CMS detector upgrades and performances

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Top-LHC France 2018, LPNHE Paris

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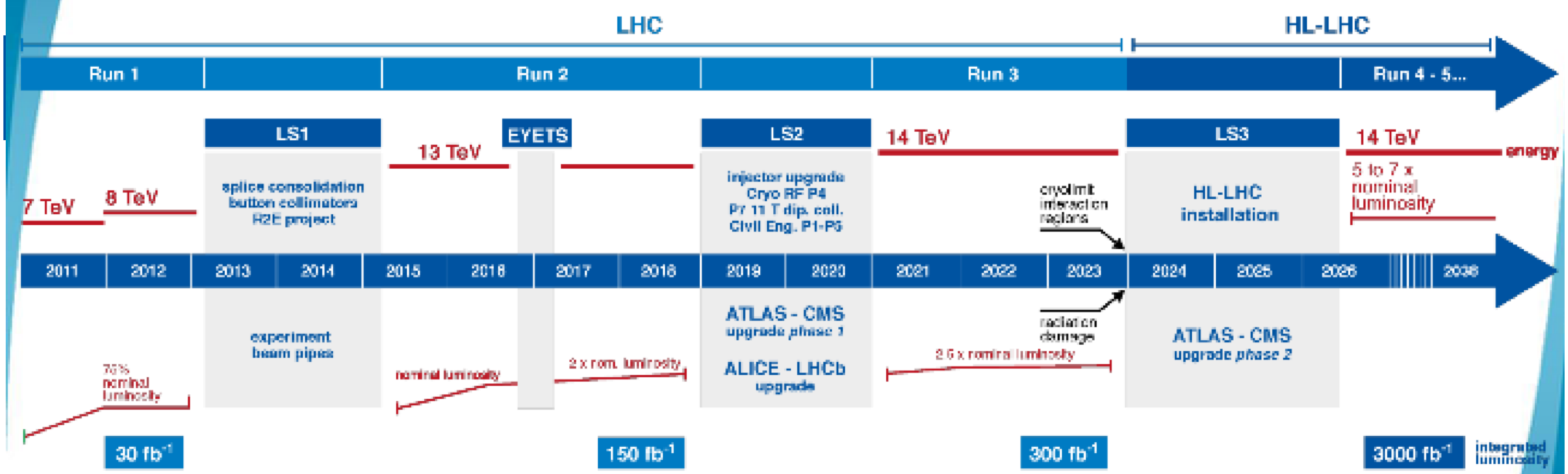
LHC / HL-LHC Plan



pileup

~20 **~40-60** **140 - 200**

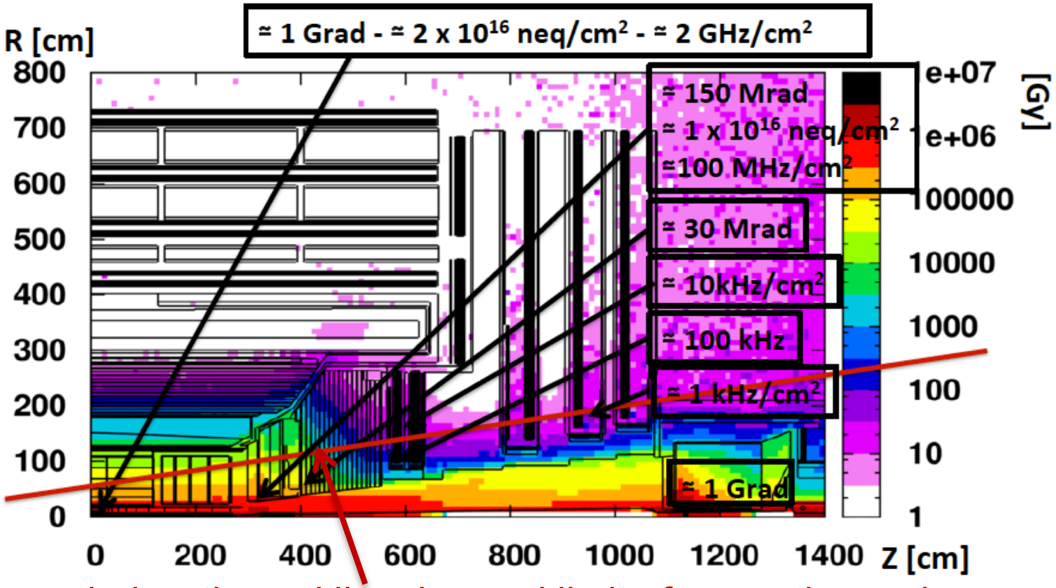
why the HL-LHC ?

- strong case to go on exploring the TeV scale:
  - Standard Model works very well but does not explain everything
    - low mass of Higgs boson and naturalness hypothesis advocate for the existence of new particles at the TeV scale
    - SM does not provide Dark Matter particle candidate
  - currently no evidence for new physics

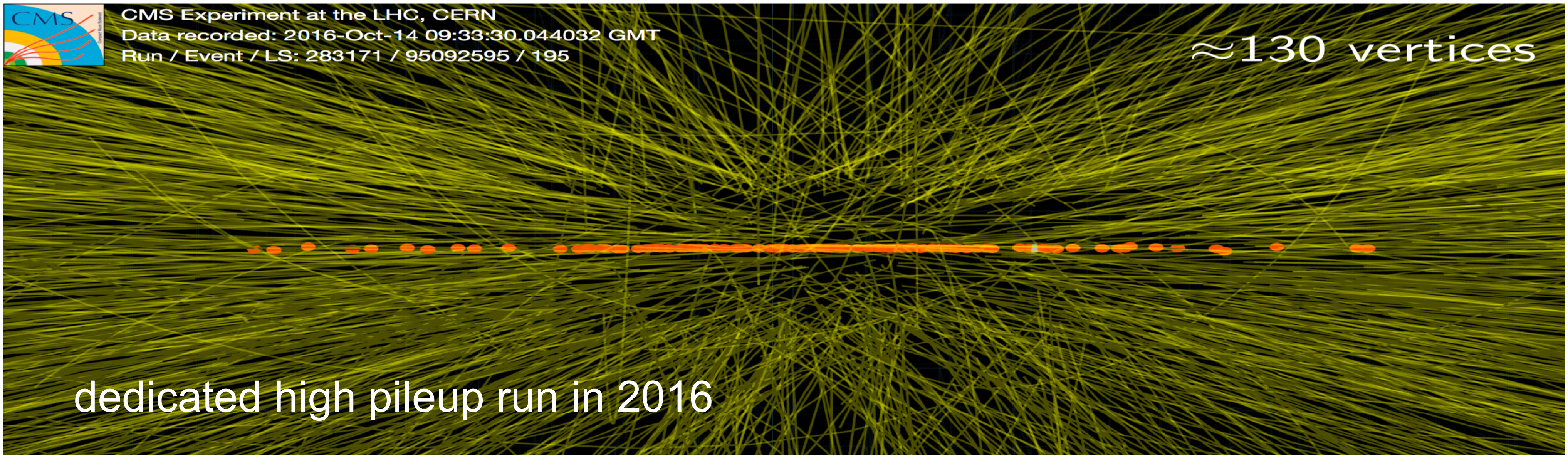
- HL-LHC will deliver 3-4 ab^{-1}, allowing
  - detailed studies of the Higgs boson : standard model or BSM ?
  - precise measurements of standard model, rare processes: indirect evidence for new physics ?
  - search for new particles and processes at the TeV scale (dark matter candidate)
  - investigate properties of any particle found at Run 2 or 3

Phase 2 detector requirements

- challenges:
  - high instant. luminosity (5 – 7.5 10^{34} $cm^{-2}s^{-1}$)
    → high pileup (140 – 200)
  - high integrated luminosity (3 – 4 ab^{-1})
    → high irradiation
- requirement of the CMS Phase 2 upgrade:
  - maintain the current physics performance during the entire HL-LHC
  - detectors must resist to the high radiation levels and many have to be replaced in LS3 !
- CMS will be a high resolution
  4D space+time (+ energy) detector



below the red line: beyond limit of currently used detector technologies in several systems

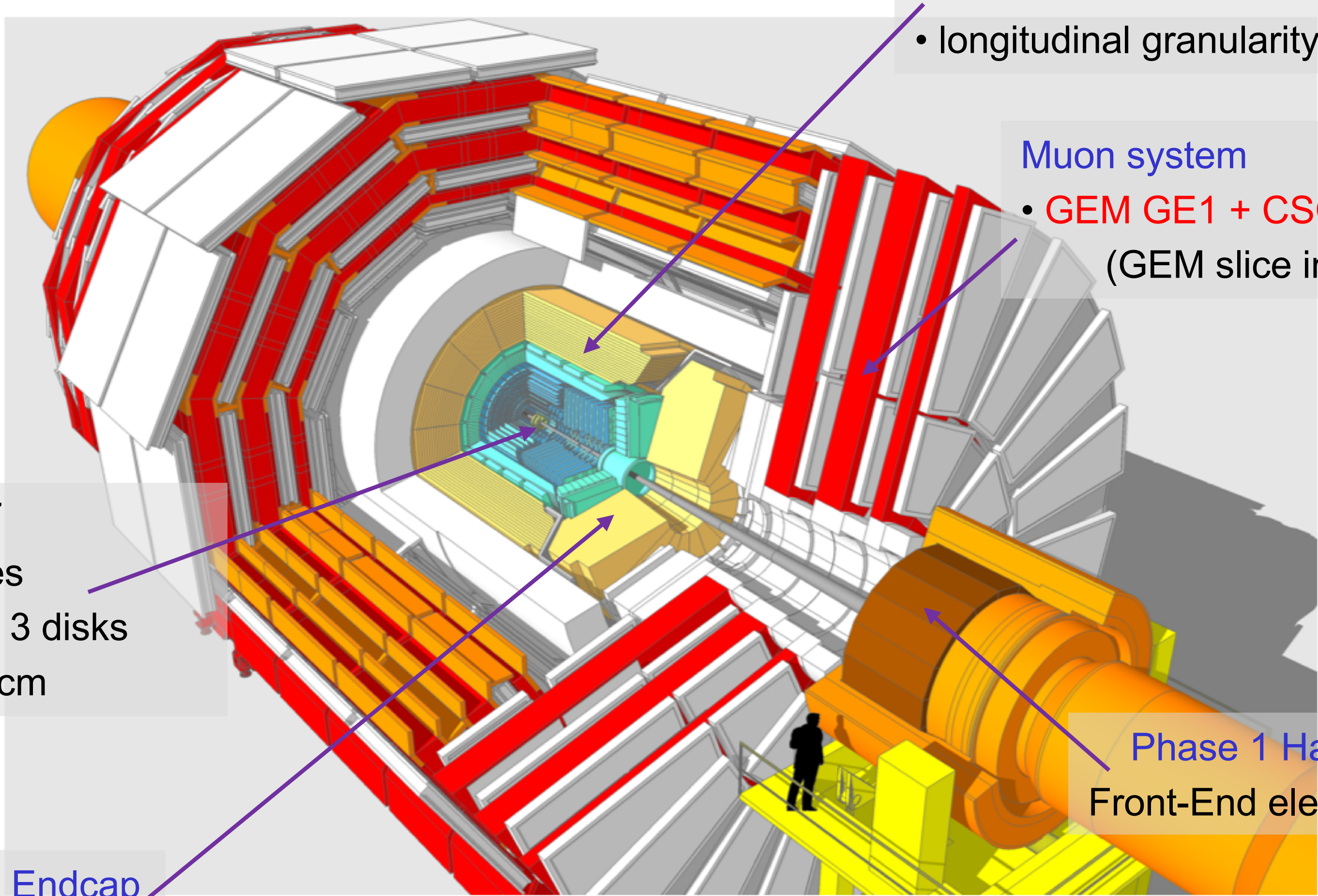


CMS Phase 1 upgrades

new L1 Trigger system
2015

Phase-1 Hadron Barrel
- SiPM read-out in LS2
- longitudinal granularity

Muon system
- GEM GE1 + CSC ME2-4 in LS2
  (GEM slice in 2017)

