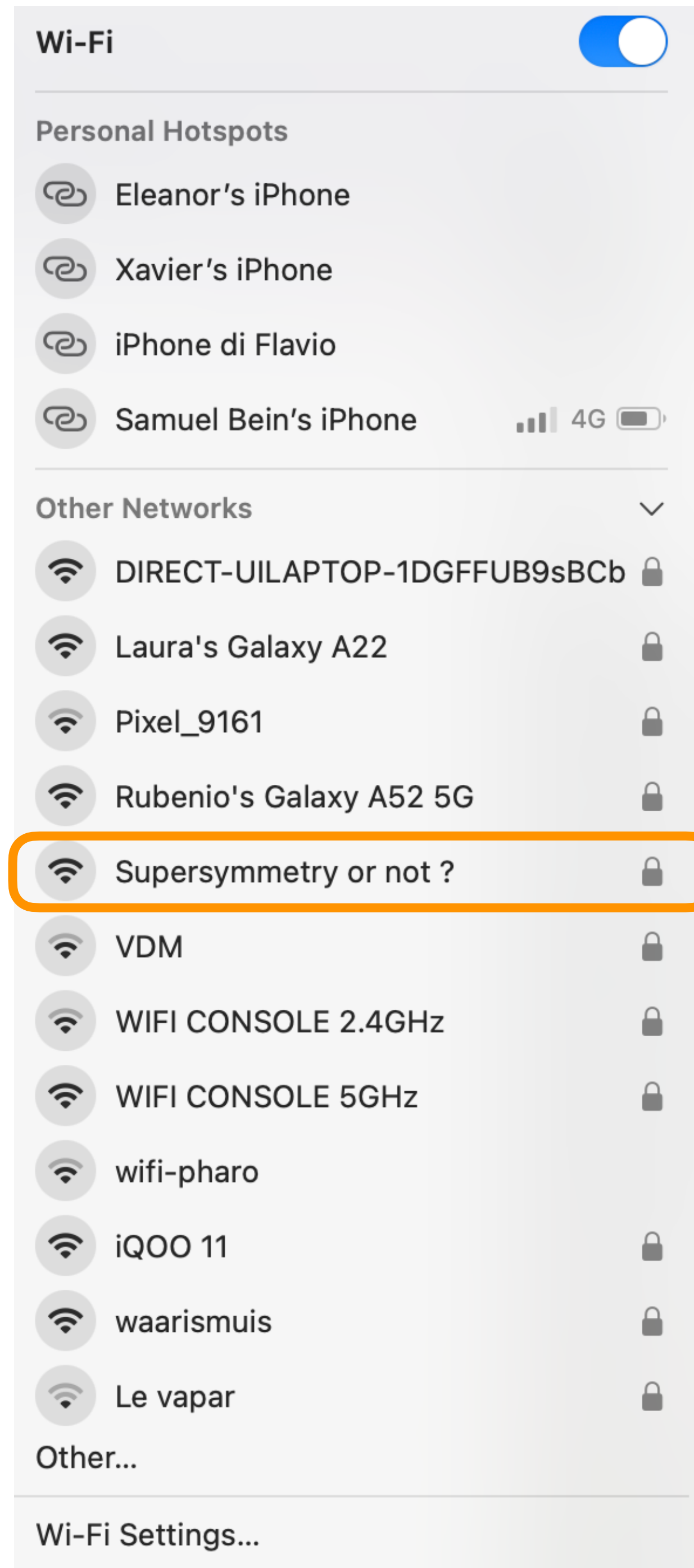
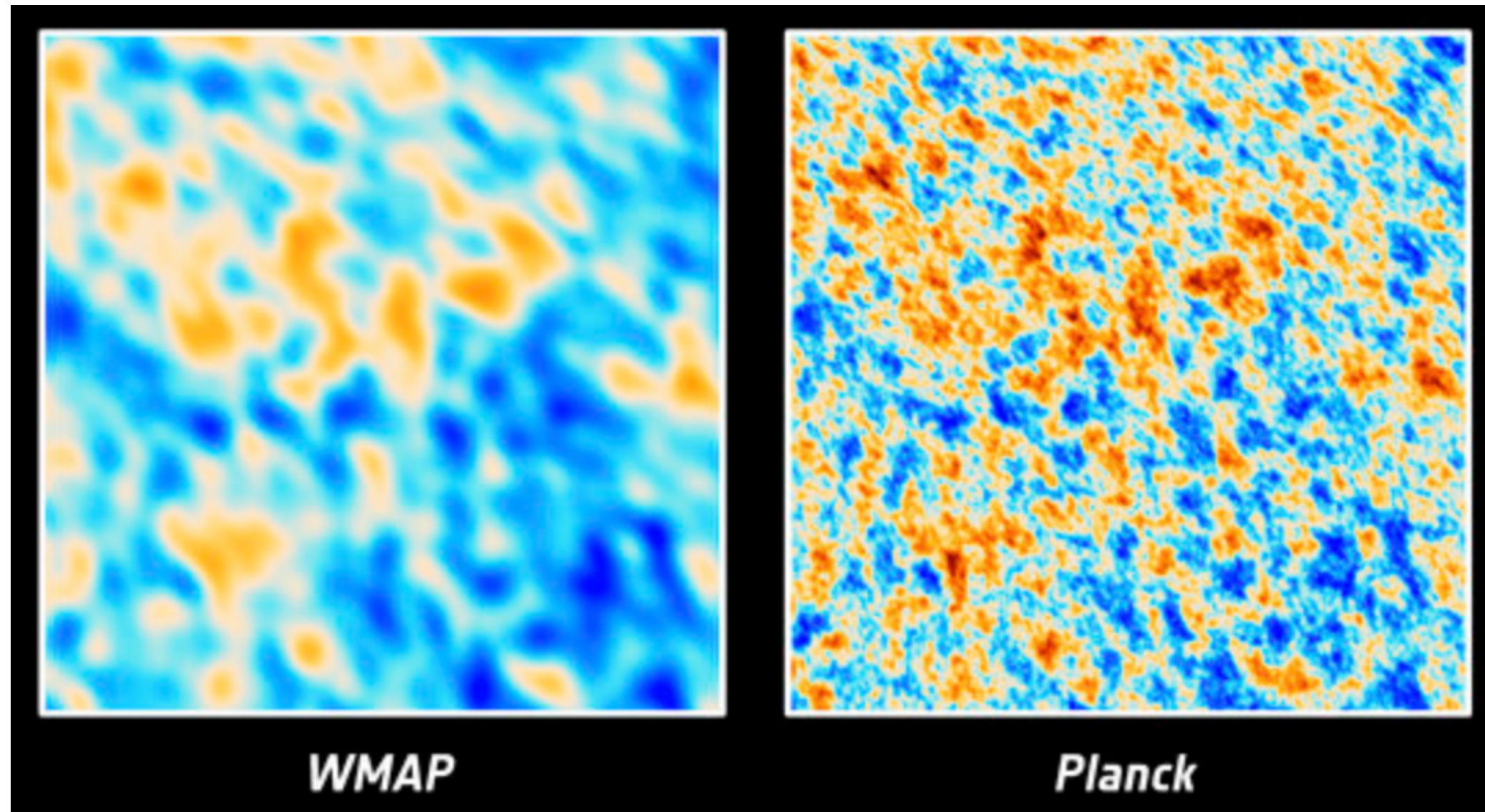


Searches for Compressed Supersymmetry at CMS

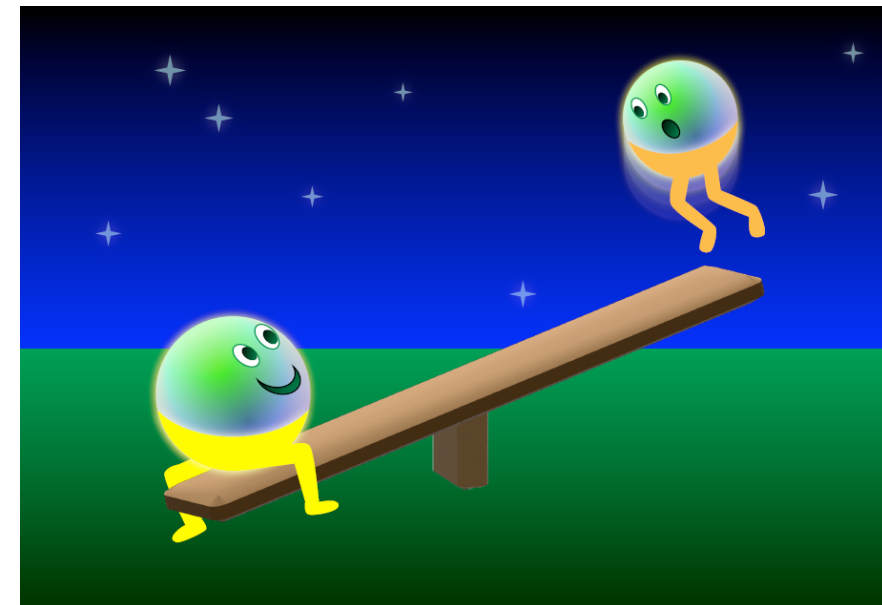
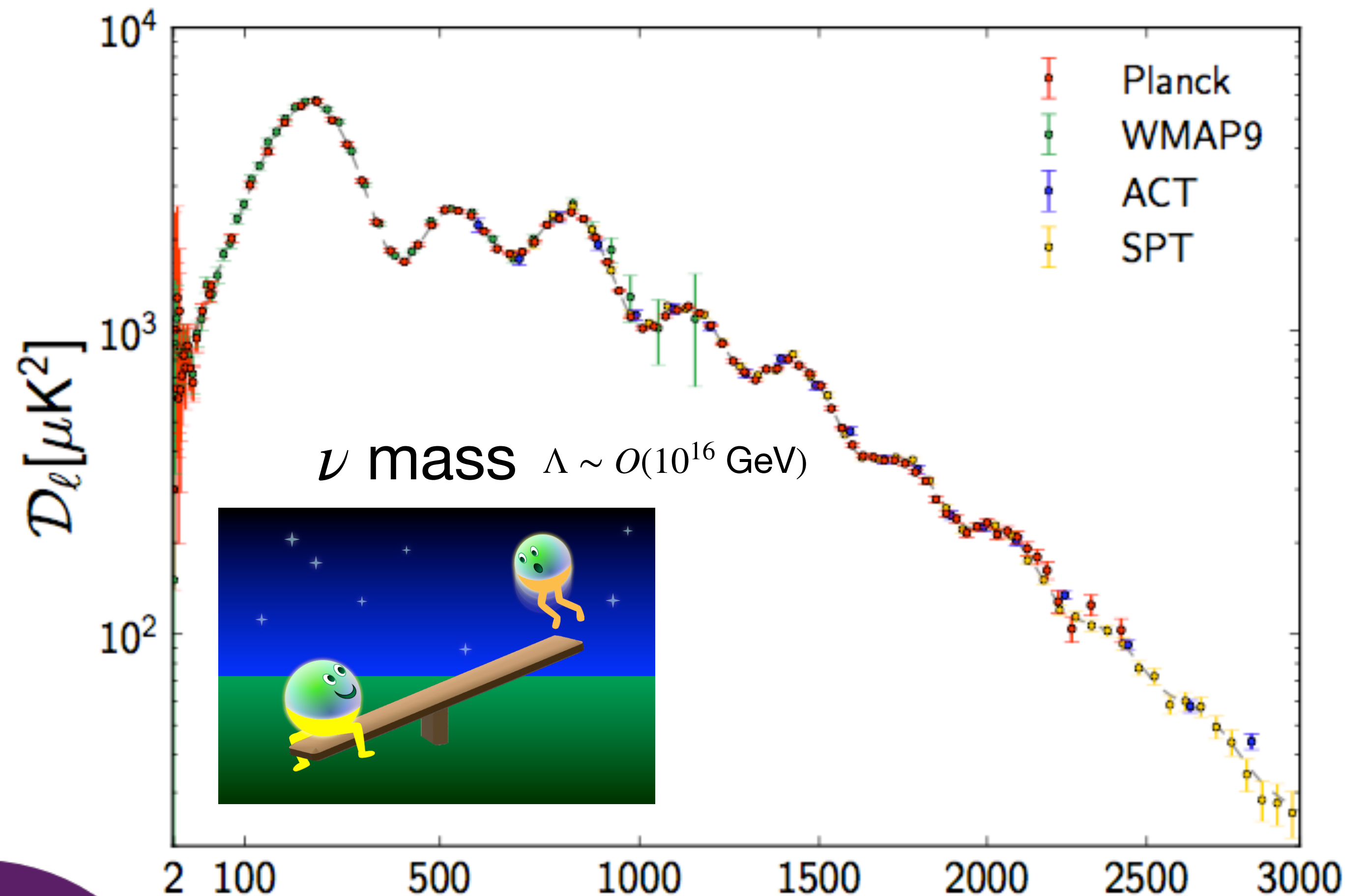
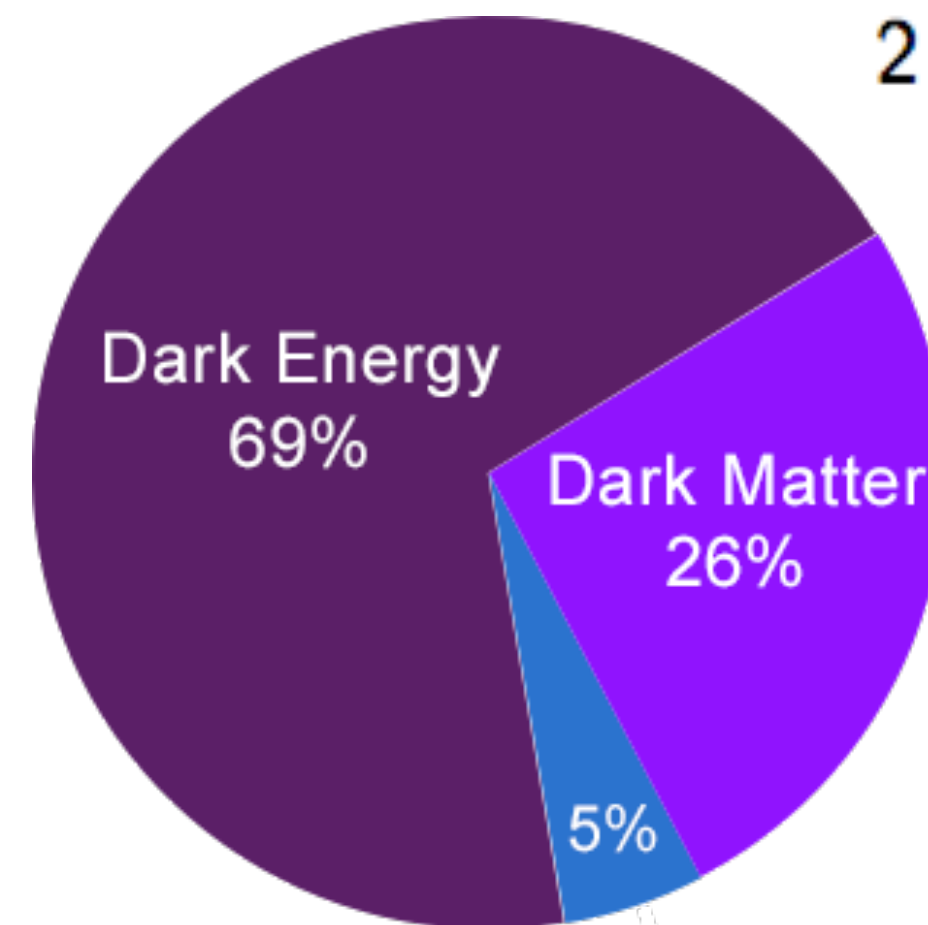
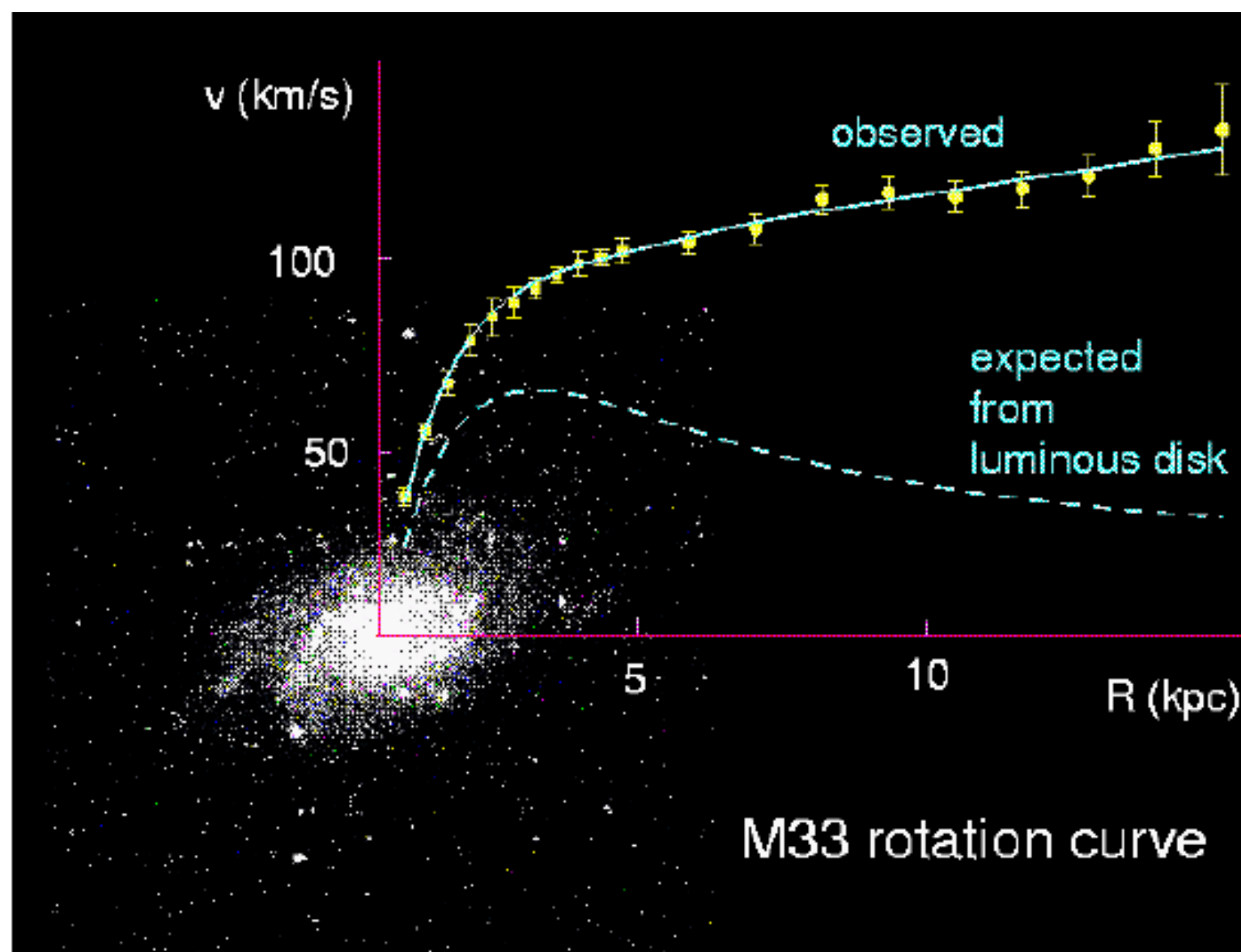


