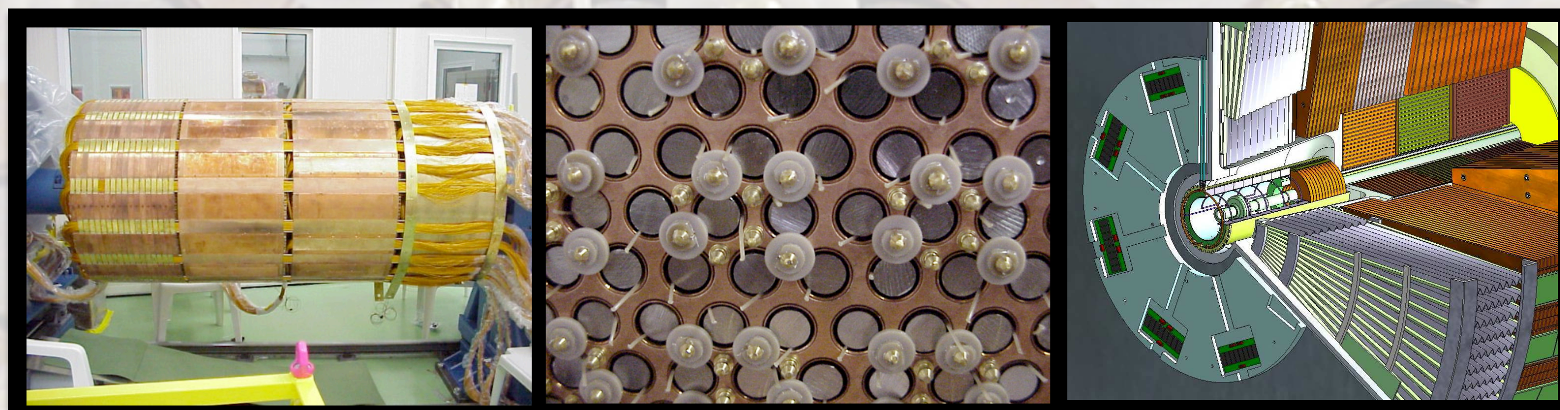
Upgrade Plans for ATLAS Forward Calorimetry for the HL-LHC

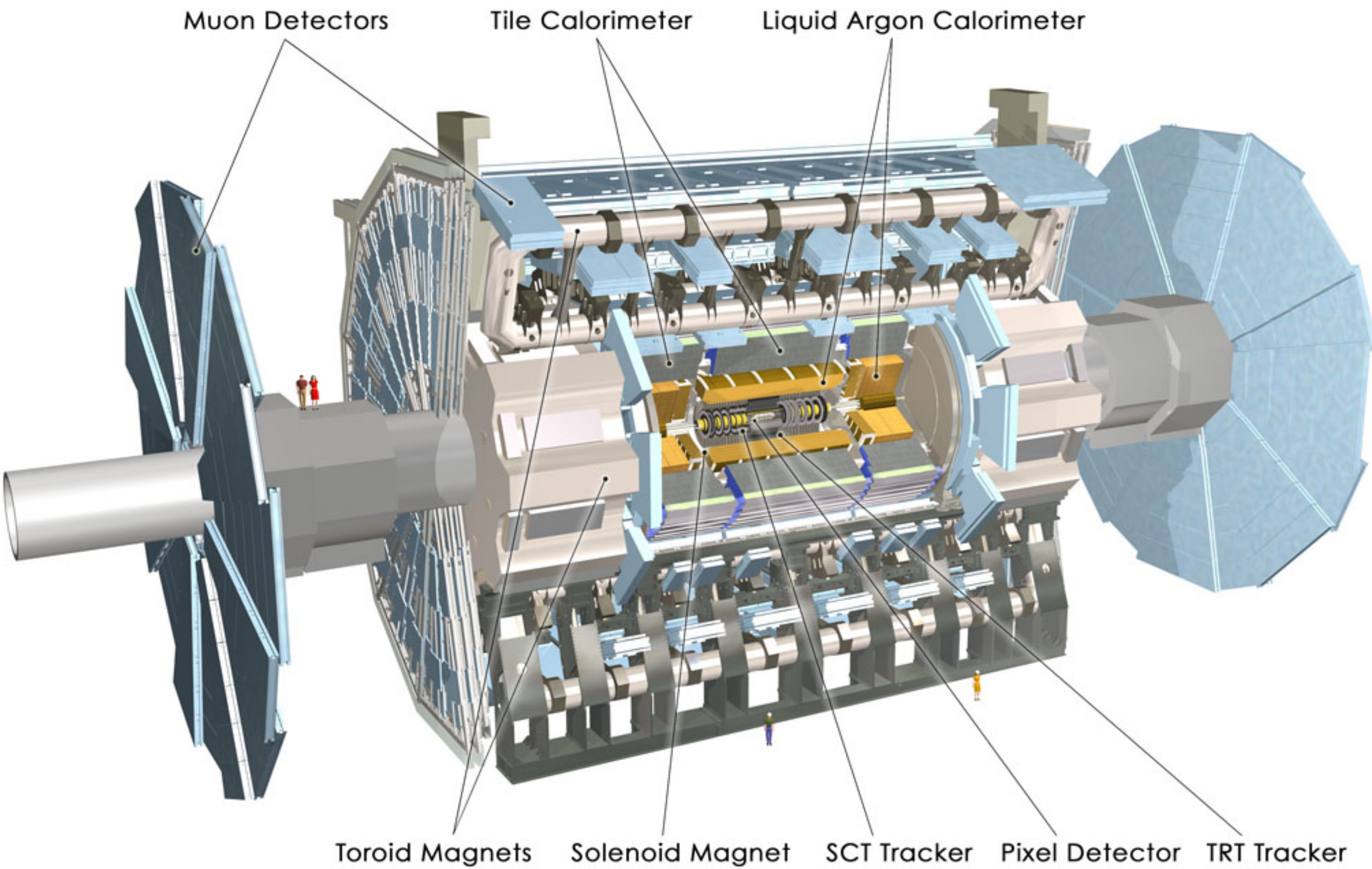
Peter Krieger, University of Toronto

CHEF, April 24, 2013, Paris

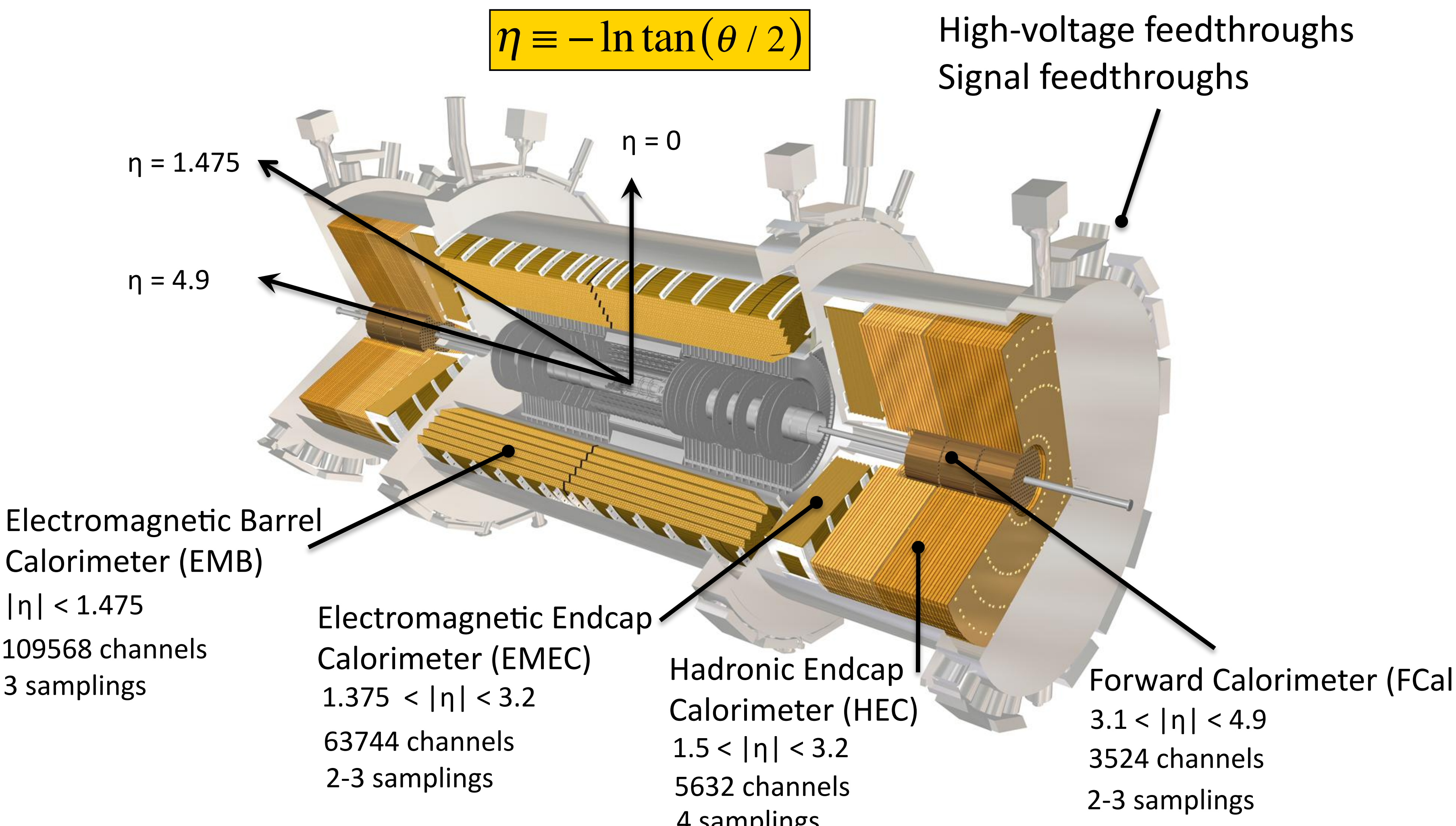
On behalf of the ATLAS Liquid Argon Calorimeter Group



