Measurement of hadronic cross sections with the KLOE experiment in Frascati

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Münster, 11.-15. March 2002

DAΦNE: A Φ-Factory

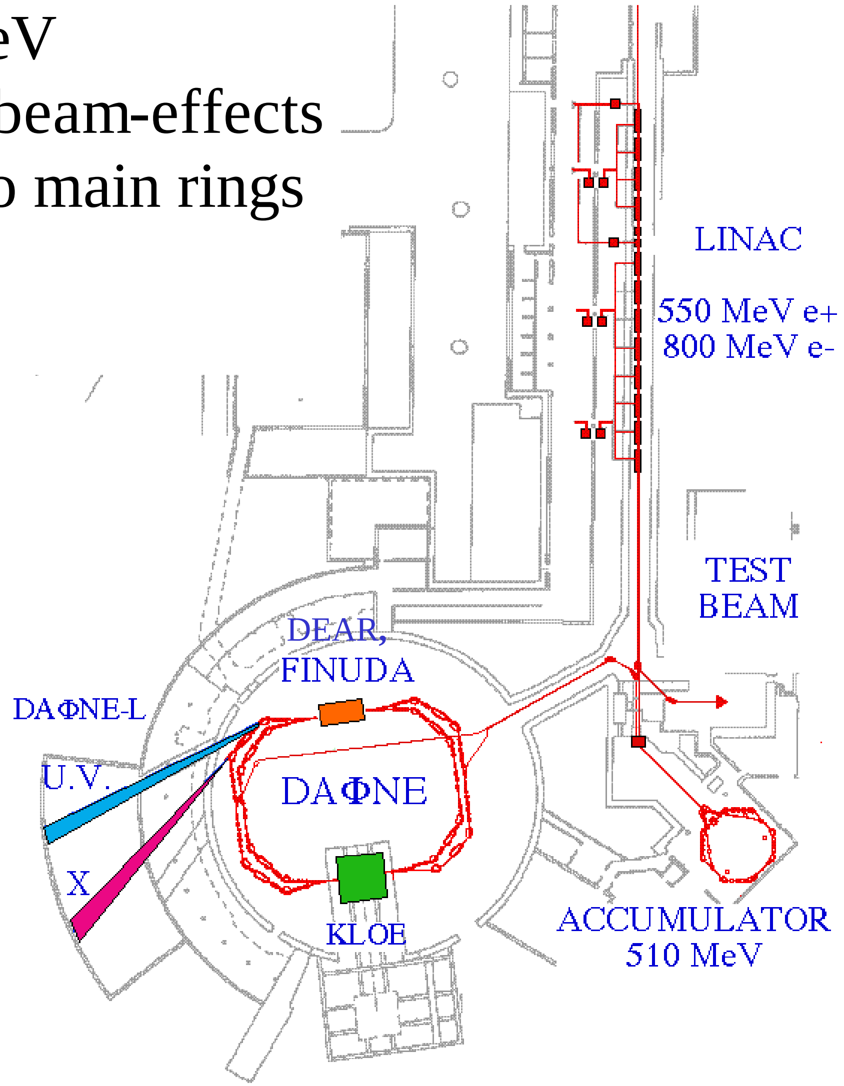
(**D**ouble **A**nnular **Φ**-Factory for **N**ice **E**xperiments)

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

BR's for selected f decays	
K^+K^-	49.1%
$K_S K_L$	34.1%
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%

$p_{K^{+-}} = 127 \text{MeV}/c$

$p_{K_{L,S}} = 110 \text{MeV}/c$



KLOE:

(KLOng Experiment)

- **Magnet:**
  Superconducting coil (B=0.5 T)

- **EM Calorimeter:**
  Lead/Scintillating fibres
  4880 PM

- **Driftchamber:**
  12582 Sense Wires
  52140 wires in total

- **Beryllium Beampipe:**
  R=10 cm, 0.5 mm thick

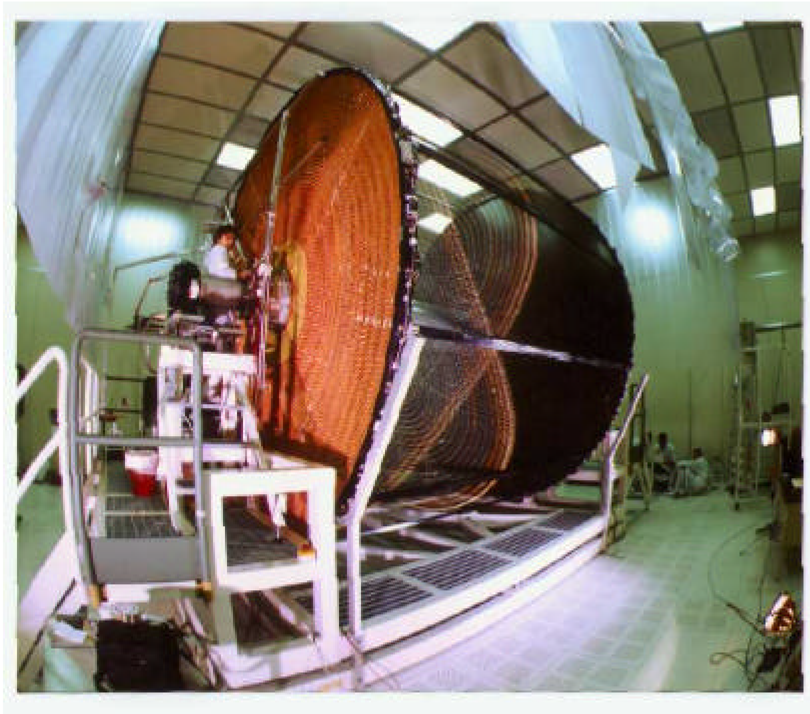
Titolo:

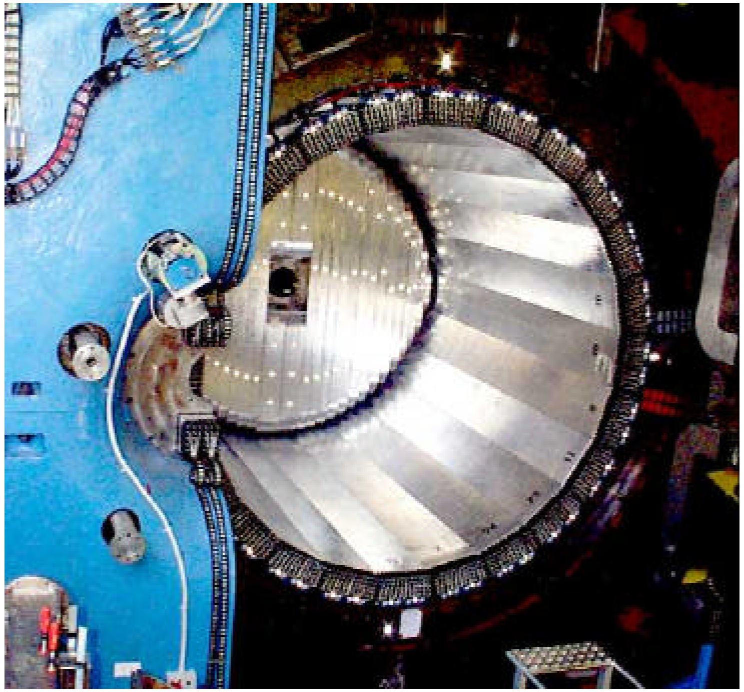
Autore:
CorelDRAW 7
Anteprima:
L'immagine EPS non è stata salvata
con l'anteprima inclusa in essa.
Commento:
L'immagine EPS potrà essere stampata con una stampante
PostScript e non con
altri tipi di stampante.

KLOE:

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
$\sigma_T = 54\ ps / \sqrt{E(GeV)} \oplus 50\ ps$
(Bunch length contribution subtracted from constant term)

Driftchamber





Electromagnetic calorimeter

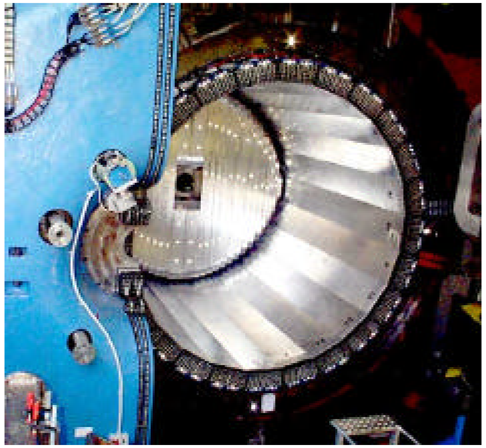
$\sigma_p/p = 0.4\%$ (for 90^0 tracks)
$\sigma_{xy} \approx 150\ \mu m$, $\sigma_z \approx 2\ \mu m$

KLOE: Calorimeter

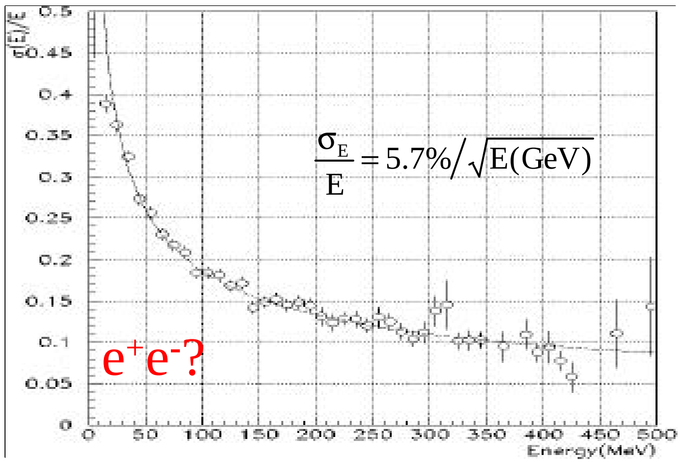
The E.-M. Calorimeter:

- Hermetical coverage (98% of 4p)
- Good resolution for energy, time and space ⇨
  (Bunch length contribution has been subtracted from constant term in σ_t)
- High efficiency for low energy photons
  (down to 20 MeV)

$$\sigma_E / E = 5.7\% / \sqrt{E(GeV)}$$
$$\sigma_t = 54ps / \sqrt{E(GeV)} \oplus 50ps$$
$$\sigma_{x,y} = 1.2cm$$
$$\sigma_z = 1.2cm / \sqrt{E(GeV)}$$



