CMS precision timing physics impact for the HL-LHC upgrade

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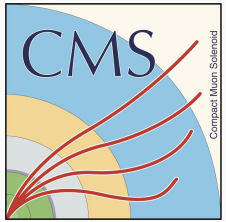
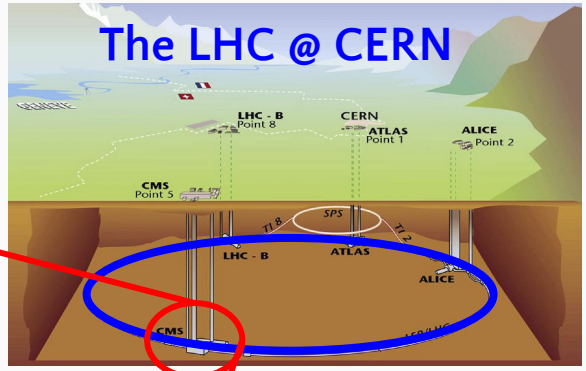
On the behalf of the CMS collaboration.

Caltech



CMS: a multi-purpose particle detector



CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

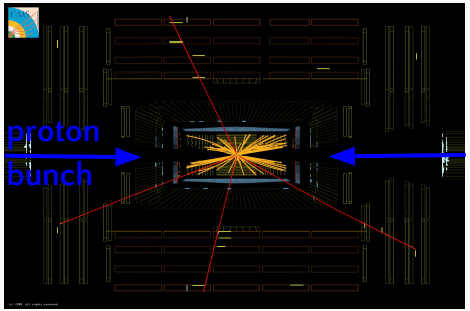
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

LHC beam line

... an event snapshot



The HL-LHC

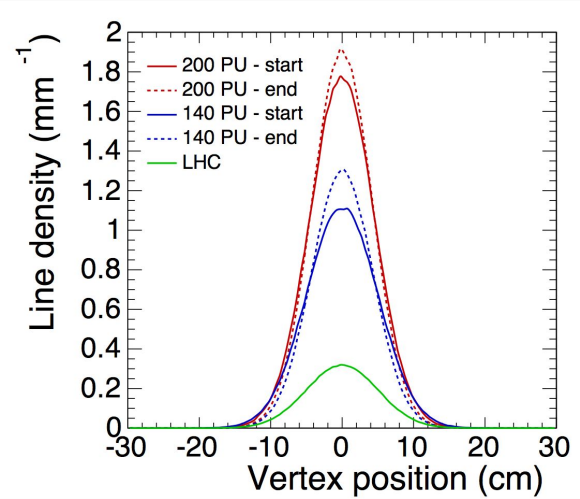
- Approved LHC upgrade
- Experiments will upgrade as well
- Installation 2022 -26
- Data taking until 2038

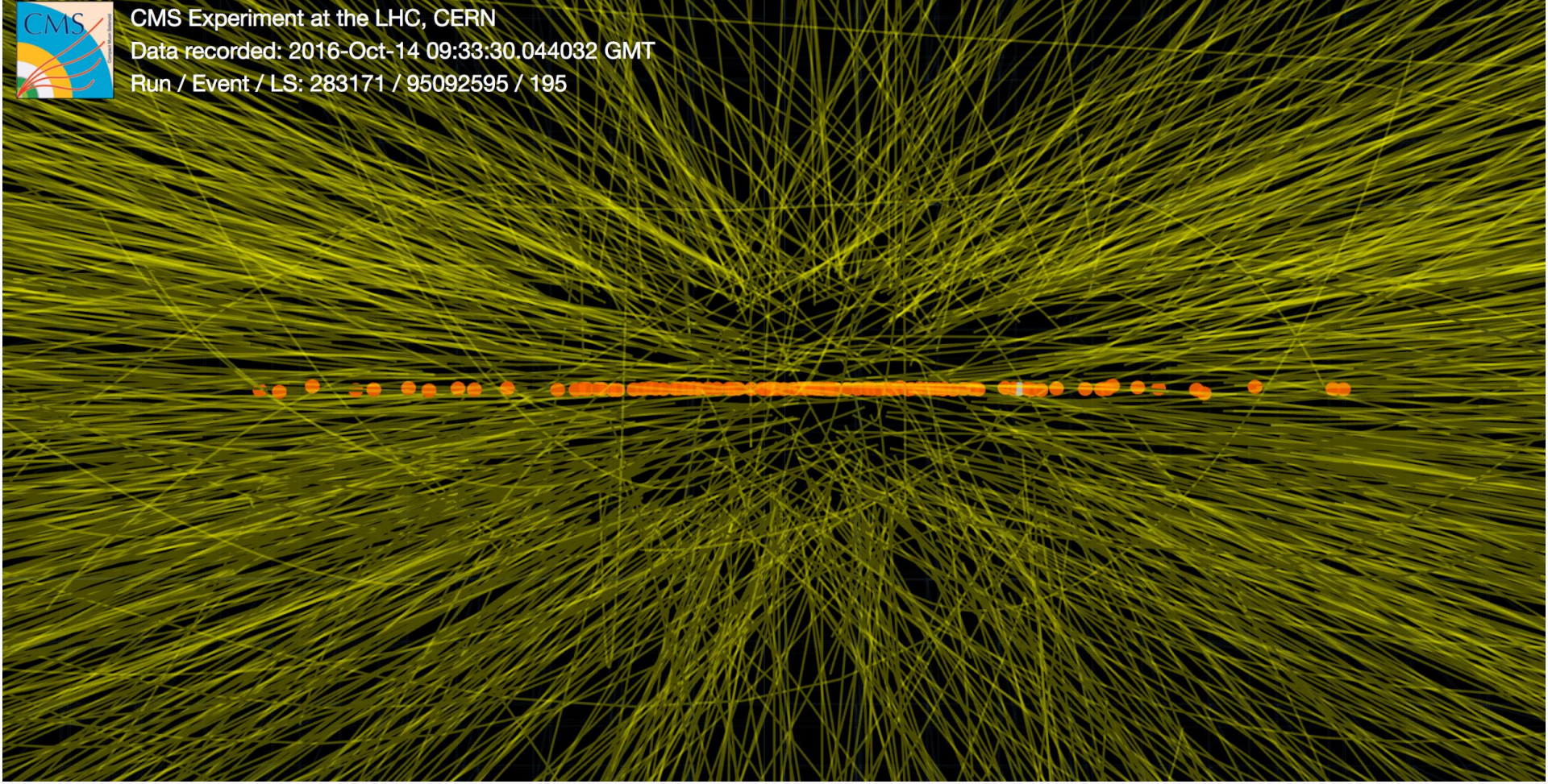
- HL-LHC: Significant upgrade of LHC and injectors
- Increase beam intensity
  - Baseline: $L = 5.0 \times 10^{34}\ cm^{-2}s^{-1}$ (140 PU)
  - Ultimate: $L = 7.5 \times 10^{34}\ cm^{-2}s^{-1}$ (200 PU)
- Ultimate achievable integrated luminosity set around 3 ab^{-1}

