

# Searches for other exotica

*Leaving no stone unturned...*

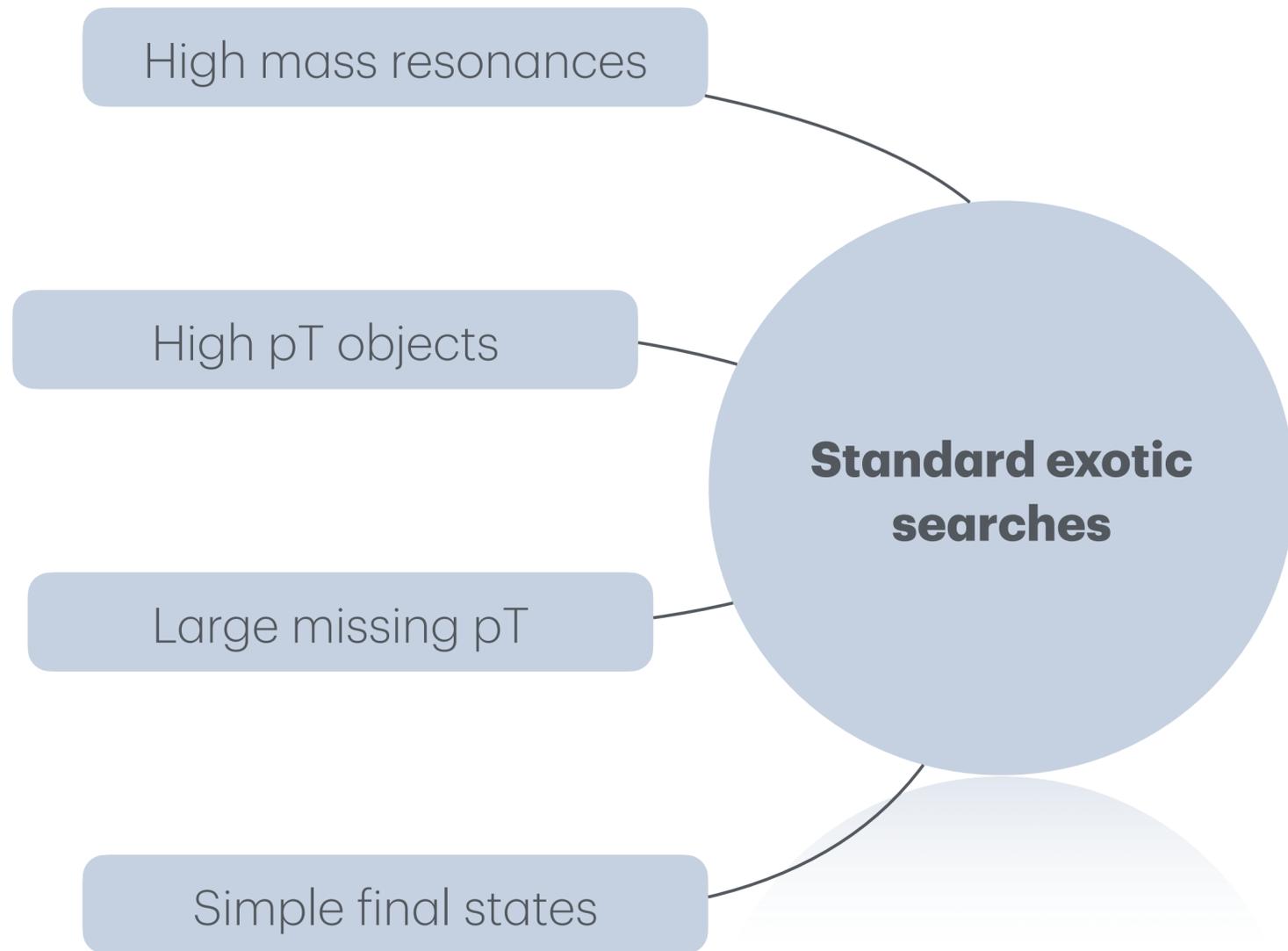
**Charis Kleio Koraka**

on behalf of the *ATLAS and CMS Collaborations*



Moriond EWK 2026  
La Thuile, 15-22 March

# Overview



# Overview

*Large couplings*

High mass resonances

High pT objects

*Standard trigger streams*

Large missing pT

Simple final states

*Standard object reconstruction*

**Standard exotic searches**

***Where else could new physics be hiding...?***

# Overview

*Expanding towards  
the 'unexplored'  
phase-space*



*Large couplings*

High mass resonances

High pT objects

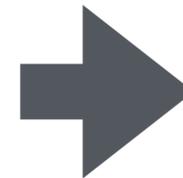
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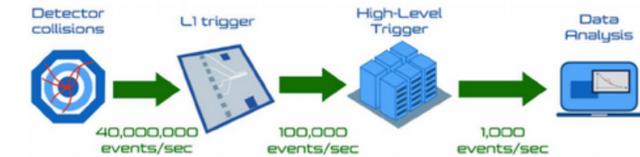
**"Other" exotic searches**

Weakly coupled, low pT

*Trigger level/scouting analyses*

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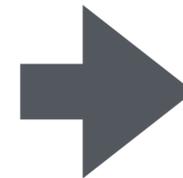
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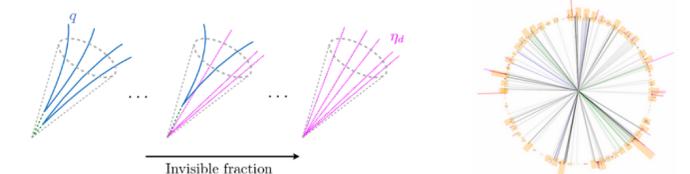
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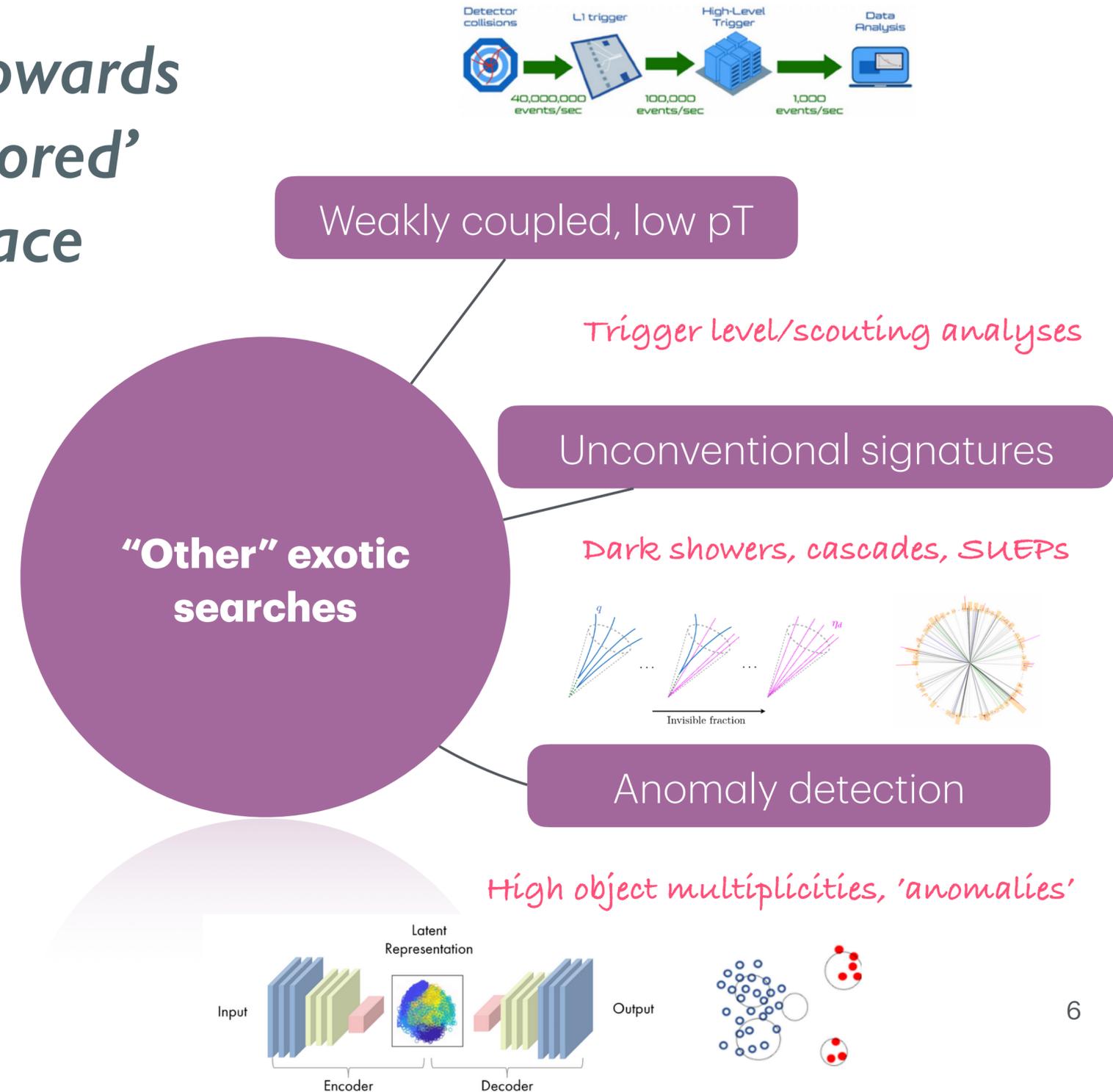
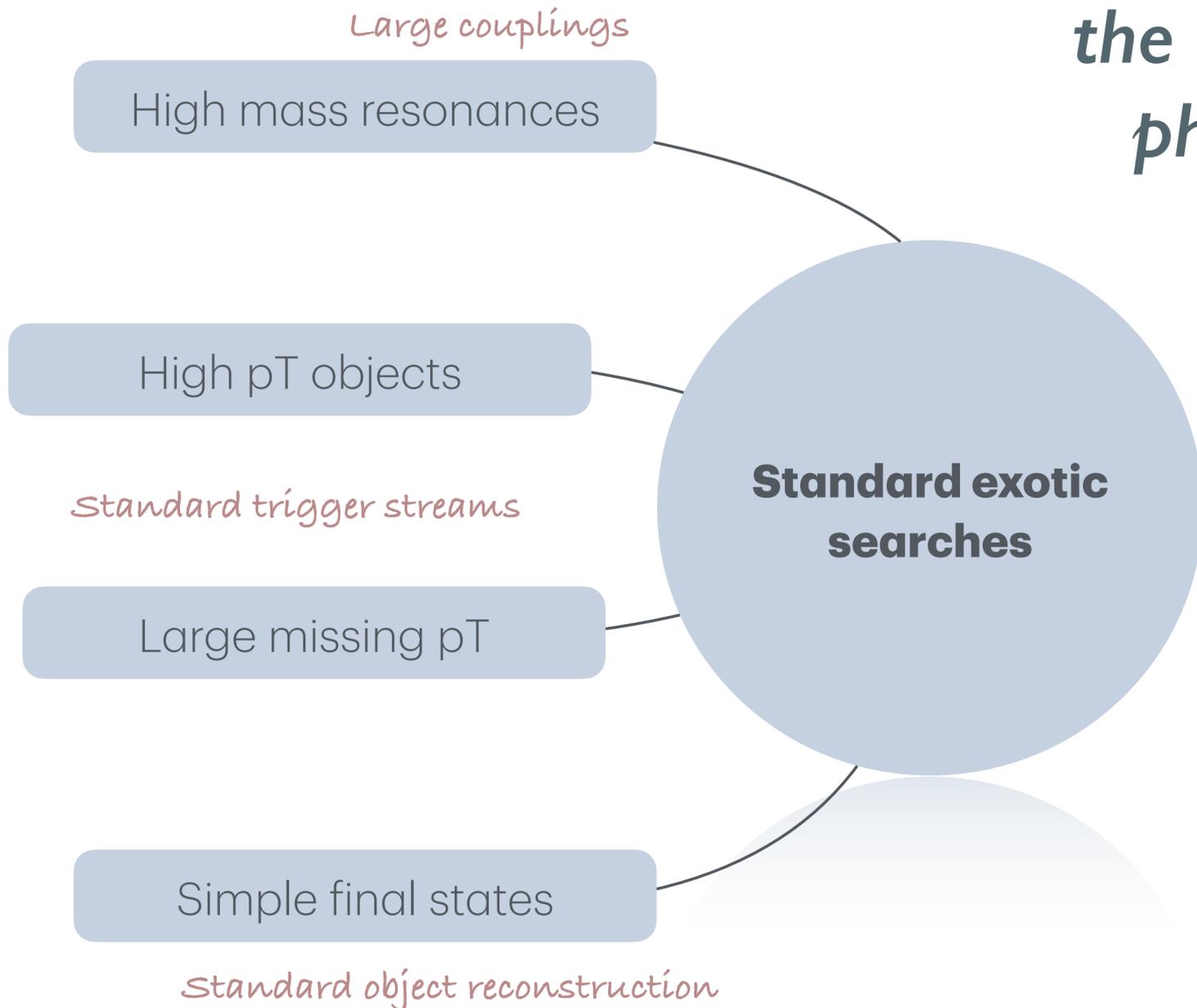
Unconventional signatures

*Dark showers, cascades, SUEPs*



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# Overview of searches presented

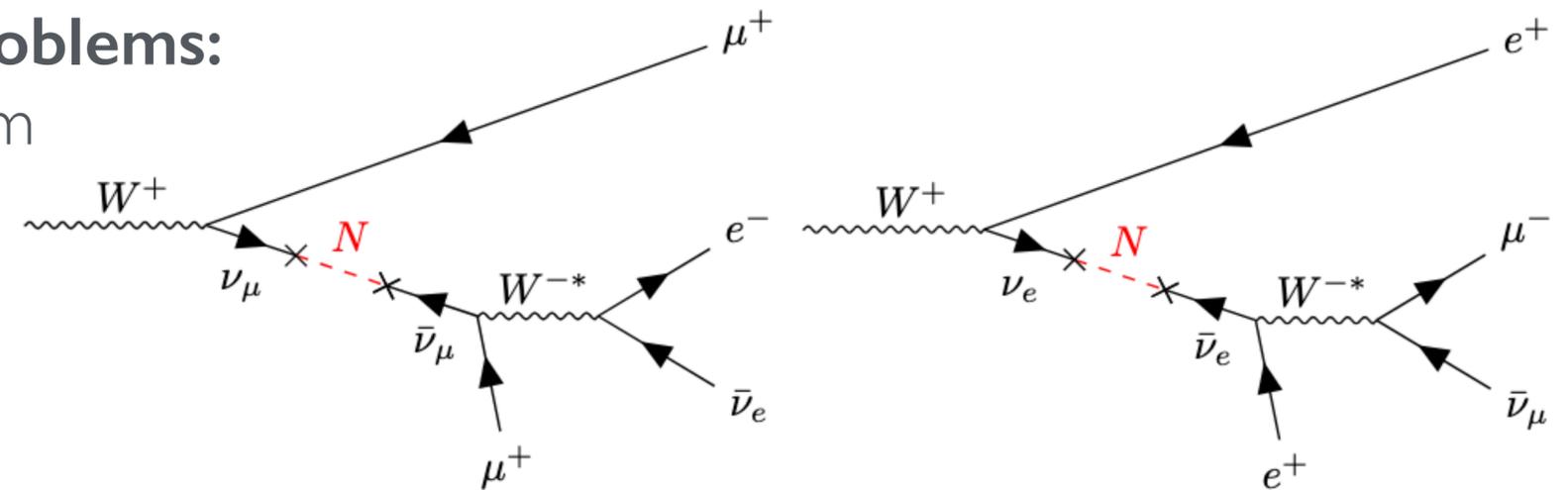
## *Results from the ATLAS and CMS experiments*

<i>Search for HNLs in decays of W bosons @ ATLAS</i>	<a href="https://arxiv.org/abs/2508.20929">arXiv:2508.20929</a>
<i>Higgs decay to scalars with unequal masses @ CMS</i>	<a href="#">CMS-NPS-25-003</a>
<i>Searches for SUEPs @ CMS</i>	<a href="#">CMS-PAS-EXO-25-007</a> , <a href="#">CMS-PAS-EXO-23-001</a>
<i>s-channel production of semi-visible jets @ CMS</i>	<a href="#">CMS-EXO-24-029</a>
<i>Search for BSM with AD in multi-lepton final states @ ATLAS</i>	<a href="https://arxiv.org/abs/2508.19778">arXiv:2508.19778</a>

# The 'ghostly' exotica: Dark & hidden sectors

## Search for Heavy Neutral Leptons in decays of $W$ bosons @13 TeV

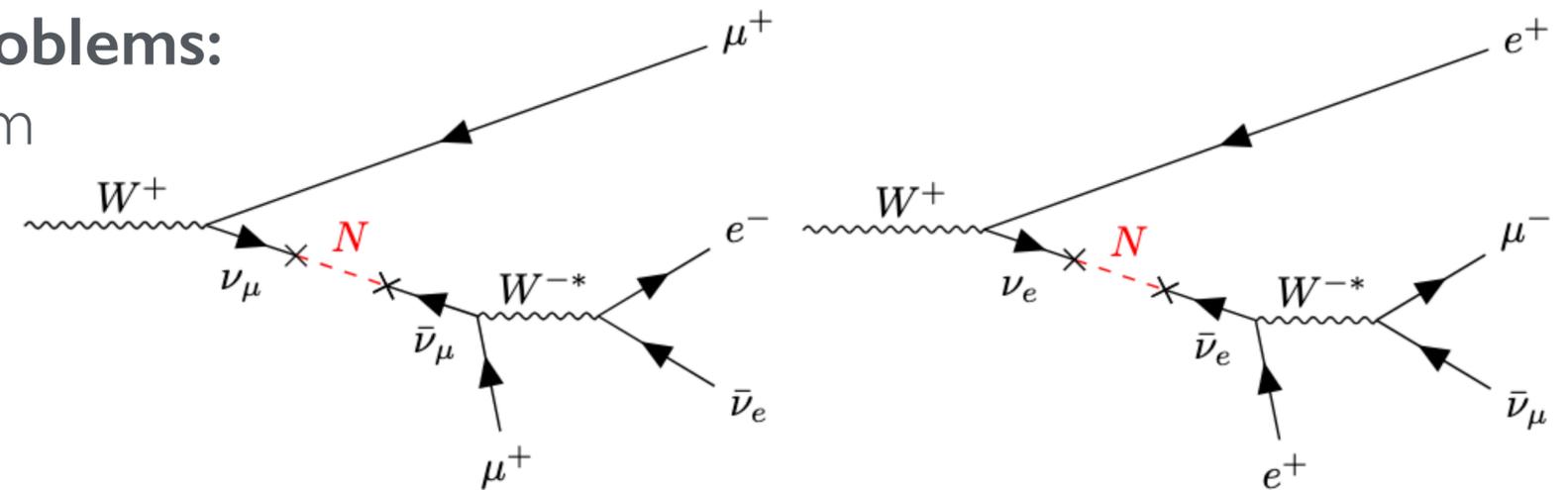
- **HNLs:** right-handed neutrinos with Majorana masses
- **Can provide solutions to three fundamental problems:**
  - explain neutrino masses via the seesaw mechanism
  - matter antimatter asymmetry
  - provide a viable DM candidate



