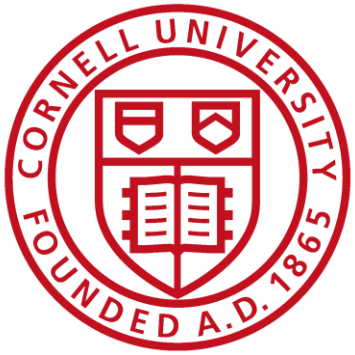
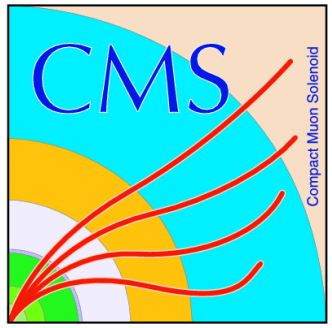




CMS Upgrade for HL-LHC

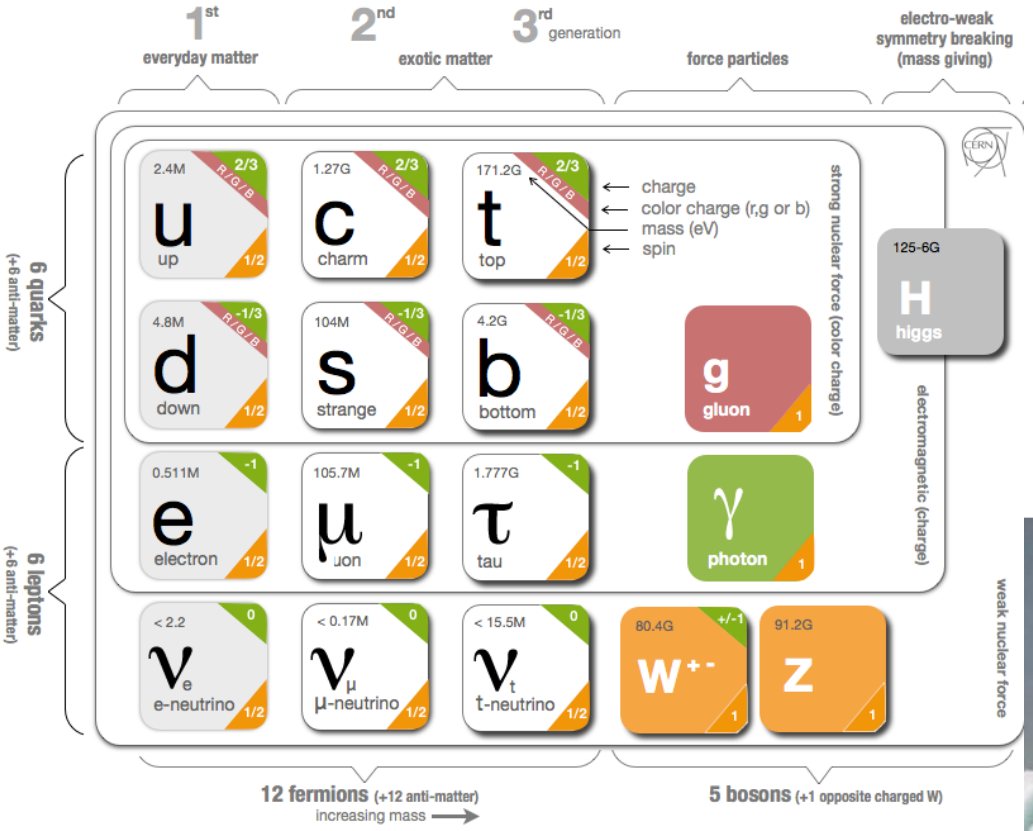
and Prospects for LLP Searches

Yangyang Cheng

LLP Workshop

October 20, 2017

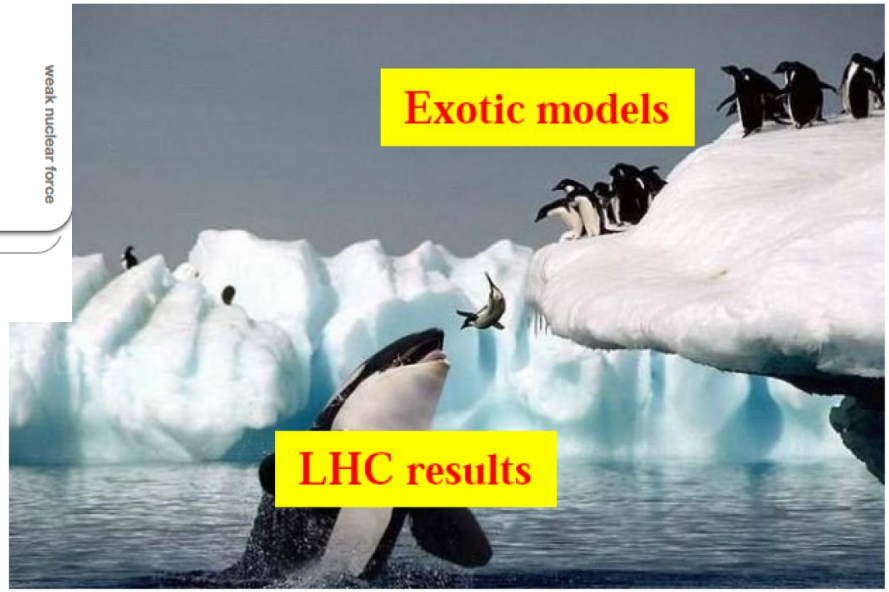
Physics Beyond the (current) LHC



- The Standard Model (SM) works very well: too well?

→ SM does not explain everything: e.g. no Dark Matter candidate

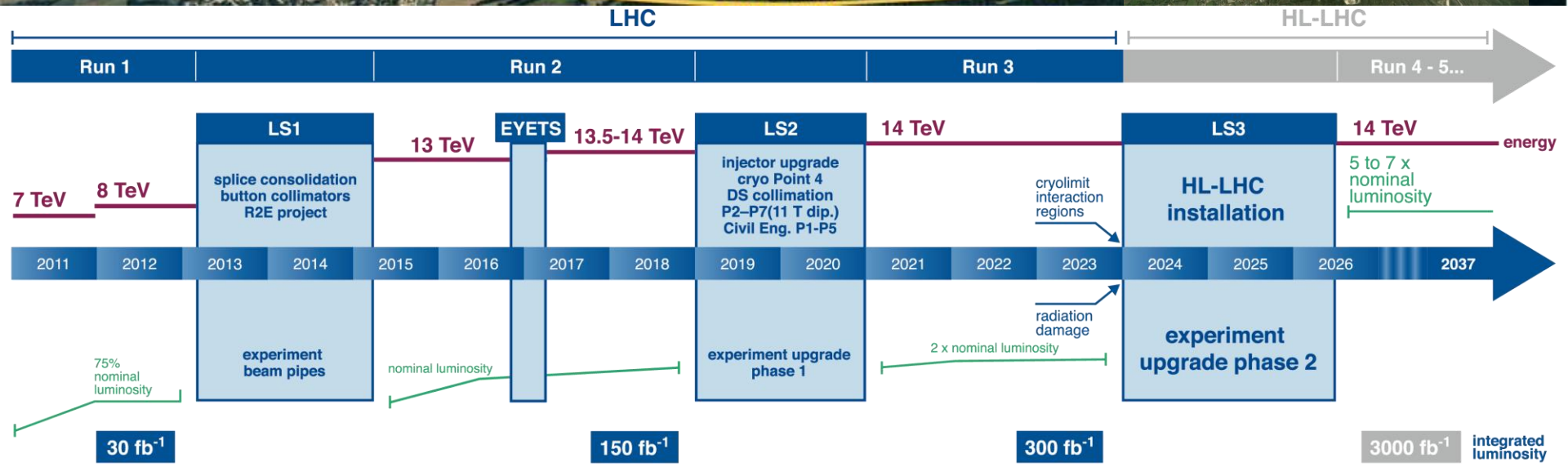
→ Naturalness & low-mass of the Higgs boson suggest physics beyond the SM (BSM)



High Lumi-LHC: x100 LHC data at TeV scale

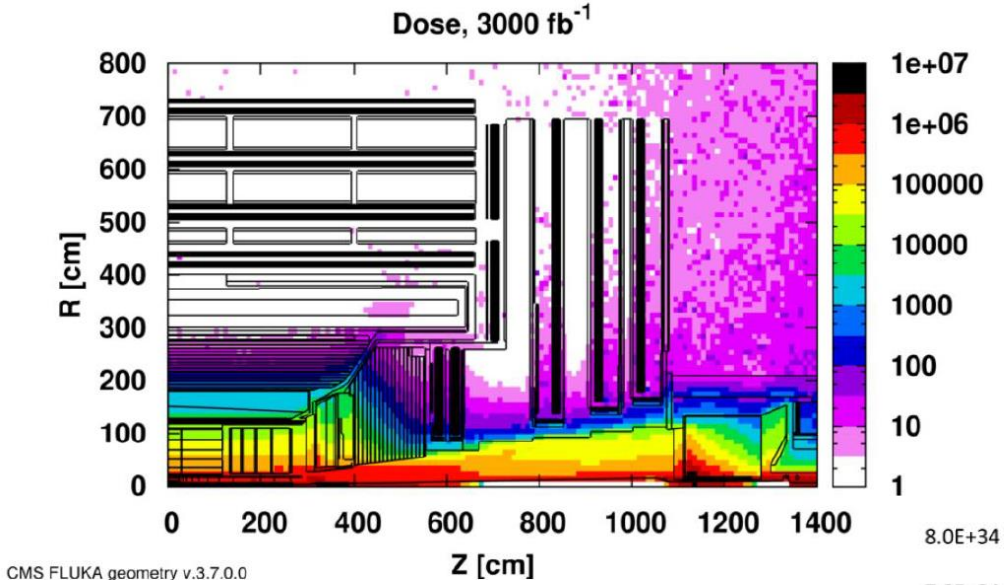
- Measure Higgs properties in detail
- Probe rare SM processes
- Search for new physics: none @LHC yet!

