The KLOE-2 e^+e^- tagging for two-photon physics

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on behalf of the KLOE-2 Collaboration

Instrumentation for Colliding Beam Physics

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DAΦNE and KLOE-2 Experiment

$\gamma\gamma$ Physics at KLOE-2

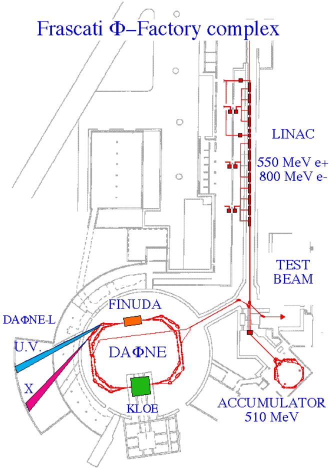
The HET Detector

Performance of the HET detector

Low angle Bhabha cross section

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

DAΦNE: THE Φ-FACTORY



e^+e^- collider @ $\sqrt{s} = M_\Phi = 1.0194$ GeV

2 interaction regions

2 separate rings

105 +105 bunches, $T_{RF} = 2.7$ ns

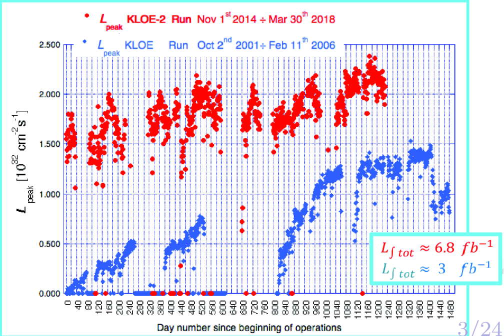
Injection during data taking

Crossing angle: 2×12.5 mrad

Best Performance (1999–2006):
$L_{\text{peak}} = 1.5 \times 10^{32}$ cm^{-2} s^{-1}

Best Performance (2014–2018):

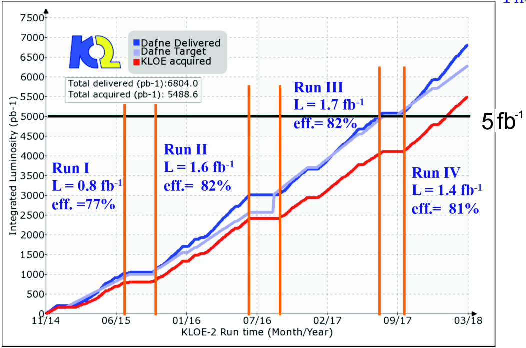
$L_{\text{peak}} = 2.4 \times 10^{32}$ cm^{-2} s^{-1}



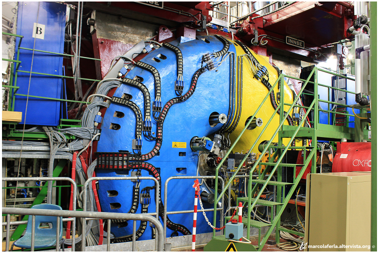
DAΦNE UPGRADES

New interaction region: large beam crossing angle + sextupoles for crabbed waist optics → 59% increase in terms of peak luminosity

THE KLOE-2 EXPERIMENT



The KLOE detector has been rolled out from the IR after almost 20 years of operation



The KLOE-2 sub-detectors

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

$$\int L_{\text{delivered}} = 6.8\ \text{fb}^{-1}$$

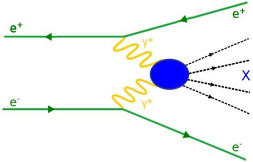
$$\int L_{\text{acquired}} = 5.5\ \text{fb}^{-1}$$

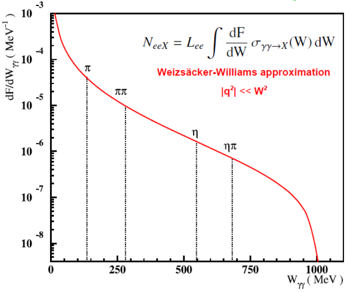
KLOE + KLOE-2 data sample:
8 $\text{fb}^{-1} \rightarrow 2.4 \times 10^{10}$ ϕ mesons produced, the largest sample ever collected at the $\phi(1020)$ peak in collider experiments

