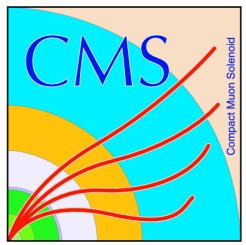
Rejecting beam induced background at the HL-LHC (CMS)

L. Thomas,
on behalf of the CMS collaboration

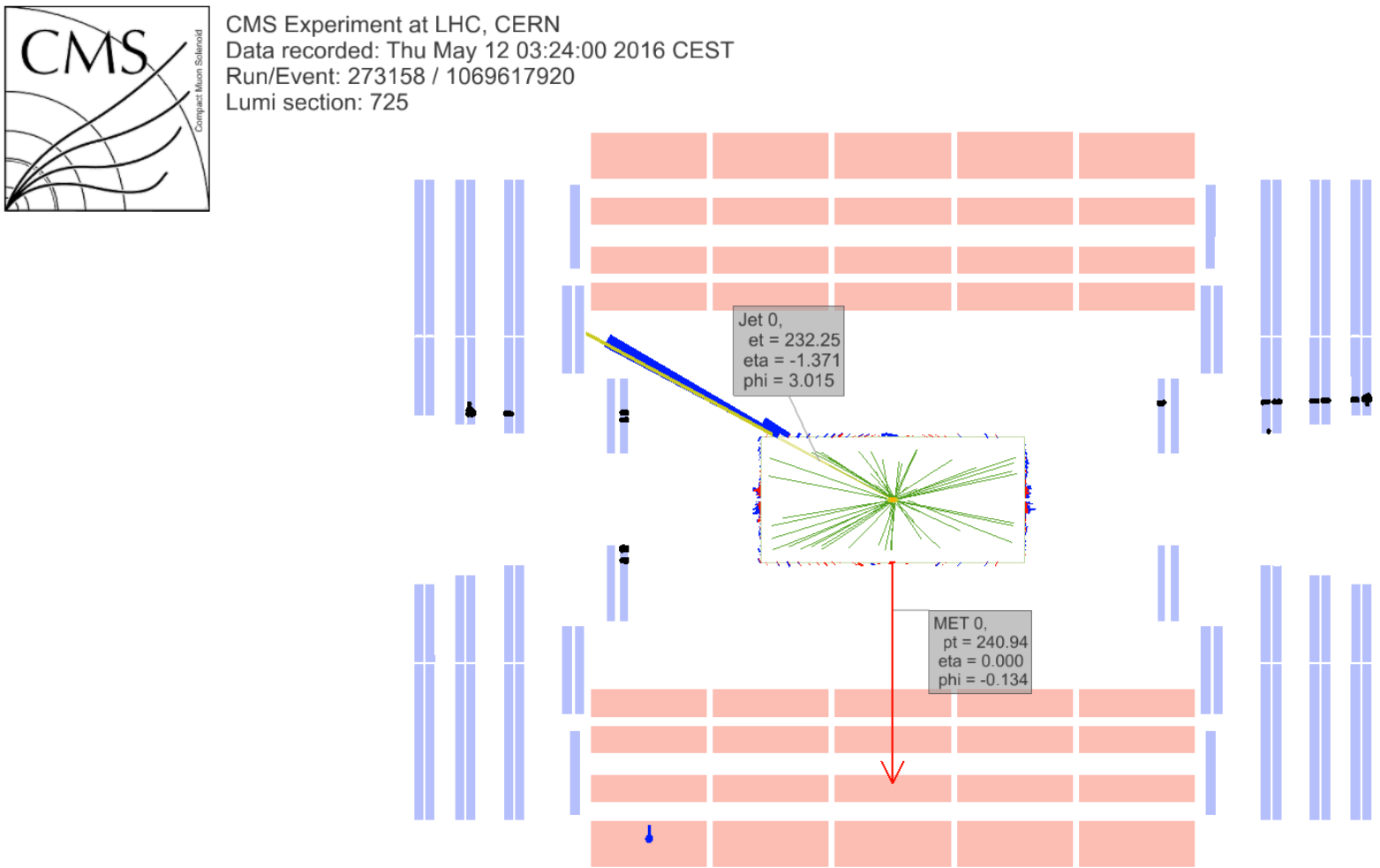
Université Libre de Bruxelles

May 26th, 2021



Introduction

- Beam halo muons interacting in the calorimeters are a well known source of fake jets/missing transverse energy (MET) since the LHC startup
- Can lead to energy deposits up to a few hundreds of GeV of (transverse) energy.
- Rate estimated to a few Hz during Run 2 data taking.



