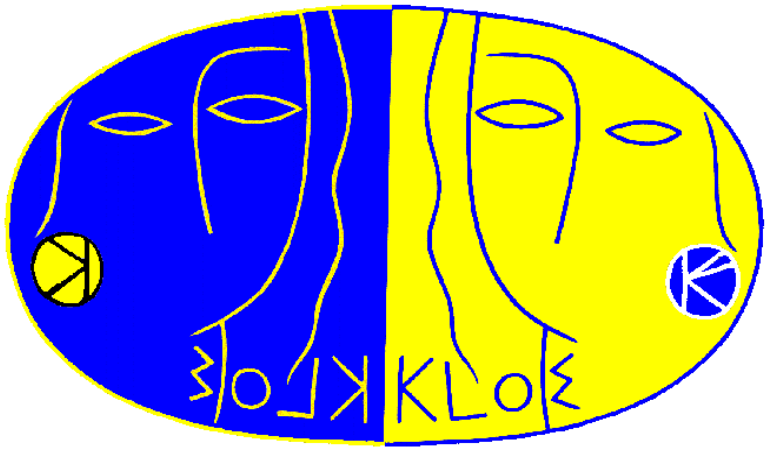
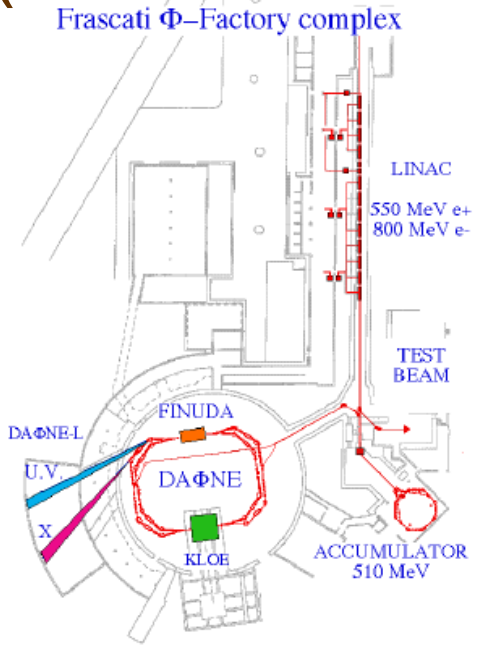
Gamma-Gamma Physics and Transition Form Factors with KLOE/KLOE-2

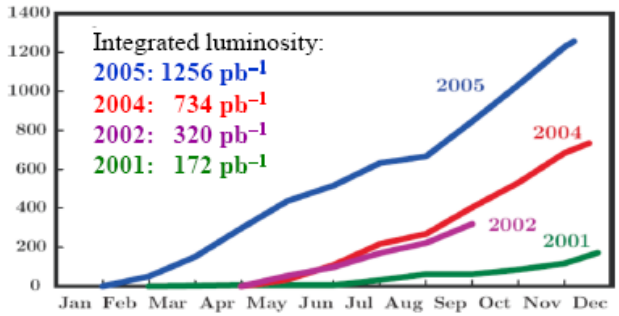


Elena Perez del Rio
on behalf of the KLOE-2 Collaboration

Phi2Psi 2017
June 26-29, 2017
Mainz, Germany

DAΦNE
(Double Annular Φ Factory for Nice Experiments)



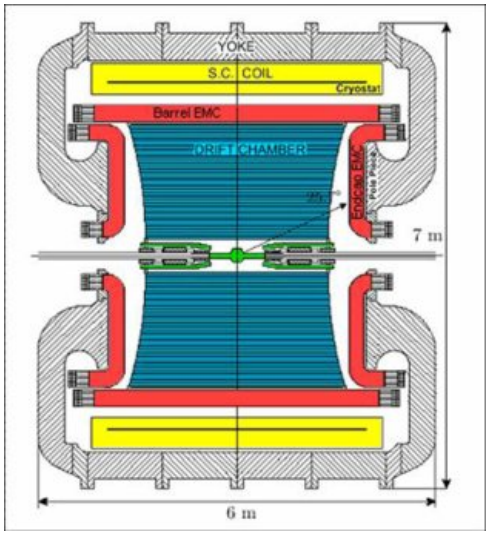


- **Drift Chamber**
- Low-mass gas mixture 90% Helium + 10% isobutane
- $\delta p_\perp / p_\perp < 0.4\%$ ($\theta > 45°$)
- $\sigma_{xy} = 150\ \mu m$; $\sigma_z = 2$ mm
- 12582 cells
- Stereo geometry
- 4m diameter, 3.3m long

- $e^+ e^-$ collider $\sqrt{s} = M_\Phi = 1019.4$ MeV
  - 2 interaction regions
  - $e^+ e^-$ separated rings
  - 105 + 105 bunches spaced by 2.7 ns
- KLOE data taking campaign ended in 2006
  - ~ 2.5 fb^{-1}
  - ~ 260 pb^{-1} off-peak
- DAΦNE upgrade (2008): new interaction scheme
  - Large beam crossing angle
  - crab waist sextupoles

- **Calorimeter**
- 98% coverage full solid angle
- $\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
- $\sigma_T = 57\ ps / \sqrt{E(GeV)} \oplus 140\ ps$
- Barrel + 2 end-caps:
  - Pb/scintillating fiber read out by 4880 PMTs

