Phase-II Plans for ATLAS Liquid Argon Calorimeter Upgrades.

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on behalf of the
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ATLAS Liquid Argon Calorimeters

Endcap Calorimeters & Cryostat

Inserting FCal Assembly into Endcap

Inserting FCal into support tube

EM Cal Structure

Pb Absorber

- Honeycomb spacer &
- Cu/Kapton electrode

HEC Structure

Cu Absorber

- Honeycomb spacer &
- Cu/Kapton electrode

FCal Structure

Electrode Rods

Cu – FCal1
W – FCal2/3

Absorber Matrix

Cu – FCal1
W – FCal2/3

Liquid Argon

LHC Upgrade Schedule

HEC Electronics & FCal Upgrade Decision Tree

Instantaneous luminosity of $5-7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, and 3000 fb^{-1} integrated luminosity

Possible problems with rates and average energy deposits → Could Influence functionality of FCal.

Build up of heavy ions in LAr gap leads to space charge distorting electric field, and HV drop due to current draw. Ionization heat load might lead to LAr boiling.

New FCal designs investigated.

Possibly replace existing FCal or add mini-FCal in front.

Possible problems with long-term radiation damage in cold electronics

May have to replace cold electronics with newer technology

HEC Cold Electronics

~2600 GaAs preamplifier-summing ASICs
– 8 input channels 2 output channels

- 2 stages – 8 preamps, 2 summing-amps
- Large Pre-Amplifier low noise input transistor
- High output impedance – summing signals after pre-amps
- Good performance up to 20 MHz
- External adjustment of Gain and Timing
- Radiation hard 12 year LHC with x10 safety factor
- Low power consumption to avoid LAr boiling

Is this adequate for Hi-Lumi LHC?

Simulated Radiation Levels in ATLAS HEC

- There is some level of uncertainty which should be pointed out
- The simulation was done in 2003 – actual radiation levels uncertain
- Also the geometry of the simulation was not completely accurate
- Assumed “Safety Factor” of 5 to cover these
- Experience with the first years of LHC – compare data and simulation
- Indicates that one can reduce SF to 1.5 for TID and 2 for NIEL
- Lacking new simulation for HEC region – upper limit
- Expect final SF for HEC to be smaller than 5 – to be calculated

Simulated Radiation Levels in ATLAS - NIEL

SAFETY FACTOR expected to be smaller

- Hi-Lumi LHC.
- 14 TeV, $L = 3 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$.
- One LHC year = 10^7 s or 300 fb^{-1} .
- Plot shows NIEL for 1 LHC year in HEC region.
- 10 years running, safety factor of 5.
- Dose received by cold electronics mapped to correspond calorimeter region.

- Simulated neutrons, hadrons ($E > 20 \text{ MeV}$), and total ionization dose since 2008
- 14 TeV, $\sigma_{\text{INEL}} = 79.3 \text{ mb}$, $L = 10^{34} \text{ cm}^{-2} \text{s}^{-1}$
- One LHC year = 10^7 s or 100 fb^{-1} per year
- ASICs are at 204cm and $429 < |z| < 597$

Simulated Radiation Dose in HEC

Hadrons > 20 MeV

Total Ionization Dose

Critical Values

NIEL:

Hadrons > 20 MeV: $5.1 \times 10^{13} \text{ h/cm}^2$

TID:

$4.1 \times 10^{14} \text{ n/cm}^2$

6.2 kGy

Now expected to be smaller

Irradiation Study of HEC Electronics

Hadrons: 200MeV protons at PSI, Switzerland.

NIEL (p,n): 36 MeV protons on D₂O , NPI at Rez near Prague.

Warm:

- DC values.
- S-parameters 300kHz to 400Mz.
- Scope Linearity Scan – 500ns triangular voltage pulses.

Cold:

- n-irradiated after 3 month re-measured S parameters and pulse response in LN2.

S-parameters: scattering

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

S_{11} : Input reflection coefficient

S_{12} : Backward transmission (reverse gain)

S_{21} : Forward transmission (gain)

S_{22} : Output reflection coefficient

In/Out Impedance - Neutrons

Forward Gain

Non-Linearity Measurements

- Non Linearity much worse cold, than warm.
- Characterize non-linearity by empirical power law fit.
- Dotted horizontal line –production QA.
- Systems non-linearity could be compensated by calibration.
- Not possible for summed individual preamps.

Simulation of Effect of GaAs Degradation using Measured S-Parameters

- Full HEC electronics chain using di-jet events.
- Gain loss and non-linearity included.
- Calibration compensates for overall gain change.
- It cannot compensate for non linearity in summed individual preamps.

