Overview on upgrades, future plans and prospects for the CMS experiment

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on behalf of the CMS Collaboration

Center for Cosmology, Phenomenology and Particle Physics (CP3)

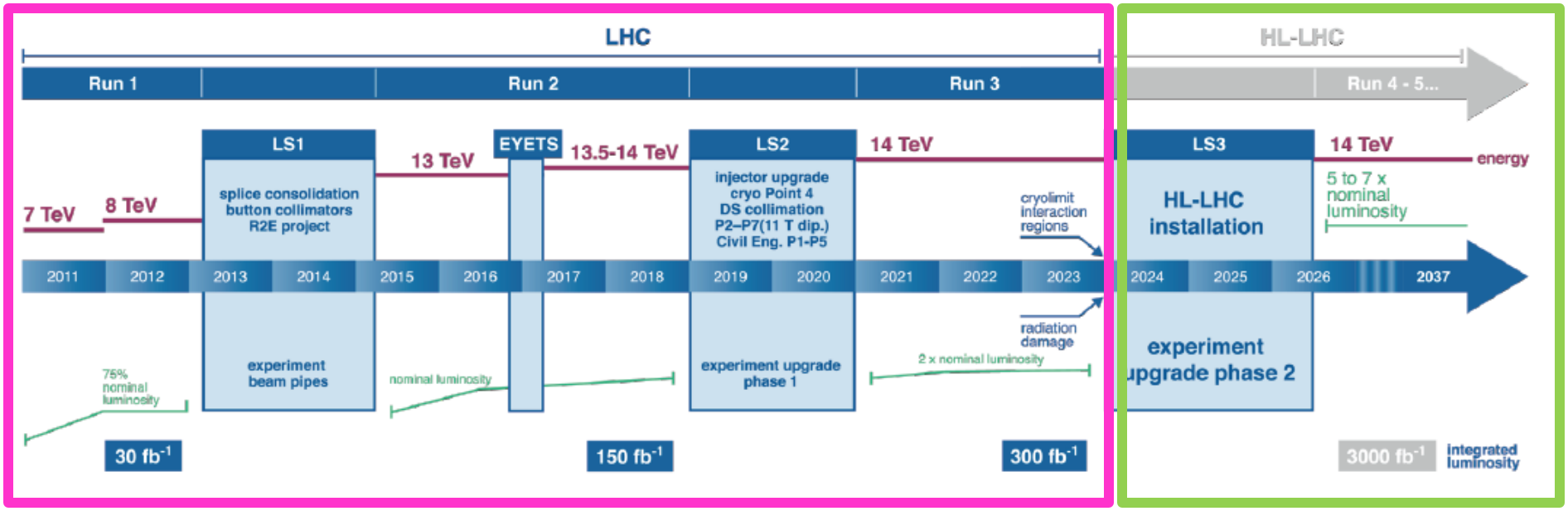
Université catholique de Louvain (UCL), Louvain-la-Neuve, Belgium

Presented at the ICNFP 2016 Conference
On 14/7/2016

Outline

- LHC schedule and CMS physics program
- Phase-1 upgrades
- Phase-2 (HL-LHC)

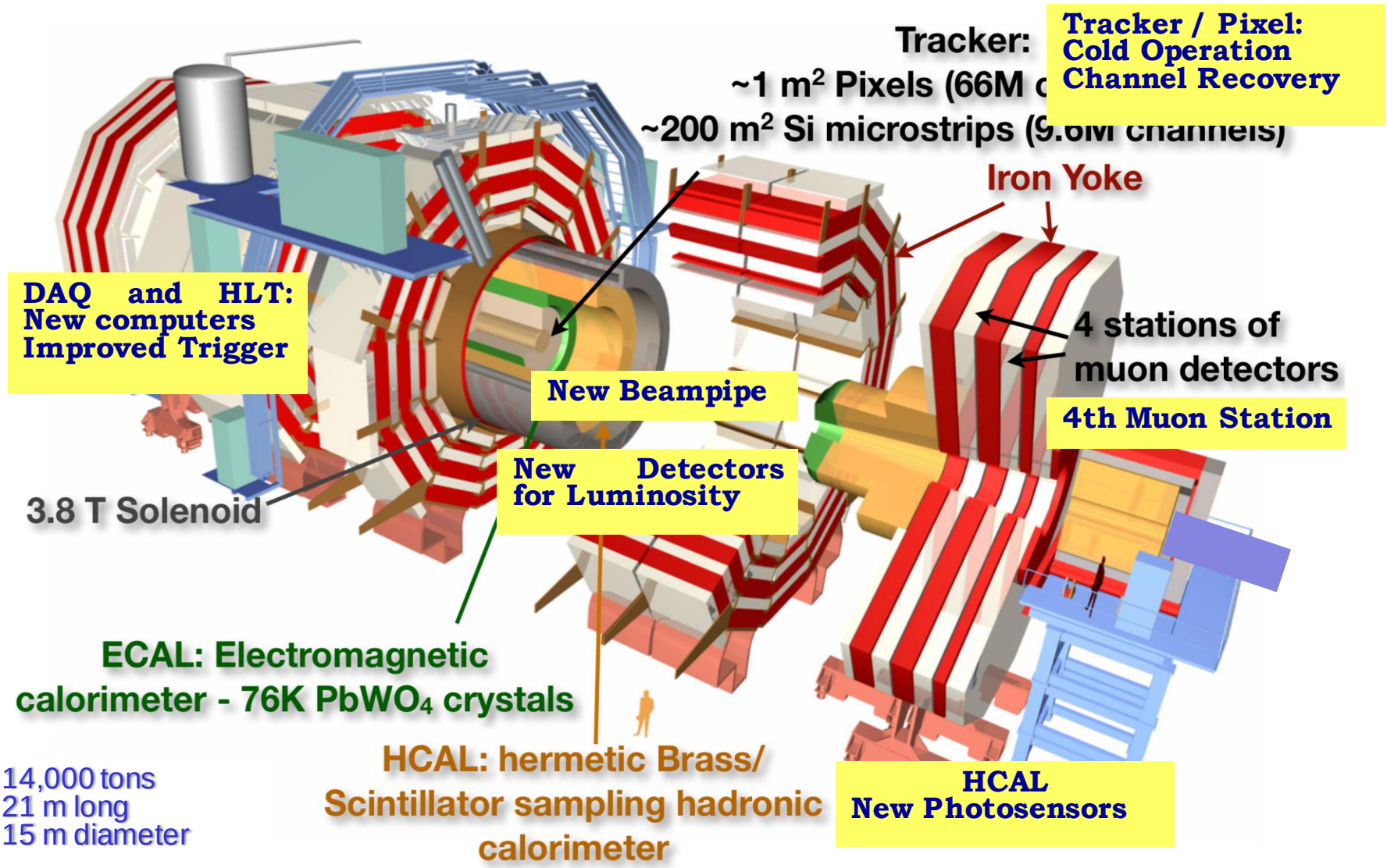
LHC Plan



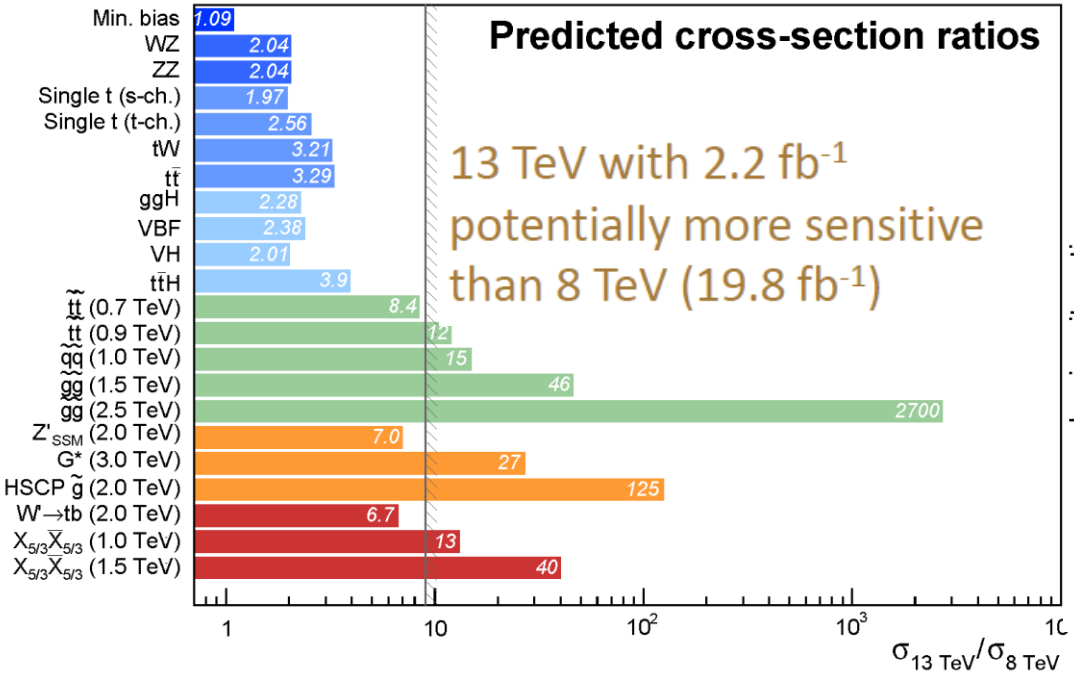
- Phase-1: Run2 and Run3 until 2023
  - Upgrades foreseen by CMS in Long Shutdown 2 (LS2)
  - 300 fb^{-1} to be collected at 13 – 14 TeV