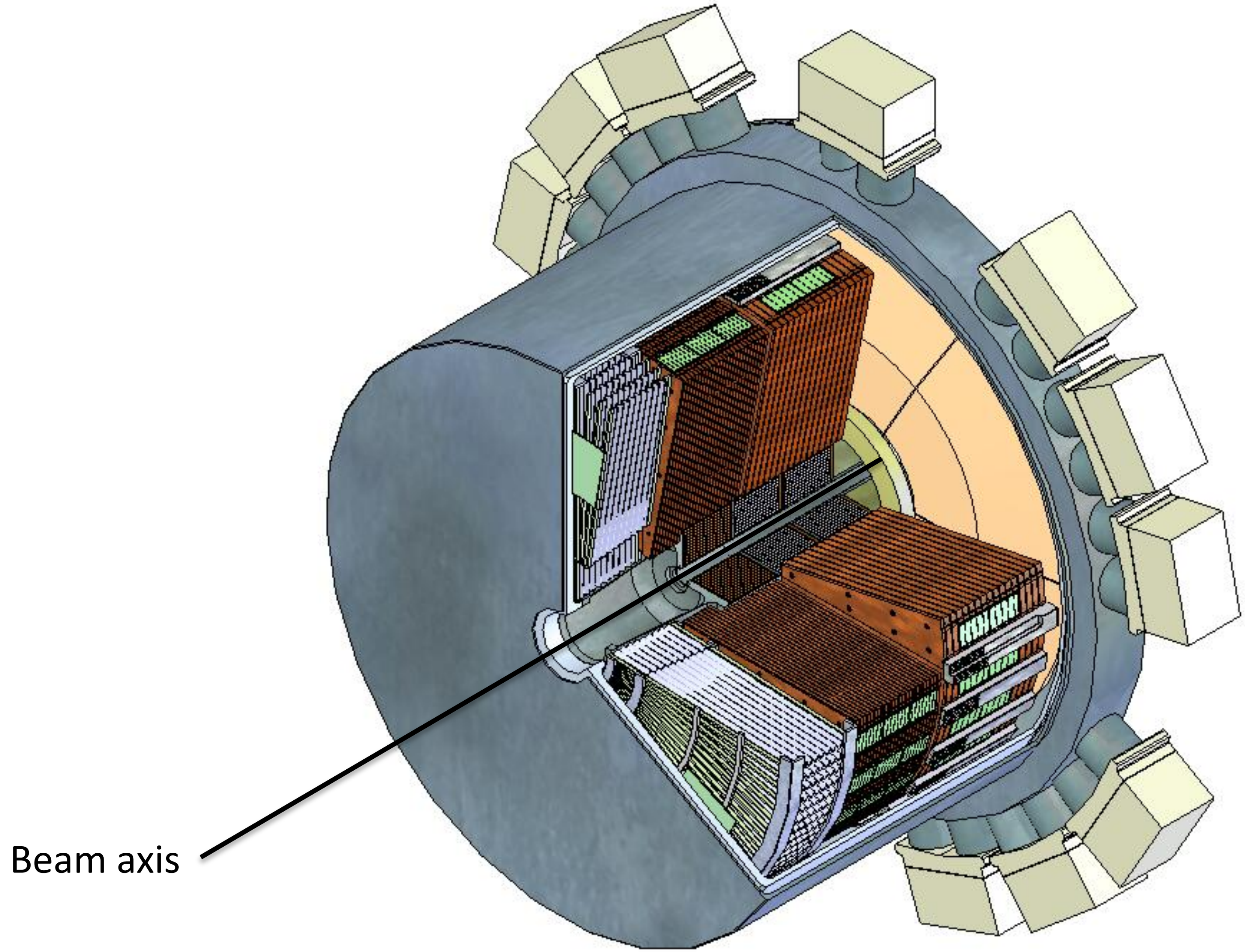
The ATLAS Detector



The ATLAS Liquid Argon Calorimeter



The ATLAS Liquid Argon Endcap Calorimeter



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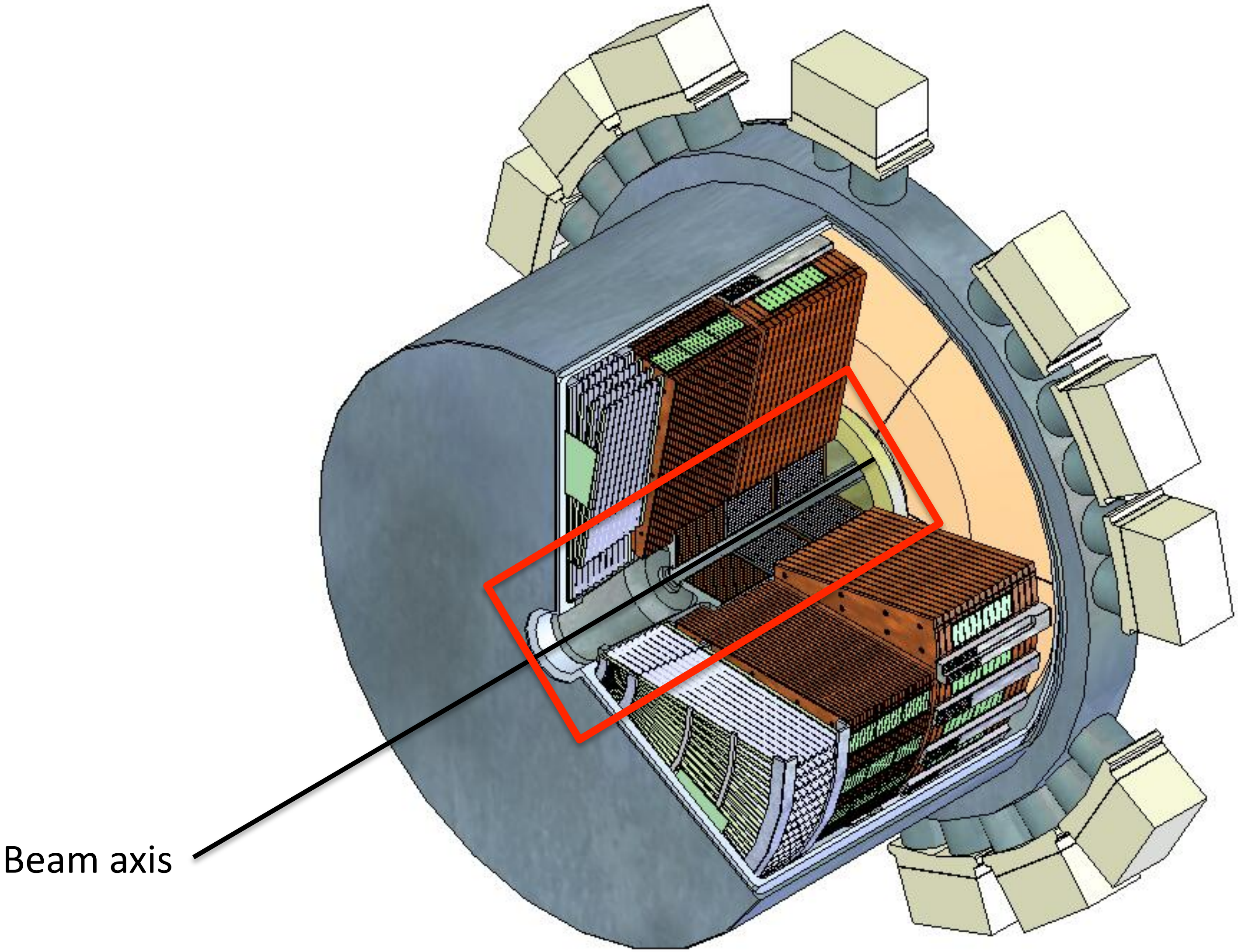
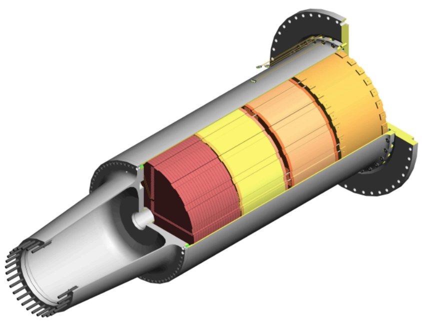
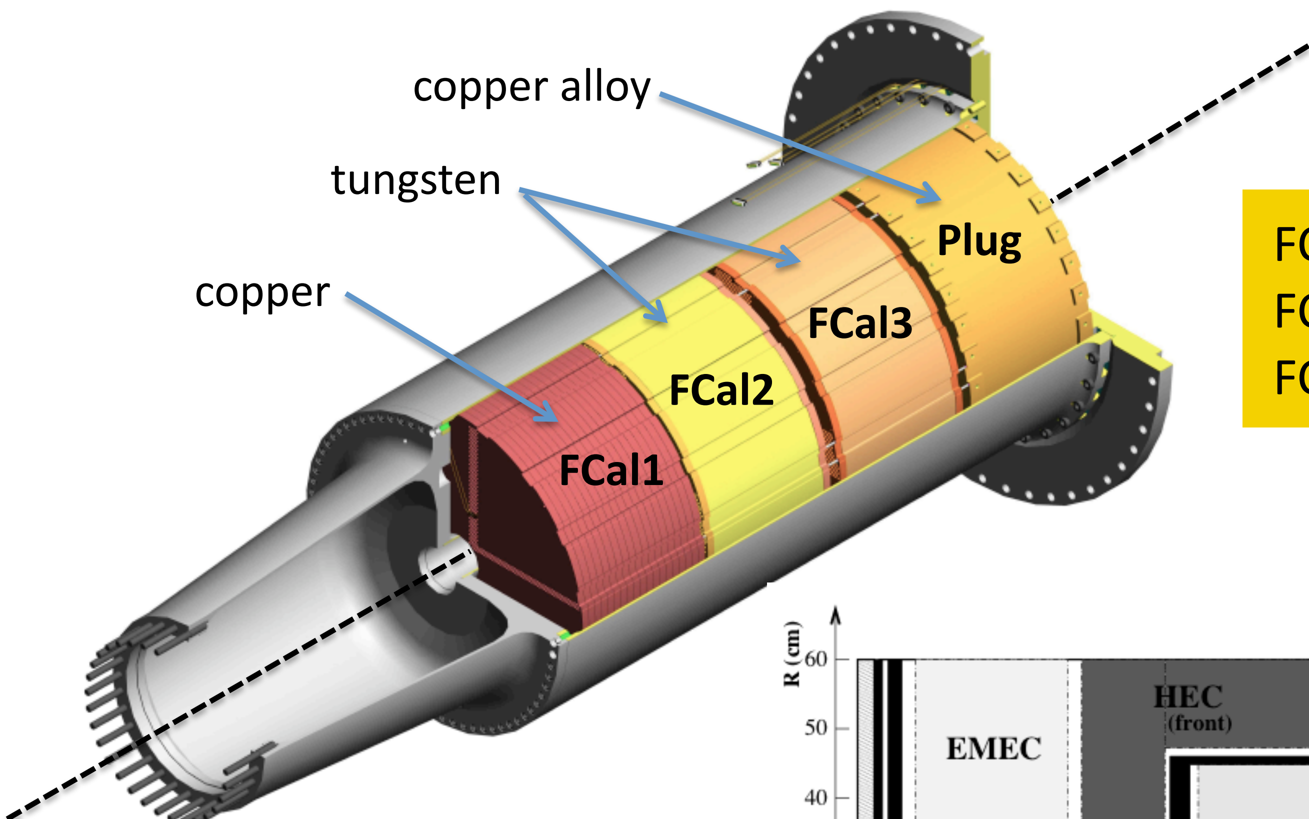


