Measurement of the hadronic cross sections using a radiated photon with the KLOE detector

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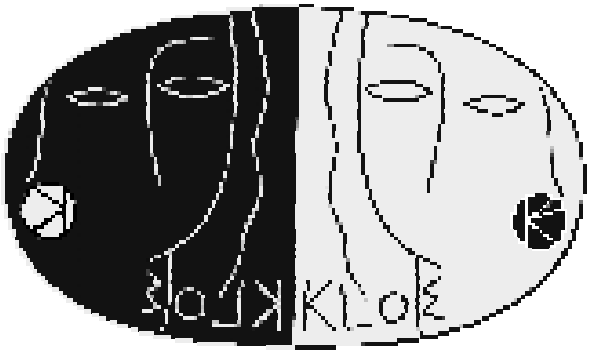
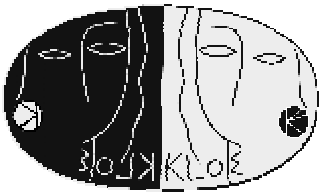


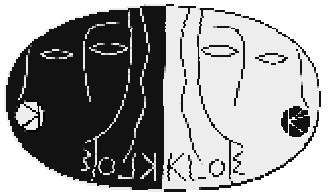
X EURODAPHNE Collaboration Meeting
Granada 10th-12th February, 2000



Outline

- Motivation:
  - $(g-2)_\mu$ and $\alpha_{em}(m_Z^2)$
- Measurement of $\sigma(e^+e^- \to hadrons)$:
  - energy scan
  - Initial State Radiation
- Measurement of $\sigma(e^+e^- \to \pi^+\pi)$ *via* a tagged photon in $e^+e^- \to \pi^+\pi^-\gamma$:
  - Results from MC
  - Preliminary results from data
- Conclusions

Motivation



Anomalous Magnetic Moment of the muon:

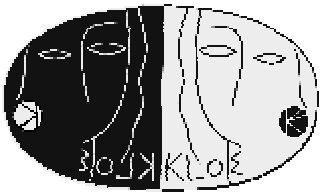
- $\alpha_\mu^{theor} = (g_\mu-2)/2 = \alpha_\mu^{QED} + \alpha_\mu^{had} + \alpha_\mu^{weak}$ $(+ \alpha_\mu^{new\ physics}\ ?)$
  - $\alpha_\mu^{QED} = (1\ 165\ 847.07 \pm 0.03) * 10^{-9}$
  - $\alpha_\mu^{had} = (\quad 68.50 \pm \mathbf{1.60}) * 10^{-9}$
  - $\alpha_\mu^{weak} = (\quad \mathbf{1.51} \pm 0.04) * 10^{-9}$

$\alpha_\mu^{theor} = (1\ 165\ 917.08 \pm \mathbf{1.6}) * 10^{-9}$

- $\alpha_\mu^{exp} = (1\ 165\ 923 \pm \mathbf{8.5}) * 10^{-9}$
- $\delta\alpha_\mu^{exp} \rightarrow 0.4 * 10^{-9}$ by E821 experiment at Brookhaven (**a factor 20!**)
- By reducing $\delta\alpha_\mu^{had}$ to the same level, it is possible to isolate α_μ^{weak} and looking for new physics ☺
- $\delta\alpha_\mu^{had}$ is, however, dominated by low energy effects, which are not computable by pQCD ☹
- These hadronic contributions can be expressed in terms of $\sigma(e^+e^- \rightarrow$ *hadrons*) in the range $\sqrt{s}<5$ GeV via a **dispersion integral:** ☺

  $\alpha_\mu^{had} = 1/4\pi^3 \int dQ^2\, \sigma(e^+e^- \rightarrow hadrons, Q^2)\, K(Q^2)$

Why DAPHNE is important for α_μ?



The energy range of DAPHNE plays a central role for α_μ: about 77% of $\delta\alpha_\mu^{had}$ comes in the region $2m_\pi < \sqrt{s} < 1.4$ GeV (66% around the ρ meson)

- An accuracy of 1% on $\sigma(e^+e^- \to hadrons)$ up to 1.4 GeV $\Rightarrow \delta\alpha_\mu^{had} = 0.7 * 10^{-9}$ (1% in [1.40 3.10]GeV $\Rightarrow \delta\alpha_\mu^{had} = 0.15 * 10^{-9}$)

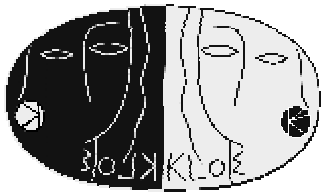
$\sigma(e^+e^- \to$ hadrons) plays also an important role for $\alpha_{em}(m_Z^2)$!!!

The standard way to measure $\sigma(e^+e^- \to hadrons, Q^2_{hadr})$ is to perform an energy scan of the beams:

- At DAPHNE this is not foreseen at short term☹

- Alternative Approach☺: (A.B.Arbuzov et al., JHEP 12 (1998) 009, S.Binner et al. hep-ph/9902399, M.Konchatnij et al. hep-ph/9903383, S.Spagnolo, Eur.Phys.J. C6 637-645(1999))
  - run at $\sqrt{s} = M_\phi$ and look for the process $e^+e^- \to hadrons+\gamma$, where γ is emitted in the initial state (ISR)
    - $d\sigma(e^+e^- \to hadrons+\gamma)/dQ^2 = \sigma(e^+e^- \to hadrons, Q^2) H(Q^2, \cos\theta_0)$
    - Q^2 is the invariant mass of the hadronic system, $Q^2 = M_\phi^2 - 2 M_\phi E_\gamma$
    - Q^2 changes continuously $4m_\pi^2 < Q^2 < M_\phi^2$

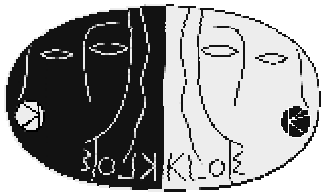
ISR vs Energy scan



The method using ISR is not a surrogate for an energy scan, but has its value in itself. It does not make, however, an independent energy scan unnecessary.

