γ–γ physics with KLOE-2 tagging system

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On behalf KLOE-2 Collaboration

"Lattice QCD Meets Experiment Workshop 2010",
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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}
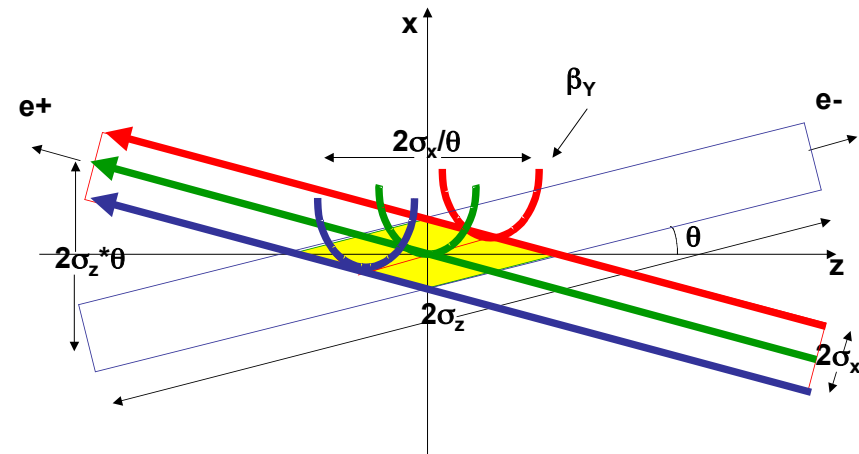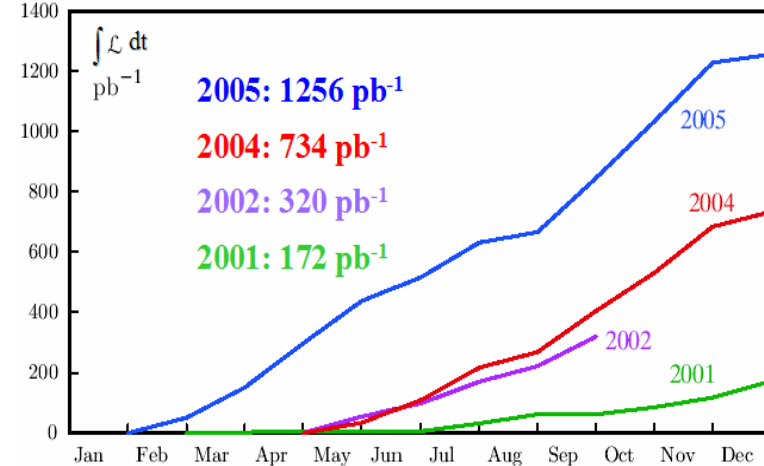 - $\int L dt = 8.5$ pb^{-1}/day

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

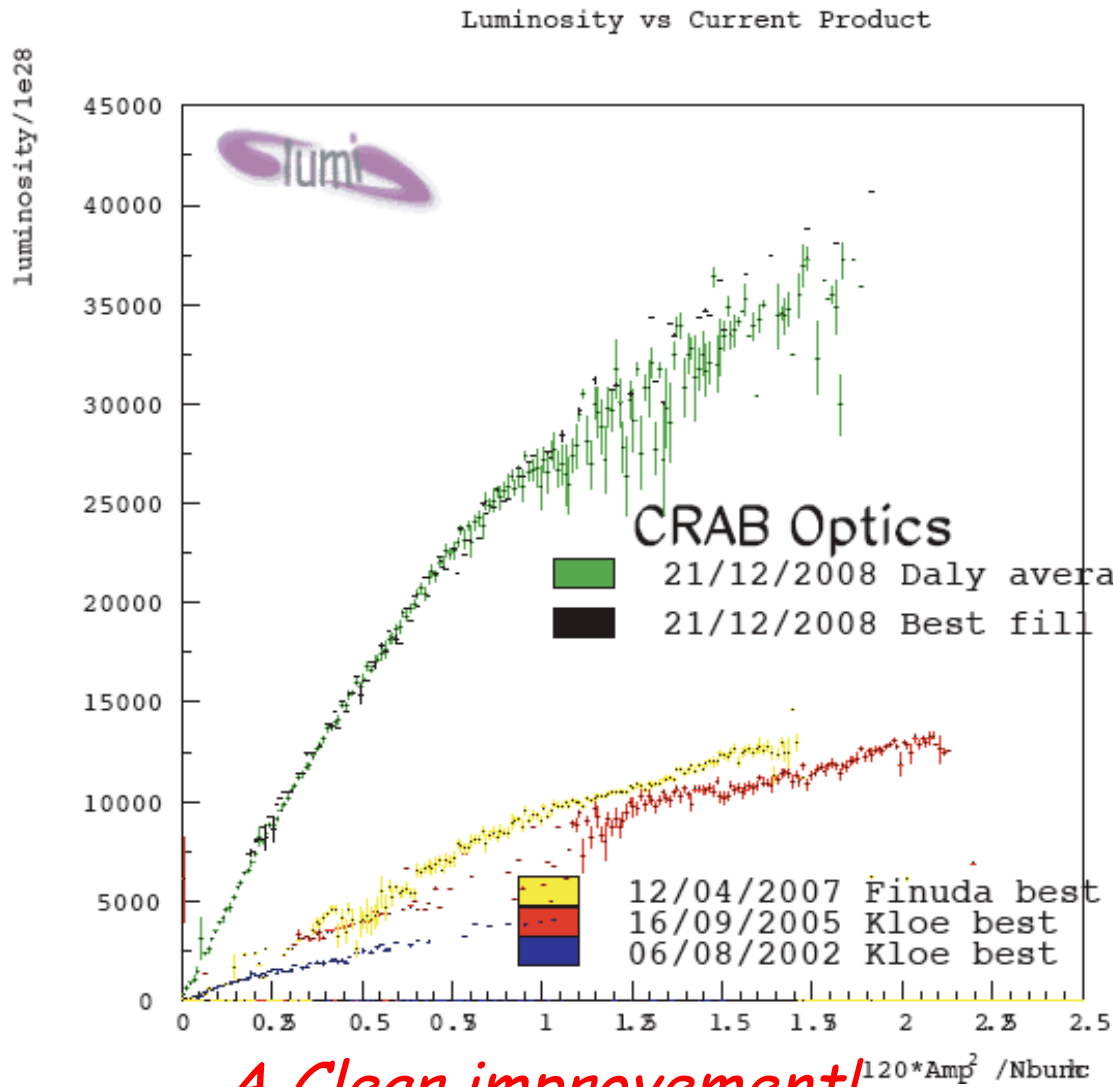- New interaction scheme implemented : large beam crossing angle + crabbed waist sextupoles

Luminosity increase factor ~ 3

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

Integrated luminosity (pb^{-1})

$\int \mathcal{L}\, dt$
pb^{-1}

2005: 1256 pb^{-1}
2004: 734 pb^{-1}
2002: 320 pb^{-1}
2001: 172 pb^{-1}

DAΦNE luminosity: new vs old

Luminosity vs Current Product

$L = 4.5 \times 10^{32}$ 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!

KLOE-2 Physics program

- $\gamma\gamma$ physics (Step0)
    - Study of $\Gamma(S/PS\to\gamma\gamma)$, test of χPT, existence and properties of $\sigma(600)$ meson, PS Transition Form Factor

- Kaon Physics (Step1)
    - 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
    - $\eta, \eta', f_0, a_0, \sigma$ in ϕ radiative decays
- Dark Matter searches (light bosons at O(1 GeV))

- Hadronic cross section from $2m_\pi$ to 2.4 GeV (Step2)
    - $\alpha_{em}(M_Z)$ and $(g-2)_\mu$

