Dark Searches and $\gamma\gamma$ Physics at KLOE

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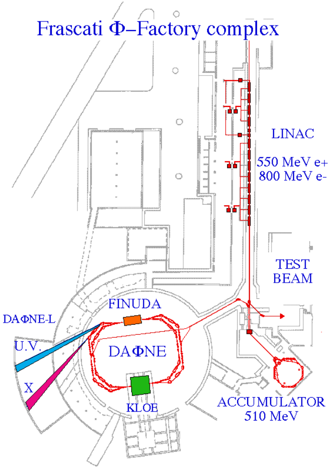
on behalf of KLOE-2 Collaboration

National Laboratories of Frascati (Italy)

ADMPP 2016
October 24-27 2016

DAΦNE: THE Φ-FACTORY



DAΦNE UPGRADES

New interaction region: large beam crossing angle + sextupoles for crabbed waist optics → Increase of luminosity by a factor $2 \div 3$

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

2 interaction regions

2 separate rings

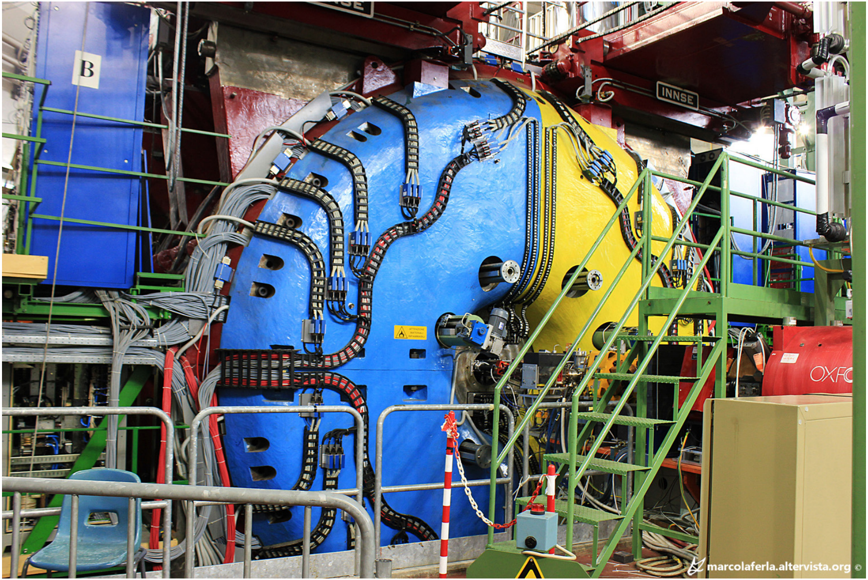
105 +105 bunches, $T_{RF} = 2.7$ ns

Injection during data taking

Crossing angle: 2×12.5 mrad

Best Performance (running period 1999-2006):

$L_{\text{peak}} = 1.5 \times 10^{32} \text{cm}^{-2}\ \text{s}^{-1}$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INNSE
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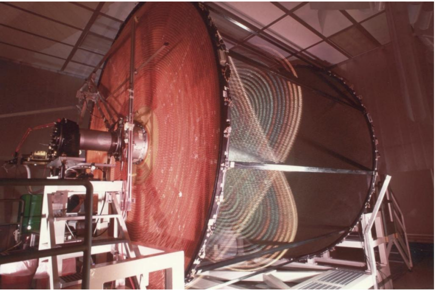
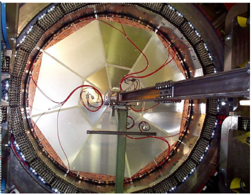
marcolaferla.altervista.org ©

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)

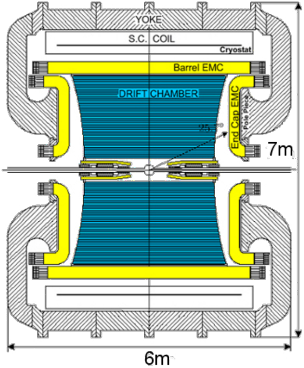
vertex resolution ~3mm

12,000 sense wires

Stereo geometry

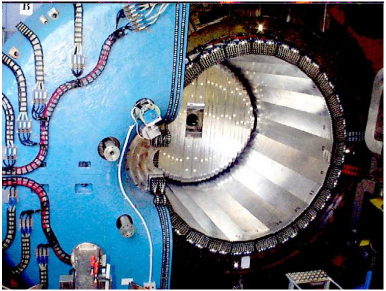
4m diameter, 3m long

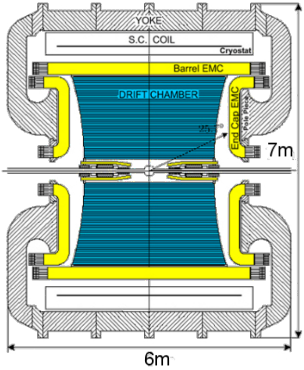
gas mixture: 90% He 10% iC_4H_{10}



Excellent momentum resolution

The KLOE EMC





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

INNER TRACKER:

- ⋆ four layers of cylindrical triple GEM
- ⋆ better vertex reconstruction near IP
- ⋆ higher acceptance to low p_t tracks

CCALT:

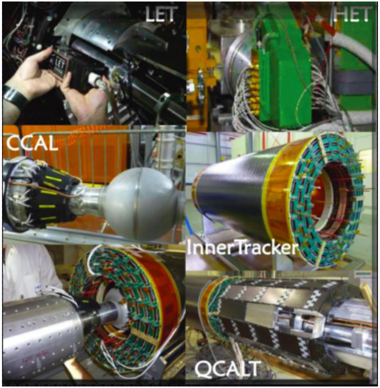
- ⋆ LYSO crystal + SiPM
- ⋆ increase of angular acceptance to γ's from IP from 21° to 10°

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

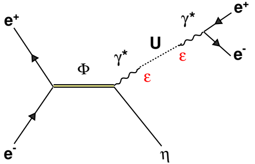


Dark Force Searches at KLOE

minimal hypothesis: visible and prompt U decays

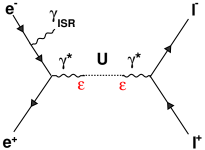
ϕ Dalitz decay:

$\phi \to \eta$U, U $\to$ e$^+$e$^-$
$\eta \to \pi^+\pi^-\pi^0$(BR=22.7%)
$\eta \to \pi^0\pi^0\pi^0$(BR=32.6%)
expected signature: peak in the dielectron inv. mass



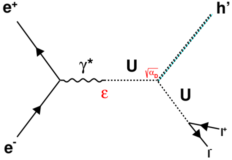
Uγ events:

$e^+e^- \to$ Uγ, U $\to$ l$^+$l$^-$(l = e, μ, π)
good knowledge of bckgs
$\sigma \sim$1/s: 100 times higher at DAΦNE w.r.t. B-factories
expected signature: resonance peak in the dilepton or dipion inv. mass

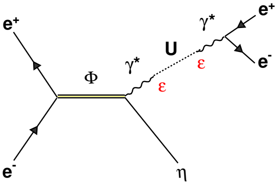


Higgsstrahlung process:

$e^+e^- \to h'$U
interesting process observed at KLOE if $m_{\mathrm{U}} + m_{h'} < m_\phi$
expected signature for $m_{\mathrm{h}'} < m_{\mathrm{U}}$: bump in the M_{ll}Vs M_{miss} plane



Search for $e^+e^- \to \phi \to \eta U$, $U \to e^+e^-$



$\phi \to \pi^+\pi^-\pi^0 e^+e^-$ ev. sel.

