ATLAS Tile Calorimeter upgrade for the high luminosity LHC

Oleg Solovyanov
on behalf of the Tile Calorimeter community

Outlook

- LHC
- ATLAS and Tile Calorimeter
- HL-LHC
- Tile Calorimeter upgrade
- Future accelerators
- Summary

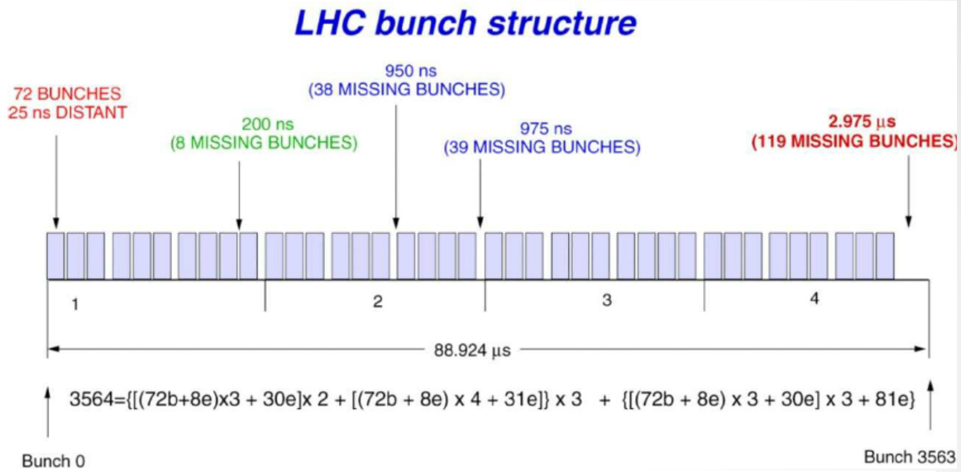
Large Hadron Collider

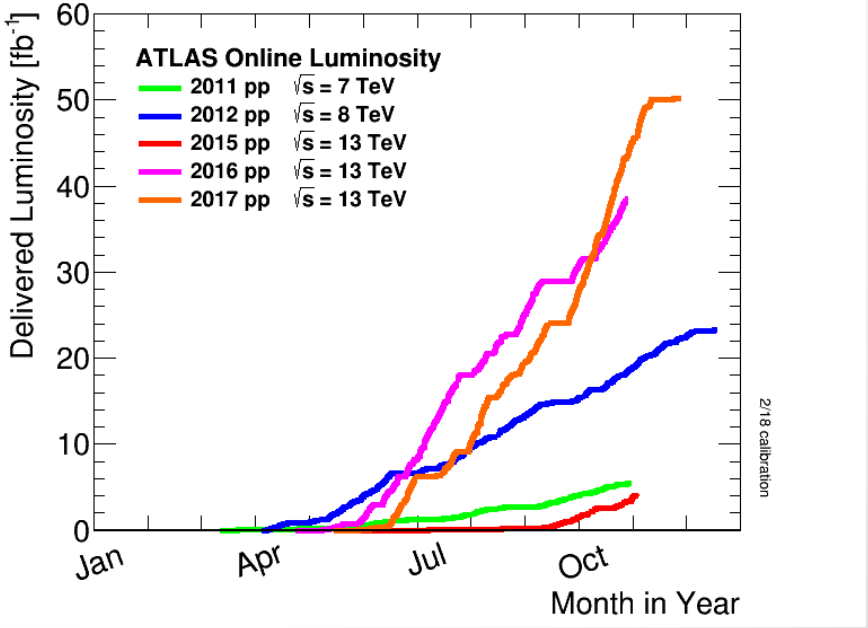
Superconducting Proton Accelerator and Collider installed in a 27km circumference underground tunnel (tunnel cross-section diameter 4m) at CERN

Tunnel built for LEP e+e- collider in 1985

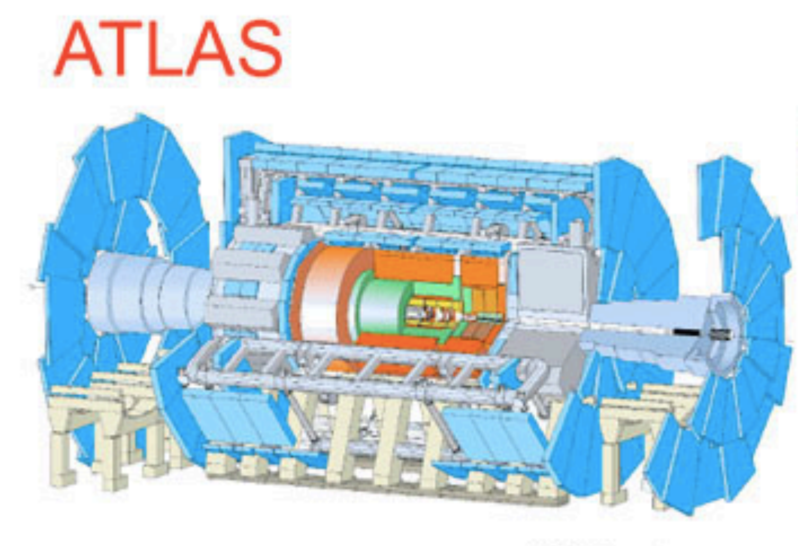
Design parameters:
c.m. energy = 14 TeV
luminosity = 10^{34} cm^{-2}s^{-1}
1.15×10^{11} p/bunch
2808 bunches/beam

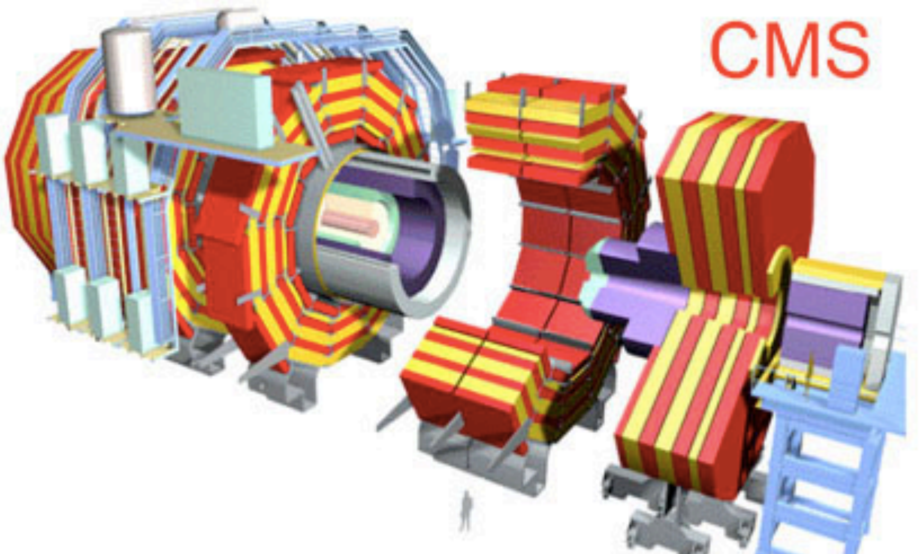
Achieved by the end of 2017:
c.m. energy = 13 TeV
Inst. lumi 2.09×10^{34} cm^{-2}s^{-1}
1.35×10^{11} p/bunch
2544 bunches/beam
~80 <mu>
5+ fb^{-1}/week

