CMS: upgrade and physics (@IPHC)

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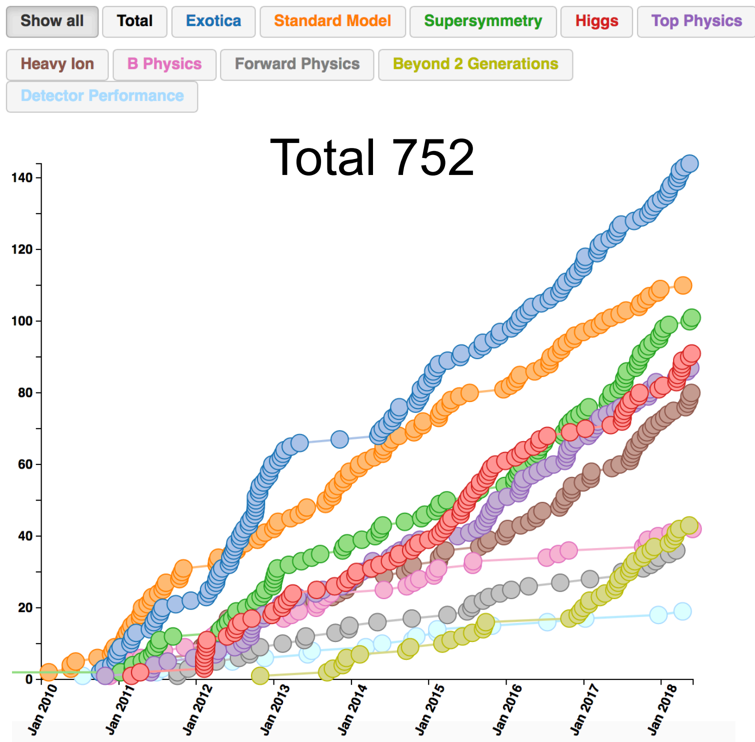
Introduction

- **CMS@LHC** => very nice detector performances and physics results, Higgs discovery (!) but also many more measurements and searches.



- Future of LHC => HL-LHC :
  - up to **3000 fb^{-1}** but with the price of huge pileup (PU), a big challenge,
  - upgrades of detectors are crucial, managing large PU but also getting beyond (larger acceptance, timing layer etc…)

- What are the physics motivations for HL-LHC :

- Searches for new particles (high mass + rare processes).

- Higgs boson : properties (such as CP, see talk V.Cherepanov) and rare production/decays (see talk of R.Salerno).

- Probing the SM :
  - **precision** measurements,
  - **rare** processes and couplings,
  - **probe SM** in every corner of the phase space (diff cross sections, asymmetries, properties etc…), ➔ indirect searches and EFTs !

Focusing here on IPHC activities/interests

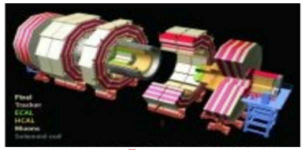
HL-LHC

We are here

Requirements for the phase 2 CMS detector

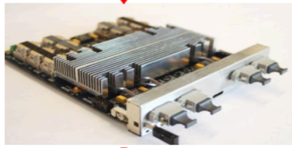
- Challenges :
  - high inst. luminosity (5-7.5 $10^{34} cm^{-2} s^{-1}$)=> **pileup (140-200),**
  - high integrated lumi (3-4 ab^{-1}) => **high irradiation**,
  - **computing** : reconstruction and storage of the data.

- Requirements of the CMS Phase2 upgrade :
  - maintain (or even improve) the current performances during the entire HL-LHC,
  - detectors need to resist to large radiation,
  - handle large number of pile-up events,
  - maintain acquisition rate to a manageable level.



Detector, take data every 25 ns.

L1 ↓ 40 MHz



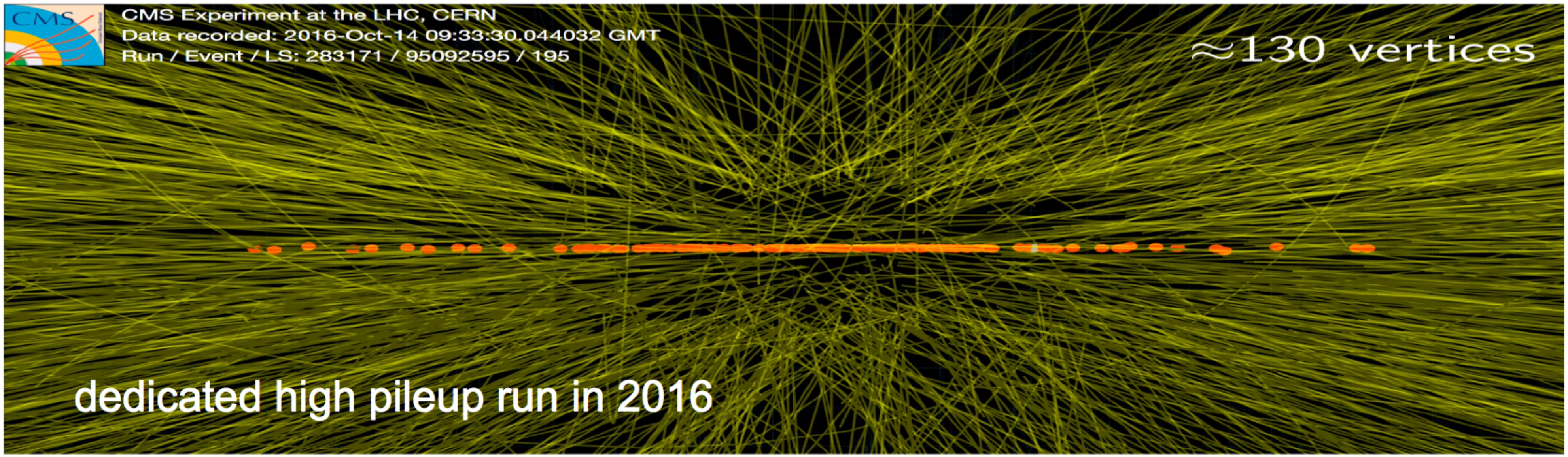
hardware latence de 12.5 μs

HLT ↓ 750 kHz

software

↓ 7.5 kHz

stockage

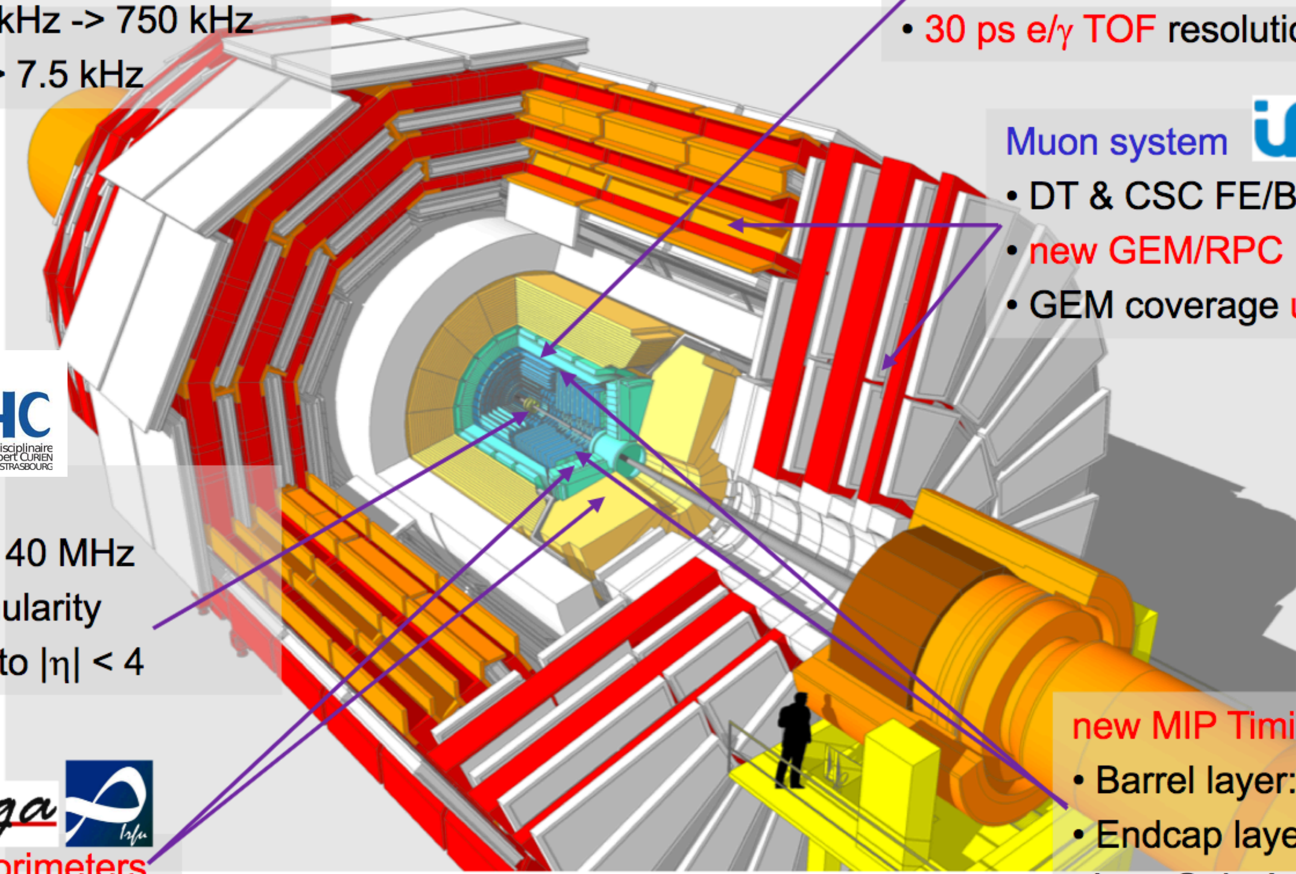


CMS Phase 2 upgrades

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 < $|\eta|$ < 2.4
- GEM coverage up to $|\eta|$ = 2.9