- 4 tracks in a cylinder around IP + 2 photon candidates
- $495 < M_{\pi\pi\gamma\gamma} < 600$ MeV
- $70 < M_{\gamma\gamma} < 200$ MeV
- $535 < M_{recoil(ee)} < 560$ MeV
- ToF cuts

$\phi \to \pi^0\pi^0\pi^0 e^+e^-$ ev. sel.

- 2 charged tracks in a cylinder around IP
- 6 prompt photons candidates:
  - $E_\gamma > 7$ MeV and not associated to any track
  - time window expected for a photon $|T_\gamma - R_\gamma/c| < \mathrm{MIN}(3\sigma_t, 2\mathrm{ns})$
  - acceptance: $|cos\theta_\gamma| < 0.92$

$\mathrm{BR}(X \to YU) \sim \varepsilon^2 \times |FF_{XY_\gamma}|^2 \times BR(X \to Y_\gamma)$

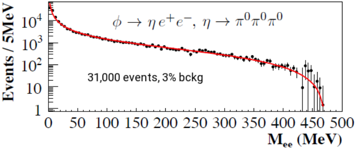
$\sigma(\phi \to \eta U) \sim 40$fb for $|FF_{\phi\eta}| = 1$, $\varepsilon \sim 10^{-3}$

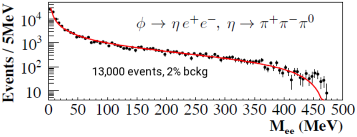
$\phi \to \pi^+\pi^-\pi^0 e^+e^-$ sample $\to$ L= 1.5fb^{-1}

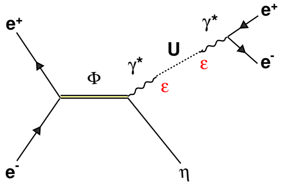
$\phi \to \pi^0\pi^0\pi^0 e^+e^-$ sample $\to$ L= 1.7fb^{-1}

$\phi \to \eta e^+e^-$ MC simulation developed according VMD model

$\phi \to \eta U$ simulation developed according to JHEP 07 051 (2009)







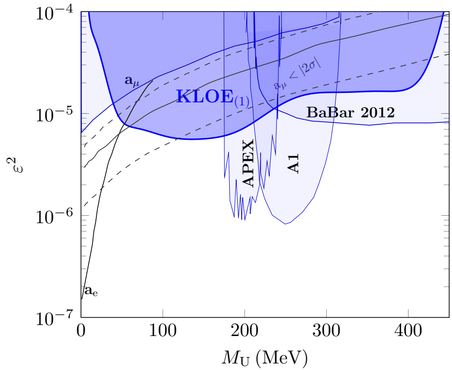
$\phi \to \eta U$ MC sample divided in sub-samples of 1 MeV width in $5 < M_{\mathrm{U}} < 470$ MeV

For each M_{U} sub-sample, average value of $\phi \to \eta e^+e^-$ background from fit to M_{ee} distribution, excluding the 5 bins centred at M_U

For each M_{U} value, signal hypothesis excluded @ 90% C.L. using the CL$_{\mathrm{S}}$ method (error on bckg included)

Phys. Lett. B 706 (2012) 251
Phys. Lett. B 720 (2013) 111

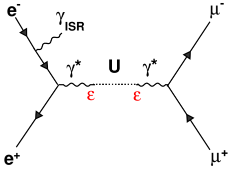
Limit on $\varepsilon \to$ formula from Reece and Wang JHEP 07 (2009)
$b_{\phi\eta} \sim 1\mathrm{GeV}^{-2}$



$\varepsilon^2 < 1.7 \times 10^{-5}$ @ 90% C.L. for $30 < M_{\mathrm{U}} < 400$ MeV

$\varepsilon^2 < 8 \times 10^{-6}$ @ 90% C.L. for the $50 < M_{\mathrm{U}} < 210$ MeV

Search for $e^+e^- \to U\gamma$, $U \to \mu^+\mu^-$



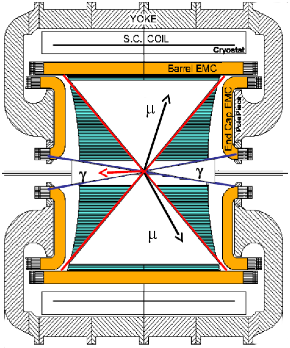
Statistics: KLOE data collected on 2002 corresponding to $L = 240\ pb^{-1}$.

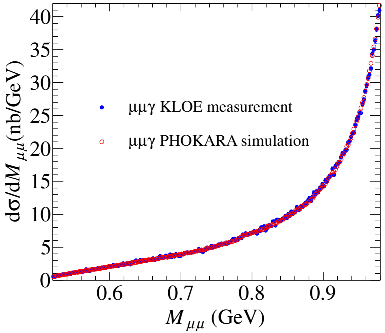
Small angle event selection
$(50 < \theta_\mu < 130,\ \theta_\gamma < 15\,, > 165)$

High statistics ISR signal

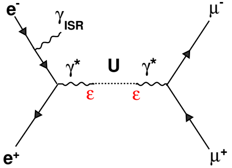
Significant reduction of ϕ resonant and FSR bckgs

Good π/μ separation thanks to kinematical cuts (M_{trk} and $\sigma_{M_{trk}}$ cuts)





Search for $e^+e^- \to \mathrm{U}\gamma$, $\mathrm{U} \to \mu^+\mu^-$



$$\varepsilon^2 = \frac{N_{CL_\mathrm{S}}/\epsilon_\mathrm{eff}}{H \cdot I \cdot L}$$

$\mathrm{N}_{CL_\mathrm{S}}$ = UL on number of U-boson candidates at 90% CL ($\mathrm{CL_S}$ technique)

$\mathrm{H} = \frac{d\sigma_{\mu\mu\gamma}/d\mathrm{M}_{\mu\mu}}{\sigma(\mu^+\mu^- \to \mu^+\mu^-, M)}$

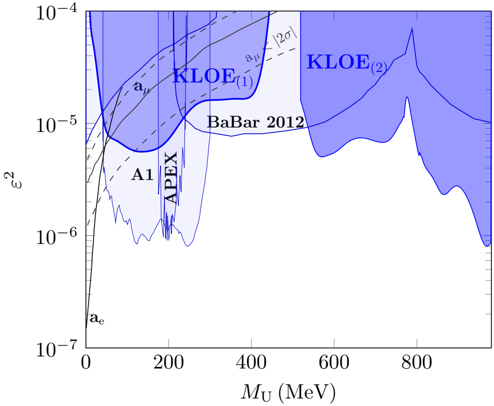
$I = \int \sigma^{\mathrm{U}}_{\mu\mu} d\mathrm{M}_{\mu\mu}$, $\varepsilon^2 = 1$

