KLOE small angle tagger

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On behalf KLOE-2 Collaboration

"INT Workshop on Hadronic Light-by-Light Contribution to the Muon Anomaly"

February 28-March 4, 2011

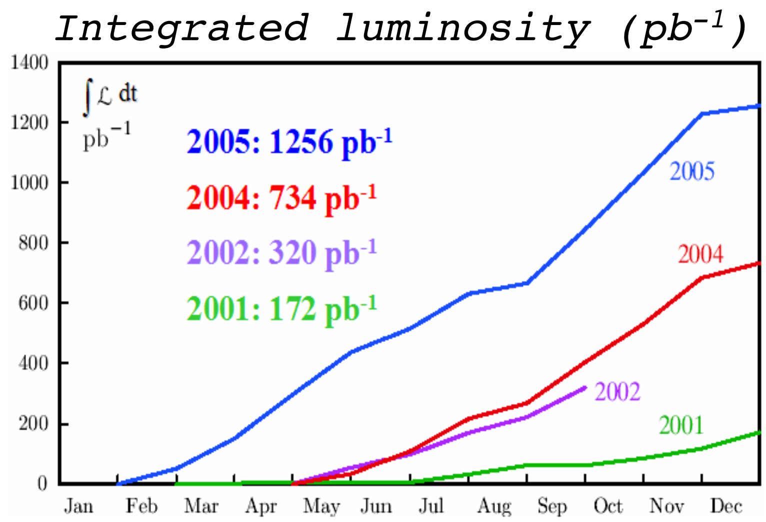
History of KLOE@DAΦNE

- Frascati ϕ-factory :

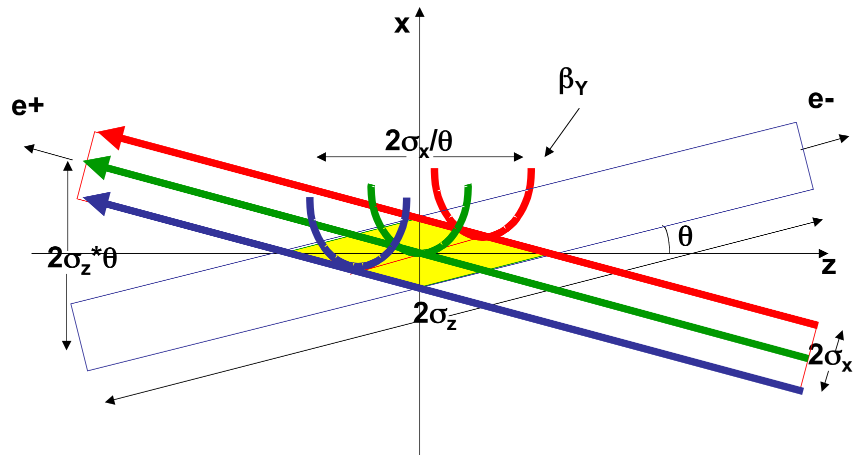
e^+e^- collider @ $\sqrt{s} \approx 1020$ MeV $\approx M_\phi$;

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

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



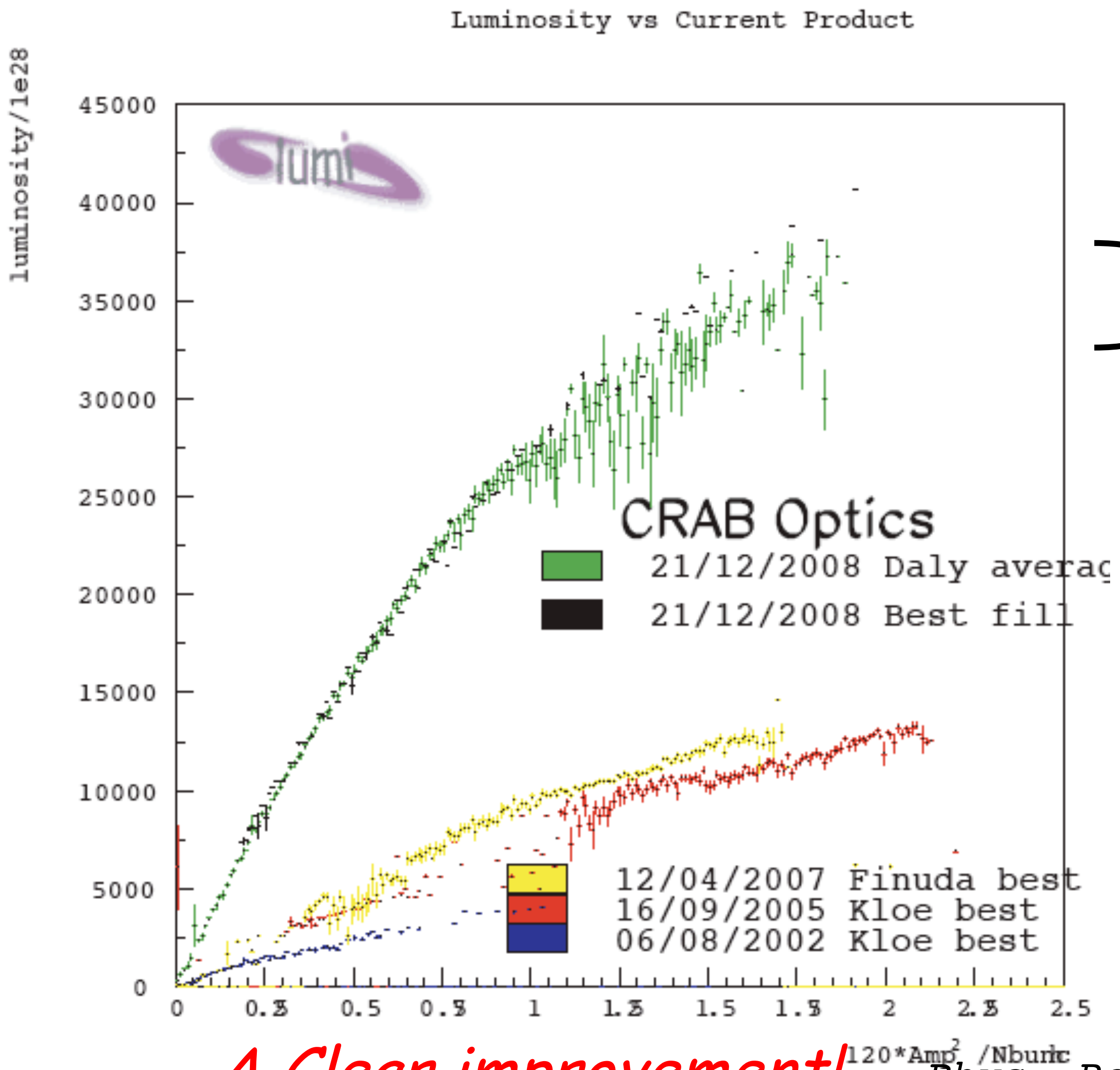
- New interaction scheme implemented : large beam crossing angle + crabbed waist sextupoles



Luminosity increase factor ~ 3

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

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

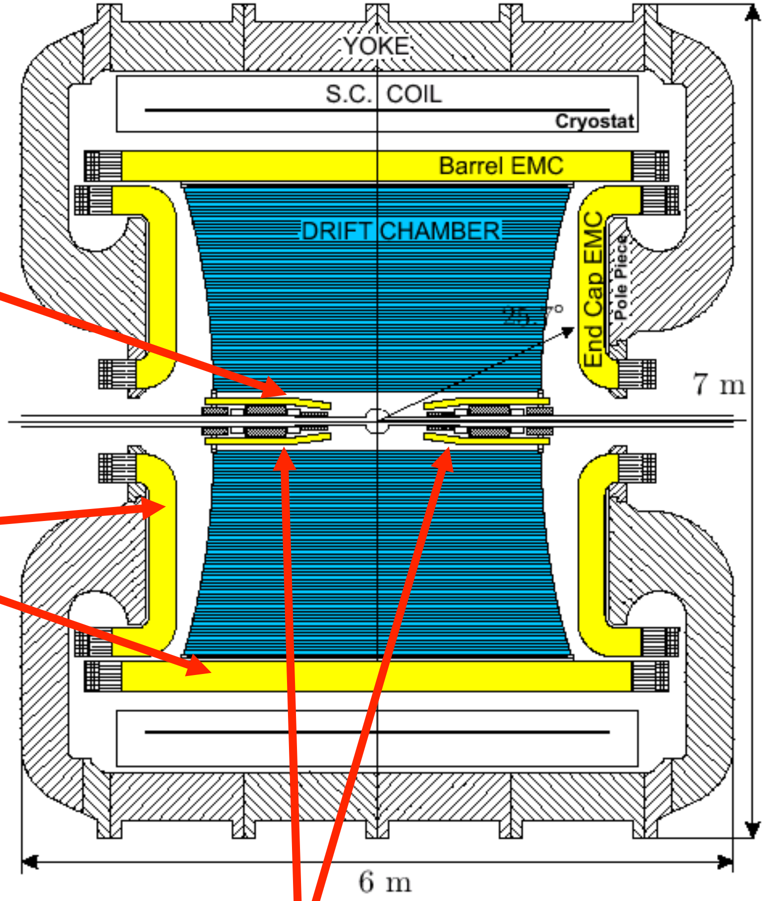
- Kaon Physics
  - Test of CPT (and QM) in correlated kaon decays
  - Test of CPT in K_S semileptonic decays
  - Test of SM (CKM unitarity, lepton universality)
  - Test of χPT (K_S decays)
- Spectroscopy of light mesons
  - η, η', f_0, a_0, σ in ϕ radiative decays
- Dark Matter searches (light bosons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

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

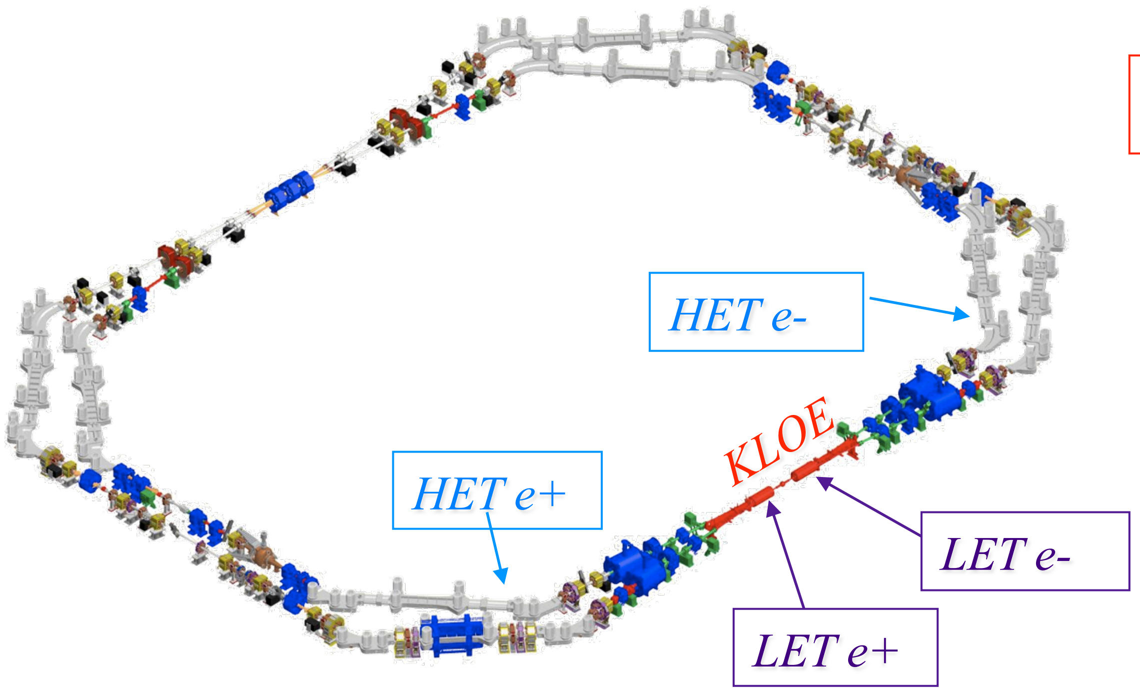
QCAL vetos: (Pb-scintillator)