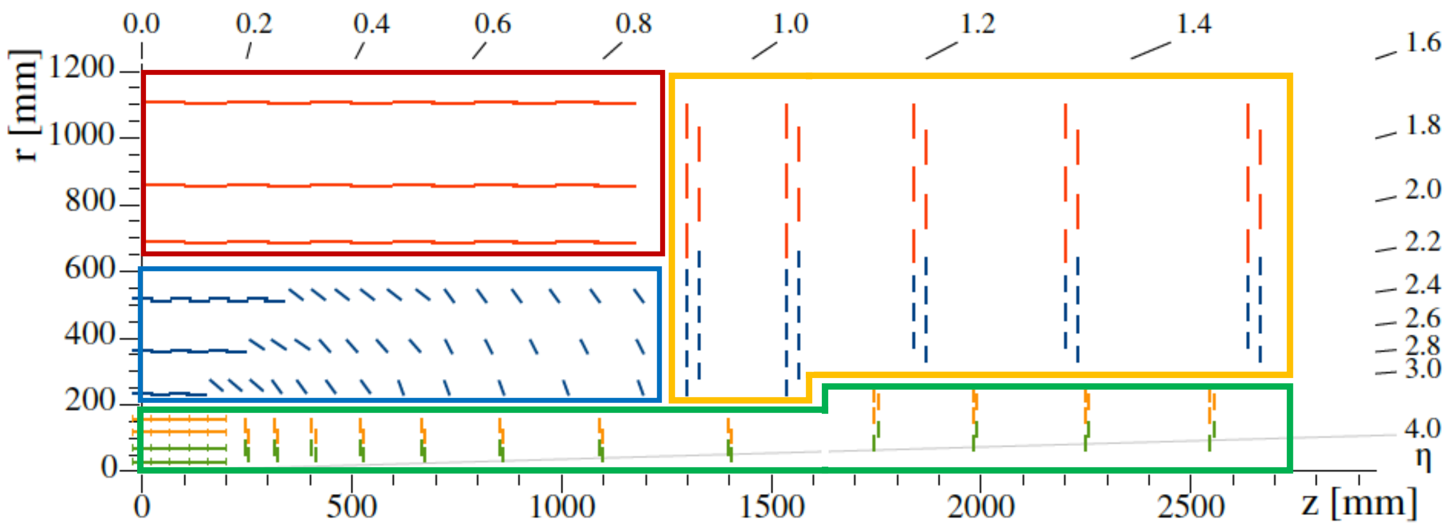


new Tracker
- track-trigger at 40 MHz
- increased granularity
- extended acc. to $|\eta|$ < 4

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: $|\eta|$ < 3
  Low Gain Avalanche Diodes
- 30 ps TOF resolution

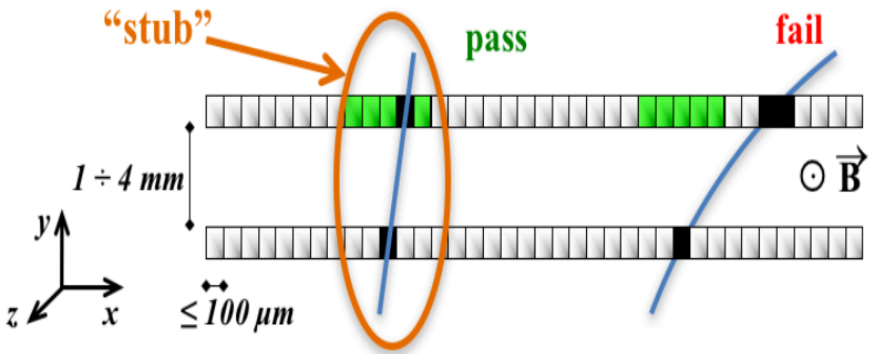
Tracker upgrade



Strips-pixel / pT modules : part of the L1 trigger system

pixels : acceptance in η extended to 3.8.

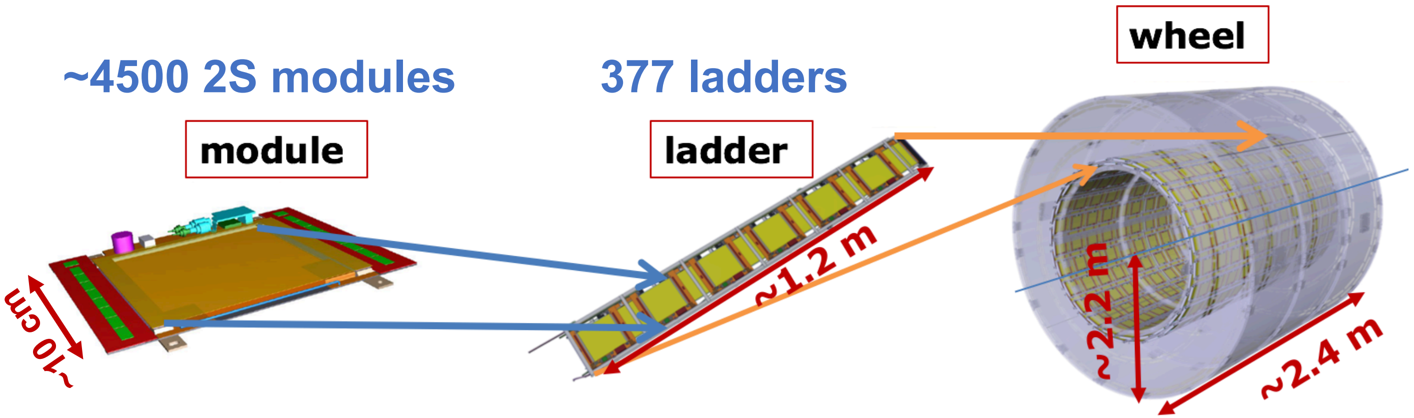
- **Entirely new design**, with reduced material budget.
- Inner tracker equipped with pixels,
- Outer tracker contains "p_T modules" :
  - fast estimation of track p_T, used at L1 trigger,
  - with 1 pixel-1 strip sensors (PS),
  - with 2 strip sensors (2S).



- Tracker Barrel "2S" (TB2S), Tracker Barrel "PS" (TBPS) and disks (TEDD, both PS and 2S).

Tracker Upgrade @IPHC

- **CMS upgrade projects at IPHC** : contributions to **the new tracker**.
- Development of firmware and software for the DAQ (inner tracker).
- Participation to the construction of TB2S :
  - integration of modules into ladders => for 50% of the ladders,
  - R&D and production of supports of the wheel,
  - assembly of the wheel (including production of the mechanicals pieces required for assembly).



- Construction of a test beam facility at IPHC : beam line (added to the CYRCé cyclotron) and a mini-telescope. Purpose : **test module performances at high particle rates**.

- Benefit a lot from the **expertise** gained during the **construction of the current tracker**:
  - Phase 1 pixel (DAQ) and construction of the endcap strip detector (TEC),
  - transmission of knowledge and expertise ongoing !

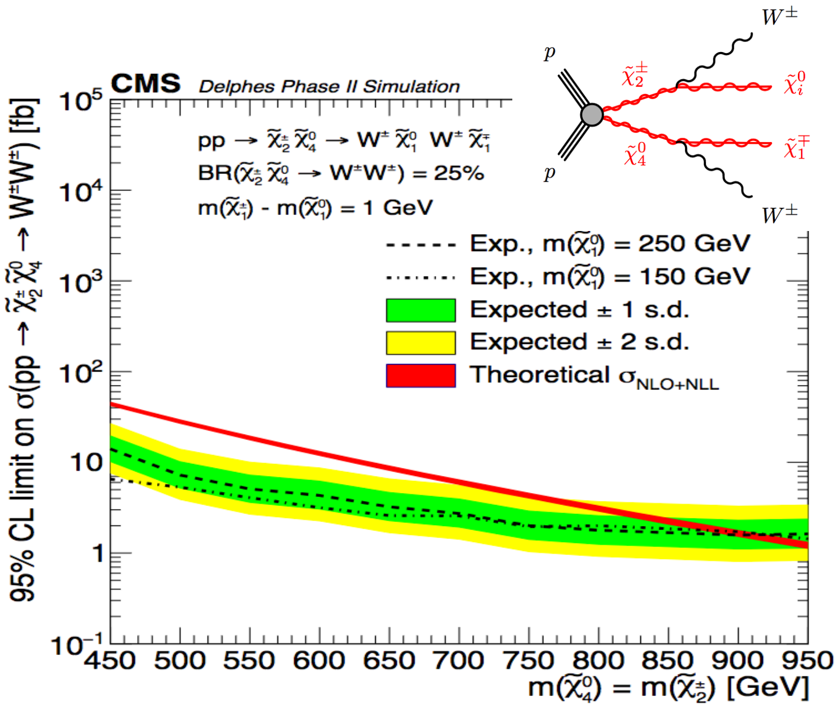
Some examples of HL-LHC prospective analyses, for direct and indirect searches

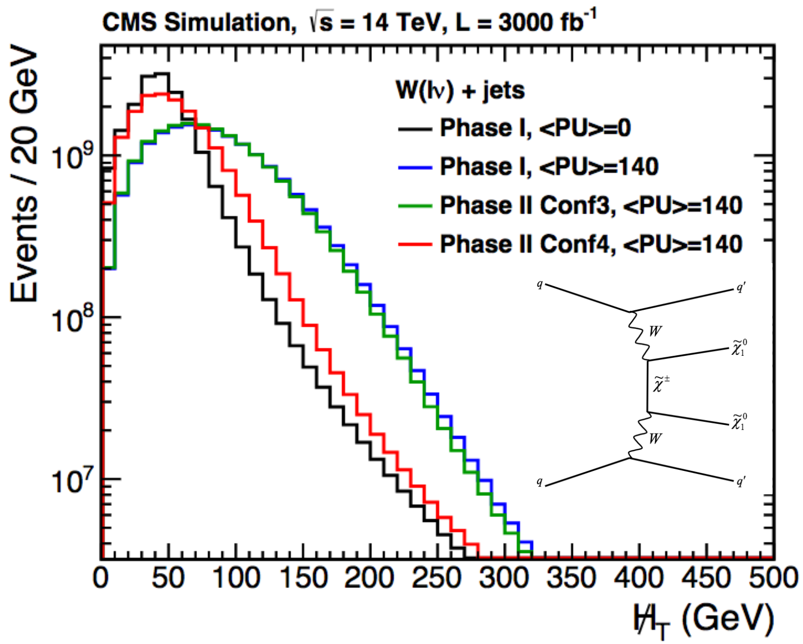
(a biased discussion)

Physics performance direct search in SUSY

CMS-TDR-019

- Search for EWKinos (lower cross section compared to strong production of SUSY particles) with final same sign dilepton states.
- Challenging : relatively low masses and low p_T spectra => **large SM background**.
- Use m_T as a discriminating variable. For a Br of 25%, the limits on neutralino $\tilde{\chi}_4^0$ and chargino $\tilde{\chi}_2^{\pm}$ masses can reach the TeV scale.