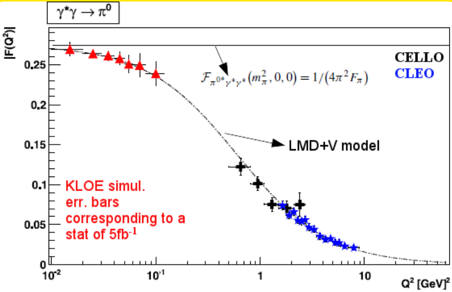
$\gamma\gamma$ Physics at KLOE-2 : Motivations

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

for quasi-real photons $J^{PC}(X) = \{0^{\pm,+}, 2^{\pm,+}\}$
$\to X = \{\pi^0,\ \pi\pi,\ \eta\}$

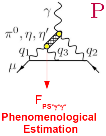






Physics goal:

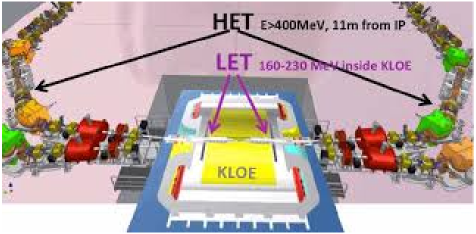
- ⋆ Precision measurement (1%) of the $\Gamma_{\pi^0\to\gamma\gamma}$
  $\Gamma^{Th.}_{\pi^0\to\gamma\gamma} = 8.09 \pm 0.11$eV (1.4% precision)
  $\Gamma^{Exp}_{\pi^0\to\gamma\gamma} = 7.82 \pm 0.22$ (2.8% precision, via Primakoff Effect, most precise measurement);
- ⋆ First measurements of the $F_{\pi^0\gamma^\star\gamma}(q^2, 0)$ in the space-like region for $q^2 < 0.1\,\mathrm{GeV}^2$



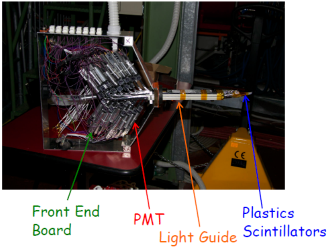
Physics motivation:
impact on the value and precision of the $a_\mu^{\mathrm{LbyL};\pi^0}$

The HET Detector

The HET stations are located 11m away the IP after the bending dipoles acting like spectrometer position detector

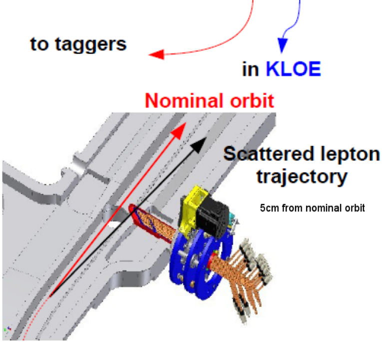


28 plastic scintillators (5x6x3 mm^3) inserted in roman pots with 1^{st} plastic at about 5 cm from the beam
1 Long Plastic for coincidence



$\sigma_\theta \sim 2,5\text{mrad},\ \sigma_r \sim 5\text{mm},\ \sigma_t \sim 500(1)\text{ps}$

$$e^+ e^- \to e^+ e^- \gamma^* \gamma^* \to \boxed{e^+ e^-} \boxed{X}$$



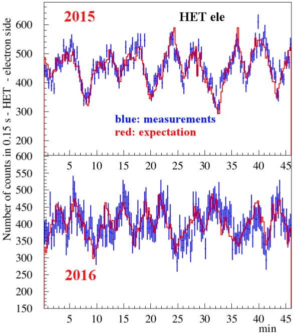
Energy acceptance $\sim$ 430–480 MeV
Angular acceptance $0^\circ \div 1.5^\circ$