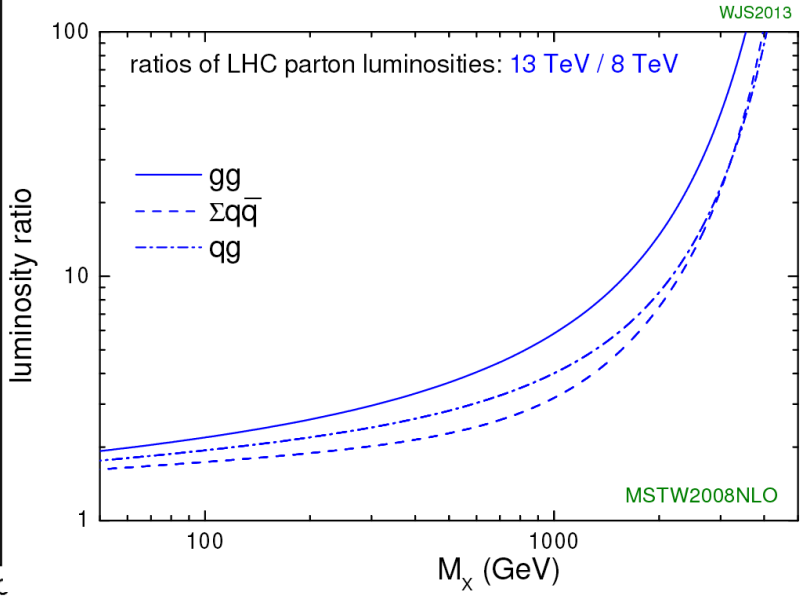
- Phase-2: High-Luminosity LHC (HL-LHC) for ~10 years starting in 2026
  - Major upgrades foreseen by CMS in LS3
  - 3000 fb^{-1} to be collected at 14 TeV

CMS after long shutdown 1



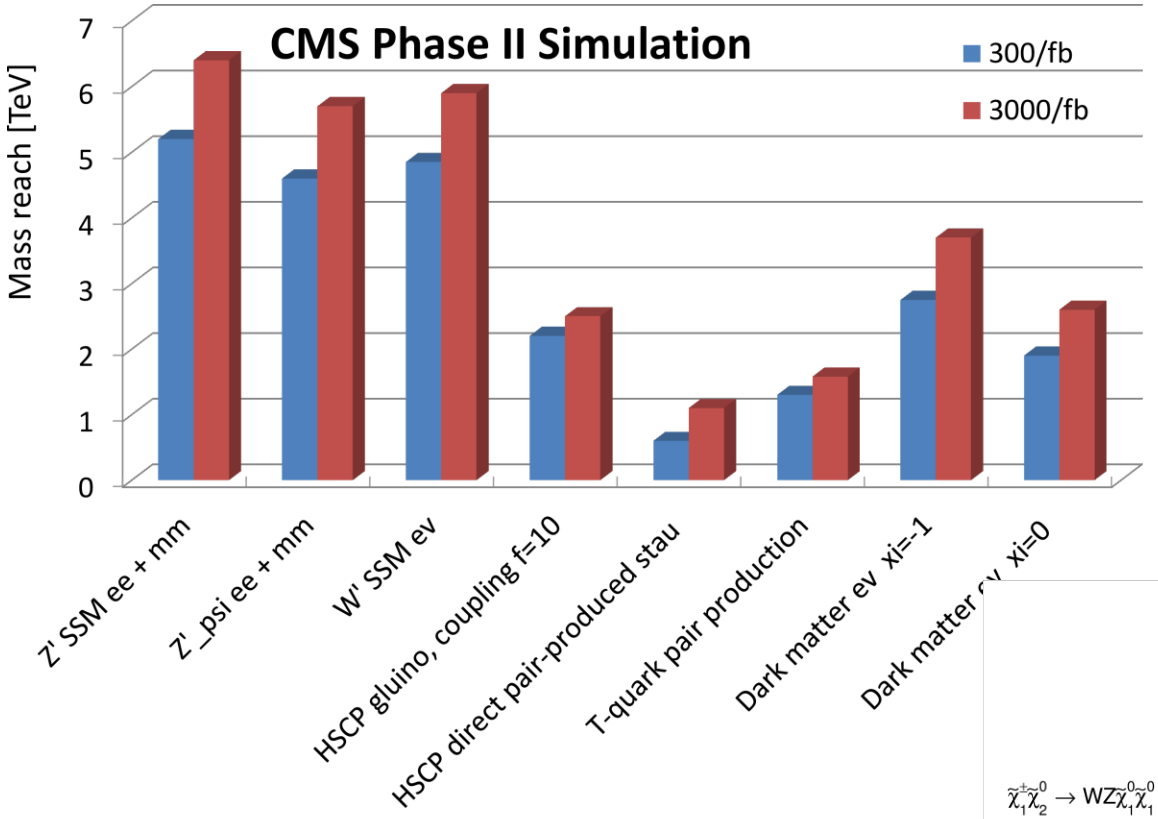
Run 2 + Run 3: the energy jump era

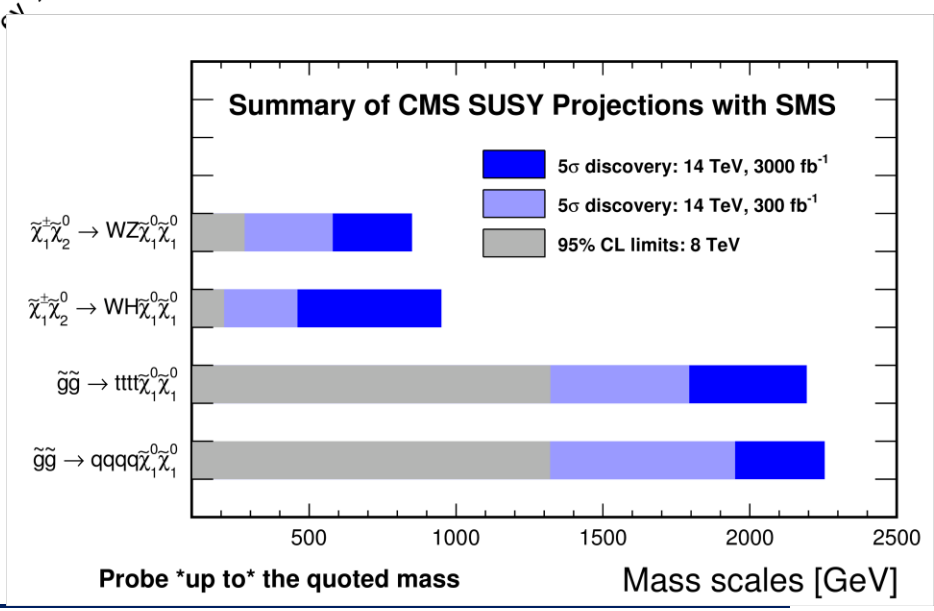




- Large increase in x-section (and thus sensitivity) for new high-mass particles

Phase I vs II: Direct discovery



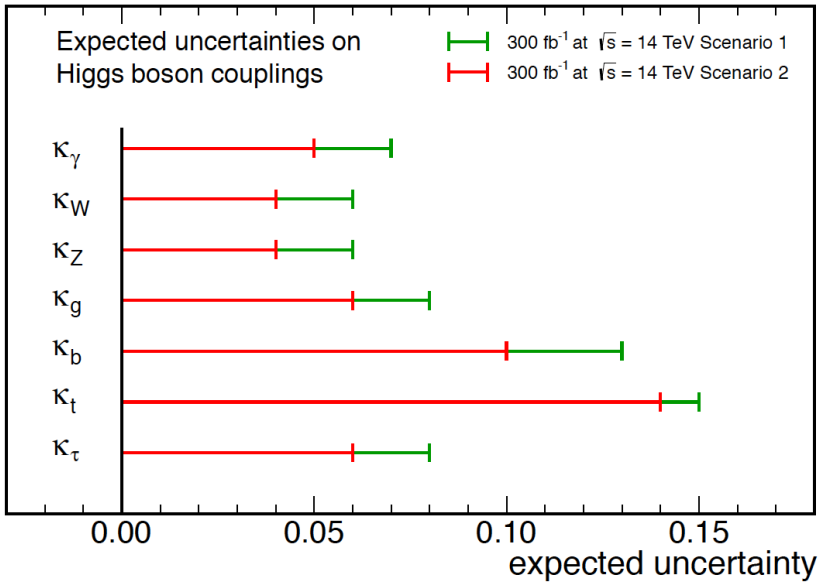


Precision physics

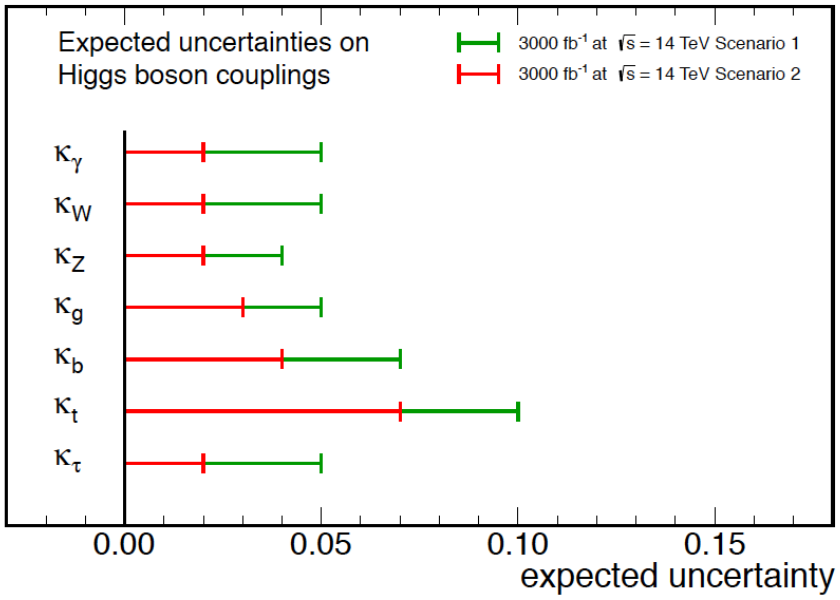
- Higgs couplings and signal strength measured up to a few percent for
  - Scenario 1: all systematic uncertainties left unchanged w.r.t. Run 1
  - Scenario 2: theoretical uncertainties and other systematics scaled by ½ and square root of integrated luminosity, respectively.

