$\gamma - \gamma$ physics at KLOE-2

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Outline

1. Physics Motivation
2. KLOE-2@DAΦNE
   - DAΦNE: the ϕ factory
   - KLOE-2
3. $\gamma - \gamma$ physics at KLOE-2@DAΦNE
   - HET Detector Idea
   - Final leptons HET acceptance
   - DAQ
   - Physics signal simulation
4. Data Analysis
   - Radiative bhabha events : $e^+e^- \to e^+e^-\gamma$
   - $\gamma\gamma \to \pi^\circ$ events search
5. Conclusions

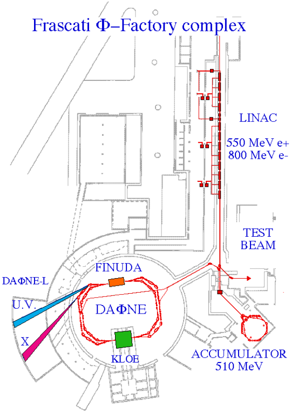
The $\pi^\circ \to \gamma\gamma$ width

- The QCD Green's function $\langle VVA \rangle$ exhibits the axial anomaly of Adler, Bell and Jackiw (non-conservation of the axial vector current), which is responsible for the decay $\pi^0 \to \gamma\gamma$.
- The anomaly is a pure one-loop effect (triangle diagram).
- Link between the strong dynamics of infrared physics at low energies (pions) with the perturbative description in terms of quarks and gluons at high energies.
- Due to the recent theoretical advances, the decay width $\Gamma_{\pi^0 \to \gamma\gamma}$ is now predicted with a 1.4% accuracy:

$$\Gamma^{\text{theor}}_{\pi^0 \to \gamma\gamma} = 8.09 \pm 0.11 \text{ eV}. \quad (1)$$

- The major experimental information on this decay comes from the photo-production of pions on a nuclear target via the Primakoff effect.

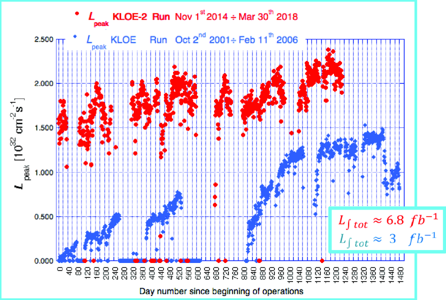
DAΦNE: the ϕ factory



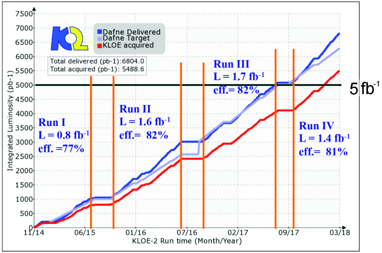
New interaction region:

- Large beam crossing angle : 2 x 12.5 mrad.
- Sextupoles for crabbed waist optics : 59% increase in terms of peak luminosity.

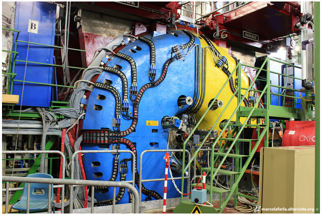
- e^+e^- collider @ $\sqrt{s} = M_\Phi = 1019.4$ MeV
- 2 interaction regions and 2 separate rings
- 105 + 105 bunches, $T_{RF} = 2.7$ ns
- Best Performance (1999–2006): $\mathcal{L}_{\text{peak}} = 1.5 \times 10^{32}$ cm^{-2} s^{-1}
- Best Performance (2014–2018): $\mathcal{L}_{\text{peak}} = 2.4 \times 10^{32}$ cm^{-2} s^{-1}



KLOE-2



The KLOE-2 data taking campaign started on November 2014



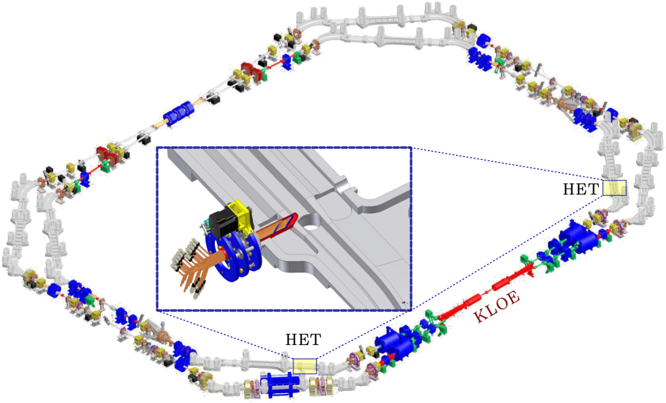
KLOE-2 experiment ended on March 30$^{\text{th}}$ 2018:

- $\mathcal{L}_{\text{delivered}} = 6.8\ \text{fb}^{-1}$.
- $\mathcal{L}_{\text{acquired}} = 5.5\ \text{fb}^{-1}$.
- KLOE + KLOE-2 data sample: $\mathcal{L}_{int} = 8\ fb^{-1} \rightarrow 2.4 \times 10^{10}$ ϕ mesons produced, the largest sample ever collected at the $\phi(1020)$ peak in collider experiments.

