Gr.1, Roma, 27 giu 2001

The KLOE experiment and the hadronic cross section measurement at low energies

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Outline :

- ✓ DAΦNE performances in 2001
- ✓ KLOE DAQ and reconstruction capability
- ✓ Preliminary results on 2000 data
- ✓ Method to measure σ_{had} at low energies

DAFNE + KLOE news jan/jun 2001

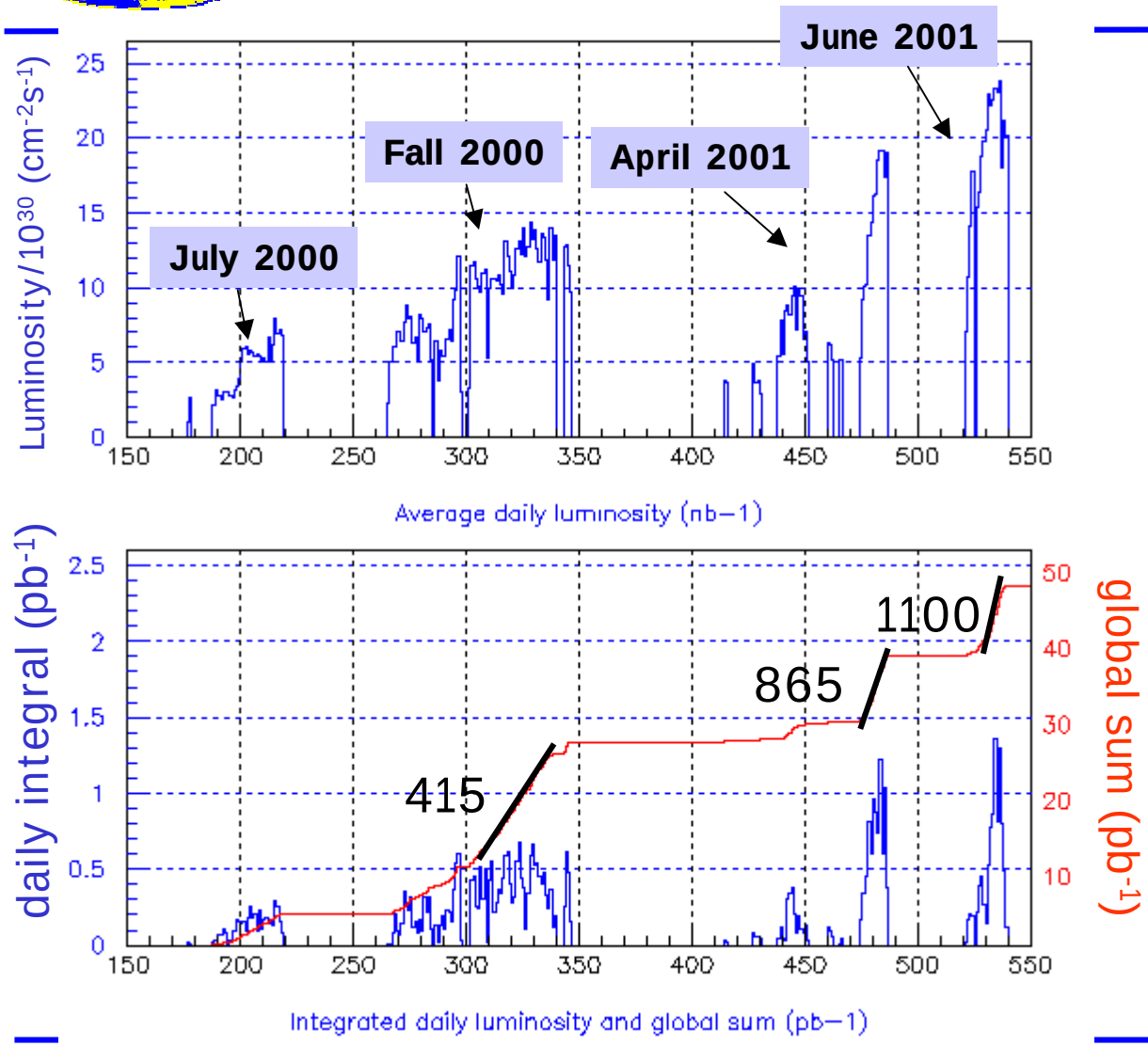
DAΦNE

- ✓ Discovery of wiggler problem
- ✓ New scrapers, new feedback amps
- ✓ More time dedicated to KLOE
- ✓ Achieved higher L(single bunch), close to $1 \mu b^{-1} s^{-1}$
- ✓ ... however also background rate increased

KLOE

- ✓ Cleaned trigger details
- ✓ Repaired DC bad channels, preamp mortality seems much better (due to bad chip bonding in a batch)
- ✓ Continouos improvements in filtering + monitoring + calibration
- ✓ May 2001: new CPUs installed, now in the reconstruction chain

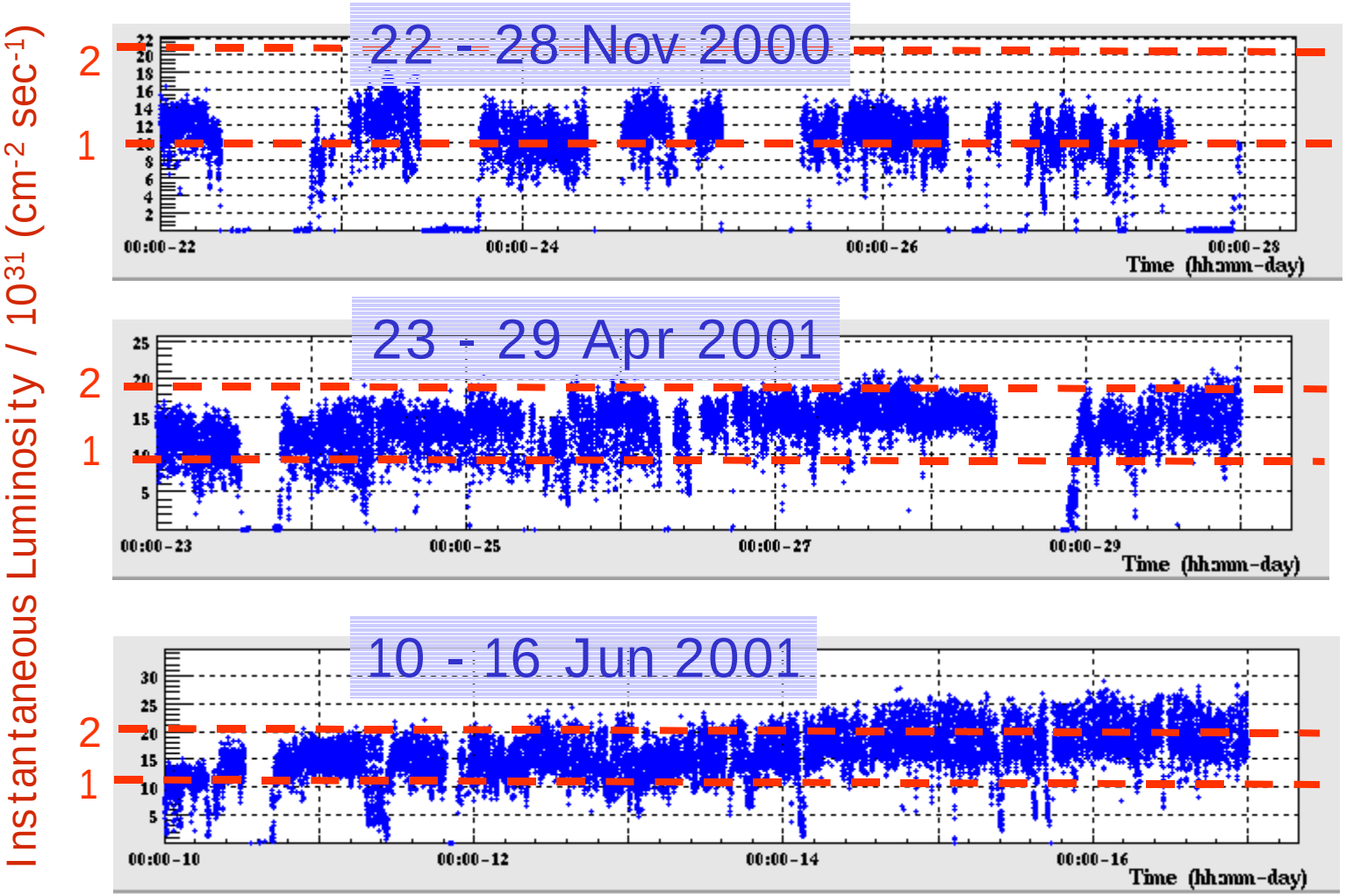
Delivered Luminosity (2000-2001)