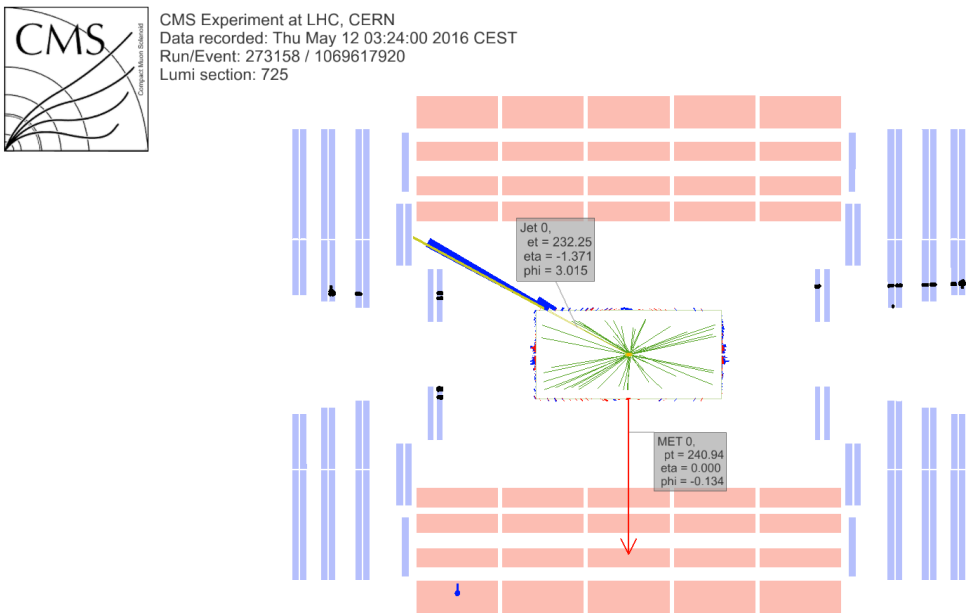
Signature

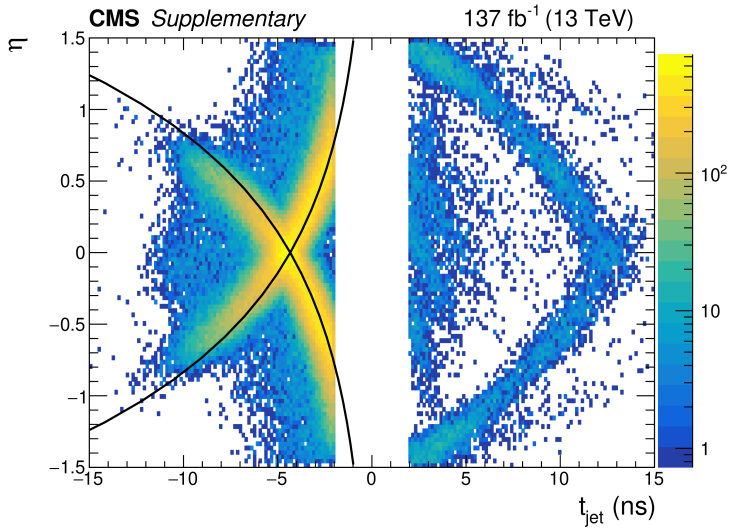
In general, very distinctive signature from physics

- Halo muon track visible in the Cathode Strips Chambers
- Energy deposit is out of time (either early or late)
- No tracks from the primary vertex pointing towards the deposit.

Generic event filter developed:

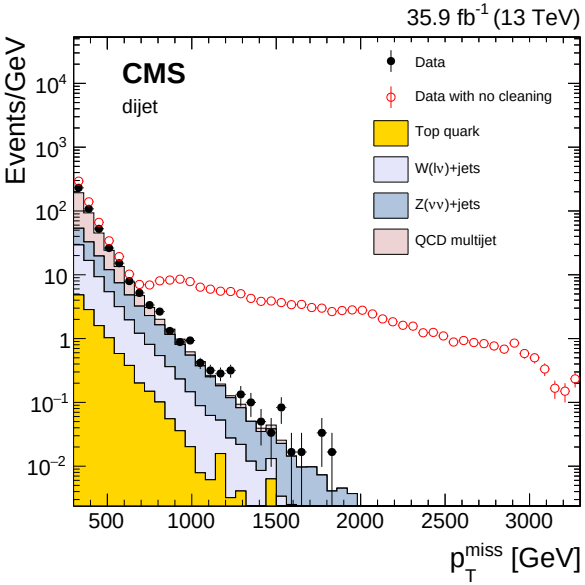
- Combines energy shower shape information (spread in η, narrow in ϕ), deposit timing and spatial+timing coincidence between with local tracks in the CSCs.
- Tagging 85-90% of the halos for $<$0.1% mistag rate

