Results and perspectives on hadron physics at KLOE/KLOE-2

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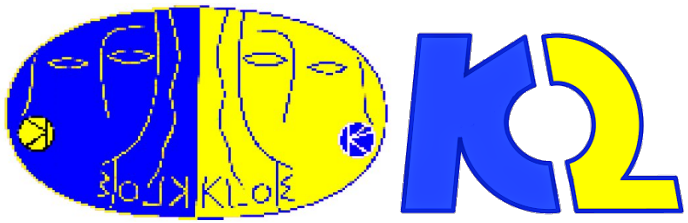

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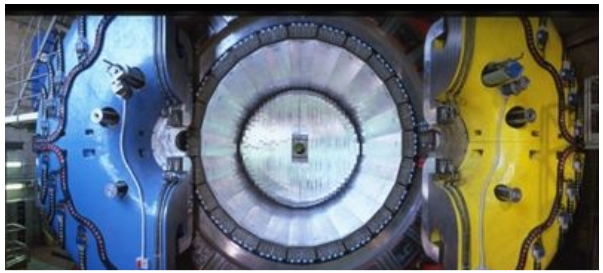
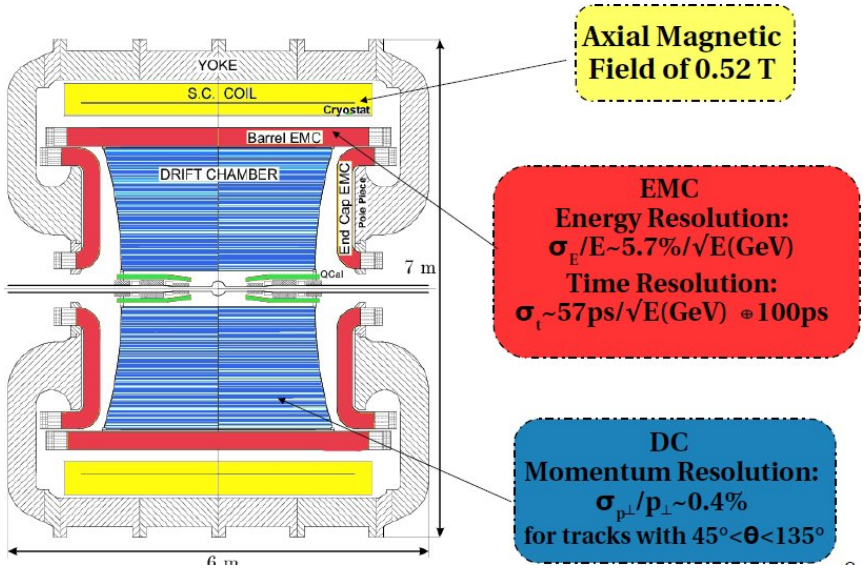
Overview

1. The Frascati Φ Factory and the KLOE/KLOE-2 detector
2. P,CP-violating process, $\eta \to \pi^+\pi^-$ decay
3. $\eta \to \pi^0\gamma\gamma$ decay
4. B boson Search
5. $\gamma\gamma$ Studies
6. Conclusions

The Frascati Φ Factory and the KLOE detector





- Double ring e^+e^- collider working at $\sqrt{s}=M\phi=1019.4$ MeV
- 2 interaction regions
- DAΦNE upgrade (2008):
  - Crab-Waist collision scheme implemented
  - Large beam crossing angle

EMC:

♦ **lead/scintillating fibers**

♦ **98% solid angle coverage**

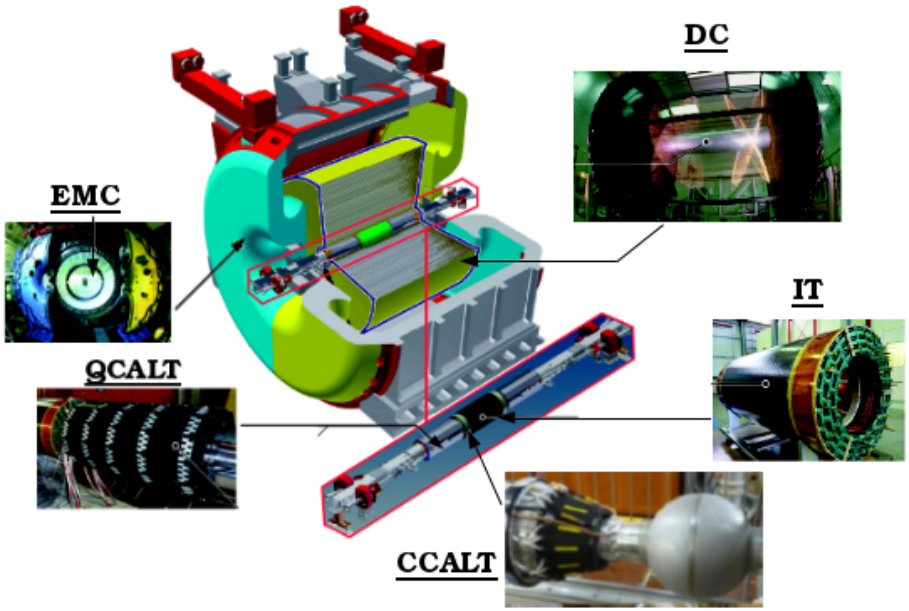
DC:

♦ **Gas mixture:** $90\%He + 10\%C_4H_{10}$

$\sigma_{xy} = 150\mu m; \sigma_z = 2mm$

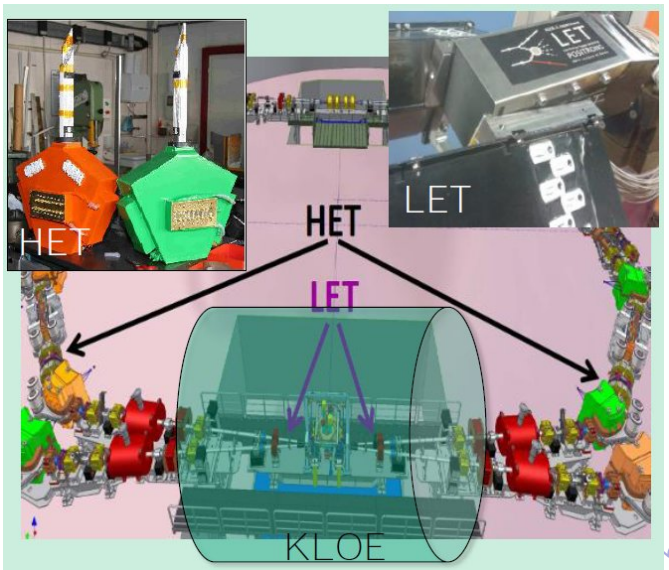
The KLOE-2 Detector

- INNER TRACKER:
  - 4 layers of cylindrical triple GEM
  - Better vertex reconstruction near IP
  - Larger acceptance for low p_t tracks
- CCALT:
  - LYSO + SiPM
  - Increase acceptance for γ from IP ($21^\circ \rightarrow 10^\circ$)
- QCALT:
  - W + scintillator tiles + WLS/SiPM



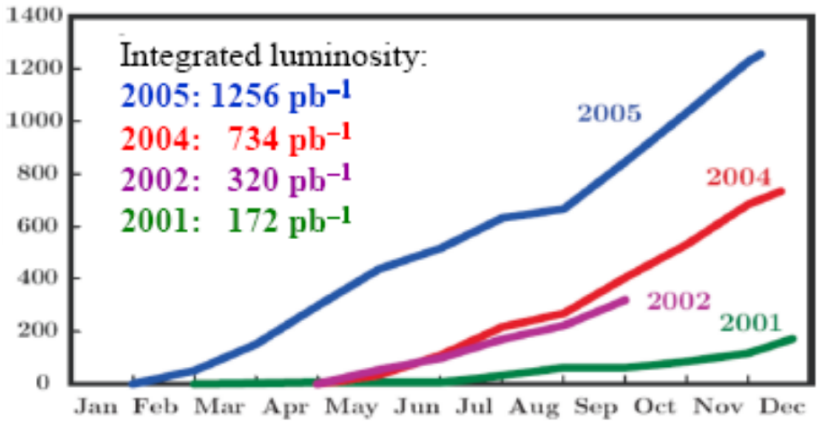
2+2 $\gamma\gamma$ KLOE-2 taggers

- LET : E=160-230 MeV
  - Inside KLOE detector
  - LYSO+SiPM
  - $\sigma_E < 10\%$ for $E > 150$ MeV
- HET : E $>$ 400 MeV
  - 11 m from IP
  - Scintillator hodoscopes
  - $\sigma_E \sim 2.5$ MeV
  - $\sigma_t \sim 500$ ps

