Probing new physics with dedicated data streams in CMS

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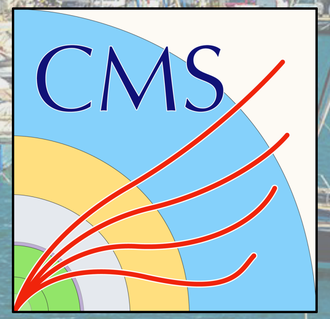
EPS 2025 - Marseille

11-07-2025



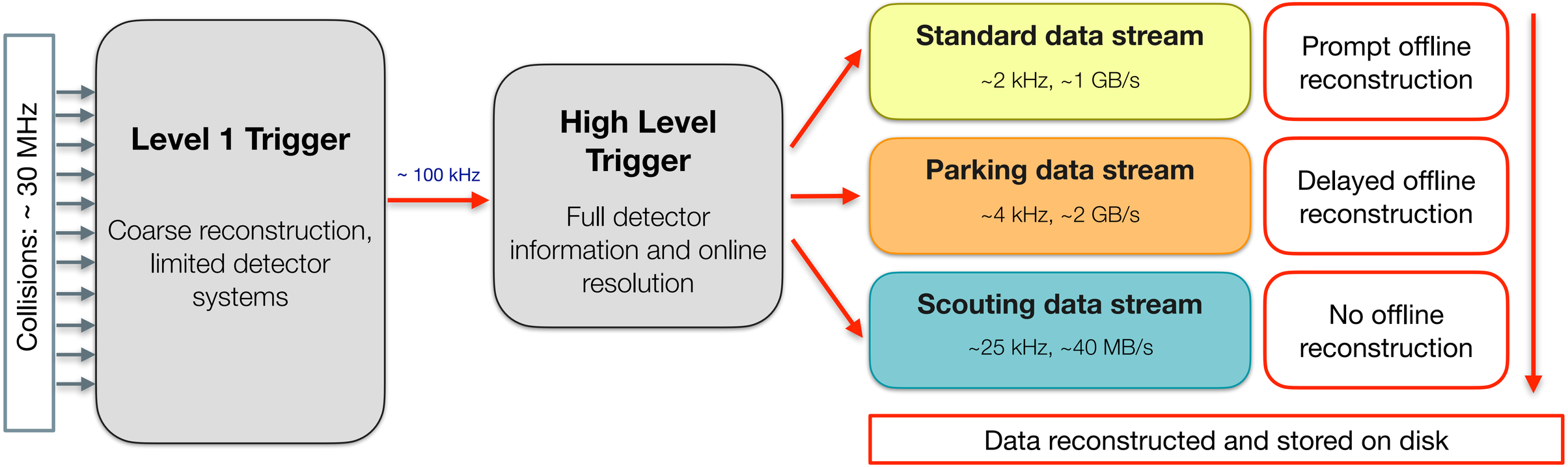
BOSTON UNIVERSITY

Special streams in CMS

Trigger is the main limiting factor for many physics searches, highly constrained by the finite availability to promptly reconstruct the events and limited permanent data storage (among others…)

→ Two **dedicated data-streams** to overcome these two limitations and lower HLT requirements:

- **Parking:** Event-reconstruction is delayed until enough resources are available
- **Scouting:** Limited even content, from High Level Trigger reconstruction only

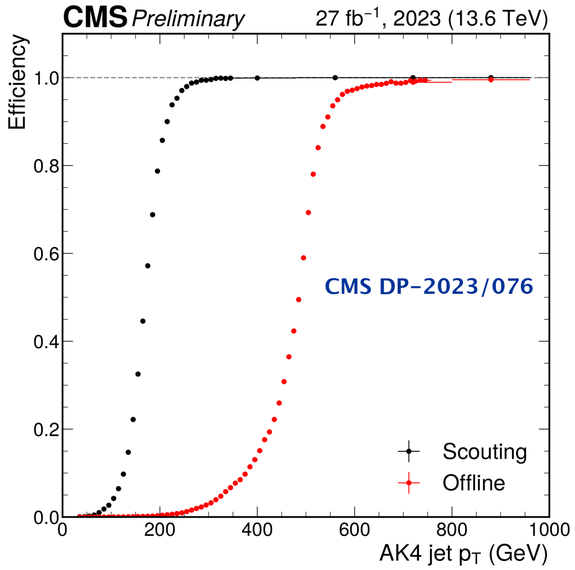


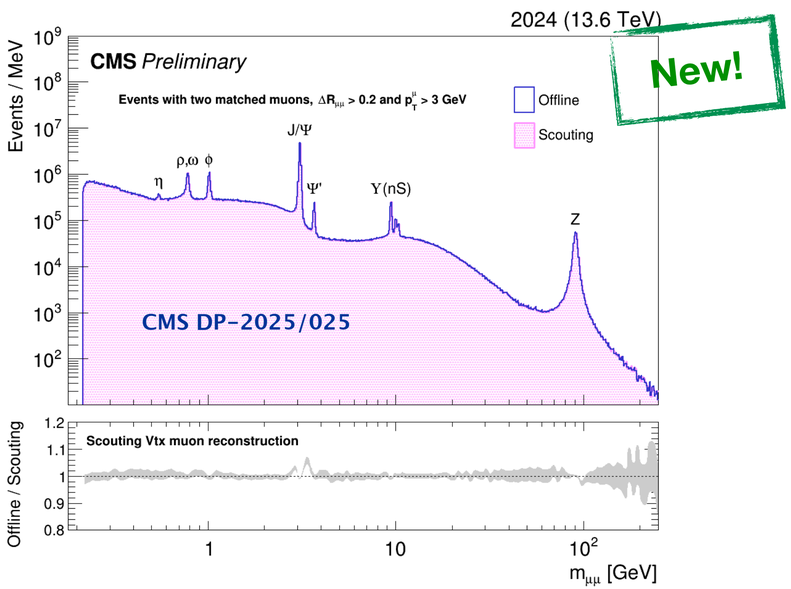
Special streams in CMS

Great opportunity to target **regions of the phase space that would remain unexplored** otherwise!

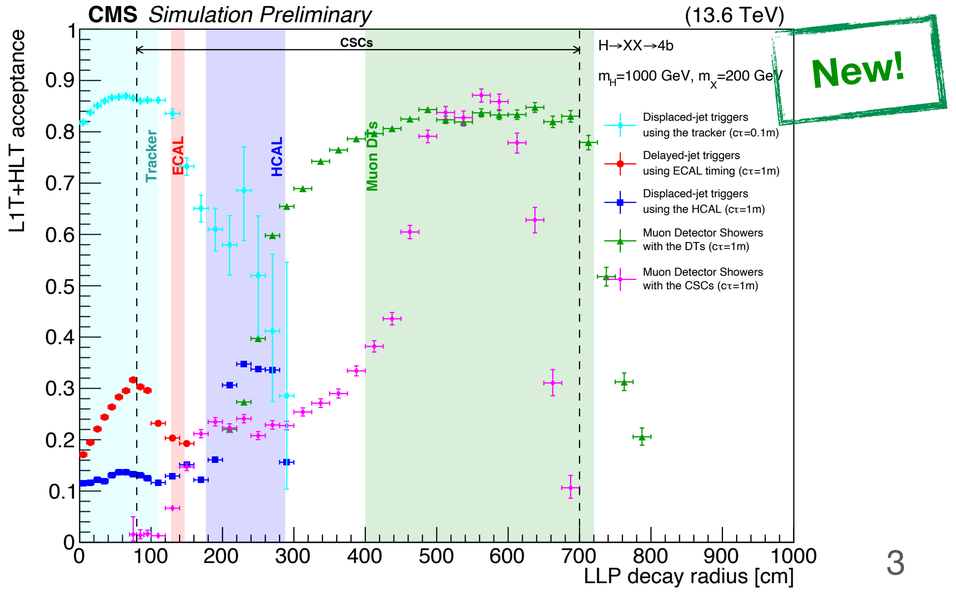
- Continuous evolution of streams. Excellent reference paper [Phys. Rept. 1115 (2025) 678]
- Great handle to study **challenging topologies** e.g. *unique signatures* from **long-lived particles (LLPs)**
  - Dedicated LLP trigger paper released in [CMS-PAS-EXO-23-016]

Dedicated scouting objects comprising jets, muons, electrons, MET and scouting particles





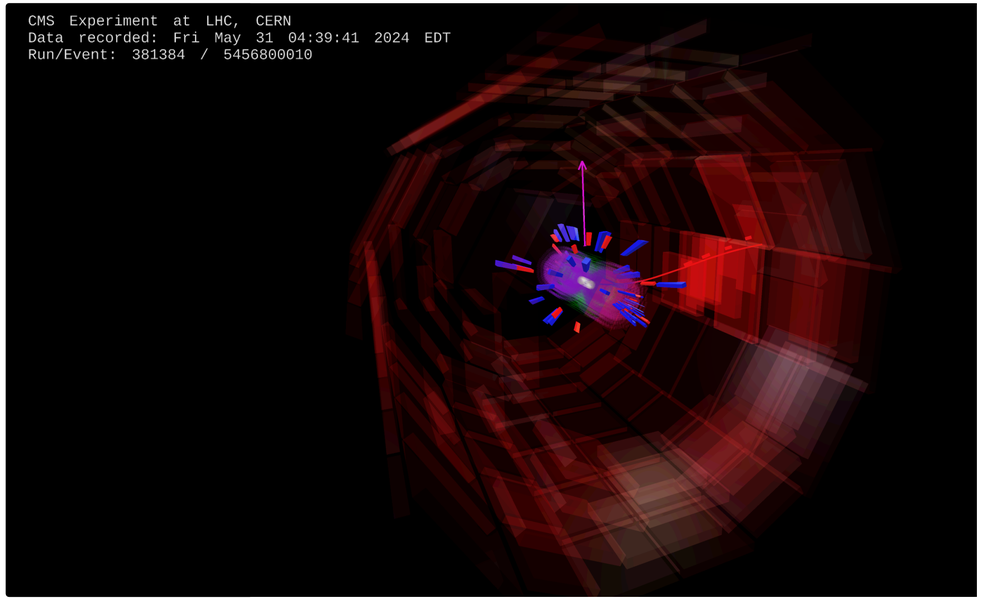
Complementarity of dedicated hadronic LLP triggers for H →XX →4b signal



CMS exotic searches with special streams

CMS has performed several recent **searches for exotic physics** using **dedicated data streams,** where advantages and limitations complement very well with searches using standard data

… in this talk we will cover four of them



Single muon event collected with parking streams in 2024

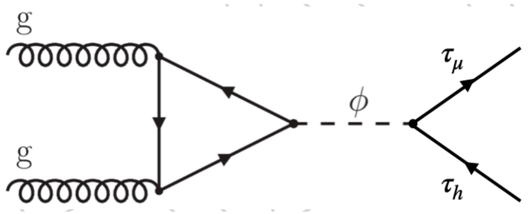
Analysis	Signature	Data stream	Trigger coverage
CMS-EXO-24-012	Low mass $\tau\tau$ resonance	Scouting **(Run 3)**	**Hadronic:** HT > 360 or p_T^{jet} > 180 GeV **e\ɣ:** p_T > 30 GeV, |η| < 2.1
CMS-EXO-24-004	Muon detector shower	Parking (Run 2)	**Single muon:** $p_T^{\mu 1}$ > 9 GeV, IP_{sig} > 3
CMS-EXO-24-008	Dark showers with displaced muons	Parking (Run 2)	**Single muon:** $p_T^{\mu 1}$ > 9 GeV, IP_{sig} > 3
CMS-EXO-24-016	Low mass multimuon final states	Scouting **(Run 3)**	**Di-muon:** p_T^{μ} > 3 GeV,

Scouting low mass $\tau\tau$ search

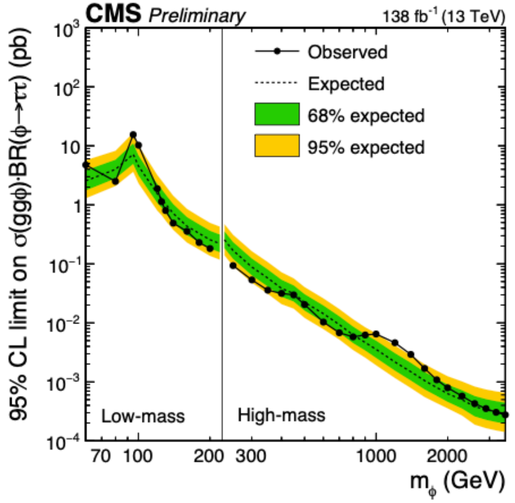
CMS-EXO-24-012

Bump-hunt **search for low mass** $\phi \to \tau\tau$ performed over the visible $m_{\tau_\mu \tau_h}$ spectrum in 2022+2023 **scouting data**, below 60 GeV.

- Using **JetHT** and **EG L1 scouting seeds**
- Dedicated τ_h **scouting reconstruction**:
  - p_T from 20 to 5 GeV!
  - Dynamic cone opening with $\Delta R \propto 1/p_T$
  - Energy flow network TauNet to reject QCD background
- 3 major **analysis regions**:
  - **Signal:** low $p_T^{\tau_h}$, low $p_T^{\tau_\mu}$ and isolated τ_μ
  - Z **region:** high $p_T^{\tau_h}$, high $p_T^{\tau_\mu}$ and isolated τ_μ
  - Υ **region:** low $p_T^{\tau_h}$, low $p_T^{\tau_\mu}$ and non-isolated τ_μ

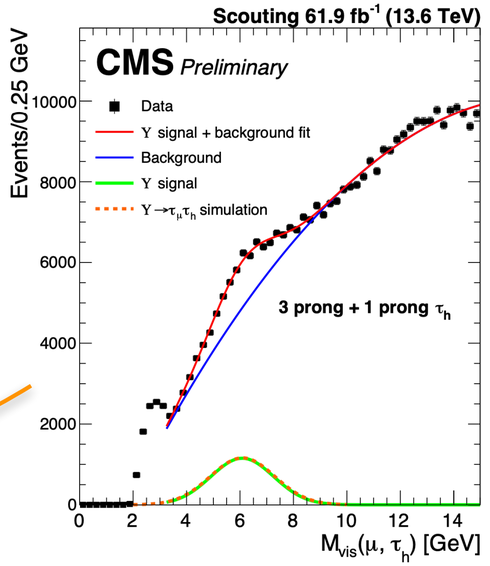


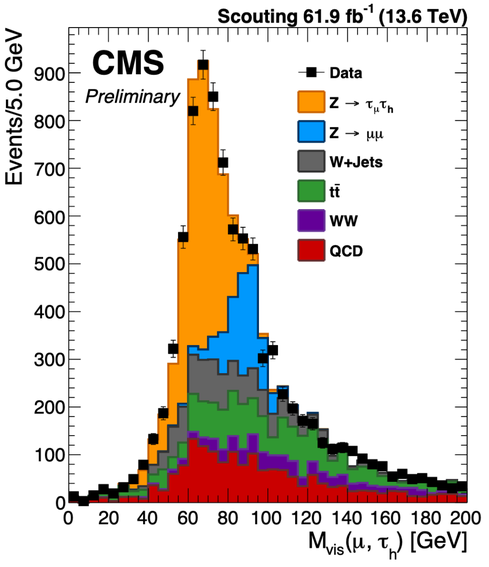
Previous results limited to > 60 GeV
J. High Energy. Phys ***2023****, 73 (2023)*



New!

Observation of $\Upsilon \to \tau\tau$ in an hadron collider!



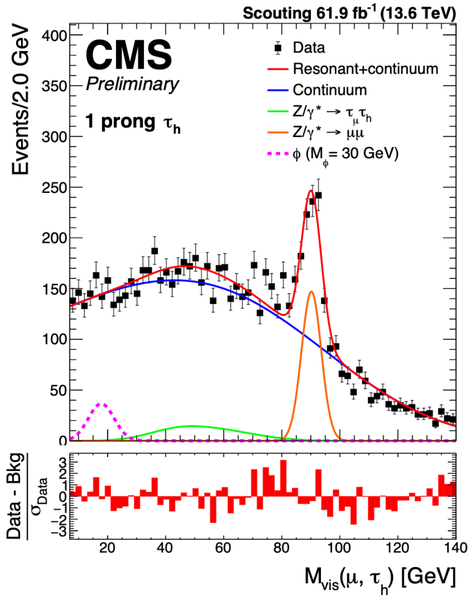


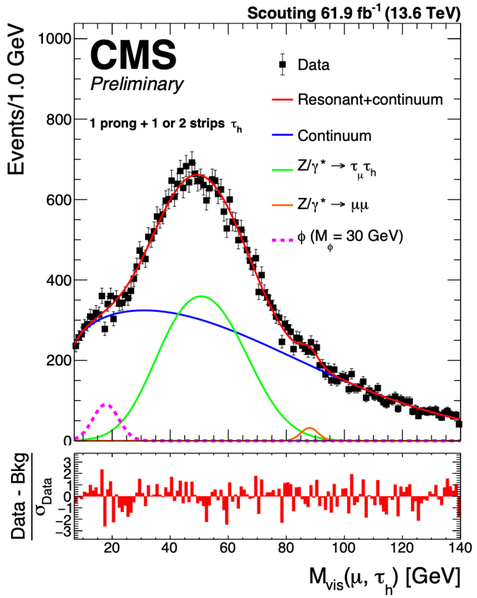
Scouting low mass $\tau\tau$ search

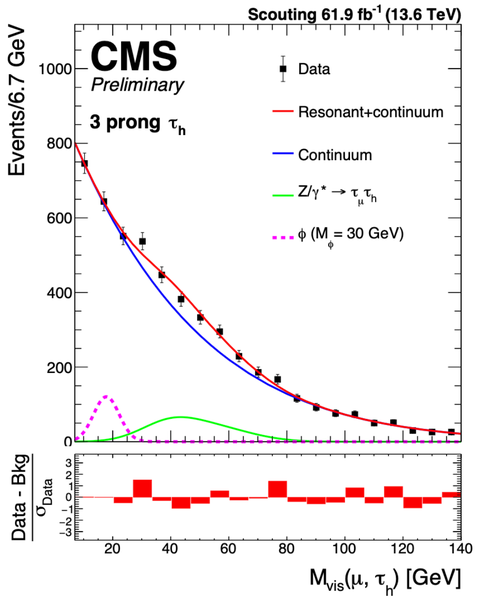
CMS-EXO-24-012

- **Signal region** split into single prong, three prong and 1 prong + N strips. Fit the visible mass in each case.
- **Systematics** account for TauNet performance, trigger efficiency and signal shape modeling

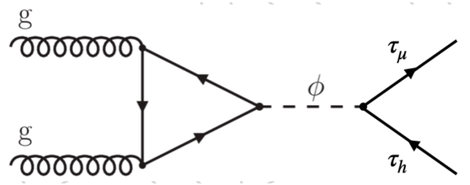
→ Set **95% CL limits** on the gluon-gluon fusion production of a benchmark scalar with **masses between 20 and 60 GeV**

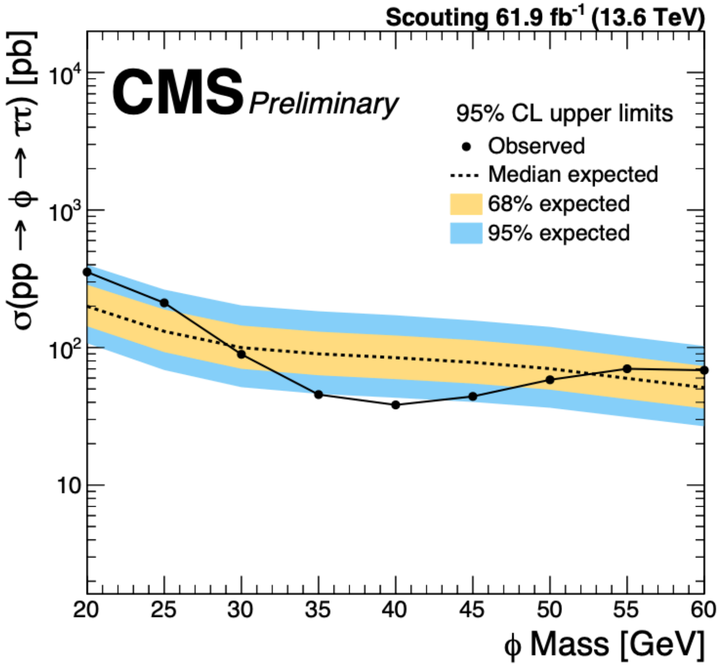






First inclusive limits set in the $\phi \to \tau\tau$ final state for masses below 60 GeV!!