Higher beam intensity

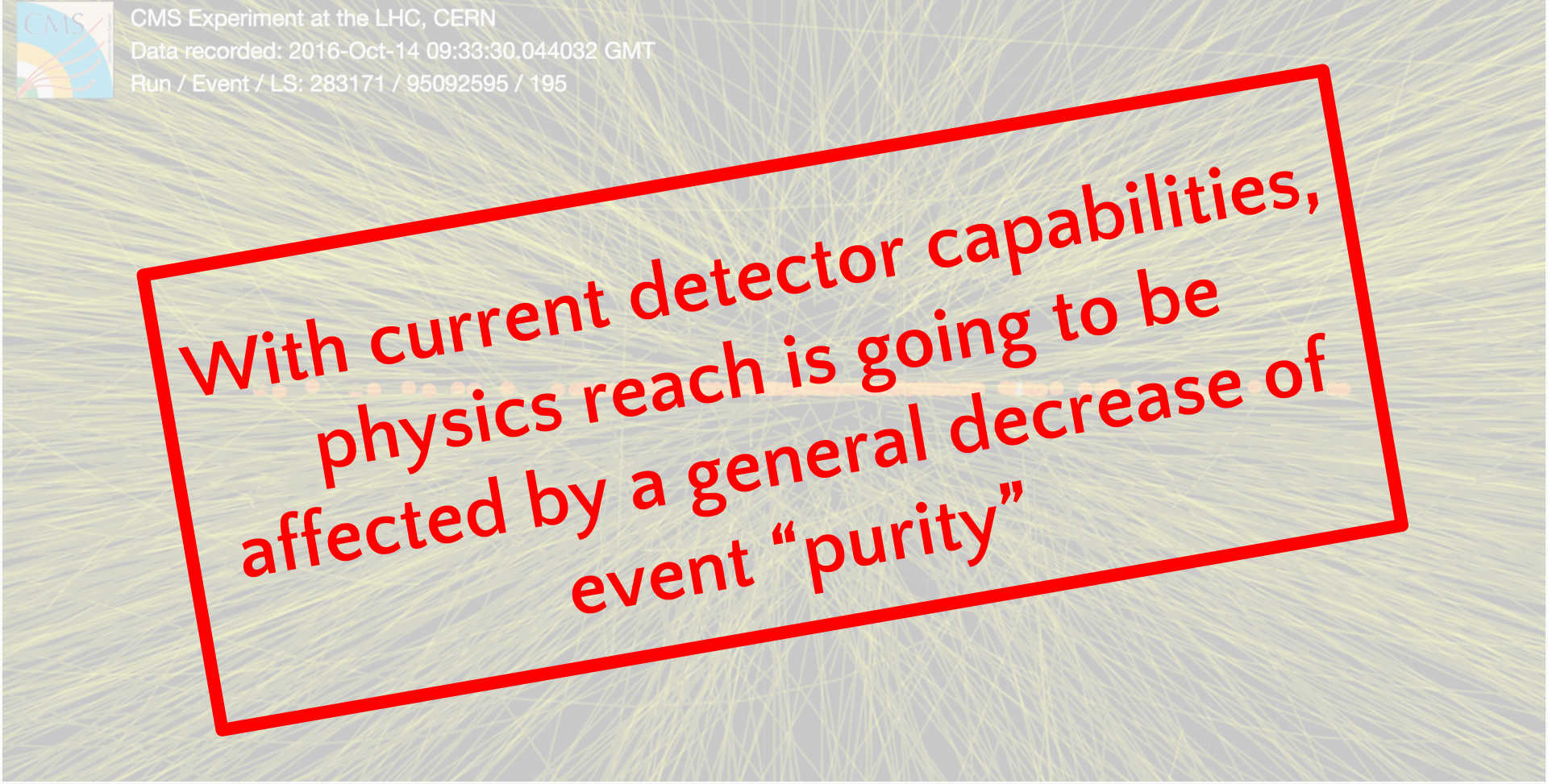
⇩

More p-p interaction per bunch xing



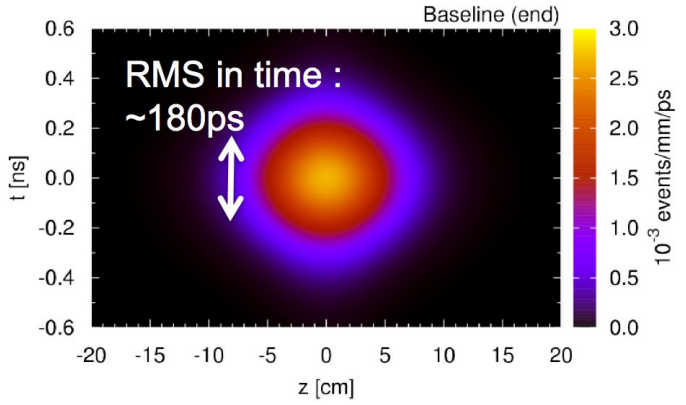


LHC 2016 event with 130 reconstructed vertices from special run in 2016

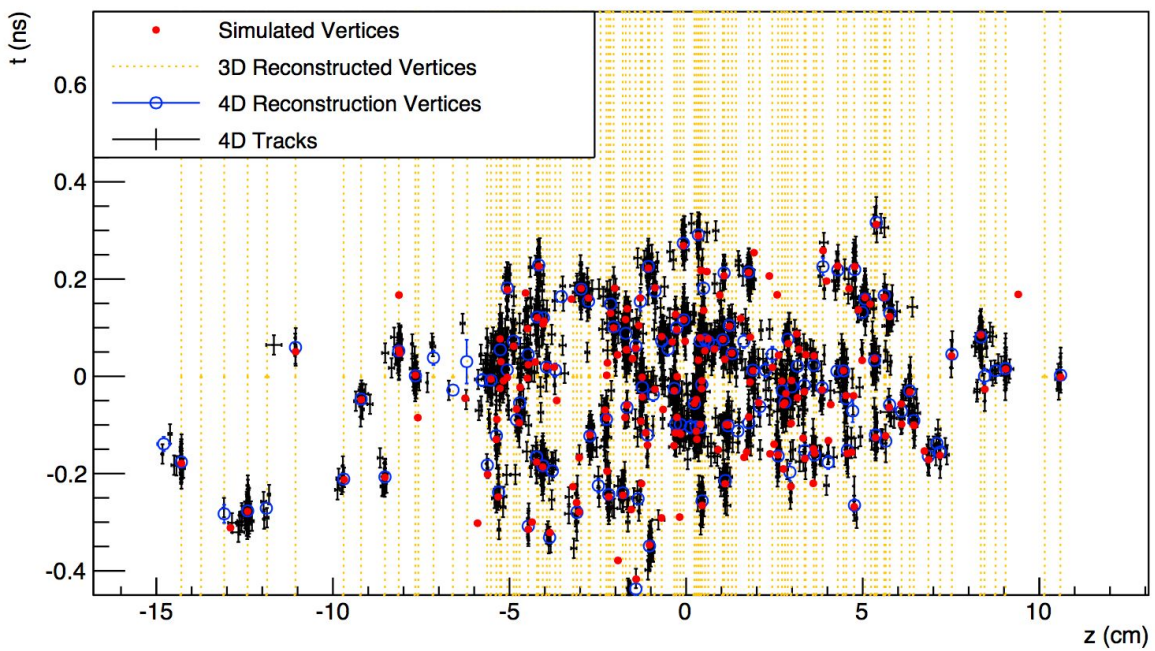


LHC 2016 event with 130 reconstructed vertices from special run in 2016