$\epsilon_\mathrm{eff} = 2 - 15\%$

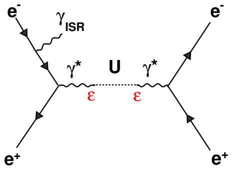
Systematic error of 1.4–1.8%

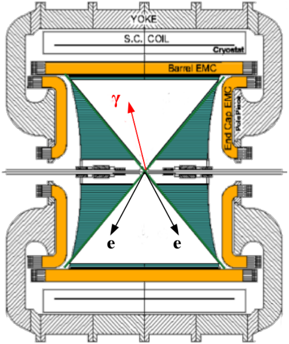
L =239.3 pb^{-1}

Phys. Lett. B 736 (2014) 459



$\varepsilon^2 < 1.6 \times 10^{-5} - 8.7 \times 10^{-7}$ @ 90% C.L. for $520 < M_\mathrm{U} < 980$ MeV





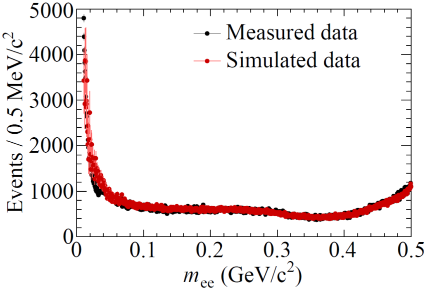
Statistics:KLOE data collected on 2004-05 corresponding to $L = \int \mathcal{L} = 1.5\text{fb}^{-1}$

2 oppositely charged tracks $(55 < \theta_e < 125)$

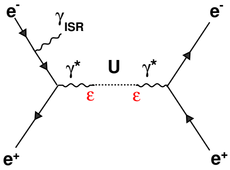
Large angle event selection $(50 < \theta_\gamma < 130)$

High statistics radiative Bhabha events in KLOE data

background contamination$< 1\%$



SEARCH FOR $e^+e^- \to U\gamma$, $U \to e^+e^-$



$$\varepsilon^2 = \frac{N_{CL_S}/\epsilon_{\mathrm{eff}}}{H \cdot I \cdot L}$$

N_{CL_S}= UL on number of U-boson candidates at 90% CL (CL_S technique)

H=$\frac{d\sigma_{ee\gamma}/dM_{ee}}{\sigma(e^+e^- \to e^+e^-, M)}$

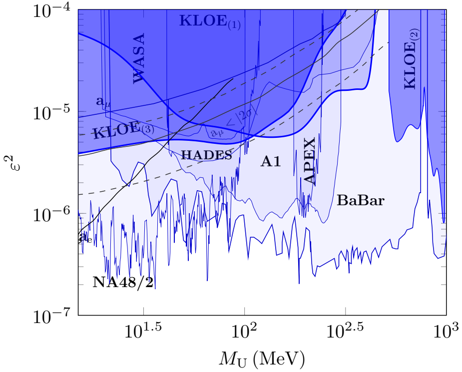
$I = \int \sigma^U_{ee} dM_{ee}$, $\varepsilon^2 = 1$

$\epsilon_{\mathrm{eff}} = 1.5 - 2.5\%$

Systematic error $< 2\%$

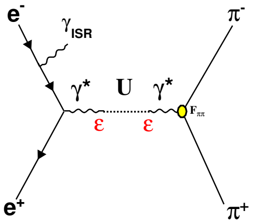
L=1.54 fb^{-1}

Phys. Lett. B 750 (2015) 633



$\varepsilon^2 \sim 10^{-6} - 10^{-4}$ @ 90% C.L. for 5< M_U < 520 MeV

Search for $e^+e^- \to U\gamma$, $U \to \pi^+\pi^-$



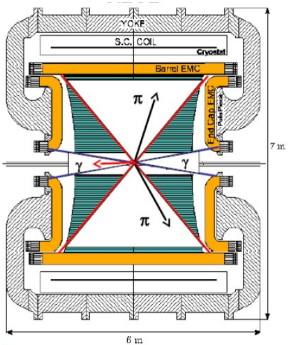
Statistics: full KLOE statistics corresponding to $L=1.93\ \mathrm{fb}^{-1}$.

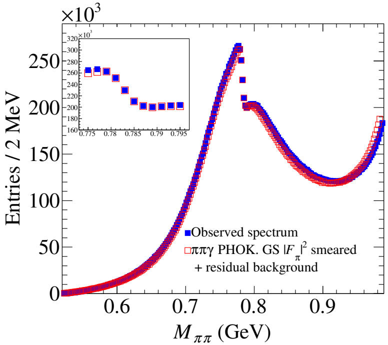
Small angle event selection
$(50 < \theta_\pi < 130,\ \theta_\gamma < 15, > 165)$

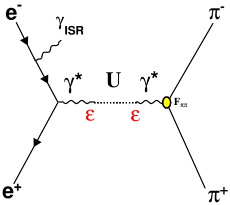
High statistics ISR signal

Significant reduction of ϕ resonant and FSR bckgs

Good π/μ separation thanks to kinematical cuts (M_{trk} cut)







$$\varepsilon^2 = \frac{N_{CL_S}/\epsilon_{\text{eff}}}{H \cdot I \cdot L}$$

N_{CL_S} = UL on number of U-boson candidates at 90% CL (CL_S technique)

$H = \frac{d\sigma_{\pi\pi\gamma}/dM_{\pi\pi}}{\sigma(\pi^+\pi^- \to \pi^+\pi^-, M)}$

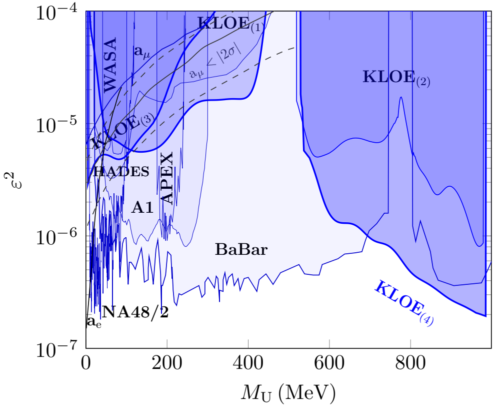
$I = \int \sigma^U_{\pi\pi} dM_{\pi\pi}$, $\varepsilon^2 = 1$

$\epsilon_{\text{eff}} = 2 - 40\%$

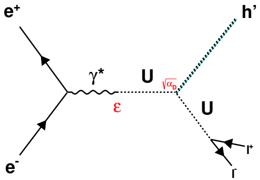
Systematic error $\leq 1\%$

L=1.93 fb^{-1}

Phys. Lett. B 757 (2016) 356



$\varepsilon^2 < 1.82 \times 10^{-5} - 1.93 \times 10^{-7}$ @ 90% C.L. for $527 < M_U < 987$ MeV



Event Selection:

Two oppositely charged tracks with vertex inside a 4×30cm cylinder around IP

EMC cluster associated to each track

Momentum direction inside the barrel: $|\cos\theta| < 0.75$

$P_{\text{track}} < 460$ MeV

$|P_{\text{miss}}| > 40$ MeV

E_{miss}: calorimeter veto

PID: two muons

vtx-IP cut (anti K^+K^-)

Two different scenarios:

