Performance improvements (on-going and for Run 3) at CMS

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on behalf of the CMS collaboration

DM@LHC,
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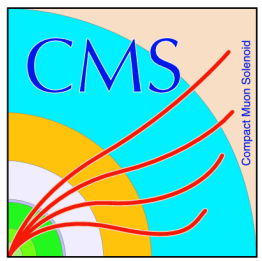


Introduction

- LHC has now entered a regime where $\sqrt{s}$ stabilizes and doubling $\int \mathcal{L}dt$ takes time.
- Limited improvement in sensitivity for direct reloads of previous searches.
- Increasing signal acceptance/background rejection is the key.
- Additionally, will need to cope with harder data taking conditions in Run 3 (pile up, detector ageing).

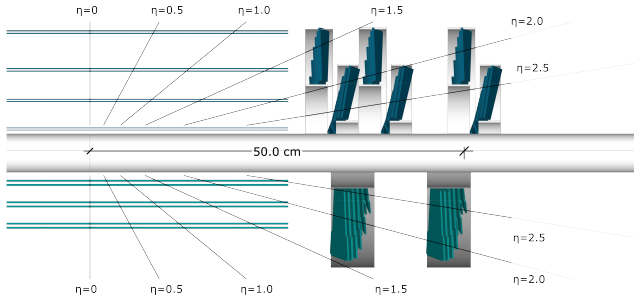
$\rightarrow$ **Time to probe unexplored territories and develop new techniques to exploit at best all the features or the detector.**

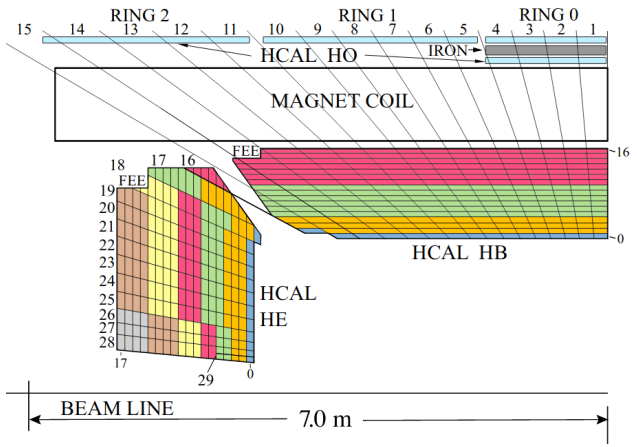
- This has already started and will expand in the future.
- Will briefly discuss a few of these improvements in CMS and stress their potential relevance for DM searches.

CMS: a continuously evolving detector

Several upgrades conducted during Run 2, in particular:

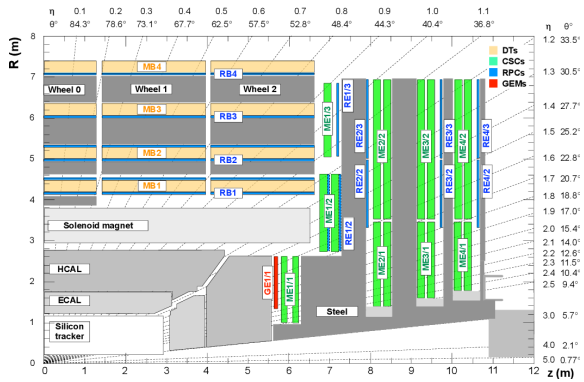
- New pixel detector (2017) with an additional layer, slightly extended η coverage, more radiation tolerant, reduced material budget
- New readout (HPD $\rightarrow$ SiPMs) in HCAL endcap: reduced electronics noise, increased depth segmentation.
- Upgrade of the Level 1 trigger system: finer spatial granularity of trigger primitives, high level quantity calculation (e.g. invariant mass), pile up mitigation





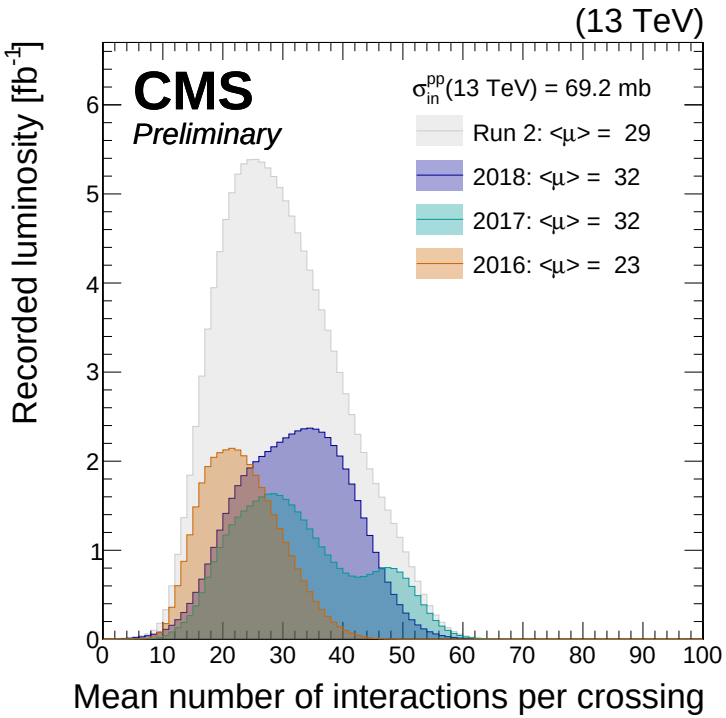
More to come for Run 3:

