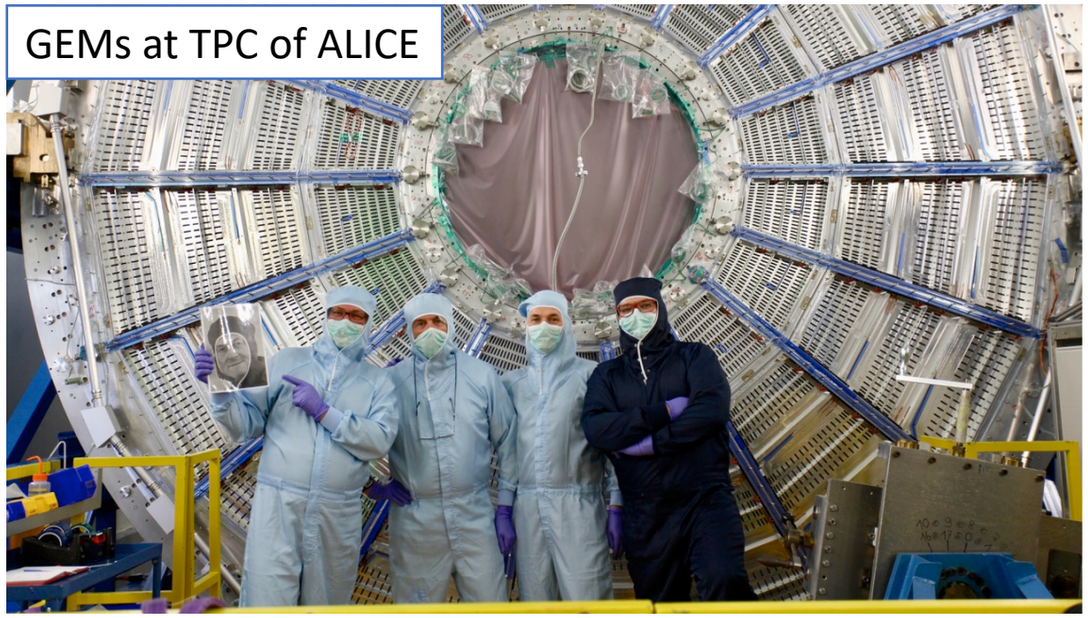
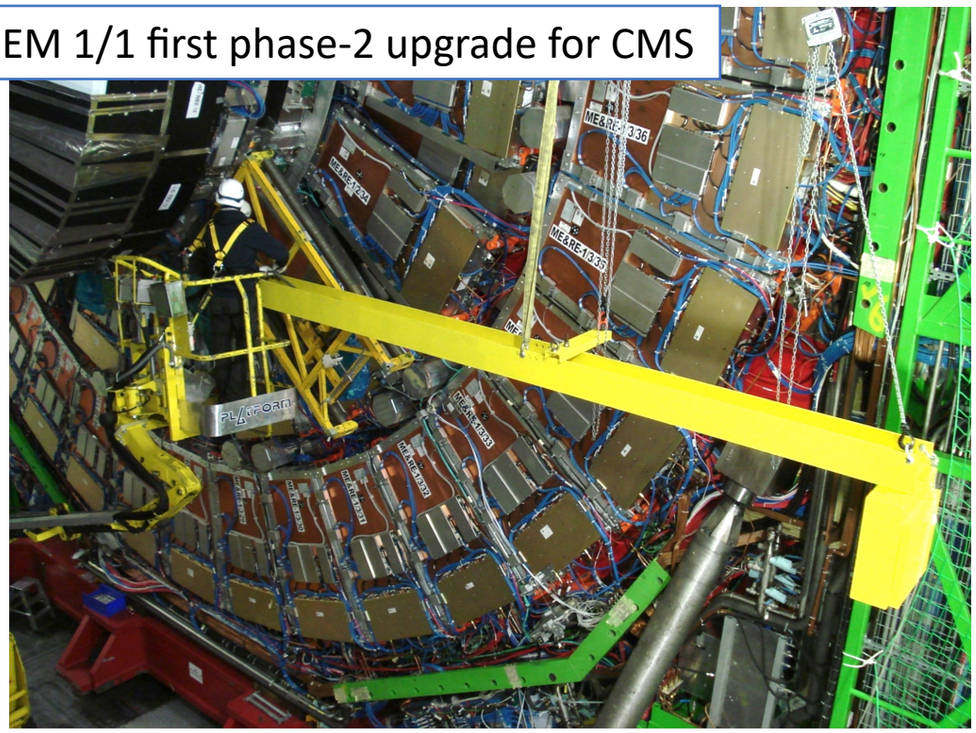
GEMs at TPC of ALICE



New Small Wheel structures for ATLAS

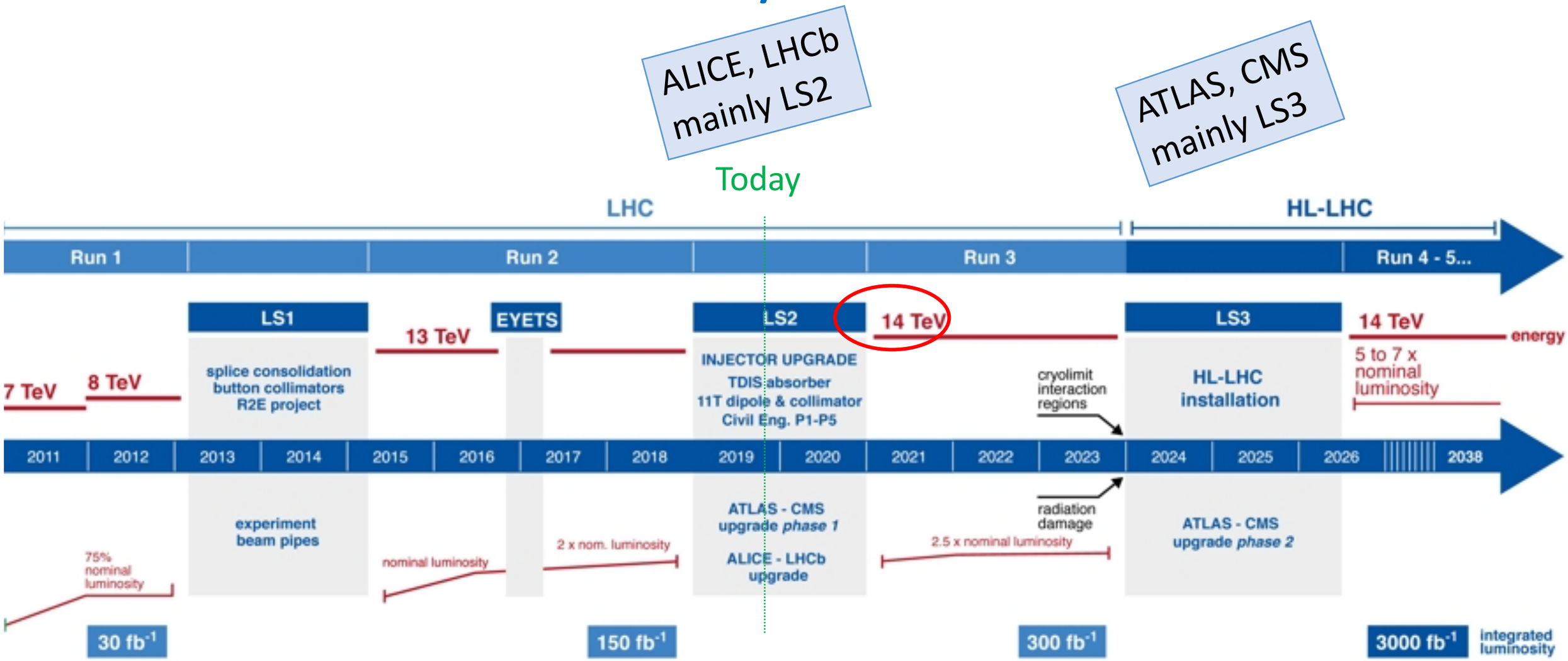
Upgrades of ALICE, ATLAS, CMS and LHCb

GEM 1/1 first phase-2 upgrade for CMS



SciFi by LHCb

The LHC Luminosity Plan



x5 Run1 x2 Run2 x10 Run3

So far LHC has delivered 5% or less of the total planned integrated luminosity!

Stay alert: High level strategy meeting on HL-LHC schedule with CERN Management 27.11.2019

Upgrades - Enormous challenge

Bonn,
Darmstadt,
Frankfurt,
Heidelberg,
München (TU),
Münster,
Tübingen,
FH Worms,
GSI

TU Dortmund,
Universität Heidelberg,
MPI für Kernphysik Heidelberg,
Universität Rostock
RWTH Aachen

Berlin (HU),
Bonn,
Dortmund,
Dresden,
Freiburg,
Gießen,
Göttingen,
Heidelberg,
Mainz,
München (LMU),
Siegen,
Wuppertal,
Würzburg,
MPI für Physik München,
DESY

RWTH Aachen,
Universität Hamburg,
Karlsruher Institut für Technologie,
DESY

On the technology aspect

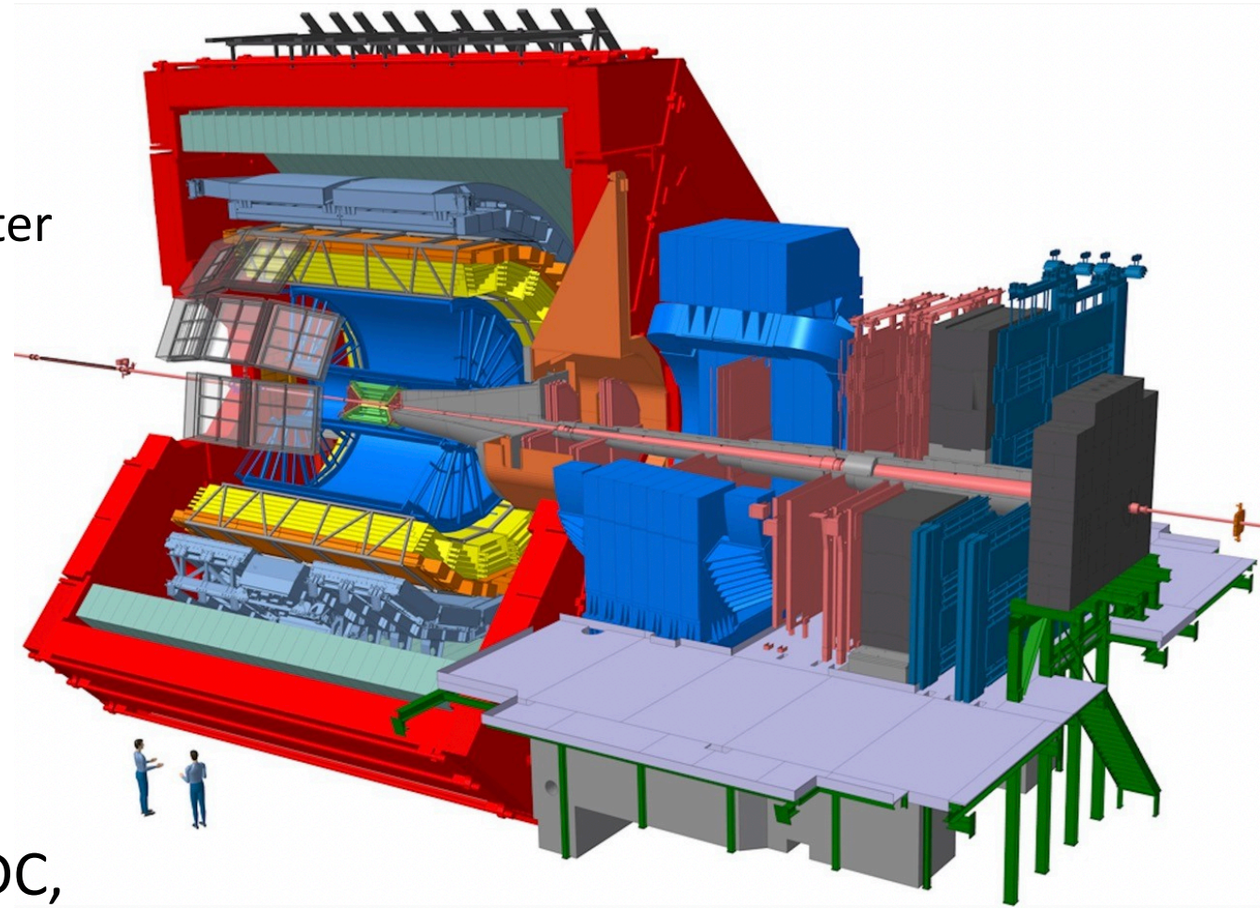
From our external reviewers:

“We want to note (again) that these projects are unprecedented in scale in particle physics, shift various paradigms, and employ technologies that have never before been exercised by the field.”

ALICE Upgrade during LS2 and LS3

LS2

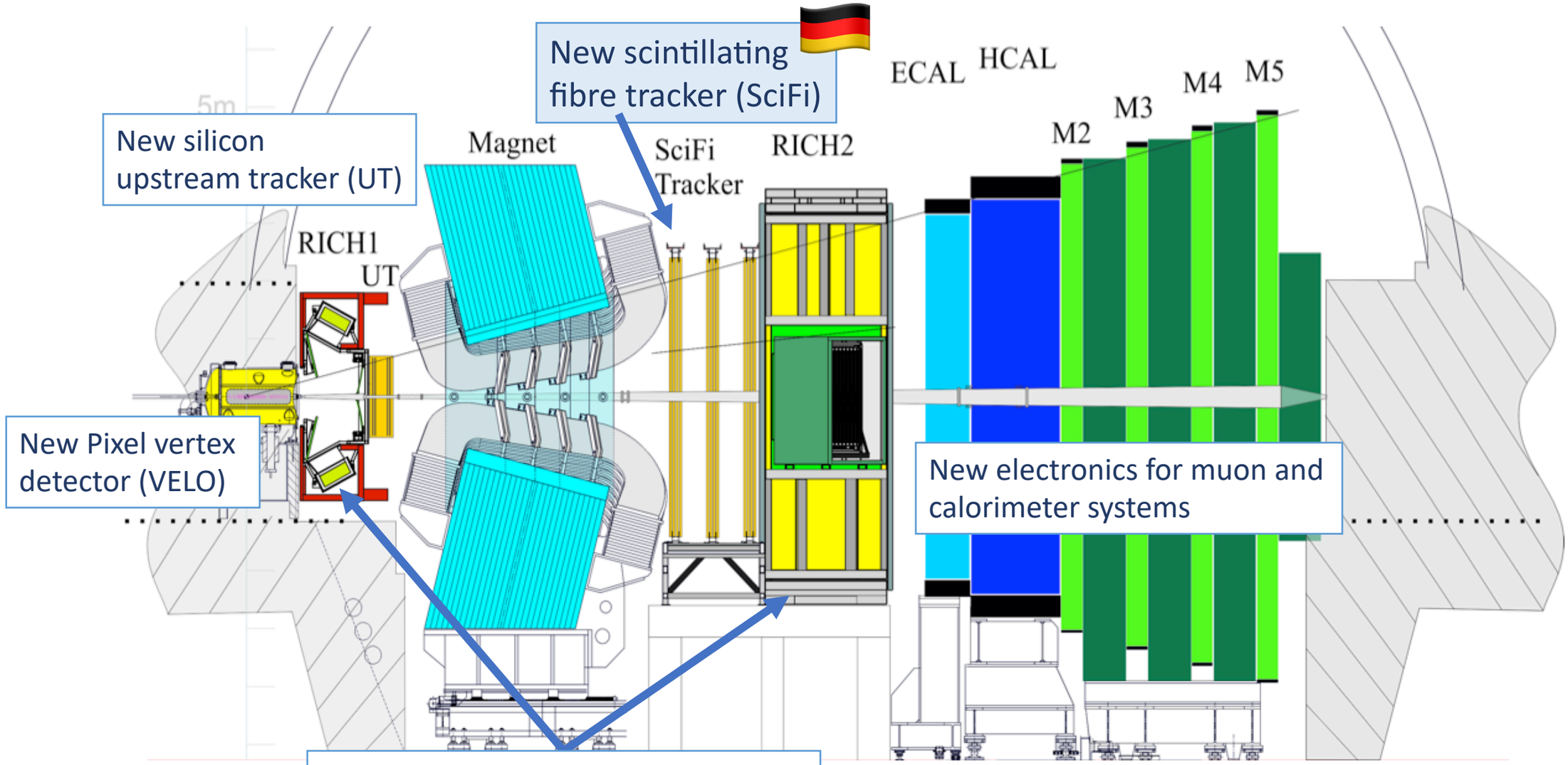
- **New** Inner Tracking System (ITS)
  - MAPS: improved resolution, less material, faster readout
- **New** Muon Forward Tracker (MFT)
  - vertex tracker at forward rapidity
- **New** TPC Readout Chambers
  - 4-GEM detectors → continuous r/o
- **New** forward trigger detectors (FIT)
  - centrality, event plane
- **Upgraded** read-out for TOF, TRD, MUON, ZDC, EMCal, PHOS, new Online-Offline
  - record minimum-bias Pb-Pb data at 50 kHz (currently <1 kHz)