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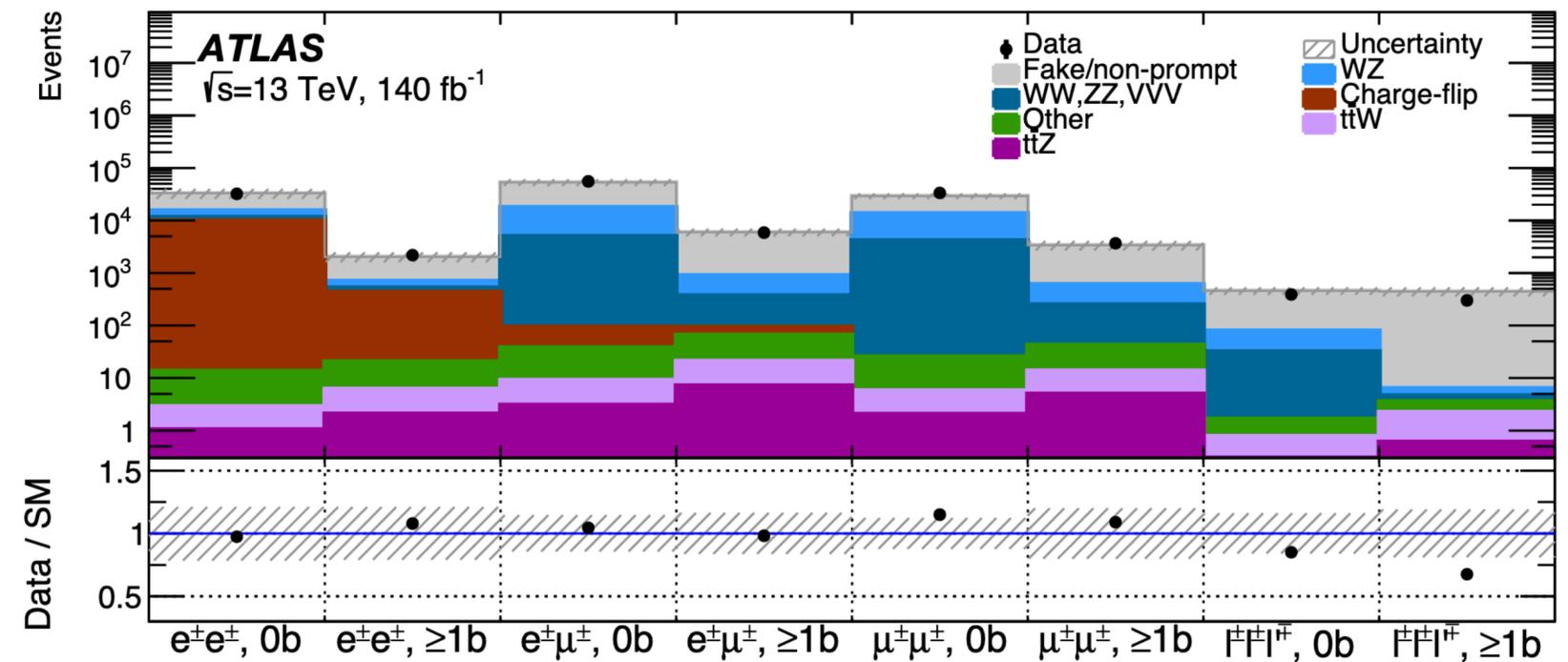


- In this search ➡ hunting for Lepton Number Violation
  - HNLs (N) produced via  $W \rightarrow \ell N$  mixing ( $\ell=e/\mu$ )
  - **prompt** leptonic decay signatures

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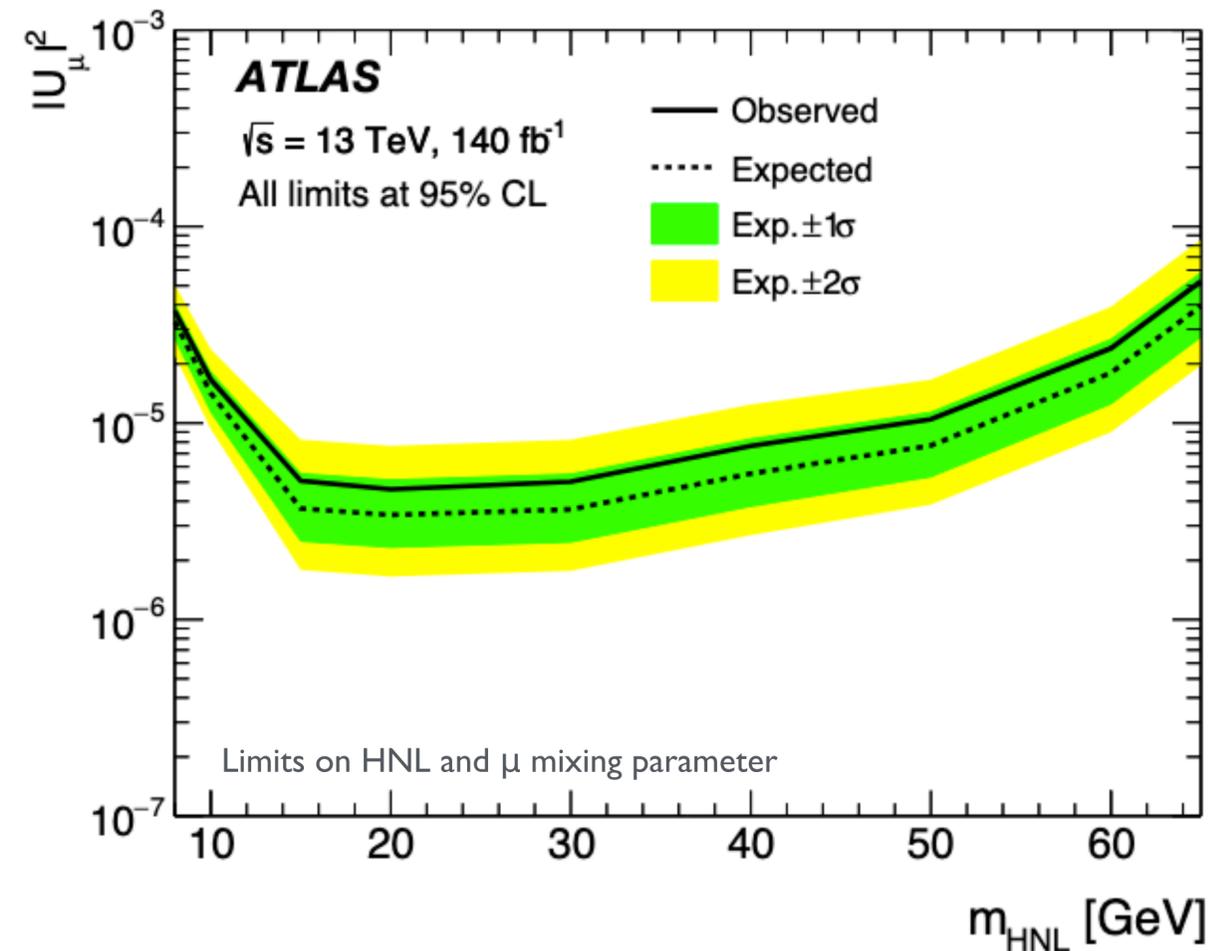
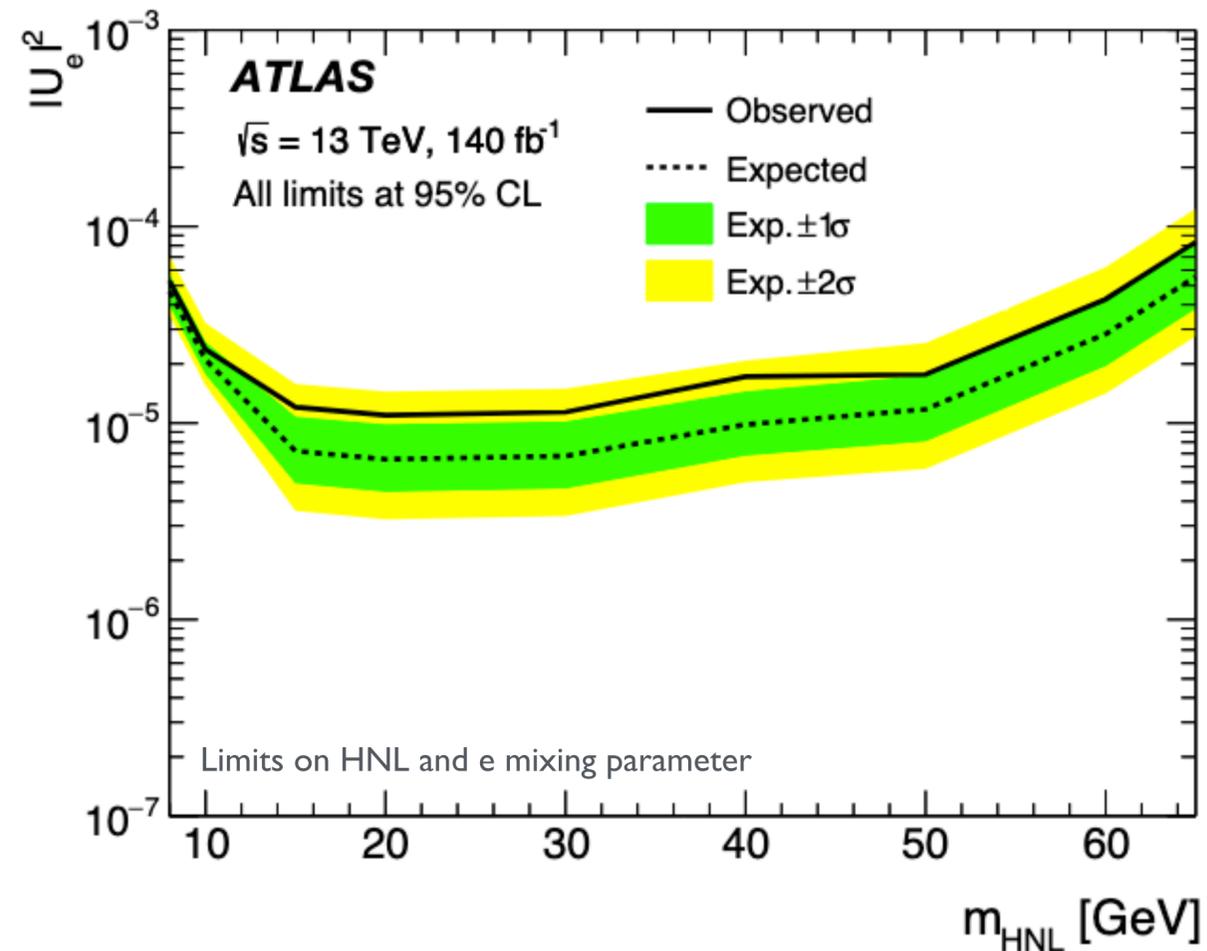
- 9 SRs optimized for different  $m_{\text{HNL}}$  &  $e/\mu$ 
  - 2 or 3 leptons with a **same-flavor same-charge lepton pair**



- **Dominant backgrounds :**
  - **Fake/Non-prompt lepton** : Data-driven Matrix Method using "Loose-vs-Tight" efficiencies.
  - **Charge mis-ID** :  $e^\pm e^\pm \ell$  channels only - data-driven, data events weighted by a charge-flip probability
  - **VV/VVV** : Simulation-based

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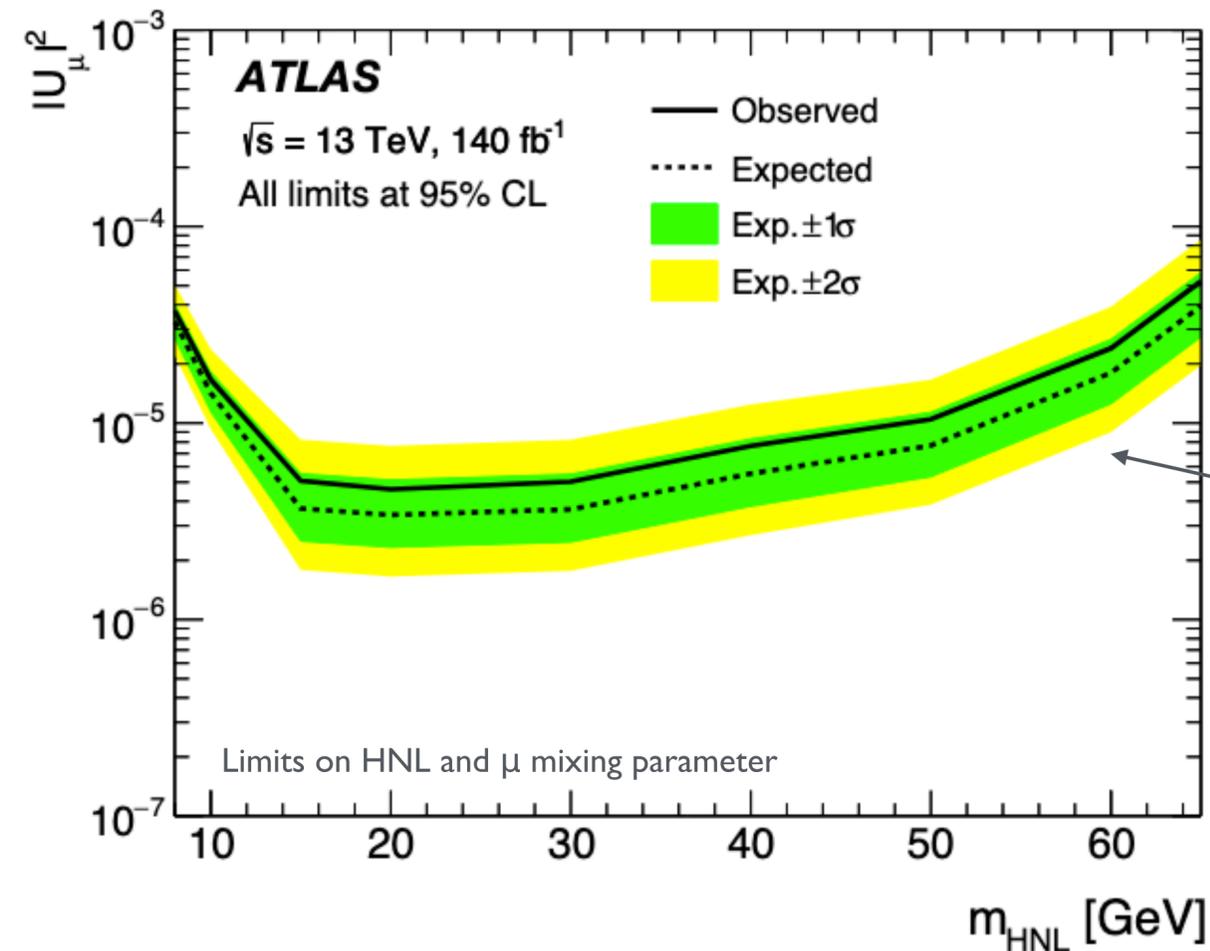
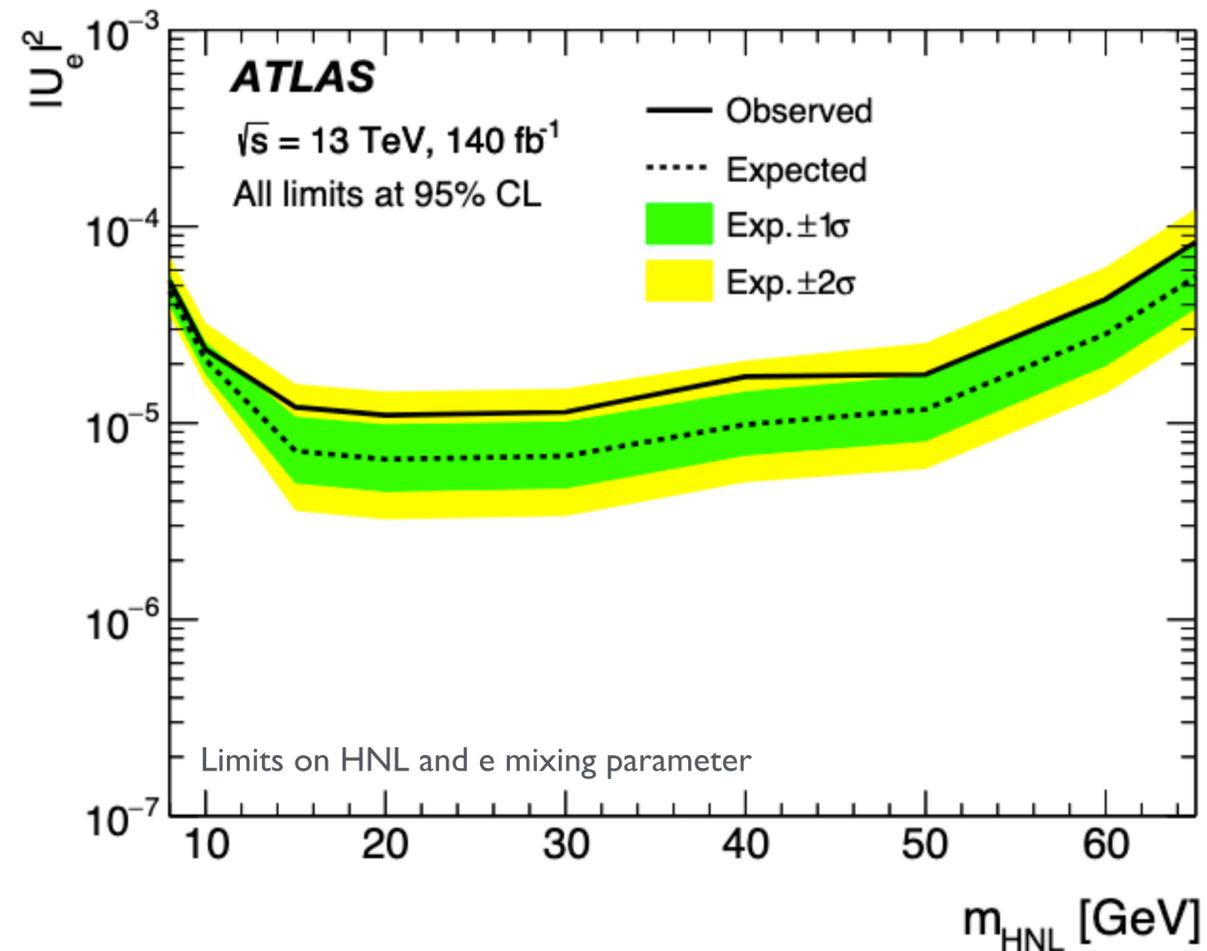
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Higher HNL masses:  
 kinematic suppression  
 of HNL production  
 in  $W$  boson decay

- **Closing the 'gap' between prompt and displaced HNL decays**
- The observed event yields are consistent with the background expectations
  - Strongest constrains: HNL mass in the range 15–30 GeV  $\sim |U_e|^2 < 1.1 \times 10^{-5}$  and  $|U_\mu|^2 < 5 \times 10^{-6}$

\*Check out also ATLAS+CMS summary plots [|U<sub>e</sub>|](#) [|U<sub>μ</sub>|](#)

