The CMS Experiment
- Upgrades in Phase 1 -

Untertitel durch Klicken bearbeiten

Stay tuned to Explore the Unknown

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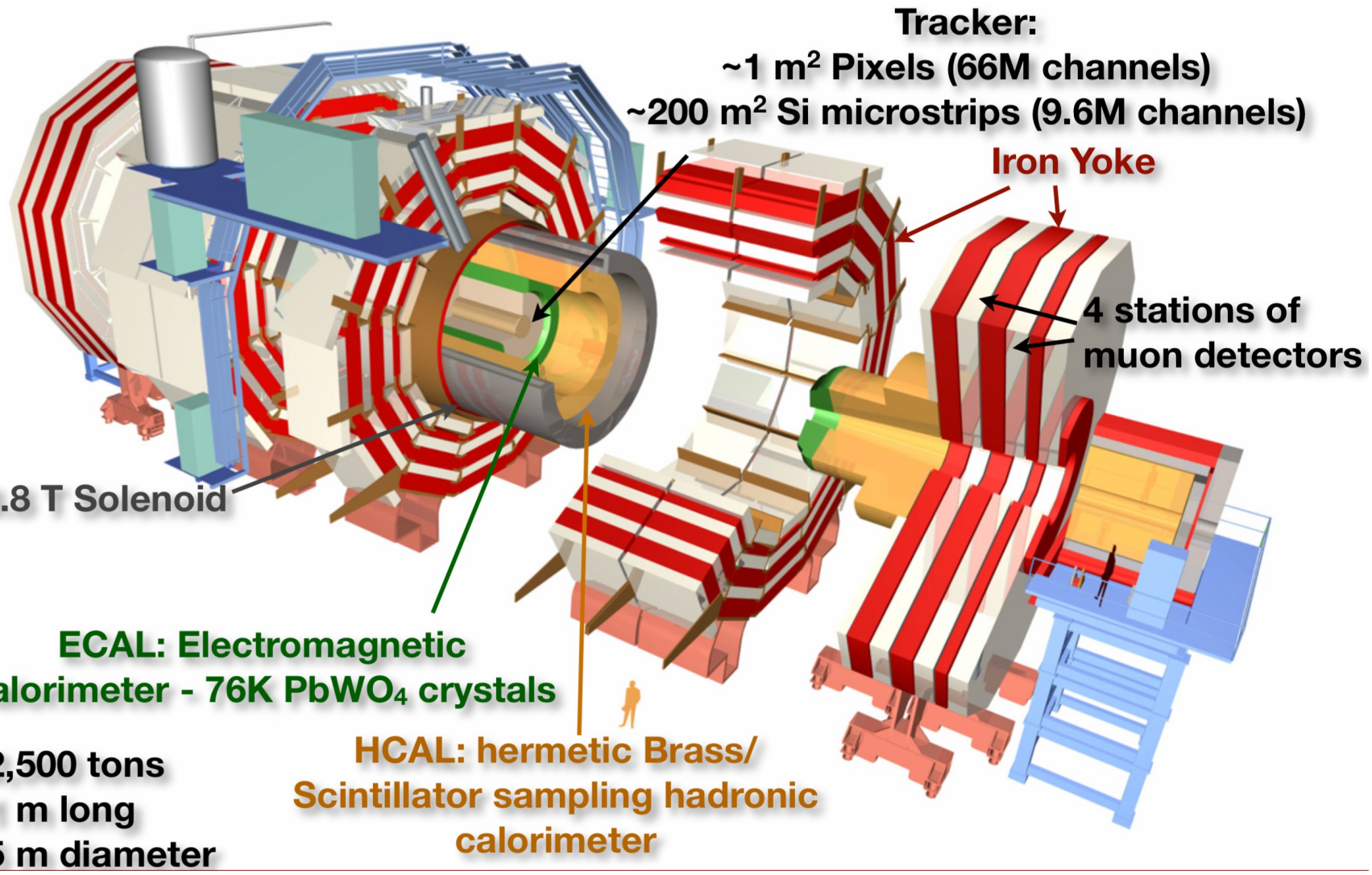
RWTH Aachen

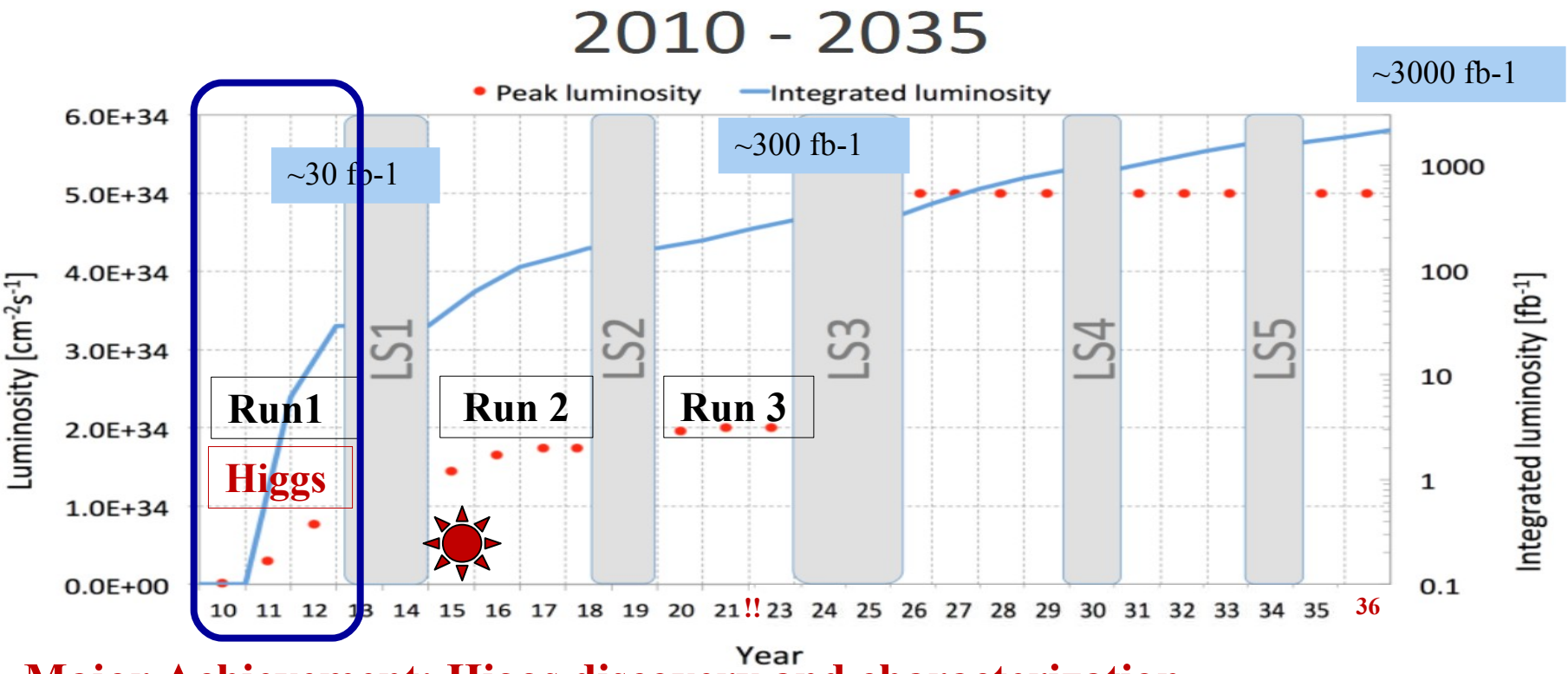
The CMS Collaboration

Many: 5000 members, 1900 physicists,
1800 students,
950 eng./ techn.
Global: 200 institutes from 43 countries
One Goal:
Unveil what our Universe is made of !

The CMS Experiment



The Harvest of Run 1



Major Achievement: Higgs discovery and characterization

- → **Mass, spin, coupling**

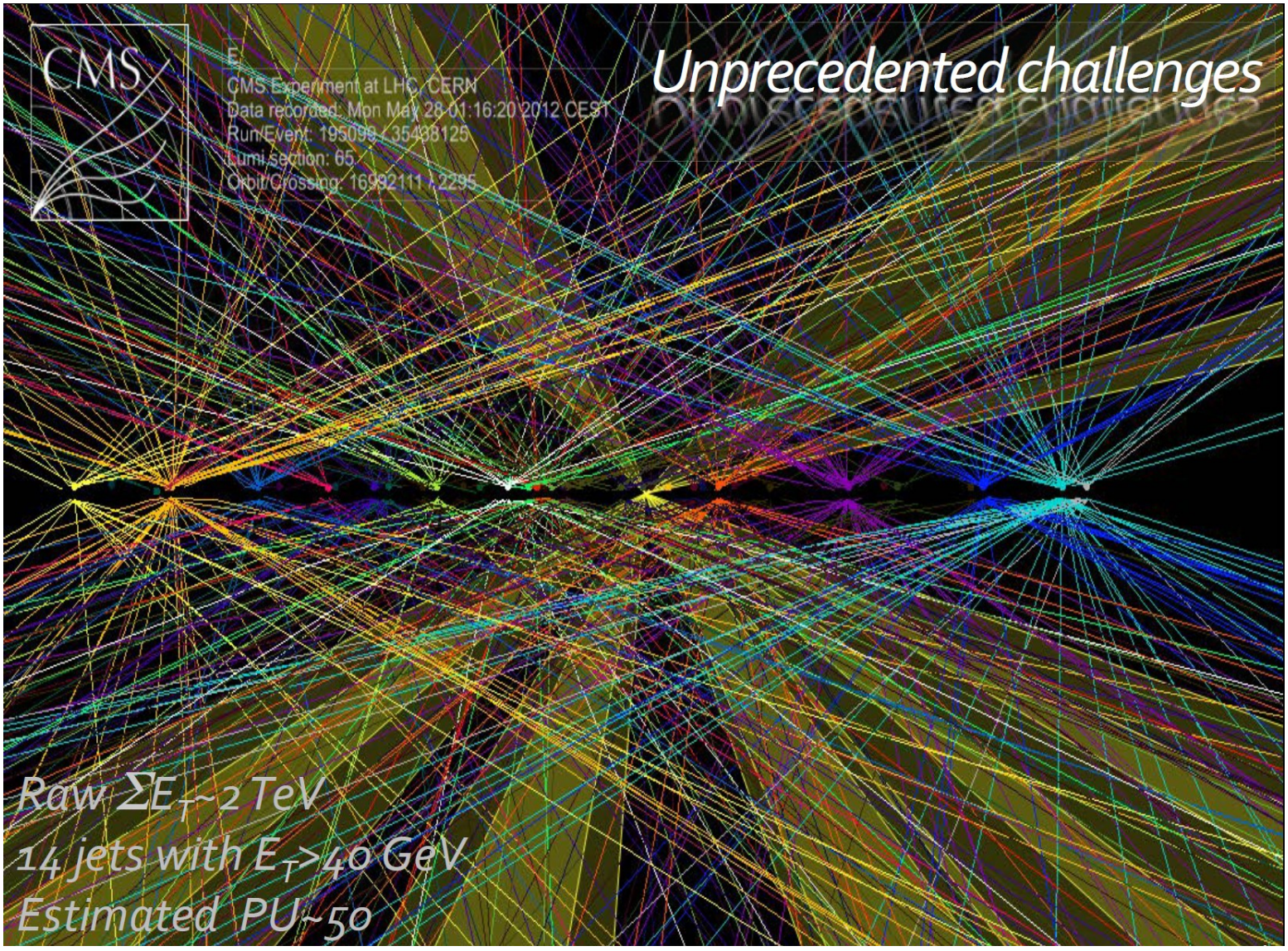
Top Quark: LHC is a top quark factory

- → **High statistics for precision measurements: mass, decays,…**

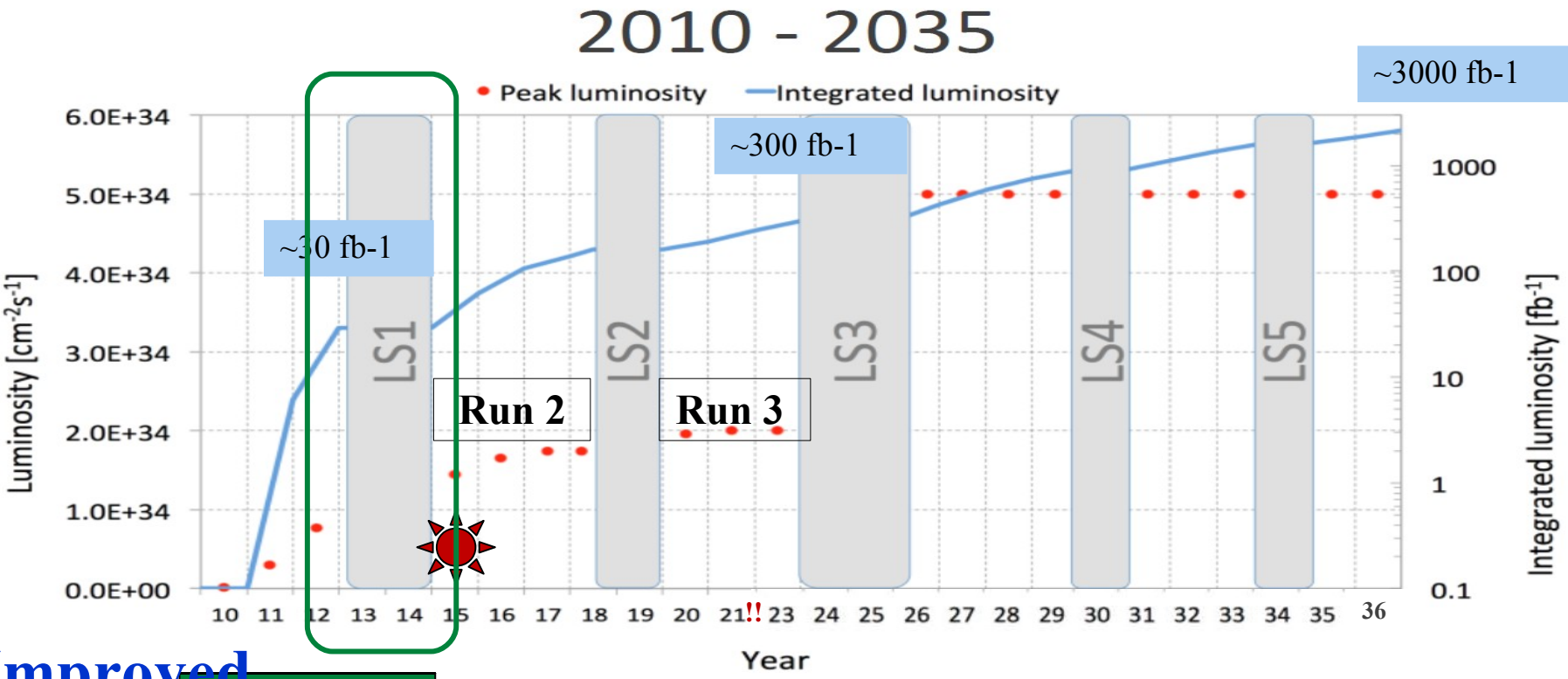
Searches for SuSy and other exotic particles beyond the SM

