Research and Computing

E.Elsen

CERN, December 15, 2020

Look back 5 years

- Higgs had (just) been discovered
- Hoping for (fairly) strongly coupling New Physics
    - energy increase
    - energy reach provided by luminosity spectrum increase
- Neutrinos to address CP violation in the leptonic sector
    - What is the nature of neutrinos (sterile, Majorana)?

and the tools 5 years ago

- Run 2 was beginning in earnest: 13 TeV
- Phase I upgrades were in full swing
- Phase II upgrades had just submitted scoping document
- Neutrino Platform was Europe's response to the Long Baseline endeavours in the US and Japan
- Machine Learning started to be introduced
- Computing challenges of Phase II had no solution that could be convincingly explained

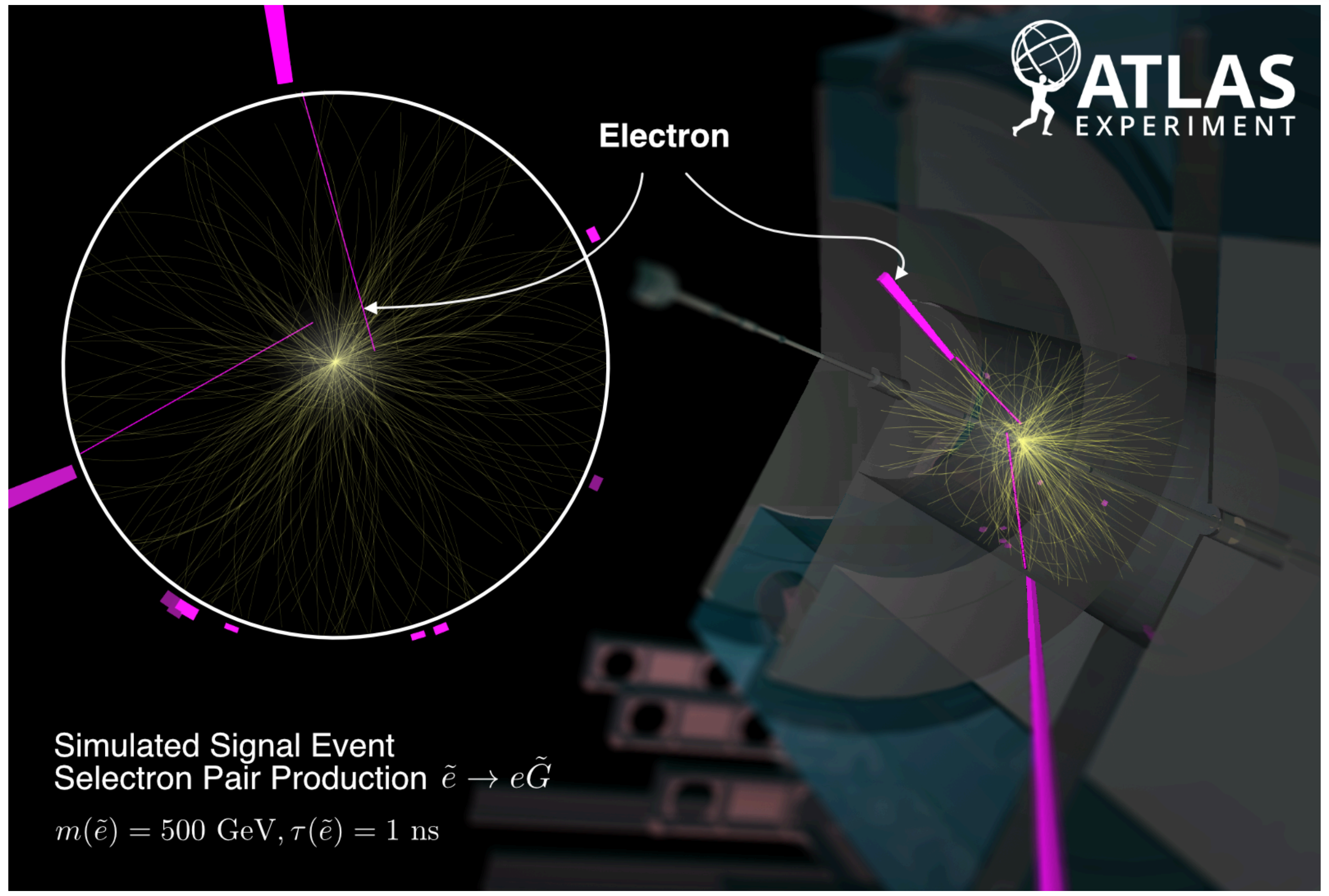
2020

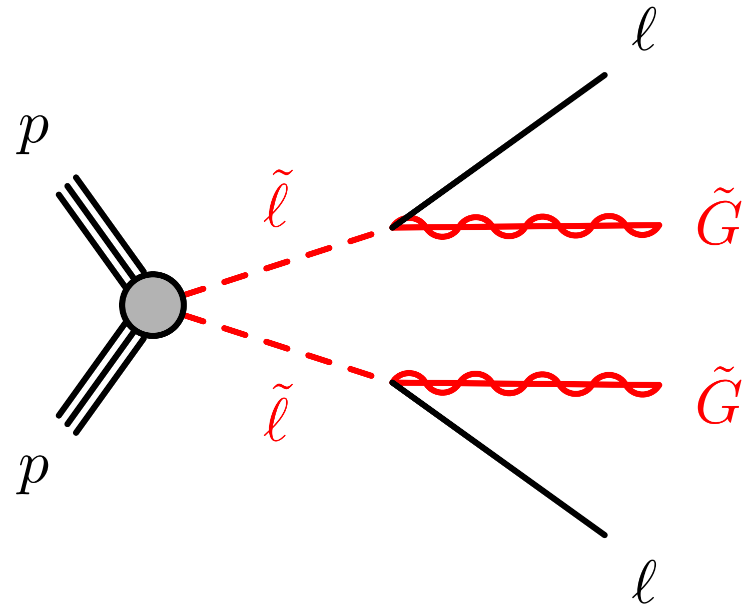
Some Physics Highlights

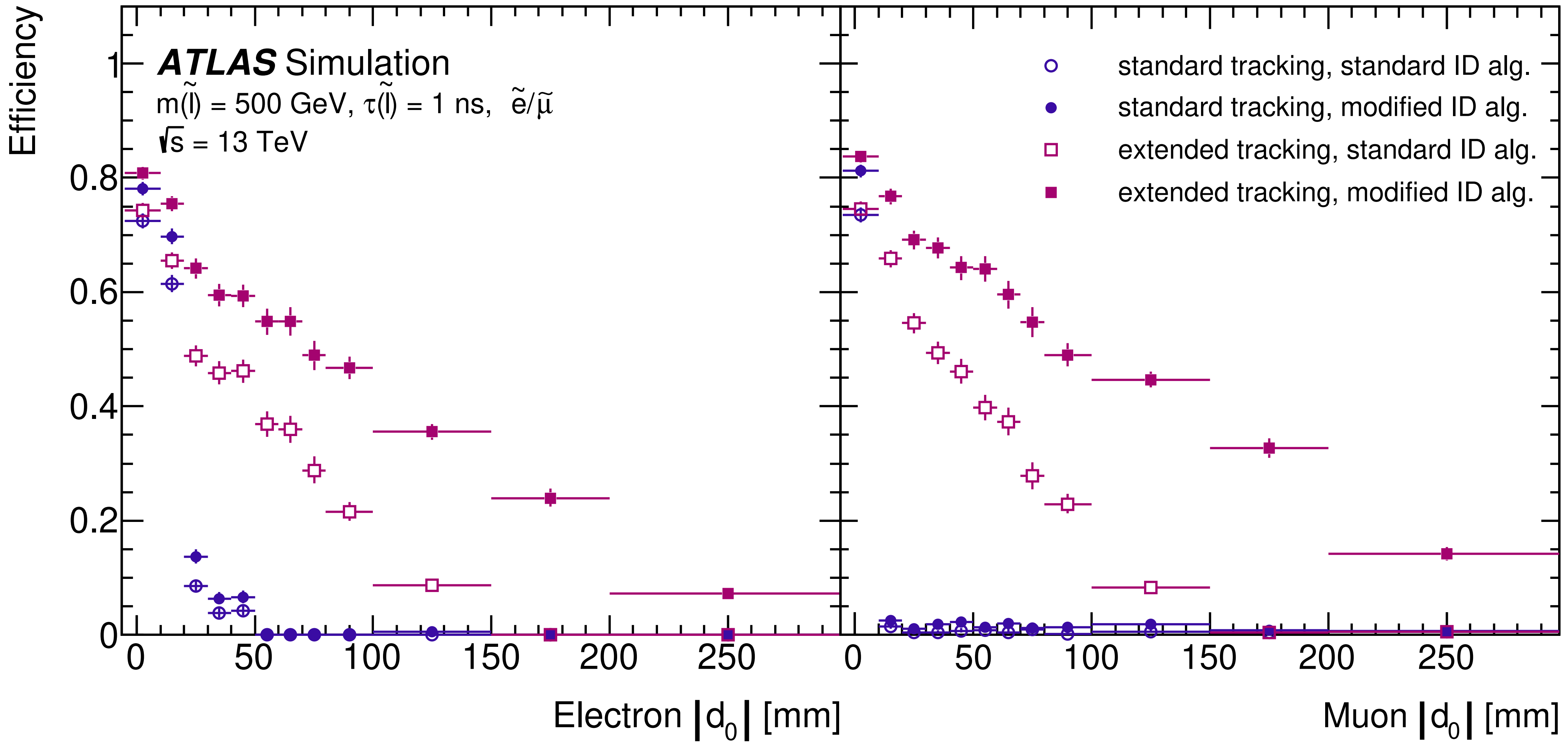
arXiv:2011.07812

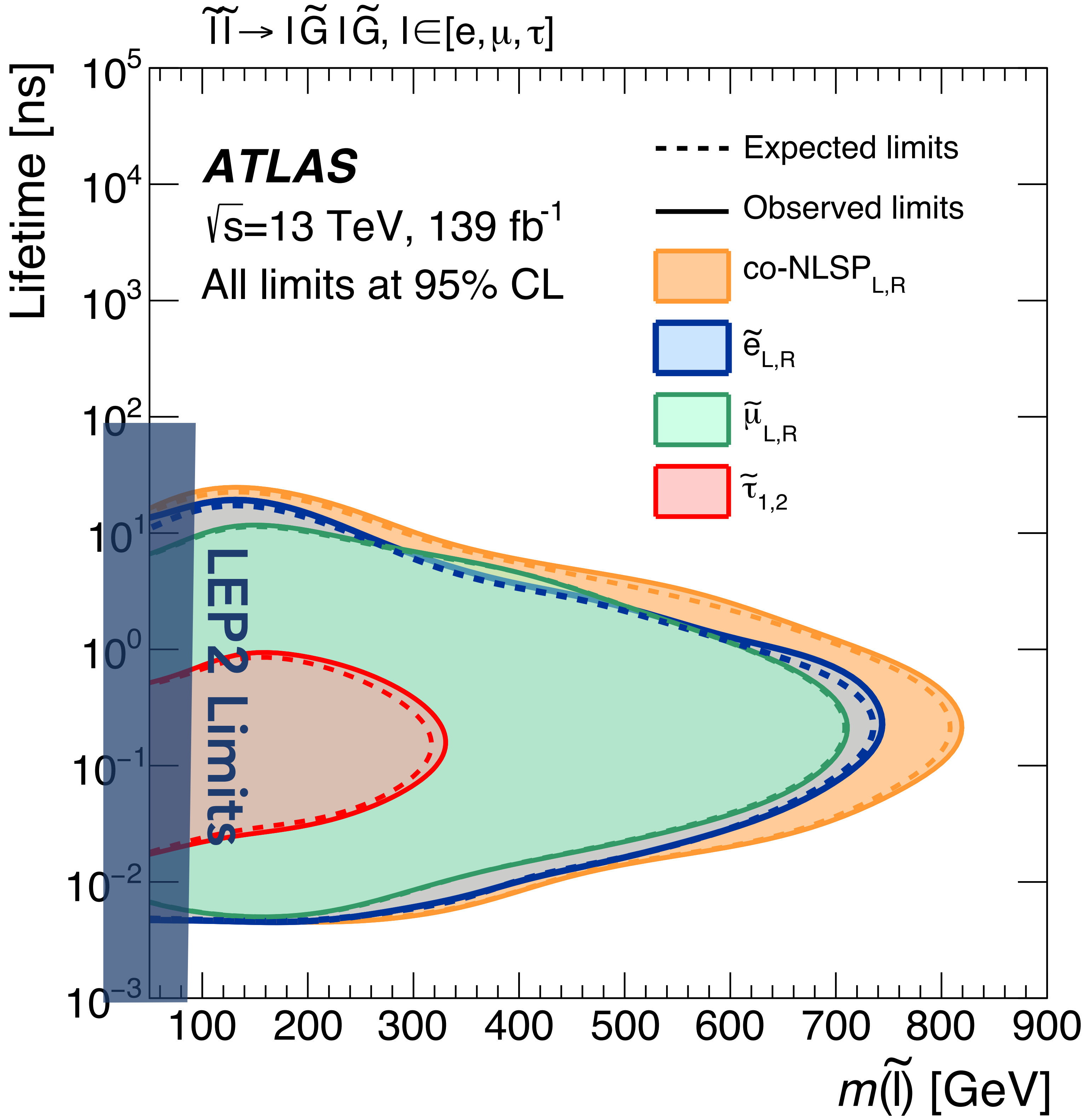
Long-Lived Sleptons

- Common in GMSB/GGM SUSY models
- Special reconstruction to retain efficiency for large impact parameter leptons
- Depending on degeneracy, mass limits up to 800 GeV for O(100) ps lifetimes
- **First sensitivity to this lifetime range since LEP!**



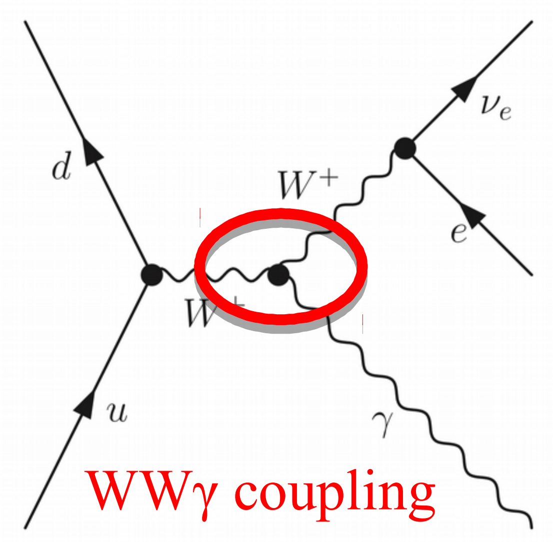




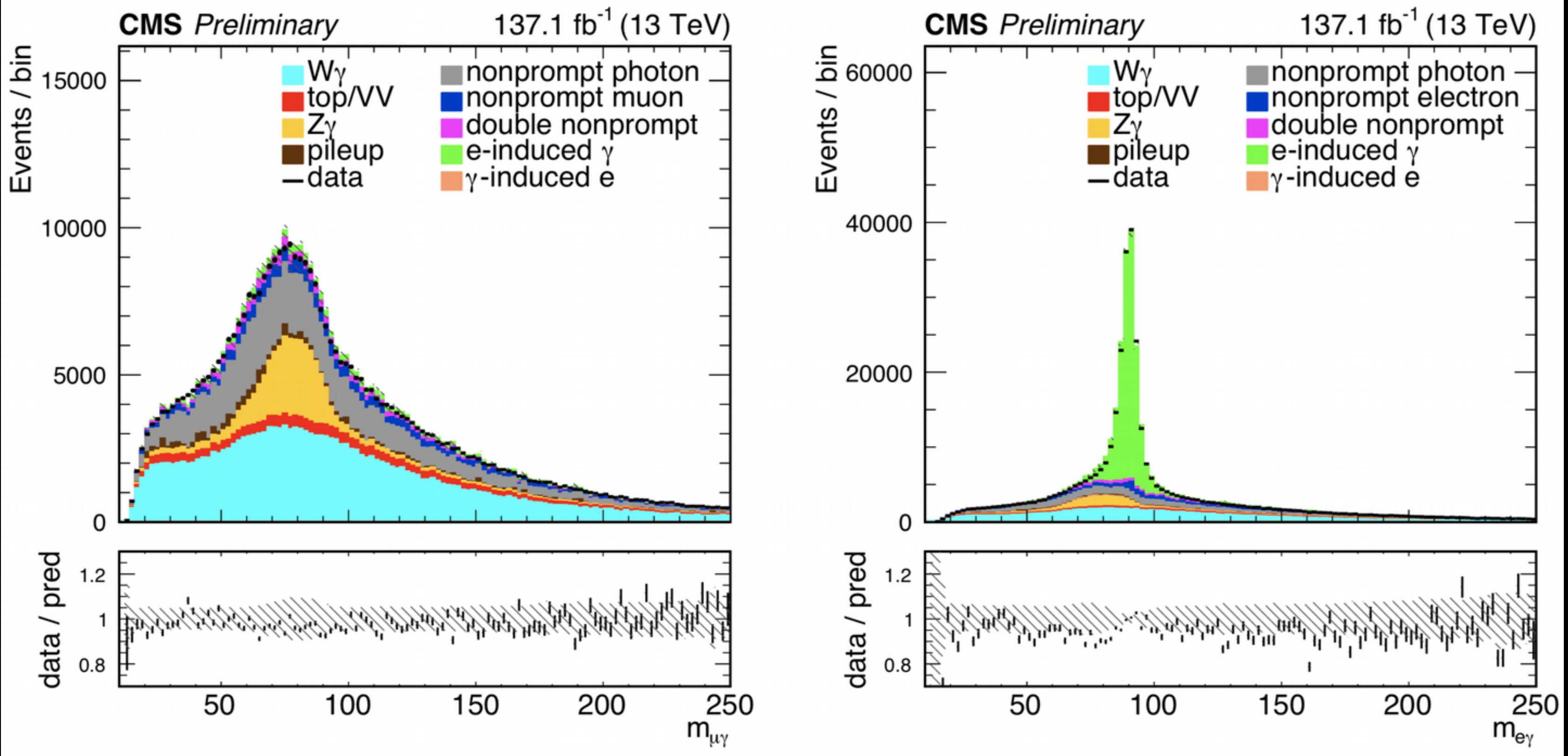


Inclusive Wγ production and EFT constraints

First measurement of $\sigma_{W\gamma}$ at 13 TeV with 137 fb^{-1} in the e/μ channels



CMS-PAS-SMP-19-002



$\sigma_{W\gamma}$=15.58 ± 0.75 pb

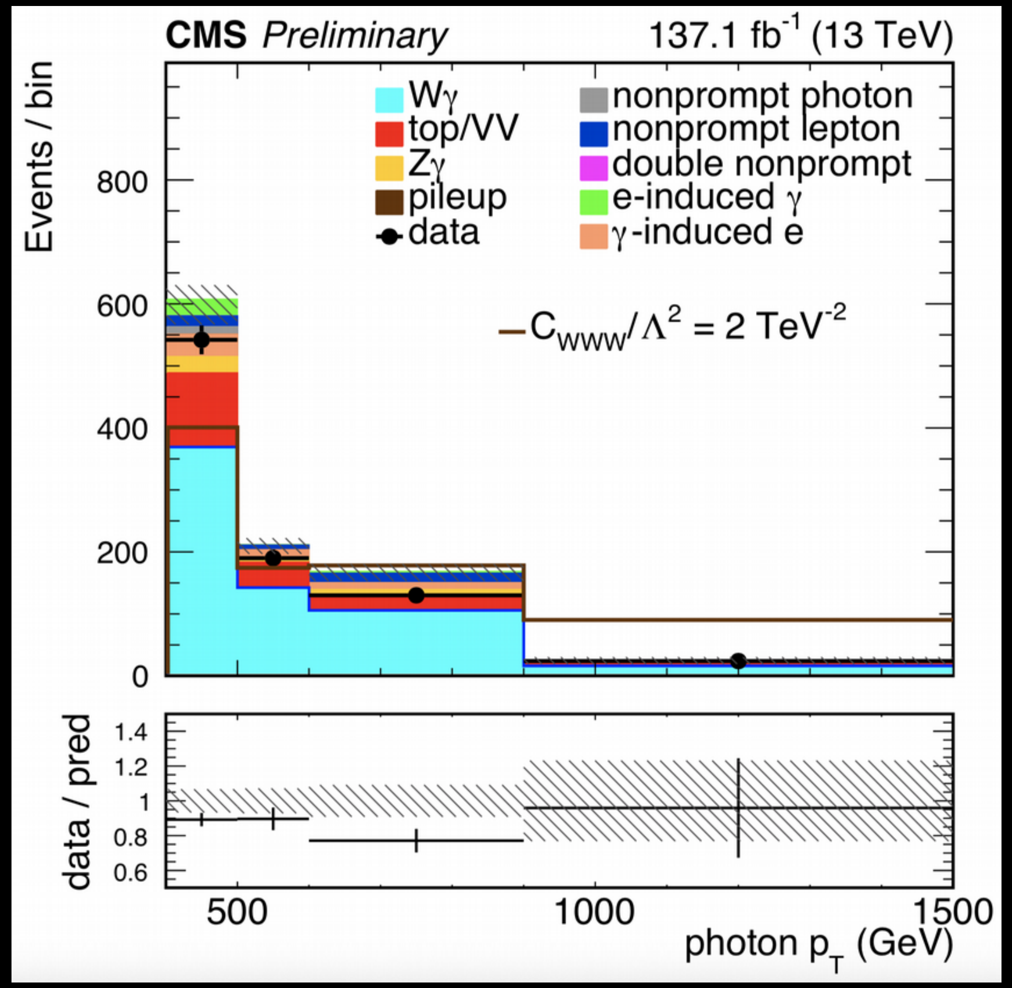
4.5% precision!

Limits on dim-6 EFT operators affecting WWγ, using photon p_T

Most stringent to date!

