The KLOE-2 High Energy Taggers

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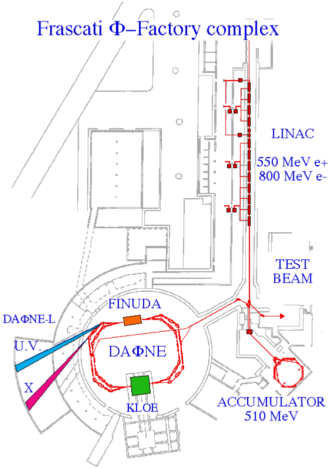
on behalf of the KLOE-2 Collaboration

Super c-tau factory workshop
Novosibirsk
26-05-2018

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}

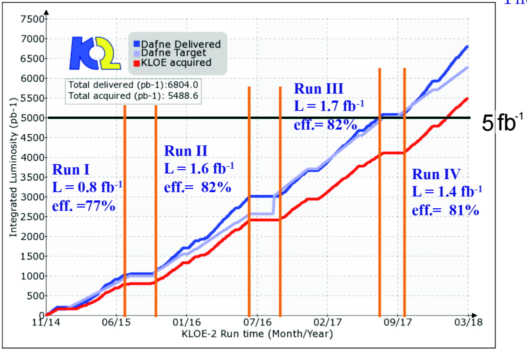
Best Performance (2014–2018):

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

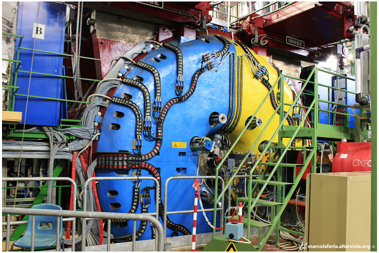
DAΦNE upgrades

New interaction region: large beam crossing angle + sextupoles for crabbed waist optics → Increase of peak luminosity by a factor 1,6

The KLOE-2 Experiment



The KLOE detector is being rolling out from the IR after almost 20 years of operation



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

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

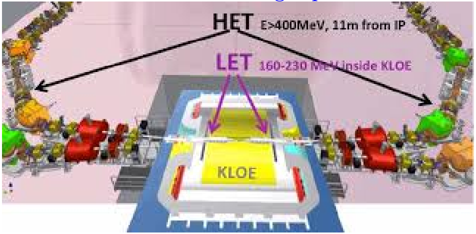
$$\int L_{\text{acquired}} = 5.5\ \text{fb}^{-1}$$

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

The KLOE-2 sub-detectors

The HET Detector

The HET stations are located 11m away the IP after the bending dipoles

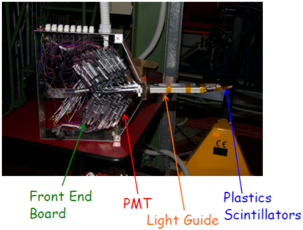


The EJ-228 plastic scintillators are inserted in roman pots: 28 of 5x6x3 mm^3

1 Long Plastic for coincidence

HAMATSU PMT R9880U-110 SEL

Quantum efficiency $\sim 35\%$



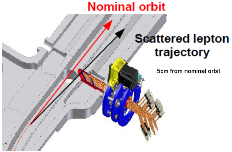
Leptons are tracked along machine optics with BDSIM package (GEANT4 appl.), MC validation in progress: BBBrem for low angle Bhabha's, Ekhara for $\gamma\gamma \to \pi^0$ events

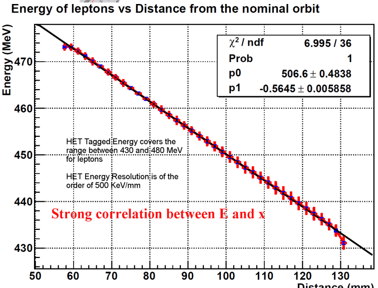
$$\sigma_\theta \sim 2,5\mathrm{mrad}, \ \sigma_r \sim 5\mathrm{mm}$$

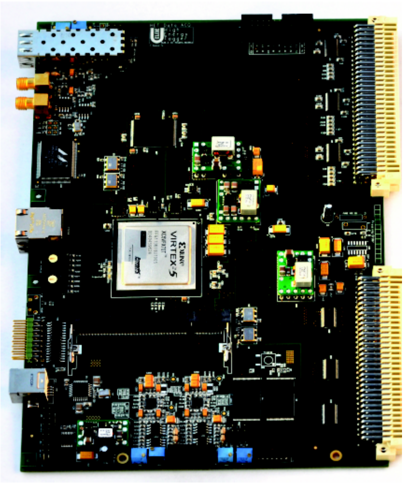
$$e^+ e^- \to e^+ e^- \gamma^* \gamma^* \to \boxed{e^+ e^-} \boxed{X}$$

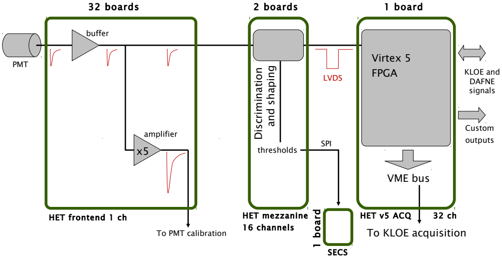
to taggers

in KLOE



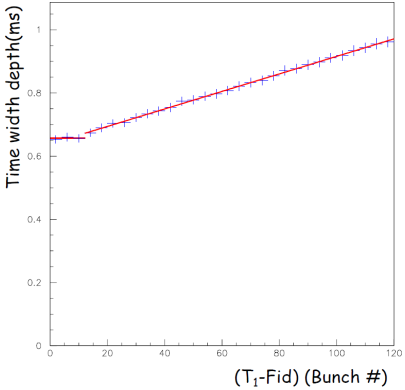


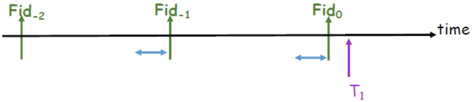




- ⋆ Discriminator provides output signal with a width of ∼2 ns → possibility to discriminate 2 consecutive bunches in DAΦNE ($\Delta T_{\text{bunch}} = 2.7$ ns)
- ⋆ TDCV5 uses custom logic in order to manage signals from HET, DAΦNE and KLOE

