High Granularity Timing Detector (HGTD)

Didier Lacour (LPNHE Paris) - Dirk Zerwas (LAL Orsay)
members of the ATLAS and Calice collaborations

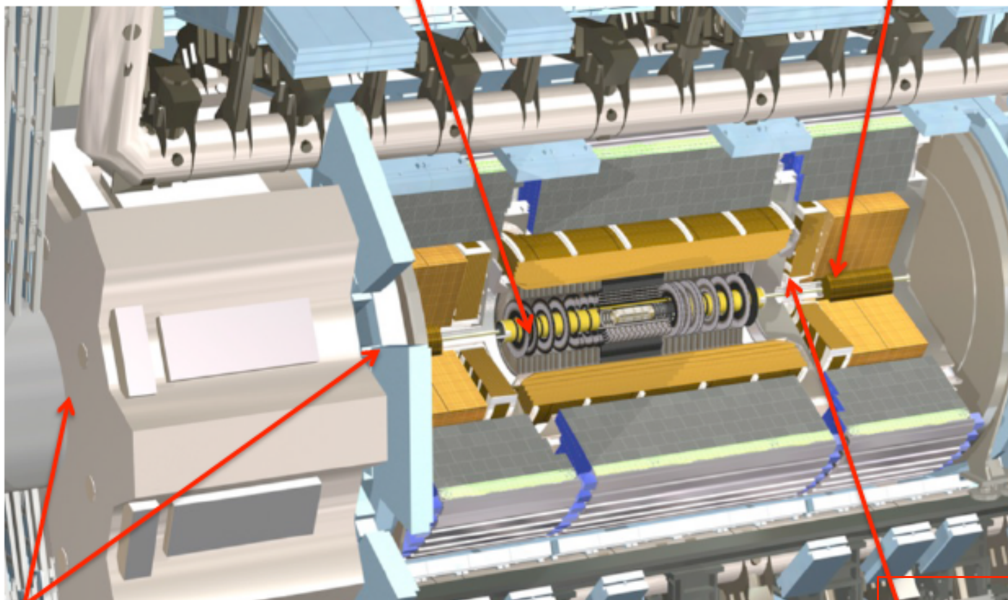
- In the framework of the "Large Eta Task Force" of the ATLAS collaboration
- Extension or improved instrumentation in the forward region at eta > 2.5
- Improvement of the phase-II ATLAS detector with much better pile-up rejection at HL-LHC
- A benefit for number of physics channels for signatures with forward jets or multiple objects and more efficient background suppression
  - Standard Model, Higgs boson VBF processes, H-> 4 leptons, ttbar background rejection for H->WW (improved missing energy transverse resolution, extended b or c tagging)
  - SM physics with VBF processes, same sign WW
  - WZ final states

Reference: Scoping document
https://cds.cern.ch/record/2055248/files/LHCC-G-166.pdf

Upgrade scenarios

Extend ITK tracker to 2.5<η<4: different pixel layouts (extended IBL, disks, rings, pixel granularity,...)

sFCal 3.1<η<4.9: FCAL1 with better transv. granularity and reduced pulse length



Trigger w/ fwd tracking:
- L0/L1 capabilities
- vertex information

Muon spectrometer options for 2.7<η<4.0:
- 1 pixelated tag chamber before EC toroid
- 2 chs (before/after EC toroid) +1.5T warm toroid

Segmented timing-preshower detector in front of EMEC/FCAL in 2.5<η<4 (MBTS location): (~100μm;~10ps)

Timing preshower detector

Multi-Channels Plate (MCP)