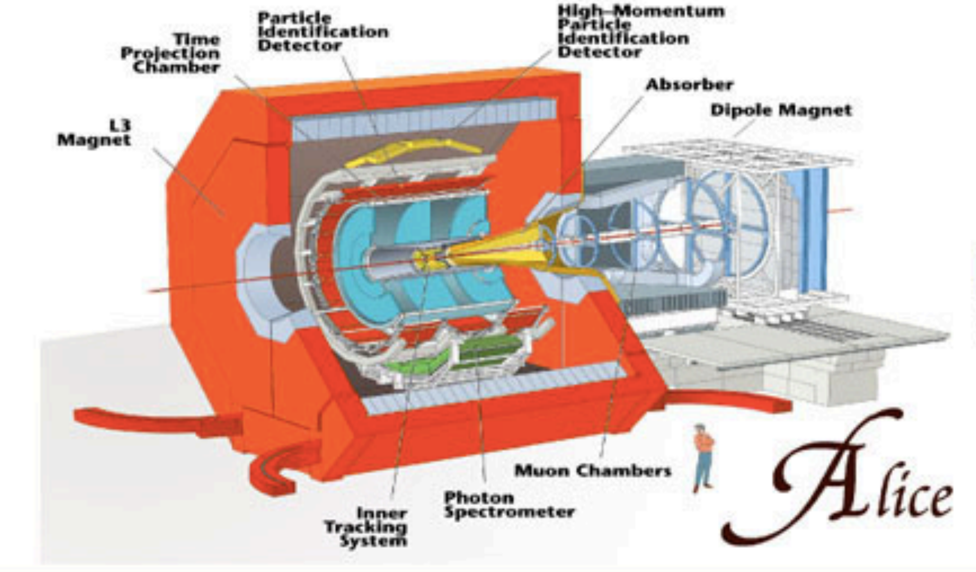


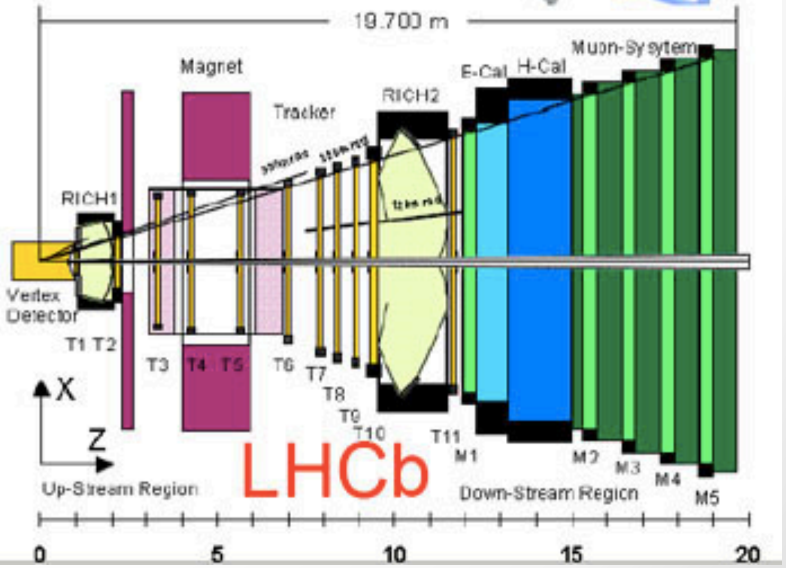


LHC Experiments

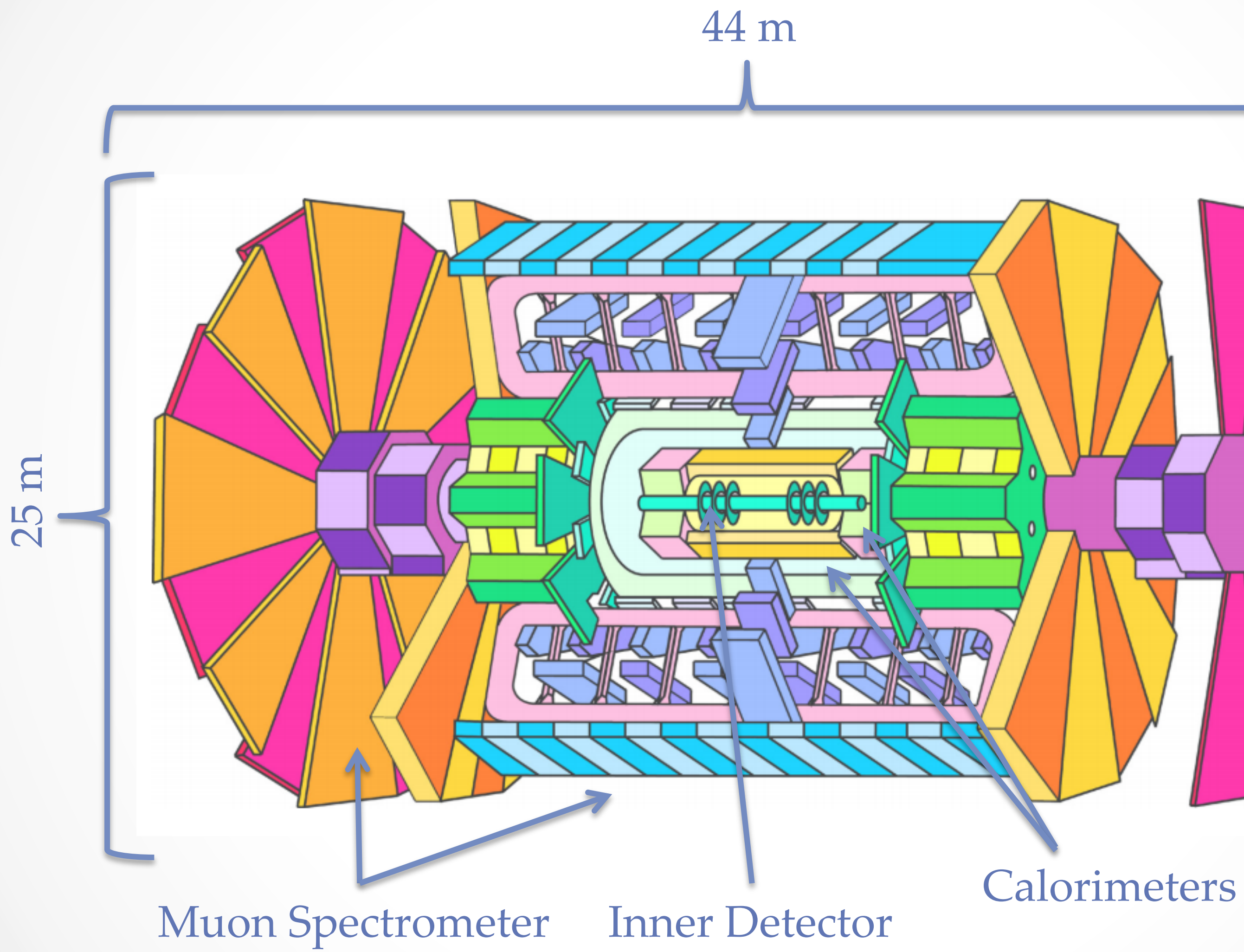






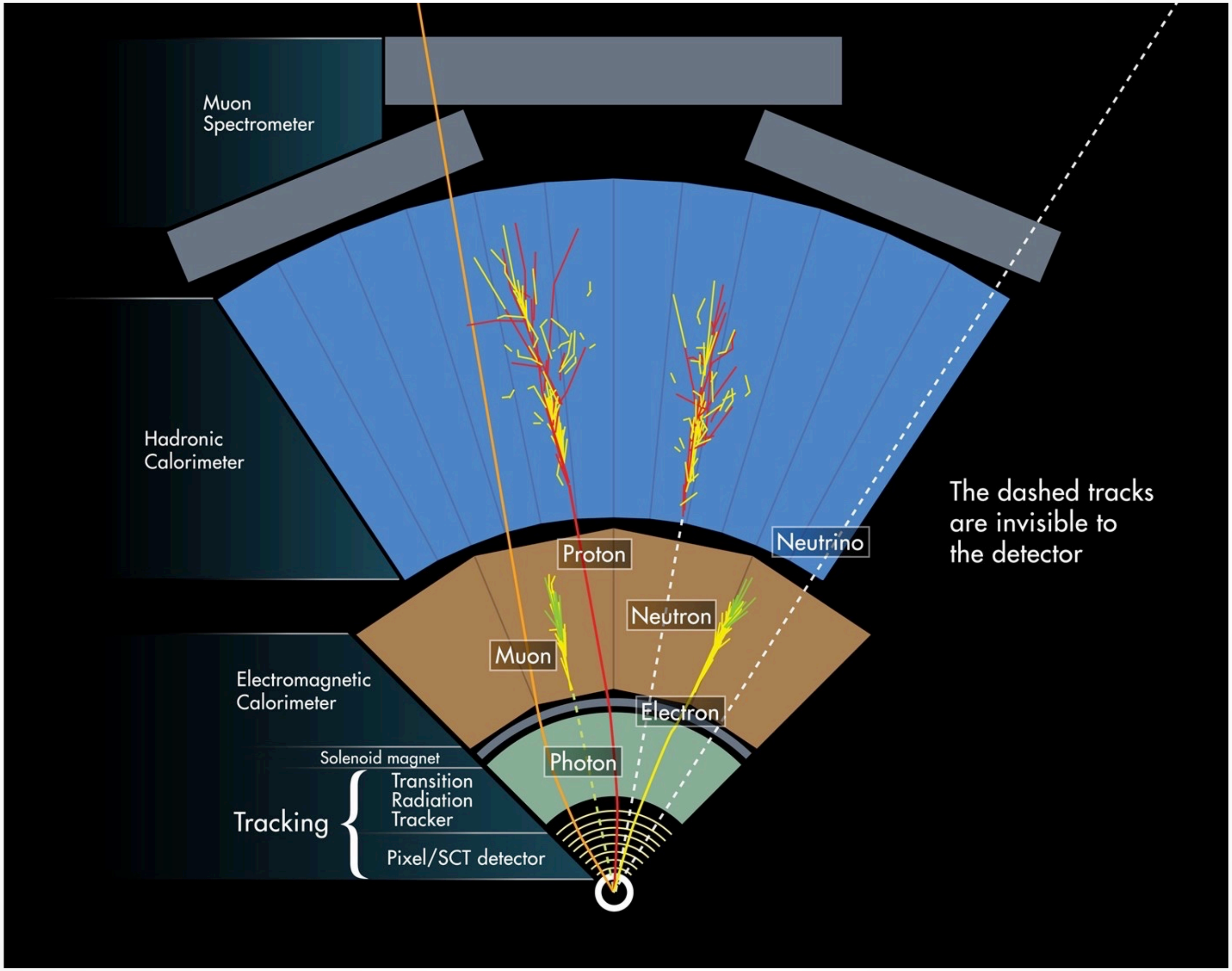


ATLAS Detector



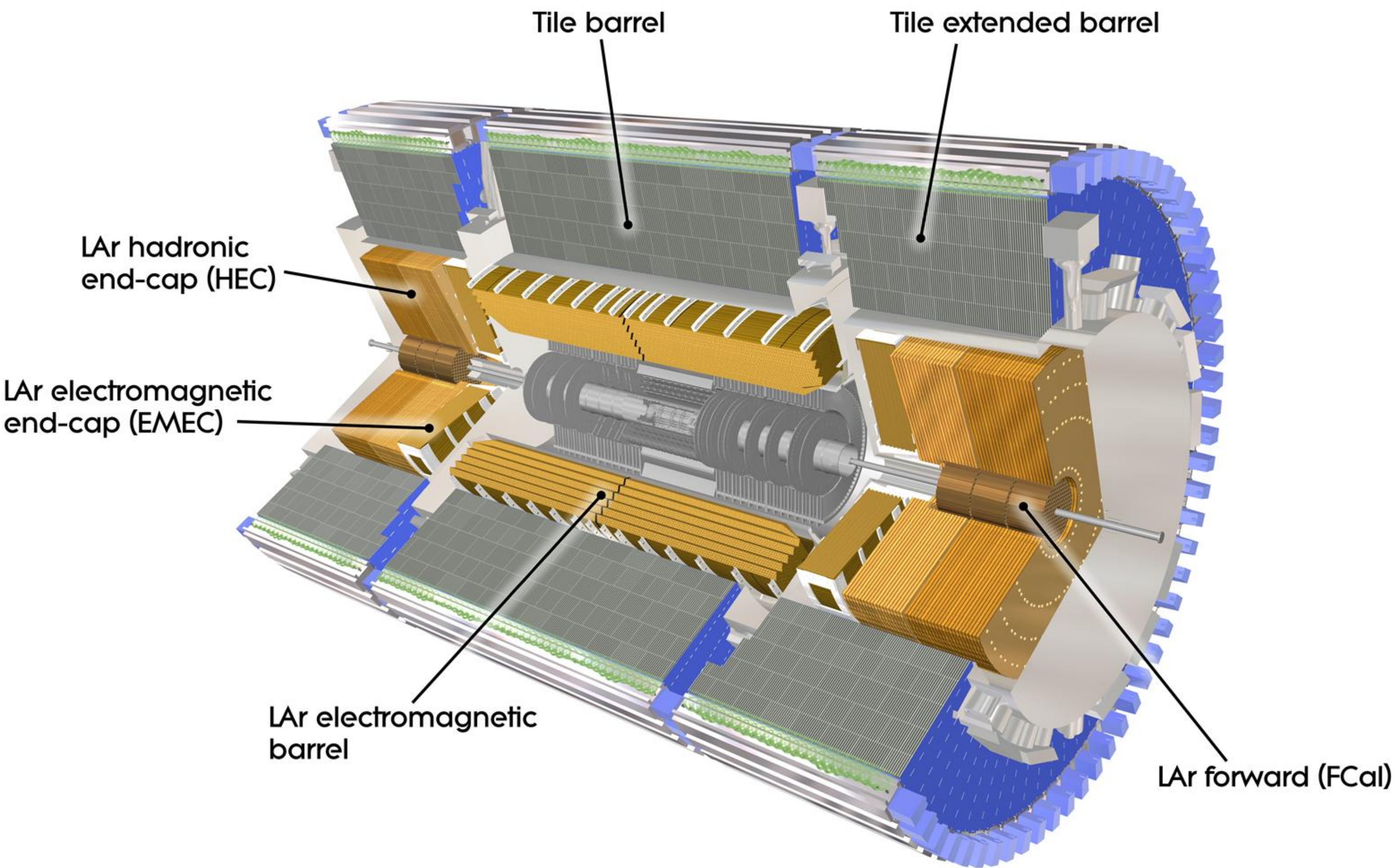
ATLAS Colouring Book

ATLAS Detector

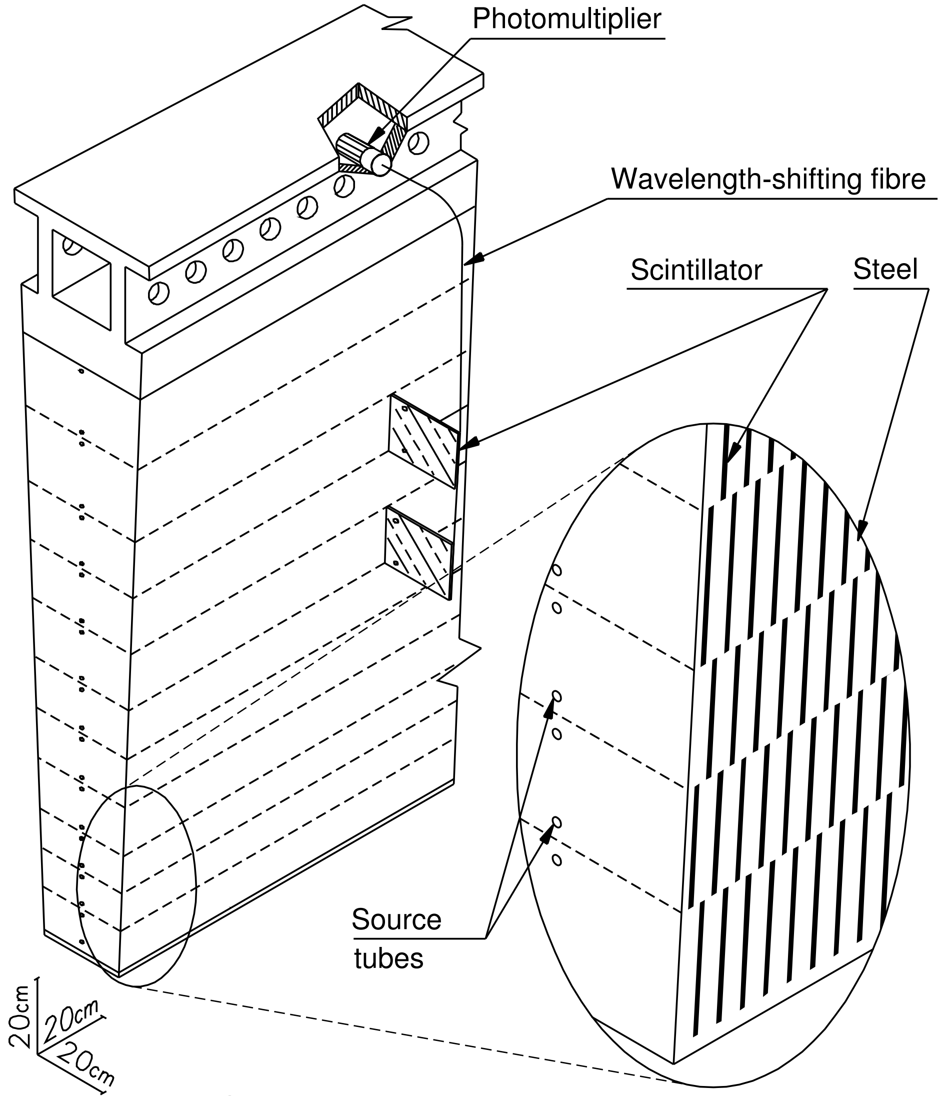


The dashed tracks are invisible to the detector

ATLAS Calorimeters



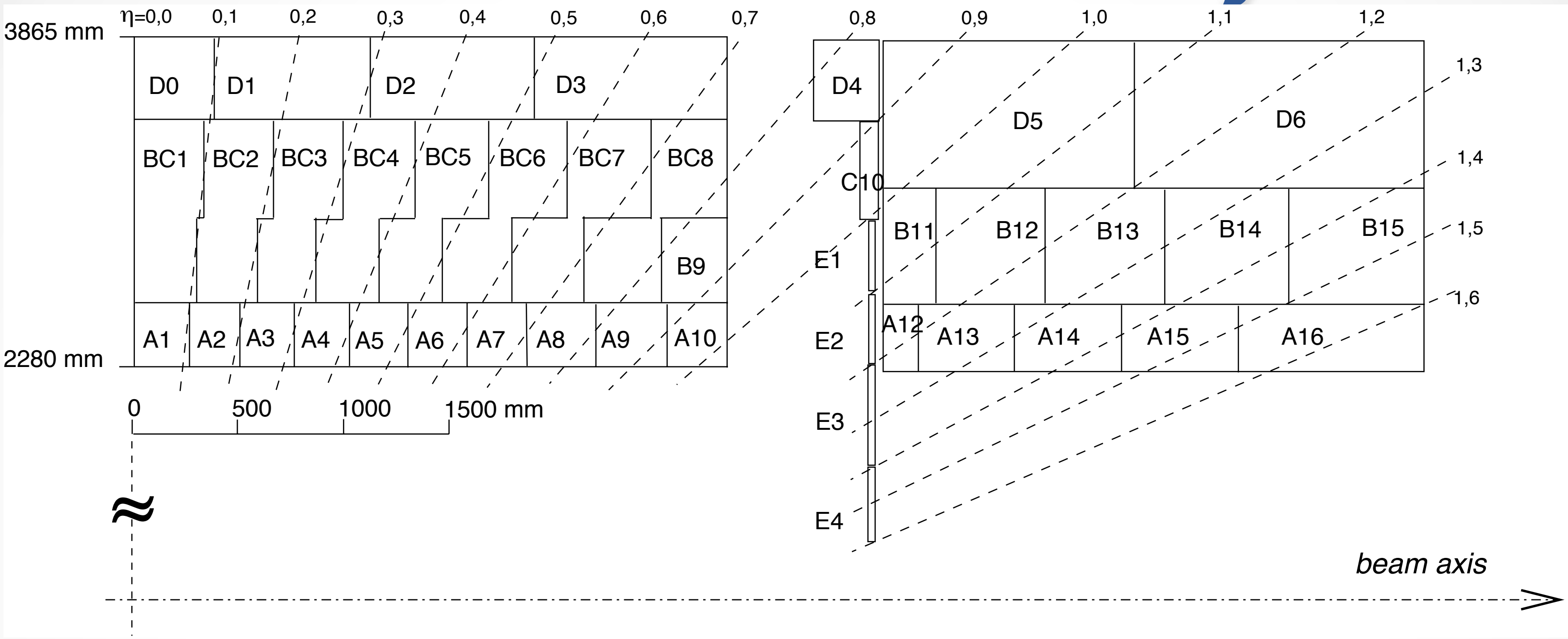
Tile Hadron Calorimeter



Tile Calorimeter module design drawing

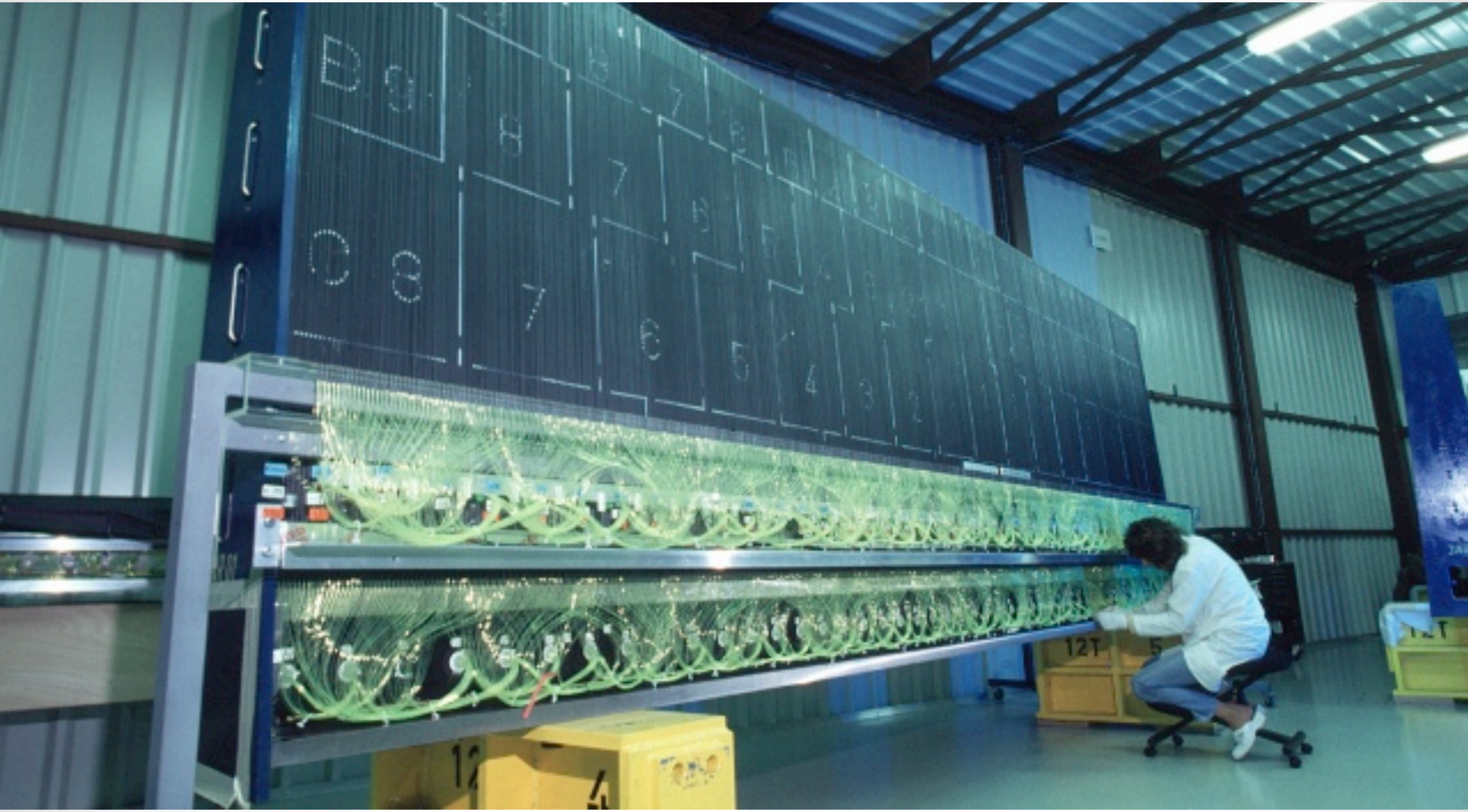
- Hadron non-compensating sampling calorimeter
  - Steel as radiator
  - Scintillating tiles as active medium
- 3 mm thick scintillating tiles (PSM, BASF polystyrene + dopants) oriented perpendicular to beam axis, wrapped in Tyvek paper
- Readout via green WLS fibres (Kuraray Y11) connected to both short edges of scintillating tiles
- Hamamatsu R7877 PMTs, located in a module's girder, collect light from the fibre bundles
- 3 cylinders: EB-A, LB, EB-C
- 64 modules in a cylinder
- One module weighs 22 tons (LB)

Calorimeter cell layout



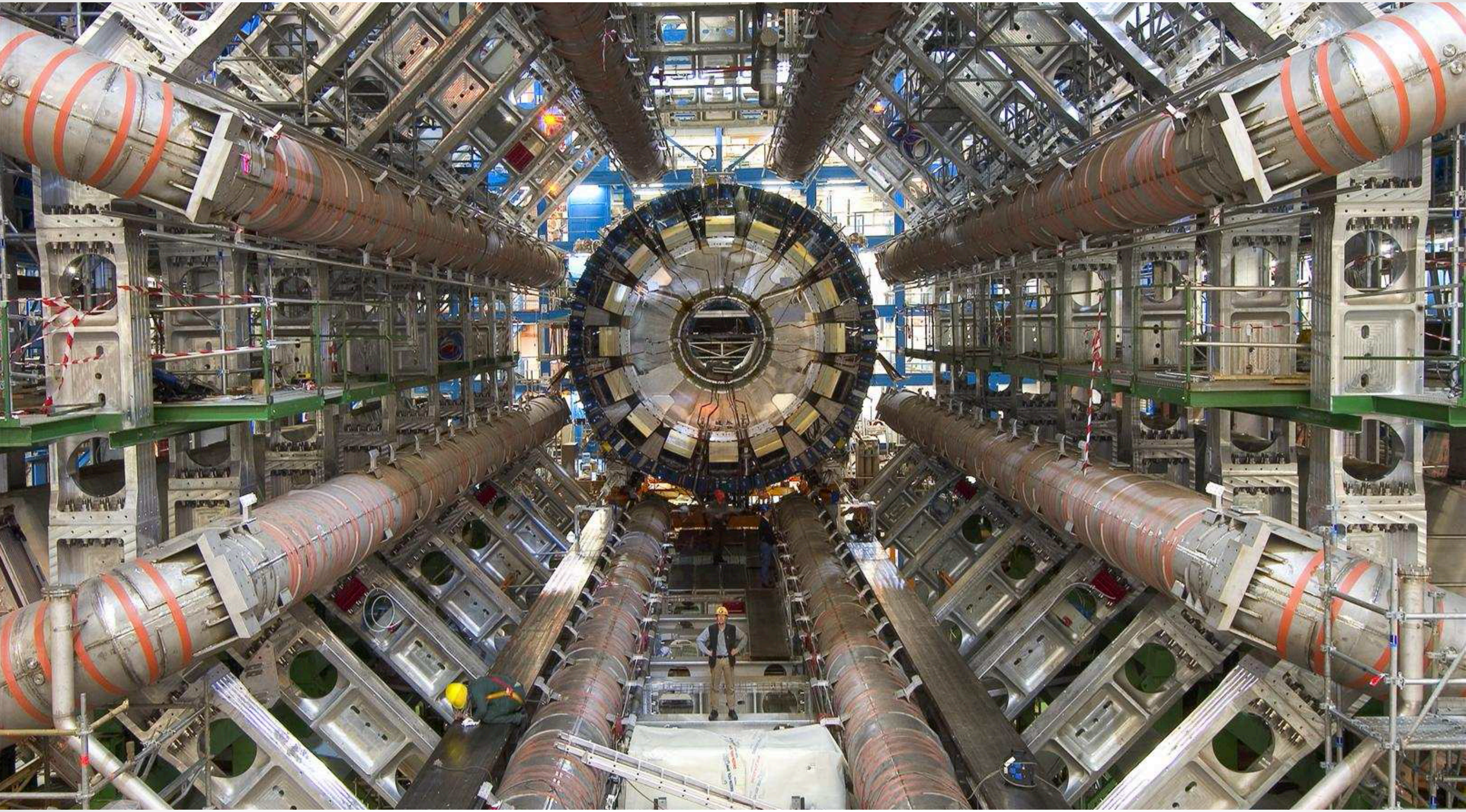
- Long barrel |η|<1.0, extended barrel 0.8 <|η|< 1.7
- WLS fibre routing defines calorimeter cells
- 0.1x0.1 ΔηxΔϕ cell granularity (0.2x0.1 for D layer cells)
- Three longitudinal layers, total thickness of about 7λ
- Pseudo-projective towers for first level trigger
- Design resolution for jets $\Delta E/E = 50\%/\sqrt{E}+3\%$

Calorimeter module



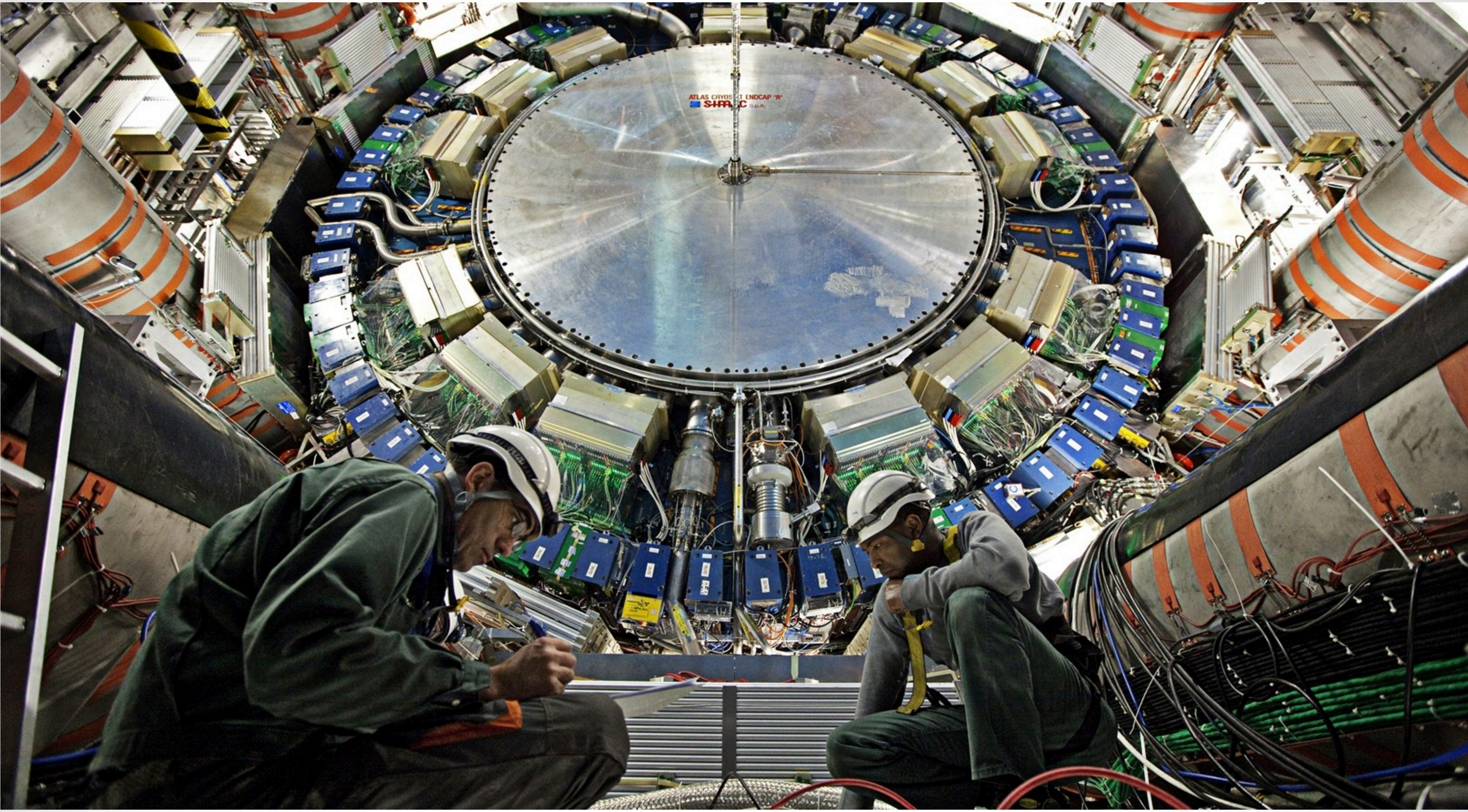
Instrumentation of the Tile Calorimeter barrel modules

Calorimeter in the cavern



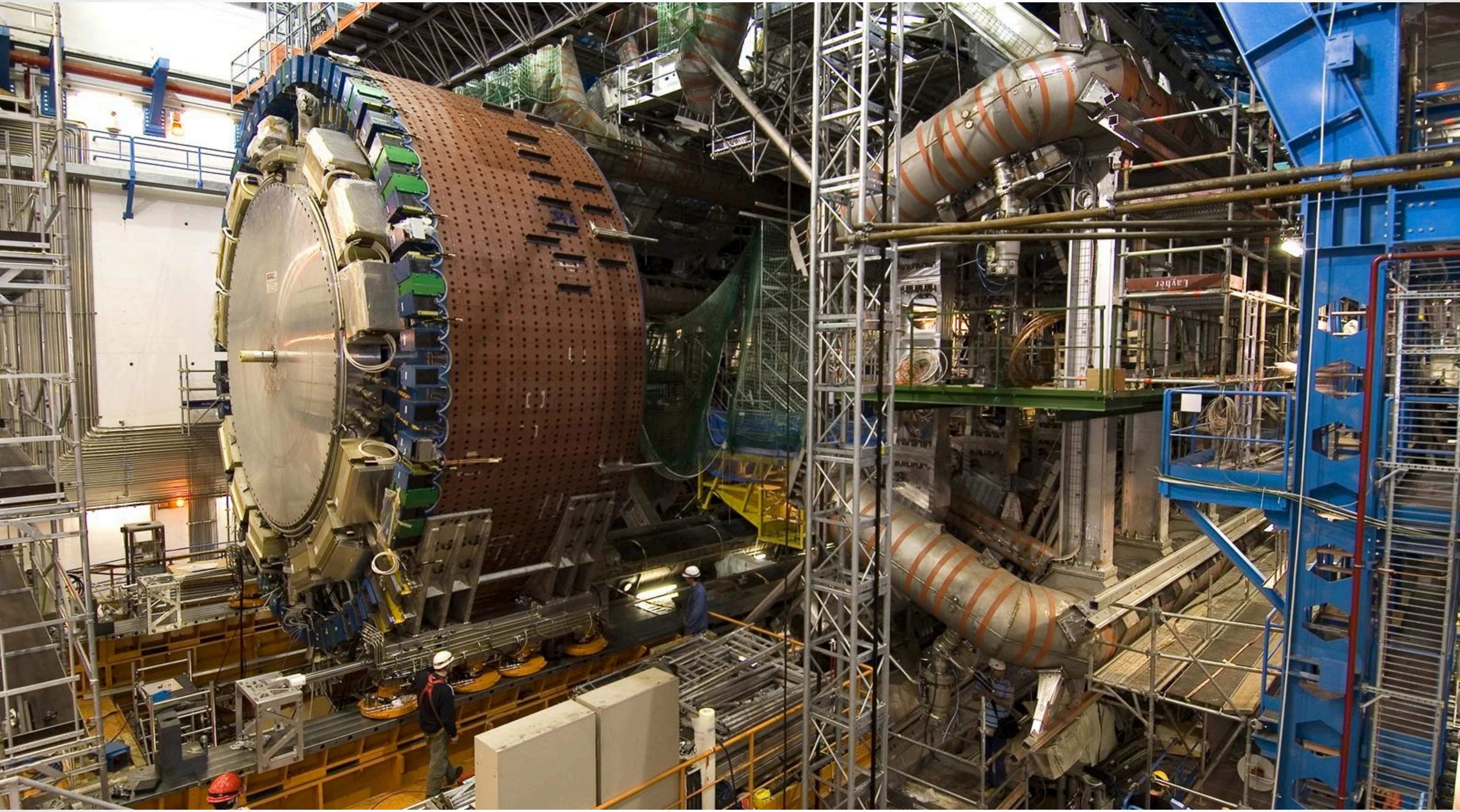
Barrel calorimeters moved to Z=0

Calorimeter in the cavern



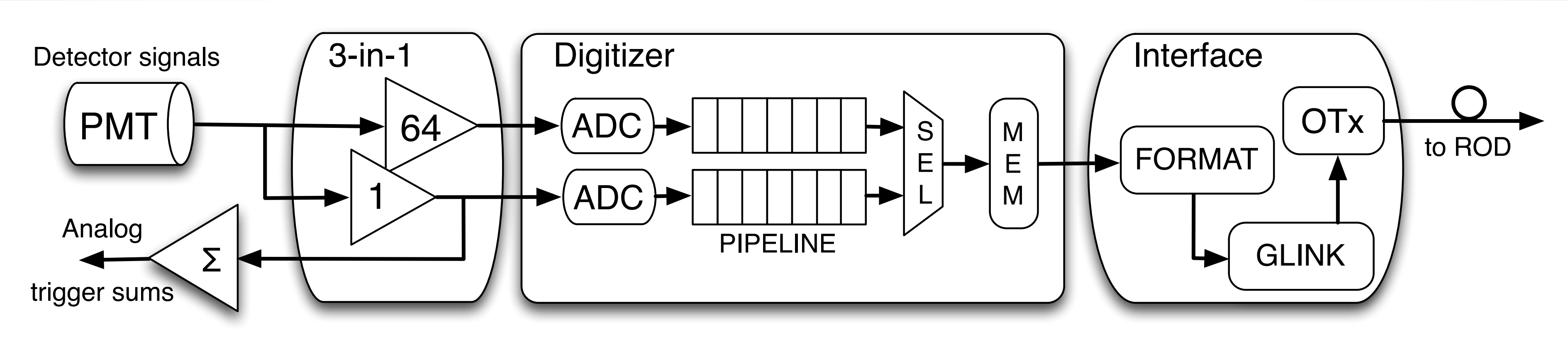
Engineers working near Extended Barrel calorimeters

Calorimeter in the cavern



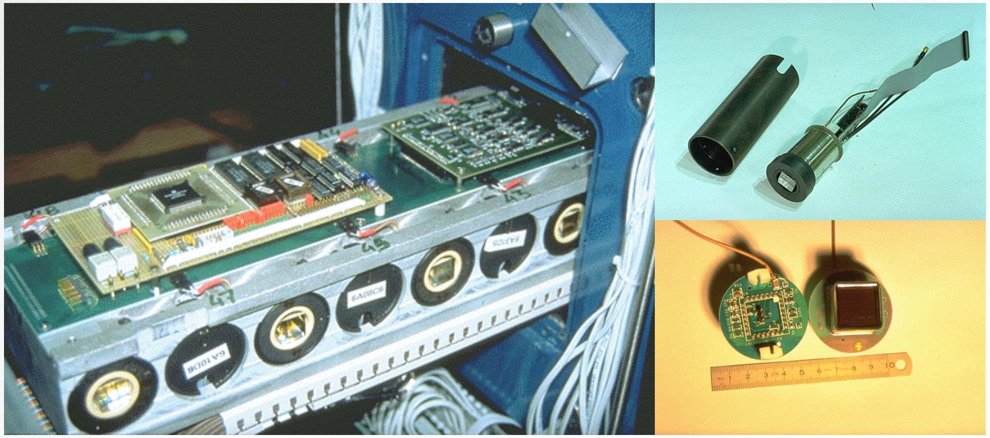
Extended Barrel calorimeters being moved to final position

Front-end electronics

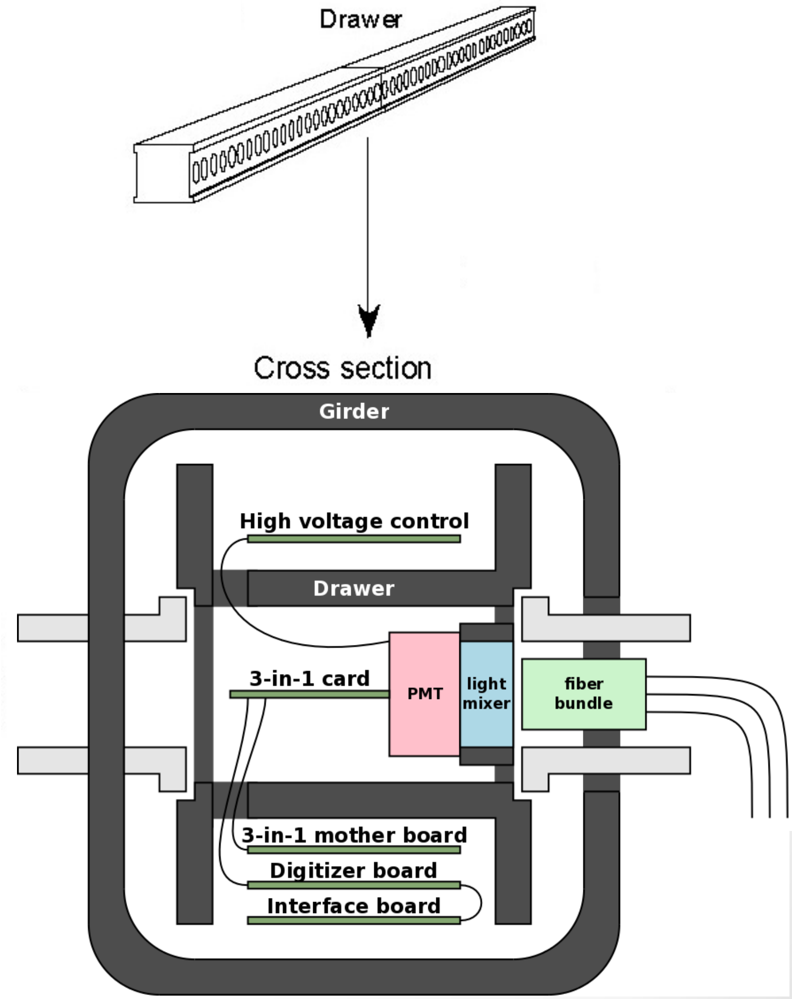


- PMTs signals are shaped and amplified with two gains (1:64)
- Analogue tower sums are provided for level one trigger
- Both gains are digitized in parallel by 40 MHz sampling 10-bit ADCs
- Digitised samples are temporary stored in pipeline memory
- Upon first level trigger decision the data of one of the gains are transferred to de-randomiser memory and then to the back-end electronics via readout fibres

