The High Energy Tagger for $\gamma \gamma$ physics at KLOE-2

presented by

Francesco Gonnella

Università e INFN Roma “Tor Vergata”
Summary

- Short introduction about $\gamma\gamma$ physics and $\sigma$ meson;

- Tagging system at KLOE-2: LET and HET;

- The HET detector;

- Test beam results.
$\gamma\gamma$ physics

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

where $X = \{ \pi\pi, \pi^0, \eta \}$

- $J^{PC}(X) = 0^{++}, 2^{++}$
  ($J^{PC} = 1^{-}$ for single $\gamma$ case)

- $\sigma \propto \alpha^4 \ln^2(s)$
  ($\alpha^2/s$ for single $\gamma$ case)

- Similar to bremsstrahlung
  $N_X \propto 1/E\gamma \rightarrow$ low $M_X$

\[ \frac{dN_X}{dW_{\gamma\gamma}} = L_{ee} \frac{dL}{dW_{\gamma\gamma}} \sigma (\gamma\gamma \rightarrow X) \]
There are many theoretical indications for the existence of the $\sigma$ meson.

What structure? (2-quark, 4-quark, …)

Experimental situation claims for new measurements in the $2\pi$-threshold region.

**Mass and Width of the Lowest Resonance in QCD**

I. Caprini

National Institute of Physics and Nuclear Engineering, Bucharest, R-077125 Romania

G. Colangelo and H. Leutwyler

Institute for Theoretical Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland

(Received 29 December 2005; published 5 April 2006)

We demonstrate that near the threshold, the $\pi\pi$ scattering amplitude contains a pole with the quantum numbers of the vacuum—commonly referred to as the $\sigma$—and determine its mass and width within small uncertainties. Our derivation does not involve models or parametrizations but relies on a straightforward calculation:

$$M_\sigma = 441^{+16}_{-8} \text{ MeV}, \quad \Gamma_\sigma = 544^{+18}_{-23} \text{ MeV}.$$
Why we need tagging

### Counting rate \( \gamma \gamma \)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Events ( (L = 10 \text{ fb}^{-1}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0 )</td>
<td>( 2 \times 10^4 )</td>
</tr>
<tr>
<td>( e^+ e^- \rightarrow e^+ e^- \pi^+ \pi^- )</td>
<td>( 2 \times 10^6 )</td>
</tr>
<tr>
<td>( e^+ e^- \rightarrow e^+ e^- \eta )</td>
<td>( 1 \times 10^6 )</td>
</tr>
<tr>
<td>( e^+ e^- \rightarrow e^+ e^- \pi^0 )</td>
<td>( 4 \times 10^6 )</td>
</tr>
</tbody>
</table>

### Background from \( \phi \) decay

<table>
<thead>
<tr>
<th>( K_S(\pi^0 \pi^0) K_L )</th>
<th>Missing</th>
<th>Events</th>
<th>BG for</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_S(\pi^+ \pi^-) K_L )</td>
<td>( K_L )</td>
<td>( \sim 10^9 )</td>
<td>( \pi^0 \pi^0 )</td>
</tr>
<tr>
<td>( \pi^+ \pi^- \pi^0 )</td>
<td>( \pi^0 )</td>
<td>( \sim 2 \times 10^9 )</td>
<td>( \pi^+ \pi^- )</td>
</tr>
<tr>
<td>( \eta(\gamma \gamma) \gamma )</td>
<td>( \gamma )</td>
<td>( \sim 10^8 )</td>
<td>( \eta )</td>
</tr>
<tr>
<td>( \pi^0(\gamma \gamma) \gamma )</td>
<td>( \gamma )</td>
<td>( \sim 5 \times 10^8 )</td>
<td>( \pi^0 )</td>
</tr>
</tbody>
</table>

With no tagging one can apply kinematical cuts based on the \( P_T \) but cuts provide only a rejection factor of 100.

**A tagging is needed on \( \phi \)-peak**
KLOE at $s = 1$ GeV$^2$ (no tagging)

- Search for $\gamma \gamma \rightarrow \pi^0\pi^0$ events in progress with KLOE;
- 200 pb-1 of off-peak data available;
- 11 pb-1 used without requiring any offline filters;
- First look at data: invariant mass of 4 photons;
- Events with 5 and 6 photons were used as BG control samples.

The Analysis are based on $\gamma$ energy, angle, $P_t$, $M\pi^0$
**γγ-physics with tagging at KLOE**

\[ e^+ e^- \rightarrow e^+ e^- + \gamma^* \gamma^* \rightarrow e^+ e^- + \pi^0\pi^0 \]

- Use Daφne magnets as a spectrometer to measure \(e^+e^-\) (tagging);
- We need knowledge of machine layout and simulation of trajectories of the off-energy particles.