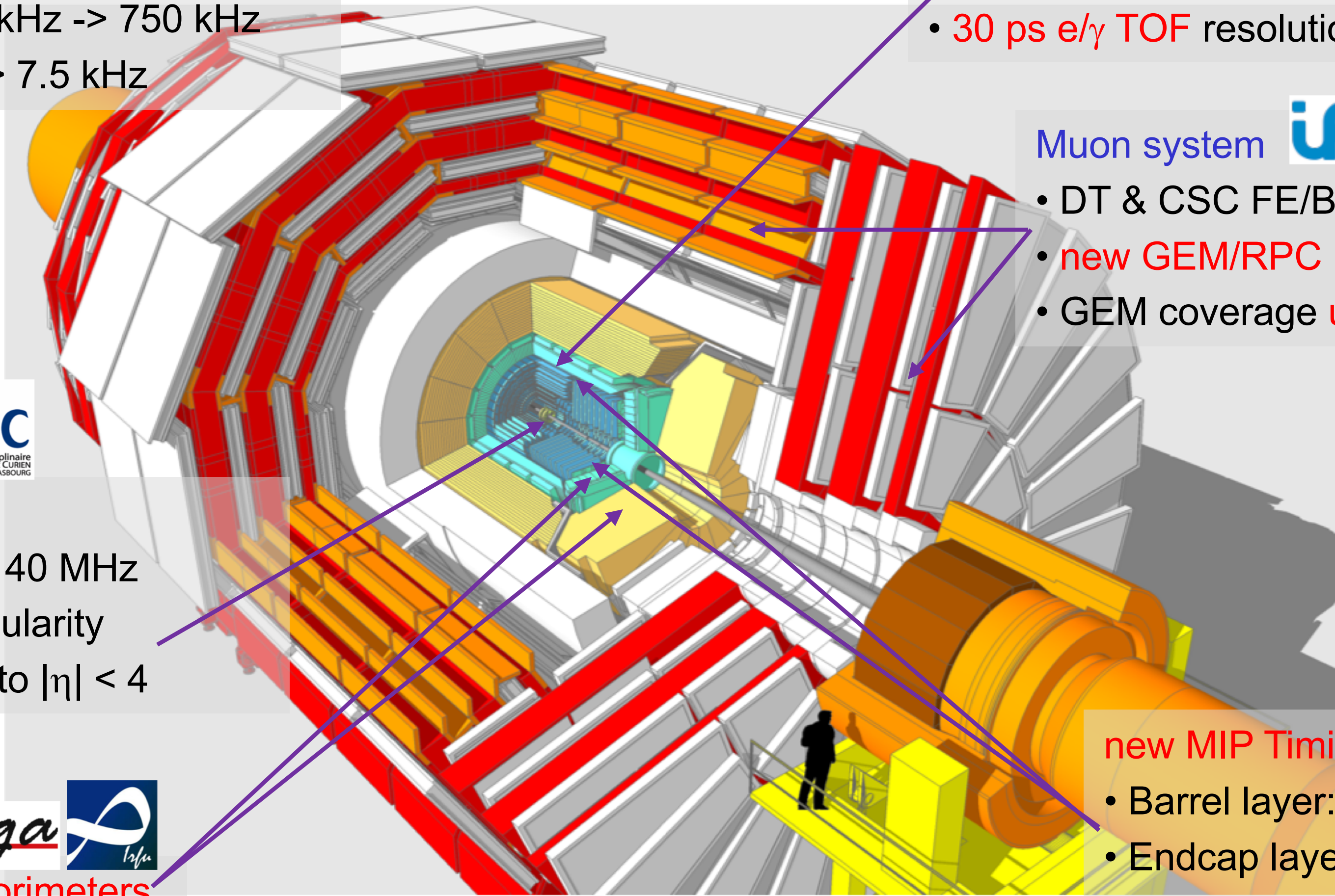


new Pixels 2017
sustain high rates
4 barrel layers + 3 disks
innemost at 2.9 cm

Phase 1 Hadron Forward
Front-End electronics, 2017

Phase 1 Hadron Endcap
- SiPM read-out, 2018

CMS Phase 2 upgrades



L1 Trigger – HLT - DAQ

- track information at L1 at 40 MHz
- latency 3.2 μs -> 12.5 μs
- HLT input 100 kHz -> 750 kHz
  output 1 kHz -> 7.5 kHz

Barrel EM Calorimeter

- crystal granularity read-out at 40 MHz
- 30 ps e/γ TOF resolution at 30 GeV

Muon system

- DT & CSC FE/BE new read-out
- new GEM/RPC 1.6 < |η| < 2.4
- GEM coverage up to |η| = 2.9

new Tracker

- track-trigger at 40 MHz
- increased granularity
- extended acc. to |η| < 4

new Endcap Calorimeters

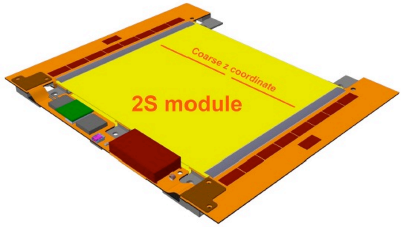
- Si/W – Scint-SiPM/SS
- 4D shower topology :
  30 ps TOF resolution

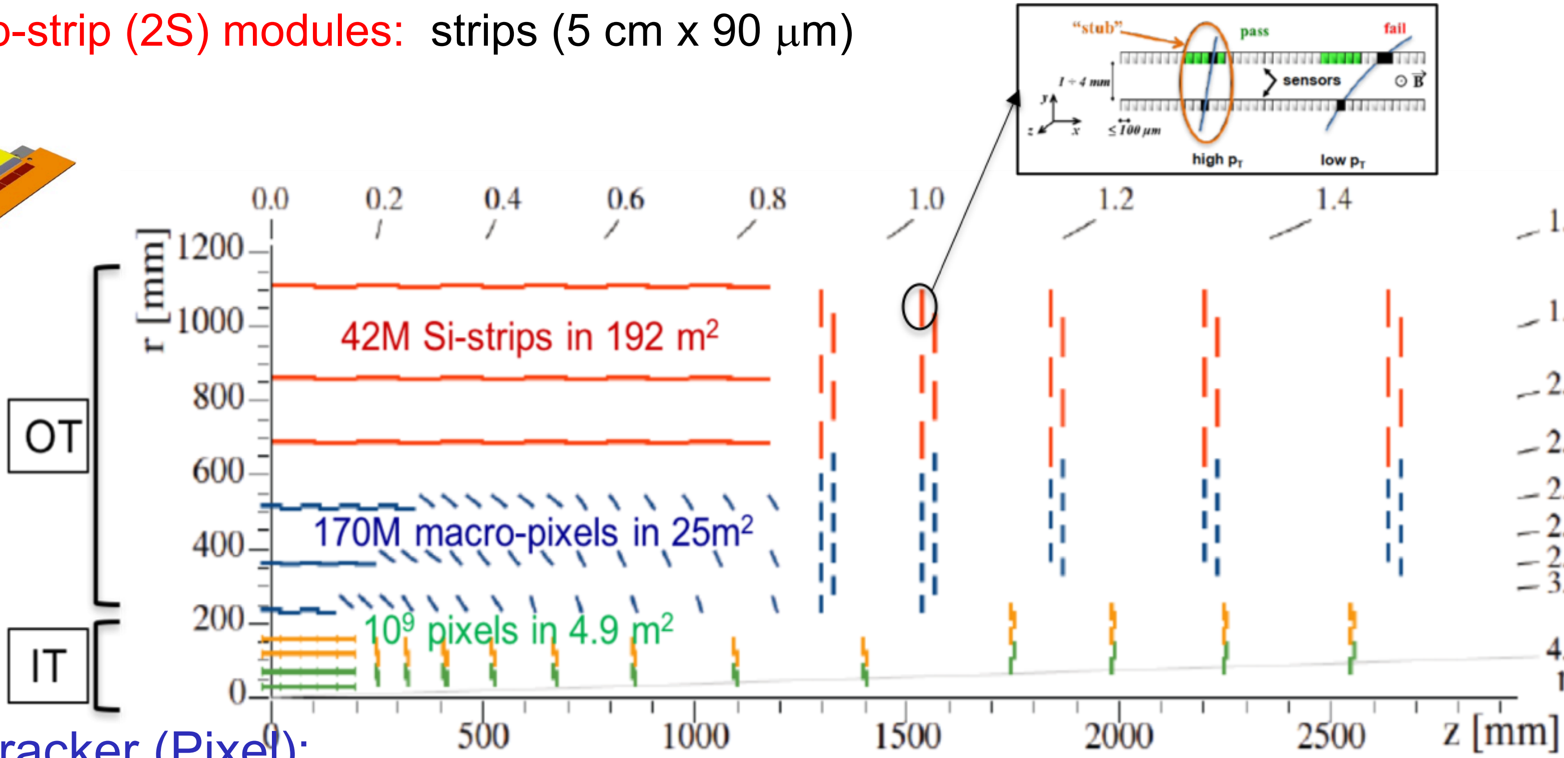
new MIP Timing Detector

- Barrel layer: crystal + SiPM
- Endcap layer: |η| < 3
  Low Gain Avalanche Diodes
- 30 ps TOF resolution

Tracker

- Outer Tracker: design driven to provide tracks (p_T > 2-3 GeV) at 40 MHz to the **L1 trigger** => each module consists of 2 closely spaced sensors (~mm)
  - pixel-strip (PS) modules: macro-pixel (1.5 mm x 100 μm), strip (2.4 cm x 100 μm) tilted in Barrel (hermetic coverage with less modules and material)
  - strip-strip (2S) modules: strips (5 cm x 90 μm)