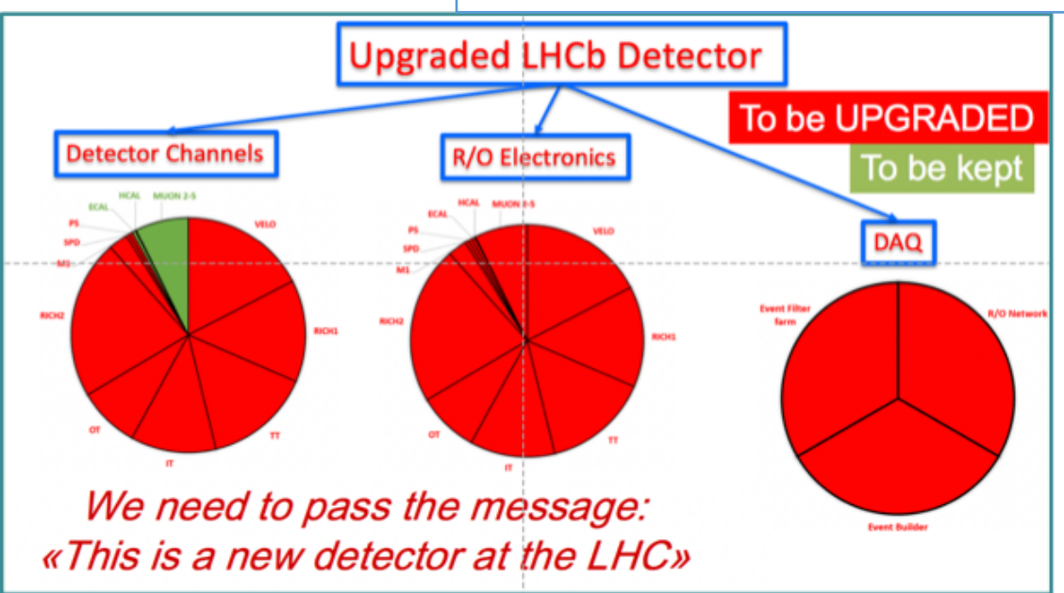


LS3

- A new ultra-light inner barrel ITS3
  - 3 truly cylindrical layers made of ~7x14 cm2 sensors thinned to 20-40 µm

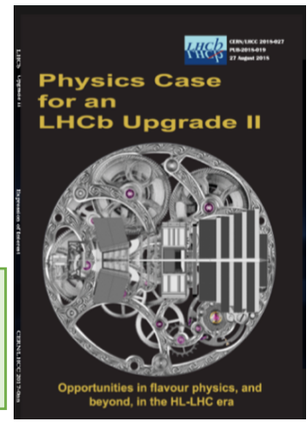
LHCB ~~Upgrade~~ new detector during LS2





+ real time analysis (RTA)
software only trigger at 30MHz

Next major upgrade in LS4
Framework TDR foreseen spring 2021



CMS HL-LHC Upgrade

L1-Trigger/HLT/DAQ

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

Barrel Calorimeters

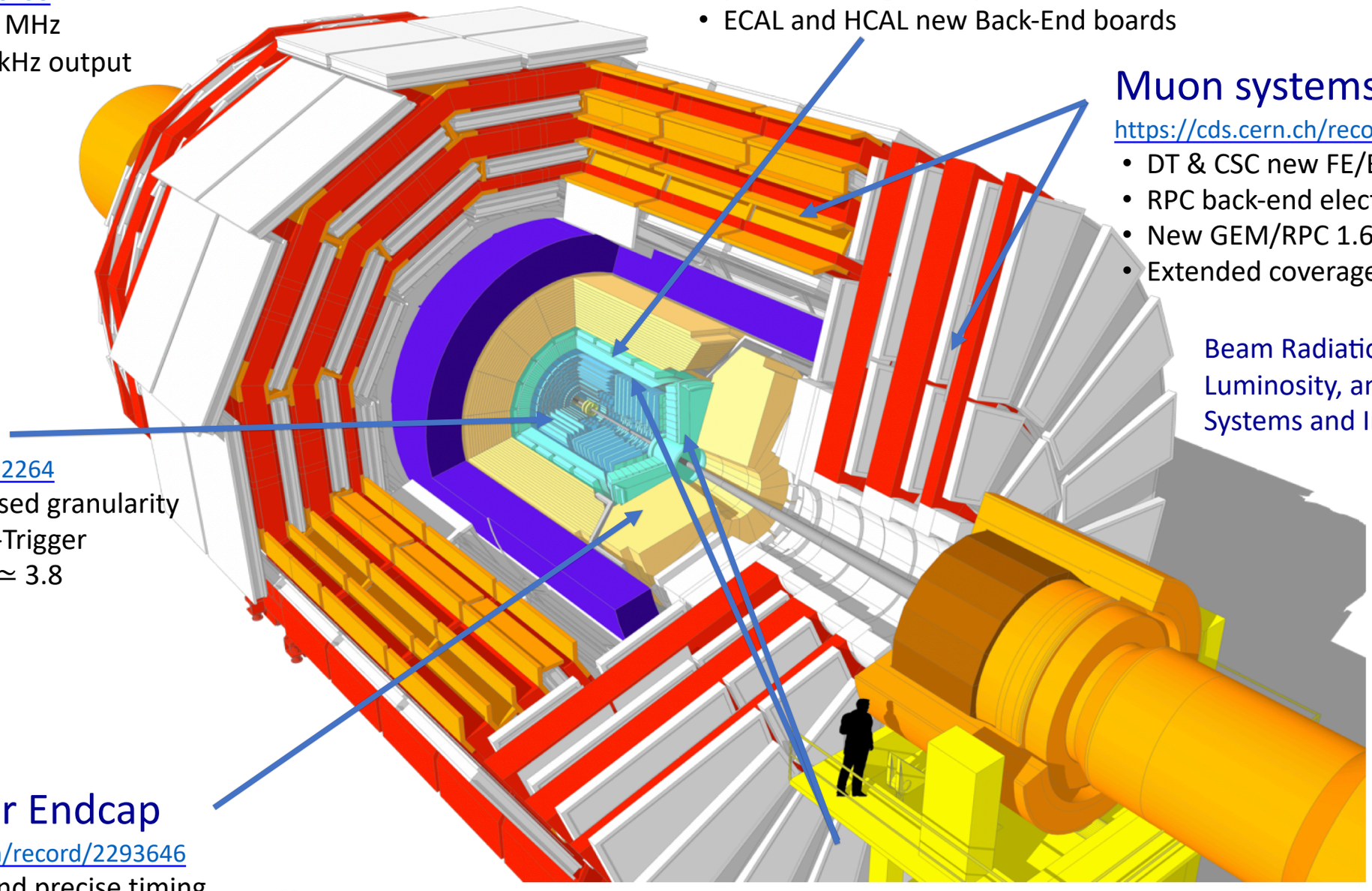
https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



Tracker

https://cds.cern.ch/record/2272264

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

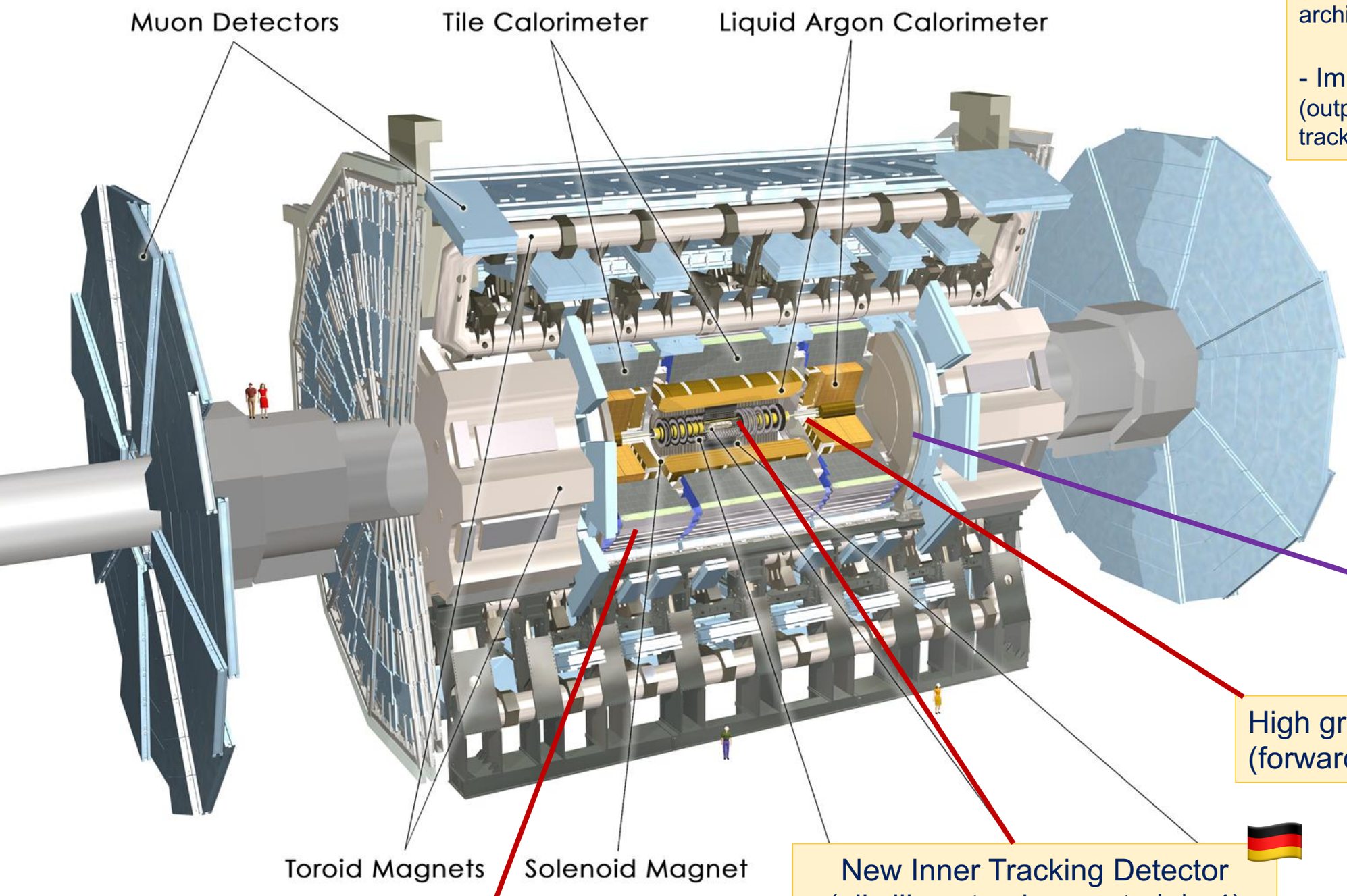
MIP Timing Detector

https://cds.cern.ch/record/2667167

Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

ATLAS – HL-LHC upgrade



Upgraded Trigger and Data Acquisition System:

- L0: at 1 MHz
(capable of evolving to a dual-level architecture with L0 at 4 MHz)

- Improved Event Filter
(output rate of 10 kHz, hardware tracking as co-processor)

Electronics Upgrade :
- LAr Calorimeter
- Tile Calorimeter
- Muon system

Phase-1
TDAQ: jFEX, L1Topo, TREX

Phase-1
New Small Wheel

High granularity timing detector
(forward region)

New Inner Tracking Detector
(all silicon tracker, up to $|\eta| = 4$)

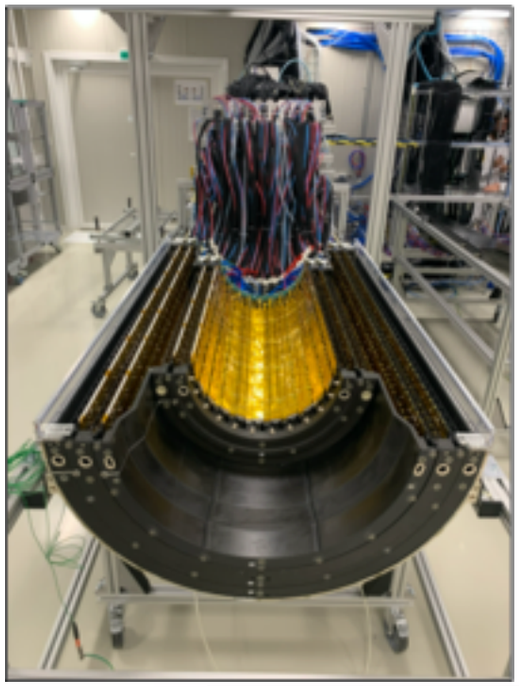
New muon chambers
in the inner barrel region

