optimization,
background evaluation

Integrated Luminosity from Bhabha scattering



4) DATA (after backgr. subtr.):
selection eff. from data control samples using MC kinematics

FIT → F_π

← *way II* ← **FIT**

*Eva: **S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999**
Phokhara: **G. Rodrigo, H. Czyz, J.H. Kühn, M. Szopa, hep-ph/0112184**
Aφρωdite: **A. Hoefer, F. Jegerlehner, J. Gluza, hep-ph/0107154**
KKMC: **S. Jadach, B.F.L. Ward, Z. Was, http://www.cern.ch/~jadach**

Main problems

•The $\pi\pi$ invariant mass ($M_{\pi\pi}$) can be lowered by the emission of γs from the pions instead of the electrons: FSR instead of ISR.
In presence of FSR the extraction of F_π from the $e^+e^- \rightarrow \pi^+\pi^-\gamma$ cross section is more tricky.

• Other processes can simulate a $\pi\pi$(+nγ) final state:

- $\phi \rightarrow \pi^+\pi^-\pi^0$: affects the low $M_{\pi\pi}^2$ region
- $\phi \rightarrow f_0\,\gamma \rightarrow \pi^+\pi^-\gamma$: affects only the high $M_{\pi\pi}^2$ region
- $e^+e^- \rightarrow e^+e^-\gamma$: requires particle identification
- $e^+e^- \rightarrow \mu^+\mu^-\gamma$: particle identification is harder because of the low momentum (but well calculable from theory)

The simplest case: small $\pi\pi$ angle, E_{miss}

SMALL ANGLE

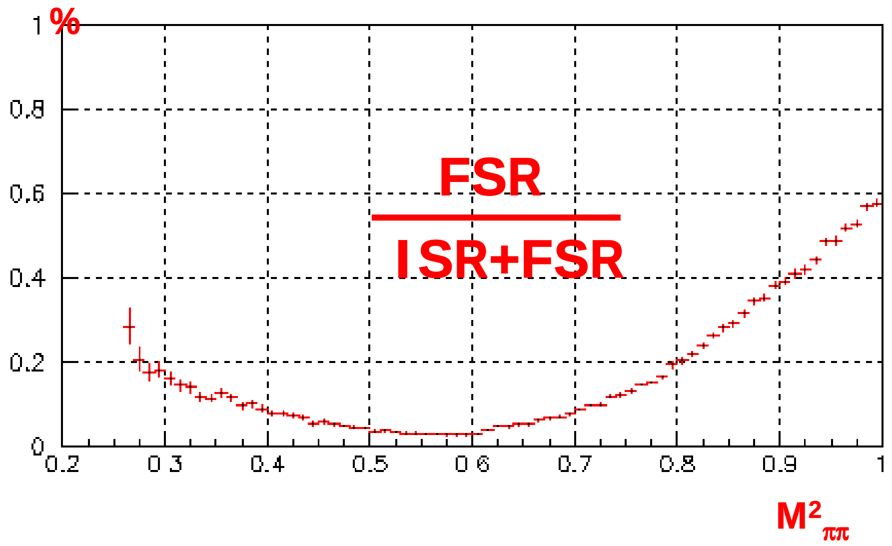
- ISR photons are mostly emitted collinear to the e^+e^- beams (*small angle*) while the FSR ones prefer the pion direction.

At leading order $\theta_{\pi\pi} = \theta_\gamma$ and then the cut:

$$\theta_{\pi\pi} < 15^o \text{ or } \theta_{\pi\pi} > 165^o$$

suppresses FSR

- Also $\pi^+\pi^-\pi^0$ background is suppressed



MISSING ENERGY

- FSR photons are mostly low energetic while high energy ISR photons are enhanced by the ρ resonance: a cut on

$$E_{miss} = M_\phi - E_{\pi+} - E_{\pi-} > 10 \text{ MeV}$$

suppresses FSR (and avoids vertices of collinear tracks!)

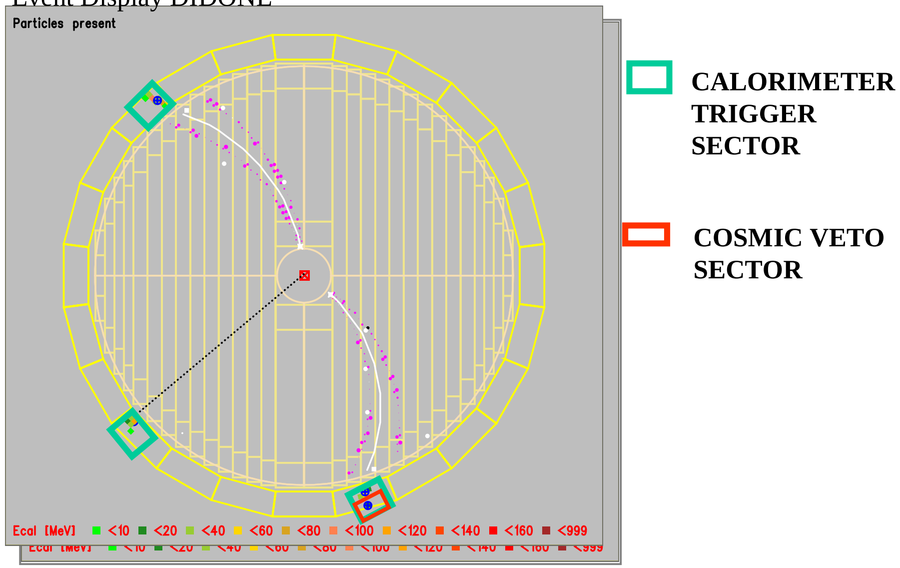
Steps of signal selection

- **Trigger** → *event is stored*
- **Offline background suppression** → *event is reconstructed*
- **Reconstruction efficiency** → *tracks reconstructed, vtx fitted*
- **Kinematic cuts** → *4-momentum conservation*
- **Particle identification (likelihood)** → $\pi^{\pm}$ *identified*
- **Specific $\pi^+\pi^-\pi^0$ suppression** → π^0 *found*

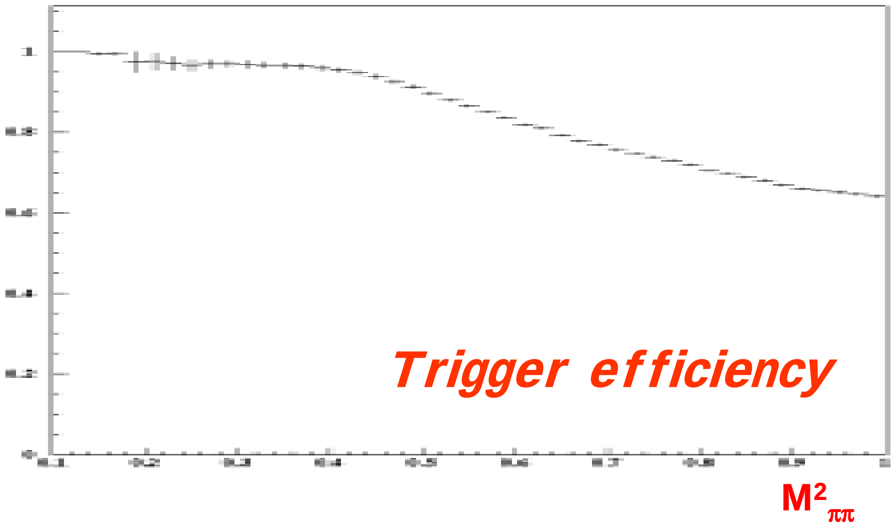
Trigger efficiency

For this kind of events the trigger is given by a ***calorimetric trigger*** *(2 energy deposits over threshold) AND a specific* ***Cosmic Veto*** *(2 energy deposits in the outer part of calorimeter).*

Event Display DIDONE



Trigger efficiency is studied composing the probability that one Trigger or Trigger Veto Sector is fired by the π^+, the π^- or by something else (photon or pileup).
This probabilities can be measured directly from data also using a reduced data sample in which the veto is switched off.
Systematic error coming from correlations is under study...



