γ-γ physics at KLOE-2

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On behalf KLOE-2 Collaboration

"Working Group on Radiative Corrections and Generators for Low Energy Hadronic Cross Section and Luminosity"
September 18-19, 2010, **University of Liverpool**

History of KLOE@DAΦNE

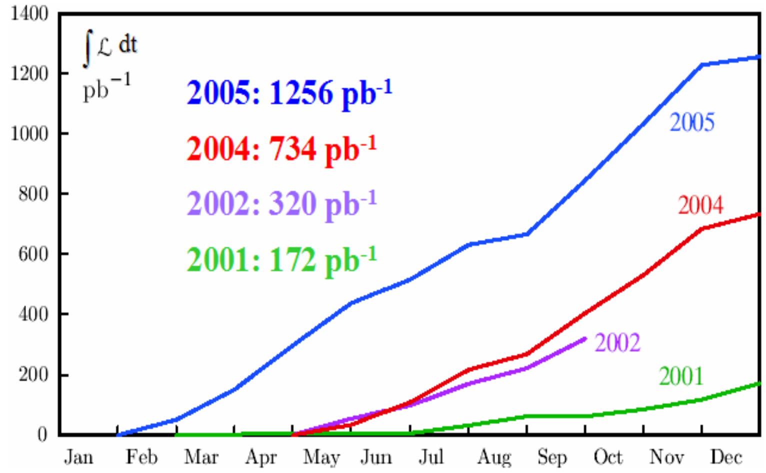
- Frascati ϕ-factory :

e^+e^- collider @ $\sqrt{s} \approx 1020$ MeV $\approx M_\phi$;

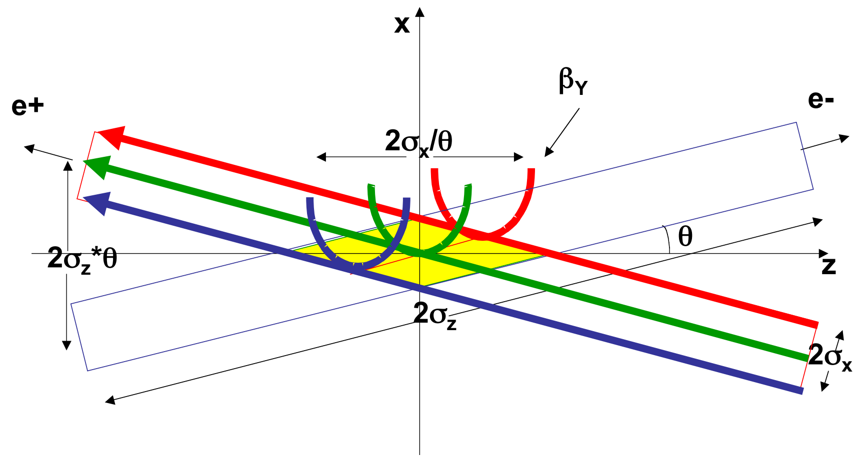
- Best performances in 2005:
  - $L_{peak} = 1.4 \times 10^{32}$ cm^{-2}s^{-1}
  - $\int L dt = 8.5$ pb^{-1}/day

- KLOE: 2.5 fb^{-1} @ $\sqrt{s} = M_\phi$ and
  + 250 pb^{-1} off-peak @ $\sqrt{s} = 1$ GeV

Integrated luminosity (pb^{-1})



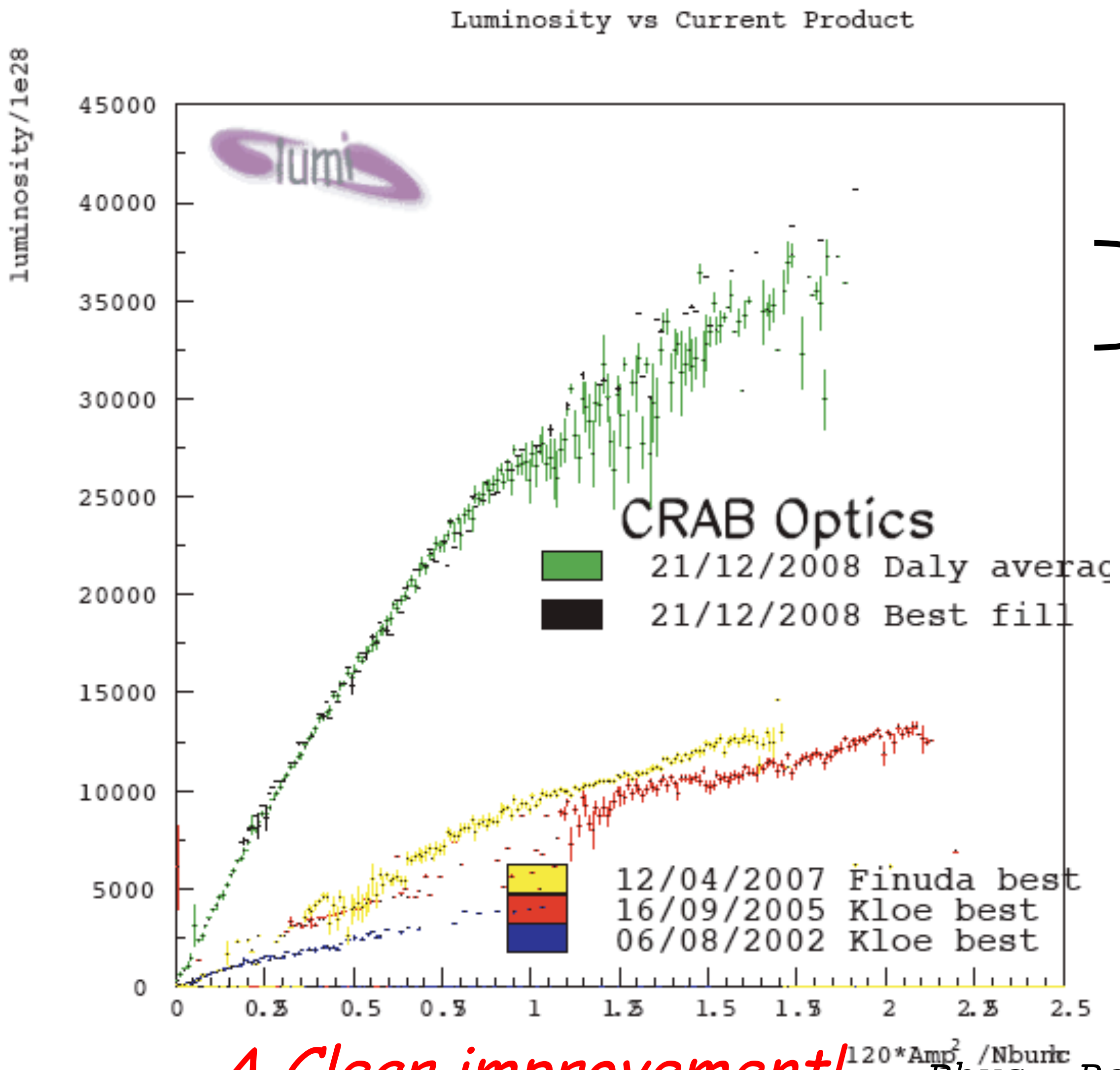
- New interaction scheme implemented : large beam crossing angle + crabbed waist sextupoles



Luminosity increase factor ~ 3

$\int L dt \approx 1$ pb^{-1}/hour

DAΦNE luminosity: new vs old



$\mathcal{L}$=5x 10^{32} $cm^{-2}s^{-1}$

SIDDHARTA Run (2008/09)

We have now a 'new' machine capable of delivering ~ 4 fb^{-1}/yr.

KLOE run (2002/05)

A Clear improvement!

Phys. Rev. Lett. 104, 174801 (2010)

KLOE-2 Physics Program

- $\gamma\gamma$ physics
  - Study of $\Gamma(S/PS \to \gamma\gamma)$, test of χPT, existence and properties of $\sigma(600)$ meson, PS Transition Form Factor

- Kaon Physics
  - Test of CPT (and QM) in correlated kaon decays
  - Test of CPT in K_S semileptonic decays
  - Test of SM (CKM unitarity, lepton universality)
  - Test of χPT (K_S decays)
- Spectroscopy of light mesons
  - η, η', f_0, a_0, σ in ϕ radiative decays
- Dark Matter searches (light bosons at O(1 GeV))

- Hadronic cross section from $2m_\pi$ to 2.4 GeV
  - $\alpha_{em}(M_Z)$ and $(g-2)_\mu$

References : KLOE-2 Collaboration EPJC**68**,(2010),619

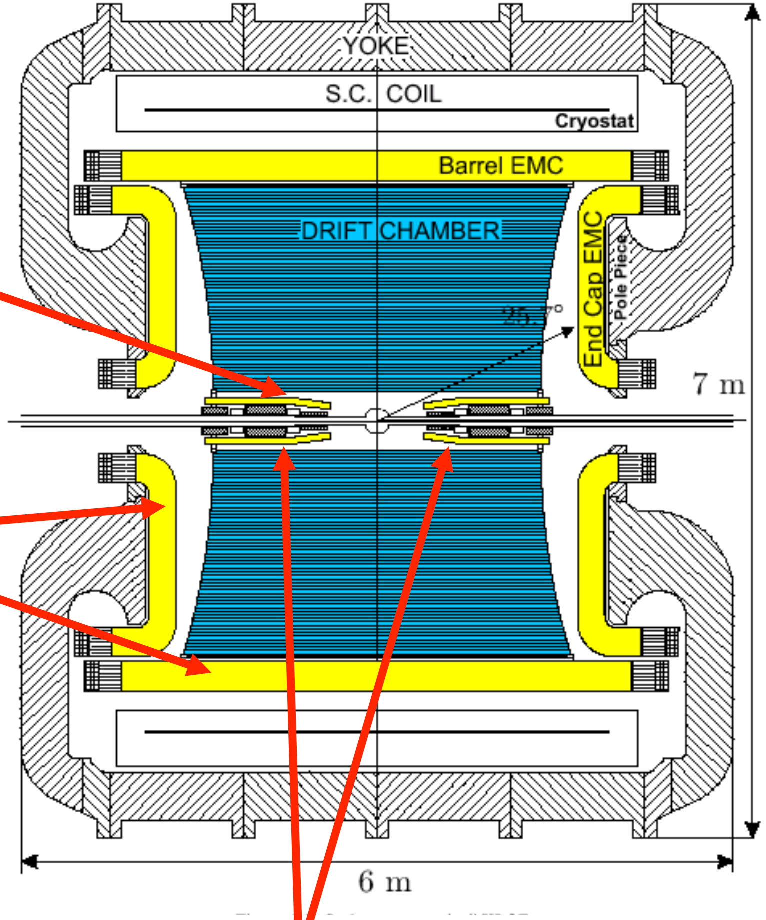
KLOE Detector

Drift chamber:

- gas: 90% He-10% C_4H_{10}
- $\delta p_T/p_T = 0.4\%$
- $\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm
- $\sigma_{vertex} \approx 1$ mm

Calorimeter (Pb-Sci.Fi.):

- $\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
- $\sigma_t = 55\ ps/\sqrt{E(GeV)} \oplus 100\ ps$
- 98% of 4π



Magnetic field: 0.52 T

QCAL vetos: (Pb-scintillator)

…to KLOE-2…(Step0)