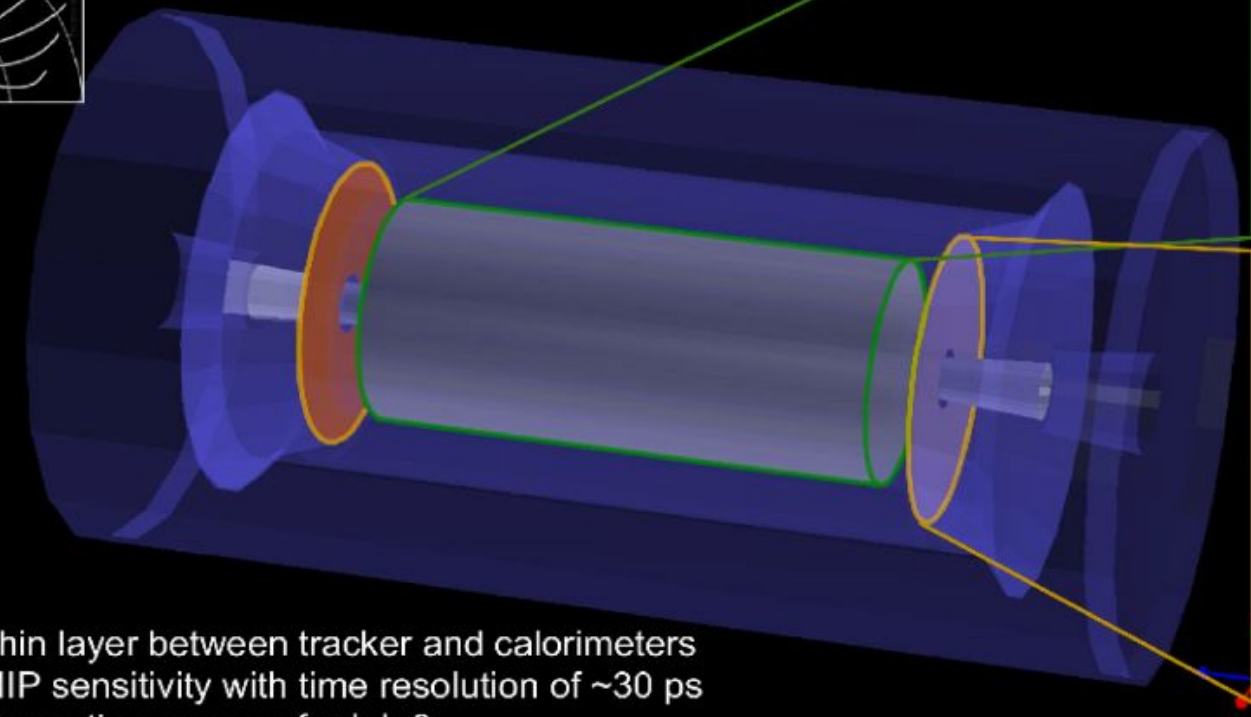
Adding a dimension



p-p interaction are spread independently in z and time

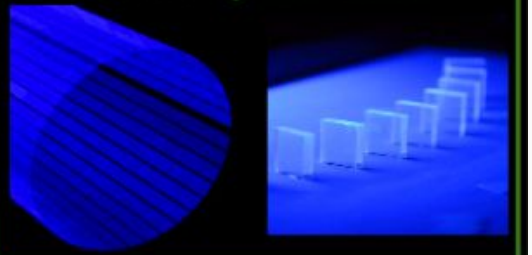


MTD design overview



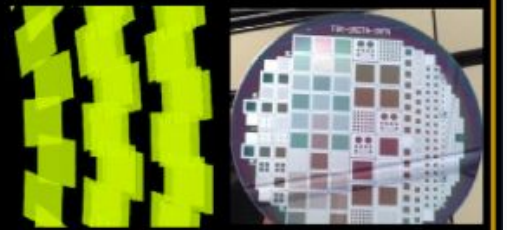
BARREL

TK/ECAL interface ~ 25 mm thick
Surface ~ 40 m²
Radiation level ~ 2×10^{14} n_{eq}/cm^2
