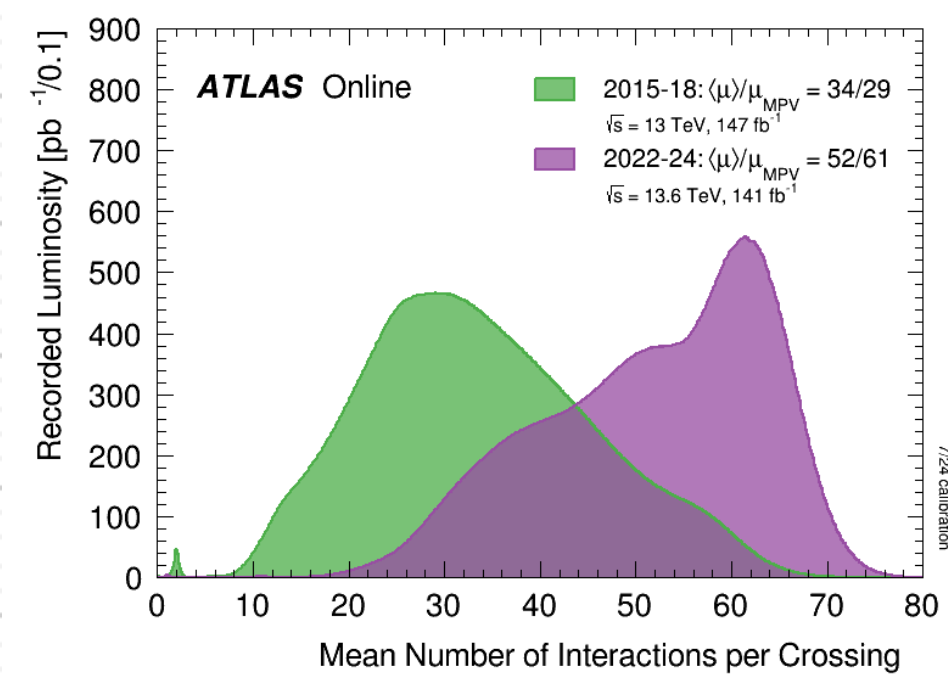
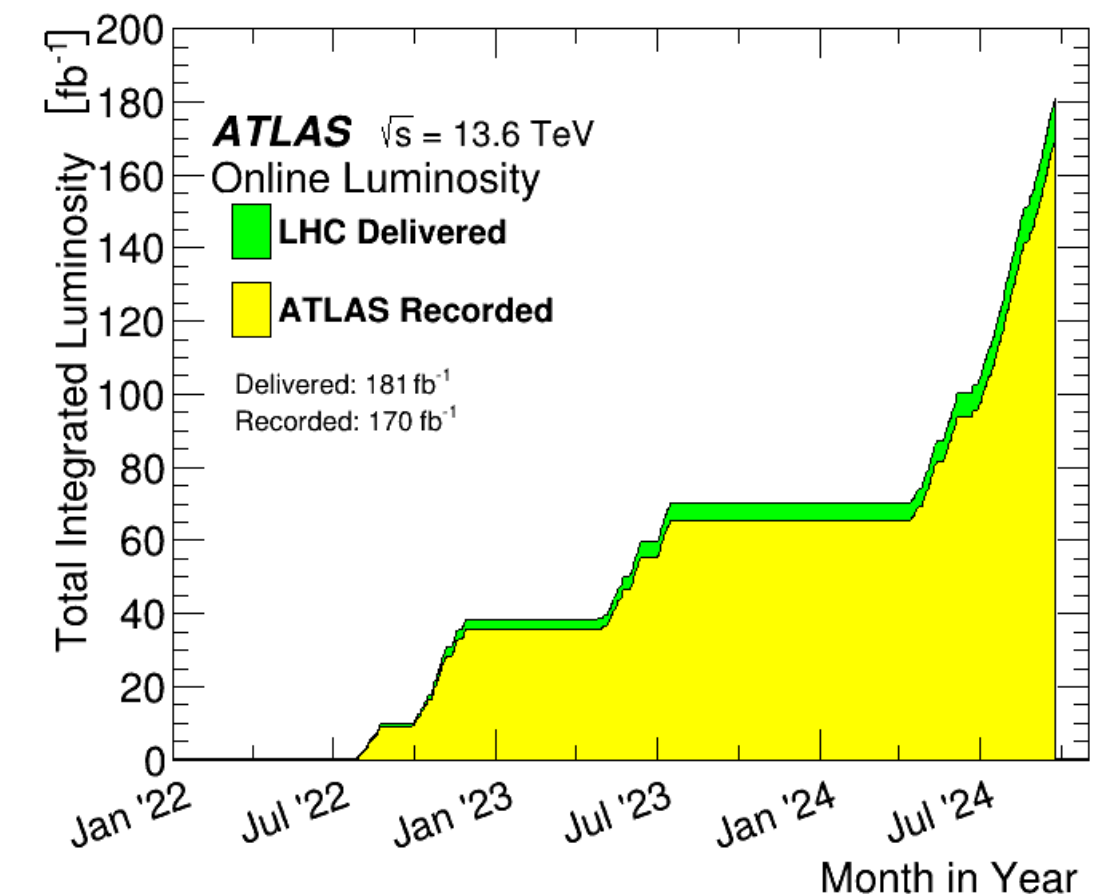
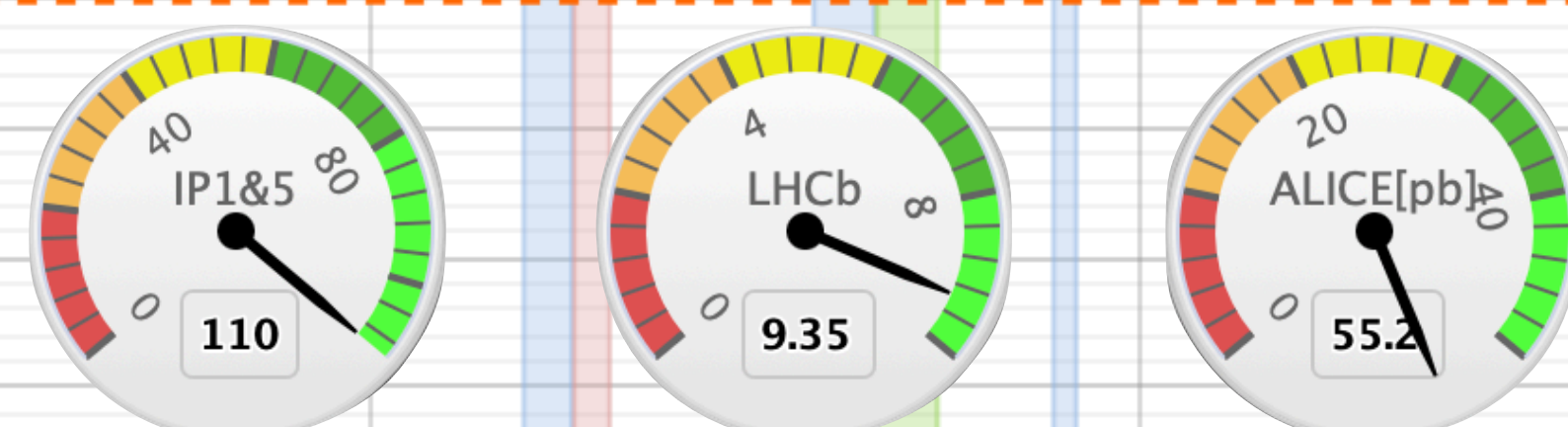
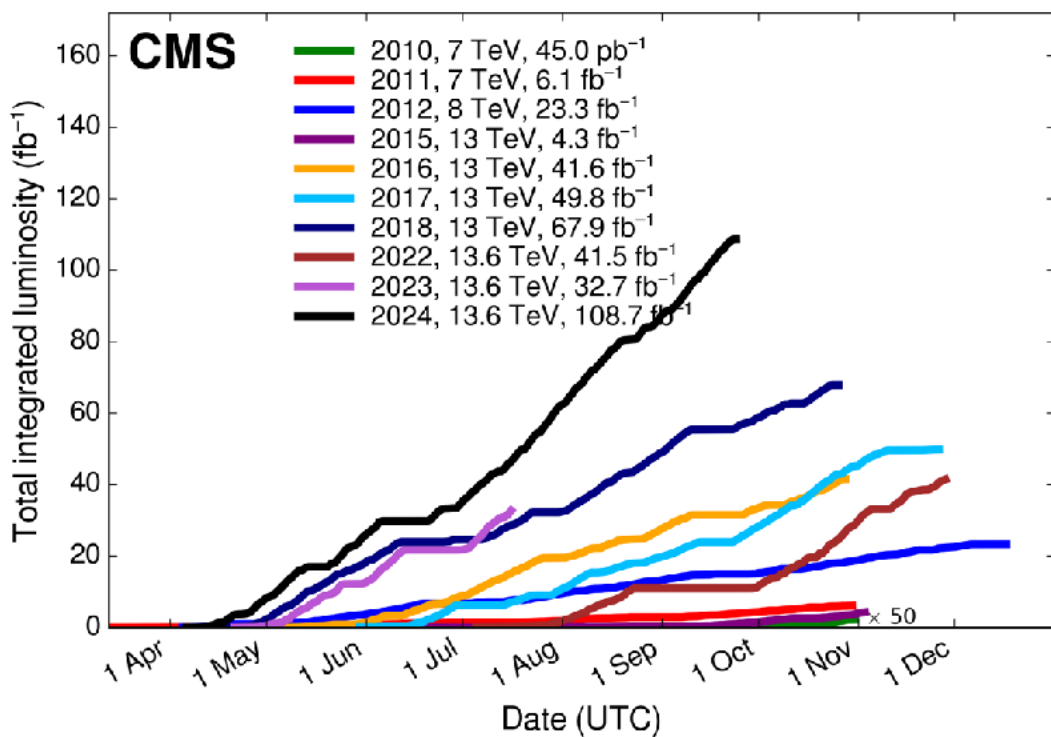
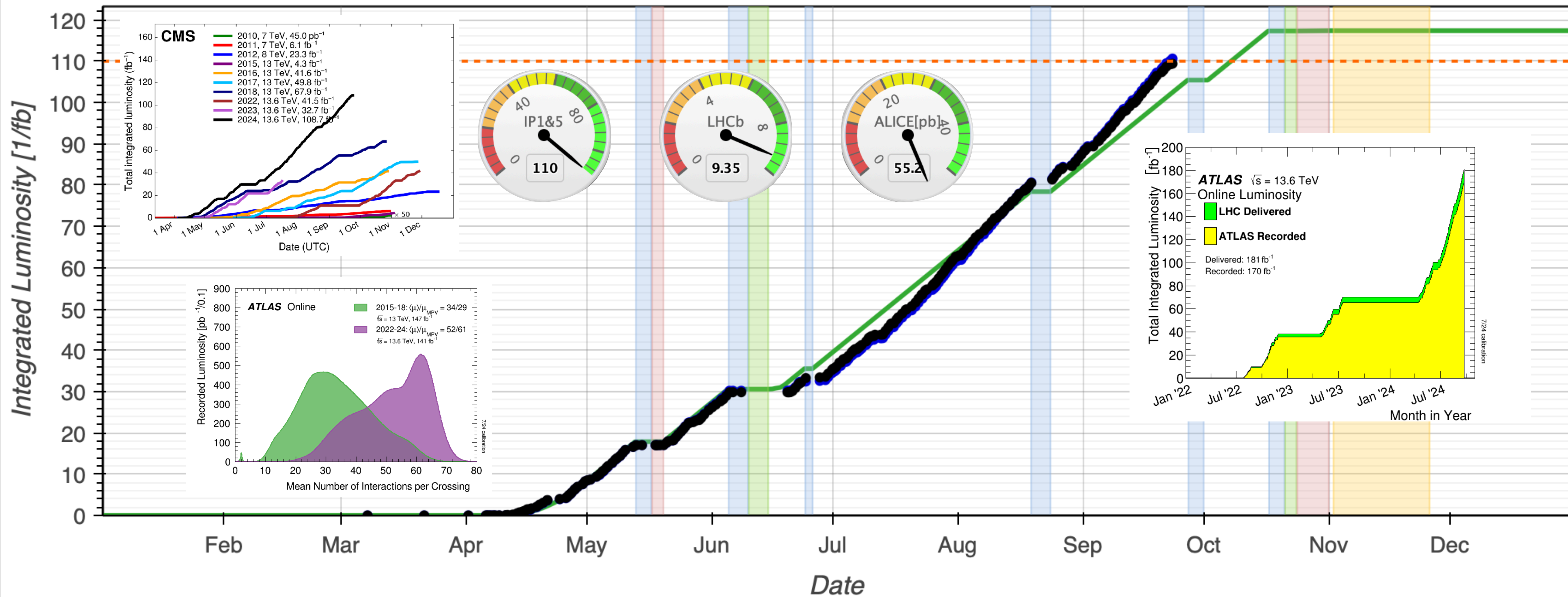