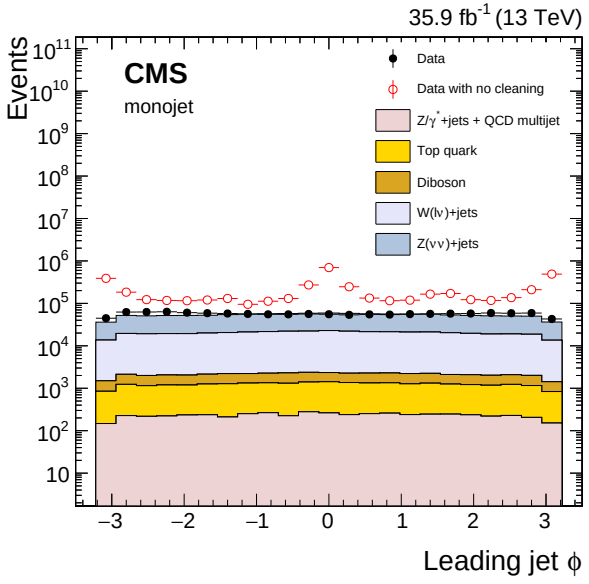


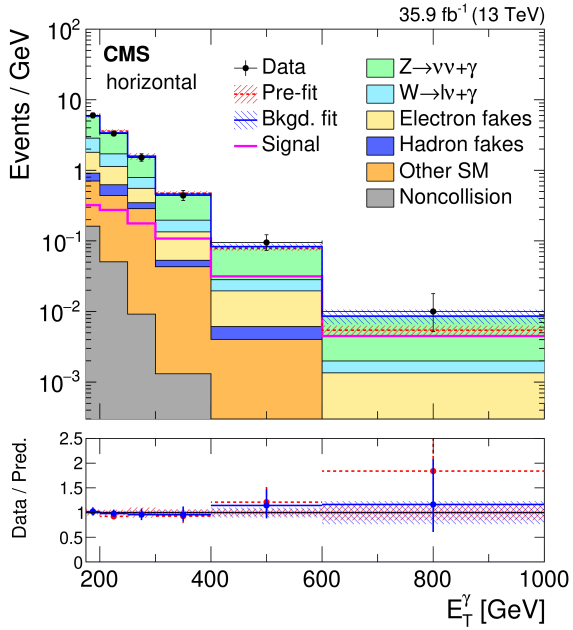


Monojet/monophoton searches (arXiv:1903.06078, arXiv:1810.00196)

- The most impacted searches using prompt objects.
- Not directly relevant for this workshop... unless your search uses an ISR jet/photon to trigger
- For jets further rejection achieved by asking some tracks inside the jets.
- Halo signature very close to prompt photons in endcaps ($|\eta|$ >1.479) and to forward jets beyond tracker coverage ($|\eta|$ >2.5). (similar shower shape and timing, no CSC coverage).
  - Such photons/jets dropped from monojet/monophoton analyses.
- Monophoton: small residual contribution estimated using the non uniform ϕ distribution

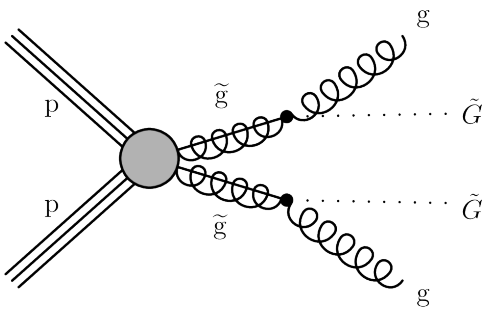


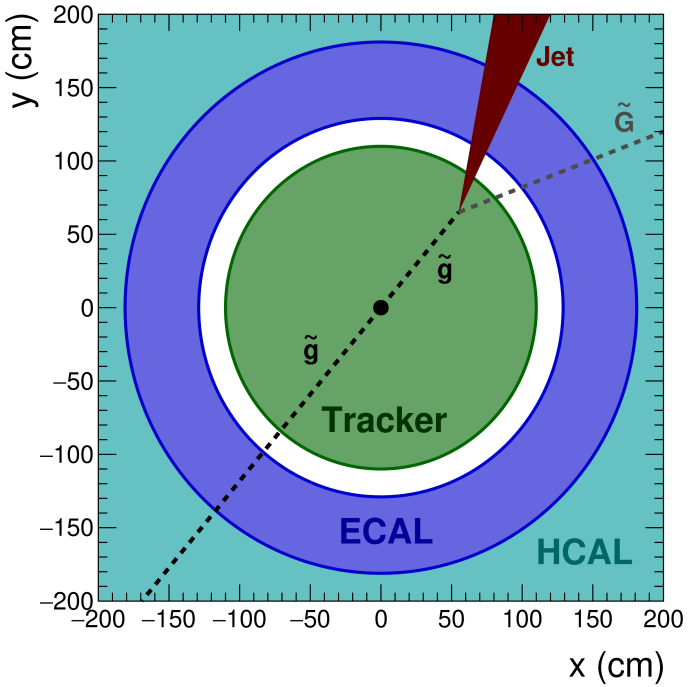




Search for LLP using nonprompt jets (arXiv:1906.06441)