From the LHC to the HL-LHC



Challenges from HL-LHC

Radiation Dose

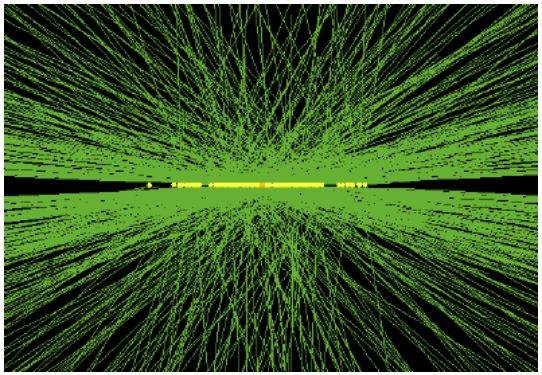


Detector elements and electronics exposed to high radiation dose
→ limits equipment lifetime & degrades signal

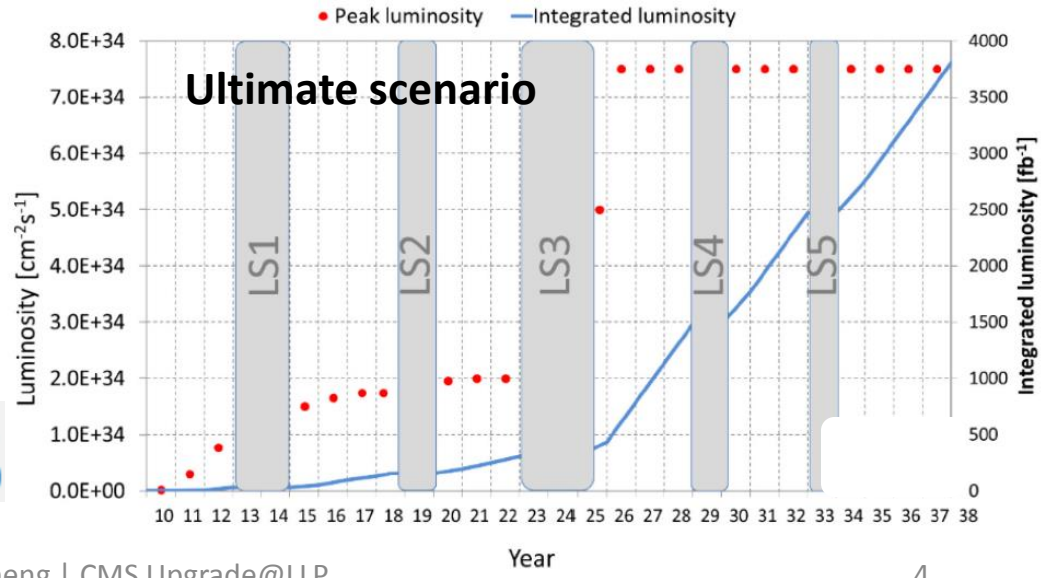
7. 5 x 10^{34} Hz/cm^2 ,
Pile-up <μ> = 200

Pile-up

140 - 200 additional pp collisions on top of process of interest



Display of a 140 PU event



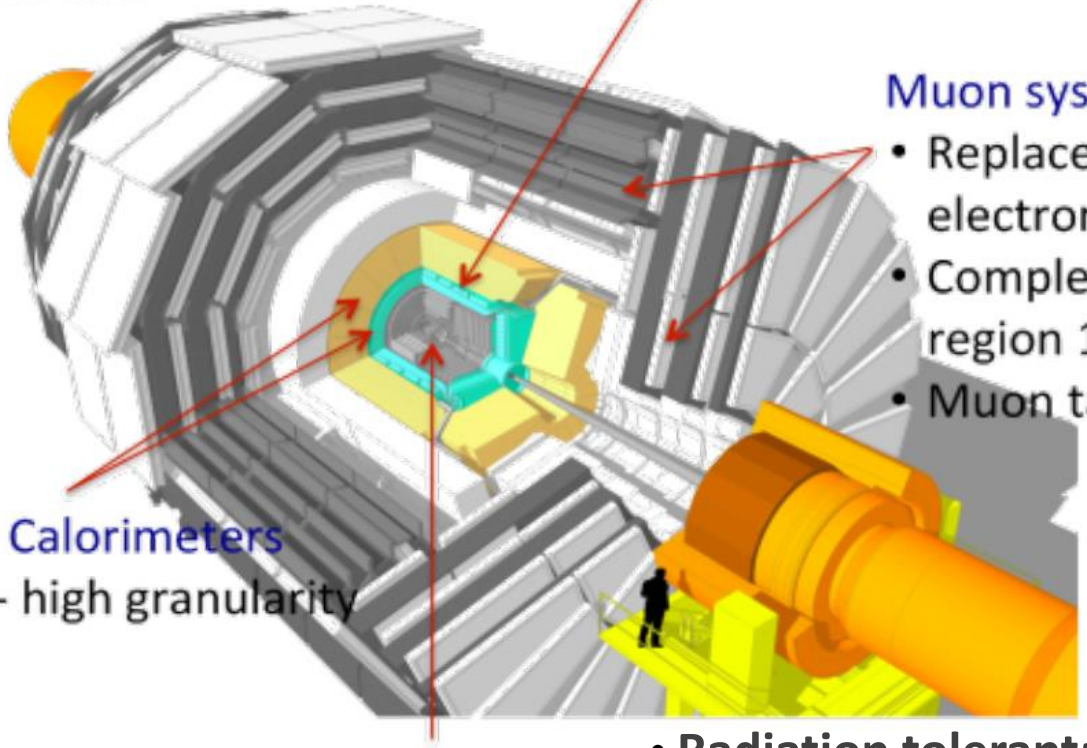
HL-LHC Upgrade: Objectives

- Replace components:
  - parts too damaged by the time of HL-LHC
  - parts that will not survive HL-LHC environment
- Extend coverage:
  - tracker, muon extension etc.
- Improve function:
  - higher granularity pixels, endcap cal; L1 tracking etc.
- New detector(s):
  - Fast timing layer
- Increase bandwith:
  - trigger & DAQ

HL-LHC Upgrade: Overview

Trigger/HLT/DAQ
- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≈7.5 kHz

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperature (8◦)



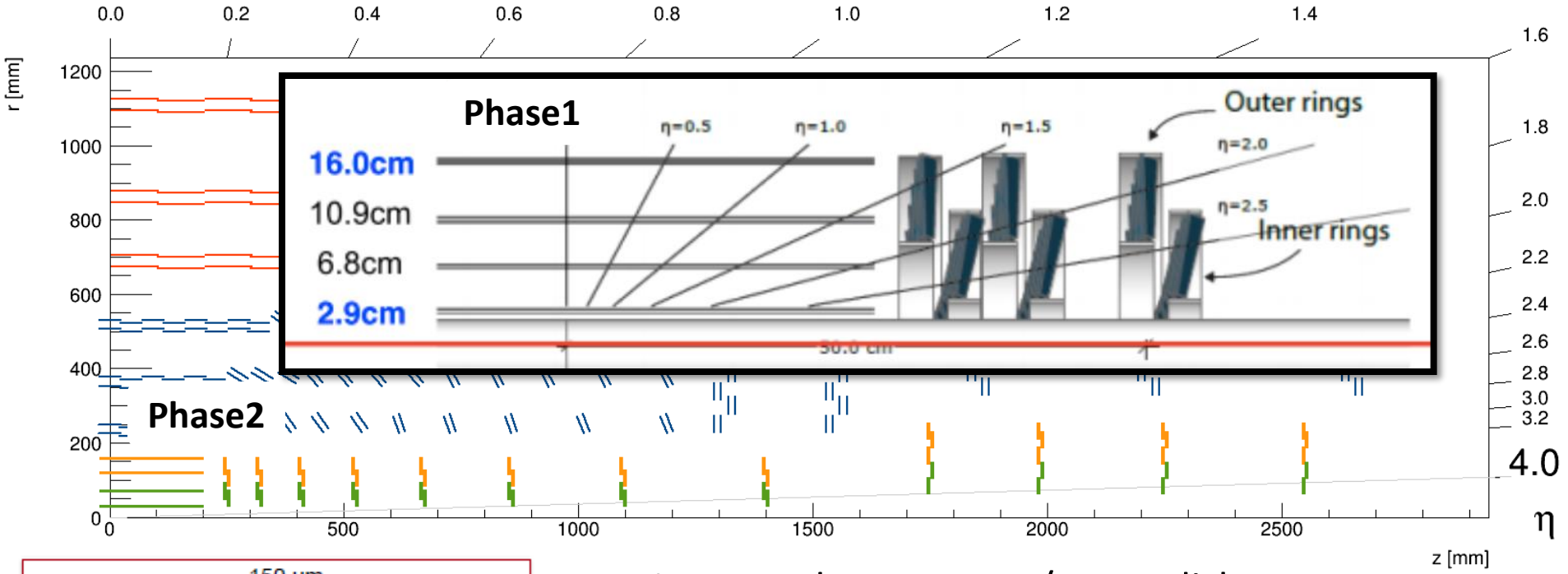
Muon systems
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