✓ Total integrated luminosity collected: **L~48 pb^{-1}**

✓Average daily luminosity AND average uptime increased steadily

Uptime in three good weeks



Parassitic KLOE running during the night

Machine time mostly dedicated to KLOE data taking

Increase in machine background

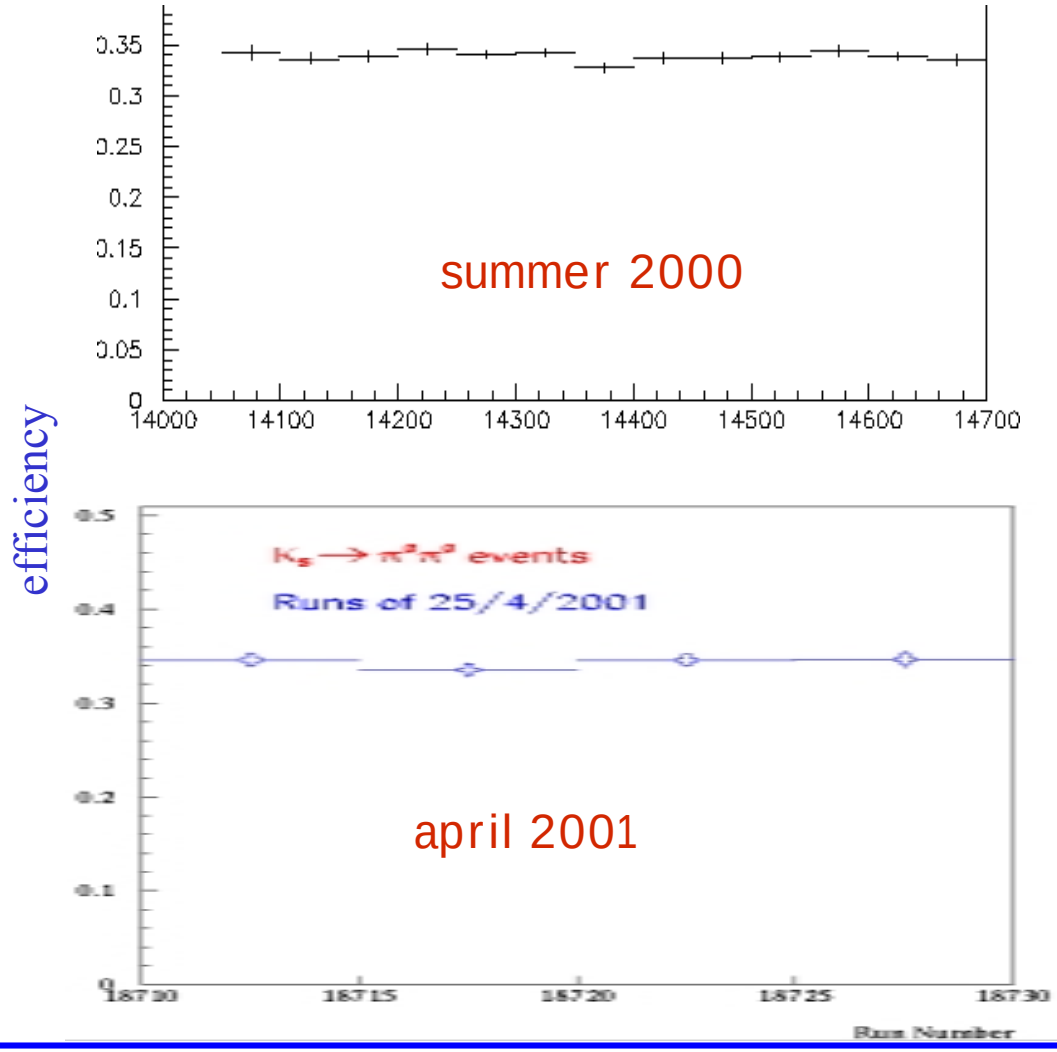
	$\langle L_{on} \rangle$ 1/μb/s	DC rate 1st layer (kHz)	Integrated charge (μc/cm/day)	Endcap rate (kHz)	Accidentals in calorimeter
Nov 00	11	16	24	60-70	3% (central) 5% (endcap)
Apr 01	14	20	33	70-80	3% (central) 8% (endcap)
Jun 01	20	22	41	100-120	4% (central) 9% (endcap)

- Both L and the background have increased.
- After analysis, we do not seem yet to see an effect (see next slides)
- However with this trend background can become a serious concern, both for the physics and the detector

Spurius clusters in calorimeter

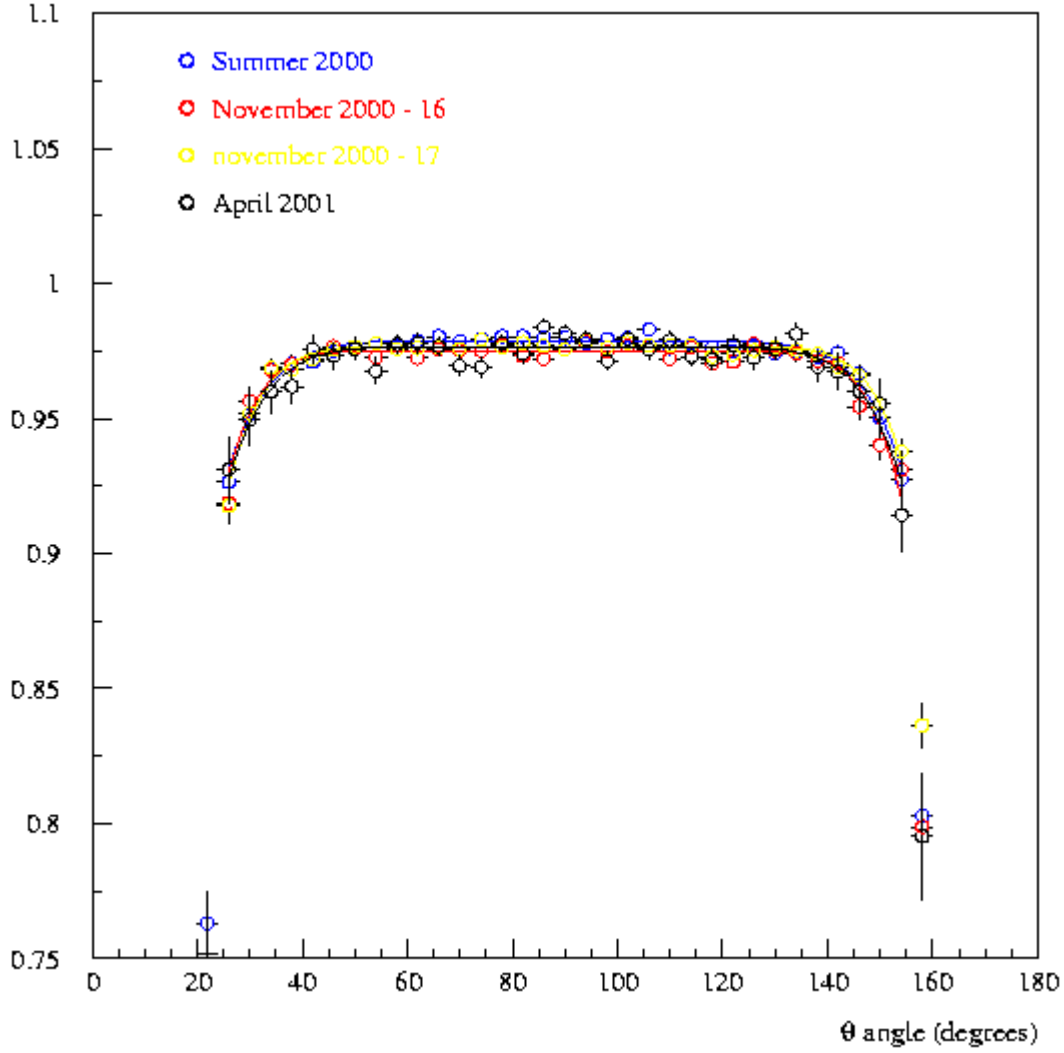
We observe no loss of efficiency due to pile up clusters in the fully neutral decay

$K_S \to \pi^0 \pi^0$ $K_L \to$ EMC



Spurius hits in the chamber

- ✓ Tracking efficiency as a function of the polar angle θ measured in $K_S \rightarrow \pi^+\pi^-$ events with a K_L cluster
  - ☞ The KL + one pion are used to close the kinematics and to measure the efficiency of the other track
- ✓ No effects on efficiency are evident after analysis cuts



Monitoring wire ageing and integrated charge

The accumulated charged has been evaluated both counting the rate using out of time events and by using a nanoamp directly connected to wires in the inner layer of the DC.

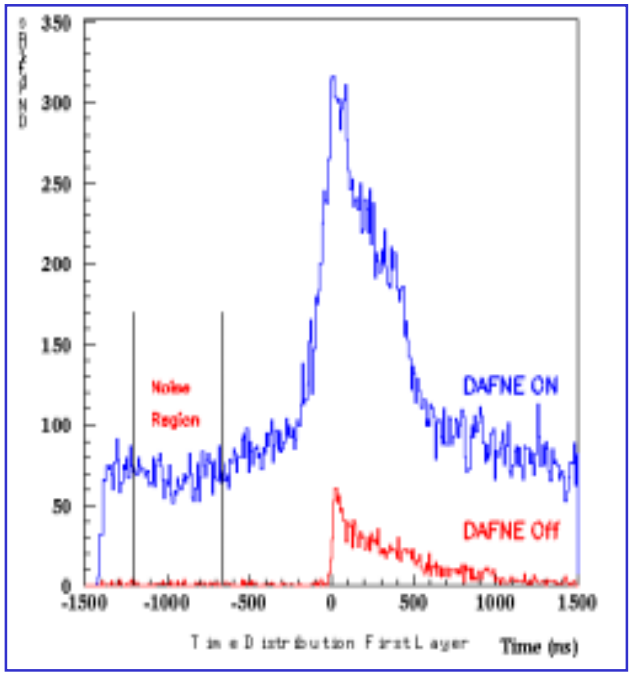
The two results are consistent.