# The 'messy' exotica: Complex final states

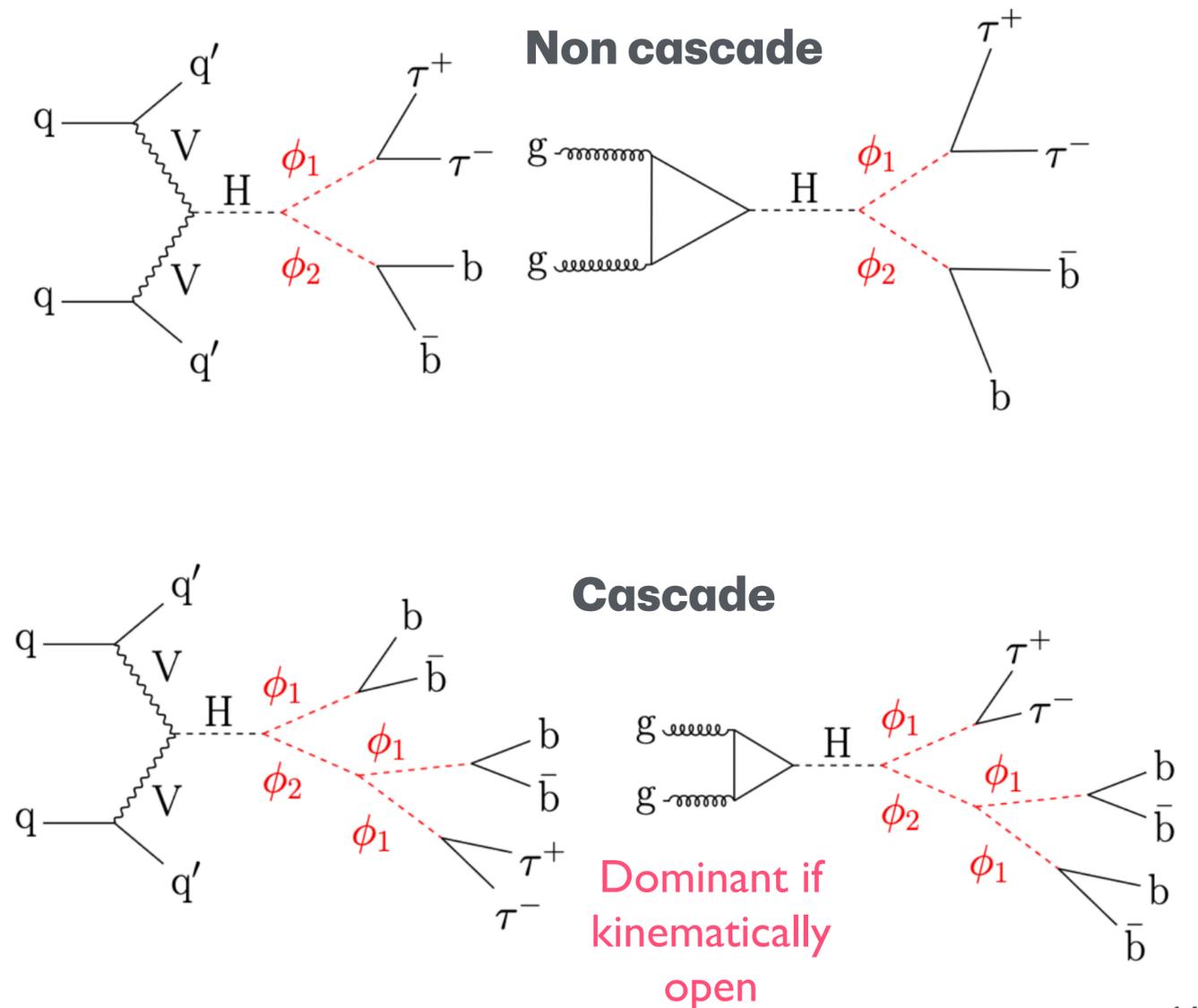
*Higgs decays into two neutral scalars with unequal masses @13TeV*

- **Extended scalar sectors** are theoretically motivated :
  - explain matter-antimatter asymmetry
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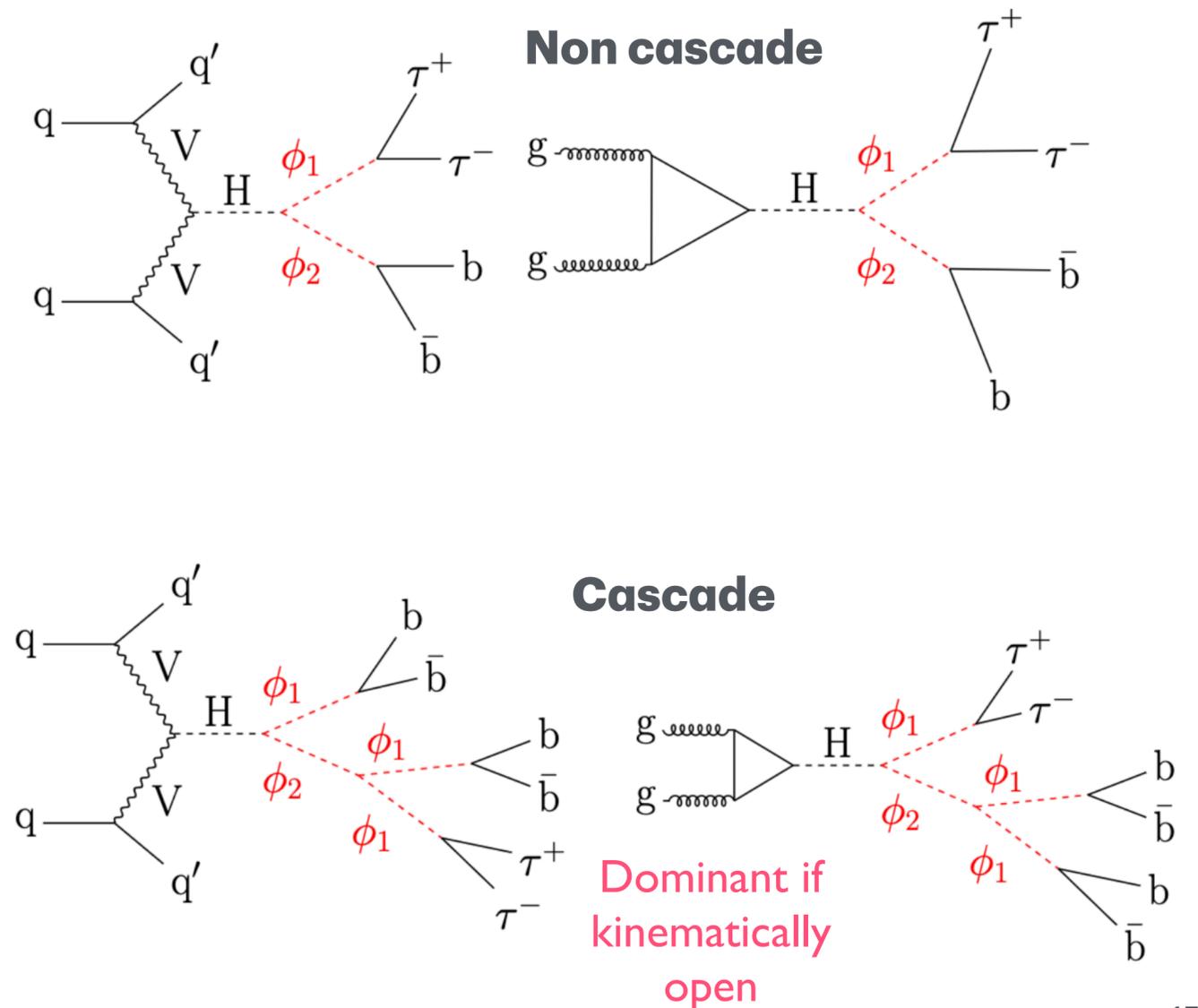
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- 2 decay topologies :
  - **Non-cascade:**  $H \rightarrow \phi_1 \phi_2$ , where both scalars decay directly to SM particles.
  - **Cascade:**  $H \rightarrow \phi_1 \phi_2$ , where  $\phi_2 \rightarrow \phi_1 \phi_1$  ( $m_{\phi_2} > 2m_{\phi_1}$ ).



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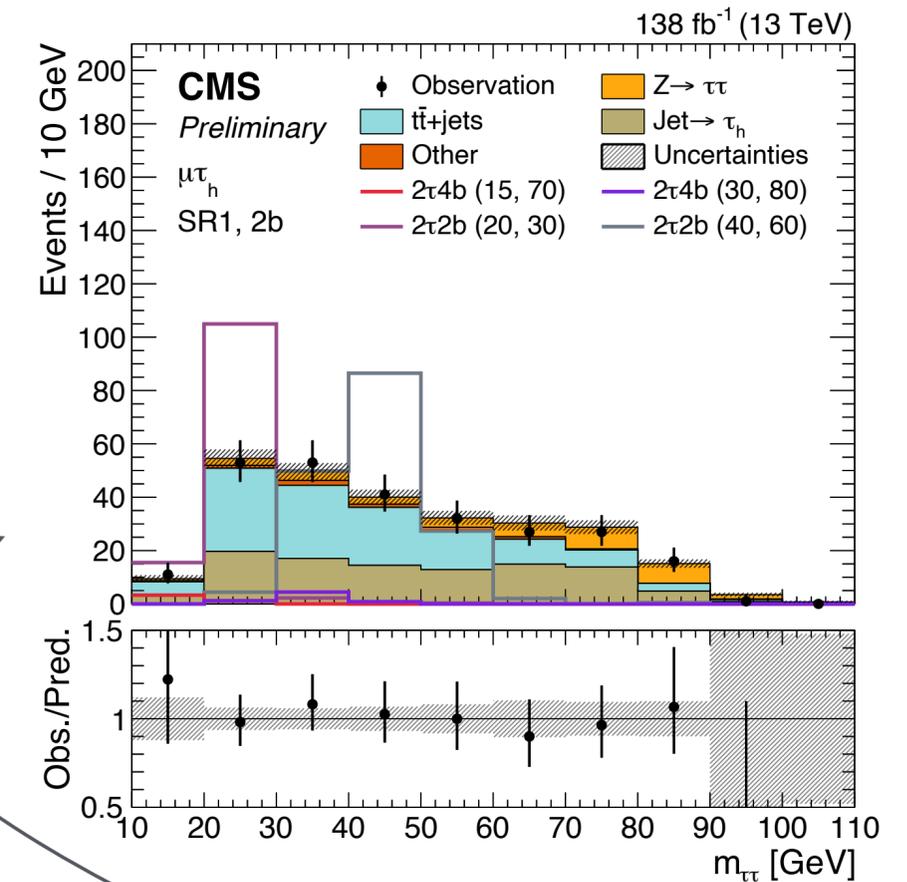
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- **Search in final states with  $\tau_h$  and b quarks**



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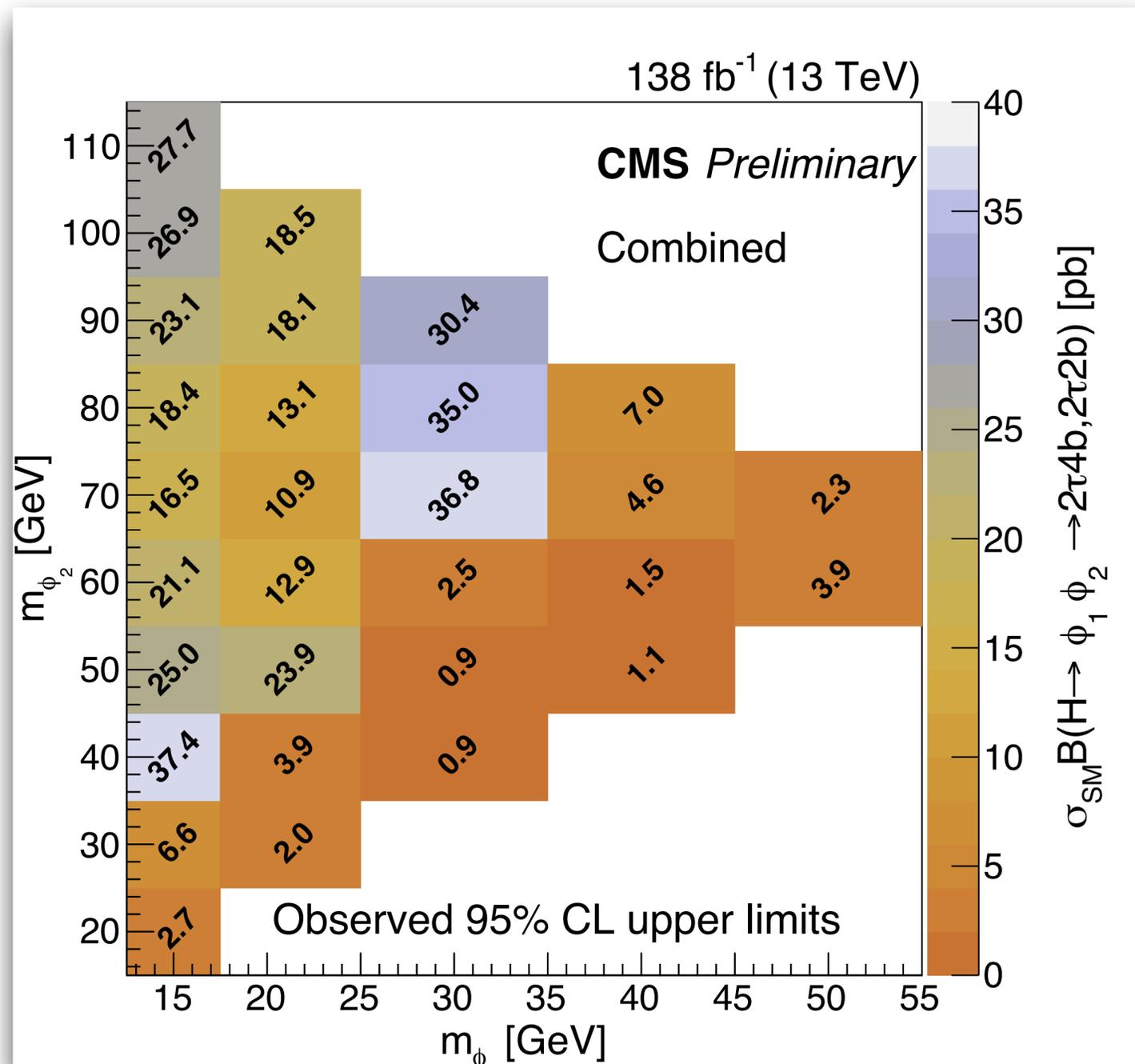
- 17 SRs split by lepton flavor & b-jet multiplicity
- 6 dedicated BDTs trained to target asymmetric mass topologies.
- Majority of backgrounds estimated from data:
  - Irreducible  $Z \rightarrow \tau\tau$  estimated via **Embedding**
  - Fake tau & QCD derived from dedicated CRs
- Fit performed on  $m_{\tau\tau}$  variable  $\rightarrow$  reconstructed via algorithm (SVFit) that accounts for the neutrino momentum



One of the most sensitive SRs

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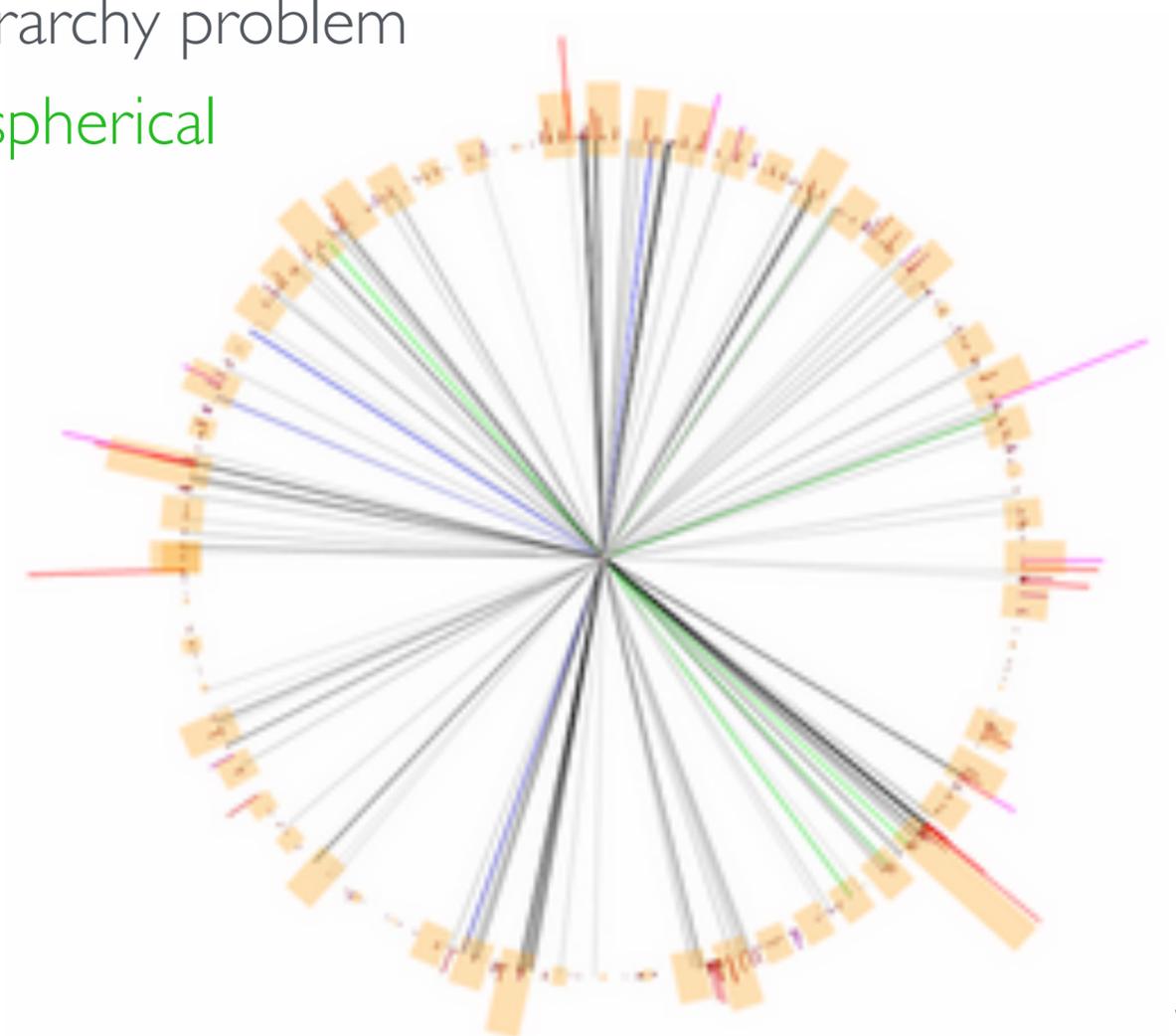


- **First CMS constraints on H decays to asymmetric scalars!**
- Upper limits shown for the non-cascade scenario
  - Peak sensitivity achieved at the (30,40) GeV mass point
  - **Observed 95% CL upper limits on the branching fraction reach as low as 1.6%.**
- Currently statistics limited

# The 'Hazy' exotica: The hidden valley

## What are SUEPs...?

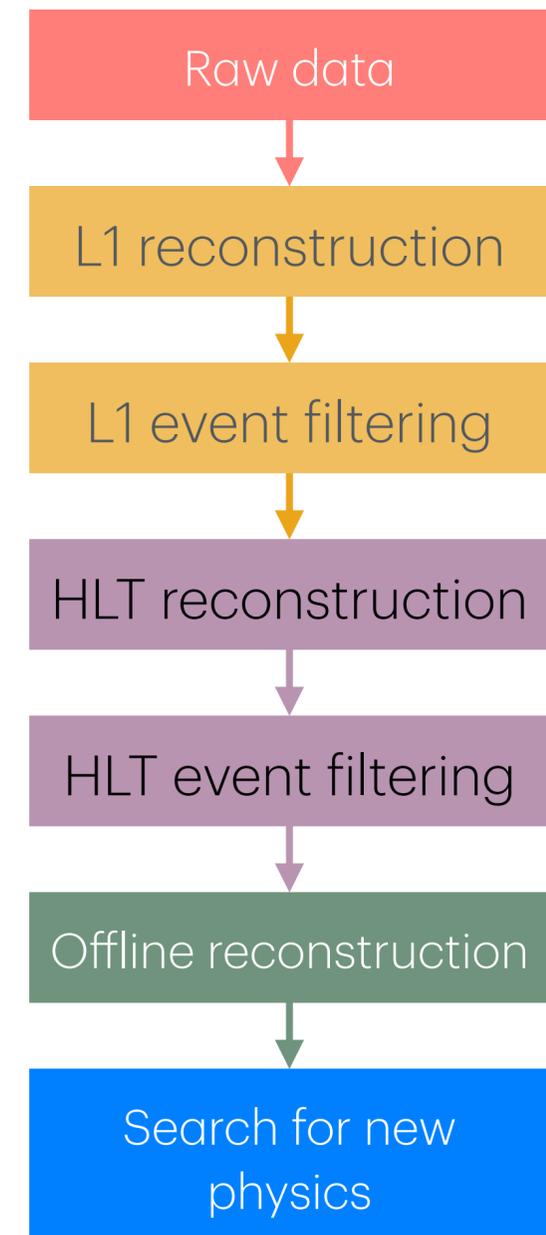
- **S**oft **U**nclustered **E**nergy **P**atterns
  - Predicted in HV models → potential solutions to DM & the Hierarchy problem
  - High 't Hooft coupling: ~~collinear jet showering non-isotropic~~ → spherical distribution of many low-momentum particles
- **SUEP** → “Soft bomb”
  - High multiplicity
  - Isotropy
  - Low  $p_T$  constituents