300 fb^{-1} uncertainties in the couplings **3000 fb^{-1}**

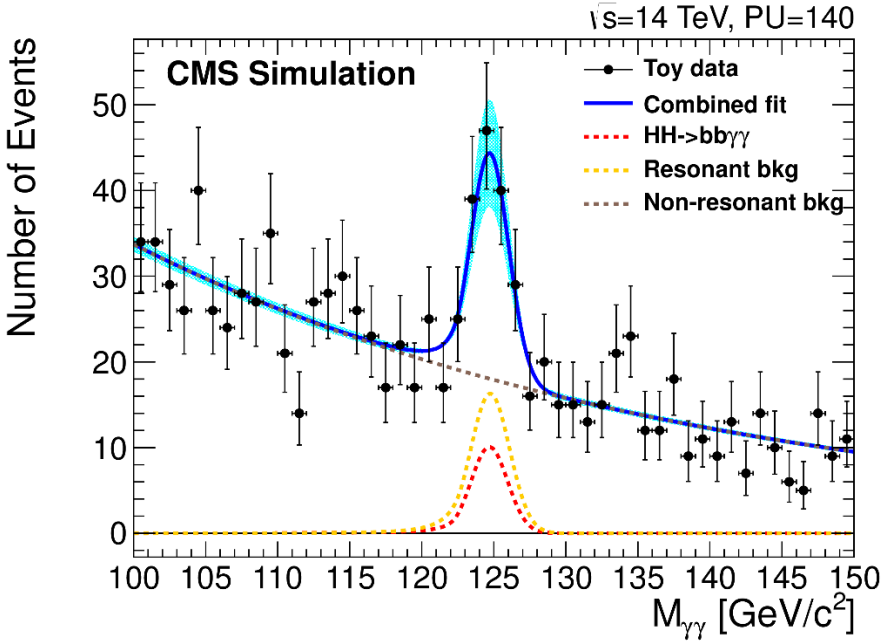
CMS Projection

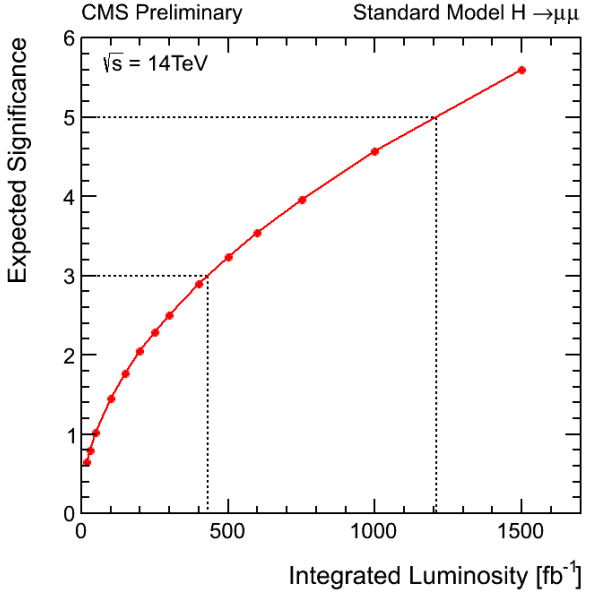


CMS Projection

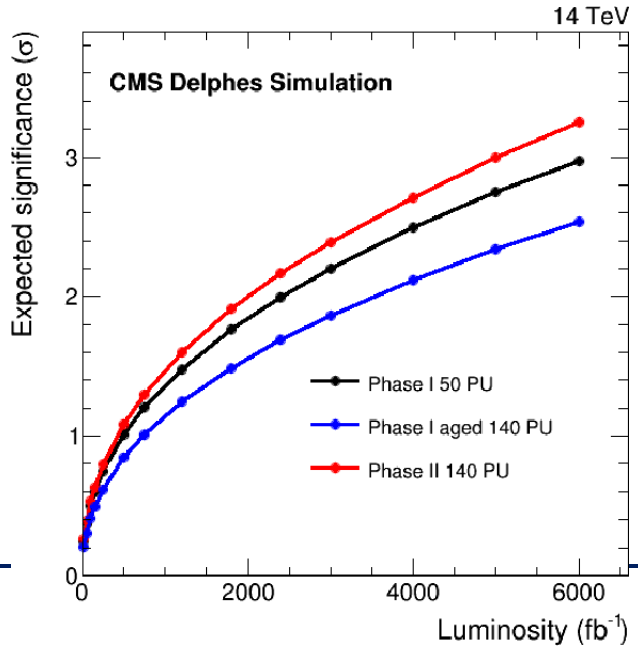


Rare processes



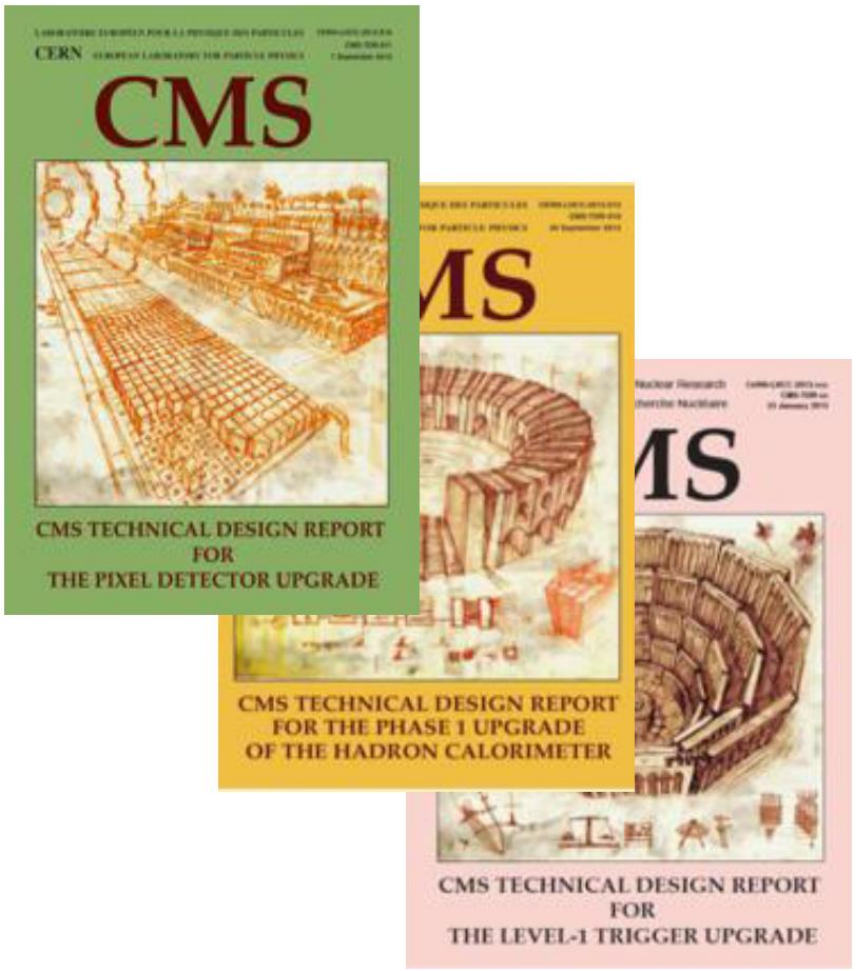


- HH → $b\bar{b}\gamma\gamma$
  - Higgs trilinear-coupling
- H→$\mu^+\mu^-$
- jj$W^+_L W^+_L$→$jjl^+l^+\nu\nu$
  - Vector boson QGC scattering

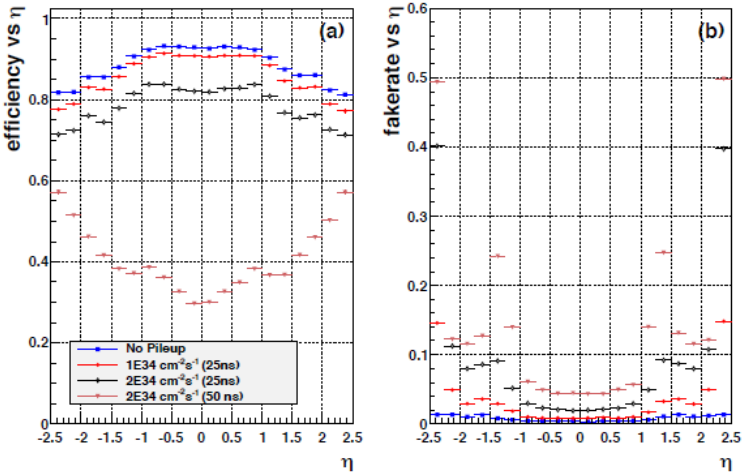


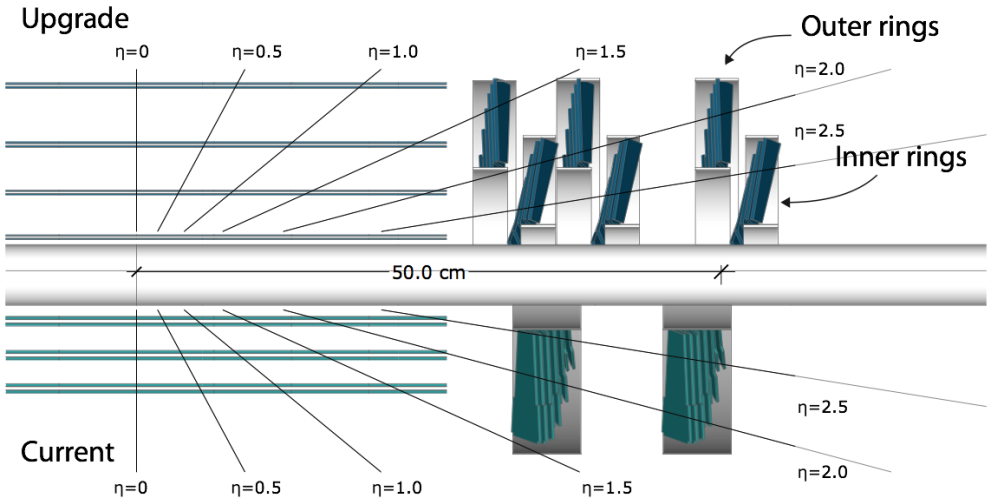
Phase-1 upgrade

- Pixel Tracker
  - New detector
  - High-rate readout chip
- Hadronic Calorimeter
  - Improved photodetectors
  - Faster and more robust electronics
- L1-Trigger System
  - Exploit additional muon and calorimeter information
  - Move to high-performance FPGA-based electronics