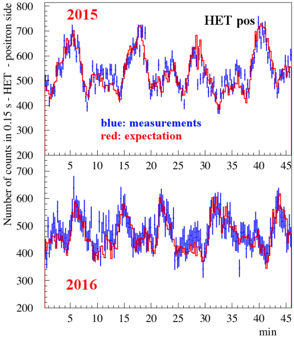
Performance of the HET detector

HET Rates are dominated by single-arm Bhabha's as observed in normal and dedicated runs

$$R_{\mathrm{HET}} = R_{\mathrm{trig}}(\alpha_{\mathrm{L_{e,p}}}\mathrm{L} + \beta_{\mathrm{e,p}}\mathrm{I}^2_{\mathrm{e,p}})$$

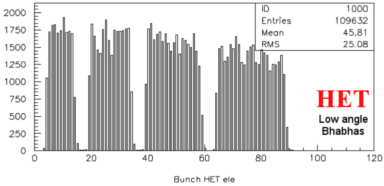
Normal run: the rate timeline strictly follows the luminosity timeline as measured by the KLOE central detector

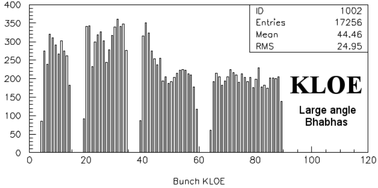




Luminometer detector: fast and reliable feedbacks on the machine operation

Run with special DAΦNE bunch pattern, both beams circulating in the machine at the same time. Holes correspond to 5 empty bunches between the filled ones.



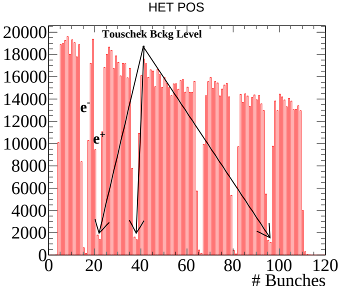


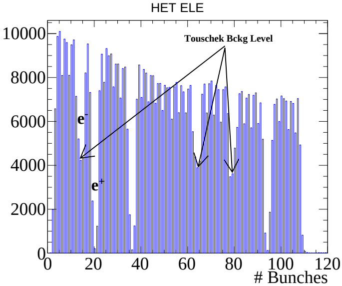
The HET hit time structure closely reproduce DAΦNE bunch structure.

The HET detector is noiseless → hit rate with no circulating beams is negligible.

The matching of the DAΦNE bunch structure seen by KLOE and HET used to synchronize the two detectors.

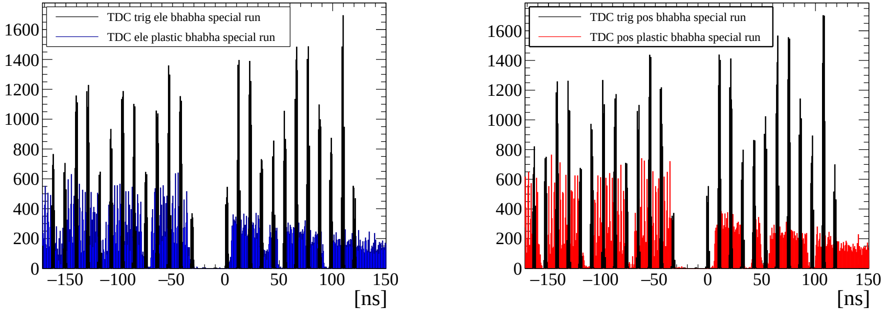
Run with special DAΦNE bunch pattern with bunches not filled, alternatively, on the electron and the positron machine.





Trigger TDCs rate compared with plastic TDCs rate for the run with a special DAΦNE bunch pattern

LA Bhabha control sample



Clearly visible the correlation between KLOE trigger and plastic rates for a physics sample

Low angle Bhabha cross section

Method:

- Clusterization of the detector response within 20 ns
- Masurement peformed per second and per bunch, on different run periods
- Online luminosity measured by KLOE used to obtain $\sigma \times A \times \varepsilon$ raw cross sections per channel

Stability of the measurements:

- HET channels closest to the beams present a completely anomalous behavior with stability over time-scale of few hours
- Rates from HET ele (pos) channels 11(18) are stable over time-scale of months/year

