Recent CMS results with long-lived particles

Andre Sterenberg Frankenthal

Princeton University

LLP2024 Workshop at U. Tokyo

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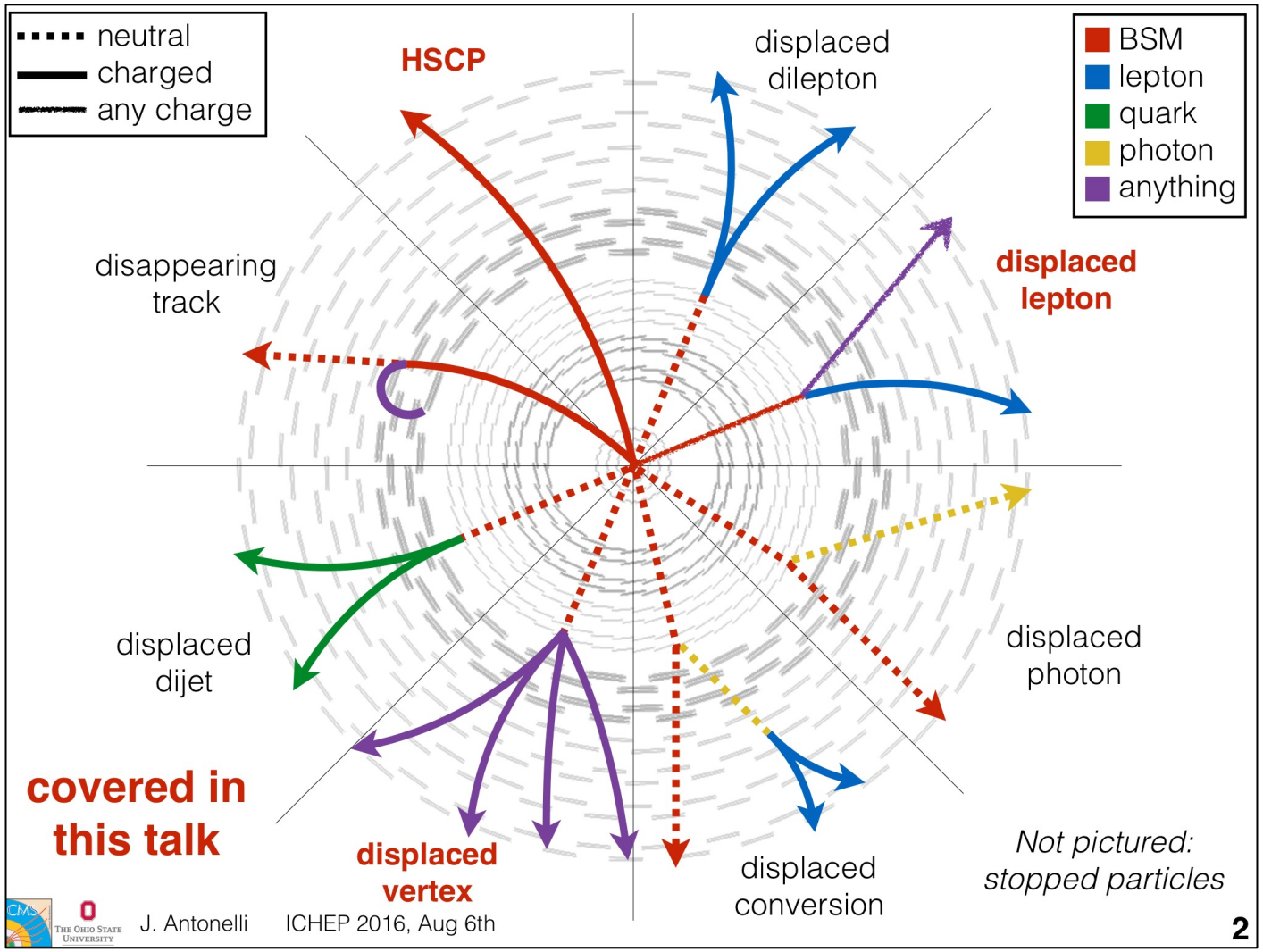
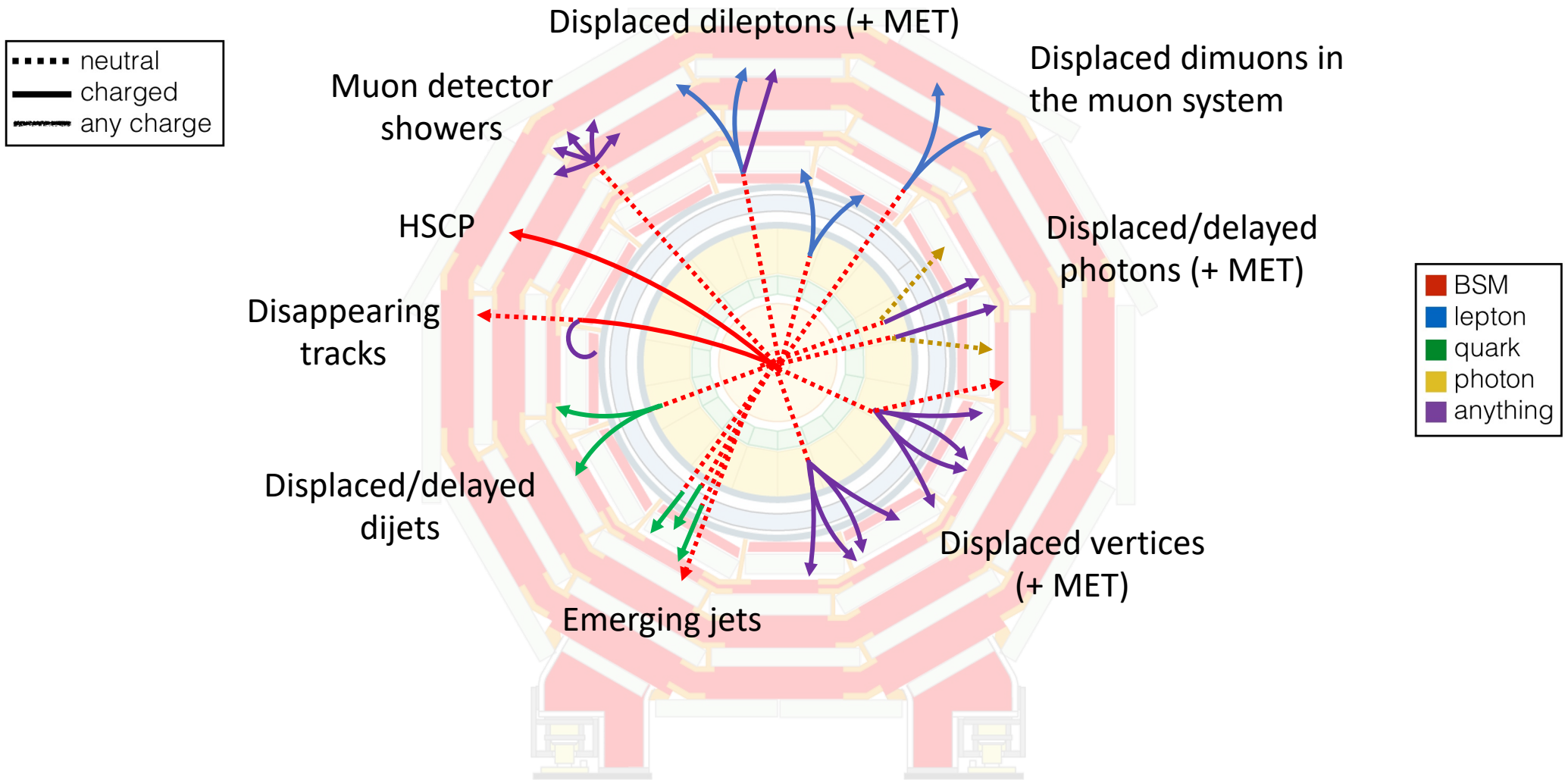
The CMS LLP program ca. 2016