Phase-1 – pixel upgrade

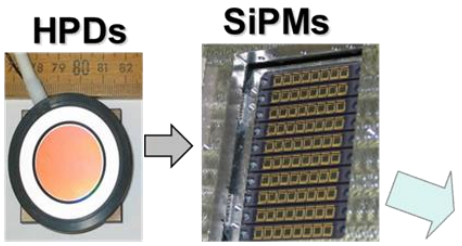




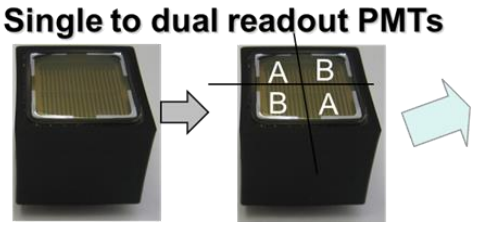
- 4 layers/3 disks (1 more space-point w.r.t. current detector)
  - 3 cm inner radius
- New readout chip: recovers inefficiency at high rate (up to PU 100)
- Less material: two-phase CO2 cooling, new mechanical structures, new cabling and powering scheme (DC-DC)
- Radiation hardness: expected to survive 500 fb-1 (5×10^{15} neq/cm^2)
- Status: full detector to be installed in Year End Technical Stop 2016-17
  - Pilot detector already taking 2016 collision data

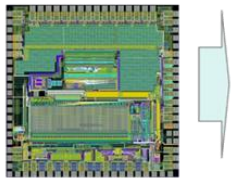
Phase-1 – HCAL upgrade

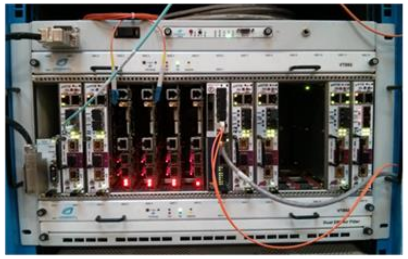
Barrel/Endcap



Forward







- Photodetectors
  - Barrel, and endcap detectors: replacement of Hybrid PhotoDiodes with SiPM
    - Solve problem of frequent electrical discharges (noise, lower gain, longevity)
    - longitudinal segmentation of readout
  - Forward detector: replacement of single-anode PMT with new dual-anode PMTs
    - Suppress anomalous signals caused by particles going through PM tubes
- Front-end electronics:
  - New readout chips (including TDC) matching SiPM
    - Allow identification of anomalous signals with timing at 25 ns operation
- Back-end electronics:
  - New µTCA system to support larger data volumes (HL-LHC like)
- Status: HF upgrades completed and taking data. The rest after LS2

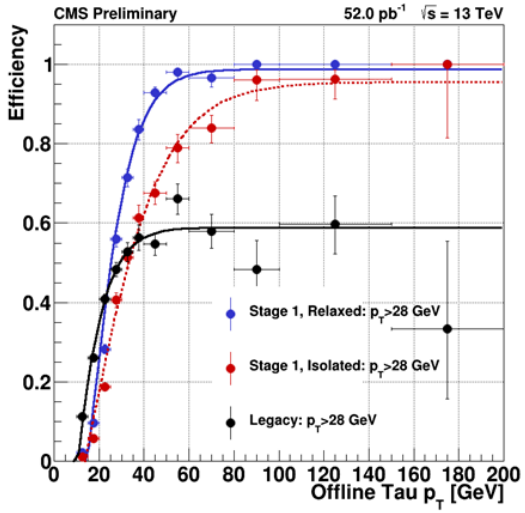
Phase-1 – L1 trigger upgrade

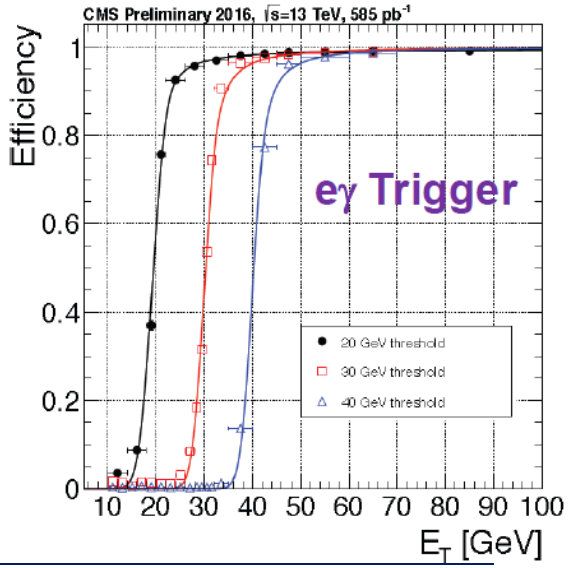
- Goal: maintain Run-1 performance during Run-2 and Run-3
  - Fight the expected x6 increase in rates
  - Pile-up subtraction and isolation
  - Improved efficiency and resolution
  - Increased flexibility

How:

- Move to FPGA-based architecture, and µTCA back-end to implement more sophisticated algorithms and exploit
  - Full granularity of CALO information
  - additional MUON information

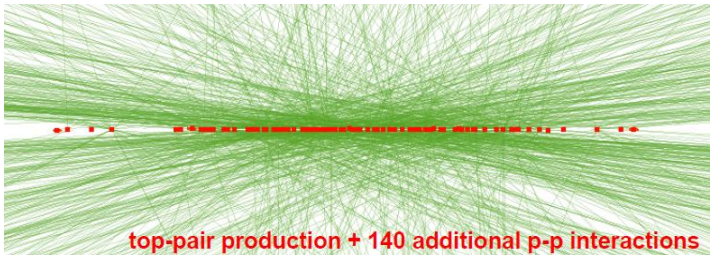
- Status:
  - Global calo trigger in operation since 2015
  - Full system deployed and currently being commissioned with collision data

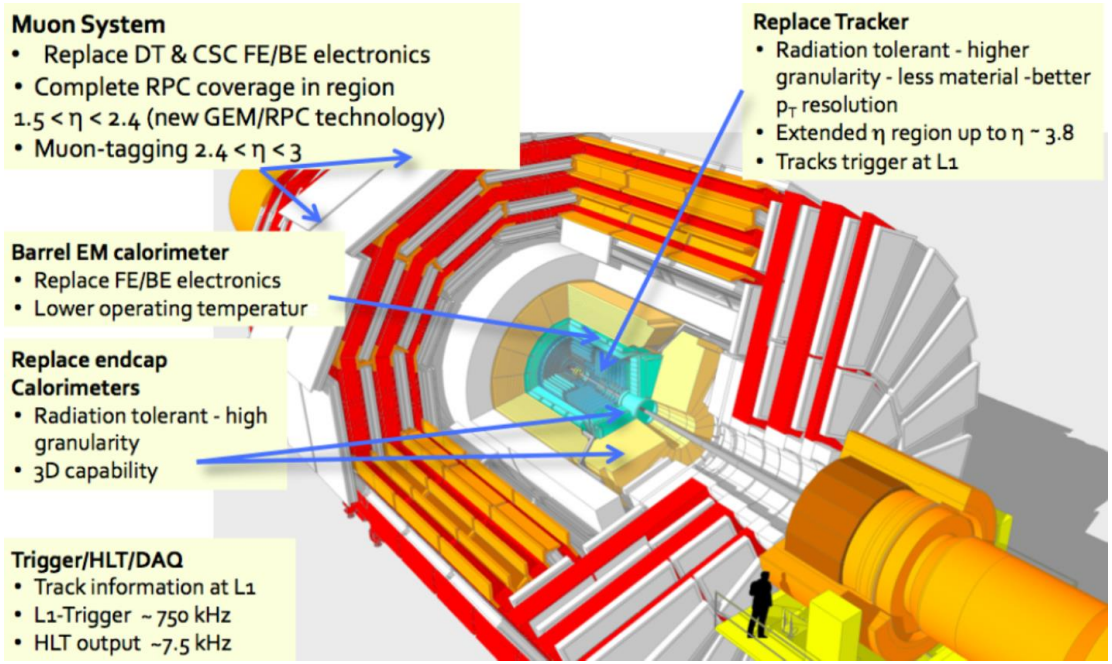




Phase 2 upgrade

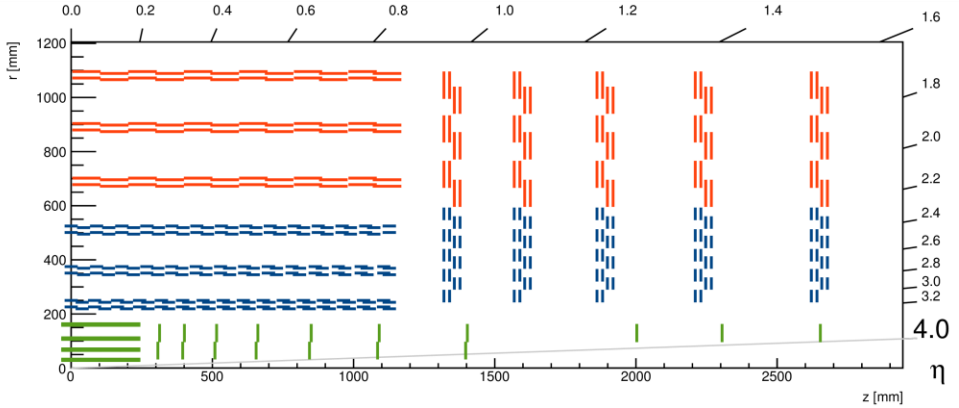
- Goal: exploit LHC physics potential at 3000 fb^{-1} and 14 TeV in 10 years of running
- Challenge:
  - Radiation-induced ageing of detectors after Run 3
  - 140 pile-up interactions (5-7×10^{34} $cm^{-2}s^{-1}$ and 25 ns operation)

