The KLOE-2 High Energy Taggers

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on behalf of KLOE-2 Collaboration

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DAΦNE and KLOE-2 Experiment

THE KLOE-2 High Energy Taggers

Operation of The HET Detector

γγ Physics at KLOE-2: π⁰ search

Conclusions
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: $2 \times 12.5$ mrad

Best Performance (running period 1999-2006):
$L_{\text{peak}} = 1.5 \times 10^{32}$ 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 about 2
KLOE-2 Physics Program:

- **γγ physics**
  Study of $\Gamma(\pi^0 \rightarrow \gamma\gamma)$, test of $\chi$PT, existence and properties of $\sigma(600)$ meson, PS Transition Form Factor

- **Kaon Physics**
  - Test of CPT (and QM) in correlated kaon decays
  - Test of CPT in $K_S$ semileptonic decays
  - Test of SM (CKM unitarity, lepton universality)
  - Test of $\chi$PT ($K_S$ decays)

- **Spectroscopy of light mesons**
  $\eta, \eta', f_0, a_0, \sigma$ in $\phi$ radiative decays

- **Dark Matter searches (light bosons at $\mathcal{O}(1 \text{ GeV})$**

- **Hadronic cross section**
  $\alpha_{em}(M_Z)$ and (g-2)

3 fb$^{-1}$ already acquired
final goal: 5fb$^{-1}$ by March 2018
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 mm³
1 Long Plastic for coincidence

HAMAMATSU PMT R9880U-110 SEL
Quantum efficiency $\sim 35\%$

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

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

$e^+ e^- \rightarrow e^+ e^- \gamma^+ \gamma^- \rightarrow e^+ e^- X$

to taggers

Nominal orbit

Scattered lepton trajectory

$5\text{cm from nominal orbit}$

Energy of leptons vs Distance from the nominal orbit

<table>
<thead>
<tr>
<th>$\chi^2$</th>
<th>$\text{ndf}$</th>
<th>$\text{Prob}$</th>
<th>$p0$</th>
<th>$p1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.995</td>
<td>36</td>
<td>1</td>
<td>506.6 ± 0.4838</td>
<td>-0.5645 ± 0.005858</td>
</tr>
</tbody>
</table>

Strong correlation between $E$ and $x$
The HET DAQ

- Discriminator provides output signal with a width of \( \sim 2 \text{ ns} \) → possibility to discriminate 2 consecutive bunches in DAΦNE (\( \Delta T_{\text{bunch}} = 2.7 \text{ ns} \))
- 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.
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 T1 in both HETs
- These signals have to be found at the same TDC channel in the first DAΦNE turn for both HETs.
- The long plastic scintillator from HETs is also acquired by the TDC of KLOE trigger

6% of the signals have instead +1 turn delay
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 $\sigma$

Time resolution is $\sigma_t = 550(1)$ 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 have been installed at the beginning of 2017.
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 $e^- (e^+)$)

$$R_{HET} = \frac{R_{trig}}{kHz} \left( \alpha_{L,e,p} \frac{Lumi}{0.2nb^{-1}s^{-1}} + \beta_{e,p} \frac{I_{e,p}^2}{A^2} \right)$$
Physics at KLOE-2: Motivations

\[ e^+e^- \rightarrow e^+e^- \gamma^*\gamma^* \rightarrow e^+e^-X \]

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

Physics goal:
* Precision measurement (1%) of the \( \Gamma_{\pi^0 \rightarrow \gamma\gamma} \)
\( \Gamma_{\text{Th.}} \pi^0 \rightarrow \gamma\gamma = 8.09 \pm 0.11 \text{eV} \) (1.4% precision) while \( \Gamma_{\text{PDG}} \pi^0 \rightarrow \gamma\gamma = 7.74 \pm 0.48 \text{eV} \) (6.2% precision due to meas incompatibility)
\( O(10^4) \gamma\gamma \) events expected for \( L= 5 \text{fb}^{-1} \)

Physics motivation:
* First measurements of the \( F_{\pi^0\gamma\gamma}(q^2, 0) \) in the space-like region for \( q^2 < 0.1 \text{ GeV}^2 \)

Impact on the value and precision of the \( a_{L\text{by}L;\pi^0} \)
Physics at KLOE-2: $\pi^0$ Search

More than 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, $\Delta T_{\text{bunch}} \sim 2.7\text{ns}, <1\%$ 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 ($-3 \leq \Delta T_{\text{tri-clu}} \leq 8$ bunches)
- in time with a bunch with 2 clu in the barrel $20 < E_{\text{clu}} < 300$ MeV
- $\Delta T_{\text{KLOE-clu-HET}} \leq 4$ 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 $\sim 550$ pb$^{-1}$ of DA events is being analyzed to search for $\pi^0$ production almost at rest.
Statistics: $10^8$ fully-reconstructed events → 650 $\gamma\gamma$ events expected from EKHARA and BDSIM simu + trig (65%) and detector eff.