- → **Many limits for masses and couplings set.**

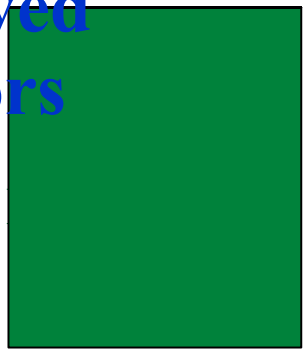
Unprecedented Challenges in Run 2



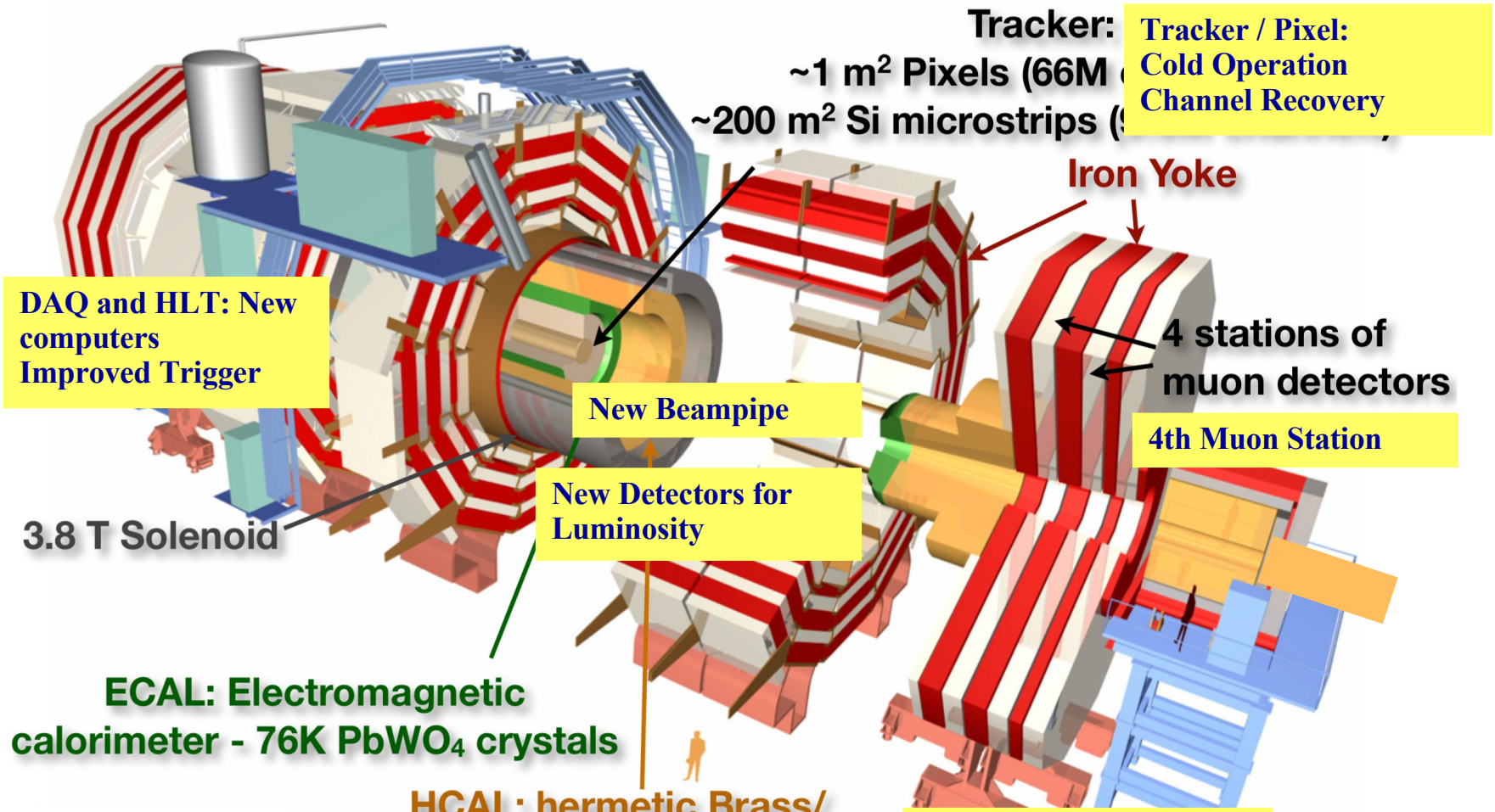
Work in Long Shutdown 1



Improved detectors



CMS after Long Shutdown 1

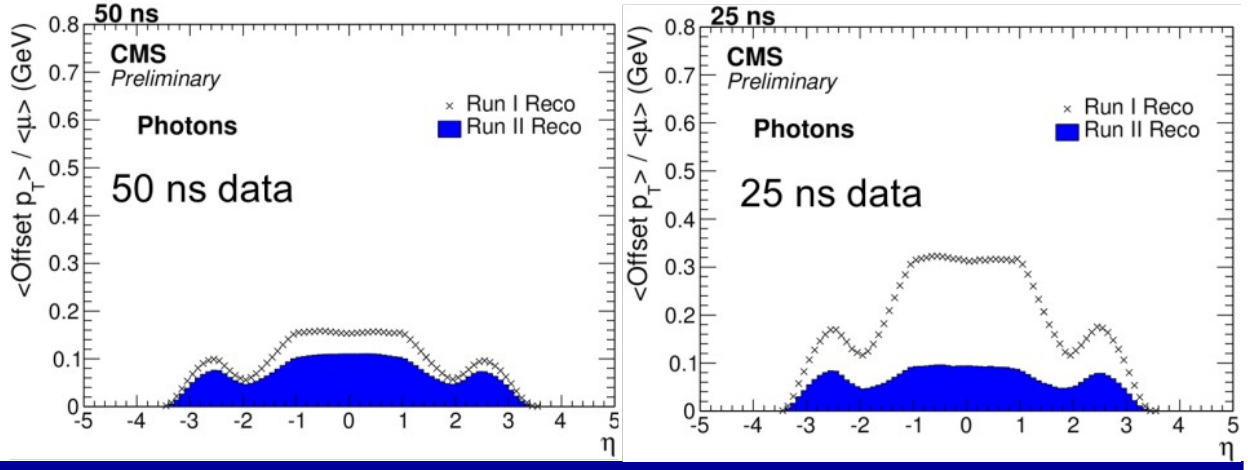


14,000 tons
21 m long
15 m diameter

Reconstruction

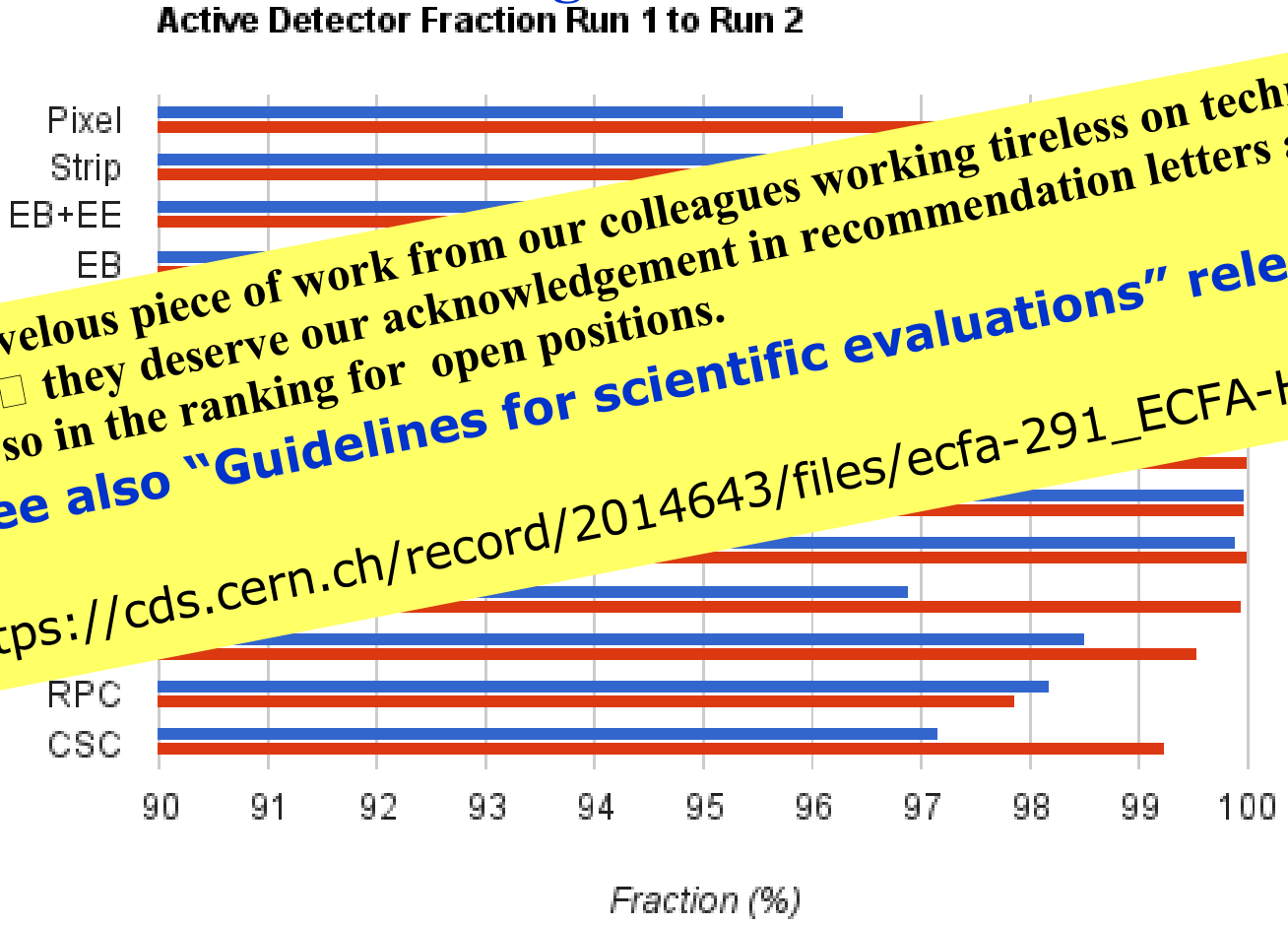
- Significant effort on algorithm improvements with emphasis on PU mitigation
  - A lot of ideas from the upgrade studies
  - Improvement on track reconstruction
  - Out of time PU mitigation in the calorimeters
  - Pulse fit in ECAL/HCAL to extract the in-time energy per cell
  - Revisiting of Particle Flow event reconstruction
- Improvements evaluated on 8 TeV data by re-reconstructing them with new algorithms

Photon Reconstruction



Detector Commissioning

- All sub-detectors ready for data-taking
- Active channel fraction higher than Run 1

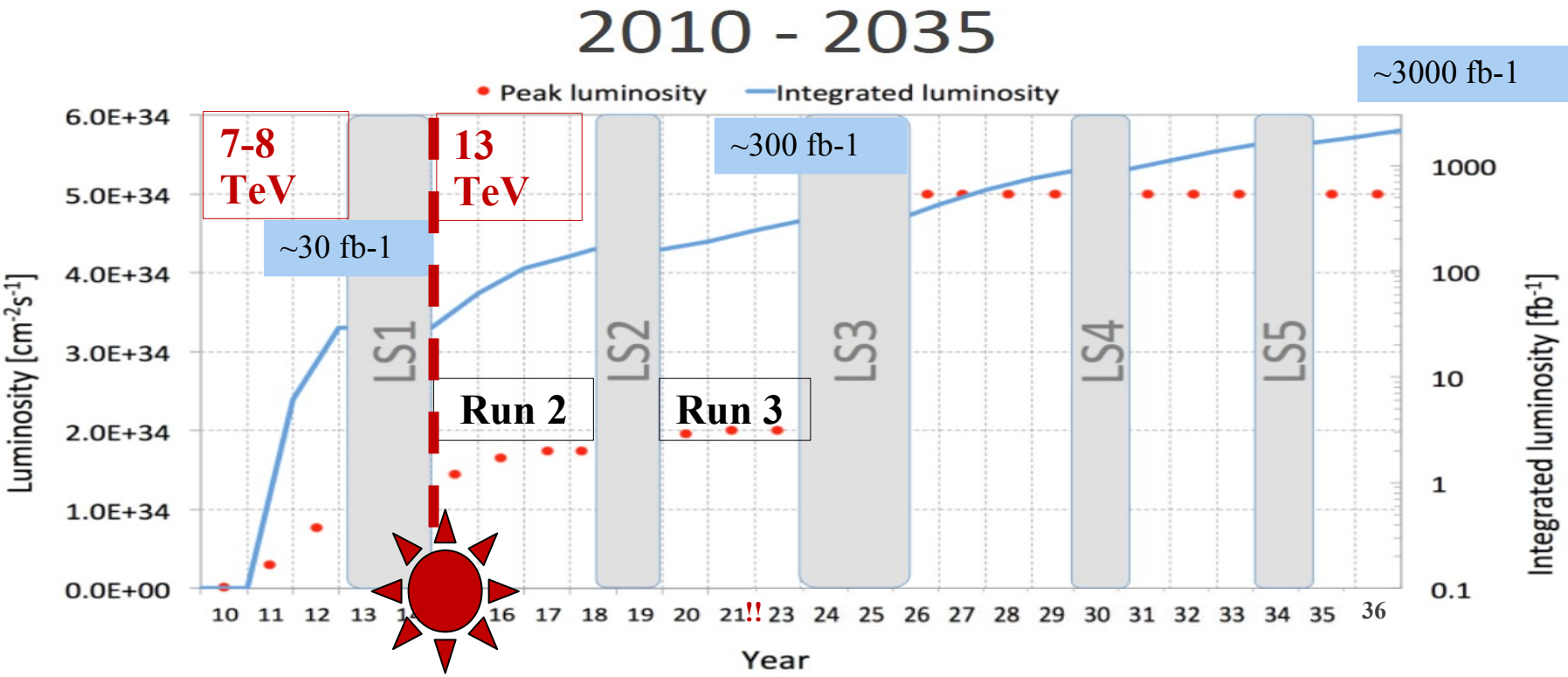


A marvelous piece of work from our colleagues working tireless on technical items they deserve our acknowledgement in recommendation letters and even more so in the ranking for open positions.

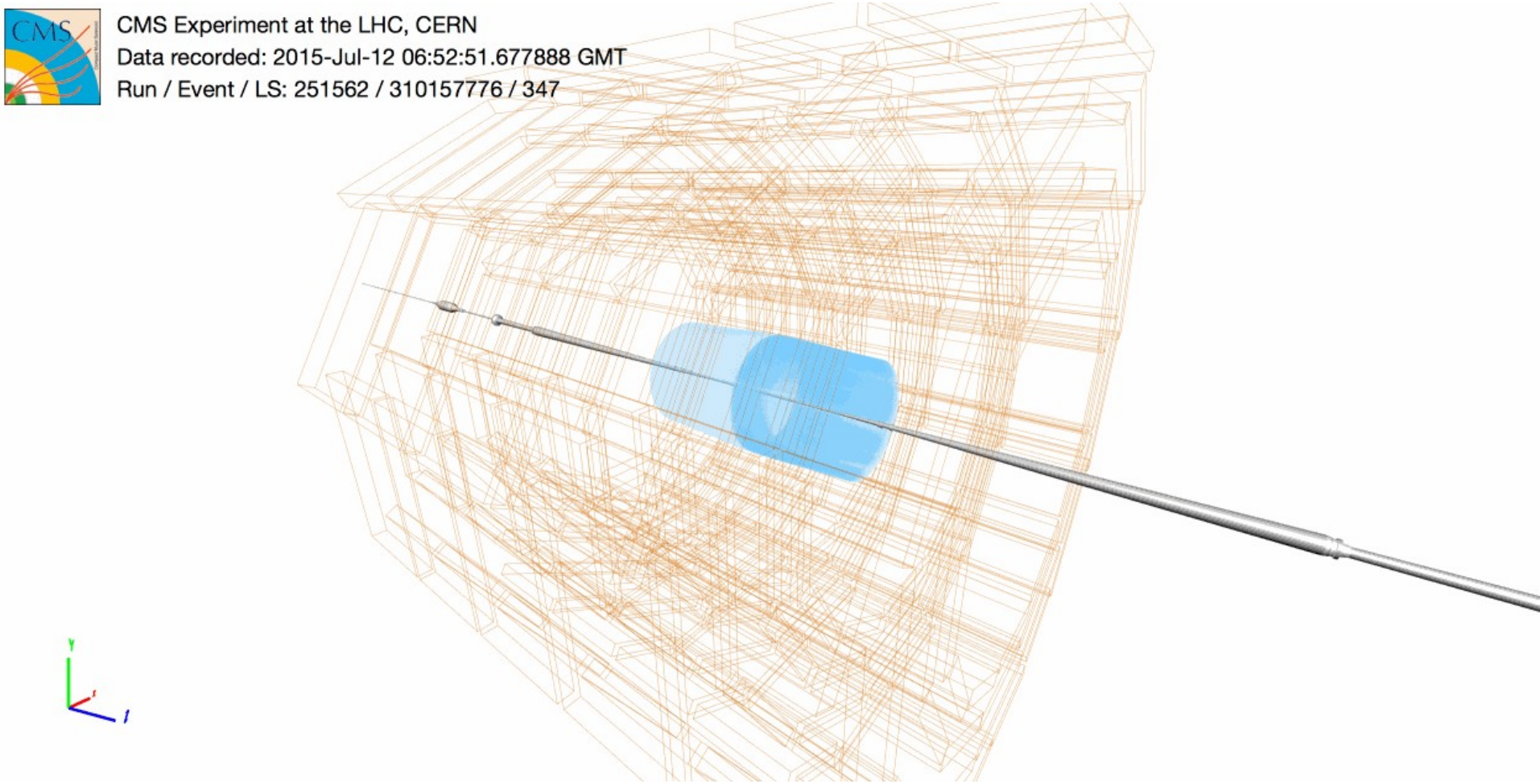
See also "Guidelines for scientific evaluations" released by ECFA

https://cds.cern.ch/record/2014643/files/ecfa-291_ECFA-HEP-evaluation.