HL-LHC

LHC Run 3

— Predicted
 ● ATLAS Achieved
 ● CMS Achieved
 - - - Target



Goal of HL-LHC upgrade project

HL-LHC operations

O. Brüning @ Higgs Hunting Workshop, Paris, 25th September 2024

- Prepare machine for operation beyond **2025 and up to ~2040**
- Operation scenarios for:
 - Total integrated luminosity of **3000fb⁻¹ to 4000fb⁻¹** in around 10-12 years [ca. 10x LHC]
 - An integrated luminosity of **~250 fb⁻¹ per year**
 - Nominal: levelled luminosity of **5 x 10³⁴ cm⁻²s⁻¹** (events/crossing ~130)
 - Ultimate: levelled luminosity of **7.5 x 10³⁴ cm⁻²s⁻¹** (events/crossing ~200)
- Operation with levelled luminosity!

HL-LHC LS3 Schedule

Warm-up and related tests

Q4 2025

LSS dismantling after cryo lockout

Cabling dismantling

Core excavation (LHC side)

Cabling installation

LSS installation

MQXFA installation planned for Q4 2027 to Q4 2028

RFD installation planned for Q1 to Q2 2028

Cool-down, related test and HWC

O. Brüning @ Higgs Hunting Workshop, Paris, 25th September 2024

Q3 2029

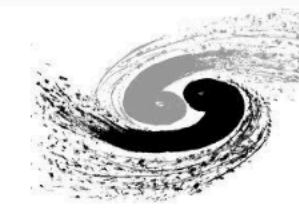
LS3 Schedule – TCC October 2023



The detectors and the accelerator complex have a packed schedule planned for the LS3 period.

Long Shutdown 3 (LS3) is going to be very busy!

Overall LS3 Schedule is under discussion.



New Inner Tracking Detector (ITk)

- All silicon with 9 layers up to $|\eta| = 4$
- Less material, finer segmentation
- Improve vertexing, tracking, b-tagging

New High Granularity Timing Detector (HGTD)

