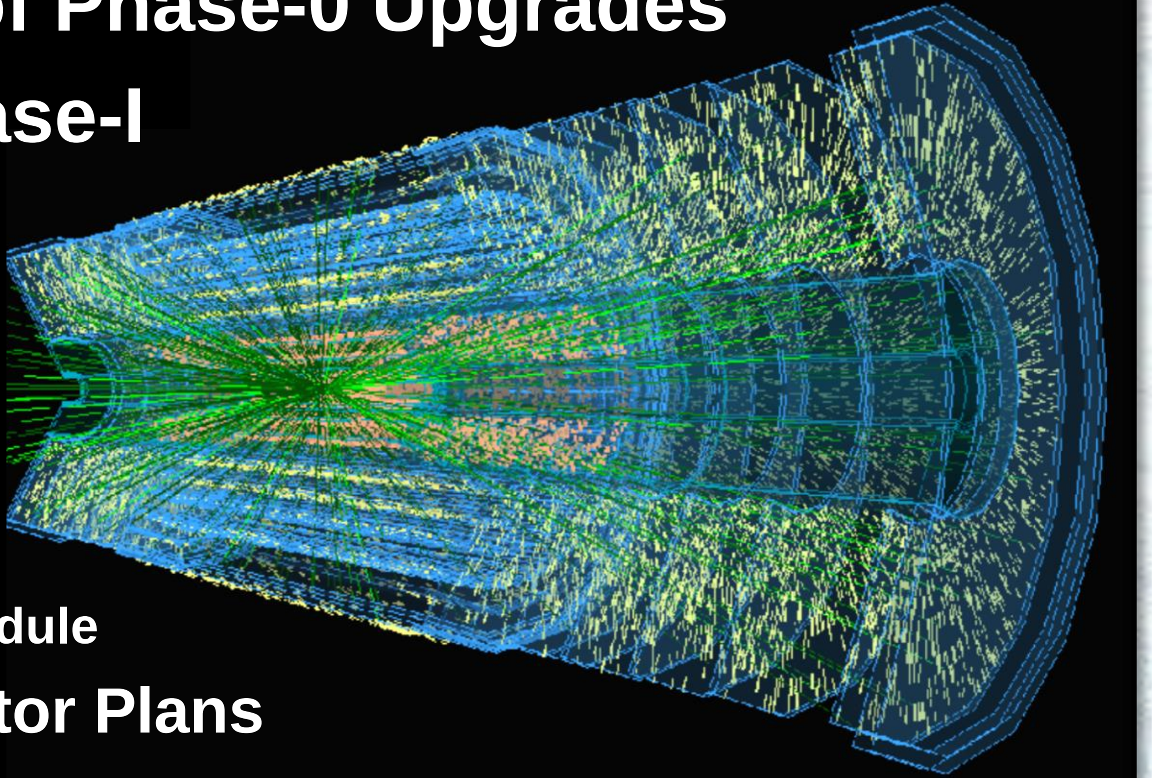
ATLAS Upgrade Overview

Phil Allport
ATLAS Upgrade Coordinator

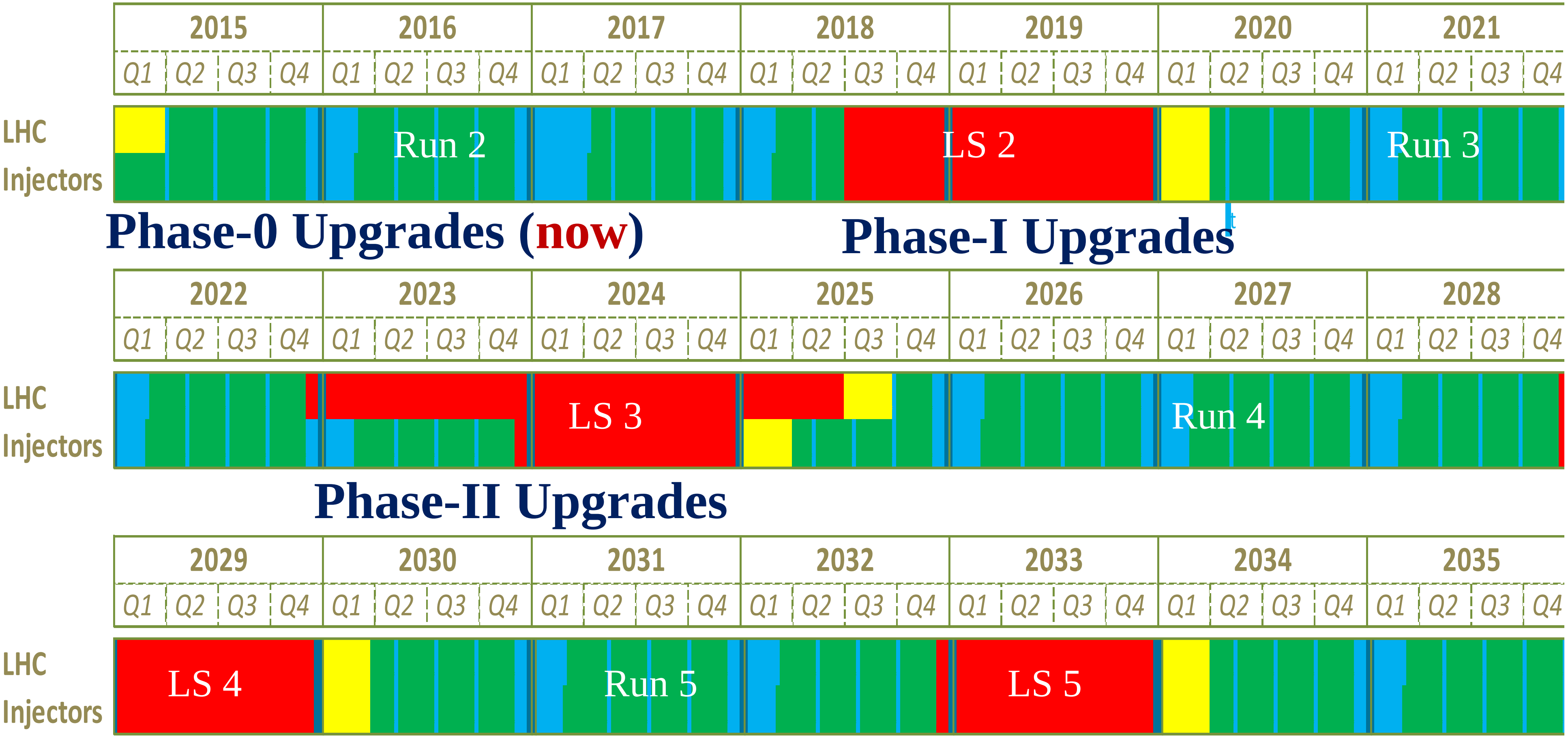
3/6/14



- Brief Overview of Phase-0 Upgrades
- Reminder of Phase-I
- Phase-II
  - New Tracker
    - Pixels
    - Strips
    - HV/HR-CMOS
    - Layout and Schedule
  - Other Sub-detector Plans
  - Revised Cost Profile
- Conclusions

New LHC schedule beyond LS1

Only EYETS (19 weeks)   (no Linac4 connection during Run2)
LS2   starting in 2018 (July)   18 months + 3months BC (Beam Commissioning)
LS3   LHC: starting in 2023 =>   30 months + 3 BC
  injectors: in 2024   =>   13 months + 3 BC



LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Current Shutdown Phase-0

- **New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe**
- **New Aluminum beam pipes to prevent activation problem and reduce muon BG**
- **New evaporative cooling plant for Pixel and SCT + IBL CO_2 cooling plant**
- **Replace all calorimeter Low Voltage Power Supplies**
- **Finish the installation of the EE muon chambers staged in 2003 + additional chambers in the feet and elevators region + RPC gas consolidation**
- **Upgrade the magnets cryogenics and decouple toroid and solenoid cryogenics**
- **Add specific neutron shielding where necessary (behind endcap toroid, USA15)**
- **Revisit the entire electricity supply network (UPS in particular)**
- **Where possible prepare Phase 1 upgrade (services, AFP, ZDC, FTK, ….)**
- **Re-align the barrel calorimeter and ID + consolidation of infrastructure and services + general maintenance**
- **Some early installation of (Phase-I) trigger upgrades which are required for above design luminosity operation are being anticipated for Run 2**
  - CTP: CTPCore and CTPOut
  - Muon endcap trigger with current small wheel (reduce fake rate)
  - Tile outer layer trigger (to help L1 muon in transition region)
  - nMCM (needed for bunch train correction)
  - CMX and L1Topo
  - Dual output HOLAs for FTK

Current Shutdown Phase-0

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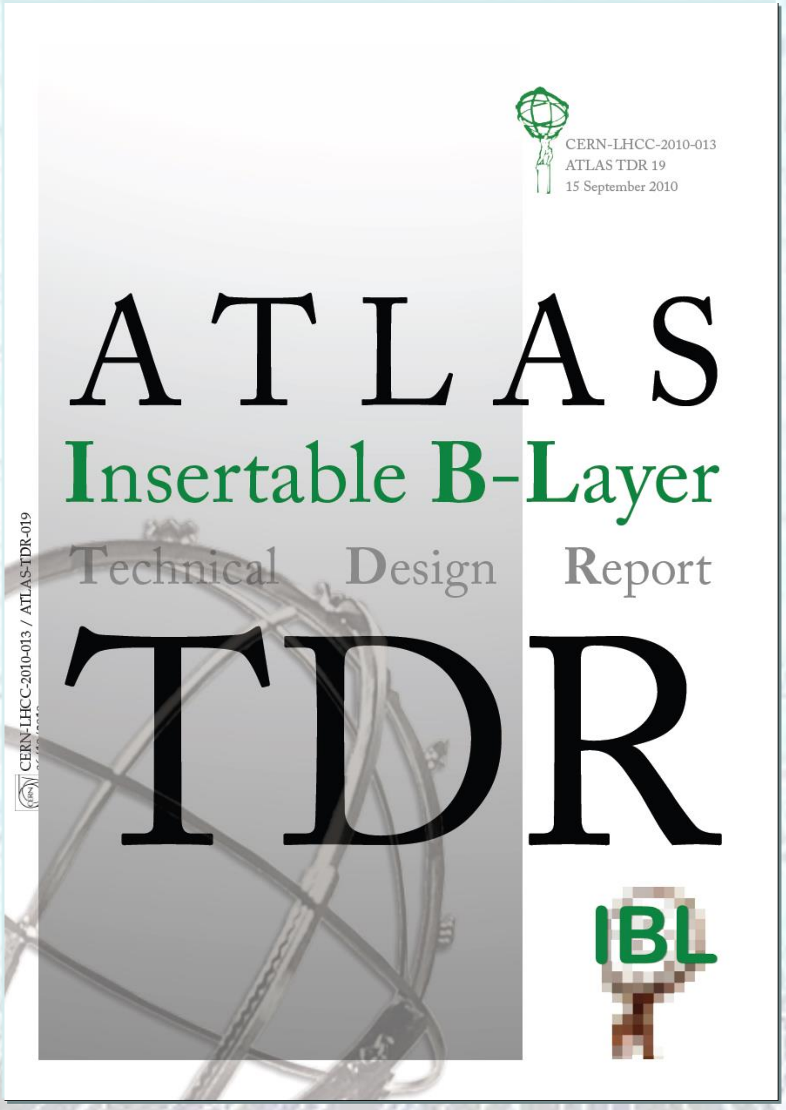
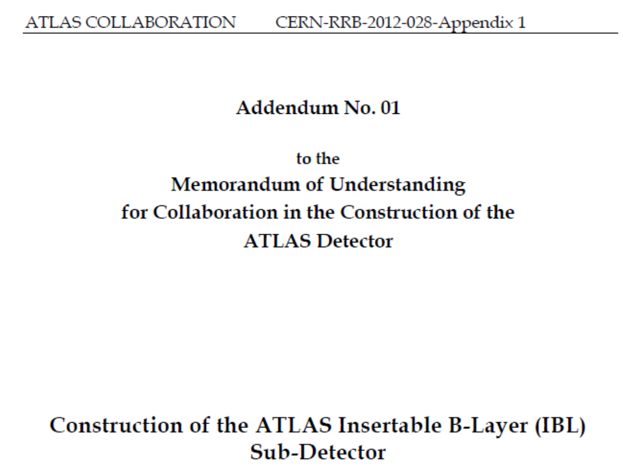


CERN-LHCC-2010-013
ATLAS TDR 19
15 September 2010

ATLAS
Insertable B-Layer
Technical Design Report
TDR

IBL

CERN-LHCC-2010-013 / ATLAS-TDR-019

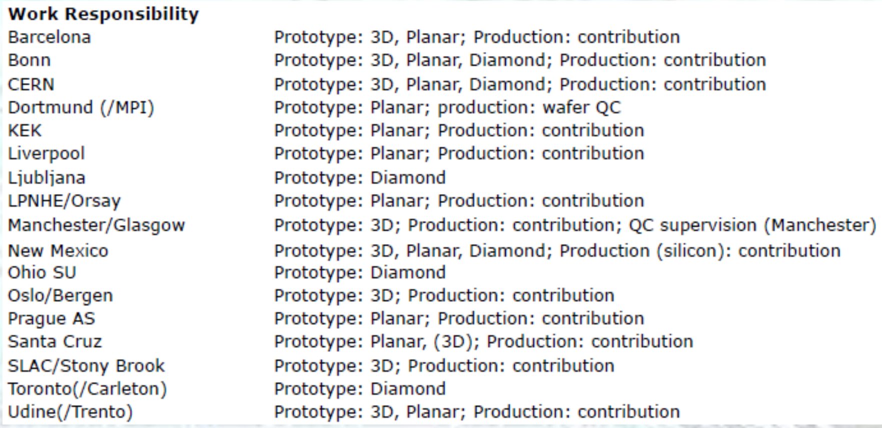


ATLAS COLLABORATION CERN-RRB-2012-028-Appendix 1

Addendum No. 01

to the
Memorandum of Understanding
for Collaboration in the Construction of the
ATLAS Detector

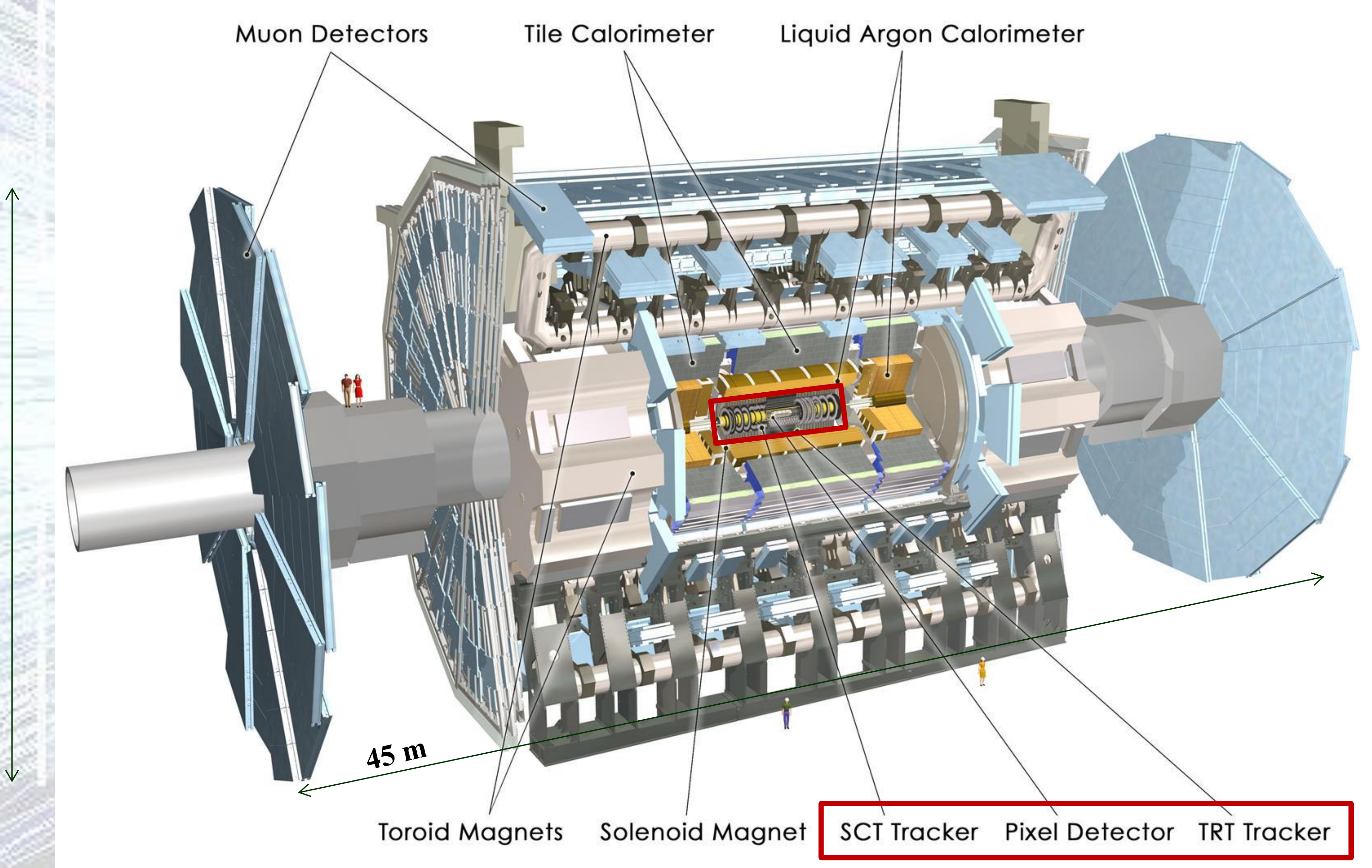
Construction of the ATLAS Insertable B-Layer (IBL)
Sub-Detector



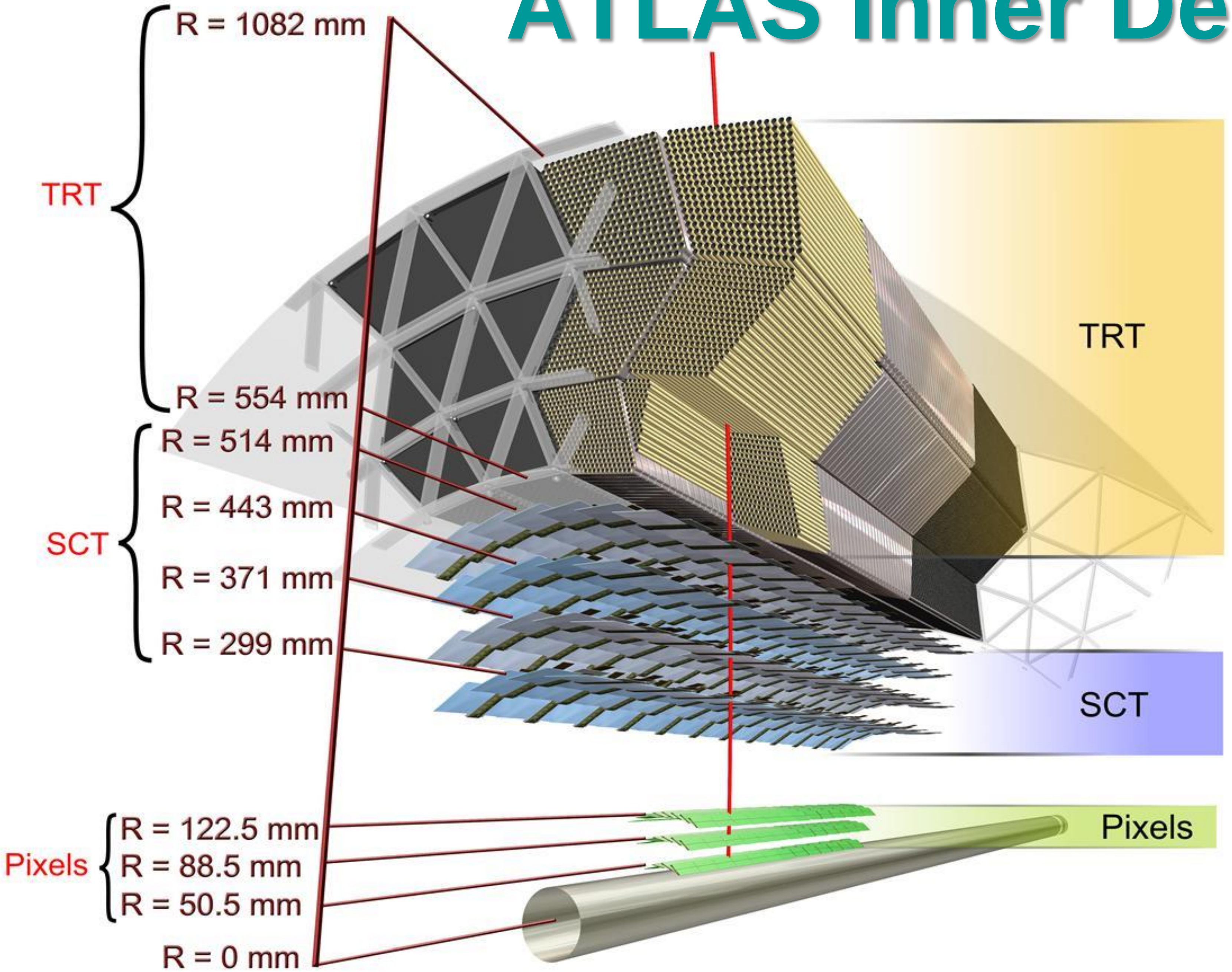
Work Responsibility

Barcelona	Prototype: 3D, Planar; Production: contribution
Bonn	Prototype: 3D, Planar, Diamond; Production: contribution
CERN	Prototype: 3D, Planar, Diamond; Production: contribution
Dortmund (/MPI)	Prototype: Planar; production: wafer QC
KEK	Prototype: Planar; Production: contribution
Liverpool	Prototype: Planar; Production: contribution
Ljubljana	Prototype: Diamond
LPNHE/Orsay	Prototype: Planar; Production: contribution
Manchester/Glasgow	Prototype: 3D; Production: contribution; QC supervision (Manchester)
New Mexico	Prototype: 3D, Planar, Diamond; Production (silicon): contribution
Ohio SU	Prototype: Diamond
Oslo/Bergen	Prototype: 3D; Production: contribution
Prague AS	Prototype: Planar; Production: contribution
Santa Cruz	Prototype: Planar, (3D); Production: contribution
SLAC/Stony Brook	Prototype: 3D; Production: contribution
Toronto(/Carleton)	Prototype: Diamond
Udine(/Trento)	Prototype: 3D, Planar; Production: contribution

ATLAS: Inner Tracking Detectors



ATLAS Inner Detector



Straw tubes

Silicon strip

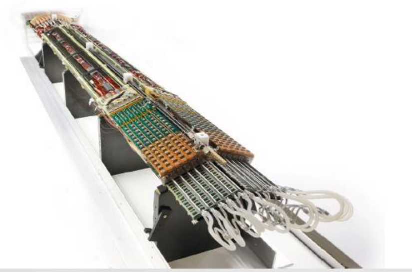
Silicon pixel

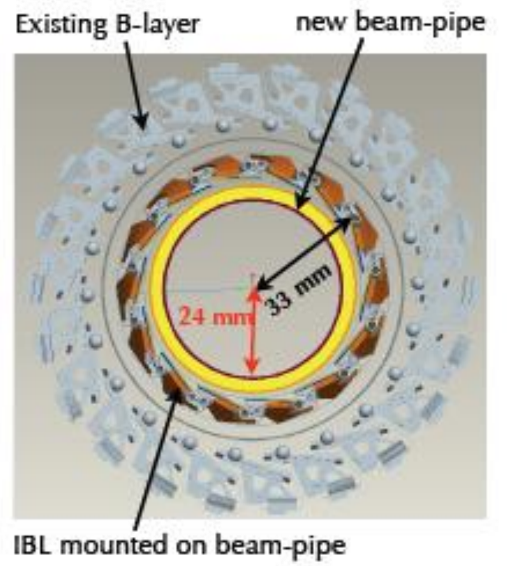
SCT Tracker Pixel Detector TRT Tracker

Insertable B-Layer

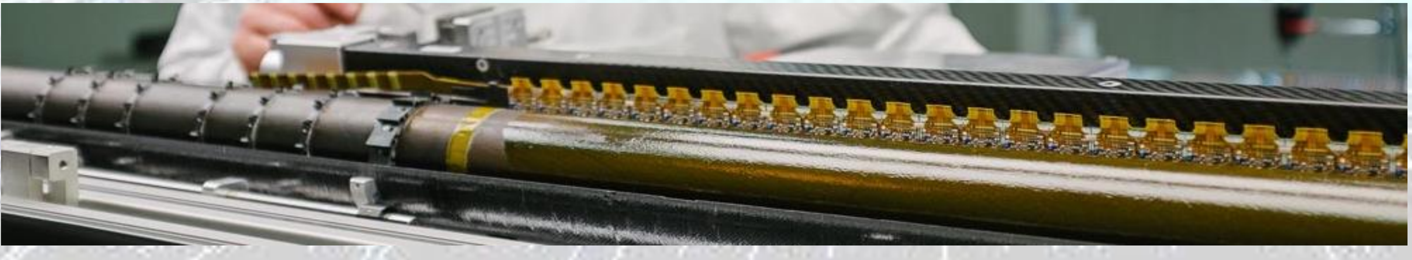
- New pixel layer around new smaller beam pipe
- Current pixel package was brought to surface allowing:
  - IBL support tube insertion at surface
  - New services installed to fix problems and improve R/O bandwidth (nSQP)
  - New diamond beam monitors with IBL (FE-I4) ASICs

- Reinserted and being reconnected
- IBL Inserted into ATLAS on 7th May
  - Services being connected and tested
  - Preparing for operation and commissioning

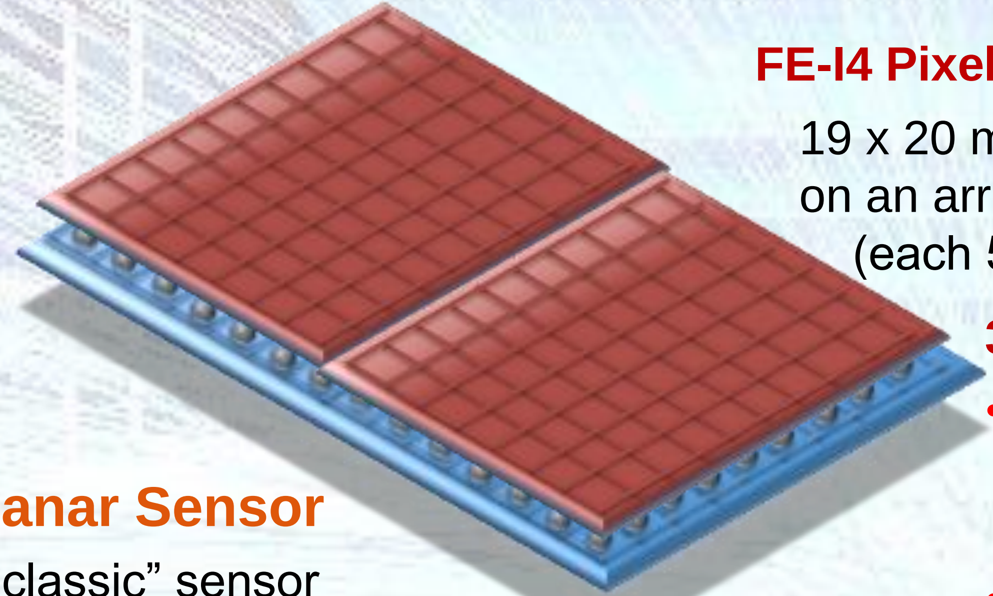




- Off-detector
  - New RODs can read-out 32 FE-I4 ASICs at a rate of 160 Mbit/s using 4 S-Links (also supports the dual output required for FTK)

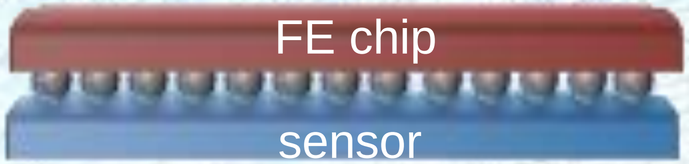


Insertable B-Layer



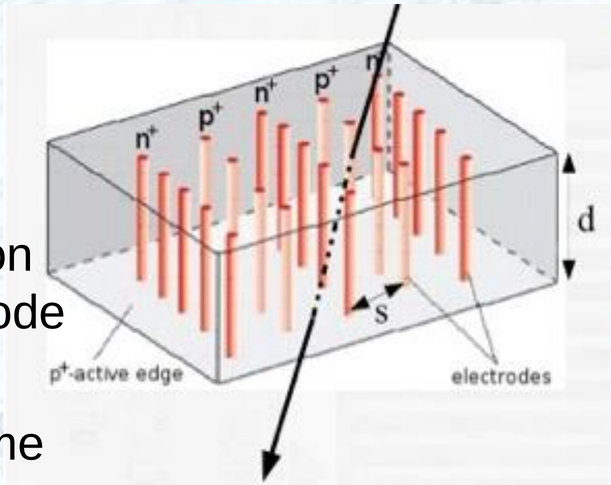
FE-I4 Pixel Chip (26880 channels)

19 x 20 mm^2 130 nm CMOS process, based on an array of 80 by 336 pixels (each 50 x 250 μm^2)



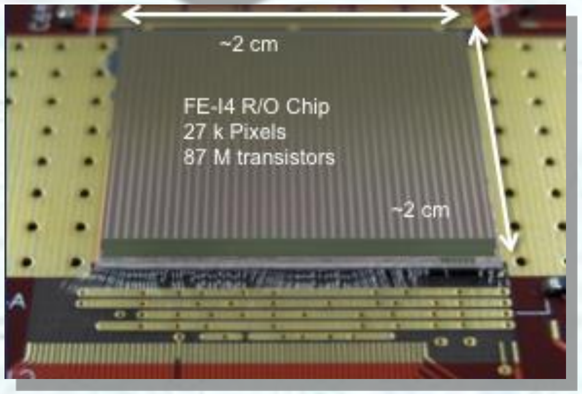
3D Sensor

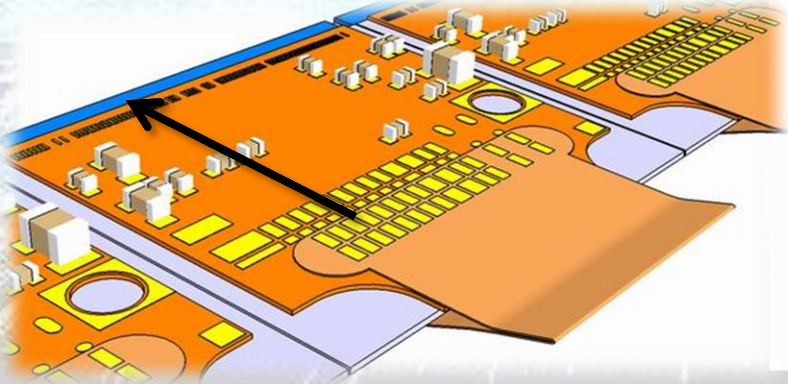
- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage

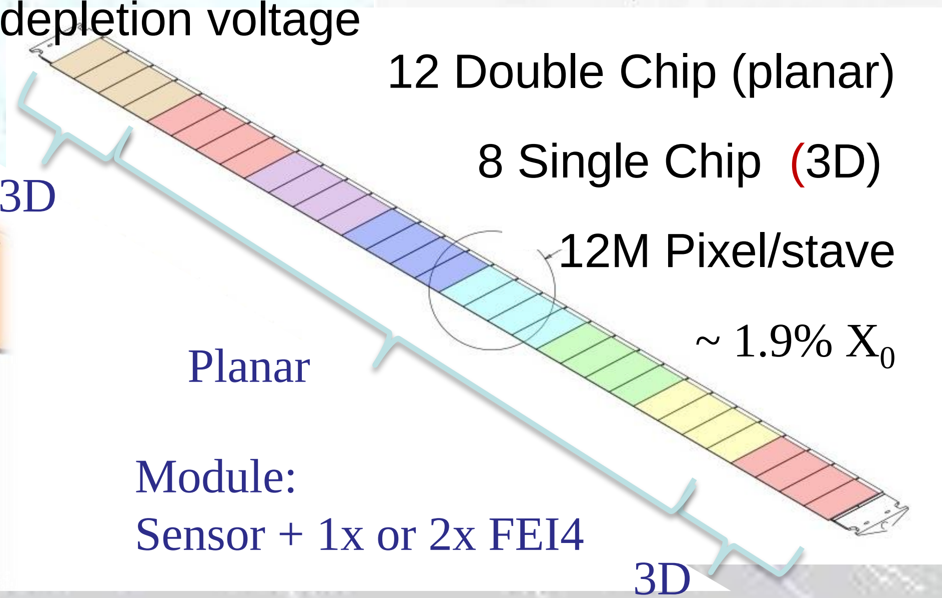


Planar Sensor

- “classic” sensor design
- oxygenated n-in-n
- 200μm thick
- Minimize inactive edge by shifting guard-ring under pixels (215 μm)
- Radiation hardness proven up to 2.4×10^{16} p/cm^2







12 Double Chip (planar)

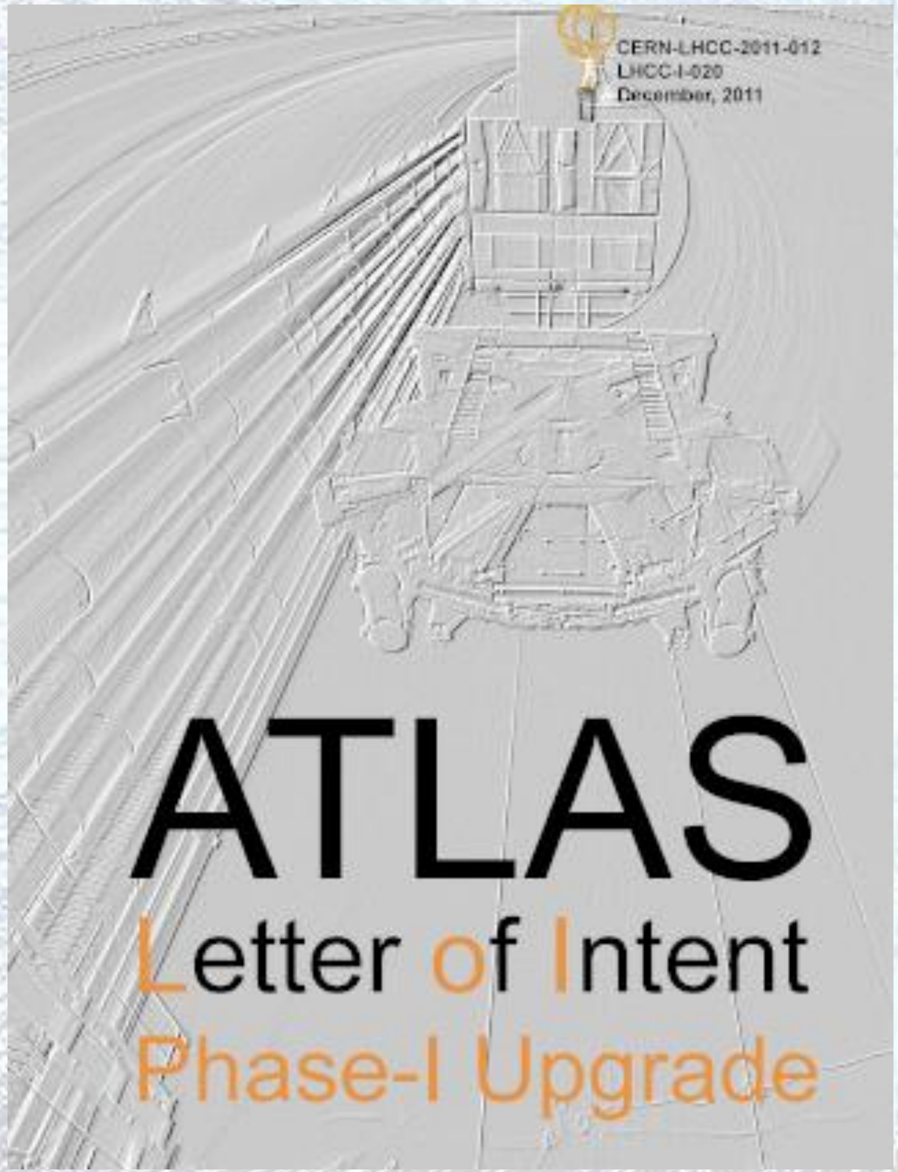
8 Single Chip (3D)