The effect of cosmic veto is dominant: in 2002 cosmic veto will be substituted with a much more efficient software trigger

Offline background suppression

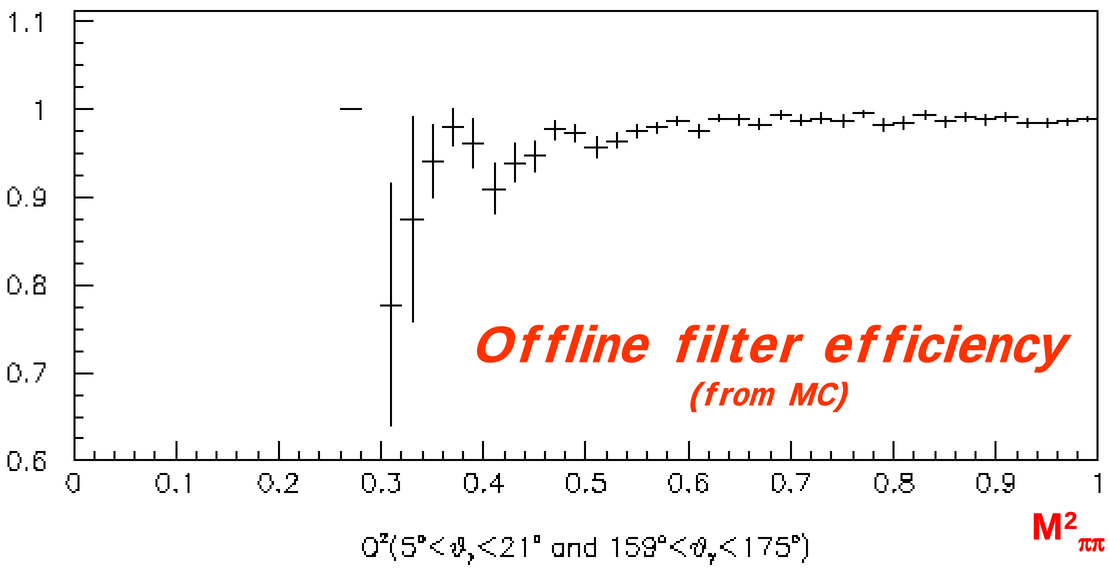
KLOE trigger (including a drift chamber trigger) has been designed to have an efficiency larger than 99% on kaon decays into $\pi\pi$ (*minimum bias trigger).*

Typical rates for an instantaneous luminosity of $5 \bullet 10^{31}$ $cm^{-2}s^{-1}$ are:

Machine background	~500-1000 Hz
Cosmic muons	~450 Hz
Bhabha scattering	~400 Hz
ϕ decays	~150 Hz
Small angle $\pi^+\pi^-\gamma$	~ 0.5 Hz

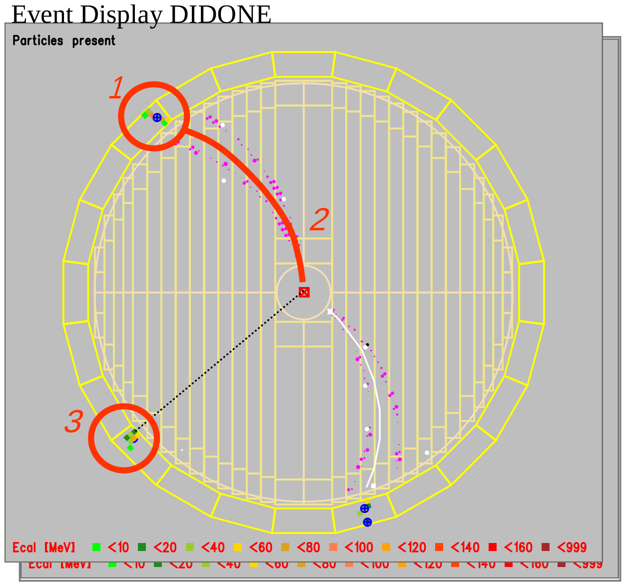
An offline filter reject inhibits event reconstruction for events of no physical interest saving CPU time and data tapes.

Unreconstructed RAW data are nonetheless saved.
The efficiency can be studied disabling the filter for a limited amount of data: ε=97-98%



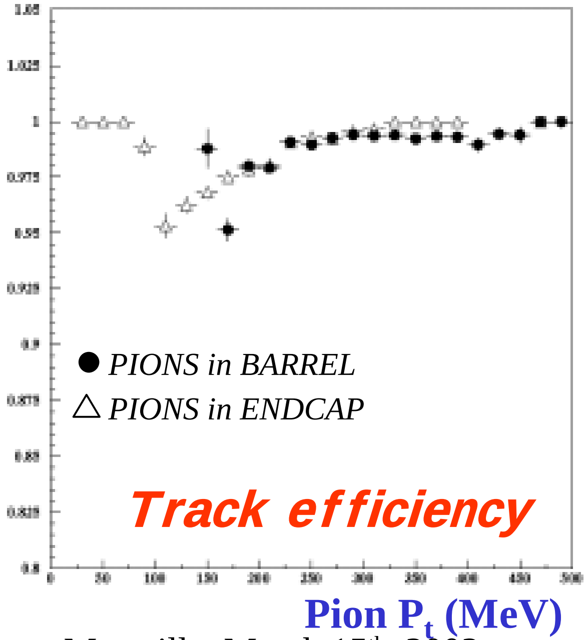
Track reconstruction efficiency

•The $\pi\pi\gamma$ **and** $\pi\pi\pi$ **events** are selected asking for *a cluster in barrel with E>300MeV* **[1]** and with a *track associated* **[2]** to it.



•The cluster+track must be recognized as a pion by the particle identification algorithm (likelihood).

•In the event there must be also **one or two prompt photons [3]**



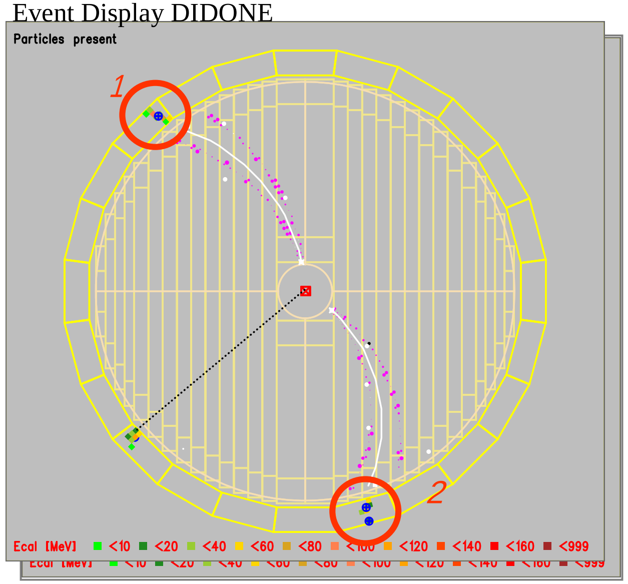
•The missing momentum determines the momentum of the second pion and allows to determine the track reconstruction efficiency as function of the pion momentum

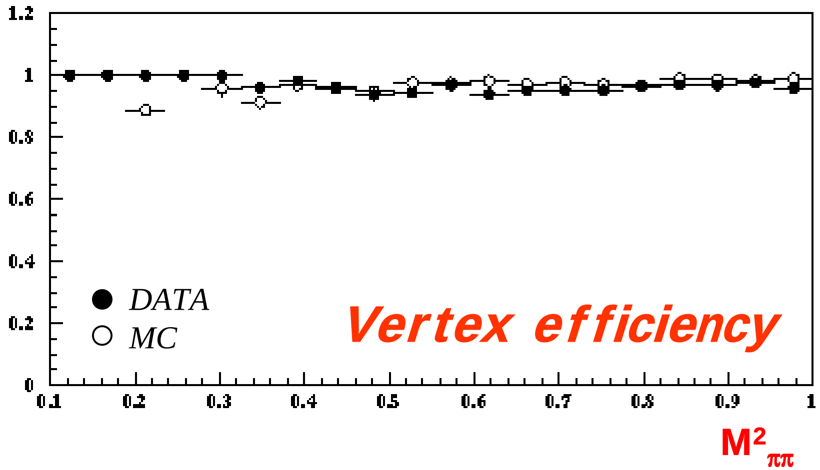
Vertex reconstruction efficiency

•It's studied using radiative Bhabha events ($e^+e^-\gamma$) selected using the calorimeter informations **[1,2]**.

•The vertex efficiency is calculated as function of the polar angle of the 2 tracks

Event Display DIDONE





•Using the momentum distribution for the two pions given by the generator, the efficiency as function of $M^2_{\pi\pi}$ is obtained.