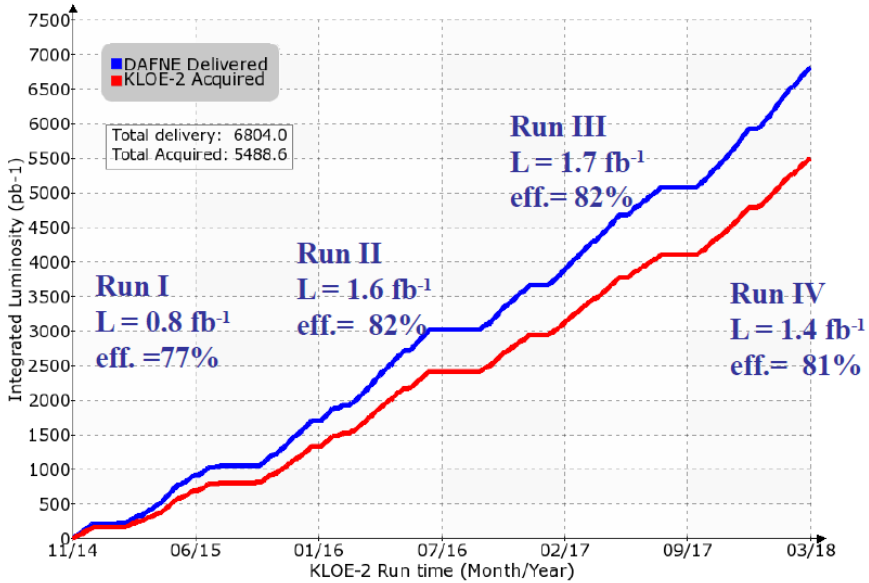


KLOE/KLOE-2 data sample

♣ KLOE Data Set:
- 2001-2005 data taking on peak ($\sqrt{s} \sim 1.02 GeV$), $2.5 fb^{-1}$
-2006 data taking off peak ($\sqrt{s} = 1.0 GeV$), $250 pb^{-1}$



♣ KLOE-2 Data Set:
- 2014-2018 data taking on peak ($\sqrt{s} \sim 1.02 GeV$), $5.5 fb^{-1}$



Total integrated luminosity of KLOE/KLOE-2 experiments $\sim 8 fb^{-1} \Rightarrow$ largest sample collected at the phi-meson mass with a collider ($\sim 2.4 \times 10^{10}$ Φ)

P,CP-violating process, $\eta \to \pi^+\pi^-$ decay

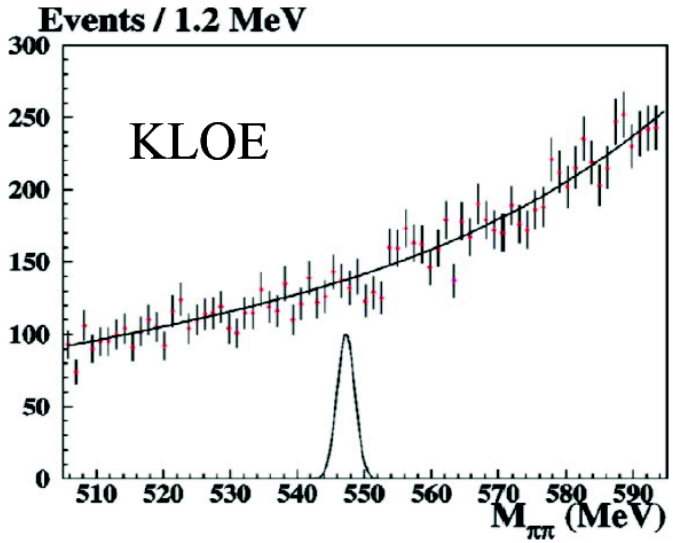
♣ In the Stardand Model the BR prediction [Phys. Scripta T99, 23 (2002)]:

- proceed only via the CP-violating in weak interaction $\to 10^{-27}$
- introducing a CP violating term in QCD $\to$ to 10^{-17}
- allowing CP violation in the extended Higgs sector $\to 10^{-15}$

The observation of larger branching ratio means new source of CP violation in the strong interaction.