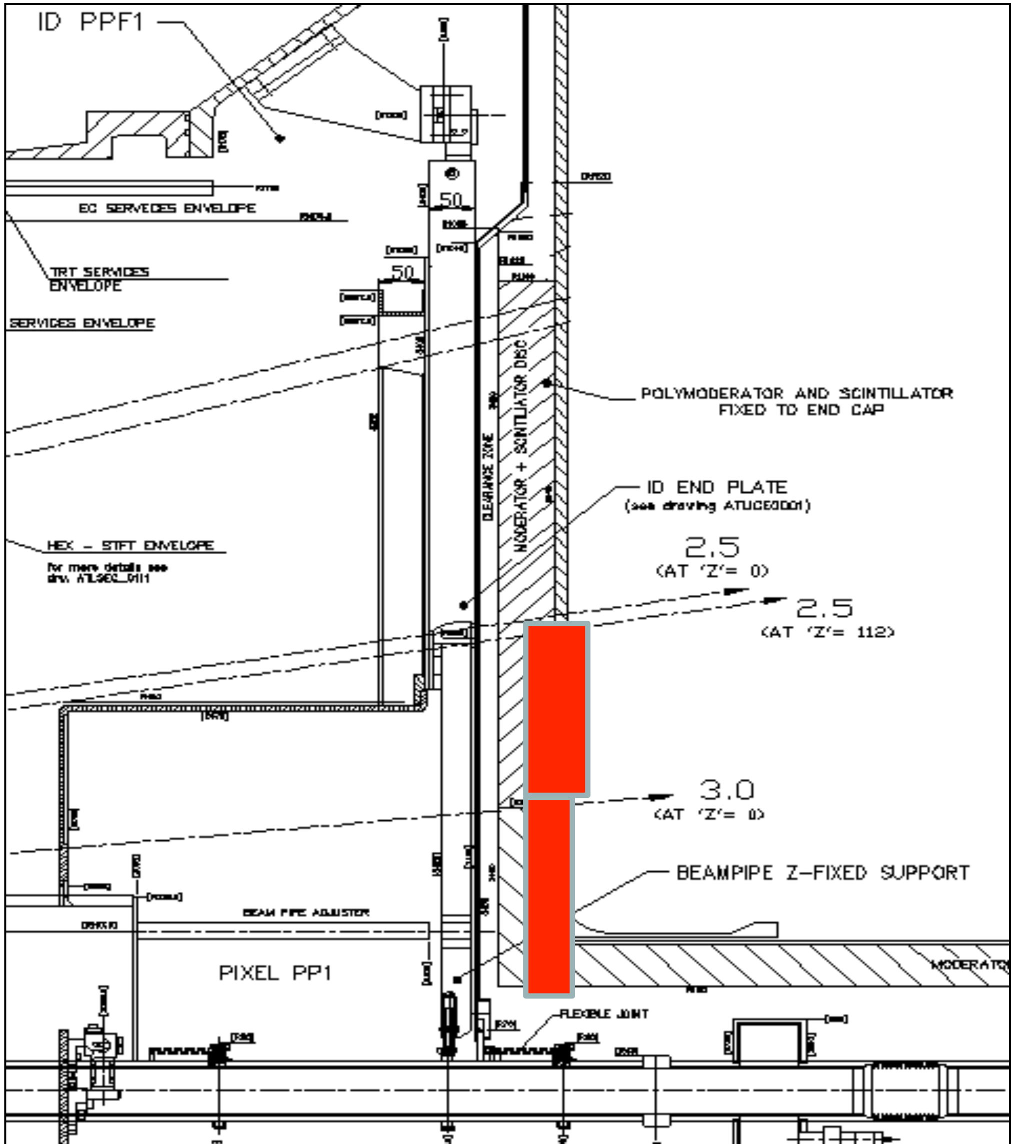
Mini-FCAL

Si-W calorimeter

…

A Silicon HGTD detector inspired by Calice

HGTD in the gap between the LAr barrel and end-cap cryostats



HGTD:

- Replaces MBTS
- Reduce pileup in phase-2
- timing to determine vertex
- Order 50ps

HGTD position:

- z=3500mm
- $2.5<\eta<5$
- 600mm>r>48mm

HGTD envelope:

- Δz=60mm
- 4 layers in depth
- Cell size order 5.5mm x 5.5mm
- Order 300k cells

HGTD timing detector:

