Heavy neutral leptons in displaced vertices at CMS

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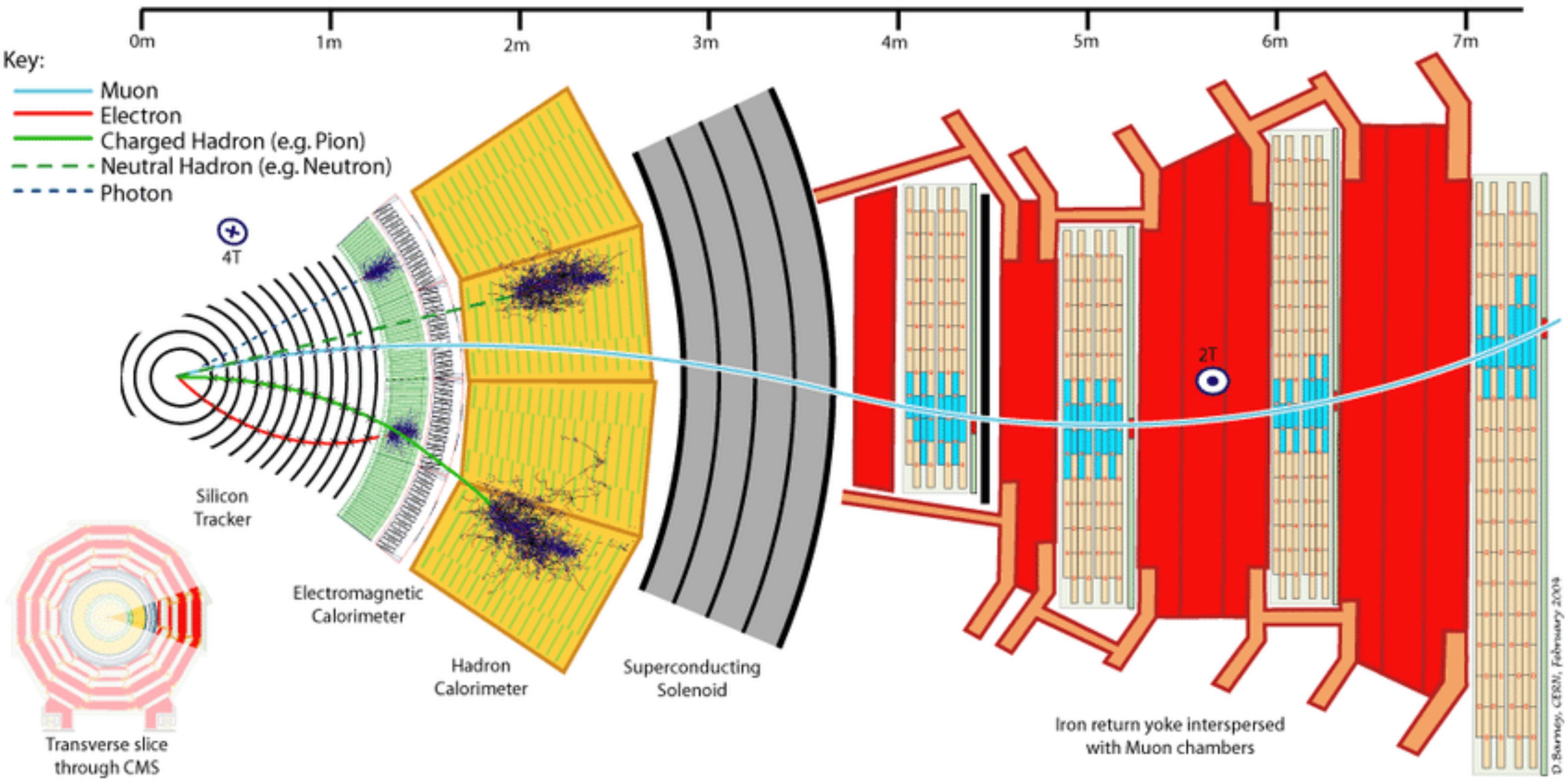
on behalf of the CMS collaboration