$m_{h'} = 2m_U$:
$h' \to UU \to 4l,\ 2l + 2\pi,\ \pi$

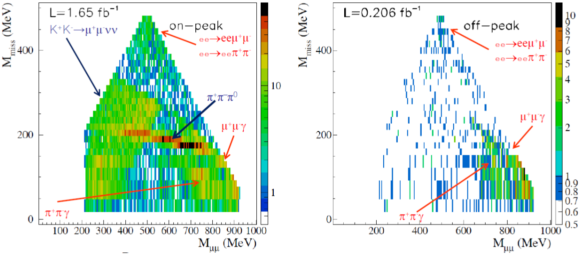
$m_{h'} < m_U$ with h' invisible

Invisible scenario :

$\varepsilon \sim 10^{-3}, \alpha_D = \alpha_{em}, m_U \sim$ 100MeV $\to \tau_{h'} <$ 5µs $\to \beta\gamma ct <$ 100m $\to$ h' invisible at KLOE up to $\varepsilon \sim 10^{-2} - 10^{-1}$ depending on $m_{h'}$

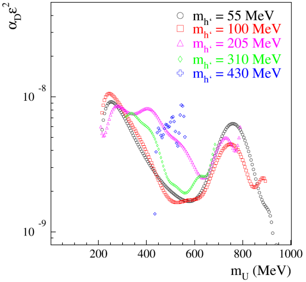
Final state signature: 2 muons+missing energy$\to$ bump in the $M_{\text{miss}} - M_{\mu\mu}$ plane

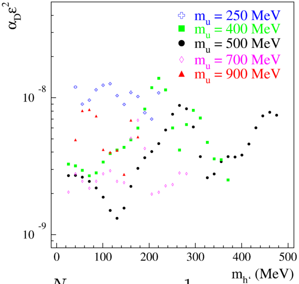
Results for on-peak (1.65 fb^{-1}) and off-peak (0.2 fb^{-1})samples



Combined UL from on- and off-peak samples: $\varepsilon^2 \sim 10^{-6} \div 10^{-8}$ (if $\alpha_D = \alpha_{em}$)

Phys. Lett. B 747, 365 (2015)





90% CL bayesian UL $N_{90\%}$ on number of events converted in terms of $\alpha_D \times \varepsilon^2$ by using:

$$\alpha_D \varepsilon^2 = \frac{N_{90\%}}{\epsilon_{eff}} \frac{1}{L \cdot \sigma_{hU}(\alpha_D \varepsilon^2 = 1)}$$

- L and signal efficiency information ϵ_{eff}
- σ_{hU} and BR of the $U \to \mu^+\mu^-$
- Combined UL takes into account the different L, signal efficiency and cross sections of the two samples
- Syst. errors included

$$\sigma_{hU} \sim \frac{1}{s} \frac{1}{(1 - \frac{m_U^2}{s})^2}$$

Batell, Pospelov, Ritz , Phys. Rev. D 79, 115008 (2009)

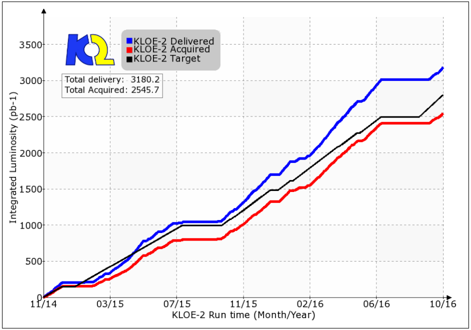
New dark analysis will profit of:

- ⋆ an increased luminosity (factor $2 \div 3$)
- ⋆ an IT-DC combined tracking(in progress) → better mass resolution and vertex reconstruction

Some new ideas under study:

- ⋆ B boson search in two channels: $\phi \to \eta \mathrm{B}, \mathrm{B} \to \pi^0\gamma$ and $\eta \to B\gamma, \mathrm{B} \to \pi^0\gamma$ (leptophobic, in progress)
- ⋆ Invisible U decays to light dark matter(with or without the single γ trigger)

2.5 fb^{-1} of data recorded from November 2014 up to July 2016



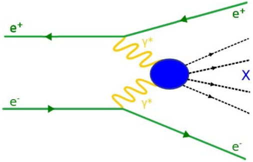
final goal: 5fb^{-1} by the end of 2017

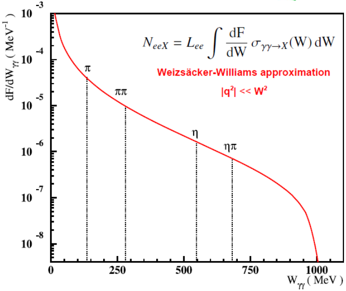
$\gamma\gamma$ Physics at KLOE

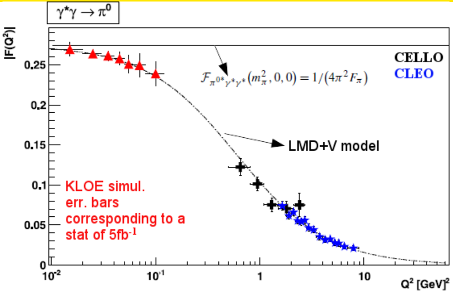
$\gamma\gamma$ Physics at KLOE: Motivations

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

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

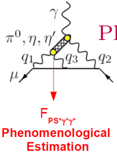






Physics goal:

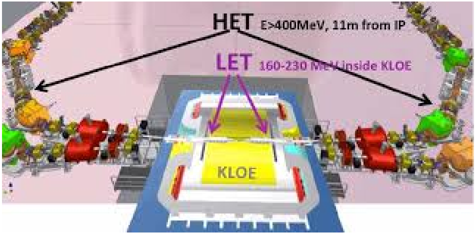
- $\star$ Precision measurement (1%) of the $\Gamma_{\pi^0\to\gamma\gamma}$
  $\Gamma^{\mathrm{Th.}}_{\pi^0\to\gamma\gamma} = 8.09 \pm 0.11\mathrm{eV}$ (1.4% precision) while $\Gamma^{\mathrm{PDG}}_{\pi^0\to\gamma\gamma} = 7.74 \pm 0.48\mathrm{eV}$ (6.2% precision due to meas incompatibility)
  $\mathcal{O}(10^4)$ $\gamma\gamma$ events expected for $L = 5\mathrm{fb}^{-1}$
- $\star$ First measurements of the $F_{\pi^0\gamma^\star\gamma}(q^2,0)$ in the space-like region for $q^2 < 0.1\,\mathrm{GeV}^2$



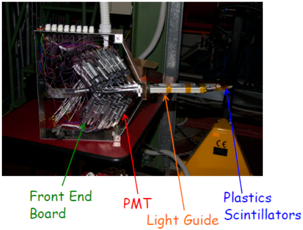
Physics motivation:
impact on the value and precision of the $a_\mu^{\mathrm{LbyL};\pi^0}$

KLOE High Energy Taggers

The HET stations are located 11m away the IP after the bending dipoles acting like a spectrometer → position detector (acceptance 425-490 MeV)



28+1 scintillators of different length

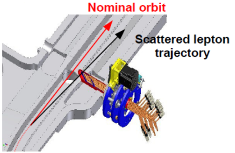


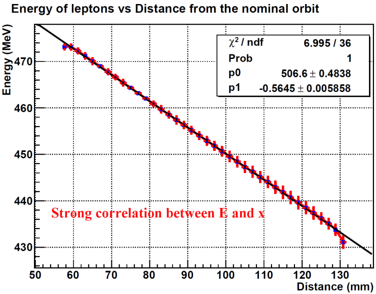
Leptons are tracked along machine optics with BDSIM package (GEANT4 appl.), MC validation in progress: Babayaga, BBBrem for Bhabha's, Ekhara for $\gamma\gamma$ events

