CMS status and its future

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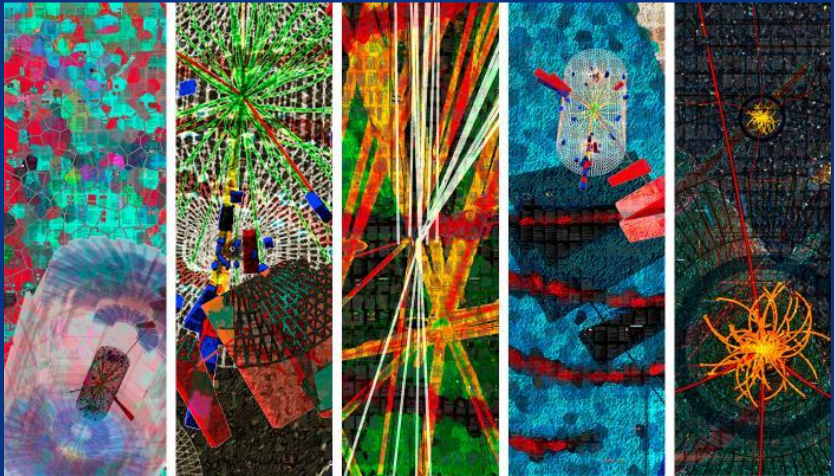
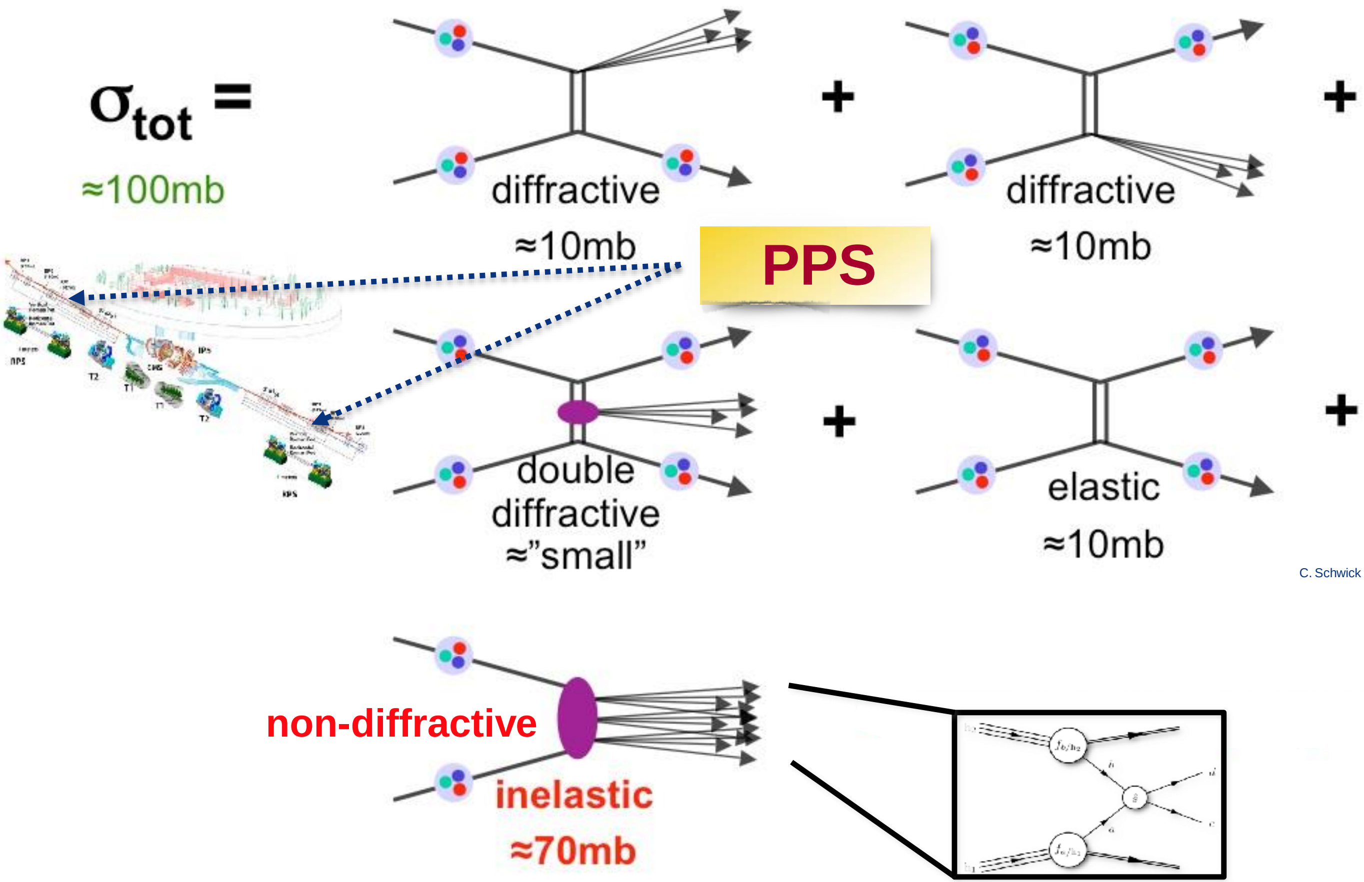
CMS DAS
Pisa Jan 28th 2019



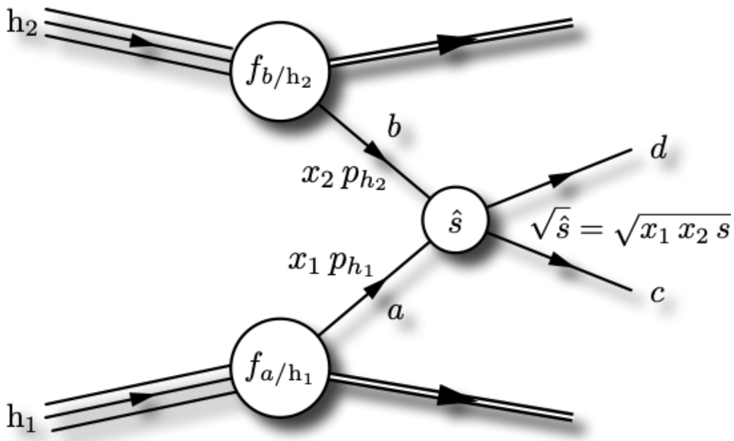
CMS is our experiment al LHC were LHC produce pp collision every 25ns (and Heavy Ions, mostly PbPb) at high energy, presently 13 TeV in the CM for pp, with very high luminosity, presently a peak of 2×10^{34} Hz/cm^2.

Given the pp inelastic cross section this means almost 60 overlapping event every 25ns

pp-Interactions at the LHC



Most of the focus: hard scattering



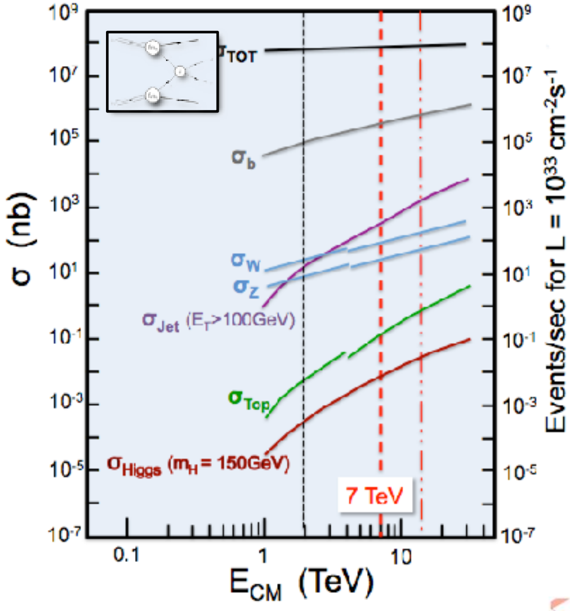
$$d\sigma(h_1 h_2 \to cd) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, \mu_F^2) f_{b/h_2}(x_2, \mu_F^2) d\hat{\sigma}^{(ab\to cd)}(Q^2, \mu_F^2)$$

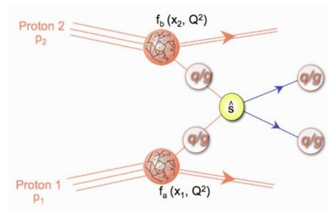
Hard Scattering = processes with large momentum transfer (Q^2)

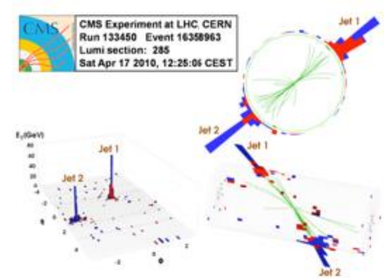
Represents only a tiny fraction of the total inelastic pp cross section (~ 70-80 mb)

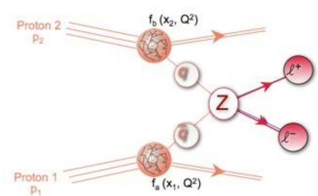
eg. **σ(pp → W+X)** ~ 150 nb ~ **2 · 10^{-6} σ_{tot}(pp)**

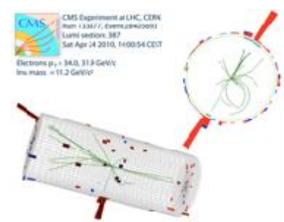
Measure a large range of Stadard Model processes and look for any signal beyond the SM