The summer 2001 estimation is of 2 mC/cm, within limits, but of some concern

<u>Wire ageing:</u>

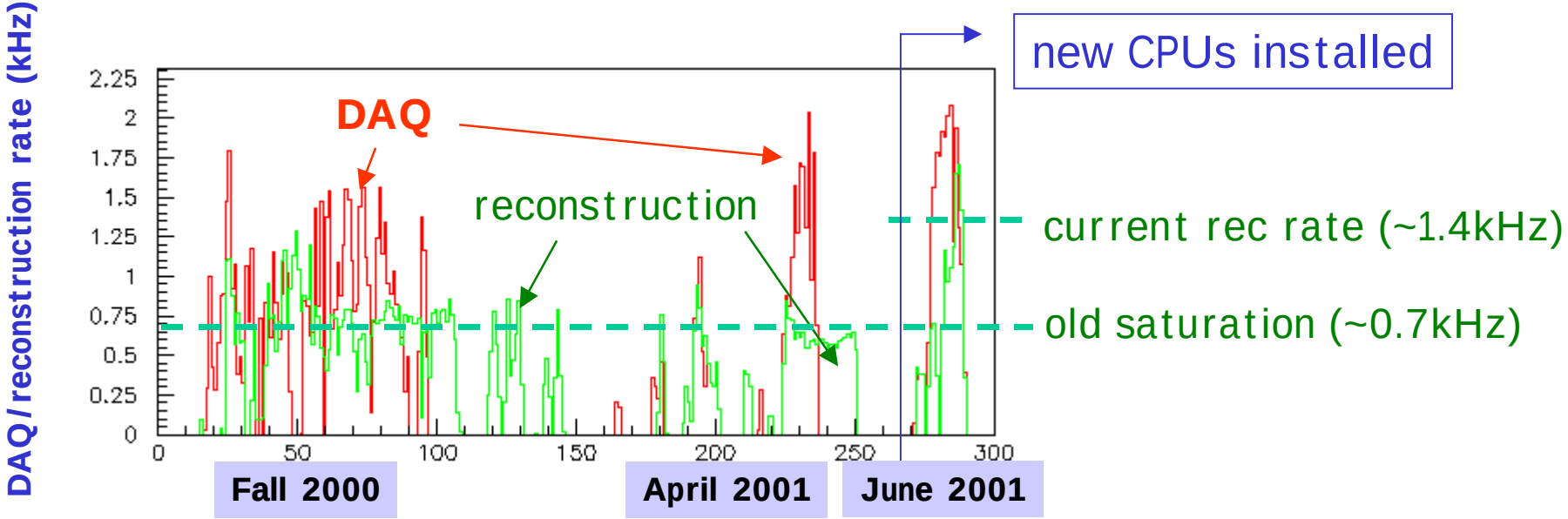
lab-tested: **Q = 2.5-5 mC/cm simulating 1 year @ design luminosity, no effect**

literature: **Q_{MAX} = 10-50 mC/cm**



Single counting rate measured from the number of hits in a time window of 200 ns before the signal region.

Reconstruction rate: new CPUs at work!



- with the new CPUs the reconstruction capability increased and we are able to keep after DAQ
- we experimented problems in the *networking* (XYLAN)
- limited also by the number of tape mount points because of the increased throughput and analysis needs

New offline farm configuration

	Farm	CPUs	Power/CPU	Total Power
OLD	10 SUN Enterprise 450	40	1.	40
NEW	24(18) IBM 7026-B80	96(72)	2.5	240(180)

- 1.4 TBytes of Disk space for the online farm
  - Increased disk buffer allows for the completion of the calibration jobs before archiving
- 3.4 TBytes of Disk space for the Offline farm
  - Data Samples for analyses can be kept on disk
  - Decrease conflicts in the archiving procedure

The DAFNE program for 2001

- ✓ Following the discussion with the LNFSC:
  - KLOE runs for 200pb-1 or until the end of the year, whichever comes first

Data Yield with 200pb-1

- Ks $2\ 10^8$
  - Tagged Ks (Kl visible Interactions) $0.6\ 10^8$
    - Ks $\pi^+ \pi^-$ $0.3\ 10^8$ x BR ~ $2\ 10^7$
    - Ks $\pi^0 \pi^0$ $0.3\ 10^8$ x BR ~ $1\ 10^7$
    - Ks $\pi e \nu$ $0.9\ 10^7$ x BR ~ 6700
    - Ks $\gamma\gamma$ $3.3\ 10^7$ x BR ~ 70
    - Ks $\pi^0 e^+ e^-$ Single Event Sens. $0.8\text{-}1.5\ 10^{-7}$
    - Ks $\pi^0 \pi^0 \pi^0$ Single Event Sens. $3\ 10^{-8}$
- Kl $2\ 10^8$
  - Tagged Kl (Ks $\pi^+ \pi^-$) $0.9\ 10^8$
    - Kl Decay in FV (D.C.) $2.5\ 10^7$
    - Kl $\pi^+ \pi^-$ ~ $2.7\ 10^4$
    - Kl $\pi^0 \pi^0$ ~ $1.0\ 10^4$
    - Kl $\gamma\gamma$ ~ $0.5\ 10^4$
- $K^{+/-}$ $3\ 10^8$
  - Tagged K^+ (K^-) $0.7\ 10^8$
    - Reconstructed K^+ (K^-) $5\ 10^7$

Highlights of 2000 data

- ✓ Neutral KAON physics
  - $K_S \rightarrow \pi e \nu$
  - $BR(K_S \rightarrow \pi^+ \pi^-)$ / $BR(K_S \rightarrow \pi^0 \pi^0)$
  - preliminary studies of $K_L \rightarrow \pi \pi$
- ✓ Charged KAONs
  - preliminary studies of $K^\pm$ BRs
- ✓ Non KAON physics
  - $\eta - \eta'$ mixing
  - $\phi \rightarrow f^0 \gamma \rightarrow \pi^0 \pi^0 \gamma$
  - $\phi \rightarrow a^0 \gamma \rightarrow \eta \pi^0 \gamma$
  - $\phi \rightarrow \pi^+ \pi^- \pi^0$
- ✓ Hadronic cross section

Start of the work on the $K_{L,S}$ BRs

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

@fixed target

@KLOE

$$= \frac{N(K_L \to \pi^0\pi^0)/N(K_L \to \pi^+\pi^-)}{N(K_S \to \pi^0\pi^0)/N(K_S \to \pi^+\pi^-)} = 1\text{-}6\Re(\varepsilon'/\varepsilon)$$

- ✓ Because of the tagging method, in KLOE the double ratio is measured by looking at KL and KS decays separately (instead of neutrals vs charged)
- ✓ Competitive measurement of $BR(K_S \to \pi^0\pi^0)/BR(K_S \to \pi^+\pi^-)$ even with low integrated luminosity

K_S tagging by K_L in EMC

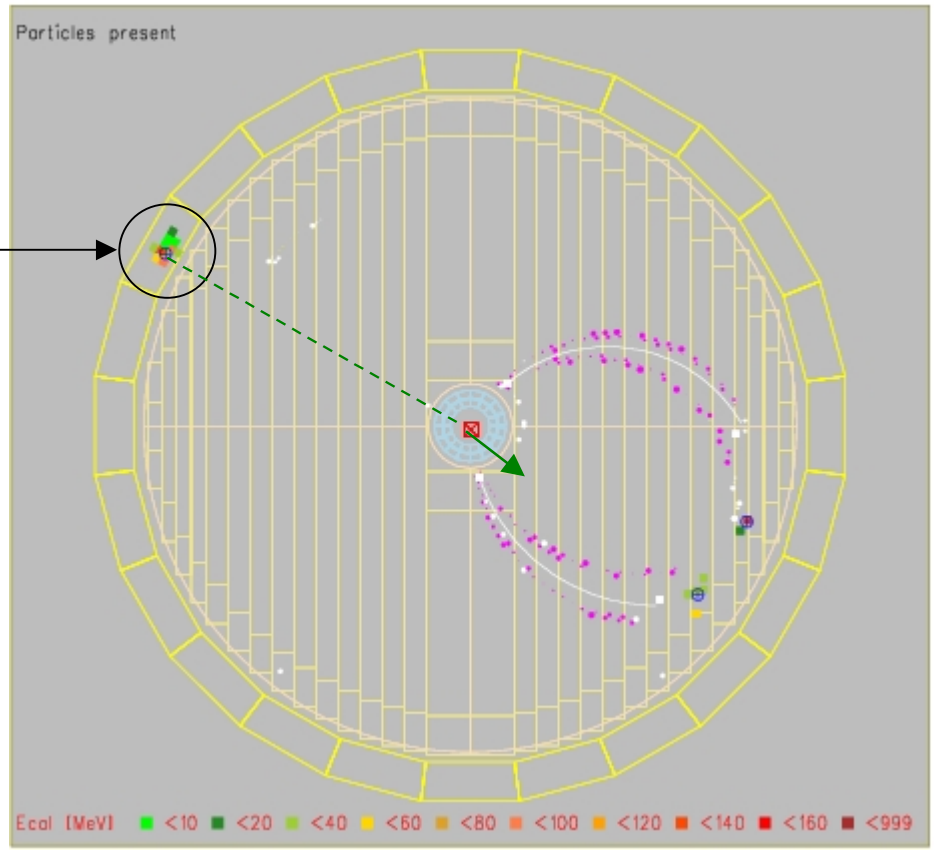
Clean K_S tagging by time-of-flight identification of K_L interacting in the EmC

