UK ATLAS Upgrade project Report to STFC OsC

Craig Buttar
University of Glasgow

Swindon 24/3/11

Outline

- Information in presentation is complementary to the OsC report
  - Heritage: ATLAS Construction and Tracker Upgrade project
  - LHC upgrade programme (presented at sLHC2011 meeting)
  - ATLAS Upgrade programme (presented at sLHC2011 meeting)
  - Highlights of work from 2010-11.

UK ATLAS Upgrade project

THE UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF CAMBRIDGE
THE UNIVERSITY OF EDINBURGH
UNIVERSITY of GLASGOW
LANCASTER UNIVERSITY
THE UNIVERSITY of LIVERPOOL
THE UNIVERSITY of MANCHESTER
UNIVERSITY OF OXFORD
Queen Mary University of London
Royal Holloway University of London
Science & Technology Facilities Council
THE UNIVERSITY OF SHEFFIELD
US University of Sussex
UCL

- 13 Universities
- STFC/RAL PPD
- STFC TD RAL/ATC
- Three year project
  - April 2010-March 2013
- R&D for ATLAS Upgrade programme
  - Maintain UK leadership
  - Builds on heritage of current ATLAS development and construction and Tracker Upgrade project

Heritage: ATLAS construction

- Last ATLAS "construction phase" oversight committee signed off on all deliverables
  - Semiconductor tracker (assembled in UK)
  - Level 1 calorimeter trigger (led by UK)
  - High level trigger & central DAQ (major aspects led by UK)
- Completed within £82M budget
- No call on £6M contingency

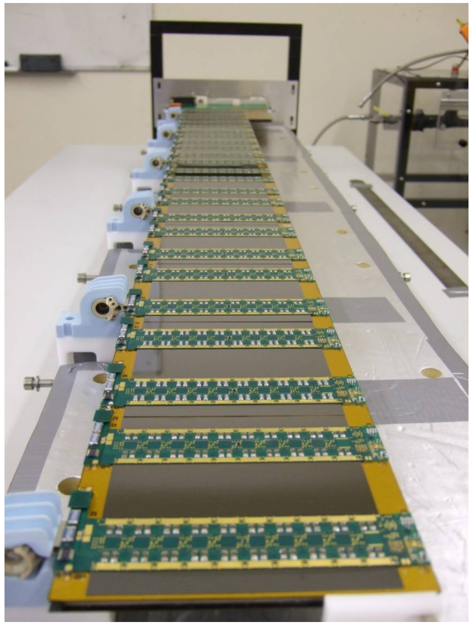
ATLAS running and Upgrade roles

- ATLAS is fully operational and is producing physics results
- Continue major roles in ATLAS operation and physics including
  - Deputy Spokesperson: Dave Charlton
  - SCT PL: Steve McMahon
  - L1CALO PL: Steve Hillier
  - Deputy Chair Publications Committee: Tony Doyle
  - Trigger co-ordination group: John Baines, Simon George
  - Physics group convenors
- Upgrade roles
  - **Upgrade coordinator: Phil Allport**
  - Thermal management: Georg Viehhauser
  - TDAQ Upgrade coordinator: Norman Gee
  - Software coordinator: Jeff Tseng
  - Phase-I TDAQ coordinator: Nikos Konstatinidis

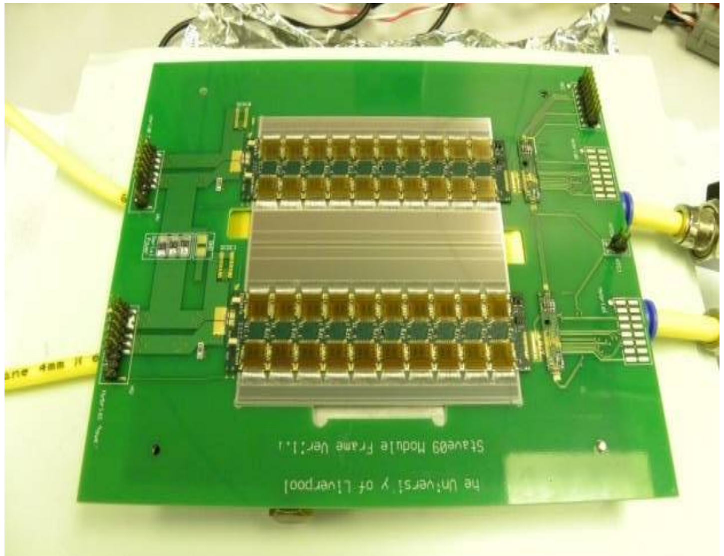
Heritage: Tracker Upgrade project

- In the last 6 months of the last grant we achieved our final deliverables, these have lead seamlessly into the ongoing work plan, but the final highlights could be described as:
  1. Completion of the first multi module object in the world and its readout through HSIO.
  2. Completion of the first thermo-mechanical stave (full size) with 24 working heat modules, fully instrumented and connected to a representative cooling plant (CO_2)
  3. Completed readout and powering systems for staves and stavelets, that are compatible with 1. and 2. and have since been used extensively to characterise both objects
- In short, the UK completed the last phase of the project by producing a 4 module full electrical prototype, and a 24 module mechanical one.
- The following 6 months (bridging and the last few months) has been spent understanding these objects and refining the design to enable the next step to the first complete electrical stave

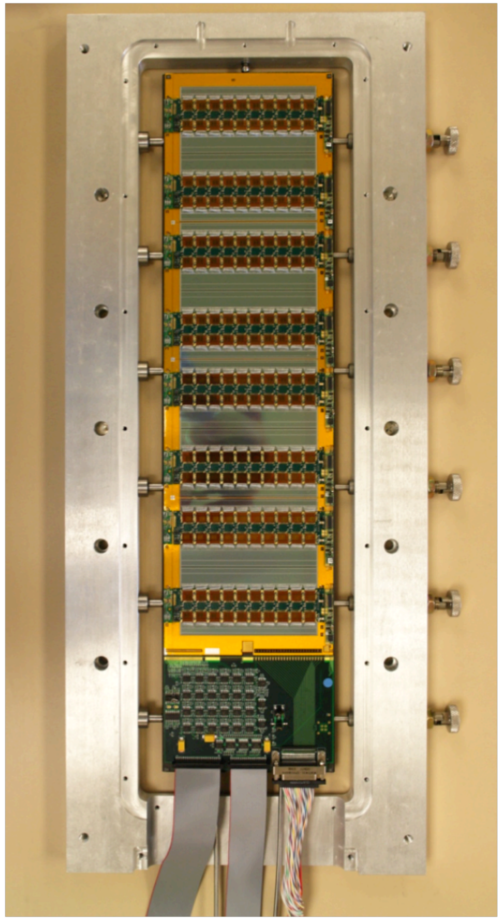
Heritage: Tracker Upgrade project



Thermo Mechanical stave about to be tested

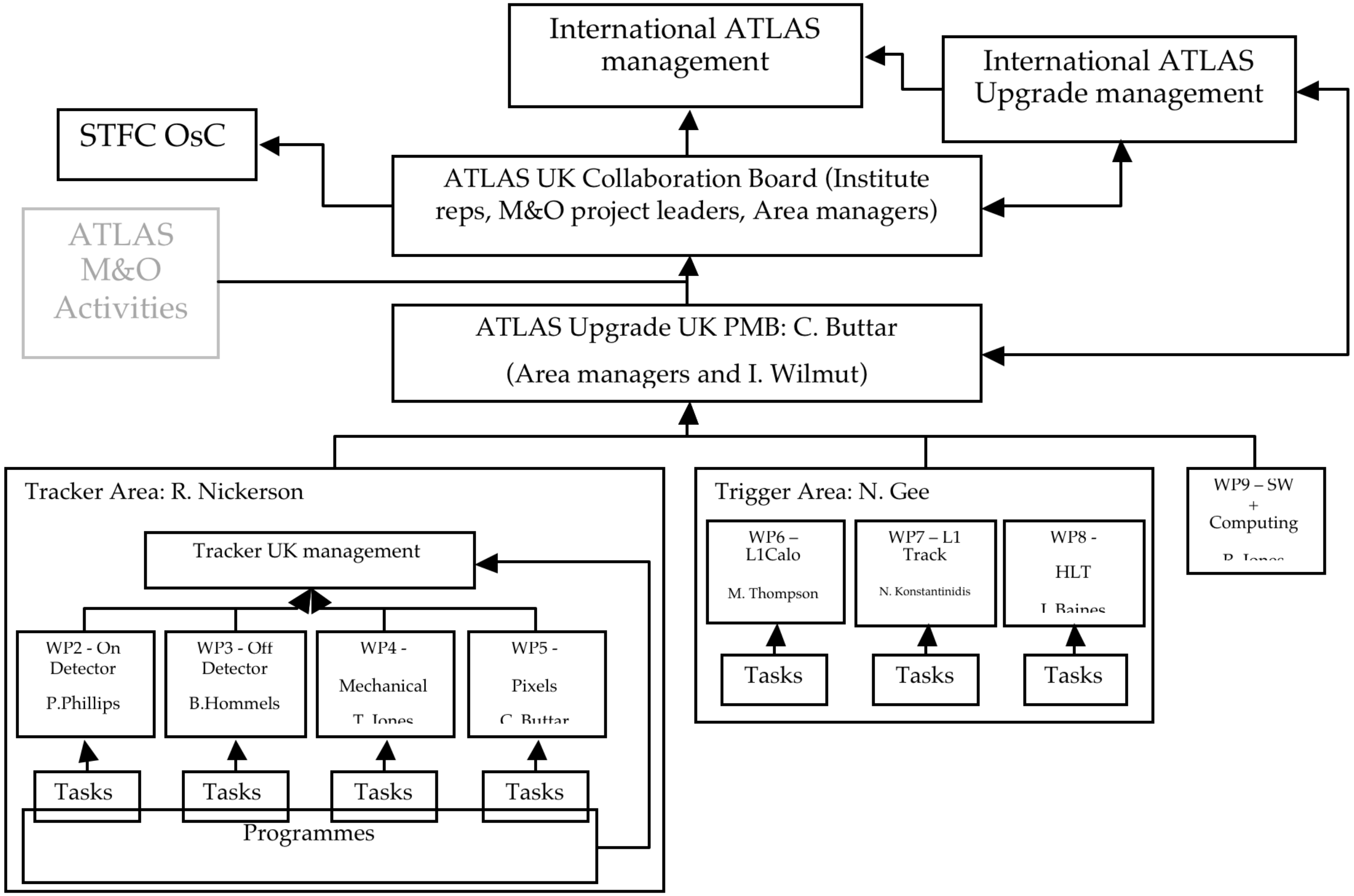


Module under test



Serially powered stavelet under test

ATLAS Organisation



LHC and ATLAS Upgrade programme

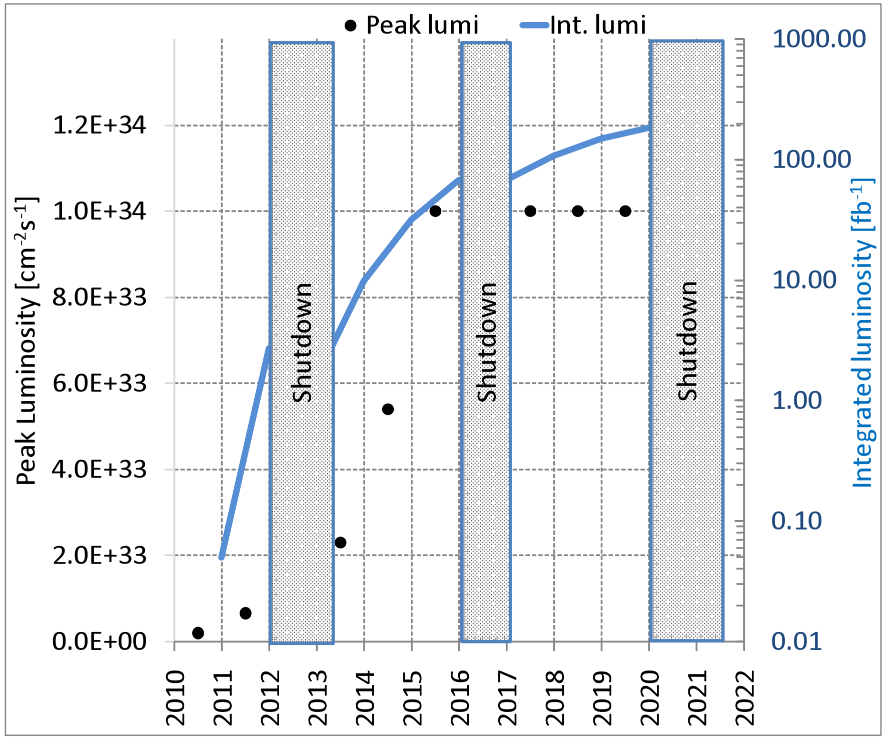
How the lumi might evolve in LHC

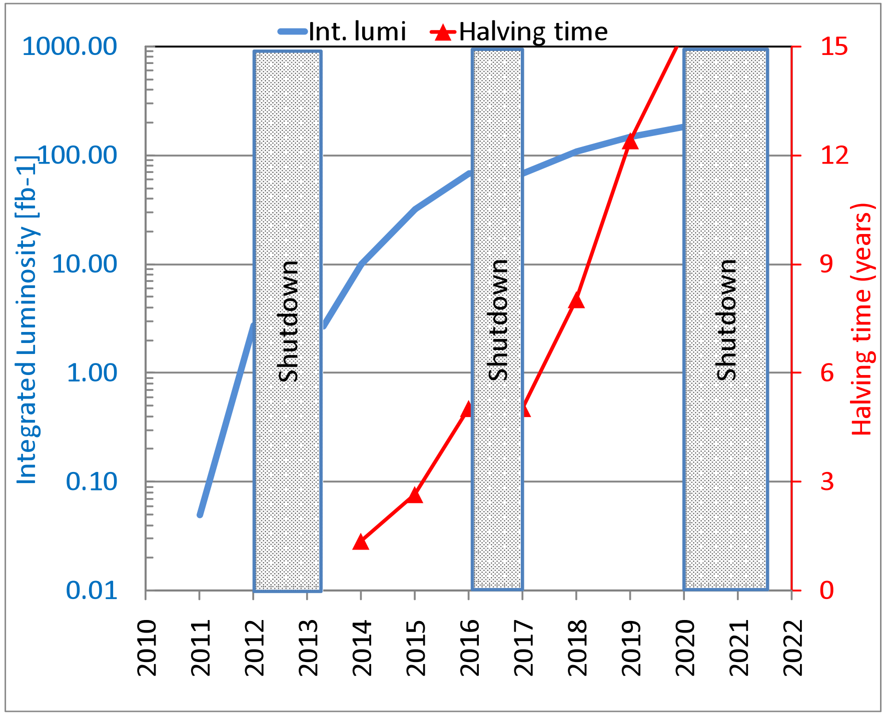
Prudent assumptions, **of September 2010**:

Better than expected LHC behaviour **is not yet** integrated.