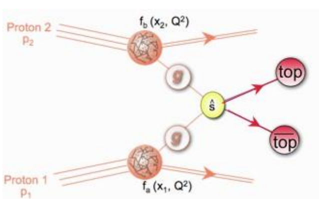


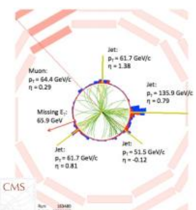


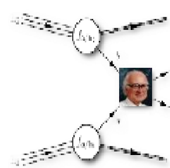


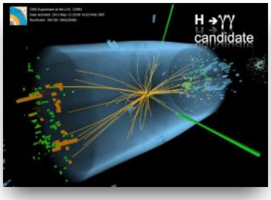




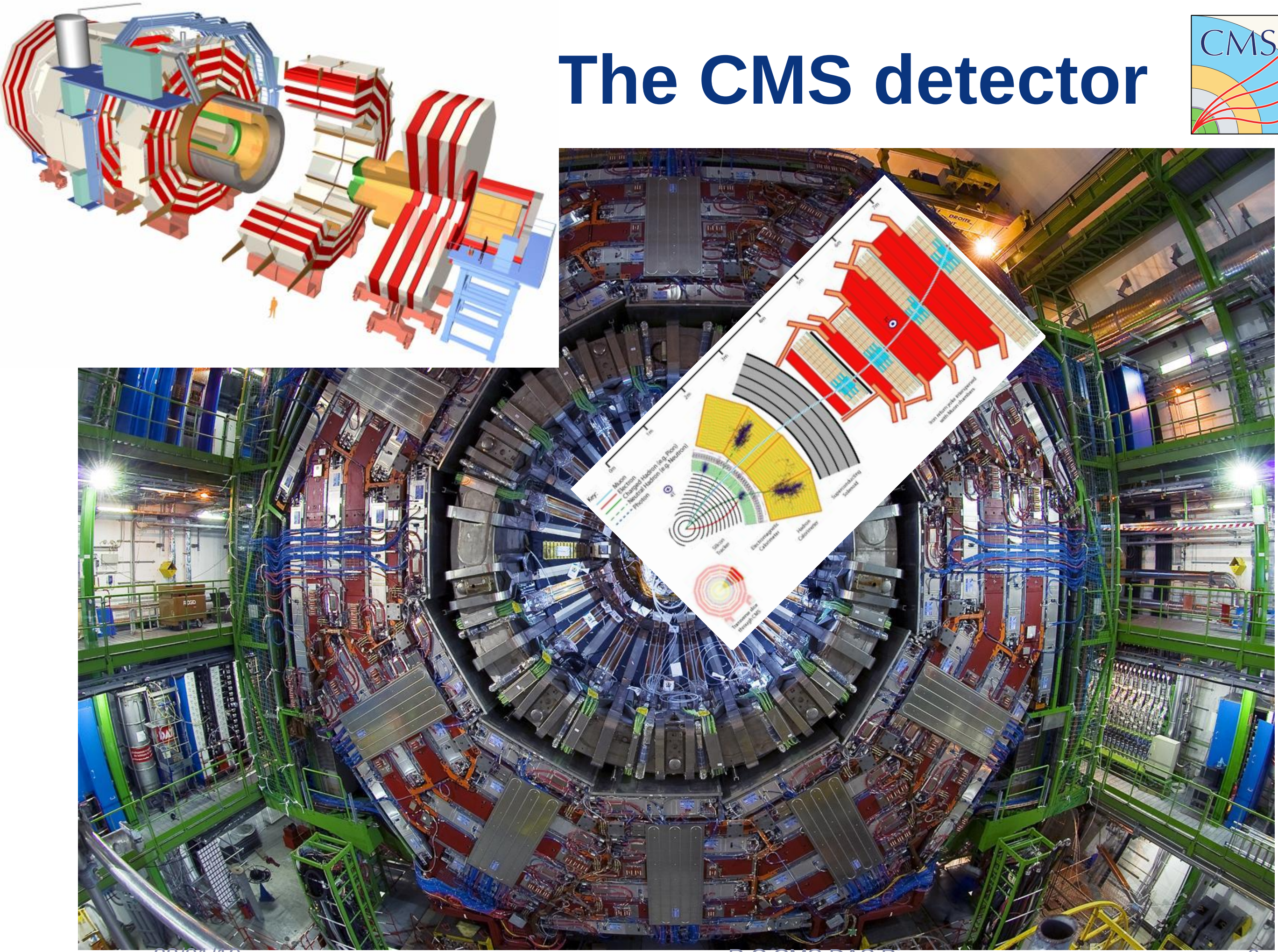




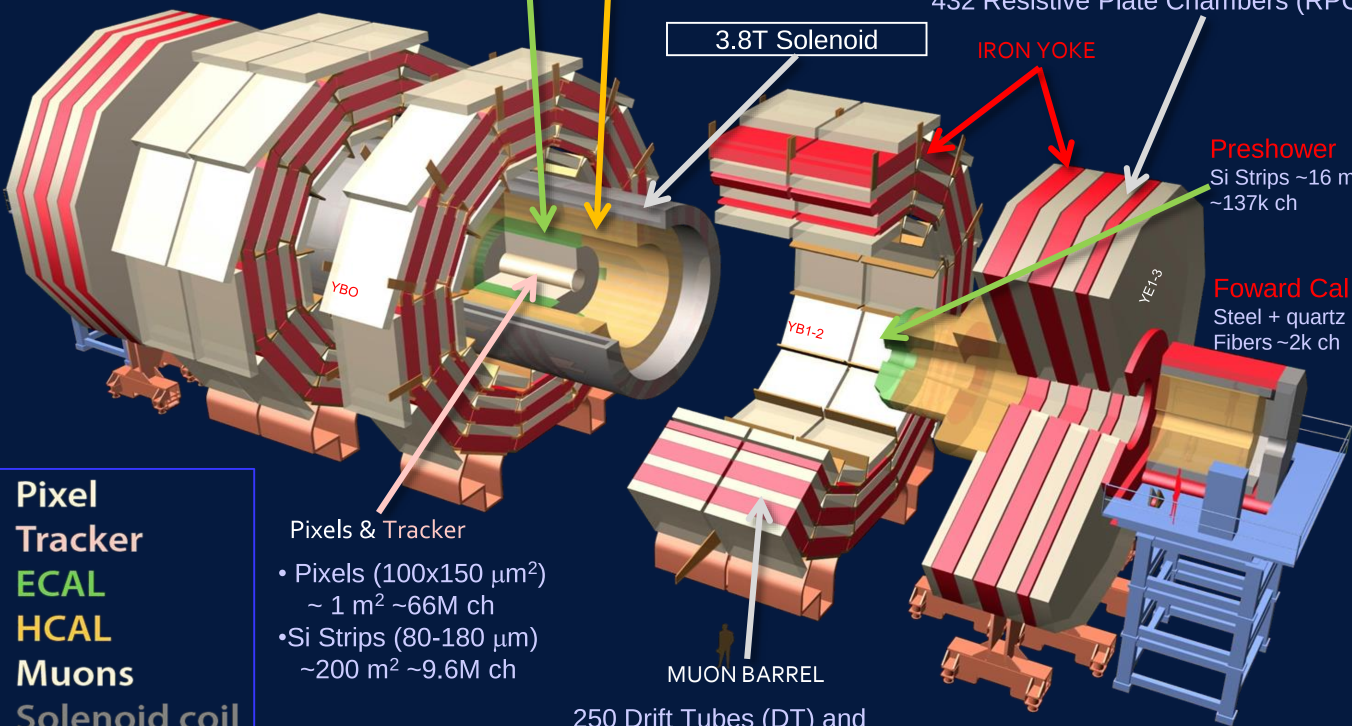




The CMS detector



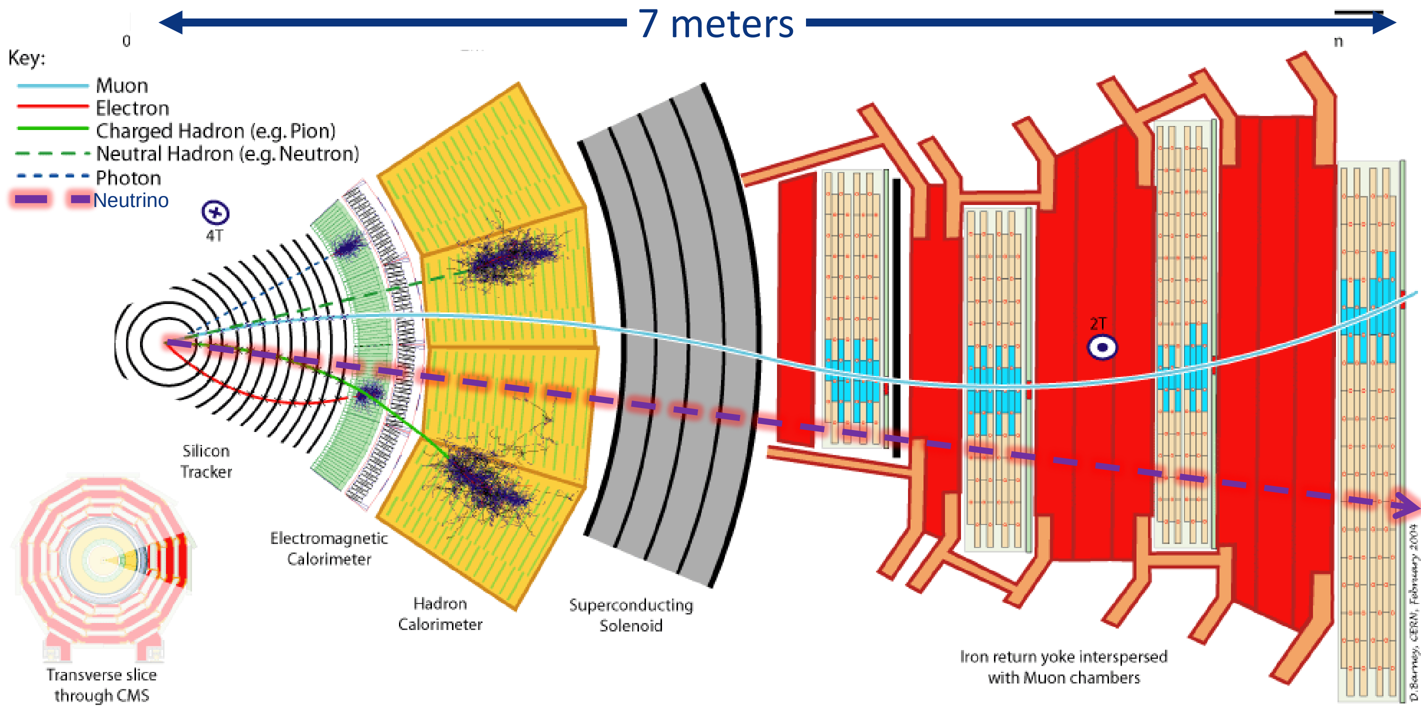
Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m



Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

Pixels & Tracker

- Pixels (100x150 μm^2)
  ~ 1 m^2 ~66M ch
- Si Strips (80-180 μm)
  ~200 m^2 ~9.6M ch

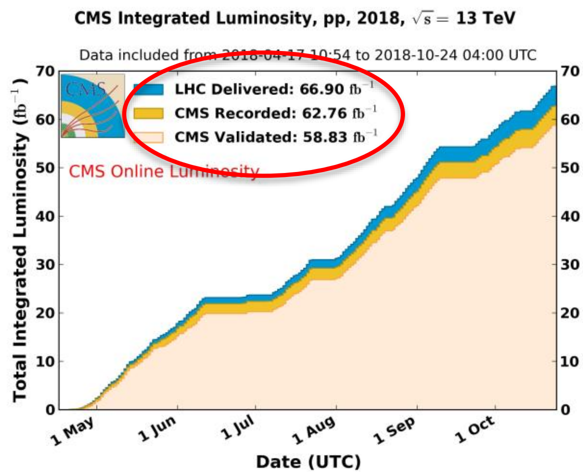

7 meters
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
Neutrino
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

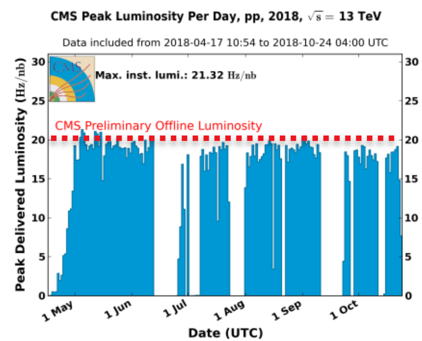
The LHC Luminosity Timeline

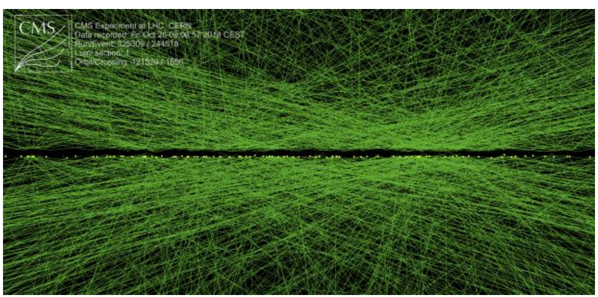
- We are at the end of a very successful pp run at 13 TeV
- We will have another pp run at 14 TeV starting in 2021, where the luminosity should at least double
- Then, after a shutdown for major upgrades, in 2026 LHC will start the high-luminosity run (HL-LHC) where the luminosity will increase x10
- **So far LHC has delivered 5% or less of the total planned integrated luminosity!**

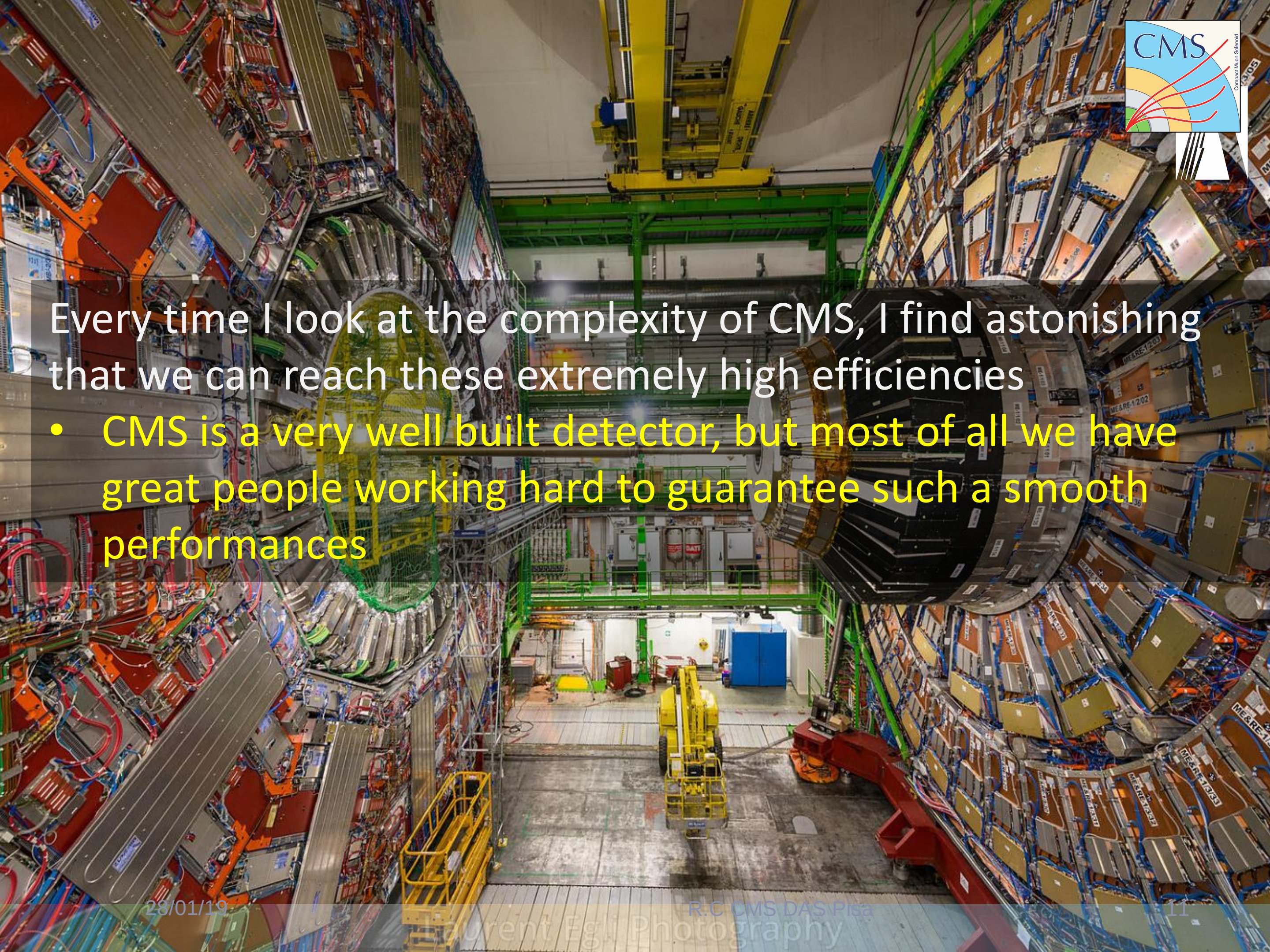
CMS proton-proton run in 2018

- **Excellent performance of CMS**
  - About 94% recording efficiency
- With peak luminosity grazing 2 10^{34} Hz/cm^2, a factor 2 higher than the initial design
  - Which means, a large number of overlapping event every crossing (pileup)





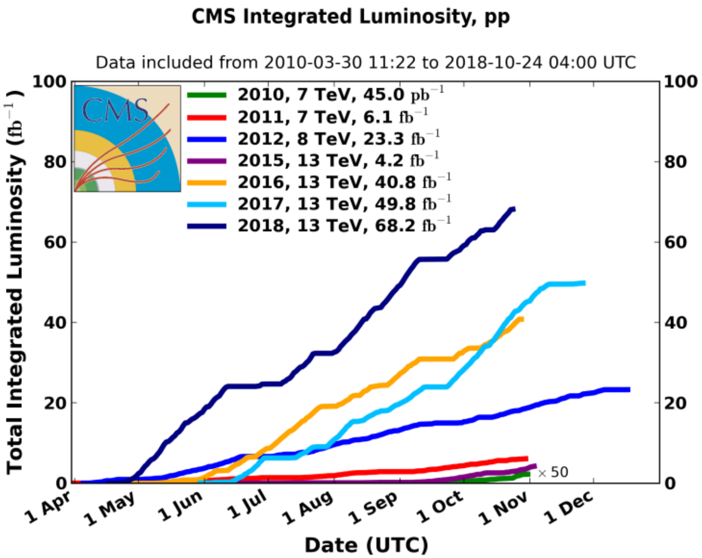




Every time I look at the complexity of CMS, I find astonishing that we can reach these extremely high efficiencies

- CMS is a very well built detector, but most of all we have great people working hard to guarantee such a smooth performances

Run 2 pp final score



Final score is:

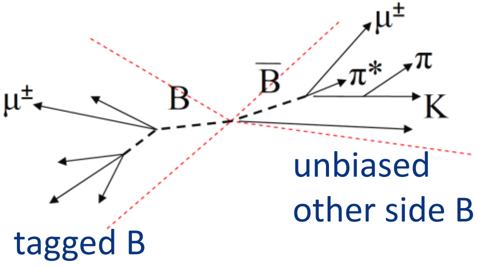
- 68.2 fb^{-1} delivered to CMS in 2018
- 163 fb^{-1} delivered overall in Run 2
- 192.5 fb^{-1} from 2010

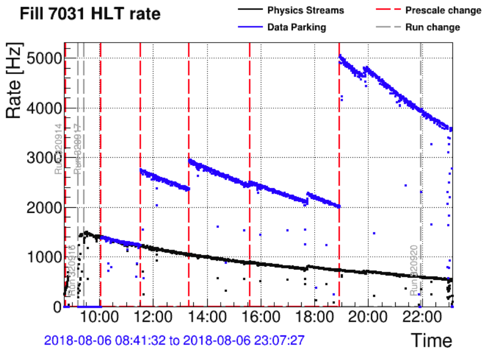
A large dataset to analyse in the coming years, before starting again in 2021

B parking

In 2018 CMS has also stored a large B hadron sample unbiased by any selection process by tagging on the «opposite side» of the $B\bar{B}$ pair

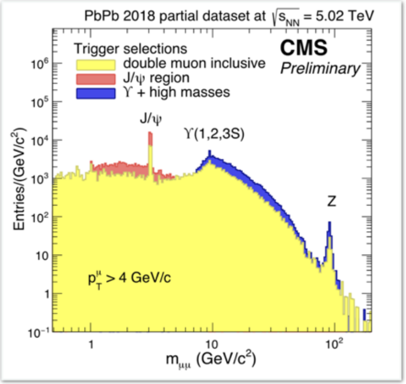
- CMS parked (→ no prompt reconstruction) 12 billions of B triggers
- Now working on improved reconstruction, in particular for low p_T electrons, to enhance the sensitivity to rare decays and flavour anomalies

