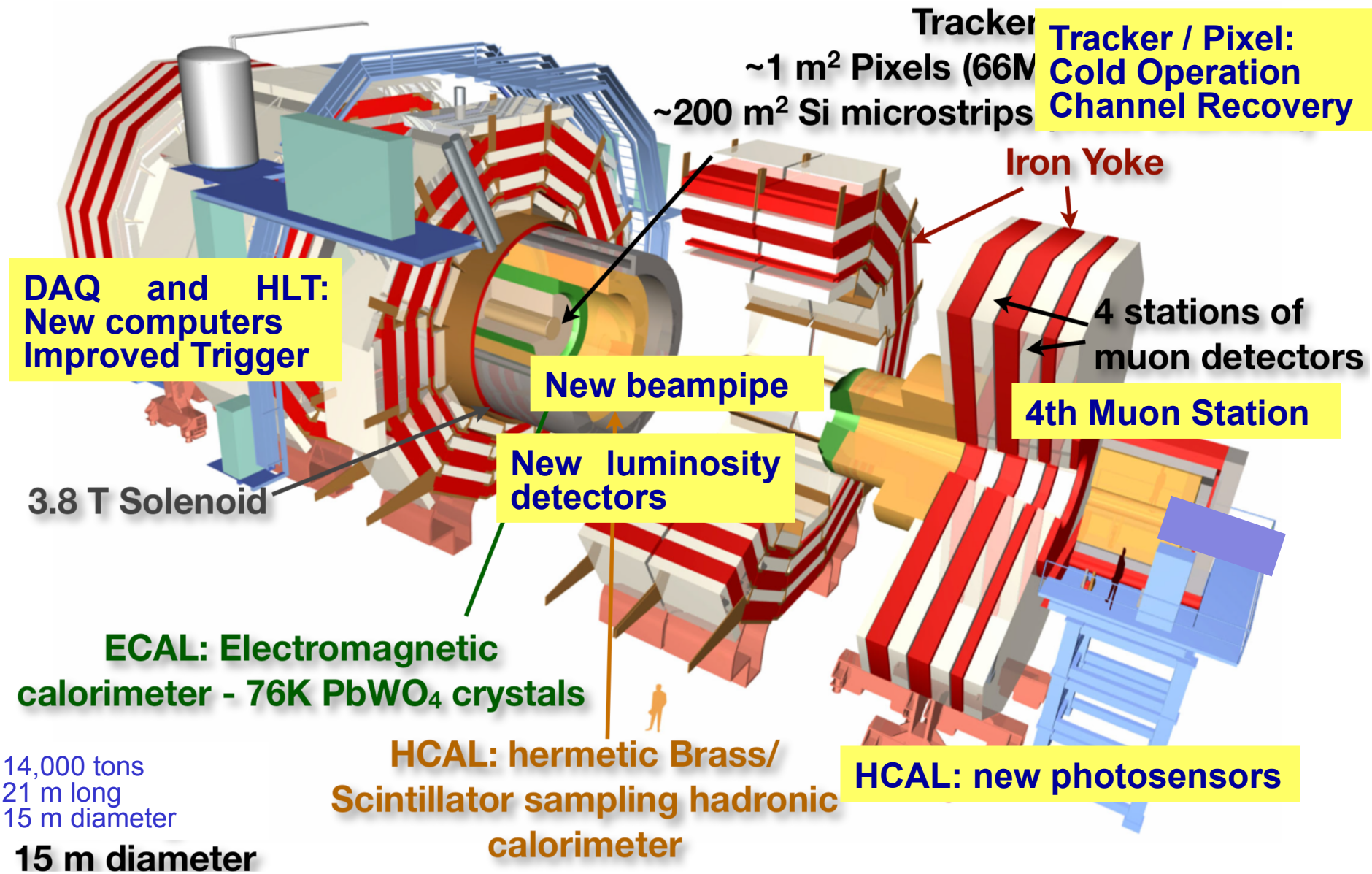
Phase 1 and Phase 2 Upgrades and prospects for Higgs and EWK measurements at CMS

