Photon Detector with $PbWO_4$ Crystals and APD Readout

APS “April” Meeting
in
Denver, CO
on
May 4, 2004

presented by
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(Hiroshima University, Japan)
for the
ALICE-PHOS Collaboration

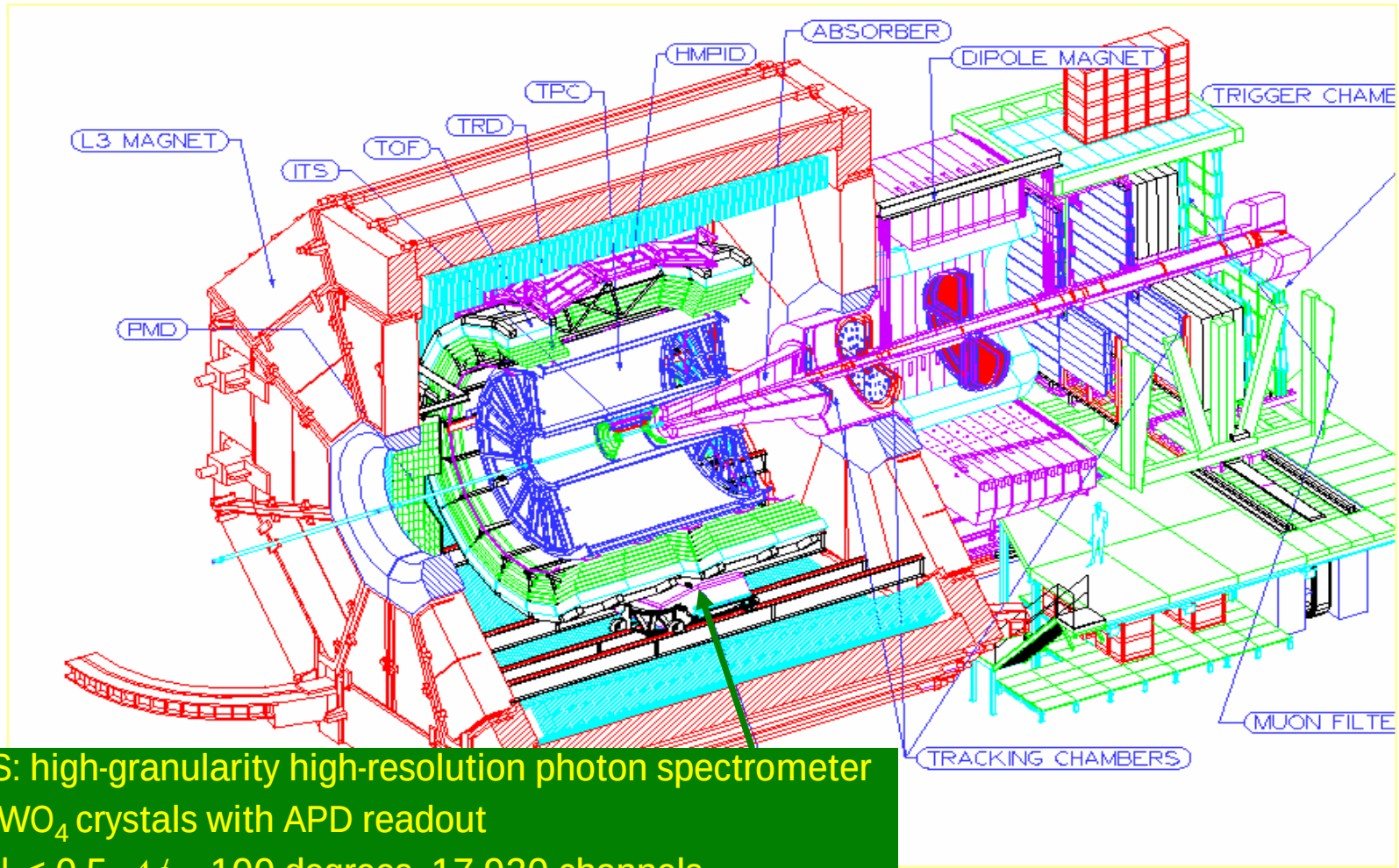
- Presentation Outline -

- 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
  - 1st stage prototypes – 3×3 assemblies
    - basic properties of $PbWO_4$ crystals and APD readout system
  - 2nd 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