It is assumed to saturate at design luminosity of 1.e34. Today we **may assume** 1.7-2 e34 !

The new shutdown plan (approved 31 January 2011) not yet integrated (shutdown in 2013)





Better performance may push the integrated lumi to 300 fb^{-1} before 2020.

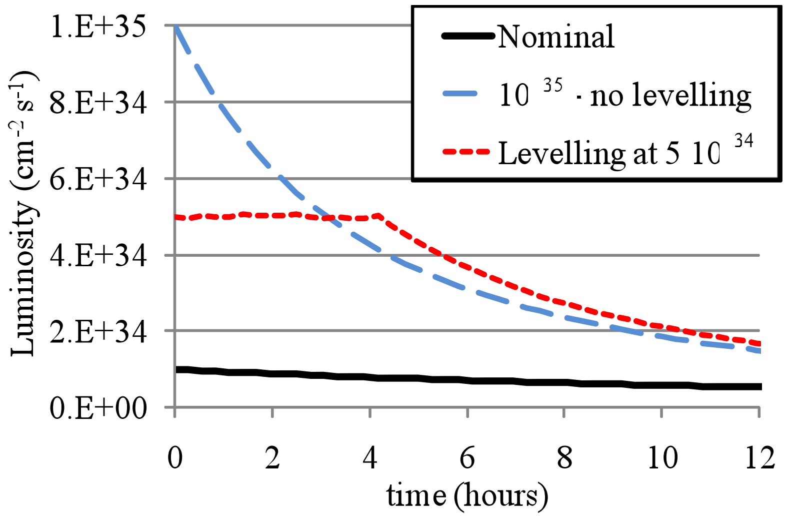
L.Rossi sLHC2011

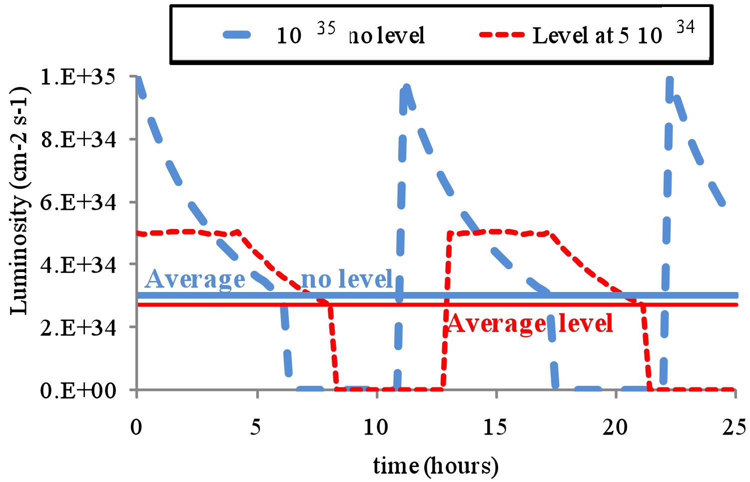
LHC Upgrade: The goal

The main objective of HL-LHC is to implement a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

•A peak luminosity of **5×10^{34} $cm^{-2}s^{-1}$ with levelling**, allowing:

•An integrated luminosity of **250 fb^{-1}** per year, enabling the goal of **3000 fb^{-1}** twelve years after the upgrade. This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.





- allow design for lower peak L, less pile up
- less peak heat deposition (a factor 2 may be the diff

L.Rossi
sLHC2011

Summary of ATLAS/LHC Upgrades Time-line

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity ATLAS Phase-0 upgrade

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

2030 — ILC, High energy LHC, ... ?

Nigel Hessey
ATLAS Upgrade
sLHC2011

Why Upgrade ATLAS?

There are many important results that will benefit from a much bigger data set

Technology improves, and we can build better performing detectors now

Detectors age, especially with accumulated radiation damage, and need replacement: better to plan ahead and replace with the best allowed by technology

The LHC will improve, in particular delivering higher instantaneous luminosity than ATLAS was designed for: needs higher granularity detectors to maintain performance

It takes a long time to install new detector elements, which has to be done with the LHC off
ATLAS will take maximum advantage of all LHC shut-downs to make the best possible detector
It takes many years to research ideas, design upgrades, and build them, especially new inner trackers, hence the work started several years ago

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2013/14: Insertable B-layer

There are several **reasons to bring forward the IBL installation into the 2013 shut-down**:

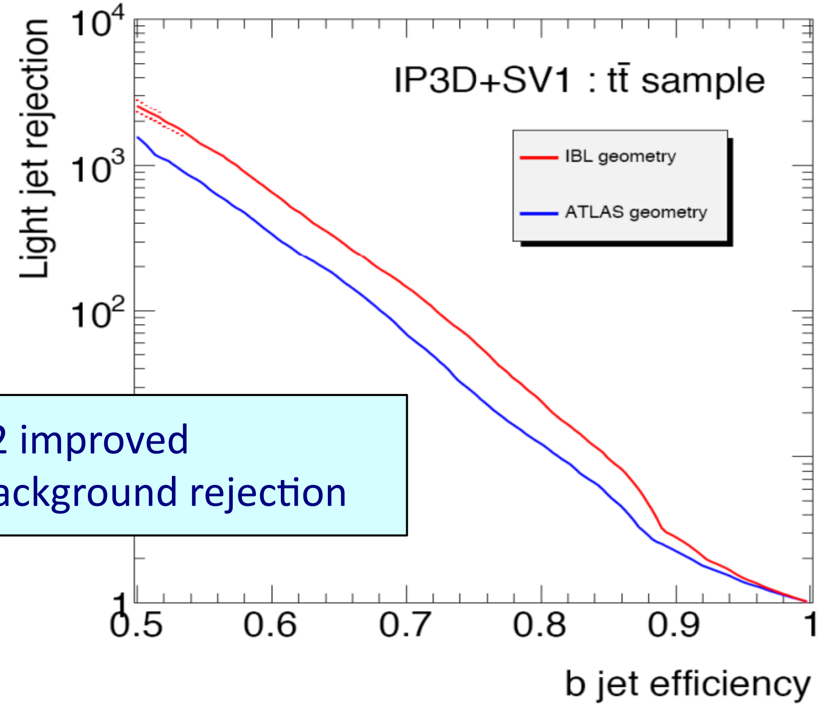
-- It improves the physics performance of ATLAS, even at low luminosity

-- Less risk/tooling needed to install when the pixel detector is removed for nSQP installation

-- Lower radiation environment in 2013 compared to 2017/18

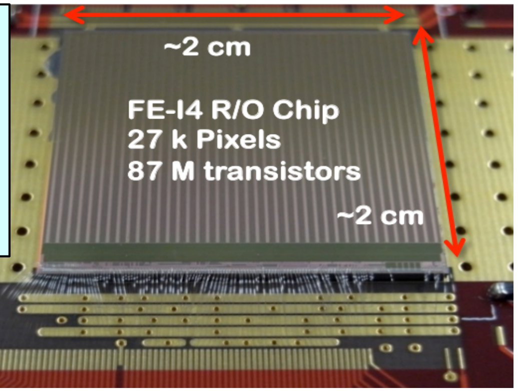
ATLAS IBL project will accelerate to install in 2013/14:

-- very challenging, but looks possible



x2 improved background rejection

New front-end readout chip FE-I4 delivered and performing very well



WP5: Pixels

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2017/18:Phase I: Conditions and trigger

About 9 months shut-down for installation of new elements

Conditions after:

Peak luminosity increasing to 2 x 10^{34} cm^{-2} s^{-1}

Total integrated luminosity before Phase-II 3-400 fb^{-1}

Phase-I Task-Force in place to optimise ATLAS Phase-I upgrades

Options under study given here; what cannot be done in Phase-I will move into Phase-II

Trigger:

Beef up processors and data links for extra data rate

Bring in "topological" triggers – the ability to look at 2 or more trigger objects at L1

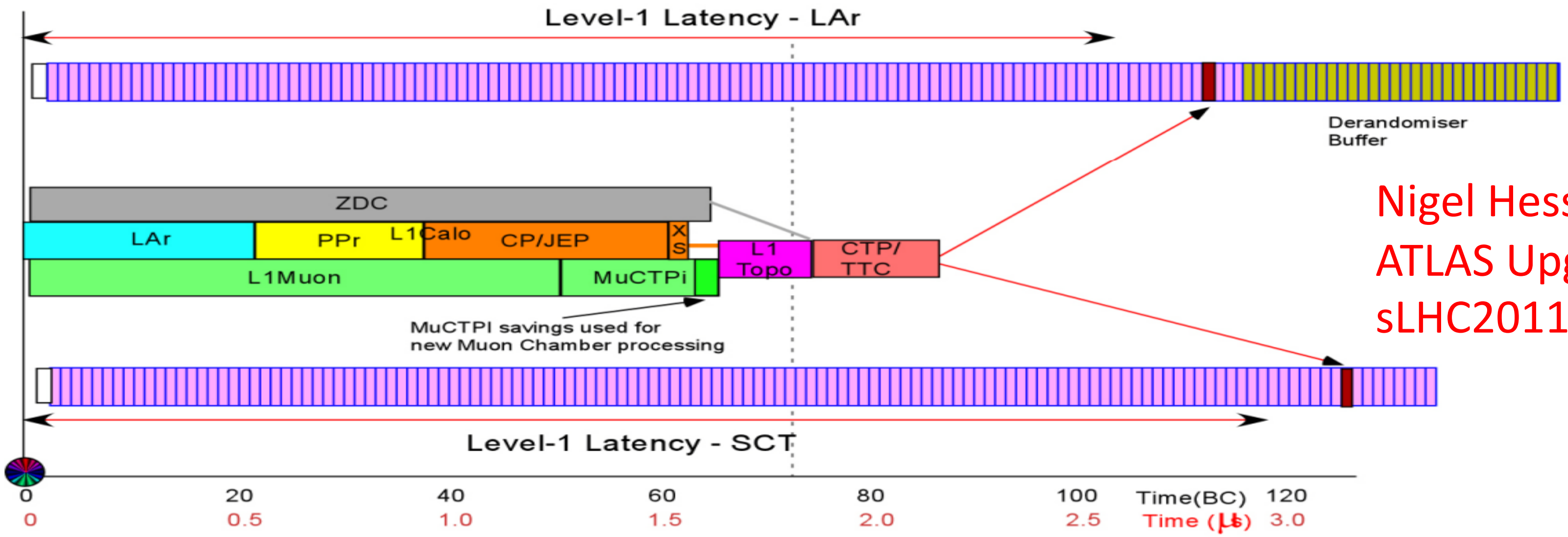
- e.g. isolated muon = muon far from any jets

