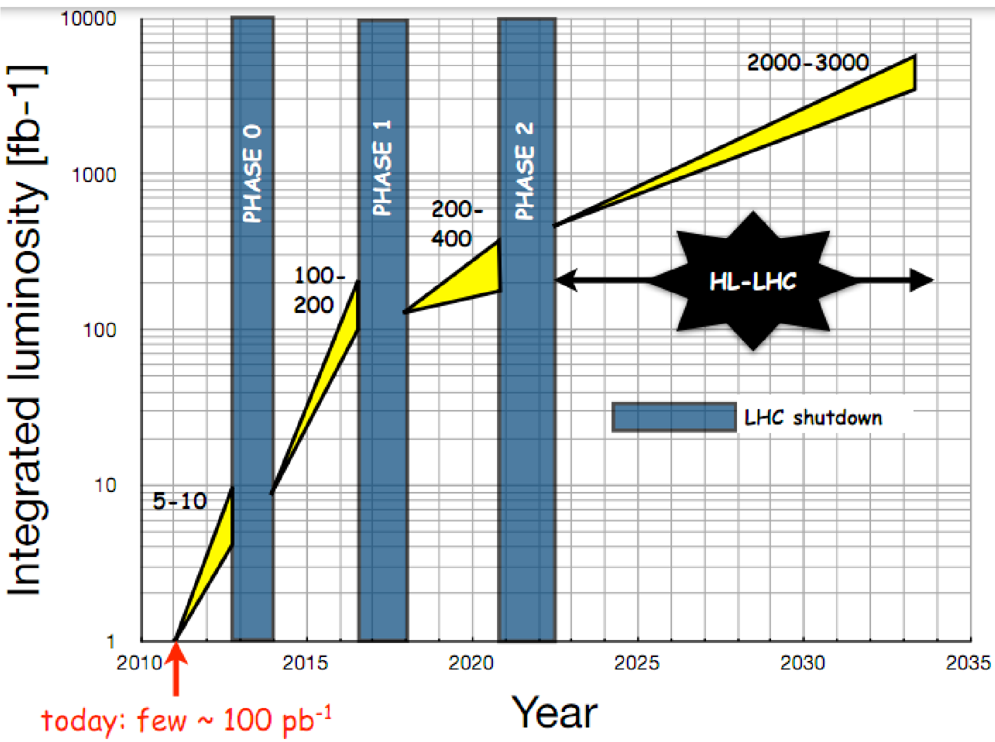
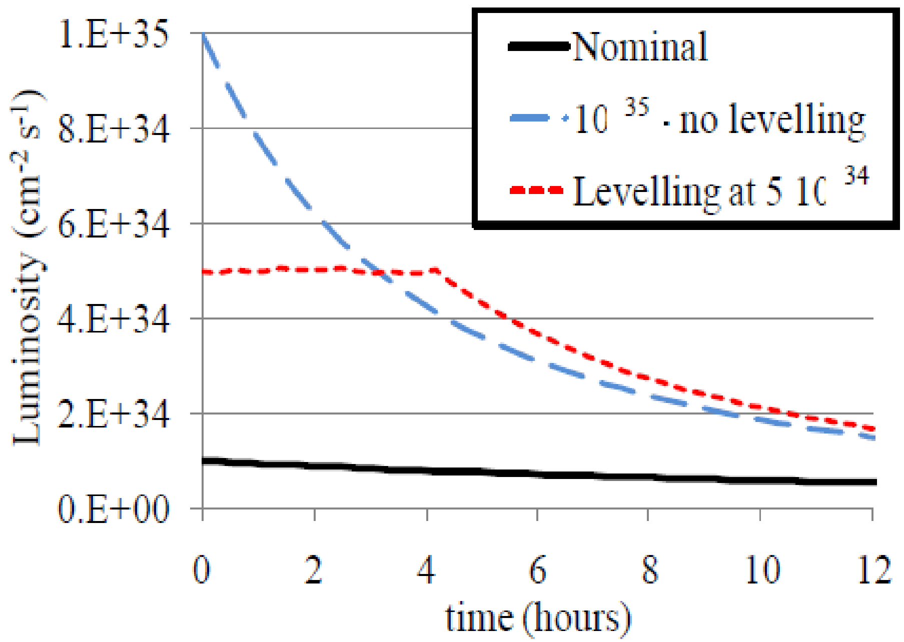
Upgrade plans for ATLAS Forward Calorimetry for the HL-LHC

Joshua Turner (Carleton University)
on behalf of the ATLAS Liquid Argon Calorimeter Group

LHC to High Luminosity LHC (HL-LHC)

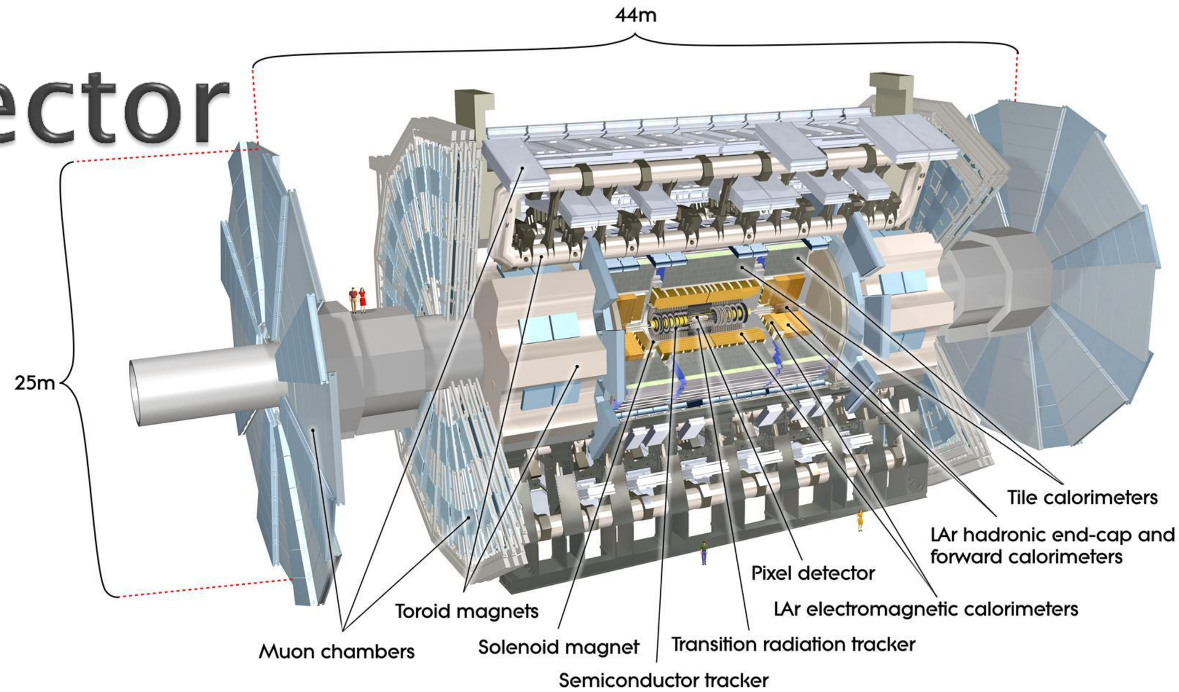
- LHC
  - $\mathcal{L} = 10^{34} cm^{-2} s^{-1}$.
- HL-LHC main objectives:
  - $\mathcal{L} = 5 \times 10^{34} cm^{-2} s^{-1}$.
  - Use levelling to maintain peak luminosity for extended periods.
  - Obtain an integrated luminosity of 250 fb^{-1} per year, for 3000 fb^{-1} after 12 years of operation, or 10 times the integrated luminosity of the LHC.