- ISR has the merits that:
  - the error of the luminosity enters the Q^2 spectrum only once, i.e. is the same for the full centre-of-mass energy range of electron positron annihilations
  - the error of the energy of electron and positron enters the Q^2 spectrum only once
  - the data are taken as a by-product within the standard research program of KLOE without changing any part of the experimental set-up
- ISR
  - is restricted to $Q^2 < M_\phi^2$
  - depends on the precise knowledge of the photon emission including radiative corrections
  - needs an efficient suppression of the radiation from the particles in the final state (FSR) (~1%)
  - requires an higher luminosity than an energy scan due to the suppression by the fine structure constant α

ISR vs FSR



ISR

is peaked at small angle of the photon

is enhanced by the ρ resonance ($\sqrt{Q^2}$=0.77 GeV $\Leftrightarrow E_\gamma$=220 MeV)

FSR

follows the angular distribution of the pions

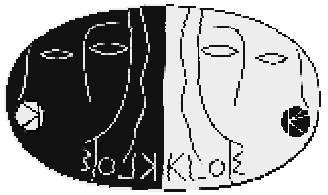
is peaked at small E_γ

We'll now restrict to the 2 pion final state: $e^+e^- \rightarrow \pi^+\pi^-\gamma$

ISR+FSR

$\theta\gamma_{MAX}\rightarrow$ $\sigma_{ISR+FSR}$(nb) $\theta\gamma_{MIN}$ $\downarrow$	**10°**	**20°**	**30°**	**40°**
7°	0.87±0.01	2.60±0.02	3.65±0.03	4.44±0.03
10°	-	1.72±0.02	2.77±0.02	3.56±0.03
20°		-	1.05±0.01	1.83±0.01
30°			-	0.79±0.01

ISR vs FSR for $e^+e^- \to \pi^+\pi^-\gamma$



Signal over Background

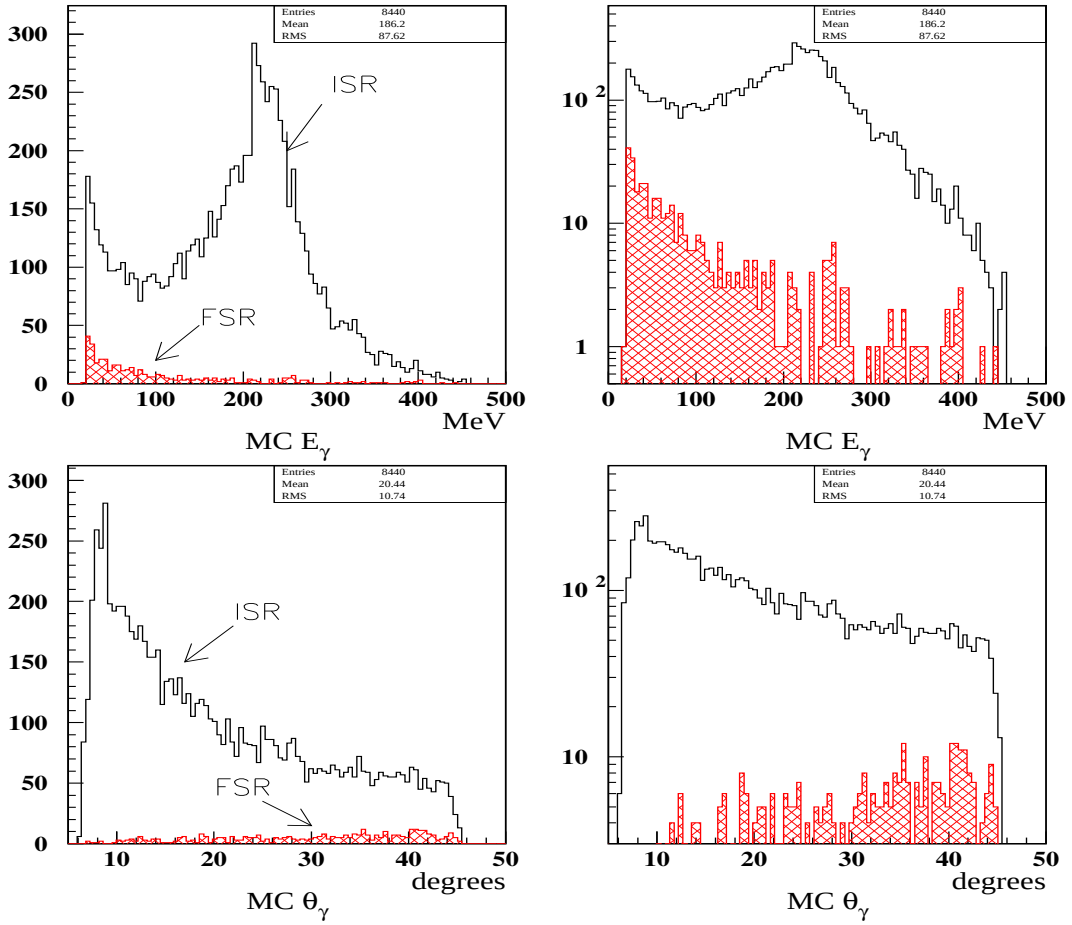
$\theta\gamma_{MAX}\to$ $\sigma_{ISR}/\sigma_{(ISR+FSR)}$ $\theta\gamma_{MIN}$ $\downarrow$	**10°**	**20°**	**30°**	**40°**
7°	0.99±0.01	0.99±0.01	0.98±0.01	0.97±0.01
10°	-	0.98±0.02	0.97±0.02	0.96±0.01
20°		-	0.96±0.01	0.94±0.01
30°			-	0.92±0.01

The acceptance region should be chosen as a good compromise between statistics and low background

Energy distributions are quite different and provide an additional cut to reduce FSR at 1% level