- ALICE Photon Spectrometer -



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
- γ-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

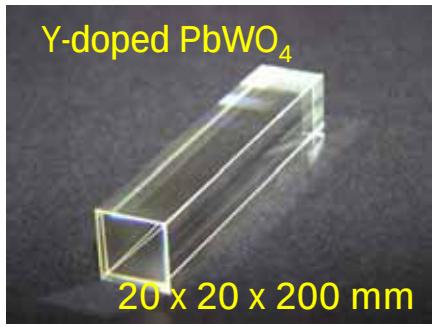
- Basics of $PbWO_4$ Crystals -

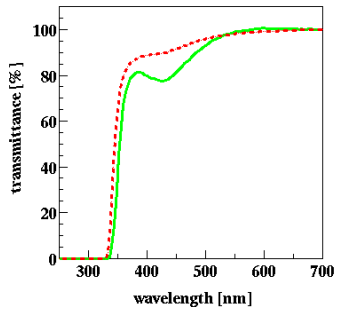
- dense, fast, radiation-hard inorganic scintillator
  - density: 8.28 g/cm^3
  - radiation length: 0.89 cm (shortest as known inorganic scintillator)
  - Moliere radius: 2.2 cm (smallest as known inorganic scintillator)
    - suitable for high-granularity calorimeter
  - refractive index: 2.3
- only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

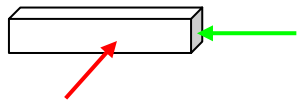
- Japanese $PbWO_4$ Crystals -

- manufactured by Furukawa, Co.

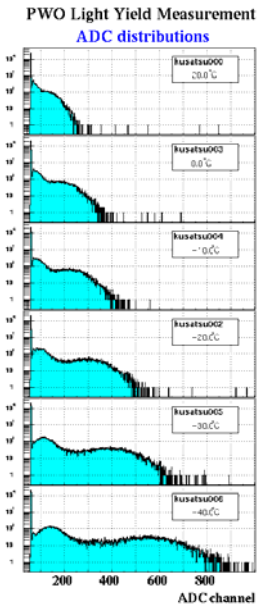
density 8.28 [g/cm³]
radiation length 0.89 [cm]
Moliere radius 2.2 [cm]
peak emission 420-440 [ns]
refractive index 2.3