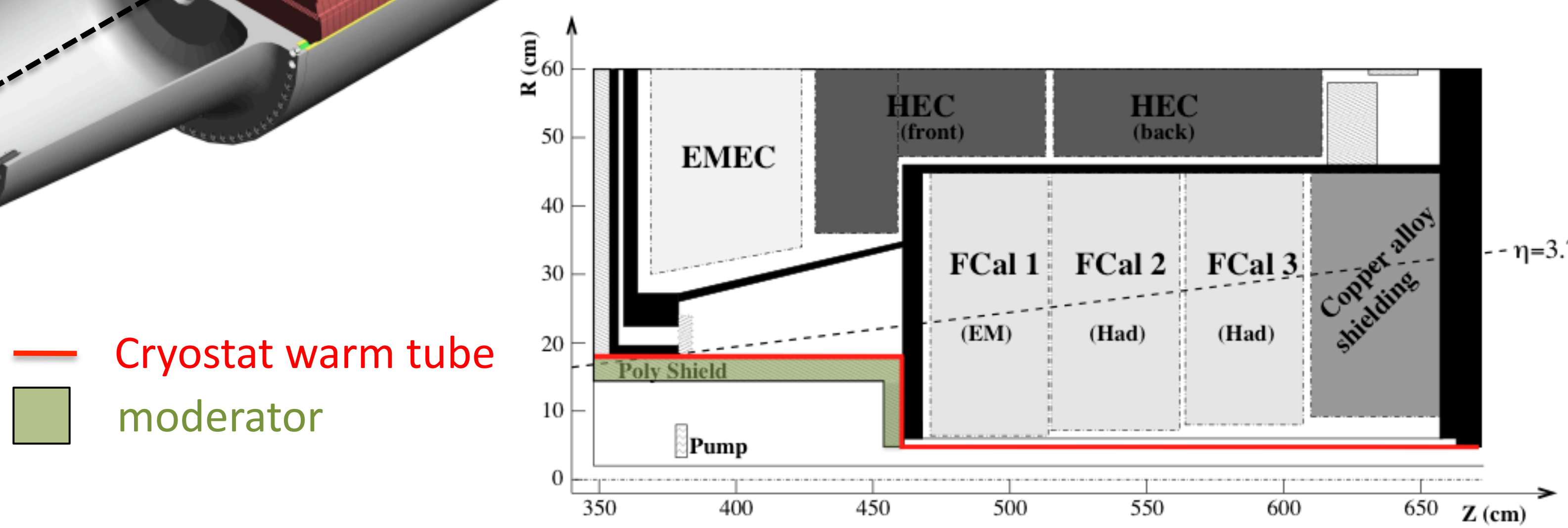
The ATLAS Liquid Argon Forward Calorimeter



The ATLAS Liquid Argon Endcap Calorimeter



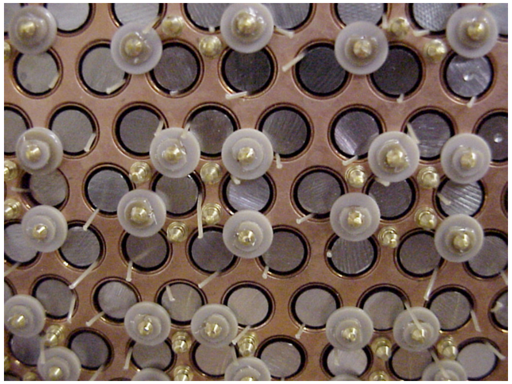
FCal1: 1008 channels
FCal2: 500 channels
FCal3: 254 channels

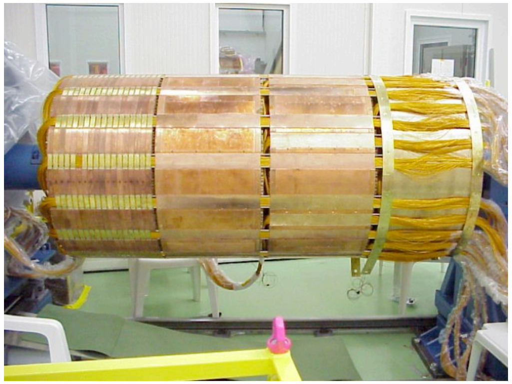


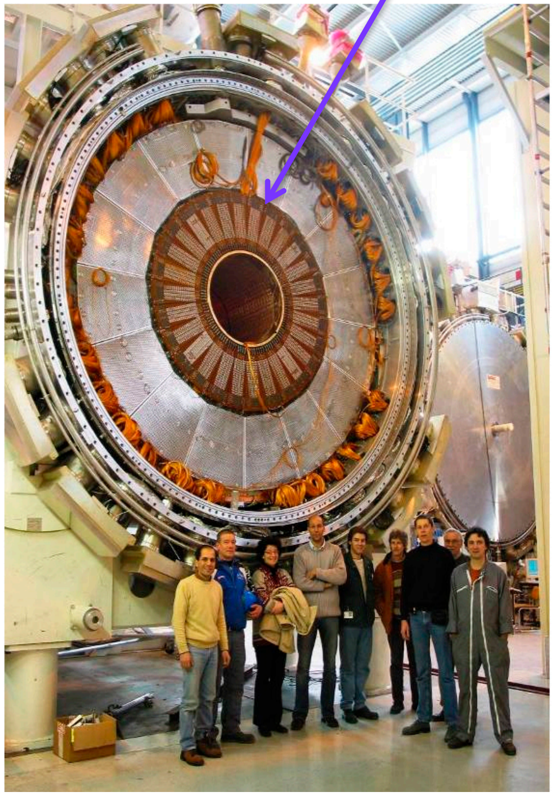
The ATLAS LAr Forward Calorimeter

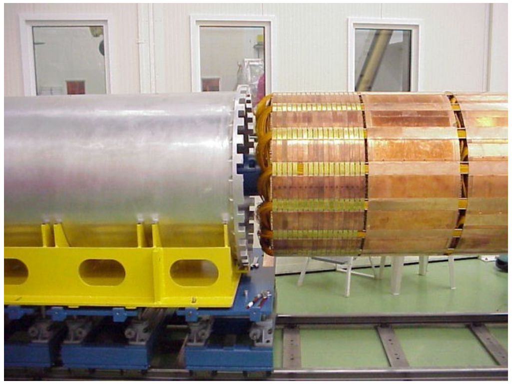
- Thin annular gaps formed by electrodes consisting of concentric rod and tube.
  - **Very narrow LAr gaps** needed to avoid ion buildup that would distort the electric field.
  - Gap sizes (269/375/500 μm) chosen for operation $\mathcal{L}_{\mathrm{inst}}$ up to 10^{34} $cm^{-2}s^{-1}$.
  - High voltage supplied to electrode via 1MΩ or 2MΩ resistors on **summing boards** located **inside the endcap cryostats**, on the rear face of the HEC [see also backup slides].