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c_{WWW}}{\Lambda^2}\mathcal{O}_{WWW} + \frac{c_W}{\Lambda^2}\mathcal{O}_W + \frac{c_B}{\Lambda^2}\mathcal{O}_B + \frac{c_{\tilde{W}WW}}{\Lambda^2}\mathcal{O}_{\tilde{W}WW} + \frac{c_{\tilde{W}}}{\Lambda^2}\mathcal{O}_{\tilde{W}}$$

Coefficient	Exp. Lower	Exp. Upper	Obs. Lower	Obs. Upper
c_{WWW}/Λ^2	−0.85	0.87	−0.90	0.91
c_W/Λ^2	−45.5	44.6	−39.7	40.7
c_B/Λ^2	−45.5	44.6	−39.7	40.7
$c_{\widetilde{W}WW}/\Lambda^2$	−0.4	0.4	−0.45	0.45
$c_{\widetilde{W}}/\Lambda^2$	−22.8	22.3	−20.3	20.0

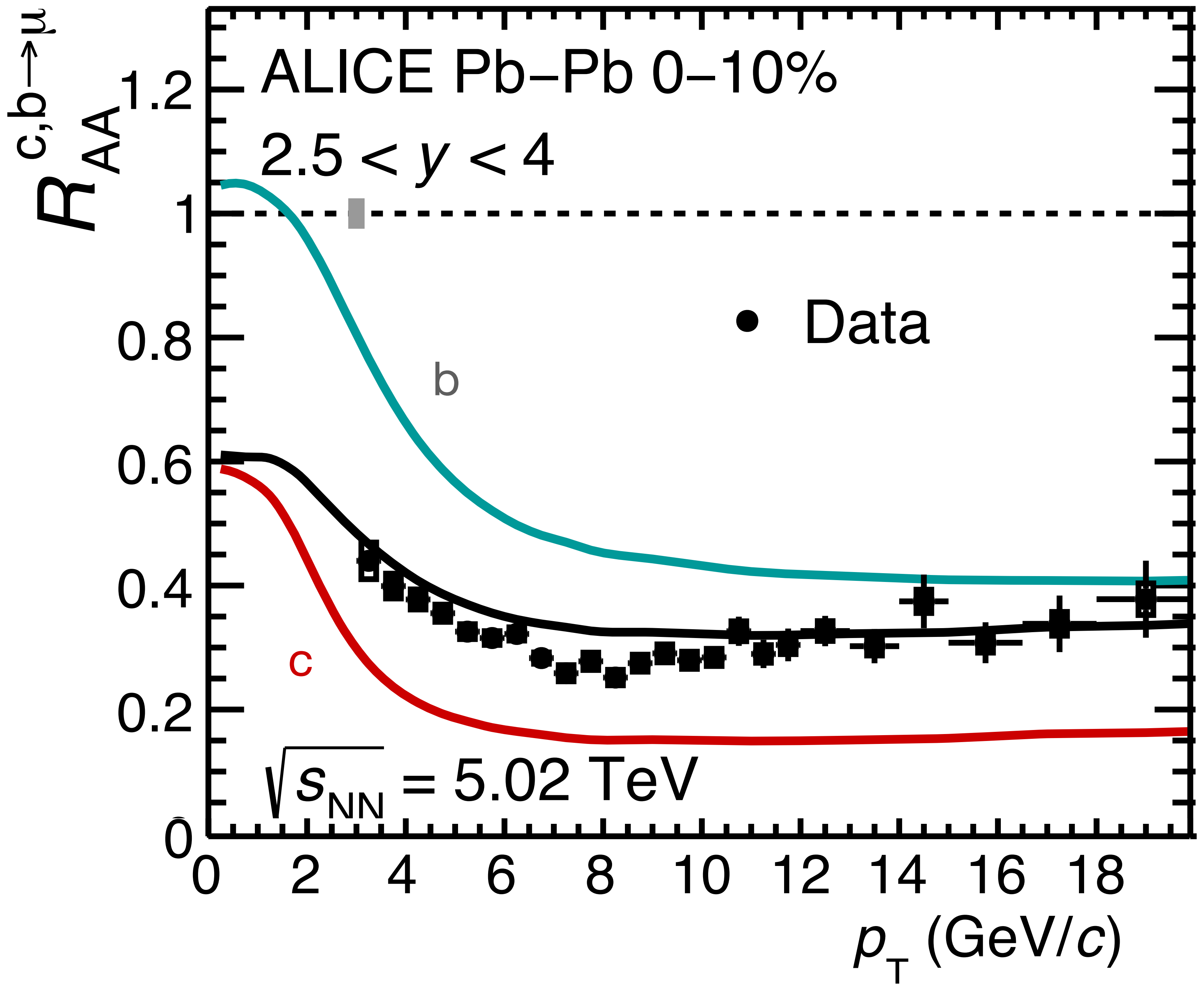


Heavy-flavour decay leptons

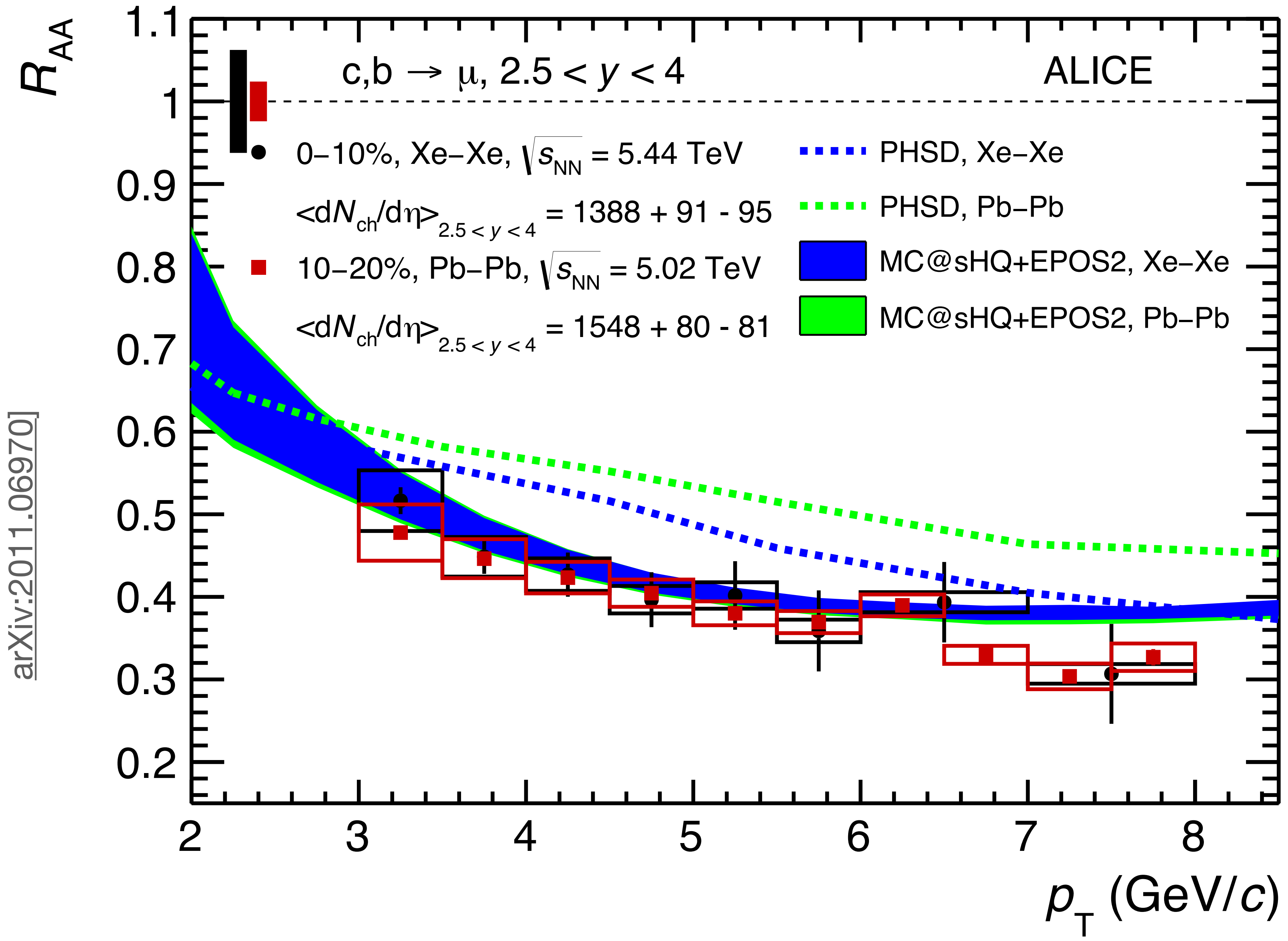
Xe–Xe 5.44 TeV [arXiv:2011.06970]

Pb–Pb 2.76, 5.02 TeV [arXiv:2011.06078]

- b and c quarks produced in initial hard scatterings:
  - witness the full evolution of the QGP
  - lose energy (different amounts are predicted for b and c)
- Suppression of charm and beauty decay muons:
  - the measurement cannot distinguish b and c
  - but it is well reproduced by models combining the two



[Production of muons from heavy-flavour hadron decays at high transverse momentum in Pb–Pb collisions at 5.02 and 2.76 TeV arXiv:2011.05718]



[Inclusive heavy-flavour production at central and forward rapidity in Xe-Xe collisions at 5.44 TeV arXiv:2011.06970]

$$R_{AA}(p_T, y) = \frac{1}{\langle T_{AA} \rangle} \cdot \frac{d^2 N_{AA}/dp_T dy}{d^2 \sigma_{pp}/dp_T dy}$$

- Comparing events with similar multiplicities, the suppression agrees between collision systems
  - this effect was also seen previously for charged particle R_{AA} at higher p_T

Measurement accurately described by models with mass-dependent energy loss for c and b quarks

CP violation in two-body decay of $B^0_{(s)}$

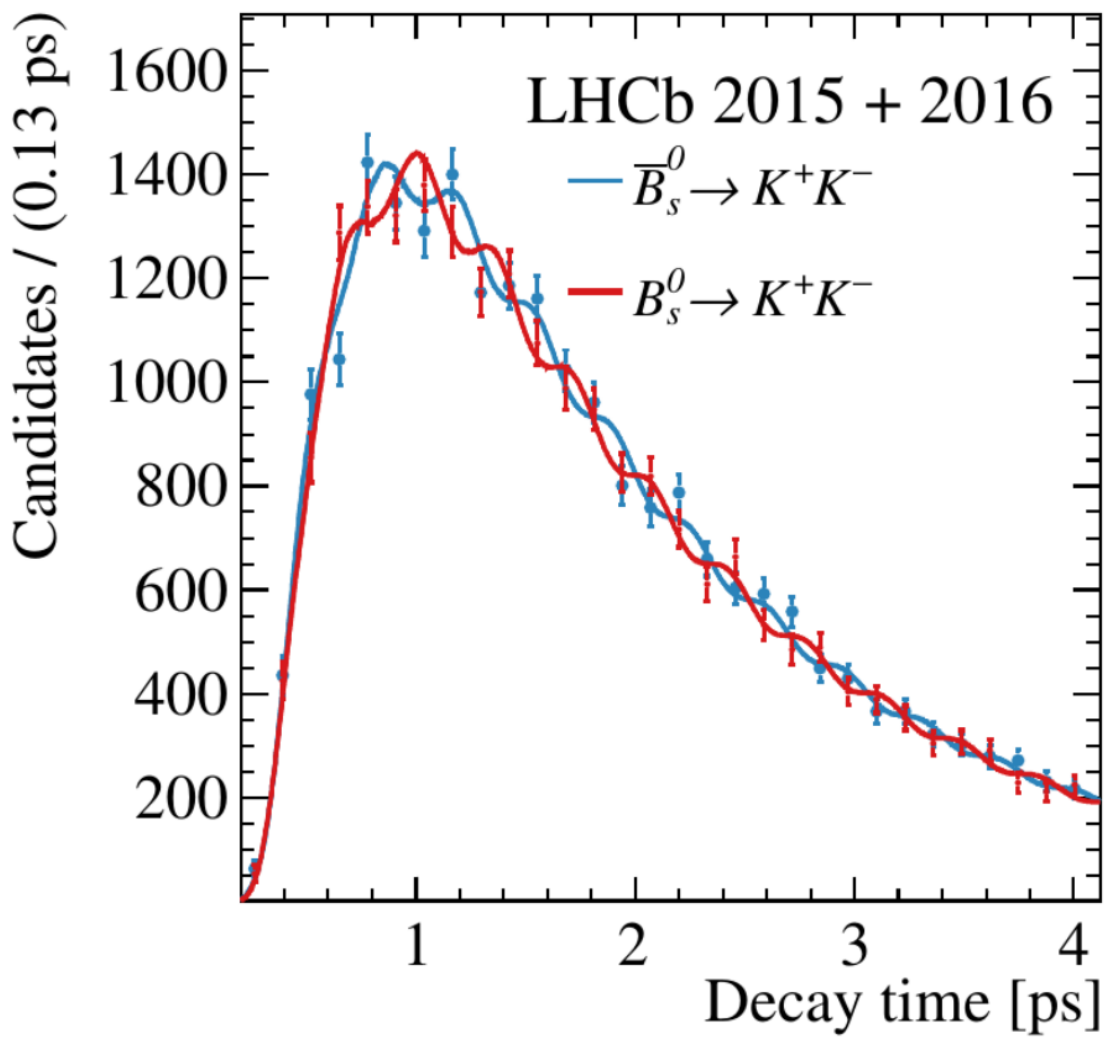
[LHCb-PAPER-2020-029]

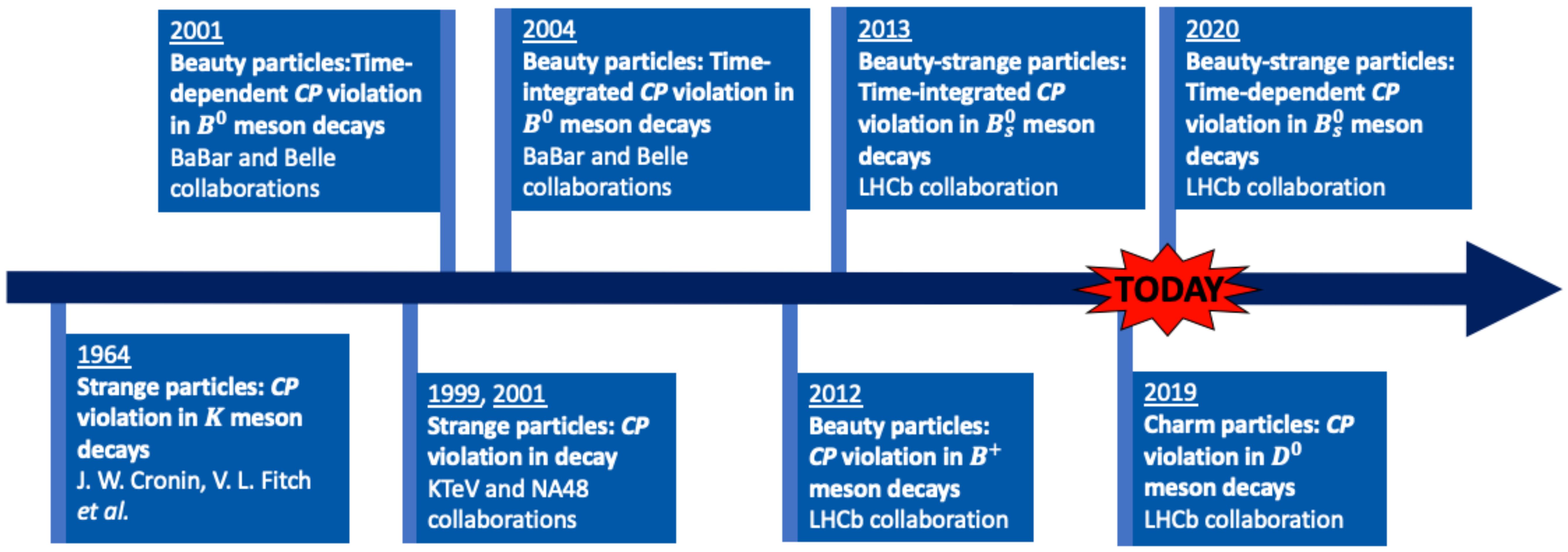
- Time dependent CP asymmetries in $B^0 \to \pi^+\pi^-$, $B^0_s \to K^+K^-$ and time integrated $B^0_{(s)} \to K\pi$
- Sensitive to β_s, γ, and $\Delta m_s, \Delta m_d$
- 2015+2016 data. Two methods used (simultaneous fit , per-event errors)

$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-C_f \cos(\Delta m_{d(s)} t) + S_f \sin(\Delta m_{d(s)} t)}{\cosh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right)}$$

- $C_{KK} = 0.172 \pm 0.031$, $S_{KK} = 0.139 \pm 0.032$

$\to$ **First observation of time dependent CP violation in B_s.**

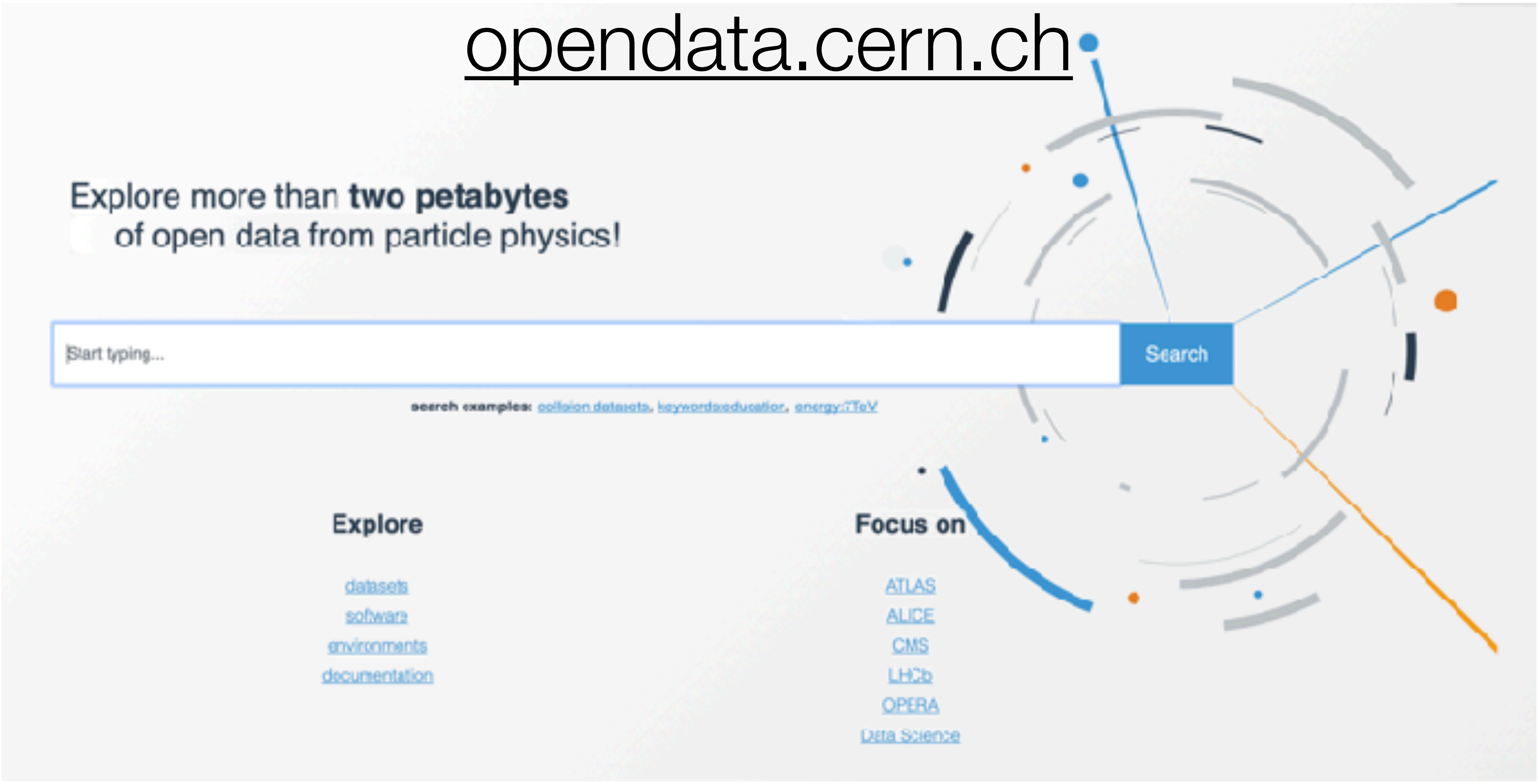




Open Data Policy

Open Data Policy Working Group for LHC Experiments

- Working Group distinguished various levels of data
  - Published Results (Level 1)
    - Open Access (for HEP: SCOAP3)
  - Outreach and Education (Level 2)
    - CERN Open Data Portal
  - **Reconstructed Data (Level 3)**
    - Suitable for physics analysis albeit not at ultimate calibration/ resolution
  - Raw Data (Level 4)
    - not really suitable for external consumption



LHC Open Data Policy

https://cds.cern.ch/record/2745133

CERN-OPEN-2020-013
20/11/2020

CERN Open Data Policy for the LHC Experiments
November, 2020

adopted by all 4 LHC Experiments

The CERN Open Data Policy reflects values that have been enshrined in the CERN Convention for more than sixty years that were reaffirmed in the European Strategy for Particle Physics (2020)[1], and aims to empower the LHC experiments to adopt a consistent approach towards the openness and preservation of experimental data. Making data available responsibly (applying FAIR standards[2]), at different levels of abstraction and at different points in time, allows the maximum realisation of their scientific potential and the fulfillment of the collective moral and fiduciary responsibility to member states and the broader global scientific community. CERN understands that in order to optimise reuse opportunities, immediate and continued resources are needed. The level of support that CERN and the experiments will be able to provide to external users will depend on available resources.

This policy relates to the data collected by the LHC experiments, for the main physics programme of the LHC — high-energy proton–proton and heavy-ion collision data. The foreseen use cases of the Open Data include reinterpretation and reanalysis of physics results, education and outreach, data analysis for technical and algorithmic developments and physics research. The Open Data will be released through the CERN Open Data Portal which will be supported by CERN for the lifetime of the data. The data will be tailored to the different uses, and will be made available in formats defined by each experiment that afford a range of opportunities for long-term use, reuse and preservation. In general, four levels of complexity of HEP data have been identified by the Data Preservation and Long Term Analysis in High Energy Physics (DPHEP) Study Group[3], which serve varying audiences and imply a diversity of openness solutions and practices.

Published Results (Level 1) Policy: Peer-reviewed publications represent the primary scientific output from the experiments. In compliance with the CERN Open Access Policy, all such publications are available with Open Access, and so are available to the public. To maximise the scientific value of their publications, the experiments will make public additional information and data at the time of publication, stored in collaboration with portals such as HEPData,[4] with selection routines stored in specialised tools. The data made available may include simplified or full binned likelihoods, as well as unbinned likelihoods based on datasets of event-level observables extracted by the analyses. Reinterpretation of published results is also made possible through analysis preservation and direct collaboration with external researchers.

Outreach and Education (Level 2) Policy: For the purposes of education and outreach, dedicated subsets of data are used, selected and formatted to provide rich samples to maximise their educational impact, and to facilitate the easy use of the data. These data are released with a schedule and scope determined by each experiment. The data are provided in simplified, portable and self-contained formats suitable for educational and public understanding purposes; but are not intended nor adequate for the publication of scientific results. Lightweight environments to allow the easy exploration of these

[1] European Strategy Group (2020), '2020 Update of the European Strategy for Particle Physics'.
[2] FAIR Guiding Principles for scientific data management and stewardship. Available at: https://www.go-fair.org/fair-principles/.
[3] Data management plans are defined by the LHC experiments to address the long-term preservation of internal data products. See: Akopov et al., Status report of the DPHEP Study Group: Towards a global effort for sustainable data preservation in high energy physics. arXiv preprint arXiv:1205.4667 (2012).
[4] Repository for publication-related High-Energy Physics data: http://www.hepdata.net.

1

data may also be provided. CERN experiments will make data of such high level of abstraction available, accessible through the CERN Open Data Portal.[5]

Reconstructed Data (Level 3) Policy: The LHC experiments will release calibrated reconstructed data with the level of detail useful for algorithmic, performance and physics studies. The release of these data will be accompanied by provenance metadata, and by a concurrent release of appropriate simulated data samples, software, reproducible example analysis workflows, and documentation. Virtual computing environments that are compatible with the data and software will be made available. The information provided will be sufficient to allow high-quality analysis of the data including, where practical, application of the main correction factors and corresponding systematic uncertainties related to calibrations, detector reconstruction and identification. A limited level of support for users of the Level 3 Open Data will be provided on a best-effort basis by the collaborations.

Public data releases will occur periodically, following an appropriate latency period to allow thorough understanding of the data, the reconstruction and calibrations, as well as to allow time for the scientific exploitation of the data by the collaboration. The size of the released datasets will be commensurate with the total amount of data collected of similar type, with the aim to commence data releases within five years of the conclusion of the run period. Data may be withheld by an experiment if there are active analyses ongoing. Full datasets will be made available at the close of the collaboration.

The data will be released from the CERN Open Data Portal under the Creative Commons CC0 waiver, and will be identified with persistent data identifiers, and the data must be cited through these identifiers. Similarly, appropriate acknowledgements of the experiment(s) should be included in publications released using such data, and the publications made clearly distinguishable from those released by the collaboration. Any scientific claims in such publications are the responsibility of their authors and not of the experiments. It is expected that scientific results released using Open Data follow best scientific practices. The experiments may impose rules related to the use of the data by members of their respective collaborations.

External authors should be aware that they will not have access to the vast amount of tacit knowledge built up within the LHC collaborations over the decades of design, construction and operation of the experimental apparatus. To allow external scientists to fully benefit from all the data, knowledge and tools, the collaborations may offer appropriate association programmes.

Raw Data (Level 4) Policy: It is not practically possible to make the full raw data-set from the LHC experiments usable in a meaningful way outside the collaborations. This is due to the complexity of the data, metadata and software, the required knowledge of the detector itself and the methods of reconstruction, the extensive computing resources necessary and the access issues for the enormous volume of data stored in archival media. It should be noted that, for these reasons, general direct access to the raw data is not even available to individuals within the collaboration, and that instead the production of reconstructed data (i.e. Level-3 data) is performed centrally. Access to representative subsets of raw data—useful for example for studies in the machine learning domain and beyond—can be released together with Level-3 formats, at the discretion of each experiment.

[5] CERN Open Data portal: http://opendata.cern.ch.