# The 'Hazy' exotica: The hidden valley

*Search for soft unclustered energy patterns using CMS data scouting @ 13 TeV*

- Conventional multi-jet searches limited by the software trigger thresholds



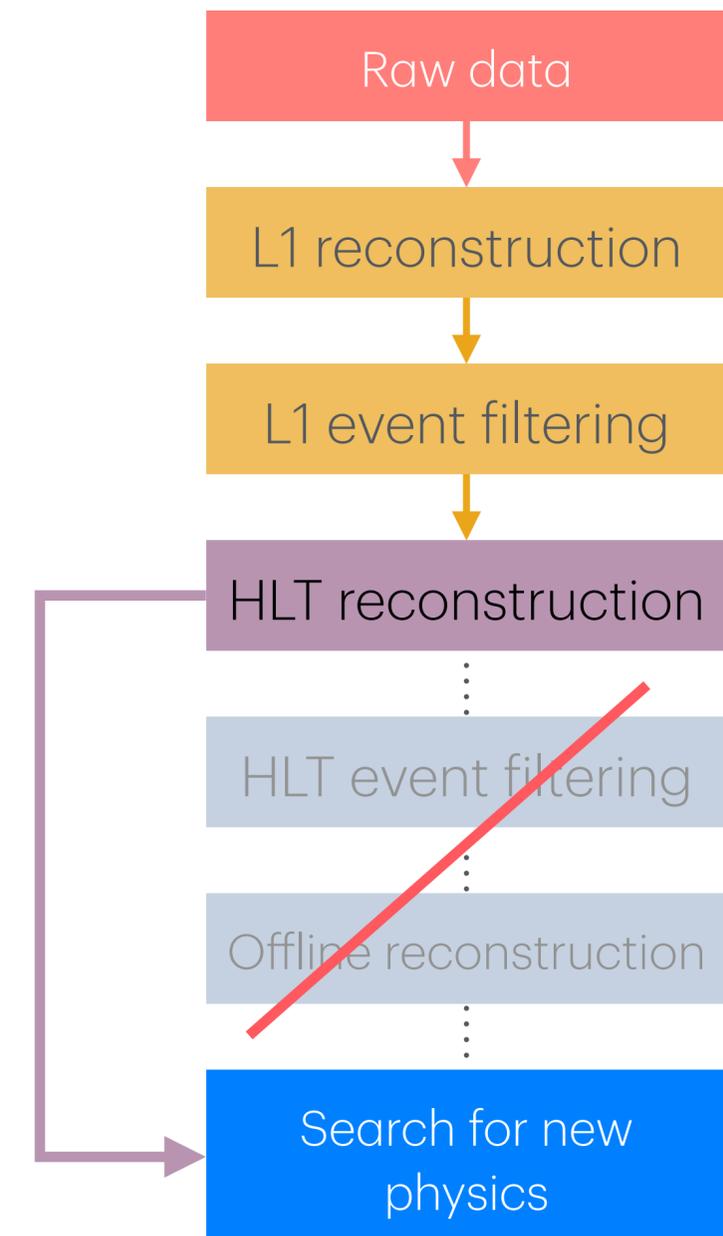
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**Data scouting to break the trigger barrier!**

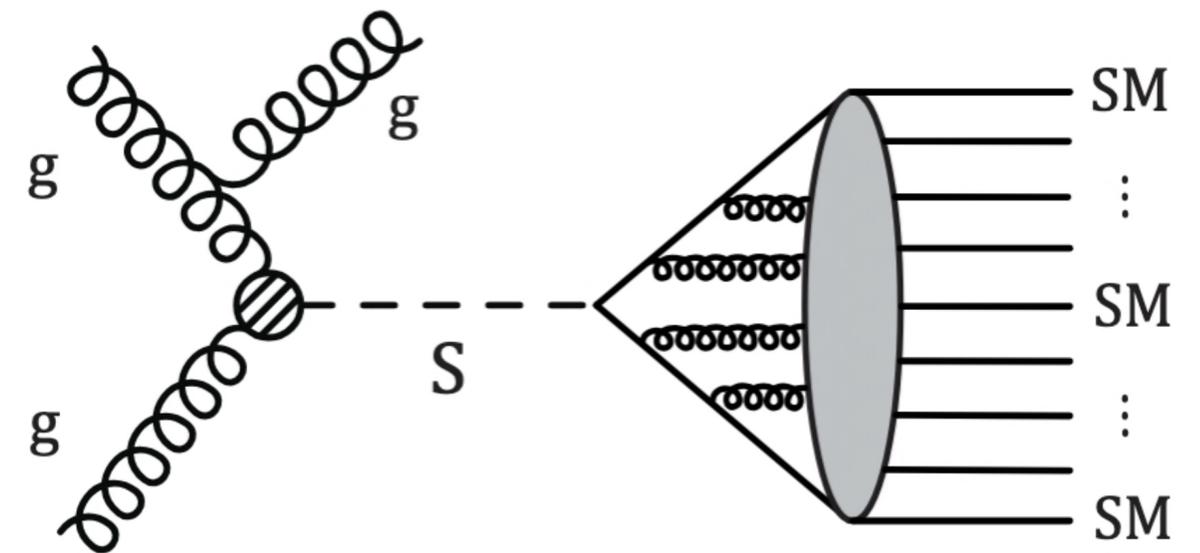
- Partial event information → reduced event size → can increase event rate  
→ can lower  $H_T$  thresholds → **Improved signal acceptance !**
- HLT threshold reduced from 1 TeV to 410 GeV**



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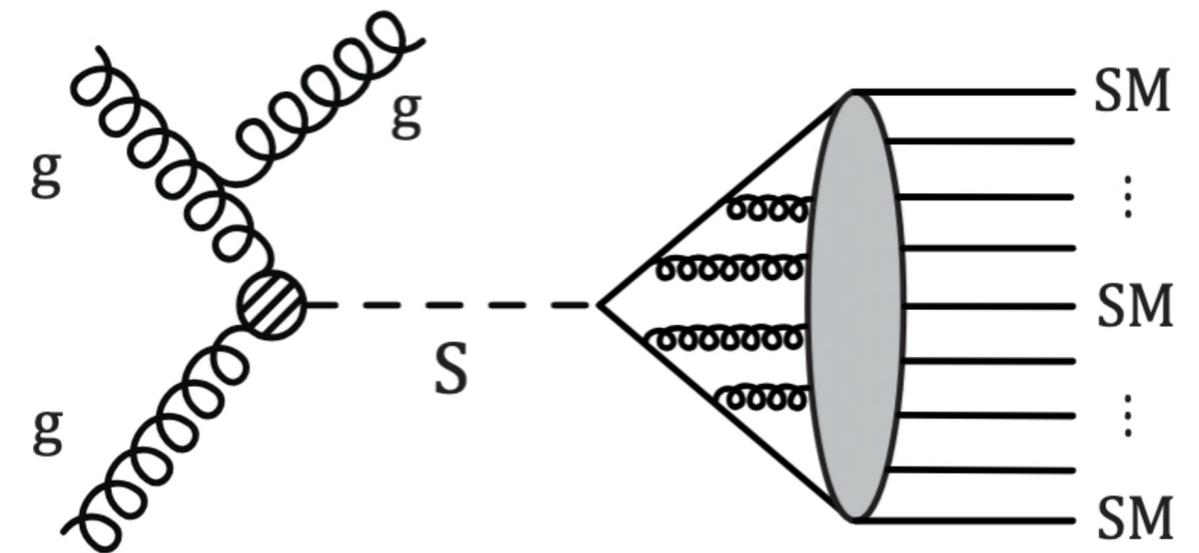
- **To reconstruct the SUEP candidates:**
  - Charged particles from the PV ( $p_T > 1$  GeV) clustered into a single "large-radius" jet ( $R=1.5$ )
  - $>50$  charged tracks in SUEP candidate



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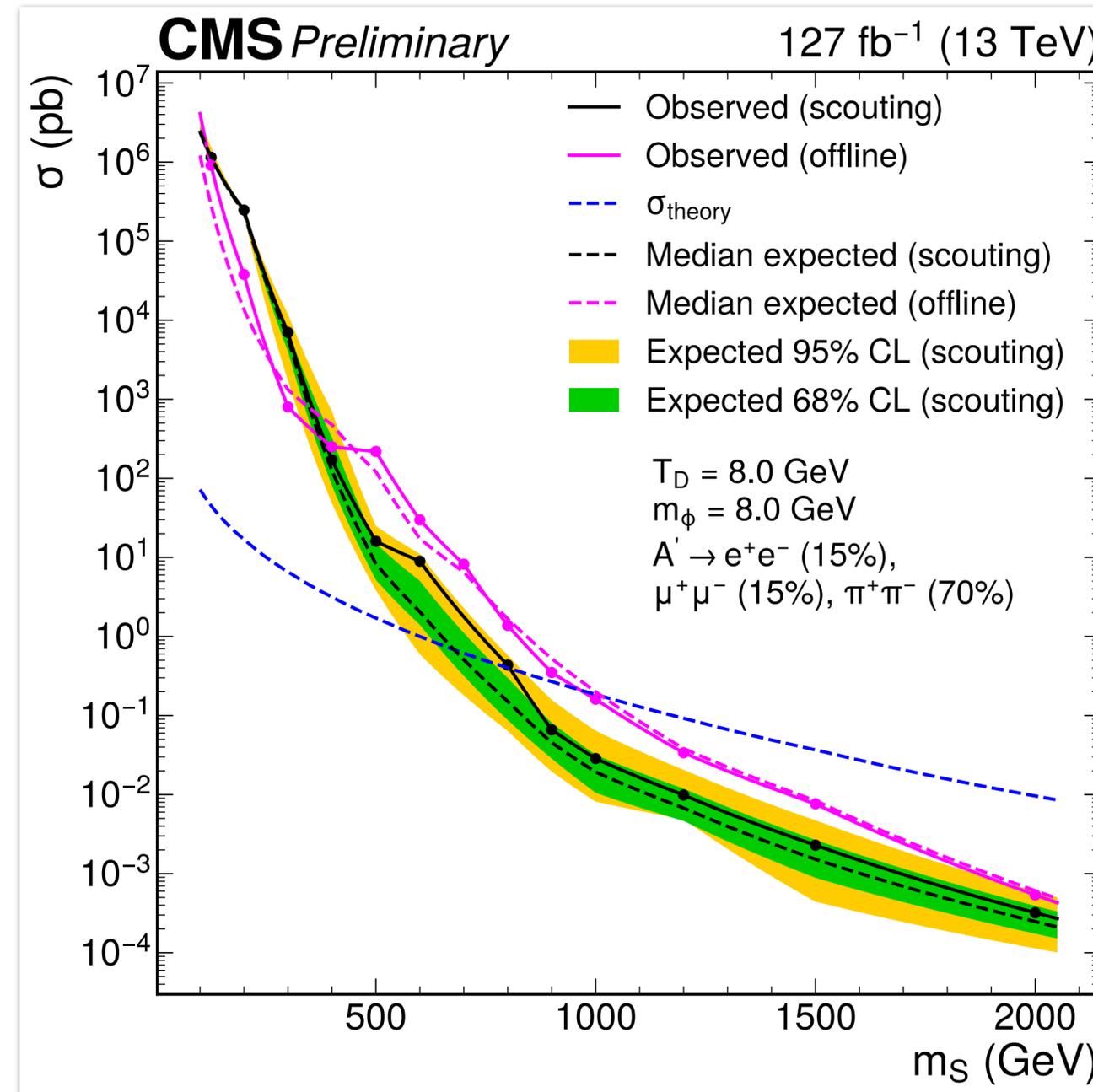
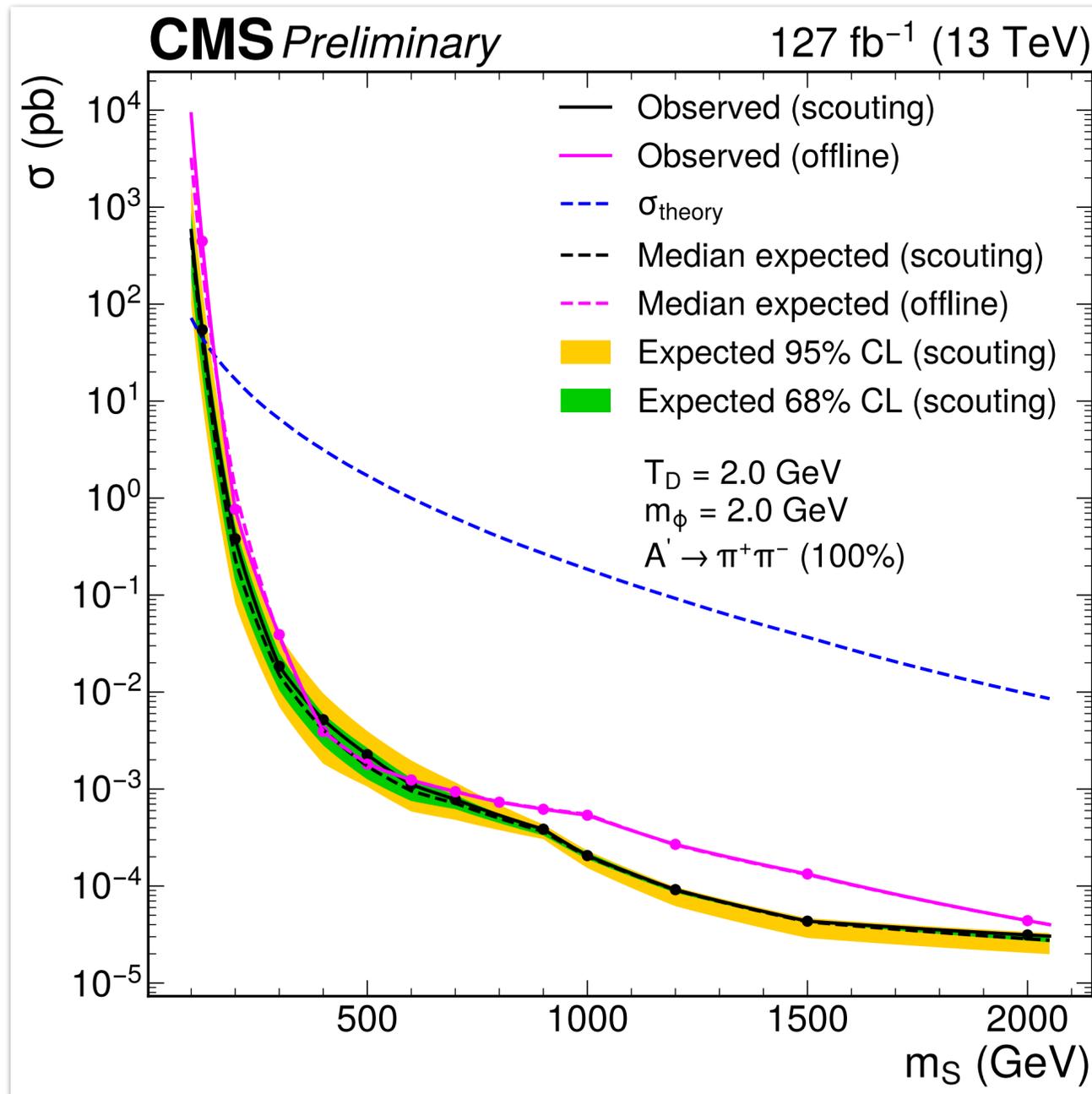
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- **Boosted sphericity** as main discriminant
- Multiple SRs defined  $\rightarrow$  binned vs  $n_{\text{constituents}}$  to increase sensitivity across different  $T_D$
- Background **dominated by multijet production**
  - Estimated from data utilizing an extended ABCD method

# The 'Hazy' exotica: The hidden valley

Search for soft unclustered energy patterns using CMS data scouting @ 13 TeV



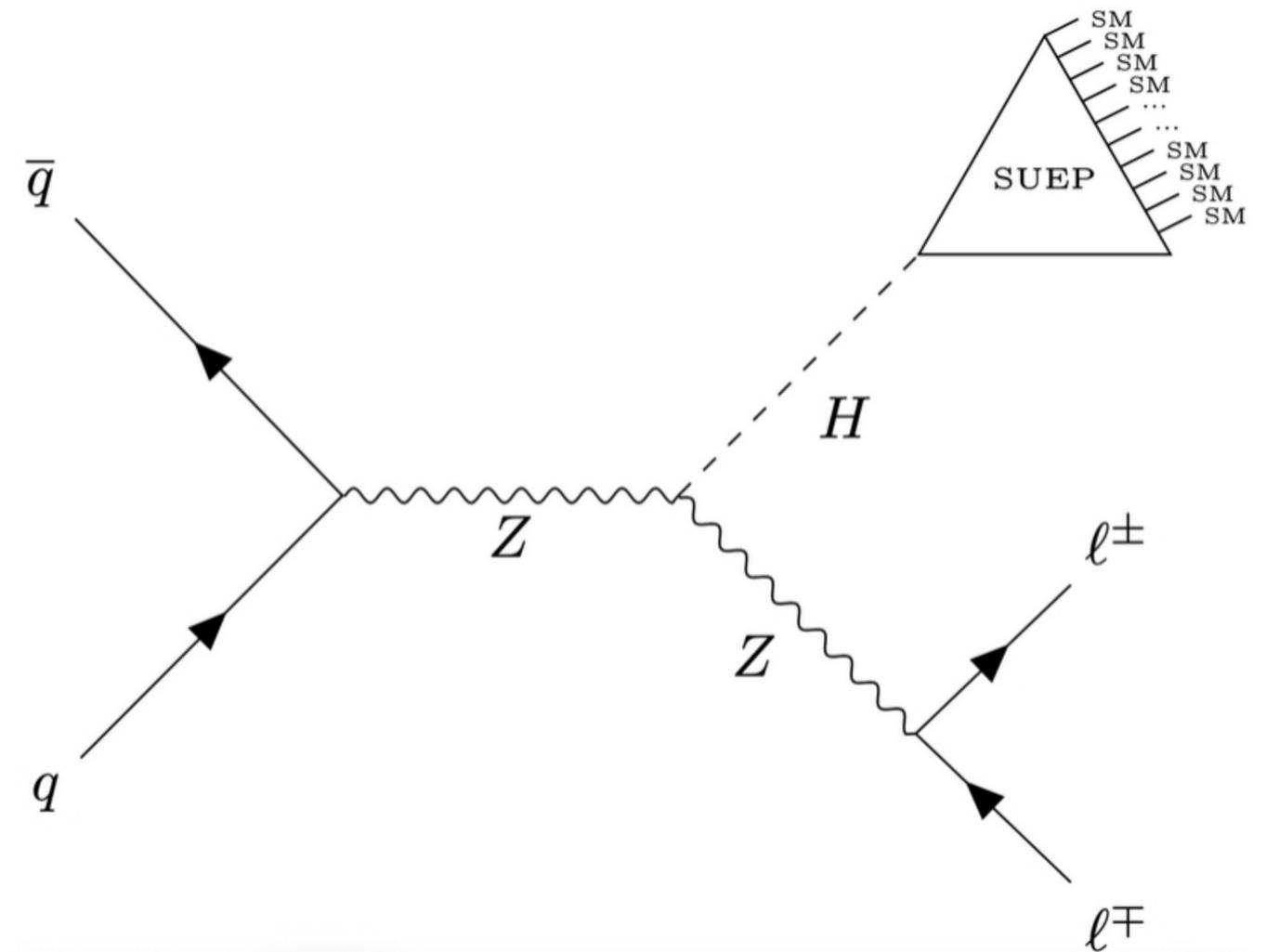
Lower  $T_D$  : more isotropic  
 Higher  $T_D$  : less isotropic

- Most stringent limits placed on large range of SUEP models !