References : KLOE-2 Collaboration ArXiv 1030.3868
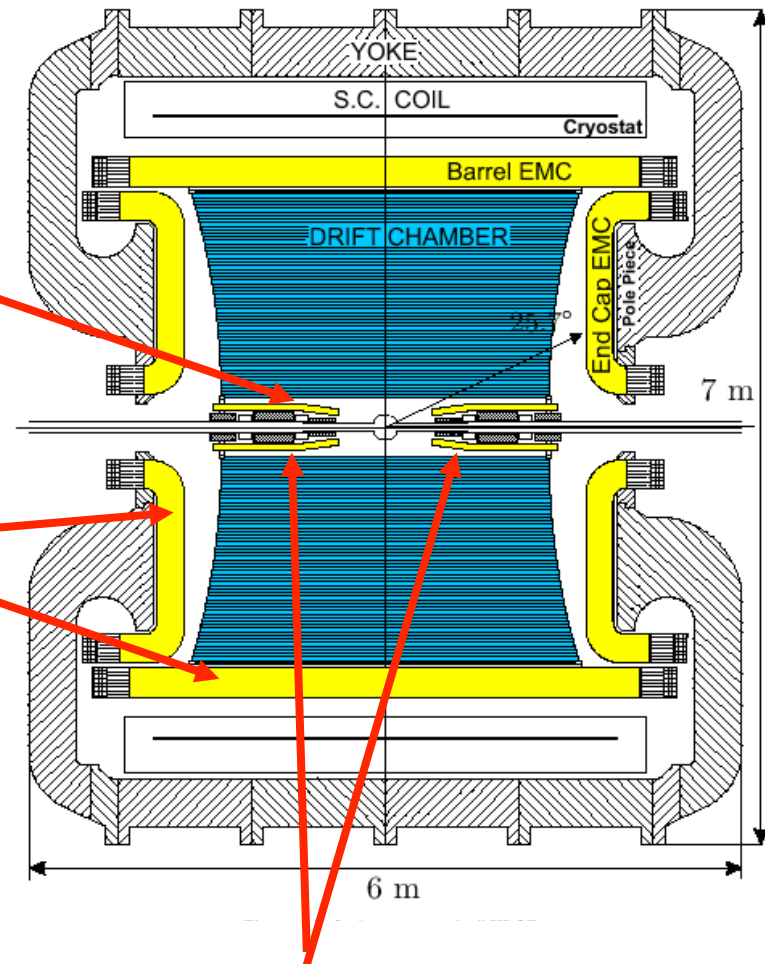
KLOE Detector

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)

YOKE
S.C. COIL
Cryostat
Barrel EMC
DRIFT CHAMBER
End Cap EMC
Pole Piece
7 m
6 m

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

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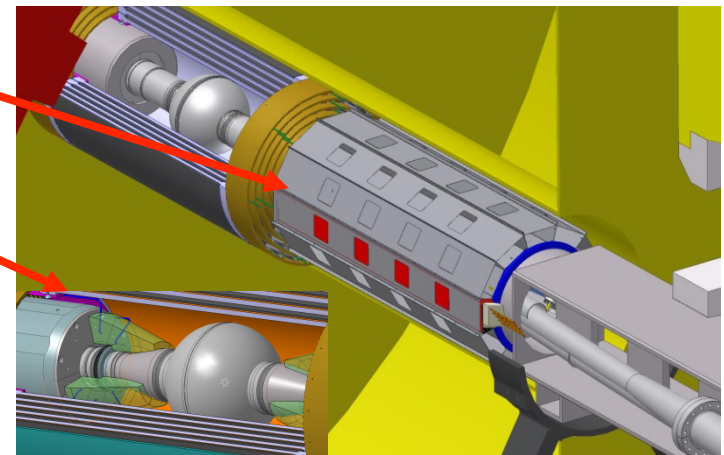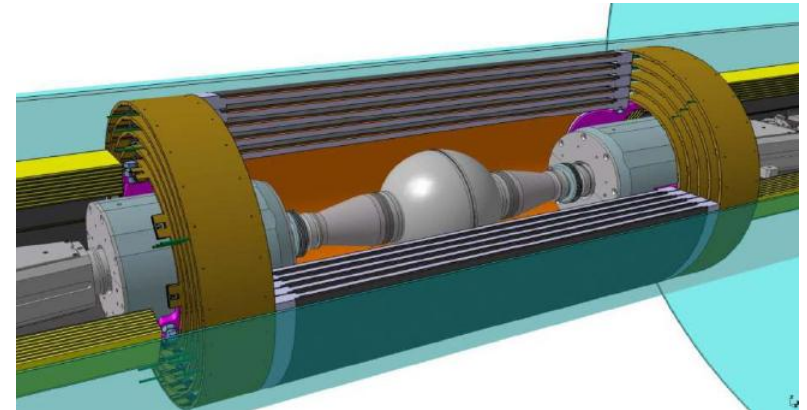
Taggers

KLOE

HET e-

KLOE

HET e+

LET e-

LET e+

Already funded
by INFN. Will
be installed in
the next months

...to KLOE-2...(Step1)

Major detector upgrade

- Inner tracker (between the beam pipe and the DC): 5 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: $21° \to 9°$)
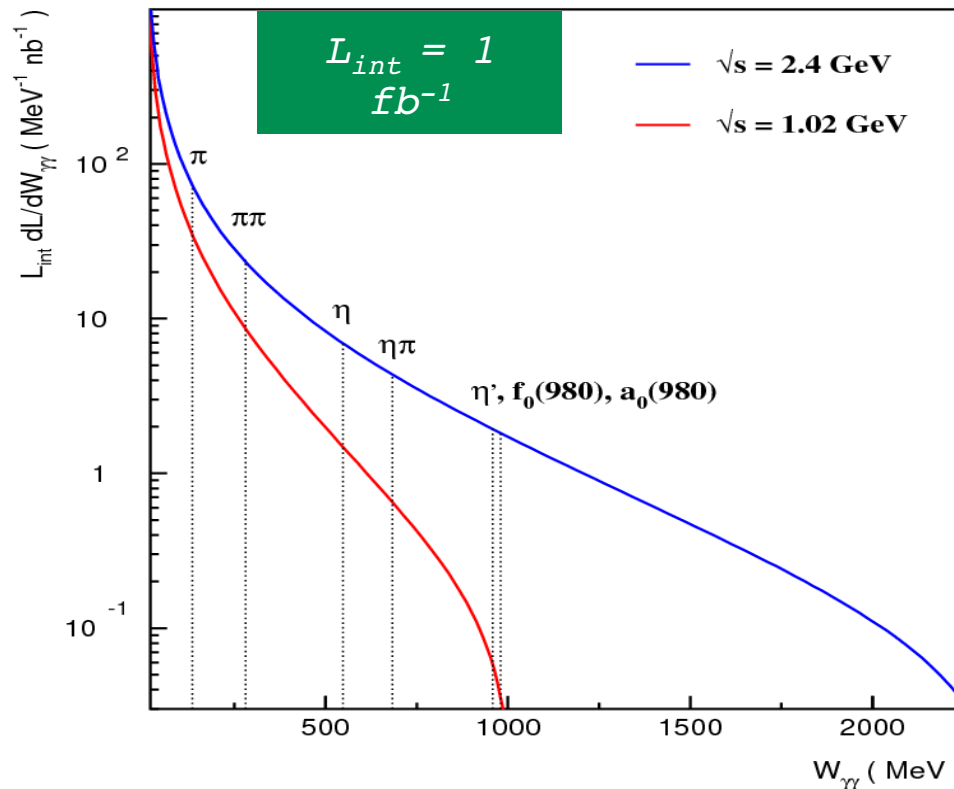- Partially funded
  Time scale: installation in late 2011

γγ - physics

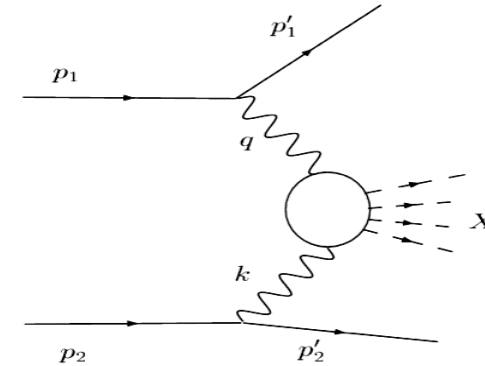$$e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^-X$$