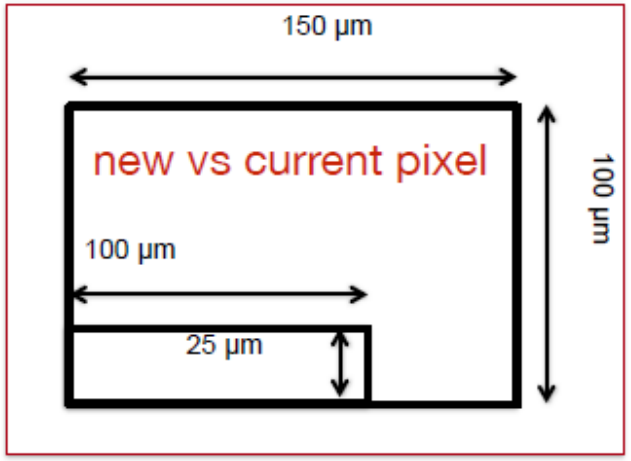
Replace Endcap Calorimeters
- Rad. tolerant - high granularity
- 3D capability

+Timing layer (outside tracking volume)

Replace Tracker
- **Radiation tolerant; high granularity**
- **Extend $|\eta|$ coverage up to 4**

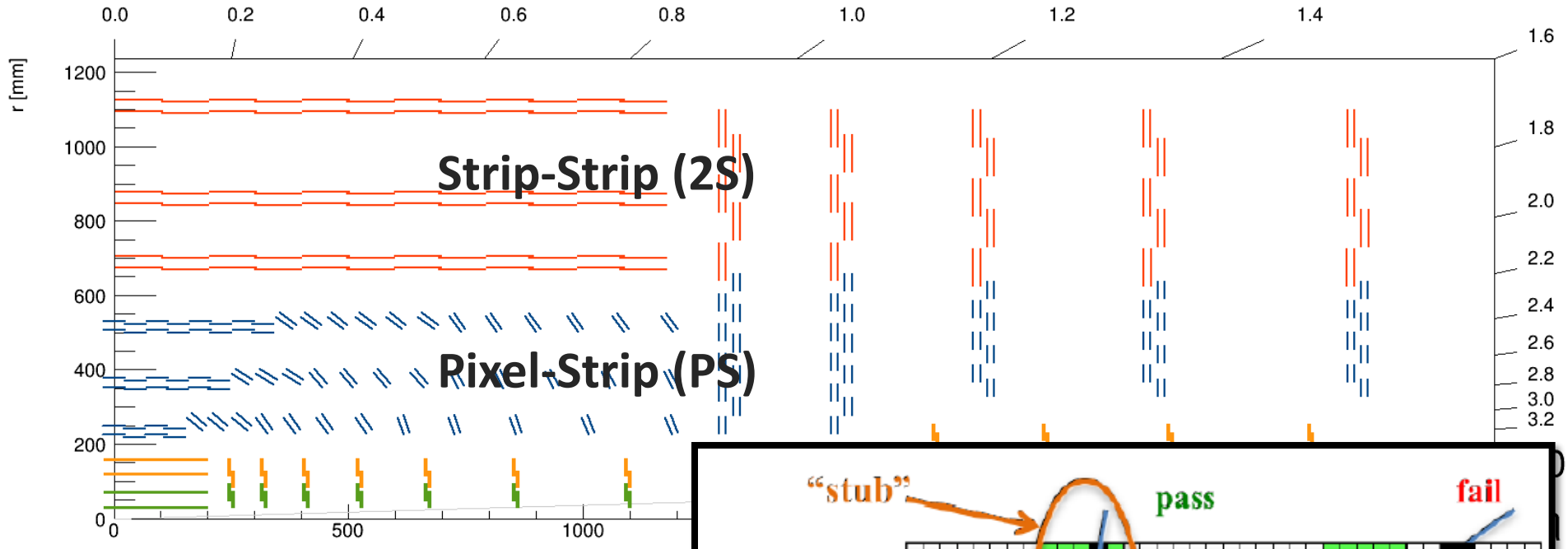
Tracker Upgrade: Pixel

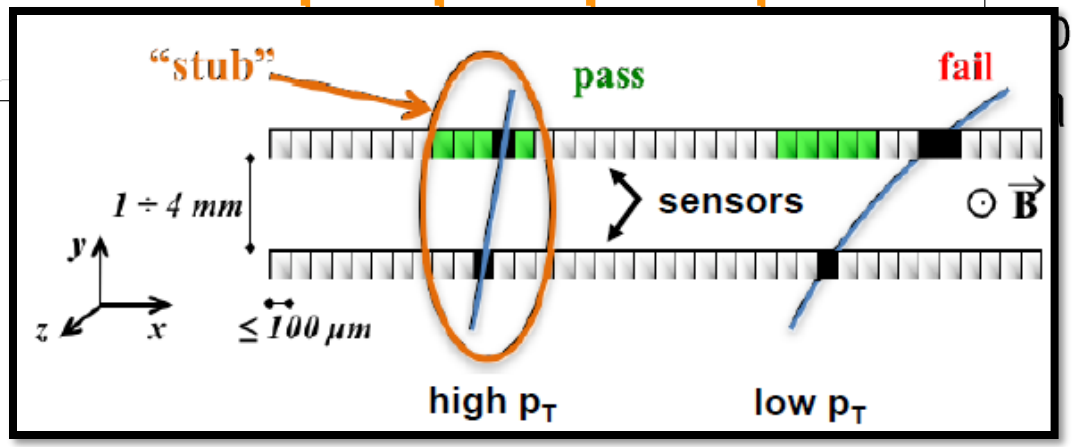




- Increased coverage w/ more disks:
  - $|\eta|\sim2.5 \rightarrow |\eta|\sim4$
- Radiation hardness w/ thinner pixels:
  - 285μm → 150μm
- Improved resolution w/ smaller pixels:
  - also maintains occupancy ~ 0.1%
- Reduced material budget

Tracker Upgrade: OT & L1 Track Trigger



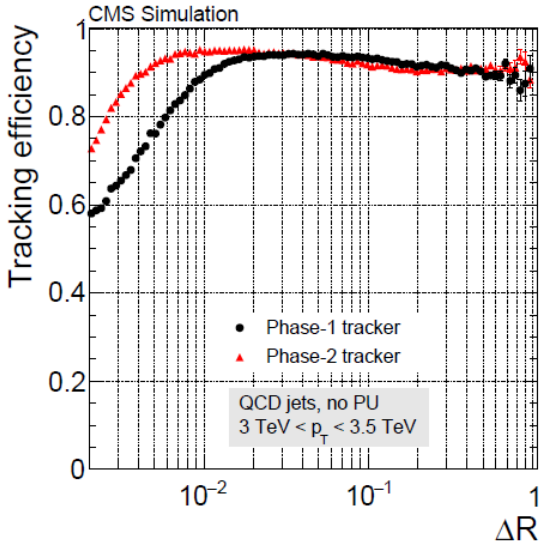


- Six layers + five disks of pixels-strip/ strip-strip modules
- Two-sided sensor modules → stubs →enable track finding at L1 for tracks w/ pT > 2GeV: ~15k stubs @ 14MHz

For more on LLP prospects w/ L1 Track Trigger, see Yuri Gershtein's talk later today!

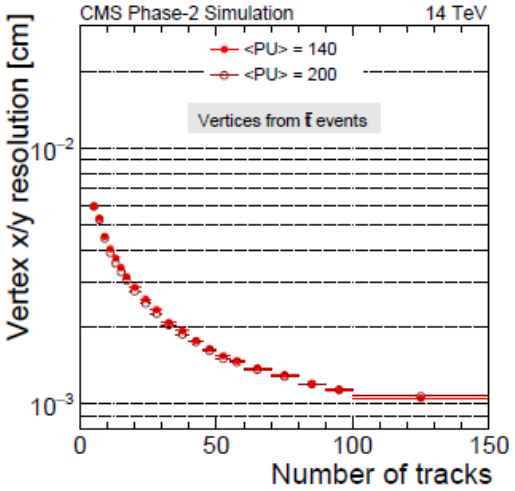
Tracker Upgrade: Performance

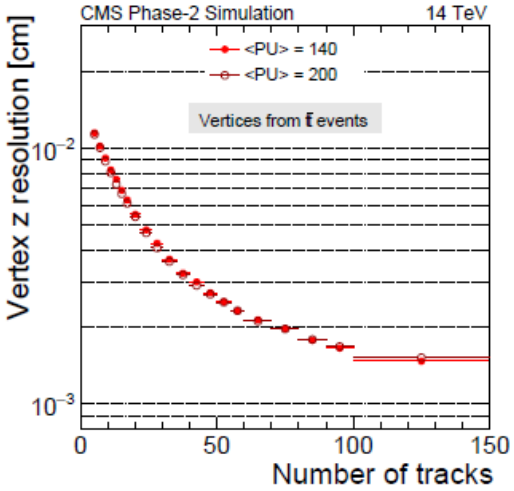
Tracking

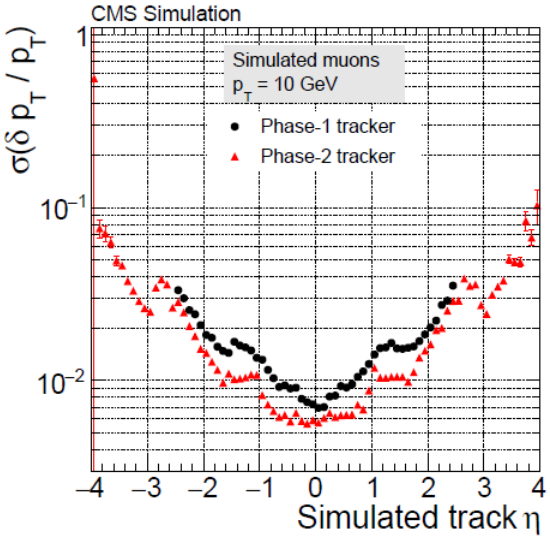


Excellent tracking performance with increased coverage and better resolution!