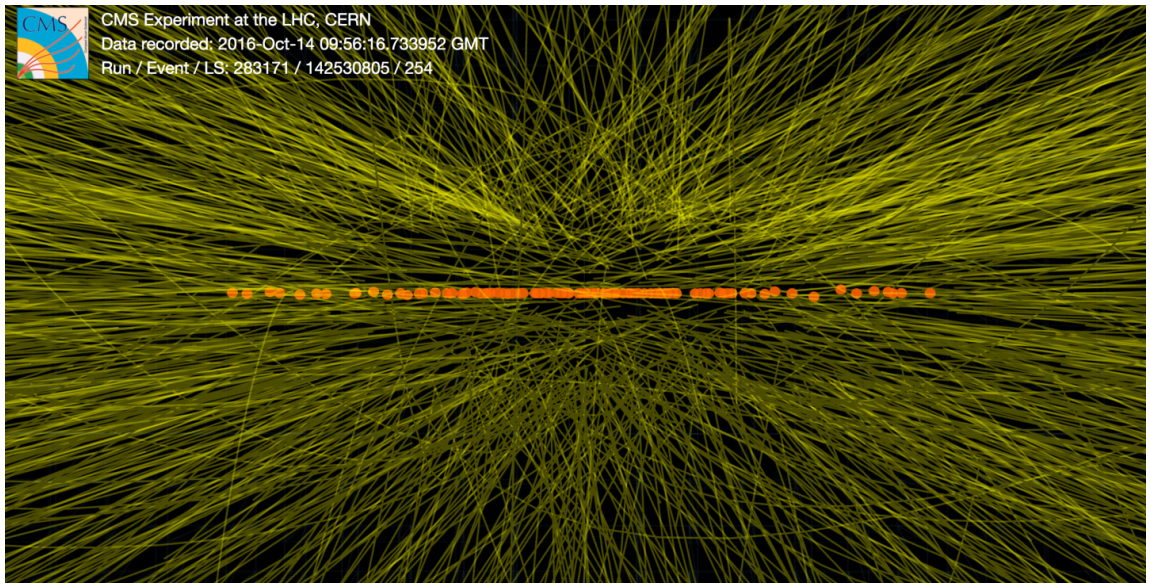
- Similar readout upgrade in HCAL barrel.
- Installation of Muon Endcap Gas Electron Multipliers (GEM) detector (2019/2020).
- Possible deployment of GPU in the High Level Trigger (HLT).



Pile up (PU)

- A key challenge for Run 2, even more for Run 3.
- PU can create "fake" jets, spoil the missing E_T (MET) resolution, affect the lepton isolation,...
- Need dedicated mitigation strategiess