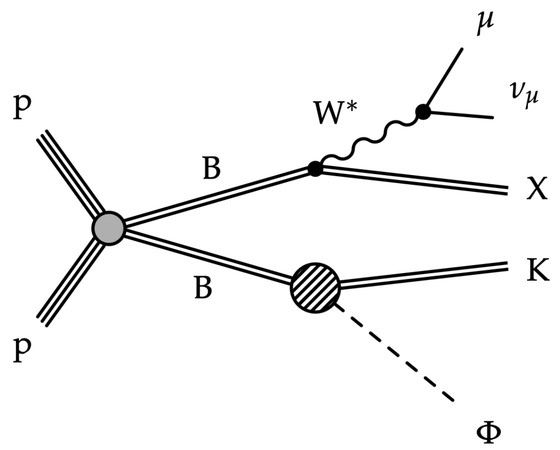




B decays into LLPs in the CMS endcaps

CMS-EXO-24-004

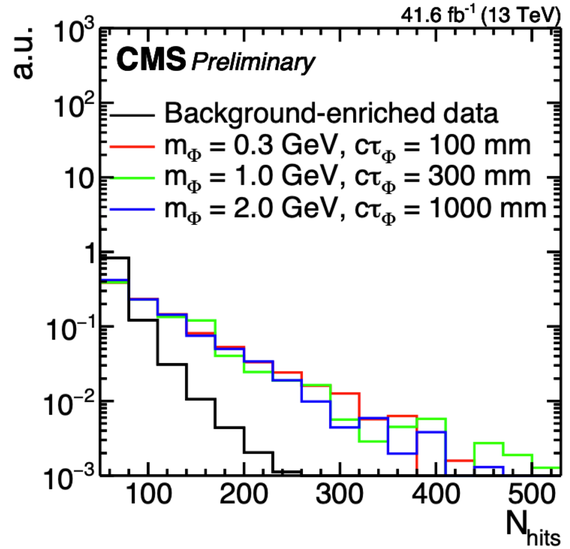
Search for **long-lived particles** (LLPs) produced in **b-hadron** decays, $B \to K\Phi$, generating **muon showers in the CMS endcaps (CSC)**, using 2018 **B-parking data**

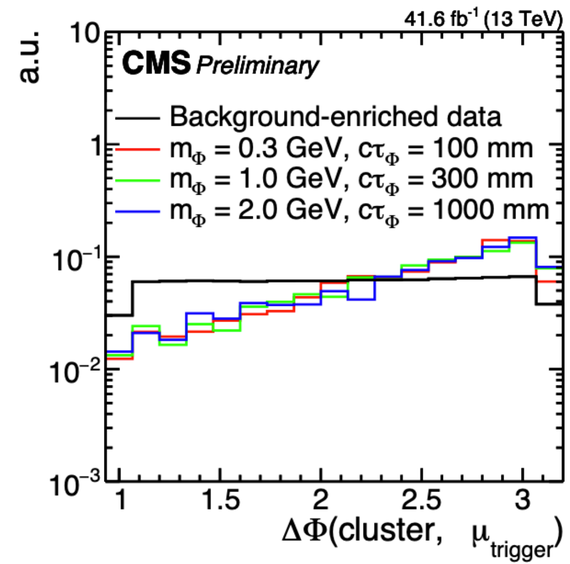


Trigger: on $B \to \mu\nu_\mu X$ with single muon triggers

+ offline requirement of a displaced muon

The $B \to K\Phi$ hadronic decay is targeted as a **Muon detector shower (MDS)** formed from CSC hits





- **Very low background**, estimated from data:
  - **Uncorrelated background** (bremsstrahlung, pile-up…) mitigated through geometric vetos and in-time selections
  - **Jet-induced background**, mostly coming from hadronic b-hadrons

Signal region: defined by MDS with $N_{\text{hits}} > 310$ and $\Delta\phi(\text{cluster}, \mu_{\text{trigger}}) > 2.2$

B decays into LLPs in the CMS endcaps

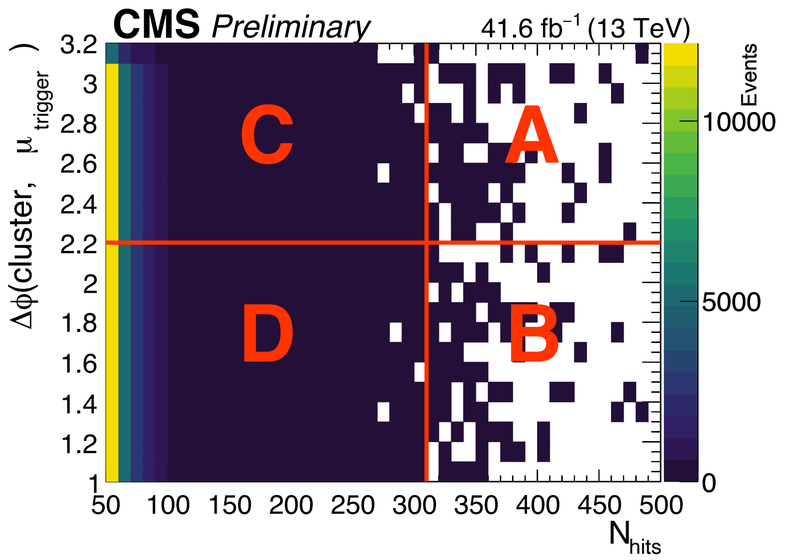
CMS-EXO-24-004

Background estimation:

- Uncorrelated background estimated using ABCD method
- Jet-induced background accounted with a fake-rate estimation

	B	C	D	A (SR)
Jet-induced background	41^{+10}_{-7}	16128^{+230}_{-230}	5701^{+93}_{-91}	156^{+31}_{-22}
Uncorrelated background	19 ± 10	42632 ± 1200	51342 ± 500	16 ± 8
Total background	60^{+14}_{-12}	58760^{+1300}_{-1300}	57043^{+500}_{-500}	171.52^{+32}_{-23}
Observed events	60	58760	57043	181

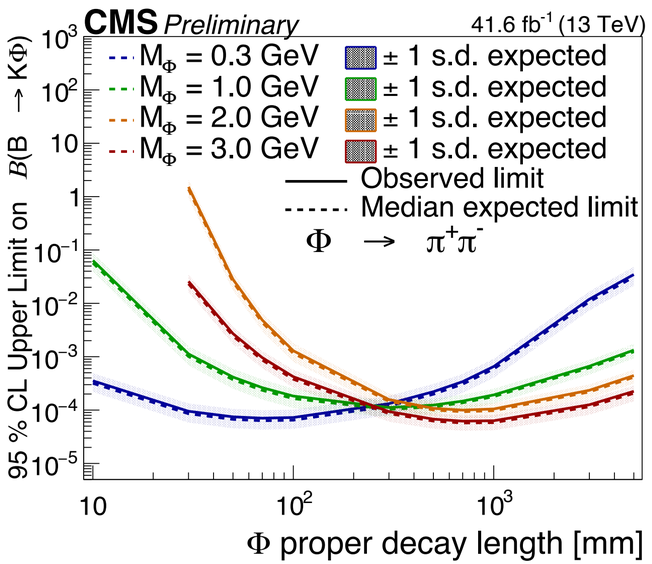
Validation in out-of-time pile up

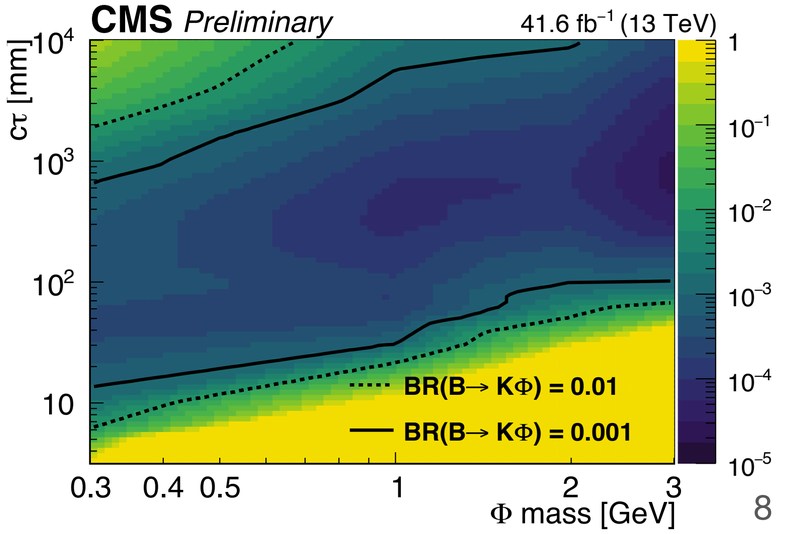


Results:

- No deviation from expectation
- Constrained $Br(B \rightarrow K\Phi)$ at 7×10^{-5} level
- First analysis considering ϕ hadronic decays

New!



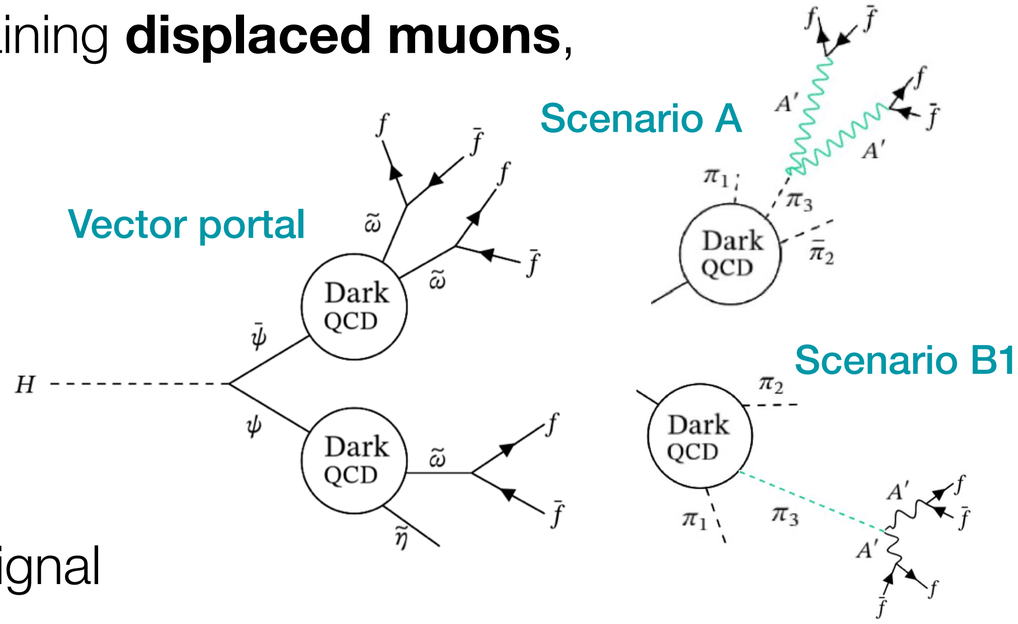


Dark showers with displaced muons

CMS-EXO-24-008

Search for **Hidden Valley models with dark showers** containing **displaced muons**, using 2018 **B-parking data**

- High multiplicity of displaced dark meson decays
- High BR to muons → **B-parking single muon triggers**



Signal: High number of muons and secondary vertices (SV)

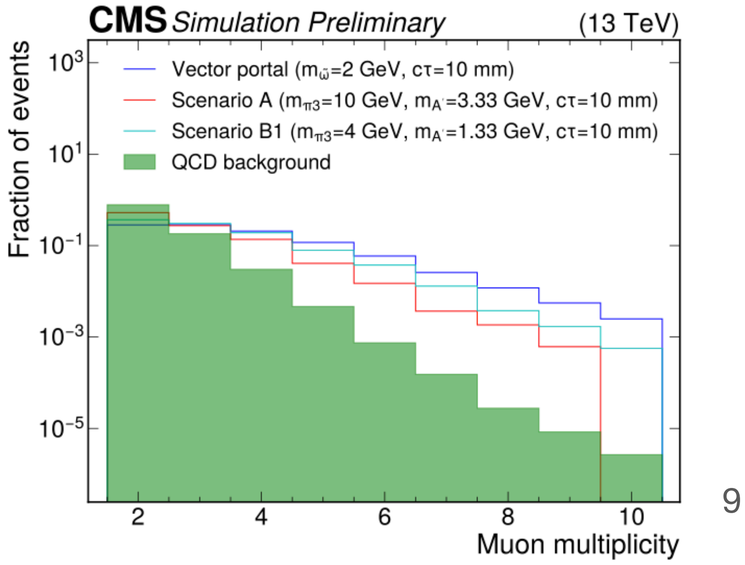
Strategy: Use a dedicated **event-level BDT** to discriminate signal from **QCD background**.

→ variables like N_{muon}, χ^2/ndof and $|d_{xy}|$

→ full reconstruction is important

Final categorization with main SV candidate:

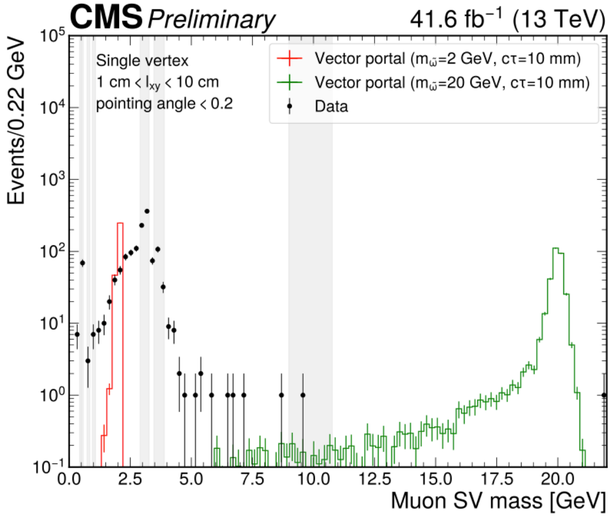
- Transverse displacement l_{xy} in [0.0, 1.0, 10.0] cm
- SV pointing angle in [0.0, 0.2, π]

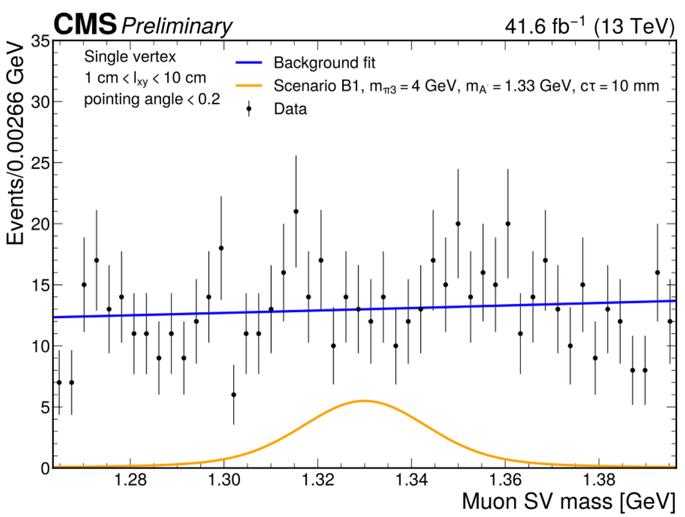


Dark showers with displaced muons

CMS-EXO-24-008

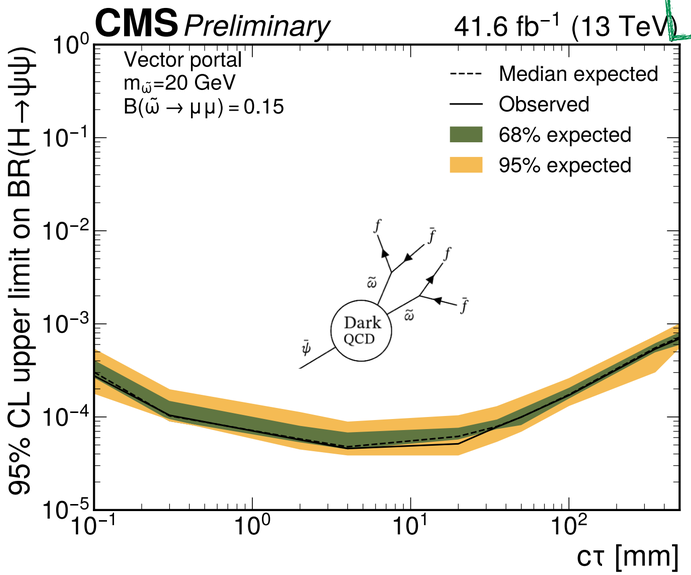
- Signal extracted by **fitting sliding windows** across the invariant mass spectra
- **First results with dark showers decaying into displaced muons**, covering lifetimes up to 10 cm
- Complements *Phys. Rev. D 110 (2024) 032007* at longer displacements





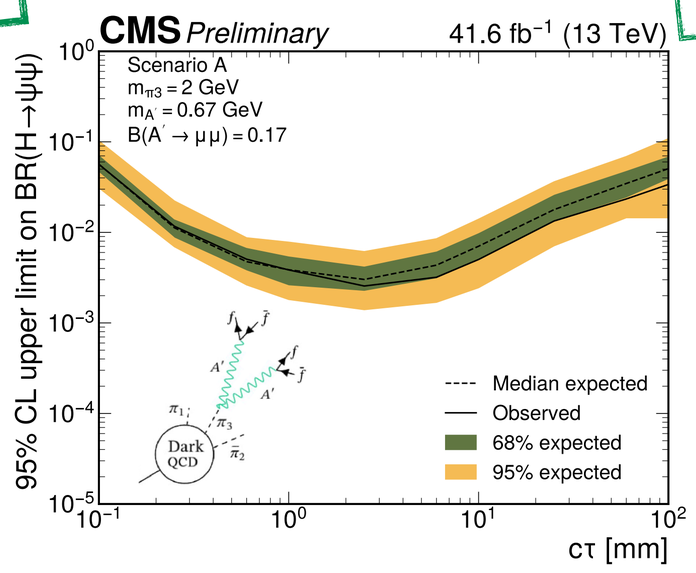
Vector portal

New!