2

data + algorithms

~5 years

IP

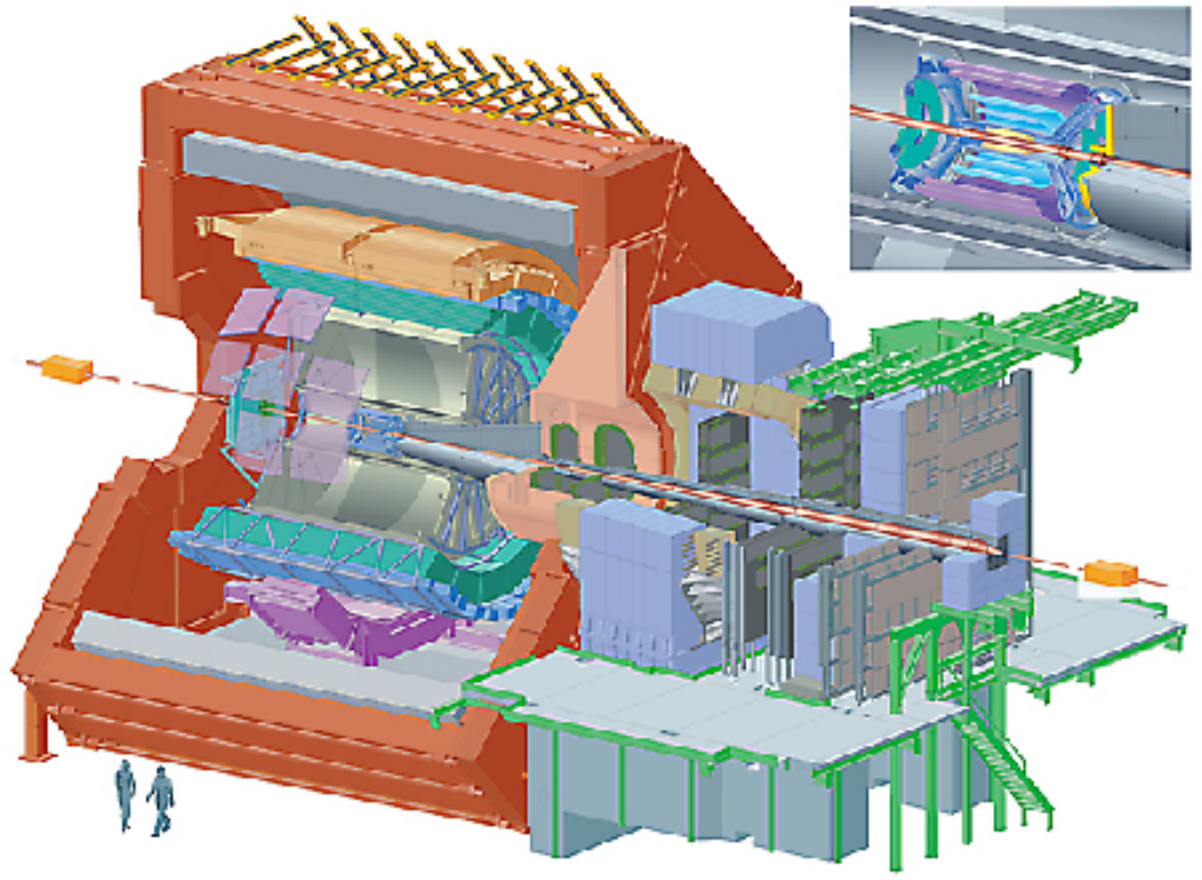
disclaimer

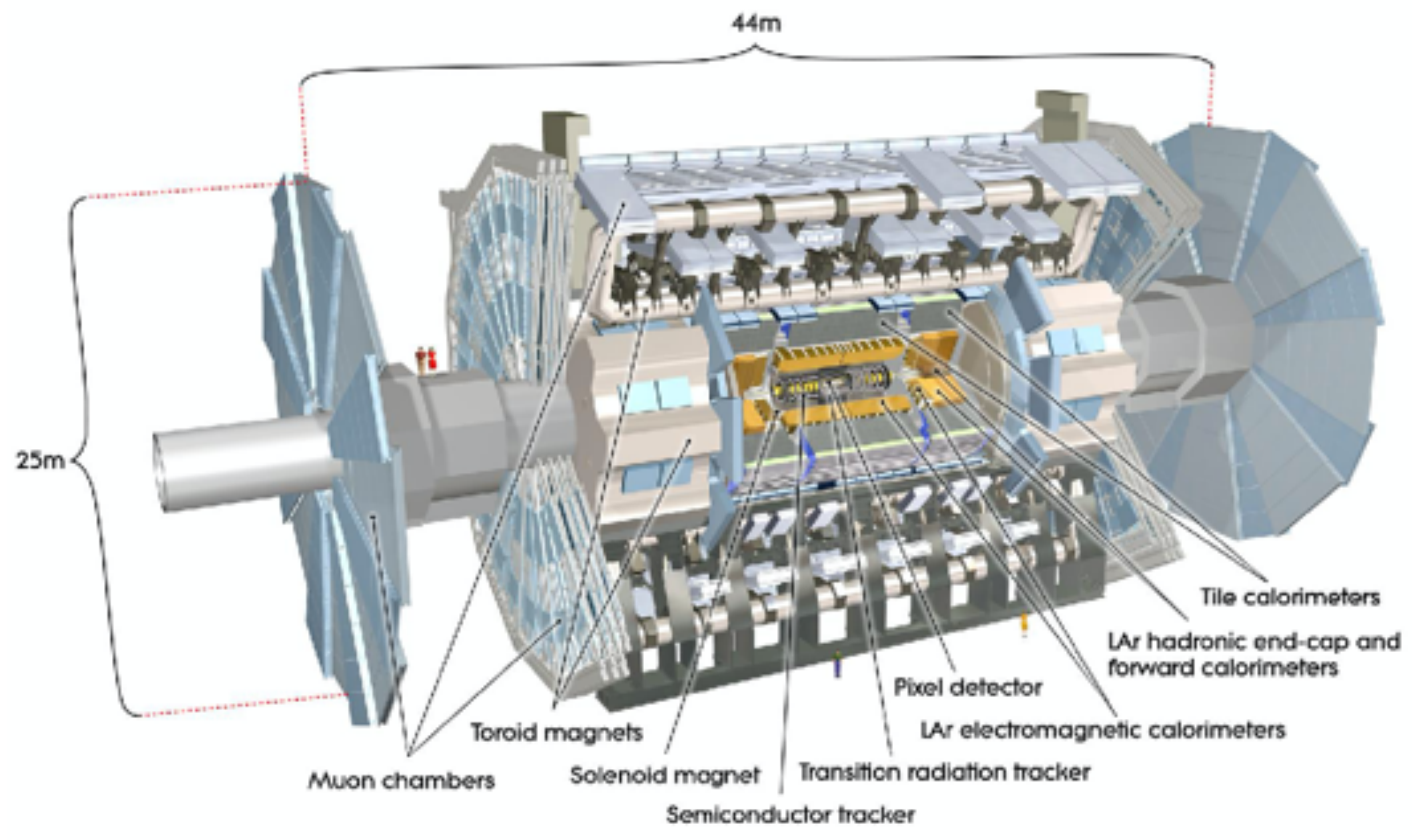
***From the minutes of the SIPB**: The Scientific Information Policy Board welcomes the initiative to establish a CERN Open Data Policy, and praises the "ODP Working Group for the LHC experiments" for its preparatory work, for the drafting of the policy document, and for achieving its approval by the experiments. The policy comprises two documents: a public one, outlining the general principles, and an internal document, outlining the implementation of the policy by each experiment. The SIPB strongly supports the CERN principle of openness and its various initiatives towards open science. The new Open Data Policy fully meets this spirit, while meeting the constraints set by the complexity of the LHC data and of their public use. In endorsing the Open Data Policy, the SIPB encourages the CERN management to extend its scope and implementation to cover the non-LHC experiments as well, and remains available to contribute.*

LS2 Shutdown Progress

Priority: completion of Phase 1 and preparation of Phase 2 upgrades

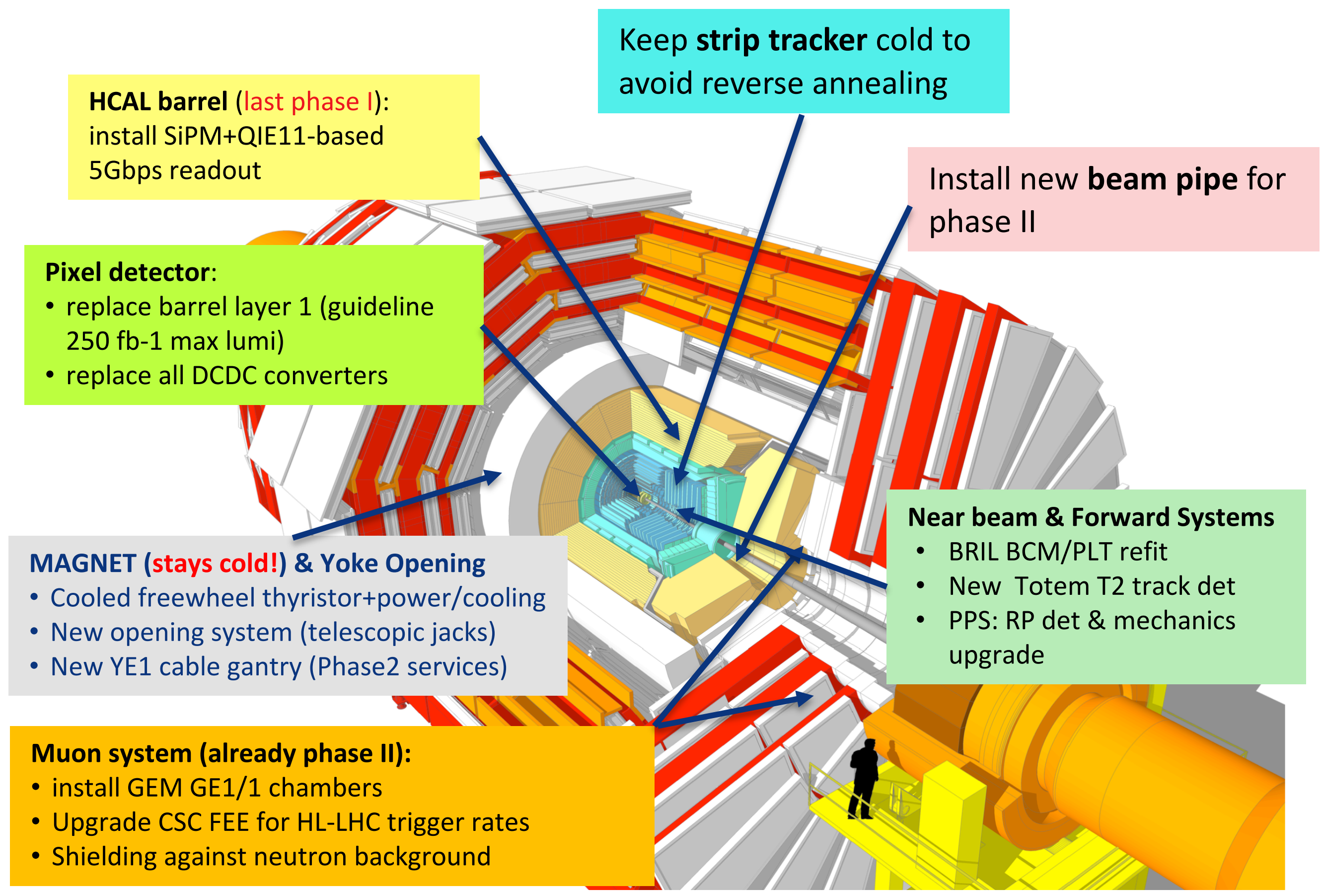
ALICE

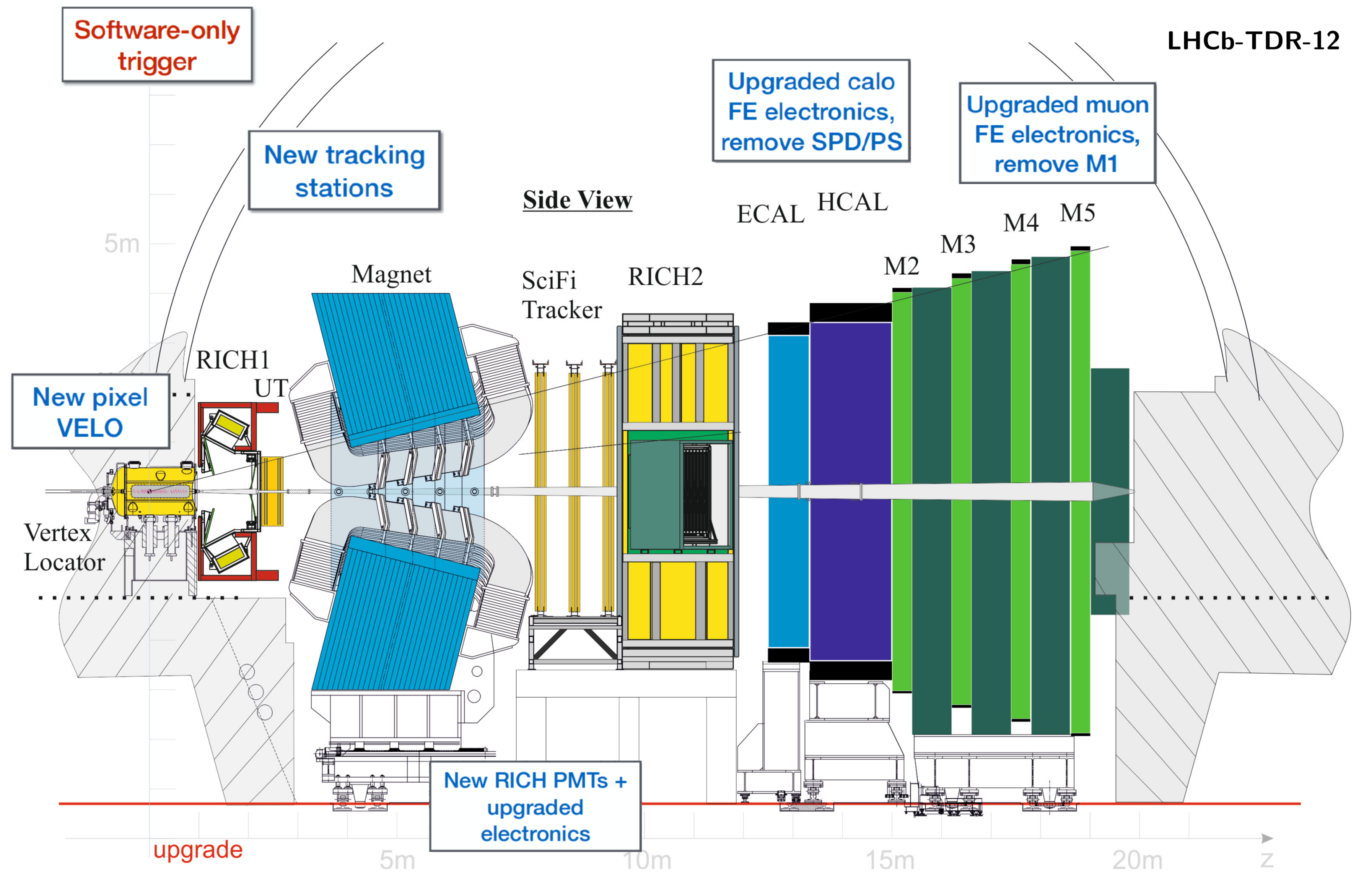




ATLAS

CMS



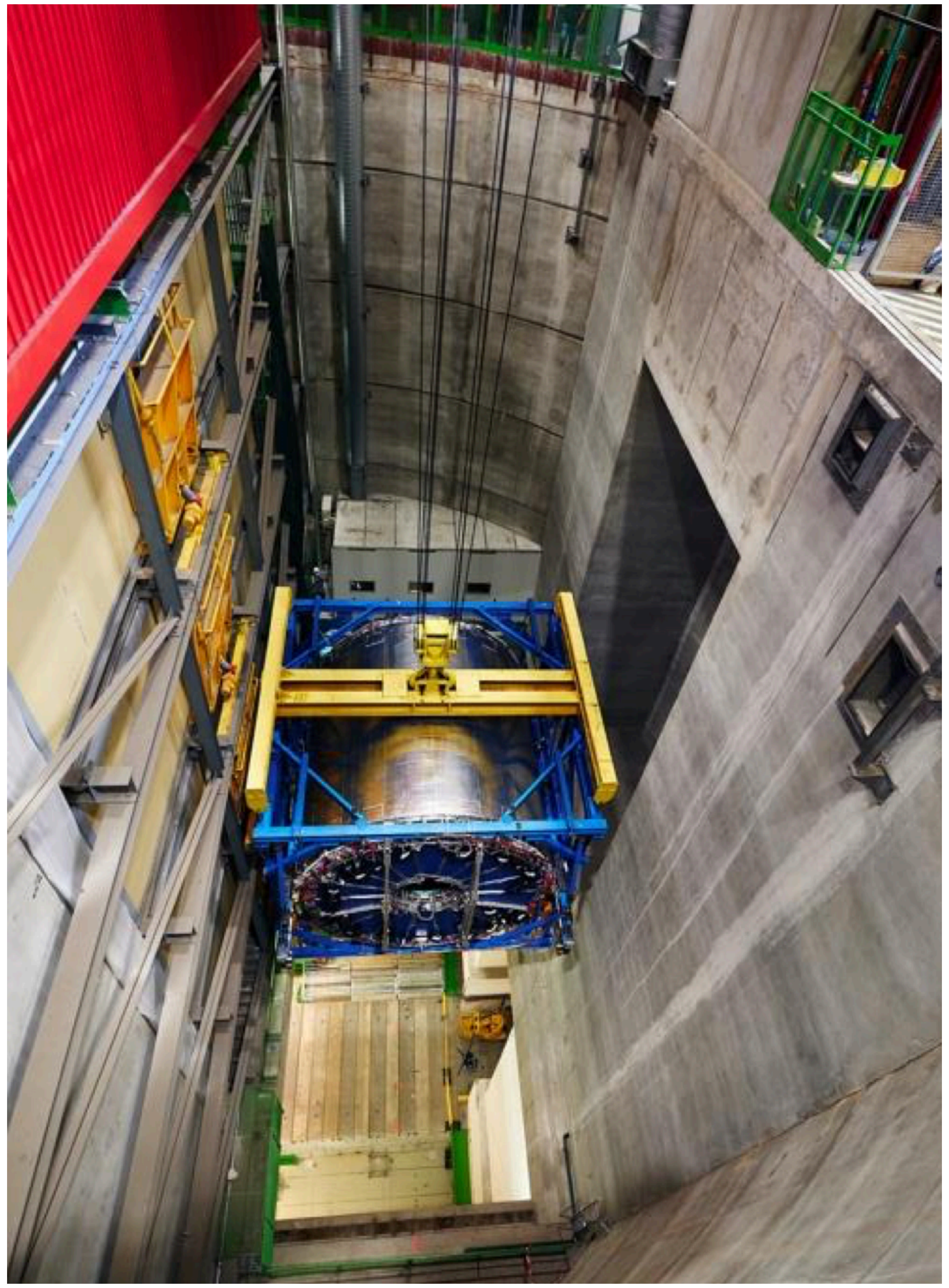


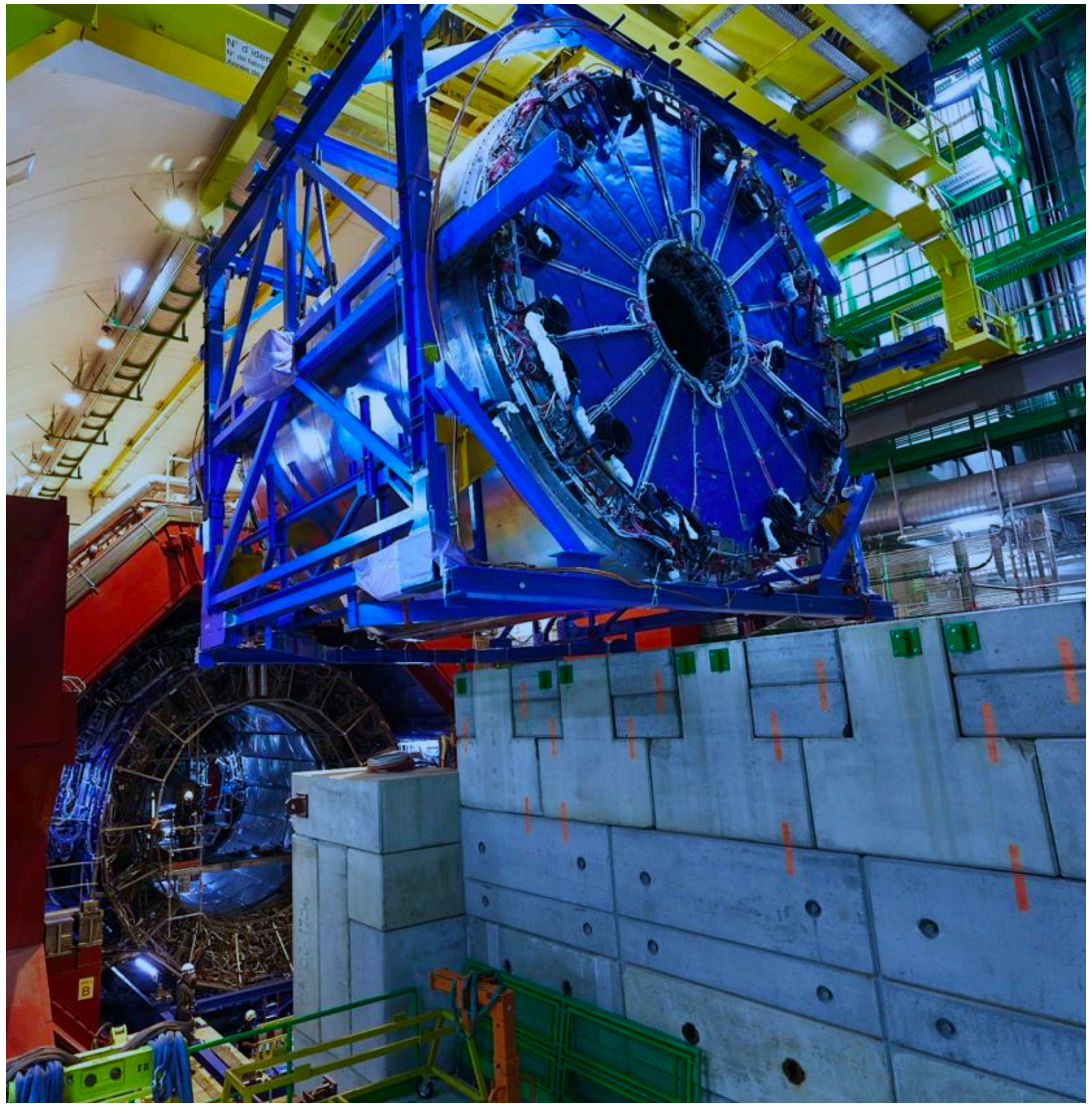
LHCb

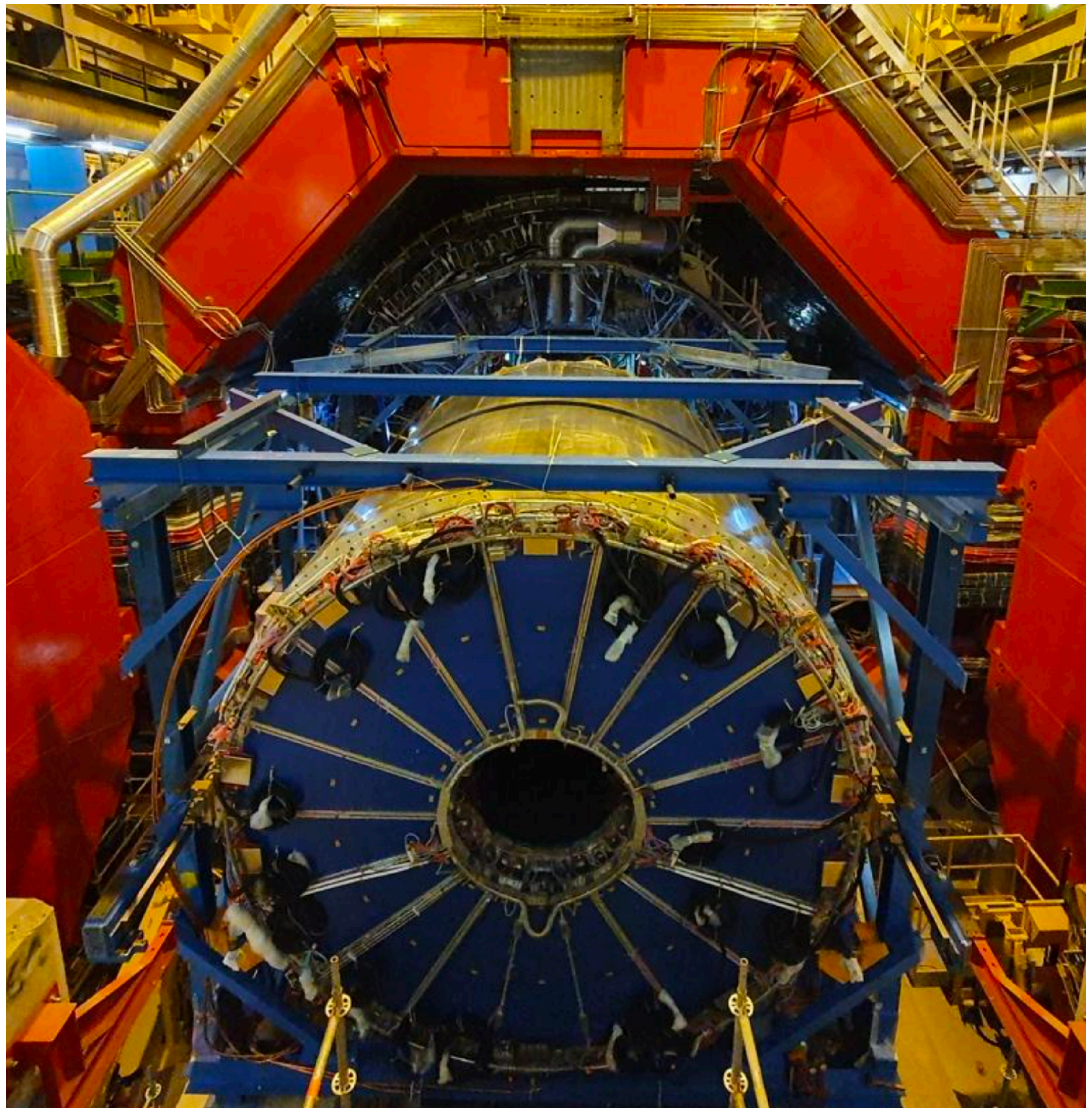
ALICE

TPC (reminder)
on-surface commissioning and transport to cavern: done

- After a successful commissioning on surface, the TPC has been lowered to and installed in the cavern