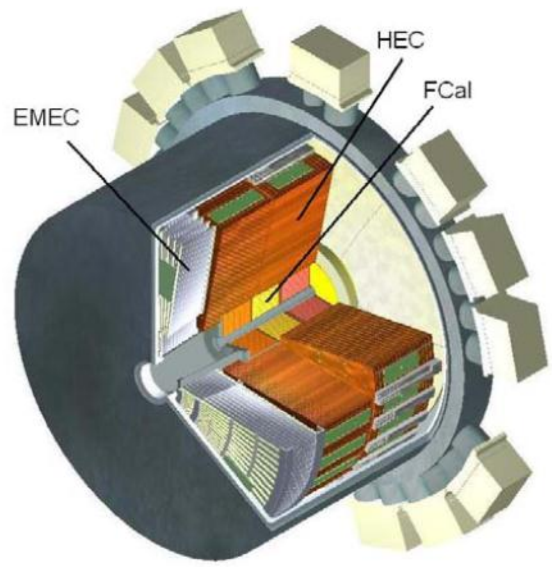




ATLAS Detector

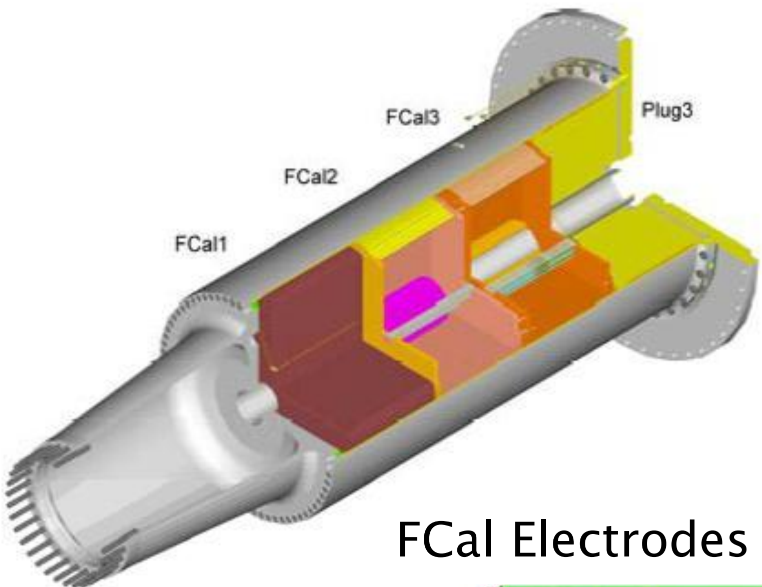
- One of two all-purpose detectors at the LHC experiment.
  - Consists of 3 types of detector systems:
    - Inner Tracking Systems.
    - Calorimetry.
    - Muon System.
- Calorimetry subdivided into 3 different regions:
  - Barrel region consisting of:
    - Electromagnetic Barrel Calorimeter.
    - Tile Calorimeter.
  - 2 End-Cap regions containing:
    - Electromagnetic End-Cap Calorimeter.
    - Hadronic End-Cap Calorimeter.
    - Forward Calorimeter.



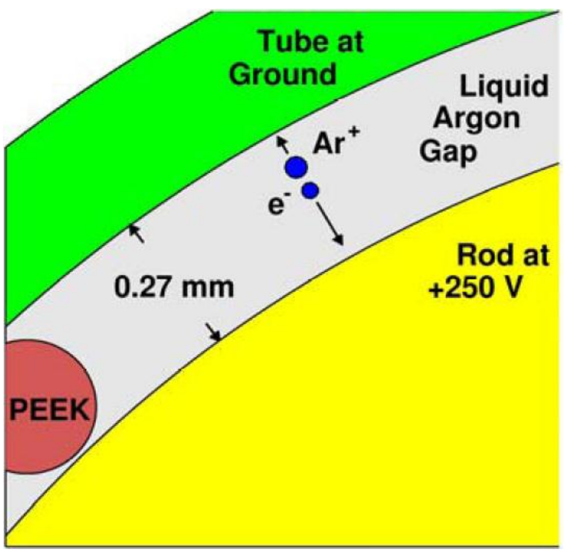


ATLAS Forward Calorimeter (FCal) and the HL-LHC

- Liquid Argon (LAr) Sampling Calorimeter.
  - Consists of 3 modules. First uses Copper absorber, others use Tungsten.
  - Electrodes consist of rod at high voltage and a tube at ground with Liquid Argon between them.
  - PEEK fibre keeps gap stable.
  - Covers small angles near beampipe.
- Expect several problems in the FCal at HL-LHC parameters:
  1. Charge build-up in Liquid Argon gap. Reduces charge collection.
  2. HV drop on FCal HV distribution resistors reduces voltage on gap significantly.
  3. Argon temperature may exceed boiling point of Liquid Argon from beam heating.



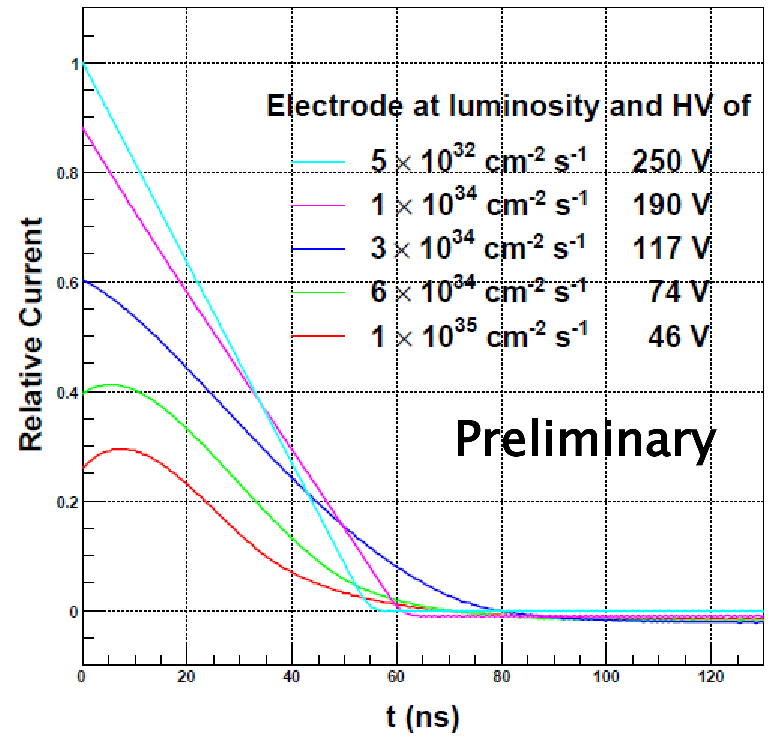
FCal Electrodes



Signal Degradation in FCal

- Expect degradation of FCal signal in innermost region.
  - $\eta < 4.5$ for $\mathcal{L} = 3e34\ cm^{-2}s^{-1}$.
- ATLAS is currently addressing this problem:
  - Comparing dose simulation with in-situ measurements.
  - Comparing current measurements with expectations.
  - Assessing impact on physics measurements as a function of degradation.