Missing Et significance trigger

WP6: L1 Calorimeter

WP7: L1 Track trigger

WP8: HLT



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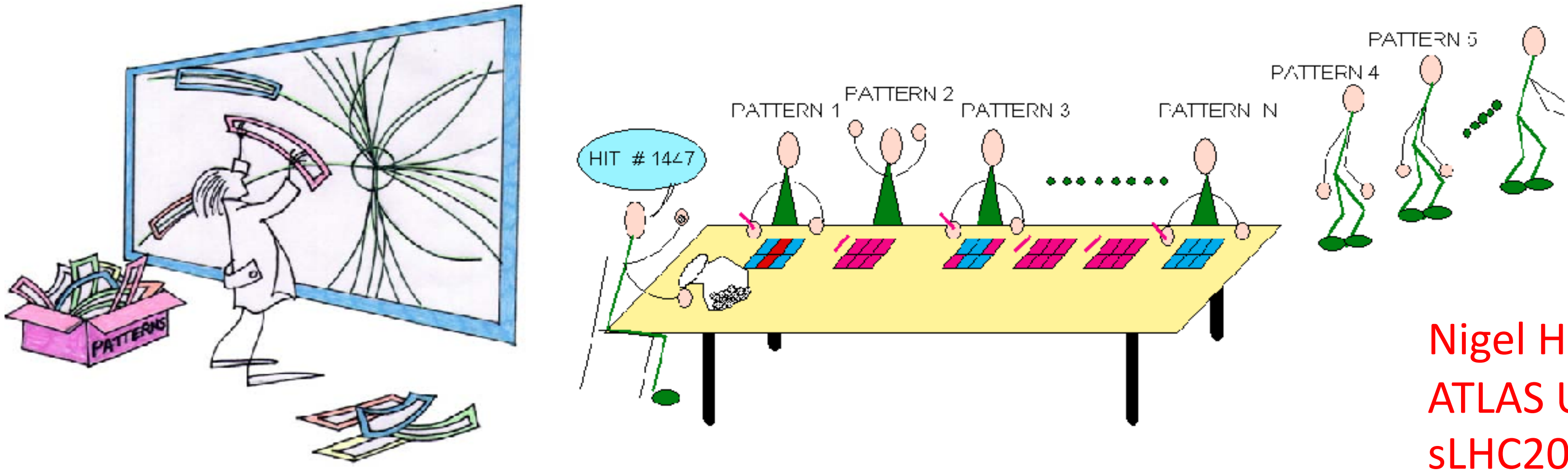
Level-2 fast track finder, FTK (before the SD)

WP8: HLT

Two time-consuming stages in tracking

- **Pattern recognition – find track candidates with enough Si hits**



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  – **10^9 prestored patterns simultaneously see each silicon hit leaving the detector at full speed.**

- **Track fitting – precise helix parameter & χ^2 determination**
  – **Equations linear in local hit coordinates give near offline resolution:**

$$p_i = \sum_{j-1}^{14} a_{ij} x_j + b_i$$ ***a* & *b* are prestored constants; VERY fast in FPGA**

March 4, 2011 FTK Status Report 2

ATLAS Changes for Phase-II, HL-LHC, around 2021

Conditions:

Peak luminosity 5 x nominal with luminosity levelling: 200 interactions per bunch crossing to be disentangled

3000 fb^{-1} good data on tape: Very big increase in integrated luminosity --> high radiation dose to detectors

18 month shut-down

Most of ATLAS can remain:

Magnets, most of muon and calorimeter systems.

Changes summary:

Trigger and DAQ: significant changes needed

Several new muon chambers needed - to be evaluated with experience

New calorimeter readout for higher granularity trigger information

Changes in LAr End-cap calorimeter

New inner detector

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Trigger at sLHC

Need to maintain low thresholds on leptons (~20 GeV), missing ET, and forward jet trigger for the physics programme.

Events are ~5x bigger, storage and bandwidth limit us to same final event rate as now (~200 events/s - but we are investigating implications of raising this)

So must reject 5x as many events of 5x the size – challenging

Single particle rates at low pT are too high; raise single object thresholds but maintain low thresholds in combination with other features.

Main improvements:
Muon trigger – increase the sharpness of the threshold at higher pT (40 GeV/c)
Calorimetry: read out all data, full granularity, and build trigger off-detector
- allows better particle ID at L1
Longer L1 latency (6 or 12 μs cf 3 now), allowing more processing for combined objects
Possible inner-tracker track-trigger at L1
Precise trigger scheme will evolve as the physics priorities and detector capabilities become better known
In addition, data storage and transfer bandwidth need beefing up

WP6: L1 Calorimeter
WP7: L1 Track trigger
WP8: HLT

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Inner Tracker: Completely New

Hit rates in current inner tracker:

Current pixel B-layer becomes noticeably inefficient at $2x10^{34}$ cm^{-2} s^{-1}, significantly so at $3x10^{34}$ cm^{-2} s^{-1}

SCT: some regions cannot readout events above $2.5x10^{34}$ cm^{-2} s^{-1}, due to optical data-link bandwidth

TRT occupancy becomes very high, although it still helps even at 3×10^{34} cm^{-2} s^{-1}

Radiation damage:

SCT designed for 700 fb^{-1}: above that, progressively worse inefficiency and other problems

Pixel B-layer considerably less

New technology:

New electronics (130 nm and smaller CMOS) allows lower power and smaller chip sizes; for pixel read-out chip, less inactive area

New bump-bonding and chip thinning allows cheaper, thinner pixels

New cooling and carbon support structures can allow lower radiation lengths

Multiplexing, e.g. local powering schemes, and CO2 cooling allow reduced material budget

Conclude:

ATLAS needs an all new Inner Tracker at Phase-II
Higher granularity detectors to keep occupancy down
Base-line is an all-silicon tracker: pixels and micro-strips

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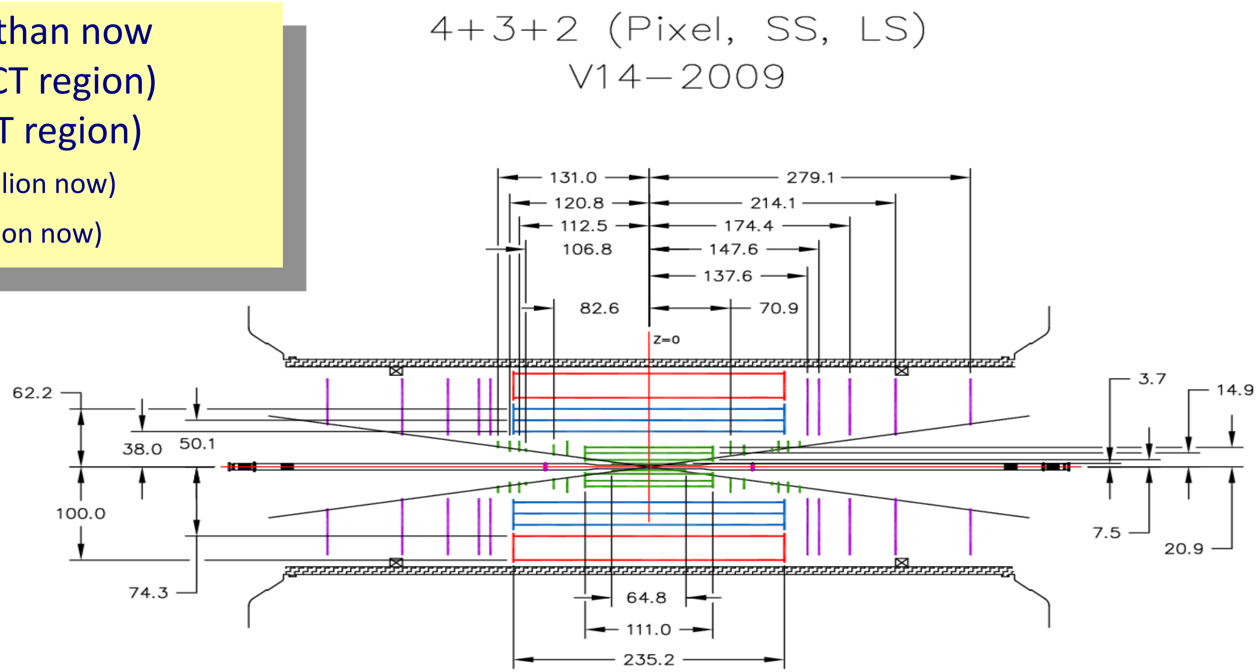
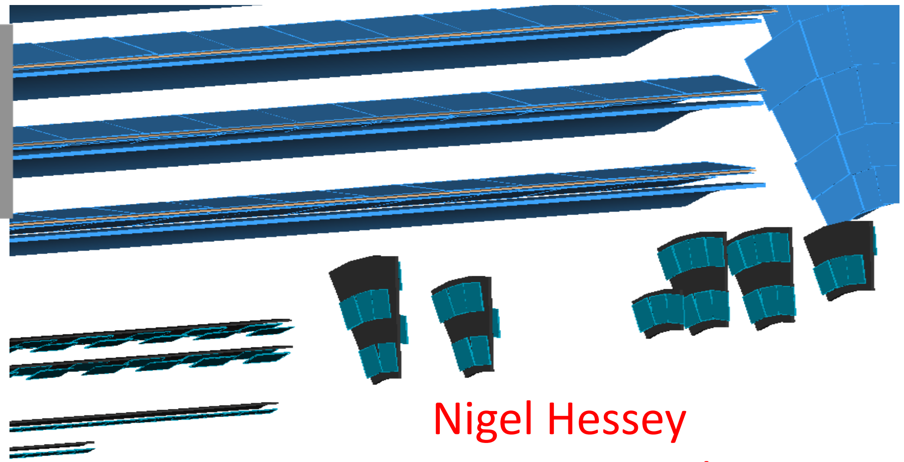
Strawman Layout of New ATLAS Inner Tracker

4 layers of pixels to larger radius than now
3 double-layers of short strips (SCT region)
2 double-layers of long strips (TRT region)
Approx. 400 Million pixels (cf 80 Million now)
Approx. 45 Million strips (cf 6.3 Million now)



WP9: Computing

Implemented in Geant, including realistic service material, to study performance and look at optimisations



Inner Tracker Sub-committee set up to further improve on this: number of layers, length of barrel, conical end-caps, maintenance

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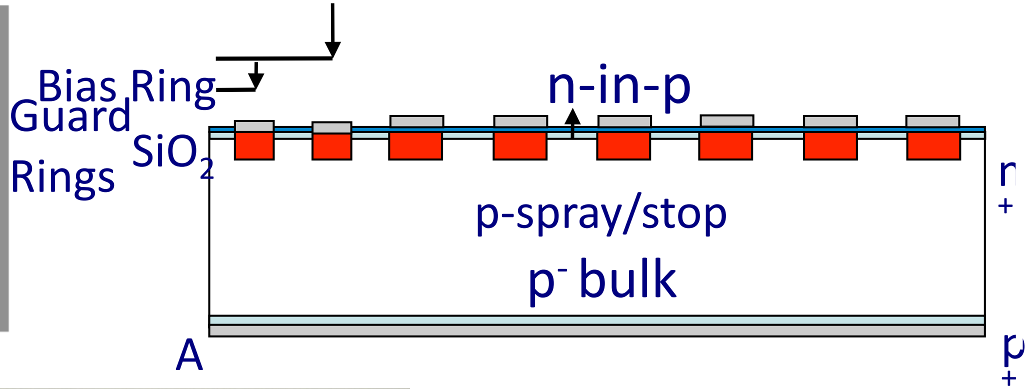
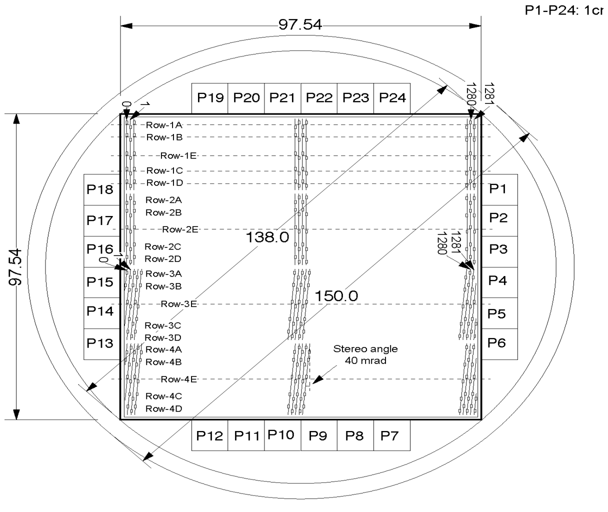
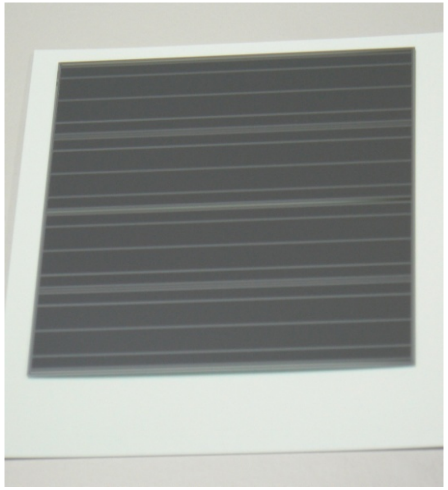
Micro-strips: sensors

Choose n-in-p (cf p-in-n now)
Faster signal collection, cheaper production than n-in-n, does not need full depletion
Successful production ATLAS07 sensors at Hamamatsu
- irradiation tests and prototyping made





Axial-Stereo Sensor



WP2: On-detector
(Tracker upgrade project)