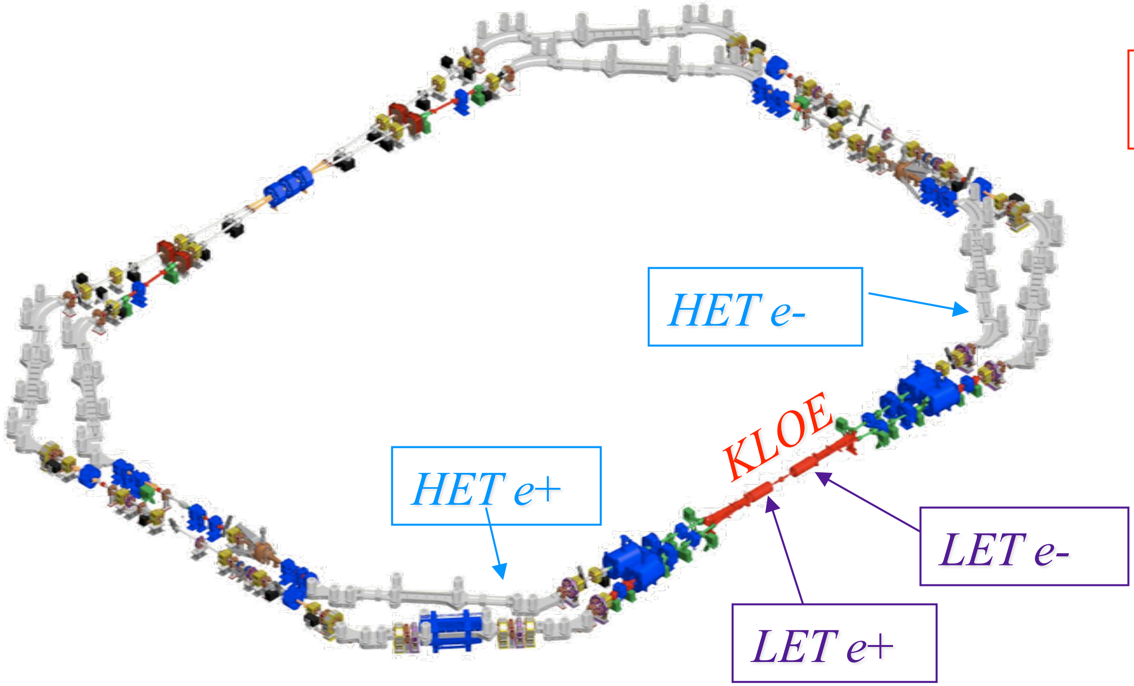
Minimal detector upgrades:

Tagger for γγ physics: detection off-momentum *leptons*

in order to study $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- \mathbf{X}$

Taggers

KLOE



Data taking start next months

Why we need taggers ?

$\gamma\gamma$ physics can be done at a ϕ–factory, on the ϕ peak:

- *gives access to many interesting final states through photon emission from both colliding electron and positron*

TRUE, BUT...

$\gamma\gamma$ events acquired at the ϕ peak would suffer from ϕ decays as background

$\gamma\gamma$ channel	(L = 10 fb^{-1})
$e^+ e^- \to e^+ e^- \pi^0$	4×10^6
$e^+ e^- \to e^+ e^- \eta$	1×10^6
$e^+ e^- \to e^+ e^- \pi^+\pi^-$	2×10^6
$e^+ e^- \to e^+ e^- \pi^0\pi^0$	2×10^4

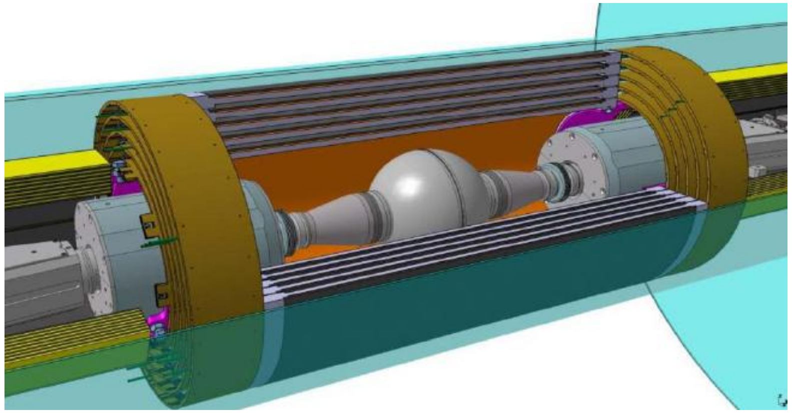
ϕ decays	Missing particle	Events ($\mathcal{L}$ = 10 fb^{-1})	Background for :
$K_S(\pi^0\pi^0)\ K_L$	K_L	$\sim 10^9$	$\pi^0\pi^0$
$K_S(\pi^+\pi^-)\ K_L$	K_L	$\sim 2\times10^9$	$\pi^+\pi^-$
$\pi^+\pi^-\pi^0$	π^0	$\sim 10^9$	
$\eta(\gamma\gamma)\ \gamma$	γ	$\sim 10^8$	η
$\pi^0(\gamma\gamma)\ \gamma$	γ	$\sim 5\times10^8$	π^0

tagging $\gamma\gamma$ events by detecting e^+e^- is mandatory to reduce backgrounds, together with P_T kinematical selection on the tagged events.

…to KLOE-2…(Step1)

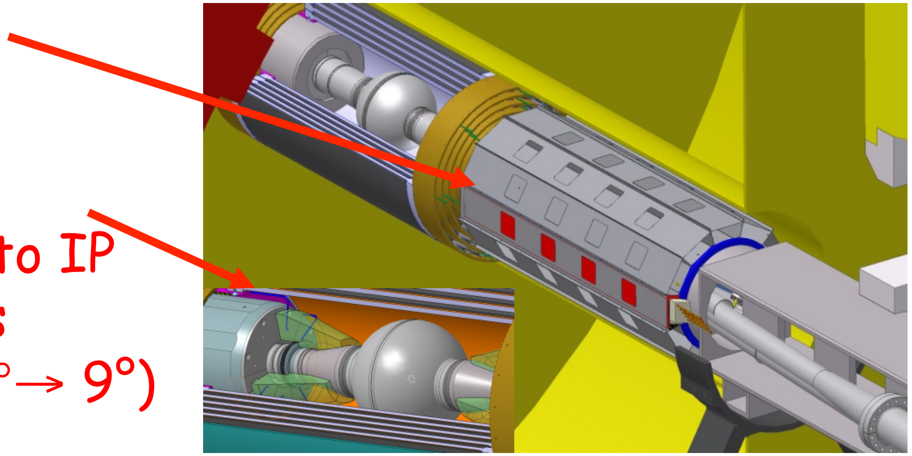
Major detector upgrade

- Inner tracker (between the beam pipe and the DC): 4 layers of cylindrical triple GEM:
  – improve vertex reconstruction near the IP



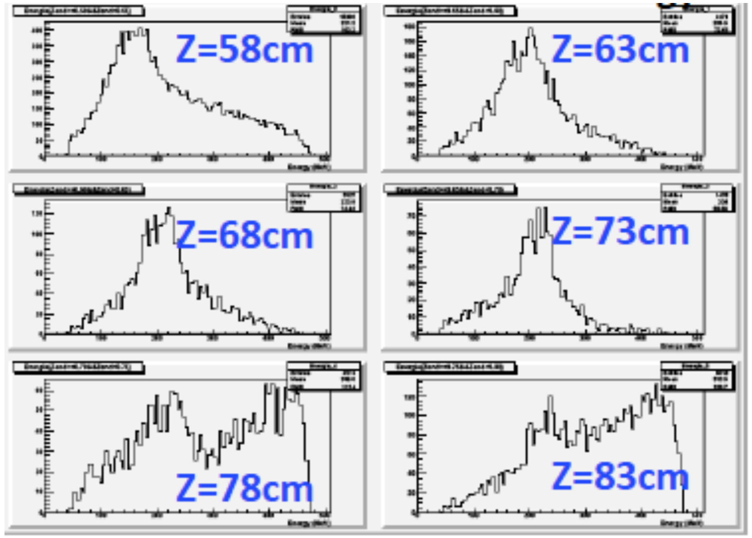
- QCALT: W + scint. tiles readout by SiPM via WLS fibers

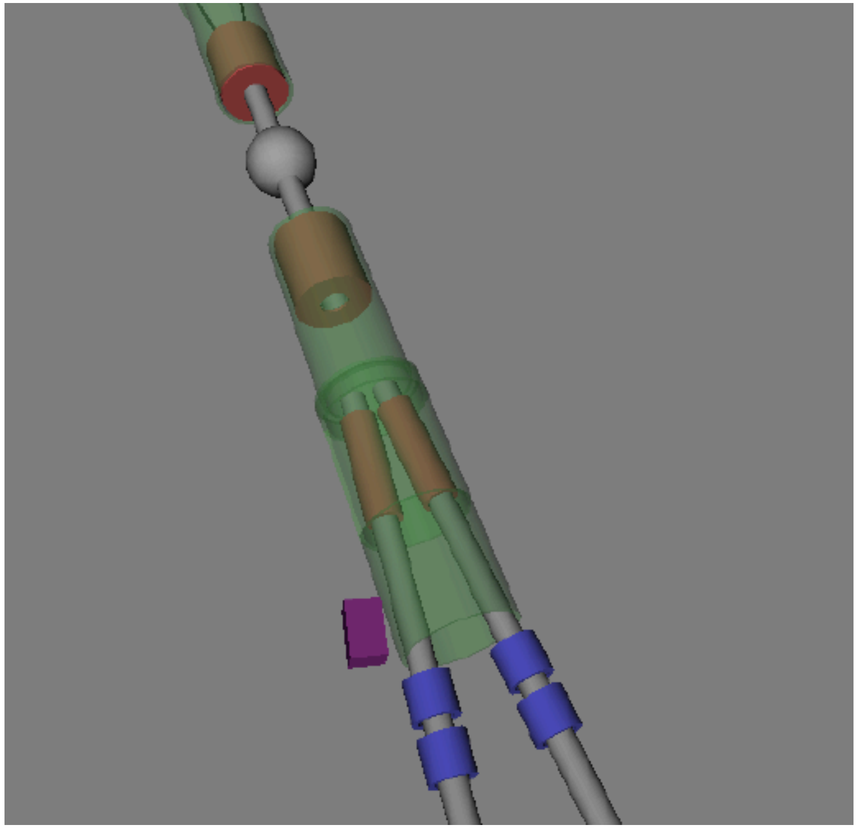
- CCAL: LYSO crystals + APD; close to IP to increase acceptance for photons coming from the IP (min. angle: 21°→ 9°)