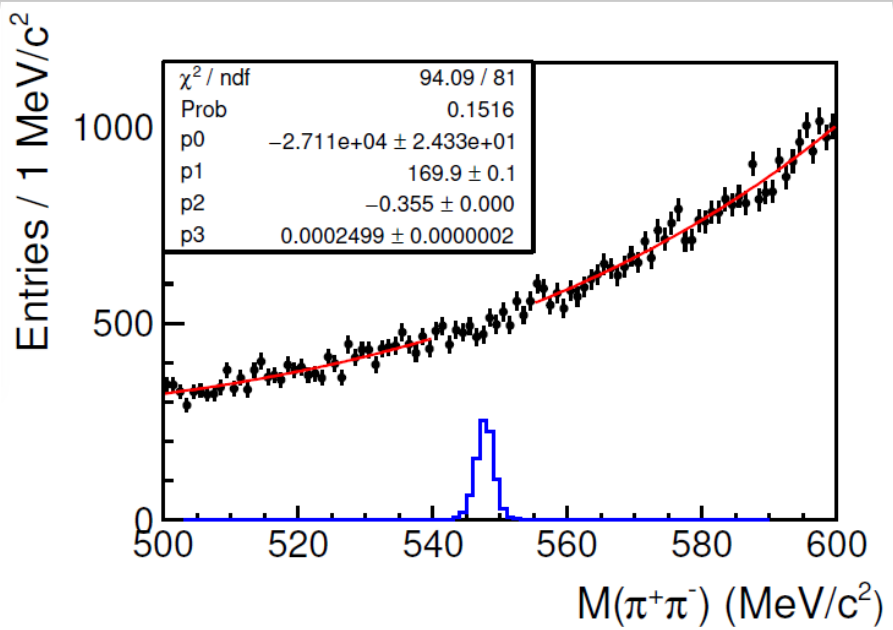
♣ The best limit 1.3×10^{-5} @90% C.L. by KLOE using a sample of$\sim$ 350 pb^{-1} [*PLB* 606 (2005) 276 – 280]

♣ Recent limit 1.6×10^{-5} @90% C.L. published by LHCb analyzing a data set of $\sim$ 3.3 fb^{-1} [*PLB* 764 (2017) 233]



P,CP-violating process, $\eta \to \pi^+\pi^-$ decay

♣ New search of $\eta \to \pi^+\pi^-$ decay based on an integrated luminosity of 1.6 fb^{-1} performed



- $\pi\pi\gamma$ background from continuum
- No event excess in the eta-meson mass region
- After all cuts, efficiency $\sim$ 14.7%

$\Rightarrow$

♣ BR($\eta \to \pi^+\pi^-$) $< 4.9 \times 10^{-6}$@ 90% C.L.

♣ **The combined upper limit with previous KLOE result is BR($\eta \to \pi^+\pi^-$) $< 4.4 \times 10^{-6}$@ 90% C.L. $\to$ submitted to JHEP (arXiv:2006.14710)**

The expected upper limit with the full KLOE/KLOE-2 statistics is 2.7×10^{-6}@ 90% C.L.

$\eta \to \pi^0\gamma\gamma$ analysis

♣ $\eta \to \pi^0\gamma\gamma$ decay discussed in the framework of SU(3) chiral perturbation theory

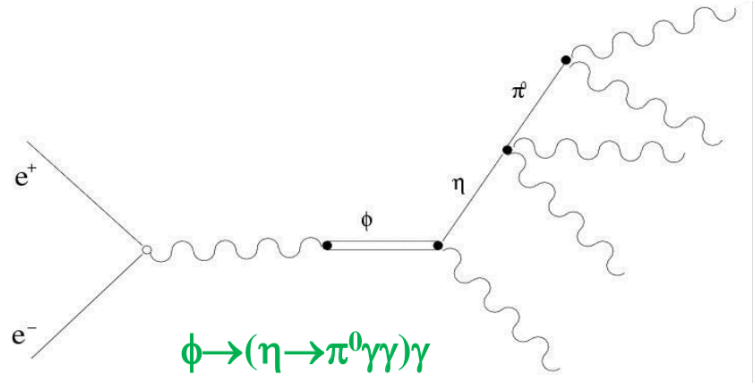
♣ Process dominated by the $O(p^6)$ in the momentum expansion