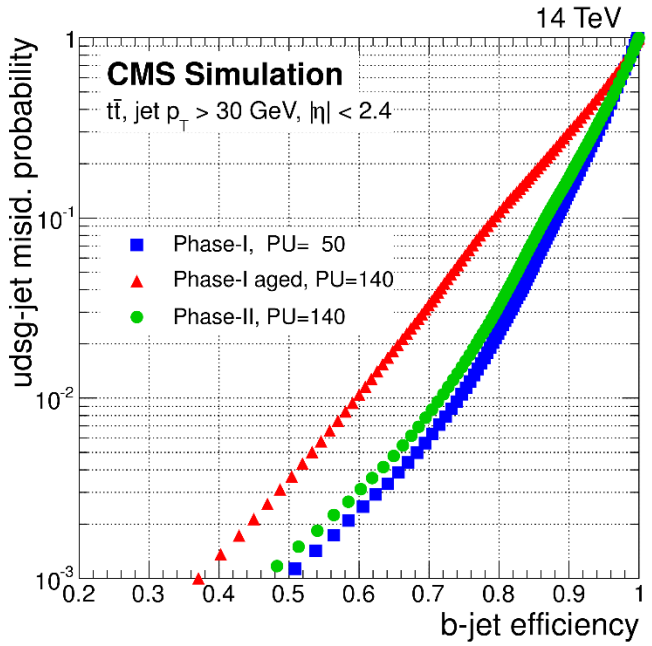




Pixel upgrade

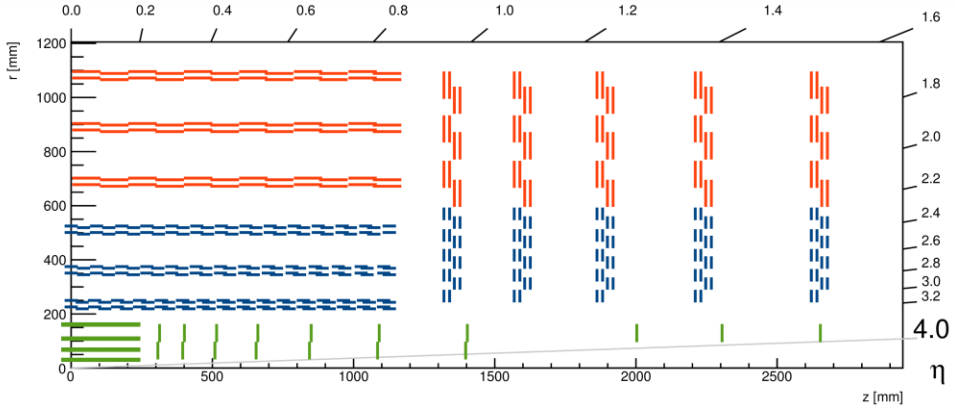
- 4 barrel + 10 forward disks
- coverage up to |η|~3.8
- High granularity (6x)
- High radiation tolerance
  - Thin planar sensors and small pixel area
- Readout at 750kHz

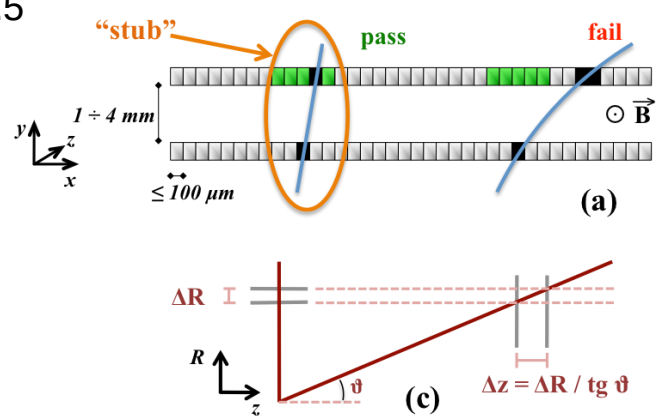


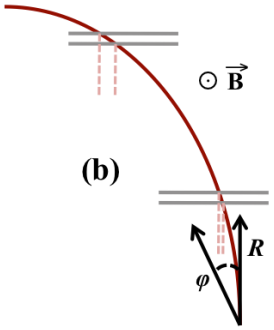


Outer tracker upgrade

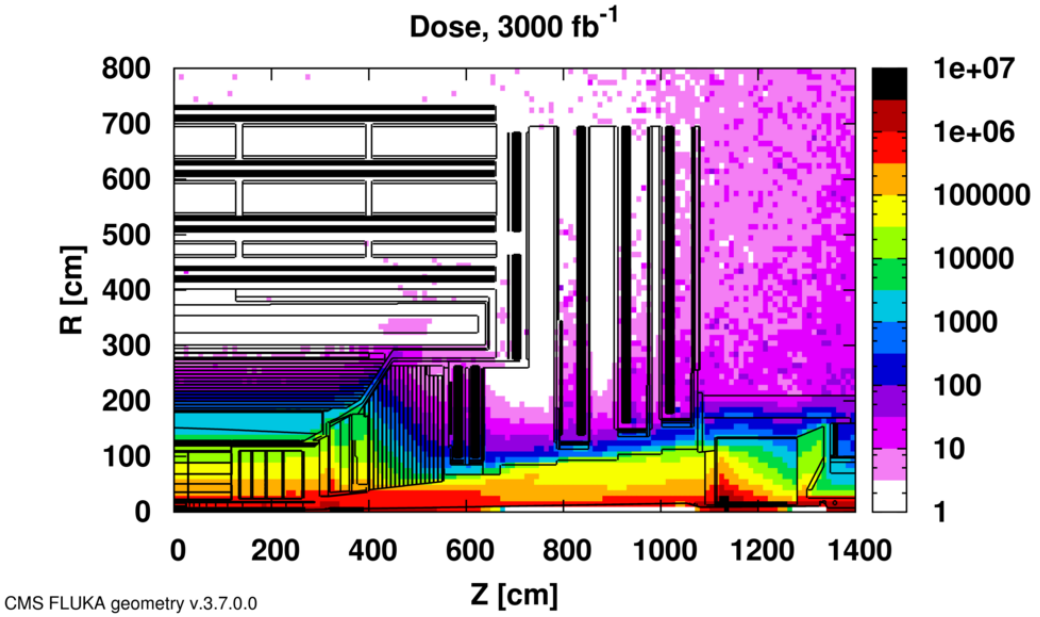
- Detectors
  - 6 barrel layers; 5 forward disks vs current 10/11
  - Double-sensor modules for trigger at L1
  - Higher granularity
    - shorter strips (2.5-5 cm) in 3 outer layers (2S)
      - 4 X current detector
    - Strips + long pixels (0.1 x 1.5 mm) in 3 inner layer (PS)
  - High radiation tolerance
- Mechanics and Electronics
  - Lower material budget
  - Operations at -30 ^{o}C
  - Readout at 750kHz

