General Searches For Compressed SUSY With the CMS Detector

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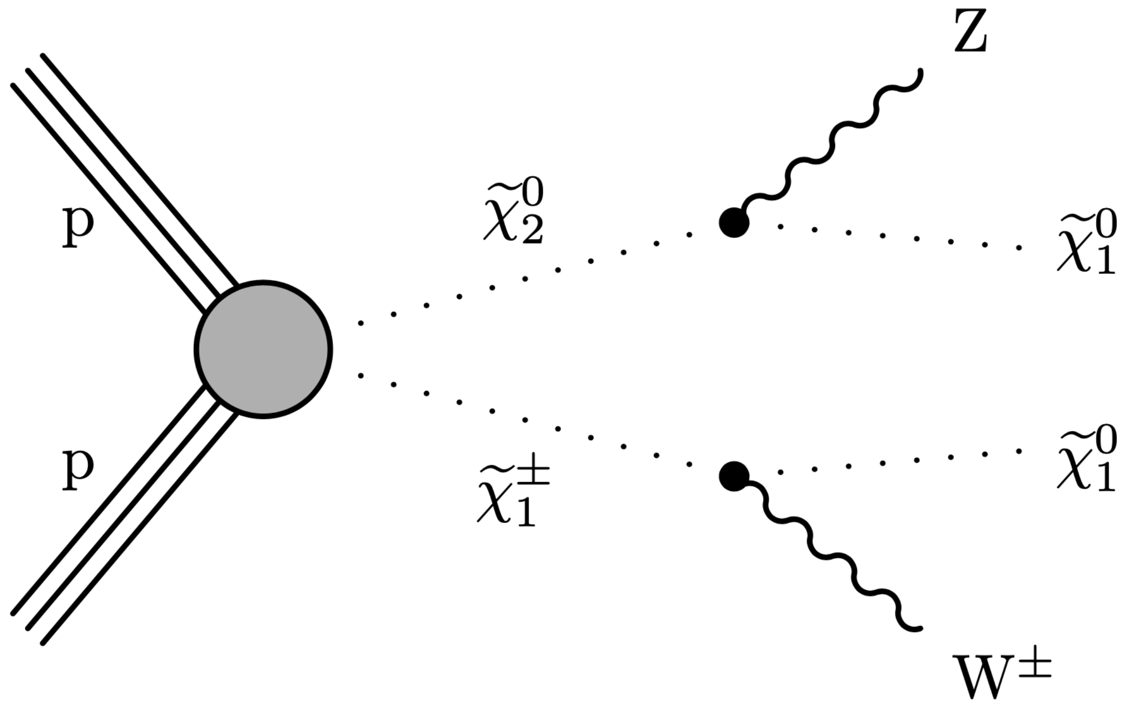
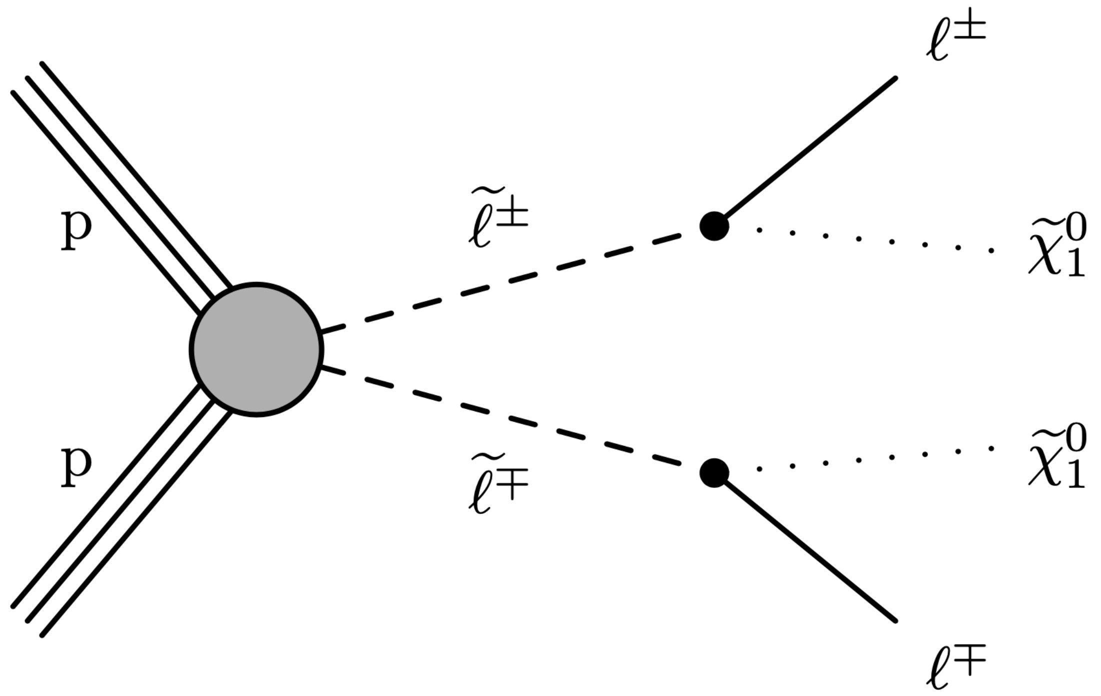
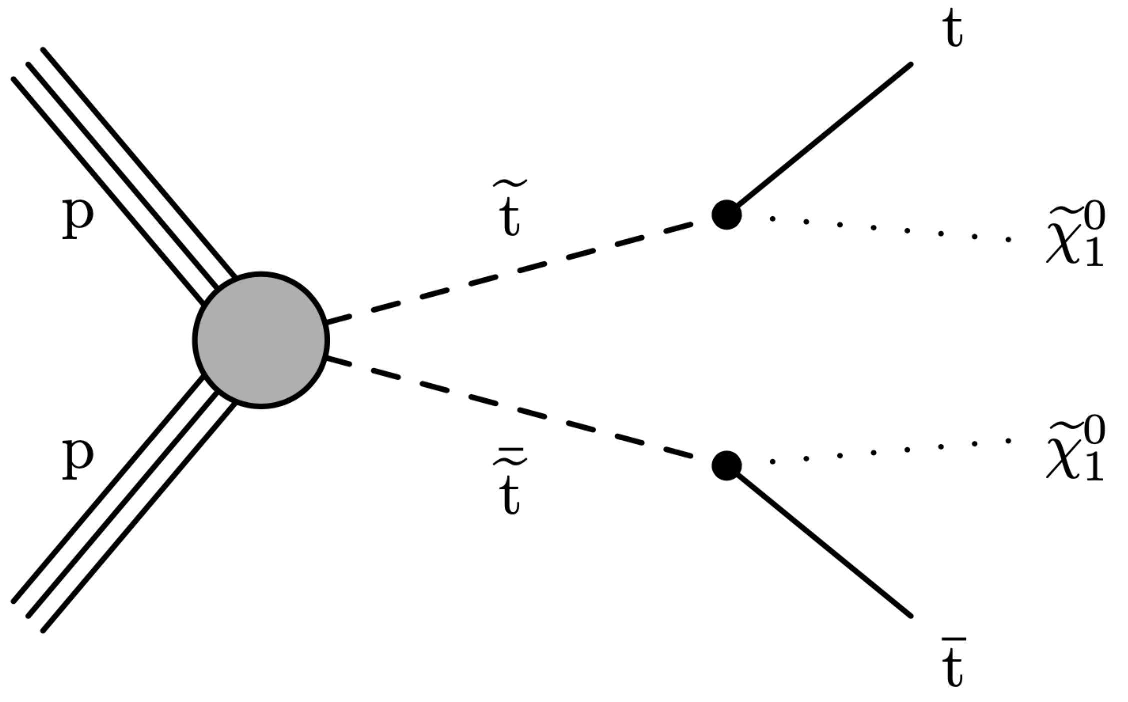
CMS



Electroweakinos

Sleptons





Top Squarks

- Searches for **compressed SUSY** at the electroweak scale:
  - **Small Δm between parent sparticle and LSP** is well-motivated.
  - LSP ($\tilde{\chi}_1^0$) is a viable candidate for **dark matter**.
- Compressed SUSY is challenging, with lot of **unexplored phase-space**.
- Three different analyses discussed.