Front-end electronics drawer

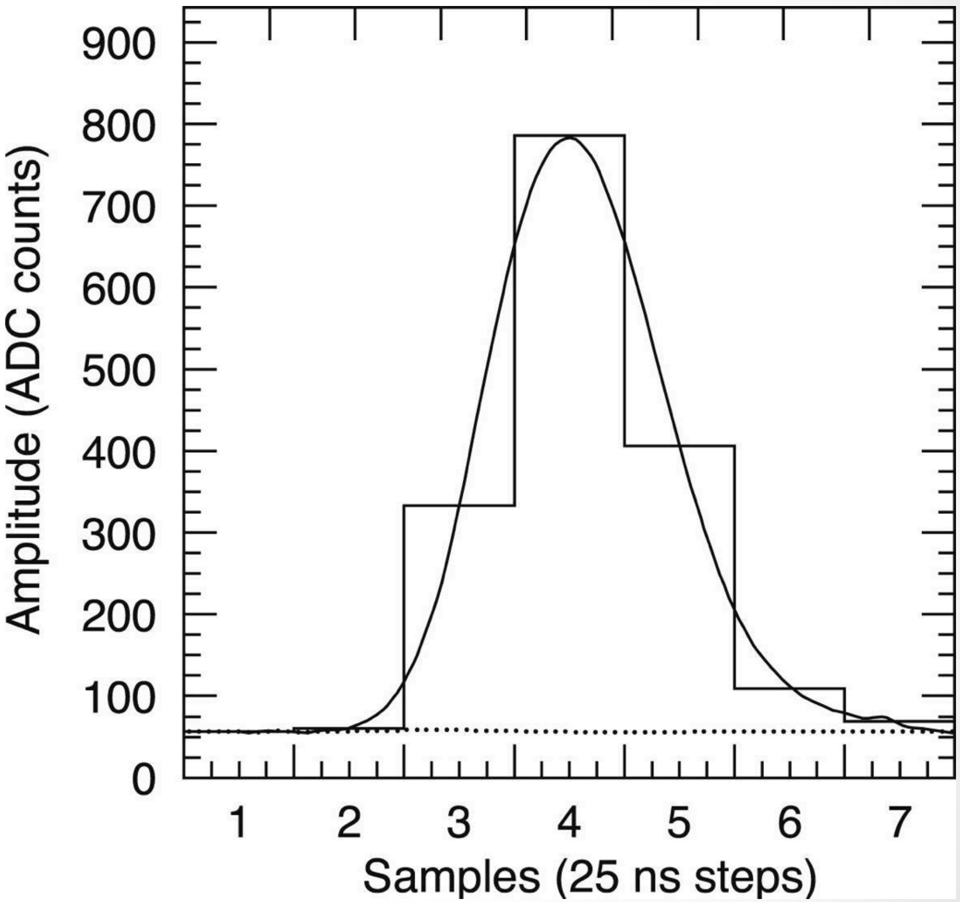


- Up to 45 PMT Blocks with HV bases
- Up to 45 3-in1 cards (shaper-amplifier-integrator board)
- 4 motherboards
- 8 digitizer boards
- one optical interface board
- one TTC receiver mezzanine card
- up to 10 analog summing cards
- one integrator readout board
- HV distribution boards
- LV distribution and sense adapters

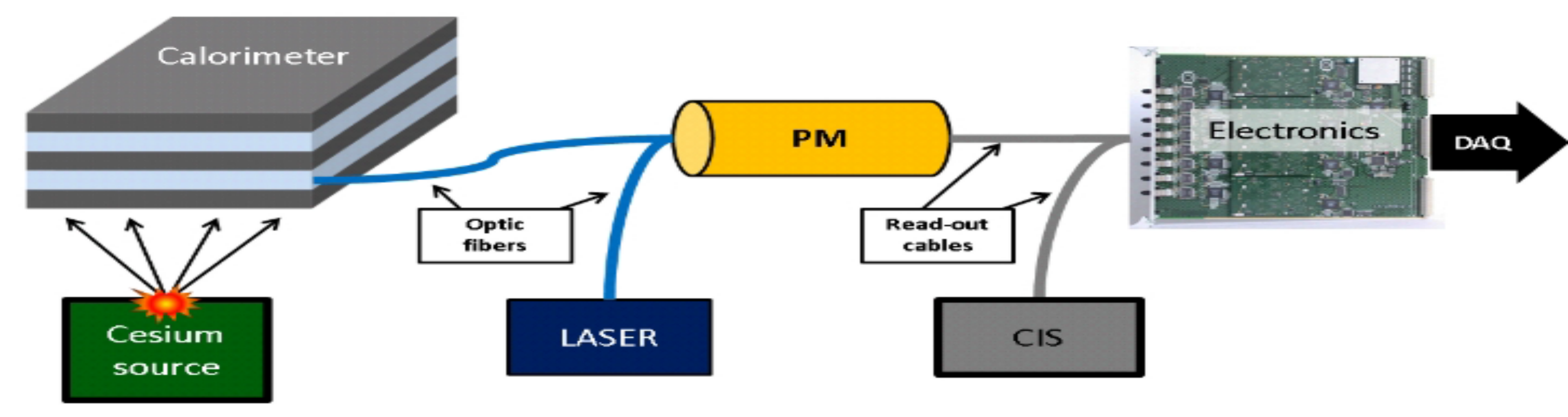


Signal reconstruction

- Signal is reconstructed from 7 samples using optimal filtering
- Energy, time and quality factor are extracted from the sampled signal
- Amplitude of the signal is proportional to the energy (shaping)



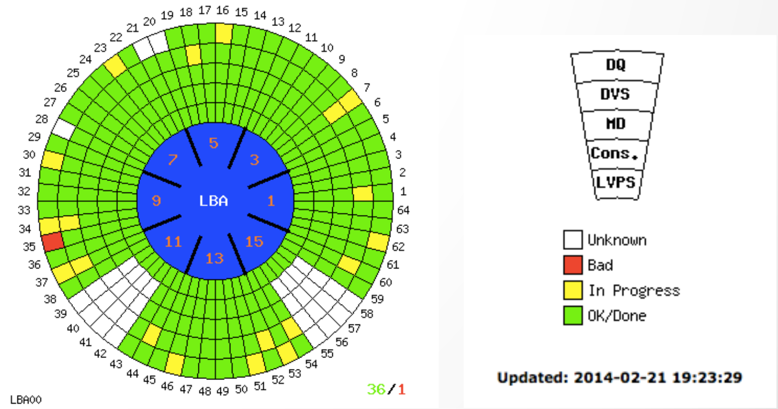
Calibration systems



- To provide correct energy and time for data reconstruction an elaborate chain of calibration systems has been conceived:
  - Charge inject system (CIS) to calibrate the response of the ADC
  - Laser calibration system to measure the performance of the PMTs
  - Cesium moving radioactive source system to calibrate the full optical path from scintillating tiles and WLS fibres down to integrated current of the PMT
  - Minimum bias monitoring system (MBM) to monitor the response of the calorimeter online
- About 11% of 192 Tile calorimeter modules were calibrated at the test beams and the EM scale was transferred to the final detector with the help of calibration systems

FE electronics maintenance

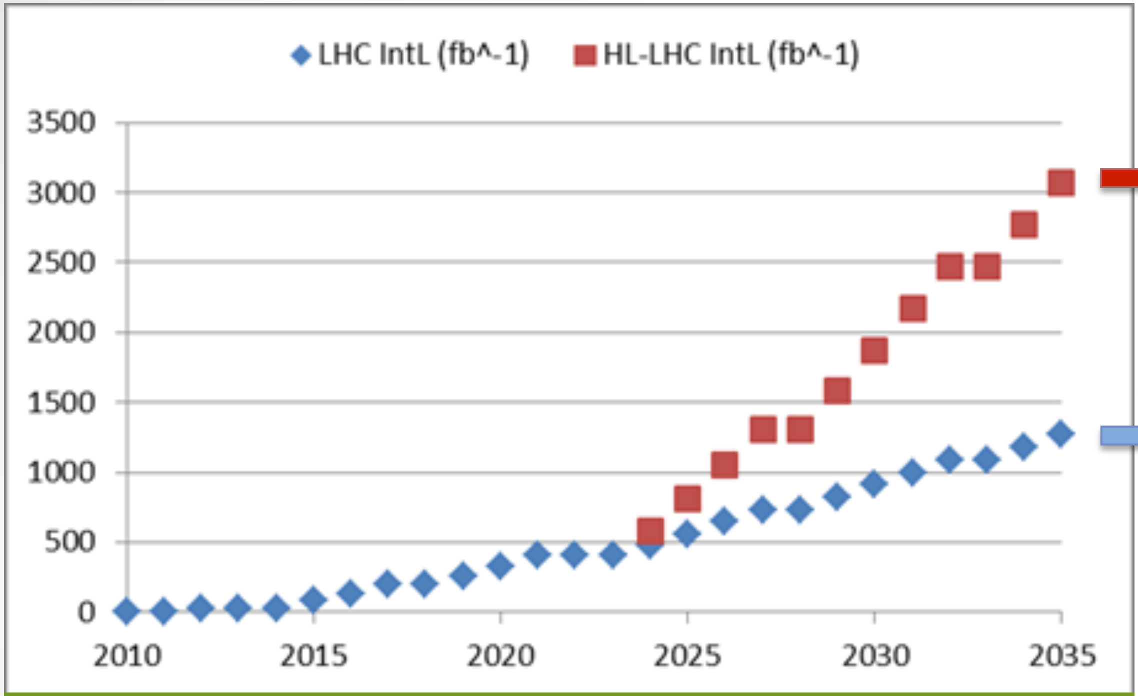
- During shutdown, when ATLAS detector is opened
- FE electronics “drawers” are extracted and bad components are replaced or fixed
- Allows to operate with minimum number of bad channels to maximize the quality of the data
- Data quality from consolidates modules is checked and the progress is tracked with web tools



Upgrade

HL-LHC

High Luminosity LHC



By implementing HL-LHC

Almost a factor of 3

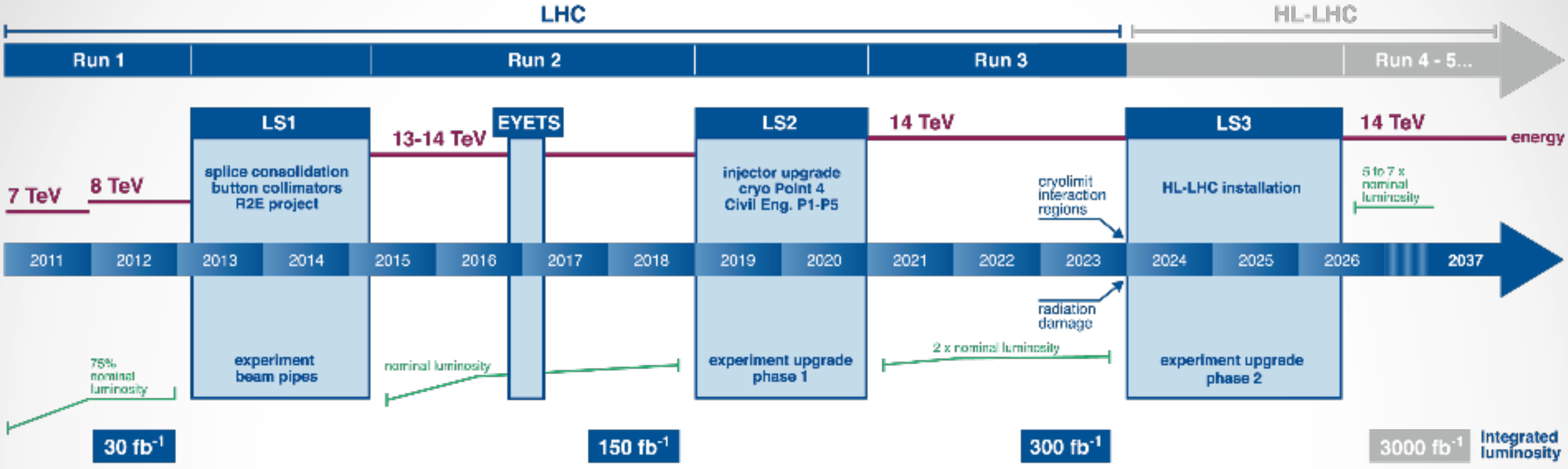
By continuous performance improvement and consolidation

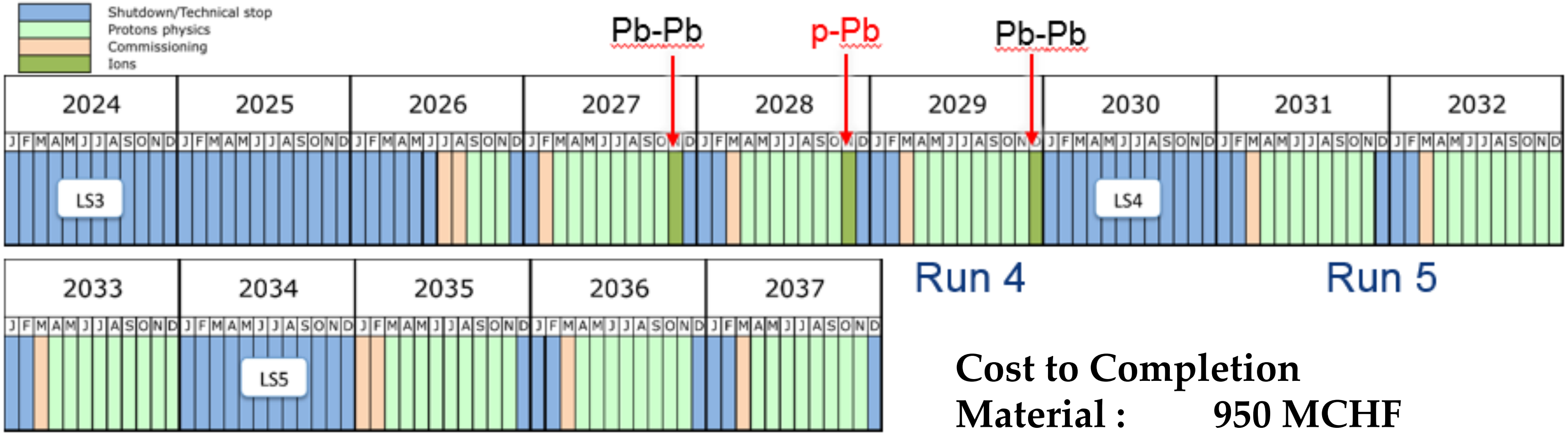
Goals of HL-LHC project:

- Prepare machine for operation **beyond 2025 and up to 2039**
- 250 – 300 fb^{-1} per year
- 'ultimate' performance of **7.5 10^{34} cm^{-2} s^{-1}**
- **4000 fb^{-1} in about 10 years - ten times the luminosity reach of first 10 years of LHC operation**

Around 300 fb^{-1} the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.

HL-LHC Plan





Run 6

Cost to Completion

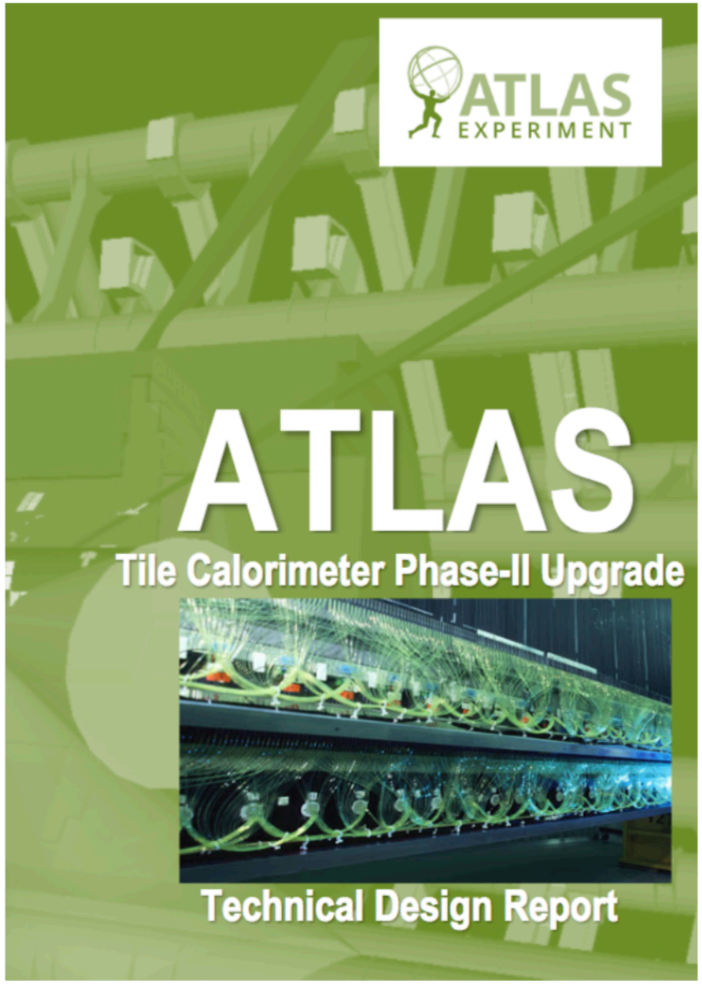
Material : **950 MCHF**

Personnel: **1600 FTE-years**

Tile Calorimeter Upgrade Program

- Advanced physics goals and LHC upgrade plans create new challenges for detectors
  - LHC upgrade program aims at 5-10 fold luminosity increase → more radiation → better radiation tolerance required
  - Ageing electronics → originally planned for 10 years of operation
  - Obsolete components → impossible to maintain
  - Higher event rates require more efficient trigger algorithms
- A multi-phase upgrade program has been conceived: Phase-0, Phase-I and Phase-II
- The major Tile Calorimeter mechanics and optics will stay, together with associated PMTs
- Front-end and back-end electronics, calibration systems, will undergo major upgrades in Phase-II
  - Complete redesign for font-end and back-end electronics
  - New electronics drawer mechanics
  - Fully digital trigger with higher selectivity and finer granularity
  - Demonstrator project to discover and solve issues as early as possible

TDR



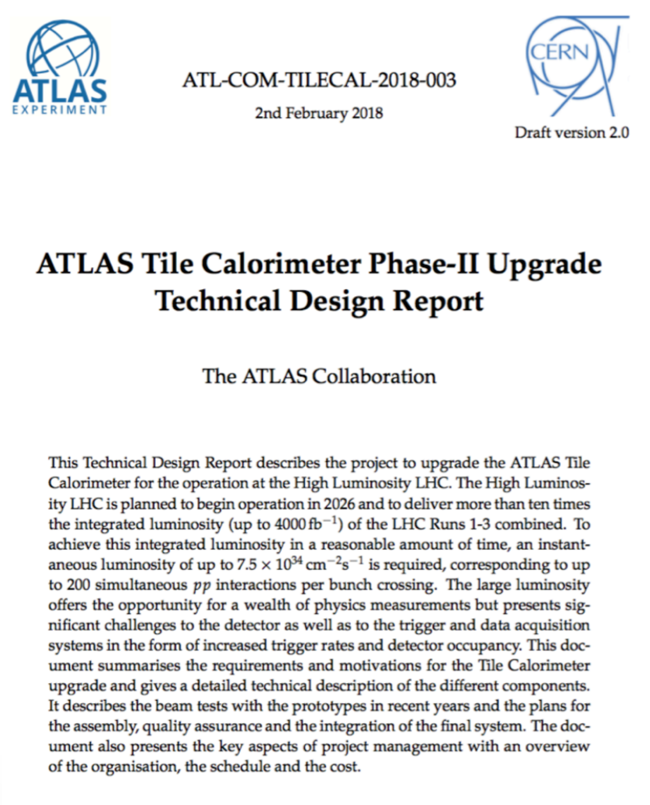
ATLAS EXPERIMENT

ATLAS

Tile Calorimeter Phase-II Upgrade

Technical Design Report

- Technical Design Report
  - Submitted to ATLAS Sep-2017
  - LHCC reviewed Nov-2017
  - CB approved Feb-2018
  - RB approval Mar-2018



ATL-COM-TILECAL-2018-003

2nd February 2018

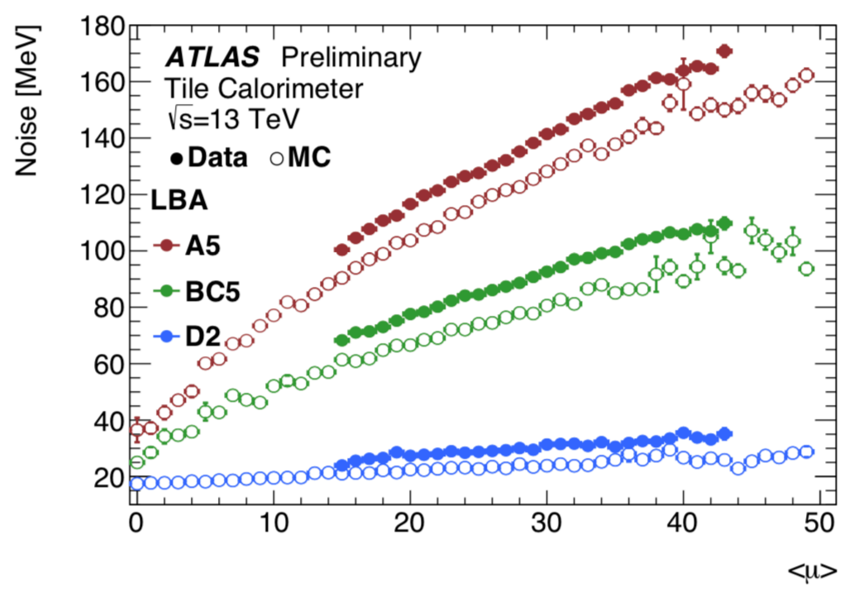
Draft version 2.0

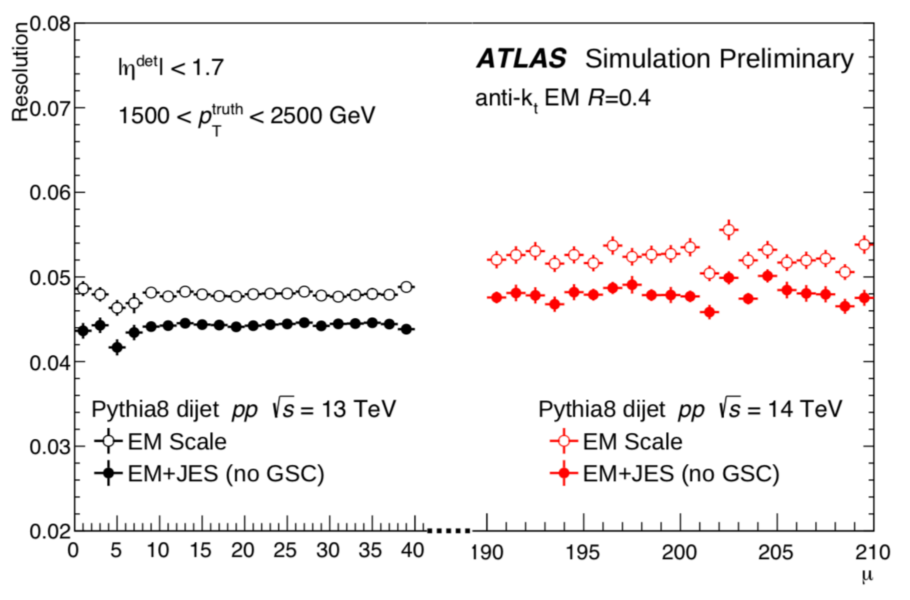
ATLAS Tile Calorimeter Phase-II Upgrade Technical Design Report

The ATLAS Collaboration

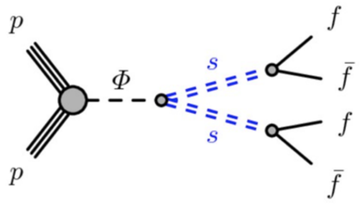
This Technical Design Report describes the project to upgrade the ATLAS Tile Calorimeter for the operation at the High Luminosity LHC. The High Luminosity LHC is planned to begin operation in 2026 and to deliver more than ten times the integrated luminosity (up to 4000 fb^{-1}) of the LHC Runs 1-3 combined. To achieve this integrated luminosity in a reasonable amount of time, an instantaneous luminosity of up to $7.5 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$ is required, corresponding to up to 200 simultaneous pp interactions per bunch crossing. The large luminosity offers the opportunity for a wealth of physics measurements but presents significant challenges to the detector as well as to the trigger and data acquisition systems in the form of increased trigger rates and detector occupancy. This document summarises the requirements and motivations for the Tile Calorimeter upgrade and gives a detailed technical description of the different components. It describes the beam tests with the prototypes in recent years and the plans for the assembly, quality assurance and the integration of the final system. The document also presents the key aspects of project management with an overview of the organisation, the schedule and the cost.