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

to taggers

in **KLOE**

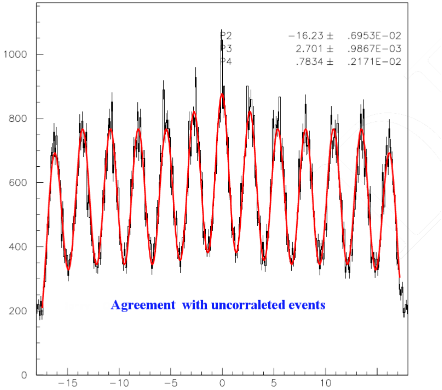




Operation of the HET detector

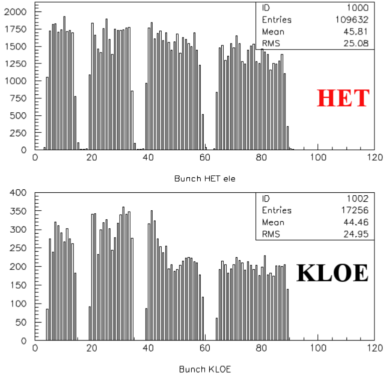
The HET has been operated since the very beginning of the KLOE-2 data-taking

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



First peak is at -16.23 ns $\rightarrow$
time offset between stations of 24.10 ps
Time resolution is σ_t=550(1)ps

DAΦNE Bunch structure as measured by the HET and KLOE central detector



Hardware Efficiency:

- ⋆ Scintillators + PM : eff. $\sim$ 100%
- ⋆ eff. discr. chan. : 70(60)% for $e^-(e^+)$ side

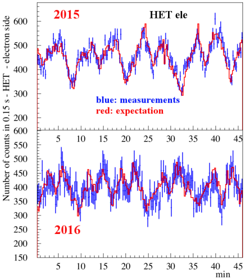
New discriminators will be installed by the end of December 2016

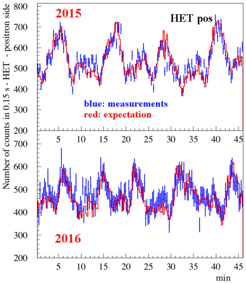
Operation of the HET detector

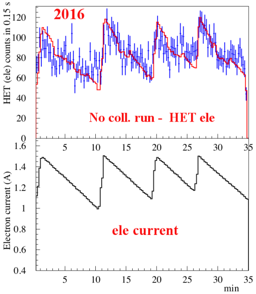
Luminometer detector: fast and reliable feedbacks on the machine operation

Rates dominated by single-arm Bhabha's (Touschek $\sim$ 45%(15%) for $e^-(e^+)$)

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







$\gamma\gamma$ Physics at KLOE: π^0 search

About 500 pb^{-1} of integrated lumi have been processed so far and 2TB of pre-filtered data have been produced

Double-Arm events (DA) $\rightarrow$

coincidence btw HET stations ($\pm$ 1 bunch expected from resol studies, $\Delta T_{\rm bunch} \sim$ 2.7ns , <1% of KLOE triggers)

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

Single-Arm events (SA) $\rightarrow$

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

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

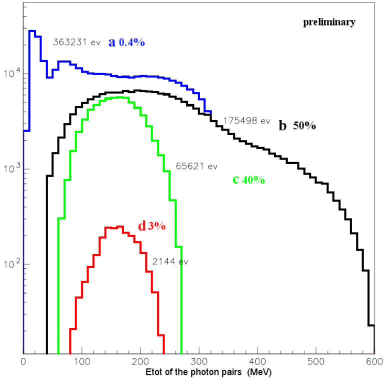
$\Delta T_{\rm KLOE_{clu}-HET} \leq 4$ bunches

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)

A sample of $\sim$330 pb^{-1} of DA events is being analyzed to search for π^0 production almost at rest

$\gamma\gamma$ Physics at KLOE: π^0 search

Statistics: 10^8 fully-reconstructed events
$\rightarrow$350 $\gamma\gamma$ events expected from EKHARA and BDSIM simu + trig (65%) and detector eff.



Bckg simulation based on machine bckg meas is in progress

Bckg meas is being done run-by-run selecting events out of the coincidence window with taggers

Analysis of the π^0 candidates requires:

(a) coincidence btw taggers hits : $|\Delta_{\rm ep}| < 2$ bunches and in time with the KLOE trig

2 KLOE clu associated with the same bunch with $\Delta T_{\rm KLOE_{clu}-HET} \leq 4$ bunches

$E_\gamma < 300$ MeV

(b) $E_\gamma > 20$ MeV (events that can trigger the KLOE DAQ)

(c) $30 < E_\gamma < 135$ MeV

(d) $P_{\pi^0} < 90$ MeV

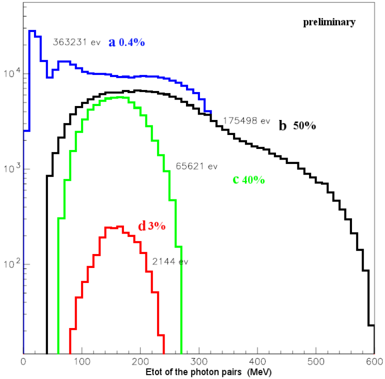
$\cos\alpha_{\gamma\gamma} < -0.8$

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

$|\Delta T - \Delta R/c| < 1.1$ ns

$\gamma\gamma$ Physics at KLOE: π^0 search

Statistics: 10^8 fully-reconstructed events
$\rightarrow$350 $\gamma\gamma$ events expected from EKHARA and BDSIM simu + trig (65%) and detector eff.

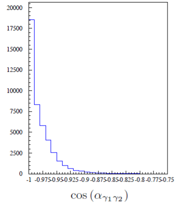


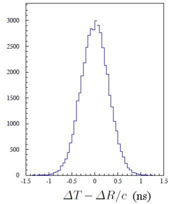
Bckg simulation based on machine bckg meas is in progress

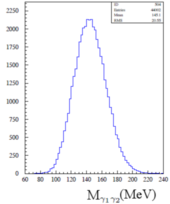
Bckg meas is being done run-by-run selecting events out of the coincidence window with taggers

Analysis of the π^0 candidates requires:

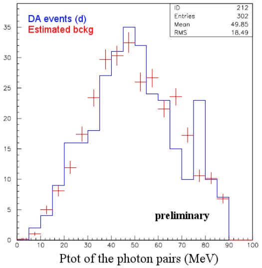
(d) $P_{\pi^0} < 90$ MeV
$\cos\alpha_{\gamma\gamma} < -0.8$
$80 < M_{\gamma\gamma} < 230$MeV
$|\Delta T - \Delta R/c| < 1.1$ ns

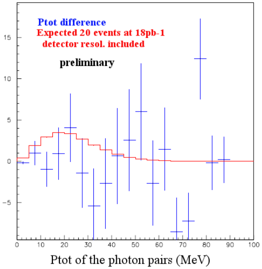






$\gamma\gamma$ Physics at KLOE: π^0 search





Bckg estimation done by using a sub-data sample of DA events (18pb^{-1}) out of the coincidence window with taggers

We are extending the bckg estimation to all analyzed data sample to measure the background of random coincidences on a run-by-run basis and perform a precision subtraction on the HETele*HETpos*KLOE coincidences

The planned measurement of the time overlap between the two asynchronous DAQs will allow to optimize the time cuts for the definition of HET*KLOE time coincidences and reduce the background.