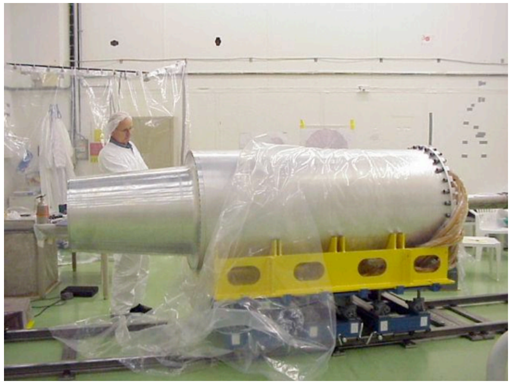
Non-readout side of FCal3









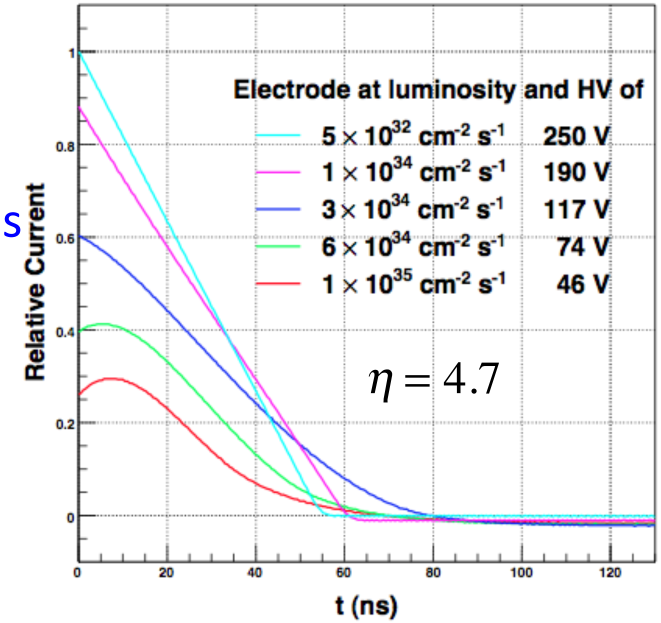


LHC Luminosity Upgrade (HL-LHC)

- Plan is for $\mathcal{L}_{\rm inst}$ = 5 x 10^{34} $cm^{-2}s^{-1}$, $\mathcal{L}_{\rm int}$ = 3000 fb^{-1}.
- ATLAS detector was not designed to run at this luminosity and some components can / may not survive the integrated dose.
- Issues for the liquid argon calorimeter:
  - Designed for $\mathcal{L}_{\rm inst}$ = 10^{34} $cm^{-2}s^{-1}$, $\mathcal{L}_{\rm int}$ = 1000 fb^{-1}.
  - Performance of the front-end electronics (not discussed here)
  - Radiation hardness of HEC GaAs cold preamplifiers (**inside endcap cryostat**)
  - Performance issues for the Forward Calorimeter (FCal):
    - Ion buildup affecting the electric field in the gap: depends on $\mathcal{L}_{inst}$ and r : e.g. the very narrow FCal LAr gaps are no longer narrow enough.
    - Higher current draw $\longrightarrow$ significant voltage drop across current limiting resistors. These are located **inside the endcap cryostat**.
    - High ionization load $\longrightarrow$ potential for boiling of liquid argon.
- FCal upgrade paths tightly coupled to decision on HEC cold GaAs preamplifiers (see talk by Martin Nagel in this session).

FCal Performance at High Luminosity

- Plot shows combined effects of decreased field (HV drop) and ion buildup on FCal performance.
  - Result is degraded response in the high |η| regions
  - Degraded region grows with instantaneous $\mathcal{L}_{\text{inst}}$
  - Has performance implications, in particular for:
    - Missing E_T resolution, tails
    - Forward jet tagging



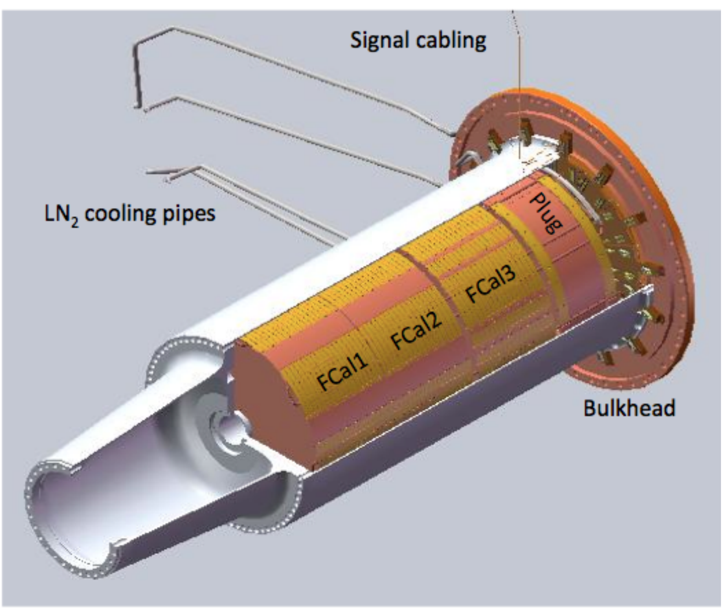
- **Upgrade goal: maintain the existing FCal performance at HL-LHC luminosities**

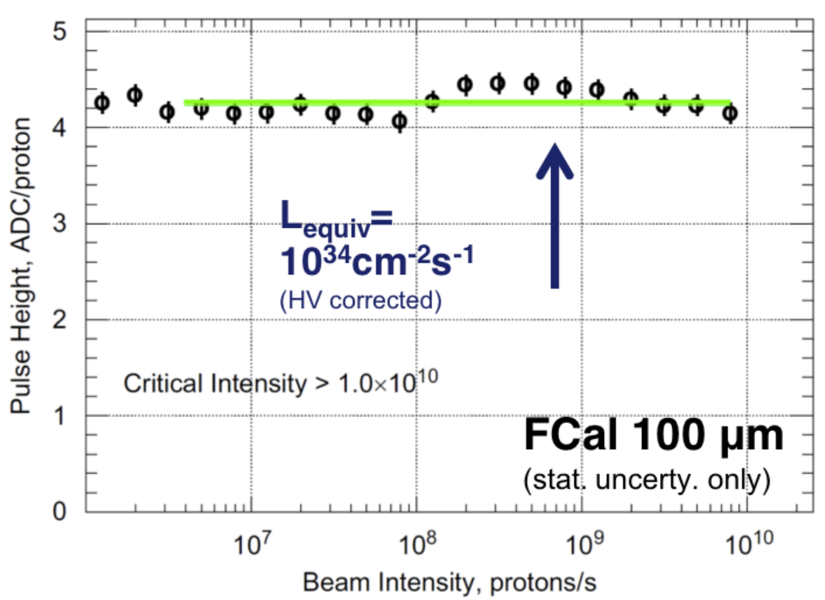
- Two approaches for addressing these problems:
  1. Replace FCal with improved detector (sFCal) - smaller gaps, new summing boards (lower resistances) and cooling loops (to avoid LAr boiling).
     - Requires opening of cryostat and a long shutdown.
  2. Small calorimeter in front of FCal (absorb particle flux at high η):
     - Referred to as the Mini-FCal: addresses all issues / three designs considered so far.
     - Does not require opening of the cold volume of cryostats.