...to KLOE-2...(Step0)

Minimal detector upgrades:
Tagger for $\gamma\gamma$ physics: detection off-momentum *leptons*
in order to study $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$

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

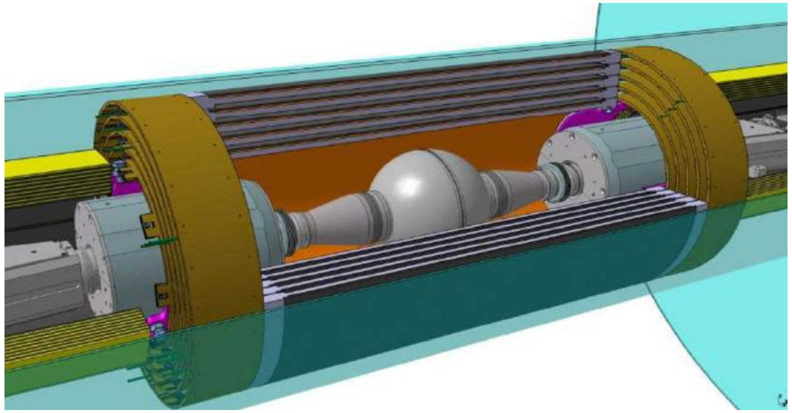
ϕ decays	Missing particle	Events ($\mathcal{L}$ = 10 fb^{-1})	Background for :
$K_S(\pi^0\pi^0)\ K_L$	K_L	$\sim 10^9$	$\pi^0\pi^0$
$K_S(\pi^+\pi^-)\ K_L$	K_L	$\sim 2\times10^9$	$\pi^+\pi^-$
$\pi^+\pi^-\pi^0$	π^0	$\sim 10^9$	
$\eta(\gamma\gamma)\ \gamma$	γ	$\sim 10^8$	η
$\pi^0(\gamma\gamma)\ \gamma$	γ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

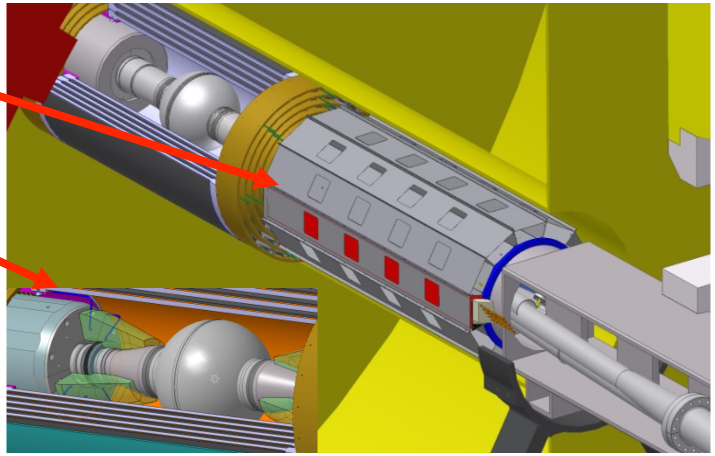
Major detector upgrade

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



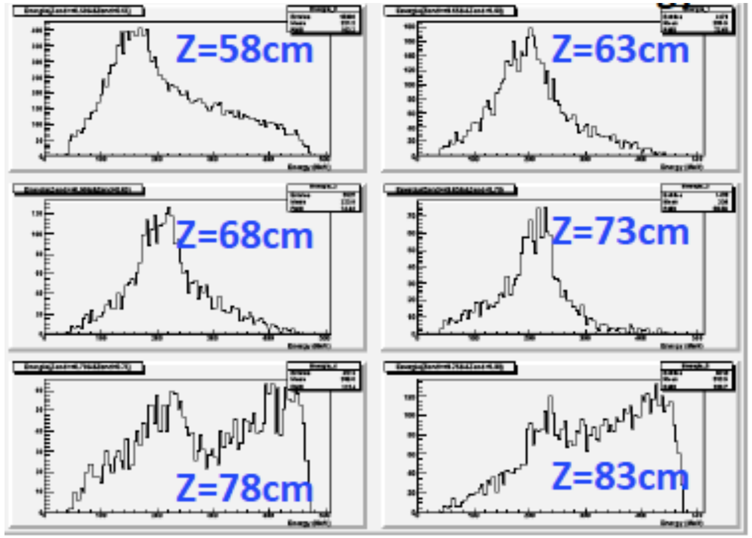
- QCALT: W + scint. tiles readout by SiPM via WLS fibers

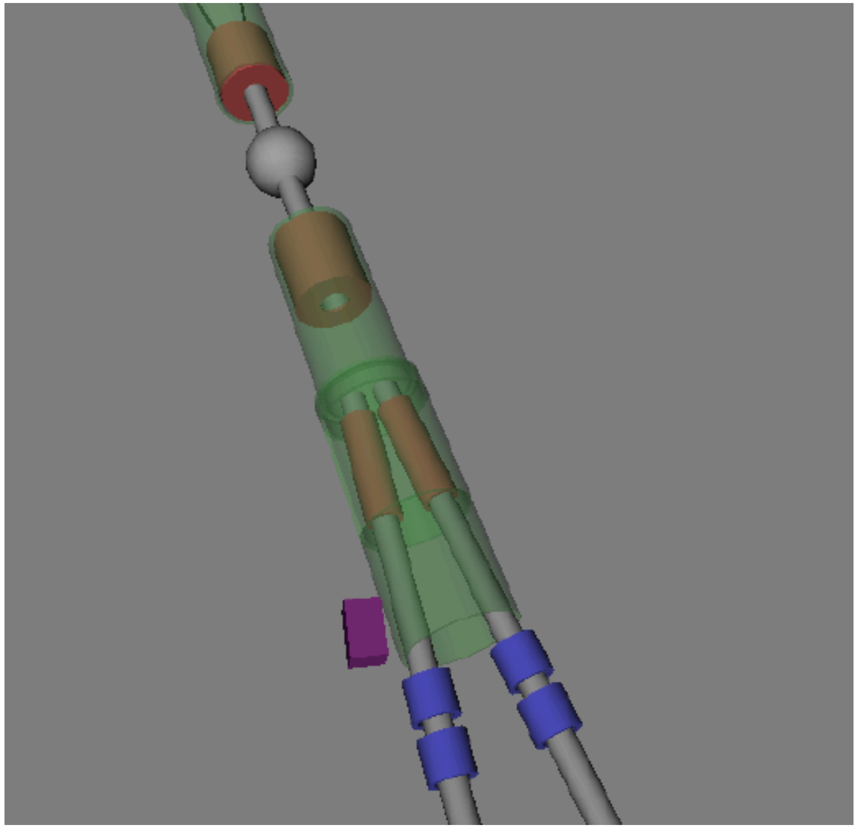
- CCAL: LYSO crystals + APD; close to IP to increase acceptance for photons coming from the IP (min. angle: 21°→ 9°)