CMS Analyses In This Talk

- Data obtained during CMS Run II (2016-2018) with Integrated Luminosity of 138 fb^{-1}.

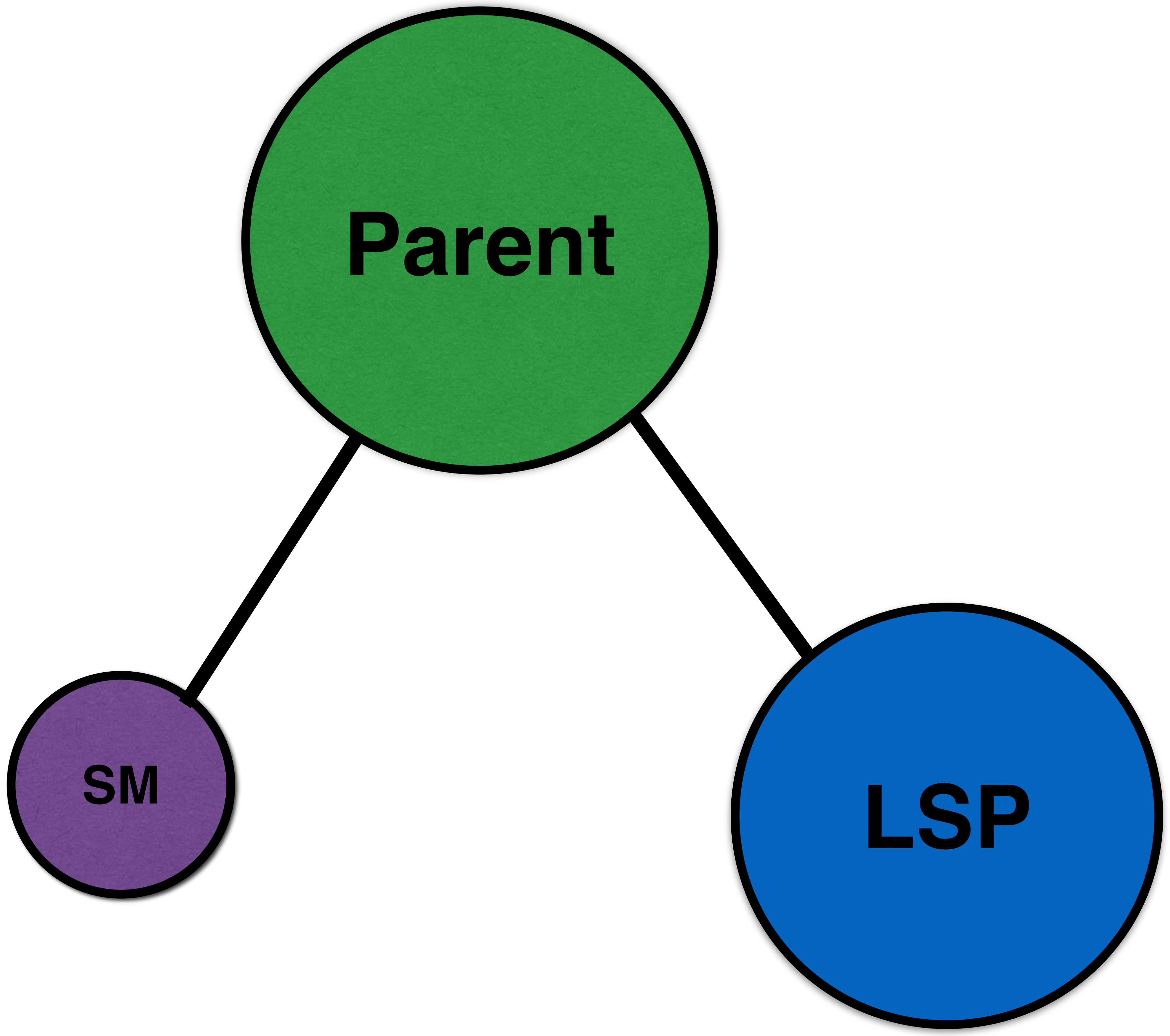
- **Analyses discussed**:

  - Search for top squark production in fully-hadronic final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV - http://arxiv.org/abs/2307.16216

  - Combined search for electroweak production of winos, binos, higgsinos, and sleptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV - https://arxiv.org/abs/2402.01888

  - General search for supersymmetric particles with compressed mass spectra in proton-proton collisions at $\sqrt{s}$ = 13 TeV (**Currently undergoing approval**).