Heavy Ions and Hidden Sectors Workshop
3-5 December, Louvain la Neuve

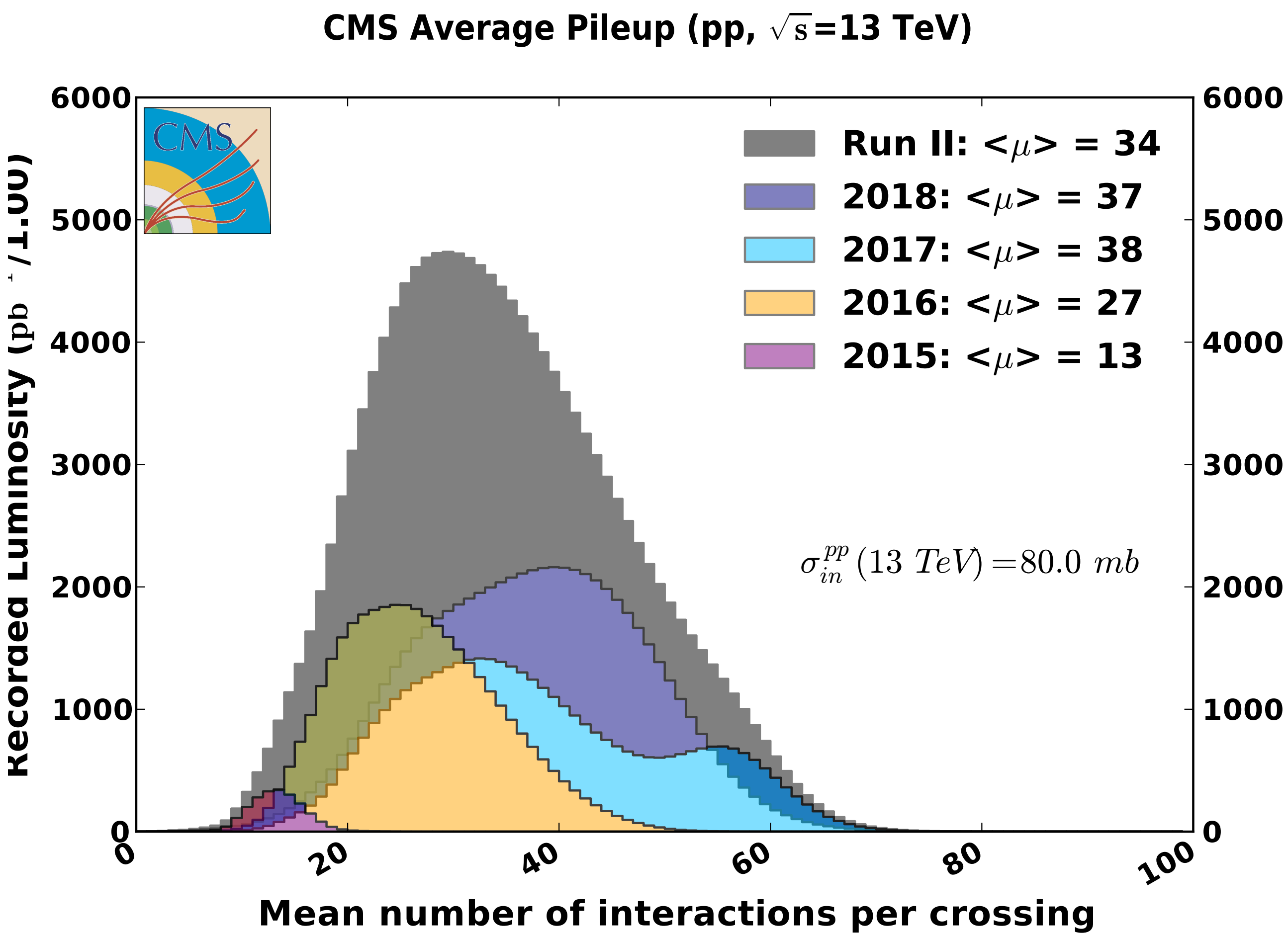
LA LIBERTÉ DE CHERCHER

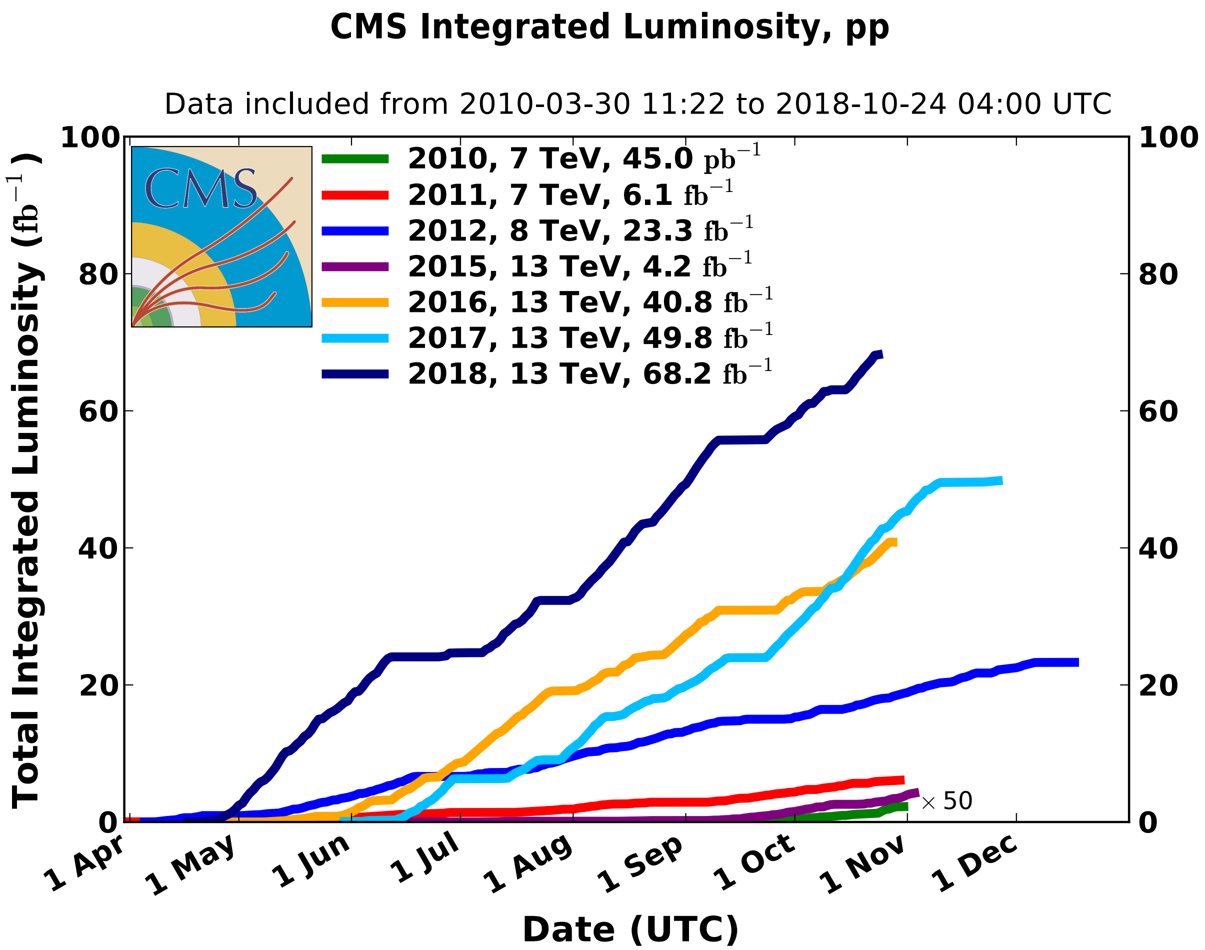
CMS
Compact Muon Solenoid

The CMS detector

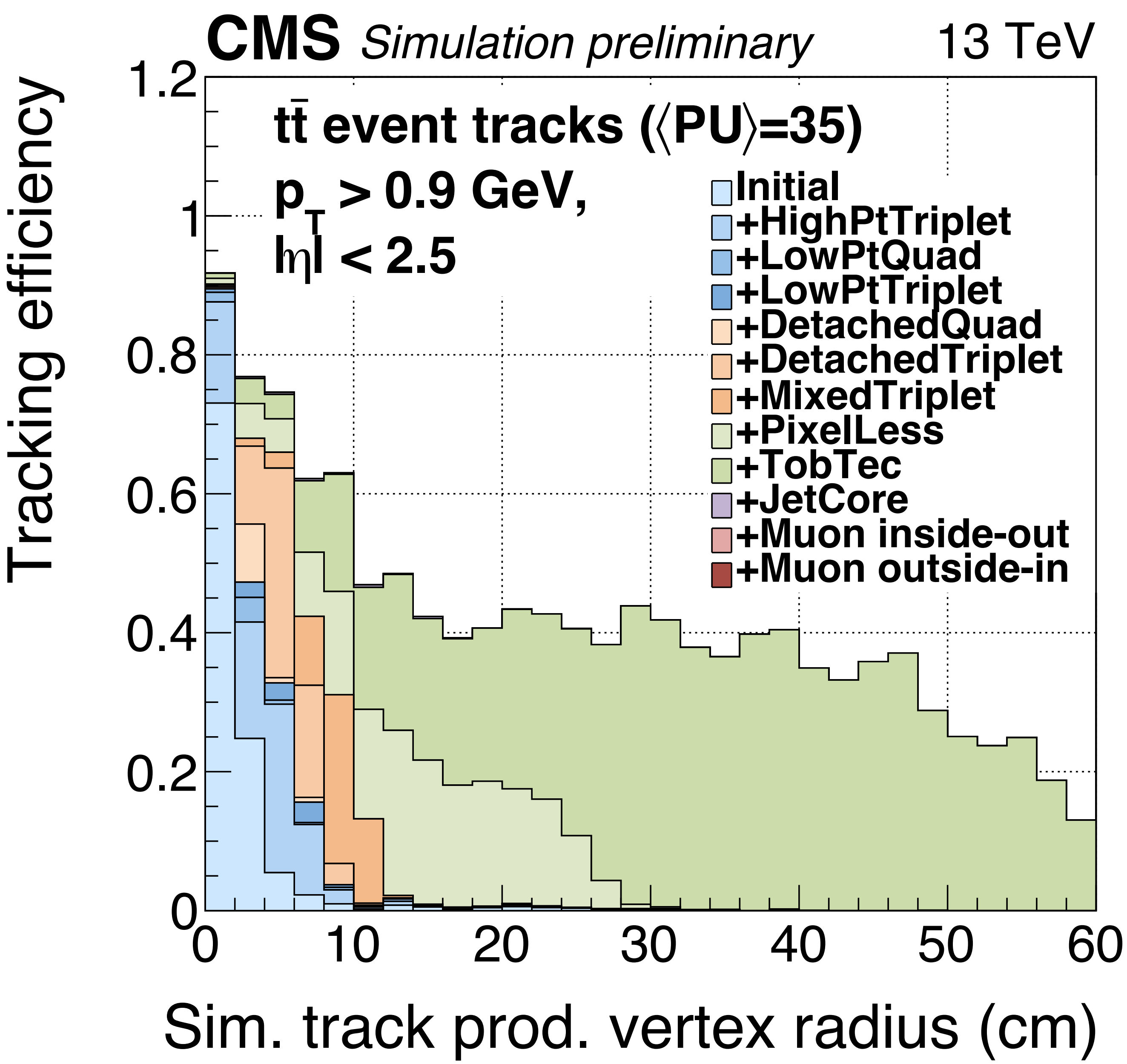


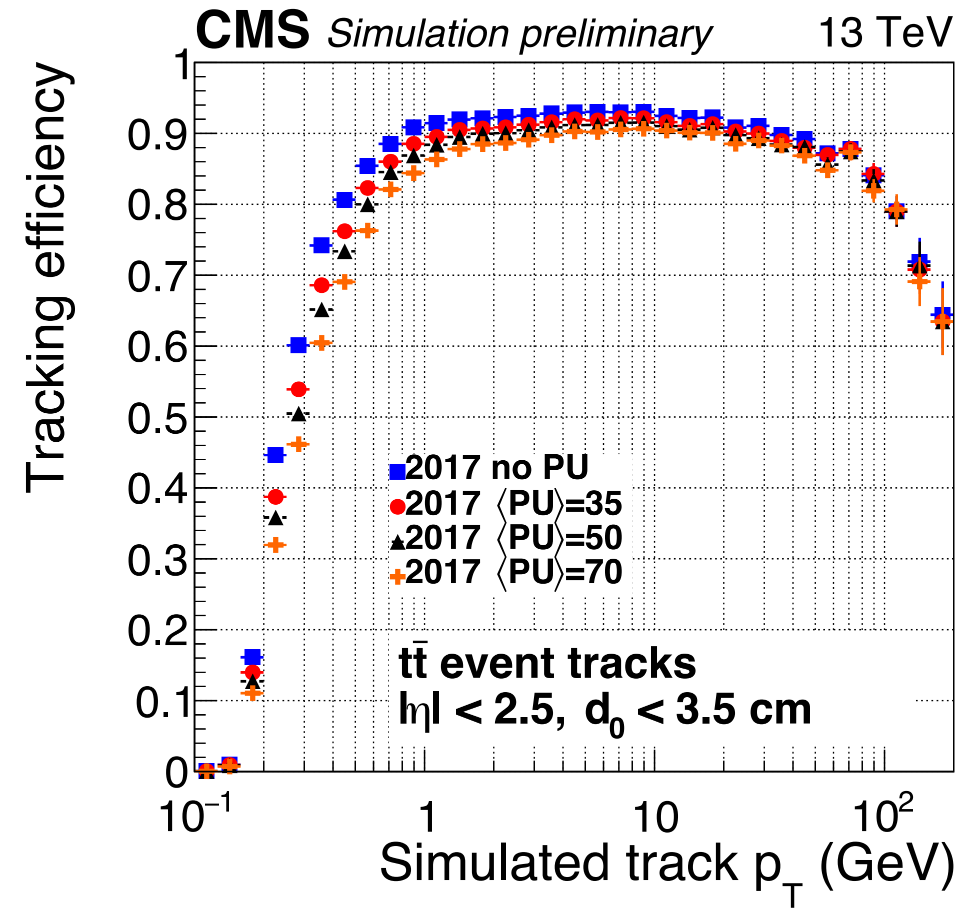
The CMS dataset

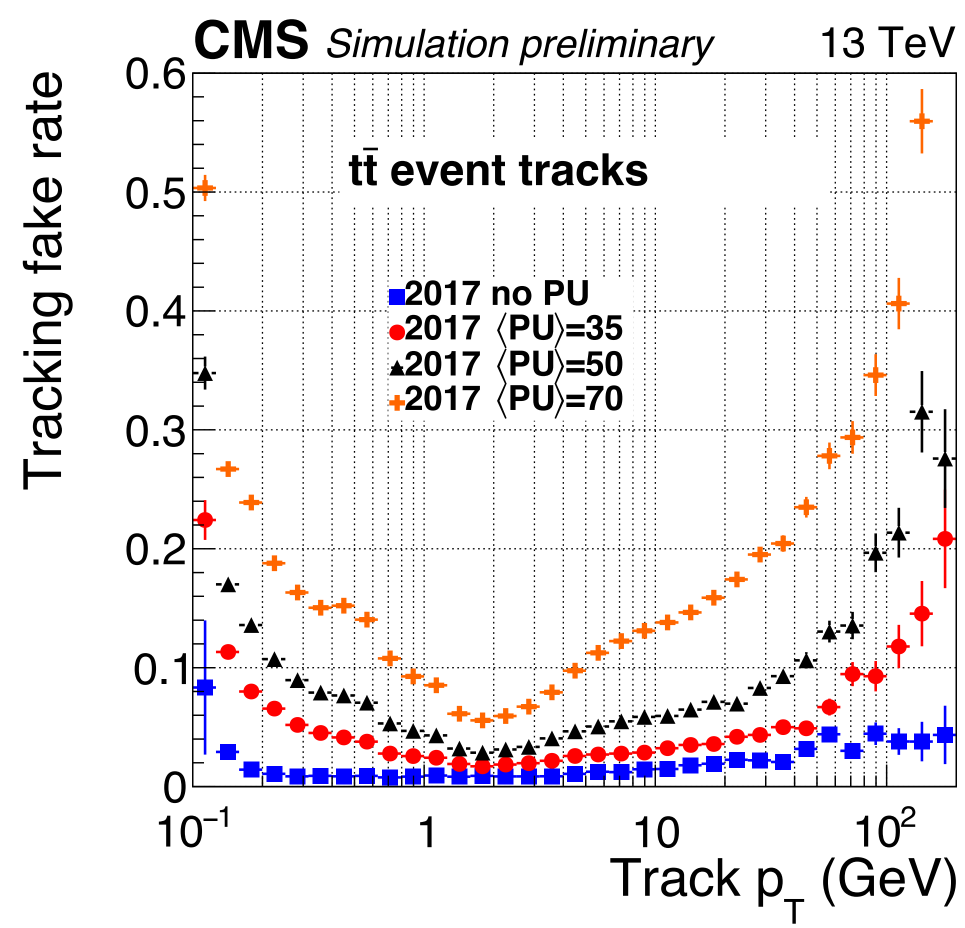




Tracking efficiency





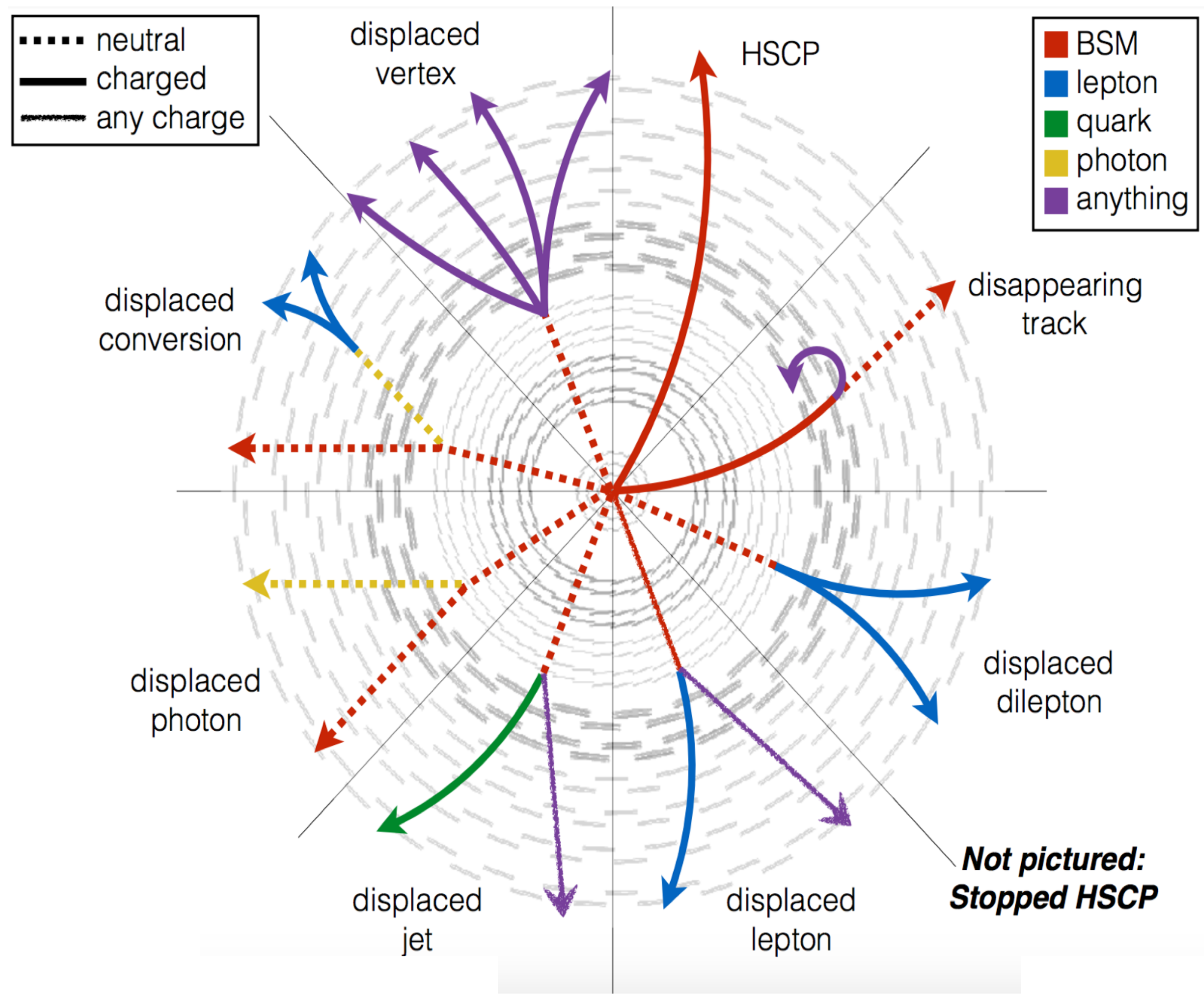


LLP searches @ CMS

- Many BSM scenarios predict LLP:
  - dark photons, SUSY, HNL

- Provides a dark matter candidate