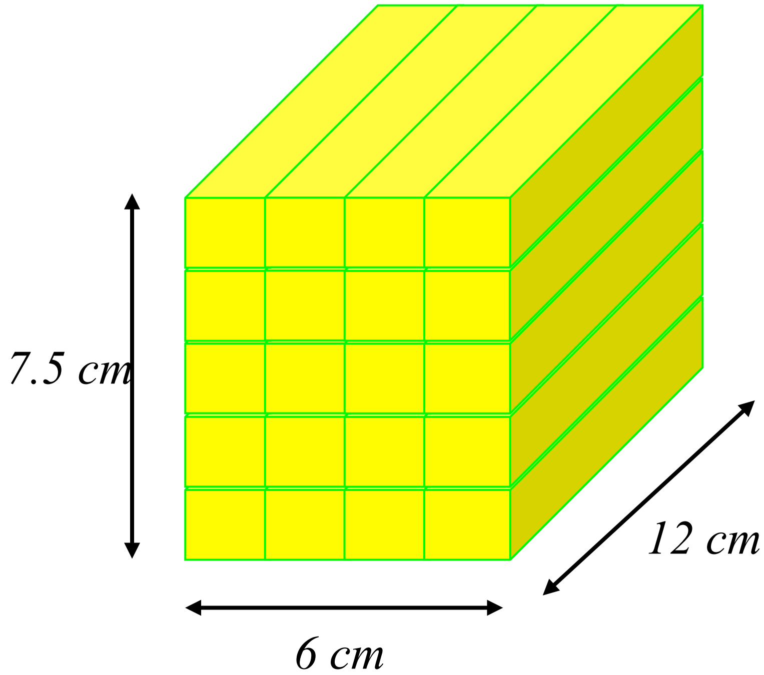


Time scale: installation in late 2011

LET Characteristics



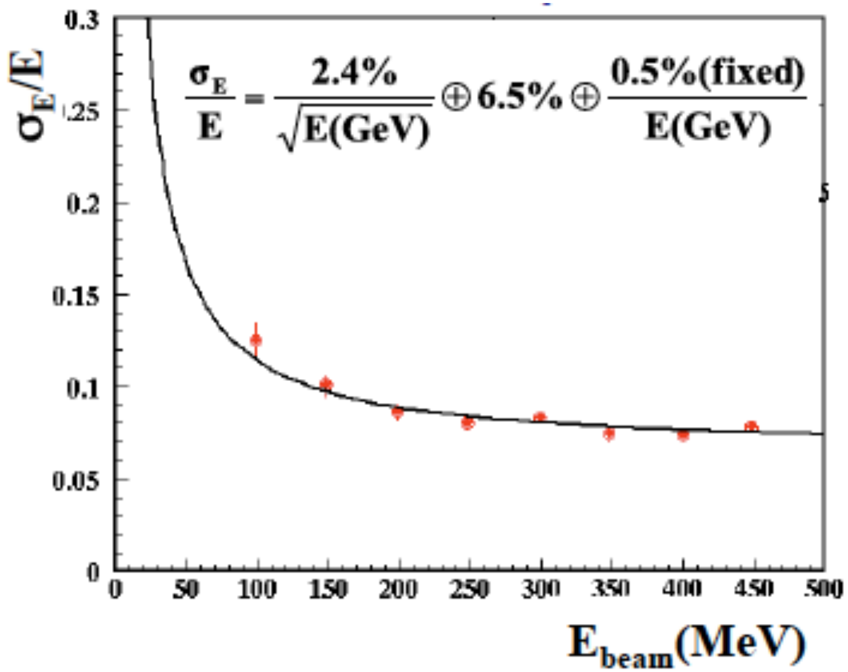


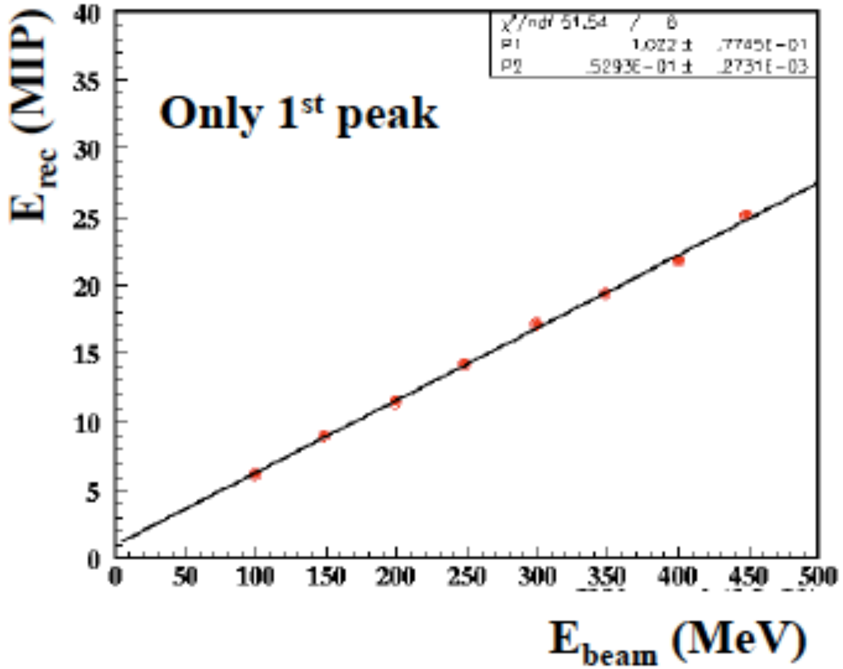


LET: Low Energy Tagger (160-230 MeV) lepton energy

Calorimeters, LYSO + SiPM

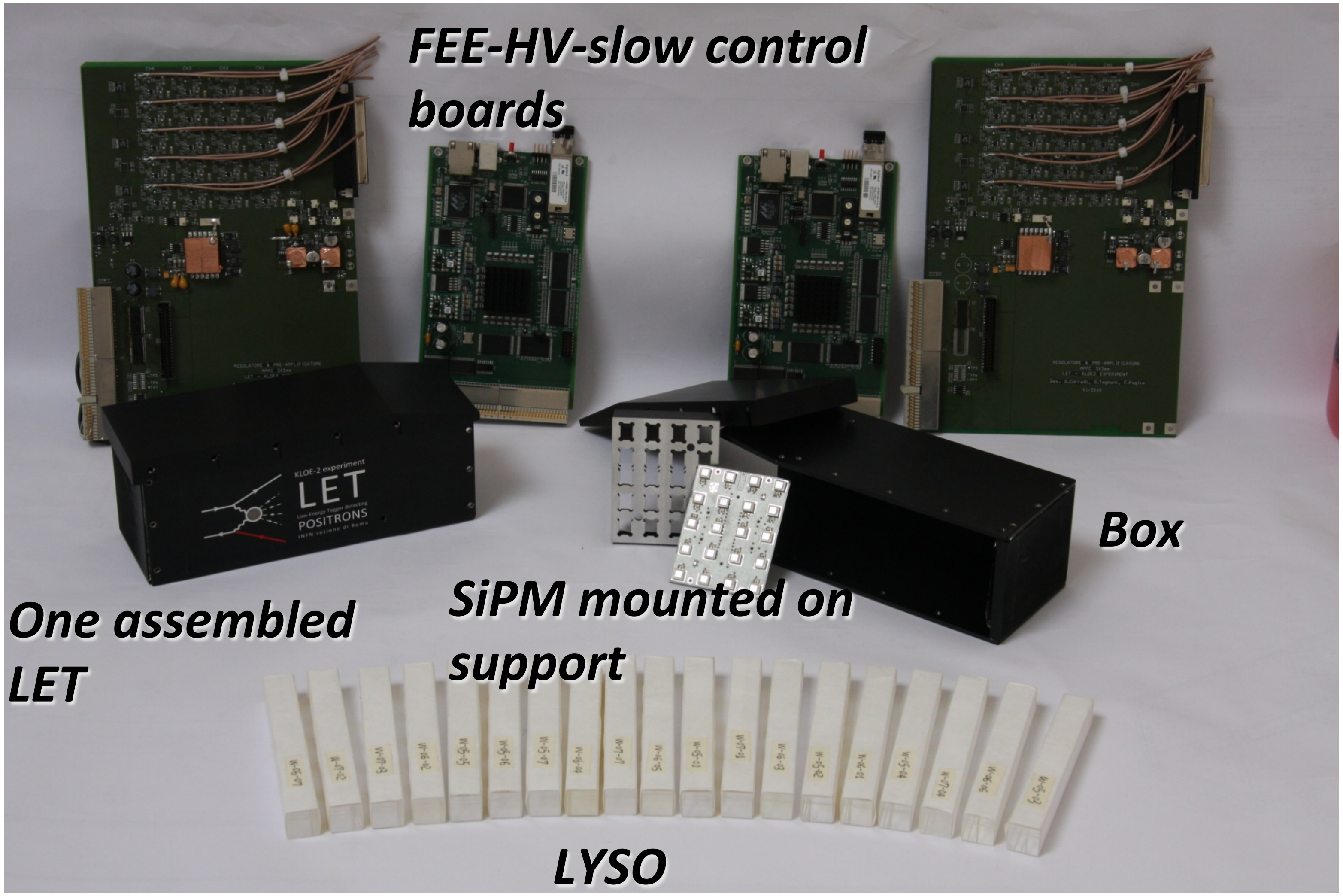
LET system and performance



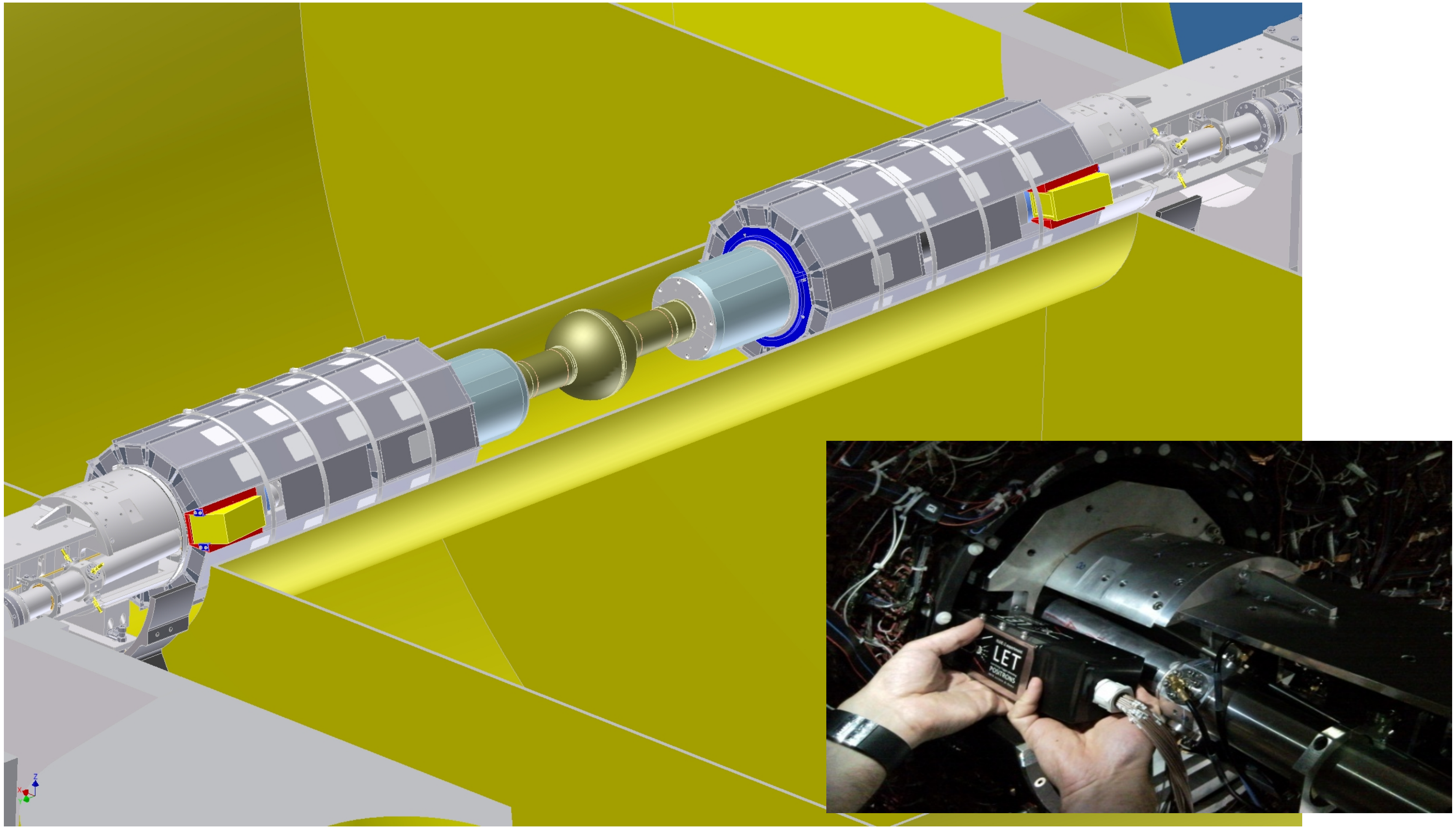


- *3rd term is fixed, since we have about 5 MeV noise*
- *Statistical term higher than expected (20 p.e./MeV → less than 1%/$E^{1/2}$(GeV))*
- *Contribution to constant term due to lateral leakage (matrix not fully readout)*
- *There is an unknown contribution from the beam*
- *Resolution is better than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