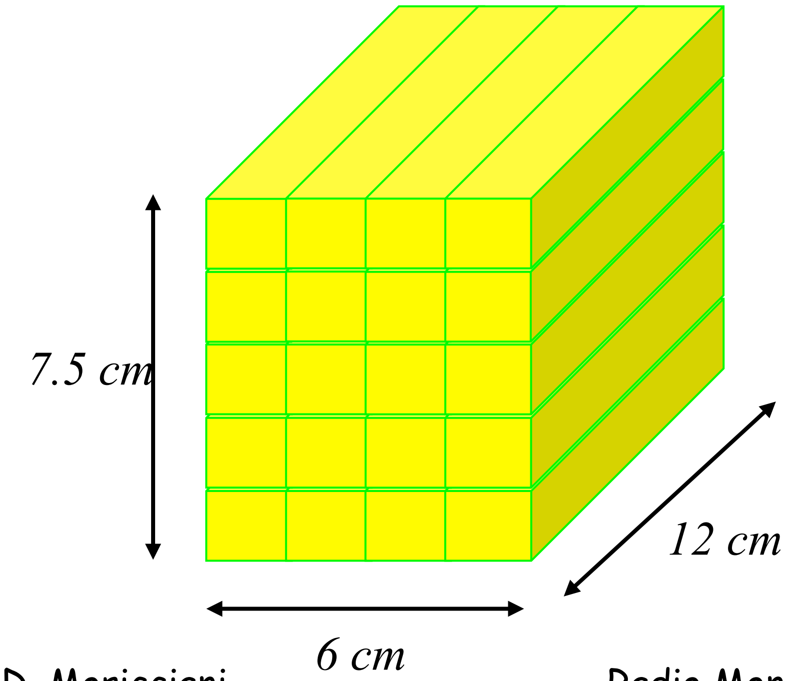


Time scale: installation in late 2011

LET Characteristics



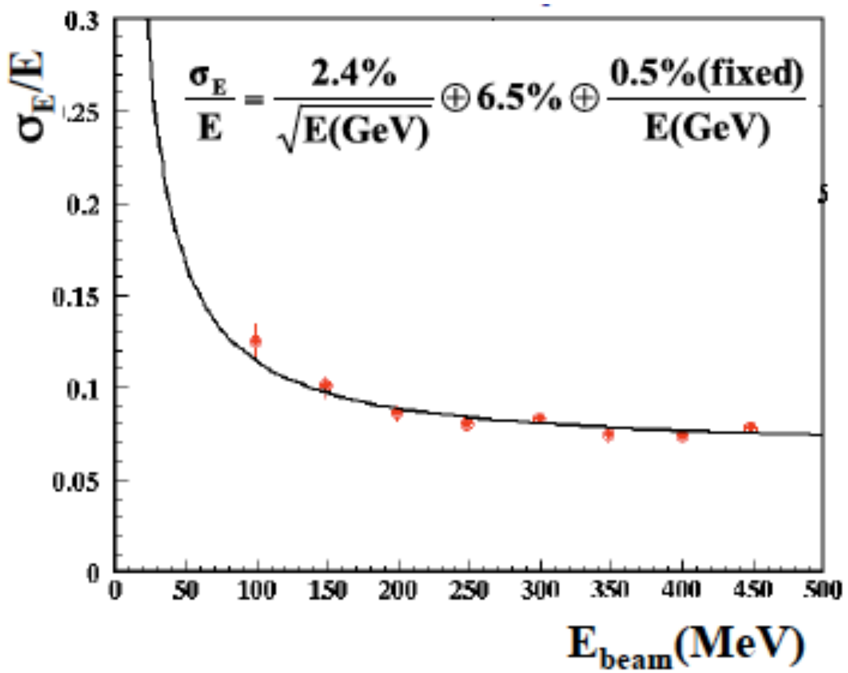


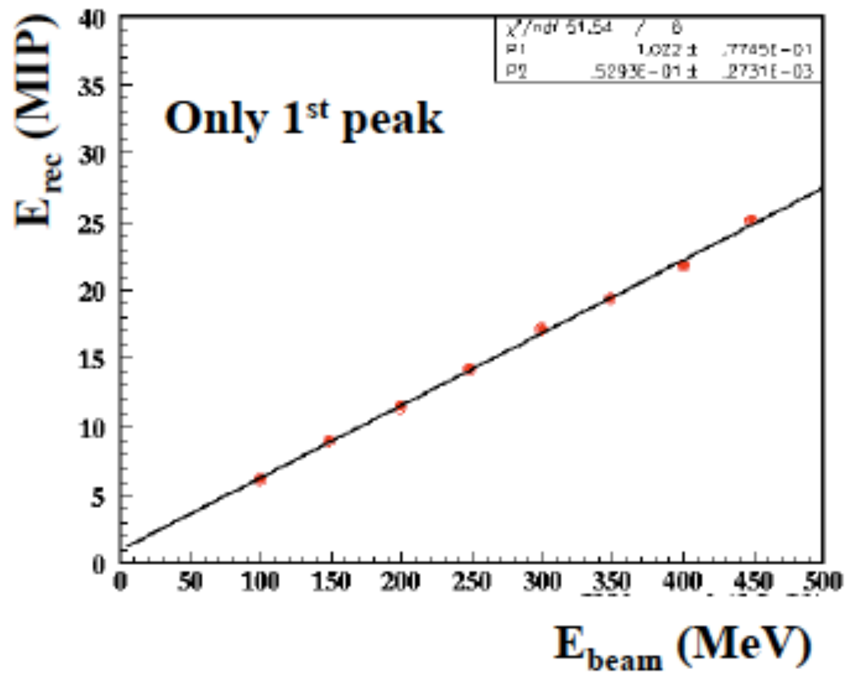


LET: Low Energy Tagger (160-230 MeV) lepton energy

Calorimeters, LYSO + SiPM

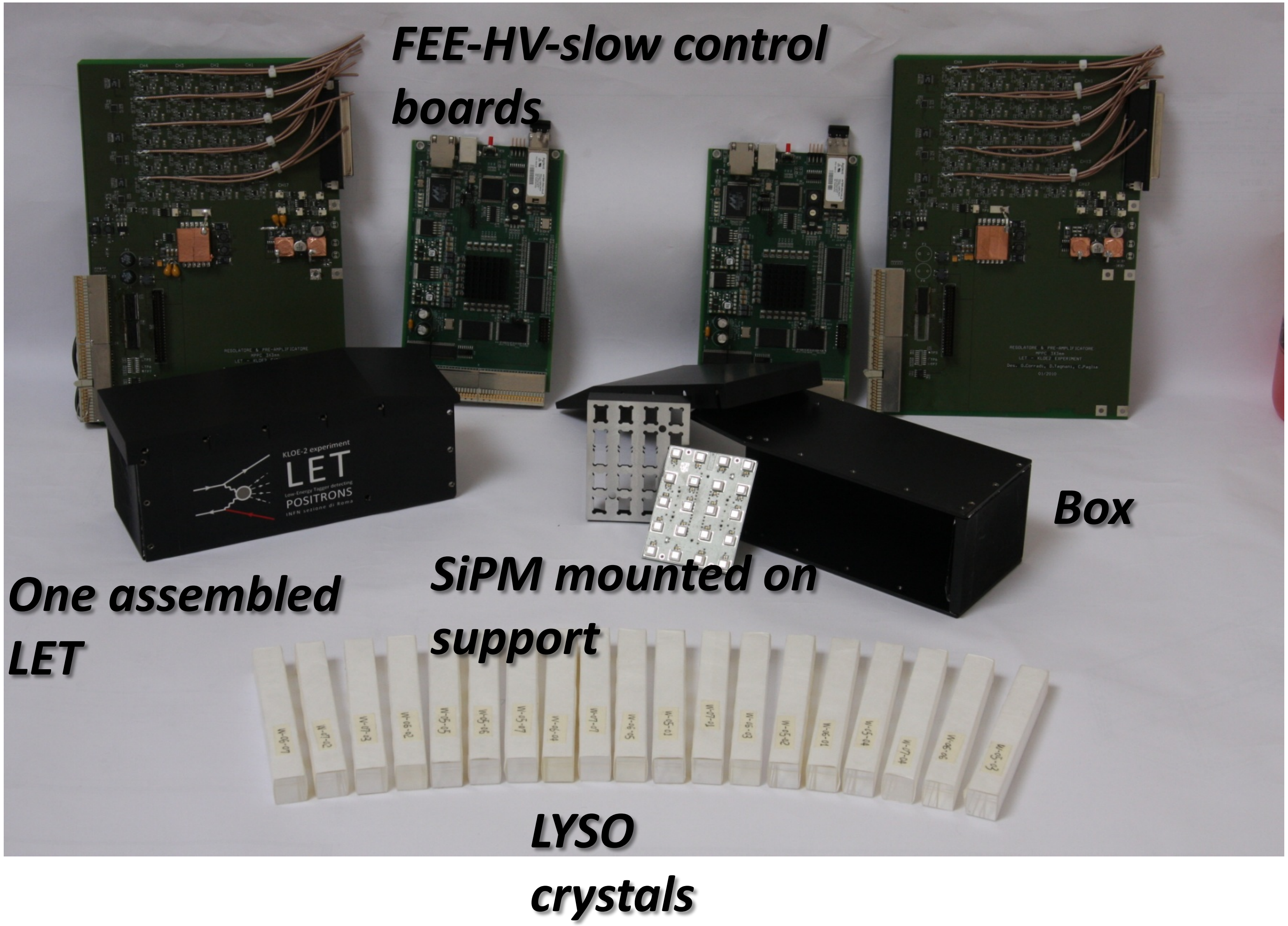
LET system and performance



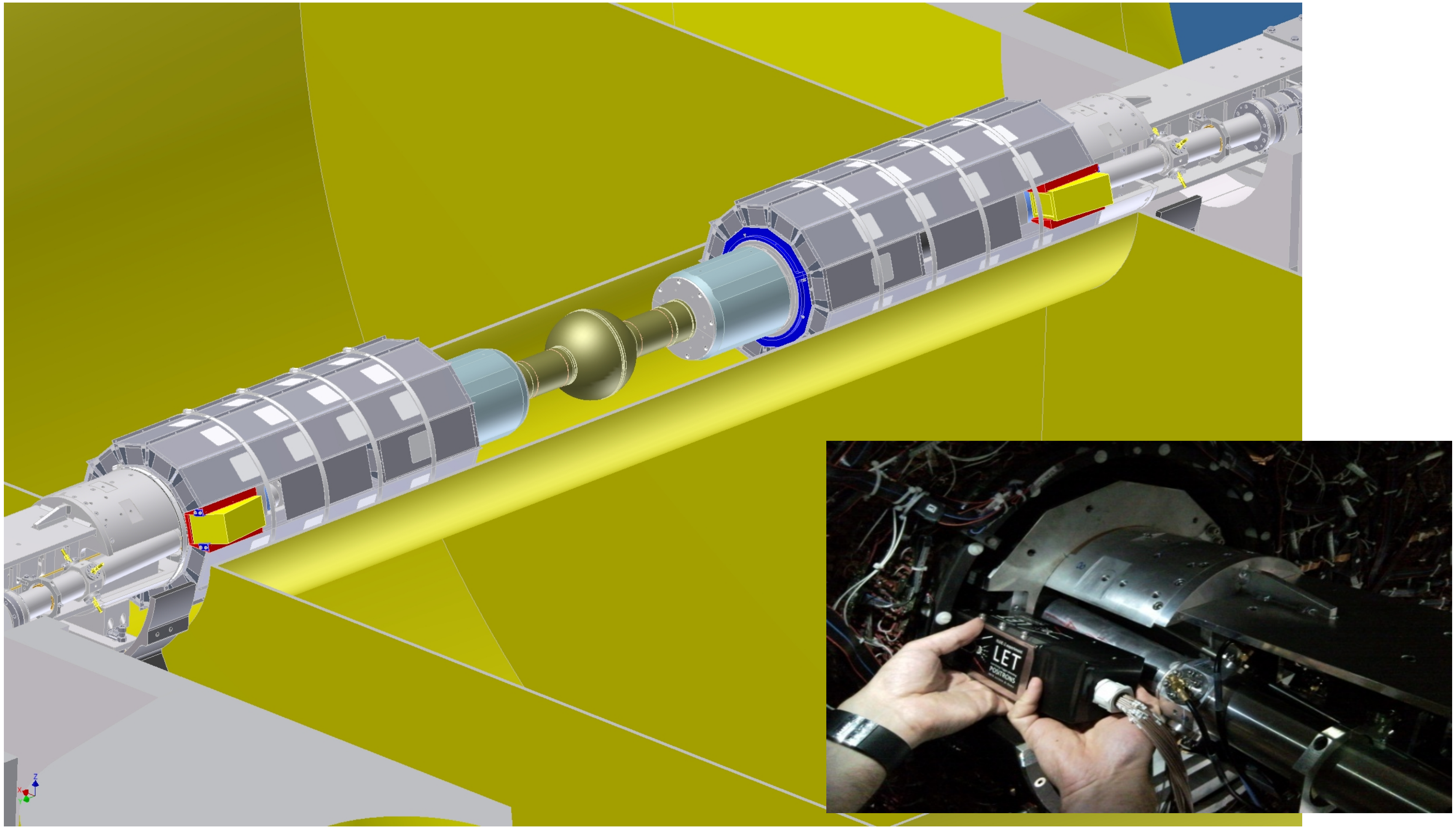


- *3rd term is fixed, since we have about 5 MeV noise*
- *Statistical term higher than expected (20 p.e./MeV → less than 1%/$E^{1/2}$(GeV))*
- *Contribution to constant term due to lateral leakage (matrix not fully readout)*
- *There is an unknown contribution from the beam*
- *Resolution is better than 10% for E > 150 MeV*