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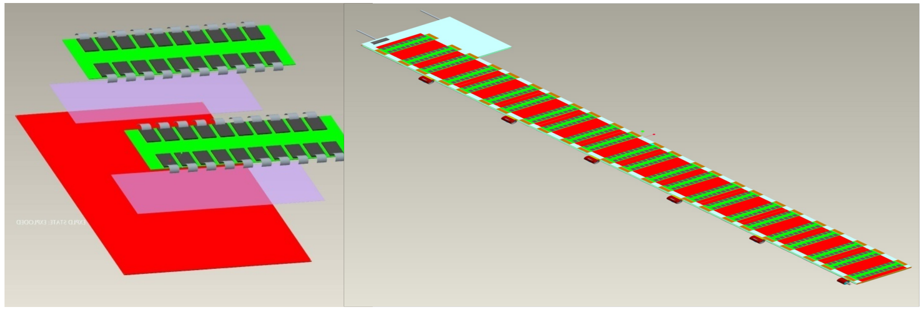
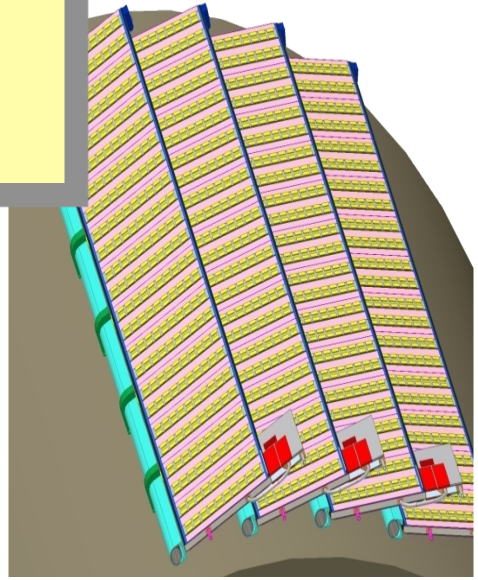
Neutron irradiation results show S/N worst case is 10:1 in strawman layout after 3000 fb^{-1} with a safety factor 2

Microstrips: Modules and staves

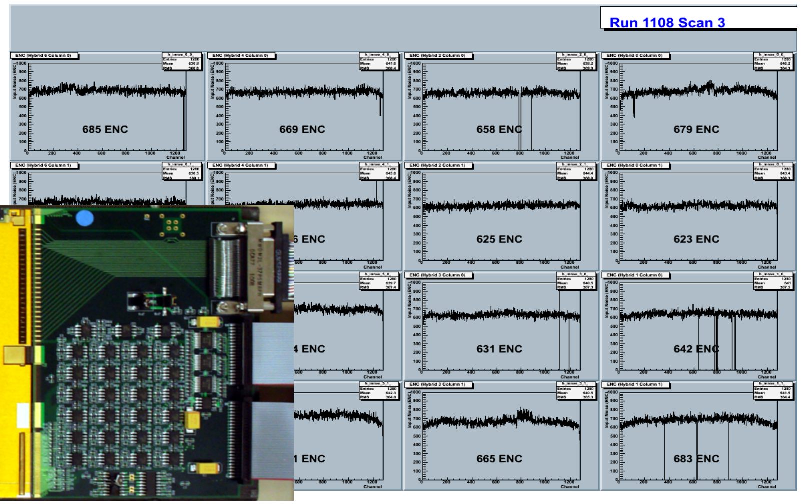
Hybrid with front-end chips glued directly to sensor
Sensor glued to cooled mechanical support - “Stave”
Staves arranged in cylinders
Stave can reduce material and helps assembly schedule by avoiding bottle-neck at module mounting on cylinders

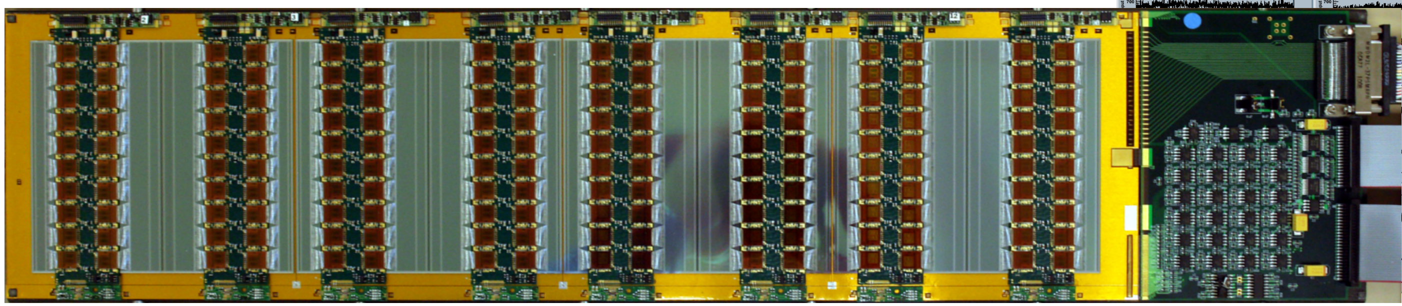




WP2: On-detector
WP3: off-detector
WP4: Mechanics
(Tracker upgrade project)

Mini-stave built: very good and uniform front end performance (noise, gain, pedestal, threshold); low dead channel count





Track Trigger at L1

Several ideas for implementing a track trigger at L1. Wanted: high-PT (~20 GeV) leptons.

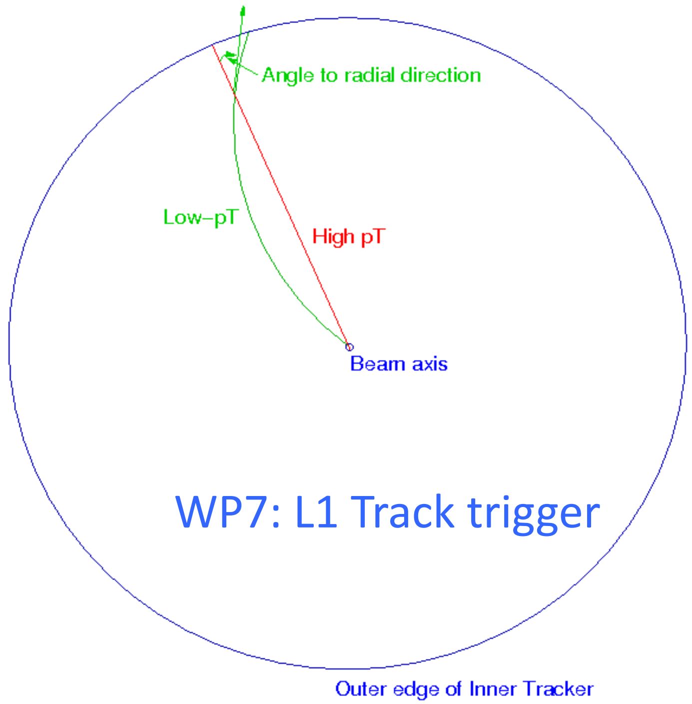
ATLAS EM calo has good identification, allowing a two-stage trigger approach:

Calorimeter or muon system identifies a candidate high-PT lepton and gives region-of-interest

Inner tracker modules in that region are read-out, and hardware track finders confirm presence of track with matching momentum

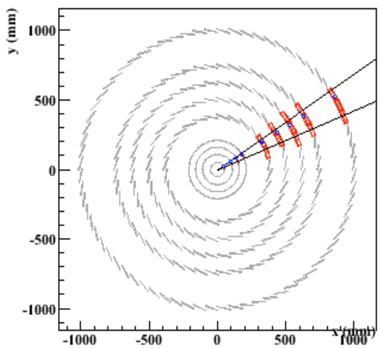
RoI is a few % of modules so small increase in bandwidth needs --> very little increase in material

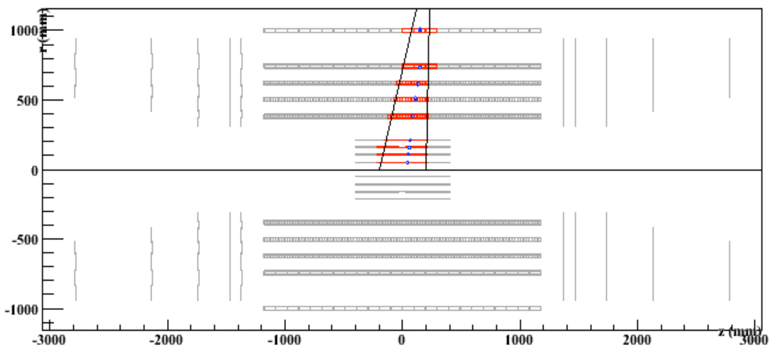
Needs additional data stream in FE chip and a lot more study, but encouraging so far



Alternatively, measure track angle to radial direction at outer edge of inner tracker - look for near radial tracks

Either with paired silicon layers or GasPix detector with 10 mm drift gap





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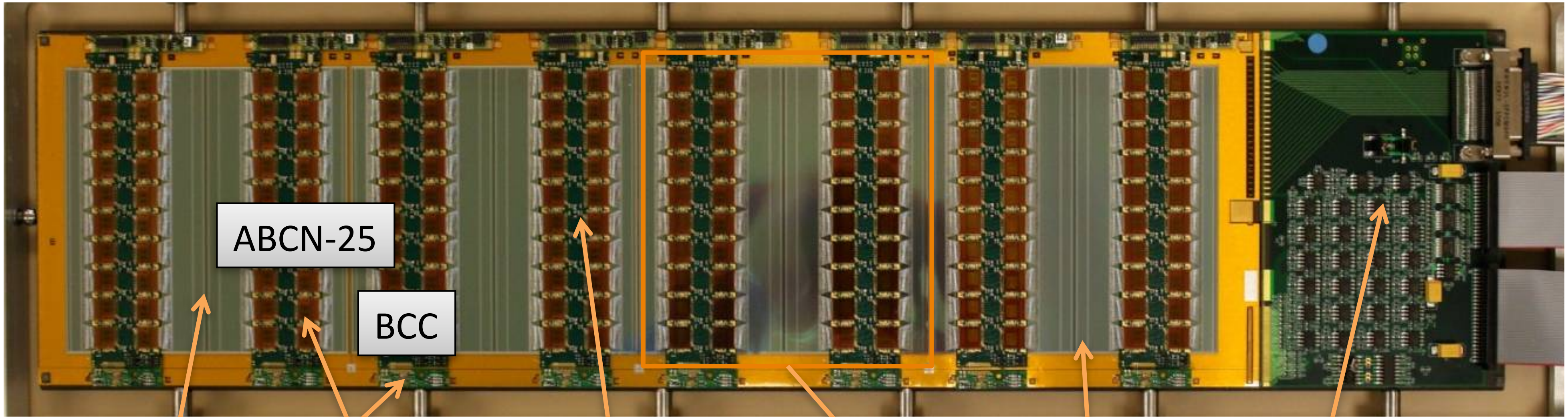
UK-ATLAS Upgrade project results from 10/11

- Tracker Upgrade
  - WP2: On-detector systems
  - WP3: Off-detector systems
  - WP4: Mechanics
  - WP5: Pixels
- Trigger Upgrade
  - WP6: Level-1 Calorimeter trigger
  - WP7: Level-1 Track triger
  - WP8: High Level Trigger
- Software, Simulation and Computing (WP9)

WP2: On Detector Systems

Delivers ASICs and Hybrids to the Module programme;
Modules, Tapes and On-Stave Interfaces to the Stavelet and Stave programmes



2.2 ASICs
- Digital Design
- Evaluation
- Wafer Test

2.4 Modules
- Build Process & Tooling
- Evaluation
- Skill Transfer

2.6 On-Stave Interface
- Design
- Evaluation

2.1 Strip Sensors
- Layout
- Evaluation

2.3 Hybrids
- Layout & Manufacture
- Die Attach Tooling
- Evaluation
- Skill Transfer

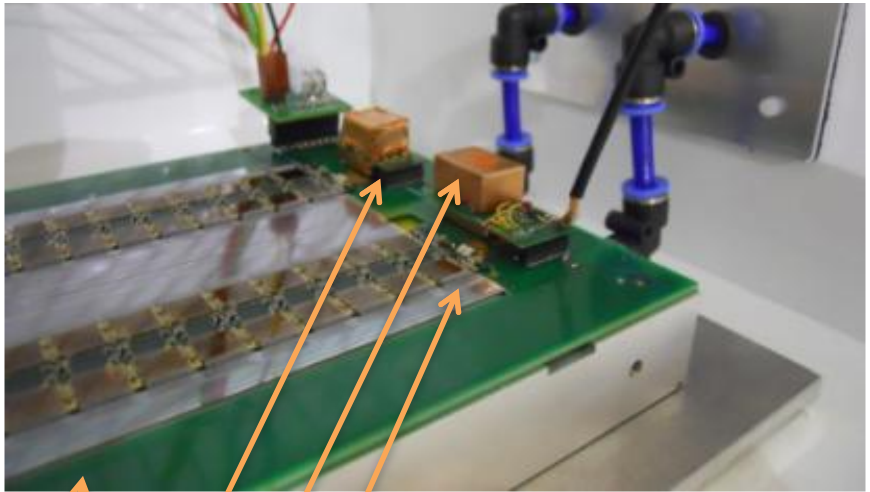
2.5 Tapes
- Layout & Manufacture
- Flying Probe Machine
- Evaluation