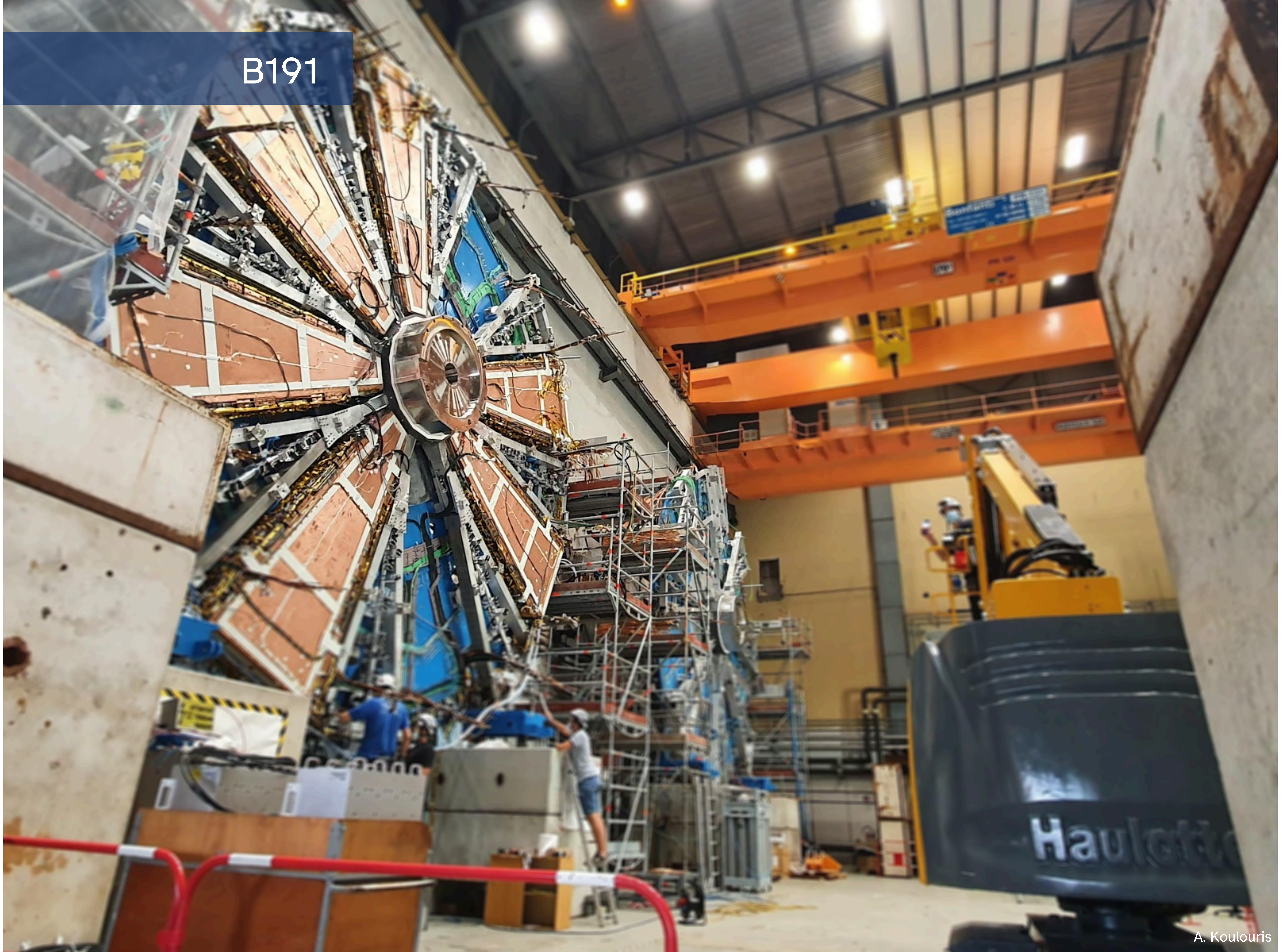




ATLAS

B191

ATLAS



A. Koulouris

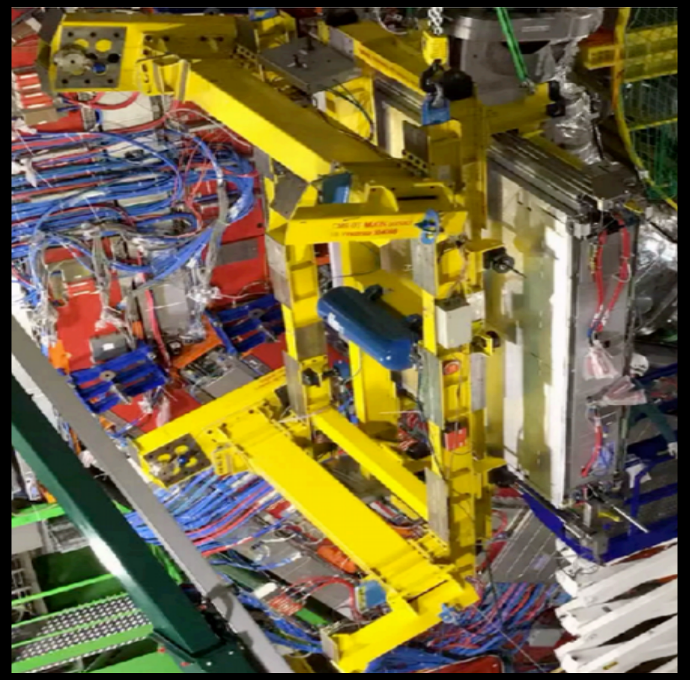
- **COVID**
  - Despite worsening situation, retained nearly full work force; continue largely unaffected
  - Some construction/integration work is sensitive to social distancing precautions
  - Travel restrictions → Firm planning for the next months is difficult
- **Timelines**
  - With many factors accounted for, present estimates
    - **NSW-A completion: Apr/May 2021**
    - **NSW-C completion: Mid Sep 2021 w/ very little contingency**

CMS

Continued LS2 activities: *muon system*

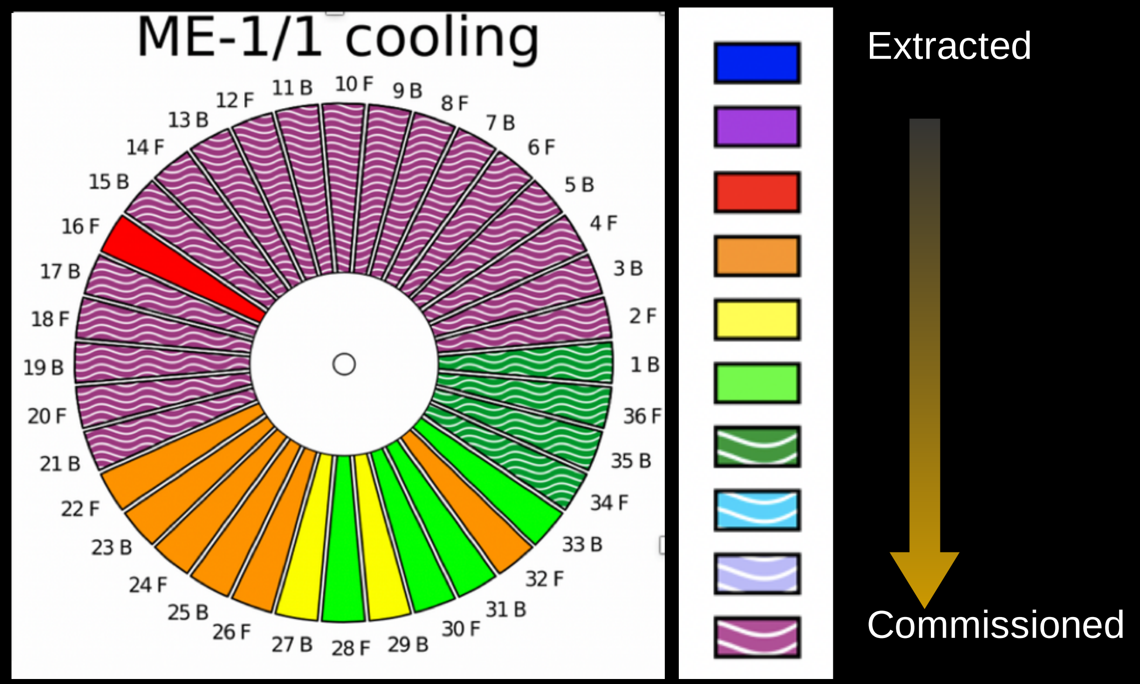
CMS

Drift Tubes had a successful data taking campaign
- Demonstrating new Phase-2 electronics architecture
- Evaluating trigger primitive algorithm performance
- LS2 maintenance almost done
- The top MB4 shielding fully installed

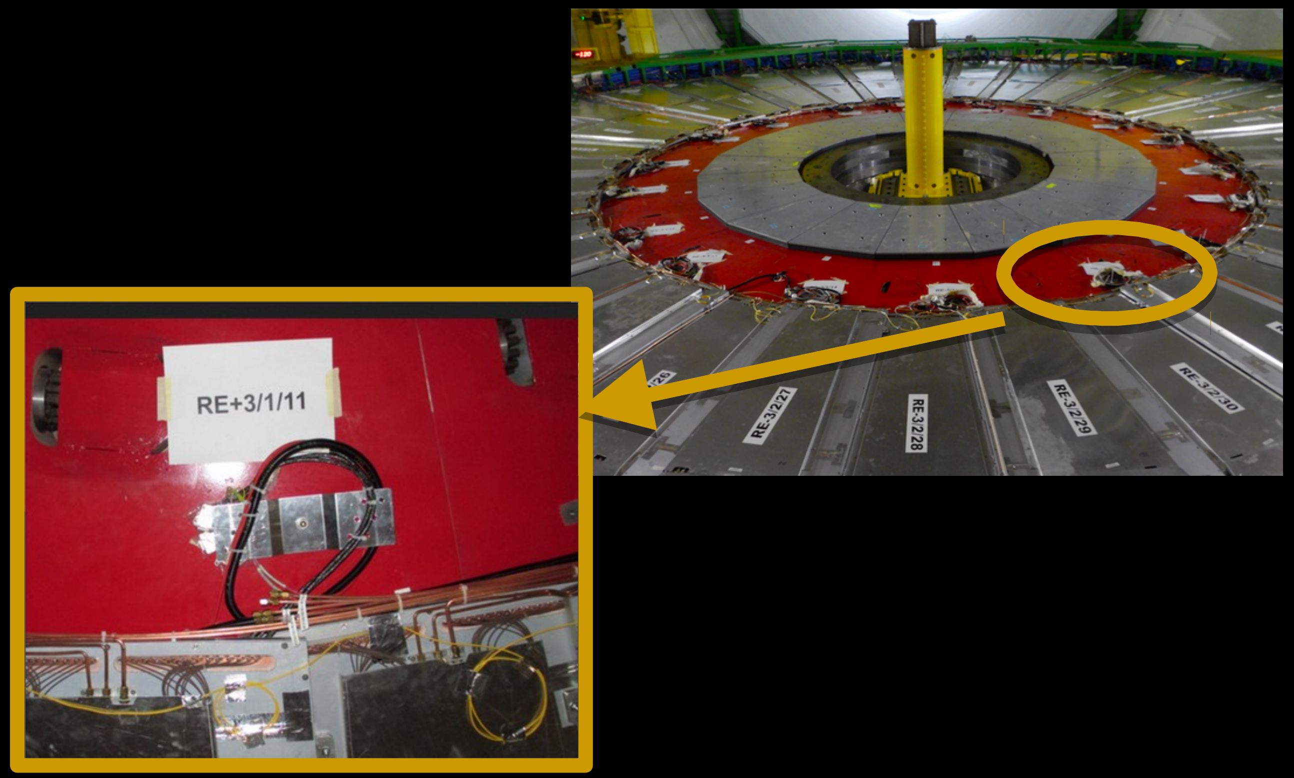


DT Chamber extraction for repair

CSC electronics replacement finished.
- The new cooling system is in place for ME1/1 and ongoing for ME–1/1



RPC has finished the services installation of RE3/1 and 4/1 sections
- Reinstallation of the RE-4 stations (dismounted for CSC electronic refurbishment) is going on and will be finished in a few days.



LHCb

Vertex locator [VELO]

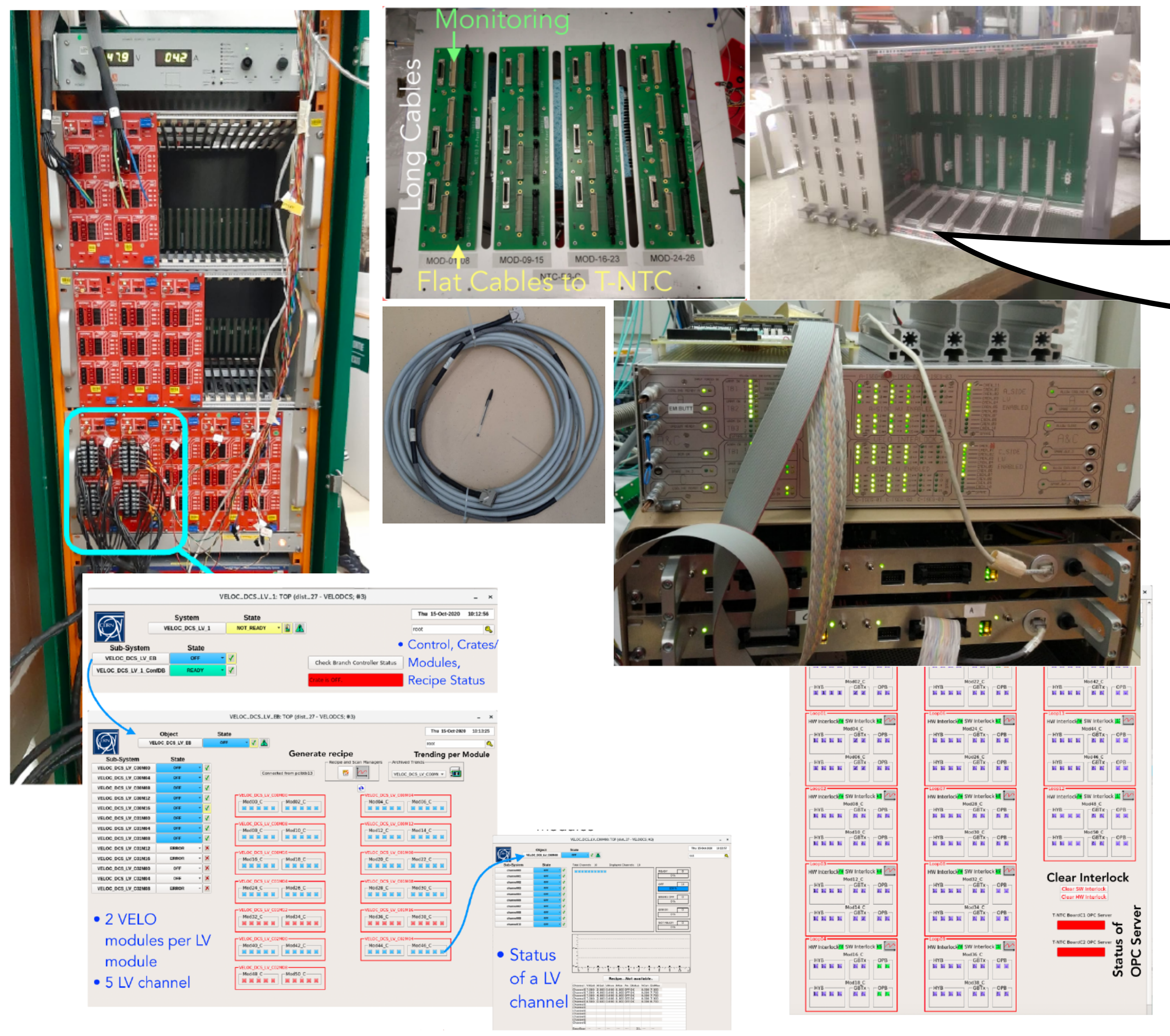
[LHCb-TDR-013]

- **Production of micro-channel** progressing ($>$ 80% soldering complete)
- **Production of modules** on-going:

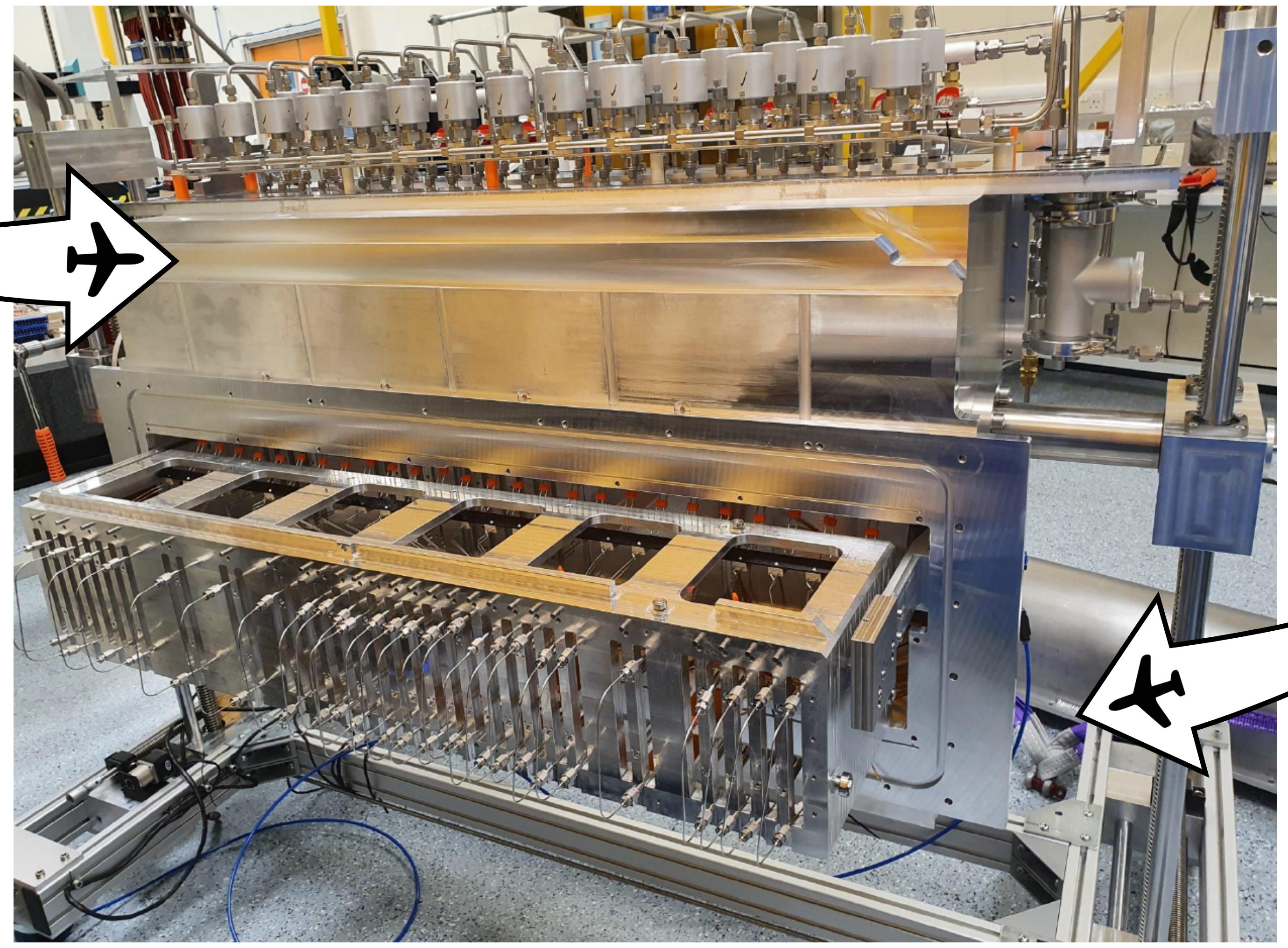
  $\rightarrow$ $\sim$12/52 at various stages of production, 4 finalised.
- **Preparation of the first halve** on-going

  $\rightarrow$ first module to be mounted beginning of 2021.
- Infrastructure for full half operation and control ready.
- **Slowdowns due to covid**, at labs level and material/expertise exchanges.

