Searches for long-lived particles and other non-conventional signatures in CMS

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On behalf of the CMS Collaboration

[(*)] *ETH Zürich*

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Context

- Search for new physics with models predicting long-lived particles (LLPs)
- LLPs travel a macroscopic distance before decaying inside the detector
  - Because of small couplings, phase space suppression, etc.

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- Split SUSY
- R-parity violating SUSY
- Models with gauge-mediated SUSY breaking
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Dark sector

- Inelastic dark matter
- Hidden Abelian Higgs model
- Dark showers
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Neutrino sector

- Neutrino Minimal Standard Model
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... and many more!

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  - Triggers, event reconstruction, analysis techniques, etc.

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$\Rightarrow$ **CMS has a rich physics program in the long-lived sector**

Searches overview

- Several new results have recently become public

Analysis	Data(*)	LLP decay position	Reference
i. LLPs with displaced vertices NEW	Run 2	Tracker	PAS-EXO-22-020
ii. Search for inelastic dark matter	Run 2	Tracker	2305.11649
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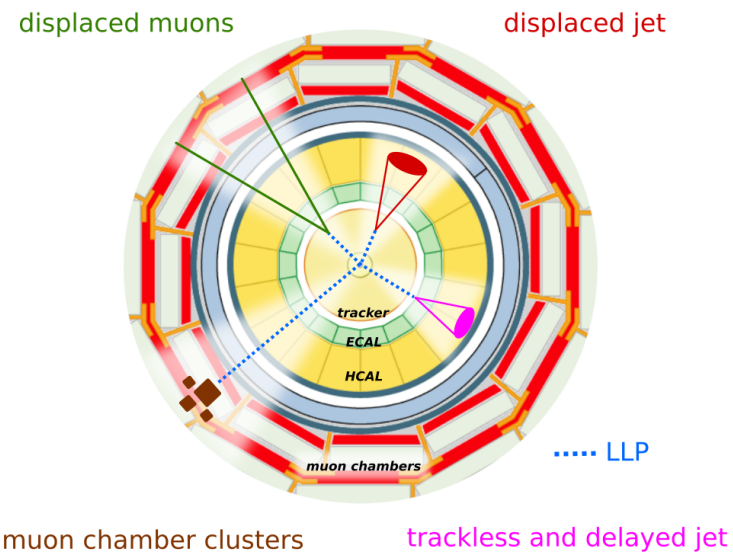
vi. LLPs decaying to a pair of muons 1st Run 3 results!	Run 3	Tracker	PAS-EXO-23-014
Outlook: long-lived triggers for Run 3 NEW			DP-2023/043

(*) Run 2: data collected in 2016-2018 at $\sqrt{s} = 13$ TeV

Run 3: data collected in 2022 at $\sqrt{s} = 13.6$ TeV



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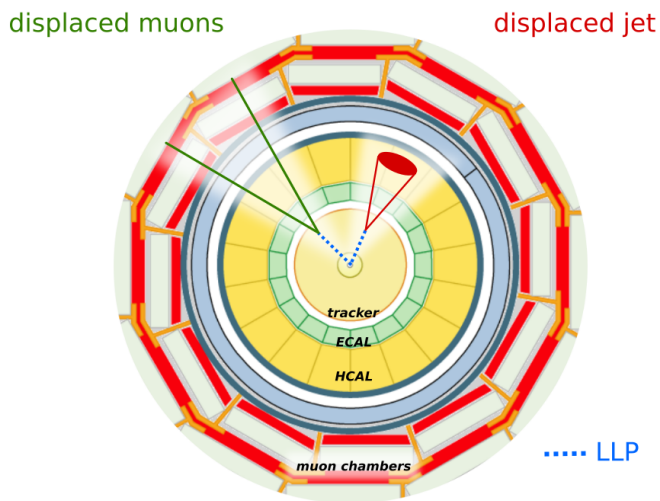

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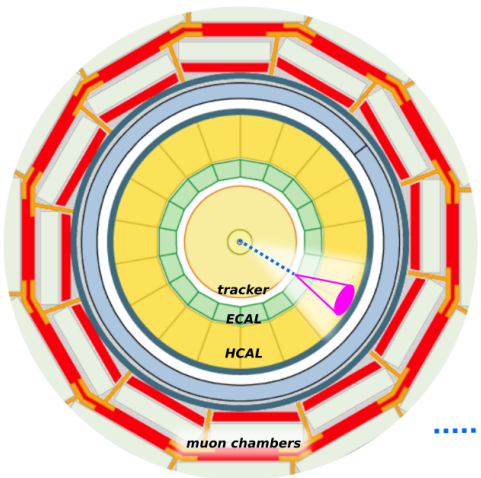

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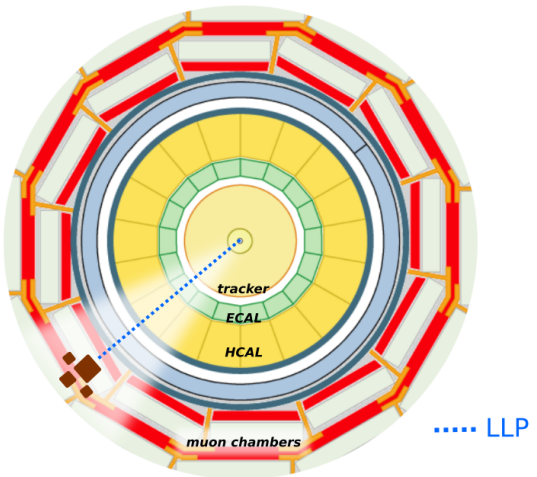

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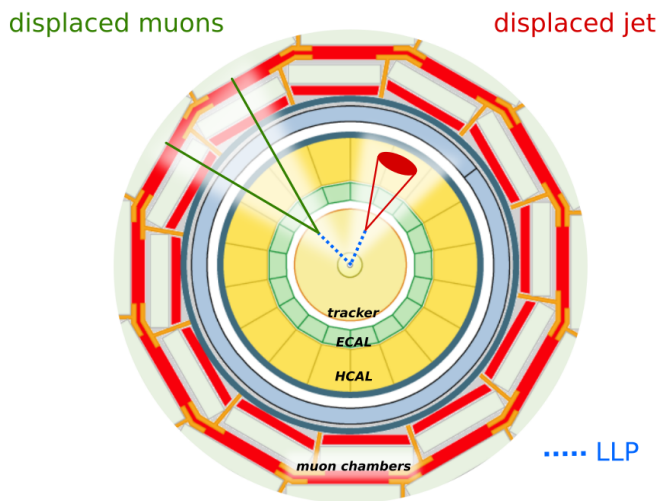

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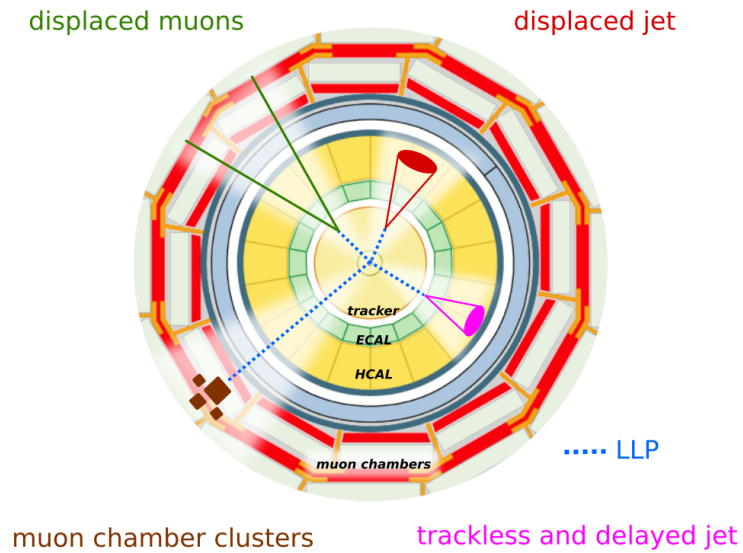