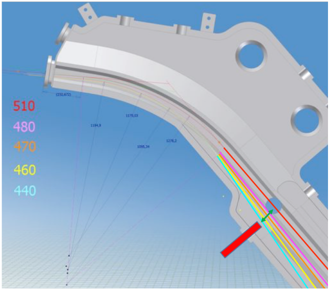
The KLOE-2 sub-detectors

HET Detector Idea

- $e^+_{in} e^-_{in} \rightarrow e^+_{fin} e^-_{fin} \gamma\gamma \rightarrow e^+_{fin} e^-_{fin} X$.
- $e^+_{fin} e^-_{fin}$ detected by HETs.
- $X = (\pi^\circ, \ \pi\pi$ or $\eta)$ detected by KLOE.



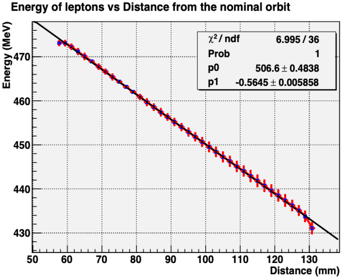
Final leptons HET acceptance



Simulation is based on BDSIM (arxiv 1808.10745) a GEANT4 toolkit

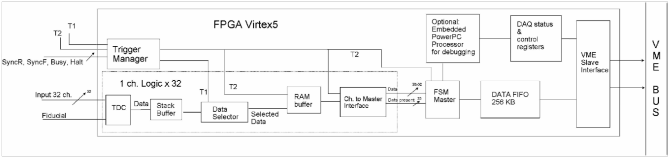
- HET tagged energy cover range between 430 MeV and 480 MeV for scattered leptons.
- Two photons cover the range from 60 up 160 MeV which overlap. with the π° at rest

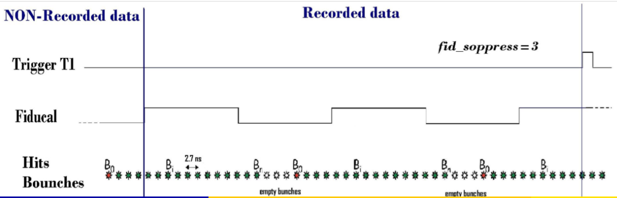
- The energy resolution is of the order of 500 KeV/mm.
- Time resolution should be less than 2.7 ns (DAFΦNE interbunch separation) in order to distinguish two consecutive bunch-cross.
- 28 plastic scintillator of 5 mm pitch should be the optimal solution.



DAQ

- Usually DAΦNE is filled with 100+X bunches over 120.
- We use the "Fiducial", a signal provided by DAΦNE (in phase with respect to the first bunch circulating in DAΦNE) as TDC common start.
- The HET DAQ could stores information corresponding to $n = 1, \cdots, 8$ turns of DAΦNE when KLOE provides the trigger (T_1 and T_2).
- The two DAQ systems (HET and KLOE) are asynchronous.

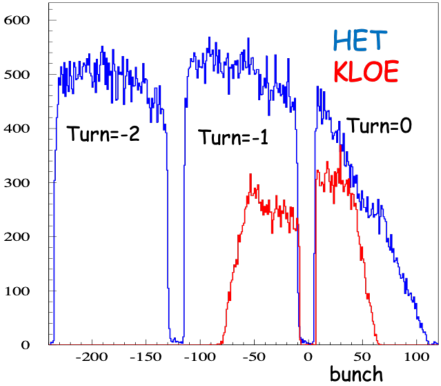




HET and KLOE time synchronization

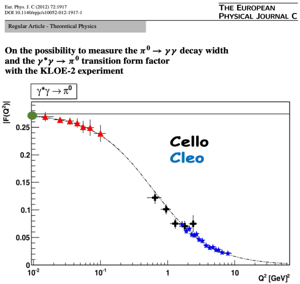
We can define

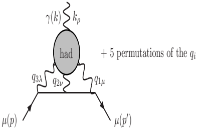
- **IN events** : the events in the overlapping (KLOE-HET) time window.
- **OUT events** : the events outside the overlapping (KLOE-HET) time window.