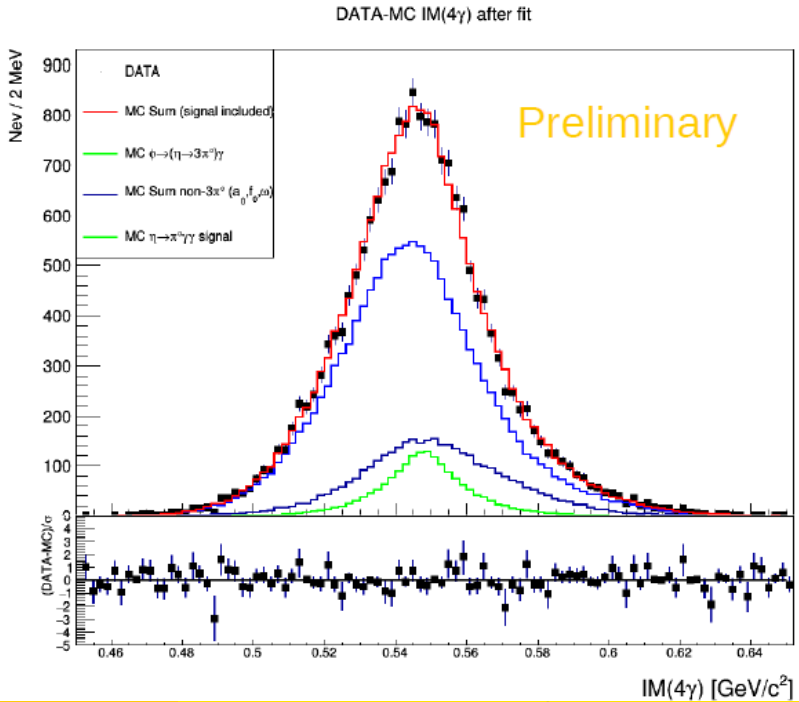
♣ Important discrepancy between the performed measurements:

-**BR=**$(22.1 \pm 2.4 \pm 4.7) \times 10^{-5}$ **CB@AGS**
[*PRC* 78 (2008) 015206]

-**BR=**$(25.2 \pm 2.5) \times 10^{-5}$ **CB@MAMI**
[*PRC* 90 (2014) 025206]

Old KLOE preliminary: $(8.4 \pm 2.7 \pm 1.4) \times 10^{-5}$
($L_{int} = 450 pb^{-1} \sim$ 70 signal events)





- **New KLOE analysis with a sample of $L_{int} = 1.7 fb^{-1} \to$ almost 4 times larger than the old KLOE preliminary**
- Background channels: $\phi \to \gamma a_0(\eta\pi^0)$, $\gamma f_0(\pi^0\pi^0)$, $e^+e^- \to \pi^0\omega(\gamma\pi^0)$,$\phi \to \gamma\eta(3\pi^0)$
- New TMVA-BDT implemented to reject the big amount of events from the $\eta \to 3\pi^0$ decay with lost or merged photons (∼50% rejected)