- Large variety of signature:
  - Charges
  - Final states
  - Lifetime

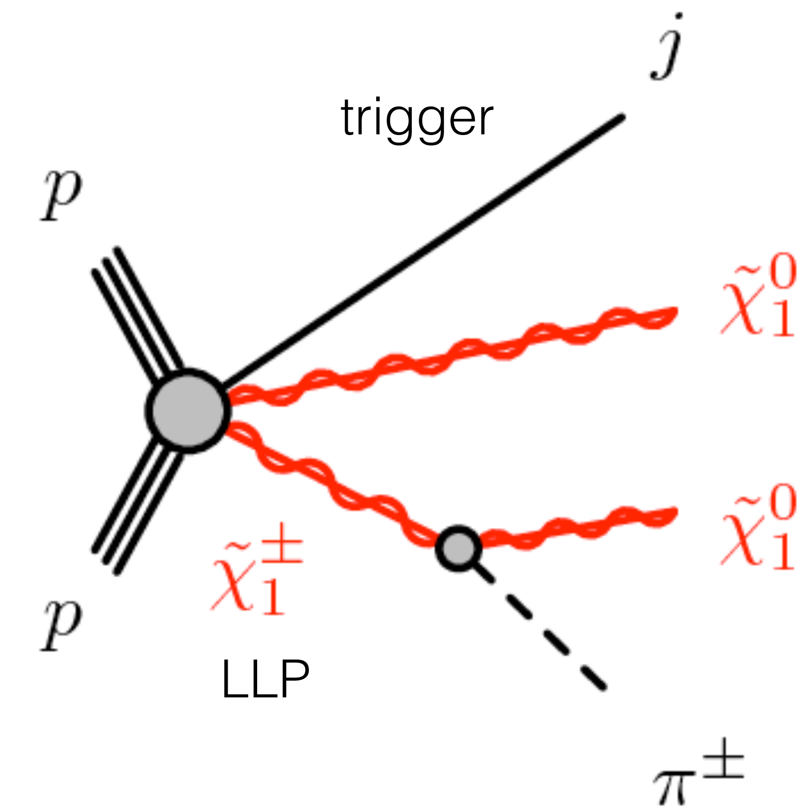


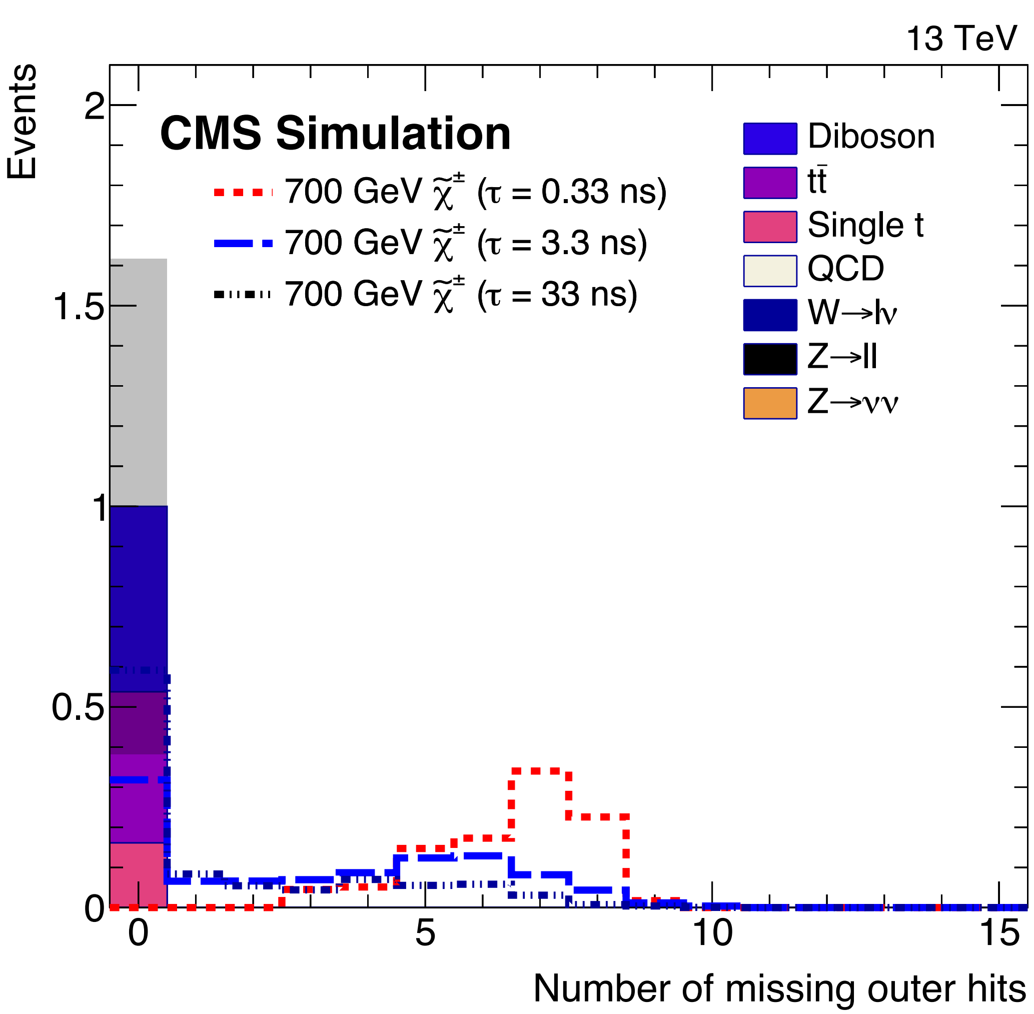
- Analyses challenges:
  - Dedicated triggers, new object reconstruction, and atypical analysis techniques

LLP searches @ CMS - Disappearing Tracks

Signature:

- Isolated track with hits only in the inner tracker layers and p_T>55 GeV
- no muon hits, no calorimeter energy deposit



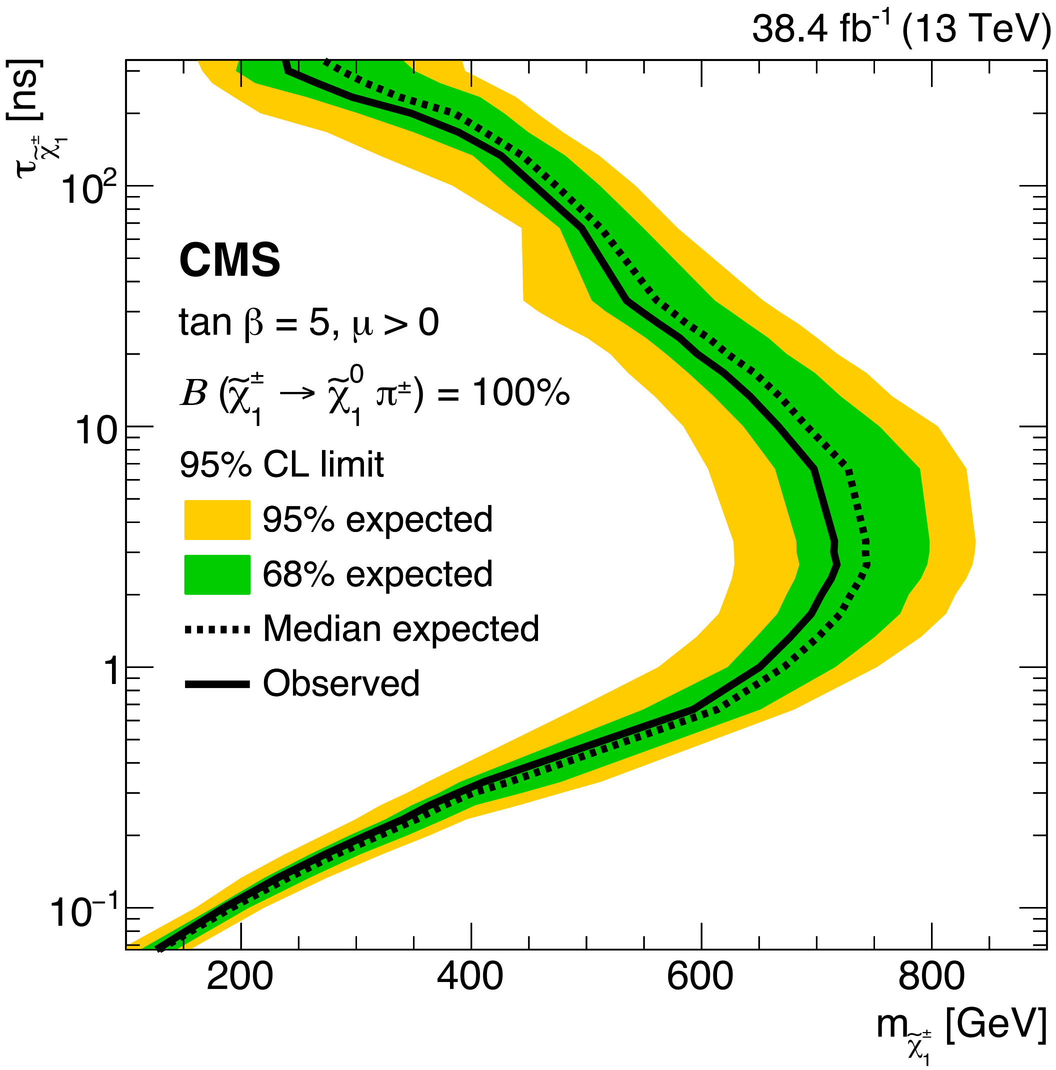


Anomaly mediated supersymmetry breaking model:

- small mass difference between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$
- decay mode: $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \pi^\pm$
- lifetime O(1ns)
- π not reconstructed

CMS-EXO-16-044, JHEP 08 (2018) 016

LLP searches @ CMS - Disappearing Tracks

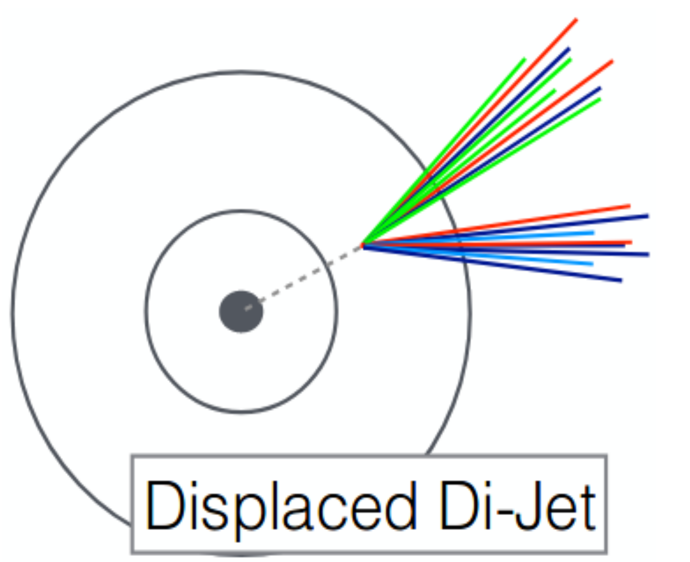


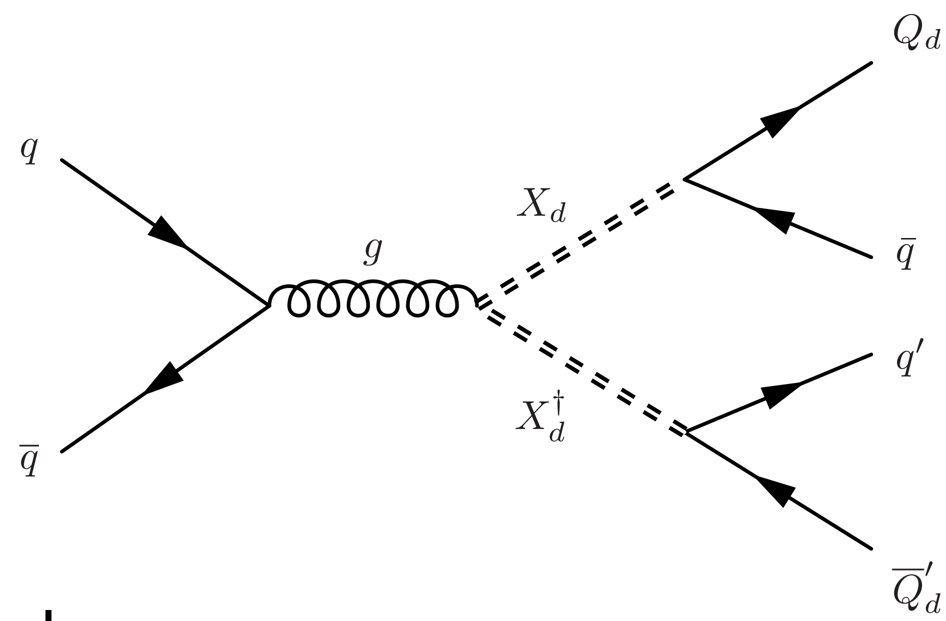
- Consistent with background only hypothesis
- Exclusion at 95% CL of:
  - $\tilde{\chi}_1^\pm$ with M< 715(695) GeV with τ ~3 (7) ns
  - $\tilde{\chi}_1^\pm$ with τ [0.5, 60]ns and M = 505 GeV

Run period	Estimated number of background events: Leptons	Spurious tracks	Total	Observed events
2015	0.1 ± 0.1	$0^{+0.1}_{-0}$	0.1 ± 0.1	1
2016A	$2.0 \pm 0.4 \pm 0.1$	$0.4 \pm 0.2 \pm 0.4$	$2.4 \pm 0.5 \pm 0.4$	2
2016B	$3.1 \pm 0.6 \pm 0.2$	$0.9 \pm 0.4 \pm 0.9$	$4.0 \pm 0.7 \pm 0.9$	4
Total	$5.2 \pm 0.8 \pm 0.3$	$1.3 \pm 0.4 \pm 1.0$	$6.5 \pm 0.9 \pm 1.0$	7

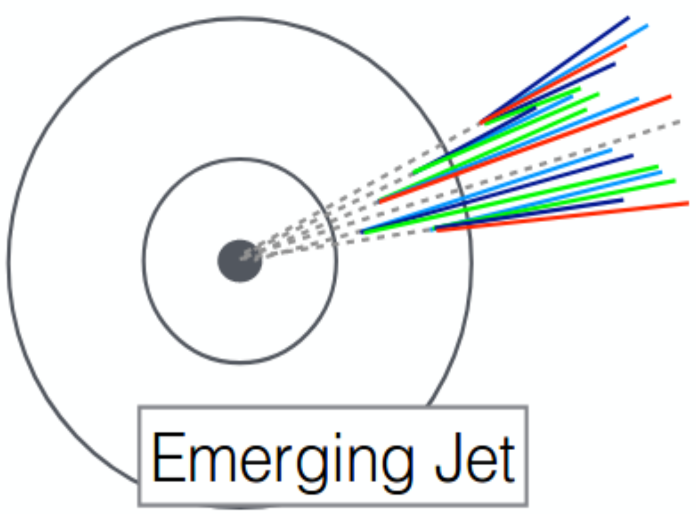
CMS-EXO-16-044, JHEP 08 (2018) 016

LLP searches @ CMS - Emerging Jets





- Dark BSSW QCD model:
  - mediator Xd, charged under QCD and dark QCD
  - dark-fermion, Qd, hadronizing in dark jets, decaying in dark-pions

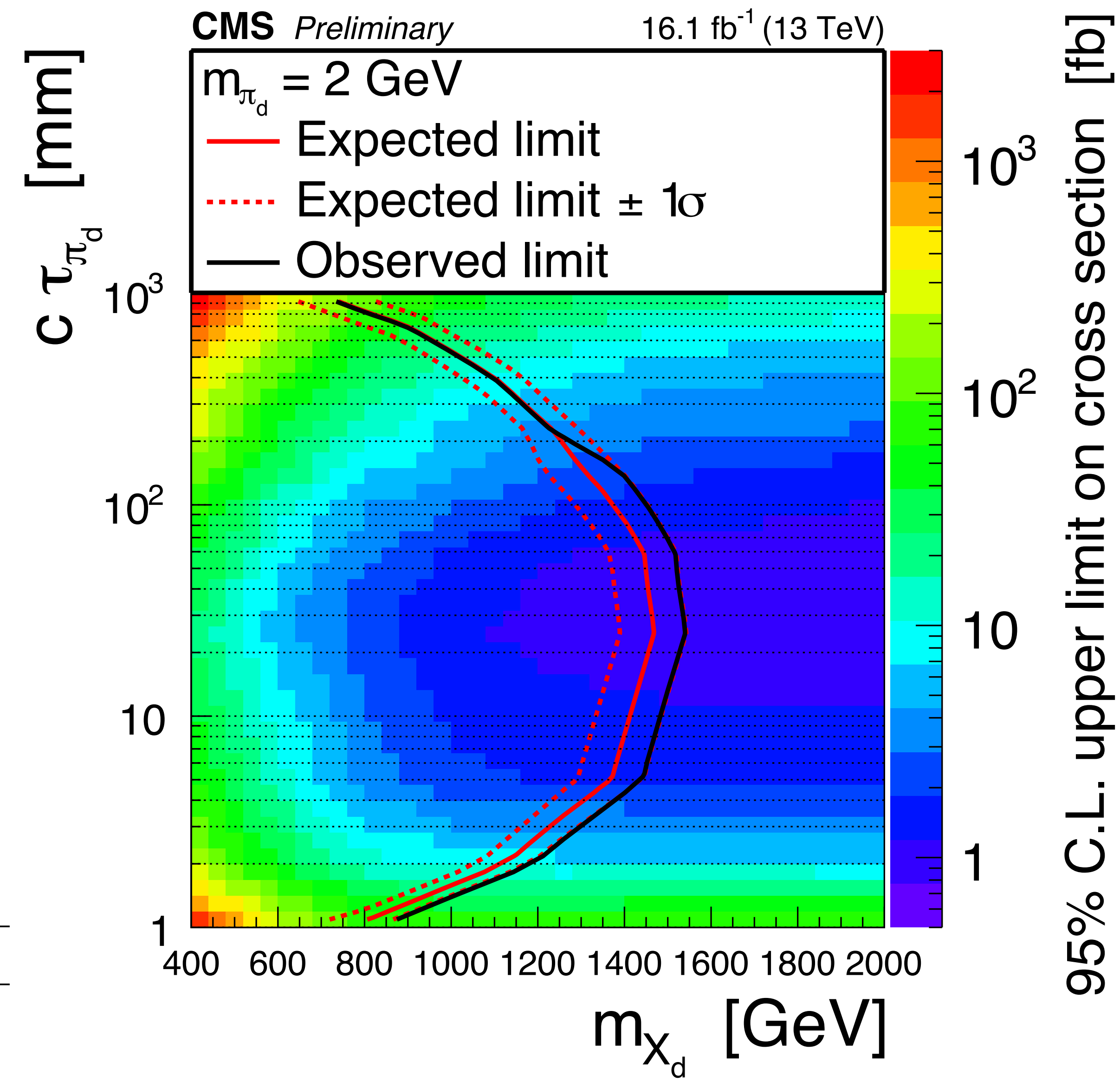


- Signature:
  - 4 jets with p_T>100GeV (2 prompt + 2 emerging)
  - Emerging jets, produced in dark fermions hadronization
  - multiple displaced vertices from decay of dark-pions