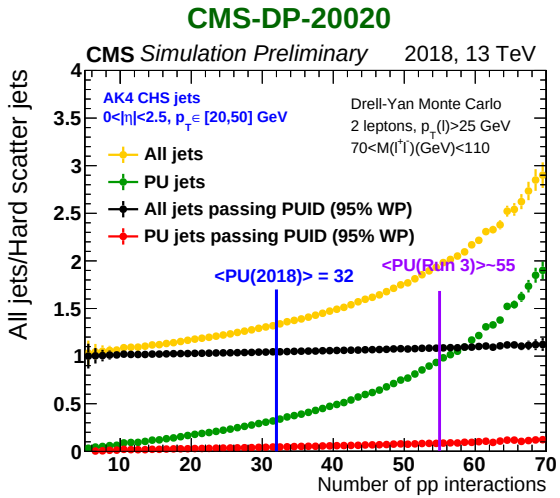


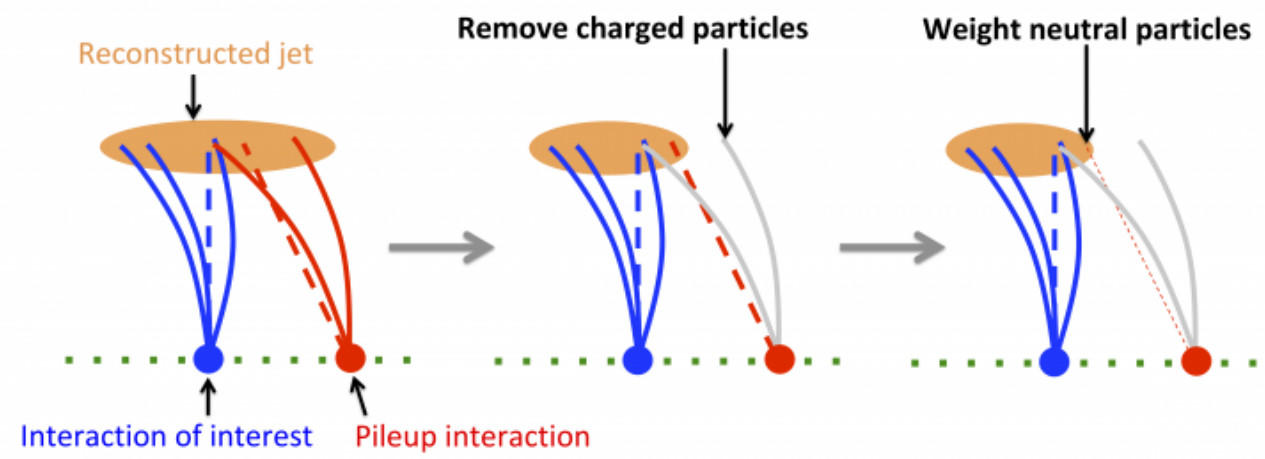


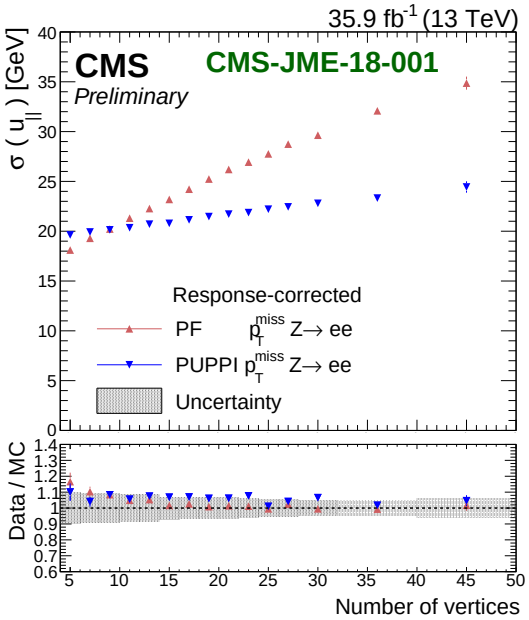
PU mitigation for jets and MET

Charged hadron subtraction from PU vertices (CHS) not enough to reject PU jets.
Two (possibly complementary) strategies considered:

- PU jet ID: BDT trained with O(15) jet variables.
- PU per particle identification (PUPPI): weight neutral particle p_T according to their likelihood to come from the hard scattering/pile up based on surrounding particles.
  - Works for jets, MET, lepton isolation.
  - **Will become the default algorithm for Run 3.**