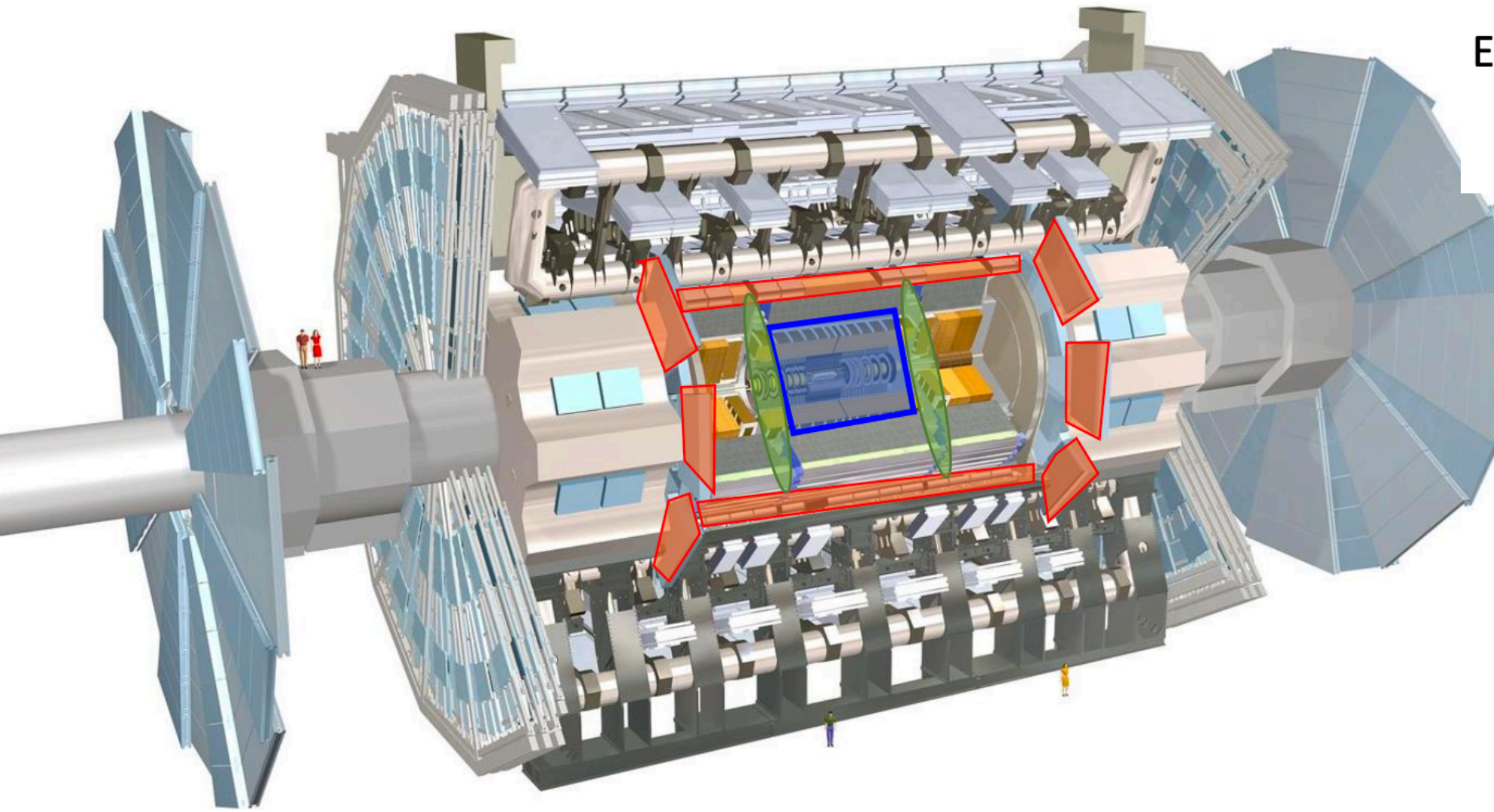
- Precision track timing (30 ps) with LGAD in the forward region
- Improved pile-up separation and bunch-by-bunch luminosity

Calorimeter Electronics

- On-detector/off-detector electronics upgrades of LAr and Tile Calorimeter
- Provide 40 MHz readout for triggering

New Muon Chambers and electronics

- Inner barrel region with new RPCs, sMDTs, and TGCs
- Improved trigger efficiency/momentum resolution, reduced fake rate



Upgraded Trigger and Data Acquisition System

- Single Level Trigger with 1 MHz output (x 10 current)
- Improved DAQ system with faster FPGAs

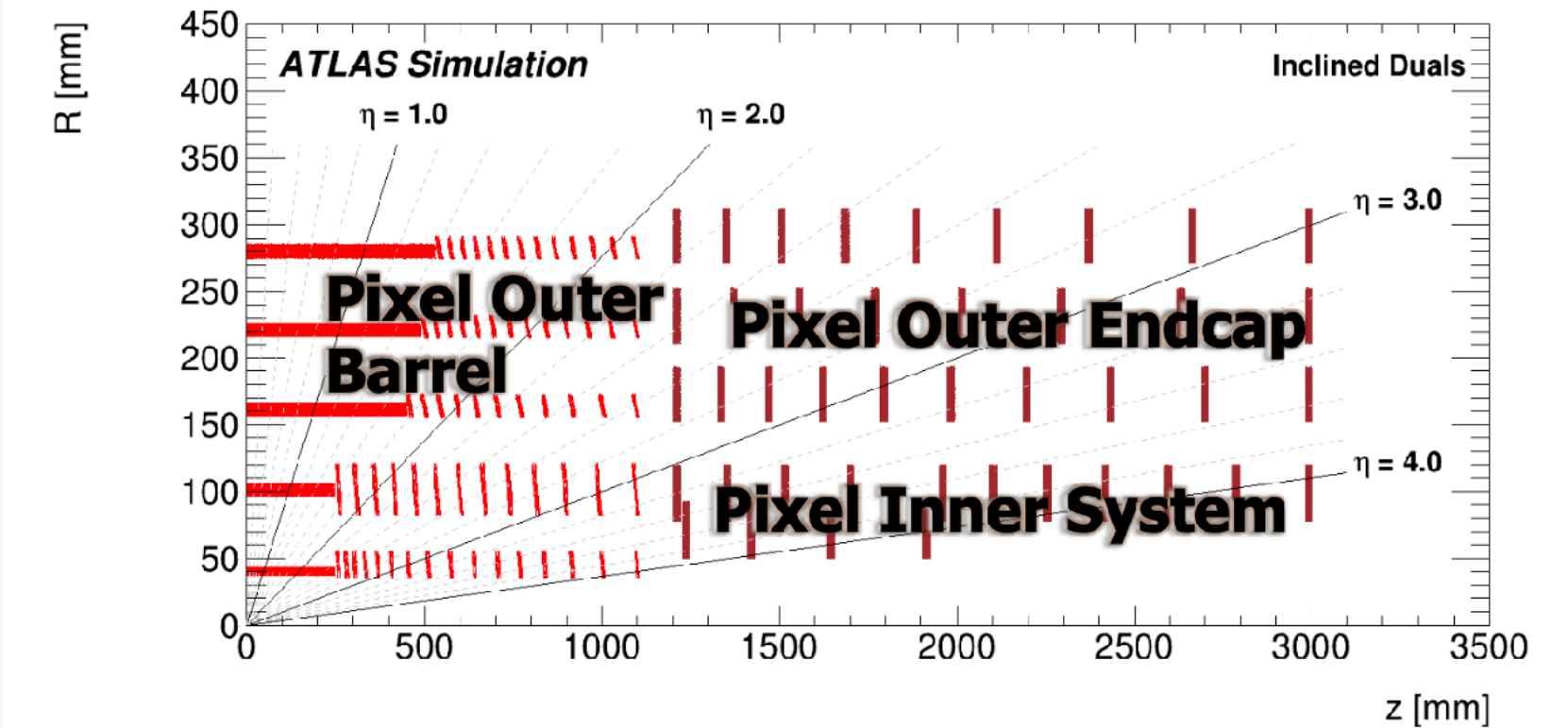
Additional small upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

Not covered in this talk!

Extended tracking acceptance up to $|\eta| = 4$:

- increased lepton reconstruction + jet flavour-tagging acceptance
- improved pile-up suppression



- Tracking to $|\eta| = 4$
- Timing ($2.4 < |\eta| < 4$)
- Trigger/DAQ upgrades
- Big increase in data rates and throughput

The HL-LHC programs challenges the detector and detector electronics

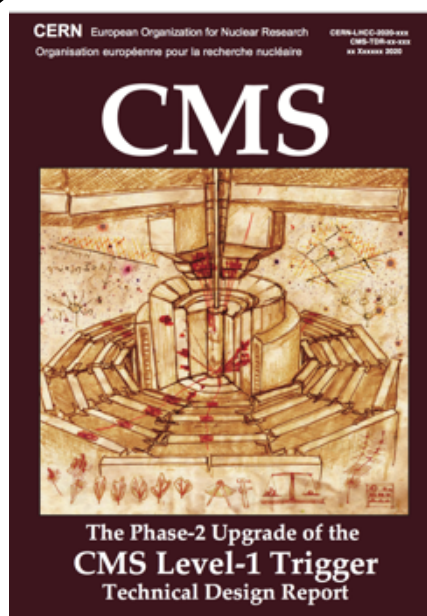
Higher luminosity => from $2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ up to $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Higher L1 trigger rates => from 100 kHz to 1 MHz

Higher pile-up conditions => from $\langle \mu \rangle = 55$ up to $\langle \mu \rangle = 200$

Increased radiation doses => about 20x increase up to a few MGy TID for 4000 fb⁻¹