CMS-PAS-EXO-18-001, Submitted to JHEP

LLP searches @ CMS - Emerging Jets

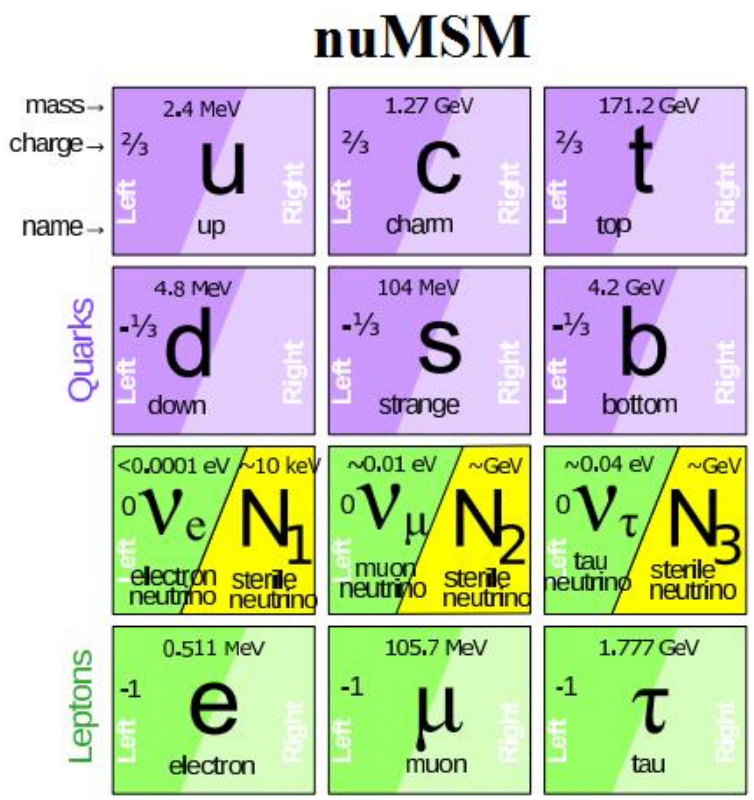
- Different cut sets optimised for different models (lifetime, masses)
- Consistent with background only hypothesis
- Mediators mass between 400 and 1250 GeV and decay lengths between 5 and 225 mm excluded



Set number	Expected	Observed
1	168 ± 15 ($syst_1$) ± 5 ($syst_2$)	131
2	31.8 ± 5.0 ($syst_1$) ± 1.4 ($syst_2$)	47
3	19.4 ± 7.0 ($syst_1$) ± 5.5 ($syst_2$)	20
4	22.5 ± 2.5 ($syst_1$) ± 1.5 ($syst_2$)	16
5	13.9 ± 1.9 ($syst_1$) ± 0.6 ($syst_2$)	14
6	9.4 ± 2.0 ($syst_1$) ± 0.3 ($syst_2$)	11
7	4.40 ± 0.84 ($syst_1$) ± 0.28 ($syst_2$)	2

CMS-PAS-EXO-18-001, Submitted to JHEP

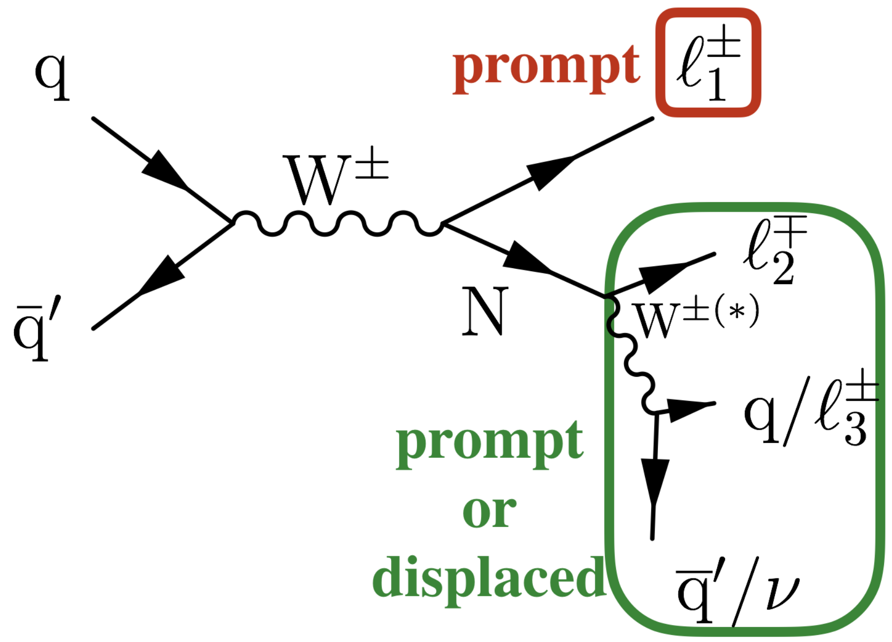
HNL searches @ CMS



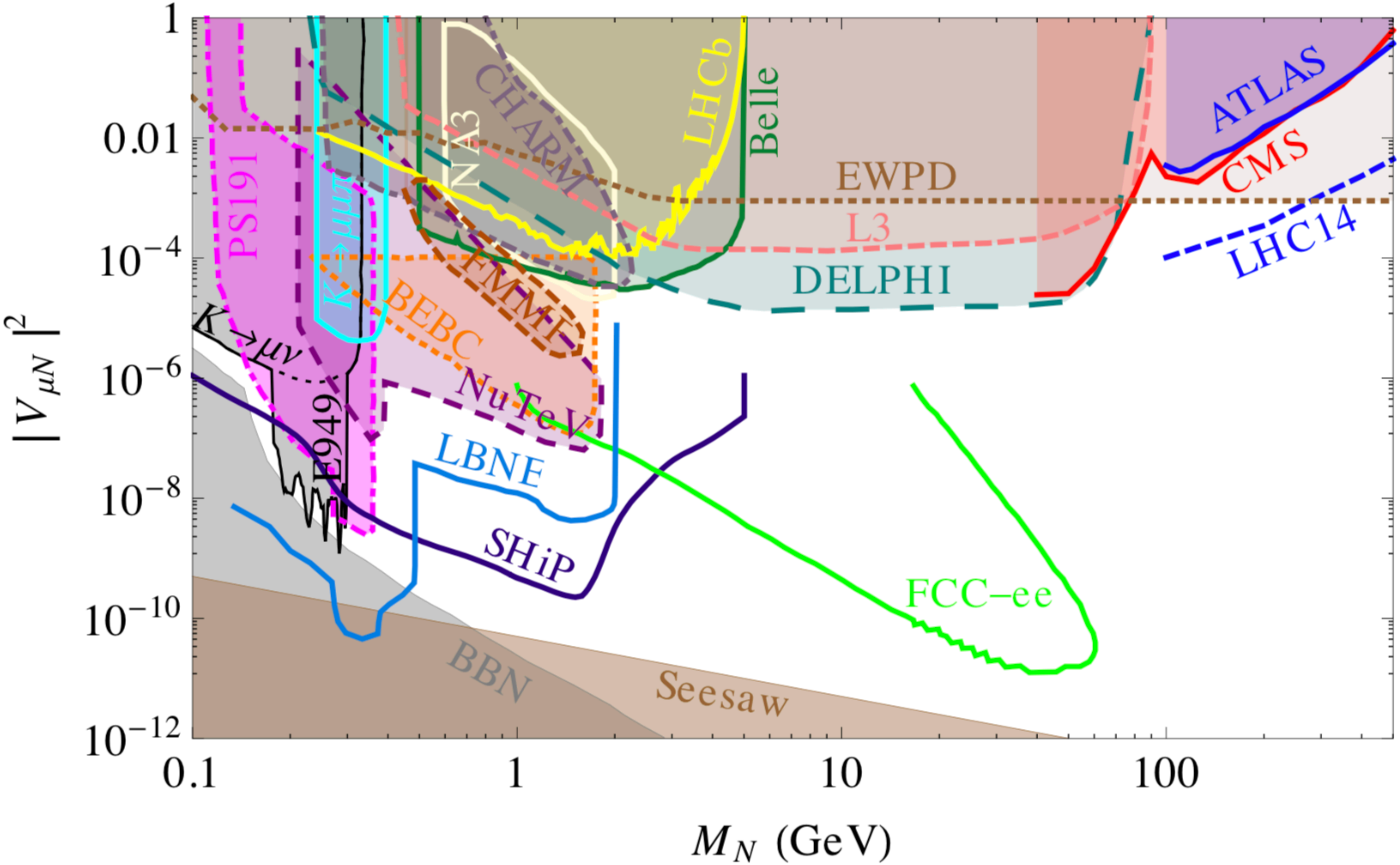
- RH neutrinos not included in the SM
- Foreseen in νMSM theory, based on the seesaw mechanism:
  - massive
  - sterile, couple to EW bosons only via ν-N mixing
- Could explain several open issues: dark matter, baryon asymmetry, neutrino masses

- HNL production happens via Drell-Yan currents, Wγ fusion and gluon fusion
- Final state under study: N → W l±
  - 3 leptons or 2 leptons + hadrons final state
  - large lifetime range allowed (from prompt to very displaced)