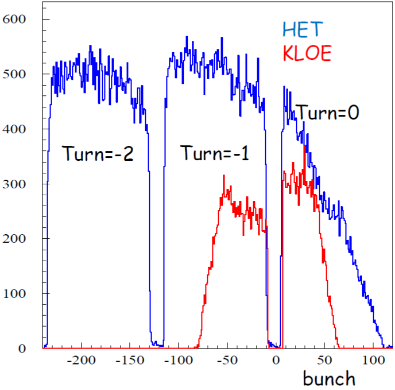
The HET DAQ





- ⋆ 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 (T_1) 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 (DAΦNE radio-frequency signal) and ranges from 660 to 970 ns
- ⋆ The HET do not provide trigger to KLOE
- ⋆ We read the history of the HET in turns of DAΦNE only when a valid KLOE trigger is asserted

The HET DAQ



- ⋆ KLOE and HET acquisition systems are asynchronous: we use the Fiducial provided by DAΦNE which is in phase with respect to the first bunch circulating in DAΦNE
- ⋆ A global delay is used for each TDCV5 in order to shift the Fiducial signal used as common start
- ⋆ We acquire also the KLOE trigger in both HETs for cross-checks and monitoring purposes.
- ⋆ The long plastic scintillator from HETs is also acquired by the TDC of KLOE trigger

- ⋆ KLOE and HET asynchronous Data Acquisition overlapping region.

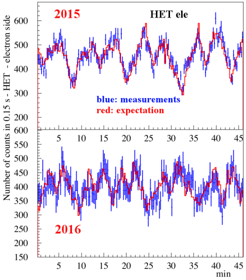
$\gamma\gamma \to \pi^0$ signal is expected in the red region , events outside the overlapping region are used as control sample

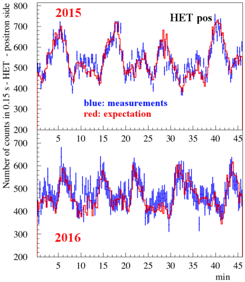
HET Rates are dominated by single-arm Bhabha's as observed in normal and dedicated runs

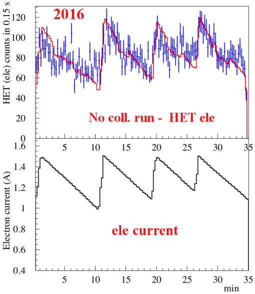
$$R_{\mathrm{HET}} = \frac{R_{\mathrm{trig}}}{\mathrm{kHz}}\left(\alpha_{\mathrm{L_{e,p}}}\frac{\mathrm{Lumi}}{0.2\mathrm{nb}^{-1}\mathrm{s}^{-1}} + \beta_{\mathrm{e,p}}\frac{I^2_{\mathrm{e,p}}}{A^2}\right)$$

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

No-collision run : the HET rate $\propto I^2_{\mathrm{e,p}}$ (Touschek bckg is $\sim 45\%(15\%)$ for $e^-(e^+)$)



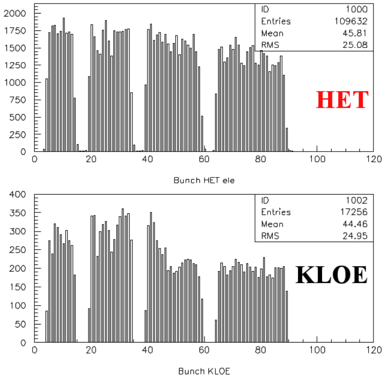




Luminometer detector: fast and reliable feedbacks on the machine operation

Performance of the HET detector

DAΦNE Bunch structure as measured by the HET with low angle Bhabha and KLOE central detector with large angle BhaBha



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.

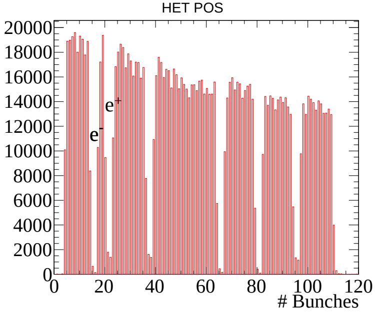
The HET hit time structure closely reproduce DAΦNE bunch structure

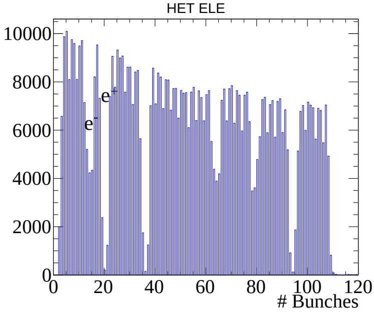
The HET detector is noiseless → hit rate with no circulating beams is negligible

The matching of the DAΦNE bunch structure seen by KLOE and HET allow us also to synchronize the two detectors

Performance of the HET detector

Special run with some DAΦNE bunches not filled, alternatively on the electron and the positron machine.

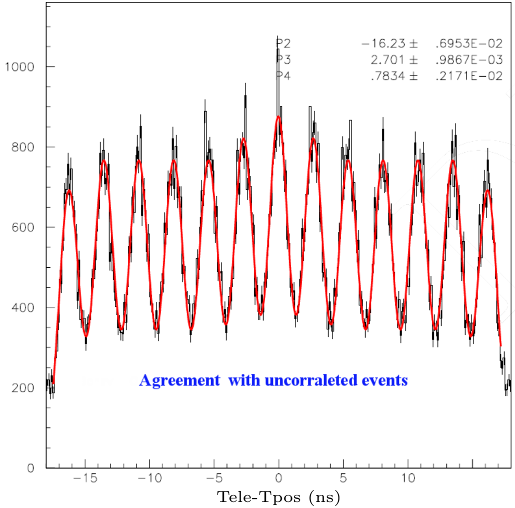




Rate variation on the two stations in the different cases shows also the higher Touschek level on the electron beam.