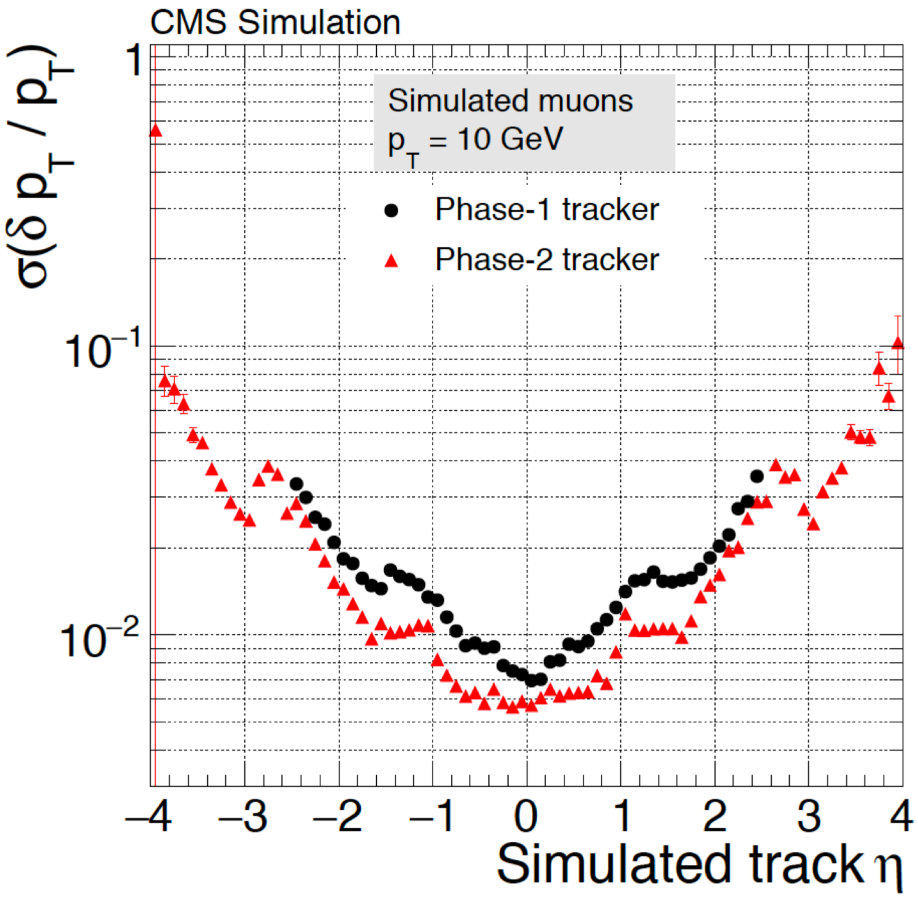


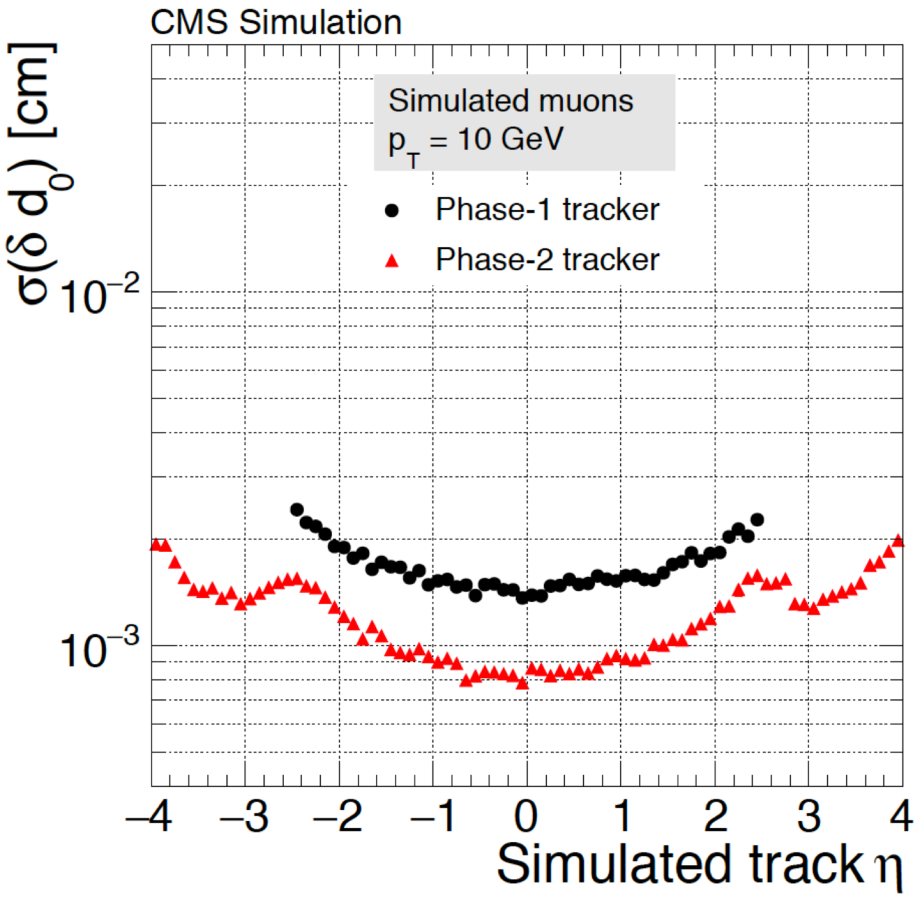


- Inner Tracker (Pixel):
  - **extended coverage up to |η| < 4.0**
  - **6x better granulariry** than current Phase 1 pixel
  - improved material budget and radiation tolerance

> 1 billion pixels and strips

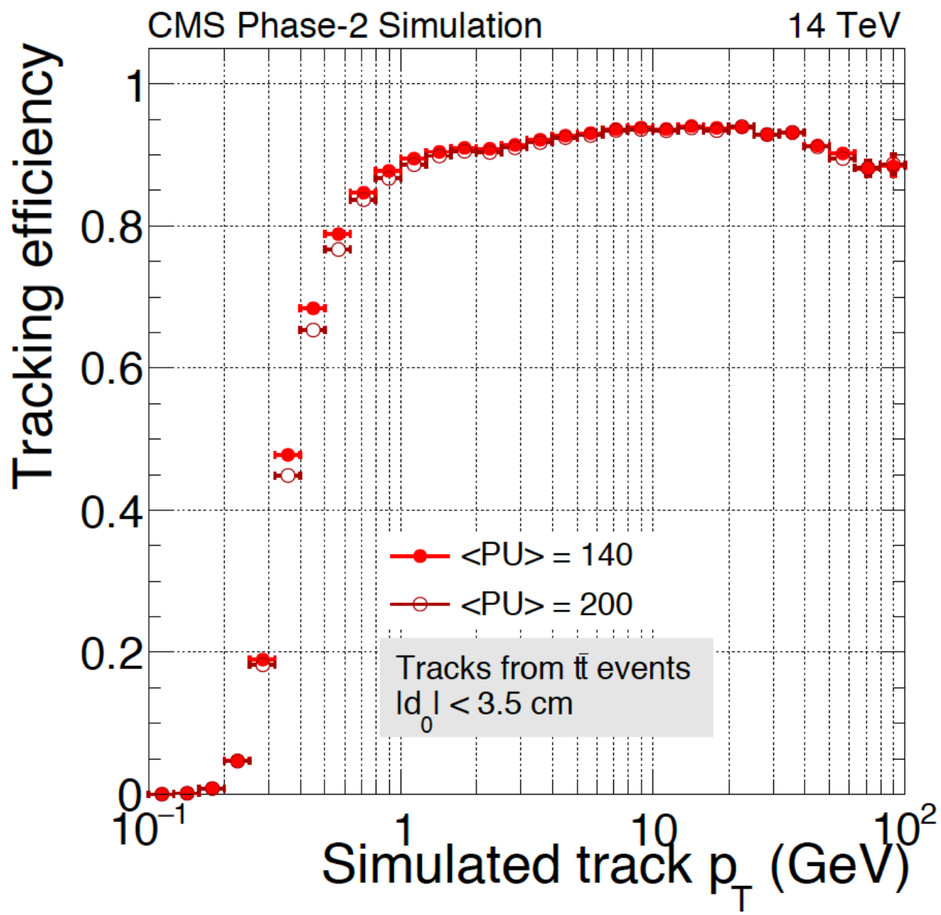
track resolution vs η

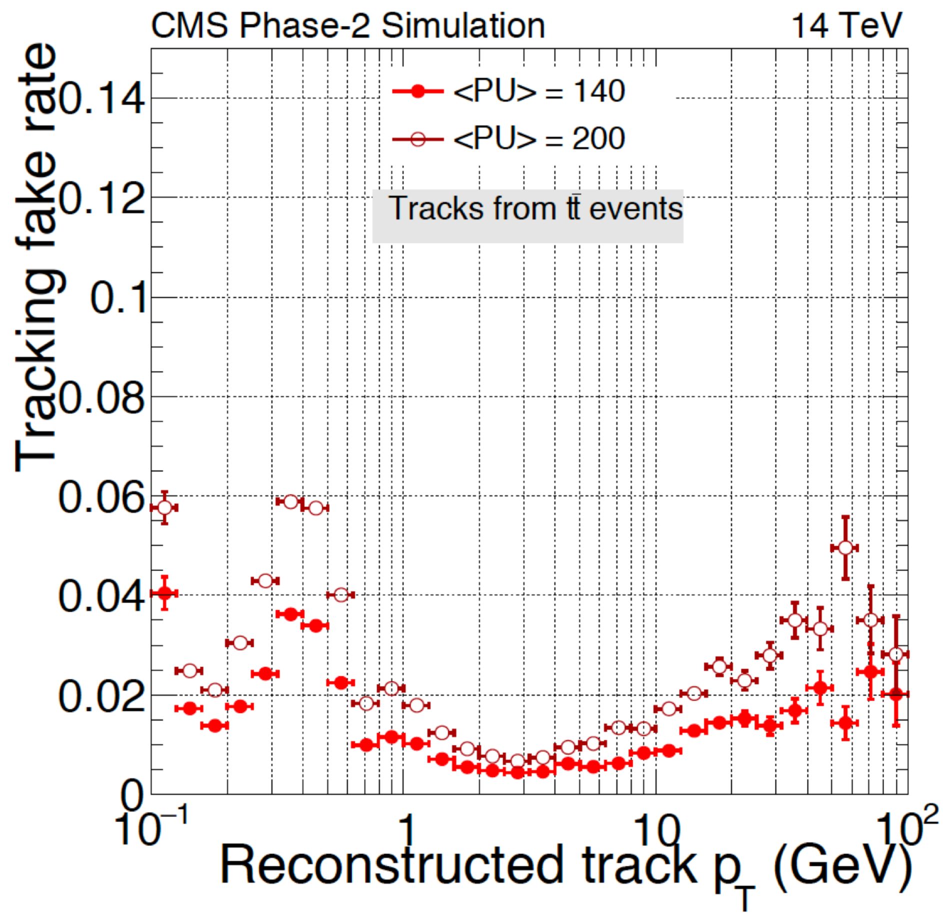




- improved resolution and extended η range with Phase 2 pixel
  (here same interactive tracking as current, adapted to Phase Tracker geometry)