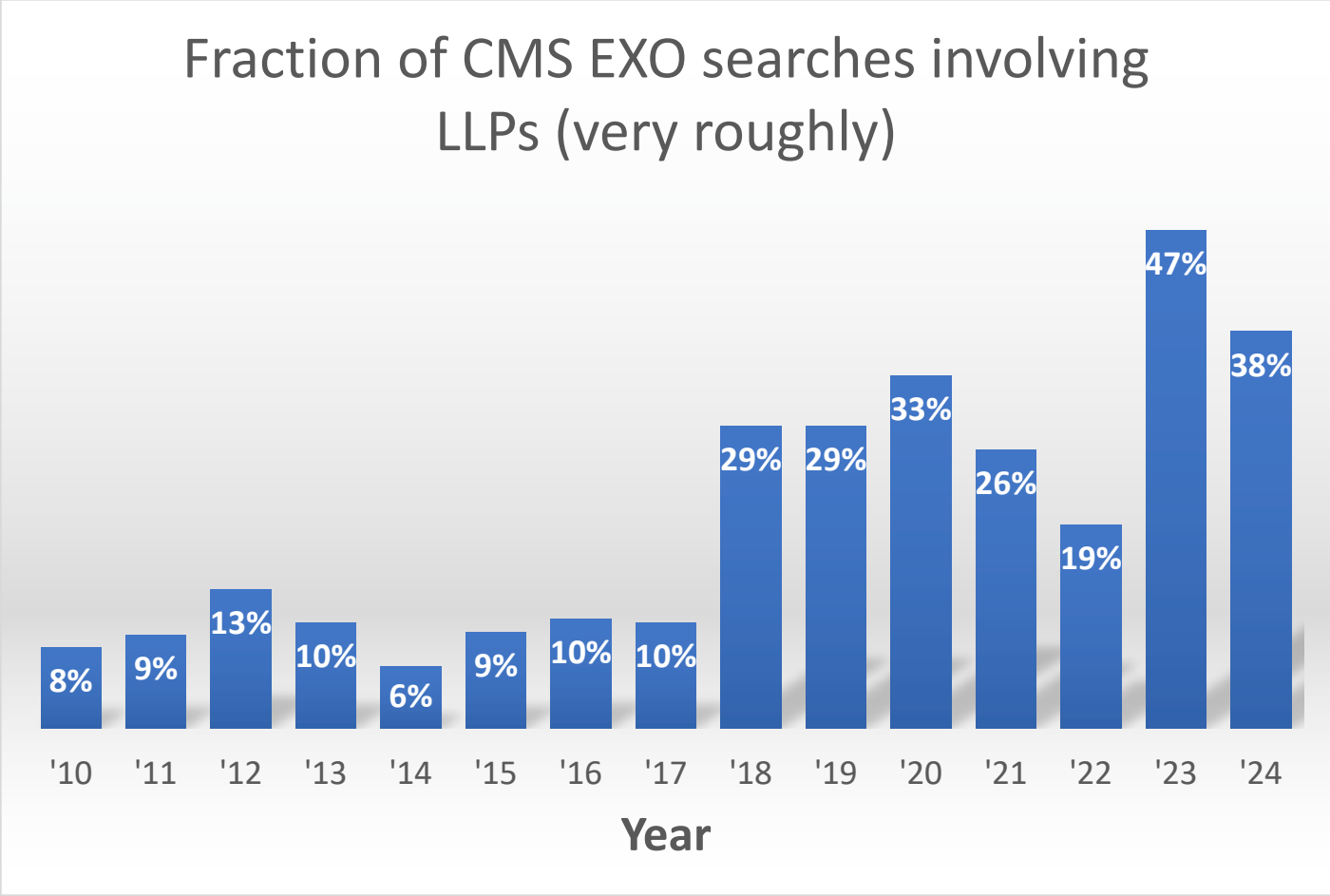
J. Antonelli, ICHEP 2016

The CMS LLP program today



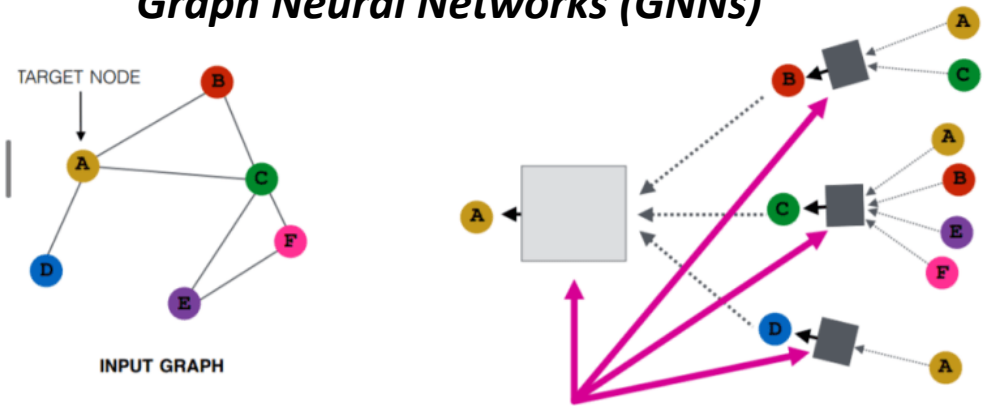
The CMS LLP program

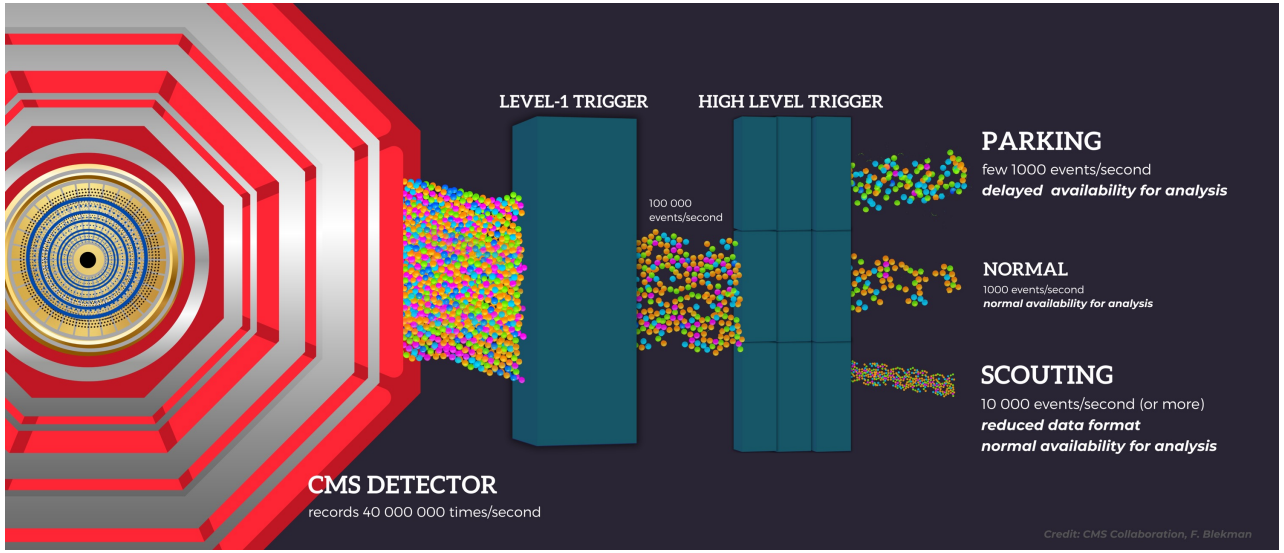
- Rich LLP program encompassing many areas
- BSM LLP searches have been carried out since dawn of LHC
- But dramatic growth in the past several years
- Very active area of research in CMS!

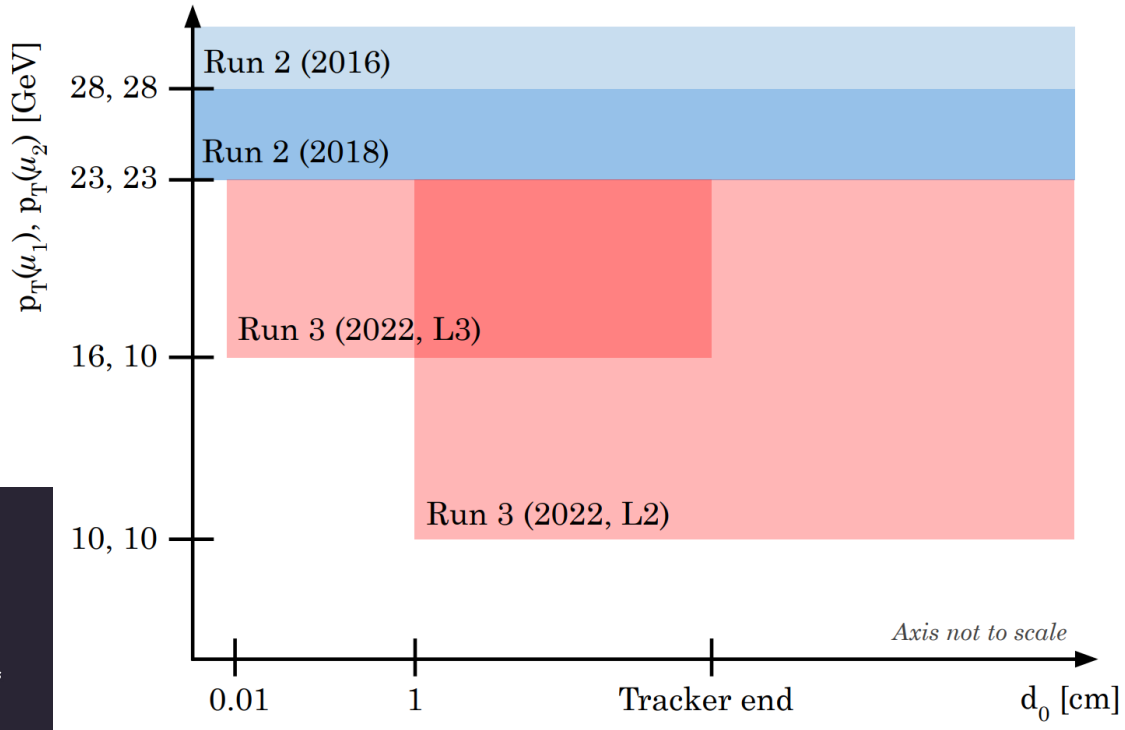


Developments across all fronts

Graph Neural Networks (GNNs)







Trigger thresholds

(Check out Kiley's Kennedy talk about CMS LLP triggers)

Data scouting and data parking

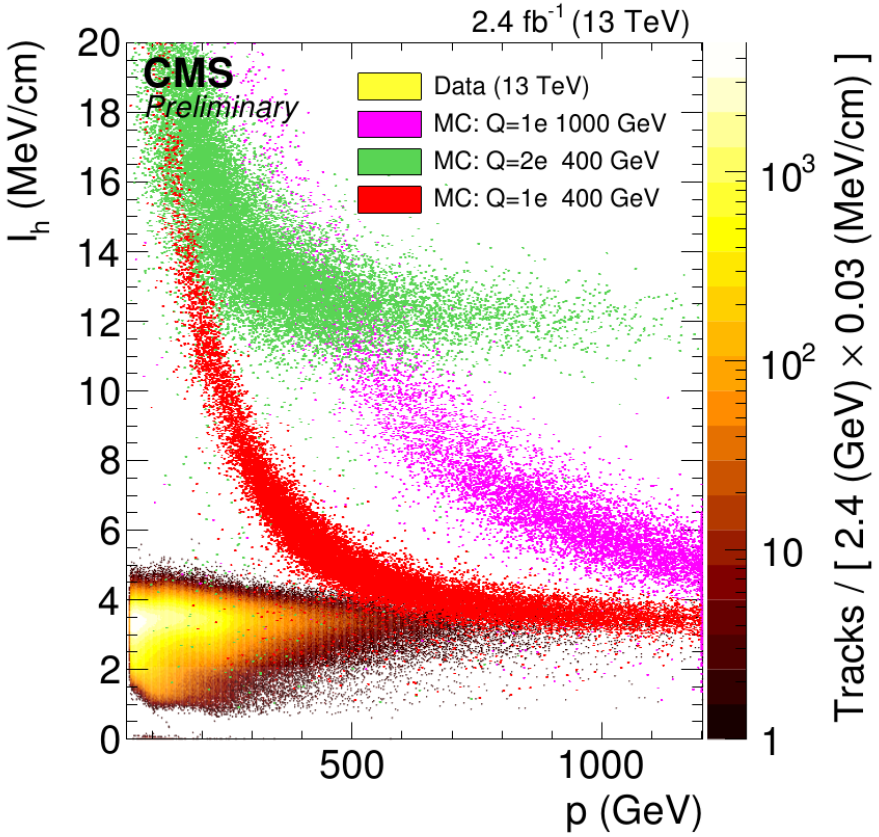
Many new CMS results since last year!

- 8 new LLP results over the past year in this workshop
- Will briefly highlight major aspects of each at a “high level”
- Make sure to attend the talks to learn more!
  - Heavy Stable Charged Particles
  - Emerging jets
  - Displaced vertices + MET
  - HNLs in the muon system
  - HNLs in the B-parking dataset
  - HNLs in semi-leptonic decays
  - Early Run 3 displaced dimuons
  - Early Run 3 displaced dijets

Heavy Stable Charged Particles (HSCPs)

CMS-EXO-18-002

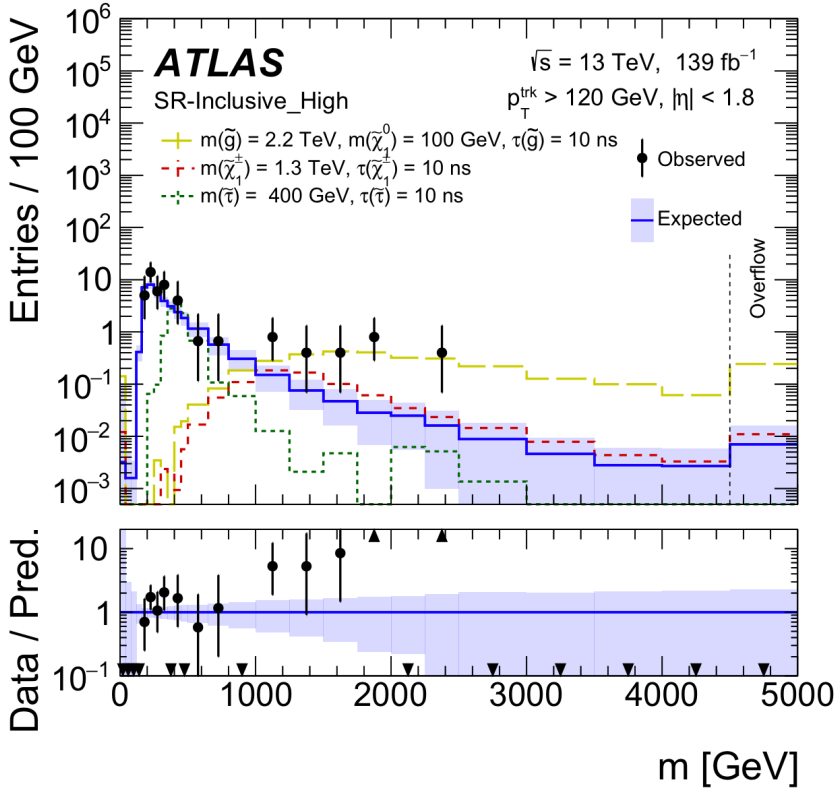
- HSCPs are hypothetical LL heavy particles that travel much slower than c
- Can be detected via unusual tracker ionization energy deposition (dE/dx)
- CMS developed two data-driven background estimation methods to cross-check any potential excesses
- First full CMS Run 2 HSCP result is now public! Check out Larry Lee's talk for the full scoop