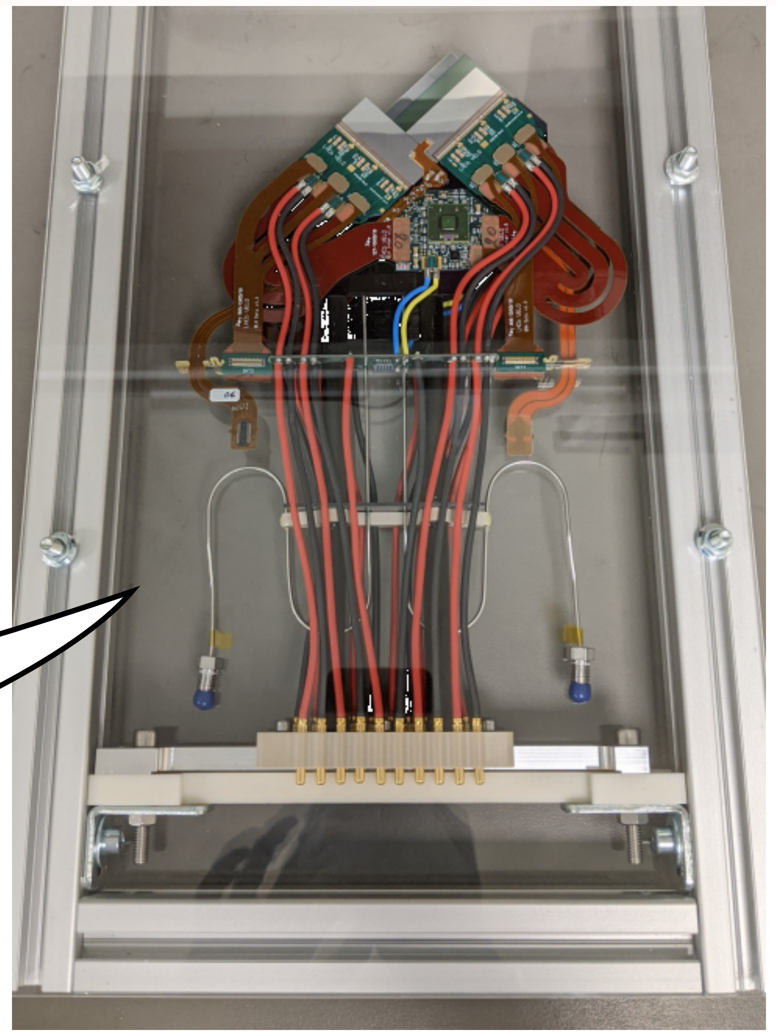
LV,HV,Temperature,interlock, ECS



Half mounting

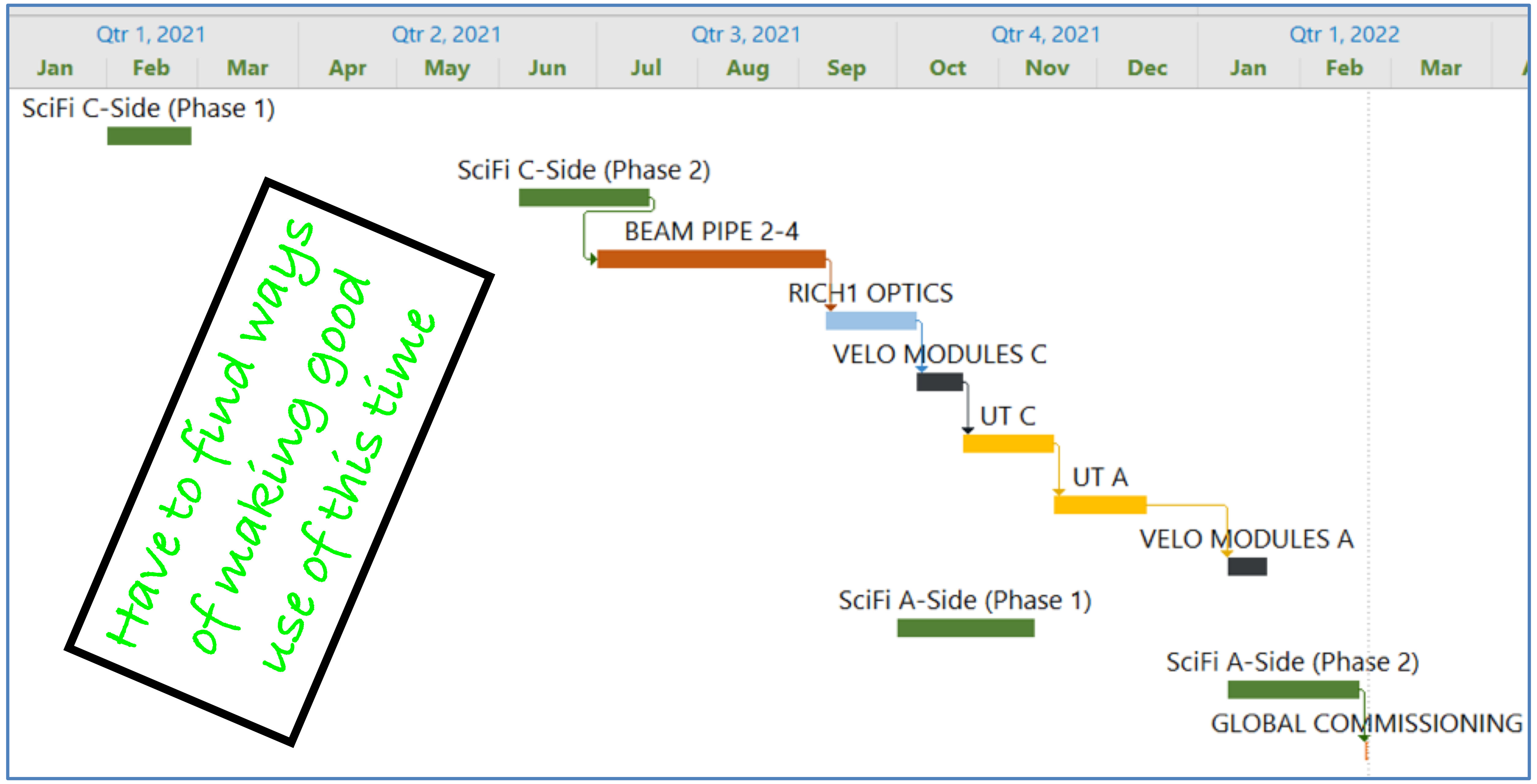


Module production



Schedule – top level key detector components

- Latest possible schedule compatible with February 2022 cavern closure



  - this is **not the aim**, this is the pessimistic planning on unblocking travel from SciFi institutes only by March 1st 2021
  - Without this unblocking a full SciFi project restructuring would be needed, this will be studied

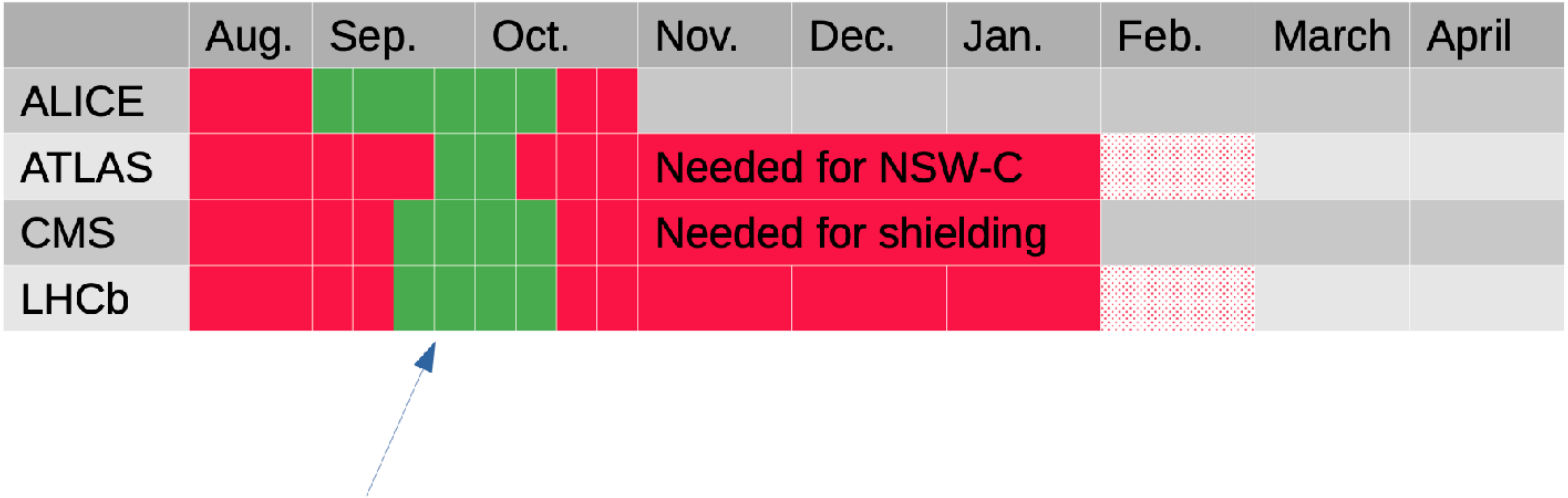
- This schedule is driven by SciFi C-side insertion
  - required for insertion and bake-out of beam-pipe
  - Beam-pipe insertion only just compatible with an LHC beam test in Sept/Oct. 2021
- If SciFi advances, VELO/UT would drive schedule

LS2 Schedule Meeting 23 October 2020

Summary of COVID-19 impact

after meeting 23.10.2020

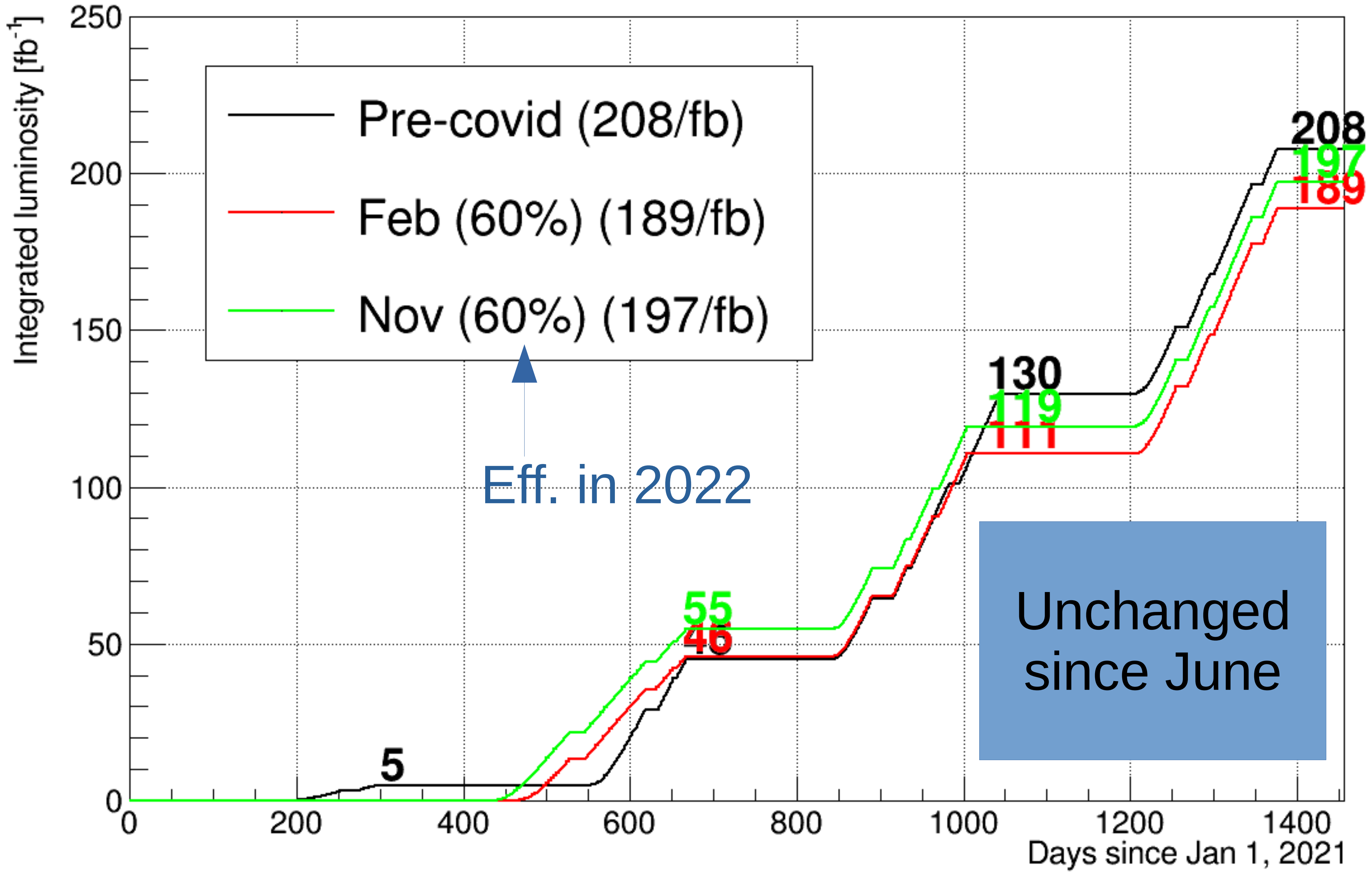
- Still significant uncertainties from COVID-19 impact
- November 2021 restart no longer looks feasible



Preferred LHC beam test window from experiments,
i.e. minimal interruptions to their schedule

LPC Run 3 Luminosity Prediction

- Luminosity comparison depends crucially on how efficient 2022 will be without a p-p run in 2021
  - For 2021, efficiency was assumed to be ~40% of normal year (i.e. 20% SB) and in addition it has low beam intensity due to LIU ramp-up
  - For 2022 LIU ramp-up well underway, so assume quick to reach 2018 perf.
  - Still expect lower LHC efficiency without ramp-up in 2021
- Have assumed 60% efficiency for 2022 and 13 week ramp-up
- *A month delay in restart or 40% efficiency in 2022 costs 10-15/fb*



Pre-covid luminosity assumed for 130 days at 100% eff. (apart 2021)

2021	10/fb
2022	70/fb
2023	80/fb
2024	85/fb

Summary of Meeting October 23, 2020

- Baseline LHC schedule from June 8 maintained
  - Close experimental caverns on February 1st, 2022
  - ATLAS installs both sides of NSW
  - CMS installs new shielding on both sides
  - ALICE and LHCb complete their phase 1 upgrades
  - Short EYETS only in 23/24 for LS3 preparation
- An earlier start (November 2021) is no longer an option
- 11T magnets will not be installed during LS2
- Beam test in weeks 39-40, 2021 (Sep 27 -Oct 10)
- Injectors will have YETS week 41, 2021 – week 4, 2022
  - ~~Likely means~~ no ion beams for fixed target experiments
- Situation to be reviewed i~~n week of~~ March 15, 2021
  - Monitor potential impact of evolving COVID-19 situation

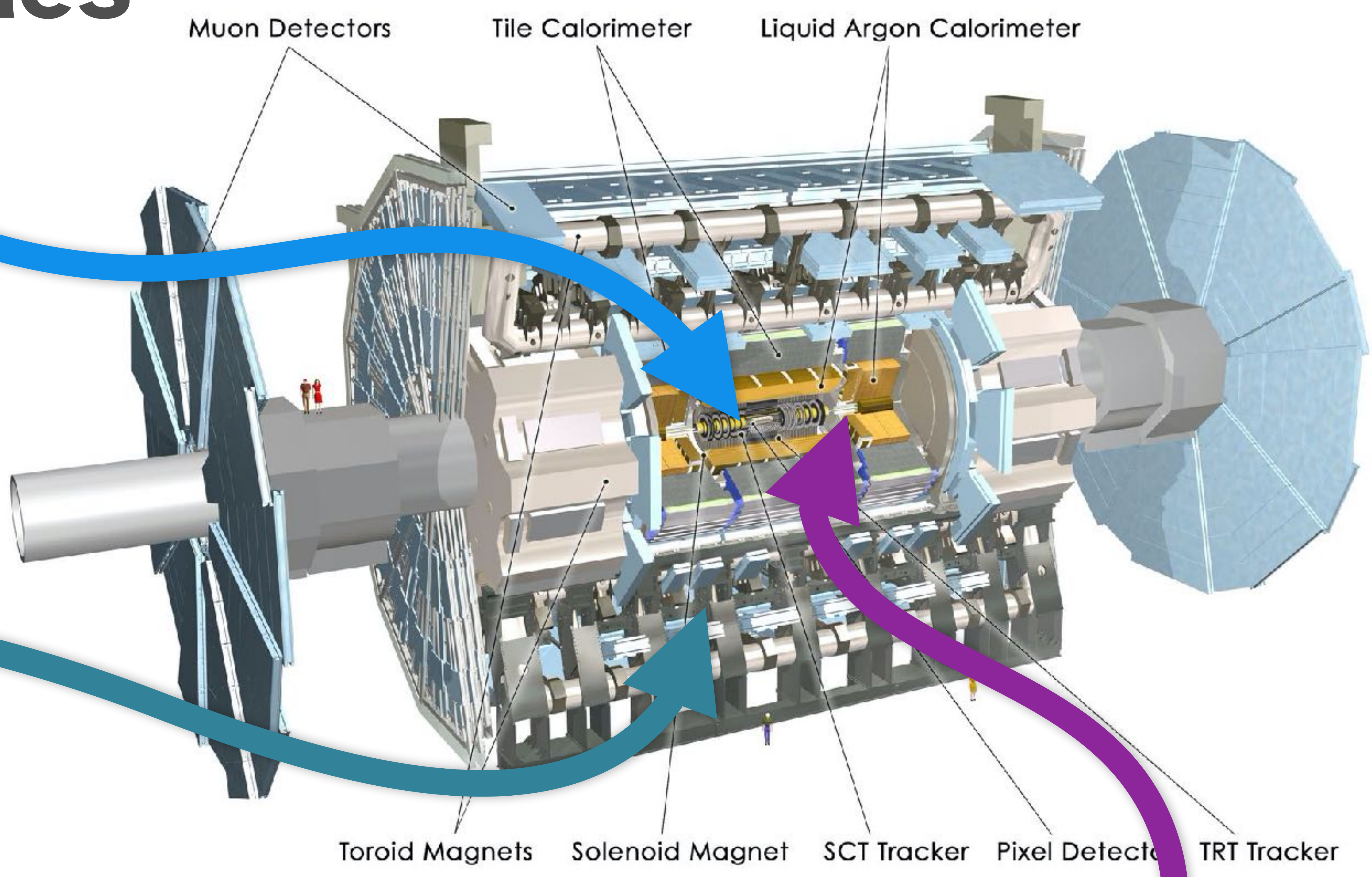
Resume LHC Running in February 2022

but confirm in spring

Upgrades beyond LS2

Phase-II Upgrades

ATLAS



Inner Tracker (ITk)

Entirely replace existing tracker
All-silicon, Acceptance for |η|<4

New Muon Chambers

Chamber replacement in inner barrel

Electronics Upgrades

LAr, Tile, Muon Systems

Trigger/DAQ

Upgrade to L0-based system at 1 MHz

High Granularity Timing Detector

Forward timing coverage from LGADs w/ 30-50 ps resolution for MIPs

Approved by CERN Research Board **Sept**

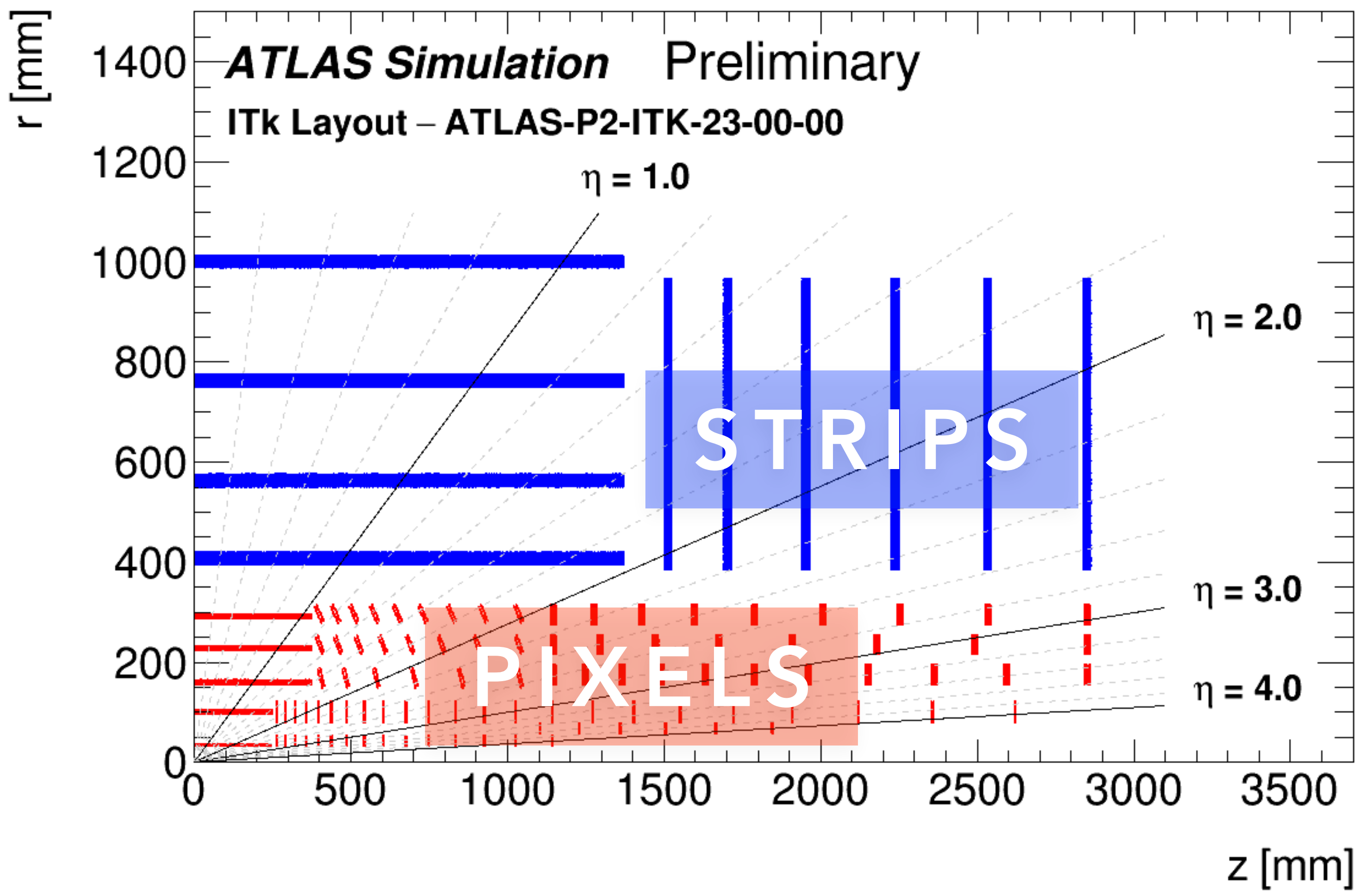
All projects progressing despite COVID concerns.
ITk gives dominant uncertainty on schedule

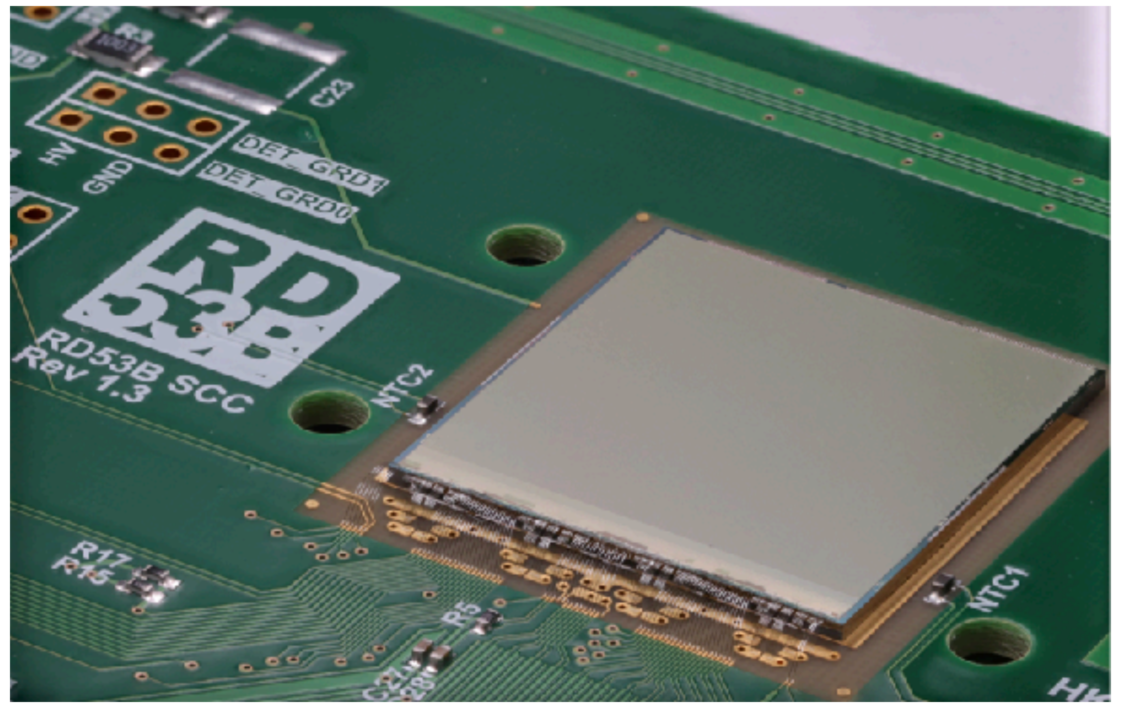
- **ITk Pixels**
  - Moving into final design phase
  - FE ASIC v1.0 found to have bug in ToT circuitry → Large current draw
    - **v1.0 otherwise OK.** v1.1 fix submitted in **Oct**
    - v2.0 (production) submission planned for **Sept 2021**
  - **Schedule now w/ negative contingency**