KLOE searched for a new light gauge boson in three processes in six different reactions:

$\phi \to \eta\mathrm{U}, \mathrm{U} \to \mathrm{e}^+\mathrm{e}^-, \eta \to \pi^+\pi^-\pi^0, \eta \to 3\pi^0$ **PLB 720 (2013) 111**

$e^+e^- \to \mathrm{U}\gamma$:

$e^+e^- \to \mathrm{U}\gamma,\ \mathrm{U} \to \mu^+\mu^-$ **PLB 736 (2014) 459**

$e^+e^- \to \mathrm{U}\gamma,\ \mathrm{U} \to \mathrm{e}^+\mathrm{e}^-$ **PLB 750 (2015) 633**

$e^+e^- \to \mathrm{U}\gamma,\ \mathrm{U} \to \pi^+\pi^-$ **PLB 757 (2016) 356**

$e^+e^- \to \mathrm{U}\mathrm{h}' \to \mu^+\mu^- + \mathrm{E}_{\mathrm{miss}}$ **PLB 747 (2015) 365**

We found no evidence of U-boson signature and set limits on the mixing parameter ε^2 ($\alpha_{\mathrm{D}} \times \varepsilon^2$) as function of U ($h'$) mass of $10^{-5} \div 10^{-7}$depending on the process.

DAΦNE increased luminosity + KLOE-2 sub-detectors are expected to improve our sensitivity by a factor ∼2 or better

Conclusions (2)

- HET stations are completely noiseless
- The timeline of the counting rate for electron AND positron stations shows only 2 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
- The rate of uncorrelated time-coincidences between KLOE and HET requires full reconstruction of a large fraction of the KLOE triggers
- We have pre-filtered candidates of single-π^0 production from $\gamma\gamma$ scattering. A total of about 500 pb^{-1} are being analyzed

Plans for the future

On the hardware side we plan:

The replacement of the discriminators, planned for December 2016 that will allow to reliably use the counting rate of single scintillators for an in-depth study of the energy acceptance.

On the analysis side we plan:

To measure the background of random coincidences on a run-by-run basis to perform a precision subtraction on the HETele*HETpos*KLOE coincidences

To carry out the analysis of SA events.

Thank You!

SPARES

$\phi \to \eta U$, $U \to e^+e^-$

$$\sigma(e^+e^- \to \phi \to \eta U) = \varepsilon^2 |F_{\phi\eta(m_U^2)}|^2 \frac{\lambda^{3/2}(m_\phi^2, m_\eta^2, m_U^2)}{\lambda^{3/2}(m_\phi^2, m_\eta^2, 0)} \sigma(e^+e^- \to \phi \to \eta\gamma)$$

$$\lambda(m_1^2, m_2^2, m_3^2) = [1 + m_3^2/(m_1^2 - m_2^2)]^2 - 4m_1^2 m_3^2/(m_1^2 - m_2^2)^2$$

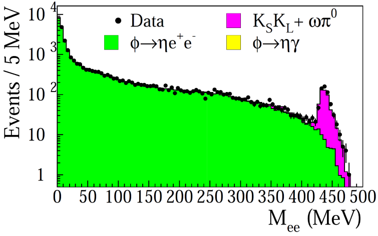
$$F_{\phi\eta}(q^2) = \frac{1}{1 - q^2/\Lambda^2} \quad q = M_{ee}$$

FF slope:

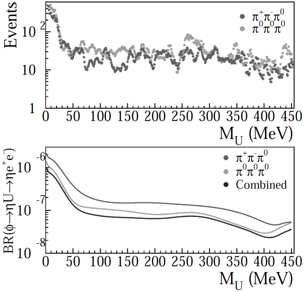
$$b = dF/dq^2|_{q^2=0}$$

$$b_{\phi\eta} = \Lambda_{\phi\eta}^{-2} \approx 1/m_\phi^2 \approx 1\mathrm{GeV}^{-2} \to$$ VMD expectation

Data/MC comparison

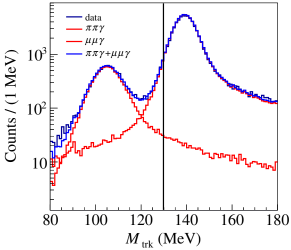


UL on Number of event (top)
UL on BR($\phi \to \eta U \to \eta e^+e^-$) for the two eta decays and the combined one (bottom)



Trackmass variable, M_{trk}, defined by momentum and energy conservation laws, by requiring that the tracks belong to particles of the same mass m_x in the process: $e^+e^- \to x^+x^-\gamma$, $x = \mu, \pi, e$

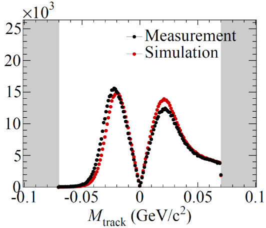
$$\left(\sqrt{s} - \sqrt{|\mathbf{p}_+|^2 + M_{\text{trk}}^2} - \sqrt{|\mathbf{p}_-|^2 + M_{\text{trk}}^2}\right)^2 - (\mathbf{p}_+ + \mathbf{p}_-)^2 = 0$$



$80\,\text{MeV} < M_{\text{trk}} < 115\,\text{MeV}$ for muons

$M_{\text{trk}} > 130\,\text{MeV}$ for pions

$-70\,\text{MeV} < M_{\text{trk}} < 70\,\text{MeV}$ for electrons

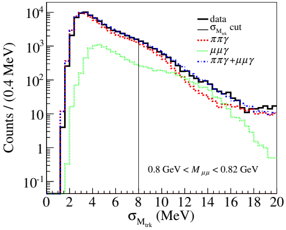


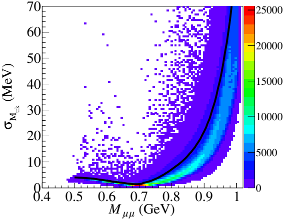
$\mu\mu\gamma$ CHANNEL: CUT ON $\sigma_{M_{\rm trk}}$

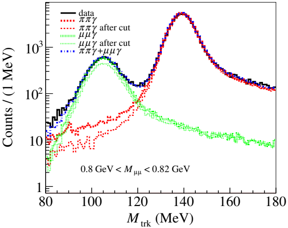
Motivation: $M_{\rm trk}$-distribution left tail of $\pi^+\pi^-\gamma$ that contaminates the signal region is mainly due to poorly reconstructed tracks

$\sigma_{\mathbf{M}_{\rm trk}}$ **cut** : quality cut based on the error on the $M_{\rm trk}$ obtained by the helix fit of both DC tracks (cut efficiency: 70-80%)

Effect: Suppression of the $\pi^+\pi^-\gamma$ fractional bckg of about 40% depending on $M_{\mu\mu}$ slice







