Calorimetry for EIC detector

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EIC detector

Barel EM calorimeter – e⁻/h, γ/π⁰

eForward EM calorimeter – e/π

iForward EM calorimeter – e/h (jets with HC), γ/π⁰

Solenoid yoke + Hadronic Calorimeter

Solenoid yoke + Muon Detector

TOF

RICH

RICH

Tracking

EM Calorimeter

HTCC

Electrons

Ions
Physics requirements to EM calorimeters

- **Electron-forward Electromagnetic Calorimeter (EFEC)** –
  - electron identification, should have enough radiation length to absorb up 10 GeV EM showers
  - fine granularity close to the beam

- **Central Barrel Electromagnetic Calorimeter (BEC)**
  - electron identification, $p < 6$ GeV
  - $\pi^0 \rightarrow \gamma\gamma$ identification, $p < 5$ GeV
  - should be compact (tight space) and insensitive to high magnetic field
  - should have fine granularity (distance from IP ~3 m) and high resolution (~4 %)

- **Ion-forward Electromagnetic Calorimeter (IFEC)** –
  - electron-hadron (jet) separation (together with HC), $p < 5$ GeV
  - $\pi^0 \rightarrow \gamma\gamma$ identification, $p \sim 10$ GeV
  - should have fine granularity (distance from IP ~4 m) and high resolution (~4 %)
Kinematics of exclusive final states

4 on 12 GeV

4 on 30 GeV

4 on 250 GeV

\[ ep \rightarrow e'\pi^+ n \]

Challenges –

- $\pi^0/\gamma$ separation in IFEC
- high radiation near beam regions
- high rates near beam regions
Choices for calorimeters

Homogenous calorimeters

- Based on dense materials that are also active in generating the signal
- Archetype is the crystal calorimeter
  - Scintillating crystals (BaF$_2$, PbWO$_4$, CsI, LYSO)
  - Cherenkov radiators (Pb-glass)
- Almost without exception used for EM calorimetry

Sampling calorimeter

- Layers of inactive, dense material (e.g. Pb, W, U) mixed with active layers
- Active layers can be
  - Scintillators (plates or fibers) or Cherenkov in SiO$_2$ fibers
  - Silicon strips
  - Cryogenic noble liquids (Ar, Kr)
  - Gaseous detectors
- The technology for HCAL, but also used in ECAL
## Photon Detectors at LHC

<table>
<thead>
<tr>
<th>Exp.</th>
<th>ATLAS</th>
<th>CMS</th>
<th>ALICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>LAr Barrel</td>
<td>LAr Endcap</td>
<td>ECAL(EB)</td>
</tr>
<tr>
<td>Structure</td>
<td>Liquid Ar</td>
<td>PWO + APD</td>
<td>0&lt;</td>
</tr>
<tr>
<td>Coverage</td>
<td>0&lt;</td>
<td>η</td>
<td>&lt;1.4, 2π</td>
</tr>
<tr>
<td>Granularity</td>
<td>0.003x0.100</td>
<td>0.025x0.100</td>
<td>0.0174x0.0174</td>
</tr>
<tr>
<td>Res.</td>
<td>10%/√E⁺, 0.5%</td>
<td>10%/√E⁺, 0.5%</td>
<td>2.7%/√E⁺, 0.55%</td>
</tr>
</tbody>
</table>
Calorimeters at JLAB

Homogenous calorimeters

- Pb-glass – Hall A and C, Primex (Hall B) $\sigma/E=6%/\sqrt{E}$
- PbF$_2$ – Hall A DVCS, $\sigma/E=4%/\sqrt{E}$
- PbWO$_4$ – Hall B, DVCS (APD readout, high magnetic field), $\sigma/E=4.5%/\sqrt{E}$
  and Primex (PMT readout), $\sigma/E=2.5%/\sqrt{E}$

Sampling calorimeter

- Pb-scintillator plate sandwich – Hall B, $\sigma/E=10%/\sqrt{E}$
- Pb-scintillating fibers – Hall D (SiPM readout, high magnetic field), $\sigma/E=7%/\sqrt{E}$
EFEC

- Area to cover - ~40 m² (similar to CLAS)
- The most economical solution - lead-scintillator sandwich
  - Extruded scintillators with WS fiber readout (CLAS12 PCAL)
  - Will provide required hermeticity and needed granularity
  - Expected energy resolution $\sigma/E = 10\%/\sqrt{E}$
- Somewhat better resolution can be achieved with “shashlyk” type configuration, used in ALICE, LHCb (LHC), HERA-B (DESY), PHENIX (RHIC), PANDA (GSI)
BEC

- Area to cover - ~30 m²
- Should be compact (tight space) with a photodetector insensitive to magnetic field
- Logical choice – crystal calorimeter, such as PbWO₄, with APD (CLAS, CMS, PANDA) or SiPM readout
2. The electromagnetic calorimeter in the target spectrometer

- Magnetic field 2T
- Compact geometry
- Nearly $4\pi$ coverage
- High rate capabilities
- Scintillator
  - Small Radiation length
  - Small Moliere radius
  - Fast response
- Lead tungstate ($\text{PbWO}_4$)
- Photo sensors APD (Barrel)
- VPT (Endcap)
- Energy from 10 MeV to 15 GeV

15552 crystals

Barrel 11360 crystals

Forward Endcap 3600 crystals

Backward Endcap 592 crystals
Optimization of the PbWO$_4$ and increase of the light output

Optimization of the PbWO$_4$ (collaboration RINP, Minsk and the manufacturer BTCP at Bogoroditsk, Russia)