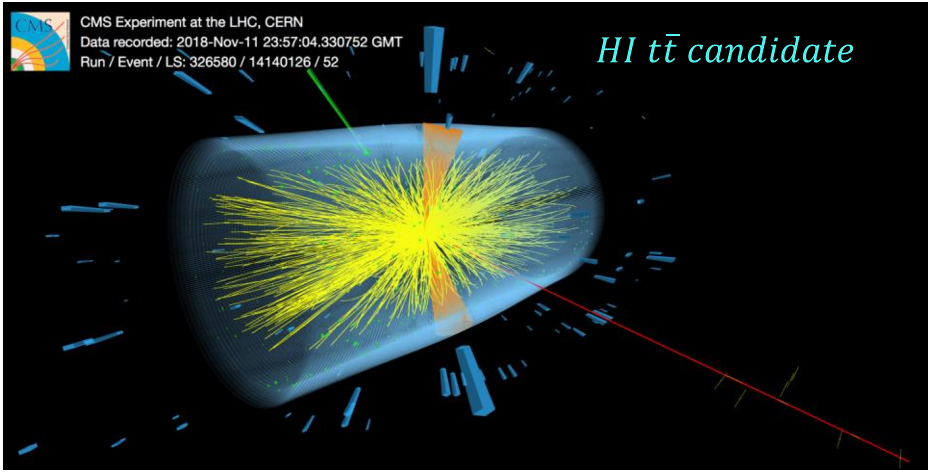


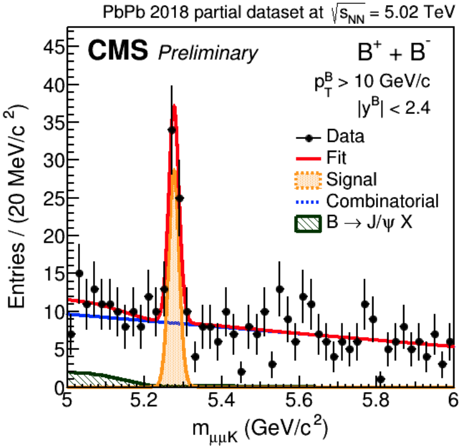


CMS is strong also on Heavy Ion physic

- **In 2018 we collected 1.80 nb^{-1} of PbPb collisions**
- **And more than 4 billions minimum bias triggers**



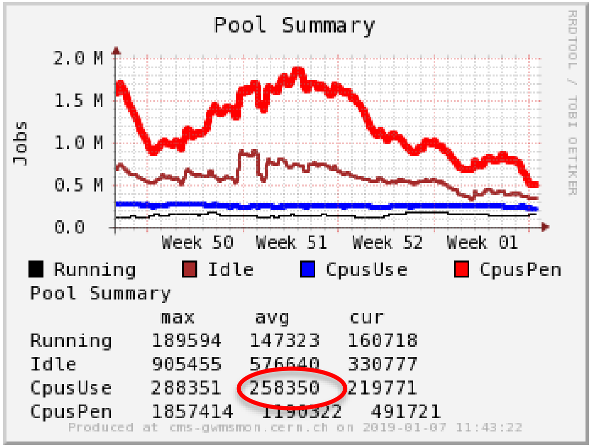




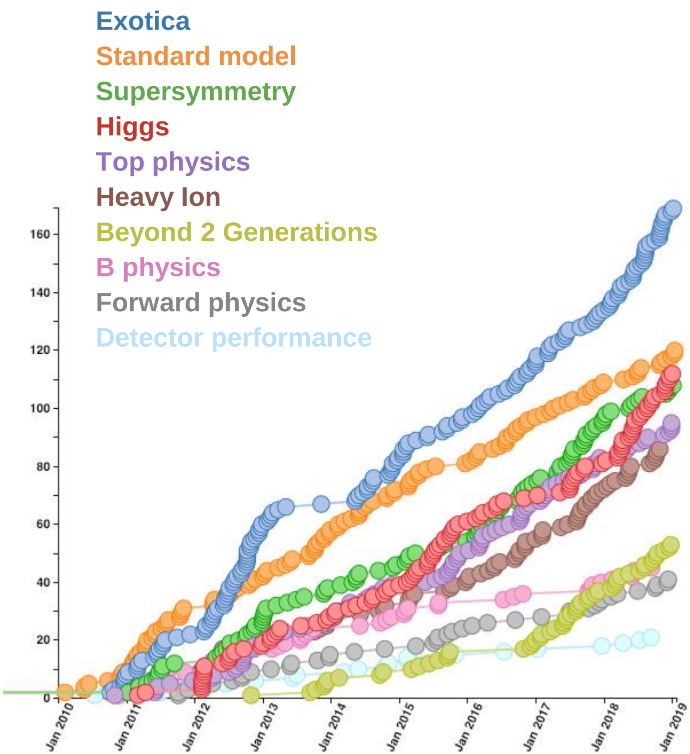
What are we doing with all the data we collected

A complex process, which we manage to handle with incredible speed

- We store it of disk and tape
  - CMS wrote 17PB of raw data only in 2018
- We reconstruct and analyse with the <u>most up-to-date algorithms</u> in a world wide distributed system
  - Average of 250k cores in use across Xmas!
- And we publish quite promptly a large amount of papers



CMS Publications

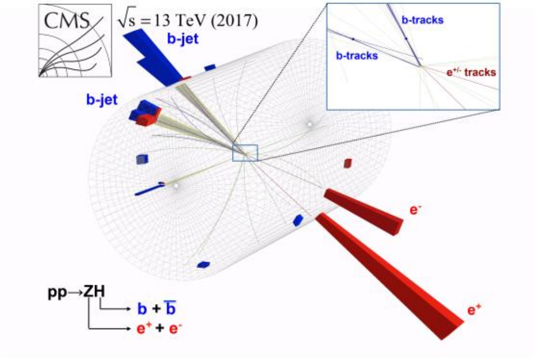


CMS has submitted, as of last week, more than 850 publications on collisions data in a wide variety of physics (and detector) topics.

- Staggering publication rate: 104 per year since Jan 2010, and growing
- 141 publications in 2018, record for any HEP experiment
  - Previous record was CMS in 2017 with 132

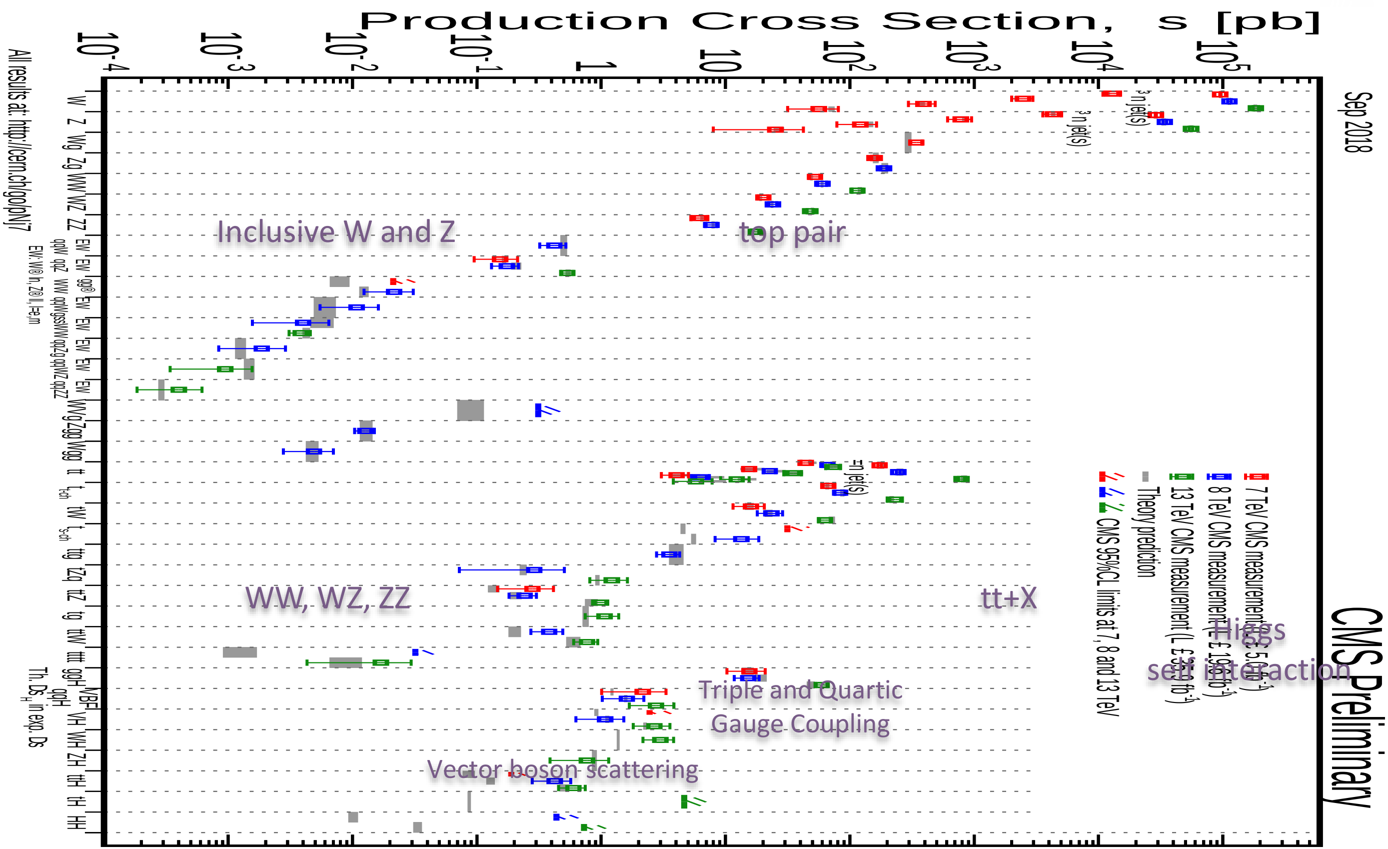
2018 was the year of the Yukawa couplings

- CMS presented the **observation** of the Higgs boson coupling to b quarks. With the observation of the couplings to τ lepton and top quark, we completed the observation of the coupling to 3rd generation fermions
  - A great success of LHC and the experiments, much earlier than expected thanks to the outstanding performance of LHC but also to very refined analysis techniques



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}D\psi$$
$$+|D_\mu\phi|^2 - V(H)$$
$$+Y_{ij}\psi_i\psi_j\phi + \text{h.c.}$$

SM cross sections range at LHC



A disclaimer

The extraordinary measurements we make result from lots of efforts over all aspects of the apparatus we use

- This may be lost on the “casual” observers who just hear a talk on physics result discussing about algorithms, plots, fits
  - Data is not a set of “four-vectors” coming from disks files, it is a complex product of our detector and selections
- There are lots of aspects that need to be understood
  - Accelerator
  - Detector
  - Trigger and Data Acquisition
  - Simulation and Offline reconstruction
  - Alignment and Calibration

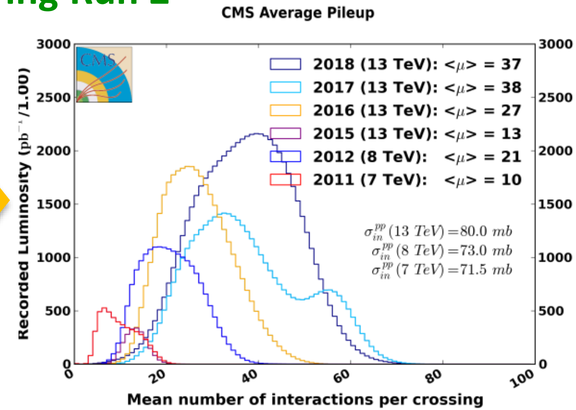
An experiment like CMS is all of this, and understanding it and working on it can be the key to the success of the analysis

CMS Phase I Upgrade

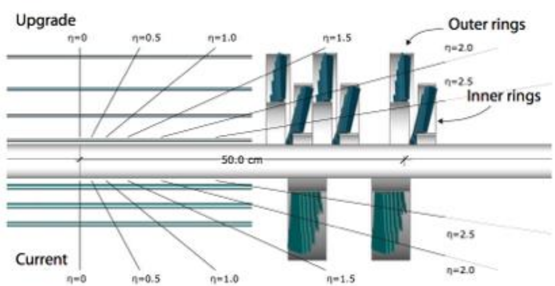
We have already upgraded substantially the detector (Phase I CMS upgrade) with substantial benefits already during Run 2

Examples (but much more was done)

- L1 Trigger upgrade was installed in 2015 and used starting in 2016. Essential to handle the very high luminosity and pileup LHC is already producing

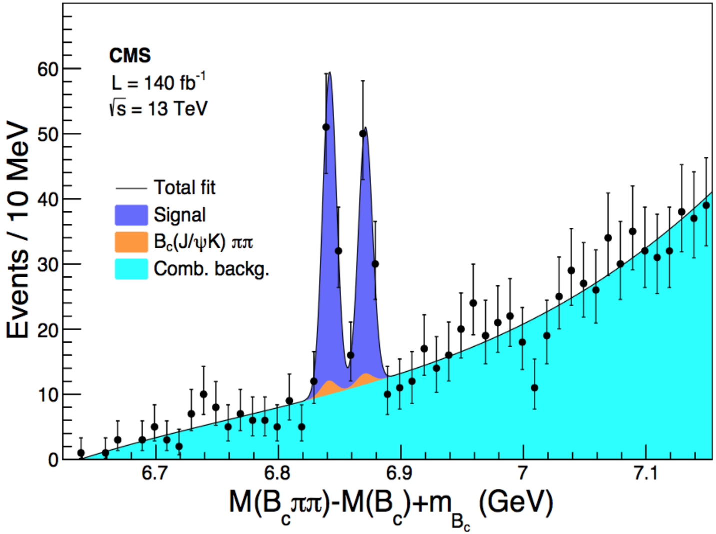


- New pixel detector (4 layers instead of 3, inner layer close to the beam, longer lever arm) installed in the extended shutdown in winter 2016/17



A recent example of data quality

- Observation of the $B_c(2S)^{\pm}$ and $B_c^*(2S)^{\pm}$ states
  - Previously ATLAS had reported a single-peak observation w/ mass consistent with the $B_c(2S)^{\pm}$
  - No significant signal reported by LHCb



1st observation of well-resolved $B_c(2S)^{\pm}$ & $B_c^*(2S)^{\pm}$ peaks

Excellent performance of our pixel and outer tracker

First full Run 2 (140 fb^{-1}) analysis to be approved

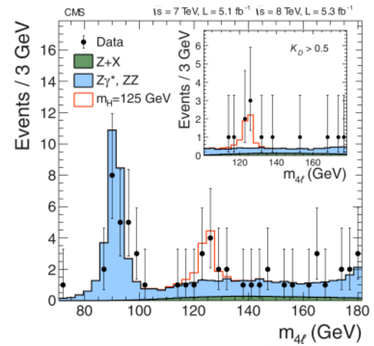
The coming years

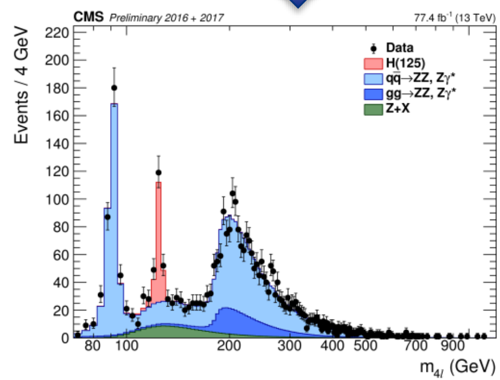
… do we really need more data?