No abs

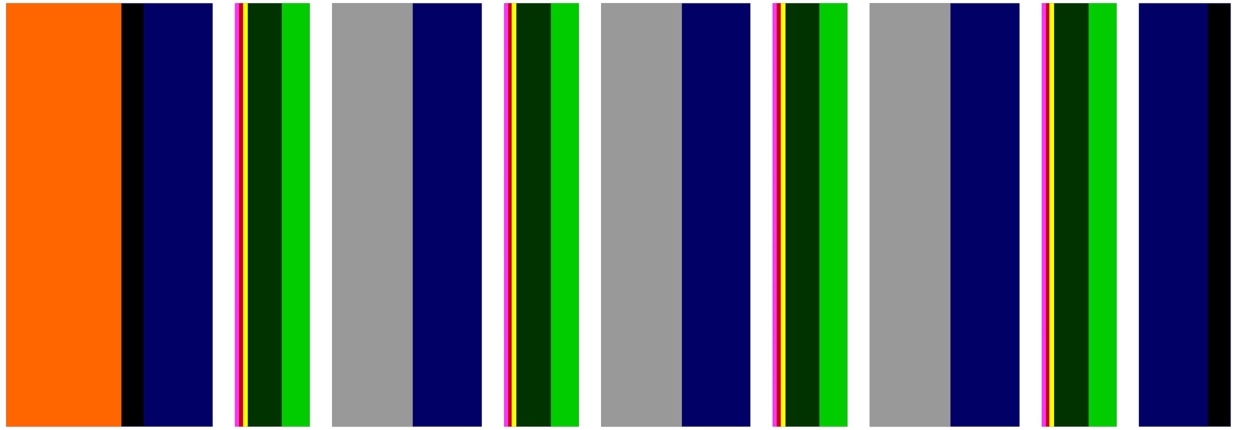
HGTD preshower detector:

3 absorbers

Absorbers in front of LArg IW only:

$2.5<\eta<3.2$, 600mm>r>175mm

« Preshower »



Ratios :
x 10:1
y 1:1

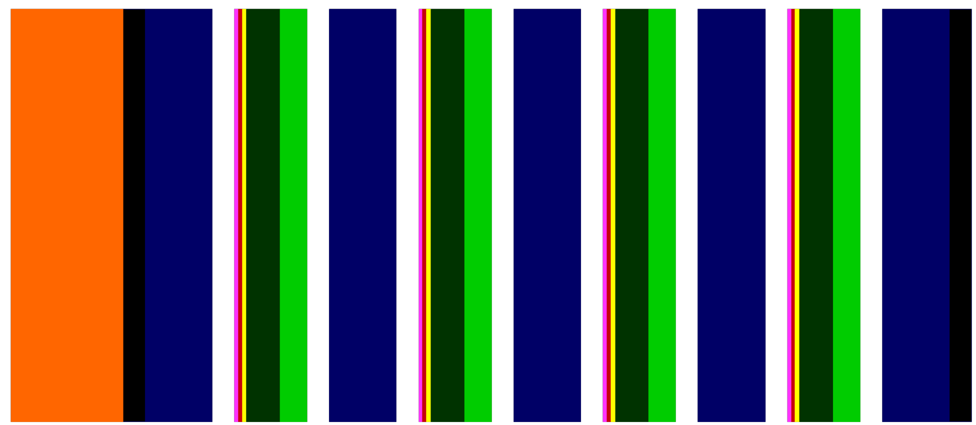
Space:
- 1mm between absorber (including cooling) and HV kapton
- 1mm between layers

Total width : 53.5mm

Aerogel: 5mm
Carbon Fiber: 1mm
Cooling : 3mm
Tungsten: 3.5mm

HV Kapton : 0.15mm
Si-Sensor : 0.2mm
Glue : 0.2mm
PCB : 1.5mm
Chip height : 1.2mm

« Timing »



Ratios :
x 10:1
y 1:1

Space:
- 1mm between absorber (including cooling) and HV kapton
- 1mm between layers