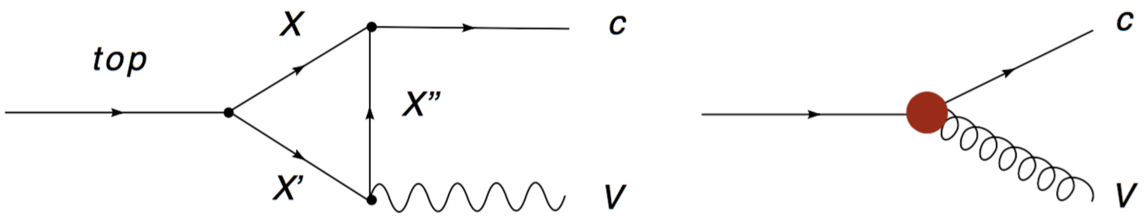


- **Background studies** for the search of DM in VBF.
- New tracker geometry (Phase II Conf4) improves very significantly the background rejection (here W+jets) compared to the current geometry (Phase II Conf3).
- Effects on missing H_T presented here.

CMS-FTR-13-014

Effective Field Theory

New vertices can arise from the contributions of new particles "living at the loop level".



If the new particles are heavy enough => modelling of the loop by a new interaction vertex.

Wilson coefficients (complex number)

Higher order are neglected

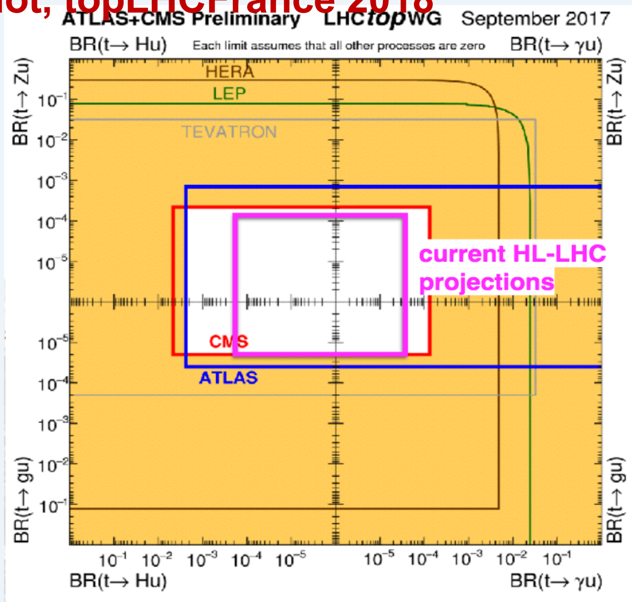
$$\mathcal{L}_{\text{eff}} = \sum \frac{C_x}{\Lambda^2}\mathcal{O}_{6,x} + \sum \frac{C_x}{\Lambda^4}\mathcal{O}_{8,x} + \sum \frac{C_x}{\Lambda^6}\mathcal{O}_{10,x} + \ldots$$

Energy scale of new physics

Dimension-6 gauge invariant operators

Physics performance
SM and EFT

F.Déliot, topLHCFrance 2018



- Search for top-quark **Flavour Changing Neutral Current in EFT** (AC).
- **Couplings investigated in top quark physics** $t \to Hq$, $t \to Zq$, $t \to gq$ and $t \to \gamma q$.
- **HL-LHC projections** => large improvements expected, in particular on top-higgs couplings.

- Measurements of Higgs production and **Higgs in association with tops** can be combined to constrains dim-6 operators.
- Comparisons of **run I measurements with expectations at HL-LHC**.
- Several SM measurements (in particular in Higgs and top sector) can be combined to constrain EFT.
- **Large statistic** => test EFT in different regions of the phase space (**differential cross sections helps !**).

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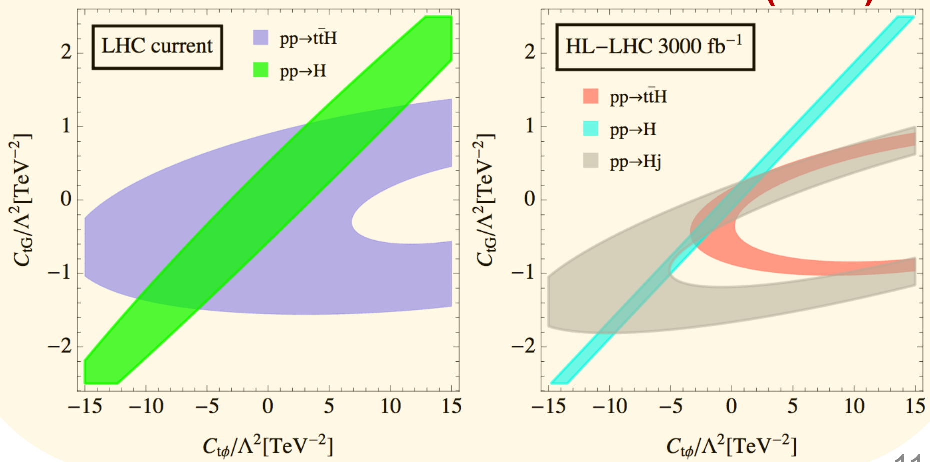
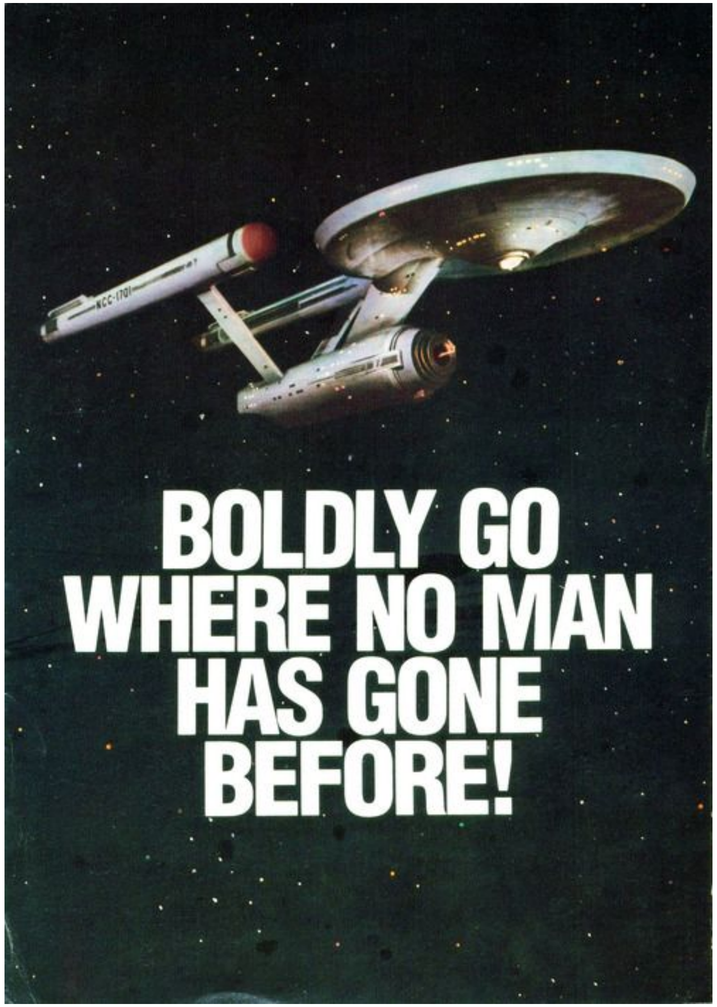


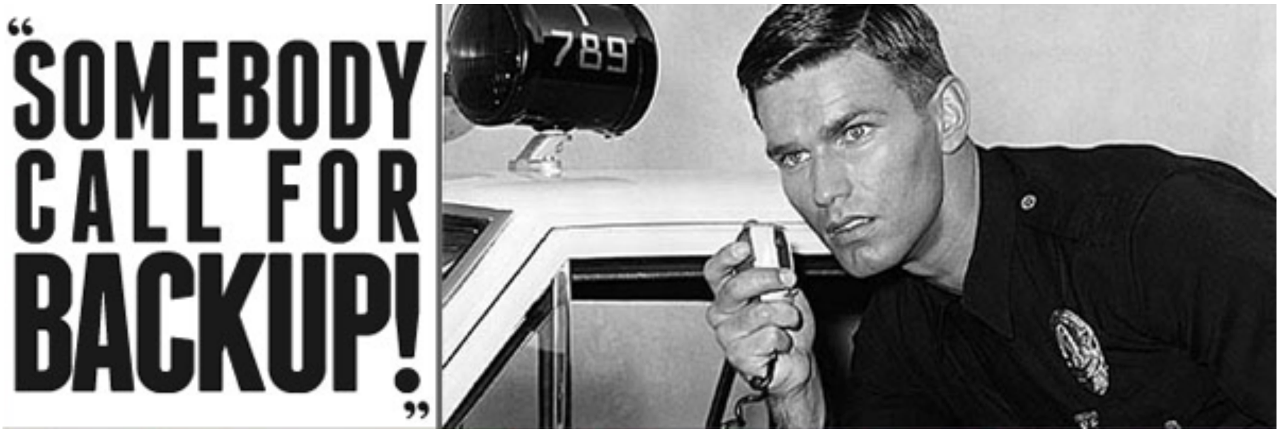
Conclusion

- The HL-LHC provides great opportunities to push forward the limits of the SM, and to search for news physics.
- Might be particularly relevant for the searches of rare processes and for probing the SM on every corner of the "phase space".
- IPHC involved in **Higgs**, **SUSY** and **top quark** physics => pursue and extend these topics in the future.
- To exploit fully the HL-LHC data, the detectors have to be "**upgraded**".
- Upgrade activities started years ago, and continue to ramp-up !
- CMS group of IPHC fully on-board!