NB: for quasi-real photons $J^{PC}(X) = 0^{\pm+}, 2^{\pm+}$
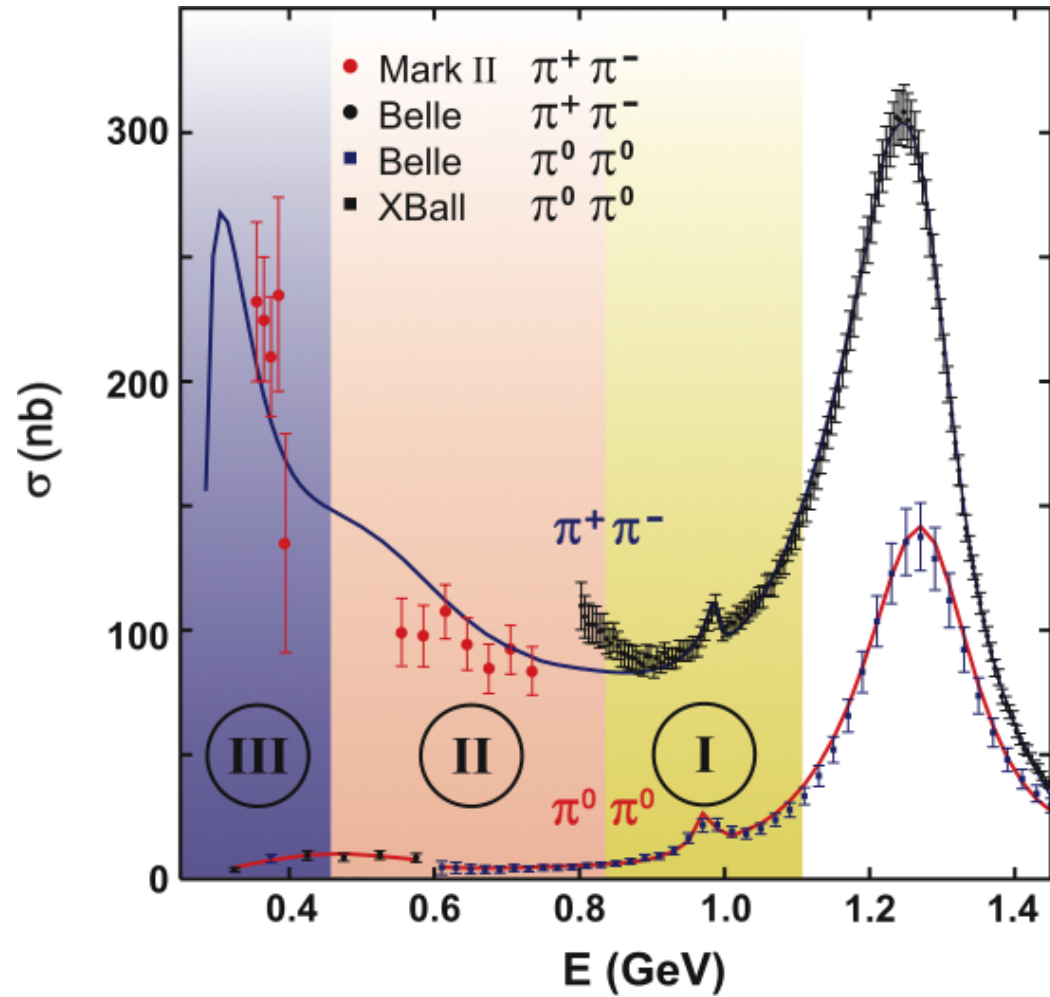
$$\frac{dN_X}{dW_{\gamma\gamma}} = L_{int}\frac{dL}{dW_{\gamma\gamma}}\sigma(\gamma\gamma \to X)$$

$X \equiv \pi\pi$ ⟶ σ meson ChPT tests

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

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

D. Moriccianni   Lattice QCD Meets Experiment 2010   8
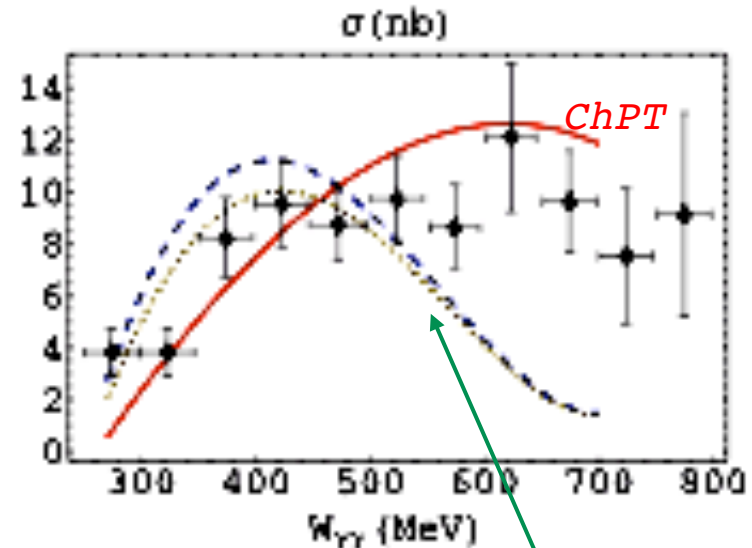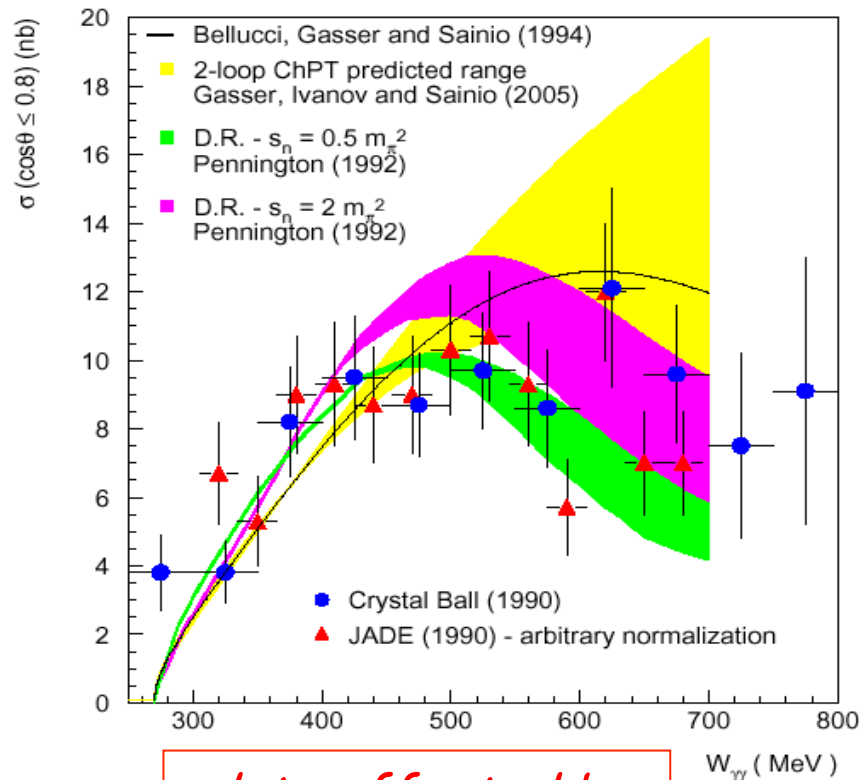
$\gamma\gamma \rightarrow \pi\pi$

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

$\gamma\gamma \to \pi^0\pi^0$

- Bellucci, Gasser and Sainio (1994)
- 2-loop ChPT predicted range Gasser, Ivanov and Sainio (2005)
- D.R. - $s_n = 0.5 \, m_\pi^2$ Pennington (1992)
- D.R. - $s_n = 2 \, m_\pi^2$ Pennington (1992)
- Crystal Ball (1990)
- JADE (1990) - arbitrary normalization

data affected by large uncertanties

$\sigma(\mathrm{nb})$

ChPT

resonant contribution

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

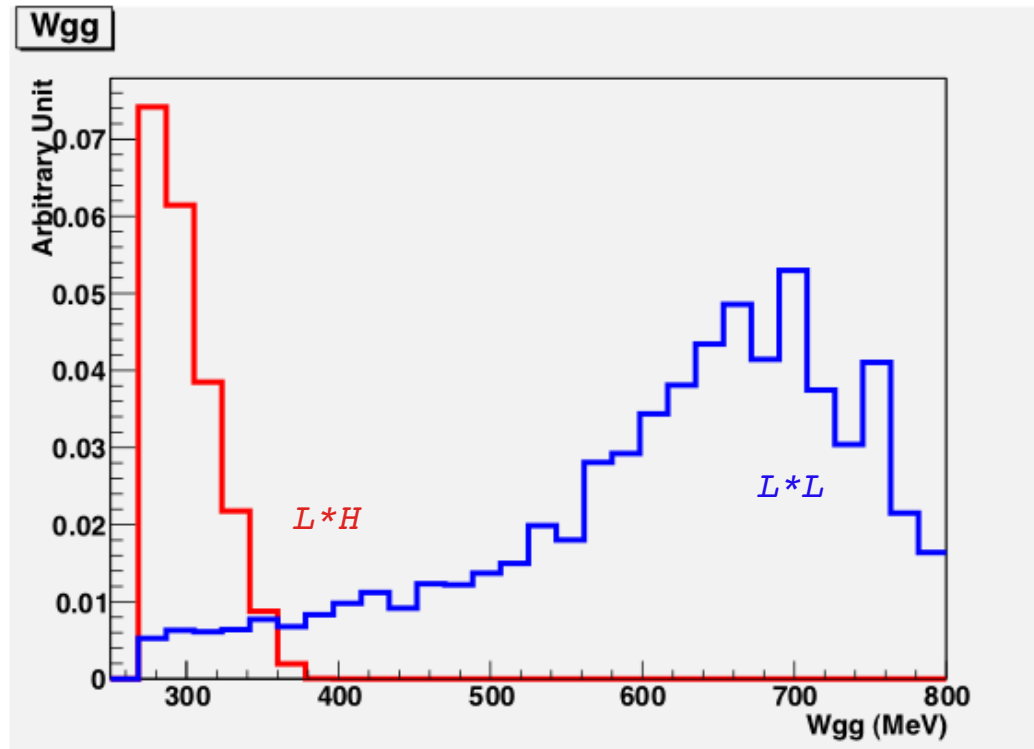*(Nguyen, Piccinini, Polosa, EPJC 47, 65 (2006))*