Upgrade Performance

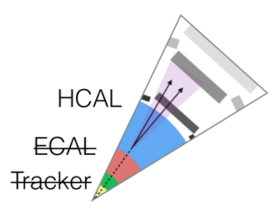


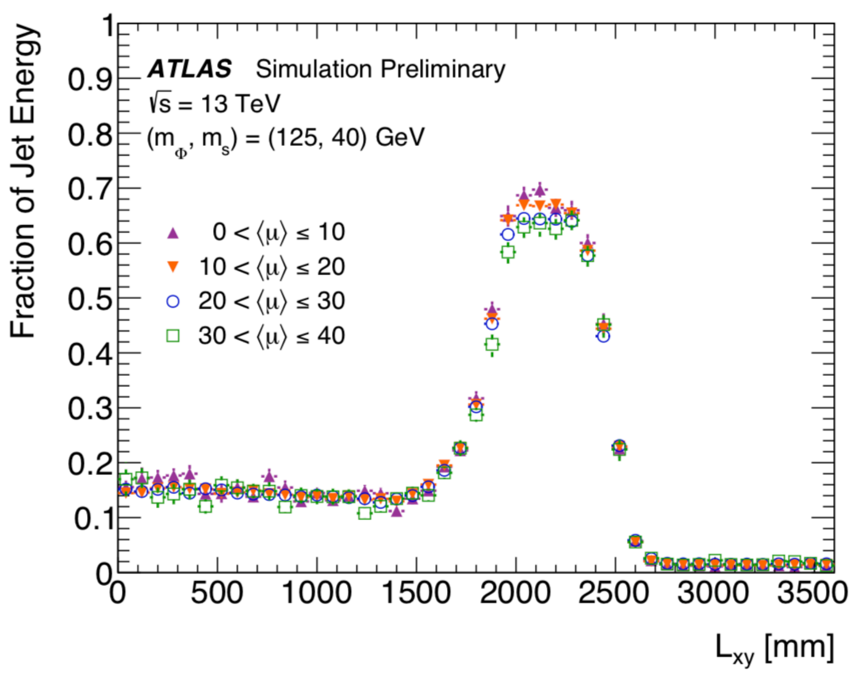


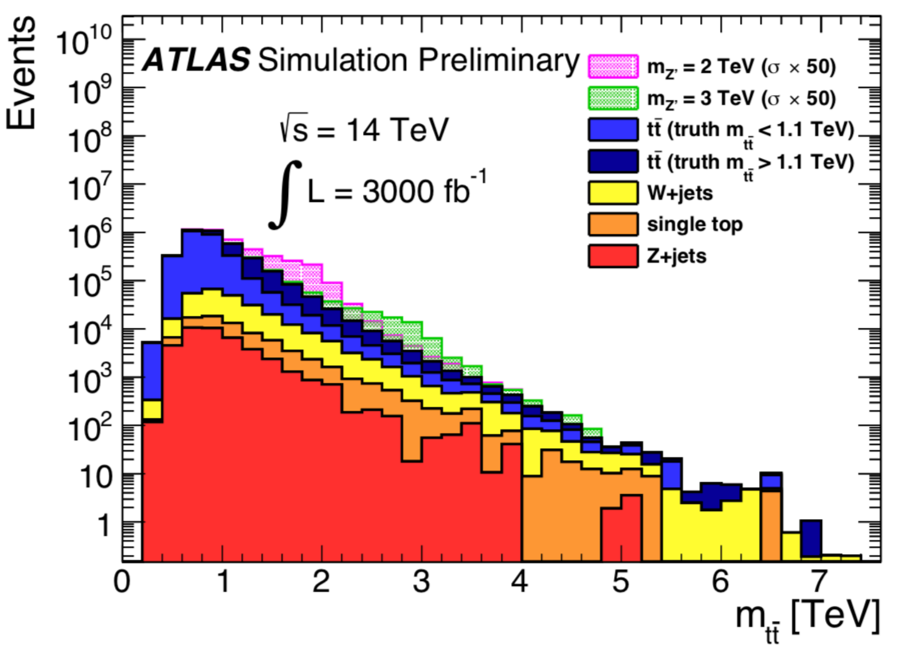
- TileCal contributes to the performance of Jets, Electron/photon, Muon and Tau
- Provides information for the calorimeter trigger
- Measurements and searches in SM/Top/Higgs/ Exotics/SUSY groups depend on the TileCal performance
- Challenges in pile-up noise
- Very stable jet response and resolution as a function of pile-up
- Jet angular resolution is very similar to that in Run-2
- Slightly worse jet energy resolution compared to that in Run-2



Upgrade Studies

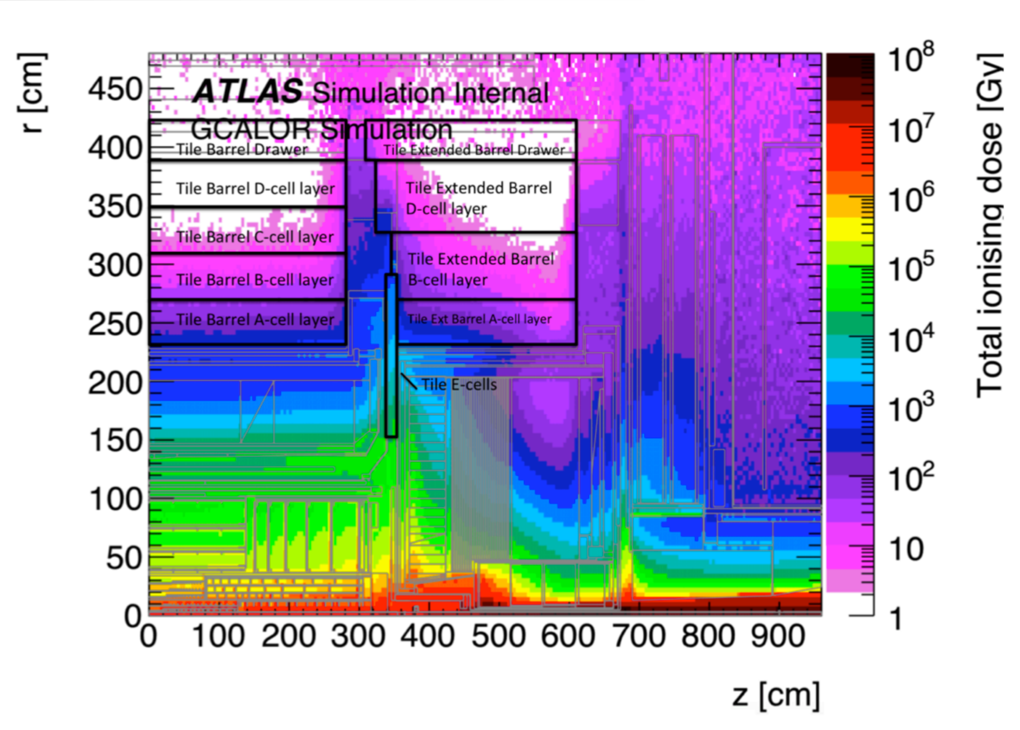


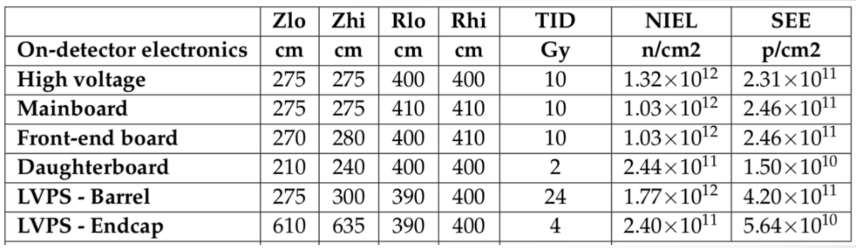




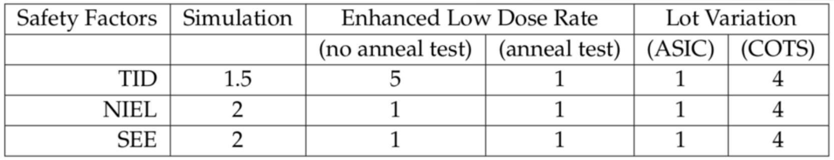
- Long Lived Particles (LLP)
  - Neutral LLP decays in TileCal -> displaced jet
  - Isolated and narrow energy deposits in TileCal
  - Hardware trigger with greater granularity
- Z’ decay to ttbar
  - *ttbar* resonance search as a benchmark for a ~TeV range new particle searches : phasespace + statistics
  - Expect to observe (or exclude) the resonances with mass up to 4 TeV

Radiation Hardness





	Zlo	Zhi	Rlo	Rhi	TID	NIEL	SEE
On-detector electronics	**cm**	**cm**	**cm**	**cm**	**Gy**	**n/cm2**	**p/cm2**
High voltage	275	275	400	400	10	1.32×10^{12}	2.31×10^{11}
Mainboard	275	275	410	410	10	1.03×10^{12}	2.46×10^{11}
Front-end board	270	280	400	410	10	1.03×10^{12}	2.46×10^{11}
Daughterboard	210	240	400	400	2	2.44×10^{11}	1.50×10^{10}
LVPS - Barrel	275	300	390	400	24	1.77×10^{12}	4.20×10^{11}
LVPS - Endcap	610	635	390	400	4	2.40×10^{11}	5.64×10^{10}

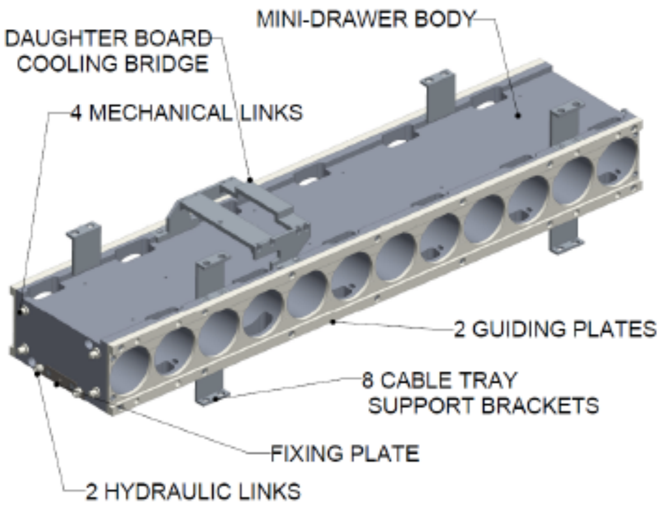


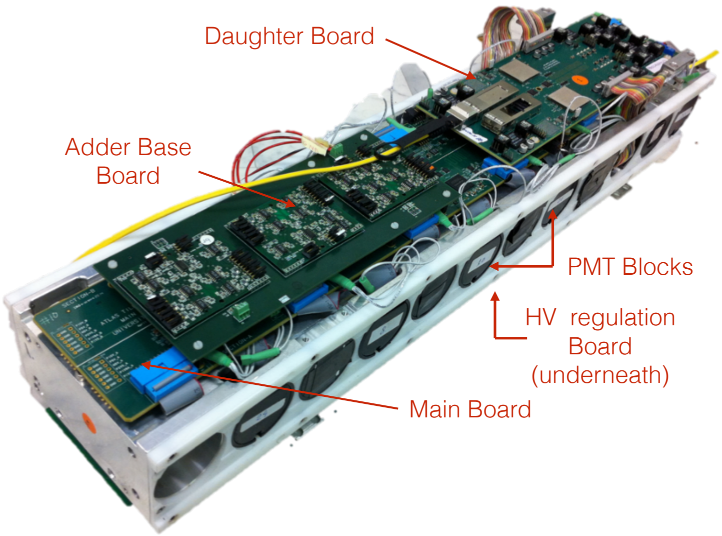
Safety Factors	Simulation	Enhanced Low Dose Rate		Lot Variation	
		(no anneal test)	(anneal test)	(ASIC)	(COTS)
TID	1.5	5	1	1	4
NIEL	2	1	1	1	4
SEE	2	1	1	1	4

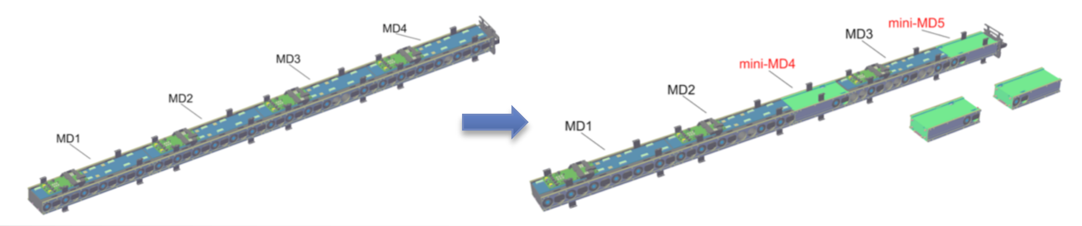
- Tile Calorimeter read-out electronics housed at the outer radius of the calorimeter, shielded by the calorimeter body
- Radiation dose requirements are not as critical as in other ATLAS sub-detectors, but…
- HL-LHC will deliver x10 more dose to the electronics
- All electronics require certification with appropriate safety factors (up to 30)

Mini Drawers

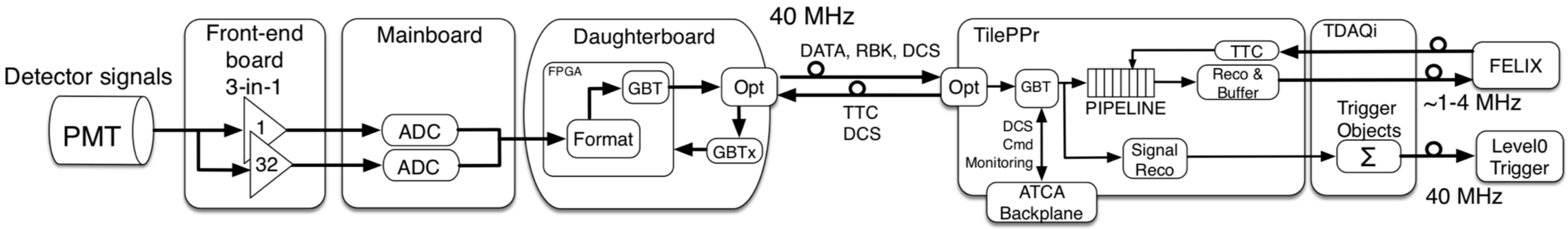
- PMTs and on-detector electronics are housed in “drawers”
- Old super-drawer design is heavy and difficult to maintain
- New design have 4 mini-drawers
- Robust mechanical links
- New cooling system
- Special installation tooling
- Special design of mini-mini drawers for extended barrels to save on electronics







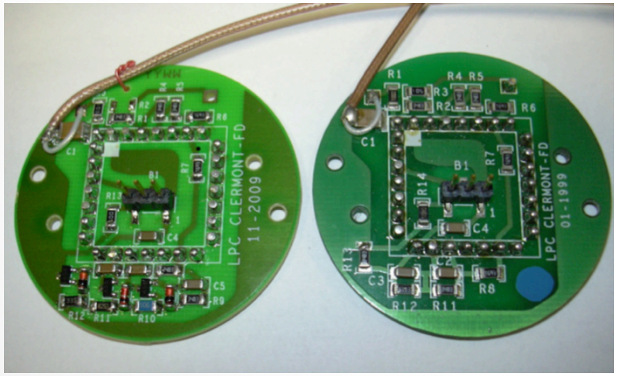
New Readout Architecture

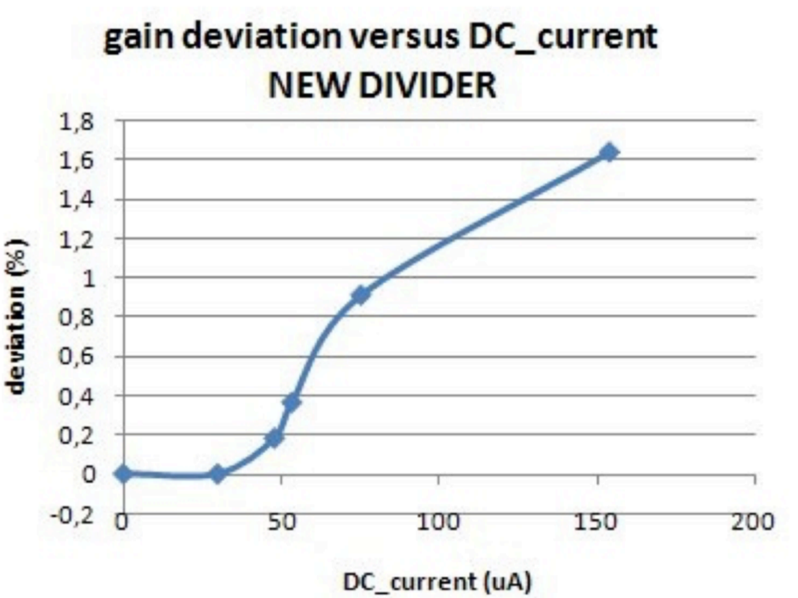


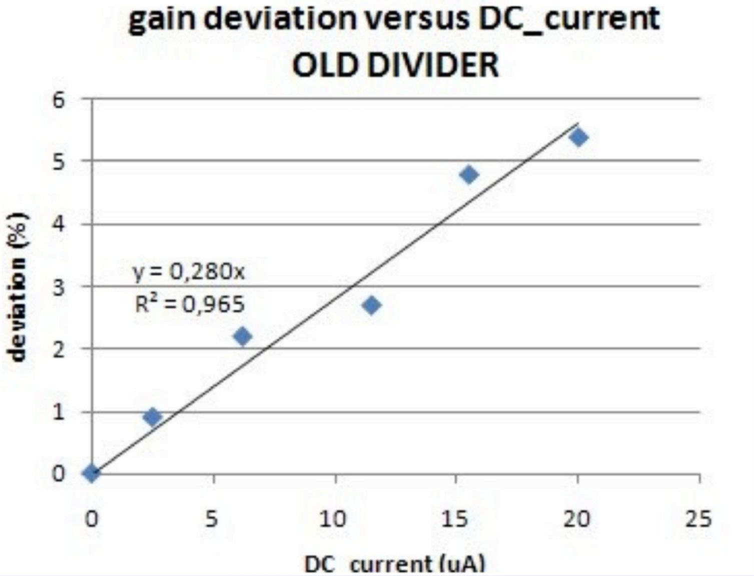
- All digital data is transmitted off-detector at 40 MHz
- The data is pipelined and processed in the off-detector pre-processor boards (TilePPrs)
- Simpler on-detector electronics
- Flexibility of the off-detector data processing for the trigger
- Redundancy and reliability

HV dividers

- Measurable deviations from linearity of the PMT response are expected for anode currents > 5 μA
- At high current the HV distribution between dynodes changes, thus changing the PMT gain
- Present Passive dividers are linear (2%) for currents < 5 μA
- Clermont-Ferrand developed an active divider for TileCal PMTs with linearity robust to the increased currents
- New active dividers were installed during LS1 shutdown (2013-2014) in gap/crack cells

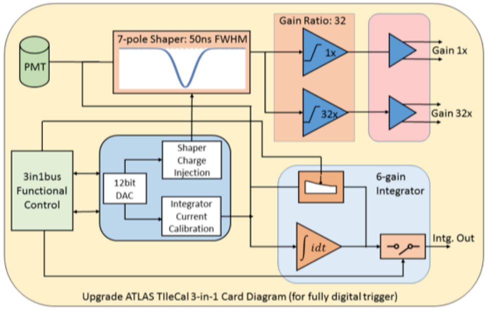



gain deviation versus DC_current
NEW DIVIDER


gain deviation versus DC_current
OLD DIVIDER

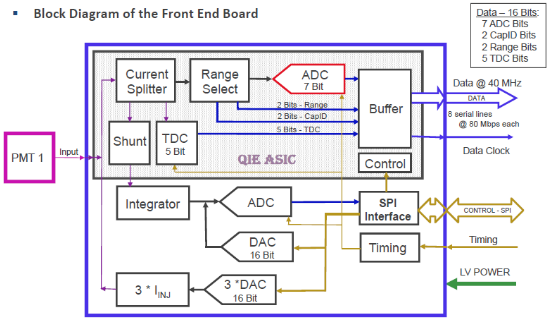
Front-End Board (FEB)

- 3 FEB options
- Discrete
  - Optimised 3in1
- ASIC
  - QIE
  - FATALIC
- Prototypes of all FEB options were tested in labs and test beams
- 3in1 option was selected as a baseline



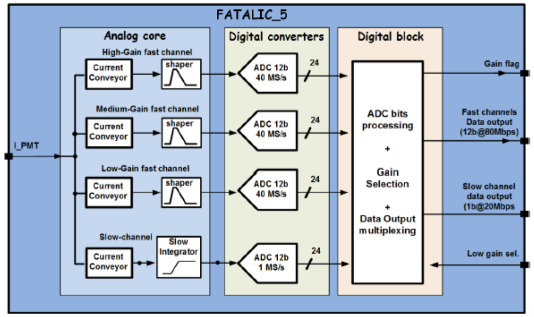
Upgrade ATLAS TileCal 3-in-1 Card Diagram (for fully digital trigger)

3in1:
- Improved linearity and rad. tolerance
- 2 gains (high and low)
- Charge injection calibration



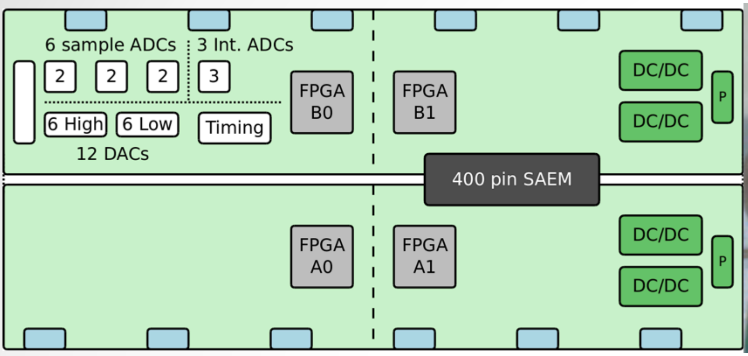
- Block Diagram of the Front End Board

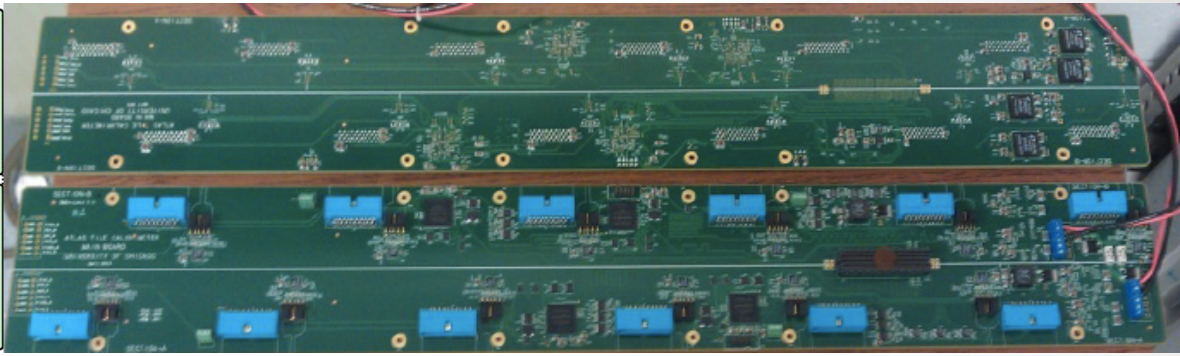
QIE:
-"Current splitter" with gate integrator
- No pulse shaping, dead-timeless digitization at 40 MHz
- Pipelined operation, 18-bit dynamic range



FATALIC:
- 3-gain PMT signal analog processing
- 3 embedded 12-bit ADCs (one per gain)
- Auto-gain selection (Medium and {High or Low})
- 12-bit output bus (data multiplexing of 2 gains)

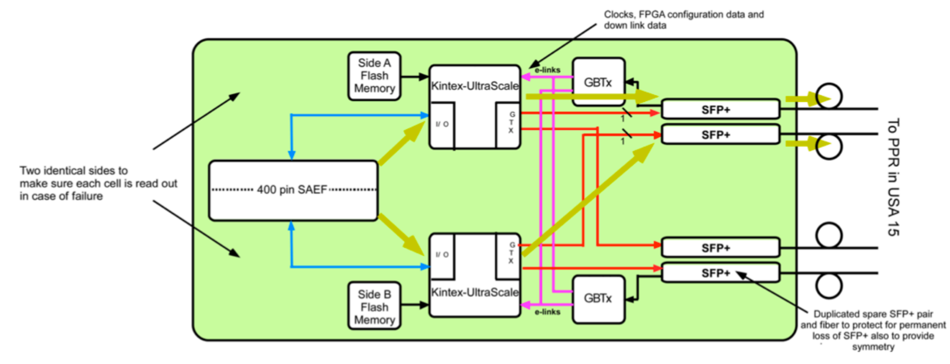
Main Board (MB)