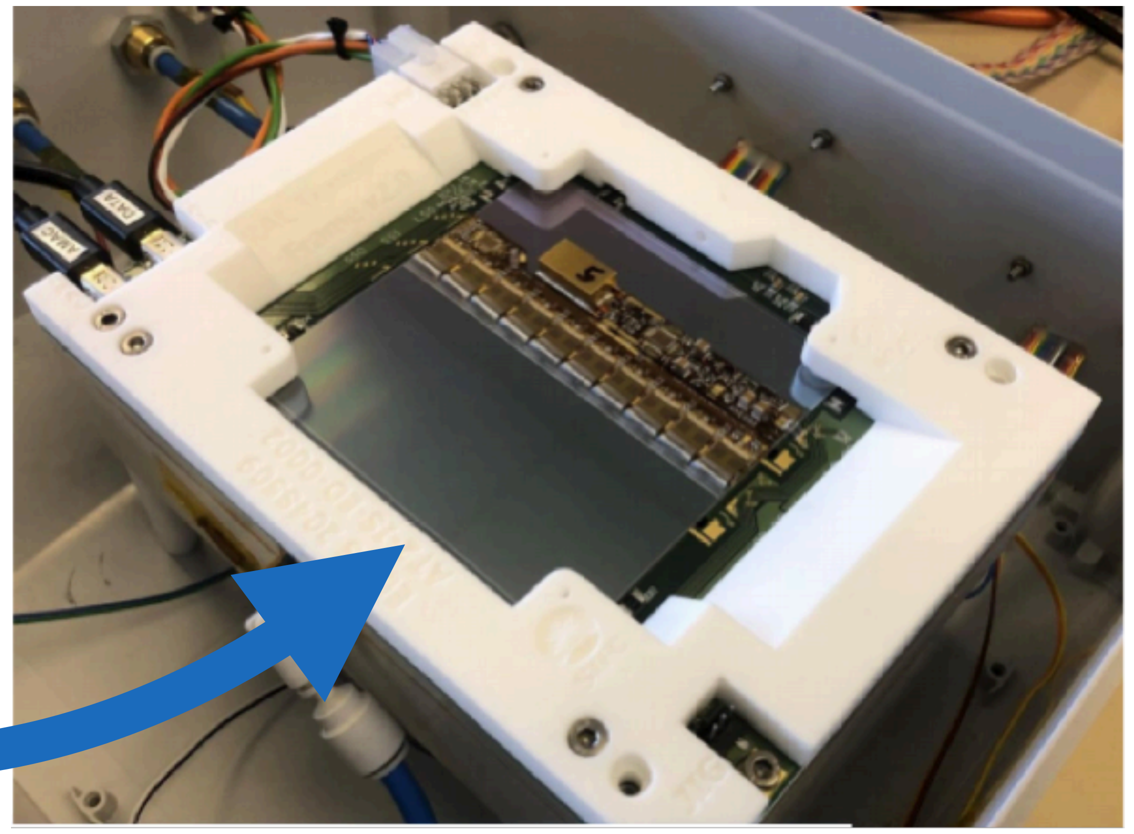
P2UG has flagged this
- some mitigation
- schedule review end 2021

- **ITk Strips**
  - Transitioning from prototyping to pre-production
  - Delivery of some preproduction sensors complete. Delays in testing from COVID.
  - **First prototype modules for barrel and endcap assembled and tested w/ pre-production sensors**
  - **Schedule contingency shrinking**

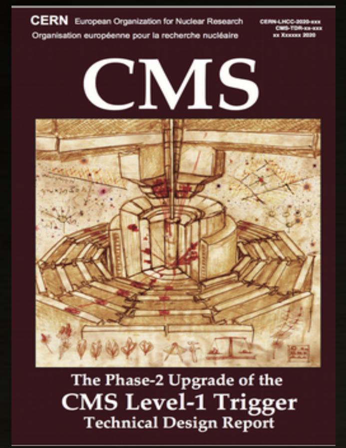
ATLAS







CMS Upgrade – *our future unprecedented beauty*

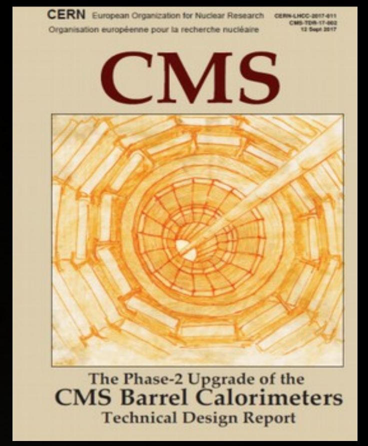


L1-Trigger HLT/DAQ

https://cds.cern.ch/record/2714892
https://cds.cern.ch/record/2283193

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

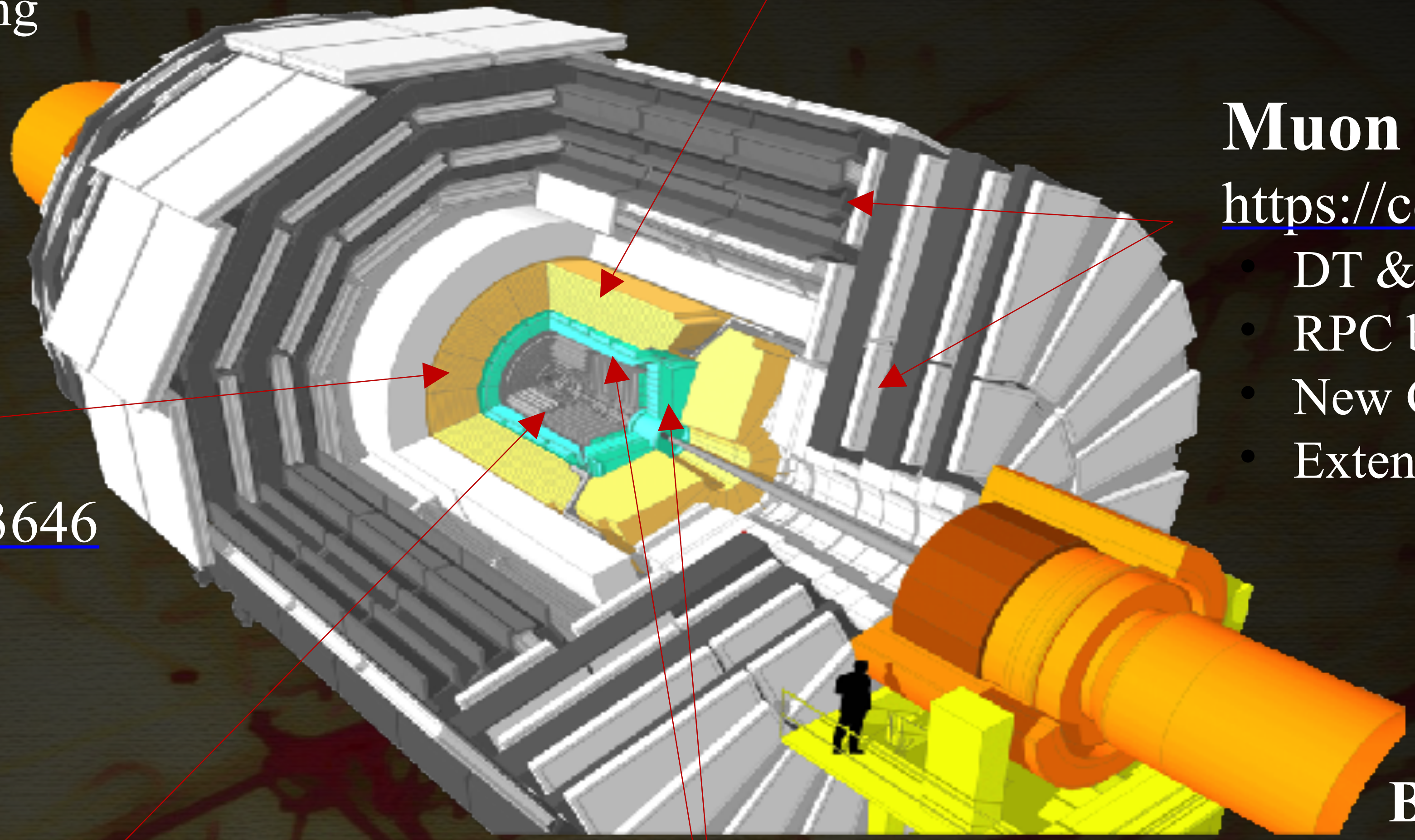
DAQ/HLT TDR Q2.2021

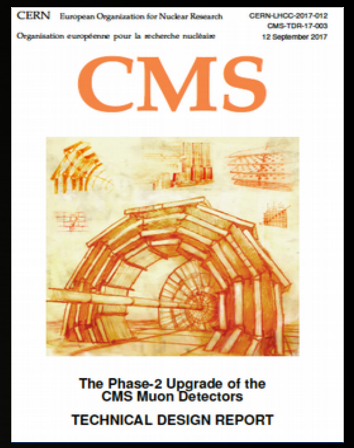


Barrel Calorimeters

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

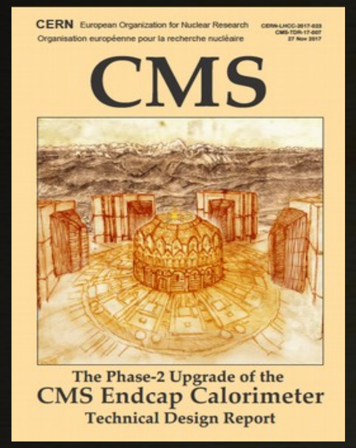




Muon systems

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 $\eta \simeq 3$



Calorimeter Endcap

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

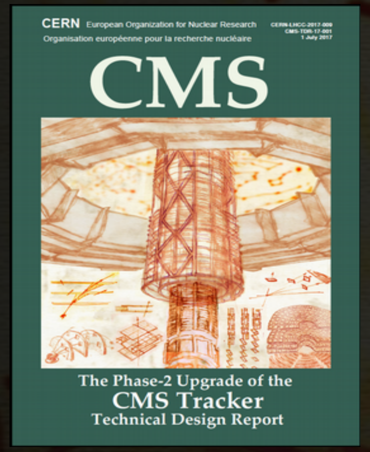
- 3D showers & precise timing
- Si, Scint+SiPM in Pb/W-SS

Beam Radiation Instr. and Luminosity

http://cds.cern.ch/record/002706512

- Bunch-by-bunch luminosity measurement: 1% offline, 2% online

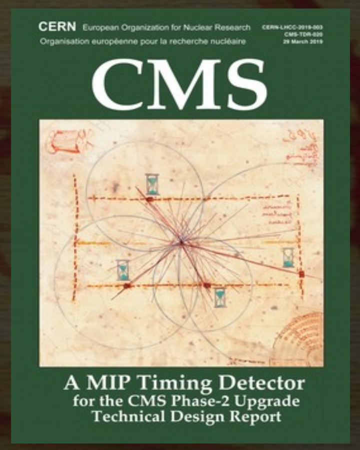
Conceptual Design
TDR Q2.2021



Tracker

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

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



MIP Timing Detector

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

Precision timing with:

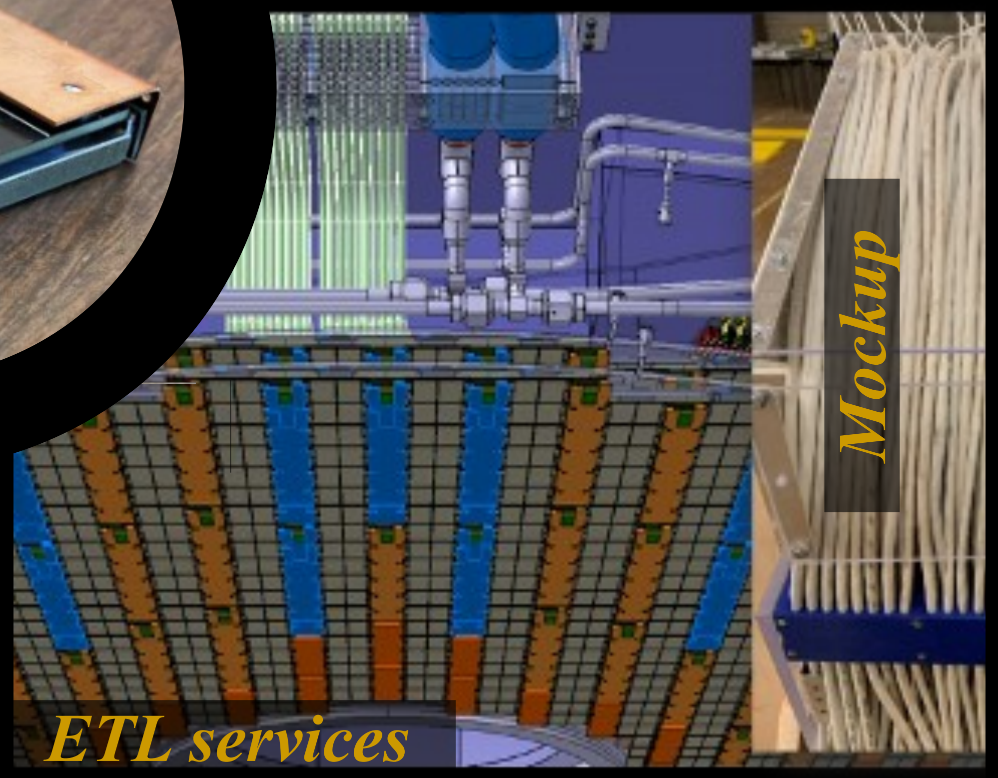
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

General good progress despite Covid-19 (3-5m delay)

CMS Upgrade – *our future unprecedented beauty*

CMS

BTL module

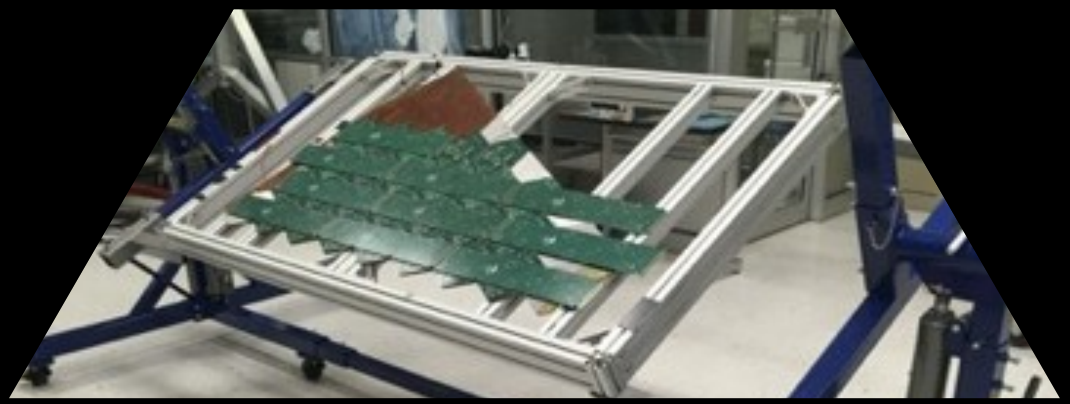


ETL services

MIP Timing Detector

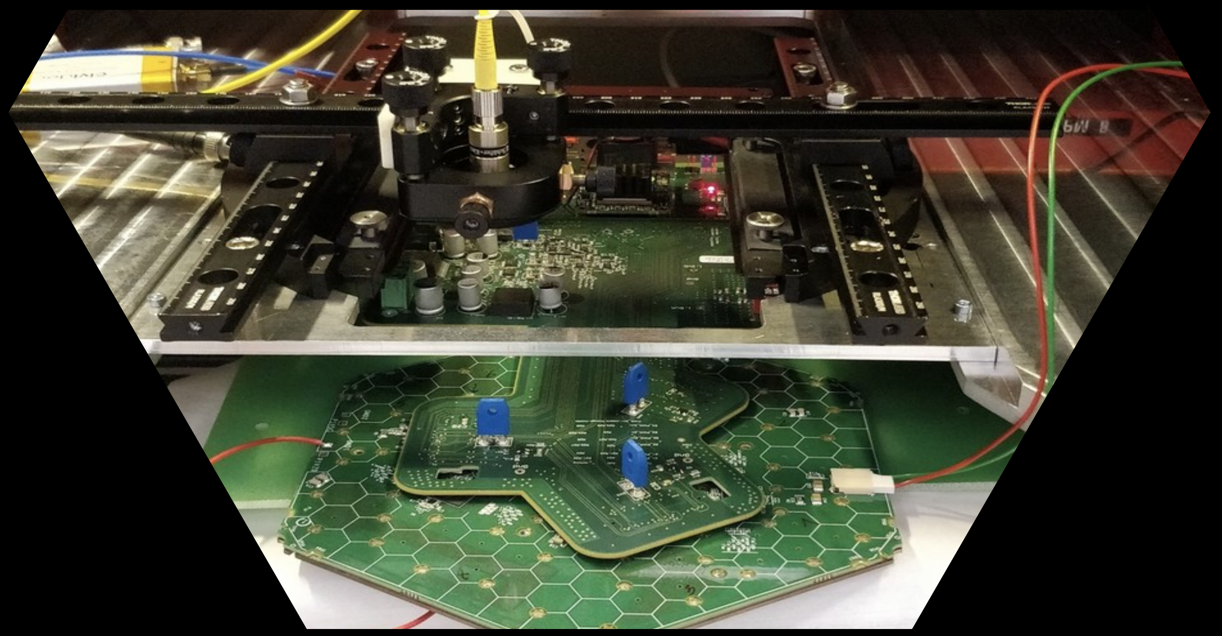
- Market survey & proceeding to tender for sensors
  - LYSO, SiPM, LGAD
- Excellent results for ASIC prototypes in barrel & endcap
- Work on reducing the operation temperature
  - Mitigate Dark Count Rate, improve time resolution
    - SiPMs show higher DCR after radiation than anticipated

Cassette proto station



HGCAL in full prototype & station setup mode

- HGROC submission by the end of the year
- Good progress on mechanics
- Several perfect 8” silicon sensor received, radiation studies ongoing. One more prototype round to go



Laser testing of silicon modules

HGROC: HGCAL Read Out

ITS3

Testbeams with bent silicon detectors

- Two successful beams campaigns (Jun/Aug 2020 at DESY)
- ALPIDEs bent in two different directions
- Paper on Jun results under internal review

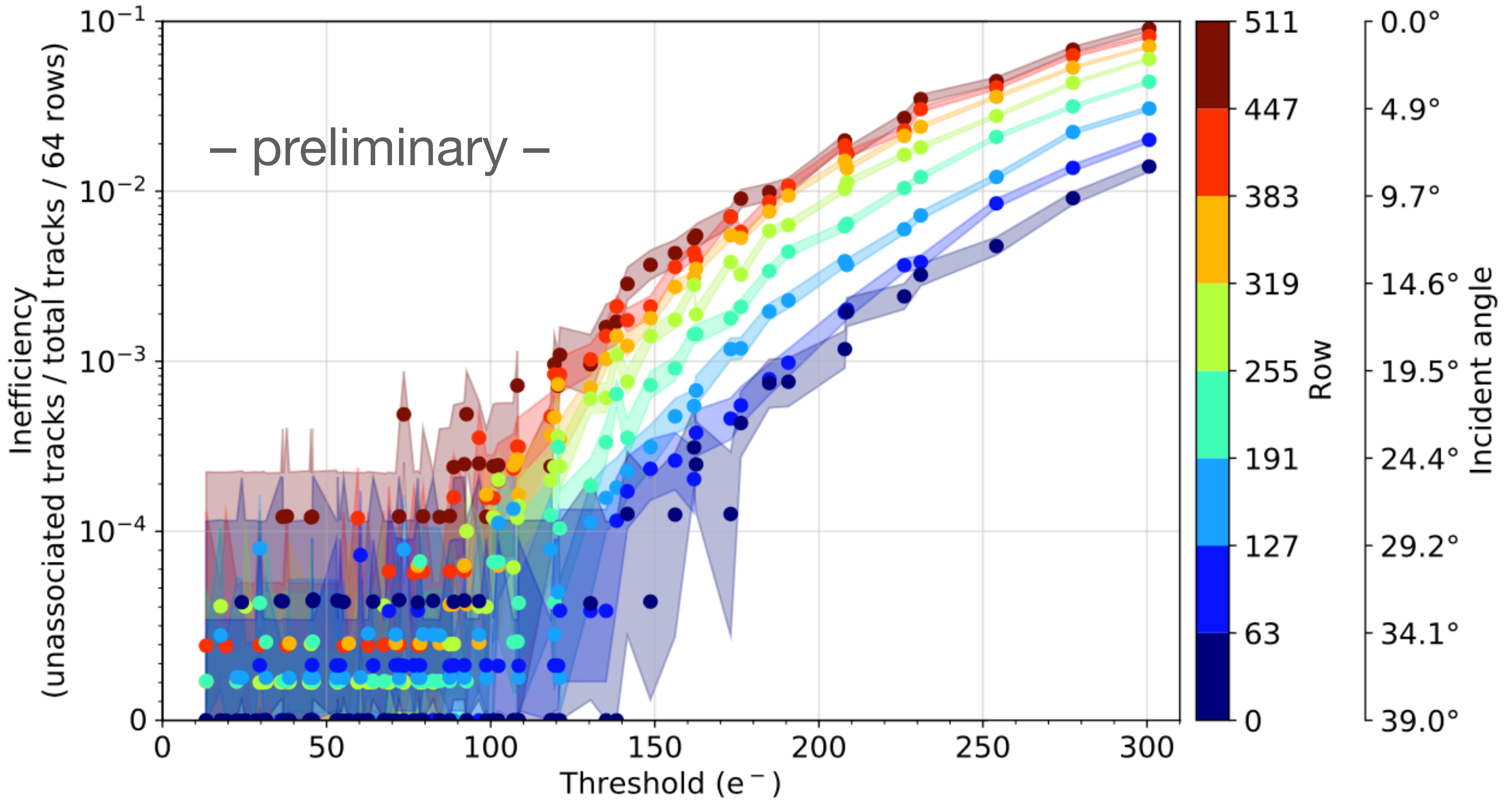
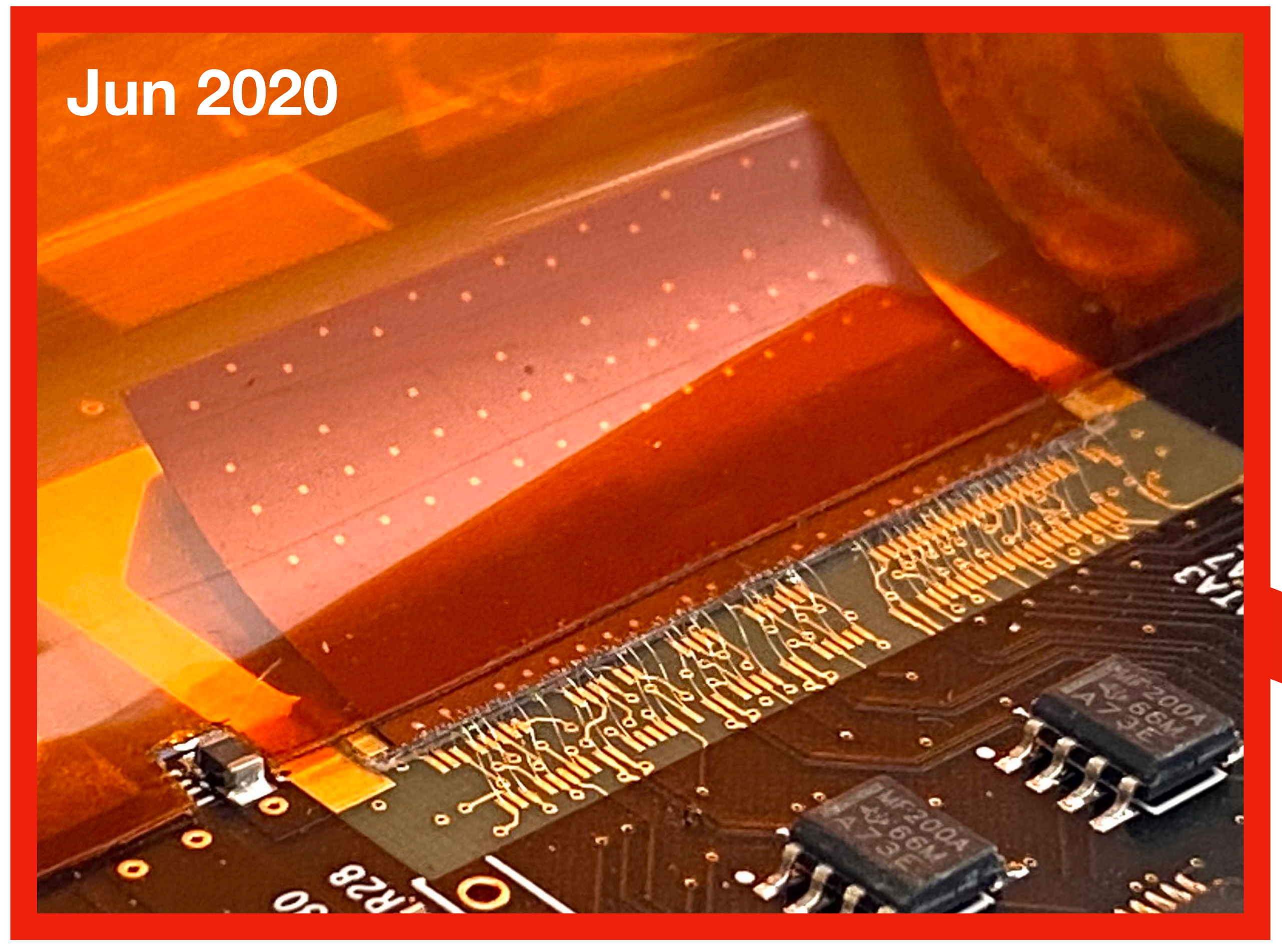
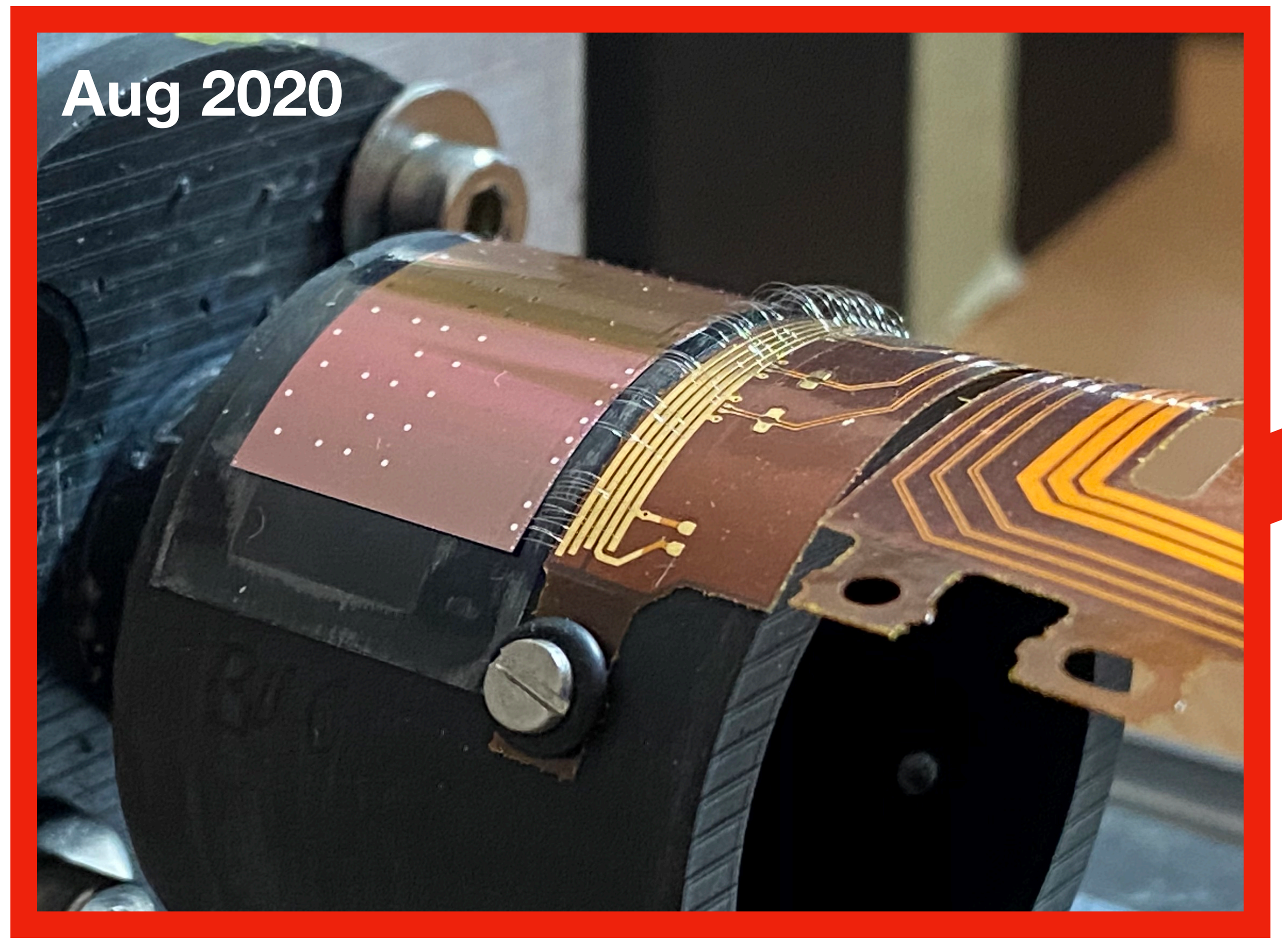