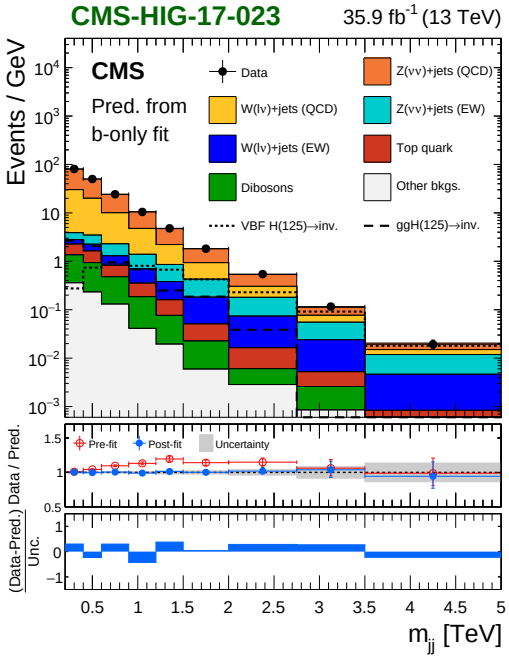


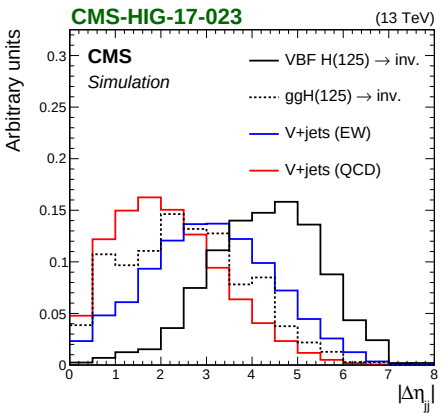


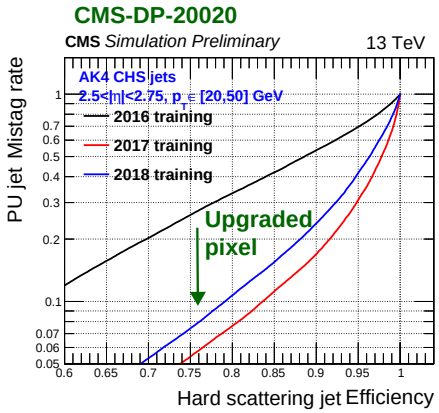


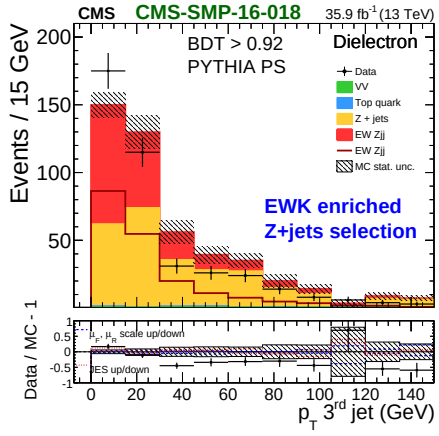
A use case: VBF H→ invisible

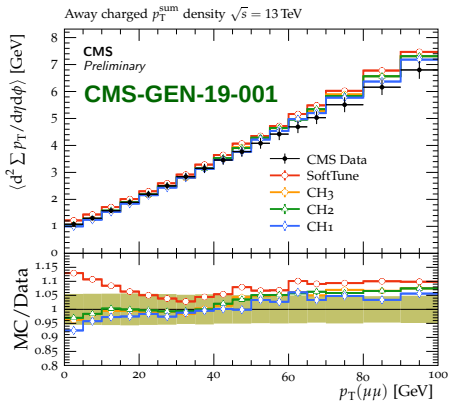
- Experimental signature: two forward jets+ MET, little central activity.
- Large rate of PU jets in the forward region.
  - Extended pixel coverage of great help here
- Better MET resolution could allow to reduce the final cut on MET and recover acceptance.
- Central activity measurement assessed with low p_T central jets, requiring good PU rejection.
- Side note: could benefit from recent studies on underlying event description.





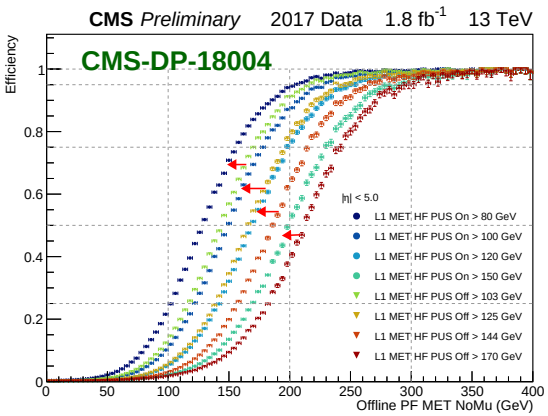


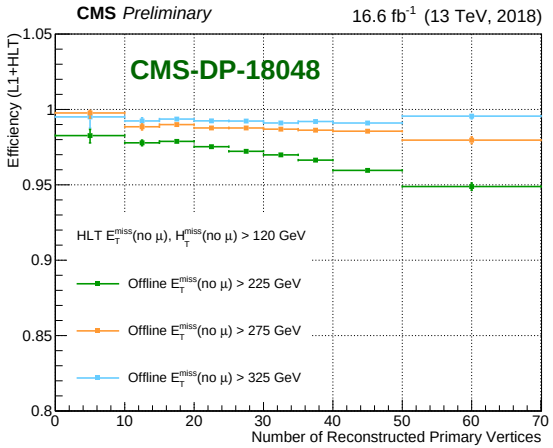


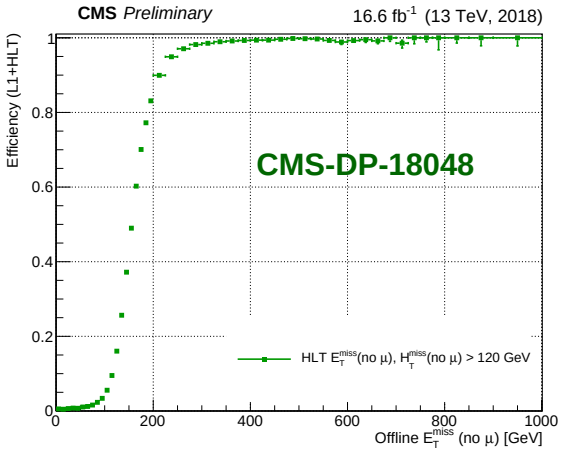


Missing E_T triggers

- Inclusive MET triggers impose to start physics analyses at MET $>\approx$ 200-250 GeV.
- Typically highly non linear rate vs PU.
- MET at Level 1 based on calorimeter only (no tracking at L1)
  - PU mitigation exists (thanks to L1 upgrade) but remains limited.
- Considering to implement CHS/PUPPI for Run 3.
  - Requires the timing expensive reconstruction of a large fraction of PU vertices at HLT.

