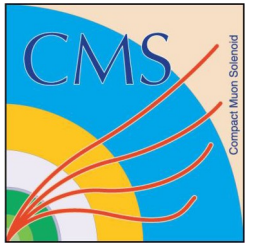


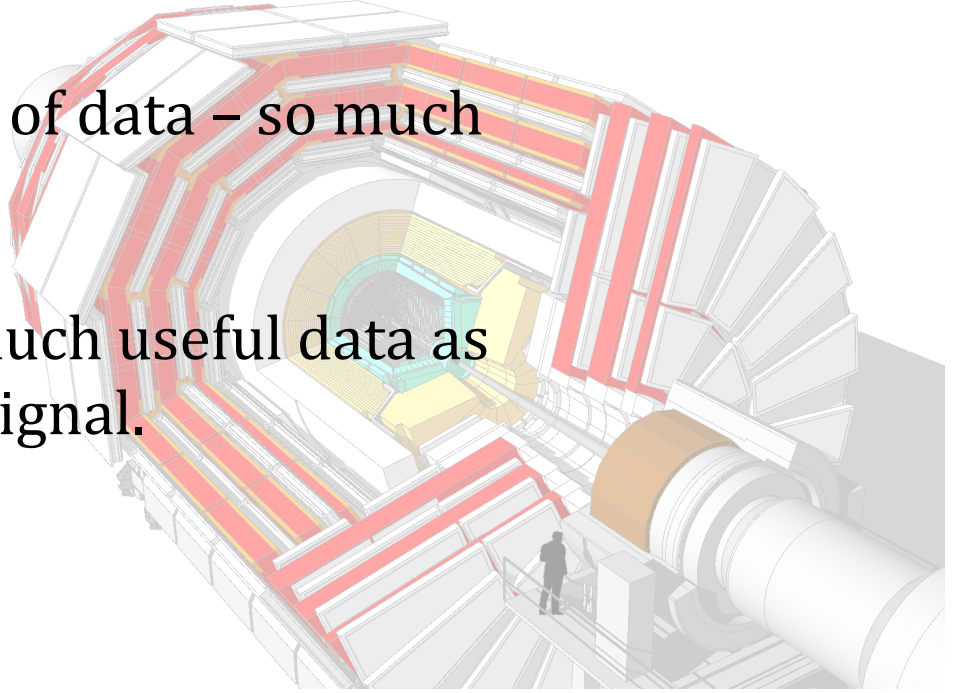
The CMS Level 1 Trigger Upgrade for the HL-LHC

Christine Nielsen, KBFI
For the 4th CERN Baltic Conference

What is the CMS trigger?

CMS generates a massive amount of data – so much so that we can't save it all.

The CMS trigger lets us keep as much useful data as we can without losing too much signal.

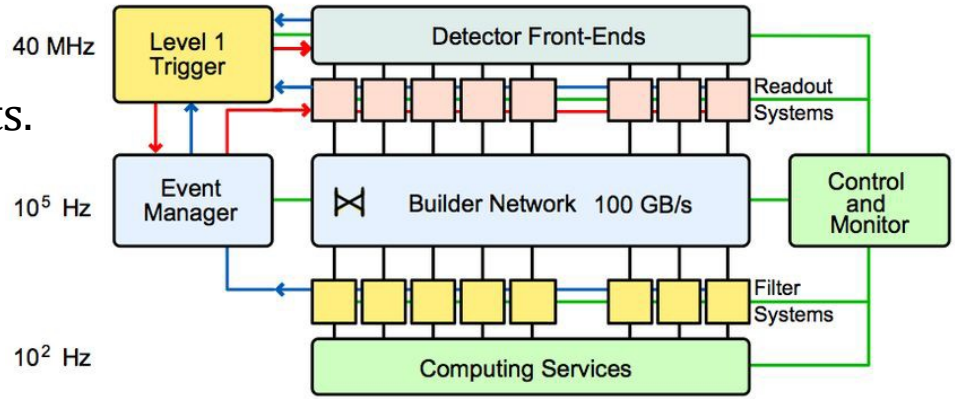


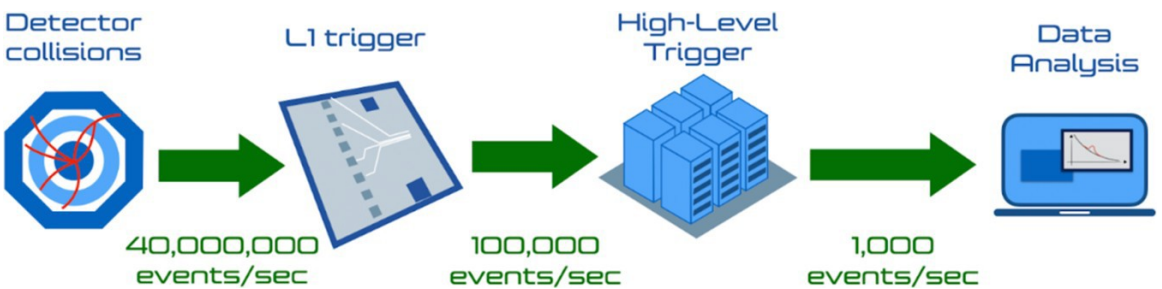
From Detector to Data

The CMS trigger consists of several steps, starting with the collection of raw detector hits.