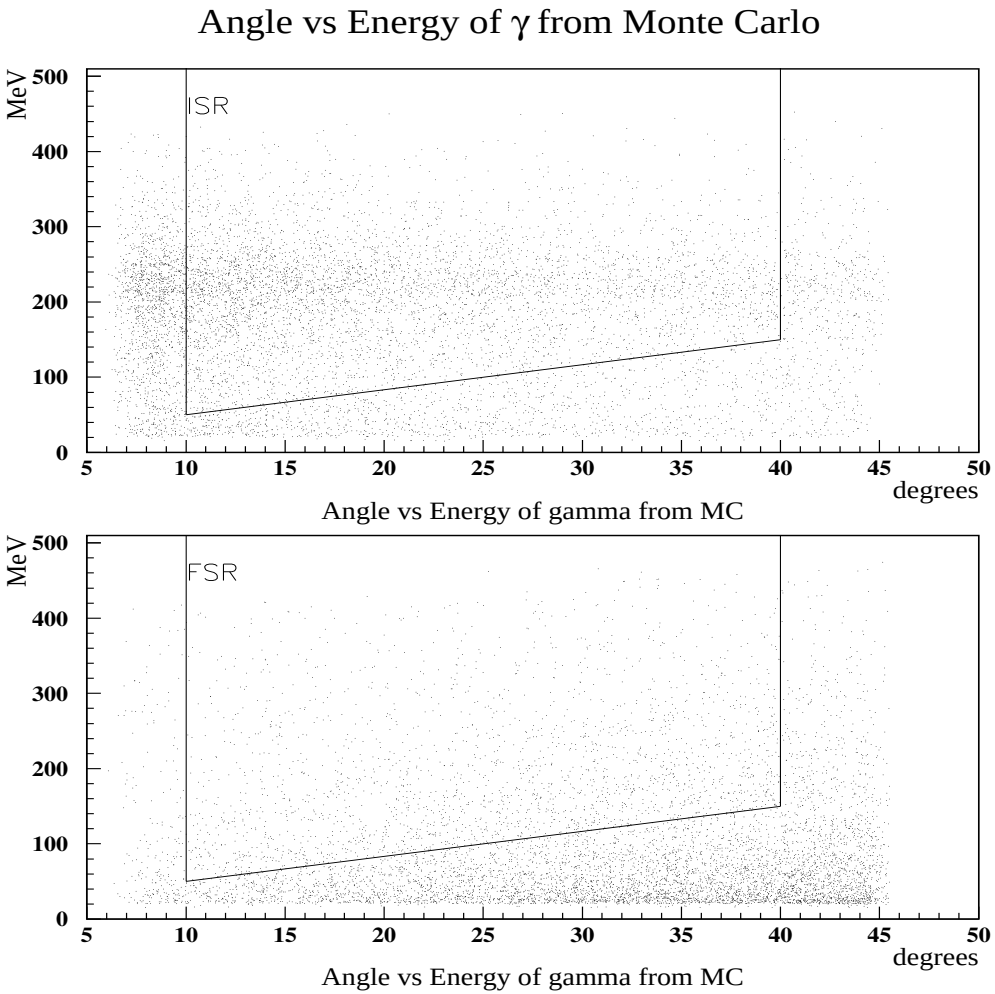
ISR vs FSR $e^+e^- \to \pi^+\pi^-\gamma$

Energy and polar angle of γ from MC, $7^o \subseteq \theta_\gamma \subseteq 45^o$



FSR can be strongly reduced by a cut on $E_\gamma - \theta_\gamma$ plane

Suppression of FSR



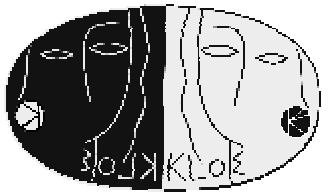
- E_γ>50 MeV
- $10° < \theta_\gamma < 40°$
- Cutting in $E_\gamma - \theta_\gamma$ plane
- $20° < \theta_\pi < 160°$
- more kinematical cuts

⇓ ⇓

ISR/(ISR+FSR)>99%

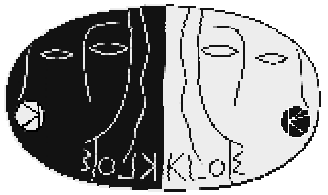
σ_{ISR}~3.5nb

What about $\phi \to \pi^+\pi^-\gamma$ background?



- The direct decay $\phi \to \pi^+\pi^-\gamma$ delivers an additional background which must be reduced at 1% level by suitable cuts
- The main problem to estimate this background is the poorly known parameters of the meson f_0, through which the decay is assumed to go: $\phi \to f_0\,\gamma \to \pi^+\pi^-\gamma$
- In particular, depending on the relative phase between the QED processes (ISR and FSR) and the direct decay, this background can be enhanced ("constructive" inter.) or suppressed ("destructive" inter.)
- A lot of models have been developed in the past years for the f_0 (exotic qq, 4q, KK, glueball, etc…) leading to different predictions for the BR($\phi \to f_0\,\gamma$) (from 10^{-6} to 10^{-4});
- Most of them, however, don't solve the sign ambiguity ☹
- Experimental value (from CMD2 collaboration at Novosibirsk):
  - BR($\phi \to \pi^+\pi^-\gamma$) ^{exp} $=(0.41 \pm 0.013)\times 10^{-4}$
  - BR($\phi \to f_0\gamma$) ^{exp} $=(1.93 \pm 0.68)\times 10^{-4}$ **destructive inter**.

Influence of $\phi \to \pi^+\pi^-\gamma$ on $\sigma(e^+e^- \to \pi^+\pi^-)$ by tagging a photon in the reaction $e^+e^- \to \pi^+\pi^-\gamma$

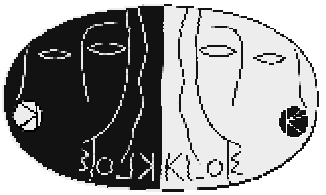


- The effect of the decay $\phi \to \pi^+\pi^-\gamma$ on the measurement of $\sigma(e^+e^- \to \pi^+\pi^-)$ at DAPHNE (by using ISR events) has been recently studied (K.Melnikov et al., hep-ph/0001064), by using three different models for the "f_0".
  - These models predict a BR($\phi \to f_0\gamma$) ranging from 0.4 to $2.5 \cdot 10^{-4}$

- Although the $\phi \to \pi^+\pi^-\gamma$ background can be strongly reduced by looking at small θ_γ, its contribution in the range
  0.836 GeV^2 $<Q^2<$ 0.996 GeV^2 (20MeV $<E_\gamma<$ 100 MeV) is still of few percent, even for destructive interference.

- More information needed on the nature of the above decay in order to reach a background suppression at 99%; information from the decay $\phi \to \pi^0\pi^0\gamma$ are eagerly awaited...

How good is the acceptance of the KLOE detector for photons at small angle?