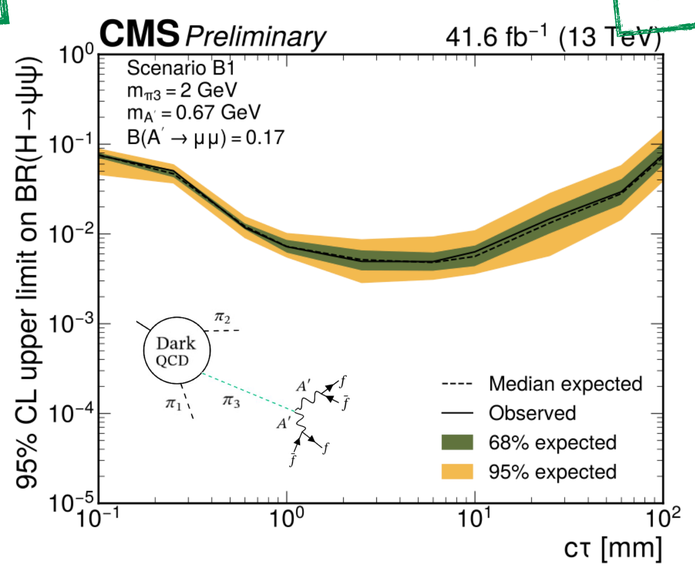
Scenario A

New!



Scenario B1

New!



Scouting displaced muon search

New!

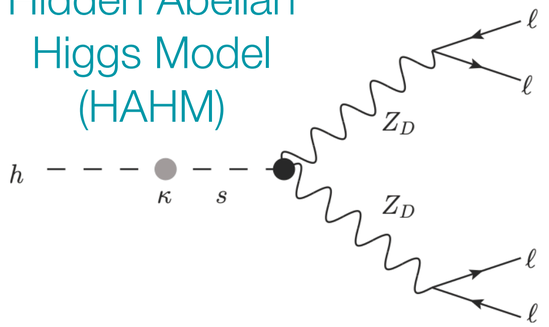
CMS-EXO-24-016

(PAS to be released soon)

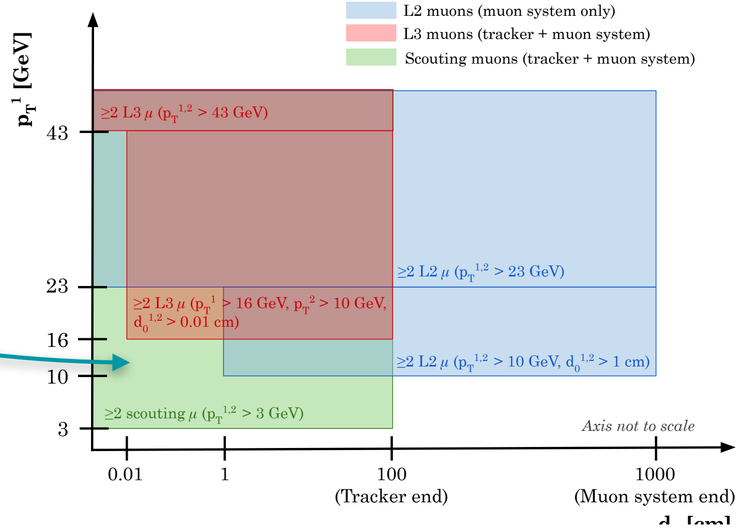
Search for **long-lived particles (LLP)** decaying into muons with 2022 + 2023 scouting data

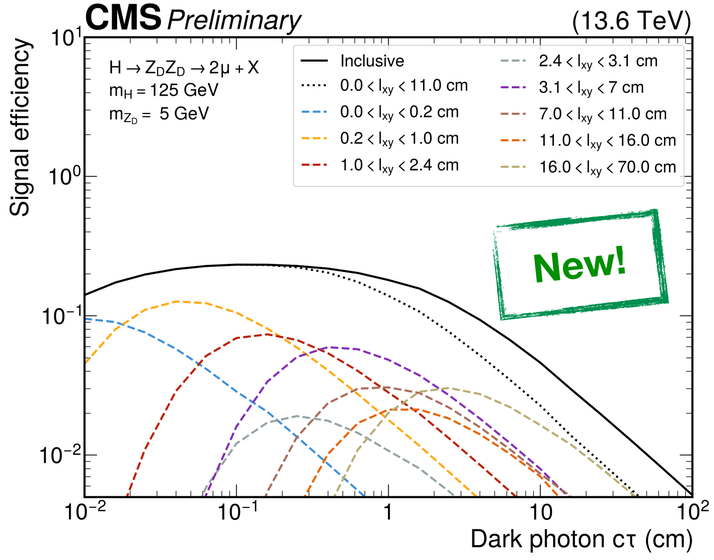
- Scouting di-muon triggers with $p_T^{\mu} > 3$ GeV
- **Inclusive general search**:
  - Di-muons, splitting in:
    - $p_T^{\mu\mu}$, isolation, pointing angle
  - Four-muons:
    - Multivertex di-muons
    - Four-muon overlapping vertex
- Main characterization done in l_{xy}
- Exploiting **improvements** from Run 3 scouting program:
  - $l_{xy} > 11$ cm becomes available for low p_T muon streams

Hidden Abelian Higgs Model (HAHM)



(figure from CMS-PAS-EXO-23-016)





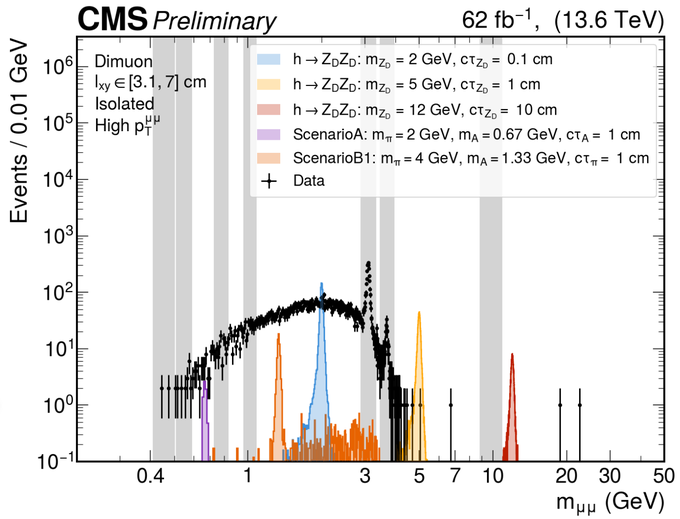
Scouting displaced muon search

New!

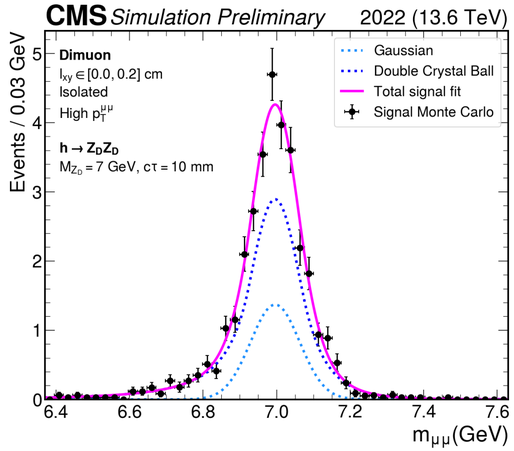
CMS-EXO-24-016

(PAS to be released soon)

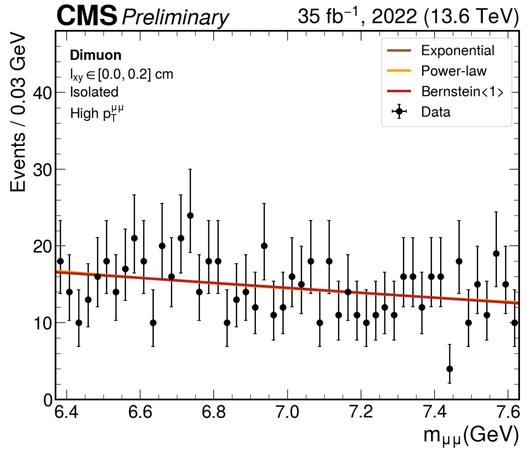
Signal extraction by sliding windows over the mass spectra for the different hypothesis



Signal

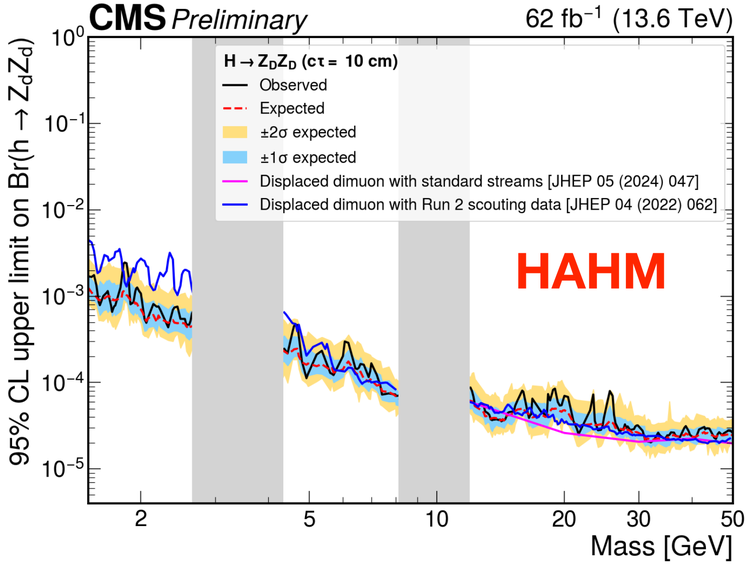


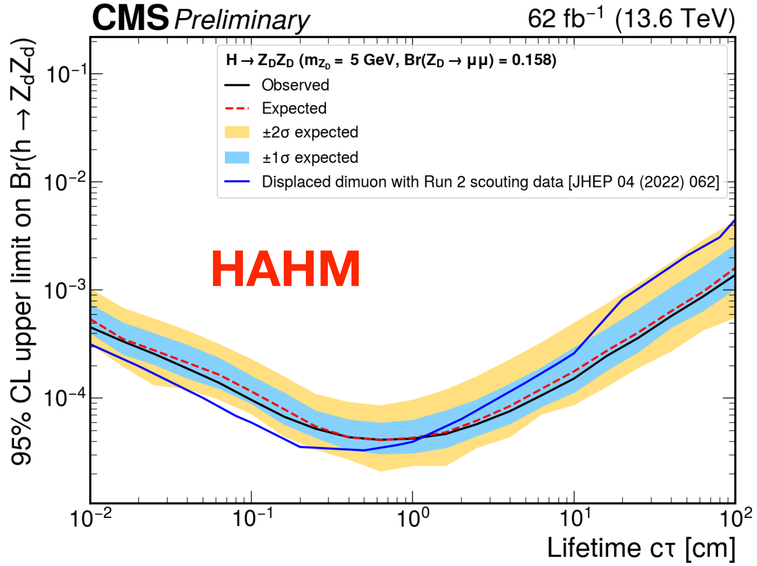
Background

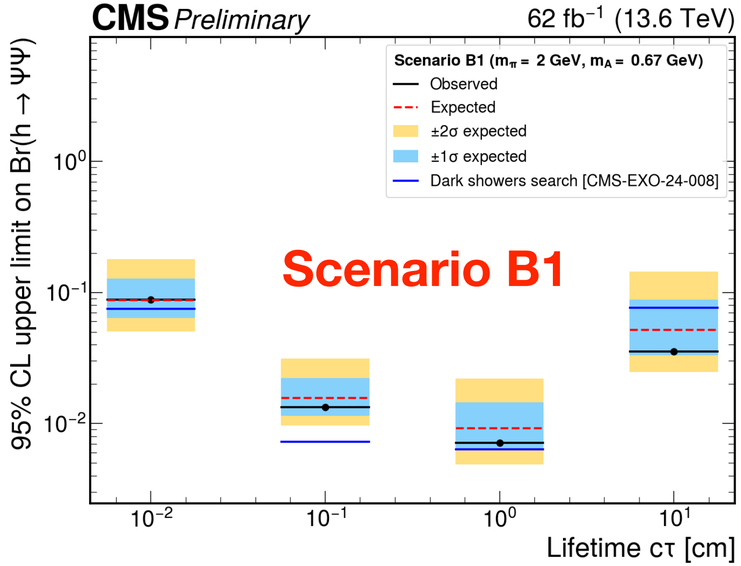


Set 95% CL upper limits on **HAHM with LL dark photons** and **dark showers scenarios**

New!







Summary and conclusions

- **Special data-streams** offer the possibility to perform **new appealing searches** while looking at regions of the phase space that would remain unexplored otherwise

- Rich program in continuous evolution, that allows to **optimize the analyses strategies** as we take more data

- **Four of the latest searches** performed with **parking** and **scouting** were presented

  - Wide variety of experimental signatures
  - Complementarity of standard data streams achieved

    … and more searches to come

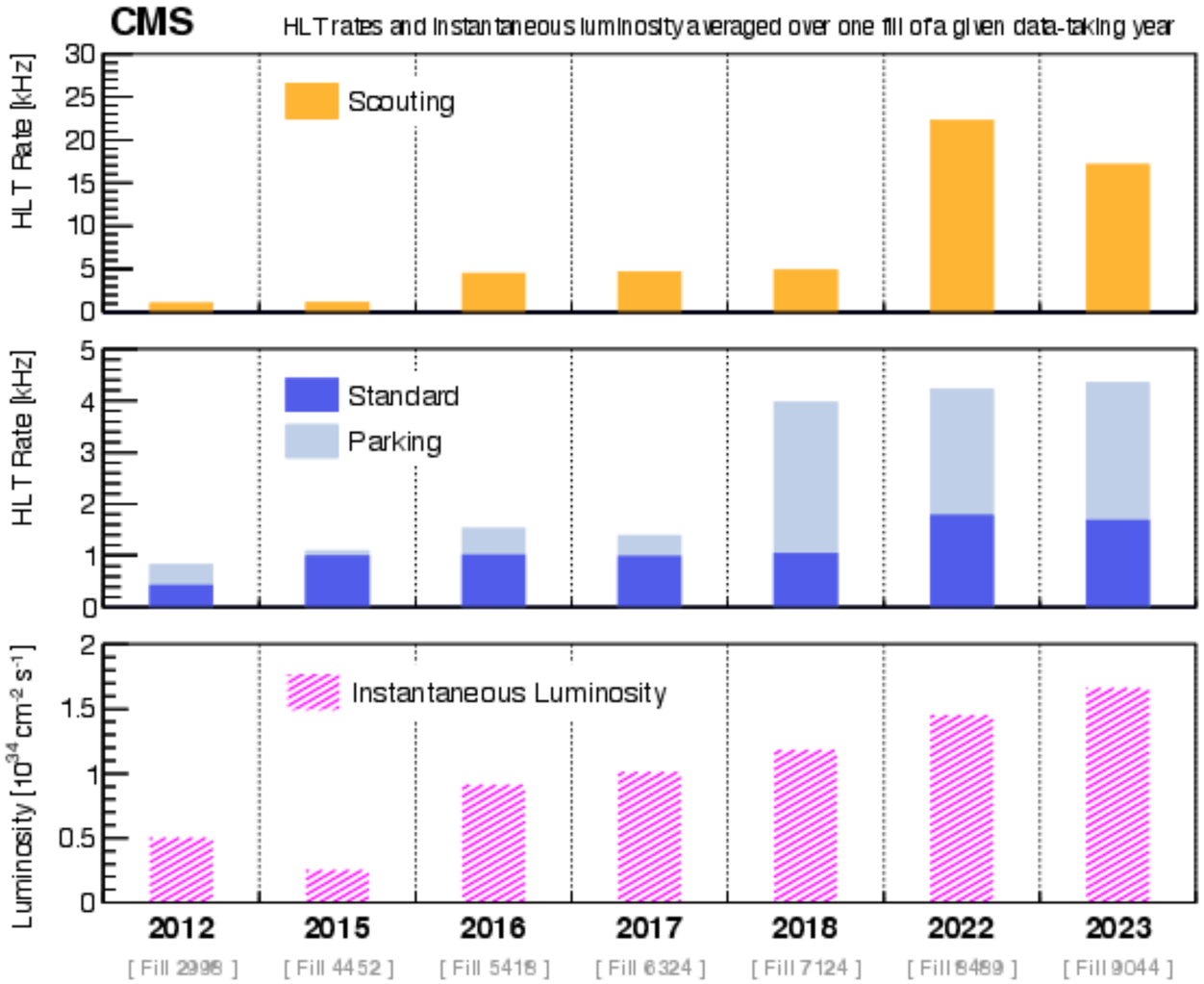
- Stay tuned!