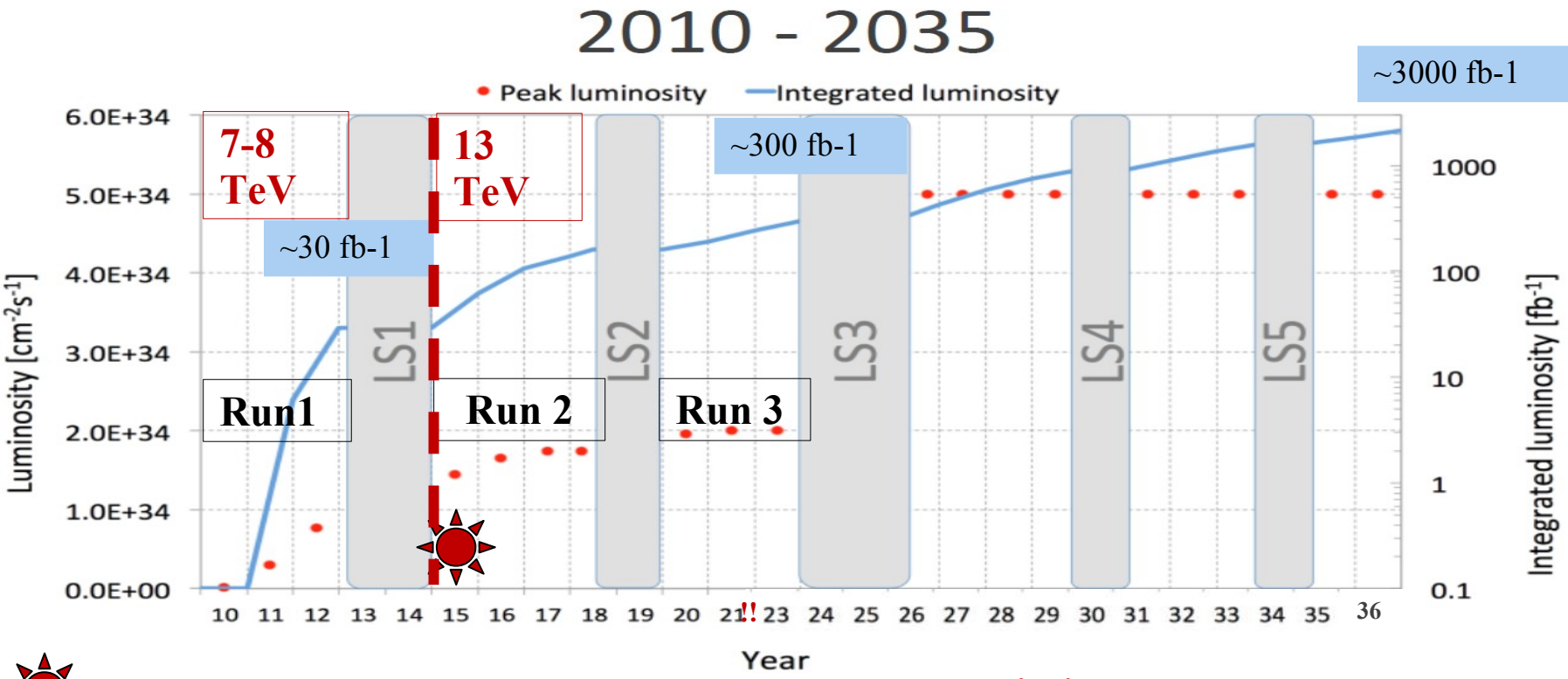
Start of Run 2



Di-Jet Event with Mjj ~ 5.4 TeV



What Next ? Future @ LHC



: new world-record energy and much more statistics

→ Opening the window to unexplored territories for much higher masses of unknown particles and forces

→ New Physics

→ Dark Matter ? SUSY ? Extra-Dimensions ?

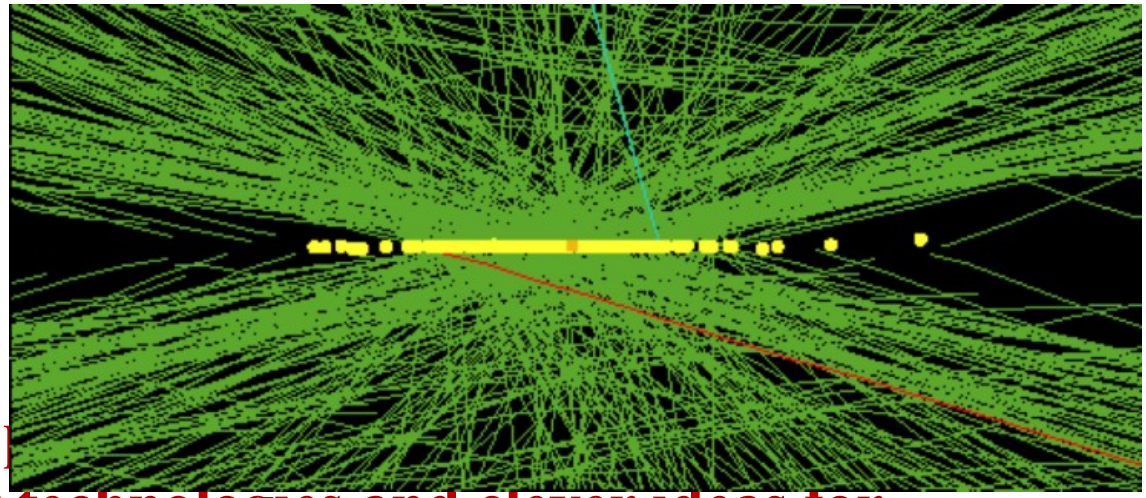
→ Precision measurements of the Higgs, top, …

Challenges @ LHC

- Highest Energies
- Intense Beams

] extreme particle flow

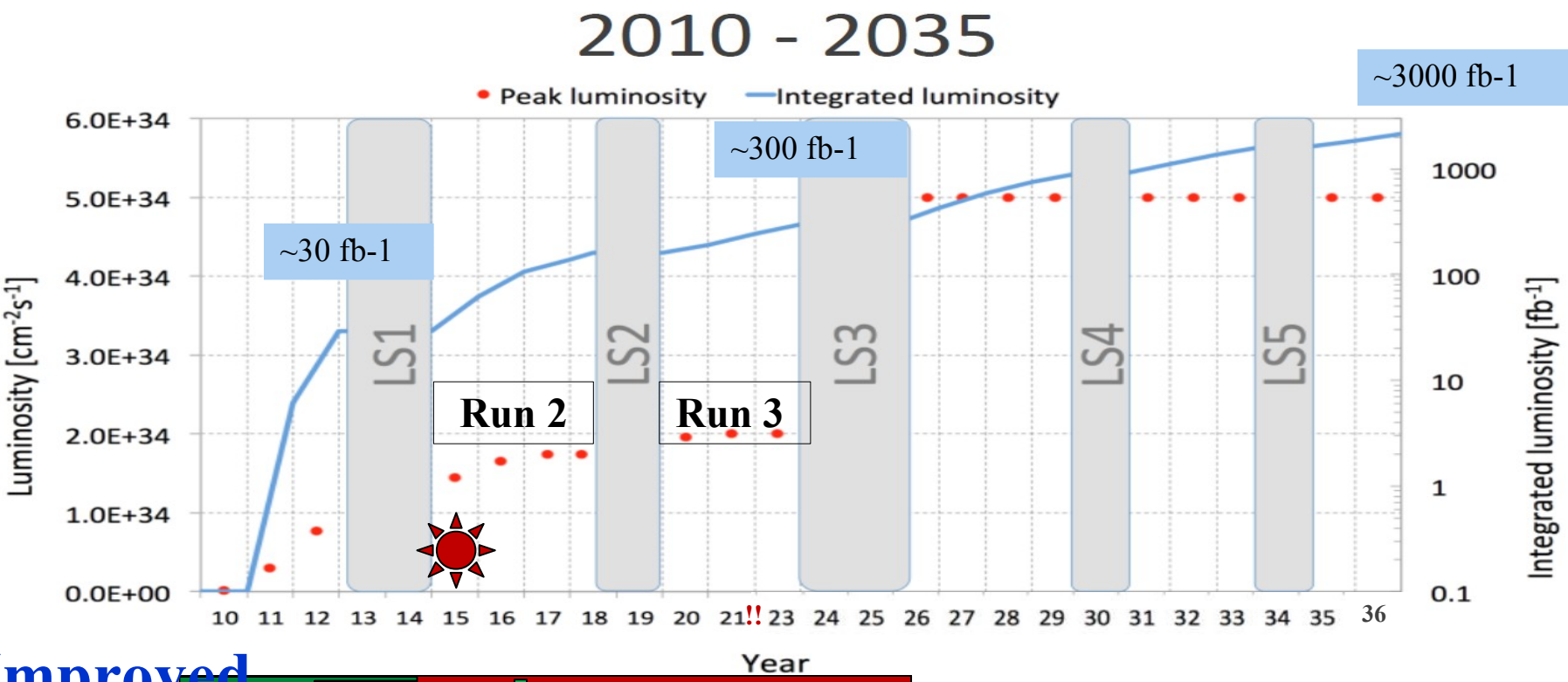
  - Pile up 20 □ 50 □ 200 □ complex analyses
  - Extreme radiation hardness of detectors
  - Extrems high readout rate (DAQ, Computing)



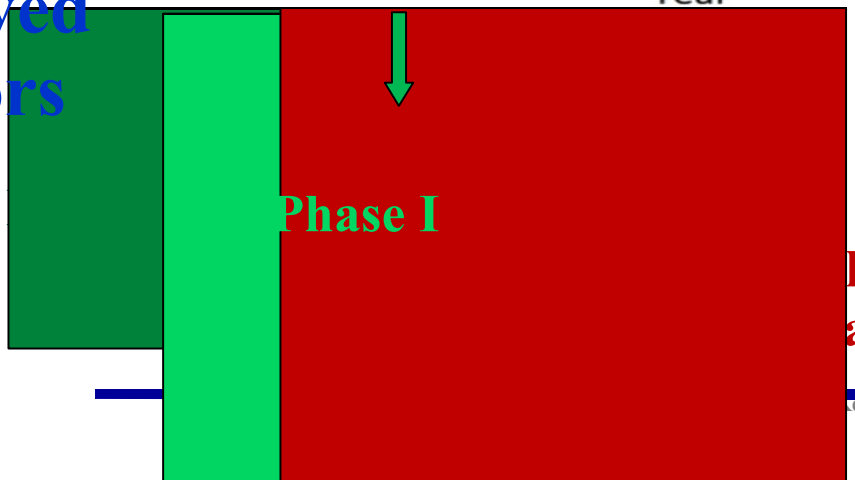
- Need to

new technologies and clever ideas for detectors, computing, analyses

Future @ LHC



Improved detectors



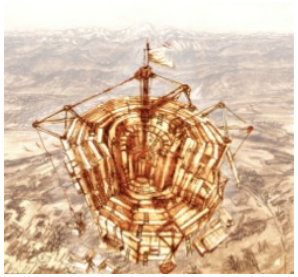
Physics studies, R&D application for funding

CMS Upgrade Goals and Strategy

LS1 **LS2** **LS3**

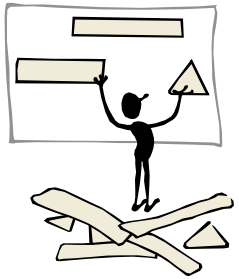
Complete original detector
Address operational issues
Start upgrade for high PU
ME4, Muon Trigger, Tracker cold,
HCAL Forward & Outer Readout
Many consolidations (DAQ2,…)

New Pixel
HCAL SiPMs (…HE)
L1 Trigger
GE1/1
Much more ….



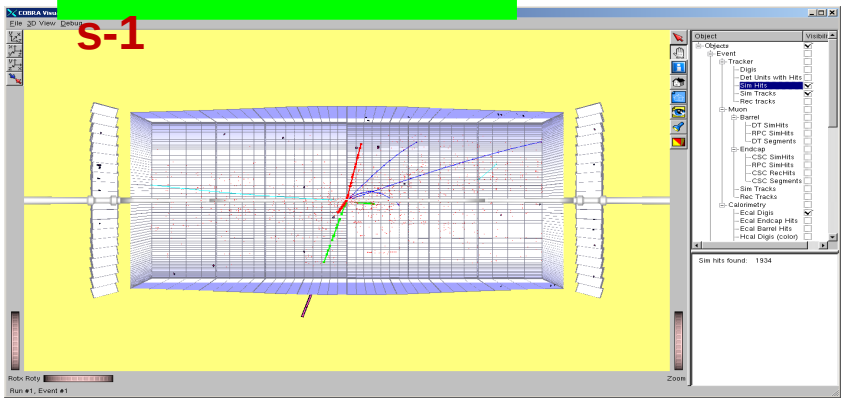
Maintain/Improve performance at extreme PU
Sustain rates and radiation doses:

- Tracker replacement/ Track Trigger
- End-Cap Calorimeter replacement
- Additional Muon chambers
- Possibly extension from $|\eta|=3$ to $|\eta|\sim 4$ (Tracker, EC Calo, Muon)
- Further Trigger/DAQ upgrade
- additionally: replacements, modifications in the infrastructure, Barrel ECAL Electronics upgrade, Barrel HCAL maintenance, BRIL, Computing, ...