EPS 2025
July 7
Marseille, France
Sam Bein
pronouns: he/him

The known unknowns



Dark matter



Gravity

$\Lambda \sim O(10^{18} \text{ GeV})$

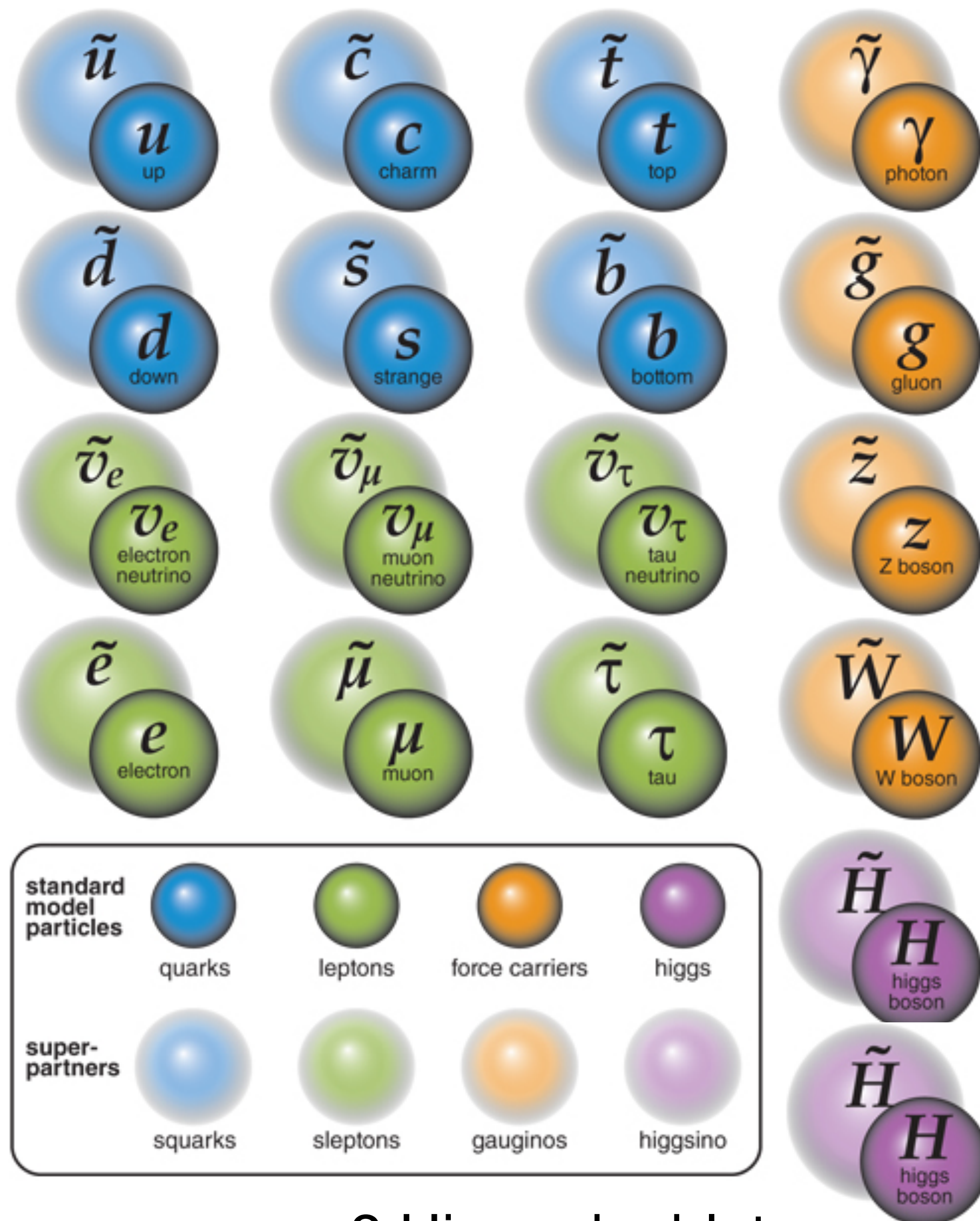


Hierarchy problem

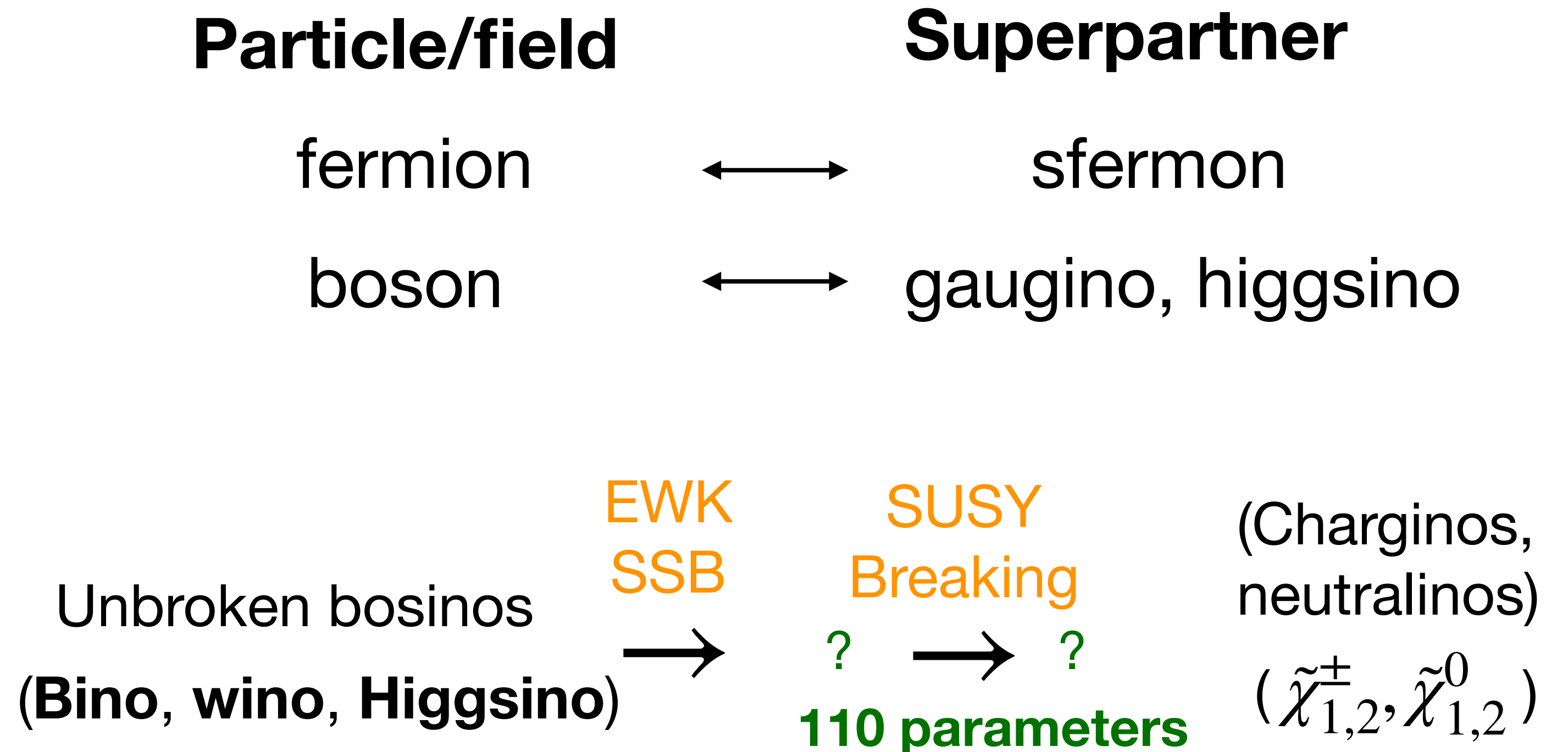
$$\begin{array}{ccc} \text{small} & \text{huge} & \text{huge} \\ \downarrow & \downarrow & \downarrow \\ m_H^2 & = & \mu_0^2 + \sum_{SM}^{\Lambda} \Delta m_H^2 \end{array}$$

Unexplained cancelations

Minimal supersymmetric standard model (MSSM) - 1981



2 Higgs doublets



R-parity

$$\rightarrow \tilde{\chi}_1^0$$

dark matter candidate

and a stable proton

~~Hierarchy problem~~

$$m_H^2 = \mu_0^2 + \sum_{SM} \Delta m_H^2$$

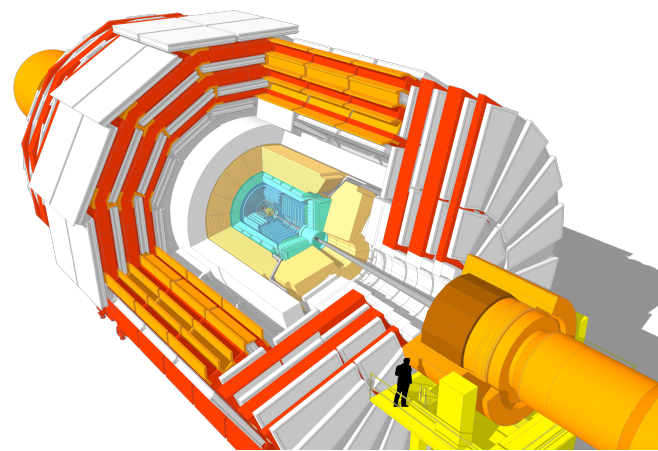
small small small

Explained cancelations! 3

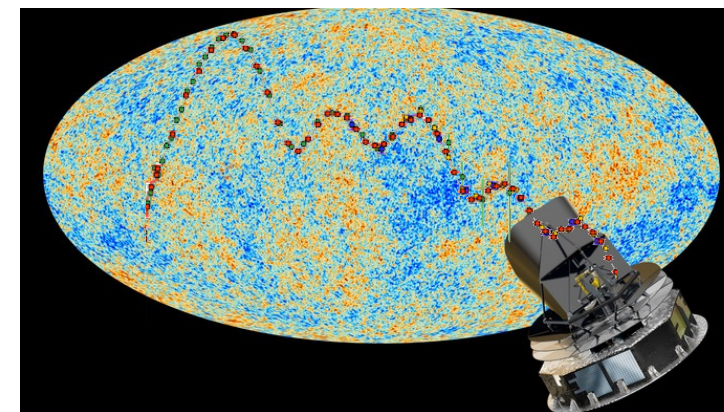
Compressed phase space special in MSSM

SUS-24-004

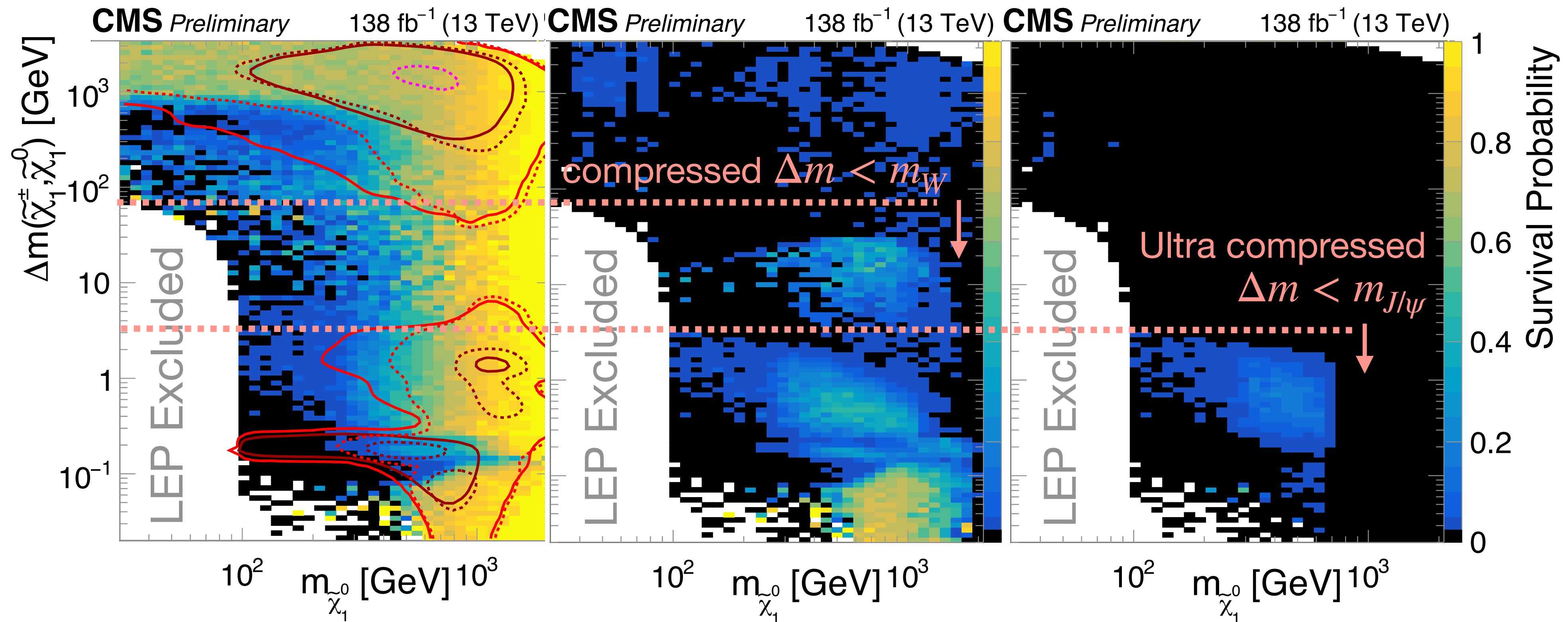
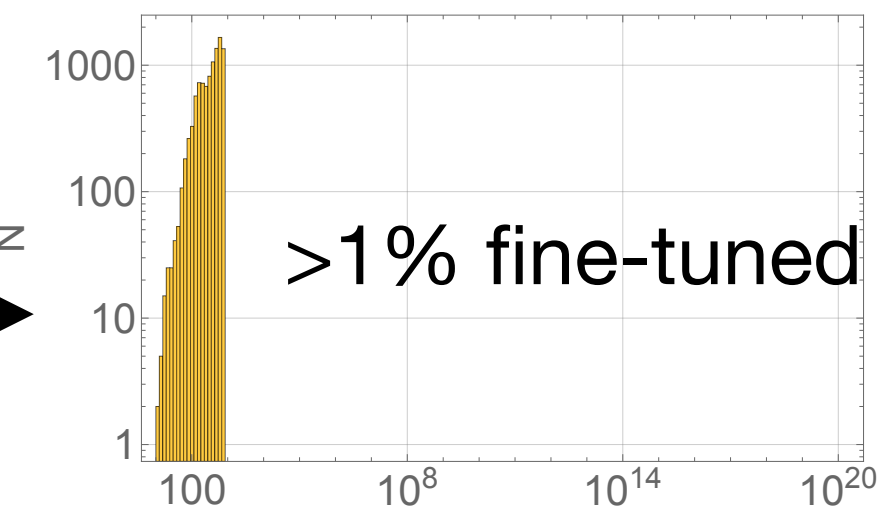
CMS Searches