- Probing very displaced jets ($c\tau > 0.5$ m).
- Looking for a delayed jet + large MET.
- Here needs to be more agressive than standard event filter as beam halo background is particularly relevant
- Only looking at barrel jets due to significantly better timing resolution and lower background (in particular: much better halo rejection)





Baseline jet selection

$|\eta| < 1.48$

$p_T > 30\,\text{GeV}$

Signal jet selection

$E_{ECAL} > 20\,\text{GeV}$

$N_{ECAL}^{cell} > 25$

$HEF > 0.2$ and $E_{HCAL} > 50\,\text{GeV}$

$t_{jet}^{RMS}/t_{jet} < 0.4$ and $t_{jet}^{RMS} < 2.5\,\text{ns}$

$PV_{track}^{fraction} < 0.08$

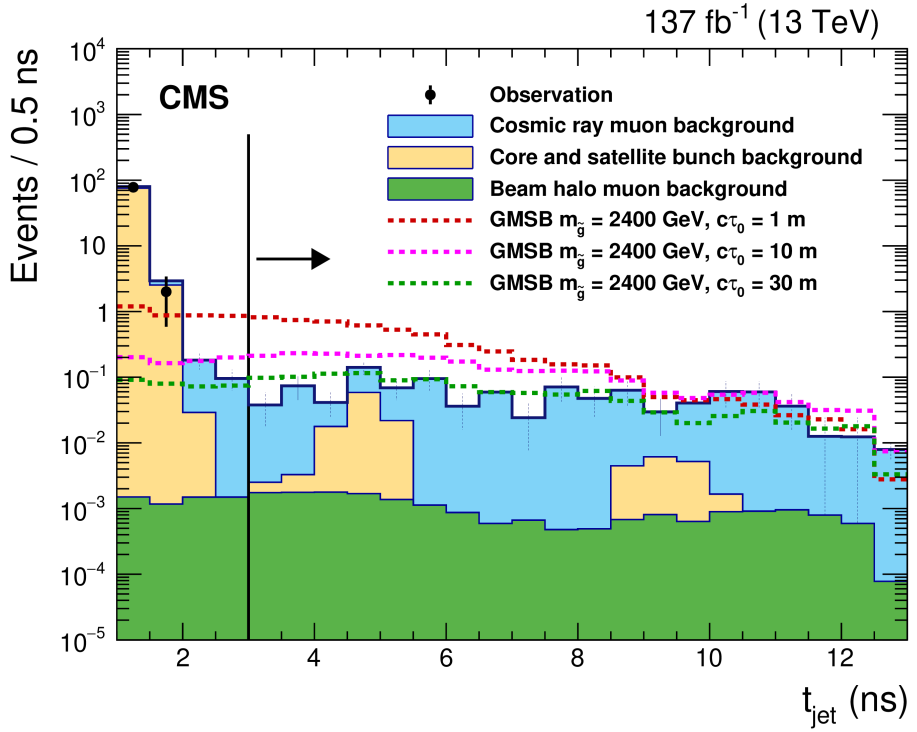
$E_{ECAL}^{CSC}/E_{ECAL} < 0.8$

$t_{jet} > 3\,\text{ns}$

Search for LLP using nonprompt jets (2)(arXiv:1906.06441)

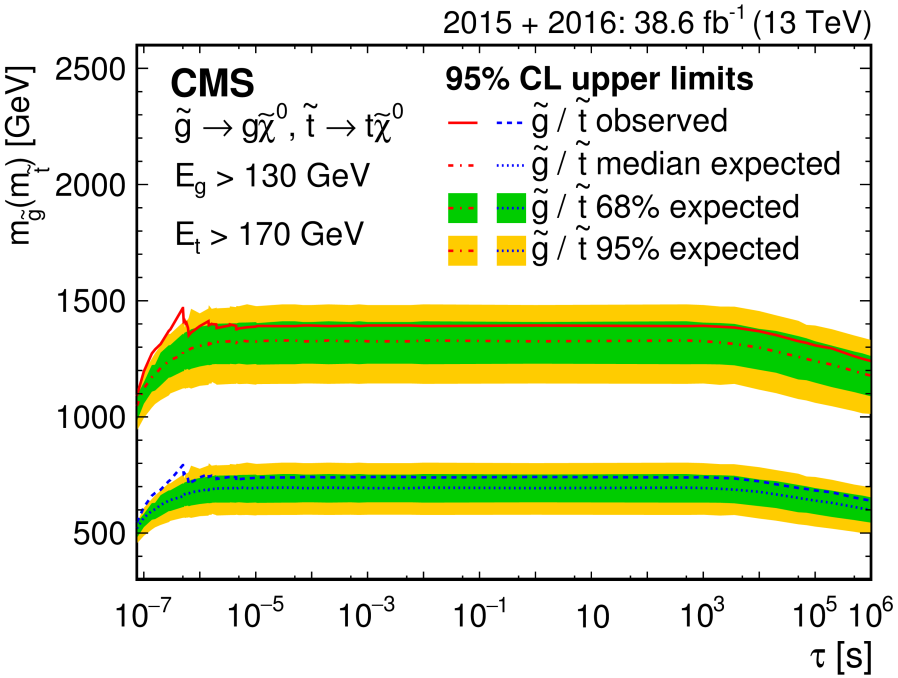
- Discriminating variable: jet time from ECAL hits.
- Residual beam halo contribution using two uncorrelated discriminating variables between signal:
  - Fraction of energy geometrically matched to CSC hits
  - Fraction of ECAL/HCAL energy.