Option 1: FCal replacement (sFCal)

- Design similar to existing FCal but:
  - Smaller LAr gaps ≈ (100/200/300 μm): a small 100 μm prototype has been operated successfully in high intensity tests in Protvino, Russia (below):
    - Critical intensity of this test above proposed HL-LHC $\mathcal{L}_{\text{inst}}$
    - Design relevant also to LAr Mini-FCal option
  - Need new cooling loops, new summing boards with lower value resistors
  - Also need to make connections to new summing boards (two options)

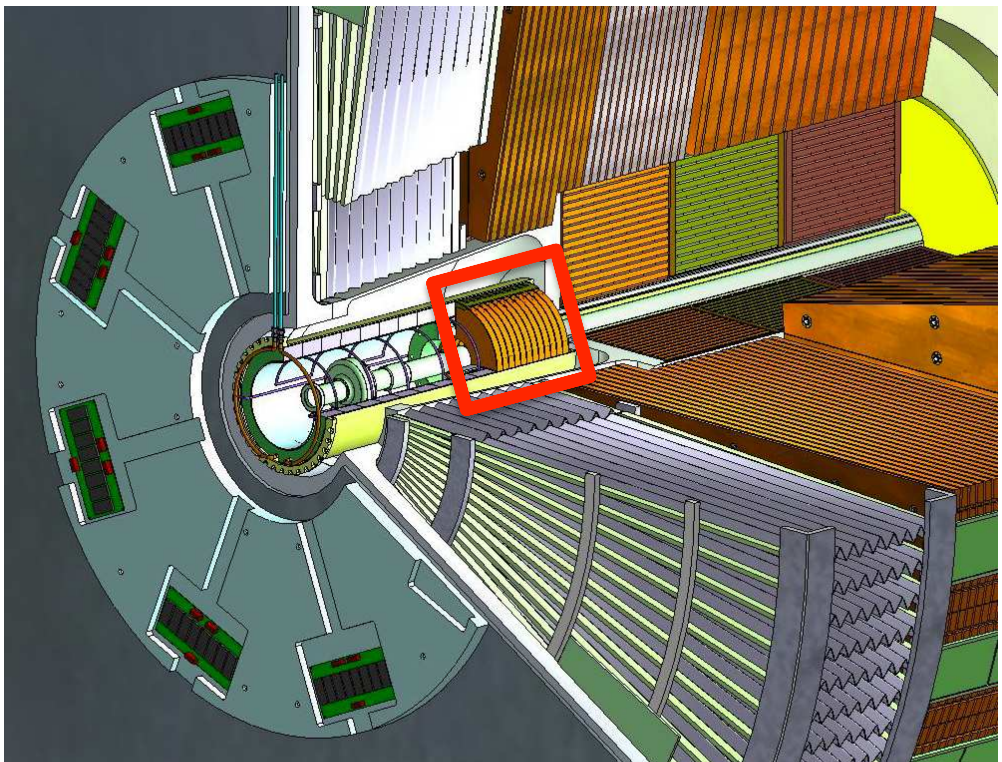
depending on whether cryostat cold cover needs to be removed

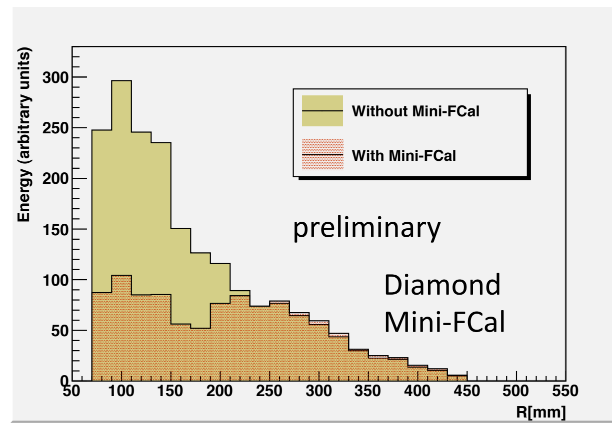




Option 2: Small Calorimeter in front of FCal

- FCal problems all related to increased current draw / ionization load.
- All are potentially addressed by reducing the amount of energy deposited in the inner part of the FCal.
- Absorb some of the energy upstream with a small calorimeter (Mini-FCal).

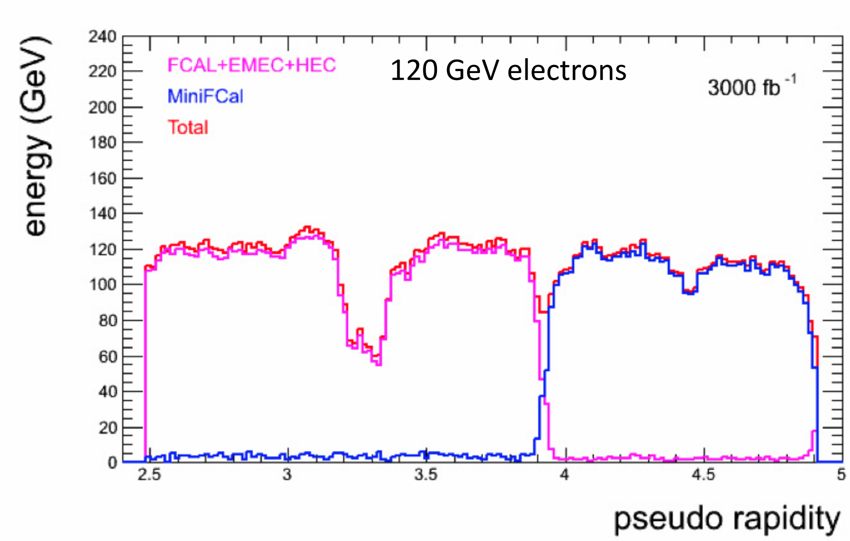




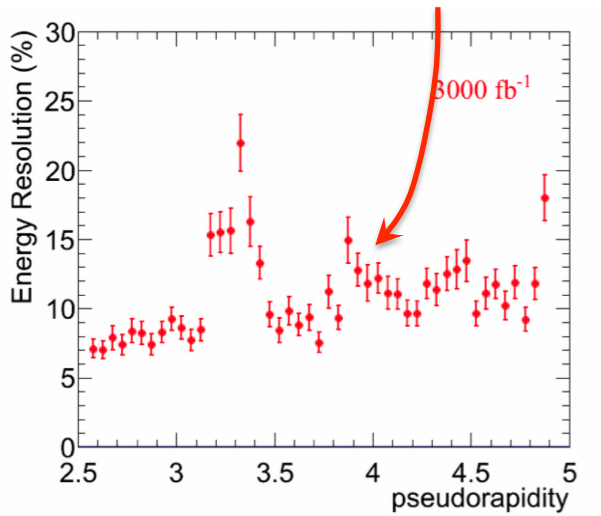
- Does not require opening of the endcap cryostat cold volume:
  – Simplest solution if HEC preamps do not need to be replaced.
- Need very radiation hard device

Mini-FCal Technology Options (1)

- Initial design: parallel plate warm calorimeter with copper plates and pCVD diamond sensor layers (illustrated on previous slide).
  - Diamond sensors investigated in two beam tests (irradiation, uniformity)
    - 5% of signal left after nominal HL-LHC exposure (proton irradiation)
  - Sensor manufacturer (DDL) ceased operations in May 2012.
  - Diamonds expensive and will have time dependent calibration (beam test results in backup slides: damage curves input to simulation below)
  - Performance (full simulation) illustrated below (includes radiation damage effects but not sensor response uniformity)

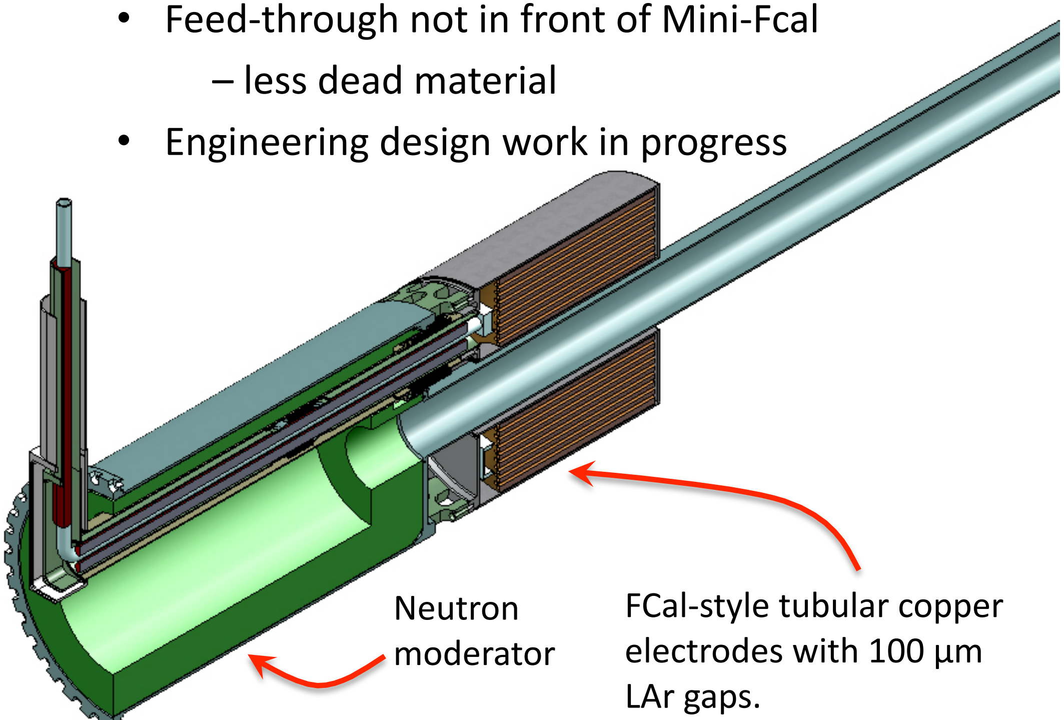


Effect of transition from Mini-FCal to FCal1

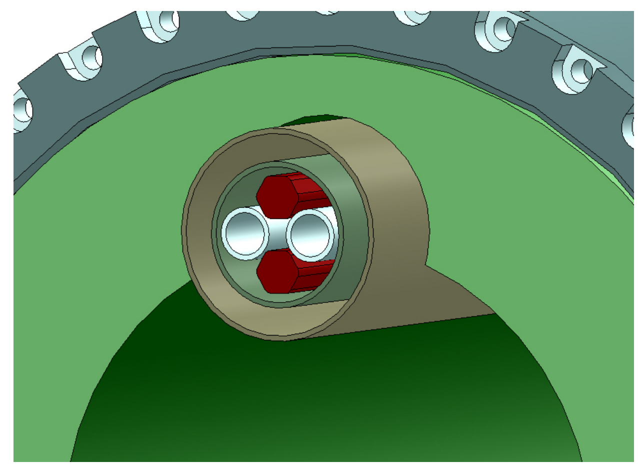


Mini-FCal Technology Options (2)