LET detectors component



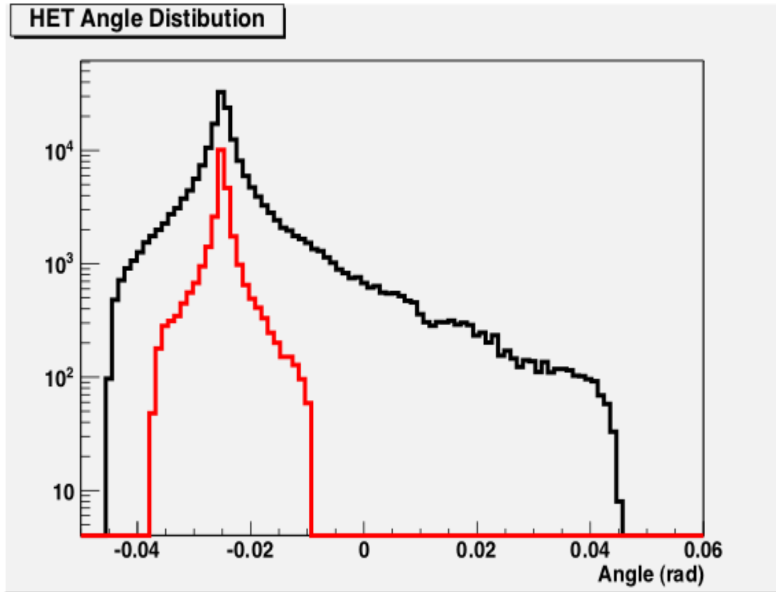
LET Installation

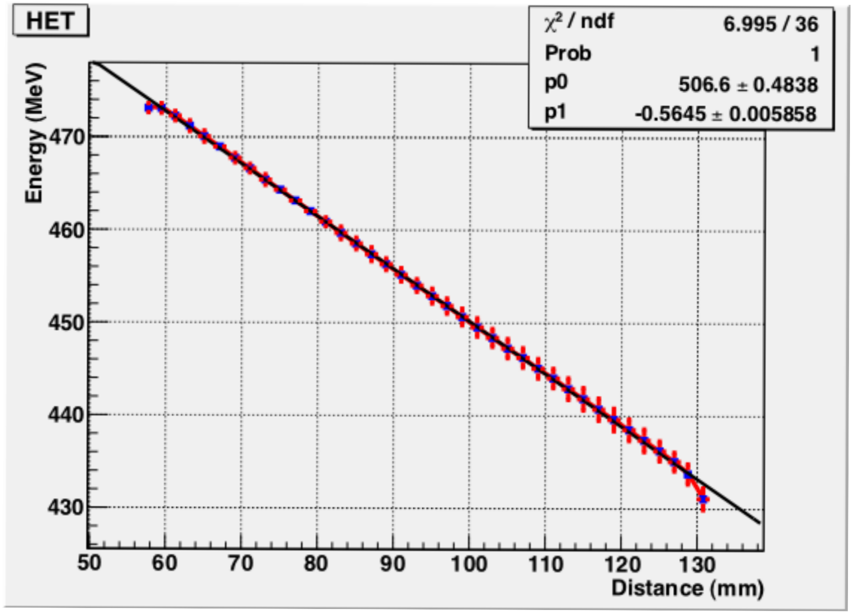


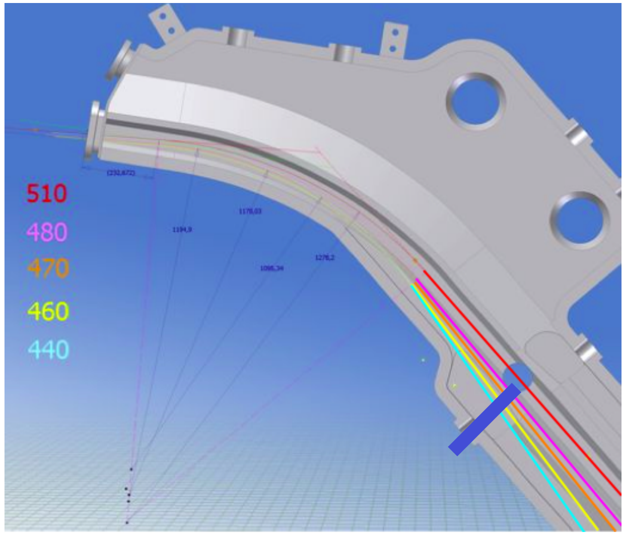
LET in place

HET characteristics

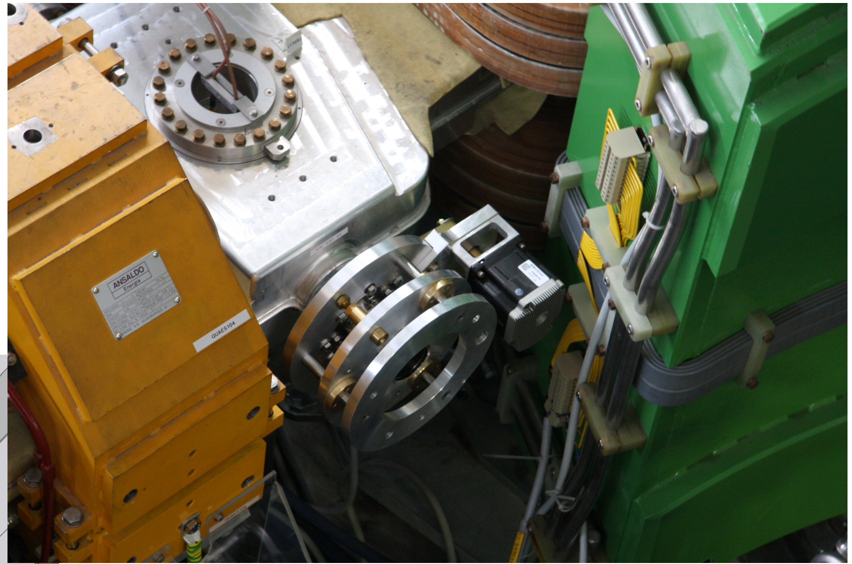
The detector will be located at 11 m from the IP behind a bending magnet. Plastics + PMTs

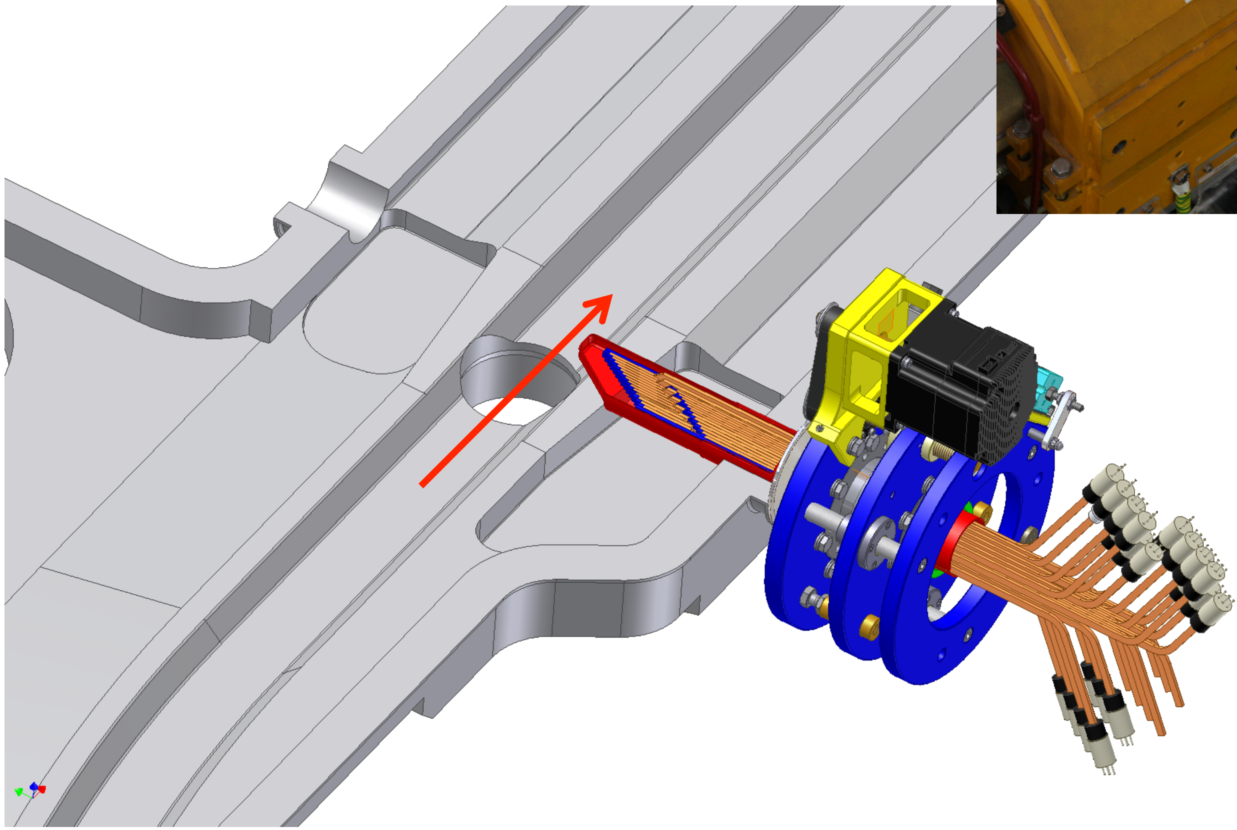




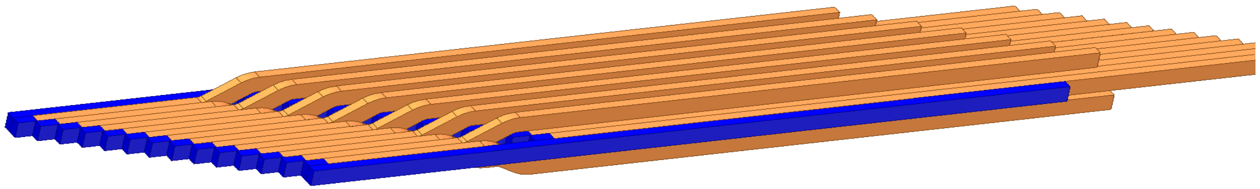


HET systems





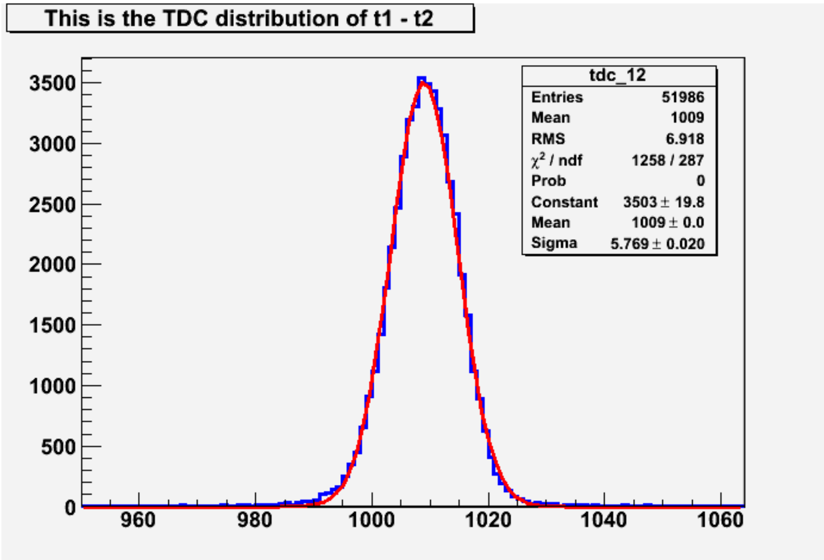
HET detector

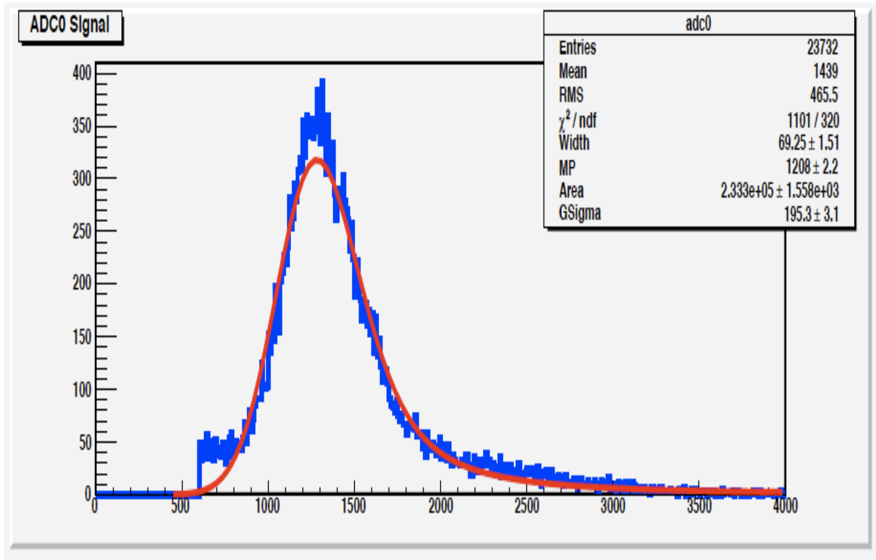


- Minimum safe distance from beam line is of 3-5 cm.
- Hodoscope made by two rows of 15 scintillators of 3x5x6 mm^3 → pitch resolution ~ 5 mm, i.e. 2.5 MeV momentum resolution.
- Fast EJ228 (ELJEN) scintillator used. Light transported to photosensor with light guides. PMT Hamamatsu R9880-U110 readout (QE≈35%).