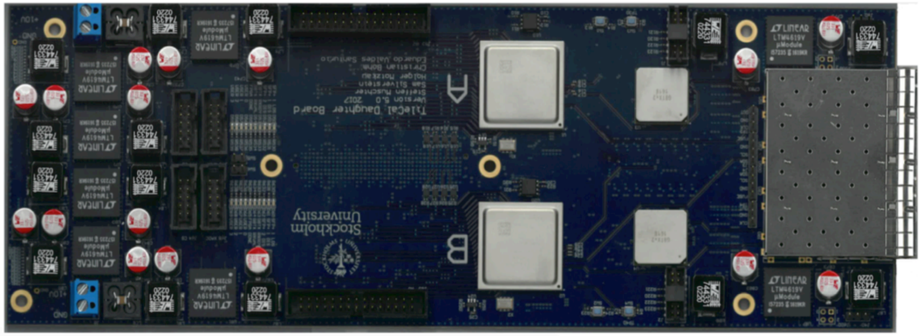


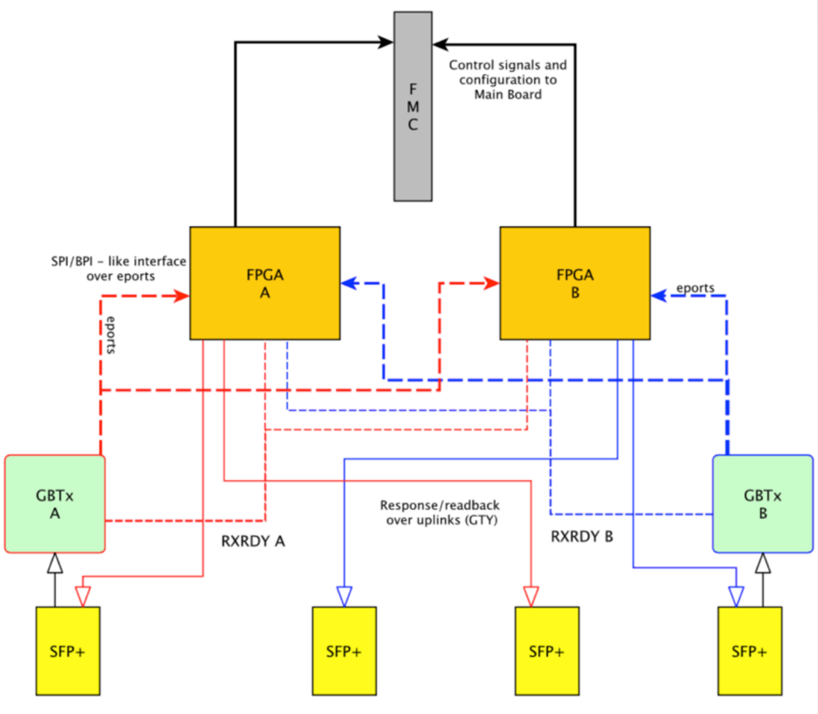


- Connects FEBs to DB
- ADCs in case of 3in1, otherwise very simple
- Split into two halves for redundancy
- Each cell read-out by two PMTs, one on each side of the mainboard
- Samples are transferred serially to the daughterboard at 600 MHz
- Commands are sent in parallel to 2 control FPGAs on each side

Daughter Board (DB)

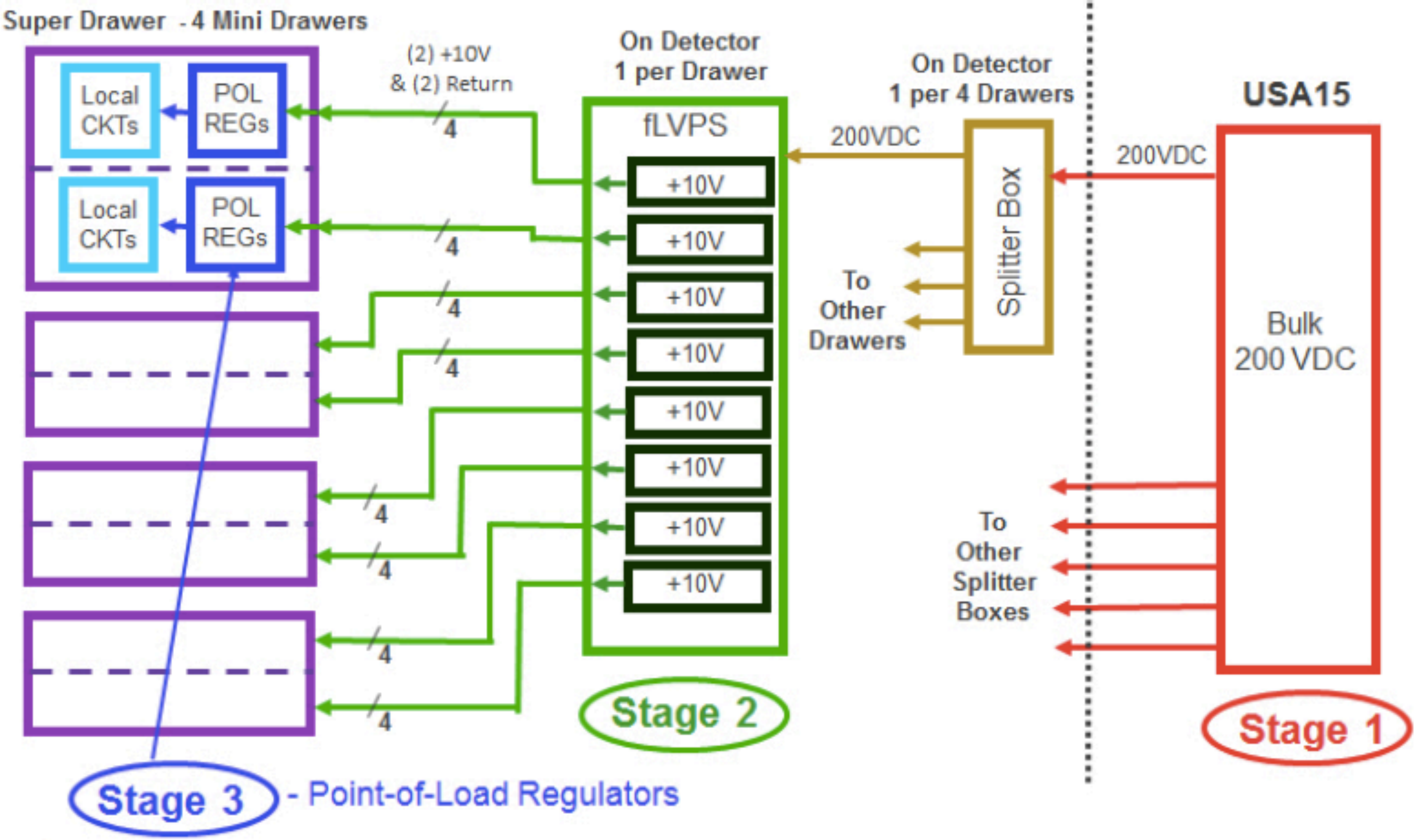






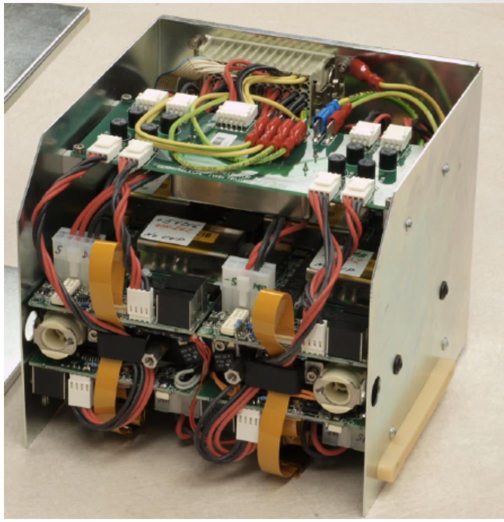
- Provides communication with back-end electronics
  - **Redundant** system on a single PCB, 14 layers
  - Two Kintex UltraScale+ FPGAs and four SFP+ Modulators
  - Two GBTx chips
  - Firmware can be uploaded through the optical link
  - TTC and data connection with PPR

LV Power Distribution

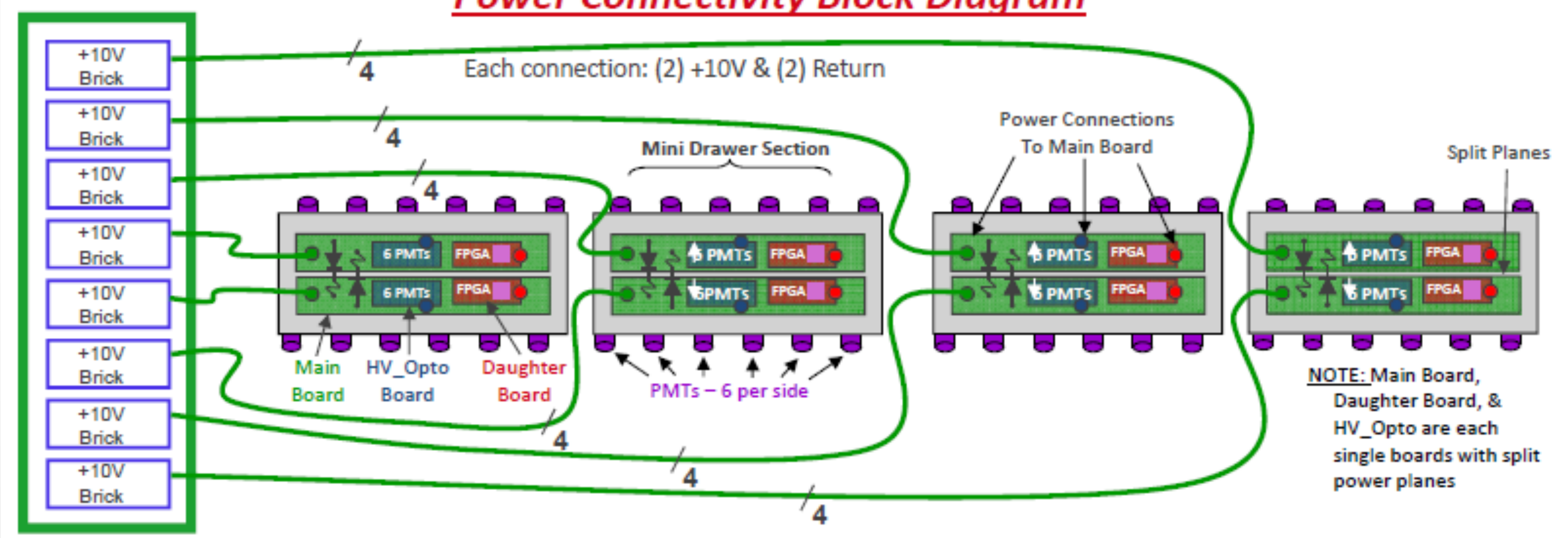


Finger LV Power Supply (fLVPS)

- Fits the same box, revision of the power distribution scheme
- Unique +10V supply, other voltages are derived in situ using point of load (POL) regulators
- Increased redundancy
- Used at test beam



Power Connectivity Block Diagram



NOTE: Main Board, Daughter Board, & HV_Opto are each single boards with split power planes

HV Power Distribution

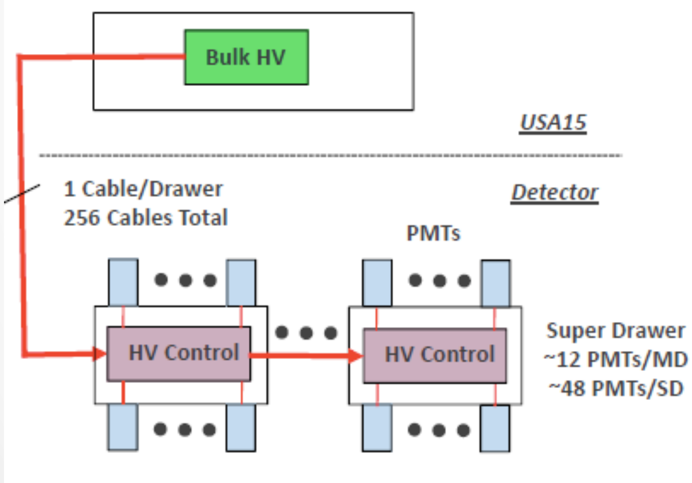
Internal (HV-opto)

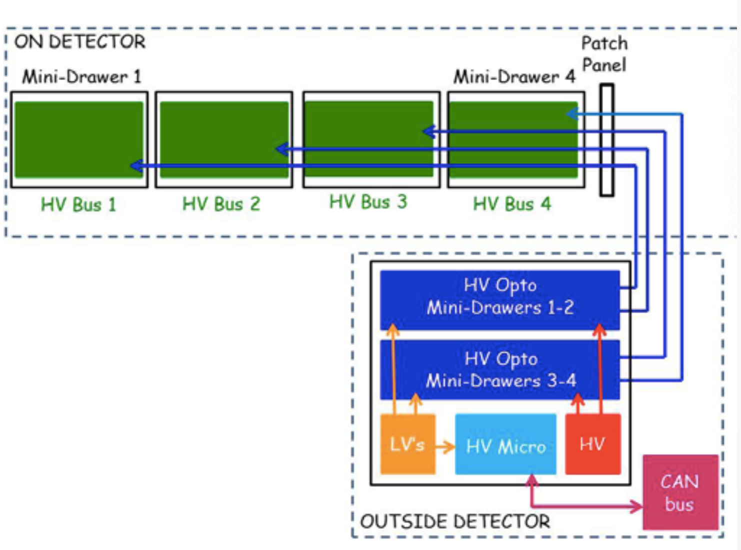
- Existing HV cable
- Internal regulation
- Subject to SEUs

Remote (HV-remote)

Baseline

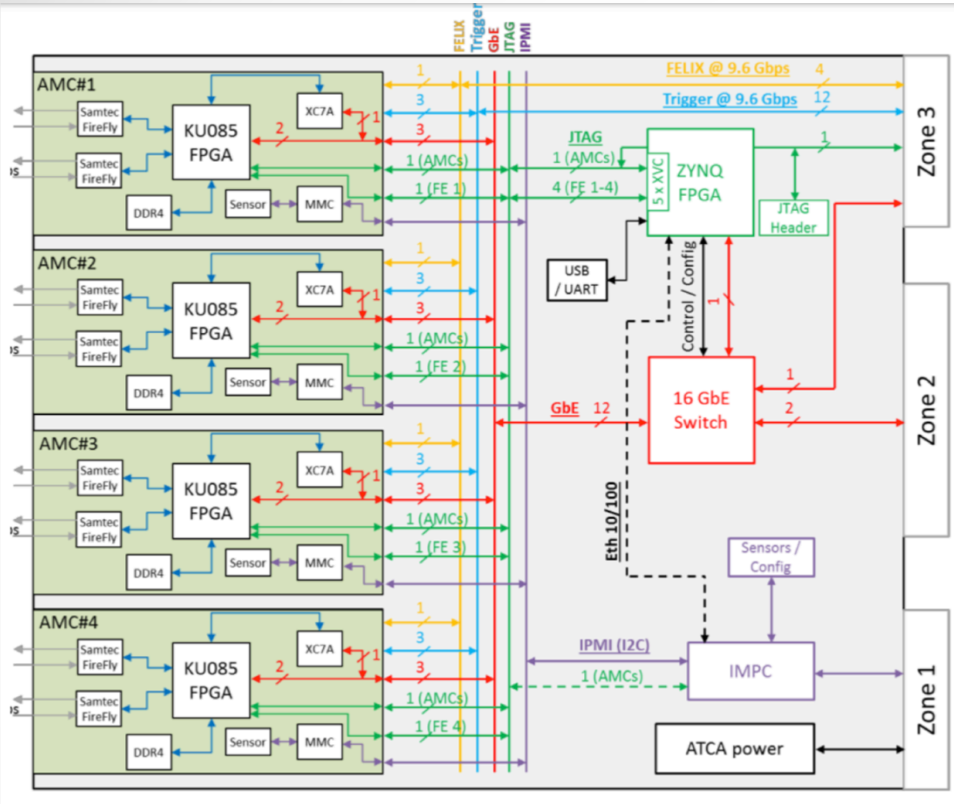
- New thick cables
- Remote regulation
- No rad. requirements

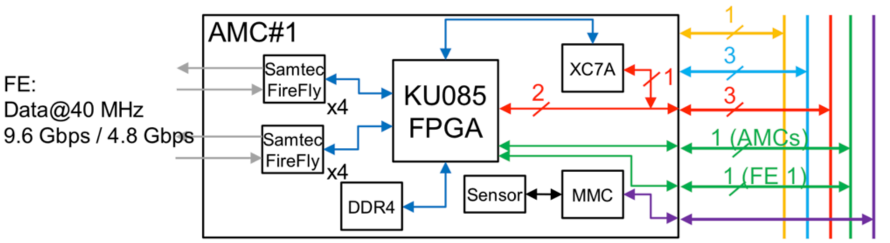


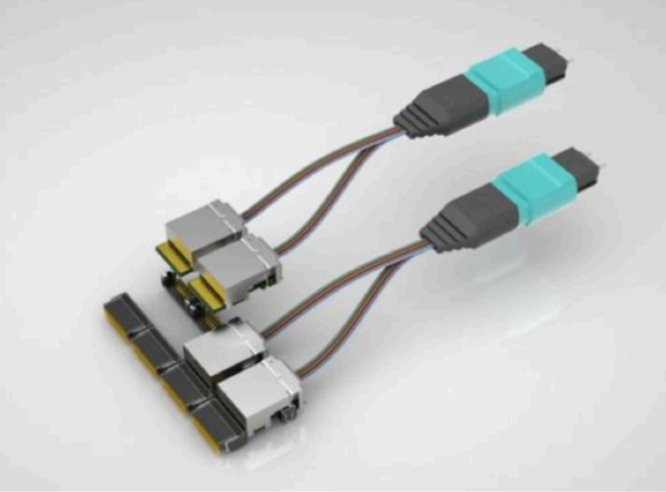


PPR

F. Carrio

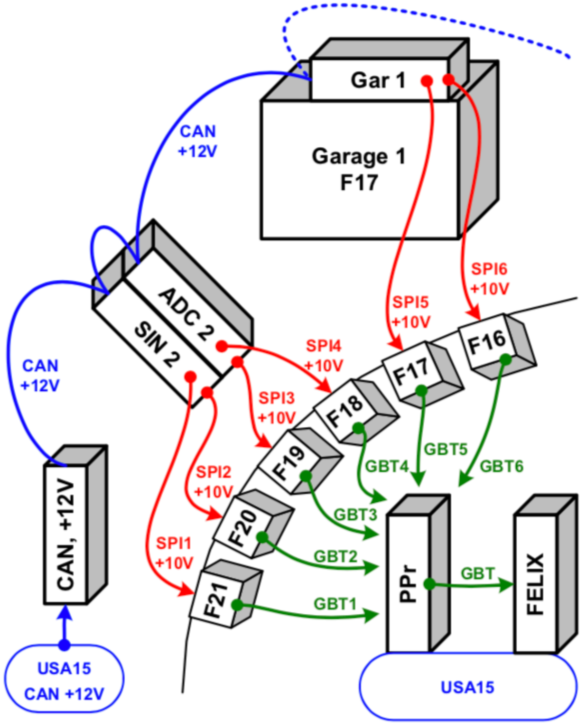


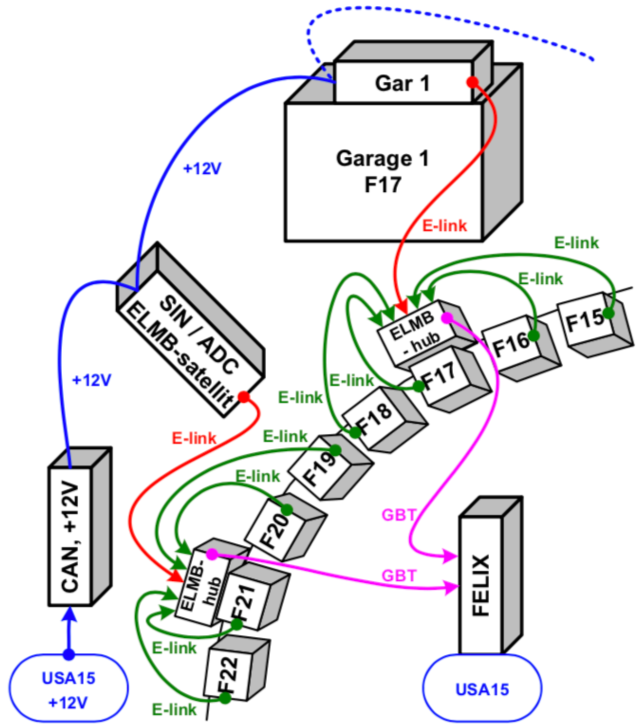


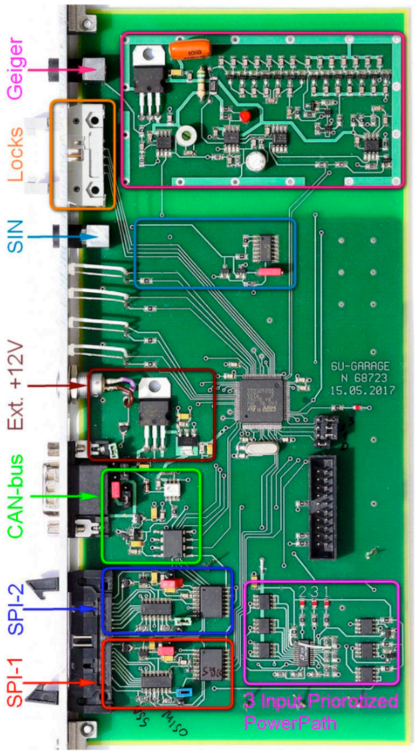


- Interface between FE/DAQ/Trigger
- ATCA blade with CPMs
- Need 32 PPRs in total
- 4x channel prototype successfully tested
- Full-size design in progress
- TDAQi RTM to transfer the data to trigger and readout

Calibration Systems

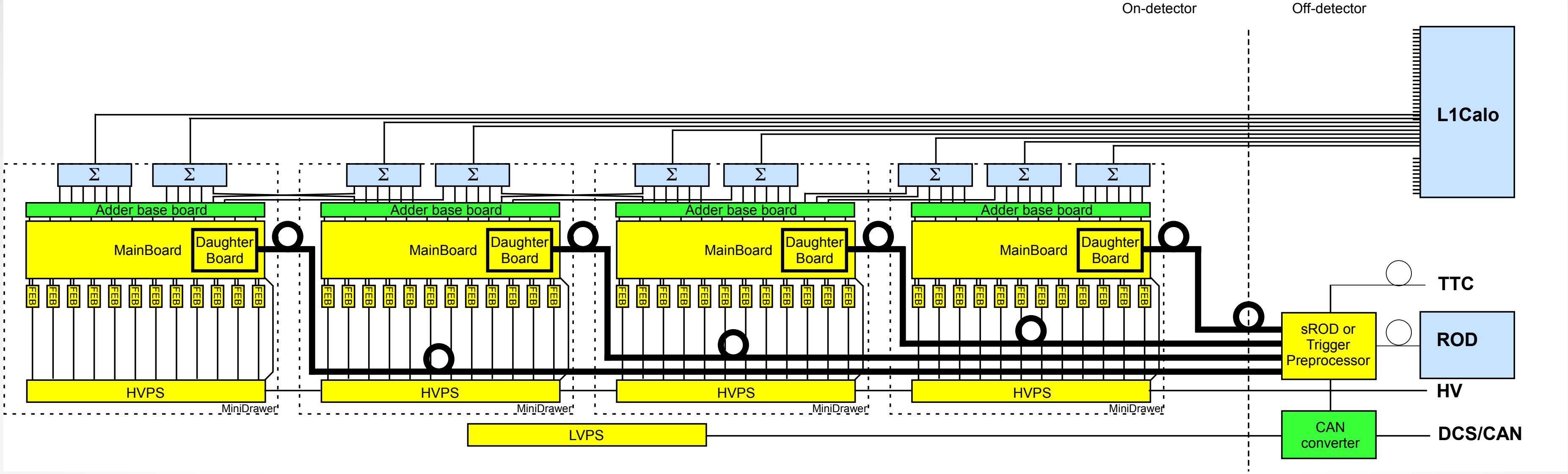






- All calibration systems will continue to be present in the upgraded electronics
- Charge Injection – for ADC calibration
- Laser – for PMT gain calibration and monitoring
- Min.Bias – for luminosity, pile-up and cell response monitoring
- Cs137 – for absolute calibration and reference