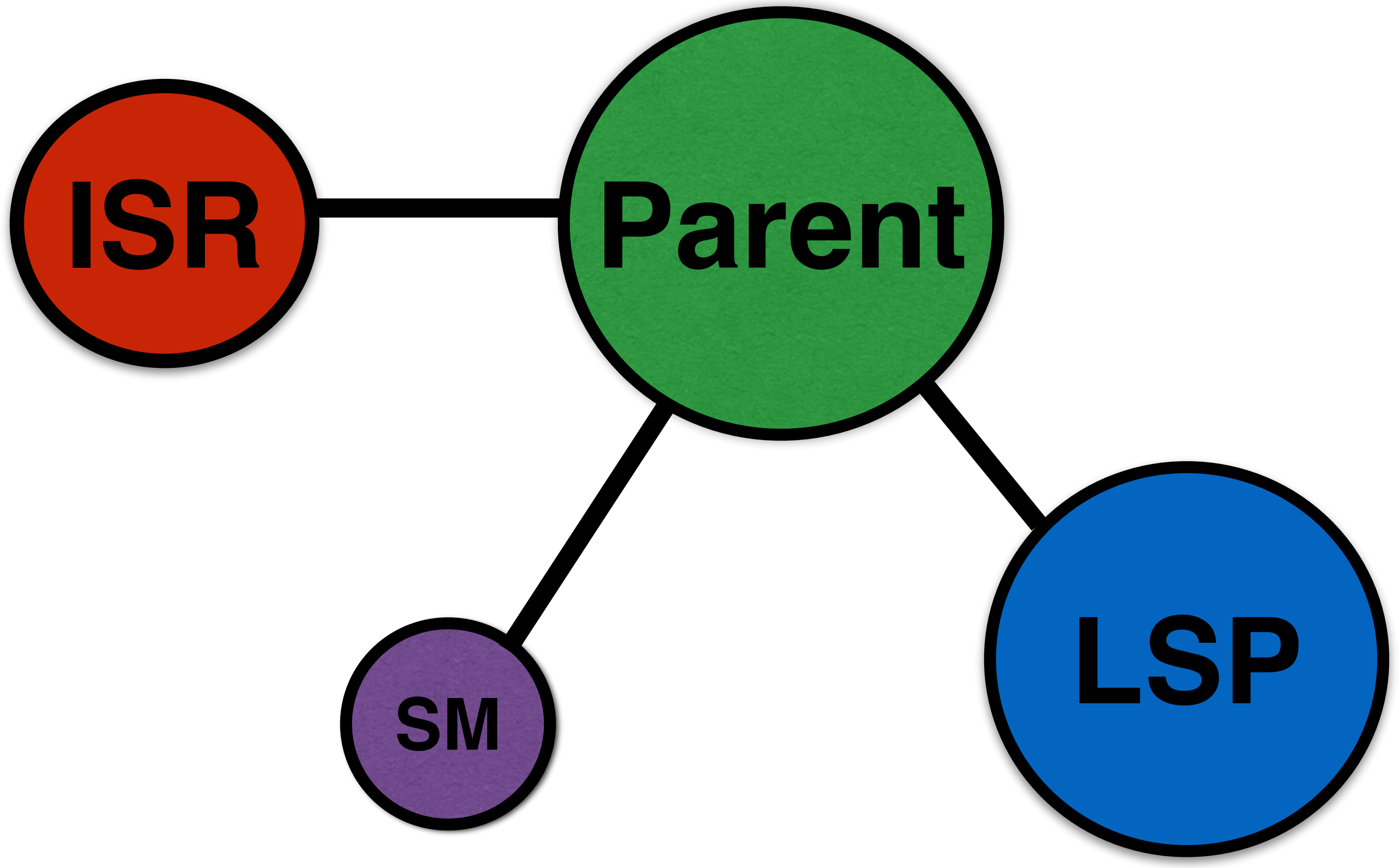
Compressed Mass Spectra SUSY

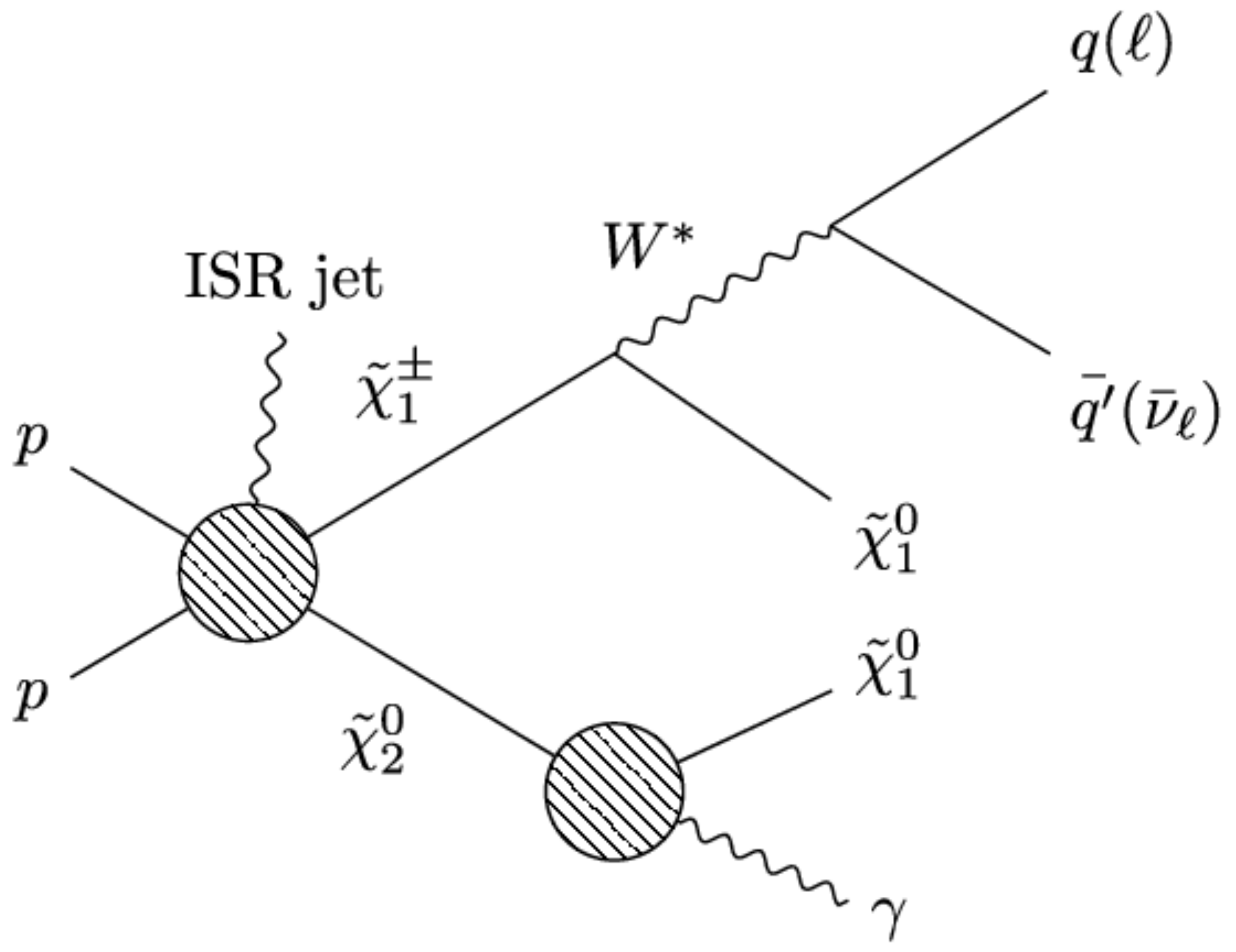


$$M_{NLSP} \sim M_{LSP}$$

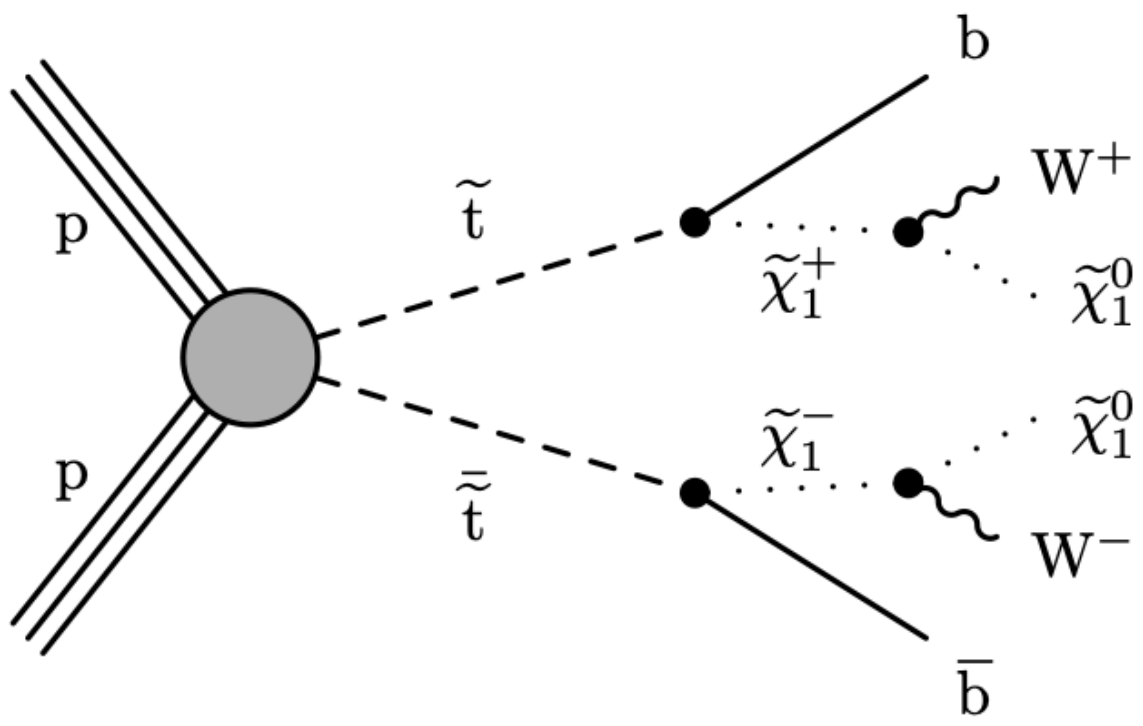
- Decay where **Parent sparticle** (electroweakinos, stops and sleptons) and **LSP** are **close in mass.**
- Very **difficult to probe** with traditional methods:
  - **Low-momentum** decay products:
    - Soft **visible particles** and small **missing energy**.
  - Indistinguishable from **SM background**.
- Can use a commonly occurring natural process to overcome these difficulties!