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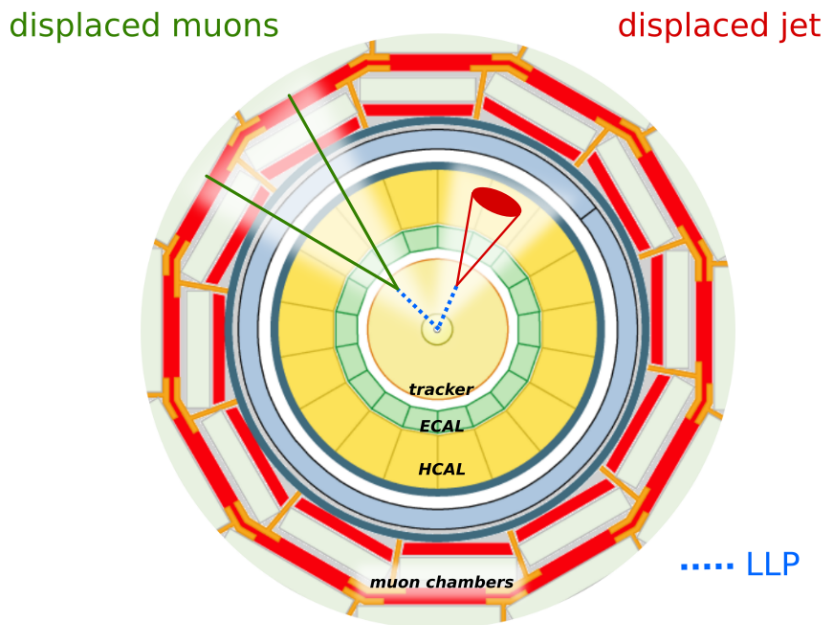
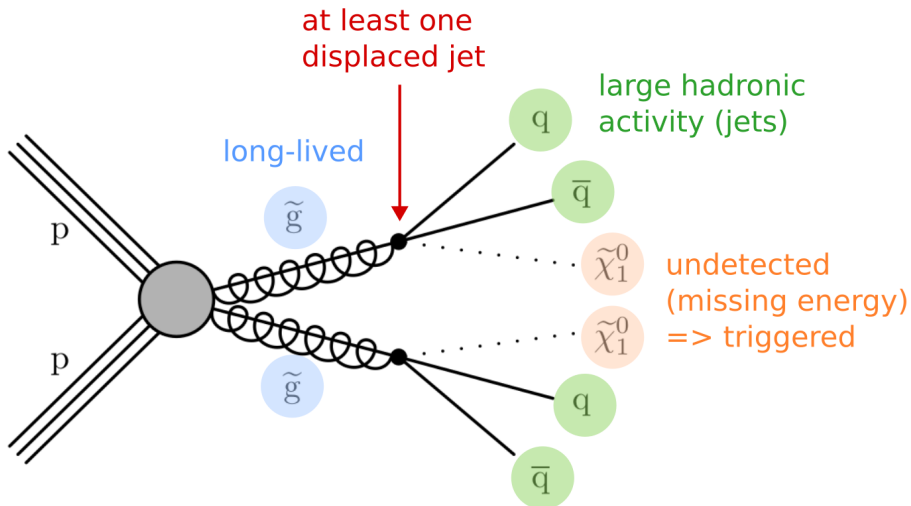


i. LLPs with displaced vertices and missing energy NEW

[EXO-22-020]

- Search targeting signatures of split SUSY models, with long-lived gluinos
  - Small mass splitting between the gluino and neutralino (compressed scenario)
- Final state with at least one displaced jet and large missing energy (triggered)

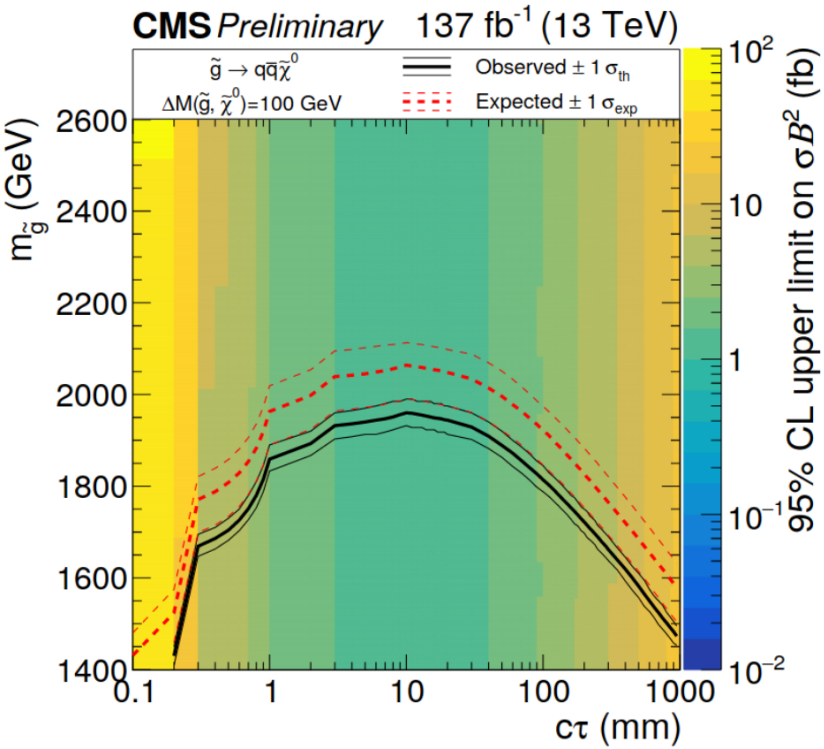


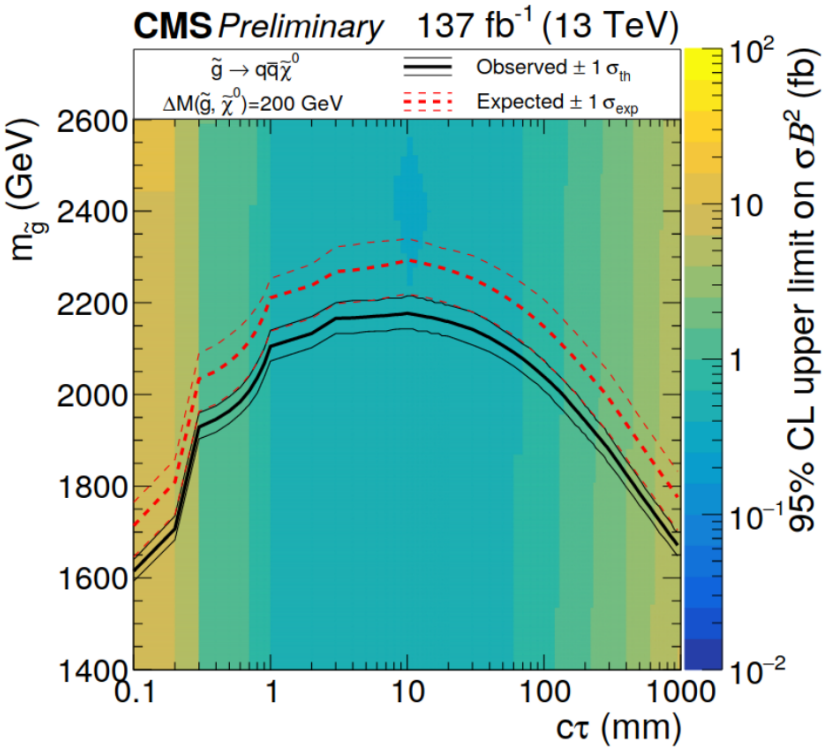
- Displaced vertices reconstructed with an algorithm based on tracks
  - Transverse displacement within the beam pipe, to reduce background originating from material interactions
- Signal significance further enhanced with machine learning (ML) using an interaction network
- Background originates from unrelated tracks that coincidentally overlap

i. LLPs with displaced vertices and missing energy NEW

[PAS-EXO-22-020]

- The observed data is consistent with the SM background prediction within 1.5σ
- Limits are set at 95%CL on the product of the cross section with the square of the branching fraction
- Most stringent limits to date for proper decay length ($c\tau$) up to 100 mm

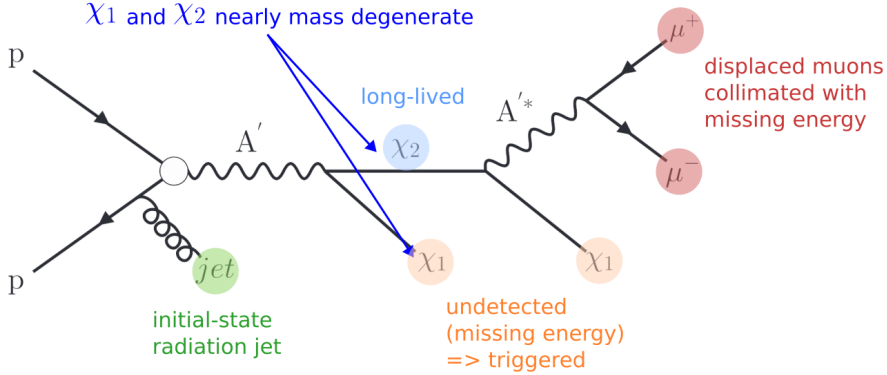




ii. Search for inelastic dark matter

[arXiv:2305.11649]

- First search for inelastic dark matter at a hadron collider!
  - More details in talk of F. Eble
- Signal signatures:
  - Large missing energy (triggered)
  - At least one energetic jet
  - Pair of displaced muons collimated with missing energy vector