LET detectors component



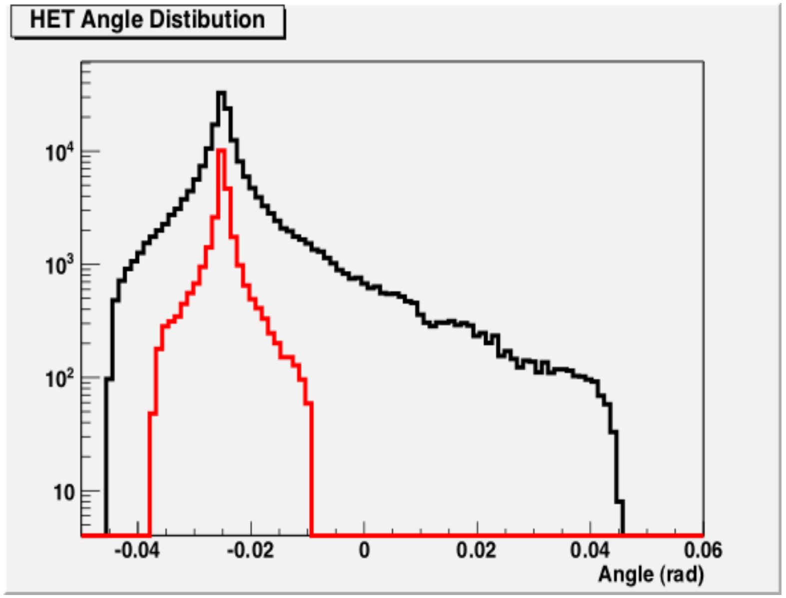
LET Installation

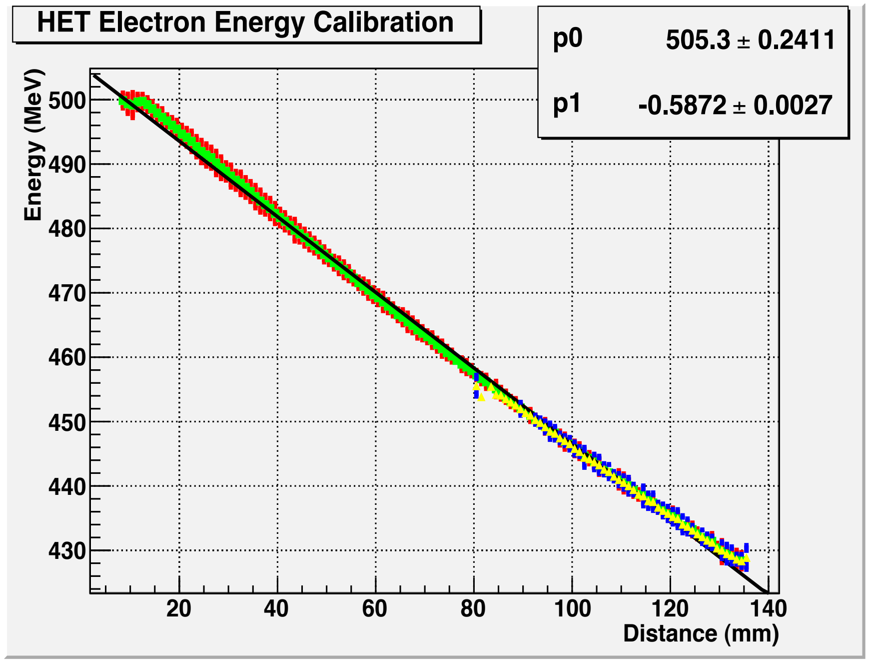


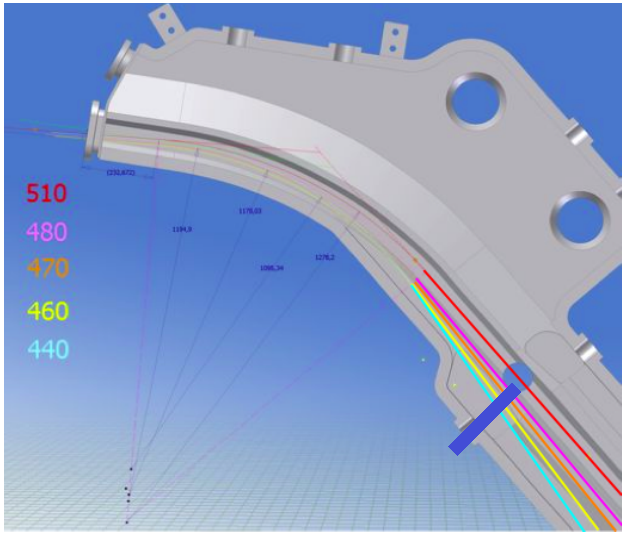
LET in place

HET characteristics

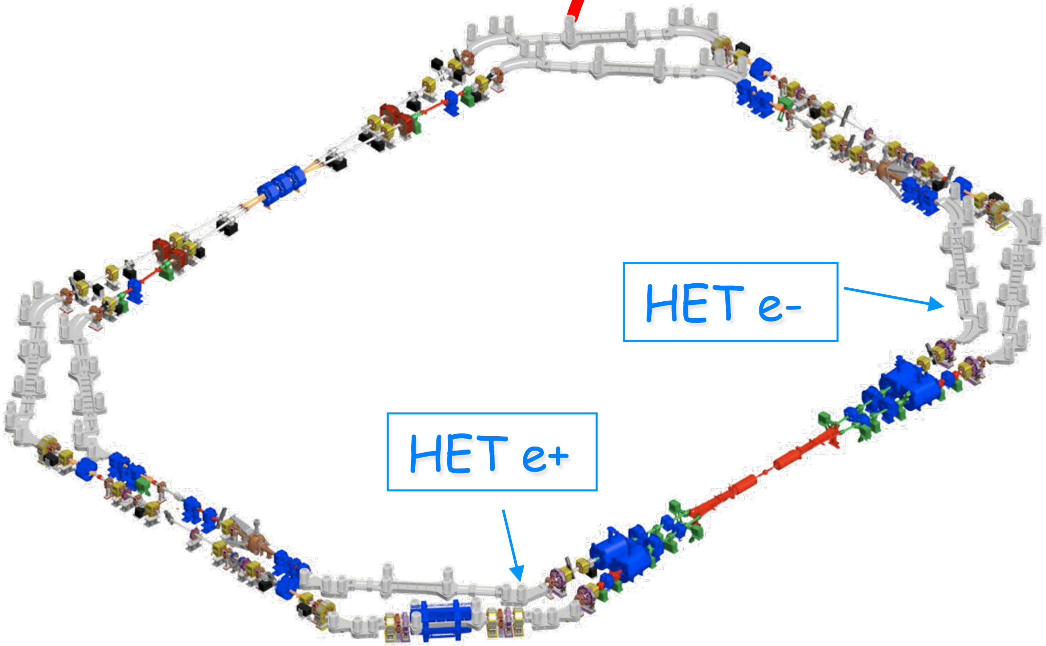
The detector will be located at 11 m from the IP behind a bending magnet. Plastics + PMTs

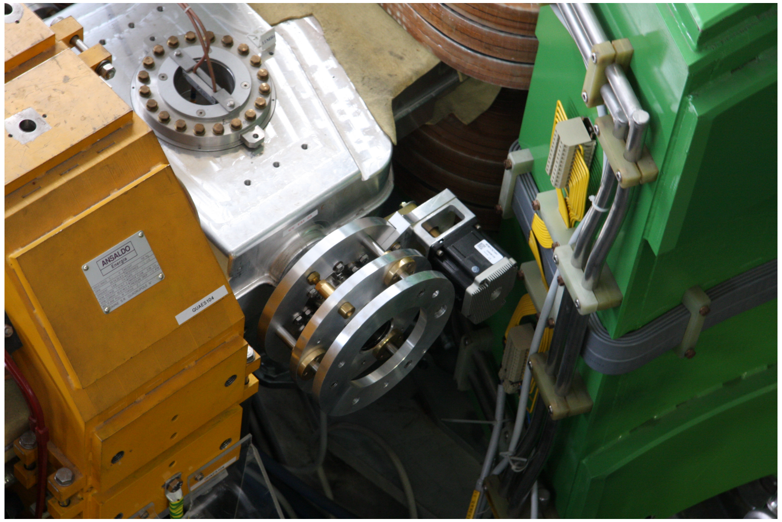


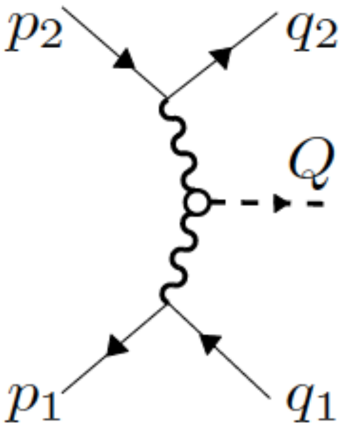


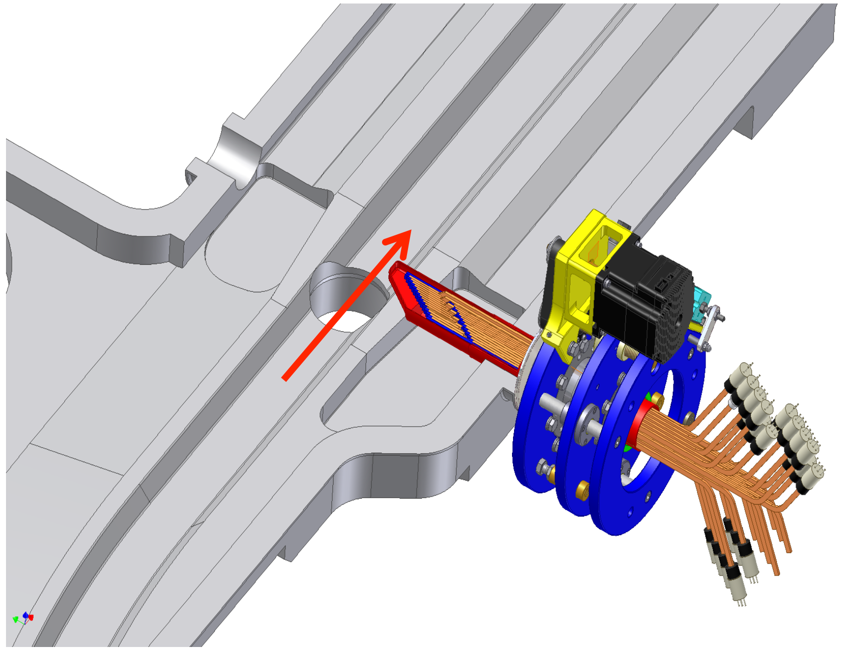


HET systems

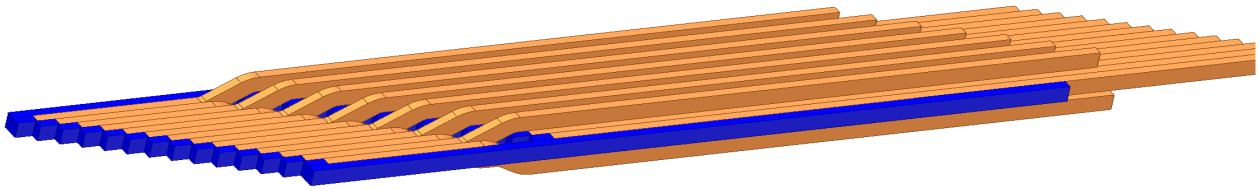








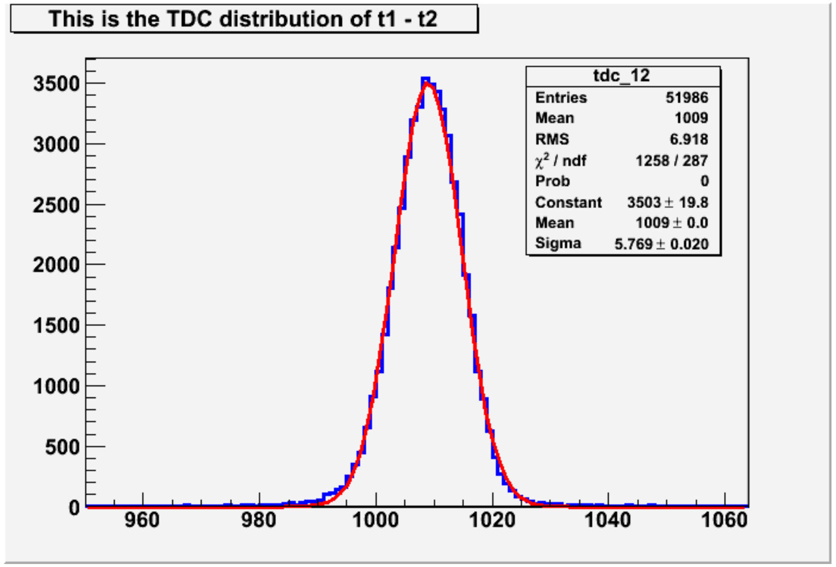
HET detector

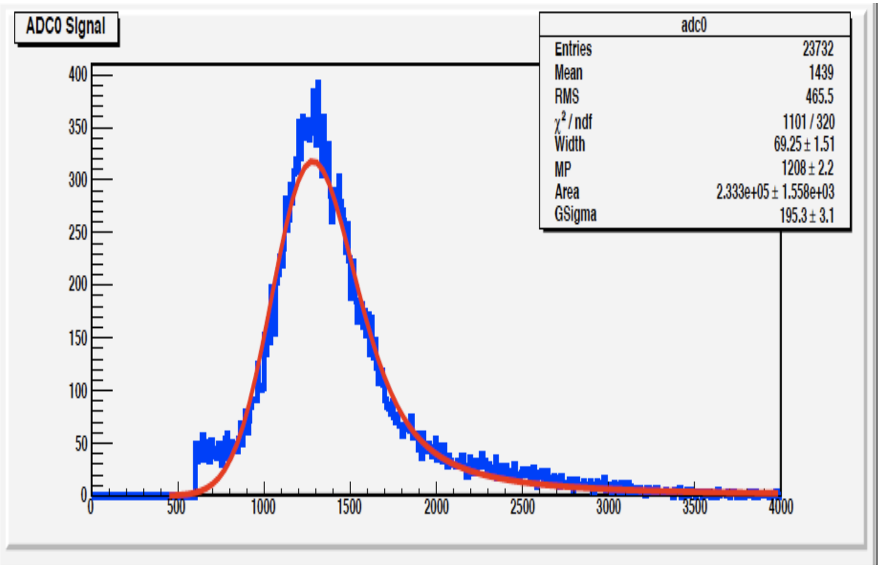


- Minimum safe distance from beam line is of 3-5 cm.
- Hodoscope made by two rows of 15 scintillators of 3x5x6 mm^3 → pitch resolution ~ 5 mm, i.e. 2.5 MeV momentum resolution.
- Fast EJ228 (ELJEN) scintillator used. Light transported to photosensor with light guides. PMT Hamamatsu R9880-U110 readout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