# The 'Hazy' exotica: The hidden valley

Search for SUEPs produced in association with a W or Z boson @ 13 TeV

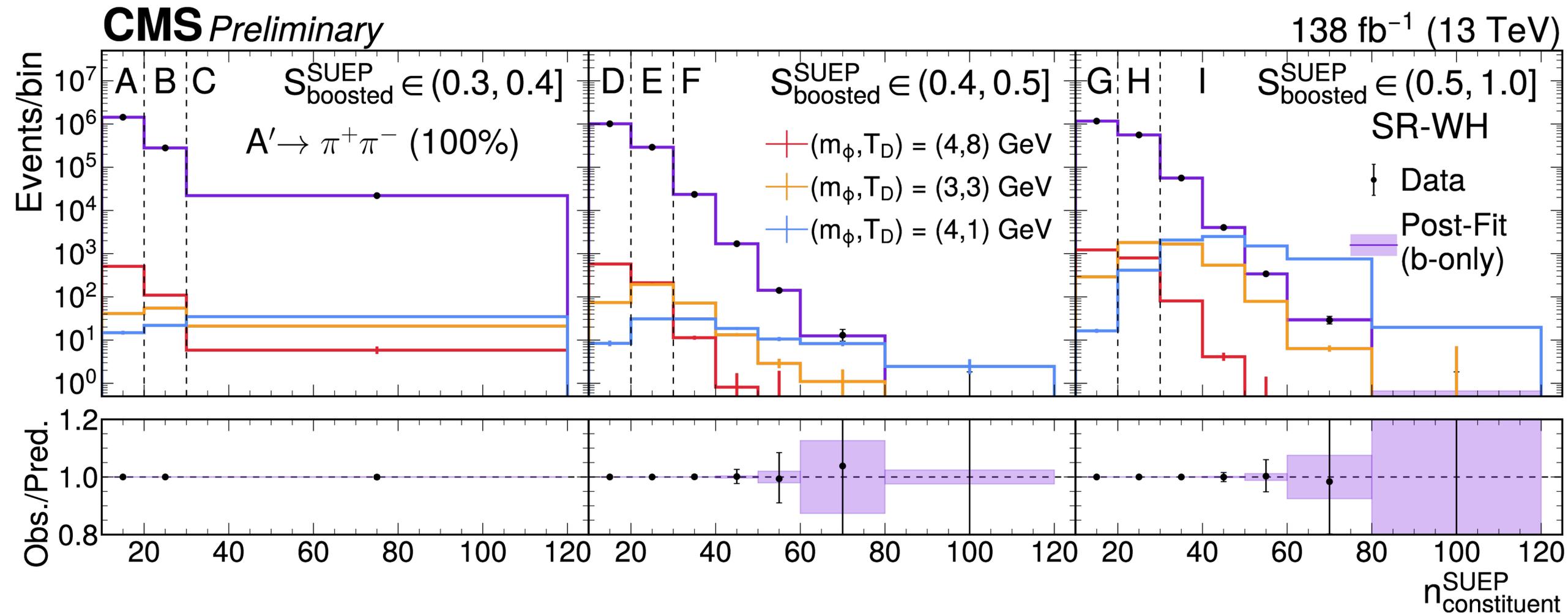
- In this search **VH production mode** (WH or ZH)
  - Complementary to hadronic search
  - **Significant reduction of multijet backgrounds!**
  - Signature consists of  $1\ell$  &  $p_T^{\text{miss}}$  or  $2\ell$  plus a SUEP candidate.



# The 'Hazy' exotica: The hidden valley

Search for SUEPs produced in association with a W or Z boson @ 13 TeV

- Signal events are expected to have a **high number of constituents** compared to SM



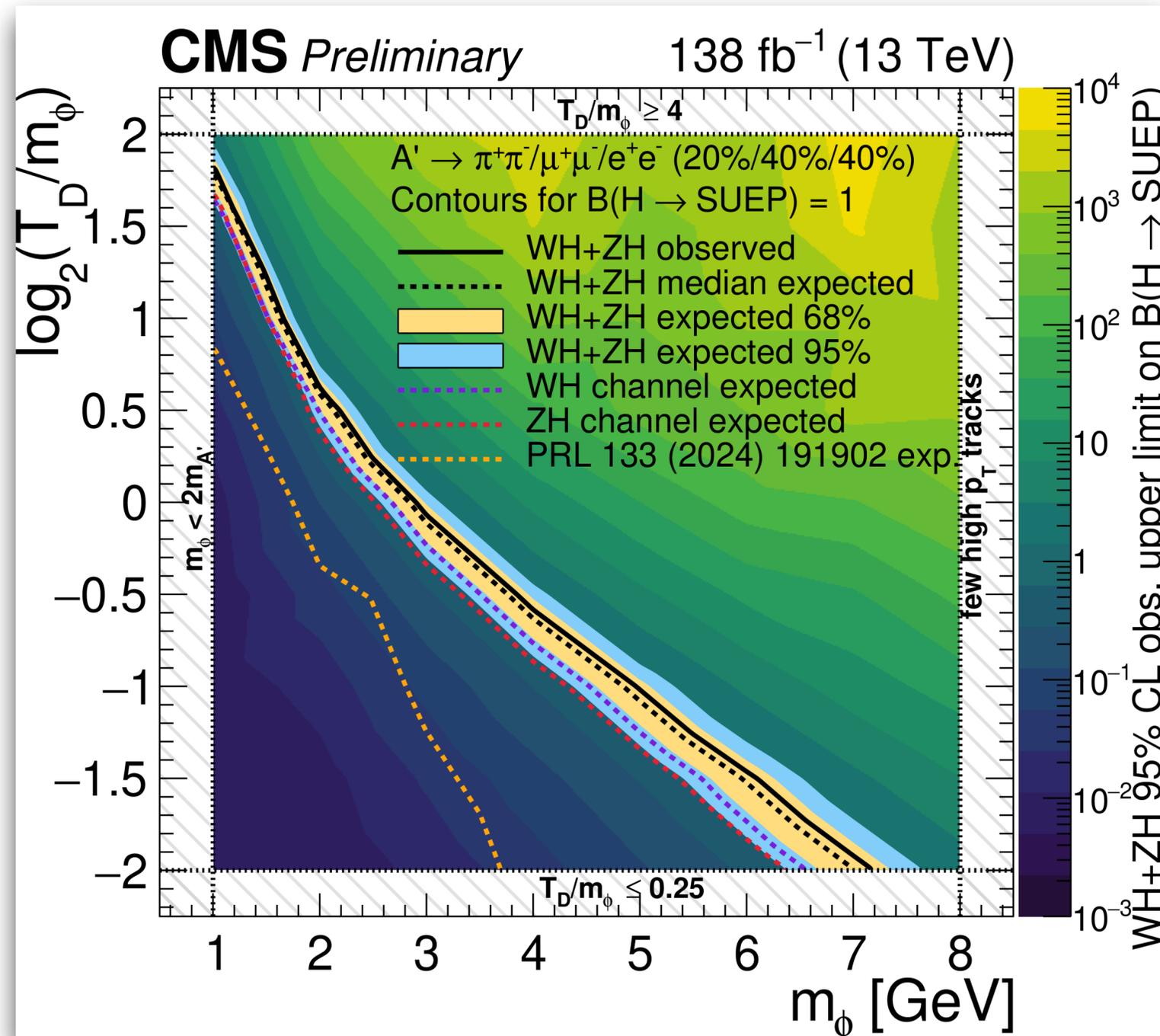
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*Search for SUEPs produced in association with a W or Z boson @13 TeV*

- Signal events are expected to have a **high number of constituents** compared to SM
- Main backgrounds:
  - WH channel :W+jets
  - ZH channel: dominated by DY
- **Backgrounds estimated from data utilizing an extended ABCD Method**
  - 2D plane Multiplicity vs. Sphericity/Jet  $p_T$
  - Extended 9 region grid: accounts for residual statistical correlations between the two variables,

# The 'Hazy' exotica: The hidden valley

Search for SUEPs produced in association with a W or Z boson @13 TeV



- Large improvement upon previous SUEP results!
  - Up to 2 orders of magnitude
- First upper limits are set on the VH production x-section and the H BR to SUEPs!

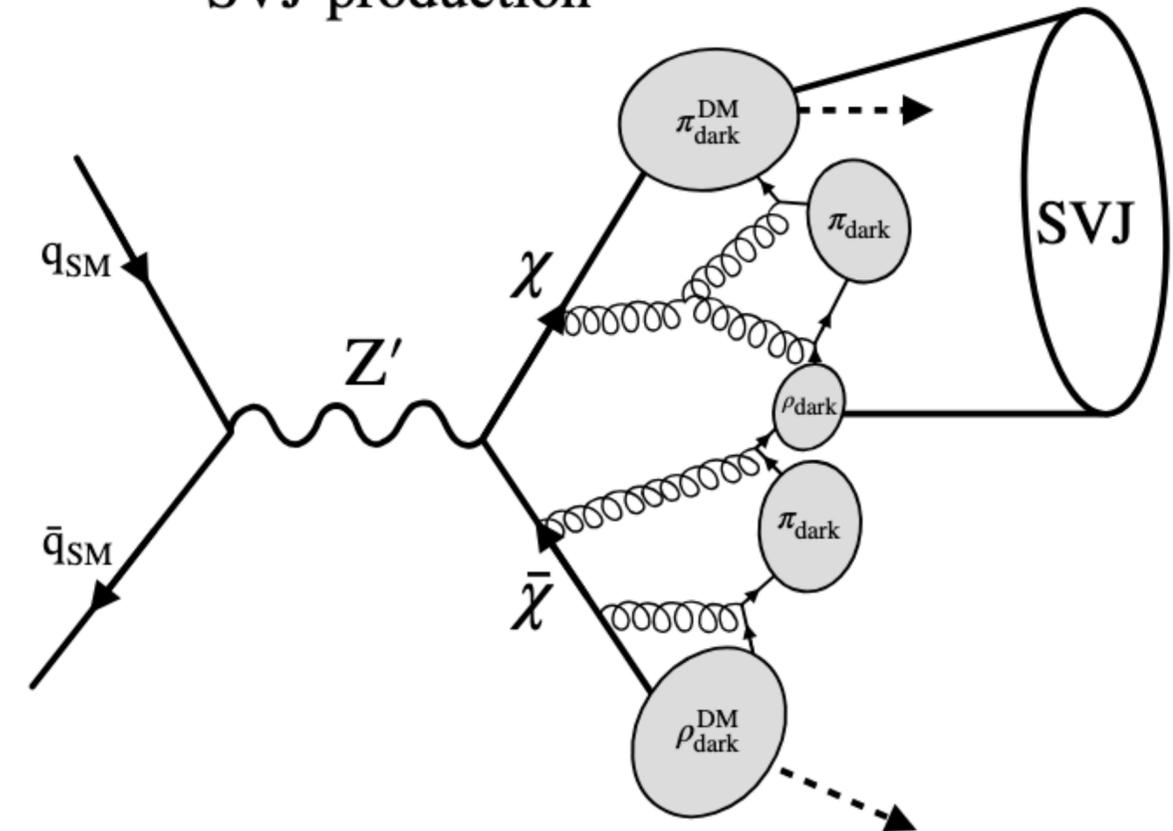


# The 'tangled' exotica: When jets go dark

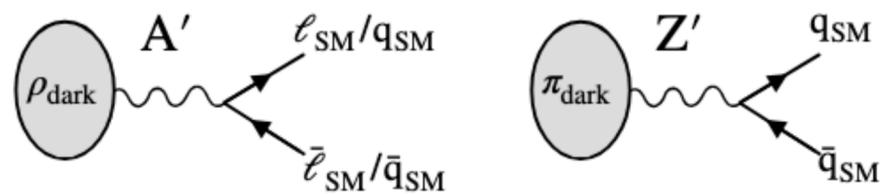
*s*-channel production of lepton-enriched semivisible jets @ 13TeV

- Semi-visible jets → Arise from a "dark QCD" sector
  - Jets contain **stable dark hadrons** →  $p_T^{\text{miss}}$  &
  - **unstable dark hadrons** → decay to SM particles.
- Targets two scenarios where dark hadrons decay into leptons :

SVJ production

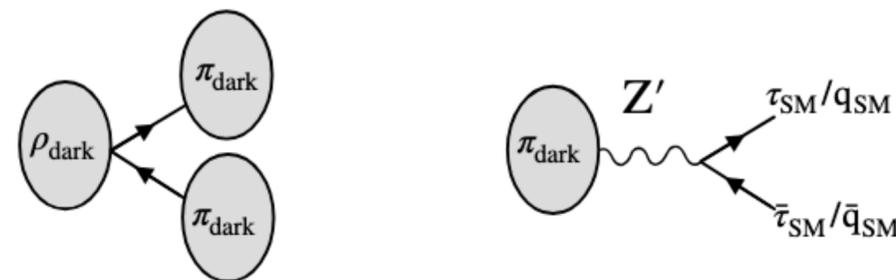


SVJ $\ell$  scenario



Decays to all leptons via a dark photon A'

SVJ $\tau$  scenario

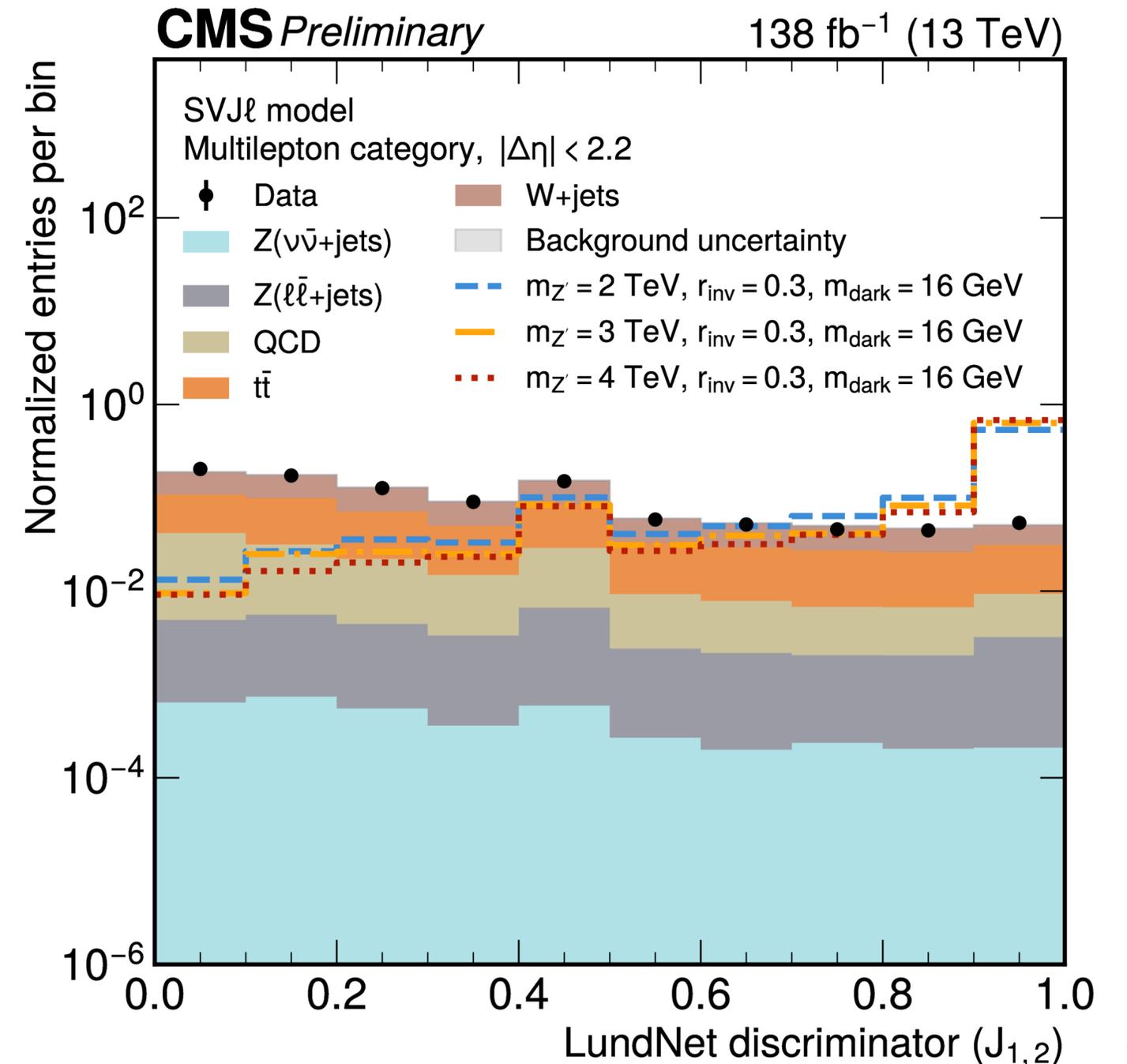


Decays to  $\tau$  leptons and heavy quarks via a Z' portal

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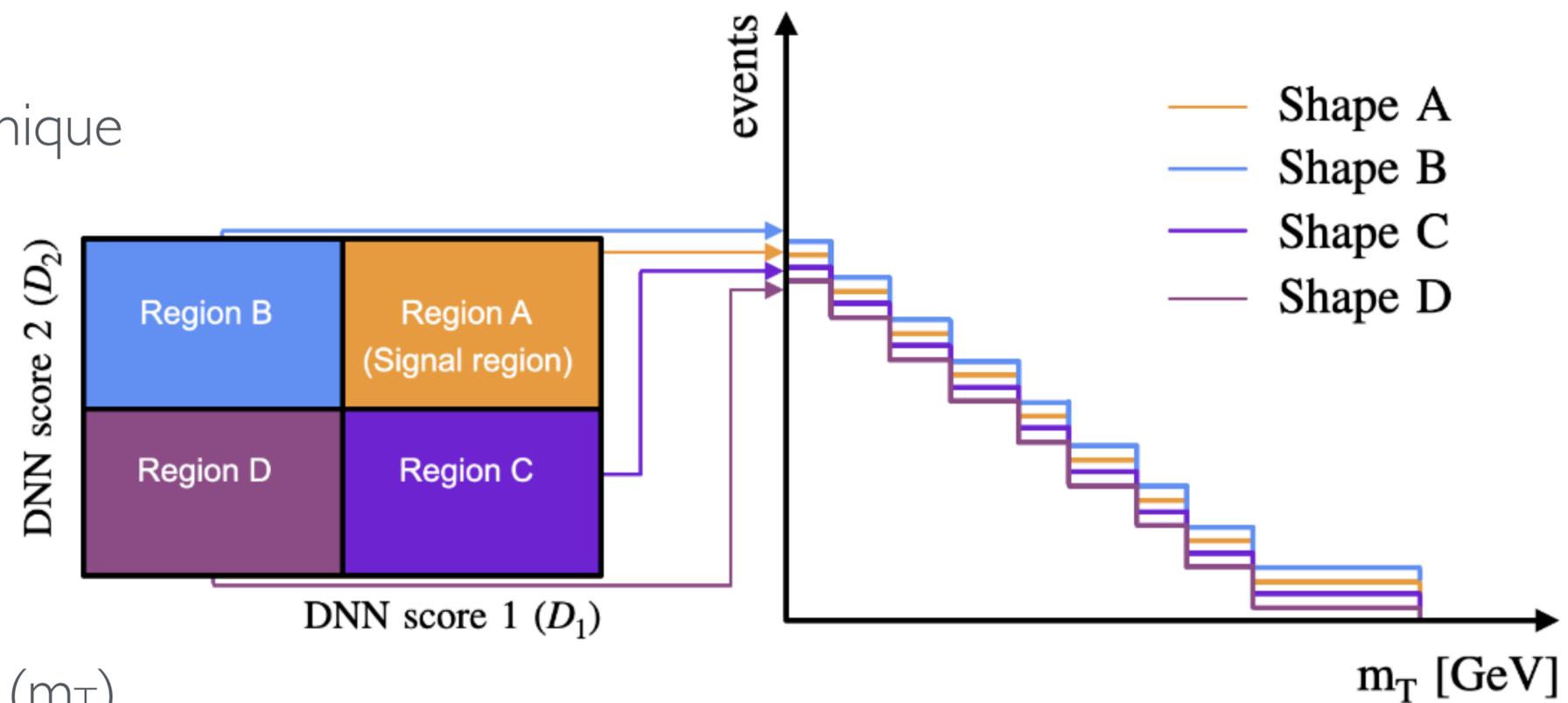
- GNN used to tag SVJs:
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- Categorization based on lepton multiplicity