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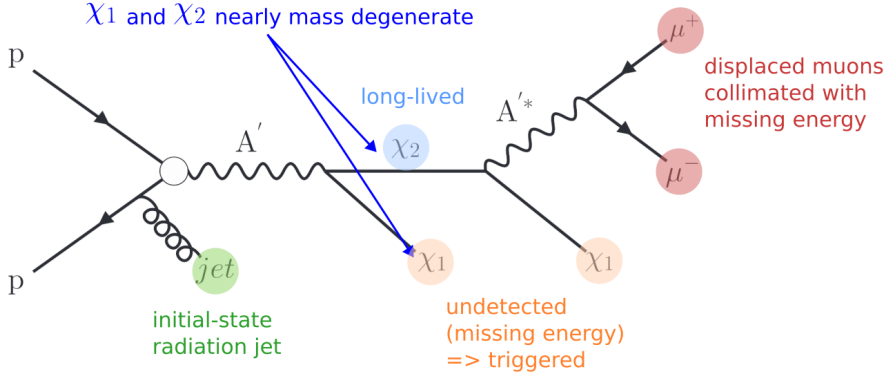
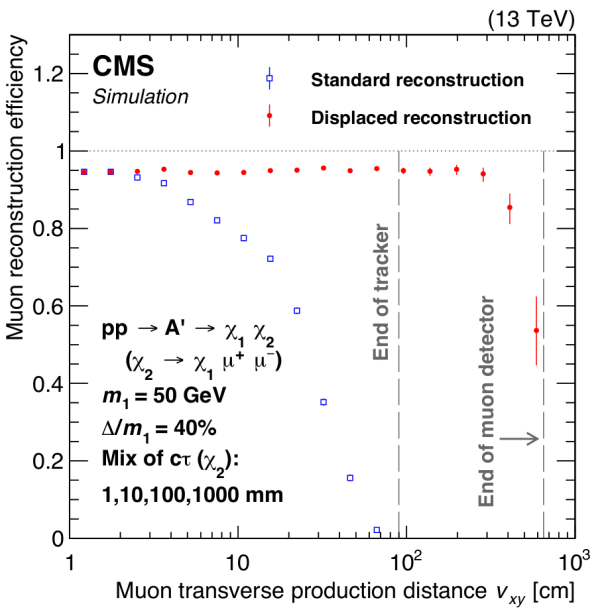
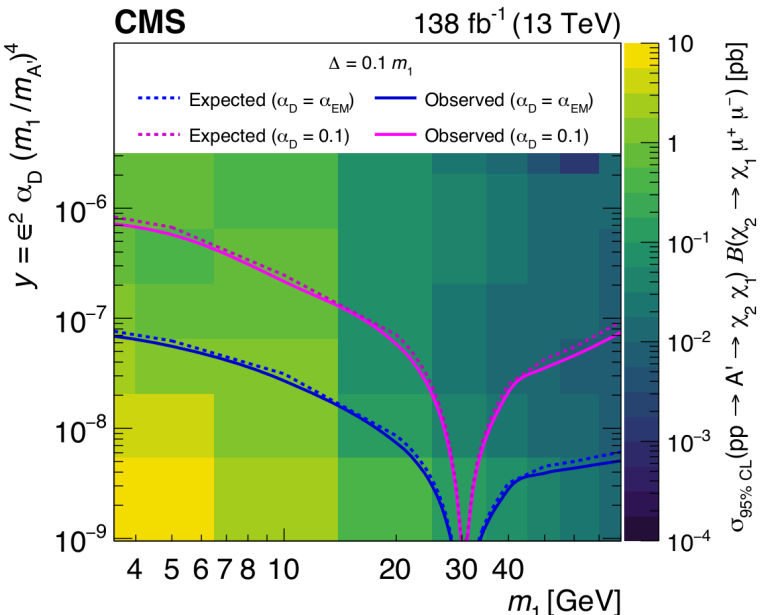


- Sensitivity enhanced by a dedicated displaced muon reconstruction algorithm





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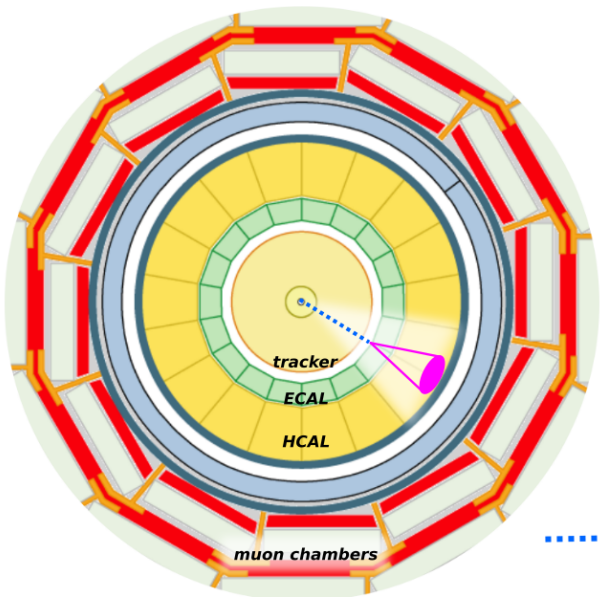


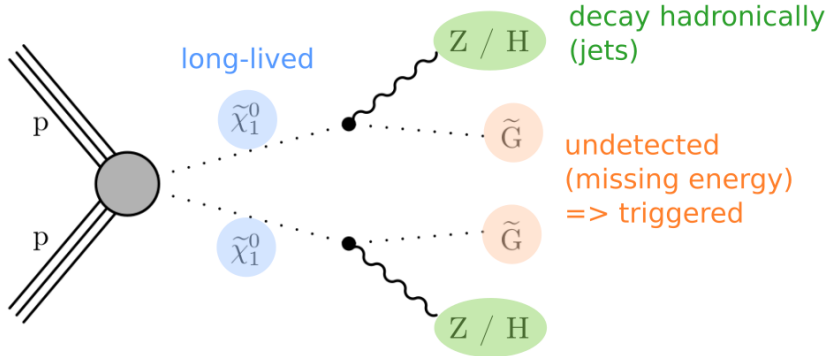
trackless and delayed jet

iii. LLPs with trackless and delayed jets

[PAS-EXO-21-014]

- Search for LLPs decaying in the outer tracker or in the calorimeters

- At least two jets with low track multiplicity, and delayed with respect to the collision time
- Large missing energy (triggered)



Neutralino pair production in the GMSB simplified model

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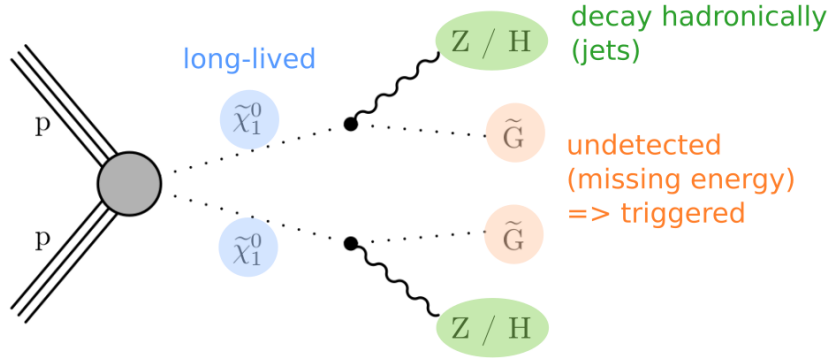
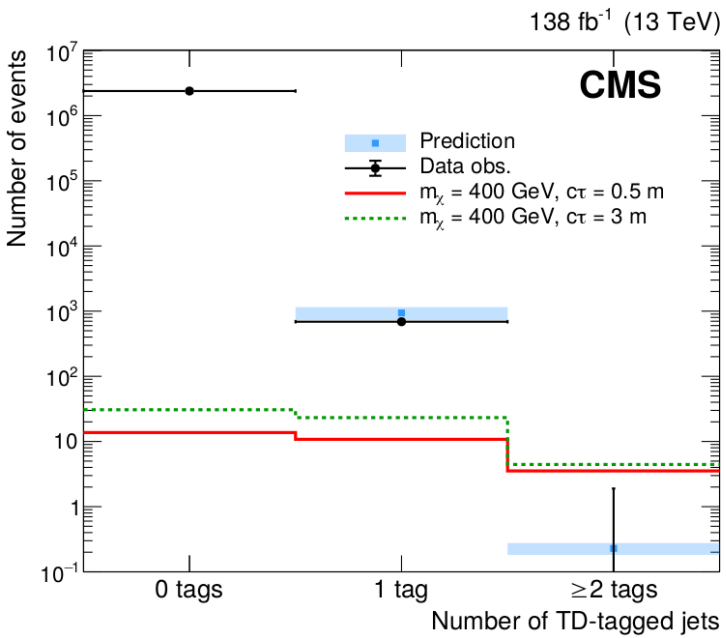
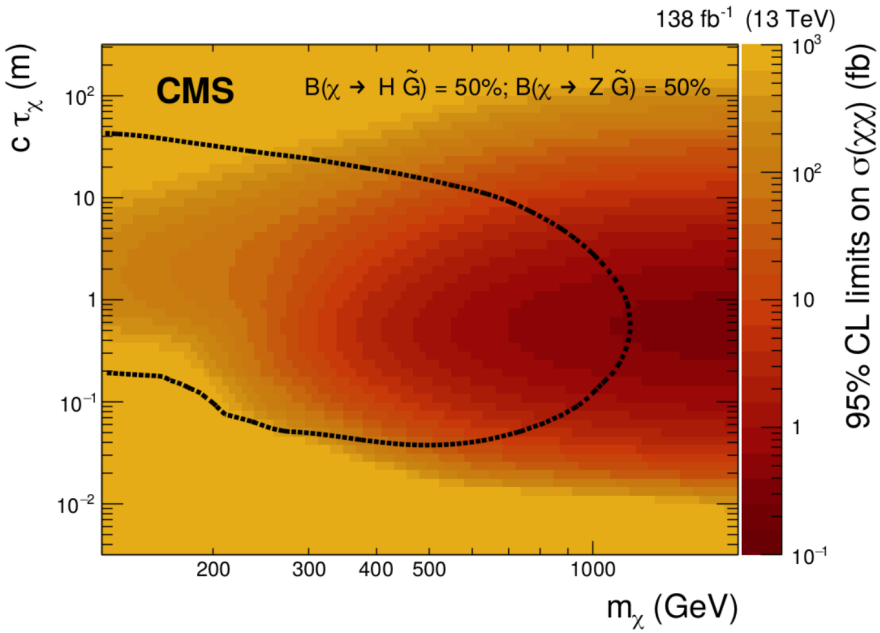