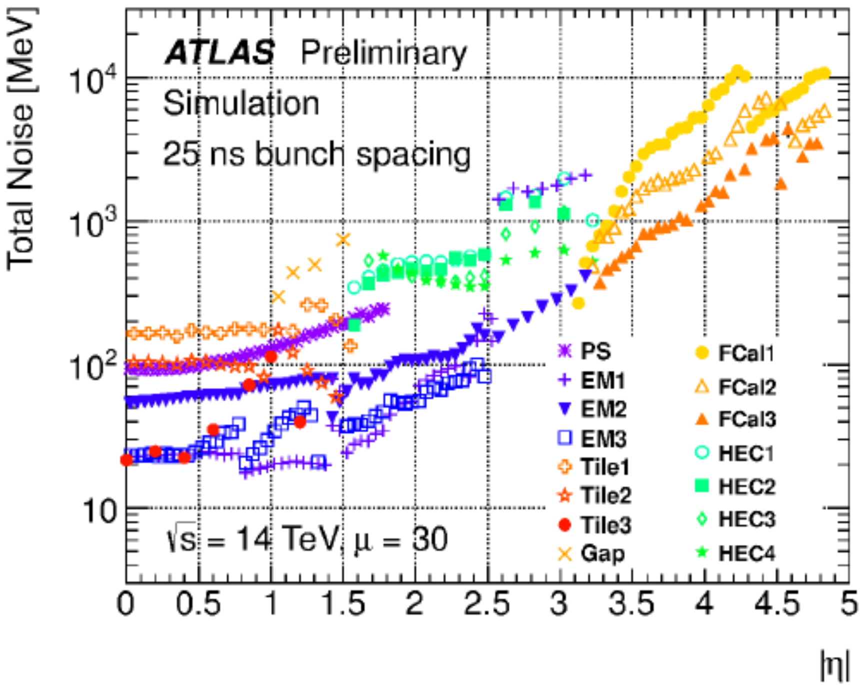
Total width : 43mm

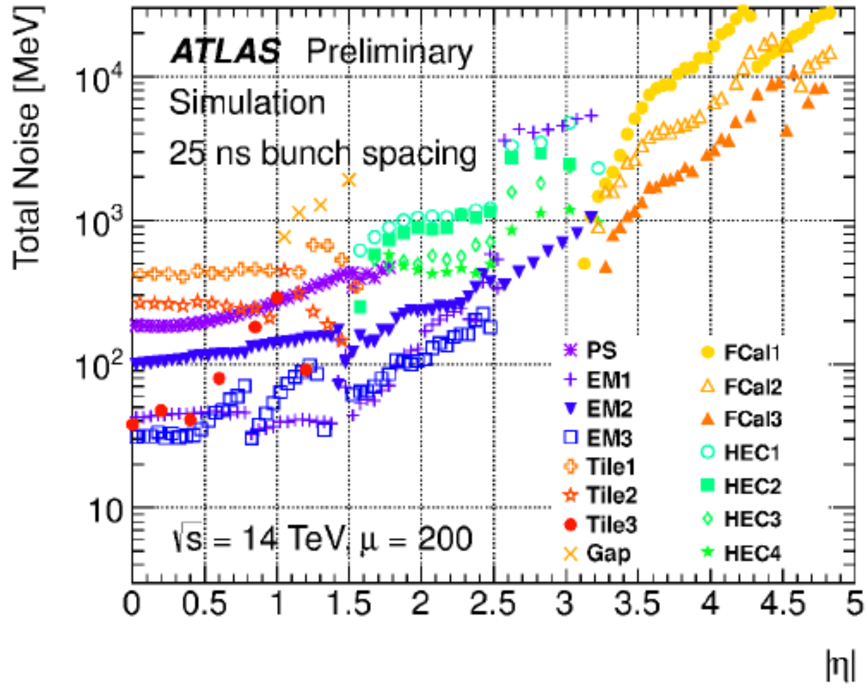
Aerogel: 5mm
Carbon Fiber: 1mm
Cooling : 3mm

HV Kapton : 0.15mm
Si-Sensor : 0.2mm
Glue : 0.2mm
PCB : 1.5mm
Chip height : 1.2mm

Calorimeter cell noise

- Degradation of the performances because of the pile-up conditions at the HL-LHC
- Increase of the total noise in individual readout channels