Picture shows Serially Powered Stavelet

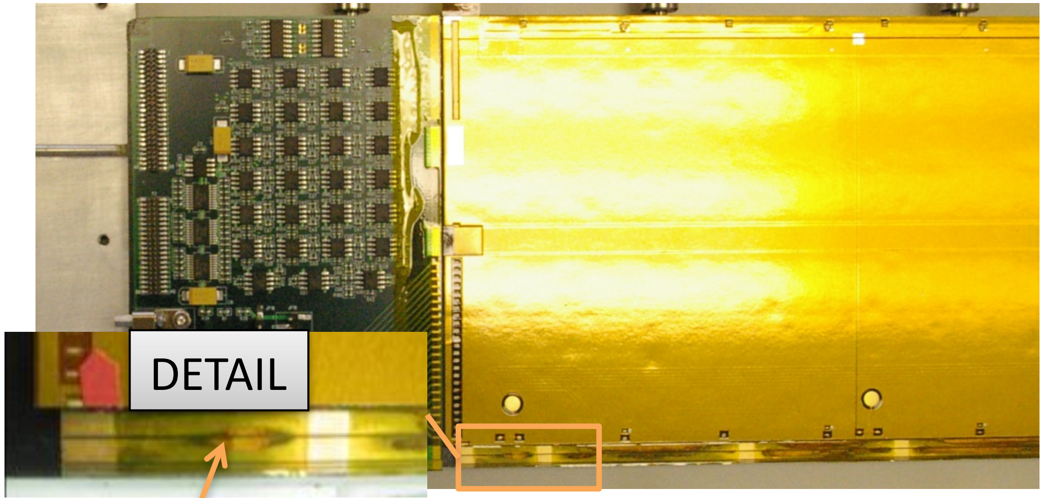
WP2: Recent Deliverables

For the DC-DC Stavelet

First DC-DC Test of Stave Module



First DC-DC Stavelet



- **Module (WP2)**
- Cu Plated Shield (WP3)
- DC-DC convertors (CERN)
- **Custom Module Frame PCB (WP2)**

- **Results in agreement with SP module** ***provided adequate shielding used***

- Stavelet Core (WP4)
- **DC-DC Power Tape (WP2)**
- **Misc. Support PCBs (WP2, not shown)**

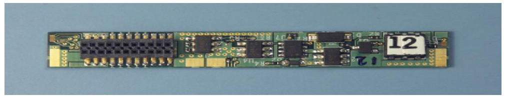
- **Construction of 4 modules in progress (WP2)**

WP3 Off-Detector Systems

Serial Power, DAQ, optics and test facilities for the stave prototyping programme

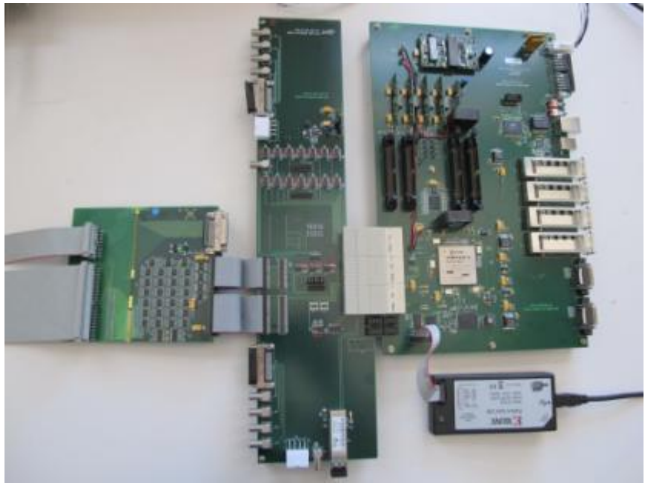
Serial Powering (M3.1, M3.3):

- Constant current supply tested, tuned, and more to come
- Power protection hardware prototype to be implemented in 130nm ASIC



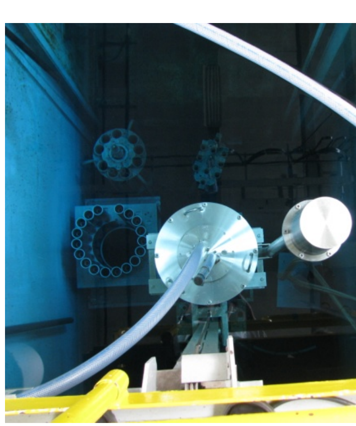
Building 180 at CERN being established as a test facility for stave(lets)

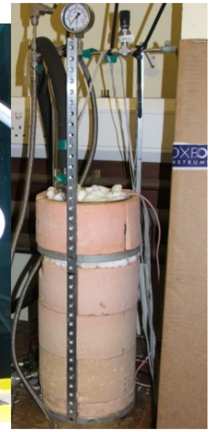
(M3.2)



Data Acquisition (M3.4, M3.5, M3.7):

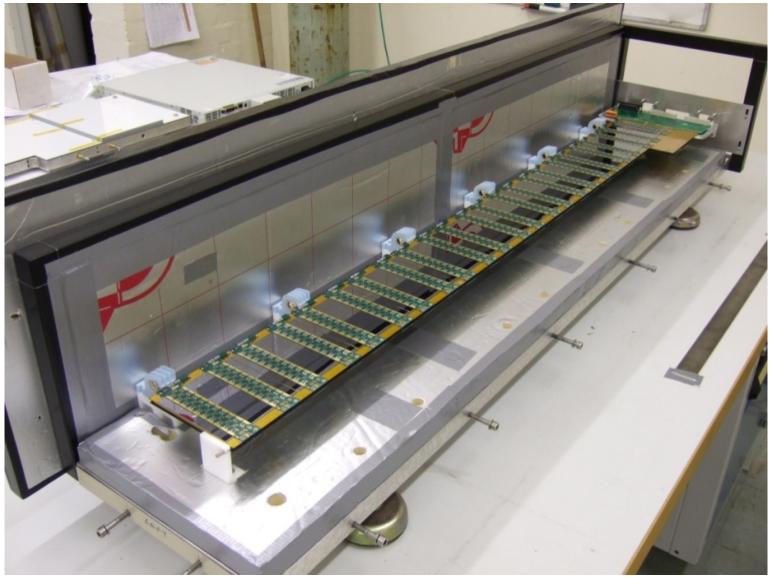
- UK provides software, firmware and support for HSIO roll-out to UK and overseas collaborators
- UK leads development for tie-in with future on-detector chipset

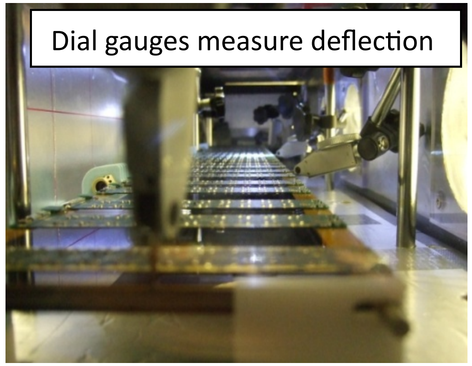




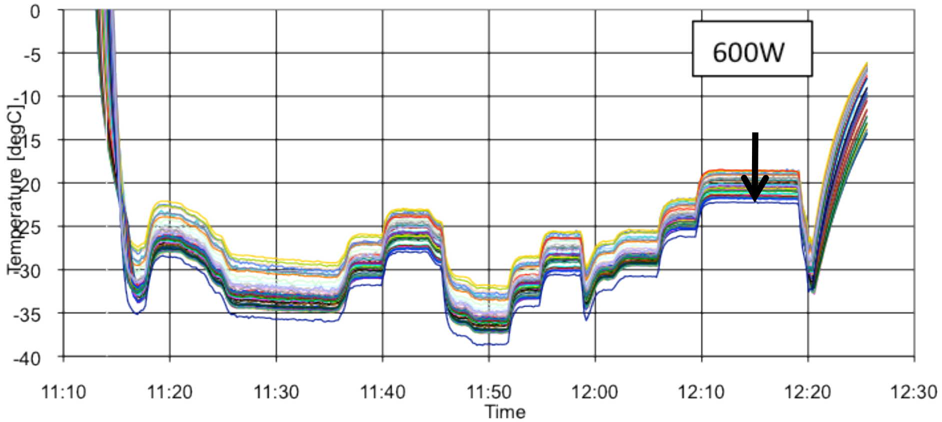
Passive Optics (M3.6): Facility for cold irradiation of candidate fibres being deployed at CERN

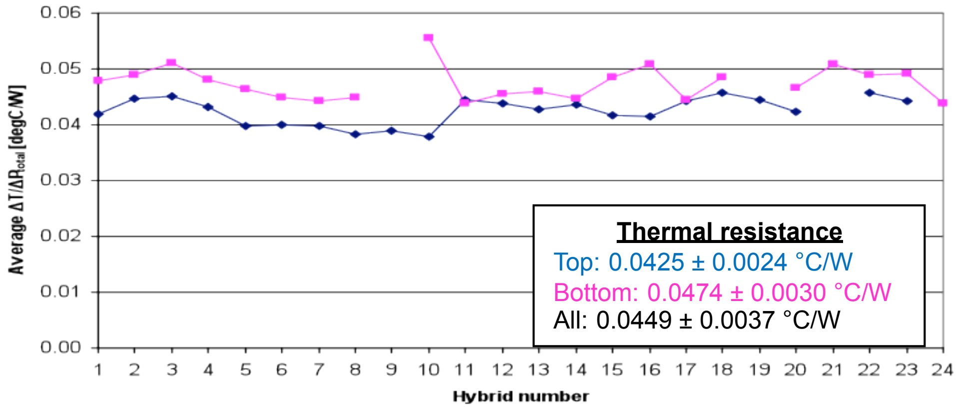
WP4: Thermo-mechanical Stave





- Full-scale thermo-mechanical mock-up of stave including;
  - Carbon-fibre/honeycomb sandwich with embedded stainless steel/Pocofoam cooling structure
  - 24 thermo-mechanical modules including silicon substrates and copper/kapton hybrids based on emerging design from WP2
- Aim: to measure thermo-mechanical performance on realistic, full-scale object & compare with FEA
- Thermal Resistance
  - FEA: 0.043 °C/W
  - TMS: 0.045 °C/W





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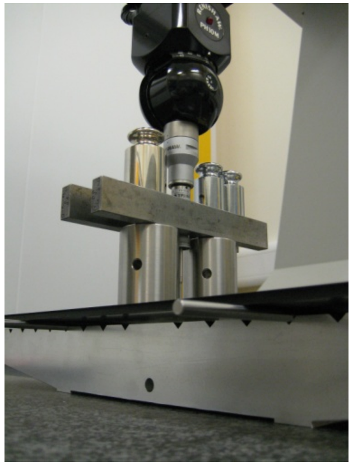
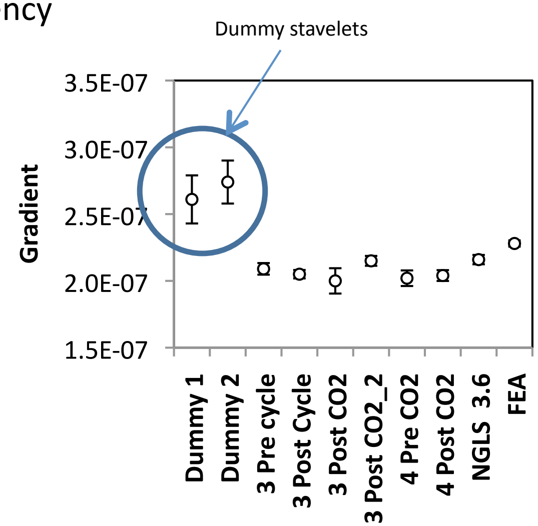
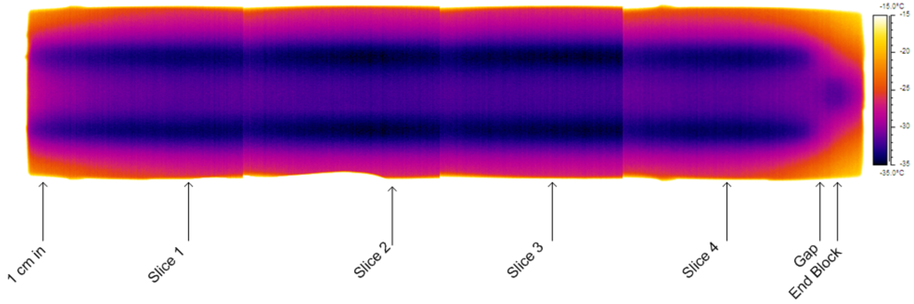
WP4: Stave QA

- 3-point bending
  - Check facesheet-core adhesion
  - Good consistency

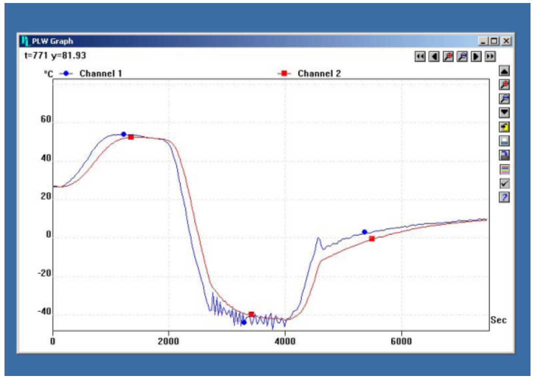




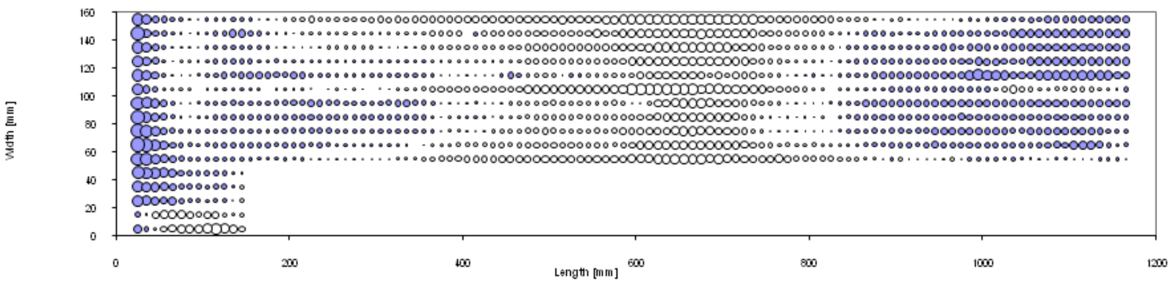
- Thermal Testing
  - IR camera
  - Good uniformity – no sign of any failures of the pipe to facesheet thermal coupling