+DM data



+Naturalness

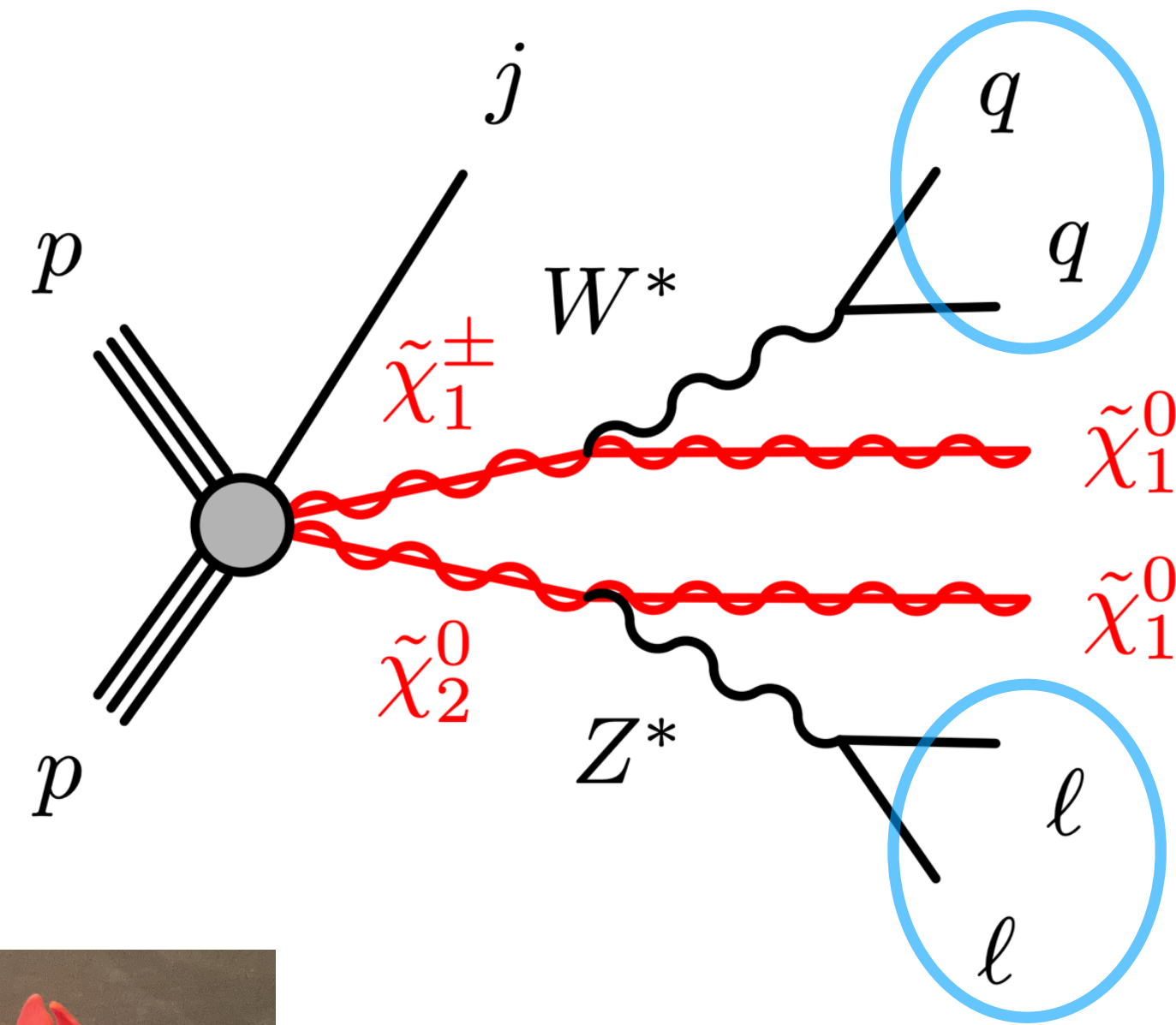


500k random MSSM scan

Black color: all models excluded

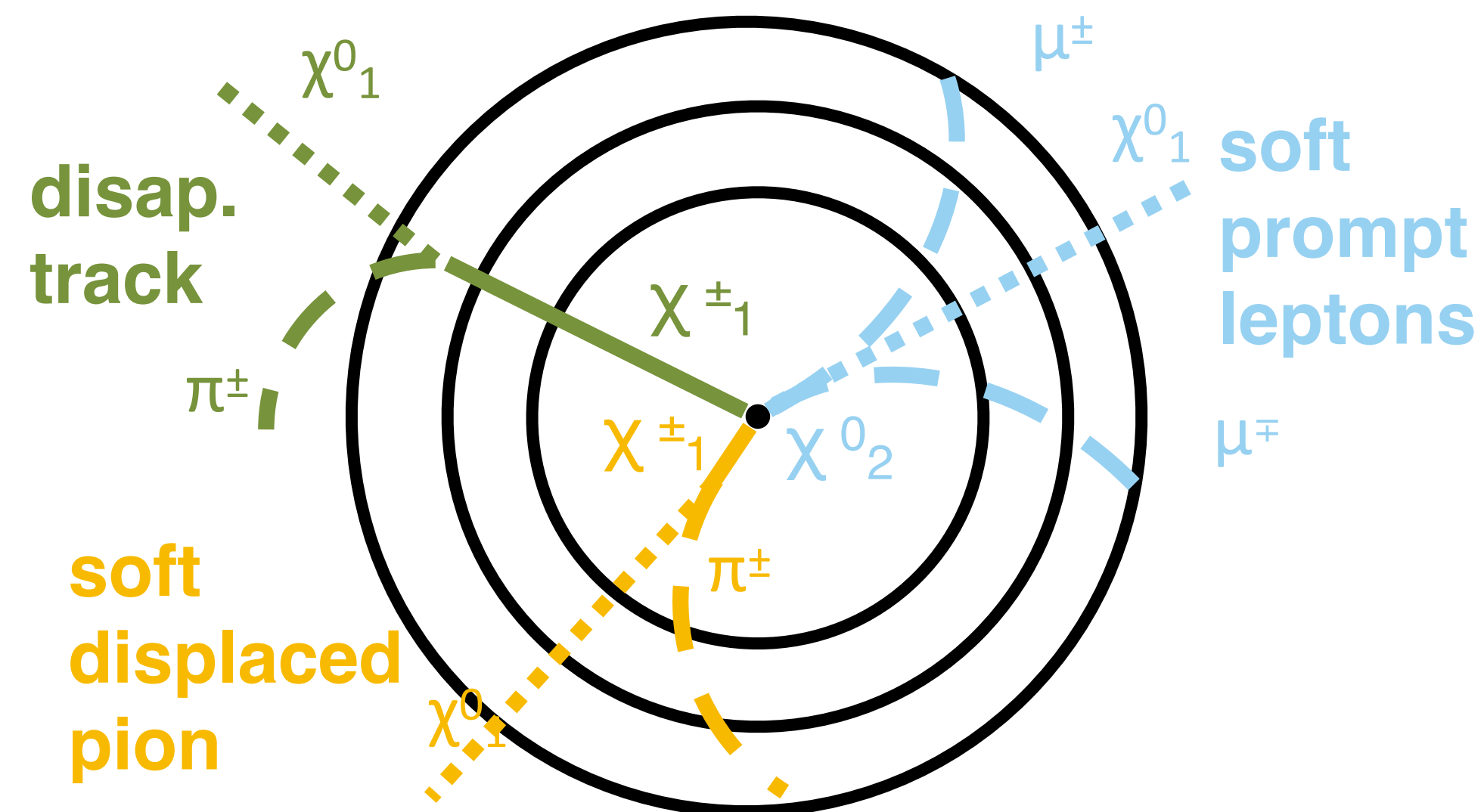
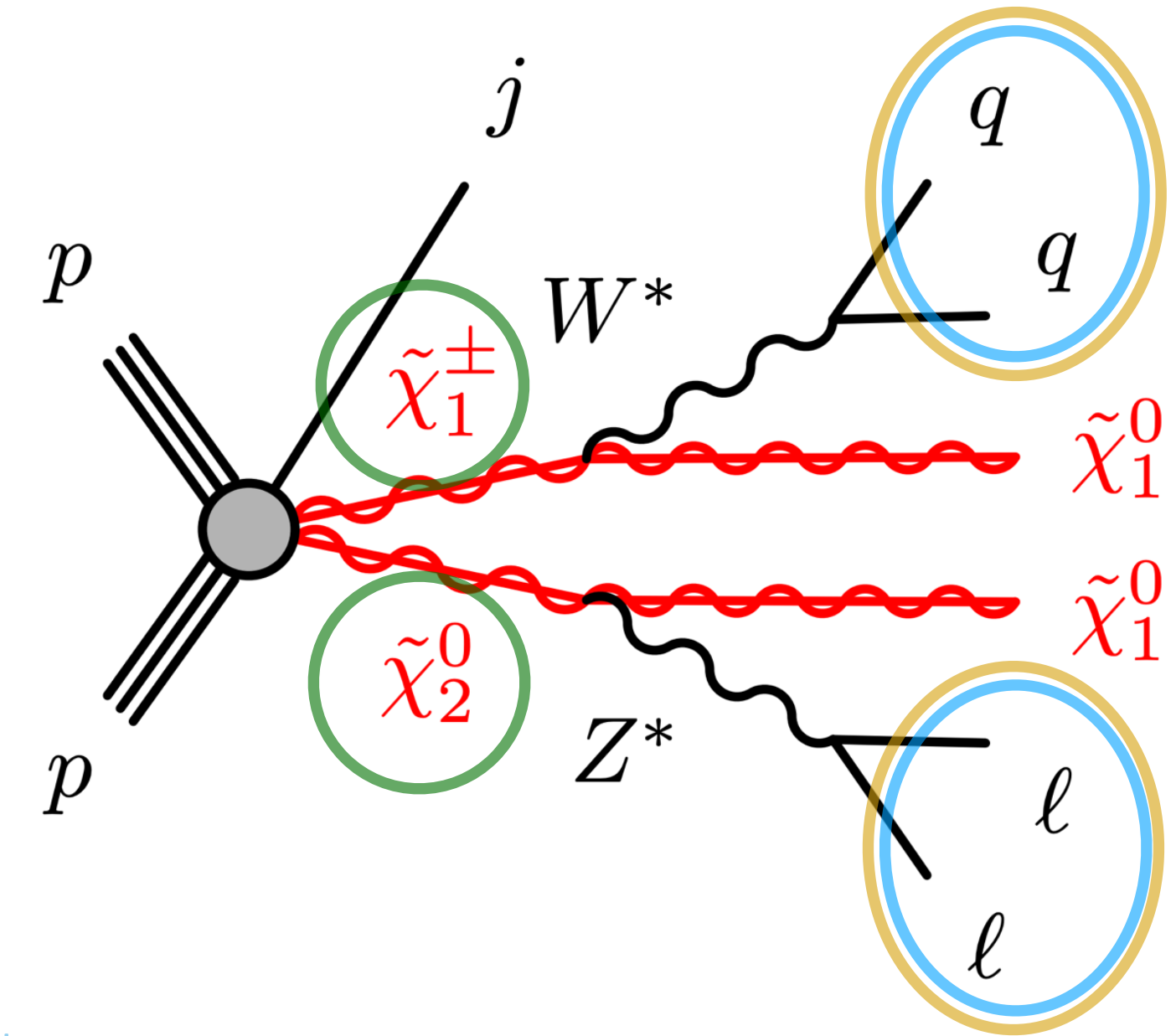
Yellow: all models survive

Compressed



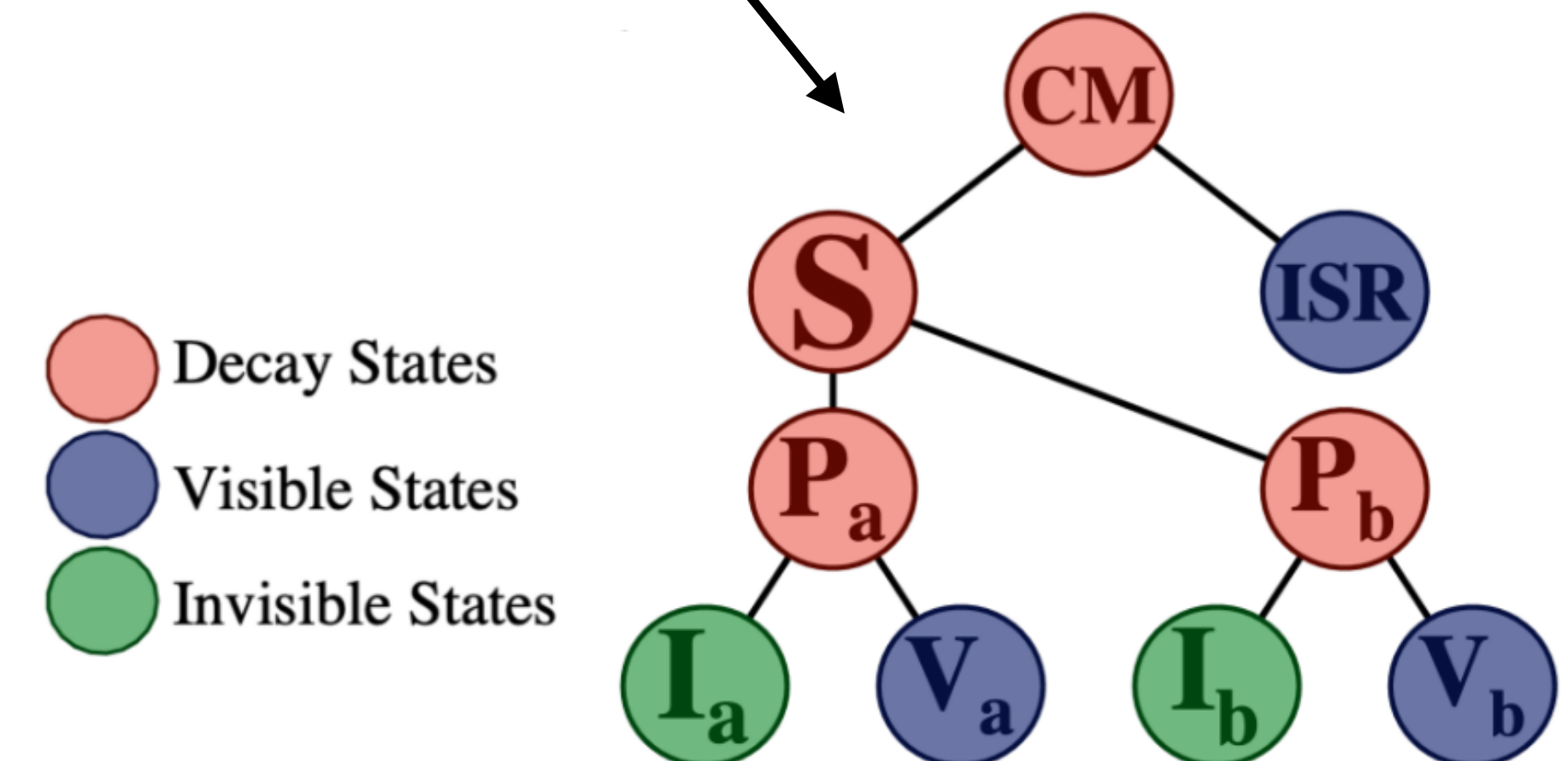
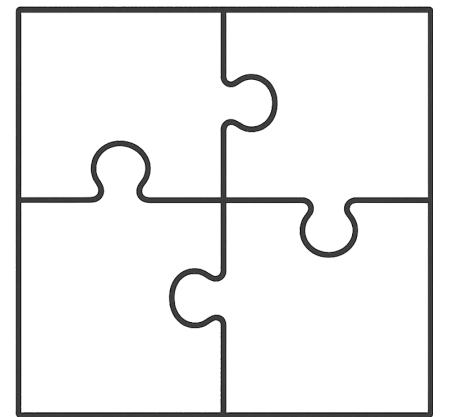
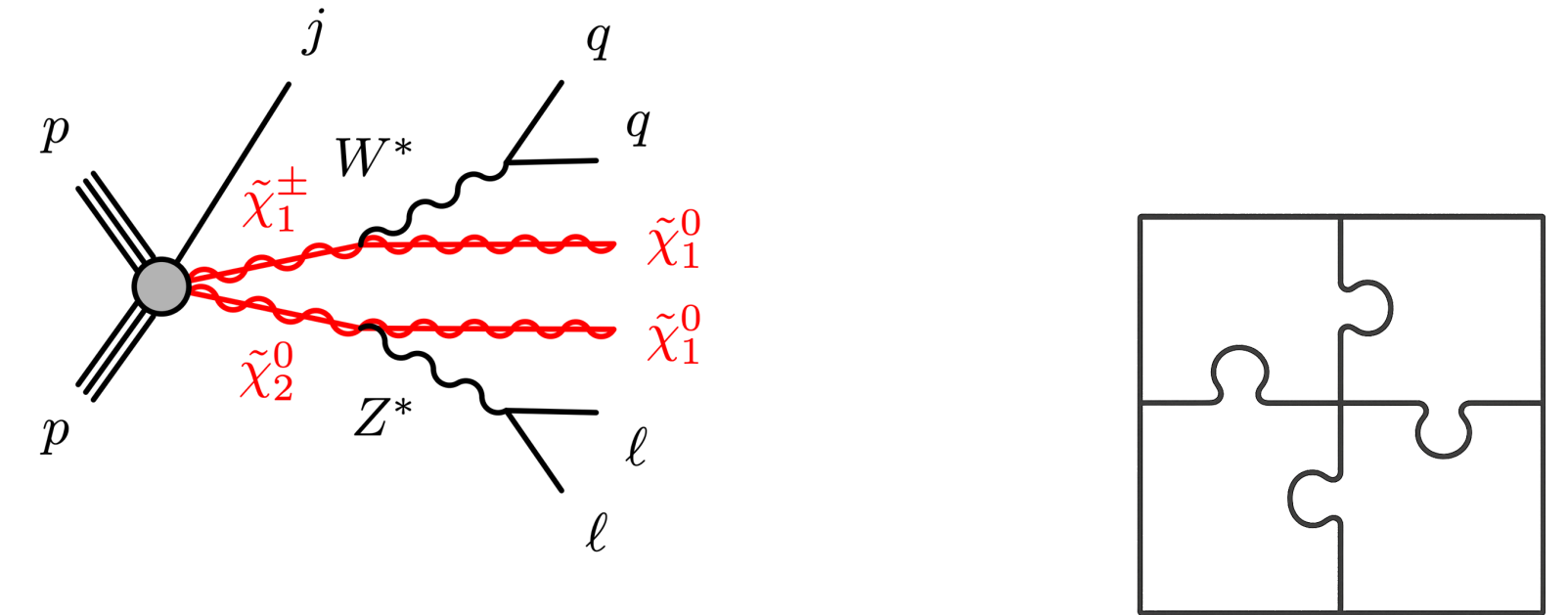
soft $p_T \sim \Delta m$
 semi-stable
 displaced

Ultra compressed



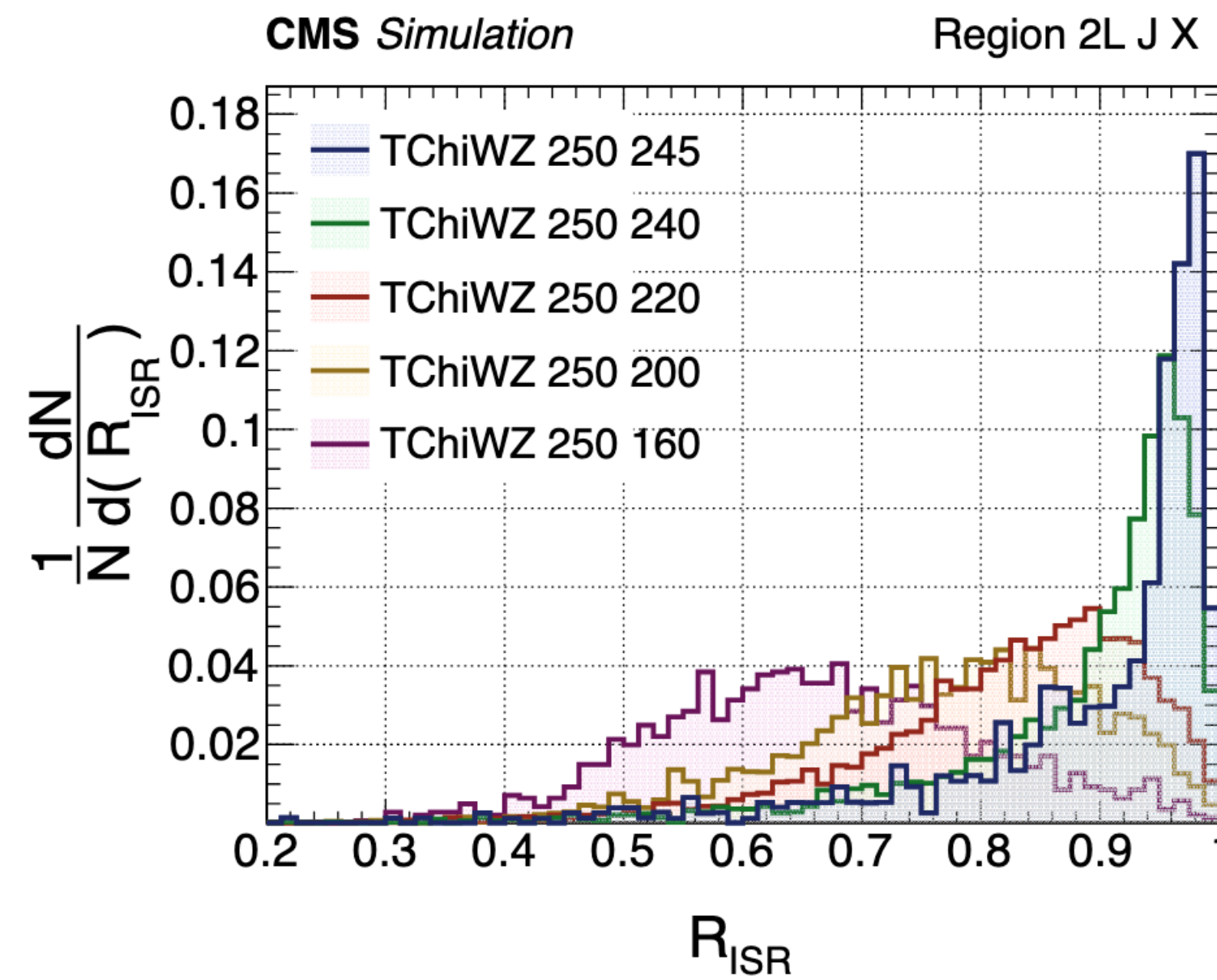
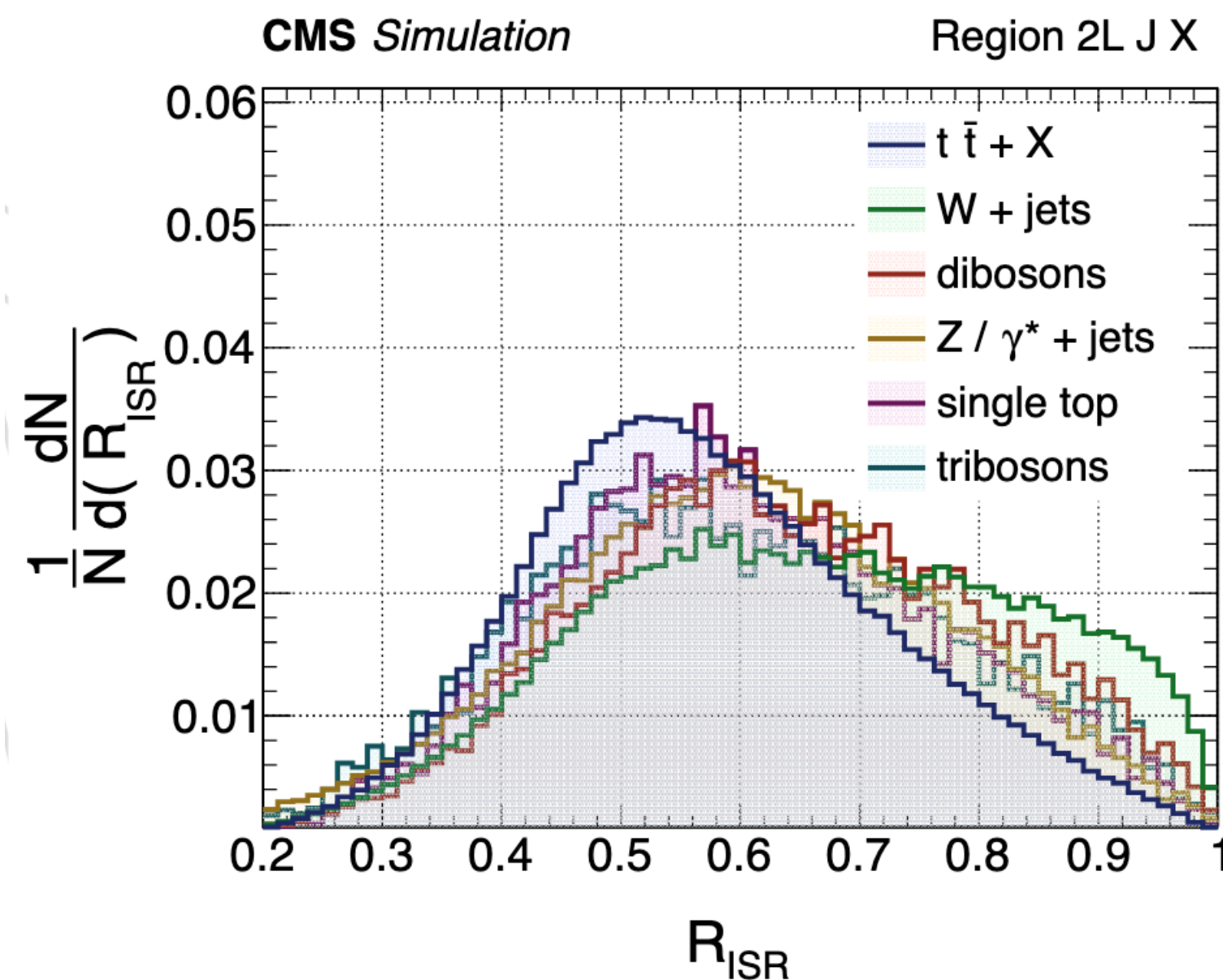
Compressed