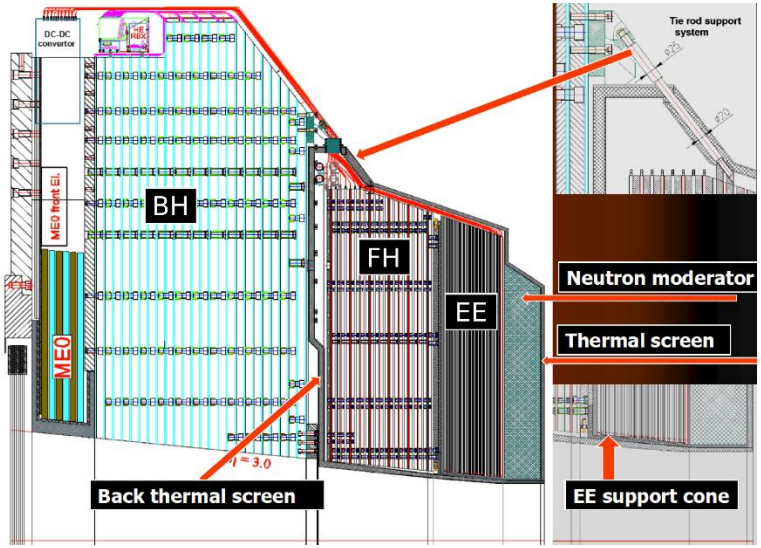






Endcap calorimeter

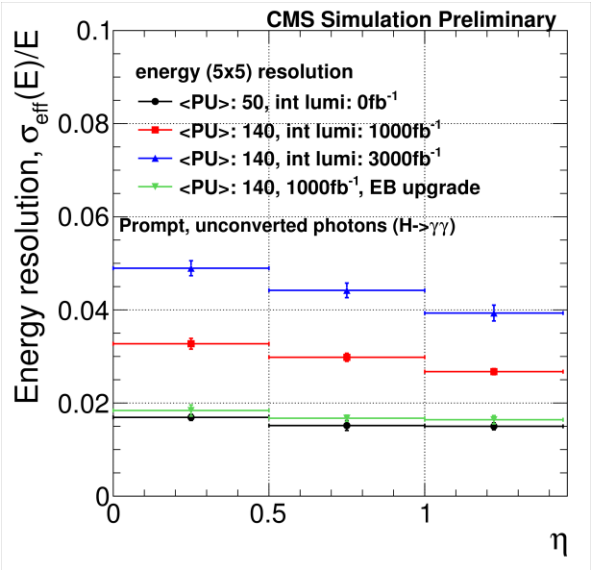


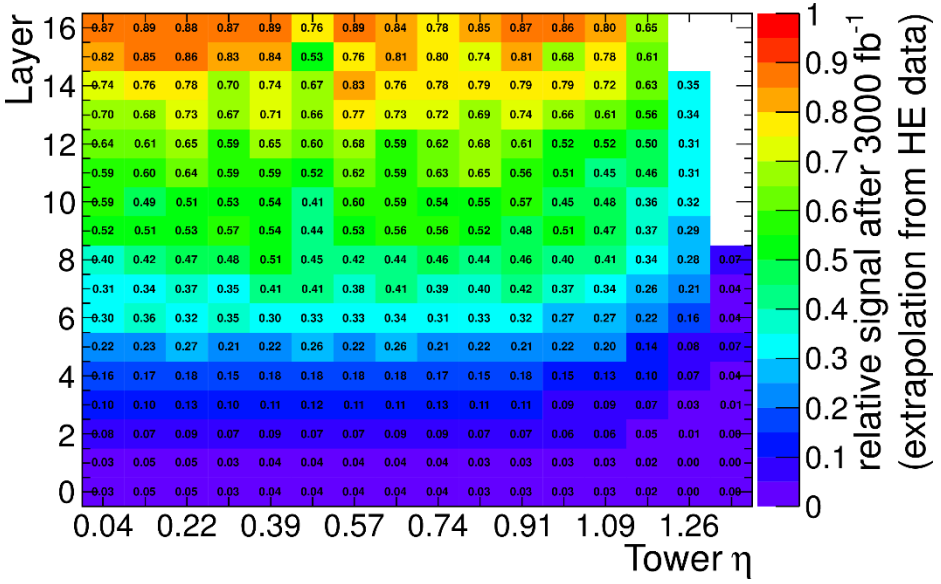


- Radiation dose in Endcap ECAL and HCAL scintillating calorimeters causes dramatic reduction in light transmission. Need for new detectors
- High-granularity sampling calorimeters (HGC):
  - Electromagnetic: EE (Σdepth~26 X_0, 1.5λ): 28 layers of Silicon-W absorber.
  - Front Hadronic: FH (Σdepth~3.5 λ): 12 layers of Silicon/Brass.
  - Back Hadronic Calorimeter (BH): Σdepth~5 λ): 12 layers of Scintillator/Brass (2 depths readout).
  - Tracking capability for pile-up rejection based on ILC Calice detector

Barrel calorimeter upgrade

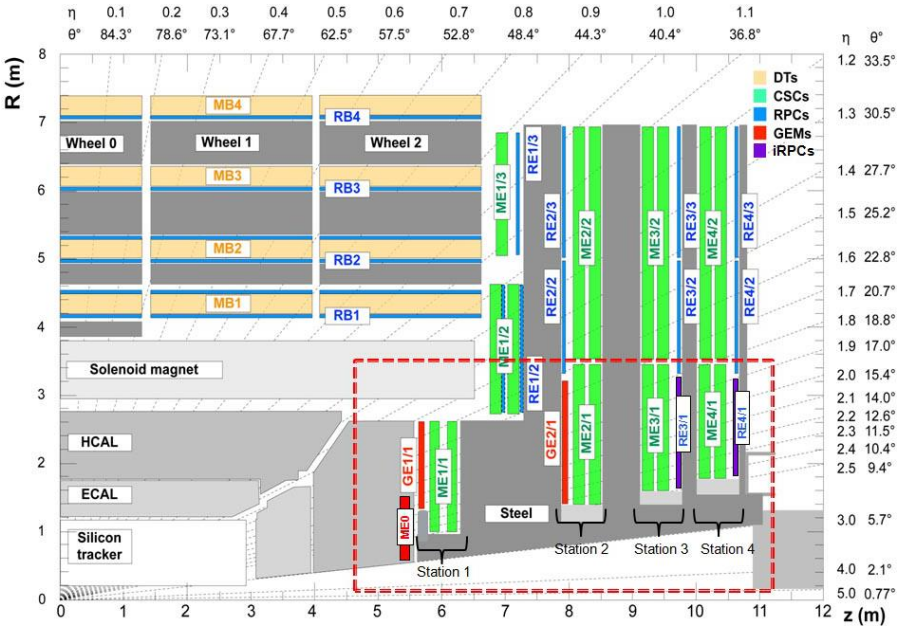
- Electromagnetic Calorimeter
  - PbWO4 crystals will receive 100 times less dose than endcap – no need for replacement
  - New front-end and back-end electronics to satisfy HL-LHC trigger requirements (12.5 μs latency and 750 kHz readout)
  - Cooling to 8 ^{0}C and optimization of VFE (very-front-end) electronics to reduce noise in the APD
  - Single crystal information to L1 trigger
- HadronicCalorimeter
  - Doubly-doped plastic scintillators will replace innermost tiles during LS3
  - Photodetectors and electronics already replaced





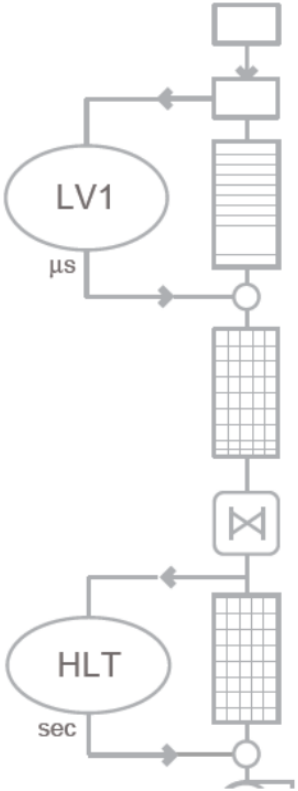
Muon detectors

- Irradiation tests to confirm prediction that current chambers should survive until end of HL-LHC
- Complete instrumentation in 1.6<|η|<2.4
  - GEM detectors in the two innermost stations
  - improved RPC in 2 outer stations
    - Higher rate capability
  - Both with finer η segmentation
- Extend coverage to match endcap calorimeter (η ~ 3) with additional GEM
- Replace DT and part of CSC electronics to cope with irradiation, trigger latency, and readout rate
- Installation schedule
  - First GEM detector to be installed in LS2
  - RPCs and remaining GEMs will be installed during LS3(2024-2025)

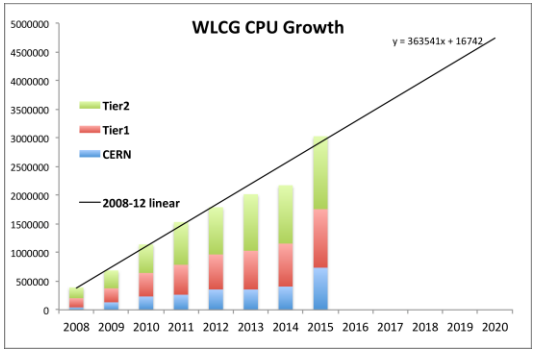


Trigger and computing

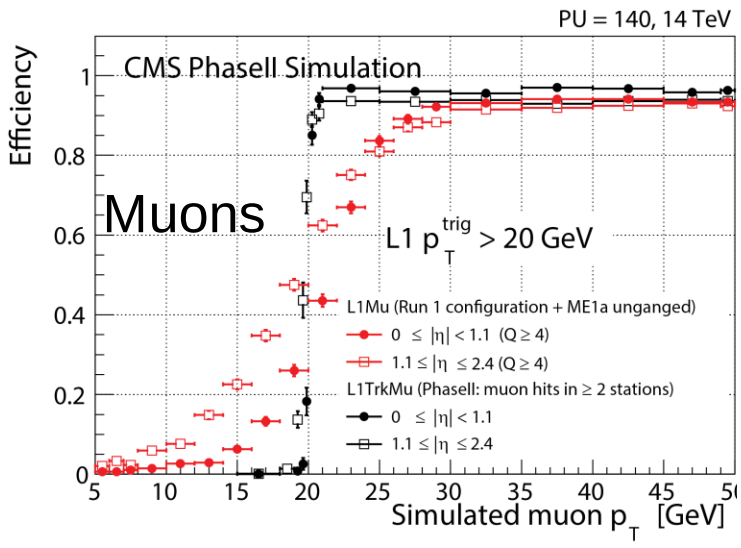
- L1 Trigger
  - Output: 100kHz → 750kHz
  - Latency: 3.4µs → 12.5µs
  - New track-trigger
  - ECAL: full crystal granularity
  - Muon: full DT η granularity (and info from new detectors)
- DAQ and High-Level Trigger
  - No major changes in the architecture and algorithms
  - Output rate: 1 kHz → 7.5kHz (keep rejection factor of 100)
  - Processing power estimated to be 25(140 PU)/50(200 PU) x w.r.t. Run-1
  - Throughput: 1 Tb/s → 30Tb/s (800 links @ 100Gb/s)
  - Output to storage: 2 / 3 GB/s→ 27 / 42 GB/s
- Software and computing
  - Many-cores and parallel computing being explored to face the expected high demands in CU and storage