Kinematic selection: "track mass"

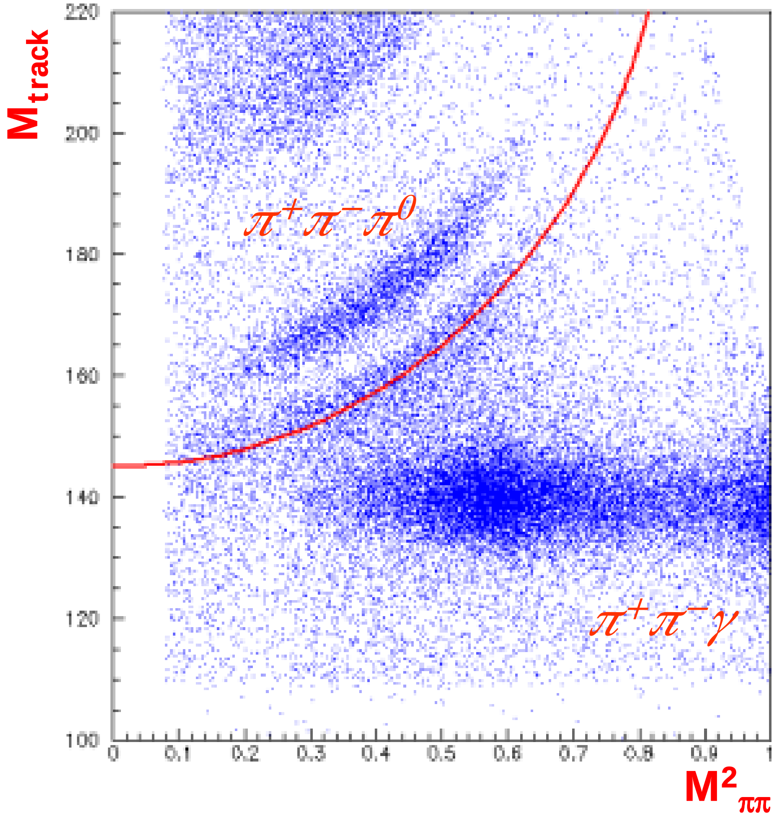
When only one photon is emitted the missing mass between the ϕ and the charged tracks (π, μ or e) is 0. Solving the equation, the mass of the charged particles (M_{track}) is obtained:

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

- The presence of a second photon produces a larger value of M_{track}

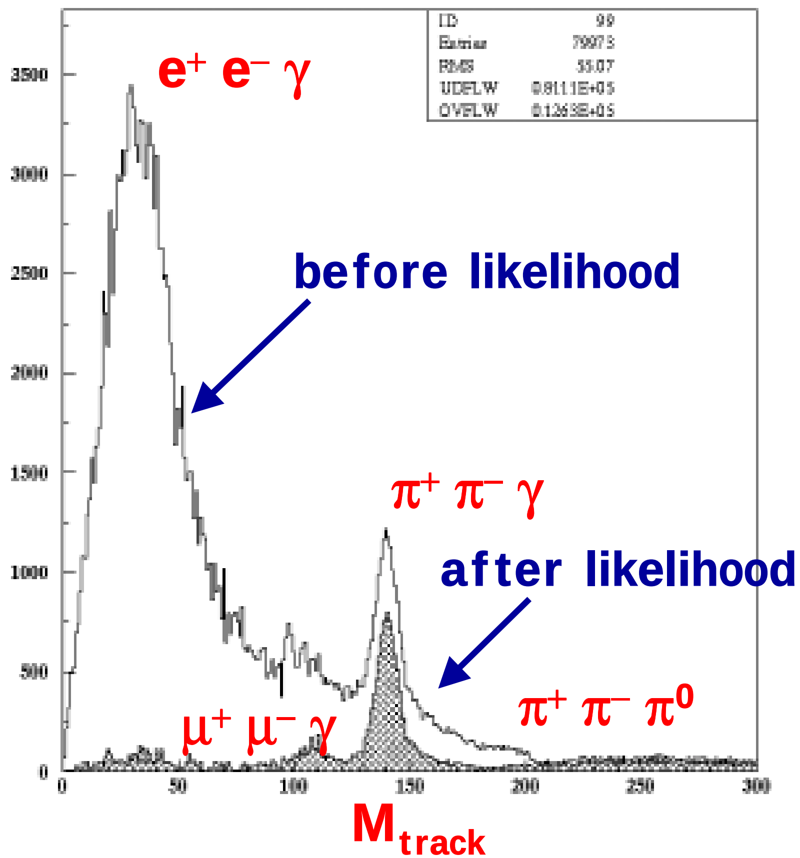
- The cut is applied in the (M_{track},$M^2_{\pi\pi}$) plane in order to preserve as much as possible the tails

- In the small $M^2_{\pi\pi}$ region the $\pi^+\pi^-\pi^0$ becomes more important and the cut is harder

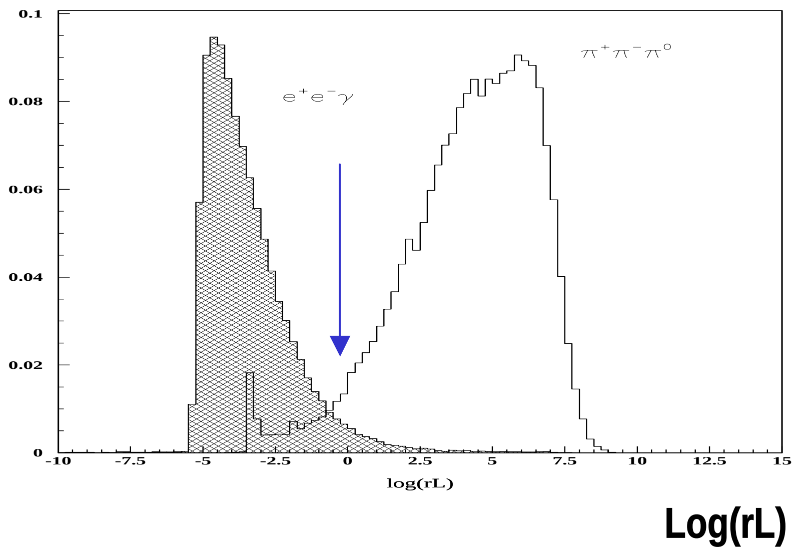


Particle identification (likelihood)

The **time of flight** and the **shape of the energy deposit in the electromagnetic calorimeter** are used to discriminate between pions and electrons by a likelihood function.



The likelihood function is built using two data sample: $e^+ e^- \gamma$ *and* $\pi^+ \pi^- \pi^0$



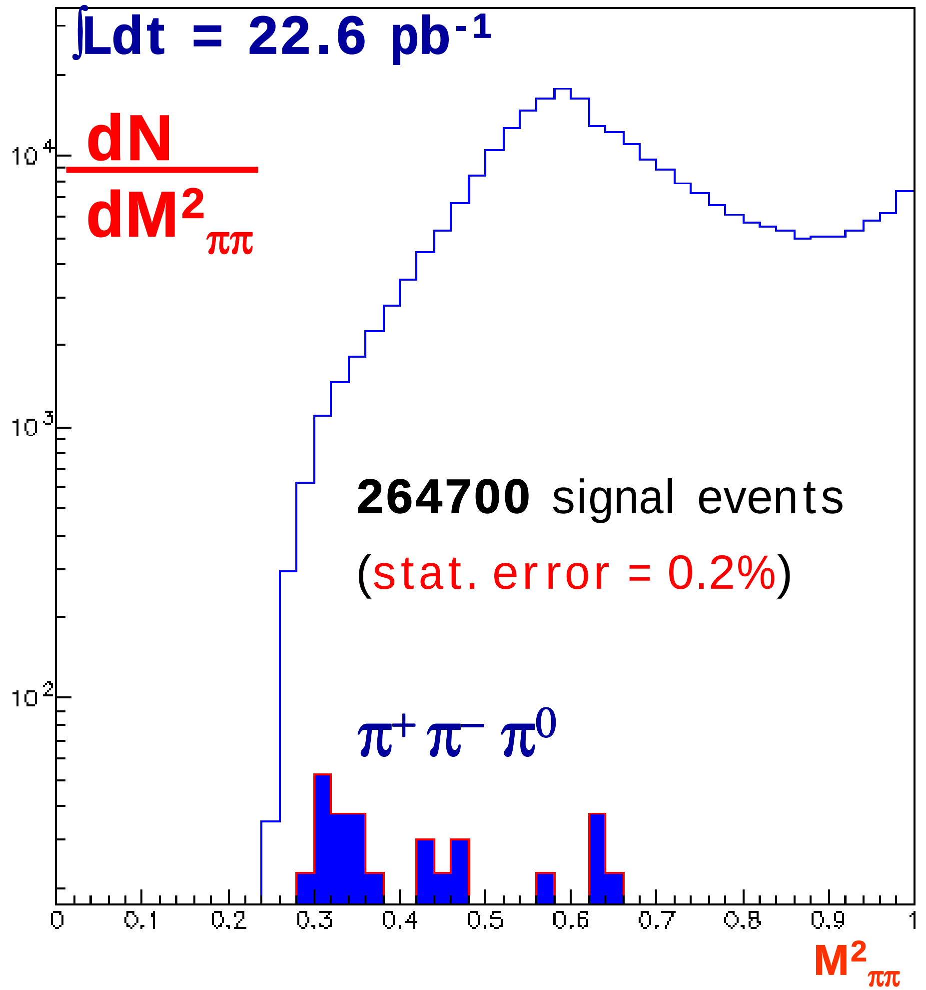
The selection efficiency is calculated using the kinematics for the $\pi^+ \pi^- (n) \gamma$ *given by the generator*