- Recursive jigsaw reconstruction
- Comprehensive set of final states
 - All lepton multiplicities $\mu(e) p_T > 3(5) \text{ GeV}$
 - Jets, b-jets, secondary vertices
 - 1795 exclusive search bins



Each event: complete system is solved

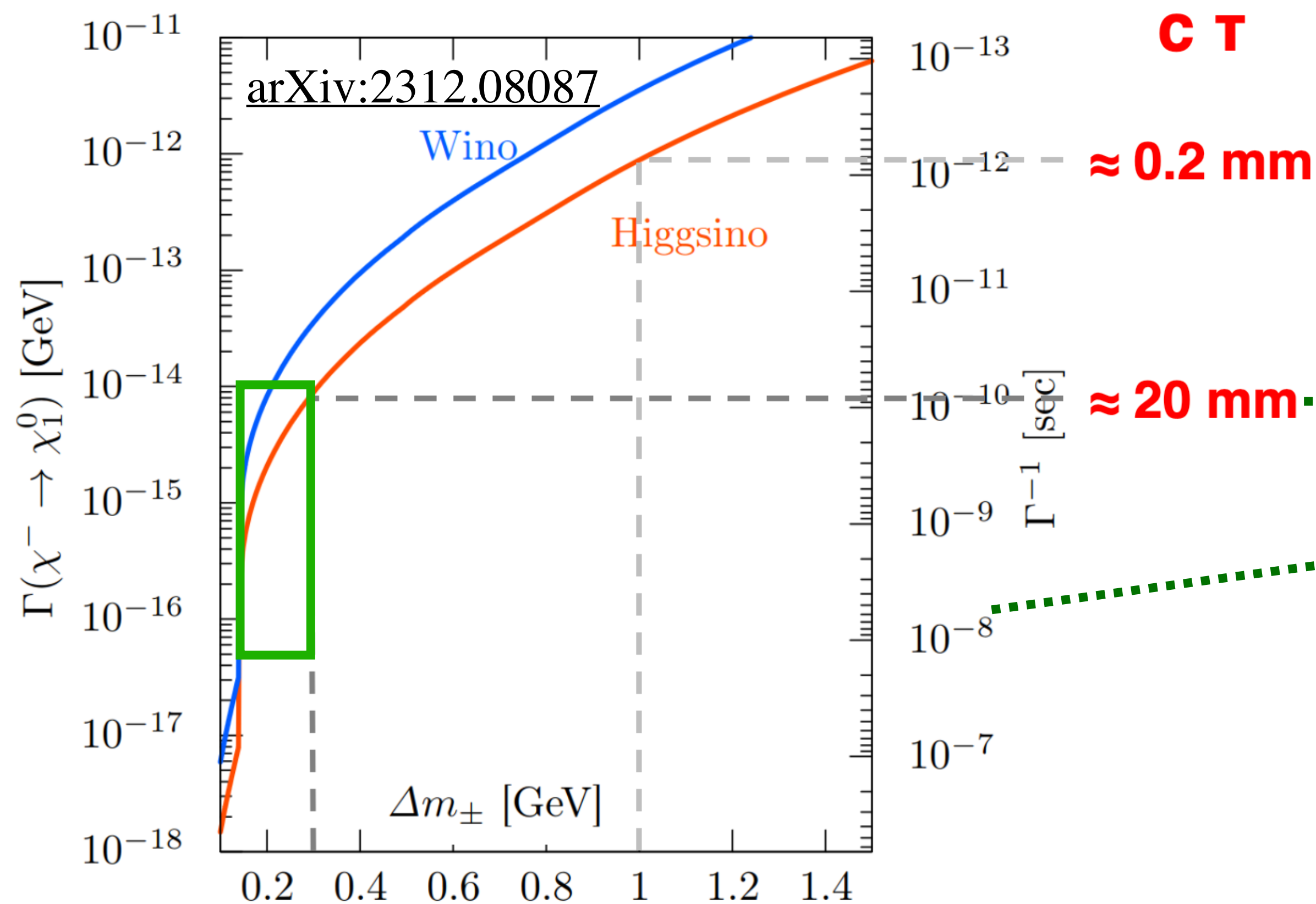
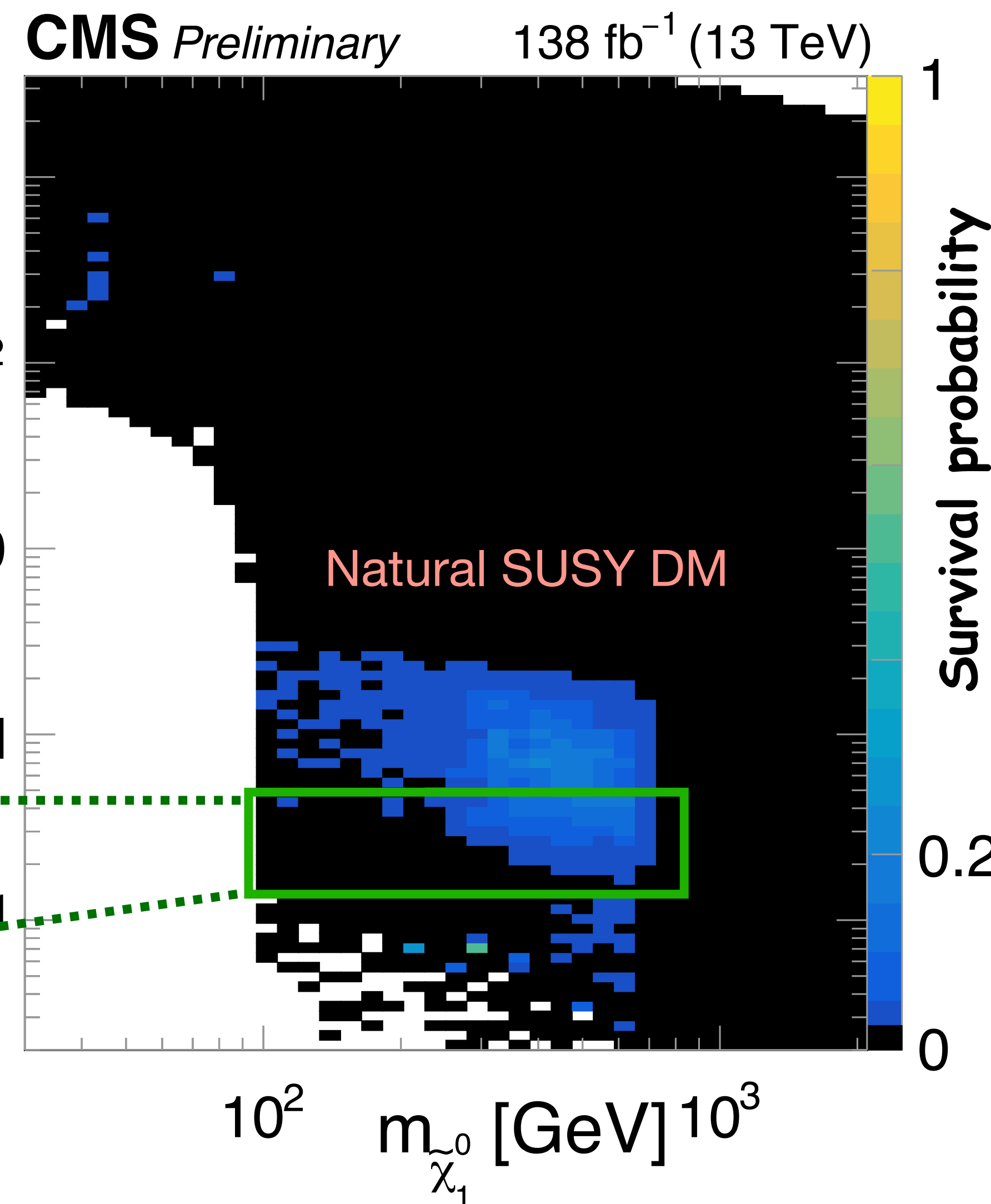
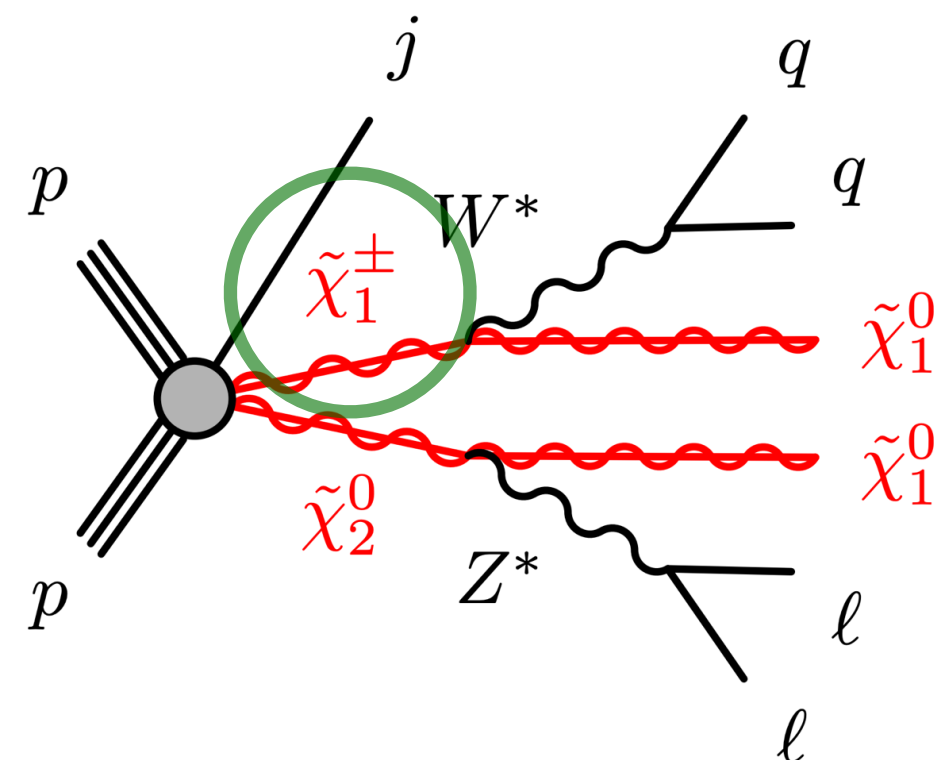
$$R_{\text{ISR}} = \frac{|\vec{p}_{\text{I}}^{\text{CM}} \cdot \hat{p}_{\text{ISR}}^{\text{CM}}|}{|\vec{p}_{\text{ISR}}^{\text{CM}}|} \sim \frac{m_{\text{I}}}{m_{\text{P}}}$$



Ultra compressed...from below

- $\tilde{\chi}_1^+$ produced at the pp vertex...

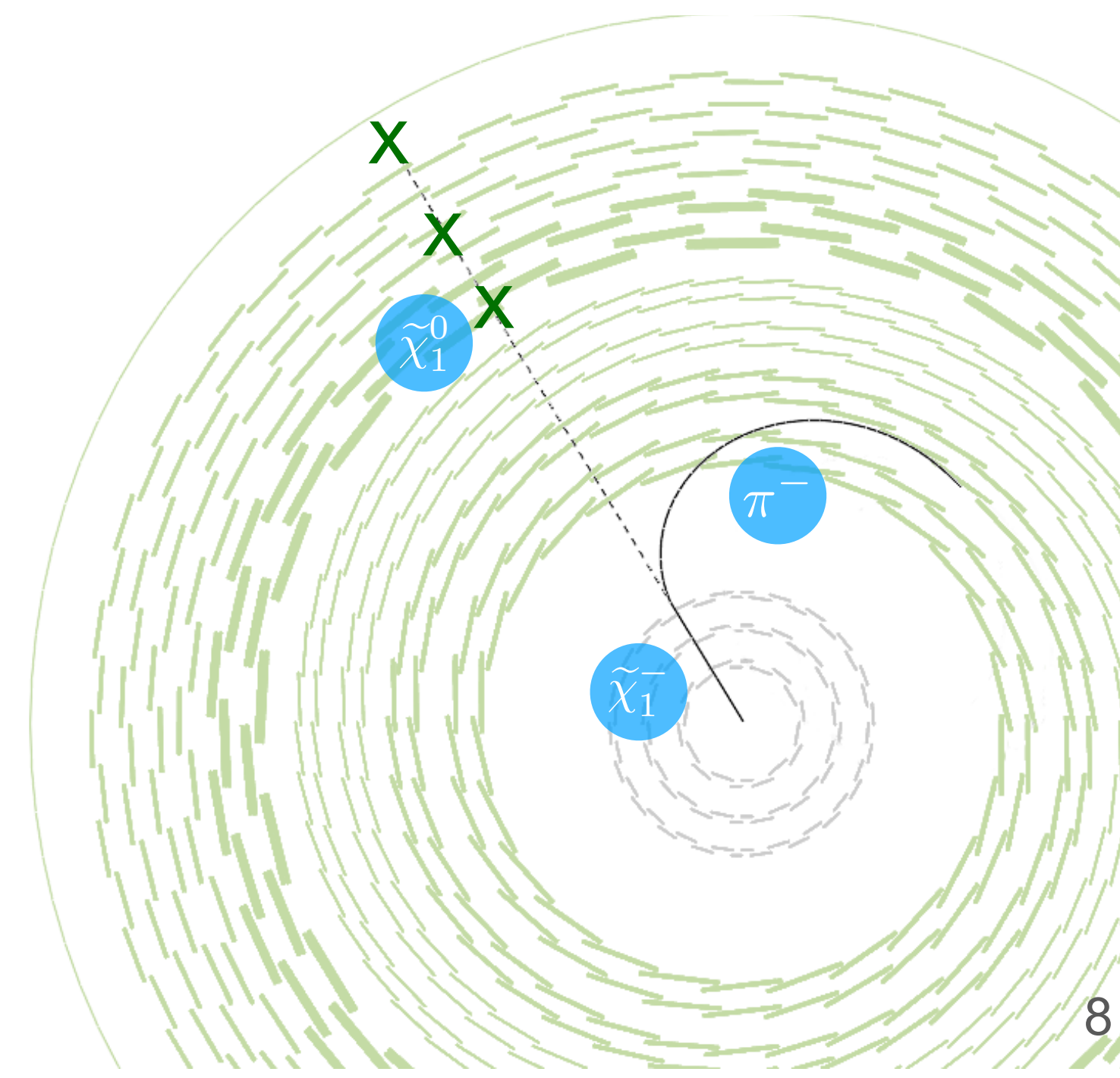
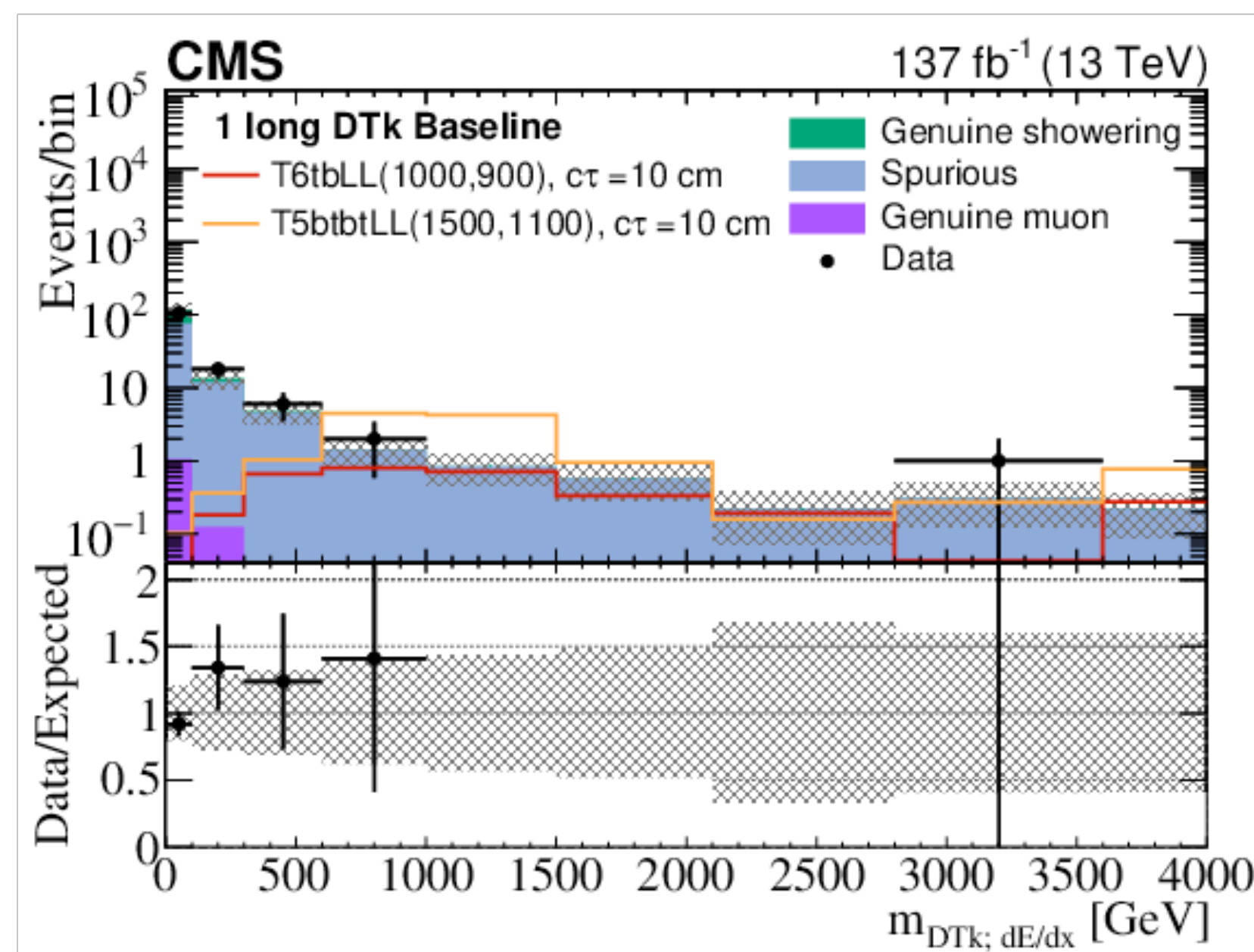
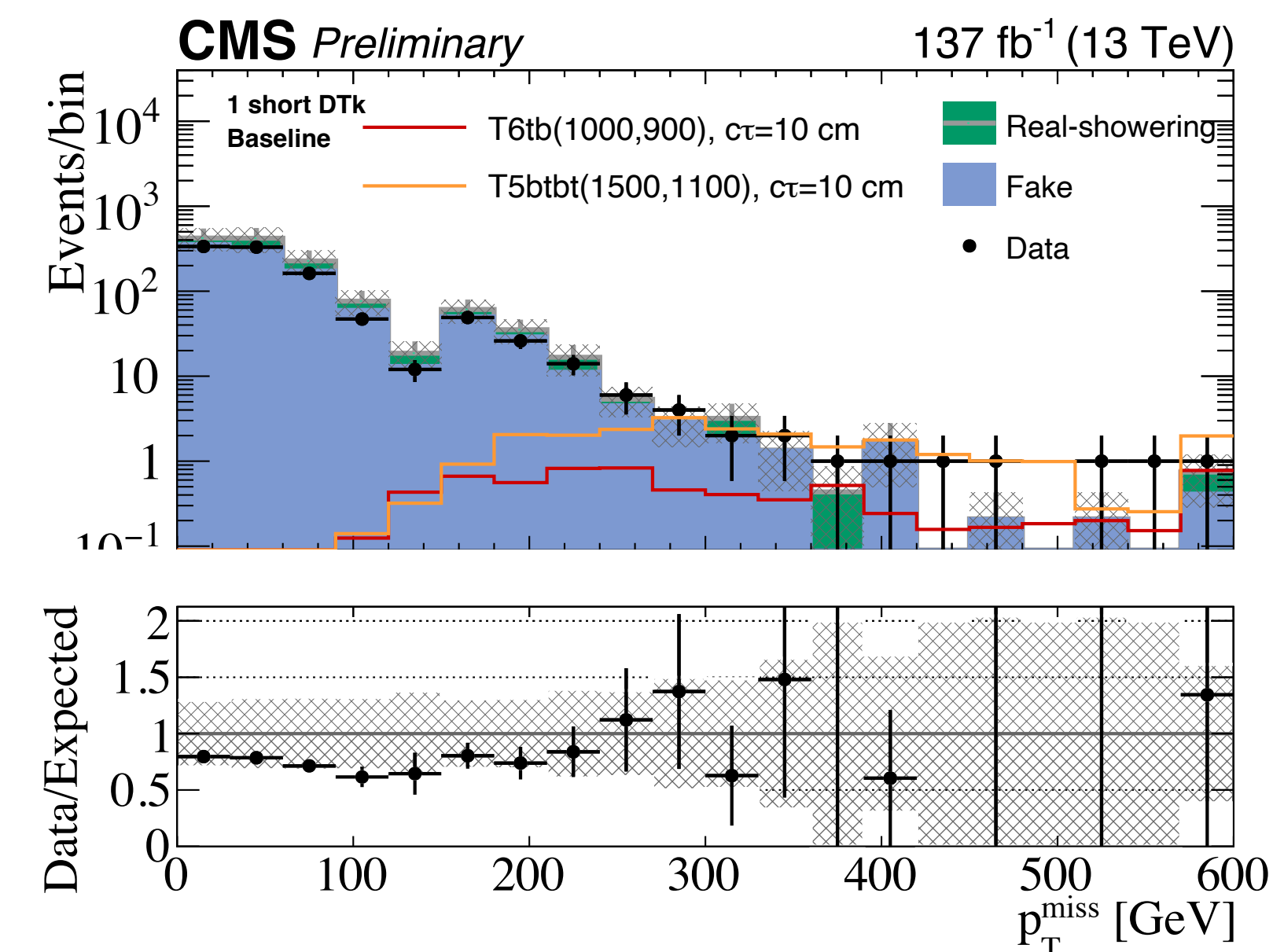
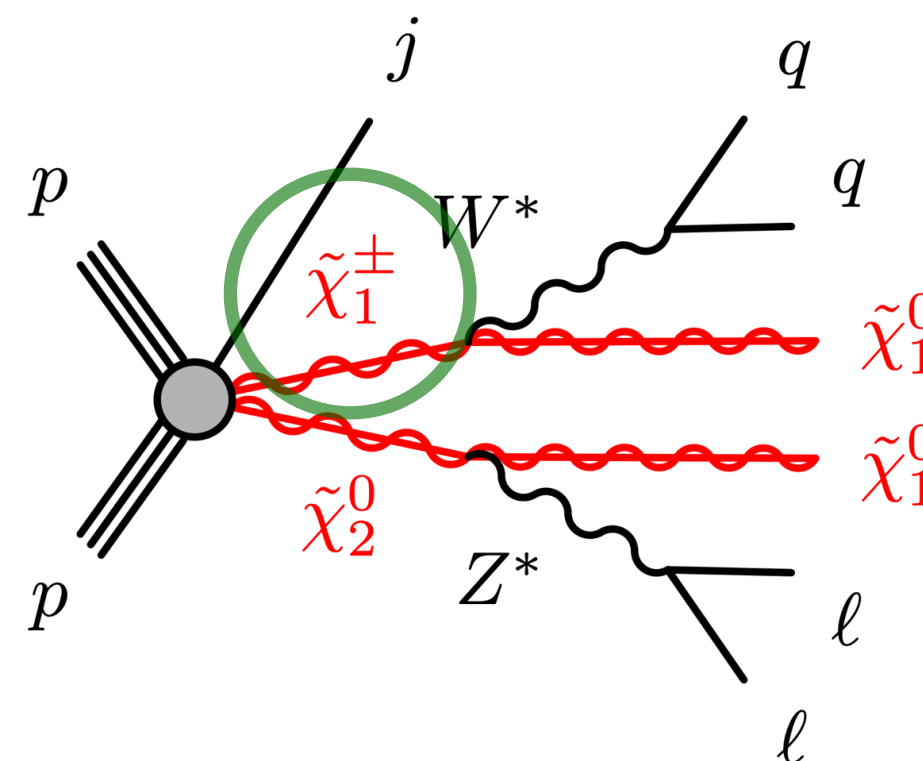
...traverses into tracker and disappears