24 barrel modules
60 cells
4.3 m length



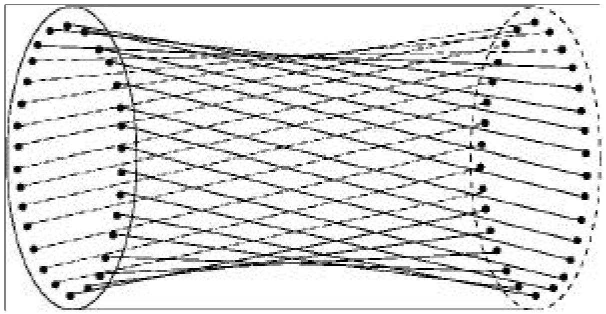
2 x 32 endcap modules
10/15/30 cells

2440 cells total = 4880 channels

KLOE: Driftchamber

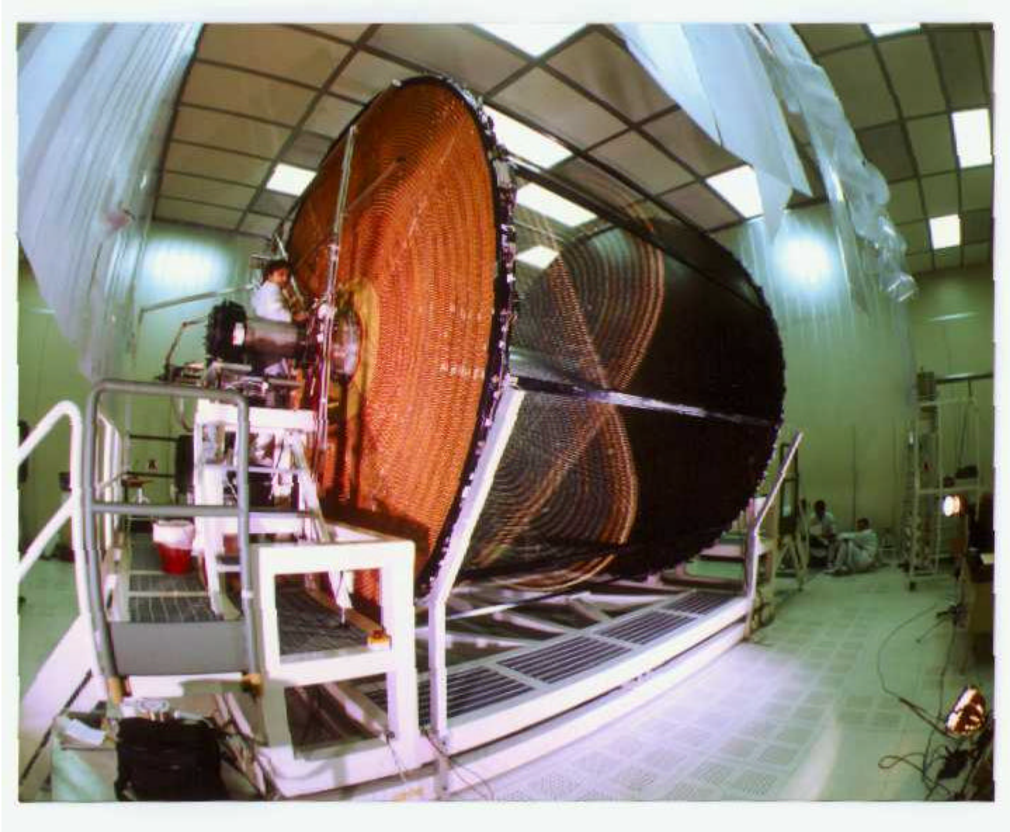
- Cylindrical geometry with d=4m, L=3.3m
- Large detection volume ($40m^3$) to detect 30% of K_L-decays ($?_L$=3.43m@ß=0.218)
- 90%He–10% iC_4H_{10}-gas mixture to reduce multiple scattering and provide high transparency for low-momentum photons

•All 52140 wires in stereo-geometry:



$\sigma_{r,\varphi} = 200\mu m$ $\quad \sigma_{p_T}/p_T = 0.5\%$

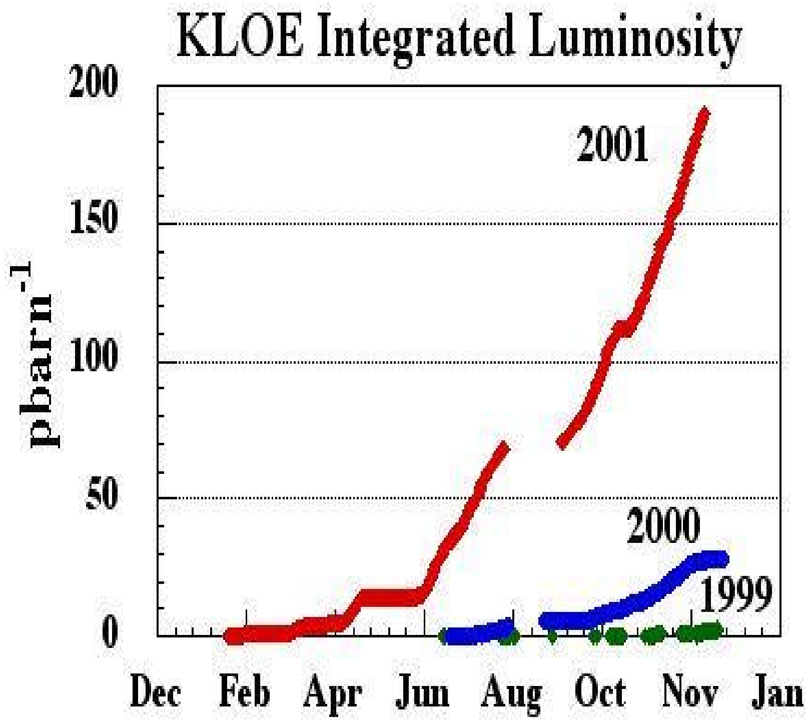
$\sigma_z = 2mm$



Achievements

Integrated luminosity:

1999: 2.5 pb^{-1}
2000: 25 pb^{-1}
2001: 175 pb^{-1}



Peak luminosity: **$5.25 \times 10^{31} cm^{-2}s^{-1}$**

Peak int. luminosity: **3 pb^{-1}/day**

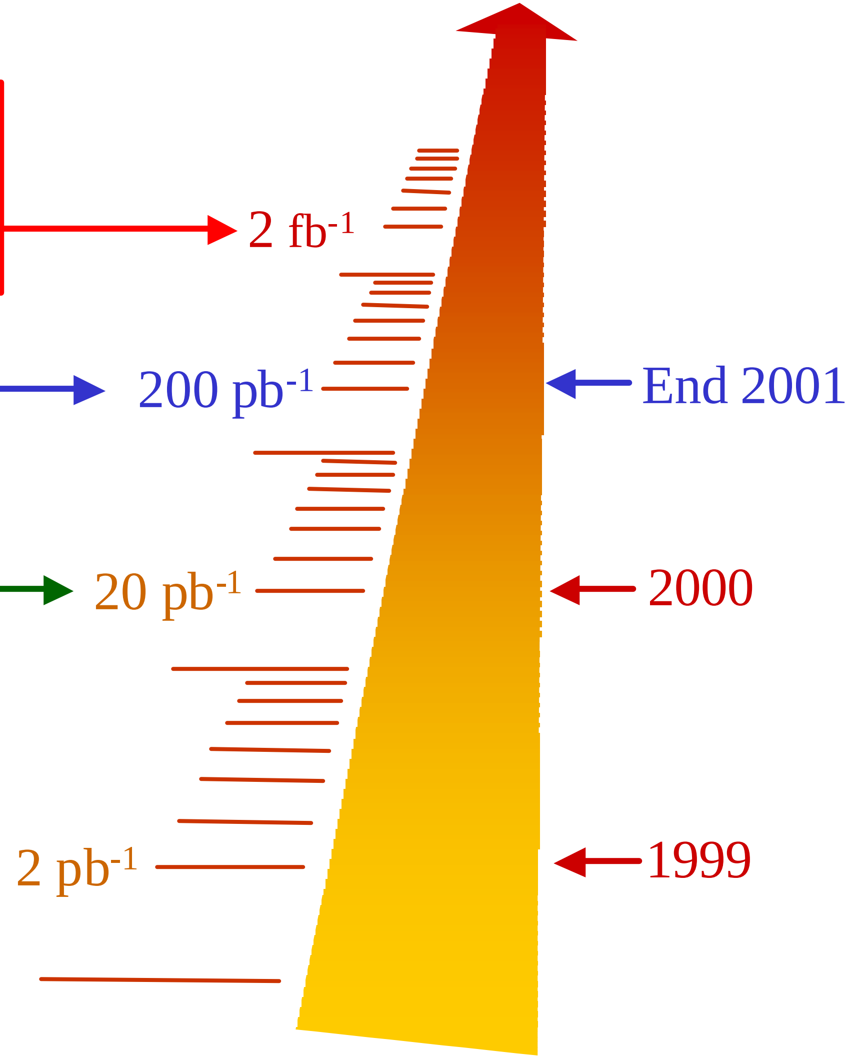
$$\int L\,dt \approx 200\,pb^{-1} \text{ on disk}$$

KLOE physics program:

ε'/ε to O(10^{-4}) via double ratio
Semileptonic asymmetry (CPT test)
Interferometry

Close out K_S and *f* physics
$K_S \to 3\pi^0$, other rare K_S decays
$K_L \to 2\pi$, $K_L \to \gamma\gamma$, form factors
s($e^+e^- \to$ **hadrons) to <1% (stat)**

K_S physics
BR($K_S \to \pi^+\pi^-$)/BR($K_S \to \pi^0\pi^0$)
BR($K_S \to \pi e \nu$)
f radiative decays
f $\to f_0\gamma$, $a_0\gamma$
f $\to \eta'\gamma$, $\eta\gamma$



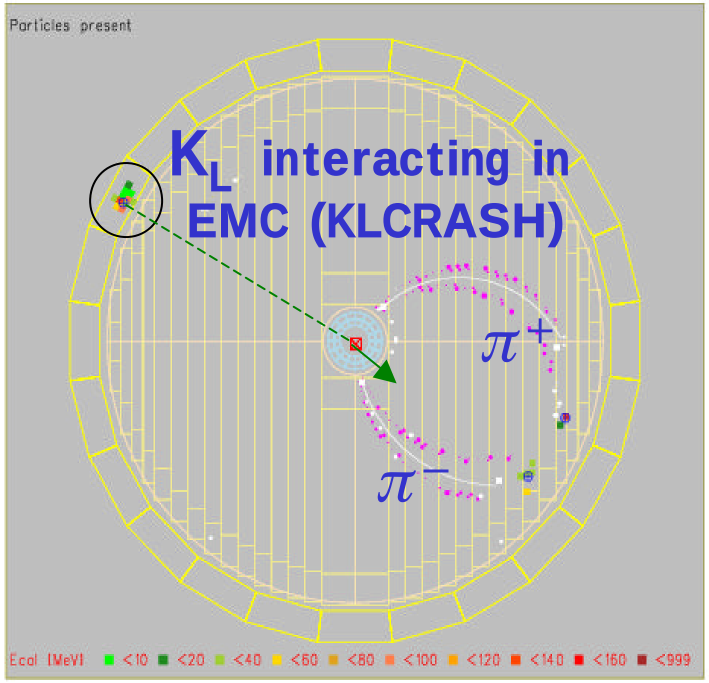
KLOE: First results

$BR(K_S \to \pi^+\pi^-)/BR(K_S \to \pi^0\pi^0)$

$$R = \frac{N(K_L \to \pi^0\pi^0)\ /\ N(K_S \to \pi^0\pi^0)}{N(K_L \to \pi^+\pi^-)\ /\ N(K_S \to \pi^+\pi^-)}$$ @ fixed target

$$R = \frac{N(K_L \to \pi^0\pi^0)\ /\ N(K_L \to \pi^+\pi^-)}{N(K_S \to \pi^0\pi^0)\ /\ N(K_S \to \pi^+\pi^-)}$$ @ KLOE