Backup slides

Scouting and Parking paper

CMS-EXO-23-007

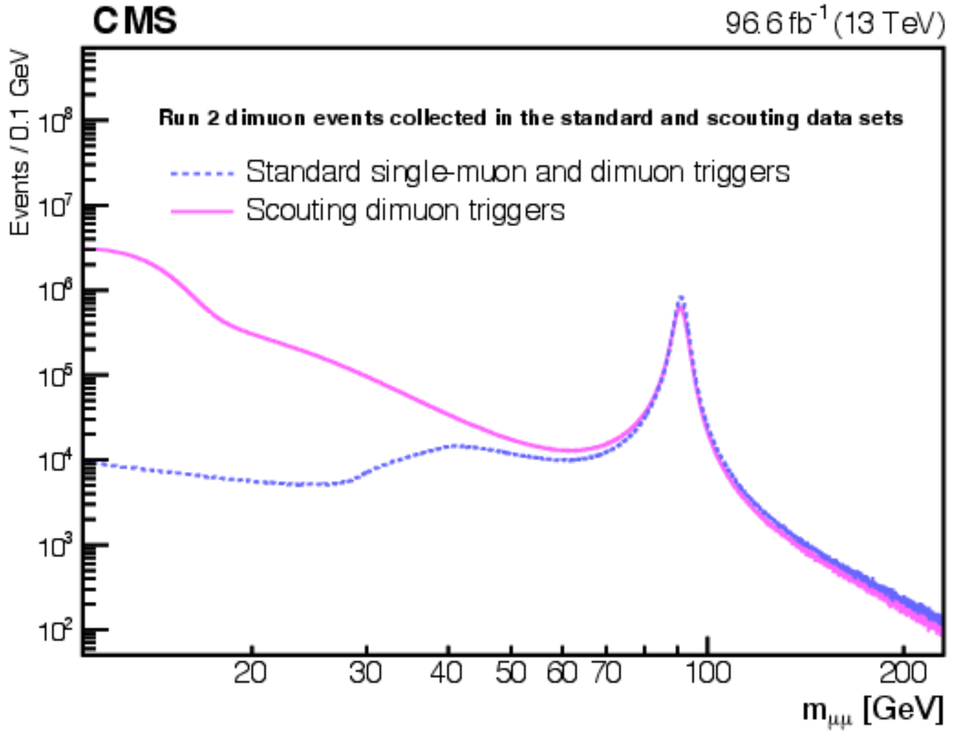
General scouting and parking rates and size



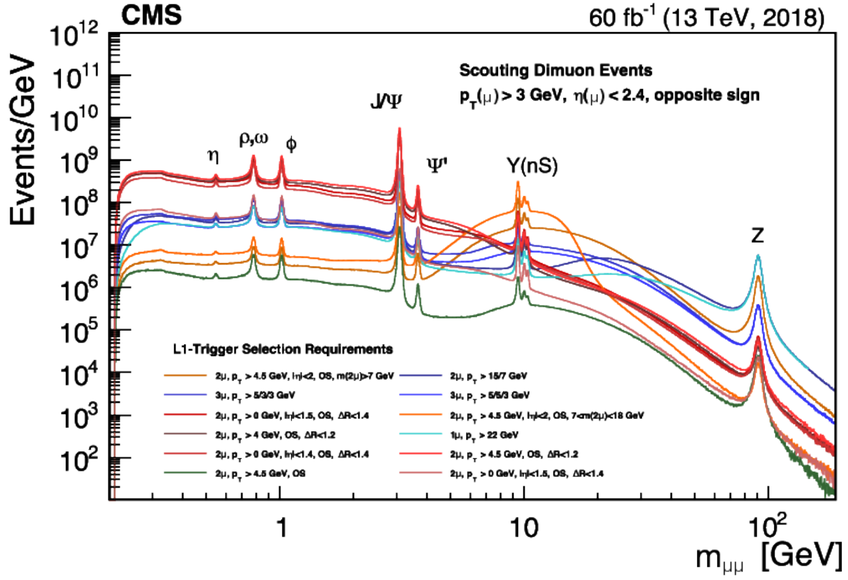
Scouting and Parking paper

CMS-EXO-23-007

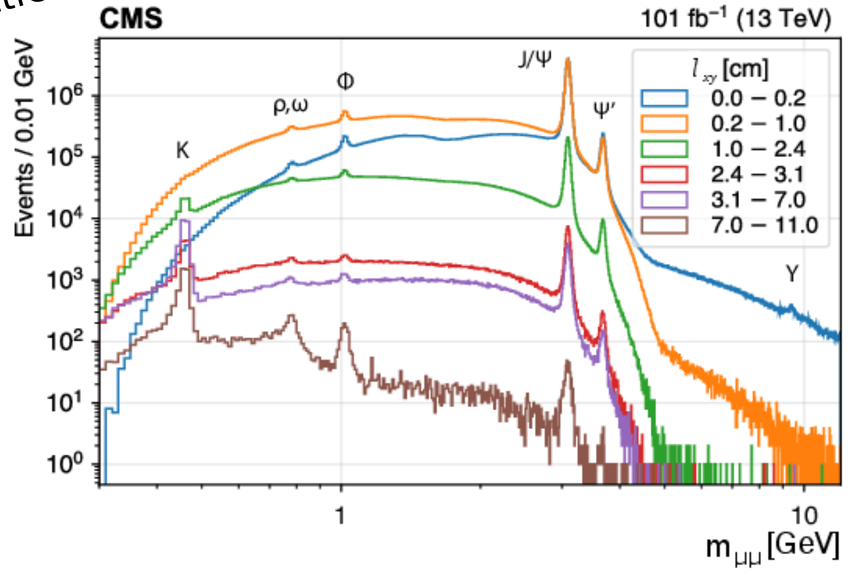
Scouting trigger vs standard



L1 seed coverage



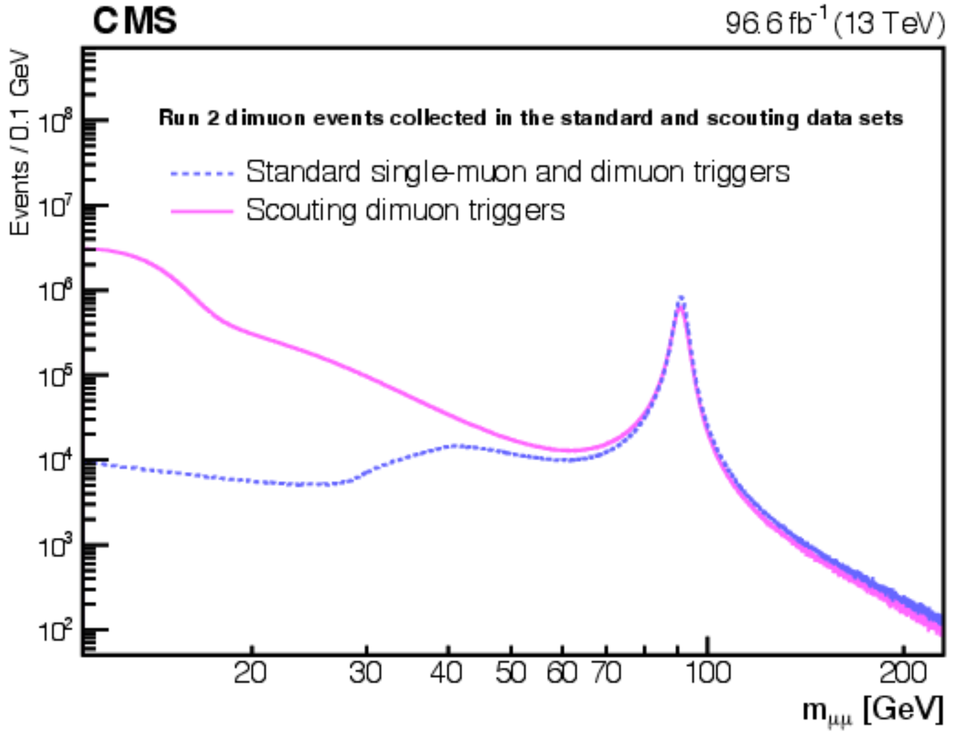
Displacement population



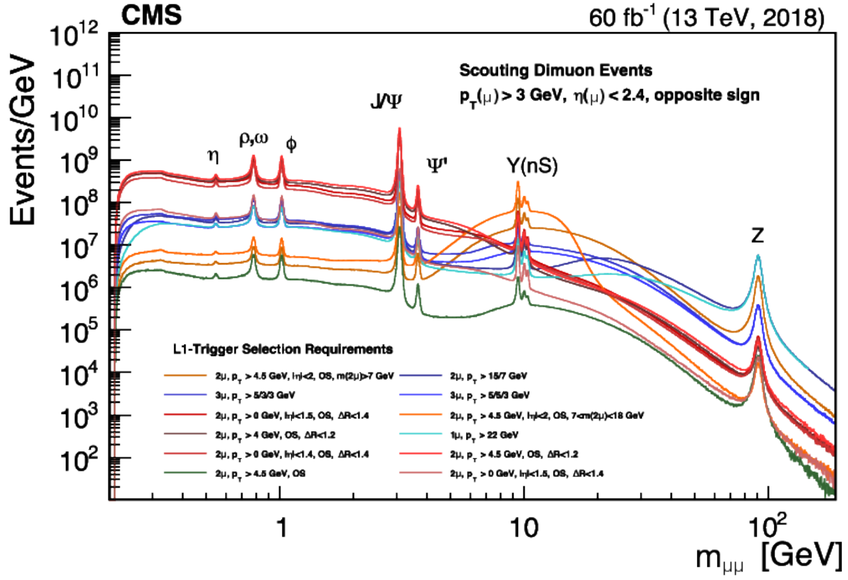
Scouting and Parking paper

CMS-EXO-23-007

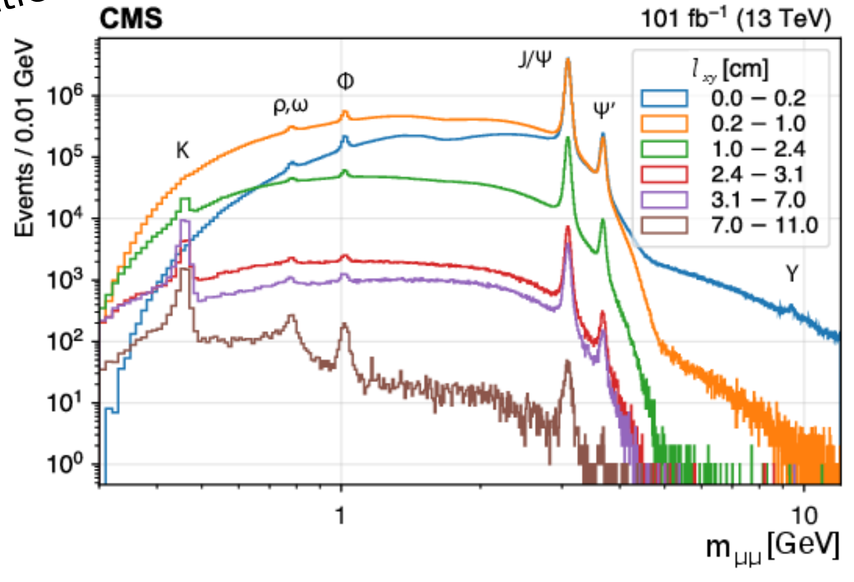
Scouting trigger vs standard



L1 seed coverage



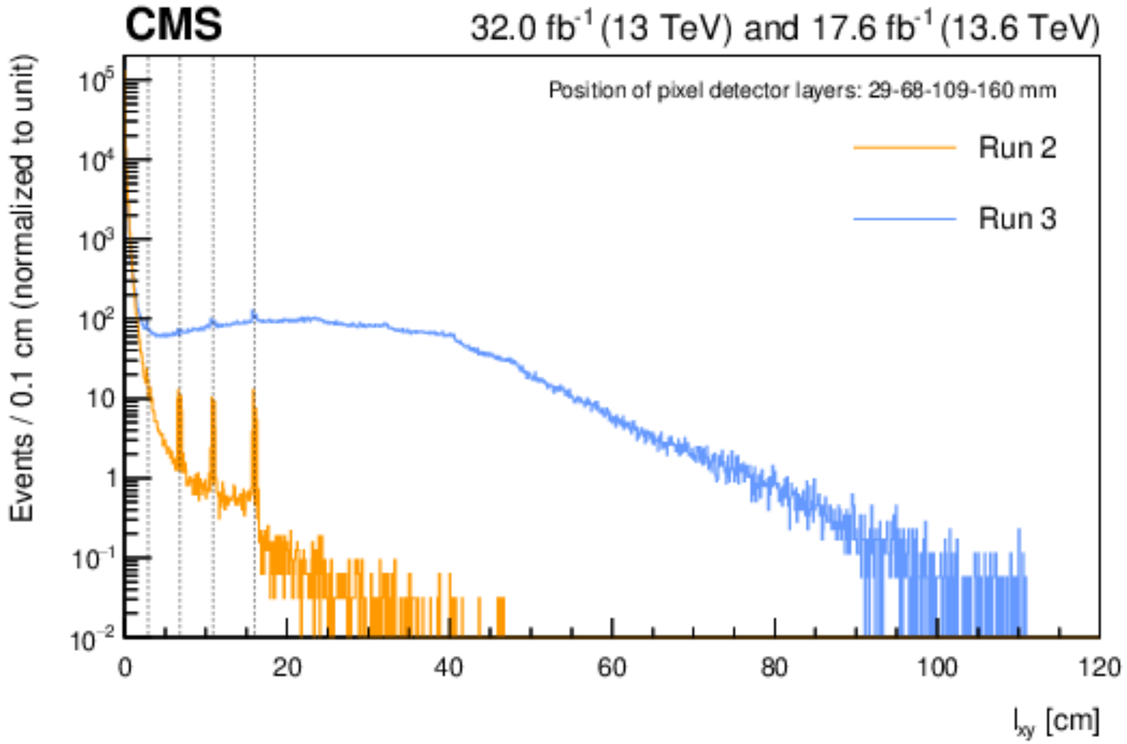
Displacement population



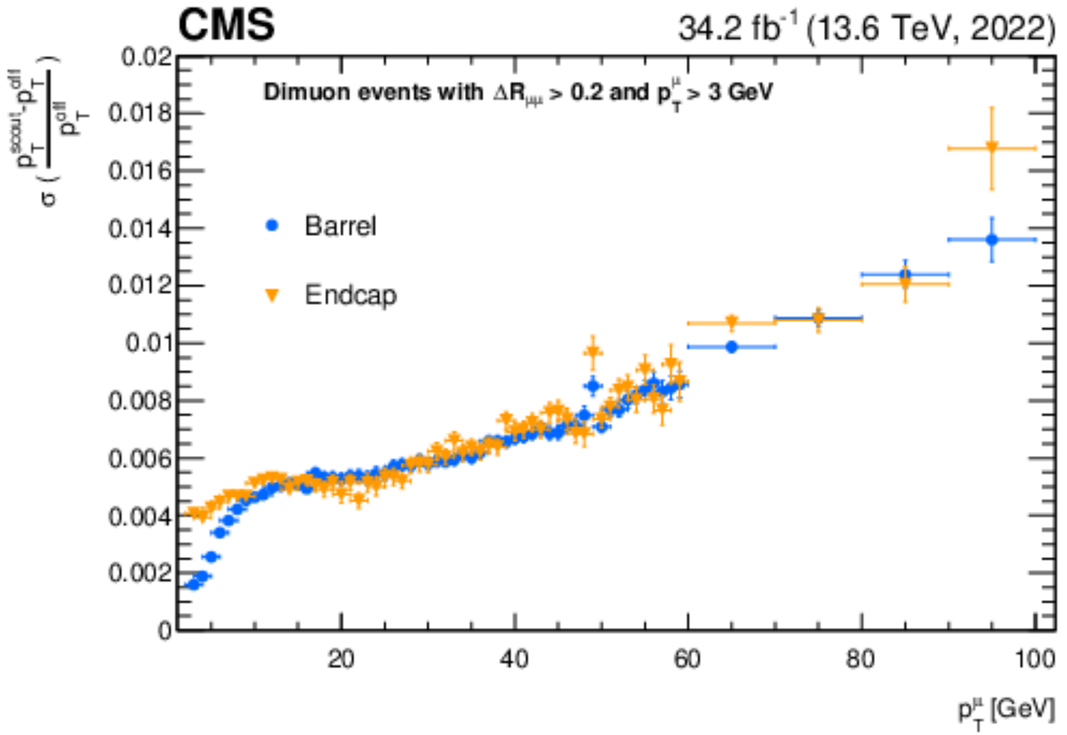
Scouting and Parking paper

CMS-EXO-23-007

Dimuon population vs displacement



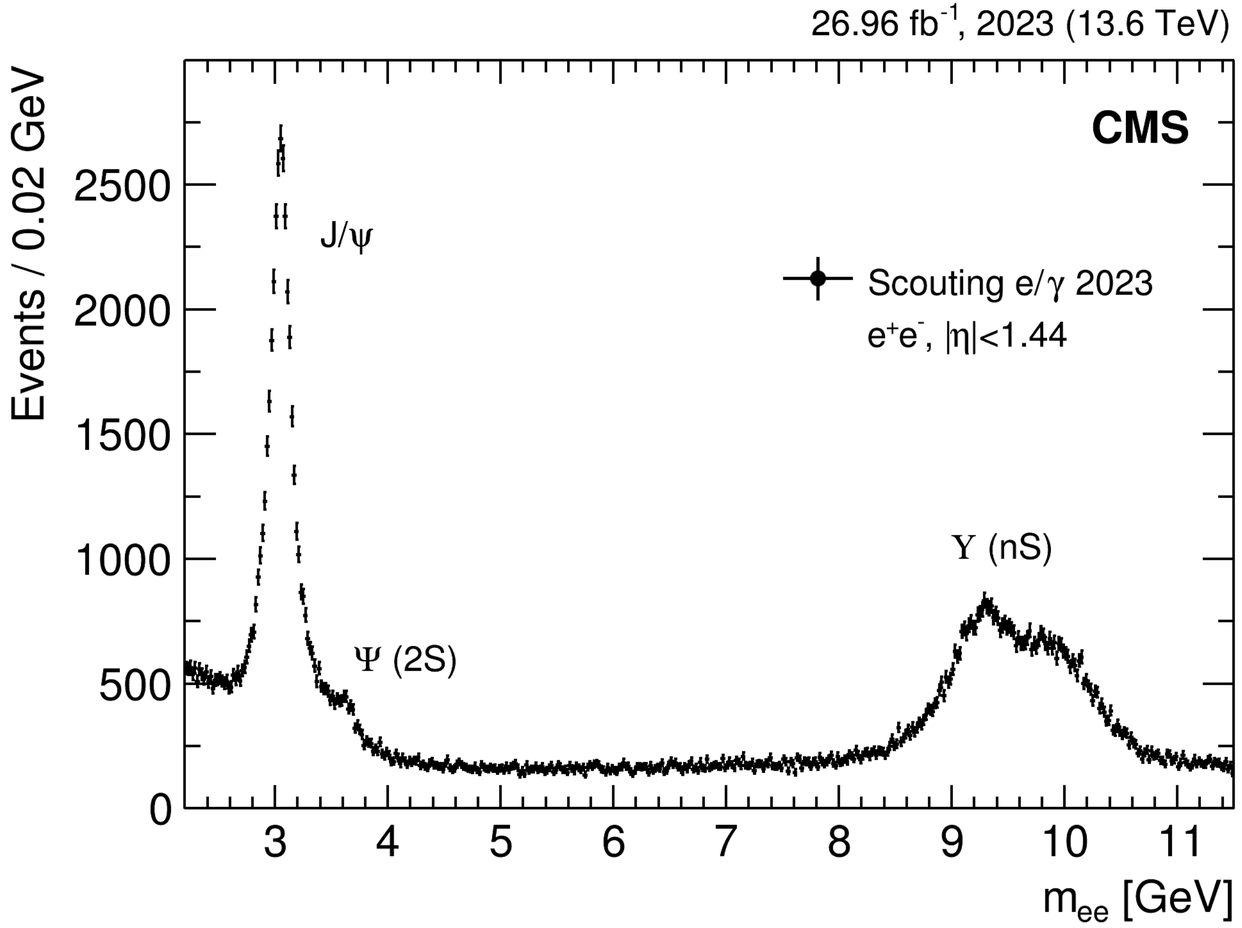
PT resolution



Scouting and Parking paper

CMS-EXO-23-007

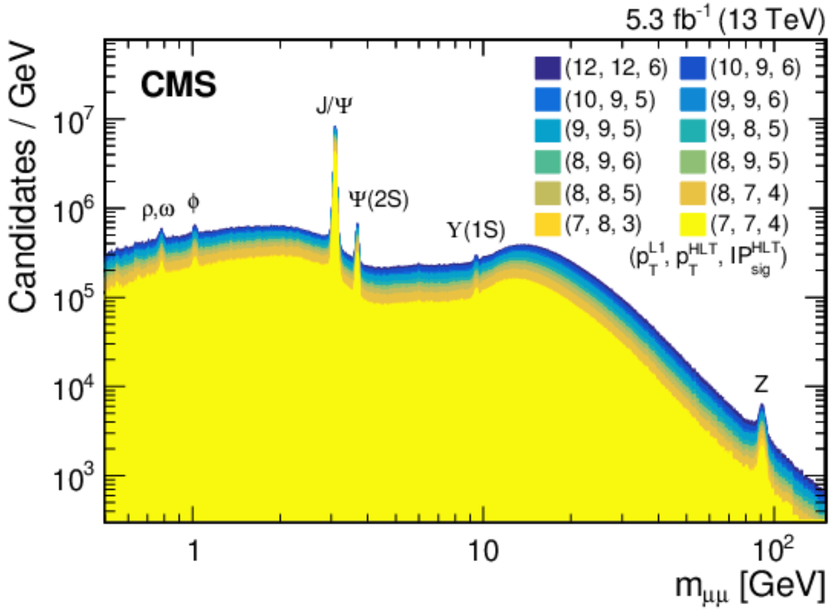
Scouting dielectron invariant mass in 2023