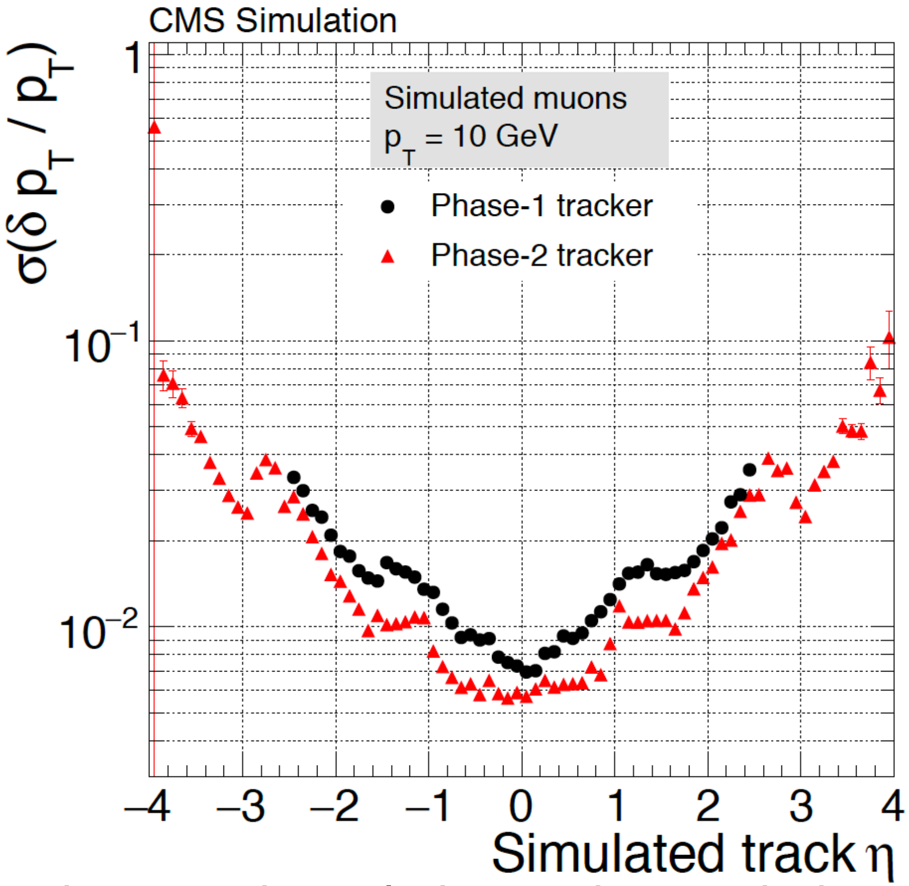


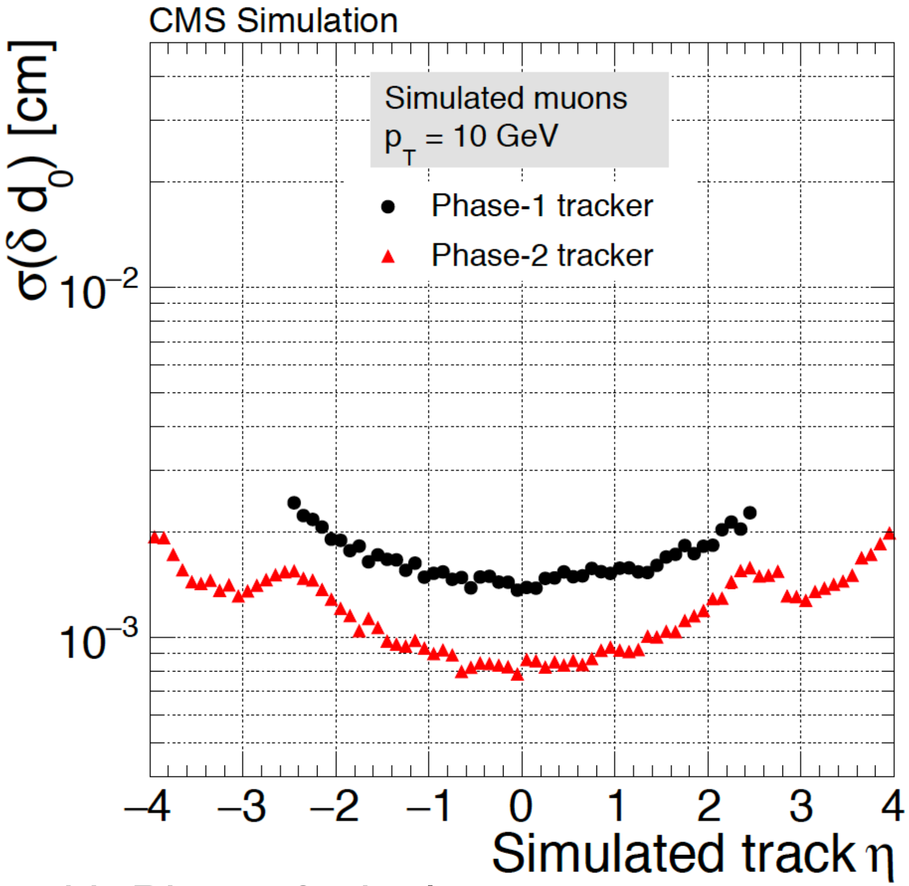
Very exiting time head !

Backup



track resolution vs η

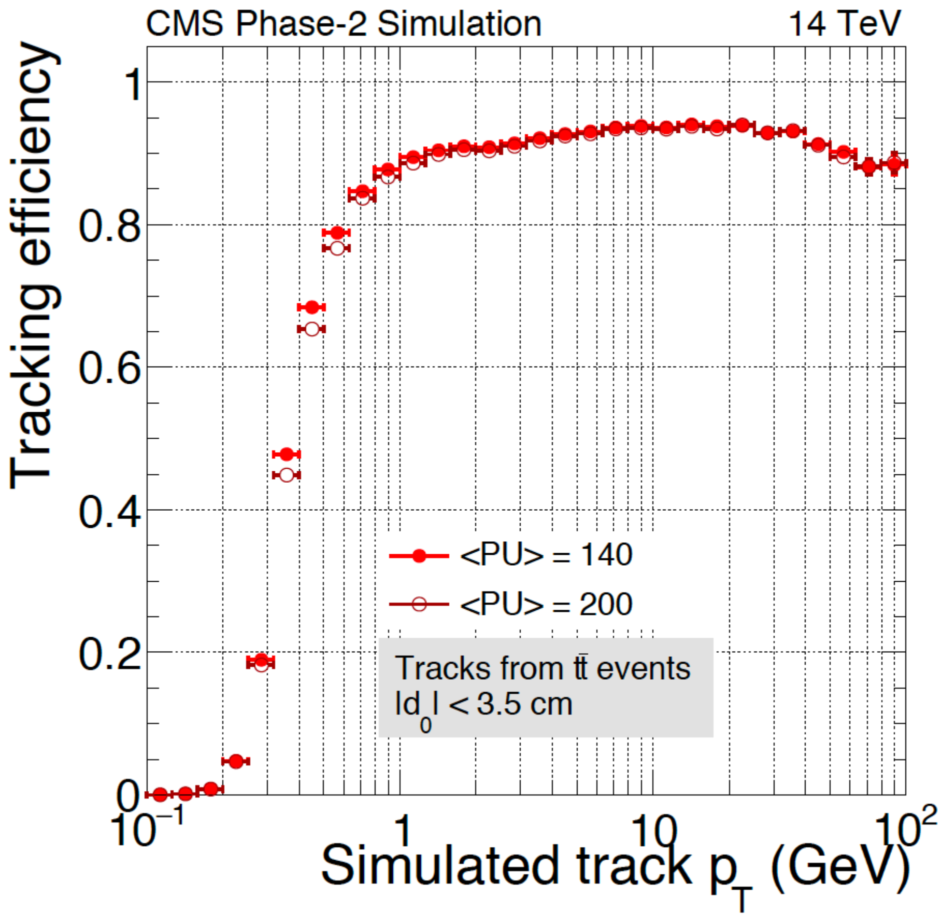


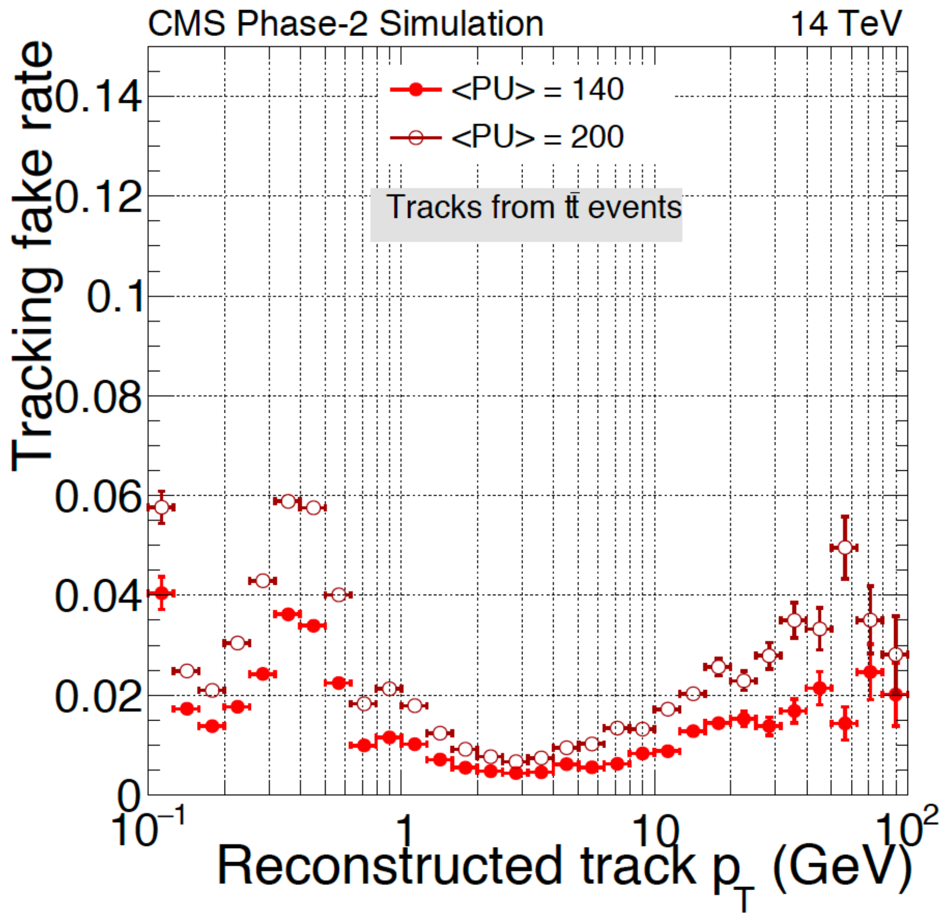


improved resolution and extended η range with Phase 2 pixel
(here same interactive tracking as current, adapted to Phase Tracker geometry)