Vertexing





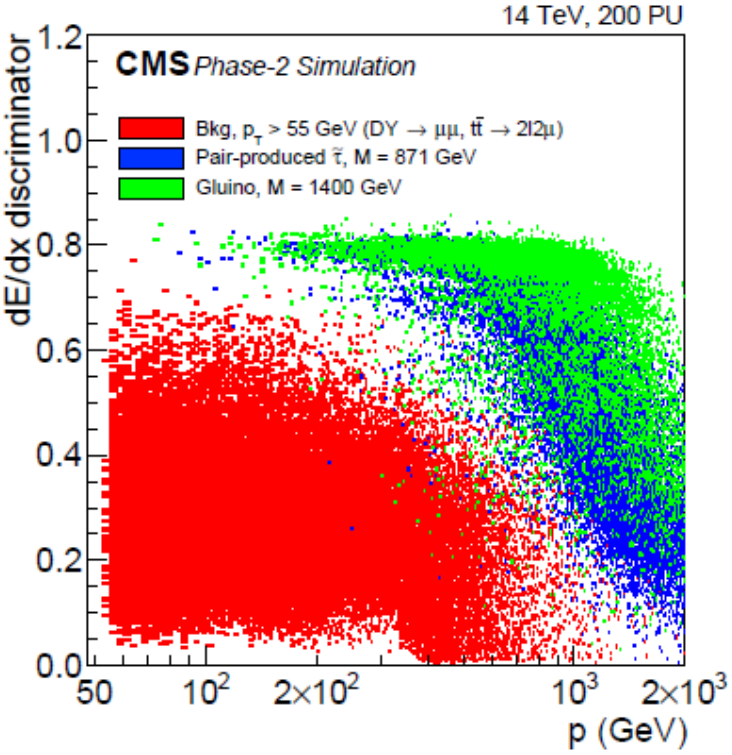


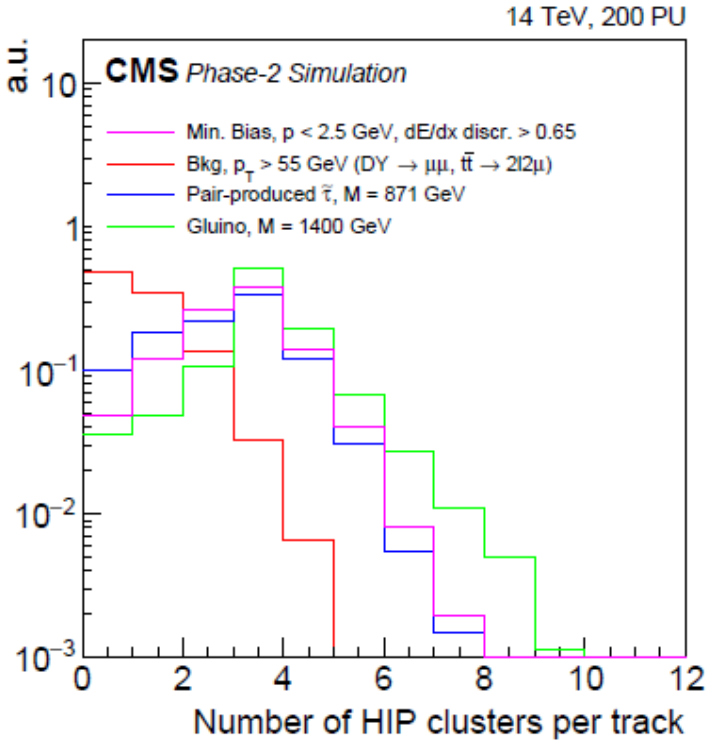
Vertexing resolution almost independent of pile-up; longitudinal resolution only ~50% worse than transverse (with 25x100x150 pixels)

Tracker Upgrade: LLP Prospects

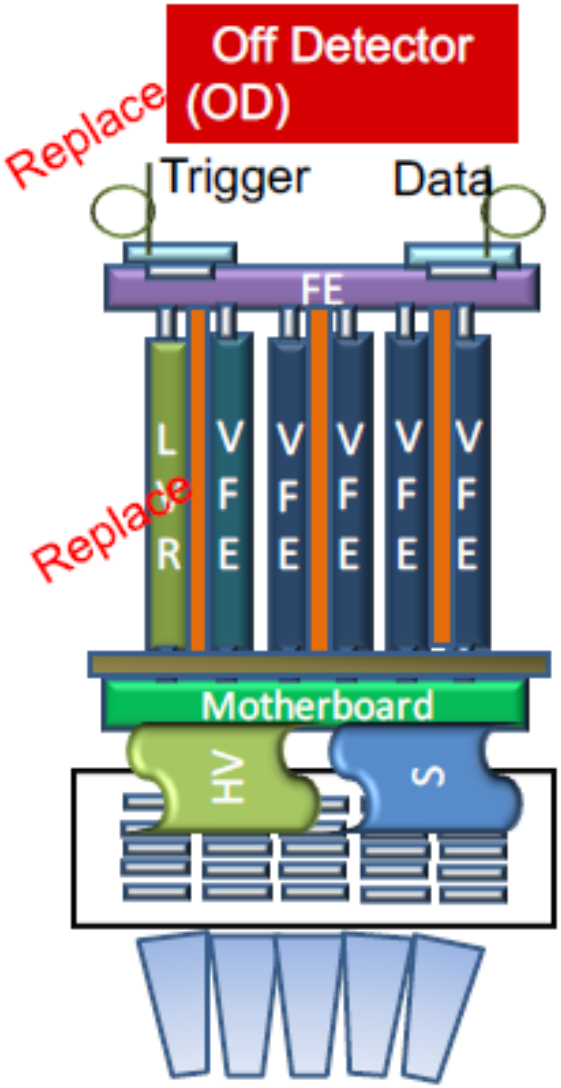
- Heavy stable charged particles (e.g. split SUSY): high dE/dx in silicon sensor
- Phase2 inner pixel has analogue readout:
  - 4 (maybe more?) bit time-over-threshold info provides good resolution
- Phase2 outer tracker has digital readout + dedicated overthreshold bit (HIP flag) with programmable threshold (currently set at 1.4MIP)

Good separation between background and signal in dE/dx and number of overthreshold clusters per track