These are then processed in the Level 1 (L1) trigger, which is entirely hardware based.

The L1T passes events on to the High Level Trigger (HLT), which is software based, and makes the final decisions on which events are kept for analysis.



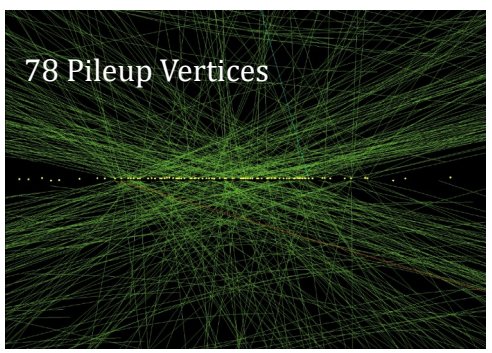


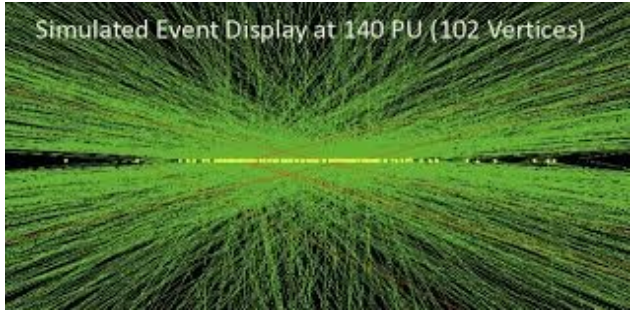
CMS and the HL-LHC

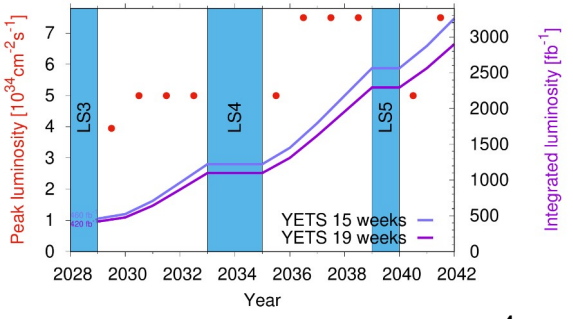
With the upcoming High-Luminosity LHC upgrade, CMS will face new challenges in data collection:

- High luminosity means much higher number of simultaneous p-p collisions, up to 3-4x current pileup
- Current triggers would be unable reduce this to a manageable rate
- Current trigger methods are not designed to discriminate between events well at high pileup

So CMS needs to upgrade too.



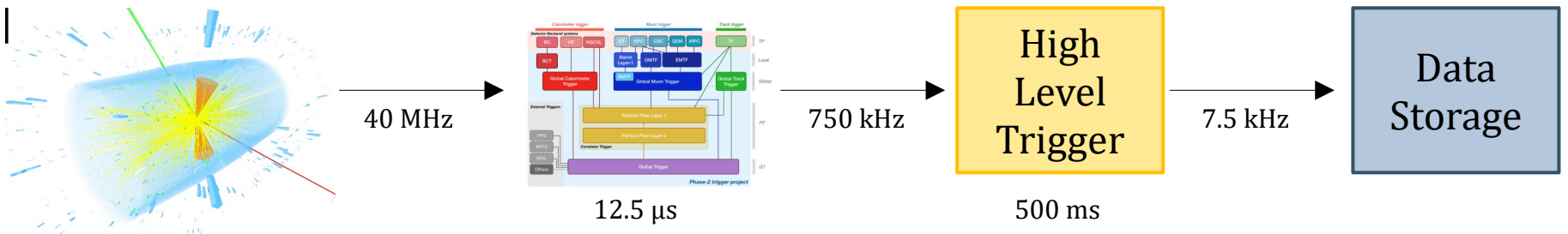




The CMS Phase 2 Upgrade

Primary Goals:

- Upgrade detectors to take advantage of the HL-LHC
- Upgrade trigger to handle high pileup
- Maintain current physic performance as in Run 2 for standard triggers
- Extend our physics acceptance from pre-upgrade – new physics potential



The CMS Level 1 Trigger Upgrade

New design brings increased latency:

- ~3μs to 12.5μs
- Effectively 9μs plus 20% buffer time

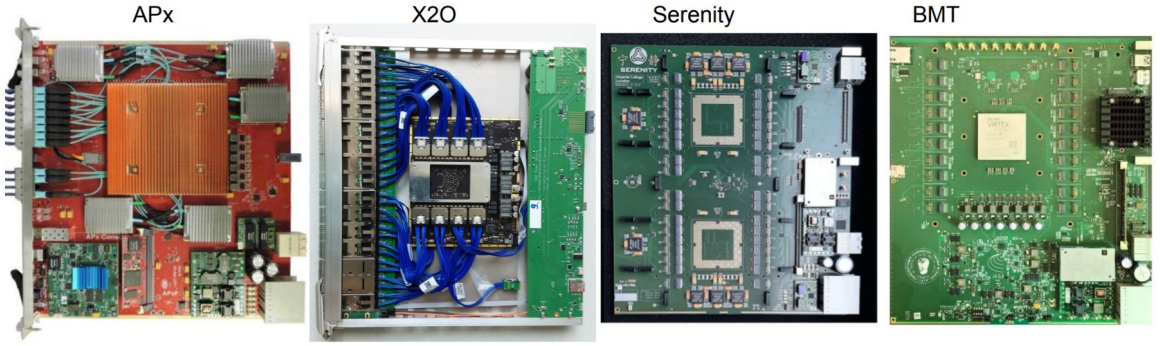
New track trigger and high level physics objects

Maximum output rate 750 kHz from 40MHz

- New event every 25ns

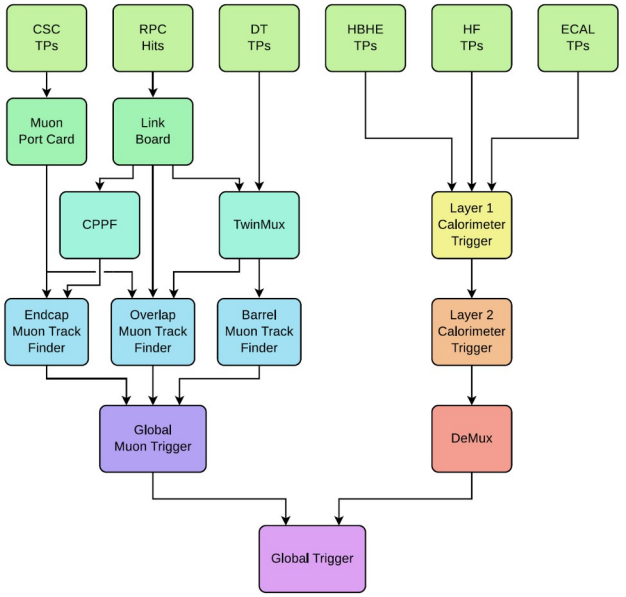
Trigger algorithms currently being tested on boards and board production is under way.

- Hundreds of custom electronics boards – multiple architectures
- FPGA-based trigger firmware (Xilinx VU13P)
- 100 high speed optical links (28Gb/s)