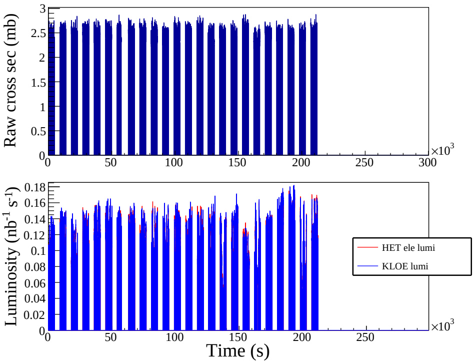
Stable HET channels used to measure $\mathcal{L}$ pattern and perform π^0 analysis

Bbbrem code (small-angle Bhabha) interfaced with GEANT4 simulation of the lepton transport within DAFNE magnetic layout used to obtain and cross-check the detector acceptance $\times$ efficiency

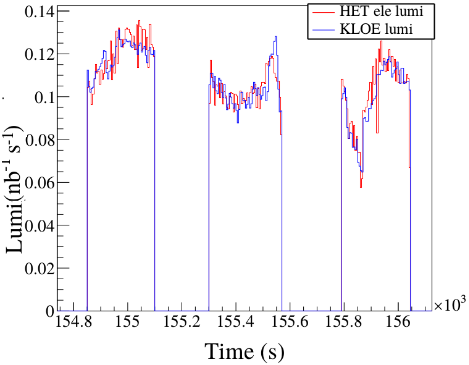
Low angle Bhabha cross section

2017 data, HET ele, plast ≥ 11

Stability of raw cross section per second (up) lumi timeline (bottom)



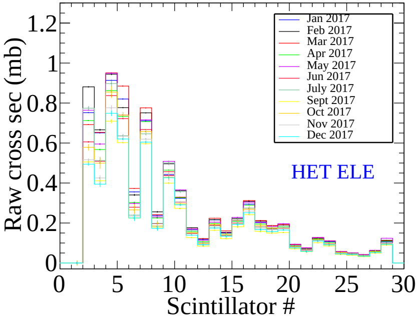
Luminosity pattern measured by HET and KLOE



$$\mathcal{L}\,[\mathrm{nb}^{-1}\mathrm{s}^{-1}] = (\mathrm{Rate} \times 10^3)/(\mathrm{Trigrate} \times \sigma[\mathrm{mb}] \times 2 \times 120 \times 2.712[\mathrm{ns}])$$

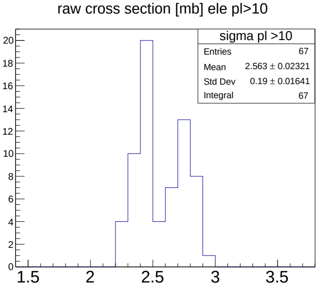
LOW ANGLE BHABHA CROSS SECTION

σ_{Bhabha} per channel, all plastics



Integrated σ_{Bhabha} distribution for plast ≥ 11 obtained using some runs acquired during the whole 2017

$\sigma_{\mathrm{Bhabha}} = 2.56\,\mathrm{mb}$, std dev is $\sim 7\%$



Cross section fluctuations Vs time are correlated with detector efficiency and/or discriminator threshold variations (under study)

Only plastics ≥ 11 are used for π^0 search

Bbbrem validation in progress

Status of π^0 Search

$1.5\ \mathrm{fb}^{-1}$ of KLOE-2 data reconstructed (full 2017-2018 KLOE-2 sample)

$0.5/1.5\ \mathrm{fb}^{-1}$ of data have been analyzed

Two tagged samples established with the analysis of 18/28 HET stable channels in the electron-side :

- Bhabha scattering events with photons in KLOE
- π^0 candidates from $\gamma\gamma$ scattering

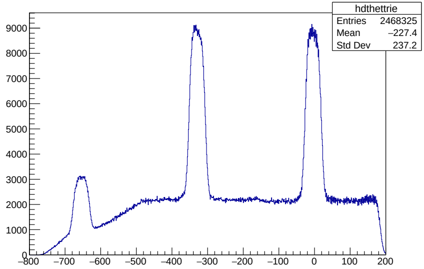
Multivariate analysis to separate the two samples

Some issues in the TDC decoding and HET-KLOE synchronization have been found and fixed