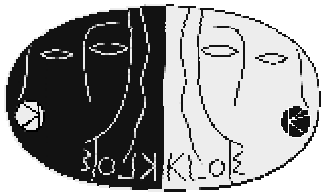
- The acceptance of the KLOE calorimeter is between 20° and 160°
  - in this range the detection efficiency is very high (~90%)
  - but it dramatically drops outside (θ_γ <20° or θ_γ >160°)

How to increase the acceptance below 20° ?

By using the QCAL's (calorimeters surrounding the focusing quadrupoles)!!!
  - These detectors cover the region 10°< θ_γ <20°, 160°< θ_γ <170° and can be used to tag the photons in this angular region

- Very important (γ tagging): the direction of the photon is obtained by momentum conservation with the DC:
  - $p_\gamma = -(p_{\pi+} + p_{\pi-})$ $\delta p_\gamma \sim 2$ MeV, $\delta\theta_\gamma \sim 7$ mrad

$e^+e^- \to \pi^+\pi^-\gamma$ selection criteria ($10° < \theta_\gamma < 40°$, $20° < \theta_\pi < 160°$)



- 1 charged vtx + 1 "prompt" neutral cluster in EMC or QCAL

  ε_{vtx} = 95%
  ε_γ = 86%
  } ε_{sel} = 82%

- Compute the invariant mass for background suppression ($|\Delta M| < 10$ MeV)