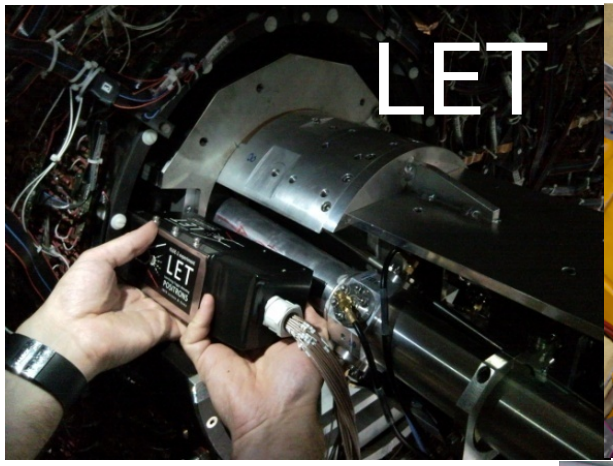
Magnetic field B = 0.52 T

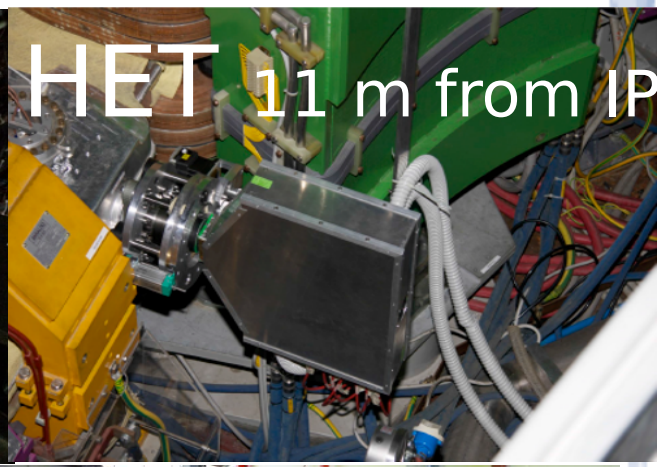


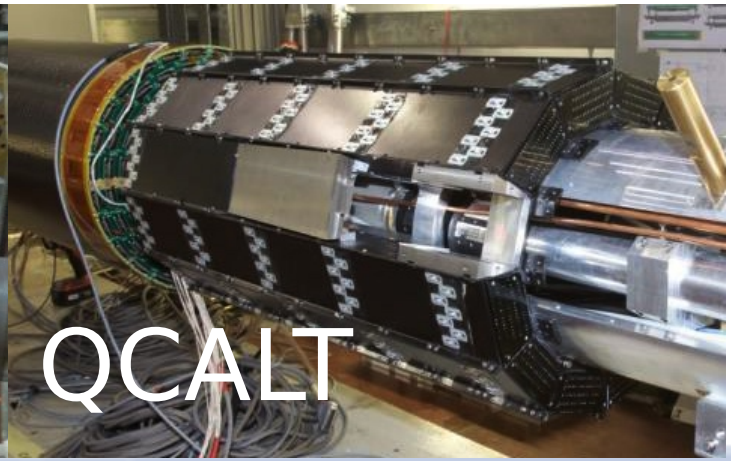
KLOE-2 Upgrade

- KLOE-2 new data taking campaign started on November 2014
- It will collect more than 5 fb^{-1} up to March 2018
- New detectors fully operative

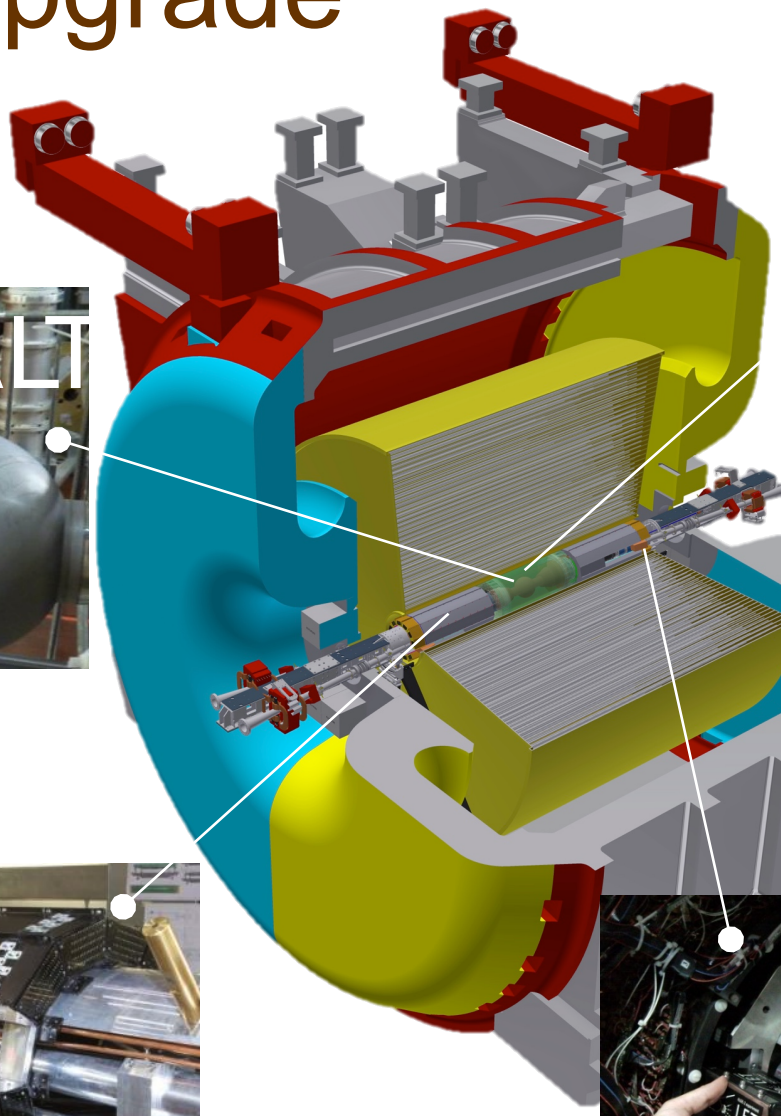
- Tagging system LET & HET
  - e+e--taggers for γγ-physics
- CCALT & QCALT
  - 2 new calorimeters
  - CCALT for low angle γ's (down to 10º)
  - Quadrupole coverage for K_L decays
- Inner Tracker
  - 4 layers of C-GEM
  - better vertex reconstruction and track parameters