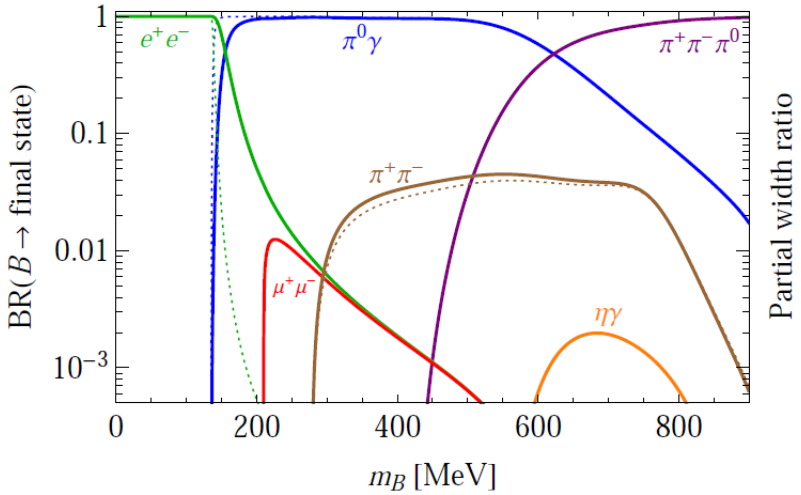
B boson Search

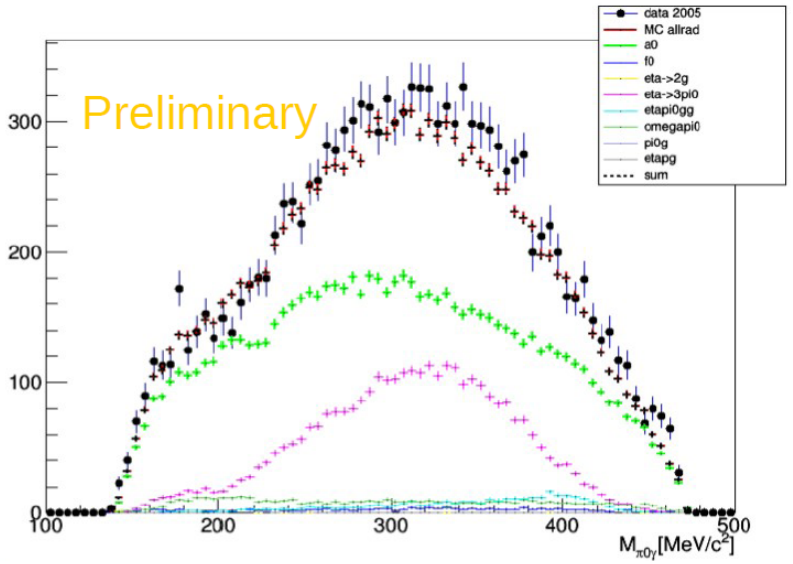
♣ Light meson decays for discovering new forces below the GeV scale
♣ The *B boson* $\rightarrow$ couples predominantly to quarks
♣ It may be observed in rare radiative decays of η,η',ω,ϕ mesons as a $\pi^0\gamma$ resonance

♣ $\phi \rightarrow \eta B$ **with** $B \rightarrow \pi^0\gamma$ **studied with KLOE** $L_{int} = 1.7 fb^{-1}$**:**

- selection of 5 prompt phtons
- main backgrounds: $\phi \rightarrow \gamma a_0(\eta\pi^0)$ and $\gamma\eta(3\pi^0)$ with lost or merged photons
- Kinematic fits to suppress backgrounds (ToF of 5γ, E&P conservation)
- signal efficiency $\sim 12.5\%$

[Tulin, PRD89(2014)114008]



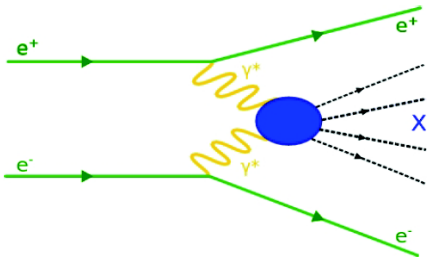


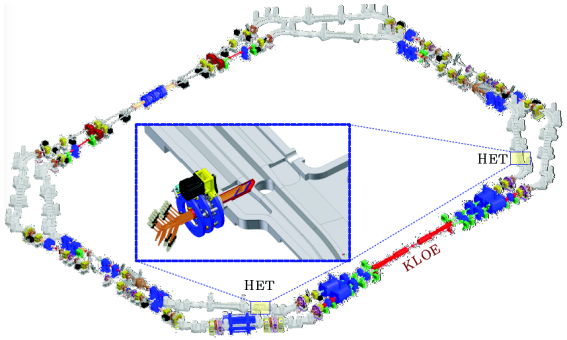
$\gamma\gamma$ physics with High Energy Tagger (HET)

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

for quasi real photon $J^{PC}(X)=\{0^{\pm,+}, 2^{\pm,+}\}$

$\to X = \{\pi^0, \pi\pi, \eta\}$

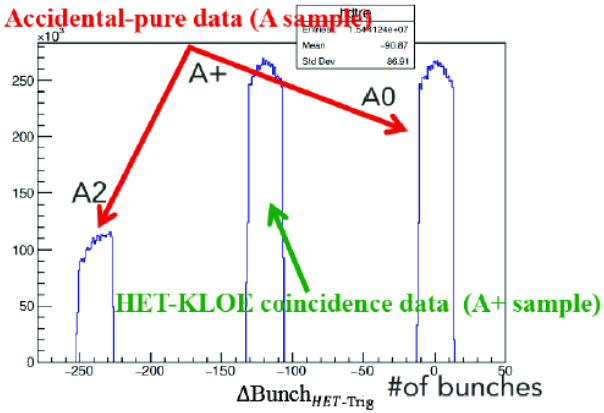




- Scintillator hodoscope + PMTs, inserted in Roman pot. pitch: 5 mm, $\sim$ 11 m from IP ($\sigma_E \sim 2.5$ MeV; $\sigma_t \sim 500$ ps)