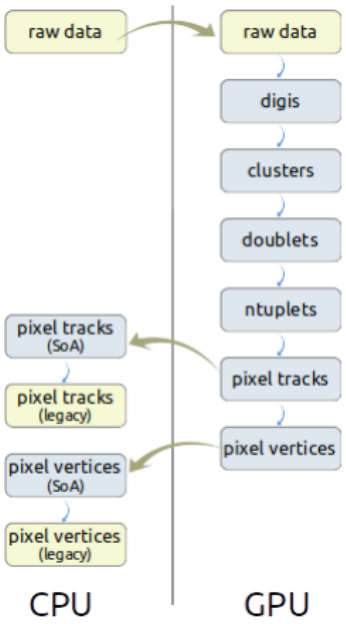


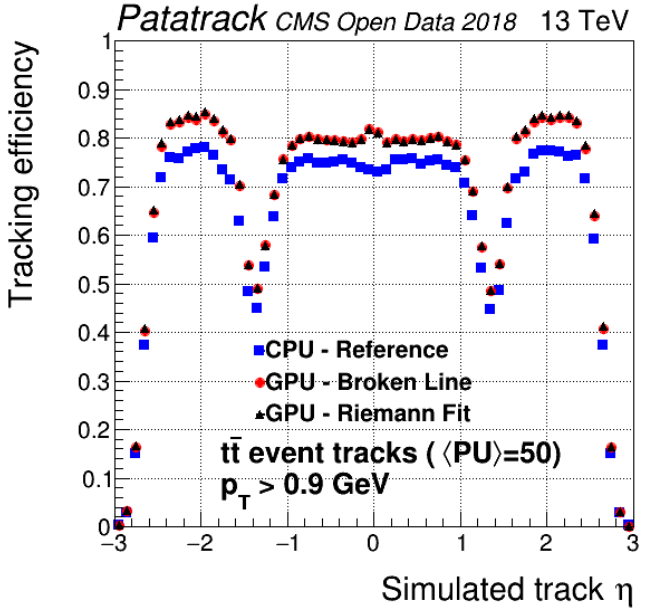


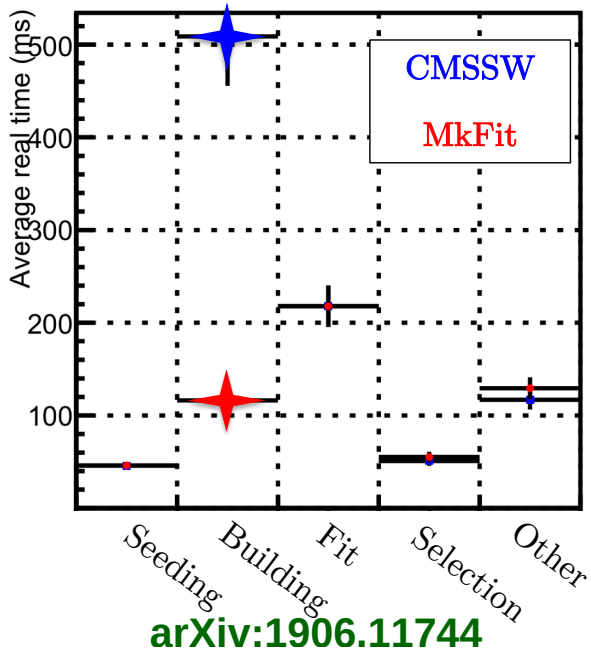


Tracking improvements at HLT

- Recent tracking developments at HLT could help to better mitigate PU in jet/MET triggers in Run 3, in particular by improving timing.
- Pixel tracking/vertexing (and more !) with GPUs ("Patatrack"). `https://patatrack.web.cern.ch/patatrack/`
- Development of a parallelized/vectorized Kalman filter ("mkFit") `http://trackreco.github.io/`