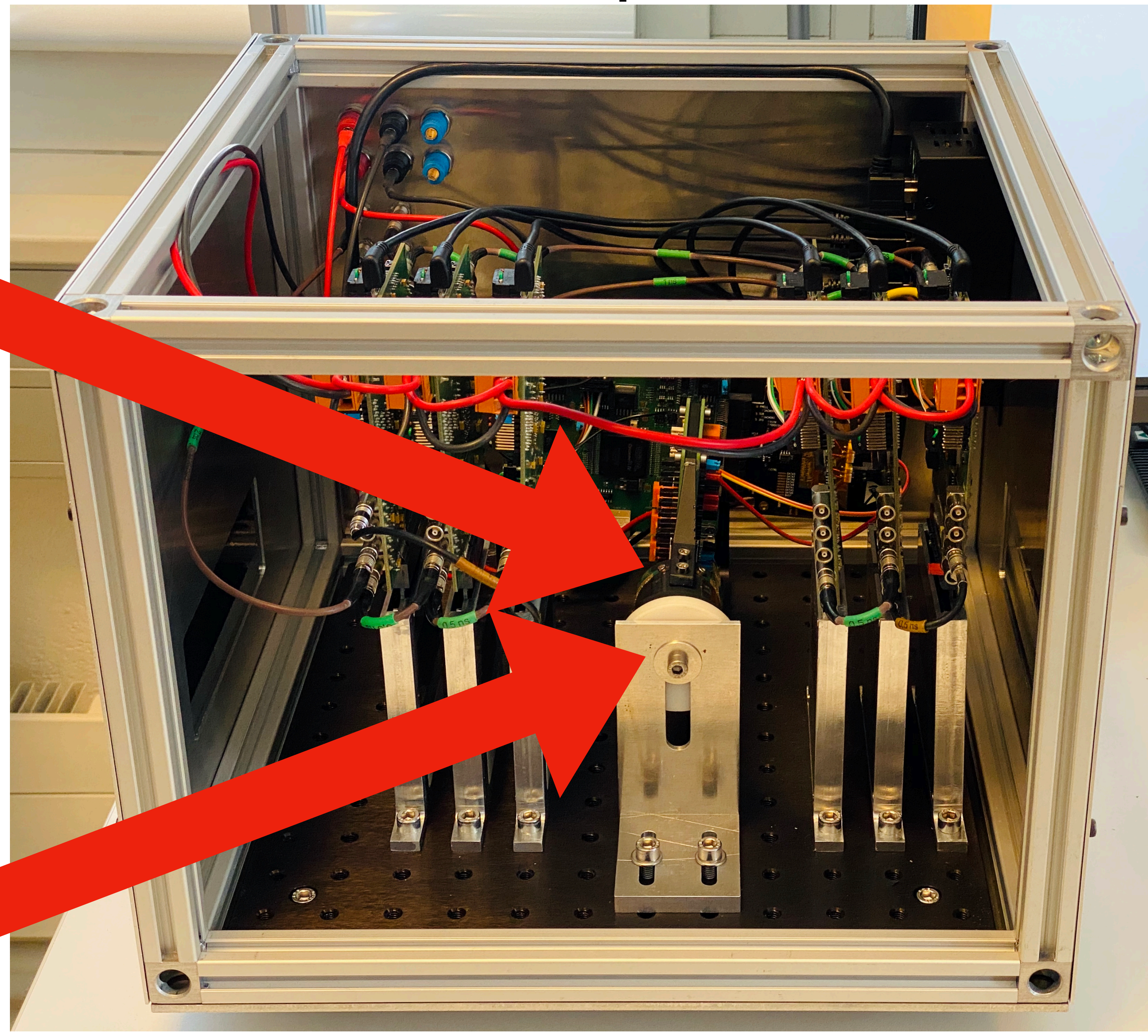
Fig. 10: Inefficiency as a function of threshold for different rows and incident angles with partially logarithmic scale (10^{-1} to 10^{-5}) to show fully efficient rows. Each data point corresponds to at least 8k tracks.

- Excellent performance is retained after bending!



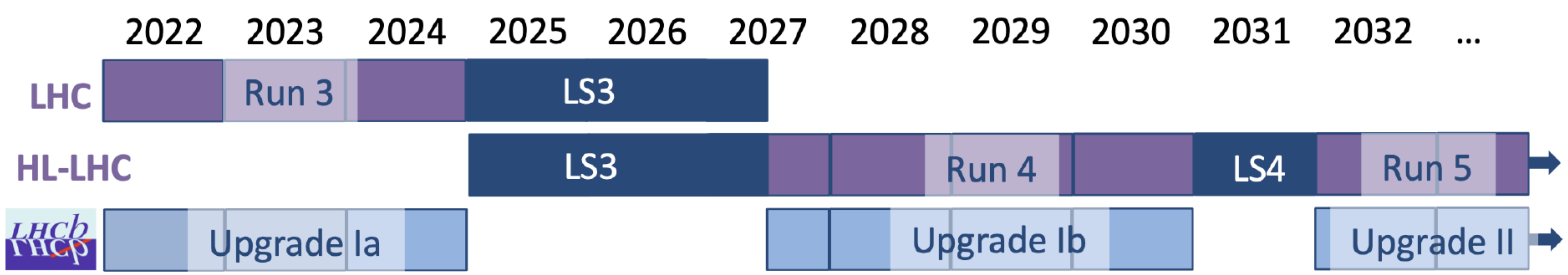


ALPIDE testbeam telescope



UPGRADE II

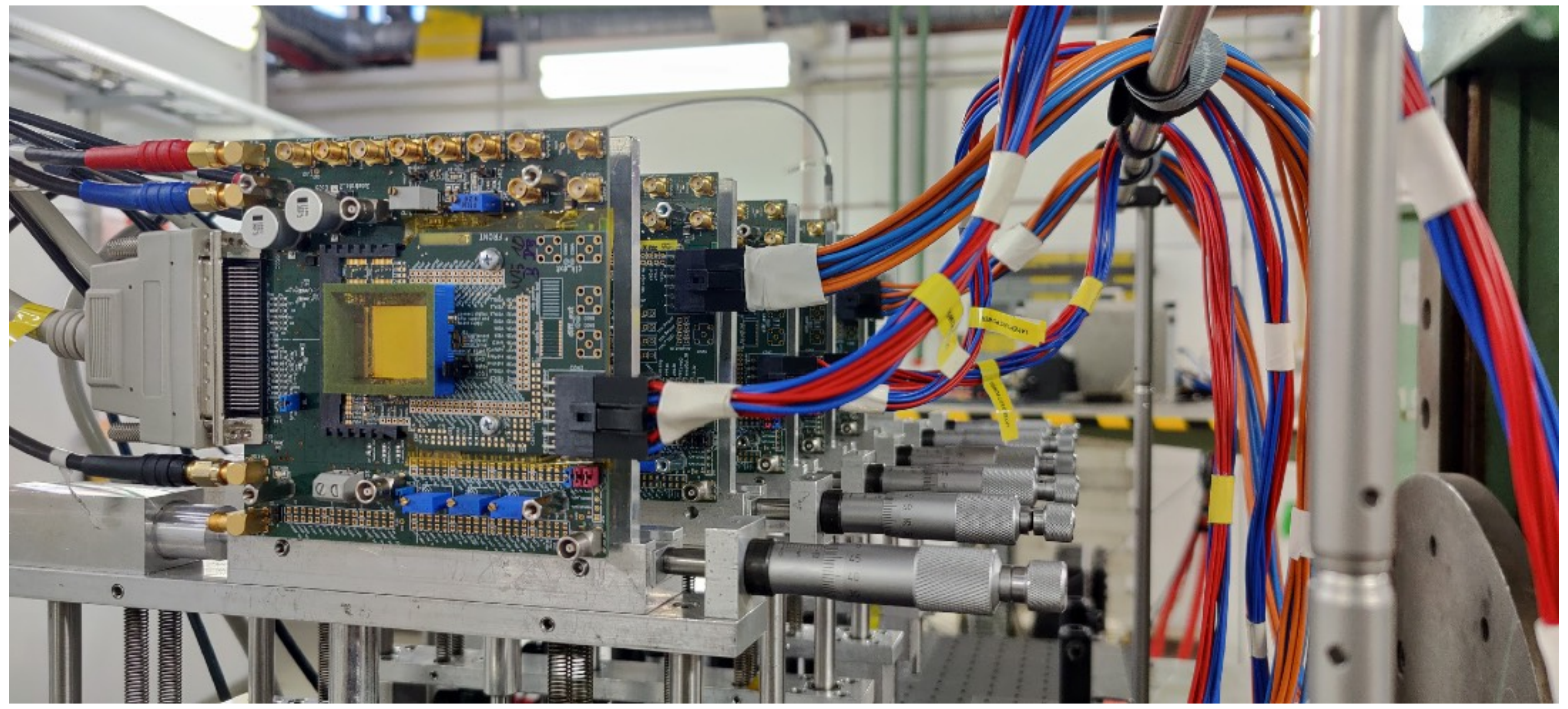
[LHCC-2018-027]



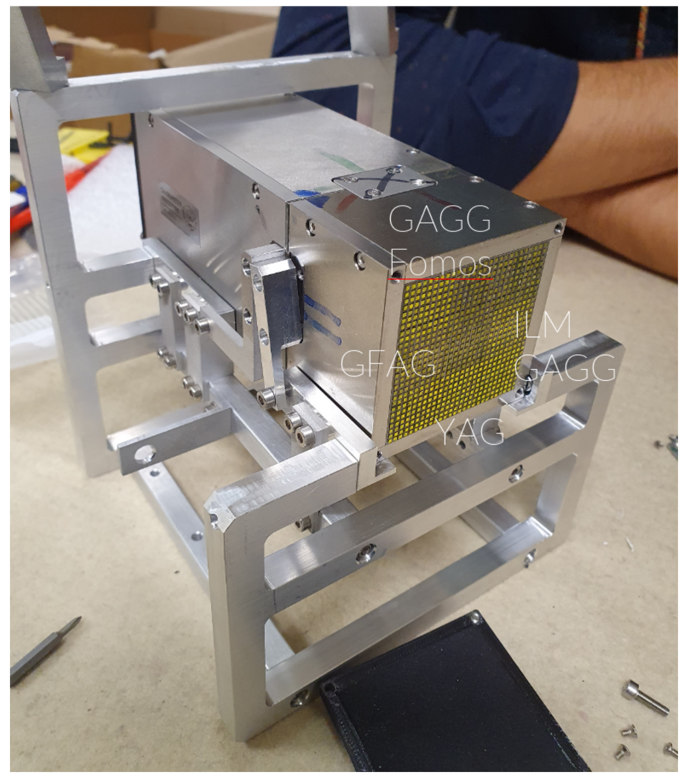
...Consolidation   Full detector

- **Upgrade II** to be installed during LS4 and aim at **collecting 300fb**$^{-1}$
- **FTDR for Upgrade II in preparation**.
- Detector planned for consolidation more advanced.
- Test-beam for ECAL and Mighty tracker @ DESY these weeks.

MightyTracker Test beam @ DESY with MuPix10



SPACAL Test beam @ DESY

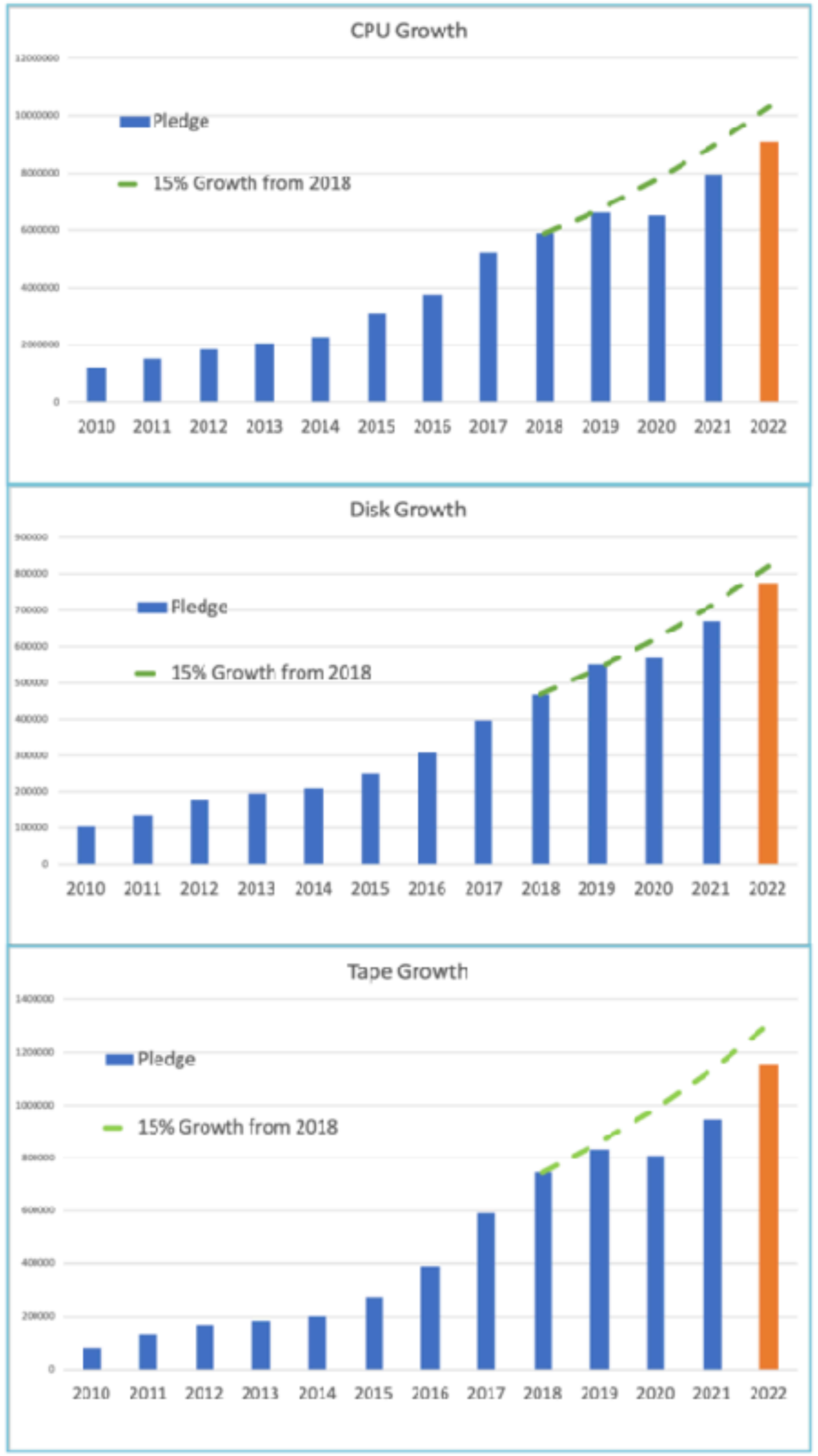


Computing

WLCG needs for Run 3

- Resource needs for the start of Run 3 seem manageable within flat budget, but
  - growth in e.g. LHCb expected above flat budget
  - Run 3 conditions after 2022 (e.g. virtual luminosity & pileup) could be challenging
- COVID is impacting economy
  - trend of hardware cost remains hard to predict

This is the result of a tremendous and continuous effort in software: compute models and use of new hardware (GPU…).



CERN Computing - towards PCC

Council approved

- CERN is reponsible for T0 in WLCG.
  - provides 20% of CPU and disk and 37% of the tape capacity
- Support of all experiments; accelerator and services

1972

2012-2019

2019-2022

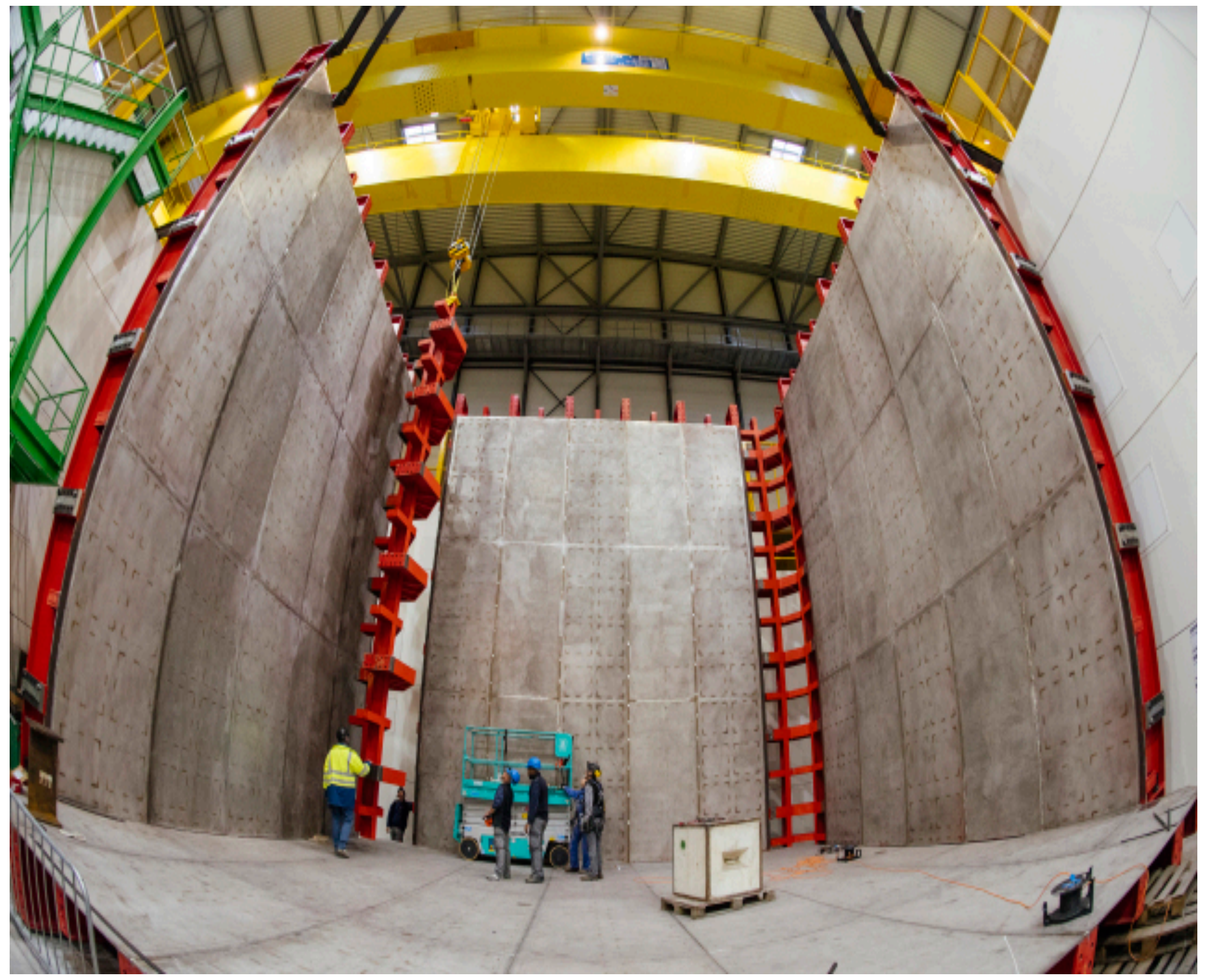
Prévessin
Computing Centre
(PCC)