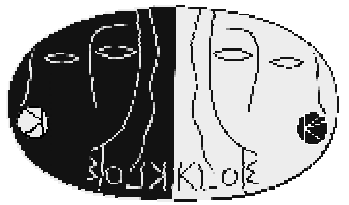
  $\varepsilon_{\Delta M}$ = 92%

- Cuts in $E_\gamma - \theta_\gamma$ plane to reject FSR

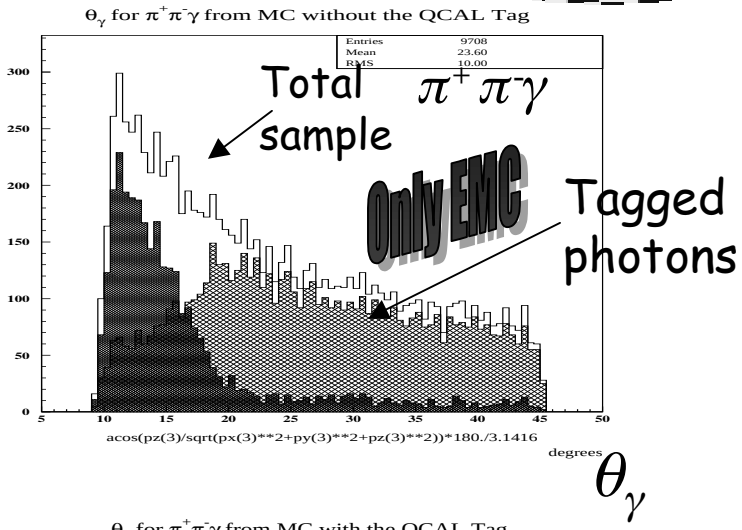
  ε_γ = 70%

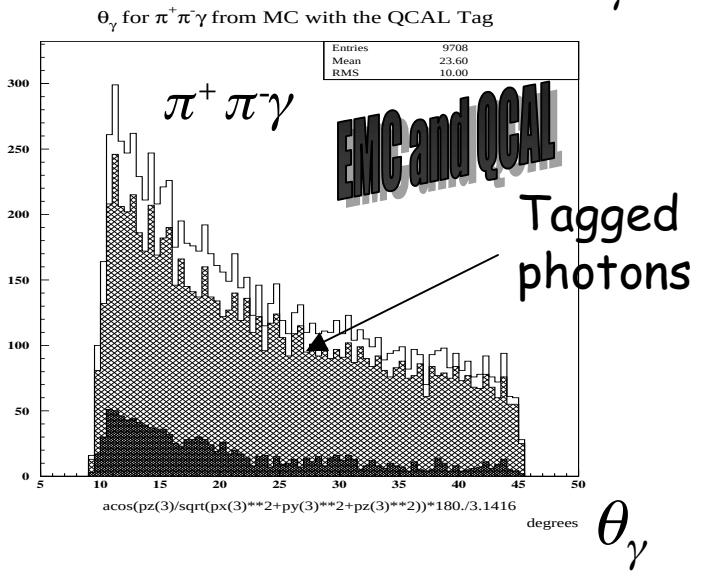
ε_{TOT} = 50%

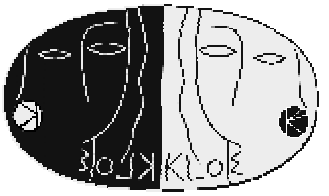
Photon Tagging efficiency with the QCAL



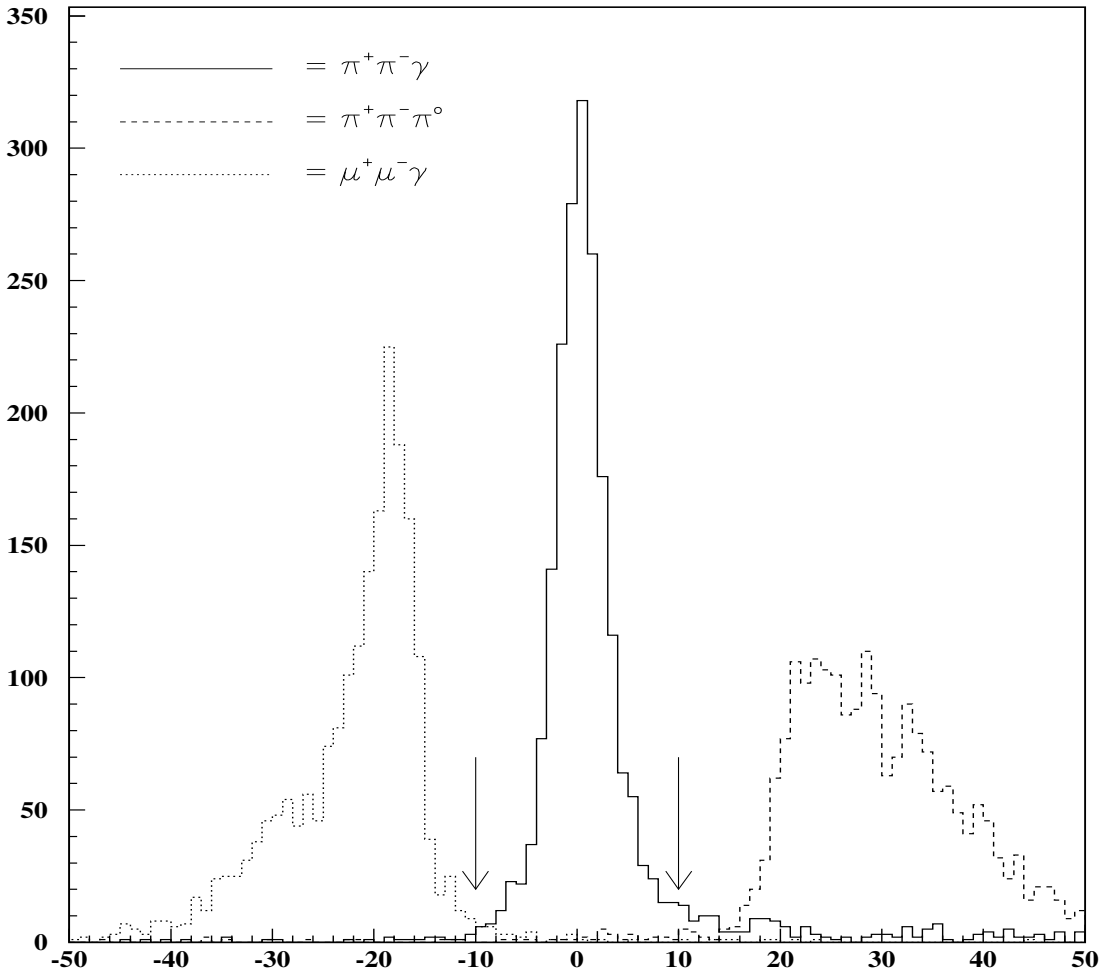
- The tagging efficiency for photons from $\pi^+\pi^-\gamma$ events has been studied from MC
- The efficiency of the EMC is
  - ~90% in the range $20° < \theta_\gamma < 160°$
  - ~42% in the range $10° < \theta_\gamma < 20°$
- By using the QCAL, the efficiency in the range $10° < \theta_\gamma < 20°$ increase from 42%→86%
- QCAL's output has been tested with $\pi^+\pi^-\pi^0$ data
  - A nice agreement has been found with the MC





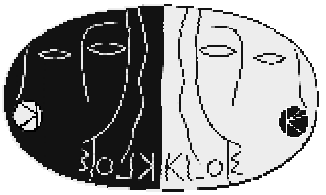


M_ϕ- $\pi^+\pi^-\gamma$ Reconstructed invariant Mass



$$\Delta M = M_\phi - \sqrt{p^2_+ + m^2_\pi} - \sqrt{p^2_- + m^2_\pi} - |p_+ + p_-|$$

Preliminary results from data



KLOE data taking

- First collision on 14th April 1999
- Short period of ϕ scan
- 4 periods of continuous data taking:
  - 10 days in August
  - 1 week in October
  - 1 week in November
  - 3 weeks in December
- Total integrated luminosity:
  L~2.4 pb^{-1} (corresponding to a relative mean luminosity of $2 \cdot 10^{30}$ cm^{-2} sec^{-1})

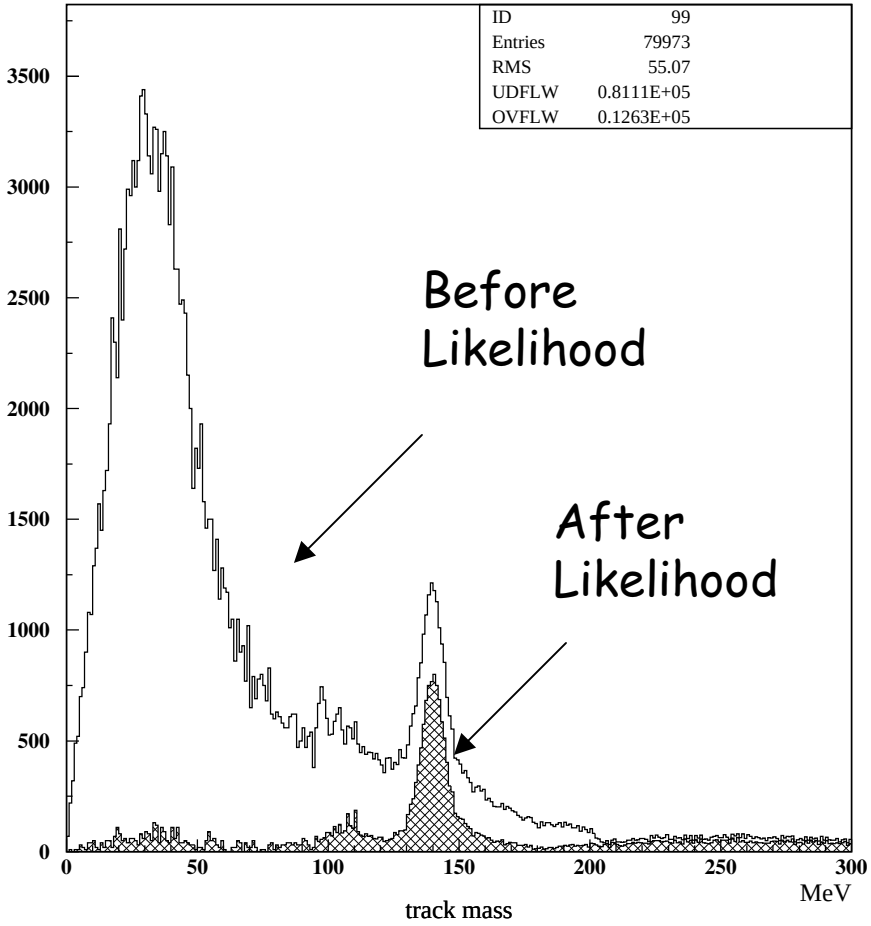
$\pi^+ \pi^- \gamma$ analysis

- Analysis has been performed with 1.8 pb^{-1} of reconstructed data
- Sample obtained after background rejection with a fast calorimeter filter and event classification
- First analysis performed only by selecting γ's in the calorimeter
- Analysis on the sample with γ's on the QCAL has just started...