Sensors: **LYSO crystals + SiPMs**



ENDCAPS

On the CE nose ~ 42 mm thick
Surface ~ 12 m²
Radiation level ~ 2×10^{15} n_{eq}/cm^2
Sensors: **Si with internal gain (LGAD)**



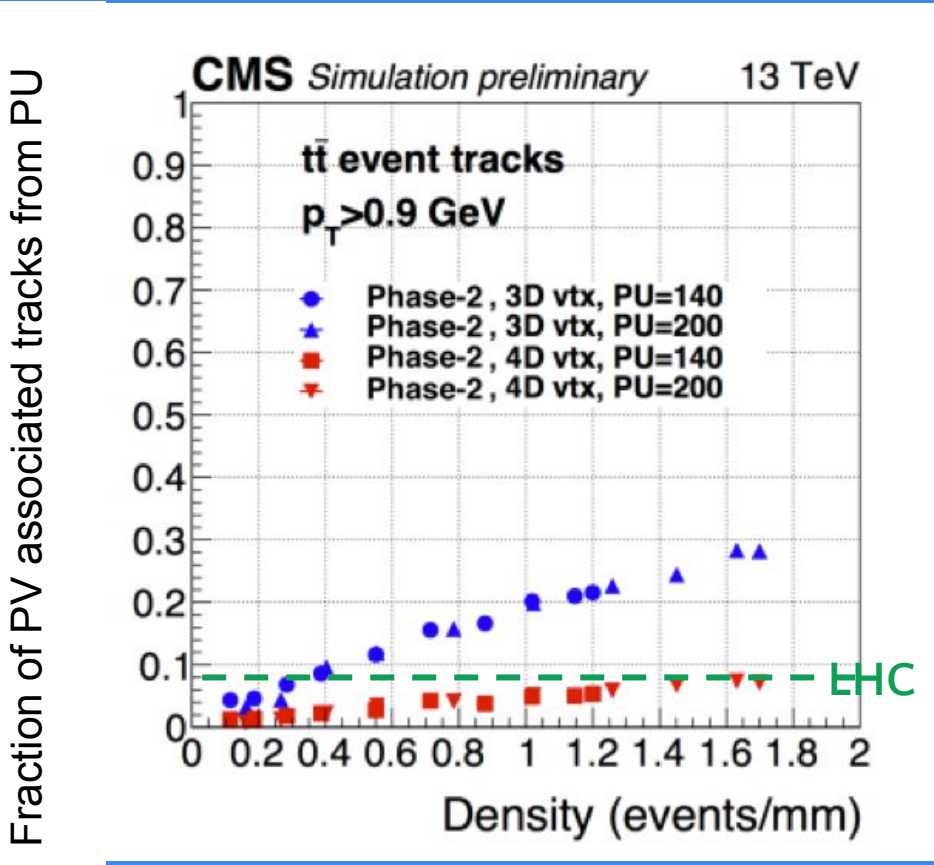
- Thin layer between tracker and calorimeters
- MIP sensitivity with time resolution of ~30 ps
- Hermetic coverage for |η|<3