Background source	Events predicted
Beam halo muons	$0.02^{+0.06}_{-0.02}\,(\text{stat})^{+0.05}_{-0.01}\,(\text{syst})$
Core and satellite bunch collisions	$0.11^{+0.09}_{-0.05}\,(\text{stat})^{+0.02}_{-0.02}\,(\text{syst})$
Cosmic ray muons	$1.0^{+1.8}_{-1.0}\,(\text{stat})^{+1.8}_{-1.0}\,(\text{syst})$



Search for decays of stopped LLP (arXiv:1801.00359)

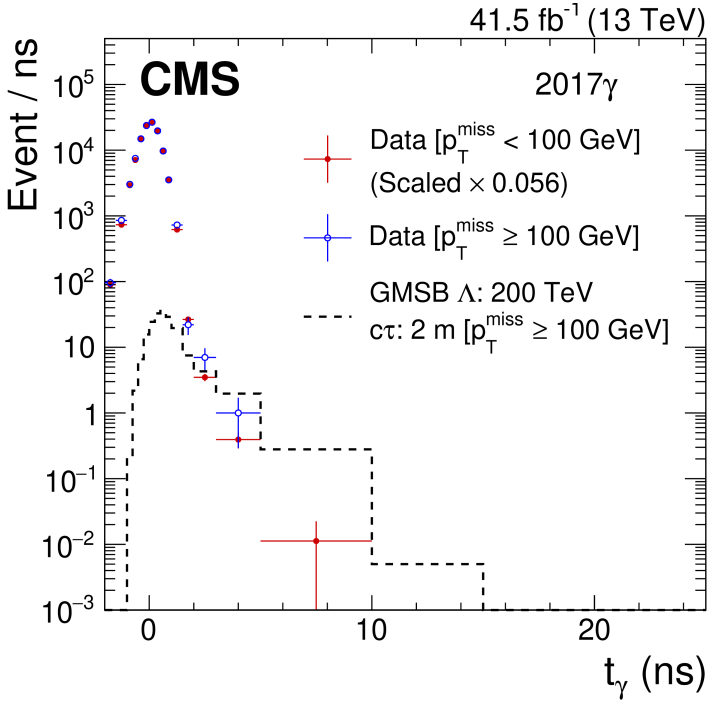
- Looking for stopped LLP decaying into jets/pair of muons with lifetimes > 100 ns up to several days.
- Triggering on empty bunch crossings containing a jet/a muon.
  - Large contribution to the rate from halo muons if endcaps (CSCs) are included for muon triggers.
- Only central jets/muons considered in the final selection to reduce the halo contribution
  - Remaining contribution negligible for the muon case (two muons, back to back)
  - Still significant for jets. Estimated using fraction of events with a halo muon track on one side/both sides of the CSCs.