HET performance

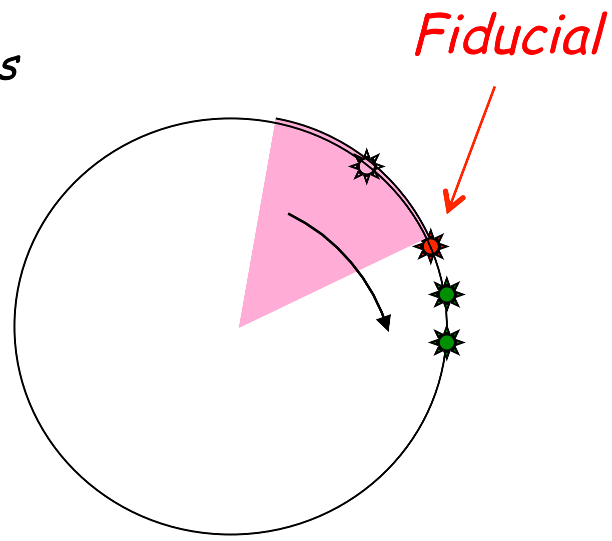
HET prototype successfully tested at LNF-BTF





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

Bunch structure on DaΦne

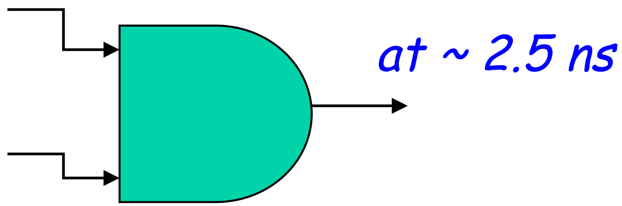


You have to take picture of HETs for any bunches:

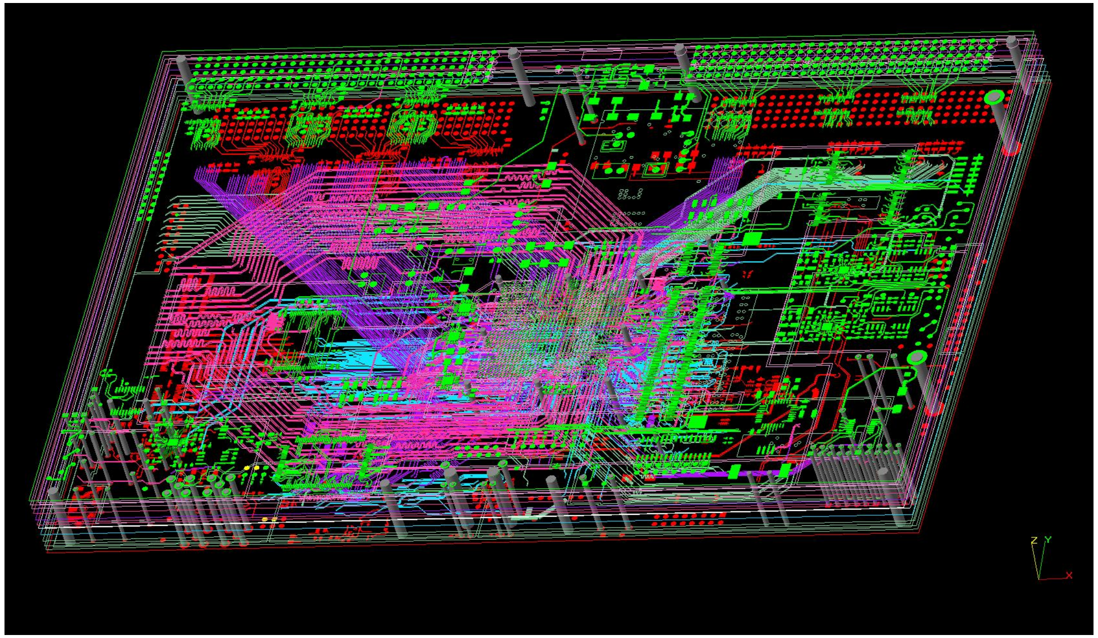
B_0 HETe$^-$, B_0 HETe$^+$
B_i HETe$^-$, B_i HETe$^+$
B_n HETe$^-$, B_n HETe$^+$

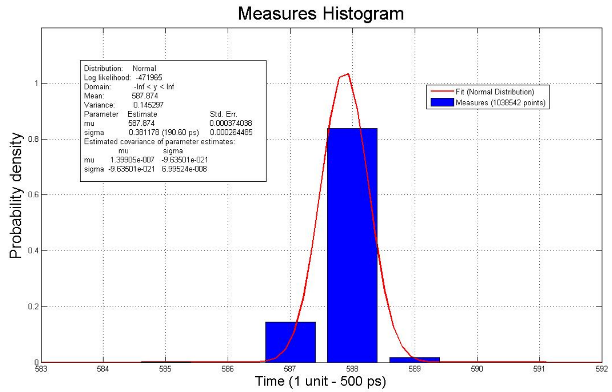
} *And store it for 2 revolution*

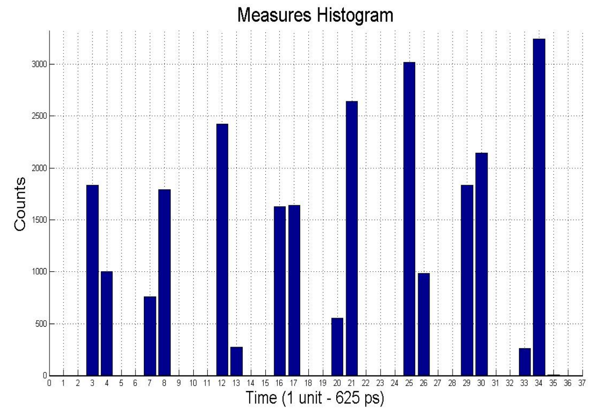
Where same B_i means software :



We need special Electronic in order to acquire data







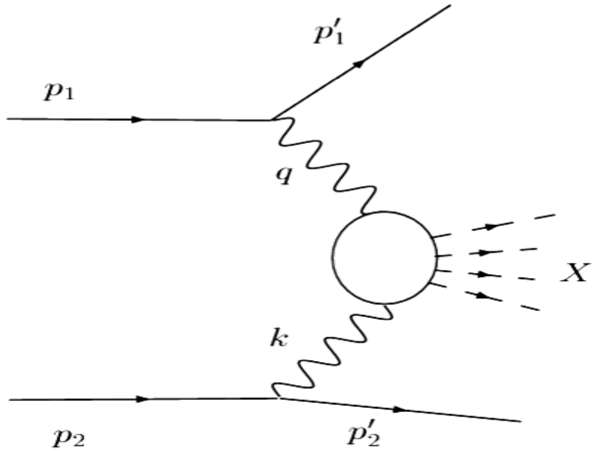
- Front End
- Discriminator
- TDC con DAQ a 368 MHz with ~ 250 ps resolution