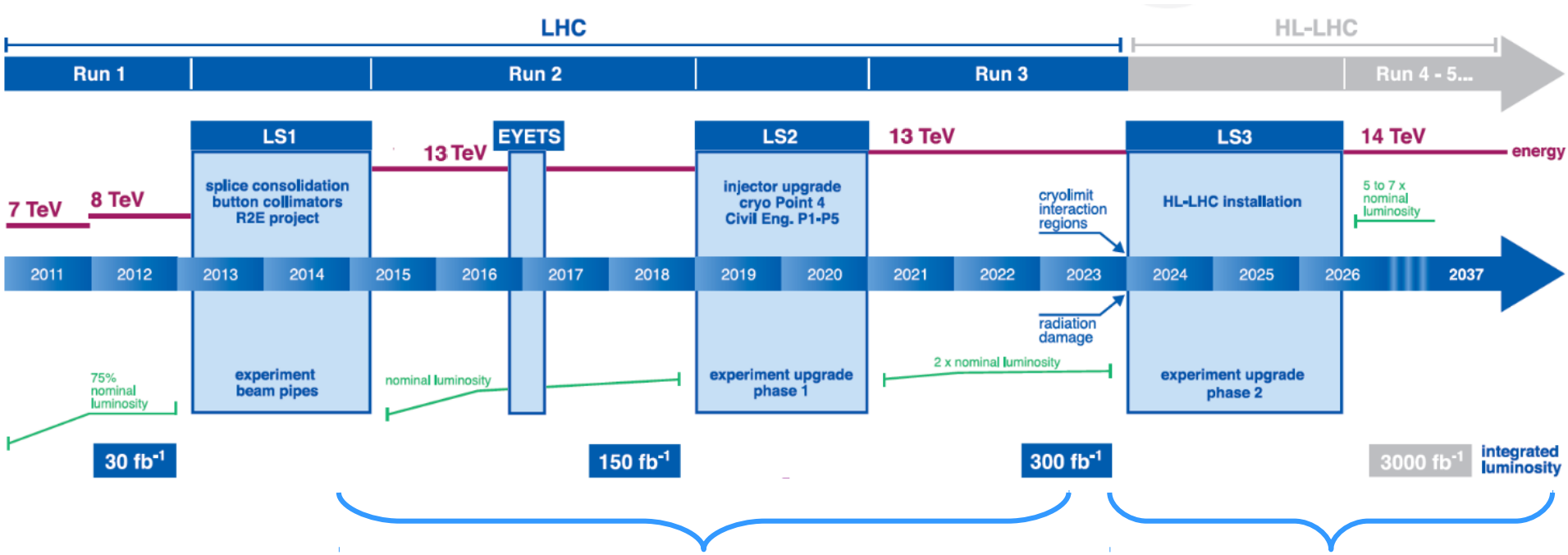
Petar Maksimovic
Johns Hopkins

WIN 2017

CMS after long shutdown



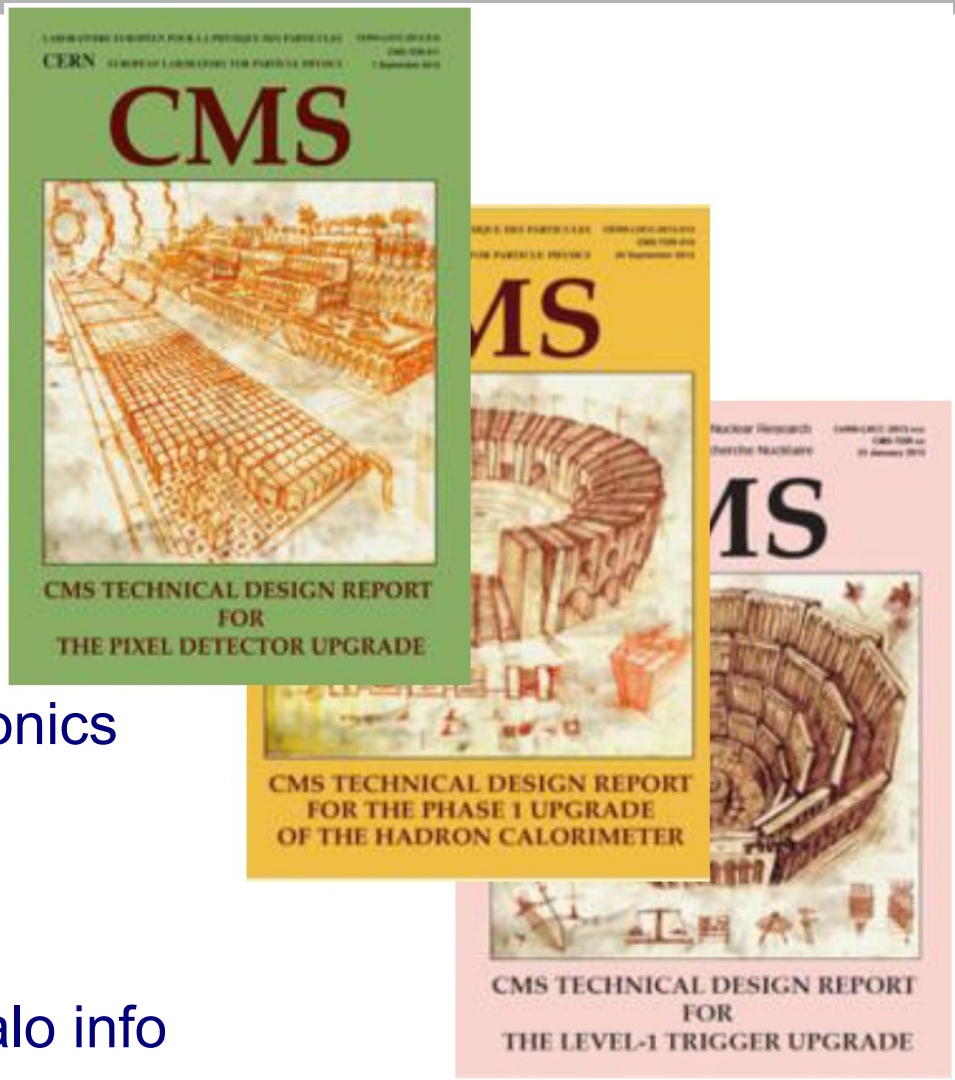
The layout of this talk



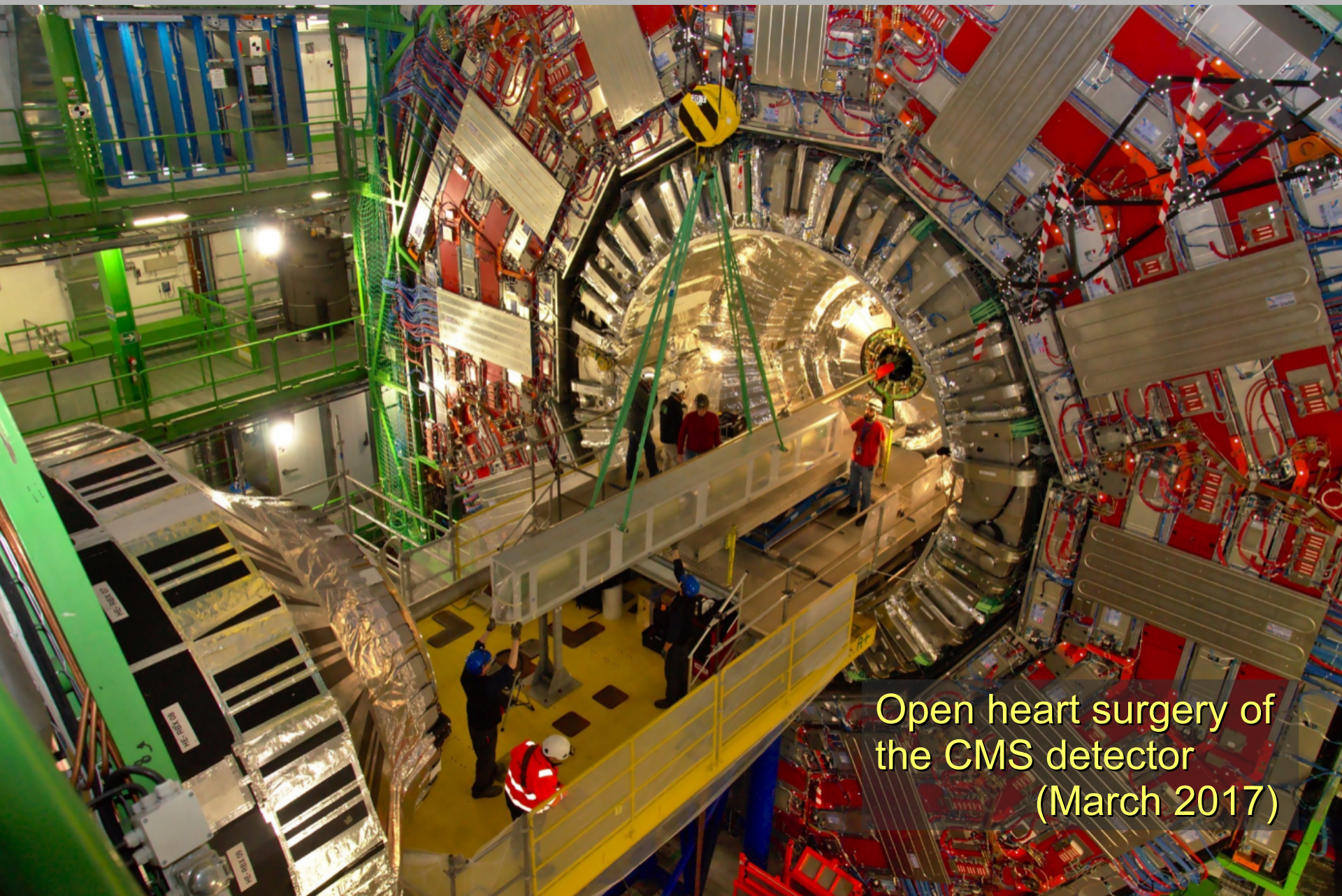
- Phase 1 Upgrade
- Phase 2 Upgrade
- HL-LHC physics prospects:
  - Higgs
  - Electroweak

Phase 1 upgrades

- Pixel tracker:
  - New detector
  - High-rate readout chip
- Hadronic Calorimeter:
  - Improved photodetectors
  - Faster & more robust electronics
- L1 trigger system:
  - Exploit additional muon & calo info
  - Move to high-performance FPGAs

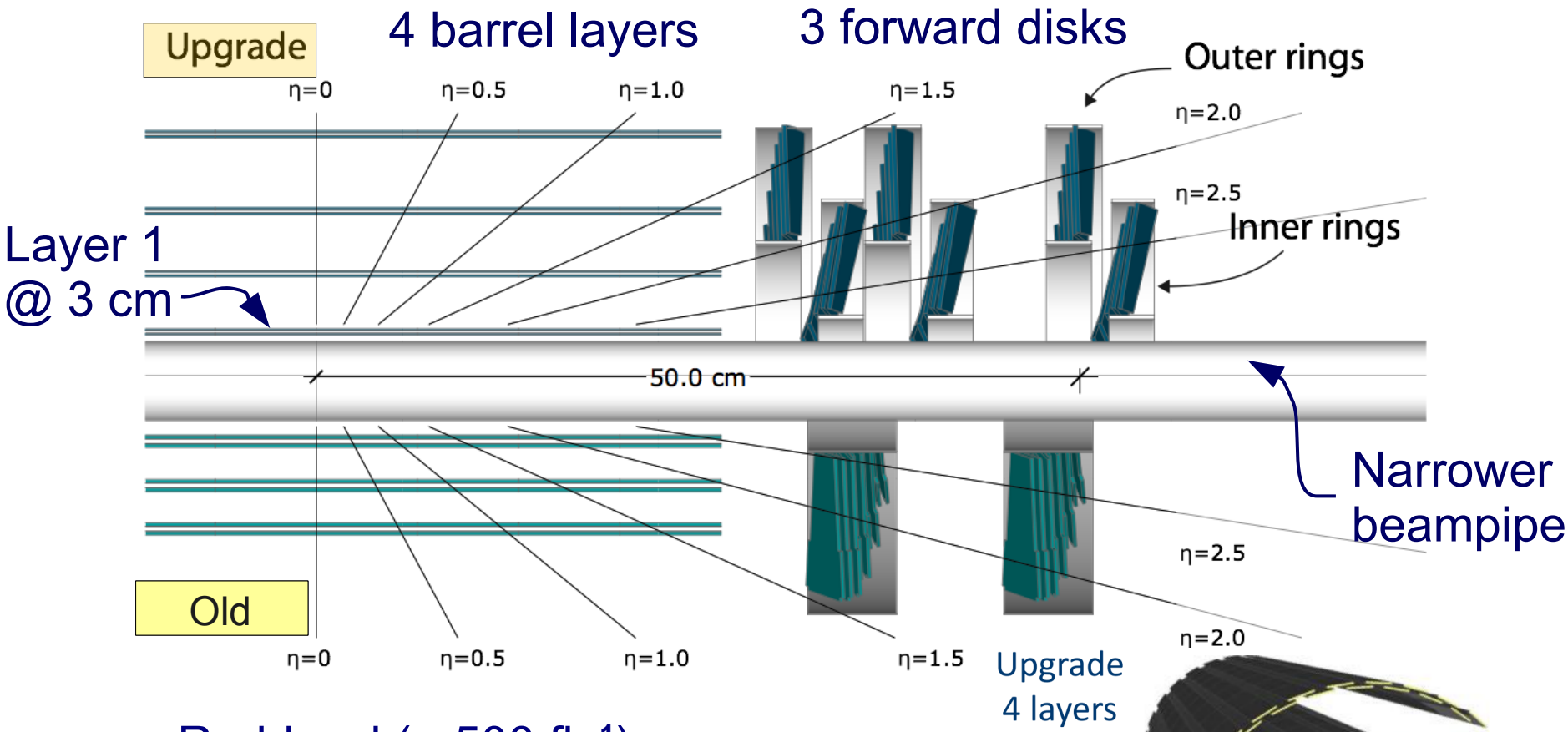


Phase 1: pixels



Open heart surgery of the CMS detector (March 2017)

Phase 1: pixels



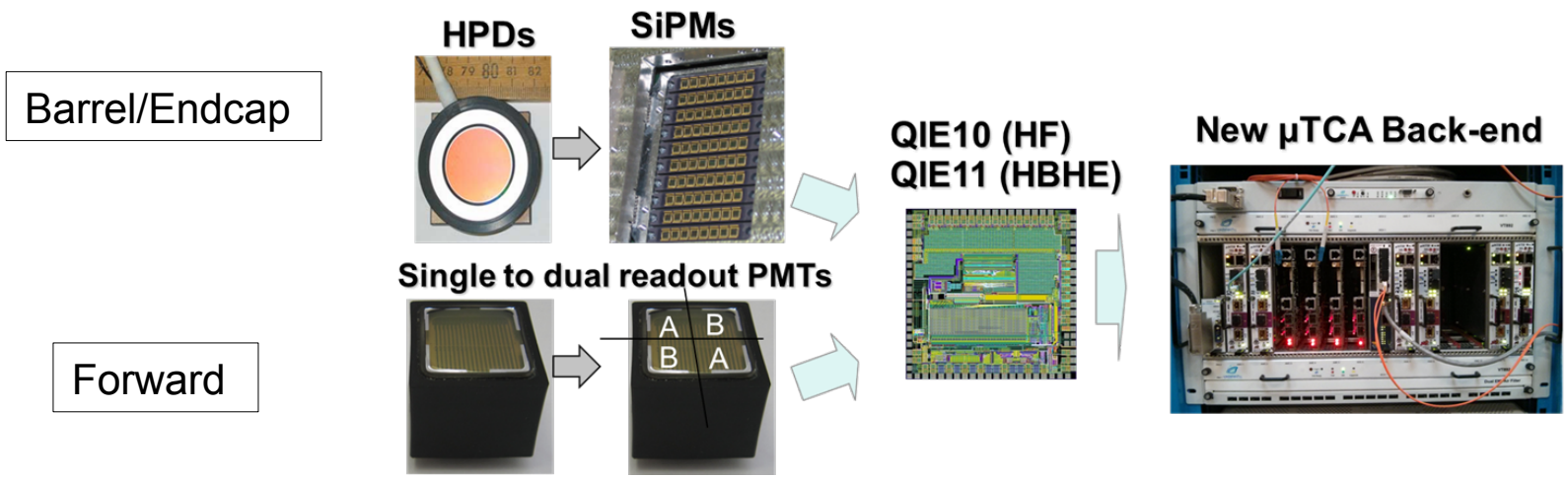
Upgrade
4 layers

Old
3 layers

- Rad-hard (~ 500 fb^{-1})
- Less material
- New readout chip
  - recovers efficiency up to PU ~ 100

Phase 1: hadronic calorimeter

- Photodetectors
  - solve frequent elec. discharges (better noise, gain, longevity)
  - forward: suppress anomalous signals (particles in PM tubes)