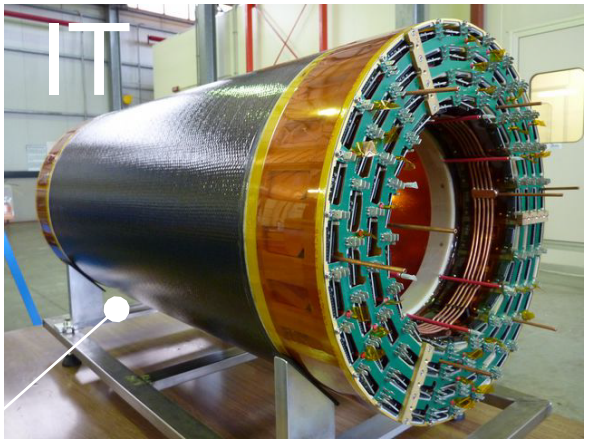


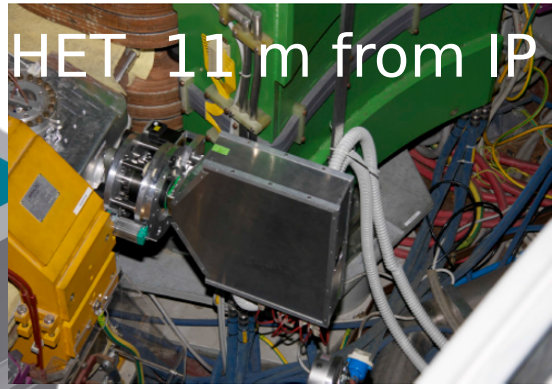


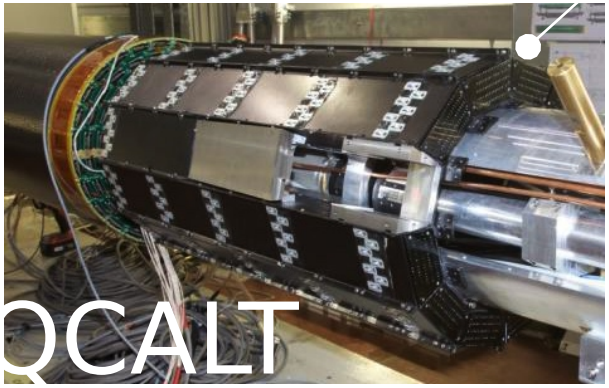


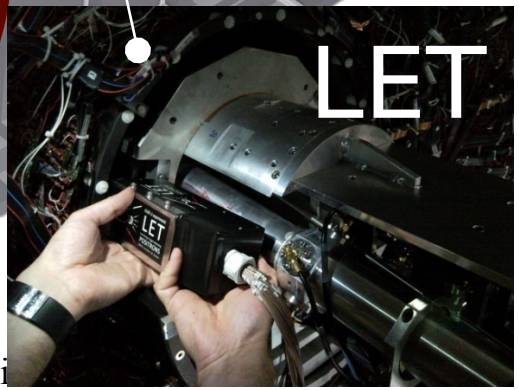
KLOE-2 Upgrade





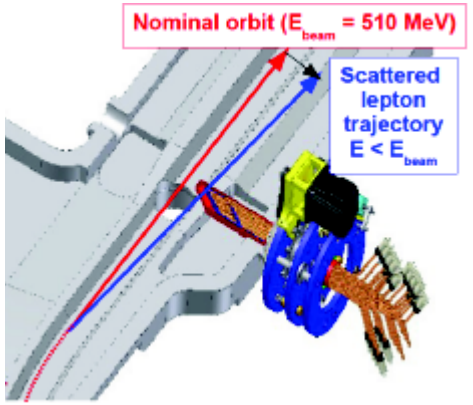


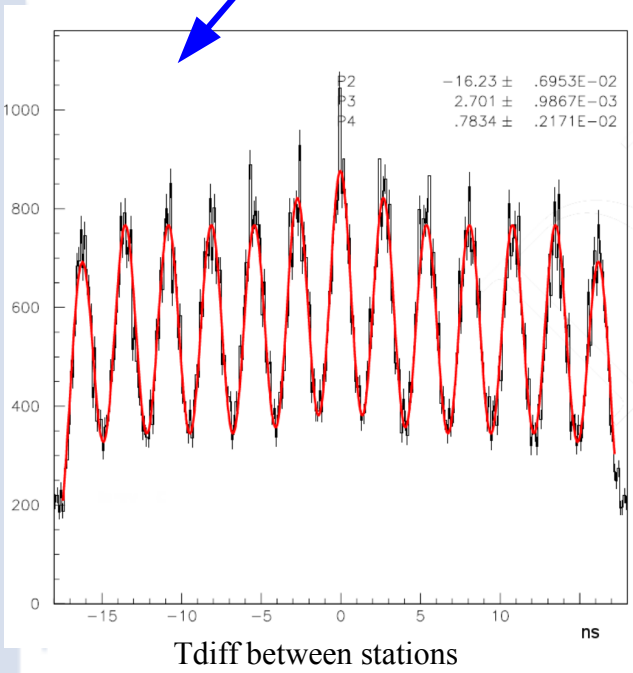




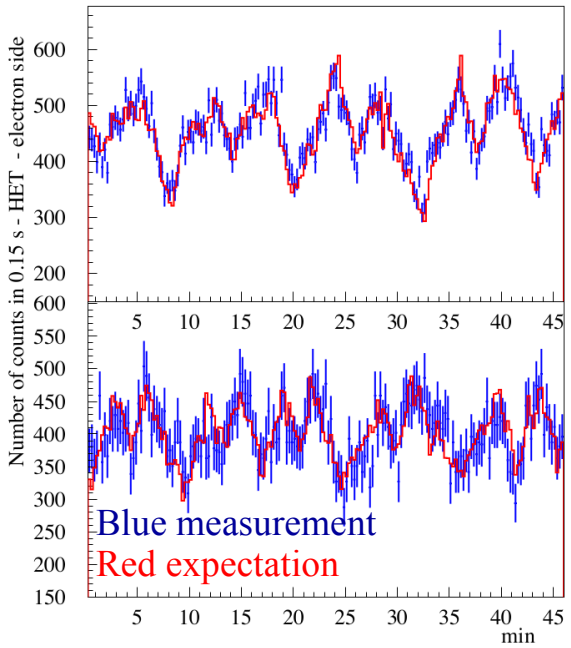
High Energy Tagger (HET)

- HET stations located approximately at 11m from IP after bending dipoles
- Strong energy-trajectory correlation
  - Scintillating hodoscope + PMTs
- **σ_t = 550(1)ps**





Tdiff between stations



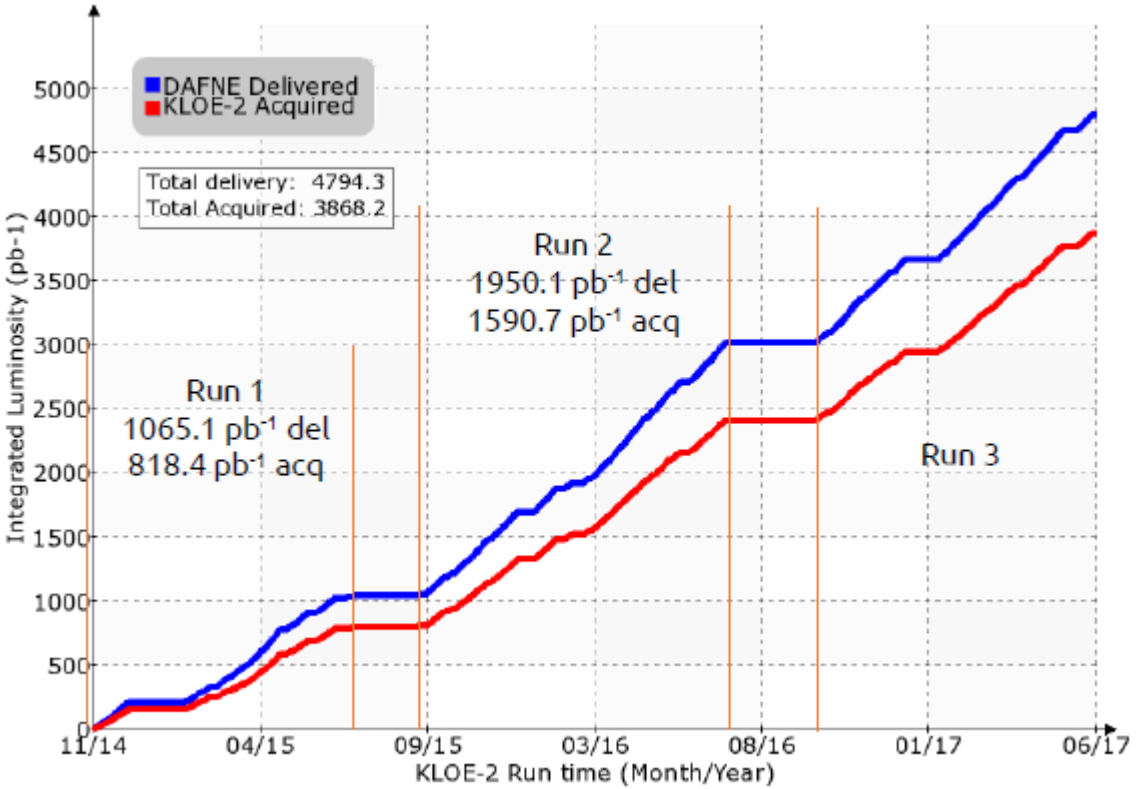
Scattered $e^{\pm}$ of E > 400 MeV escape beam pipe after first bending dipole of DAΦNE → spectrometer