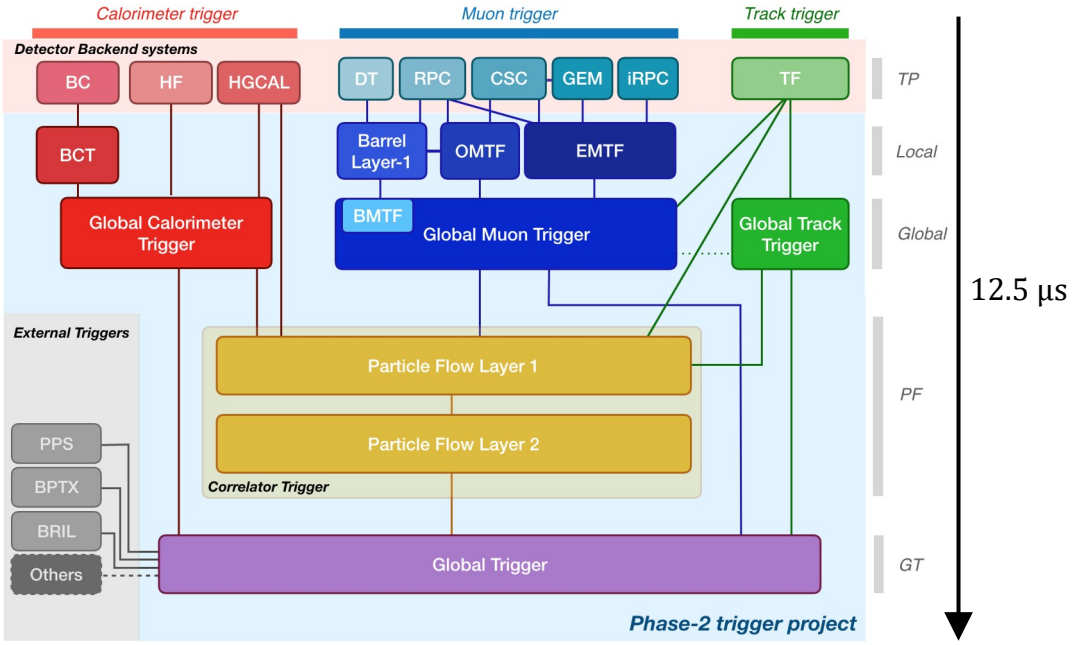


The CMS Level 1 Trigger Upgrade

Phase 1



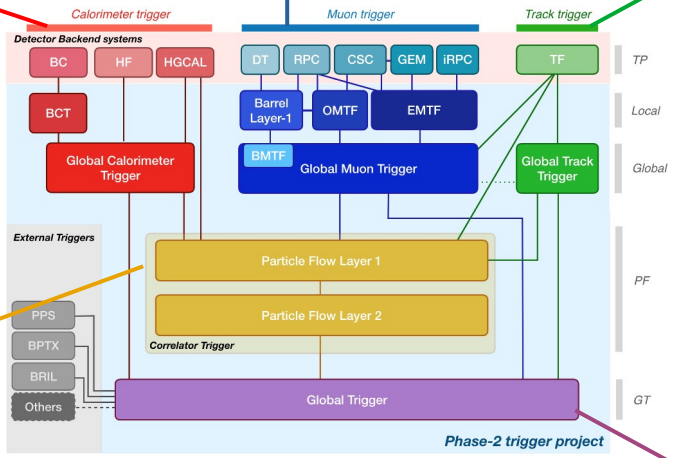
Phase 2



Candidate reconstruction from calorimeter deposits
- HGCAL detector information
- Improved granularity from detector upgrades

Muon candidate reconstruction
- 3 regions: barrel, endcap, and overlap
- Extended η coverage, $|\eta| < 2.4 \rightarrow 2.8$
- Track matching for muon candidates

Track trigger - new to Phase 2 L1 Trigger
- Vertex reconstruction
- Charged particle candidates
- Expands what we can reconstruct: displaced tracks and jets, light resonances



Matches trigger objects between calo, track and muon
- Offline-like physics objects and algorithms

Final event selection decision using all trigger objects
- L1physics menu – compare objects against sets of conditions
- Interface to external triggers
- ML-based methods in the works
- New objects – new menu options

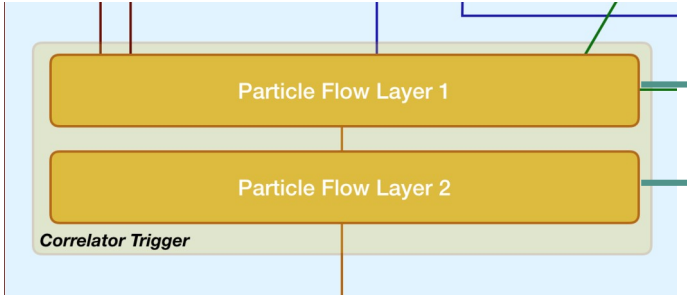
Aiming for offline-like global reconstruction at the trigger level!

The Correlator Trigger

New track trigger objects and longer latency enable high level algorithms at the trigger level

- Adaptation of algorithms that were previously offline-only due to complexity

Consists of two sequential layers, with Layer 2 relying on Layer 1.



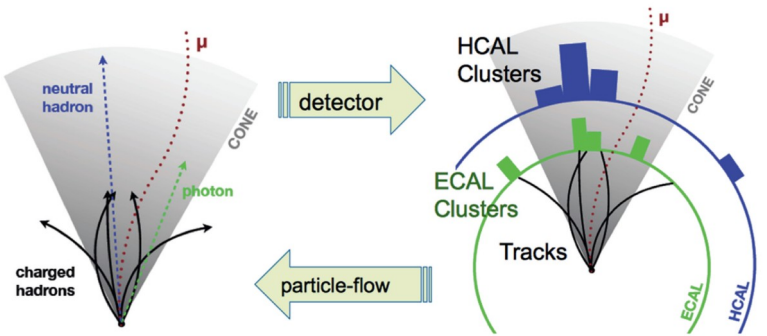
Layer 1: Creates particle candidate objects

Layer 2: Builds final trigger objects, with particle ID and isolation

Correlator Trigger Layer 1

Two primary components: Particle Flow and PUPPI (PileUp Per Particle Identification)

- Originally CMS offline reconstruction algorithms
- Also provides vertex reconstruction and e/γ tagging