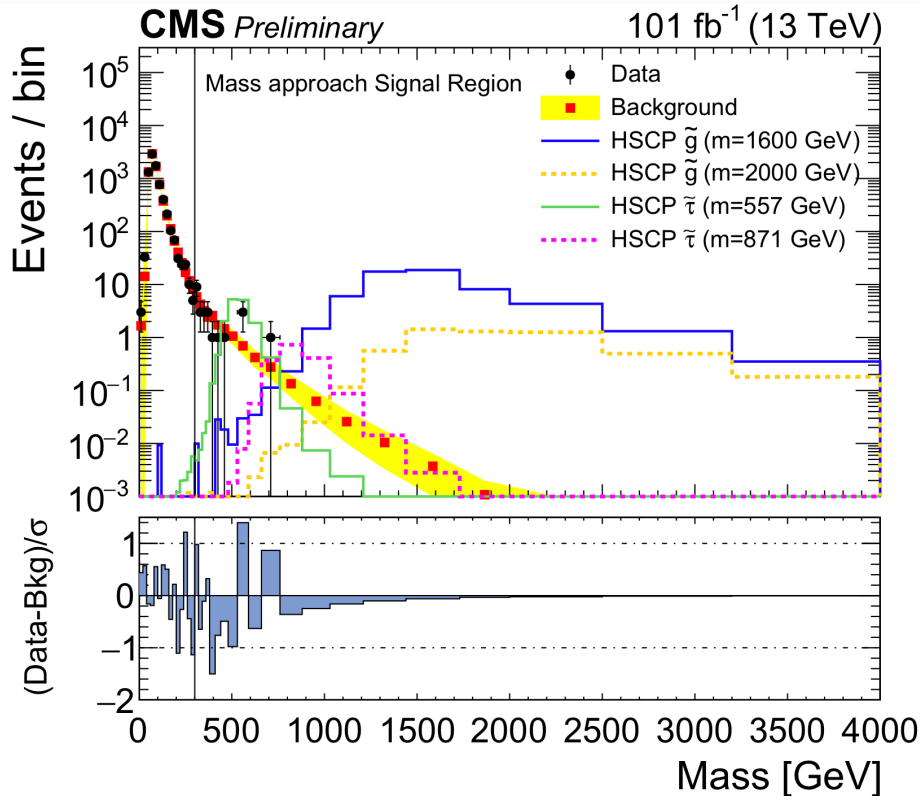


Heavy Stable Charged Particles (HSCPs)

- ATLAS found a 3.3σ global excess in their Run 2 analysis
- But CMS **does not** see any excesses in the same region

CMS-EXO-18-002





Emerging jets

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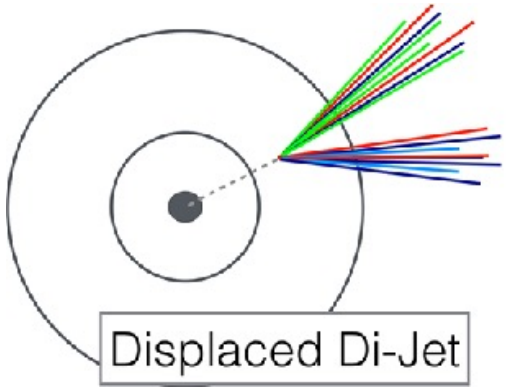
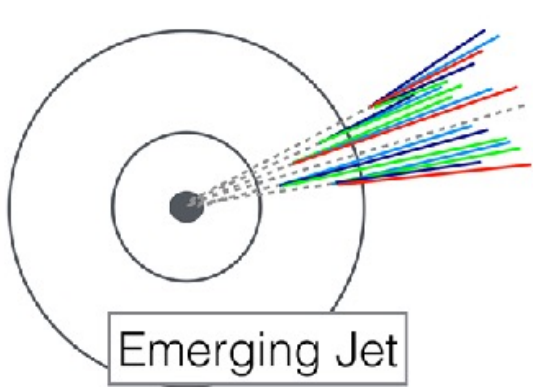
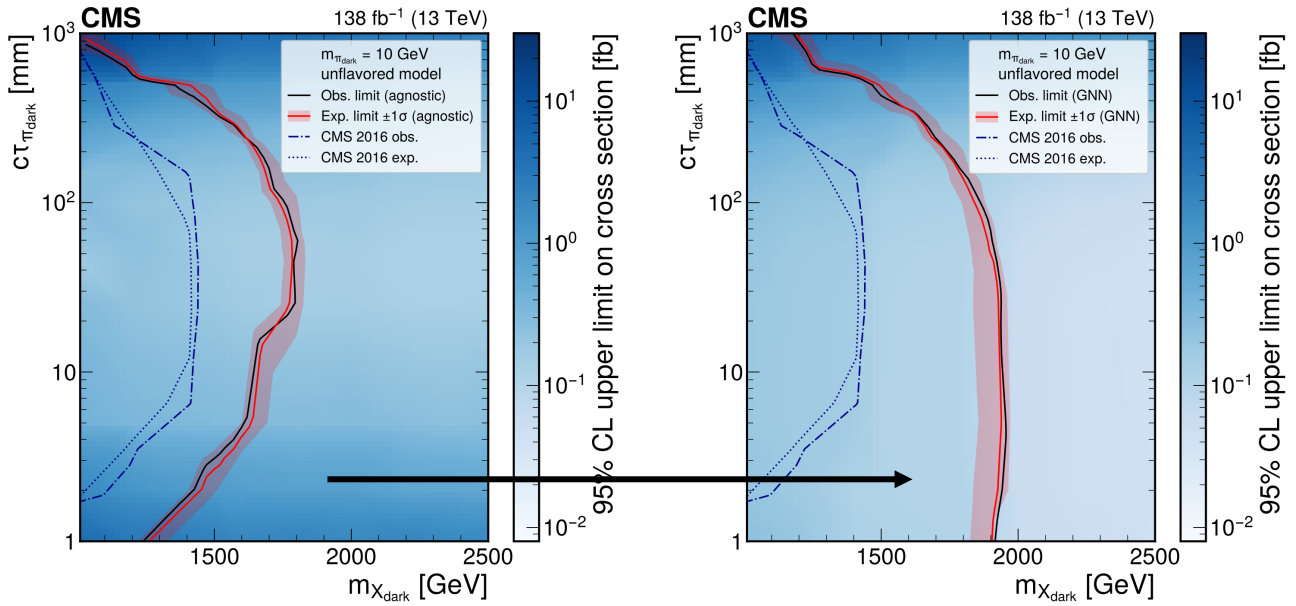
CMS-EXO-22-015

- If dark sector features QCD-like symmetry, LHC could produce dark quarks and mesons
- CMS studies this possibility by searching for “emerging jets”
- New powerful GNN-based tagging method to increase sensitivity
- Latest search does not find evidence for this model
- See Claire Savard’s talk for more details!

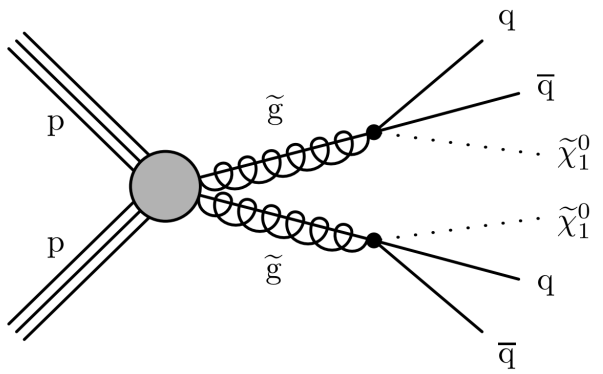






Displaced vertices plus MET

- New search for mildly displaced vertices (inside the beampipe), accompanied by MET
- Vertices from LLP decays are required to have at least 5 tracks
- A new ML algorithm improves the background rejection by 10x
- Can require only one displaced vertex now, also reaching sensitivity to much more compressed scenarios
- See more details in talk by Ang Li



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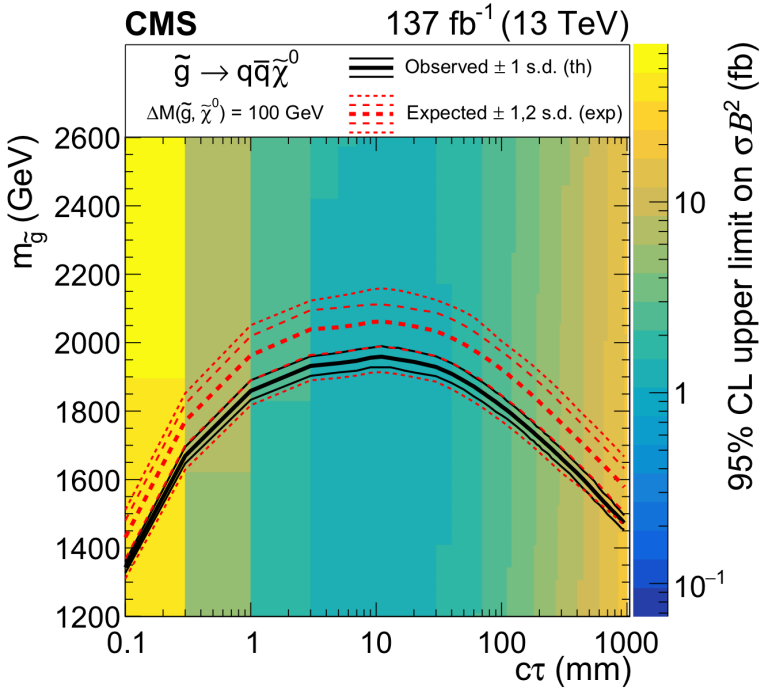
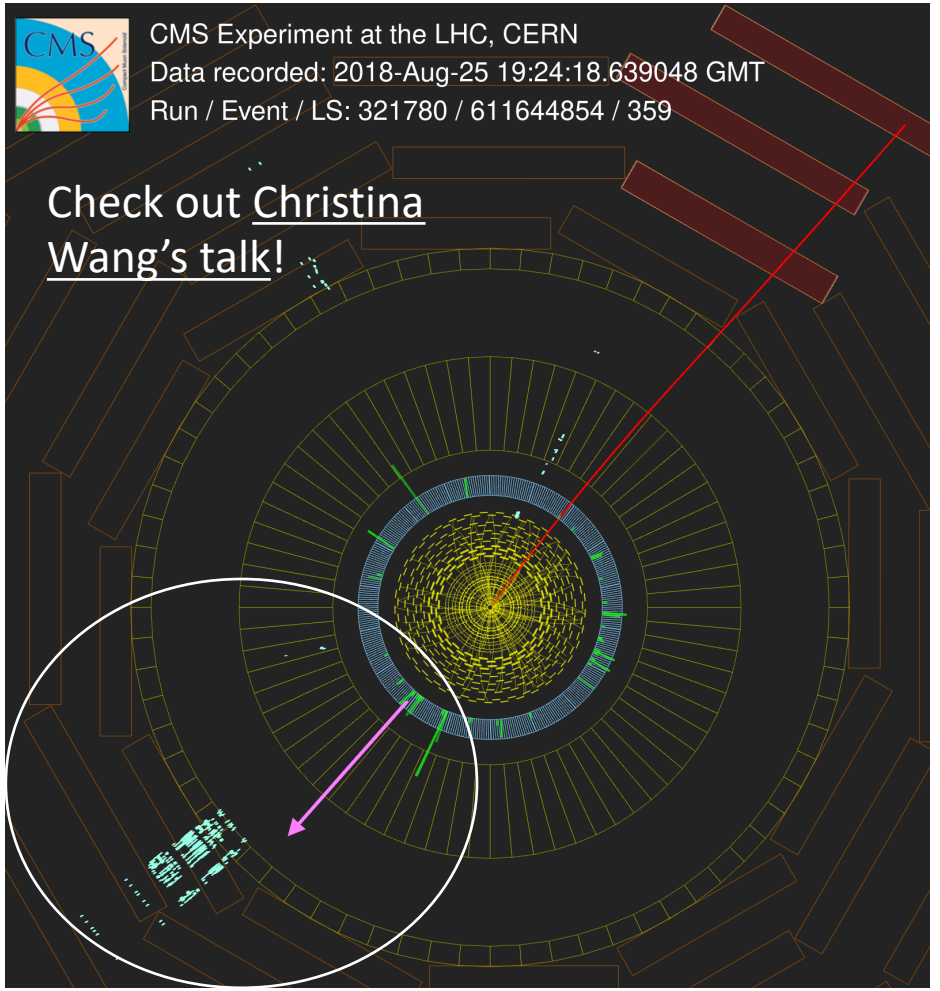
CMS-EXO-22-020



HNL searches

HNLs and muon detector showers

- Heavy Neutral Leptons (HNLs) are a popular way to explain nonzero neutrino masses via “seesaw” mechanism
- HNLs could be long-lived since their lifetimes are inversely proportional to $m_N^5 \, |V_{Nl}|^2$
- CMS recently introduced an entirely new experimental signature: muon detector showers (MDS)
- Clever use of muon system as a sampling calorimeter, extending LLP sensitivity at very large displacements



HNLs in the muon system

- Now we have published the first search for HNLs using MDS!
- The very large displacement acceptance translates to exquisite sensitivity to small V_{Nl} values in the mass range 1--3 GeV
- See talk by Martin Kwok for more details!