12M Pixel/stave

~ 1.9% X_0

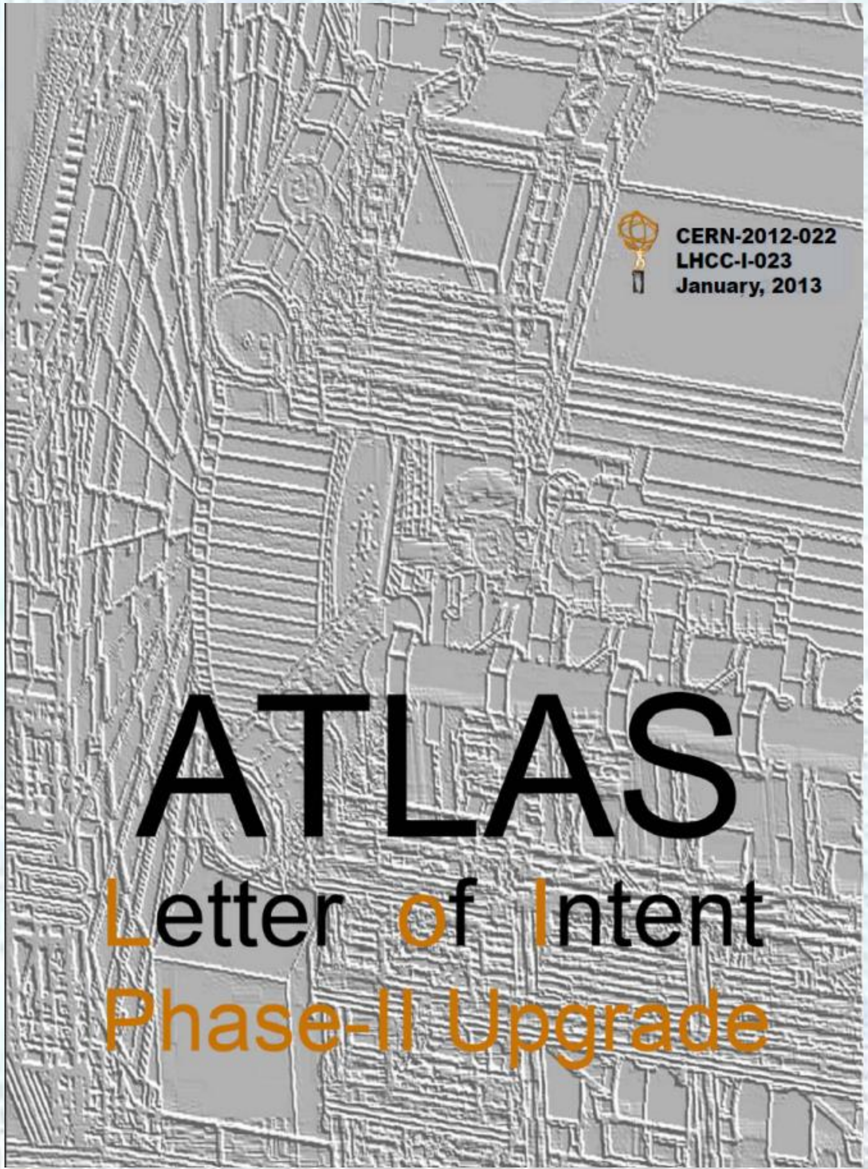
Module:
Sensor + 1x or 2x FEI4

Future Upgrade Planning



CERN-LHCC-2011-012
LHCC-I-020
December, 2011

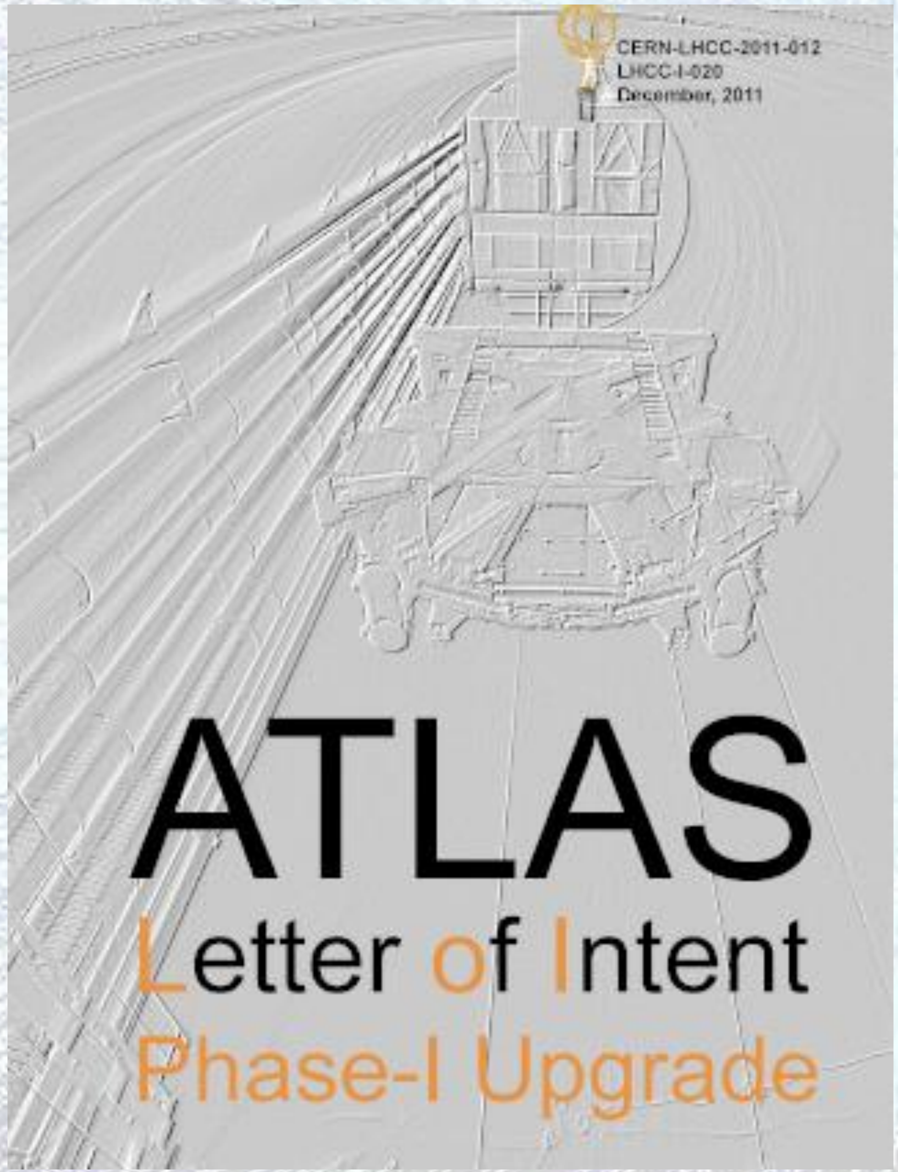
ATLAS
Letter of Intent
Phase-I Upgrade



CERN-2012-022
LHCC-I-023
January, 2013

ATLAS
Letter of Intent
Phase-II Upgrade

Future Upgrade Planning



CERN-LHCC-2011-012
LHCC-I-020
December, 2011

ATLAS
Letter of Intent
Phase-I Upgrade

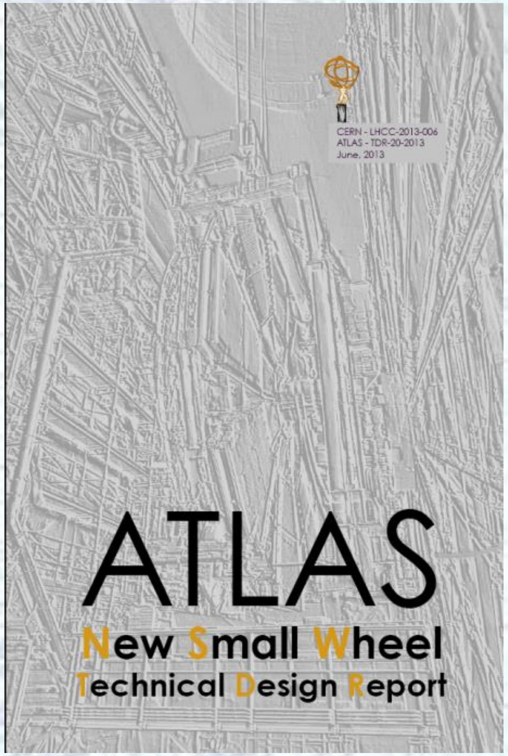
Phase-I Upgrade

(LS2)

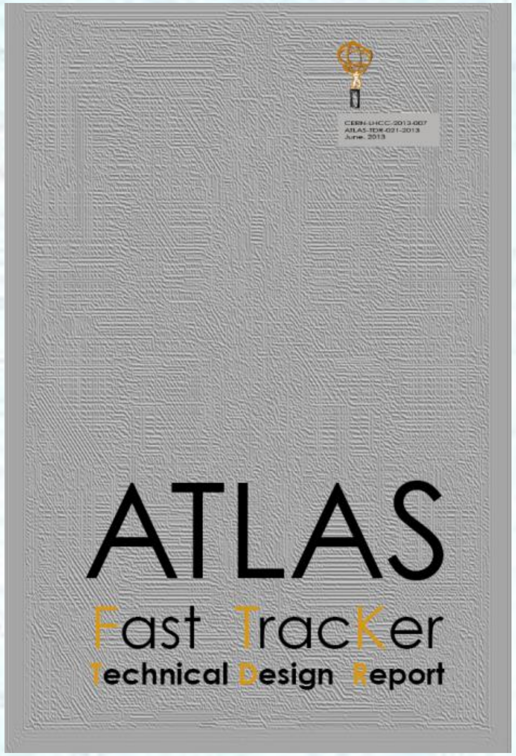
Starts Middle 2018

Future Upgrade Planning

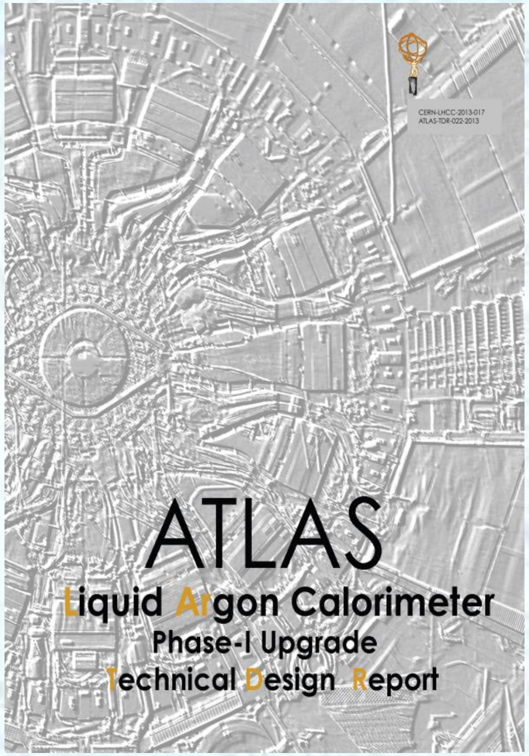
In 2013, 4 TDRs for Phase-I construction projects were prepared within ATLAS, approved by the CB and submitted to the LHCC


CERN - LHCC-2013-006
ATLAS - TDR-20-2013
June, 2013

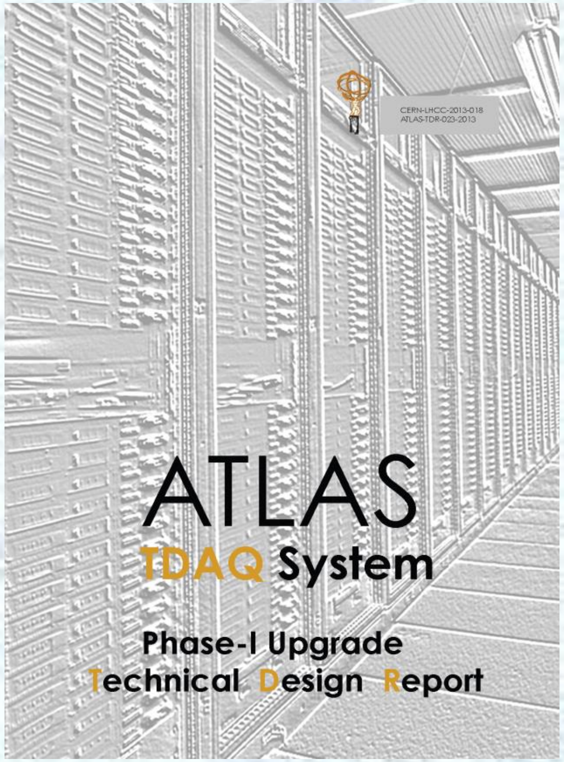
ATLAS
New Small Wheel
Technical Design Report


CERN-LHCC-2013-007
ATLAS-TDR-021-2013
June, 2013

ATLAS
Fast TracKer
Technical Design Report


CERN-LHCC-2013-017
ATLAS-TDR-022-2013

ATLAS
Liquid Argon Calorimeter
Phase-I Upgrade
Technical Design Report


CERN-LHCC-2013-018
ATLAS-TDR-023-2013

ATLAS
TDAQ System
Phase-I Upgrade
Technical Design Report

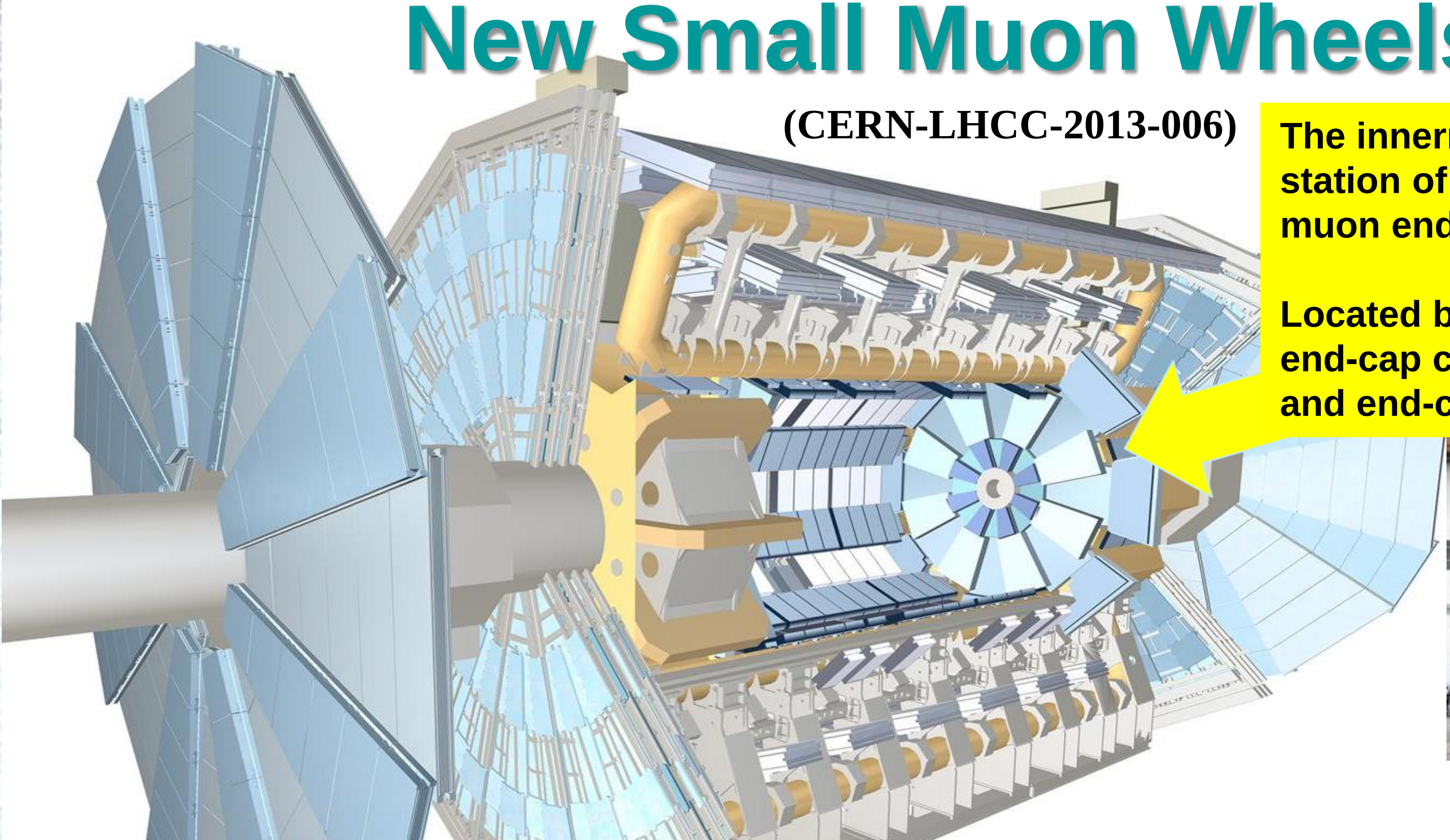
As of 5th December 2013 all 4 were endorsed by the LHCC

Upgrade Cost Group approval reported at 4th March LHCC

MoUs, with signatures from the CERN Director of Research and Computing, are now in circulation to Funding Agencies.

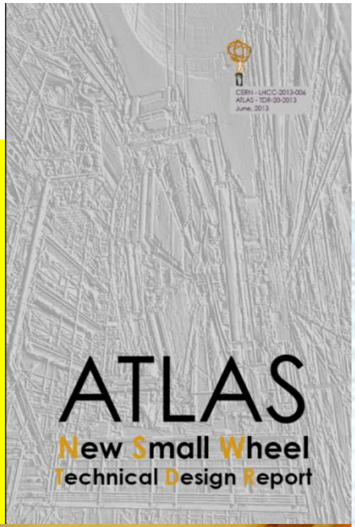
New Small Muon Wheels

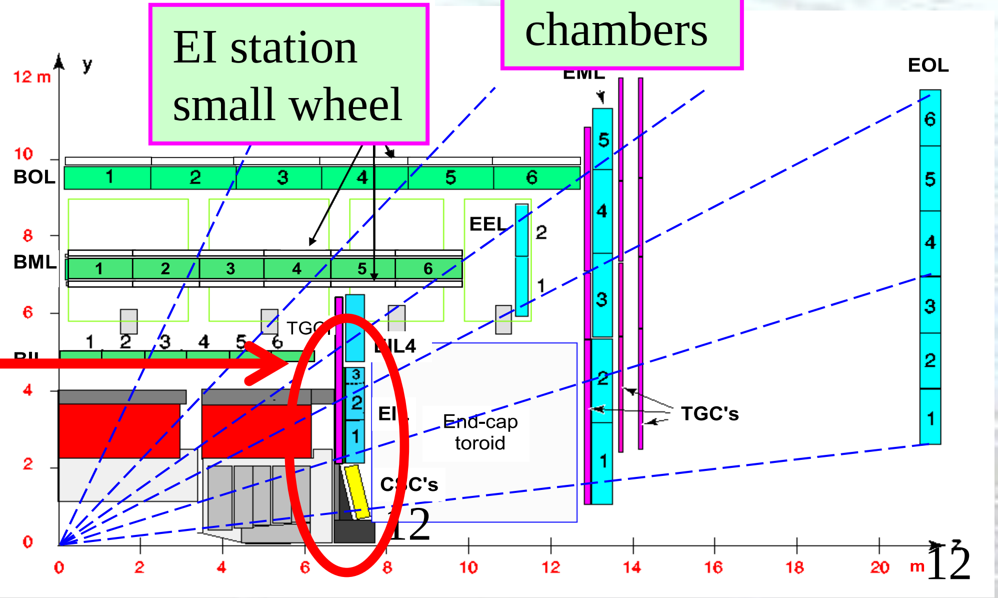
(CERN-LHCC-2013-006)



The innermost station of the muon end-cap

Located between end-cap calorimeter and end-cap toroid





- **In furthest forward direction, chamber efficiencies fall with hit rate as luminosity goes well above the design values**
- **Rate of L1 muon triggers exceeds available bandwidth unless thresholds raised**

→ Replace “small“ muon wheels

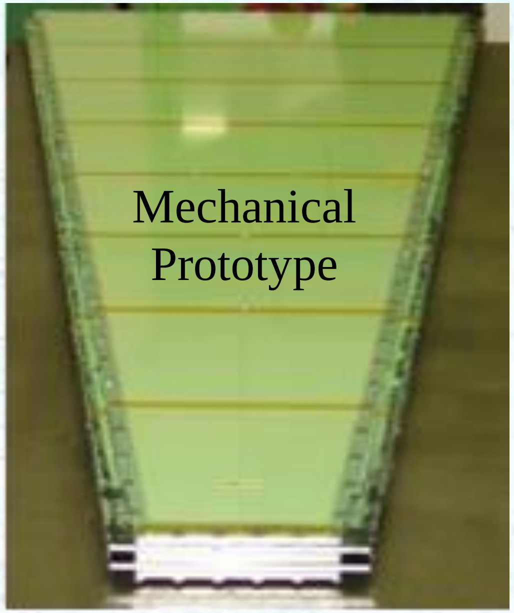
- **Kill fake muon triggers by requiring high quality (σ_θ~ 1mrad) pointing to interaction region**
- **Precision chambers combine sTGC and micromegas technologies for robustness to Phase-II luminosities**

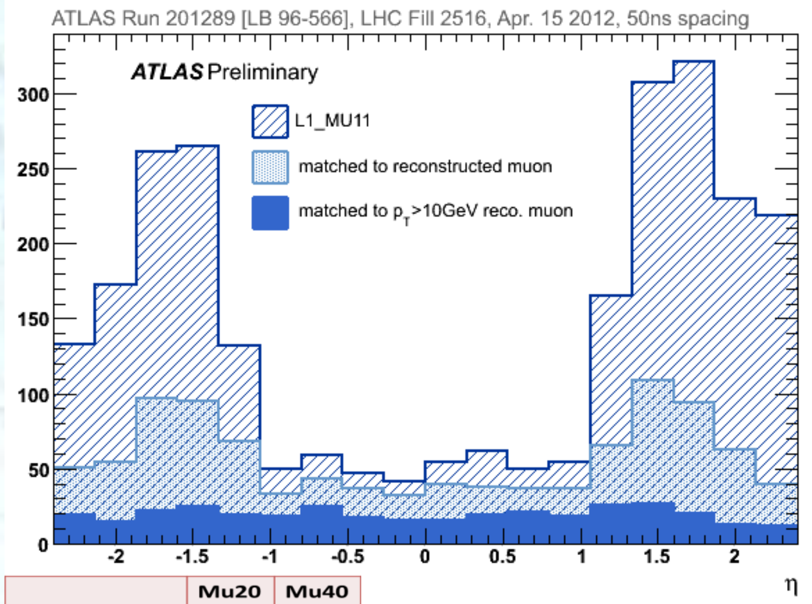
New Small Muon Wheels

(CERN-LHCC-2013-006)

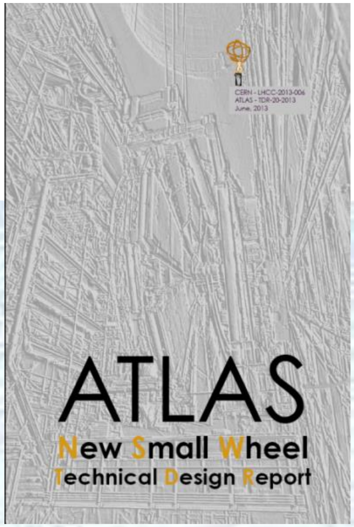
sTGC Prototype

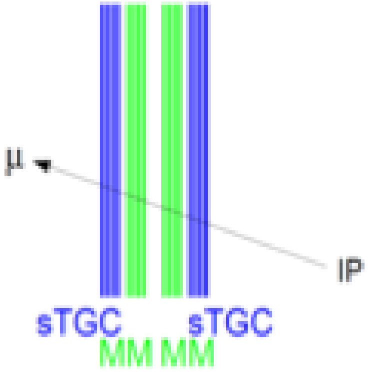
Micromegas Prototype





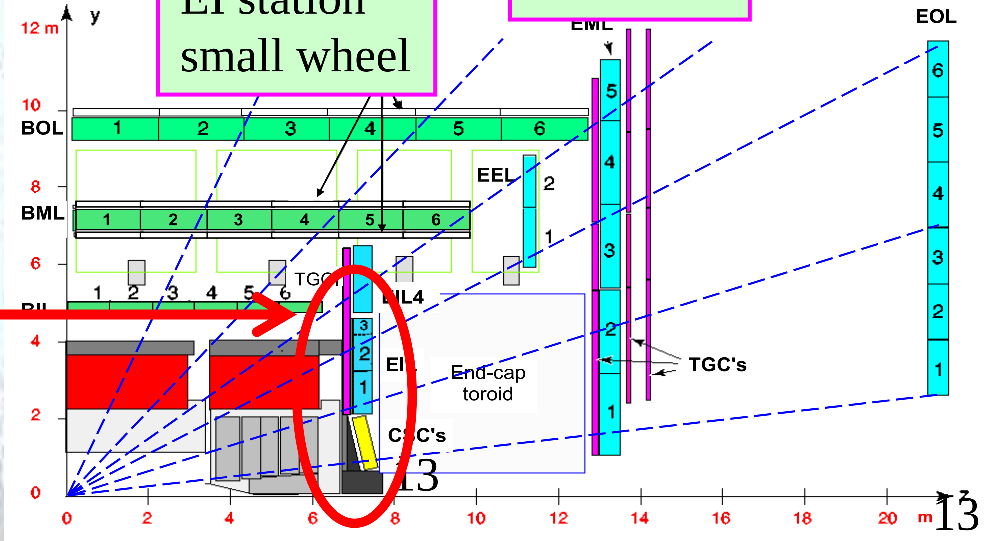
	Mu20	Mu40
Without NSW	60	29
With NSW	22	10
NSW + phase-0	17	8





EI station small wheel

L1 trigger chambers



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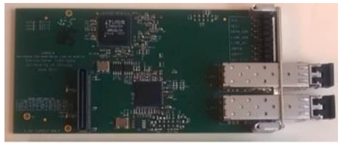
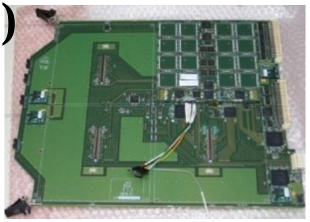
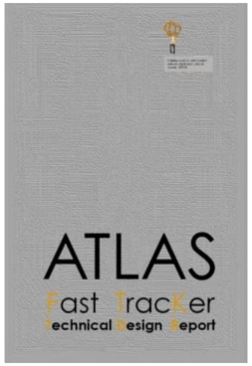


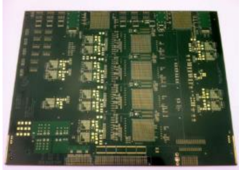
Fast TracKer (FTK)

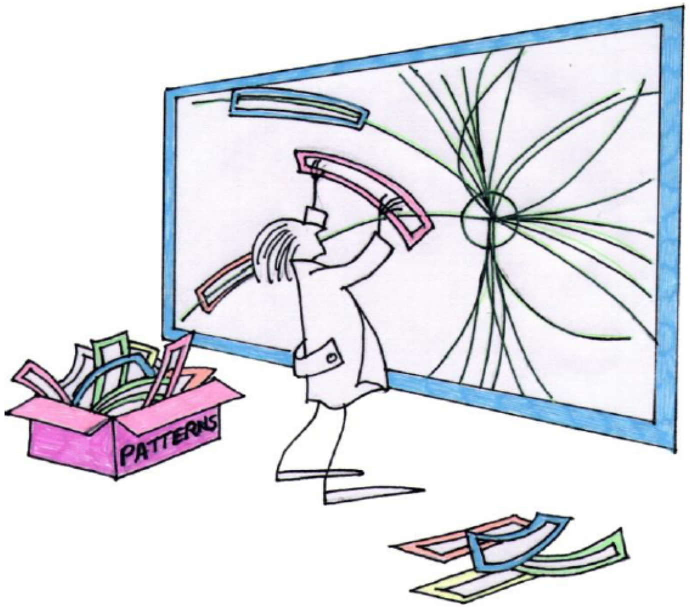
(CERN-LHCC-2013-007)

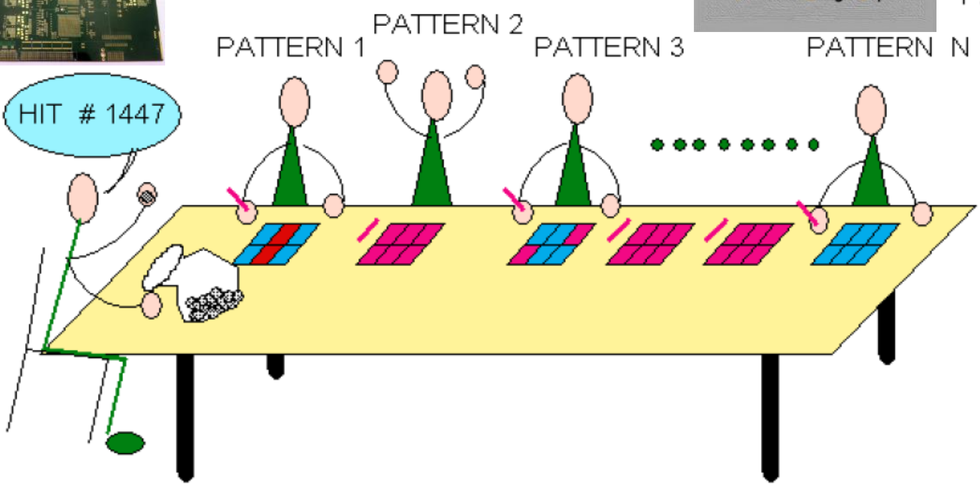


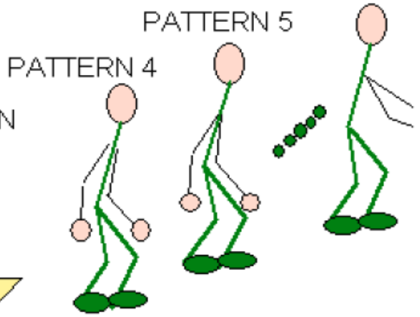


- Rapid pattern recognition









  - A pattern consists of a Super-Strip in each layer (10s of pixels/strips wide).
  - Uses HEP-specific content addressable memory (CAM) custom chip.
  - Patterns determined from full ATLAS simulation.
  - ~ 10^9 patterns see each hit almost simultaneously.
  - When hits have all been sent off detector, pattern recognition is ~ done.
    → This is then followed by FPGA based track fitting (1 fit/ns)

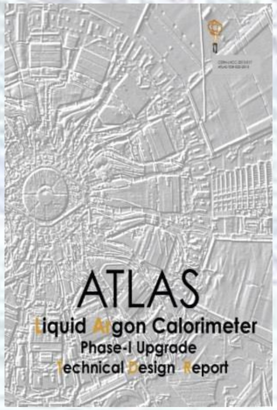
Many boards in pre-production and pre-final CAM chip version submitted

Designed for installation before Phase-I to provide HLT with full tracking at start

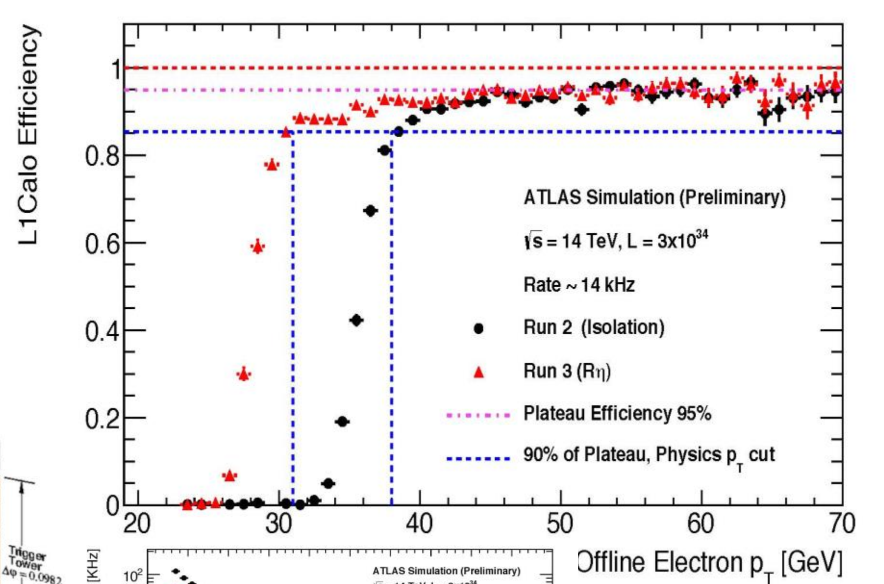
(For Phase-II need to speed up to fit tracks in RoI as input to Level-1.)

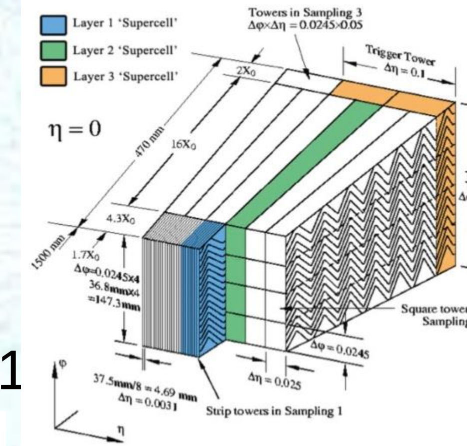
LAr Electronics Upgrades

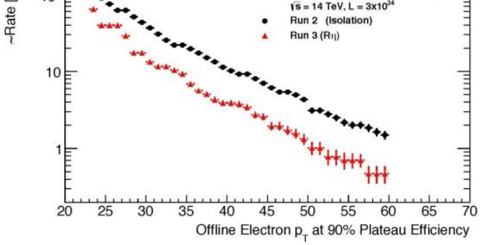
(CERN-LHCC-2013-0017)

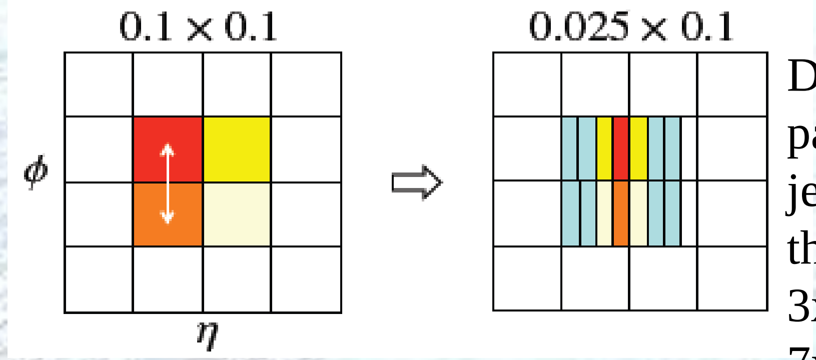


- Key target (as for New Small Wheel) is to maintain high efficiency for Level-1 triggering on low P_T objects (here electrons and photons)
- In the LAr calorimeter this implies changes to the front-end electronics to allow finer granularity to be exploited at Level-1

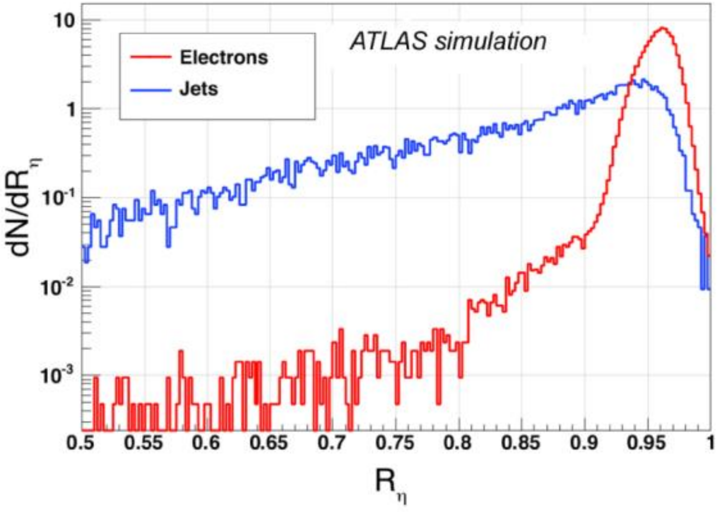






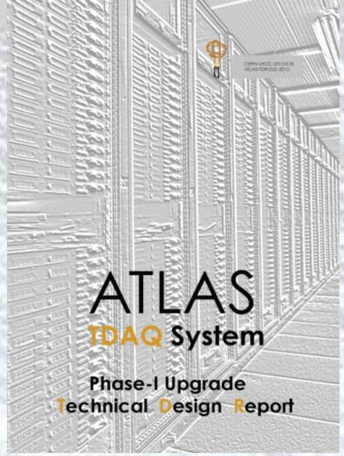


Distribution of the R_η parameter for electrons and jets, defined as the ratio of the energy in the 3x2 over the energy in the 7x2 clusters of the 2nd layer of the EM calorimeter.



(Phase-I Level-1 designed to be able to become Level-0 at Phase-II.)

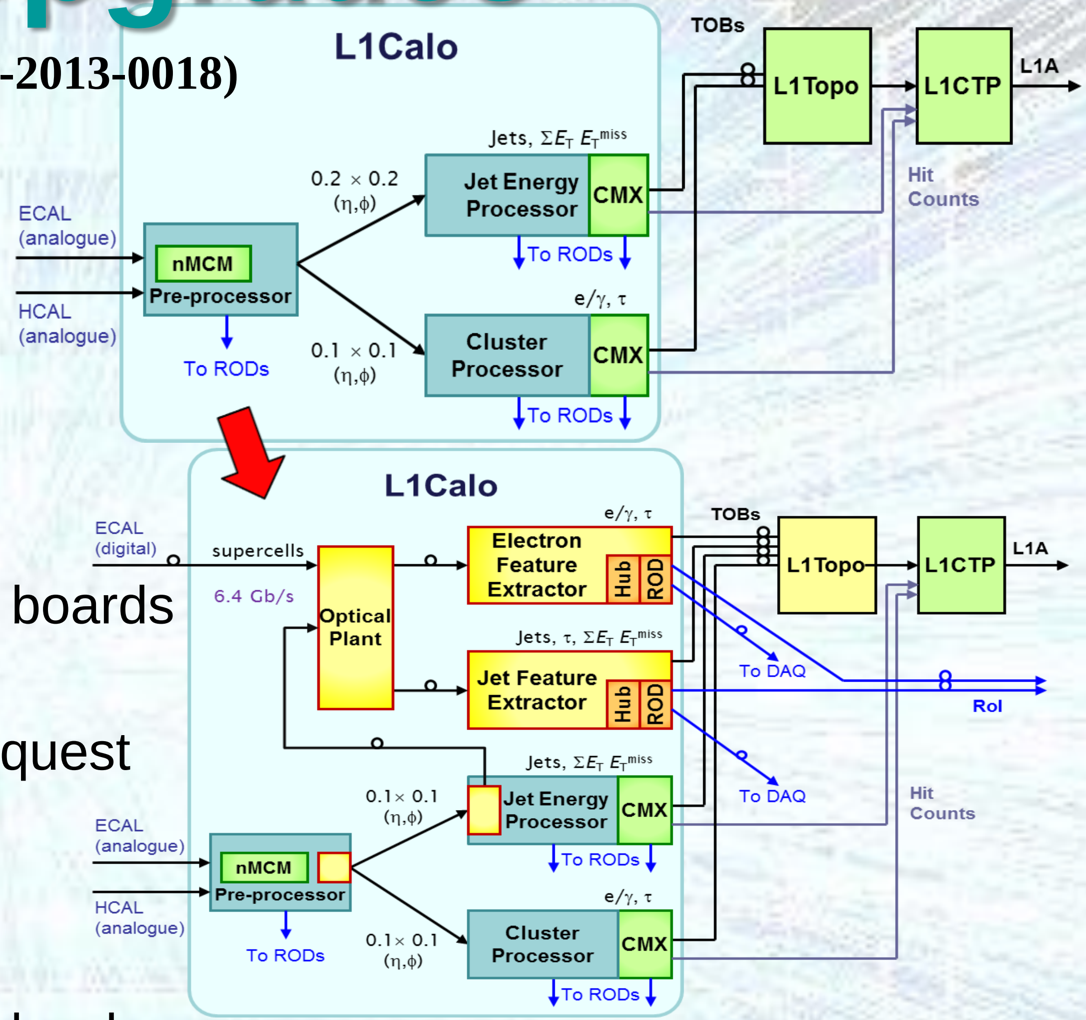
TDAQ Upgrades



ATLAS
TDAQ System
Phase-I Upgrade
Technical Design Report

Level-1: (CERN-LHCC-2013-0018)

- Phase I: completely new L1 electron and jet triggers.
- Very complex ATCA modules. Requires mastery of 6-10 Gb/s signal handling. R&D with demonstrator to check simulations of distribution on boards



HLT:

- Increase DataFlow throughput
  => higher request rates, more data per request
- Maintain rejection & limit rise of CPU times
- Provide for new detectors: FTK, IBL, NSW

Dataflow:

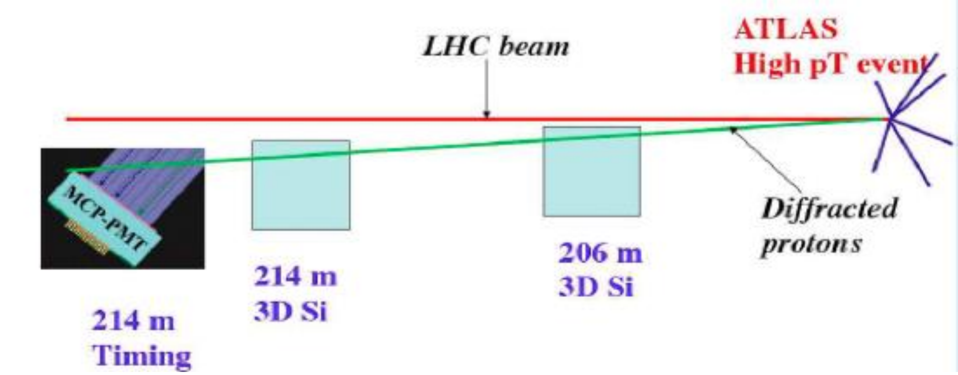
- New ROB being implemented on C-RORC hardware

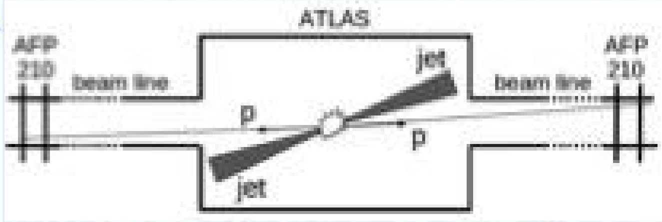

C-RORC

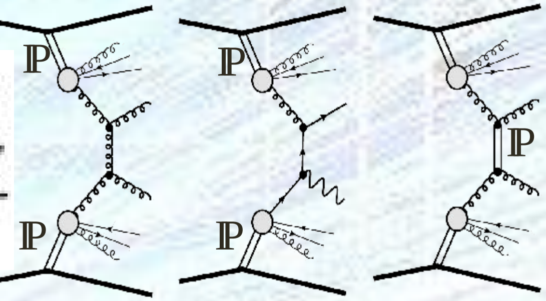
HLT core software:

- Merge L2 & EF:
  - Upgrading HLT Steering software
  - Implementing new chains in Trigger menu
- Minimize *cost* of Trigger selection (cost ∝ data rate & trigger rates & CPU)

ATLAS Forward Proton (AFP)







- ATLAS review process

1. Initial design review
2. Kick off Institutes meeting
3. EB approval
4. CB endorsement
5. IMOU TDR
6. LHCC and RRB approval

- AFP physics review looked at capabilities in dedicated low <μ> short runs and concluded in January 2014:

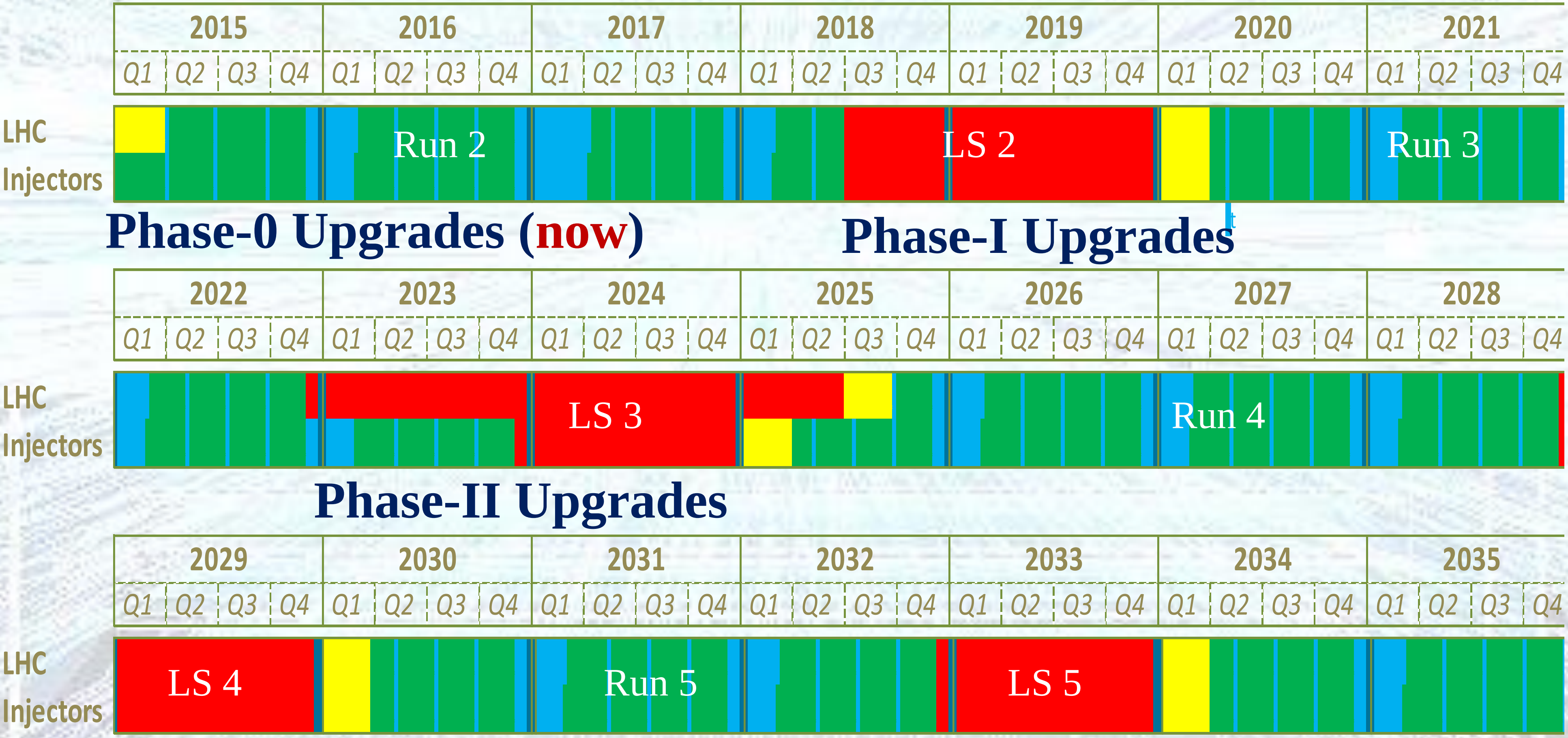
The proposed physics programme of AFP special runs to take place between LS1 and LS2 includes some diffractive and QCD physics topics which cannot otherwise be covered by ATLAS and which will be of substantial interest to a sizable external community. These include dijet and W boson production in single diffractive dissociation and Double Pomeron Exchange dijet production with double proton tags.