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

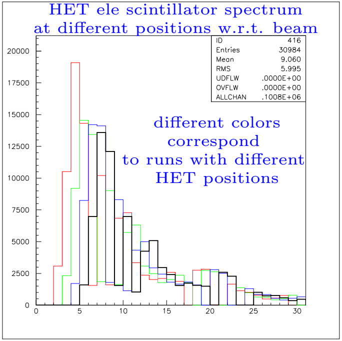
Efficiency Measurements : Method

Measurements of the BhaBha flux at the same distance from the beam with different HET scintillators: many runs acquired with HETs in different positions wrt beam during the whole data-taking period.

The measurements give the relative efficiency of each scintillator on respect another one as reference.

Ref efficiency obtained using long scintillator which covers whole x-window of all small plastics.

Dependence of the efficiency of the long scintillator on the distance from the beam, taken into account.

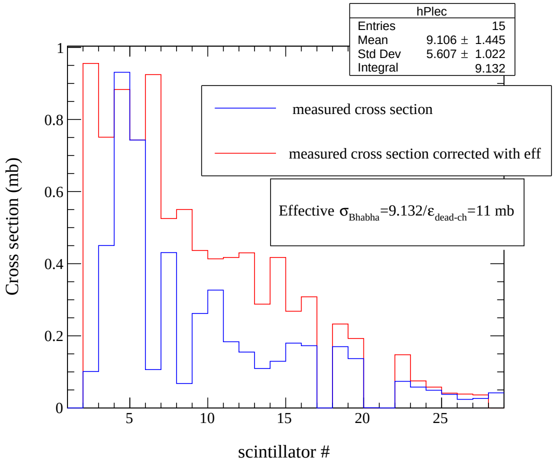


$$\varepsilon_i = \frac{\varepsilon_{\rm i}}{\varepsilon_{\rm ref}}\varepsilon_{\rm ref} = \alpha_i \varepsilon_{\rm ref}, \quad N_{\rm long} : \sum_{i=1}^{28} \frac{N_{\rm pl_i}}{\alpha_i \varepsilon_{\rm ref}} \varepsilon_{long(i)},$$

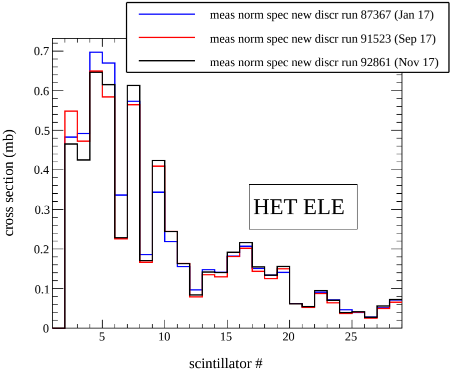
$$\varepsilon_{\rm ref} = \frac{\sum_{i=1}^{28} \frac{N_{\rm pl_i}}{\alpha_i} \varepsilon_{long(i)}}{N_{\rm long}}.$$

The HET rate and the channel-by-channel efficiency measurements allow us to evaluate the low angle Bhabha cross section

Cross section as obtained from the DAFNE luminosity measured with Bhabha at large angle by the KLOE-DAQ system



Preliminary evaluation of effective σ_{Bhabha} gives $\sim$ 11 mbarn on the electron side and $\sim$ 14 mbarn on the positron side

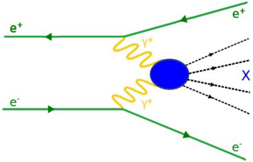


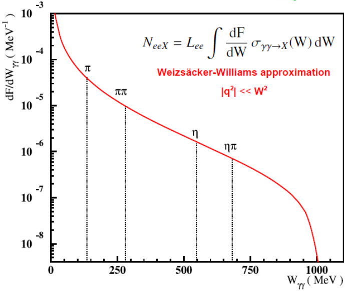
Comparison of Bhabha cross section in 2017

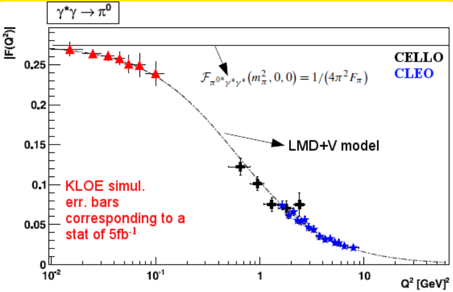
- ⋆ Next Steps:
  - ⋆ Perform again the cross section measurement using data acquired in special runs of 2017-2018.
  - ⋆ Subtract the Touschek background from the measured Bhabha flux.
  - ⋆ Validate the BBBREM generator, the only available for very low angle Bhabhas.

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

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

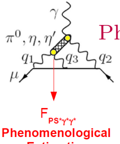






Physics goal:

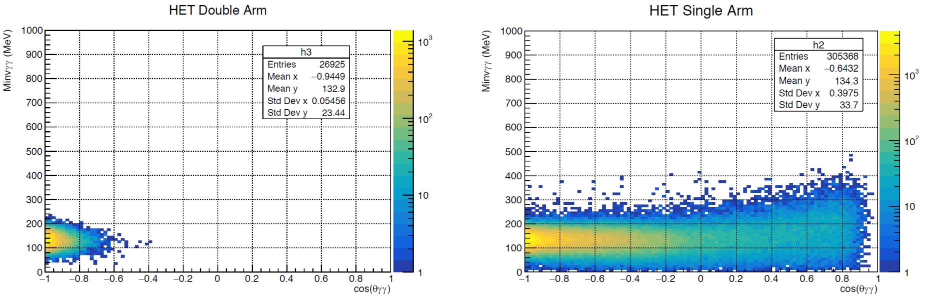
- ⋆ Precision measurement (1%) of the $\Gamma_{\pi^0\to\gamma\gamma}$
  $\Gamma^{Th.}_{\pi^0\to\gamma\gamma} = 8.09 \pm 0.11$eV (1.4% precision) while
  $\Gamma^{PDG}_{\pi^0\to\gamma\gamma} = 7.74 \pm 0.48$eV (6.2% precision due to meas incompatibility)
  $\mathcal{O}(10^4)$ $\gamma\gamma$ events expected for L= 5fb^{-1}
- ⋆ 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 $a_\mu^{\mathrm{LbyL};\pi^0}$