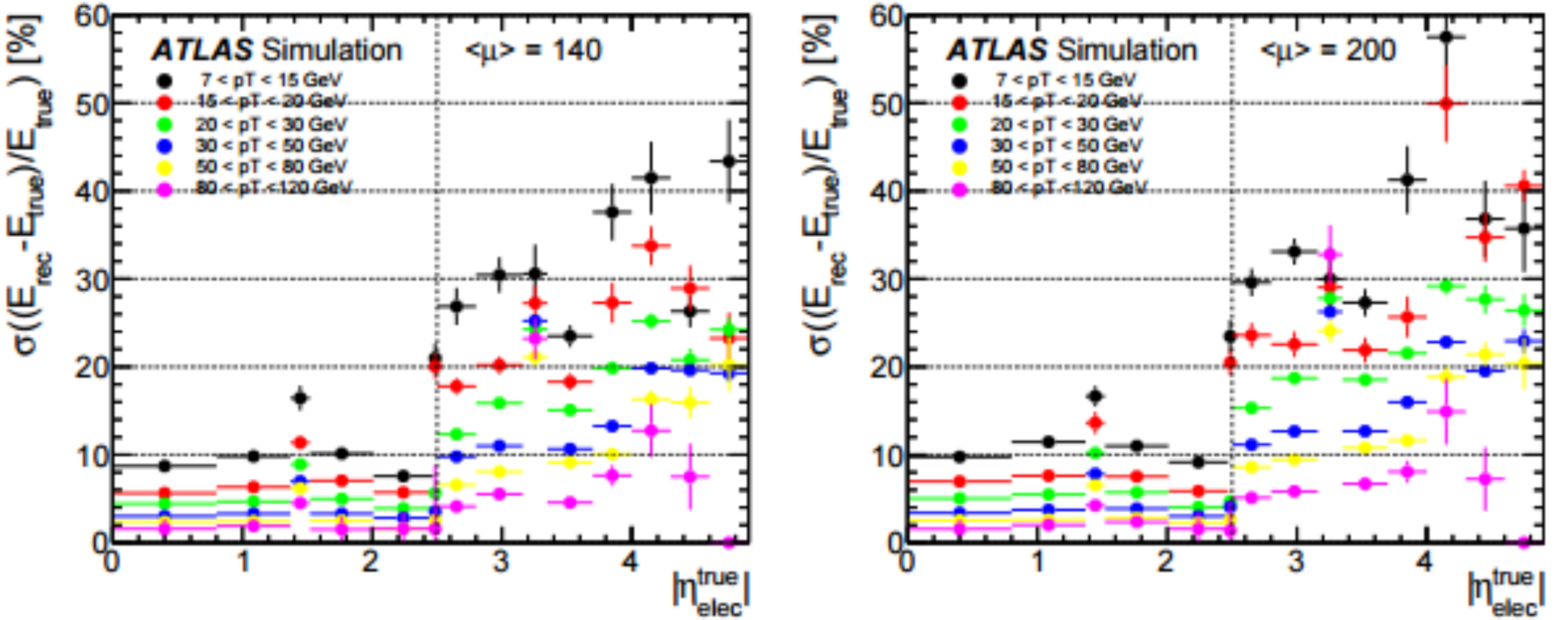




Expected total noise energy (electronic + pile-up) of the cells at different eta for an average number of interactions mu=30 and mu = 200

- Large cells in the LArInnerWheel (>2.5)
- Only 2 samplings
- Significant increase of noise for eta>2.5
- Use HGTD for pileup mitigation in offline and trigger
- Measure arrival time with precision of 50ps

