The Electromagnetic Calorimeter for the Target Spectrometer

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CALOR 2018
FAIR - Future Facility for Antiproton and Ion Research near Darmstadt
FAIR - Future Facility for Antiproton and Ion Research near Darmstadt

- FAIR a unique facility: various physics programs can be operated in parallel
  - APPA, CBM, NUSTAR …
- Primary beams:
  - Protons up to 30 GeV/c
  - Heavy ions up to 35 GeV/c (U^{92+})
- Secondary beams:
  - Radioactive isotopes
  - Antiprotons up to 15 GeV/c
    - High-energy storage ring (HESR) with stochastic and electron cooling
      - High resolution down to $\Delta p/p = 4 \times 10^{-5}$
      - High luminosity up to $10^{32}$ cm$^{-2}$ s$^{-1}$
- **PANDA @ HESR** will be one of the key experiments at FAIR
Physics program of PANDA:

- Charmonium spectroscopy
- Gluonic excitations
- In-medium effects of hadronic particles
- Open-charm spectroscopy
- Hypernuclei
- Electromagnetic processes
PANDA Setup

- Cooled antiproton beams between 1.5 GeV/c and 15 GeV/c

- Fixed target experiment
  - Hydrogen and other

- High luminosity
  $10^{32}$ cm$^{-2}$s$^{-1}$

- Magnets
  - Forward 2 Tm dipole
  - Interaction region 2 T
• Final states with many $e^+$, $e^-$ and $\gamma$ are the prime signals

→ High geometrical acceptance needed

(\textit{with forward spectrometer: }4\pi)

• Inside 2 T superconducting magnet

→ Compact

• High interaction rates up to $10^7 \text{ s}^{-1}$

→ Fast response

• Annual dose up to 30 Gy

→ Radiation hard

• Effective background rejection

→ Good energy resolution over huge dynamic range from 10 MeV up to 15 GeV
Target Calorimeter

- Based on 15,740 high quality PWO-II (PbWO$_4$) crystals
  - Small radiation length $X_0= 0.89$ cm
  - Short decay time $\tau=6.5$ ns
- Physics goals require improved scintillators

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PWO-I (CMS)</th>
<th>PWO-II (PANDA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>luminescence maximum, nm</td>
<td>420</td>
<td>420</td>
</tr>
<tr>
<td>La, Y concentration level, ppm</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>expected energy range of EMC</td>
<td>150MeV - 1TeV</td>
<td>10MeV - 10GeV</td>
</tr>
<tr>
<td>light yield, phe/MeV at room temperature</td>
<td>8-12</td>
<td>17-22</td>
</tr>
<tr>
<td>EMC operating temperature, °C</td>
<td>+18</td>
<td>-25</td>
</tr>
<tr>
<td>energy resolution of EMC at 1GeV, %</td>
<td>3,4</td>
<td>2,0</td>
</tr>
</tbody>
</table>

increases LY ~4x further
- PANDA Target Calorimeter - Scintillator Material -

- Main part produced at BCTP (Bogoroditsk Plant of Technochemical Products, Russia)

- Missing 41% of the crystals will be produced at Crytur (Czech Republic)
  - Up to now: 150 preproduction PWO-II crystals in PANDA geometry
    - All crystals have been tested at the facilities at Giessen in order to compare the results to the required specifications for PANDA
      - Scintillation yield and kinetics
      - Optical transmission
      - Radiation hardness
Almost all preproduction crystals pass the requested spec. limits:

- $\text{LY@18}^\circ\text{C} > 16 \text{ phe/MeV}$
- $\text{LY(100ns)/LY(1\mu s)} > 0.9$
Measured along full length:

- No color centers visible
- Stable absorption edge

PANDA specification limits:

- T @ 620 nm > 70 %
- T @ 420 nm > 60 %
- T @ 360 nm > 35 %
• Set of five $^{60}$Co sources
• Crystals irradiated with a dose of 30 Gy within 26 minutes
• Transmission measurement started 30 minutes after irradiation
• Absorption coefficient ($k$) has been calculated to take crystal dimensions into account $I(x) = I_0 \cdot e^{-kx}$
• $\Delta k = k_{\text{after rad.}} - k_{\text{before rad.}}$
PANDA specification:

- $\Delta k \leq 1.1 \, \text{m}^{-1}$ (room temp. & 30 Gy)
Prototype Tests

Objectives reached, especially at low energies
Assembly of:

- 710 Crystals in 11 different geometries
- 1420 matched APDs after 1st screening, gamma irradiation, 2nd screening.
- 360 left- and 360 right-handed APFEL-ASIC flex PCBs
- 178x3 Backplanes for
  - HV distribution and individual adjustments
  - Connection of signal cables, slow control…

More than 4500 m of signal cables.
Assembly Procedure - Detector Preparations

- **Gluing:**
  - Cleanroom environment
  - Rad. hard optical glue
  - Several stations available for precise and parallel processing
  - At the moment:
    - 40 crystals per week (one module block)
    - 3 slices per year
  - Reflective foil wrapping
    - Precise laser-cut foils
  - 3D printed capsules
• Crystals inserted into carbon fiber alveoles
• 18 differently shaped alveoli are necessary from 7(-) to 11 (+)
• PWO-II $\Delta L/Y^\circ C = 3\%$
  • Precise temperature monitoring of whole cooled volume necessary
  • TDR $\Delta T < 0.1\, ^\circ C$
  • Special ultrathin temperature sensors developed
    • Thickness < 160 µm
ASIC insert will be glued to carbon alveole

