Photon Detector with PbWO₄ Crystals and APD Readout

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- Presentation Outline -

- physics via photon channels at LHC-ALICE
- calorimeters in relativistic heavy ion experiments
  - working environments and performance requirements
  - best scintillation crystal and readout device candidates
- basic properties of key components
  - PbWO$_4$ crystals
  - avalanche photo diode readout system
- prototypes of PbWO$_4$/ APD calorimeter
  - 1$^{st}$ stage prototypes – 3×3 assemblies
    - basic properties of PbWO$_4$ crystals and APD readout system
  - 2$^{nd}$ stage prototype – 16×16 assembly
    - ALICE-PHOS performance evaluation
- summary and outlook
- Physics via Photon Channels at LHC-ALICE -

✦ photons in relativistic heavy ion experiments
  • vital probes of initial/hot/dense phase of collision system
    • direct thermal photons
    • photon HBT correlations
    • jet quenching
  • experimental virtues
    • photons and neutral mesons measured in same detector
    • particle identification to very high transverse momentum

✦ photons: promising though difficult
  • many interesting physics outcome at RHIC
  • many more waiting at LHC
    • even more powerful tool
      • large direct photon rate up to ~100 GeV
      • large neutral meson ("background") suppression
PHOS: high-granularity high-resolution photon spectrometer
- PbWO$_4$ crystals with APD readout
- $|\eta| < 0.5$, $\Delta\phi \sim 100$ degrees, 17,920 channels
- photons and neutral mesons
- $\gamma$-jet tagging
- Calorimeters in Relativistic Heavy Ion Exp. -

🌞 working environments
- high particle multiplicity
- high particle spatial density
- possibly in (high) magnetic field

🌞 performance requirements
- high two-cluster separation capability with high granularity
- high energy resolution
- energy range from ~100 MeV to ~100 GeV

🌞 best scintillation crystal and readout device candidates
- PbWO$_4$ (PWO)
  - short radiation length
  - small Moliere radius
- avalanche photo diode (APD)
  - magnetic-field resistance
  - compactness
- Basics of PbWO\textsubscript{4} Crystals -

- dense, fast, radiation-hard inorganic scintillator
  - density: 8.28 g/ cm\textsuperscript{3}
  - radiation length: 0.89 cm (shortest as known inorganic scintillator)
  - Moliere radius: 2.2 cm (smallest as known inorganic scintillator)
    - suitable for high-granularity calorimeter
  - refractive index: 2.3

- only a few manufacturers available
  - Furukawa (Japan), North Crystal (Russia), RI&NC (Belarus), …

- optical and scintillating properties investigated
  - transmittance
  - scintillation light yield
    - temperature dependence
  - scintillation decay time
    - ditto
- Japanese PbWO$_4$ Crystals -

- manufactured by Furukawa, Co.

- Density 8.28 [g/cm$^3$]
- Radiation length 0.89 [cm]
- Moliere radius 2.2 [cm]
- Peak emission 420-440 [ns]
- Refractive index 2.3

Y-doped PbWO$_4$

20 x 20 x 200 mm

Transmittance measured with Hitachi U3010 spectrophotometer

ALICE-PHOS operation point

Light Yield vs. Temperature

Mean Decay Time vs. Temperature

Temp. Coefficient: -3.6 [%/°C]

Temp. Coefficient: -3.3 [%/°C]
- PbWO₄ Crystals from Other Manufacturers -

- RI&NC Co. in Minsk, Belarus
  - adopted by CMS
  - investigated; similar properties as Furukawa’s
    - ref. graduation thesis by K.Yokoyama (available only in Japanese)

- North Crystal Co. in Apatity, Russia
  - adopted by ALICE-PHOS
  - further tests at Hiroshima being prepared
- Avalanche Photo Diode Readout System -

◆ advantages over conventional PMT readout
  • magnetic-field resistance
  • compactness
  • low power consumption
  • high quantum efficiency