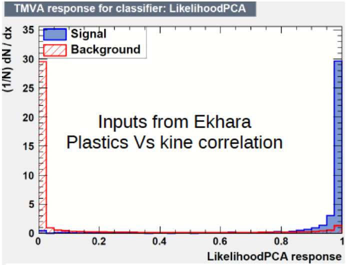
$e^+e^- \to \pi^0 e^+e^-$ simulation based on EKHARA generator (Comp.Phys.Com 182 (2011), 1338)

Tracking of the final state leptons from IP to HET position based on BDISM (arxiv 1808.10745) a Geant4 toolkit

Analysis Criteria



Delay between HET hits and Trigger [ns]



The analysis cannot be based only on HET-KLOE time coincidences, accidentals must be subtracted (affecting precision achievable in the measurement)

Double arm selection:

Time coincidence between the two stations within 12 ns

Single Arm selection:

Sample of 2 clusters associated with the same bunch crossing in the KLOE barrel calorimeter (50MeV Vs 100 MeV trigger threshold in the endcaps), trigger efficiency for 70 MeV γ about 80%

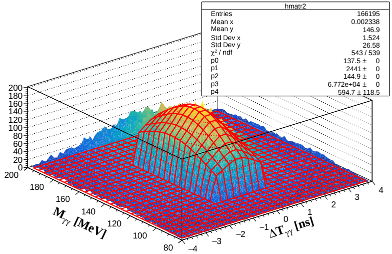
selected bunch crossing, and, independently selected HET signal, are in a time window of 30 ns around the KLOE trigger

very loose kinematic cuts

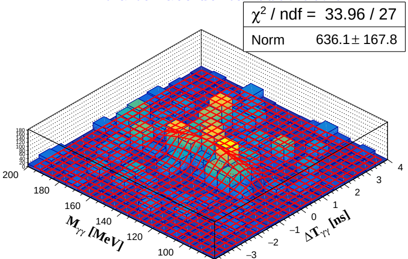
MVA: several training performed, with very basic MVA classifier and with plastics Vs kinematic correlations

Tagged Sample : Preliminary

2D-fit of signal + accidental data sample, all parameters are fixed but signal normalization. Background function is determined by the fit of the accidental-pure sample. Signal resolution parameters fixed to: $\sigma_{M_{\gamma\gamma}}$=20 MeV, $\sigma_{\Delta T_{\gamma\gamma}}$=400 ps



2D-fit after accidental subtraction



Evidence of tagged events established with the analysis of 500 pb^{-1} of reconstructed data

Amount of accidental coincidences still too high, it is mandatory to reduce it in order to perform a precise measurement

Some issues affecting energy resolution, accidental amount evaluation and HET-KLOE synchronization have been found and fixed

Currently, we are reprocessing all reconstructed data using optimized calibration constants for the calorimeter cluster energy and time in order to improve as much as possible our energy and time resolutions