---

**LET** (200 MeV region)

**HET** (450 MeV region)

inside KLOE to Tagger
\gamma \gamma - event generators (1)

- **Courau generator:**
  The reaction is divided in 2 subreactions:
  - Bremsstrahlung photon emission:
    \[ e^+ e^- \rightarrow e^+ e^- + \gamma \gamma \]
  - Pion production:
    \[ \gamma \gamma \rightarrow \pi^0 \pi^0 \]
  
  We made use of a 2-loop Chiral Perturbation Theory Cross Section [Gasser, Ivanov, Sainio, Nucl. Phys.B, B728, 31 (2005)]

- **Nguyen, Piccinini, Polosa**
  This MC code treats the reaction: \[ e^+ e^- \rightarrow e^+ e^- + \pi^0 \pi^0 \]
  by mean of the four kinematics with the inclusion of a \( \sigma \) particle as a Breit-Wigner resonance

- **TREPS: Montecarlo generator from Belle**
  This MC code, called TREPS, is an event-generator for two-photon processes at e\(^+\)e\(^-\) colliders. TREPS uses an EPA in which the virtuality of photons is taken into account.
Energy Spectra

Difference with respect to TREPS

Courau
Nguyen Piccinini Polosa
TREPS

TREPS - Courau
TREPS - NPP
Simulation of trajectories in DAΦNE

- MAD works at nominal beam energy and consider the magnetic elements as thin lens.
- BDSIM works in GEANT and is able to work also at lower momenta.
- Comparison MAD-BDSIM trajectories OK for nominal beam energy. Insertion of KLOE B-field, done up to end of QF1 region.
Electron tracking inside KLOE (LET)

- The low energy leptons from IP reaching LET cross only QD0;
- They are deflected from main orbit since they are off-axis w.r.t. QD0.
Energy distribution for various slices (5 cm) in the LET region
Energy vs angle (LET)

- Distributions evaluated with a sample of $\gamma \gamma \rightarrow \pi^0 \pi^0$ events done with Courau generator + full BDSIM tracking.
- At the same impact position in Z corresponds a broad distribution of energy and angle for the scattered leptons.

We need a colorimeter with high resolution:
LET (Stefano Miscetti’s talk)
Electron tracking outside KLOE (HET)

- The beam-pipe works as an angular filter for scattered leptons.
- After the dipole present at 11 m from the IP, there is a large correlation between the lepton energy and the distance from the beam axis.

**A position detector is enough → resolution of 1 mm → 0.56 MeV**
Angular distribution of the scattered leptons at IP (black) compared to the distribution of the leptons exiting from the dipole (red)

The vacuum chamber acts as an angular filter
Mass coverage of the tagger

- Single arm coverage (1HET (14%), 1LET (17%));
- Single Total acceptance = 54%;
- Double arm coverage (H*H + 2*L*(H)+L*L) = 2+5+3 = 10%.

More than 500 pb⁻¹ of clean γγ physics in Step-0

- Space for a MET possible: (z = 4-9 m, simple position measurement) would extend the coverage of a large factor. Step-1?
HET proposal
The hodoscope is constituted by two rows of 15 scintillators of 3x5x6 mm$^3$; (Pitch resolution ~ 2 mm, 1 MeV/c momentum resolution)

- Two 3x5x120 mm$^3$ scintillators for coincidence;
- Fast EJ-228 scintillators used. Light is transported to photosensor (R9880U-110 sel) with clear optical fibers.
- Light yield in excess of 50 pe/MIP $\rightarrow$ 300 ps resolution which should allow a sharp separation between consecutive bunches.
- Drawing of the moveable station ready and “agreed upon” with accelerator experts;
- Minimum safe distance from beam line is of 3 cm;
- Simple step-motors needed.
Test Beam Setup (BTF @ LNF)

- Two small scintillators (3x6x5 mm$^3$) 1 and 2;
- One long scintillator: (3x6x120 mm$^3$) 3;
- One BGO crystal (for beam energy checking);
Test Beam: ADC results

We made several modifications to the setup and acquired the ADC spectra.

There is no significant signal loss.
Test Beam: TDC results

Time difference between 1 and 2.

- With twisted light guide;
- With twisted light guide, steel box, and splitter;
- With twisted light guide and steel box;
Test Beam: TDC results

- $\sigma = 140$ ps;
- With twisted light guide: $\sigma = 160$ ps;
- With steel box: $\sigma = 160$ ps (the box does nothing);
- With electronic splitter: $\sigma = 280$ ps.
Conclusions

- Simulation of trajectories almost completed (study of the effect of the KLOE B-field and compensators in progress);
- HET prototype exists;
- HET tests yielded the results we expected;
- Big effort to be ready for the installation of the taggers during KLOE roll-in.
Thanks for your attention.