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 w/ quantum numbers of vacuum

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

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

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

➢ $\phi \to \pi^0\pi^0\gamma$ KLOE

Taggers acceptance

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

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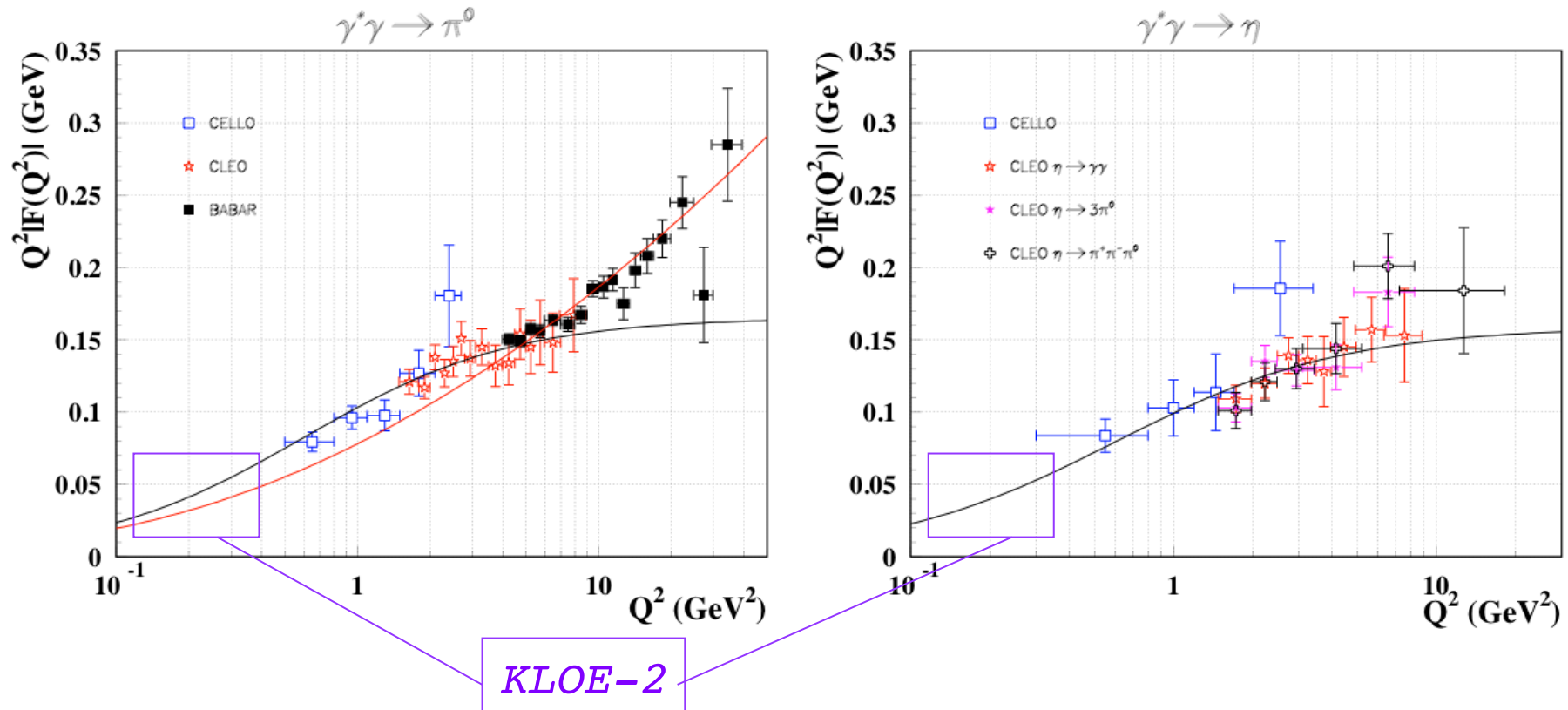- Double arm acceptance (H*H + 2*L*(H) + L*L) = 2+5+3 = 10%

KLOE data at √s=1 GeV

Meson transition FFs

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

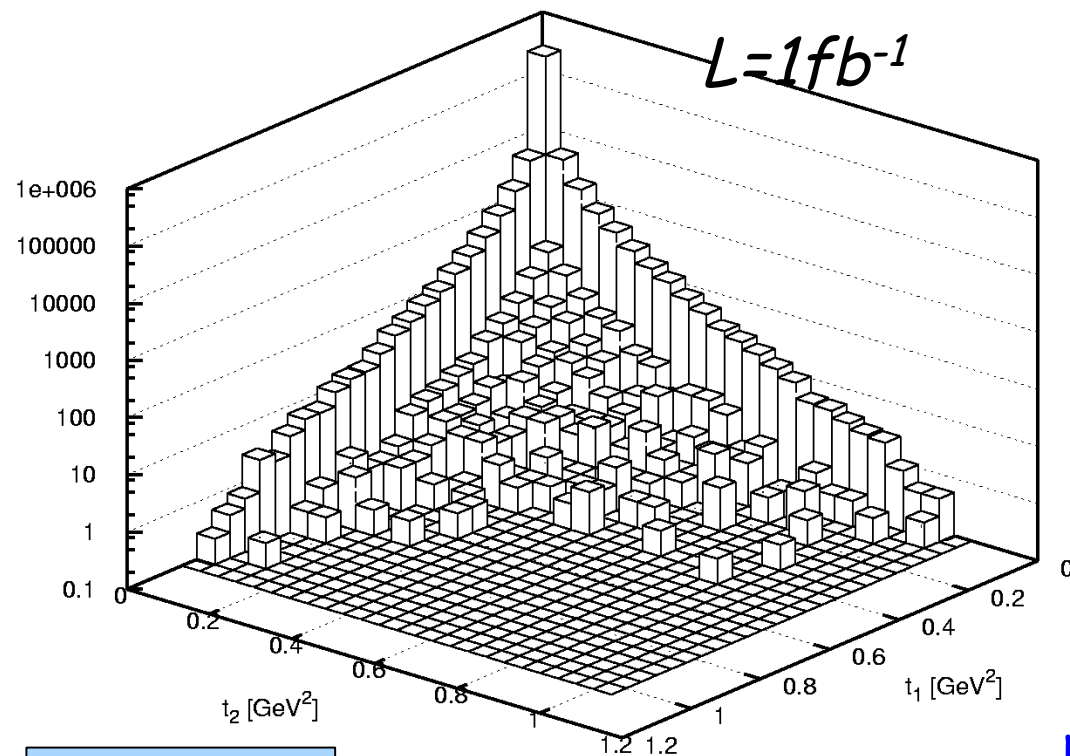$\gamma^* \gamma \rightarrow M \quad \rightarrow$ Amplitude $\propto F(M^2, Q^2, 0)$