Yes

- We make progress with:
  - <u>Larger datasets</u>
  - Increased energy (will go to 14 TeV in 2021, not a big step)
  - <u>New ideas and techniques</u>

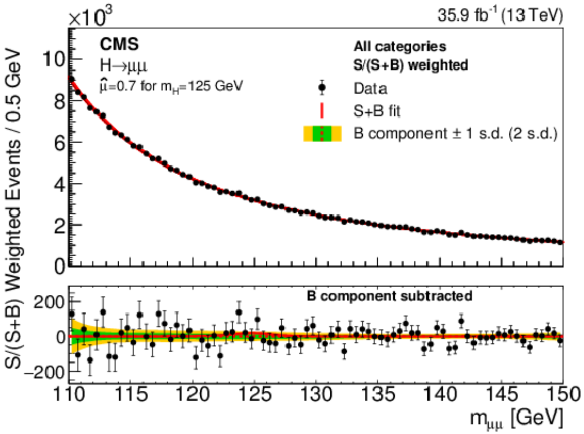
- And we need to make progress, because we don't know what is next, but we now it must be there, as Standard Model fails to explain important observations
  - It is not "a needle in a haystack" like for the Higg, is "God knows what in the haystack"
  - Direct searches are still open for rare processes
  - Precision (i.e. challenging, do not come automatically with statistics) measurements, e.g. in the Higgs sector
    - Probing the SM, which we have just started to measure, testing extended Higgs sectors etc

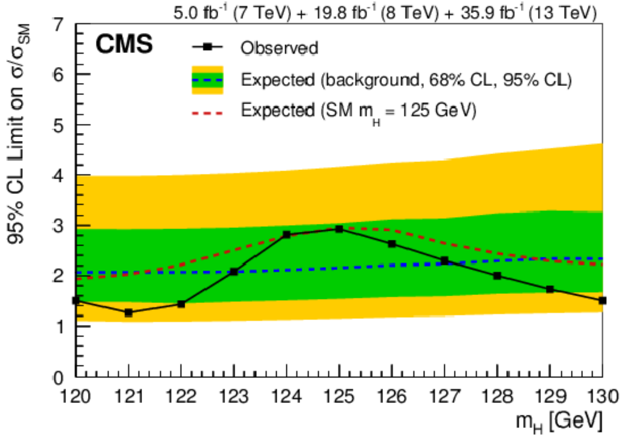




example H $\rightarrow\mu\mu$

Phys. Rev. Lett. 122, 021801 (2019)





Already tackling H →μμ thanks to excellent detector performance

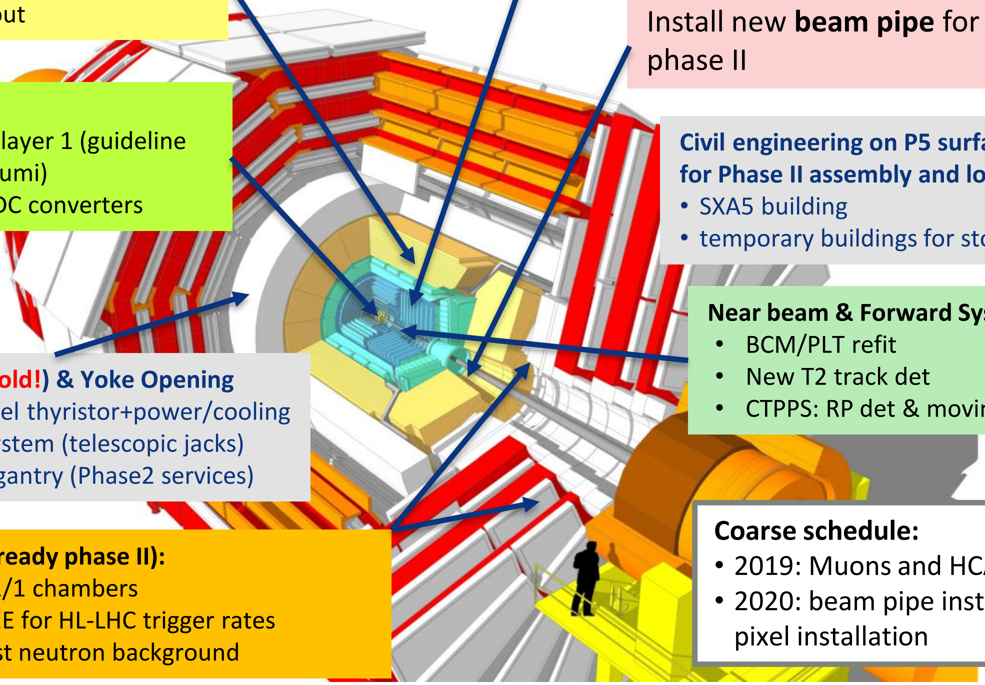
- Looking forward to updated result **with a larger dataset**
- Expect evidence with Run 3 dataset

Upper limit on the SM Higgs branching fraction to muons of 6.4 x 10^{-4}.

- This observed limit is 2.92 (2.16 expected) times the SM value.

2016

A challenging shutdown (LS2) in the next 2 years



Keep **strip tracker** cold to avoid reverse annealing

HCAL barrel (last phase I): install SiPM+QIE11-based 5Gbps readout

Install new **beam pipe** for phase II

Pixel detector:
- replace barrel layer 1 (guideline 250 fb-1 max lumi)
- replace all DCDC converters

Civil engineering on P5 surface to prepare for Phase II assembly and logistics
- SXA5 building
- temporary buildings for storage/utility

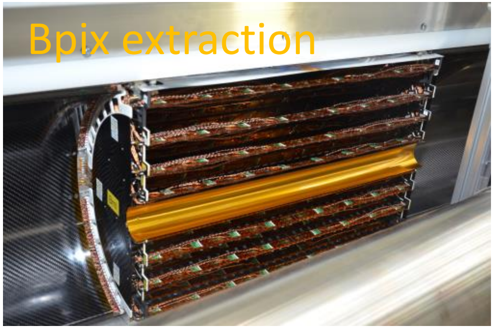
Near beam & Forward Systems
- BCM/PLT refit
- New T2 track det
- CTPPS: RP det & moving sys upgrade

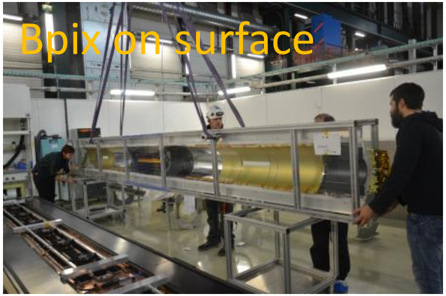
MAGNET (stays cold!) & Yoke Opening
- Cooled freewheel thyristor+power/cooling
- New opening system (telescopic jacks)
- New YE1 cable gantry (Phase2 services)

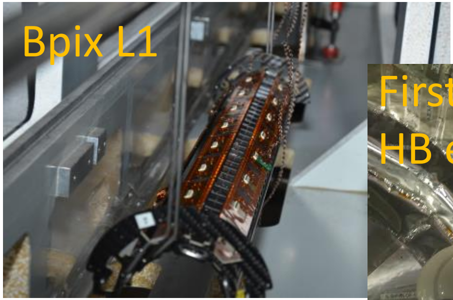
Muon system (already phase II):
- install GEM GE1/1 chambers
- Upgrade CSC FEE for HL-LHC trigger rates
- Shielding against neutron background

Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

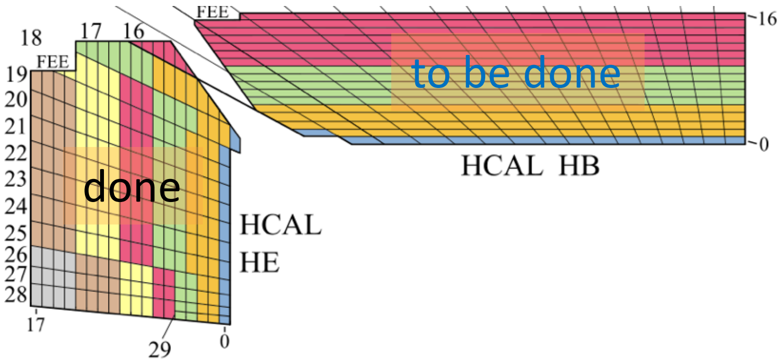
LS2 has started

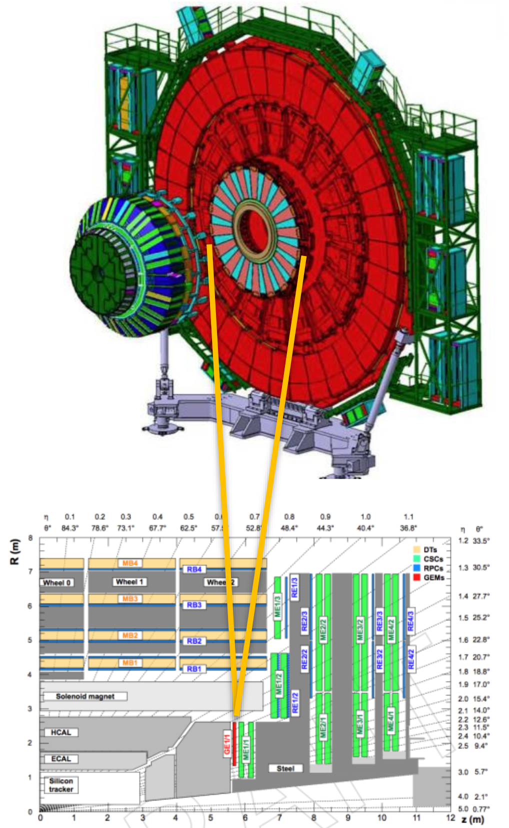






CMS after Long Shutdown 2



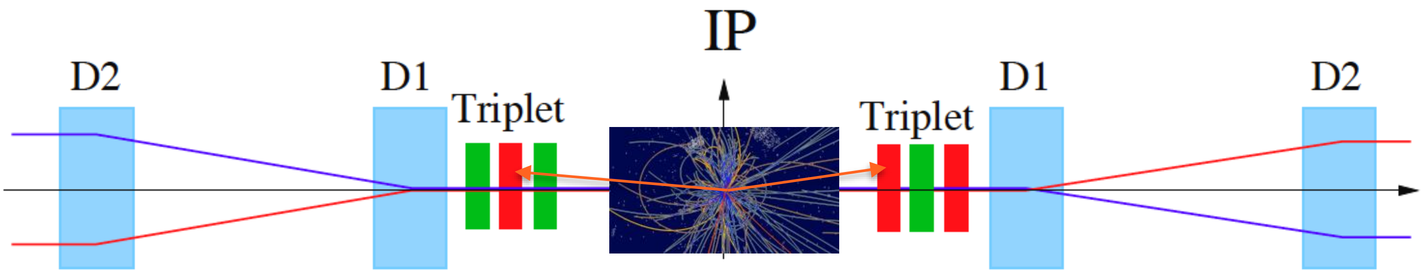


- **After LS2 CMS (and its data) will be, again, different:**
  - **Longitudinal segmentation (and much better S/N) in the HCAL**
  - **New muon GEM detector in the endcap**

so, CMS is evolving

- CMS is an evolving detector, which lives in an evolving accelerator:
  - New, better performing detectors that need to be commissioned, understood and calibrated to make the best use of the data
    - E.g. the new depth segmentation of the Hadronic Calorimeter, how to better make use of it in trigger and Particle-Flow reconstruction (hence in the final analyses)?
  - Pile-up continuously increasing, putting new requirements on detectors, triggers and analyses
  - Very large data set, allowing precision measurements but requiring more resources and improved or new analysis techniques
- Lot of latitude to work, for (young) scientists

What do we expect in Run 3 (2021-2023)



- Debris from pp interactions reach “Triplet” superconducting magnets, releasing energy proportional to the instantaneous luminosity that need to be cooled
- Triplets cooling limits the peak luminosity to ~ $2x10^{34}$Hz/cm^2 at 14 TeV
- The integrated dose received by the Triplets is also limiting the total integrated luminosity before HL-LHC to ~ 450 fb^{-1}
  - Limit is 30MGy, how it translates to integrated luminosity depends on the details of machine optics used

What do we expect in Run 3 (2021-2023)

- We have already collected ~ 190 fb^{-1} so we expect to be limited to ~ 260 fb^{-1} in Run 3 by the radiation damage in LHC
- But will LHC be able to deliver that luminosity in 2021-2023?
- Probably yes. LHC expects to deliver 20-50 fb^{-1} in the first year (depending on the machine efficiency after the shutdown) and 100-110 fb^{-1} in the following two years

	2021	2022	2023
Intensity ramp up [10^{11} p/b]	0 → 1.4	1.4 → 1.8	1.8
	Round optics (Flat optics)		
Optimal fill length [h]	-- → 9.8 (10.8)	9.8 (10.8) → 14.6 (16.4)	14.6 (16.4)
β* [m] at IP1/5	**0.28 (0.50/0.15)**		
Integrated lumi in IR1/5 [fb^{-1}]	18 (19)	97 (102)	106 (110)

Then HL-LHC

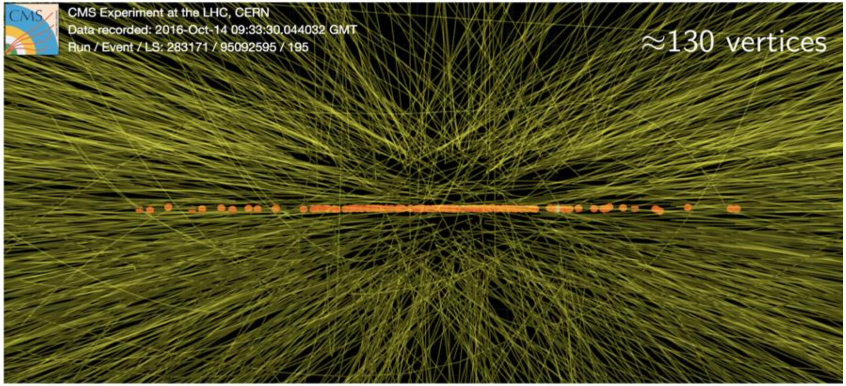
x5 Run1 x2 Run2 x10 Run3

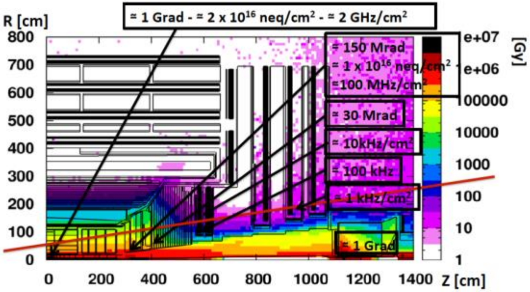
LHC will address the present limitations, in particular (but not only!) replacing the inner triples with 12T large aperture magnets