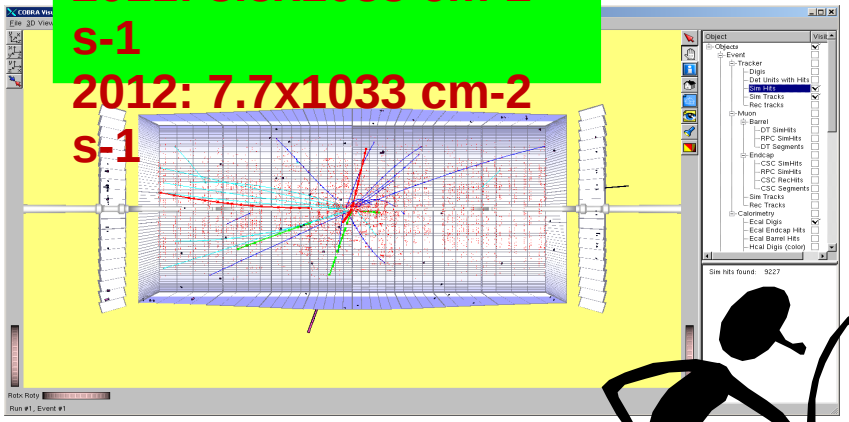
Challenges at the HL-LHC

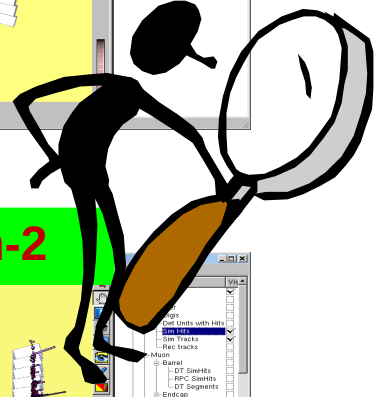
2010: 1032 cm-2 s-1



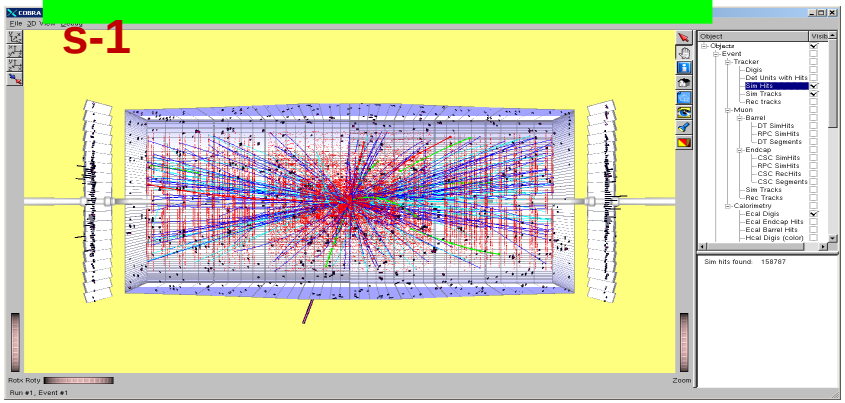
2011: 3.5x1033 cm-2 s-1

2012: 7.7x1033 cm-2 s-1

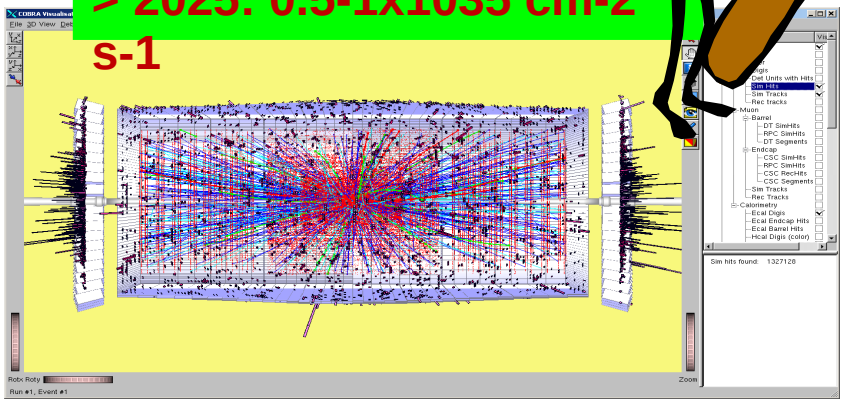




2015-2022: 2.5x1034 cm-2 s-1



> 2025: 0.5-1x1035 cm-2 s-1

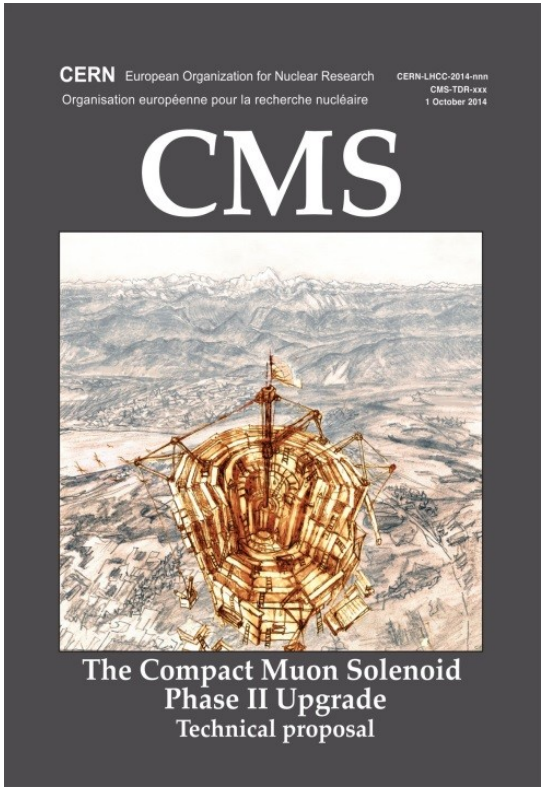


→ **Challenges for Tracking, Calorimetry and Triggering, in particular for low to medium pT objects need fine granular and radiation hard detectors, new strategies in Trigger and Software**

The Technical Proposal

- Demonstrates the motivation: detector longevity and performance issues at high luminosity
- Describes detector conceptual designs
- Presents supporting performance studies on physics objects, trigger and key physics signals
  - Baseline for studies is 5x1034 cm-2 s-1 and <PU> =140
  - Performance potential <PU> =200 with few selected studies

- Demonstrates that feasible solutions have been identified, and present plans for completion of necessary R&D
- Presents preliminary production cost
- Separately: Scope Document



CERN-LHCC-2015-010
https://cds.cern.ch/reco

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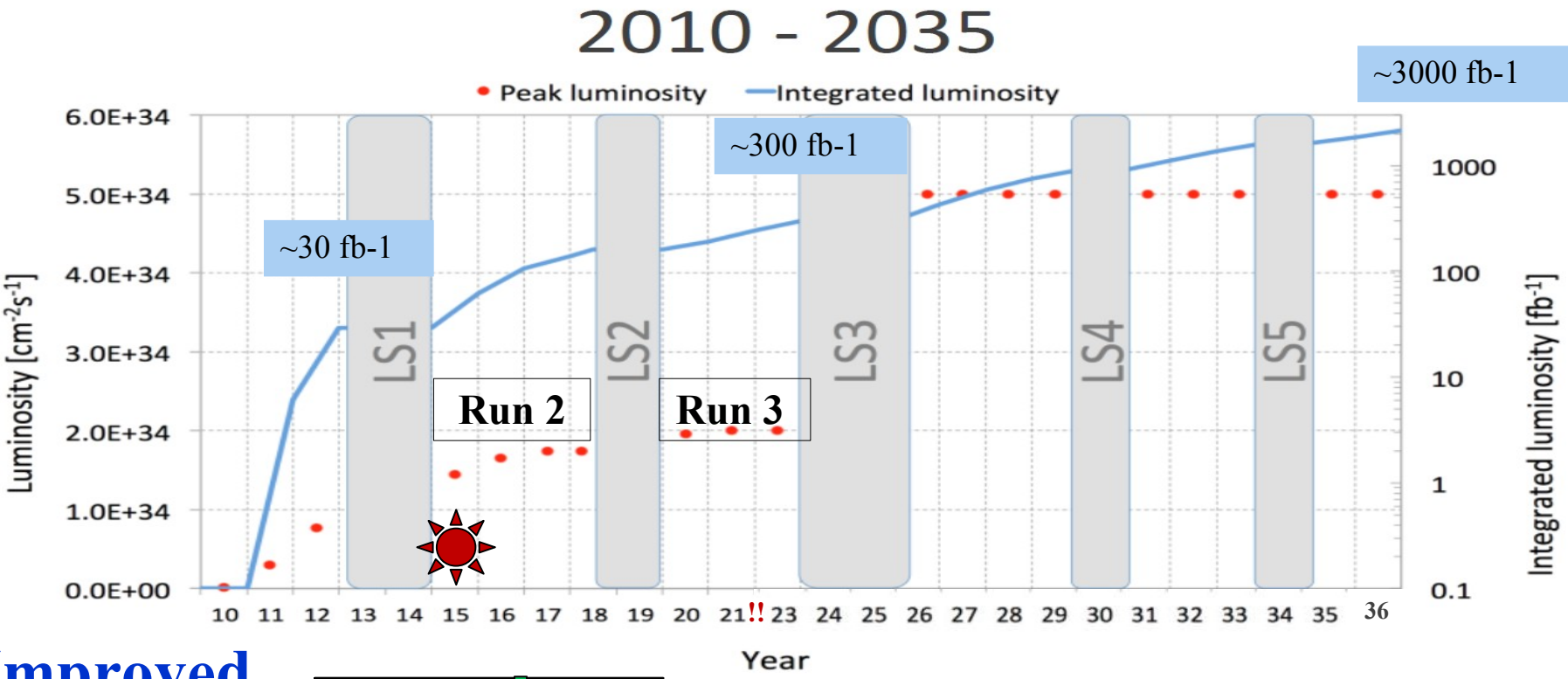
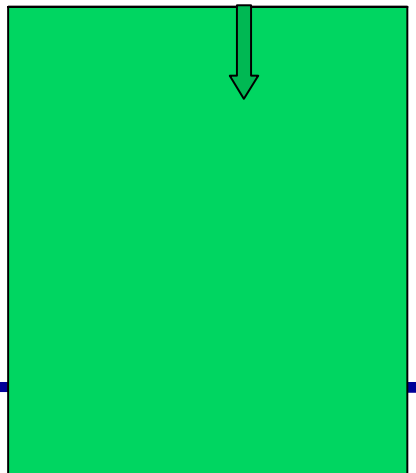
Future @ LHC - Phase I Upgrade



Improved detectors

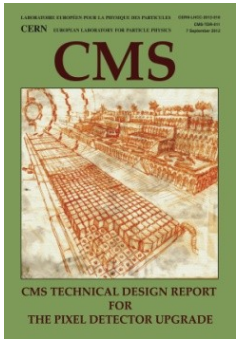


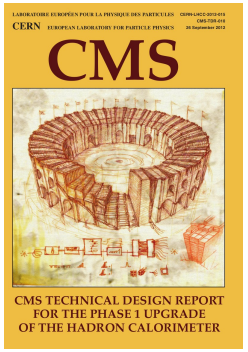
Phase 1 Upgrade Scope

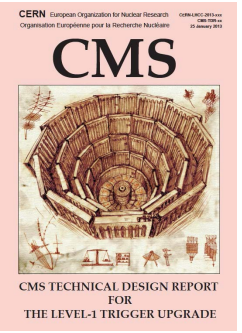
- **Upgrade goal: provide strong physics performance for luminosities up to twice the original design (2 x 1034) and manage radiation-damage effects up to 500 fb-1**

- **Upgrades planned to three subsystems**

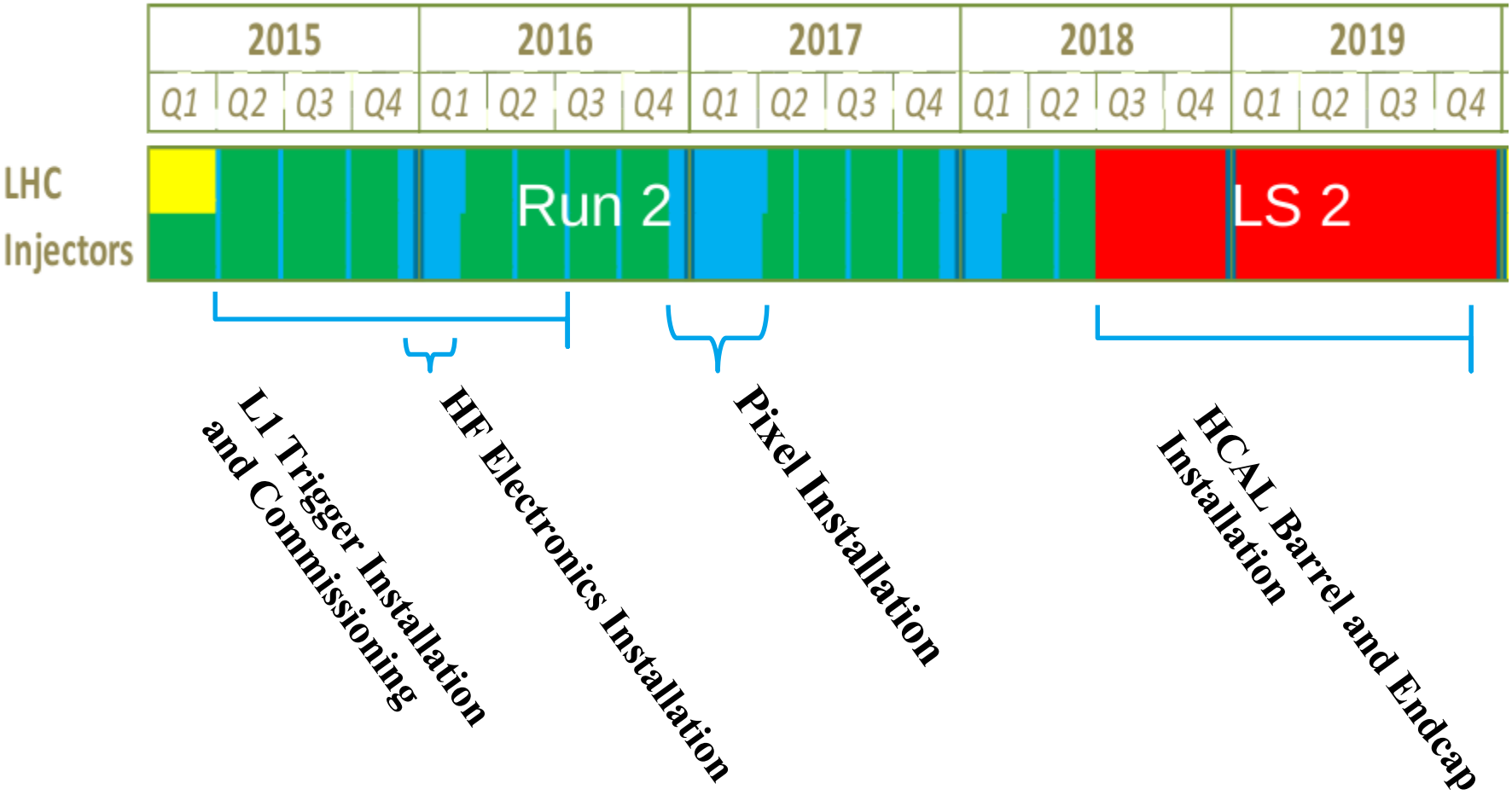
  - **<u>Pixel Tracker:</u> four-layer barrel and 3 forward-disk pixel tracker with new readout chip (ROC) capable of higher hit rate**
  - **<u>Hadron Calorimeter:</u> Installation of SiPM devices in the barrel/endcap calorimeters and new electronics in the forward calorimeter allowing timing-based background rejection**
  - **<u>Level-1 Trigger:</u> upgrade to the muon and calorimeter L1 trigger systems and global trigger processor to handle higher luminosities without loss of efficiency for key physics channels**







Schedule of the Installations



L1 Trigger Upgrade

Complete replacement for deployment in 2016

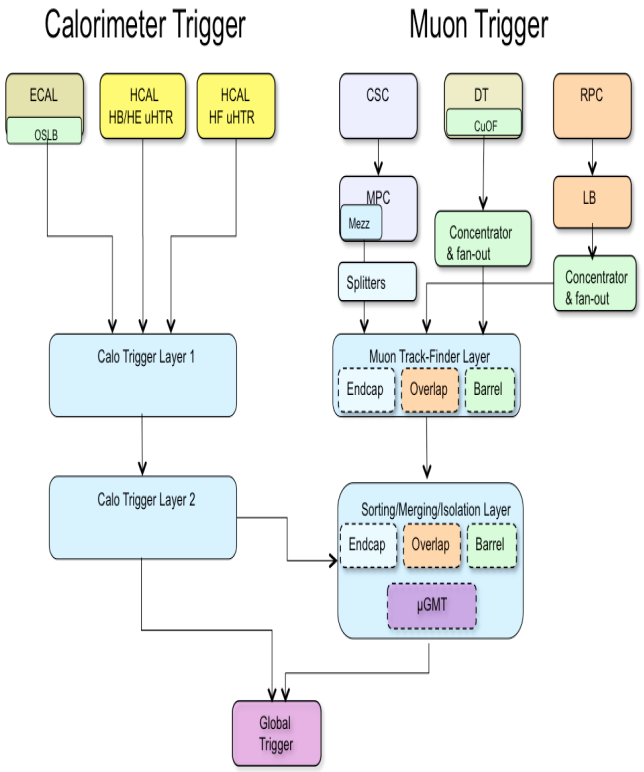
- Meet challenges of Run 2 & 3 luminosity and increased √s with similar sensitivity as for Run 1
- Build and commission upgrade in parallel with current trigger
- Early partial deployment of calorimeter trigger improvements in 2015 (Stage-1)

Two-layer Calorimeter Trigger with

- calorimeter tower-level precision
- improved tau and electron isolation
- pile-up subtraction

