CHEF 2019

Calorimetry for the High Energy Frontier

CALORIMETERS: Today and for future projects

25 - 29 November 2019, Fukuoka

I. Laktineh

Contact:
http://chef2019.rcapp.kyushu-u.ac.jp
chef2019@epp.phys.kyushu-u.ac.jp

Program Committee:
M. Aleksee (CERN)
M. Asai (SLAC)
D. Barney (CERN)
J. Brau (Univ. of Oregon)
JC Briant (LLR-CNRS/IPP)-Co-Chair
G. De la Taille (Omega-CNRS/IPP)
K. Kawagoe (Kyushu Univ.)
I. Laktineh (IPNL-UCB)-Chair
J. Liu (HEP Beijing)
A. Schopper (CERN)
F. Simon (MPI Munich)

Local Organizing Committee:
D. Jeans (KEK)
K. Kawagoe (Kyushu Univ.)-Chair
W. Ootani (Univ. of Tokyo)
S. Shigematsu (Kyushu Univ.)
T. Suehara (Kyushu Univ.)-Co-Chair
T. Tanabe (Univ. of Tokyo)
T. Yoshioka (Kyushu Univ.)
Large and rich participation
8 sessions

- Nuclear, Astro-Particles and non-collider Physics
- Future detector systems
- Calibration, R&D, TB
- Sensors
- Running performance, upgrade
- Electronics, DAQ
- Simulation, Geant4, PFA
- PID, TB
Running experiments

Calorimeters of the LHC experiments are being upgraded (Phase 1 Upgrade) for RUN3.

Changes are most essentially on the Trigger Level to keep the L1 trigger at the same level as for RUN2 and to cope with the higher PileUP → Electronics & Algorithms.
Running experiments

Most of the LHC experiments have started the preparation for the HL-LHC phase II Upgrade.

\[ \mathcal{L} \sim 7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}, \quad <\mu> \sim 200 \]

In most cases FE Electronics is to be replaced and in some cases the detector itself is to be replaced.

**Challenges:** increased rate and radiation
Radiation Levels and Technology Choices

Driving Layout and Granularity

Active Elements:
Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
"Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
Scintillating tiles with SiPM readout in low-radiation regions of CE-H

Key Parameters:
~215 tonnes per endcap, full system at -30°C
~620m2 Si sensors in ~30000 modules
~6M Si channels, 0.5 or 1cm2 cell size
~400m2 of scintillators in ~4000 boards
~240k scint. channels, 4-30cm2 cell size
Power at end of HL-LHC:
~125 kW per endcap, transferred via front-end DCDC. Two phase CO2 cooling

Electromagn. calorimeter (CE-E):
Si, Cu & CuW & Pb absorbers, 28 layers, 25 X0 & ~1.3λ

Hadronic calorimeter (CE-H):
Si & scintillator, steel absorbers, 22 layers, ~8.5λ
New Front-end electronics for the new Endcap Calorimeters
- Two versions: Silicon and SiPM
- Rad. Tolerant (200 Mrad, $1 \times 10^{16} \text{n}_\text{eq}/\text{cm}^2$)
- Power consumption: 20 mW per channel
- Noise $\sim 0.3 - 0.4 \text{ fC}$
- Charge measurement: 0.2 fC to 10 pC
- Pileup mitigation
  - Fast shaping time (peak<25 ns)
  - Precise timing capability (25 ps binning)
HGCROCV2 overview

Overall chip divided in two symmetrical parts
- 1 half is made of:
  - 39 channels: 18 ch, CM0, Calib, CM1, 18 ch (78 channels in total)
  - Bandgap, voltage reference close to the edge
  - Bias, ADC reference, Master TDC in the middle
  - Main digital block and 3 differential outputs (2x Trigger, 1x Data)

Measurements
- Charge
  - ADC (AGH): peak measurement, 10 bits @ 40 MHz, dynamic range defined by preamplifier gain
  - TDC (IRFU): TOT (Time over Threshold), 12 bits (LSB = 50ps)
- ADC: 0.2 fs resolution. TOT: 2.5 fs resolution
- Time
  - TDC (IRFU): TOA (Time of Arrival), 10 bits (LSB = 25ps)

Two data flows
- DAQ path
  - 512 depth DRAM (CERN), circular buffer
  - Store the ADC, TOT and TOA data
  - 2 DAQ 1.28 Gbps links
- Trigger path
  - Sum of 4 (9) channels, linearization, compression over 7 bits
  - 4 Trigger 1.28 Gbps links

Control
- Fast commands
  - 320 MHz clock and 320 MHz commands
  - A 40 MHz extracted, 5 implemented fast commands
- I2C protocol for slow control

Ancillary blocks
- Bandgap (CERN)
- 10-bits DAC for reference setting
- 11-bits Calibration DAC for characterization and calibration
- PLL (IRFU)
- Adjustable phase for mixed domain

D. Thienpont
Atlas Tile CAL

Long Barrell SD

Extended Barrell SD

Longer cables for PMTs on micro-drawers do not induce extra-noise.