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

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

studies with **EKHARA Monte Carlo** generator

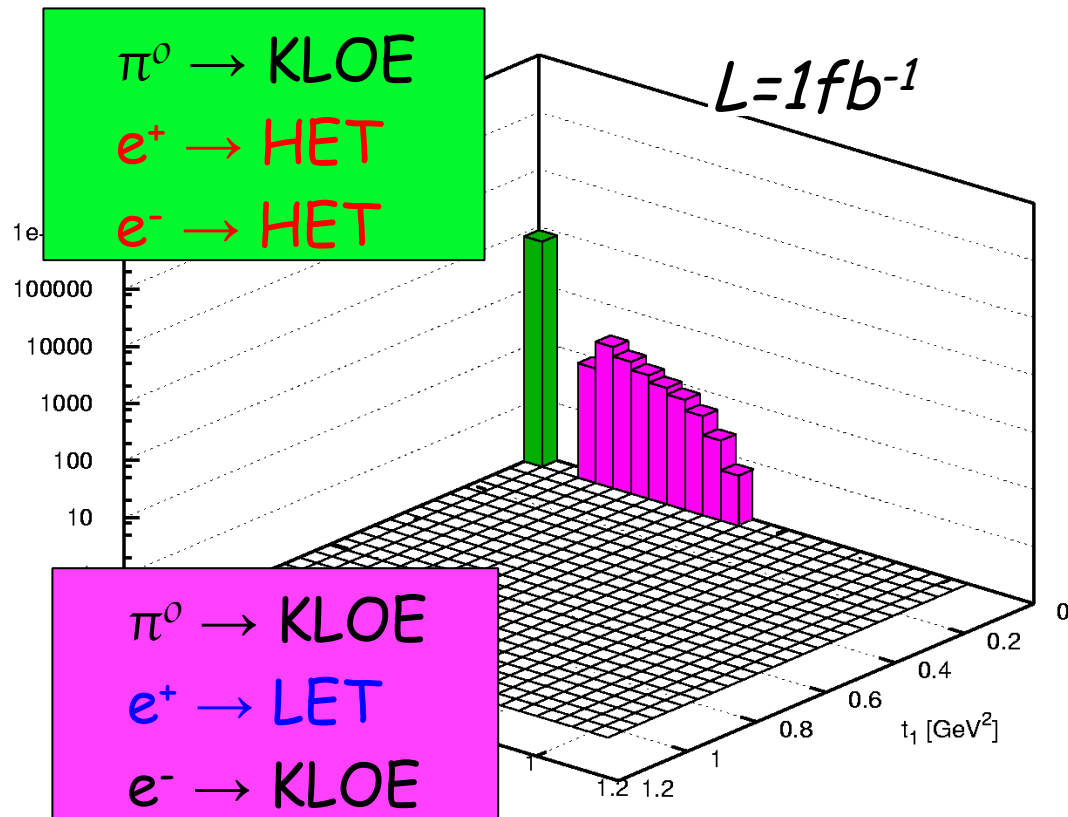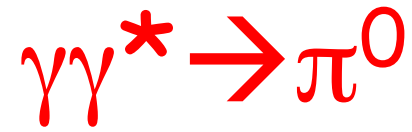### ($e^+e^- \to e^+e^-\pi^0$ added in a new version)

Preliminary

- Henryk Czyz

  (Katowice)

- Sergiy Ivashyn

  (Katowice, Kharkov)

No tagging

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

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

studies with **EKHARA Monte Carlo** generator

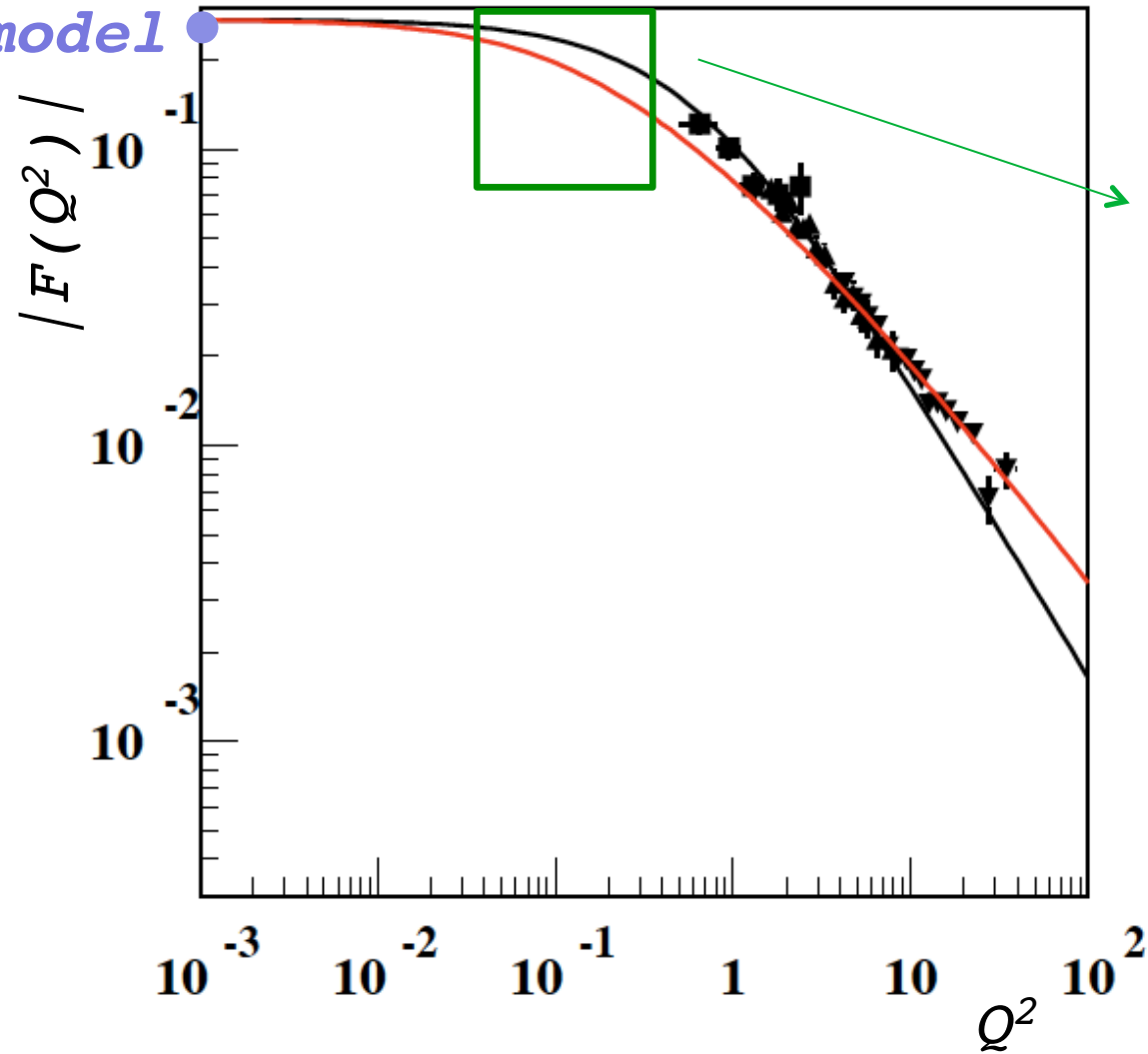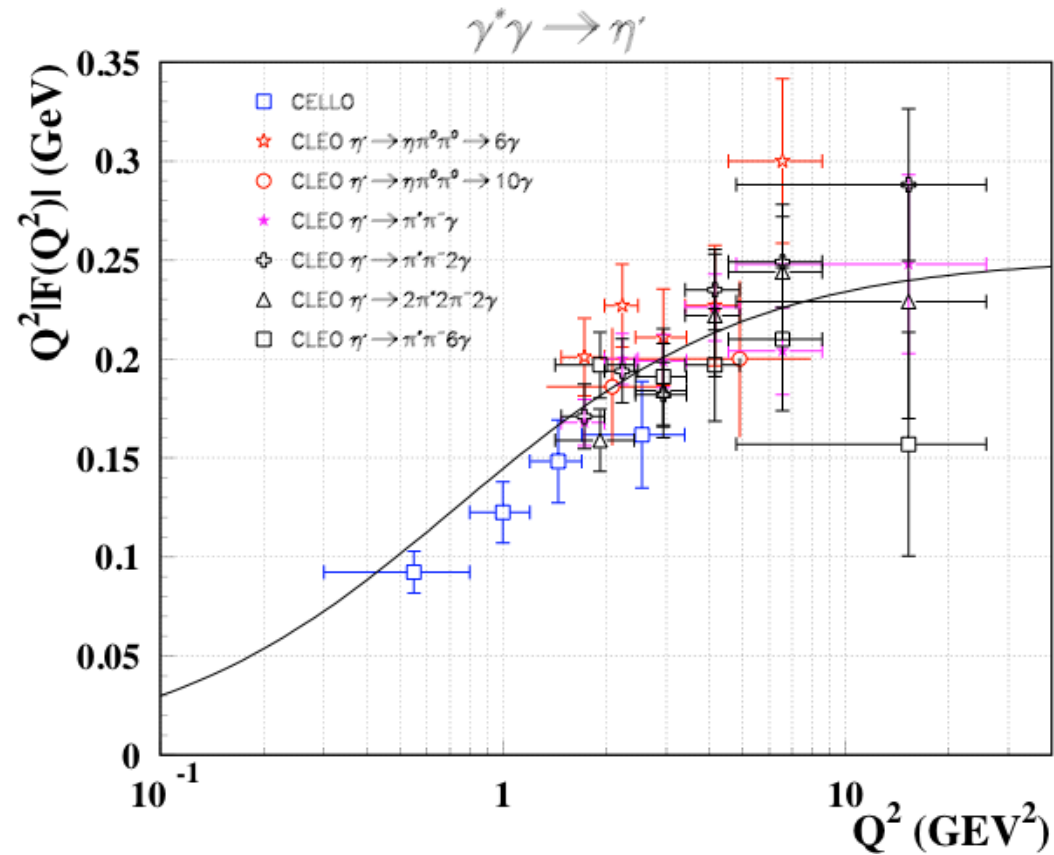### ($e^+e^- \rightarrow e^+e^-\pi^0$ added in a new version)