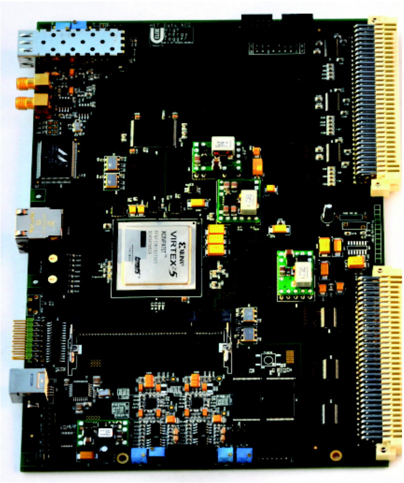
Conclusions

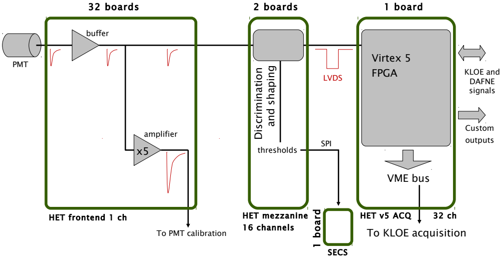
- ⋆ HET stations are noiseless with timeline counting rate showing only two visible contributions : from luminosity and from Touschek particles.
- ⋆ The total rate, dominated by very low angle Bhabha scattering events, is at the level of 500-600 kHz.
- ⋆ The low angle Bhabha cross section measurement has been performed with HET data. The validation of the BBBREM generator, to extract $A \times \varepsilon$ of the detector, is in progress.
- ⋆ The performance of the HET, and its fast and reliable feedbacks on machine operation, makes this detector a luminometer as well.
- ⋆ 500 pb^{-1} have been analyzed: a statistical evidence of tagged events has been obtained with 18/28 stable HET channels, on the electron side.
- ⋆ Accidental amount must be reduced to perform a precise measurement.
- ⋆ Some issues affecting the analysis have been found and fixed.
- ⋆ We are reprocessing data using optimized calibration constants for the calorimeter cluster energy and time in order to improve our energy and time resolutions.

Thank You!

SPARES

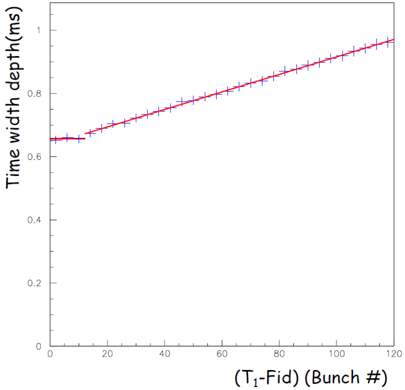
The HET DAQ



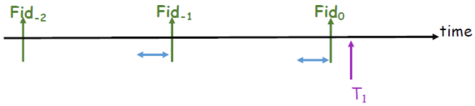


- ⋆ Discriminator provides output signal with a width of ∼2 ns → possibility to discriminate 2 consecutive bunches in DAΦNE ($\Delta T_{\text{bunch}} =$ 2.7 ns)
- ⋆ TDCV5 uses custom logic in order to manage signals from HET-DAΦNE and KLOE
- ⋆ KLOE and HET acquisition systems are asynchronous: we use the Fiducial provided by DAΦNE (radio-frequency signal) which is in phase with respect to the first bunch circulating in DAΦNE
- ⋆ The HET do not provide trigger to KLOE
- ⋆ We read the history of the HET in turn of DAΦNE only when a valid KLOE trigger (T_1) is asserted

The HET DAQ

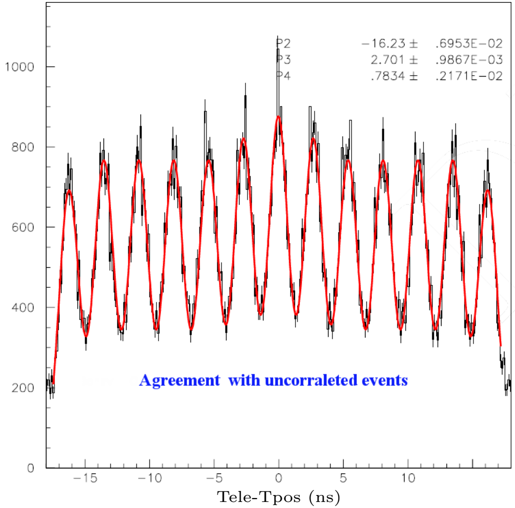


- ⋆ HET data acquisition system has been designed to register hits from two complete machine turns plus the part of a third turn preceding the trigger signal from KLOE
- ⋆ The time-depth for the HET data recording has been measured as a function of the delay between KLOE trigger and the Fiducial and ranges from 660 to 970 ns