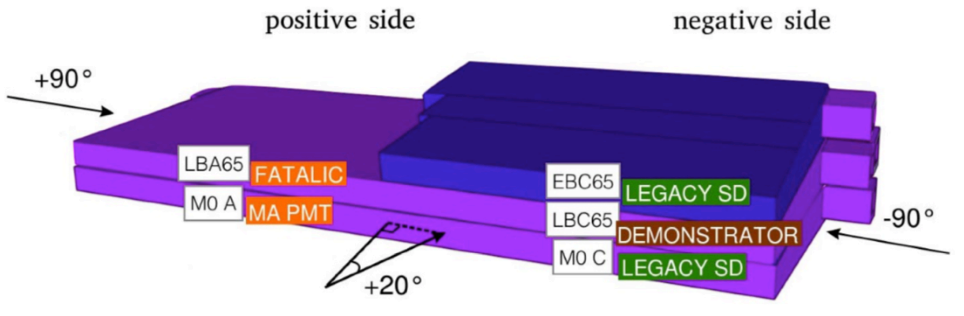
Hybrid Demonstrator

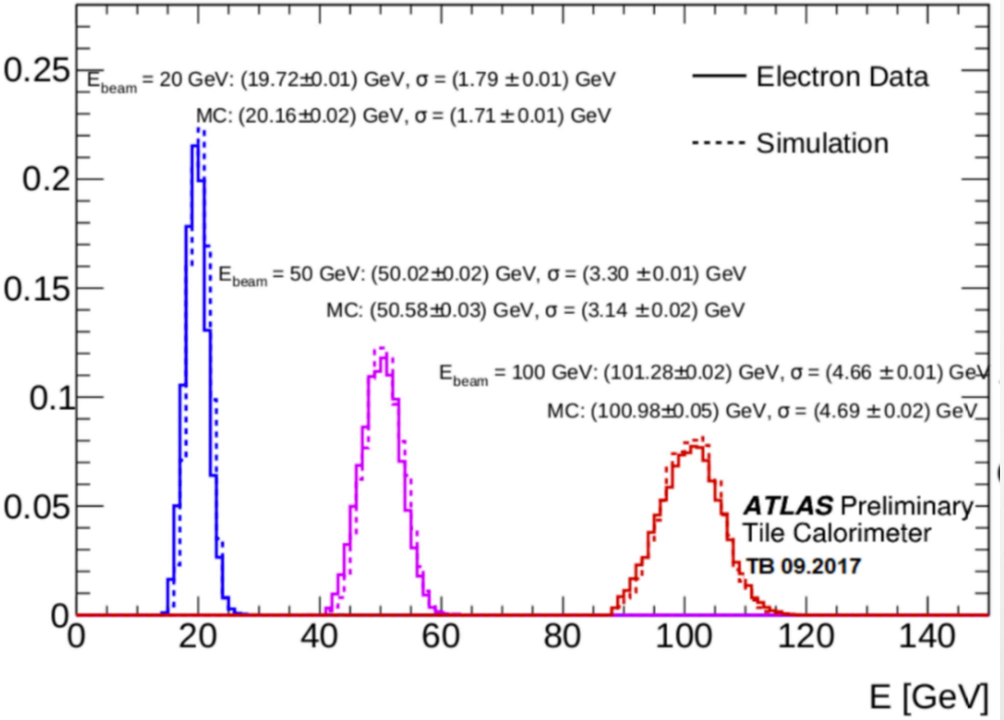


- To fully test new electronics in real conditions
- Compatible with existing analog L1 Calorimeter trigger
- Used at test beam for 3in1 FEB option
- Ideally to be installed in one of the next shutdowns

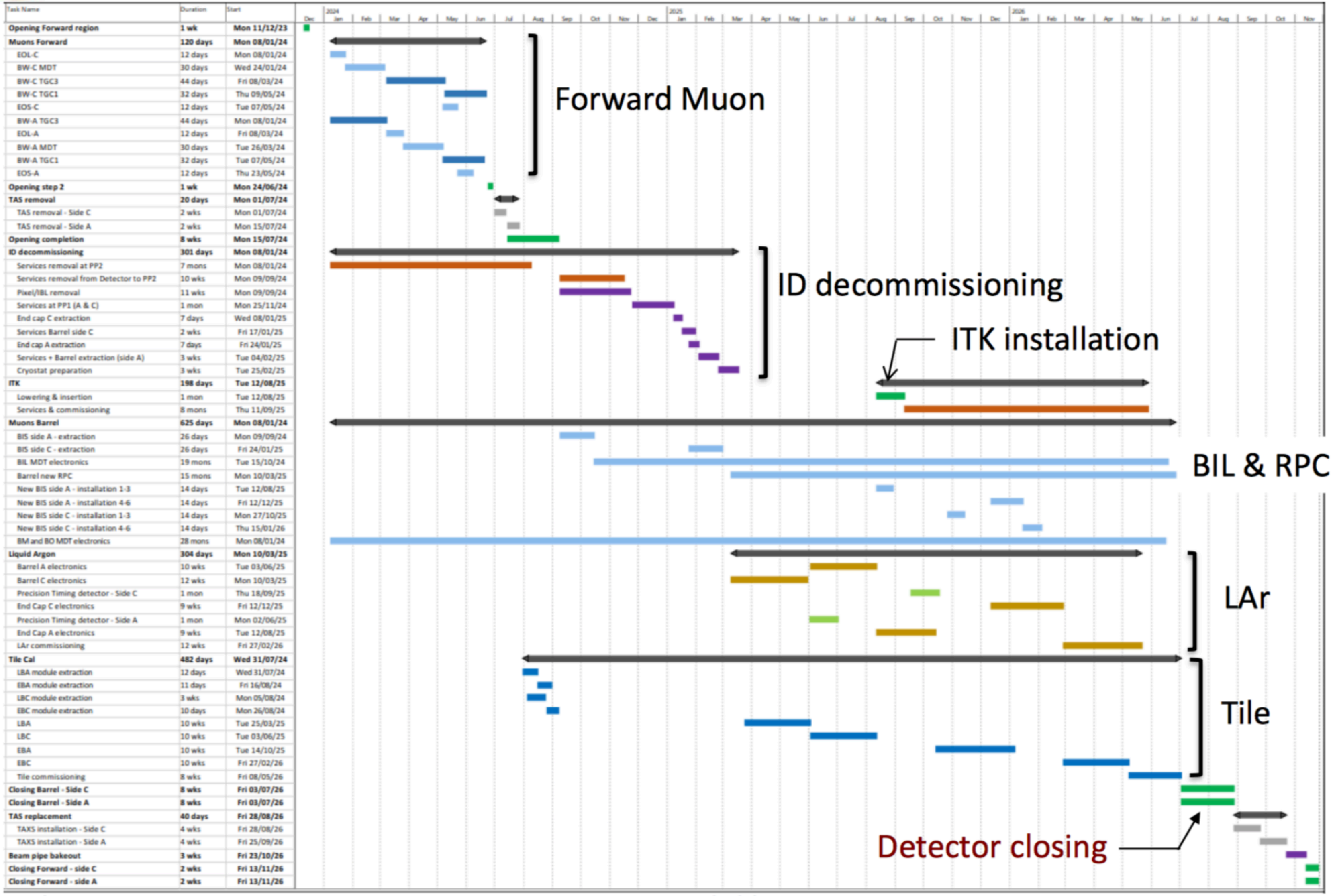
Test Beams

- Study performance of different front-end options (3IN1, QIE, FATALIC) and HV options
- Electron, hadron and muon beams, charge injection and cesium calibration
- Studies at 350 GeV for GEANT4 shower development
- Allow new TileCal colleagues to touch detector and DAQ



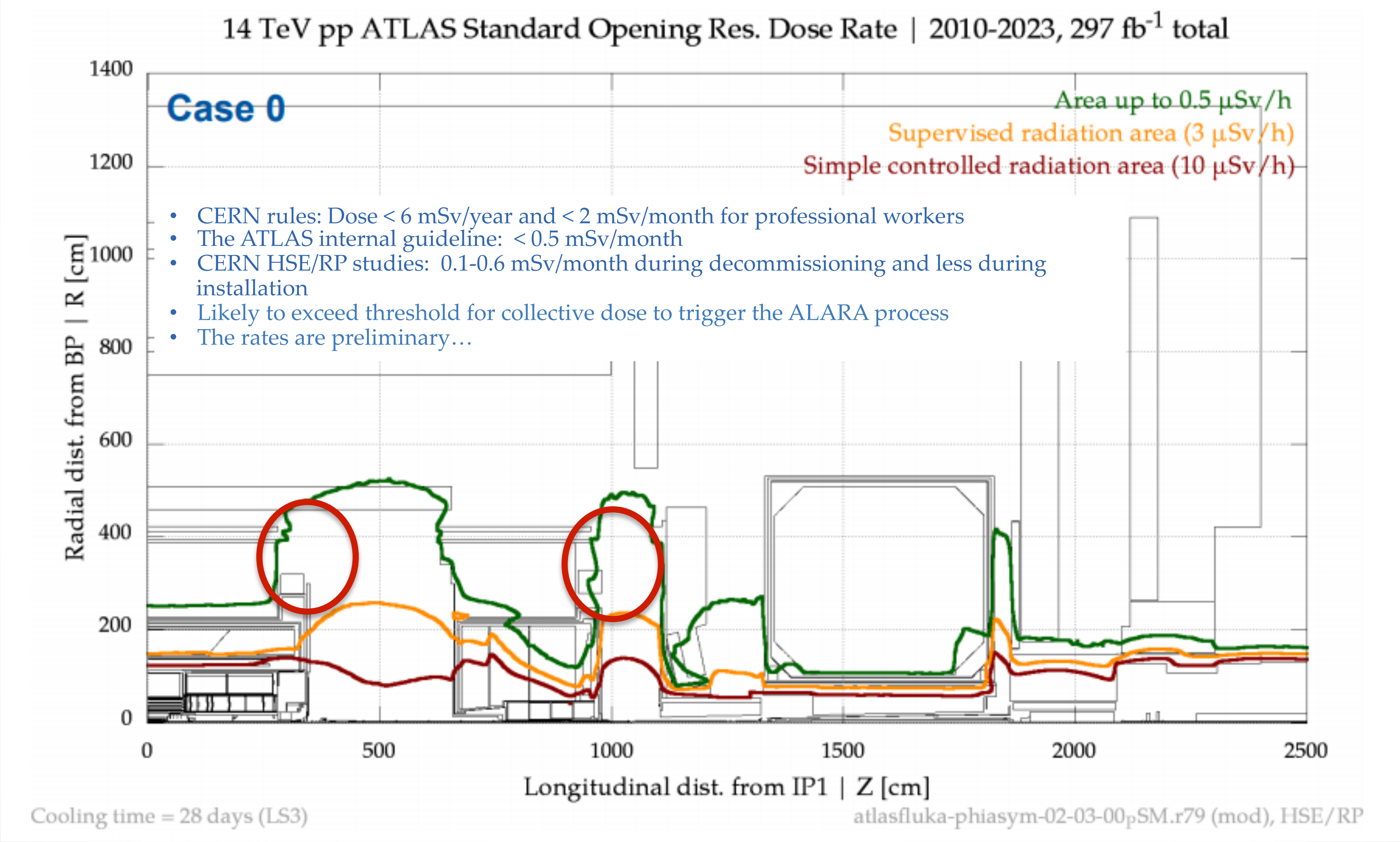


New LS3 schedule (still in work) G. Usai



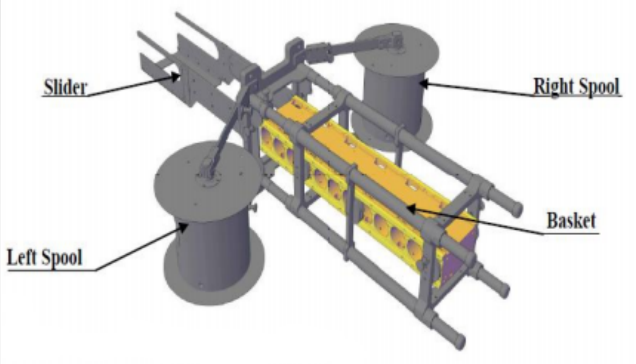
Task Name	Duration	Start
Opening Forward region	**1 wk**	**Mon 11/12/23**
Muons Forward	**120 days**	**Mon 08/01/24**
EOL-C	12 days	Mon 08/01/24
BW-C MDT	30 days	Wed 24/01/24
BW-C TGC3	44 days	Fri 08/03/24
BW-C TGC1	32 days	Thu 09/05/24
EOS-C	12 days	Tue 07/05/24
BW-A TGC3	44 days	Mon 08/01/24
EOL-A	12 days	Fri 08/03/24
BW-A MDT	30 days	Tue 26/03/24
BW-A TGC1	32 days	Tue 07/05/24
EOS-A	12 days	Thu 23/05/24
Opening step 2	**1 wk**	**Mon 24/06/24**
TAS removal	**20 days**	**Mon 01/07/24**
TAS removal - Side C	2 wks	Mon 01/07/24
TAS removal - Side A	2 wks	Mon 15/07/24
Opening completion	**8 wks**	**Mon 15/07/24**
ID decommissioning	**301 days**	**Mon 08/01/24**
Services removal at PP2	7 mons	Mon 08/01/24
Services removal from Detector to PP2	10 wks	Mon 09/09/24
Pixel/IBL removal	11 wks	Mon 09/09/24
Services at PP1 (A & C)	1 mon	Mon 25/11/24
End cap C extraction	7 days	Wed 08/01/25
Services Barrel side C	2 wks	Fri 17/01/25
End cap A extraction	7 days	Fri 24/01/25
Services + Barrel extraction (side A)	3 wks	Tue 04/02/25
Cryostat preparation	3 wks	Tue 25/02/25
ITK	**198 days**	**Tue 12/08/25**
Lowering & insertion	1 mon	Tue 12/08/25
Services & commissioning	8 mons	Thu 11/09/25
Muons Barrel	**625 days**	**Mon 08/01/24**
BIS side A - extraction	26 days	Mon 09/09/24
BIS side C - extraction	26 days	Fri 24/01/25
BIL MDT electronics	19 mons	Tue 15/10/24
Barrel new RPC	15 mons	Mon 10/03/25
New BIS side A - installation 1-3	14 days	Tue 12/08/25
New BIS side A - installation 4-6	14 days	Fri 12/12/25
New BIS side C - installation 1-3	14 days	Mon 27/10/25
New BIS side C - installation 4-6	14 days	Thu 15/01/26
BM and BO MDT electronics	28 mons	Mon 08/01/24
Liquid Argon	**304 days**	**Mon 10/03/25**
Barrel A electronics	10 wks	Tue 03/06/25
Barrel C electronics	12 wks	Mon 10/03/25
Precision Timing detector - Side C	1 mon	Thu 18/09/25
End Cap C electronics	9 wks	Fri 12/12/25
Precision Timing detector - Side A	1 mon	Mon 02/06/25
End Cap A electronics	9 wks	Tue 12/08/25
LAr commissioning	12 wks	Fri 27/02/26
Tile Cal	**482 days**	**Wed 31/07/24**
LBA module extraction	12 days	Wed 31/07/24
EBA module extraction	11 days	Fri 16/08/24
LBC module extraction	3 wks	Mon 05/08/24
EBC module extraction	10 days	Mon 26/08/24
LBA	10 wks	Tue 25/03/25
LBC	10 wks	Tue 03/06/25
EBA	10 wks	Tue 14/10/25
EBC	10 wks	Fri 27/02/26
Tile commissioning	8 wks	Fri 08/05/26
Closing Barrel - Side C	**8 wks**	**Fri 03/07/26**
Closing Barrel - Side A	**8 wks**	**Fri 03/07/26**
TAS replacement	**40 days**	**Fri 28/08/26**
TAXS installation - Side C	4 wks	Fri 28/08/26
TAXS installation - Side A	4 wks	Fri 25/09/26
Beam pipe bakeout	**3 wks**	**Fri 23/10/26**
Closing Forward - side C	**2 wks**	**Fri 13/11/26**
Closing Forward - side A	**2 wks**	**Fri 13/11/26**

ATLAS opening (ALARA)

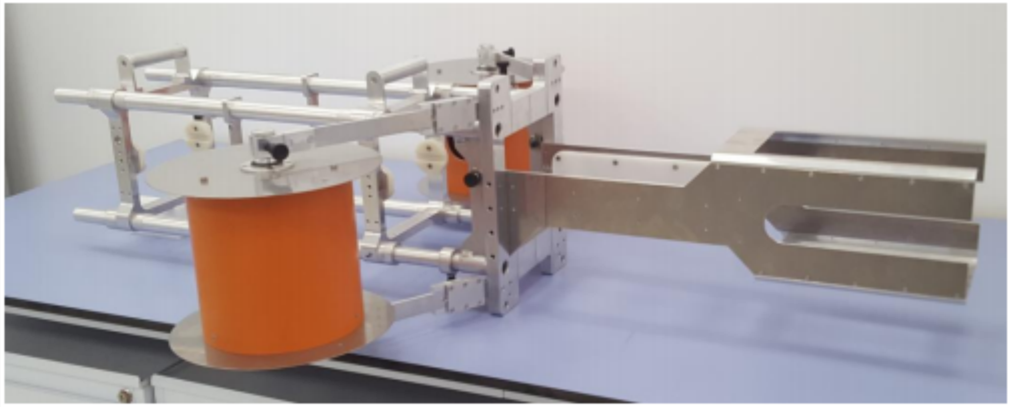


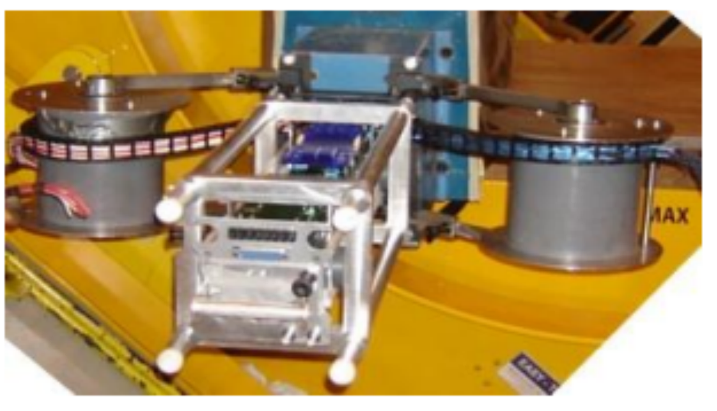
- CERN rules: Dose < 6 mSv/year and < 2 mSv/month for professional workers
- The ATLAS internal guideline: < 0.5 mSv/month
- CERN HSE/RP studies: 0.1-0.6 mSv/month during decommissioning and less during installation
- Likely to exceed threshold for collective dose to trigger the ALARA process
- The rates are preliminary…

New installation tools

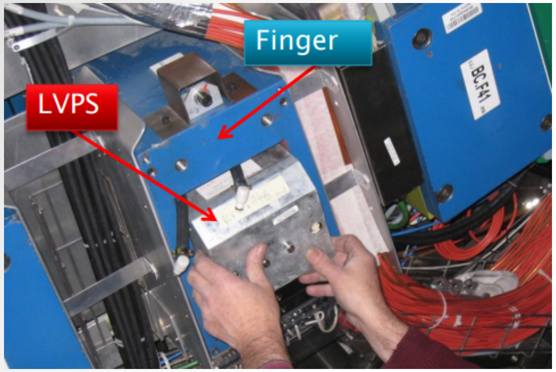


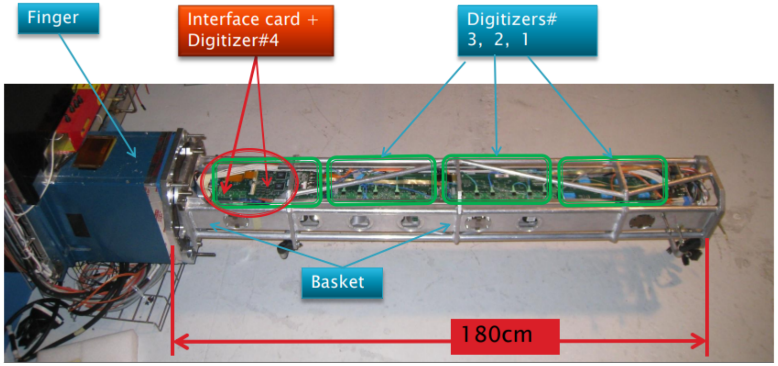
- A set of new installation tools was developed for new mini-drawer mechanics concept
- Successfully tested and validated in the labs, test beam and real detector

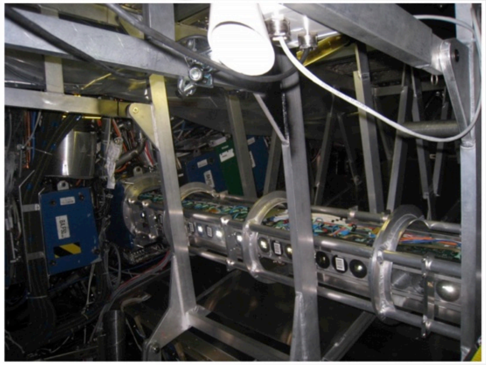


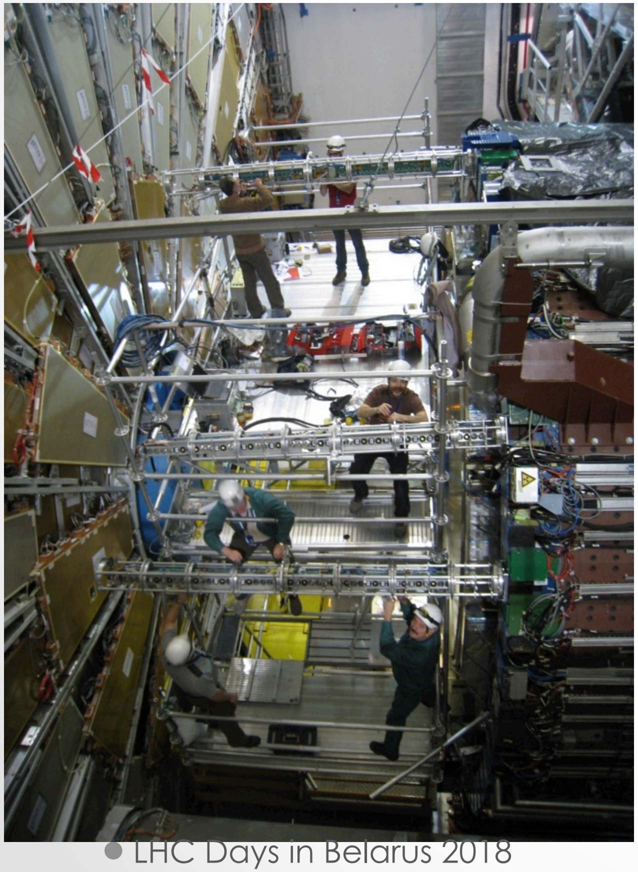


Past experience (LS1)

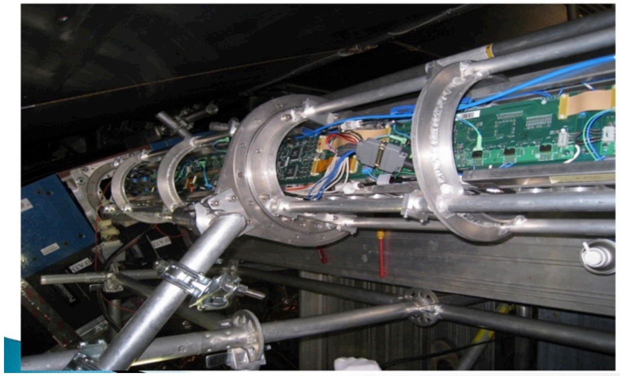






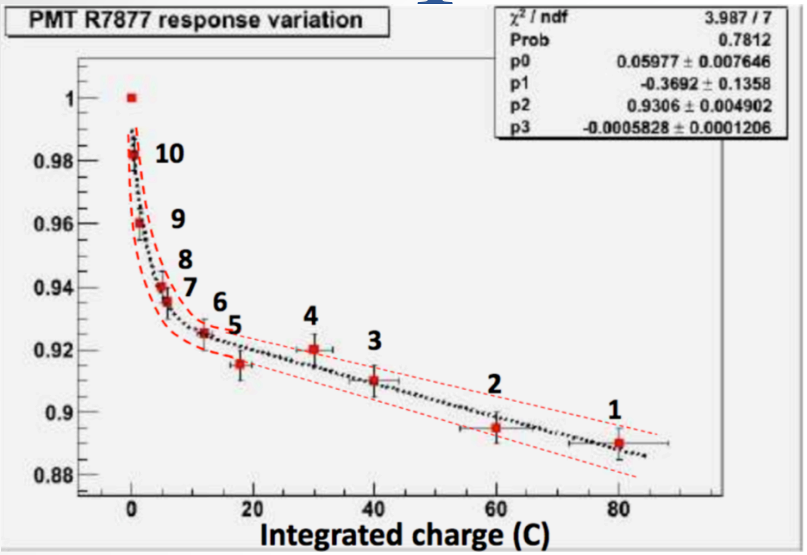


EB module extraction from rear side (if no enough access to the Finger). Special 3m basket, additional platform , more complicate => much more time.