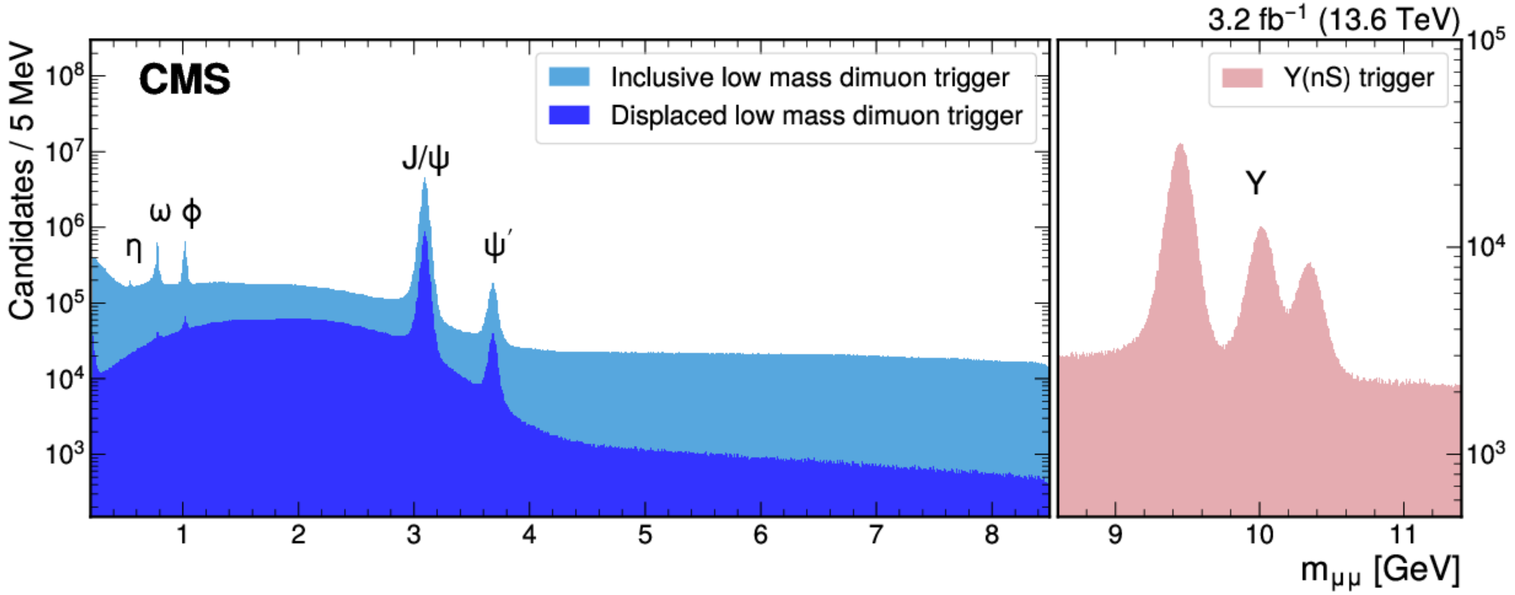
Scouting and Parking paper

CMS-EXO-23-007

Parking muon triggers coverage in B-parking data

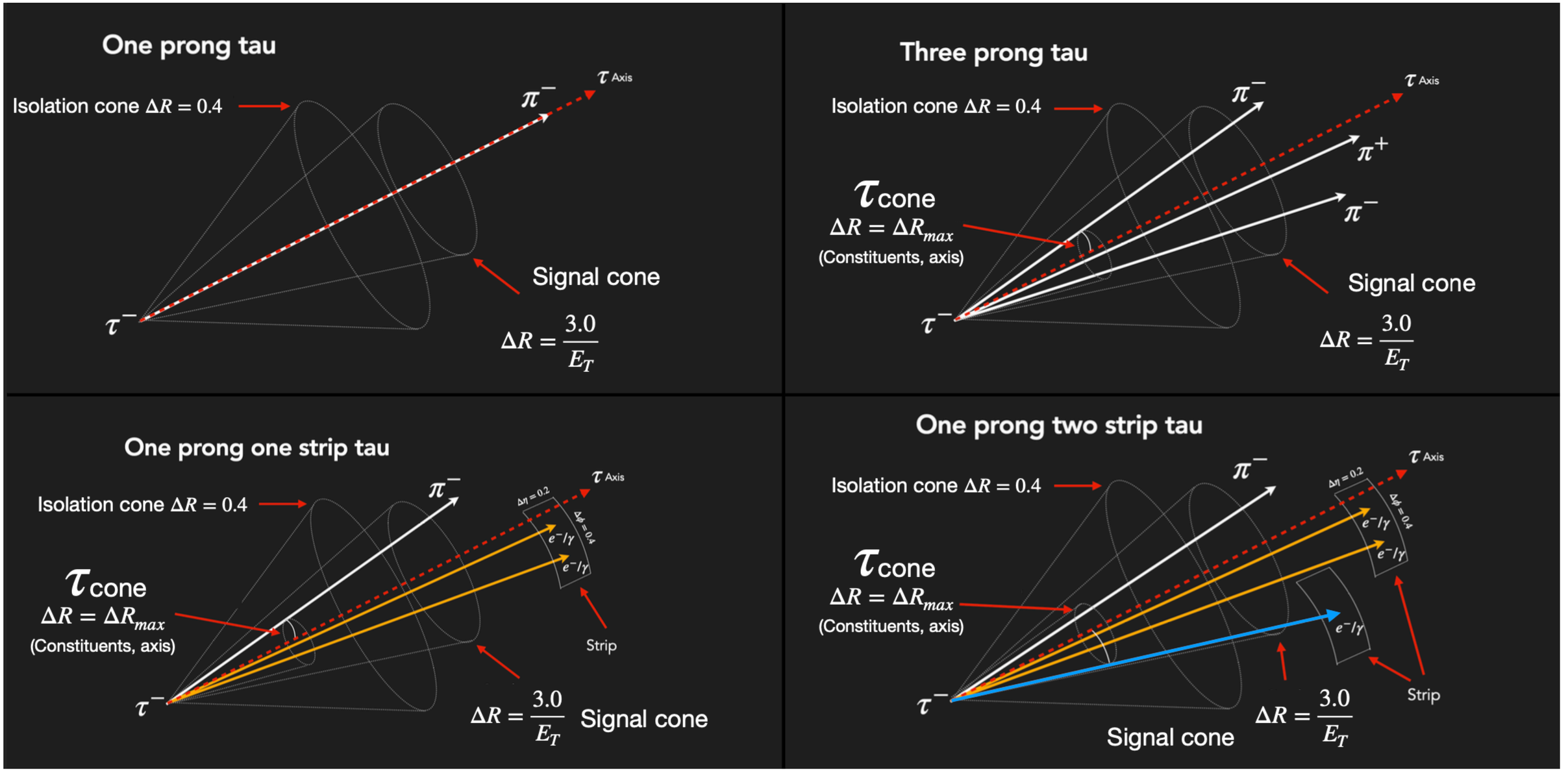


Low mass dimuon b-parking triggers in 2022



Hadronic tau categories

CMS-EXO-24-012



Hadronic tau reconstruction

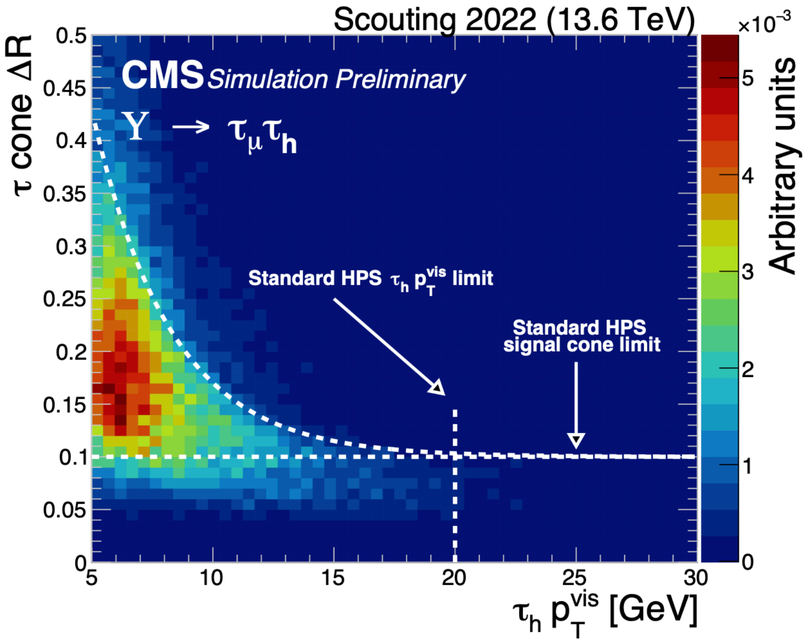
CMS-EXO-24-012

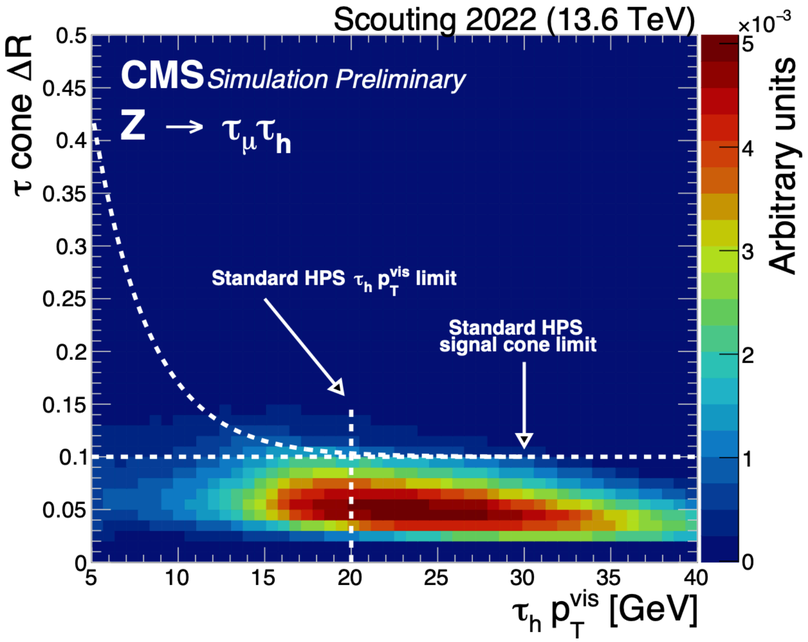
Scouting Hadron Plus Strip reconstruction

Ingredients:

- Neutral Hadron reconstruction from e/γ scouting candidates
  - Same algorithm as standard, but adapted to scouting
- Hadron plus strips -> Clustering strips and $\pi^{\pm}$ with AK4 jet reconstruction
  - Dynamic signal cone $= 2.8^{-0.3\times(p_T(\tau_h)\ [\text{GeV}]-1.4)+0.1}$

Dedicated DP Note
CMS-Note-24-006





Hadronic tau discriminator

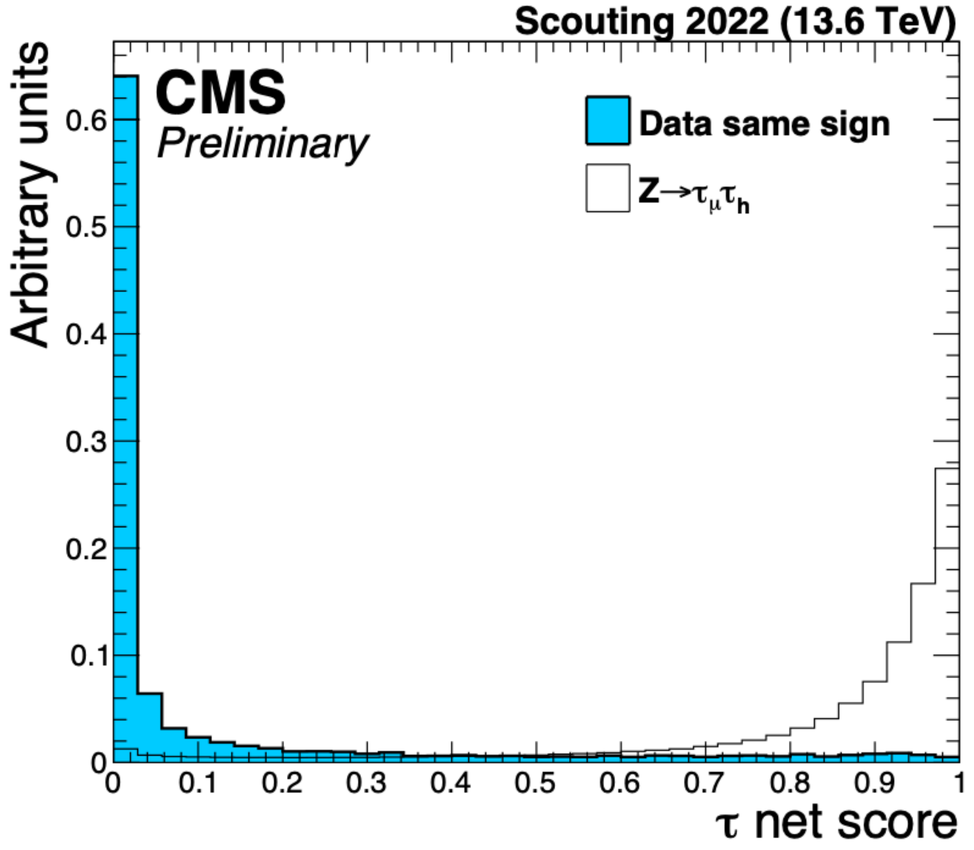
CMS-EXO-24-012

TauNet discriminator

Neural Network trained on 2.5 τ_h decays:

- $\Delta\phi$ between PF particle and jet axis
- $\Delta\eta$ between PF particle and jet axis
- ΔR between PF particle and jet axis
- $\log(p_T^{PF}/p_T^{jet})$ between PF particle and jet
- $\log(E^{PF}/E^{jet})$ between PF particle and jet
- Is the PF particle a hadron
- Is the PF particle e/γ
- d_{xy} of PF particle if charged
- d_z of PF particle if charged
- If the PF particle a constituent of HPS tau?

Dedicated DP Note
CMS-Note-24-006

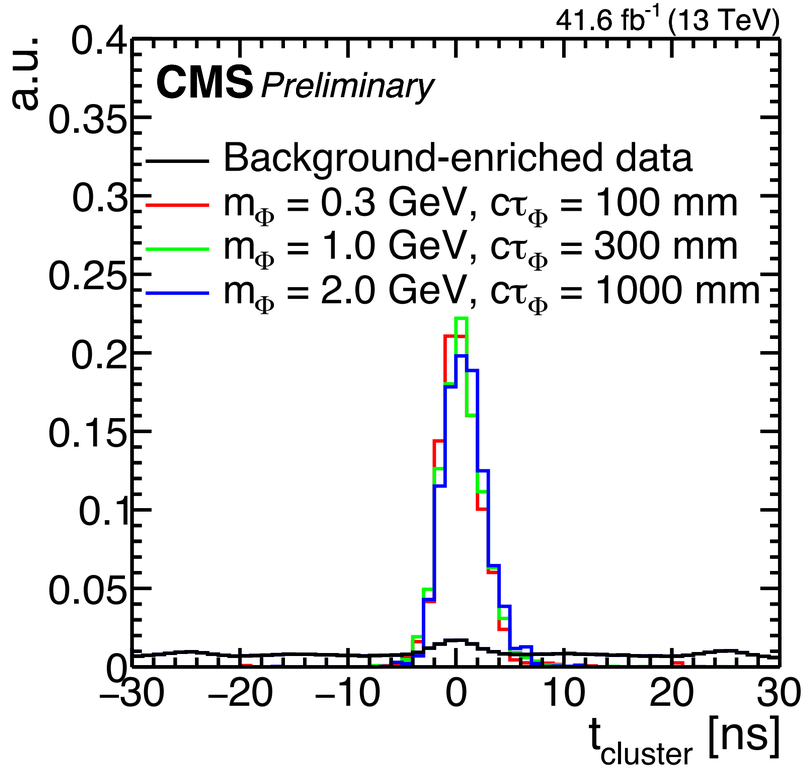


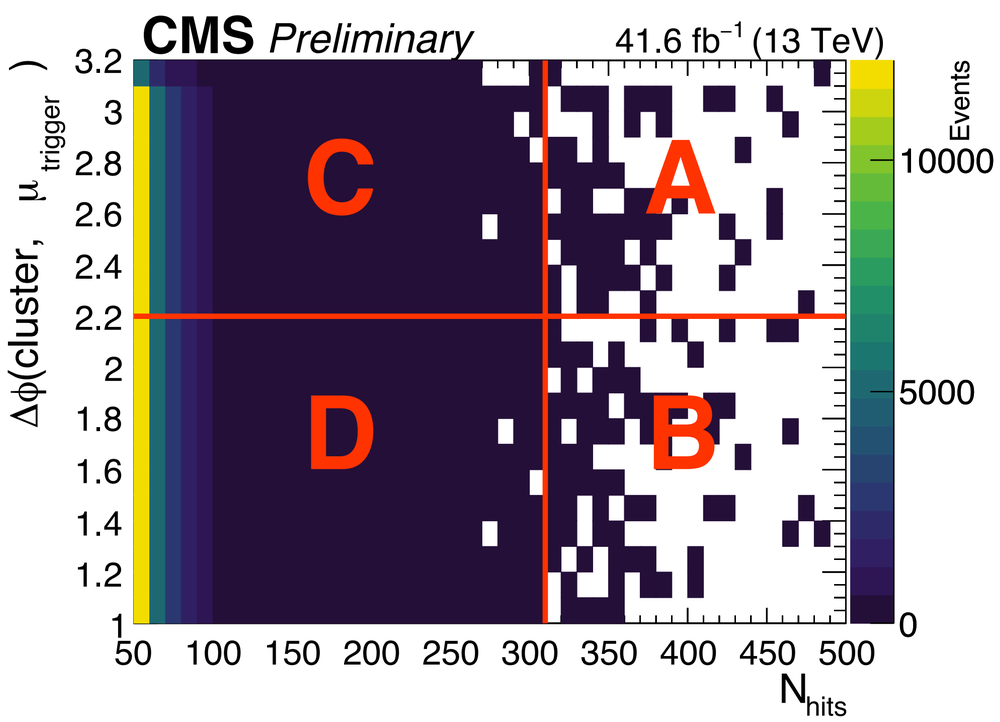
B-hadron decays into LLP: Out-of-time PU

CMS-EXO-24-004

Signal is targeted by selecting on the time of the supercluster within [-5, 12.5] ns

Out-of-time pile up control region is defined by events out of this range.