Technical review report (May 2014) encouraged AFP to proceed to kick-off meeting, request EB approval and to target CB endorsement in near future

New LHC schedule beyond LS1

Only EYETS (19 weeks)   (no Linac4 connection during Run2)

LS2	starting in 2018 (July)	18 months + 3months BC (Beam Commissioning)
LS3	LHC: starting in 2023 =>	30 months + 3 BC
	injectors: in 2024 =>	13 months + 3 BC



Phase-0 Upgrades (now)

Phase-I Upgrades

Phase-II Upgrades

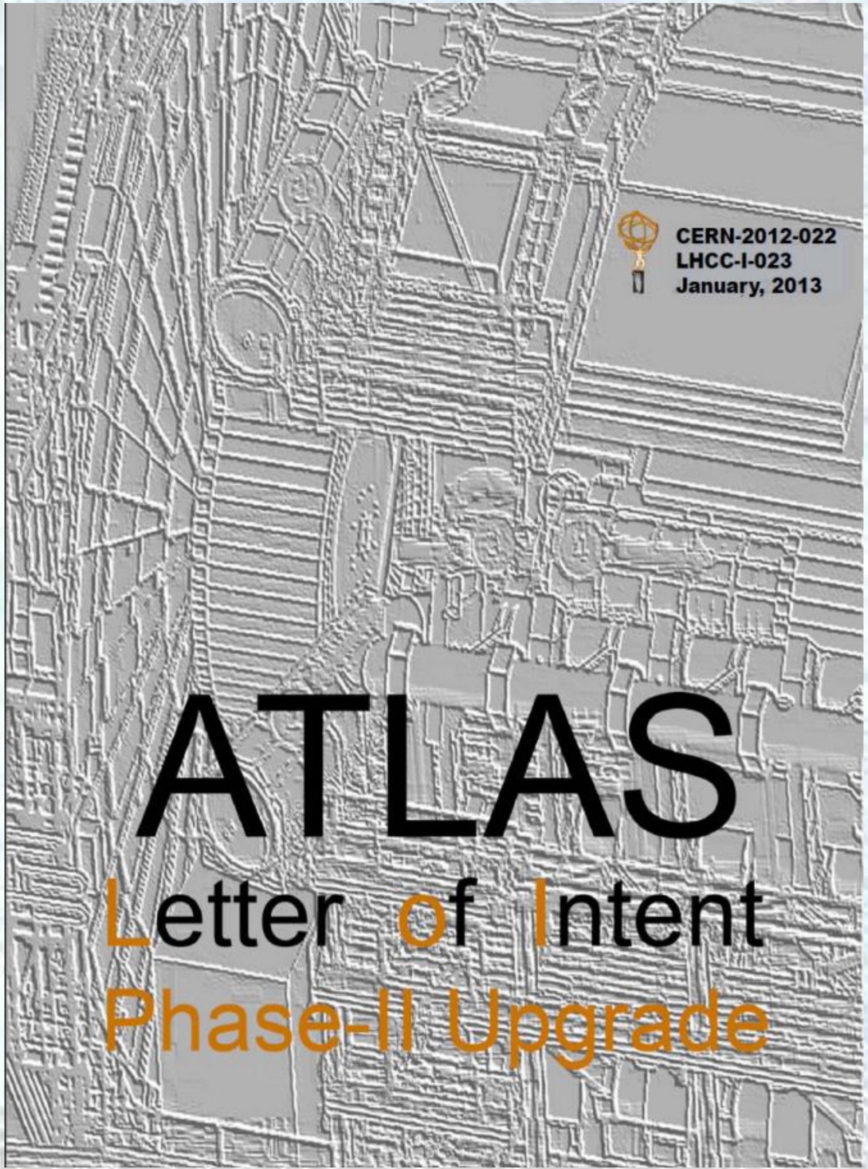
LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Future Upgrade Planning

Phase-II Upgrade

(LS3)

Starts End 2022



CERN-2012-022
LHCC-I-023
January, 2013

ATLAS

Letter of Intent

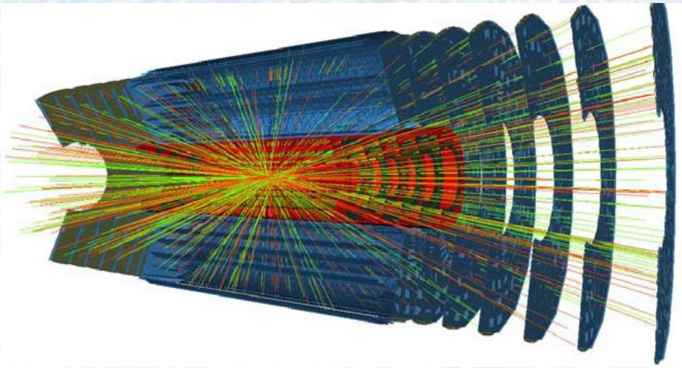
Phase-II Upgrade

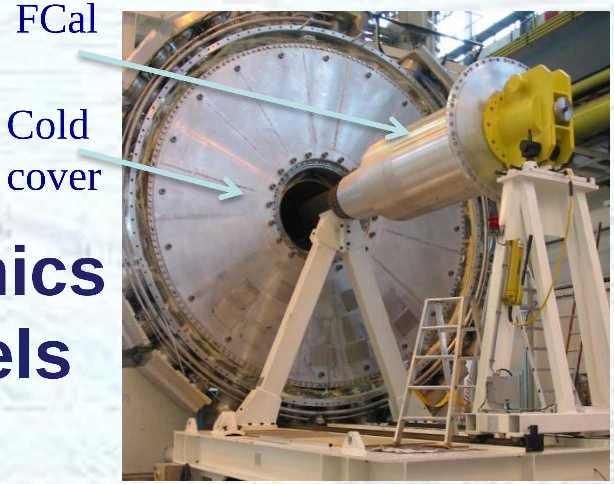
Phase-II Detector Upgrades

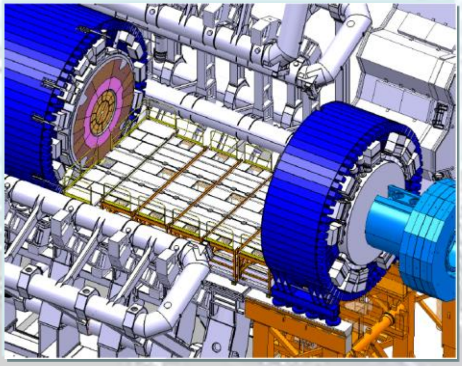
Integrated radiation levels (up to 2-3×$10^{16} n_{eq}/cm^2$) and plan to cope with up to 200 interactions every 25ns

Implications of this include:

- **New Inner Detector (strips and pixels)**
- **Trigger and data acquisition upgrades**
- **L1 Track Trigger**
- **New LAr front-end and back-end electronics**
- **Possible upgrades of HEC and FCal**
- **New Tiles front-end and back-end electronics**
- **Muon Barrel and Large Wheel trigger electronics**
- **Possible upgrades of TGCs in Inner Big Wheels**
- **Forward detector upgrades**
- **TAS and shielding upgrade**
- **Various infrastructure upgrades**
- **Common activities (installation, safety, …)**
- **Software and Computing**





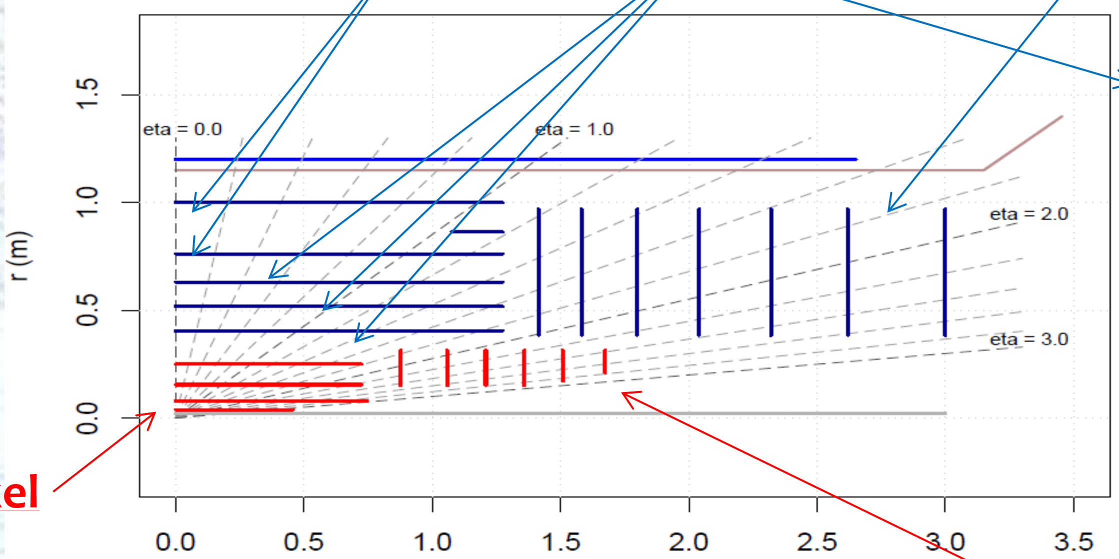


ATLAS: New All-silicon Inner Tracker

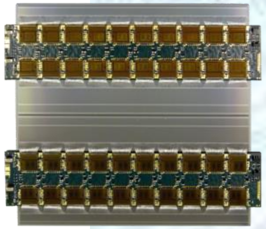
Long Barrel Strips

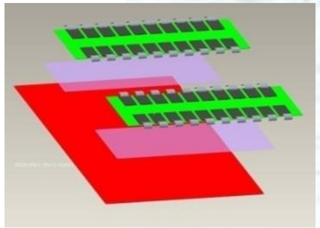
Short Barrel Strips

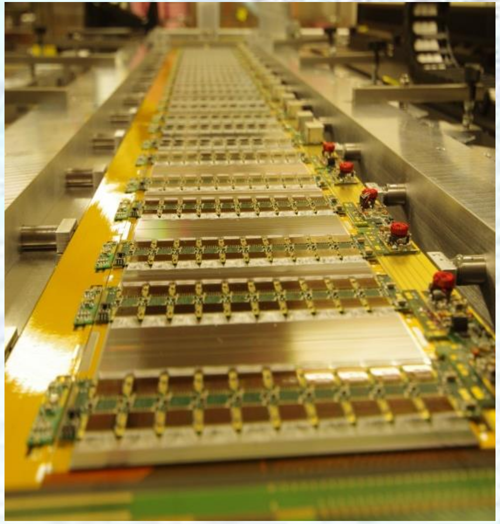
Forward Strips



Barrel pixel

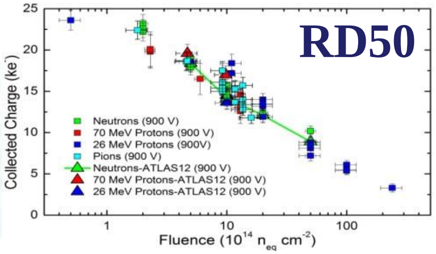






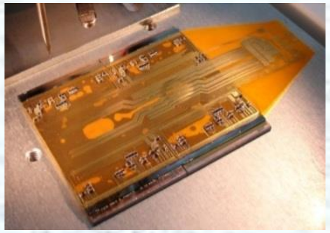
Microstrip Stave Prototype

Signal vs dose
(1 MeV n equivalent)

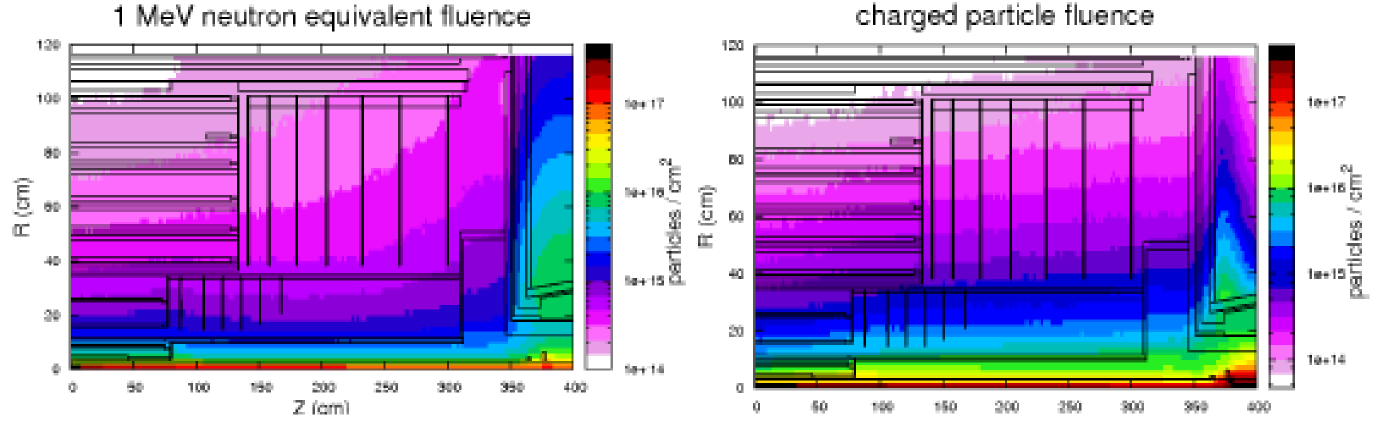


Baseline layout of the new ATLAS inner tracker for HL-LHC Aim to have at least 14 silicon hits

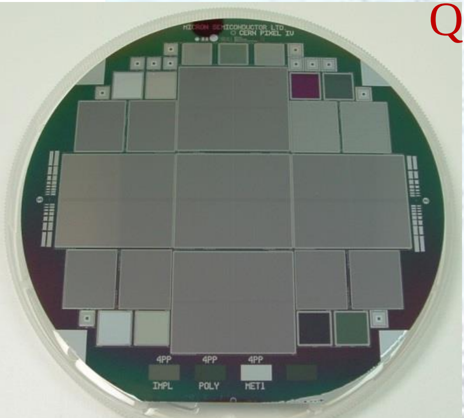
Forward pixel



Quad Pixel
Module



14 TeV collisions; integrated luminosity = 3000fb^{-1}

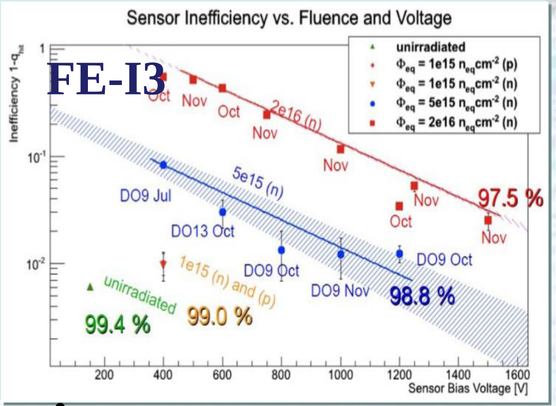


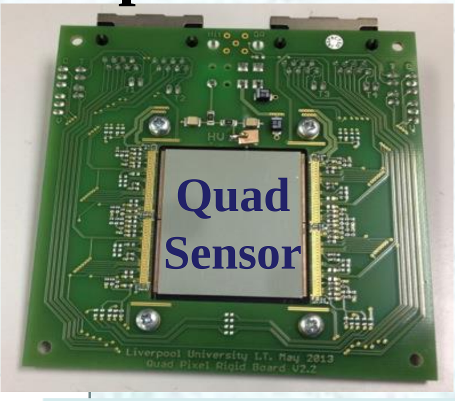
Quad Pixel Sensor Wafer

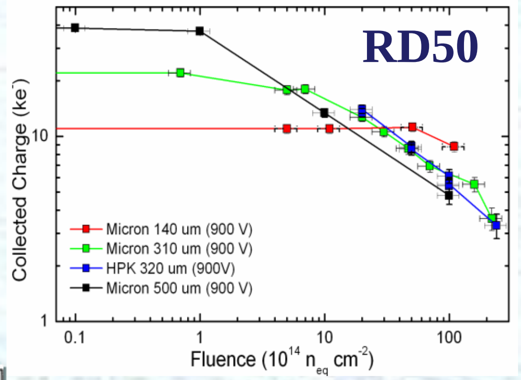
New All-silicon Inner Tracker

Pixel Detector

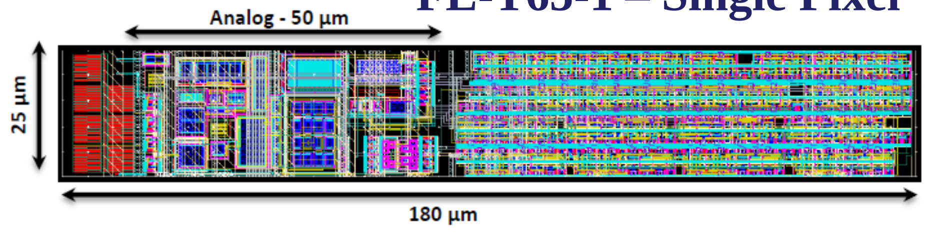
- n-in-n, n-in-p planar, 3D and diamond sensors proved to doses up to $2\times10^{16}n_{eq}/cm^2$ and 1Grad
- Probably use TSMC 65nm technology which should allow pixel sizes down to 50μm×50μm or 25μm×100μm (RD53)
- Test structures in 65nm produced and studied after irradiation
- Larger area sensors (n-in-p) quads/sextuplets produced on 150mm diameter wafers with several foundries
- Irradiated quad pixel modules studied in test-beam with excellent performance
- Prototyping of local supports for various concepts has been carried out
- A number of support designs and service routings have been studied

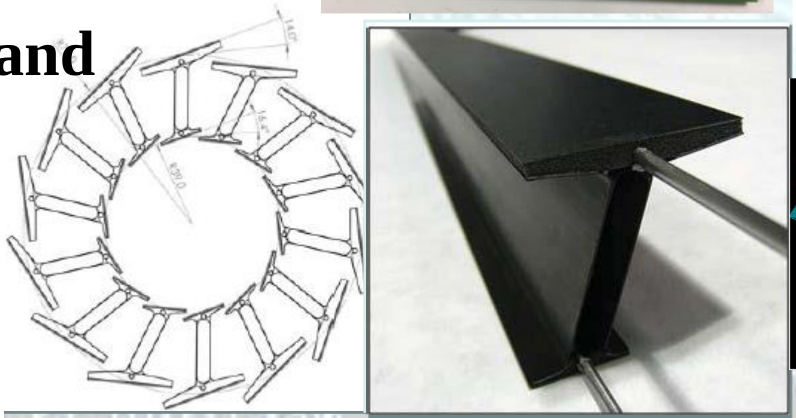




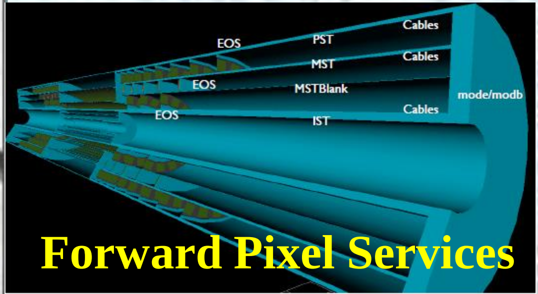


FE-T65-1 – Single Pixel





Possible Barrel Support Concept



RD53 Summary

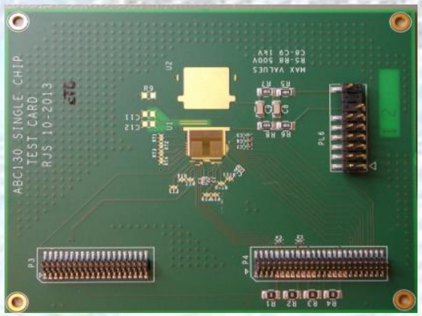
- Highly focused ATLAS-CMS-LCD/CLIC RD collaboration to develop/qualify technology, tools, architecture and building blocks required to build next generation pixel chips for very high rates and radiation
- Synergy with other pixel projects when possible
- Centered on technical working groups
- Baseline technology: 65nm
  - CERN frame contract/NDA/design kit .
  - Will evaluate alternatives ("emergency" plan)
- 17 Institutes, 100 Collaborators
- Initial work program of 3 years
  - **Goal: Full pixel chip prototype 2016**
  - Working groups have gotten a good start.
  - Common or differentiated final chips to be defined at end of 3 year R&D period

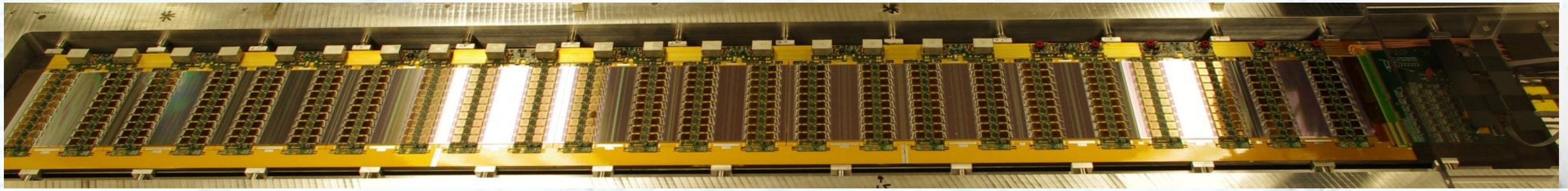
IBM announced (Feb 2014) foundries for sale
New CERN contract with TSMC until end 2017
Both 65 nm and 130 nm
Mixed signal design kit available for the 65 nm
2 metal stacks: 6+1 and 9+1
130 nm could be used as an alternative to IBM
Design kit being developed
Radiation hardness tests to be completed

New All-silicon Inner Tracker

Strip Detector

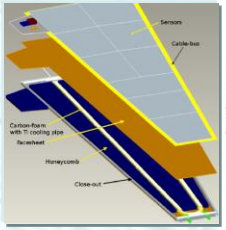
- New prototype n-in-p sensors delivered with 4 rows of 2.4cm long strips at 74.5µm pitch
- New (256 channel) 130nm CMOS ASIC received (resubmission delivery end June)
- Many strip modules (single and double sided) prototyped with 250nm ASICs
- Large area stave DC-DC prototype (120cm×10cm) produced and under study

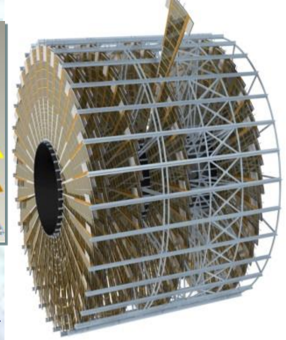


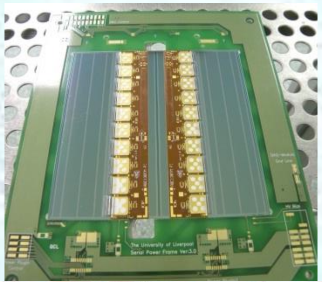


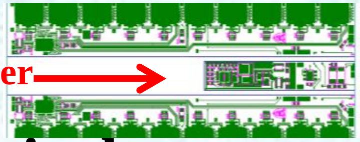
Fully functional forward module

- Serial and DC-DC powering studied in detail on short versions of 250nm stave
- Several other new chips (HCC, HV multiplex, SP, DC-DC,..)
- Hybrid/module designs to use these completed

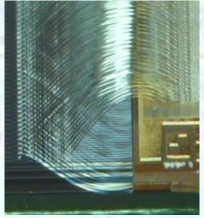








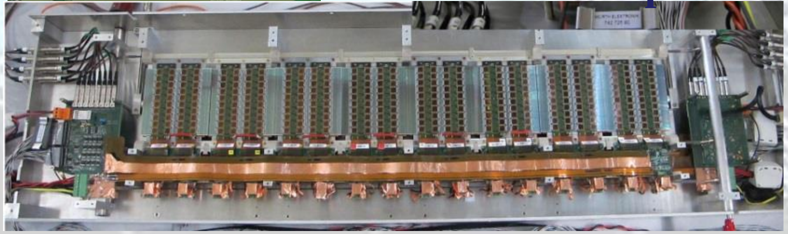
Module with on-board DC-DC converter



4 row wire bonds

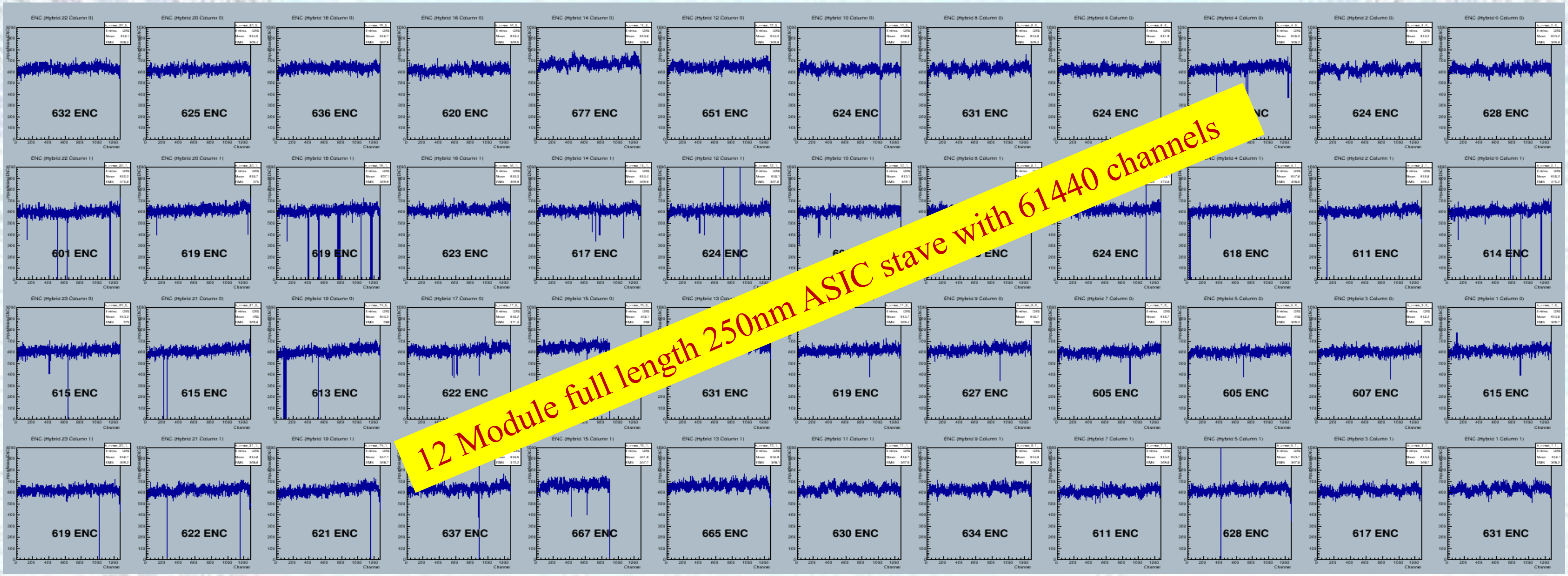
- Local supports extensively prototyped and further material reduction achieved
- Progress in Petal and Stave support designs
- End-of-stave card for 130nm developed

8 double-sided module 250nm super-module

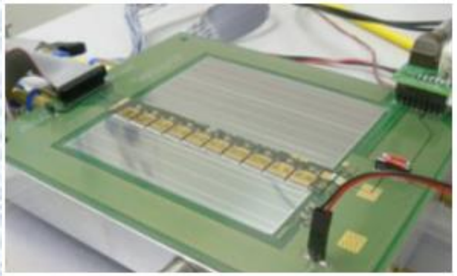


New All-silicon Inner Tracker

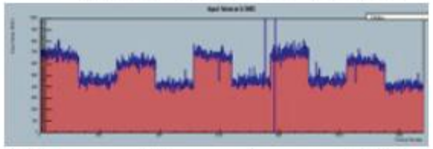
Strip Detector



12 Module full length 250nm ASIC stave with 61440 channels

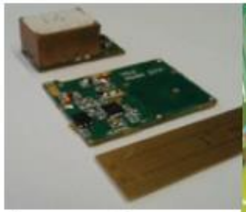


Hybrid with 5+5 ABC130

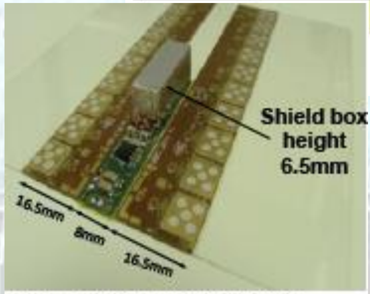


With one of two columns of strips bonded

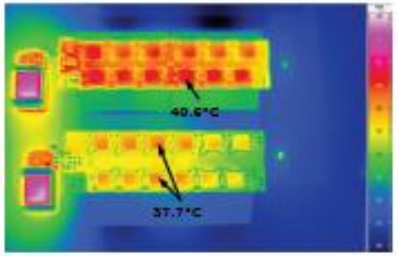
- Thin build FR4 hybrid made quickly
  - 10 ABC130 attached, 5 off "FIB'd" and 5 off "non-FIB'd"
  - All 10 ABC130s linked serially (for data readout) with common TTC bus
- Wire-bonding much simpler/faster
  - Benefit of collaborating with asic designers to 'fix' geometry
- Hybrid/module behaves as expected:
  - Data Passing at 80MHz RCLK works
  - Hybrid draws ~810mA when configured (PTOTAL~ 1.2W/hybrid)
  - Total power consumption of ~3W/module (inc.HCC)
  - Current ABCN-25 module power consumption is ~20W
  - Output noise as expected and extremely regular



STV10 DC-DC on module

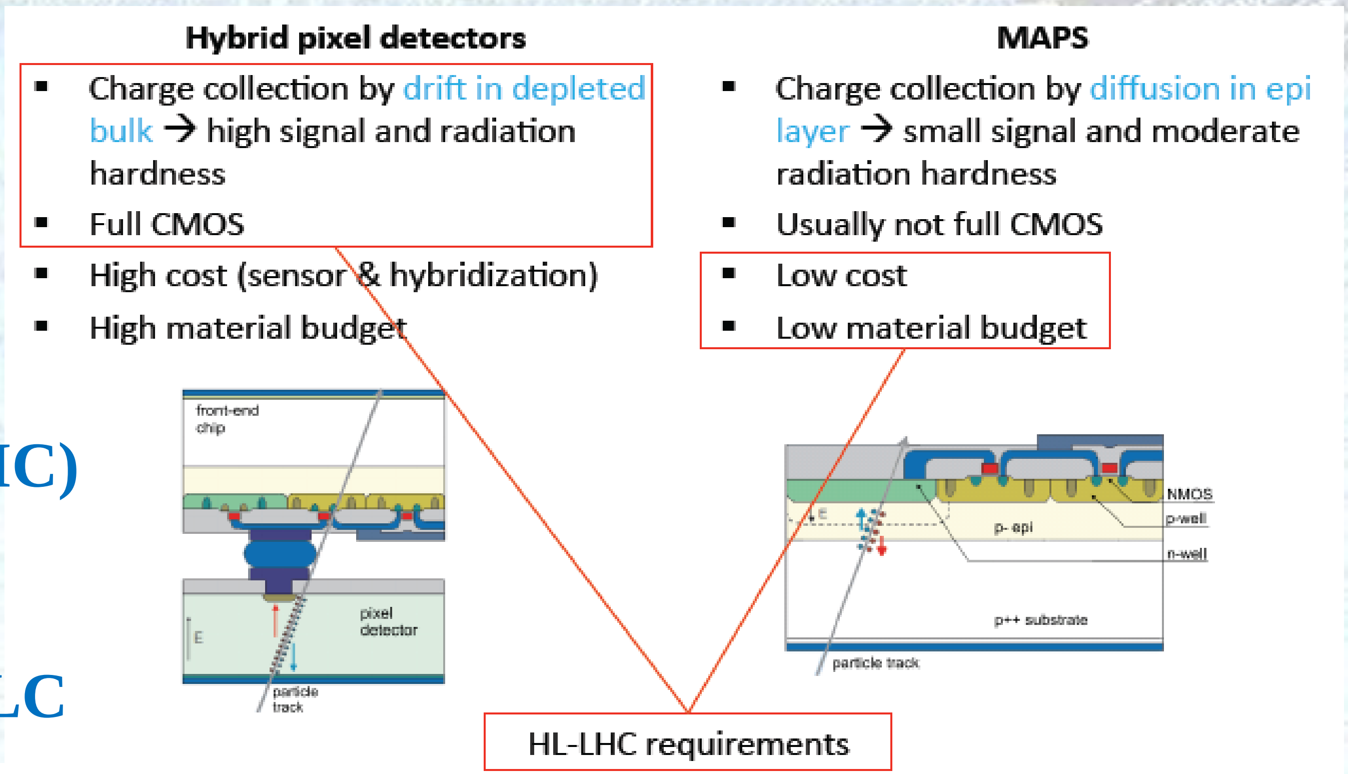


Thermo-Mechanical Module with compact DCDC converter



HV/HR-CMOS R&D

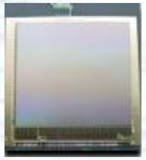
Potential technologies under study to bring some of the advantages of monolithic active pixel sensor (MAPS) technology to the ITk.