Ultra compressed...from below

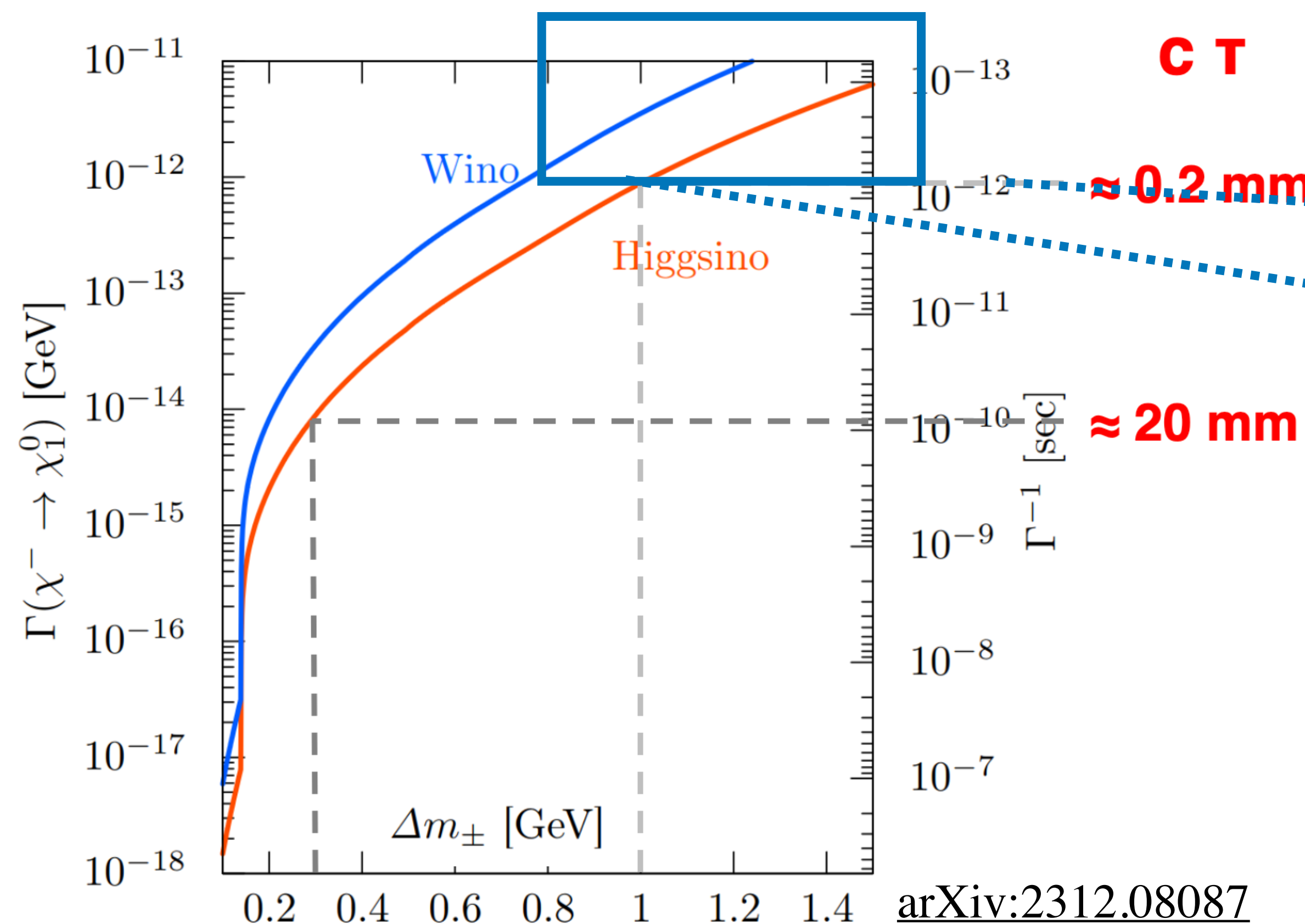
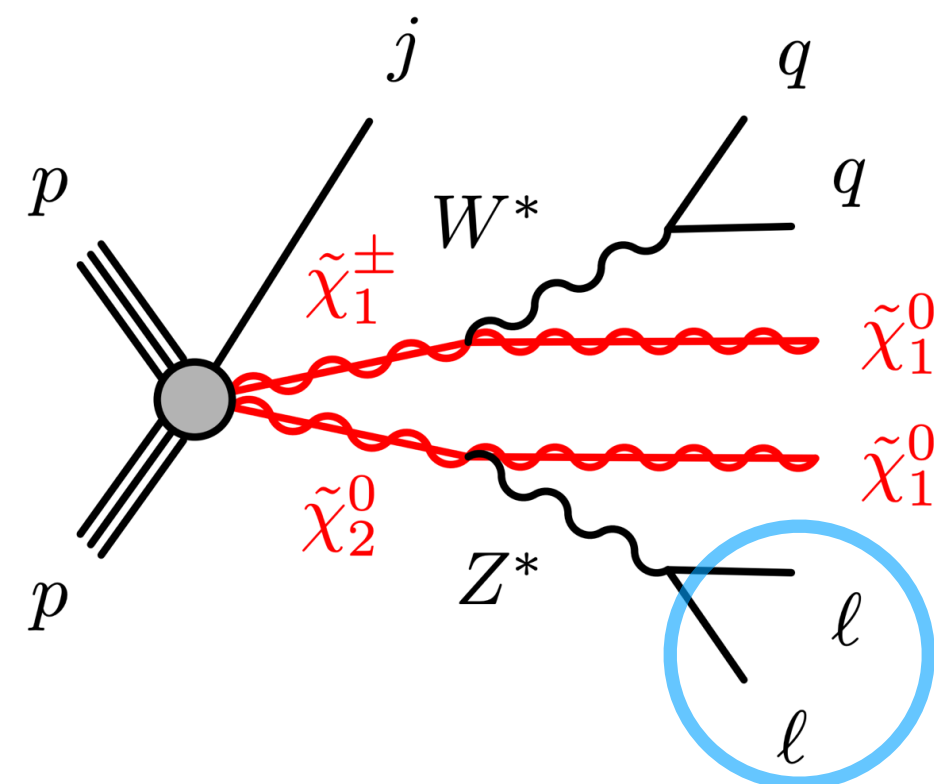
Reconstruct $\tilde{\chi}_1^\pm$ as **disappearing track**

- ≥ 2 **missing outer tracker hits**
- Optimized BDT for short tracks, long track separately
- Validate signal with shortened μ 's
- dE/dx calibrated with $\Lambda^0 \rightarrow (\text{soft}) p^\pm \pi^\mp$

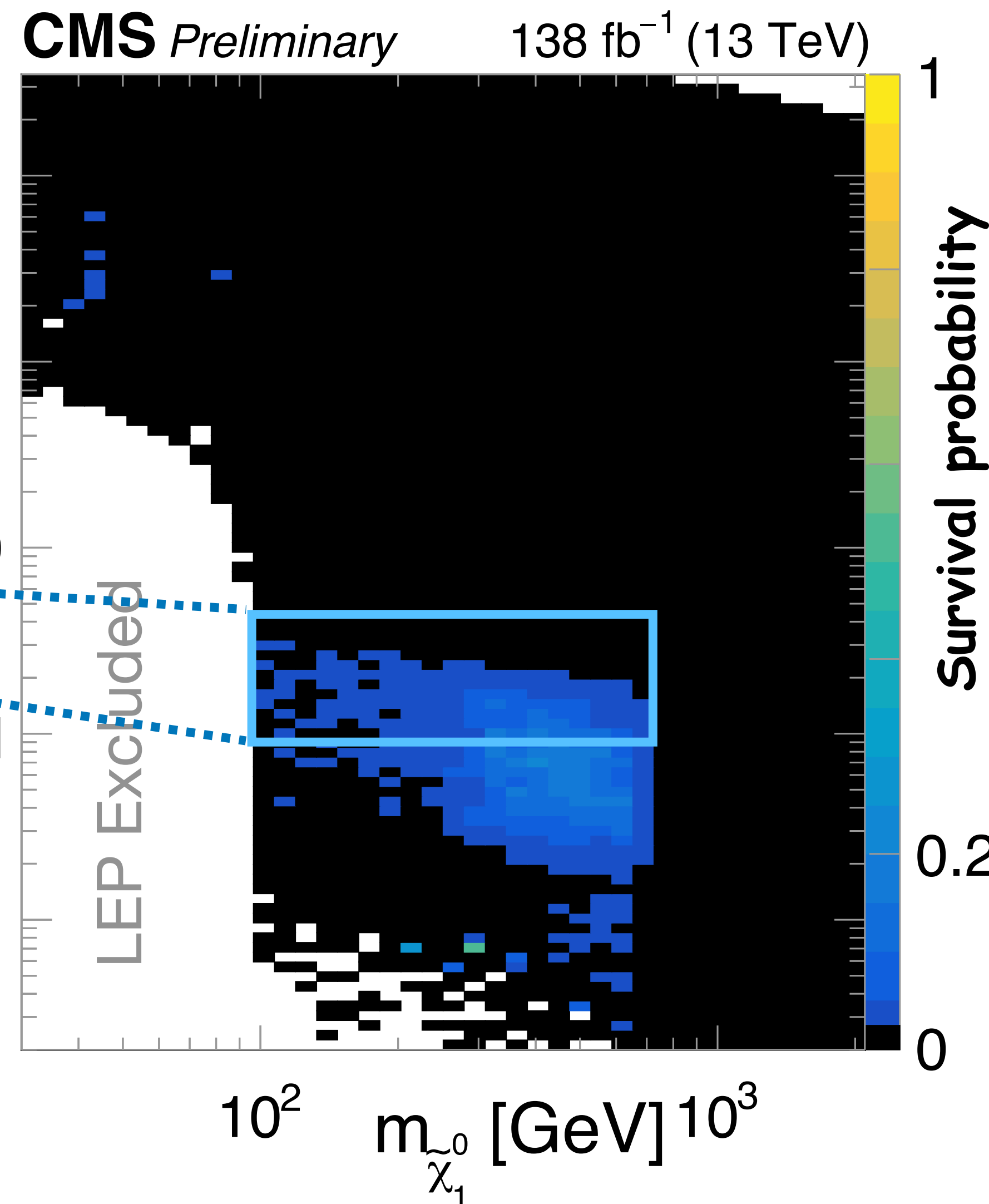


Ultra compressed...from above

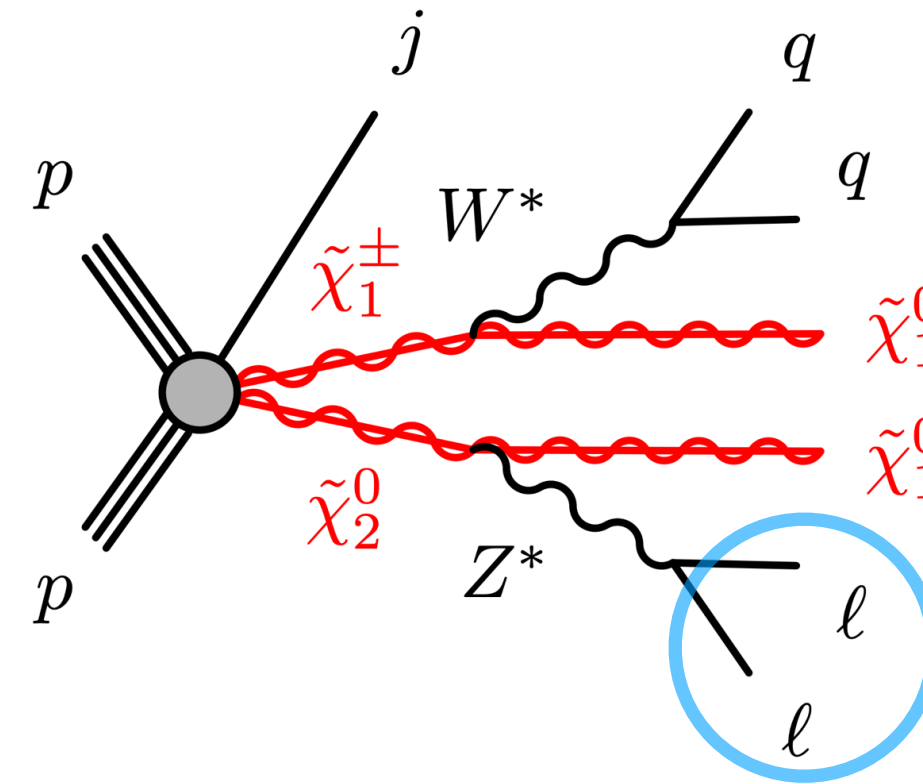
- $\tilde{\chi}_2^0$ produced and decay at the PV
- Two leptons from $\tilde{\chi}_2^0 \rightarrow \ell\ell\tilde{\chi}_1^0$