HET performance

HET prototype successfully tested at LNF-BTF

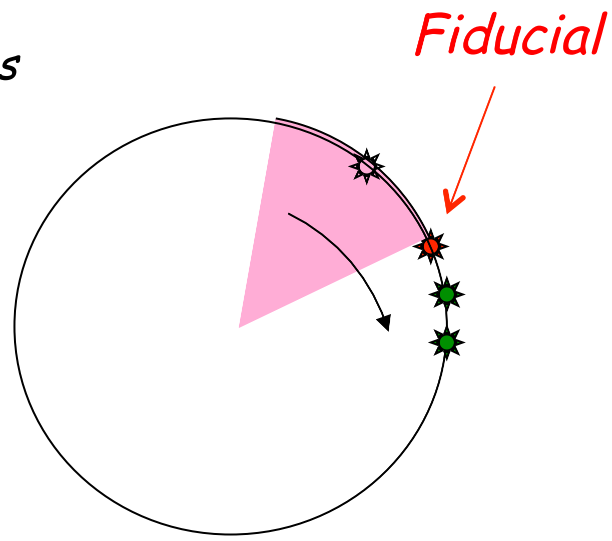




L.Y. in excess of 40 pe/MIP → 200 ps resolution which should allow clear separation between consecutive bunches.

Complete detectors should be tested at BTF at the beginning of October and installed in DAFNE starting from the second half of October

Bunch structure on DaΦne

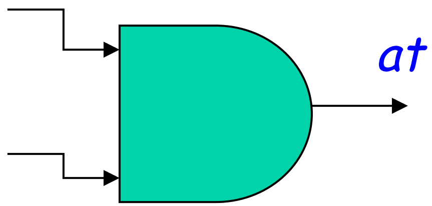


You have to take picture of HETs for any bunches:

B_0 HETe$^-$, B_0 HETe$^+$
B_i HETe$^-$, B_i HETe$^+$
B_n HETe$^-$, B_n HETe$^+$

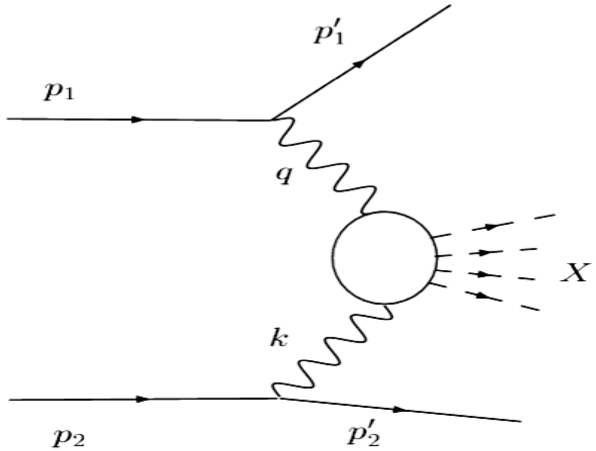
} *And store it for 2 revolution*

Where same B_i means software :

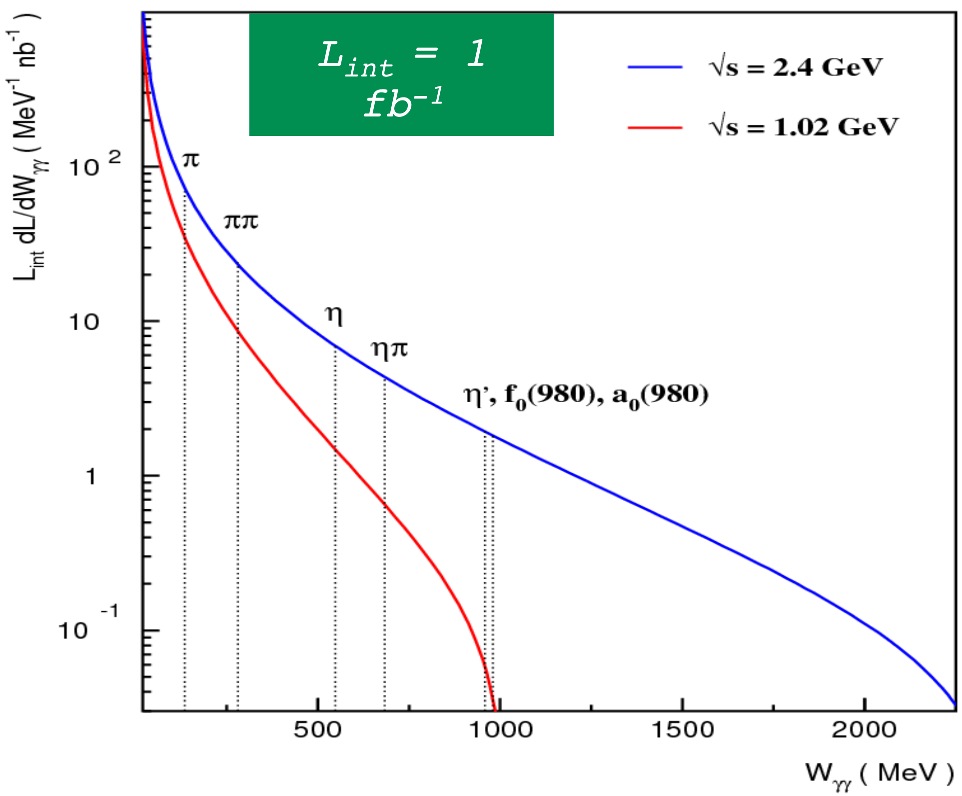


γγ - physics

$e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- X$



$$\frac{dN_X}{dW_{\gamma\gamma}} = L_{int} \frac{dL}{dW_{\gamma\gamma}} \sigma \, (\gamma\gamma \to X)$$

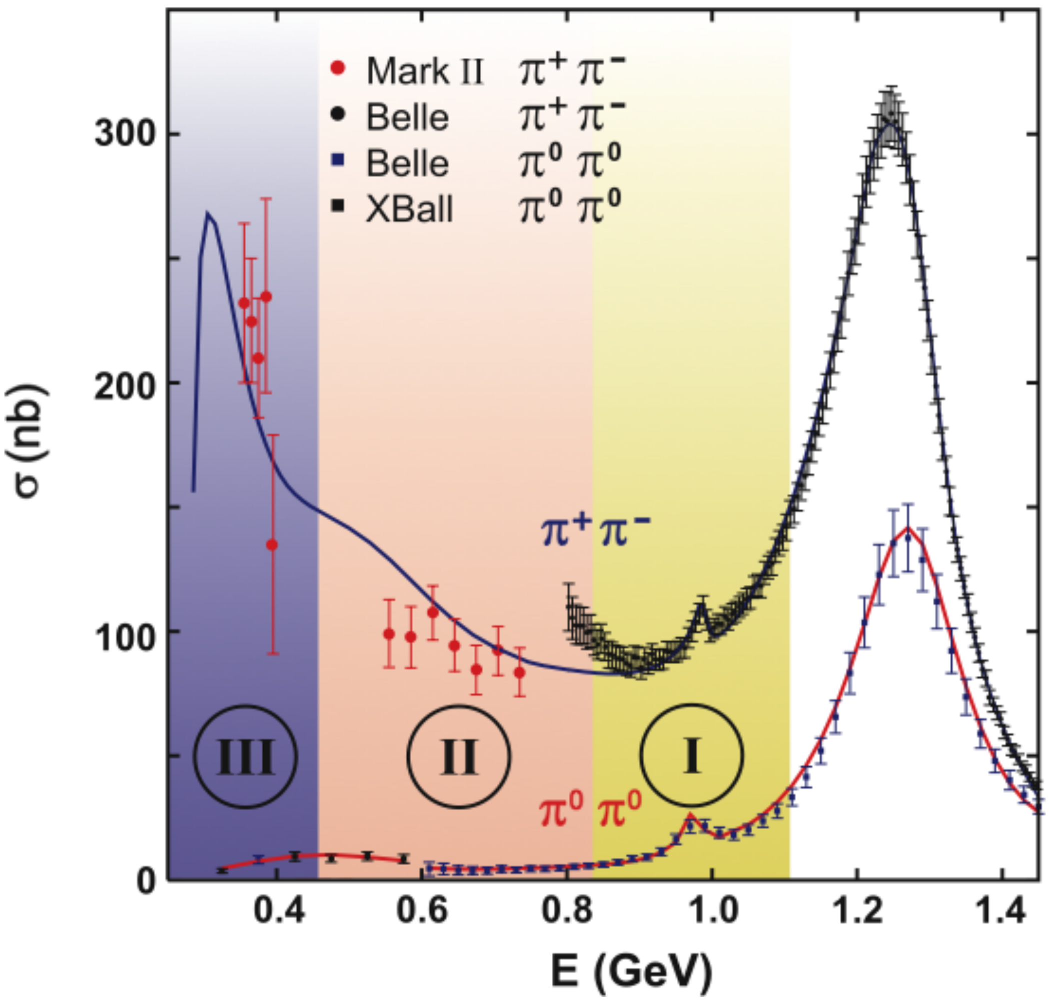


$X \equiv \pi\pi$ → σ meson, ChPT tests

$X \equiv \pi^0, \eta$ → 2-photon widths, transition FFs @ low q^2

$(W_{\gamma\gamma} = M_X)$

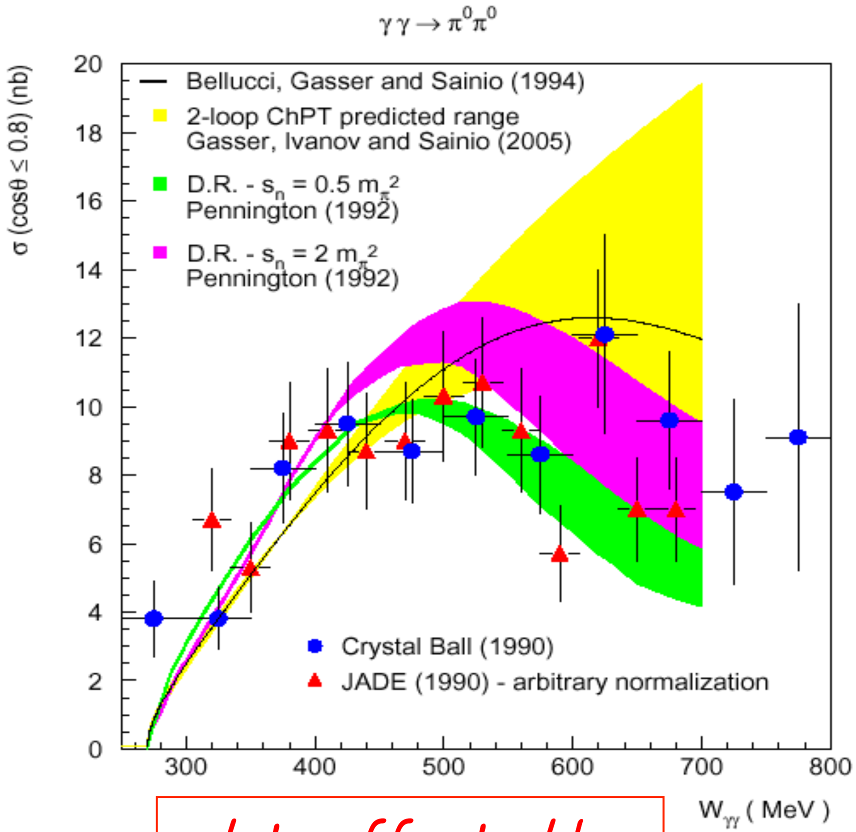
$\gamma\gamma \rightarrow \pi\pi$

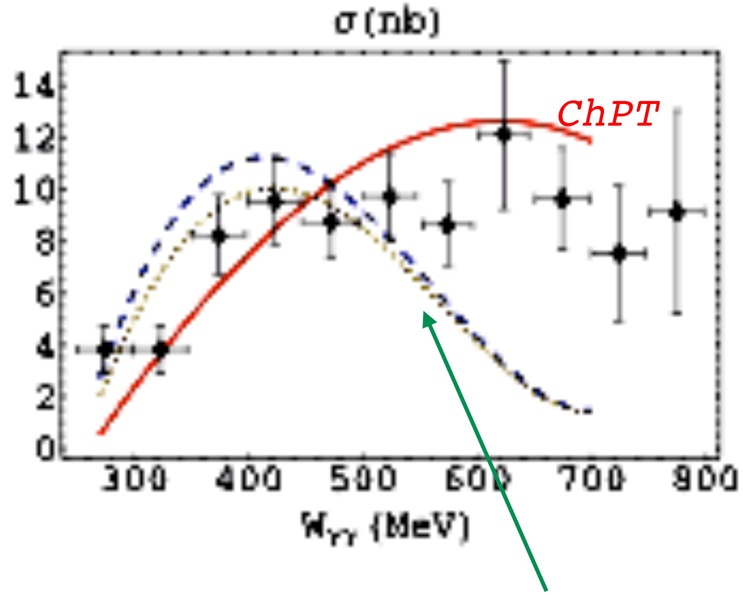


M. R. Pennington (arXiv:0906.1072)

σ meson case

Cleanest channel to assess existence & nature (2q vs 4q) of the σ is $\gamma\gamma \to \pi^0\pi^0$ at low energy