Selection cuts:

- $E_{clus} \geq 100$ MeV
- $|\cos(\theta_{clus})| \leq 0.7$
- $\beta^* \in [0.195, 0.2475]$

(β^* = K_L velocity in the ϕ rest frame)

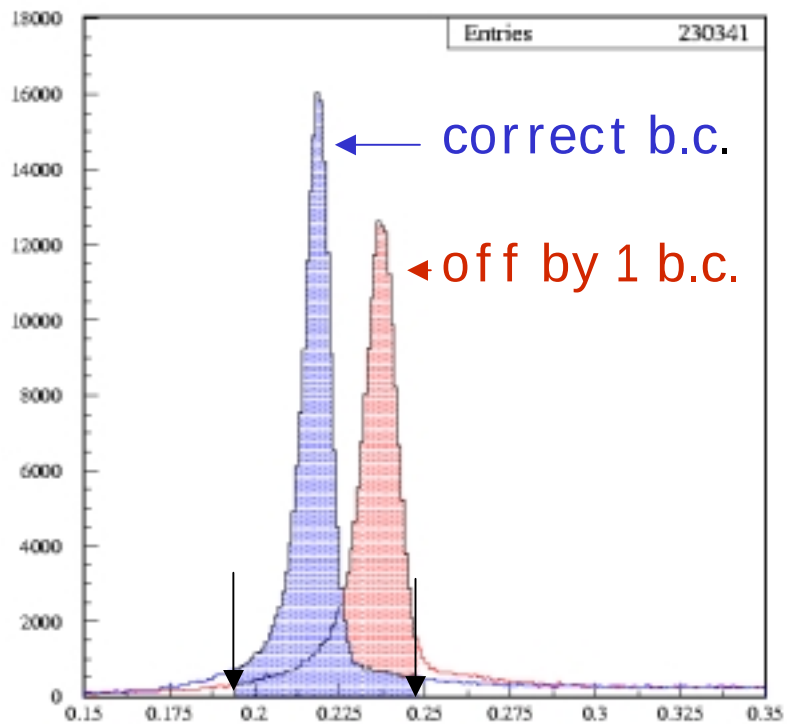
Given the two body ϕ decay, the position of the KL cluster provides the KS momentum (useful in semil. decays)



$\Delta|p|=2$MeV ; $\Delta\theta_S=2^o$

Measuring the global t_0

- ✓ To get the particle TOF, the global event t_0 must be fixed
- ✓ The trigger is syncronized with an *integer multiple of the bunch crossing frequency*
- ✓ Correct crossing is evaluated offline by looking at the fastest cluster in the event (possible problems with pile up clusters here)
- ✓ **Tag efficiency is slightly dependent on the K_S decay due to the different global t_0 estimations**



β* for KLCRASH events

$K_S \to \pi^+\pi^-/K_S \to \pi^0\pi^0$ result

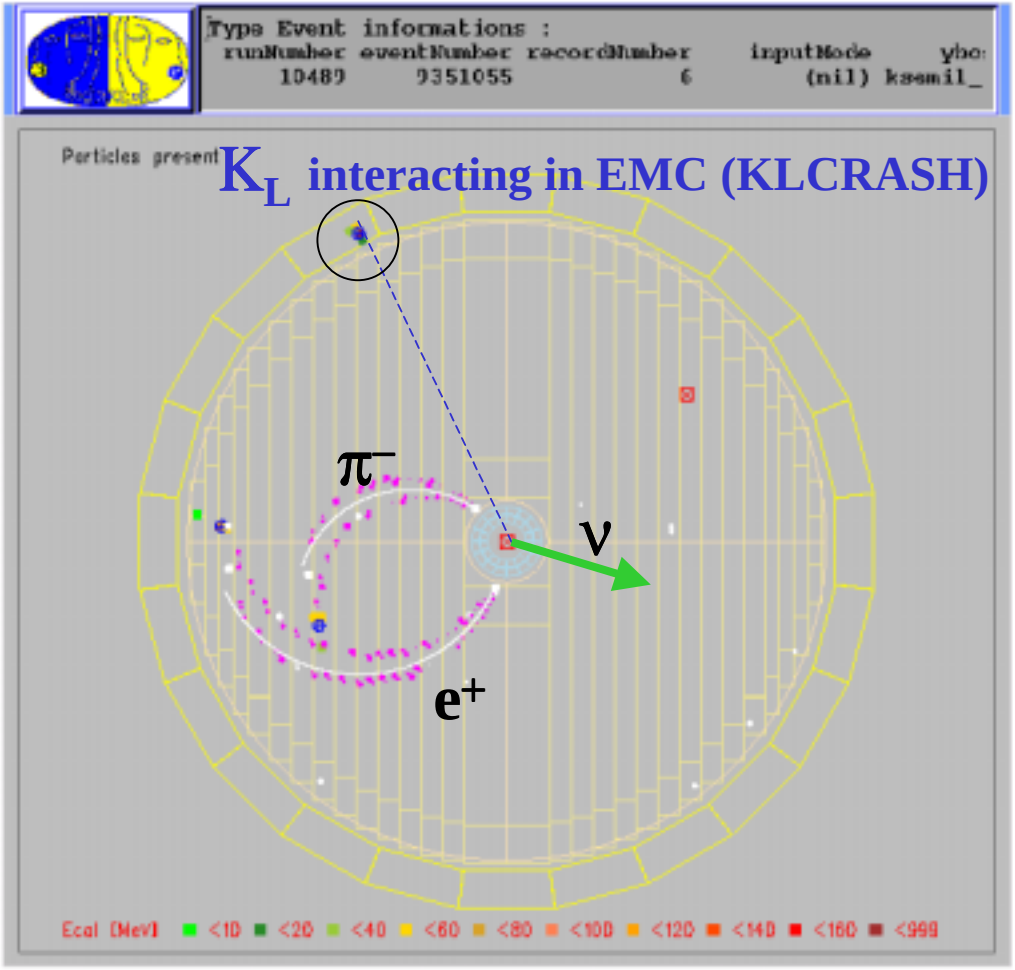
PDG 2000 Ratio = $2.197 \times [1 \pm 1.2 \times 10^{-2}$ (stat) $\pm 0.6 \times 10^{-2}$ (syst)]

KLOE 2000 Ratio = $2.23 \times [1 \pm 0.35 \times 10^{-2}$ (stat) $\pm 1.5 \times 10^{-2}$ (syst)]

preliminary ***Systematics under study***

Contribution to systematics	%
Tag bias	1
$K_S \to p^0p^0$ selection	1
$K_S \to p^0p^0$ trigger	0.02
$K_S \to p^+p^-$ selection	0.1
$K_S \to p^+p^-$ trigger and t0	0.5
Total	1.5

Analysis of $K_S \to \pi e \nu$ (1)



Events selection summary

- Kcrash tag
- Kinematics preselection
- Track to cluster association to apply *time of flight* **π–e** *identification*
- Close kinematically the event to get p_ν

Normalization to $K_S \to \pi^+ \pi^-$

- Kcrash tag bias estimation due to the T_0 effect

Analysis of $K_S \to \pi e \nu$ (2)

•2 methods to estimate TCA, T_0 and calorimeter trigger efficiencies:

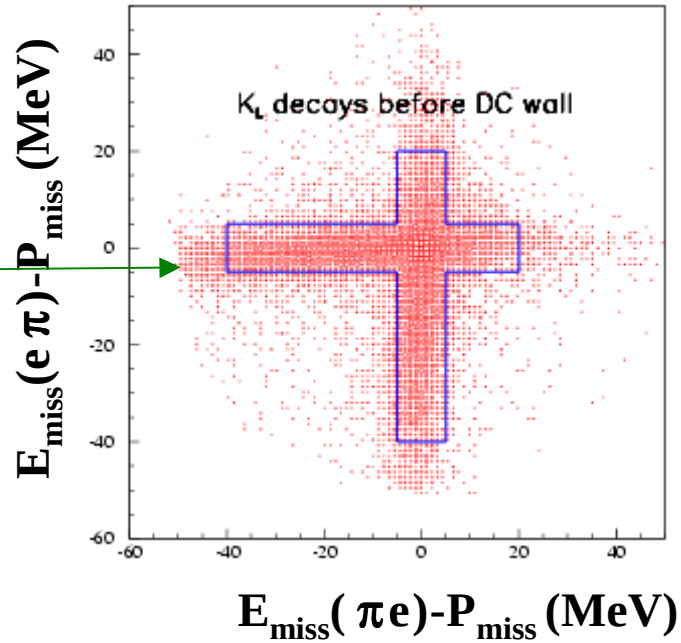
1. Single particle efficiencies taken from data using $K_S \to \pi^+\pi^-$ subsamples and $K_L \to \pi e \nu$, $\phi \to \pi^+\pi^-\pi^0$ control samples. Efficiencies for π^+, π^-, μ^+, μ^-, $e^\pm$ used to weight the Monte Carlo:

$$\varepsilon_1 = (82.1 \pm 0.5)$$

2. Efficiencies directly from data using $K_S \to \pi^+\pi^-$, $K_L \to \pi e \nu$ control sample, *selected using DC information only*

$$\varepsilon_2 = (81.4 \pm 0.6)\%$$

$$\varepsilon_{TCA+T0+TRG} = (81.7 \pm 0.5)\%$$



$K_S \to \pi e \nu$ signal

- ✓ The fit is performed in the variable E_{miss}-P_{miss} (must be 0 in signal events)
- ✓ A fit is performed on data using MC spectra for background and signal

- ✓ PDG2000 (CMD2) :

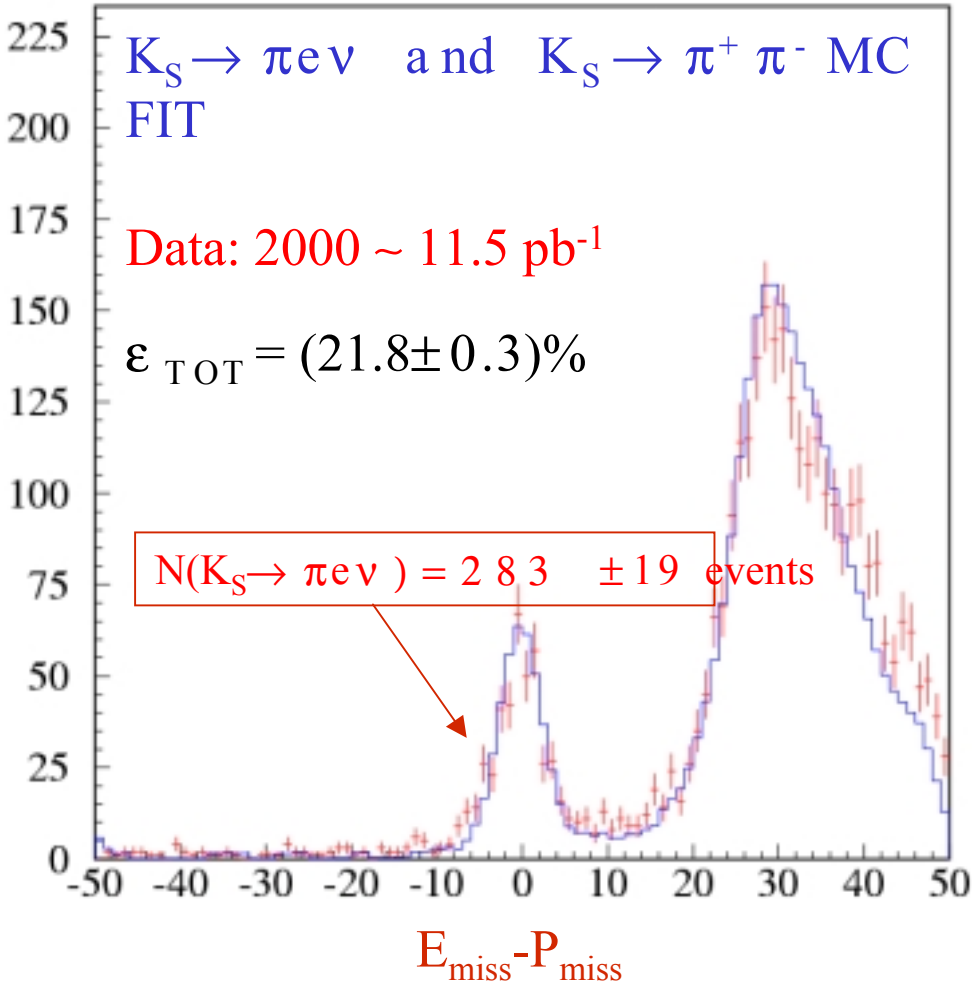
$BR(K_S \to \pi e \nu) = [7.2 \pm 1.2] \times 10^{-4}$

- ✓ KLOE preliminary result:

$BR(K_S \to \pi e \nu) = [7.47 \pm 0.51(stat)] \times 10^{-4}$

(systematics under evaluation)

- ✓ In a 5MeV window:
  - signal 248 ± 17
  - background 9.0 ± 1.4



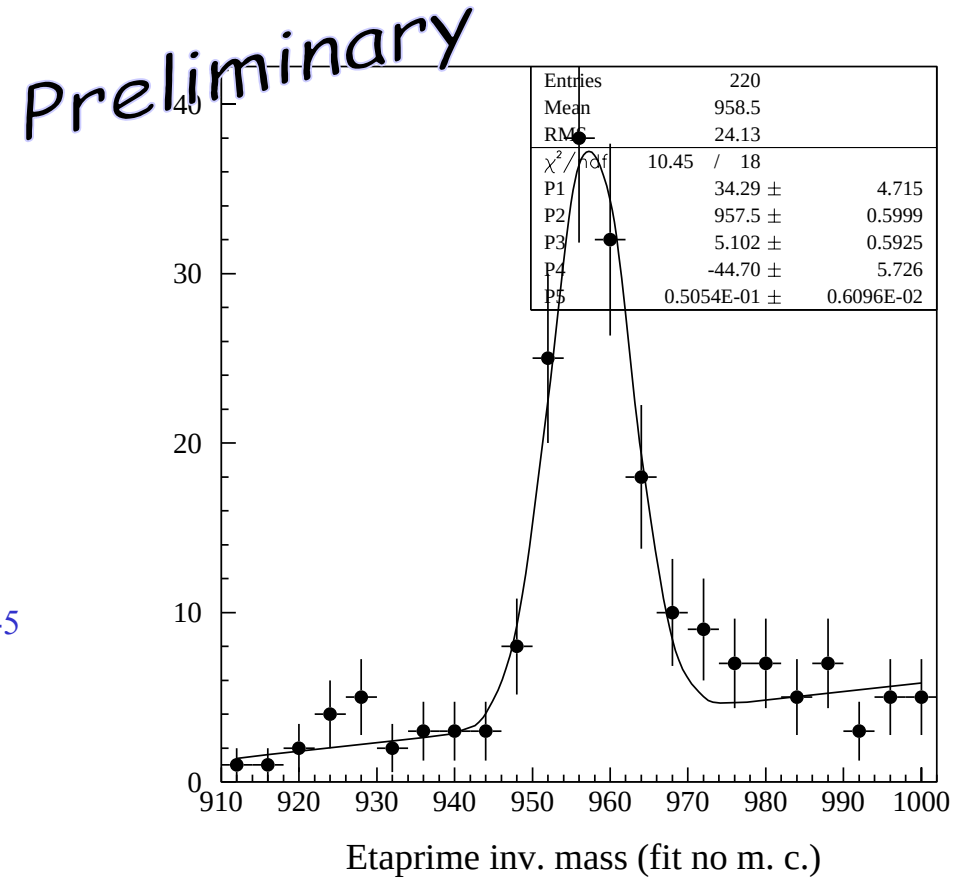
$\phi \to \eta'\gamma$ Branching Ratio and η'–η mixing angle

$\phi \to \eta' \gamma \to \pi^+\pi^- 7\gamma$
favourable S/B
223 events selected in '00
  22 ± 7 background sidebands
196 ± 20 expected signal

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

$BR(\phi \to \eta'\gamma) = (6.9 \pm 0.6 \pm 0.5) \times 10^{-5}$
(PDG2000: BR = $(6.7 \pm 1.5) \times 10^{-5}$)