Natural Solution: Initial-State Radiation



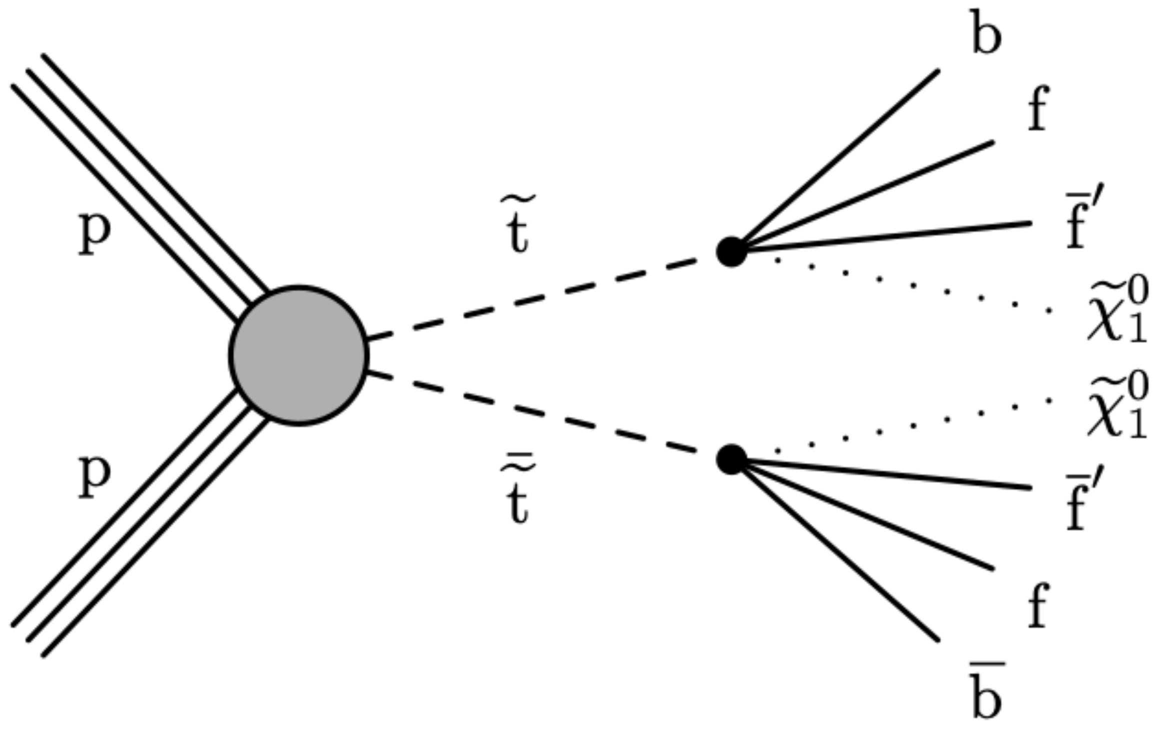


- Use events accompanied by jets from **initial-state radiation** (**ISR**):
  - ISR jets are **very common** at the LHC.
  - Recoil from ISR can "**kick**" the system leading to **significant missing energy**.
  - **Direct correlation** between p_T^{ISR} and p_T^{LSP}.
  - All analyses discussed here include ISR jets (some implicitly).