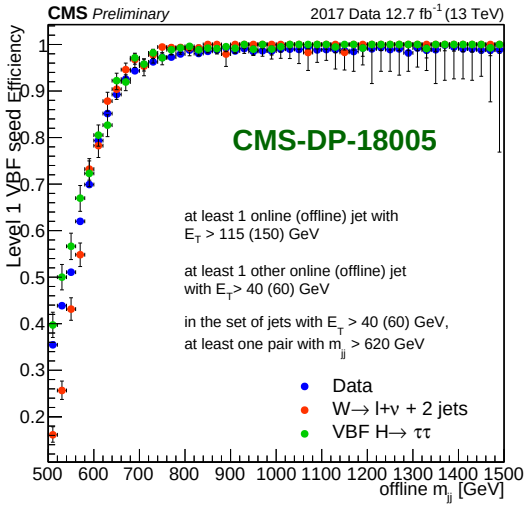


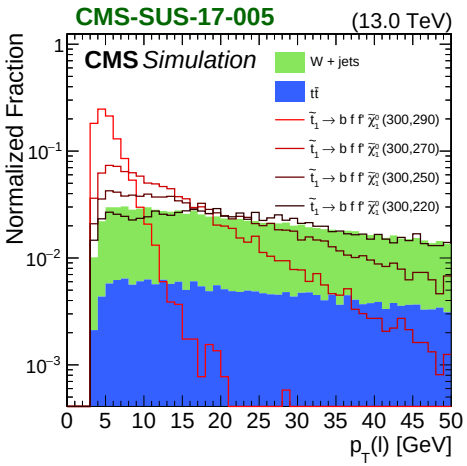


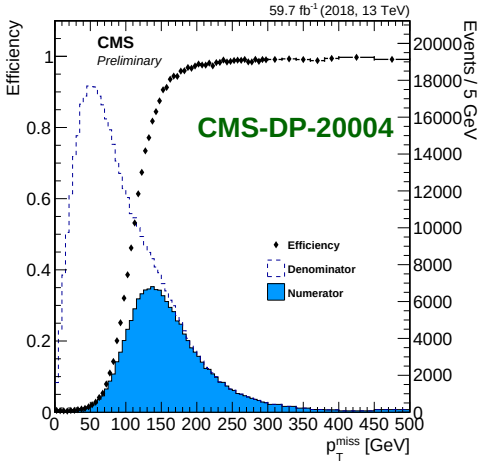
arXiv:1906.11744

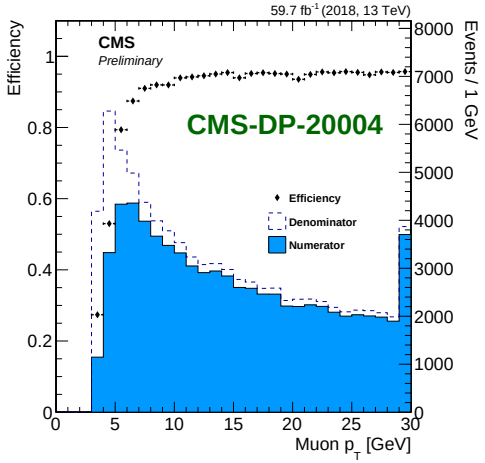
Analysis specific MET+X triggers

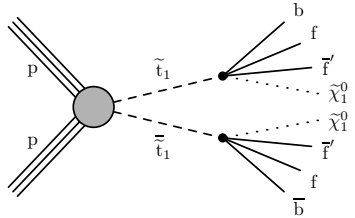
- More and more analyses developing their own MET+X triggers.
- Same goal: reduce/drop MET condition at HLT/L1 by triggering also on other objects.
- Some relevant examples: MET+high mass dijet (VBF H→inv.), soft lepton(s)+MET to target complicated phase space regions (e.g. compressed SUSY spectrum)





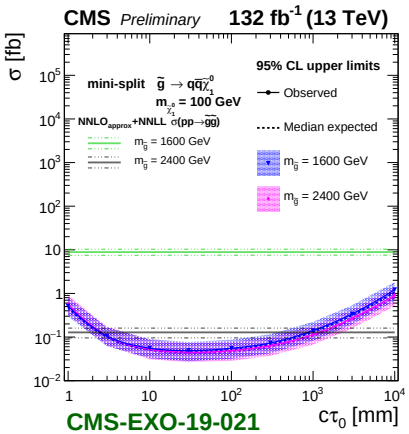


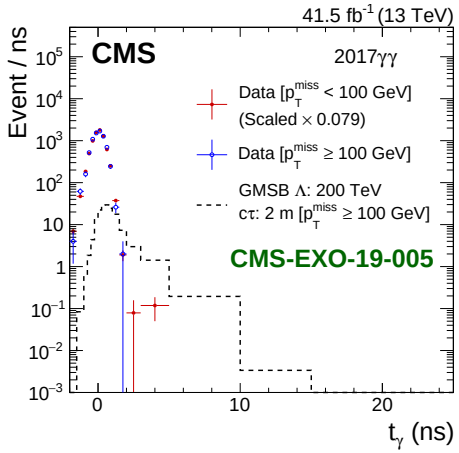


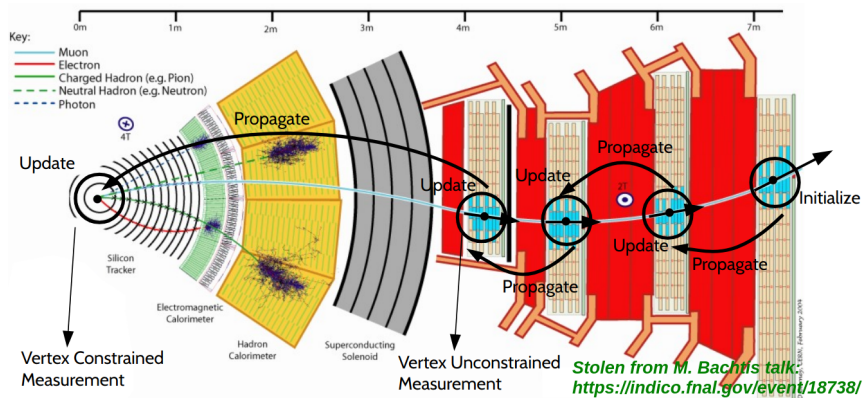


Triggers: displaced signatures

- Growing interest to develop new triggers targeting displaced signatures.
- **A hot topic at the *LHC LLP workshop last week.***
- Displaced jets or photons triggers introduced used in Run 2 targeting e.g. LL SUSY particles decaying into LSP.
- HCAL depth segmentation/timing information could significantly help for Run 3.
  - Even available at Level 1 (with limited precision).
  - Could reduce current L1 HT thresholds ($\approx$ 400 GeV).
- ECAL timing could also be explored at HLT.
- Ongoing study of a Kalman filter in L1 Muon reconstruction
  $\rightarrow$ improves p_T measurement of displaced muon.