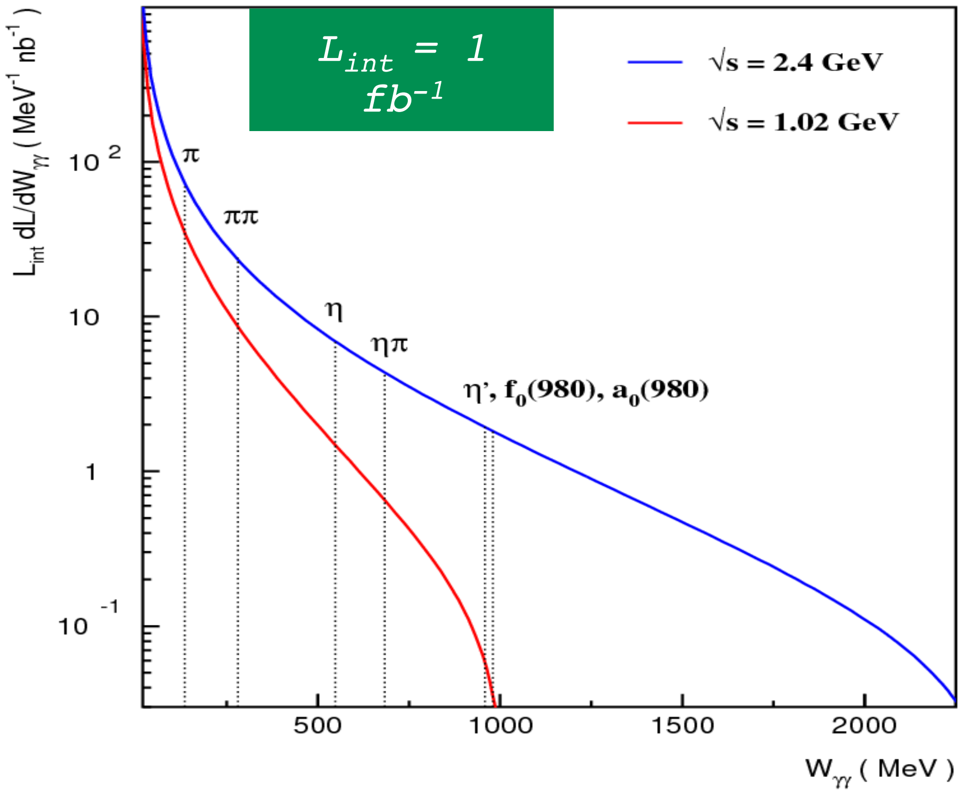
VIRTEX 5 FPGA

$\gamma\gamma$ - physics

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

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



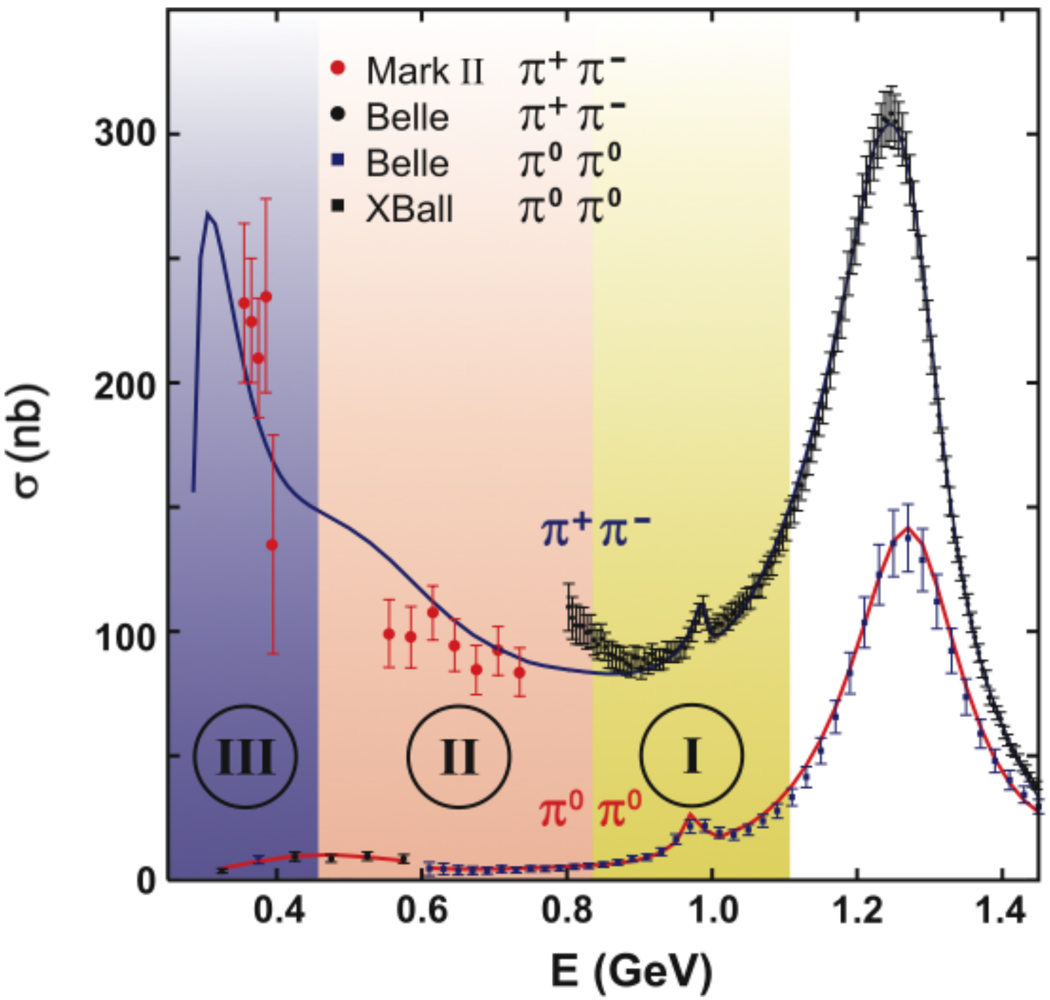


$X \equiv \pi\pi$ → σ meson, ChPT tests

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

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

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

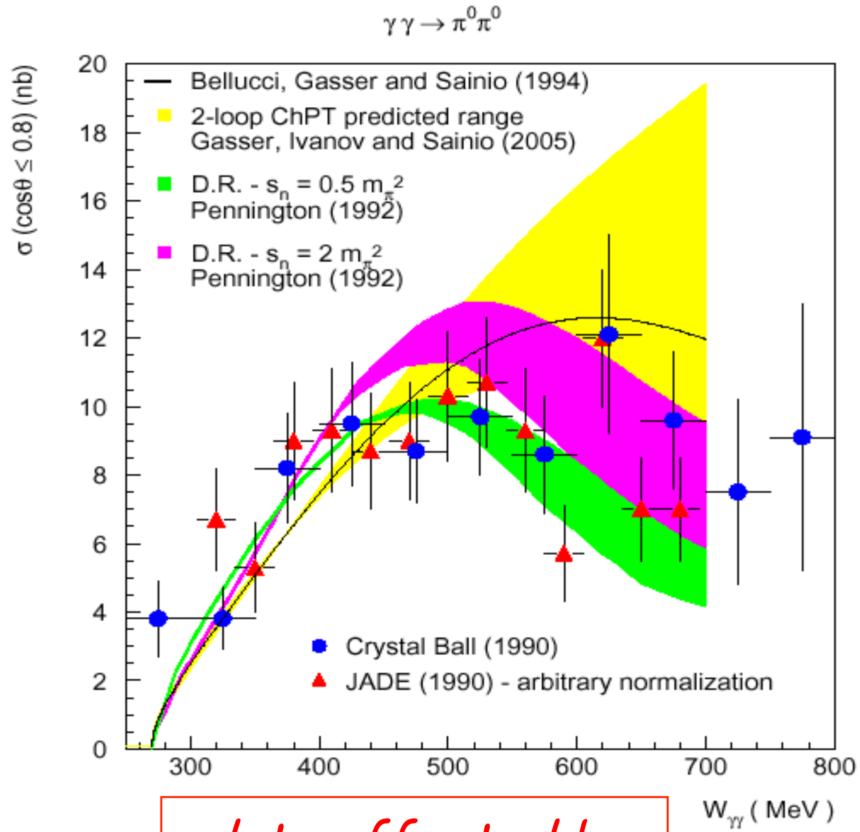


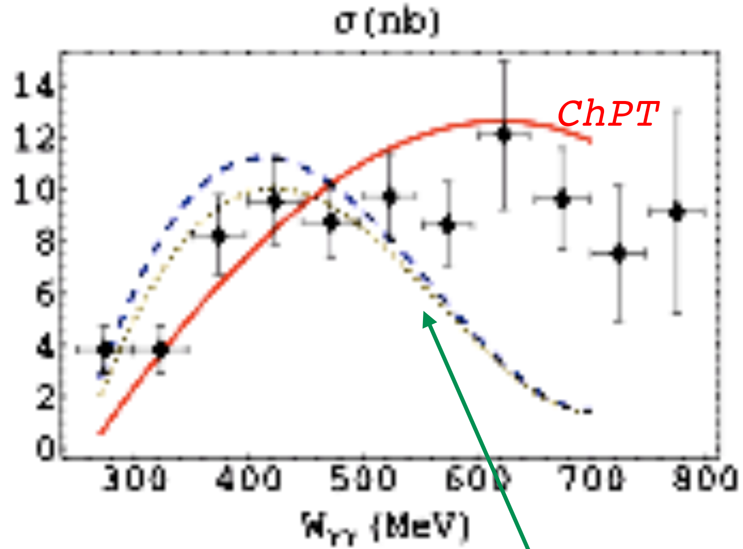
M. R. Pennington (arXiv:0906.1072)

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*

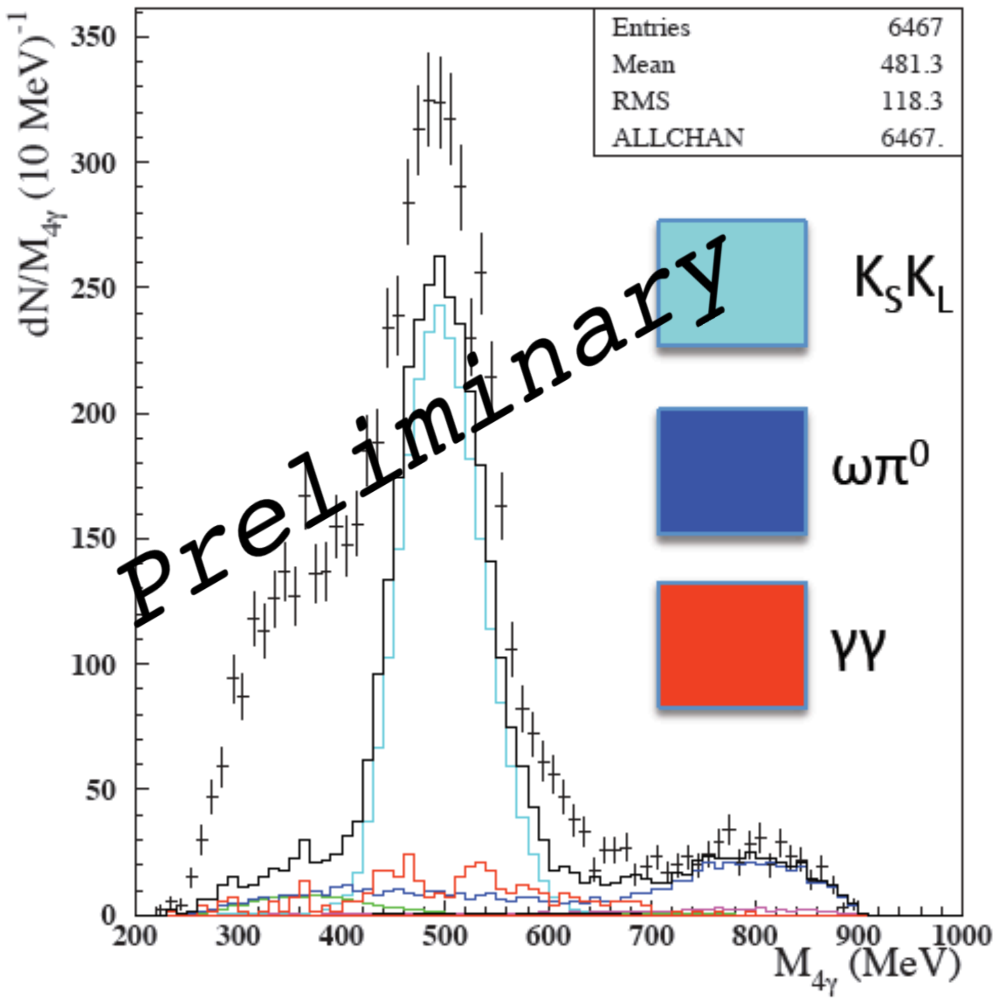
  (Caprini, Colangelo, Leutwyler, PRL 96, 132001 (2006))

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

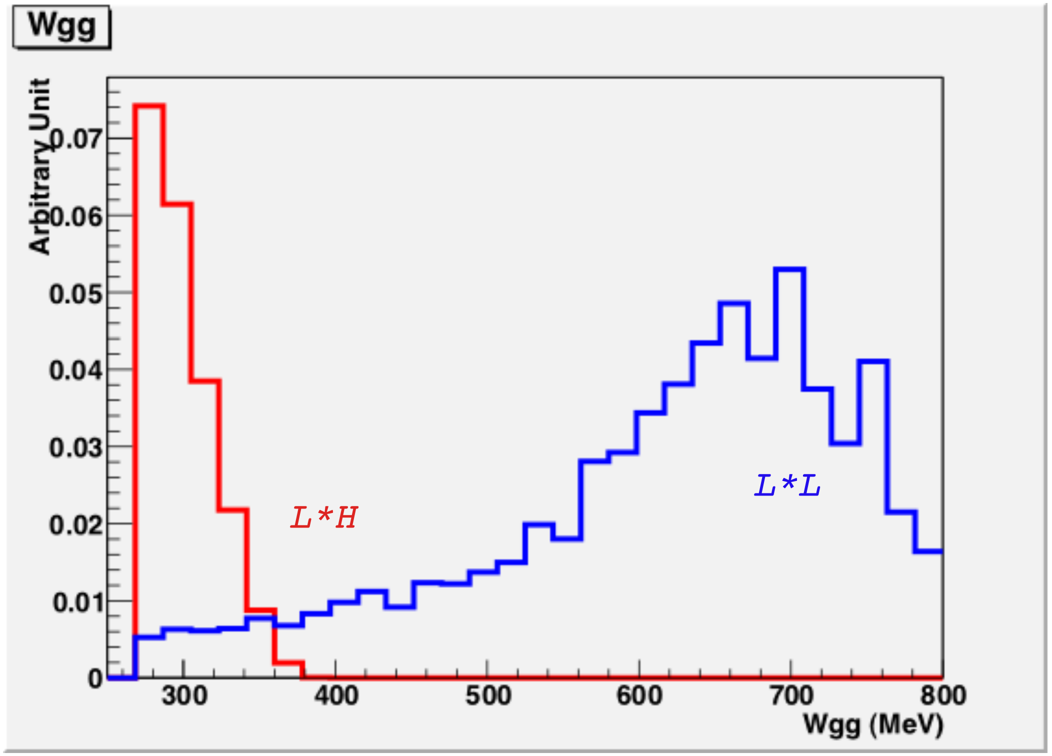
- $D \rightarrow 3\pi$ *Dalitz plot analysis (E791) and* $J/\psi \rightarrow \omega\pi^+\pi^-$ *(BES)*

- $\phi \rightarrow \pi^0\pi^0\gamma$ *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%