Analysis of the $\pi^0$ candidates requires:

(a) coincidence btw taggers hits: $|\Delta_{ep}| < 2$ bunches and in time with the KLOE trig
2 KLOE clu associated with the same bunch with
$\Delta T_{KLOE_{clu}-HET} \leq 4$ 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
Physics at KLOE-2: $\pi^0$ Search

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Bckg simulation based on machine bckg meas is in progress

Bckg meas is being done run by run using an “untagged” data sample containing events out of the coincidence window with taggers and KLOE
Physics at KLOE-2: $\pi^0$ search

- Bckg estimation done run by run by using an “untagged” data sample (DA events which are out of coincidence window with taggers and with KLOE DAQ)
- Bckg normalization done using the data to bckg ratio in the supposed signal free region (1.1 < $|\Delta T - R/c| < 2.2$ ns)
- No significant excess can be seen in the $P_{tot}$ distribution
- We are addressing some issues that can be the source of lack of signal (HET acceptance, simulation issues, KLOE magnet field)
- In the meanwhile we are carrying out also the analysis of SA events
Conclusions

★ 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
★ We have pre-filtered candidates of single-$\pi^0$ production from $\gamma\gamma$ scattering. A total of about 500 pb$^{-1}$ are being analyzed
★ We are addressing several issues that can be the source of lack of signal
Thank You!
SPARES
The KLOE Detector
The KLOE DC

\[ \sigma_{xy} \sim 150\mu m \]
\[ \sigma_z = 2\text{mm} \]
\[ \sigma_{p \perp } / p \perp \sim 0.4\% \text{ (LA tracks)} \]
vertex resolution \( \sim 3\text{mm} \)

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

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

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

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 $\gamma$'s from IP from $21^\circ$ to $10^\circ$

**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 scintillator hodoscope + Xilinx Virtex-5 FPGA
Operation of the HET detector

2015 HET ele
blue: measurements
red: expectation

Number of counts in 0.15 s: HET - electron side

2016

2015 HET pos
blue: measurements
red: expectation

Number of counts in 0.15 s: HET - positron side

2016

Electron
Positron

Counts in 0.15 s

Normal runs
No-collision mode

Touschek/tot. count. rate

2015
2016
Operation of the HET detector

**2016**

No coll. run - HET ele

Ele current

No coll. run - HET pos

Pos current
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 efficiency on 70 MeV energy photons is of about 80%.

The simulated experimental distributions take into account calorimeter energy resolution and trigger threshold as measured on control samples of radiative Bhabhas.
Gent4 toolkit used to transport lepton through the DAΦNE magnetic lattice from IP up to HET position locate after 11 m

KLOE axial B field produce vertical shift \((e^+, e^-)\) of off energy leptons
HET Expected events with $L_{\text{int}} = 5 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma$ (pb)</th>
<th>HET Acceptance</th>
<th>$\sigma_{\text{eff}}$ (pb)</th>
<th>$N_{\text{ev}}$ (events)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma$</td>
<td>Single Arm</td>
<td>Double Arm</td>
<td>$\sigma_{\text{eff}}$</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow e^+e^-\pi^0$</td>
<td>273.4</td>
<td>7.9 % - 1.0 %</td>
<td>21.81 - 2.71</td>
<td>109050 - 13550</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow e^+e^-\pi^0\pi^0$</td>
<td>11.7</td>
<td>6.5 % - 0 %</td>
<td>0.76 - 0</td>
<td>3800 - 0</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow e^+e^-\pi^+\pi^-$</td>
<td>749.7</td>
<td>5.8 % - 0 %</td>
<td>43.5 - 0</td>
<td>217500 - 0</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$</td>
<td>11.5 nb</td>
<td>10.1 % - 0 %</td>
<td>1160 - 0</td>
<td>5827700 - 0</td>
</tr>
</tbody>
</table>

KLOE Trigger Efficiency should be included