Simulation: $e^+e^- \to e^+e^-\pi^0$ process

Simulated Invariant mass Vs $\cos\theta_{\gamma\gamma}$ distributions for Double-Arm (DA) and Single-Arm (SA) events (Ekhara + Bdsim + Kloe resolution and trigger efficiency)



Effective cross sections:

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

Pre-processing: SA and DA

A data sample statistics of 550 pb^{-1} (from Nov. 15 to June 16) has been processed so far and 2TB of pre-filtered data have been produced

DA events $\rightarrow$

coincidence btw HET stations ($\pm$ 1 bunch expected from resol studies,

$\Delta T_{\mathrm{bunch}} \sim$ 2.7ns , <1% of KLOE triggers)

control sample of events with $2 \leq \Delta T_{ep} \leq 7$ bunches

SA events $\rightarrow$

in time with KLOE trig ($-3 \leq \Delta T_{\mathrm{tri-clu}} \leq 8$ bunches)

in time with a bunch with 2 clu in the barrel $20 < E_{clu} < 300$ MeV

$\Delta T_{\mathrm{KLOE_{clu}-HET}} \leq 4$ bunches

Fine inter-calibration of HET and KLOE TDCs based on bunch structure seen by the KLOE EMC and HET (shift of $\pm 1-2$ bunches induced by the EMC time calib)

By taking into account the full simulation (Ekhra+BDSIM+kloe trigger eff + ECAL resol) and the performed efficiency measurement, we expect 100 DA events and 1100 SA events in the analyzed data sample (550 pb^{-1})

DA Analysis

Signal selection:

Coincidence btw taggers hits : $|\Delta T_{\mathrm{ep}}| < 2$ bunches

Events in time with the KLOE trig ($-3 < \Delta T_{\mathrm{trig-clus}} < 8$ bunches)

2 KLOE clu associated in the barrel with the same bunch with $20 < E_\gamma < 350$ MeV

HET events in time with KLOE DAQ

Kine cuts:

$30 < E_\gamma < 135$ MeV

$P_{\pi^0} < 90$ MeV

$\cos\alpha_{\gamma\gamma} < -0.8$

$80 < M_{\gamma\gamma} < 230$ MeV

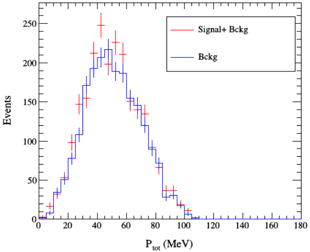
$|\Delta T_{\gamma\gamma} - \Delta R_{\gamma\gamma}/c| < 1.1$ ns

Background evaluation :

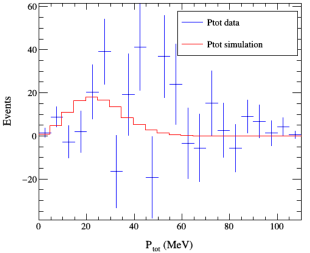
We can use as control samples:

1) Events which don't match the bunch
2) Events matching the bunch but out of time with KLOE DAQ

- Bckg normalization done using the data to bckg ratio in the signal free region suggested by simulation ($1.1 < |\Delta T_{\gamma\gamma} - R_{\gamma\gamma}/c| < 2.2$ ns)



Ptot diff compared with expectation (100 ev)



SA Analysis (HET ele)

Signal selection (ele/pos):

HET ele events in time with KLOE trig ($-3 < \Delta T_{\text{trig}-\text{clus}} < 8$ bunches)

2 KLOE clu associated in the barrel with the same bunch with $\Delta T_{\text{KLOE}_{\text{clu}}-\text{HET}} \leq 4$ bunches

$20 < E_\gamma < 350$ MeV

HET ele events in time with KLOE DAQ

"isolation cut meant to increase S/B ratio"
$E^{tot} - (E_{\gamma_1} + E_{\gamma_2}) < 290$MeV

Kine cuts:

$30 < E_\gamma < 180$ MeV

$\cos\alpha_{\gamma\gamma} < -0.3$

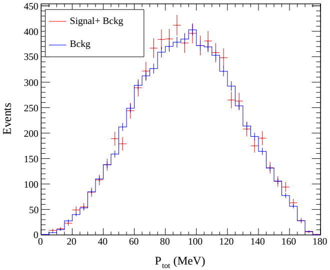
$80 < M_{\gamma\gamma} < 230$ MeV;
$|\Delta T_{\gamma\gamma} - \Delta R_{\gamma\gamma}/c| < 1.1$ ns

$P_{tot} < 150$ MeV

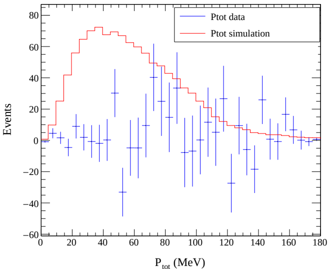
Background evaluation :