♣ Precision measurement of $\Gamma_{(\pi^0\to\gamma\gamma)}$

♣ Impact on value and precison of $a_\mu^{LbL;\pi^0}$

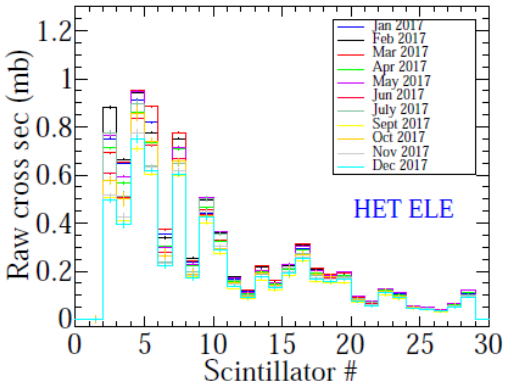


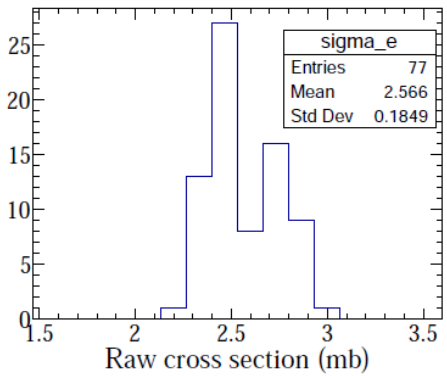
♣ Analysis strategy:

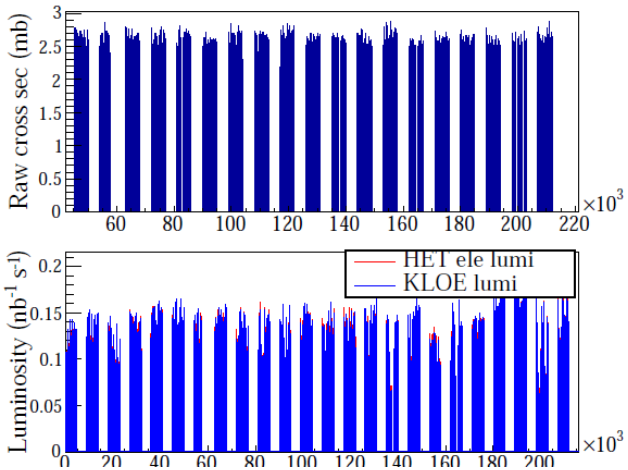
- Hits in one HET station and 2 clusters in KLOE originating from the same bunch crossing (A_+ sample)
- Evaluation of the uncorrelated HET-KLOE time coincidences (A sample)
- Number of π^0 tagged events from $\gamma\gamma$ fusion estracted from $(A_+ - A)$ sample.

Low angle radiative Bhabha cross section

♣ HET counting rate dominated by low-angle radiative Bhabha scattering

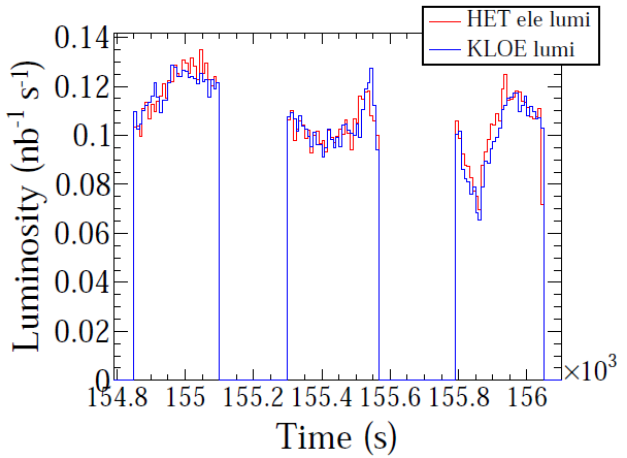






♣ σ_{BHA} useful to check HET detector operational stability and validate acceptance and efficiency of the detector by comparison with the BBREM simulation