2000 Data at small angle

Final cut: the radiated photon is not used to select the signal, however, if two photons are detected, a cut on the total energy and on the relative angle of the two photons in the π^0 center of mass is used to reduce the already small $\pi^+ \pi^- \pi^0$ contamination

At the end:

- **265200** events are selected
- **490** background events are expected from MC



Luminosity measurement

In order to compare data and the Montecarlo prediction the integrated luminosity is needed…

Use Large Angle Bhabhas (σ_{eff} = 425nb):

- **$55° < \theta_{+-} < 125°$**
- **Acoll. $< 9°$**
- **$E_{+-} \geq$ 400 MeV**

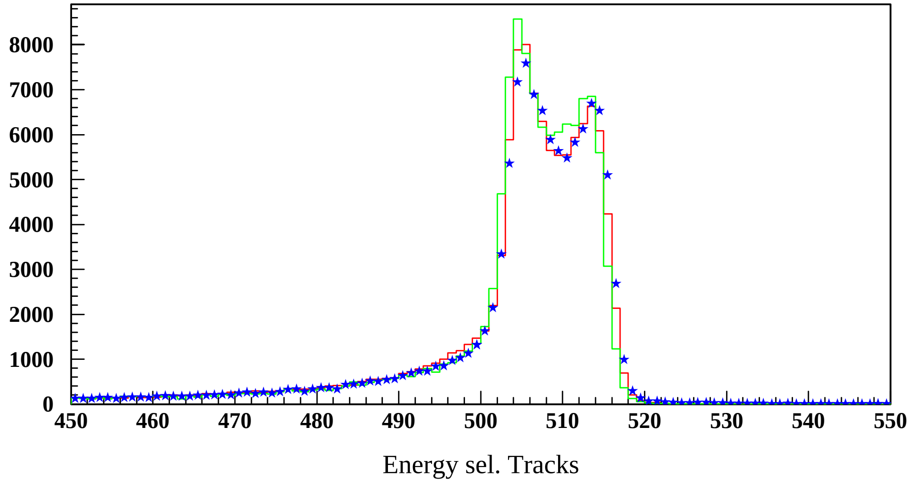
$$\int L dt = \frac{N_{LAB}(\Theta)\cdot(1-\delta_{Background})}{\sigma^{MC}_{LAB}(E)}$$

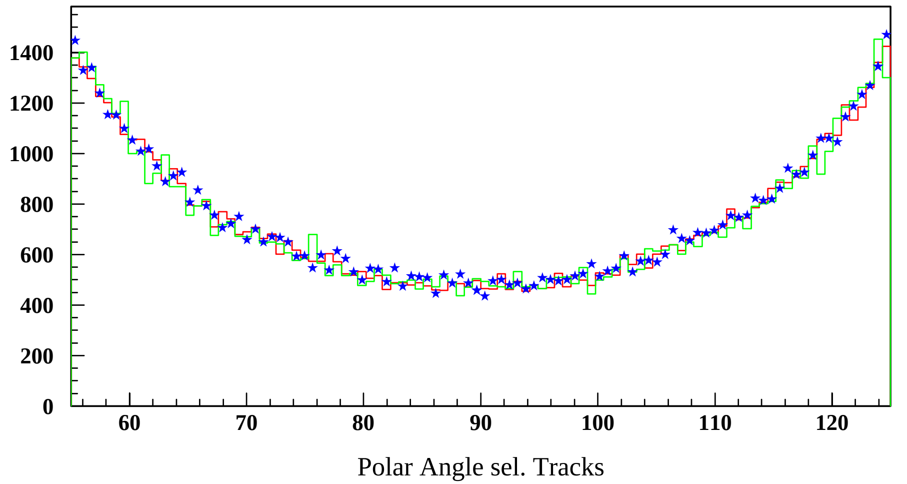
LAB - Candidates
(Systemat., Accept.)

Theoret. Generators
with rad. corrections

Berends/Drago/Venanzoni
BABAYAGA*

Background
($\gamma\gamma$, $\pi\pi\gamma$, ...)