ALICE

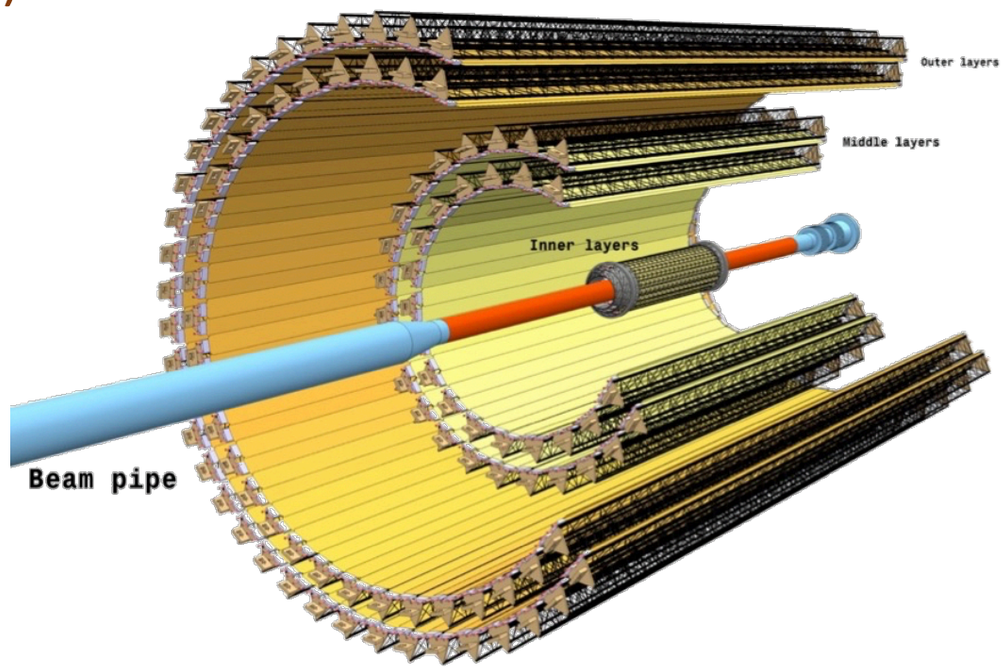
Highlights

- Inner Tracking System
- GEMs for TPC

The ‘big’ example of MAPS - ALICE

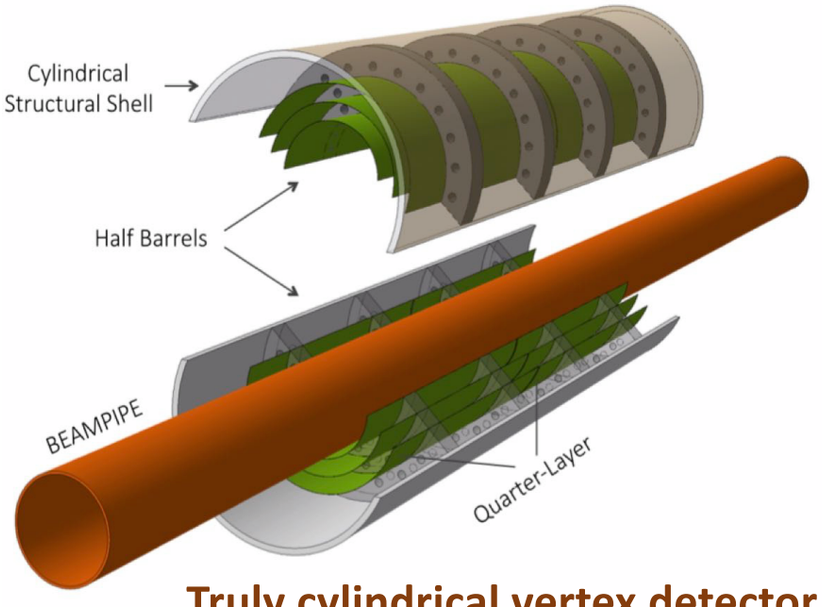


- **LS2:** 3+4 layers of MAPS (CMOS) **~10m²**
  - 27x29 μm² pixels - **12.5 G-pixels**
  - MAPS thinned to 50 μm
    - ~0.3 % X_0 per layer
- Radial coverage R= ***21*** **-** 400 mm



		Inner Barrel			Outer Barrel			
		Layer 0	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
1st Half-Barrel (Top)	Half-layer assembly	Done	Done	Done	Done	Done	Done	Done
	Half-barrel assembly	Done	Done	Done	Done	Done	Done	Done
2nd Half-Barrel (Bottom)	Half-layer assembly	Done	Done	Done	Done	Done	Done	Done
	Half-barrel assembly	Done	Done	Done	Week 48	Week 46	Done	Done

- **Future:** ALICE upgrade (ITS3) – HR/HV CMOS
  - Push technology further: **thinner,** large sensors through stitching
  - Faster signal, more radiation hard
  - Pixel sizes 10x10μm² → 3μm position resolution
  - X/X0 per layer 0.05%
  - **CURVED**



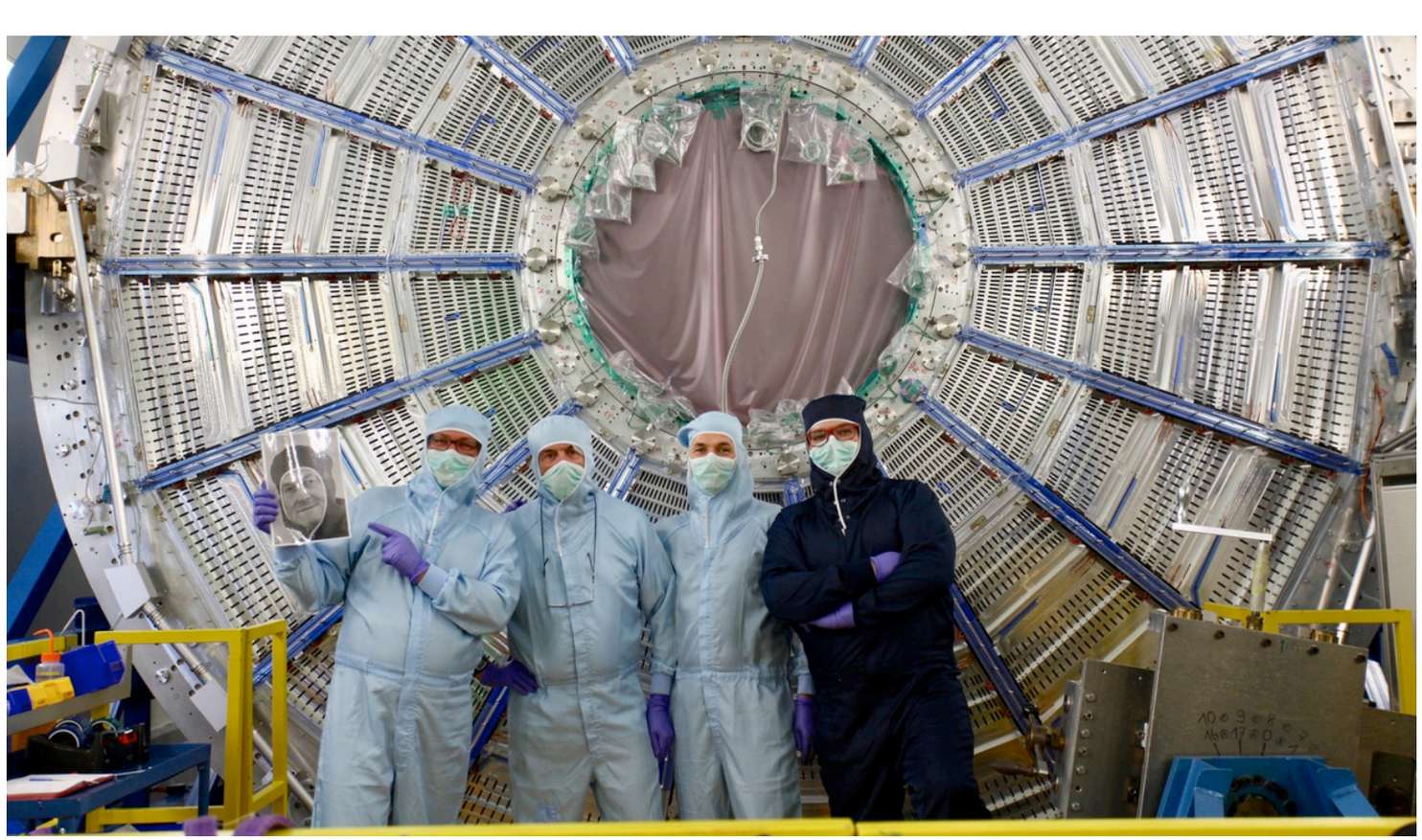
Truly cylindrical vertex detector

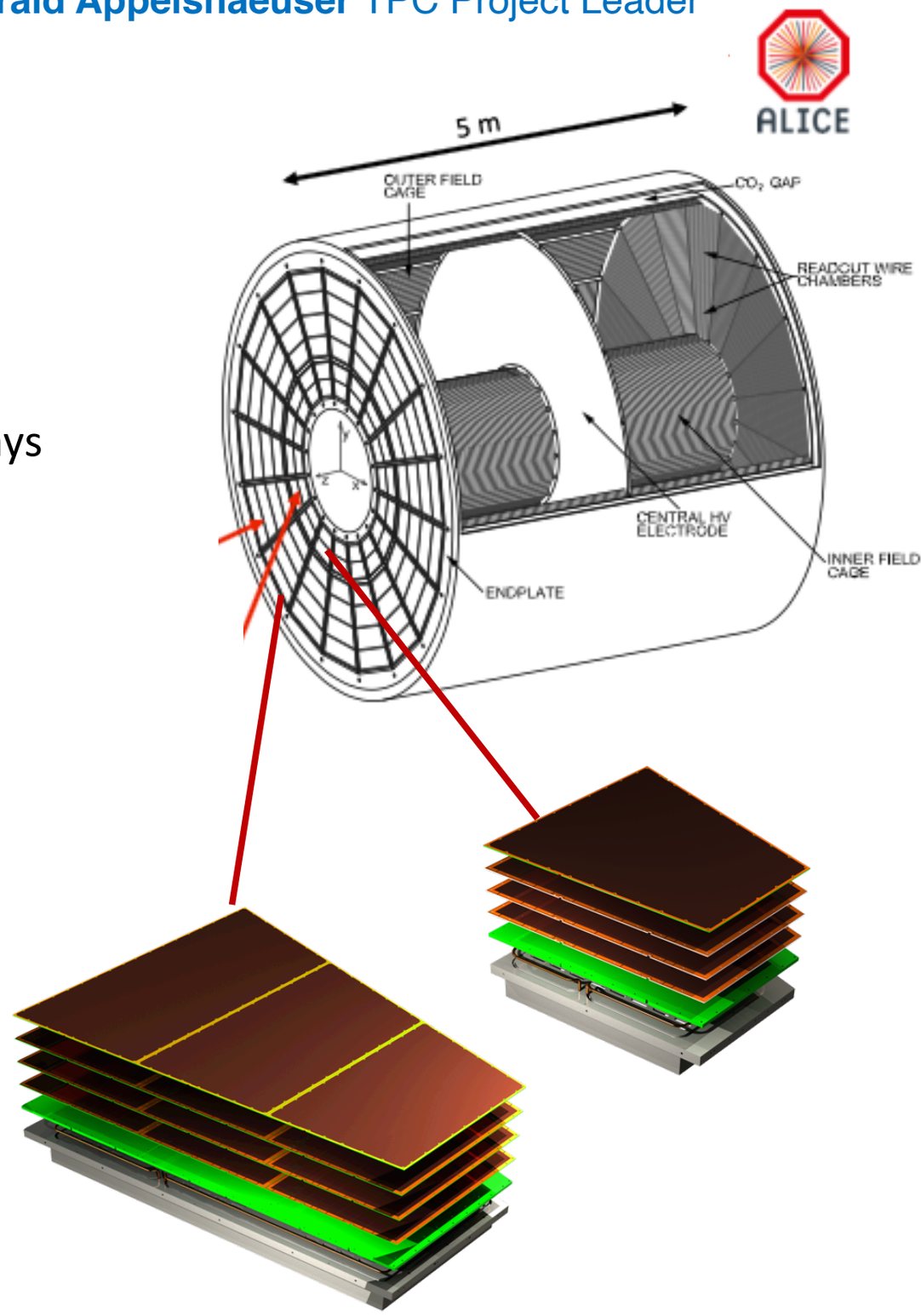
ALICE ITS Upgrade TDR CERN-LHCC-2013-024
ALICE-PUBLIC-2018-013

ALICE TPC Read out chambers – LS2

Harald Appelshaeuser TPC Project Leader

- Replace MWPC-base readout chambers and FE electronics in LS2 to allow **continuous readout** of Pb-Pb collisions at 50kHz in Run-3 and Run-4
  - **4-layer GEM detectors**
- Installation of GEMs and FE electronics completed
  - Next: pre-commissioning with laser, cosmics, pulser, X-rays





- **Plus German coordination (V. Lindenstruth) of Event Processing Nodes (EPN – GPU farm) within the O^2 project, important to calibrate (among others) the enormous TPC data**

ATLAS

Highlights

- Phase-1
- Inner Tracking System
- Electronics
- High Granular Timing Detector

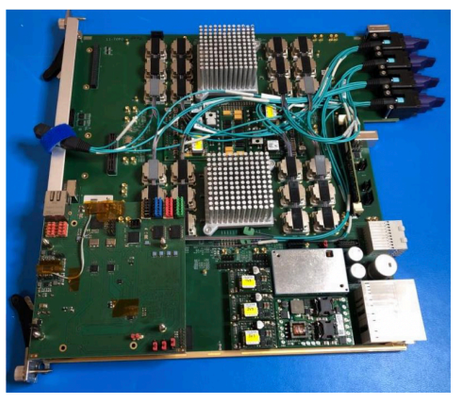
ATLAS Phase-1

- (i) **LAr Trigger Electronics upgrade**
  - enhance granularity at trigger level

Required speed achieved in routine operations to remove/install electronics

On Track

- (ii) **Trigger / DAQ**
  - Take full advantage of the LAr trigger electronics upgrade and improved end cap muon trigger (NSW)



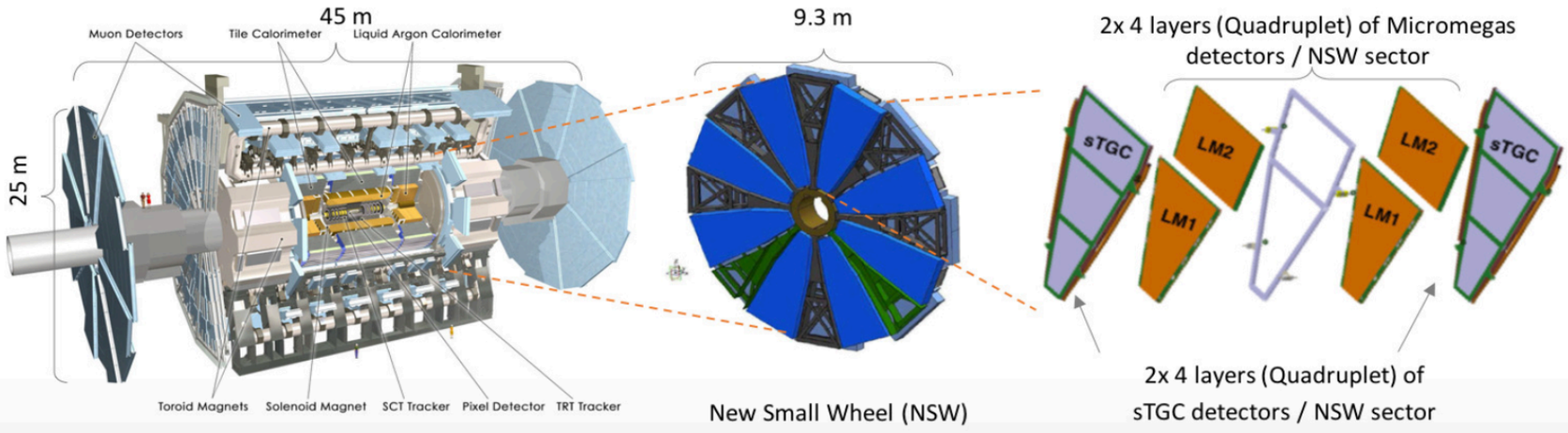
Schedule consistent with LS2 installation and commissioning plans

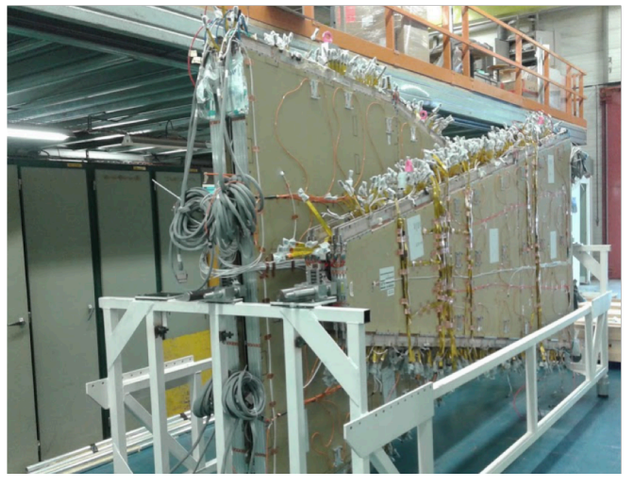
On Track

- (iii) **Muon System: New Small Wheel**
  - Replace inner muon station in the endcap → reduced muon fake trigger rate, preserve position resolution and efficiency at HL-LHC
    - **Micromegas MM & Thin Gap Chambers (sTGC)**