- fast feedback on machine operation
- Rates dominated by single arm Bhabha's

$$R_{HET} \sim R_{trig}(\alpha L + \beta I^2)$$

Physics with KLOE-2

- KLOE-2 has started a new data campaign in November 2014
  - All KLOE-2 detectors operational
  - It will collect more than 5 fb^{-1} till the end of March 2018
- DAΦNE luminosity: peak = 2.2×10^{32} & daily delivered >10 pb^{-1}



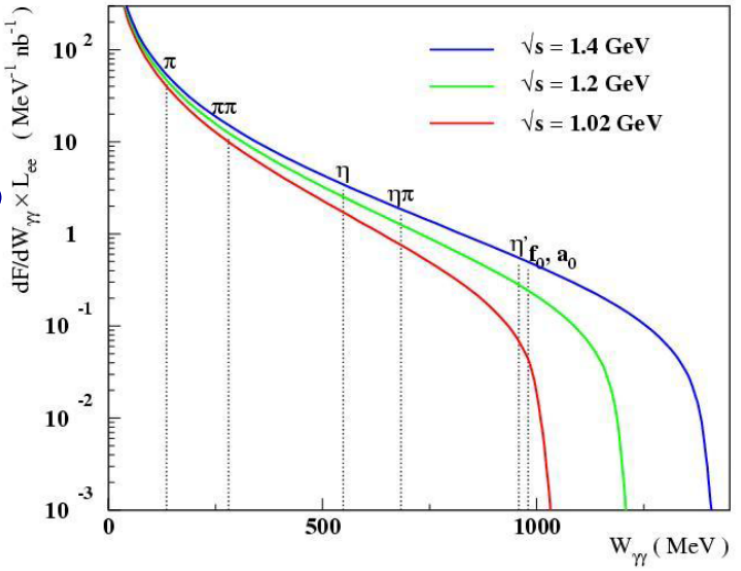
γγ Physics with KLOE

KLOE-2 Program: Eur. Phys. J C68 (2010) 619

- Photon coupling to S and P mesons → meson quark structure

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X \qquad \frac{dN}{dW_{\gamma\gamma}} = L_{int}\frac{dF}{dW_{\gamma\gamma}}\sigma(\gamma\gamma \to X)$$

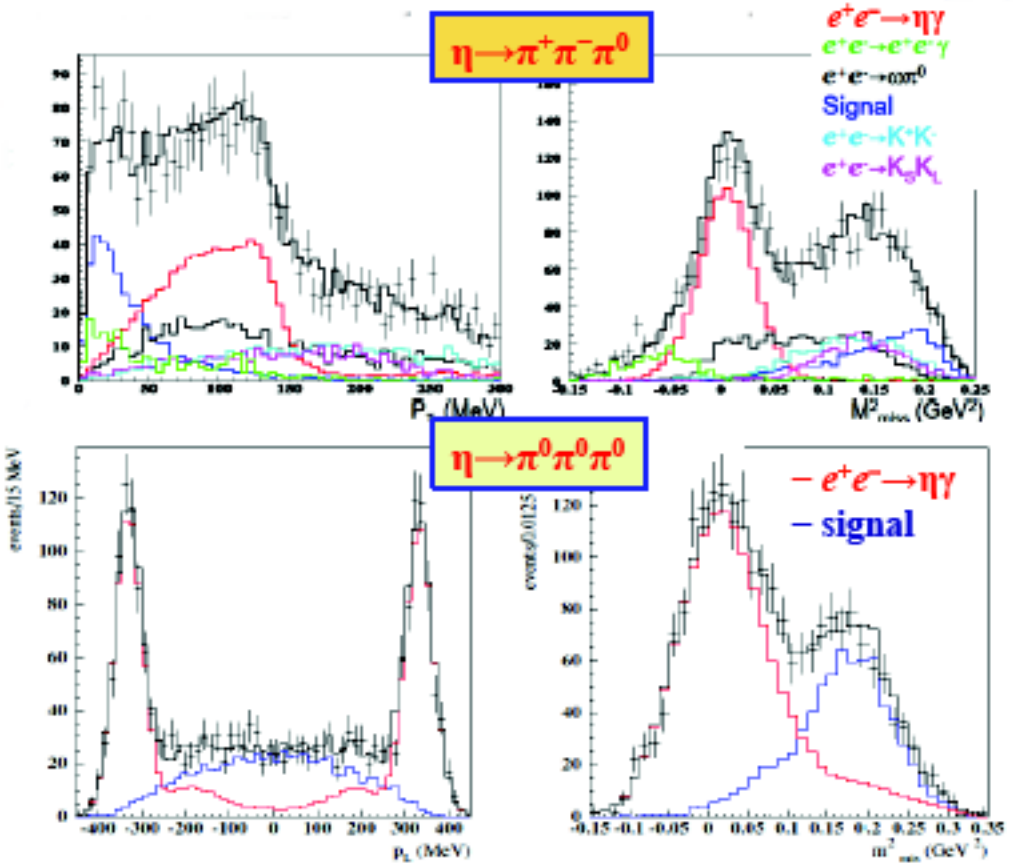
- X = η, π^0
  - $\Gamma(X \to \gamma\gamma)$ at ~ 1%
  - TFF $F_{x\gamma^*\gamma^*}(q_1^2, q_2^2)$
    - Input for the light-by-light contribution to (g-2) of muon
- $X = \pi^0\pi^0 \to f_0(500)$
- KLOE data → no $e^{\pm}$ tagging → off-peak data



$\gamma^*\gamma^* \rightarrow \eta$ @KLOE

- Data sample off-peak @ $\sqrt{s}$ = 1.0 GeV
  - Sample of 240 pb^{-1}
  - No taggers
- Main background from $e^+e^- \rightarrow \eta\gamma$ with lost γ
- Selection:
  - $\eta \rightarrow \pi^+\pi^-\pi^0$ events with two tracks and two prompt protons
  - $\eta \rightarrow \pi^0\pi^0\pi^0$ events with no tracks and 6 prompt protons
- 2-D fit in the (M_{miss}, p)