Jet induced background estimation

CMS-EXO-24-004

This background arises from SM decays of b-hadrons, expected to be back-to-back with the muon used for triggering.

Fake-rate: Rate of a jet to induce a fake shower in the muon system

Using a sample of W+jets with single lepton and photon triggers and identify with the isolated lepton.

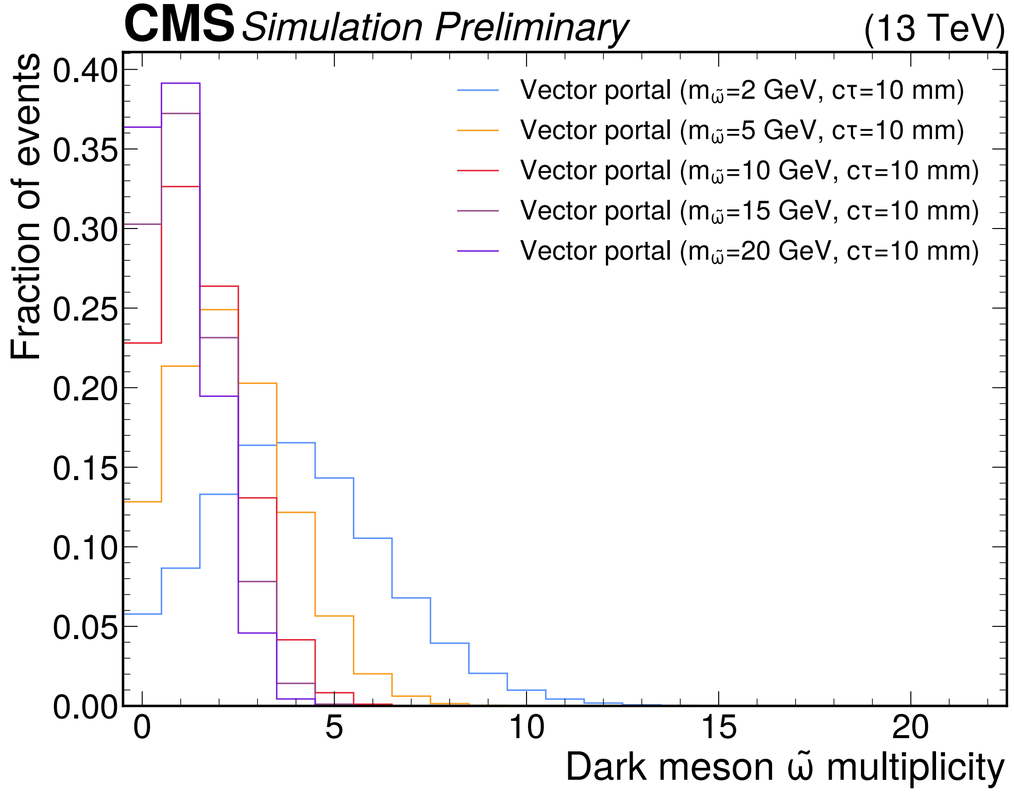
-> Measure the fraction of SM jets inducing showers

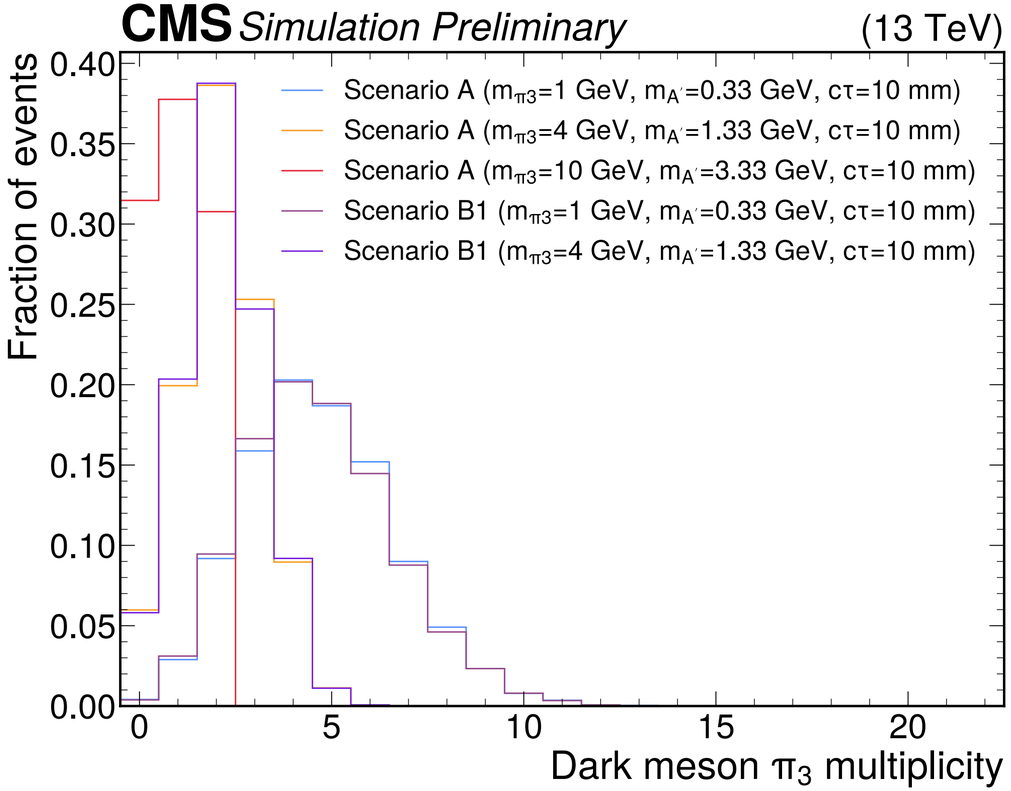
Validated in sidebands of SR defined with $1 < \Delta\phi(\text{cluster}, \mu_{\text{trigger}}) < 2.2$