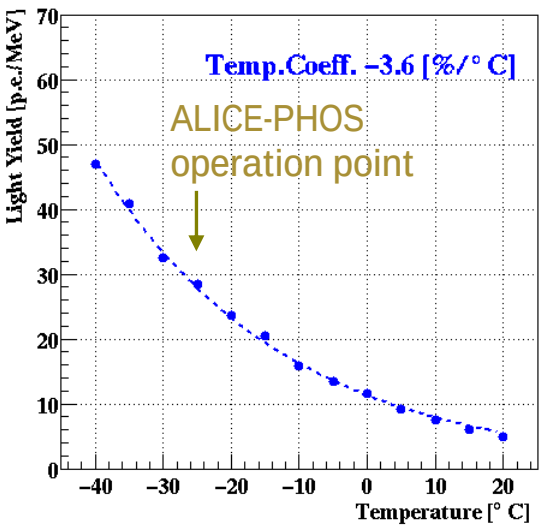




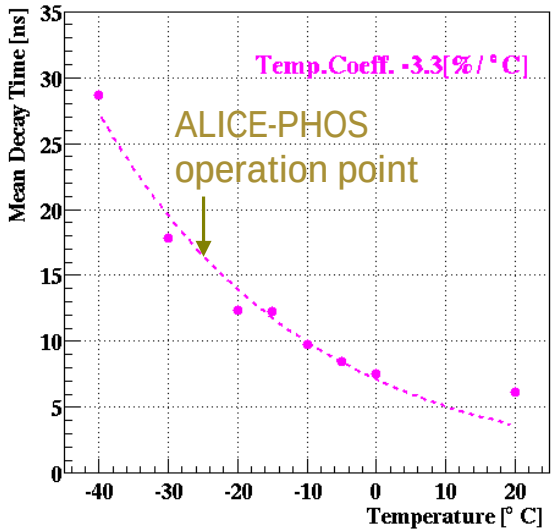


transmittance
measured with
Hitachi U3010
spectrophotometer

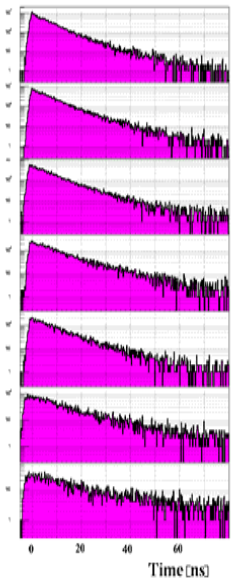




light yield

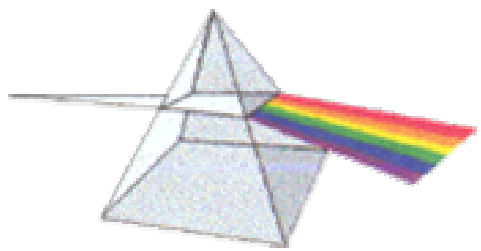


mean decay time



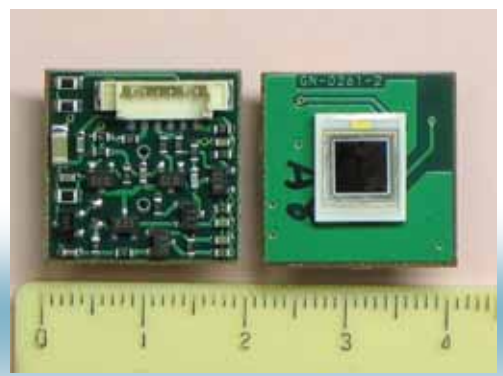
- $PbWO_4$ Crystals from Other Manufacturers -

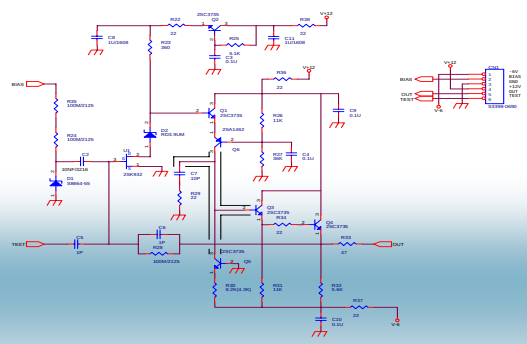
- RI&NC Co. in Minsk, Belarus
  - adopted by CMS
  - investigated; similar properties as Furukawa's
    - *ref.* graduation thesis by K.Yokoyama *(available only in Japanese)*
- North Crystal Co. in Apatity, Russia
  - adopted by ALICE-PHOS
  - further tests at Hiroshima being prepared



- Avalanche Photo Diode Readout System -

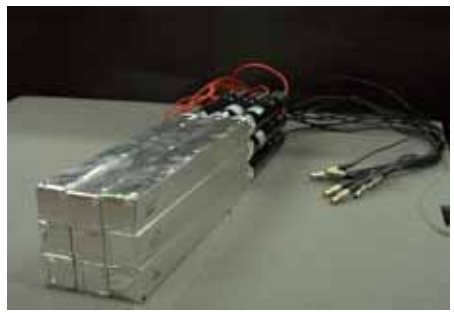
- advantages over conventional PMT readout
  - magnetic-field resistance
  - compactness
  - low power consumption
  - high quantum efficiency
- ALICE-PHOS choices
  - APD: Hamamatsu S8664 (short wavelength enhanced type)
    - basic properties investigated
      - breakdown voltage
      - inverse current
  - pre-amplifier: Bergen/Hiroshima design
    - final decision on rise time and power consumption soon