Physics signal simulation simulation: $\mathcal{L}_{int} = 5\ \text{fb}^{-1}$

- Simulation of the signal is based on `Ekhara V2.1`: Comput.Phys.Commun. **182** (2011) 1338-1349 + `BDSIM` for final leptons tracking from IP to HET.
- HETs cross section for $e^+e^- \to e^+e^-\pi^\circ$: $\sigma_H \simeq 8$ pb, $\sigma_{HH} \simeq 2$ pb.
- **Our physic goal #1:** $\Gamma_{\pi^0 \to \gamma\gamma}$ at 1 % level (green point).
- **Our physic goal #2:** first measure of the $\mathcal{F}_{\pi^0\gamma^*\gamma}(Q^2)$ at $Q^2_{\gamma^*} \leq 0.1$ GeV^2 (red points).
- **Our physic goal #3:** have impact on $a_\mu^{\mathrm{HLbL};\pi^0}$ (red numbers).

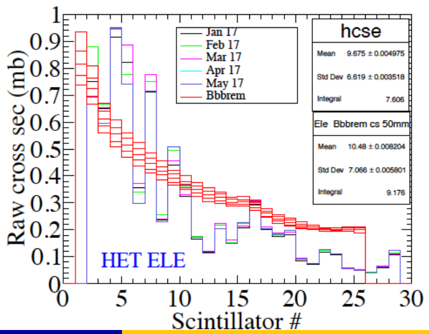




Model	Data	$\chi^2/d.o.f.$	$a_\mu^{\mathrm{LbyL};\pi} \times 10^{11}$
VMD	A0	6.6/19	$(57.2 \pm 4.0)_{JN}$
VMD	A1	6.6/19	$(57.7 \pm 2.1)_{JN}$
VMD	A2	7.5/27	$(57.3 \pm 1.1)_{JN}$
LMD+V, $h_1 = 0$	A0	6.5/19	$(72.3 \pm 3.5)_{JN}$ * $(79.8 \pm 4.2)_{MV}$
LMD+V, $h_1 = 0$	A1	6.6/19	$(73.0 \pm 1.7)_{JN}$ * $(80.5 \pm 2.0)_{MV}$
LMD+V, $h_1 = 0$	A2	7.5/27	$(72.5 \pm 0.8)_{JN}$ * $(80.0 \pm 0.8)_{MV}$
LMD+V, $h_1 \neq 0$	A0	6.5/18	$(72.4 \pm 3.8)_{JN}$ *
LMD+V, $h_1 \neq 0$	A1	6.5/18	$(72.9 \pm 2.1)_{JN}$ *
LMD+V, $h_1 \neq 0$	A2	7.5/26	$(72.4 \pm 1.5)_{JN}$ *
LMD+V, $h_1 \neq 0$	B0	18/35	$(71.9 \pm 3.4)_{JN}$ *
LMD+V, $h_1 \neq 0$	B1	18/35	$(72.4 \pm 1.6)_{JN}$ *
LMD+V, $h_1 \neq 0$	B2	19/43	$(71.8 \pm 0.7)_{JN}$ *

Radiative bhabha events: $e^+e^- \to e^+e^-\gamma$

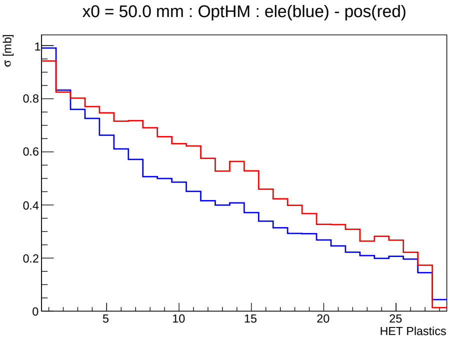
- Using the luminosity measured by KLOE we can measure the radiative bhabha cross section at very forward angle (seen by HETs).
- HETs acceptance is provided by the simulation which is based on BBBREM: Comp.Phys.Com. **81**, (1994), 372 + BDSIM for final leptons tracking from IP to HET.
- $\sigma_{e^+} \simeq 10.5$ mb, $\sigma_{e^-} \simeq 7.1$ mb.
- **From the comparison of data and simulation we could measure** $(A \times \varepsilon)_{HET}$



Radiative bhabha cross section asymmetry

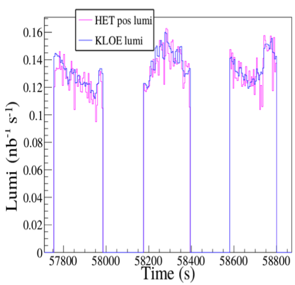
Asimmetry on radiative bhabha cross section $\sigma_{e^+} \simeq 10.5$ mb, $\sigma_{e^-} \simeq 7.1$ mb.