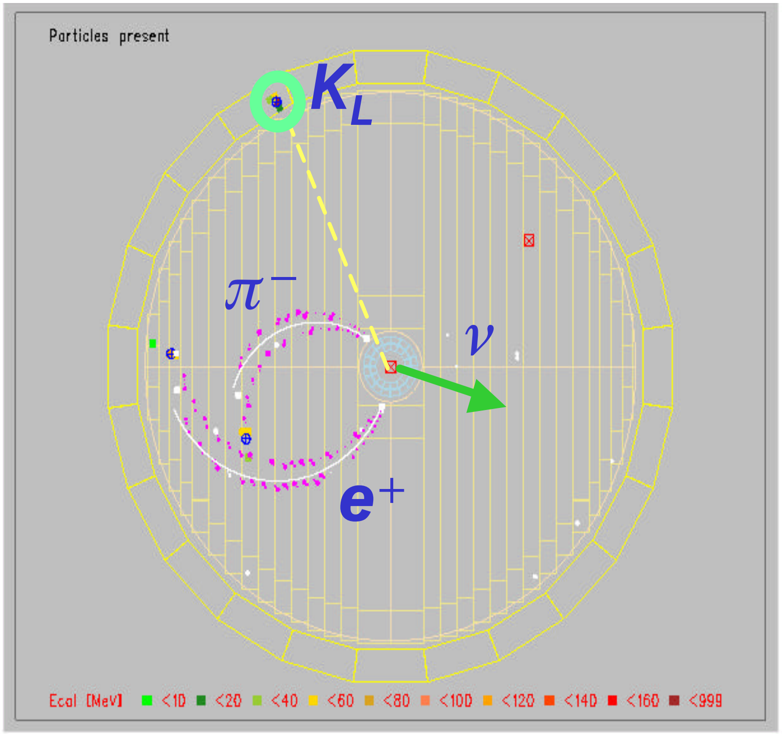
The K_S is tagged by a K_L in the EmC.

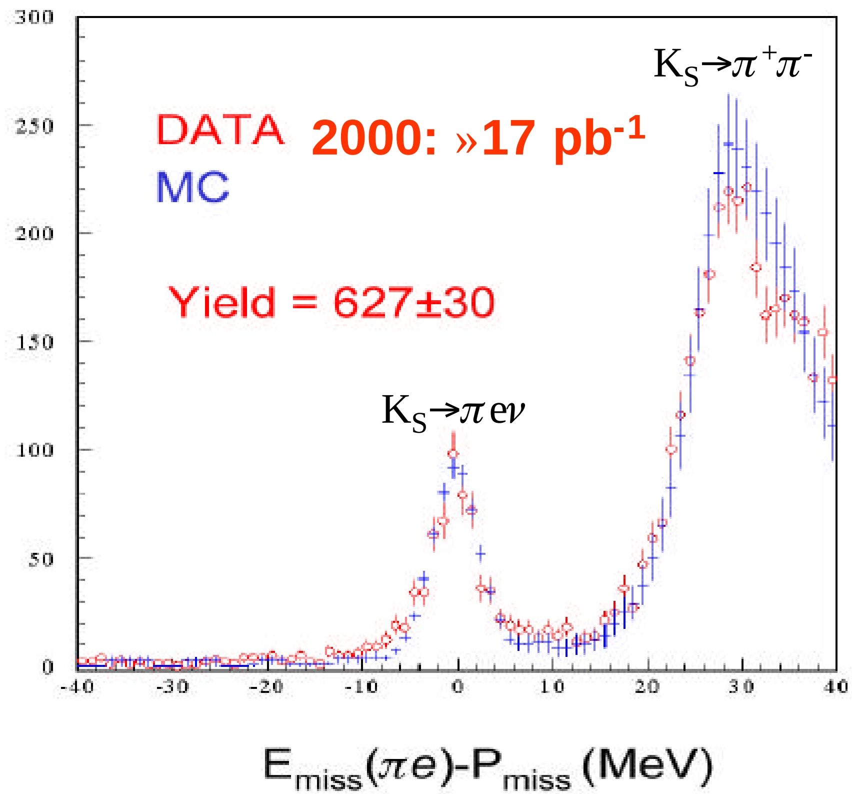


KLOE 2000 preliminary:	$2.230 \pm 0.008_{stat} \pm 0.033_{syst}$
PDG 2000:	$2.197 \pm 0.026_{stat} \pm 0.013_{syst}$

KLOE: First results

$K_S \to \pi e \nu$ decay





KLOE 2000 (17 pb^{-1}):	$[\ 6.79 \pm 0.33_{stat} \pm 0.20_{syst}\ ] \times 10^{-4}$
PDG 2000 (CMD2):	$[\ 7.2 \pm 1.2\ ] \times 10^{-4}$

KLOE: First results

ϕ radiative decays studies:

Scalar sector (preliminary):

$BR(\phi \to f_0\gamma \to \pi^0\pi^0\gamma) = [7.9 \pm 0.2\ (stat)] \times 10^{-5}$

$BR(\phi \to a_0\gamma \to \eta\pi^0\gamma) = [5.8 \pm 0.5\ (stat)] \times 10^{-5}\ (\eta \to \gamma\gamma)$

Assuming $BR(\phi \to f_0\gamma) \approx 3 \times BR(\phi \to f_0\gamma \to \pi^0\pi^0\gamma)$ and $BR(\phi \to a_0\gamma) \approx BR(\phi \to a_0\gamma \to \eta\pi^0\gamma)$:

$BR(\phi \to f_0\gamma)\ /\ BR(\phi \to a_0\gamma) = 4.1 \pm 0.4\ (stat)$

the analysis is going on to evaluate systematic errors

Pseudoscalar sector:

$BR(\phi \to \eta'\gamma)\ /\ BR(\phi \to \eta\gamma) = [5.3 \pm 0.5_{stat} \pm 0.3_{syst}] \times 10^{-3}$

$M_{\eta'} = [958.0 \pm 0.6]\ MeV/c^2$

$BR(\phi \to \eta'\gamma) = [6.8 \pm 0.6_{stat} \pm 0.5_{syst}] \times 10^{-5}$ (PDG2000: $BR= [6.7 \pm 1.5] \times 10^{-5}$)

$\varphi_{mix} = [40^{+1.7}_{-1.5}]^o$ (flavour basis)

$= [-14.7^{+1.7}_{-1.5}]^o$ (singlet-octet basis)

Status on $(g\text{-}2)_\mu$:

The current status of a_μ from experiment and (SM-) theory:

a_μ^{exp}

$(g_\mu-2)/2 = (11\,659\,202.0 \pm \mathbf{14.0}) \times 10^{-10}$ E821, hep-ex/0102017

$a_\mu^{theor,SM}$

$(g_\mu-2)/2 = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak}$

$a_\mu^{QED} = (11\,658\,470.6 \pm 0.3) \times 10^{-10}$ Czarnecki, Marciano 2000

$a_\mu^{weak} = (\mathbf{15.2} \pm 0.4) \times 10^{-10}$ Czarnecki, Krause, Marciano 1998

a_μ^{had}* = $(690.9 \pm \mathbf{6.7}) \times 10^{-10}$ ← **Davier, Höcker 1999, τ decays**

a_μ^{had}* = $(695.9 \pm \mathbf{10.8}) \times 10^{-10}$ ← **Jegerlehner 2001, without τ decays, new CMD2 and BESII data**

* Including averaged light-by-light-scattering result from hep-ph/0202275

$a_\mu^{exp} - a_\mu^{theor,SM} = 1.1 - 1.6\,\sigma$ difference

The reduction of the error on the hadronic contribution to the SM calculation of a_μ could (together with a reduction of the experimental error) give this discrepancy between theory and experiment a higher significance.

a_μ^{had}:

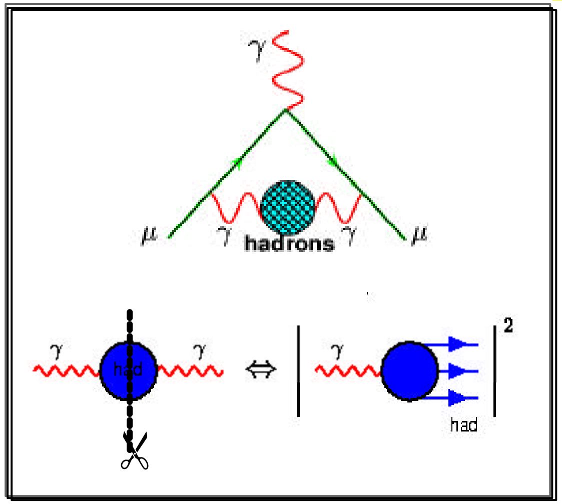
$$a_\mu^{had} = a_\mu^{had}(lo) + a_\mu^{had}(nlo) + a_\mu^{had}(lbl)$$

(see also Melnikov, hep-ph/0105267; Miller, hep-ex/0111036)

$a_\mu^{had}(lo)$	$= (692.4 \pm 6.2) \times 10^{-10}$	DH98, hep-ph/9812370
	$= (697.4 \pm 10.5) \times 10^{-10}$	FJ01
$a_\mu^{had}(nlo)$	$= (-10.0 \pm 0.6) \times 10^{-10}$	Krause, hep-ph/9607259
$a_\mu^{had}(lbl)$	$= (+8.5 \pm 2.5) \times 10^{-10}$	KN, hep-ph/0111058 BPP, hep-ph/0112255 HK, hep-ph/0112102
a_μ^{had}	$= (690.9 \pm 6.7) \times 10^{-10}$	DH98
	$= (695.9 \pm 10.8) \times 10^{-10}$	FJ01

Dispersion integral:

a_μ^{hadr} can be expressed in terms of $\sigma(e^+e^- \to \text{hadrons})$ by the use of a dispersion integral:



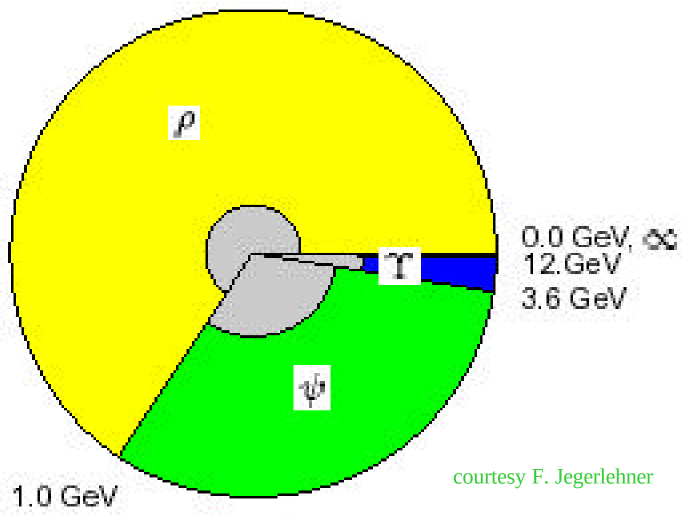
$$a_\mu^{hadr} = \frac{1}{4\pi^3}\left(\int_{4m_\pi^2}^{E_{Cut}^2} ds\, \sigma^{hadr,exp}(s) K(s) + \int_{E_{Cut}^2}^{\infty} ds\, \sigma^{hadr,pQCD}(s) K(s) \right)$$

- E_{cut} is the threshold energy above which pQCD is possible
- s is the c.o.m.-energy squared of the hadronic system
- K(s) is a steady function that goes with 1/s, ***enhancing low energy contributions of $\sigma^{hadr}(s)$***

Low energy contribution:

The region around the energy of the ρ-meson adds with ca. 61% to the total value of a_μ^{hadr}, assuming an E_{cut} of 12 GeV above which the dispersion integral is evaluated with pQCD.

[Jegerlehner; hep-ph/0104304]



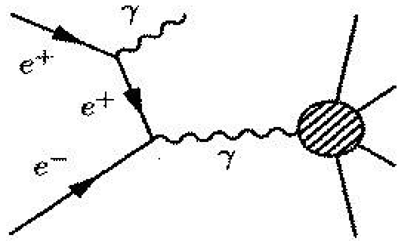
The ρ-meson decays to 100% in $\pi^+\pi^-$, so in this energy region the analysis efforts concentrate on the determination of

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

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

The standard method of measuring $\sigma(e^+e^-\rightarrow\pi^+\pi^-)$ is an energy scan by varying the beam energy within the desired range. Since at DAΦNE the collision energy is fixed, one uses radiative return method which exploits the process

e^+ e^- ® g + Hadrons ,



where the photon is emitted in the initial state (ISR).
[Binner, Kühn, Melnikov; hep-ph/9902399]

Q^2 , the invariant mass of the hadronic system, varies continuously between:

$$4m_\pi^2 \le Q^2 = (m_\phi^2 - 2m_\phi \cdot E_\gamma) \le m_\phi^2$$

With the radiation function $H(Q^2, \cos\theta_0)$, the total cross section can be calculated taking the formula

$$d\sigma\,(e^+e^- \longrightarrow \text{hadrons}+\gamma) / dQ^2 = \sigma\,(e^+e^- \longrightarrow \text{hadrons}, Q^2)\ H\,(Q^2, \cos\theta_0)$$

with θ_0 the angle of the radiated photon.

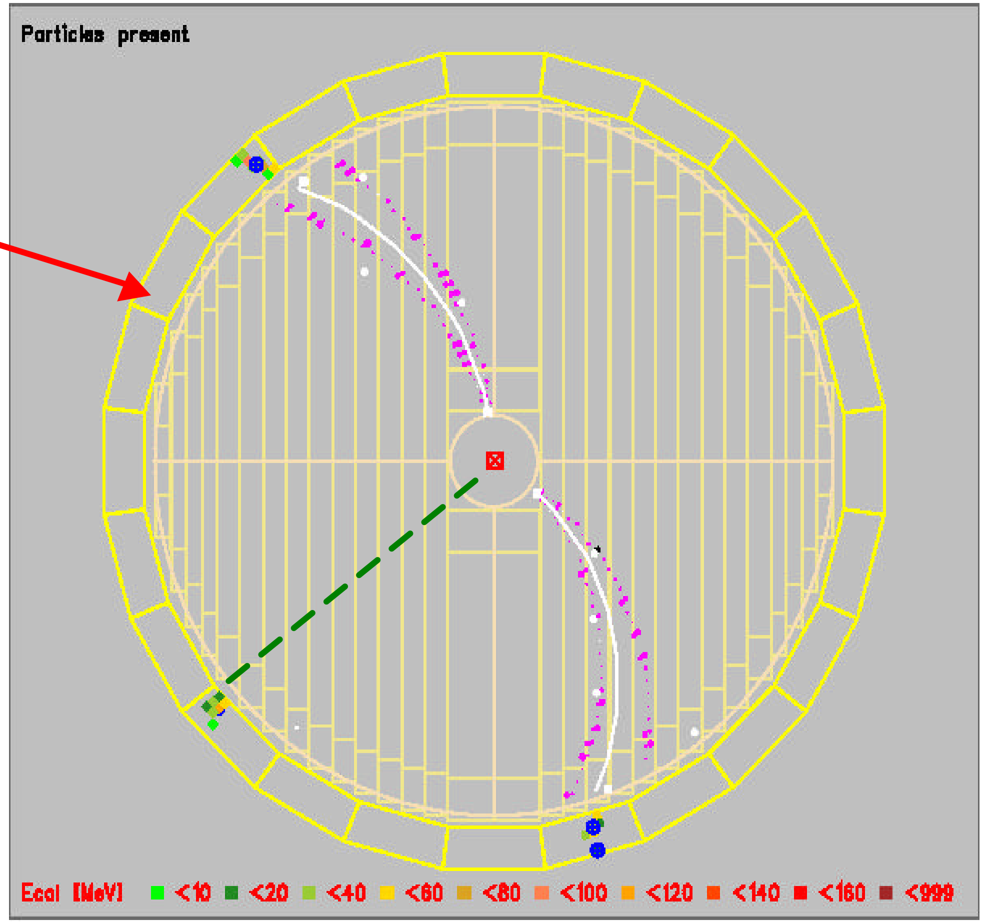
In this approach the overall normalisation enters the measurement **only once!**

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

$\pi^+\pi^-\gamma$ events are selected by asking for two tracks connected to a vertex in the IR with

- both tracks $40° < \theta_\pi < 140°$
- $p_t > 160$ MeV/c
- on one track tighter cuts are applied, this track is used later for PID

Event Display DIDONE



E_γ and θ_γ are then evaluated using the tracks-momenta and the ϕ-boost

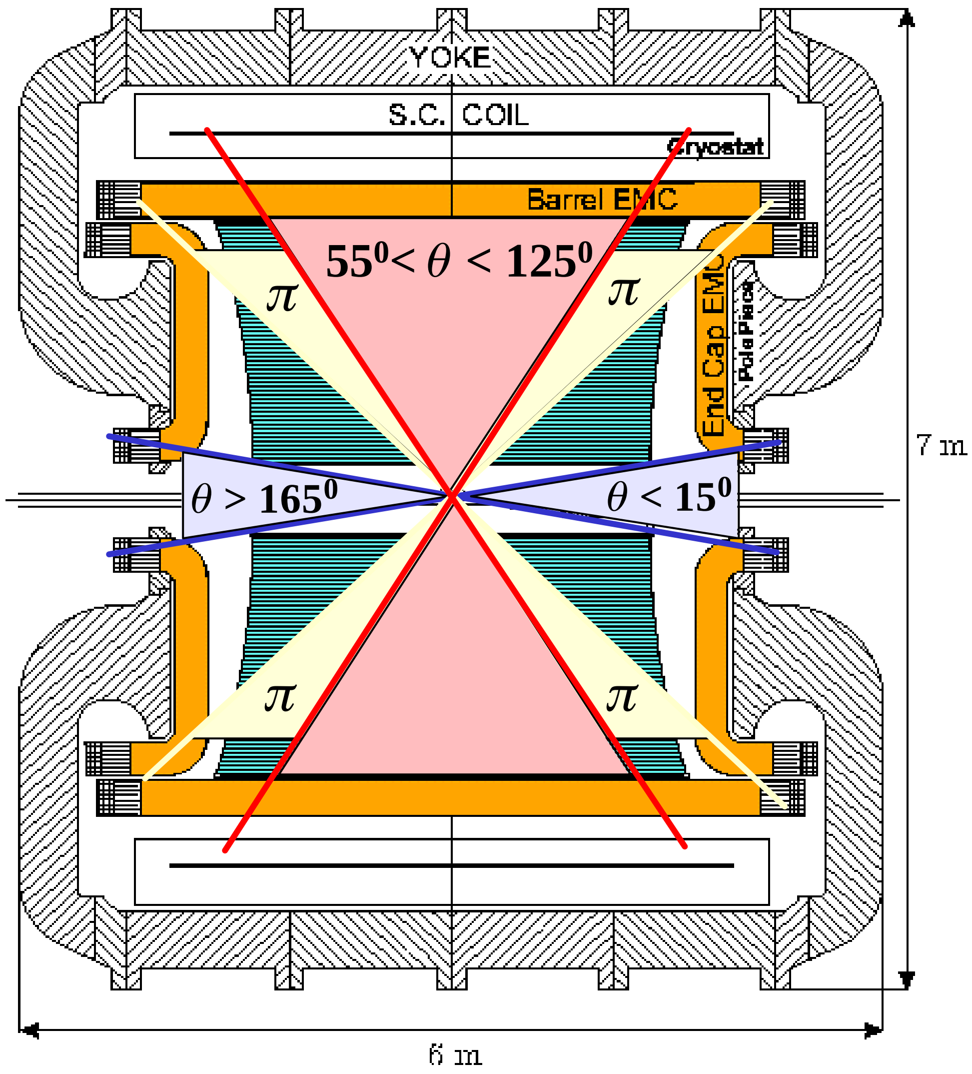
Some background channels are selected together with the signal:

- **e^+e^-** ® **e^+e^-** g
- **e^+e^-** ® m^+m^- g
- **e^+e^-** ® f ® $p^+p^-p^0$

Fiducial volumes:

Two fiducial volumes are currently studied:

- small angle: $\theta_\gamma < 15^o$ and $\theta_\gamma > 165^o$
  - highest cross section; small background from $\pi\pi\pi$; small contribution from FSR; no photon tagging possible
- large angle: $55^o < \theta_\gamma < 125^o$
  - large background from $\pi\pi\pi$, especially at low $M^2_{\pi\pi}$; photon detected in the EmC



The pions must be central (40^o-140^o) to cut down the background ($e^+e^-\gamma$, $\mu^+\mu^-\gamma$)