◆ ALICE-PHOS choices
  • APD: Hamamatsu S8664 (short wavelength enhanced type)
    • basic properties investigated
      • breakdown voltage
      • inverse current
  • pre-amplifier: Bergen/ Hiroshima design
    • final decision on rise time and power consumption soon
- PbWO₄ EMC 1st Stage Prototypes -

- base prototypes - 3×3 assemblies
  - purposes
    - basic properties of PbWO₄ crystals
    - R&D of APD readout system
  - components
    - PbWO₄ crystals: Furukawa (Japan) / RI&NC (Belarus)
    - PMT: Hamamatsu R1450
    - APD: Hamamatsu S8664
    - pre-amplifier: Hiroshima ver.1/2
  - tests in Japan
    - Tohoku-LNS (2002); photons at 0.8 – 1.2 GeV
    - Hiroshima-REFER (2003); electrons at 150 MeV
    - KEK-PS (planned in May/June, 2004); electrons at 1 – 3 GeV
- PbWO$_4$ EMC Basic Properties -

- energy resolution $\sigma_E/E = 2.5\% / \sqrt{E\ [GeV]} \oplus 1.3\%$ with PMT
- position resolution $\sigma_x = 2.3\ mm / \sqrt{E\ [GeV]}$ with PMT
- noise problem with APD at room temperature

![Energy Resolution at Calorimeter](image)

$$E_{\text{total}} = 141\ MeV$$

$$\frac{\sigma}{E_{\text{total}}} = 7.3\% = 2.8\% / \sqrt{E}$$
- PbWO$_4$/ APD EMC 2$^{nd}$ Stage Prototype -

- second stage prototype – 16×16 assembly
  - purposes
    - ALICE-PHOS performance evaluation and final design
  - components
    - PbWO$_4$ crystal: North Crystal (Russia)
    - APD: Hamamatsu S8664
    - pre-amplifier: Hiroshima ver.2
      - 64 channels in fast timing mode
      - 192 channels in low power consumption mode
    - cooled and stabilized at –25 ± 0.1 ºC
  - tests at CERN
    - PS/SPS (2003): electrons and hadrons at 0.6 – 180 GeV
    - more tests at PS/SPS (planned in June – November, 2004)
- ALICE-PHOS Performance Evaluation -

\[ \frac{\sigma_E}{E} = 1.3\% / E \, [\text{GeV}] \oplus 3.6\% / \sqrt{E} \, [\text{GeV}] \oplus 1.1\% \text{ at } -25^\circ \text{C} \]
- Neutral Meson Measurement Capabilities -

- hadron beams at 30 – 70 GeV/c
- copper target of 6 cm thickness
- invariant mass resolution $\sigma_m/m = 7\%$ for $\pi^0$, $3\%$ for $\eta^0$
- Summary and Outlook -

◆ high-granularity high-resolution electromagnetic calorimeter
  - PbWO₄ – scintillating crystal with smallest Moliere radius
  - APD – compact and magnetic-field resistant readout

◆ properties of key components investigated

◆ several prototypes fabricated/ tested in Japan/ Europe
  - energy resolution $\sigma_{E}/E \sim 3 \%/ \sqrt{E}$ [GeV]
  - clear $\pi^0$ and $\eta^0$ peaks observed

◆ first (out of 5) ALICE-PHOS module in 2005
  - $56 \times 64$ Russian PbWO₄ crystals + Japanese APD readout system
  - various R&D/ design/ production work in progress
  - assembly/ commissioning/ tests planned in 2005

◆ ALICE at LHC starting in 2007
- ALICE-PHOS Collaboration -

- CERN
- China (Beijing, Wuhan, Wuhan)
- Czech Republic (Prague)
- Germany (Münster)
- France (Nantes)
- Japan (Hiroshima)
- Norway (Bergen, Oslo)
- Poland (Warsaw)
- Russia (Dubna, Moscow, Protovino, Sarov)