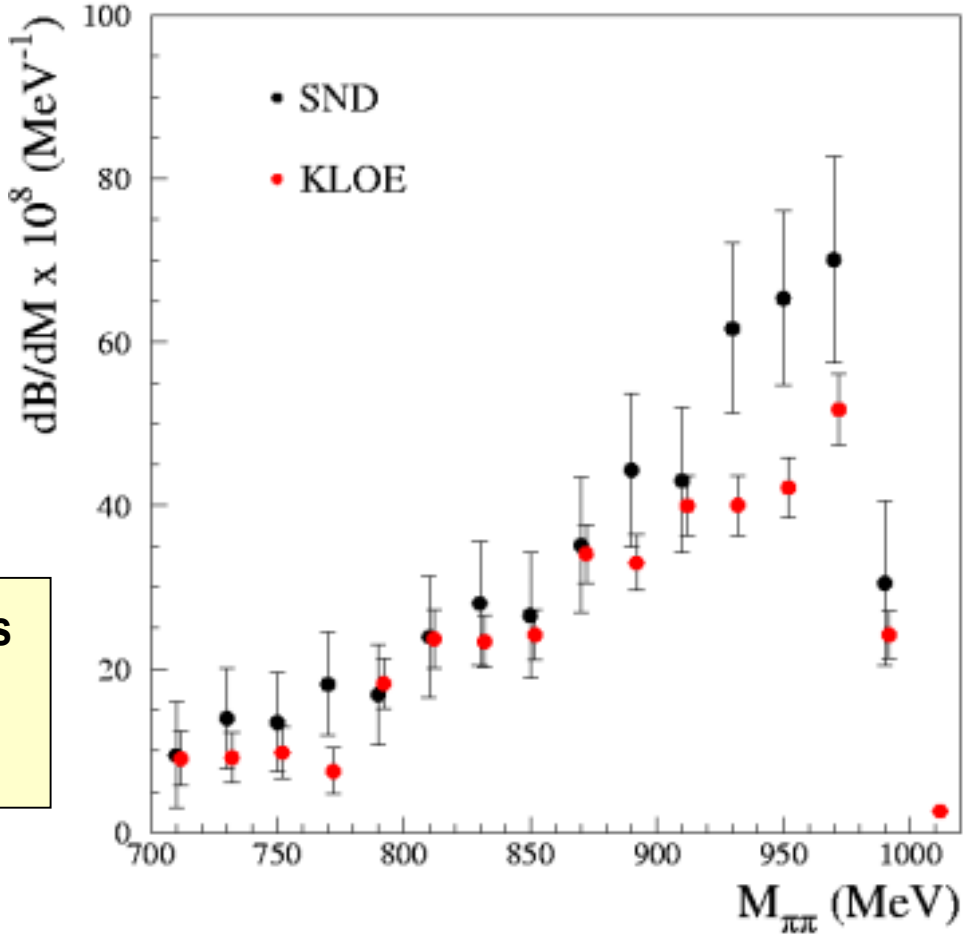
$\Theta_P = (-14 \pm 1.6)^o$



$\phi \rightarrow f_0\gamma \rightarrow \pi^o\pi^o\gamma$ decay

Fit Procedure:

- ✓ First fit: (E,p) and TOF constraints applied
- ✓ Pairing: best γ's pairing with $2\pi^o + M_{\pi o \pi o} > 700$ MeV
- ✓ Second fit: constraints on π^o masses also required



<u>Preliminary result</u>: Excess of *1960 ±56* events

$$BR(\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma) = (0.79 \pm 0.02 \pm 0.08) \cdot 10^{-4}$$

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

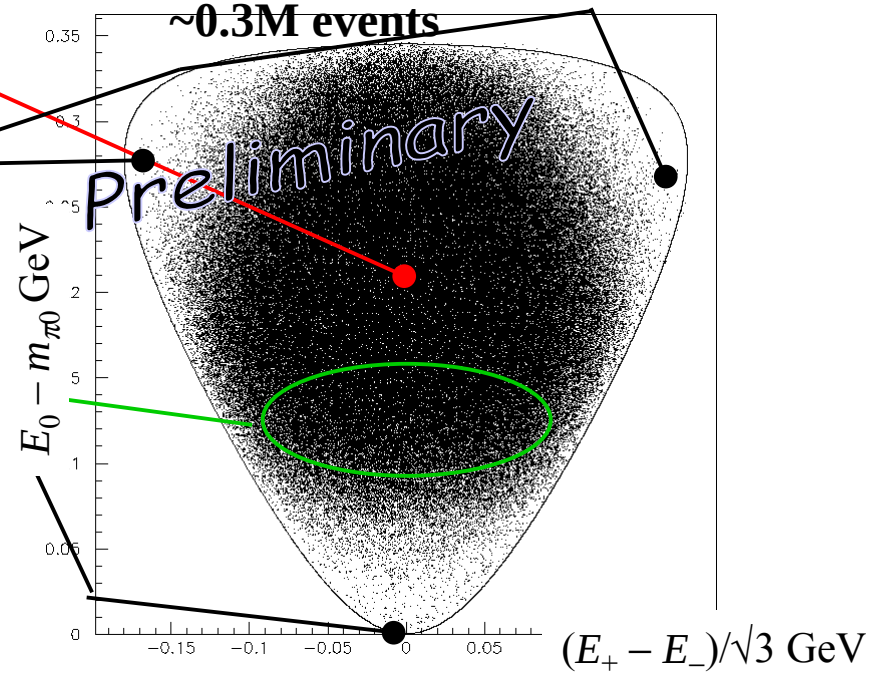
3 contributions to Dalitz plot

$\phi \rightarrow \rho^{\pm,0}\pi^{0,\pm}$

$\phi \rightarrow \pi^+\pi^-\pi^0$ (direct)

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

in the fit the mass and width of the ρ, the $\Delta M(\rho^{\pm},\rho^0)$ and the direct decay contribution are left free



	A_1 (x10^{-2})	ϕ_1 (deg)	$M(\rho^{+,-})$	$M(\rho^0)$	Γ	$\Delta M(+,-)$
KLOE	8.5 ± 0.5	88 ± 9	775.3 ±0.4	773.0 ±0.6	149.1 ± 1.0	0.4 ± 0.3 (*)
PDG	-15 ±11 (CMD-2)			776.0 ± 0.9 (**)	150.2 ± 0.8	-

(*) CPT test at < 5 x 10^{-4}

(**) mixed charges (τ decay and e^+e^-) average: $M(\rho^0) - M(\rho^{+,-}) = 0.4 \pm 0.8$

Efficiency (X,Y) from Montecarlo: fine tuning in progress to reduce systematic effects on $M(\rho^0)$ (now at 2 MeV level)

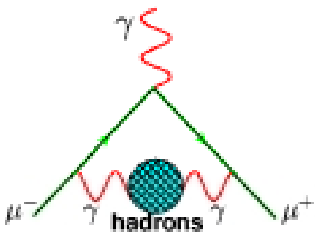
Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ @ $\sqrt{s} \rightarrow 1$ GeV

- ✓ The measurement of the hadronic cross section below the ϕ threshold has been included in the first studies on KLOE @ DAFNE (see articles in the first and the second DAFNEphysics handbook)
- ✓ However the proposed method has always been the classical one of the energy scan
- ✓ In 1996/97, thanks to the interactions of physicists from KLOE with the theoriticians of the *Eurodafne* community, the possibility of using the radiative return method (a photon radiated in the initial state that lowers the available energy) to measure σ_{had} was proposed and investigated

$$M^2_{\pi\pi} = M_\phi^{\,2} - 2 M_\phi E_\gamma$$

σ_{had} and a_μ

- ✓ the interest in the measurement of σ_{had} has increased recently with the new results of the BNL g-2 experiment
- ✓ a_μ is correlated to the hadronic cross section via the dispersion integral:



$$a_\mu^{had} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \left(\int_{4m_\pi^2}^{E_{cut}^2} ds \frac{R^{data}(s)\hat{K}(s)}{s^2} + \int_{E_{cut}^2}^{\infty} ds \frac{R^{pQCD}(s)\hat{K}(s)}{s^2} \right)$$

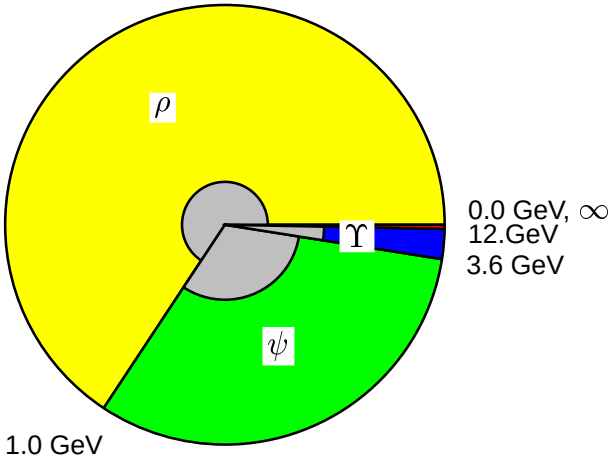
- ✓ In the case of a radiative photon the cross section is related to σ_{had} via the radiator function H:

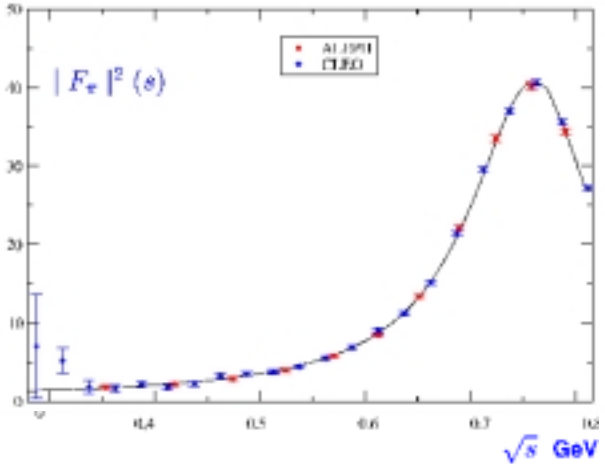
$$M_{had}^2 \frac{d\sigma\left(e^+e^- \to hadrons + \gamma,\ M_{had}^2\right)}{dM_{had}^2} = \sigma\left(e^+e^- \to hadrons,\ M_{had}^2\right) \times H\left(M_{had}^2,\ \cos\theta_\gamma\right)$$