Neutralino pair production in the GMSB simplified model

- Up to a factor 20 increased sensitivity compared to previous searches





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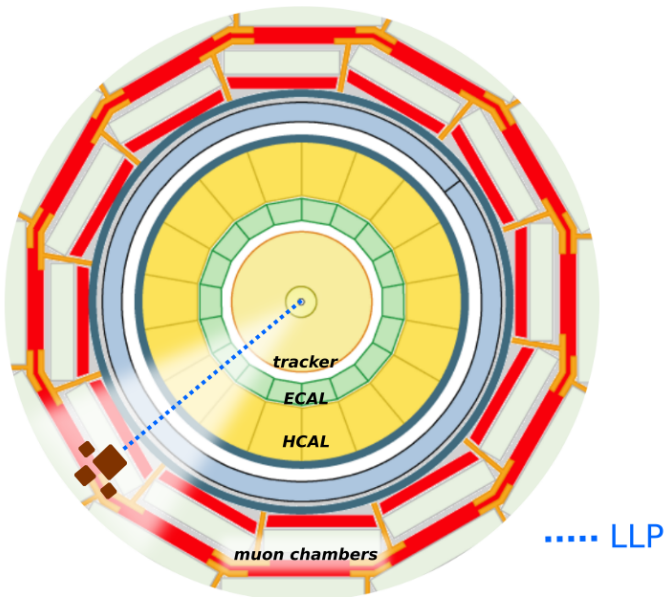

muon chamber clusters

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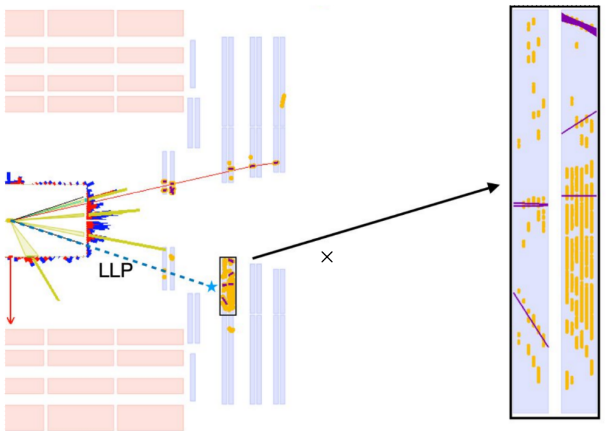
NEW

[PAS-EXO-21-008]

- Muon detectors used as a sampling calorimeter to identify particle showers from LLP decays
  - Sensitivity to LLPs decaying to hadrons, taus, electrons and photons
  - Background significantly reduced from the shielding material
  - Equal sensitivity to all LLP masses



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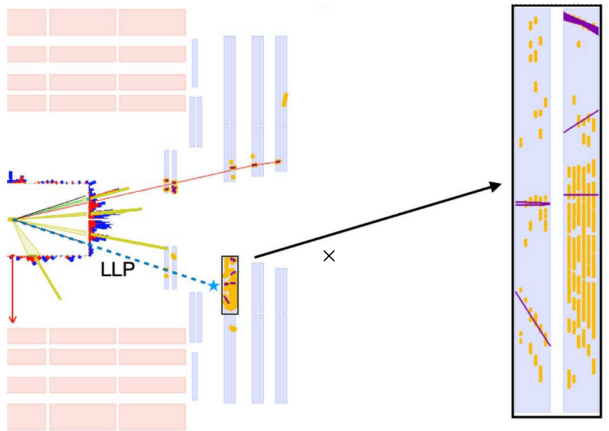
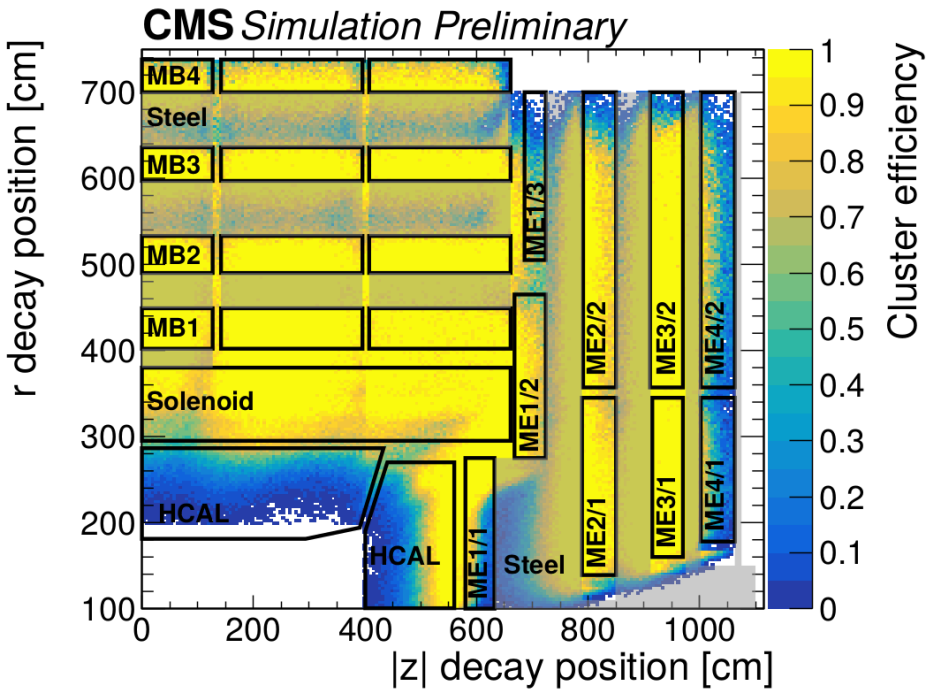


- Muon cluster algorithm yields a high reconstruction efficiency



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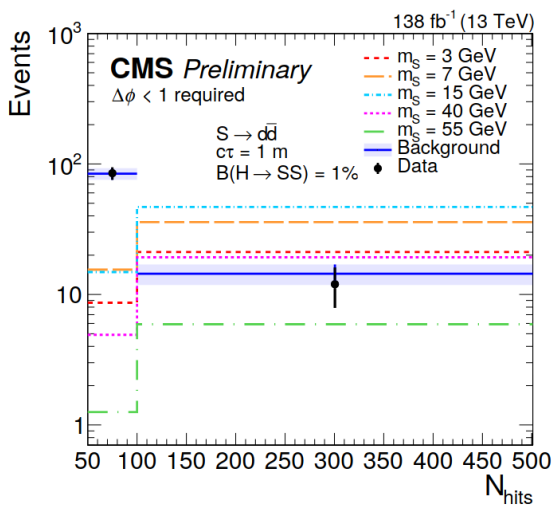