APD capsule

electronic boards

support beam

support feet

preamplifiers

alveoles insert

crystals with APDs

carbon alveoles

front thermal shield

Assembly Procedure - Modules Readout -

22 May 2018
Assembly Procedure - Supermodules & Slice -

Supermodule assembly
Slice assembly
Slice test turning device

transportation & lifting unit
Assembly Procedure - Supermodules & Slice -

- Backplanes will sit inside support beam
- Thermal insulation feet between cooled crystal volume and support beam
Assembly Procedure - Light Pulser Monitoring -

- **Light Pulser Monitoring** for stable operation during experiments

**typical PbWO$_4$ crystal**

- **expected annual dose**

**no thermal annealing** at -25°C / -13°F

- light yield loss due to rad. damage will be annealed with high power LEDs on every crystal

- for stable operation during experiments online monitoring system

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22 May 2018

-Markus Moritz-

Justus-Liebig-University Giessen
Assembly Procedure - Barrel Backplanes -

- Present design: 3 Layers
  - HV distribution & regulation
    - Adjust bias voltage of 8 APDs
    - 50V from HV input downwards in < 0.1V steps
  - All channels fed from the same HV source
  - Online measurement of APD voltage and current
- Connector board for ultrathin custom signal cables
- Board for FlexPCBs / ASICS
  - Connectors to FEs
  - 8x2 Diff. Line drivers
  - APFEL I/F buffers
  - Temp/Humidity sensors

4-ch prototype
• **Crystals:**
  - Crytur produced 150 promising preproduction crystals
    - In the beginning some rejection mainly due to rad. hardness
    - All other: already used to build the PANDA detector
  
  Mass production of the crystals (for the second slice) will start this year

• **Barrel:**
  - First slice of the Target Spectrometer Calorimeter is assembled
  
  Mass production of the mechanics will start this year
Thank you for your attention.

Collaboration

more than 700 physicists from 70 institutions in 19 countries
-BACKUP SLIDES-
PANDA Target Calorimeter
Scintillatormaterial – Optical Transmission -

transmission 420 nm / %

crystal number

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PANDA Target Calorimeter – Readout

- Barrel & Backward End Cap: LAAPDs
- Forward End Cap
  - Outside: LAAPDs
  - Inside: VPTTs
    - Very high count rates
    - Only 1.05 T

<table>
<thead>
<tr>
<th>VPTT</th>
<th>LAAPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE / %</td>
<td>23</td>
</tr>
<tr>
<td>active area / mm²</td>
<td>200</td>
</tr>
<tr>
<td>dark current / nA</td>
<td>&lt;1</td>
</tr>
<tr>
<td>gain</td>
<td>50</td>
</tr>
<tr>
<td>capacity / pF</td>
<td>22</td>
</tr>
</tbody>
</table>
\[ \frac{\sigma}{E} = \frac{a}{E/\text{GeV}} \oplus \frac{b}{\sqrt{E/\text{GeV}}} \oplus c \]

<table>
<thead>
<tr>
<th>case</th>
<th>ADC</th>
<th>thresh. /MeV</th>
<th>a in %</th>
<th>b in %</th>
<th>c in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROTO 60 (type 6)</td>
<td>peak sensing</td>
<td>1.0</td>
<td>0.15</td>
<td>2.16</td>
<td>1.47</td>
</tr>
<tr>
<td>PROTO 60 (type 6)</td>
<td>peak sensing</td>
<td>2.8</td>
<td>0.32</td>
<td>2.11</td>
<td>1.6</td>
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<tr>
<td>PROTO 60 (type 6) [KBD11]</td>
<td>sampling</td>
<td>2.0</td>
<td>&lt; 10(^{-4})</td>
<td>2.01</td>
<td>1.66</td>
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<tr>
<td>PROTO 120 polished</td>
<td>sampling</td>
<td>2.8</td>
<td>0.34</td>
<td>2.07</td>
<td>2.18</td>
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<tr>
<td>PROTO 120 de-polished</td>
<td>sampling</td>
<td>2.8</td>
<td>0.27</td>
<td>2.30</td>
<td>0.5</td>
</tr>
<tr>
<td>straight crystals [NDD08]</td>
<td>peak sensing</td>
<td>1.0</td>
<td>&lt; 10(^{-4})</td>
<td>2.10</td>
<td>1.1</td>
</tr>
</tbody>
</table>

![Graph showing energy resolution](image)
Special Ultra-thin differential cables developed in corporation with company BEDEA (Germany)
Barrel Prototypes - PROTO60 -

- First prototype for the Barrel EMC
- 60 PbWO$_4$ crystals Type 6 geometry
- Operation temp.: -25°C
- Housing:
  - Thermally insulated
  - Flushed with dry nitrogen
- One LAAPD ($10\times10$ mm$^2$) per crystal
- Discrete charge preamplifier:
  - Commercial J-FET transistors
  - Low noise
  - Low power
Energy Resolution Achieved With Peak Sensing ADCs

\[ \sigma = \frac{2\%}{E/\text{GeV}} + 1\%^2 \]

\[ \sigma = \sqrt{\left( \frac{1.86}{E/\text{GeV}} \right)^2 + \left( \frac{0.25}{E/\text{GeV}} \right)^2 + 1.46^2} \]

2.38\% @ 1 \text{ GeV}
• Close to final design
• 120 PbWO$_4$ crystals
• Operation temp.: -25°C
• Readout:
  • 2 LAAPDs per crystal
  • APFEL ASIC
    • High dynamic range
    • High count rates
    • Low power consumption
  • Sampling ADCs