Particle Flow

- Takes inputs from the track trigger, calorimeter trigger and muon trigger
- Combines and links these inputs into particle candidates
  - Charged/neutral hadrons: tracks + calo clusters
  - Electrons/photons: tracks + muons

PUPPI

Uses vertices and particle flow candidates to identify and isolate particles that originate from primary interactions

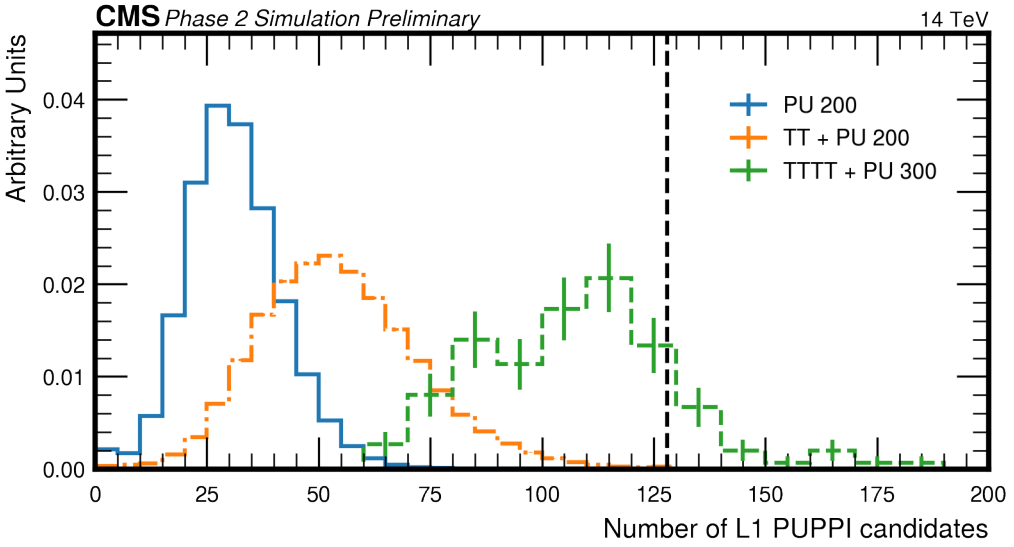
- Vertex association
- Nearby energy weighting

Creates the set of objects passed to Layer 2

Correlator Trigger Layer 2

Algorithms that use the Layer 1 candidates

- ~1 μs latency
- Combination of ML and standard physics algorithms
- Reconstructs complex physics objects such as jets and hadronic taus to pass to the Global Trigger
- Multiple potential algorithms for each physics object



Layer 2 algorithms use PUPPI candidates to avoid issues from input bottlenecks in firmware

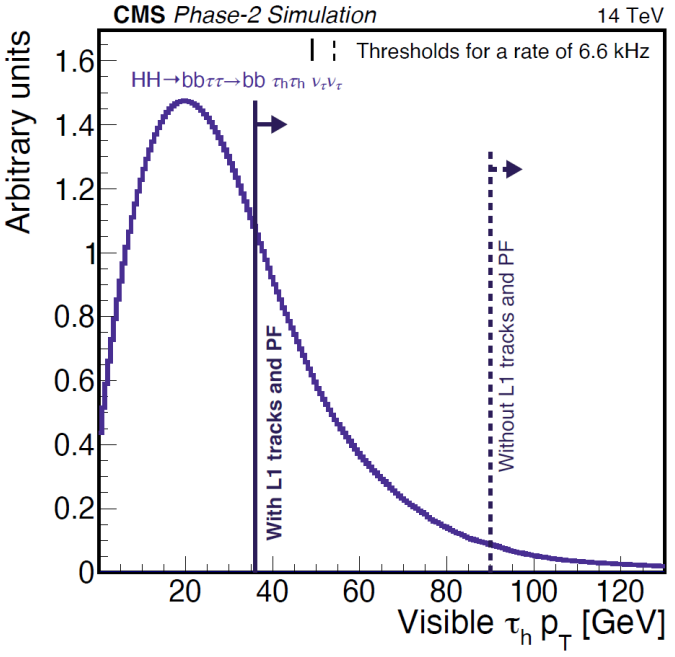
- Cutoff at 128 particle candidates

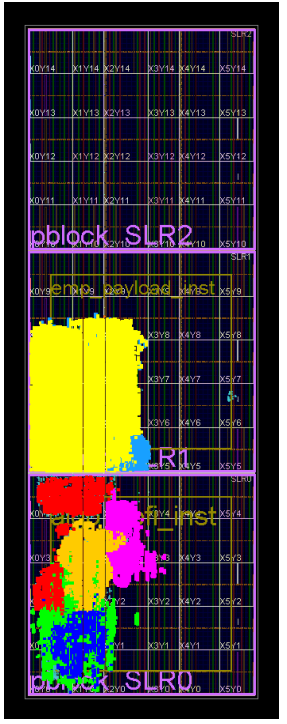
Tau Identification in the Correlator Trigger

Critical for identifying hadronically decaying τ

- Both single and double-τ
- Multiple algorithmic approaches to handle high pileup including
  - ML-based NN Tau algorithm
  - HPS Tau algorithm (adaptation o offline reconstruction methods) – in development at KBFI in collaboration with TalTech
  - Technically challenging to fit into available resources and timing

Addition of tracks at the trigger level enables lower cutoffs and better algorithms than Phase 1 tau triggers.