iv. LLPs decaying in the muon detectors

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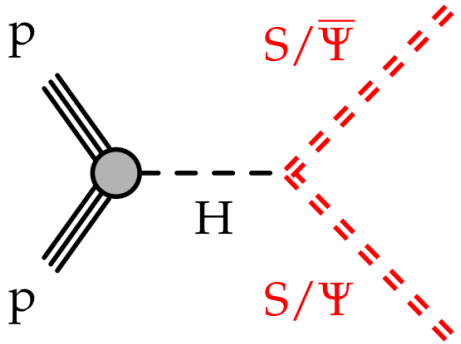
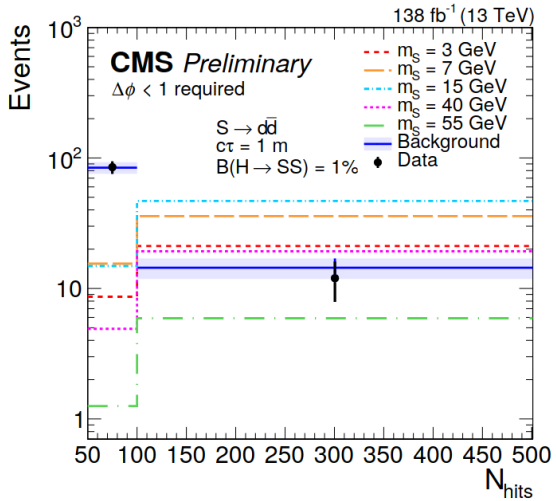
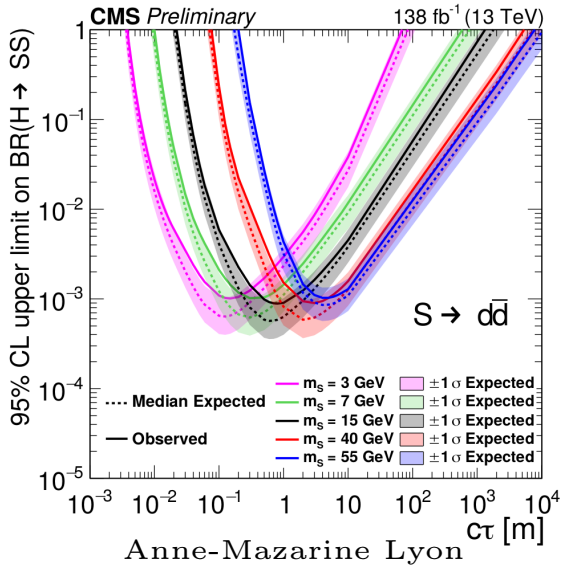
- No significant deviation with respect to the SM background prediction is observed
- Limits are set on two families of benchmark models
  - Twin Higgs model
    - Long-lived scalar S decays to a pair of fermions or photons



- Most stringent limits to date for twin-Higgs model





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[PAS-EXO-21-008]

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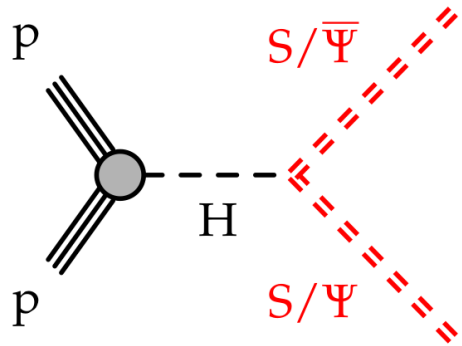
- Limits are set on two families of benchmark models
  - Twin Higgs model
    - Long-lived scalar S decays to a pair of fermions or photons
  - Dark showers model
    - Dark quark Ψ hadronises into a dark shower



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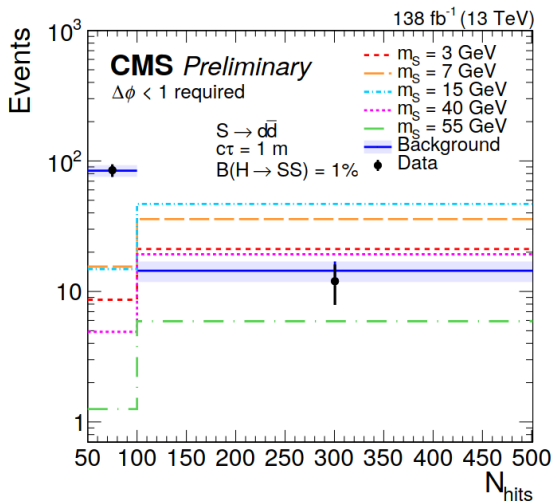
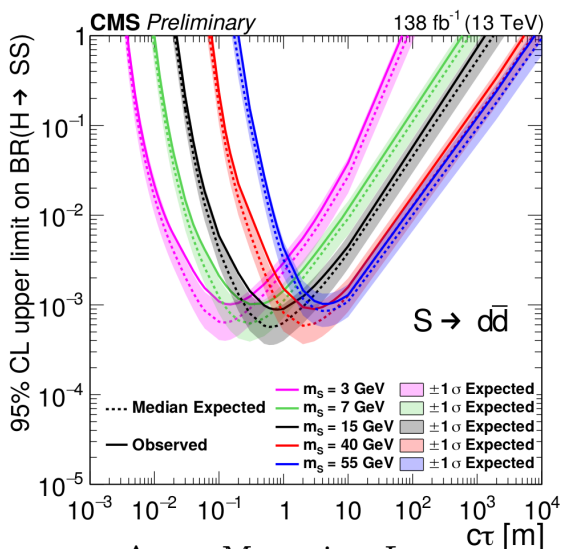
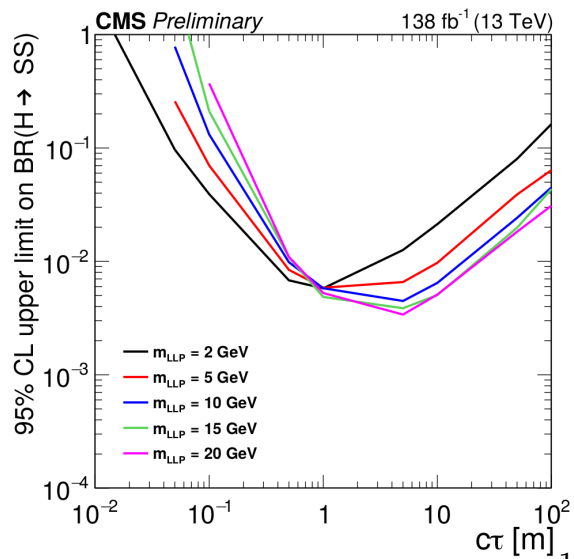
- First LHC limit set on such a dark model!







v. HNLs decaying in the muon detectors

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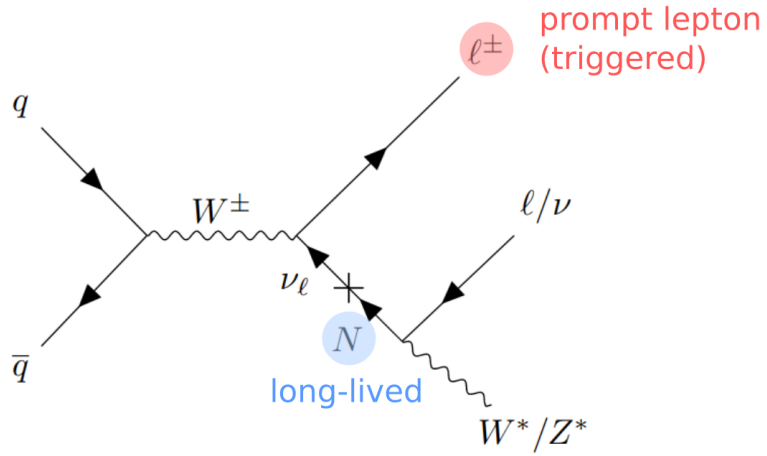
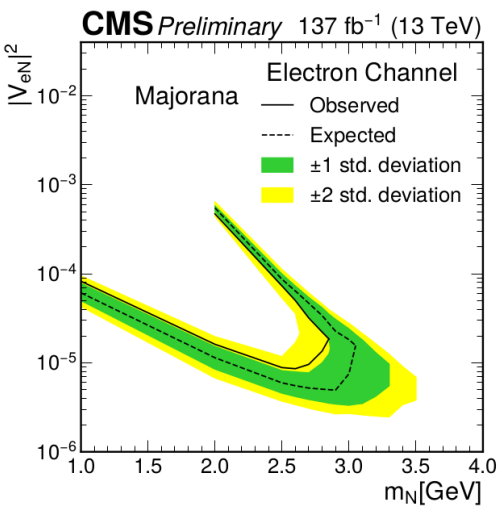
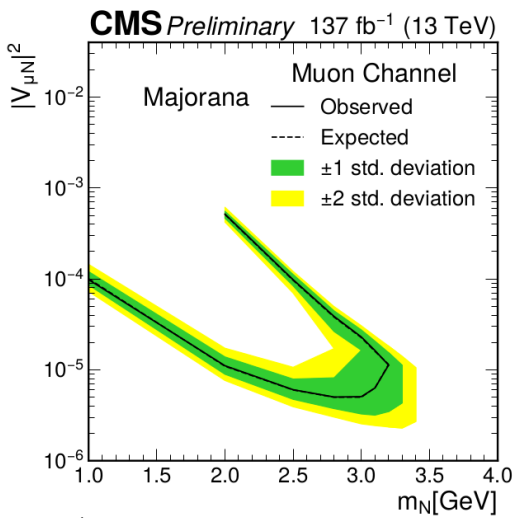
[PAS-EXO-22-017]