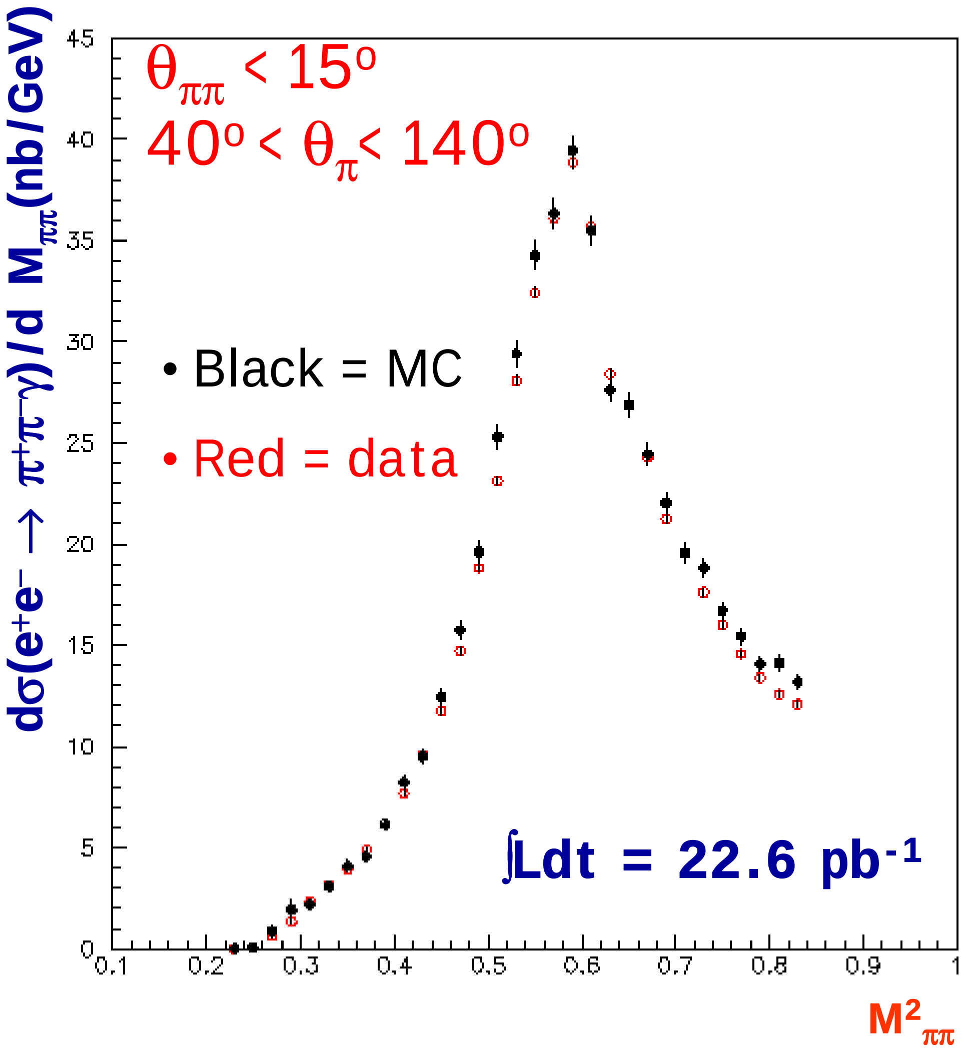


Luminosity- Measurement on % Level

agreement with independent $\gamma\gamma$-Counter < 1%

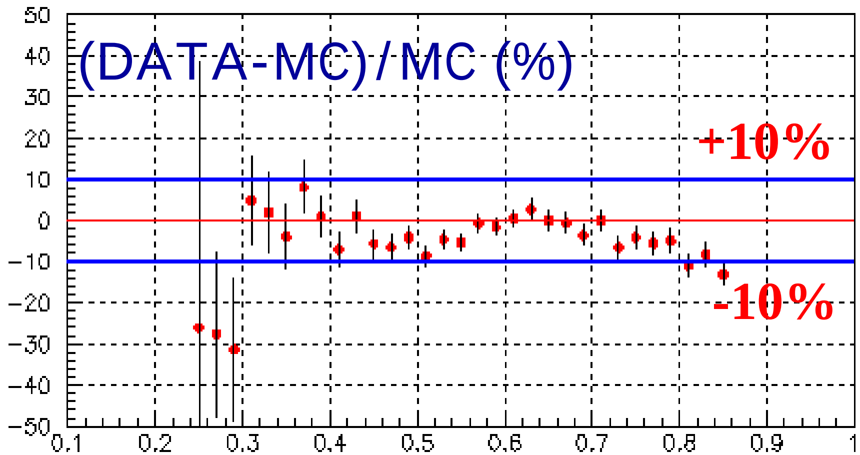
* *C.M.C. Calame et.al. Nucl. Phys., B 584 (2000)*

Small angle 'results'



•MC: **EVA** generator (ISR O(a)+coll.rad., FSR pointlike) with a lower cut on $\theta_{\pi\pi}$ at 0.1^o

•For a realistic comparison the **NLO** generator is needed: the PHOKHARA* generator has been made available in December and is now going to be inserted into KLOE MC.



No fit has been tried yet…

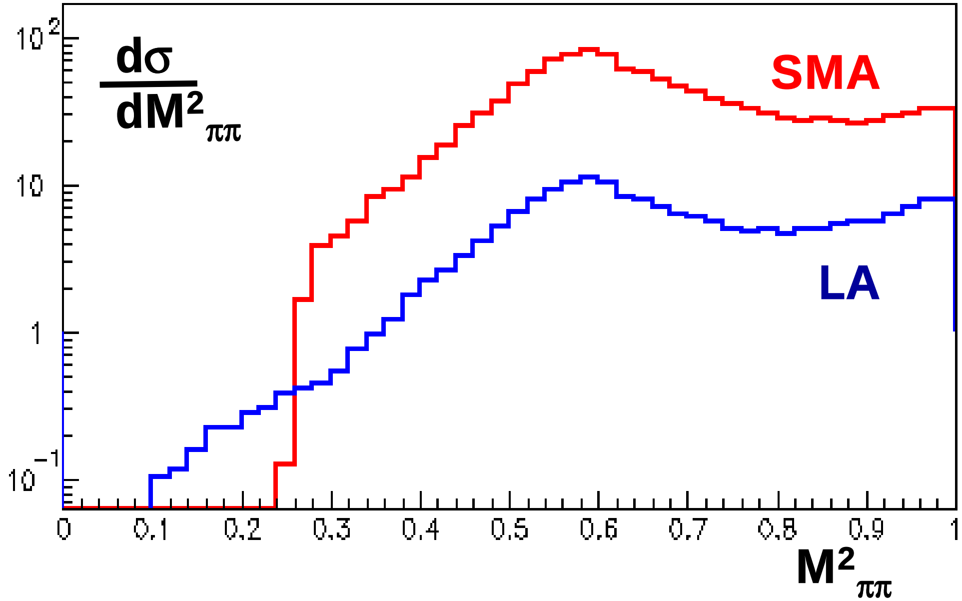
* *Phokhara:* ***G. Rodrigo, H. Czyz, J.H. Kühn, M. Szopa, hep-ph/0112184***

Large angle analysis

The ISR cross section in the small $\theta_{\pi\pi}$ angle region is significantly larger than the one in the large angle region:

- $\theta_{\pi\pi} < 15^o$ or $\theta_{\pi\pi} > 165^o$, σ = **21nb**
- $55^o < \theta_{\pi\pi} < 125^o$, σ = **3 nb**

However, at small angle the $M^2_{\pi\pi}$ spectrum is kinematically limited.



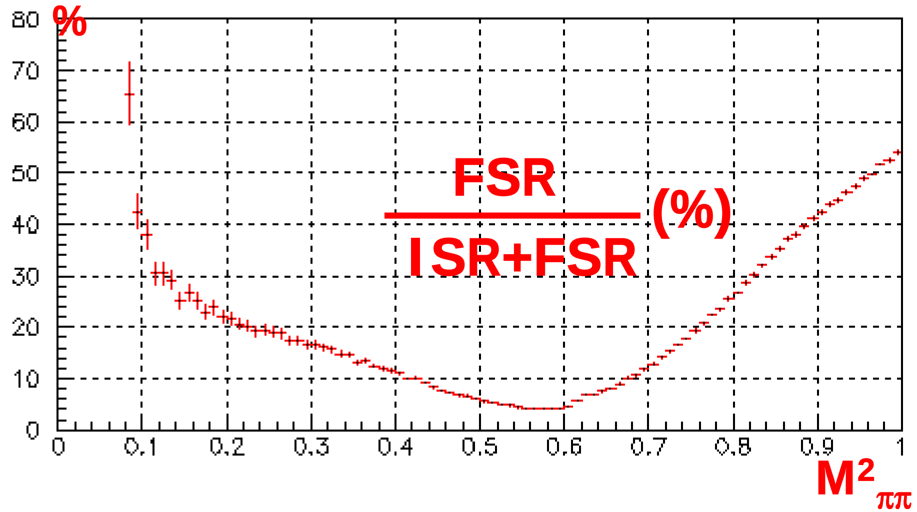
In order to cover the $\pi\pi$ **threshold** region a large angle analysis is needed.

Background at large angle

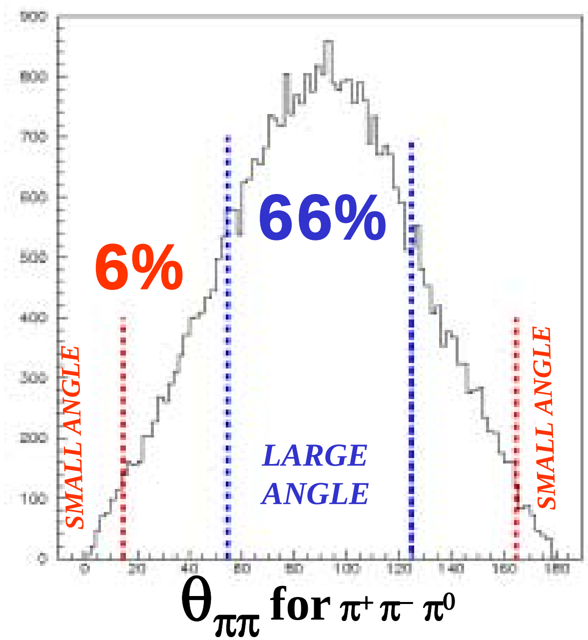
• The relative contribution of **F**inal **S**tate **R**adiation in the region

$$55^o < \theta_{\pi\pi} < 125^o$$

is absolutely not negligible: ~20%



Also the $\pi^+ \pi^- \pi^0$ contamination is much larger:

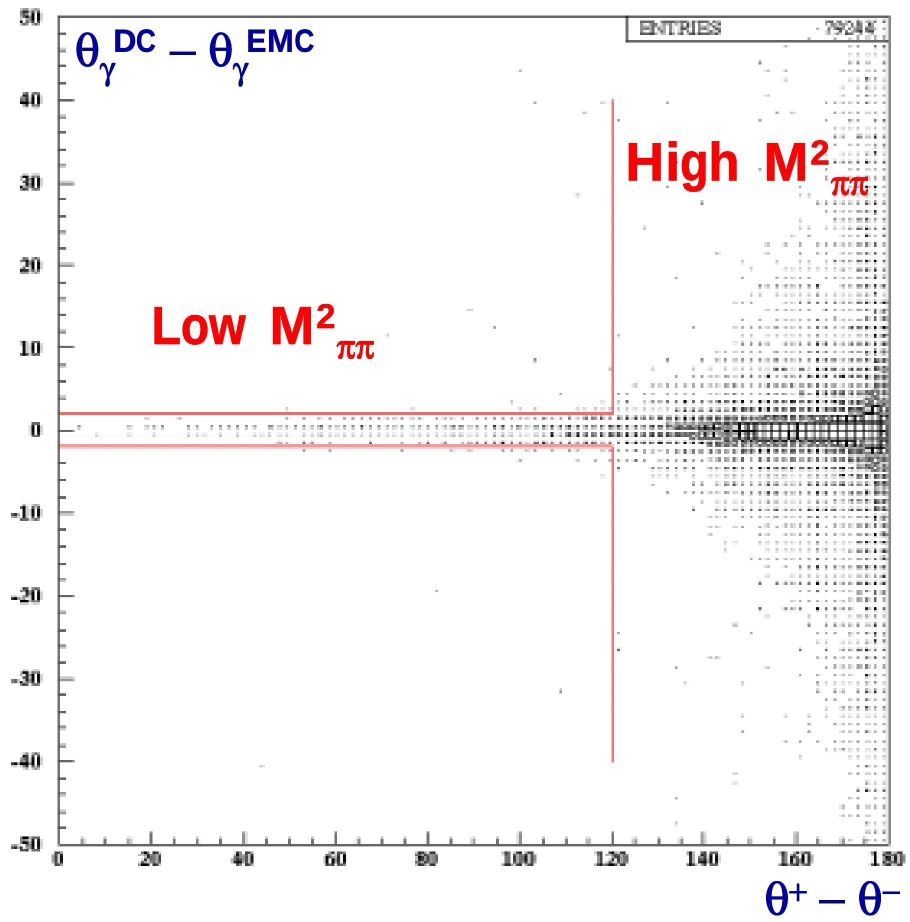


$\pi^+\pi^-\pi^0$ rejection at large angle

Nonetheless additional stringent **constraints on the kinematics** can be applied, since the radiated photon is detected by the calorimeter.

The photon must be inside **2^0** from the direction calculated using the pion momenta in the hypothesis of only one photon radiated (θ_γ^{DC}) .

The cut is not applied if the pions are almost collinear, **$(\theta^+ - \theta^-) < 120^o$**, because in this case the vertex reconstruction (and then the missing momentum information) is not so reliable and, furthermore, because this region corresponds to the high $M^2_{\pi\pi}$ region where the $\pi^+\pi^-\pi^0$ background is negligible.

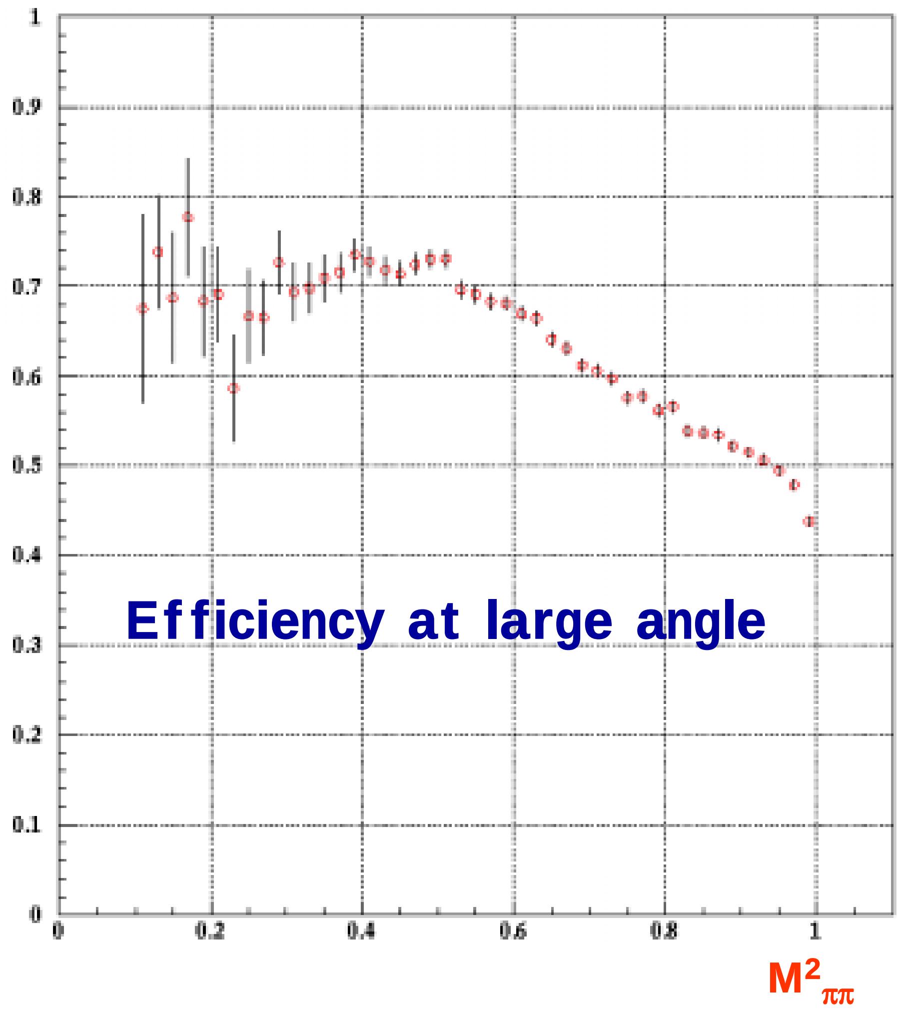


Large angle analysis efficiency

When all the cuts described for the small angle analysis and the additional $\pi^+\pi^-\pi^0$ background suppression are applied, the average efficiency is ~ 60%.

The errors are **statistical only**. At low $M^2_{\pi\pi}$ values they are dominated by the low MC statistics used.

Systematics are still under study.