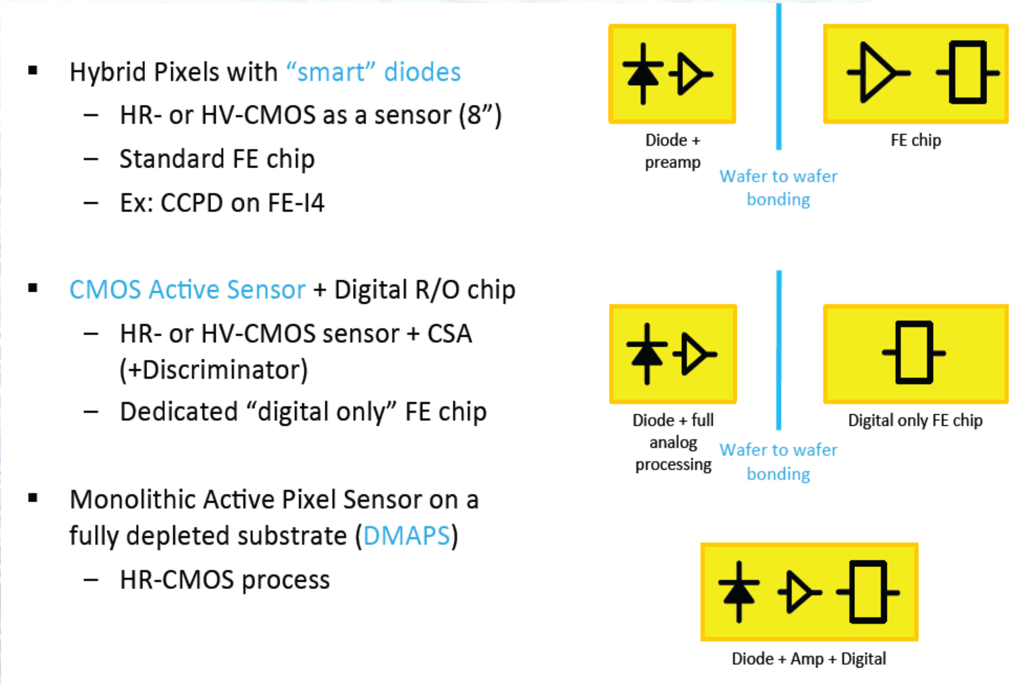
Hybrid pixel detectors	MAPS
Charge collection by drift in depleted bulk → high signal and radiation hardness	Charge collection by diffusion in epi layer → small signal and moderate radiation hardness
Full CMOS	Usually not full CMOS
High cost (sensor & hybridization)	Low cost
High material budget	Low material budget

HL-LHC requirements

Already installed at STAR (RHIC)



and proposed for ALICE and ILC



- Hybrid Pixels with "smart" diodes
  - HR- or HV-CMOS as a sensor (8")
  - Standard FE chip
  - Ex: CCPD on FE-I4
- CMOS Active Sensor + Digital R/O chip
  - HR- or HV-CMOS sensor + CSA (+Discriminator)
  - Dedicated "digital only" FE chip
- Monolithic Active Pixel Sensor on a fully depleted substrate (DMAPS)
  - HR-CMOS process

Could also envisage using the "smart diode" approach to propose a single-sided strip replacement with z encoding

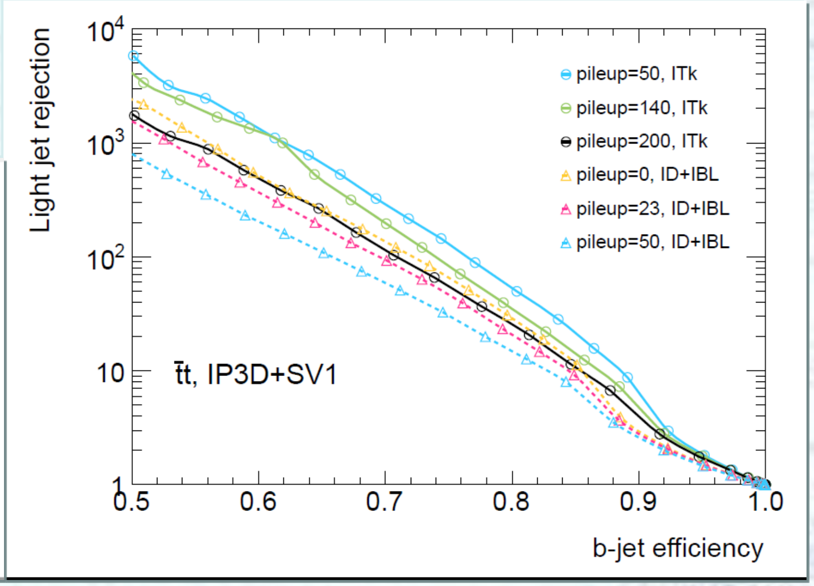
Many technologies under investigation for potential use in pixel system at higher radii or allowing less expensive 5th layer

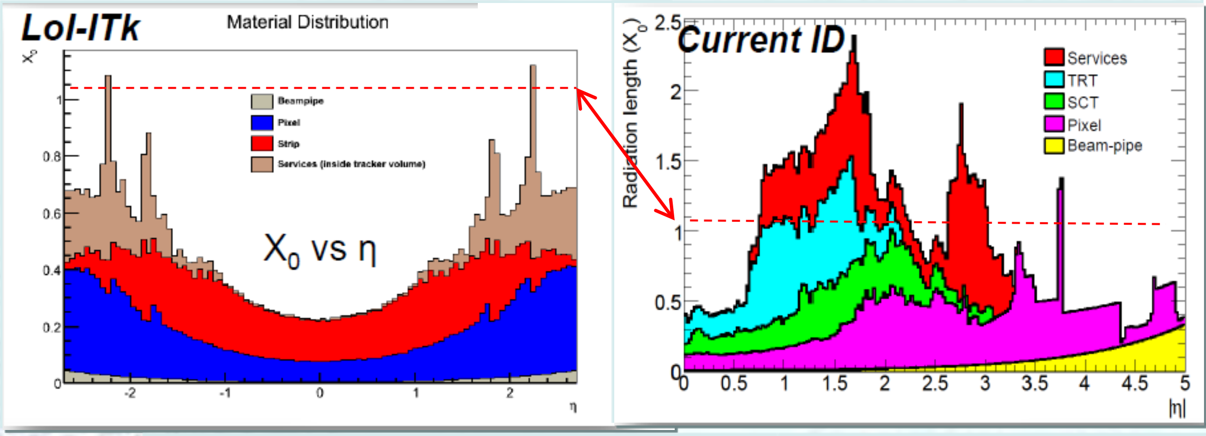
Cost evaluation depends critically on yield estimates for large format detectors

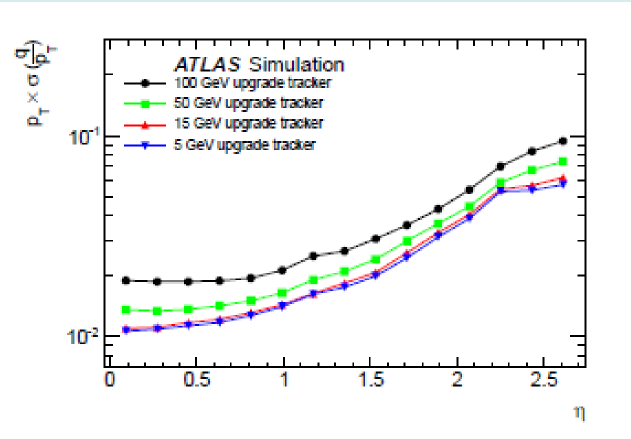
New All-silicon Inner Tracker

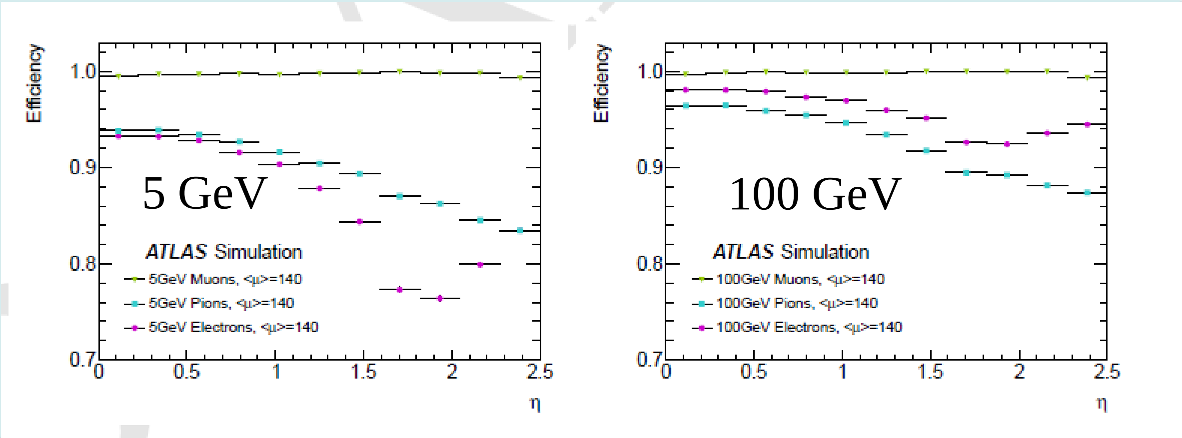
Integration and Performance

- Cooling, services, integration, removal, installation etc all being studied and key is understanding <u>activation</u> issues
- Optoelectronics (GBT) being working on in common with other experiments
- DAQ/DCS exists for prototype operation but not yet designs for final system
- Detailed layout optimisation underway to understand cost/performance trade-offs





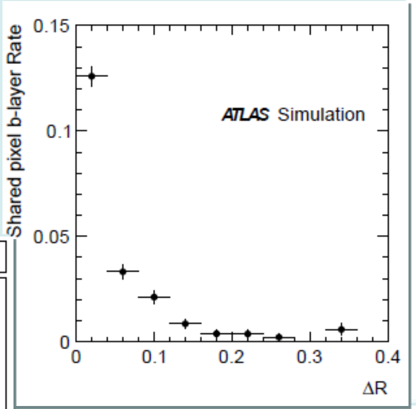


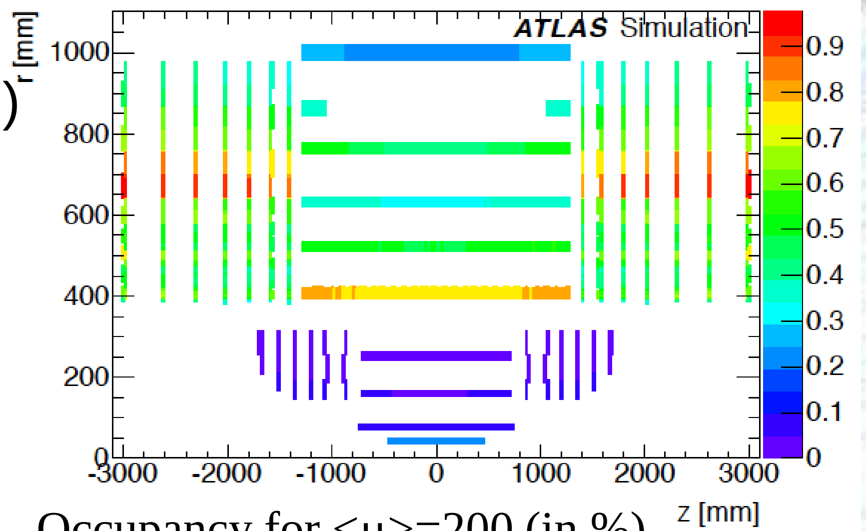


Baseline Tracker Performance

- New Inner Detector Improved granularity
  (Smaller pixels and 2.45cm and 4.9cm strips (74.5µm pitch)
  - Improved radiation hardness
  - Reduced material
  - Extended forward coverage
  - Robust tracking (14 layers)

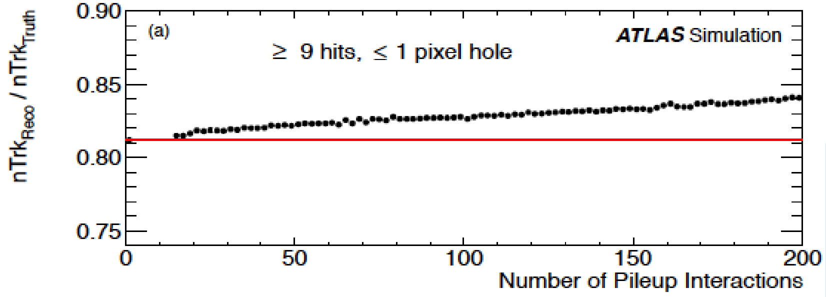
parameter	layer 1	layer 2	layers 3 + 4	disks
chips (ϕ x z)	FE-5 2x1	FE-5 2x2	FE-I4 2x2	FE-I4 2x3
pixel size (μm^2)	25 x 150	25 x150	50x 250	50x 250
nb of pixels in ϕ	672	1348 +12 ganged	672 + 6 ganged	672 + 6 ganged
nb. of double columns in z	68	68	40	60
length of sensor at gap (μm)	300	300	450	450
distance to module edge (μm)	150	150	500	500
distance active to cut edge (μm)	100	100	100	100
active size (mm^2)	16.8 x 41.1	34.0 x 41.1	33.9 x 40.4	33.9x60.8
physical size (mm^2)	18.8 x 41.3	38.0 x 41.3	38.0 x 41.1	38.0x61.3
power (W)	0.9	1.8	1.8	2.7

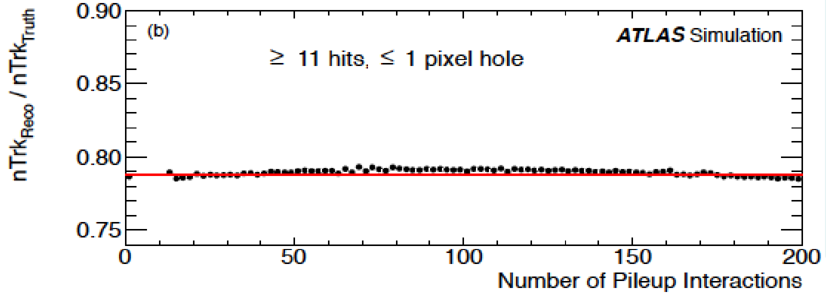




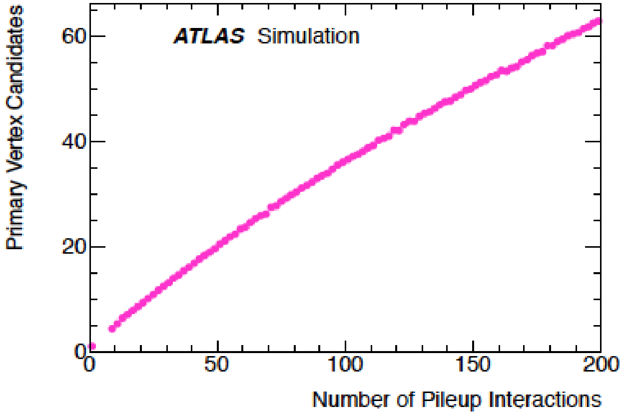
Occupancy for <μ>=200 (in %)

Track parameter $\lvert\eta\rvert < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50

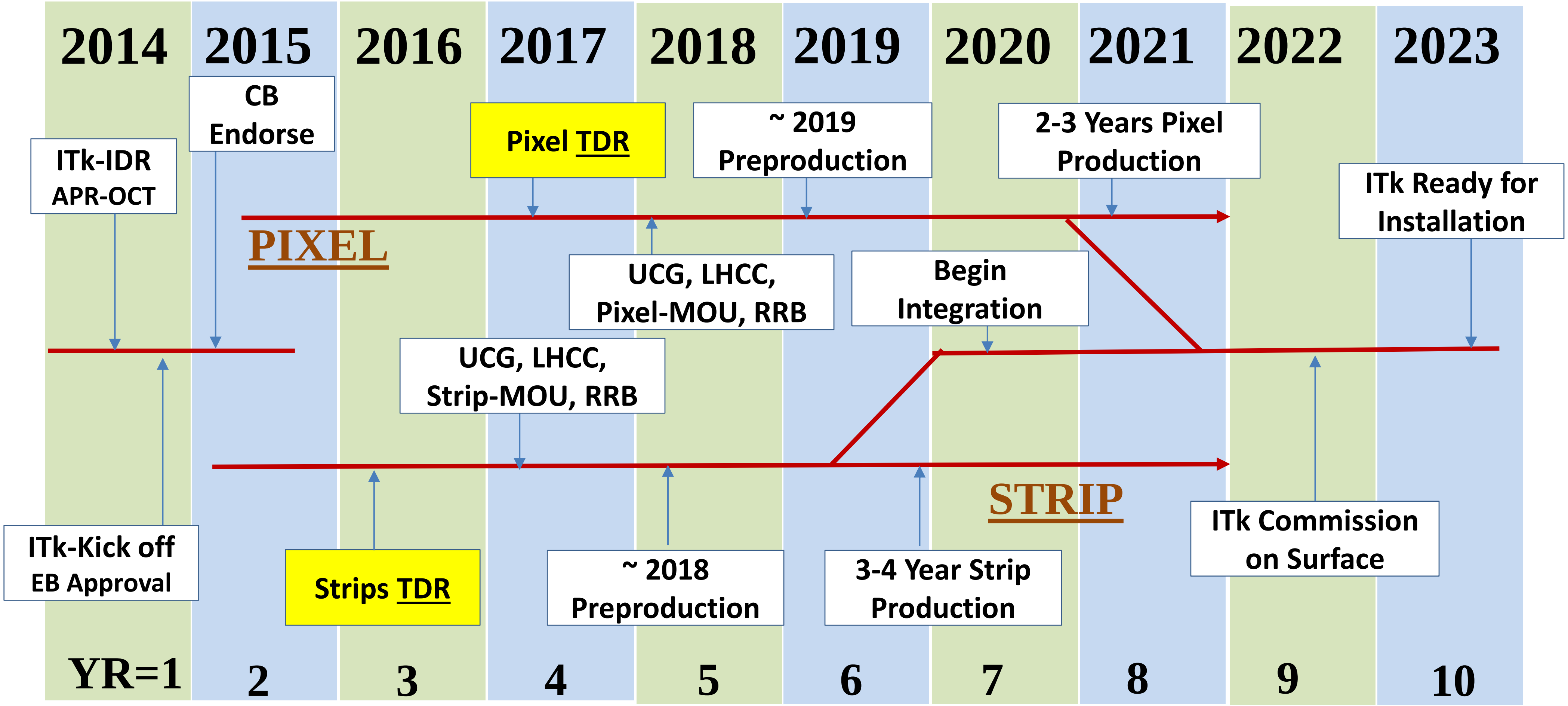




Detector:	Silicon area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**



ITk: Draft Schedule



CB= collaboration board, EB=executive board, IMOU=interim memorandum of understanding, UCG=upgrade cost group, RRB= Resources review board, IDR=initial design review (internal), TDR=technical design report (external)

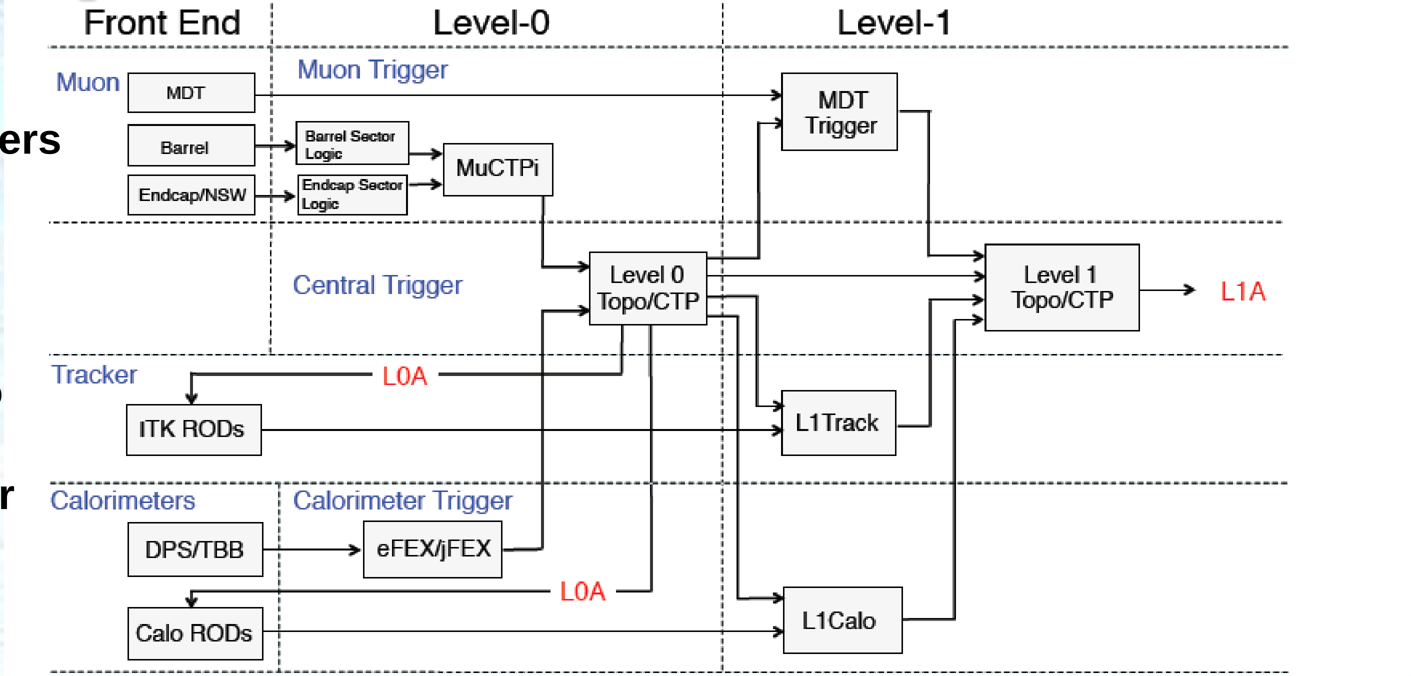
Phase-II Split TDAQ L1 Scheme

Simulation studies show that including a track trigger complements muon and EM triggers

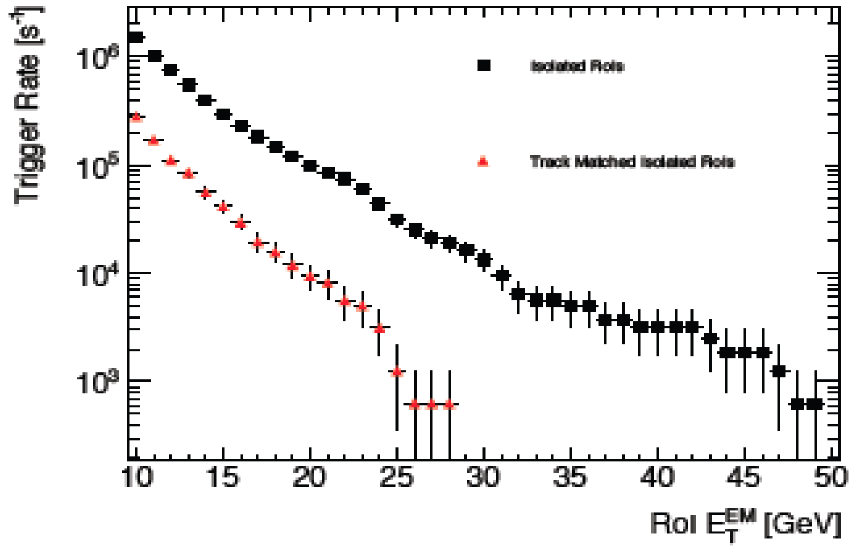
- ➢ **Improves muon P_T resolution**
- ➢ **Improves EM identification by matching to track**

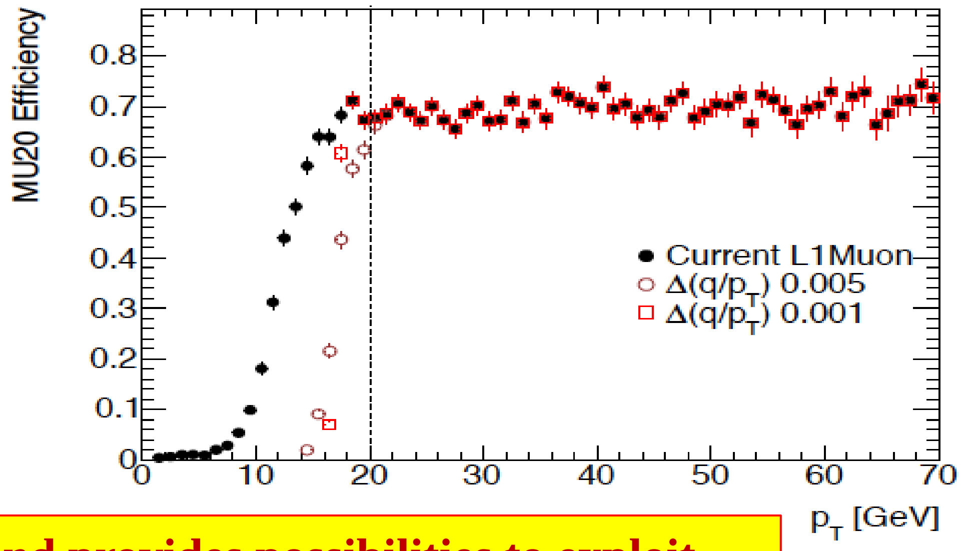
Implemented as 2-level scheme to accommodate legacy electronics and reduce links from strip tracker → reuses Phase-I L1 trigger improvements for new L0

LOA scheme and buffering fully integrated in ABCn130 ASIC



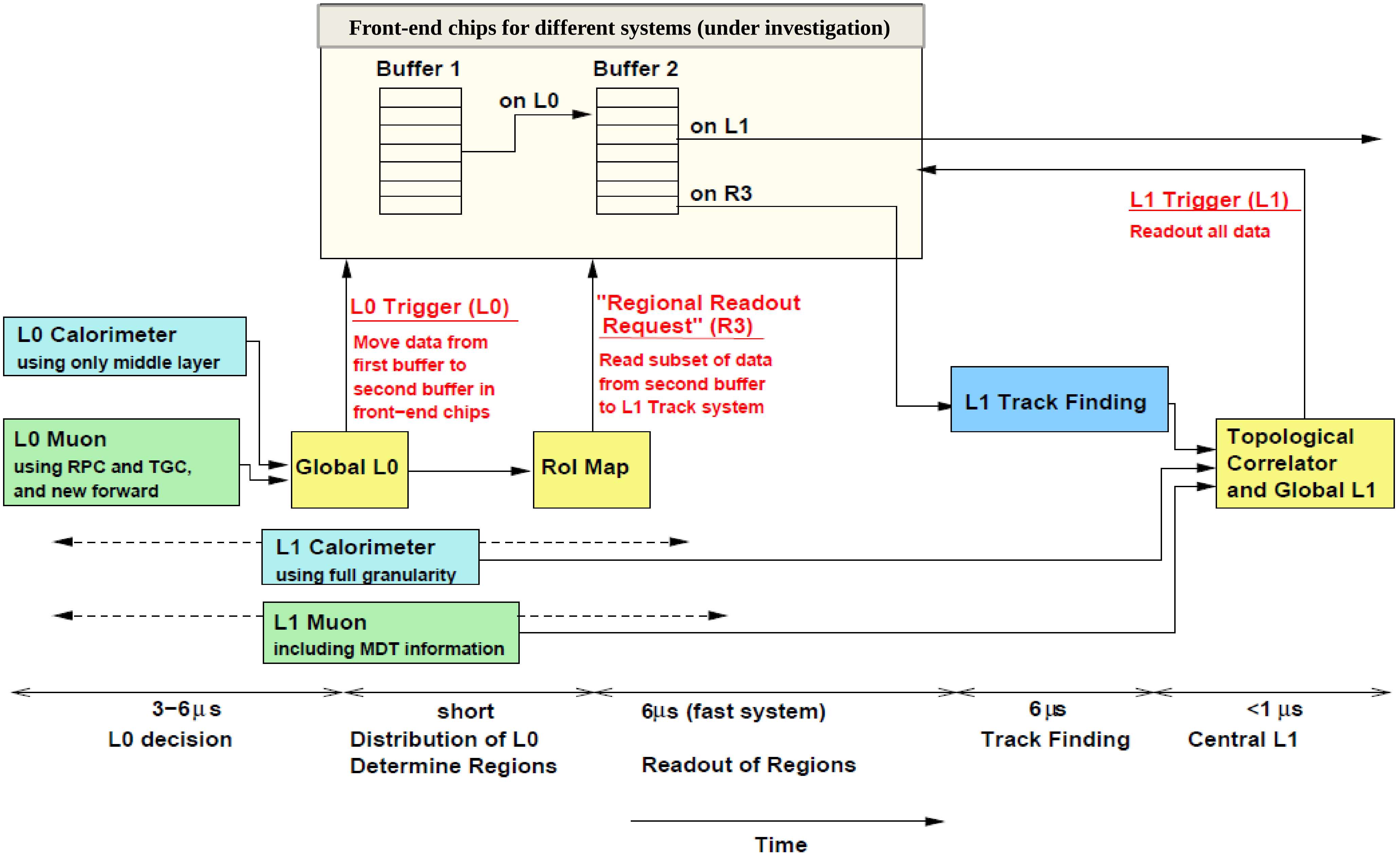
FTK technology could be used to perform fast track fit in L0 defined Region of Interest (RoI)





Note this scheme impacts the electronics in all systems and provides possibilities to exploit the L0/L1 structure to have more extensive information from all sub-detectors at L1

Phase-II Split TDAQ L1 Scheme



Front-end chips for different systems (under investigation)

Buffer 1

on L0

Buffer 2

on L1

on R3

L1 Trigger (L1)

Readout all data

L0 Trigger (L0)

Move data from first buffer to second buffer in front–end chips

"Regional Readout Request" (R3)

Read subset of data from second buffer to L1 Track system

L0 Calorimeter
using only middle layer

L0 Muon
using RPC and TGC, and new forward

Global L0

RoI Map

L1 Track Finding

Topological Correlator and Global L1

L1 Calorimeter
using full granularity

L1 Muon
including MDT information

3–6 μs
L0 decision

short
Distribution of L0
Determine Regions

6 μs (fast system)
Readout of Regions

6 μs
Track Finding

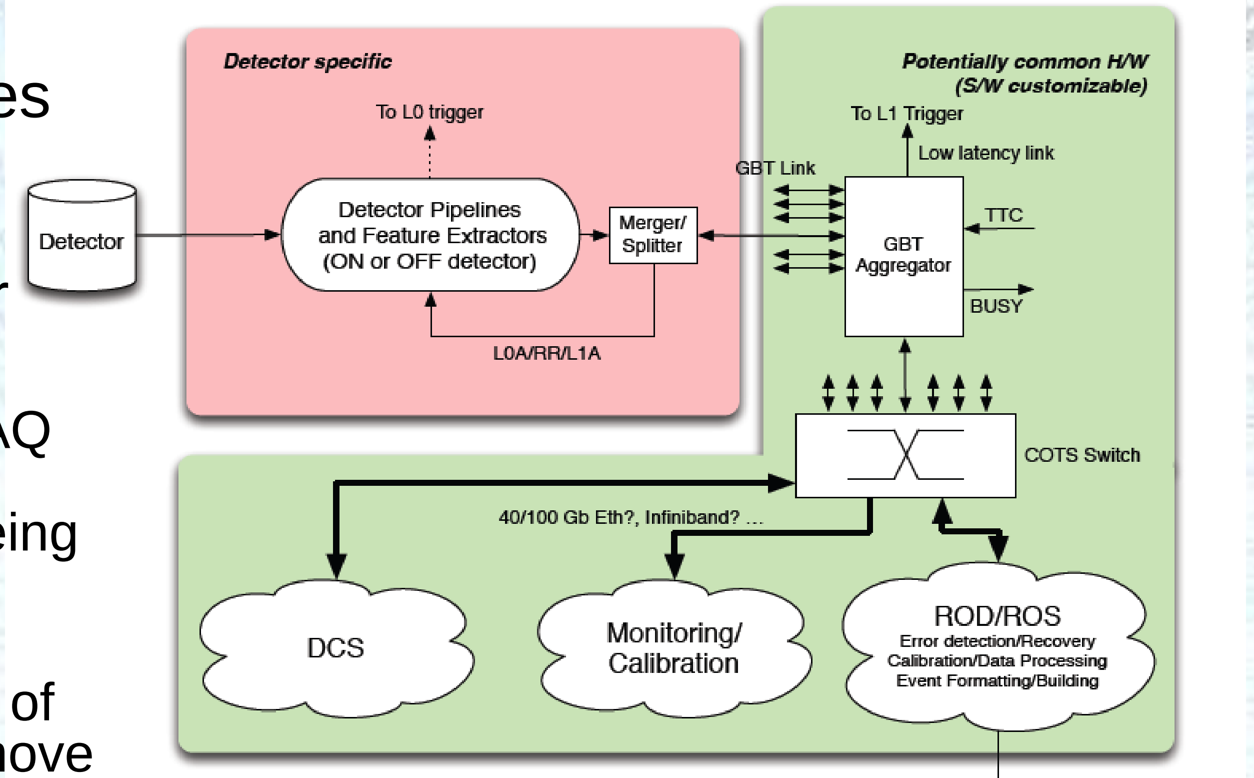
<1 μs
Central L1

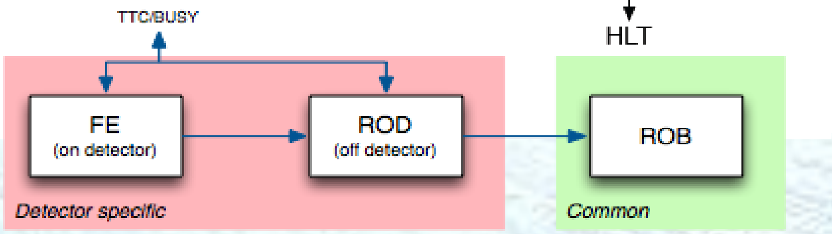
Time

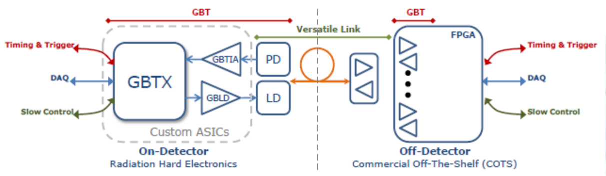
Note latencies, rates and use of R3 read-out are evolving in the light of improved understanding of possible trigger menus for Phase-II and exploration of higher speed data transfer

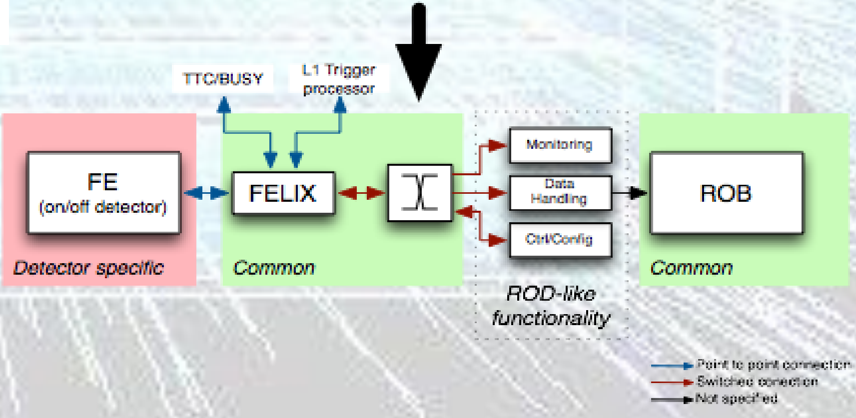
TDAQ and Detector Readout

- New TDAQ architecture requires upgrade to readout of detector systems
- General comments on need for upgrades of detector readout:
  - In addition to the changes in TDAQ architecture. Upgraded readout electronics is required due to ageing and radiation damage.
  - More functionality moved to the counting room, taking advantage of large bandwidth optical links to move data off-detector; allows use of FPGAs rather than dedicated ASICs
  - Custom low power (lpGBTx) 4.8Gbps rad-hard ASIC can be reasonably assumed available in low mass custom package (or 9.6 Gbps with similar power as current GBTx)
  - Detectors are evaluating a common readout architecture based on GBTs and common Front-End interface

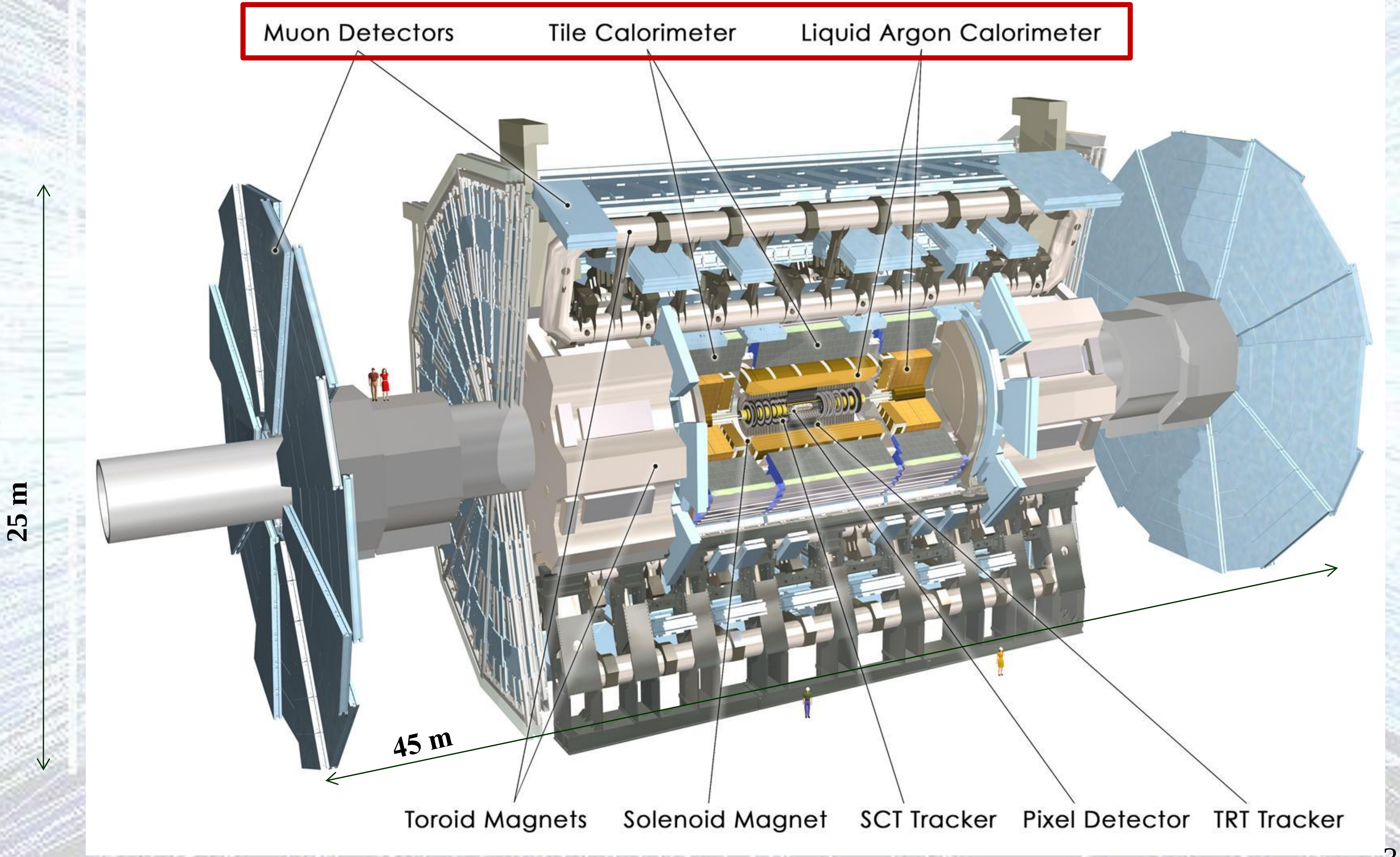








The ATLAS Experiment

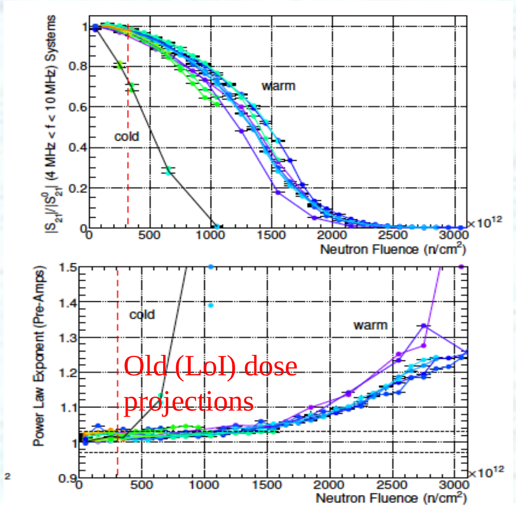


Phase-II Upgrades to LAr Electronics

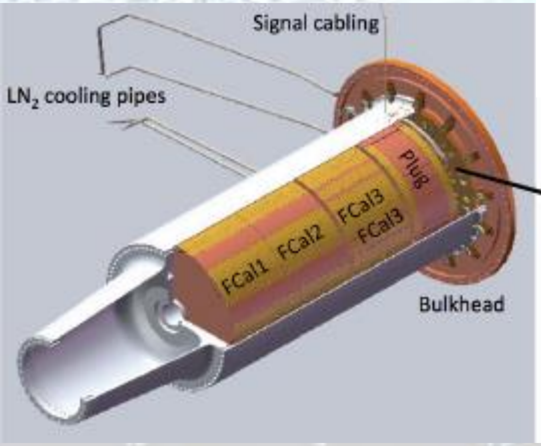
- Replace all FE boards (warm)
  - Gives flexible, free-running architecture sending data off-detector for all bunch-crossings
  - Natural evolution of Phase-I new digital trigger boards
  - Replacement required due to aging and radiation limits
  - Allows implementation of L0/L1 scheme using Phase-I L1 upgrades for Phase-II L0

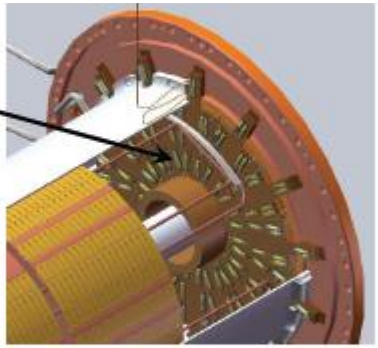
- Replace Hadronic Endcap Calorimeter electronics **if required**
  - Replace HEC cold (GaAs) preamps if significant degradation in performance expected during HL-LHC operation but this requires FCAL removal so new sFCAL would also need to be installed

    (Indications that expected doses are manageable given better dose projections but aging of electronics still needs to be understood)
- Replace just the Forward Calorimeter (FCal) **if required**
  - Install new sFCAL in cryostat or miniFCAL in front of cryostat if significant degradation in current FCAL expected at HL-LHC

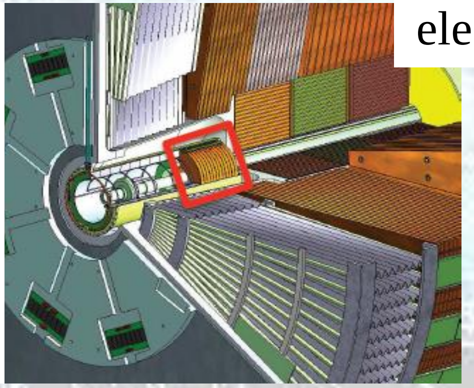


Performance of cold HEC electronics under irradiation





Reduce gap sizes from 269/375/500 µm, new summing boards and cooling loops (to avoid boiling)

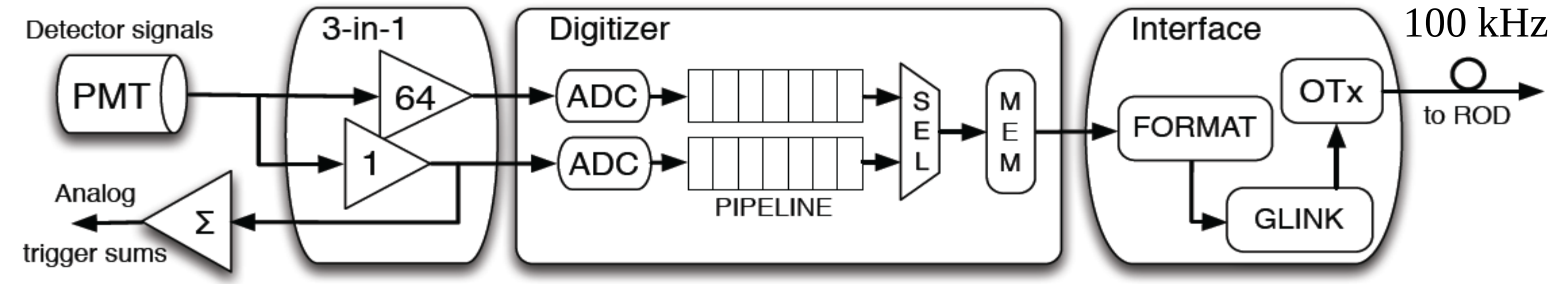


miniFCAL absorbs energy upstream of current FCAL Cold Cu/LAr device [100µm LAr gaps]

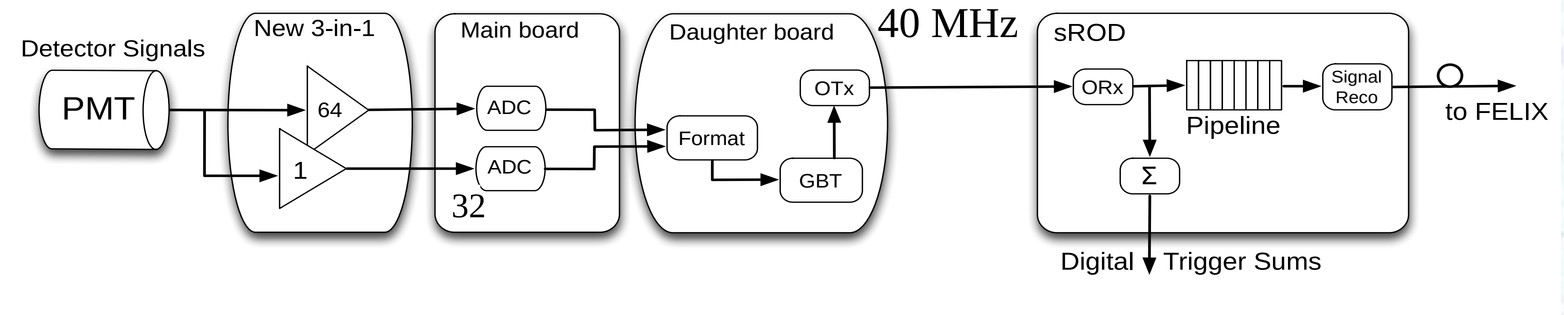
Tile Calorimeter

- No major changes foreseen in the readout or trigger during Phase-I
- In Phase-II complete FE&BE electronics replacement.
  - **Full digitization** of data at 40MHz and transmission to off-detector system
  - **Digital** information to L1/L0 **trigger**

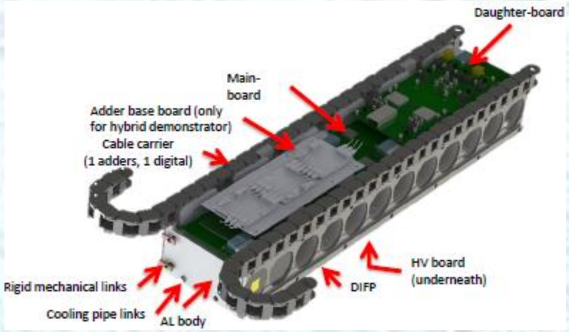
Present



Phase-II Upgrade



Up Link only	Present	Upgrade
Total BW	~ 165 Gbps	~80 Tbps
Nb fibers	256	8192
Fiber BW	640 Mbps	10 Gbps
Nb RODs	32	32?
ROD Crates	4	4
In BW/ROD	5 Gbps	2 Tbps
Out BW/ROD $_{DAQ}$	2,56 Gbps	~ 5 Gbps
Out BW/ROD $_{L1}$	Analog FE	< 80 Gbps



- Also significantly improve robustness
  - **Reduce the complexity** and connections inside the front-end drawers. Moving from dependent drawers to independent **mini-drawers** (readout and power).
  - Use a real-complete **redundant readout** – from cell to back-end
  - **Redundant Power** Supply system introducing Point-of-Load regulators

Muon Electronics Upgrade

Replace existing electronics to accommodate:

- Increased level-1 trigger latency.
- Need for sharpening the trigger threshold using MDT precision chamber hits at level 0/1.