- Front-end
  - new chips: @25 ns readout (= 40 MHz)
- Back-end
  - new µTCA board (large data volumes)

Phase 1: Level 1 Trigger

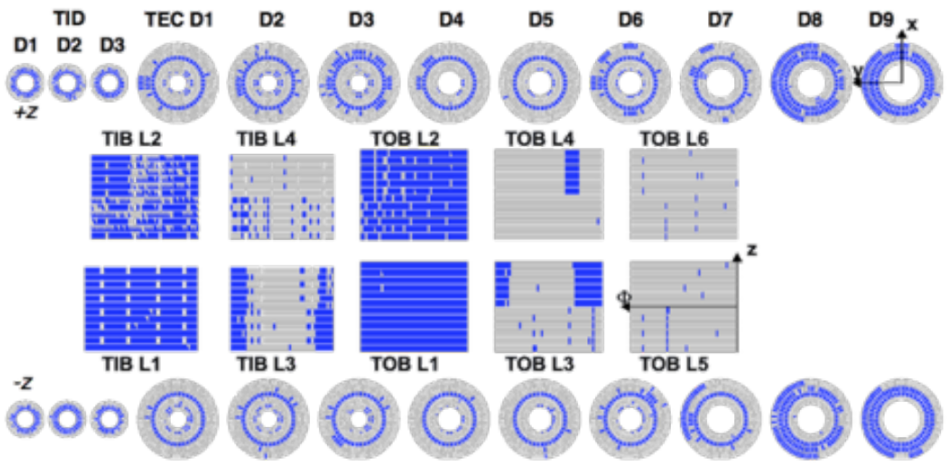
- Goal: maintain performance in Run2 and Run3
  - increase in rate ~ x6
  - need to subtract PU
  - improve efficiency & resolution
  - keep it flexible!

- Sophisticated algorithms (FPGAs) in μTCA to exploit
  - full granularity of CALO info
  - additional MUON info

- In operation since 2015!

HL-LHC Challenge

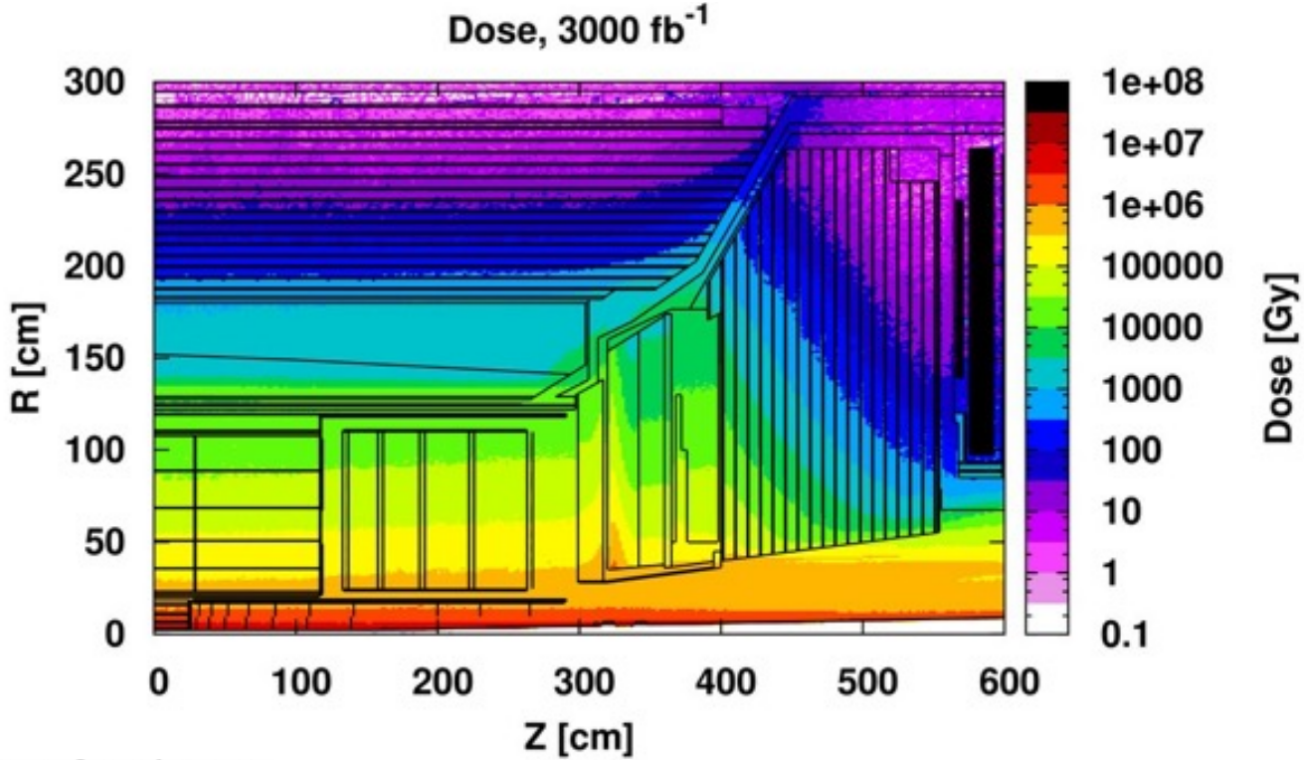
- Detectors have to operate in extreme environment



Blue tracker modules are inactive after 1000 fb^{-1} due to very high leakage currents induced by neutron fluence.

- By 2025 the detectors will be running (radiated) for 15 years.

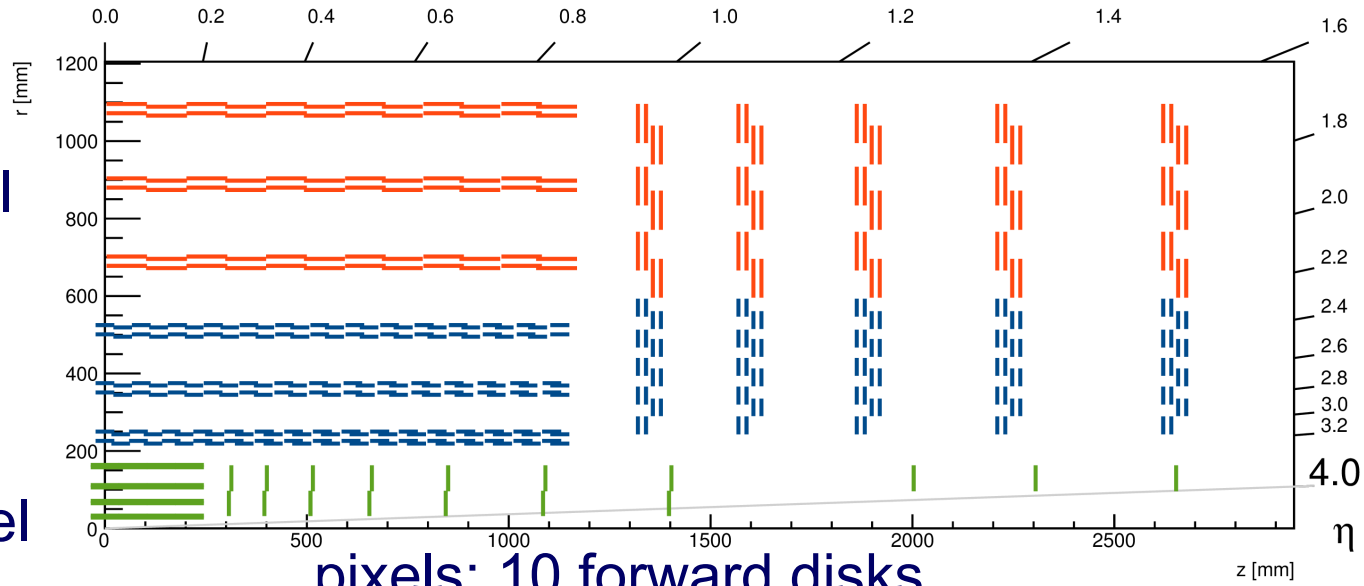
  = Severe aging effects.



Phase 2: tracker (a possible layout)

strips: 6 barrel layers

pixels: 4 barrel layers



pixels: 10 forward disks

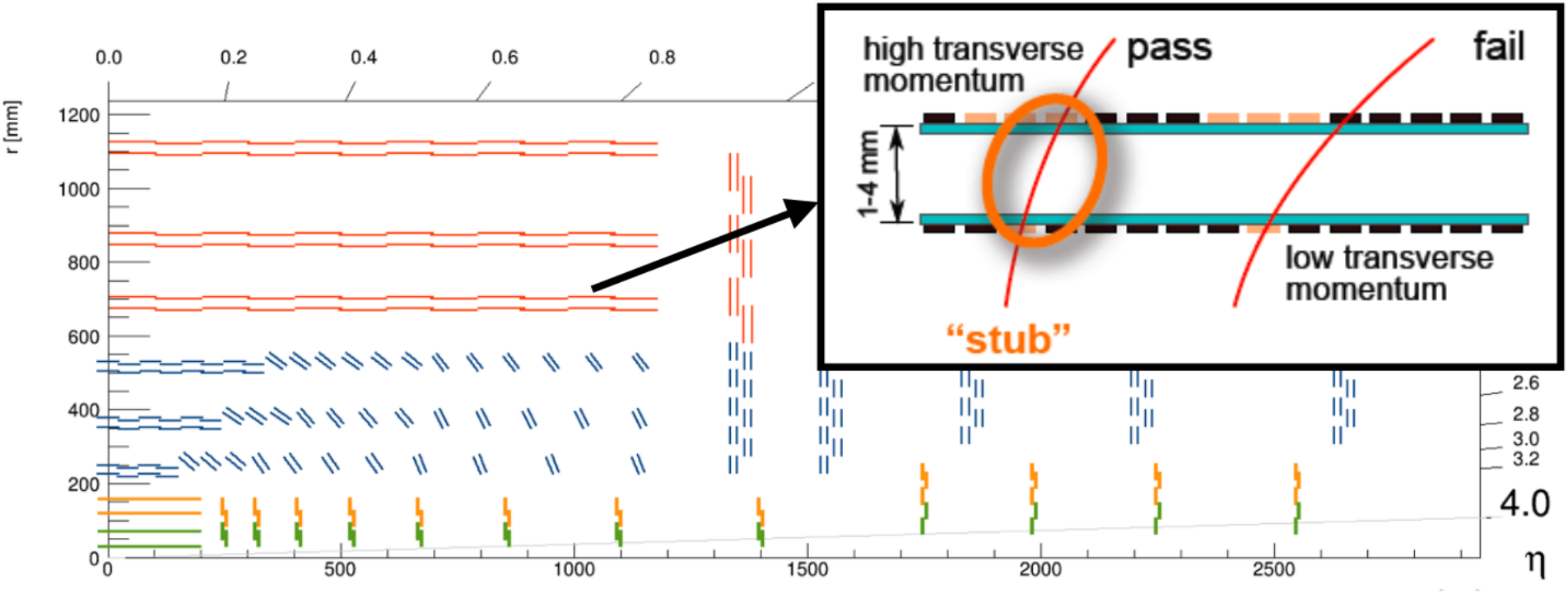
strips: 5 fwd. disks

coverage up to $|\eta| \sim 4$

- Strips: x4 granularity
- Pixels: 6x granularity (25x100, 50x50) → Reduce hit merging
- Thinner sensors → Rad-hard, less material
- Readout: 750 kHz