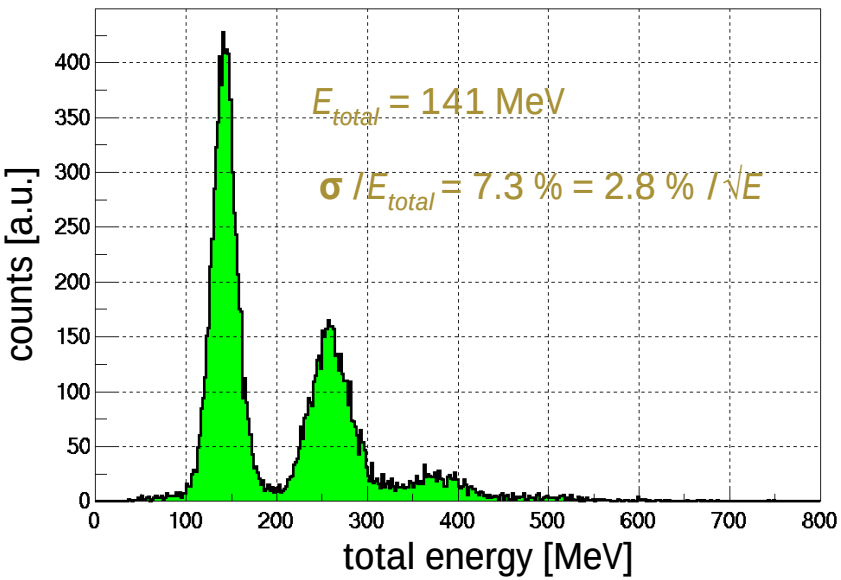
- $PbWO_4$ EMC 1st Stage Prototypes -

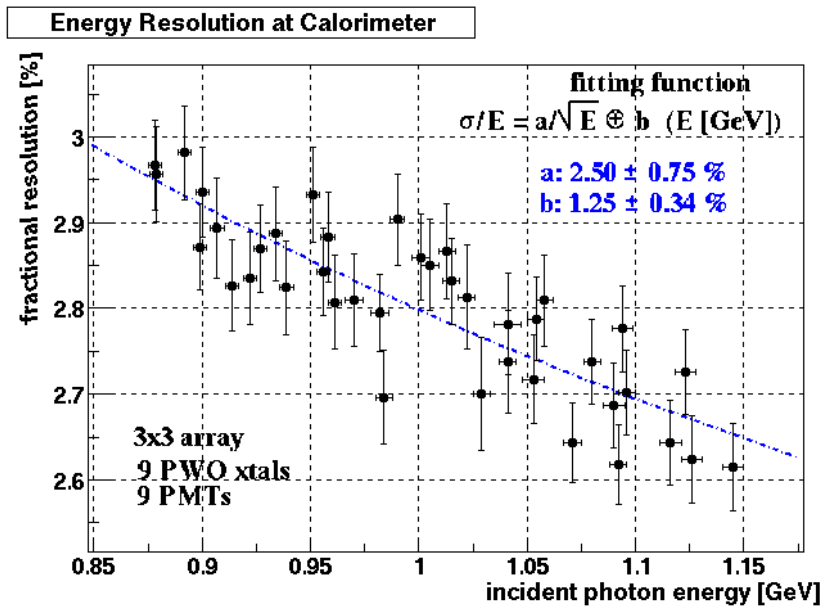
- base prototypes – 3×3 assemblies
  - purposes
    - basic properties of $PbWO_4$ crystals
    - R&D of APD readout system
  - components
    - $PbWO_4$ crystals: Furukawa (Japan) / RI&NC (Belarus)
    - PMT: Hamamatsu R1450
    - APD: Hamamatsu S8664
    - pre-amplifier: Hiroshima ver.1/2
  - tests 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