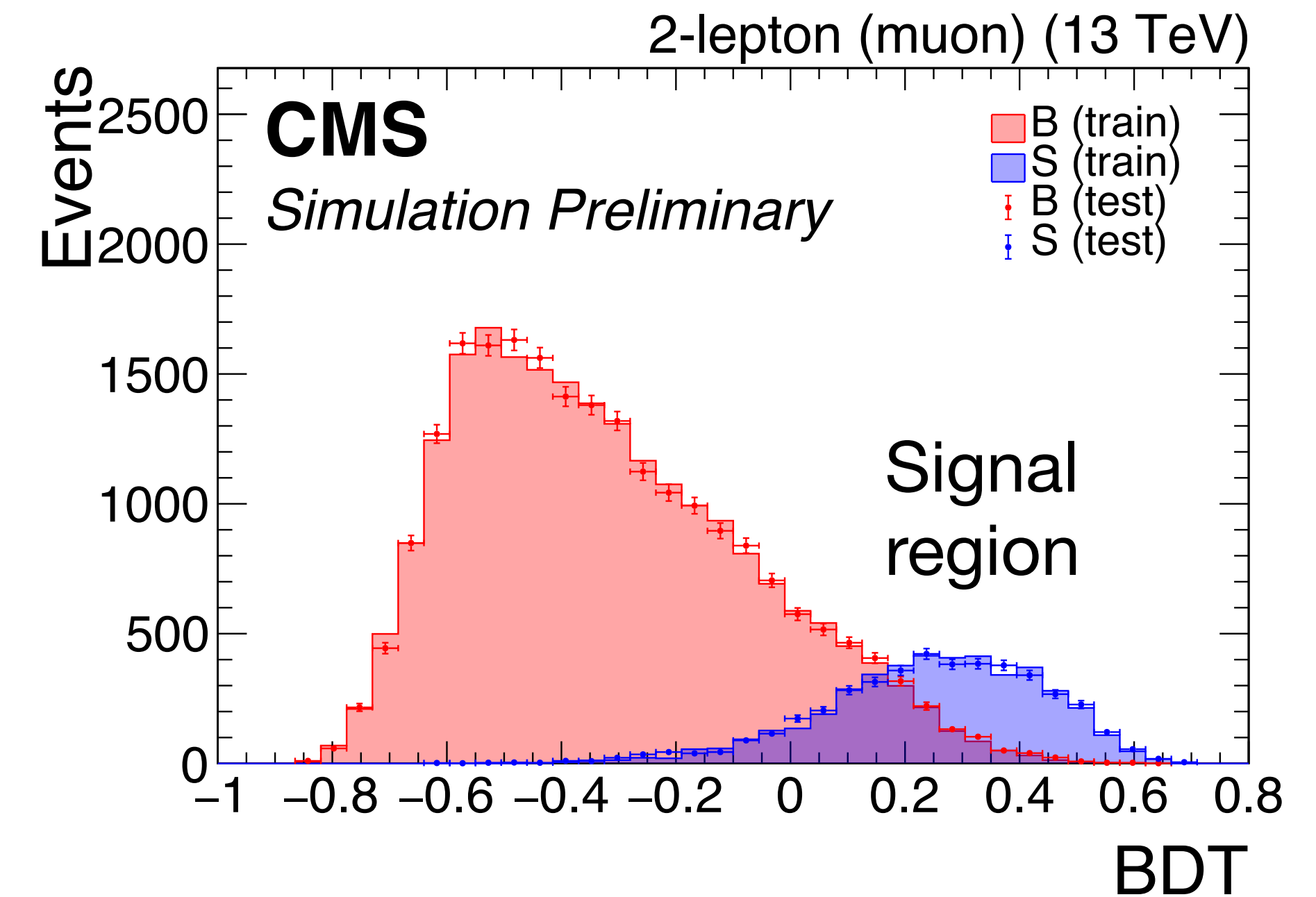
$$\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$$



Ultra compressed...from above

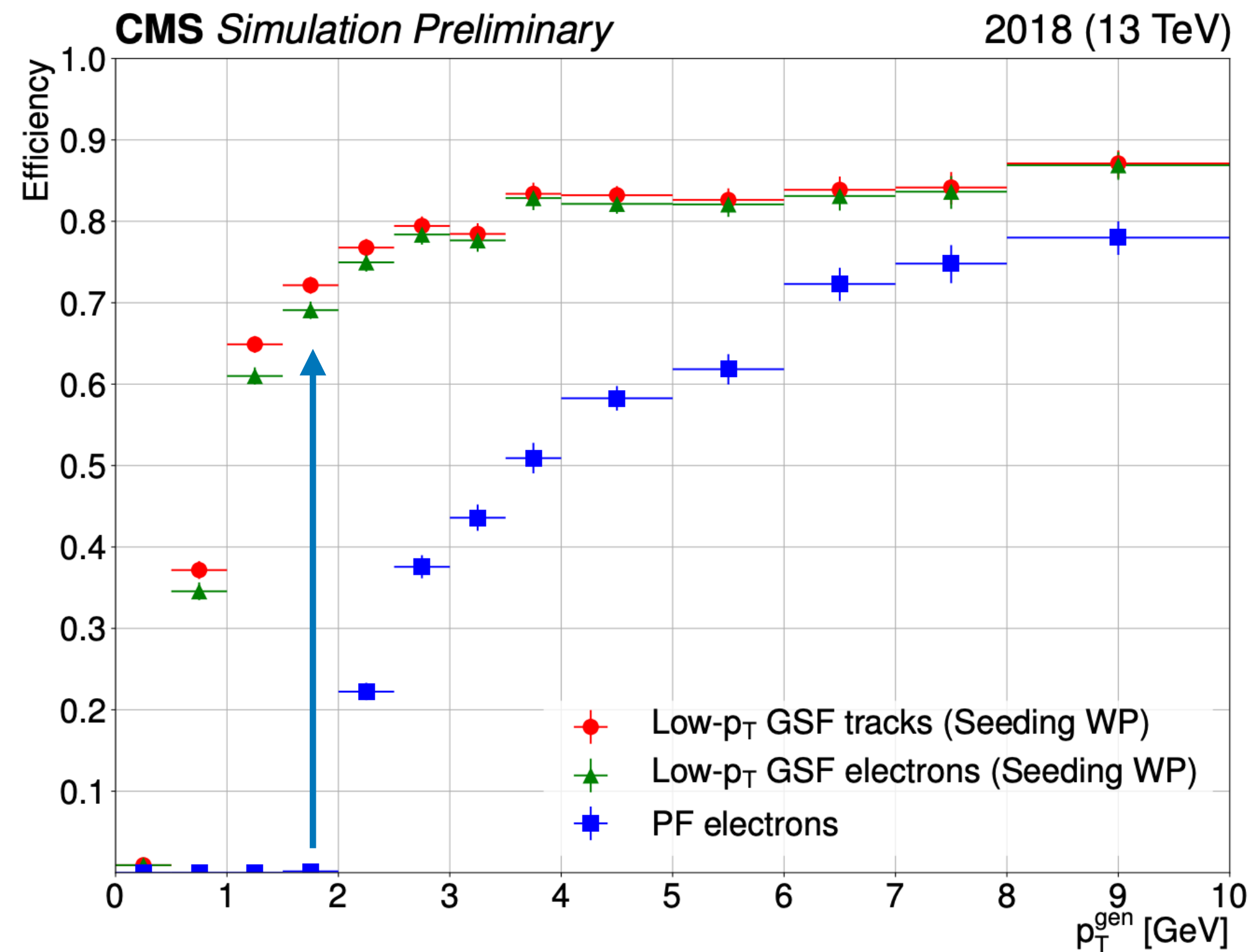


- 2 soft muons with $p_T < 3$ GeV **OR** $\Delta R < 0.3$
- Pairs of track+lepton, lepton=(e, μ)
- BDTs for track picking **and** event selection
- $p_{T_t}, \phi_t, \eta_t, \Delta\eta(j_1, t), \Delta R(t, \ell), m_{T_t}, p_{T_\ell}, \phi_\ell, \eta_\ell, \Delta\phi(H_T^{\text{miss}}, t), m_{\ell_t}$



Ultra compressed...from above

- Largely inspired by LHCb results, CMS invested strongly in
 - Scouting, data parking, offline reconstruction - *ultra soft electron tag*



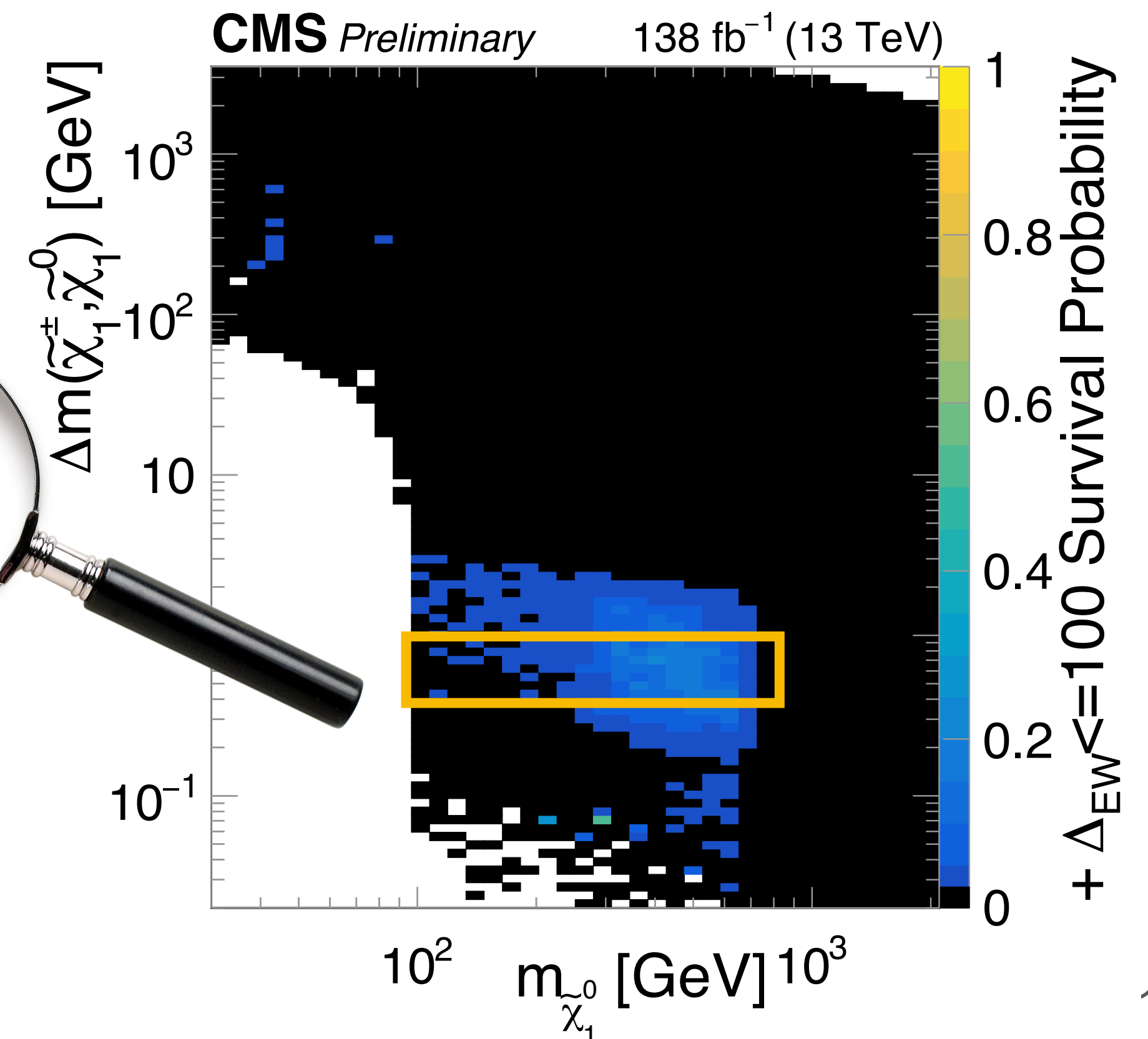
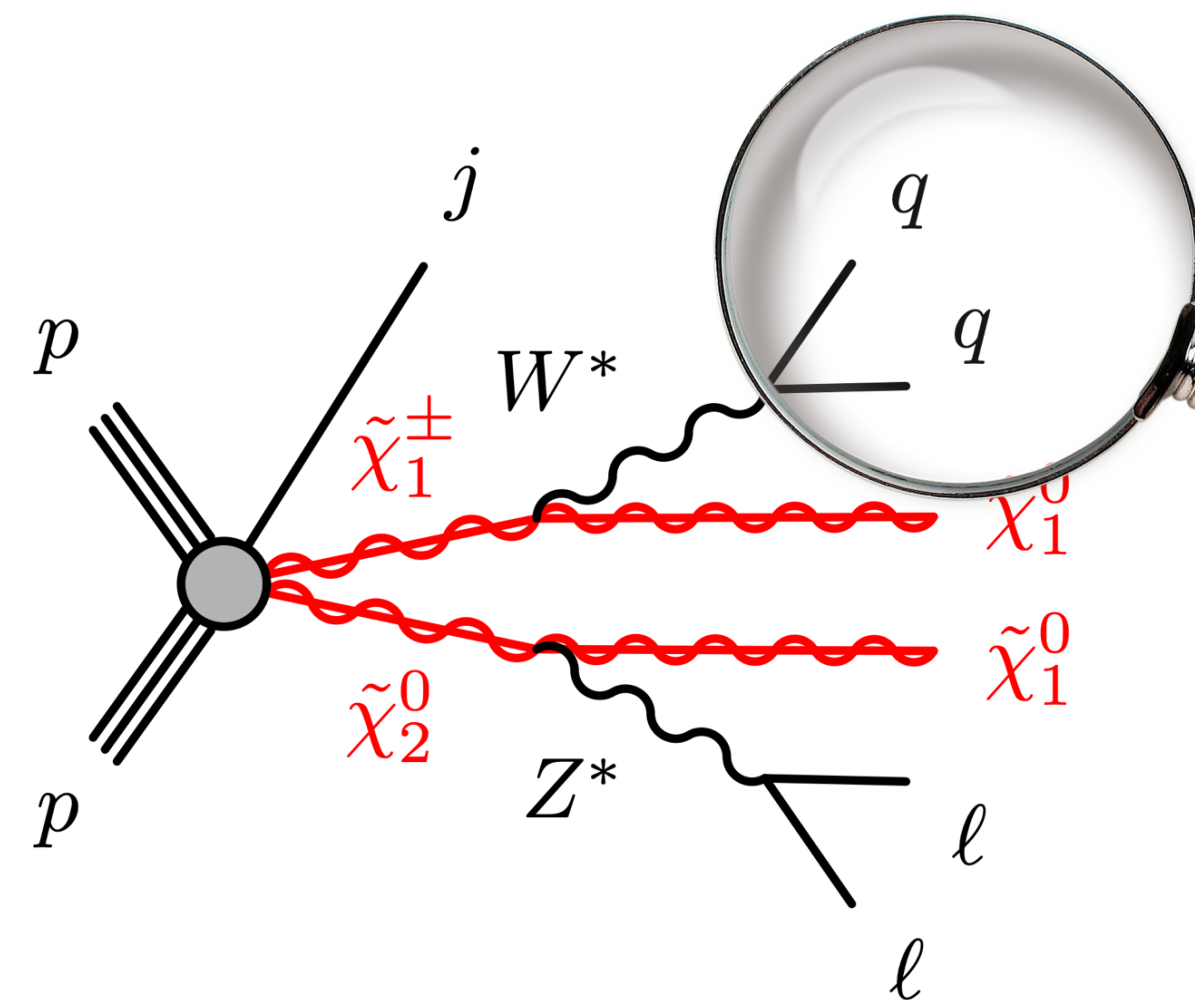
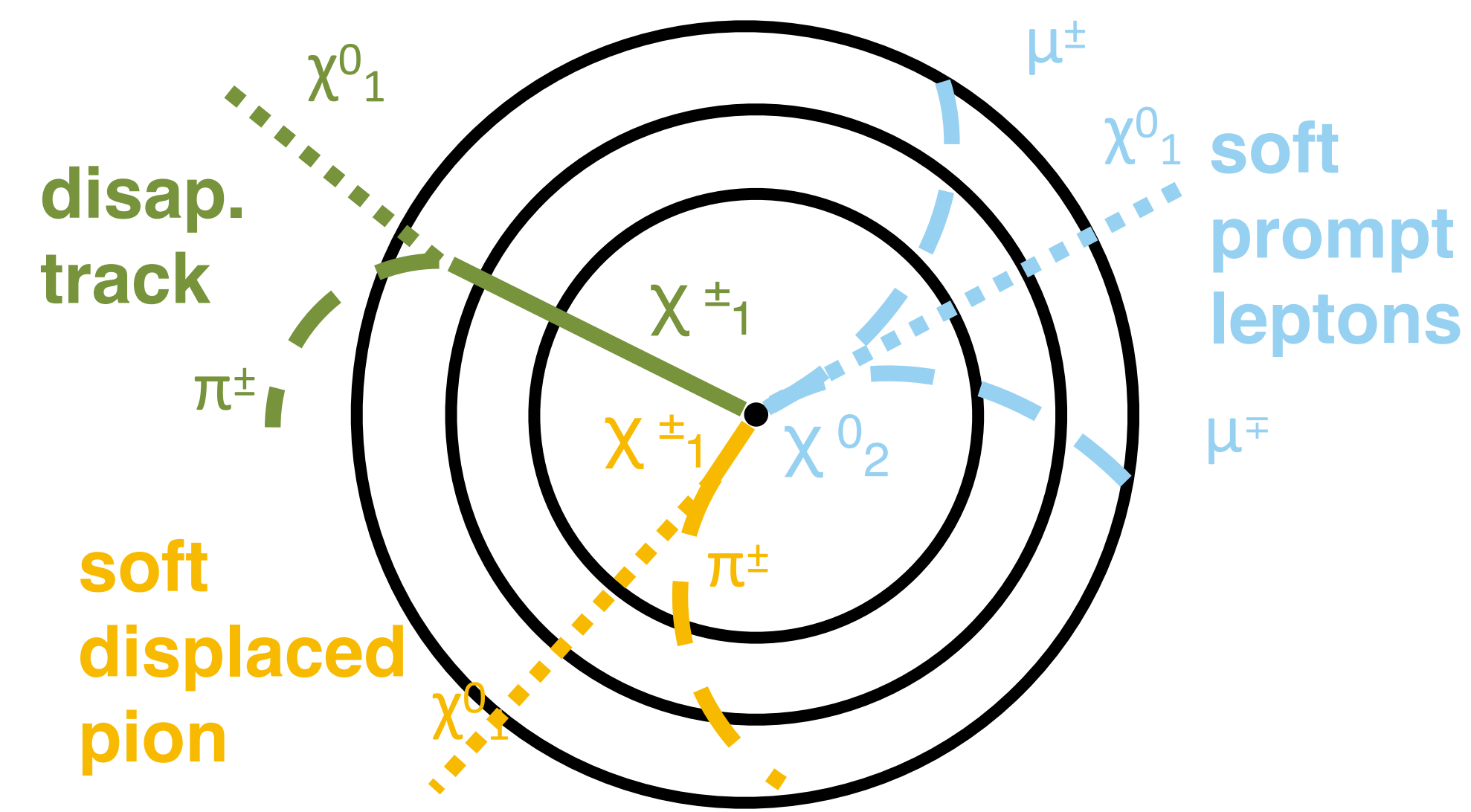
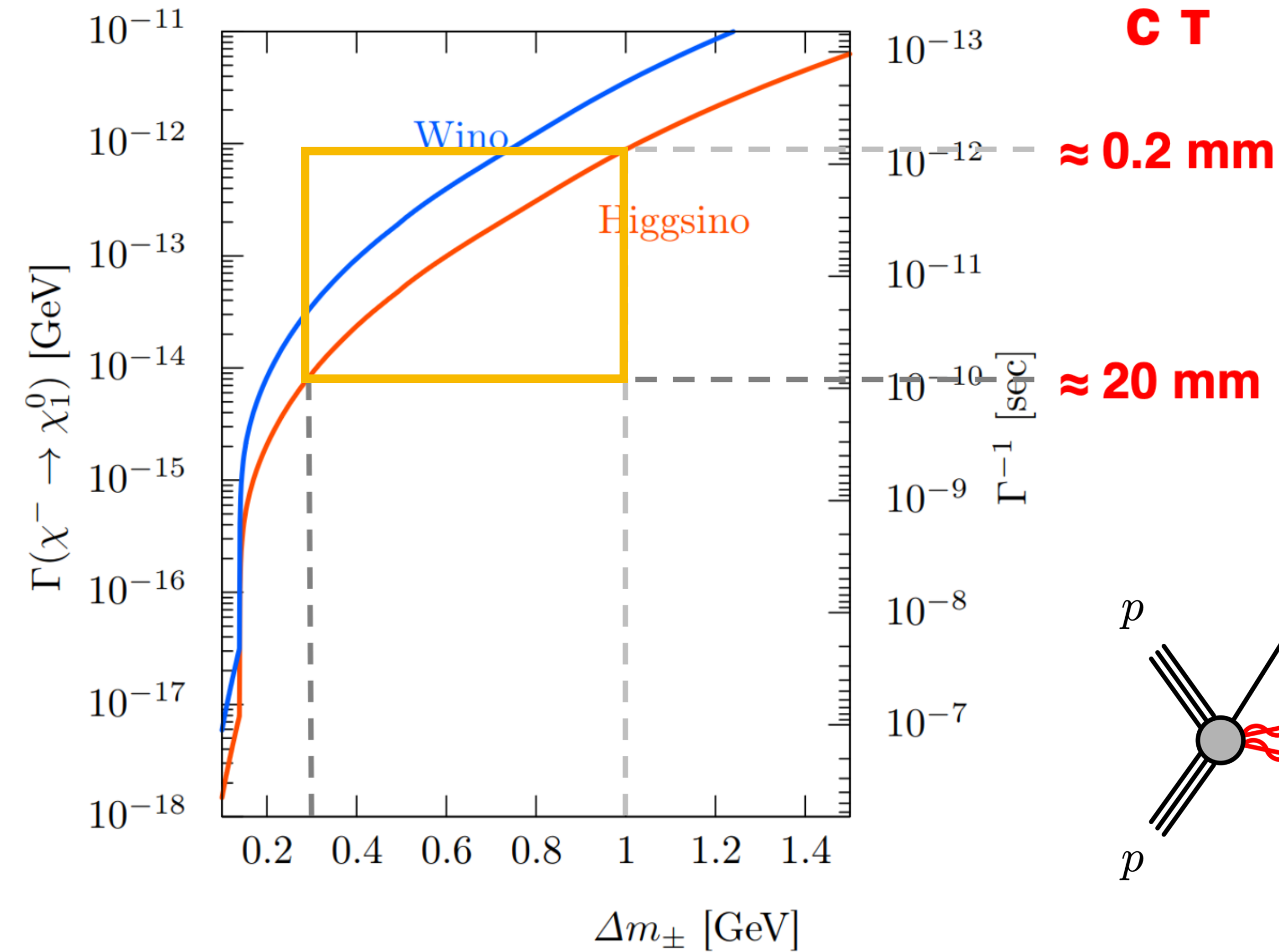
EPJ Web Vol. 245, 2020