S. Zimmermann - Upgrade Project Leader of NSW

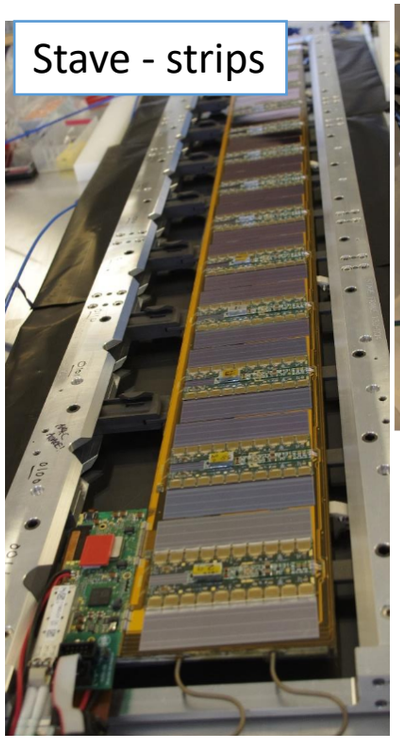
Plan to install **NSW-A** in LS2 and NSW-C in a later EYETS
Slice Test early Nov. confirms this plan (on critical path)

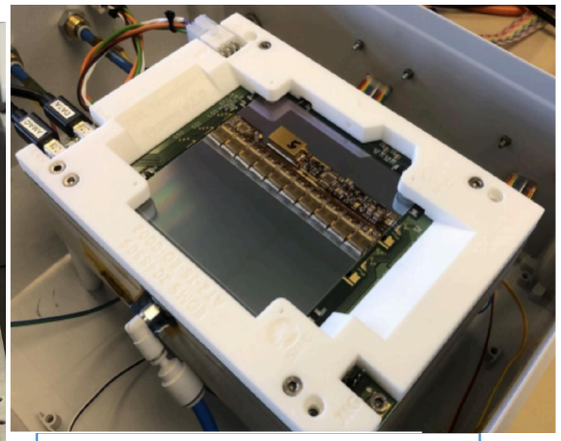




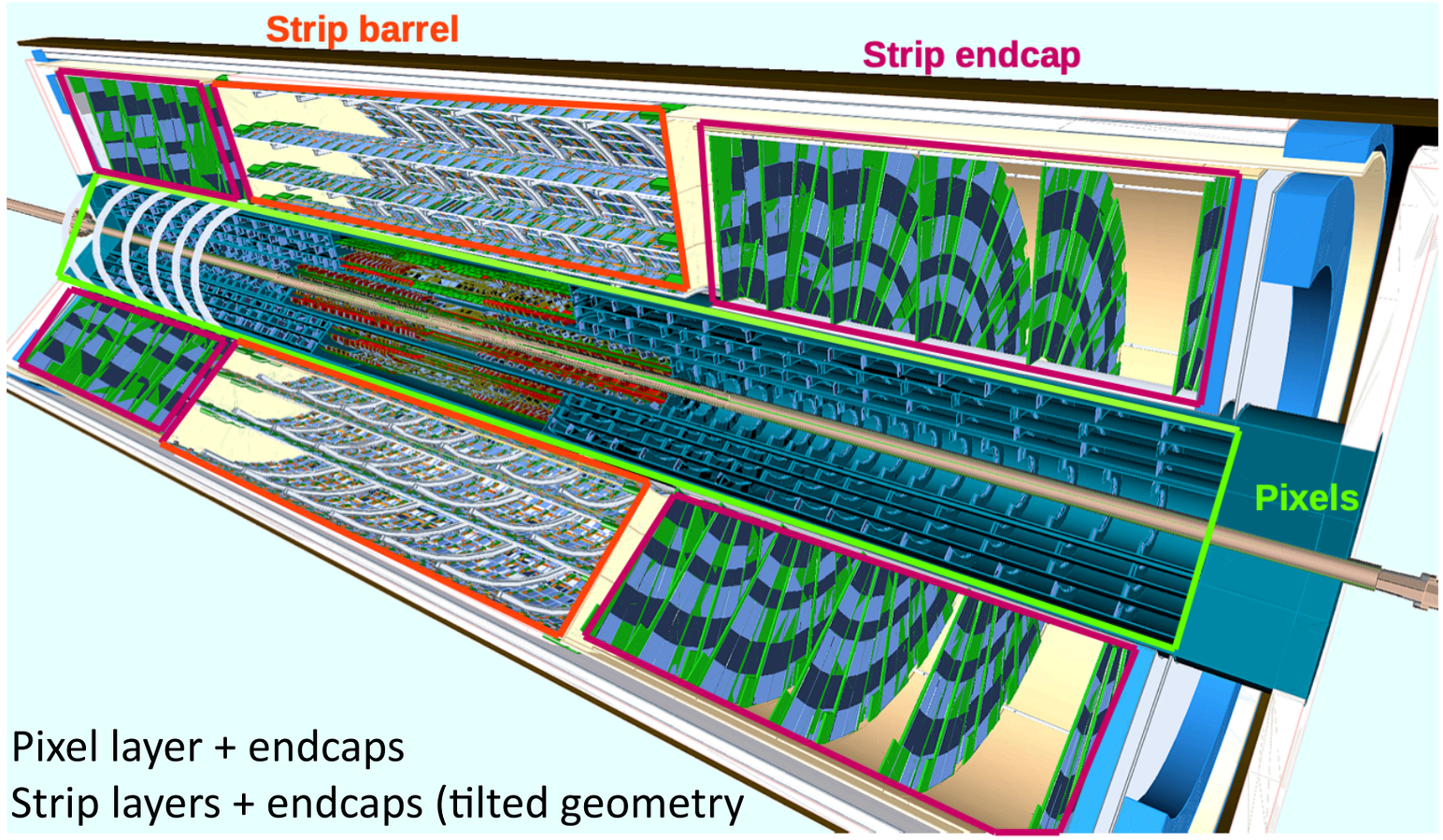
Completed Micromegas double wedge

ATLAS Phase-2 Inner Tracker





Barrel strips module with hybrid / ASICs



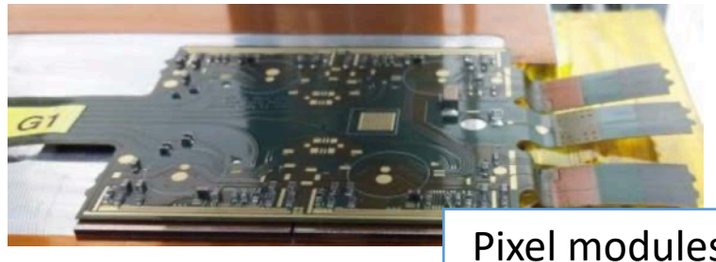
5 Pixel layer + endcaps
4 Strip layers + endcaps (tilted geometry

All-Silicon Tracker

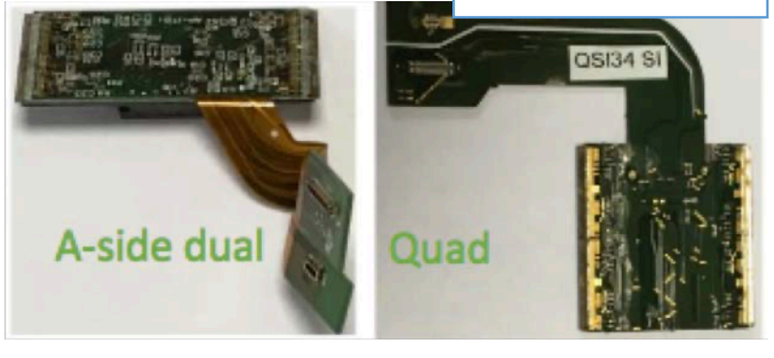
- Strips: Final Design reviews of many components passed
  - Sensors, chips, stave and petal bus tapes, modules and their components (hybrids, power boards)

Largest Pixel Detector ~13m^2

- Market survey of module hybridization in final stage
  - 200 modules being constructed with RD53A chip (→ system tests, test of serial powering and assembly)



Pixel modules



Convener Strips
I. Bloch: Modules
I. Gregor: Integration
P. Göttlicher: Local Support Electronics
D. Spärlich: System Test

Convener Pixel
J. Weingarten: Sensors
T. Flick: On-detector services
F. Huegging: Hybridization
M. Hamer: Off-detector services

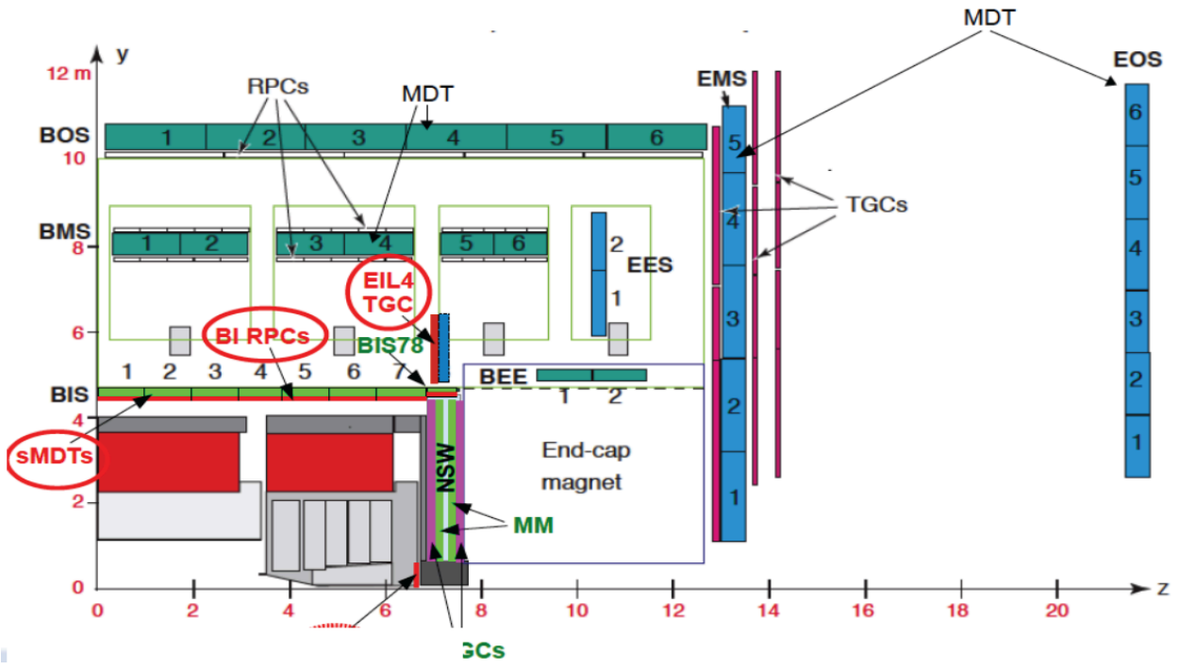
ATLAS Phase-2 Muon Spectrometer

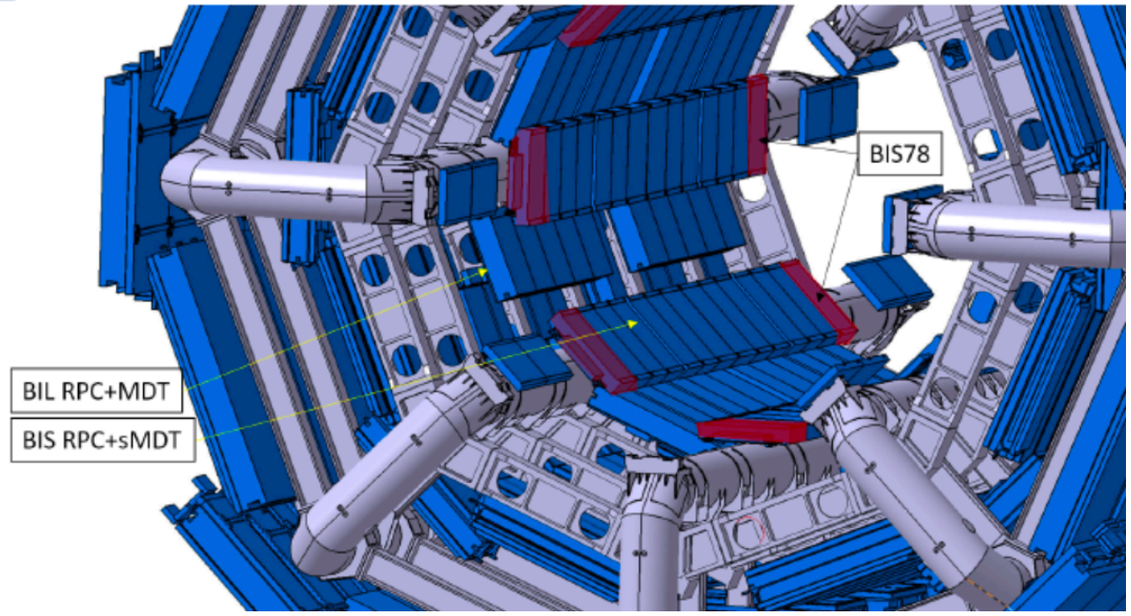
- **Inner Barrel sMDT:**
  - chamber design almost finished

- **Inner Barrel RPC:**
  - Single channel prototype of front-end ASIC produced

- **MDT/sMDT electronics**:
  - Amplifier-Shaper-Discriminator ASIC (ASD)
  - New TDC ASIC (for MDT drift time)

- **TGC electronics:**
  - Patch Panel ASIC entering production (~11'000 ASICs by June 2020)



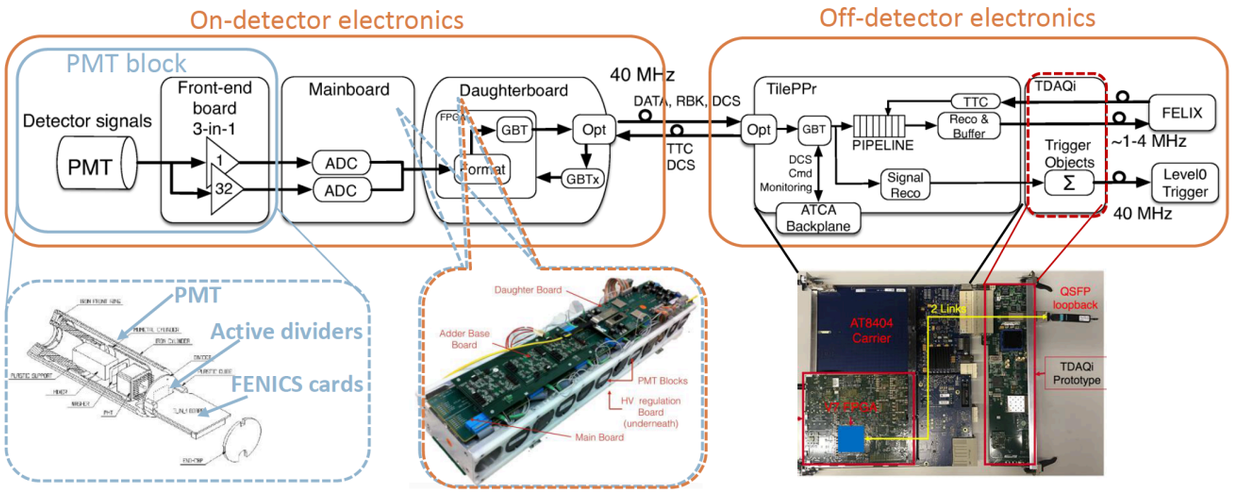


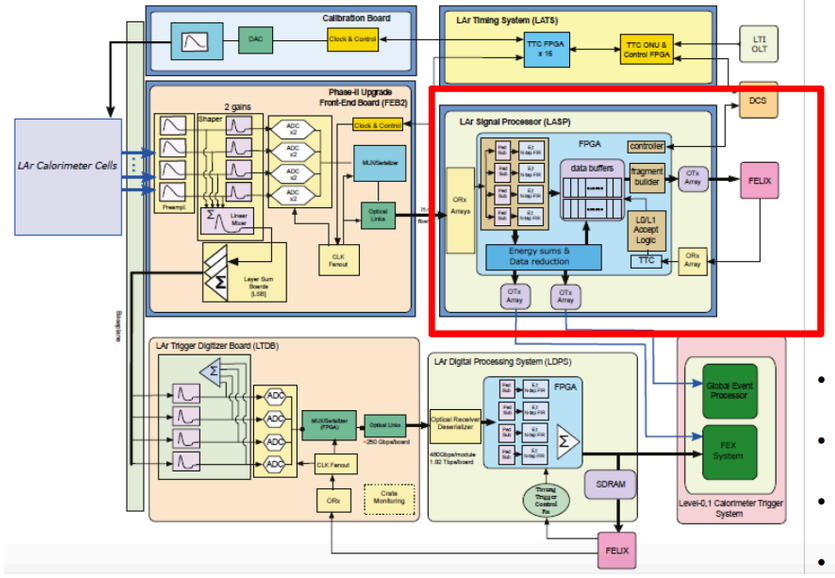
All sub-projects are progressing well, without serious issues