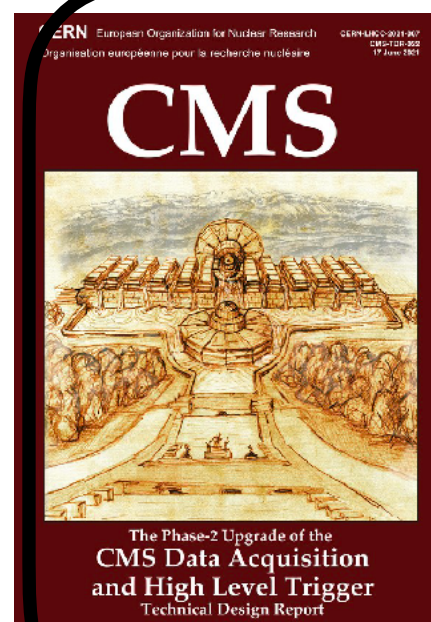
Overview of the CMS Upgrades for HL-LHC



L1-Trigger

<https://cds.cern.ch/record/2714892>

- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

<https://cds.cern.ch/record/2759072>

- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

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

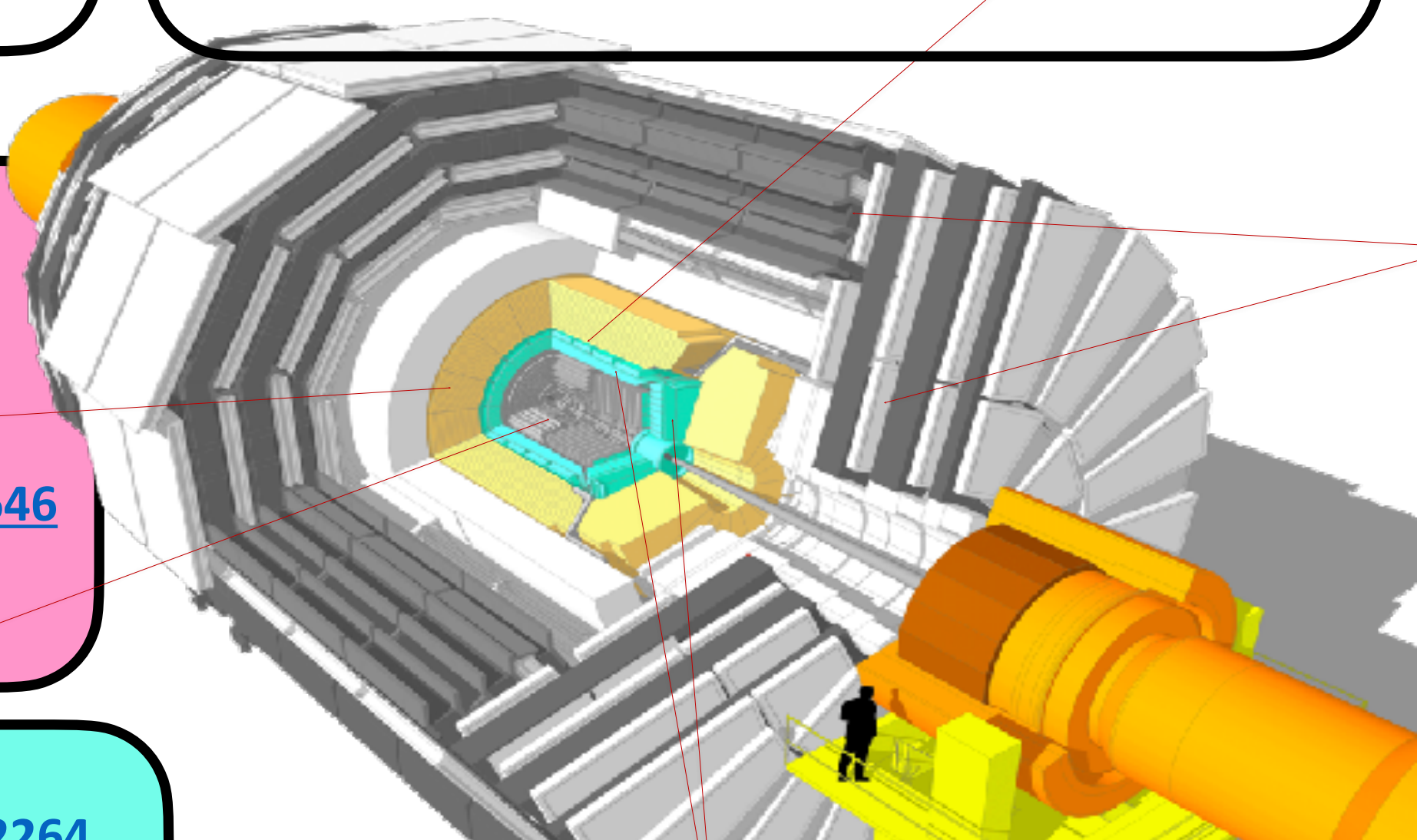
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Calorimeter Endcap

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

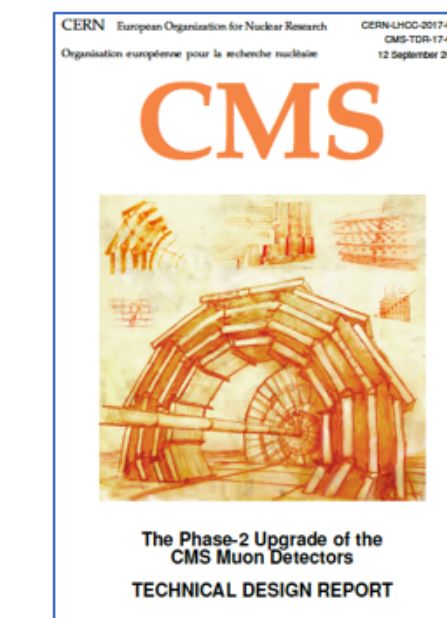
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



Muon systems

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

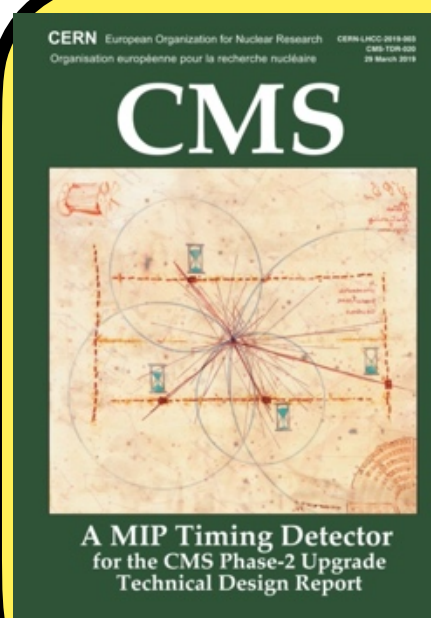
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$



Tracker

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

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



MIP Timing Detector

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

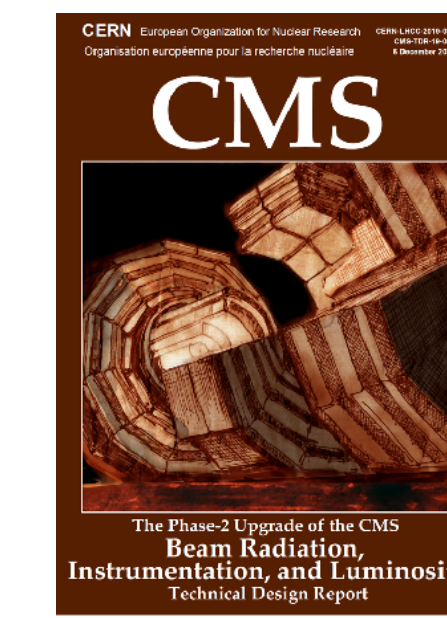
Precision timing with:

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

Beam Radiation Instr. and Luminosity

<http://cds.cern.ch/record/2759074>

- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors



What's next

Learning from data

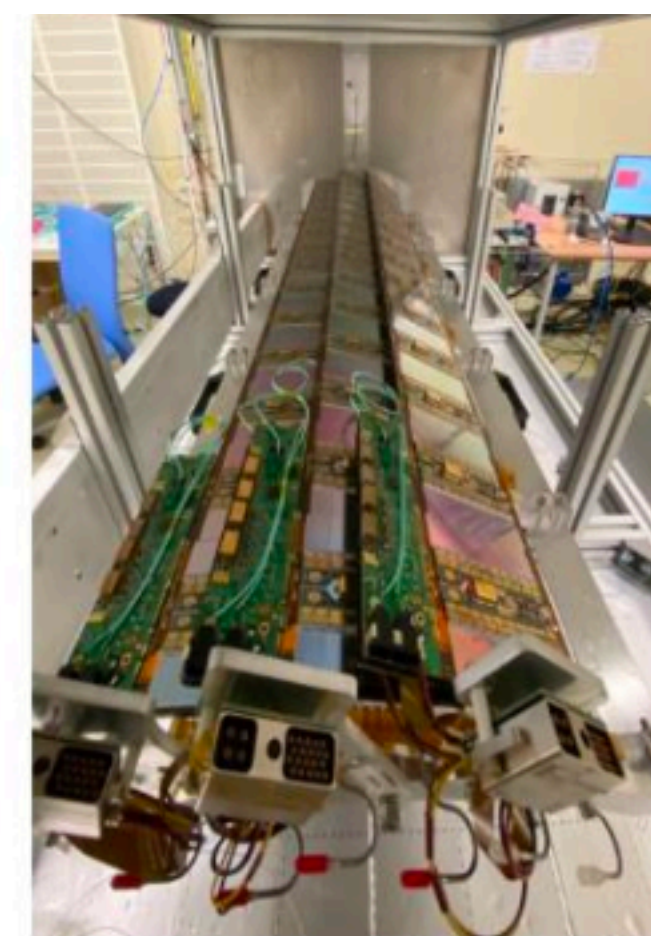
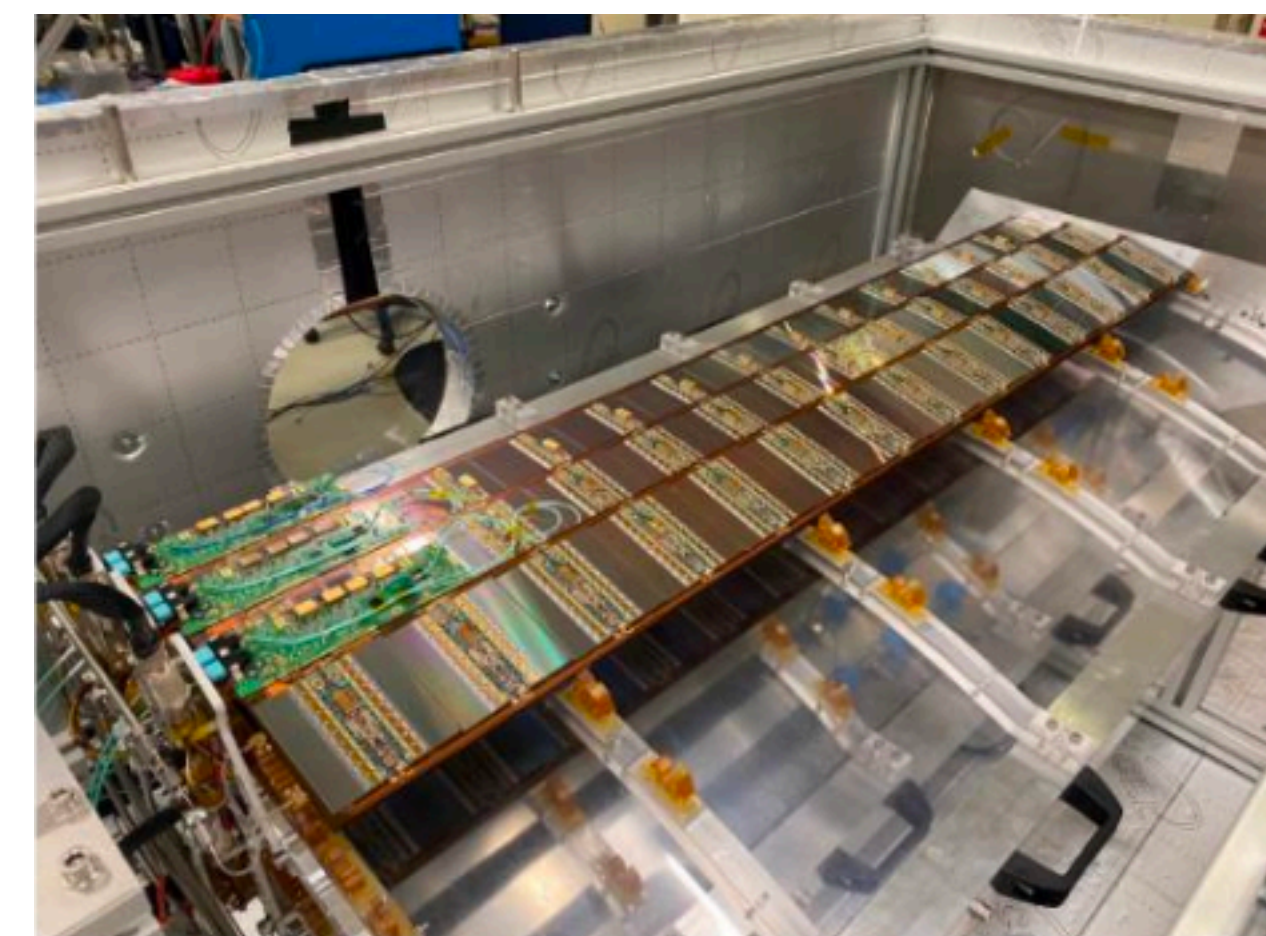
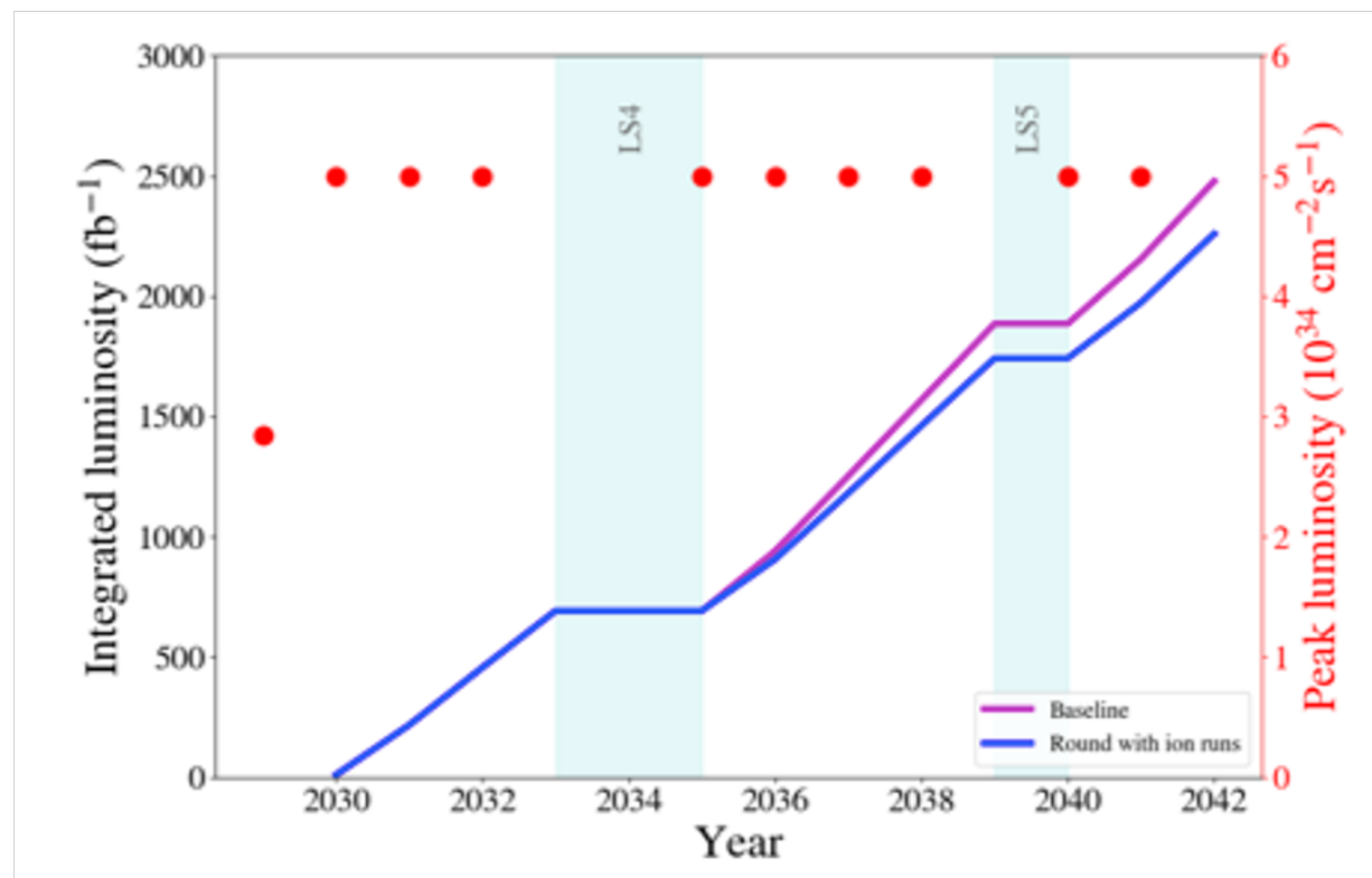
- Physics capabilities are outlined in detector TDRs, in Yellow Report studies for the previous European Strategy and in Snowmass studies.
 - Some new projections are being prepared for the next European Strategy Update. (Next second part of the session)
- One important lesson from Run 1 and Run 2 is that sensitivities improve greatly by working with the data.
 - Run 3 integrated luminosity has recently surpassed Run 2 so we can expect lots of improvements and innovations - new triggers, new ideas and building on Run 2 algorithms and taggers.
- HL-LHC will be a challenging environment - still some unknowns: 200 PU? 14 TeV?