Here and next slides from D.Bloch [link]

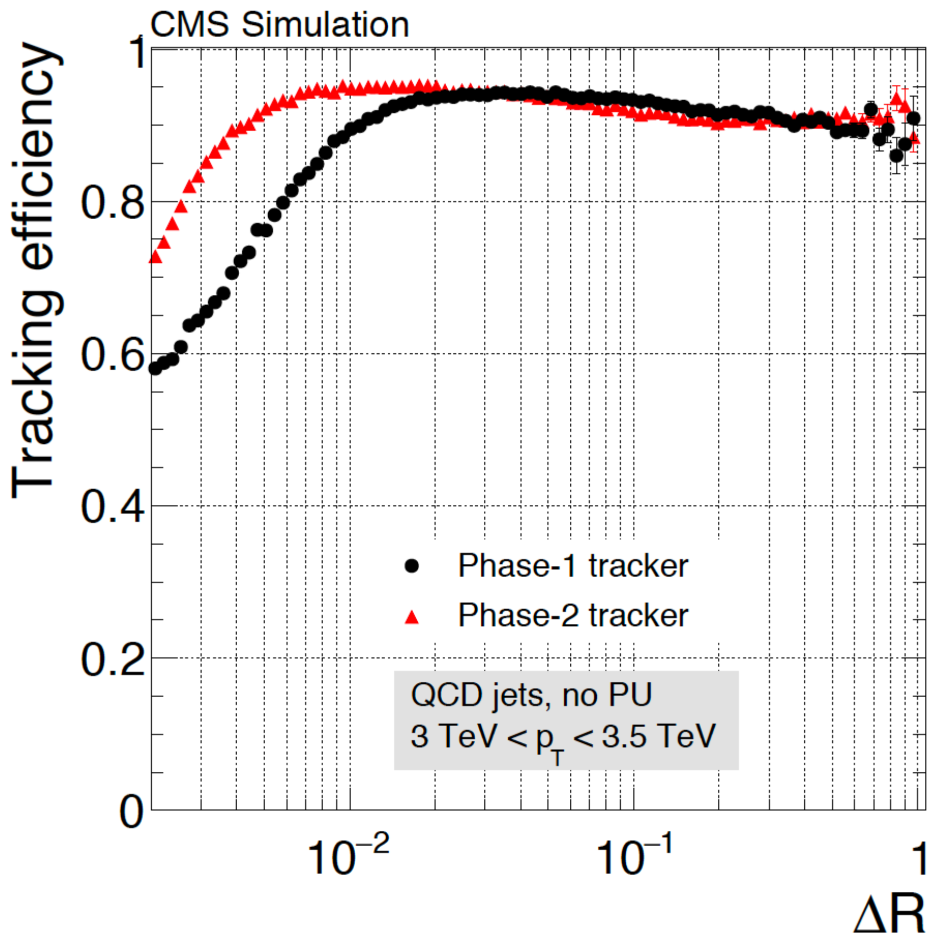
track and fake efficiency vs p_T





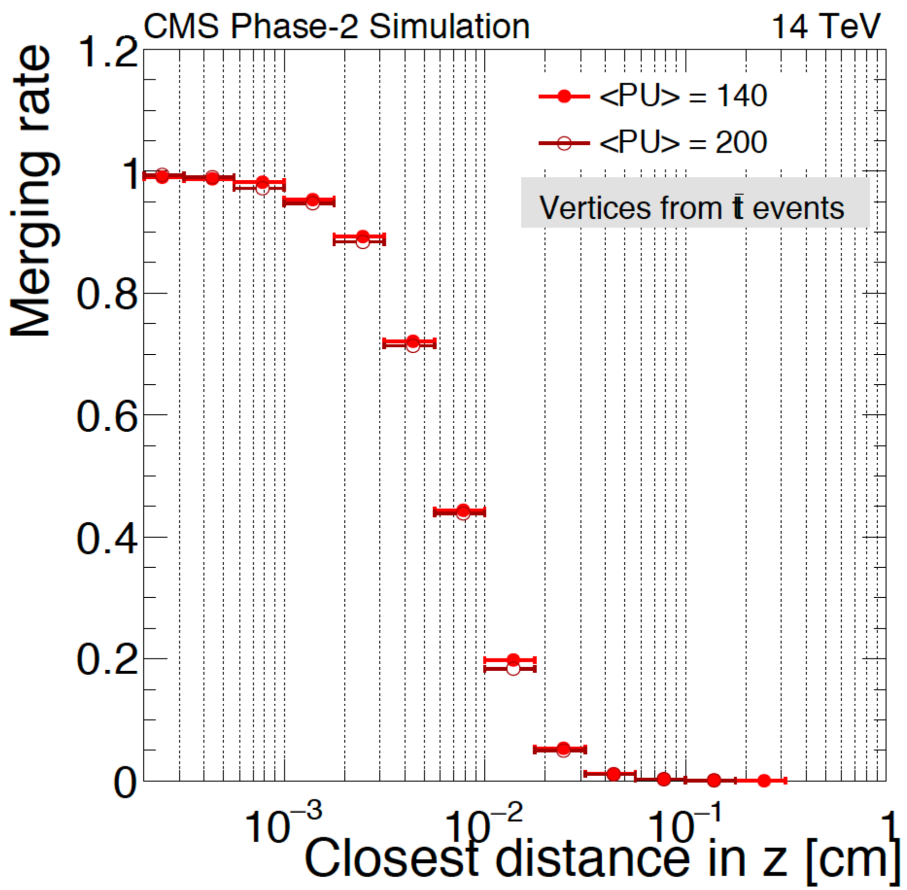
track reconstruction efficiency > 90% for p_T > 1 GeV
fake rate < 2% (4%) at 140 (200) PU for p_T within 1-100 GeV