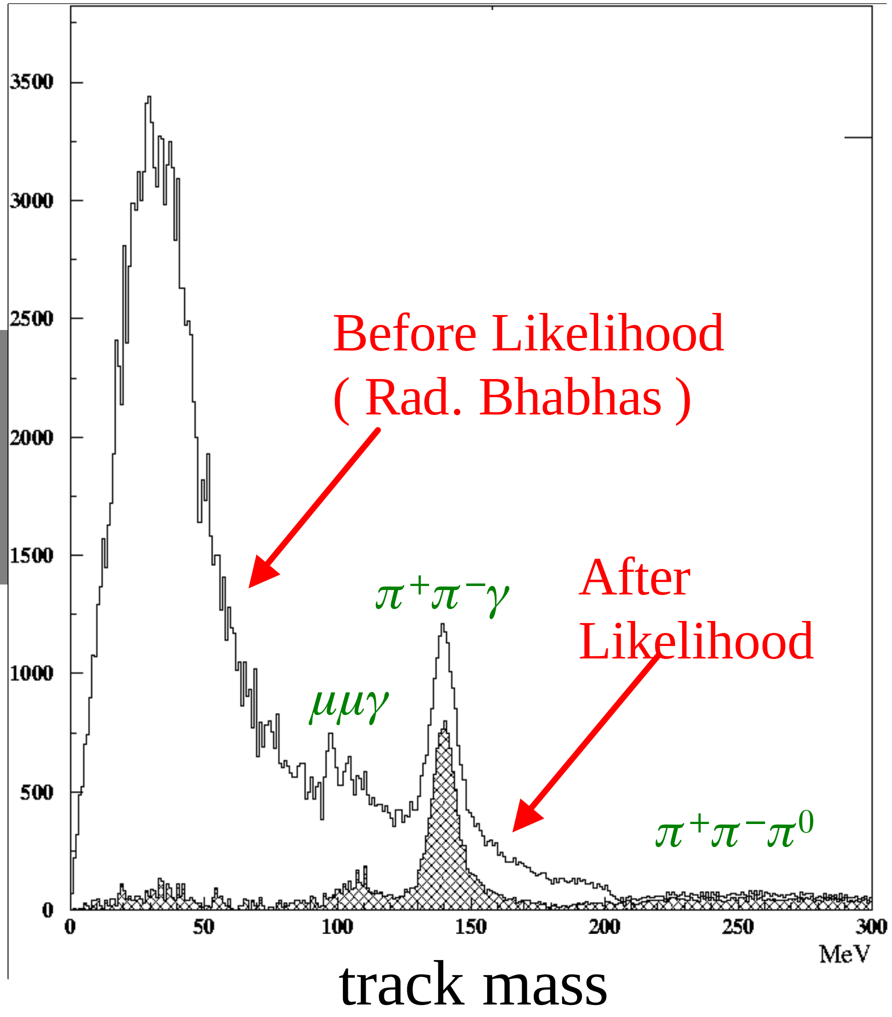
Signal selection:

To reduce Bhabha contamination, a Likelihood-method is used based on:

- **TOF of charged clusters**
- **Shape and energy deposition of the "charged" cluster**

$\pi\pi\pi$ and radiative bhabhas are used as control samples.

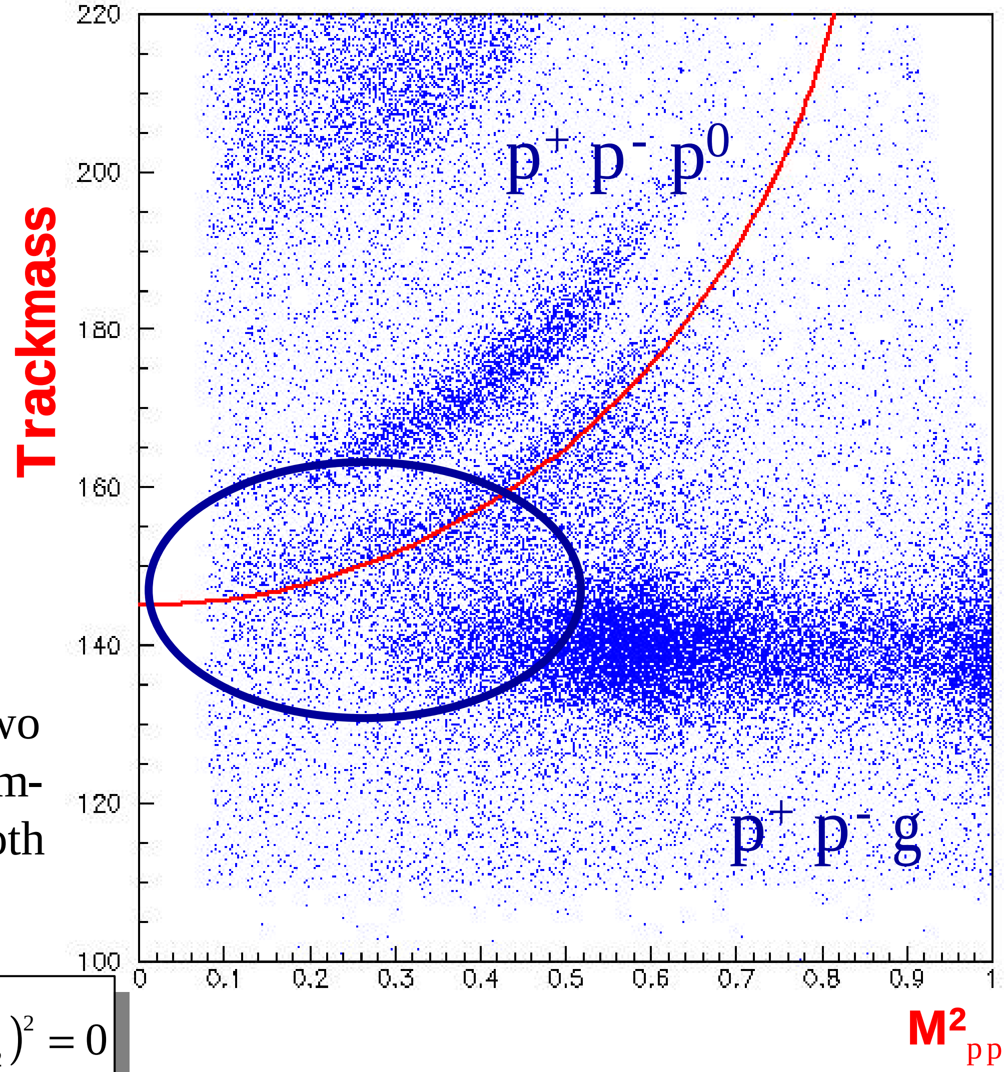
At least one charged cluster should fulfill the Likelihood-condition (gold pion)



Signal selection:

The signal is further selected by performing a cut in the **trackmass** variable in order to reduce

$p^+ p^- p^0$ **background**:



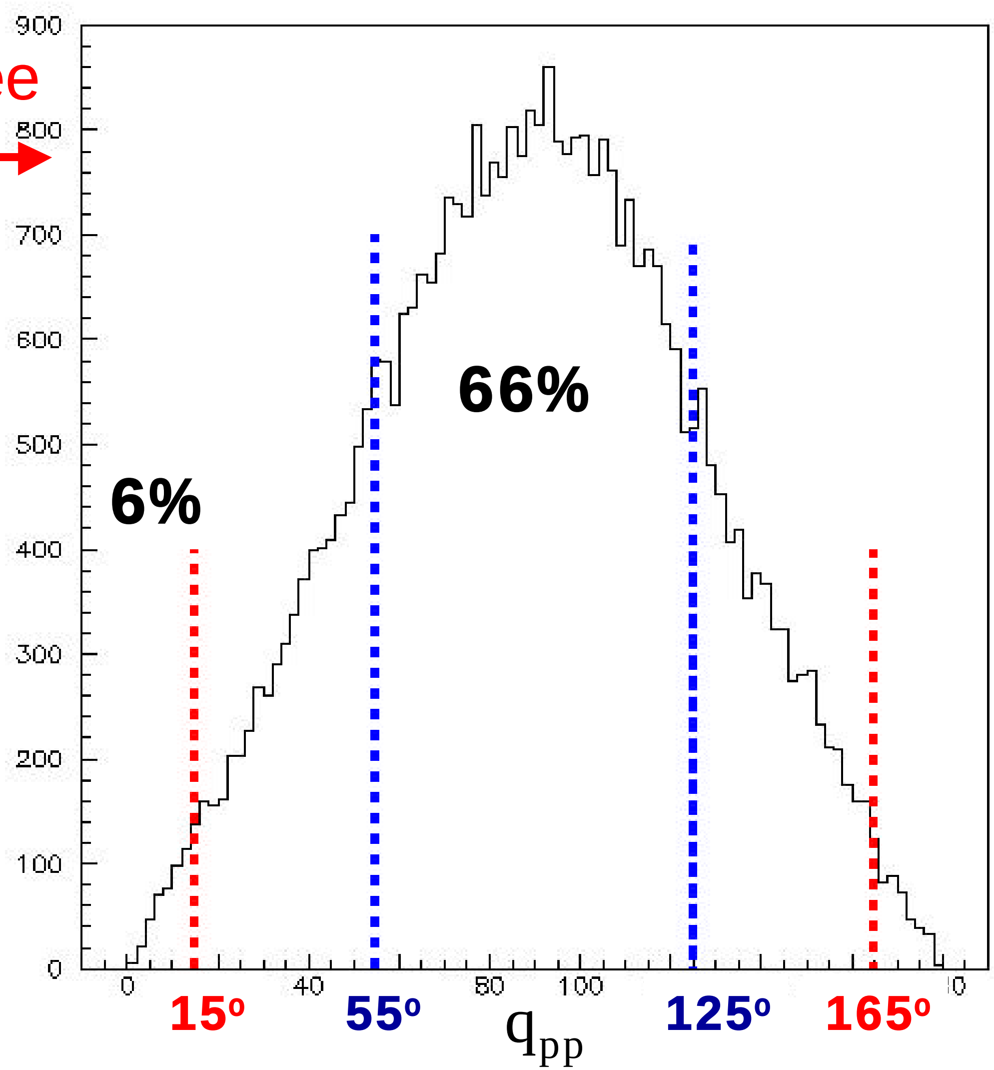
This background contamination is more significant at **small $M^2_{\pi\pi}$ values** and affects mainly the **L.A. region**

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}:

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

$p^+ p^- p^0$ background:

$\theta_{\pi\pi}$ distribution for three pion events →



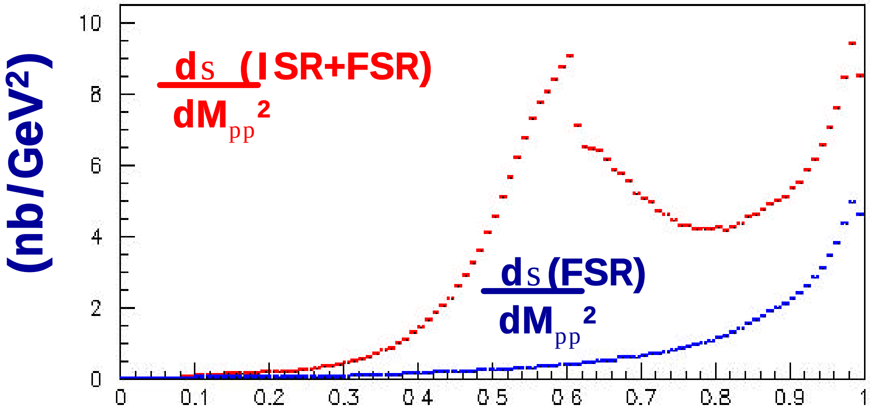
The region outside of the **red lines** is selected in the <u>small angle</u> analysis.

