High Performance PbWO₄- Lead Glass Hybrid Calorimeter at Jefferson Lab

M. Kubantsev
ITEP, Moscow, Russia/Northwestern University, Evanston, USA
A. Gasparian
NC A&T State University
Greensboro, NC USA
I. Larin
ITEP, Moscow, Russia
for the
PrimEx Collaboration

Outline

1. Requirements for the Calorimeter
2. The HYCAL calorimeter design
3. Physics run performance
4. Summary.
Requirements for the Calorimeter

Forward electro-photoproduction of neutral mesons ($\pi^0\eta\eta'$) @ 1-10 GeV requires:
- High energy resolution;
- High position resolution;
- Good photon detection efficiency @ few GeV;
- Large geometrical acceptance.

$\pi^0$ life-time measurement at JLab (the PrimEx experiment E-02-103):

$\langle\theta_{Pr}\rangle_{peak} \sim 0.3$ mrad
Design Concept and Resolutions

\( \gamma\gamma \) Invariant Mass Resolution

Angular Resolution

Calor-2006, June 05

M. Kubantsev ITEP/NWU
Design Concept

Resolution
PbWO₄ crystal
+ Detectors

Budget
Pb – glass Cherenkov
detectors
Design Concept

Experimental Setup

with
11 GeV Photon Tagger

HYCAL with veto
Modules:
PWO: 34x34–4 = 1152
LG: 4x6x24 = 576
PbWO$_4$ Crystal Dimensions

Dimensions:

20.5 x 20.5 x 180.0 mm$^3$

Tolerances (mm):

20.5 + 0.0 - 0.1

180.0 + 0.3 -0.0

Specified

Measured
PbWO$_4$ Crystal Optical Properties

Optical Transparency

@ 360 nm

@ 420 nm
HYCAL – The Hybrid Calorimeter

Detector assembly and preparation tests
HYCAL Calibration

Scheme of calorimeter irradiation with tagged photon beam during calibration
HYCAL Energy Resolution

Energy resolution for the PWO crystal central part and lead glass periphery for tagged photons during calibration run.

Calor-2006, June 05
M.Kubantsev ITEP/NWU
HYCAL Energy Resolution

Energy Resolution dependence on coordinate in transition region

Energy resolution (σ), %

E_γ ≈ 5 GeV

Detector coordinate, X, mm

Center of Crystal

Transition region

Center of Glass
HYCAL Position Resolution

Position Reconstruction

Xc Beam Position (mm)

Reconstructed Position in X (mm)

PWO: Dx = 2.2 mm @ 1-3 GeV

LG: Dx = 4 mm @ 1-3 GeV

Center of Crystal

Transition Region

Center of Glass

Logarithmic Method

Center-of-Gravity

Calor-2006, June 05

M.Kubantsev ITEP/NWU
HYCAL Light Monitoring

Light monitoring system with blue LED: stability over period of 500 hours
HYCAL Performance for Physics Processes:

**Compton scattering at small angles mostly (only PWO):**
- $P_t = 0$ constraint
- Angular correlations as additional check of resolution

**$\pi^0$ production and decay to two photons at all angles (PWO and LG):**
- Constraint on mass of $\pi^0$
- Comparison of regions of the HYCAL: PWO, LG, PWO-LG border
HYCAL Resolution for Compton Events:

Ratio of sum of electron and photon energies measured in the calorimeter and tagged \( \gamma \) energy at \( \sim 5.2 \, \text{GeV} \)

- After calibration: \( \sigma = 1.5\% \)
- After \( Pt = 0 \) correction: \( \sigma = 1.1\% \)
- Only coordinate information: \( \sigma = 1.7\% \)

Calor-2006, June 05

M. Kubantsev ITEP/NWU
**HYCAL π⁰ Resolution: PWO**

\[ \sigma = 2.3 \text{ MeV/c}^2 \]

\[ M_{\gamma\gamma}, \text{GeV/c}^2 \]

after calibration

after correction on tagged photon energy: smearing due to coordinate resolution

Calor-2006, June 05

M. Kubantsev ITEP/NWU
HYCAL $\pi^0$ Resolution: PWO-LG Border

$\pi^0$ mass resolution after calibration: one photon in PWO another at the border

$\sigma = 2.6$ MeV/$c^2$

$\sigma = 1.4$ MeV/$c^2$

$M_{\gamma\gamma}$, GeV/$c^2$ after correction on tagged photon energy: smearing due to coordinate resolution

Calor-2006, June 05

M.Kubantsev ITEP/NWU
HYCAL \( \pi^0 \) Resolution: PWO + LG

\( \sigma = 4.5 \text{ MeV/c}^2 \)

\( \sigma = 2.4 \text{ MeV/c}^2 \)

\( \pi^0 \) mass resolution after calibration: one photon in PWO another in LG

\( M_{\gamma\gamma}, \text{GeV/c}^2 \)

after correction on tagged photon energy: smearing due to coordinate resolution
**π⁰ Angular Distribution**
(experiment, preliminary)

![Graph](image)

π⁰ production angle distribution

12C target

Primakoff π⁰

208Pb target

Primakoff π⁰
Summary

- A high performance hybrid PbWO$_4$ calorimeter (~2000 channels) has been developed, constructed and run in PrimEx experiment at JLab.

- HYCAL took physics data in November 2004:
  - Energy and position calibration with tagged photons of 1 – 5.5 GeV
  - $\pi^0$ mass resolution $\sigma_{\pi^0} = 2.3$ MeV (PWO),
    (with energy constraint on the tagger 1.3 MeV)
  - Rich high quality data sets have been collected to extract $\pi^0$ lifetime

- We expect first physics results this summer:
  http://www.jlab.org/primex/

  - This project is supported by the US NSF MRI grant (PHY-0079840)
  - This project is supported by the RFBR Grant 04-02-17466
Spare slides
PbWO$_4$ Detector Response vs. Dose Rate

Relative Rate

Relative Pulse Height (%)

100 102 104 106 108 110

1 10 10$^2$ 10$^3$ 10$^4$ 10$^5$ 10$^6$ 10$^7$

5 KHz

Green – Shanghai
Red – Bogoroditsk

Calor-2006, June 05
M. Kubantsev ITEP/NWU
Reconstruction of photon positions in the transition region between PWO crystal central part and lead glass periphery
HYCAL Position Resolution

Coordinate of the cluster:
\[ X_c = \frac{\sum (x_i w_i)}{\sum w_i} \]

Center-of-Gravity:
\[ W_i = E_i \]

Logarithmic:
\[ W_i = 4.2 + \ln\left(\frac{E_i}{E_9}\right) \]