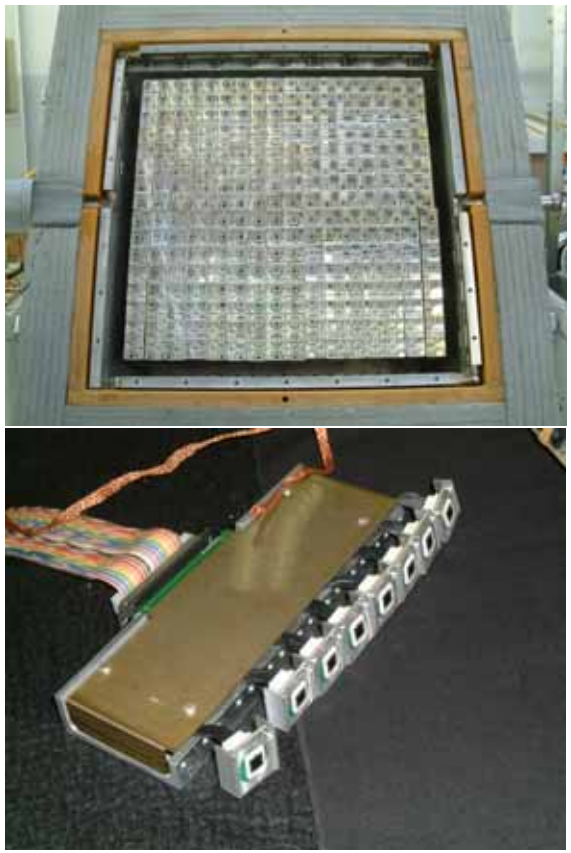


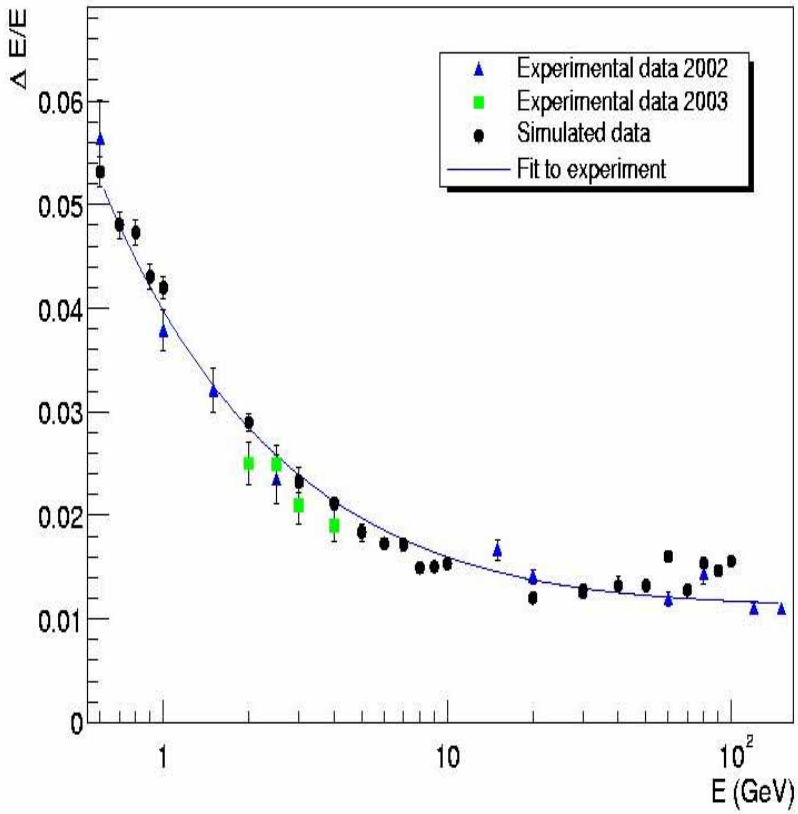
- $PbWO_4$/APD EMC 2nd Stage Prototype -