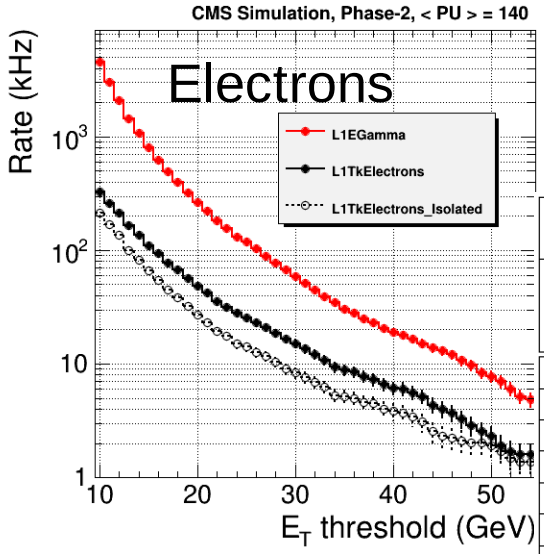


	LHC Run-I	LHC Phase-I upgr.	HL-LHC Phase-II upgr.	
Energy	7-8 TeV	13 TeV	13 TeV	
Peak Pile Up (Av./crossing)	35	50	140	200
Level-1 accept rate (maximum)	100 kHz	100 kHz	500 kHz	750 kHz
Event size (design value)	1 MB	1.5 MB	4.5 MB	5.0 MB
HLT accept rate	1 kHz	1 kHz	5 kHz	7.5 kHz
HLT computing power	0.21 MHS06	0.42 MHS06	5.0 MHS06	11 MHS06
Storage throughput (design value)	2 GB/s	3 GB/s	27 GB/s	42 GB/s

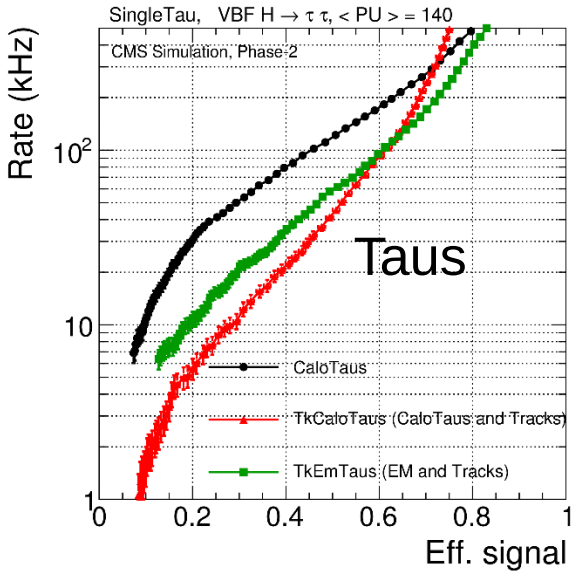


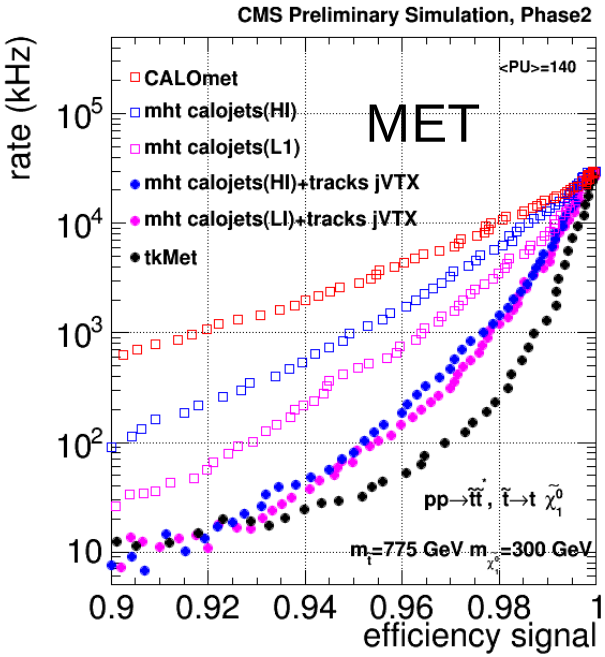
L1 (track-)Trigger performance



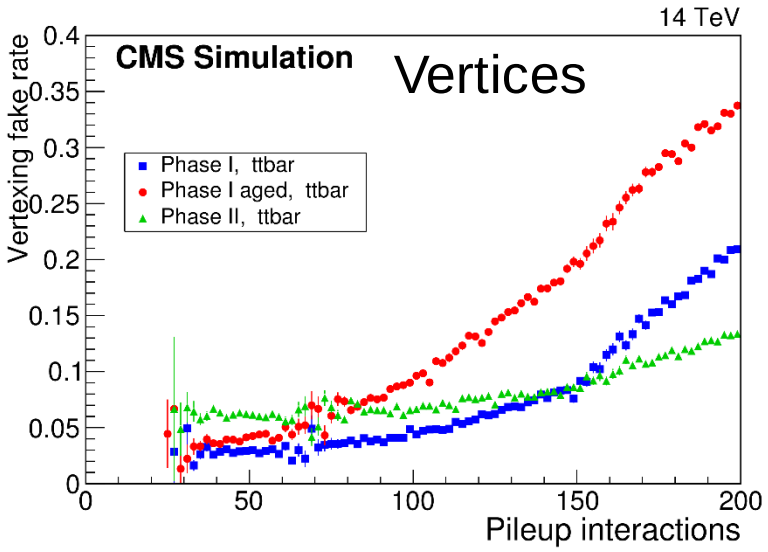


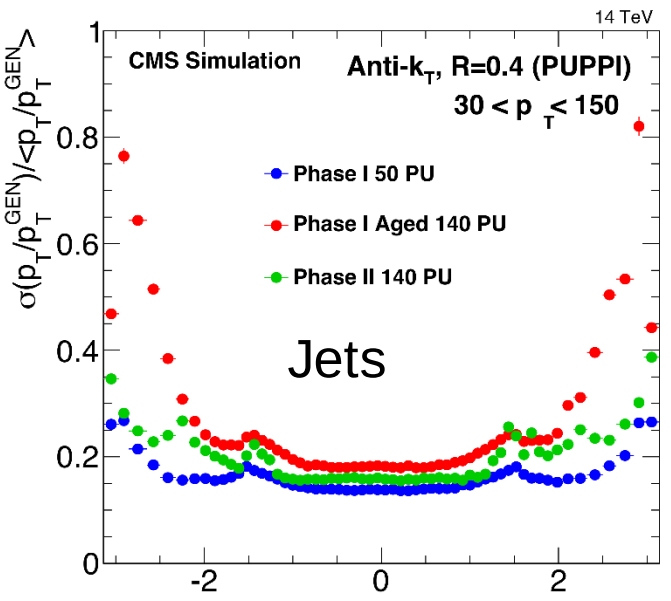
$L = 5.6 \times 10^{34}$ cm^{-2}s^{-1} $\langle PU \rangle = 140$	Level-1 Trigger with L1 Tracks	
Trigger Algorithm	Rate [kHz]	Offline Threshold(s) [GeV]
Single Mu (tk)	14	18
Double Mu (tk)	1.1	14 10
ele (iso tk) + Mu (tk)	0.7	19 10.5
Single Ele (tk)	16	31
Single iso Ele (tk)	13	27
Single γ (tk isol)	31	31
ele (iso tk) + e/γ	11	22 16
Double γ (tk isol)	17	22 16
Single Tau (tk)	13	88
Tau (tk) + Tau	32	56 56
ele (iso tk) + Tau	7.4	19 50
Tau (tk) + Mu (tk)	5.4	45 14
Single Jet	42	173
Double Jet (tk)	26	2@136
Quad Jet (tk)	12	4@72
Single ele (tk) + Jet (tk)	15	23 66
Single Mu (tk) + Jet (tk)	8.8	16 66
Single ele (tk) + H_T^{miss} (tk)	10	23 95
Single Mu (tk) + H_T^{miss} (tk)	2.7	16 95
H_T (tk)	13	350
Rate for above Triggers	180	
Est. Total Level-1 Menu Rate	**260**	