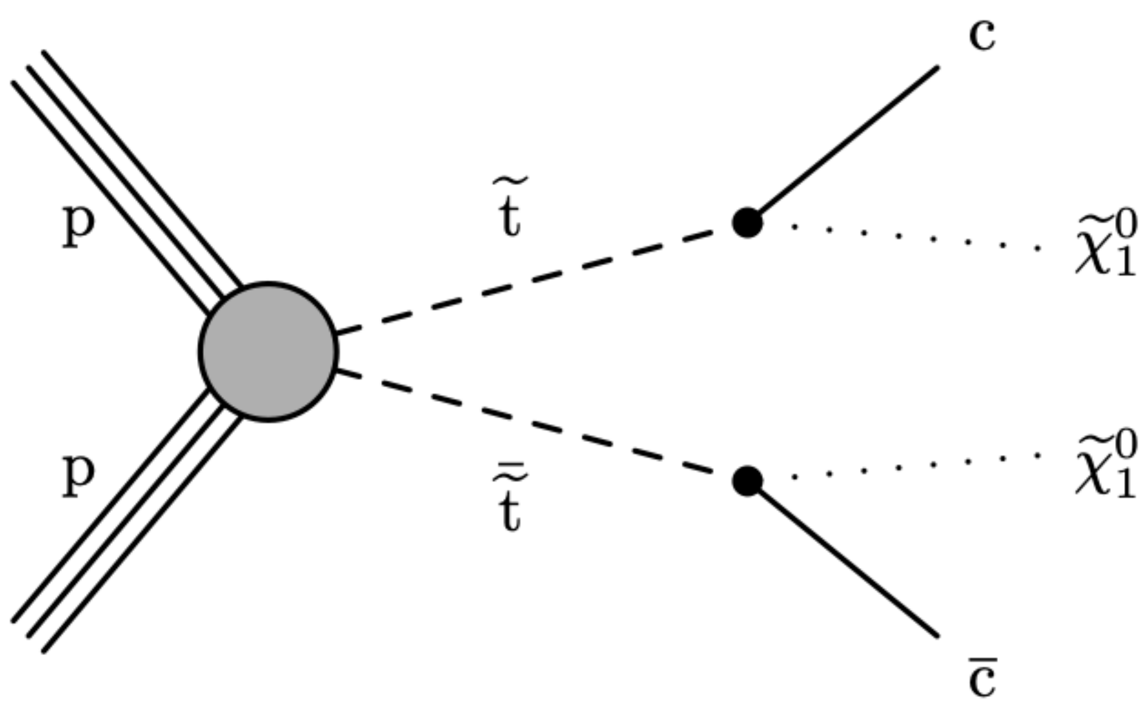


$\tilde{t} \rightarrow b\, \tilde{\chi}_1^{\pm}$

$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^{0}\, W^{\pm}$



$\tilde{t} \rightarrow b\, f\, \bar{f}'\, \tilde{\chi}_1^{0}$



$\tilde{t} \rightarrow c\, \tilde{\chi}_1^{0}$

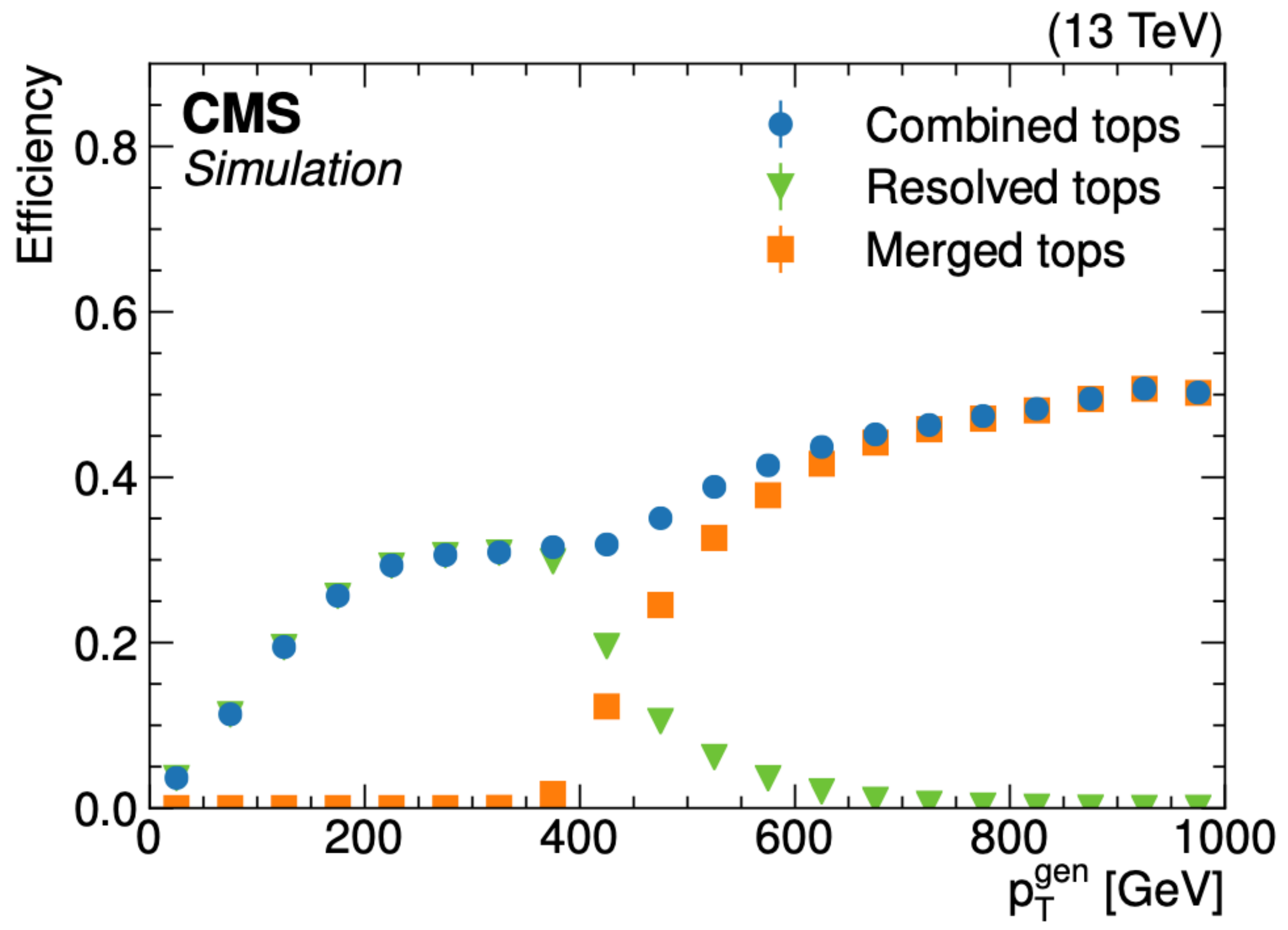
- Models with small $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$ align with dark matter relic density predictions.
- Final State: **Fully-hadronic**.
- Signal regions divided into **low** and high Δm.

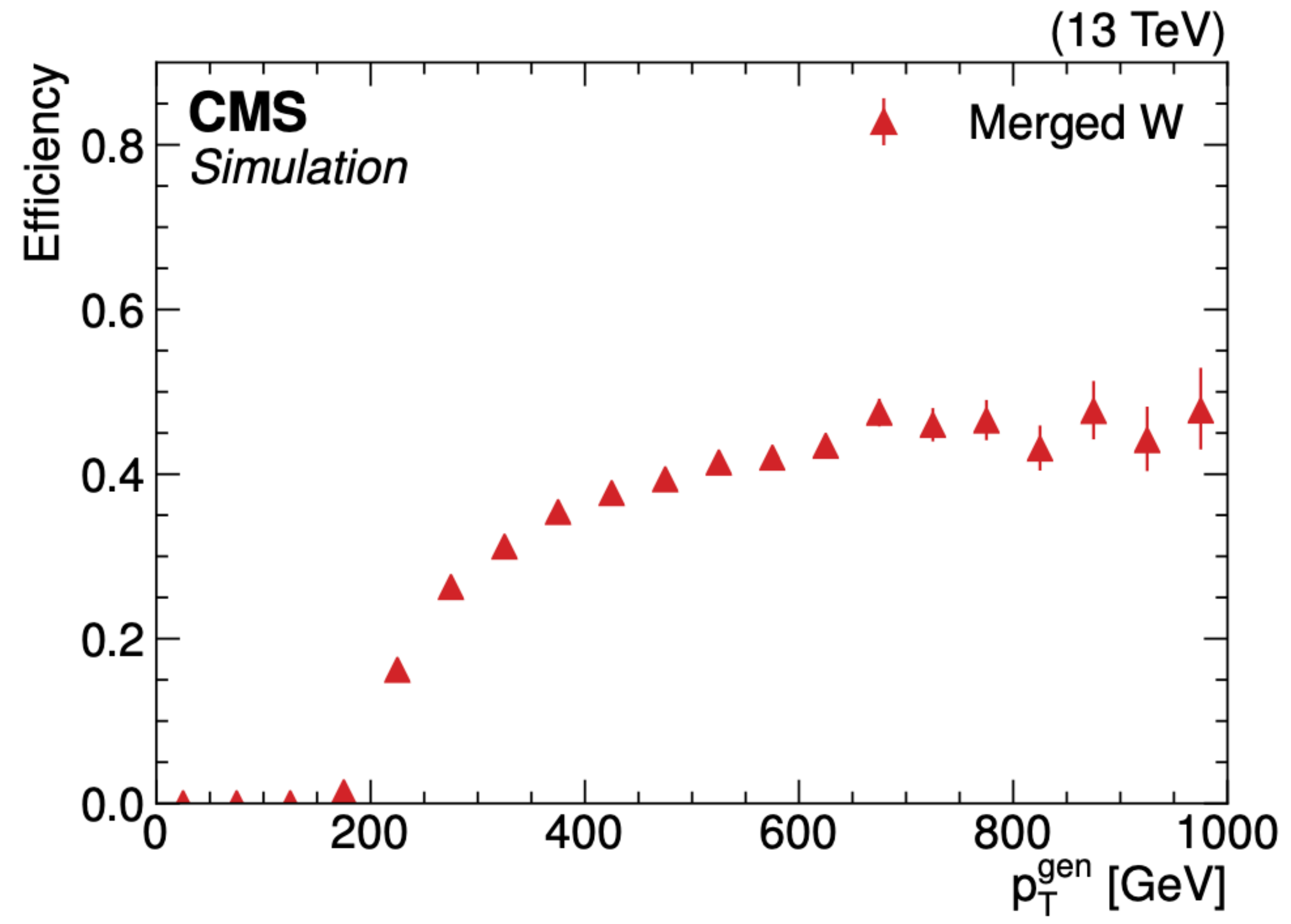
Low Δm baseline selection

$N_{\mathrm{t}}, N_{\mathrm{W}}, N_{\mathrm{res}}$	$N_{\mathrm{t}} = N_{\mathrm{W}} = N_{\mathrm{res}} = 0$
$m_{\mathrm{T}}^{\mathrm{b}}$	$m_{\mathrm{T}}^{\mathrm{b}} < 175\,\mathrm{GeV}$ (for events with $N_{\mathrm{b}} \geq 1$)
ISR jet	$N_{\mathrm{j}}(\mathrm{ISR}) = 1$ $(R = 0.8)$, $p_{\mathrm{T}}^{\mathrm{ISR}} > 200\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.4$ $\Delta\phi\left(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{j}_{\mathrm{ISR}}\right) > 2$
$p_{\mathrm{T}}^{\mathrm{miss}}$	$p_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{H_{\mathrm{T}}} > 10\,\sqrt{\mathrm{GeV}}$