~2023

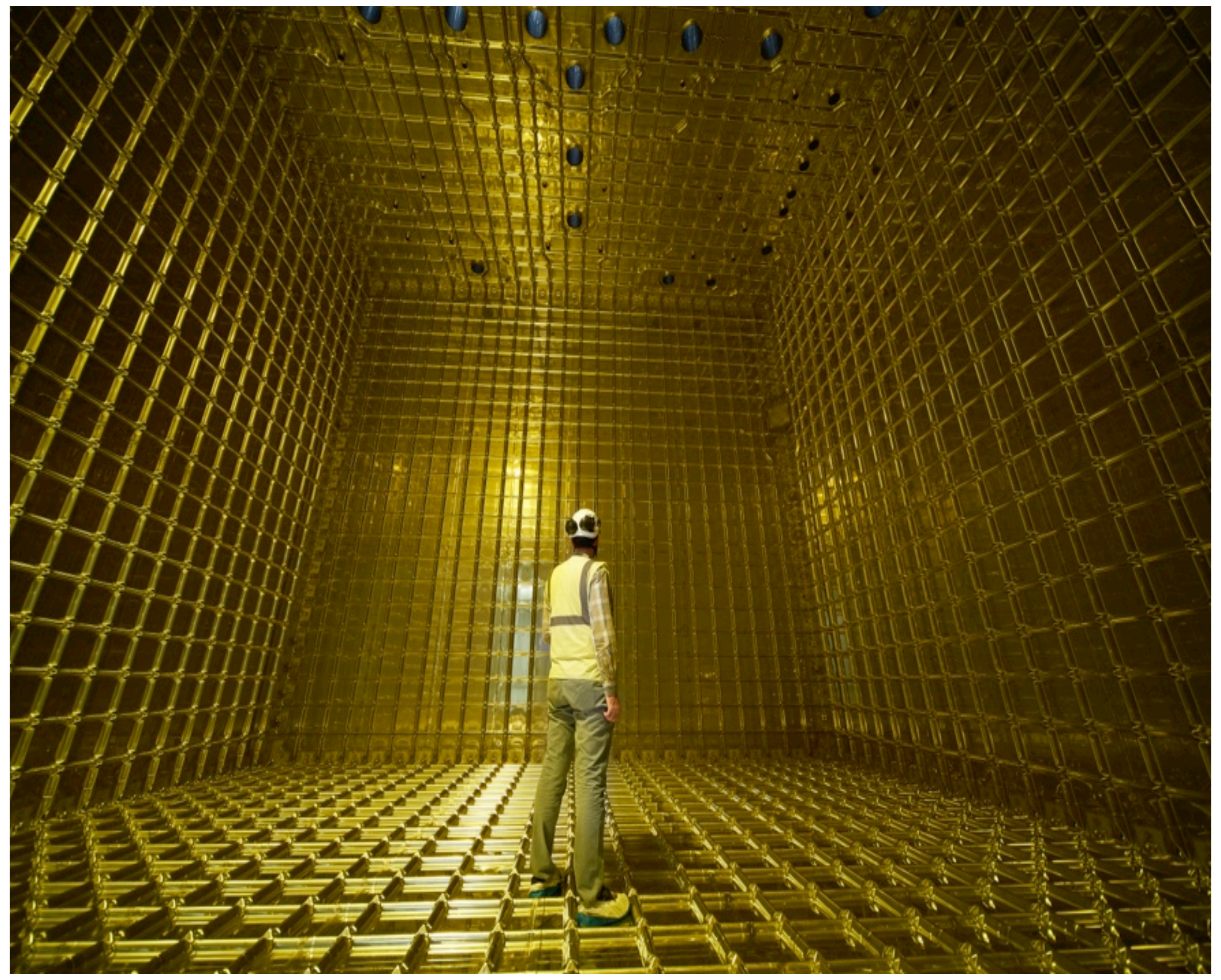
Neutrino Platform

PROTO DUNE SP in few snapshots

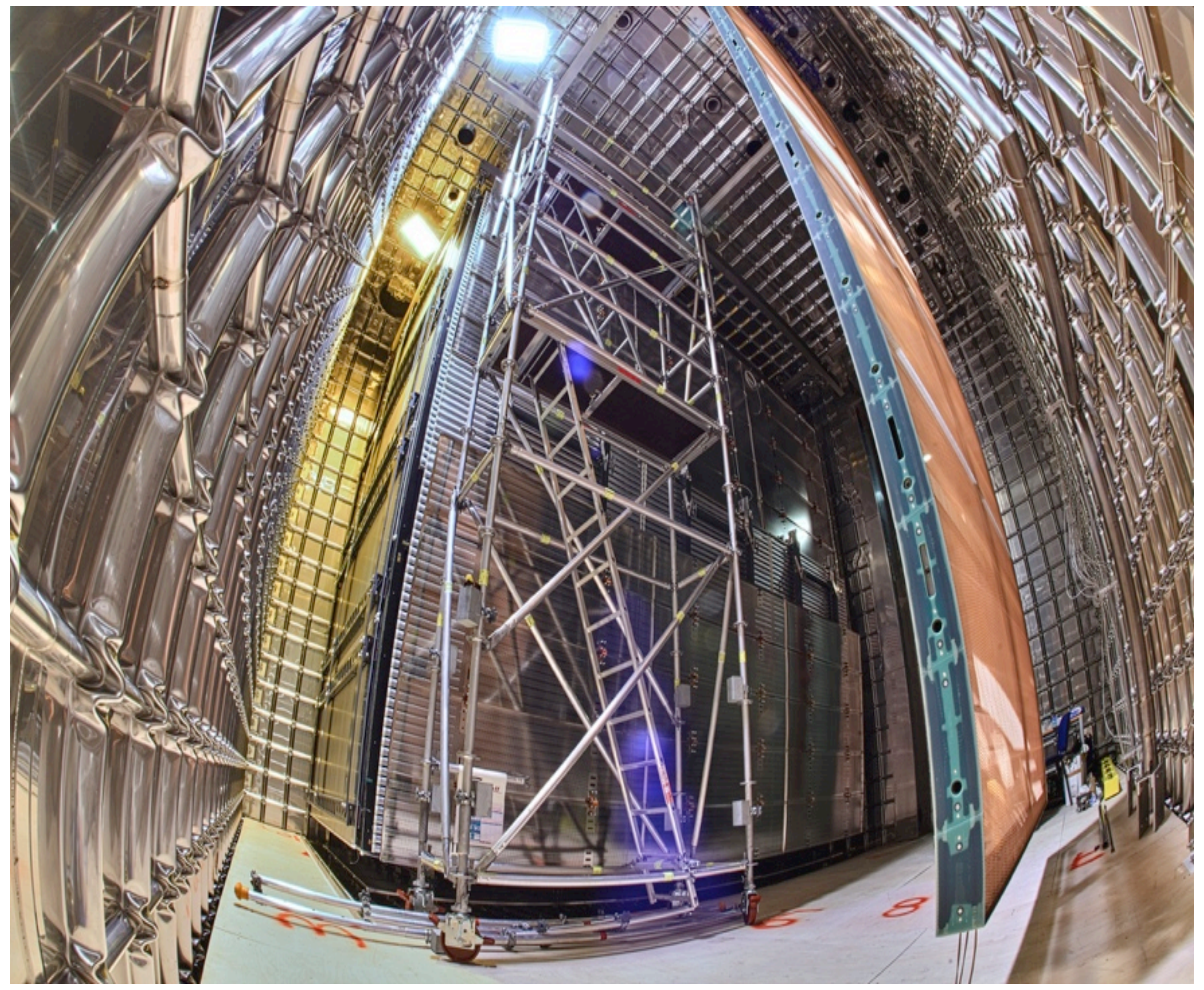
March 2016, construction of EHN1 extension



November 2016, cryostat structure assembly

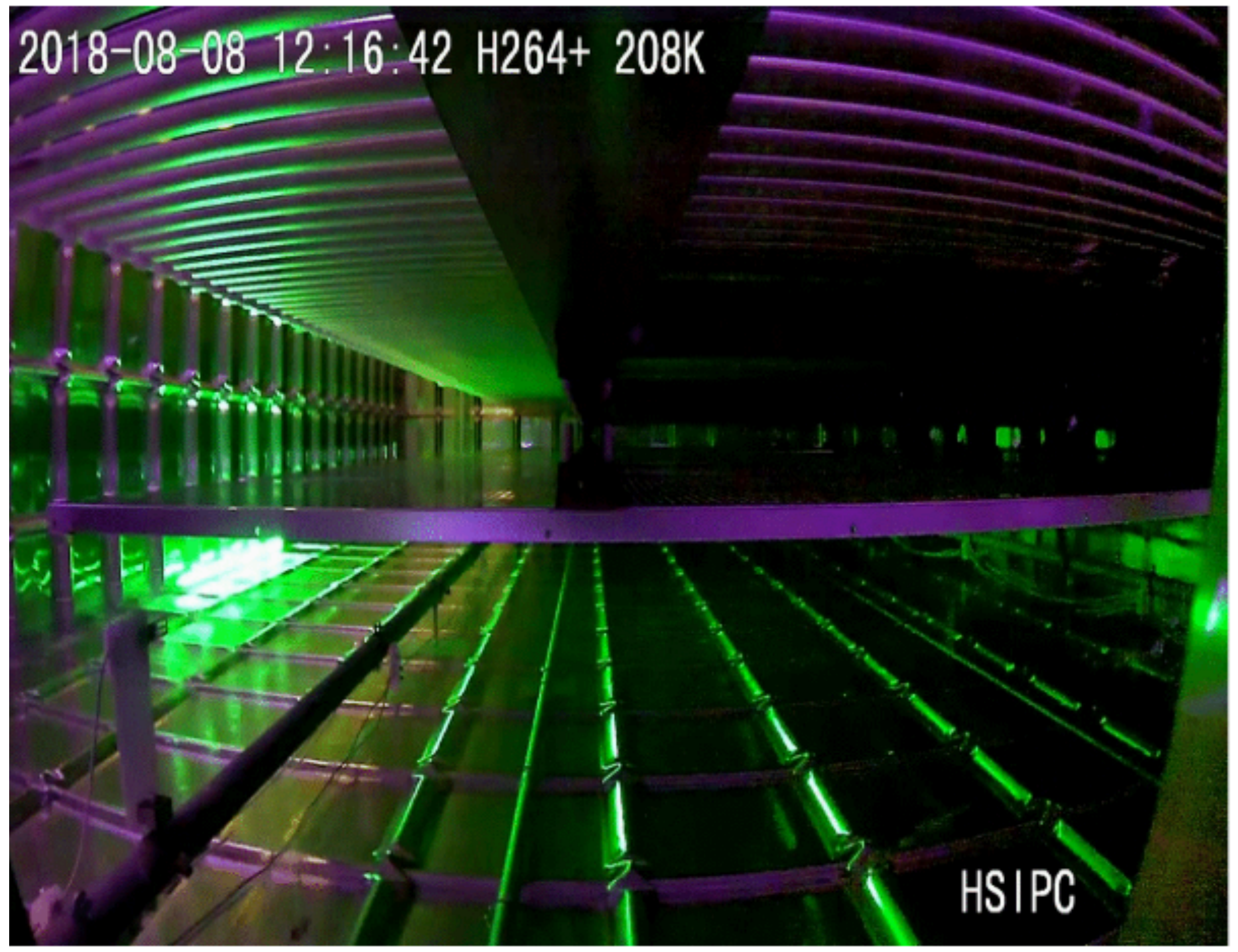


September 2017, cryostat completed

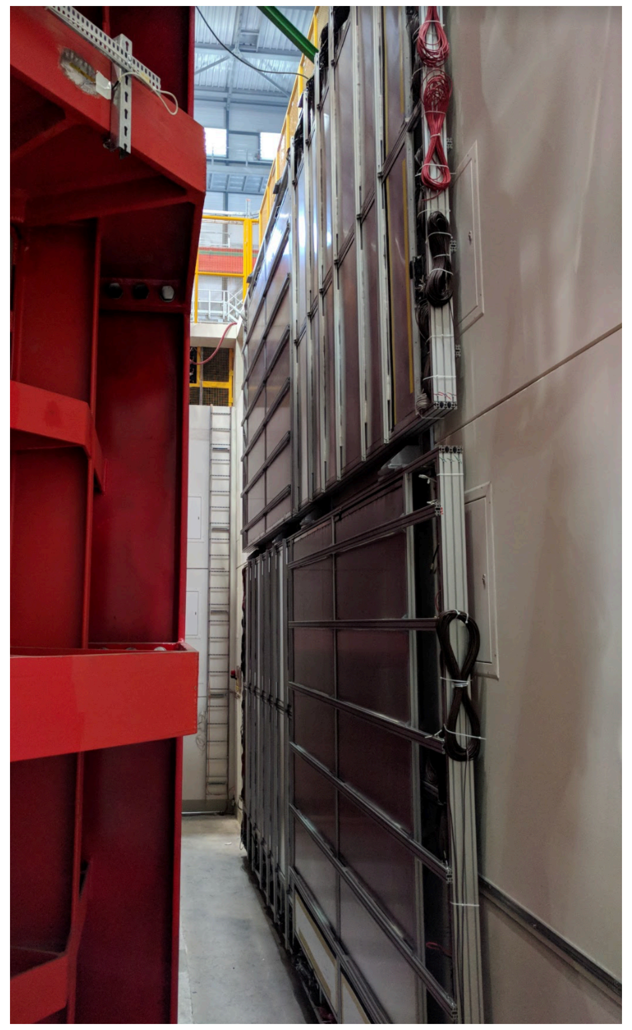


February 2018, detector assembly (ship-in-a-bottle)

April 2018, TCO closing

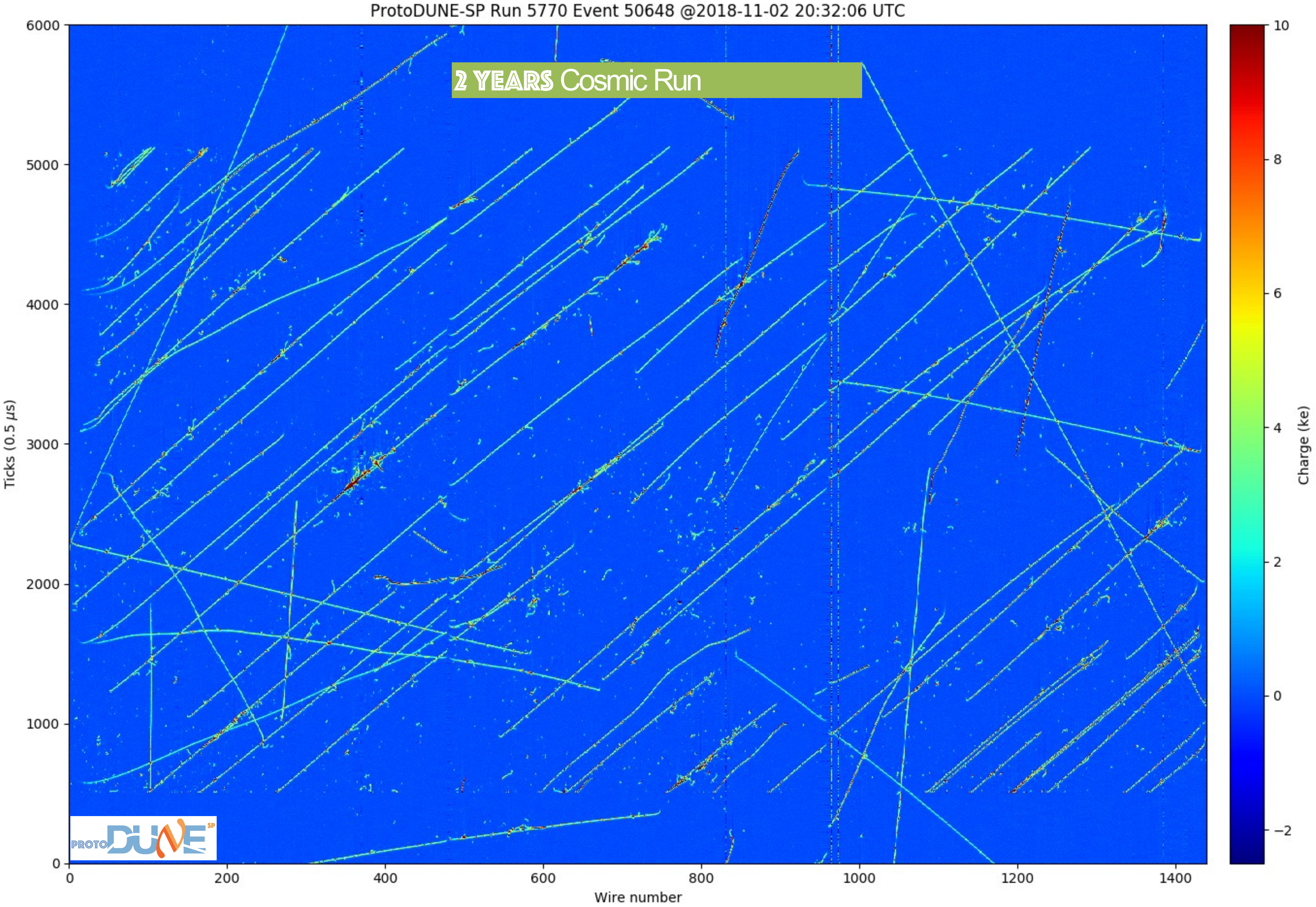


August 2018, LAr filling



September 19, 2018 - DAQ and CRT: ready for beam!

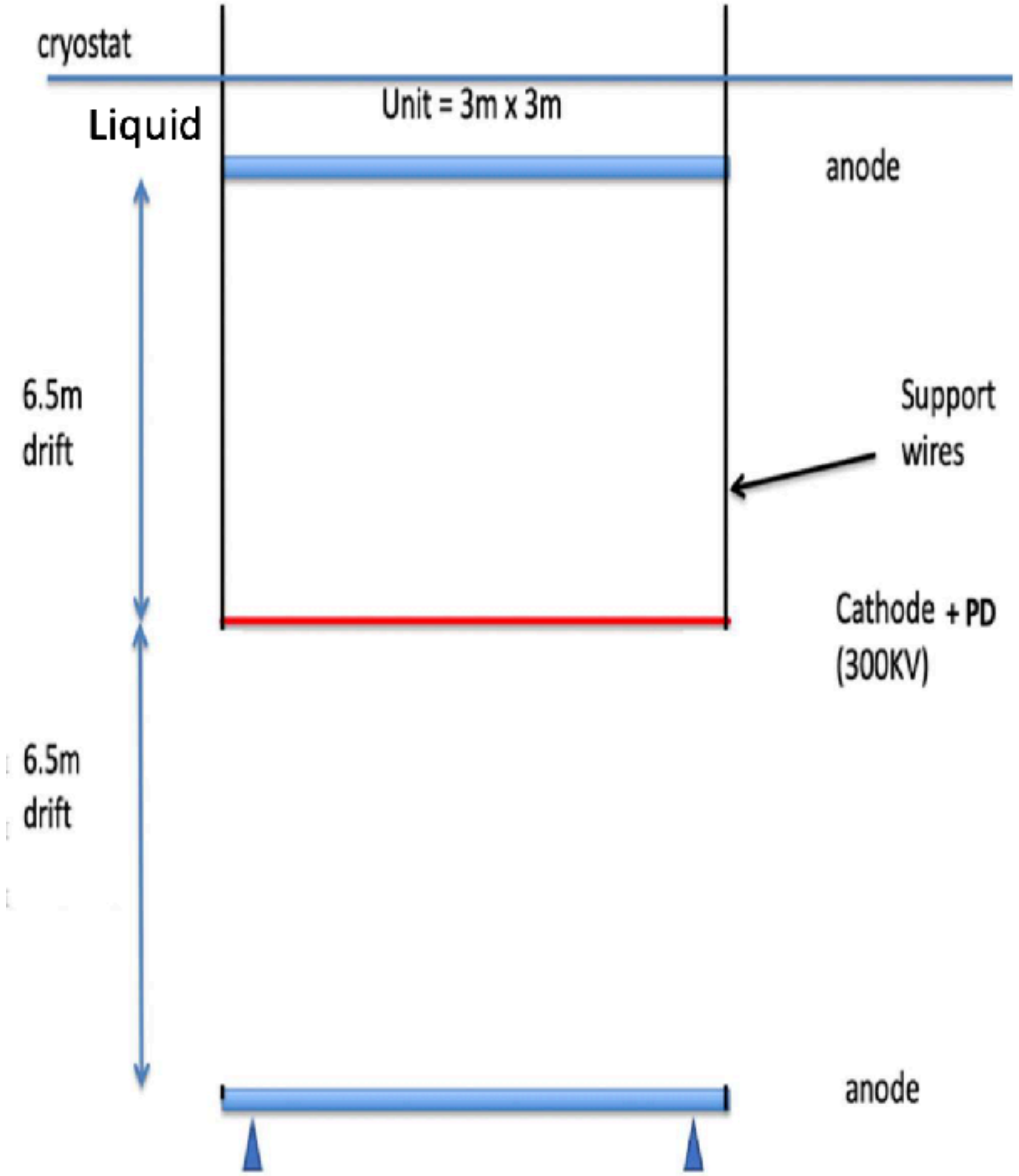
Muon bundle in a cosmic ray atmospheric Shower



A cosmic muon bundle event.

ProtoDUNE - NP02

- Dual Phase readout proved to be very challenging
  - HV stability
  - liquid surface; maintain gap
- but the high purity LAr allows for much larger drift (6.5 m) and hence simpler design
  - perforated PCB



5 years later we have a new strategy

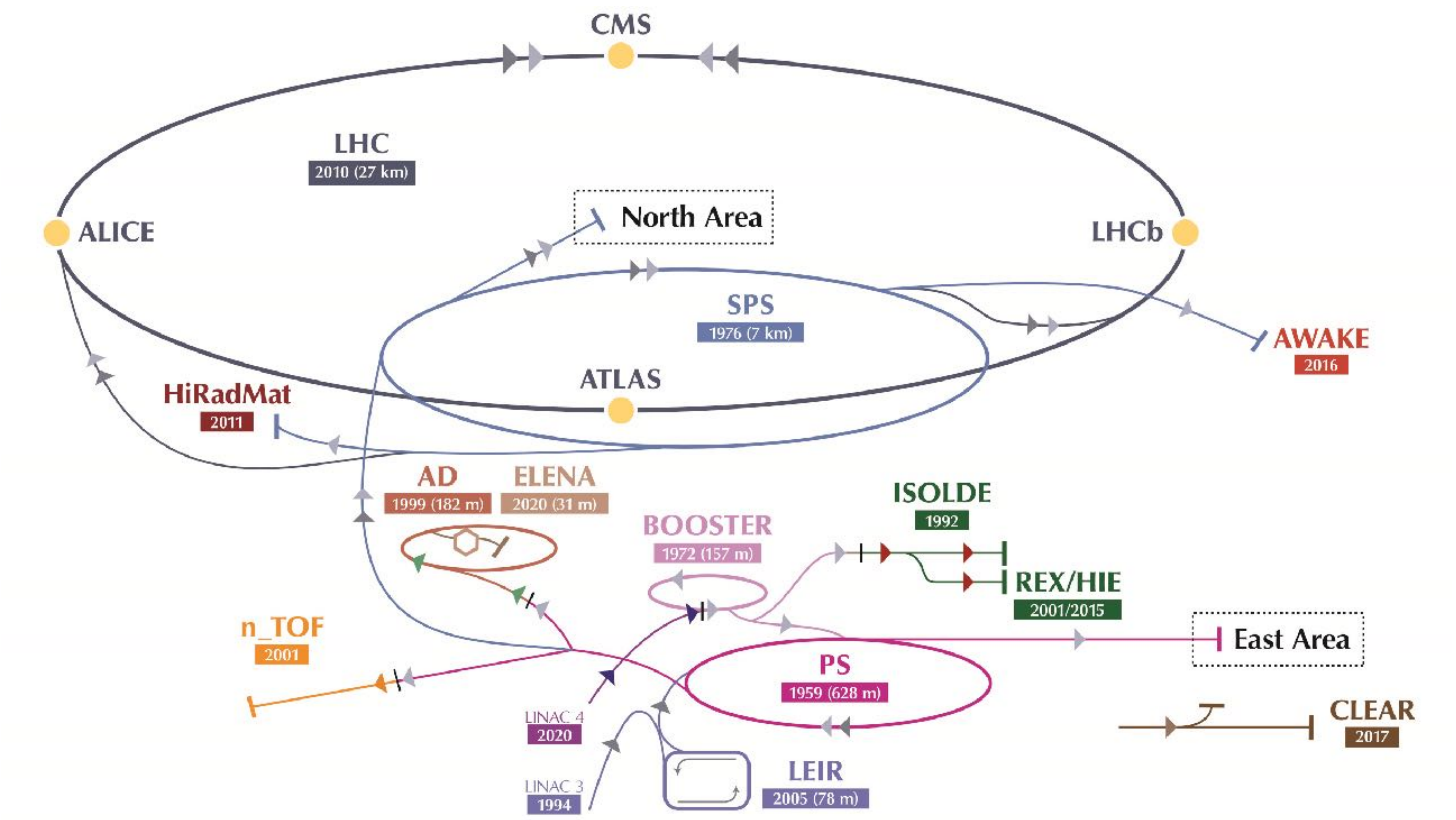
- Higgs had (just) be discovered — Need for Higgs precision physics: HL-LHC and e^+e^-
- Hoping for (fairly) strongly coupling New Physics
  - energy increase — even stronger case for Hl-LHC and a leap in energy: FCC-pp
  - energy reach provided by luminosity spectrum increase
- Neutrinos to address CP violation in the leptonic sector — LBNF/DUNE and T2K → Hyper-K
  - ~~What is the nature of neutrinos (sterile, Majorana)~~ (not in ESPP) — maybe SBN?
- New physics feebly interacting? — Physics Beyond Collider

and the tools 5 years ago

- Run 2 was beginning in earnest: 13 TeV — √
- Phase I upgrades were in full swing — almost done – but NSW
- Phase II upgrades had just submitted scoping document — all TDRs approved in time and funding largely committed
- Neutrino Platform was Europe's response to the Long Baseline endeavour in the US and Japan — ProtoDUNEs are the pathfinders for DUNE/LBNF; ND280 for J-PARC
- Machine Learning started to be introduced — moving forward to Quantum
- Computing challenges of Phase II had no solution that could be convincingly explained — heterogeneous platforms come to the rescue: CPU/GPU/FPGA

Many thanks to all Experiments and Collaborations

Many thanks to all friends and colleague for making CERN the wonderful place it is...



...and giving me the opportunity to experience this