$$\tau_N \propto |V_{NL}|^{-2} M_N^{-5}$$

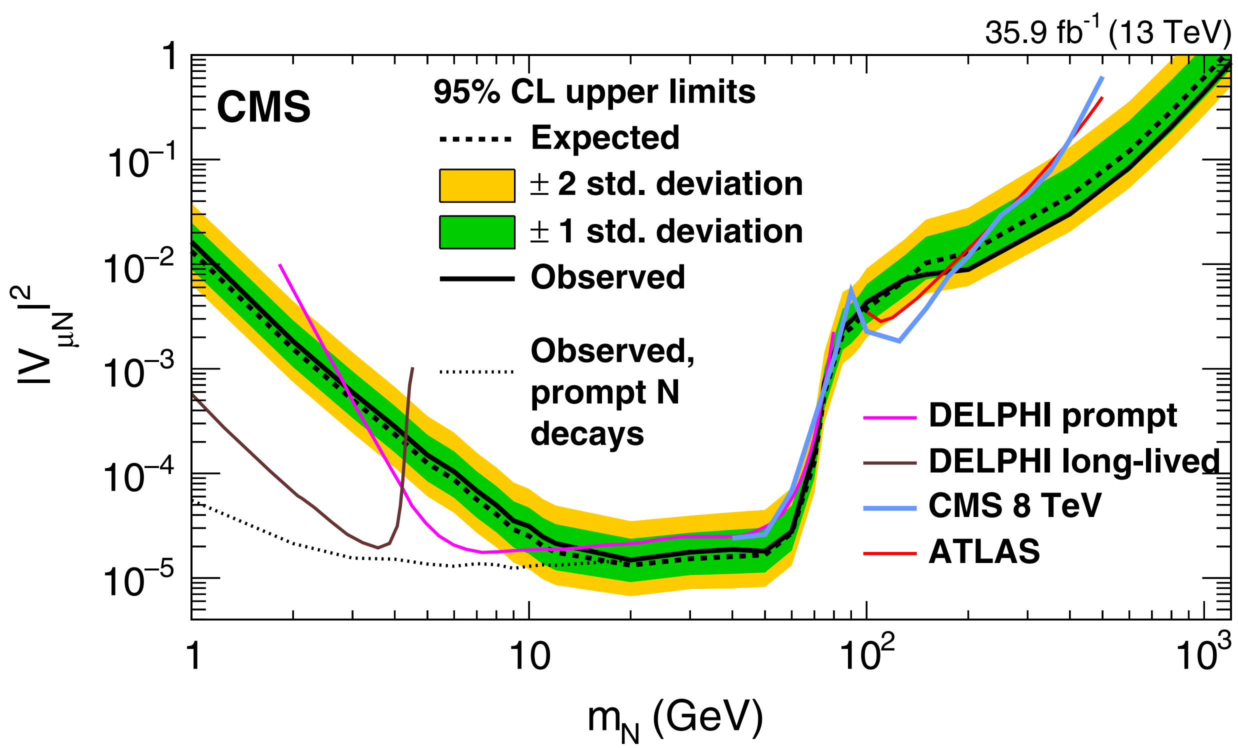


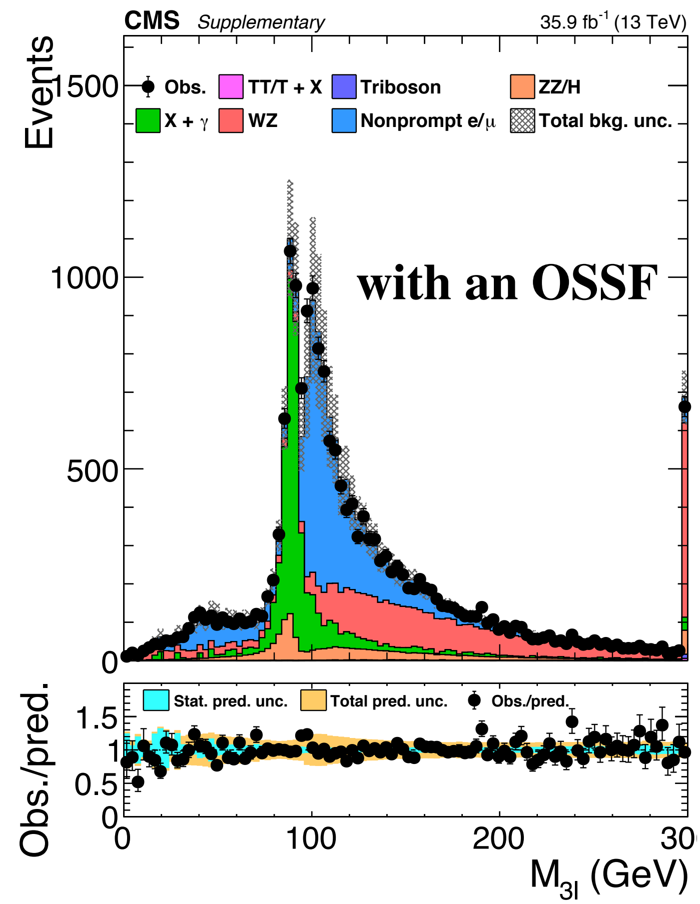
HNL searches - current and foreseen limits

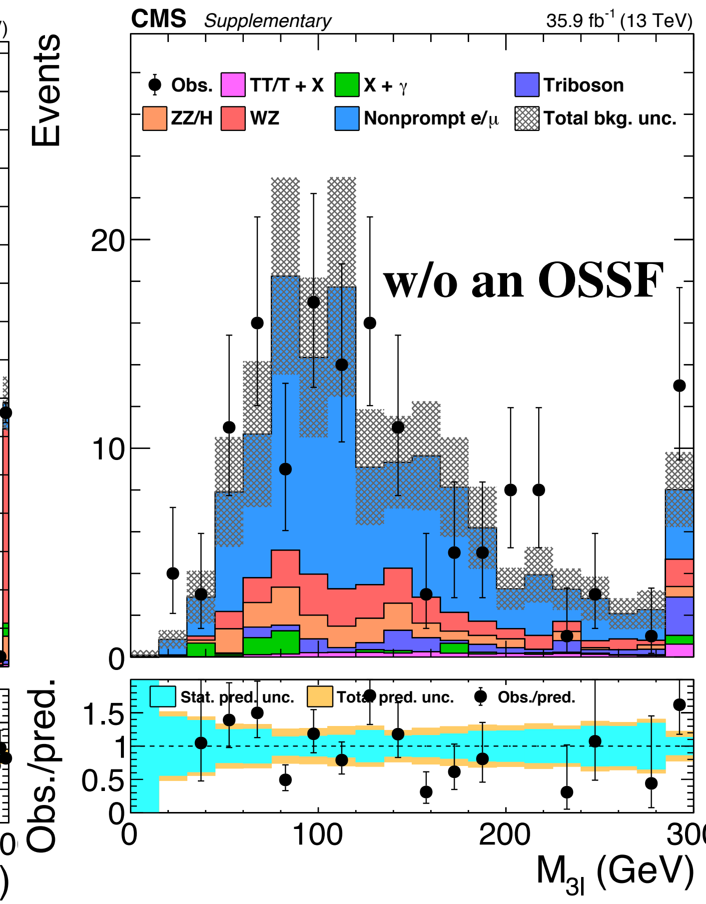


HNL searches @ CMS

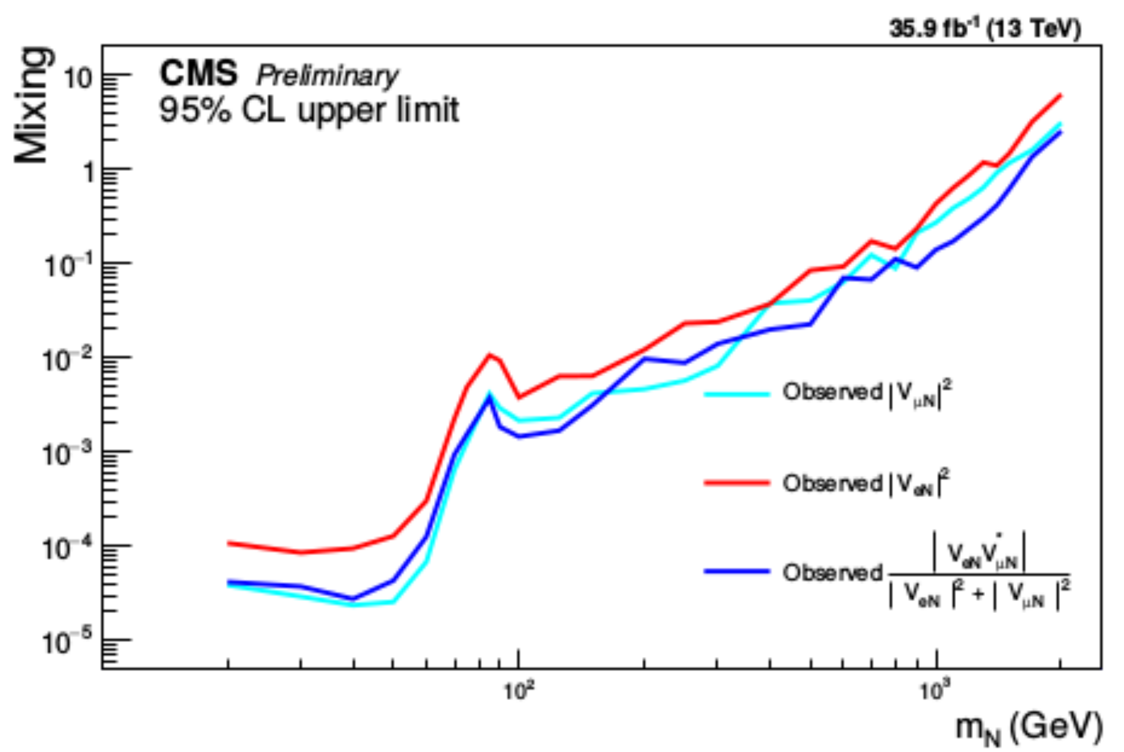
- Search of prompt HNL decays in the fully leptonic channel is public (doi:10.1103/PhysRevLett.120.221801)



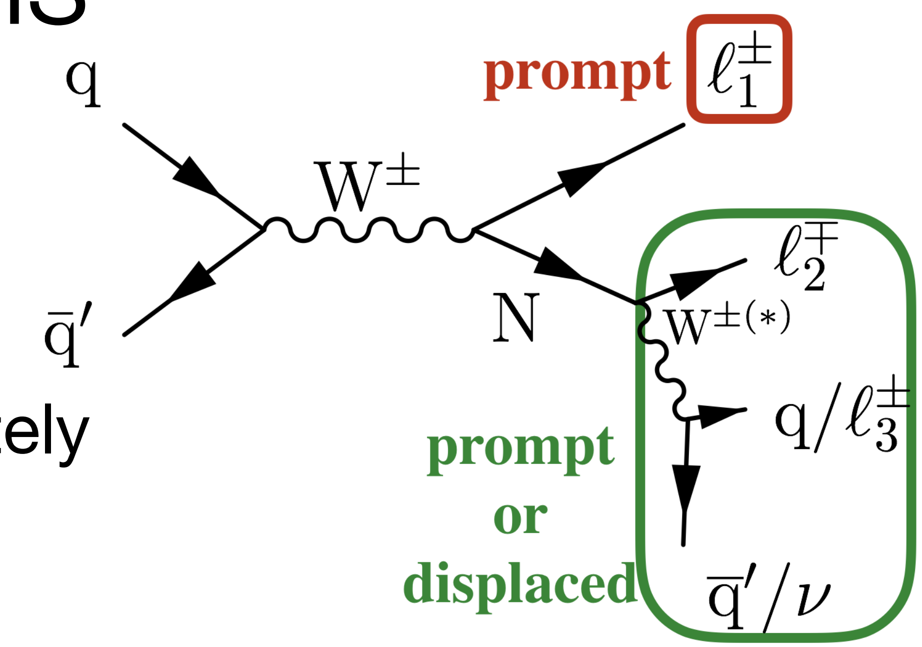




- Prompt 2l2q analysis probe $m_{HNL} \approx 20$–1200GeV (arXiv:1806.10905 , submitted to JHEP)