Bhabha's rejection

- Large contamination from Bhabha's which survive the BCKG filter and satisfy the following selection criteria:
  - 1 charged vtx and ≥1 "prompt" neutral cluster in EMC or QCAL
- This contamination can be strongly reduced by a Likelihood method based on:
  - Time of Flight of charged particles
  - Shape and energy deposition of the "charged" cluster

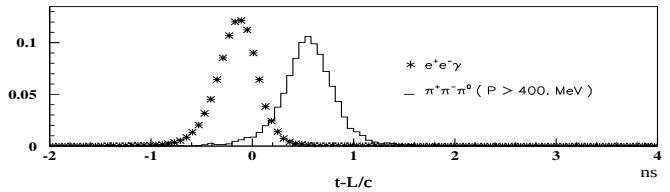
$\varepsilon_{Likelihood}$~97%

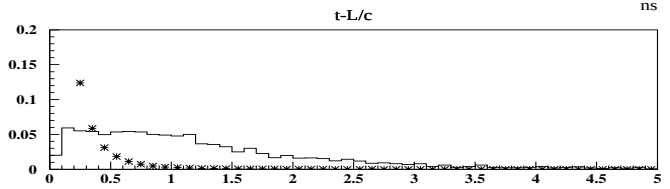


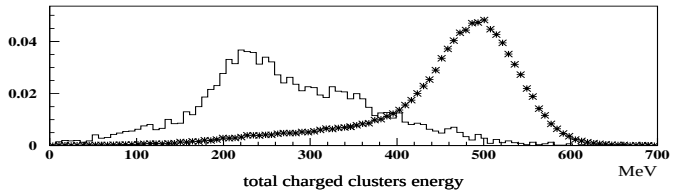
$25° < \theta_\gamma < 155°,\ 50° < \theta_\pi < 130°$

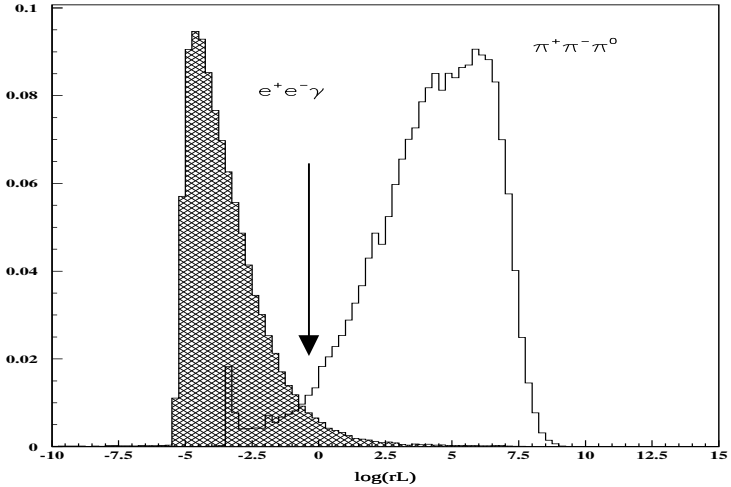
Likelihood method

- Two control samples are used to find the variables that best separate electrons from pions:
  - $\pi^+\pi^-\pi^0$ with p>400 MeV are used for $\pi^+\pi^-\gamma$
  - $e^+e^-\gamma$ surviving the BCKG online filter
- A probability function $f_i(x_i)$ is fitted for each distribution
- An absolute likelihood function is defined for electron and pions:
  - $aL^{e,\pi} = \prod f_i^{e,\pi}(x_i)$
- A relative Likelihood rL is defined as the following ratio:
  - $rL = aL^{\pi}/aL^{e}$