“Recording and reconstructing 10 billion unbiased b hadron decays in CMS”

First-time access to electrons with $p_T < 2$ GeV

Ultra compressed...from the core

- Closely examine: large variation in lifetime, kinematics with small changes in $\Delta m_{\pm}$



Ultra compressed...from the core

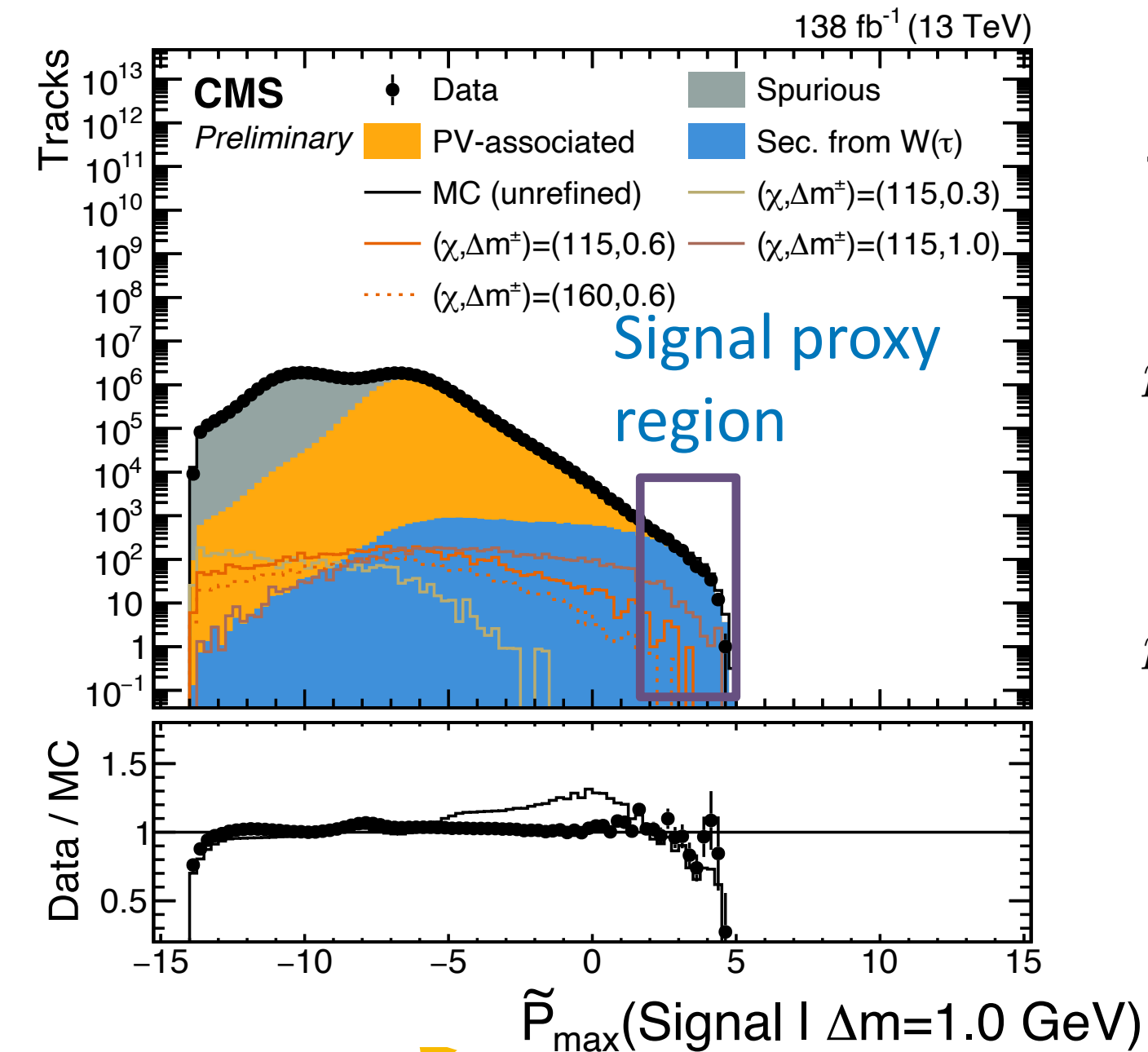
Soft isolated track

NN classifier

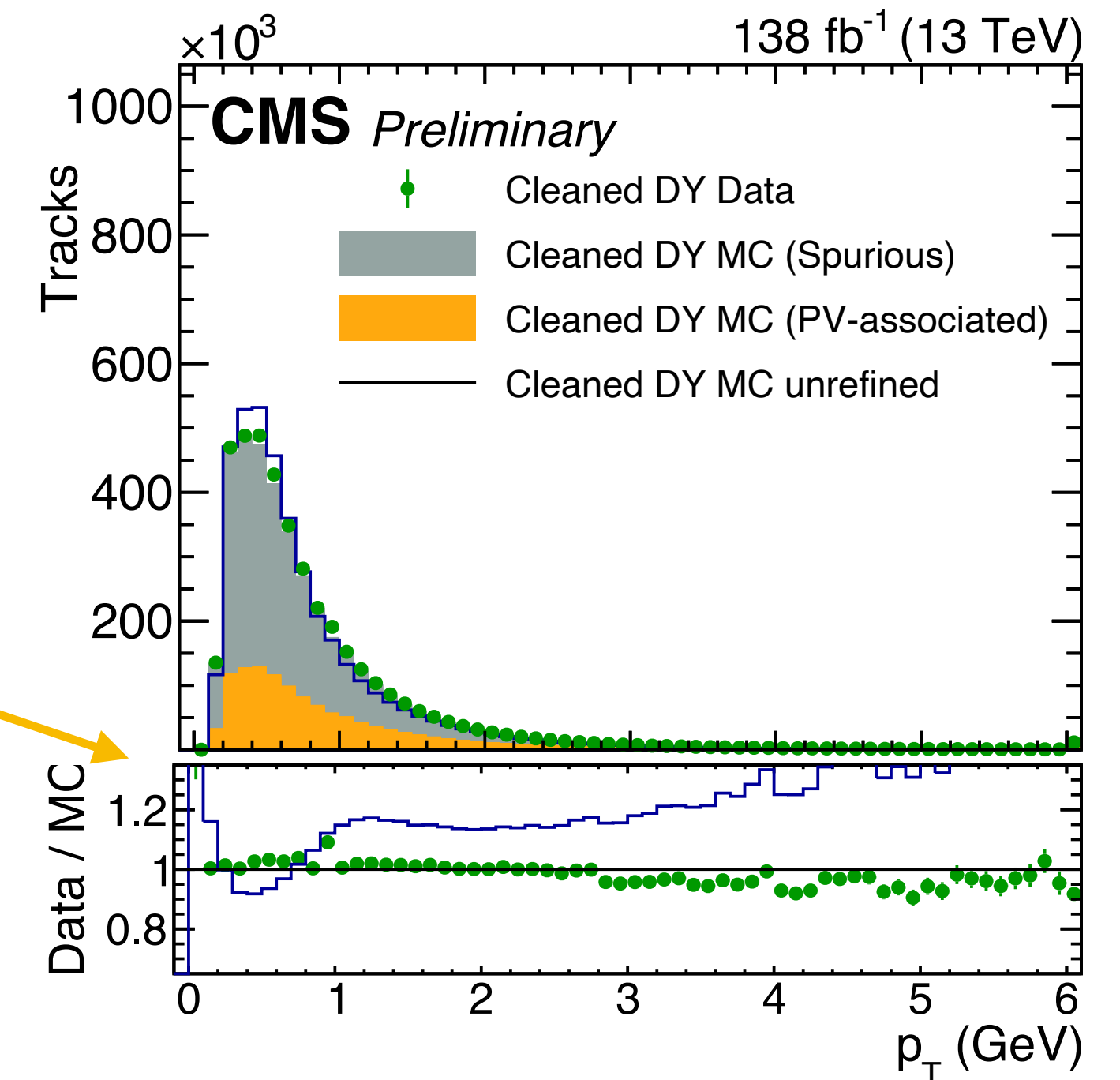
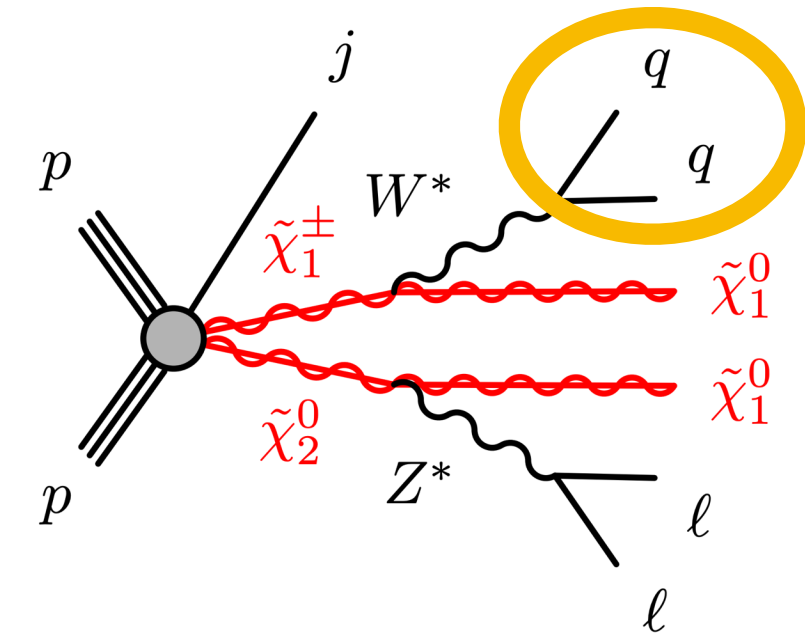
- Classifier parametrized with Δm
 - Exploit trade-off between p_T and displacement
- input: track kinematics, displacement, event variables
- Output nodes; signal; fake, prompt, secondary, tau backgrounds -> max scoring signal for SRs

NN refiner

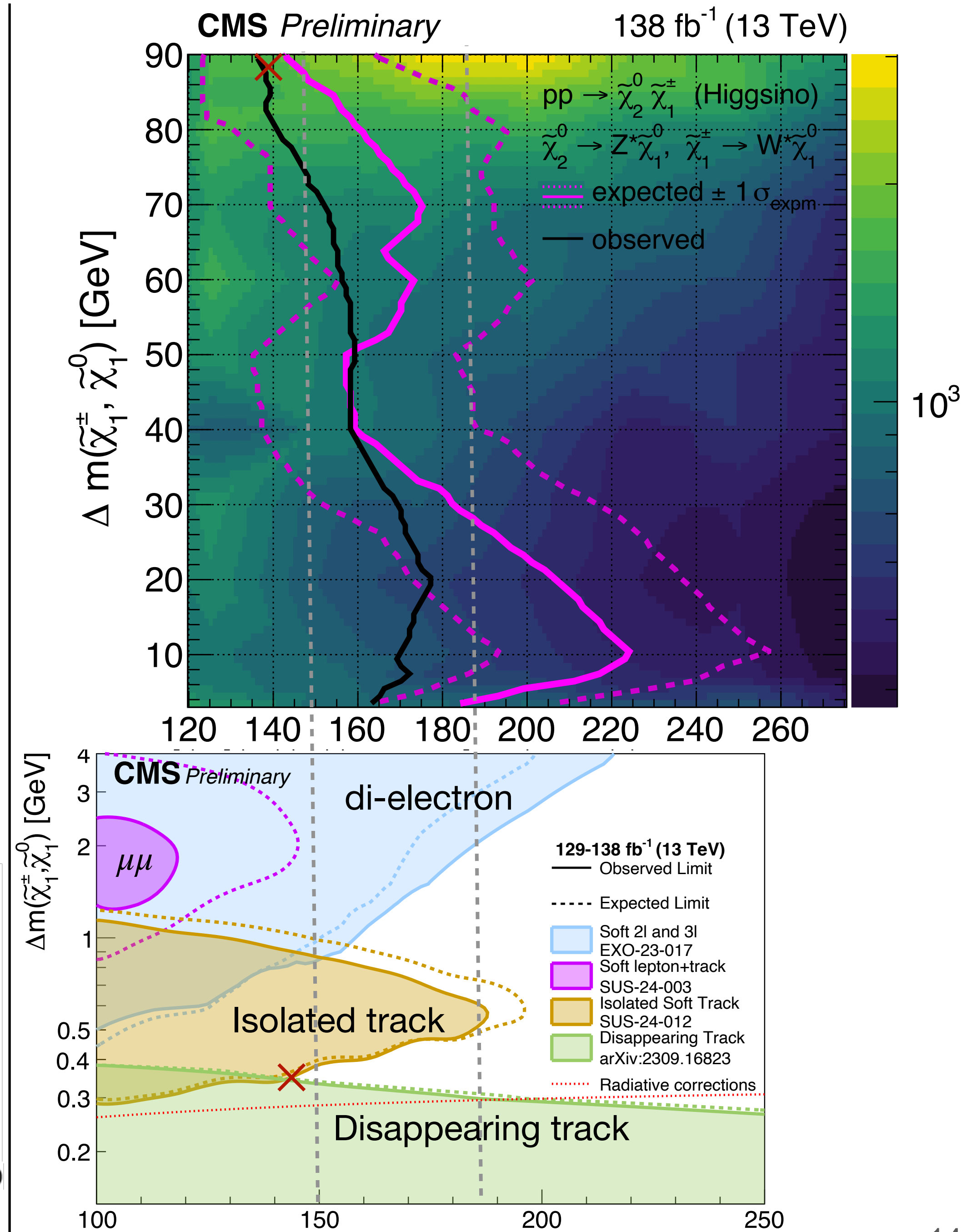
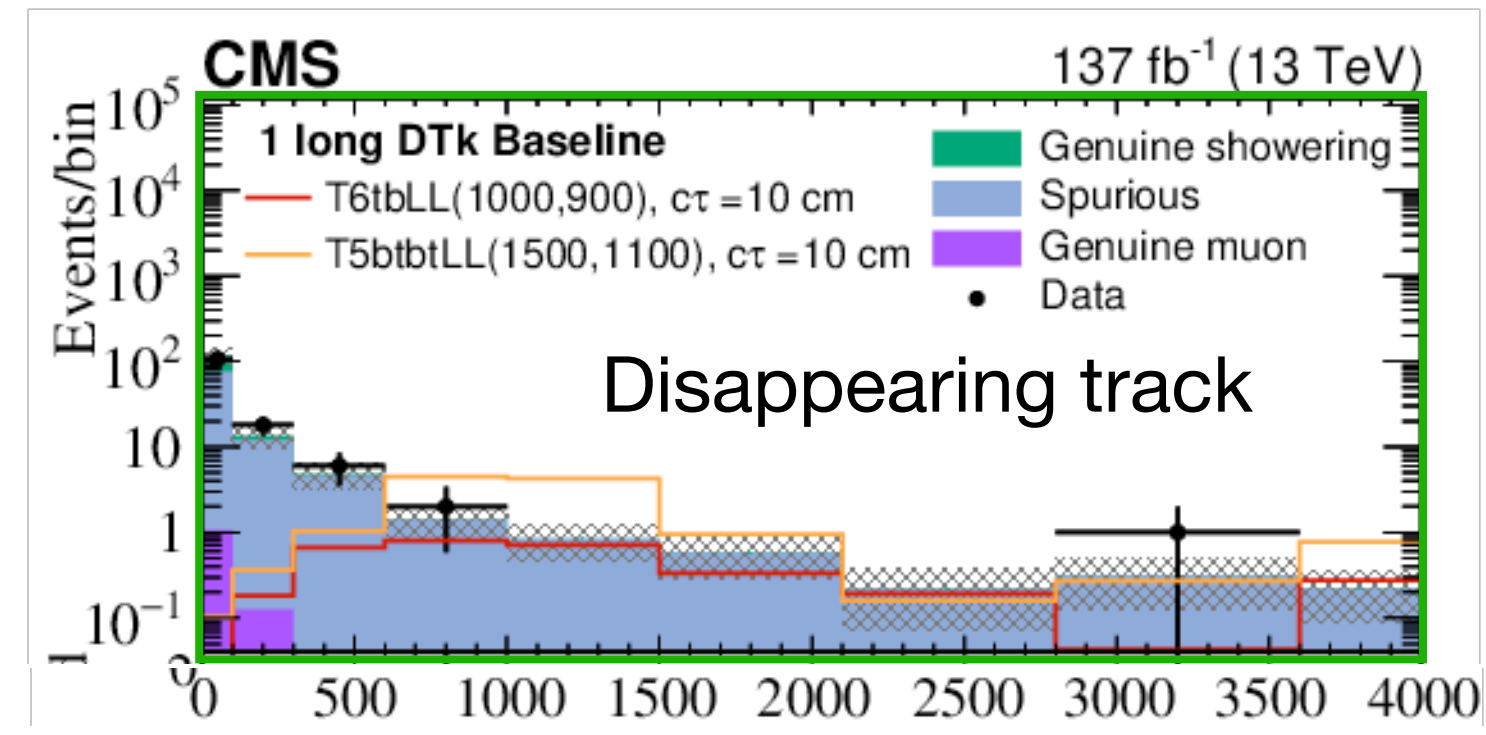
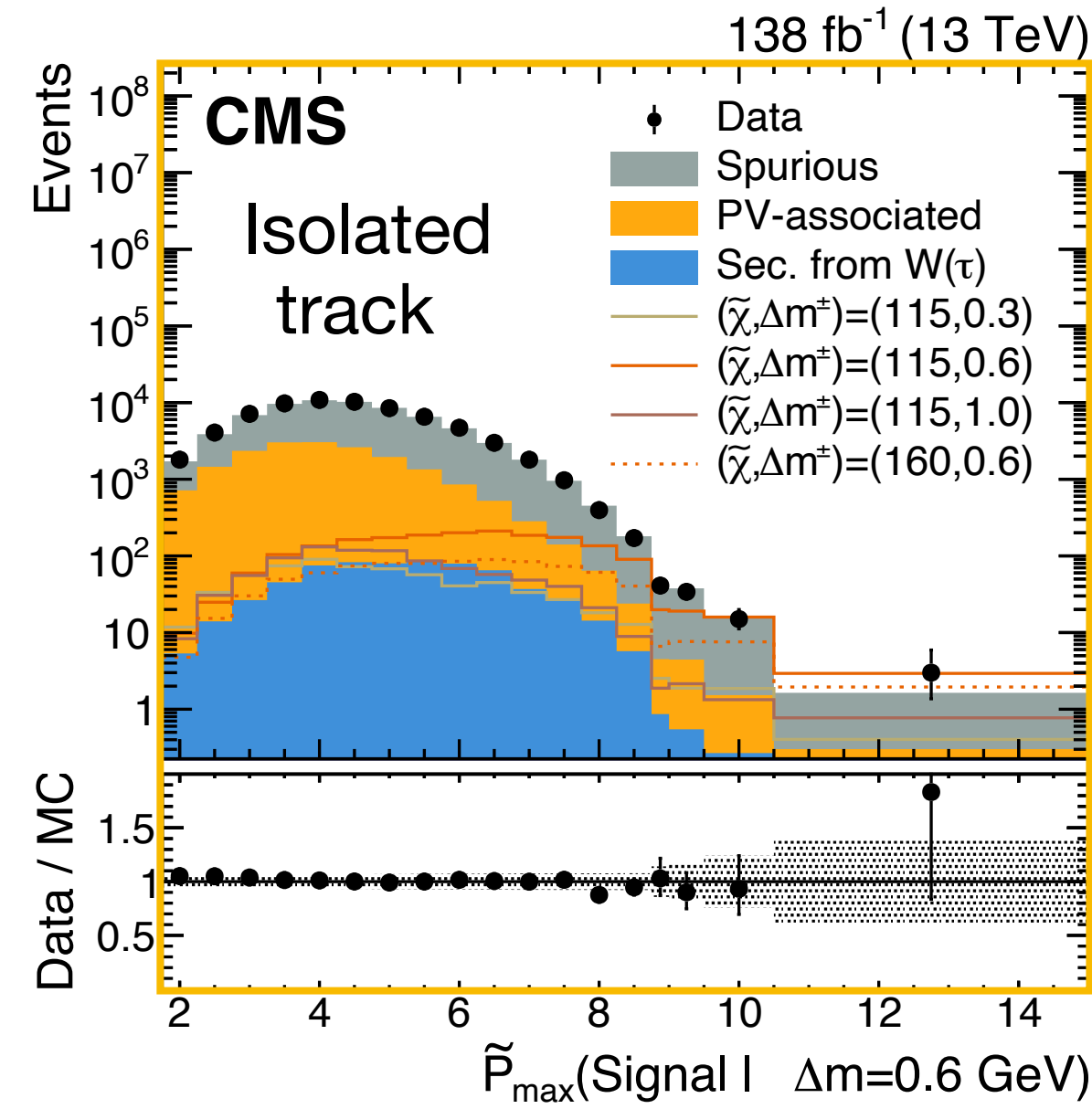
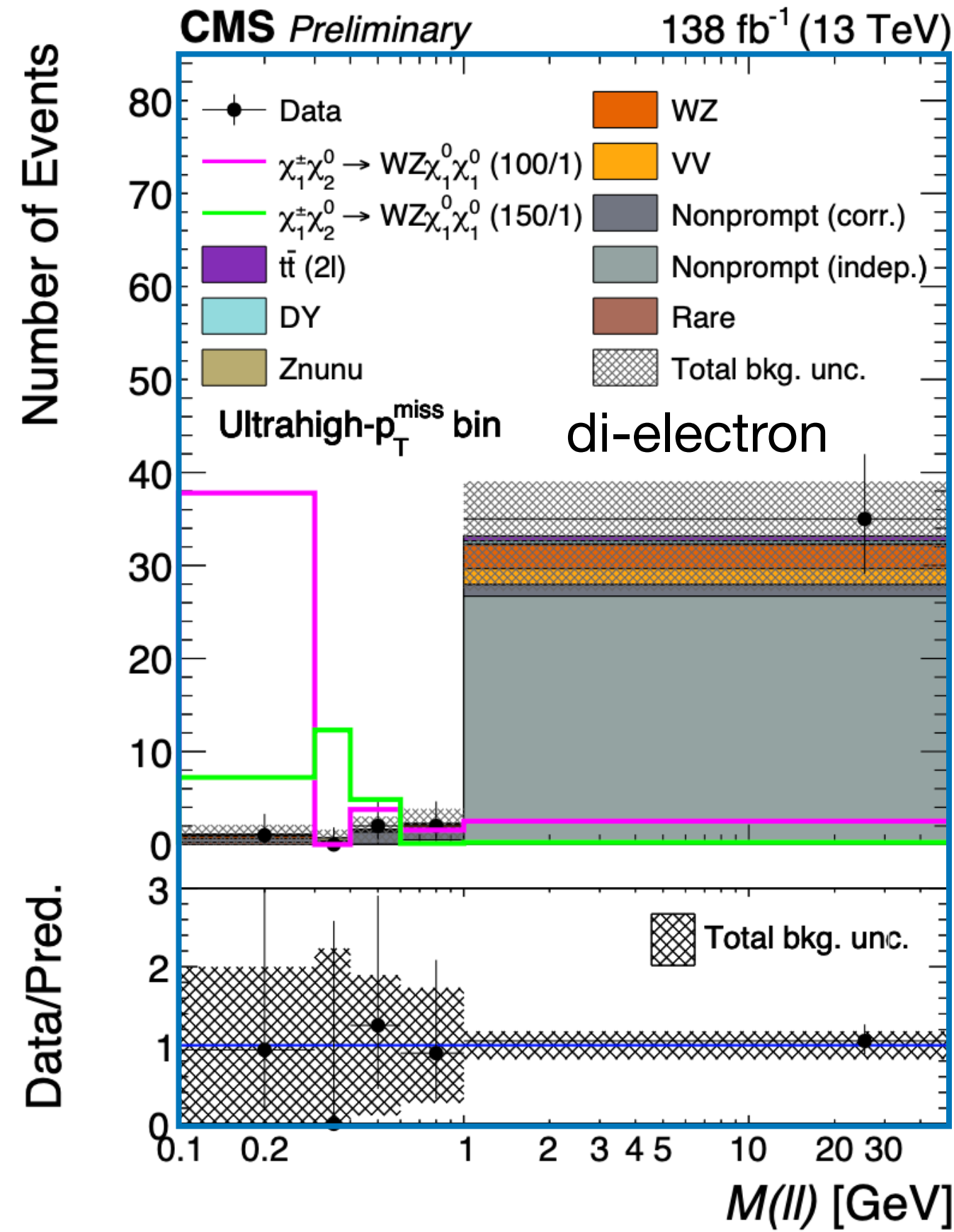
- Refine simulated tracks with ML to match data in CR
[arXiv:2410.15992](https://arxiv.org/abs/2410.15992)