FCal Signal degradation simulation at $\eta = 4.7$



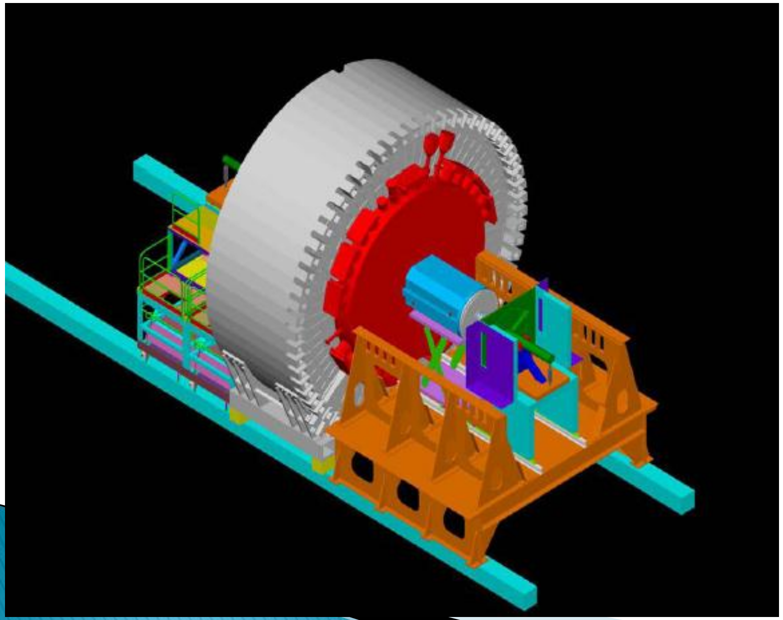
Solutions to FCal Problem

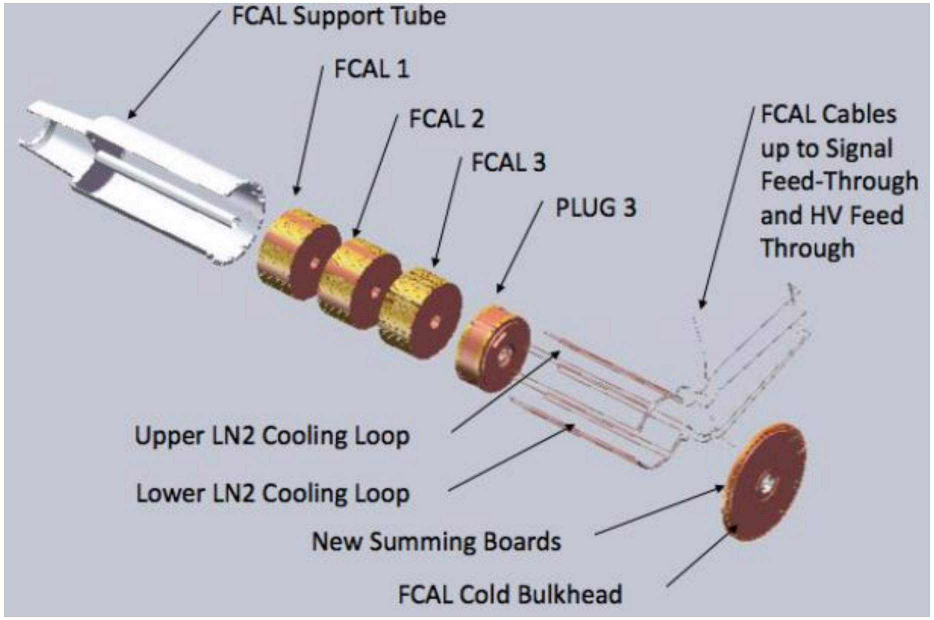
- Current FCal will be highly activated at time of shutdowns. Very difficult to modify. Two options considered if FCal replacement is required:

1. Replace FCal with super FCal (sFCal):
   - Smaller gaps – reduce ion build-up.
   - New HV protection resistors – prevent HV drop.
   - Install additional cooling – prevent local boiling.
2. Insert Warm Calorimeter (Mini-FCal) in front of FCal.
   - Measure energy.
   - Reduce flux of particles and energy deposited in rest of FCal.
   - Prevents all 3 problems facing the FCal.

FCal Replacement

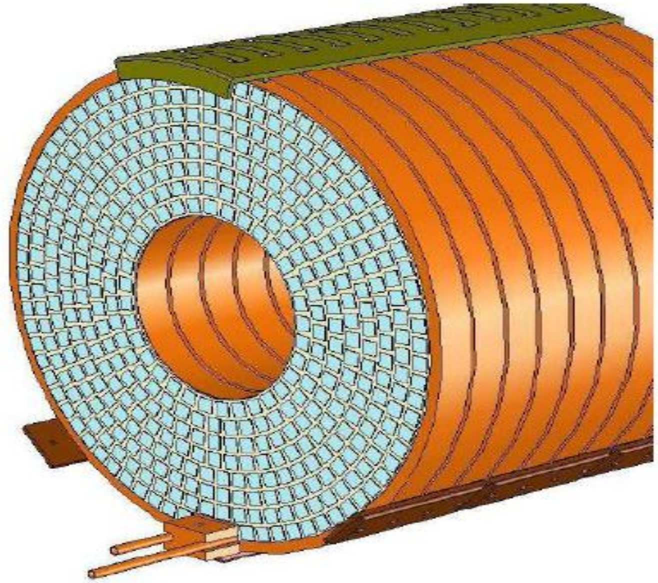
- FCal1 gaps reduced from 250 μm to 100 μm.
  - Prototype LAr calorimeter with 100 μm gaps shown to operate successfully in High Lumi tests in Protvino.
- HV protection resistors located on signal summing boards.
  - Complete replacement with lower resistance HV protection resistors required.
- Require new cooling loops.
- Installation possible on the order of 12 months.
  - Requires partial opening of end-cap cryostats and replacement of whole FCal assembly.