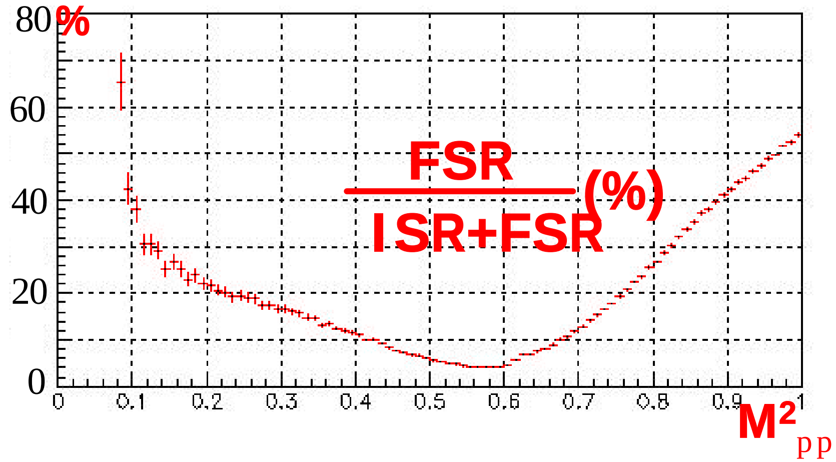
The region between the **blue lines** corresponds to the <u>large angle</u> analysis.

ISR + FSR:

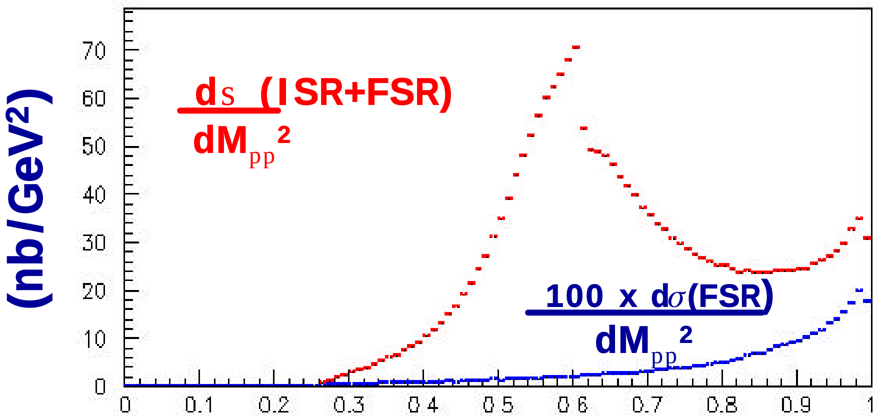
Both **I**nitial **S**tate **R**adiaiton and **F**inal **S**tate **R**adiation are implemented in the EVA-MC-Generator (Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999**)** used for this analysis.

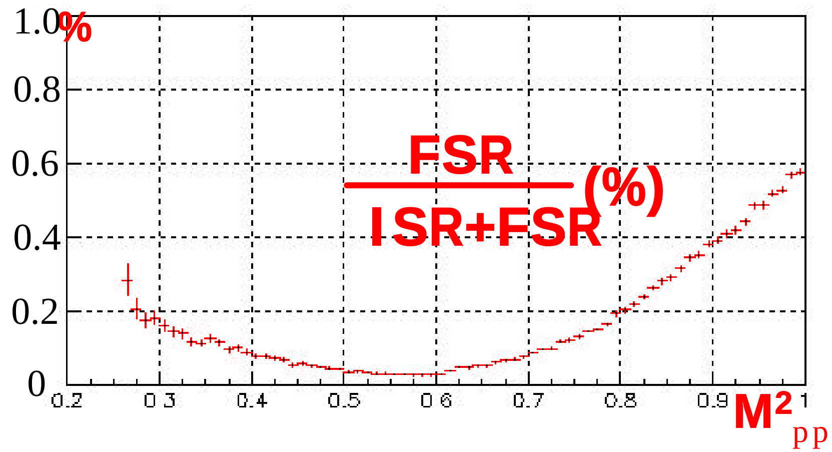
Contributions for ISR and FSR for **55° <** q_{pp}**< 125° (large angle region):**





Contributions for ISR and FSR for q_{pp}**< 15° or** q_{pp}**> 165° (small angle region):**

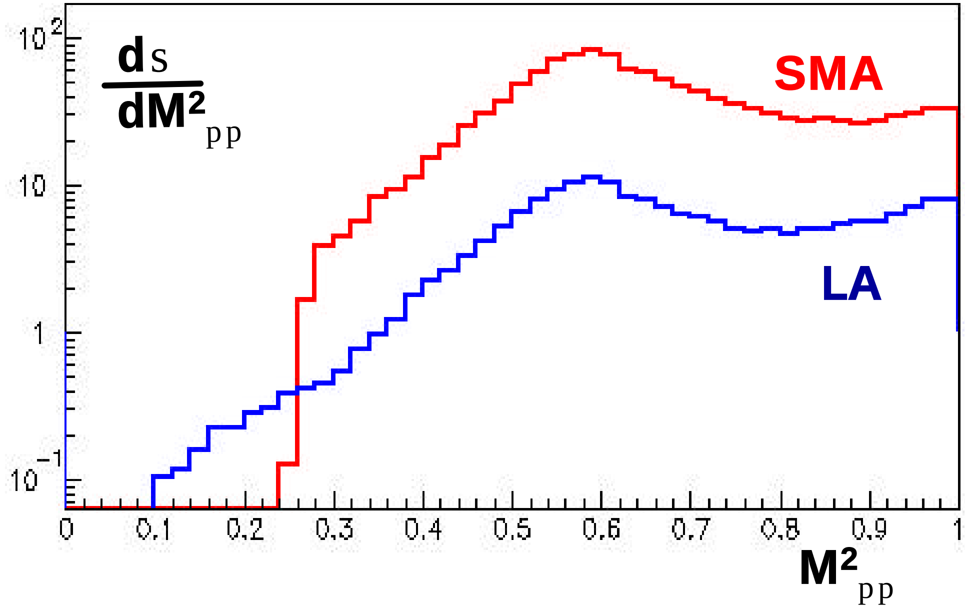




The $\pi\pi$-threshold:

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

- $q_{pp} < 15^o$ **or** $q_{pp} > 165^o$, s = 21nb
- $55^o < q_{pp} < 125^o$, s = 3nb



- At small $M^2_{\pi\pi}$, the small angle analysis is kinematically limited
- The $\pi\pi$-threshold can be accessed with the large angle analysis!!

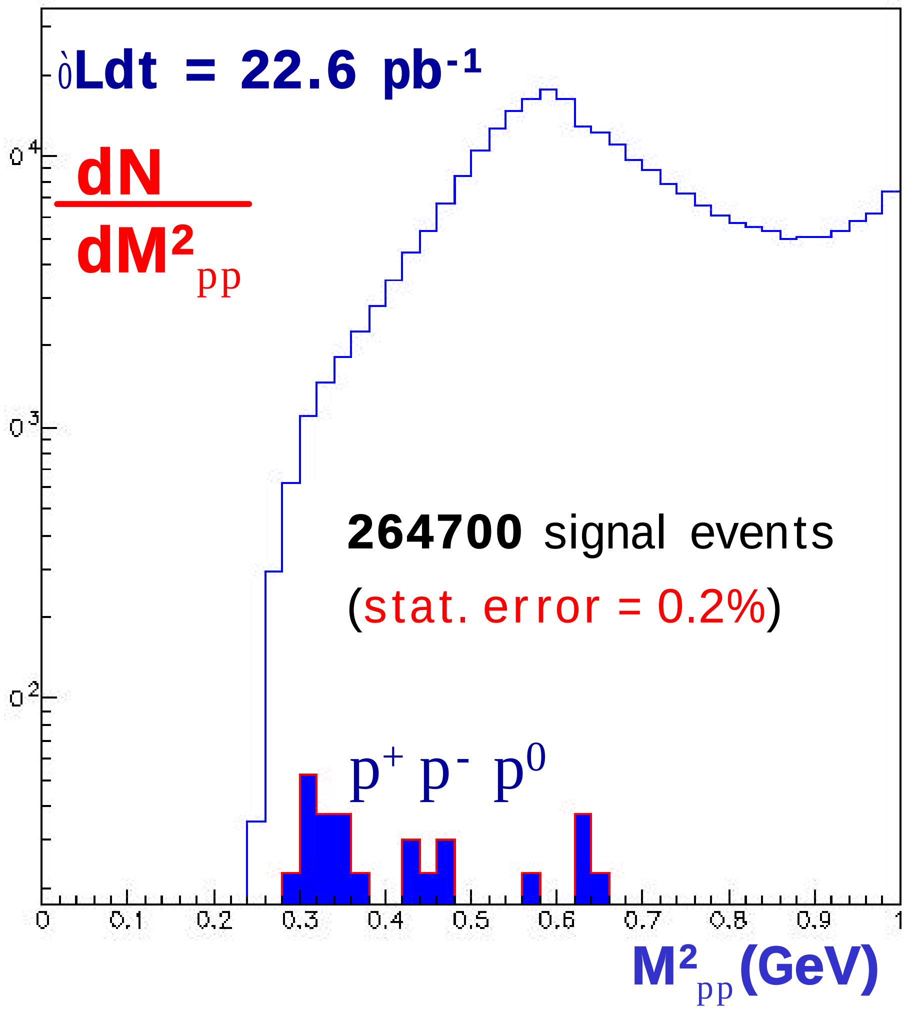
The small angle analysis :

In this analysis, it's not possible to close the kinematics. The direction and energy of the photon in $\pi^+ \pi^- \gamma$ is evaluated using the two tracks in the DC.

However, if two photons are found in the event, 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.