SUS-19-010
arXiv:2103.01290

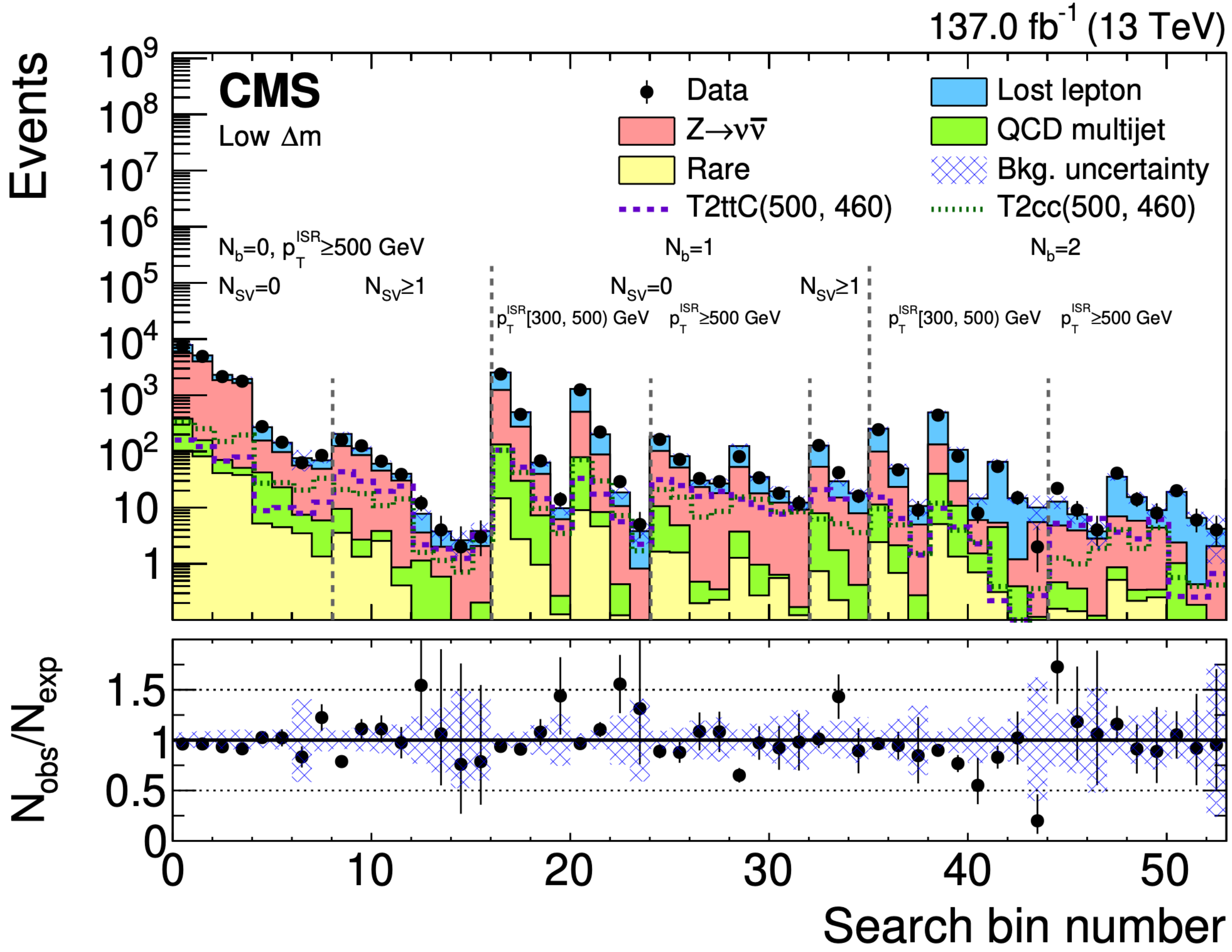
Search for Top Squarks: Low Δm Strategy



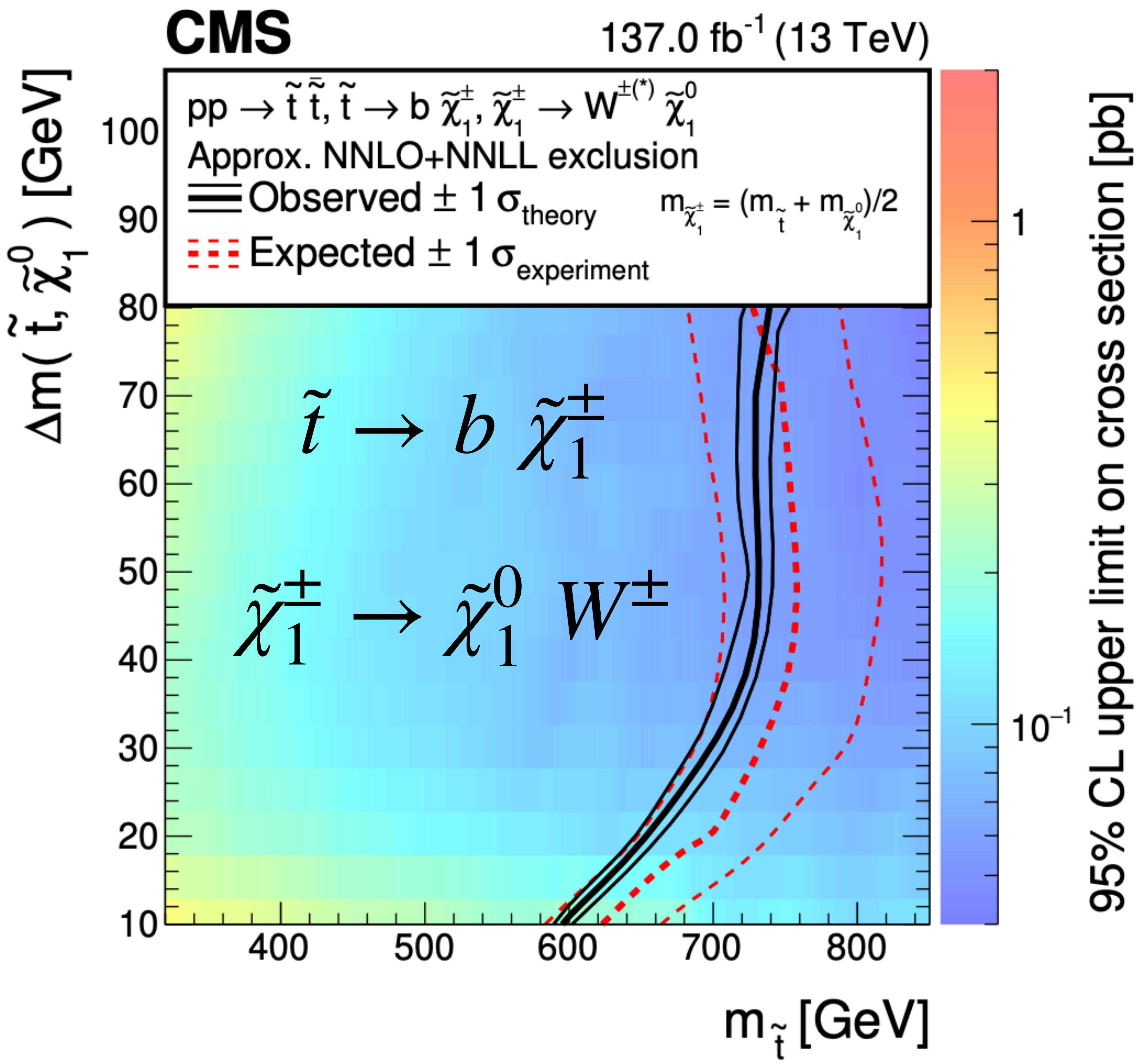


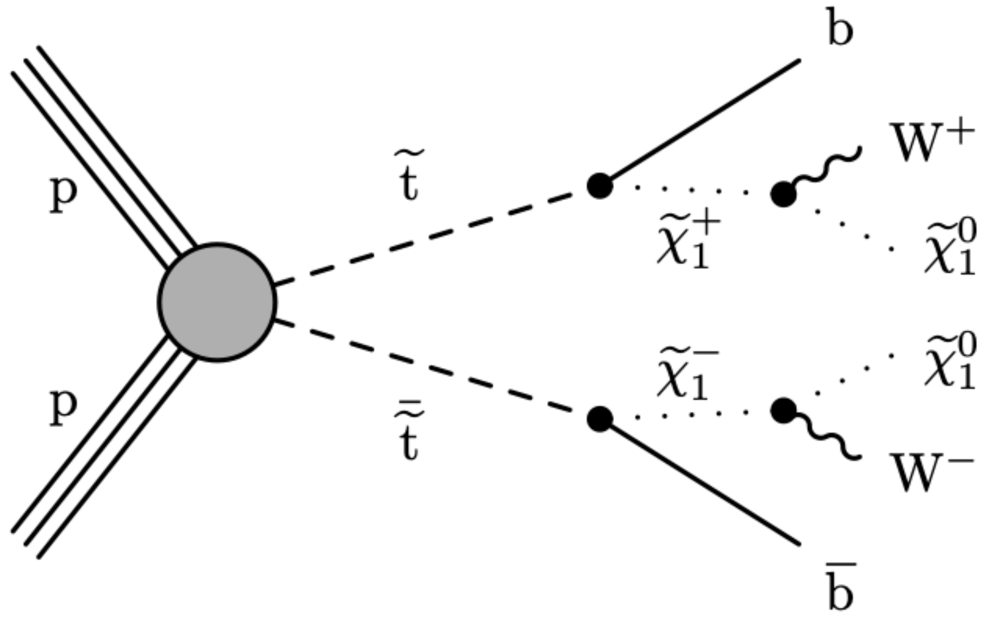
- Targets models where $\Delta m(\tilde{t}, \tilde{\chi}_1^0) < m_W$:
  - Events with ISR identified from large jets must **fail the b-tagging ID**.