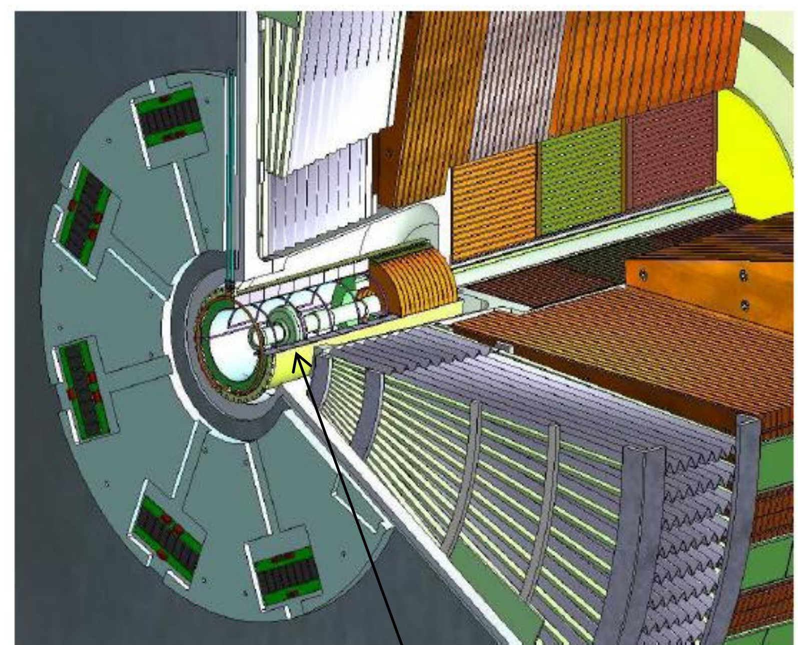




Mini-FCal

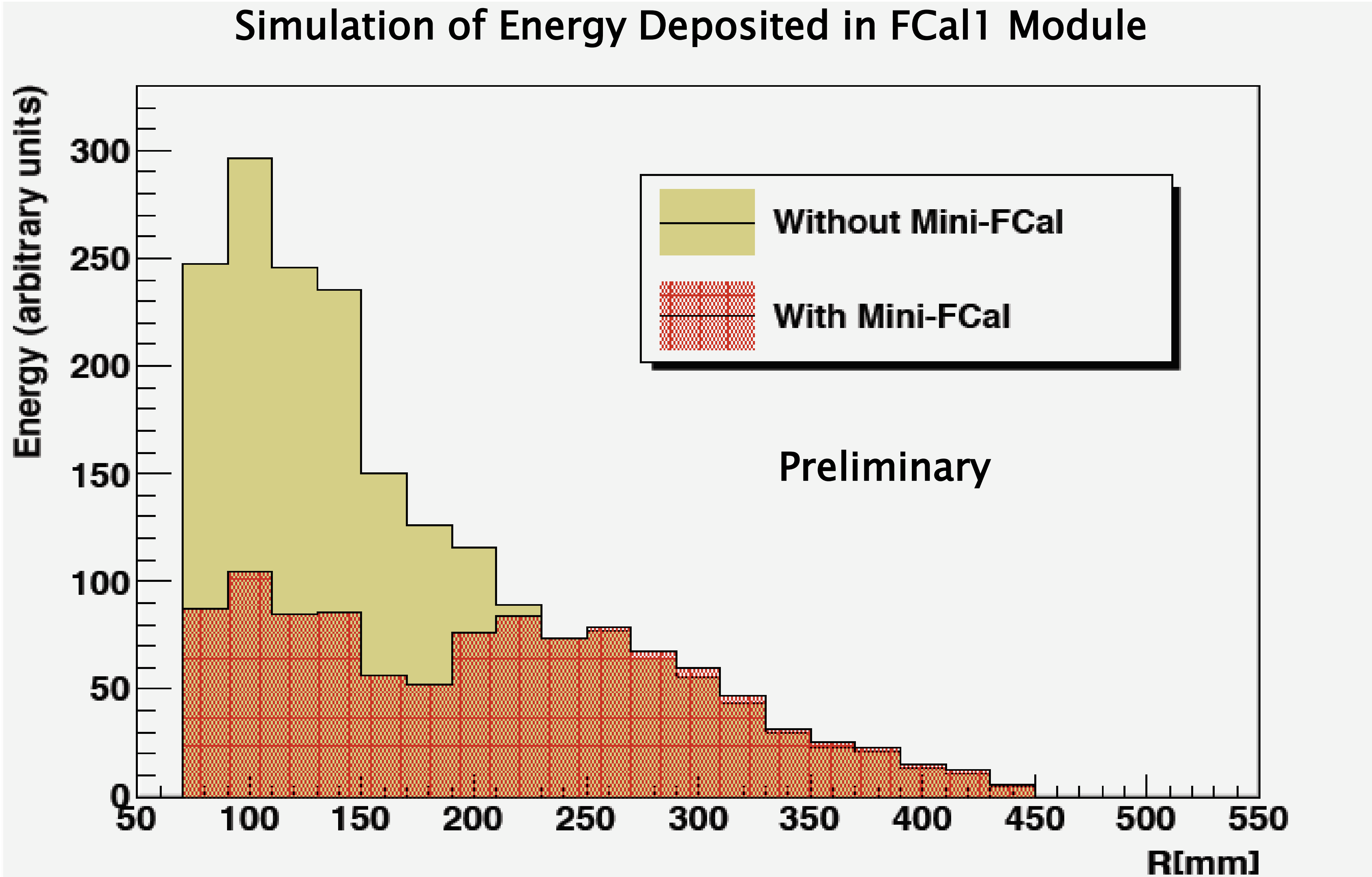
- Baseline Mini-FCal design.
  - 12 layers of copper plates.
  - 11 diamond detector planes.
  - 18.8 radiation lengths.
- Diamonds mounted on substrate.
  - Latest design calls for diamond sensors on both sides of substrate.
    - Optimizes coverage of single layer.
- Volume prior to Mini-FCal lined with neutron-absorber/moderator.
  - Investigating various materials. Current material (borated-polyethylene) tested to HL-LHC levels.
- Relatively simple installation:
  - Insert into cryostat warm tube. Opening cryostat unnecessary.
  - But … Investigating whether warm tube can support additional load. May require replacement.