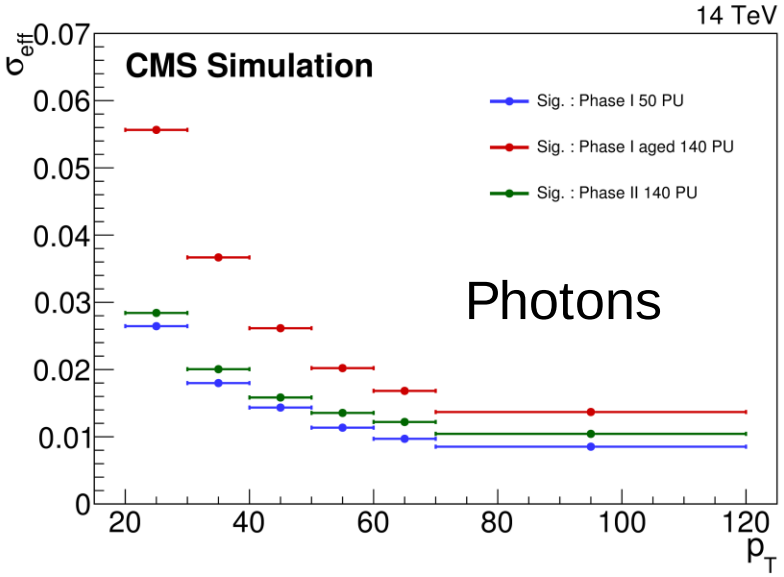


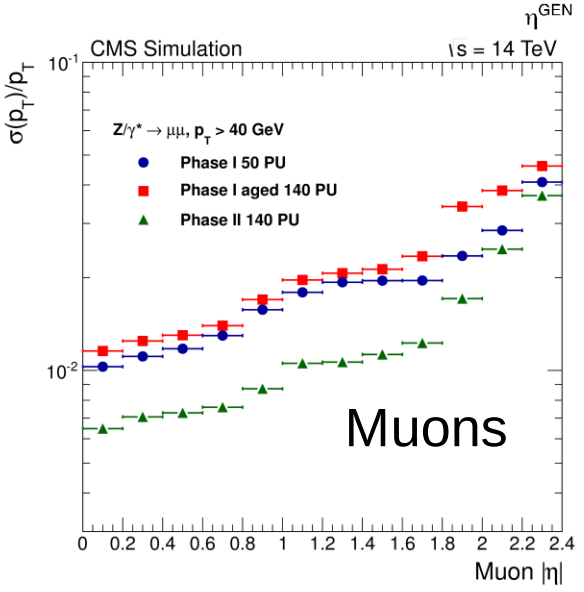


Offline performance

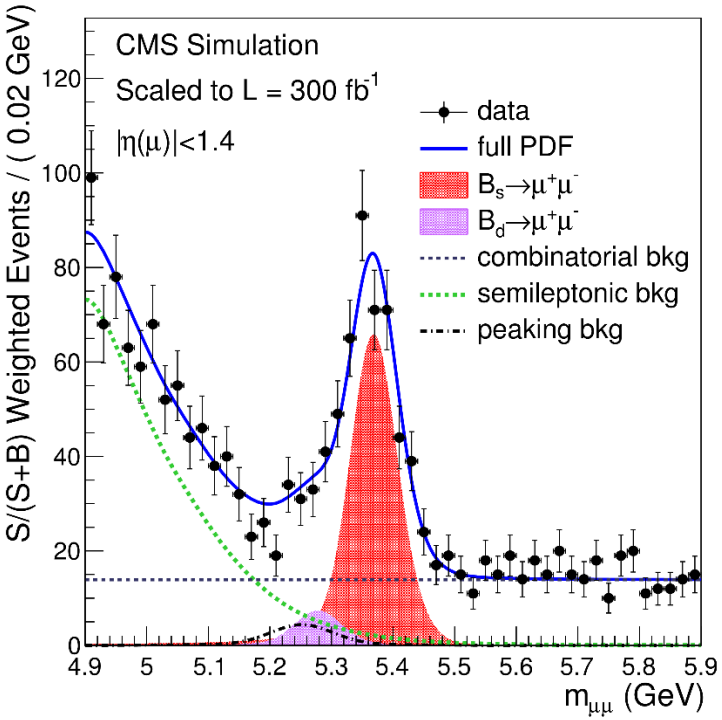


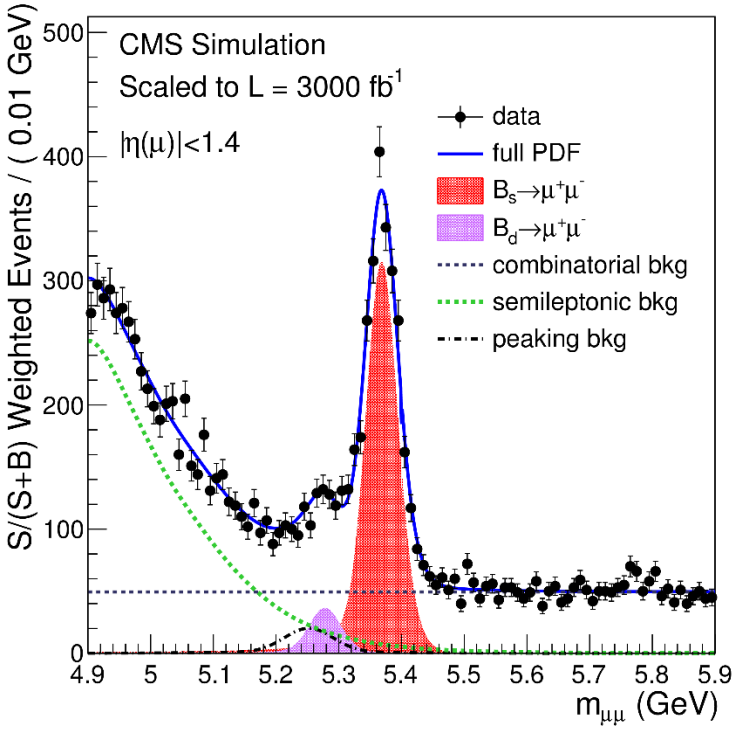






Physics performance: B→μ⁺μ⁻





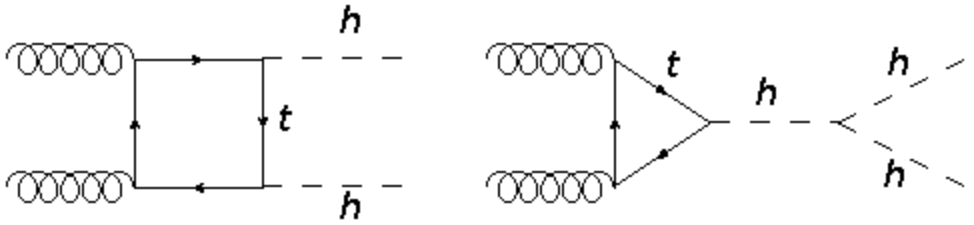
$\mathcal{L}$ (fb^{-1})	$N(B_s^0)$	$N(B^0)$	$\delta\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}(B^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$
20	18.2	2.2	35%	> 100%	$0.0-1.5\,\sigma$	> 100%
100	159	19	14%	63%	$0.6-2.5\,\sigma$	66%
300	478	57	12%	41%	$1.5-3.5\,\sigma$	43%
300 (barrel)	346	42	13%	48%	$1.2-3.3\,\sigma$	50%
3000 (barrel)	2250	271	11%	18%	$5.6-8.0\,\sigma$	21%

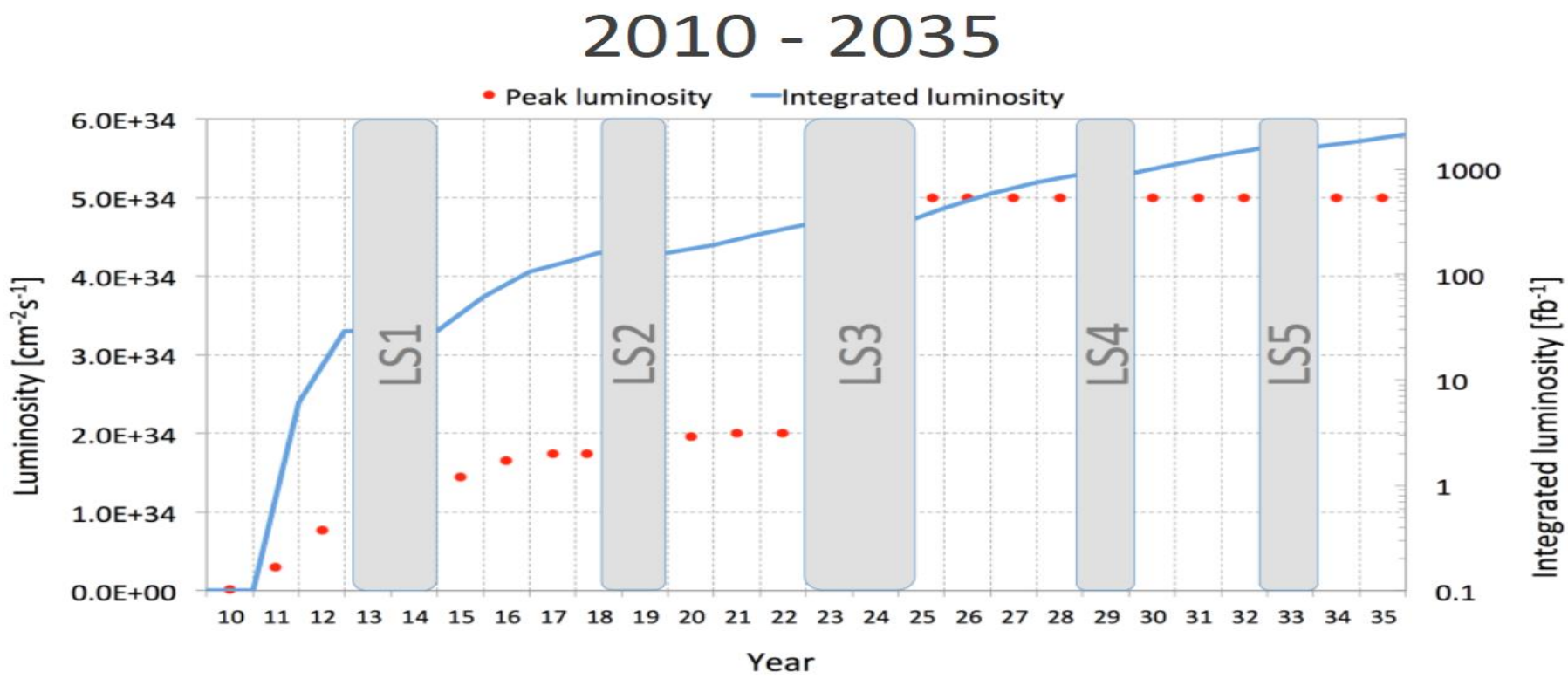
Outlook

- HL–LHC is a tough machine mostly for precision physics and rare processes observation
- The next few years will tell us if there will be more to be studied in detail
- CMS has taken up the challenge

BACK-UP

Double Higgs




2010 - 2035
Peak luminosity
Integrated luminosity
6.0E+34
5.0E+34
4.0E+34
3.0E+34
2.0E+34
1.0E+34
0.0E+00
Luminosity [cm-2s-1]
LS1
LS2
LS3
LS4
LS5
1000
100
10
1
0.1
Integrated luminosity [fb-1]
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Year