We use as control sample events out of time with KLOE DAQ

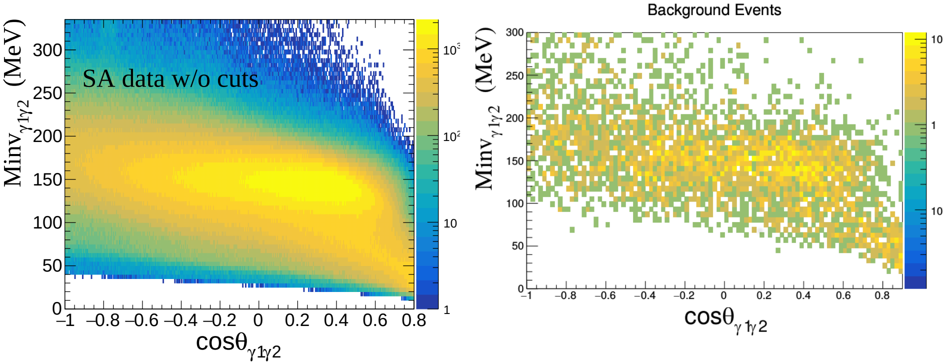
- Bckg normalization done using the data to bckg ratio in the signal free region suggested by simulation ($1.1 < |\Delta T_{\gamma\gamma} - R_{\gamma\gamma}/c| < 2.2$ ns)



Ptot diff compared with expectation (1100 ev)



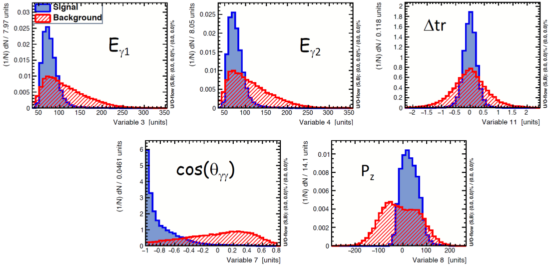
We investigated the origin of the background and simulated the distribution of Touschek-pairs starting from real distributions recorded by the experiment.
We have used the distribution of pairs reconstructed far from the trigger (not-triggering pairs).
Then, we have applied the trigger conditions to such pairs to reproduce those we have in our data as bckg



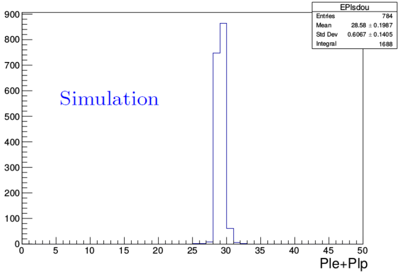
The sample used (dominated by Touschek background) is able to cover the entire kinematic range found for the background at low invariant masses

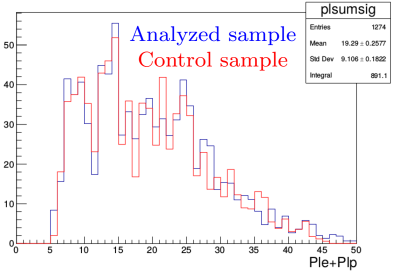
MVA

- ⋆ In order to use all the possible information in our data and correlation we performed a Multivariate Analysis (based on the root package TMVA)
- ⋆ We used as signal sample data from simulation : ekhara + bdsim + Kloe resolution and trigger efficiency
- ⋆ We use as “background” data events out of the overlapping window between KLOE and HET and also data events in which we don’t have the matching of the bunch between KLOE and HETs
- ⋆ We studied both single and double arm samples (550 pb^{-1})
- ⋆ We trained the MVA by using:
  - ⋆ the angle between selected clusters
  - ⋆ the cluster energies
  - ⋆ the π^0 Pz
  - ⋆ the time resolution taken from the two clusters ($\Delta T_{\gamma\gamma} - \Delta R_{\gamma\gamma}/30$)



MVA: Scintillator spectrum DA

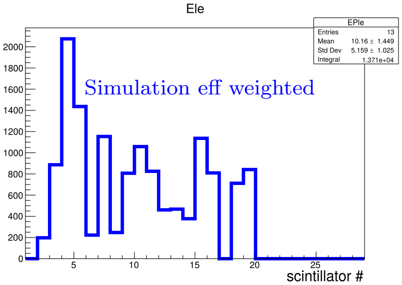


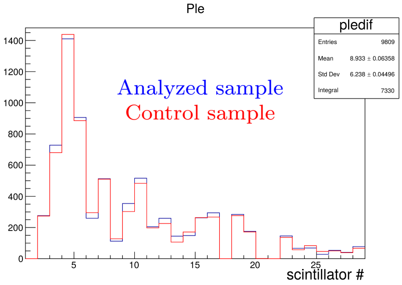


One of the control variables studied is the sum of the plastic numbers. From simulation (Ekhara+BDSIM) we expect strong anti-correlation in the energy of the leptons.

Comparison of the sum of plastic number distributions for events inside the two DAQs overlap window (blue) and out the overlap window (red)

MVA: Scintillator spectrum SA Ele





SA ele plastic distribution expected from full simulation and weighted for measured eff

Comparison of the ele plastic distribution for events inside the overlap window (blue) and out (red)

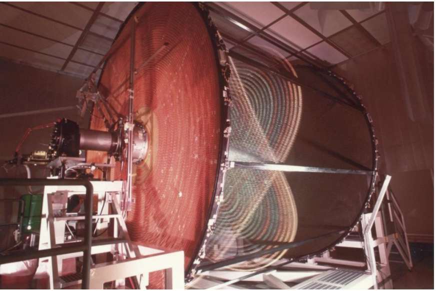
Conclusions

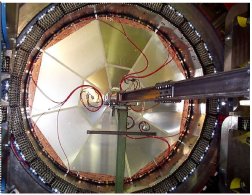
- ⋆ HET stations are noiseless with timeline counting rate showing only two visible contributions : from luminosity and from Touschek particles.
- ⋆ Machine background reaches a maximal relative contribution of 45% for electron and 15% for positron beams.
- ⋆ The total rate dominated by Bhabha scattering is at the level of 500-600 kHz.
- ⋆ Efficiency of the HET stations measured channel by channel on a data set of year 2016. Special runs taken in 2017 and 2018 to repeat the measurements.
- ⋆ Preliminary measurement of very low angle Bhabha cross section performed.
- ⋆ An integrated luminosity of about 550 pb^{-1} has been analyzed. No clear evidence of $\gamma\gamma \to \pi^0$ processes has been established so far by the analysis of both DA and SA events.
- ⋆ A Multivariate analysis on DA and SA events on the 550 pb^{-1} sample has been also performed. Again with the sample selected in the signal region we do not obtain any firm evidence for the π^0 production.
- ⋆ Our plans:
- ⋆ Reconstruction of a new data sample of 500 pb^{-1}, improving selection (200 pb^{-1} of the new sample already reconstructed).
- ⋆ New data reduction processing more info on candidates to test other criteria for bckg suppression (big data volume is an issue).
- ⋆ Measurement of the Bhabha cross section at very low angle and validation of the BBBREM generator.