$\mu\mu\gamma$ CHANNEL: ERROR ON M_{trk}

$$\sigma^2_{M_{\text{trk}}} = \sum_{i,j} \frac{\partial M_{\text{trk}}}{\partial x_i} \mathbf{M}_{i,j} \frac{\partial M_{\text{trk}}}{\partial x_j}$$

$\sigma^2_{M_{\text{trk}}}$: error of a function of many variables, x_i (x_j): i_{th} (j_{th}) variables of the function
covariance matrix $\mathbf{M}$ with elements: $\mathbf{M}_{i,i} = \sigma^2_{x_i}, \quad \mathbf{M}_{i,j} = \rho_{x_i x_j}$

$$\sigma^2_{M_{\text{Trk}}} = \begin{pmatrix} \frac{\partial M_{\text{trk}}}{\partial k_1} & \frac{\partial M_{\text{trk}}}{\partial \cot\theta_1} & \frac{\partial M_{\text{trk}}}{\partial \varphi_1} & \frac{\partial M_{\text{trk}}}{\partial k_2} & \frac{\partial M_{\text{trk}}}{\partial \cot\theta_2} & \frac{\partial M_{\text{trk}}}{\partial \varphi_2} \end{pmatrix} \times$$

$$\begin{pmatrix} \sigma^2_{k_1} & \rho_{k_1 \cot\theta_1} & \rho_{k_1\varphi_1} & 0 & 0 & 0 \\ \rho_{\cot\theta_1 k_1} & \sigma^2_{\cot\theta_1} & \rho_{\cot\theta_1\varphi_1} & 0 & 0 & 0 \\ \rho_{\varphi_1 k_1} & \rho_{\varphi_1 \cot\theta_1} & \sigma^2_{\varphi_1} & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma^2_{k_2} & \rho_{k_2 \cot\theta_2} & \rho_{k_2\varphi_2} \\ 0 & 0 & 0 & \rho_{\cot\theta_2 k_2} & \sigma^2_{\cot\theta_2} & \rho_{\cot\theta_2\varphi_2} \\ 0 & 0 & 0 & \rho_{\varphi_2 k_2} & \rho_{\varphi_2 \cot\theta_2} & \sigma^2_{\varphi_2} \end{pmatrix} \times \begin{pmatrix} \frac{\partial M_{\text{trk}}}{\partial k_1} \\ \frac{\partial M_{\text{trk}}}{\partial \cot\theta_1} \\ \frac{\partial M_{\text{trk}}}{\partial \varphi_1} \\ \frac{\partial M_{\text{trk}}}{\partial k_2} \\ \frac{\partial M_{\text{trk}}}{\partial \cot\theta_2} \\ \frac{\partial M_{\text{trk}}}{\partial \varphi_2} \end{pmatrix}$$

No correlation assumed between variables associated to **different tracks**
Available information: Error on track curvature k, on polar and azimuthal angle and on $\sigma^2_{x_i}, \rho_{x_i x_j}$

Missing information: $\vec{p_1}$ and $\vec{p_2}$ components

$U\gamma$ CHANNEL: EXTRACTION FORMULA

$$H(s, s_l, \cos\theta) = \frac{\mathrm{d}\sigma_{ll\gamma}}{\mathrm{d}s_l} / \sigma(e^+e^- \to l^+l^-, s_l)$$

$s_l = M_{ll}^2 \;\; s = E_{\mathrm{cm}}^2 \;\; l = e, \mu$

$$H = \frac{\alpha}{\pi s}\left[\frac{s^2+s_l^2}{s(s-s_l)} \log\frac{1+c_{\min}}{1-c_{\min}} - \frac{s-s_l}{s} c_{\min}\right]$$

$c_{\min} < \cos\theta_\gamma < c_{\min}$

$$\sigma(e^+e^- \to \mu^+\mu^-, s_\mu) = \frac{4\pi\alpha^2}{3s_\mu}\frac{\beta_\mu(3-\beta_\mu^2)}{2}$$

$$\beta_\mu = \sqrt{1 - \frac{4m_\mu^2}{s_\mu}}$$

$$N_{QED} = \sigma_i^{ll\gamma,\mathrm{QED}} \cdot L =$$
$$= \int_{\Delta_i} \frac{\mathrm{d}\sigma_{ll\gamma}}{\mathrm{d}s_l}\mathrm{d}s_l \cdot L = \left\langle \frac{\mathrm{d}\sigma_{ll\gamma}}{\mathrm{d}s_l}\right\rangle \Delta_i \cdot L$$

$$N_{\mathrm{U}} = \sigma_i^{ll\gamma,\mathrm{U}} \cdot L = \left\langle \frac{\mathrm{d}\sigma_{ll\gamma,\mathrm{U}}}{\mathrm{d}s_l}\right\rangle \Delta_i \cdot L =$$

$$= \langle\sigma_{\mathrm{U}} H\rangle_i \Delta_i \cdot L \approx \langle H\rangle_i \frac{\int_{\Delta_i}\sigma_{\mathrm{U}}^{ll} ds}{\Delta_i}\Delta_i \cdot L =$$
$$\int_i \sigma_{\mathrm{U}}^{ll}\, ds_l \cdot HL = I_l' \cdot H \cdot L$$

$$I'(s_l) = \int_i \sigma_{\mathrm{U}}^{ll}\, ds_l$$

$$= \int \frac{12\pi\Gamma(\mathrm{U}\to e^+e^-)\Gamma(U\to\mu^+\mu^-)}{(s_l-m_U^2)^2 + M_{\mathrm{U}}^2\Gamma_{\mathrm{tot}}^2}\, ds_l =$$

$$= \frac{12\pi^2\Gamma(\mathrm{U}\to e^+e^-)\Gamma(\mathrm{U}\to\mu^+\mu^-)}{M_{\mathrm{U}}\Gamma_{\mathrm{tot}}}$$

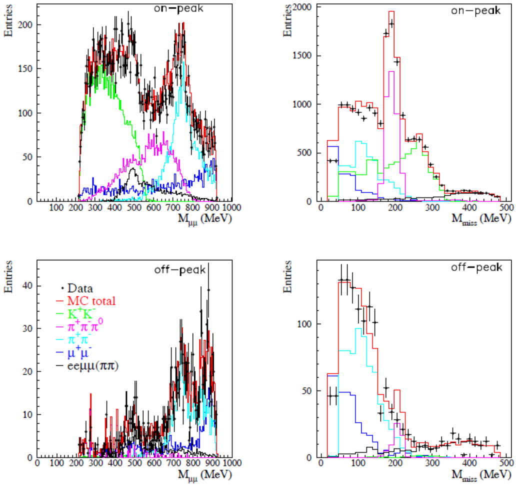
$$I'(\sqrt{s_l}) \approx I'(s_l)/2\sqrt{s_l} \quad I' = \varepsilon^2 I$$

$$\frac{N_{\mathrm{U}}}{\sqrt{N_{\mathrm{QED}}}} = \frac{\int_i \sigma_{\mathrm{U}}^{ll}\mathrm{d}s_l \cdot HL}{\sqrt{N_{\mathrm{QED}}}} = 1$$