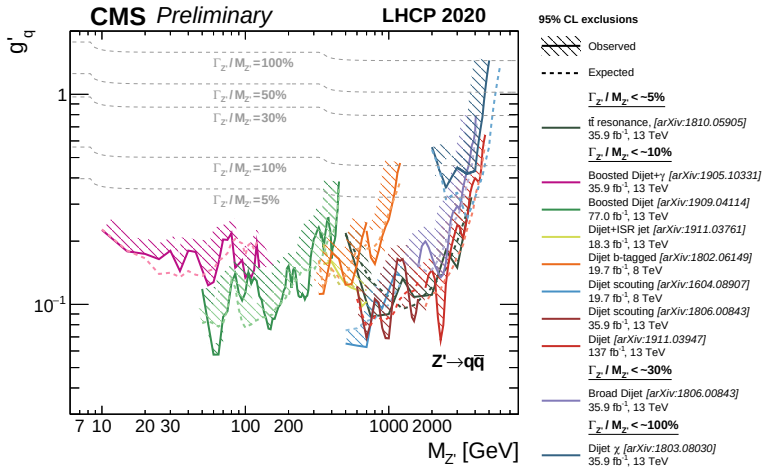


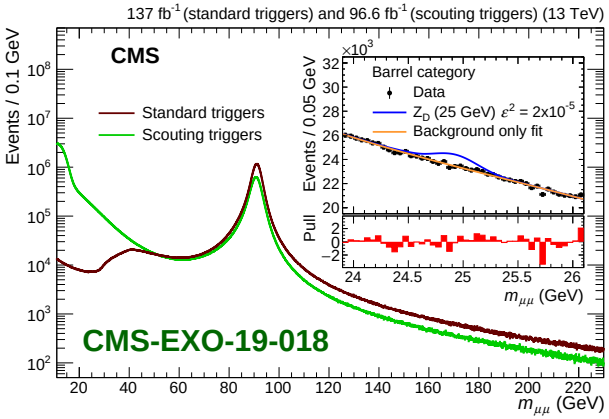


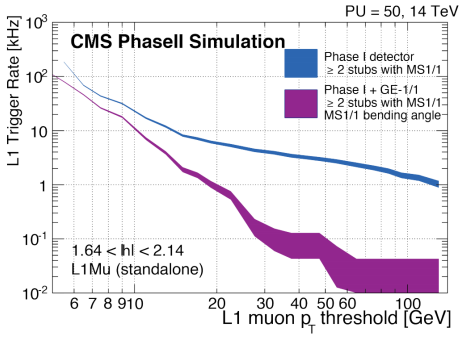


Triggers: "scouting"

- "Scouting": Record large event rate (few kHz) saving HLT information only.
- Allows us to bring HLT thresholds close to L1.
- So far used for low mass dijet/mutijet or dimuon resonances searches e.g. setting limits on generic DM mediator ($Z' \to q\bar{q}$) or dark photons.
- Could for example be expanded to photons with p_T below 100 GeV (e.g. to probe very low mass $Z' \to q\bar{q}$?)
- GEMs could also help to reduce L1 muon rates/thresholds.