KLOE contribution to the measurement

The KLOE detector @DAΦNE can study:

- ✓ the ρ resonance, which contributes to ~65% of the dispersion integral
  - ➢ this measurement has been recently performed by the CMD-2 detector at Novosibirsk with a precision of ~1%
  - ➢ however, as recent history has shown, precision measurements should be performed more than once
- ✓ the hadronic cross section above threshold
  - ➢ this has become recently interesting after the fit of Jegerlehner et al. of the NA7 $e\pi \rightarrow e\pi\gamma$ data
  - ➢ the fit can be analitically extrapolated in the timelike region and used to test τ data



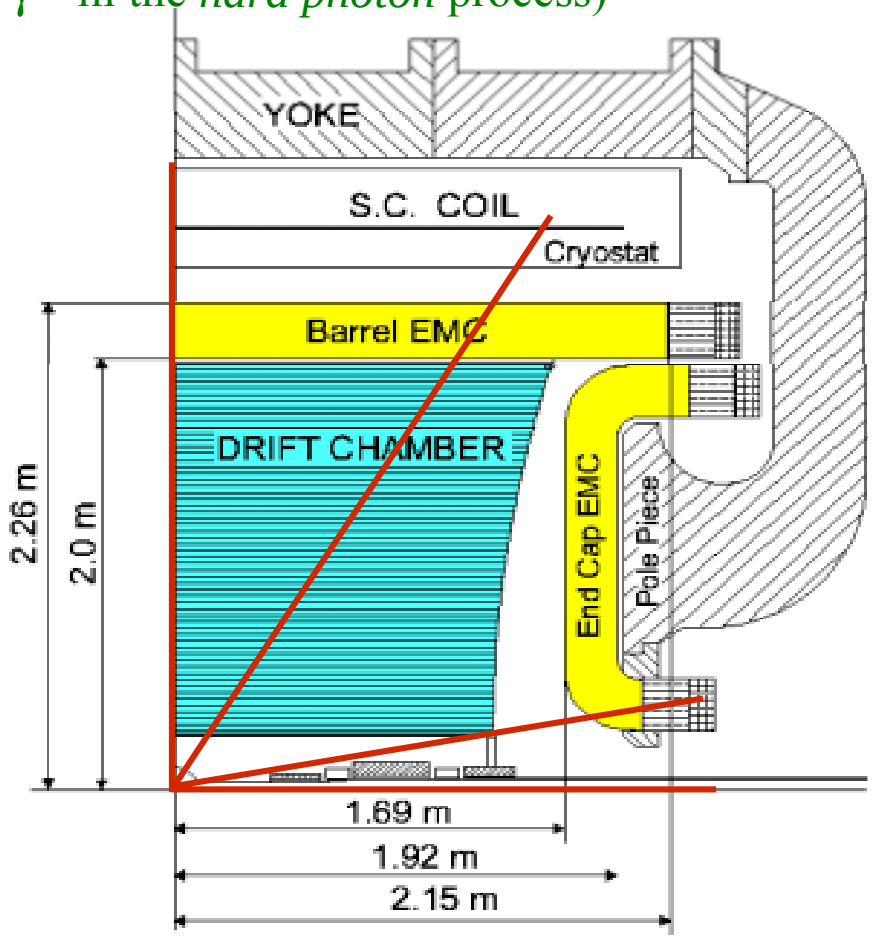


The fiducial volume

Two fiducial volumes are currently studied:

- ✓ small angle: $\theta_\Sigma < 21^o \cup \theta_\Sigma > 169^o$
  - ➢ highest cross section; small bckd from $\pi\pi\pi$; no photon tagging available ⇒ **ρ resonance**
- ✓ large angle: $60^o < \theta_\Sigma < 120^o$
  - ➢ large bckd from $\pi\pi\pi$, especially at low Q^2; possibility of using the calorimeter to discriminate ⇒ **$m_{\pi\pi}$ at threshold**
- ✓ the pions must be central (55° - 125°) to cut down the background

("Σ" is the 2-pion system; equivalent to "γ" in the *hard photon* process)



The Montecarlo: EVA

- ✓ EVA generates the process $ee \rightarrow \pi\pi\gamma(\gamma)$, with a hard photon ($E_\gamma$>10MeV) emitted by ISR or by FSR, and an eventual soft photon (collinear radiation)
- ✓ The current version supplies only the Born level, therefore we must apply a lower limit to the polar angle to avoid divergences; because of this the current definition of small angle is:

$$5^o < \theta_\Sigma < 21^o \quad \cup \quad 159^o < \theta_\Sigma < 175^o$$

- ✓ This implies a loss of a factor ~6 in statistics and a problem with the detector angular resolution at small angles (smearing)
- ✓ Kuehn et al. have published (hep-ph/0106132 , 13 Jun 2001) the NLO corrections to the process; the new version of EVA will be soon available

The method

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

$$\varepsilon = \varepsilon_{acc}\ \varepsilon_{sel}\ \varepsilon_{trig}$$

- the acceptance ε_{acc} is evaluated from MC (large angle; small angle)
- the global selection efficiency ε_{sel} is evaluated from DATA+MC
- the trigger efficiency ε_{trig} is evaluated from DATA

- the experimental **Backgrounds** come from:

$e^+ e^- \rightarrow e^+ e^- \gamma$ (radiative Bhabha)

$e^+ e^- \rightarrow \mu^+\mu^-\gamma$

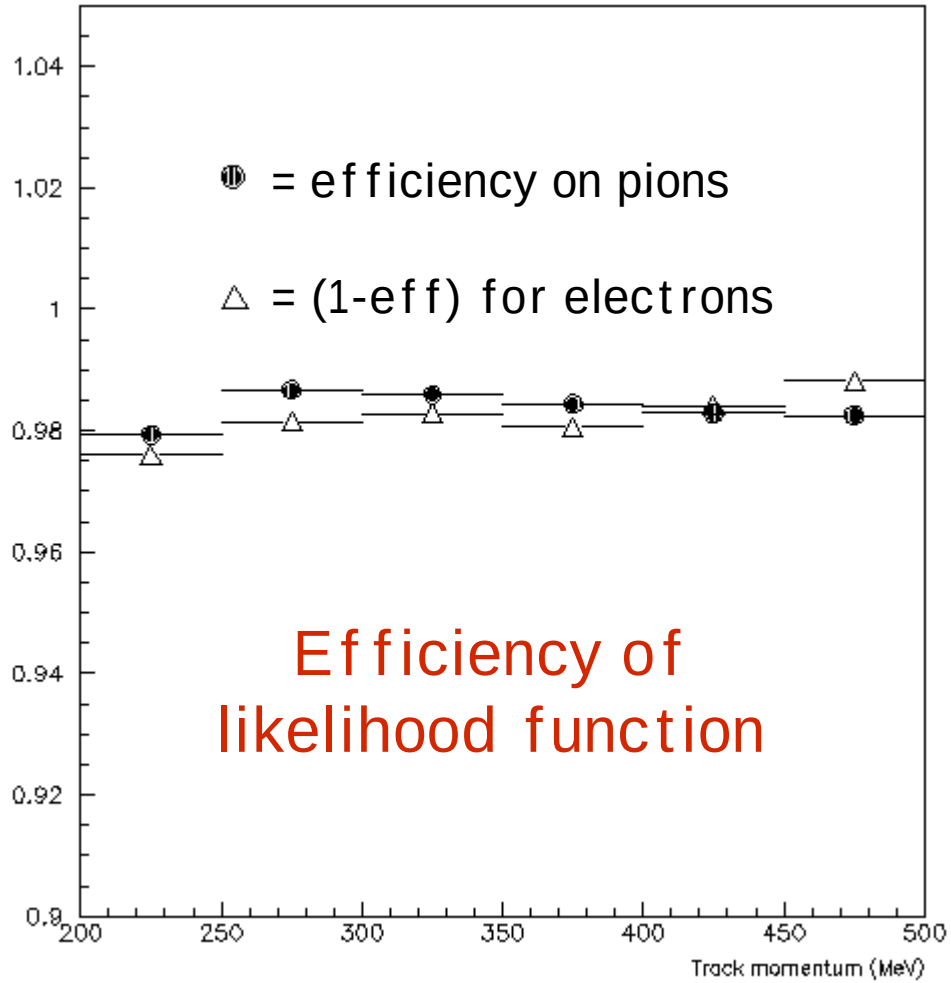
$e^+ e^- \rightarrow \phi \rightarrow \pi^+\pi^-\pi^0$ (BR = 15.5 %)

$e^+ e^- \rightarrow \pi^+\pi^-\gamma$ (Final State Radiation)