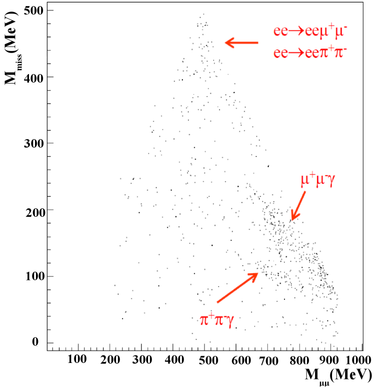
$$\frac{\varepsilon^2 I \cdot HL}{N_{\mathrm{U}}} = 1$$

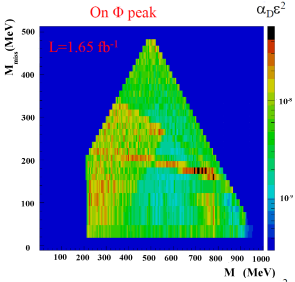
$$\varepsilon^2 = \frac{N_{\mathrm{U}}/L}{H \cdot I} \quad N_{\mathrm{U}} = N_{\mathrm{CL_S}}/\epsilon_{\mathrm{eff}}$$

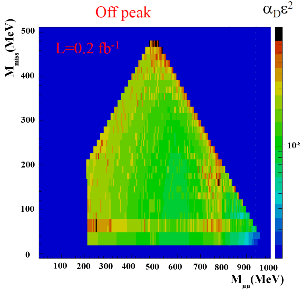
Higgsstrahlung process: $M_{\mu\mu}$ and $\mathrm{M}_{\mathrm{miss}}$ spectra



HIGGSSTRAHLUNG PROCESS: OFF-PEAK SAMPLE-BIDIMENSIONAL LIMITS



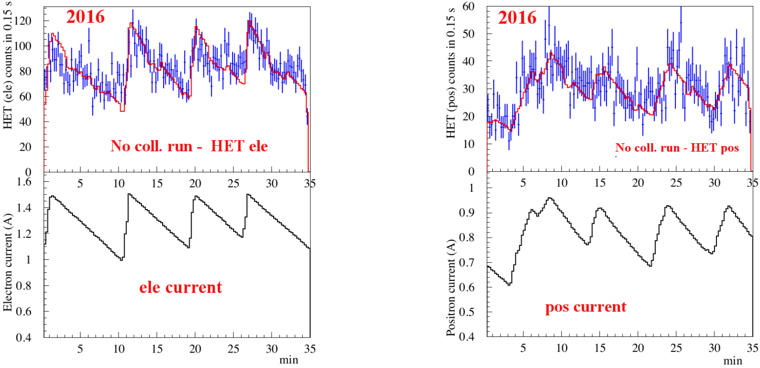




off-peak results (0.2 fb^{-1})

Operation of the HET detector

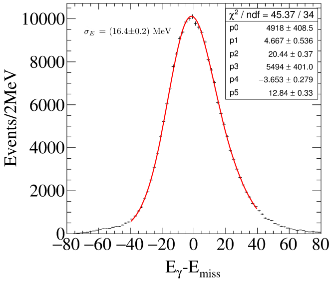
$$R_{\mathrm{HET}} = \frac{R_{\mathrm{trig}}}{\mathrm{kHz}} \left(\alpha_{\mathrm{L}_{\mathrm{e,p}}} \frac{\mathrm{Lumi}}{0.2\mathrm{nb}^{-1}\mathrm{s}^{-1}} + \beta_{\mathrm{e,p}} \frac{I^2_{\mathrm{e,p}}}{A^2} \right)$$

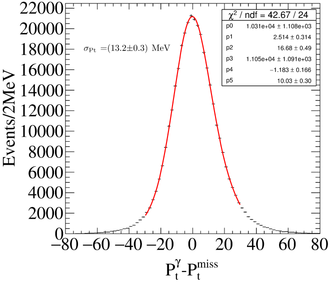


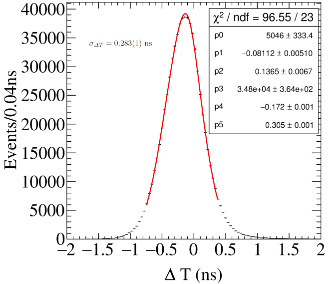
Upper plots : Timelines of HET counting rate from a no-collision run.
Red lines are expectation(* for L=0) assuming stable DAΦNE operation and a dependence from the Touschek contribution $\propto I^2_{\mathrm{e,p}}$.
Lower plots : timelines of the circulating current for the same run.

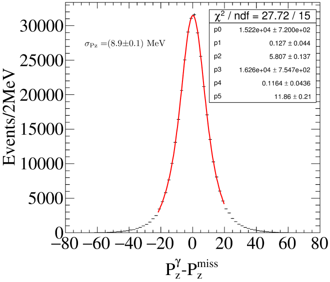
Resolution studies

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



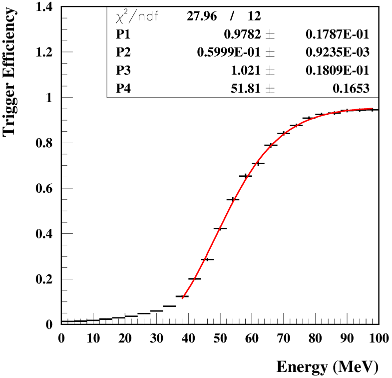


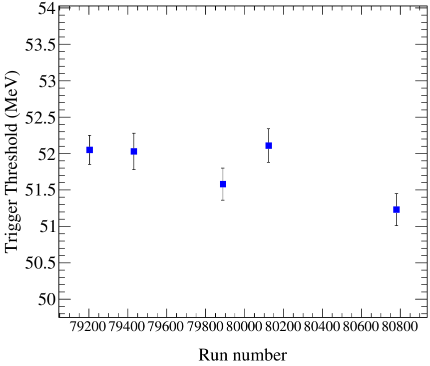




Trigger efficiency

Study based on a control sample of radiative Bhabhas

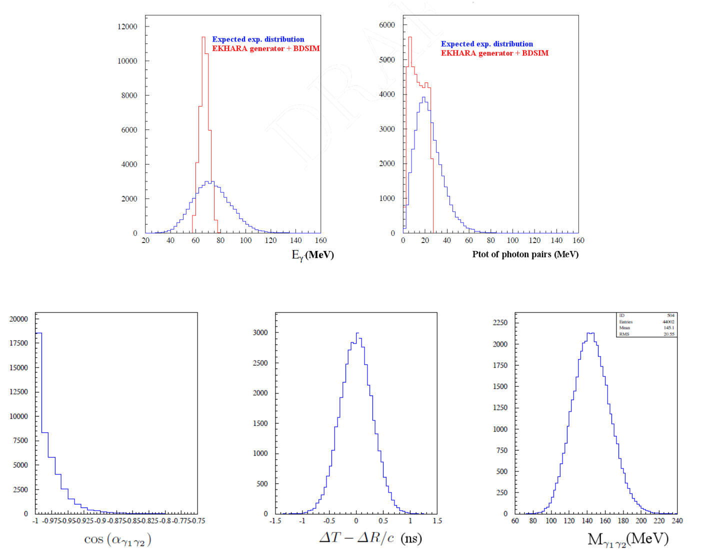




Trigger eff on 70 MeV energy photons is of about 80%

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

EKHARA SIMULATION



The simulated experimental distributions take into account calorimeter energy resolution and trigger threshold as measured on control samples of radiative Bhabhas.