- Parallel plate warm design with copper absorber & high-pressure Xenon:
  - Still needs basic R&D on gas properties at required pressure (up to 10 bar)
- Cold copper / LAr device [based on FCal1 design with 100 µm LAr gaps]:
  - Initial design had technical problem and lots of material associated with feed-throughs
  - New design as of Sept. 2012
    - Separate LAr cryostat
    - Feed-through not in front of Mini-Fcal
      - less dead material
    - Engineering design work in progress



Cryogenic line carries HV/signal cables



Summary

- Existing FCal will not function properly at the HL-LHC.
- Four upgrade paths, depending on whether HEC electronics need replacement:
  - In either case we can:
    - ① Do nothing (loss of performance being studied)
  - If replacing HEC electronics:
    - ② Replace FCal with sFCal and old summing boards with new summing boards at rear of HEC (with 10 times lower HV protection resistors)
  - If NOT replacing the HEC electronics:
    - ③ Replace FCal with sFCal with it's own summing boards (abandon old ones)
    - ④ Mini-FCal (need to decide on technology).

- Work on simulations (physics case and performance) continues.
- All options [sFCal + Mini-FCal(s)] described in LAr section of ATLAS Phase-2 LOI
- sFCal R&D and construction time estimate ~ 7 years.
  - Would need to start by 2015, so need a decision by ~ end of 2014.

FCal Upgrade Scenarios

Backup Slides

Use of FCal in ATLAS Physics Analyses

- Measurement of E_T flow in minimum-bias events and studies of the underlying event over full acceptance of ATLAS calorimeter (for generator tuning).
- Measurement of inclusive jet and dijet cross-sections for jet rapidities out to 4.4.

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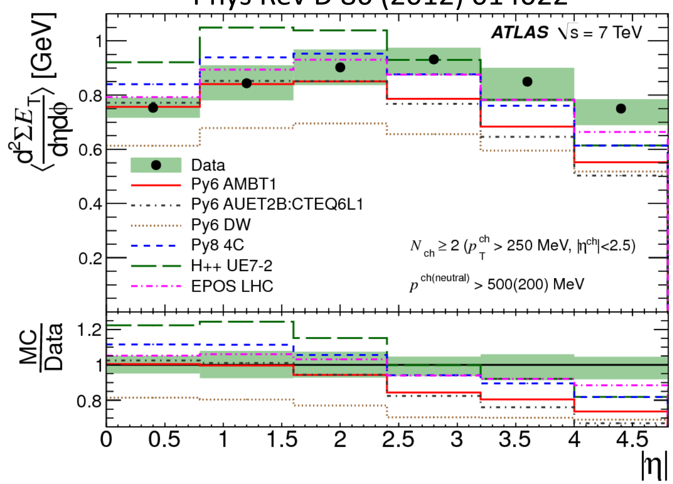

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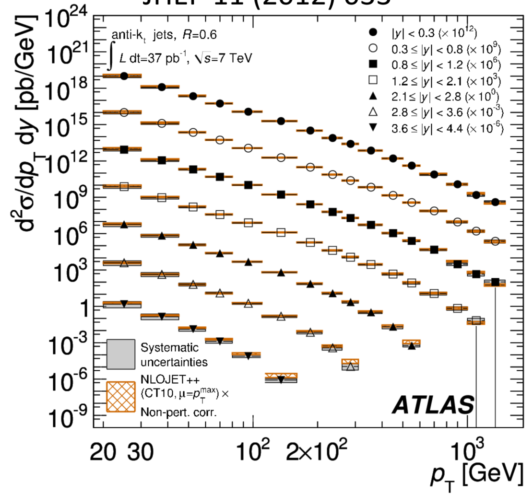
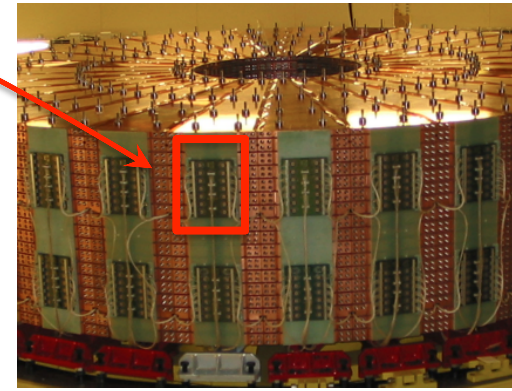


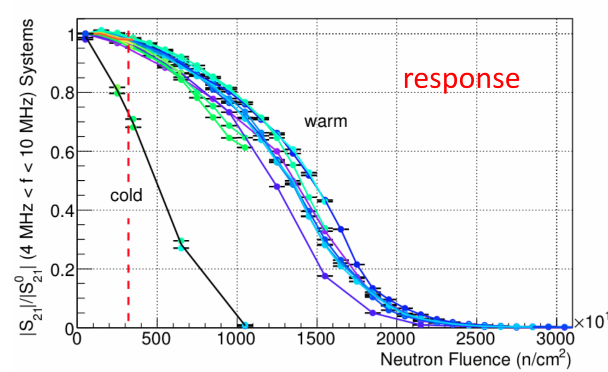
- Forward electrons (e.g. for Z A_{FB} measurement – presented this week at DIS2013)
- Used for centrality and event plane determination in Heavy Ion analyses.
- Important for missing-E_T resolution, forward-jet tagging.

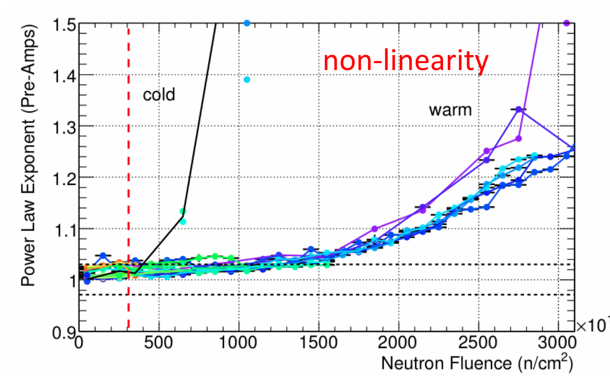
Issues for HEC GaAs (Cold) Preamplifiers

- Preamps sit on HEC modules inside cryostat.
- Performance OK for LHC design parameters, but may be significant degraded for integrated dose at HL-LHC.
- Irradiation → reduced output, non-linear response: unevenly for different channels. Channels summed in the cold so cannot correct for this in FE electronics.



- To install new preamps, need to remove HEC wheels from the cryostats.
- Requires removal of both warm and cold covers of cryostat. The latter is welded shut. Also requires removal of FCal.
- Results of most recent irradiation tests (in warm and cold) indicate that HEC electronics would be operating at its limit at HL-LHC (for safety factor of 5).
- Still need better understanding of actual cavern radiation levels in region of HEC cold electronics.

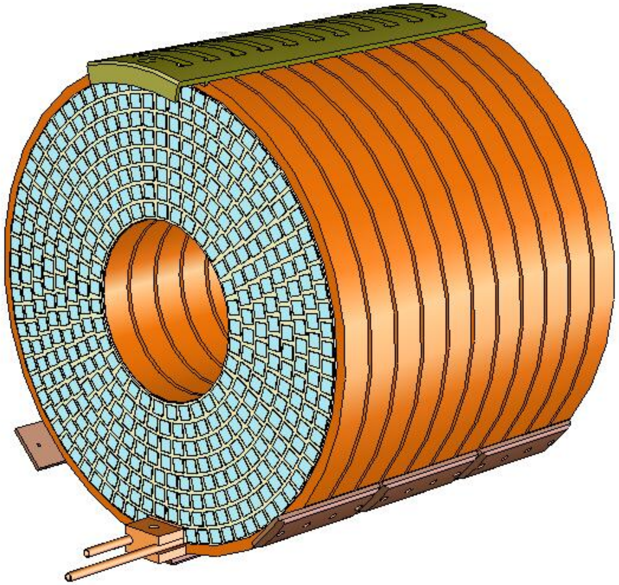




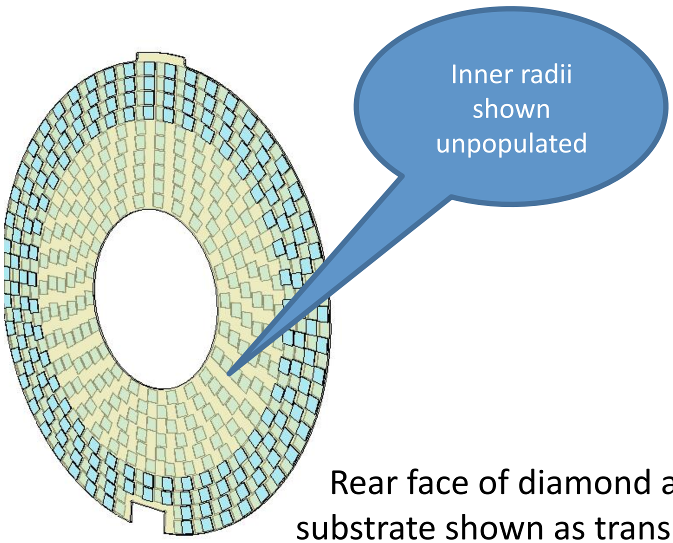
[See talk by M. Nagel in this session]

Copper / pCVD Diamond Mini-FCal Design

- 12 absorber plates (22.25 mm thick) with 11 detector planes (≈18.8 X_0)
- Absorber plates are copper (tungsten would give 3 x the neutron flux)
- Detector plane is ceramic disc covered with rings of ~1 cm^2 diamond detectors – use trapezoidal shape to minimize cracks.
- Reduce gaps by tiling both sides of disc in checkerboard pattern
- Roughly 8000 sensors / Mini-FCal.