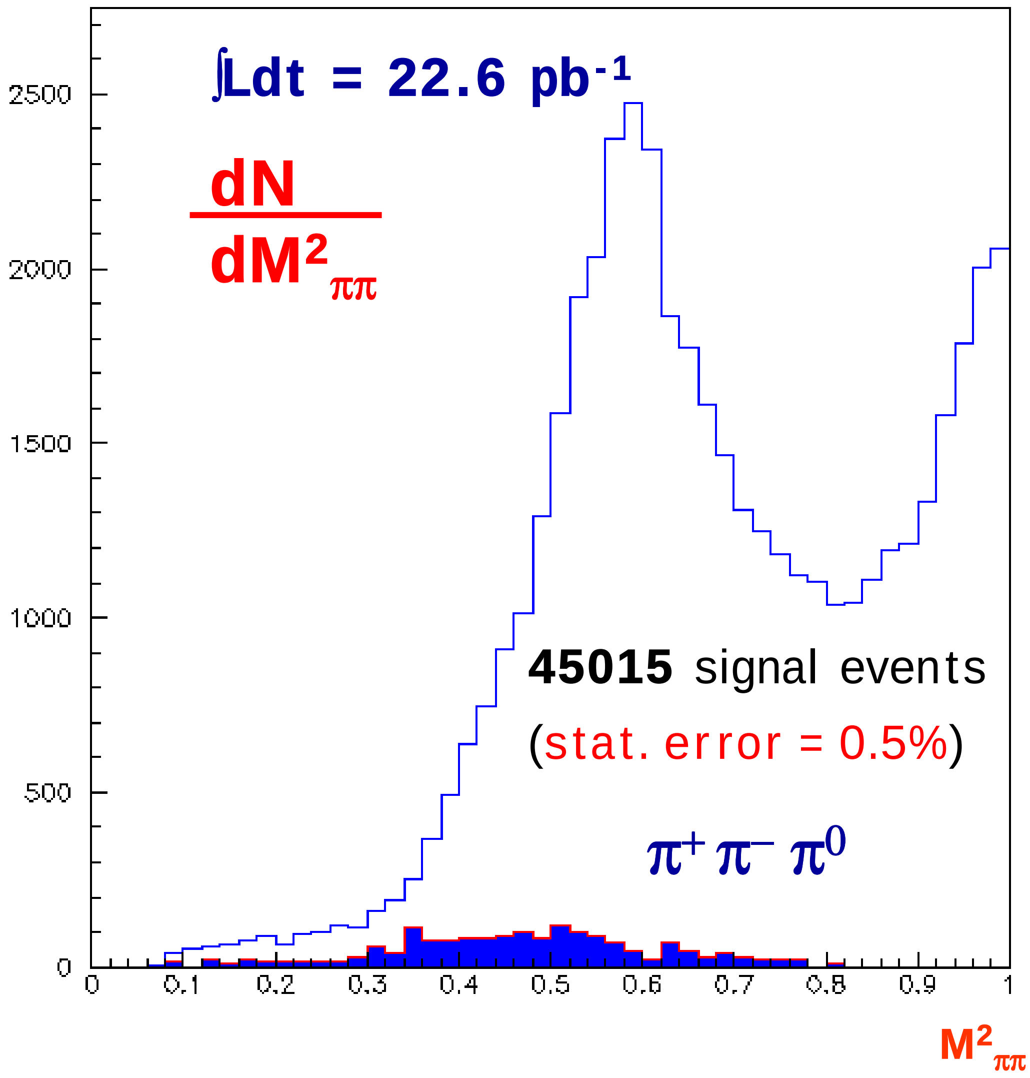


2000 Data at large angle

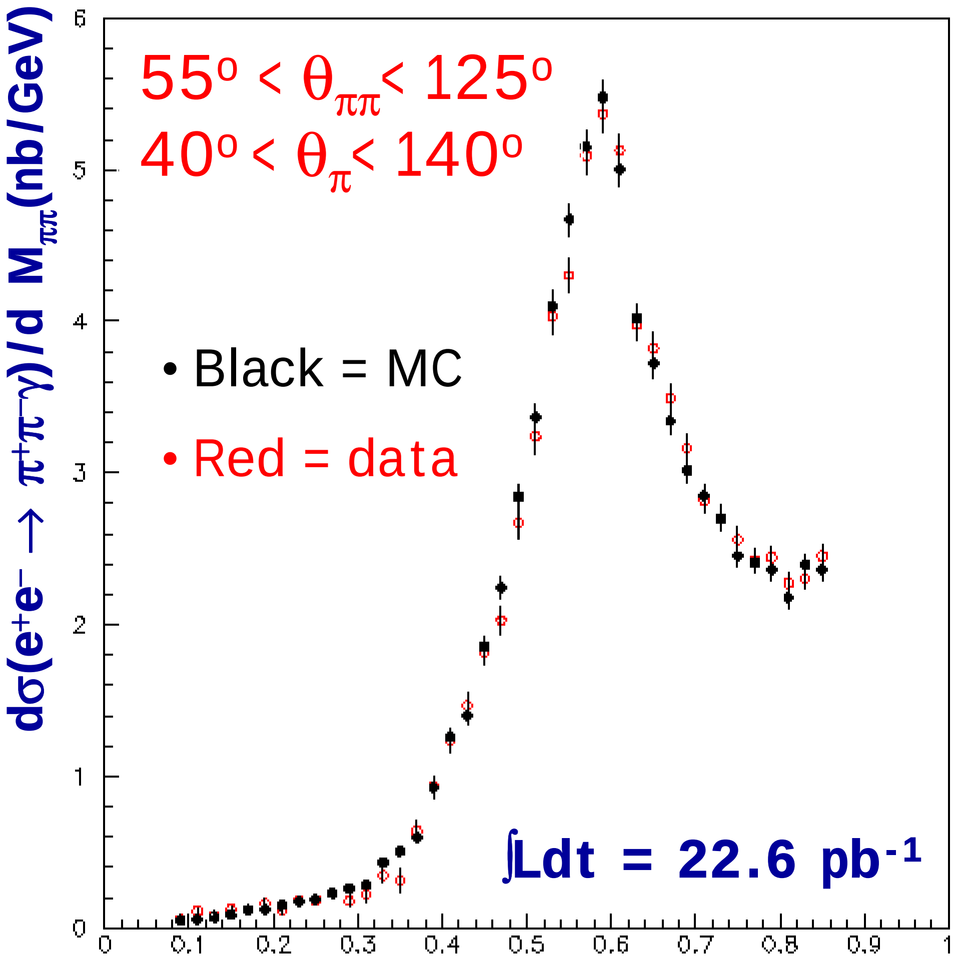
Data are not corrected for the selection efficiencies.

Contamination from three pion events is evaluated from MC

- **46715** events are selected
- **1700** background events are still expected from MC

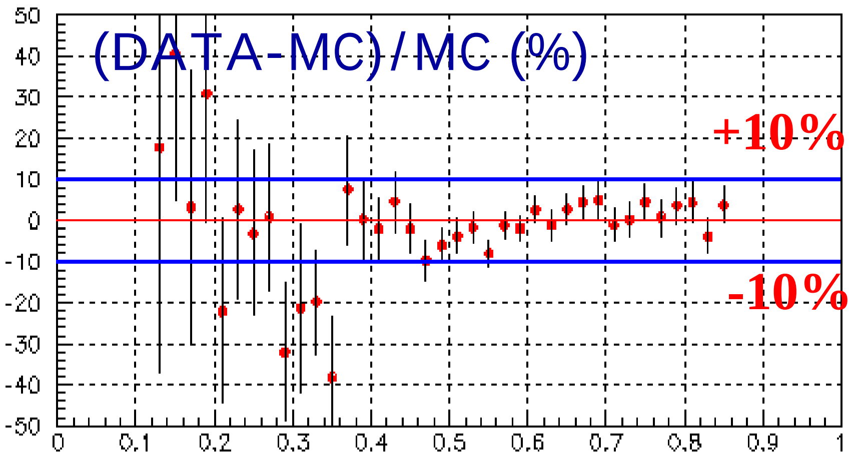


Large angle 'results'



- MC: **EVA** generator (ISR O(a)+coll.rad., FSR pointlike) corrected for the selection eff.
- DATA without any correction

The largest error comes from the background subtraction



$M^2_{\pi\pi}$

No fit has been tried yet…

* *Phokhara:* ***G. Rodrigo, H. Czyz, J.H. Kühn, M. Szopa, hep-ph/0112184***

Summary an Outlook

- The analysis of 2000 data (**22.6 pb^{-1}**) has shown the feasibility of the radiative return method.

- Up to now two different analyses have been performed:

SMALL ANGLE

The ρ resonance can be studied with very high statistics but the low $M^2_{\pi\pi}$ region cannot be accessed.

Stat. Error = **0.2%** (da_μ/a_μ = 0.35%)

Syst. Error: low contamination from FSR and $\pi^+ \pi^- \pi^0$; Lum. measurement; systematics on efficiencies still under study;

agreement with MC better than a few percent.

LARGE ANGLE

The $\pi^+ \pi^-$ threshold can be accessed

Stat. Error = **0.6%** (da_μ/a_μ = 0.8%) [background subtraction not taken into account]

Syst. Error: significant background from FSR and $\pi^+ \pi^- \pi^0$; Lum. measurement; systematics on efficiencies still under study;

agreement with MC better than a few percent.

- The luminosity measurement has a precision on the percent level.
- Current MC event generator (EVA) has a precision of 2-3%.

Summary an Outlook(II)

•The statistics collected by KLOE in 2001 (**170 pb^{-1}**) is enough to measure the hadronic cross-section $\sigma(e^+e^- \to \pi^+\pi^-)$ with a statistical error of ~ 0.1% at S.A. and ~ 0.2% at L.A (still without considering background subtraction).

•The NLO generator from Kühn et al., released in December, improves the theoretical description of ISR in our MC.

The uncertainty from unaccounted higher order ISR is estimated to be around 0.5% (hep-ph/0112184)

•Collaboration with other theoretical groups (F. Jegerlehner, A. Hoefer, S. Jadach) started and should also produce an improvement in the knowledge of the radiation function and in the luminosity measurement.