Summary

In preparation of the HL-LHC upgrade and increase in luminosity, CMS detector and trigger upgrades are well under way.

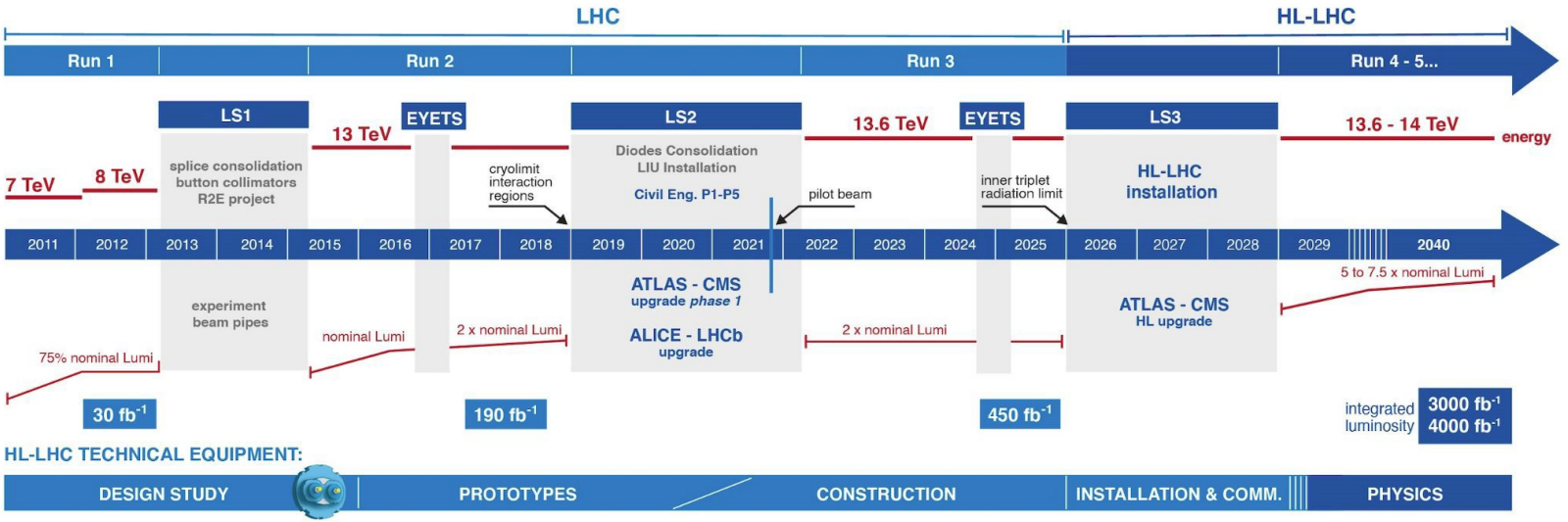
- Big challenges – but also big benefits
- New algorithms and electronics will be able to handle the data rate demands of the HL-LHC
- Will benefit both current rate-limited CMS analyses and enable new physics searches

The L1 Trigger Upgrade will have upgraded electronics and optics links

- Enables new algorithms and physics potential – including complex reconstruction algorithms similar to offline
- Gearing up for the long shutdown and electronics production
  - Hardware demonstrators and board-to-board tests are in progress
  - KBFI is contributing to the Correlator Trigger development