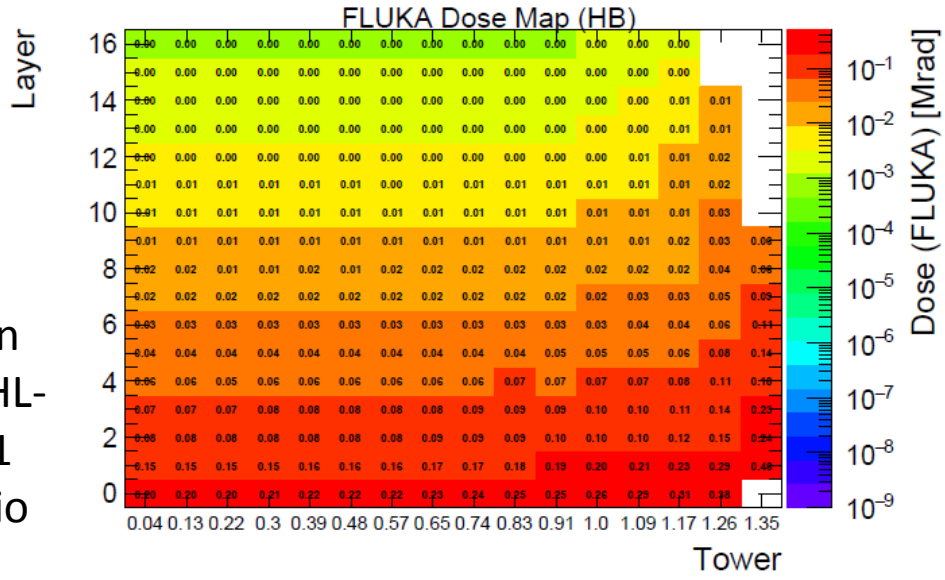


Calorimetry Upgrade: Barrel

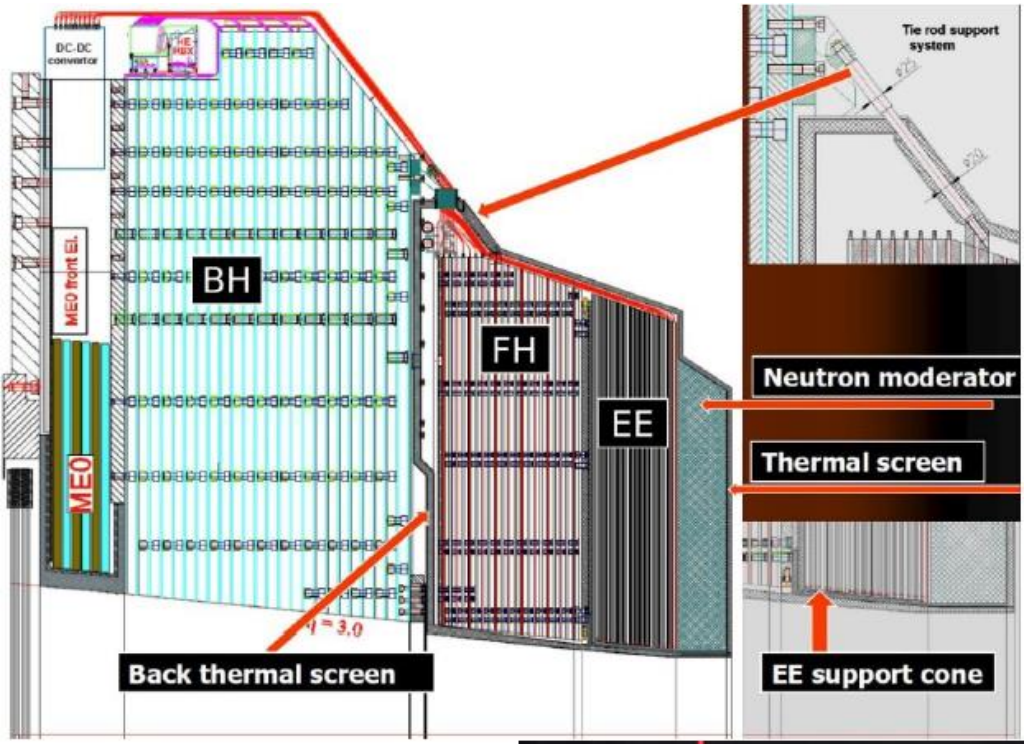


- The crystals in the ECAL will be kept for duration of LHC
- The **FE & BE electronics will be replaced** for more precise timing, useful in both pile-up mitigation and searches for new physics
- Target (hardware fundamental limit): **~30ps for E > ~30GeV** (1/10 of current limit)
- Current studies on HCAL Barrel radiation damage suggest no need for replacement at HL-LHC: pending further study

Expected dose in HCAL Barrel at HL-LHC, in 4500fb-1 ultimate scenario

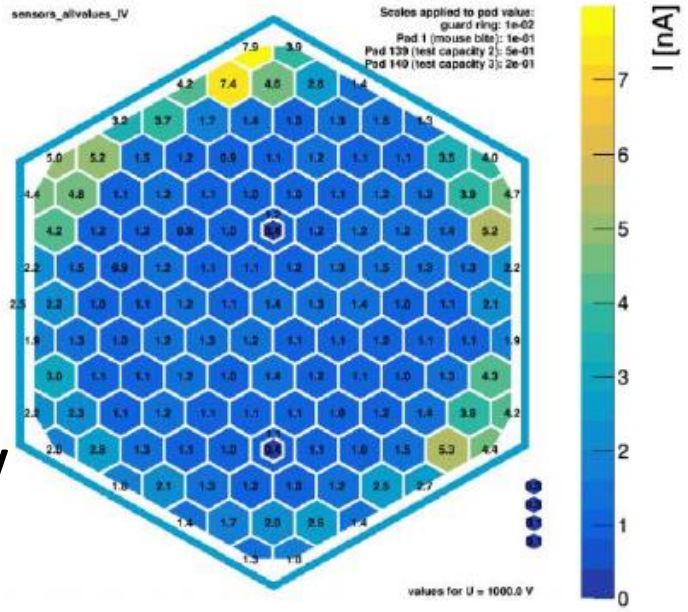


Calorimetry Upgrade: Endcap



- EM Endcap: Pb/W/Cu + Si
- Front Hadronic endcap: SS + Si
- Backing Hadronic endcap: brass + plastic
- Hexogonal silicon sensors
  - 100/200/300µm thick: per radius
  - CO_2 cooling to operate at -30C to minimize radiation damage

Leakage current @ 1000V



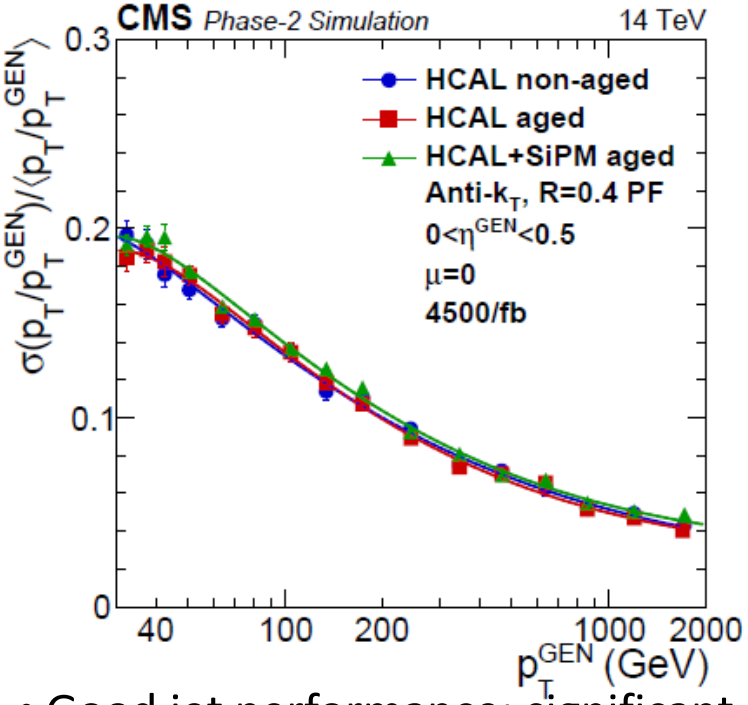
The endcap calorimeter will be replaced with a silicon-based calorimeter:

- high granularity and 3D imaging to help mitigate PU
- Fast signal collection (<10ns) and **fast timing capability (few tens of ps)**

→ 4D info in space-time to reconstruct showers

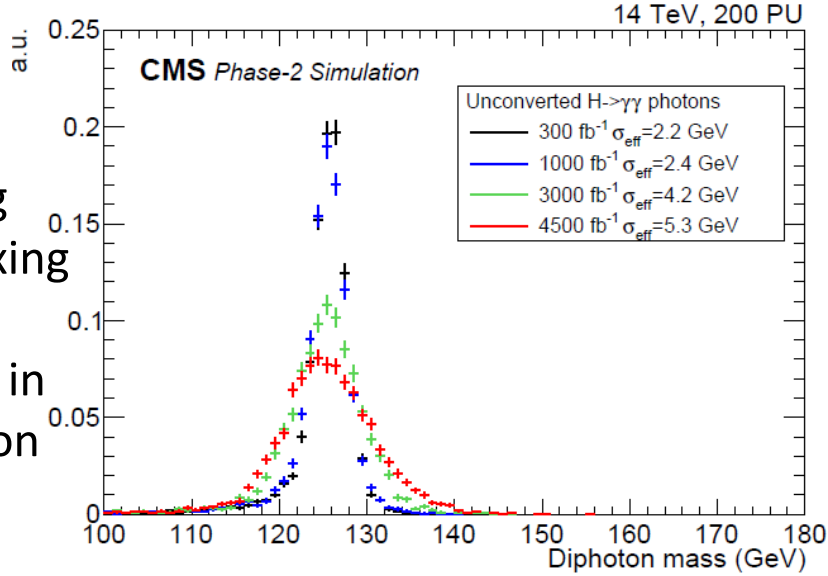
Calorimetry Upgrade: Performance

Results shown for barrel calorimetry upgrade: HGCAL results in progress

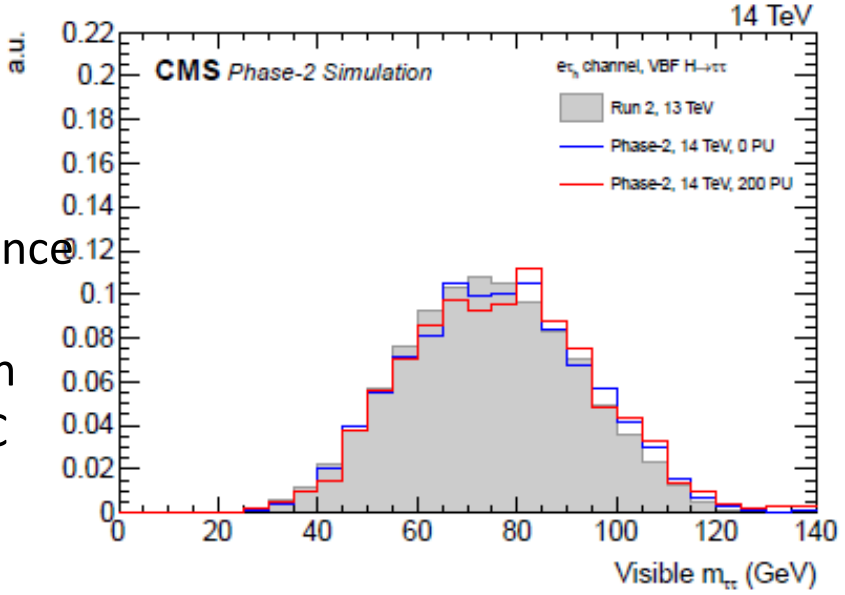


- Good jet performance: significant improvement with upgrades
- PUPPI works well for PU mitigation
- Aging effect minimal w/ recalibration