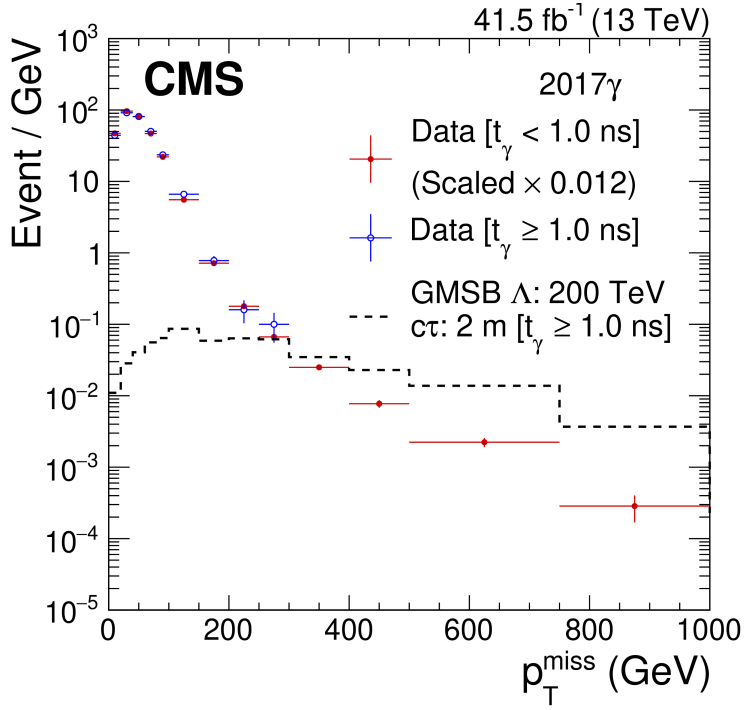


LHC period	Trigger livetime [hrs]	HCAL noise	Cosmic ray muons	Beam halo	Total background
2015	135	$0.4^{+2.9}_{-0.4}$	2.6 ± 0.9	1.1 ± 0.1	$4.1^{+3.0}_{-1.0}$ (6.2)
2016	586	$0.0^{+9.8}_{-0.0}$	8.8 ± 3.1	2.6 ± 0.2	$11.4^{+10.3}_{-3.1}$ (17.4)

Search for LLP with delayed photons (arXiv:1909.06166)

- Here targeting signatures with delayed photons and MET.
- Analysis only considers timing for barrel photons.
- Used a control region with early photons to infer that halo contribution in the signal region is indeed negligible.
- Halo muons may become more relevant if endcaps are included?



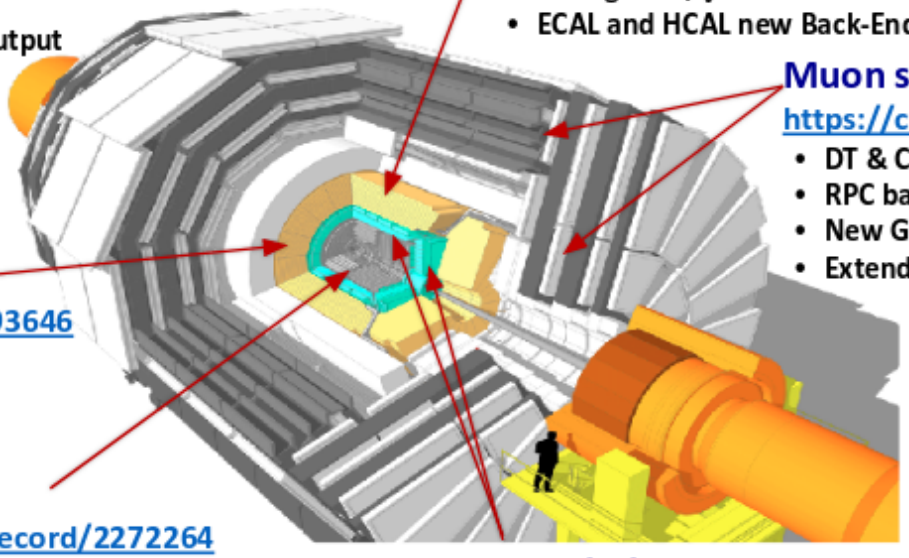


The CMS Phase 2 Upgrade

L1-Trigger/HLT/DAQ
https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193
- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure
https://cds.cern.ch/record/2020886

Tracker https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

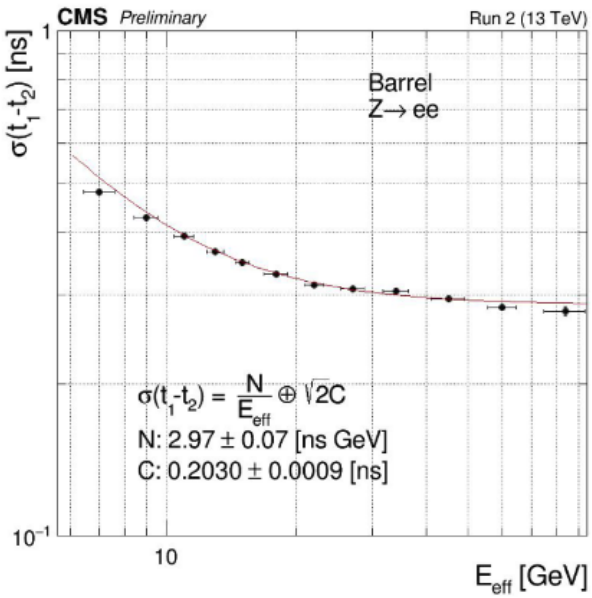
MIP Timing Detector
https://cds.cern.ch/record/2296612
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity

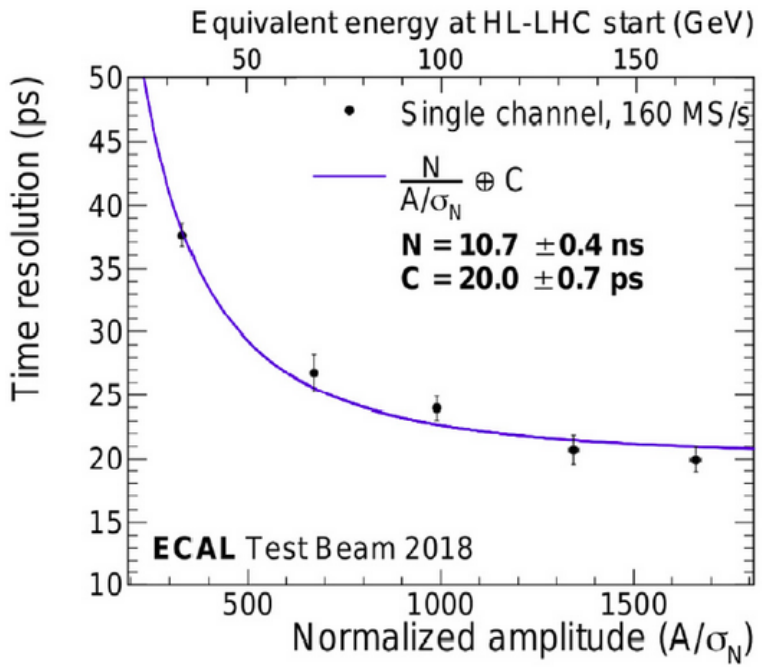
ECAL upgrade (CMS-TDR-015)

- New very front end will allow to significantly improve timing, down to 30 ps for E=50 GeV.
  → Should clearly improve halo rejection.
- Full crystal granularity at the Level 1 trigger
  → Some interest for LL triggers, e.g. displaced photons (and halo rejections)?

Run 2



Phase 2

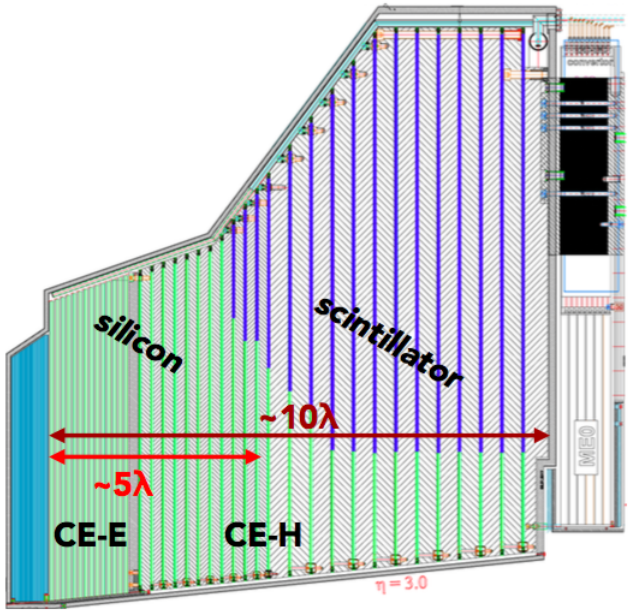


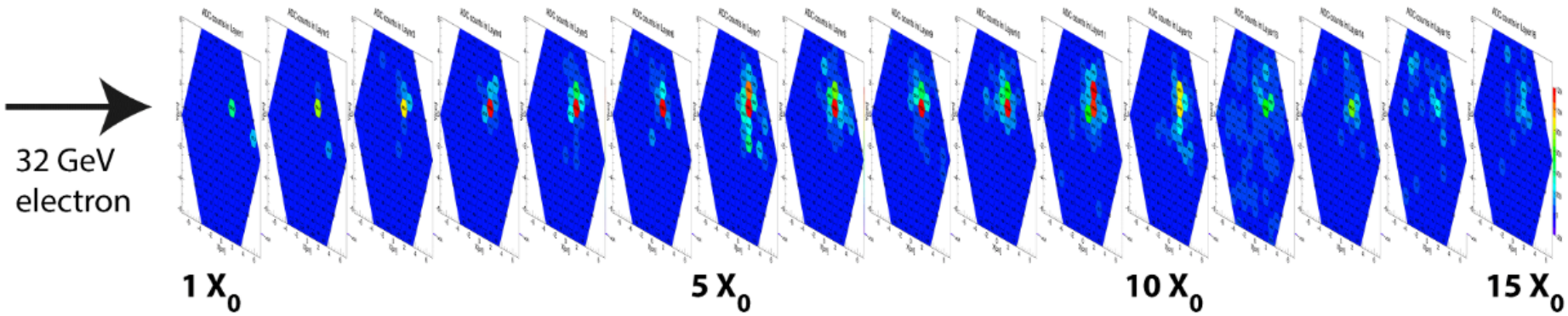
(Not an exact apple to apple comparison)