♣ Only scintillators from 11 to 28 are used for π^0 search



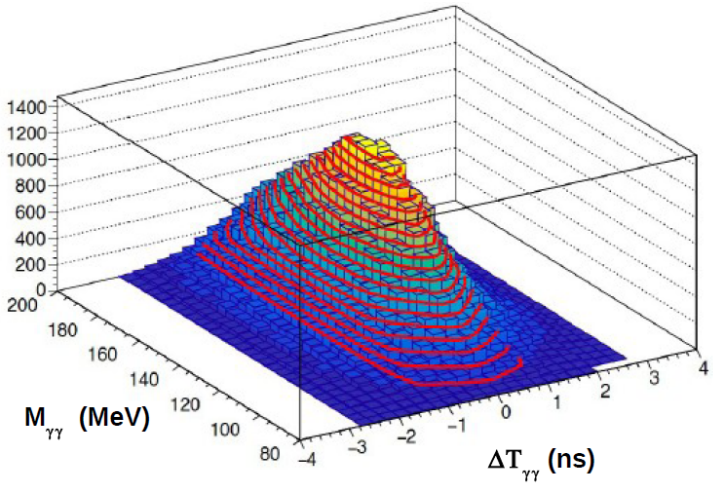
♣HET luminosity evaluated as:

$$L[nb^{-1}s^{-1}] = (Rate \times 10^3)/Trigrate \times \sigma[mb] \times 2 \times nbunch \times 2.712[ns]$$

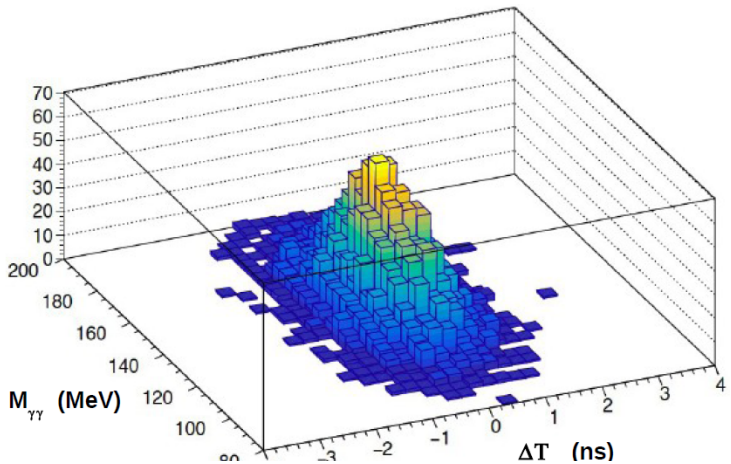
$\gamma^*\gamma^* \to \pi^0$ Search

♣ Comparison of A/A+ samples for 1fb^{-1} data set shows 3.5(0.7)k tagged events in the mass region where π^0 from fusion are expected

A+ sample , HET ele, 1fb^{-1}



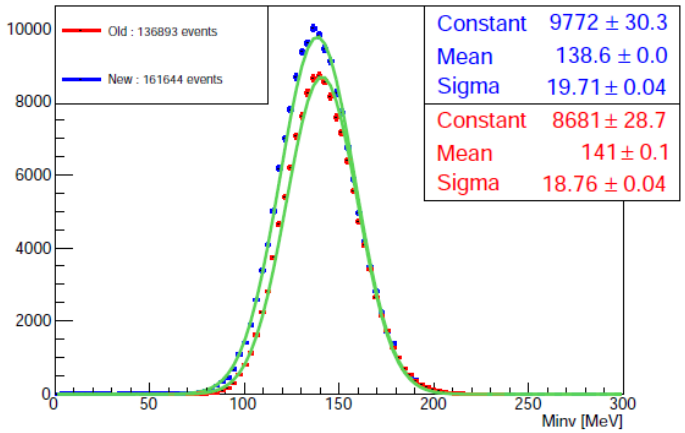
Amount of EKHARA signal events estimated with the fit for $\sigma_T = 500ps$



EkharaV3.0

♣ New signal modelling using outcome from up-to-date resolution and trigger threshold studies

♣ MVA analysis with accurate signal modelling crucial to improve precision and eventually estimate tagged events → ongoing on the full reconstructed data sample ($\sim$ 2.5fb^{-1})



Conclusions

♣ The KLOE/KLOE-2 data sample corresponds to $2.4 \times 10^{10} \phi$ mesons $\Rightarrow$ **Unprecedented statistics**

♣ The large data sample of light mesons available provided important results on decay dynamics together with limits on new physics: the most stringent UL on the $\eta \to \pi^+\pi^-$ decay has been presented together with the preliminary results on the B boson search, $\eta \to \pi^0\gamma\gamma$ decay and the progresses on the $\gamma^*\gamma^* \to \pi^0$ search

Thank you!!!