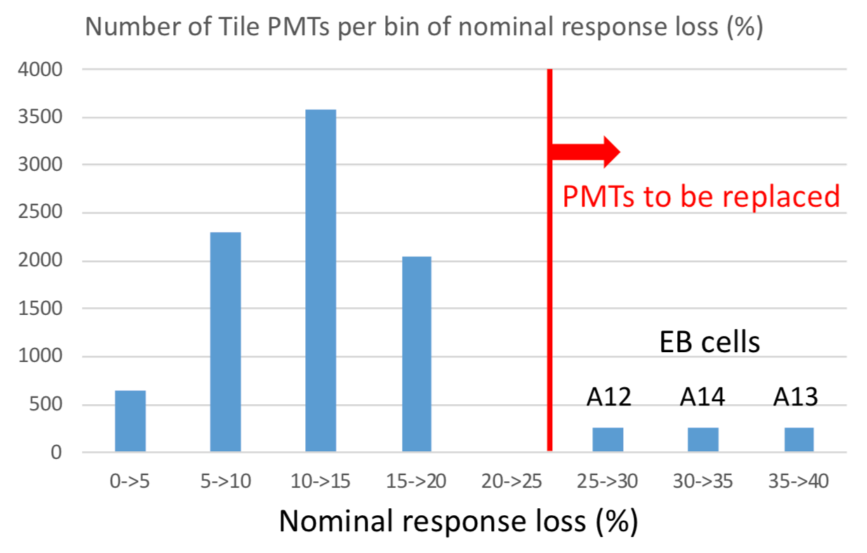
- All 256 Super-drawers were extracted, refurbished and put back during LS1
- Great teamwork

Optics Robustness

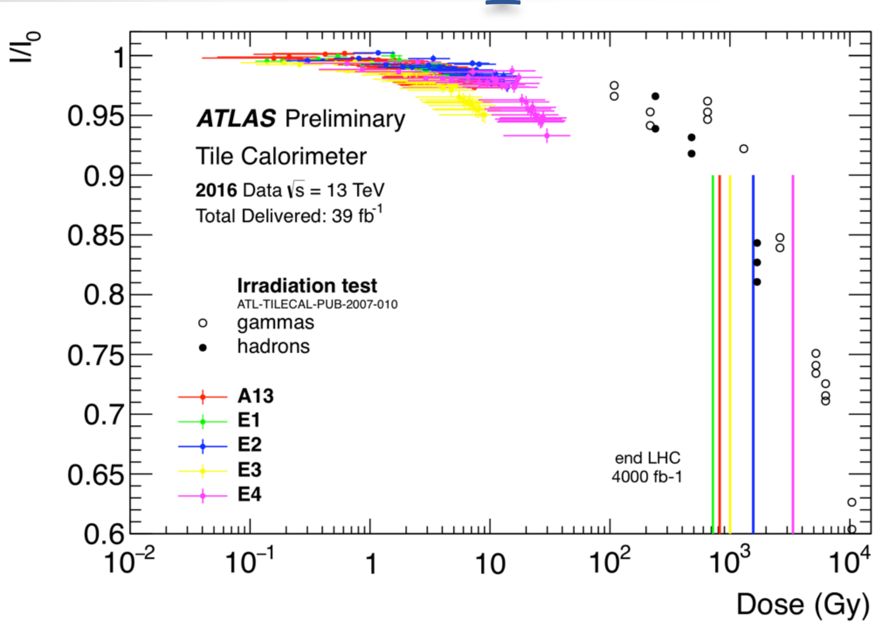


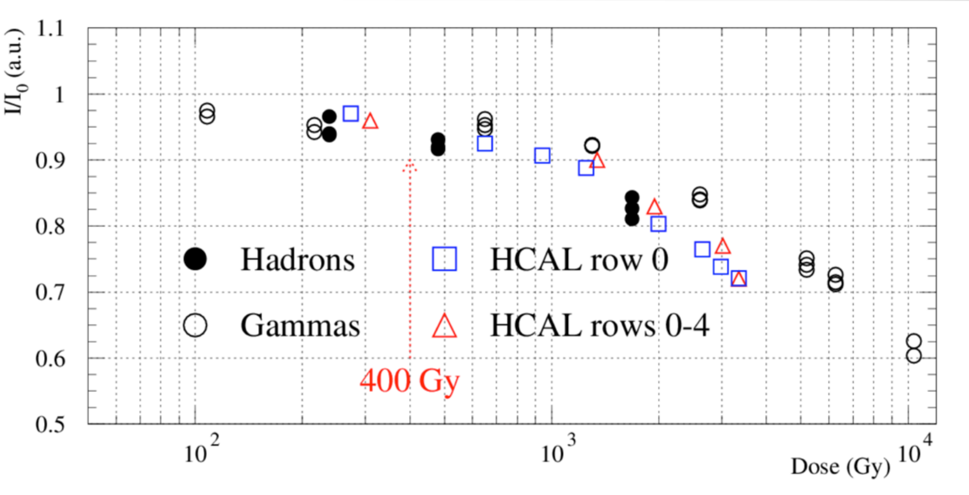
- Scintillator and fiber optical qualities degrade with integrated dose
- Current estimation is <10% for the inner layer
- Even in case of dramatic loss of 50% do not expect significant performance degradation

- PMT response degrades with integrated anode current
- PMTs in the lab have integrated up to 270C of charge, we expect 600C for 4000 fb^{-1} at HL-LHC.
- Extrapolated average signal loss at 600C: −36%±6%
- Decided to replace the most affected PMTs (~800 out of 10000) with more recent and stable version R11187SEL



Optics Robustness

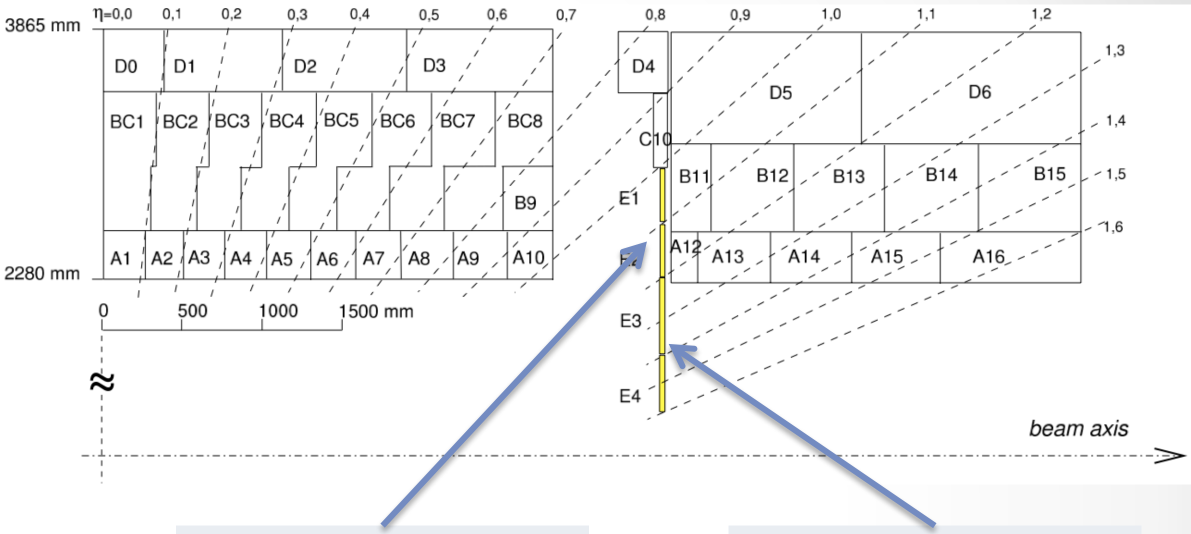




- Tile scintillators custom made from PS (PSM-115, BASF-165H) and PTP+POPOP more than 20 years ago
- Radiation hardness tests showed acceptable degradation for 10 years of original LHC
- LHCb uses almost the same scintillator material but under harsher conditions
- Gap/crack (E) scintillators are made from different materials

Other studies

Gap/crack scintillators

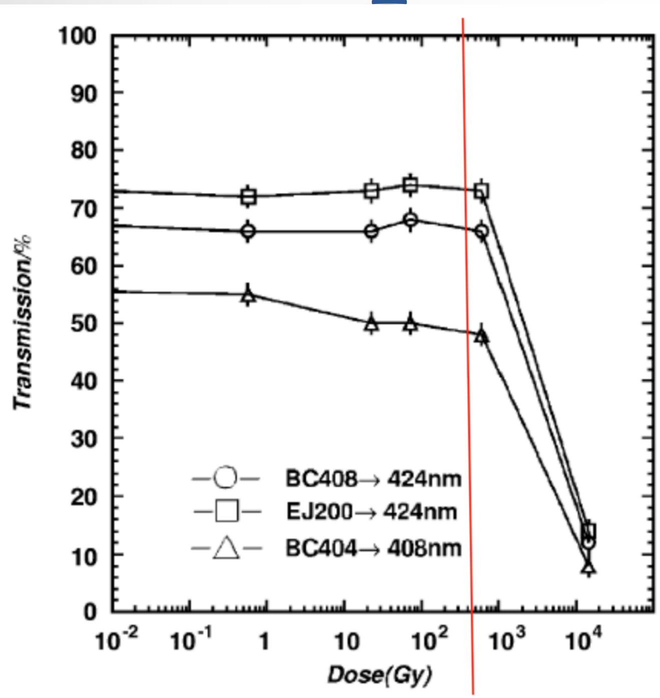


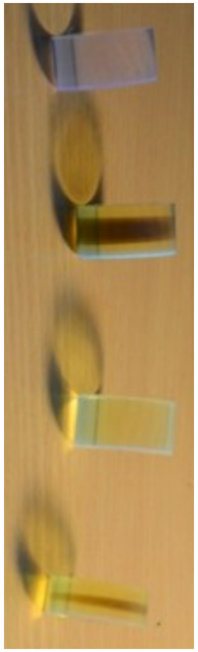
Gap scintillators
E1 (1.0 < |η| < 1.1)
E2 (1.1 < |η| < 1.2)

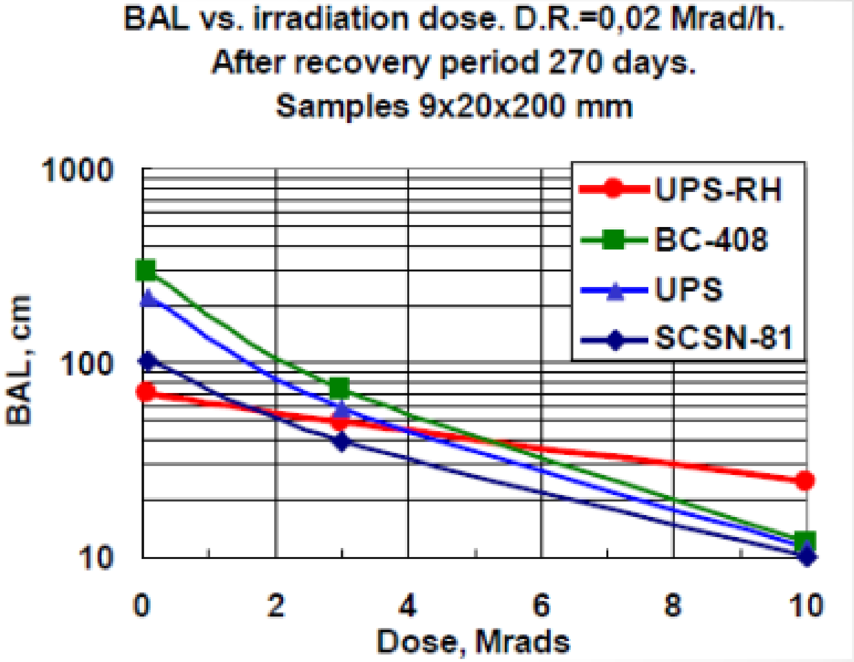
Crack scintillators
E3 (1.2 < |η| < 1.4)
E4 (1.4 < |η| < 1.6)

- 512 scintillation detectors
- Cells E1-E2(gap), E3-E4(crack)
- Light collected by WLS fibres and then transported by clear fibres
- Read out by Tile PMTs

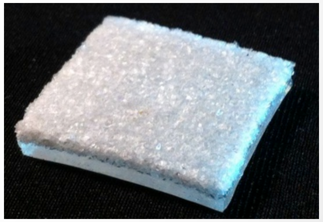
Gap/crack scintillators





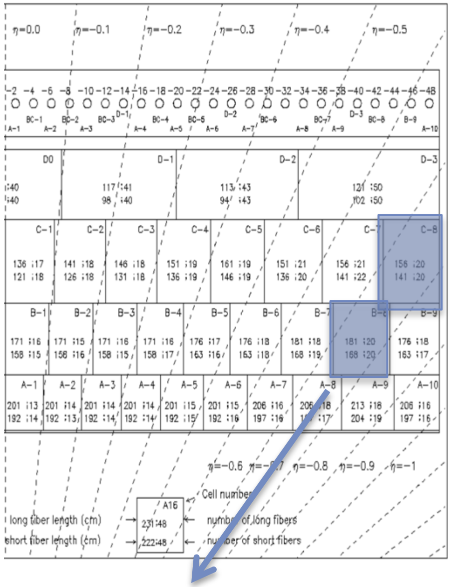


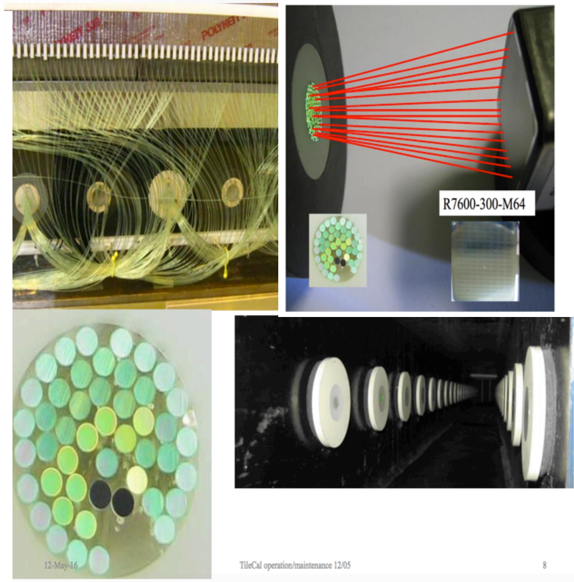
- Tile gap/crack scintillation counters play an important role in e/gamma and Jet/Etmiss performance
- Counters can be replaced after irradiation damage
- New, more segmented geometry and increased radial coverage up to $\eta\sim1.75$ improve physics performance
- The new, more radiation hard scintillation material and detector geometry is being studied, including more pile-up robust reconstruction algorithms
- Few counters were replaced in LS1 with new scintillator and new geometry
- Green plastic and crystal composite scintillators are also being studied

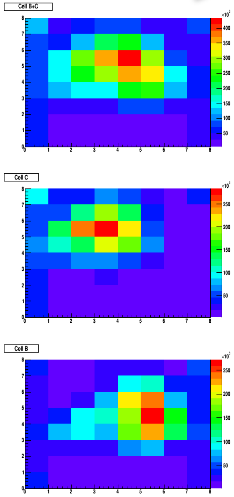


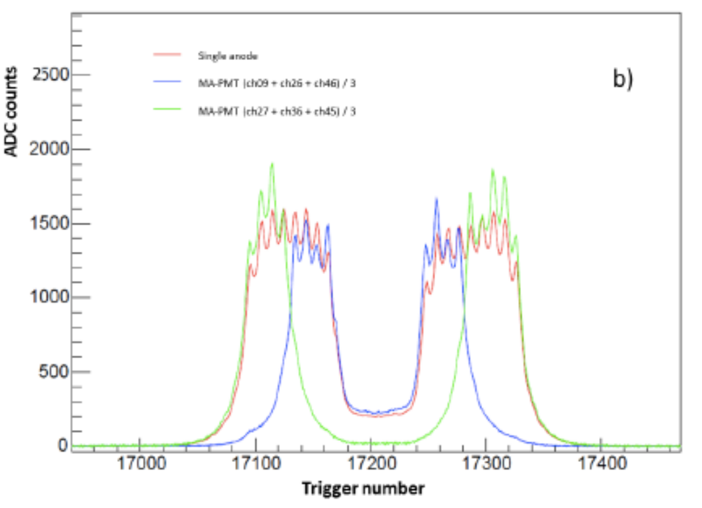
MAPMT idea

- **Tile granularity shows limitations on high p_T boosted jets, jet substructure, long lived particles (NNLP)**
- Can not and do not plan to change the calorimeter in Phase 2, however…
- **Individual fibres bring information from different cell regions, in η and R**
- Map fibres onto multi-anode PMT
- Configurable analogue sum of 8x8 channels of MAPMT (used in ALFA and LHCB) to split fibres into 2-4 areas
- Identify and calibrate with Cs scan
- **Difficult!!! Possible???**
- Evaluate in parallel: physics gain, impact on electronics layout and bandwidth
- Improved granularity scenarios:
  - *1)* ***Inner A barrel layer η granularity: by factor 2-4, $\Delta\eta$= 0.1→ 0.05-0.025***
  - *2) Separate B and C cells in R: A=1.5 λ;* ***B~1.9λ ;C~2.3 λ*** *;D=1.9 λ*
- IDR chapter with lots of material
- Not mature enough for TDR, continue with R&D to be ready for future upgrades (if any)



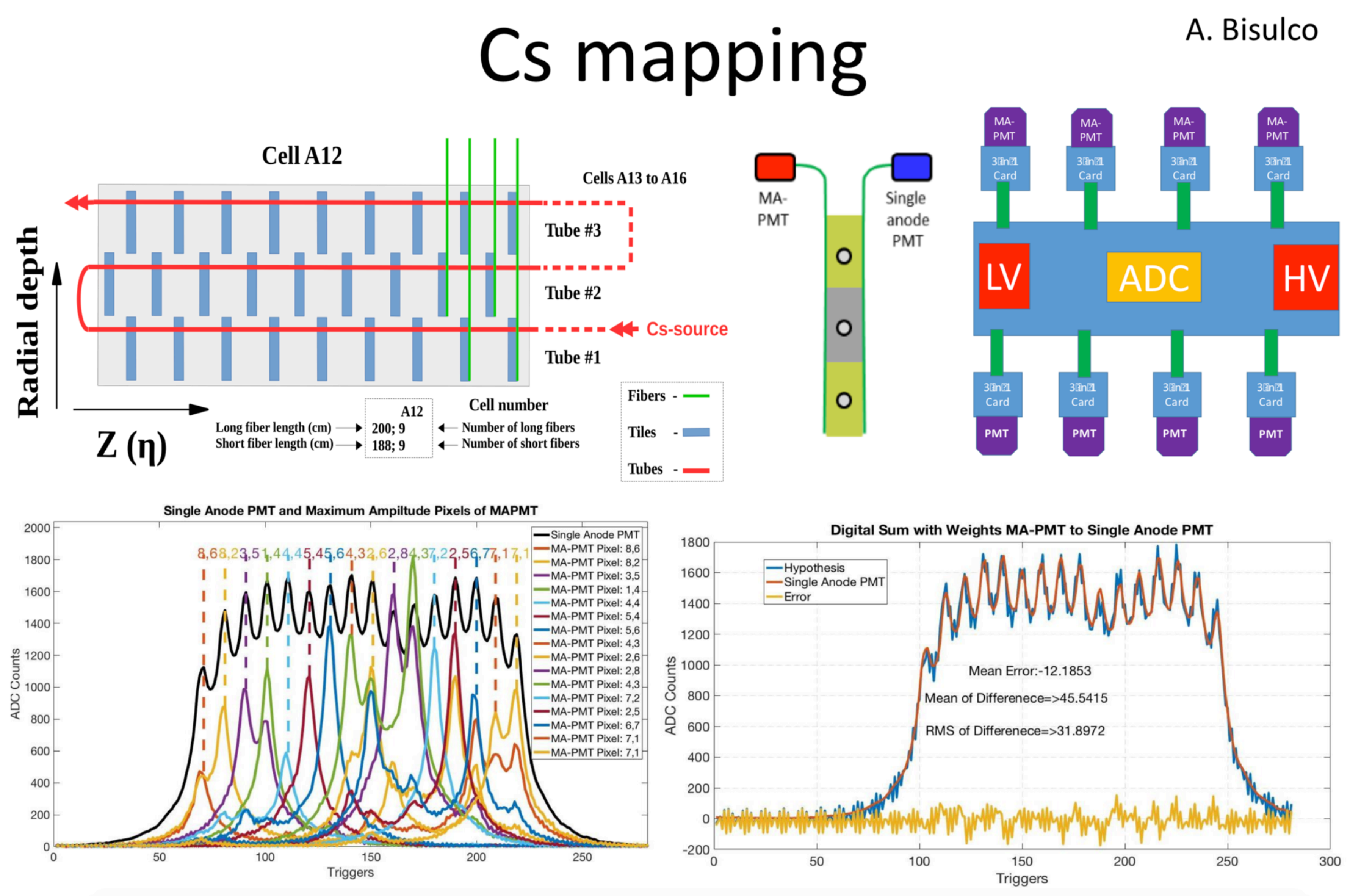






B/C separation

MAPMT calibration



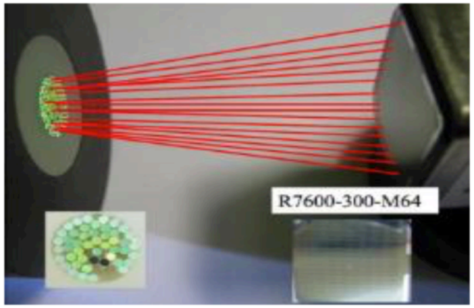
Cs mapping

A. Bisulco

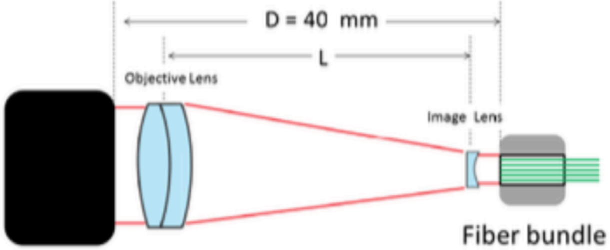
MAPMT coupling

Light guides

A. Bisulco



Air



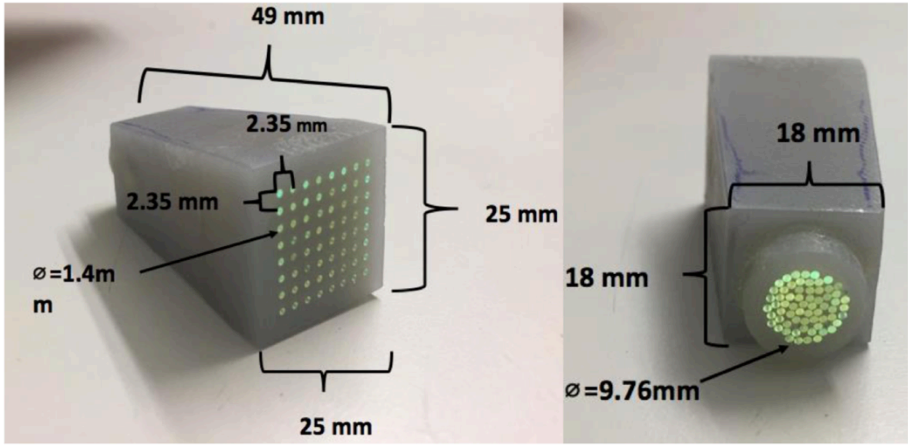
MA-PMT $L = \text{Focal Length}_{\text{Objective Lens}} + \text{Focal Length}_{\text{Image Lens}}$

Magnification factor $MF = FL_{\text{objective}} / |FL_{\text{image}}|$

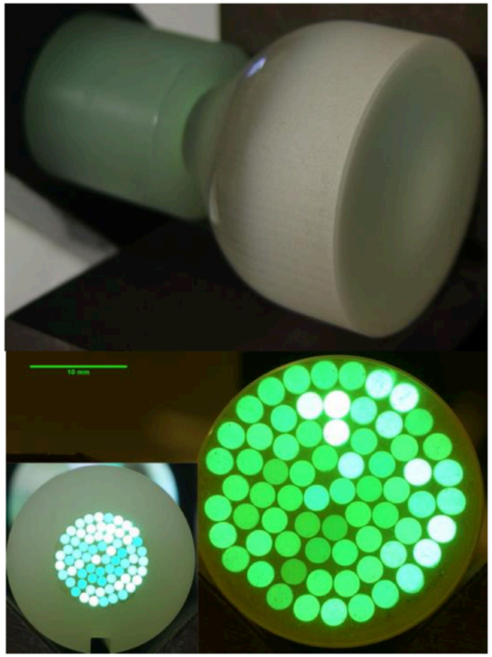
$MF = 2.0$ ==> $FL_{\text{objective}} = 50$ mm, $FL_{\text{image}} = -25$ mm, $L = 25$ mm

$MF = 2.4$ ==> $FL_{\text{objective}} = 60$ mm, $FL_{\text{image}} = -25$ mm, $L = 35$ mm