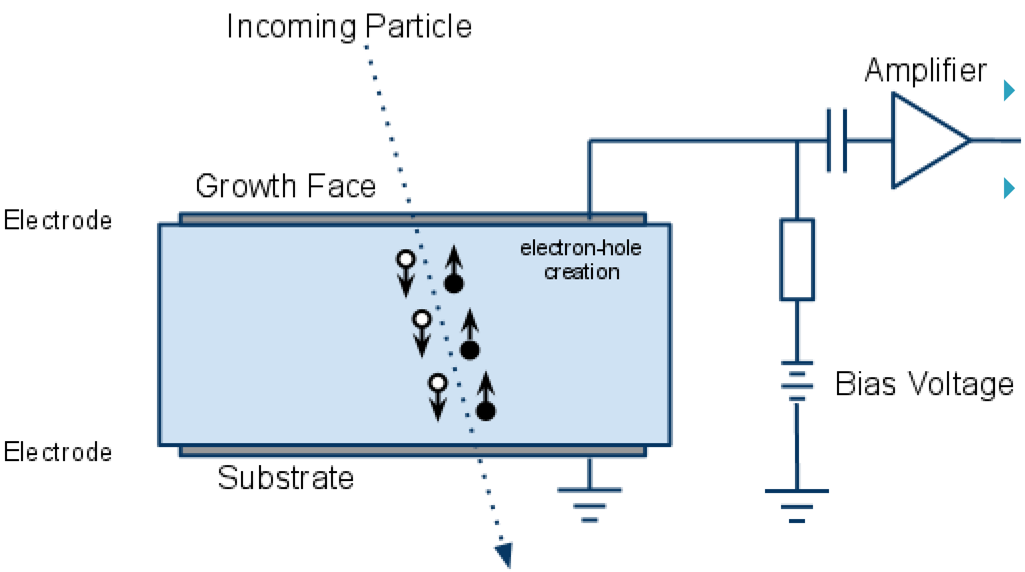


Warm Tube

Effect of Mini-FCal on FCal1



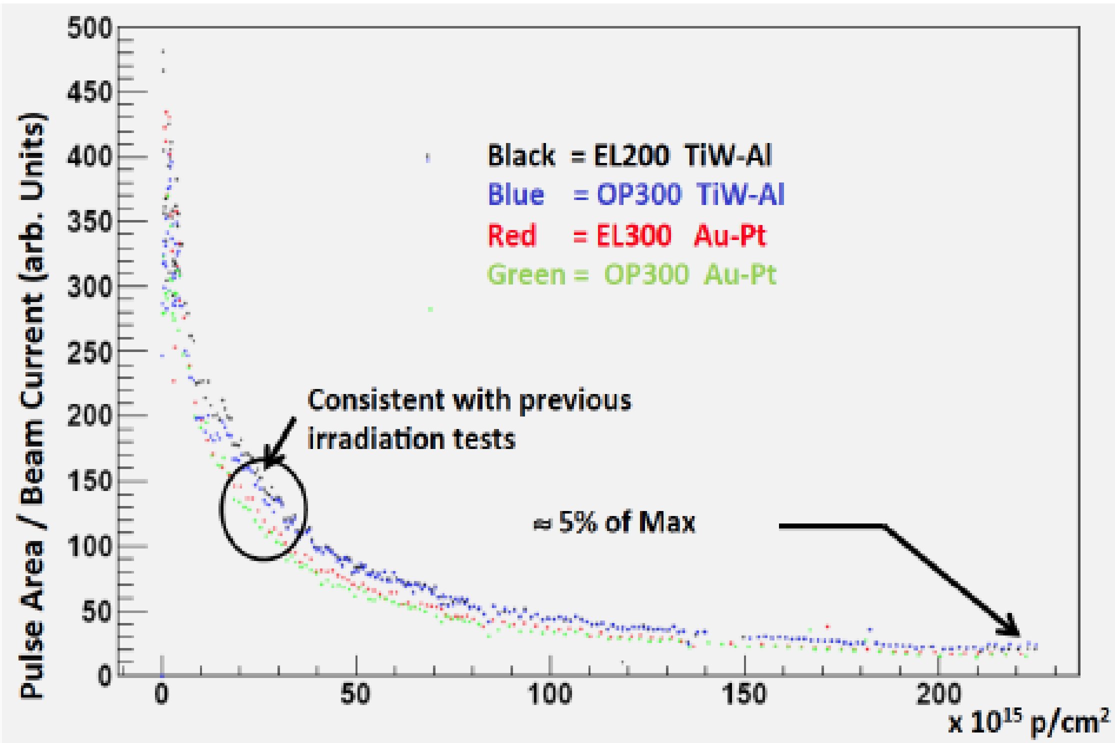
Diamond Detectors



- Particles create electron-hole pairs.
  - Apply high voltage across detector to gather charge.
  - Amplify charge collected, read out signal.
- Diamonds grown via chemical vapour deposition.
- Come in two types:
  - Single crystal (sCVD) diamond.
  - Polycrystalline (pCVD) diamond.
    - Non-uniform crystal growth throughout diamond.
    - Nitrogen used to speed growth.
      - Electrical (EL) grade, least nitrogen, highest price.
      - Optical (OP) grade, middle nitrogen, middle price.
      - Polycrystalline (PC) grade, most nitrogen, lowest price.
- Our tests involve OP and EL grade diamonds.

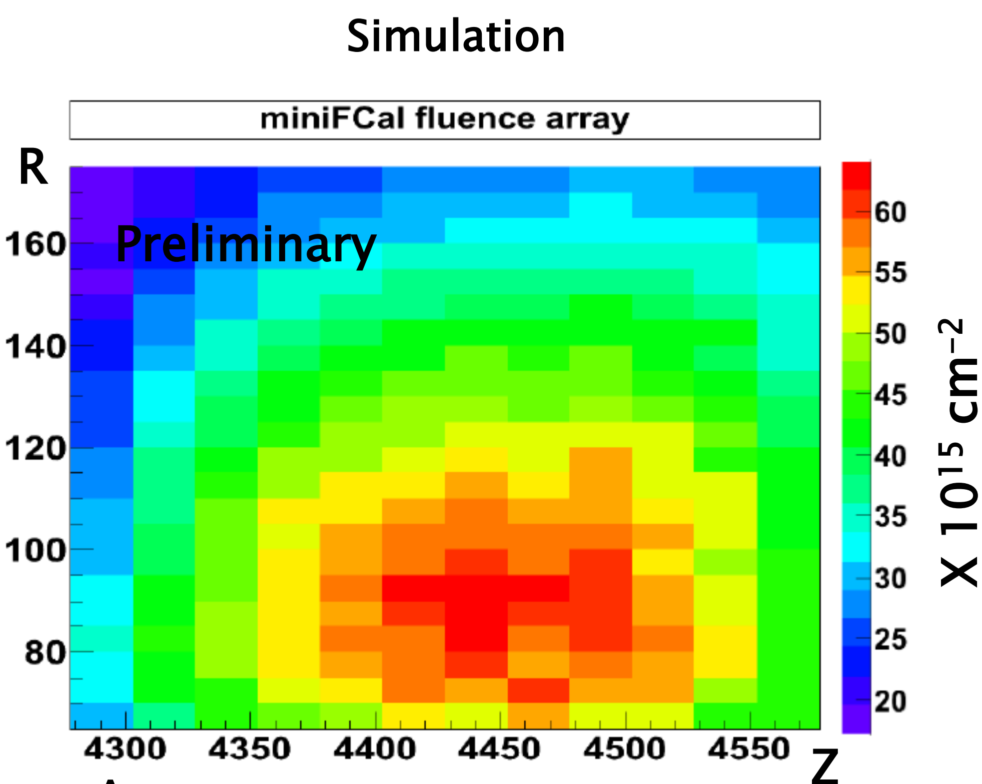
Diamond Detector Tests

TRIUMF Irradiation Test Data



- Irradiation test of pCVD diamond in TRIUMF BL1A.
  - Located at UBC.
  - 500 MeV/c protons.
- Fluence increased throughout experiment:
  - Signal decays quickly. Start slow to accurately observe.
- Reached average fluence of 2.25e17 p/cm^2.
- Peak fluence of 5e17 p/cm^2 at centre of detectors.
  - All detectors functional at the end of test.
  - Signal reduced to ~ 5 %.
- Further irradiation tests planned with protons and neutrons.
- Spatial tests planned for Sept.
  - pCVD diamond response non-uniform.
  - Test results to be used in further simulations of Mini-FCal response.