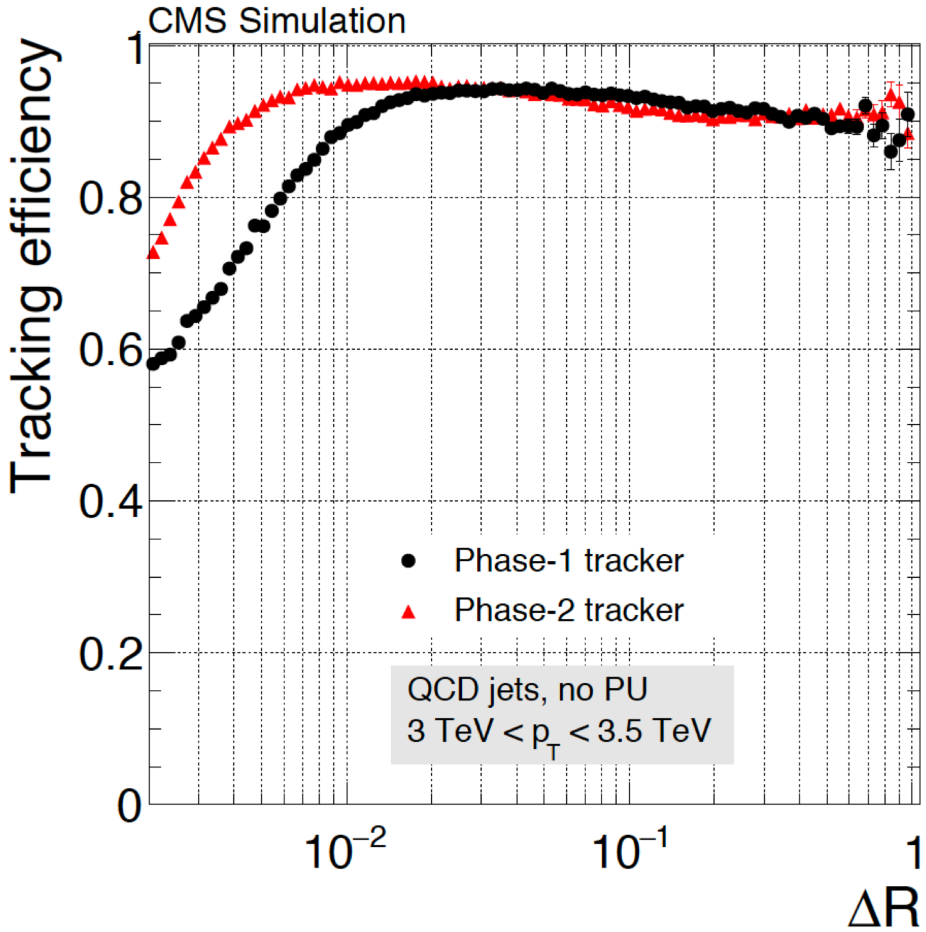
track and fake efficiency vs p_T





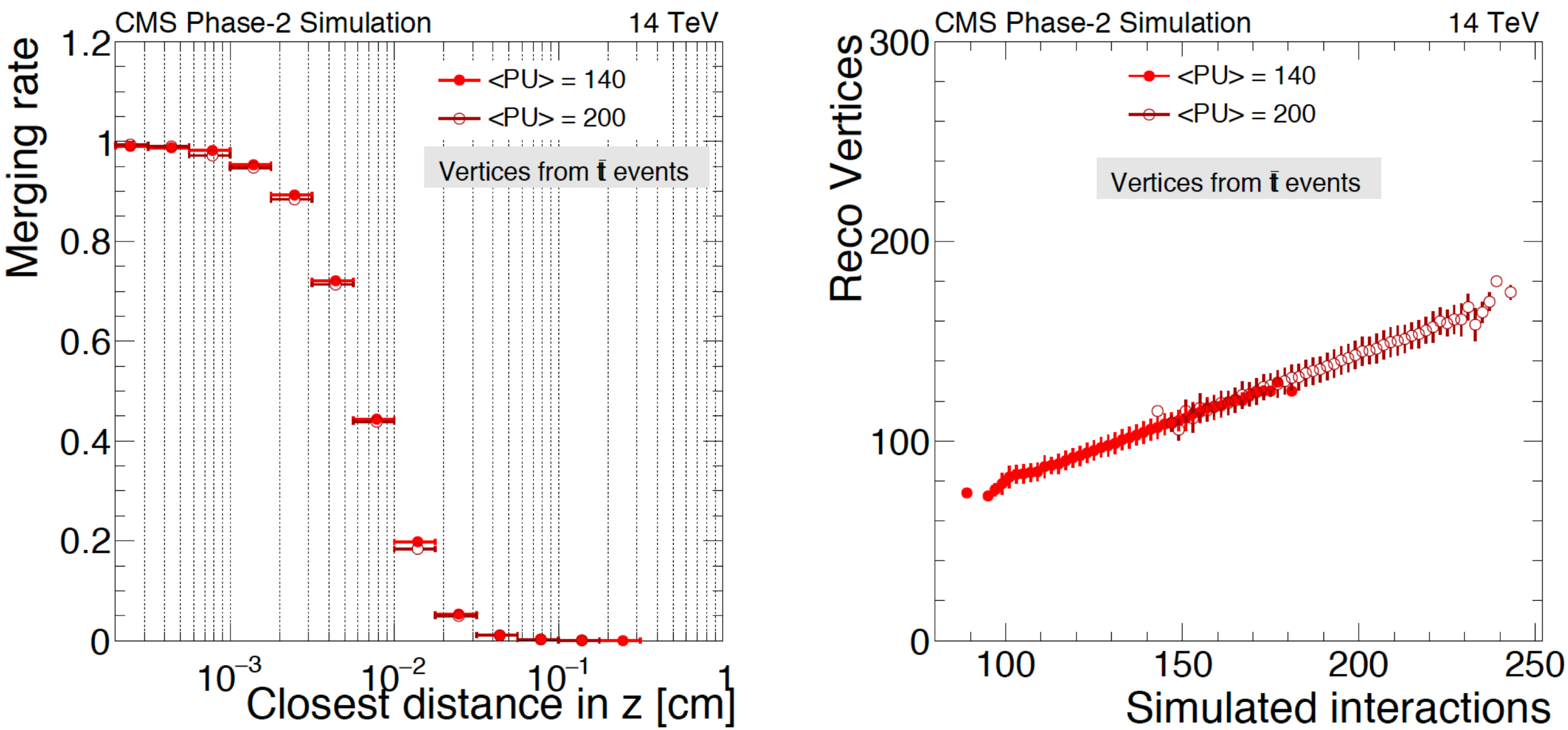
- track reconstruction efficiency > 90% for p_T > 1 GeV
- fake rate < 2% (4%) at 140 (200) PU for p_T within 1-100 GeV

track efficiency in jet core



- improved tracking in jet core thanks to better tracker granularity
- important for high p_T jets and boosted objects measurements !

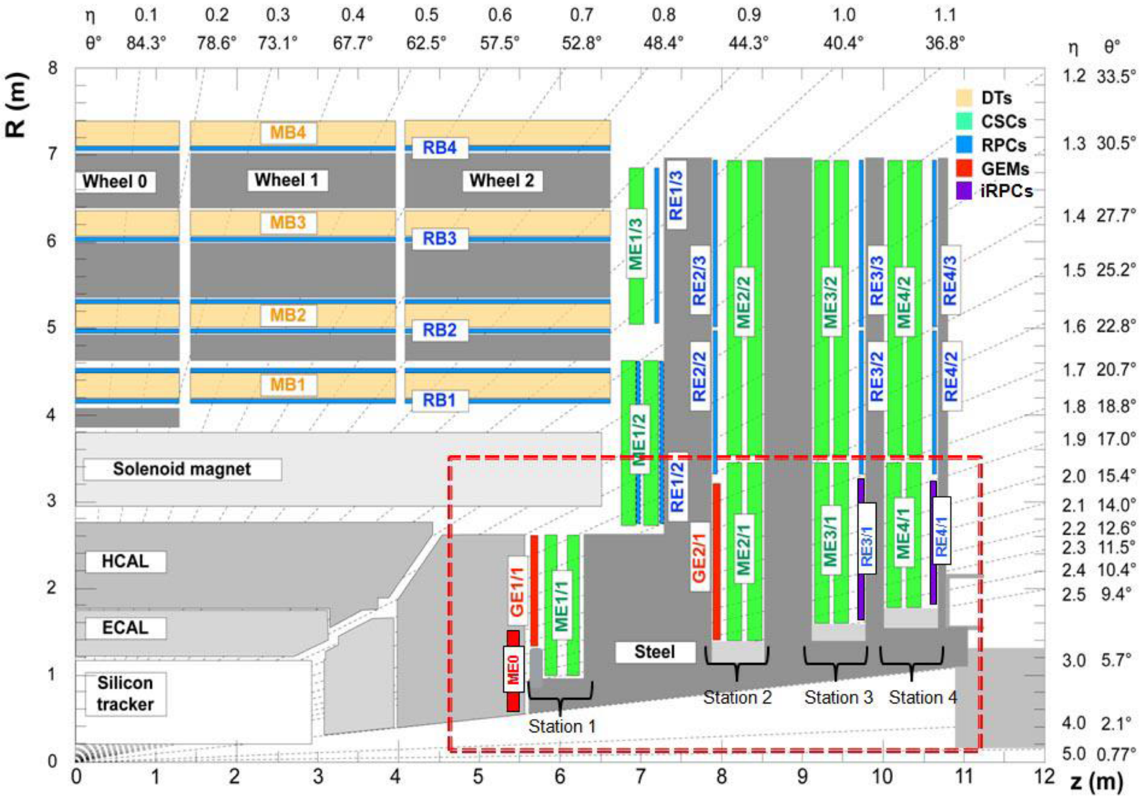
Primary Vertex efficiency

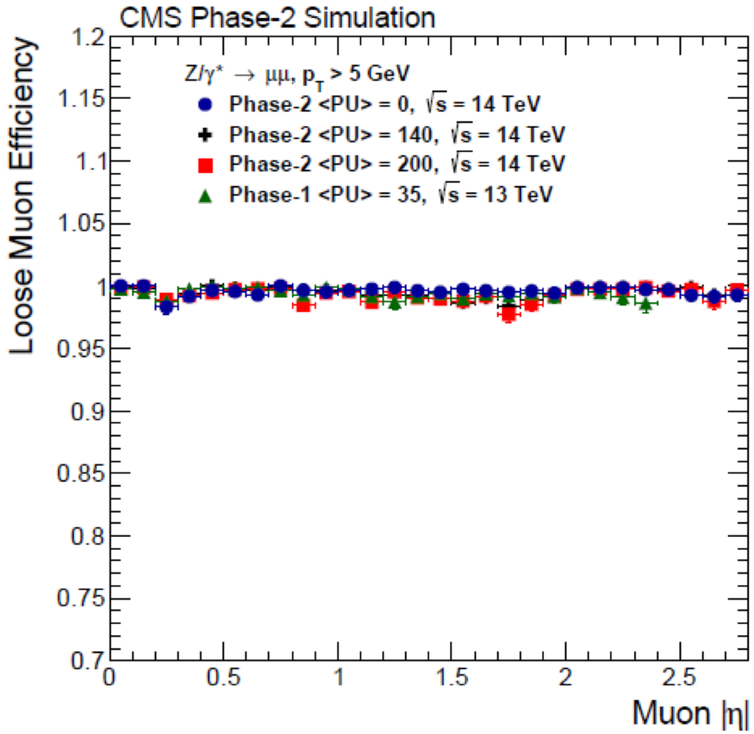


- good PV reco. efficiency: linear dependence as a function of pileup
- in the absence of timing info: PV merging rate significant for $|\Delta z| < 300\ \mu m$