- reduction of defects (oxygen vacancies)
- reduced concentration of La-, Y-Doping
- better selection of raw material
- optimization of production technology

Development of the PWO-II: Light yield increased

- 4x lighter if cooled down
- 3x3 matrix
- 20x20x200mm$^3$
- PM-readout

Response to high energy photons @MAMI, Mainz

LY = 92 p.e./MeV
## Crystals for HEP calorimeters

<table>
<thead>
<tr>
<th>Crystal</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>CsI(Na)</th>
<th>CsI</th>
<th>BaF_2</th>
<th>CeF_3</th>
<th>BGO</th>
<th>PWO(Y)</th>
<th>LSO(Ce)</th>
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</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>3.67</td>
<td>4.51</td>
<td>4.51</td>
<td>4.51</td>
<td>4.89</td>
<td>6.16</td>
<td>7.13</td>
<td>8.3</td>
<td>7.40</td>
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<tr>
<td>Melting Point (°C)</td>
<td>651</td>
<td>621</td>
<td>621</td>
<td>621</td>
<td>1280</td>
<td>1460</td>
<td>1050</td>
<td>1123</td>
<td>2050</td>
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<tr>
<td>Radiation Length (cm)</td>
<td>2.59</td>
<td>1.86</td>
<td>1.86</td>
<td>1.86</td>
<td>2.03</td>
<td>1.70</td>
<td>1.12</td>
<td>0.89</td>
<td>1.14</td>
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<td>Molière Radius (cm)</td>
<td>4.13</td>
<td>3.57</td>
<td>3.57</td>
<td>3.57</td>
<td>3.10</td>
<td>2.41</td>
<td>2.23</td>
<td>2.00</td>
<td>2.07</td>
</tr>
<tr>
<td>Interaction Length (cm)</td>
<td>42.9</td>
<td>39.3</td>
<td>39.3</td>
<td>39.3</td>
<td>30.7</td>
<td>23.2</td>
<td>22.8</td>
<td>20.7</td>
<td>20.9</td>
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<tr>
<td>Refractive Index a</td>
<td>1.85</td>
<td>1.79</td>
<td>1.95</td>
<td>1.95</td>
<td>1.50</td>
<td>1.62</td>
<td>2.15</td>
<td>2.20</td>
<td>1.82</td>
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<tr>
<td>Hygroscopicity</td>
<td>Yes</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Luminescence b (nm)</td>
<td>410</td>
<td>550</td>
<td>420</td>
<td>420</td>
<td>300</td>
<td>340</td>
<td>480</td>
<td>425</td>
<td>402</td>
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<tr>
<td>Decay Time b (ns)</td>
<td>245</td>
<td>1220</td>
<td>690</td>
<td>30</td>
<td>650</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>40</td>
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<tr>
<td>Light Yield b,c (%)</td>
<td>100</td>
<td>165</td>
<td>88</td>
<td>3.6</td>
<td>36</td>
<td>7.3</td>
<td>21</td>
<td>0.3</td>
<td>85</td>
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<tr>
<td>d(LY)/dT b (%/°C)</td>
<td>-0.2</td>
<td>0.4</td>
<td>0.4</td>
<td>-1.4</td>
<td>-1.9</td>
<td>0</td>
<td>-0.9</td>
<td>-2.5</td>
<td>-0.2</td>
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</table>

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Crystal</th>
<th>BaBar</th>
<th>BELLE</th>
<th>BES III</th>
<th>KTeV</th>
<th>(L⁺)</th>
<th>(GEM)</th>
<th>TAPS</th>
<th>L3</th>
<th>BELLE</th>
<th>CMS</th>
<th>ALICE</th>
<th>PANDA</th>
<th>SuperB</th>
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<tbody>
<tr>
<td></td>
<td>Ball</td>
<td></td>
<td></td>
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*a. at peak of emission; b. up/lower row: slow/fast component; c. QE of readout device taken out.*
IFEC

- Area to cover - ~40 m²
- The most demanding in terms performance – wide energy range of particles and requires high resolution
- Challenge - \( \pi^0 / \gamma \) separation, important DVCS/DVMP

Example from CLAS EC

- Crystal calorimeter – continue BEC coverage
- Must find solution for near beam coverage

Efficiency of two photon reconstruction from high energy \( \pi^0 \rightarrow \gamma \gamma \) decays
Near-beam calorimetry

- Challenges – high density and high rate of outgoing particles (especially in ion beam direction) and high radiation

- 1 or 2 bit digital sampling calorimeter (IFEC/HC), e.g. W (absorber) with silicon readout
  - One can increase detector granularity and hence PFA performance while reducing cost.
  - Cheap, robust detectors suitable for the digital version exist and are very attractive: GRPC, µMEGAS, GEM…

- Quartz fiber calorimeter (IFEC/HC)
- Scintillating fiber tungsten powder calorimeter (EFEC)
Summary

- Challenges to EM calorimeters are not too demanding
- Many collider detectors solve bigger issues
- Solutions exist with today's technologies
- Future technologies might give better handle on rates, coverage, triggering, resolution, integration with HCAL
- Some of challenges in PID can be solved combining ECAL and HCAL solutions (in particular IF detector)
Other options (HCAL)

- Novel multi-pixel Geiger mode photodiodes (SiPMs)
  - B-field proof, small, affordable
- High granularity with scintillator at reasonable cost
  - photo-sensors integrated

- Opens revolutionary design options:
  - embedded electronics and calibration system for minimal dead zones
  - thin readout gap
- Granular, compact, hermetic