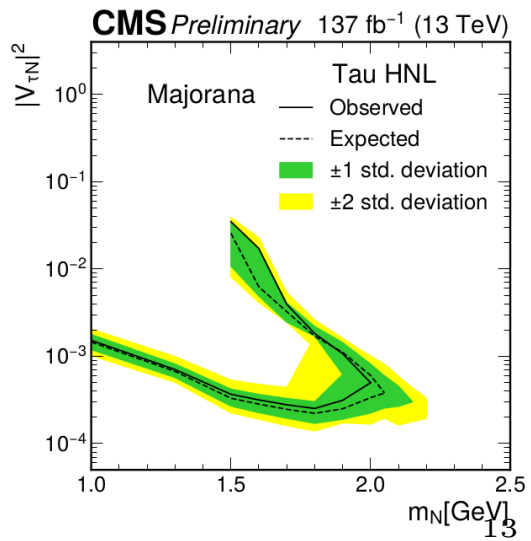
- Apply similar techniques as the previous analysis to a search for heavy neutral leptons (HNLs)
- More details in talk of M. Komm



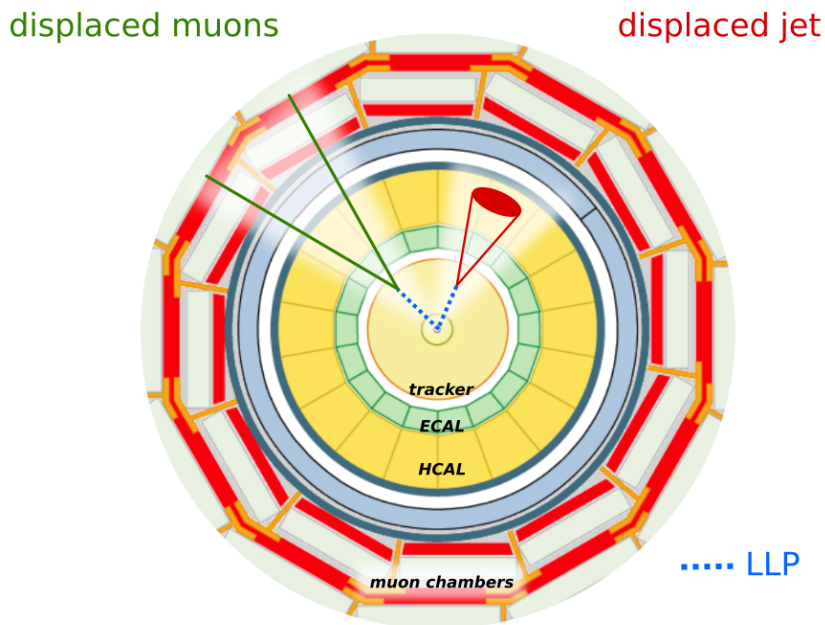
- No significant excess over the SM background prediction is observed
- Limits set on both Majorana and Dirac scenarios
- Most stringent limits between 2 and 3 GeV







4. Run 3 searches for LLPs decaying in the tracker

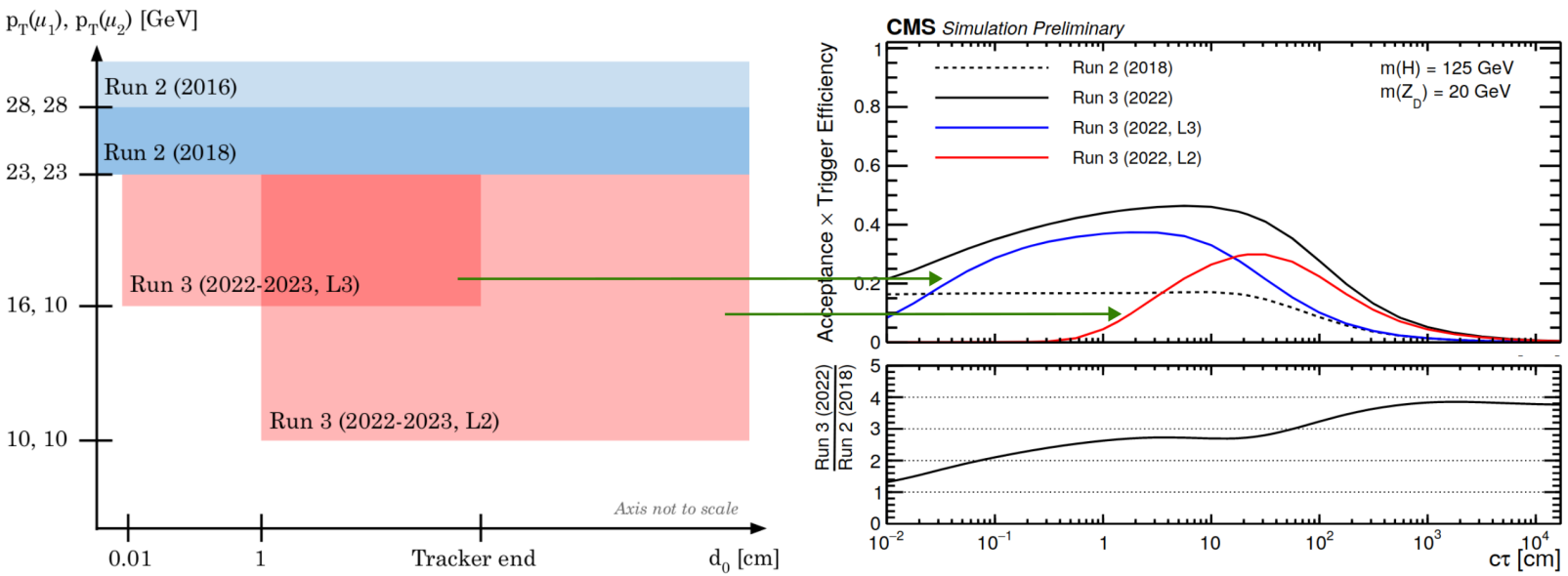


vi. LLPs decaying to a pair of muons

[PAS-EXO-23-014]

1st Run 3 results!

- Analysing data collected in 2022 at $\sqrt{s} = 13.6$ TeV (36.7 fb^{-1})
- Search targeting models with displaced di-muon in the final state
- Data collected thanks dedicated displaced di-muon trigger
  - Substantial improvement in efficiency compared to previous Run 2 search



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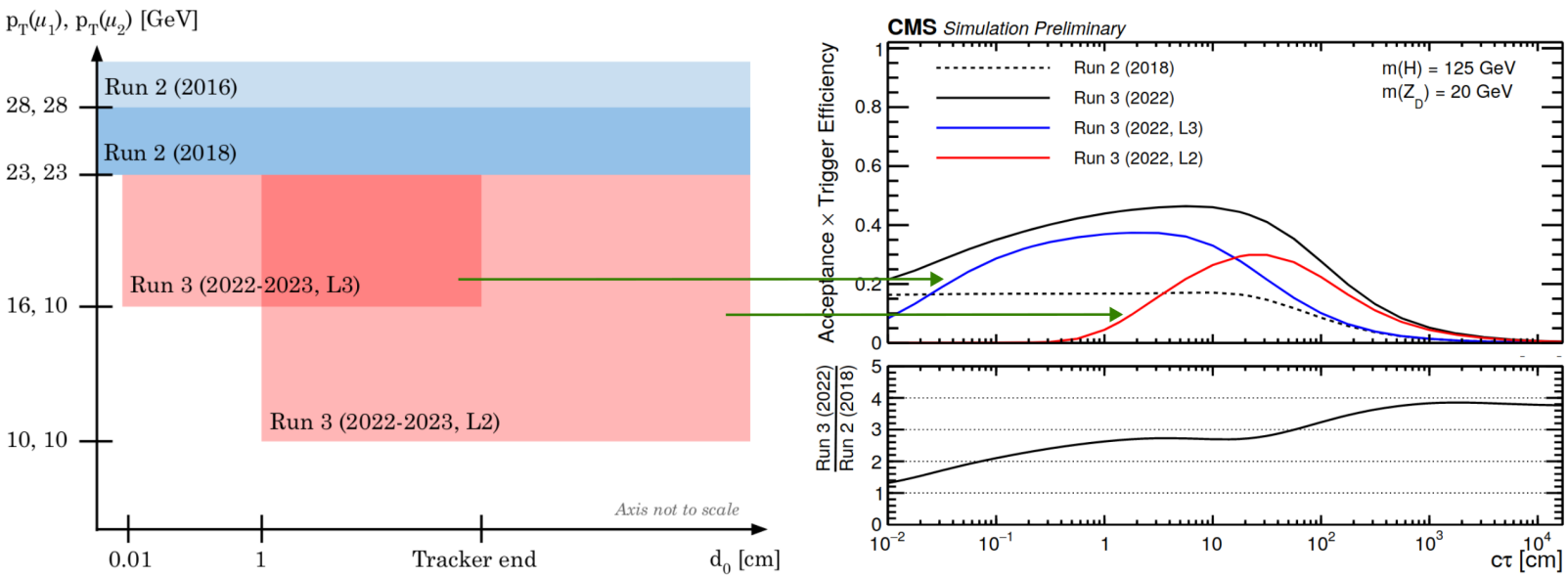