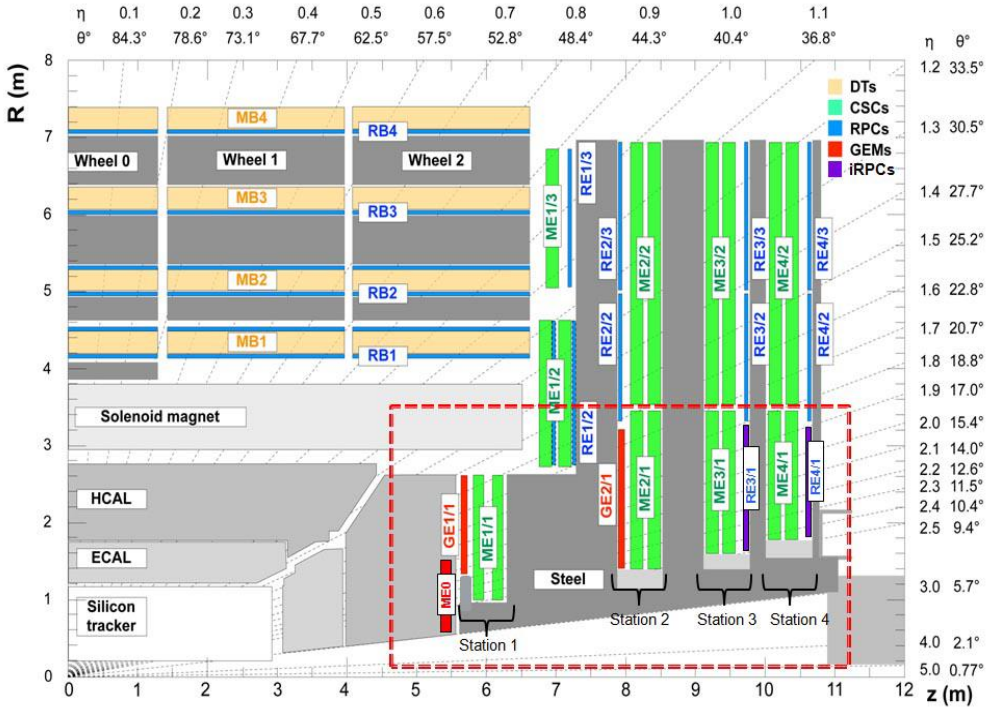
H→ γγ:
precision timing improves vertexing resolution;
expect degrade in energy resolution



H → ττ:
maintain performance for mass resolution at HL-LHC vs Run2

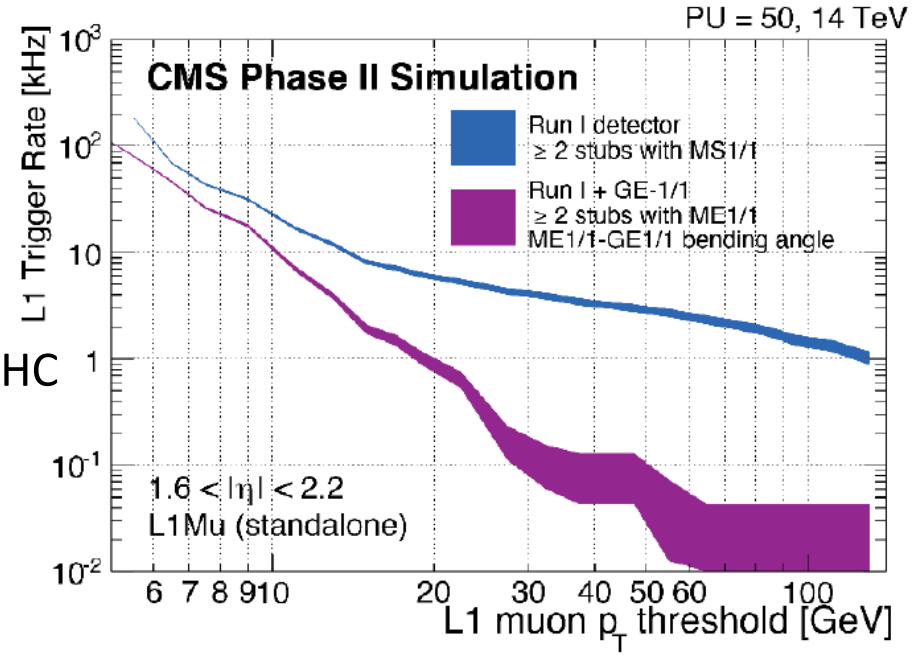


HL-LHC Upgrade: Muon System



Muon system upgrade scope for HL-LHC:

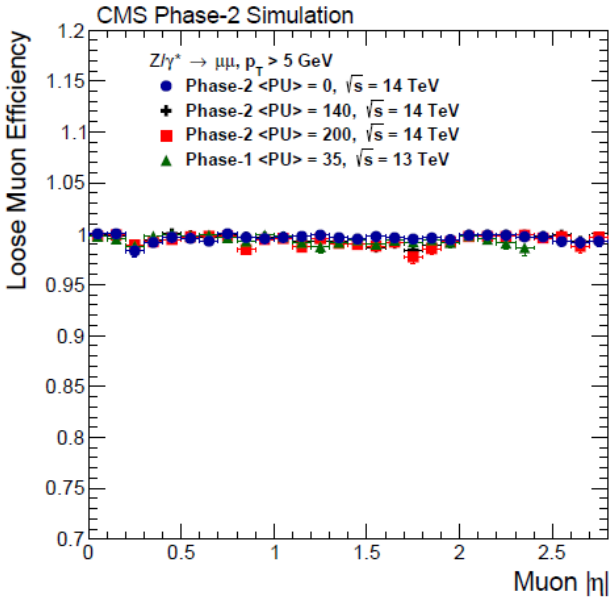
- Existing detectors:
  - upgrade barrel DT and endcap CSC electronics for 40MHz readout
- Extend forward coverage:
  - GEM & RPC detectors: 1.6<η<2.4
  - ME0 (for trigger): 2.4< η<2.9



Standalone muon trigger at L1:

- Keep rate under control:
  - single muon threshold 20-25GeV @ HL-LHC
- Provide good resolution and efficiency
- Provide capabilities not covered by L1 track trigger, e.g. displaced tracks & slow moving particles

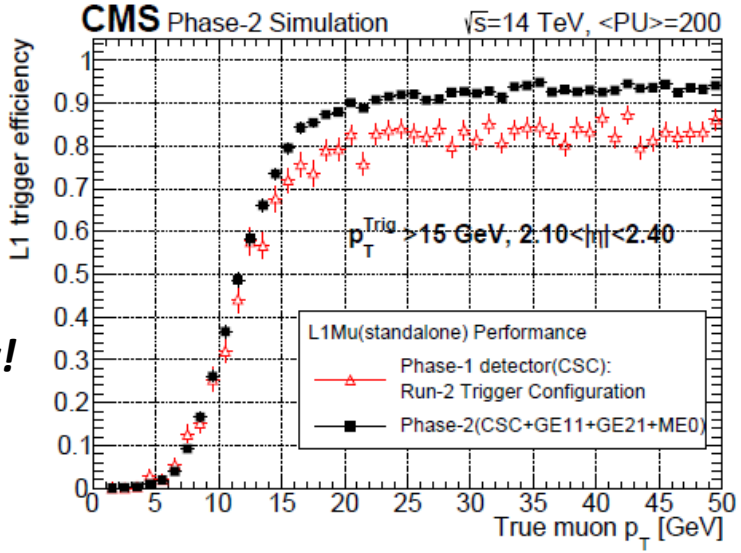
Muon Upgrade: Performance

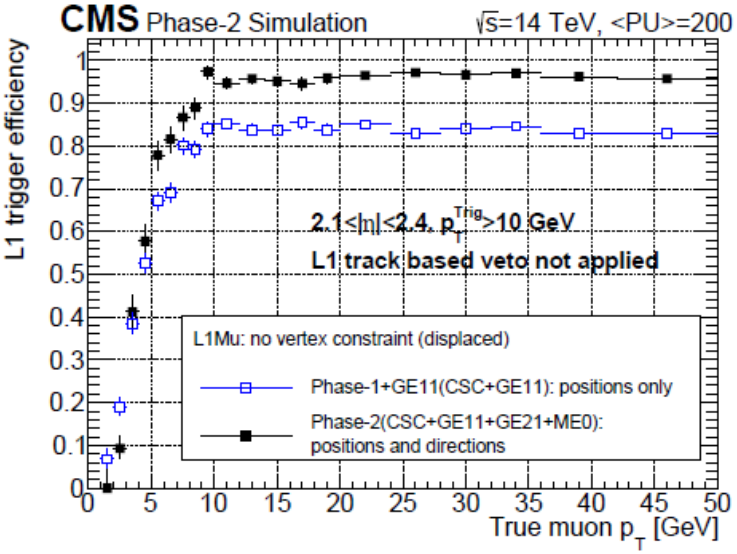


Improved performance with HL-LHC upgrade:

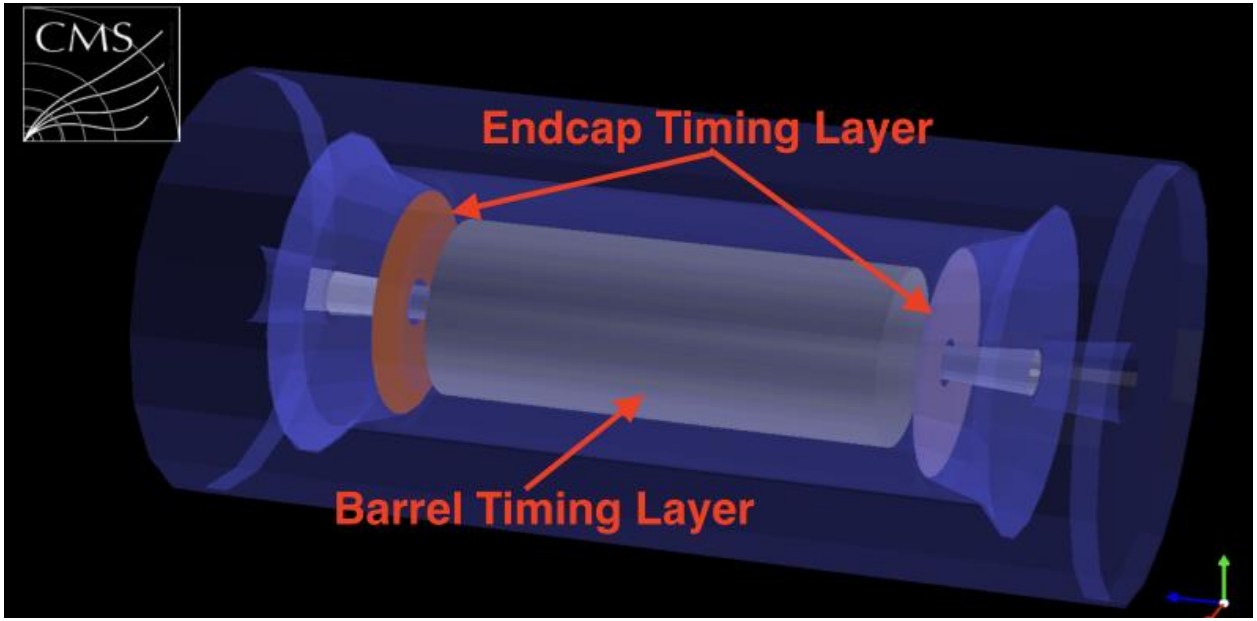
- Higher efficiency: minimal dependency on pile-up
- Lower rate: better measurement → much purer sample
- Improved timing resolution w/ eletronics upgrade
  - 12.5 ns → 1ns in DT
- Extended forward coverage : |η|<2.4 → |η|<2.8
- Benefits from the L1 track trigger for prompt muons

Prospects on LLP searches: See Henning Keller's excellent talk on Wednesday!

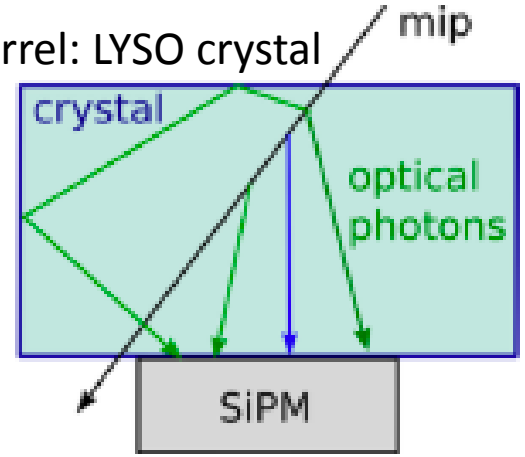




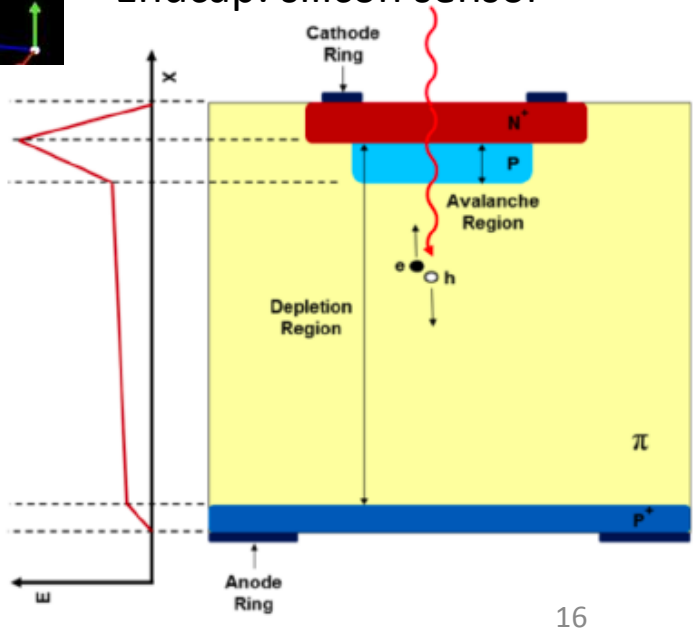
HL-LHC Upgrade: Fast Timing



Barrel: LYSO crystal



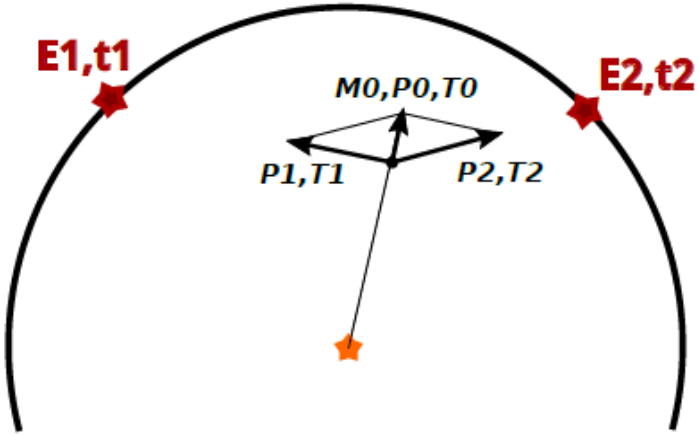
Endcap: silicon sensor



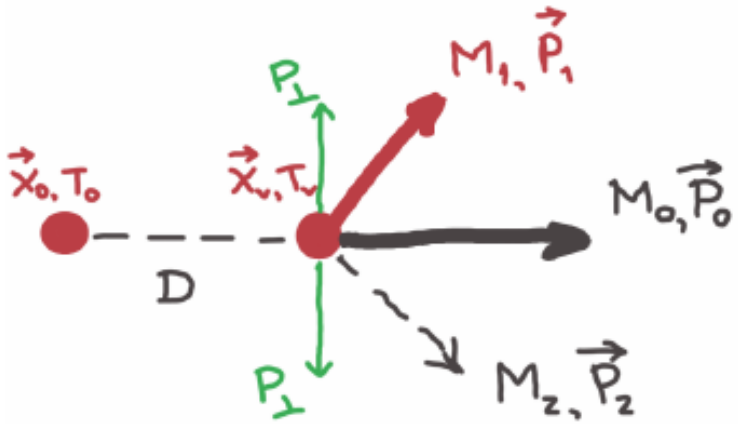
- Calorimeter upgrades (ECAL electronics + HGCAL) will provide precise (a few 10s of ps) timing for high energy photons in barrel and high energy hadrons/photons in endcap
- Additional timing layer (outside tracker volume) can provide precision timing for charged hadrons & converted photons down to a few GeV.
- Traditional 3D vertex fit upgraded to a 4D fit

Timing Upgrade: LLP Prospects

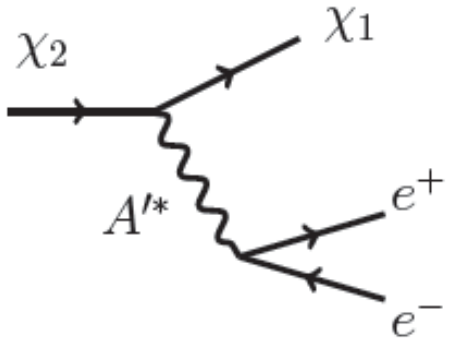
(Illustrations c/o A. Ledovskoy)
For more info, see dedicated talk later today!



Scenario 1: Long-lived particle (neutral or charged) is produced at IP, & at secondary vertex (SV), decays into two observable particles (neutral or charged)
→With timing info (t1,2→T1,2; T0=T1=T2)
the scenario has unique solution for SV
→ full reconstruction!