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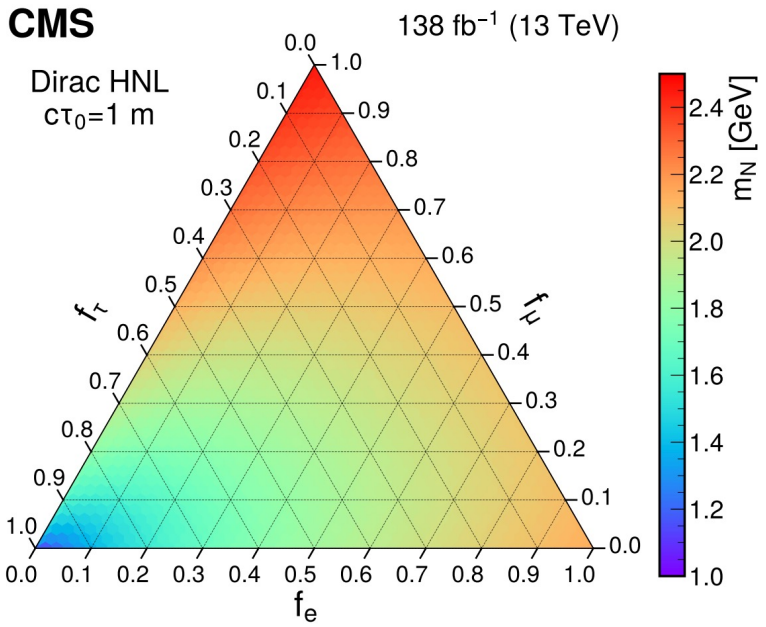
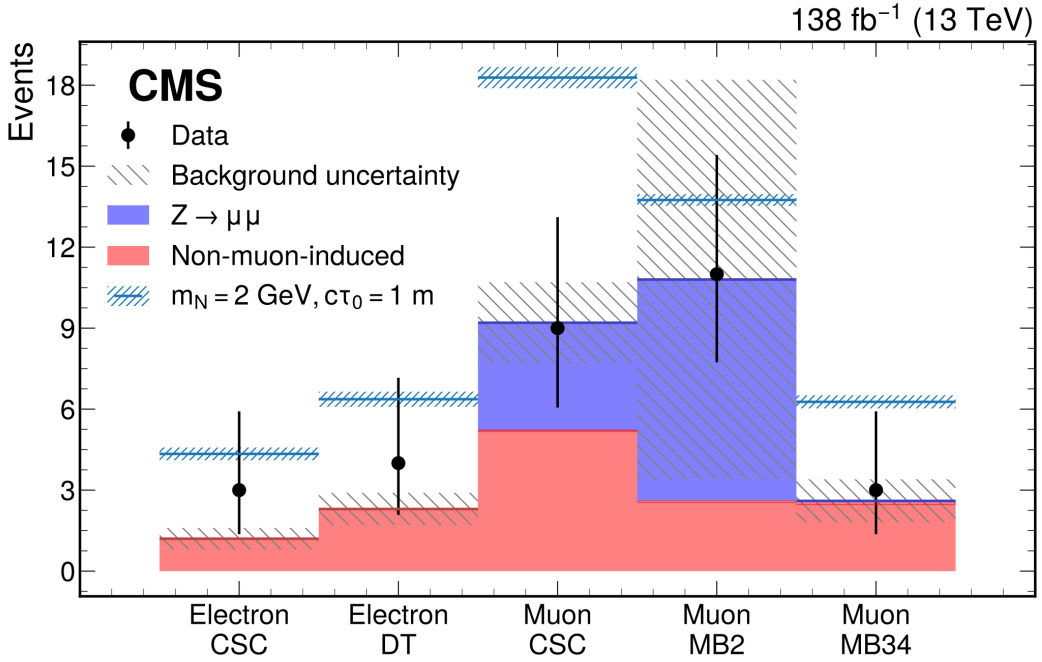
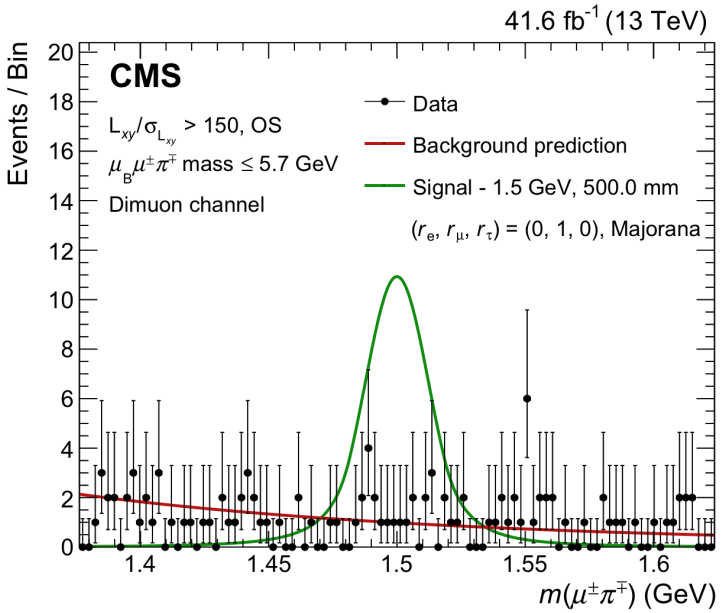
CMS-EXO-22-017





HNLs in the B-parking dataset

- We present a search for LL HNLs in our Run 2 B-parking dataset
- Look for HNLs produced in B meson decays: $B \rightarrow l_B N X$, $N \rightarrow l\pi$
- Provides excellent sensitivity in intermediate m_N ranges, ~3-6 GeV
- First EXO search using parking dataset! Anne-Mazarine Lyon's talk will cover this result



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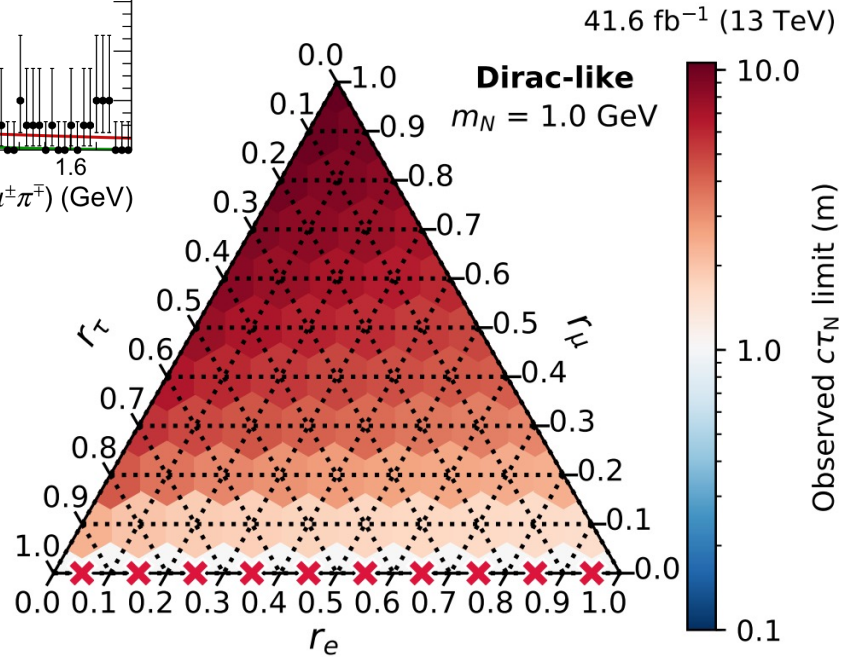
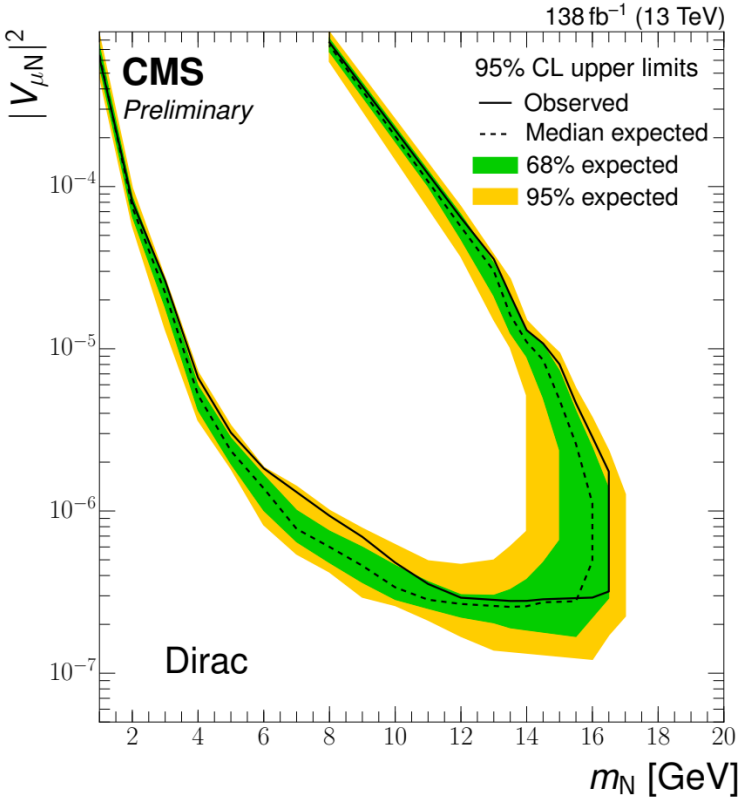


HNLs in semi-leptonic decays

CMS-EXO-21-011

- We also search for HNLs decaying semi-leptonically
- Specialized ML algorithm to reconstruct the displaced vertex consisting of a nonprompt lepton and merged jet
- Provides the best sensitivity in the 11-16 GeV m_N range
- See talk by Mohamed Darwish for more