data affected by large uncertanties

resonant contribution
$\gamma\gamma \to \sigma \to \pi^0\pi^0$

(Nguyen, Piccinini, Polosa, EPJC 47, 65 (2006))

σ meson case

Is it difficult to extract the parameter of σ from data. Now, indications of some structure in low energy $\pi\pi$ scattering

- $\pi\pi$ *amplitude contains a pole with the quantum numbers of vacuum*

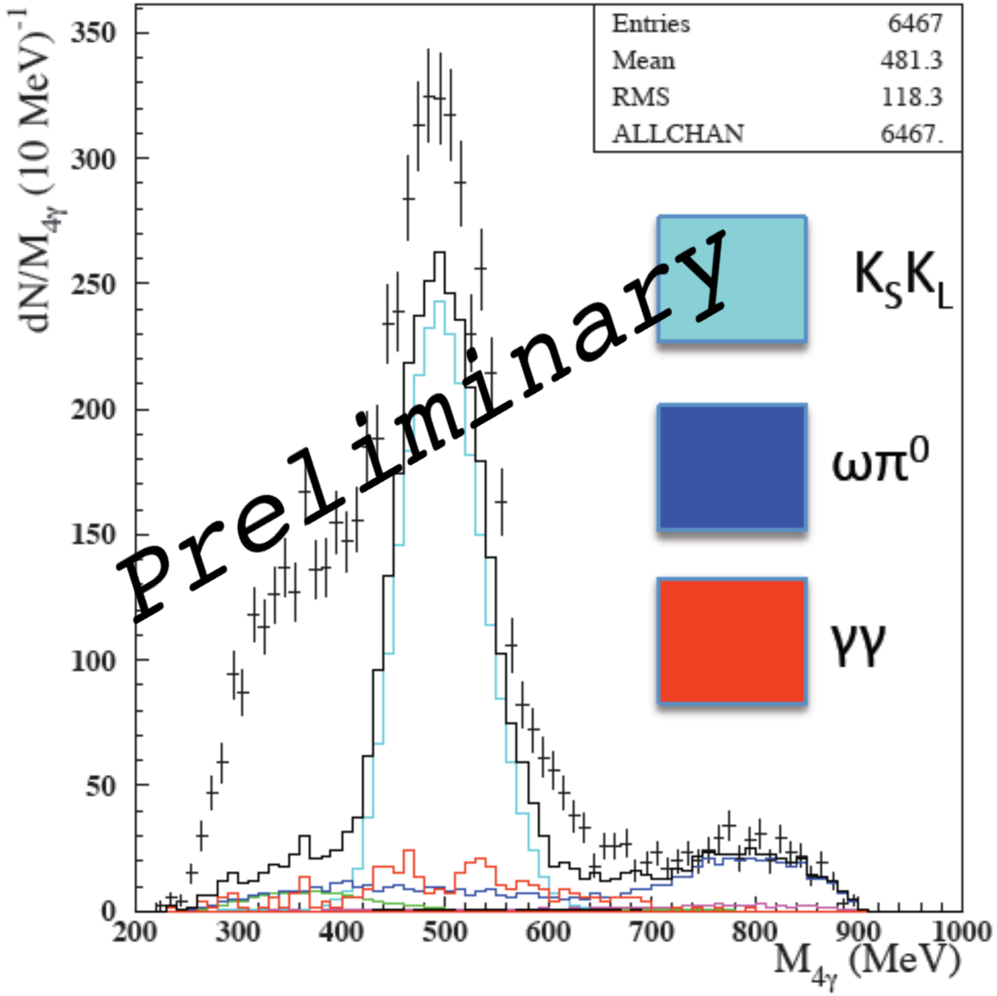
  (Caprini, Colangelo, Leutwyler, PRL 96, 132001 (2006))

  $M_\sigma = 441^{+16}_{-8}$ MeV $\qquad \Gamma_\sigma = 544^{+25}_{-18}$ MeV

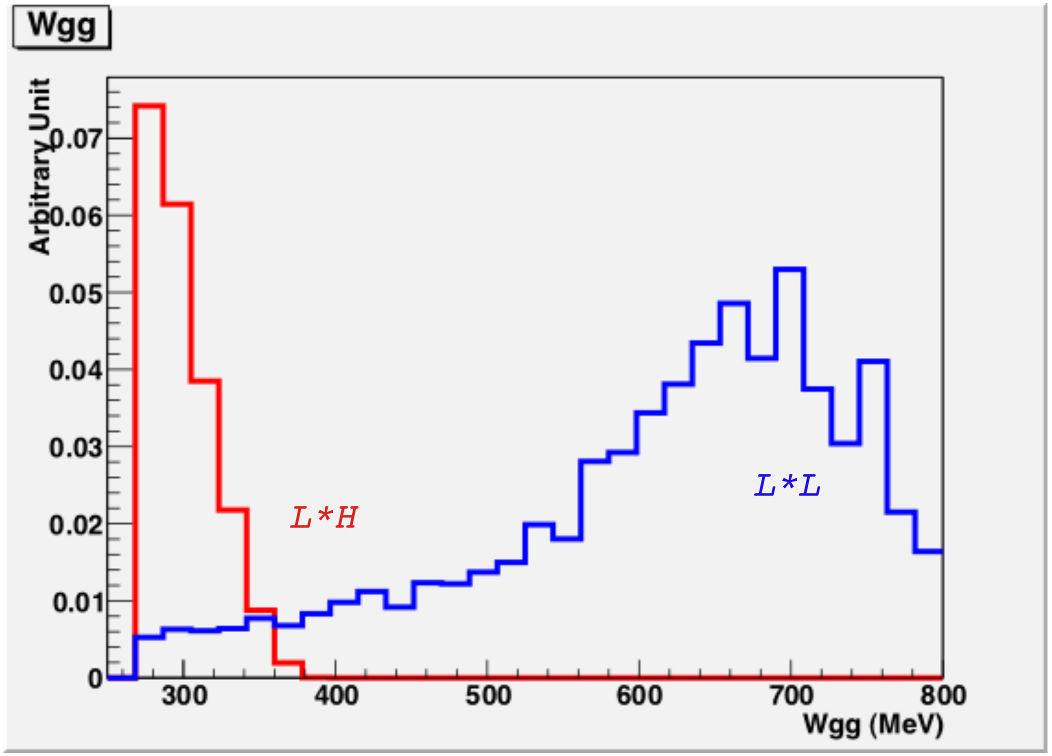
- $D \to 3\pi$ *Dalitz plot analysis (E791) and* $J/\psi \to \omega\pi^+\pi^-$ *(BES)*

- $\phi \to \pi^0\pi^0\gamma$ *KLOE*

KLOE data at √s=1 GeV



Taggers acceptance



In this study we consider only the reaction $\gamma\gamma \rightarrow \pi^0\pi^0$

- Single arm acceptance: HET = 14%, LET = 17%
- Single Total acceptance (only 1 tagger fired) = 54%
- Double arm acceptance (H*H + 2*L*(H) + L*L) = 2+5+3 = 10%

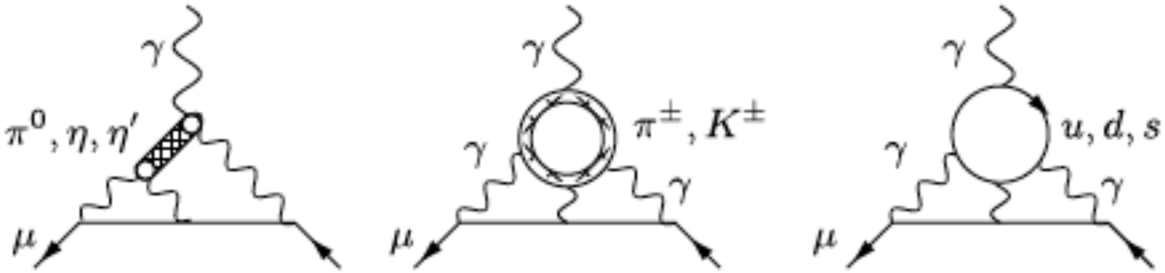
Meson transition FFs

$e^+e^- \to e^+e^- M$

$\gamma^* \gamma \to M \quad \to$ Amplitude $\propto \mathcal{F}(M^2, Q^2, 0)$

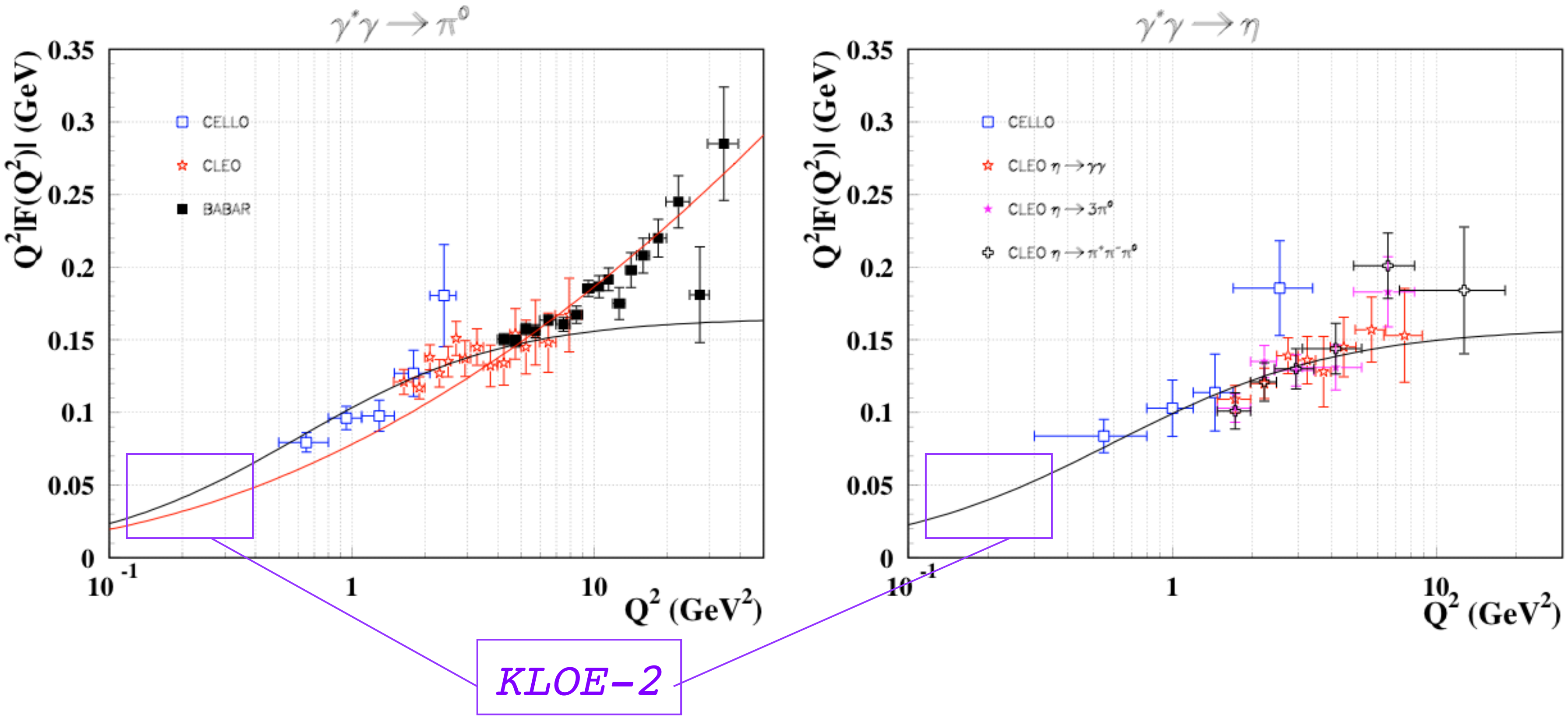
slope of $\mathcal{F}$ near $Q^2 = 0$ crucial for hadronic LbL contribution to a_μ