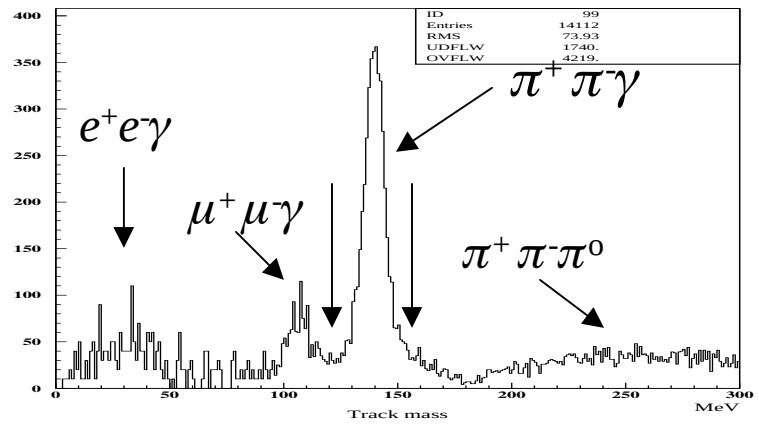


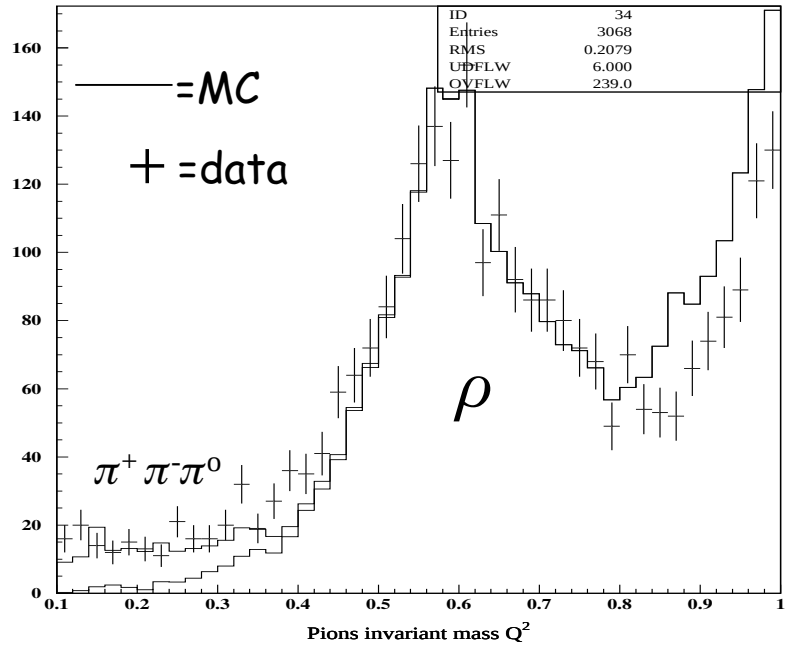




Comparison of Q^2 distribution from data and MC

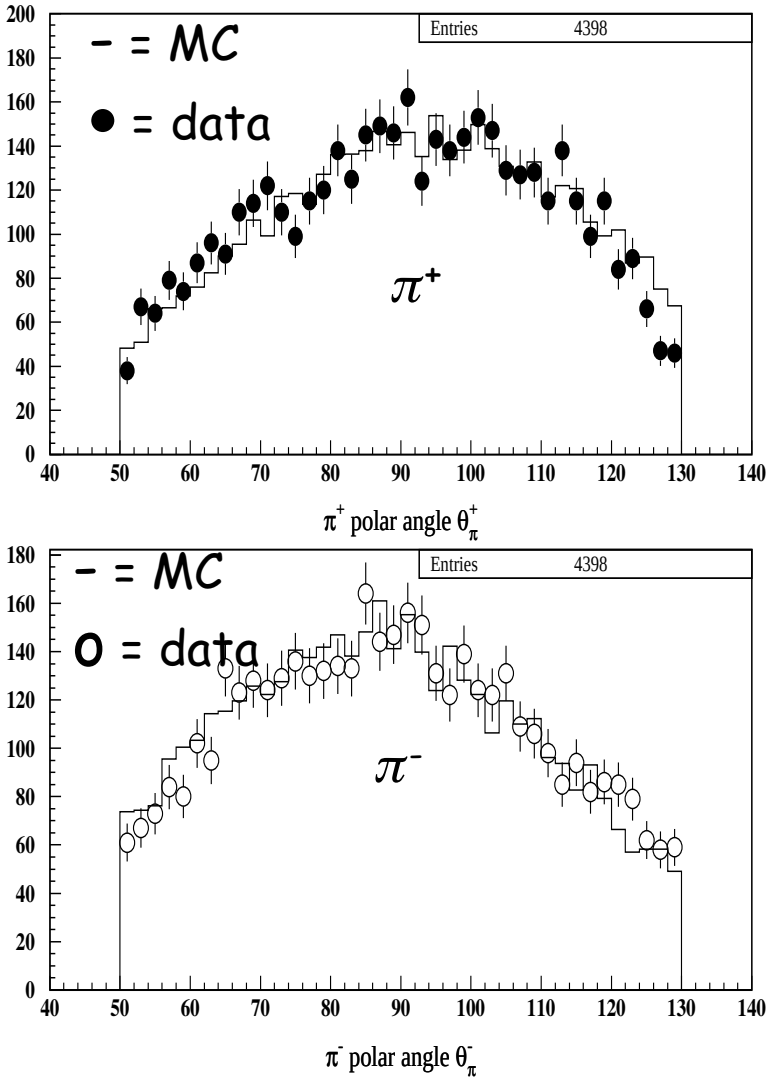
- After using the likelihood method, $\pi^+\pi^-\gamma$ are selected: ($|mass_{trk}-139.5|<10$ MeV)
- A cut on $60° < \theta_\gamma < 120°$ is added
- The Q^2 spectrum is then compared with the expected one from Monte Carlo
- The distributions show an NICE agreement
- The deficit for data at $Q^2 > 0.8$ GeV^2 has been understood:
  - it is due to the cosmic veto of the trigger, which in that range is not well simulated from MC
- The quality of the FSR parametrization can be tested in this kinematical region (FSR/(ISR+FSR)~20%)



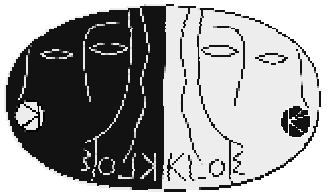


Testing the model for the FSR

- In order to test the MC description for the FSR, S.Binner *et al.* (hep-ph/9902399) have proposed to use the $\pi^{\pm}$ forward-backward asymmetry.
- In the region $60° < \theta_{\gamma} < 120°$, $50° < \theta_{\pi} < 130°$ the asymmetry of $\pi^{\pm}$ angular distribution should be statistically significant (20% for our parametrization)
- A comparison with data indeed shows the expected asymmetry
- Again the agreement with the MC is very good



Conclusion



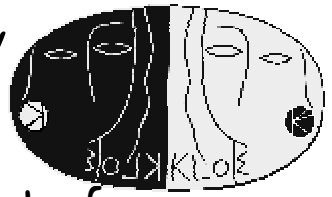
- A method to measure $\sigma(e^+e^- \rightarrow hadrons)$ by using the reaction $e^+e^- \rightarrow hadrons+\gamma$ at DAPHNE has been recently proposed
  - This method, which is complementary to the beam energy scan, allows to scan the region $Q^2<1GeV$ while running at fixed energy $\sqrt{s}= M_\phi$

- The final goals are:
  - the reduction of $\delta\alpha_\mu^{had}$ to $0.7 * 10^{-9}$, corresponding to $\sigma(e^+e^- \rightarrow hadrons)$ at 1% level ($\delta\alpha_\mu^{had} \Rightarrow 0.15 * 10^{-9}$ with 1% error in the region [1.40 3.10]GeV)
  - the reduction of $\delta\alpha_{em}^{had}(m^2_Z)$ which is right now the limiting factor for precision tests and prediction of the SM

- MC studies for the measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ using the process $e^+e^- \rightarrow \pi^+\pi^-\gamma$ show that KLOE is able to do this measurement with the required accuracy
  - Efficiencies, Systematics, Statistics, Background…

(see also A.Denig talk in DAPHNE99)

Conclusion *cont'd*



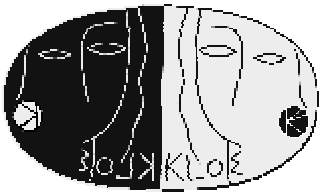
- The effect of the direct decay $\phi \to \pi^+\pi^-\gamma$ on the measurement of hadronic cross section has been studied by MC
  - Effect of few % in the region E_γ<100 MeV
  - More information from $\phi \to \pi^0\pi^0\gamma$ are needed

- Preliminary results on $\pi^+\pi^-\gamma$ from data in the region 60°< θ_γ <120°, 50°< θ_π <130° show a good agreement with the MC on:
  - Q^2 distribution
  - $\pi^\pm$ angular distribution

- We are now improving the analysis:
  - Adding the QCAL information
  - Refining the analysis for photon in the calorimeter
  - Reducing the FSR at the required value (<1%)

...We are ready for more data...