Electron energy resolution

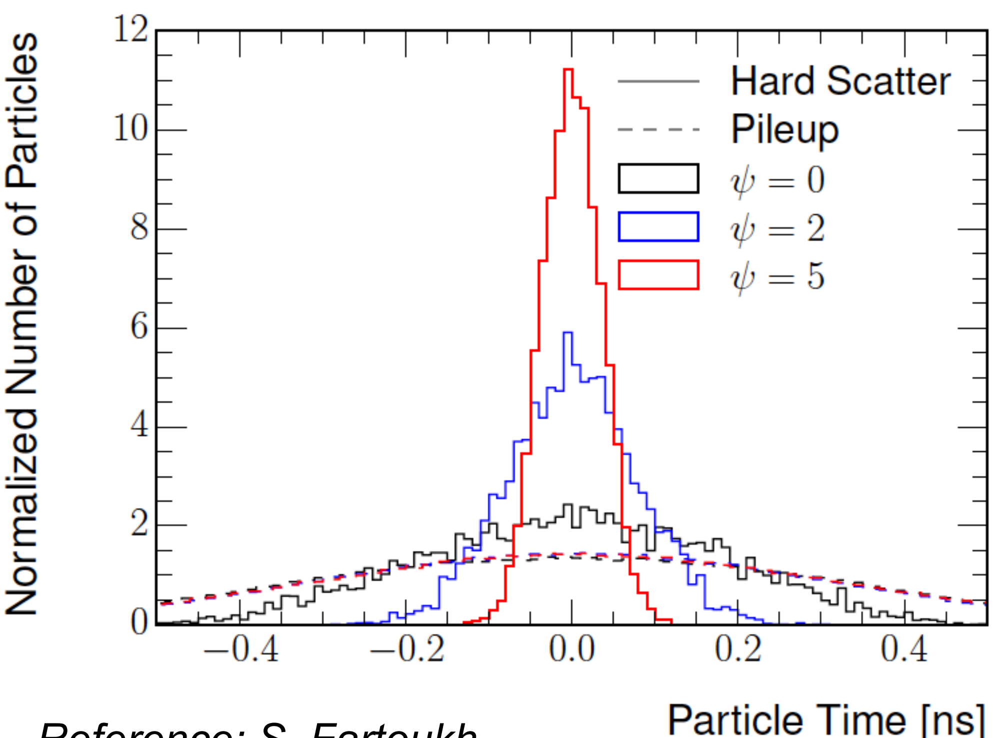


Energy resolution for electrons as a function of pseudo-rapidity and for different ranges of the electron transverse momentum for mu=140 and mu = 200

-> degradation of the resolution due to pileup

High Granularity Timing Detector

- Capability to identify the vertex origin of forward jets
- Pile-up vertices produced at different z positions: particles from different vertices arrive at different times
- Crab-kissing: a novel colliding scheme to extend the spatial pile-up density profile and to reduce the spread of the time density of hard scatter interactions



Run1 (solid and dashed black lines): very small separation for signal and pile-up due to the large time spread of collisions relative to the z spread of the bunch

Crab-kissing: significant sharpening of the time distribution for hard scatter particles, maintaining a large spread for pile-up particles

Reference: S. Fartoukh,
Pile up management at the high-luminosity LHC and introduction to the crab-kissing concept, Phys. Rev. ST Accel. Beams 17,111001 (2014).

HGTD ATLAS based on CALICE

ATLAS

- measurement: t and E
- 4 layers in depth (z)
- Granularity: ~5.5mm x 5.5mm
  - Option (limit): 2mm x 2mm
- Same basic structure
- Options: No absorber/Absorber

Weaker constraints:

- 4 layers in 6cm ~1.5cm per layer: Chip+PCB+Glue+Wafer=3.225mm, leaves 1cm for cooling and absorber: tungsten 3.5mm (baseline) or Pb 5.6mm 1X0 in support structure

Harsher constraints:

- Cooling of sensors -20deg
- RadHardness of FE electronics
- RadHardness of Glue (measurements foreseen in 2015-2016)
- Time measurement (order 50 ps)
- shorter peaking time
- 40MHz

ILD

- Measurement: E (and t)
- 30 layers
- Absorber: tungsten
- 30 layers in 18cm ~0.6cm per layer
- includes tungsten absorber
- Cooling of electronics (passive)
- Zero suppression/Power pulsing
- 5Hz 1ms bunchtrain

Signal:

- Large MIP signal (roughly 10-15 for CALICE)
- Occupancy (rough estimate): ¼ (at η=4)
- Intrinsic timing resolution ~150 ps per RO for S/N=25-30
  - 4 measurements per track?
  - Per jet/area?
  - Add absorber to increase signal? Which material? Impact on energy resolution?
  - LGAD sensors with intrinsic amplification?
- Granularity variation from 2mm to 10mm?

Readout:

- 5.5mm x 5.5mm pads:
  - 38x4x2 ASUs
  - 304k channels (=1.5*LArg)

Data throughput:

- 3 ASUs=3072 channels : 4Tb/s
- Zero suppression: ¼ (not sufficient)
- Reduction to Gb/s:
  - More than 1 link per ASU
  - Lvl1 reduction of 500-1000 (buffering on ASU →redundancy)
  - Local clustering?