Convener
H. Kroha: sMDT sub-project coordinator

ATLAS Phase-2 Calorimeter LAr and Tile

- Replace complete front- and back-end electronics
  - Plus, replace some PMTs of the Tile Calorimeter plus some new mechanics

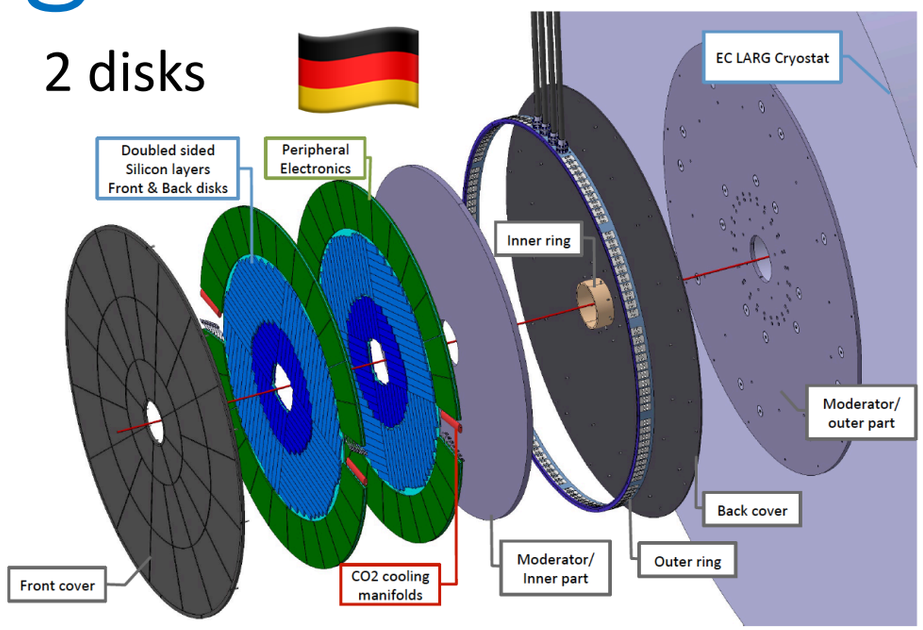




Hans-Christian Schultz-Coulon L1Calo Project Leader

and High Granularity Timing Detector

- ATLAS HGTD project is very challenging
  (new technology, major R&D, late start, challenging environment)
- Significant Progress towards **submission of TDR in April 2020**
- **Sensors:** LGAD irradiated with neutrons, protons and X-rays.



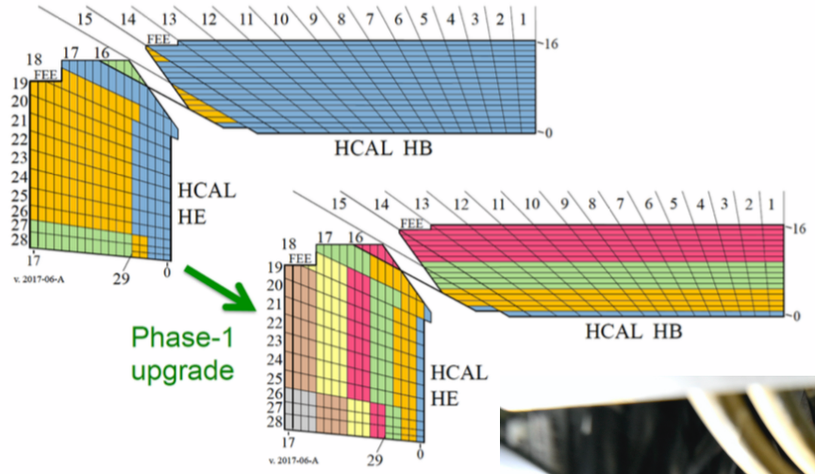
Convener: **L. Masetti:** modules

CMS

Highlights

- Tracker
- Muons
- High Granularity Calorimeter

CMS Phase -1
Concluded!



- Hadron Barrel installation finished commissioning including ^{60}Co scan early Nov.

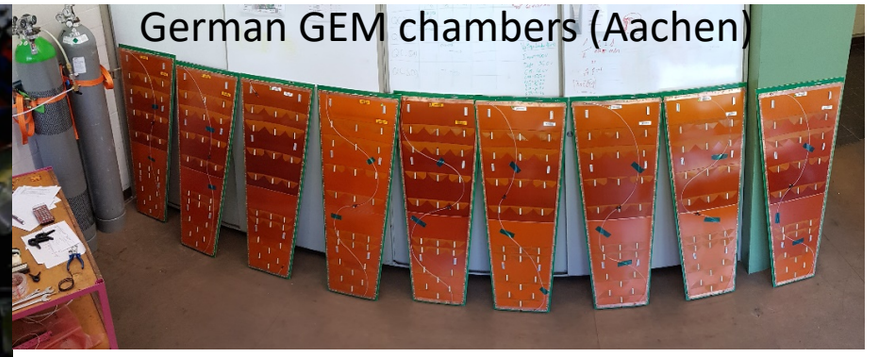
🇩🇪

- Pixel Layer 1 replacement on track
  - New DCDCs for the whole detector
  - Layer 1
    - Improved ROC
    - Voltage now up to 800V

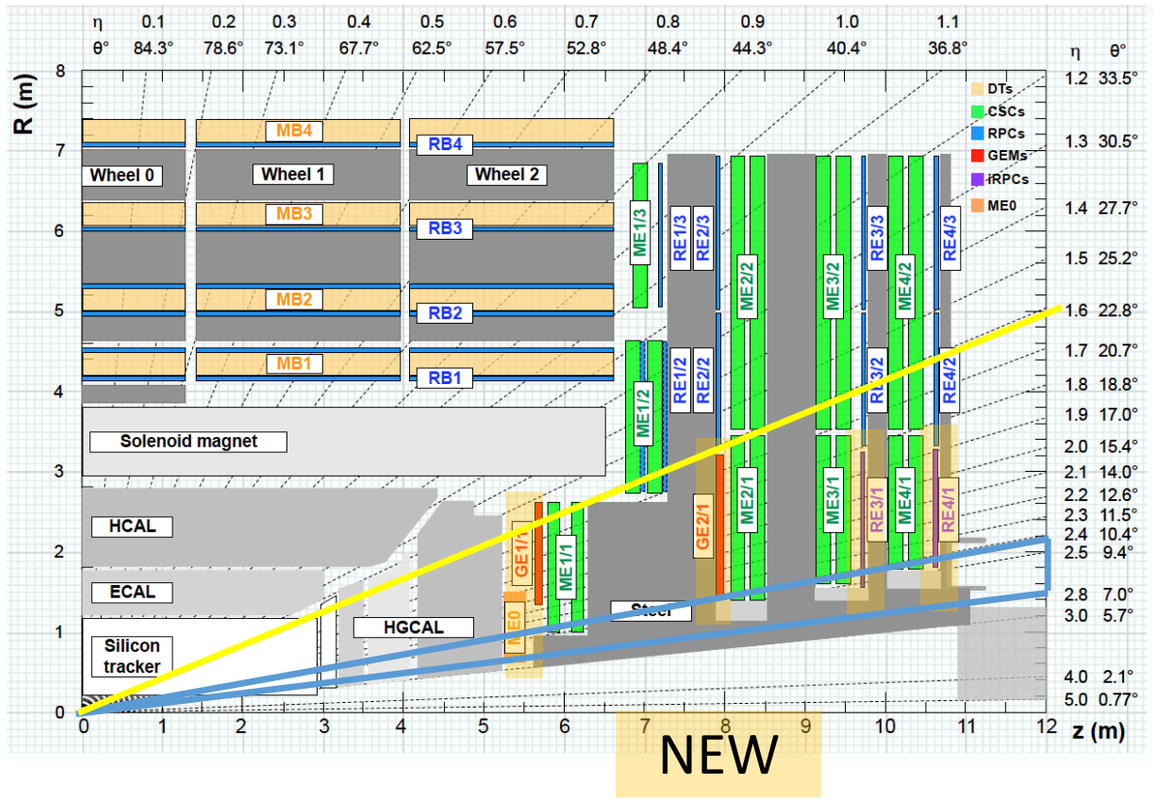
K. Hoepfner - DT system IB chair

CMS Muons Phase-2 🇩🇪

Installation of first CMS Phase-2 detector GE1/1
- 1st end installed!
- 2nd end early 2020 🇩🇪



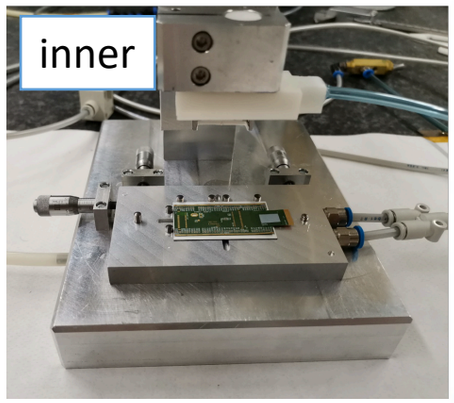
Installation of services for future detectors
- GEM GE2/1 services
- RPC RE34/1 services 🇩🇪

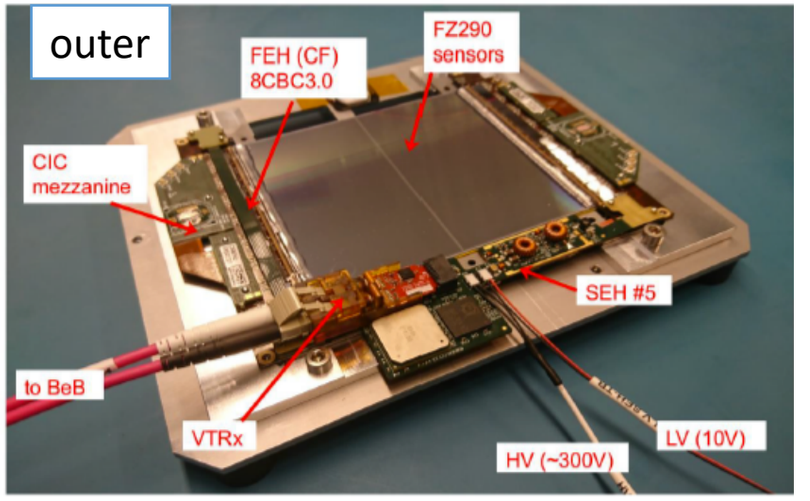


- **Fully replace to cope with 10-fold rates**
- Add new detectors in very-forward region
  - $2.4 < |\eta| < 2.8$

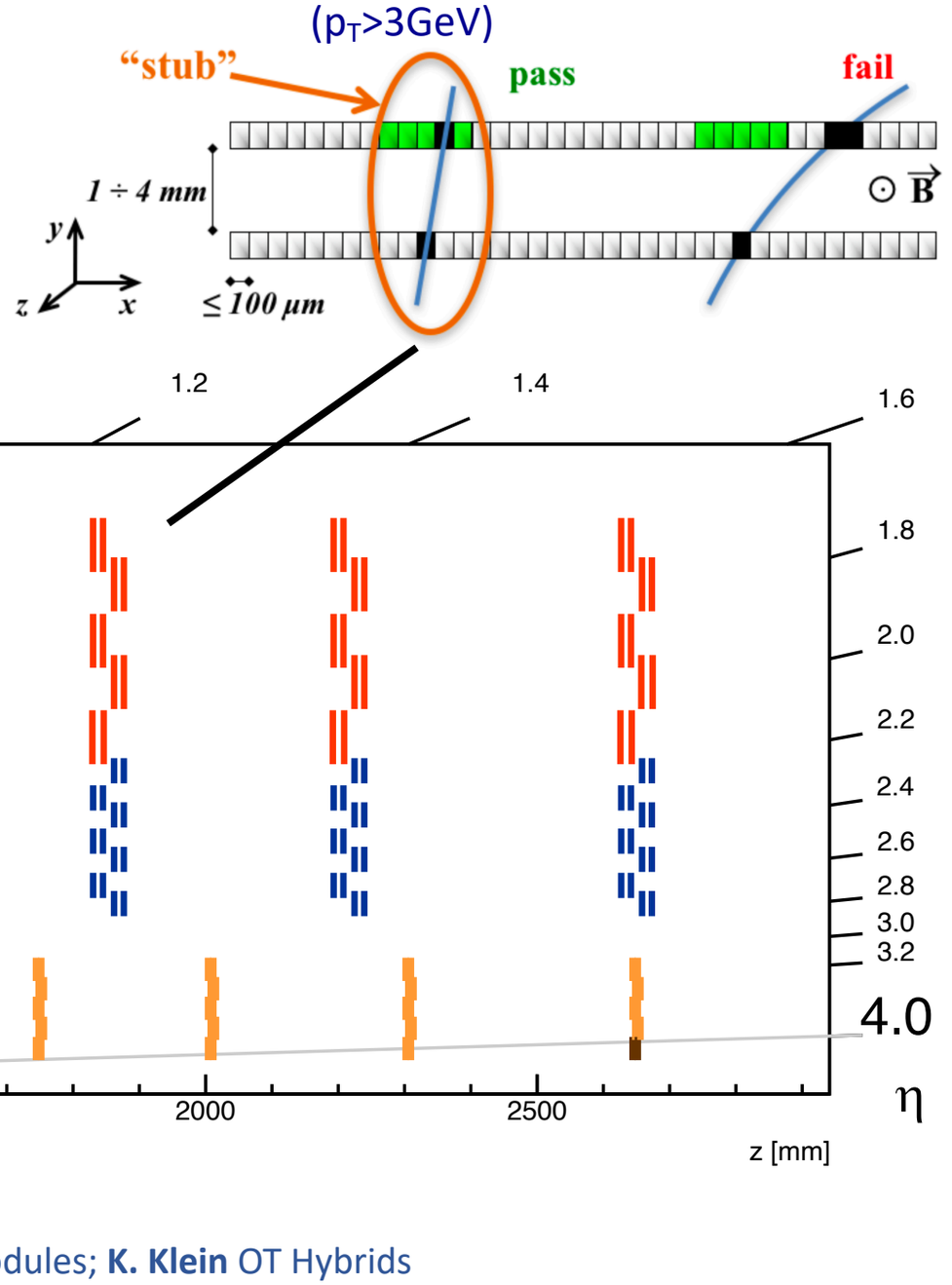
CMS Tracker - LS3

- Outer Tracker design driven by ability to provide **tracks at 40 MHz to L1-trigger** (p_T>3GeV)
- Tilted modules in three OT layers
- Inner Tracker (pixel) extend coverage to η ≃ 3.8
- **Market Survey, System test, prototyping, engineering of all components ongoing**