- Long-term thermal cycling
  - Chamber constructed
  - First trials in progress

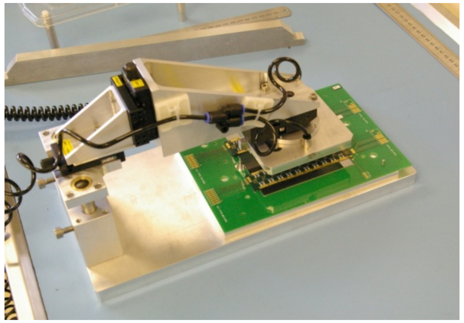


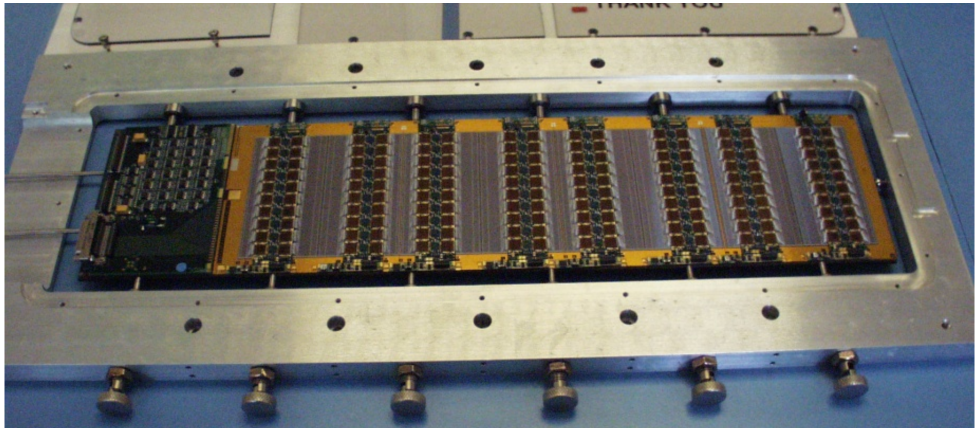
- Flatness
  - CMM touch probe scan
  - Typically within +/- 0.1mm
  - New tooling should result in better flatness



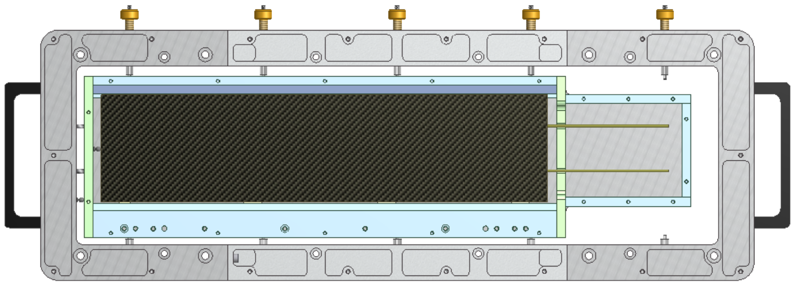
WP4: Module Mounting & Stave Containers

- Module Mounting (2010)
  - 24 thermo-mechanical
  - 4 electrical modules
- Plans for 2011
  - Extend to full length stave
  - Develop pick-up tooling
  - Glue studies

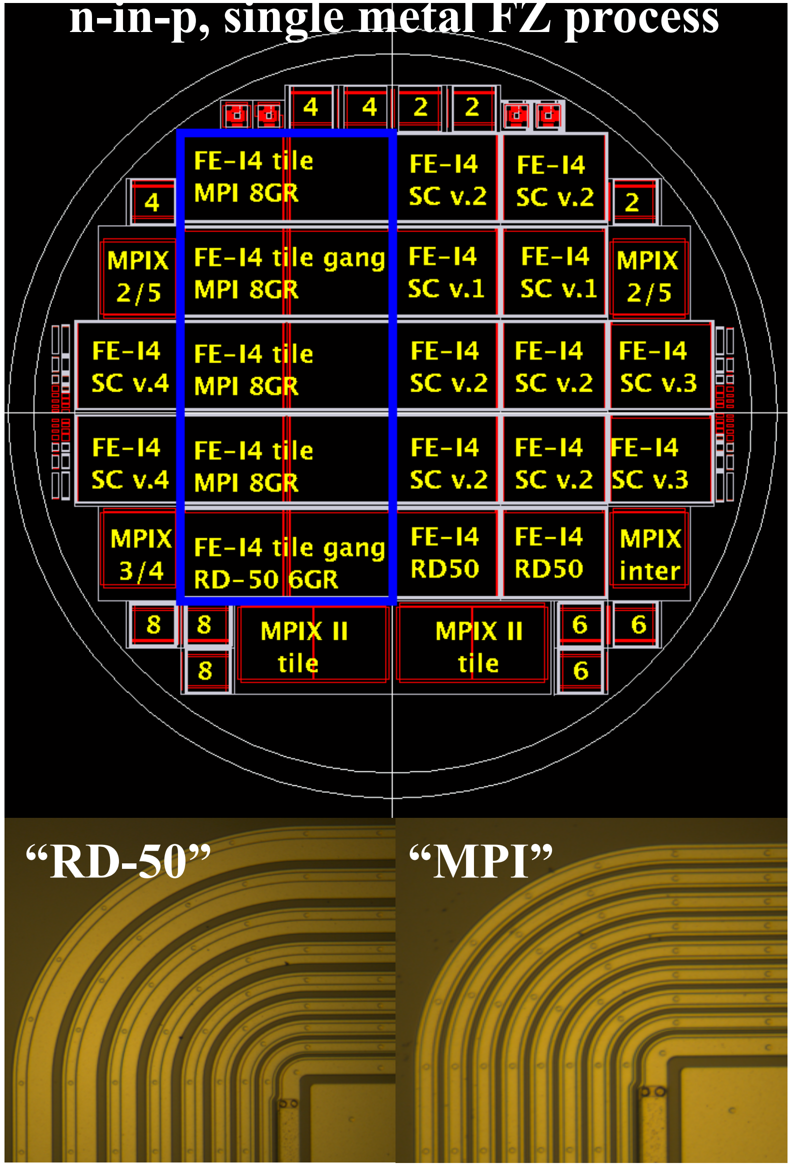




- Stave Containers
  - Stavelet container defined
  - New Module-mounting frame defined
  - Manufacture imminent
  - Scheduled to link in with international stavelet programme



WP5: Sensors: 6" Micron Pixel Wafer



The 2nd mask will be used to have devices for IBL qualification and PPS studies of radiation hardness and high voltage operations

5 FE-I4 tiles/wafer

- **4 with 8 MPI "style" guard rings**
- **1 with 6 RD-50 "style" guard rings**

14 FE-I4 single chips/wafer

- **2 with RD-50 "style" guard rings (390 μm wide)**
- **8 with 8 MPI "style" guard rings (390 μm wide)**
- **4 with 4 MPI "style" guard rings (200 μm wide)**

And other test devices

Available, 2nd mask:

8x300μm thick wafers.

2x150μm n-in-p wafers

2x150μm p-in-n wafers

In preparation (ready end of April):

2x300μm n-in-n wafers

3x150μm n-in-n wafers

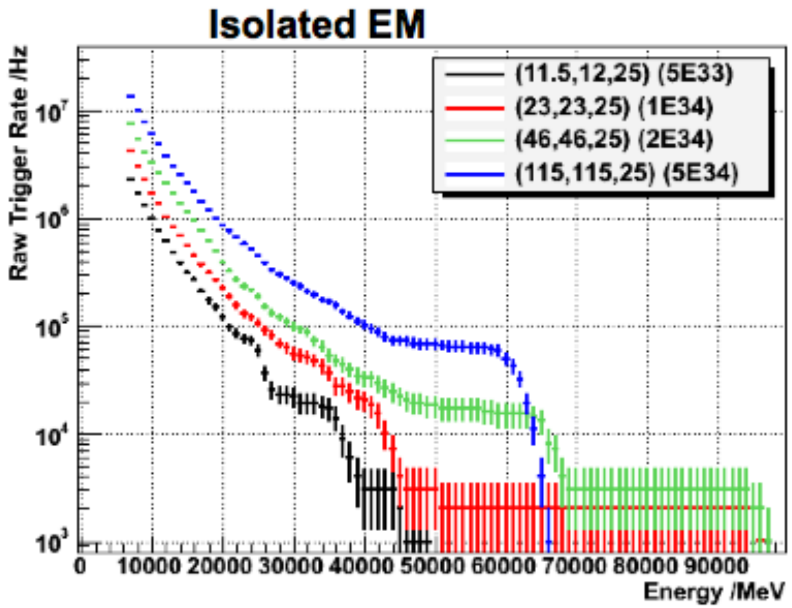
3D sensors delivered for IBL prototyping and pre-production

WP5: Planar 4-chip module

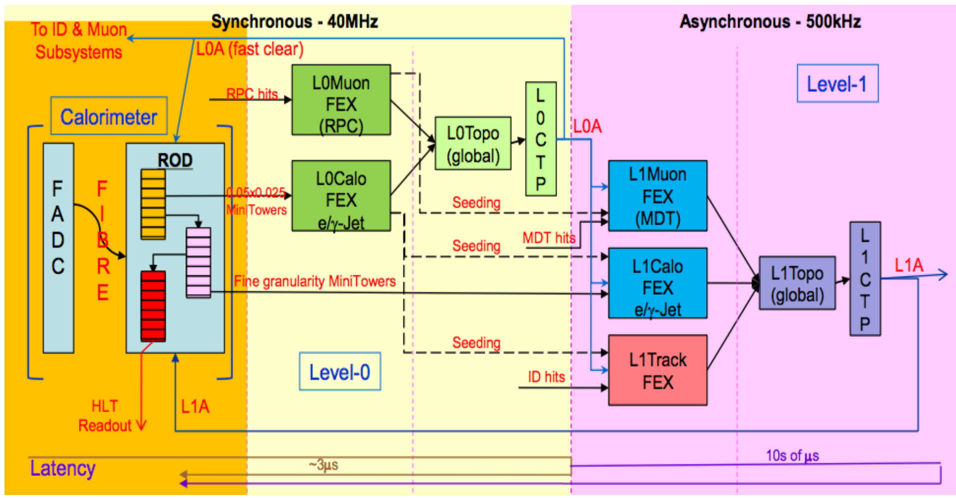
- Use Micron sensors: including 4-chip (quad) sensor
- One FE-I4 wafer
- Use VTT for bonding
- VTT first
  - Use 6 off existing microns sensors
  - Note lots of experience so don't feel they need heavy qualification
- Quad and singles
  - New Micron wafer
  - Produce Quads for module programme and singles for HV tests, testbeam etc
- Mechanicals
  - Make sensor/detector daisy chain for mechanicals with over hang for wire bonding
  - From new Micron wafer
- Timescales
  - Quad design ready 12/4/11
  - Quad sensors ready 30/09/11
  - Mechanical module 02/12/11
  - Electrical module 10/08/12

- 3D sensor and module development

WP6 Calorimeter Trigger



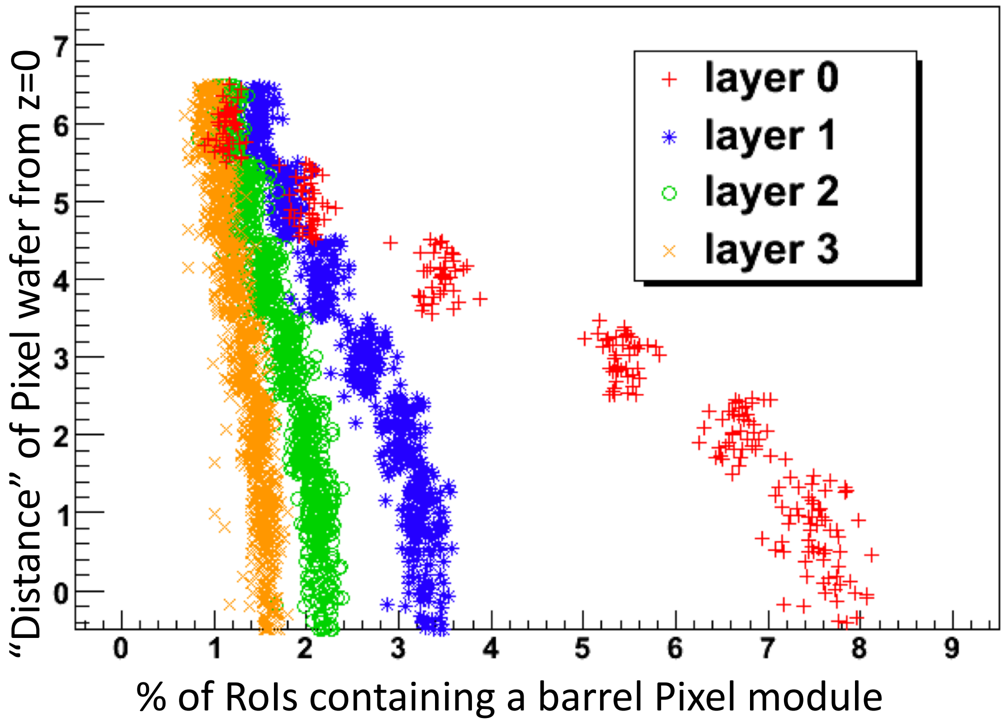
Simulation of L1 calorimeter trigger rates at different luminosities and with different thresholds
Presented at L1CALO week in Cambridge, this week



One possible strawman design for Phase-II L1Calo upgrade consisting of two parts, a fast synchronous level-0 accept followed by an asynchronous level-1 system incorporating higher granularity features.