Upgrades for HL-LHC

- The ATLAS and CMS detector upgrades for the HL-LHC are entering production (mostly at the module level); no clear showstoppers at this moment, but lots of interesting challenges before steady state production
 - **The detectors must be ready and commissioned for the start of Run 4.**
- European strategy preparation- **What can we learn from 3000 fb⁻¹ ?** (big picture)
- **The HL-LHC program must be successful!**



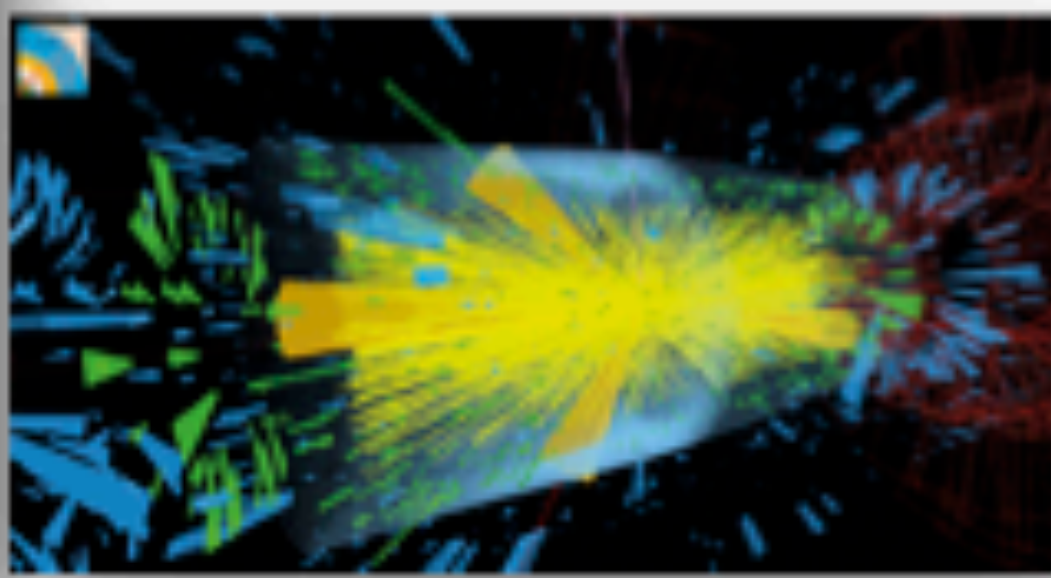
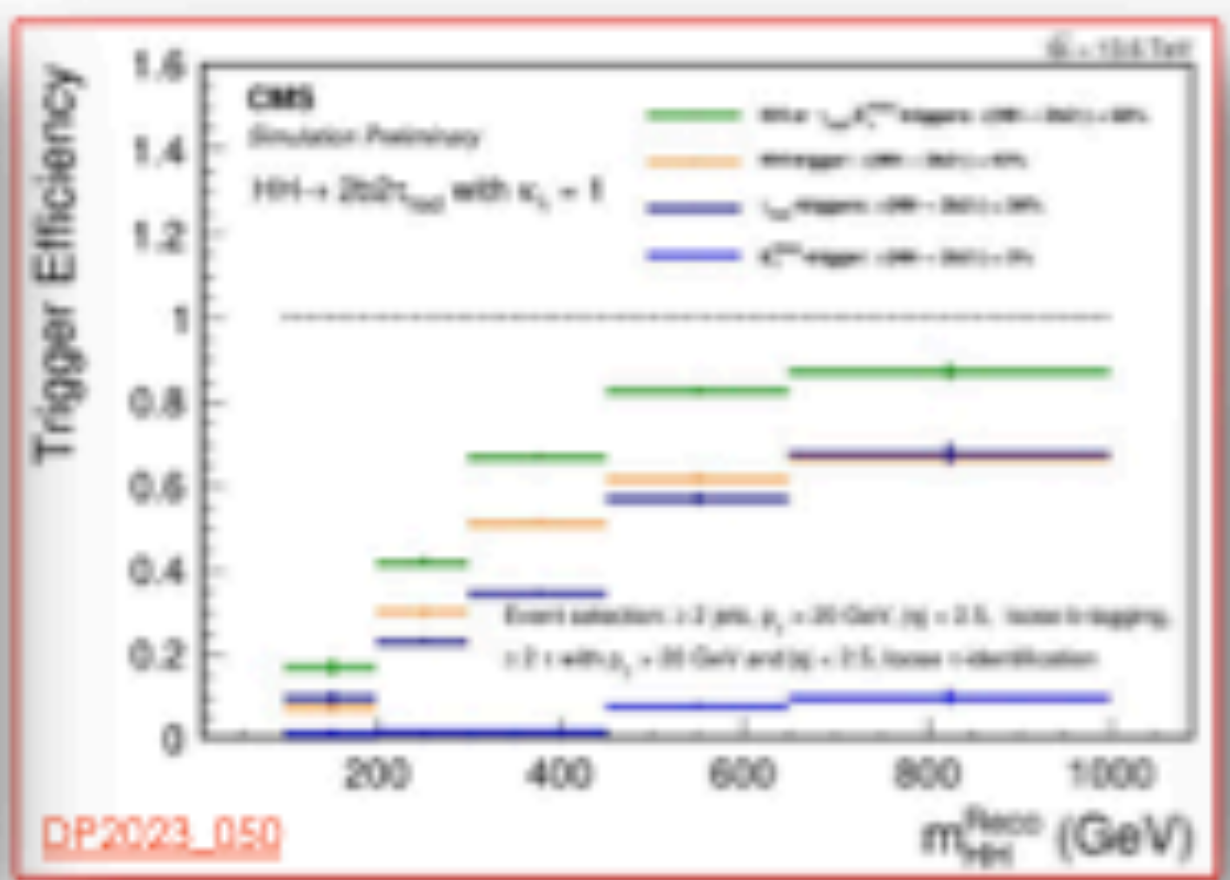
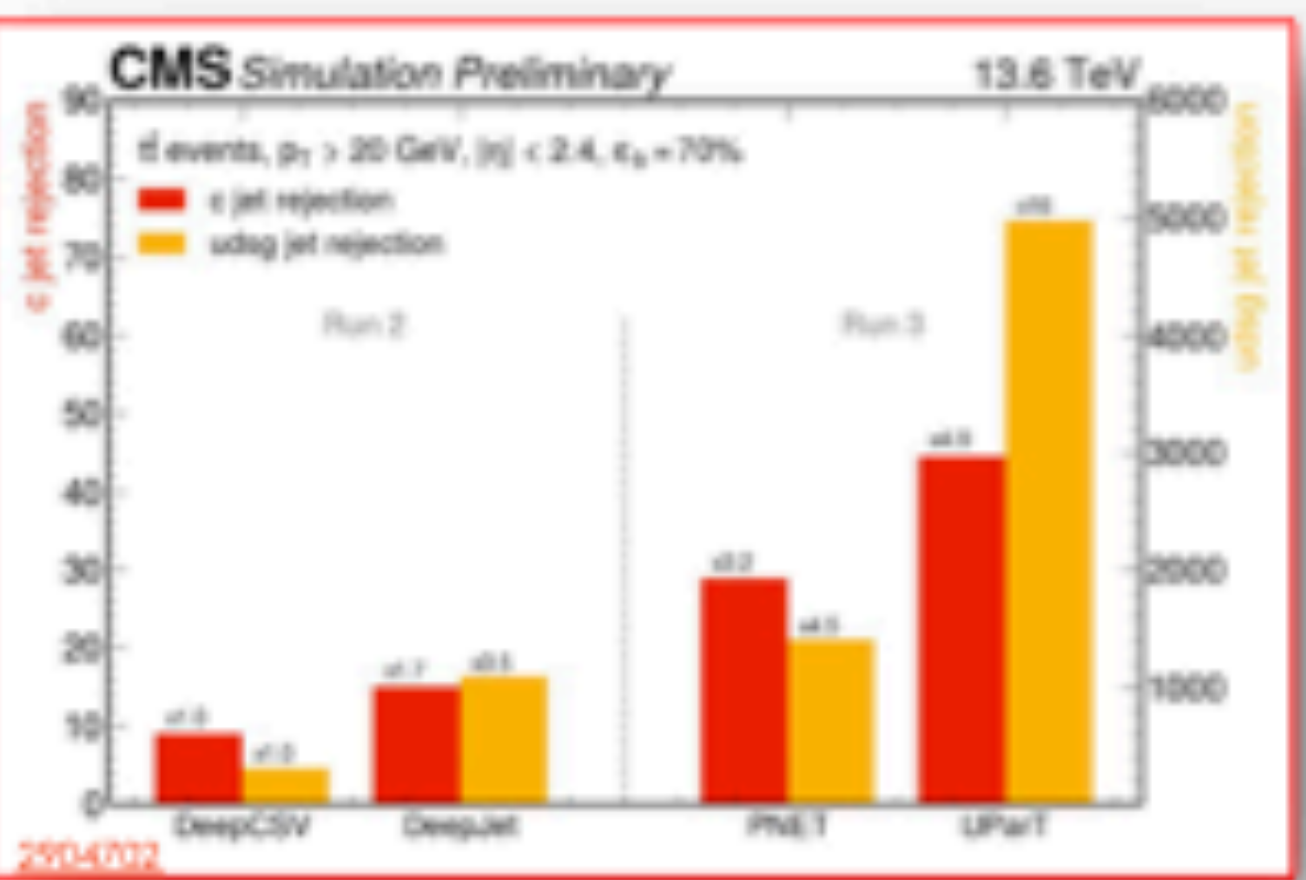
CMS HGCAL