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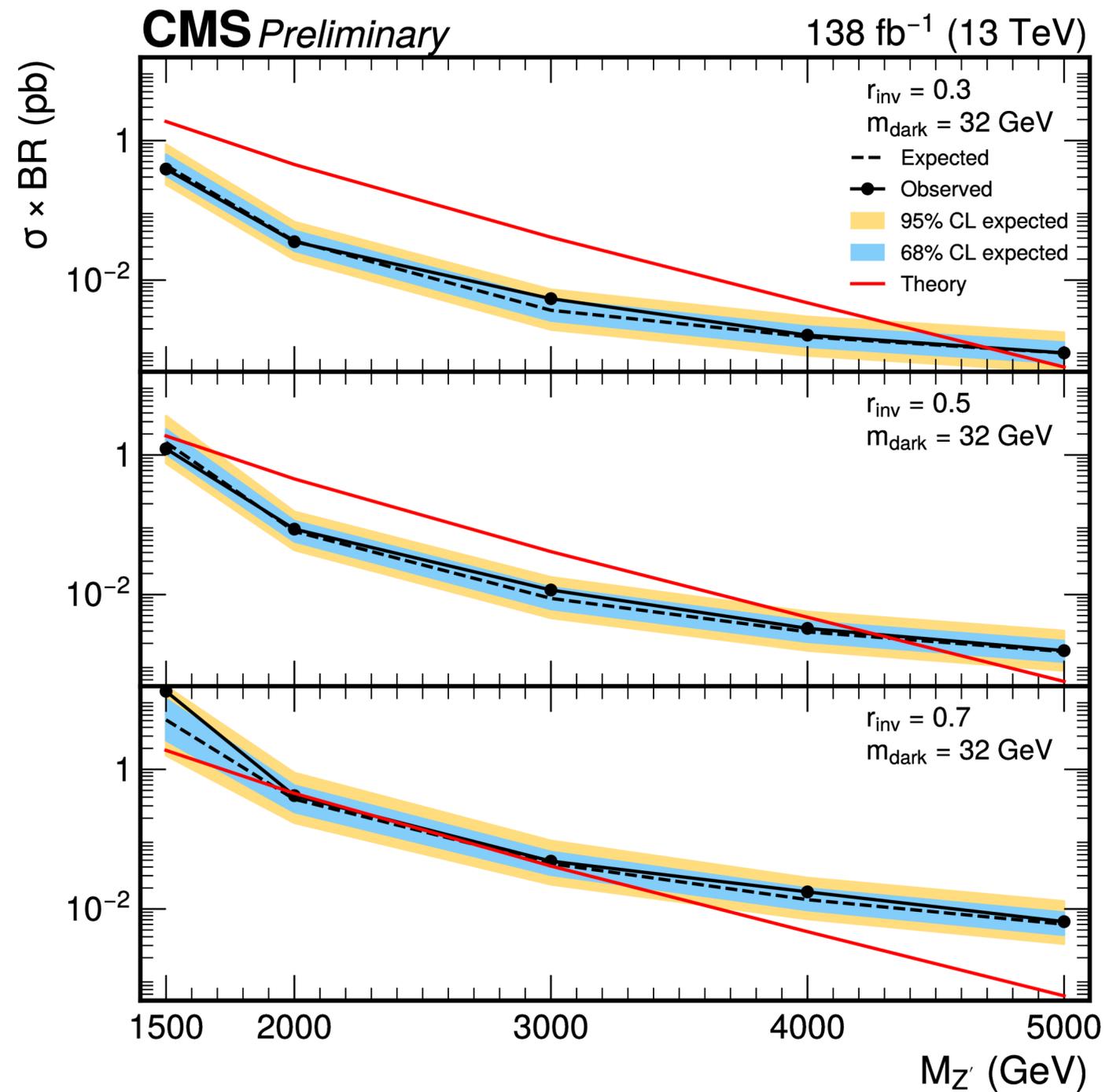
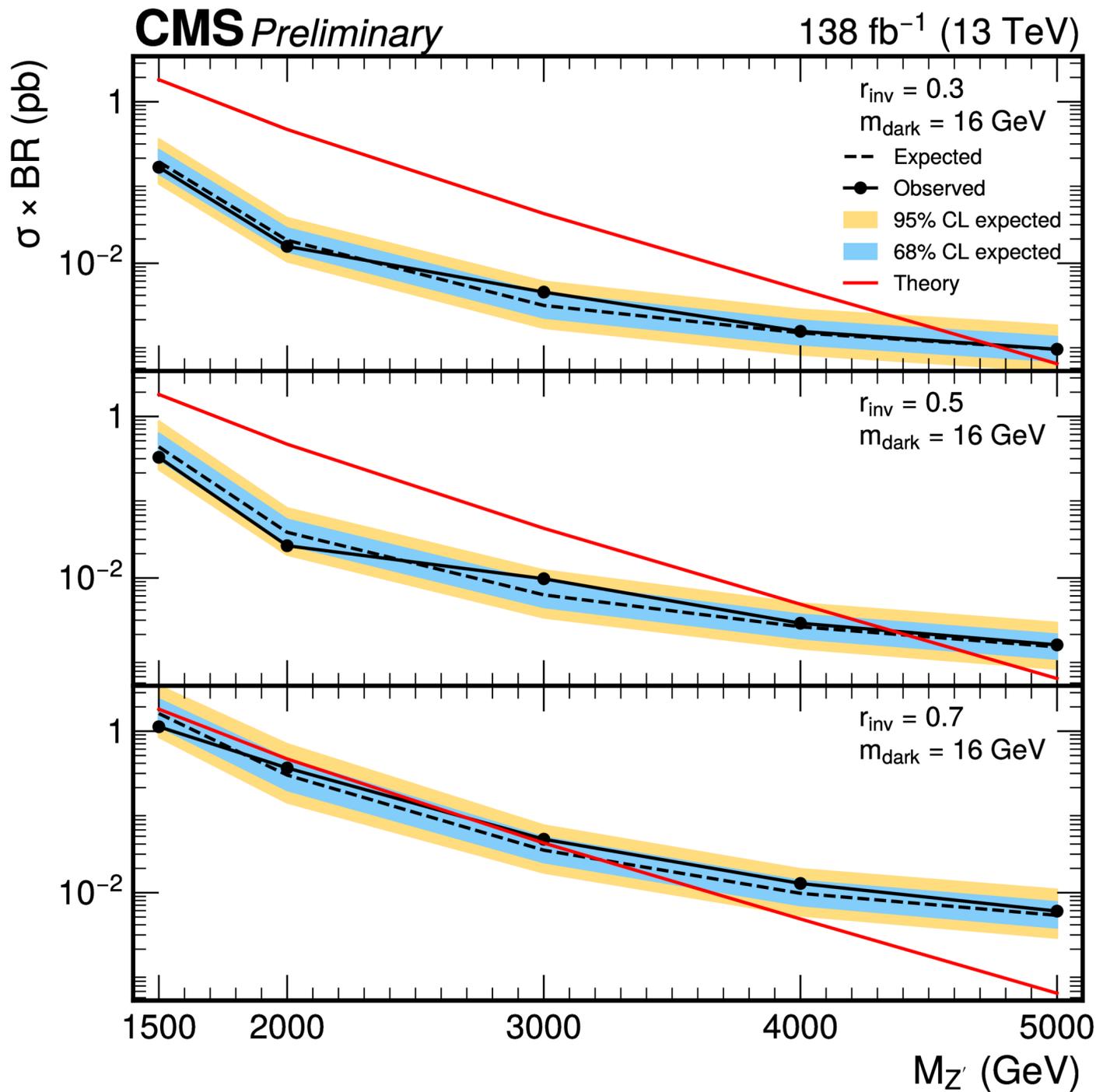
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- **Categorization based on lepton multiplicity**
- **Novel background estimation uses 2 DNNs:**
  - The networks are trained to be statistically independent (using distance correlation).
  - Decorrelated from the dijet transverse mass ( $m_T$ )
  - ABCD method then applied to estimate the background in each bin of  $m_T$ .



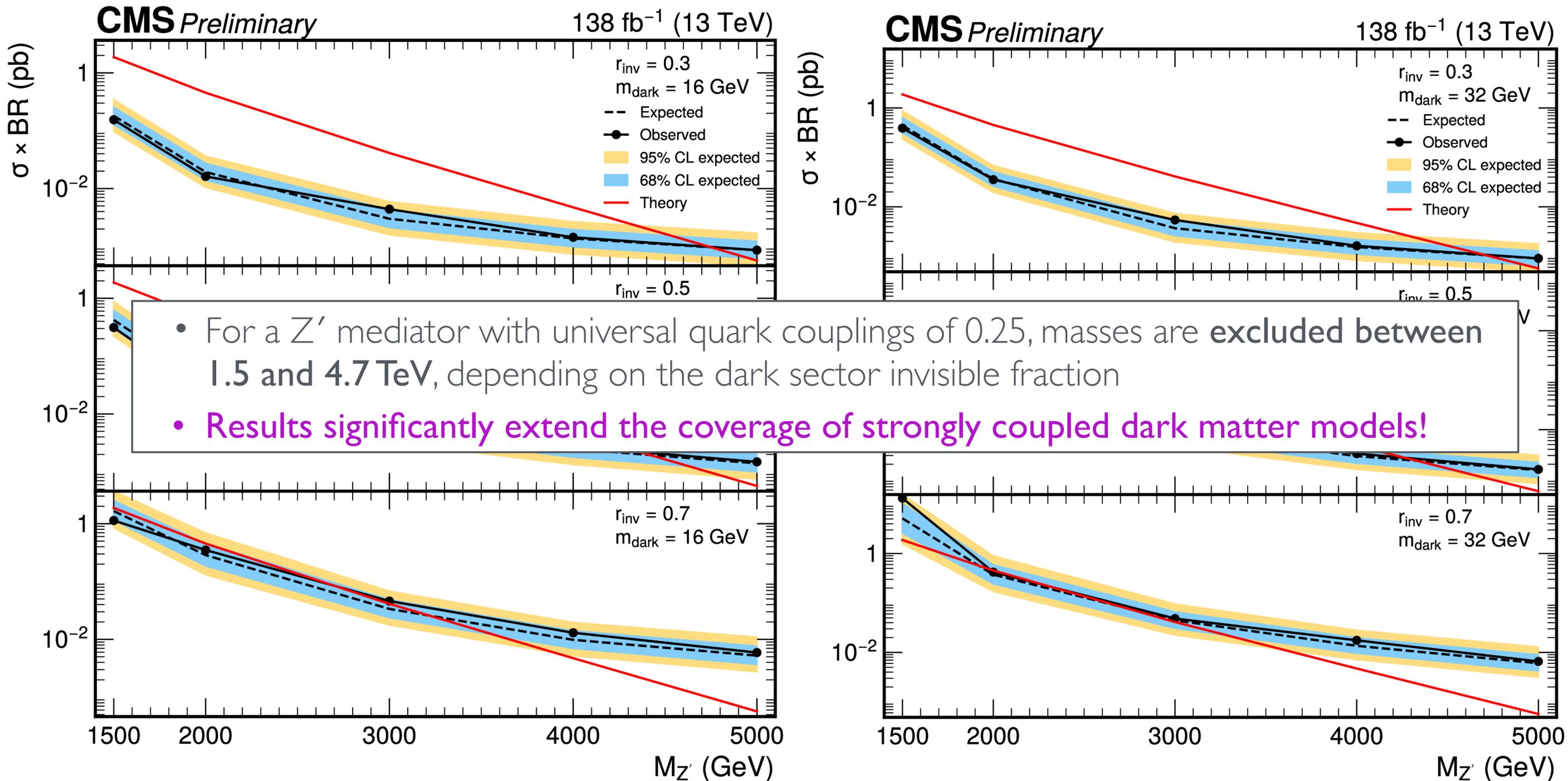
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# The unknown exotica: Looking for anomalies

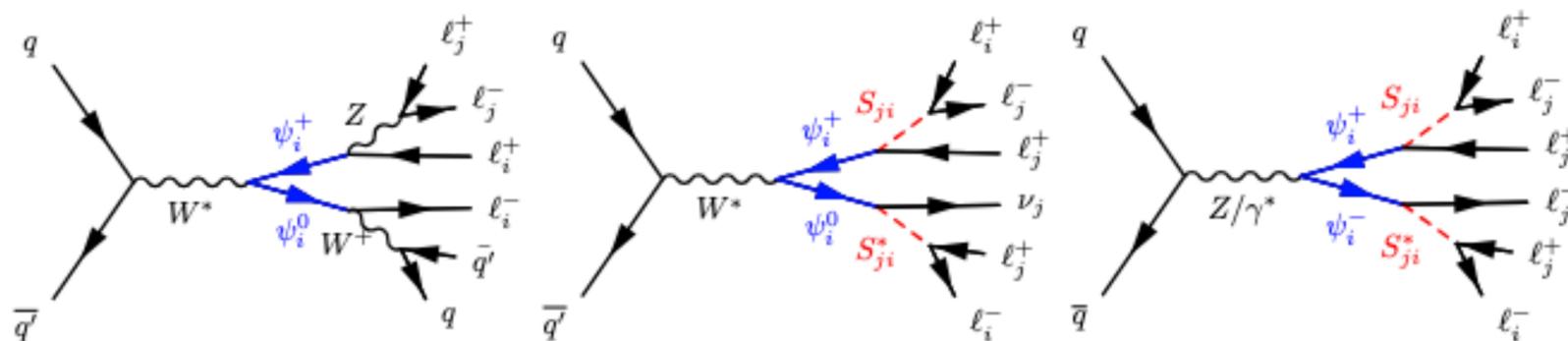
*Searching for BSM physics with anomaly detection in multilepton final states @13 TeV*

- **First search using Anomaly Detection (AD) for multilepton final states!**
  - AD → learn the "shape" of the SM & flag anything anomalous in the tails of the distribution
  - Based on normalizing flow
  - Sensitive to BSM physics populating low probability regions of phase space

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- **SM rarely produces 4 or 5 leptons:**
  - Many BSM models do! e.g. VLLs, SUSY (RPV), or Charginos/Neutralinos



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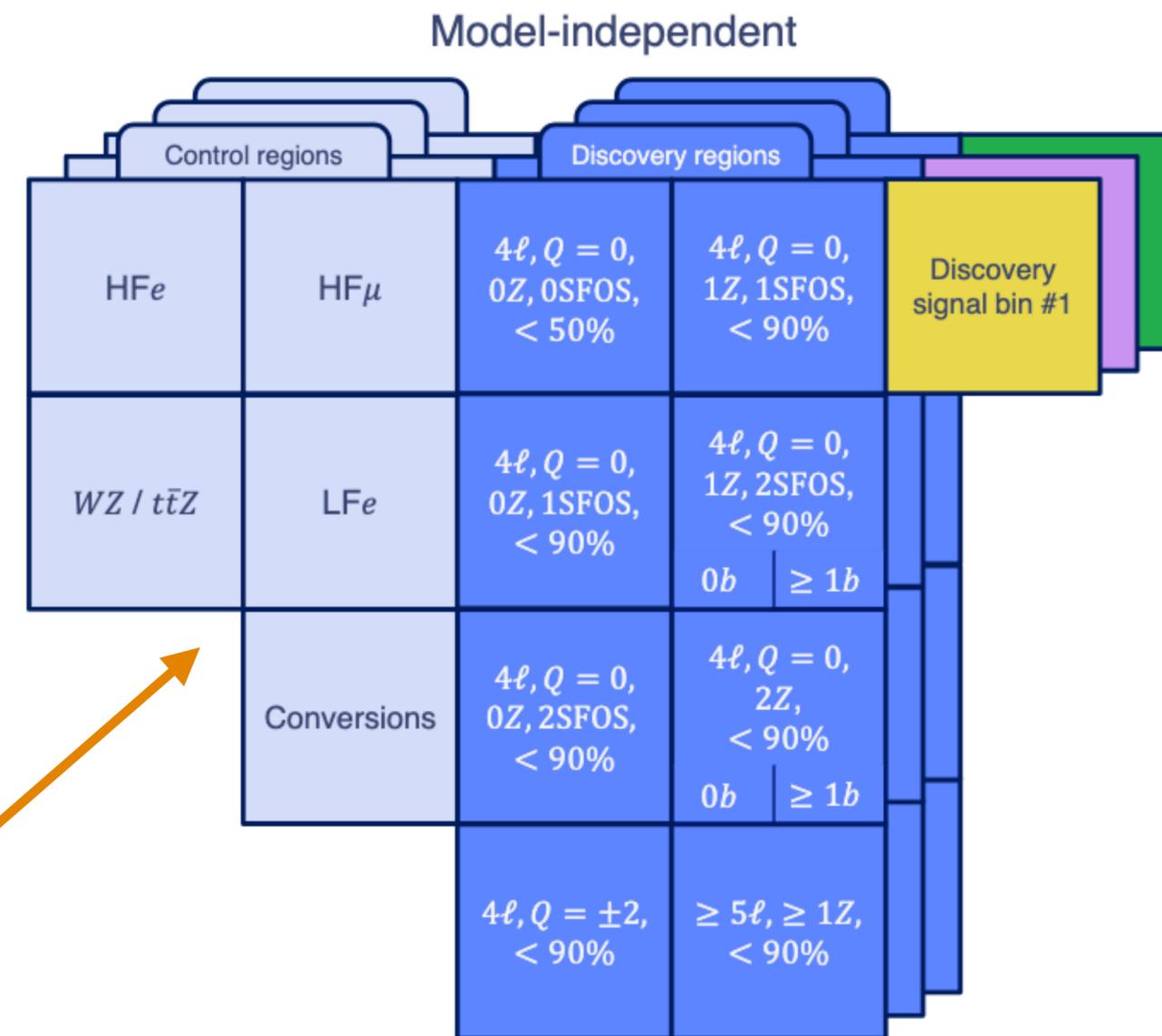
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    - Dominant are  $VV$ ,  $ttV/H$ ,  $VVV$  and non-prompt
- Model learns the probability density for 15 high-level kinematic variables
  - Each event is assigned an anomaly score
  - **Model independent** discovery regions defined based on object multiplicities and anomaly score
  - Each **region is fit separately**, but simultaneously with its CRs