Impact on physics object

Pileup mitigation

- Time-of-arrival measurement can discriminate between collisions occurring very close in space, but separated in time

- Suppress spurious track-to-PV association by more than factor of 3

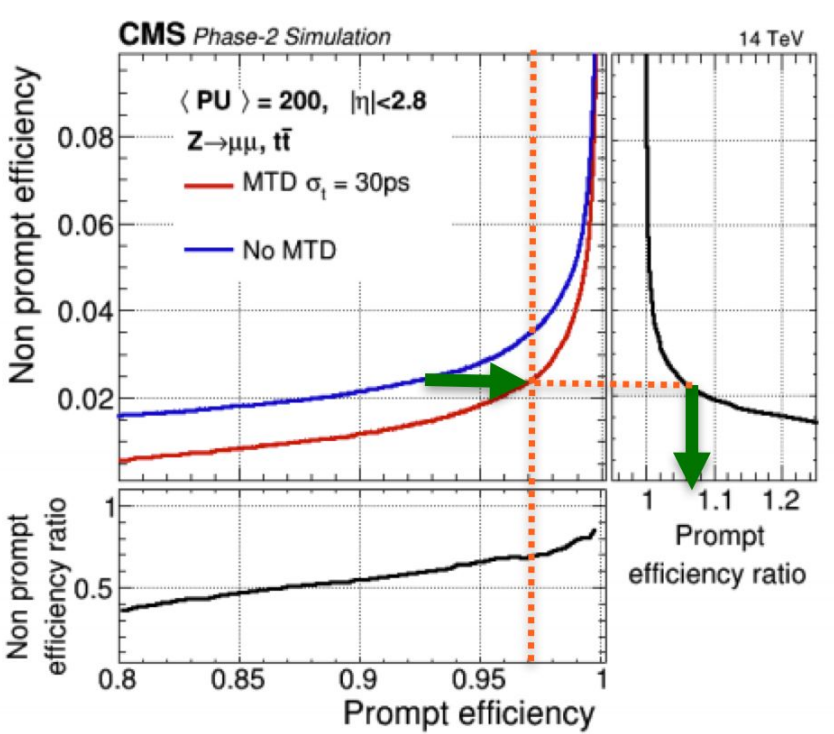


Keep the same LHC performances

Lepton isolation

Lepton & Photon isolation discrimination improves:

- @ 97% efficiency with MTD, for same background, efficiency ~6-7% better than no MTD
- Critical to maintain low fake lepton bkg due to large systematic uncertainties



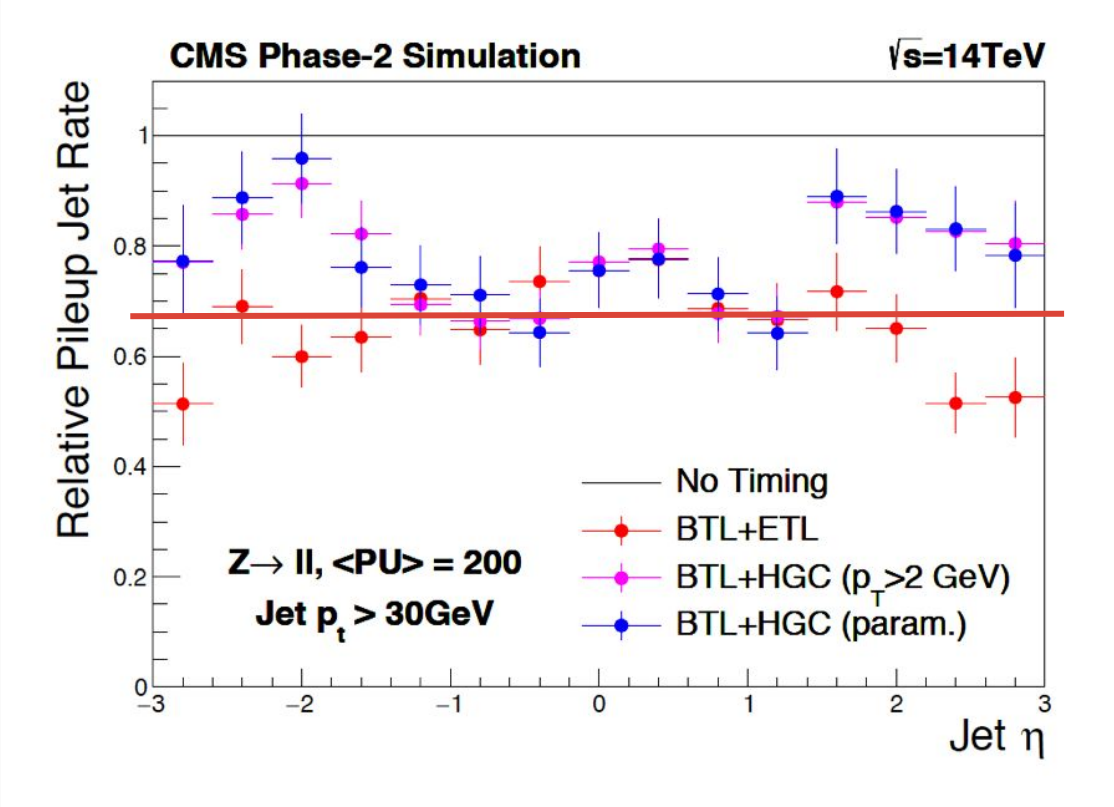
Example:

- H → ZZ → 4l : 26% improvement
- Fake leptons dominated bkg analysis (like H→ WW or SUSY searches)
  - WP around 90% implies 20% improvement for each lepton

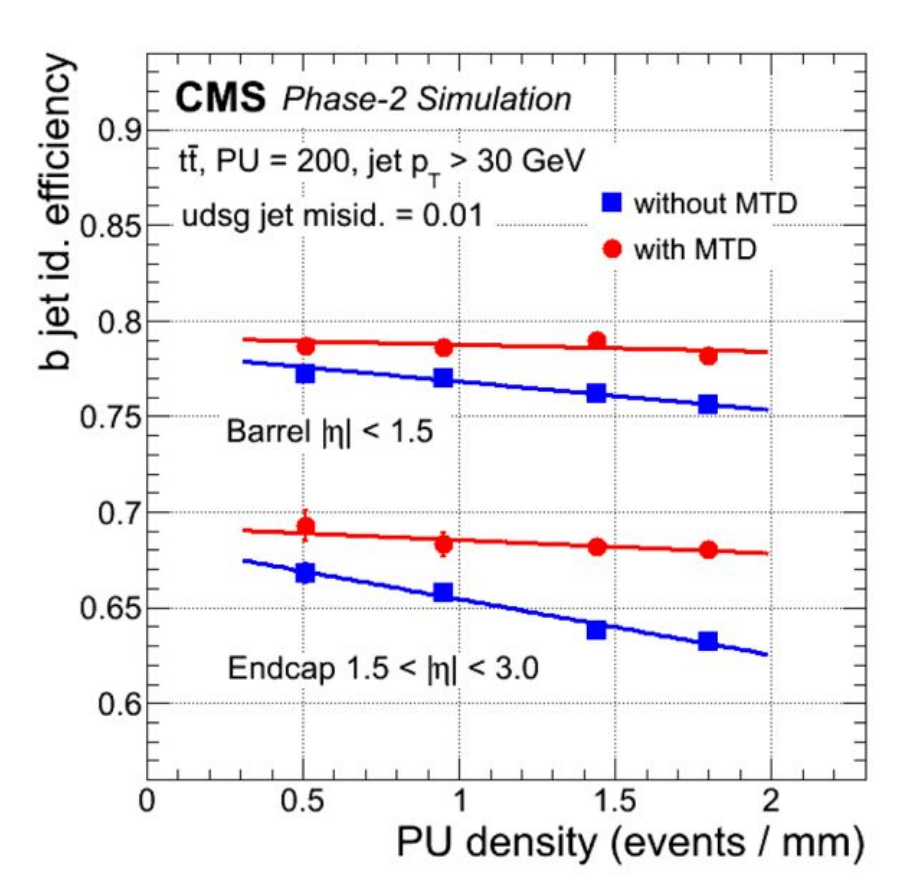
Jet: Pileup contamination

- Significant Reduction in Pileup Jet Rate: ~30-40%

- Crucial for Jet resolution:
  - VB scattering
  - Jet mass resolution



b-jets tagging



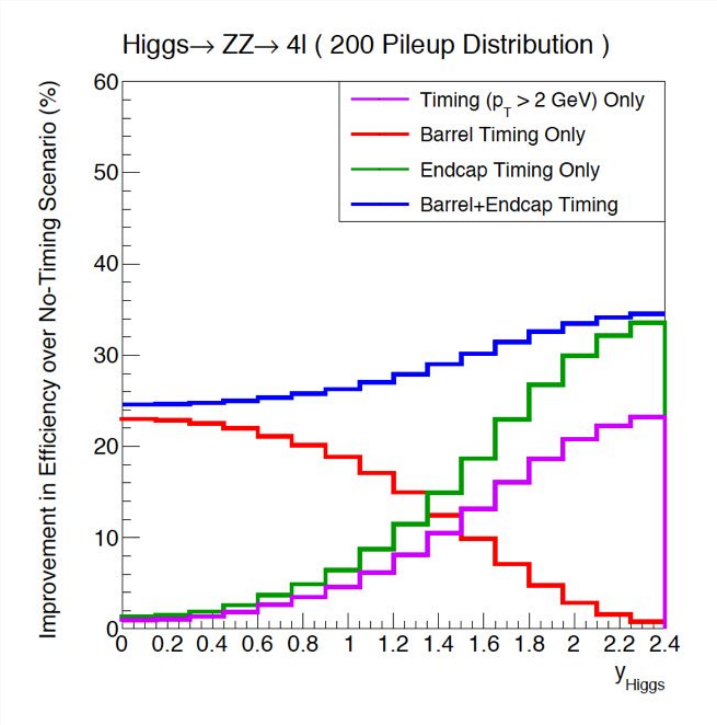
- PU dependence reduced
- 3-5% efficiency improvement