Alternative Technologies to GaAs have been irradiated

Average gain degradation after irradiation with expected HL-LHC radiation levels:

Technology	Neutron test	Proton test	
	NIEL: $4.1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$	Φ_{had} : $5.1 \cdot 10^{13} \text{ h}/\text{cm}^2$	TID: 6.2 kGy
Si CMOS FET	-0.2%	-2.5%	-0.5%
SiGe Bipolar	-1.0%	-2.7%	-0.5%
GaAs BB96 (warm)	-5.0%	-5.1%	-1.3%
GaAs BB96 (cold)	-15.0%	n/a	n/a

$$10^{13} \text{ p}(200\text{MeV})/\text{cm}^2 \equiv 6\text{kGy} + 10^{13} \text{ n}_{\text{eq}}/\text{cm}^2 \text{ in Si}$$

- Alternative technologies are more radiation hard than existing GaAs
- GaAs degrades, but does not breakdown
- SiGe are bipolar transistors and so require a resistor network to stabilize the working point
- Prefer Fet -> SiCMOS

Forward Calorimeter Issues

The FCal1 has severe issues at the high luminosity foreseen

- The FCal was designed with narrow LAr gaps in order to cope with +ve ion space charge and consequent distortion of electric field in the gap. The +ve ion space charge again becomes critical in FCal1.
- The high rate leads to a high current draw in HV protection resistors. Significant voltage drop effects signal.
- The high rate, and high ionization, also leads to a significantly higher heat load. Possibility of LAr boiling.
- Need new HV resistors, modified FCal geometry.
- The actual approach depends critically on whether the HEC cold preamps have to be changed.

Position of HV Protection Resistors Inside Endcap Cryostat.

Degradation of FCal1 Signal

- +ve ion buildup distorts electric field in gap
- High rate causes voltage drop across resistors

Poor signal quality degrades physics performance.

- Resolution and tails in E_T
- Tagging Forward jets

Test Beam Studies by HiLum Group in ATLAS LAr

- Small simulacra of electrode structures for existing LAr calorimeters.
- Narrow gap structure for FCal1 - 100μ

HEC module

EMEC module

FCal1/sFCal module

FCal1 - 100 μ

- Signals of EMEC, HEC flat to $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- FCal1 (250 μ) already drops at $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- FCal1 (100 μ) stable up to $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

EMEC

FCal 250 μm gap

nominal LHC = $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

HEC

FCal 100 μm gap

FCal Upgrade Scenarii

- Replace existing FCal with new Detector (sFCal)
  - Easier to optimize design
  - Requires opening cryostat
  - Could only be done in long shutdown
  - If HEC cold electronics replaced – Remove Rear Cryostat cover
  - If HEC cold Electronics NOT replaced – Remove only FCal assembly
- Do NOT replace FCal – small device in front of existing FCal – miniFCal
  - Absorbs particle flux at high μ - solves ionization issue in existing FCal1
  - Must be an extremely radiation hard device:
  - Cold - Independent FCal1-style LAr calorimeter with 100 μ gaps
  - Warm – Diamond sensor
  - Warm – High pressure xenon gas
  - Warm – Some other technology

REMOVE COLD COVER TO EXPOSE REAR FACE OF HEC2

Removal of Endcap rear cover to remove HEC

Remove FCal Only

Complete FCal Replacement

- Essentially same design as present FCal
- Reduced LAr gaps (100/200/300 μ)
- HILUM beam tests show this will cope with Hi-Lumi LHC
- Heat load requires new LN₂ cooling pipes.

- Present summing boards with 1 (2) M Ω resistors replaced with 10 x smaller values
- If HEC is removed – replace present boards
- If only FCal removed
  - New boards on rear of FCal
  - Some gymnastics to get cables out

Mini-FCal Approach

- Absorber in front of FCal1 solves ionization load problem.
- Must be active calorimeter to maintain physics performance.

- Does not require opening of cryostat.
- Load must be supported by forward cone.
- Technically simplest if HEC cold electronics not replaced.
- Requires an extremely radiation hard device.

Hot Regions, Total Neutrons, with/without MiniFCal

Units: kHz/cm²

Strawman
MiniFCal –
11 Gaps

No
MiniFCal

In these GCalor simulations, neutrons are propagated down to thermal energies. The MiniFCal intercepts much of the forward neutron flux.

pCVD Diamond Sensors

Copper Absorber Planes

- Warm calorimeter $\sim 18.8 \chi_0$.
- Copper absorber.
- Diamond sensors on ceramic plate.
- Radiation damage varies over volume – varying response.
- Signal drops to 5% after nominal HL-LHC exposure.
- Extremely expensive.
- Manufacturer of tested sensor out of business.

Warm – High Pressure Xenon Calorimeter

- Has to be constructed of rad-hard materials.
- High pressure up to 10 bar needed for adequate energy resolution.

- R&D Required.
- No data on Xe properties above ~ 1 bar.
- In order to understand space charge:
  - Mobility.
  - Recombination rate – field dependent.
- Gas handling for radio-activated high pressure gas.

LAr Mini-FCal

Signal and HV cables inside cryoline

- 100 μ gap copper FCal1.
- Independent cryostat in vacuum space between new warm tube, and front of existing cryostat- common warm wall.
- Well understood, conservative technology.
- Main issues are engineering, in order to minimize material in front of mini-FCal.
  - Cryo-lines.
  - Signal feed-throughs.

Summary

- Existing FCal performance will seriously degrade at the HL-LHC.
- Possible actions:
  - Do nothing – accept performance loss – need to study.
  - If HEC cold electronics replaced:
    - Replace FCal with sFCal.
    - Replace old summing boards with new boards, 10x lower HV protection resistors.
  - If HEC cold electronics not replaced:
    - Remove FCal, replace with sFCal with integral new summing boards.
    - Leave existing FCal
    - Install mini-FCal – need to decide on acceptable technology
  - sFCal R&D and construction ~7 years
  - Start in 2015 – decision by end of 2014

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