J. Abdallah
**ECAL upgrade: possible options**

<table>
<thead>
<tr>
<th>Homogeneous Crystal</th>
<th>Shashlik Module</th>
<th>Spaghetti Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires long crystal (order 40 cm) to contain 25 $X_0$</td>
<td>Can be made very compact (~ 15-20 cm)</td>
<td>Can be made very compact (~ 15-20 cm)</td>
</tr>
<tr>
<td>Fixed Moliere Radius</td>
<td>Tunable Moliere Radius</td>
<td>Tunable Moliere Radius</td>
</tr>
<tr>
<td>Good energy resolution, few %/$\sqrt{E}$ (but material budget in front of ECAL should be kept at minimum)</td>
<td>Good energy resolution</td>
<td>Challenging optimization to reach good energy resolution</td>
</tr>
<tr>
<td>Very good homogeneity</td>
<td>No radiation-hard WLS fibers (yet) to transport light</td>
<td>Fibers scintillate AND transport light!</td>
</tr>
<tr>
<td>Large volume of crystal $\Rightarrow$ high cost</td>
<td>Some cost optimization possible</td>
<td>Some cost optimization possible</td>
</tr>
</tbody>
</table>

Started R&D on Spaghetti type module (SPACAL)
Belle II inherited Belle CsI(Tl) counters

In total, 8736 CsI(Tl) crystals (6624 in Barrel, 1152 in Fwd. Endcap and 960 in Bwd. Endcap)

Covering $12^\circ < \theta < 155^\circ$ in Lab. frame.

Inner radius = 1250mm.

K. Miyabayashi
\[\pi^0, \eta \rightarrow \gamma \gamma \text{ reconstruction}\]

Peaks from \(\pi^0\) and \(\eta\) are properly seen in two-photon mass spectrum.

K. Miyabayashi
Calorimeters for future colliders: ILC, CLIC, CEPC, FCC....

Many R&D are being followed.

- PFA-based calorimeters with high granularity as the most important feature
- Dual readout
- "Old" concepts that resist....
Si-W ECAL

R. Poeschl, A. Irles

J. Kunath

CORE-MOTHER
CORE-Daughter
Control & Readout Kapton
The IDEA calorimeter

Design of the fully projective fiber calorimeter

Tower segmentation: $\Delta \theta = 1.125^\circ$, $\Delta \phi = 10.0^\circ$
Number of towers in barrel: $40 \times 2 \times 36 = 2880$
Number of towers per endcap: $35 \times 36 = 1260$
Theta coverage up to $\sim 0.100$ rad
FCC-hh Electromagnetic Calorimeter (ECAL)

- Compared to ATLAS, FCC-hh Calo needs finer longitudinal and lateral granularity
  - Optimized for particle flow
  - 8 longitudinal compartments, fine lateral granularity
  - Granularity: $\Delta \eta \times \Delta \phi \approx 0.01 \times 0.01$; first layer $\Delta \eta \times \Delta \phi \approx 0.0025 \times 0.02 \rightarrow \sim 2.5$M channels

- Noble liquid (LAr) as active material
  - Radiation hardness, linearity, uniformity, stability

- Possible only with straight multilayer electrodes (no accordion)
  - Straight absorbers ($Pb +$ stainless steel sheets in EM section)
  - Readout and HV on straight multilayer electrodes (PCBs, 7 layers, 1.2mm thick)

- EM Barrel: Absorbers 50° inclined with respect to radial direction
  - $\rightarrow$ Sampling fraction changes with depth $f_{\text{sampl}} \approx 1/7$ to $1/4$
  - $\rightarrow$ LAr gap 2 x 1.15mm to 2 x 3.09mm
  - $\rightarrow$ Longitudinal segmentation essential to be able to correct!