- 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 -

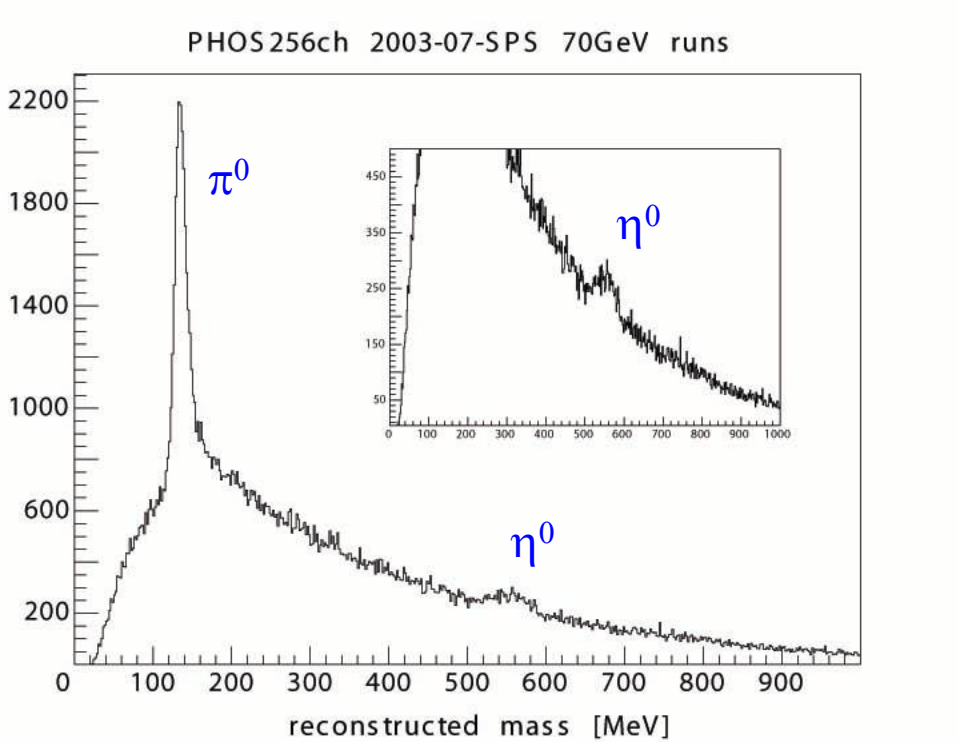
- $\sigma_E/E = 1.3\ \%/E\ [GeV] \oplus 3.6\ \%/\sqrt{E}\ [GeV] \oplus 1.1\ \%$ at – 25 °C





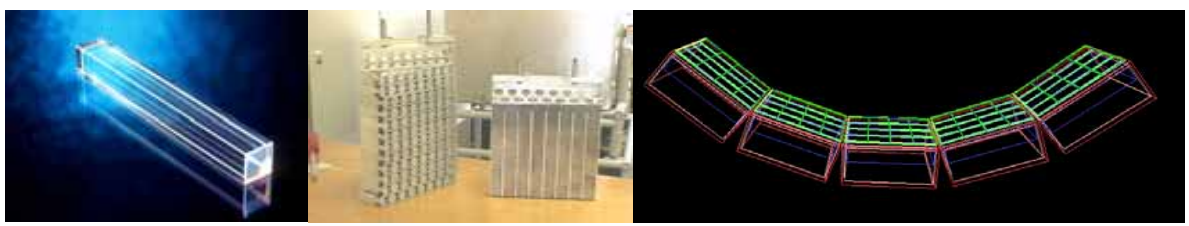
- Neutral Meson Measurement Capabilities -

- hadron beams at 30 – 70 GeV/*c*
- copper target of 6 cm thickness
- invariant mass resolution σ_m/m = 7 % for π^0, 3 % for η^0



- Summary and Outlook -

- high-granularity high-resolution electromagnetic calorimeter
  - $PbWO_4$ – 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 π^0 and η^0 peaks observed
- first (out of 5) ALICE-PHOS module in 2005
  - 56×64 Russian $PbWO_4$ 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)

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- Norway (Bergen, Oslo)
- Poland (Warsaw)
- Russia (Dubna, Moscow, Protovino, Sarov)