Ganging and Radiation Damage

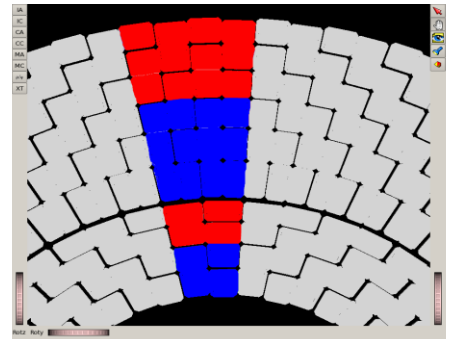
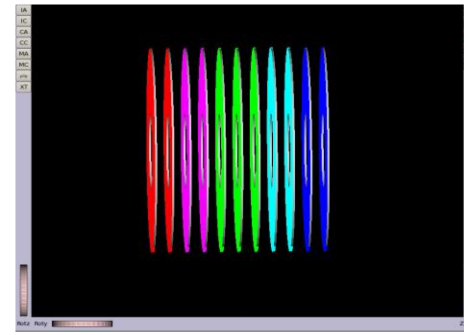
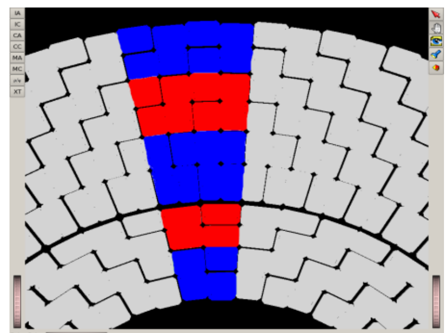
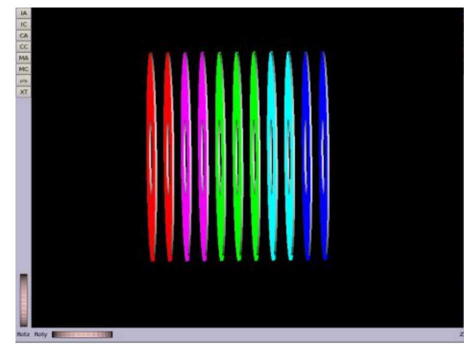
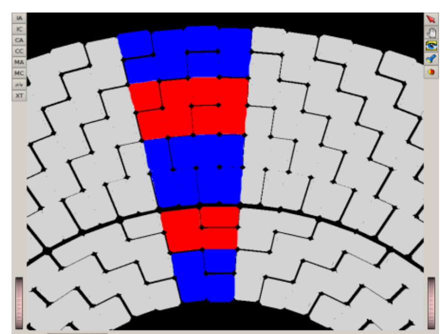
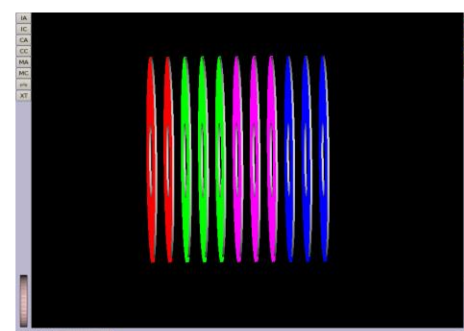


- Assumes:
  - $\int \mathcal{L} dt = 250\ fb^{-1}$.

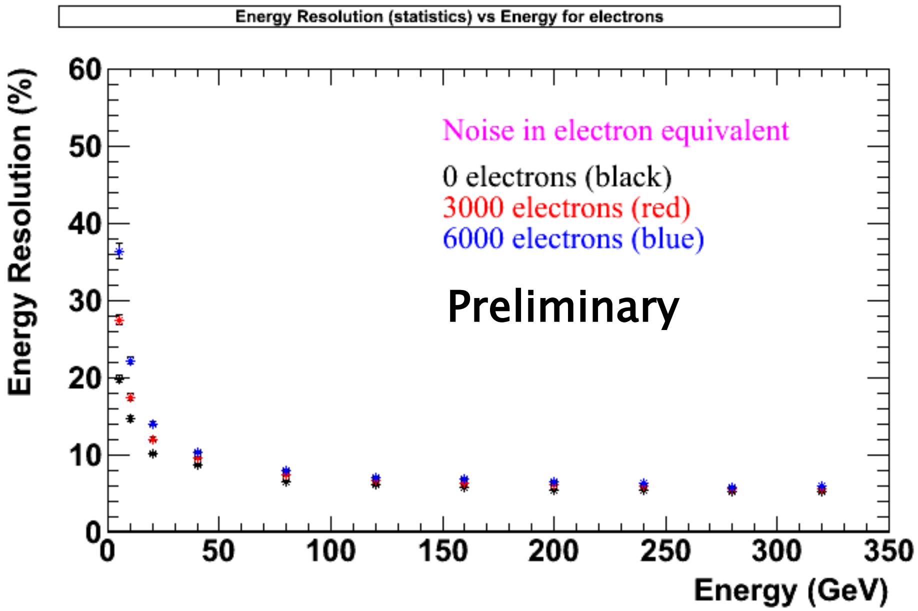
- Each Mini-Fcal will consist of ~ 8000 diamond wafers.
  - Wish to use < 1000 electronic channels. Need to gang wafers.
- Signal degrades with fluence (refer to slide 11).
  - Must apply correction to signal.
- Ganging complicated by varying fluence throughout Mini-FCal.
  - Wish to gang similarly irradiated wafers.
- Fluence changes rapidly with R and Z. Constant in ϕ.

Ganging Schemes

- Gang1 – 480 channels per Mini-FCal.
  - R (eta) ganged by 2 for inner 4 rings, and by 3 for outer 6 rings.
  - Phi ganged by 2 for inner 4 rings, and by 4 for outer 6 rings.
  - Z ganged as {2,2,3,2,2}.
- Gang2 – 600 channels per Mini-FCal.
  - R (eta) ganged by 2.
  - Phi ganged by 2 for inner 4 rings, and by 4 for outer 6 rings.
  - Z ganged as {2,2,3,2,2}.
- Gang3 – 480 channels per Mini-FCal.
  - R (eta) ganged by 2.
  - Phi ganged by 2 for inner 4 rings, and by 4 for outer 6 rings.
  - Z ganged as {2,3,3,3}.