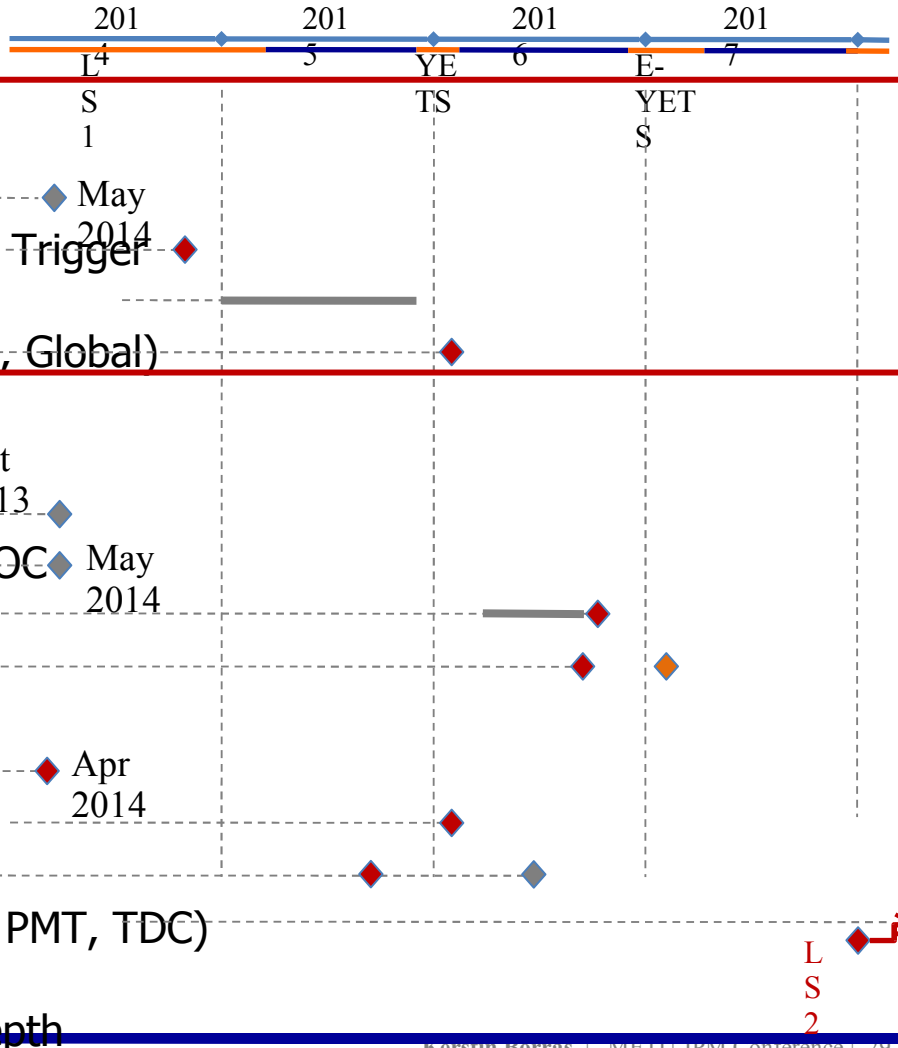
Integrated Muon Trigger combining all 3 muon systems in 'early' track-finding

- higher robustness and efficiency
- more sophisticated pT measurement



Phase I: Activities in LS1 – LS2

- Major milestone
- System comes into operation



L1-Trigger http://cds.cern.ch/record/1556311

- Installation of parallel paths Calo Trigger — May 2014
- Interim Calo Trigger operational
- Slice of TDR Trigger (Calo, Muon, Global) operating
- Full TDR Trigger commissioned — Oct 2013

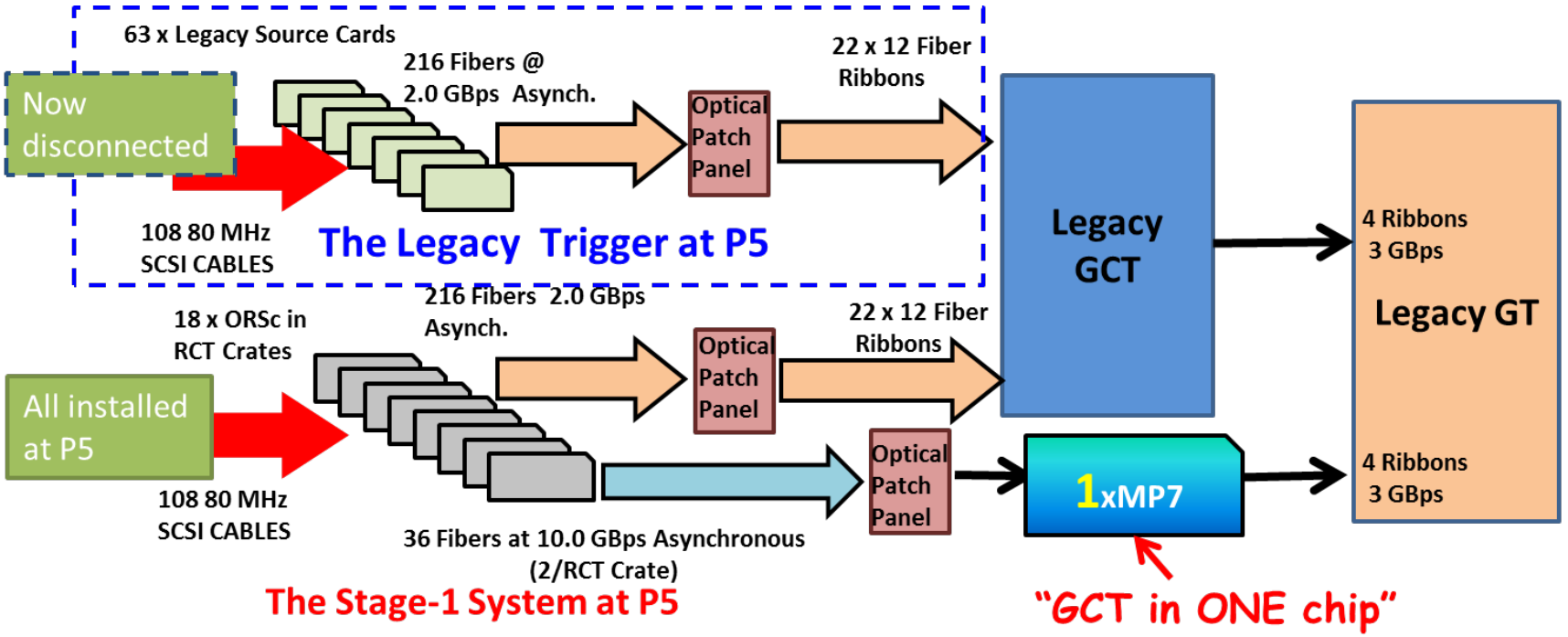
PIXELS

- Start sensor prod, submit final ROC — May 2014
- Install pilot blades
- Start module production
- DAQ operational at P5
- Ready for Installation — Apr 2014

HCAL

- HF BE upgraded to µTCA
- HF FE upgraded (2-channels per PMT, TDC)
- HBHE BE upgraded to µTCA
- HBHE FE upgraded (SiPM and depth segmentation)

2015 CALO Trigger Initial Upgrade



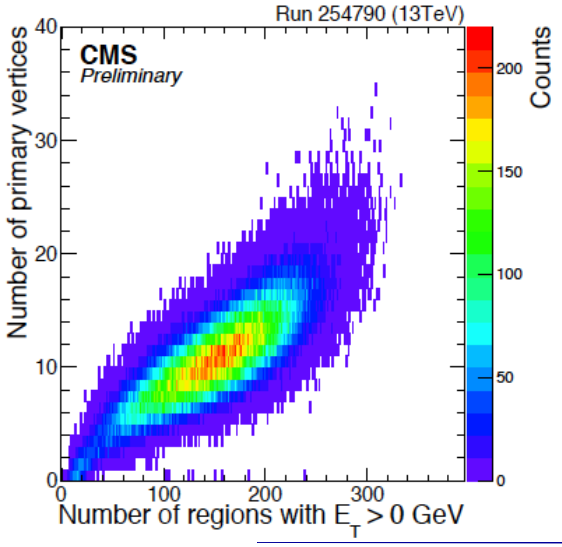
Shore up existing calorimeter trigger to add:

- pile-up energy subtraction,
- improved tau trigger,
- e/g isolation, ….

Replace Global Calorimeter trigger with ONE new µTCA card

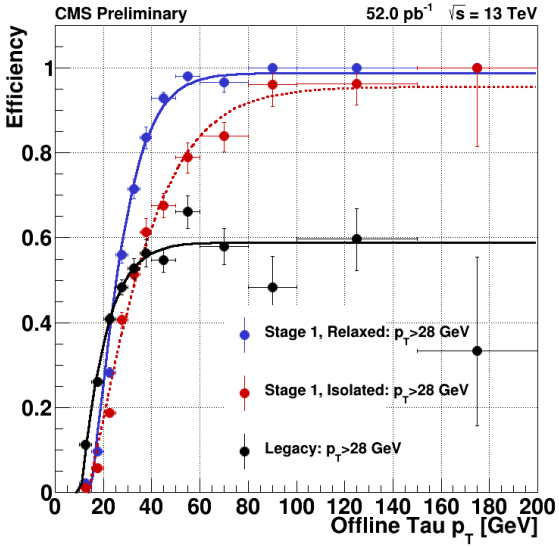
L1 Calo Trigger Upgrade – 2015

- **Since the start of the 25ns running period, we have switched to the "Stage-1" calorimeter upgrade**
  - **Essentially replaces the legacy Global Calorimeter trigger with a single board/ single FPGA solution offering a better tau trigger and pile-up subtraction on jets, isolation, and energy sums**



Number of reconstructed vertices vs. calo trigger regions

New Tau trigger efficiency with and without isolation compared to legacy

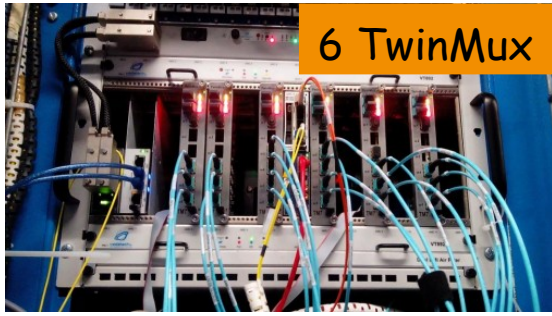


L1 Calo Trigger Upgrade – 2016

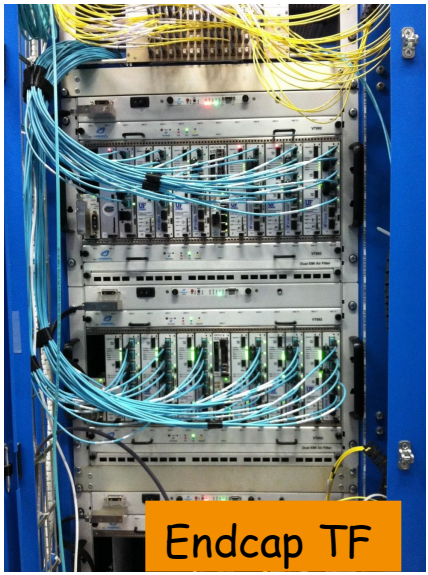
- Trigger system for 2016 operates on full trigger-tower granularity. Expands number of processors for second level. Uses time-multiplexing to get data from entire event into one processor.
- Status:
  - Calorimeter inputs fully duplicated/split for parallel operation
  - All ECAL and HCAL links (1152) connected to first layer, all validated but last 56 of HCAL
  - Layer-1 and Layer-2 interconnected (864 fibers)
  - Algorithms validated for EG, Tau, Jet, E-Sum
  - Pattern tests validated links to uGT
  - Layer-1 ready to integrate into DAQ readout
- Being prepared to run in parallel during last data taking period

L1 Trigger Upgrade – Muons

- **TwinMux, data concentration/fanout**
  - Detector slice set up with DT and RPC connections for 6 modules.
  - Ready to integrate into DAQ readout
  - Final production underway for 60 modules



- **Muon Track-Finders**
  - **Barrel TF** has 1 slice installed with connections established and input from TwinMux working
  - **Endcap TF** is fully installed with all CSC inputs validated. Chain test to uGMT is in progress
  - **Overlap TF** has 25% of processors installed with rest in production (complete ~1 month). Firmware is in good shape.
  - **uGMT has successfully tested inputs from all TFs**



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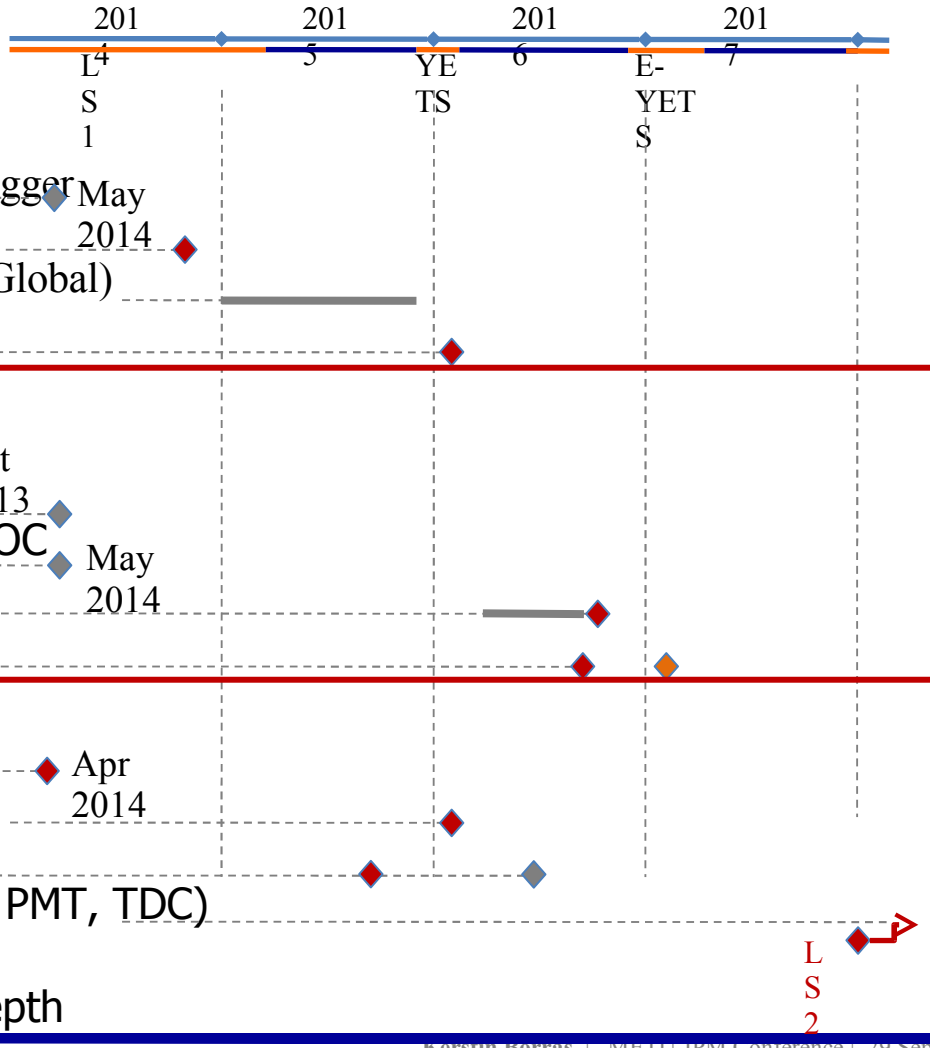

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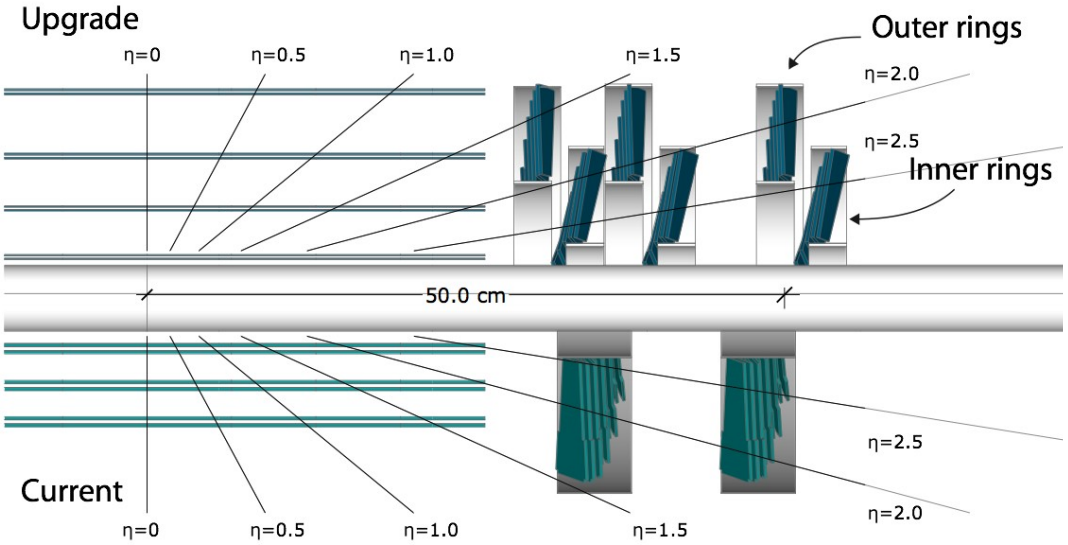
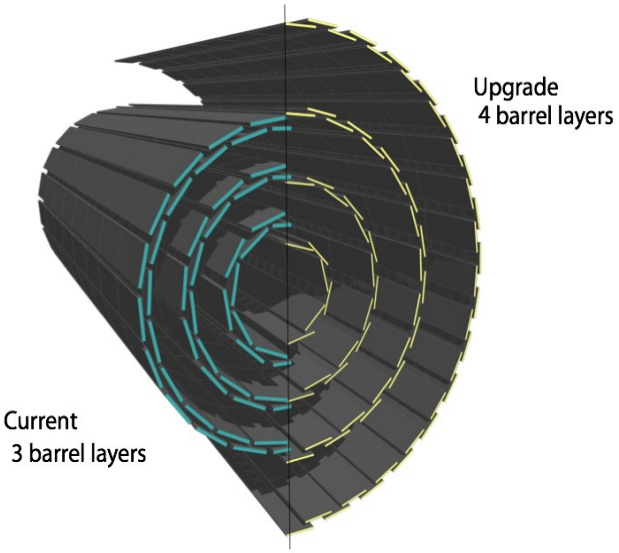
Phase I – Pixel Upgrade