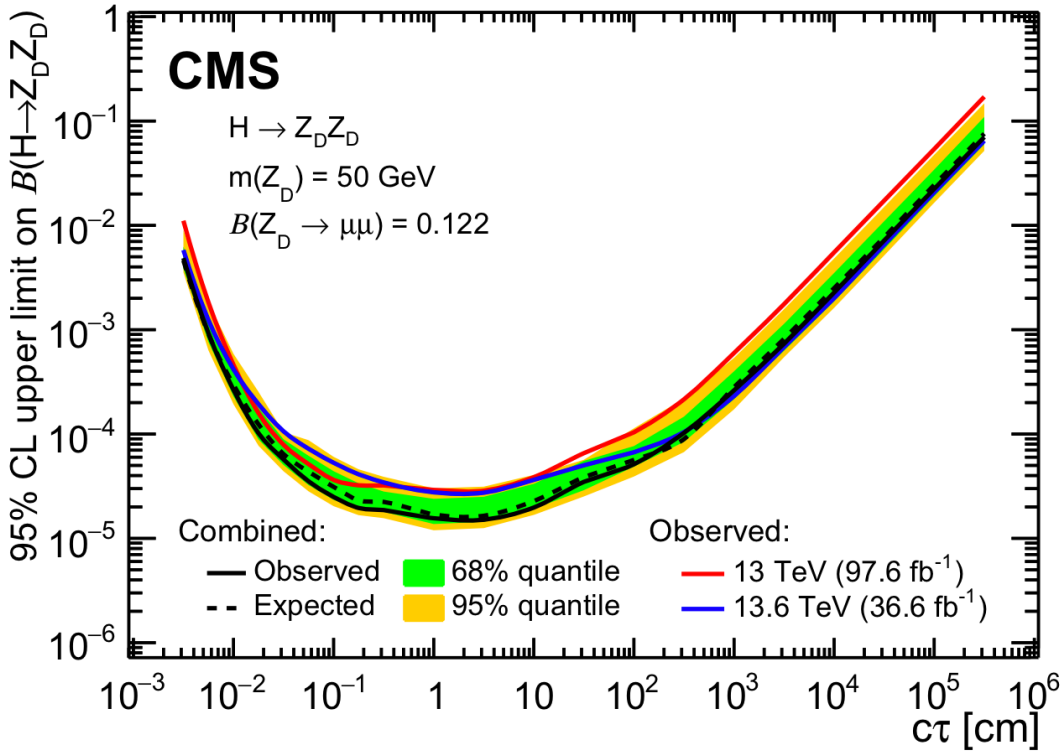


Early Run 3 results

Displaced dimuons in early Run 3

JHEP 05 (2024) 047
CMS-EXO-23-014

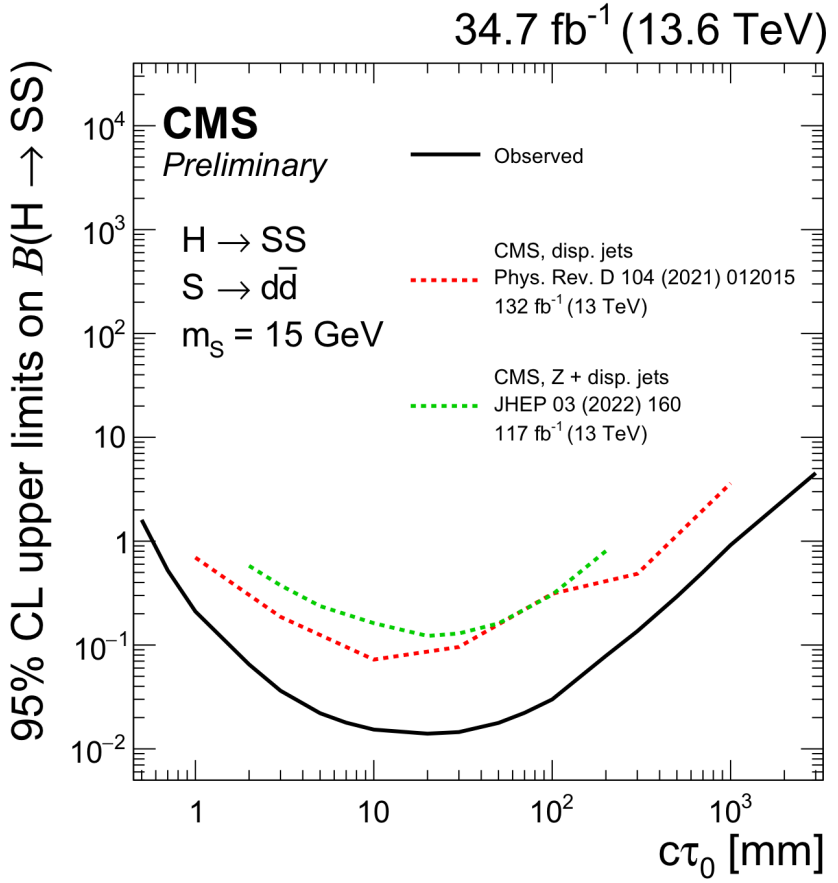
- General search for displaced dimuons
- Significant trigger improvements in Run 3
- Additional benchmark signal models tested
- Sensitivity comparable to Run 2 with only 1/3 of the data
- First EXO result with Run 3 data!
- See talk by Mangesh Sonawane for details



Displaced dijets in early Run 3

CMS-EXO-23-013

- General search for displaced dijets
- Huge improvements on trigger and object reconstruction using GNNs
- New sensitivity to light LLPs with mass < 60 GeV
- Factor of 10 improvement over previous results with only ¼ of the data
- See talk by Jingyu Luo for details



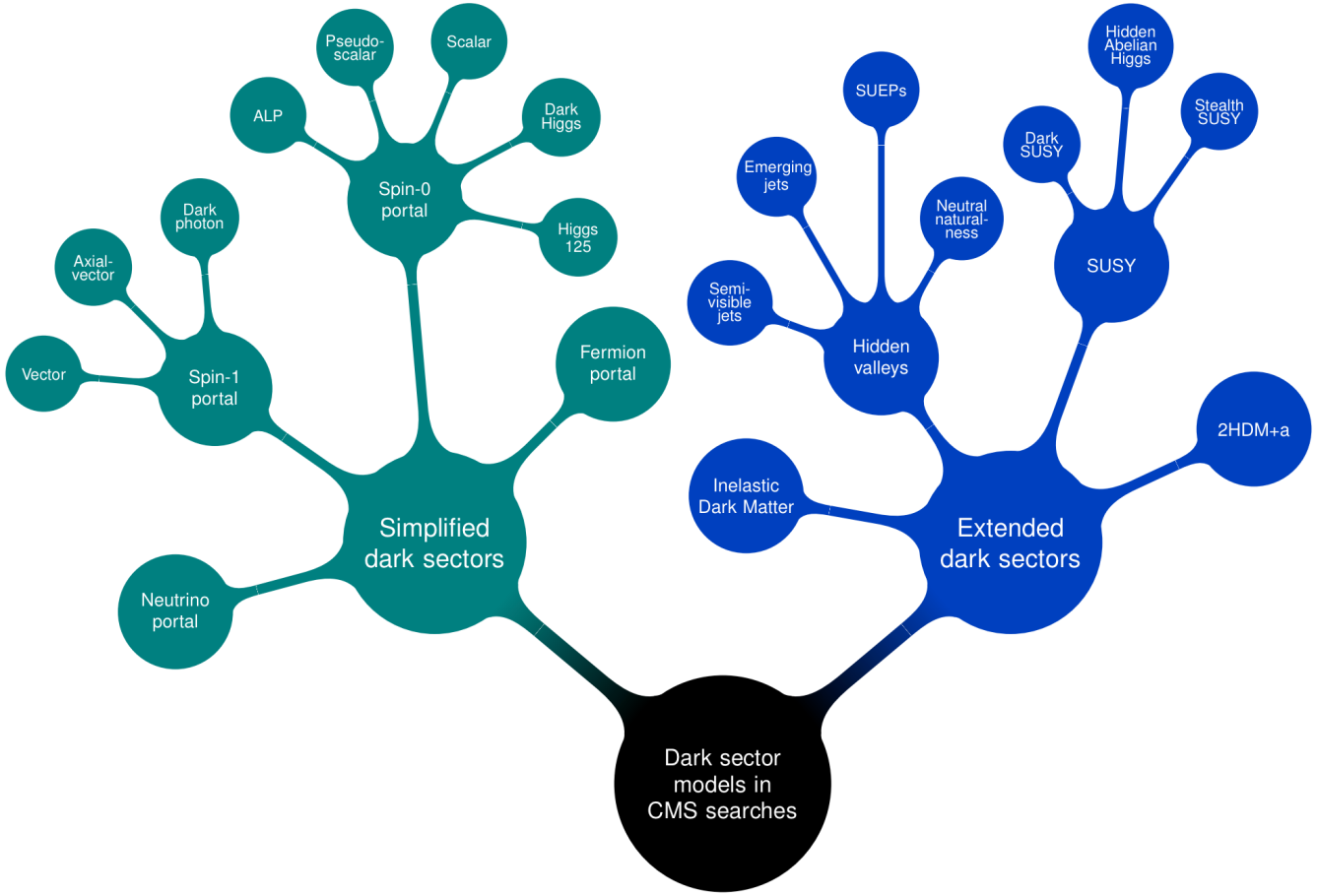
EXO review papers

Review papers

- Intense effort over the past year to produce comprehensive CMS review papers
- 7 papers in total, 3 of which relevant to BSM (and LLP) searches:
  - *Physics of Dark Sectors in CMS*
  - *Review of searches for vector-like quarks, vector-like leptons, and heavy neutral leptons in proton-proton collisions at* $\sqrt{s} = 13$ *TeV at the CMS experiment*
  - *Enriching the physics program of CMS through data scouting and data parking*
- Recently submitted to Physics Reports
- Very useful documents summarizing the many experimental results published by CMS and the techniques employed
- Could be read as (very) long papers or as used as a reference

CMS and dark sectors

- Summary and combination of CMS searches for dark sectors



CMS and dark sectors

- Summary and combination of CMS searches for dark sectors

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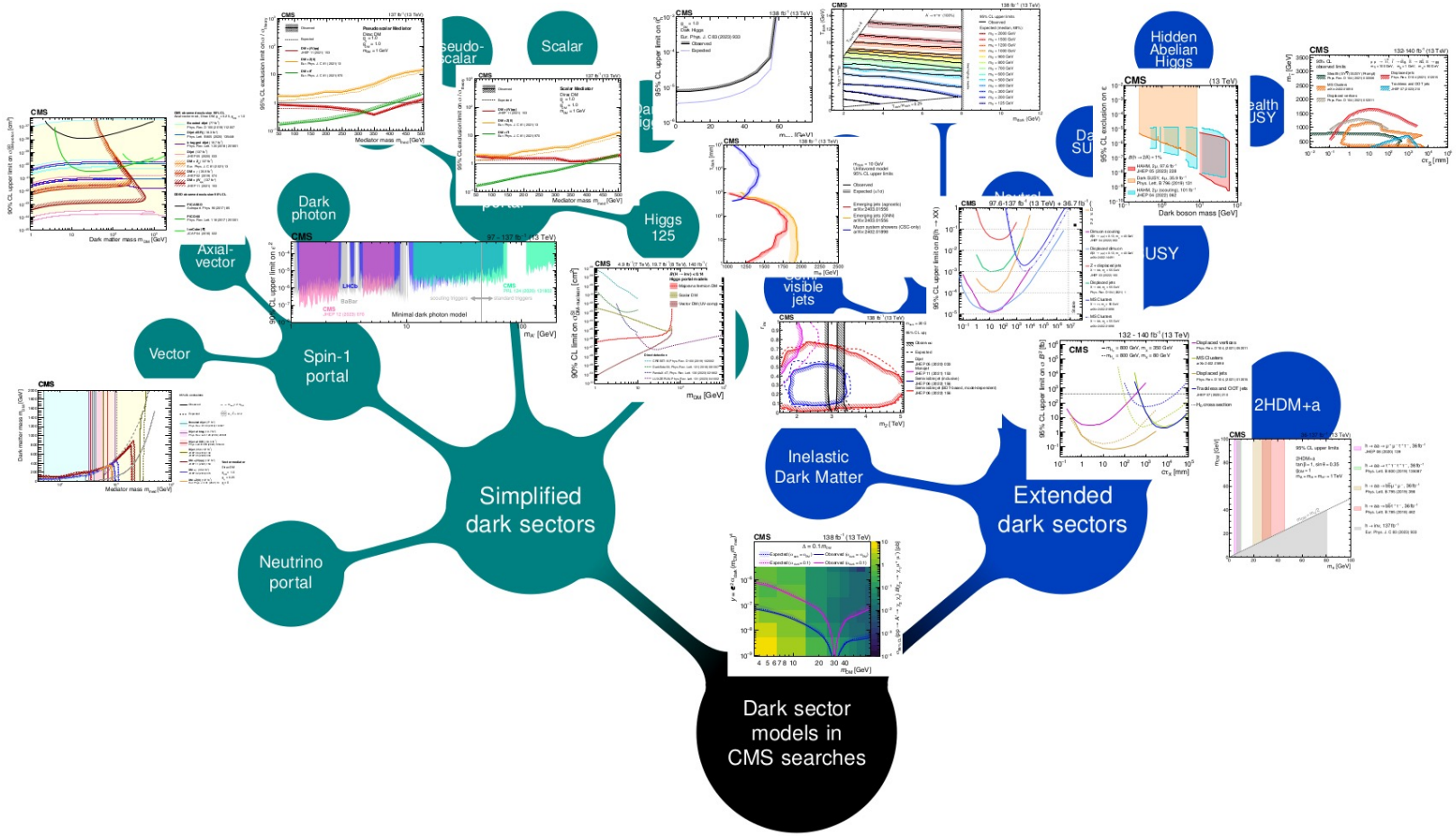
CMS-EXO-23-005



CMS and dark sectors

- New summary plots of parameter space coverage
- With several minimal models (e.g. pseudoscalar a and dark photon A')