Muon system

- DT and RPC: new readout with improved z and time precision
- CSC forward: new readout at high bandwidth
- forward extension: new stations GEM, RPC at |η| ≤ 2.4
  and new GEM ME0 (for trigger) within 2.4 ≤ |η| ≤ 2.9

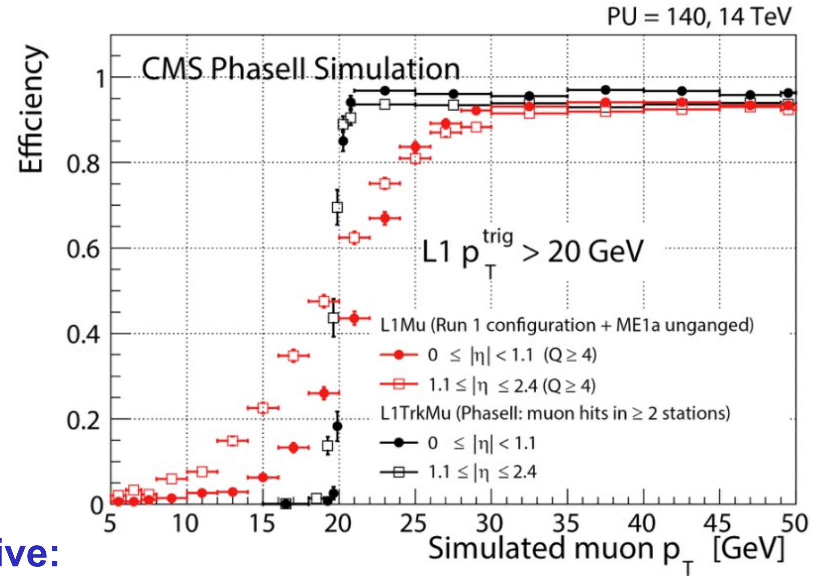


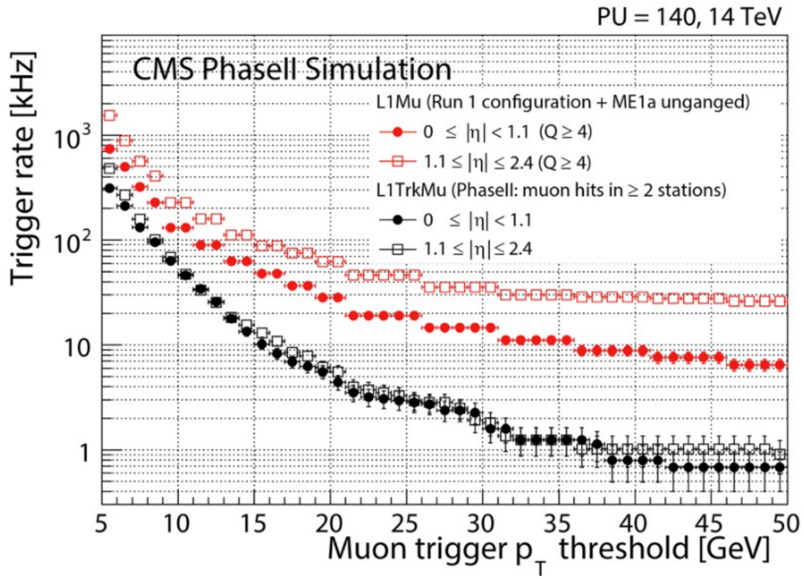


excellent muon reconstruction efficiency up to |η| < 2.9

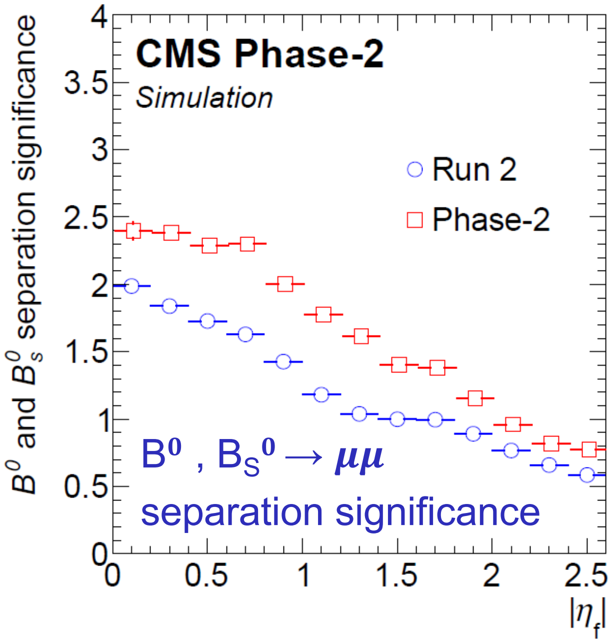
physics benefit

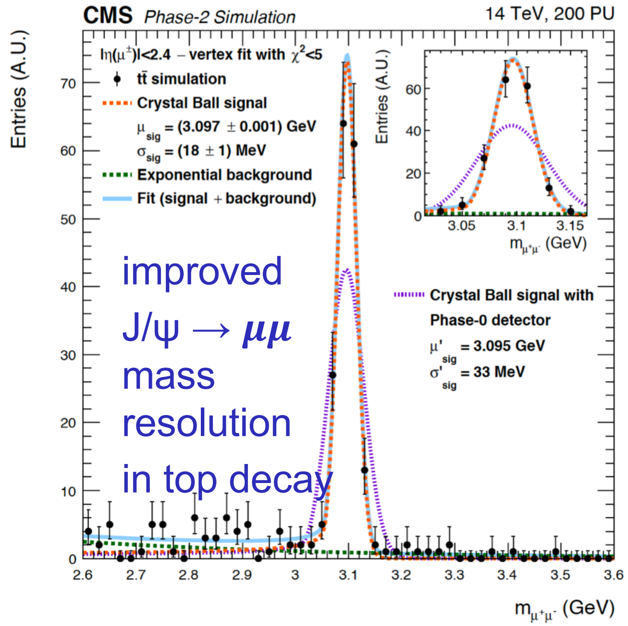
track-trigger allows improved L1 muon turn-on and much reduced rate

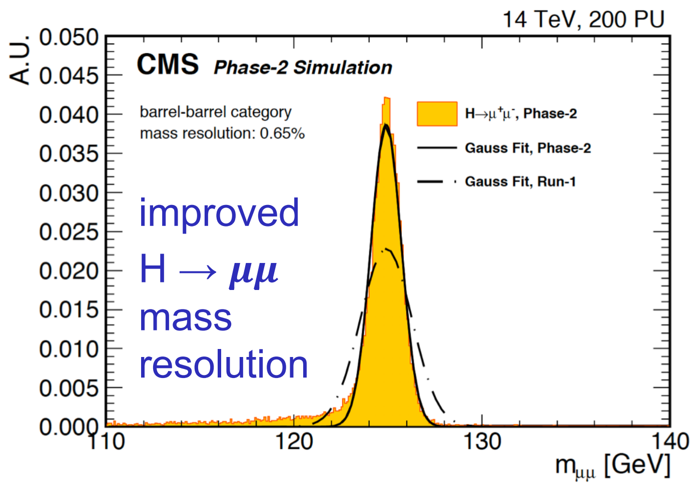




just illustrative:



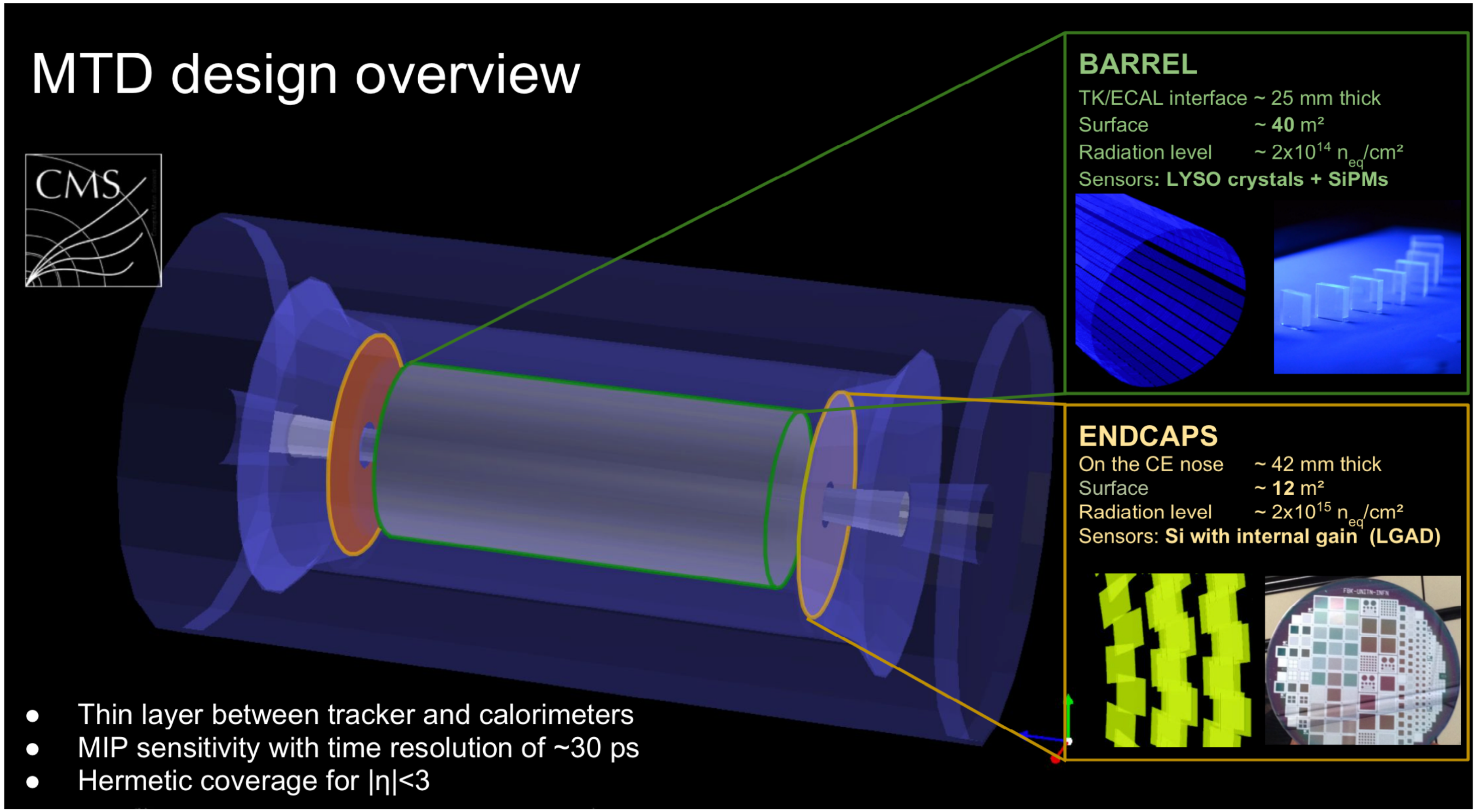




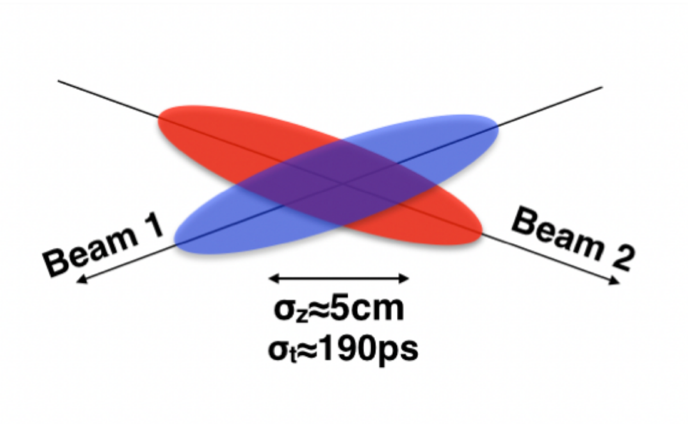
MIP Timing Detector

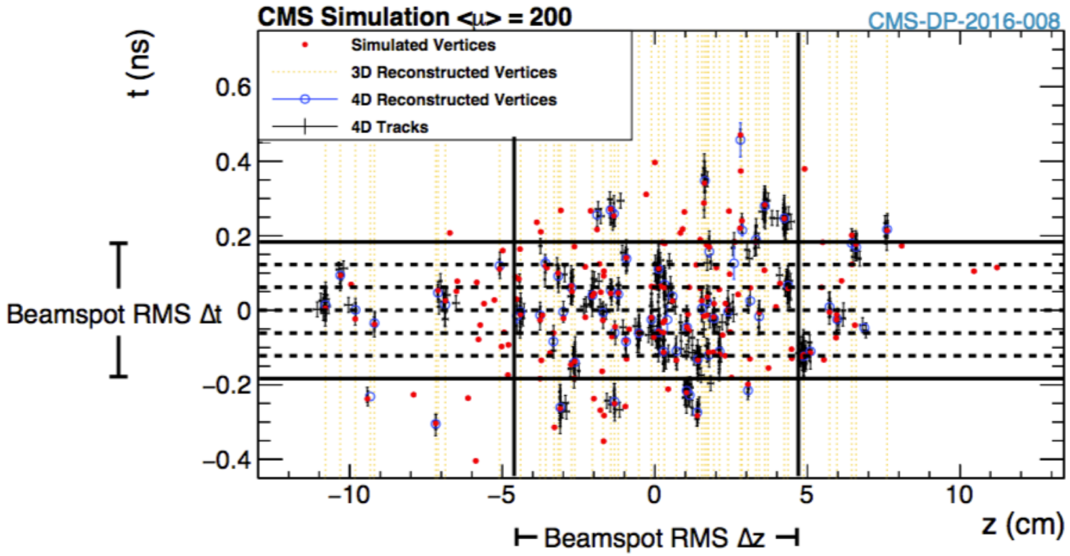
30 ps time of flight resolution for charged particles within $|\eta| < 3.0$

- Barrel Timing Layer within Tracker Support Tube
  - thin crystals (Lyso) 11x11 mm^2 + SiPM 4x4 mm^2, ~250k channels, 40 m^2
- Endcap Timing Layer in front of High Granularity Calorimeter
  - Si sensors with gain (LGAD) 1x3 mm^2 pads, ~250k channels, 12 m^2

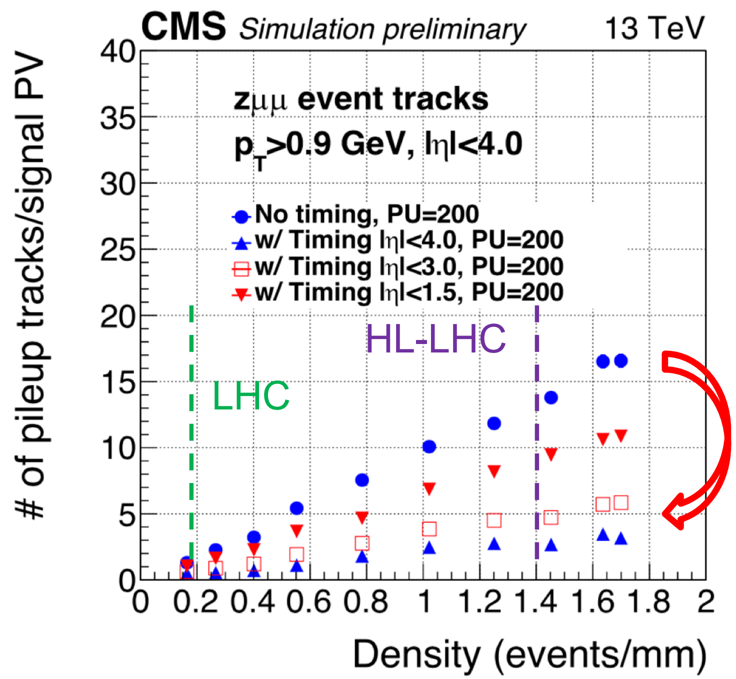


precision timing at HL-LHC

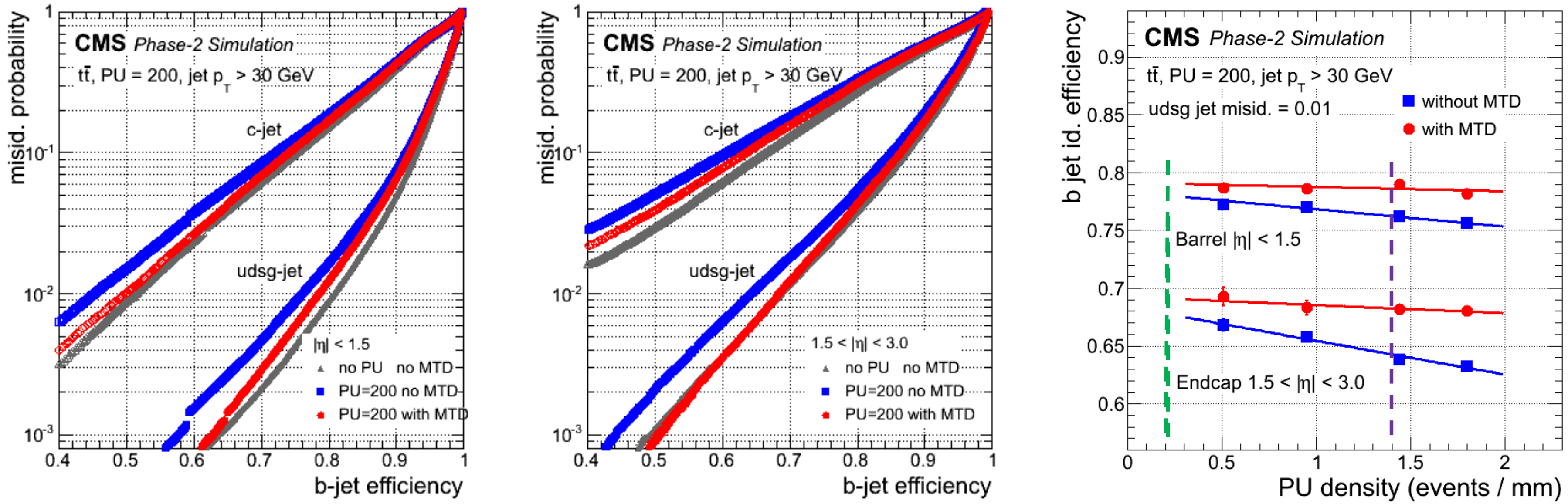




- pileup vertices spread along beam direction and time: precision timing for charged and neutral particles will be a key to reduce pileup contamination
  - track timing (σ_t~30 ps) will allow 4D (space+time) vertex reconstruction
  - x 4-5 reduction of vertex merging rate and number of pileup tracks associated to the signal PV

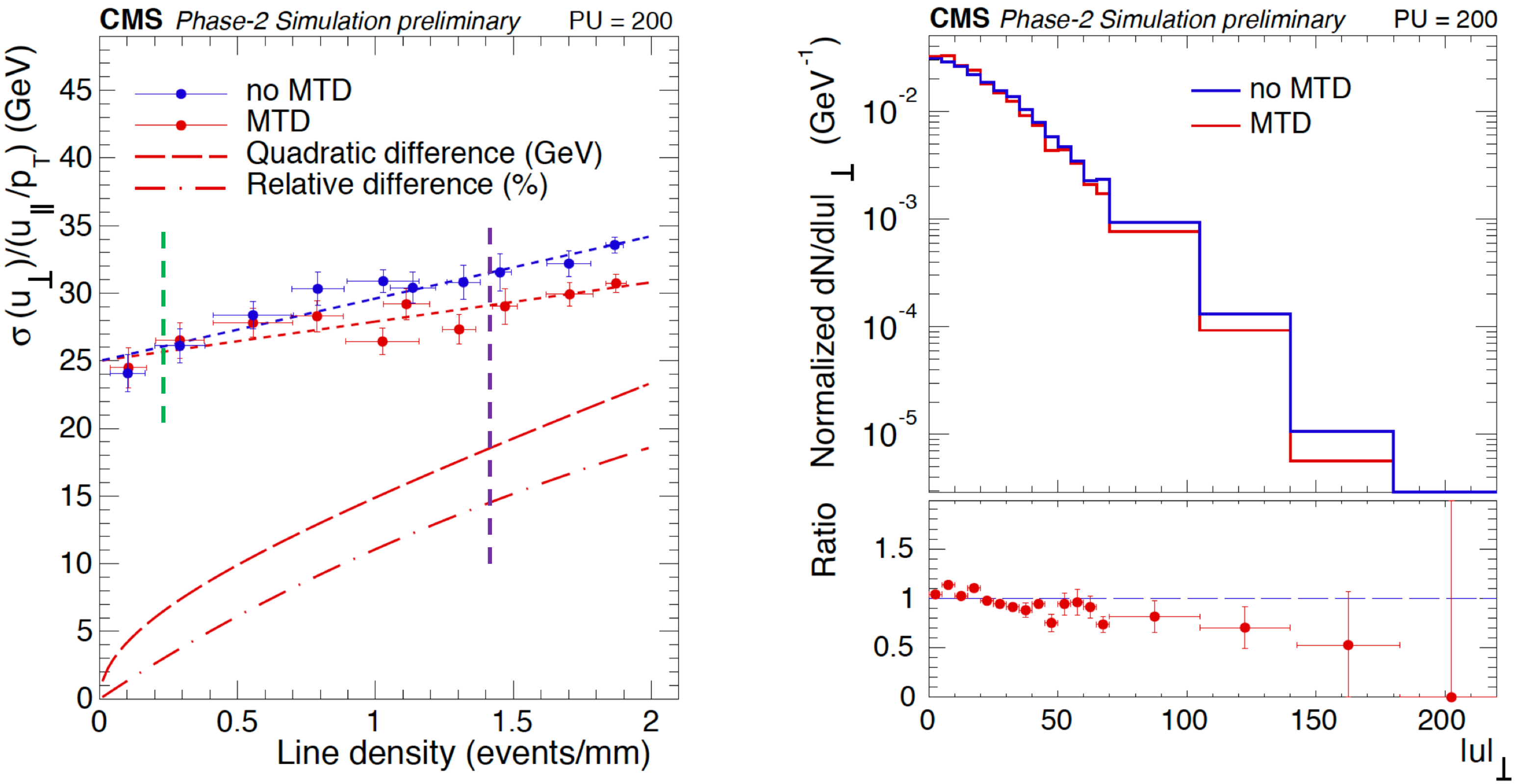


object performance: b-tagging



with timing information, b-tagging performance improves and is moderately sensitive to the high pileup conditions