SUS-24-012



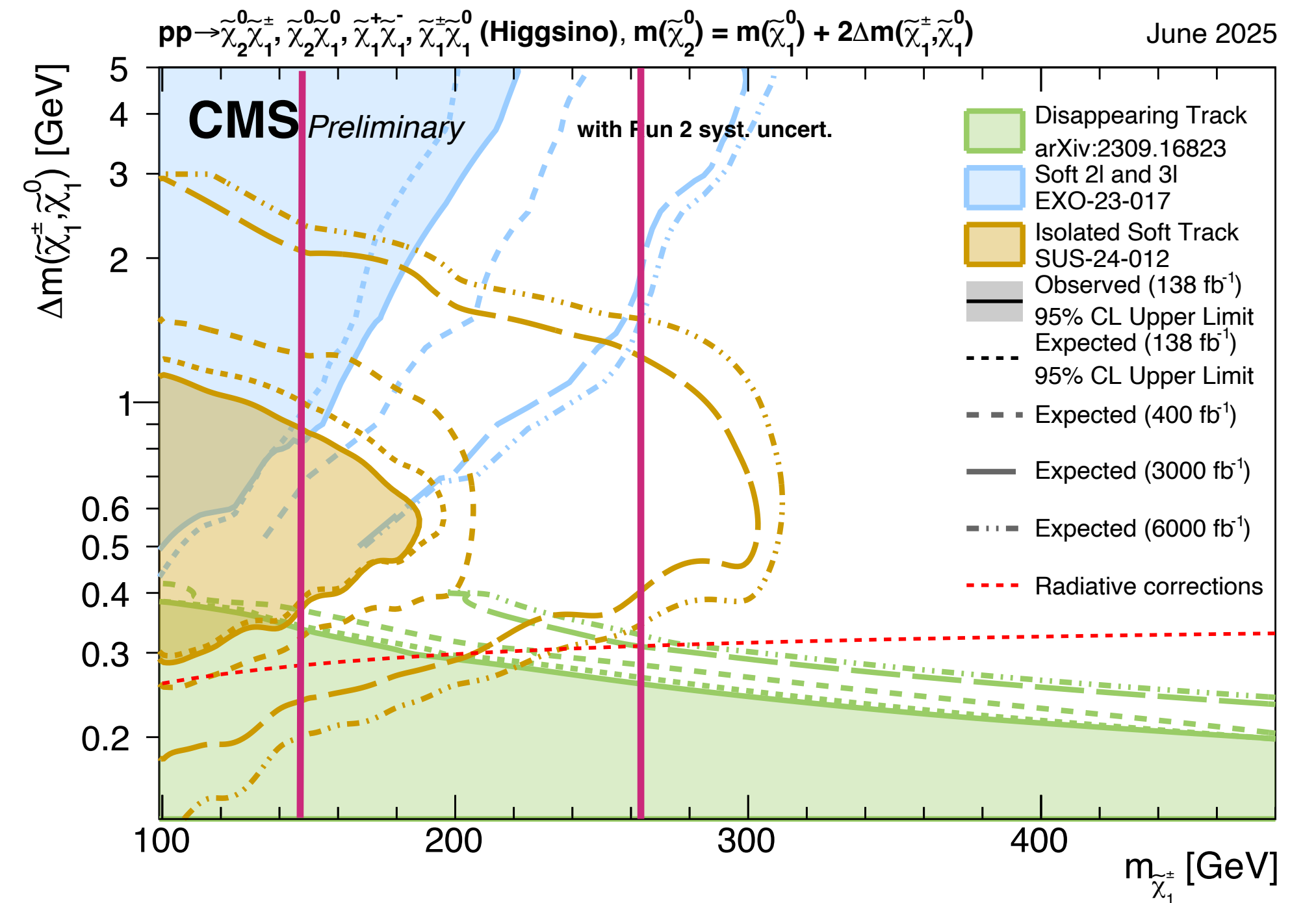
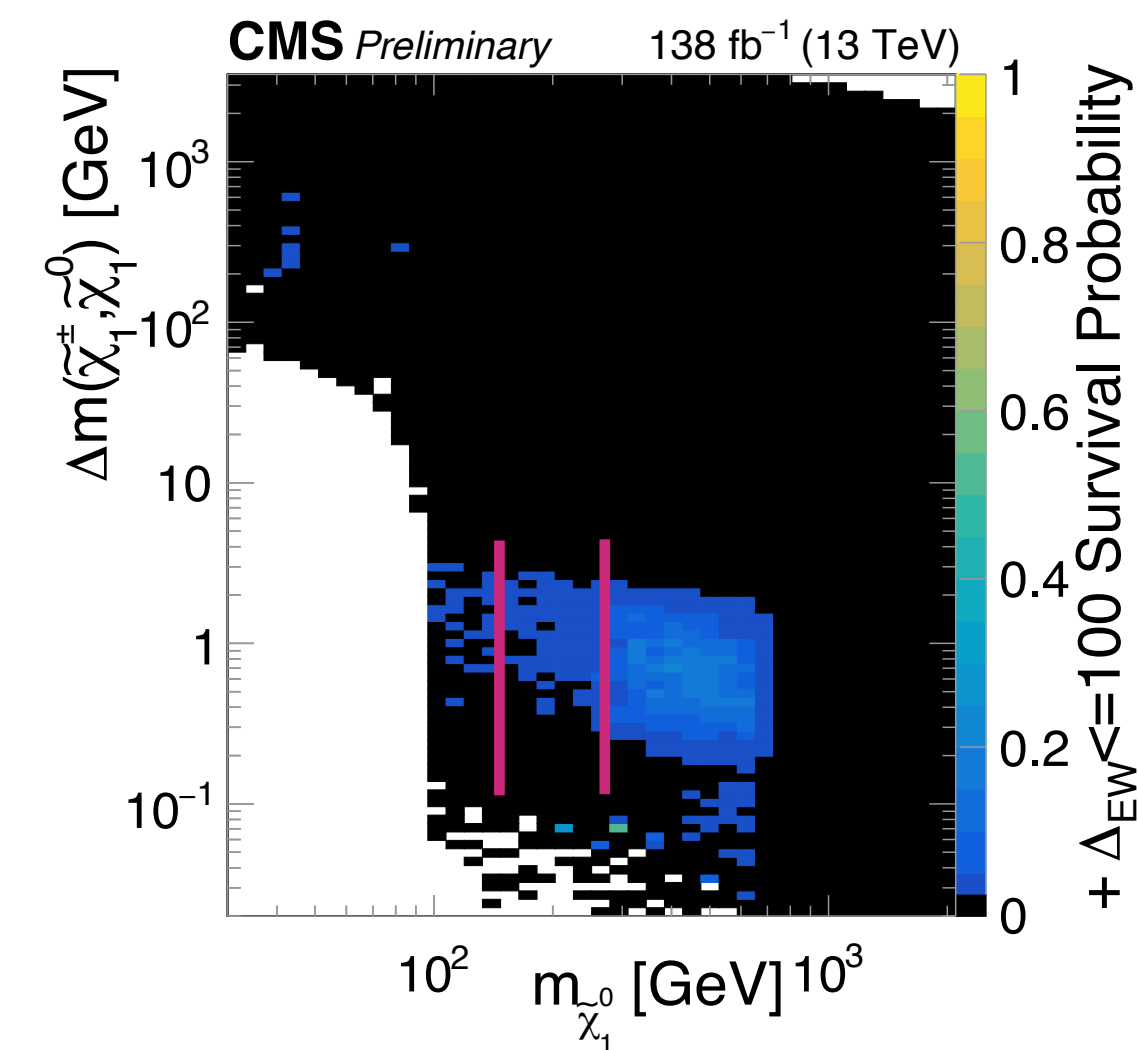
Results and interpretation



×-Higgsinos excluded up to > 140 GeV for all $\Delta m^\pm$

Run 2, Run 3, and Beyond

- Compressed SUSY often natural and DM-consistent
- Soft/ultra-soft objects cover full range of phase space for the first time
- Run 2 - excludes $m(\tilde{h}) < 145$ GeV
- HL-LHC to probe $m(\tilde{h}) < 260$ GeV
- How can we reach beyond current limits?
 - Triggering, offline ID, dE/dx of hits, ...
 - Production: stops, gluinos decay into Higgsinos
 - Other :) ...

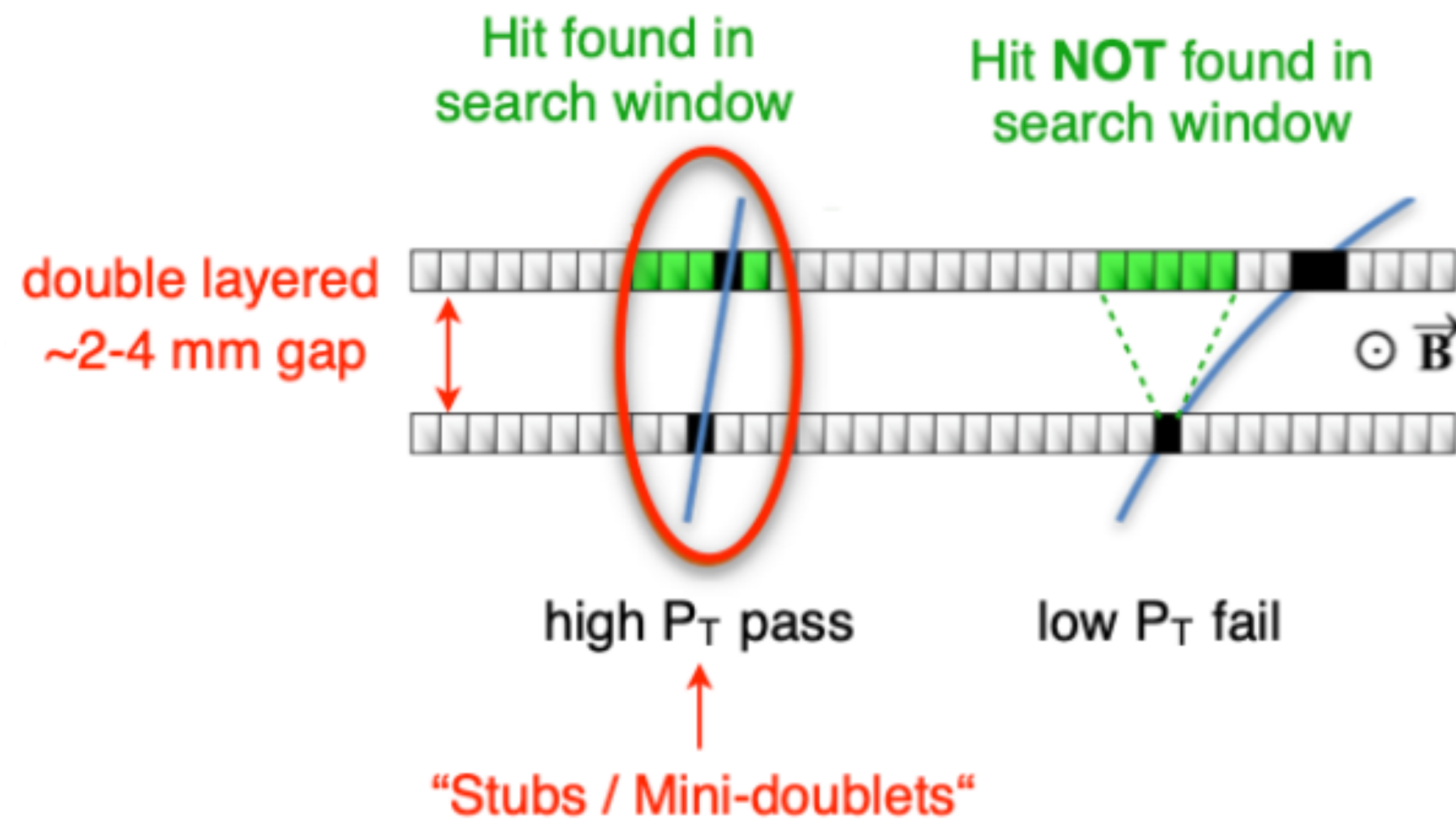


Thank you!

Backup

A look ahead

- The Phase-2 Upgrade of the CMS Level-1 Trigger
CMS-TDR-017
- 2-layered silicon modules with 2 mm gap



- Run 2 iso track analysis loses $>90\%$ of events due to MET trigger
- Possibility to trigger tracks with $p_T > 2$ GeV at Level-1
 - But need to design trigger paths!