- Employ both the standard and displaced (see Search ii.) muon reconstruction algorithms

vi. LLPs decaying to a pair of muons

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[PAS-EXO-23-014]

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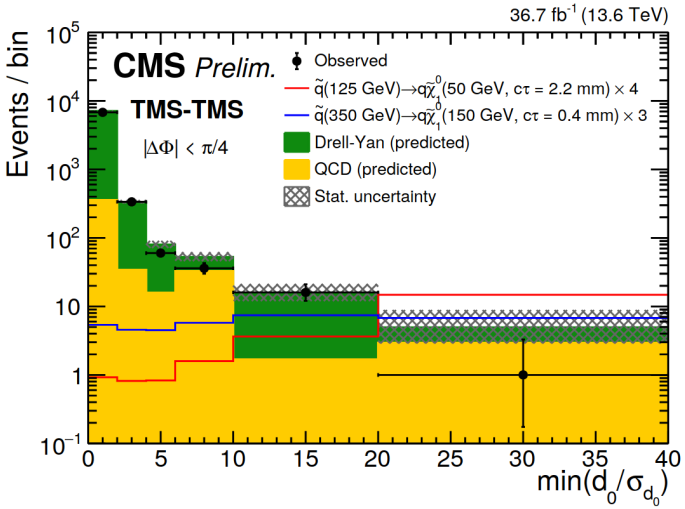

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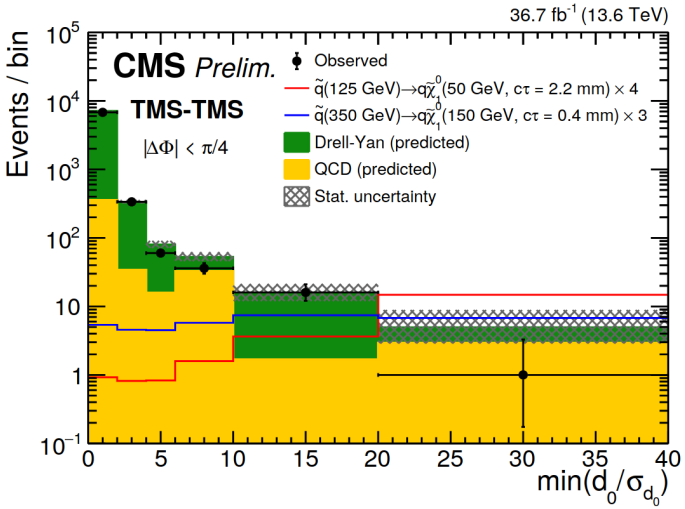
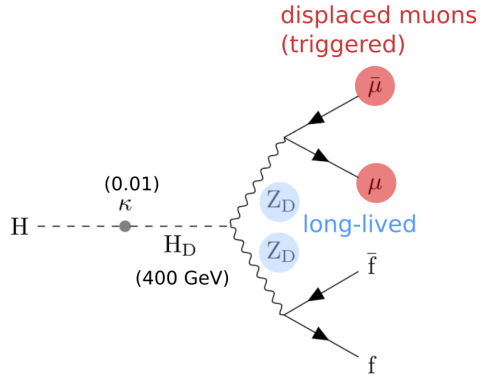
[PAS-EXO-23-014]

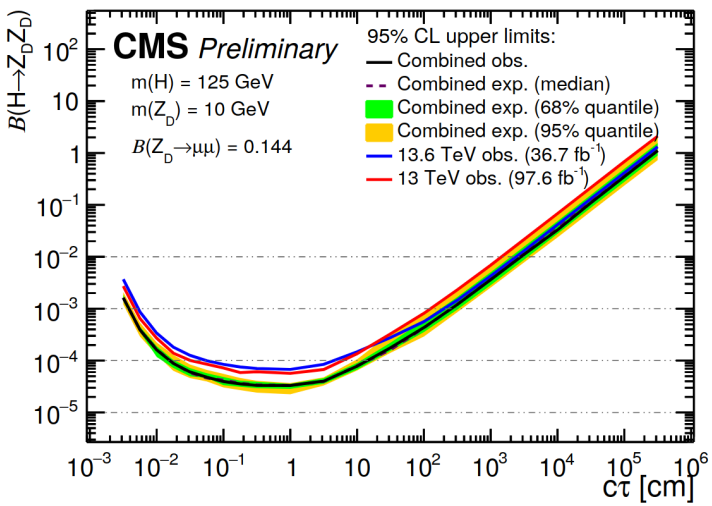
- Number of observed data events consistent with SM background predictions
- Two sets of benchmark models targeted





Hidden Abelian Higgs Model (HAHM)

- Improved sensitivity on the probed models with respect to previous results



Similar sensitivity as with the full Run 2 data achieved with only 1/3 of the luminosity in Run 3!

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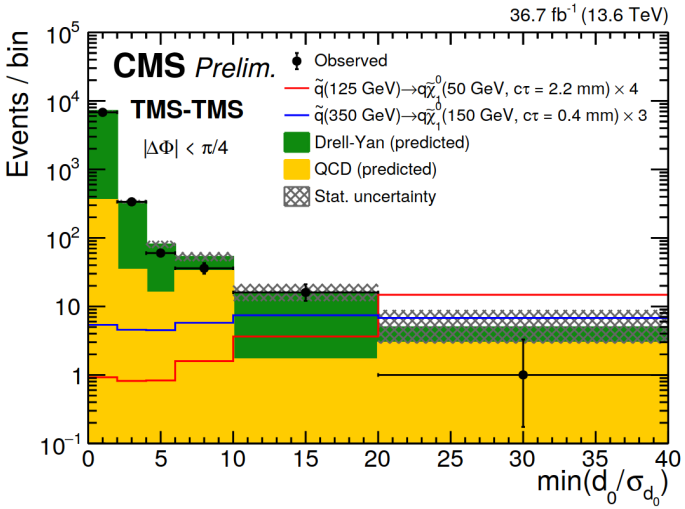

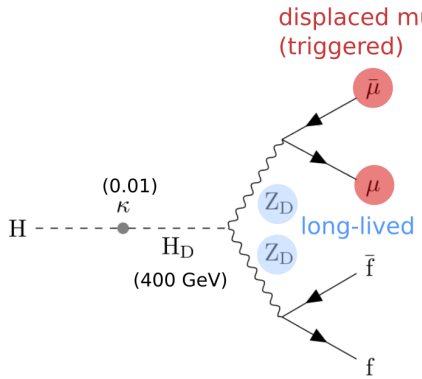

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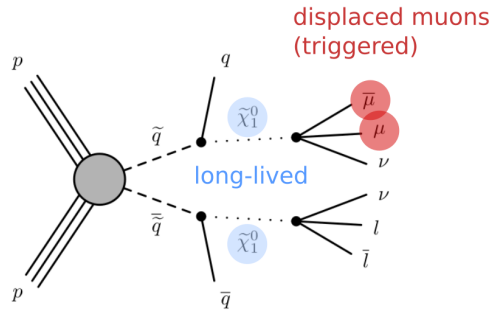

R-parity violating SUSY

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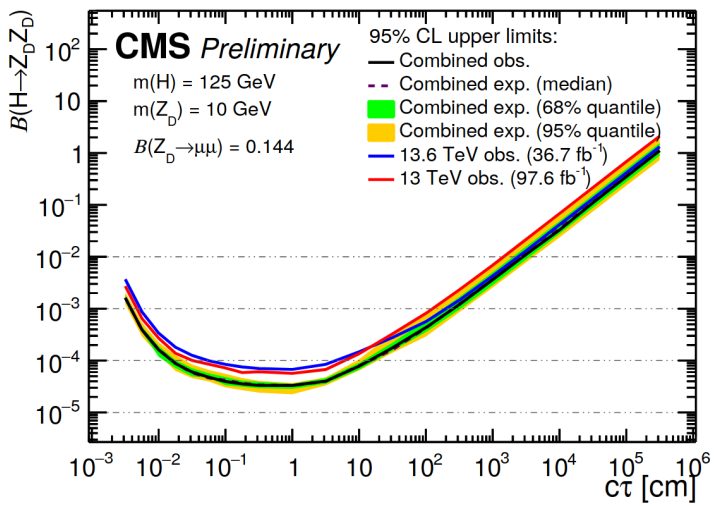
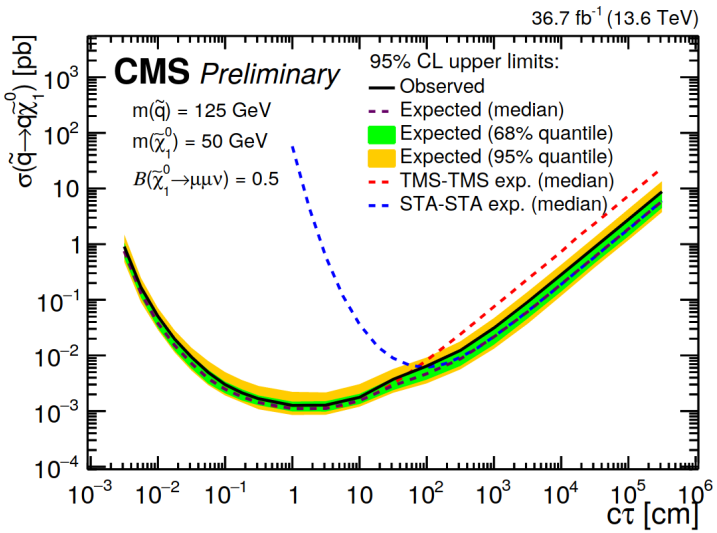