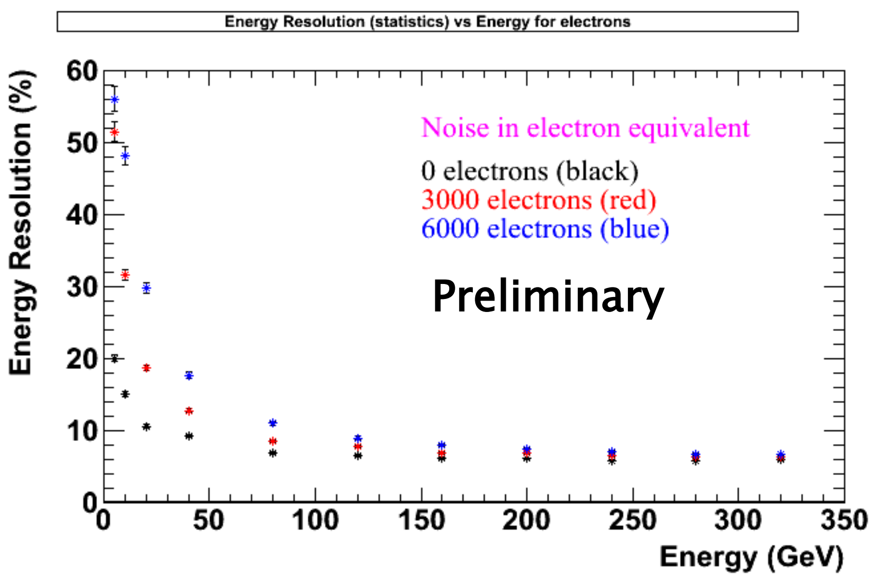







Mini-FCal Noise Simulations



- Effects of electronic noise after:
  - Left – 2 years running, or 500 fb^{-1}.
  - Below – 8 years running, or 2000 fb^{-1}.

- Resolution levels out at 10 % for high energy particles.