Notice, this is the Nominal Scenario:
L = **5.0**x10e^{34} cm^{-1}s^{-1} up to 3000 fb^{-1} **(140 PU)**
The Ultimate Scenario foresees:
L = **7.5**x10e^{34} cm^{-1}s^{-1} up to 4000 fb^{-1} **(200 PU)**

HL-LHC

- What is the impact on CMS detector: two strong requirements
  - Be able to trigger, readout and analyse data with high instantaneous luminosity and PU up to 140 (200)
  - Be able to cope with a much higher instantaneous and integrated radiation dose

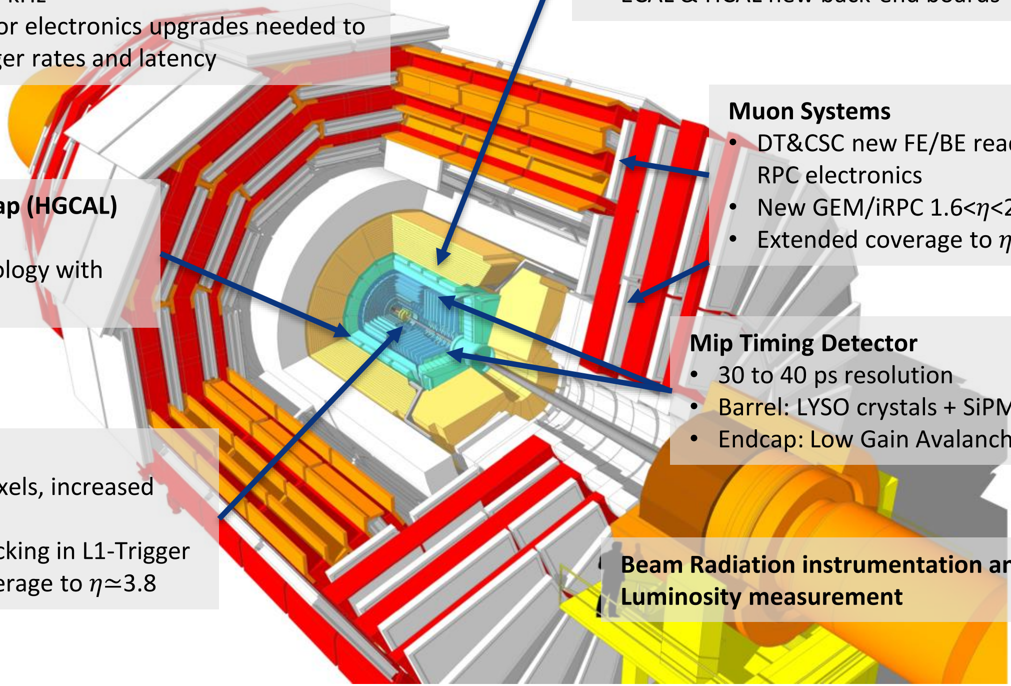




CMS Phase-II upgrades for HL-LHC

L1-Trigger/HLT/DAQ
- Tracks in L1-trigger at 40MHz for 750 kHz PFlow-line selection rate
- Latency up to 12.5 μs
- HLT output 7.5 kHz
- Several detector electronics upgrades needed to cope with trigger rates and latency

Barrel Calorimeters
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30GeV
- Low operating temperature $\simeq$ 10C
- ECAL & HCAL new back-end boards



Muon Systems
- DT&CSC new FE/BE readout, new RPC electronics
- New GEM/iRPC 1.6<η<2.4
- Extended coverage to $\eta\simeq3$

Calorimeter Endcap (HGCAL)
- Si, Scint+SiPM
- 3D shower topology with precise timing

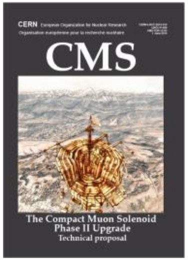
Mip Timing Detector
- 30 to 40 ps resolution
- Barrel: LYSO crystals + SiPMs
- Endcap: Low Gain Avalanche Diodes

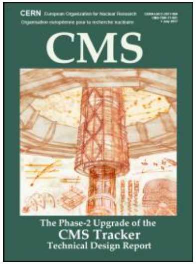
Tracker
- Si-Strip and pixels, increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta\simeq3.8$

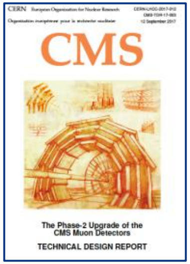
Beam Radiation instrumentation and Luminosity measurement

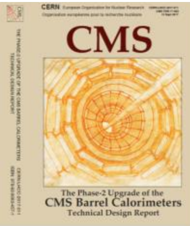
CMS is proud of the design of an upgrade with many innovative detectors

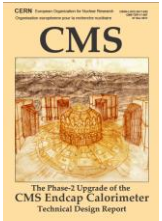
- **Tracker** is AGAIN ALL SILICON but now with much higher granularity, **and out to |η| =4** with >2 billion pixels and strips
  - Tracker designed to find all tracks with P_T>~2 GeV < 4 μs.
  - Tracking information in “L1 track-trigger”
- **High Granularity Endcap Calorimeters**
  - With combination of silicon pixels and scintillator to map full 3-dimensional development of all showers (~6M channels in all)
- **Precision timing of all objects**, including single charged tracks, provides a
  4th dimension to CMS object reconstruction to combat pileup
- **Extended muon coverage** up to η < 3 and ability to trigger on long-lived particles



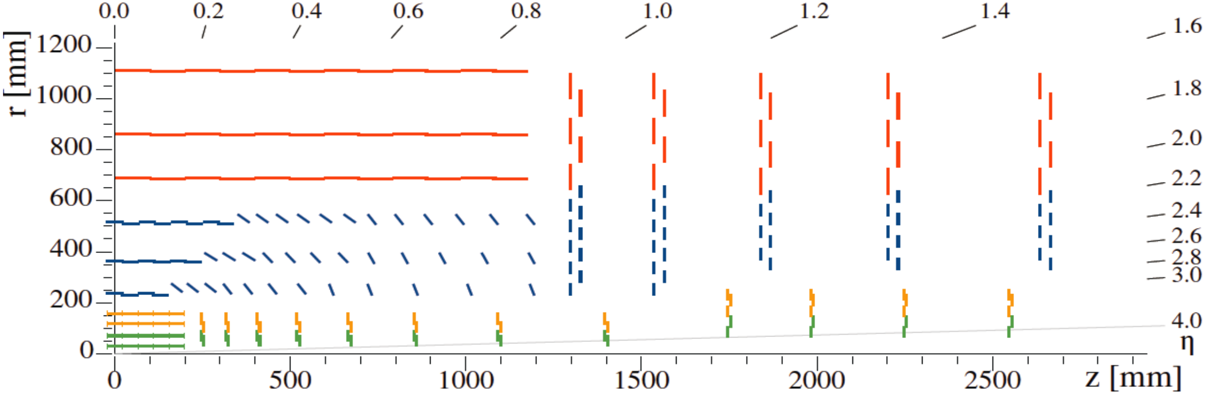






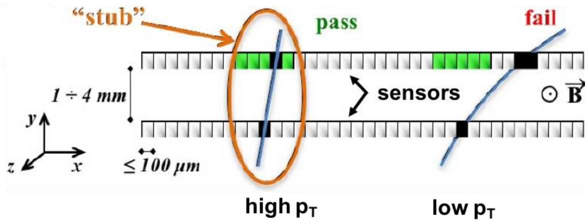


Tracker



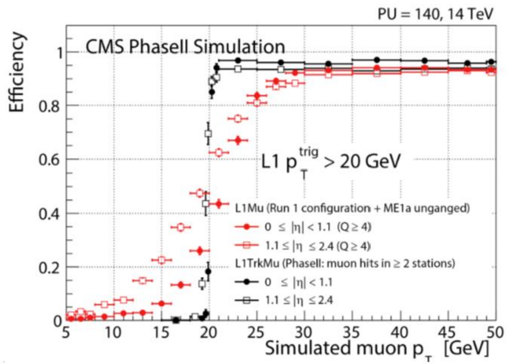
- **Acceptance up to |η| ~ 4**
- **Inner Tracker**
  - 4.9m^2, 2 x 10^9 pixels (6x smaller pixels than Phase-1 pixel detector)
- **Outer Tracker** with two types of modules: **s**trip **s**trip (2S) and **s**trip macro-**p**ixel (PS)
  - 192m^2, 42M strips, 170M macro-pixels (25m^2)
  - **Innovative tilted geometry in inner barrel layers of the outer tracker**

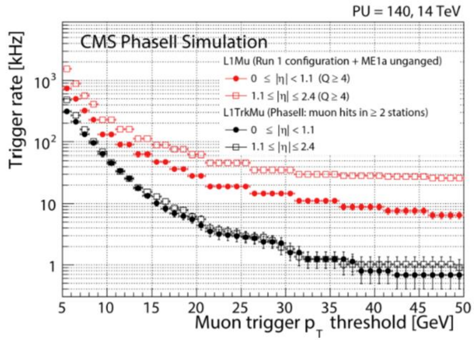
Tracker provides trigger primitives to L1



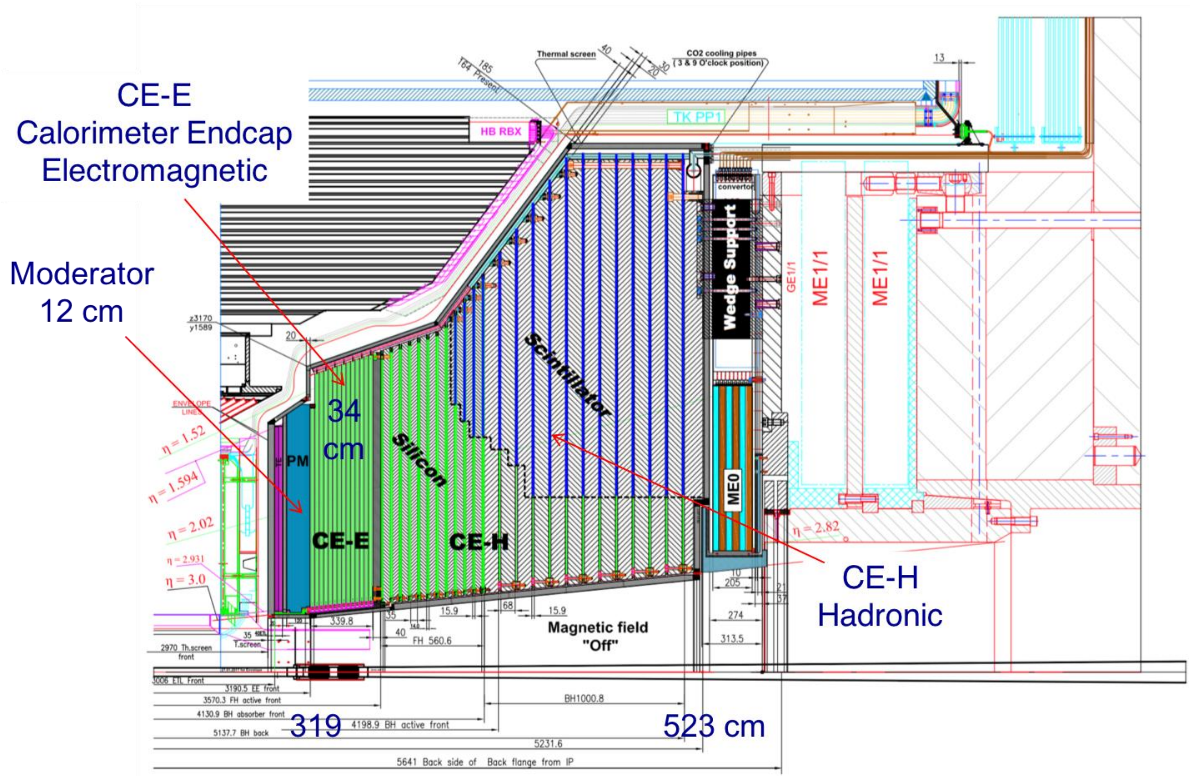
Outer tracker

- **"p_T modules"** with 2 sensors
- **Tracking at 1st trigger level** down to p_T~2GeV, |η|<2.4
- **"on detector" data reduction**
- **Fully independent source of trigger primitives (no "Region Of Interest" from outside)**





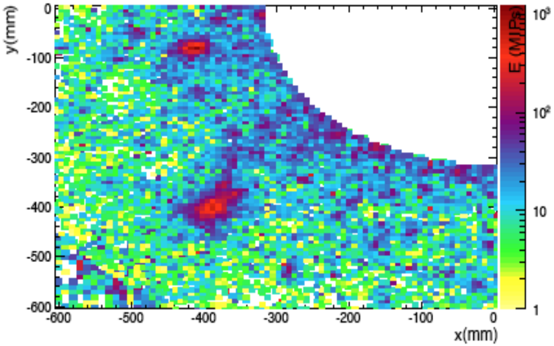
Endcap Calorimeter



Endcap Calorimeter

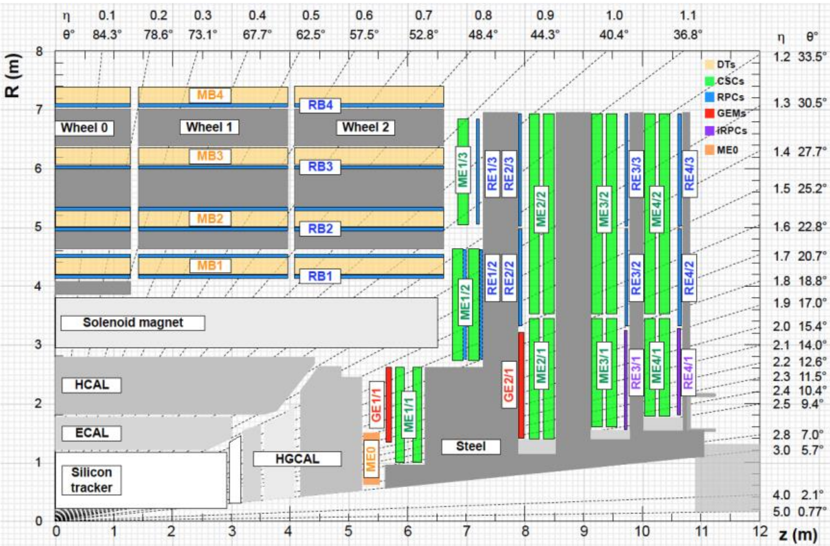
Another challenging design of CMS: highly-granular calorimeter endcap

- Mixed Si-Scintillator design, to guarantee the needed radiation hardness in different areas, and the granularity to survive in the high density environment of LH-LHC
- ~6M channels
  - 2% energy resolution for unconverted photons
  - As good or better e/γ identification as in Run 2
  - As good or better jet reconstruction
  - ~30-100 ps time resolution
  - Sensitivity to off-pointing γ, e, τ and jets
  - MIP (muon) tracking and identification capability