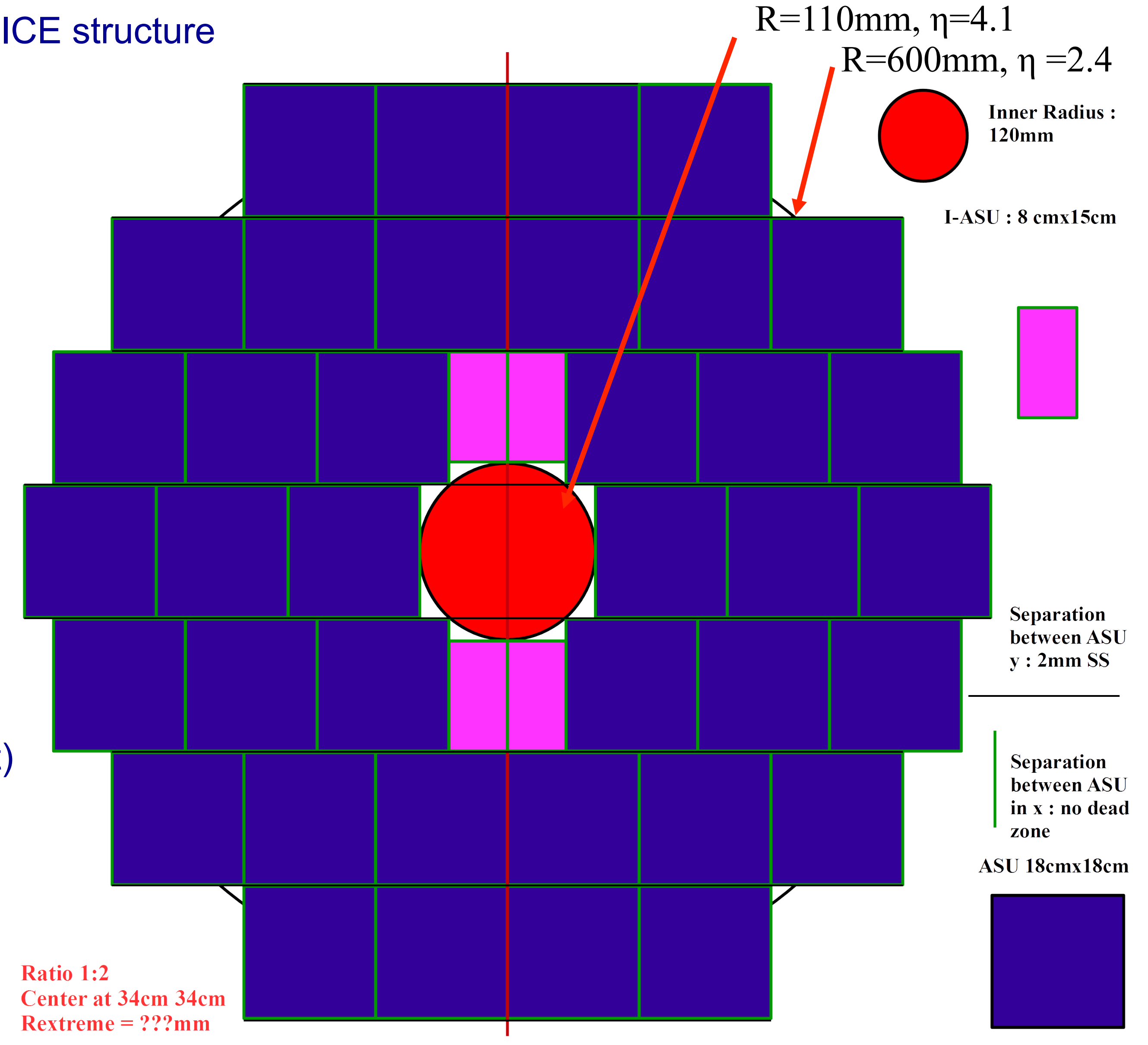
Sketch of an implementation in ATLAS

Preserve basic CALICE structure

Slabs CALICE-like:
- 2ASUs
- 3ASUs

Alternative:
- Single PCB
- Pro: less interconnections
- Con: planarity

Support structure (attached to cryostat)
- Material?
- Alveola?
- Direct mounting?



- Geometry in full simulation:
  - Geant4 implementation in progress
- Hits level:
  - Simulate fine granularity
- Reconstruction level
  - Sum to granularity
- Performance studies:
  - Signal per readout cell
  - Optimization of granularity
  - Absorber or no absorber
  - Use of timing in full reconstruction
  - Impact on e/gamma reconstruction in LAr Inner Wheel (energy and time)
  - Impact on jet reconstruction
  - Impact on ETmiss reconstruction

Time-line and milestones for the implementation of the HGTD