Dark showers models

CMS-EXO-24-008

Multiplicity of dark mesons

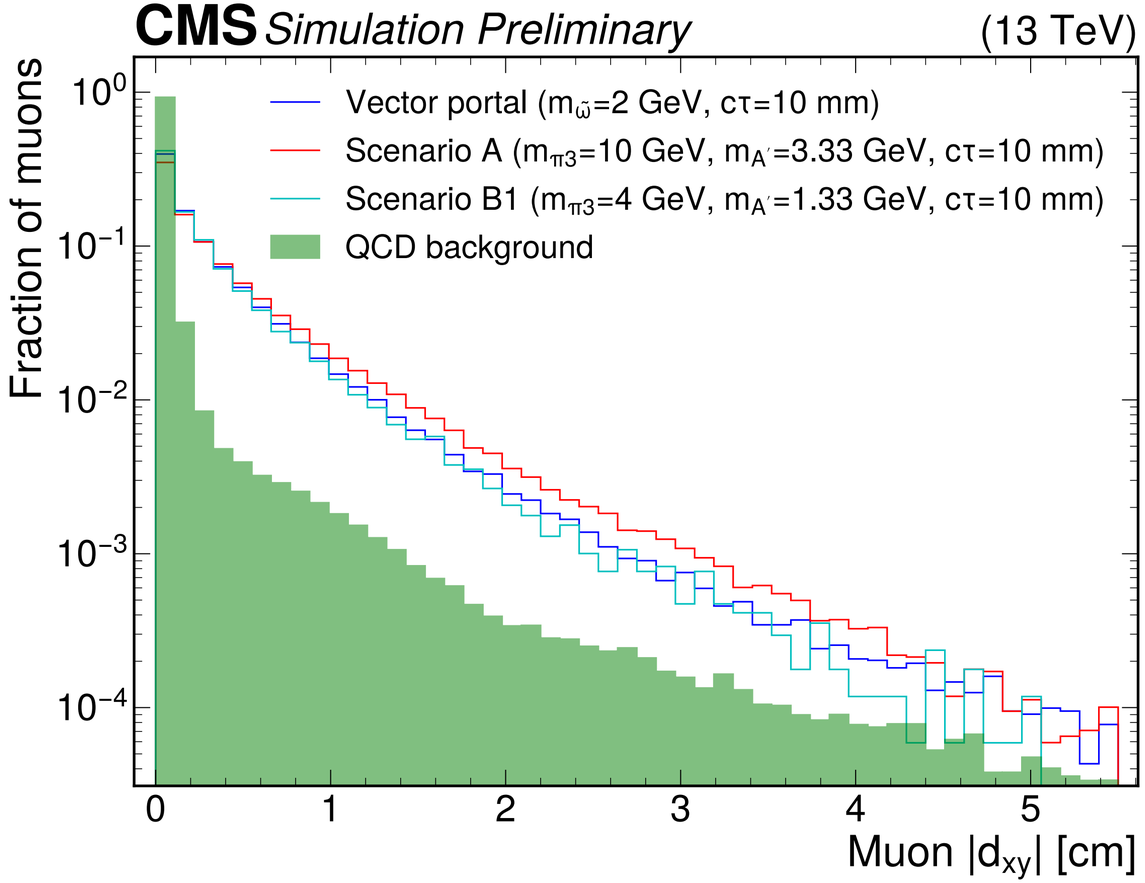


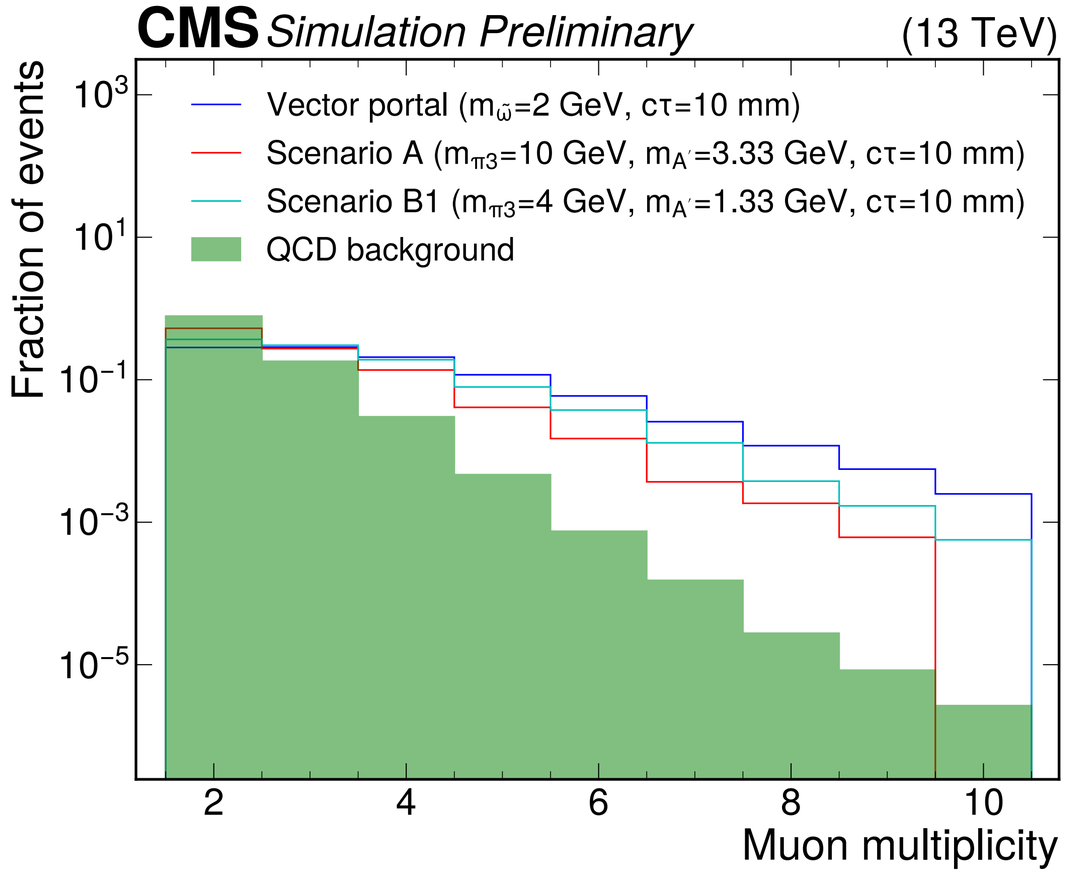


Dark showers models

CMS-EXO-24-008

Training variables for BDT

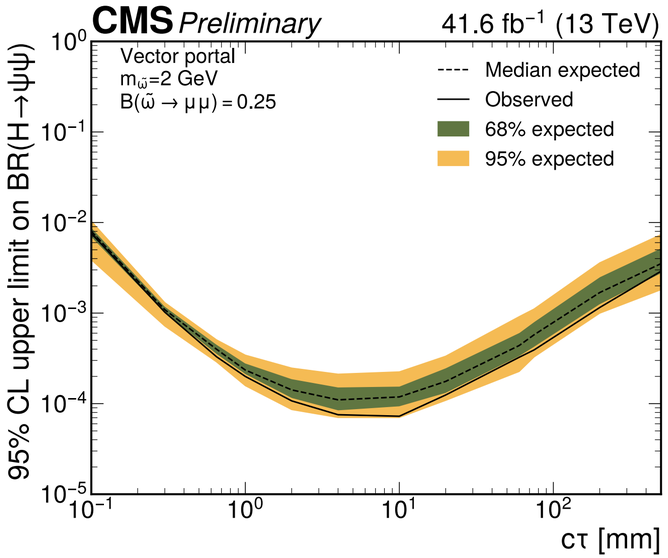


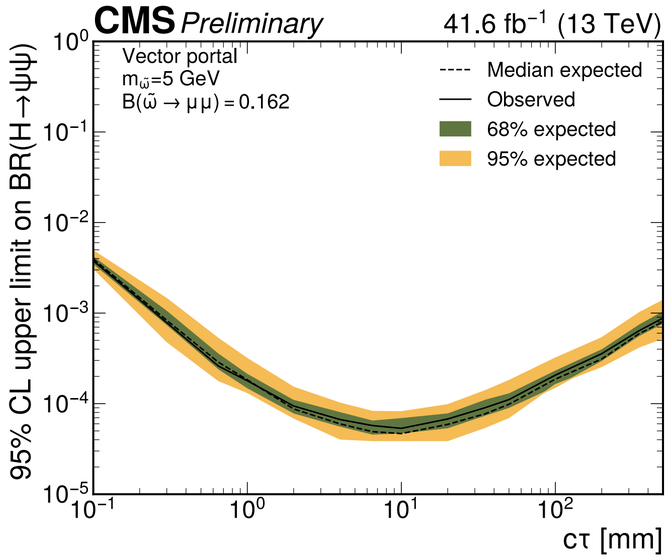


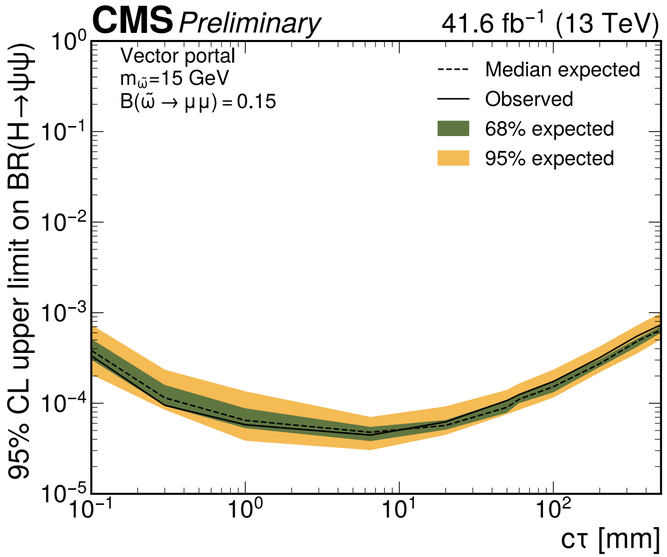
Dark showers limits: Dark portal

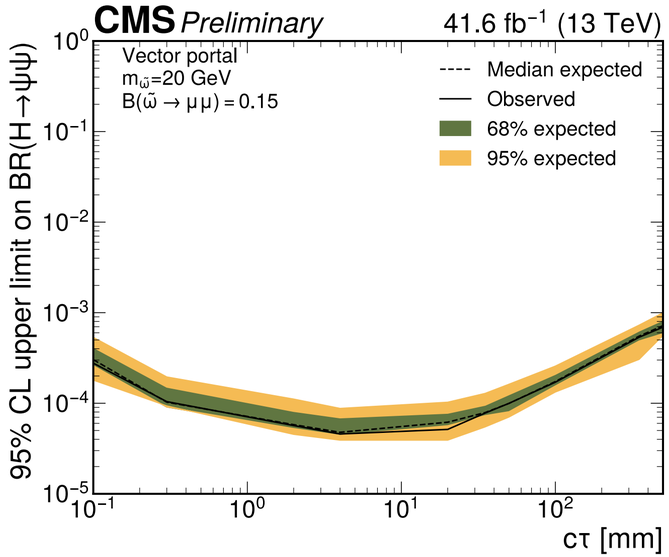
CMS-EXO-24-008

Dark portal limits





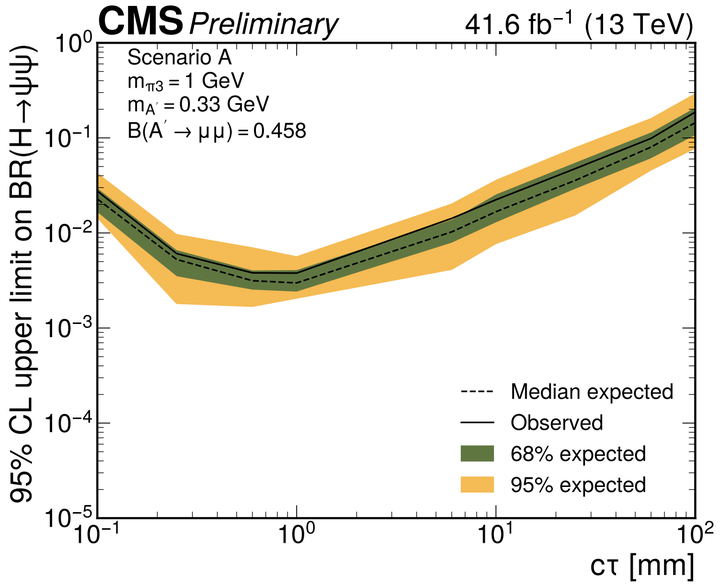


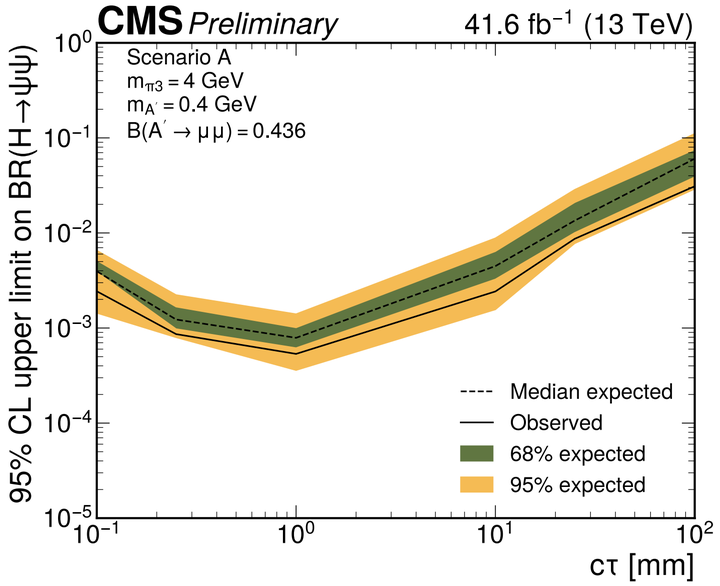


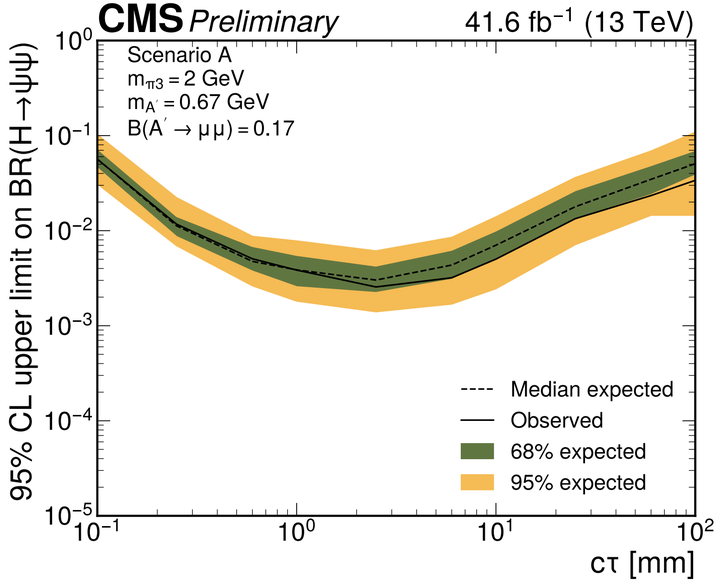
Dark showers limits: Scenario A

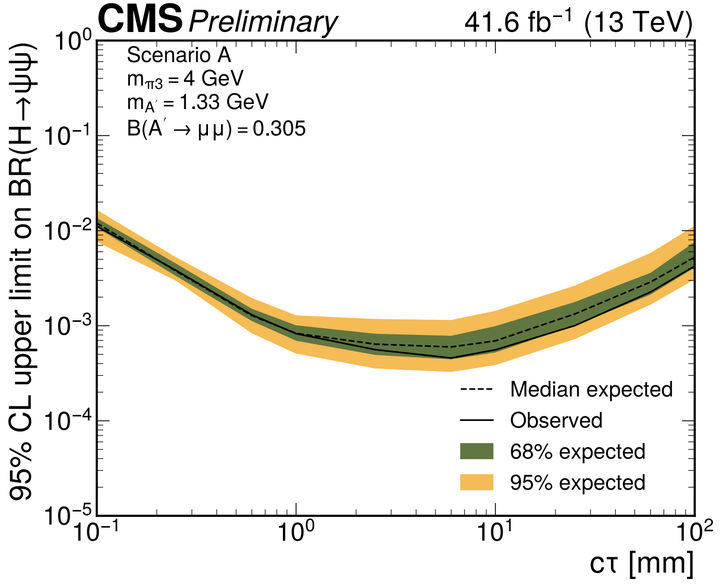
CMS-EXO-24-008

Scenario A





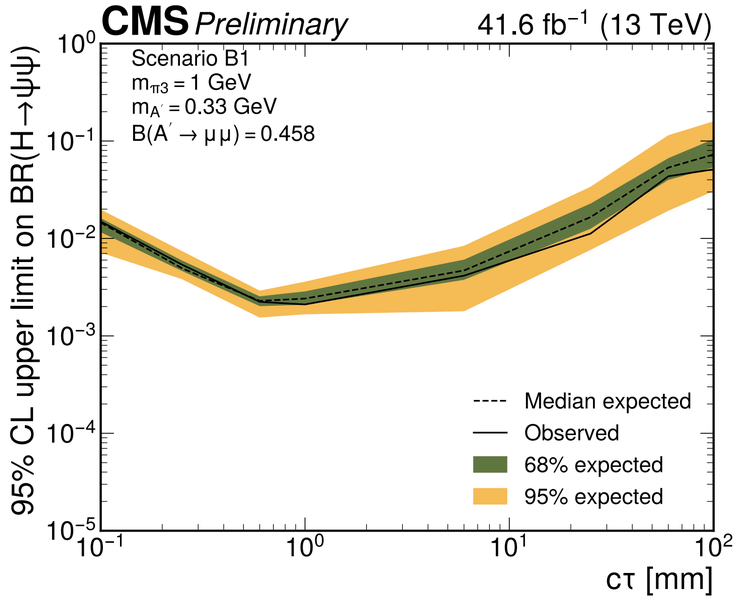


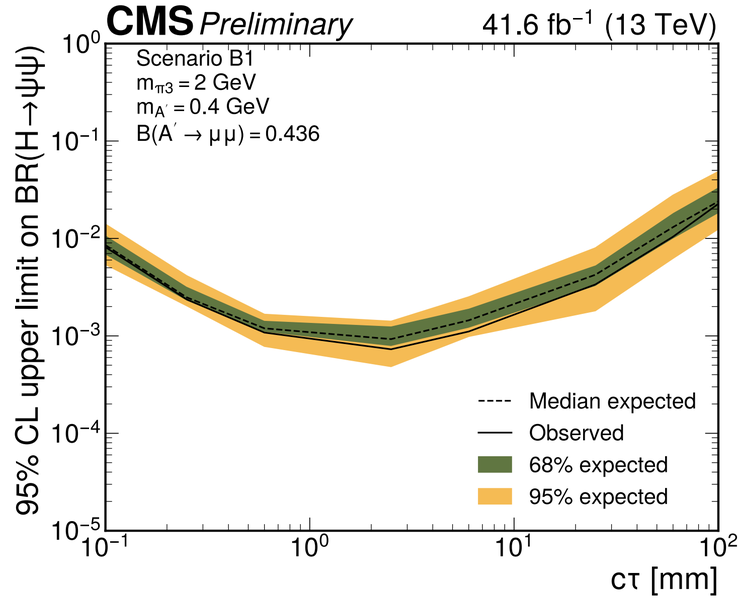


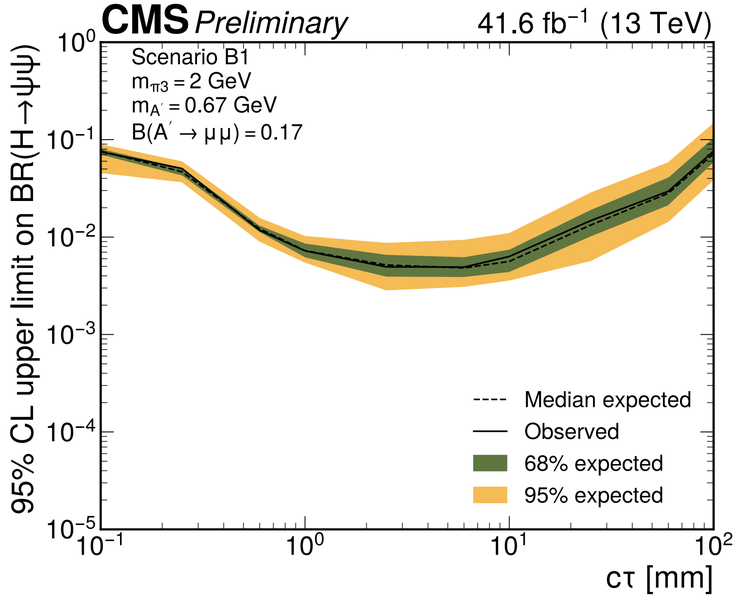
Dark showers limits: Scenario B1

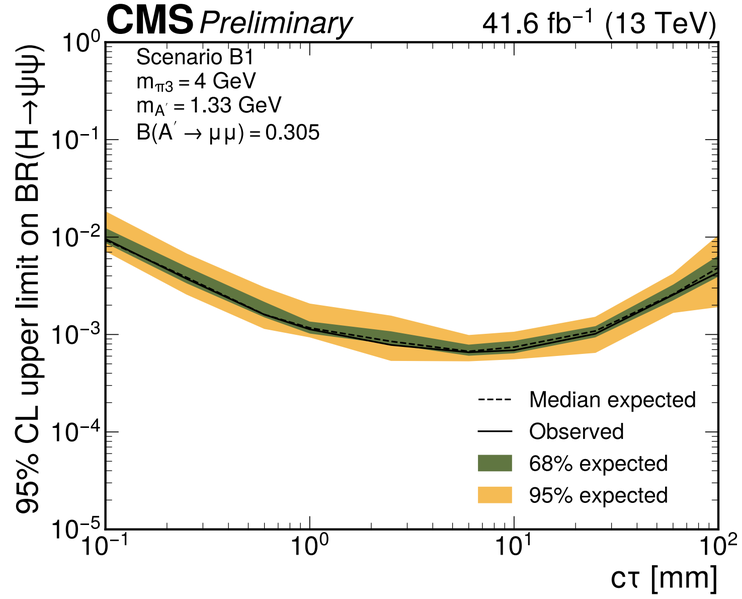
CMS-EXO-24-008

Scenario B1





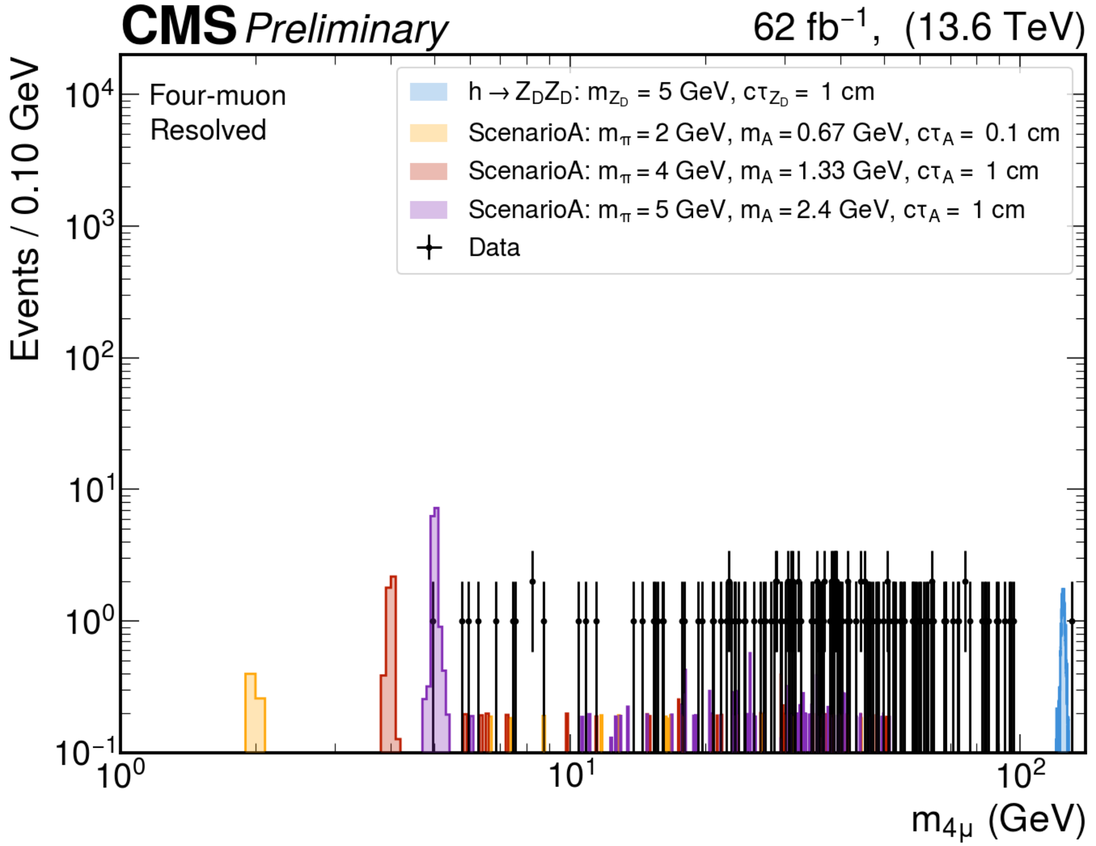