Thank You!

SPARES

The KLOE DC





$\sigma_{xy} \sim 150\mu\text{m}$

$\sigma_z = 2\text{mm}$

$\sigma_{p_\perp}/p_\perp \sim 0.4\%$ (LA tracks)

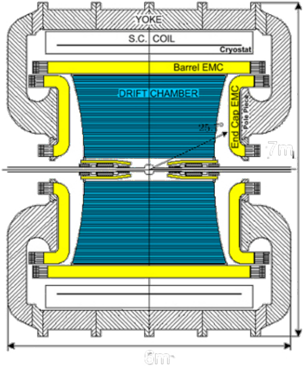
vertex resolution $\sim$3mm

12,000 sense wires

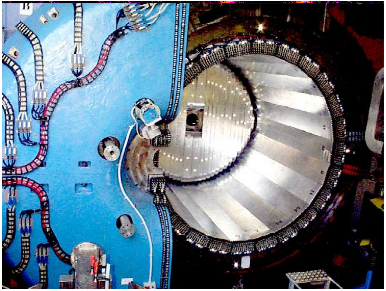
Stereo geometry

4m diameter, 3m long

gas mixture: 90% He 10% iC_4H_{10}



Excellent momentum resolution



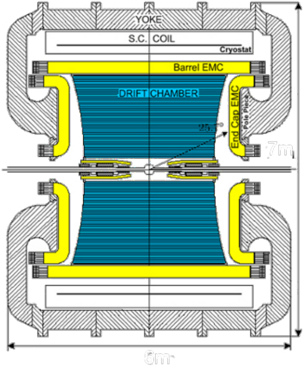
End-caps C-shaped to minimize dead zones: 98% coverage of full solid angle

$$\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$$

$$\sigma_T = 54ps/\sqrt{E(GeV)} \oplus 140ps$$

Barrel + 2 end-caps:

Pb/scintillating fiber, 4880 PM



Excellent time resolution

THE KLOE SUB-DETECTORS

INNER TRACKER:

- ⋆ four layers of cylindrical triple GEM
- ⋆ better vertex reconstruction near IP
- ⋆ higher acceptance to low p_{t} tracks

CCALT:

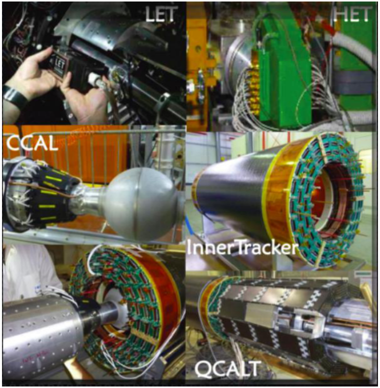
- ⋆ LYSO crystal + SiPM
- ⋆ increase of angular acceptance to γ's from IP from 21° to 10°

QCALT:

- ⋆ W + Scintillator tiles+ WLS/SiPM
- ⋆ QUADS coverage for K_{L} decays

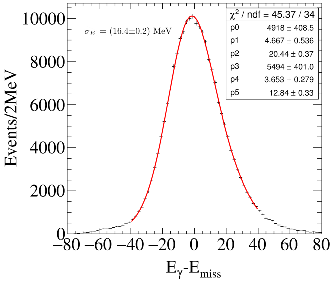
LET and HET :

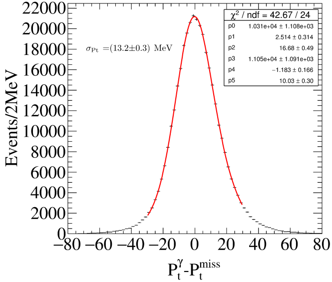
- ⋆ Low and High energy tagger stations for e^+e^- coming from two-photon interaction
- ⋆ LET: LYSO + SiPM
- ⋆ HET: EJ228 plastic scinitllator hodoscope + Xilinx Virtex-5 FPGA

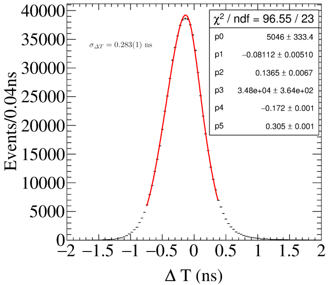


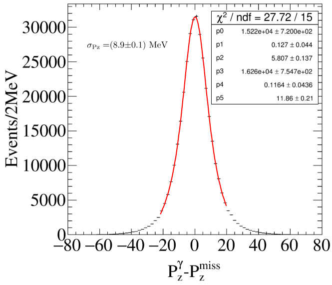
Resolution studies

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



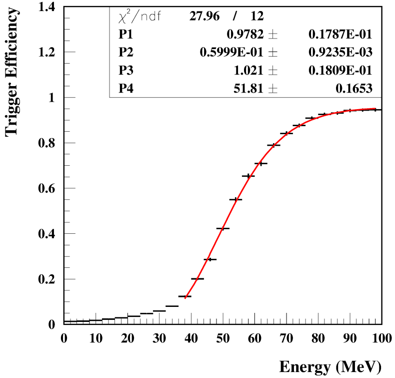




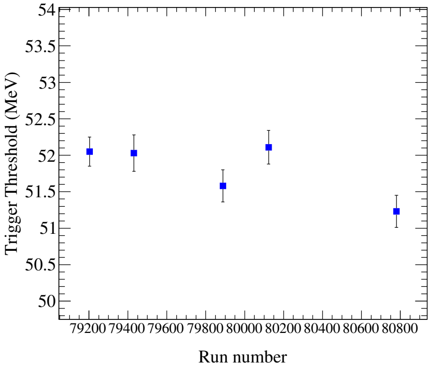


Trigger efficiency

Study based on a control sample of radiative Bhabhas



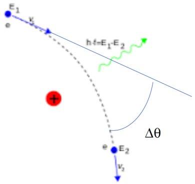
Trigger eff on 70 MeV energy photons is of about 80%