Finally:

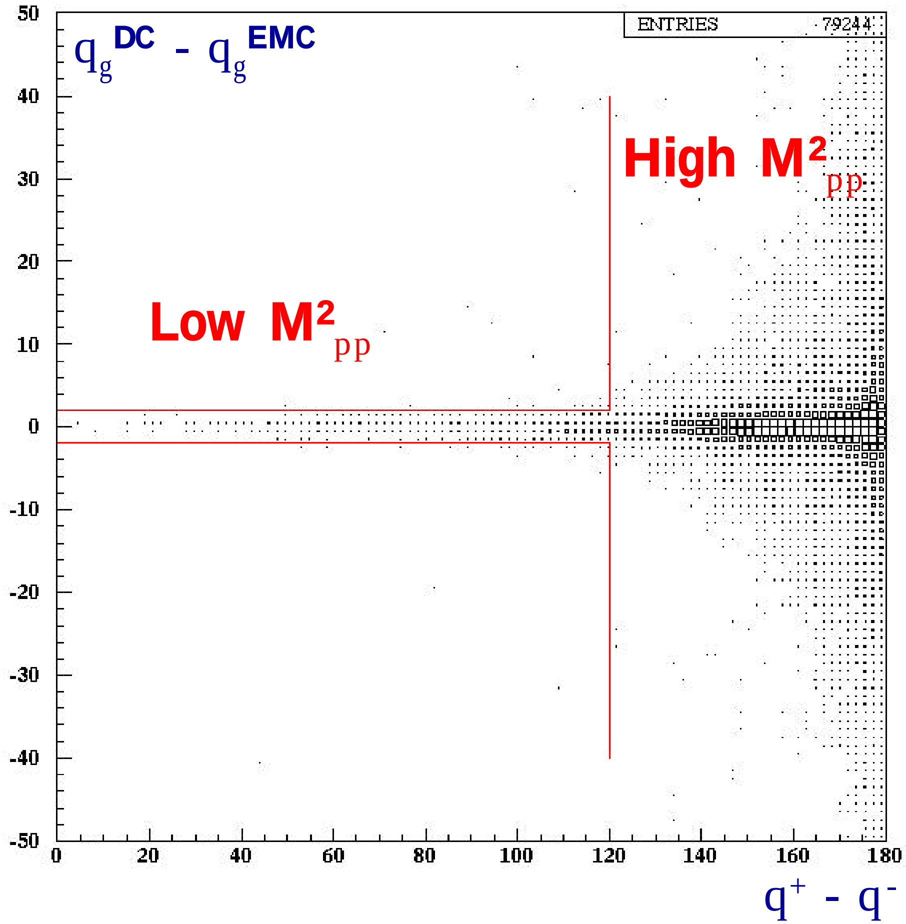
- **265200** events are selected
- **490** background events are expected from MC



The large angle analysis :

Despites the significant three pion background expected at large $\theta_{\pi\pi}$ values, this analysis has the advantage that stringent **constraints on the kinematics** can be applied, since the radiated photon is detected.

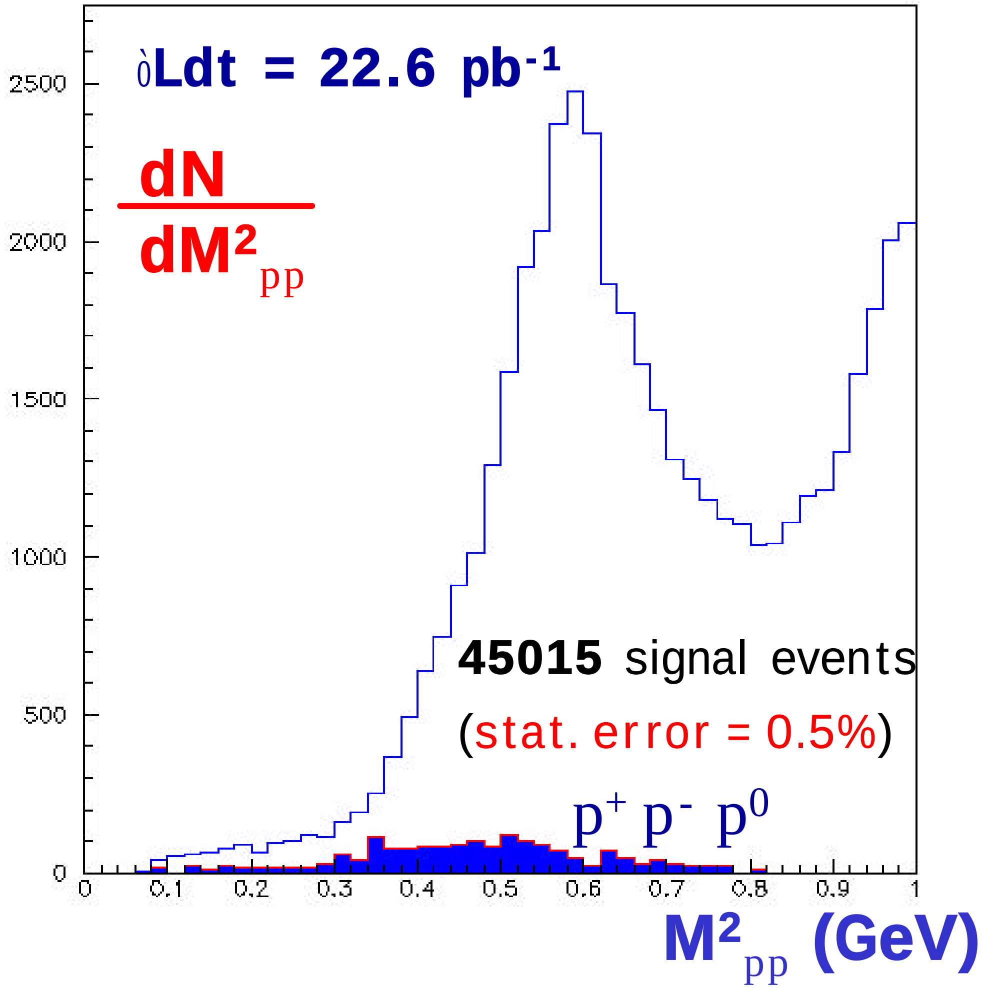
A cut on the difference between the direction of the photon as reconstructed by the EmC and the DC is applied when the two tracks are not collinear, $(q^{+} - q^{-}) < 120^{o}$.



The large angle analysis :

After this cut, the contamination from three pion events is reduced, but it is still present:

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



Effective cross section :

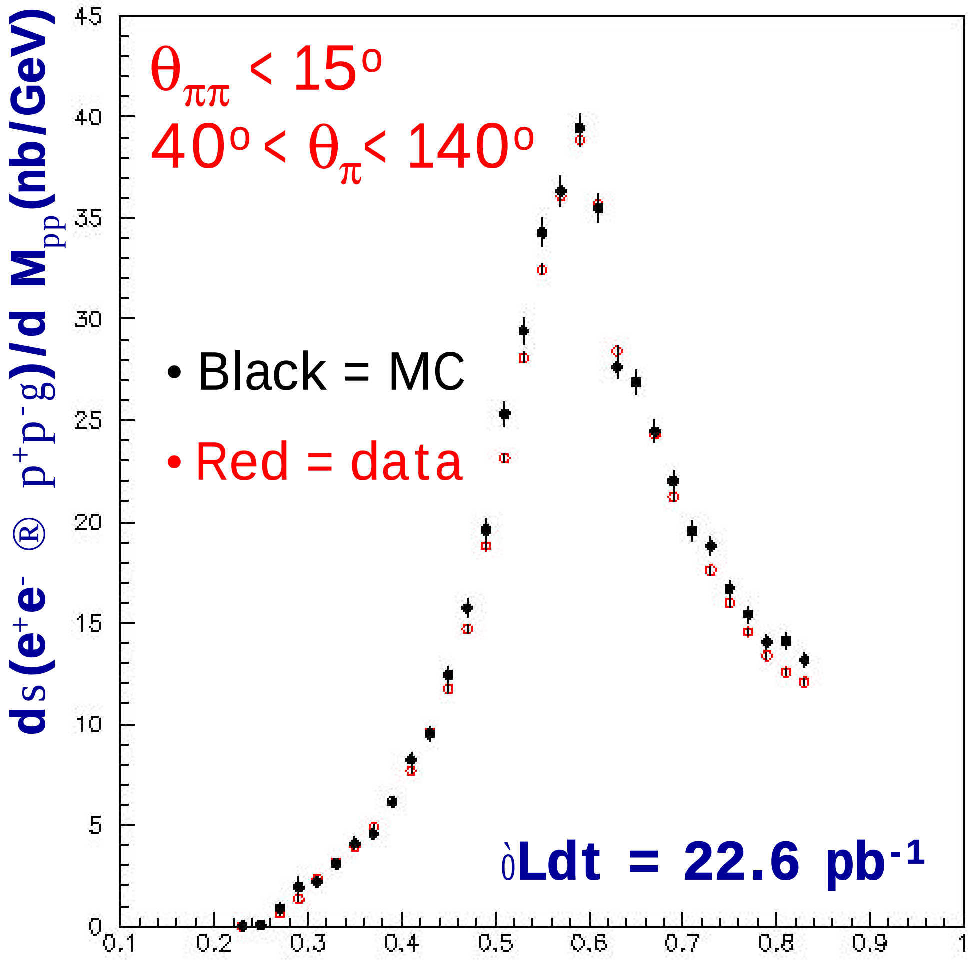
The experimental spectrum, after background subtraction, is compared with the MC:

$$\frac{d\sigma}{dM^2_{\pi\pi}} = \frac{N^{obs} - N^{bkg}}{\Delta M^2_{\pi\pi}} \times \frac{1}{L}$$

Integrated luminosity

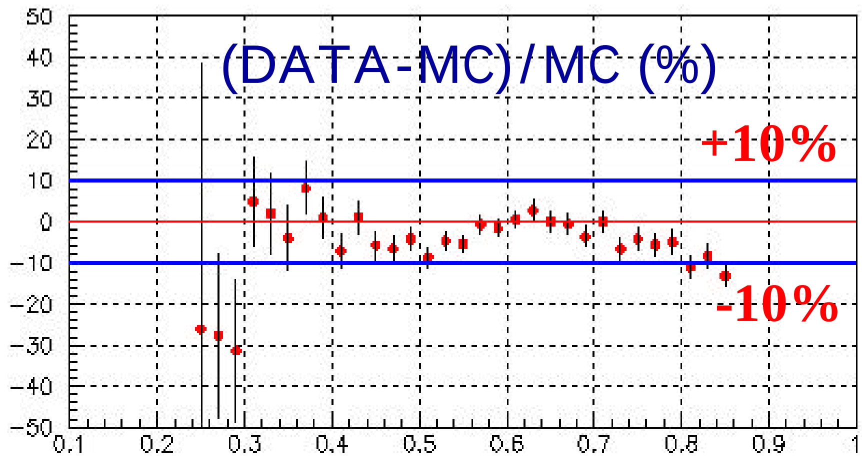
- No unfolding has been applied to the data spectrum.
- Some corrections have been applied to the MC spectrum to have a **more realistic description of experimental efficiencies**:
  - the **trigger** and **vertex reconstruction efficiencies** have been studied using **data**;
  - the **photon detection efficiency**, as a function of the photon energy, has been measured using radiative bhabha events
  - the average efficiency is ~ 60%
- the **Luminosity** is measured using the Bhabha scattering at large angles