Phase 2: track trigger

- New tracker can provide 2-layer “stubs” to L1 trigger

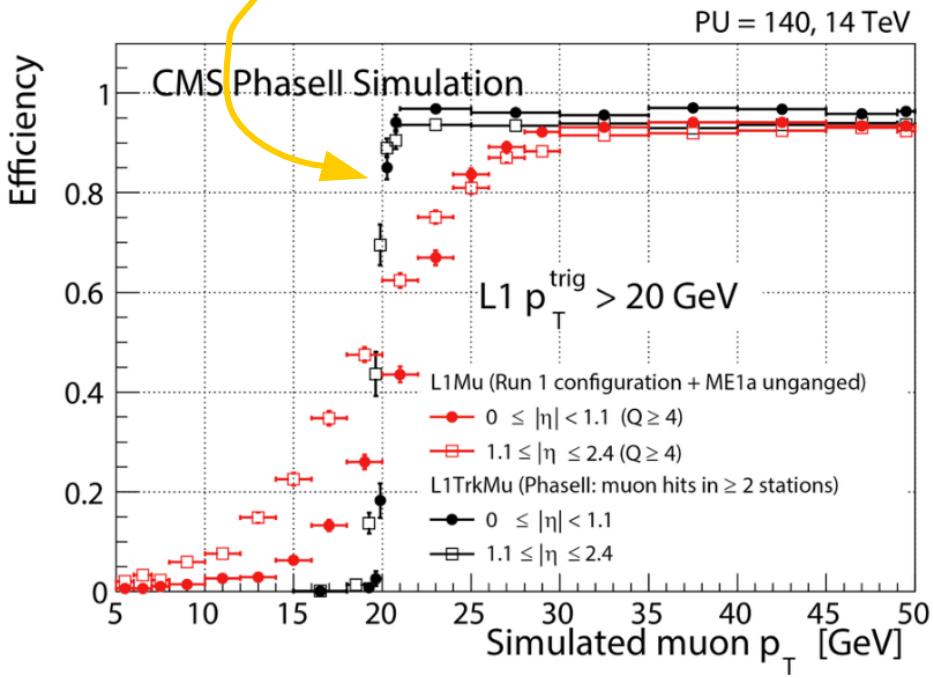


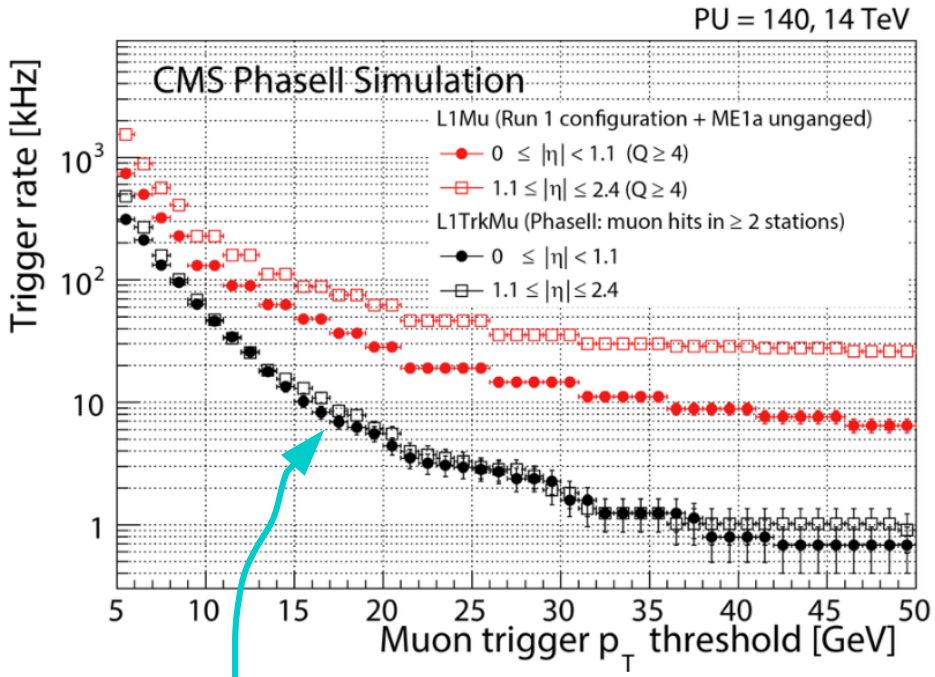
- 6 stubs for tracks with pT > 2 GeV @ 40MHz, latency < 4 μs
- Studies with hardware demonstrators in progress

Phase 2: track trigger (2)

- Precision from new tracker → powerful background rejection at L1 of trigger!

Sharper turn on



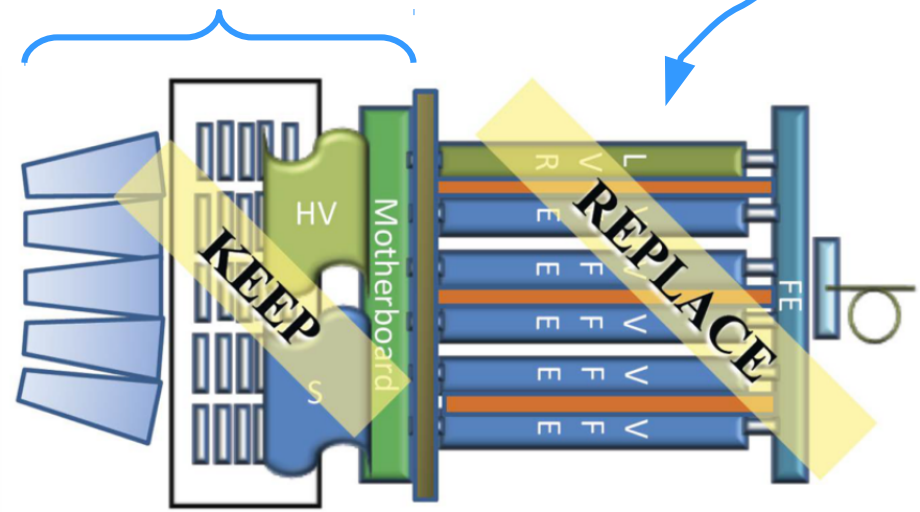


Much lower rates

Phase 2: barrel EM calorimeter

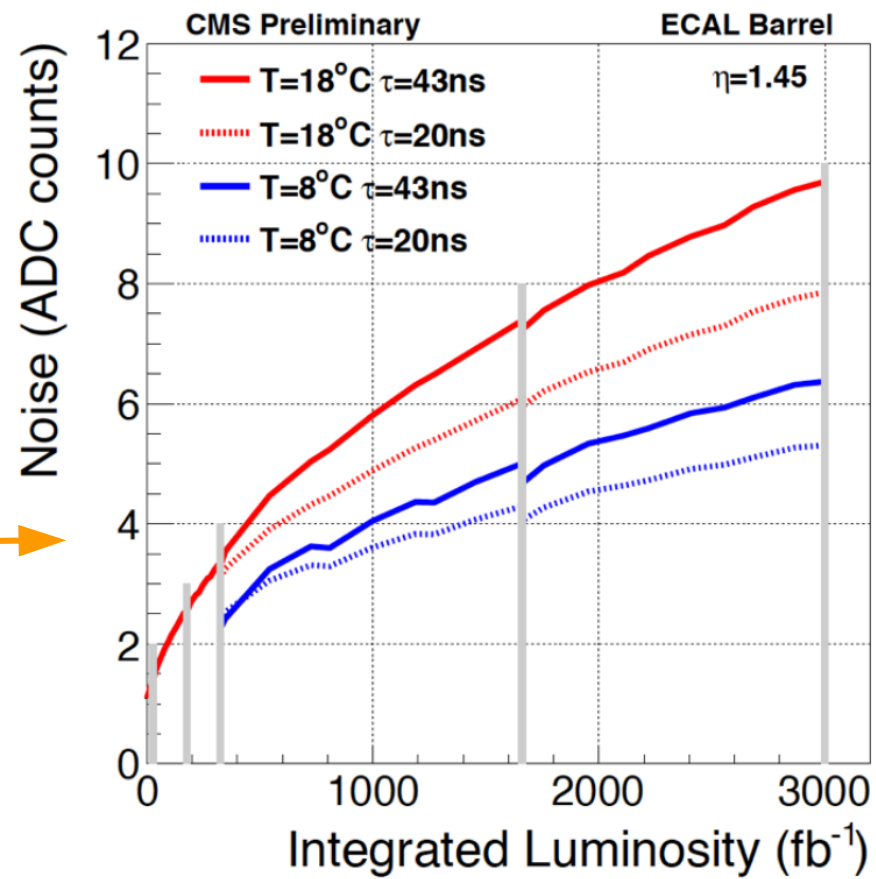
Keep lead tungstate crystals and avalanche photodiodes (APD)

Replace electronics for L1 trigger
- single-crystal readout (instead of 5x5 tower) at 40 MHz