- EM EndCap (EMEC): Straight Pb + steel absorbers and multilayer electrodes perpendicular to the beam axis

- Hadronic EndCap (HEC) and Forward Calorimeter: Straight Cu absorbers and multilayer electrodes perpendicular to the beam axis
Calorimetry is also a principal actor at lower energies. Important calorimetry developments are being followed @NICA.
Infrastructure

- Migration of HyperNews fora to Discourse •
- Migration of web site to Drupal-8
  - Upgrade from existing Drupal-7 site
- Testing infrastructure in Jenkins •
  - Adoption of Docker containers for testing
  - Versioning of builds through pipelines
- Enhancements to Geant4 GitLab workflow •
  - Addition of code formatting hooks; integration with Coverity analysis; ...
  - Adaptation to new features in future versions of GitLab; study of GitLab CI use
- Build and publication of Docker/Singularity images for releases
- Migration of static preprocessor -D flags to #define/undef directives •
- Modularization of Geant4 Libraries •
  - Global/granular/optional
- Optimization of Data Libraries
  - Simplify data library configuration/location using layered lookup via self-location, single environment variable, UI commands/C++ API
  - Provide C++ API for accessing/parsing data libraries
  - Optimize file access patterns and formats to minimize number of small files opened
Physics Lists for Calorimeters

- Geant4 recommended Physics List is FTFP_BERT
  - For detailed studies of new calorimeter response FTFP_BERT_EMZ may be used
    - More accurate EM physics
    - Substantial slow down of simulation
  - For high energy projectile QGSP_FTFP_BERT may be tried
    - Above 25 GeV QGS string model
- FTF_BIC and QBBC may be recommended for more accurate fragmentation below 1 GeV
- FTFP_INCLXX provides more accurate production and interaction of light ions
  - Is slower than the default physics
- Radioactive decay may be added on top of any Physics List
  - Long lived isomers will be produced and tracked

V. Ivantchenko
Detectors & sensors are the heart of the calorimeters

- New material: new tiles, new crystals...
- R&D on photon detectors Si-PM
GAGG(Gd$_3$Al$_2$Ga$_3$O$_{12}$(Ce)) Crystal

- High density
- High light yield (as high as NaI)
- Fast response

<table>
<thead>
<tr>
<th></th>
<th>GAGG(Ce)</th>
<th>Mg-doped GAGG(Ce)</th>
<th>Undoped CsI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm$^3$)</td>
<td>6.67</td>
<td>6.67</td>
<td>3.67</td>
</tr>
<tr>
<td>Light yield (NaI(Tl)=100)</td>
<td>127</td>
<td>100</td>
<td>1.1</td>
</tr>
<tr>
<td>Decay time (ns)</td>
<td>90</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>Peak emission (mm)</td>
<td>520</td>
<td>520</td>
<td>310</td>
</tr>
</tbody>
</table>
GAGG(Gd₃Al₂Ga₃O₁₂(Ce)) Crystal

- High density
- High light yield (as high as NaI)
- Fast response
<table>
<thead>
<tr>
<th>Company</th>
<th>Hamamatsu</th>
<th>SenSL</th>
<th>NDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Active Area</td>
<td>1mm*1mm</td>
<td>3mm*3mm</td>
<td>3mm*3mm</td>
</tr>
<tr>
<td>Effective Pitch</td>
<td>10μm</td>
<td>35μm</td>
<td>10μm</td>
</tr>
<tr>
<td>Pixel Number</td>
<td>10 K</td>
<td>5 K</td>
<td>90 K</td>
</tr>
<tr>
<td>Recommended Temperature</td>
<td>25°C</td>
<td>21°C</td>
<td>20°C</td>
</tr>
<tr>
<td>Operation Voltage</td>
<td>69.5V</td>
<td>-27V</td>
<td>32.5V</td>
</tr>
<tr>
<td>Gain</td>
<td>5E5</td>
<td>3E6</td>
<td>2E5</td>
</tr>
<tr>
<td>PDF@420nm</td>
<td>10% (+4.5V)</td>
<td>41% (+5V)</td>
<td>31% (+5V)</td>
</tr>
</tbody>
</table>
MPPC PDE Degradation

- Possible cause = “surface damage by VUV-light”
  - Electron-hole pair generated in SiO₂
  - Holes are trapped at interface SiO₂ - Si
  - Accumulated positive charge will reduce electric field near Si surface, which reduces the collection efficiency of charge carrier
    - Note that charge carrier generated within 5nm at Si surface for VUV
- Similar phenomena are known for UV photo diode
  - But degradation happens only with much higher amount of light at room temp.
  - Degradation saturated at certain level
- Still to be understood
  - It seems that the degradation is enhanced at low temperature
  - Degradation can saturate?
A few words

- Impressive works on calibration of running calorimeters
- Readout electronics becomes as important as the detectors/sensors
- 5D calorimeters are becoming the standard
- Beam tests are crucial to improve on calorimeters' performance and understanding
- New PFA algorithms (ARBOR, APRIL) are winning maturity
- There is place for many technologies in the future experiments
Conclusion

I would like to congratulate the speakers for the excellent quality of their presentations and remind them to prepare their paper to be submitted by January 31, 2020.

I would like to thank the local organizing committee for the wonderful organization and hospitality.