F. Jegerlehner, A. Nyffeler / Physics Reports 477 (2009) 1–110



$$a_\mu^{\mathrm{LbL};\pi^0} = -e^6 \int \frac{d^4 q_1}{(2\pi)^4} \frac{d^4 q_2}{(2\pi)^4} \frac{1}{q_1^2 q_2^2 (q_1+q_2)^2 [(p+q_1)^2 - m_\mu^2][(p-q_2)^2 - m_\mu^2]}$$
$$\times \left[\frac{\mathcal{F}_{\pi^0*\gamma^*\gamma^*}(q_2^2, q_1^2, q_3^2)\, \mathcal{F}_{\pi^0*\gamma^*\gamma}(q_2^2, q_2^2, 0)}{q_2^2 - m_\pi^2} T_1(q_1, q_2; p) \right.$$
$$\left. + \frac{\mathcal{F}_{\pi^0*\gamma^*\gamma^*}(q_3^2, q_1^2, q_2^2)\, \mathcal{F}_{\pi^0*\gamma^*\gamma}(q_3^2, q_3^2, 0)}{q_3^2 - m_\pi^2} T_2(q_1, q_2; p) \right],$$

KLOE-2 contribution ??



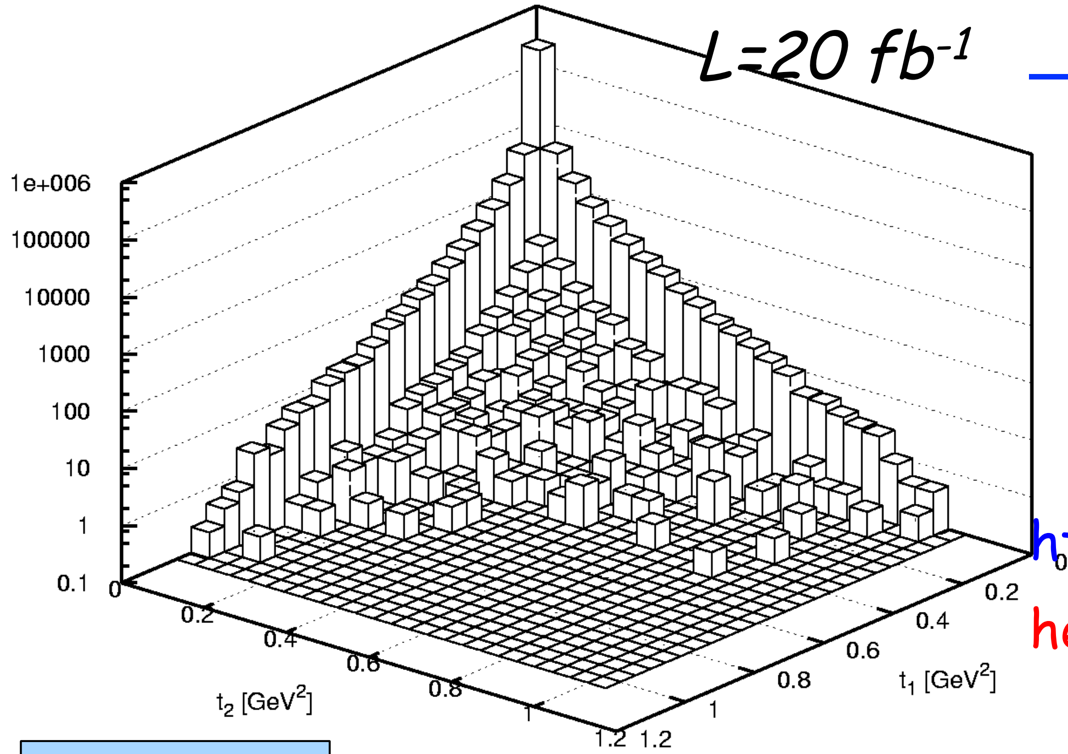
$\gamma^*\gamma^* \to \pi^0$ from KLOE-2

studies with **EKHARA Monte Carlo** generator

(**$e^+e^- \to e^+e^-\pi^0$** added in a new version)

L=20 fb^{-1}

Preliminary



No tagging

- Henryk Czyz
(Katowice)
- Sergiy Ivashyn
(Katowice, Kharkov)

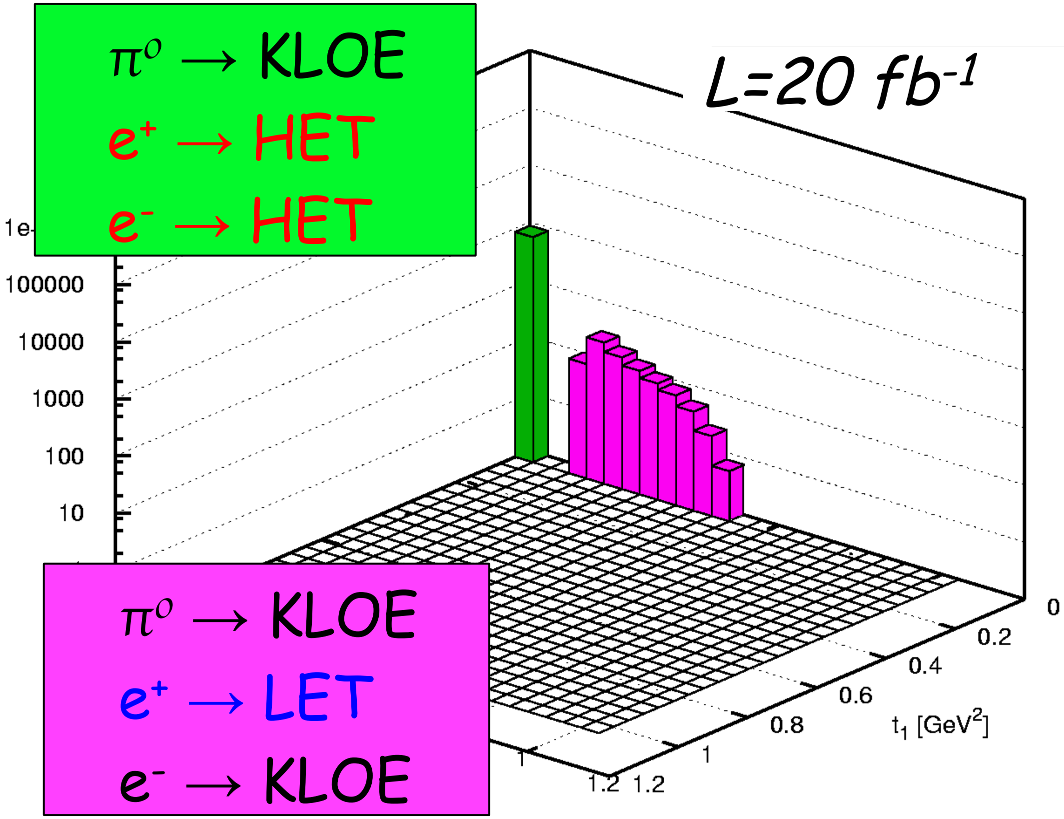
http://prac.us.edu.pl/~ekhara

hep-ph 1009.1881

$\gamma^*\gamma \to \pi^0$ from KLOE-2

studies with **EKHARA Monte Carlo** generator

(**e^+e^-** $\to$ **e^+e^-**π^0 added in a new version)



Preliminary

- Henryk Czyz (Katowice)
- Sergiy Ivashyn (Katowice, Kharkov)