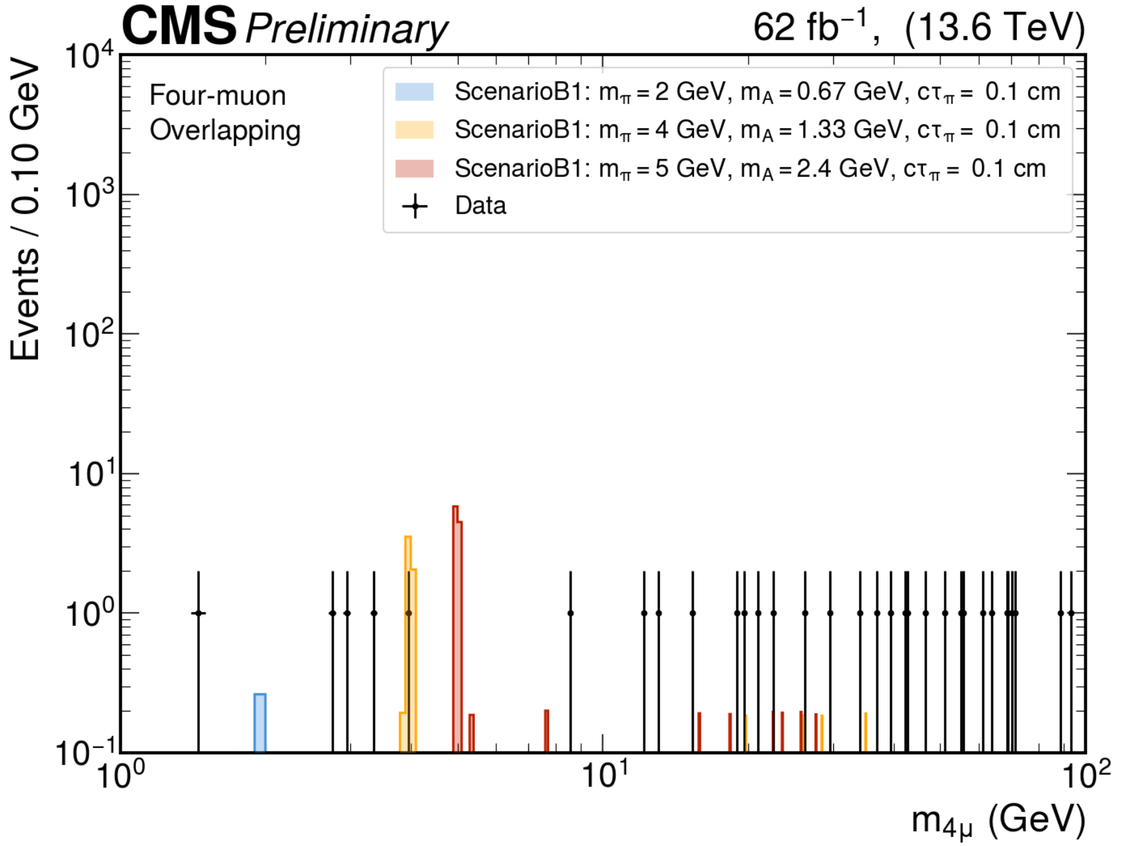
Dimuon scouting: Four muon mass

CMS-EXO-24-016

Resolved

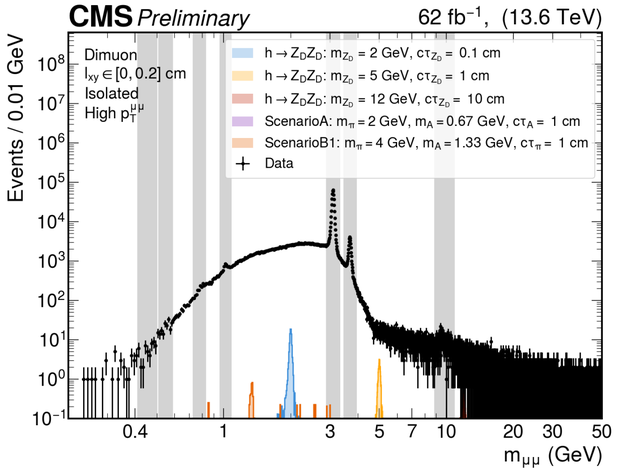


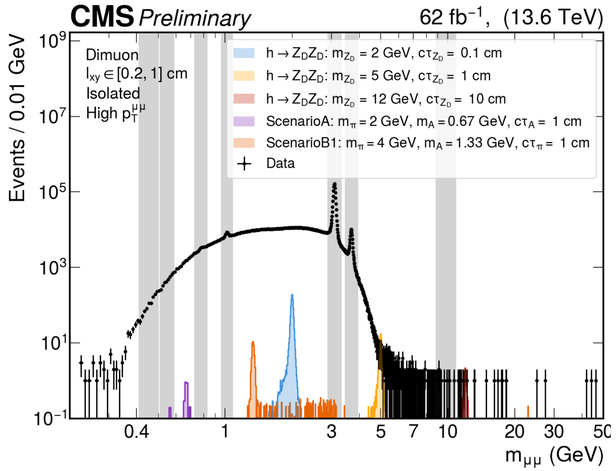
Overlapping

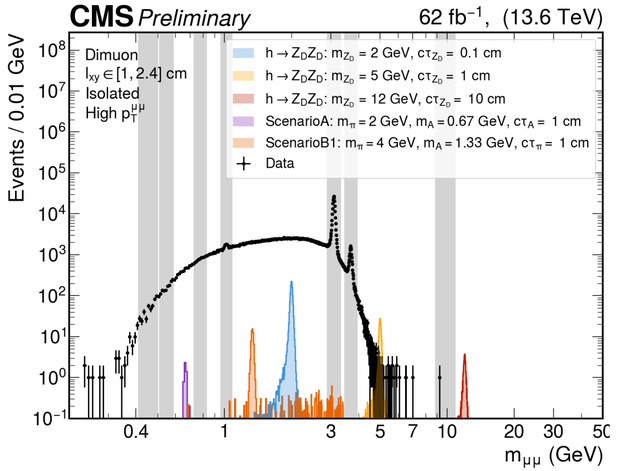


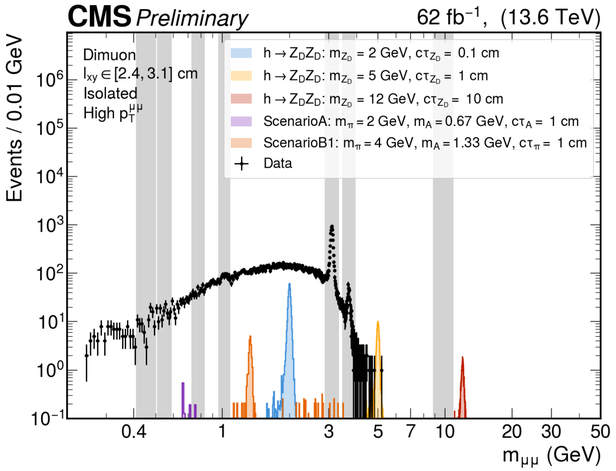
Dimuon scouting: Invariant mass

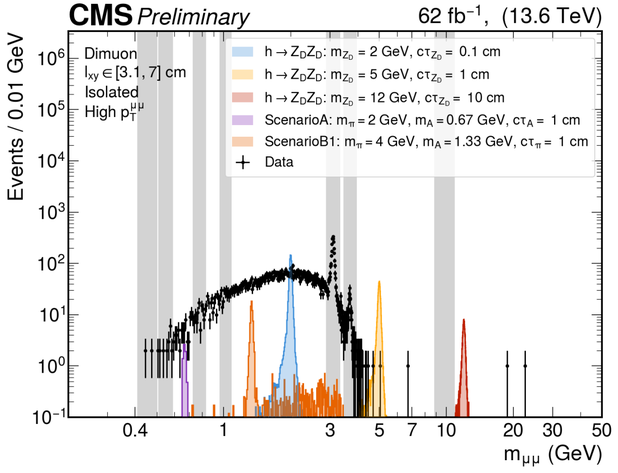
CMS-EXO-24-016

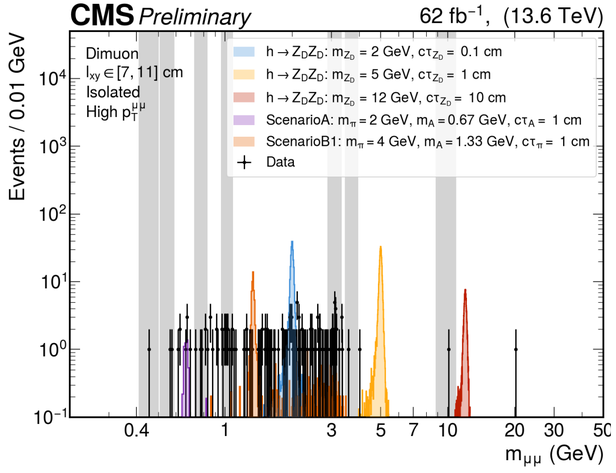


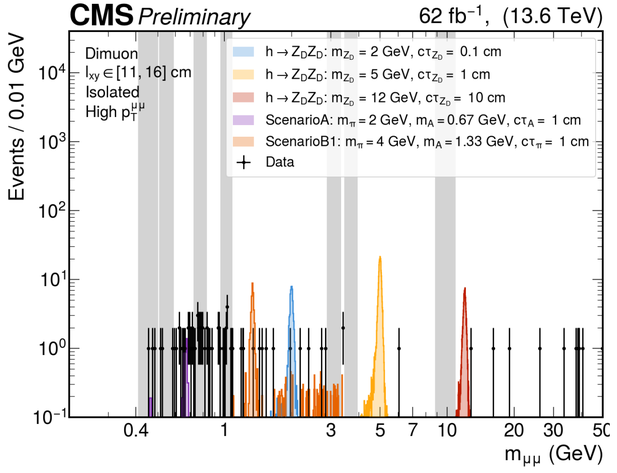


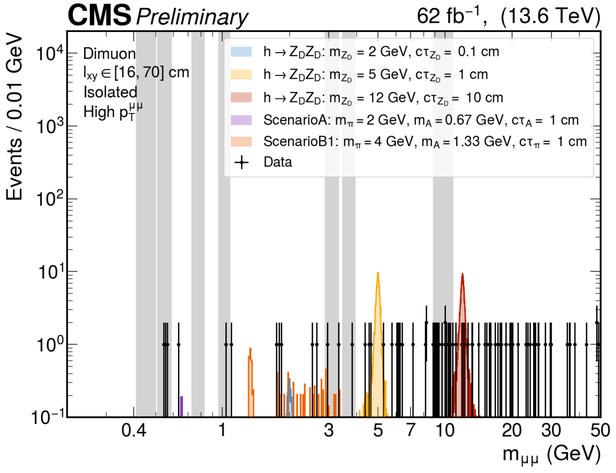






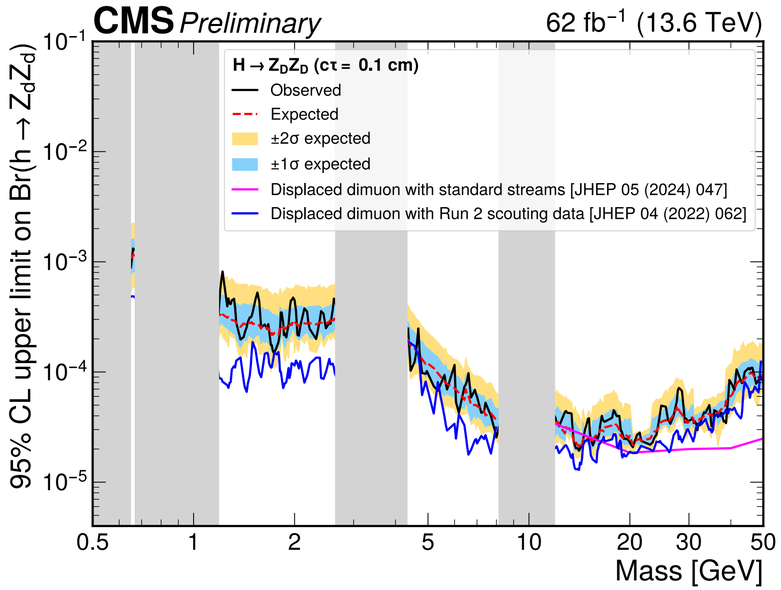


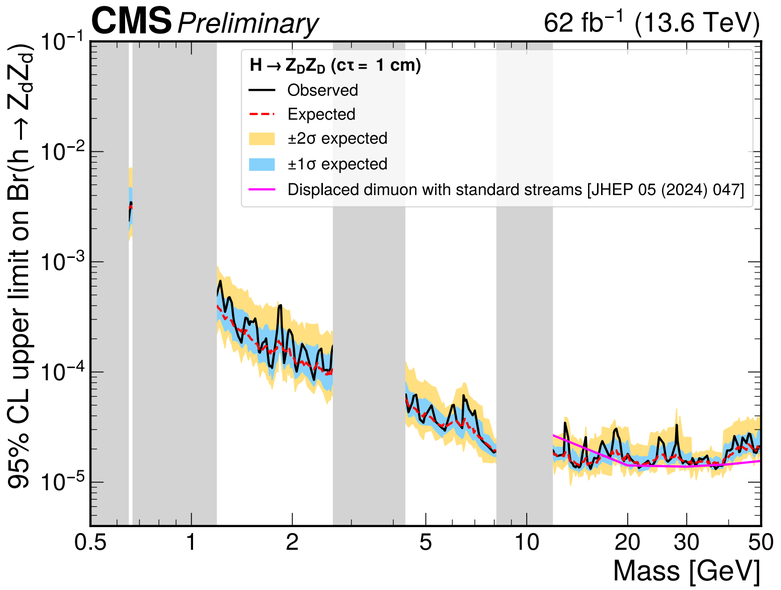


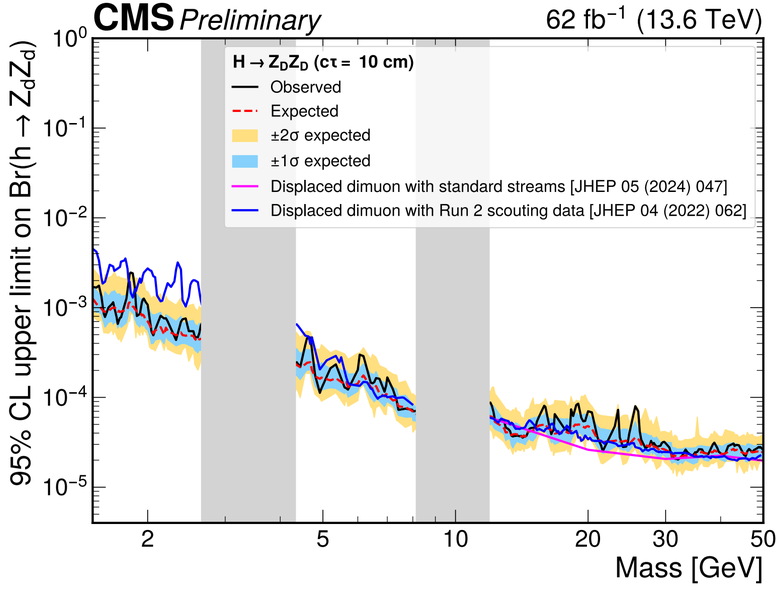


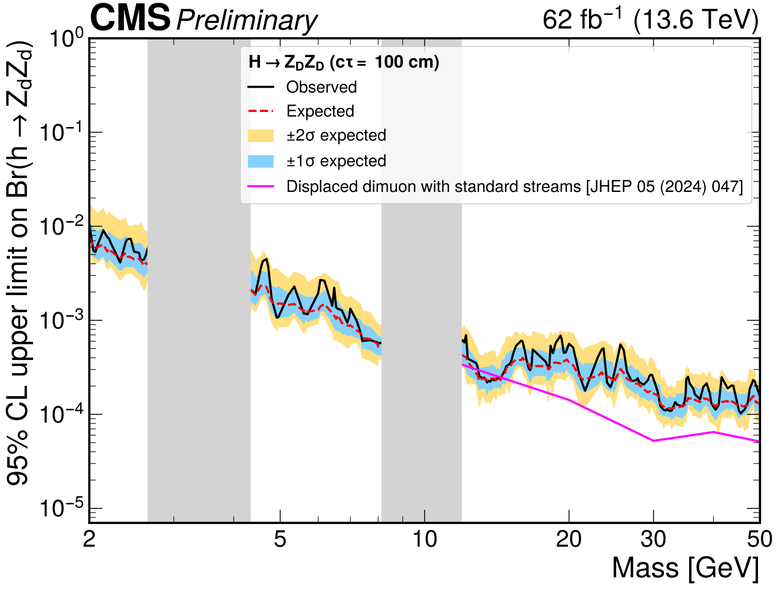
Dimuon scouting: HAHM vs mass

CMS-EXO-24-016



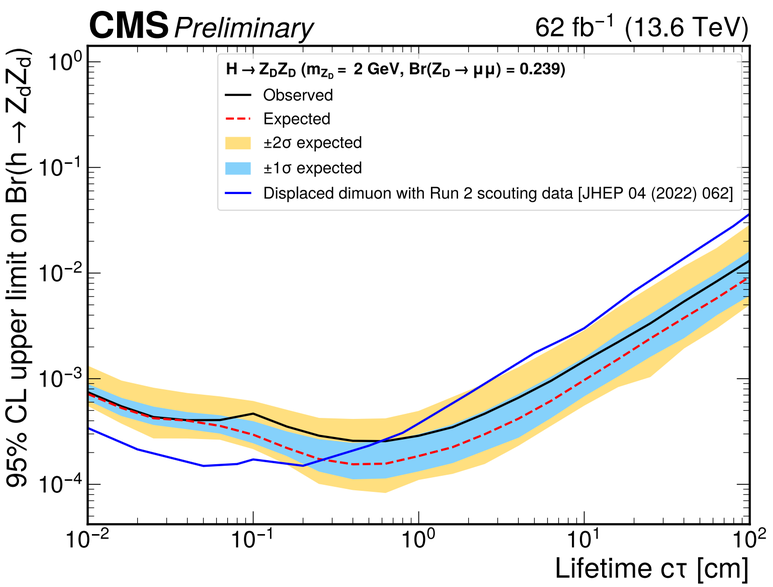


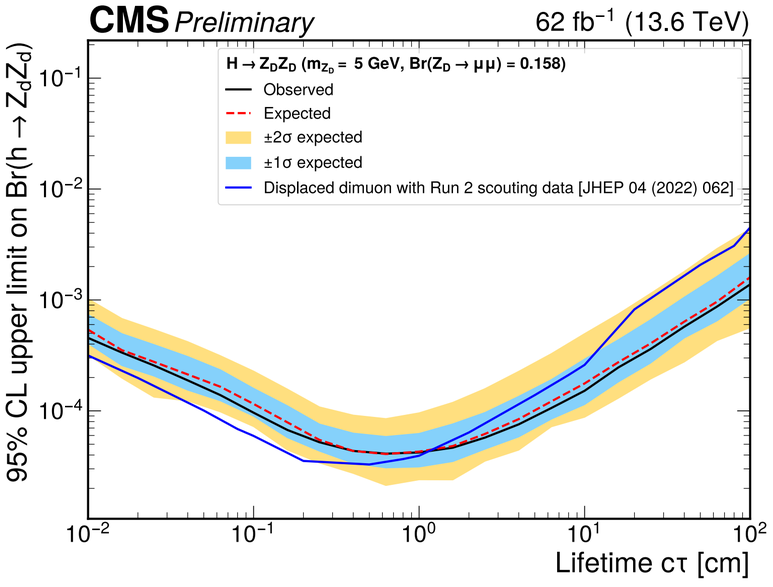


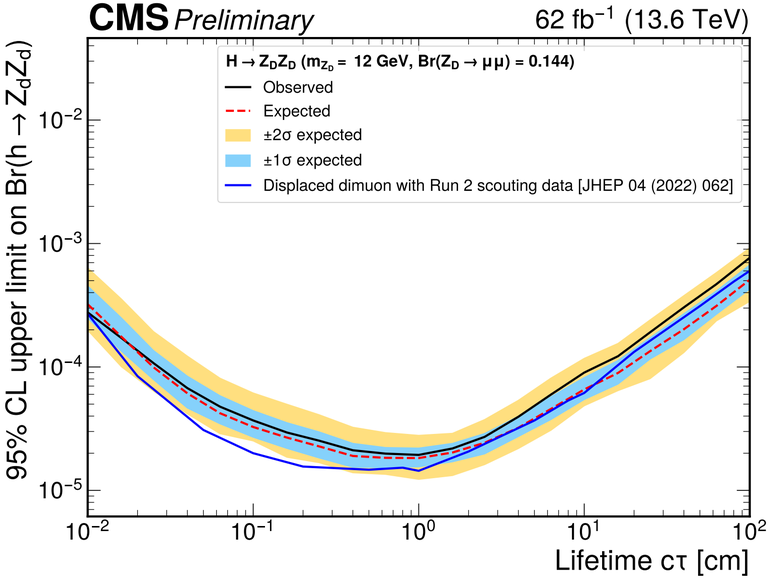


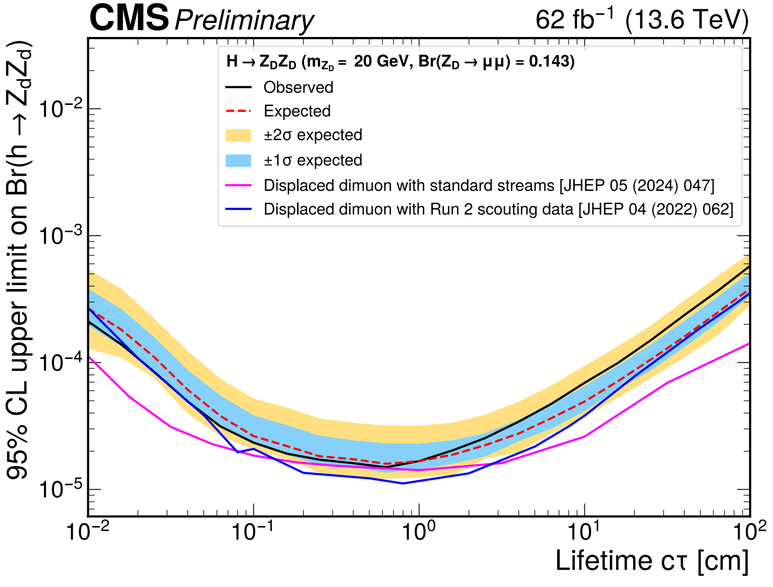
Dimuon scouting: HAHM vs lifetime

CMS-EXO-24-016









Dimuon scouting: dark shower limits

CMS-EXO-24-016