Combining both channels



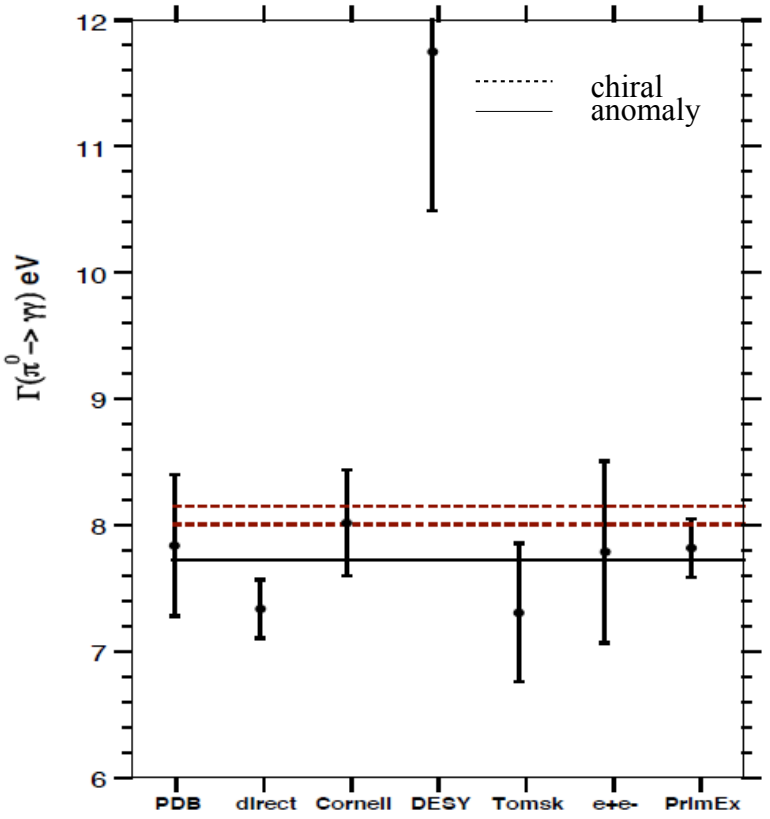
$\sigma(e^+e^- \rightarrow e^+e^-\eta) = (32.7 \pm 1.3 \pm 0.7)$ pb

$\Gamma(\eta \rightarrow \gamma\gamma) = (520 \pm 20 \pm 13)$ eV

KLOE - JHEP01(2013)119

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

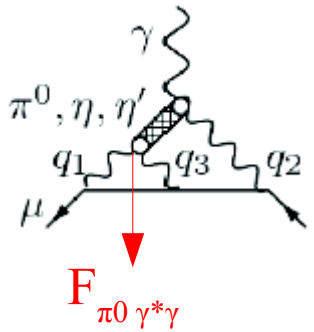
- Precision measurement of $\Gamma(\pi^0 \rightarrow \gamma\gamma)$
- $L = 5\ fb^{-1}$
- KLOE-2 aims to measure down to
  - $\delta\Gamma(\pi^0 \rightarrow \gamma\gamma) \approx 1\%$
- Measurement with taggers
  - HET-HET coincidence + 2 γ's in EMC
  - $\sigma_{TOT}\ (e^+e^- \rightarrow e^+e^-\pi^0) \approx 0.28$ nb



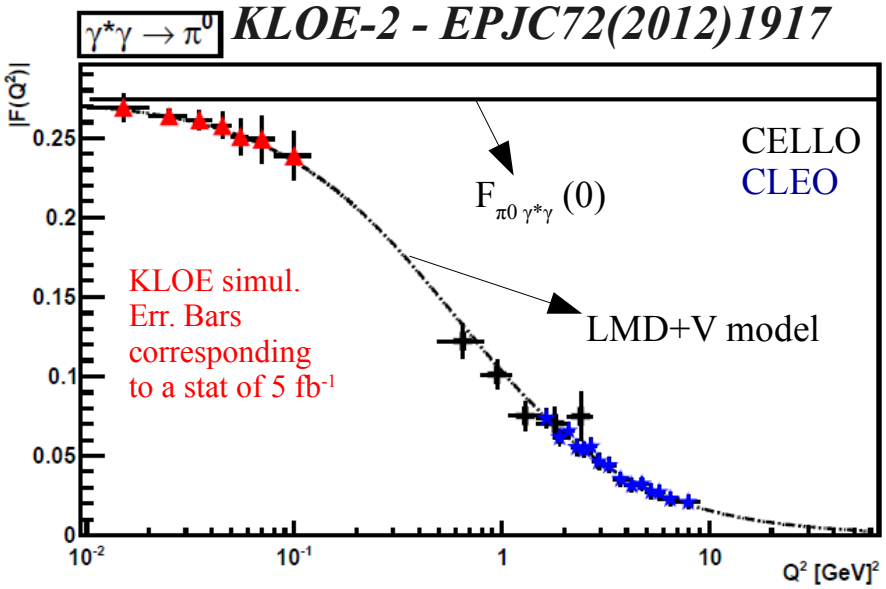
$\Gamma^{th}(\pi^0 \rightarrow \gamma\gamma) = (8.09 \pm 0.11)$ eV ==> 1.4% uncertainty *PRD79(2009)076005*

$\Gamma^{exp}(\pi^0 \rightarrow \gamma\gamma) = (7.82 \pm 0.14(stat) \pm 0.1(syst))$ eV
==> 2.8% uncertainty (PrimEx coll. @ JLAB) *PRL106(2011)162303*

γ*γ* → π⁰ @ KLOE-2



- First measurement of π^0 $\gamma^*\gamma$ TFF
- $F_{\pi 0\,\gamma^*\gamma}$ $(q^2,0)$ in the space-like region $q^2 < 0.1$ GeV^2
- 2 γ's in EMC + HET
  - Lepton detection in DCH/EMC $|q^2| < 0.1$ GeV^2
  - Lepton detection in HET $|q^2| \approx 0$
- Impact in the precision of the $a_\mu^{LbyL;\pi 0}$
- L = 5 fb-1 ==> 6% uncert. at each point
- Uncertainty in the single π0 contribution to the HLbL can be reduced by a factor of ~ 2