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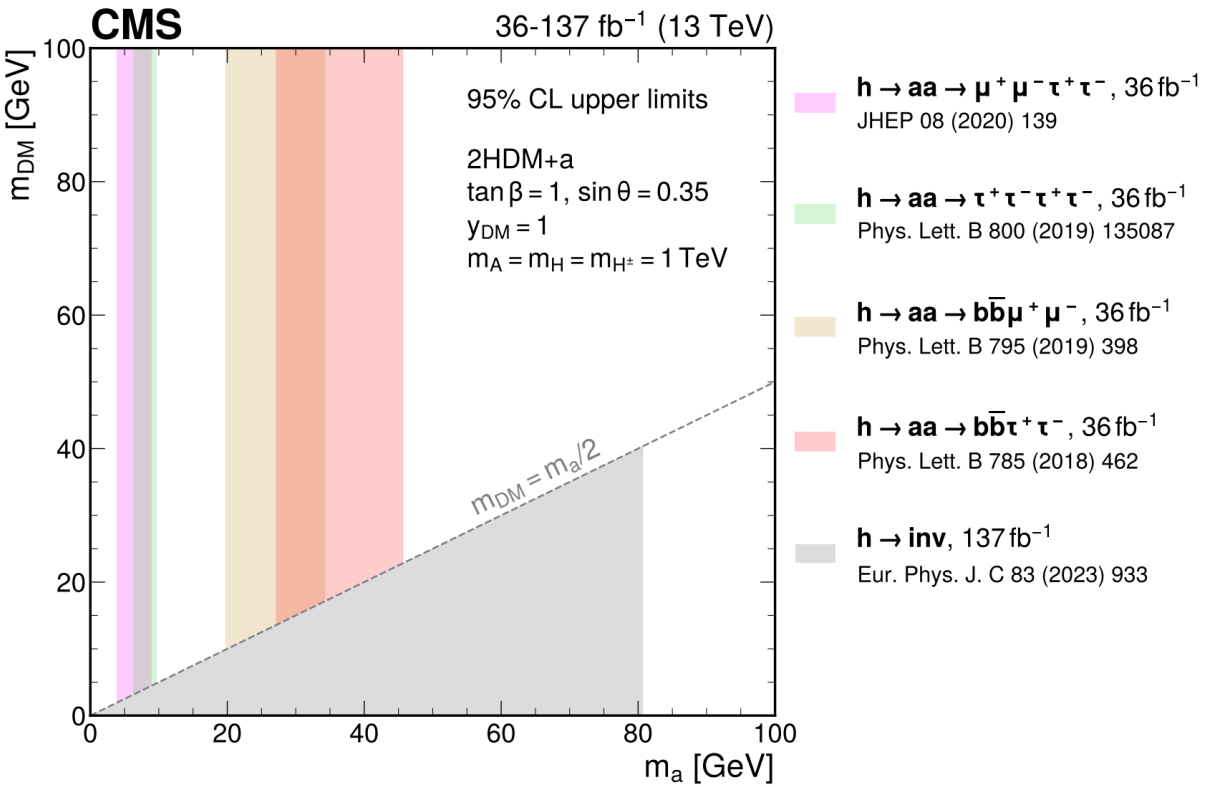
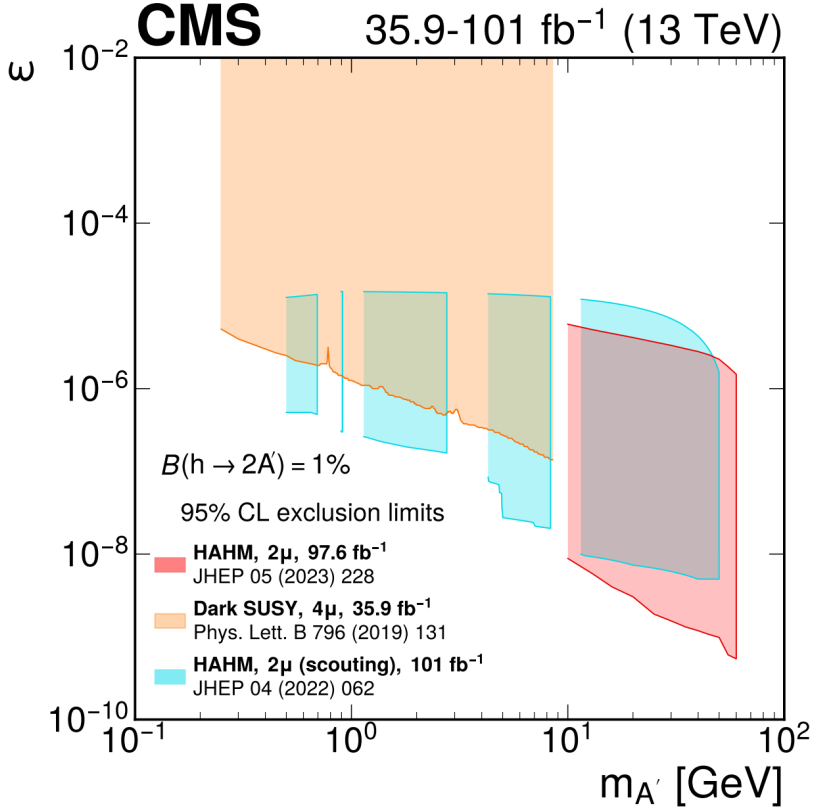
CMS-EXO-23-005





CMS and dark sectors

- New summary plots of parameter space coverage
- Several LLP searches included in the combinations

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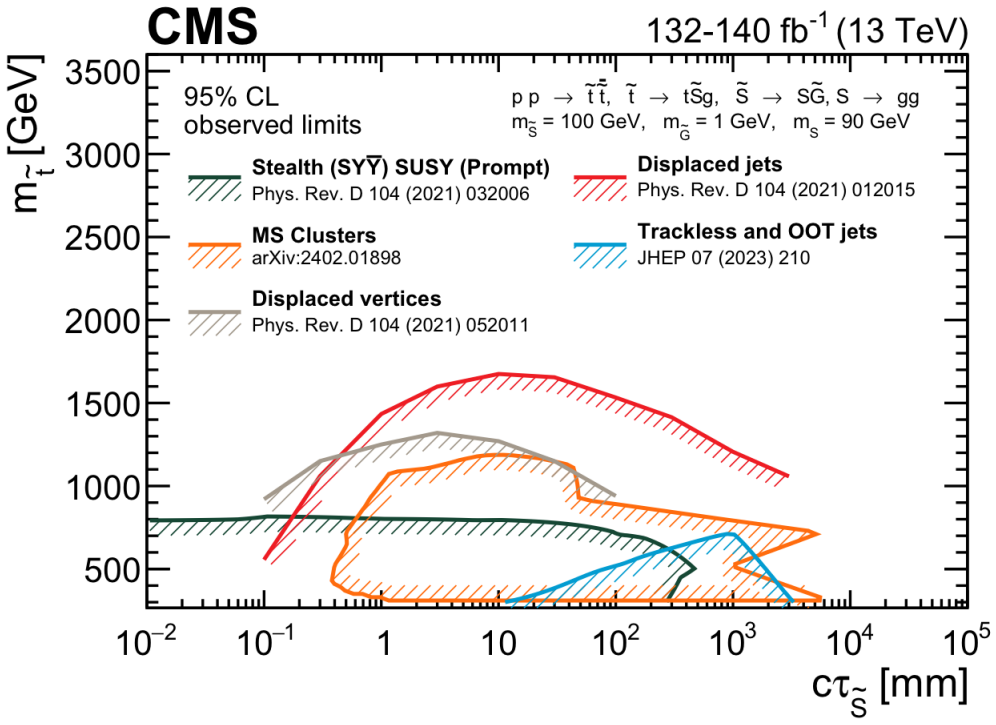
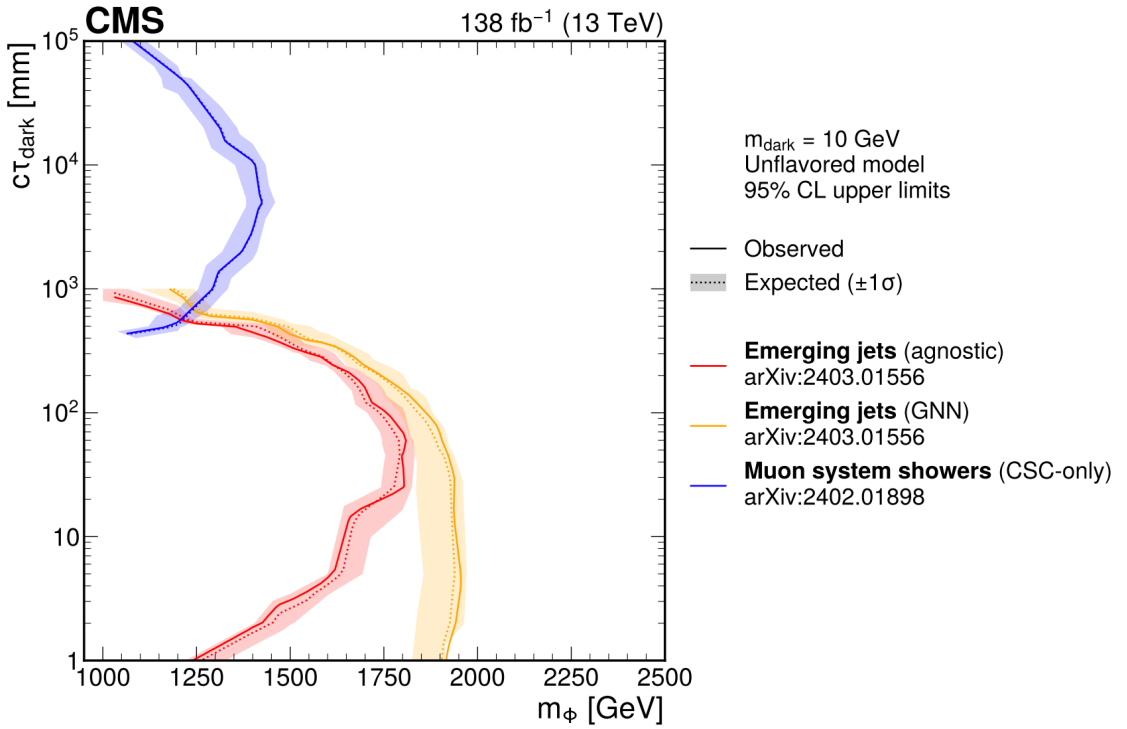
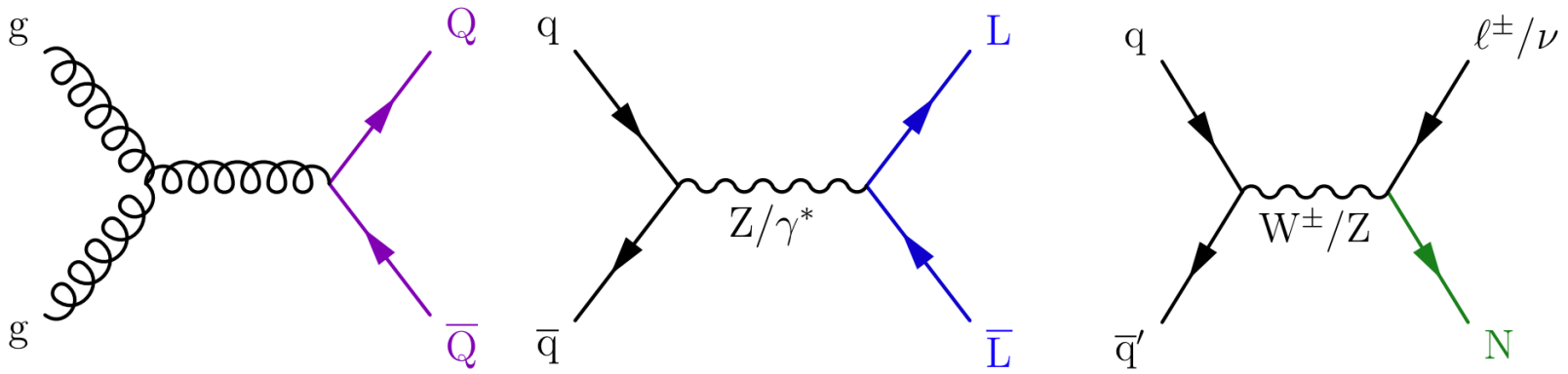
CMS-EXO-23-005