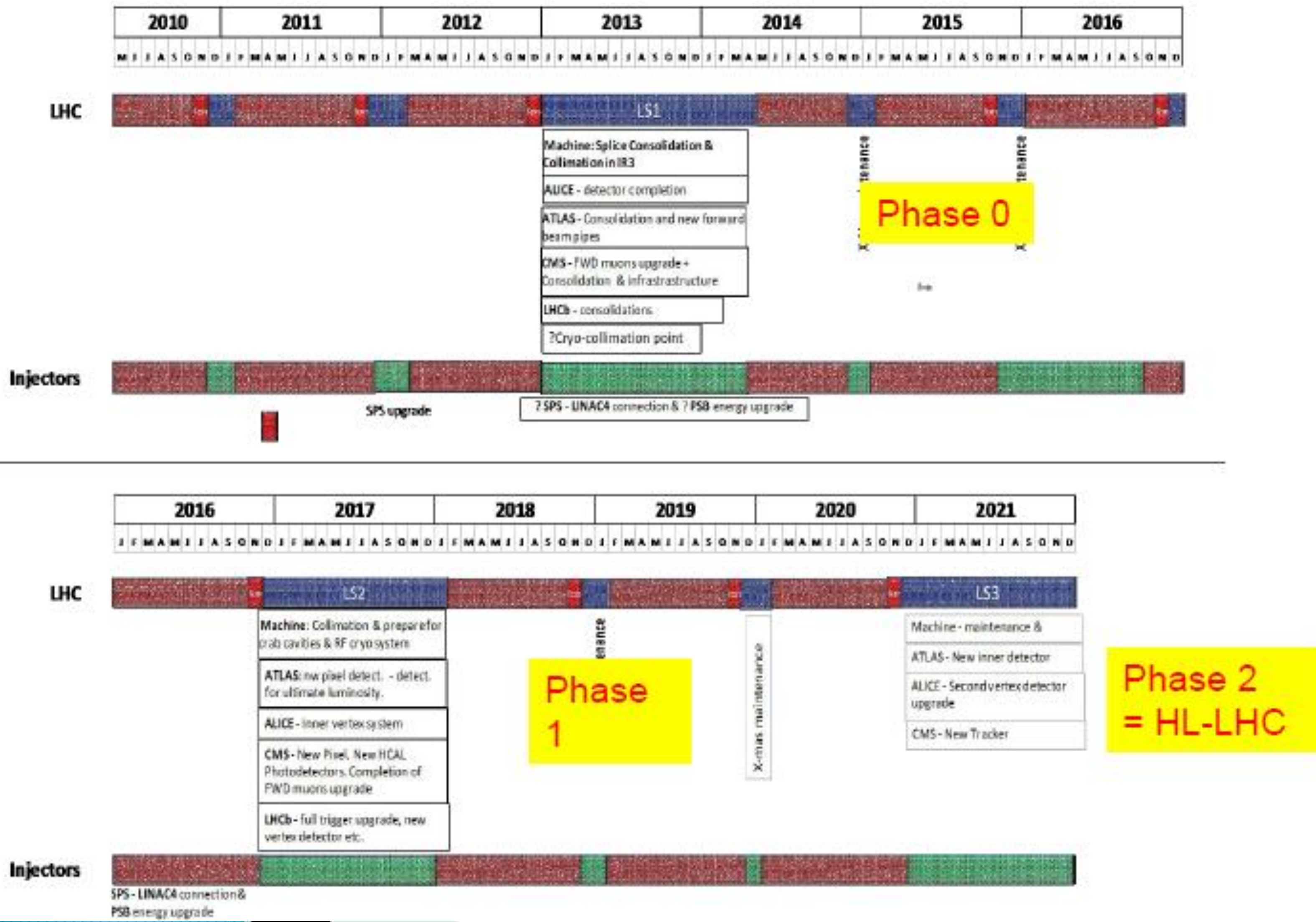


Summary

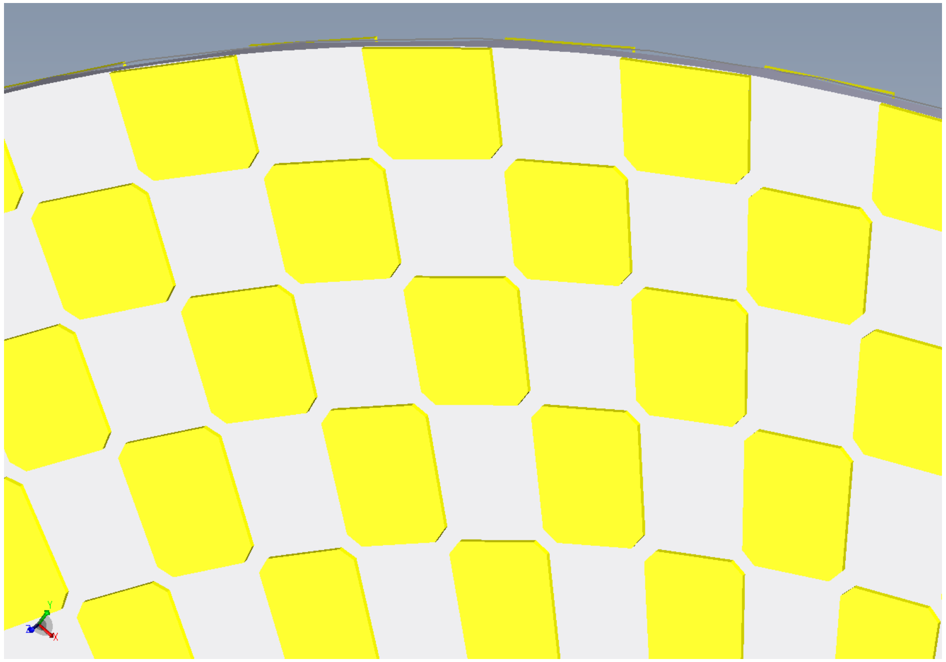
- There are 3 potential problems facing the FCal at the HL-LHC:
  1. Charge build-up in Liquid Argon gap.
  2. HV drop on FCal HV distribution resistors.
  3. Argon boiling.
- Studies are ongoing to understand the extent of signal degradation in the FCal at the HL-LHC and its effect on physics measurements.
- In case signal degradation proven to impact ATLAS physics program, there are 2 solutions being studied:
  1. sFCal
     - Replacement FCal with:
       - Smaller Liquid Argon gaps.
       - Lower resistance HV distribution resistors.
       - Additional cooling loops.
     - Proven technology.
  2. Mini-FCal
     - Designed to prevent loss of signal in the inner edge of the FCal1 at HL-LHC parameters.
     - Exploring diamond option.
       - Diamond sensors operational after fluence of 2.25e17 p/cm^2 at 5 % of initial signal.
       - Spatial tests planned to measure non-uniform response in pCVD diamond.
       - Further simulations will model Mini-FCal response in preparation for use in ATLAS, if technology is proven.

Extra Slides

Detailed Upgrade Schedule

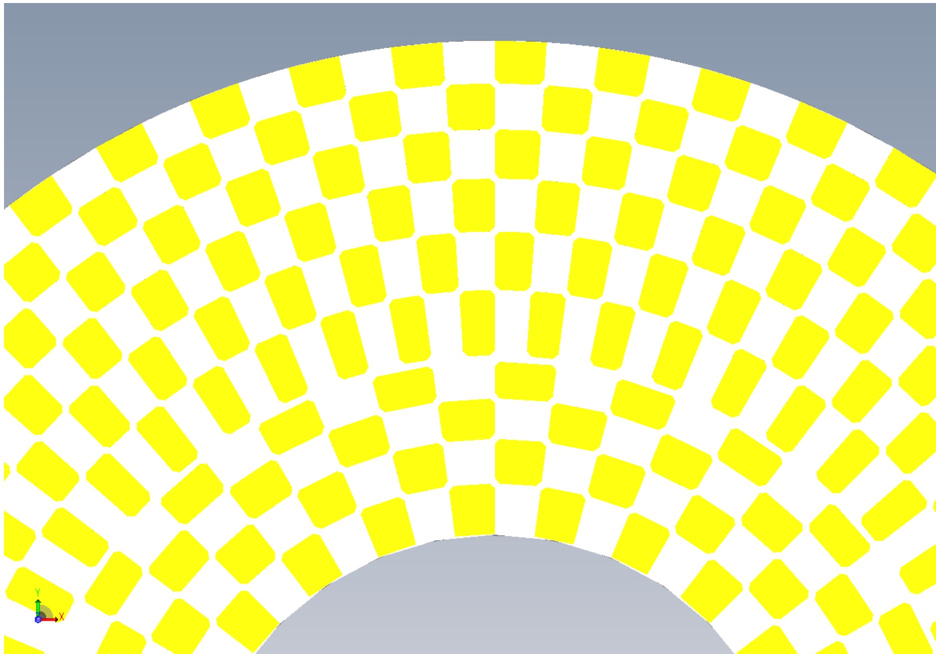


Wafer Layout

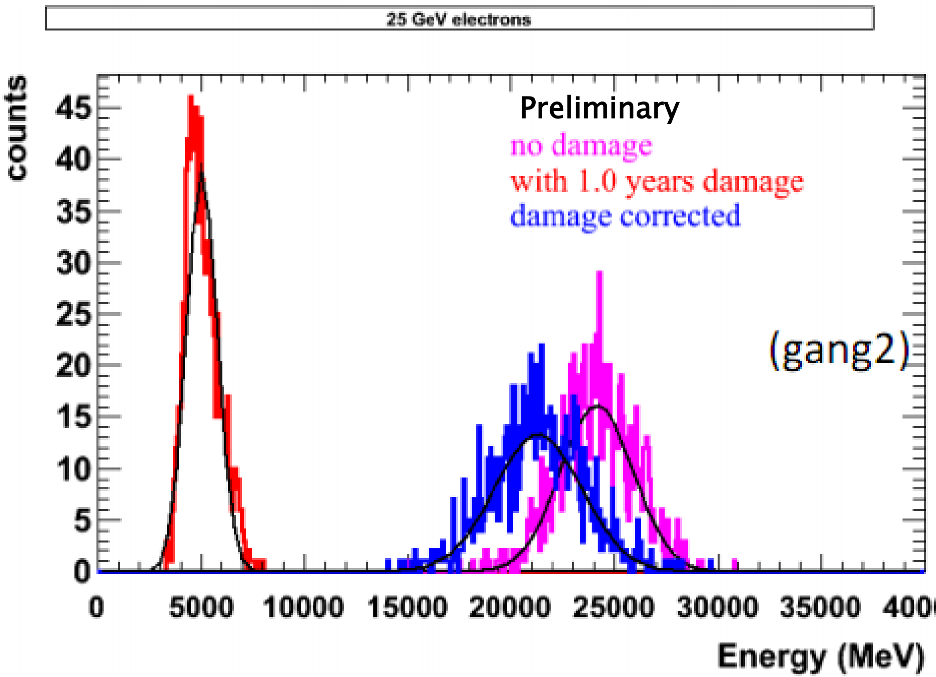


- 11 layers.
- 8448 wafers per Mini-Fcal.
- Substrate 1.5 mm thick.
- Yellow = Wafer
- White = Substrate

- 10 rings of wafers.
- 1.5 mm gap between inner 4 and outer 6 rings
- Wafers are 0.3 mm thick.
- Wafers are notched at each corner.
- Inner radius of 65.5 mm (η=4.88).
- Outer radius of 172.0 mm (η=3.91).
- Wafer area ranges from [99.6,100.6] mm^2.



Damage Correction



- Note – Plots do not account for electronic noise
- Left – Signal before and after radiation damage and possible correction.
- Below –Energy resolution before and after radiation damage and possible correction.