The KLOE detector



- Electromagnetic Calorimeter (EMC)
  - *Fine sampling Pb (0.5 mm thick) / Scifi (1 mm ø)*
  - *Hermetical coverage*
  - *High efficiency for low energy photons*

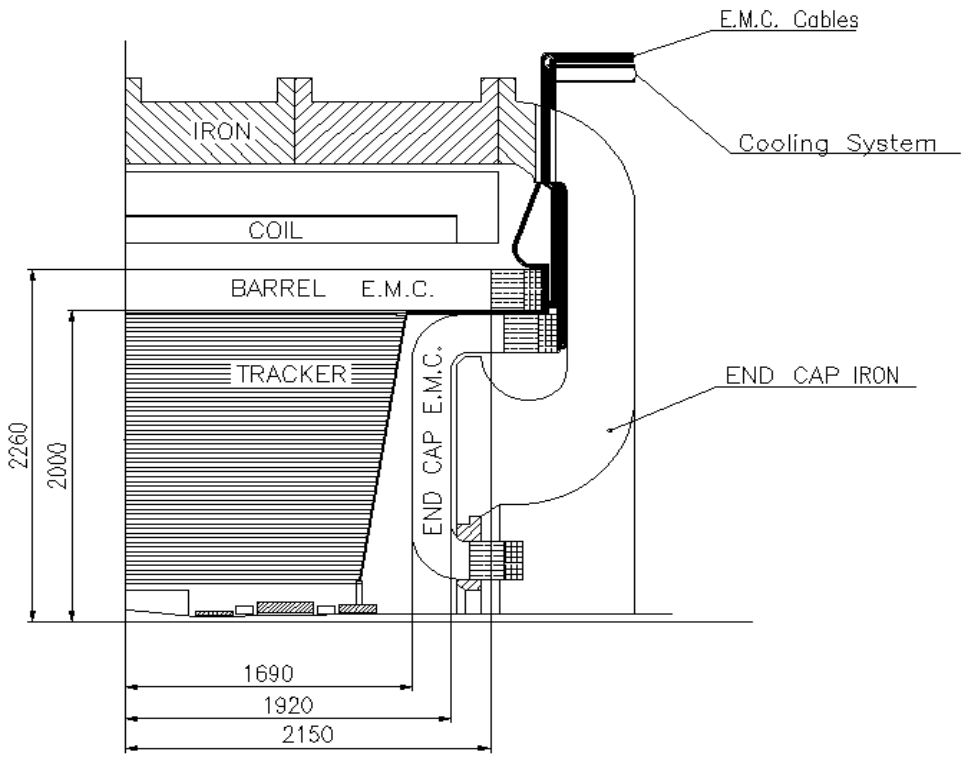
    $\sigma_E = 5\%/\sqrt{E(GeV)}$ $\sigma_t = 50ps/\sqrt{E(GeV)}$

    $\sigma_{x,y} = 1.2$ cm $\sigma_z = 1.2cm/\sqrt{E(GeV)}$
- Central drift chamber (DCH)
  - *Large detection volume*
  - *Uniform tracking and vertexing in all volume*
  - *Helium based gas mixture*

    $\sigma_v = 1$ mm $\sigma_{pt}/p_t = 0.5\%$

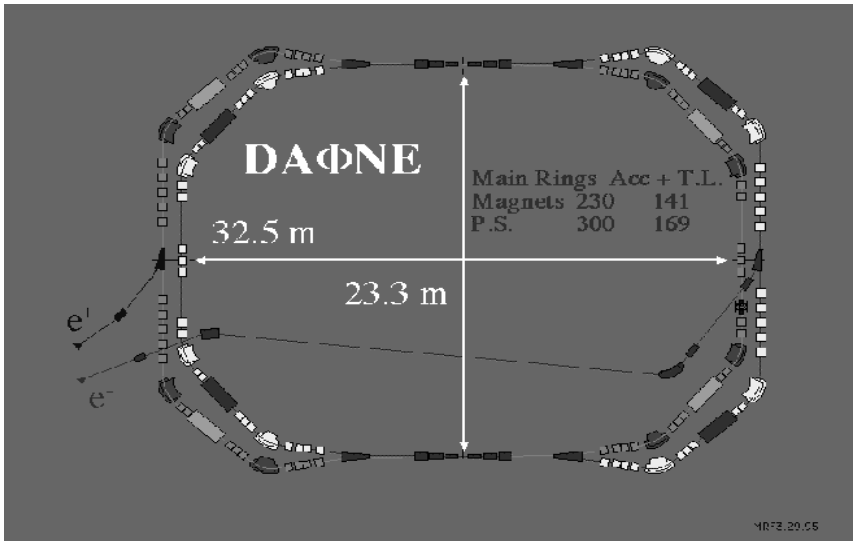
    $\sigma_{r,\phi} = 200\ \mu m$ $\sigma_z = 2$ mm
- Quadrupoles' calorimeter (QCAL)
  - *Pb/Sci tile calorimeter covering quads inside KLOE*

The KLOE detector



The DAΦNE collider

- $e^+ e^-$ collider at ϕ peak with very high luminosity: $L=5 \times 10^{32}$ $cm^{-2} s^{-1}$



M_ϕ =1.02GeV

Γ_ϕ = 4.4 MeV

$\sigma(\phi)$ = 4.4 μb

⇓

$2.2 \times 10^{10} \phi$/year

φ decay	k^+k^-	$k_l k_s$	$\rho\pi, \pi^+\pi^-\pi^0$	$\eta\gamma$	others
BR(%)	49.5	34.4	14.8	1.3	1