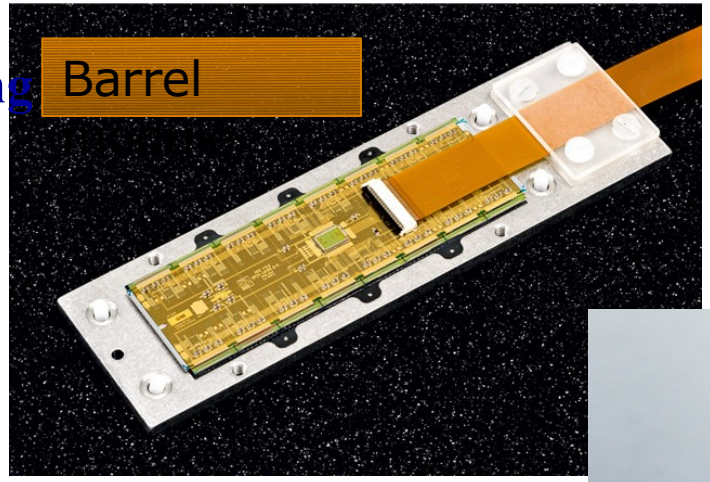
- 4 layers/3 disks (1 more space-point extended range from lower to larger radius)
  - 3 cm inner radius
- New readout chip (recovers inefficiency at high rate and pileup)
- Less material (CO2 cooling, new cabling and powering scheme (DC-DC))

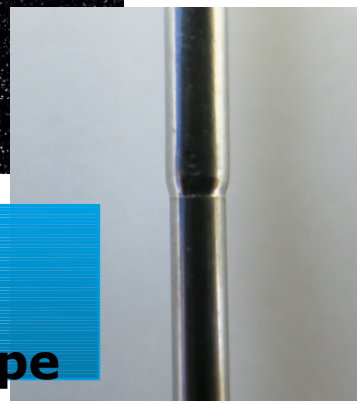
  - Tolerate rates up to PU 100
  - Survive Integrated Luminosity of 500 fb-1 (5x 1015 neq/cm2)
    - layer 1 exchange after 250 fb-1
  - Improved track resolution and efficiency, and reduce fake rate

- Installation in Year End Technical Stop 2016-17

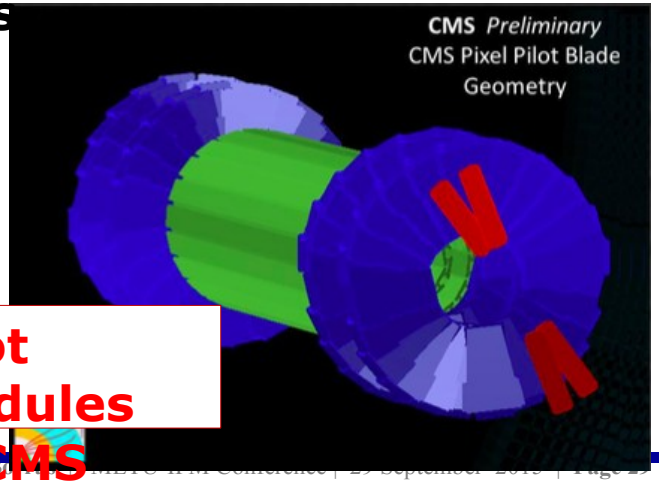
Pixel Phase 1 Upgrade

- **Barrel module production is ramping up: more than 14% of the modules produced (grade A+B)**
  - Forward disk module production to be started soon
- **Mechanics and service cylinders**
  - All details sorted out
  - First final pieces ready
- **Eight pilot modules installed in CMS have been calibrated and joined the global run: looking forward to collecting collision data**





Laser welding chosen for the cooling pipe joints

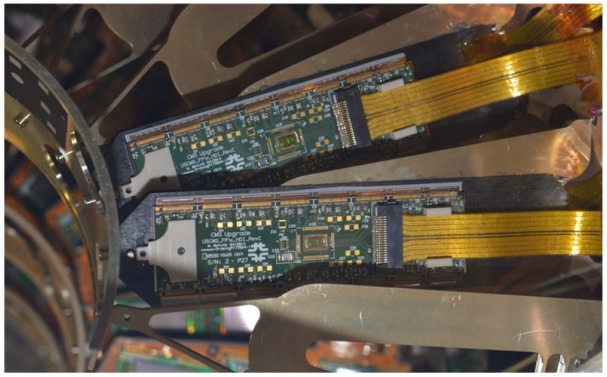


Pilot modules in CMS

Pilot Detector – 2014/2015

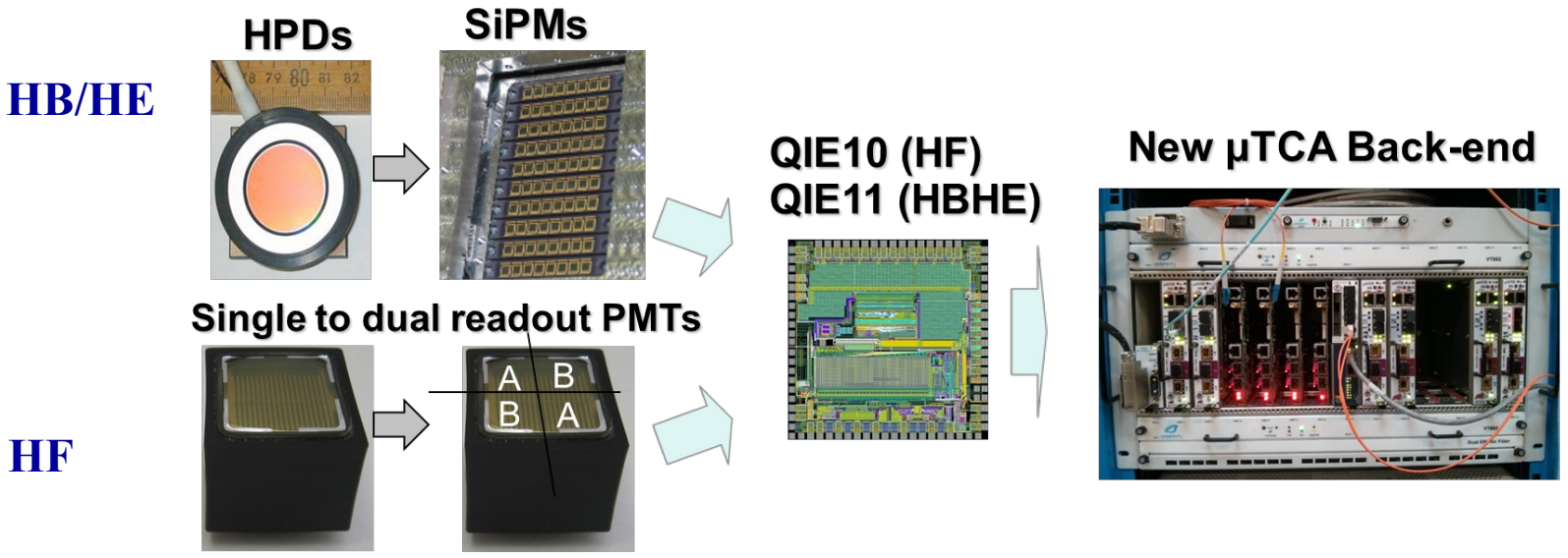
FPIX reinstalled in CMS with Pilot Detector

- Pilot detector is crucial for understanding problem with original design of readout of upgraded pixel detector
  clock jitter issue
  - 8 FPIX-style modules (TBM08b, PSI46digv2.1) and flex cables
    all working
  - 4 modules with DC-DC converters
  - Extra DC-DC converters with dummy load
- December 2014: cooling established, initial checkout completed prior to Xmas CERN closure
- Switch from using commissioning tool software to pixel online software
- Operating cold and with high voltage on, initial calibration ongoing
- Ran standalone, join data taking soon

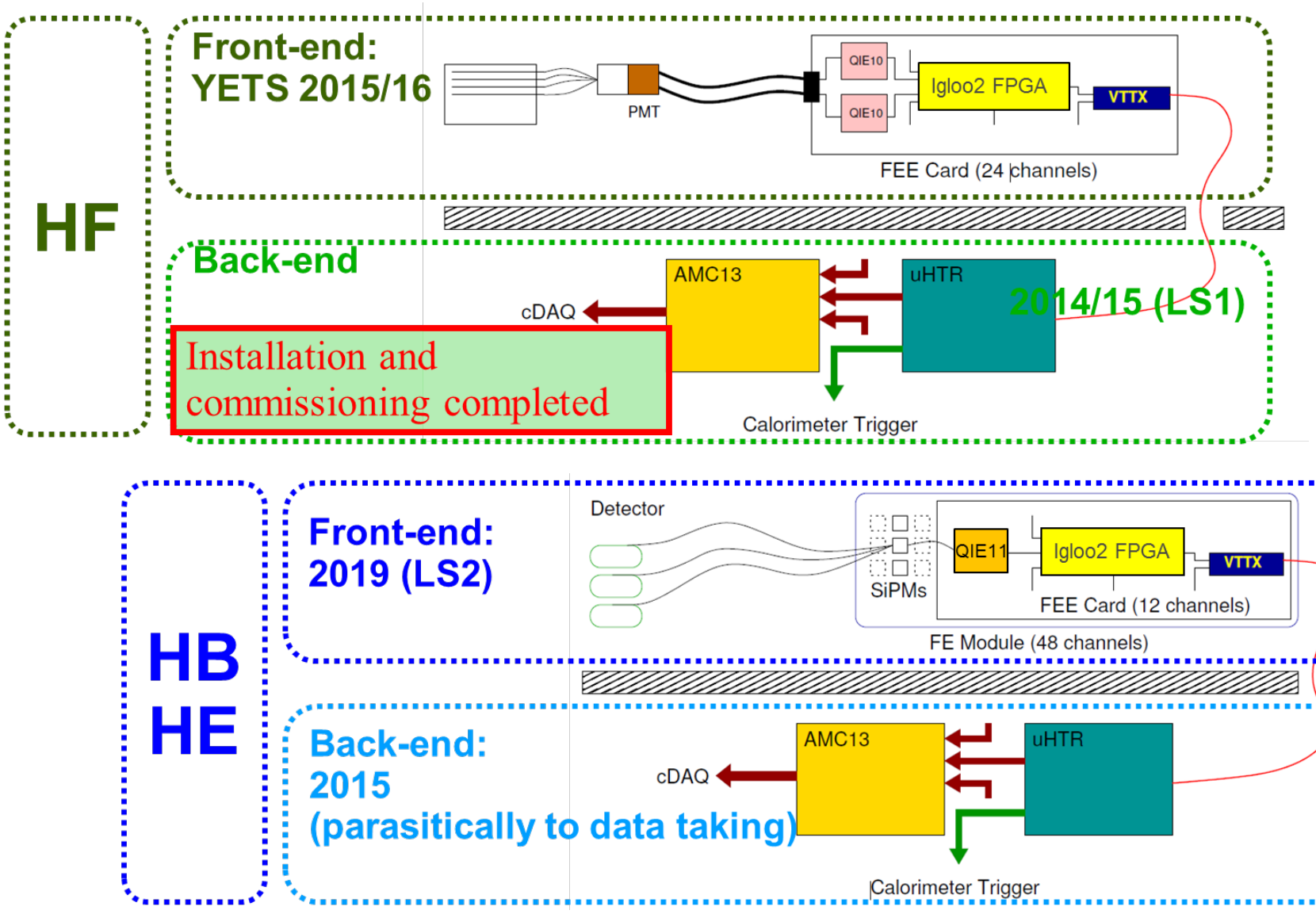


Phase I: HCAL Upgrade

- **Improved photodetectors**
  - **HB/HE: HPD → SiPM (allows longitudinal segmentation of readout)**
  - **HF: single-anode PMT → dual-anode readout PMTs (improved discrimination of anomalous signals)**
- **New front-end electronics, including TDC**
- **New back-end electronics (μTCA) to support larger data volumes**



Phase I HCAL Upgrade Timeline



HF Frontend Upgrade

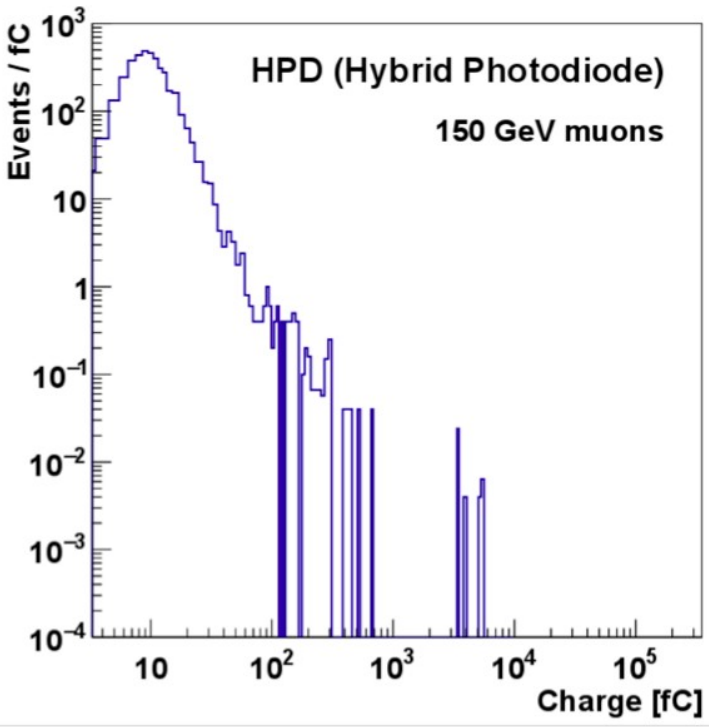
- **Production of QIE10 boards for HF Front-End upgrade completed on time in Turkey. Full set of boards delivered to CERN.**
- **QC/calibration/burn-in stand has been set up in B904.**
- **FRONT End board optical drivers (VTTX) component defining the schedule: expected delivery early November, just in time to burn-in and install during End of this end of the Year Technical Stop**

HB/HE Upgrade

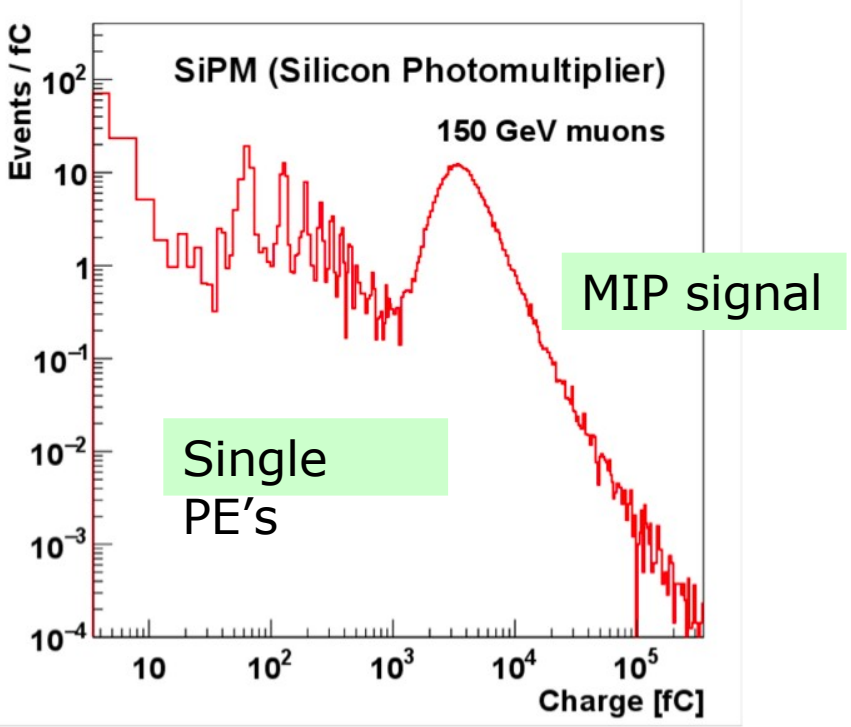
HE Front-End:

- Test-beam in H2 beam line at CERN with prototype SiPM & QIE11 cards
- Production Readiness Review in Nov-2015

HPDs (12 layers)

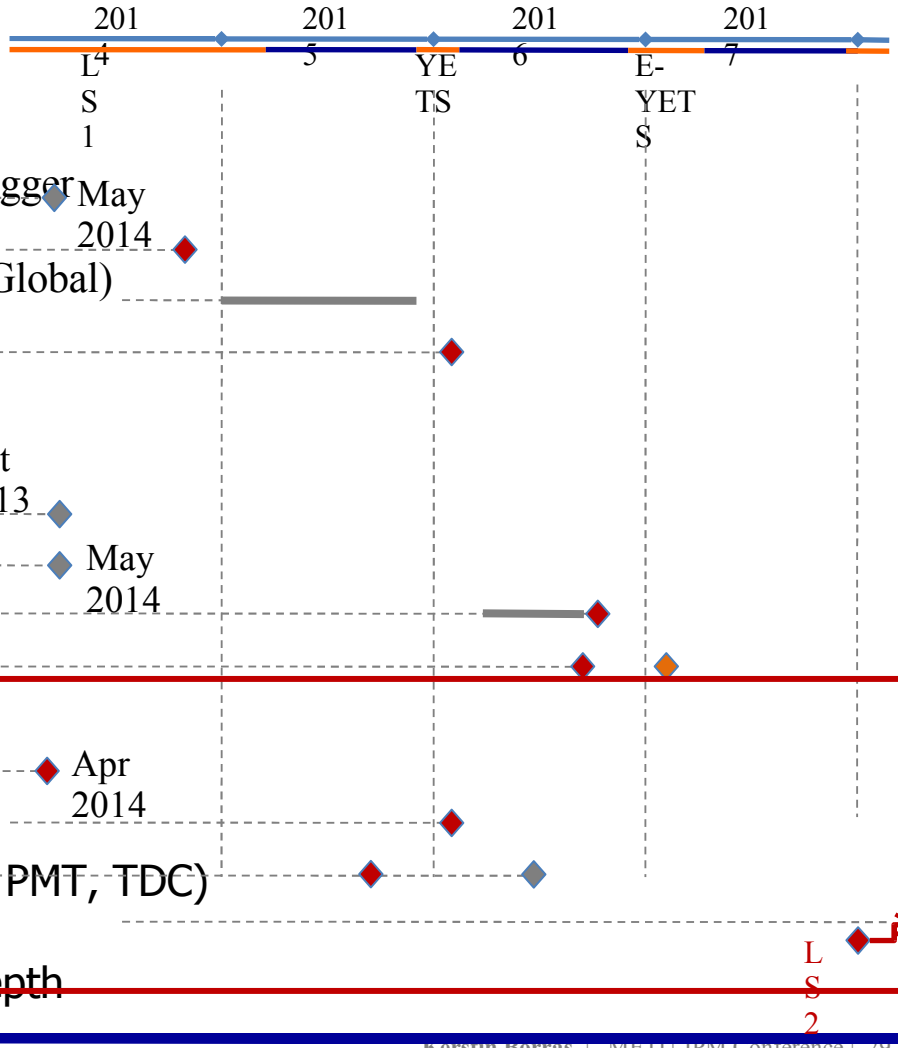


SiPM (4 layers)



Phase 1: Activities in LS1 – LS2

- Major milestone
- System comes into operation



L1-Trigger

Installation of parallel paths Calo Trigger

Interim Calo Trigger operational — May 2014

Slice of TDR Trigger (Calo, Muon, Global) operating

Full TDR Trigger commissioned

PIXELS

Start sensor prod, submit final ROC — Oct 2013

Install pilot blades

Start module production — May 2014

DAQ operational at P5

Ready for Installation

HCAL http://cds.cern.ch/record/357153

HF BE upgraded to µTCA — Apr 2014

HF FE upgraded (2-channels per PMT, TDC)

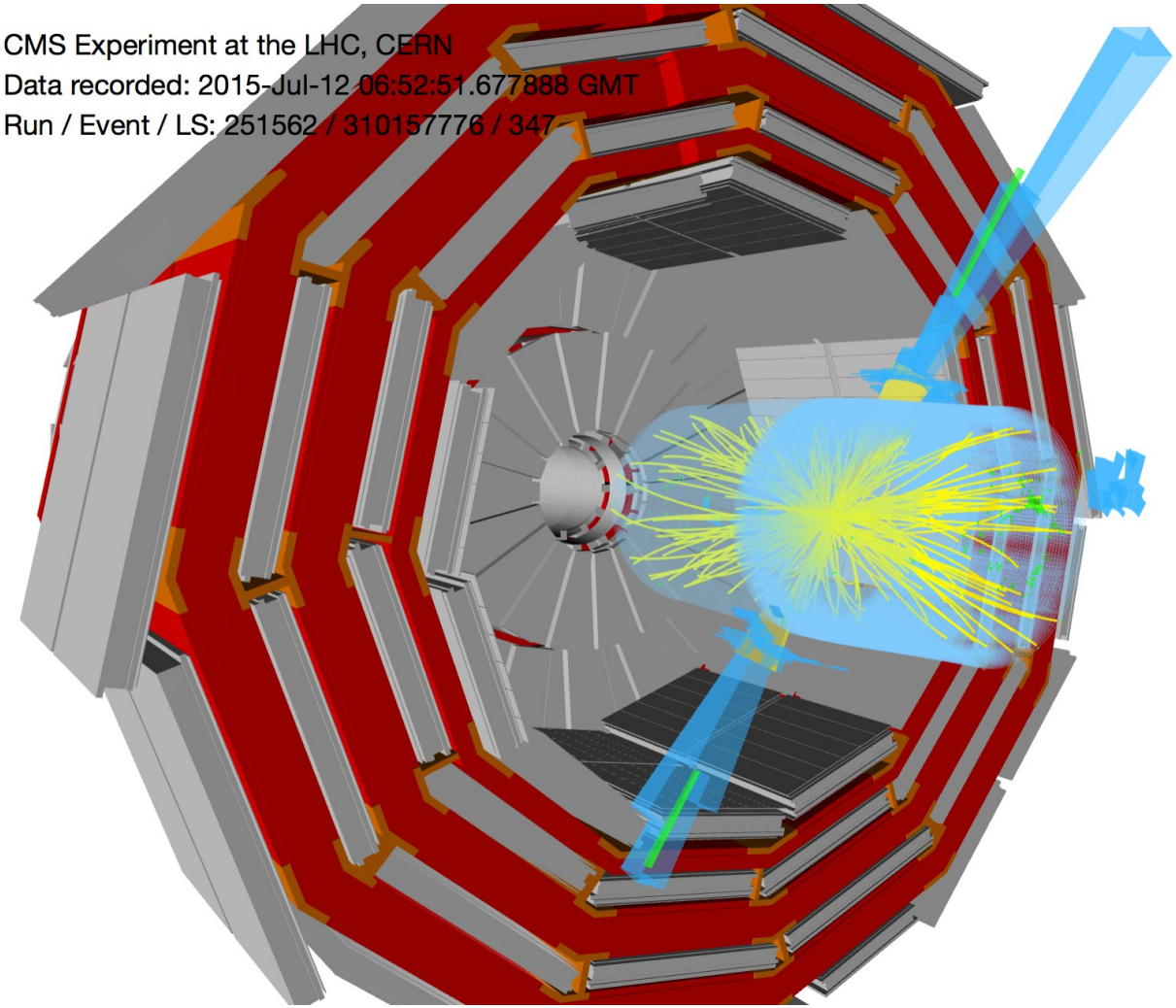
HBHE BE upgraded to µTCA

HBHE FE upgraded (SiPM and depth segmentation)

Summary

- CMS is following the defined Upgrade Strategy
- Detector improvements in LS 1 completed and working
- CMS returns to discovery mode in Run 2
  - Improved Detectors, Trigger and reconstruction algorithms
- Road to the future paved:
  - Phase I upgrades proceeding well:
    - L1 Trigger upgrade in initial “Stage – 1” working
    - HCAL Upgrade progressing for HF and HB/HE
    - Phase 1 Pixel construction well underway.
  - Phase II Technical Proposal submitted, as well as the Scope Document

Our Future has just started



Let‘s see,

what Nature has in stock for us !

Any questions?

BackUp

Detector Consolidation in LS1

Prepare for 13-14 TeV, ~100fb-1, ~1 x 1034cm-2s-1, 25ns

Summary status

Tracking region:

Beampipe remove 59.6mm central beampipe/ install 45.0mm. — Installed, baked out,vac10-10

Yoke and Tracker bulkhead humidity seal revision + new dry gas system (for colder Tracker operation) — Tracker OK at -20deg C, Det. dry gas system installed

CO2 system + cabling + demonstrators for Phase-1 pixel upgrade — Final pressure tests done

New PixelLumiTelescope + BeamHaloMonitor, revised BCM — PLT/BCM BHM done,

Calorimeters:

HF calorimeters PMT multi-anode PMT — PMT's & cabling done

HO calorimeter HPD SiPM — All wheels done

HB/HE control module replacement, cable/fibre installation for LS2 — Done

Minor revisions and repairs of EB/EE — Done

ES removal, repair and re-installation (unexpected) — Done

Muon detectors:

Yoke Endcap disk 4 construction at +z and −z ends in situ. — +z &-z done incl -z pushback

4'th muon endcap stations +z and −z (CSC & RPC) — Both ends commissioned

1'st endcap station (CSC) readout granularity restoration +z and −z — Both ends commissioned

Complete for all wheels

Phase I: Activities in LS1 – LS2

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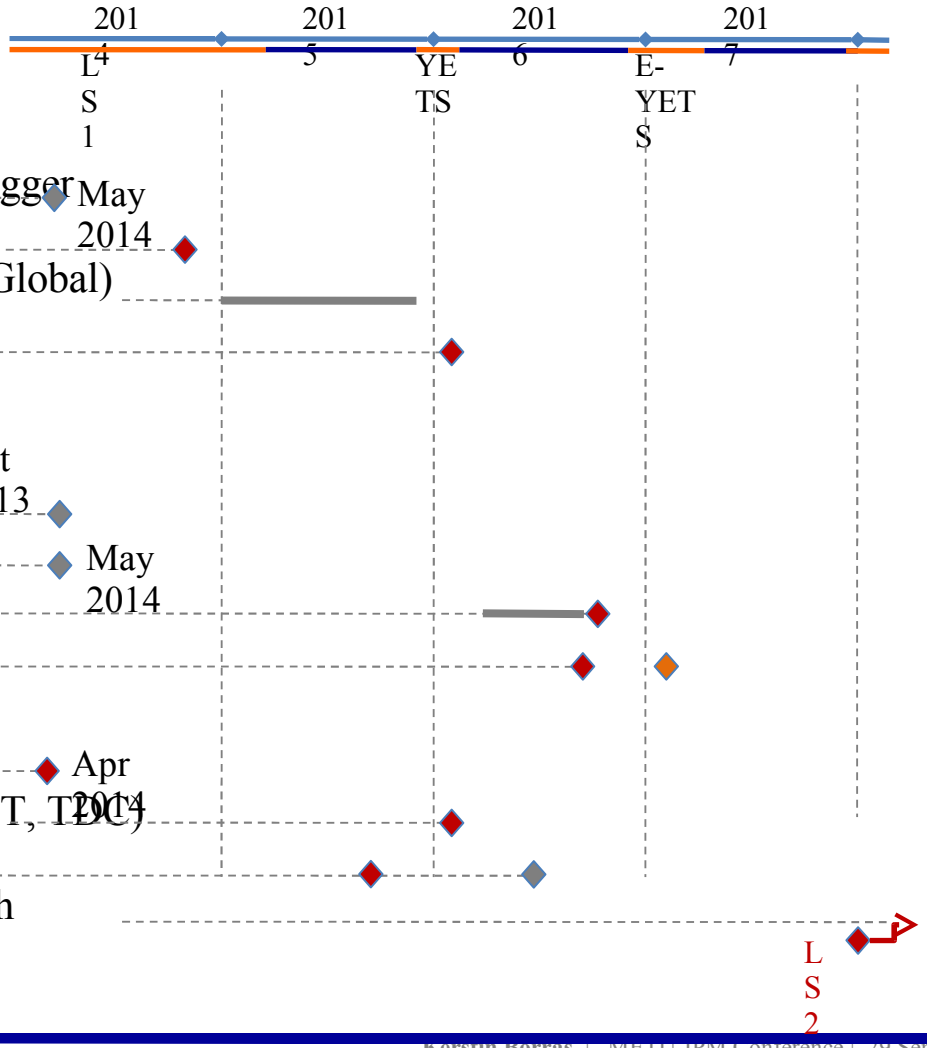
- System comes into operation



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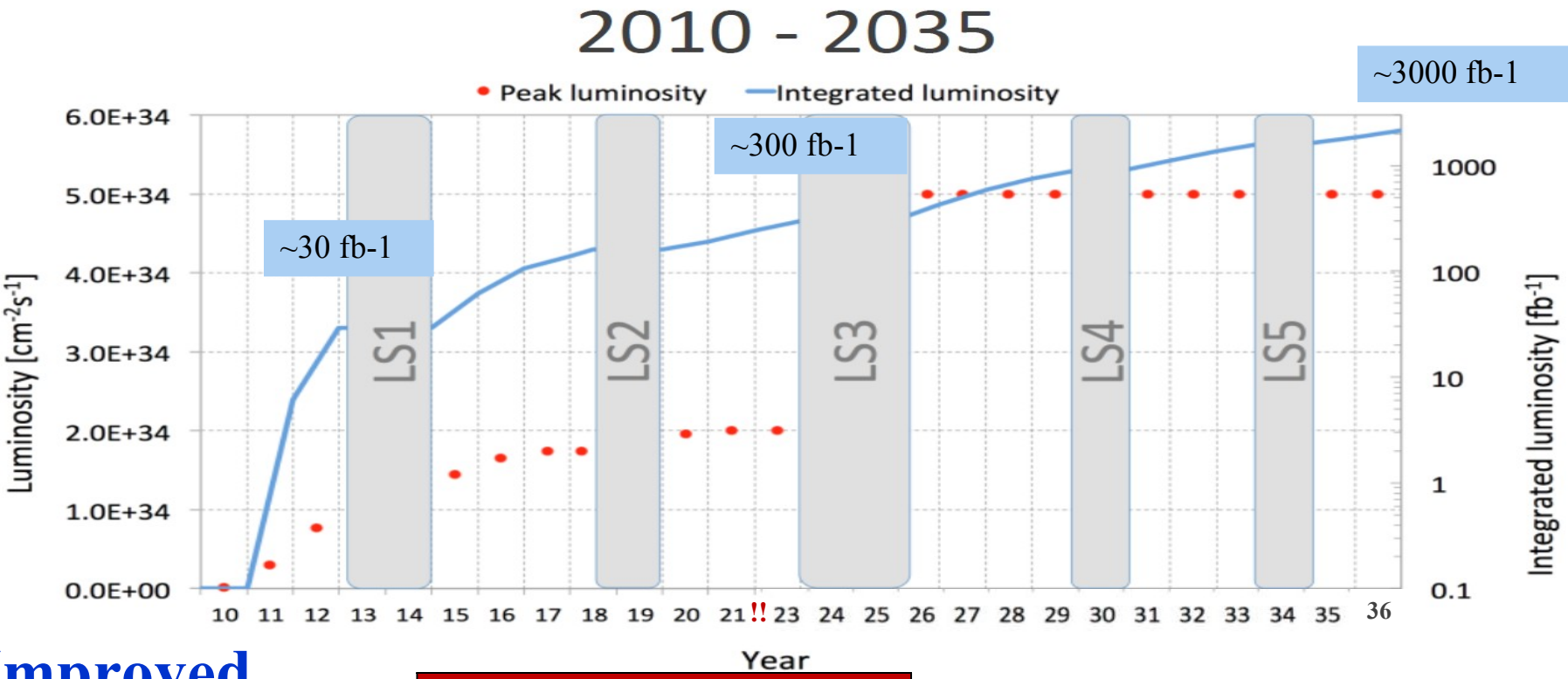
Future @ LHC - Phase II Upgrade