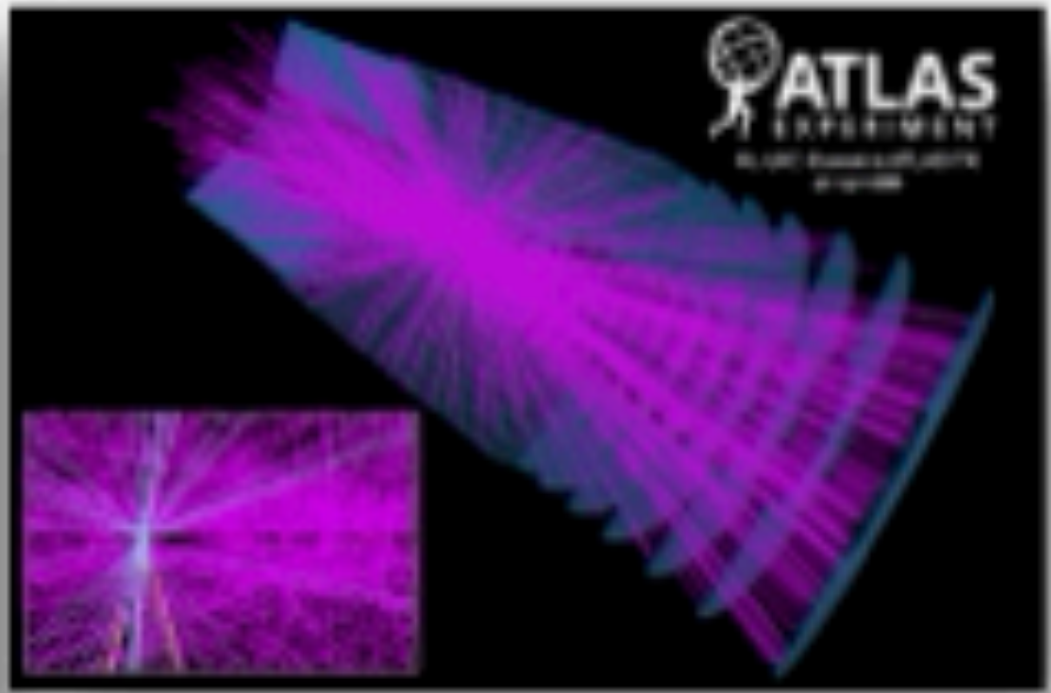
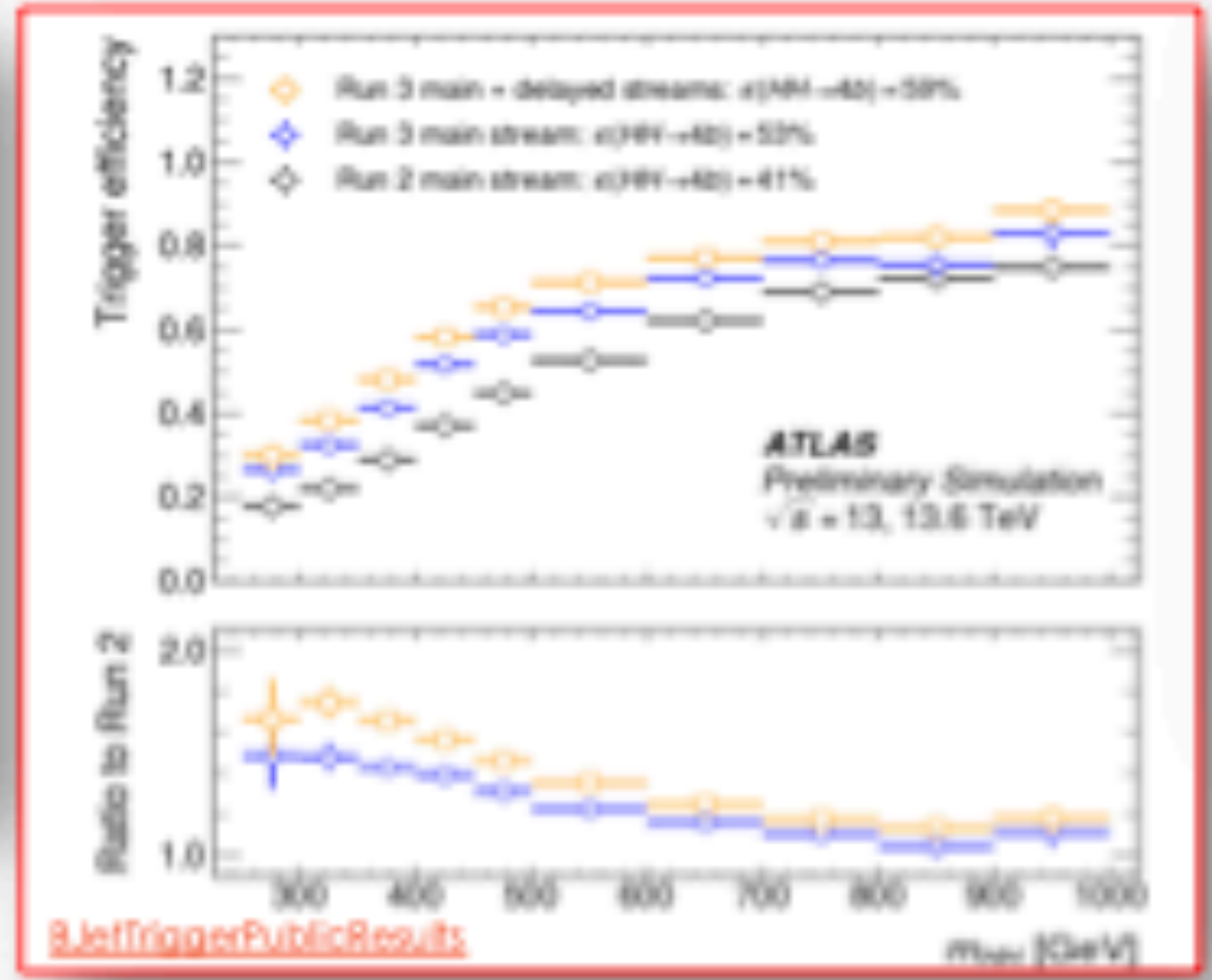
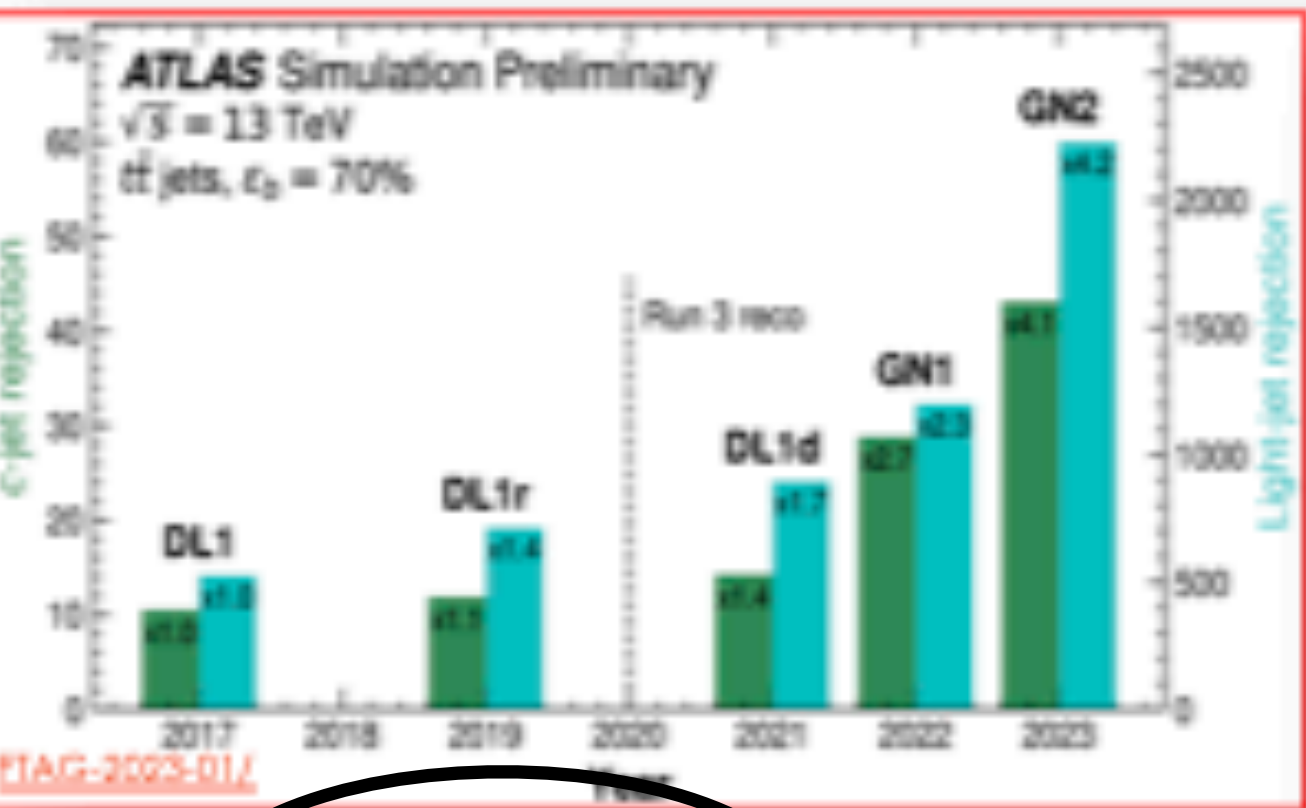
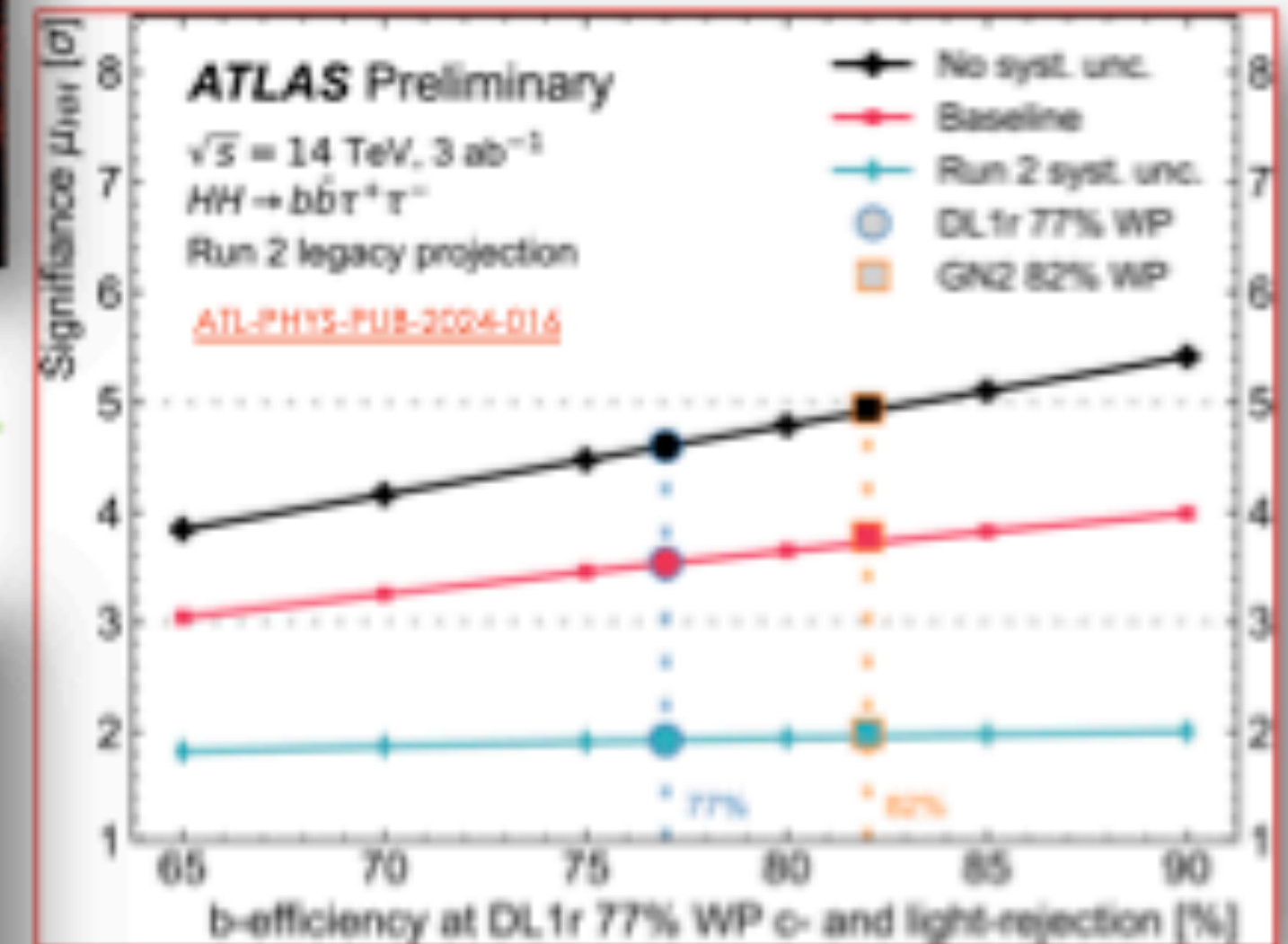
ATLAS ITK

WHAT'S NEXT?

Impressive improvements in flavour tagging (resolved and boosted) & very promising hadronic triggers



Where will new technologies and new algorithms take us during HL-LHC?



Theory improvements also key, "baseline" assumes th. uncertainties halved!

V.M.M.CAIRO

We will come back to this in the next talks