  - Uses W and top-tagger to **veto events with on-shell W bosons and top quark jets**.
  - Specialized algorithm for identifying **soft b-quarks** ($p_T < 20$ GeV).
  - 53/183 search bins sensitive to the low Δm region.

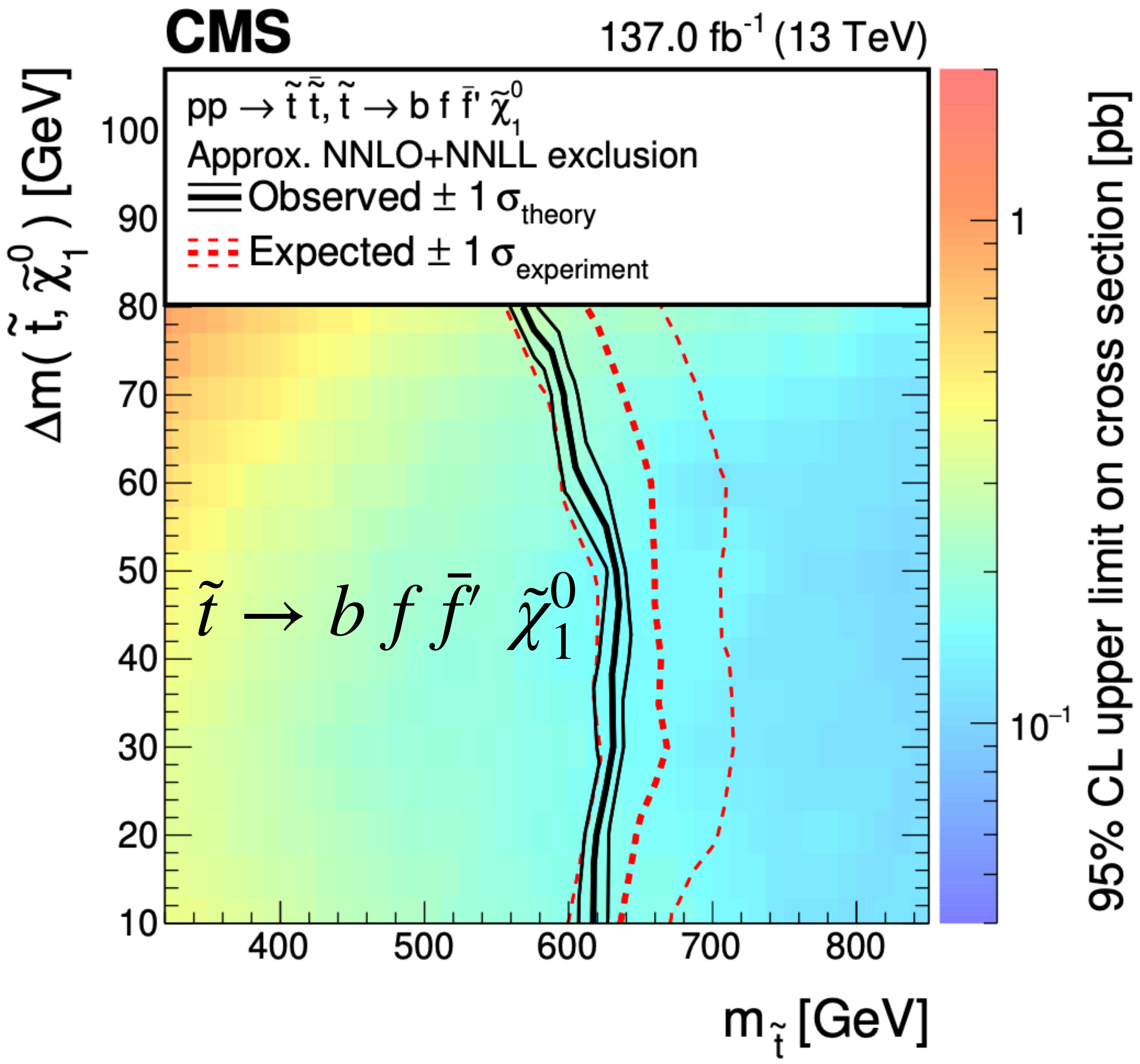
Search for Top Squarks: Low Δm Search Regions