Vector-like quarks & leptons and HNLs

- VLQs, VLLs, and HNLs are proposed new fermions to complete the SM
- Several motivations: neutrino masses, baryon asymmetry, SM families, etc.
- CMS has a comprehensive program to search for these particles (which may be LLPs)



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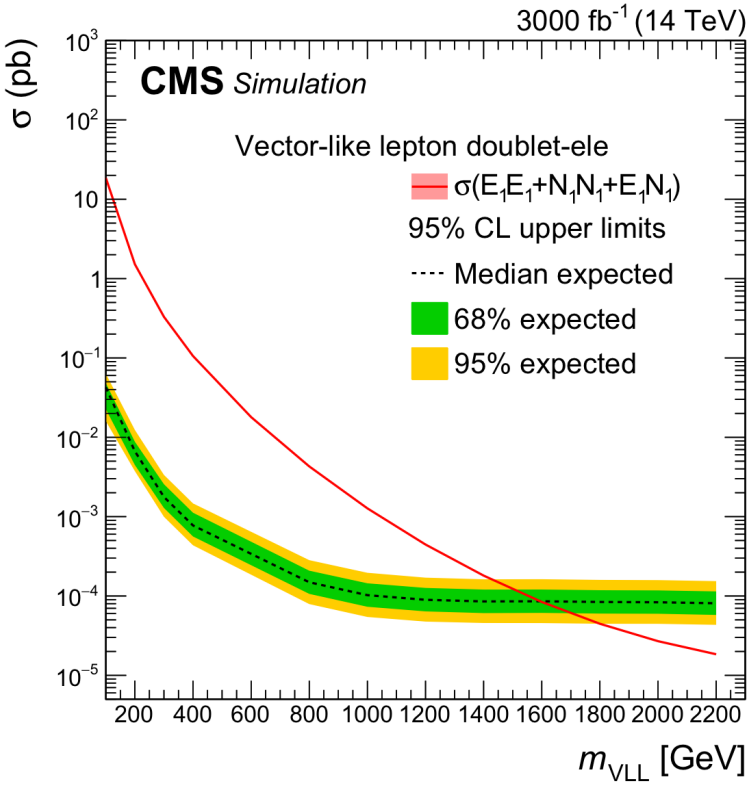
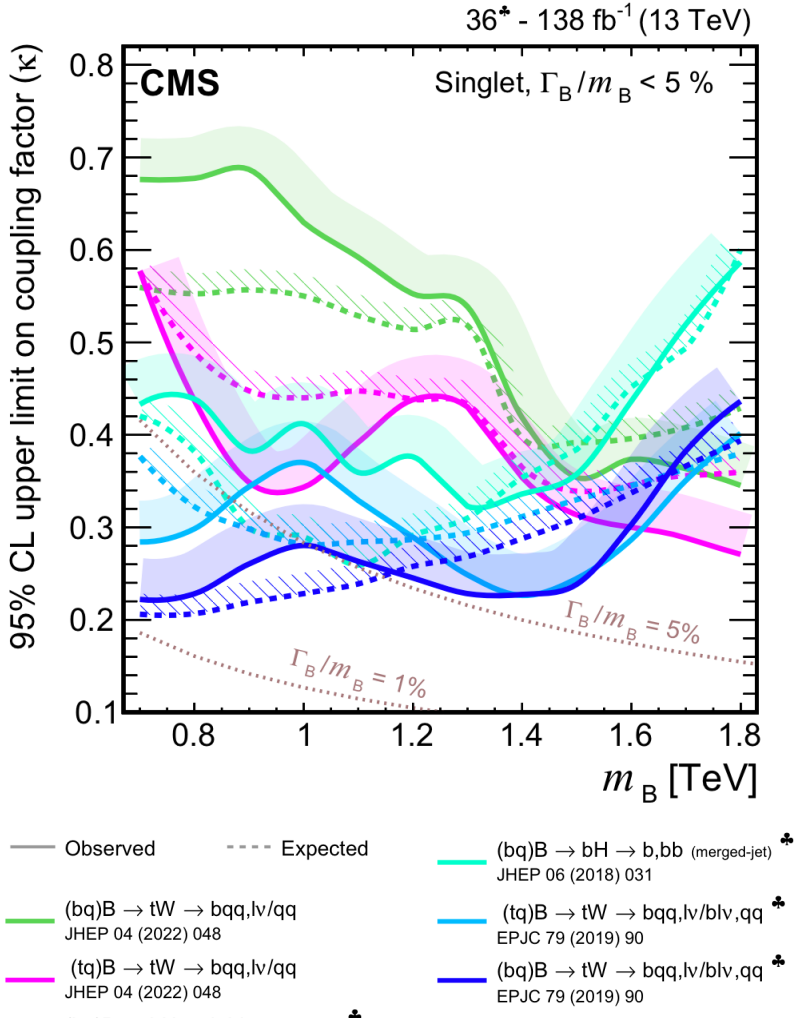
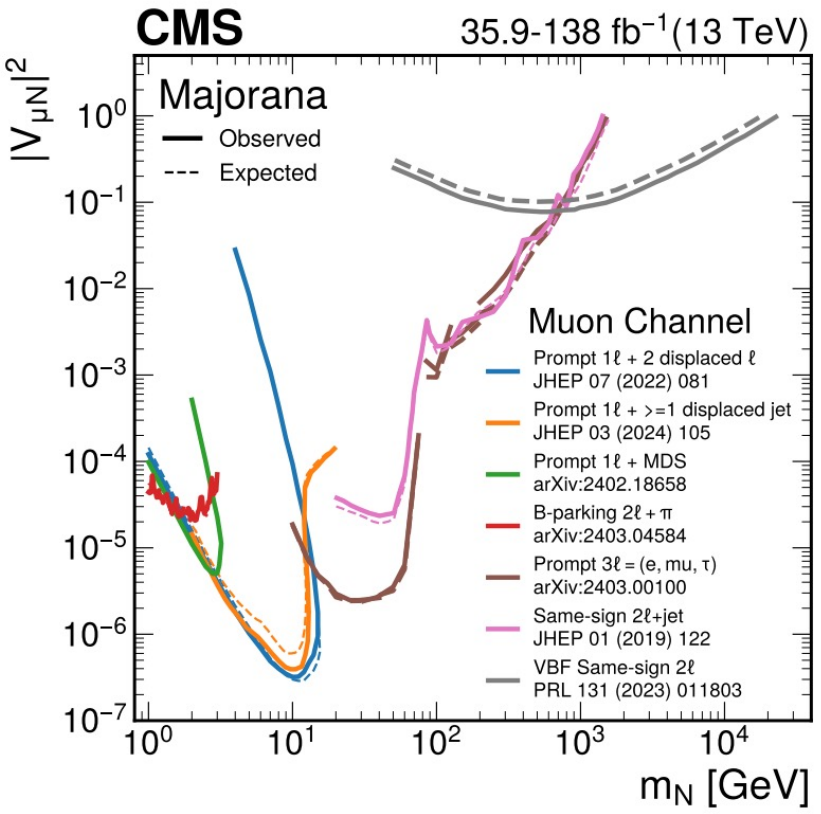
CMS-EXO-23-006

Vector-like quarks & leptons and HNLs







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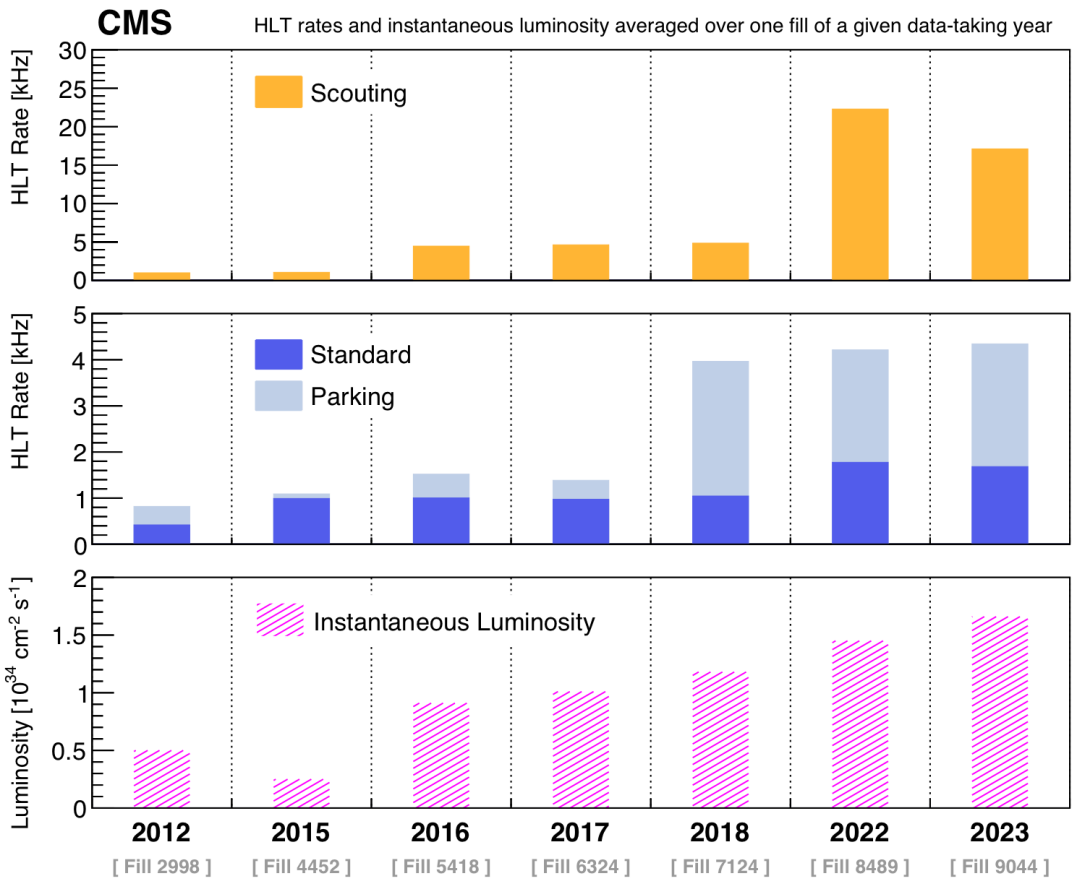
CMS-EXO-23-006

Data scouting and data parking

- Goal: increase the CMS trigger rate
- **Scouting**: Save limited information per event, at trigger level (no offline reconstruction)
- **Parking**: Park the raw data until availability of computational resources (delayed offline reconstruction)
- Remarkable success at targeting low-mass and rare processes (including LLPs)



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CMS-EXO-23-007

Data scouting and data parking

- Many more low-mass dimuon events collected
- Significant displacement improvement in Run 3