Features of the new RPC electronics:

- Capable of higher level-1 trigger rate and longer latency.
- Time-over-threshold mode to measure charges deposited on the pick-up strips.

→ Centroid of the charge distribution for improved track point resolution.

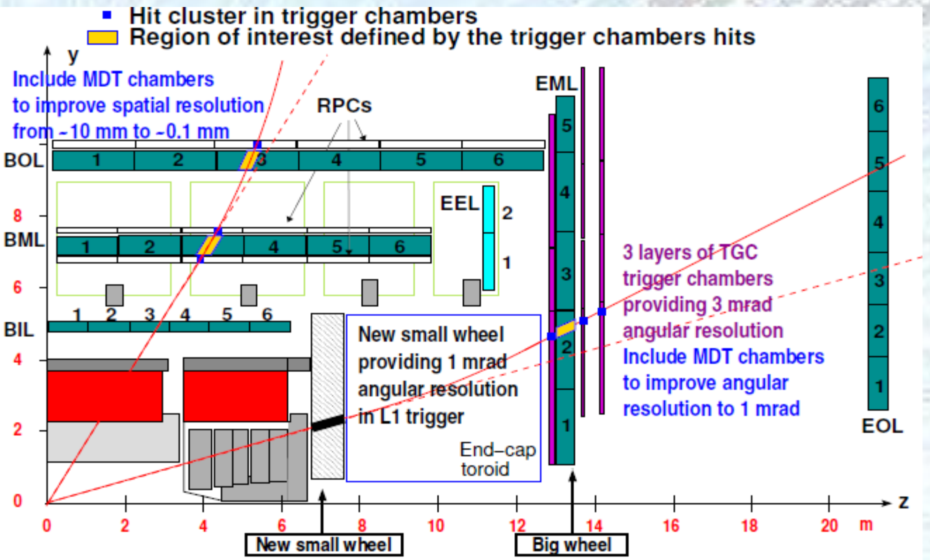
Features of the new TGC electronics:

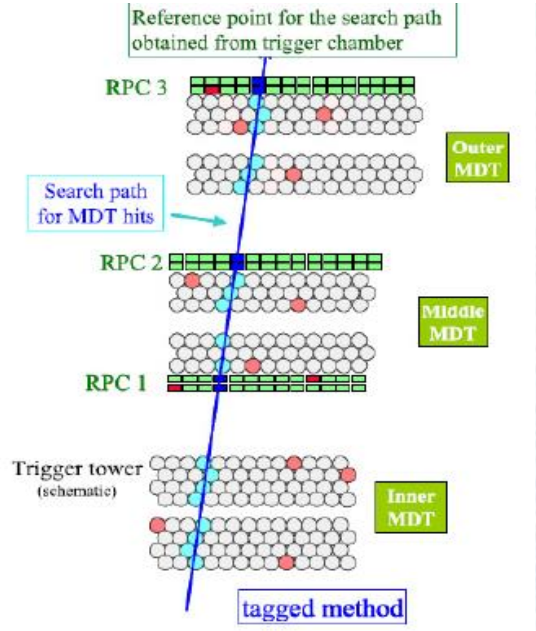
- Existing on-chamber ASD pre-ampliers will be kept.
- New TGC read-out electronics chain compatible with HL-LHC requirements with most of the logic functions moved to radiation free zone (USA15).

→ Use of FPGAs for the first level trigger decision

Features of the new MDT electronics:

- Capable of level-1 trigger rate and longer latency in high background regions.
- Additional fast read-out chain for MDT level-0/1 trigger.





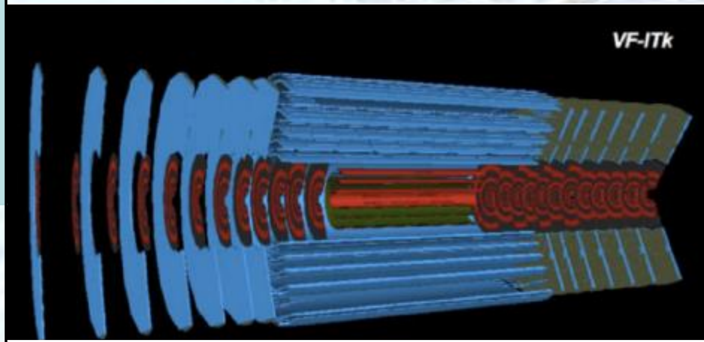
Possible Extensions to Large η

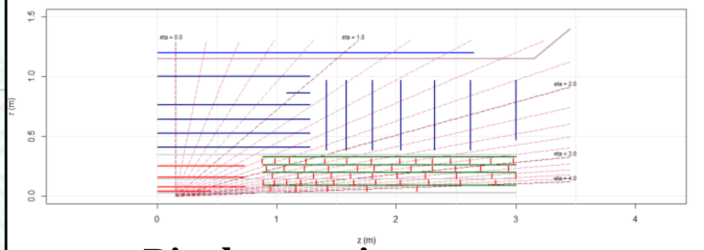
Physics Channels Under Investigation

SM	1) VBS W+W+ for VBF jet reconstruction 2) Tribosons as multi-lepton measurement reference 3) Inclusive W/Z production 4) Exclusive processes (γγ ->WW)
SUSY	1) VBF production for EWKinos & optimisation for VBF reconstruction 2) JP determinations for observations of SUSY states 3) t-channel processes for stop production
Higgs	1) Di-Higgs reconstruction/acceptance in bbgg and bbττ. 2) VBF Di-Higgs production modes 3) H->WW for fwd jet veto & b-jet veto optimization 4) H->4l for optimization of lepton coverage 5) H->WW; H->tτ for optimization of VBF reconstruction 6) Higgs invisible and MET requirements 7) t-channel mode for single-top associated H production
Exotics	1) JP determinations for Z' versus KK graviton 2) Single-VLQ t-channel production
top	Single-top modes like t-channel production with very forward topology for light jet and b-jet reconstruction

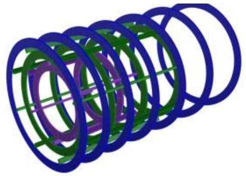
Studies of physics motivations and requirements are proceeding in parallel with studies of possible technical options

- **Extend tracking to η>4?**





Pixel extension in "ring design"



- **Segmented timing detectors at MBTS location?**
- **New FCAL with improved timing and granularity?**
- **Pixelated muon tagger behind ECAL η = 2.7 – 4.5?**
- **Muon spectrometer with magnetized forward shielding?**

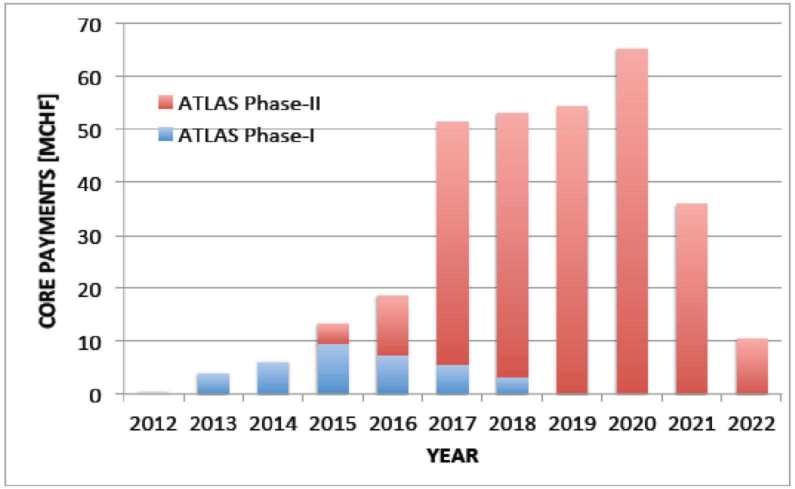
LoI Core Costs

Cost Time Profile

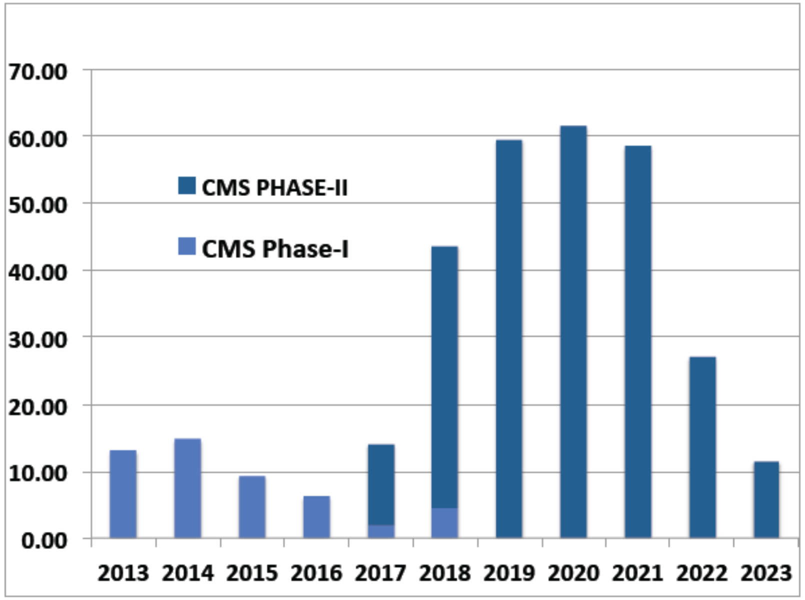
CORE costing

Phase-1 uses
TDR costings

Phase-2 uses
LoI costings,
and includes
options



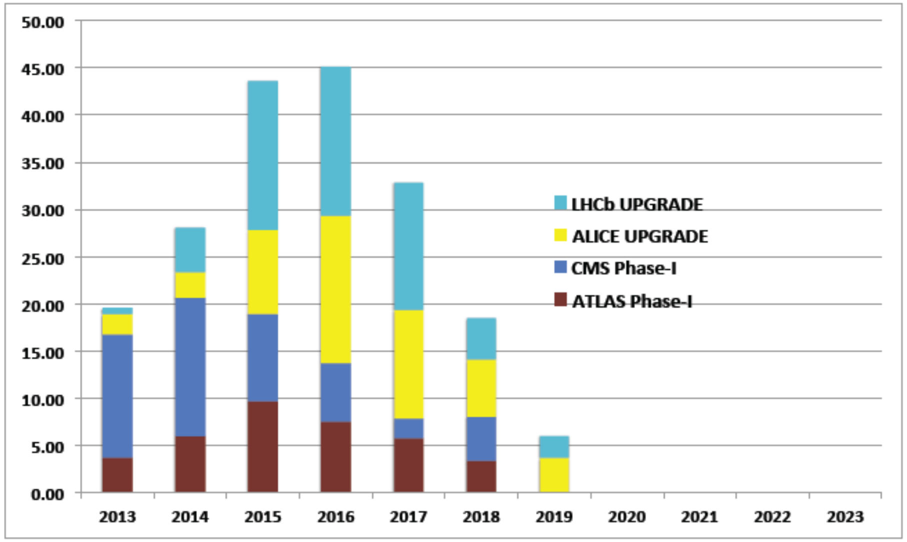
Tracker total: 132 MCHF out of 231M CHF
(plus 45 MCHF of total possible additional costs)



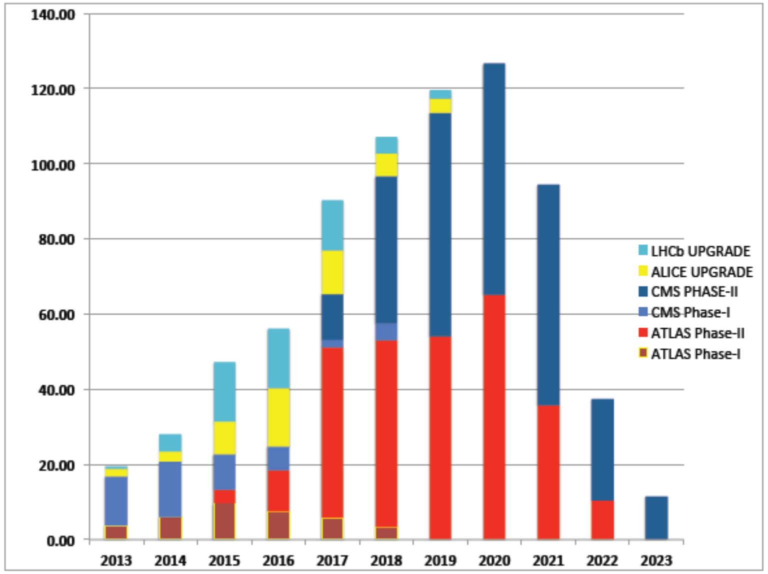
Phase-I LoI Costs see:
https://edms.cern.ch/document/1164764

Phase-II LoI Costs see:
https://edms.cern.ch/document/1258343

Summary: from now to LS2 (Phase-I)



All Upgrades



New LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)

LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

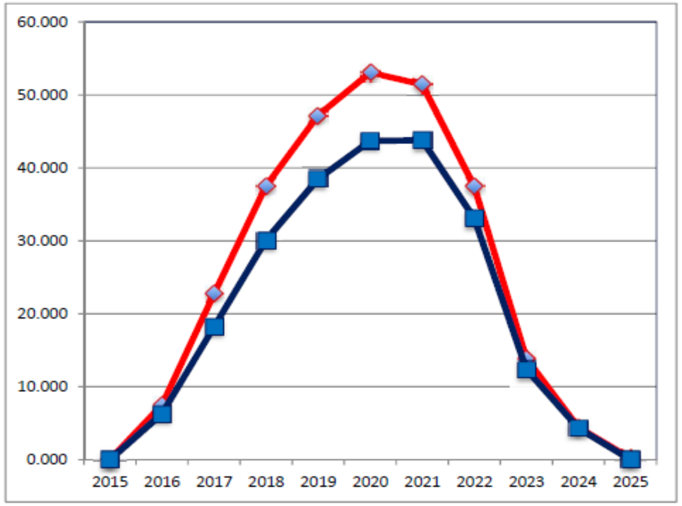
injectors: in 2024 => 13 months + 3 BC

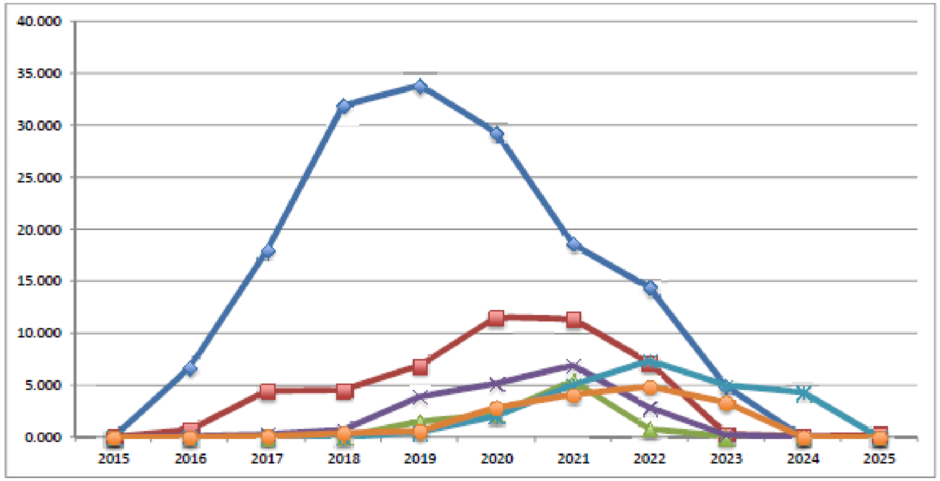
LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Re-profiled Phase-II Core Costs

New ATLAS PHASE II upgrade (LS3) with Options Included

		it will happen [MCHF]	it might happen [MCHF]	2015 [MCHF]	2016 [MCHF]	2017 [MCHF]	2018 [MCHF]	2019 [MCHF]	2020 [MCHF]	2021 [MCHF]	2022 [MCHF]	2023 [MCHF]	2024 [MCHF]	2025 [MCHF]	total [MCHF]
1	New Inner Detector	*131.500*	*26.000*	0.000	6.707	17.906	31.919	33.836	29.284	18.565	14.373	4.911	0.000	0.000	157.500
2	LAr upgrades	*32.124*	*15.096*	0.000	0.700	4.458	4.519	6.895	11.554	11.371	7.162	0.289	0.091	0.182	47.220
3	Tiles upgrades	*7.483*	*2.517*	0.000	0.000	0.000	0.000	1.499	2.177	5.439	0.804	0.080	0.000	0.000	10.000
4	Muon spectrometer upgrades	*19.632*	*0.500*	0.000	0.103	0.282	0.692	3.888	5.169	6.922	2.871	0.205	0.000	0.000	20.132
5	TDAQ upgrades	*23.315*	*0.900*	0.000	0.000	0.000	0.000	0.500	2.020	5.020	7.355	5.000	4.320	0.000	24.215
6	Infrastructure items	*16.280*	*0.000*	0.000	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	0.000	0.000	16.280
	TOTAL	*230.334*	*45.013*	*0.000*	*7.510*	*22.746*	*37.530*	*47.218*	*53.054*	*51.416*	*37.445*	*13.835*	*4.411*	*0.182*	*275.347*





Re-profiled Phase-II Core Costs

New ATLAS PHASE II upgrade (LS3) with Options Included

		it will happen [MCHF]	it might happen [MCHF]	2015 [MCHF]	2016 [MCHF]	2017 [MCHF]	2018 [MCHF]	2019 [MCHF]	2020 [MCHF]	2021 [MCHF]	2022 [MCHF]	2023 [MCHF]	2024 [MCHF]	2025 [MCHF]	total [MCHF]
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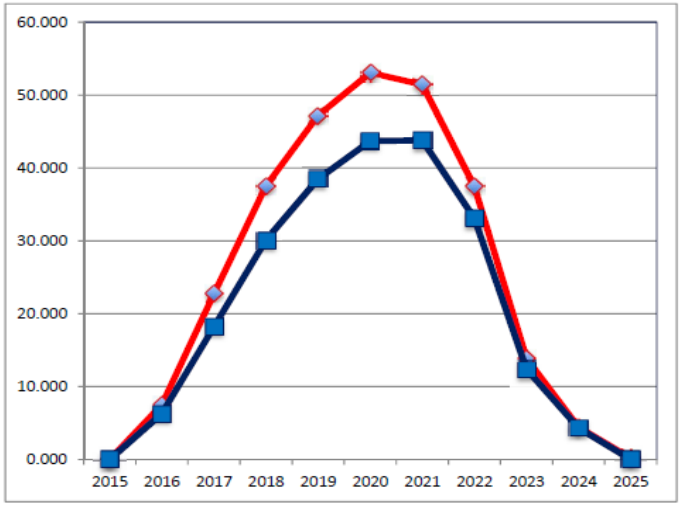


New Phase-II Profile

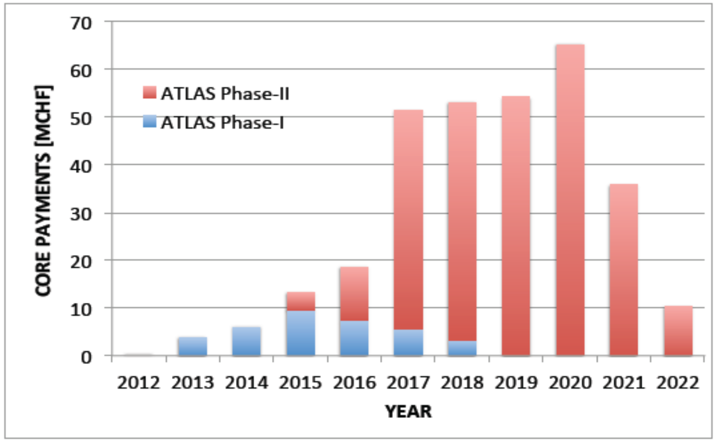
LoI Core Costs

Cost Time Profile

CORE costing

Phase-1 uses TDR costings

Phase-2 uses LoI costings, and includes options



Old LoI Based Profile for Comparison

ECFA High Luminosity LHC Experiments Workshop

Physics and technology challenges

1st – 3rd October

Aix-les-Bains

France

https://indico.cern.ch/conferenceDisplay.py?confId=252045

Programme Committee

P. Allport
A. Ball
S. Bertolucci
P. Campana
D. Charlton
D. Contardo
B. Di Girolamo
P. Giubellino
J. Incandela
P. Jenni
M. Krammer
M. Mangano
S. Myers
B. Schmidt
T. Virdee
H. Wessels

Local Organising Committee

P. Allport, D. Contardo, D. Hudson, C. Potter

Picture Credit: OT Aix-les-Bains / Gilles Lansard

2nd ECFA HIGH LUMINOSITY LHC Experiments Workshop

Physics and technology developments

21st - 23rd OCTOBER 2014

Aix-les-Bains | France

Programme Committee:

P. Allport | A. Ball | S. Bertolucci | F. Bordry | T. Camporesi | D. Charlton | D. Contardo | B. Di Girolamo
P. Giubellino | M. Krammer | M. Mangano | L. Rossi | B. Schmidt | T. Virdee | J.P. Wessels | G. Wilkinson

Organising Committee:

P. Allport | D. Contardo | D. Hudson | C. Potter

Registration and further information at https://indico.cern.ch/event/315626/
or
dawn.hudson@cern.ch and connie.potter@cern.ch

Conclusions

- ATLAS has a coherent plan for upgrades through the coming decade to meet the challenges up to and including the HL-LHC era, which are embodied in the two LoIs and four TDRs which have been through full LHCC approval
- The understanding of the full physics potential of the HL-LHC is advancing rapidly, with greatly increased activity on both detector and accelerator preparations following the adoption by CERN Council of the Updated European Strategy for Particle Physics, with the HL-LHC as its highest priority, and the strong endorsement in the recent P5 report
- There are designs for a replacement tracker that should withstand both the pile-up and radiation conditions at the HL-LHC, with performance able to not just fully recover, but also improve on, the current capabilities at low pile-up.
- Major R&D programmes are targeting all the upgrades needed for ATLAS to operate at luminosities far above the initial design requirements.

However, it is critical for these programmes to proceed rapidly that there be adequate resources now to develop optimized, fully cost-effective solutions.

Back-up

HL-LHC Planning

- The stated target of the European strategy set the overall framework *"Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma."* (Adopted by CERN Council May 2013, see http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf).
- All 4 experiments, the accelerator and the theory community were represented at the October 2013 ECFA HL-LHC Experiments Workshop at Aix-les-Bains http://indico.cern.ch/conferenceDisplay.py?confId=252045
- The report from this to ECFA can be found at https://cds.cern.ch/record/1631032 which focusses on the detector requirements and physics reach with 3000fb^{-1}
- There were also presentations on accelerator upgrade preparations but these have been to some extent superseded by more recent workshops:
  - "The Review of LHC and Injector Upgrade Plans Workshop" from 29th to 31st October at Archamps, France (**RLUIP**: https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492)
  - "The 3rd **Joint HiLumi LHC_LARP** Annual Workshop" from 11th to 15th November at Daresbury (STFC) Laboratory, UK (https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=257368)
- The next in the ECFA HL-LHC workshop is planned for 21st-23rd October 2014

CERN-Council-S/106
Original: English
7 May 2013

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For Approval	**EUROPEAN STRATEGY SESSION OF COUNCIL** 16th Session - 30 May 2013 **European Commission** **Berlaymont Building - Brussels**	Simple Majority of Member States represented and voting

The European Strategy for Particle Physics
Update 2013

Having finalised its text by consensus at its Session of 22 March 2013, the Council is now invited to formally adopt the Update of the European Strategy for Particle Physics set out in this document.

Snowmass 2013

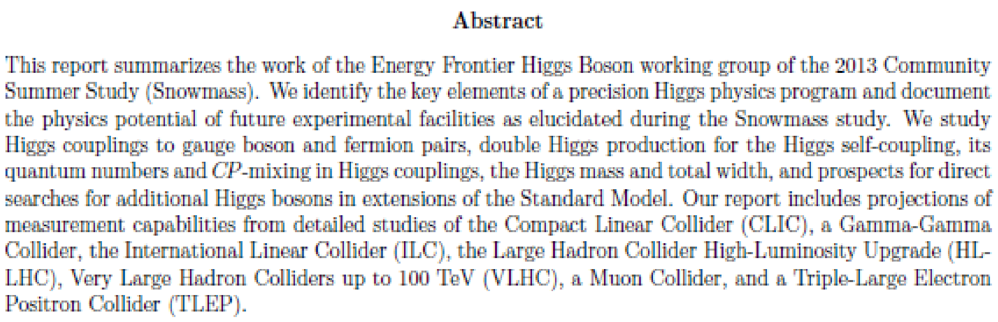
1

Higgs working group report

Conveners: Sally Dawson (BNL), Andrei Gritsan (Johns Hopkins), Heather Logan (Carleton), Jianming Qian (Michigan), Chris Tully (Princeton), Rick Van Kooten (Indiana)

Authors: A. Ajaib, A. Anastassov, I. Anderson, O. Bake, V. Barger, T. Barklow, B. Batell, M. Battaglia, S. Berge, A. Blondel, S. Bolognesi, J. Brau, E.Brownson, M. Cahill-Rowley, C. Calancha-Paredes, C.-Y. Chen, W. Chou, R. Clare, D. Cline, N. Craig, K. Cranmer, M. de Gruttola, A. Elagin, R. Essig, L. Everett, E. Feng, K. Fujii, J. Gainer, Y. Gao, I. Gogoladze, S. Gori, R. Goncalo, N. Graf, C. Grojean, S. Guindon, T. Han, G. Hanson, R. Harnik, B. Heinemann, S. Heinemeyer, U. Heintz, J. Hewett, Y. Ilchenko, A. Ismail, V. Jain, P. Janot, S. Kawada, R. Kehoe, M. Klute, A. Kotwal, K. Krueger, G. Kukartsev, K. Kumar, J. Kunkle, I. Lewis, Y. Li, L. Linssen, E. Lipeles, R. Lipton, T. Liss, J. List, T. Liu, Z. Liu, I. Low, T. Ma, P. Mackenzie, B. Mellado, K. Melnikov, G. Moortgat-Pick, G. Mourou, M. Narain, J. Nielsen, N. Okada, H. Okawa, J. Olsen, P. Onyisi, N. Parashar, M. Peskin, F. Petriello, T. Plehn, C. Pollard, C. Potter, K. Prokofiev, M. Rauch, T. Rizzo, T. Robens, V. Rodriguez, P. Roloff, R. Ruiz, V. Sanz, J. Sayre, Q. Shafi, G. Shaughnessy, M. Sher, F. Simon, N. Solyak, J. Stupak, S. Su, T. Tanabe, T. Tajima, V. Telnov, J. Tian, S. Thomas, M. Thomson, C. Un, M. Velasco, C. Wagner, S. Wang, A. Whitbeck, W. Yao, H. Yokoya, S. Zenz, D. Zerwas, Y. Zhang, Y. Zhou

arxiv.org/pdf/1310.8361v1



Abstract

This report summarizes the work of the Energy Frontier Higgs Boson working group of the 2013 Community Summer Study (Snowmass). We identify the key elements of a precision Higgs physics program and document the physics potential of future experimental facilities as elucidated during the Snowmass study. We study Higgs couplings to gauge boson and fermion pairs, double Higgs production for the Higgs self-coupling, its quantum numbers and *CP*-mixing in Higgs couplings, the Higgs mass and total width, and prospects for direct searches for additional Higgs bosons in extensions of the Standard Model. Our report includes projections of measurement capabilities from detailed studies of the Compact Linear Collider (CLIC), a Gamma-Gamma Collider, the International Linear Collider (ILC), the Large Hadron Collider High-Luminosity Upgrade (HL-LHC), Very Large Hadron Colliders up to 100 TeV (VLHC), a Muon Collider, and a Triple-Large Electron Positron Collider (TLEP).

P5 Report May 2014 at http://science.energy.gov/hep/hepap/reports/ . Section 2.2 is particularly relevant. "Recommendation 10: Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project."

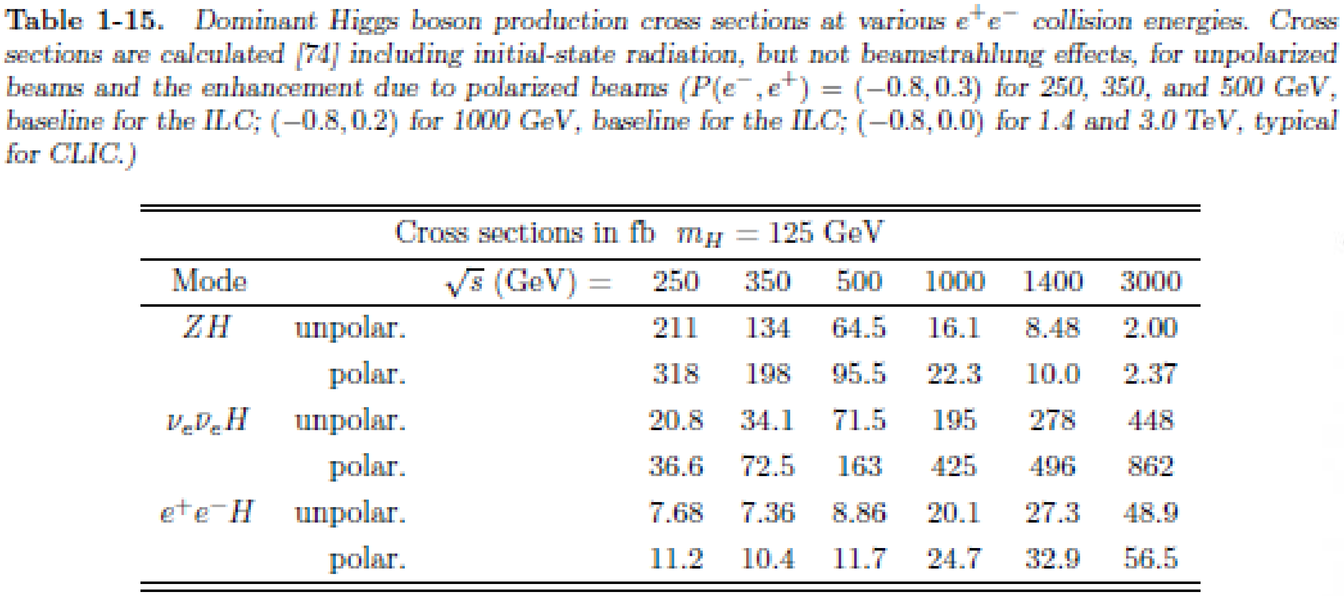
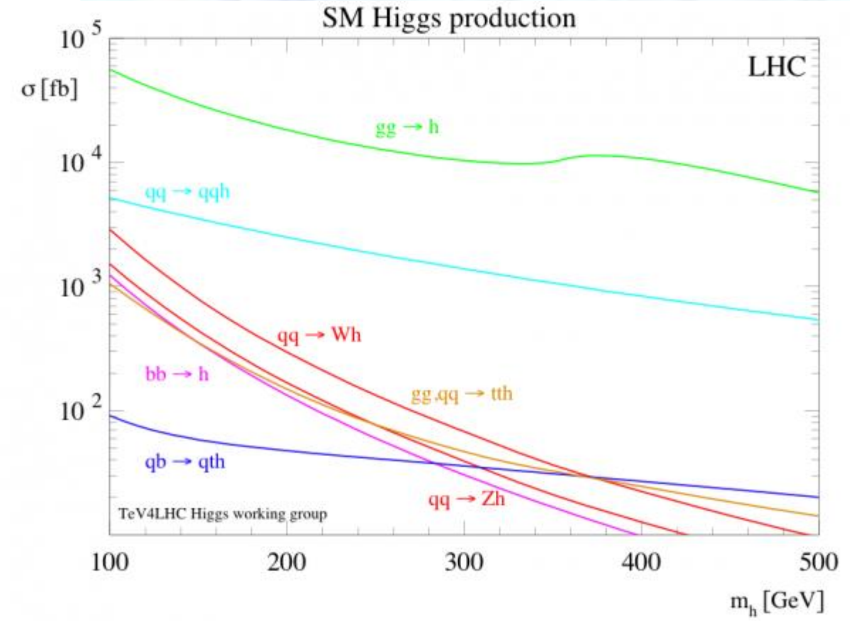


Table 1-15. *Dominant Higgs boson production cross sections at various e^+e^- collision energies. Cross sections are calculated [74] including initial-state radiation, but not beamstrahlung effects, for unpolarized beams and the enhancement due to polarized beams ($P(e^-, e^+) = (-0.8, 0.3)$ for 250, 350, and 500 GeV, baseline for the ILC; $(-0.8, 0.2)$ for 1000 GeV, baseline for the ILC; $(-0.8, 0.0)$ for 1.4 and 3.0 TeV, typical for CLIC.)*

Cross sections in fb $m_H = 125$ GeV							
Mode		$\sqrt{s}$ (GeV) = 250	350	500	1000	1400	3000
ZH	unpolar.	211	134	64.5	16.1	8.48	2.00
	polar.	318	198	95.5	22.3	10.0	2.37
$\nu_e\bar{\nu}_e H$	unpolar.	20.8	34.1	71.5	195	278	448
	polar.	36.6	72.5	163	425	496	862
e^+e^-H	unpolar.	7.68	7.36	8.86	20.1	27.3	48.9
	polar.	11.2	10.4	11.7	24.7	32.9	56.5



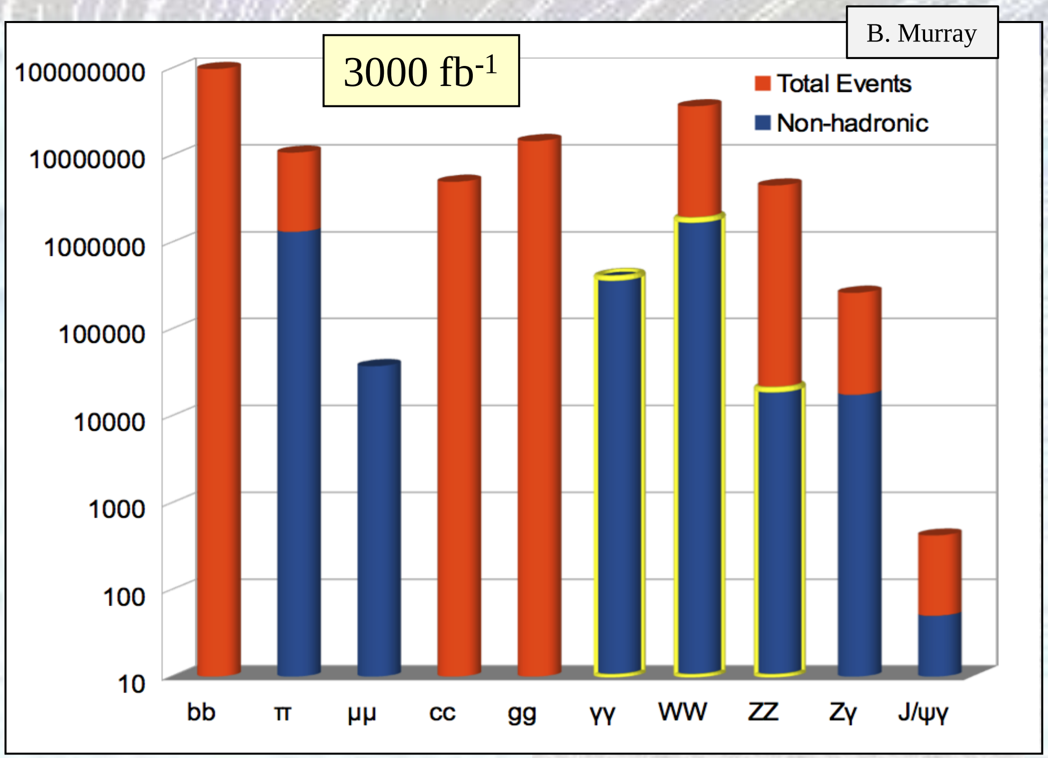
Physics Studies

Aim to measure as many Higgs couplings to fermions and bosons as possible to really test if this is the SM Higgs or a pointer to the BSM physics we know has to exist

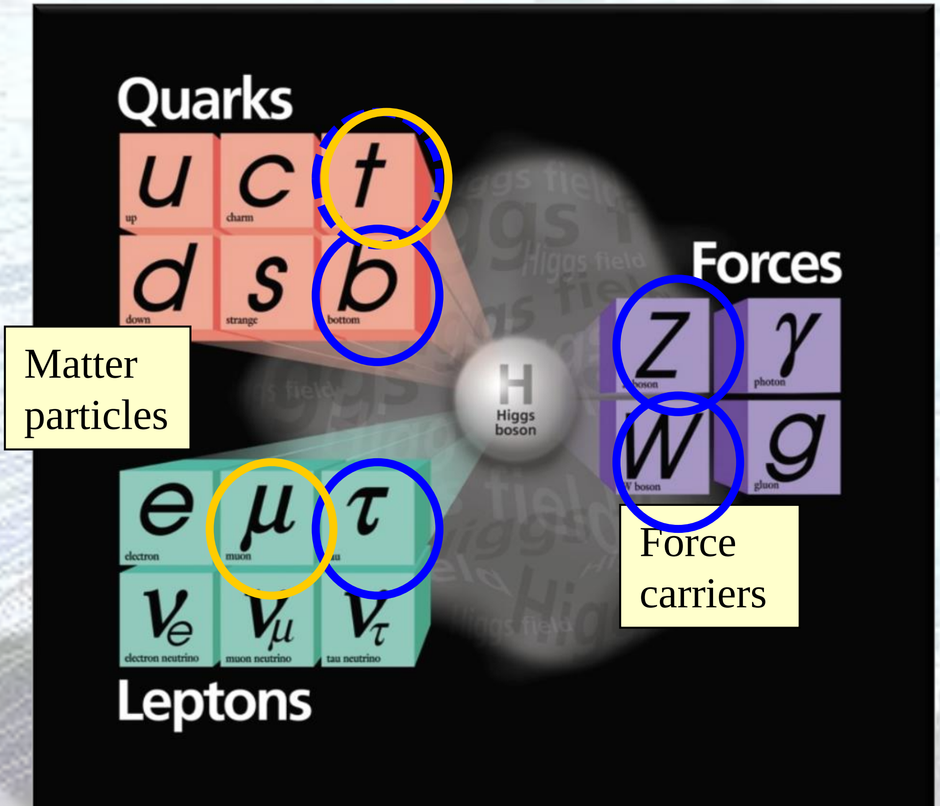
HL-LHC (3000 fb^{-1}): a true Higgs factory:

- ☐ > 170M Higgs events produced
- ☐ > 3M useful for precise measurements (more than or similar to ILC/CLIC/TLEP)

LHC gg→ H (50pb); e^+e^-→ ZH (0.2-0.3pb)

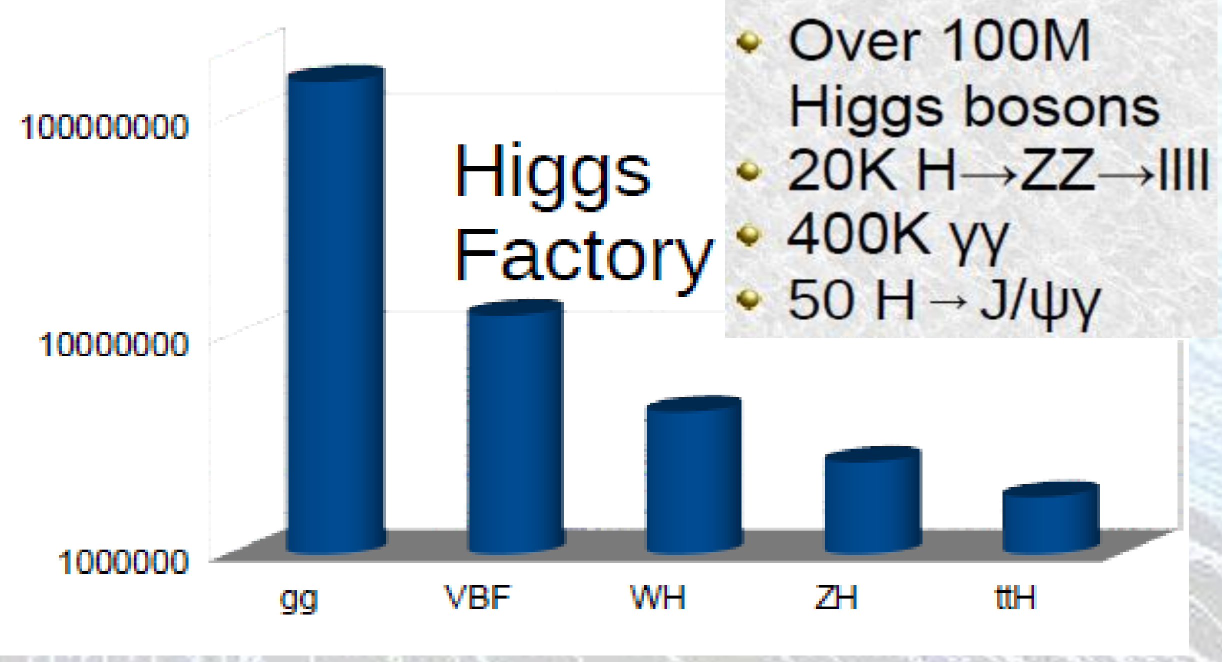

B. Murray

3000 fb^{-1}



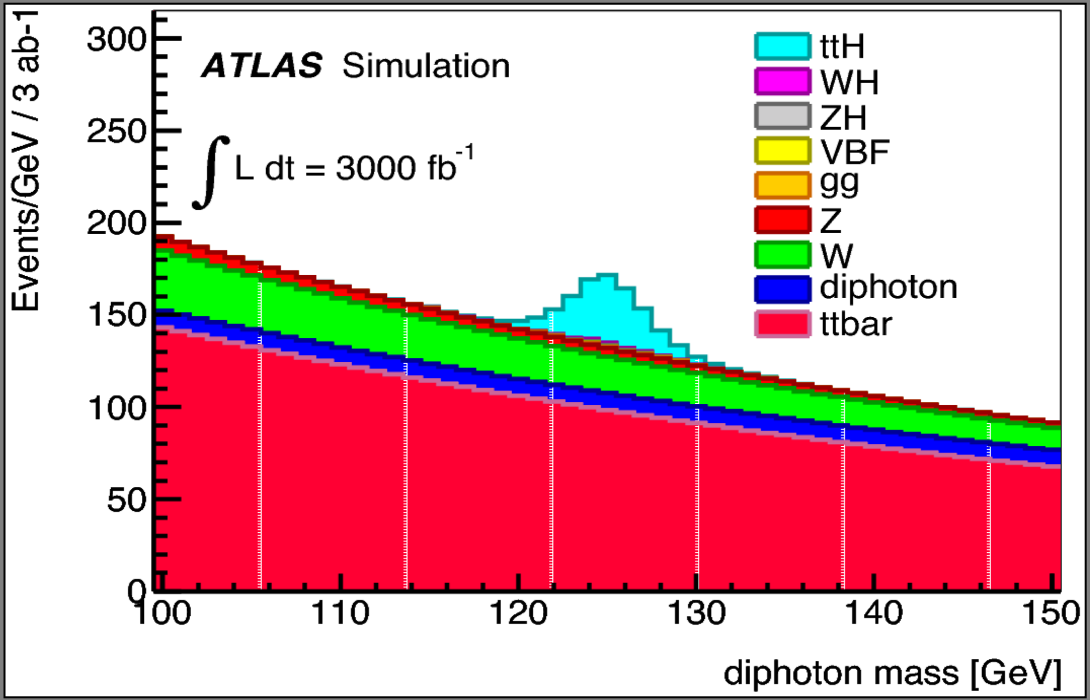
Matter particles

Force carriers

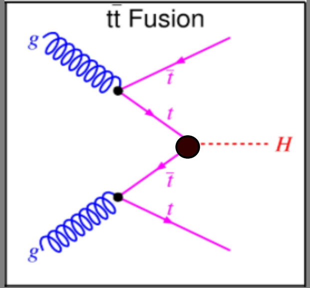


Higgs Factory

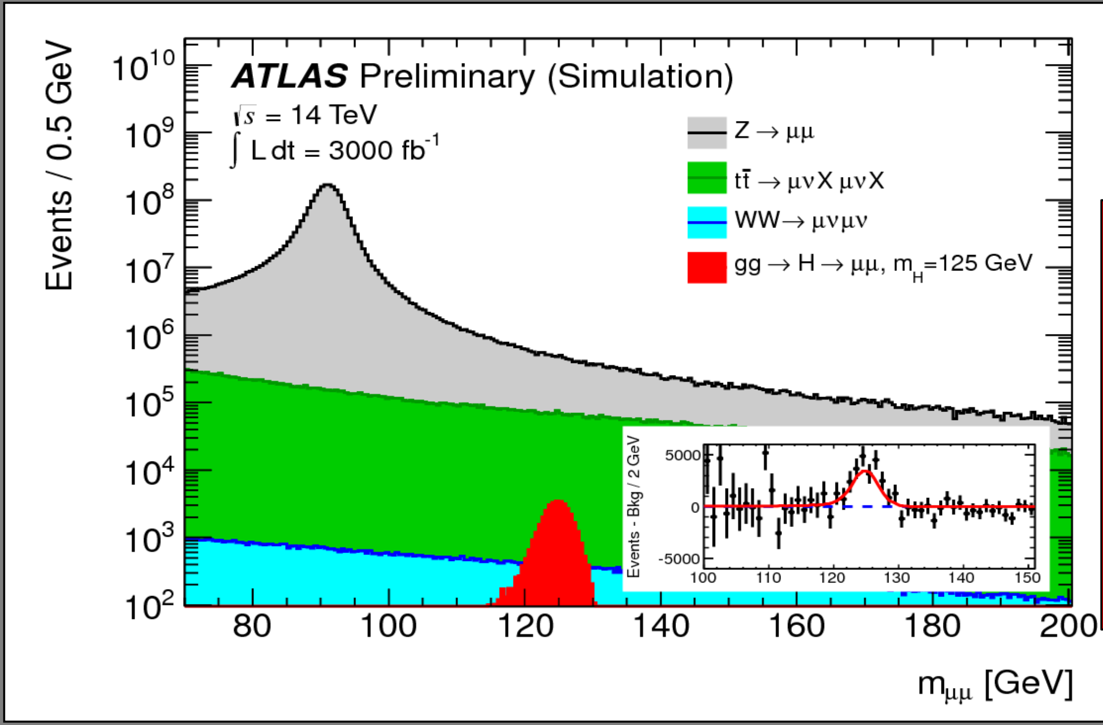
- Over 100M Higgs bosons
- 20K H→ZZ→llll
- 400K γγ
- 50 H→J/ψγ



ttH production with H → γγ

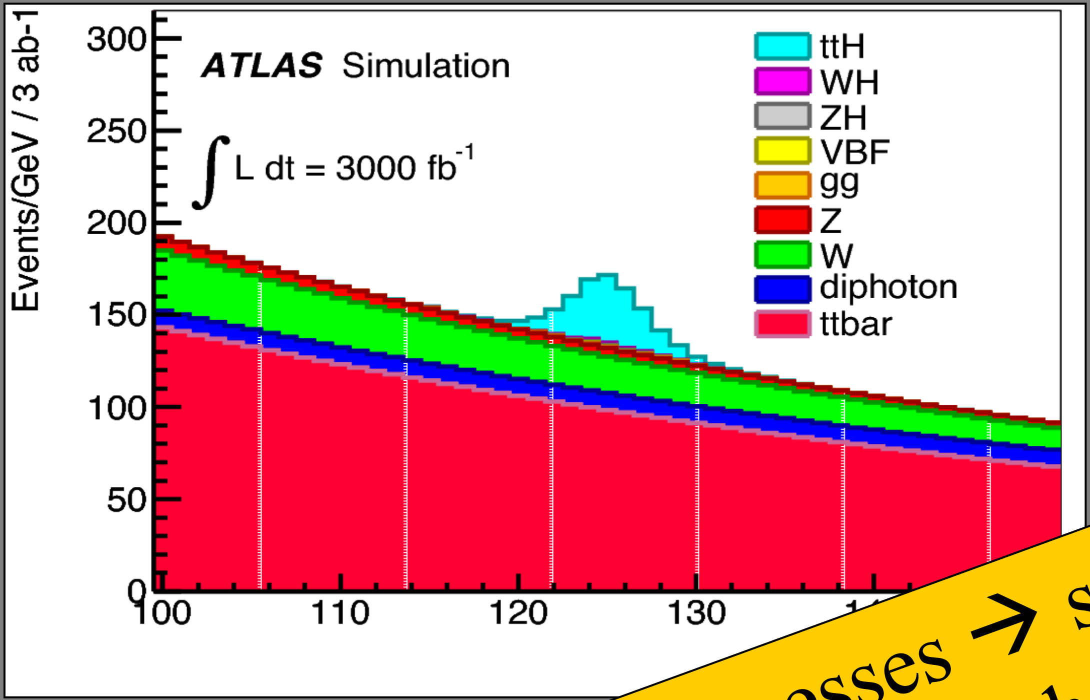


- ☐ Gives direct access to Higgs-top coupling (intriguing as top is heavy)
- ☐ Today's sensitivity: 6xSM cross-section
- ☐ With 3000 fb^{-1} expect 200 signal events (S/B ~ 0.2) and > 5σ
- ☐ Higgs-top coupling can be measured to about 10%

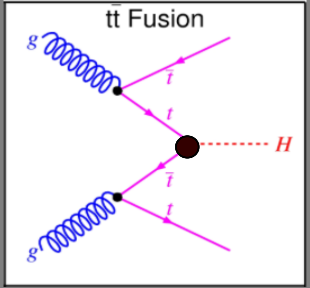


H → μμ

- ☐ Gives direct access to Higgs couplings to fermions of the second generation.
- ☐ Today's sensitivity: 8xSM cross-section
- ☐ With 3000 fb^{-1} expect 17000 signal events (but: S/B ~ 0.3%) and ~ 7σ significance
- ☐ Higgs-muon coupling can be measured to about 10%

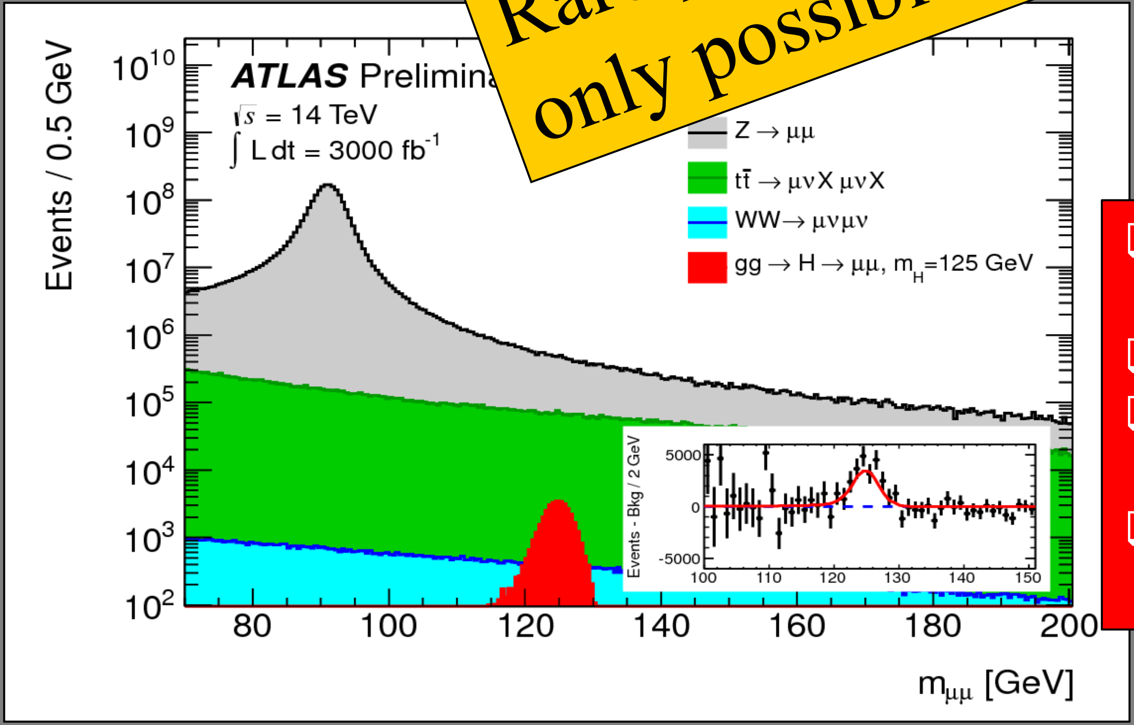


ttH production with H → γγ



- ❑ Gives direct acce… o Higgs-top coupling (i… s top is heavy)
- ❑ T… SM cross-section … 200 signal … and > 5σ
- … p coupling can be … easured to about 10%

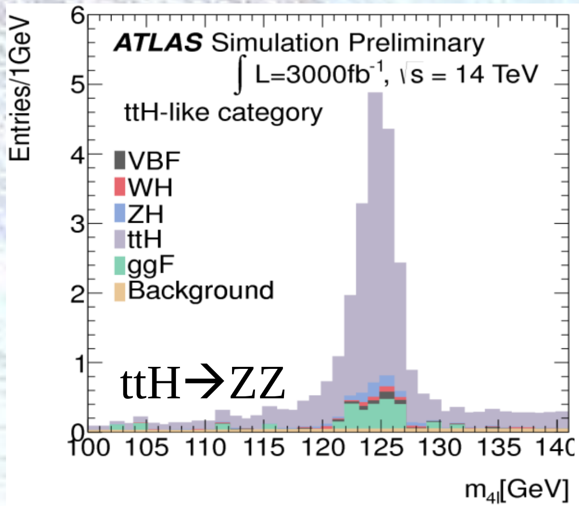
Rare processes → sensitive studies only possible with 3000 fb^{-1}



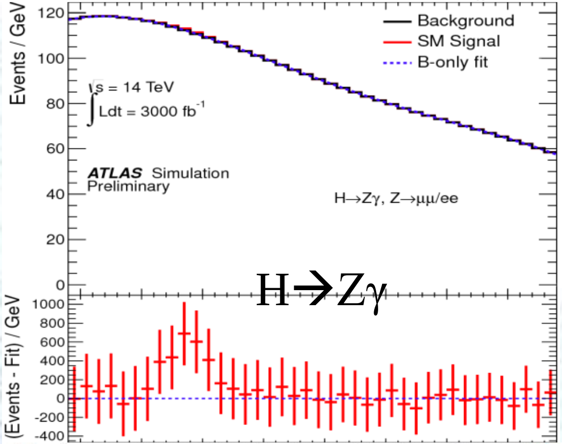
H → μμ

- ❑ Gives direct access to Higgs couplings to fermions of the second generation.
- ❑ Today's sensitivity: 8xSM cross-section
- ❑ With 3000 fb^{-1} expect 17000 signal events (but: S/B ~ 0.3%) and ~ 7σ significance
- ❑ Higgs-muon coupling can be measured to about 10%

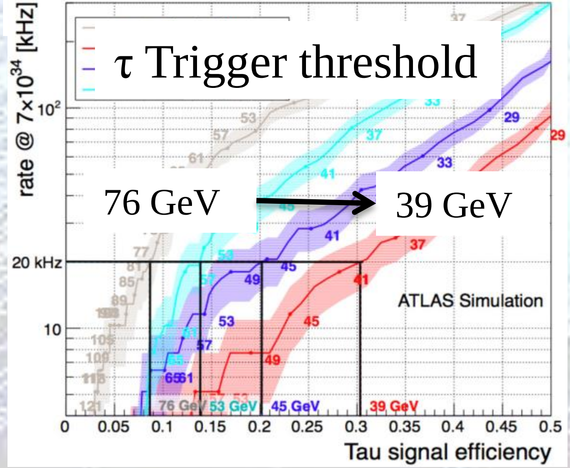
Physics Studies at Aix-les-Bains



ttH→ZZ

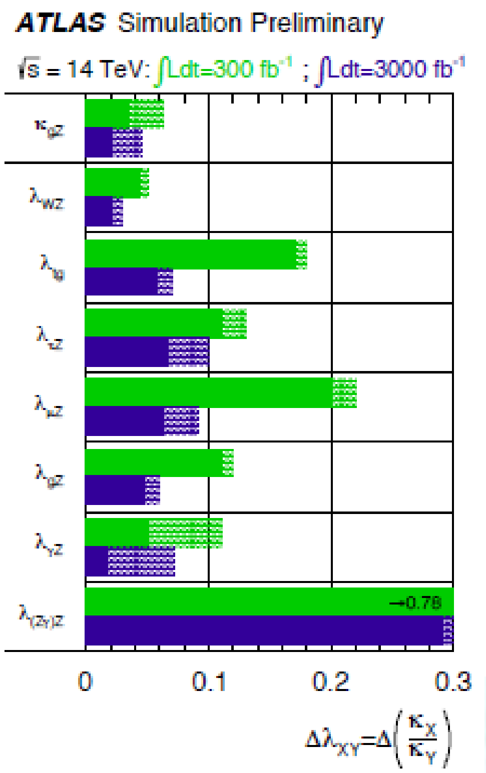


H→Zγ

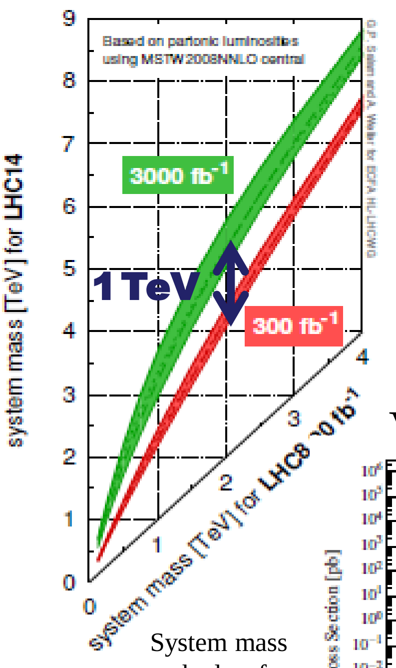


τ Trigger threshold

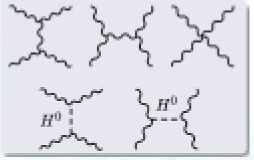
76 GeV → 39 GeV

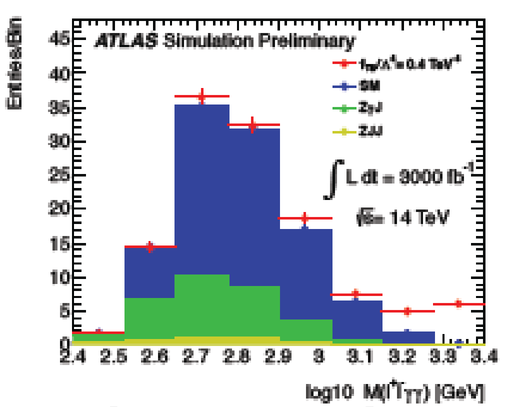


Improvements in coupling ratios with HL-LHC. (Range depends on handling of systematics and theoretical uncertainties)

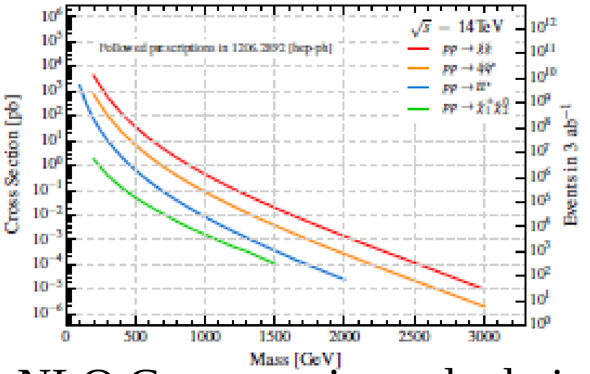


System mass probed so far

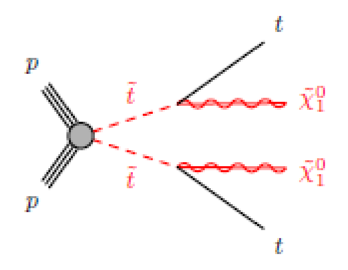


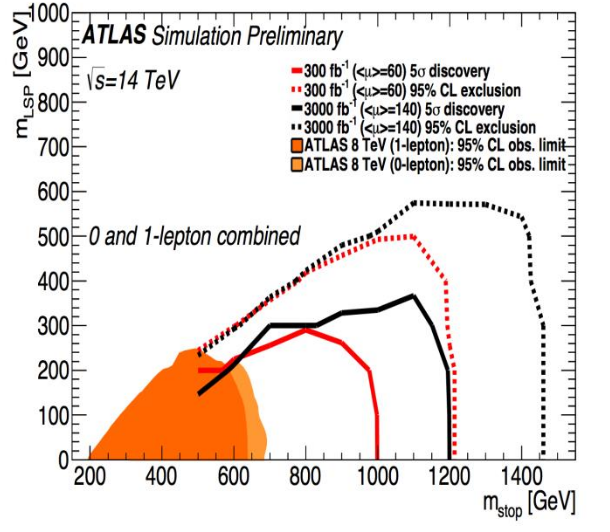


Vector boson anomalous couplings



NLO Cross-section calculations





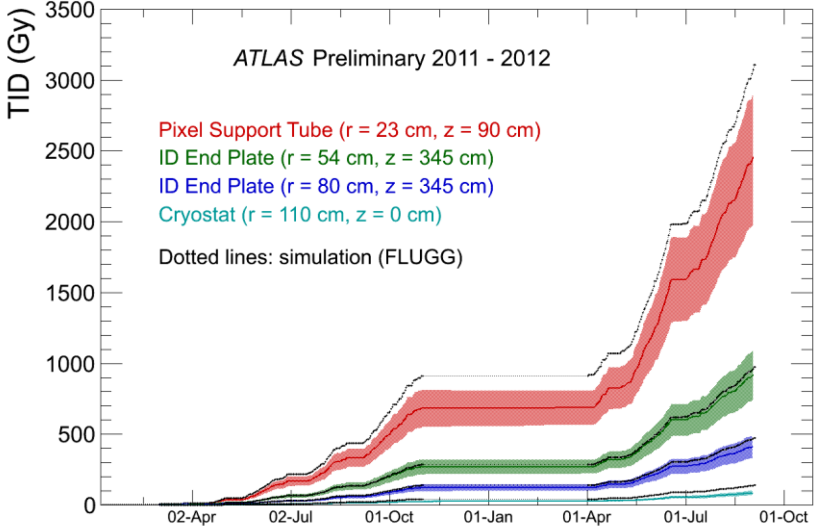
H→ττ trigger threshold improvements with track trigger at L1

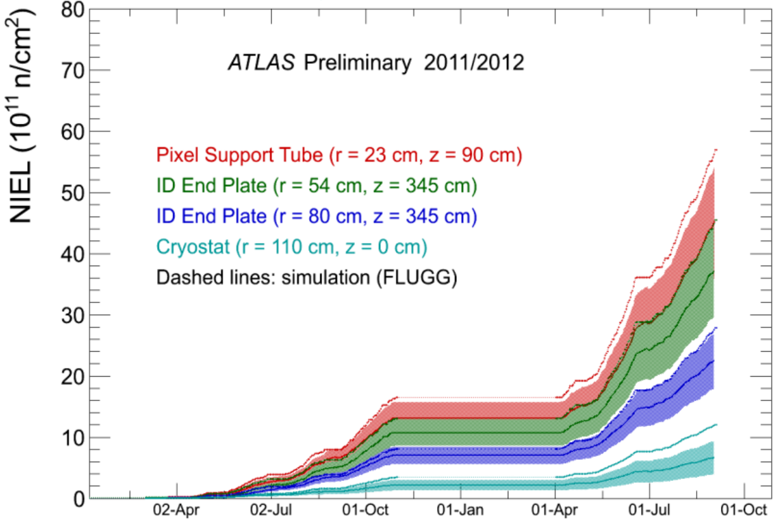
Current Detector Radiation Simulation

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SCTPublicResults#Figures

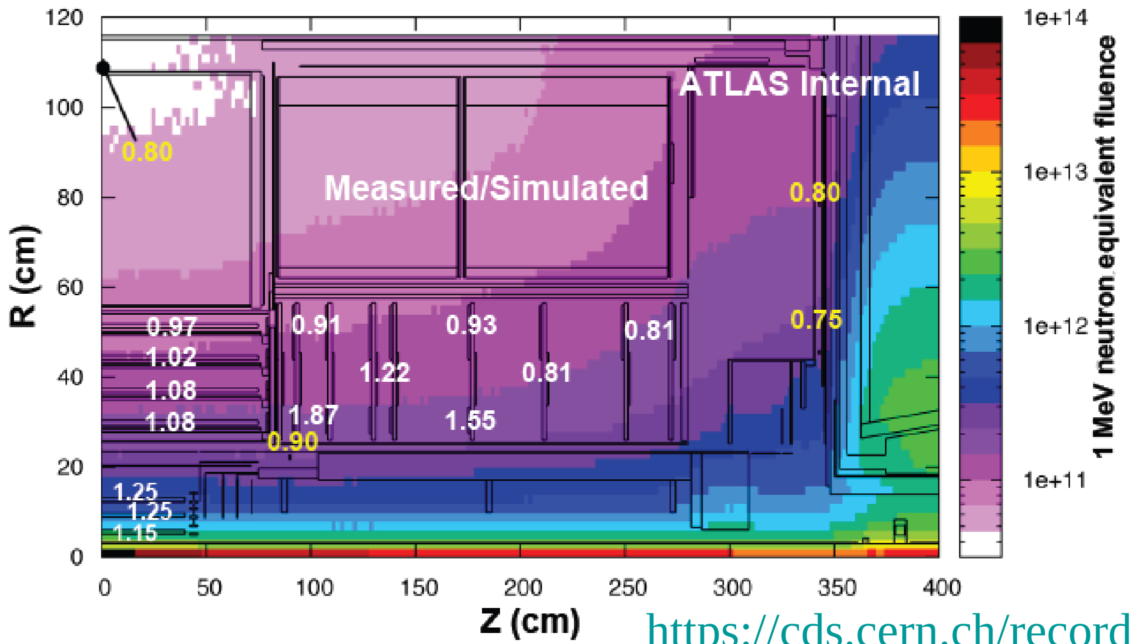
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsPixel#Radiation_damage_plots

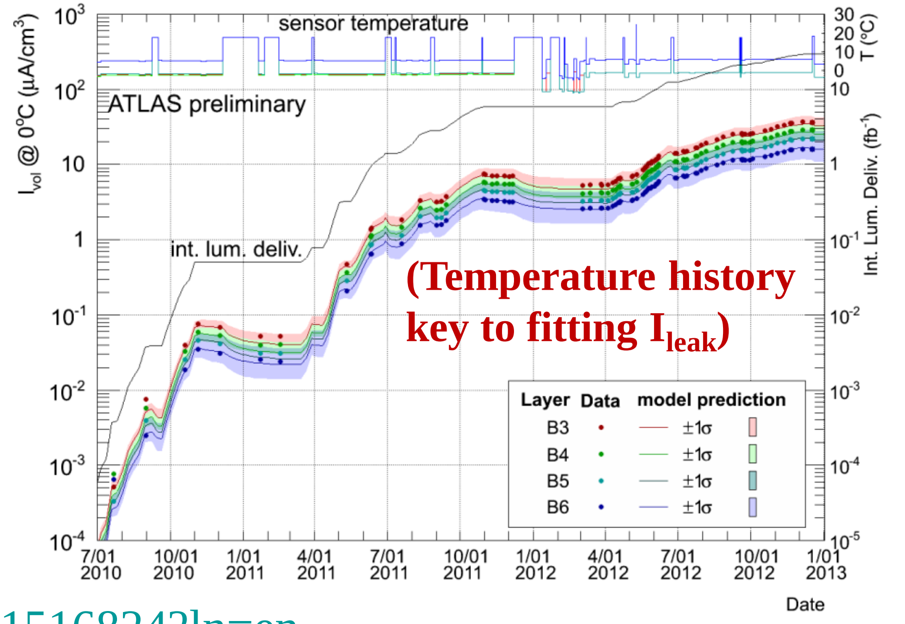
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/InDetTrackingPerformanceApprovedPlots#Alignment





Simulation results fit with data to much better than a factor of 2
(and safety factor of 2 was assumed in dose specifications)



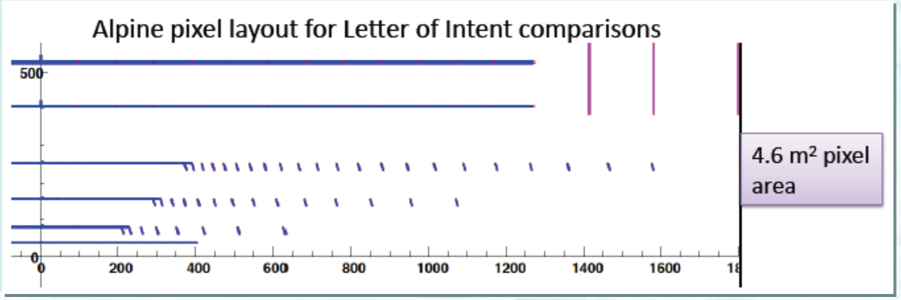


(Temperature history key to fitting I_{leak})

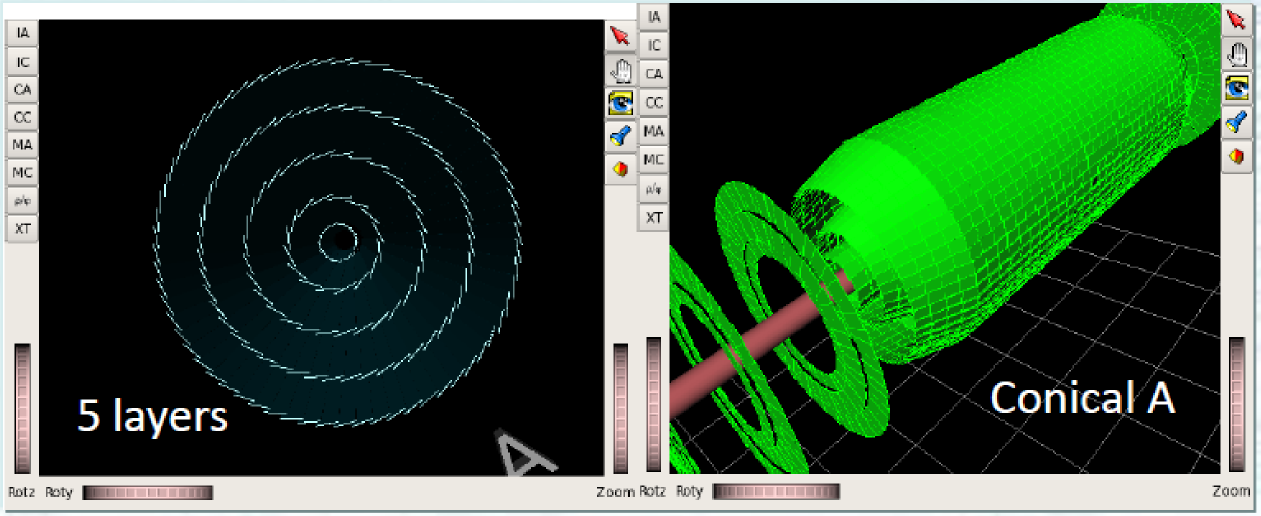
https://cds.cern.ch/record/1516824?ln=en

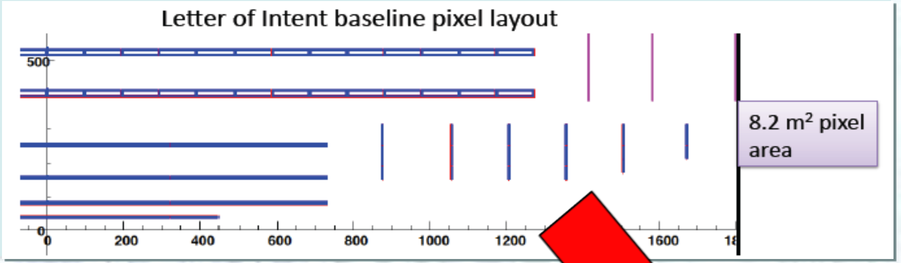
New All-silicon Inner Tracker

- **Alternative layouts being considered which include either a further pixel layer or inclined pixel sensors attached to the same barrels (Alpine layout)**


Alpine pixel layout for Letter of Intent comparisons

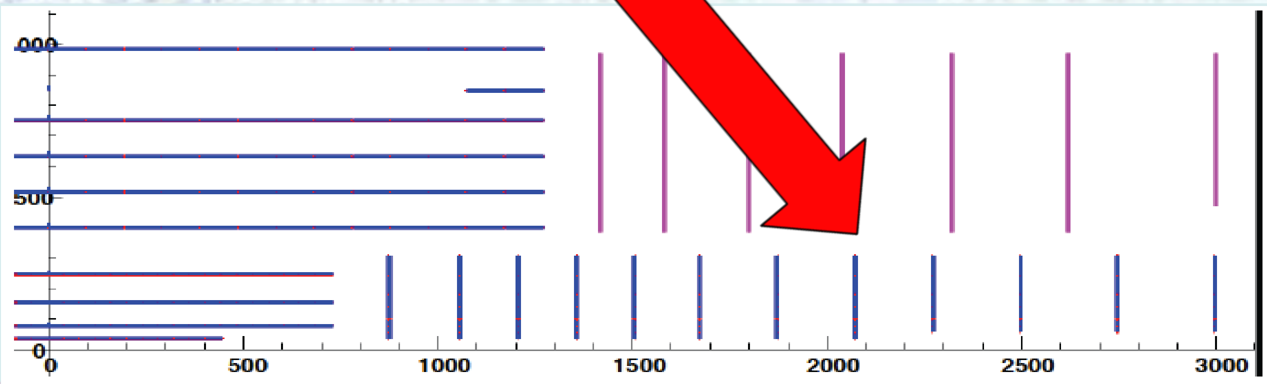
4.6 m² pixel area

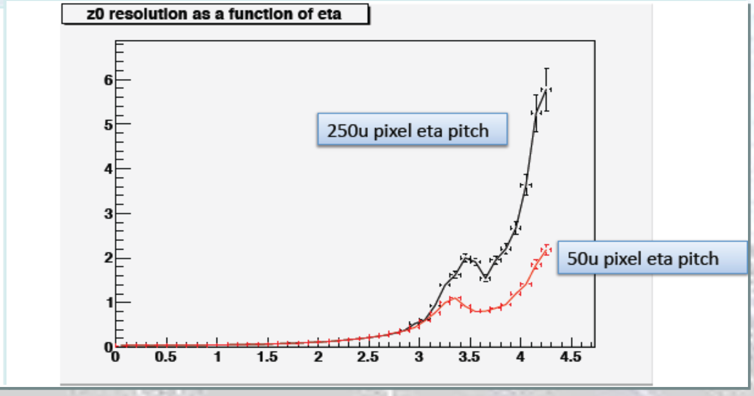



Letter of Intent baseline pixel layout

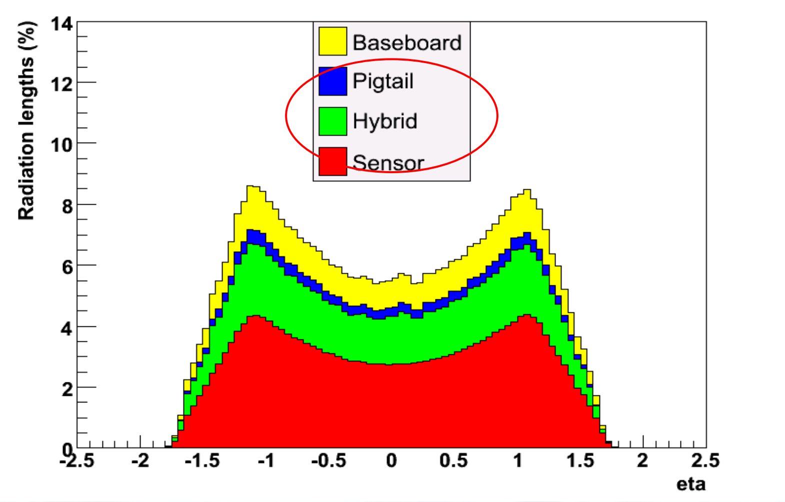
8.2 m² pixel area

Extended η coverage needs more detailed physics motivation





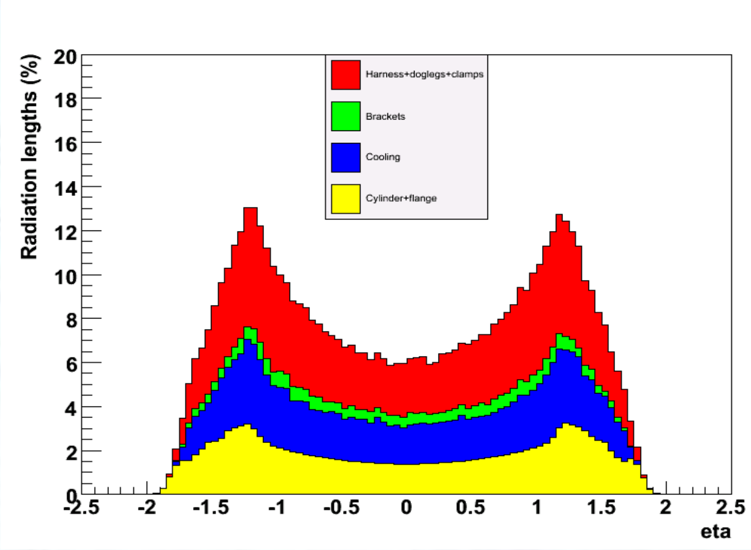
Current Silicon Microstrip (SCT) Material



Current Silicon Tracker
(4 barrel strip layers)

Module Material

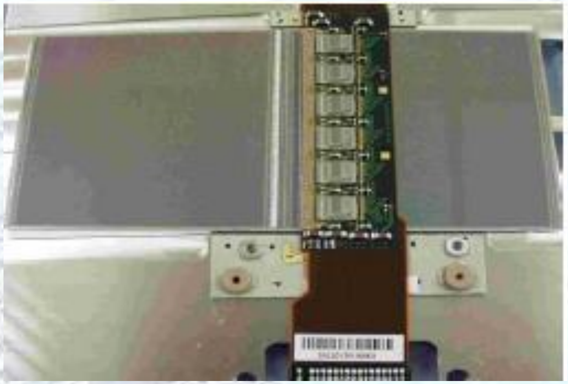
Support Material



Old ATLAS Barrel Module

12 ASIC of 300µm thickness for double-sided module read-out

(*ie* just 6 read-out chips per side)



"The barrel modules of the ATLAS semiconductor tracker".
Nucl.Instrum.Meth.A568:642-671,2006.