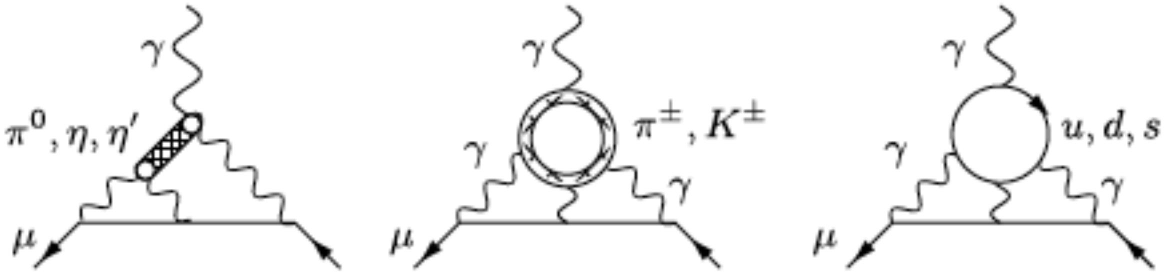
Meson transition FFs

$e^+e^- \rightarrow e^+e^- M$

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

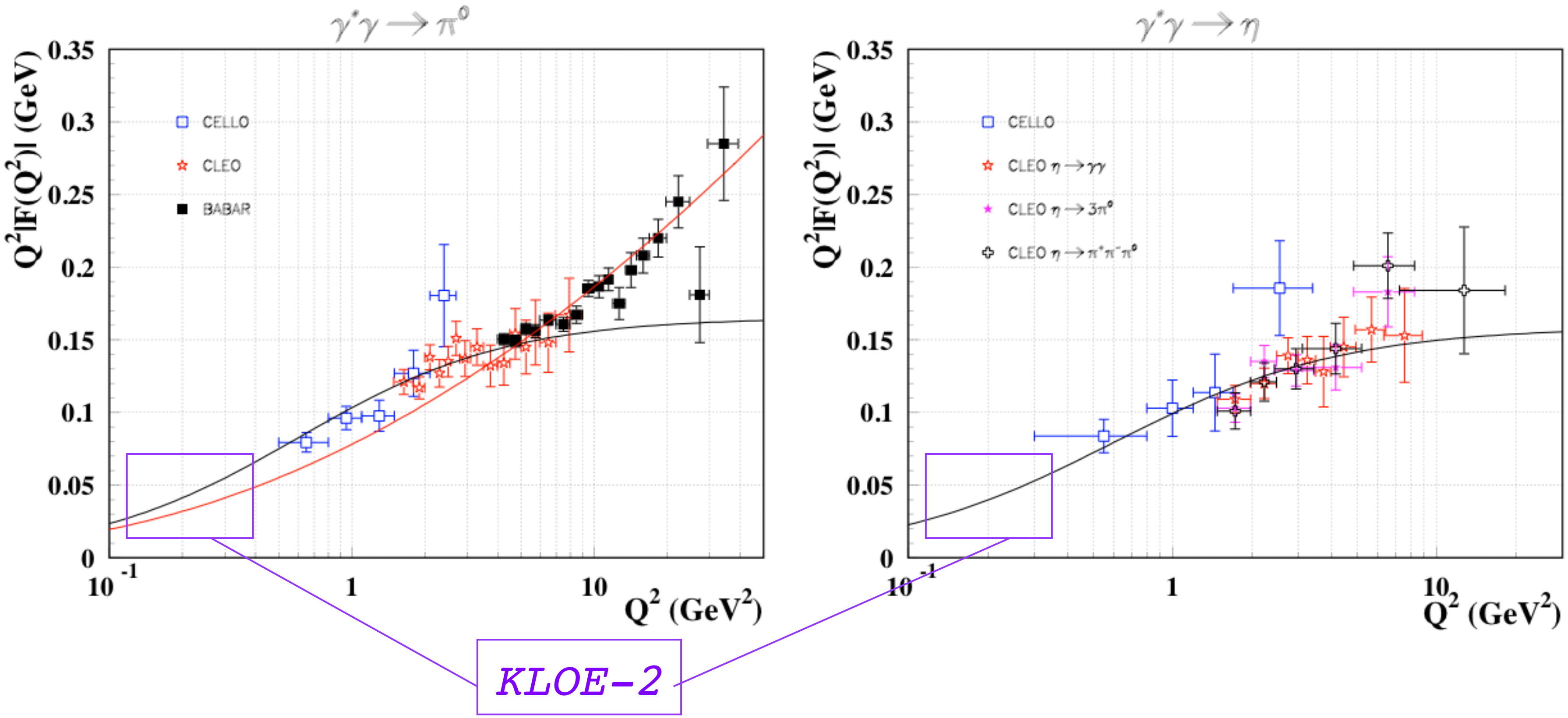
slope of $\mathcal{F}$ near $Q^2 = 0$ crucial for hadronic LbL contribution to a_μ

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



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

KLOE-2 contribution ??



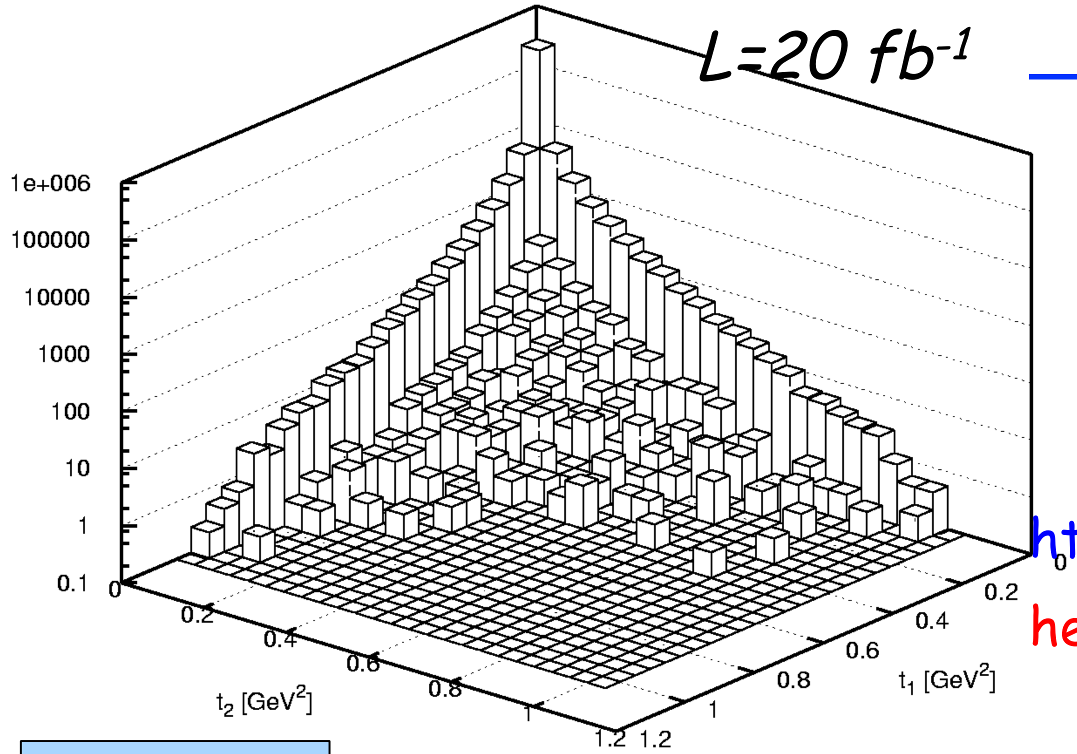
$\gamma^*\gamma^* \to \pi^0$ from KLOE-2

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

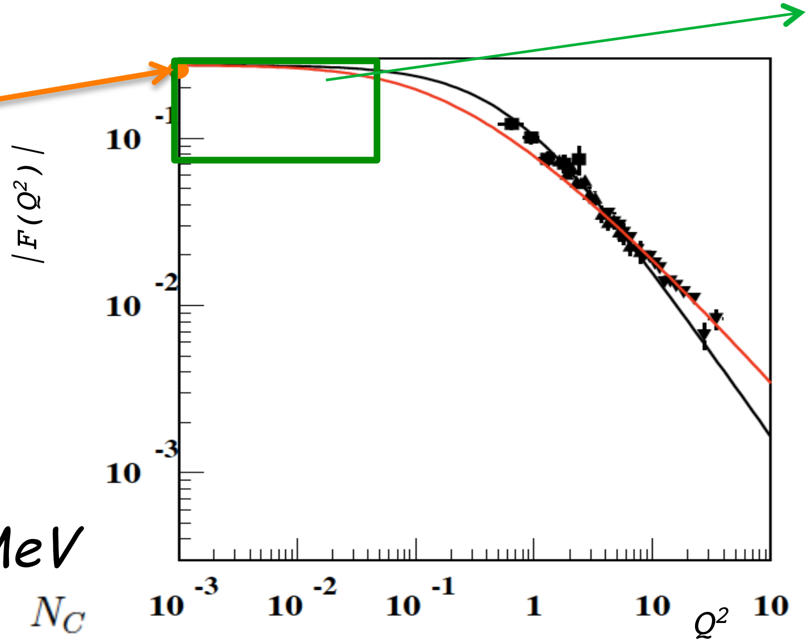
hep-ph 1009.1881

$\pi^0 \rightarrow \gamma\gamma$ case

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

WZW term

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



Where F_π come from π->$\mu\nu(\gamma)$ decay :

F_π=92.2±0.14 MeV

$$\mathcal{F}_{\pi^0\gamma\gamma}(m_\pi^2,0,0) = -\frac{N_C}{12\pi^2 F_\pi}$$

$$\mathcal{F}^2_{\pi^0\gamma\gamma}(m_{\pi^0}^2,0,0) = \frac{1}{(4\pi\alpha)^2}\frac{64\pi\Gamma(\pi^0\rightarrow\gamma\gamma)}{M_{\pi^0}^3}$$

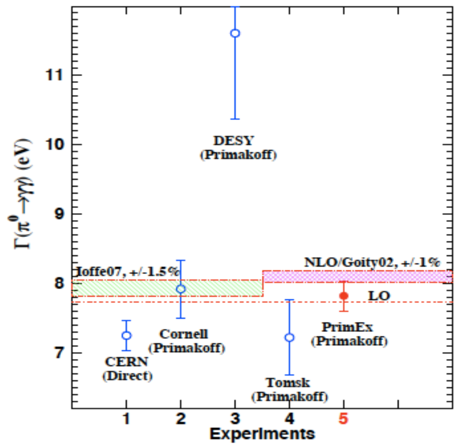
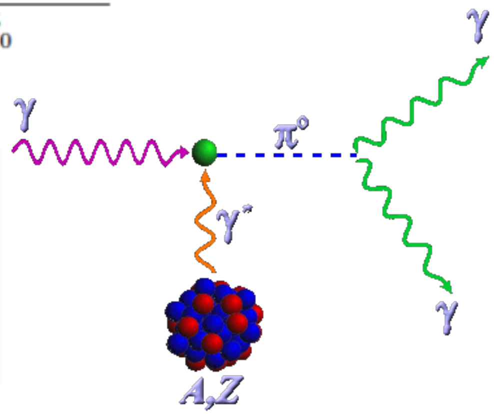


FIG. 1: $\pi^0 \rightarrow \gamma\gamma$ decay width in eV. The dashed horizontal line is the LO chiral anomaly prediction. NLO ChPT prediction [4] is shown as the shaded band on r.h.s. The l.h.s shaded band is the prediction from Ref. [7]. The experimental results, included in the PDG average, are for: (1) done with the direct method [12], (2, 3, 4) with the Primakoff method [9–11], and (5) is the current PrimEx result.