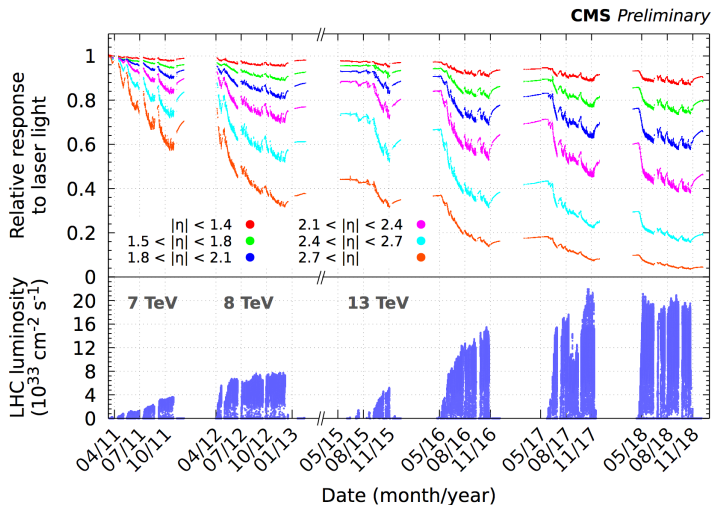


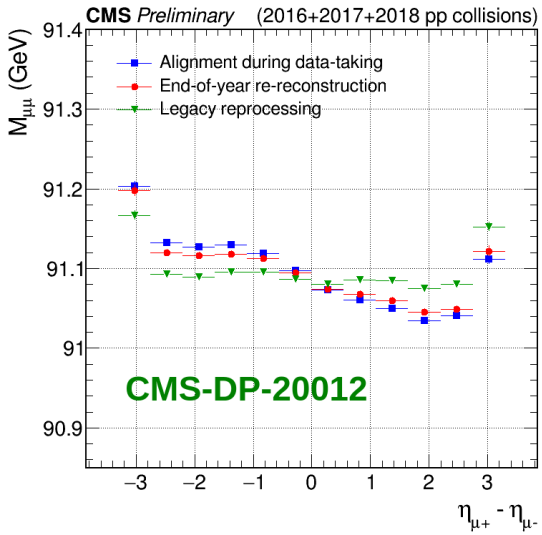


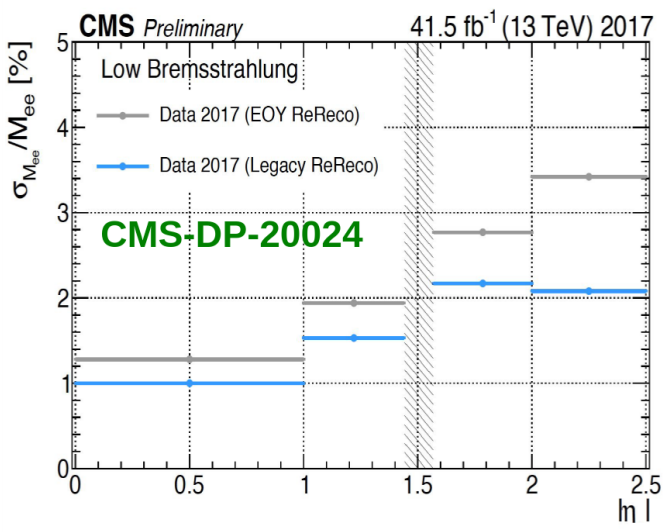


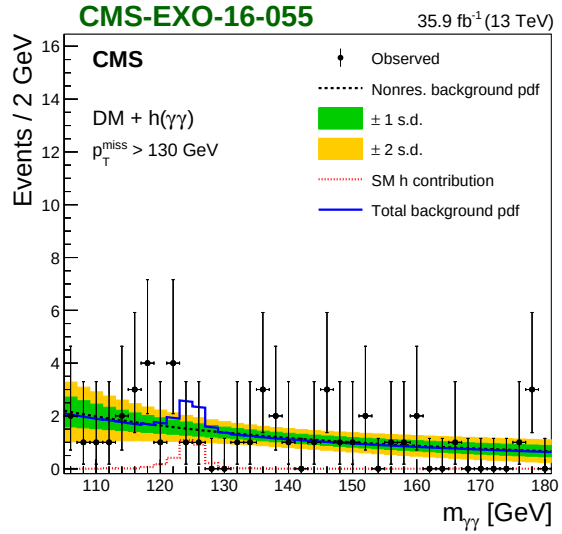
Run 2 Legacy Reprocessing

- In parallel to Run 3 preparations, important effort invested in the legacy reprocessing of the Run 2 dataset.
- Updated calibration, alignment and noise cleaning.
- Significant gain expected for energy resolution of photons/forward jets from finer calibration of forward ECAL region.
- Any analysis targeting $H \to \gamma\gamma$ or vector boson fusion/scattering could possibly benefit from this.



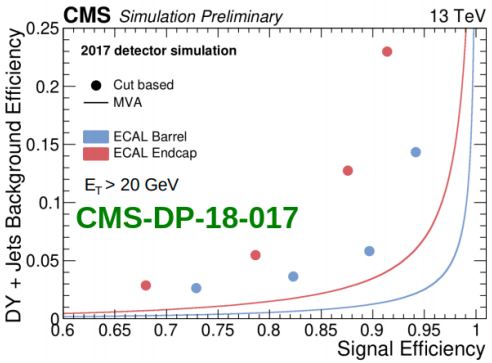


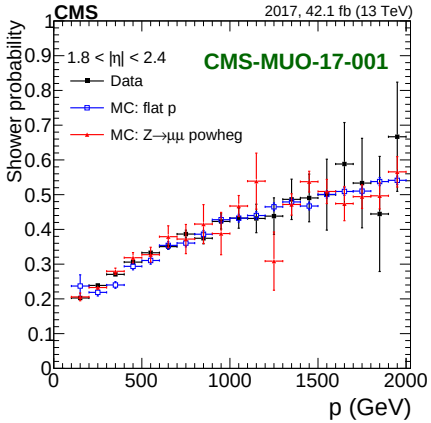


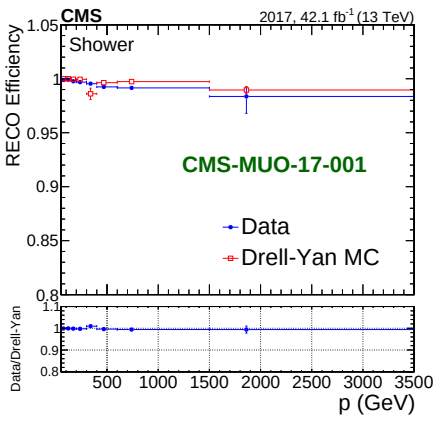


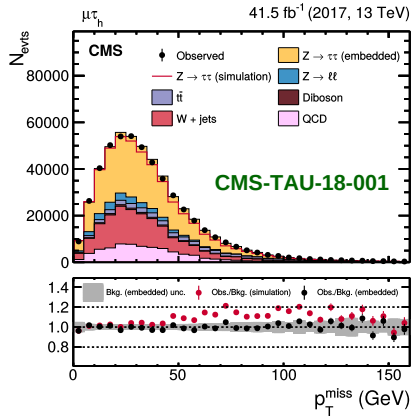
Lepton reconstruction/identification developments

- Many developments during Run 2 to improve lepton selection/fake rejection (BDT for electrons/muons, DNN for taus,...).
- Large recorded dataset now allows us to study leptons (e.g. muons) with p_T up to several hundred of GeV.
  $\rightarrow$ Allows to test simulation (both for signal selection and "lost lepton" estimate).
- Proper simulation of $e/\mu/\tau$ reconstruction allows us to estimate hadronic tau background in a semi data driven way, using dimuon data events ("embedding")
  $\rightarrow$ avoids in particular to rely on simulation for the MET description.









Summary

- Improvement in analyses techniques is the key for a successful Run 3 physics program.
- Pile up mitigation and trigger developments (including fast tracking and displaced objects) are two obvious topics of interest.
- Work has already started to get the most of the various detector upgrades.
- Precise detector calibration/alignment expected to become more and more crucial in the future.
- **If dark matter is to be found at the LHC, it will only be possible thanks to all of this ongoing (and past) developments**