Outlook: Long-lived triggers during Run 3

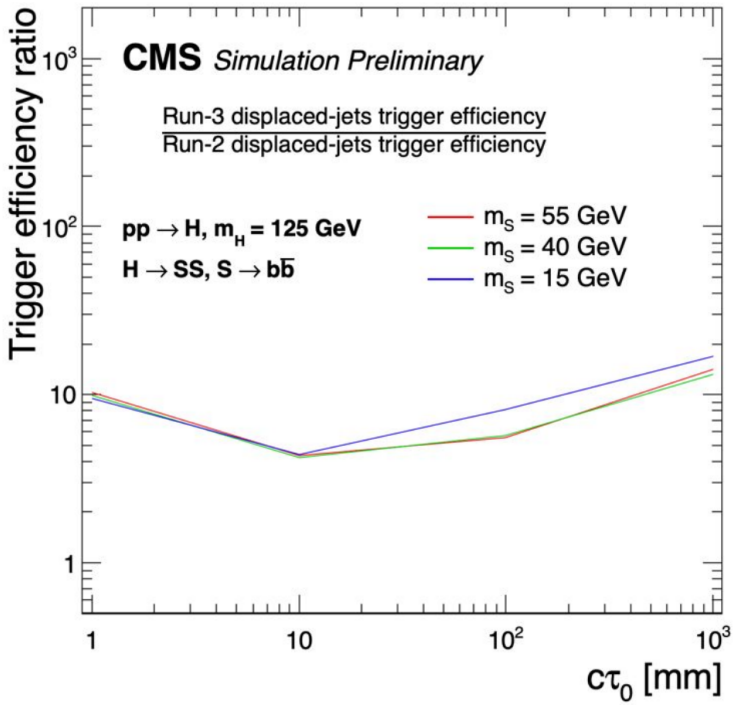
Outlook - Triggers in Run 3

NEW

[DP-2023/043]

- A series of triggers targeting LLP decays have been designed for Run 3
  - More details in talk of E. Yigitbasi

1. **Displaced** jet triggers
   - Using track information
   - Efficiency improved for low-mass LLPs compared to Run 2 displaced jet trigger



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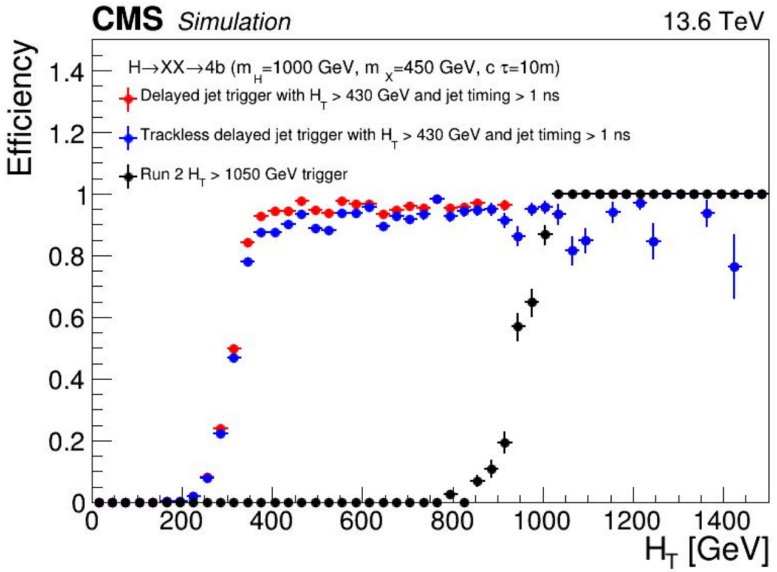

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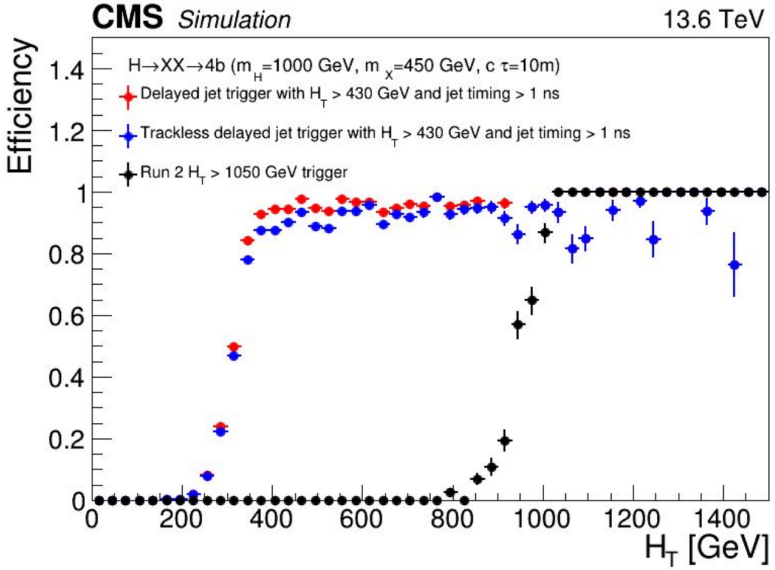

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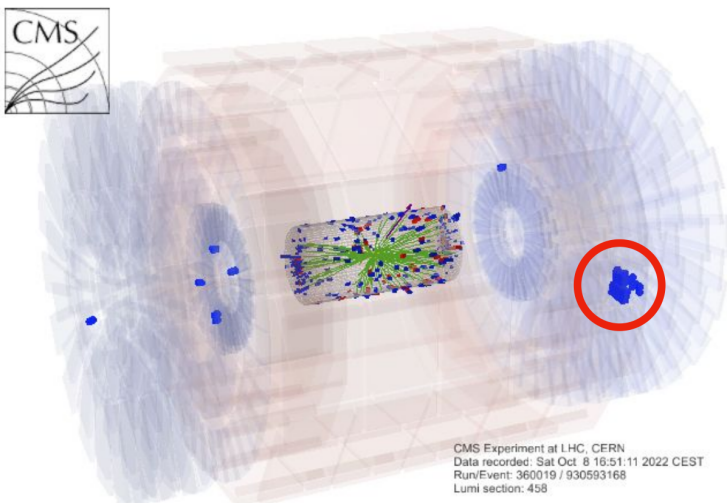

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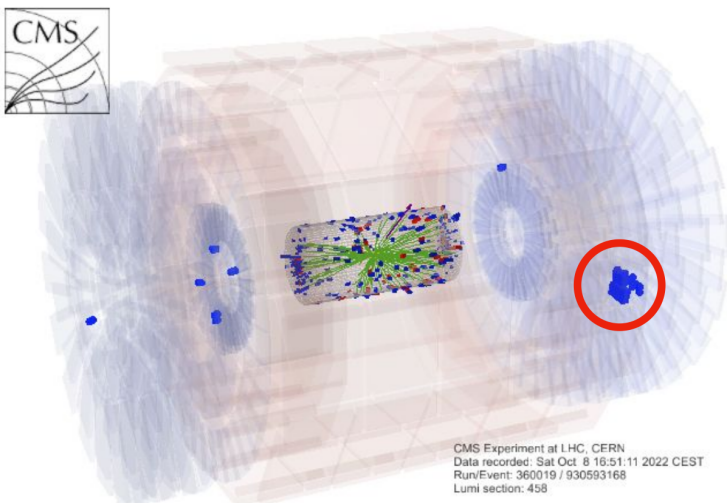

⇒ **Sensitivity to LLPs will be further enhanced during Run 3!**

Summary

- CMS has established a vast physics program for searches for LLPs
- Results recently made public target
  - LLPs decaying in the tracker
  - LLPs decaying in the calorimeters
  - LLPs decaying in the muon chambers
- Many analyses techniques have been designed to improve the sensitivity to LLP decays
  - New event reconstruction algorithms
  - New particle reconstruction algorithms
  - Advanced signal significance enhancement techniques (e.g. using ML)
  - New triggers
- Searches for LLPs will be at the core of the CMS physics program during Run 3

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Thank you!

List of acronyms

- **ECAL** electromagnetic calorimeter
- **HCAL** hadron calorimeter
- **HLT** high level trigger
- **ML** machine learning
- **SM** standard model
- **SUSY** supersymmetry