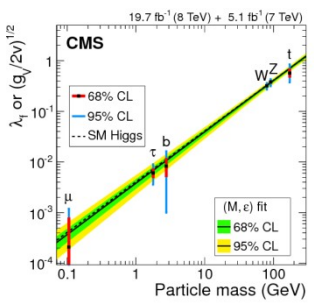
Improved detectors

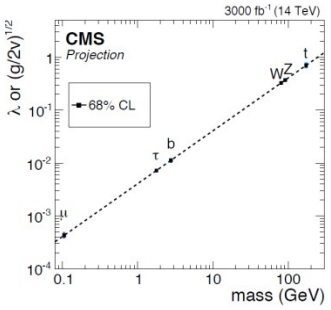
Physics studies, R&D application for funding

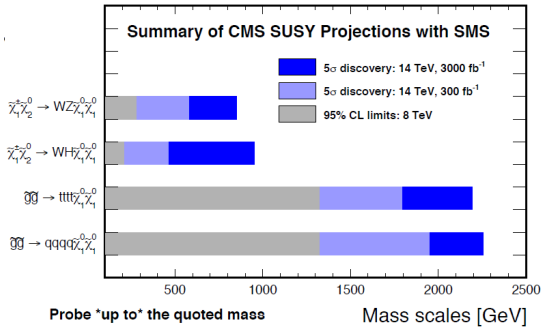
High Luminosity LHC

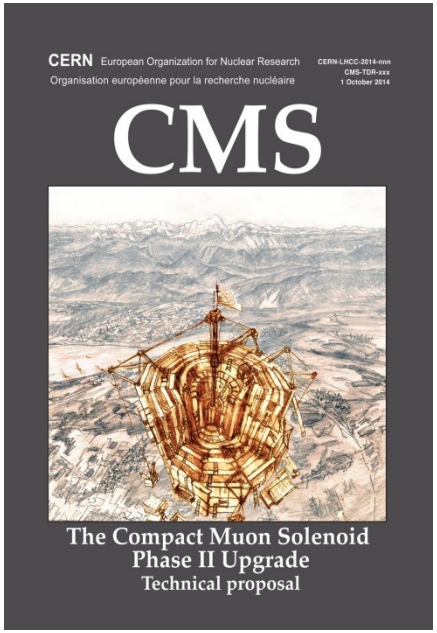
Physics Topics:

- Higgs Physics
- Searches
- VBF / VBS
- … many more









Technical Proposal for the CMS Phase II Upgrade:

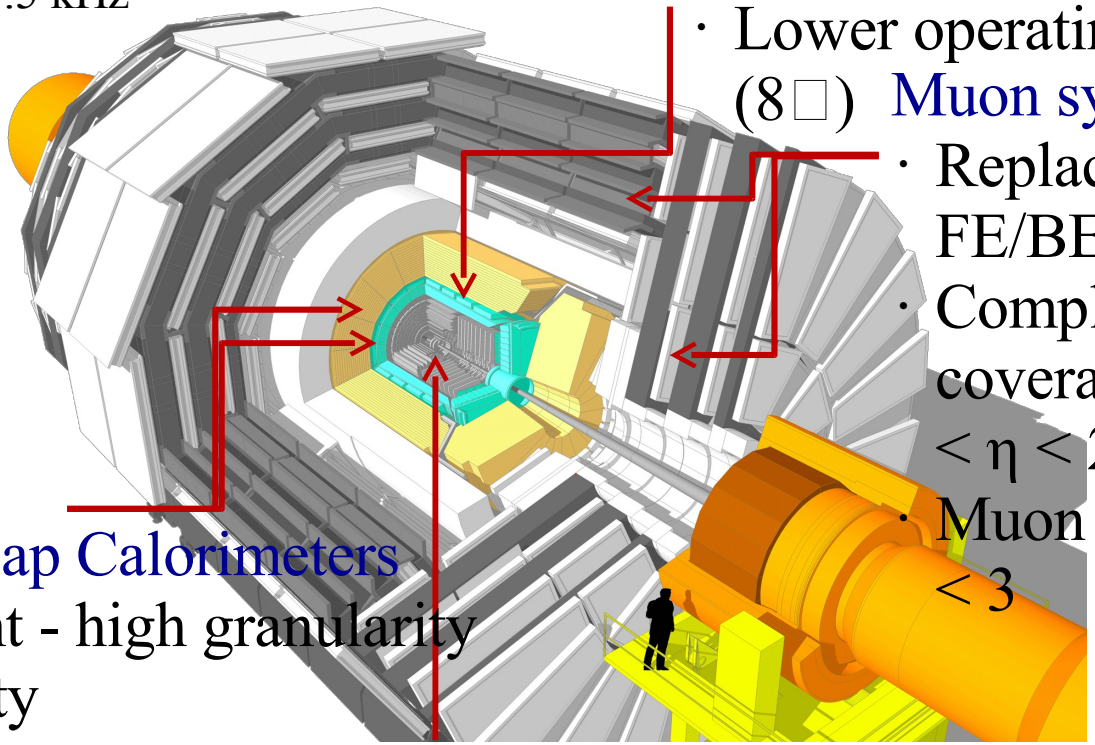
- Physics motivation
- Detector Upgrades & Performance
- Physics Object Performance
- Physics Performnace
- Core Costs

CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886

CMS Phase II Upgrades

Trigger/HLT/DAQ

- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≃7.5 kHz



Barrel EM calorimeter

- Replace FE/BE electronics
- Lower operating temperature (8□)

Muon systems

- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

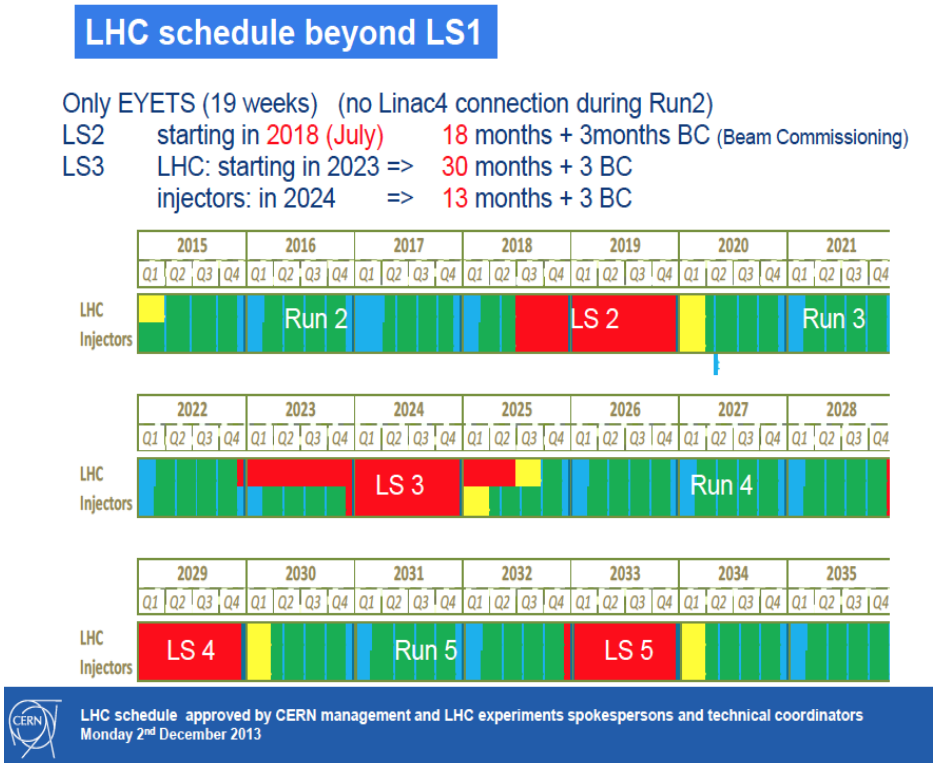
Replace Endcap Calorimeters

- Rad. tolerant - high granularity
- 3D capability

Replace Tracker

- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger
- Extend coverage to $\eta = 3.8$

LHC Future Performance



Design:

Energy: 13-14 TeV

Lmax(pp) ~ 1034 Hz/cm2 @ 25ns

Projection:

Before LS3:

Total Lint(pp) 300 – 500 fb-1

Lmax(pp) ~ 2.5 1034 Hz/cm2

After LS3:

High Luminosity (HL) LHC

Total Lint(pp) 3000 fb-1

Llevel(pp) ~ 5 1034 Hz/cm2

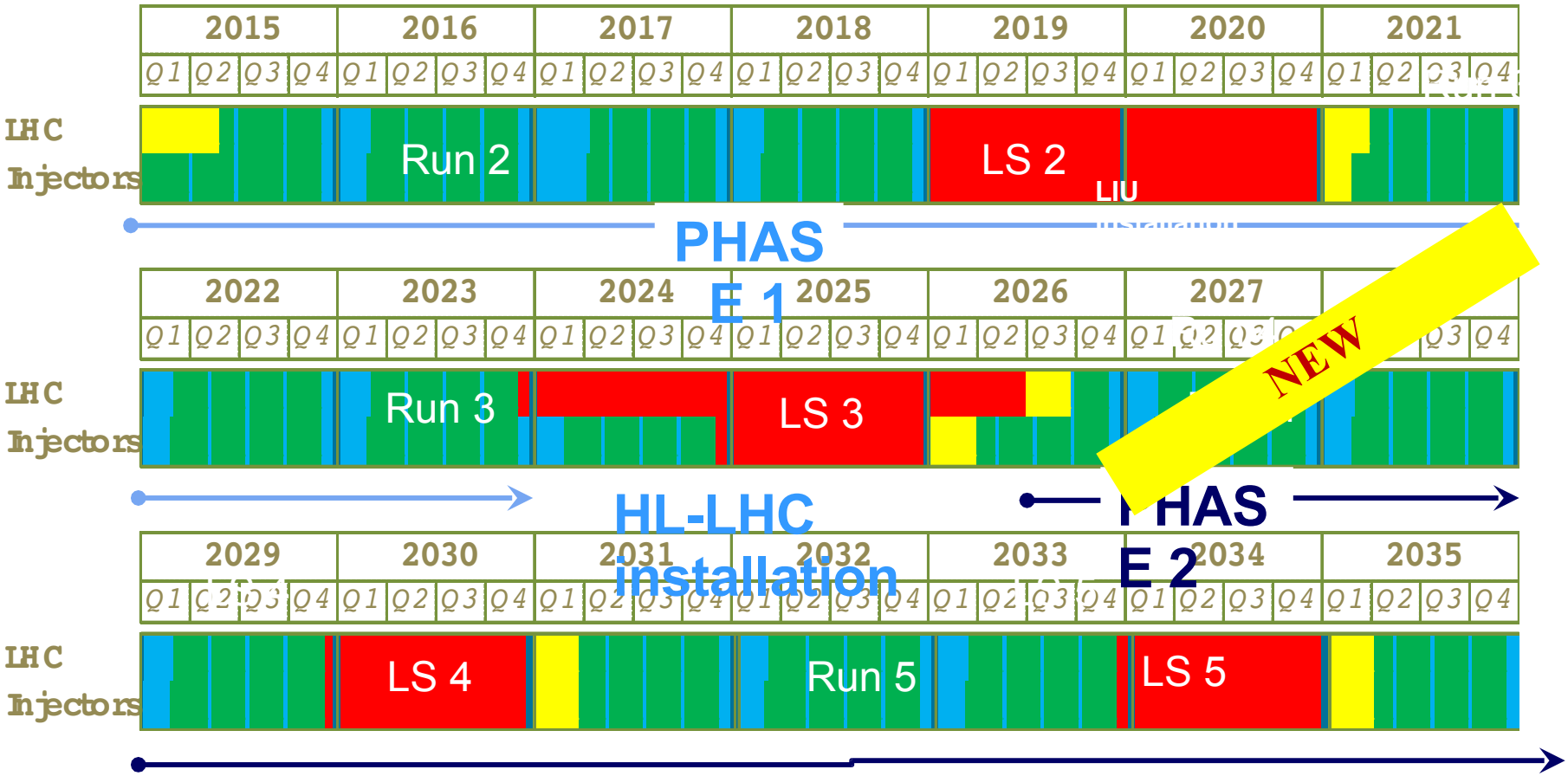
High Intensity & Pile-Up (PU)

Maintain present performance

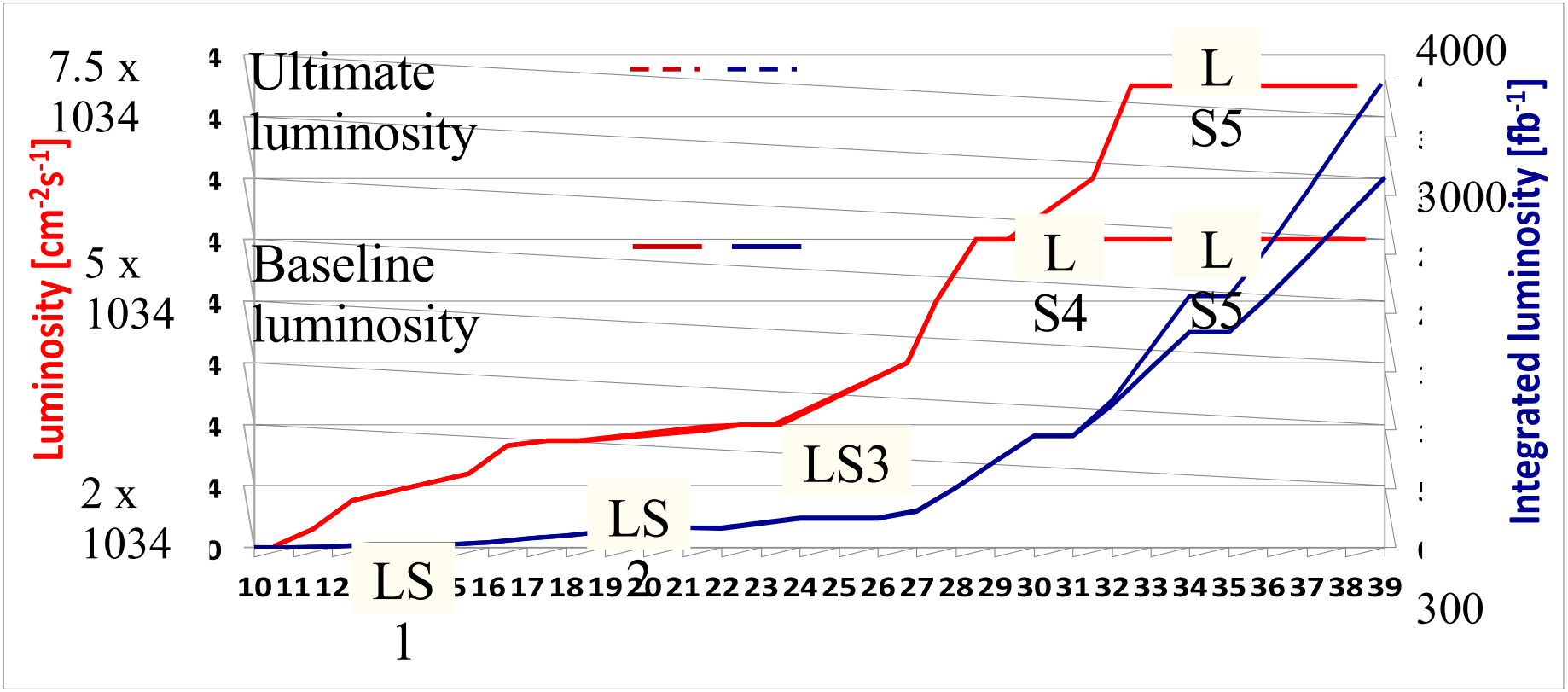
- **Fine granularity detectors**
- **Radiation hard detectors**
- **New trigger strategy & hardware**

LHC roadmap: according to MTP 2016-2020

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC



HL-LHC planning and luminosity projections



From private communication of L. Rossi