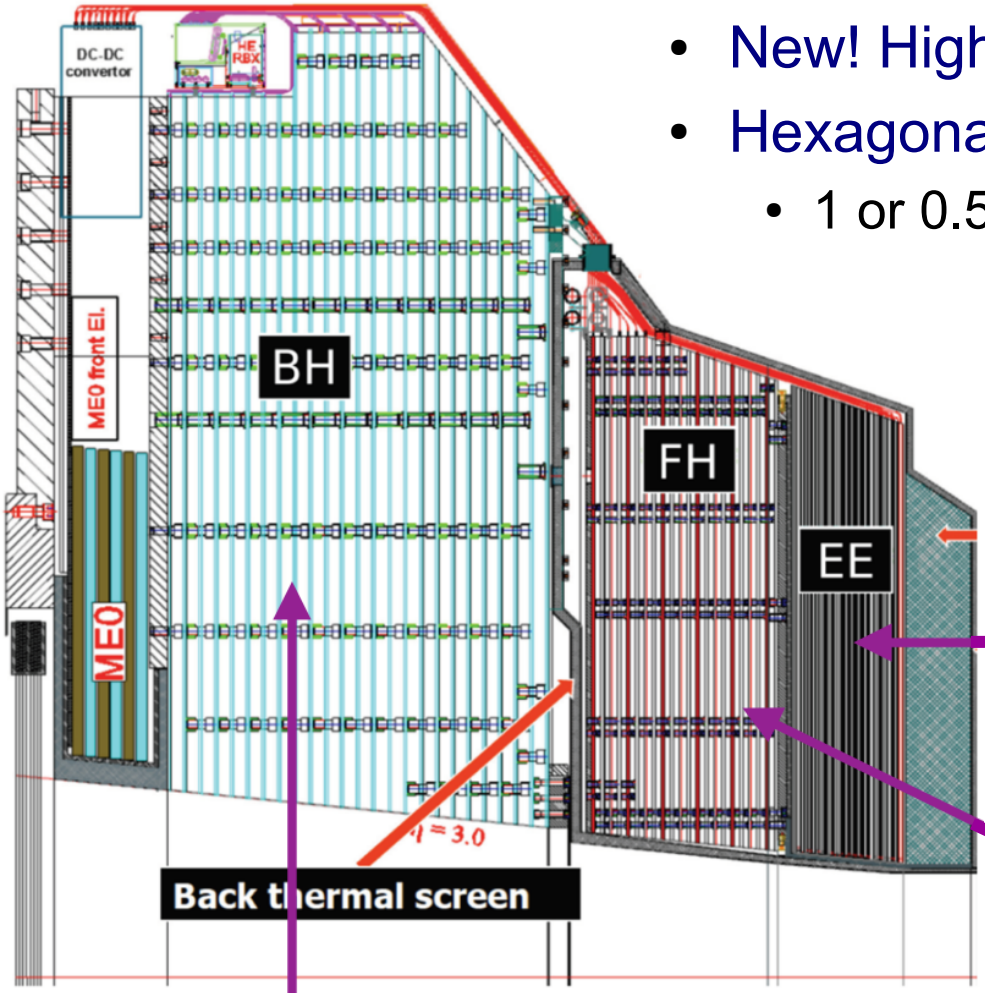


Mitigate APD noise with

- lower operating temperature
- optimized readout shaping time



Phase 2: endcap calorimeter



- New! High Granularity Calorimeter (HGC)
- Hexagonal silicon sensors
  - 1 or 0.5 cm² hex cell size, 6M channels
  - Excellent longitudinal and transverse segmentation
  - Rad-hard

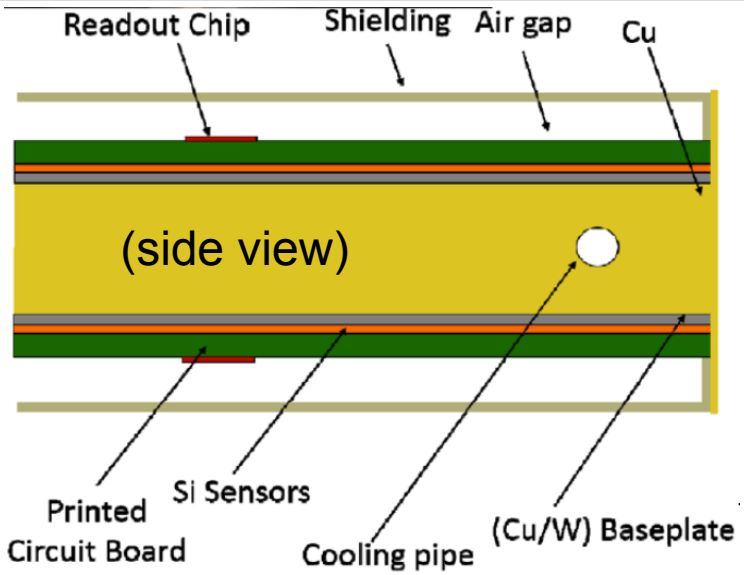
<u>Endcap EM</u> section
28 tungsten and copper plates,
25 radiation and 1.5 interact. lengths

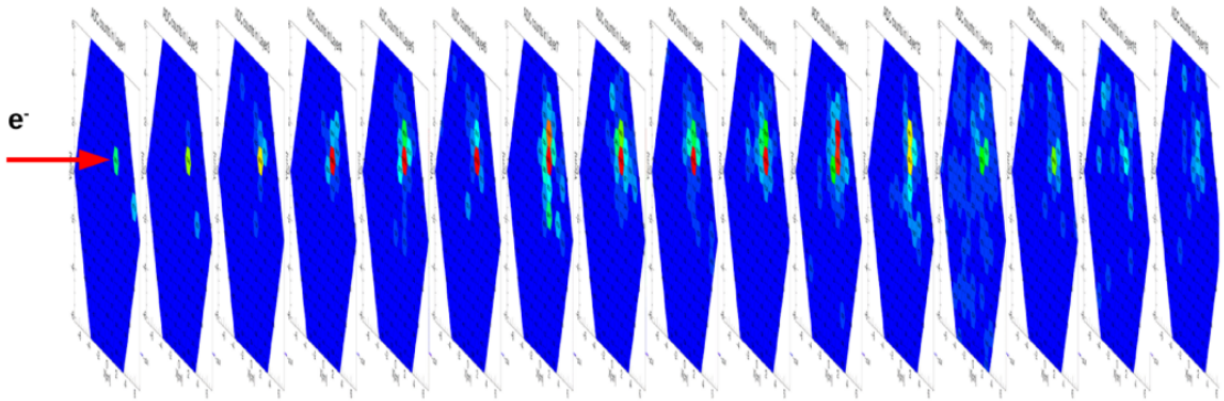
<u>Front Hadron</u> section
12 brass and copper plates,
3.5 interaction lengths

<u>Backing Hadron</u> section
Brass plates + plastic scintillating tiles, 5 interaction lengths

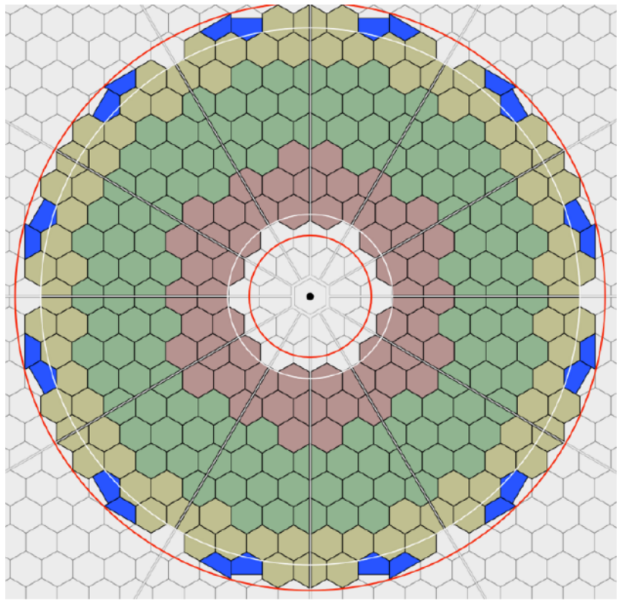
Phase 2: endcap calorimeter

- Measurement of shower shape + its time development.
  - Enhances particle ID, energy resolution and PU rejection