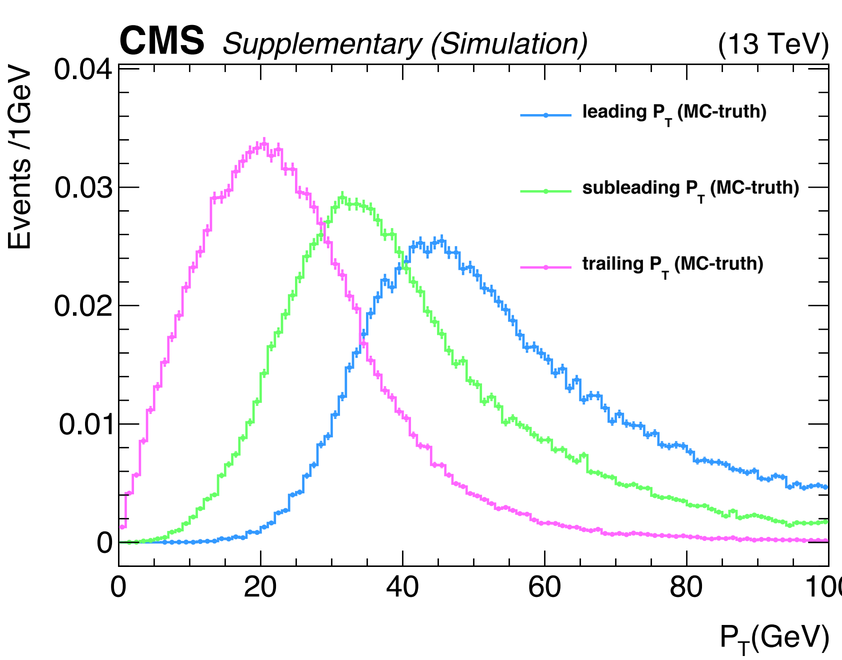


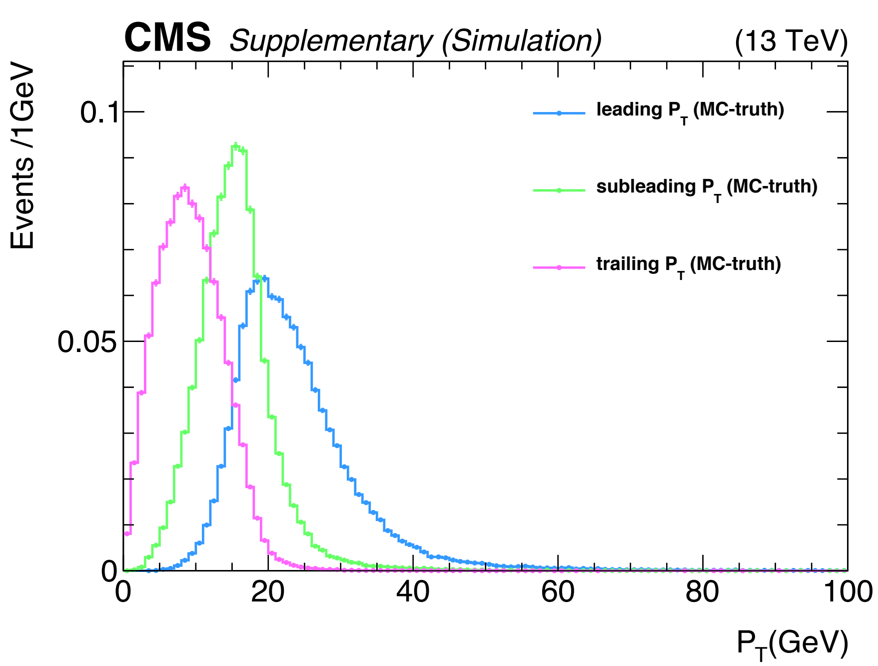
HNL searches @ CMS

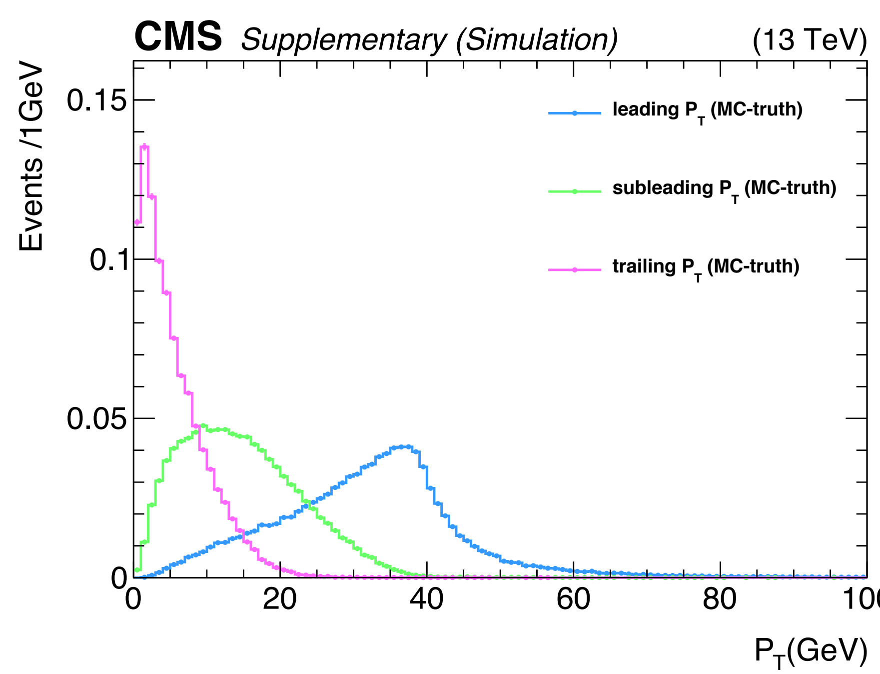


- Search for displaced signatures:
  - 3 l + 1 ν and 2 l + 2q (l = e, μ)
- SS and OS di-leptons (l_1 and l_2) considered separately

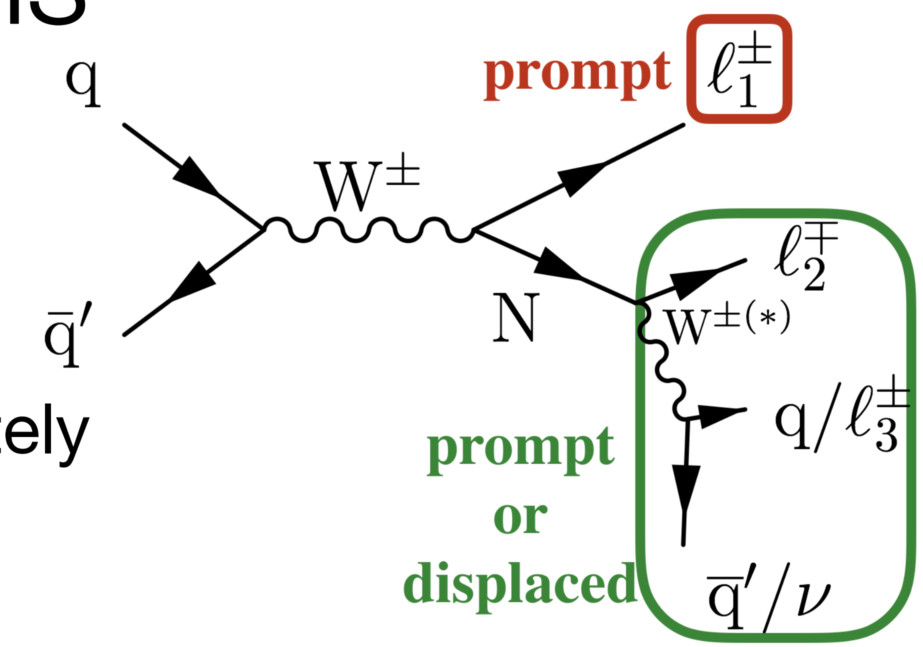
- Analysis challenges:
  - lower masses: lower pt spectra (i.e lower trigger efficiency)





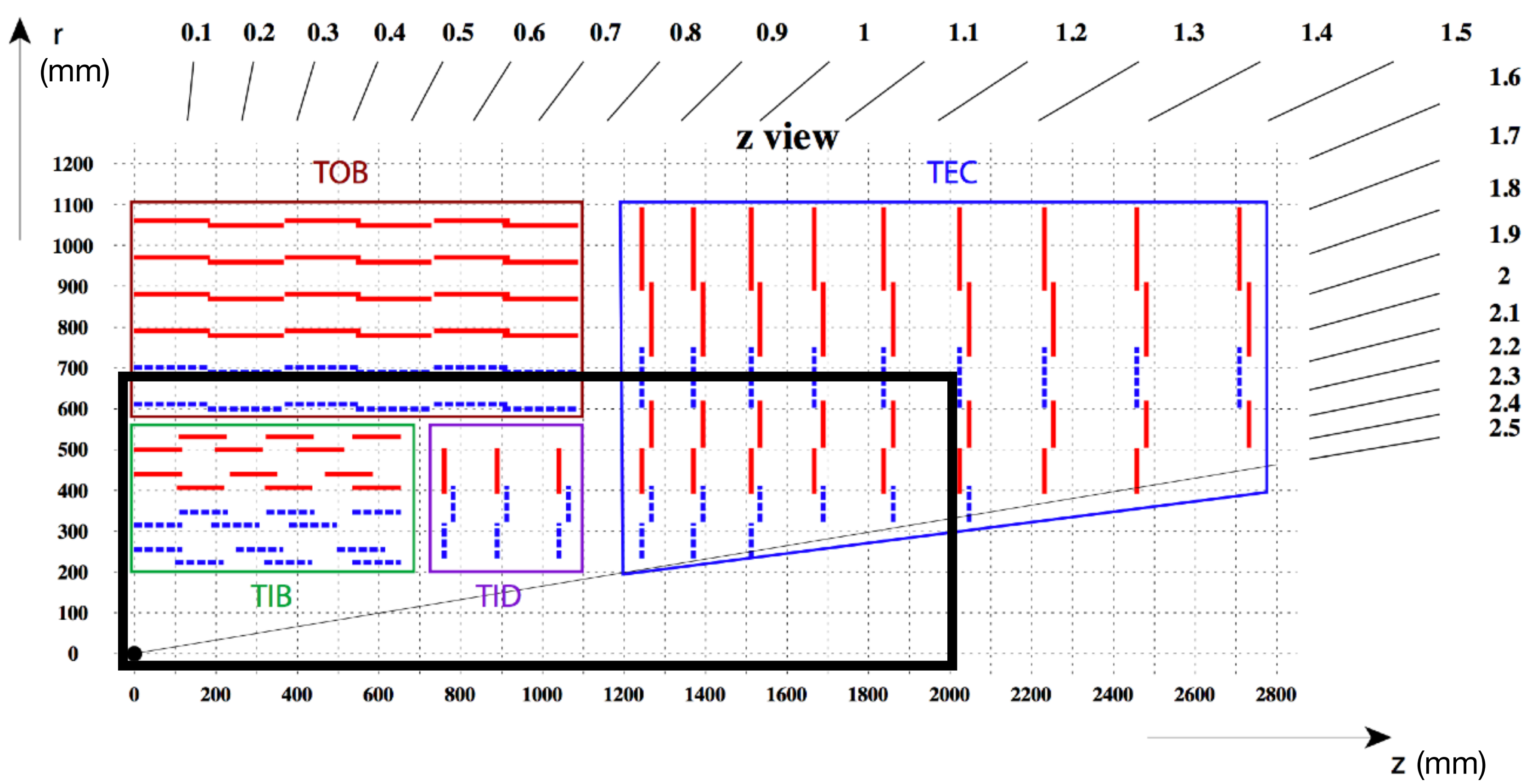


HNL searches @ CMS



- Search for displaced signatures:
  - 3 l + 1 ν and 2 l + 2q (l = e, μ)
- SS and OS di-leptons (l_1 and l_2) considered separately