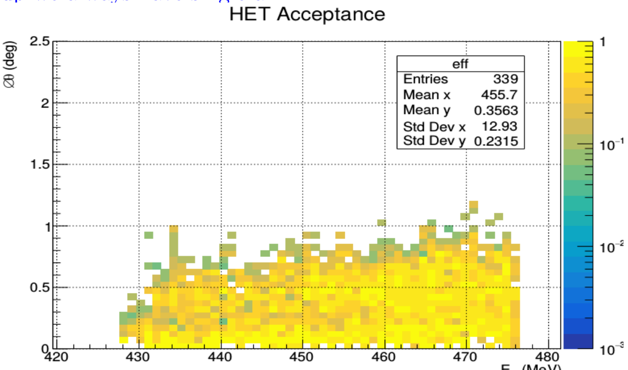


Stability of the trigger threshold over the running period November 2015–January 2016

HET Design Acceptance

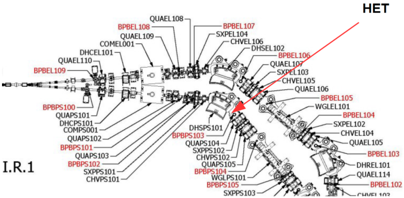
- ⋆ HET acceptance is between 425 and 475 MeV in energy and between 0 and 1.5 degree in angle
- ⋆ All the work is essentially made by the dipole before HET
- ⋆ All the previous magnets work as angular filters
- ⋆ If these regions (E, θ) move for a different DAΦNE setup we always have single arm acceptance





Bdsim Tracking

- ⋆ Bdsim is GEANT4 toolkit used to simulates the particle trajectory from the IP to the HET in the DAFNE magnetic fields
- ⋆ All magnets are simulated : Electron and Positron Rings are not exactly the same
- ⋆ Tiny adjustments of the DAFNE magnetic fields needed for the machine operation (background minimization vs luminosity maximization) can change particle orbits differently in the electron and positron beam
- ⋆ HET vertical dimension is the critical point for the tagger acceptance
- ⋆ We have compared the simulated orbits with the Beam-Position-Monitors placed in DAFNE and slightly modified the magnetic setup in order to fit at best such positions.
- ⋆ We obtained good agreement with the BPM placed before the corrector DHCPS101 and only marginal agreement with the BPM placed near the HET

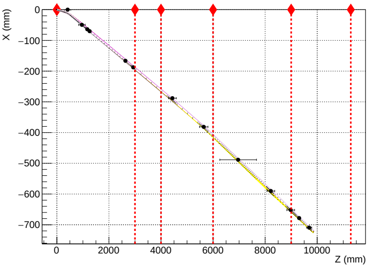


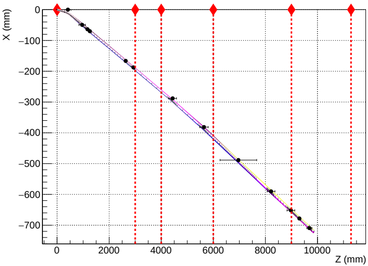
- ⋆ In conclusion we expect to operate with an energy-dependent acceptance mostly due to the vertical dimension of the taggers
- ⋆ Such an effect is expected much more critical for the double-arm coincidences than for the single-arm ones
- ⋆ For this reason the analysis of single-arm events takes great importance

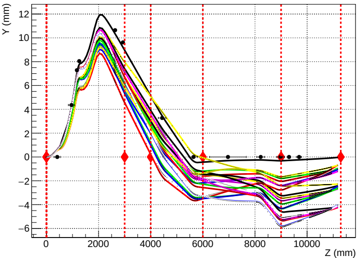
$3{\times}10^5$ magnetic setup simulated, the trajectory with the best agreement with BPM is chosen

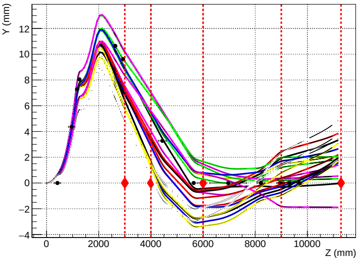
electron traject

positron traject.