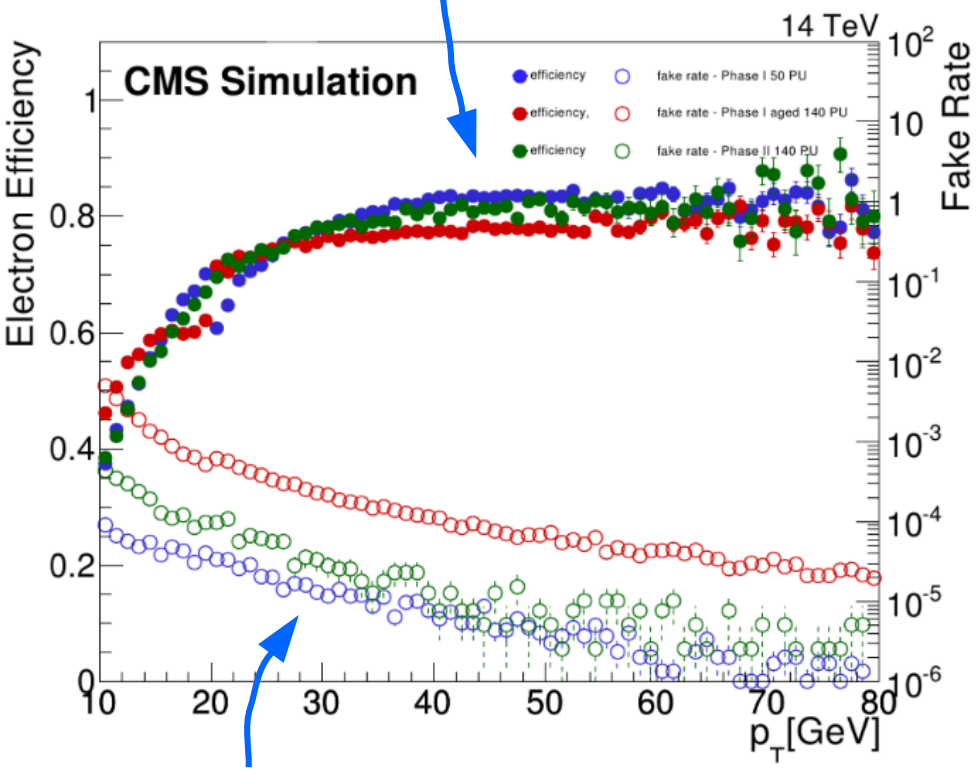
32 GeV electron
at Fermilab Test Beam



Phase 2: endcap calorimeter

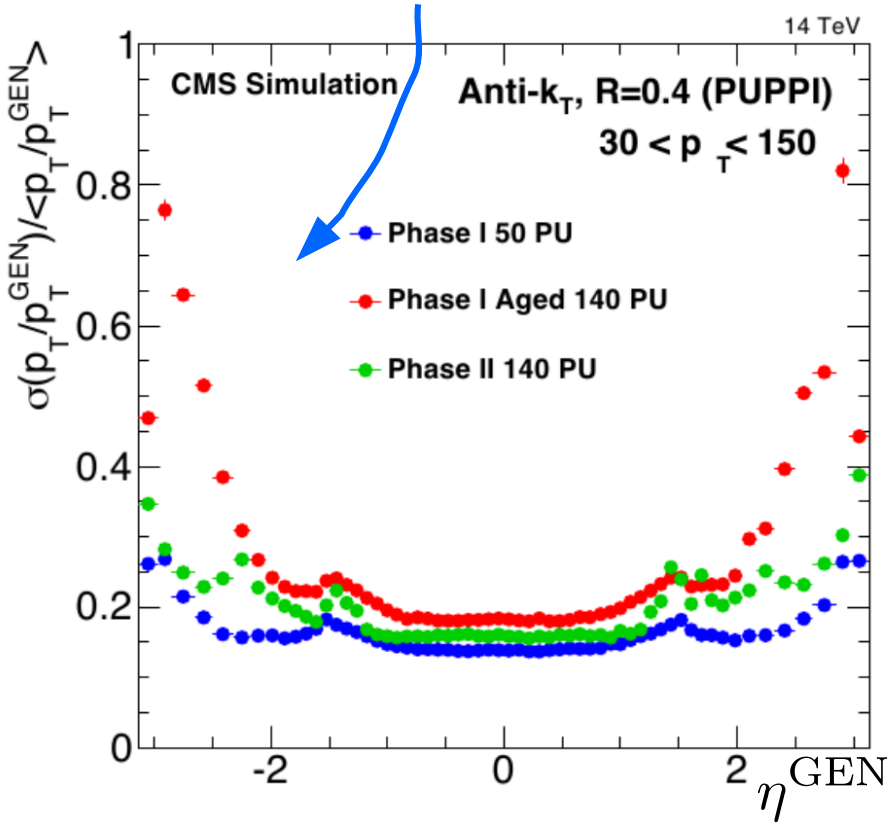
- Simulated performance:

Electron ID efficiency



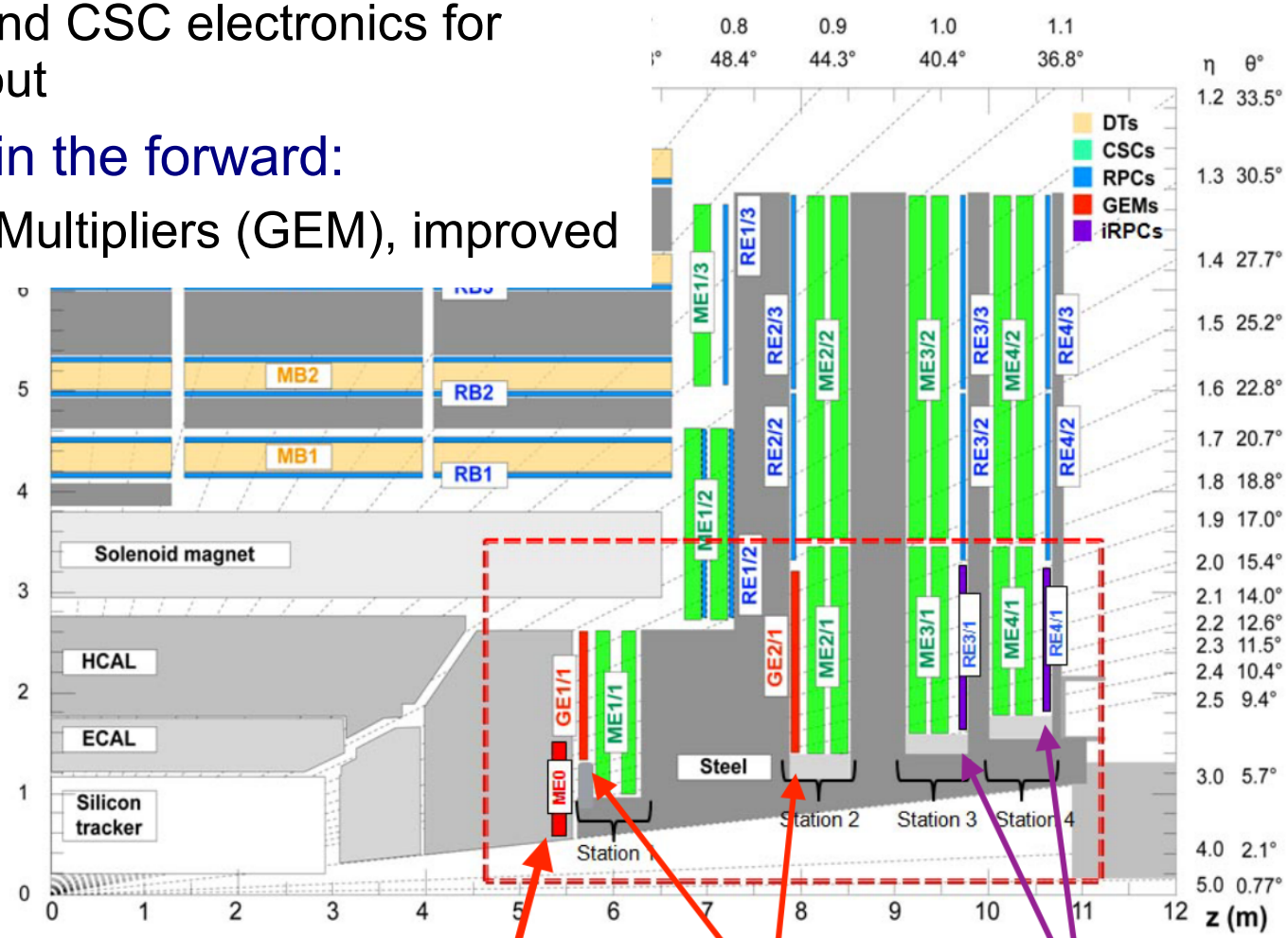
Electron ID fake rate

Jet Energy Resolution



Phase 2: muon system

- Existing chambers will survive HL-LHC
  - Replace DT and CSC electronics for 40 MHz readout
- New chambers in the forward:
  - Gas Electron Multipliers (GEM), improved RPC



Coverage up to $|\eta| \sim 3.0$

Forward muon tagger – MEO

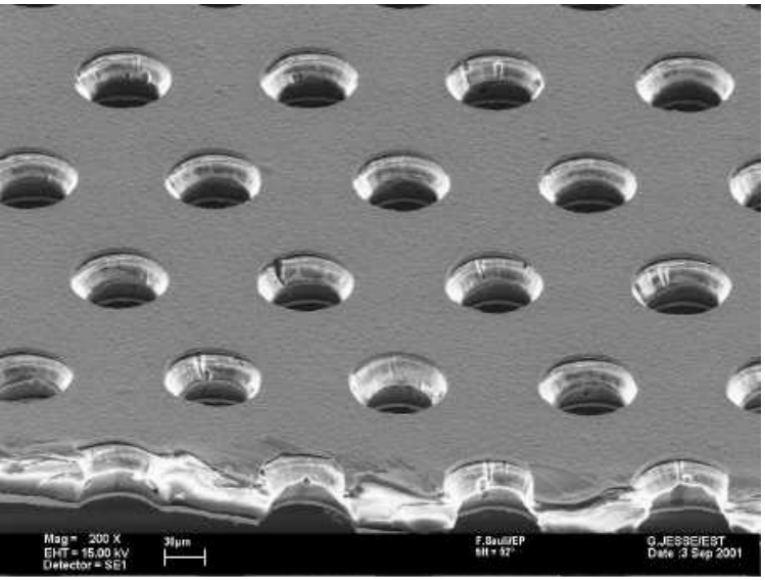
GEM

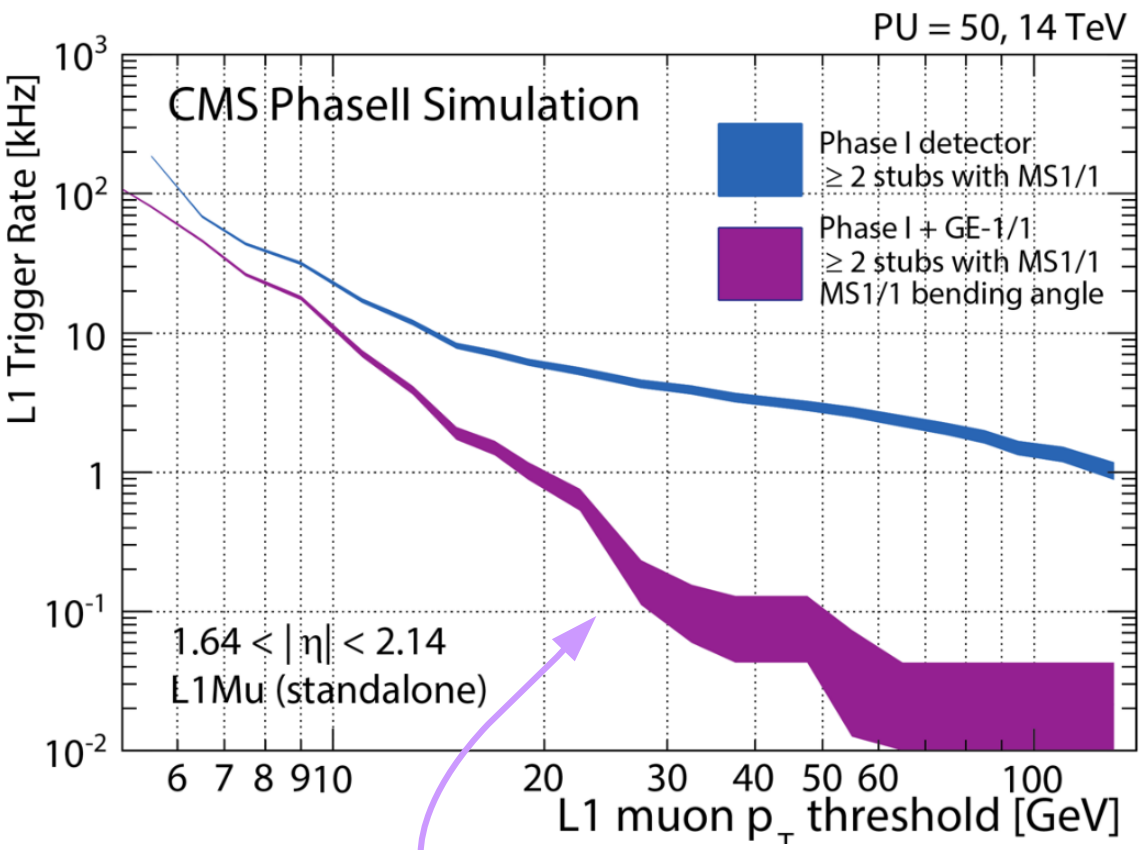
iRPC

Phase 2: muon system

GEM:

- Improves p_T resolution for L1 trigger muons
- Muon ID to η ~ 3.0
- Pilot system (5 super-chambers) installed at Muon endcap station 1





Muon trigger rate reduction by adding GE1/1

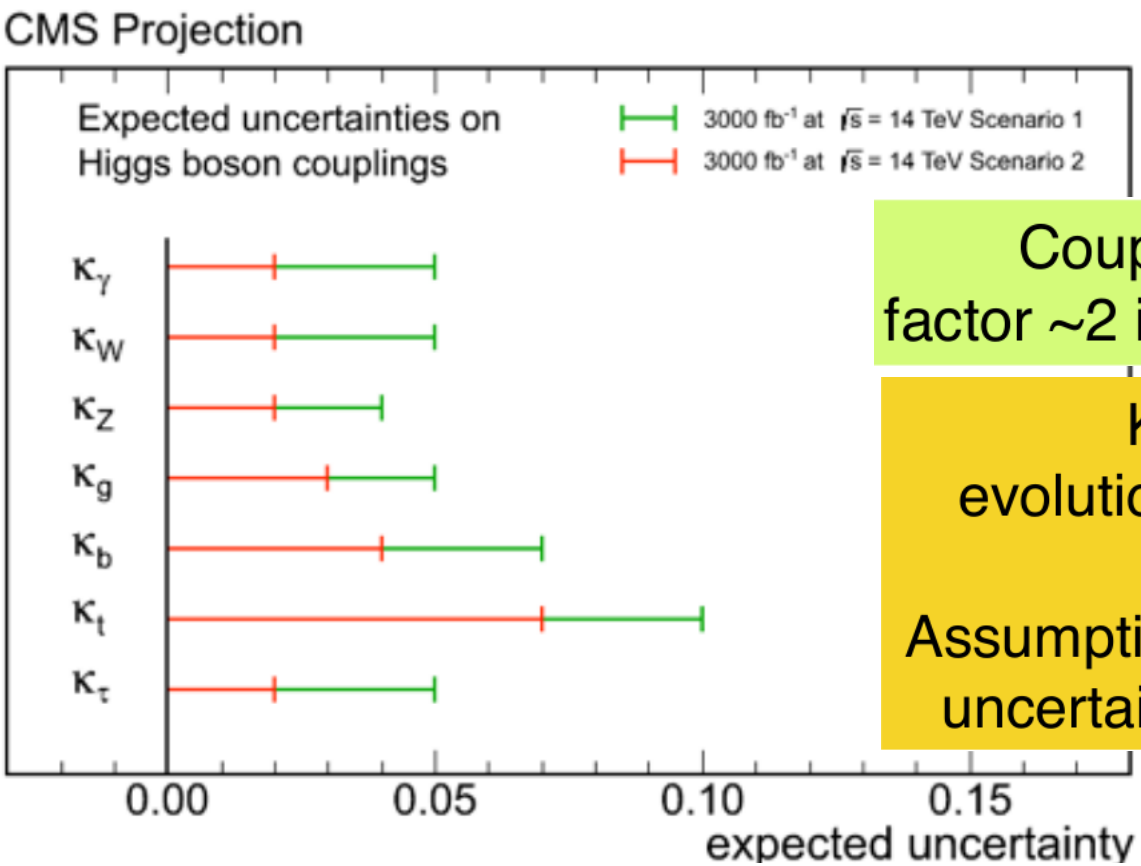
Phase 2: trigger

- L1 Trigger new capabilities
  - Track trigger - better lepton p_T resolution
  - Finer calorimeter info
  - Additional muon chambers for $\eta > 1.6$
  - Sub-detector electronics upgrade to handle higher rate
- L1 Trigger rate ~ 750 kHz @ 200PU (now 100 kHz)
  - Thresholds comparable to what are used now
  - 12.5 μs latency (now 3.4 μs latency)
    - sufficient time for Track Trigger
      = hardware track reco + matching with muon and calo info
- High-Level Trigger (HLT) rate ~ 7.5 kHz (now 1 kHz)

HL-LHC Physics

- Higgs discovery at the start of LHC was exceptional
- Goals of LHC and HL-LHC:
  - Explore energy frontier!
    (extension of discovery reach in high-mass region)
  - Precision measurements of SM parameters
    (including the Higgs boson)
  - Sensitivity to rare SM & rare BSM processes

Higgs Prospects: couplings



Coupling precision 2-10 %
factor ~2 improvement from HL-LHC

Key question is the
evolution systematic uncertainty

Assumptions made on cross section
uncertainties already superseded

Rare-decays

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	κ_μ
300	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]	[41,41]	[23,23]
3000	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]	[10,12]	[8,8]

arXiv:1307.7135

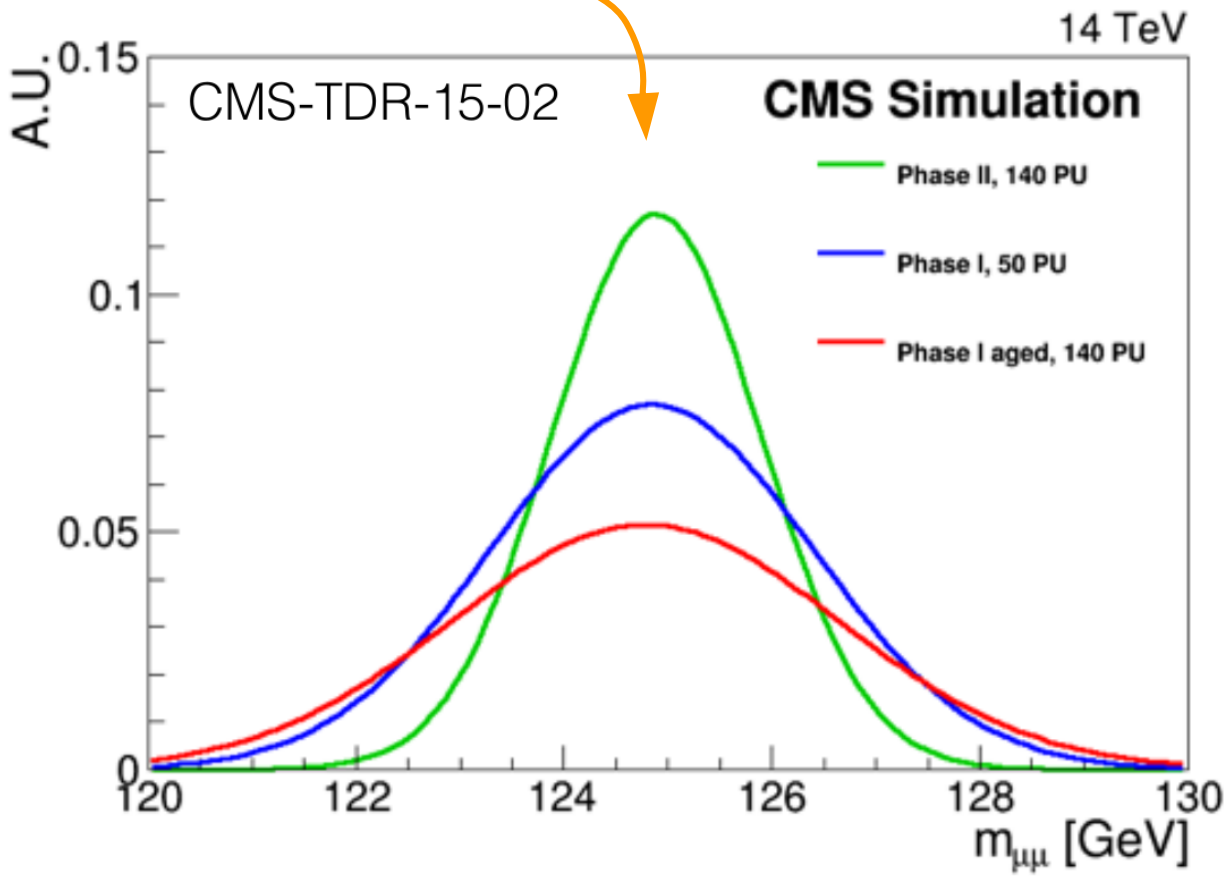
Higgs Prospects: $H \to \mu\mu$

- narrow resonance with huge DY background
  - ~45% improvement in resolution
  - ~20% improvement in efficiency

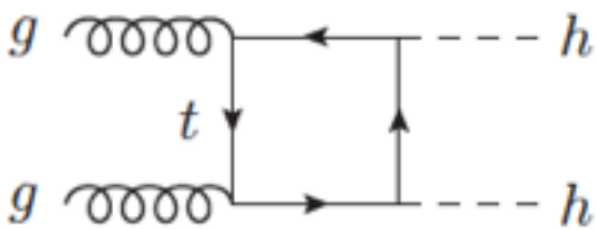
  } wrt Phase1 aged + PU=140

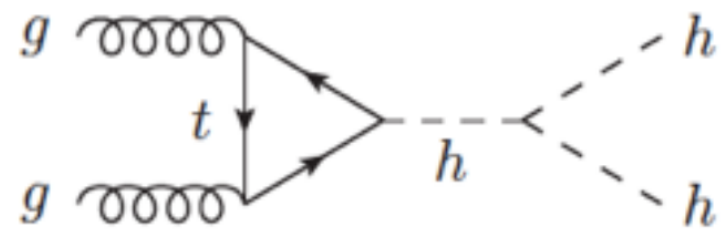
- results scale with square-root of improved yield