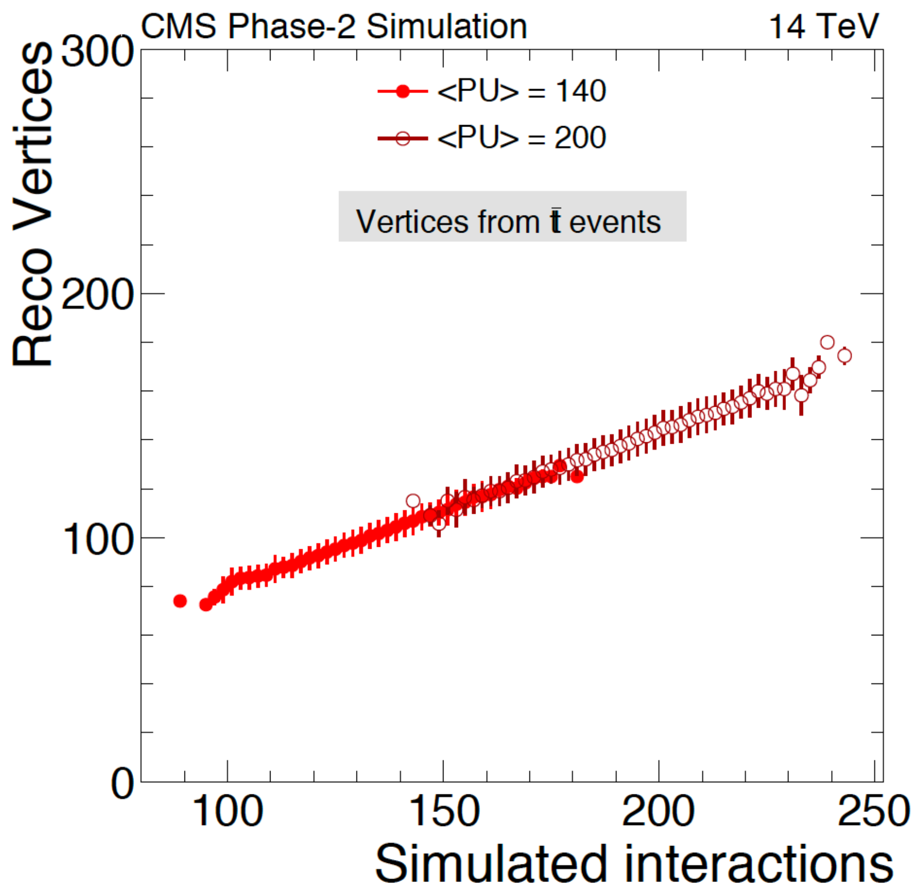
track efficiency in jet core



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

Primary Vertex efficiency

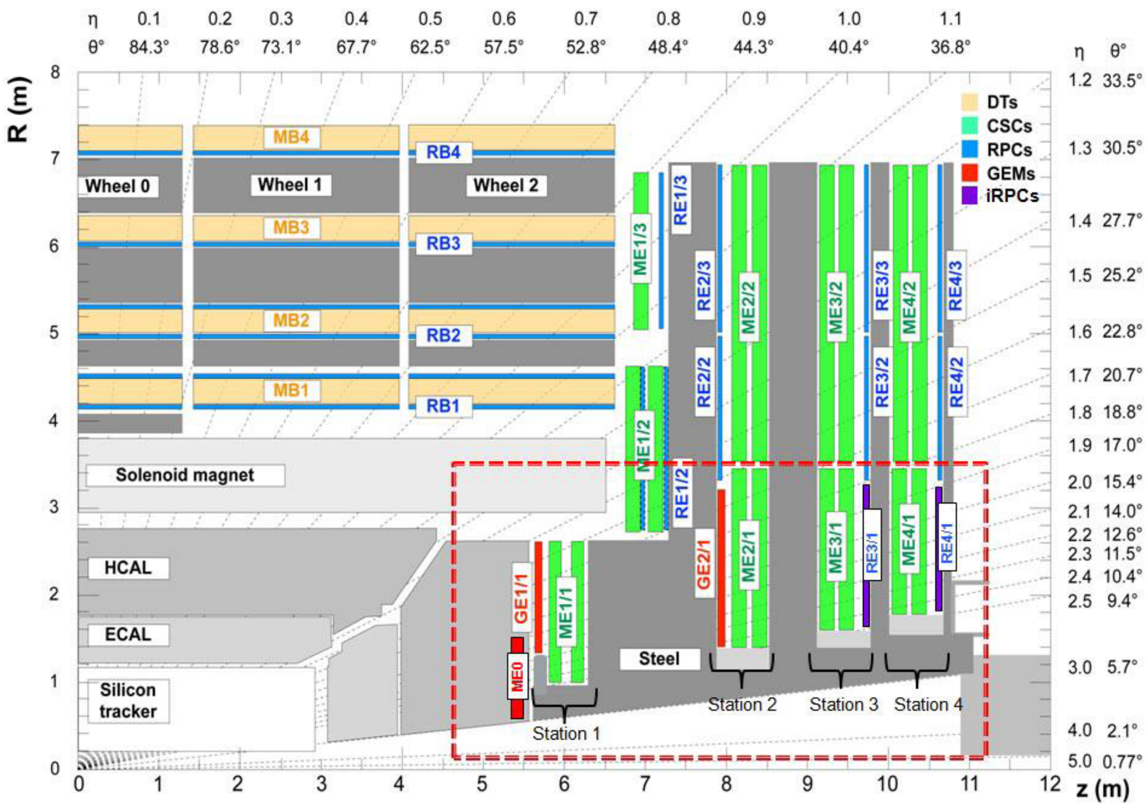


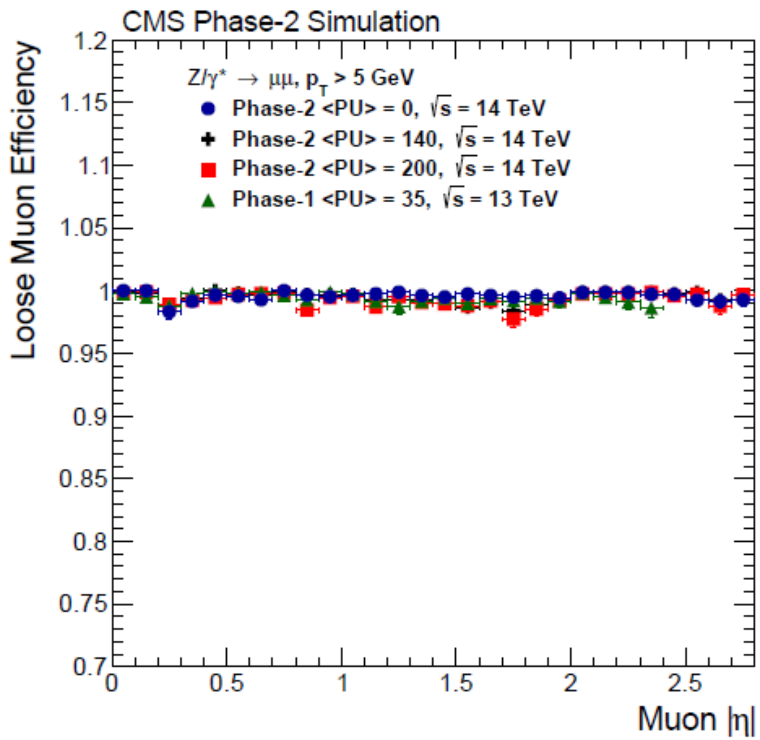


good PV reco. efficiency: linear dependence as a function of pileup
in the absence of timing info: PV merging rate significant for $|\Delta z| < 300\ \mu m$

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

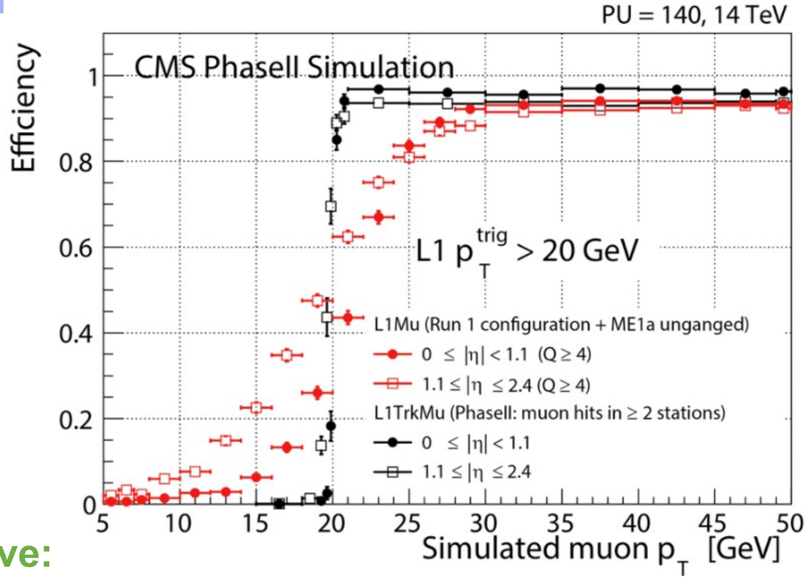


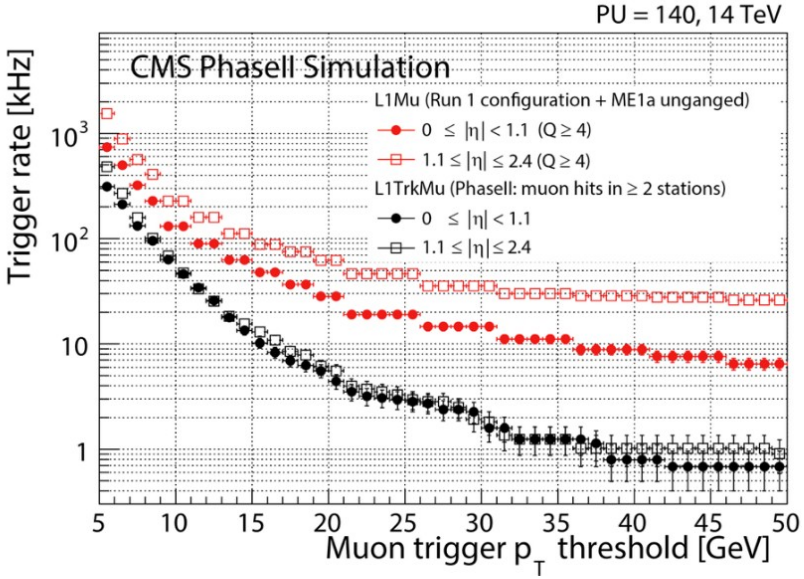


excellent muon reconstruction efficiency up to |η| < 2.9

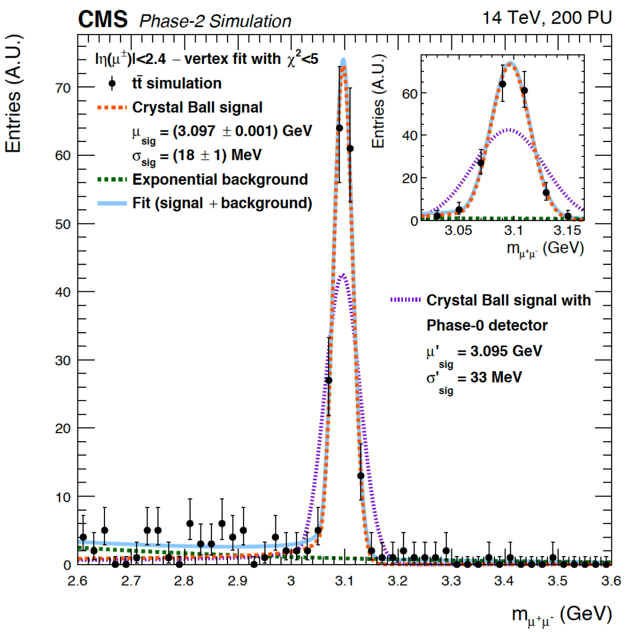
physics benefit

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

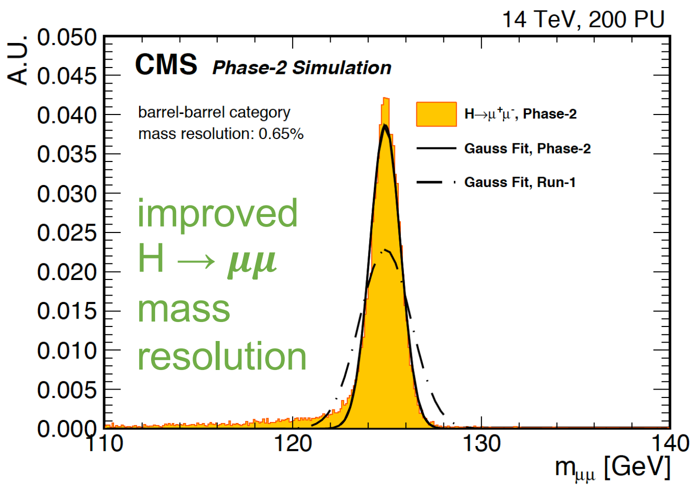




just illustrative:



improved
J/ψ → $\mu\mu$
mass
resolution
in top decay

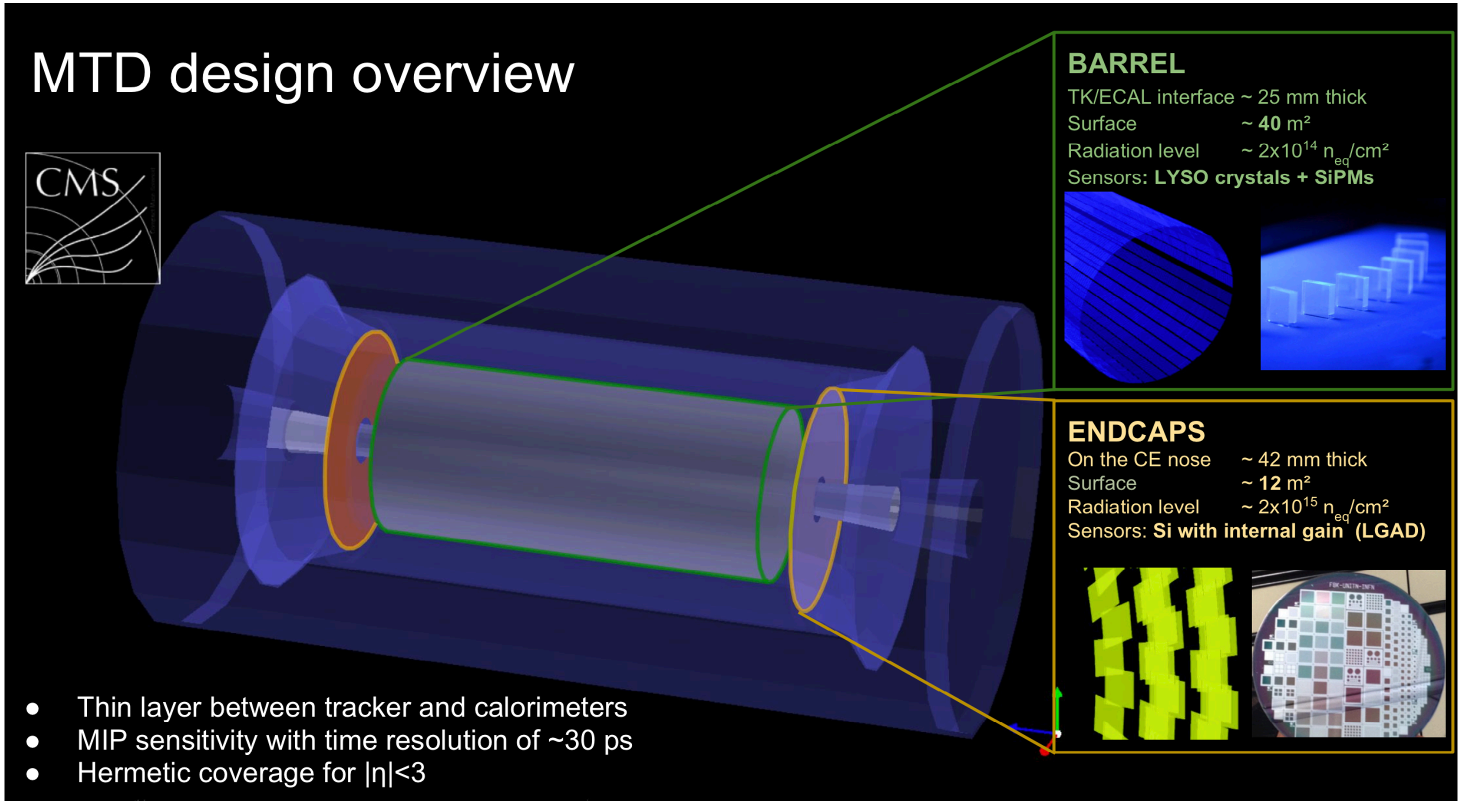


improved
H → $\mu\mu$
mass
resolution

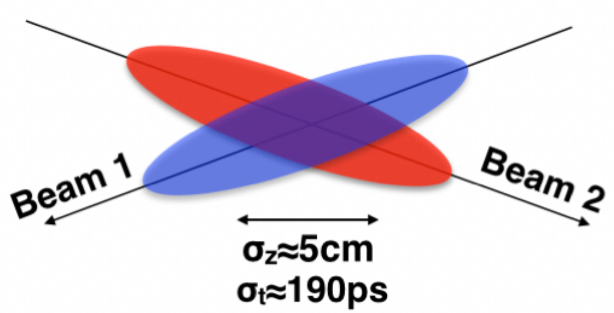
MIP Timing Detector

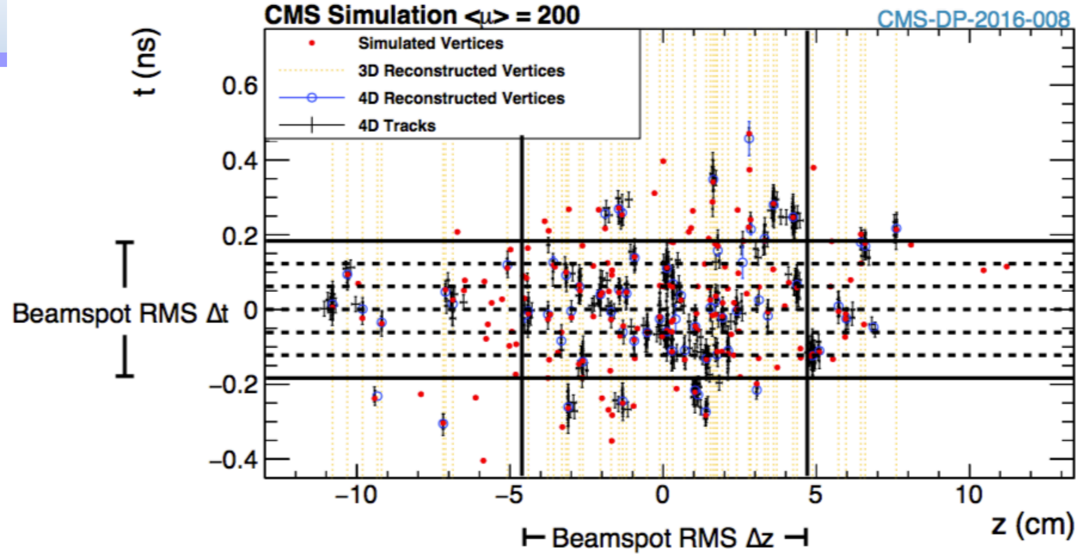
30 ps time of flight resolution for charged particles within |η| < 3.0

- 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

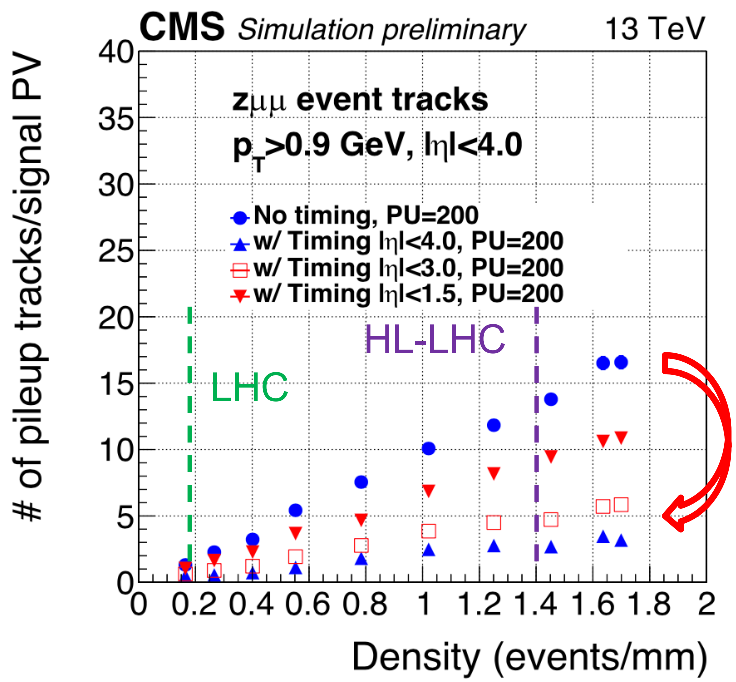


precision timing at HL-LHC

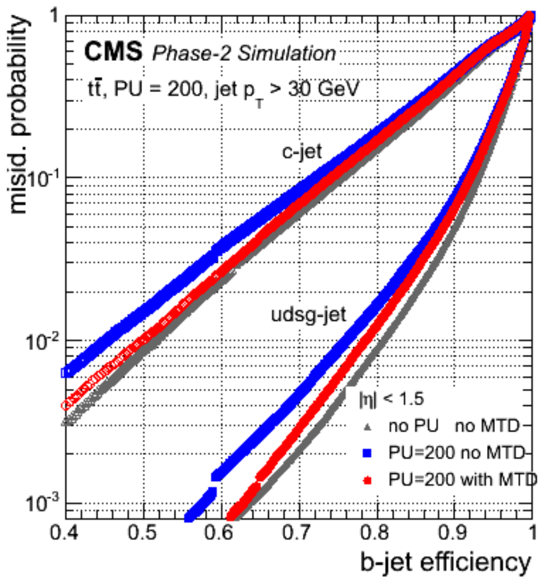


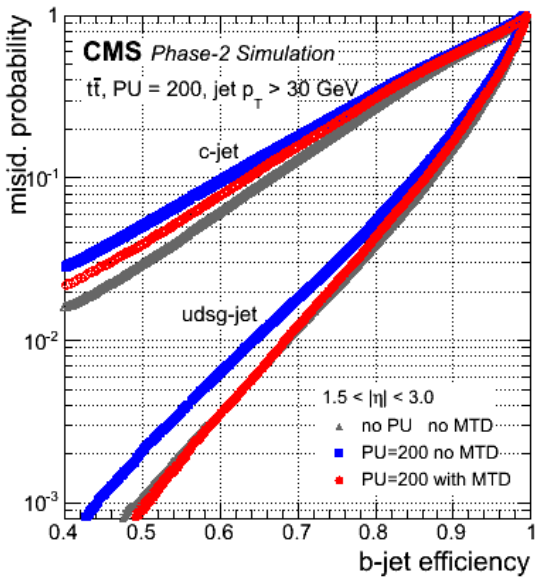


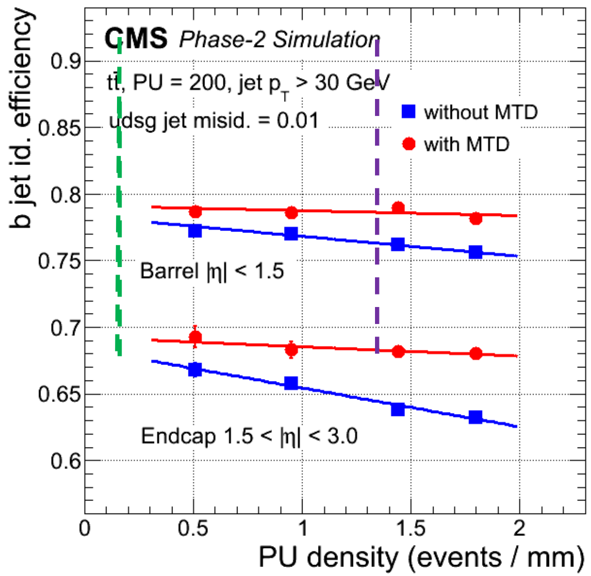
- pileup vertices spread along beam direction and time: precision timing for charged and neutral particles will be a key to reduce pileup contamination
  - track timing (σ_t~30 ps) will allow 4D (space+time) vertex reconstruction
  - x 4-5 reduction of vertex merging rate and number of pileup tracks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