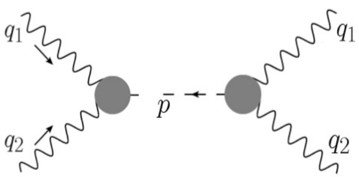
If we want to use direct measure of $\Gamma(\pi^0\rightarrow\gamma\gamma)$ then we need a error (sys + stat) better than 1 %

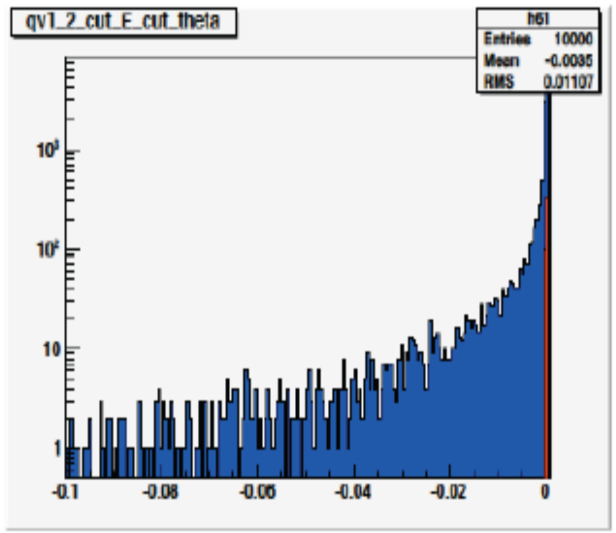


PRIMEX data

Target	$\Gamma(\pi^0\rightarrow\gamma\gamma)$ [eV]	
^{12}C	7.79±0.18	2.3 %
^{208}Pb	7.85±0.23	2.9 %

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



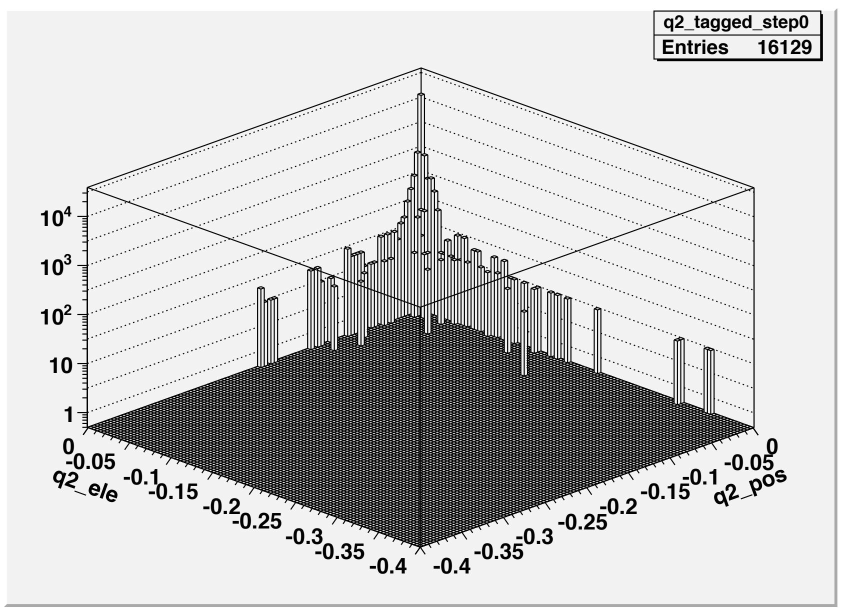


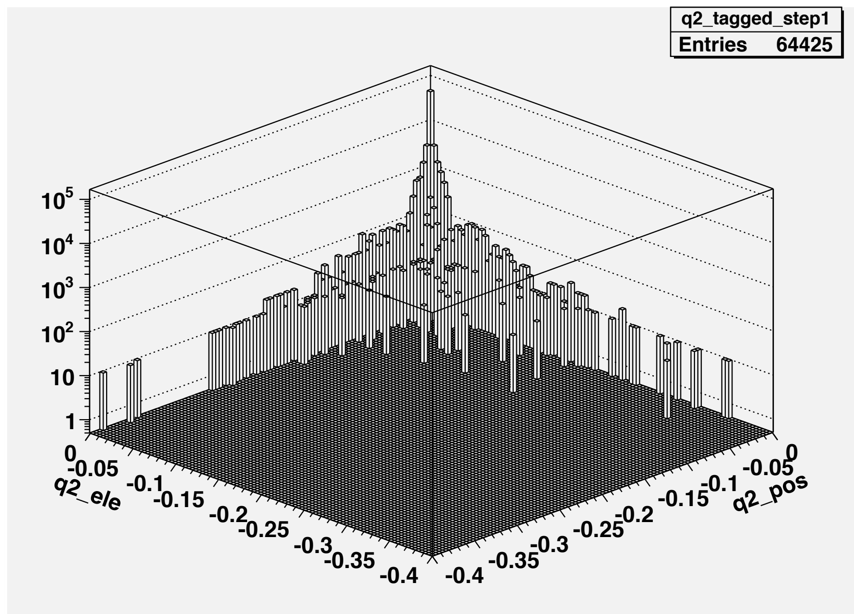
$$\mathcal{F}^2_{\pi^0\gamma\gamma}(m^2_{\pi^0},0,0) = \frac{1}{(4\pi\alpha)^2}\frac{64\pi\Gamma(\pi^0\to\gamma\gamma)}{M^3_{\pi^0}}$$

$\sigma \approx \Gamma(\gamma^*\gamma^* \rightarrow \pi^o)\,\Gamma(\pi^o \rightarrow \gamma\gamma) = \Gamma^2(\pi^o \rightarrow \gamma\gamma)$

σ_{tot}(1020 MeV) = 0.28 nb $\sigma_{exp} = \sigma_{tot}$ * 1.9% (H_e*H_e)

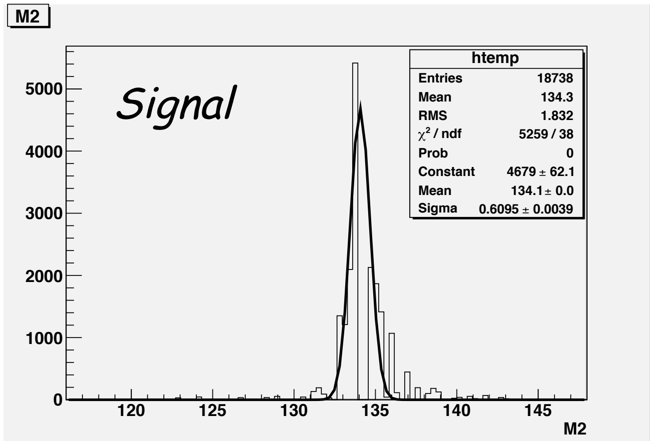
$N_{ev} = \sigma_{exp}\,\mathscr{L}_{ee}\,\varepsilon_K$ (ε_K=37%)   **N_{ev}=10000/(5 fb^{-1})**

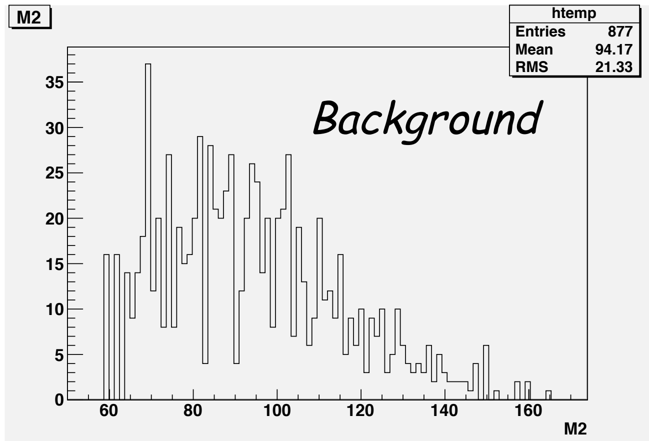




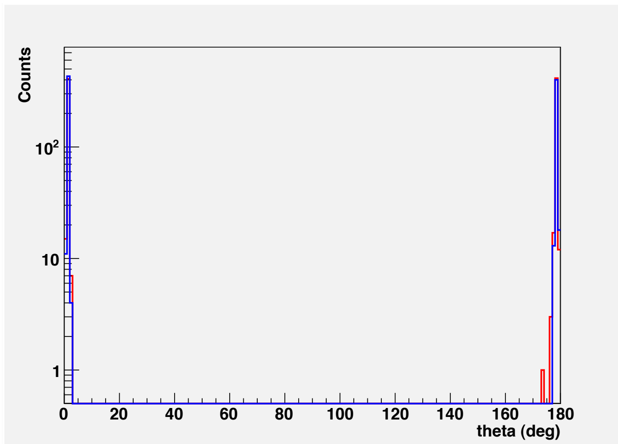
How can we improve efficiency ?

We can use HET taggers data in order to measure the missing mass of the the reaction $e^+e^- \rightarrow e^+e^- X$



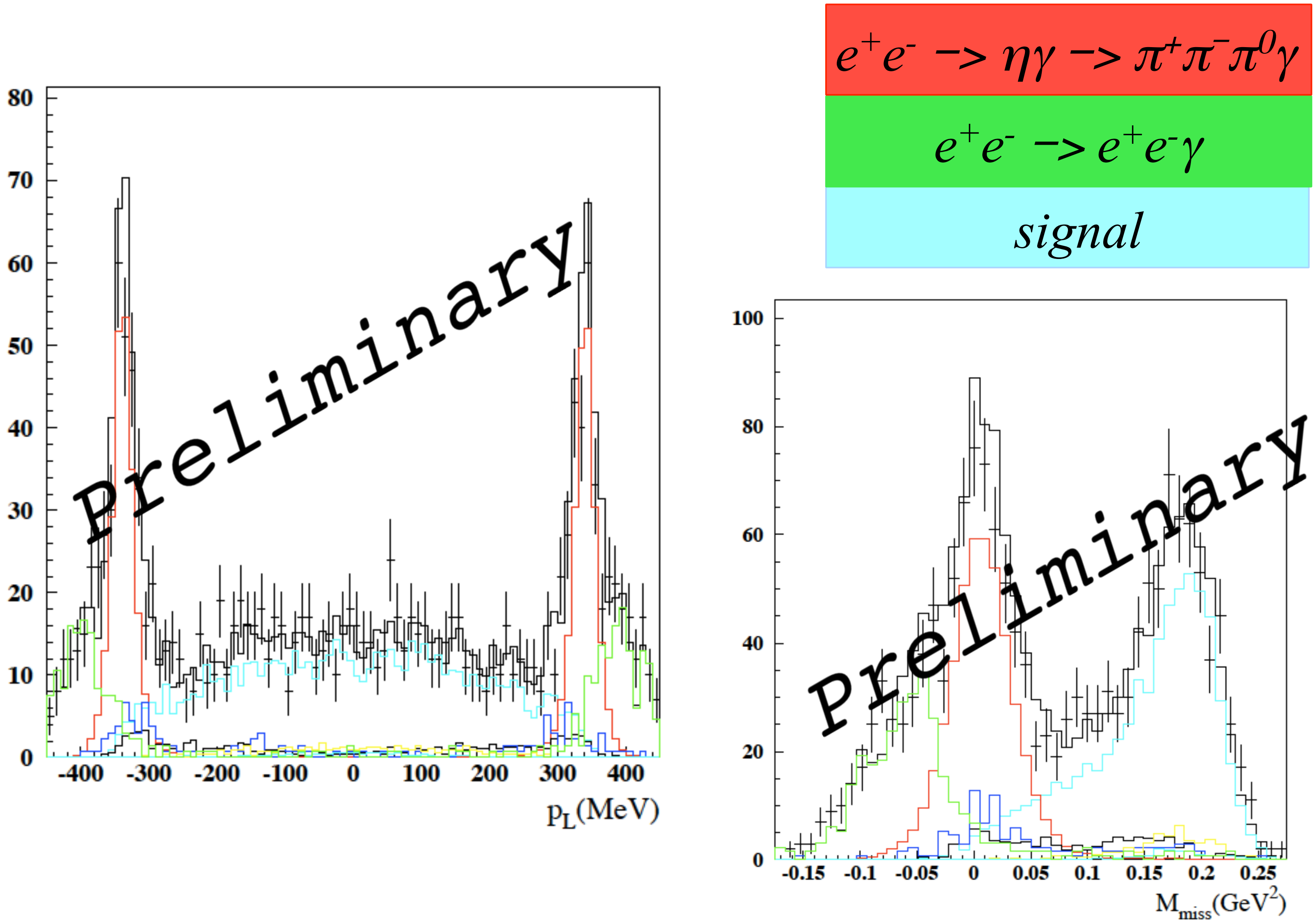


$$\frac{Signal}{Background} \sim 10^{-6}$$



We can use new Trigger & DAQ system: $H_1 * H_1 * K(1\gamma)$

KLOE data at √s=1 GeV



Summary

Tagging detectors ready → LET already installed, HET : mechanics is ready, detector is ready and electronics is in commissioning phase : we plan to install HET next April
DAΦNE : first collissions before Christmas, then we got problem in an injection magnet, collissions will restart in March/April

γγ-physics program @ KLOE-2:

- ✓ *$\gamma\gamma \to \pi\pi$ 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*