$\pi^0 \rightarrow$ KLOE
$e^+ \rightarrow$ HET
$e^- \rightarrow$ HET

$L=1fb^{-1}$

Preliminary

1e
100000
10000
1000
100
10

$\pi^0 \rightarrow$ KLOE
$e^+ \rightarrow$ LET
$e^- \rightarrow$ KLOE

- Henryk Czyz

  (Katowice)

- Sergiy Ivashyn

  (Katowice, Kharkov)

0
0.2
0.4
0.6
0.8
1
1.2 1.2
1

t_1 [GeV^2]

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

D. Moricciani   Lattice QCD Meets Experiment 2010

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

WZW model

$|F(Q^2)|$

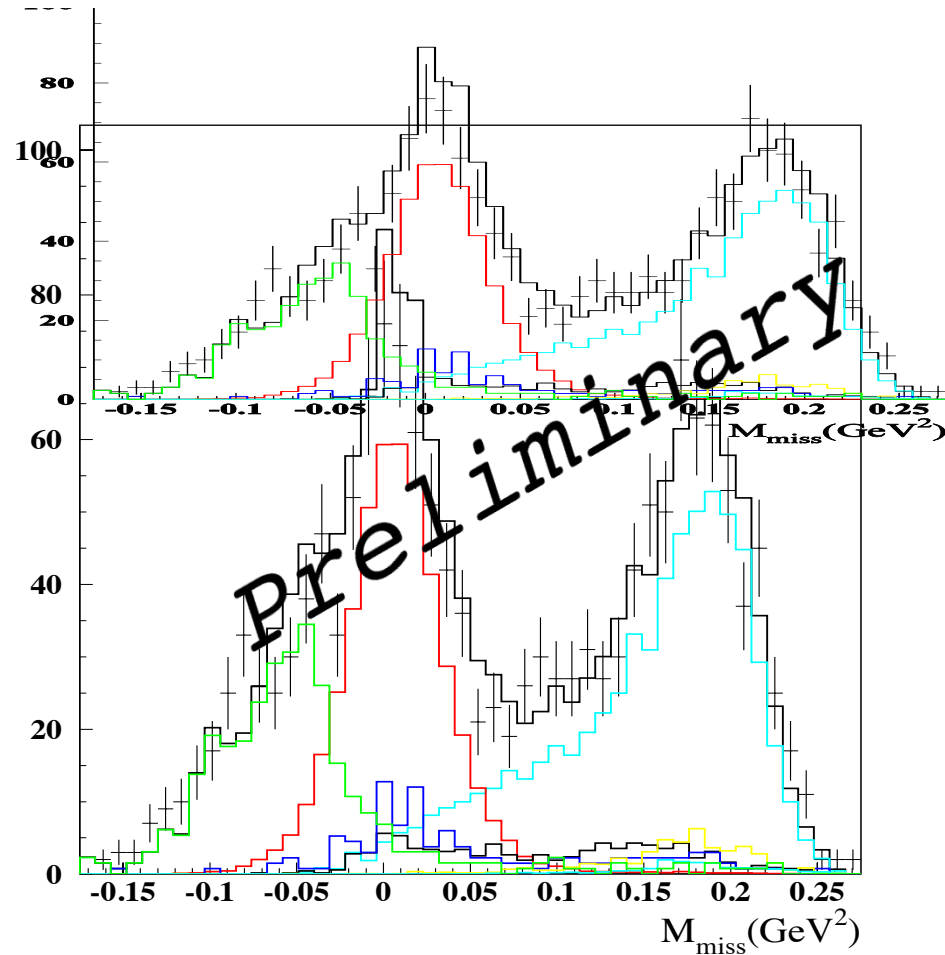Kloe-2 data will fix the slope at $Q^2=0$

Q^2

Meson transition FFs

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

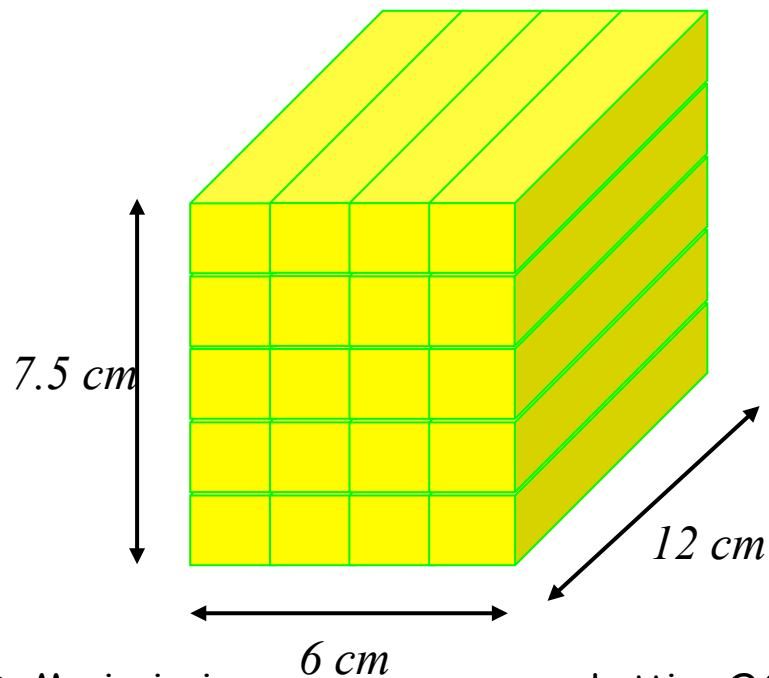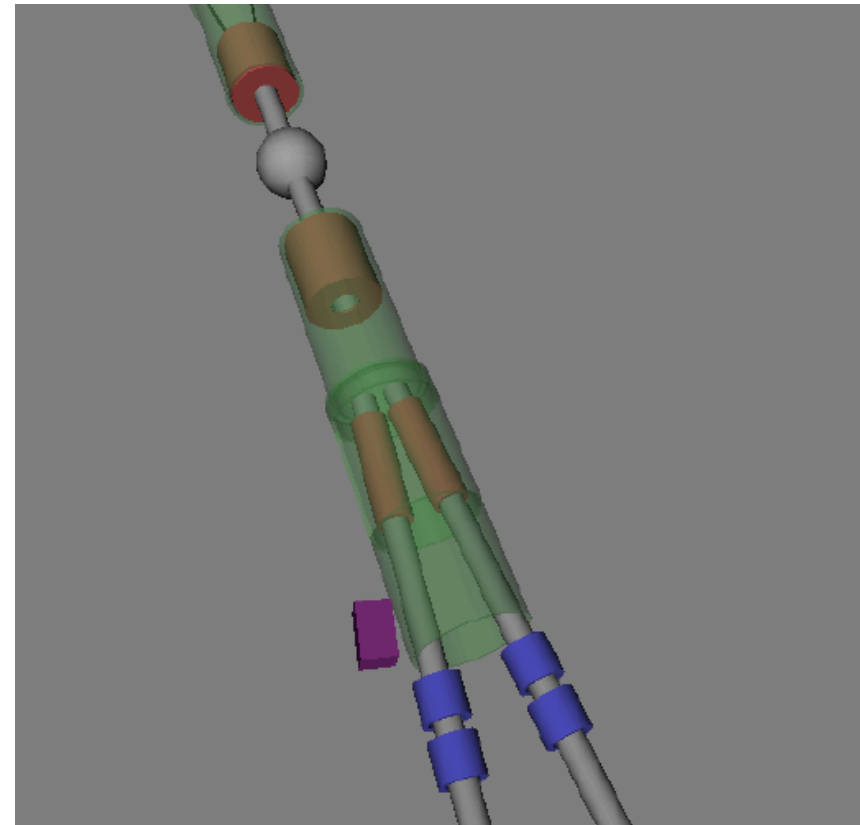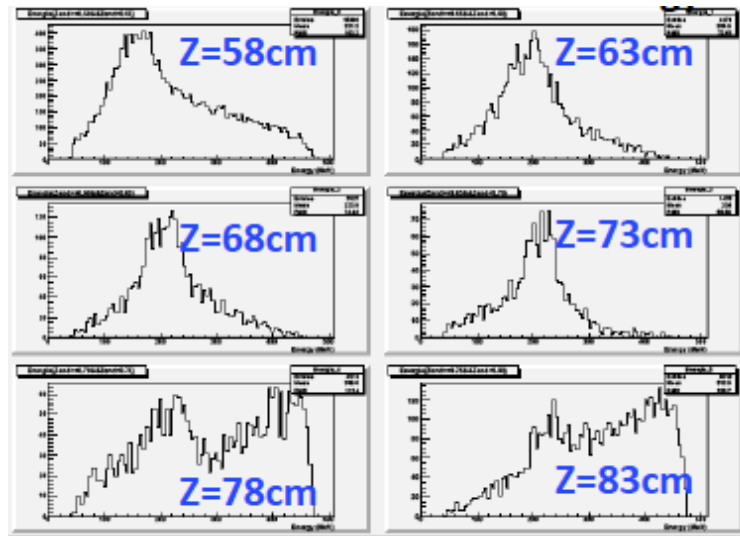*This is a option under study*