Table 1
Radiation lengths and weights estimated for the SCT barrel module

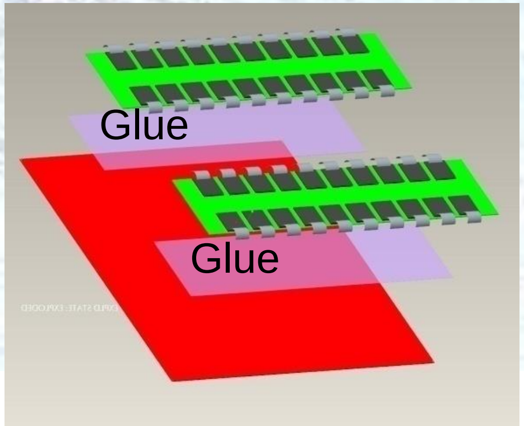
Component	Radiation length [%Xo]	Weight [gr]	Fraction [%]
Silicon sensors and adhesives	0.612	10.9	44
Baseboard and BeO facings	0.194	6.7	27
ASIC's and adhesives	0.063	1.0	4
Cu/Polyimide/CC hybrid	0.221	4.7	19
Surface mount components	0.076	1.6	6
Total	1.17	24.9	100

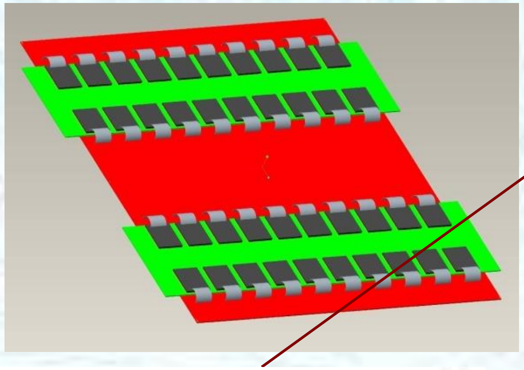
New ATLAS sLHC-Tracker Module

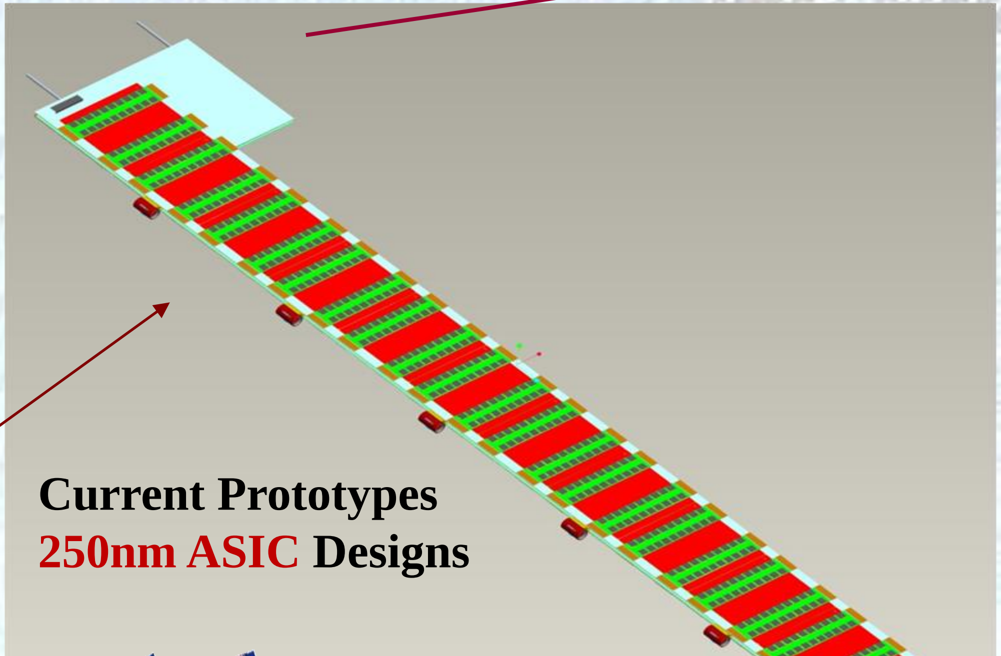
will have 80 ASICs in two hybrid fingers for just one-sided read-out

Hybrid area per module roughly ×2 at HL-LHC: much higher R/O granularity

Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate

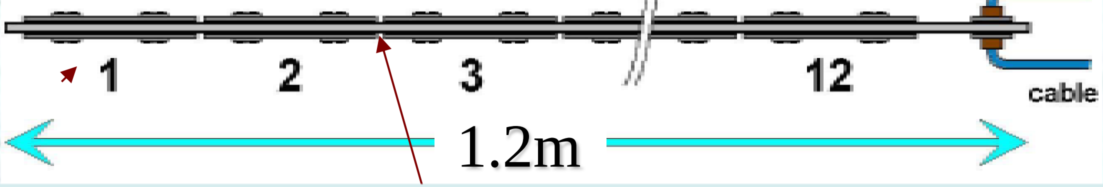


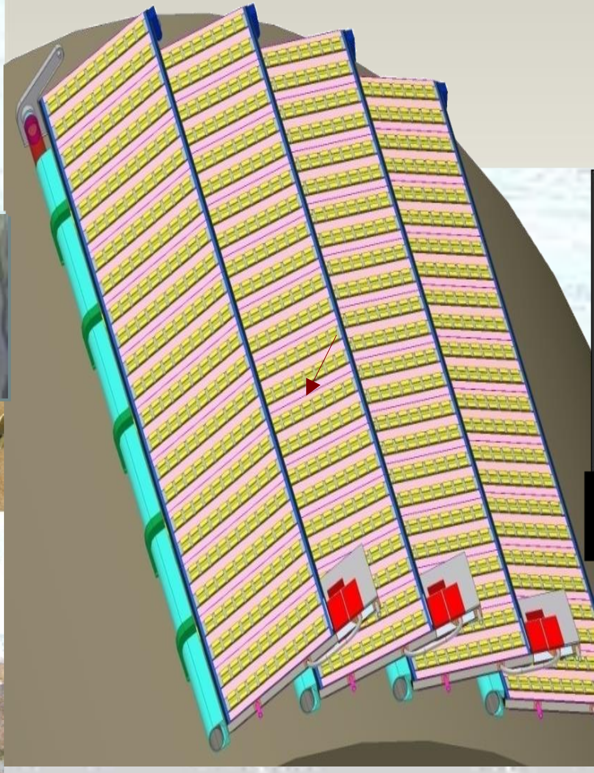


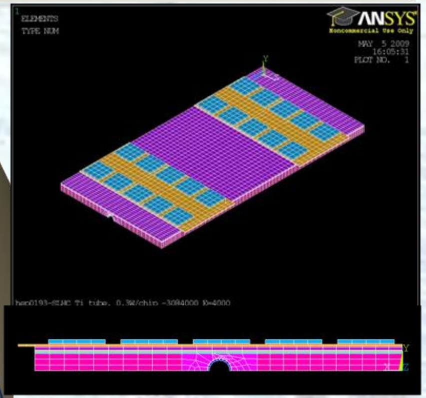


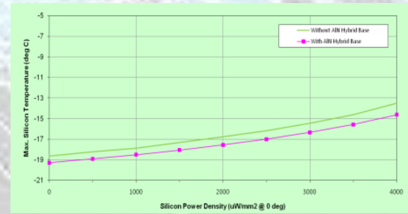
Current Prototypes

250nm ASIC Designs

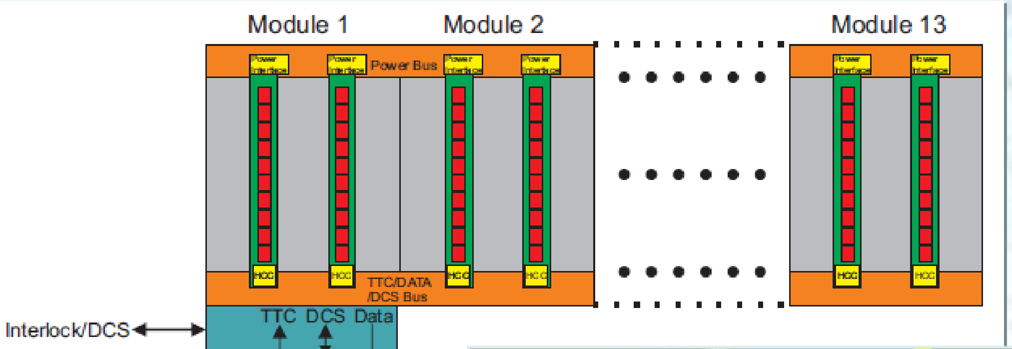


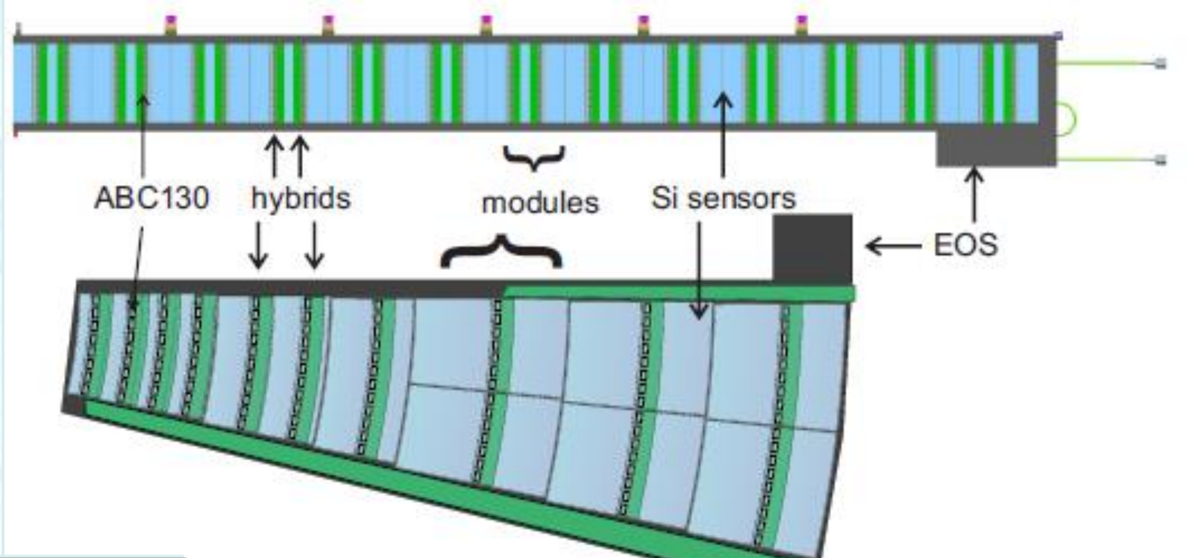


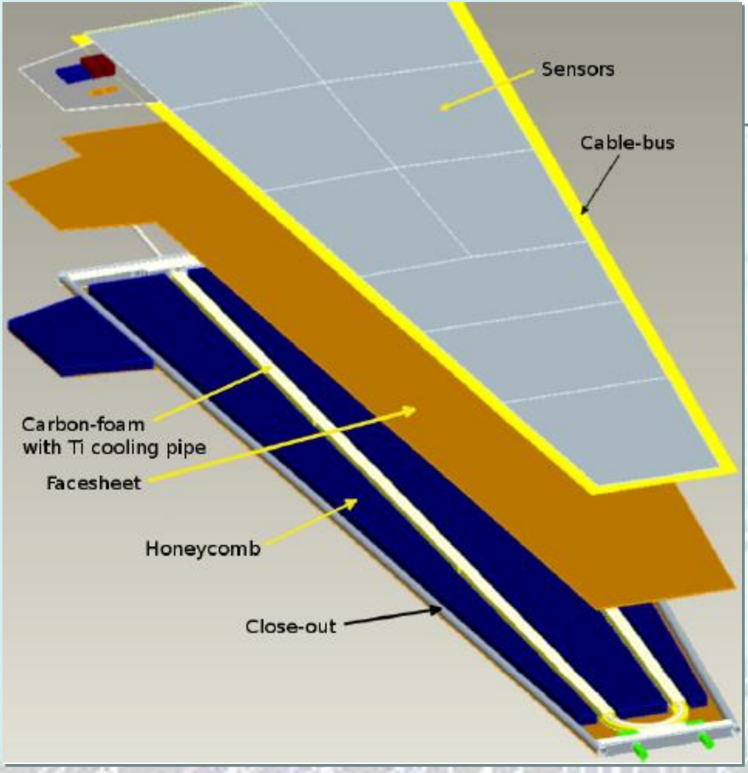




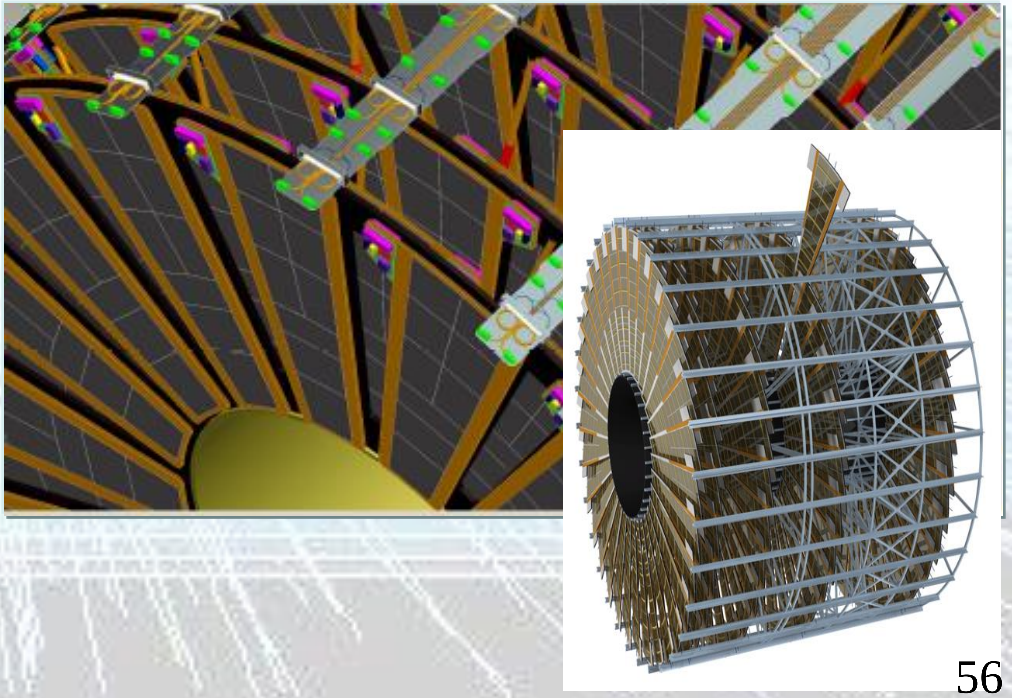
Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate



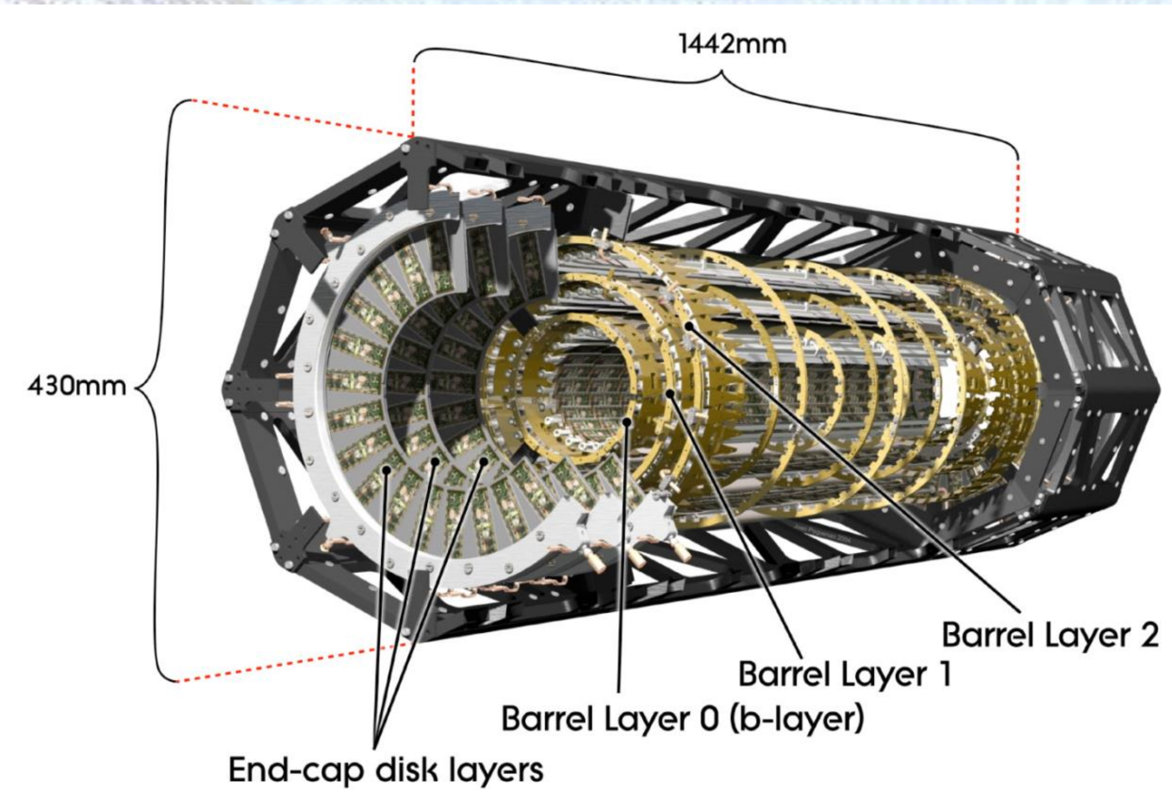


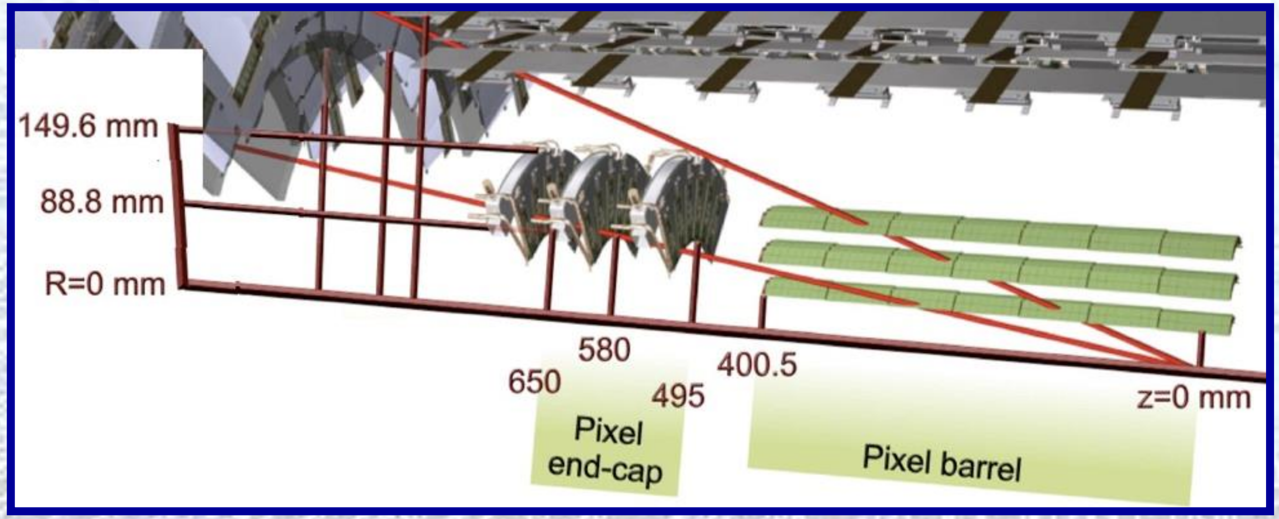


Module, Stave and Petal concepts with 130nm ASIC: 256 channels so each row of ASICs address two rows of strips



The ATLAS Pixel Detector

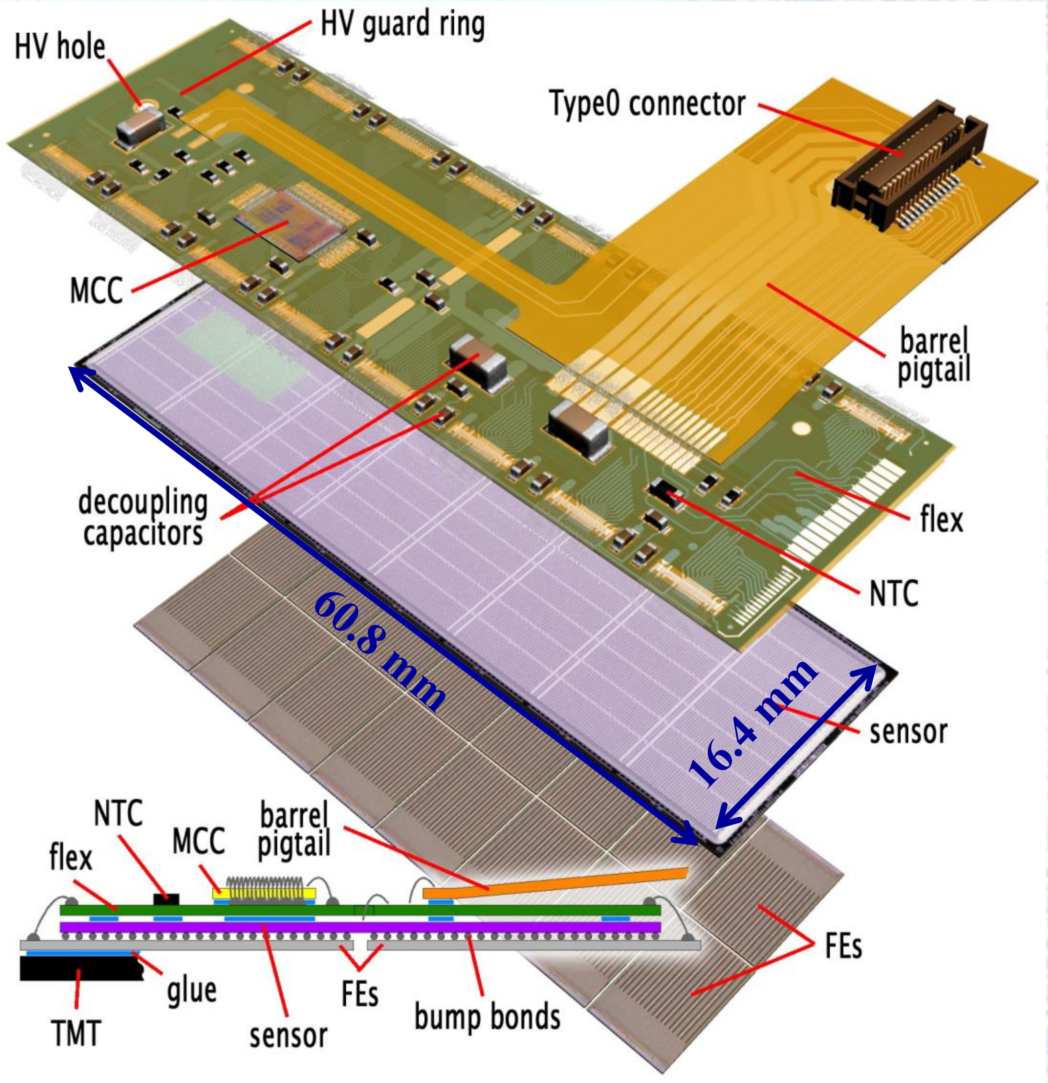




- **Three barrel layers:**
  - R= 5 cm (B-Layer),
    9 cm (Layer-1), 12 cm (Layer-2)
  - modules tilted by 20° in the $R\phi$ plane to overcompensate the Lorentz angle.
- **Two endcaps:**
  - three disks each
  - 48 modules/disk
- **Three precise measurement points up to $|\eta|<2.5$:**
  - $R\Phi$ resolution:10 μm
  - η (R or z) resolution: 115 μm
- 1456 barrel modules and 288 forward modules, for a total of 80 million channels and a sensitive area of 1.7 m^2.
  - Environmental temperature about -10 ºC
  - 2 T solenoidal magnetic field.

Module Overview

- **Sensor**
  - 47232 n-on-n pixels with moderated p-spray insulation
  - 250 μm thickness
  - 50 μm (RΦ) × 400 μm (η)
  - 328 rows (x_{local}) × 144 columns (y_{local})
- **16 FE chips**
  - bump bonded to sensor
- **Flex Hybrid**
  - passive components
  - Module Controller Chip to perform distribution of commands and event building.
- **Radiation-hard design:**
  - Dose >500 Gy
  - NIEL >10^{15} n_{eq}/cm^2 fluence

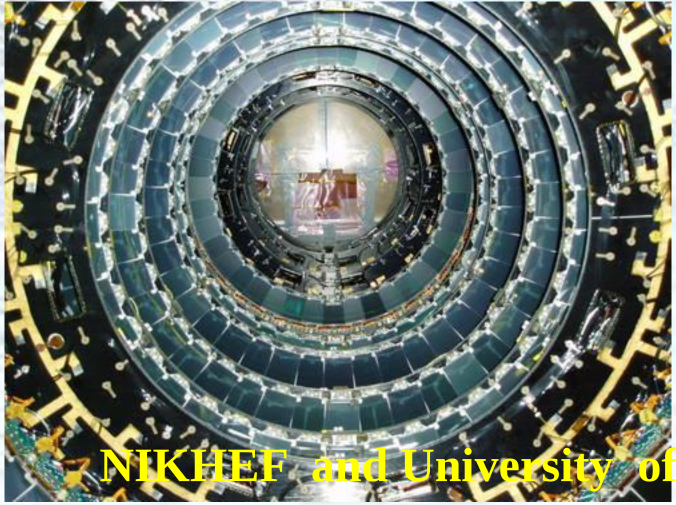


ATLAS Silicon Strip Detectors

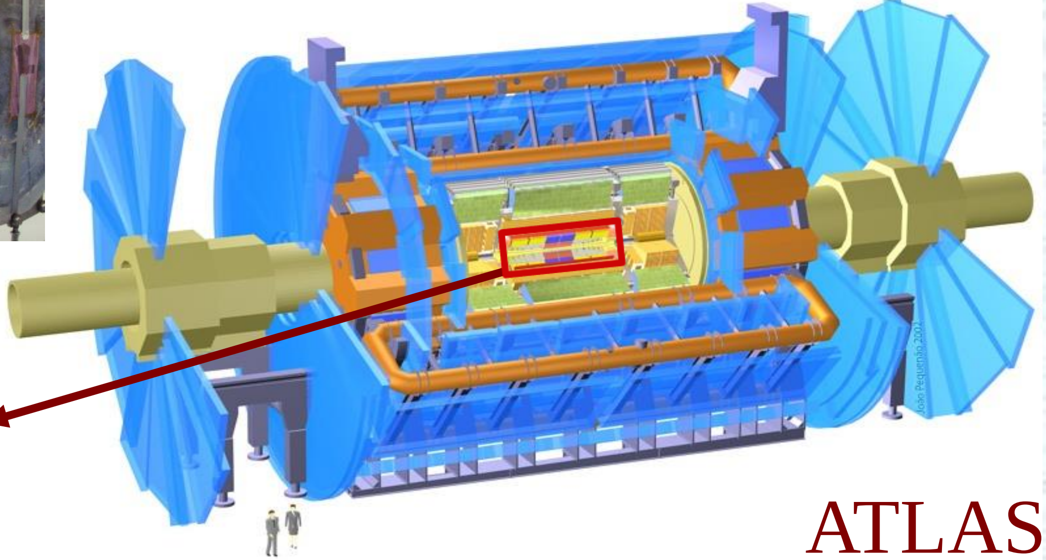
4 barrels (2112 modules) and 2×9 disc end-caps (1976 modules)

61m^2 of silicon micro-strip detectors

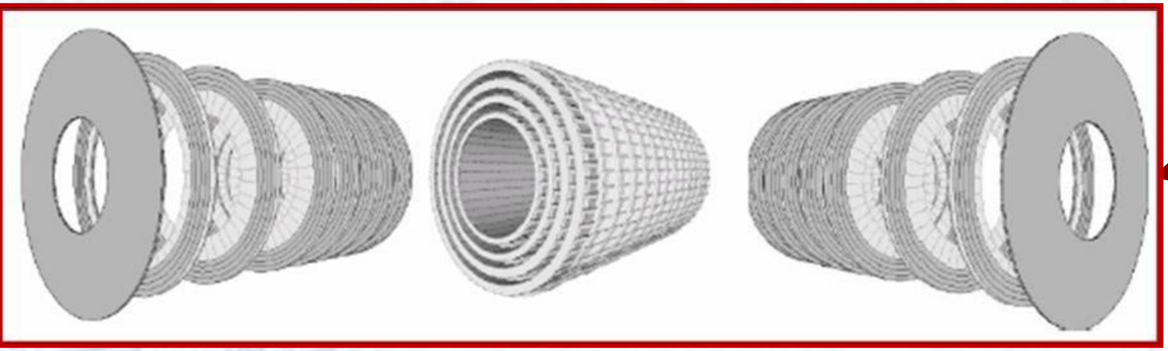
~20,000 separate 6cm×6cm sensors

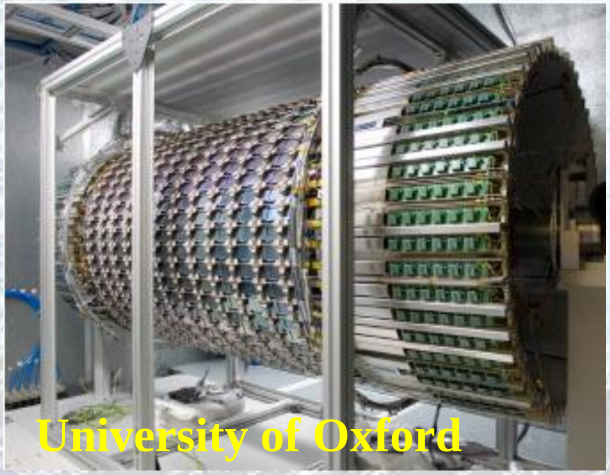


NIKHEF and University of Liverpool



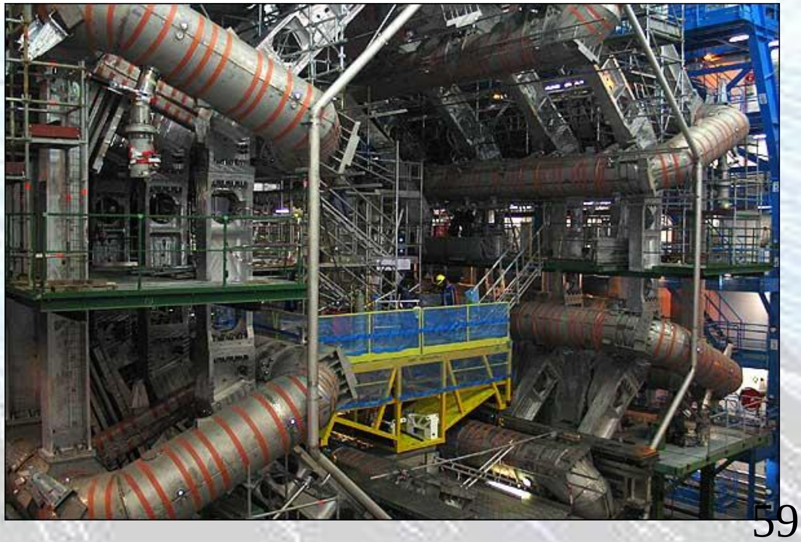
ATLAS





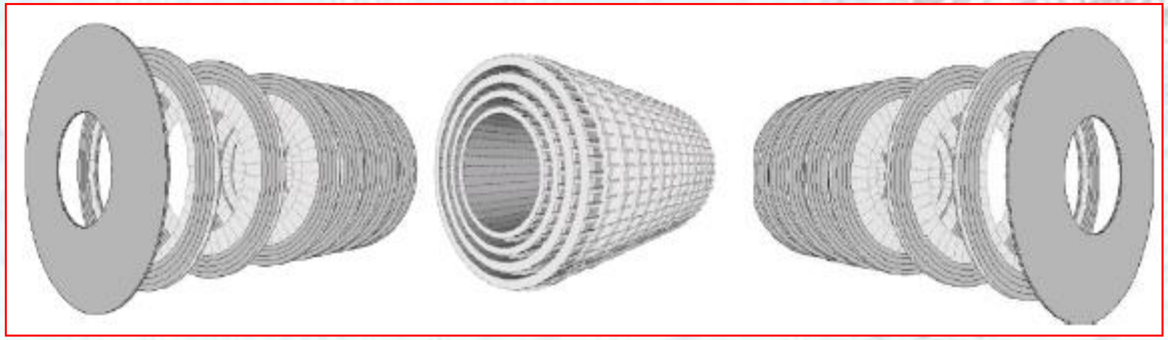
University of Oxford

CERN

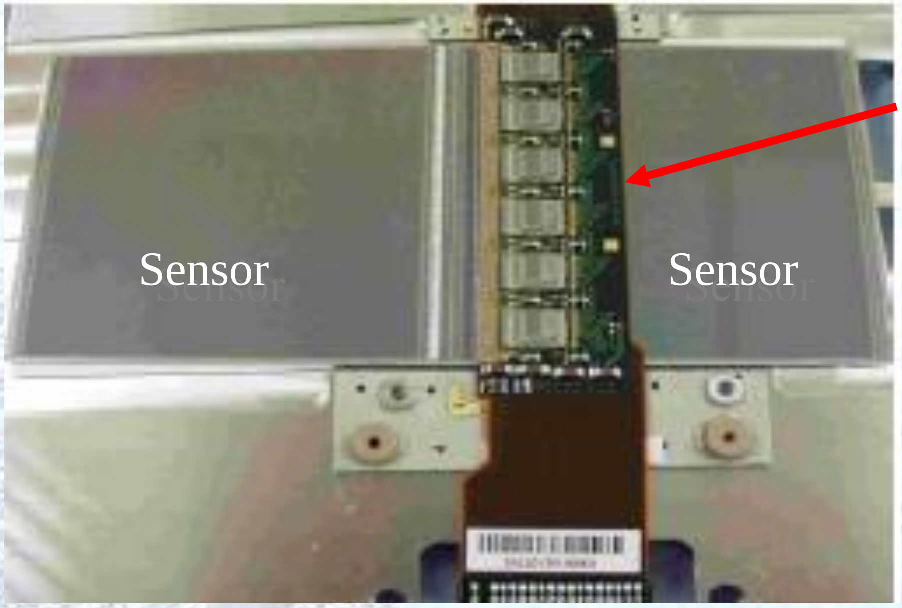


Current SCT ATLAS Module Designs

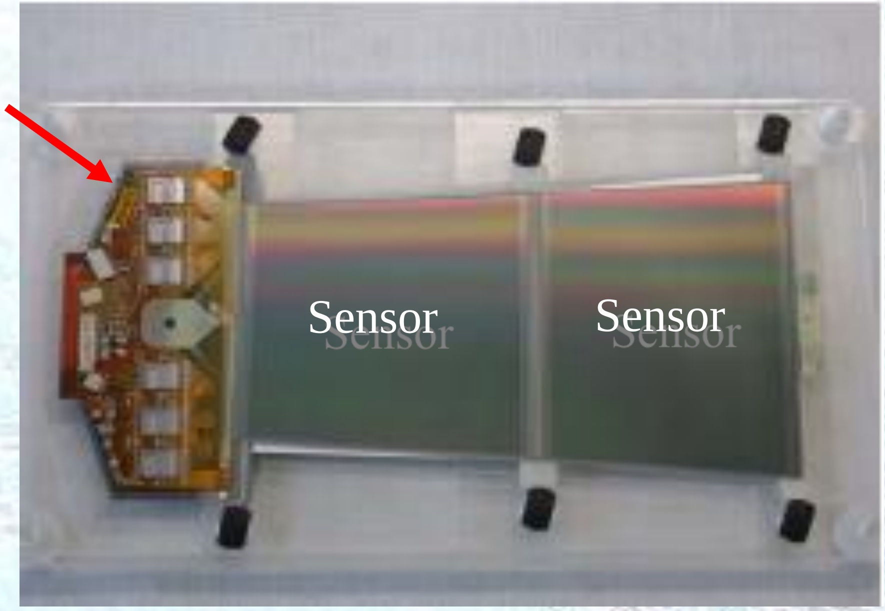
ATLAS Tracker Based on Barrel and Disc Supports



Effectively two styles of double-sided modules (2×6cm long) each sensor ~6cm wide (768 strips of 80µm pitch per side)



Hybrid cards carrying read-out chips and multilayer interconnect circuit



Barrel Modules
(Hybrid bridge above sensors)

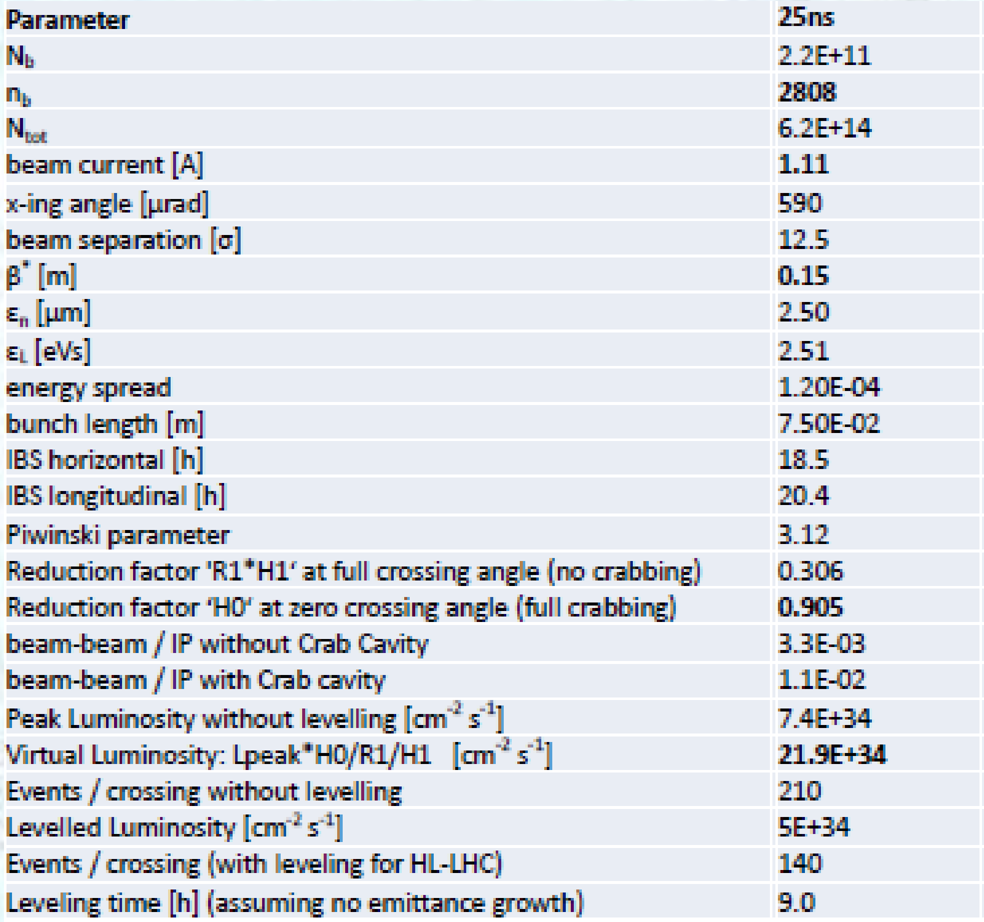
Forward Modules
(Hybrid at module end)

Future Upgrade Planning

Phase-II Upgrade

(LS3)