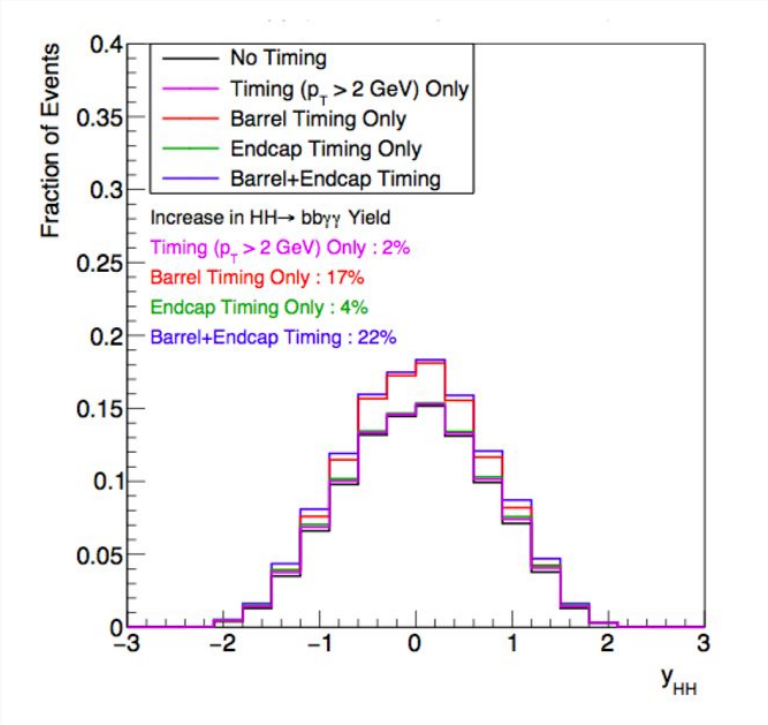
Impact on analysis

HL-LHC Higgs program

Effective luminosity increase:

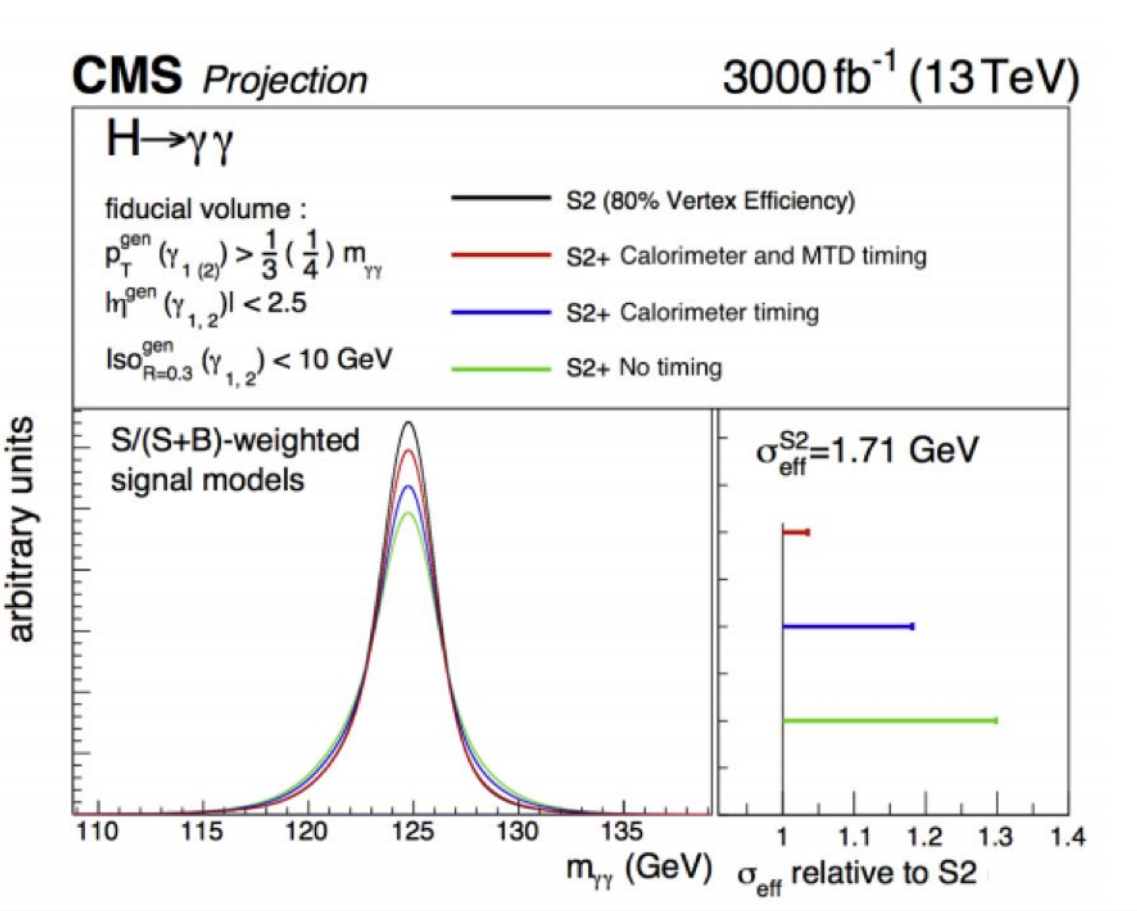
- $H \rightarrow ZZ \rightarrow 4l$: 26%
- $HH \rightarrow bb\gamma\gamma$: 22%