KLOE data at √s=1 GeV

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

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

signal

LET Characteristics

Z=58cm Z=63cm
Z=68cm Z=73cm
Z=78cm Z=83cm

7.5 cm

12 cm

6 cm

LET: Low Energy Tagger
    (160-230 MeV) lepton
    energy
Calorimeters, LYSO + SiPM

LET system and performance

$$\frac{\sigma_E}{E} = \frac{2.4\%}{\sqrt{E(GeV)}} \oplus 6.5\% \oplus \frac{0.5\%(fixed)}{E(GeV)}$$

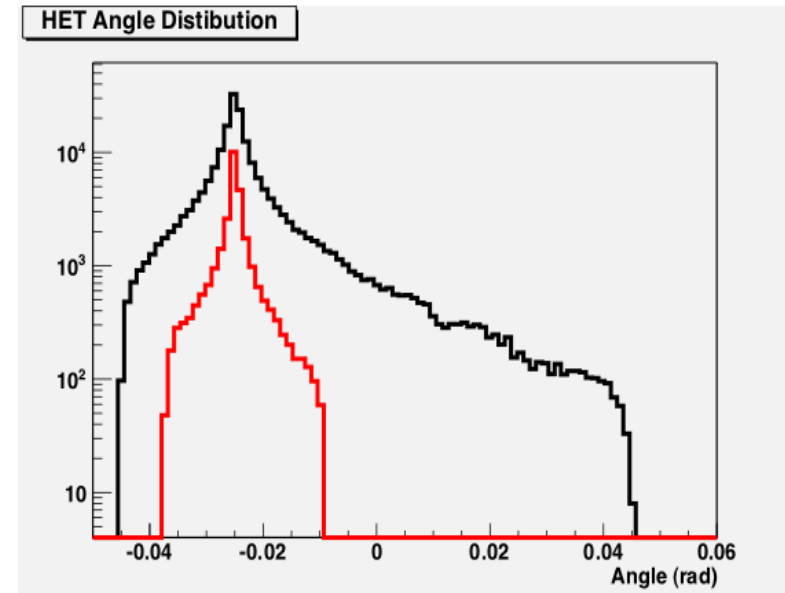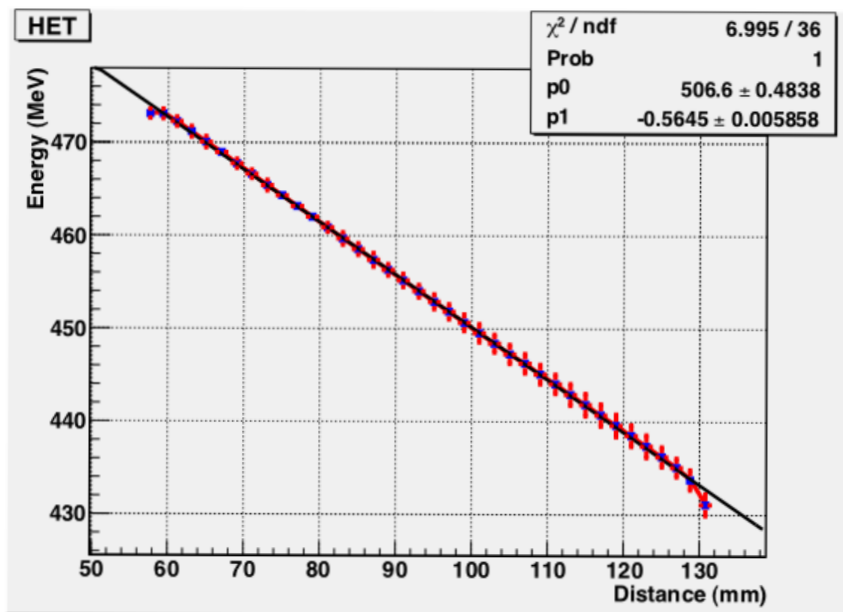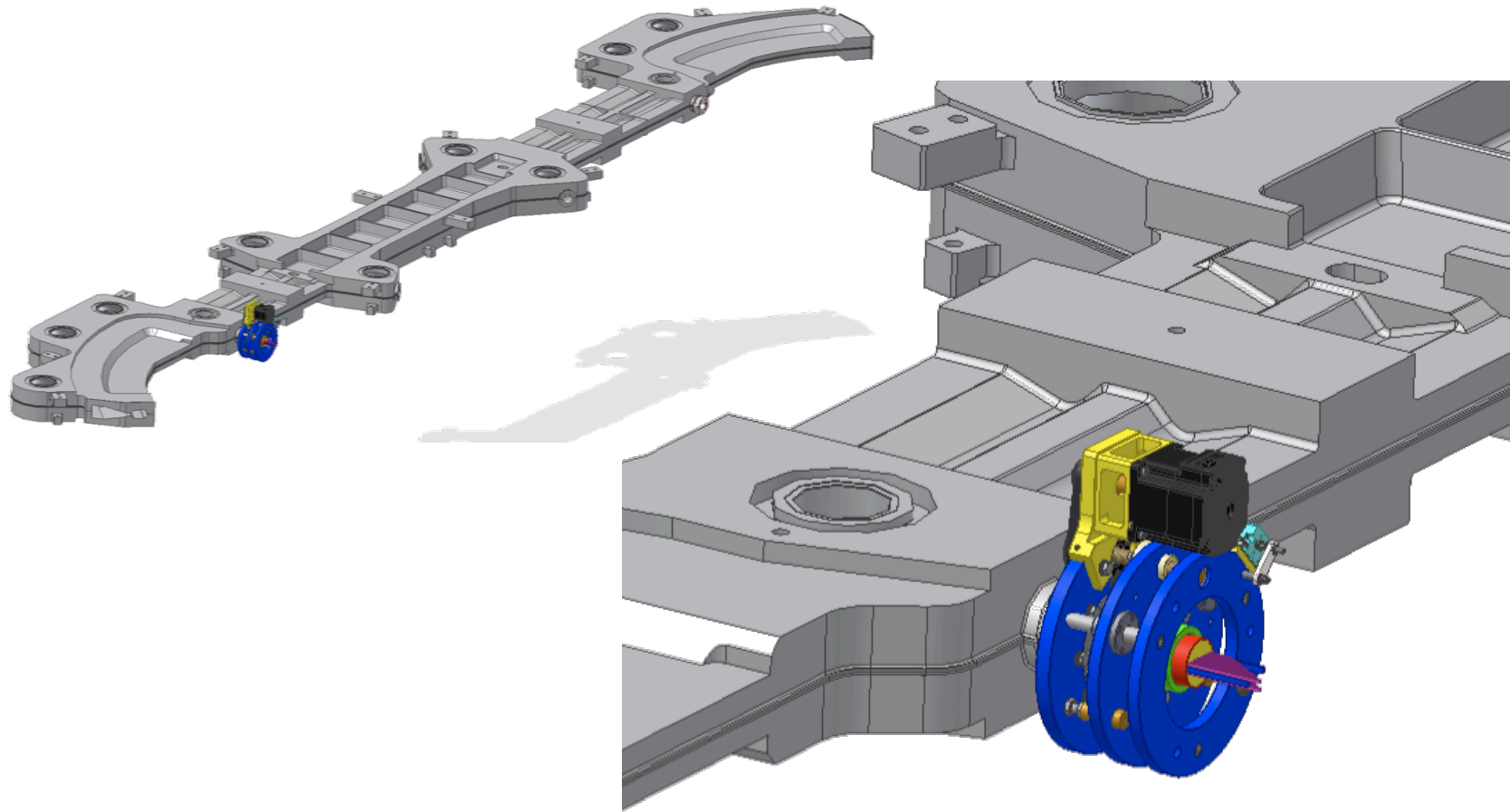Only 1st peak