L1Track simulation studies

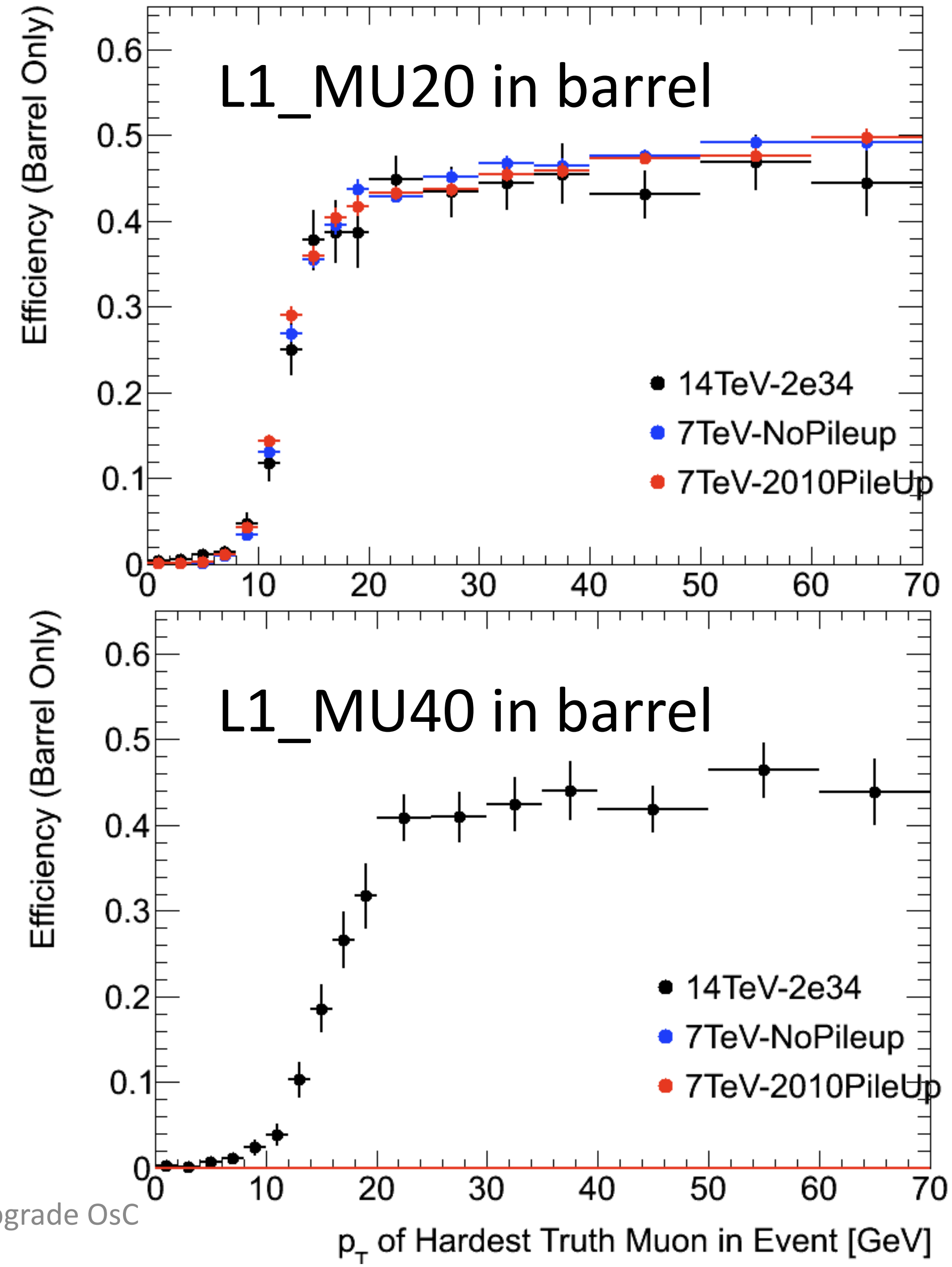
- Developed framework for readout modeling studies
  - To investigate/optimize data formats for readout, bandwidths etc, both for track trigger and normal readout, working together with experts from the Tracker upgrade project
  - To understand requirements for track trigger and feed into the design



Due to spread of LHC luminous region in z, modules near z=0 more often inside a Region of Interest.

L1Track: L1 trigger studies at 2e34

- Validation of ATLAS high luminosity simulation
- L1 muon turn-on curves show that above 20GeV the current L1Muon system has small discrimination power in pT
  - Raising pT thresholds cannot provide adequate improvement in L1 rate rejection
  - Further information required by trigger – track trigger?
- Studies being extended to
  - higher luminosities
  - tau and electron triggers



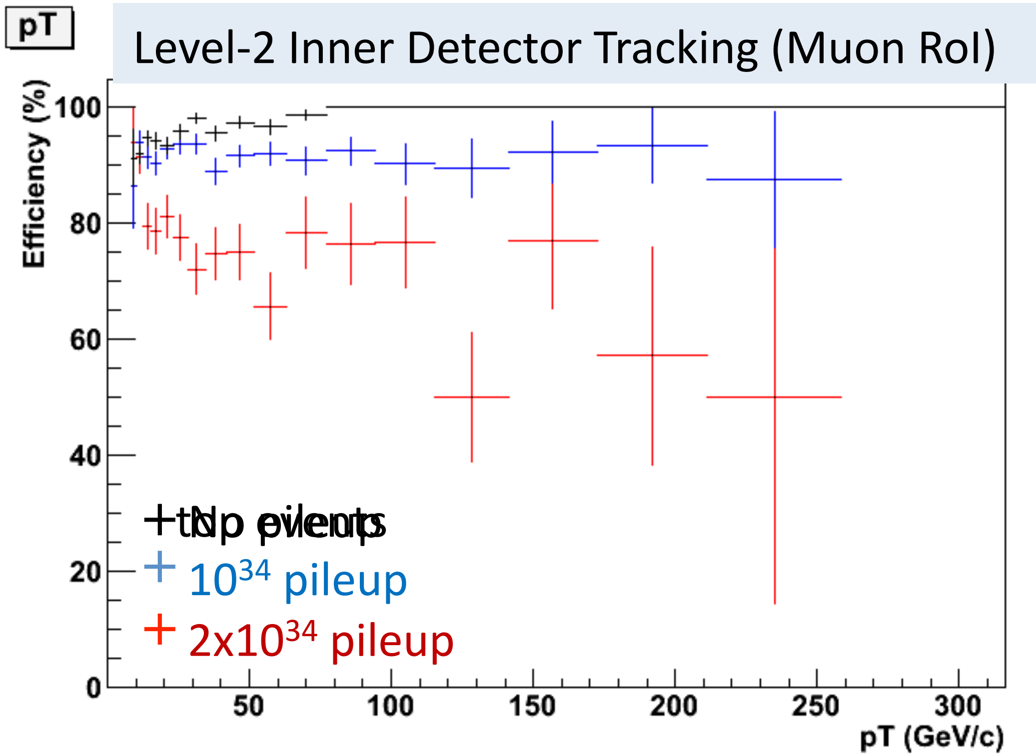
WP8 : Performance Benchmarking

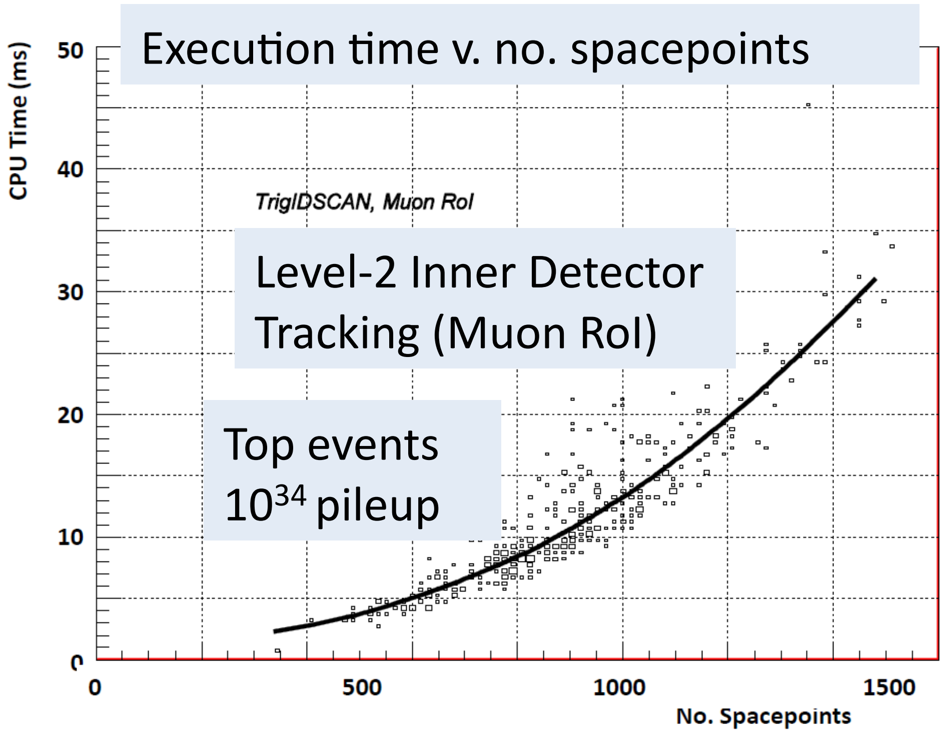
Have established test-bed to benchmark performance on MC datasets up to $2x10^{34}\ cm^{-2}s^{-1}$

- Measured performance:
    - Efficiency of track reconstruction as a function of luminosity
    - Execution time as a function of occupancy
- Identified areas for optimisation & improvement

New Level-2 Inner Detector Tracking Package created :

- Will incorporate optimised L2 components
- Allows evaluation of different reconstruction strategies.

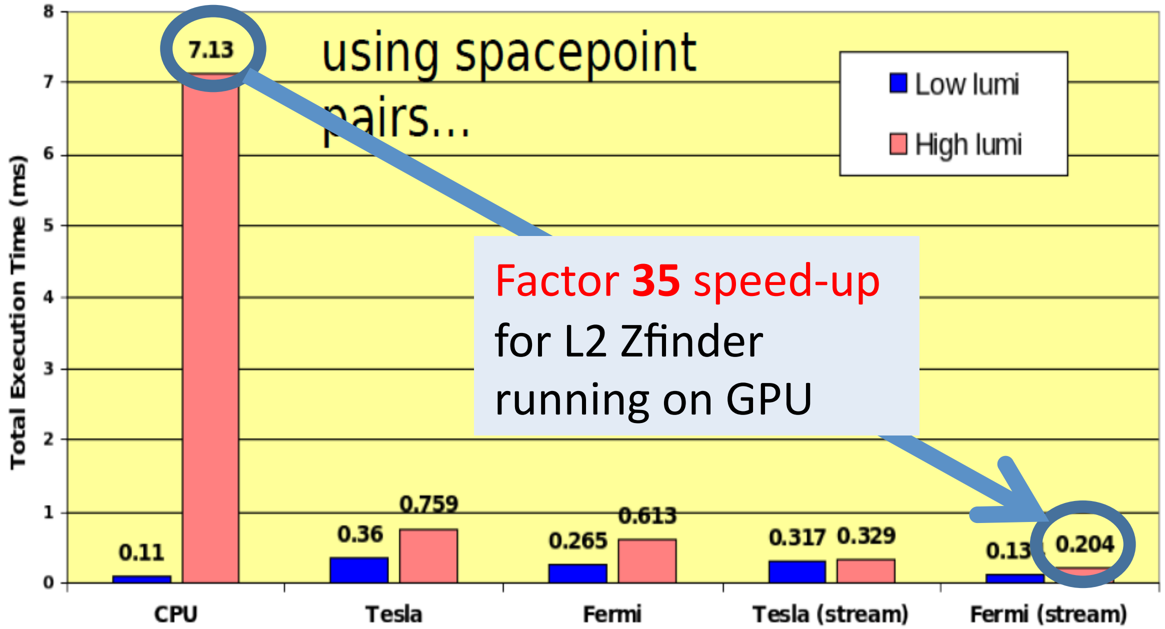


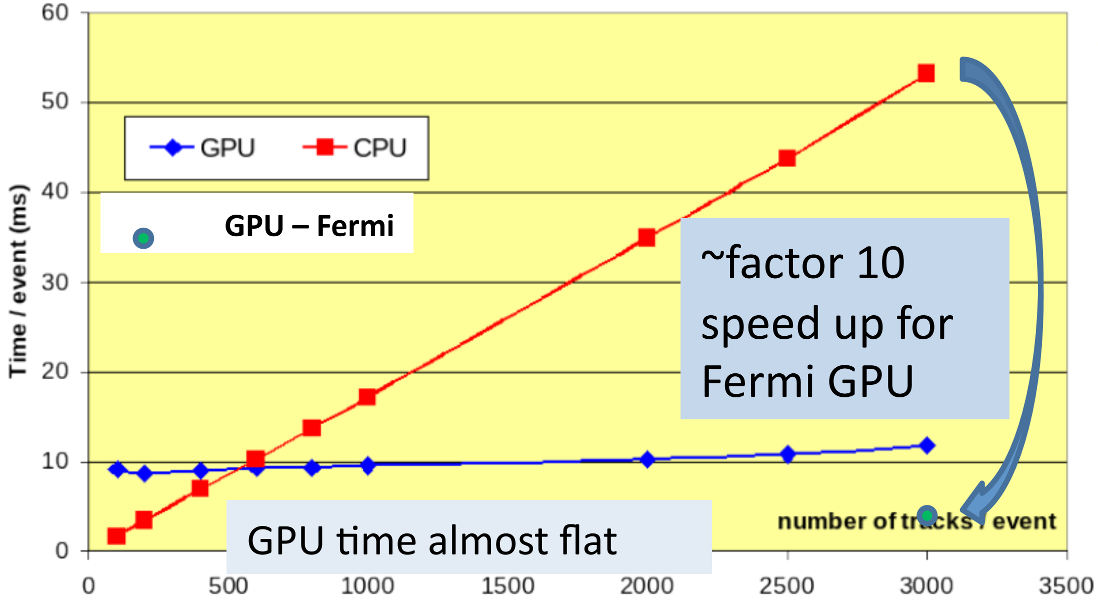


WP8 & WP9: Use of GPU in the HLT

Measure possible speed-up of L2 code on GPU c.f. CPU

- Ported HLT code to GPU:
  - Zfinder
  - Track Fitter
- Measure execution times c.f. CPU