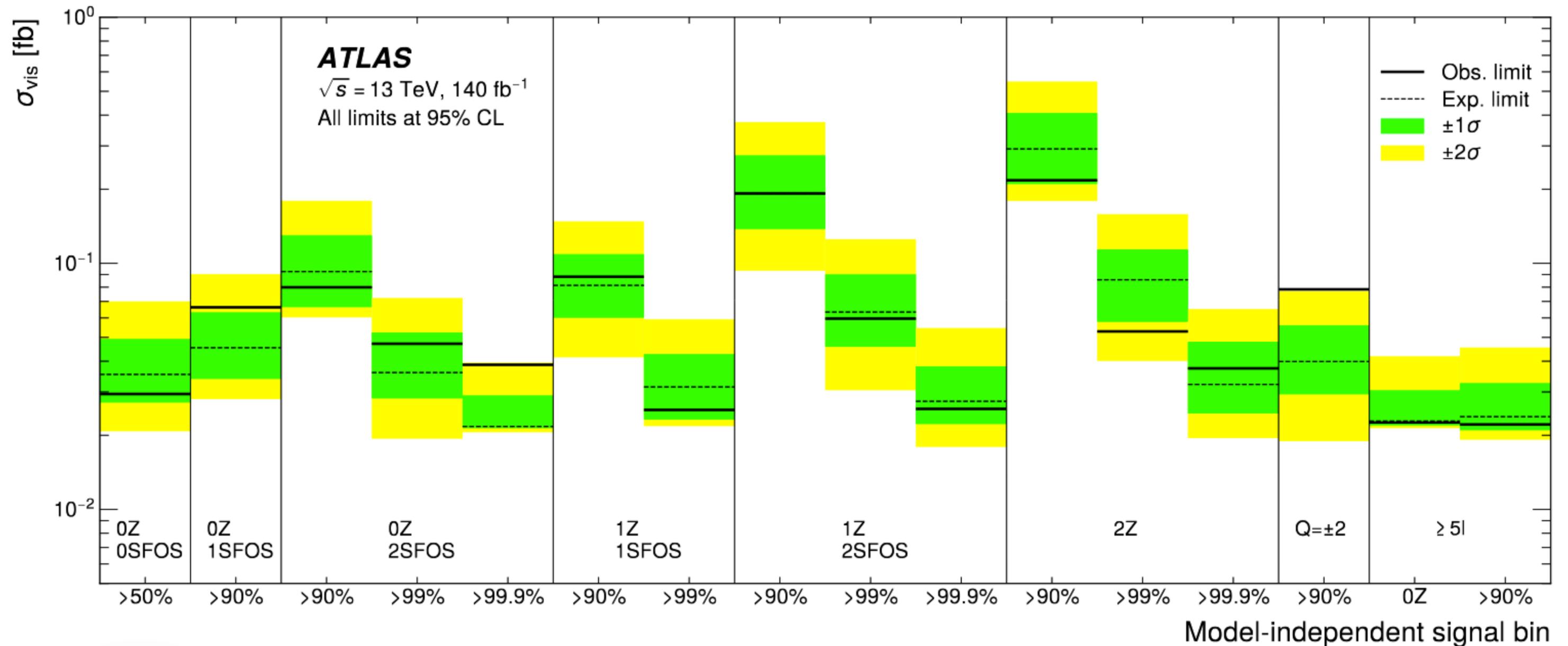


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**Model independent approach**

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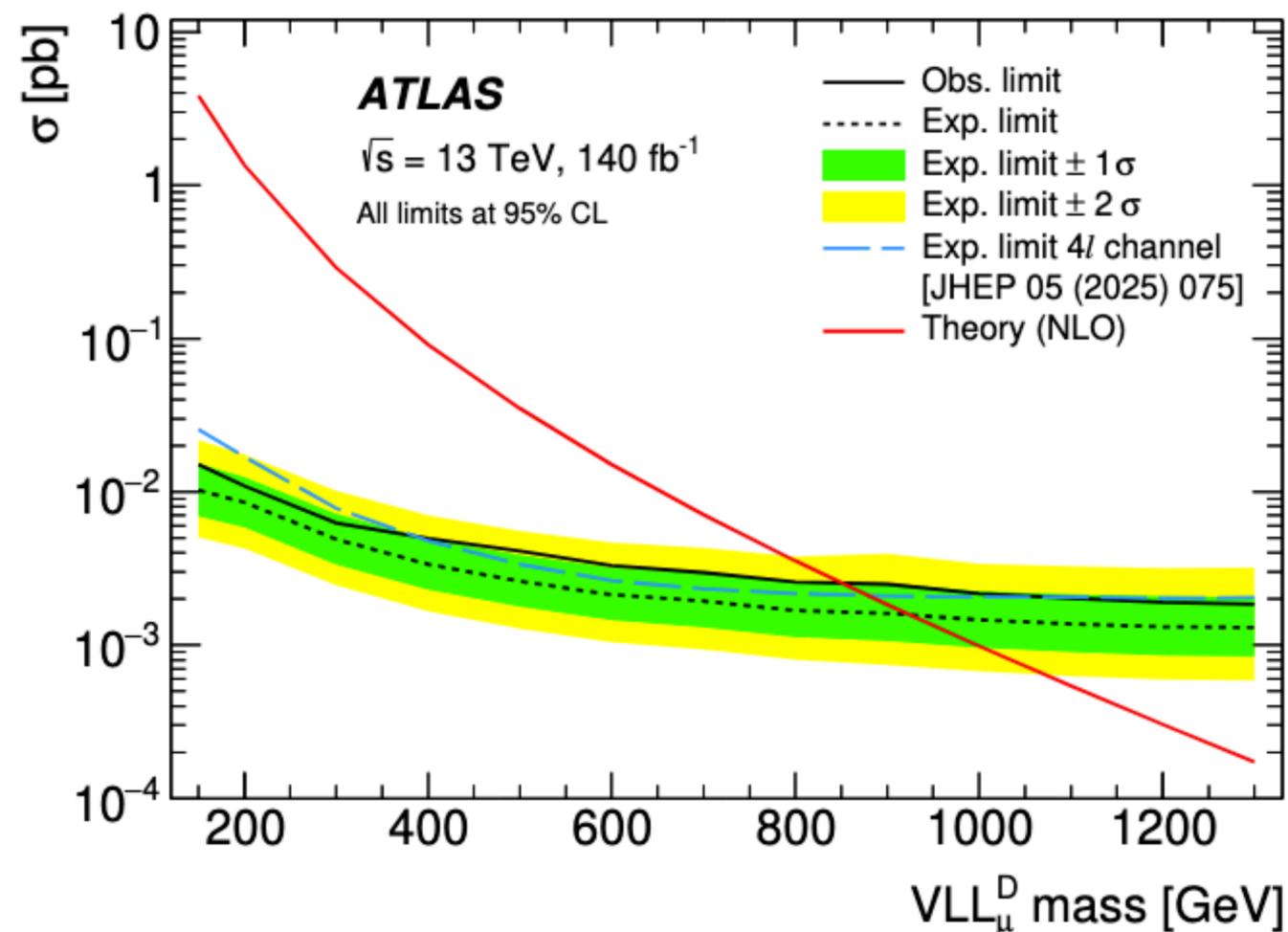
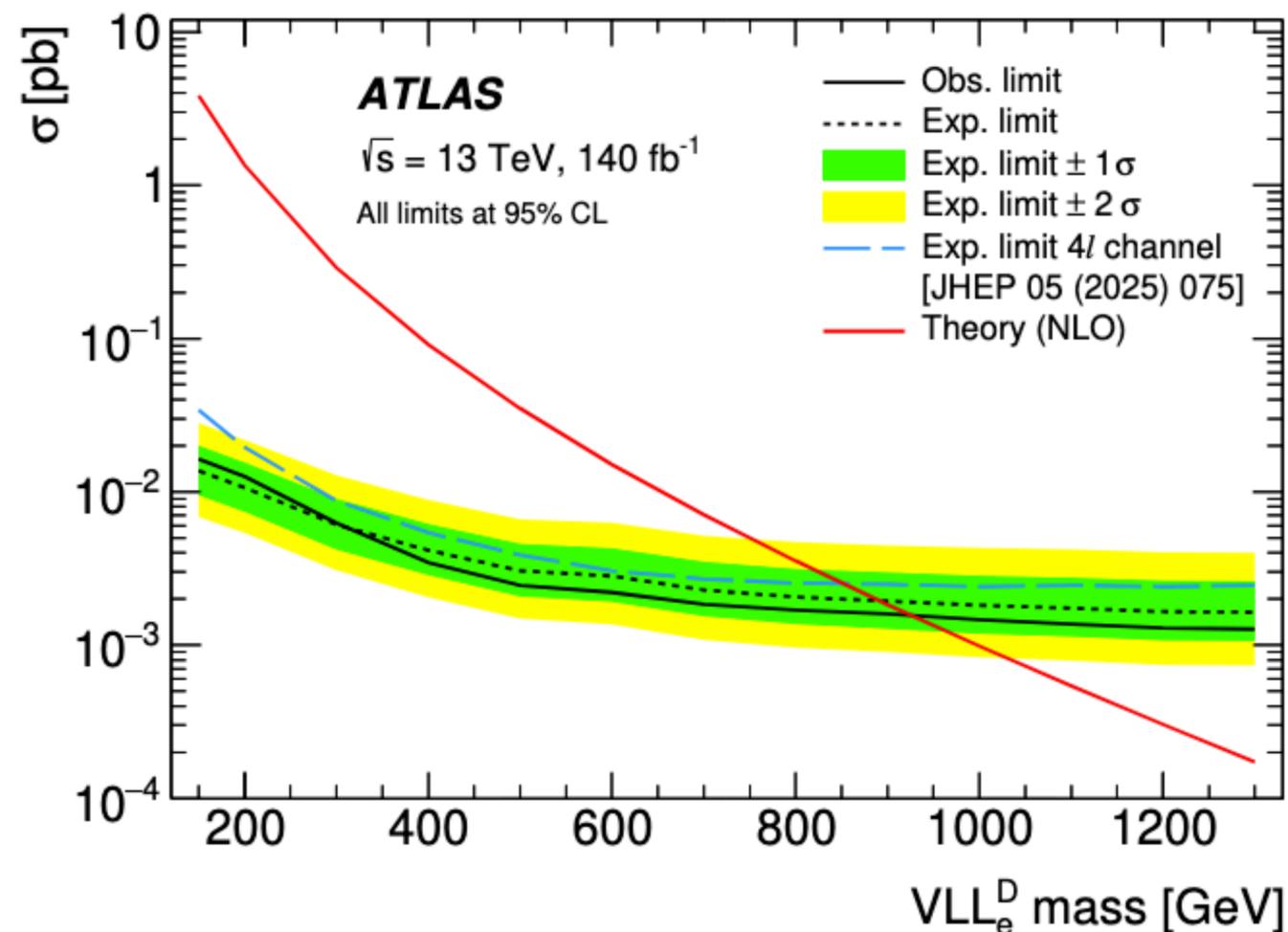


- No significant excess was observed → limits places in visible x section

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## Searching for BSM physics with anomaly detection in multilepton final states @13 TeV

- Results also shown following a model dependent approach
  - 32 SRs further split based on b-jet multiplicity
  - All regions included in simultaneous fit to the data



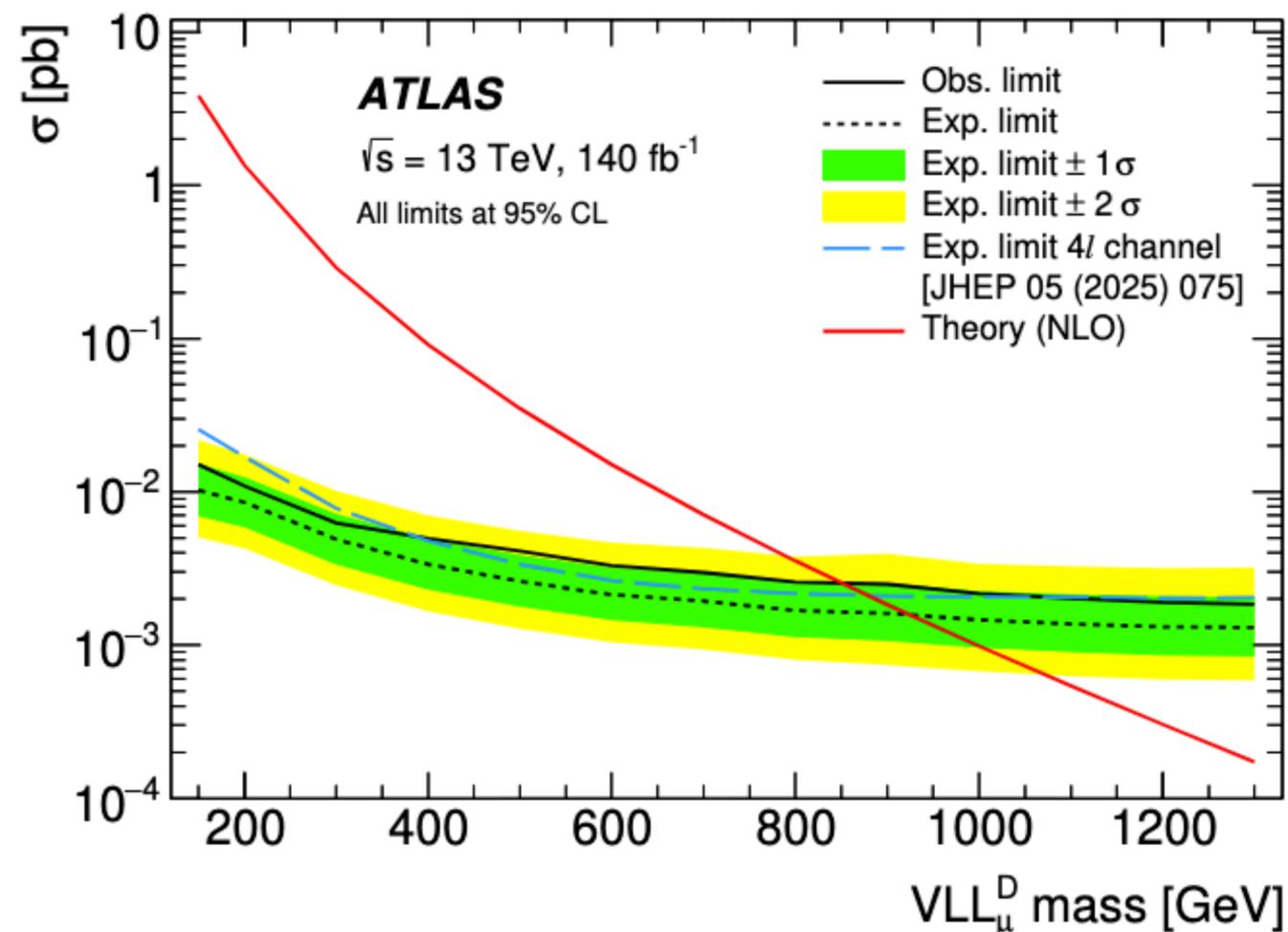
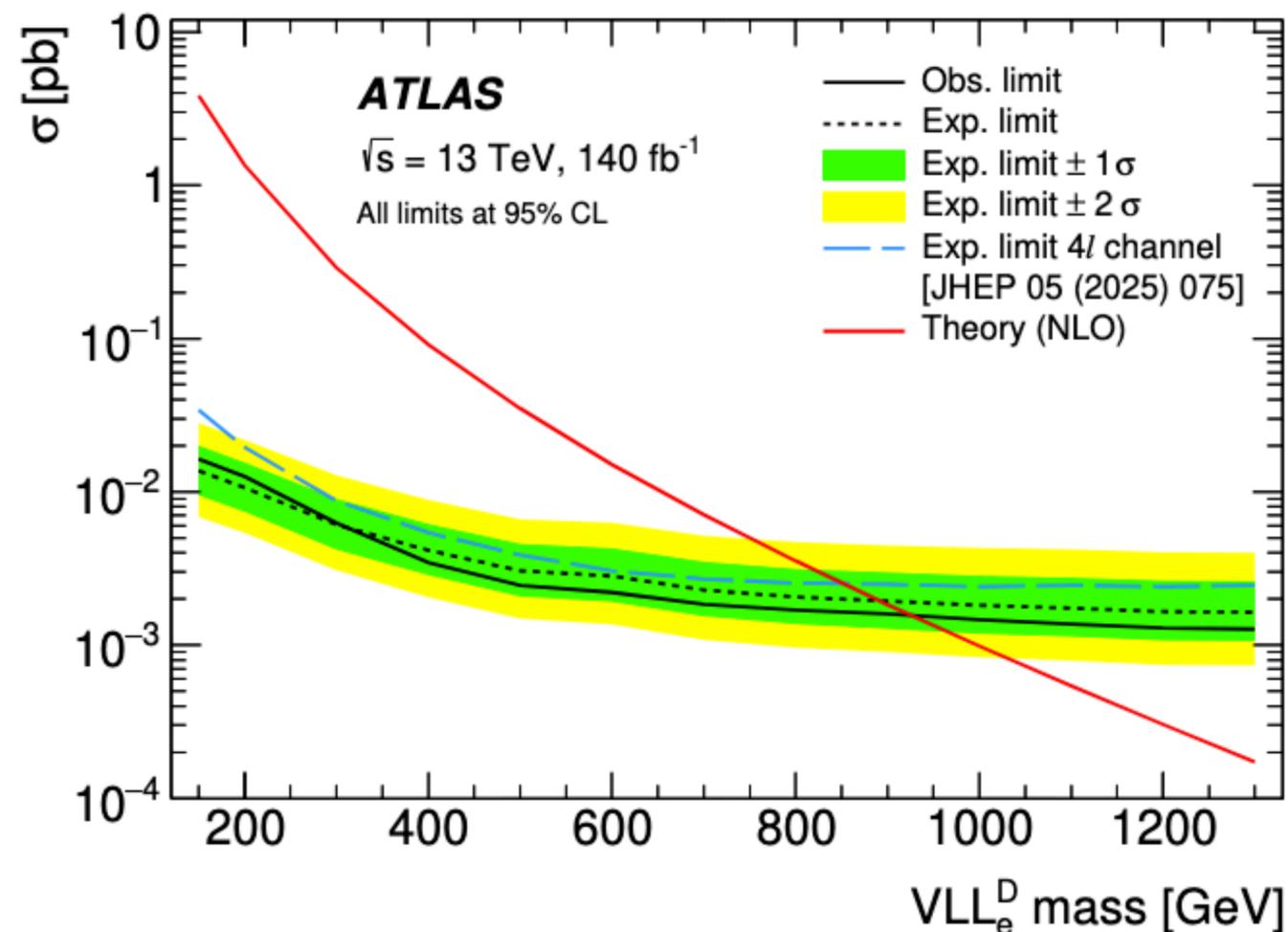
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## Searching for BSM physics with anomaly detection in multilepton final states @ 13 TeV