- 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
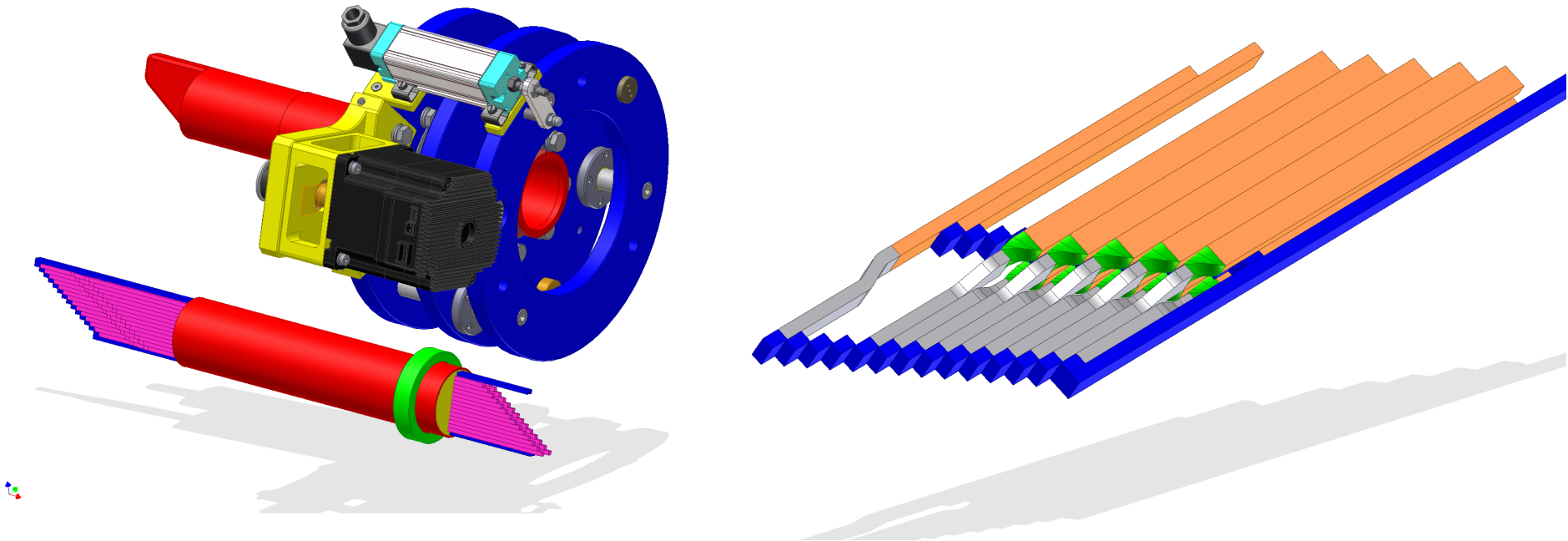- Resolution is better than 10% for E > 150 MeV

HET characteristics

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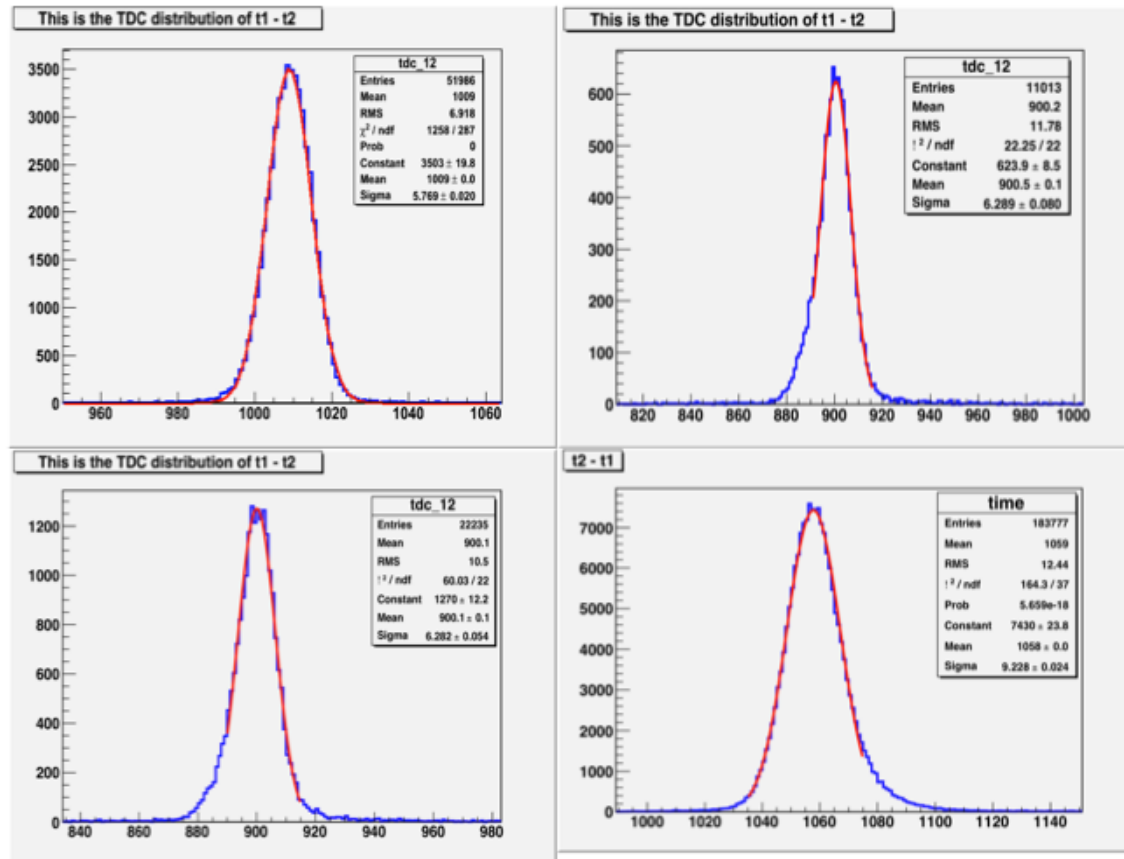
HET systems

HET systems

- ❑ 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 during September 2009

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

Summary

Tagging detectors ready → installation in progress
DAΦNE commissioning starts in May

⬇

γγ-physics program @ KLOE-2:

✓ $γγ → ππ$ *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 $a_μ$*

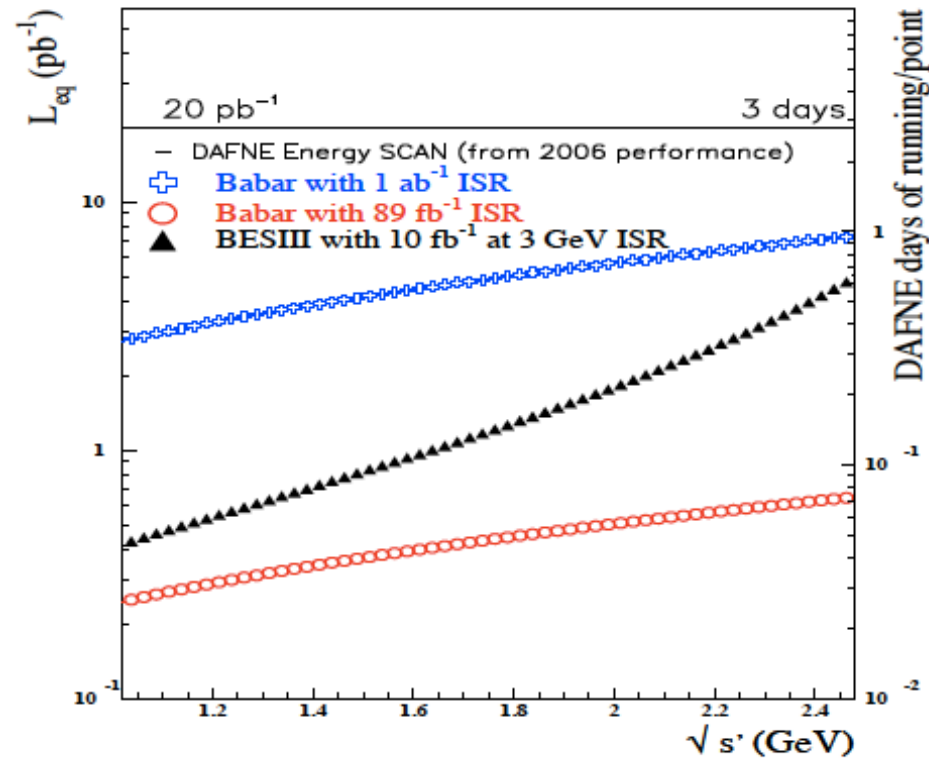*(energy upgrade of DAΦNE under study → $η'$, f_0, a_1 TFFs !)*

a_μ^{HLO} @ Step2

Figure 5: Equivalent luminosity for: BaBar with 1 ab^{-1} (cross); BaBar with 89 fb^{-1} (circle); BES-III with 10 fb^{-1}, using ISR at 3 GeV (triangle). A bin width of 25 MeV is assumed. A polar angle of the photon larger than 20° is assumed.