Endcap calorimeter upgrade (CMS-TDR-019)

- Fully new high granularity calorimeter (Si+Scintil. with SiPMs)
- 28 layers for EM calo, 24 for hadron calo.
- 0.5/1 cm^2 Si sensor.
- Timing resolution $\leq$ 30ps for $p_T > 5$ GeV

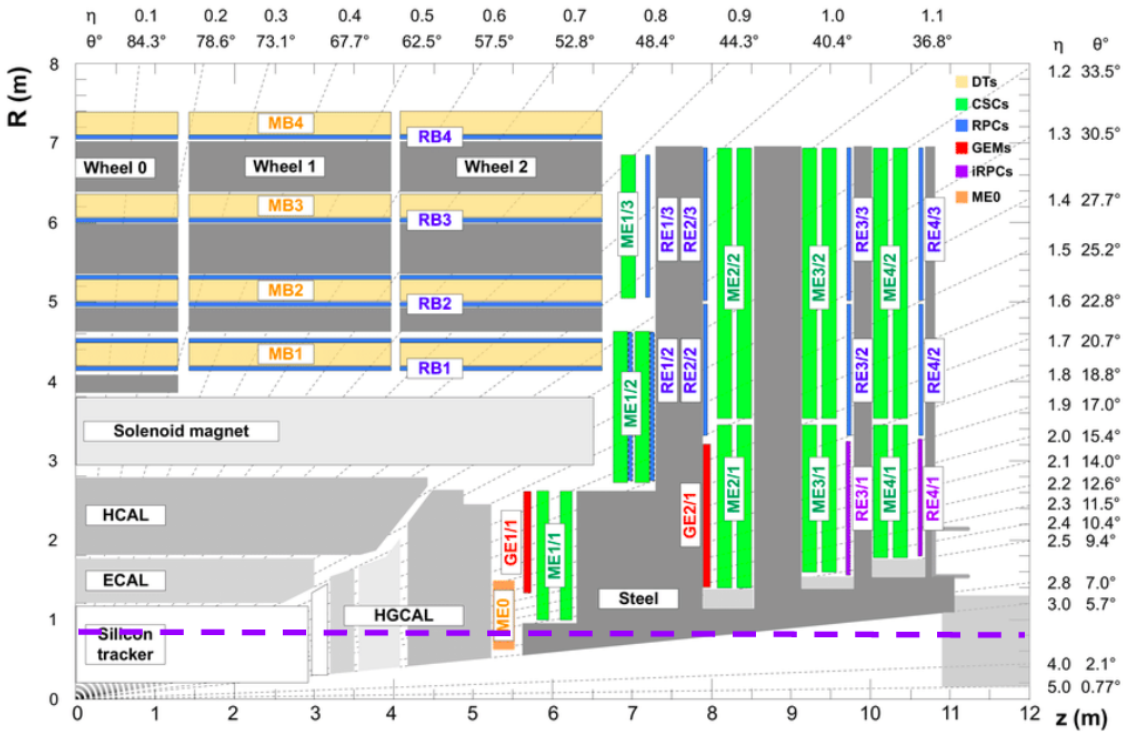
$\rightarrow$Suggests in particular a significant improvement in halos vs prompt photons separation.

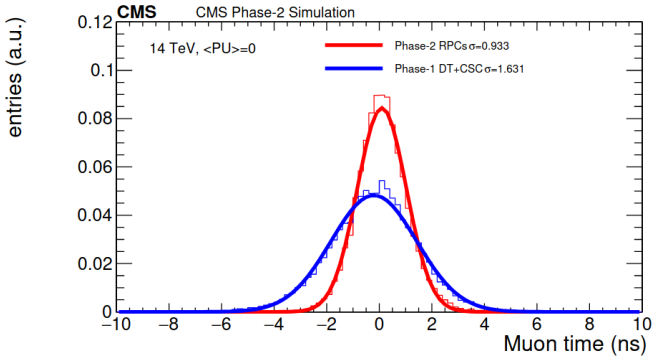




Endcap muon upgrade (CMS-TDR-016)

- Installation of two sets of GEM chambers (GE2/1 and ME0) after Run 3.
  → ME0 particularly relevant here as it extaned the halo muon coverage in the endcaps and in HF
- Extended coverage for RPC (RE3/1, RE4/1) and improved timing (new link system).
  → Expect strong reduction of the halo rate, also at trigger level.





Summary

- Beam induced backgrounds are real and can induce fake physics signatures.
- Efficient mitigation techniques have been developed and allows to reduce its contribution to a negligible level in most cases.
- Yet, some improvements remain possible, in particular in the forward region.
- New features offered by the CMS Phase 2 upgraded detector (improved timing, extended tracking/muon coverage) should significantly help.