object performance: MET



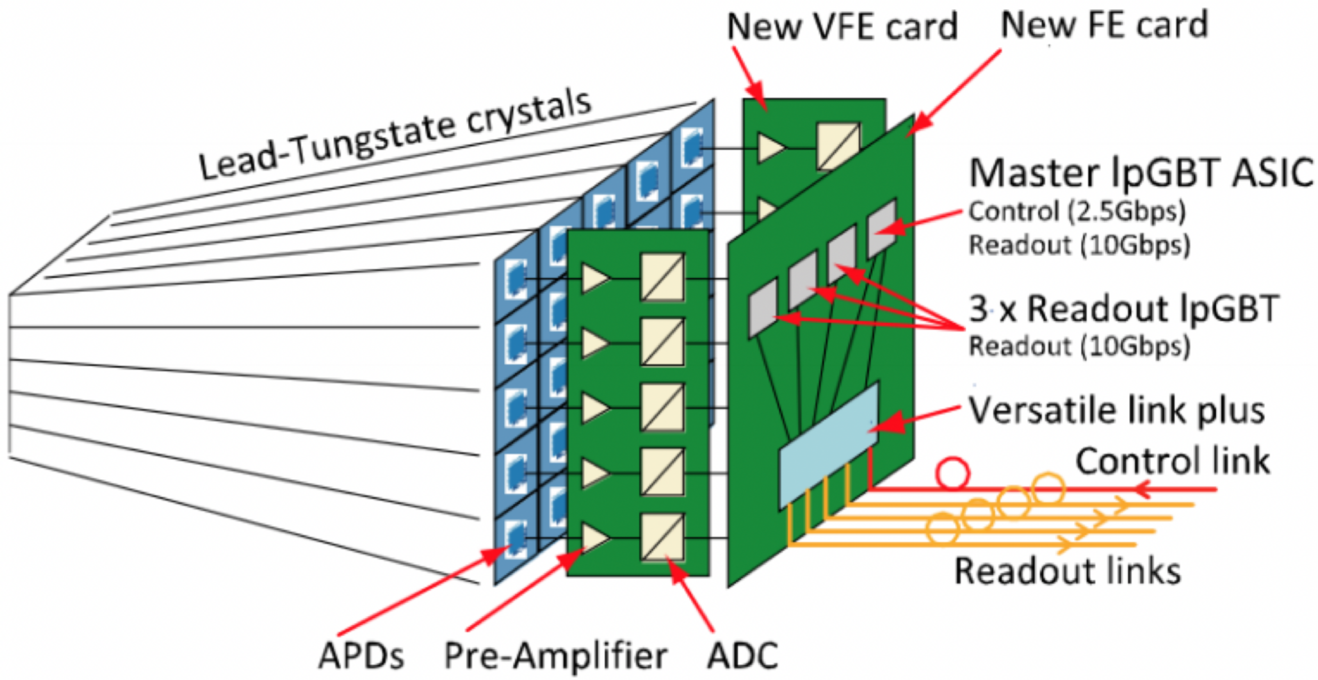
(a) MET Resolution (b) MET Tails

15% improvement in MET resolution,

> 30% reduction in tail (will reduce background for BSM searches)

Barrel calorimeter

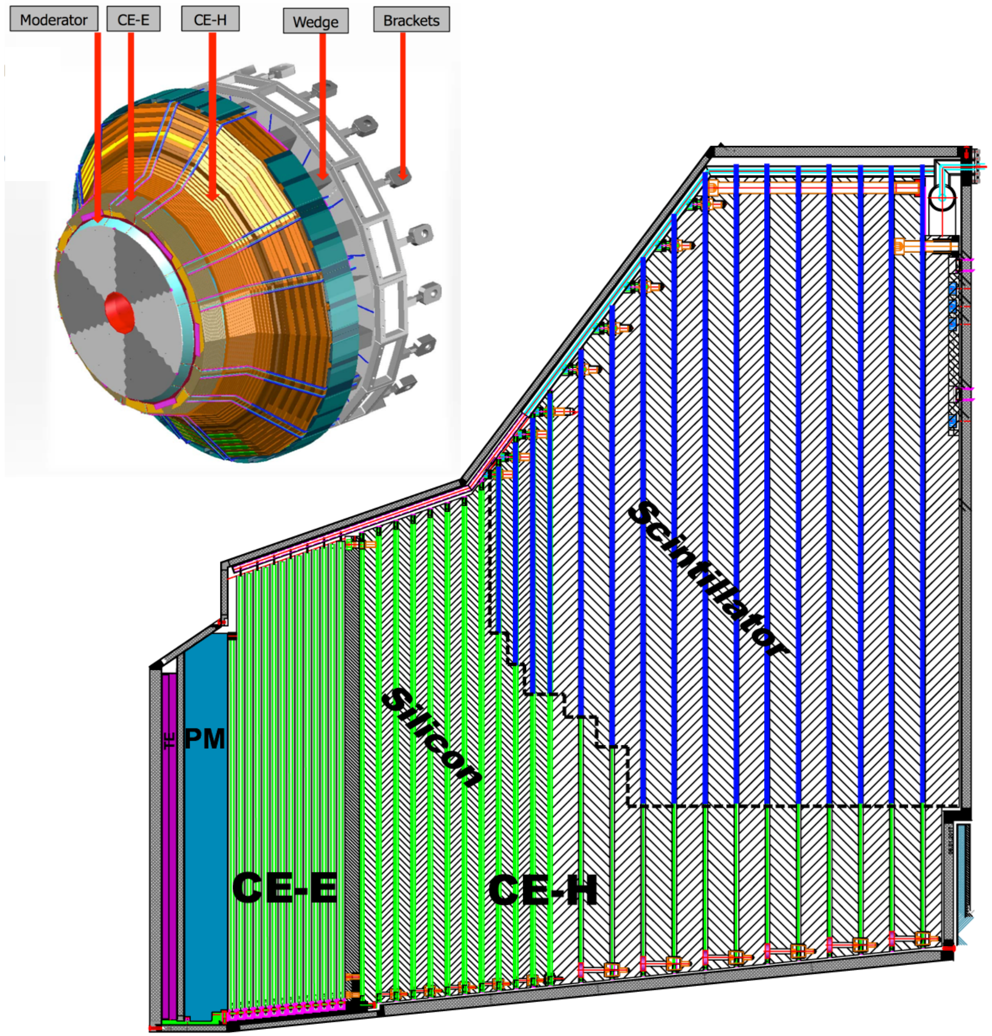
- maintain $PbWO_4$ crystal granularity readout (Avalanche PhotoDiodes) at 40 MHz in high pileup conditions
- replace fron-end electronics:
  - 160 MHz sampling against spikes (hadron interactions within APD volume),
  - 30 ps resolution for 30 GeV e/γ
  - all cells available at L1
- new ATCA back-end boards
- operate from 18^o to 9^{o}C to mitigate APD aging

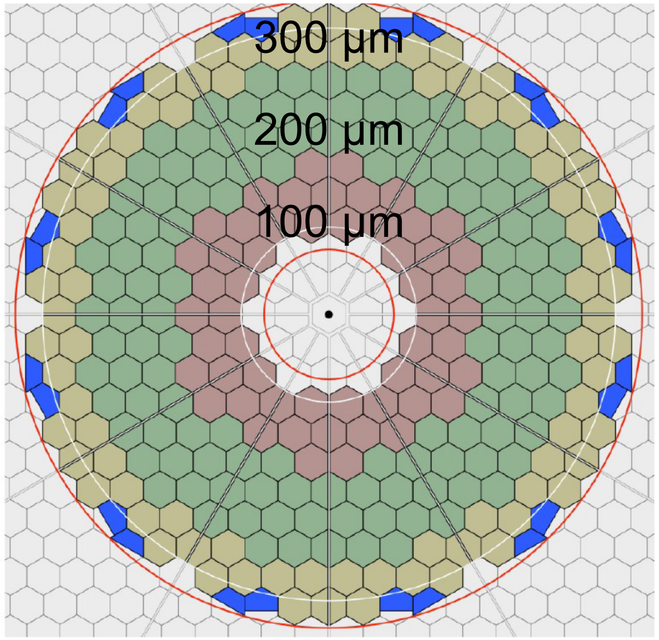


High Granularity endcap Calorimeter

4D shower topology with timing resolution ~30 ps

- electromagnetic calo: 28 layers Silicon/W-Pb (26 X_0 - 1.7 λ)
- hadronic calo: 8 layers Si + 16 mixed Si-Scintillators tiles within stainless still absorber (9 λ)