- expect ~5% uncertainty on 2nd generation Higgs coupling



Higgs Prospects: HHH coupling



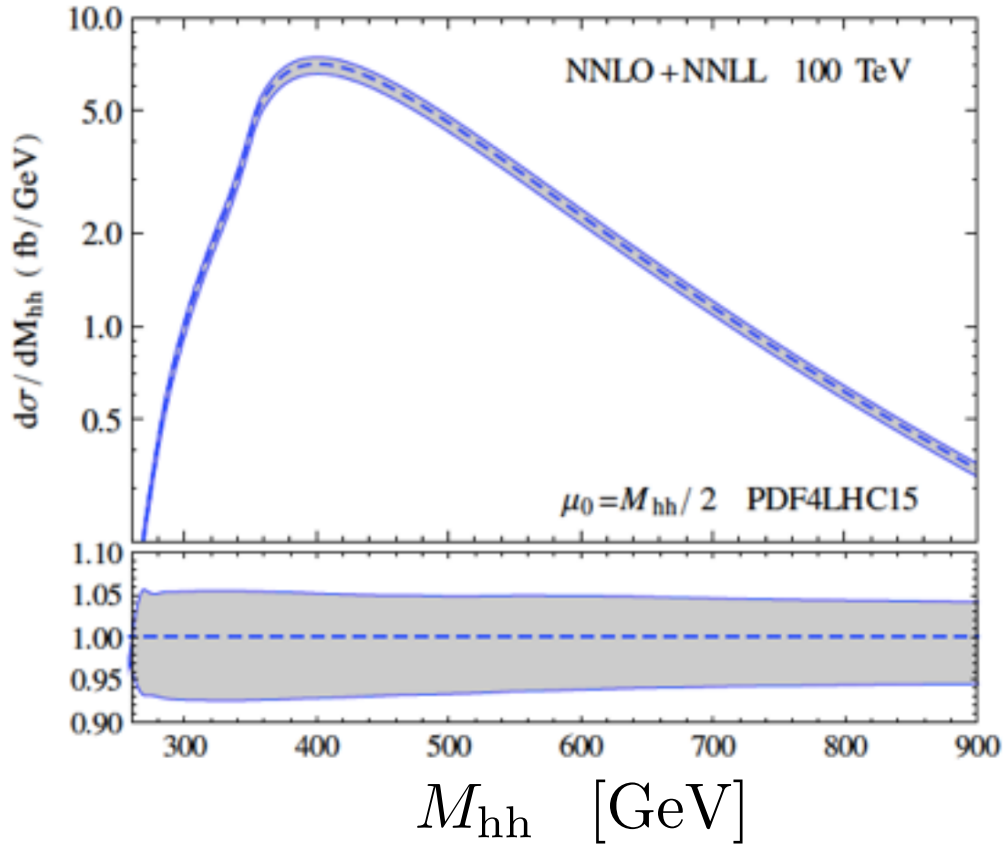


- Reconstruct Higgs potential
  - Check EWSB!

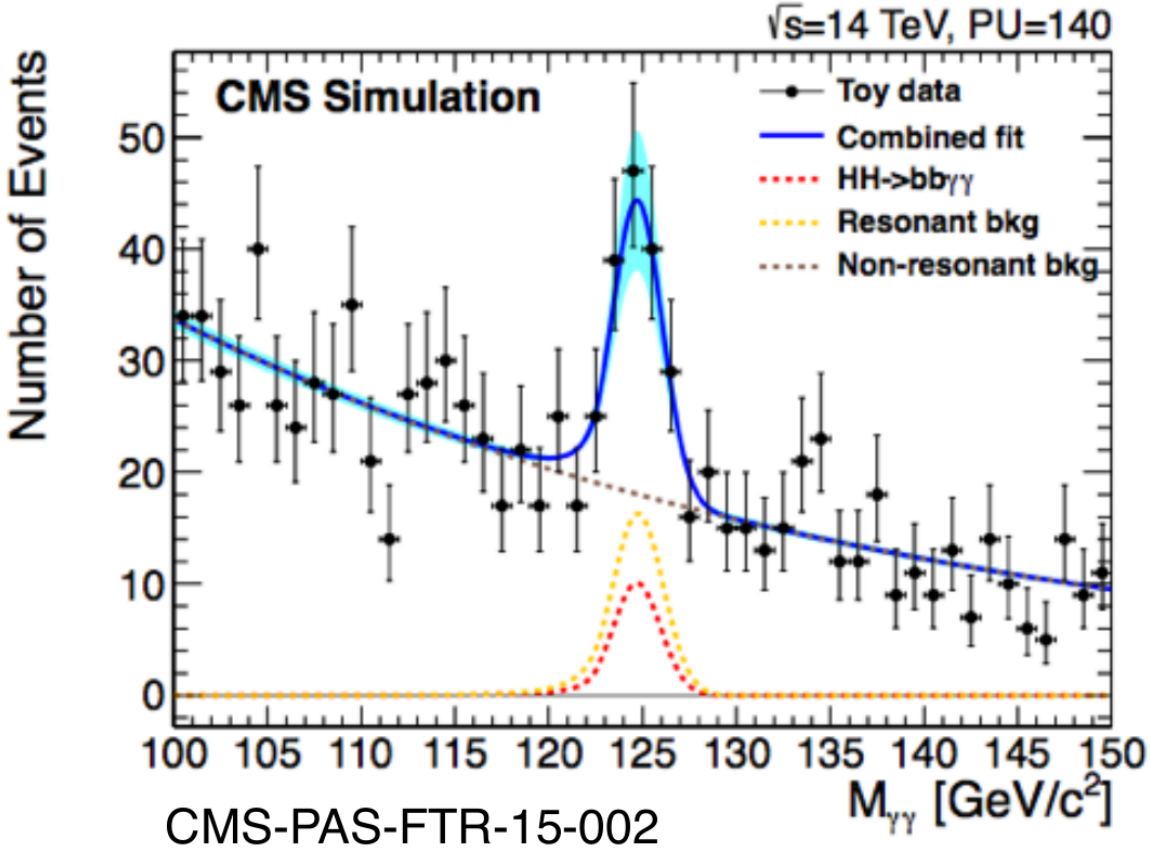
$$\mathcal{L} = -\frac{1}{2}m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4$$

EFT Lagrangian

- BSM can significantly enhance rate
- Exhaustive program at LHC and HL-LHC



Higgs Prospects: HHH coupling (2)

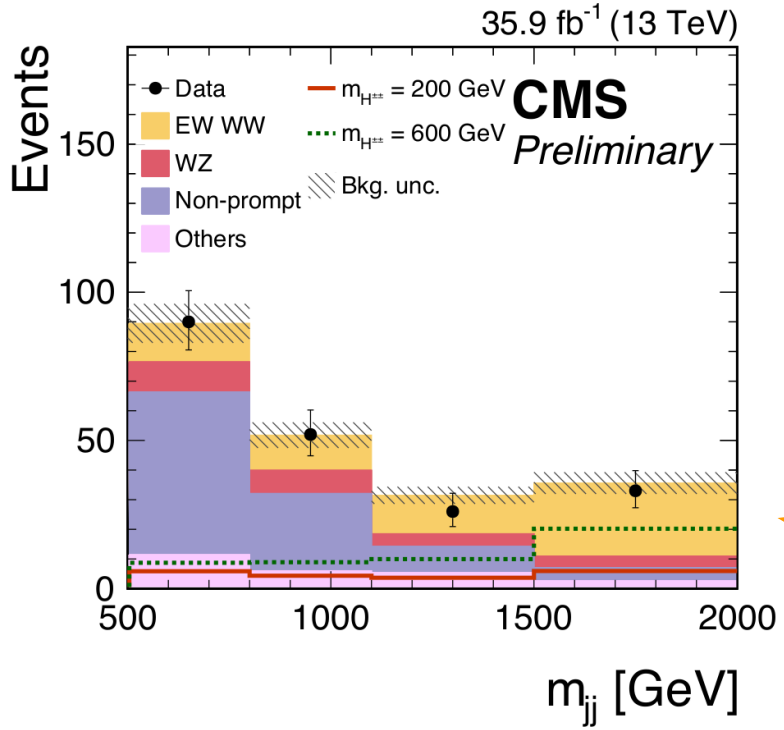


CMS-PAS-FTR-15-002

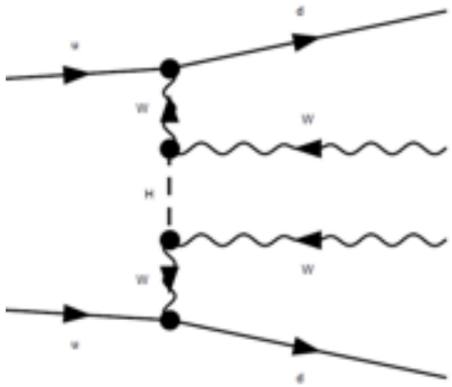
- Demonstrate Phase2 detector's capabilities
  - b-tagging, photon, and tau-Id
  - case for the track trigger
- Sensitivity
  - ~10 signal events
  - ~2σ

- Further improvements
  - additional channels (4b, 2b+VV*, 2b+ττ, etc.), improved pixel detector (b-tagging), resolution (regression)...

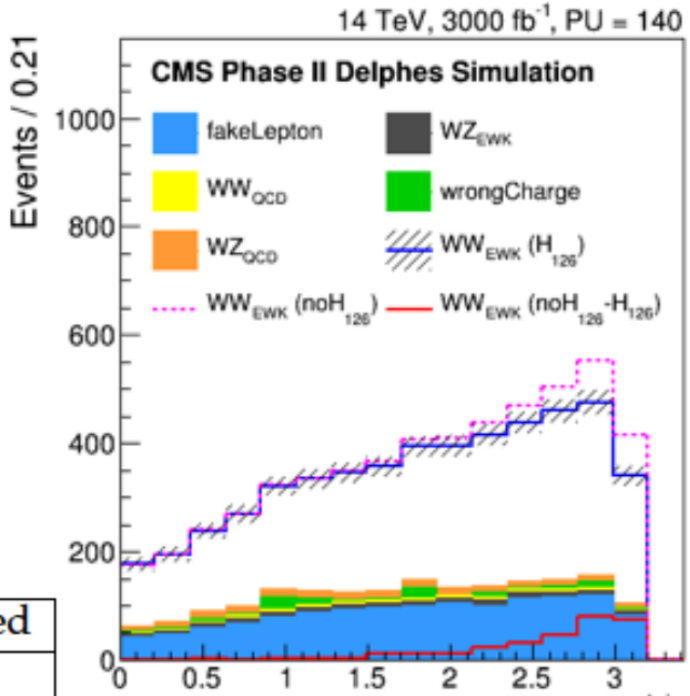
Prospects for Vector Boson Scattering



Access VBS via same-sign WW



- first observation: CMS-SMP-17-004
- longitudinal scattering cross section
- anomalous couplings
- input to Higgs couplings



CMS-SMP-14-008

3000 fb^{-1}, 14 TeV	Phase-I	Phase-II	Phase-I aged
Higgsless 95% CL μ exclusion	0.14	0.14	0.20
V_L V_L scattering significance	2.50	2.75	2.14

Conclusions

- Phase1 upgrades
  - being commissioned now
  - doing well so far
- Phase 2 upgrades
  - studies in progress
- HL-LHC Physics Prospects:
  - detector performance maintained – or improved!
  - Higgs and other precision physics
  - extensive program of searches for BSM and rare SM processes

BACKUP MATERIAL