VBF $H \rightarrow \gamma\gamma$

Muon system



Barrel and endcaps:

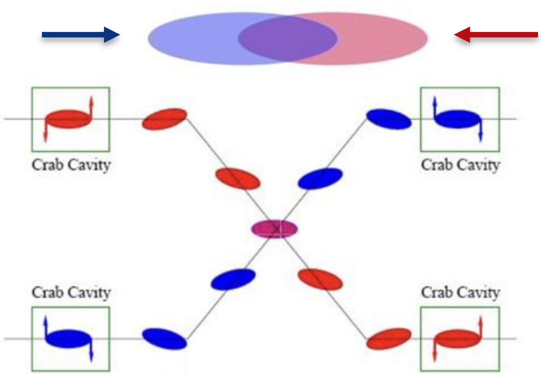
- replacement of readout electronics for the new L1 trigger conditions

Endcaps:

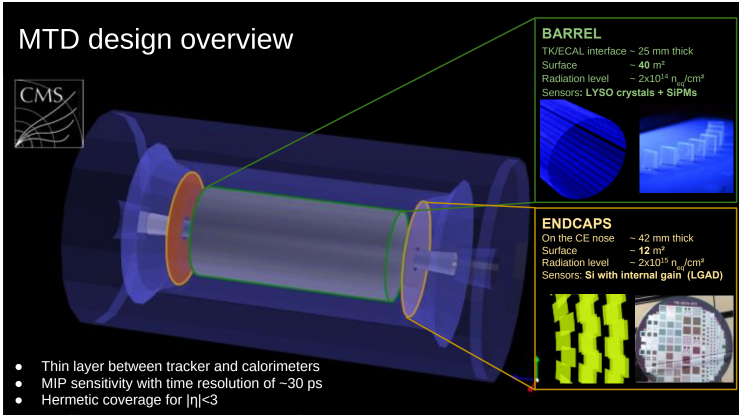
- **Robust trigger up to $|\eta|=2.4$** thanks to new RE3/1 and RE4/1 RPC stations and GE1/1 and GE2/1 GEM stations
- **Coverage extension up to $|\eta|=2.8$** by ME0 GEM station
- Standalone p_T measurement for **off-pointing muons** with 2 combined GEM/CSC stations

MIP timing detector (MTD)

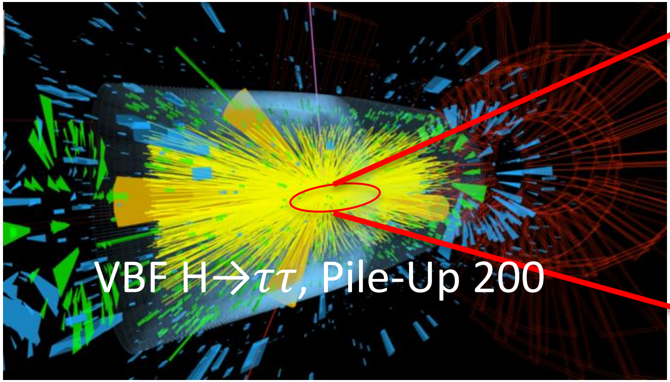
- Proton Collision in the LHC bunches are Spread in Time over an RMS of ~180 ps
  - **Currently CMS sees only the integral of this process over time**
  - An additional high resolution (~ 30 ps) **MIP Timing Detector** can help in discriminating charge particles from different vertices

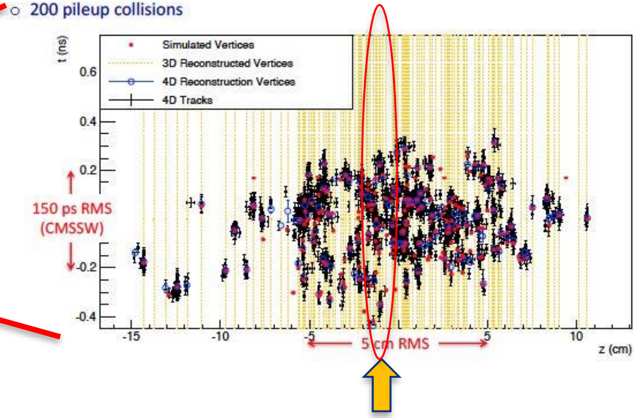


~ 180 ps RMS



MIP timing detector





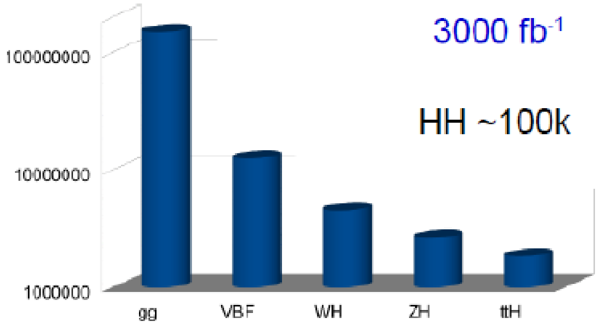
At a given z position, different vertices can be discriminated by time if the resolution is enough w.r.t. the time spread

What for?

Very few examples

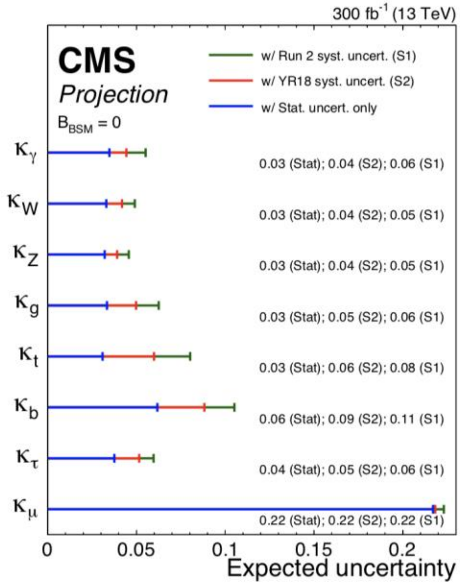
HL-LHC as Higgs factory

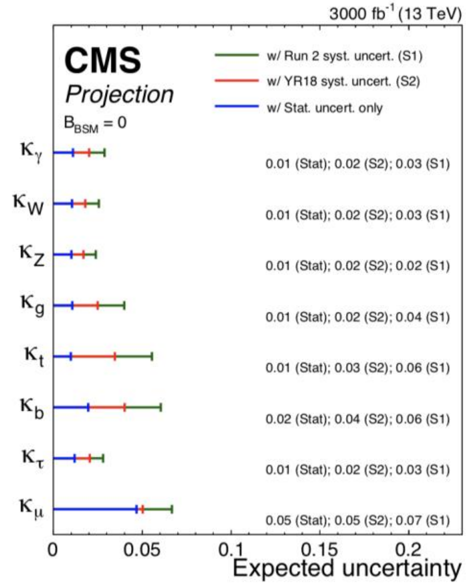
- HL-LHC is a Higgs factory, will produce > 150M Higgs bosons
  - Including ~120k of pair produced events



- Enables a broad program:
  - Precision O(1-10%) measurements of coupling across broad kinematics
    - can reveal new particles in loops or non-fundamental nature of Higgs
  - Exploration of Higgs potential (**HH** production)
  - BSM Higgs searches (extra scalars, BSM Higgs resonances, exotic decays…)

Sensitivity projections for Higgs boson properties

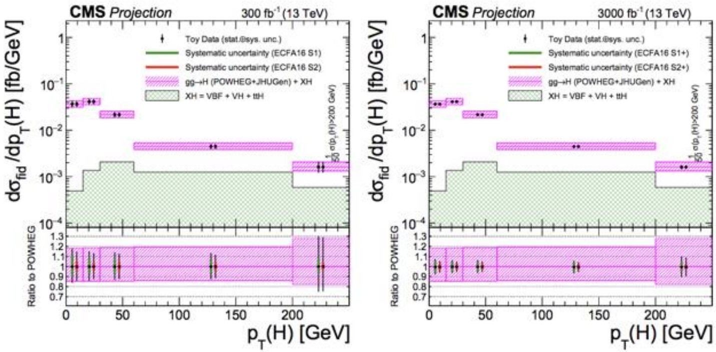


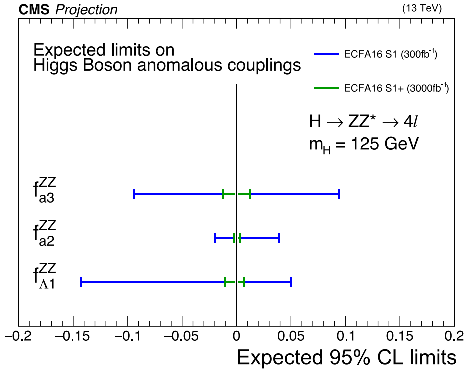


Detailed studies in the Higgs sector

Detailed studies of Higgs boson properties. Exclusive measurements will provide significant improvements. Examples:

- Differential cross section measurement of H→ZZ*→4l as a function of the Higgs p_T
- constraints on anomalous HVV tensor couplings



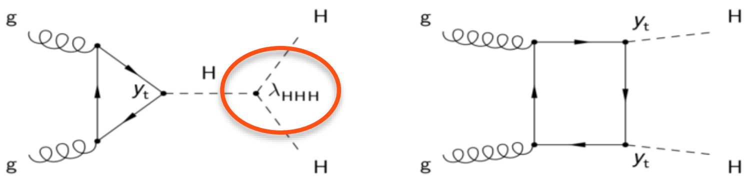


Higgs Self-Interaction

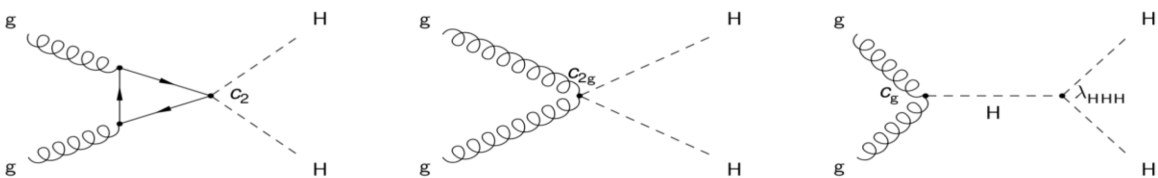
Measuring triple-Higgs coupling is a fundamental test of the SM

- SM predicts an extremely small cross section for HH production (39 fb at 14 TeV)

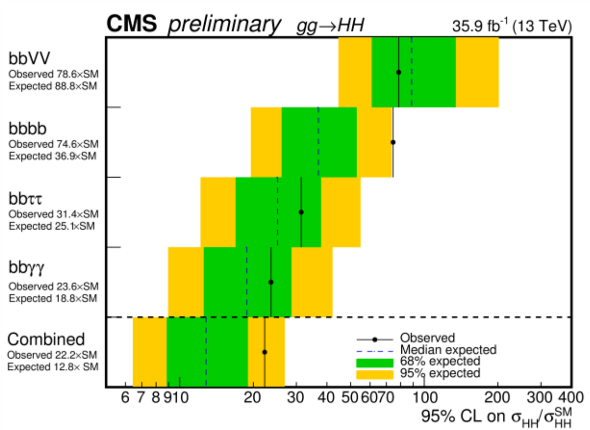
Standard Model

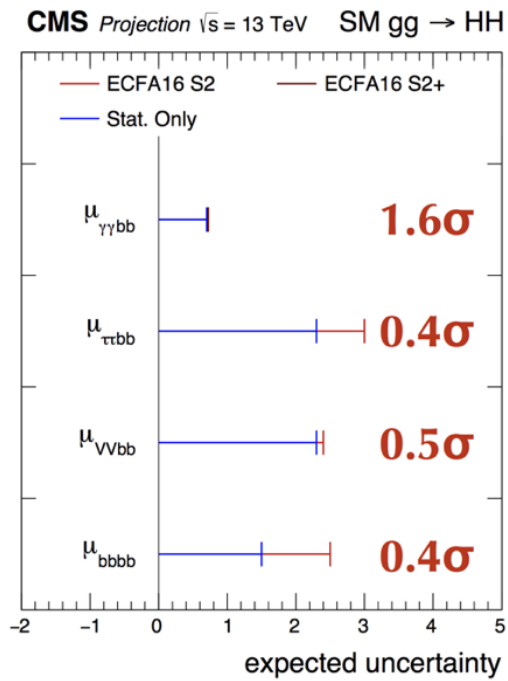


New Physics



Higgs Self-Interaction

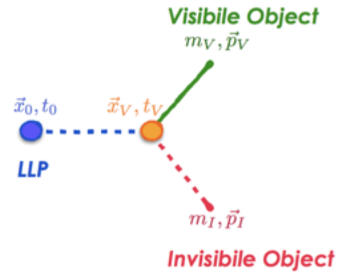


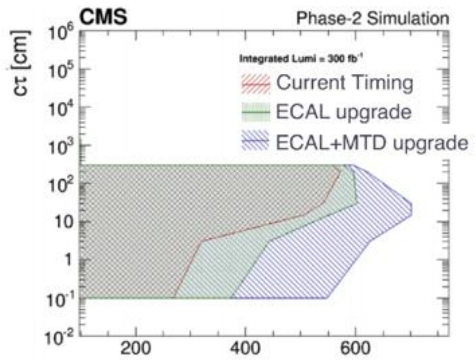


- Presently too small to measure, we can only put limits much above the SM prediction
- One clear goal of HL-LHC is to address the Higgs self-interaction

Long Lived Particles

- detection with dE/dx for Heavy Stable Charged Particles (HSCP)
  - Phase 2 Outer Tracker will include a threshold to separate “HIP” (particles with high dE/dx) from MIP
- Detection with displaced muons
  - Need ability to trigger muons without the vertex constraint (i.e. without the tracking trigger)
  - Benefit from the additional detectors in the Forward Muons System
- Detection with the timing detectors (MTD+Calorimeters)
  - Particles with a Long Life Time will arrive at the Timing Layer with some delay as compared to SM particles , with large increase in search reach





(a) $\chi_1^0 \rightarrow G + \gamma$ Limits

Summary and Outlook

- The quality of CMS Physics results continues to be excellent with many exciting analyses, using state of the art techniques,
- We will continue use the full Run 2 dataset, including the parked events, a large HI dataset and the results of 2018 special runs
- At the same time, while starting the HL-HLC upgrade, we will get ready to collect another large set of data in Run 3 from 2021 to 2023

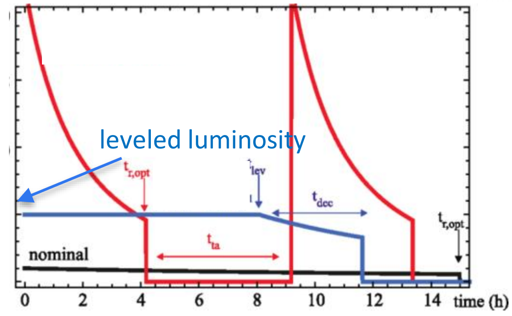
Closing Remarks

- **It is a very interesting time for (young) people working at LHC. We are at the same time:**
  - **Developing and building new detectors**
  - **Maintaining and upgrading present detector**
  - **Taking (a lot of) data**
  - **Analyzing an unprecedented amount of data, and developing new strategies to do that**
- **It is not common to have to do all this together, and it it is a unique opportunity for a student to learn all aspects of a very complex job.**