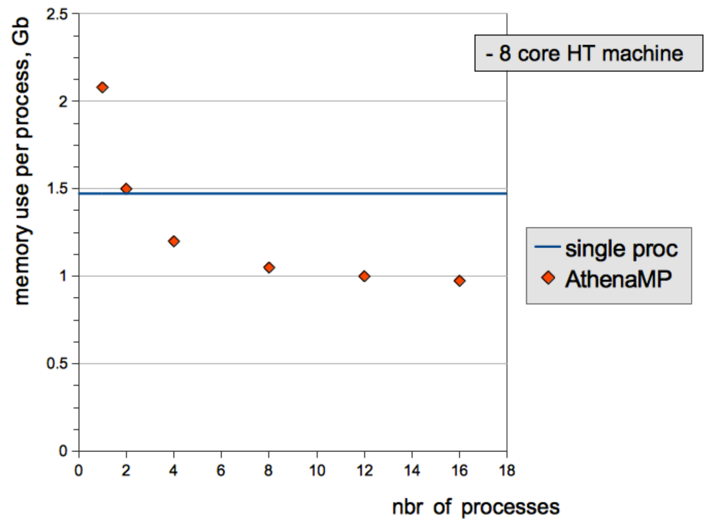
Next steps:

- Increase parallelisation of fitter
- Add:
  - Data preparation
  - Pattern Recognition

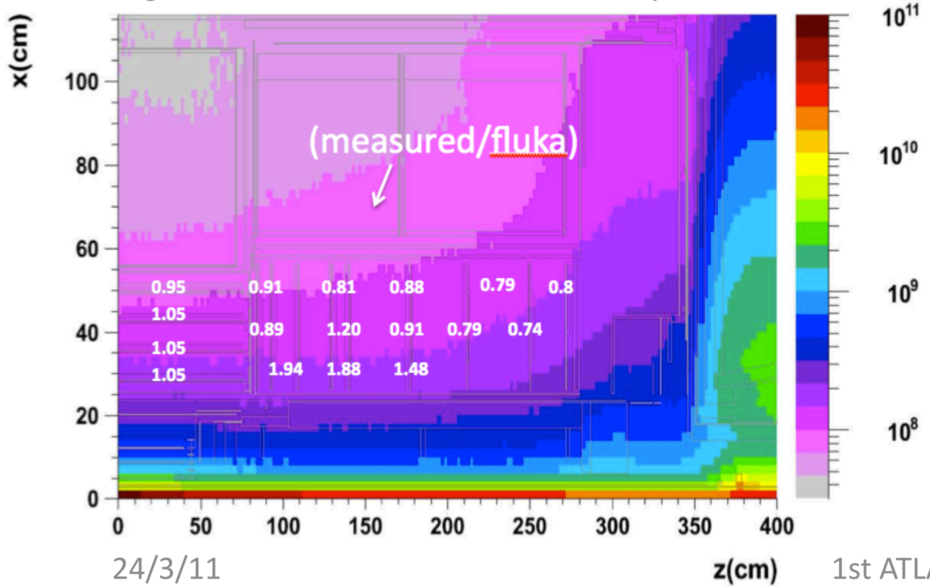
=> Complete tracking chain on GPU

WP9: Athena, Radiation

- Work ongoing on putting AthenaMP on Grid
  - Makes more optimal use of all cores on a node
  - Big improvement in throughput & memory per process
- Test queue at RAL established for 'whole node' scheduling
  - Commissioning studies to finish in July



Comparison of 1MeV neutron equivalent fluences determined from SCT leakage current measurements with simulated FLUKA predictions @ 7 TeV.



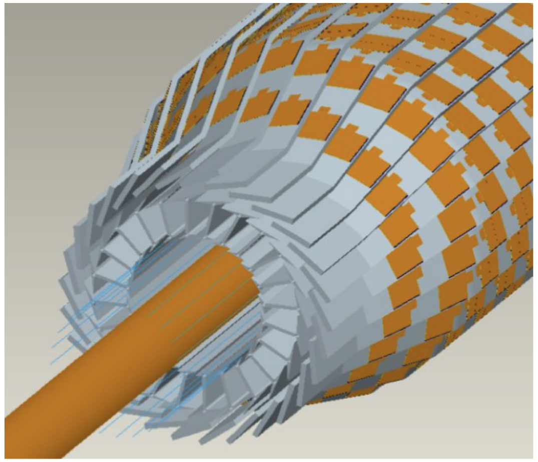
Radiation Environment

- Simulations compared with 2010 data
  - Reliable 1MeV neutron equivalent damage fluences established
- Detailed detector material and services added to FLUKA simulations
  - Good description for SCT barrel and RadMons (that measure ionizing dose)
  - Poorer description for SCT endcap inner modules under investigation

WP9: Simulations etc

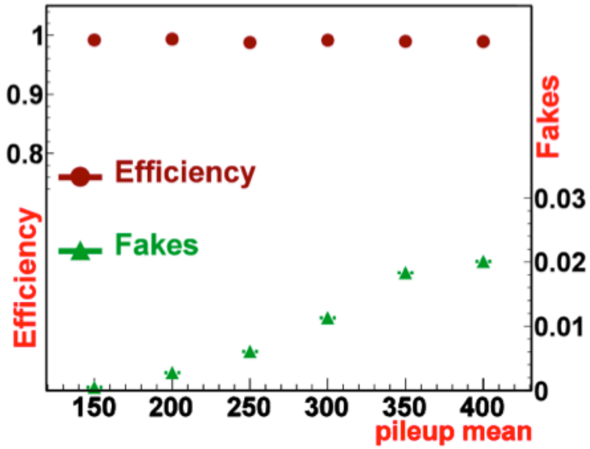
Framework development

- Made robust and adapted to incorporate new geometries
- New, radical, geometries implemented
- Advances in efficient handling of pile-up
- Reduced memory requirement for digitisation



Conical pixel Layout

- Modifications for Inner Beam layer project
- Histograms, including those for Atlfast tuning
- Patches to be integrated with the main software release



Studies of current Utopia layout

- Help design, test simulation & reconstruction
- Fake rates reduced but still significant

Summary

- Changes to LHC schedule have been addressed by ATLAS
  Clear programme of R&D established towards TDRs
- Representation at highest levels of ATLAS management allows UK to influence and adapt to changes
  - UK Upgrade programme has adapted to changes in ATLAS programme
- UK Upgrade programme is up and running
  - Results presented at ATLAS Upgrade week at CERN
  - New results will be presented at ATLAS Upgrade week in Oxford
- UK is maintaining and enhancing its leadership within the upgrade programme

BACK UP SLIDES

Physics goals of sLHC

Main ATLAS Physics goals:

Higgs discovery: Mass and understanding electro-weak symmetry breaking

Unification of forces, gravity, SUper SYmmetry, extra dimensions

New forces (W', Z')

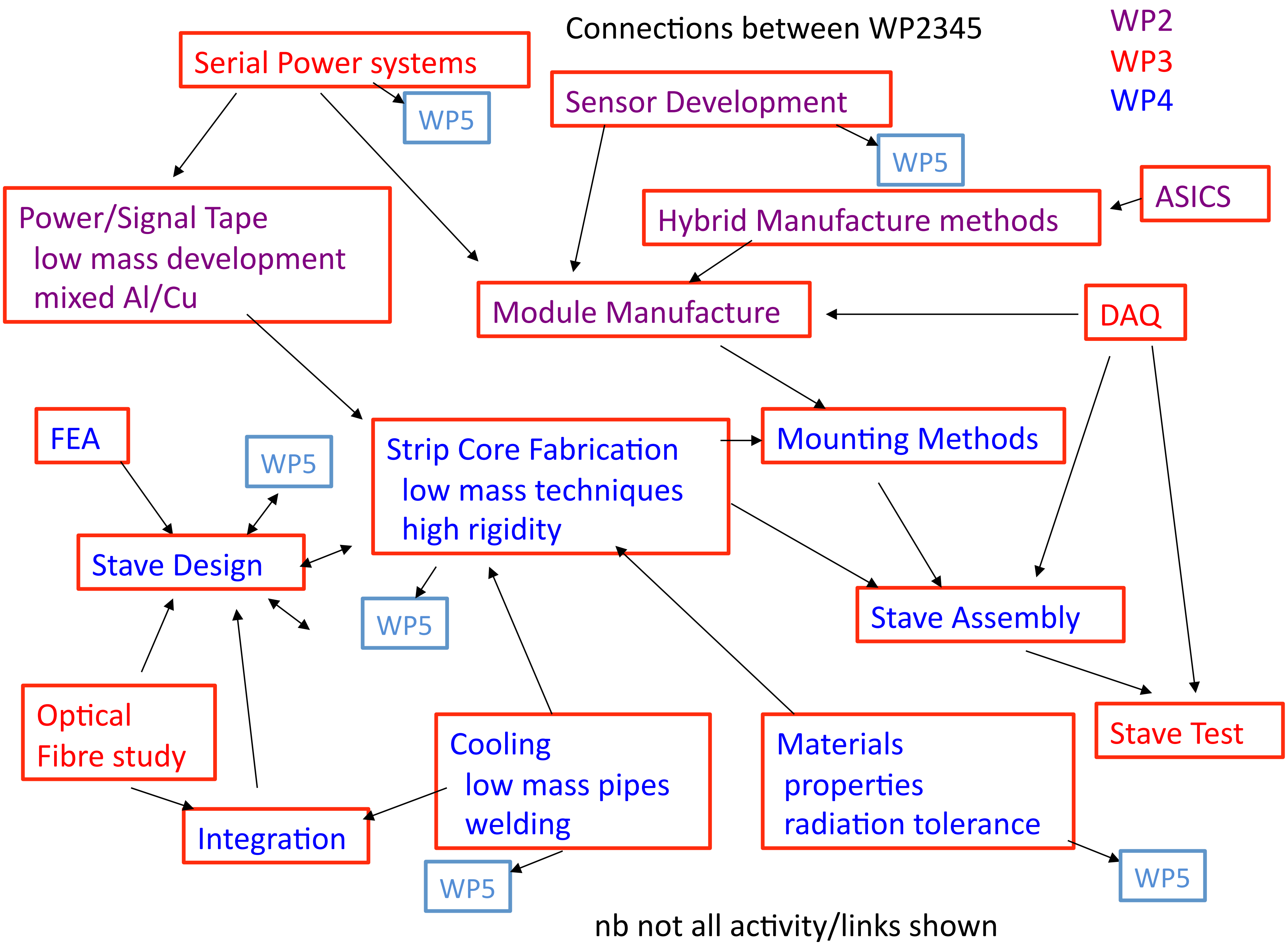
Flavour: why 3 families, neutrino mass, dark matter

Whatever is discovered at the LHC will need a lot of data to understand exactly what has been discovered: characterising the discoveries.
In addition, the sLHC can extend the discovery potential, to higher masses or lower cross-sections.
While the LHC aims at ~300 fb^{-1} per experiment, the sLHC aims for 3000 fb^{-1} of data, opening up new possibilities for channels limited by statistics at the LHC

There are many measurements where extending the LHC data set is important, including:

1. Higgs couplings
2. Triple gauge-boson couplings
3. Vector boson fusion at ~1 TeV
4. SUSY – discovery or spectroscopy
5. New forces: W', Z' to higher limits

Nigel Hessey
ATLAS Upgrade
sLHC2011


Connections between WP2345
WP2
WP3
WP4
Serial Power systems
WP5
Sensor Development
WP5
ASICS
Hybrid Manufacture methods
Power/Signal Tape
low mass development
mixed Al/Cu
Module Manufacture
DAQ
FEA
WP5
Strip Core Fabrication
low mass techniques
high rigidity
Mounting Methods
Stave Design
WP5
Stave Assembly
Optical
Fibre study
Cooling
low mass pipes
welding
Materials
properties
radiation tolerance
Stave Test
Integration
WP5
WP5
nb not all activity/links shown