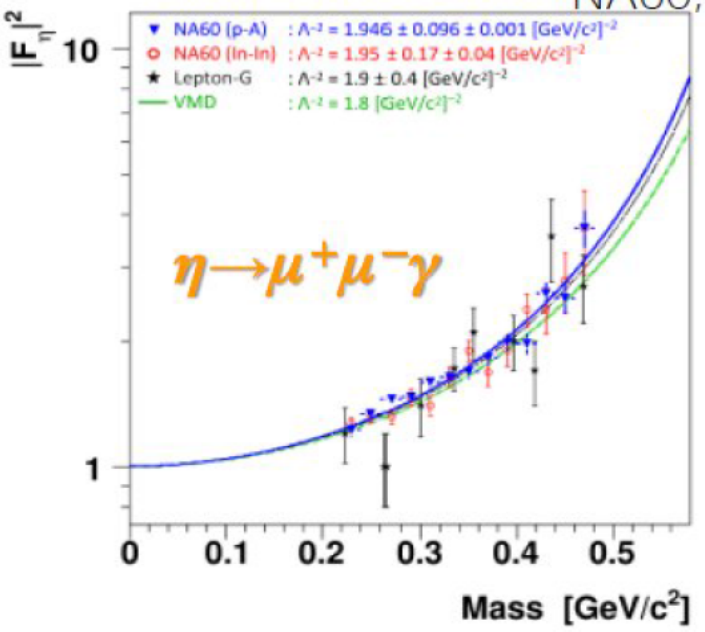


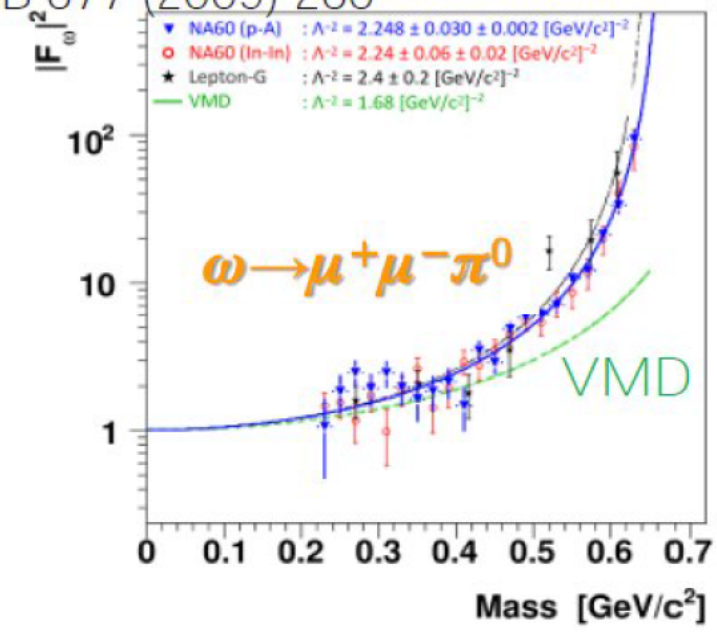
Meson Transition Form Factors

- $V \rightarrow P\,\gamma^* \rightarrow P\,l^+l^-$
  - Test on the theoretical description of meson structure
  - TFF(q^2) where $q^2 = m^2_{l+l-}$ coupling of meson to virtual photons
- Light-by-Light contribution to a_μ
- Used to determine upper limit in dark forces searches
- Vector Meson Dominance (VMD) TFF described as $F(q^2) = 1/(1 - q^2/\Lambda^2)$
  - VMD predictions discrepancy for $\omega \rightarrow l^+l^-\pi^0$
  - Models developed to explain discrepancy

Terschlusen and Leupold, Phys. Lett. B 691 191 (2009)
Ivashyn, Prob. Atom. Sci. Tech. 2012N1 179 (2012)
Schneider Kubis Nieking, Phys. Rev. D86 054013 (2012)

NA60, PLB 677 (2009) 260

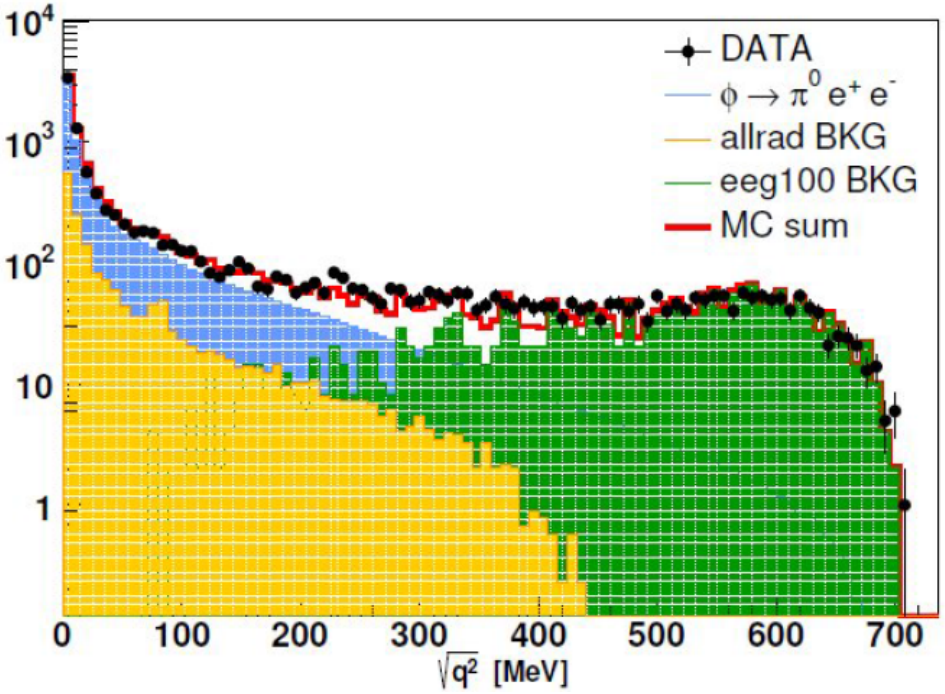


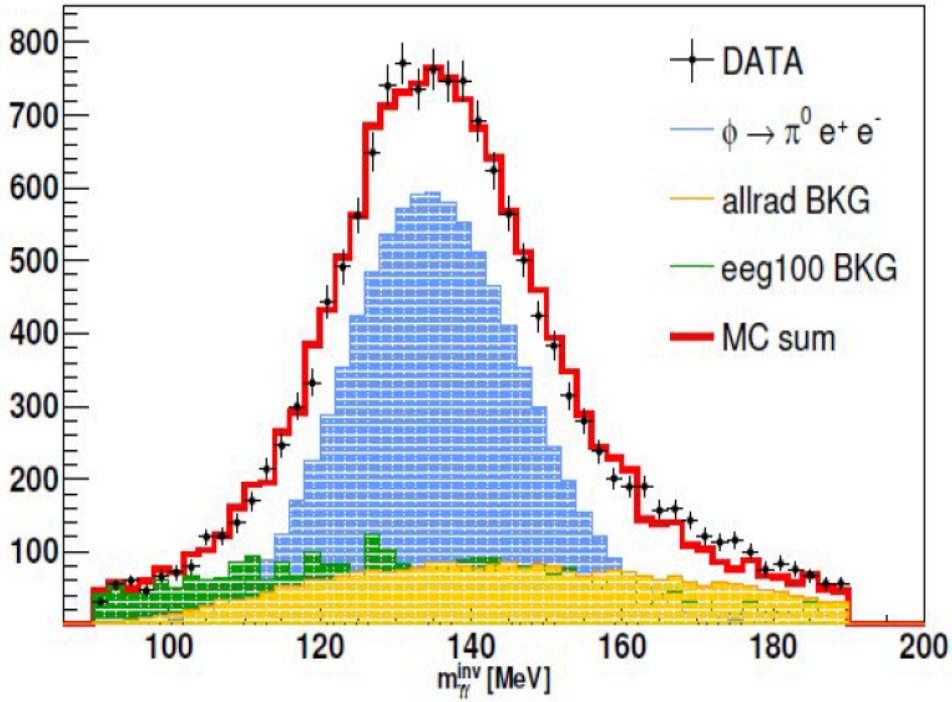


Meson Transition Form Factors
$\Phi \rightarrow \pi^0 e^+ e^-$

- $L_{int} = 1.7\ fb^{-1}$ and ~ 9500 signal events selected
- Main background contributions: radiative bhabha scattering and $\Phi \rightarrow \pi^0 \gamma$ with photon conversion
- Overall efficiency 15%