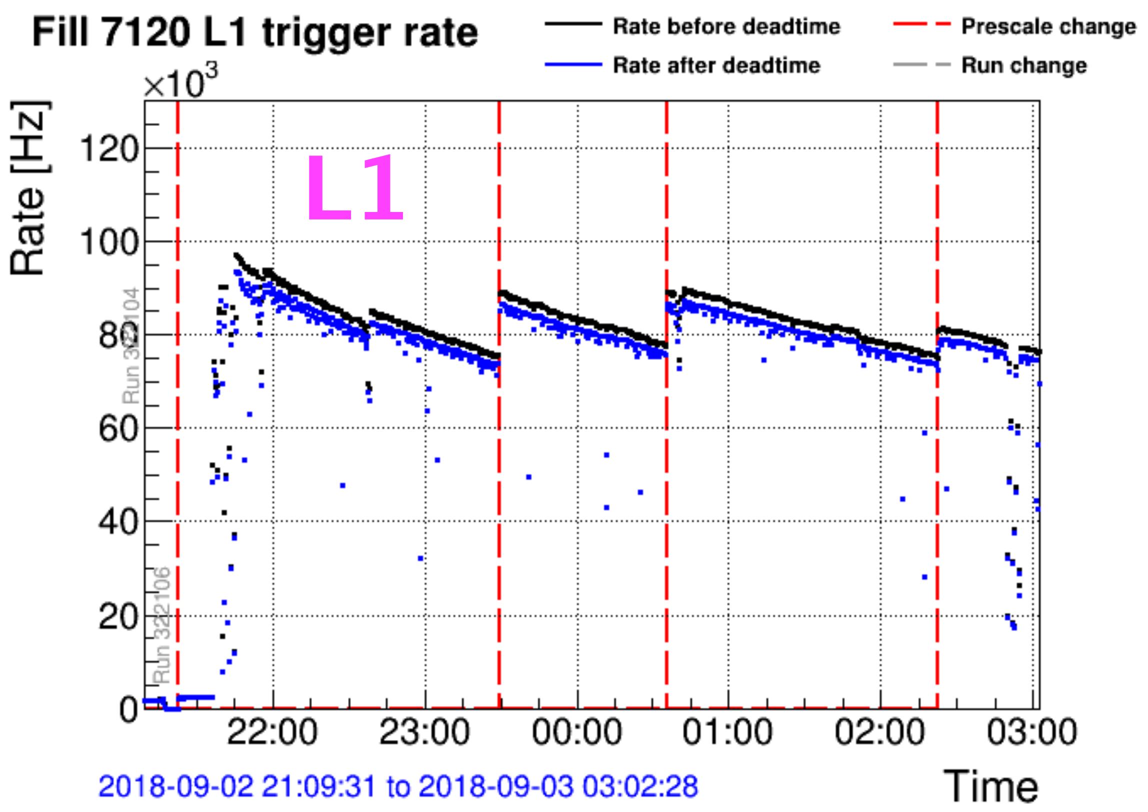
- Analysis challenges:
  - displaced object: lower reconstruction efficiency

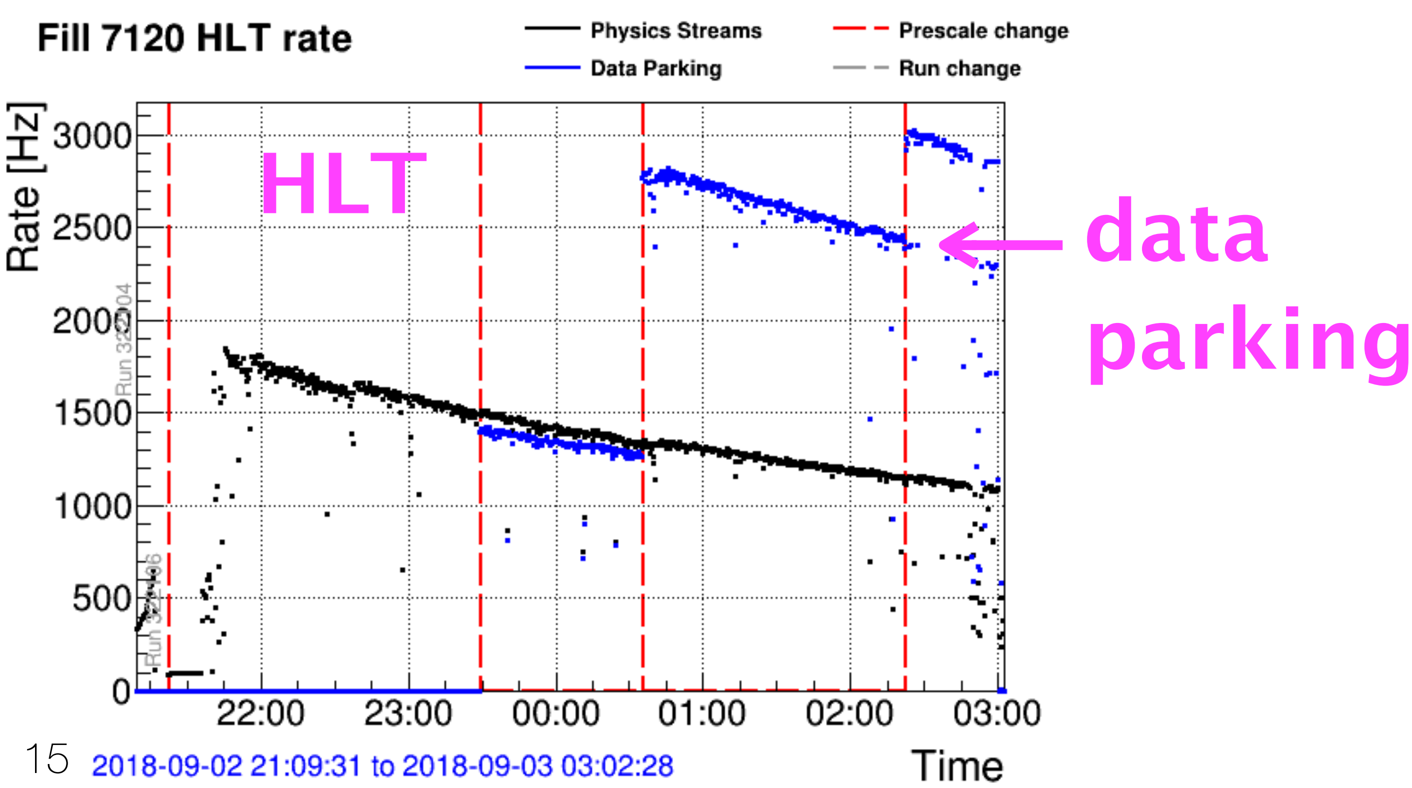


B parking

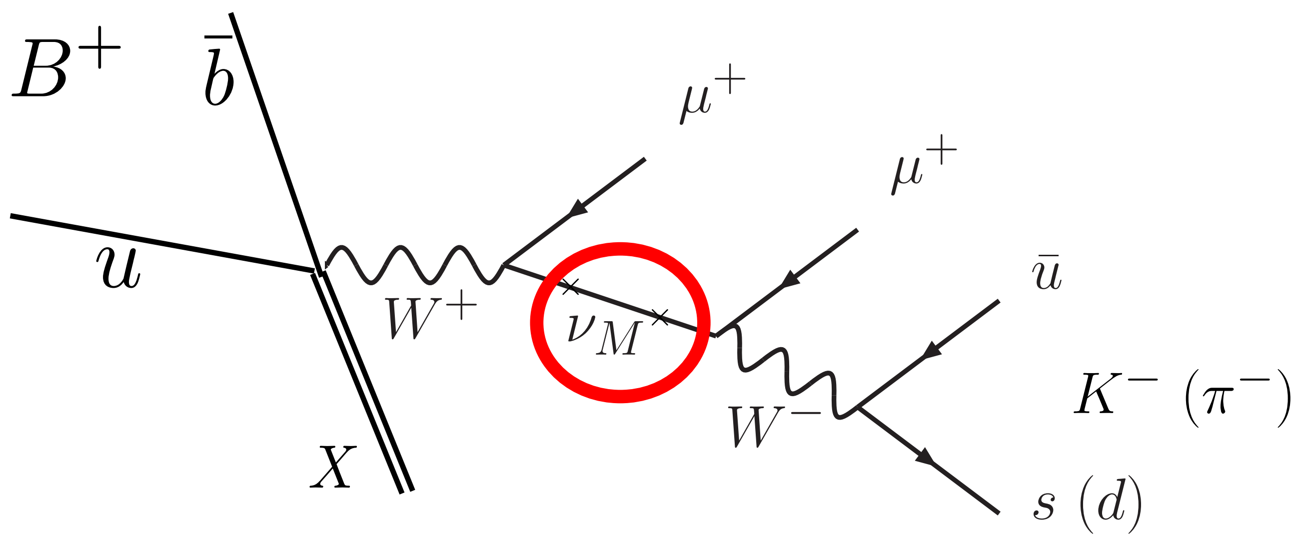
Parking of an unbiased sample of B mesons:
- motivated by study of B anomalies
- rates up to 5 kHz
- ~10^{10} events recorded

Strategy:
- trigger on muon from one B (tag)
- collect unbiased B on the other side (probe)





HNL from B decays



Possibility to exploit the large data sample collected for HNL searches

Candidates also (mainly!) from the tag side of B parking samples

- assurance to have a muon from the B meson

HNL from B decays vs HNL from W decays

Statistics

- 10^{10} B->μX (only 2018!)
- Even better if B parking in Run 3….

- ~10^{9} W->μν in Run2 triggered and reconstructed

HNL from B decays vs HNL from W decays

Efficiency

- Where is higher?

  - Only HNL displacement in W-> HNL decays: higher acceptance for given mass and coupling

- What about boost?

  - naively HNL from B more boosted (to be verified)

  - in such case, higher reconstruction efficiency for B->HNL decays

HNL from B decays vs HNL from W decays

Mass spectrum and final states

- Mass below 5 GeV (B mass)
- Possibility to select final state fully reconstructible:
  - B mass constrain can be applied

- Wider mass spectrum to probe
- Both OS and SS analyses feasible
- Both fully leptonic and semileptonic analyses feasible

HNL from B decays vs HNL from W decays

Background

- Main backgrounds:
  - charm
  - QCD
  - partially reconstructed / mis-reconstructed B decays

- W+ jet main background
- Very low background expected at large displacement

HNL from B decays - HI

- Single muon triggers available:
  - no p_T requirement, low energy in HF (2% of total rate)
  - p_T > 12 GeV (0.7% of total rate)

HNL from HI vs HNL from pp

HNL from HI:
- No pileup
- Higher cross section

HNL from pp:
- Less tracks per vertex
- More luminosity
- Higher collision energy

Summary

- Large variety of searches for LLP in CMS
  - many different models and signatures
  - several challenges: triggers, reconstruction..
- HNL searches are a trending topic in HEP:
  - prompt analyses in CMS published
  - now moving towards displaced searches
- B parking provide a large sample of B->μX decays:
  - new place where to look for HNL?