Fully equipped 8CBC3 based 2S module at Aachen



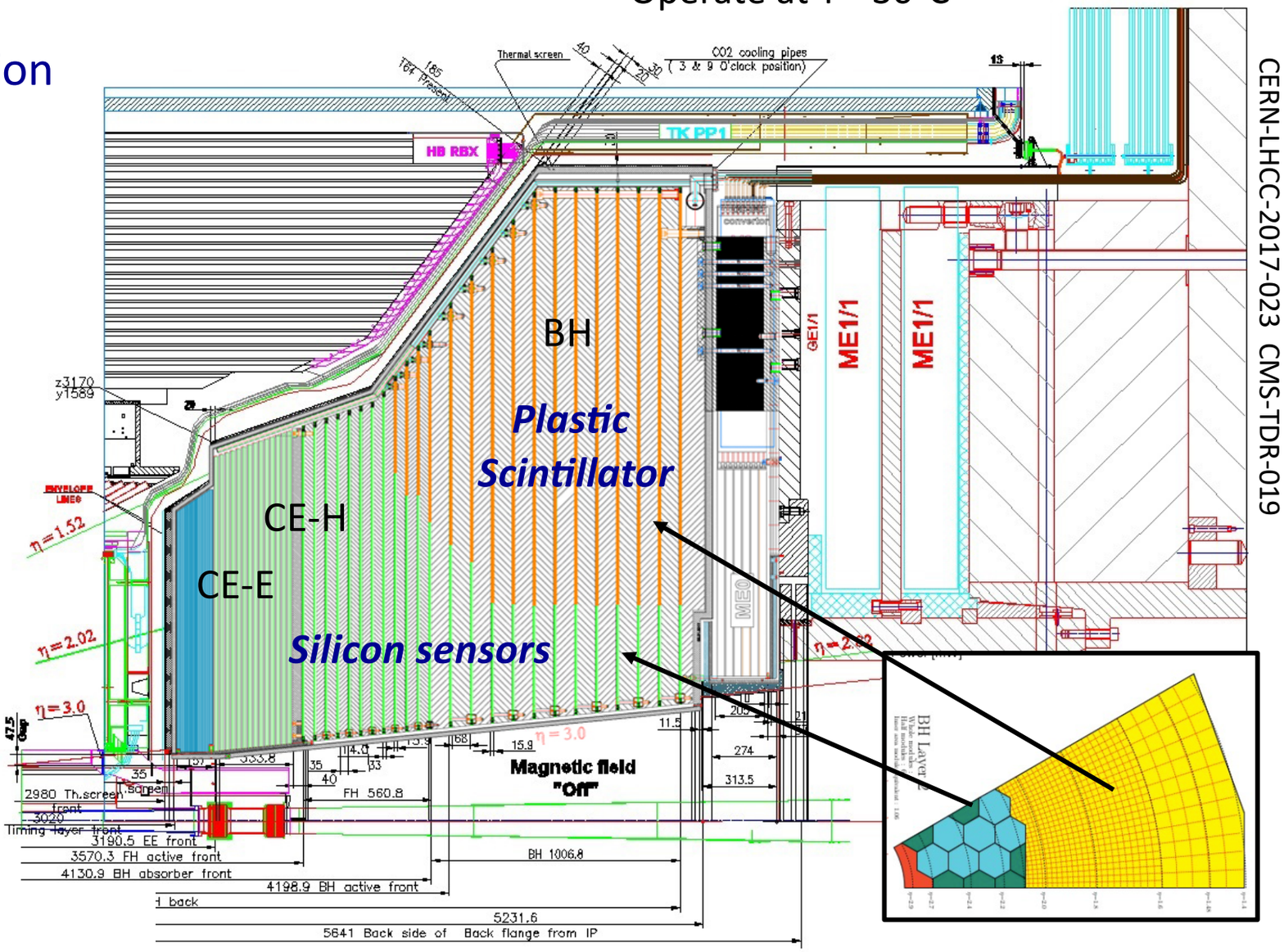
Conveners from Germany – Tracker Project Manager Erik Butz

A. Dierlamm: OT sensors and system test; **G. Steinbrueck:** IT sensors; **A. Mussgiller:** OT Modules; **K. Klein** OT Hybrids

Silicon enters calorimetry on large scale – LS3

- 3D shower topology and time resolution of ~ 30 ps (p_T > few GeV) **- 5D**
- **The silicon part** (*more rad tolerant*)
  - 640 m^2 of silicon
  - 8” wafers
  - 6M channels, 0.5 or 1 cm^2 cells
  - 25000 modules
- **Plastic scintillator** (*less rad tolerant*)
  - 500 m^2 of scintillators
  - ~400k scintillator & SiPMs on tile*
- High granularity
  - A dream for Particle Flow concept (PF)

Operate at T=-30°C



Cu/CuW/Pb stainless steel

*CE-E: **28** sampling layers – 26 X_o + ~1.7 λ* ***22** sampling layers – 8 λ*

Convener from Germany:
F. Sefkow: Scintillators and SiPMs

*SiPM-on-tile initially developed in the BMBF framework Scintillator-R&D

ATLAS & CMS more highlights

An important milestone - CERN, 23rd August 2019:

- Signature of frame contract between CERN and Hamamatsu Photonics on production of silicon sensors for ATLAS and CMS Phase-II
  - ATLAS ITk strips,
  - CMS strip tracker,
  - CMS endcap calorimeter

More than 1000m^2 of silicon

LHCB

Highlights

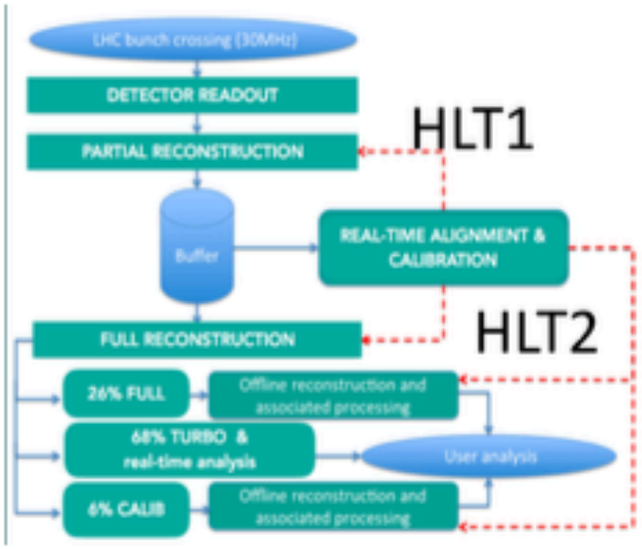
- SciFi
- Real Time Analysis Project

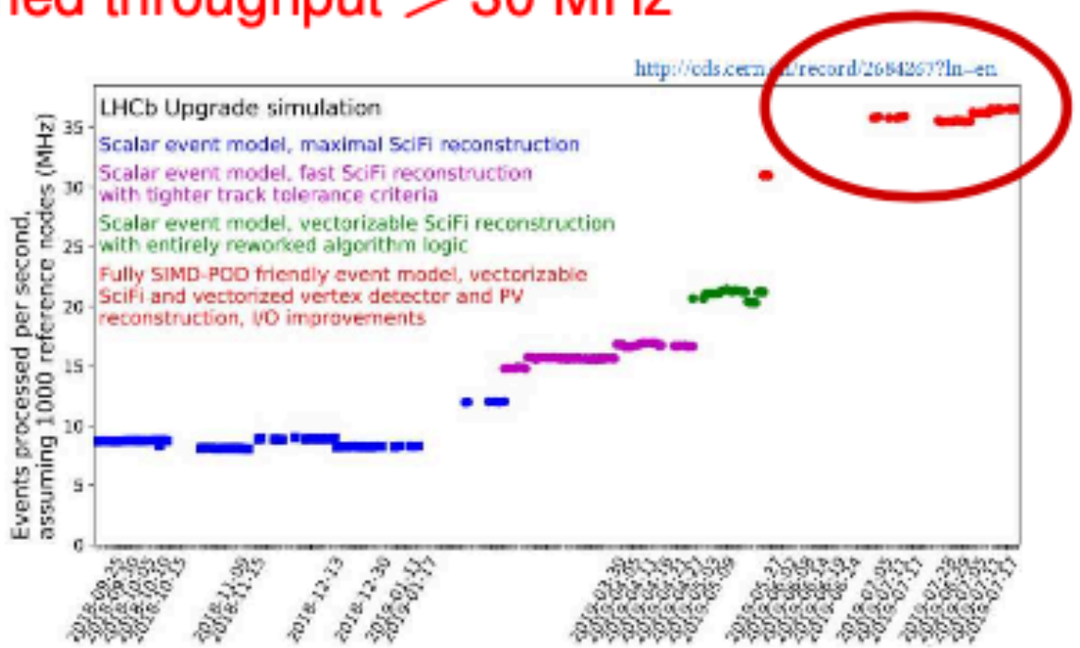
The march towards the Upgrade-I is continuing

- All subsystems progressing - installation ongoing!
- Schedule is tight, working hard to be ready for LHC Run 3!

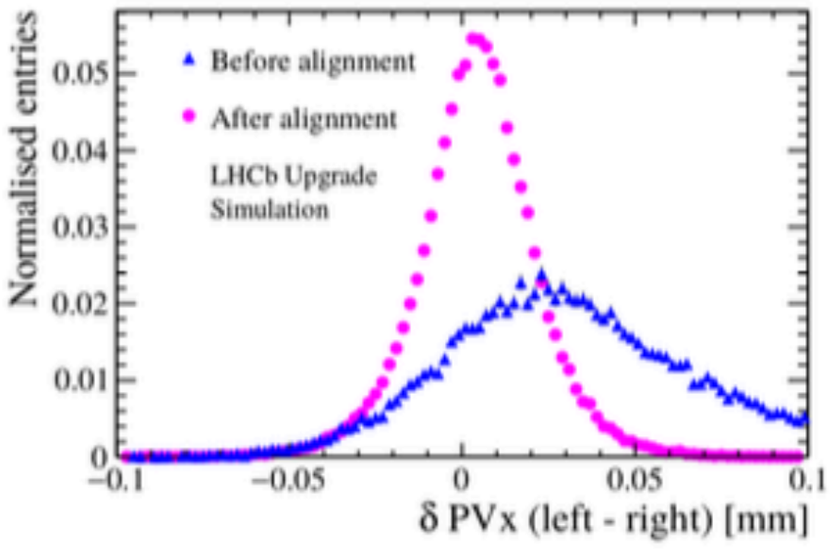
LHCb Real Time Analysis Project (RTA)

- Baseline CPU-based HLT1 reached throughput > 30 MHz





- physics performance studies ongoing
  - triggering in beam gas mode
    → test full flexibility
  - real time alignment
  - ...

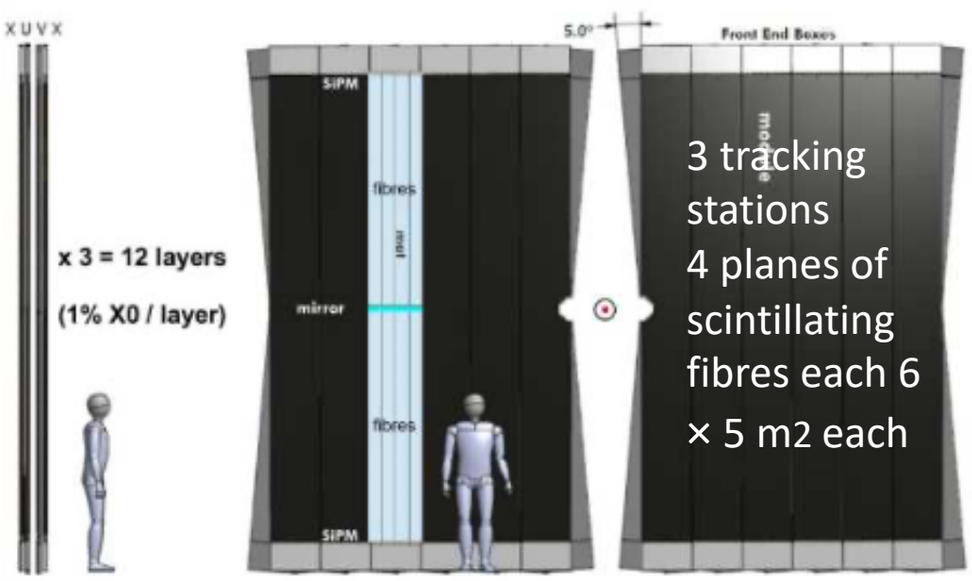


- Deployment of HLT2 lines started
- In parallel evaluation of accelerators for HLT1 (FPGA clustering, GPU reconstruction, ...)

U. Uwer: project coordinator

LHCb SciFi

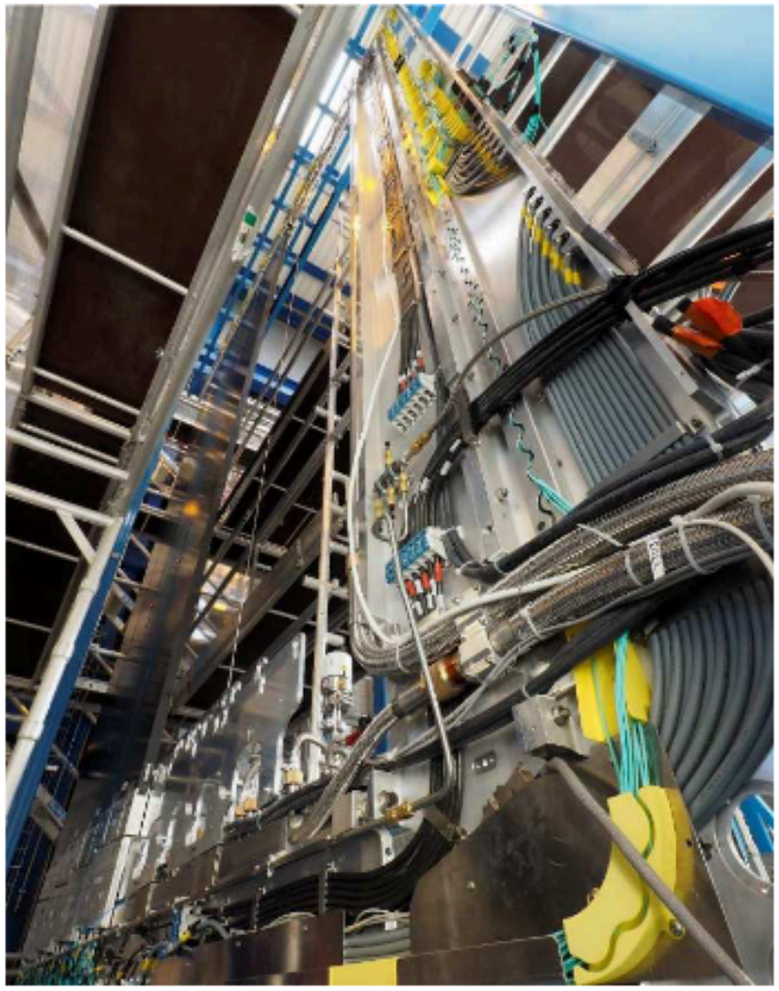
Module production & test finished,
SiPM tests finished,
test of front-end electronic ongoing,
main work now: detector frame assembly &