- Results also shown following a model dependent approach

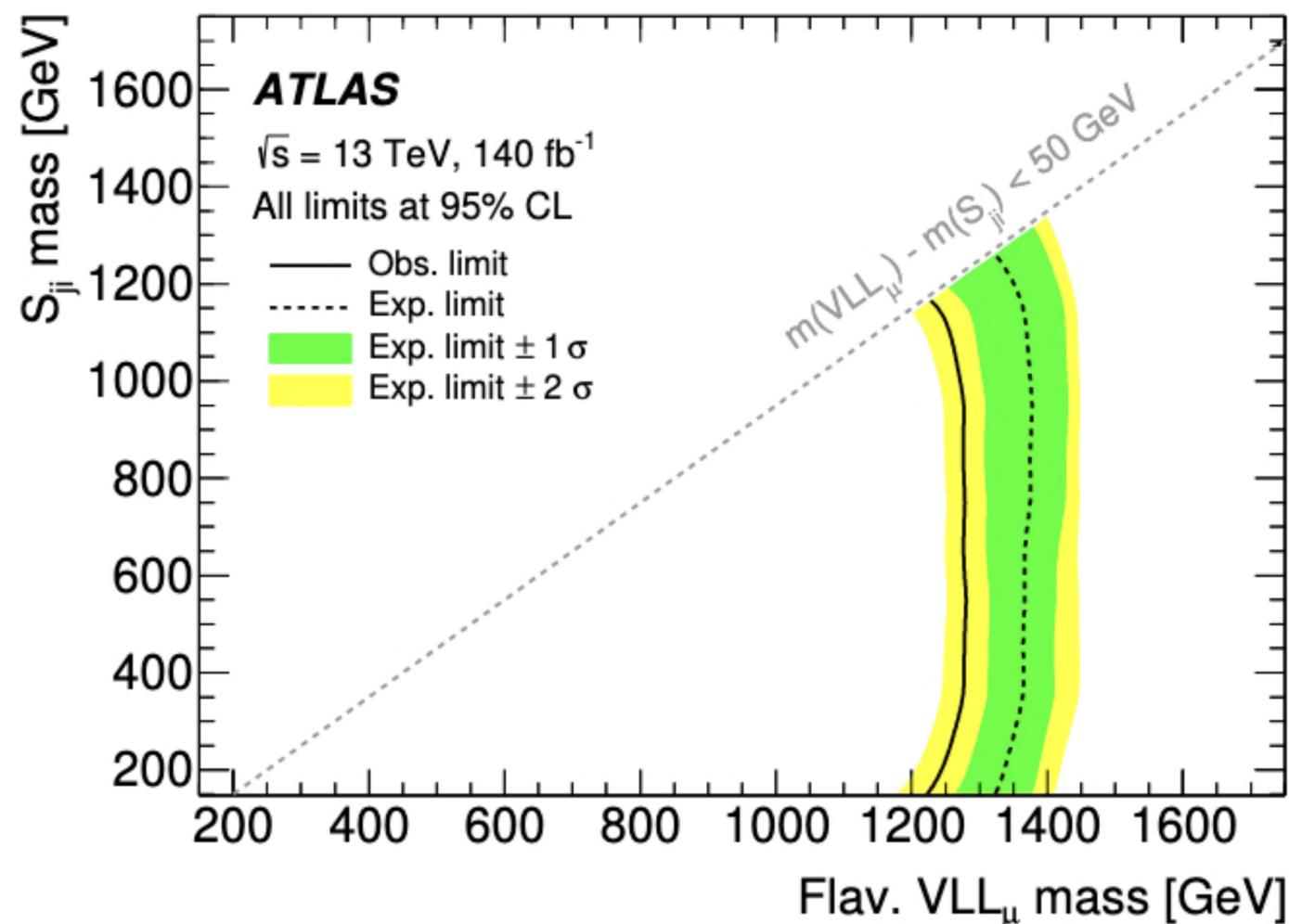
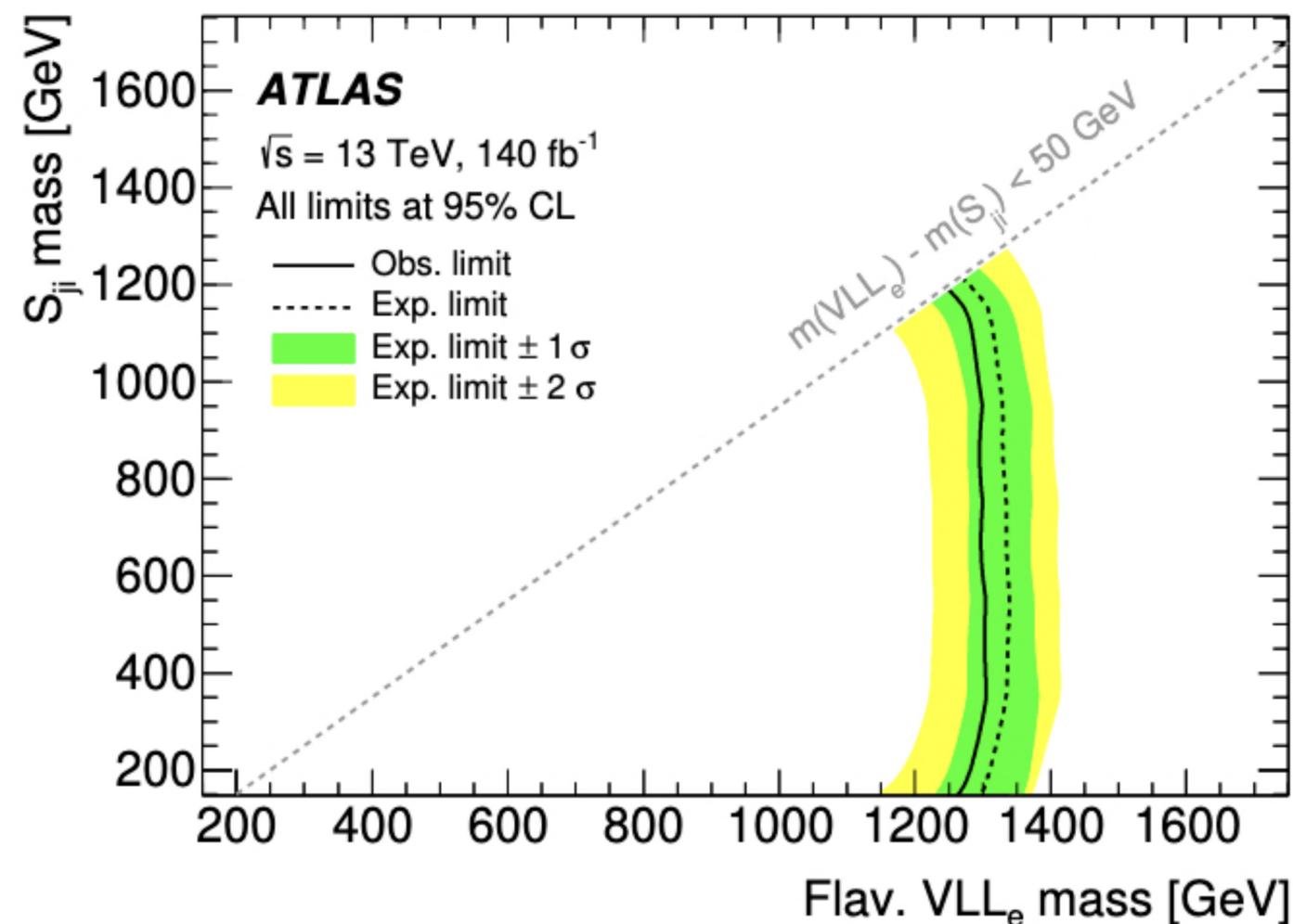
- 32 SRs further split based on b-jet multiplicity
- All regions included in simultaneous fit to the data

Limits competitive or better with ones of dedicated 4l channel search!



# The unknown exotica: Looking for anomalies

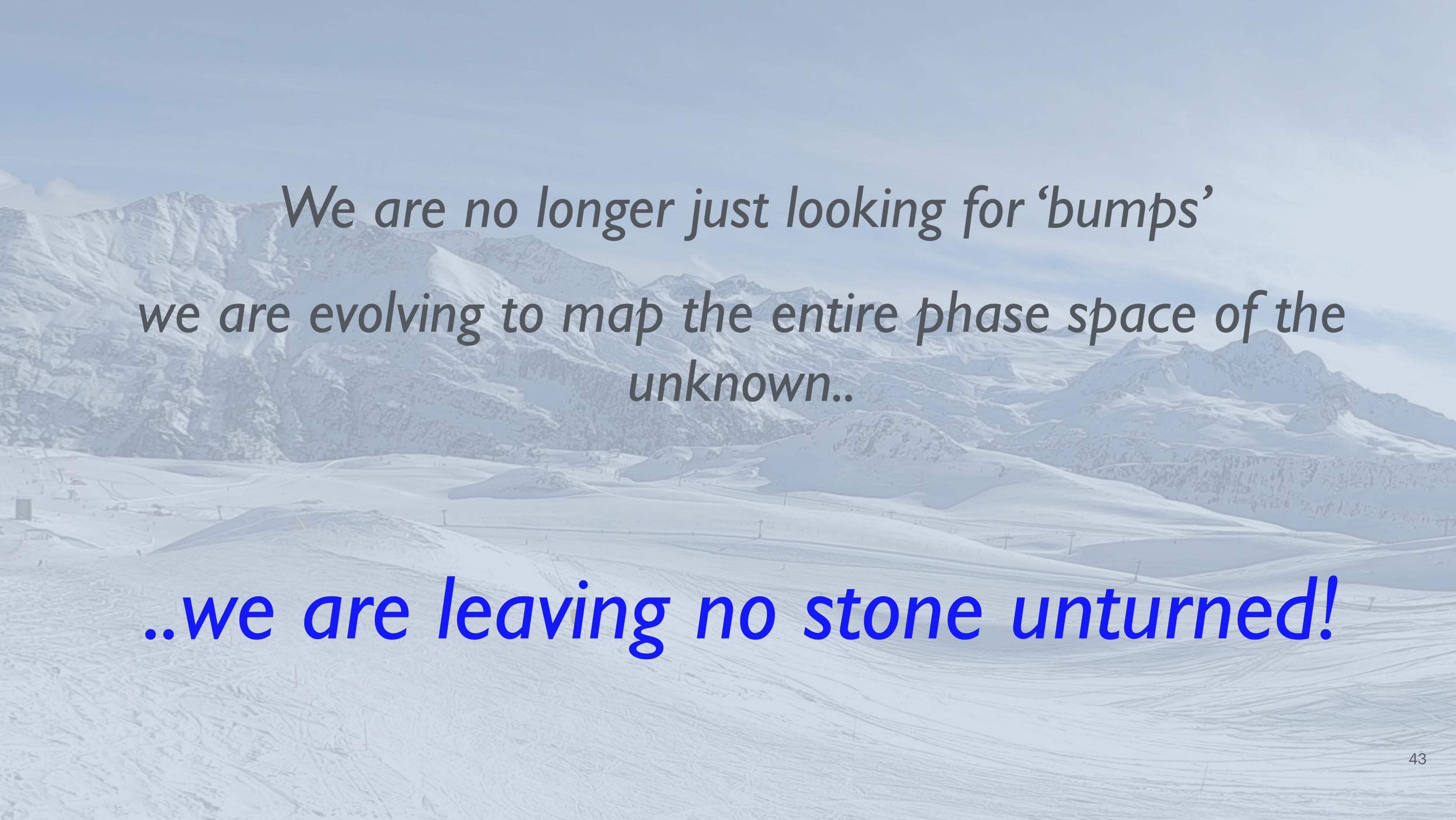
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**First limits on the 'flavourful' VLL model** excluding VLL masses up to 1300 GeV (e-channel) and 1280 GeV ( $\mu$ -channel)



*We are no longer just looking for ‘bumps’  
we are evolving to map the entire phase space of the  
unknown..*



*We are no longer just looking for ‘bumps’  
we are evolving to map the entire phase space of the  
unknown..*

***..we are leaving no stone unturned!***

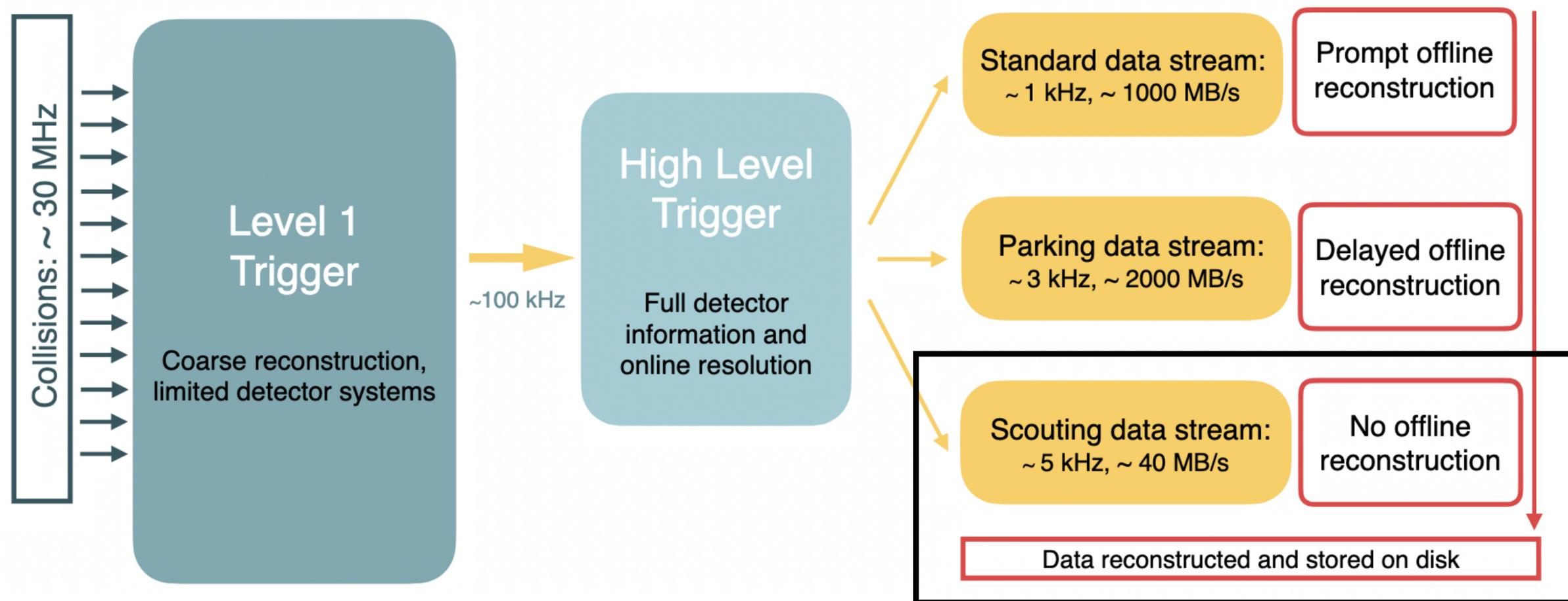


Thank you!!

# Back-up

# CMS scouting

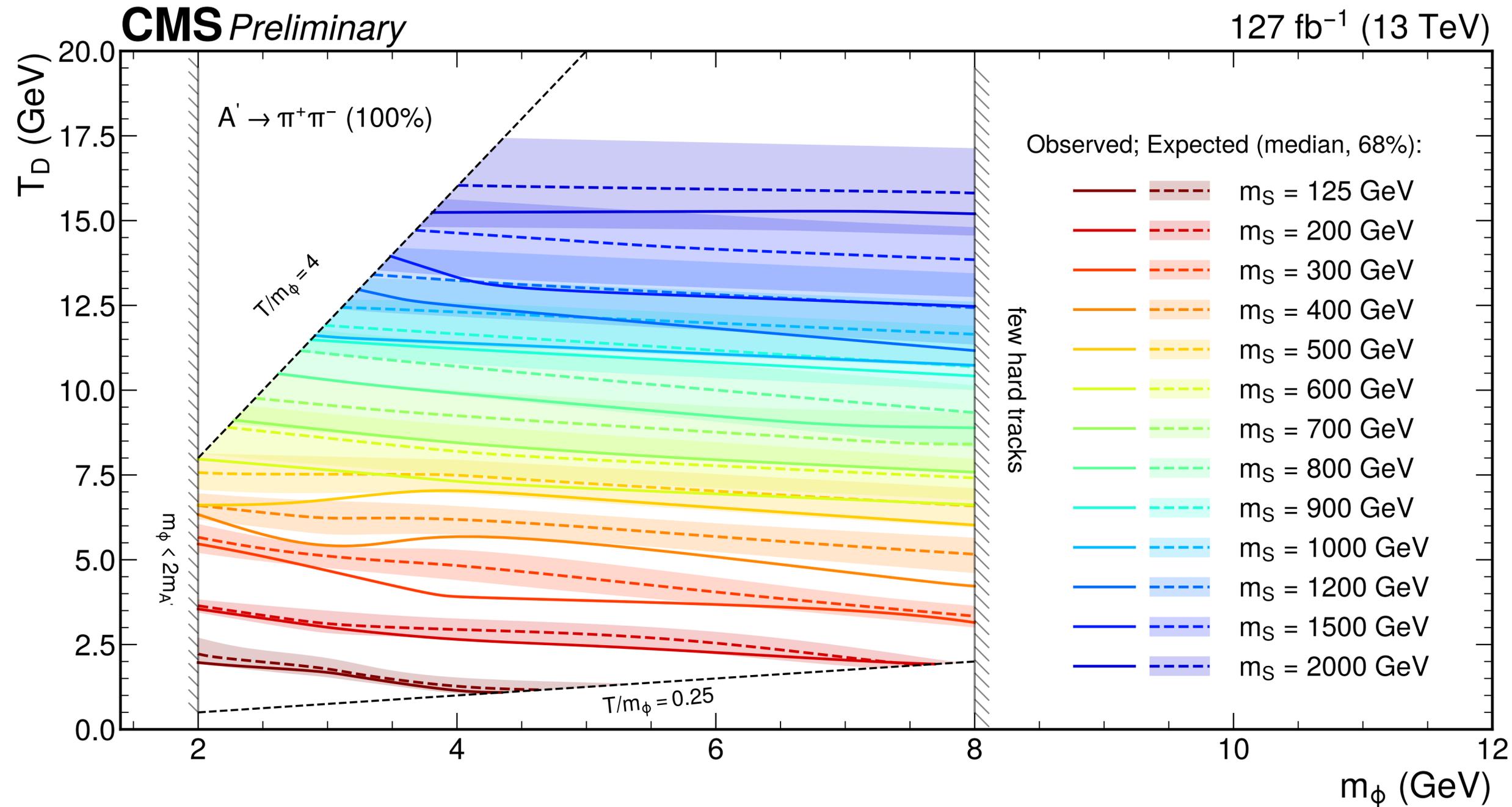
Data flow for a typical 2018 data-taking scenario



- Enhances sensitivity to low-energy physics processes by significantly lowering the HLT thresholds and storing a reduced event content on disk.
  - Event content includes online reconstructed physics objects: calorimeter-based jets, electrons & muons, PF candidate information,  $E_T^{\text{miss}}$ , PV information etc.
  - In Run-3 use of GPUs@HLT allowed to perform tracking@HLT using the pixel tracker !

# The 'Hazy' exotica: The hidden valley

Search for soft unclustered energy patterns using CMS data scouting @ 13 TeV



# The unknown exotica: Looking for anomalies

Searching for BSM physics with anomaly detection in multilepton final states @ 13 TeV