- the **Luminosity** is measured using the Bhabha scattering at large angles

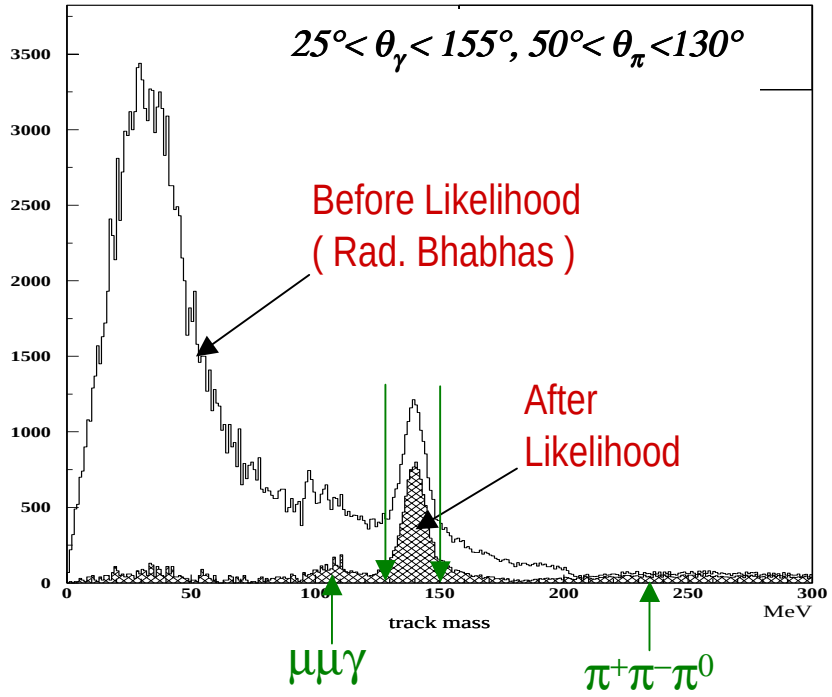
Background suppression

- ✓ Bhabha events are rejected with a likelihood function based on the *TOF* and on the *shape of the energy deposit* in the EMC
  - ➢ the likelihood function is built from data using $\pi\pi\pi$ and $ee\gamma$ events
- ✓ $\mu\mu\gamma$ and $\pi\pi\gamma$(FSR) events are suppressed by the acceptance cuts and, anyhow, they populate the high $M_{\pi\pi}$ region



Cutting on M_{trk}

- ✓ After the likelihood cut the signal peak is clearly visible in the M_{trk} variable
- ✓ The final background suppression is obtained by cutting 10MeV around the pion mass
- ✓ Note that the M_{trk} definition implies a hard photon
- ✓ For an inclusive analysis this cut must be released on the high M_{trk} side ; however a way to handle the copious $\pi\pi\pi$ background must be studied



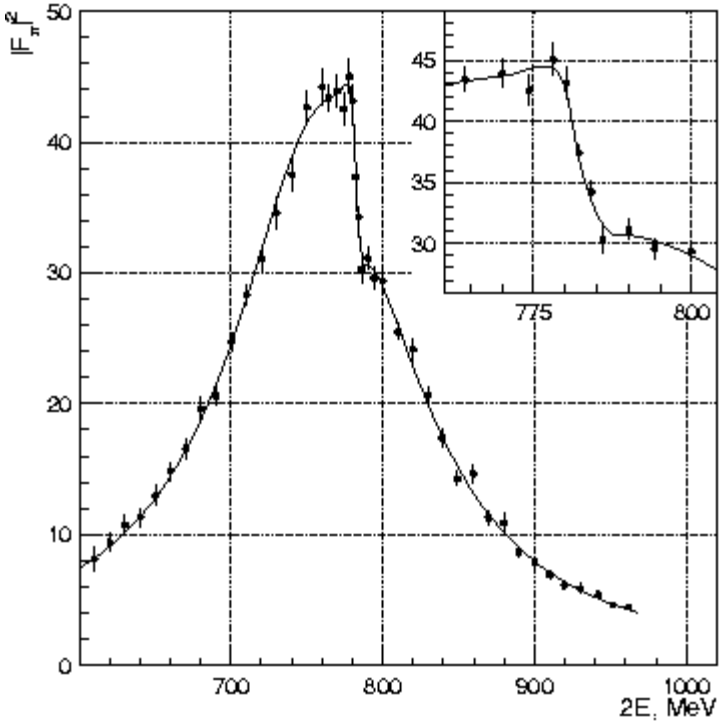
M_{trk} is defined by the following relation

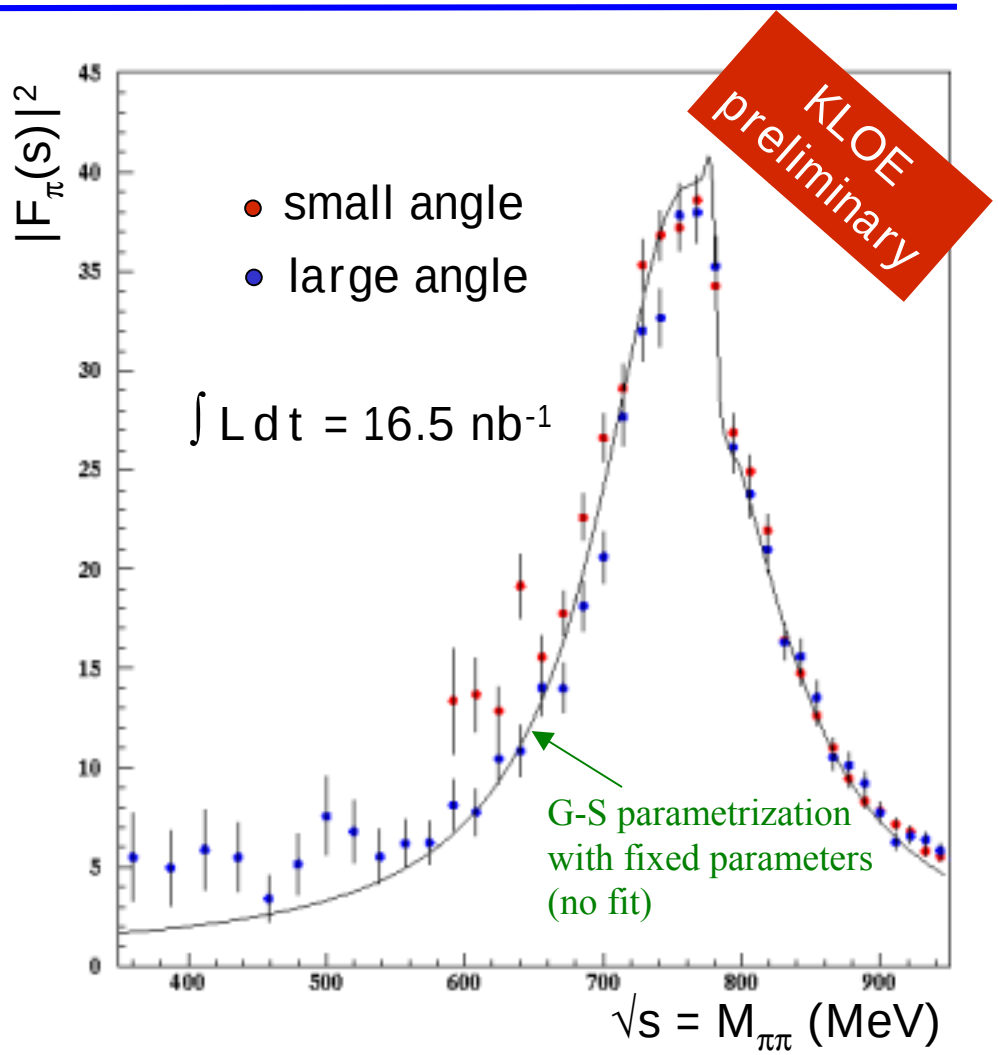
$$q_\gamma^2 = \left(M_\phi - \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} - \sqrt{\vec{p}_2^{\,2} + M_{trk}^2} \right)^2 = 0$$

The pion form factor

- ✓ The error on the small angle points will decrease by ~3 once we can lower the angular cut

CMD-2 result : hep-ex/9904027 26 Apr 1999





Summary and outlook

- ✓ DAFNE luminosity is increasing (the background also!)
- ✓ *200pb^{-1} expected by year end is very credible*
- ✓ Preliminary results show the good performances of the KLOE detector
- ✓ Several well advanced analysis:
  - ➢ $K_S \to \pi e \nu$; $BR(K_S \to \pi^+\pi^-)/BR(K_S \to \pi^0\pi^0)$
  - ➢ η' mass and η–η' mixing angle ; $\phi \to f^0\gamma \to \pi^0\pi^0\gamma$; $\phi \to a^0\gamma \to \eta\pi^0\gamma$
- ✓ *KLOE can measure $\sigma_{\pi\pi}$ with good accuracy, but the measurement is delicate*
- ✓ The complete calculations of the process are necessary with the corresponding radiative corrections
- ✓ Since *Exp-Theory ~ 3 × (EW corrections)* , all possible checks are necessary