object performance: b-tagging

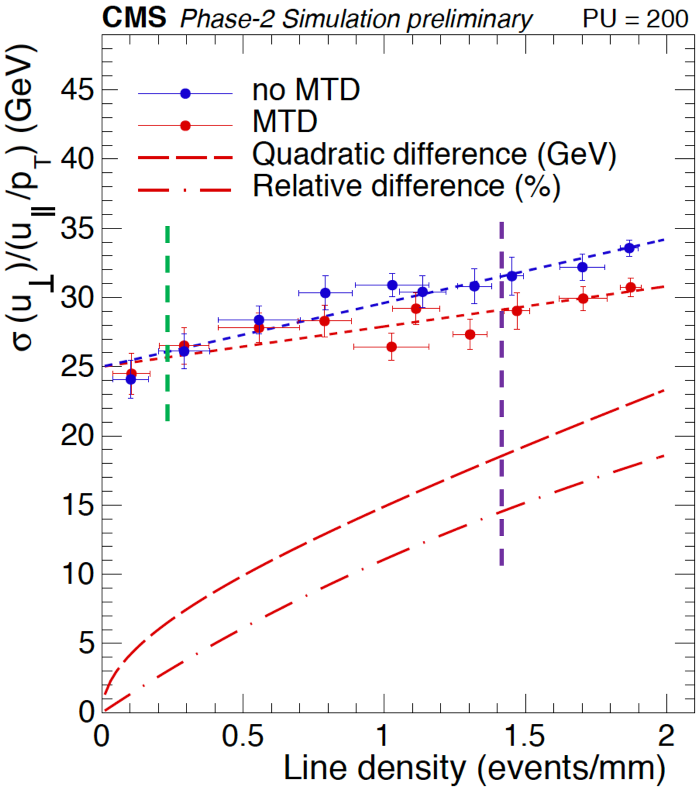




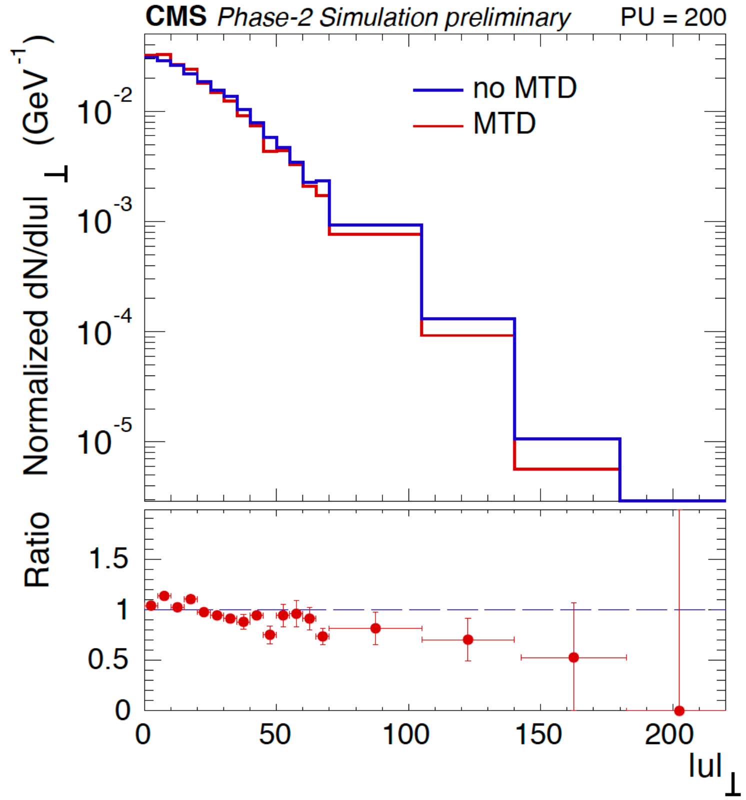


with timing information, b-tagging performance improves
and is moderately sensitive to the high pileup conditions

object performance: MET



(a) MET Resolution



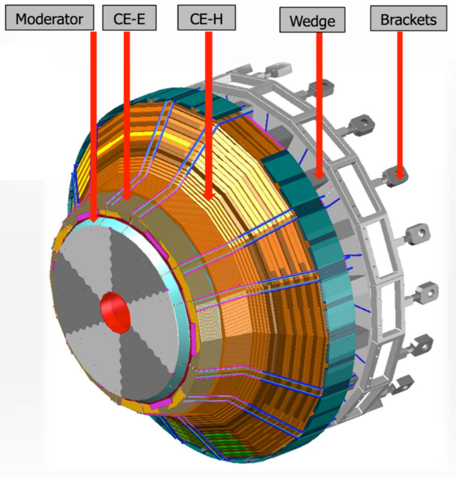
(b) MET Tails

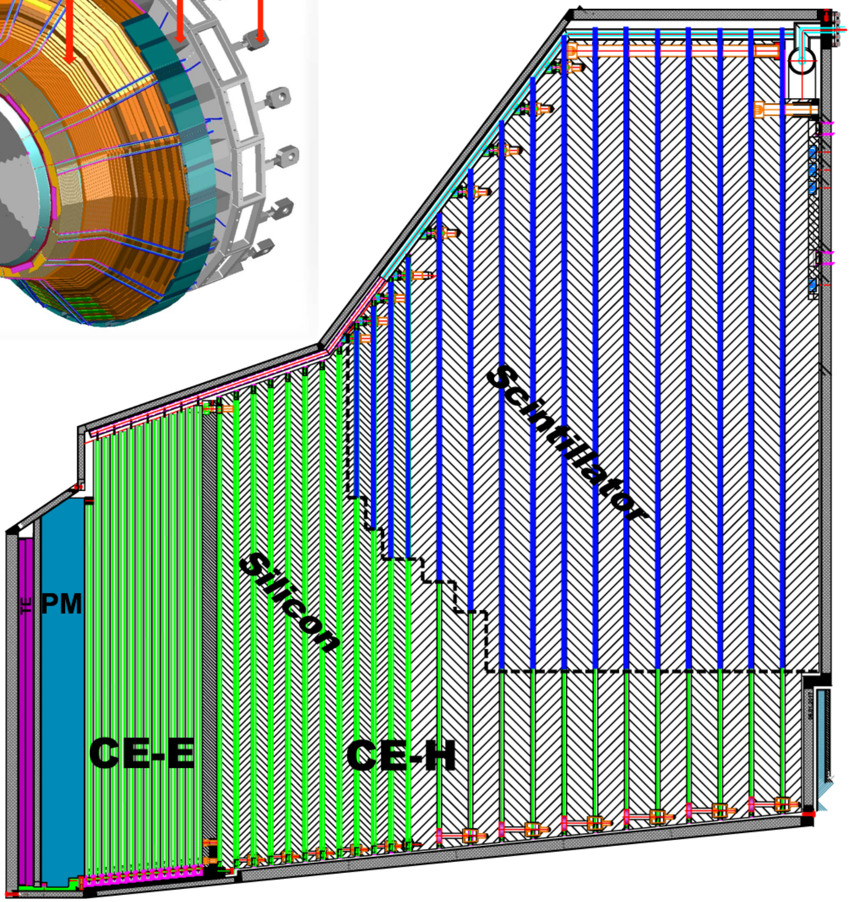
15% improvement in MET resolution,
> 30% reduction in tail (will reduce background for BSM searches)

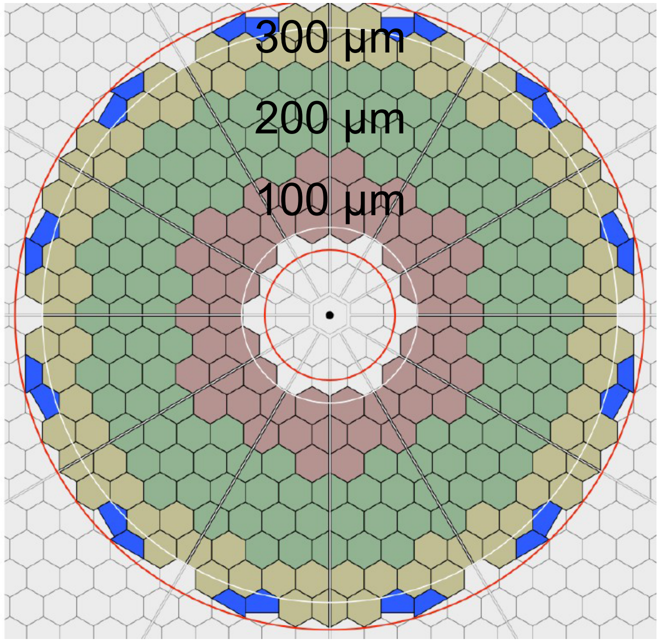
High Granularity endcap Calorimeter

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