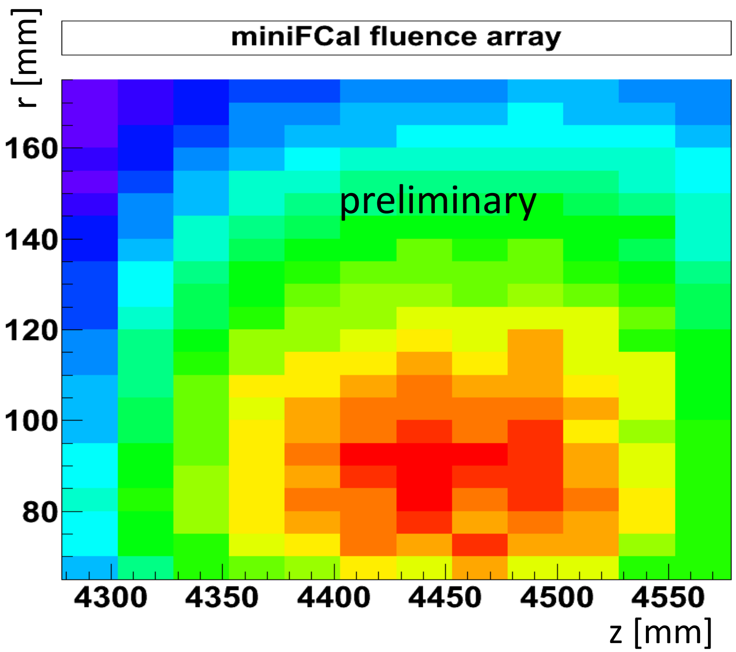
Front absorber removed to illustrate detector plane

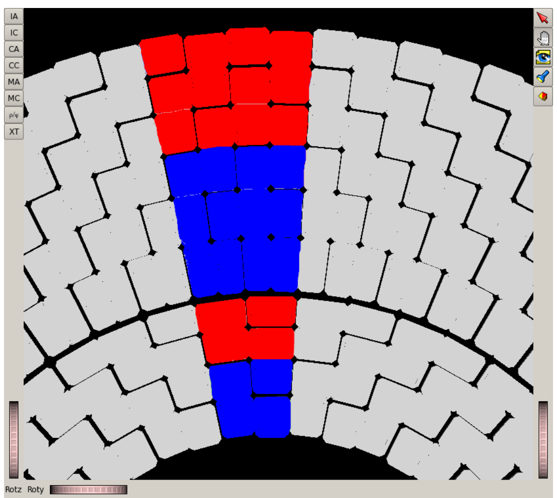


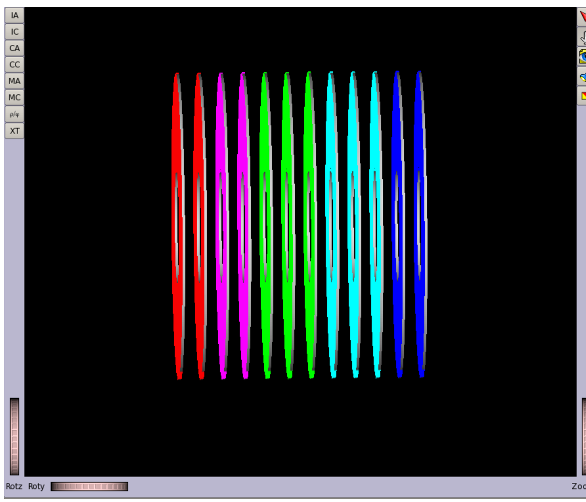
Rear face of diamond array substrate shown as transparent

Diamond Sensor Ganging and Irradiation

- 8000 sensors / Mini-FCal: readout limits number of channels to < 10^3. Ganging scenarios studied in simulation (transverse and longitudinal).
- Complicated by the differential radiation damage of wafers due to the difference in the fluence over the Mini-Fcal volume.
- The fluence changes rapidly in some regions with r and z. Need to gang in both.

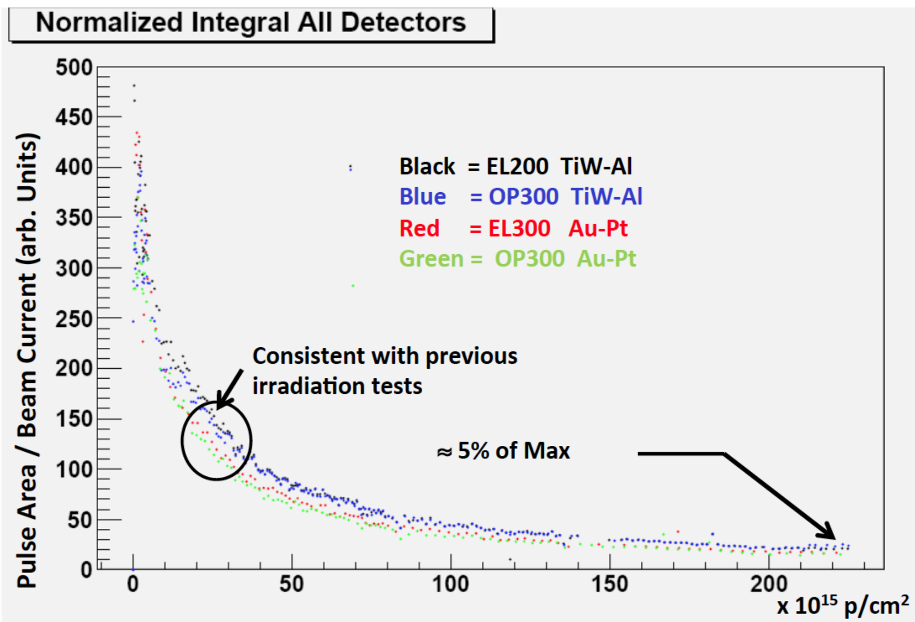






Challenges for the Diamond Mini-FCal

- Main issue is radiation hardness of the sensors: previous diamond irradiation tests (RD42) irradiated with protons only up to $2x10^{16}/cm^2$.
- Exposure at HL-LHC expected to be ≈ $2x10^{17}$ particles/cm^2 in the region $\eta > 4.0$.
- Tests undertaken using 500 MeV proton beam from the TRIUMF cyclotron.
- Responses of 2 DDL pCVD detector grades (optical, electronic) with two different metallizations (TiW-Al, Au-Pt) were continuously monitored during (average) exposure 2.2 x 10^{17} p/cm^2



- Peak exposure ~ 5 x 10^{17} p/cm^2 at centre of detector
- Damage curves used as input to Mini-FCal simulations.