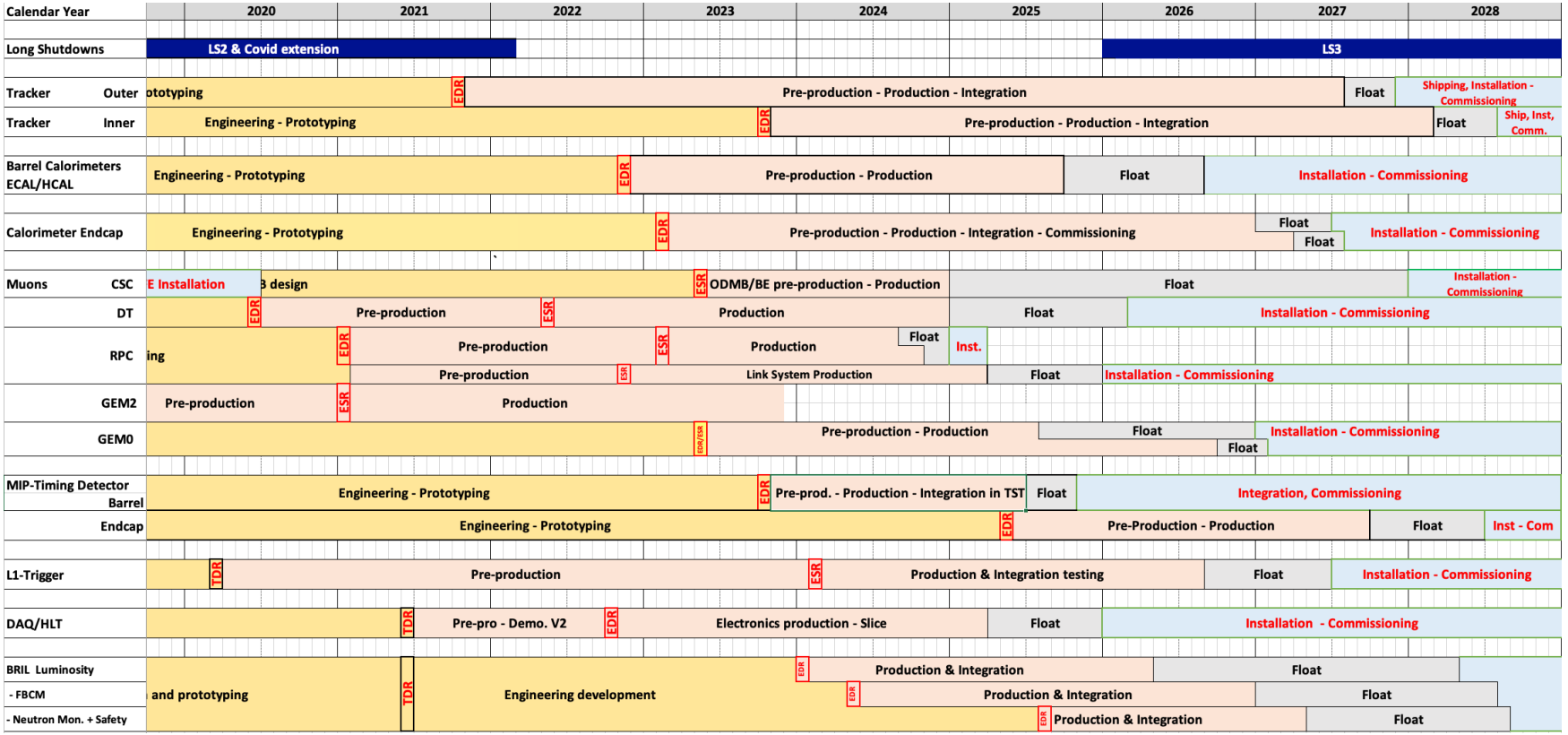
Backup

LHC / HL-LHC Plan



HL-LHC TECHNICAL EQUIPMENT:

HL-LHC CIVIL ENGINEERING:


Calendar Year
2020
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2024
2025
2026
2027
2028
Long Shutdowns
LS2 & Covid extension
LS3
Tracker Outer
ototyping
EDR
Pre-production - Production - Integration
Float
Shipping, Installation - Commissioning
Tracker Inner
Engineering - Prototyping
EDR
Pre-production - Production - Integration
Float
Ship, Inst, Comm.
Barrel Calorimeters ECAL/HCAL
Engineering - Prototyping
EDR
Pre-production - Production
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Installation - Commissioning
Calorimeter Endcap
Engineering - Prototyping
EDR
Pre-production - Production - Integration - Commissioning
Float
Float
Installation - Commissioning
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ESR
ODMB/BE pre-production - Production
Float
Installation - Commissioning
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EDR
Pre-production
ESR
Production
Float
Installation - Commissioning
RPC
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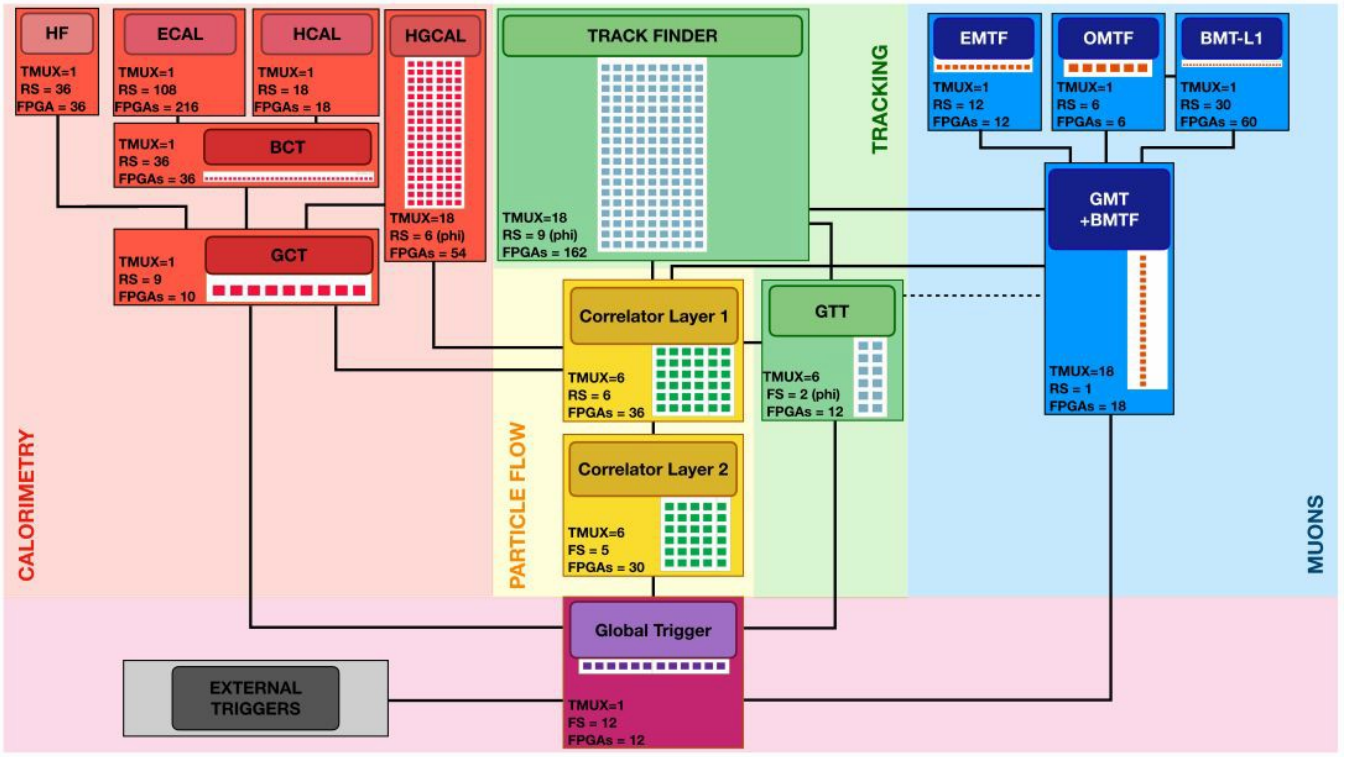
EDR
Pre-production
ESR
Production
Float
Inst.
Pre-production
ESR
Link System Production
Float
Installation - Commissioning
GEM2
Pre-production
ESR
Production
GEM0
EDR/ESR
Pre-production - Production
Float
Float
Installation - Commissioning
MIP-Timing Detector Barrel
Engineering - Prototyping
EDR
Pre-prod. - Production - Integration in TST
Float
Integration, Commissioning
Endcap
Engineering - Prototyping
EDR
Pre-Production - Production
Float
Inst - Com
L1-Trigger
TDR
Pre-production
ESR
Production & Integration testing
Float
Installation - Commissioning
DAQ/HLT
TDR
Pre-pro - Demo. V2
EDR
Electronics production - Slice
Float
Installation - Commissioning
BRIL Luminosity
- FBCM
- Neutron Mon. + Safety
and prototyping
TDR
Engineering development
EDR
Production & Integration
Float
EDR
Production & Integration
Float
EDR
Production & Integration
Float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FPGA = 36
ECAL
TMUX=1
RS = 108
FPGAs = 216
HCAL
TMUX=1
RS = 18
FPGAs = 18
HGCAL
TMUX=18
RS = 6 (phi)
FPGAs = 54
TMUX=1
RS = 36
FPGAs = 36
BCT
TMUX=1
RS = 9
FPGAs = 10
GCT
CALORIMETRY
TRACK FINDER
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RS = 9 (phi)
FPGAs = 162
TRACKING
EMTF
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RS = 12
FPGAs = 12
OMTF
TMUX=1
RS = 6
FPGAs = 6
BMT-L1
TMUX=1
RS = 30
FPGAs = 60
GMT
+BMTF
TMUX=18
RS = 1
FPGAs = 18
MUONS
Correlator Layer 1
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RS = 6
FPGAs = 36
GTT
TMUX=6
FS = 2 (phi)
FPGAs = 12
Correlator Layer 2
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FS = 5
FPGAs = 30
PARTICLE FLOW
Global Trigger
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FS = 12
FPGAs = 12
EXTERNAL
TRIGGERS