Telescope

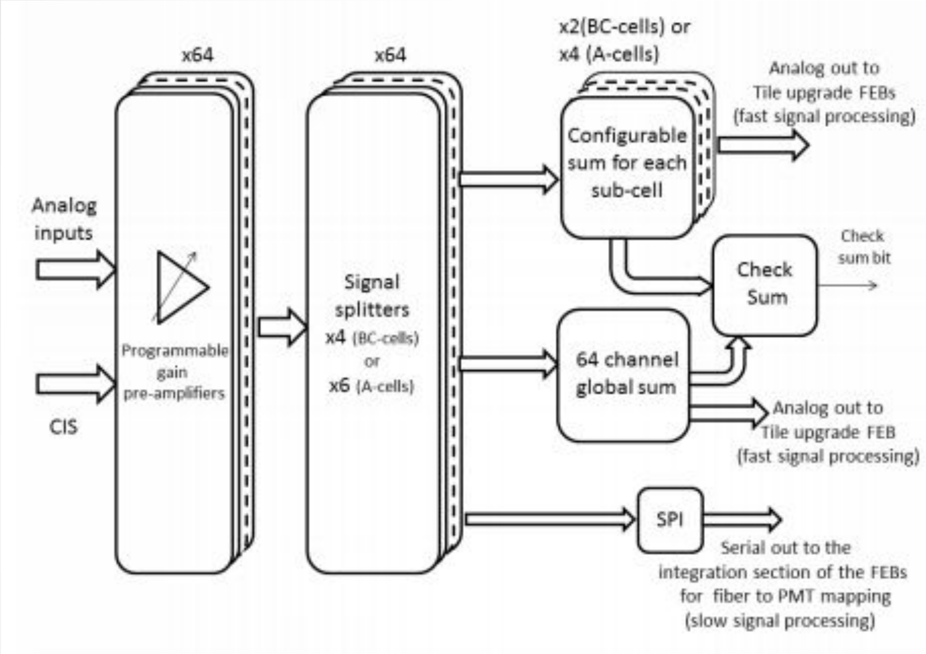


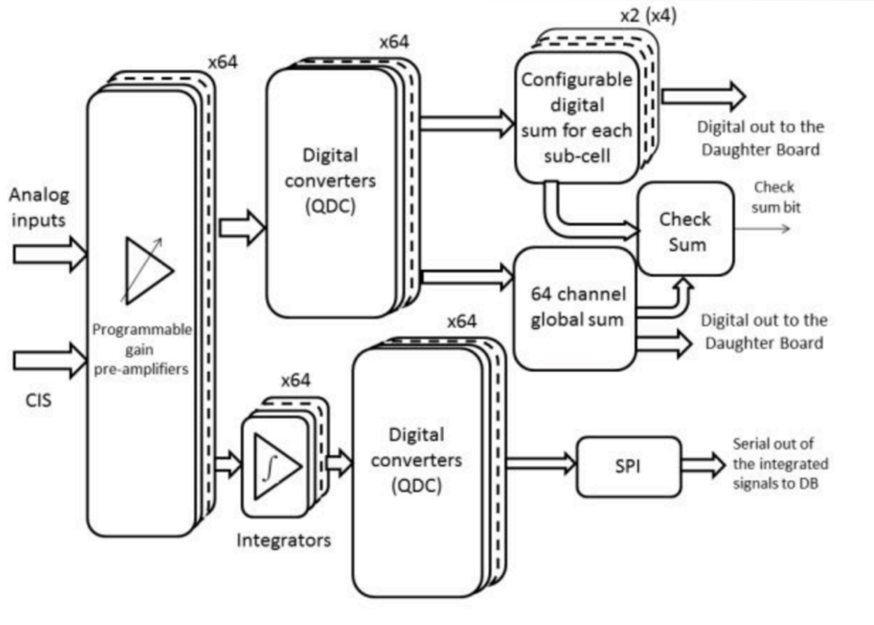
Fibre



Fokon

MAPMT readout





- Main problem – 64x number of channels
- Need to sum-up sub-cells
- Two concepts – analogue and digital sum

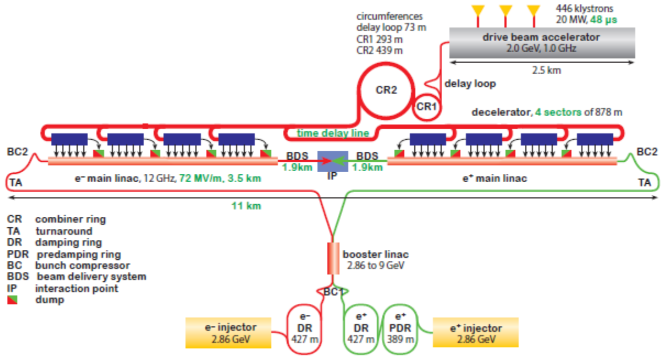
Future Accelerators

Compact Linear Collider (CLIC)

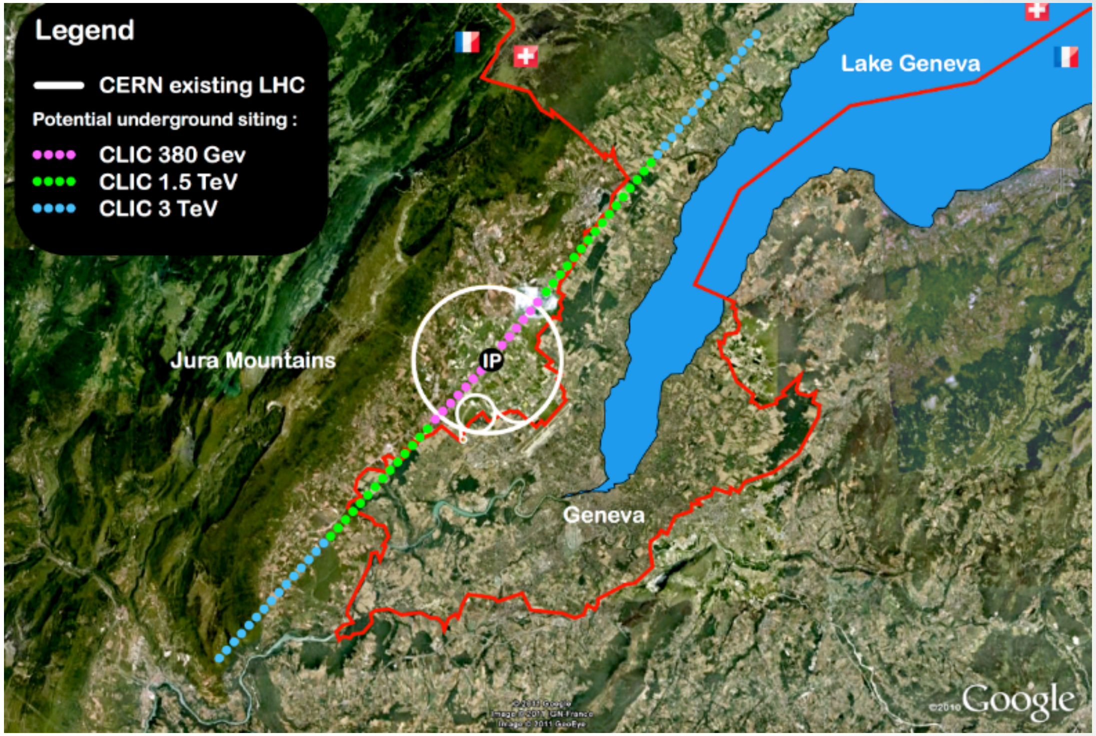
Linear e^+e^- collider $\sqrt{s}$ up to 3 TeV

100 MV/m accelerating gradient needed for compact (~50 km) machine

→ based on normal-conducting accelerating structures and a two-beam acceleration scheme



Most recent operating scenario: start at $\sqrt{s}$=380 GeV for H and top physics



Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of $\sqrt{s}$	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100

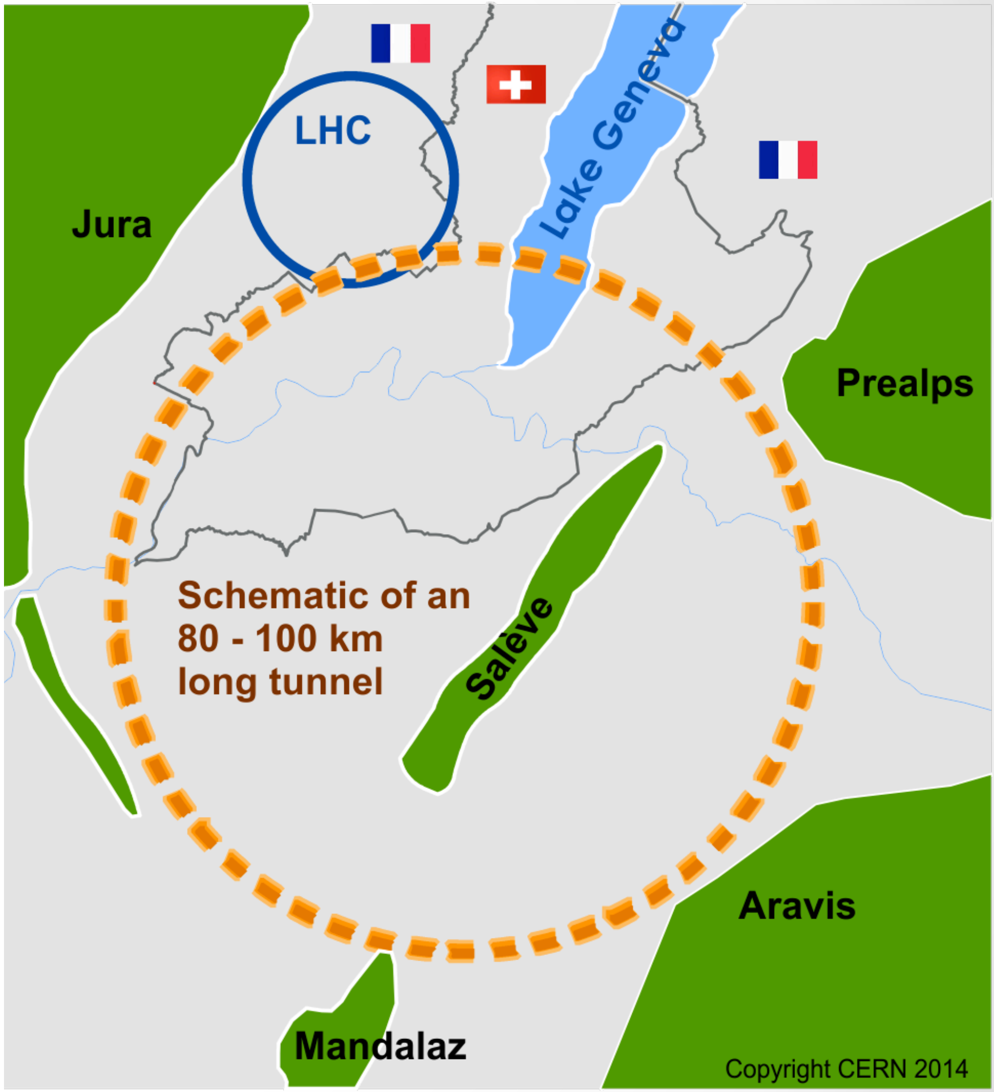
Future Circular Collider (FCC)

International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis - defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km tunnel infrastructure** in Geneva area, site specific
- **e^+e^- collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, FCC-hh & ERL
- **HE-LHC** with *FCC-hh* technology
- CDR for European Strategy Update 2018



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FCC-hh

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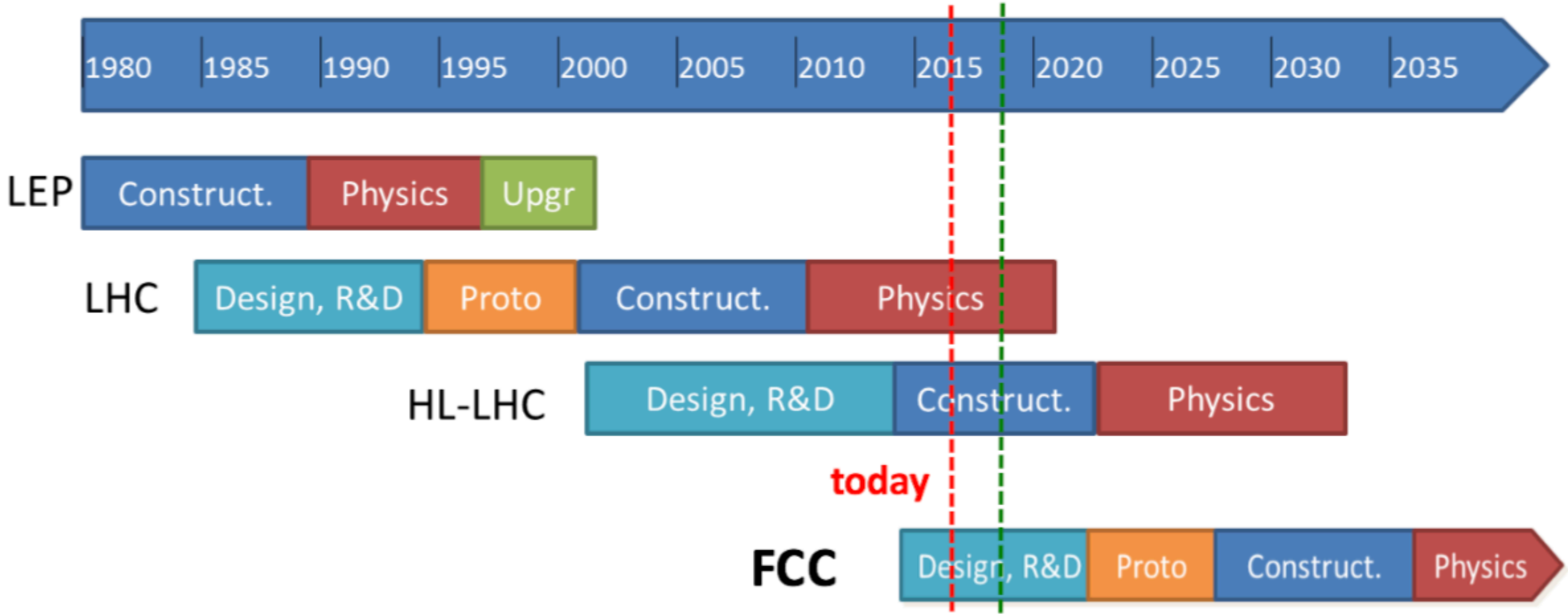


2019 – conceptual design & cost review

- HL-LHC operation until 2035
  - ~ 30 years from design to data taking
  - Development of FCC collider and detector needed NOW
  - To be ready after HL-LHC ~2036

C. Neubüser

FCC-hh detector

baseline FCC week Berlin May 2017

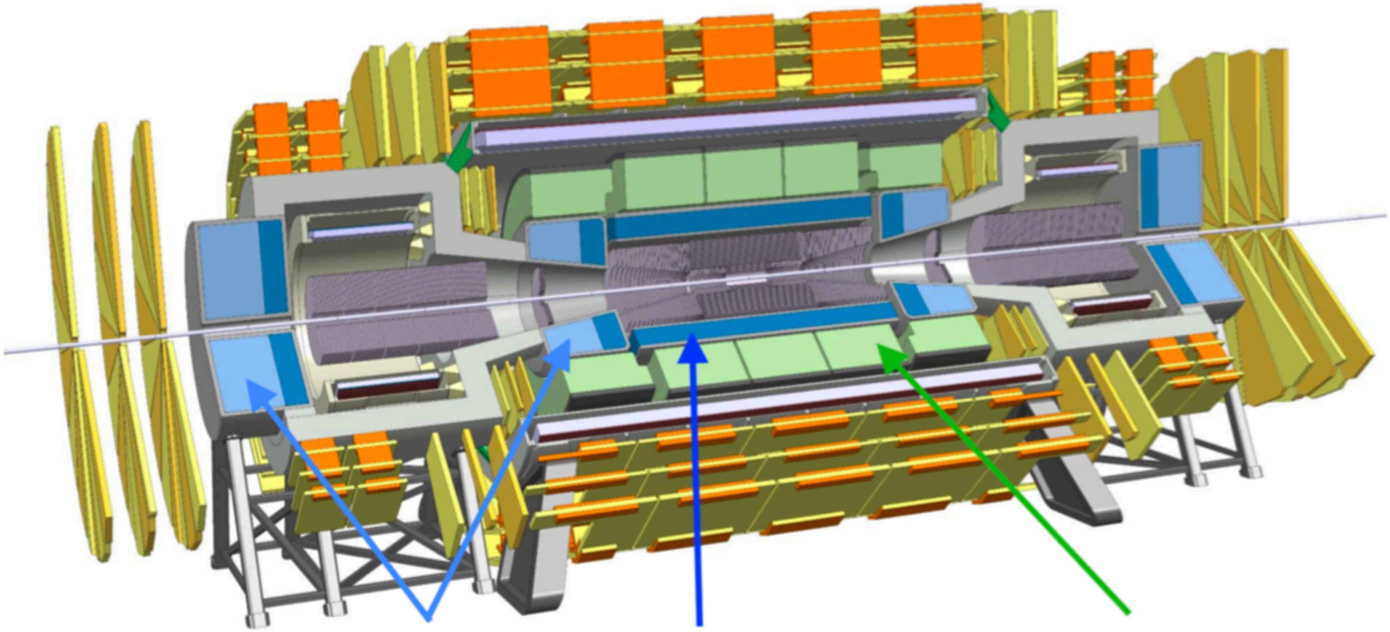
total length ~47 m, height ~18 m

Magnet

3 solenoids
not fully shielded
4 T, 2.5 and 5 m radius

Tracker

1.5 m radius
$\sigma p_T/p_T \sim 10\,\%$
(10 TeV)



Forward calorimeter & tracker
up to η=6

HCAL EC+HFCAL

LAr with Cu/W absorber
$\sigma_E/E \sim 50/100\%/\sqrt{E} \oplus 3/5\%$

ECAL B+EC+FCAL

LAr with Pb absorber
$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$

HCAL B+EB

Sci-Steel with SiPM readout
$\sigma_E/E \sim 50\%/\sqrt{E} \oplus 3\%$

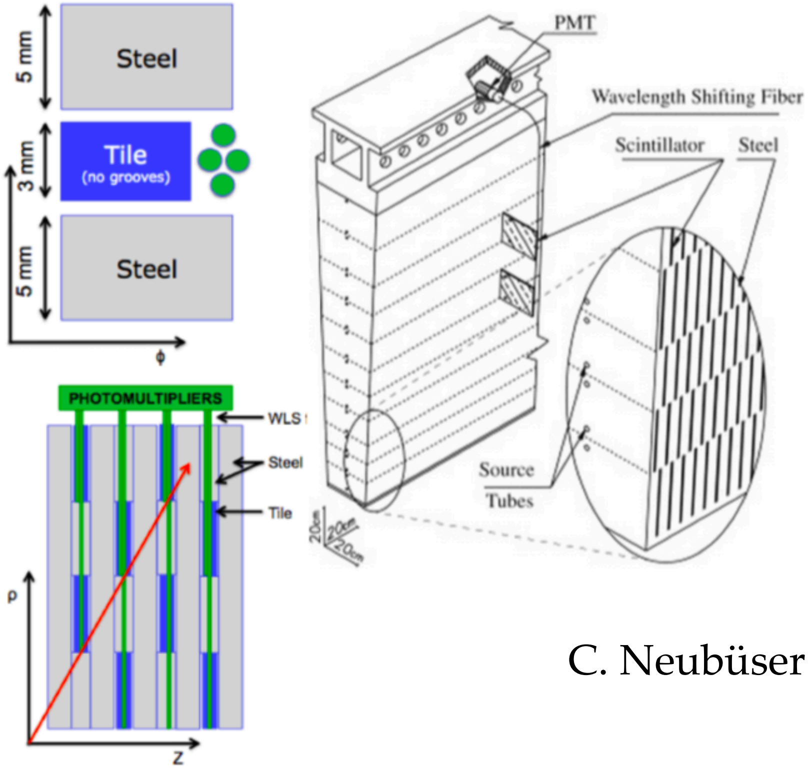
FCC-hh hadronic calorimeter – Scintillator-Steel I

1. Current baseline for FCC-hh

ATLAS type, Scintillator tile - Steel

changes for FCC-hh:

- 4 times higher granularity $\Delta\phi \times \Delta\eta = 0.025 \times 0.025$
- 10 instead of 3 longitudinal layers
- Steel –> stainless Steel absorber (Calos in magnetic field)
- SiPM readout –> faster, less noise, less space



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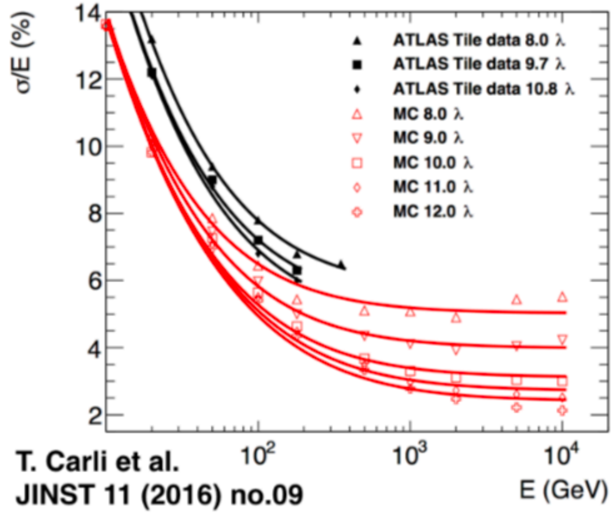


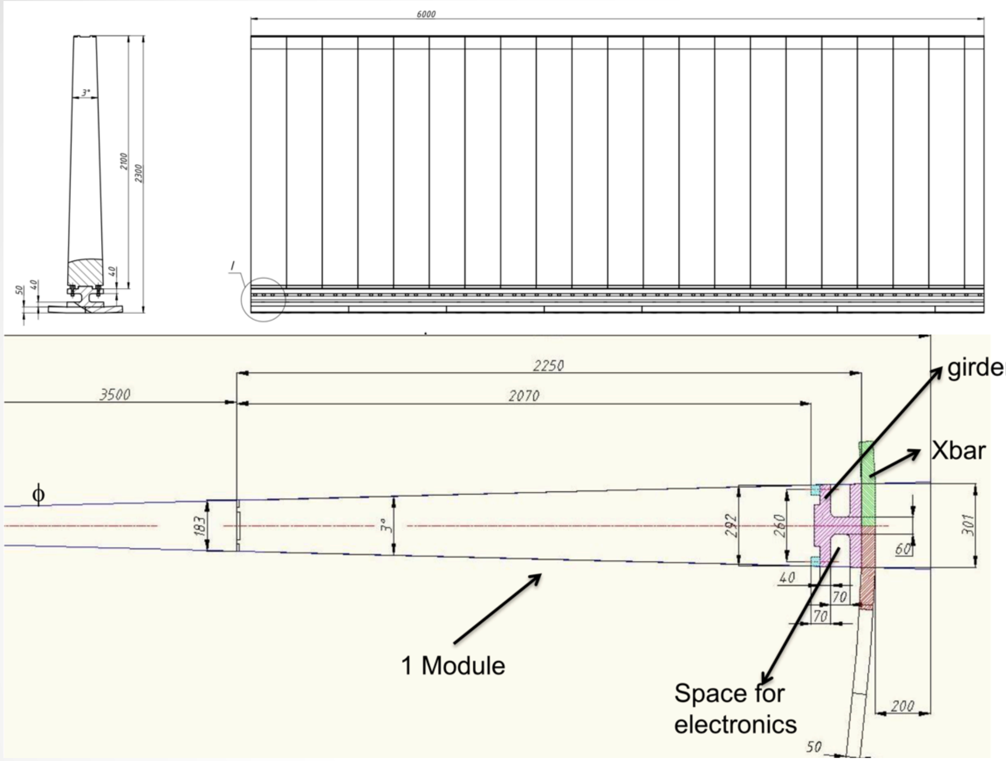
T. Carli et al.
JINST 11 (2016) no.09

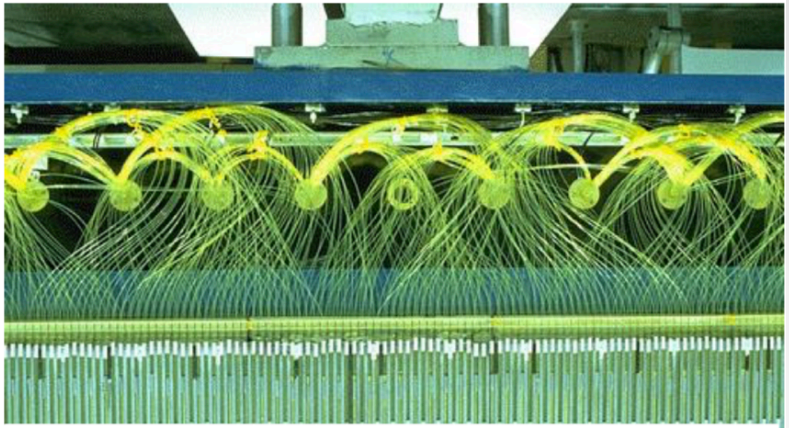
Resolution for single pions in 11 λ HCAL:

$$\sigma E/E = 43\%/\sqrt{E} \oplus 2.7\%$$

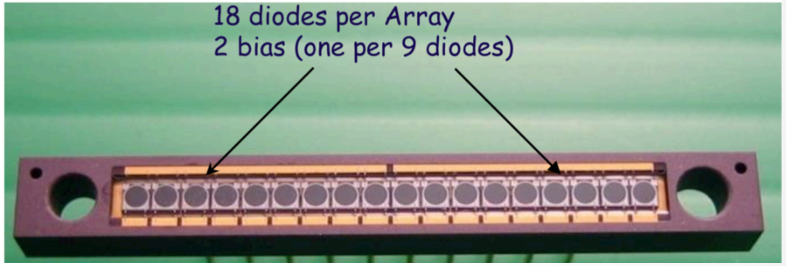
Good containment achievable with $\sim 11\lambda$ calorimeter system (ECAL+HCAL) at $\eta = 0$

Hadronic Calorimeter II





Fibre bundles in ATLAS Tilecal



- 120 modules in phi , 6m long in Z is ok => Df =0.05, 2 times better than ATLAS Rmin=3.5m. Rout =5.8m. Need 20cm for cables before solenoid
- Depth Outer Supports=20cm (15cm girder+5cm Xbars);~1.5 shorter than ATLAS!
- 20 tons each module of 6 m long in Z + 0.7 tons Xbars per module
- Total FCC TileCal barrel weight of 18m long = 7500 tons (3x2500)

A. Henriques, N. Topilin

Summary

- Tile Hadron Calorimeter is an important part of ATLAS detector at LHC, CERN
- High Luminosity LHC upgrades poses significant challenges and requires a full redesign and replacement of front-end and back-end electronics
- Prototypes of several options are available and are being tested in the labs and at test beam
- Submitted the ATLAS TileCal Phase-II Upgrade TDR
- Future experiments at future accelerators might benefit from TileCal-like calorimeters