Neutrons in the Mini-FCal

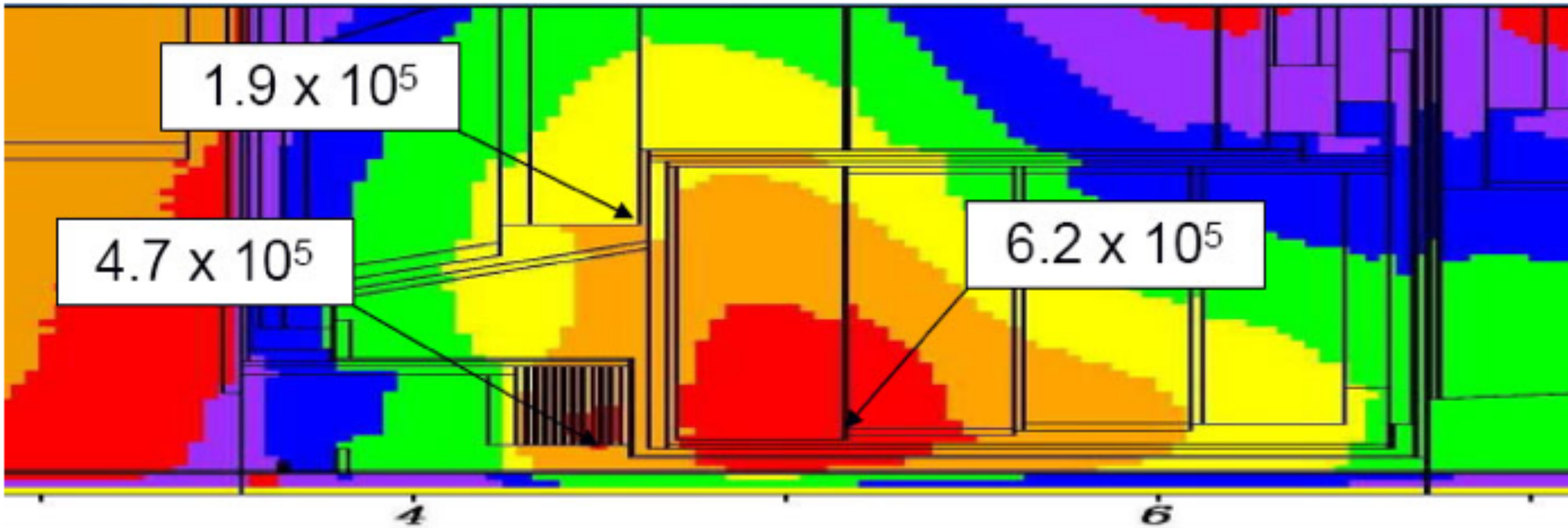
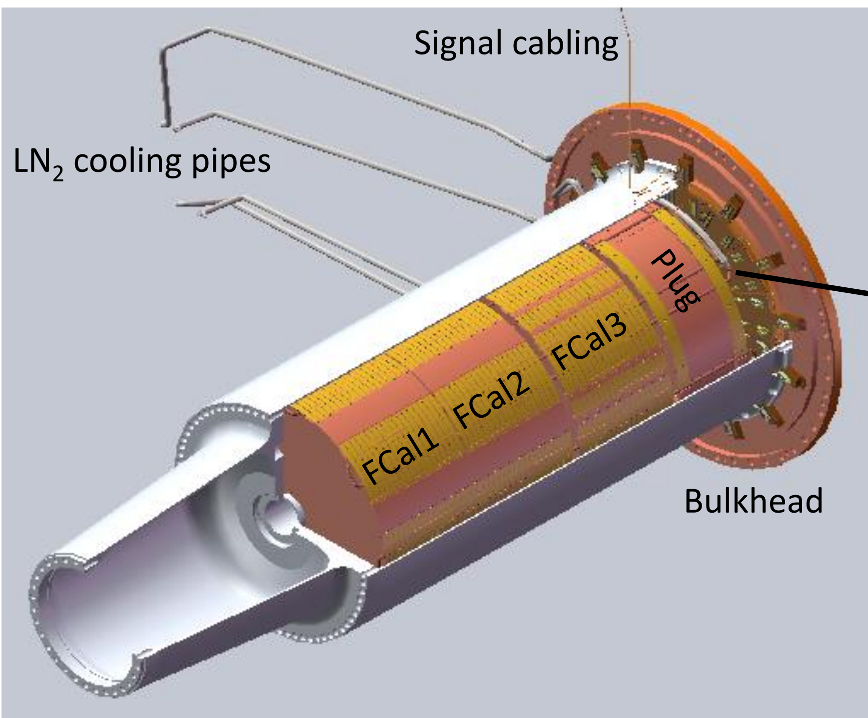


Figure 3. Neutron flux in the region of the Mini-FCal (kHz/cm^{-2}) produced using Phojet/G-Calor. The numbers shown are neutron fluences in kHz/cm^{-2} at LHC intensities. The horizontal scale is the distance in meters from the Interaction Point. The vertical scale is exaggerated for clarity. The peak neutron flux in the Mini-FCal is 4.7×10^5 kHz.cm^{-2} which corresponds to an integrated dose of 1.5 $\times 10^{17}$ cm^{-2} for an integrated flux of 3000 fb^{-1}. Different generators give variations of up to 25% in the neutron flux.

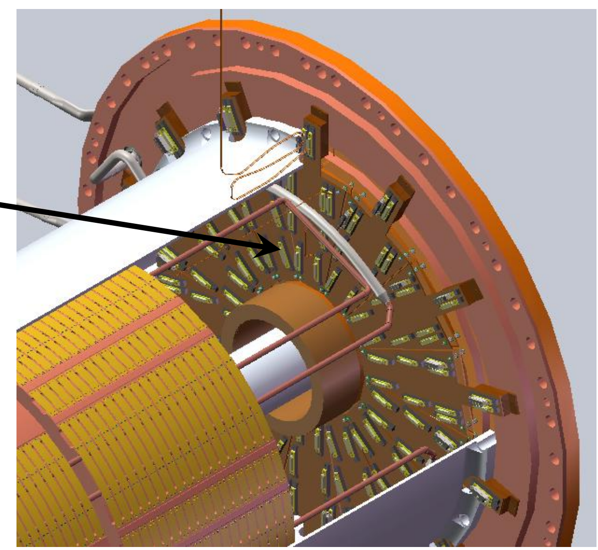
Diamond sensors also shown to function after exposure to 1.5 x 10^{17} n/cm^{-2} (IBR-2m reactor in Dubna: also used for sFCal / Mini-FCal material testing).

sFCal: Summing Board Locations

- If HEC is removed this is straightforward: new summing boards on rear of HEC
- If cryostat does not need to be opened:
  - Install new summing boards at back of FCal
  - Thread the cable between the old summing board and the plug in front of cold cover OR
  - Install new feedthrough in FCal region



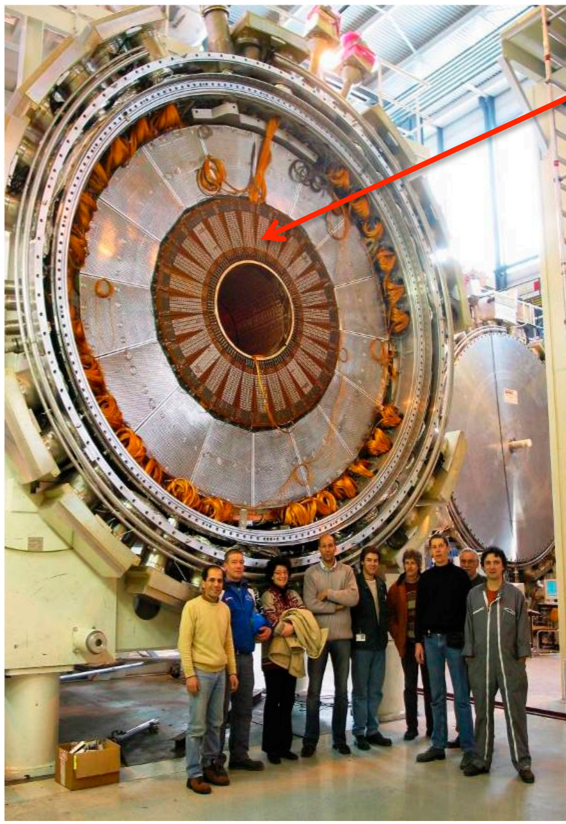
New summing boards could be mounted on FCal cold bulkhead

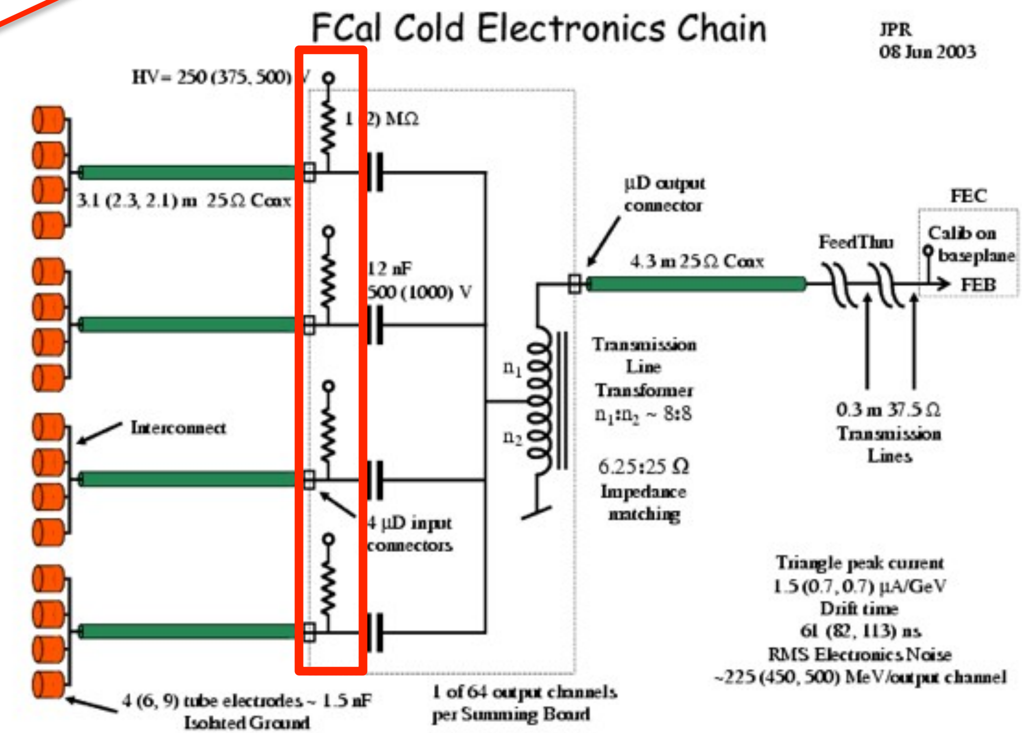


Need to ensure slightly reduced depth
Plug would still be OK for shielding

Forward HV Distribution / Signal Summing

- HV distribution and signal summing done on boards mounted to HEC rear face





HV delivered via 1MΩ or 2MΩ resistors in the cold.
Need to reduce by factor of 10 for HL-LHC operation.

ATLAS Liquid Argon Endcap Cryostat