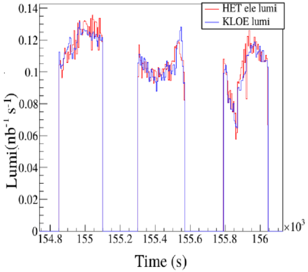
- The DAΦNE electron and positron machines are not perfectly symmetric.
- Could be an effect of the IP z coordinate displacement w.r.t z=0?



Data Quality

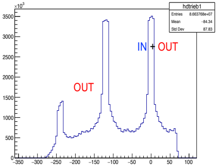
- Knowing $(A \times \varepsilon)_{HET}$ and radiative bhabha's cross section we can compare luminosity measured by HETs and KLOE.
- We have stable data (over years) for HETs plastics $11 \to 28$.
- The HET plastics $1 \to 10$ are dominated by Touschek particles, which strongly depend on the DAFΦNE running condition.
- **Using this procedure we can select good runs.**

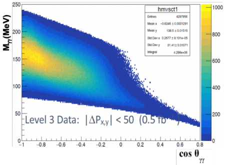


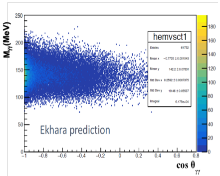


$\gamma\gamma \to \pi^\circ$ events search

- 500 pb^{-1} of 2017 data are ricostructed.
- Double Arm
  - hits in both HET stations with $|\Delta T|$ within 4 DAFΦNE bunches.
- Single Arm
  - hits in one HET station and at least one bunch in KLOE associated with only 2 neutral clusters in the EMC.
  - KLOE and HET bunch times compatible with Trigger signal.
  - DAΦNE turn is not considered, the control sample stored as well $\to$ event by event subtraction of accidentals.
- $|\Delta P_{x,y}|_{\gamma\gamma} < 50$ MeV.

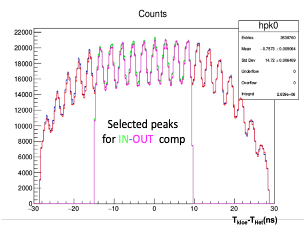


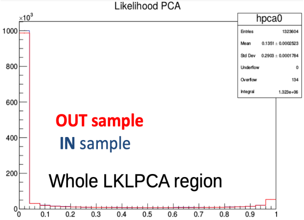


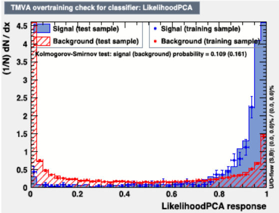


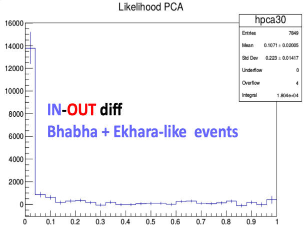
MVA

- We have to subtract IN and OUT events in the same time window.
- Multivariate analysis helpful to separate signal (Ekhara-like) from radiative Bhabha's events.



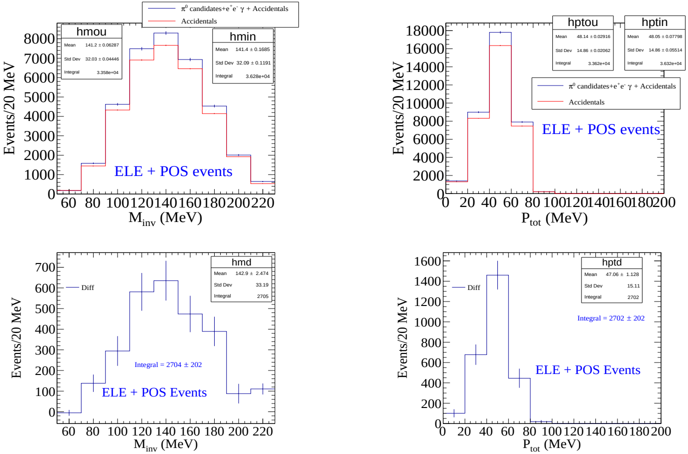






Control Sample

Some kinematical variables are used to validate the analysis procedure



Conclusions

- All triggers in 500 (330) pb^{-1} with 2-clusters and HET selected channels (showing operational stability) have been studied.
- Statistical evidence of a tagged sample has been obtained on the electron side.
- More reconstructed data are needed to confirm the effect with the positron-side (futher data quality studies ongoing).
- The tagged sample consists of radiative Bhabha's with photons in KLOE and π°'s from $\gamma - \gamma$ scattering
- MVA classifiers used to separates the two samples.