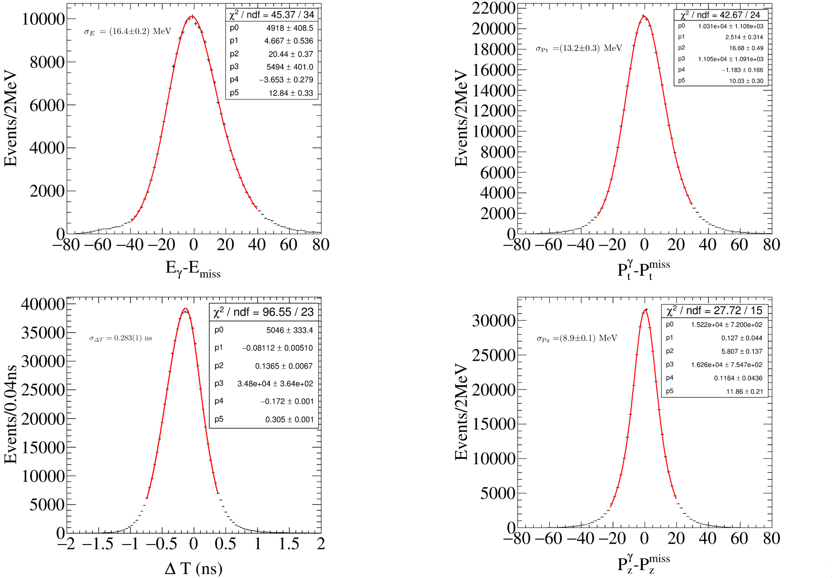
Time resolution of the HET detector

Hit delay distribution between HET ele-pos
Fit performed with 13 Gaussian of same σ



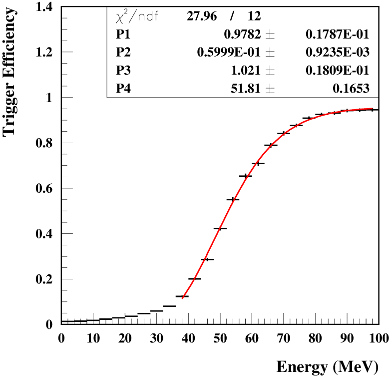
Time resolution is σ_t=550(1)ps
Time offset between stations of 24±10 ps

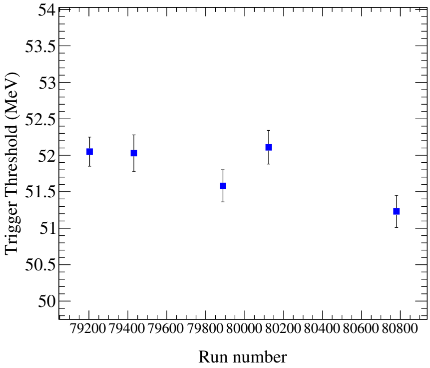
Energy, momenta and time resolutions on 70 MeV energy photons. The study was performed by means of a control sample of radiative Bhabhas



Trigger efficiency

Study based on a control sample of radiative Bhabhas

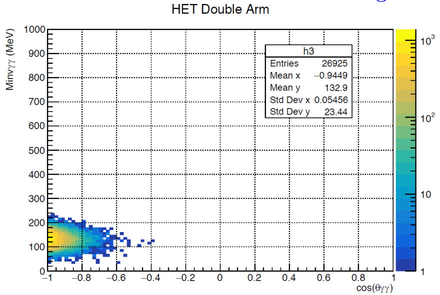


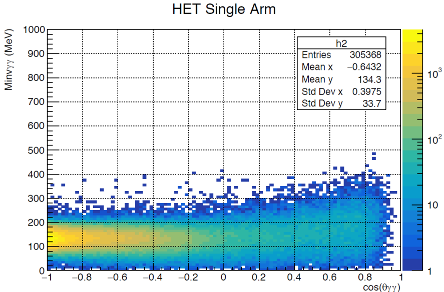


Trigger efficiency on 70 MeV energy photons is of about 80%

Stability of the trigger threshold over the running period November 2015–January 2016

Simulated Invariant mass Vs $\cos\theta_{\gamma\gamma}$ distributions for Double-Arm (DA) and Single-Arm (SA) events





Full Simulation:

Ekhara 2.1* for the signal : $e^+e^- \rightarrow e^+e^-\pi^0$
+ Bdsim for beam transport along the machine lattice
+ Kloe resolution on 70 MeV energy photons
+ trigger efficiency on 70 MeV energy photon ($\sim 80\%$)

Effective cross sections:

$\sigma_{\rm tot} = 283.7$ pb $\sigma_{\rm KLOE} = 41$ pb $\sigma_{\rm SA} = 7$ pb $\sigma_{\rm DA} = 2$ pb

* Computer Physics Comunications 182 (2011) 1338-1349