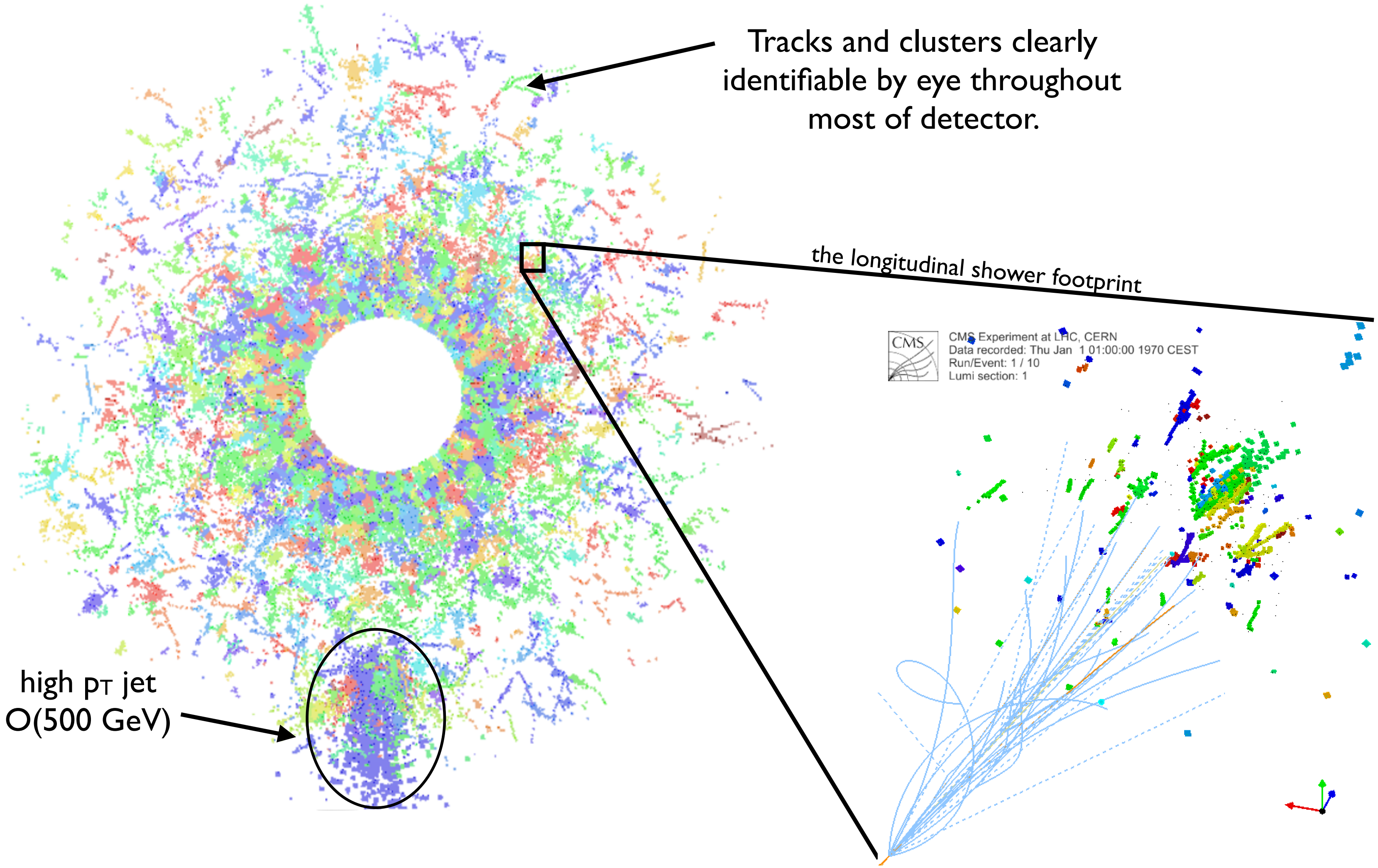




- 6 million Silicon channels
  - 600 m^2 ≈ 3x CMS Tracker
  - hexagonal silicon sensors
  - 100/200/300µm thick
- mixed layers in hadronic part
  - 500 m^2 plastic scintillator
  - SiPM-on-tile readout
- operation at -30° C
  - with CO_2 cooling to mitigate increase of Si leakage current after irradiation

HGCAL has the potential to visualize the full em showers

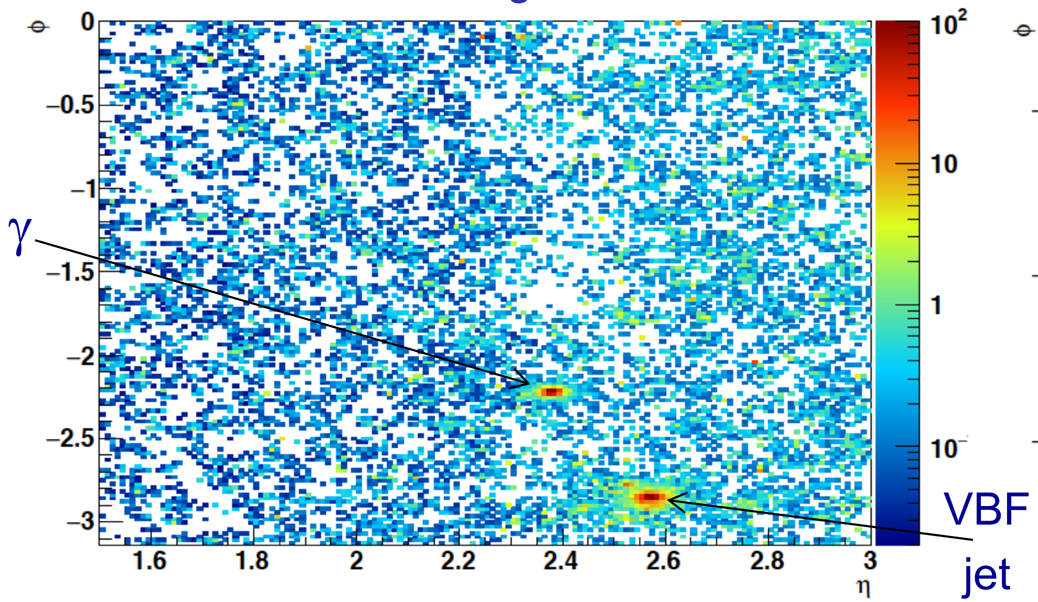
simulation of PU=140 events



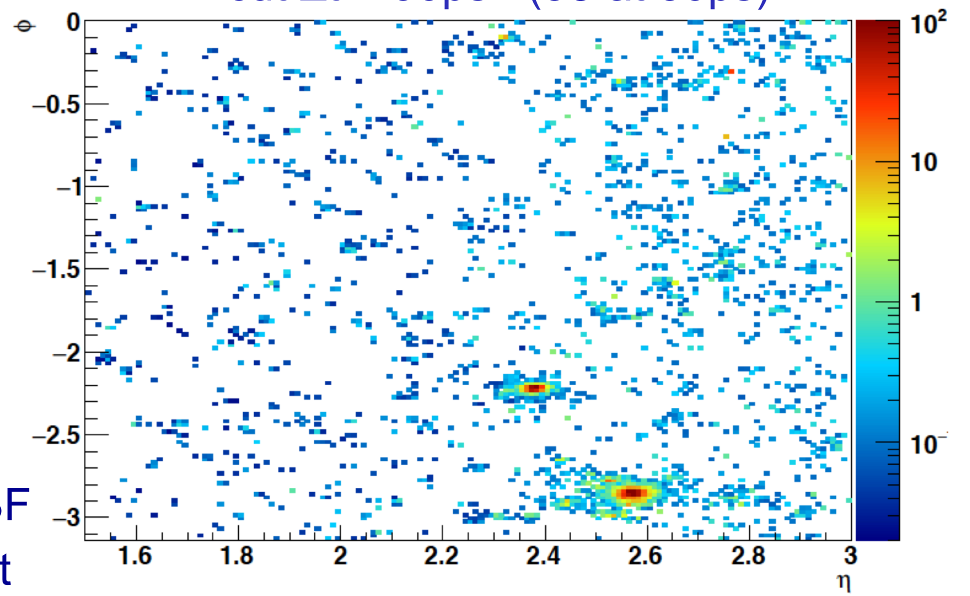
(from Dave Barney, CERN seminar, April 2018)

precision timing and H → γγ

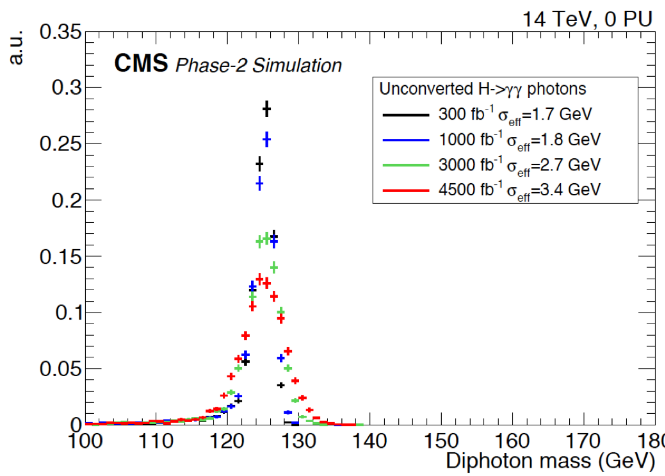
no timing cut

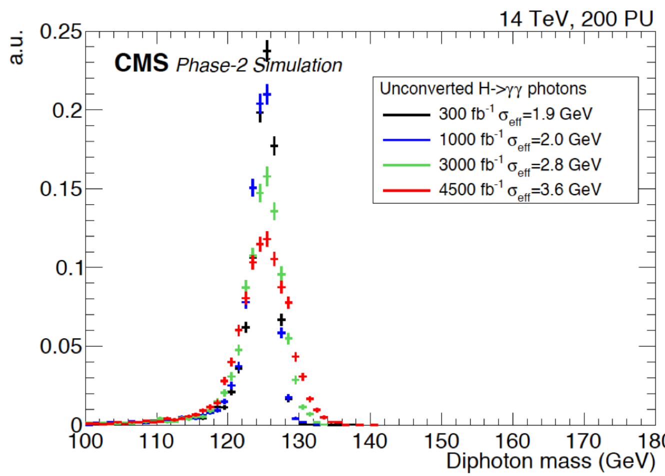


cut Δt < 90ps (3σ at 30ps)

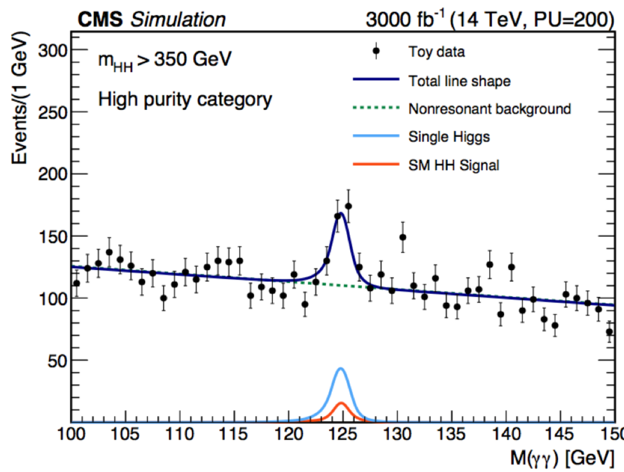


precision timing from HGCAL also important to constrain the PV from γ direction: can provide high H→γγ mass resolution even at PU=200





benefit for HH→bbγγ



(from Paolo Rumerio, Nov. 2017)

performance benefit with timing

Signal	Projected Physics Impact
$H \to \gamma\gamma$	25% improvement in statistical precision on xsecs $\to$ couplings
VBF $H \to \tau\tau$	20% improvement in statistical precision on xsecs $\to$ couplings
HH	20% increase in signal yield/decrease in running time $\to$ consolidate searches
EWK SUSY	40% reducible background reduction $\to$ +150 GeV mass reach
Long-Lived Particles	Peaking Mass Reconstruction $\to$ Unique sensitivity and discovery potential

(from Josh Bendavid, CERN seminar, May 2018)

Conclusion

Intense activity in the collaboration:

- several Technical Proposals and Technical Design Reports already accepted by LHCC
  - 2015: Phase 2 CMS TP and scope documents
  - 2017: TDRs for Tracker, Muon, Barrel Calorimeters
    + interim TDRs for L1 triggers and DAQ
  - 2018: TDRs for Endcap calorimeters
  - end 2018: TDR for MIP Timing Detectors
- physics preparation on-going:
  - CERN yellow report by end of the year
- large construction in front of us, but tight schedule:
  - R&D and pre-production up to ~2020-2021
  - production, construction ~2021-2024
  - installation ~2024-2025
  - commissioning and HL-LHC begins 2026