KLOE - Phys.Lett. B757 (2016) 362-367





Meson Transition Form Factors

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

KLOE - Phys.Lett. B757 (2016) 362-367

- Branching Ratio measurement

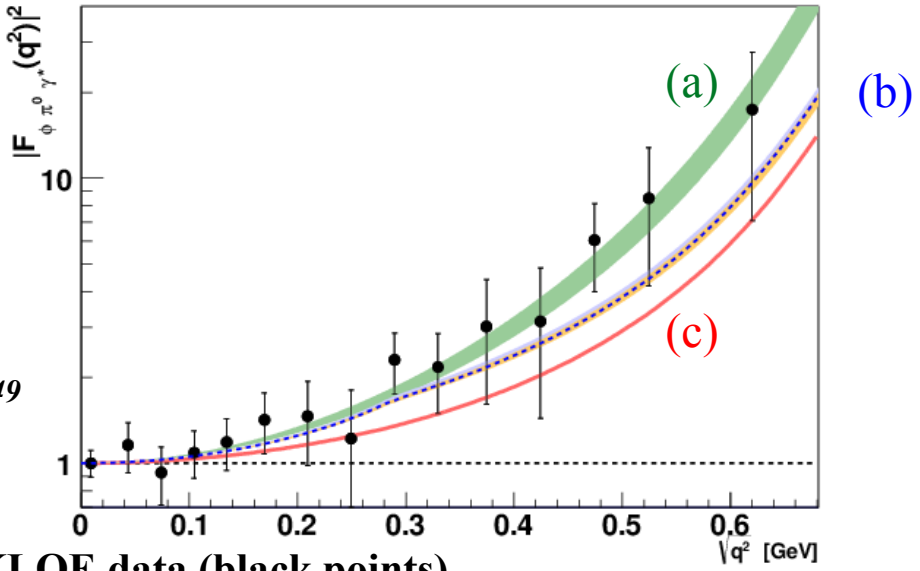
$$BR(\Phi \rightarrow \pi e e) = (1.35 \pm 0.05^{+0.05}_{-0.10}) \times 10^{-5}$$

Expt.	BR $(\phi \rightarrow \pi^0 e^+ e^-) \times 10^5$	
SND	$1.01 \pm 0.28 \pm 0.29$	*JETP Lett 75 (2002) 449*
CMD-2	$1.22 \pm 0.34 \pm 0.21$	*PLB 503(2001)237-244*
PDG	1.12 ± 0.2	

- Transition Form Factor Slope

$$b_{\pi^0,\Phi} = (2.02 \pm 0.11)\, GeV^{-2}$$

KLOE data factor of 3.6 better accuracy



KLOE data (black points)

(a) Chiral theory:
S. Ivashyn, Prob. Atomic Sci. Technol. 2012N1 (2012) 179

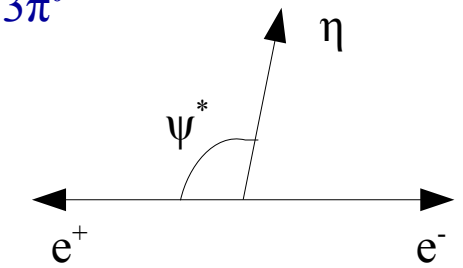
(b) Dispersive analysis:
S. P. Schneider , B. Kubis, F. Niecknig Phys. Rev. D 86 (2012) 054013 and I. Danilkin, et al. Phys. Rev. D 91 (2015) 094029

(c) VMD:
L. G. Landsberg Phys. Rept. 128 (1985) 301

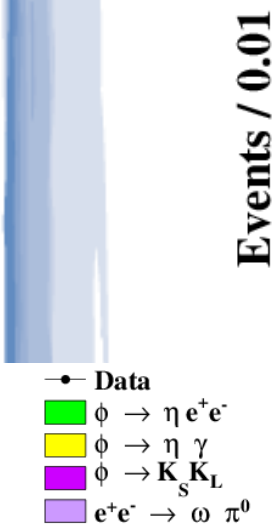
Meson Transition Form Factors

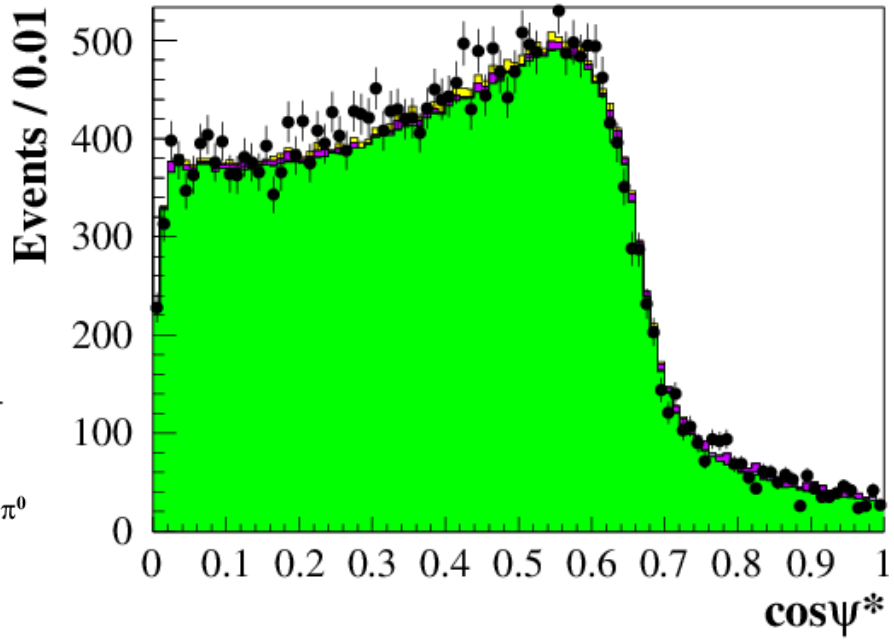
$\Phi \rightarrow \eta\, e^+\, e^-$

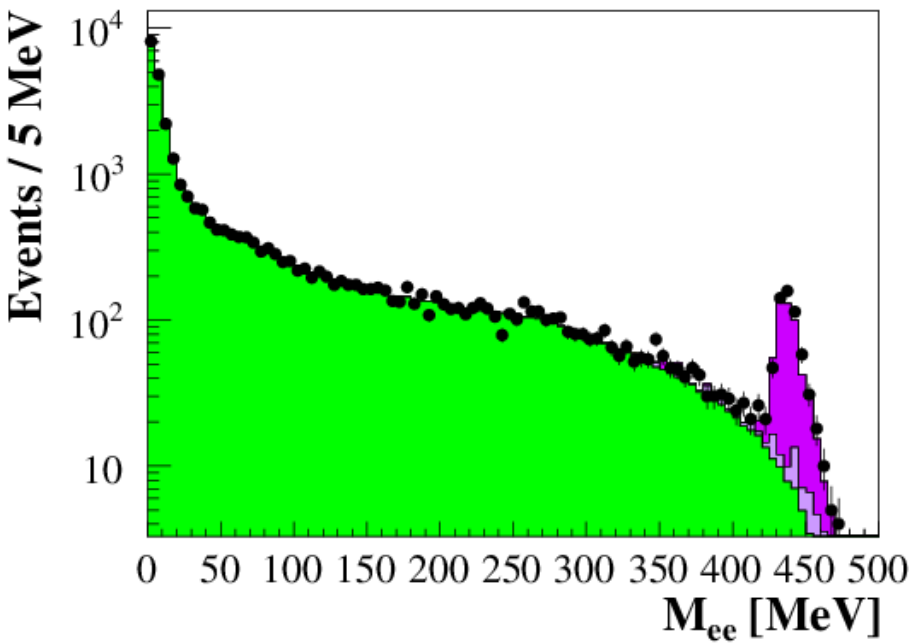
- L_{int} = 1.7 fb^{-1} and ~ 31000 signal events selected with $\eta \rightarrow 3\pi^0$
- Background contribution (~ 3%) dominated by $\Phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- 3\pi^0$ and $\Phi \rightarrow \eta\, \gamma$
- Analysis efficiency ~ 15%
- Bin to bin background subtraction ~ 29600 event candidates