http://prac.us.edu.pl/~ekhara

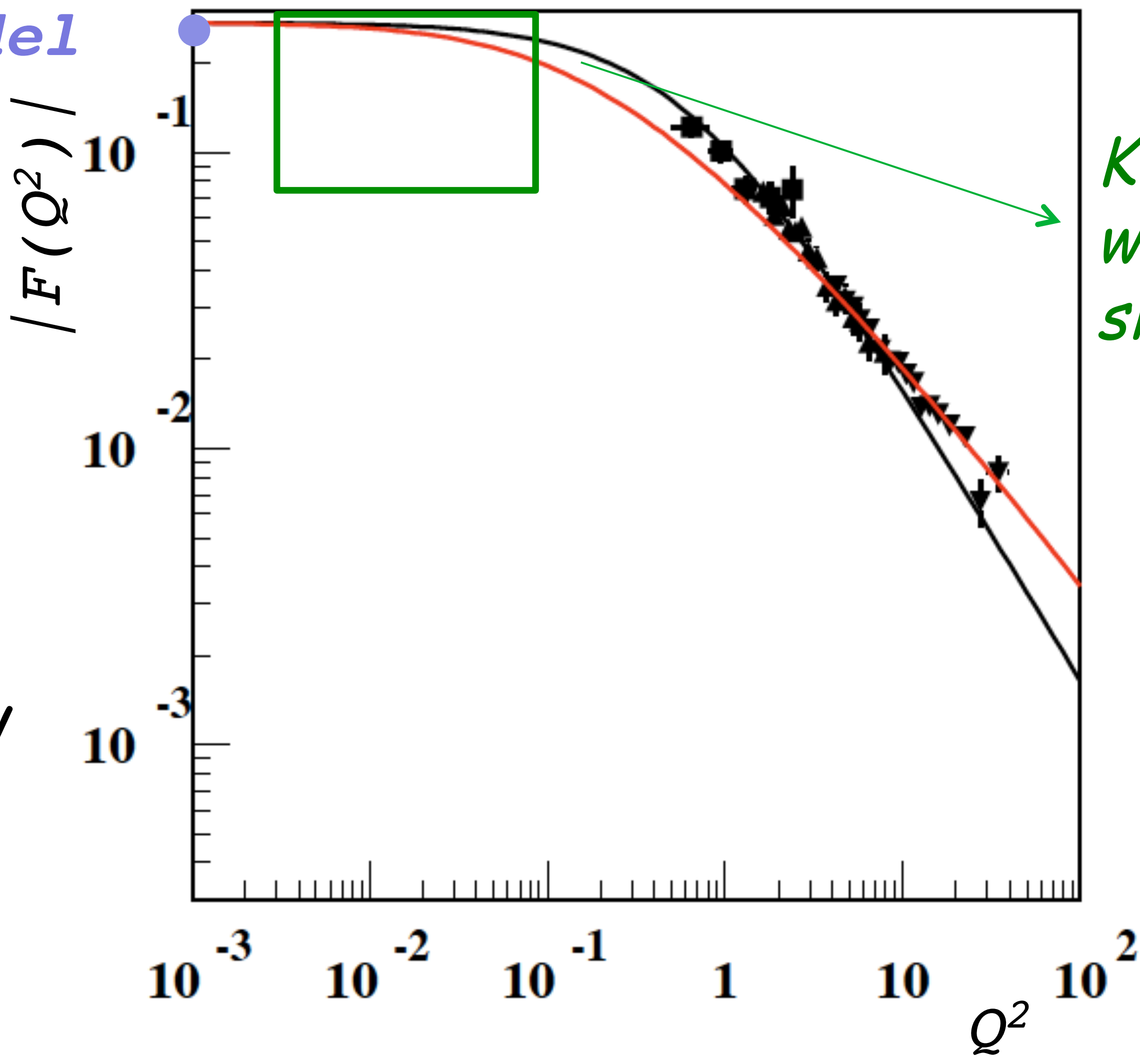
hep-ph 1009.1881

$\gamma\gamma^* \rightarrow \pi^0$

WZW model

$$\frac{1}{4\pi^2 f_\pi}$$

Where f_π come from $\pi\text{->}\mu\nu$ decay

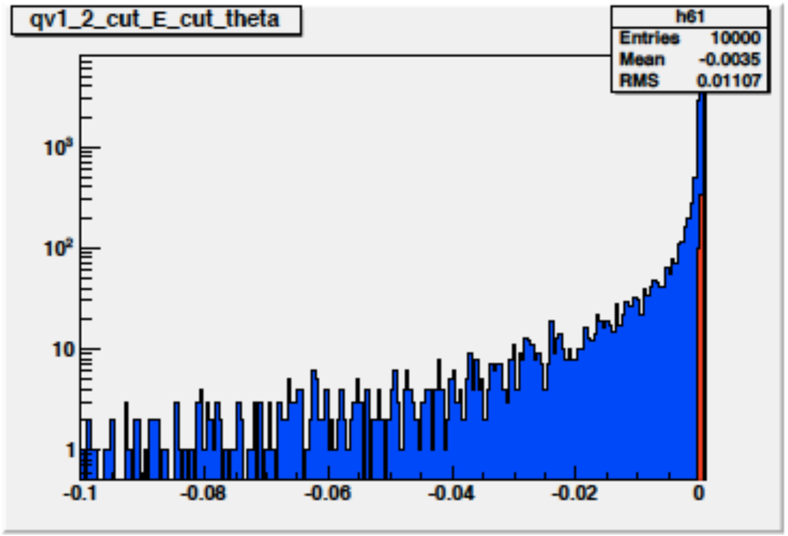


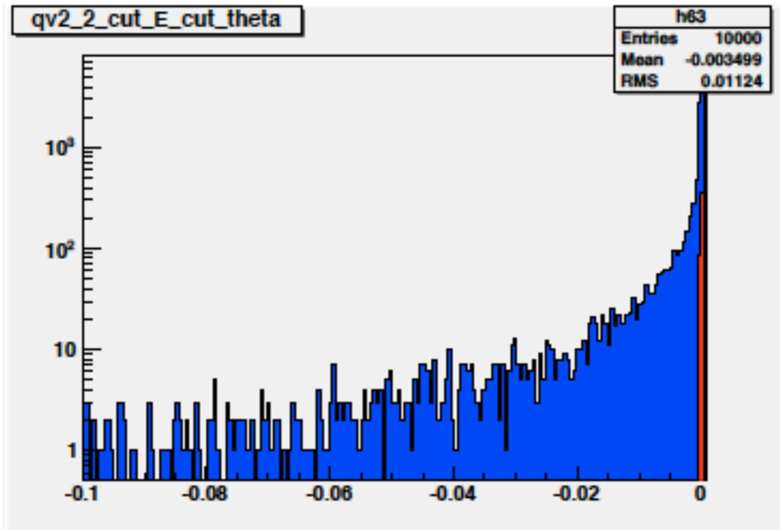
Kloe-2 data will fix the slope at $Q^2=0$

$\Gamma(\pi^o \to \gamma\gamma)$

$$\mathcal{F}^2_{\pi^0\gamma\gamma}(m^2_{\pi^0},0,0) = \frac{1}{(4\pi\alpha)^2}\frac{64\pi\Gamma(\pi^0\to\gamma\gamma)}{M^3_{\pi^0}}.$$

$$\sigma \propto \Gamma(\gamma^*\gamma^* \to \pi^o)\Gamma(\pi^o \to \gamma\gamma) \approx \Gamma^2(\pi^o \to \gamma\gamma)$$





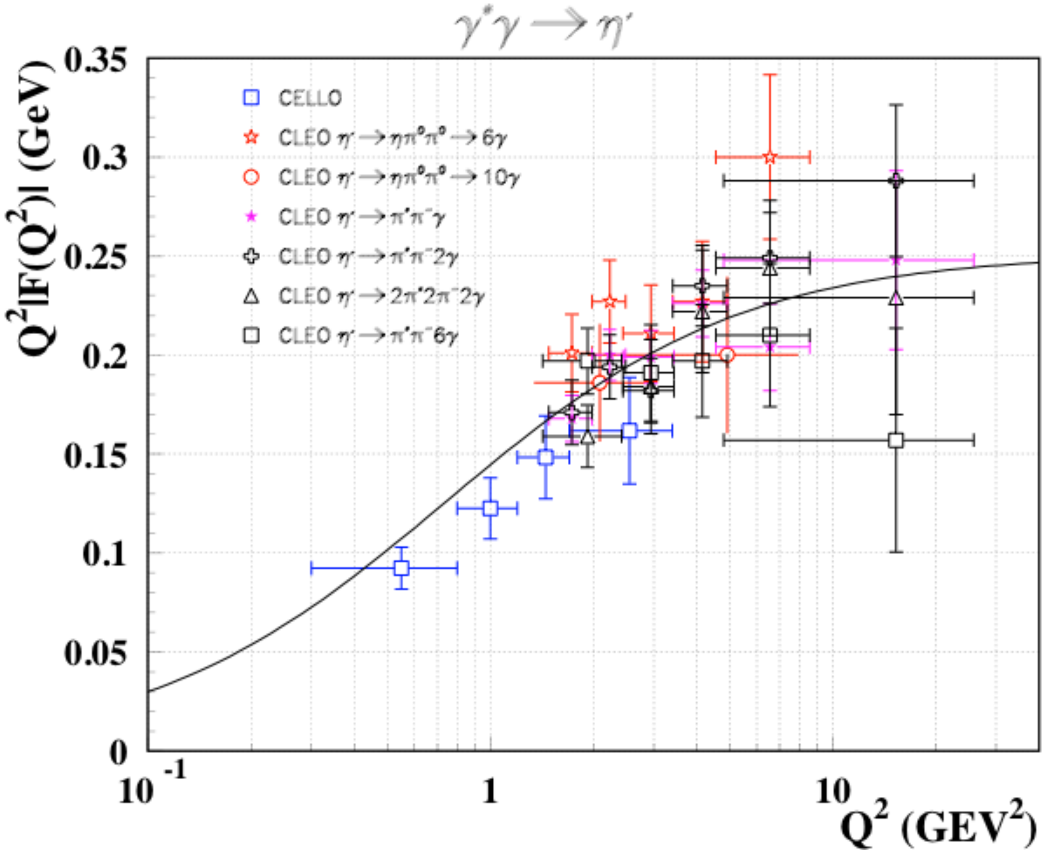
$\sigma_{tot}(1020)=0.28$ nb $\quad \sigma_{exp}=\sigma_{tot}*3.7\% \quad N_{ev}=\sigma_{exp}L_{ee}\varepsilon$

N_{ev}=2500/year also with ε=50%

Meson transition FFs

DAΦNE energy upgrade → higher mass states accessible: η', f_0, a_1 …

This is a option under study

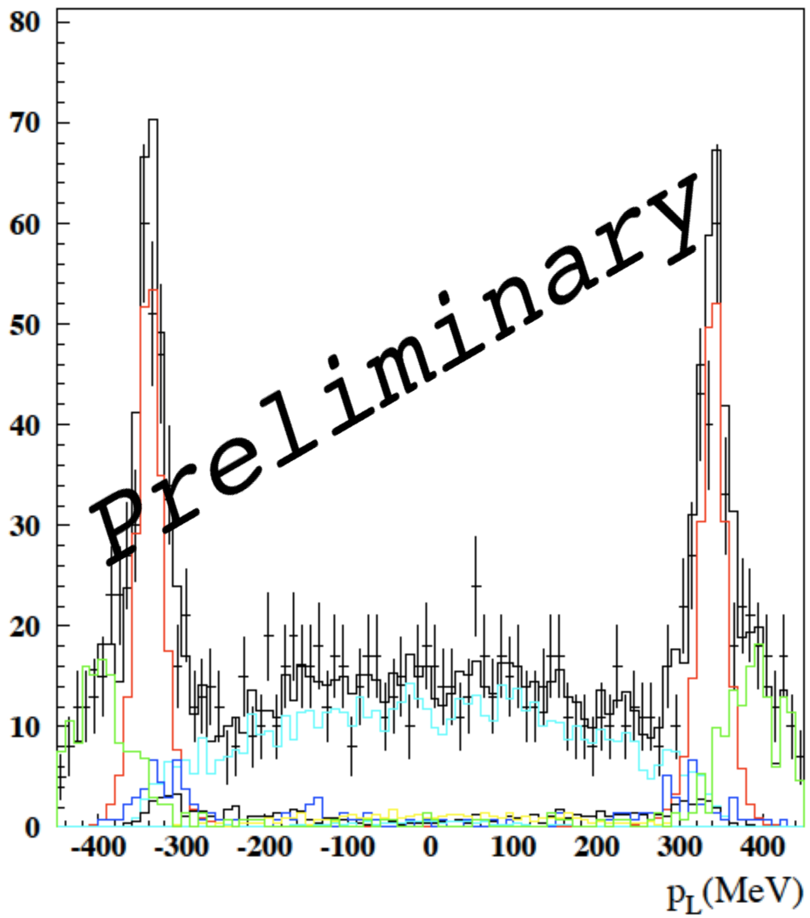


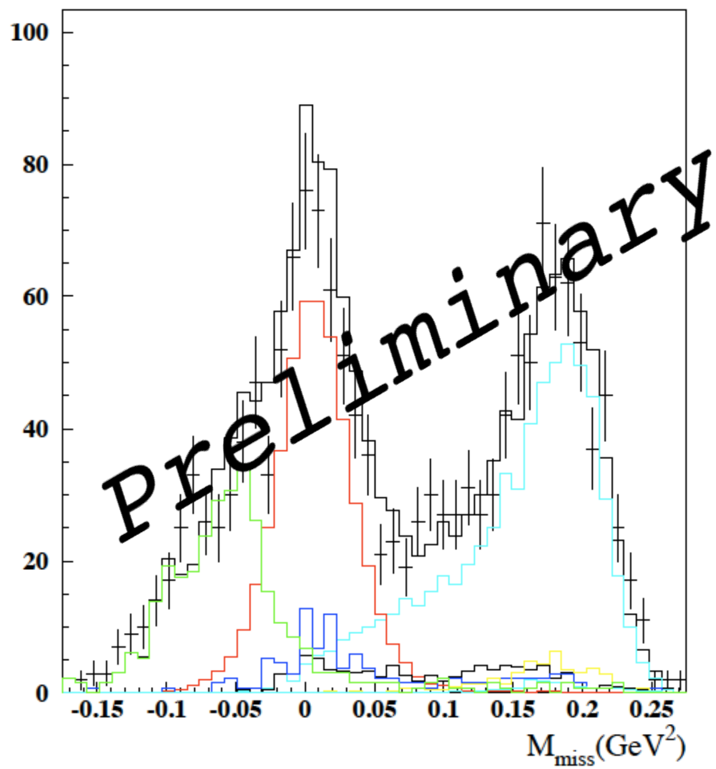
KLOE data at √s=1 GeV

$e^+e^- \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$

$e^+e^- \to e^+e^-\gamma$

signal





Summary

Tagging detectors ready → LET already installed, HET will be installed in October
DAΦNE commissioning in progress

⇩

$\gamma\gamma$-physics program @ KLOE-2:

- ✓ $\gamma\gamma \rightarrow \pi\pi$ *x-sect. in the low energy region → the final word (hopefully) about the σ meson;*

- ✓ π^0 *and* η *TFFs @ very low* q^2 *→ consistent reduction in uncertainty of the hadronic LbL contribution to* a_μ

(energy upgrade of DAΦNE under study → η', f_0, a_1 *TFFs !)*