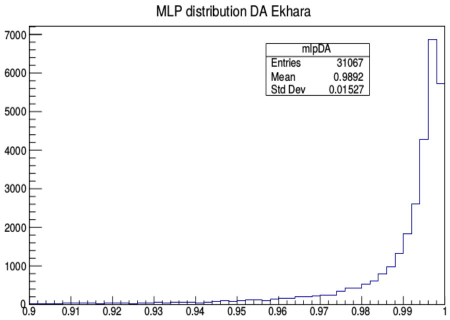


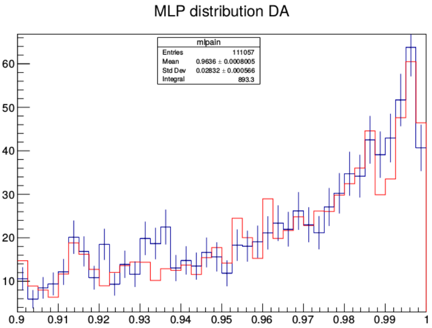






MVA: MLP distribution DA



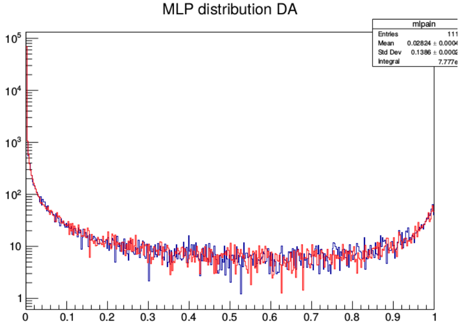


MLP distribution expected from Ekhara in the signal region

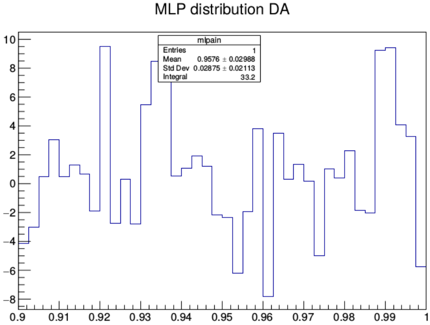
MLP distribution comparison for events in the overlapping window of the HET and KLOE DAQs (blue) and out of the overlapping region (red).
The distributions have been normalized at the same number of events in the background region.

No significant excess is found

MVA: MLP distribution DA

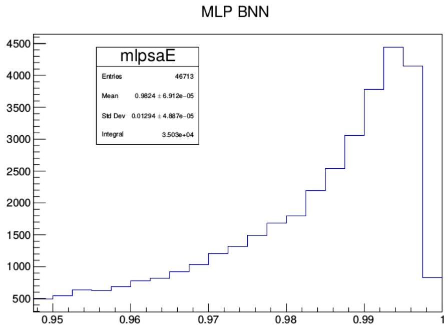


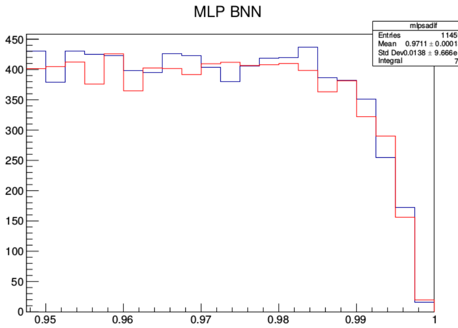
MLP distribution comparison for events in the overlapping window of the HET and KLOE DAQs (blue) and out of the overlapping region (red) in the whole MLP range



MLP distribution difference in the signal region

MVA: MLP distribution SA



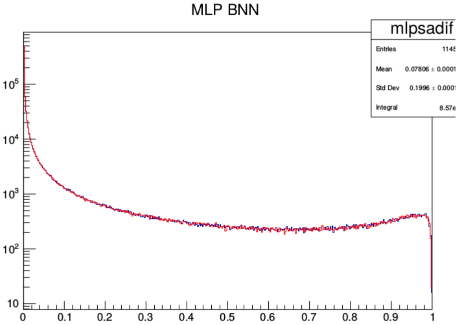


MLP distribution expected from Ekhara in the signal region

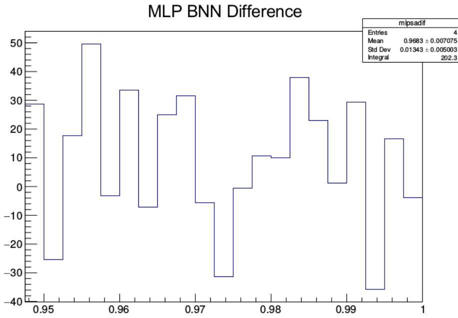
MLP distribution comparison for events in the overlapping window of the HET and KLOE DAQs (blue) and out of the overlapping region (red)

Also in this case no significant excess is found

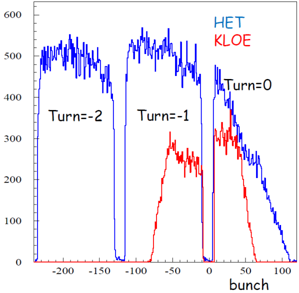
MVA: MLP distribution SA



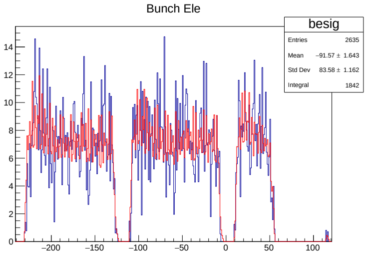
MLP BNN Distributions



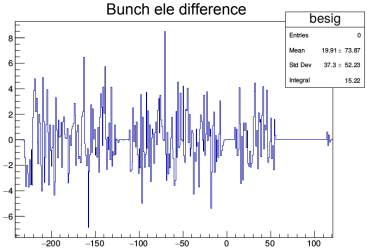
Difference between the MLP distributions in the signal region



Red : events in the bckg region
Blue: events in the sig region

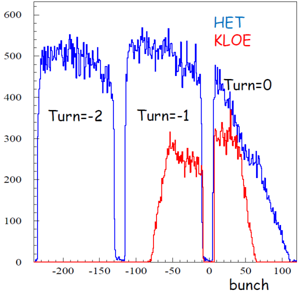


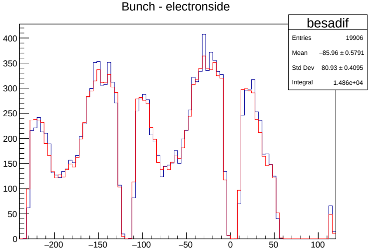
- ⋆ KLOE and HET asynchronous Data Acquisition overlap in the red region.
- ⋆ Another control distribution studied is the bunch distribution, as recorded within the ∼2.5 DAΦNE turns from the HET acquisition.
- ⋆ We compare the distributions for triggers on the signal side (mva variable) with those in the bckg region normalizing with an equal number of events in the region where KLOE-HET acquisition DO NOT overlap.
- ⋆ in case of π^0 signal from $\gamma\gamma$ scattering we expect to see an increasing of events in the overlapping region w.r.t. the others turns.



MVA: TDC DISTRIBUTION SA

Red : events in the bckg region
Blue: events in the signal region.





KLOE and HET asynchronous Data Acquisition overlap in the red region.

Same comparison done for DA events is shown for SA events