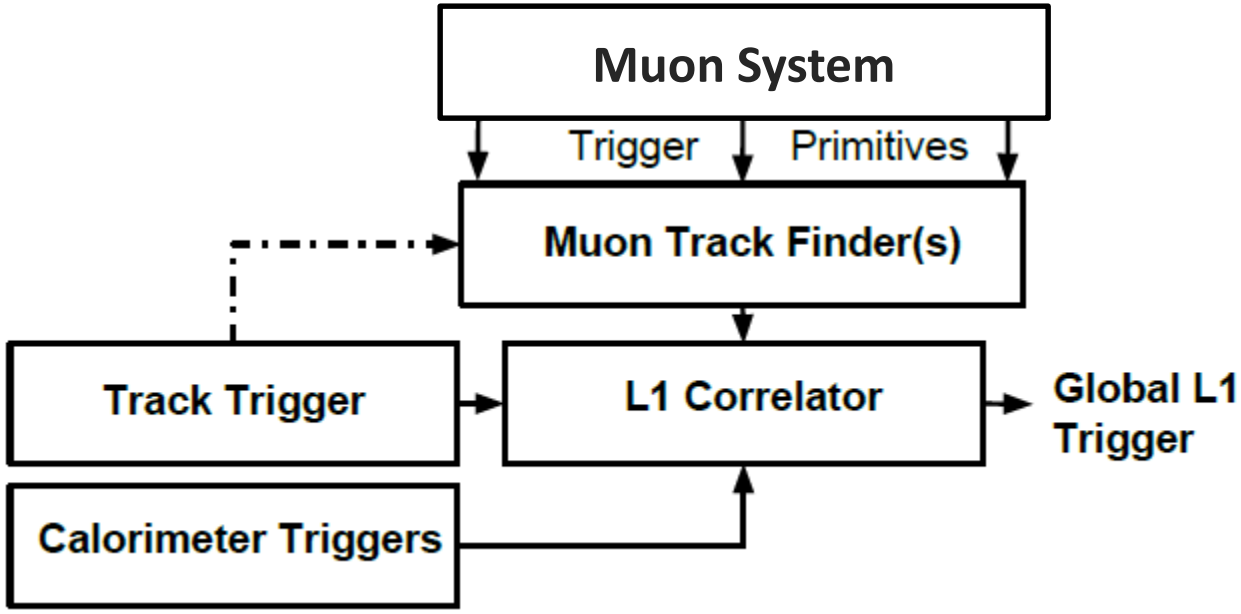


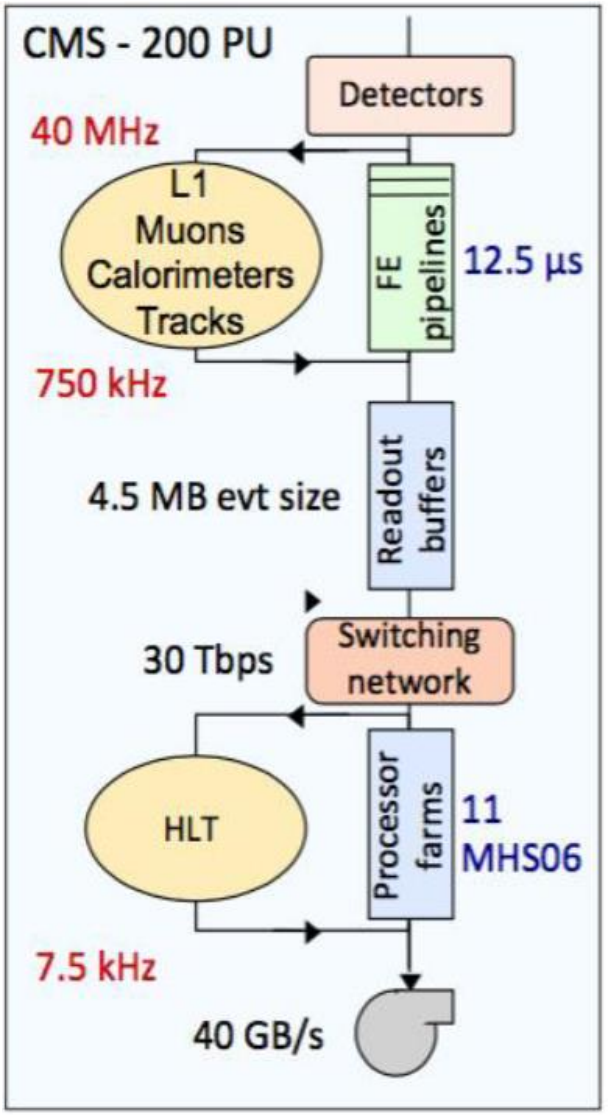
Scenario 2: LLP decays to visible + invisible particles.
If the invisible particle mass is known + additional timing info → enough constraints for unique solution
→applicable for GMSB, iDM dark photon etc.



HL-LHC Upgrade: Trigger

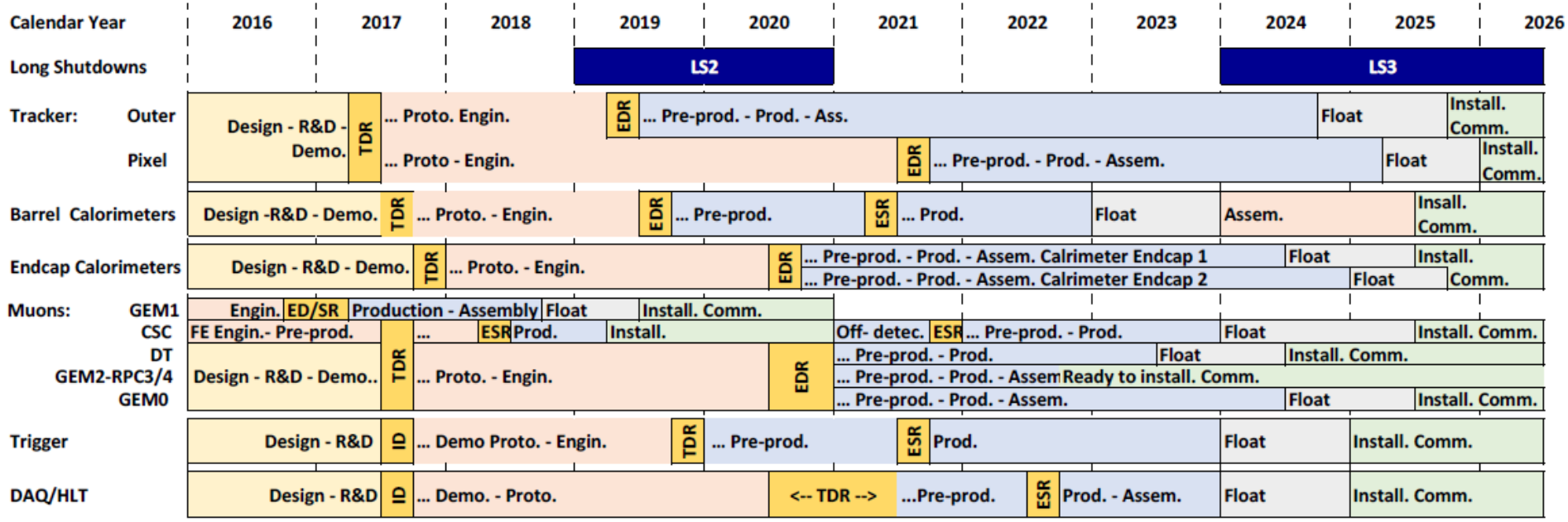
- L1 Trigger:
  - Increase output: 100kHz→750kHz,
  - Increase latency: 3.4μs → 12.5μs
  - New track trigger at L1 (+ calo, muon, global)
- High-Level Trigger:
  - Processing power scales with pile-up and L1 rate
  - Output rate increase to 7.5kHz (up to 10kHz)





HL-LHC Upgrade: Timeline

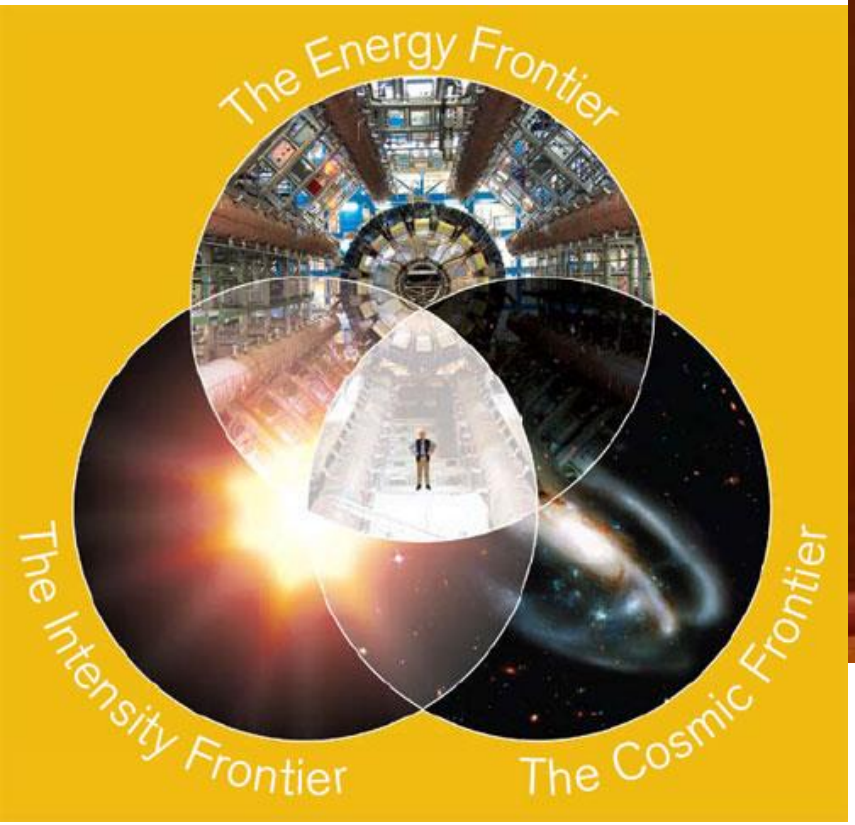
- Tracker TDR
  - May 2017: pre-view document; end of June 2017: provide CMS approved version - including cost and responsibilities
  - Nov. 2017: final approval of the Tracker TDR
- Barrel Calorimeters and Muons TDRs
  - Sep. 2017: provide CMS approved TDRs - including cost and responsibilities
  - Feb. 2018: final approval of the BC and Muons TDRs
- Endcap Calorimeter TDR
  - Nov. 2017: provide CMS approved TDR - including cost and responsibilities
  - May. 2018: final approval of the Endcap Calorimeter TDRs



Conclusions and Outlook

- The High-Luminosity LHC brings exciting physics potential #MoarData and many experimental challenges:
  - high radiation, high pile-up, high data-rate
- Comprehensive upgrade program to address these challenges and meet physics potential
  - improved spacial resolution: tracker; HGCAL; …
  - increased forward coverage: pixel extension; muon; …
  - improved timing information: HGCAL; MIP; electronics; …
  - L1 tracking & other trigger/DAQ upgrades
- Higher luminosity + a more powerful machine + improved techniques → new possibilities for LLP searches

THANK YOU!



Keep looking with a magnifying glass; you never know what you might find…