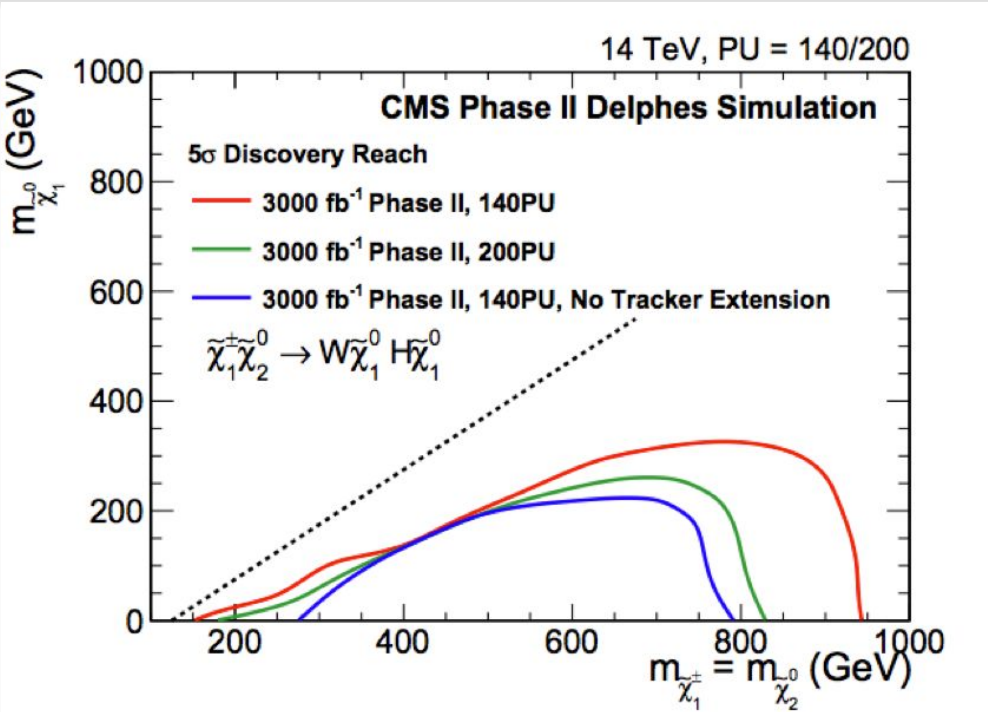
Higgs mass resolution

- Crucial for the H→ γγ channel
- About 15% improvement



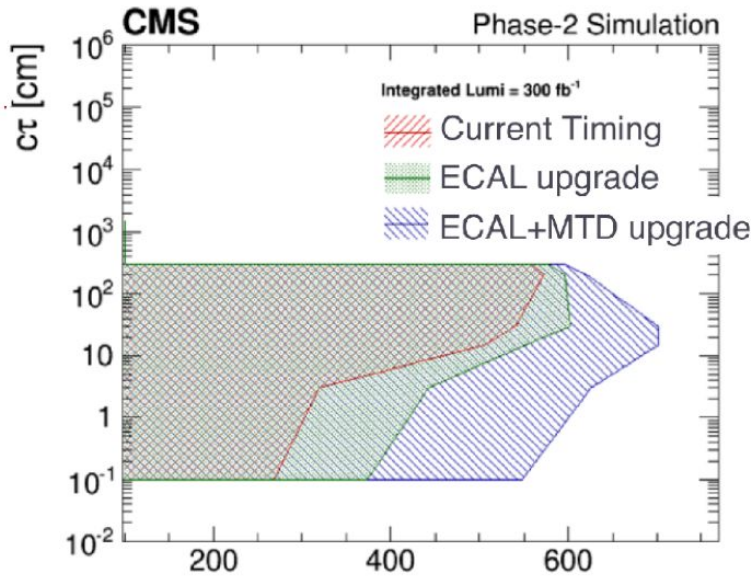
Electro-Weak SUSY production

- MET tail improvement has significant impact on New-Physics Reach
- Roughly recover the performance of the less intense pileup scenario

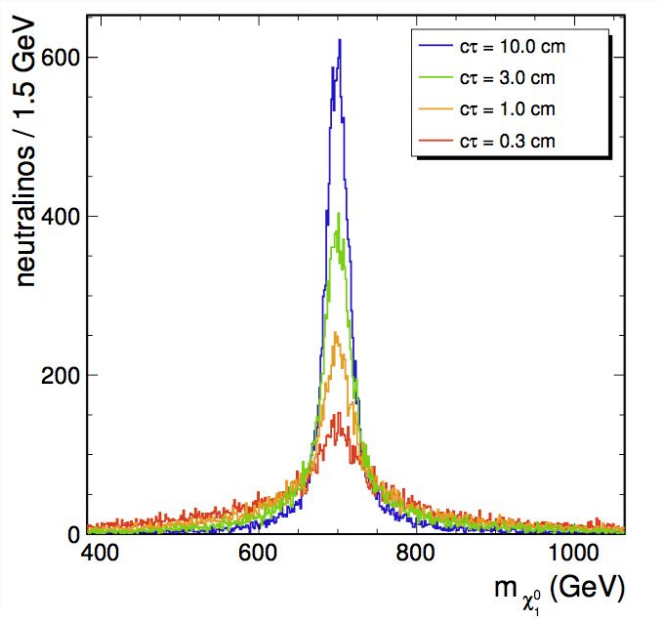


Uniquely expanded reach for Long-lived particles

- Vertex timing enhances LLP program
- For topologies involving secondary vertices, MTD provides new capability to reconstruct the mass of long-lived NEUTRAL particles



$\chi_1^0 \to G + \gamma$ Limits



$\chi_1^0 \to G + Z$ Peaking Variable

Summary

MIP Timing Detector will significantly improve detector capabilities and expand physics reach of the CMS HL-LHC program

- ➔ Impact main physics object performance
  - PU mitigation, jet, isolation
  - New capabilities: Time-of-flight studies are ongoing (not public yet)
- ➔ Improve physics analysis performance
  - Overall Higgs program improvement of about 20%
  - Expanded reach for new physics searches
  - New capability for long-lived particles