Prel. Results: S. A. region



• MC: **LO** EVA generator with a lower cut on $\theta_{\pi\pi}$ at 0.1°

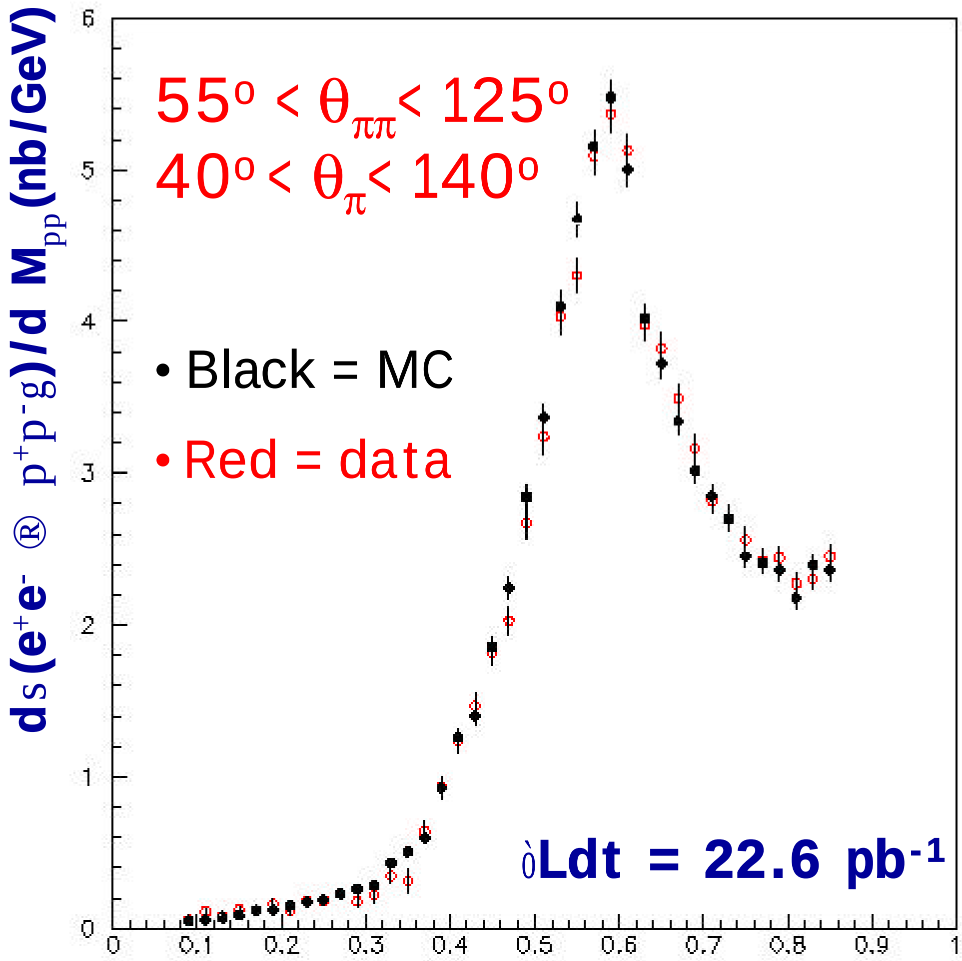
• For a realistic comparison the **NLO** generator is needed: This generator is available since Dec. 01* and will be inserted into the official **KLOE MC** soon.



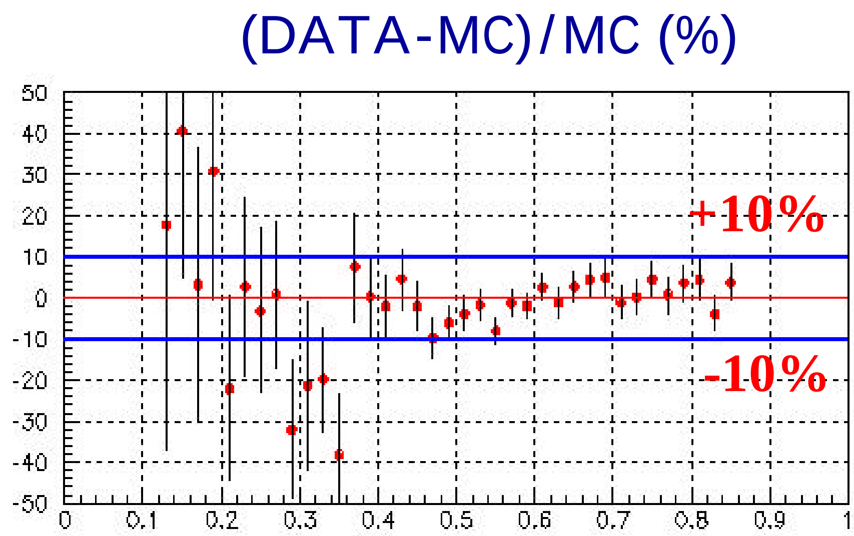
M²pp(GeV)

*Kühn, Czyz, Rodrigo, Szopa, hep/0112184

Prel. Results: L. A. region



The largest error comes from the background subtraction



$M^2_{\pi\pi}$(GeV)

Conclusions

The performance of DAΦNE has considerably increased in the last two years, resulting in

- 200 pb^{-1} collected till Dec.2001
- First results for 20 pb^{-1} taken in 2000 for

  $BR(K_S \to \pi^+\pi^-)/BR(K_S \to \pi^0\pi^0)$, $BR(K_S \to \pi e \nu)$

  η-η' mixing angle

  $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ and $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decays

The analysis of the 2000 data has also shown the feasibility of the *radiative return method*:

- The statistical error is already better than 1%
- Systematic errors: Contamination from FSR and $\pi^+\pi^-\pi^0$ in large angle region;
  luminosity measurement;
  systematics on efficiencies still under study;
  agreement with MC better than a few percent
- Luminosity measurement precision is at the percent level
- Current (EVA-) MC-generator (O(α), coll. rad., FSR) has a precision of 2-3%

Outlook

The collected statistics of $175 pb^{-1}$ is enough to measure the hadronic cross section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ with a statistical error of

~ 0.2% in the small angle region

~ 0.4% in the large angle region

Further future improvements:

- The NLO generator of **Kühn et al**. was released in December 2001 and will improve the theoretical description of ISR (the uncertainty from unaccounted higher order ISR is estimated to be around 0.5%)

- Collaboration with other theoretical groups (**F. Jegerlehner, A.Höfer, S.Jadach**) started in order to bring an improvement in the knowledge of the radiation function and also in the luminosity measurement

- Systematic errors on the efficiencies will be reduced with the larger statistics available

Improved results are expected before end of the year!

Luminosity measurement

DAΦNE does not have Luminosity Monitors at small angles

☞ **use KLOE itself for measurement :**
Large Angle Bhabhas (s $_{eff}$ = 425nb)

- **55° < q $_{+-}$ < 125 °**
- **Acoll. < 9 °**
- **E$_{+-}$ ³ 400 MeV**

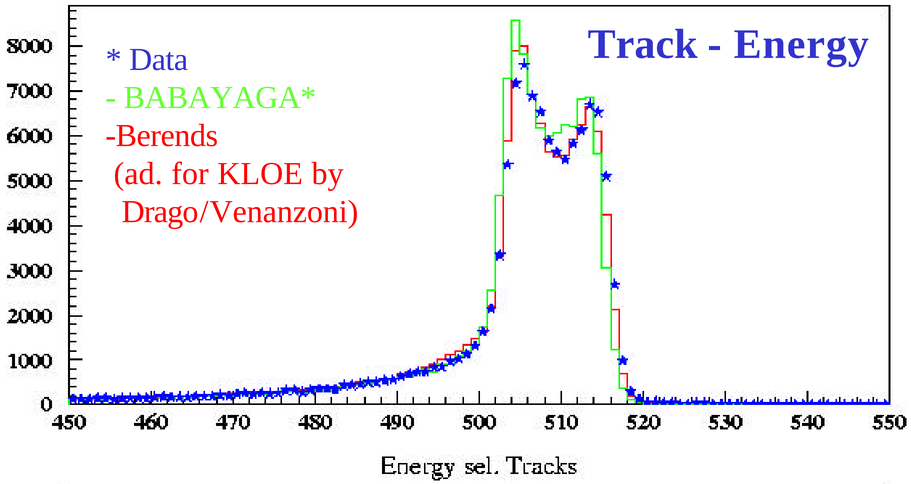
$$\int L dt = \frac{N_{LAB}(\Theta)\cdot(1-d_{Background})}{s^{MC}_{LAB}(E)}$$

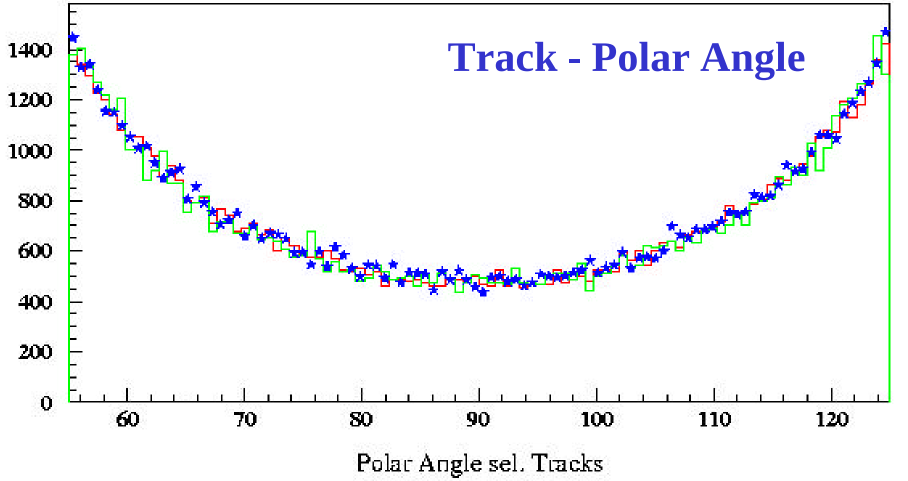
LAB - Candidates (Systemat., Accept.)

Background (γγ, ππγ, ...)

Theoret. Generators with rad. corrections

Berends (Drago/Venanzoni)
BABAYAGA*





☞ **Luminosity- Measurement on Percent Level**
agreement with independent γγ-Counter < 1%

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