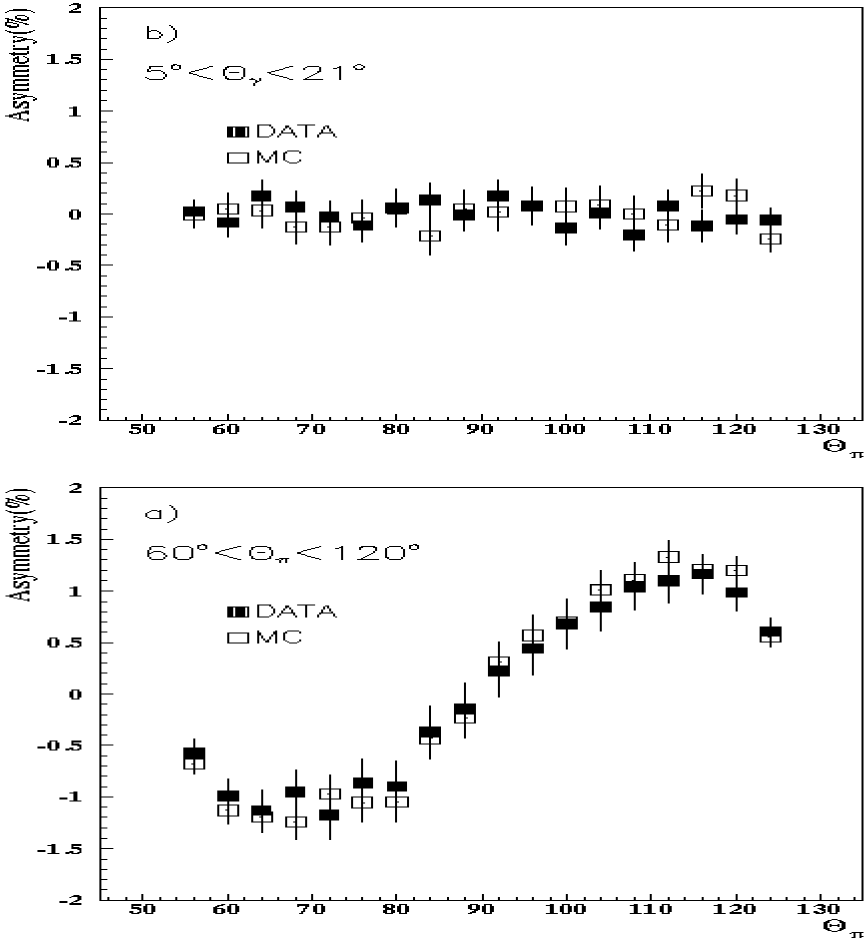
•Systematical error on efficiencies will be reduced with the larger statistics available.

NEW RESULTS are soon foreseen!!

Test of ISR/FSR simulation*

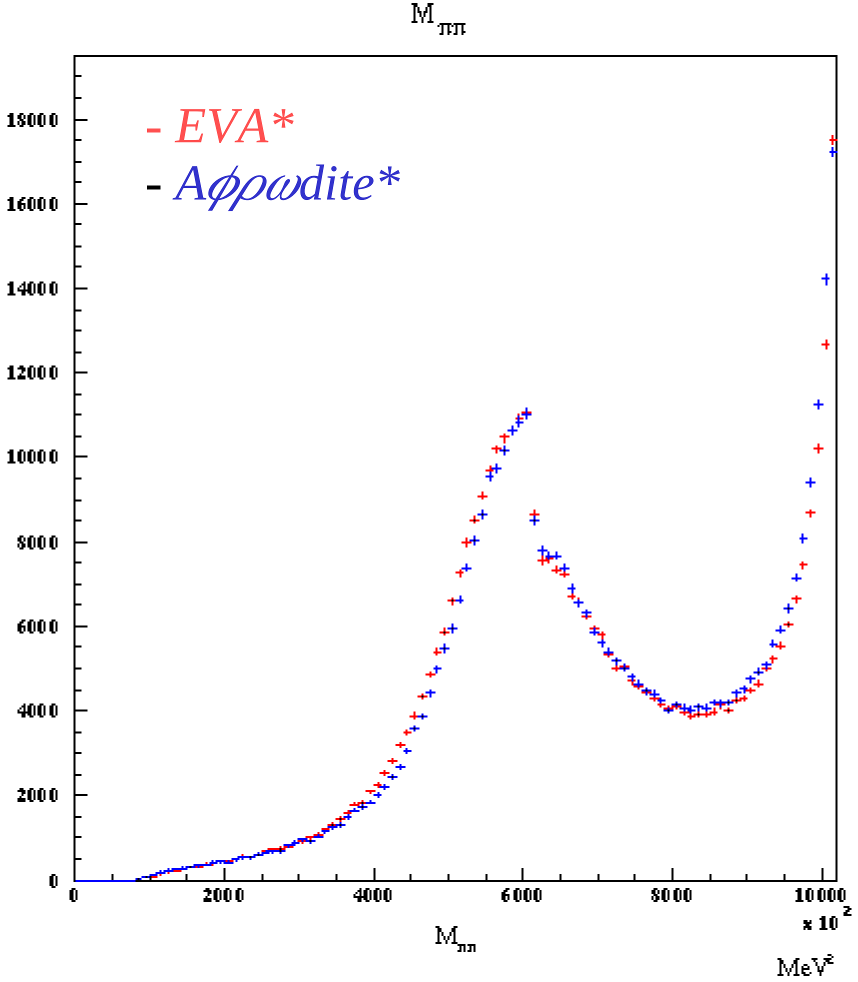
Pion charge asymmetry:

$$A(\theta_i) = \frac{N^{\pi^+}(\theta_i) - N^{\pi^-}(\theta_i)}{N^{\pi^+}(\theta_i) + N^{\pi^-}(\theta_i)}$$



**S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459 (1999)*

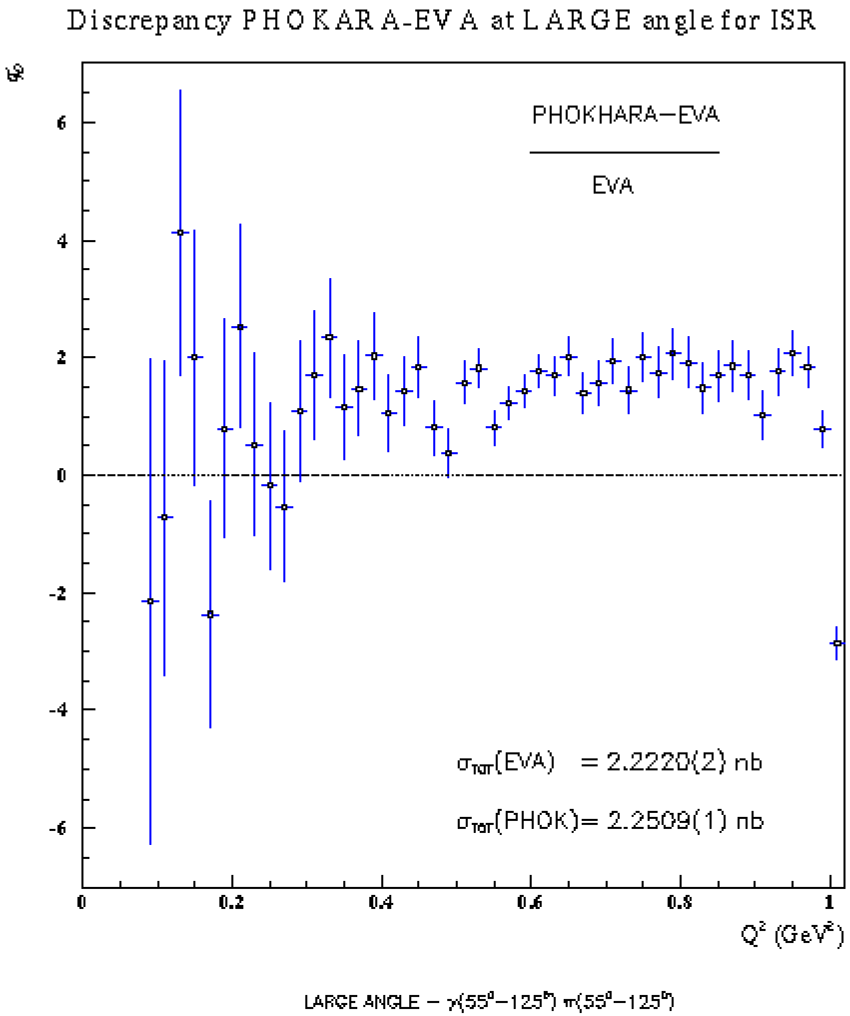
Comparison Eva-A$\phi\rho\omega$dite



*Eva: **S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999***

*A$\phi\rho\omega$dite: **A. Hoefer, F. Jegerlehner, J. Gluza, hep-ph/0107154***

Comparison Eva-Phokhara



Eva:* ***S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999*

Phokhara: ***G. Rodrigo, H. Czyz, J.H. Kühn, M. Szopa, hep-ph/0112184***