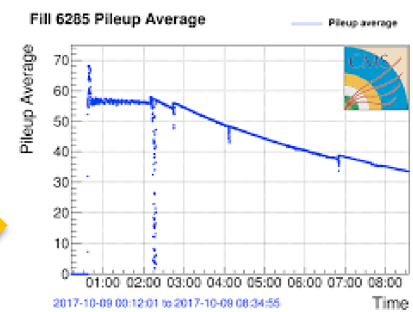
Backup slides

What do we expect in Run 3 (2021-2023)

- How?
  - The present bunch intensity was limited to 1.1 10^{11} protons/bunch in 2018, is expected to grow to 1.4 10^{11} in 2021 and 1.8 10^{11} in 2022-23 because of the new injector chain (LIU)
  - The peak luminosity was already at 2 10^{34} Hz/cm^2 with 1.1 10^{11} p/bunch so cannot grow, but we can run for long with “luminosity levelling“ (expected for 5h at the end of 2021 and 9h in the following years
  - This means that the average pile-up will be higher than in the past



8b4e - levelled



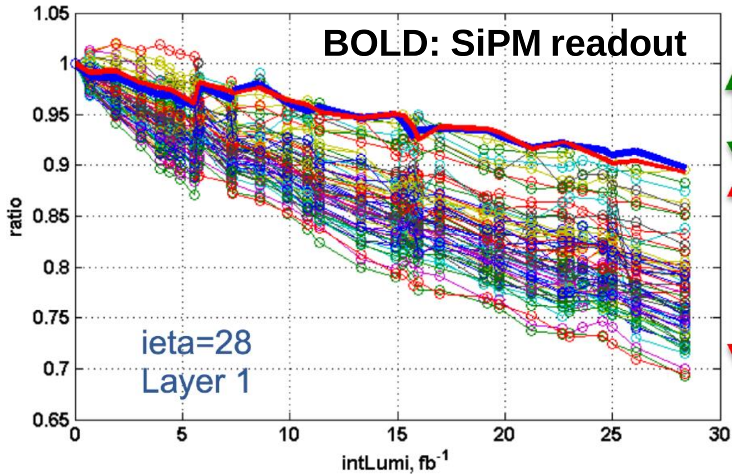
We were already levelled in 2017

GE1/1 production

Barrel Calorimeter

Thanks to the studies on the HE phase 1 upgrade we could decide that we do not need to replace scintillator layers in the Barrel HCAL, much of the observed HE damage was due to HPD deterioration.

- **Upgrade scope in EB and HB is “limited” to the electronics an cooling**



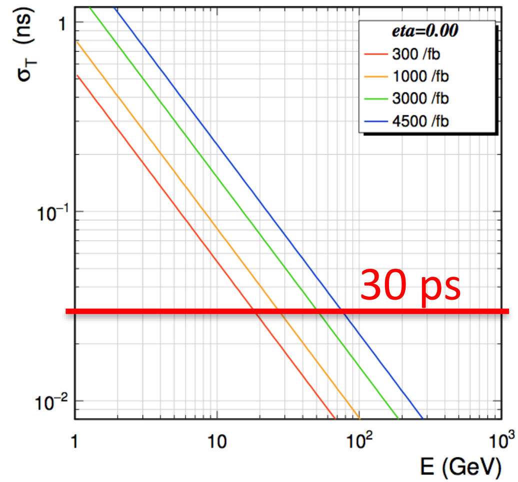
Barrel Calorimeter

improve !

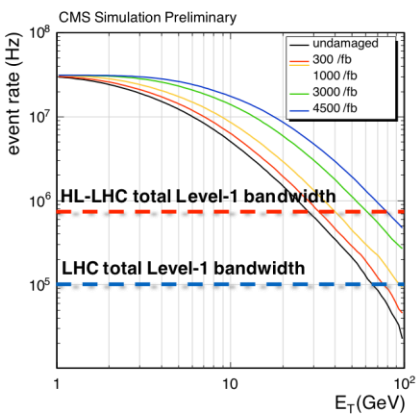
- The aim of the upgraded detector is ~~to preserve~~ the current Run 1 performance in the challenging HL-LHC conditions
- EB+HB
  - New common backend board to cope with increased L1 trigger rate and latency
- EB
  - Cool supermodules to 9℃ to mitigate APD noise increase
  - New on-detector electronics
    - Full granularity to L1 trigger and APD spike rejection
    - Shorter signal shape to minimize noise and allow 30ps time resolution for >30 GeV showers

Barrel Calorimeter

- 30ps time resolution reachable for reasonable photon energies, significantly improving the vertex localization



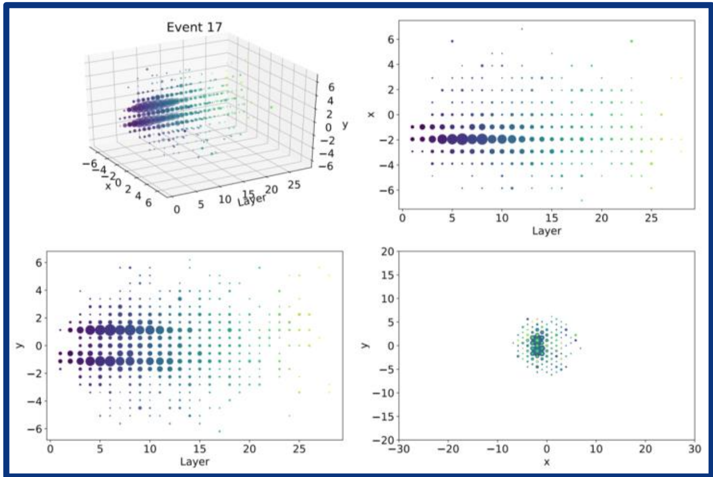
APD spike in CMS



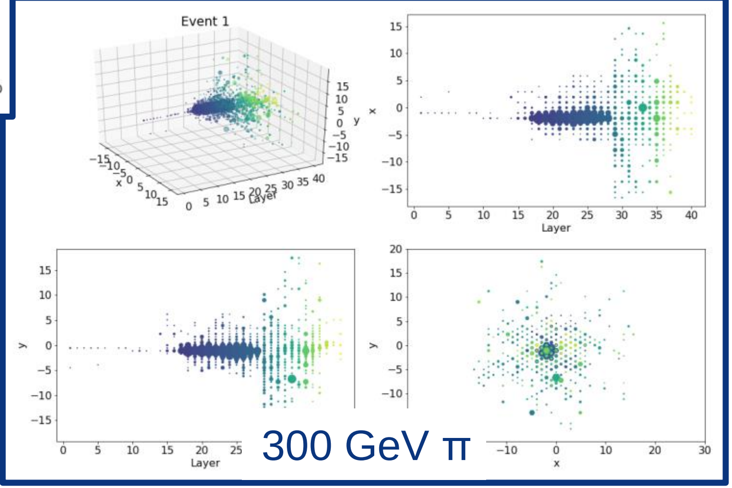
Spike rate vs E_T threshold at HL-LHC
(with no spike mitigation applied)

APD spikes already a severe problem now, mandatory to improve in HL-LHC

Displays from recent HGCAL test beams

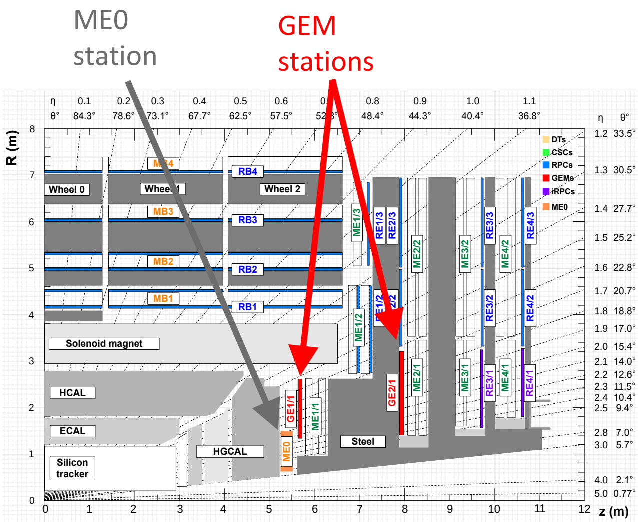


Two EM clusters spatially resolved



300 GeV π

New GEM stations GE1/1 GE2/1, ME0

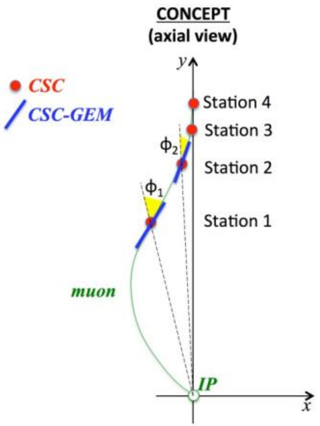


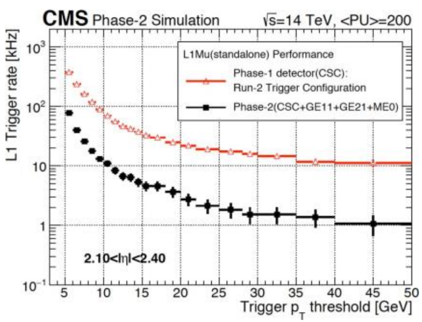
- Goals
- ME0: add trigger capabilities and offline acceptance for 2.4 <|η|<2.8 and large trigger rate reduction for 2.1 <|η|<2.4
- GE1/1, GE21: add redundancy and complementarity to ME1/1 and ME2/1, substantial rate reduction for displaced muons

ME0: 6-layer GEM detectors covering 2.0 < |η| < 2.8
GE2/1: 2-layer GEM detectors covering 1.6 < |η| < 2.4

NB GE1/1 to be installed soon, GE2/1 during the short technical stops in Run 3. GEM are the first new HL-LHC detector to be installed in CMS

Improvements-GEM

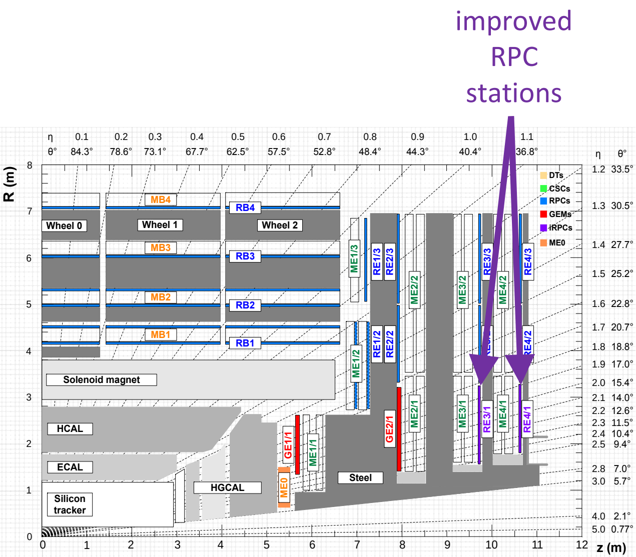


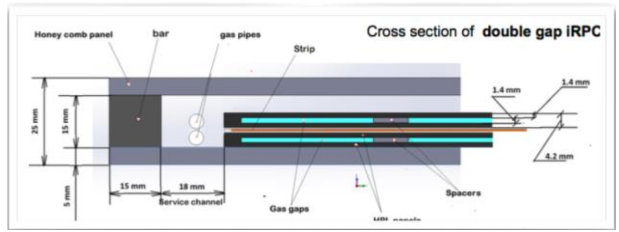


IMPROVED TRIGGER:

- GEM-CSC tandems in ME1 and ME2 stations will give better measurement of muon "local" direction sensitive to muon p_T
- p_T measurement improves and, hence, the L1-trigger rate drops; the gain is as large as a factor of 10
- This is true for stand/alone trigger, combination with the new tracker trigger would help, but stand-alone muon trigger are important for long-lived particles
- ME0 extends η coverage to 2.8

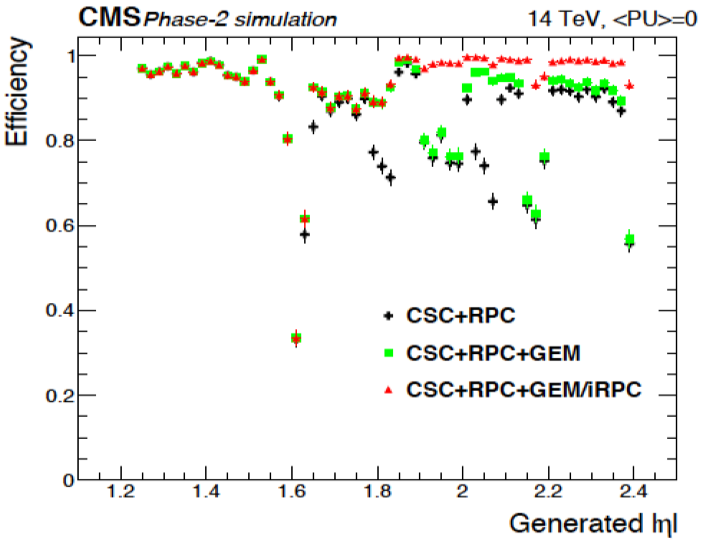
New RPC stations RE3/1 RE4/1





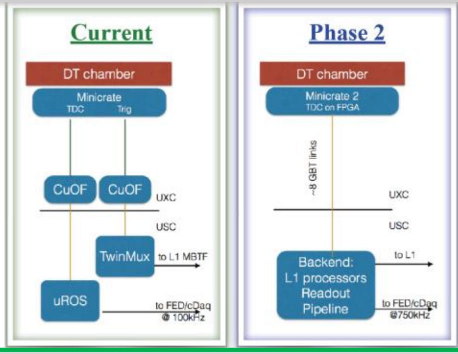
- Goal: more redundancy at $1.8<|\eta|<2.4$, better timing resolution, better ability to trigger muon stand-alone
- New thinner gaps improved RPC and electronics, able to cope with the higher occupancy

Improvements-iRPC

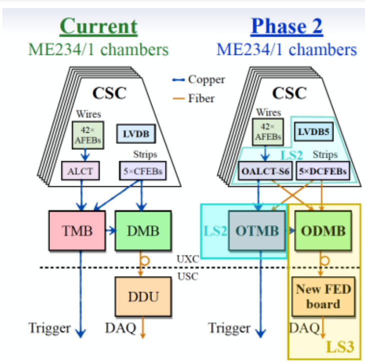


- iRPC hits improve CSC segment finding efficiency as we have already seen in the present data at lower η
- iRPCs will provide true 2D hits with O(1) cm resolution in both dimensions, which will help resolve combinatorial background in CSCs