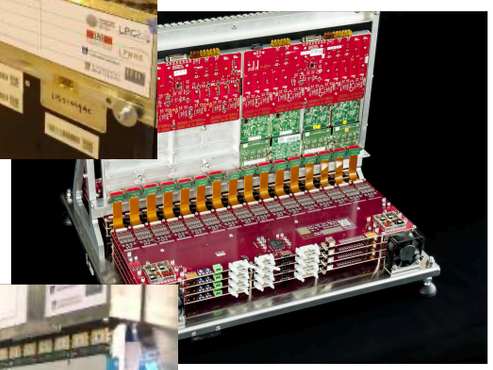
Novel detector

- read out by SiPMs, cooled to -40°C
- 1% X_0 per detector plane
- 99% single hit efficiency
- σ_x < 100 µm
  - (in test beam σx < 70 µm)

3 (out of 12) C-frames assembled



Cold boxes



FE tester

FE boxes

Tight schedule: installation of first 6 C frames scheduled early spring 2020

Conclusion

- Massive work ongoing at all four LHC sites
  and it will be even more during LS3
  - **Very strong and continuous German contribution!**
- These beautiful upgrades will give us even more opportunities to understand the complex events at high pile-up
  - Completely new electronics
  - New Trackers, partially new Muons
  - New DAQ, Trigger
  - Precision timing

Sorry if I did not fit your favorite detector

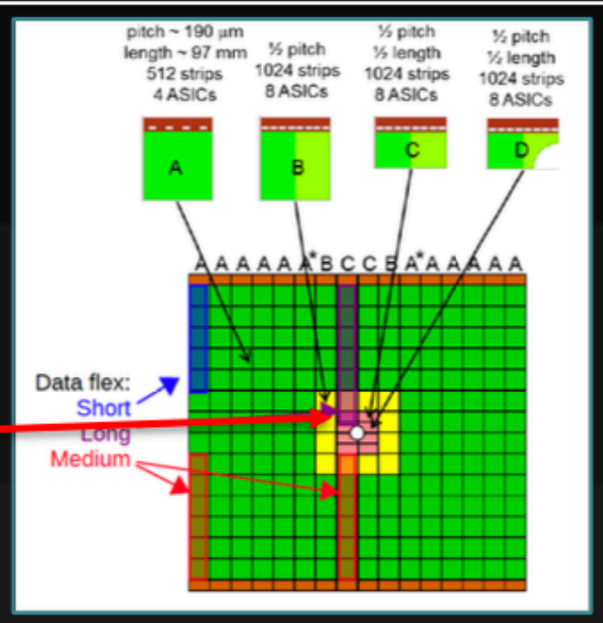
- Slides and information mainly from the last RRB and many dear colleagues:
  - Stephanie Menzemer, Stephanie Zimmermann, Volker Buescher, Karl Jakobs, Harald Appelshäuser, Arnulf Quadt, Hans-Christian Schultz-Coulon, Lucia Masetti, Francesco Lanni
- **And big thanks to our funding agencies**

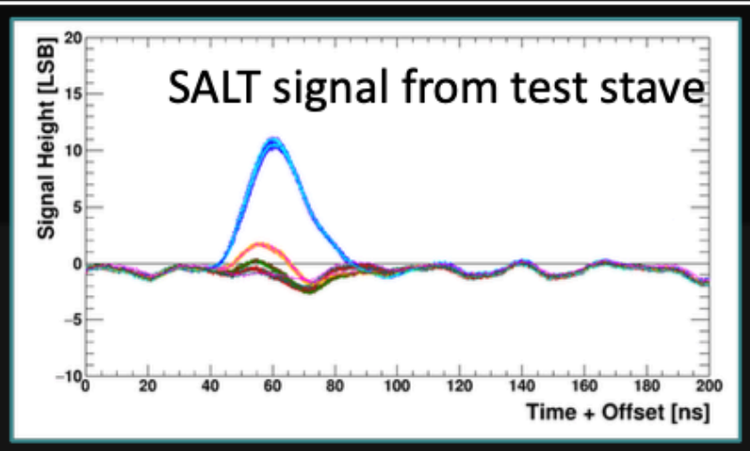
Bundesministerium für Bildung und Forschung
Forschungsinfrastrukturen (FIS)
MAX-PLANCK-GESELLSCHAFT
HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

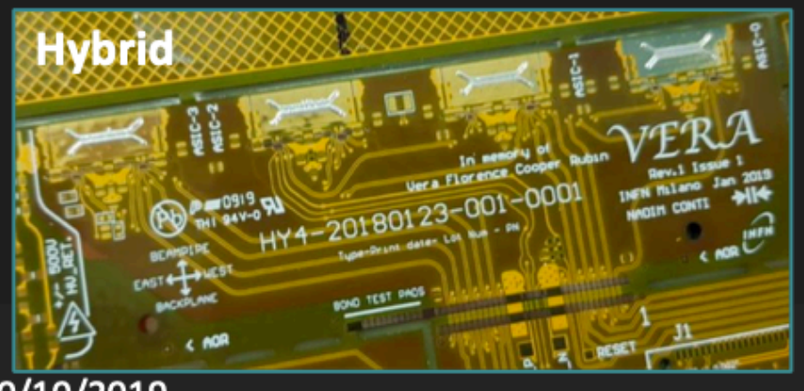
Backup

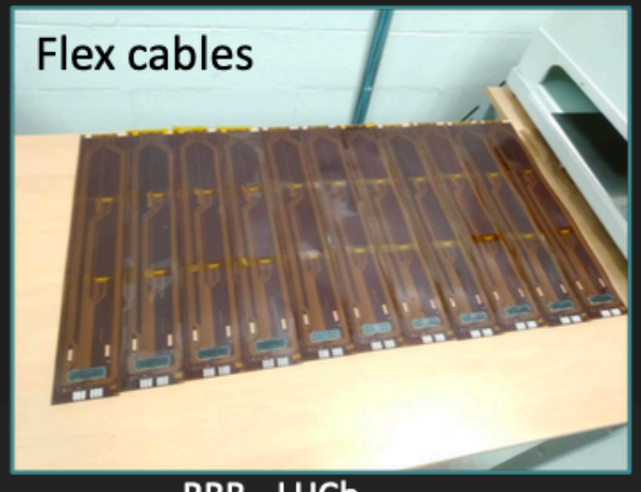
Upgrade: UT

- SALT3.5
  - ★ 18 wafers received in early July
  - ★ Wafer testing completed in summer
  - ★ Good yield: ~82 % => ~6850 chips
- SALT3.8 (8-chip hybrid version): diced chips at CERN, ready for final tests
- Hybrids and flex cables being produced
- Ready to start stave production
- Readout electronics and mechanics progressing well
- Tight schedule !





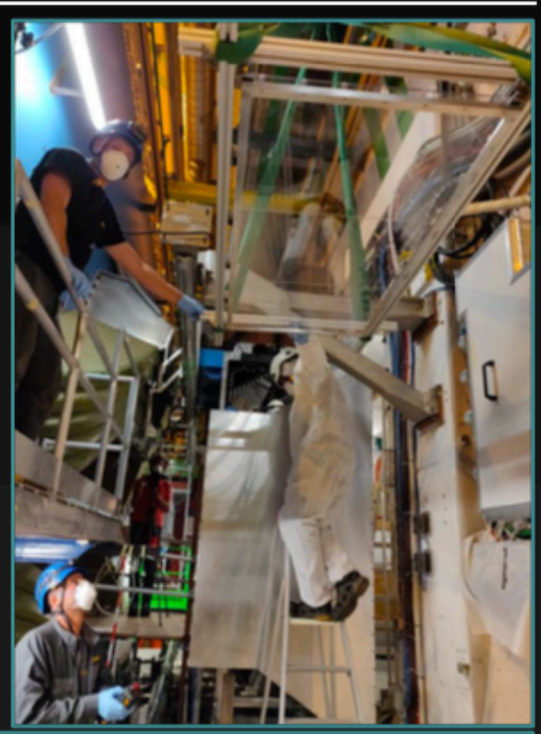


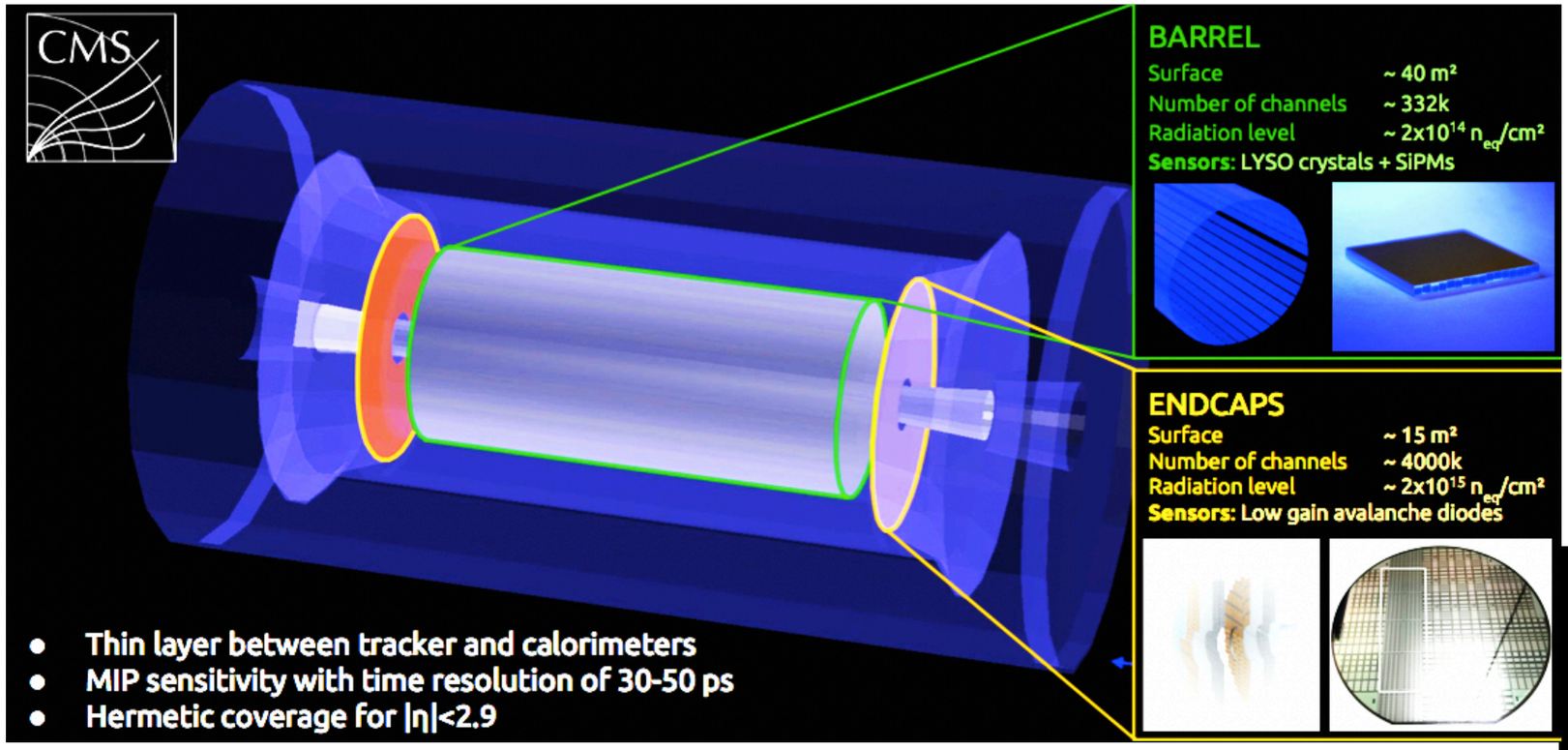


UT slice test with an instrumented stave at CERN

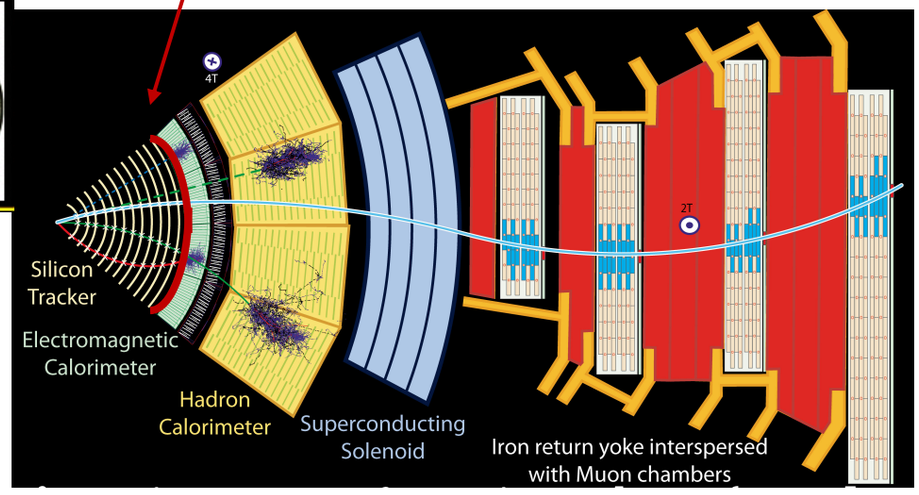
Upgrade: RICH

- All components for photon detection system at hand
- Readout electronics produced
- Q&A well advanced, components at CERN for “column” assembly
- RICH1 spherical mirrors at CERN for coating
- Mechanics progressing well
- RICH1 MaPMT support chassis and gas enclosure installed.
- Unfortunately problem: the quartz window cracked
  - ★ Need to build a new one
  - ★ Essentially no input on schedule but additional work needed