KLOE - Phys.Lett. B742 (2015) 1-6



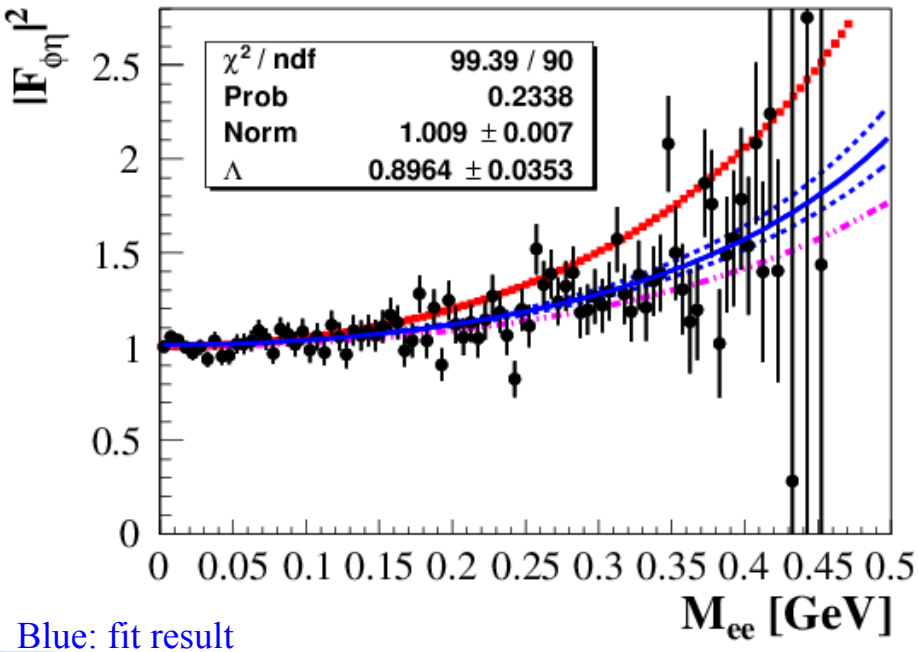




Meson Transition Form Factors

$\Phi \rightarrow \eta e^+ e^-$

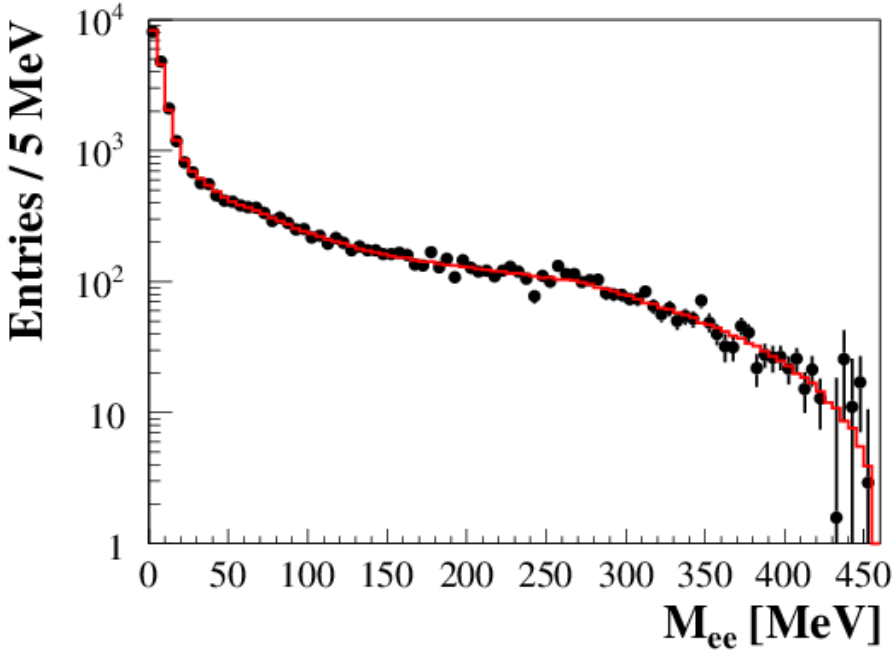
KLOE - Phys.Lett. B742 (2015) 1-6



Blue: fit result
Red:C. Terschlusen and S. Leopold, Phys. Lett. B 691 (2010) 191-201
Pink: VMD expectation

$$b_{\eta,\Phi} = \left(1.28 \pm 0.10^{+0.09}_{-0.08}\right) GeV^{-2}$$

VMD: ~1 GeV^{-2} (*Phys. Rev.C 61 (2000) 035206*)
SND: (3.8 ± 1.8) GeV^{-2} (*PLB 504 (2001) 275*)
KLOE result precision factor of 5 better



$$BR(\Phi \rightarrow \eta e e) = (1.075 \pm 0.007 \pm 0.038)\, x\, 10^{-4}$$

VMD: ~1.1 x 10^{-4} (*Phys. Rev.C 61 (2000) 035206*)
SND: (1.19 ± 0.31) x 10^{-4} (*PLB 504 (2001) 275*)
CMD-2: (1.14 ± 0.16) x 10^{-4} (*PLB 501 (2001) 191*)

Summary

- KLOE has delivered the most precise measurement of the two-photon width of the η meson by using off-peak data
- With the KLOE-2 taggers and luminosity we can measure the π^0 width with 1% accuracy
- By using the HET of KLOE-2 also the TFF of π^0 $\gamma^*\gamma$ with a quasi-real photon and a real one can be measured, covering a totally unexplored region of q^2
- Large data sample of light mesons available at KLOE provides important results on decay dynamics and transition form factor, together with limits on new physics, giving the most precise measurements for TFF for the reactions $\Phi \rightarrow \eta\, e^+ e^-$ and $\Phi \rightarrow \pi^0\, e^+ e^-$
- KLOE-2 presently acquired ~ $4 fb^{-1}$ with the aim of collecting more than 5 fb^{-1} by the end on March 2018

Backup slides

γγ Physics with KLOE-2

KLOE-2: Eur. Phys. J C68 (2010) 619

- Photon coupling to S and P mesons → meson quark structure

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

$$\frac{dN}{dW_{\gamma\gamma}} = L_{int}\frac{dF}{dW_{\gamma\gamma}}\sigma(\gamma\gamma \to X)$$

- X = η, π^0
  - Γ(X → γγ) at ~ 1%
  - TFF $F_{X\gamma^*\gamma^*}(q_1^2, q_2^2)$
    - Input for the light-by-light contribution to (g-2) of muon
- X = $\pi^0\pi^0$ → $f_0(600)$
  - KLOE measurement at √s = 1 GeV
- KLOE-2 e-taggers for high and low energy →
  - rejection of background from Φ
  - Close kinematics
  - Better statistical accuracy

4γ invariant mass distribution