Starts End 2022

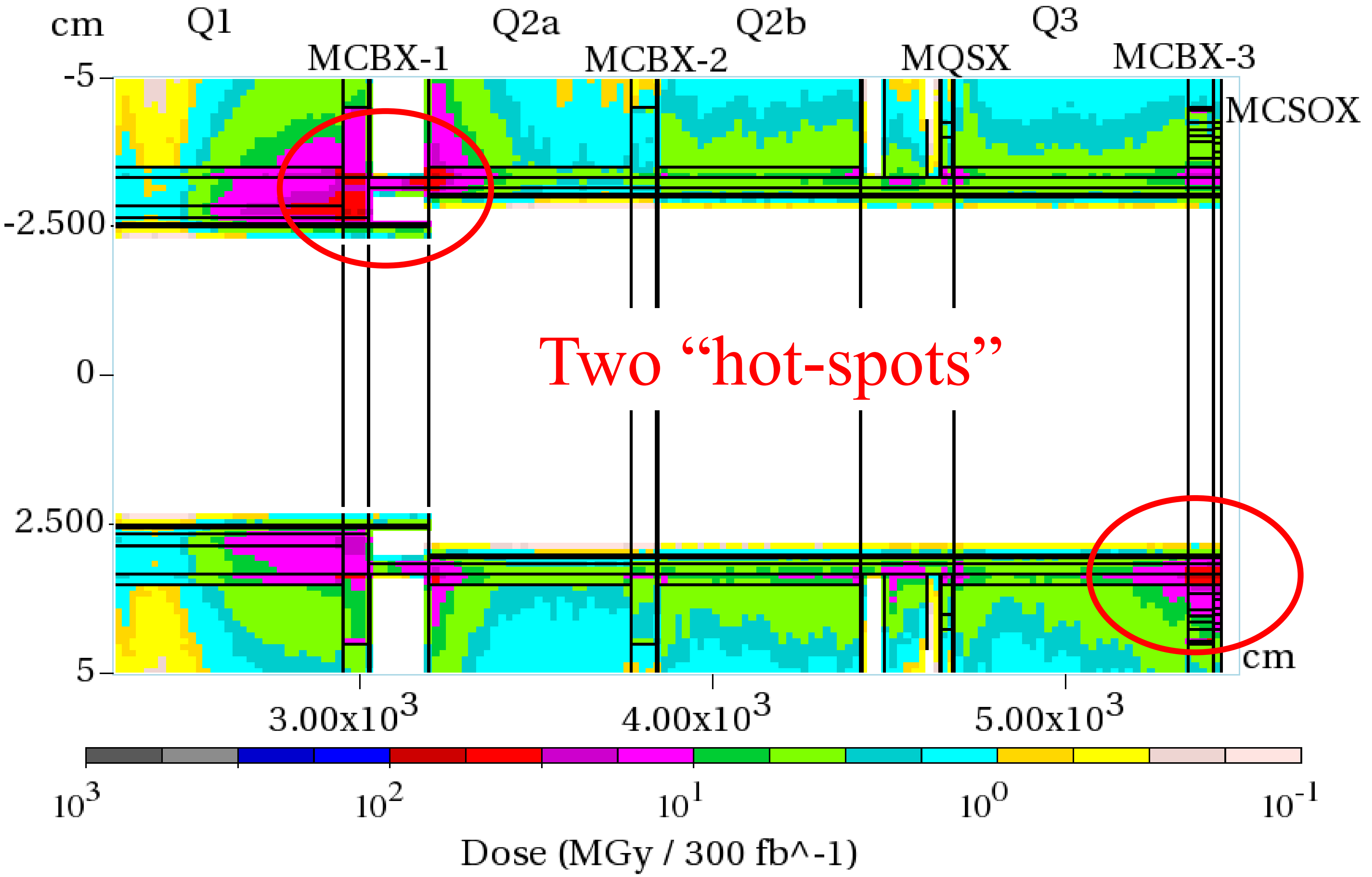


Parameter	25ns
N_b	2.2E+11
n_b	2808
N_{tot}	6.2E+14
beam current [A]	1.11
x-ing angle [μrad]	590
beam separation [σ]	12.5
β^* [m]	0.15
ε_n [μm]	2.50
ε_L [eVs]	2.51
energy spread	1.20E-04
bunch length [m]	7.50E-02
IBS horizontal [h]	18.5
IBS longitudinal [h]	20.4
Piwinski parameter	3.12
Reduction factor 'R1*H1' at full crossing angle (no crabbing)	0.306
Reduction factor 'H0' at zero crossing angle (full crabbing)	0.905
beam-beam / IP without Crab Cavity	3.3E-03
beam-beam / IP with Crab cavity	1.1E-02
Peak Luminosity without levelling [$cm^{-2} s^{-1}$]	7.4E+34
Virtual Luminosity: Lpeak*H0/R1/H1 [$cm^{-2} s^{-1}$]	21.9E+34
Events / crossing without levelling	210
Levelled Luminosity [$cm^{-2} s^{-1}$]	5E+34
Events / crossing (with leveling for HL-LHC)	140
Leveling time [h] (assuming no emittance growth)	9.0

(https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=257368)

Radiation dose in the present triplet (300 fb^{-1})

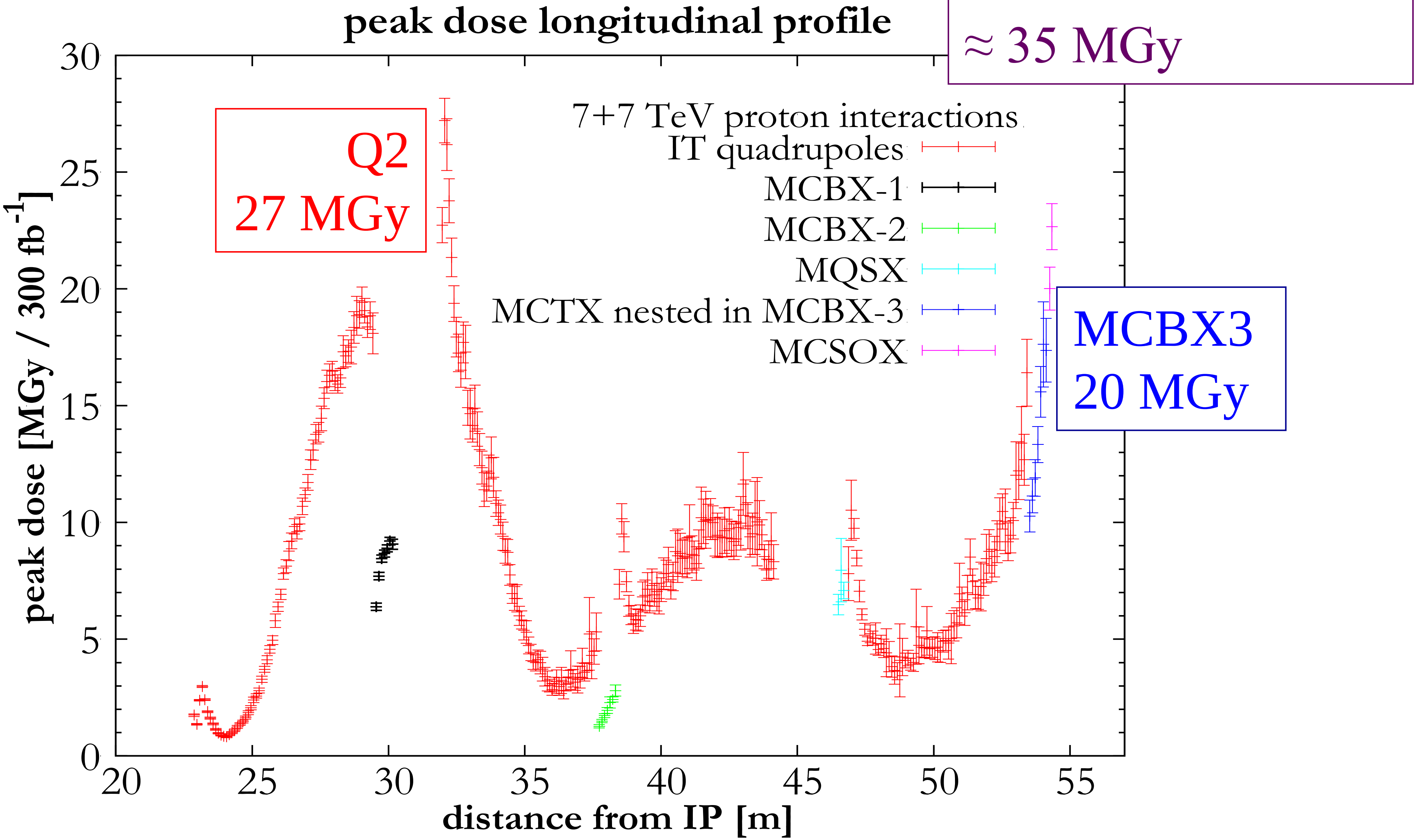
L. Bottura



F. Cerutti, et al., WP10: Energy Deposition and Radiation Damage in Triplet Magnets, April 2013
https://indico.fnal.gov/conferenceDisplay.py?confId=6164

Radiation dose in the present triplet (300 fb^{-1})

L. Bottura



Q2
27 MGy

Cold bore insulation
≈ 35 MGy

MCBX3
20 MGy

F. Cerutti, et al., WP10: Energy Deposition and Radiation Damage in Triplet Magnets, April 2013
https://indico.fnal.gov/conferenceDisplay.py?confId=6164

RLIUP Summary on LHC Inner Triplets

L. Bottura https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492

- Expected dose by LS3 (300 fb^{-1}) with 50 % uncertainty(3)
  - Range of 27 [18…40] MGy in the Q2
  - Range of 20 [13…30] MGy in the MCBX
- Bonding strength (shear) of epoxies is strongly degraded (80 %) above 20 MGy
- Fracture strength of insulating materials degrades by about 50 % in the range of 20 MGy (G11) to 50 MGy (epoxies, kapton)
- Insulations (polyimide) become brittle above 50 MGy
- Triplet magnets may experience mechanically-induced insulation failure in the range of 300 fb^{-1} (LS3 ± 1 year)
  - Premature quenches (cracks in end spacers)
  - Insulation degradation (monitor on line(4))
  - Mechanical failure (nested coils in MCBX)

HL-LHC matrix: equipment, time, cost

LS2 - 1 y (14 months access)		**LS3 - 2 y (26 months access)**					
	PIC		**US1**	**US2**	**Cost (MCHF)**		**In kind**
	LS2	*LS3*	*LS3*	*LS3*			**in part**
P4 new cryoplant	Y				15		
H SC link P7	Y				5		
IR (IT,D1, TAS)	%	Y			210		**YES**
P1-P5 cryoplant	%	Y			75		
SC link (EPC&DFBX on surface)	%	Y			40		
Collimators IR		Y			10		
Collimators MoGr	%	Y			15		
Collimators for INJ &TCLA Q4/Q5)		Y			5		
DS cryocoll.(11T) P2	Y				20	395	
LRBB comp.wires			Y		10		
DS cryocoll.(11T) P7			Y		25		
DS cryocoll (11 T) P1-P5			Y		40		
SC link (EPC&DFB on surface) for MS			Y		20	95	
MS new layout (P1-P5) and Q5 in P6				Y	30		**YES**
Machine & Magnet QPS (Availability)				Y	25		
CC cavity P1-P5				Y	95		**YES**
SCRF 2nd Harmonic				Y			
Crystal Coll				Y ?			**YES ?**
Halo control (e-lens)				Y ?			**YES**
High Band Feedback System				Y ?		150	
Studies					10		
Other systems (Studies, Vacuum, Diagnostics, Remote handling					30		
Infrastructure, Logistics, Integration,Installation HWC					130	170	
Total					**810**	**810**	

L . Rossi

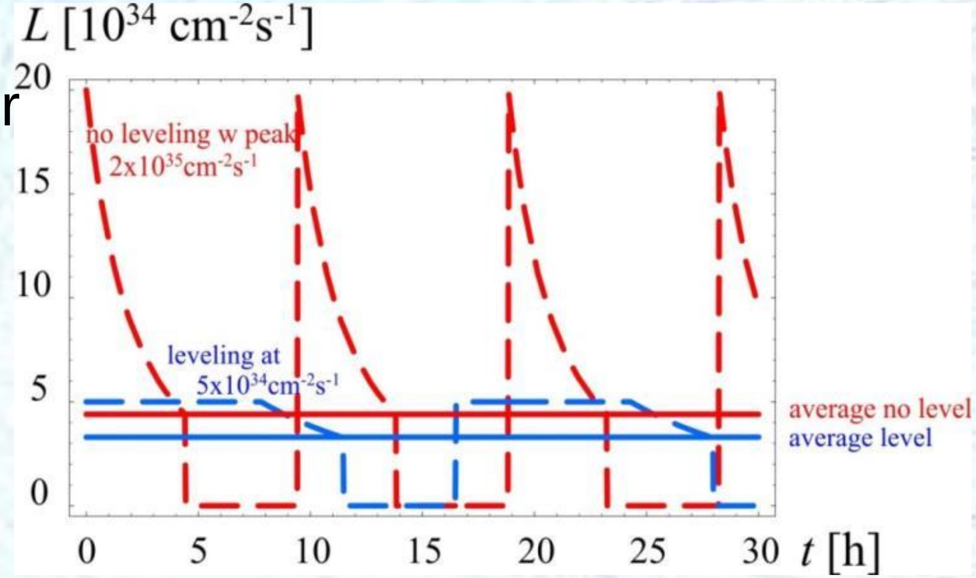
Conclusions

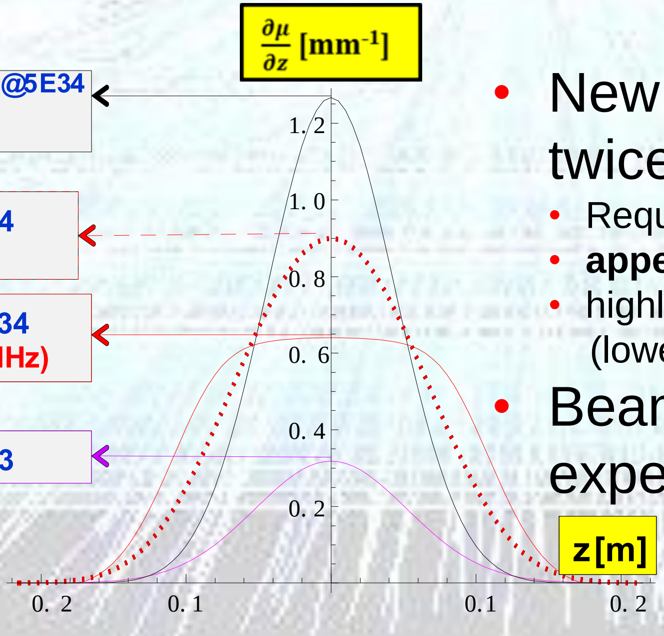
- **The upgrade is robust for 250 (300) fb^{-1}/y**
  - Means to maintain or increase availability are under study
- **All hardware is more robust for 3000 fb^{-1} than it is today for 300 fb^{-1}**
- **Design Study finished by 2015 with the TDR**
- Margins are there and – once established and proved:
  - Possible to decrease pile-up density and/or increase to 350 fb^{-1} ($7 \cdot 10^{34}$ of L_{level}) thanks **to crab kiss (CC in II & ⊥ planes) and β* of 10 cm (large aperture IT & ATS)**
  - **Increase data collection to > 4000 fb^{-1}??**

L . Rossi

Interface with Accelerator

- In the context of the 3000fb^{-1} by “around 2030”, given that levelling at 5×10^{34} cm^{-2}s^{-1} is based on an effective luminosity of 2×10^{35} cm^{-2}s^{-1}, this raises the question of the ultimate acceptable pile-up (average # collisions each 25ns)
- The “crab-kissing” scheme offers an extended interaction region in z with lower pile-up density (better vertex finding)
- The question arises for mean pile-up, <μ>, = 140 (5×10^{34} cm^{-2}s^{-1}, 25ns); if the vertex density could drop from 1.3/mm to 0.7/mm could <μ> be even higher?





HL-LHC baseline and backup (25 ns): 250 fb^{-1}/y, μ_{tot}= 140 @5E34
(BB wire .or. crab w/o CK scheme)

“HL-LHC+”(25ns): 250 fb^{-1}/y, μ_{tot}= 140 @5E34
(BB wire .and. crabs with CK scheme)

“HL-LHC++”(25ns): 250 fb^{-1}/y, μ_{tot}= 140 @ 5E34
(BB wire .and. crabs with CK scheme .and. 800 MHz)

LHC2012 (50 ns): 25 fb^{-1}/y, μ_{tot}= 40 @ 7.5E33

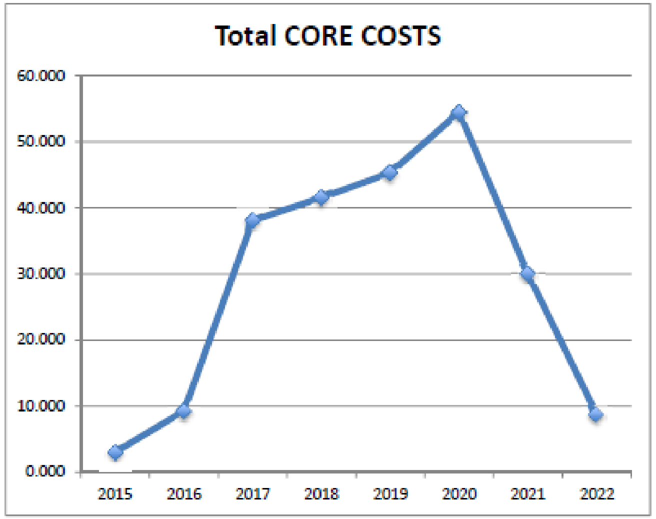
S. Fartoukh

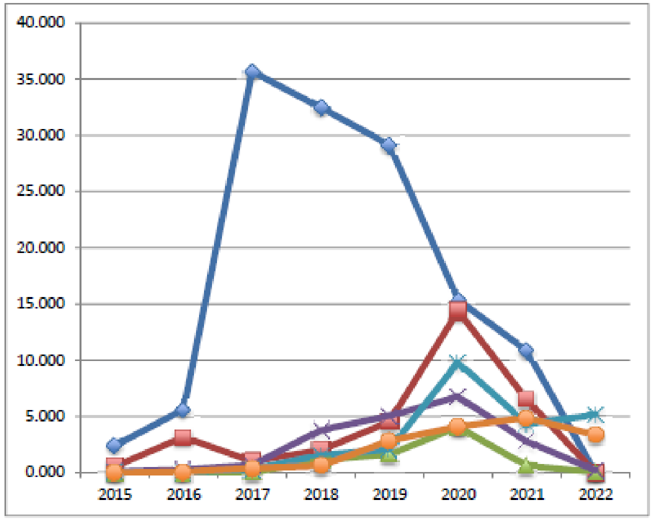
- New Triplets at Interaction Region will have twice present aperture
  - Requires modification of absorbers in the interaction region
  - **appears compatible with small radius beam pipe**
  - highly desirable to anticipate work in LS2 (lower activation - time gained for LS3)
- Beam loss risks (for new crab cavities and experiments)
  - Appear manageable from preliminary studies –
  - More (common) work needed

See Phase-II LoI Section 10 page 134 and https://edms.cern.ch/document/1258343 referenced on page 135

ATLAS PHASE II upgrade (LS3)

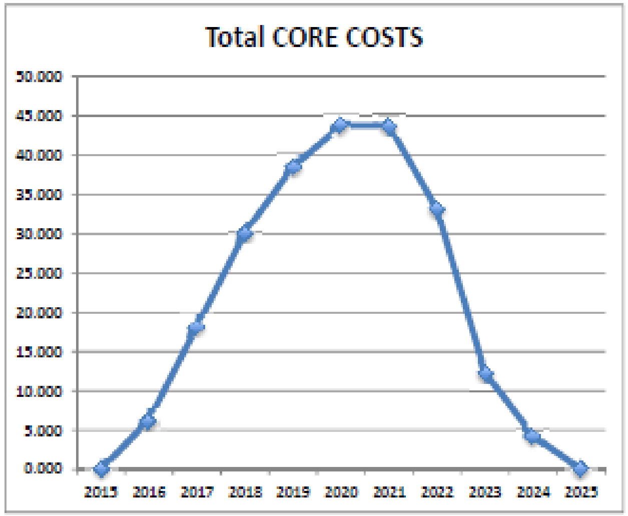
		it will happen	it might happen	2015	2016	2017	2018	2019	2020	2021	2022	total
		[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]
1	New Inner Detector	*131.500*	*26.000*	2.400	5.600	35.660	32.460	29.160	15.360	10.860	0.000	131.500
2	LAr upgrades	*32.124*	*15.096*	0.547	3.170	1.015	2.003	4.517	14.379	6.494	0.000	32.124
3	Tiles upgrades	*7.483*	*2.517*	0.000	0.000	0.000	1.122	1.629	4.070	0.602	0.060	7.483
4	Muon spectrometer upgrades	*19.632*	*0.500*	0.100	0.275	0.675	3.791	5.041	6.750	2.800	0.200	19.632
5	TDAQ upgrades	*23.315*	*0.900*	0.000	0.075	0.315	1.565	2.085	9.805	4.350	5.120	23.315
6	Infrastructure items	*16.280*	*0.000*	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	16.280
	TOTAL	*230.334*	*45.013*	*3.047*	*9.220*	*38.065*	*41.541*	*45.282*	*54.464*	*29.986*	*8.730*	*230.334*

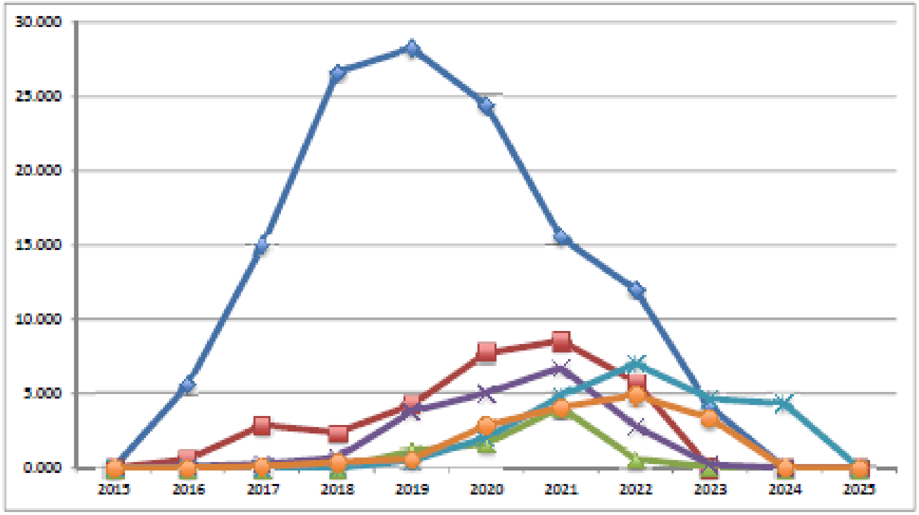




New ATLAS PHASE II upgrade (LS3)

		it will happen	it might happen	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	total
		[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]
1	New Inner Detector	131.500	26.000	0.000	5.600	14.950	26.650	28.250	24.450	15.500	12.000	4.100	0.000	0.000	131.500
2	LAr upgrades	32.124	15.096	0.000	0.584	2.873	2.383	4.231	7.717	8.547	5.790	0.000	0.000	0.000	32.124
3	Tiles upgrades	7.483	2.517	0.000	0.000	0.000	0.000	1.122	1.629	4.070	0.602	0.060	0.000	0.000	7.483
4	Muon spectrometer upgrades	19.632	0.500	0.000	0.100	0.275	0.675	3.791	5.041	6.750	2.800	0.200	0.000	0.000	19.632
5	TDAQ upgrades	23.315	0.900	0.000	0.000	0.000	0.000	0.500	2.020	4.820	7.005	4.650	4.320	0.000	23.315
6	Infrastructure items	16.280	0.000	0.000	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	0.000	0.000	16.280
	TOTAL	230.334	45.013	0.000	6.284	18.198	30.108	38.494	43.707	43.787	33.077	12.360	4.320	0.000	230.334





New ATLAS PHASE II upgrade (LS3)

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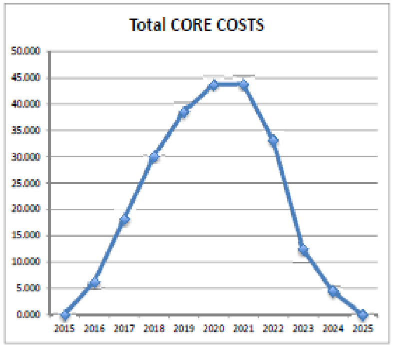
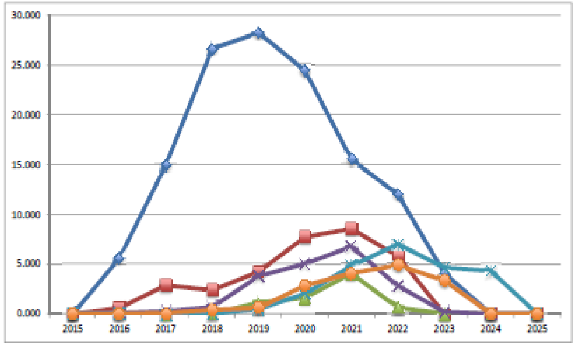
		[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	
1	New Inner Detector	*131.500*	*26.000*	0.000	5.600	14.950	26.650	28.250	24.450	15.500	12.000	4.100	0.000	0.000	131.500	**See new sheet 1-ID for details of new profile provided by Steve and Craig**
2	LAr upgrades	*32.124*	*15.096*	0.000	0.584	2.873	2.383	4.231	7.717	8.547	5.790	0.000	0.000	0.000	32.124	**See new sheet (2-LAr) for details of new profile provided by Arno (new version of 16/3/14)**
3	Tiles upgrades	*7.483*	*2.517*	0.000	0.000	0.000	0.000	1.122	1.629	4.070	0.602	0.060	0.000	0.000	7.483	**Sheet 3-Tiles globally moved by one year after consultation with Irene and Ana**
4	Muon spectrometer upgrades	*19.632*	*0.500*	0.000	0.100	0.275	0.675	3.791	5.041	6.750	2.800	0.200	0.000	0.000	19.632	**Sheet 4-Muon globally moved by one year after consultation with Christoph and Ludo**
5	TDAQ upgrades	*23.315*	*0.900*	0.000	0.000	0.000	0.000	0.500	2.020	4.820	7.005	4.650	4.320	0.000	23.315	**See new sheet 5-TDAQ for details of new profile provided by David**
6	Infrastructure items	*16.280*	*0.000*	0.000	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	0.000	0.000	16.280	**Sheet 6-IN globally moved by one year.**
	TOTAL	*230.334*	*45.013*	*0.000*	*6.284*	*18.198*	*30.108*	*38.494*	*43.707*	*43.787*	*33.077*	*12.360*	*4.320*	*0.000*	*230.334*	





ATLAS PHASE II upgrade (LS3)

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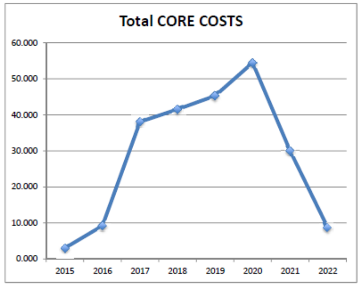
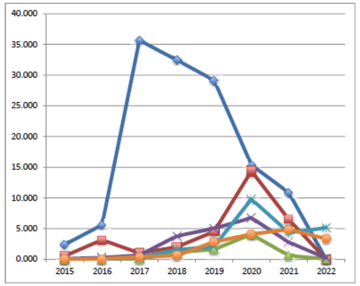
	TOTAL	*230.334*	*45.013*	*3.047*	*9.220*	*38.065*	*41.541*	*45.282*	*54.464*	*29.986*	*8.730*	*230.334*





Conclusions and plans

- The different alternatives and possibilities to keep or upgrade **all the parts** of the system being evaluated
  - First version of each component ready to be tested

  https://indico.cern.ch/event/311205/

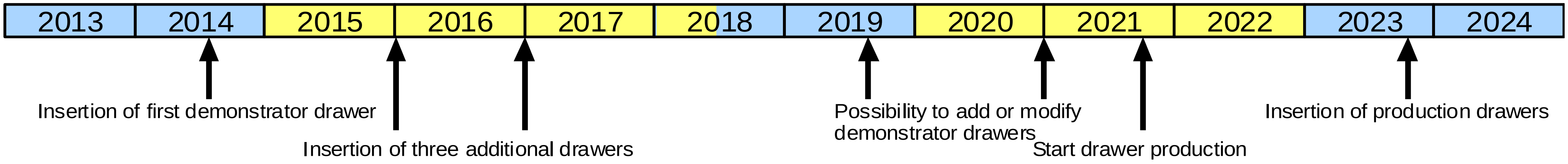
- Still more than 8 years for the installation but… some milestones coming really soon

Short term plans

- Expert days next week at CERN to test the readout of one minidrawer
- Design review in May
- Installation of one demonstrator in P1 in August

Long term

- 2015/2016 – Test beams, performance studies and possible installation of more units.
- 2020 - Final review of the the demonstrator - LS2
- 2021 – Components production and set up the FE assembly
- 2023 – Installation of new electronics



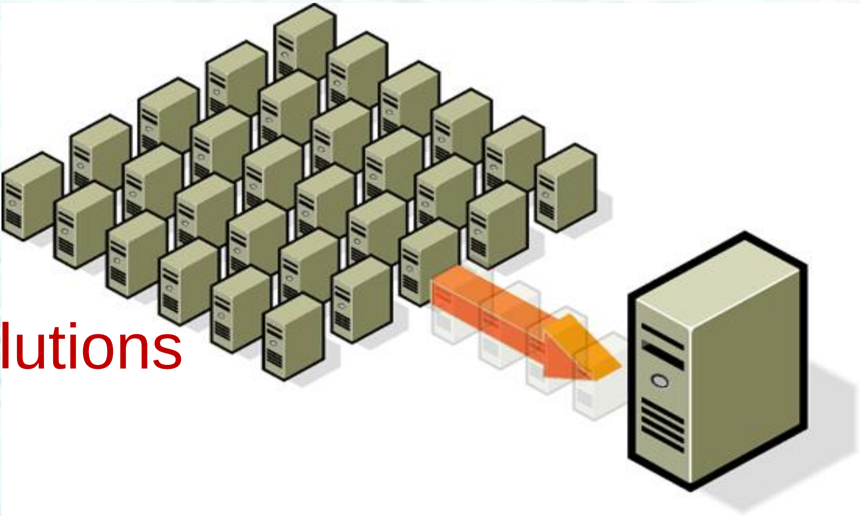
Computing and Software

- Resources needed for computing at HL-LHC are large - but not unprecedented.
  - However, depending on technology assumptions, flat resources can only provide a factor of 2 to 10 times less CPU power than needed
    - Cloud federation may be a way to build the next Grid
    - Possible usage of specialized track processing (eg GPUs as used by ALICE HLT)
    - Multi-core processors will need major software developments to minimize computing demands

➢ The use of more specialized hardware to optimize overall costs implies the need for frameworks able to seamlessly adapt and use much more heterogeneous computing resources

➢ CERN WLCG provides a possible framework for development of future solutions

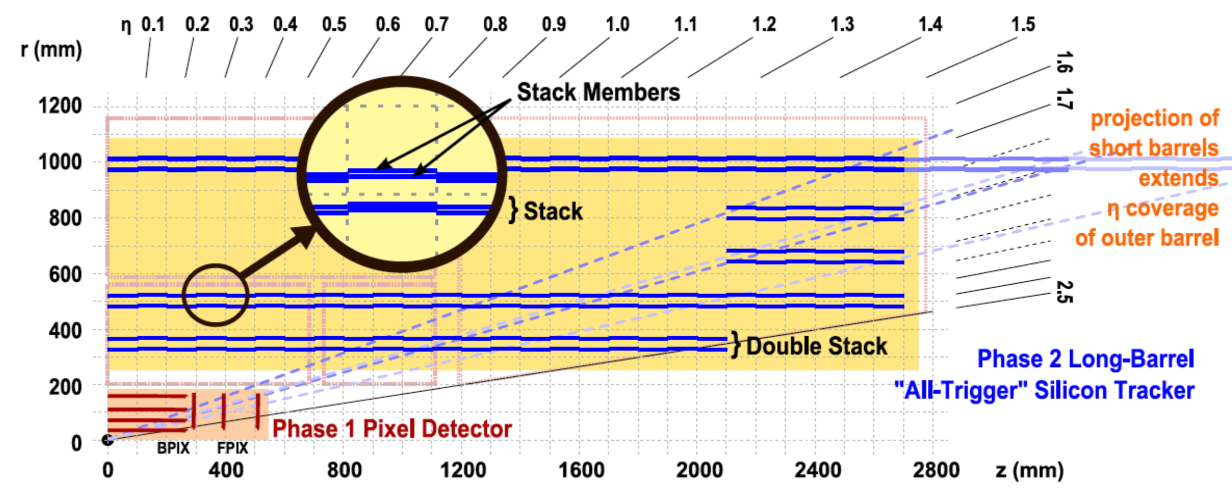
➢ All LHC experiments could benefit from better coordinated efforts to develop new programming techniques



Virtualization is the key technology behind the Cloud

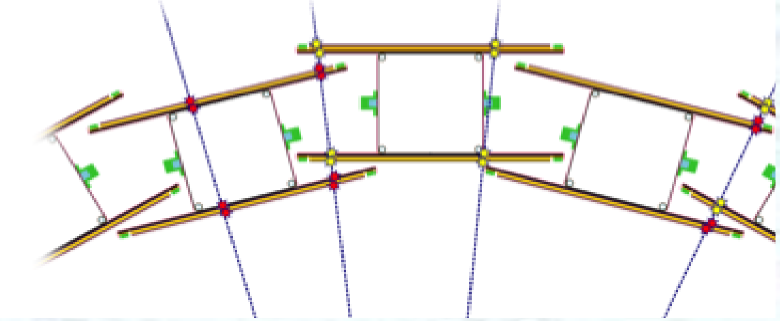
CMS: “Long-Barrel” Double-Stack Concept

- Layout optimized for L1 track finding. Geometry helps to keep problem “local”
- Within double-stack, each lower module is combined with two upper modules to form “Tracklets”
- Tracklets in each “super-layer” are extrapolated to the other two super-layers

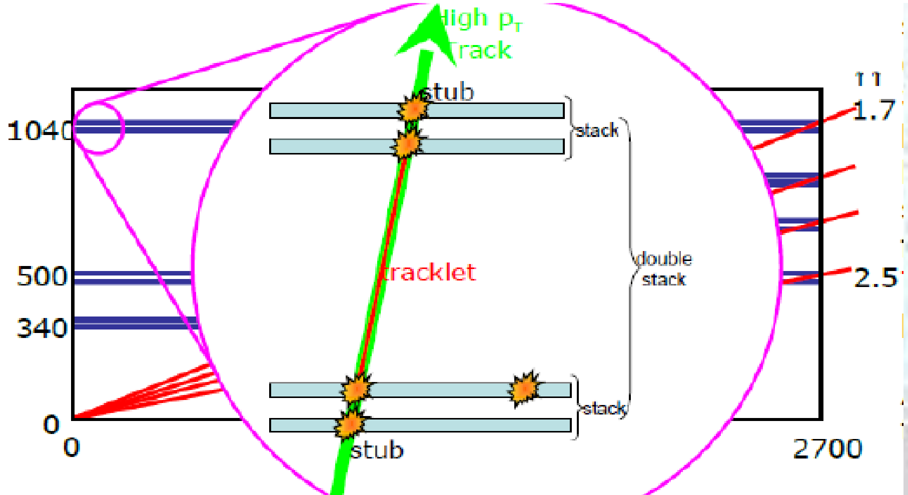


6 long layers = 3 Super layers

ϕ arrangement within double-stack layer

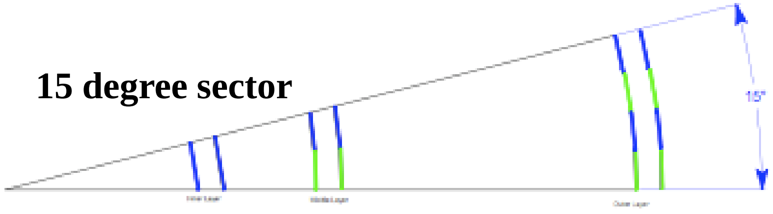


Common supporting mechanics



Pairs of stubs are combined to form “tracklets”

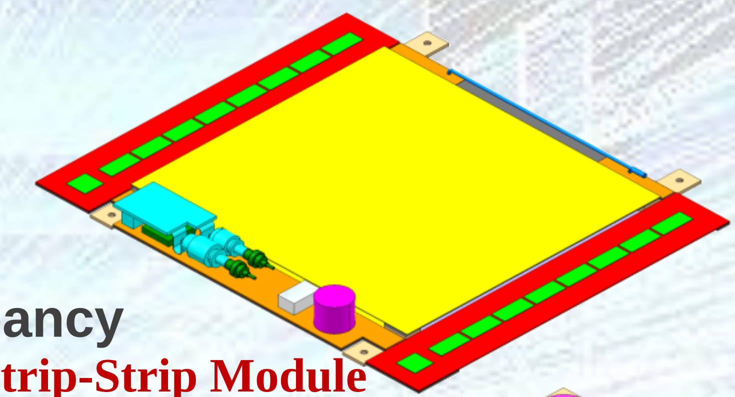
Self-contained ϕ sectors.
Each sector needs to be combined with the two neighbouring sectors (left and right) to “contain” ~2.5 GeV tracks.



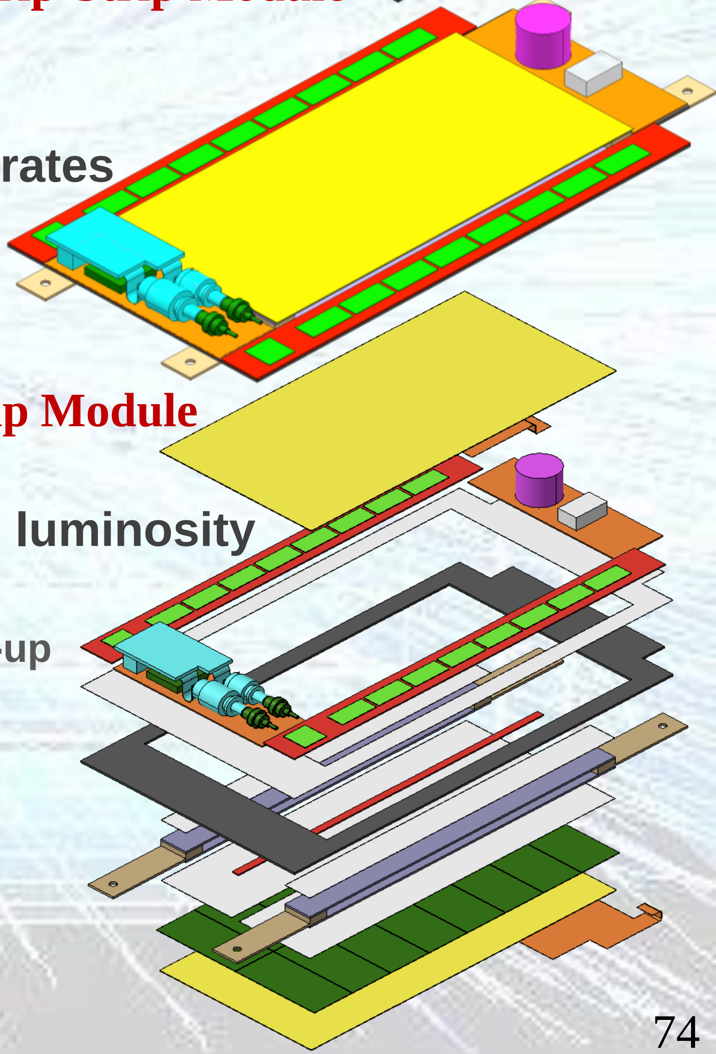
CMS: Phase-II Requirements and Guidelines

- **Radiation hardness**
  - **Ultimate integrated luminosity considered ~ 3000 fb^{-1}**
    - To be compared with original ~ 500 fb^{-1}

- **Resolve up to ~200 collisions per BX, with few % occupancy**
    - Higher granularity



- **Improve tracking performance**
  - **Improve performance @ low p_T ,reduce particle interaction rates**
  - **Reduce material in the tracking volume**
  - **Improve performance @ high p_T**
    - Reduce average pitch



- **Tracker input to Level-1 trigger**
  - **μ, e and jet rates would become unacceptably large at high luminosity**
    - Even considering “phase-1” trigger upgrades
    - Performance of selection algorithms degrades with increasing pile-up
  - **Add tracking information at Level-1**
    - Move part of HLT reconstruction into Level-1!
  - **Objective:**
    - Reconstruct “all” tracks above 2 - 2.5 GeV
    - Identify the origin along the beam axis with ~ 1 mm precision