DT, CSC, RPC electronics

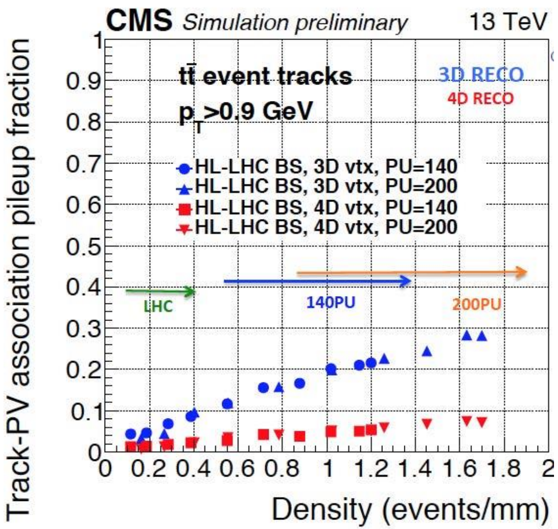


DT electronics: read full information (1ns drift resolution) at 40MHz and move complexity and L1 interface to backend (merging DT and RPC information)



RPC: upgrade of the link system, higher bandwidth and improved time resolution (25→1.6 ns)

MIP timing detector

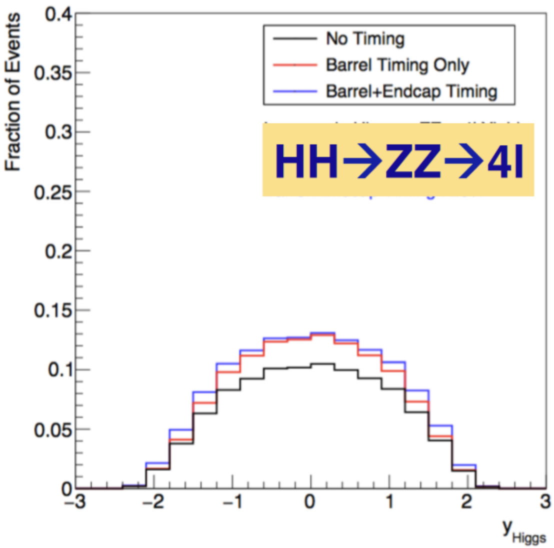


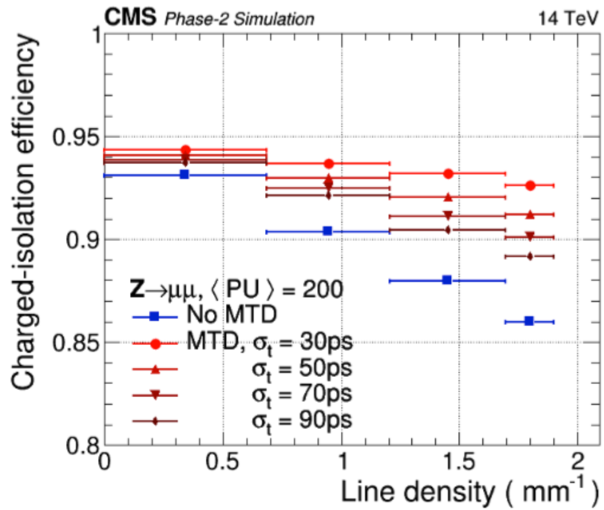
~ 30ps TOF precision for individual tracks just outside the tracker, $|\eta|<3$

- **Complements similar time resolution for showers in the upgraded calorimeters**
- **Provides a factor 4-5 effective pileup reduction**
- **Reduces merged vertices in high density events**
- **Provides flexibility adding a 4th coordinate to CMS event reconstruction**

MIP timing detector

- A hermetic MTD improves the full range of Phase 2 physics

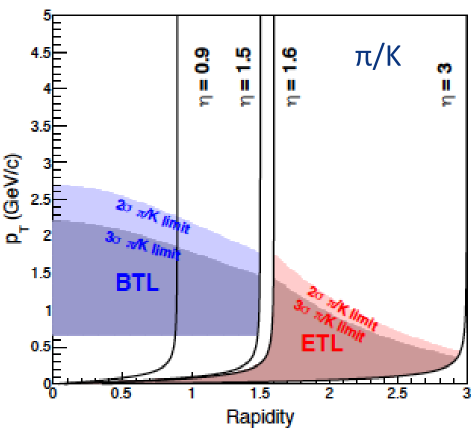


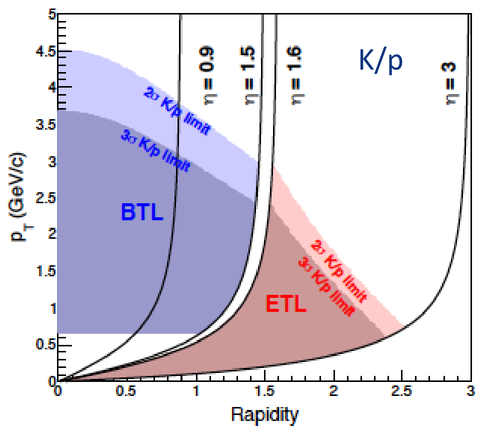


- Need to guarantee a sufficient time resolution also after irradiation
  - Values around 50ps still provide significan gain

MTD as Particle id detector

- Particularly important for Heavy Ions physics
  - MTD ToF measurement can provide efficient PID
    - With 30 ps CMS would approach ALICE performance at central rapidity (|y|<0.9) and have extended PID coverage up to |y|=2.9
    - A resolution of 50 ps would still provide acceptance gain and a better separation than the STAR-TOF experiment (the irradiation in Run-4 should not yet affect resolution)

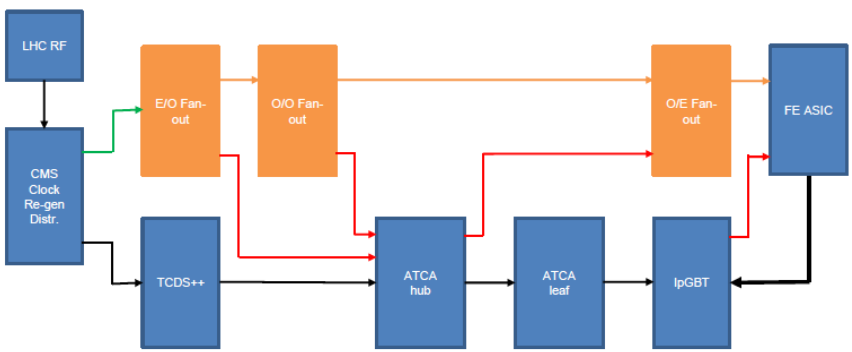




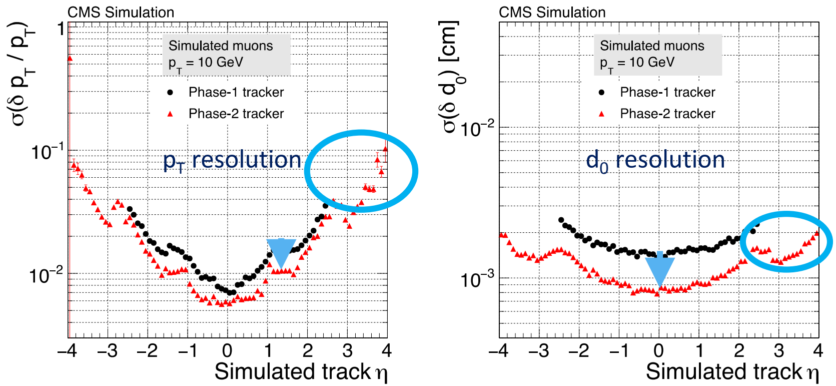
Precise Clock Distribution

DAQ has also to provide precise Clock distribution for Calorimeters and MTD

- Target ≃ 10 ps resolution - two path investigated
- Through BE boards and GBT or Through additional OL directly to FE



Phase 2 CMS tracker, a substantial improvement of an already great detector



- **Innovative, aggressive design**
  - **Extended coverage**
  - **Reduced material**
  - **Higher granularity**
  - **Provides independent input to L1 trigger for all tracks with p_T>2 GeV**

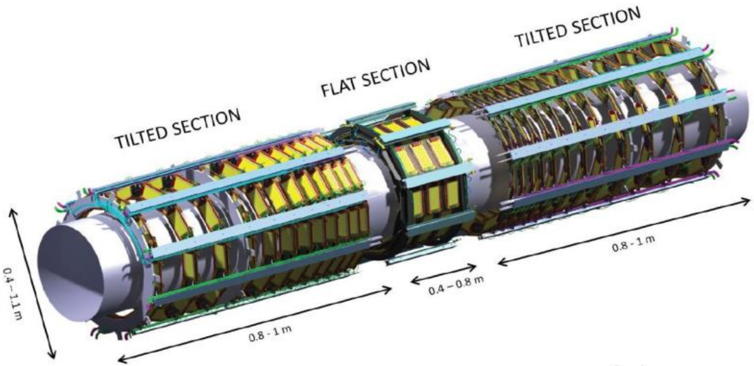
$H \rightarrow \mu\mu$: coupling to muons

- 65% improvement on $m_{\mu\mu}$ in barrel-barrel category (0.65% mass resolution)
- 5% precision on coupling to muons possible with 3000fb^{-1}

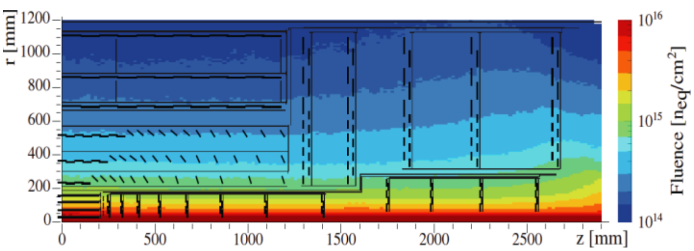
Di-Higgs production in $HH \rightarrow bbbb$ channel

- +8% acceptance
- +50-70% efficiency for tagging 4 b-jets at 200 pileup events w.r.t. Run 2

State of the art detector for a harsh environment

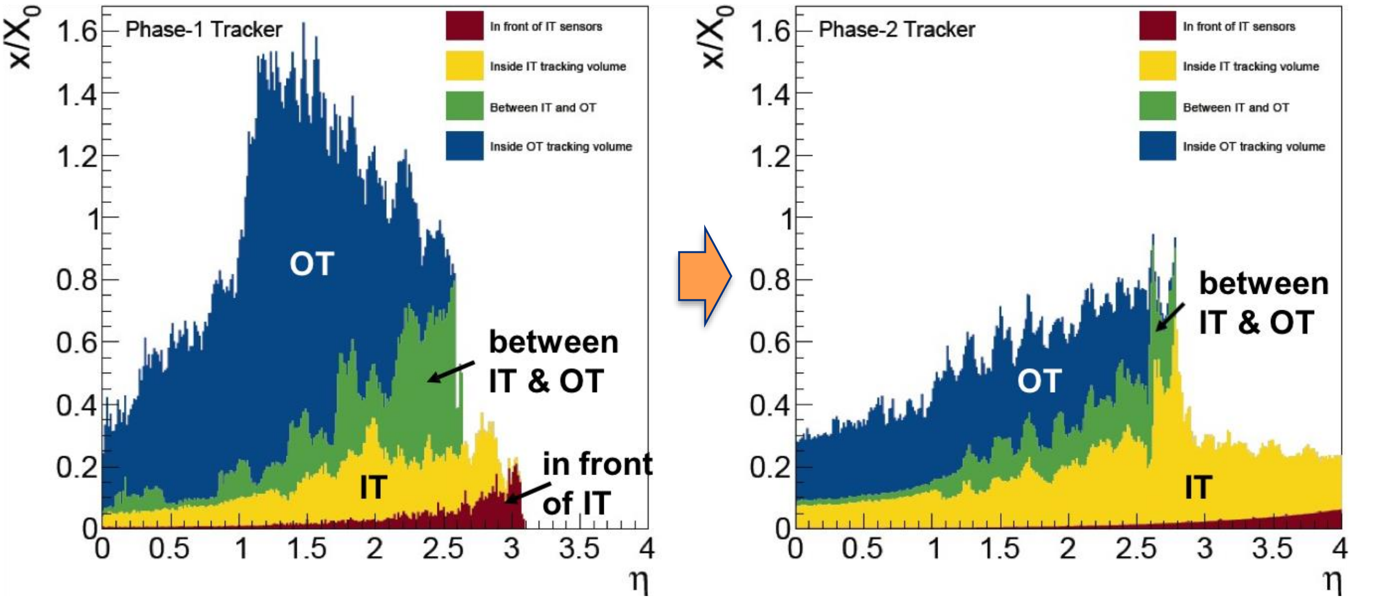


State of the art mechanics, CO_2 cooling (150kW w.r.t the present 15 kW of the pixel detector), electronics.



- Fluence (1-MeV neutron equivalent) and total ionizing dose (TID) maps from FLUKA simulations
- Maximum expected levels:
  - Outer Tracker: 9.6 x 10^{14} n_{eq}/cm^2 and 56 Mrad TID
  - Inner Tracker: 2.3 x 10^{16} n_{eq}/cm^2 and 1.2 Grad TID

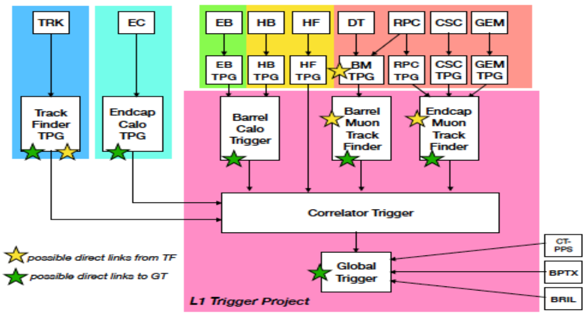
Phase II tracker is lighter



Very significant reduction, in particular around |η| = 1.5

All this needs trigger!

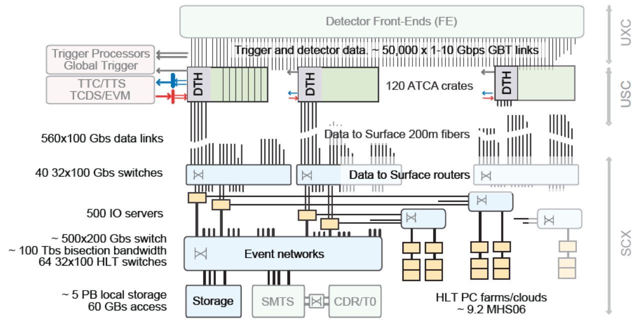
- Level 1 trigger
  - **Will use also input from the Si outer tracker detector**
    - This will allow to port Particle Flow algorithms already at L1 trigger
  - Increased latency to 12.5μs (from 5μs) and output rate up to 750kHz (from the present 100kHz)
    - So more time to decide (latency) and more bandwidth available



- High Level Trigger
  - High rate of much more complex data to select
  - Planning to use new computing architectures (e.g. GPUs)

DAQ

Baseline: HLT output at 7.5 kHz



Is it possible a “triggerless” readout at 40 Mhz, using tracker trigger primitive and full information from (some) other subdetectors?

- “Triggerless” means no L1 trigger, fast targeted data analyses on alternative processors (e.g. GPUs
- Being investigated
- A test beam with triggerless 40 MHz readout, with the new HL-LHC electronics for the DT minicrates, has been successful few weeks ago