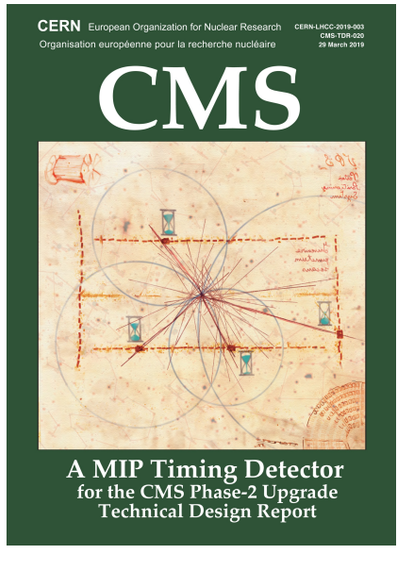
Between Tracker and Calorimeter



30 ps timing – the extra independent parameter **makes the difference**

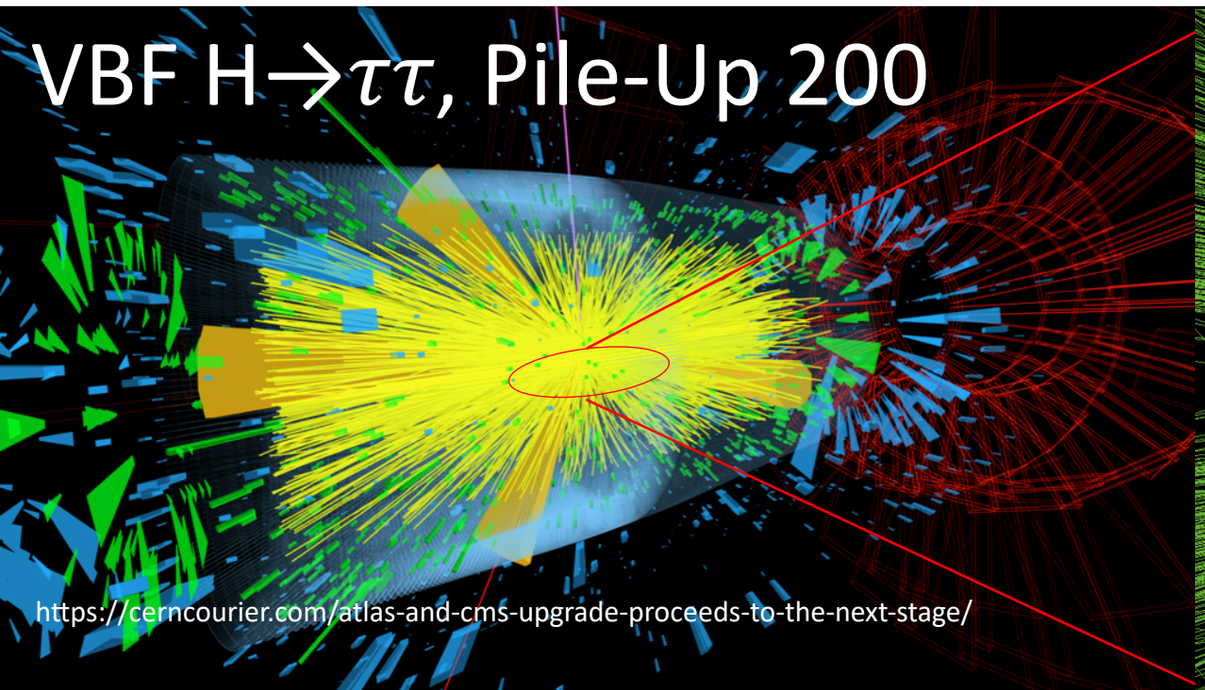
MTD MIP Timing Detector

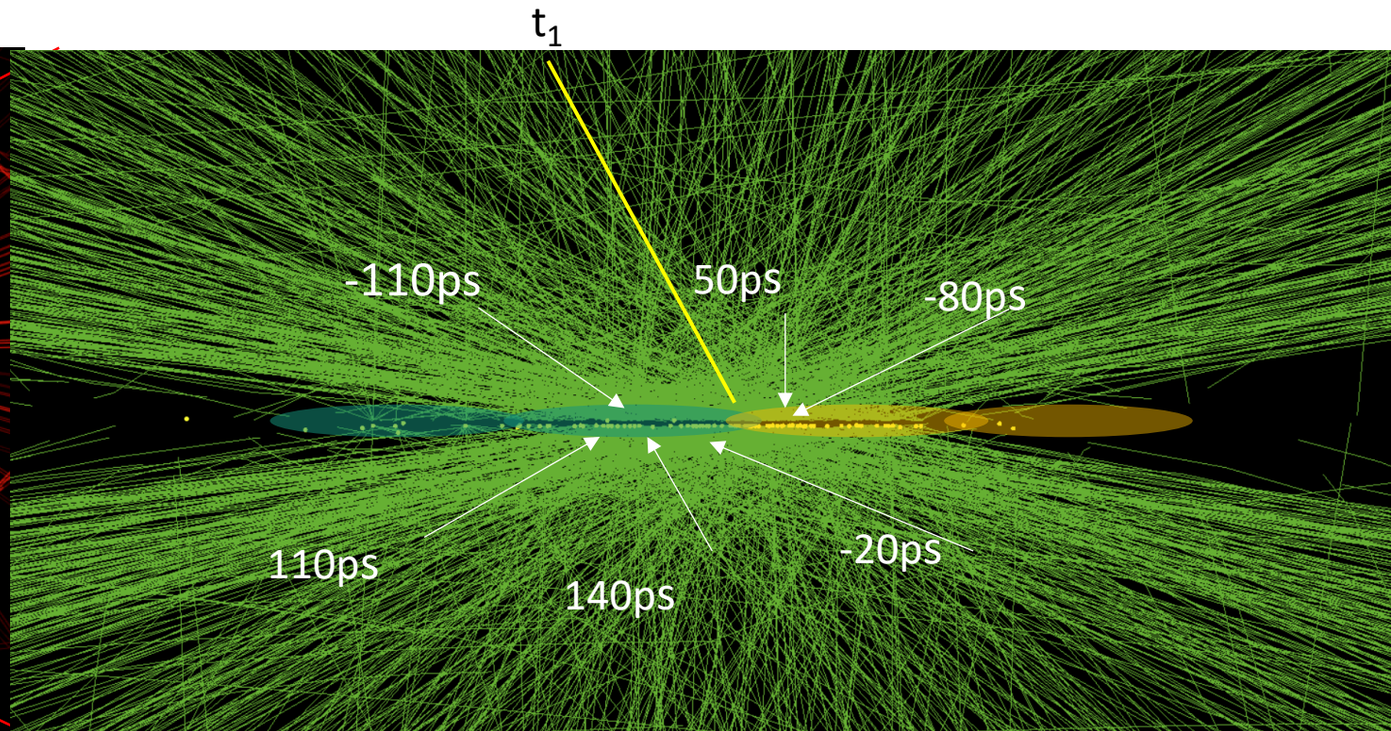
this is new

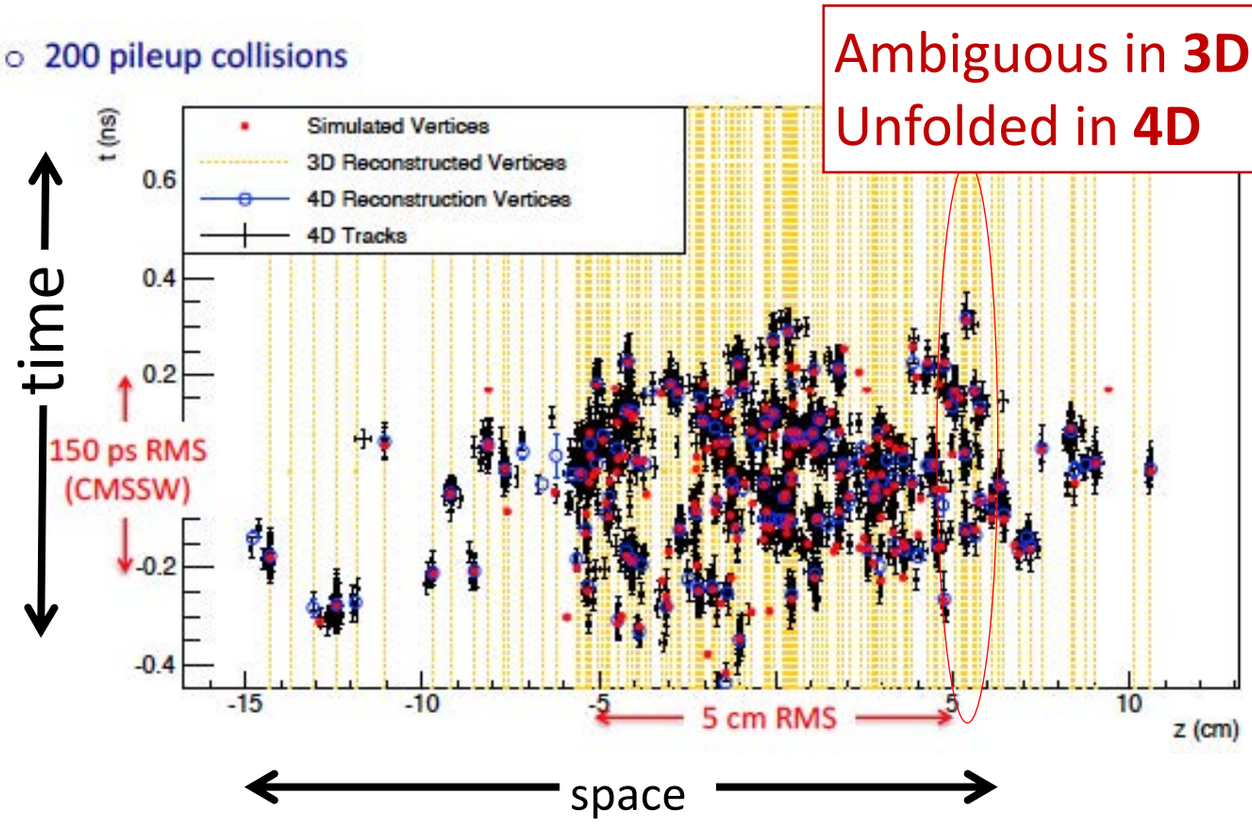


CERN-LHCC-2019-003 CMS-TDR-020

Sorting the mess even better







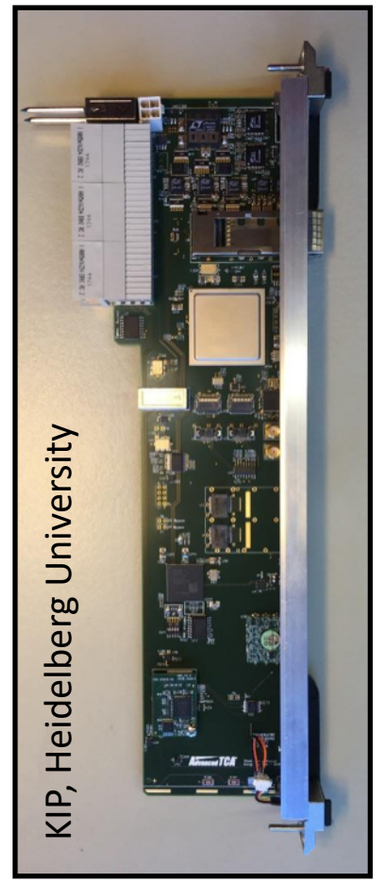
~10’000 tracks
per collision bunch

- @ PU=200
  Vertex density ~2 vertices/mm
  - Unfold pile-up =
    sort 180ps collision area
    into ’30ps blocks’

ATLAS Tile Pre-Processor Upgrade

New electronics for pre-processing Hadron Tile Calorimeter Trigger Data

TDAQi
Prototype



ATLAS Phase-2:

Digitisation of Tile Trigger data at front-end

Provides full cell granularity to trigger

Requires new readout and trigger electronics

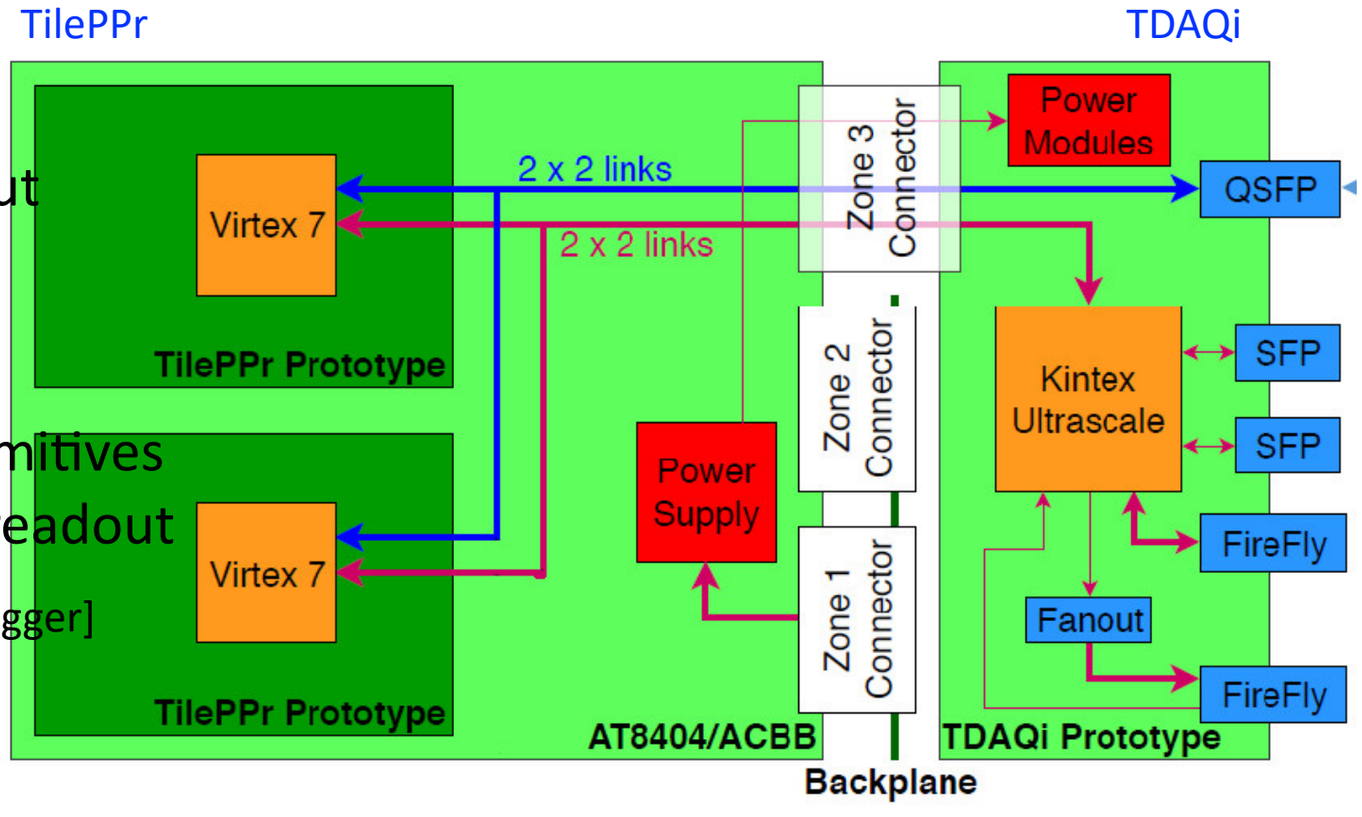
Tile Pre-Processor:

Data pre-processing and data handling for trigger and readout

TDAQ-Interface (TDAQi):

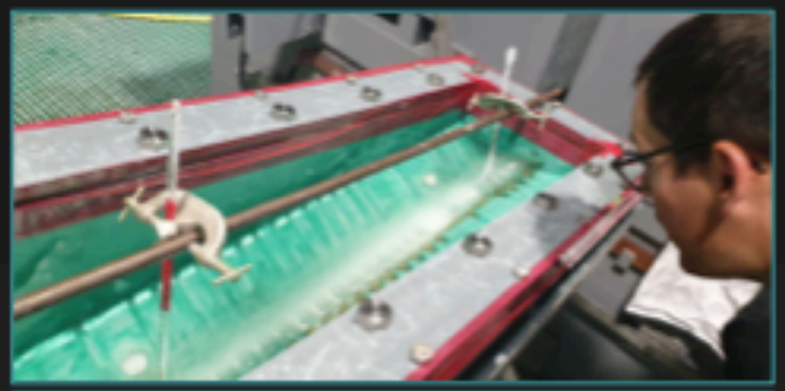
Computation of trigger primitives and interface to trigger & readout

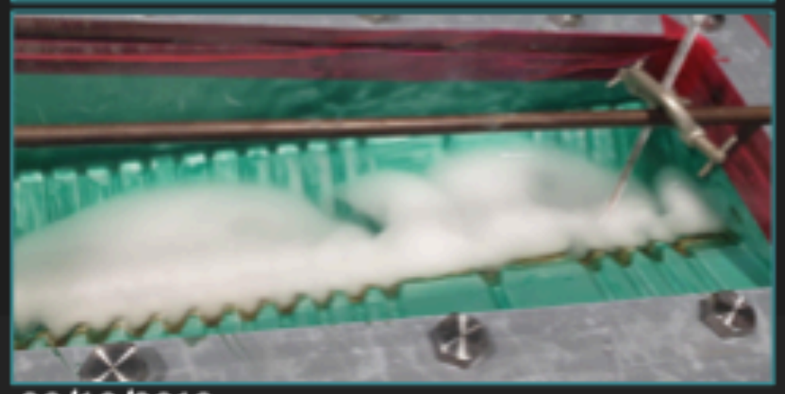
[Input for L0Calo, L0Muon, Global Trigger]



Upgrade: VELO

- Production of VELO modules started, although still not at the nominal pace
- Mechanics and readout electronics progressing well
- Important decision to proceed to RF-foil etching: successfully thinned down to 150 µm
- Tight schedule!





VELO etching with NaOH solution
Green area is passivated
Etched boxes are now at Nikhef for final metrology and coating