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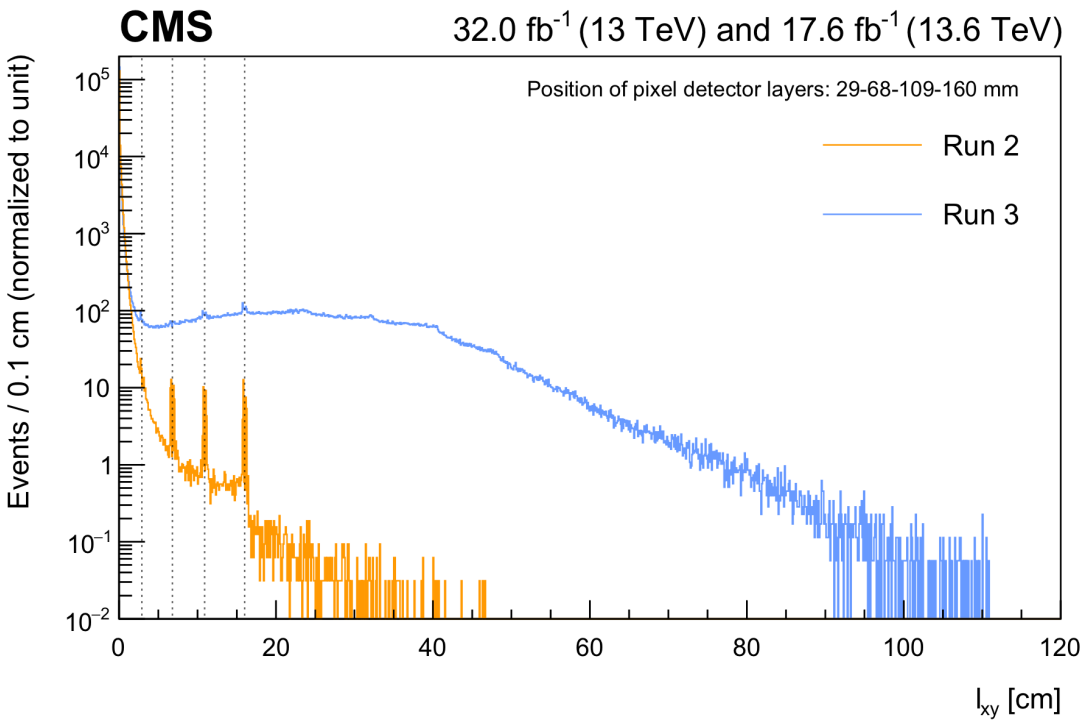
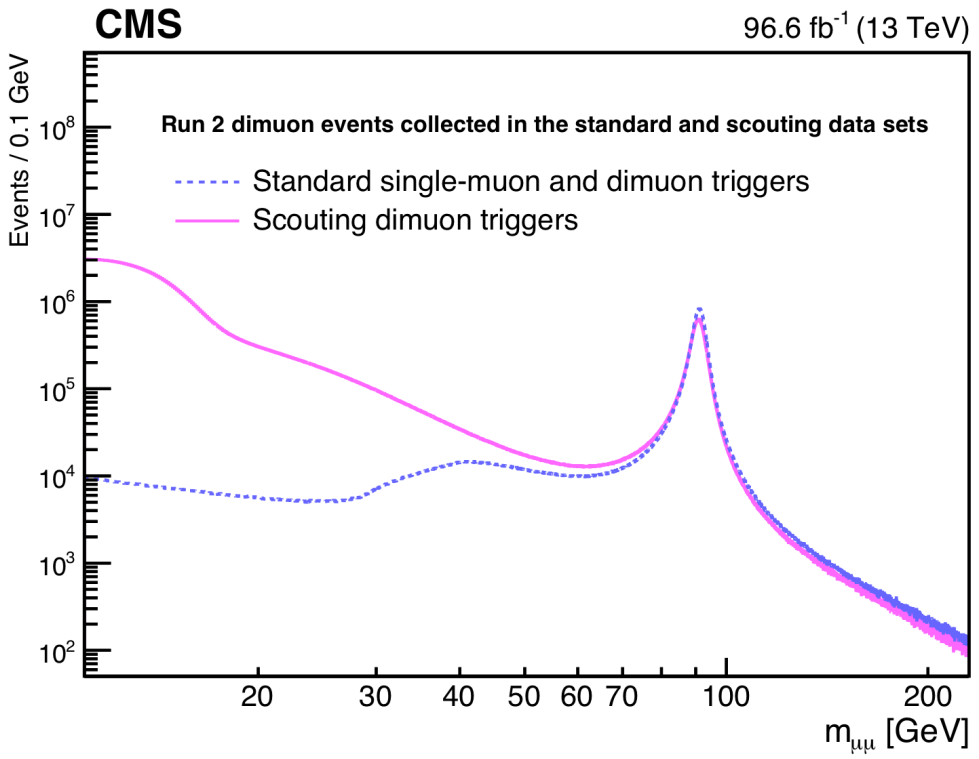
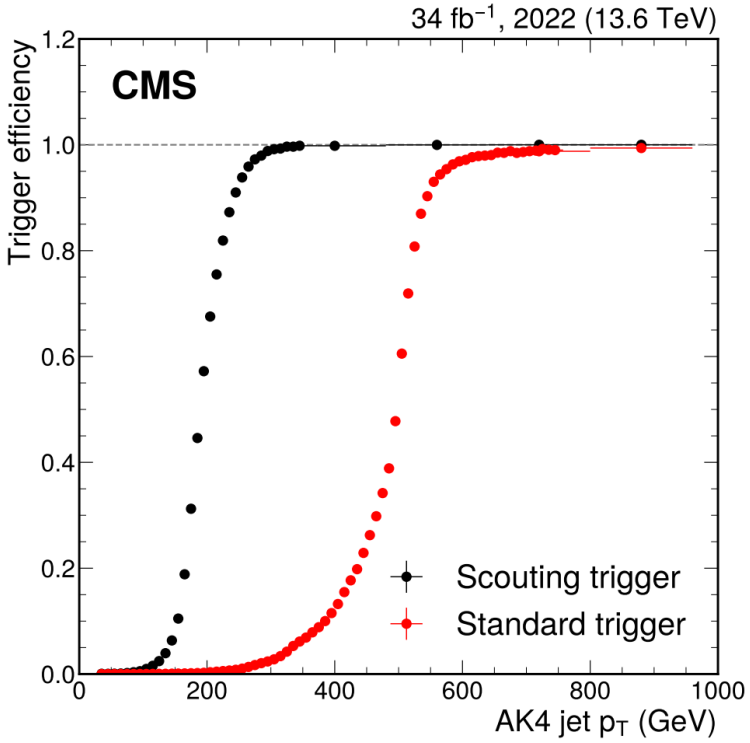
CMS-EXO-23-007

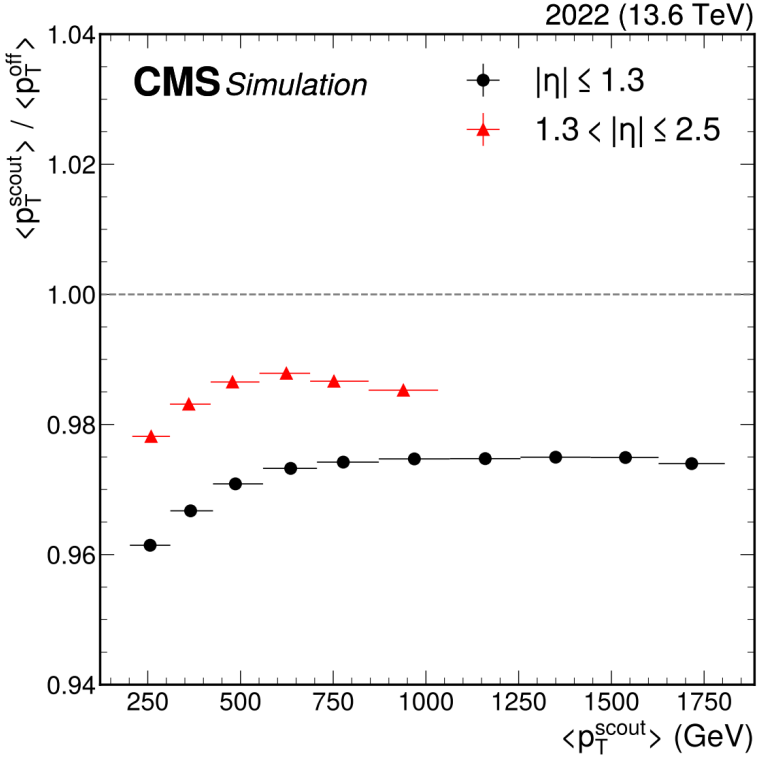




Data scouting and data parking

- Much lower scouting jet trigger thresholds than standard triggers
- And very little penalty in performance despite trigger-level objects





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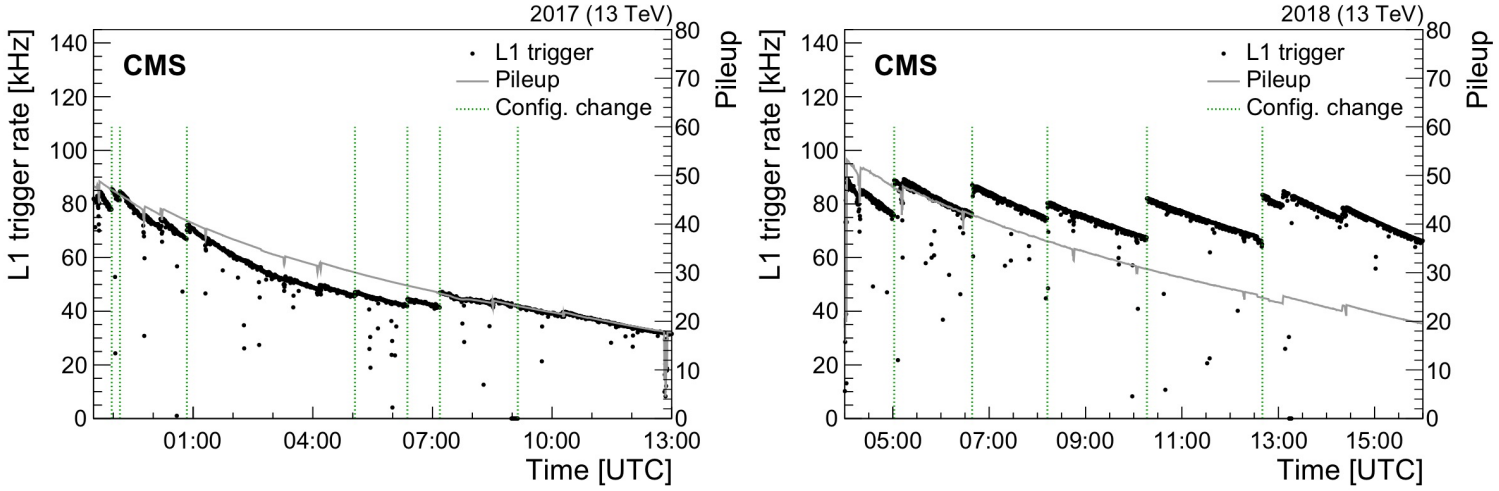
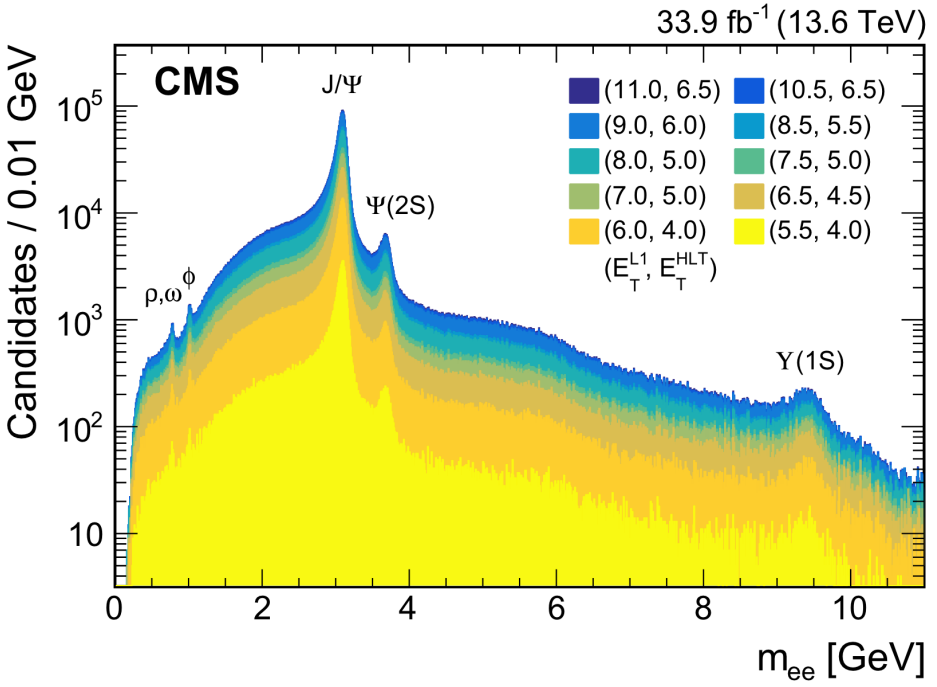
CMS-EXO-23-007

Data scouting and data parking

- Low-mass dielectron resonances visible with low-p_T electron parking
- Luminosity-leveling technique considerably enhances trigger rate





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CMS-EXO-23-007

Conclusions

- The CMS LLP program is very active and has grown considerably in the past few years
- Several new recent results will be discussed in this workshop, including our first two BSM searches with Run 3 data
- We also have put a lot of effort over the last year to compile our results into a set of review papers to be published in Physics Reports
  - This will hopefully be a helpful resource for many years to come!
- Check out all the other exciting talks in this workshop!