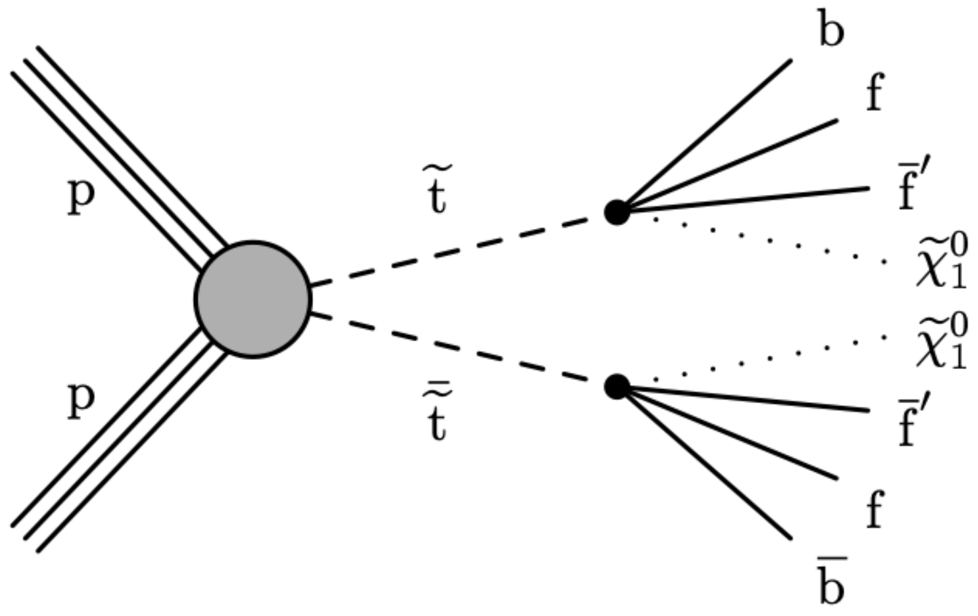


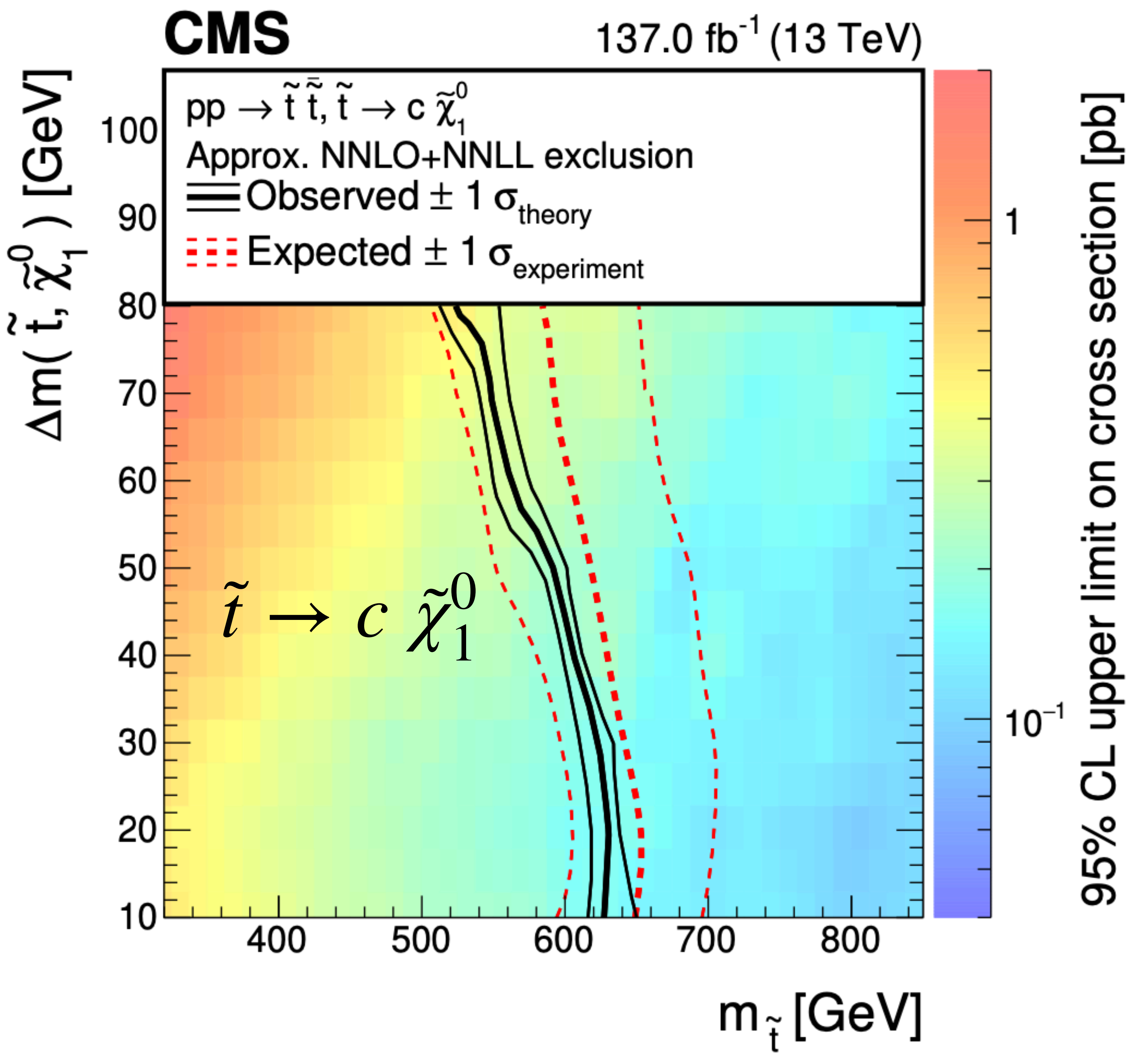
Search For Top Squarks - Results

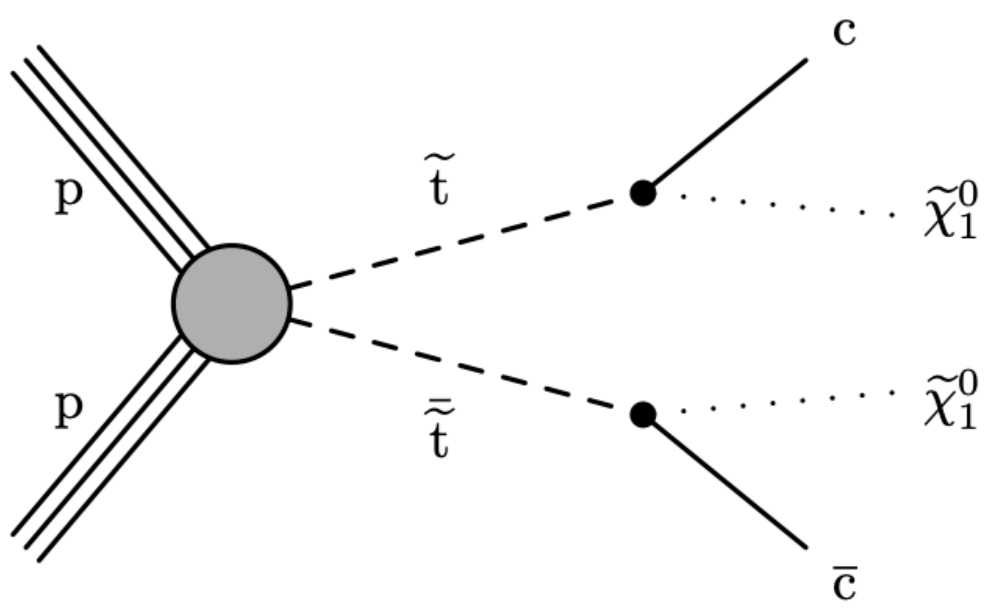






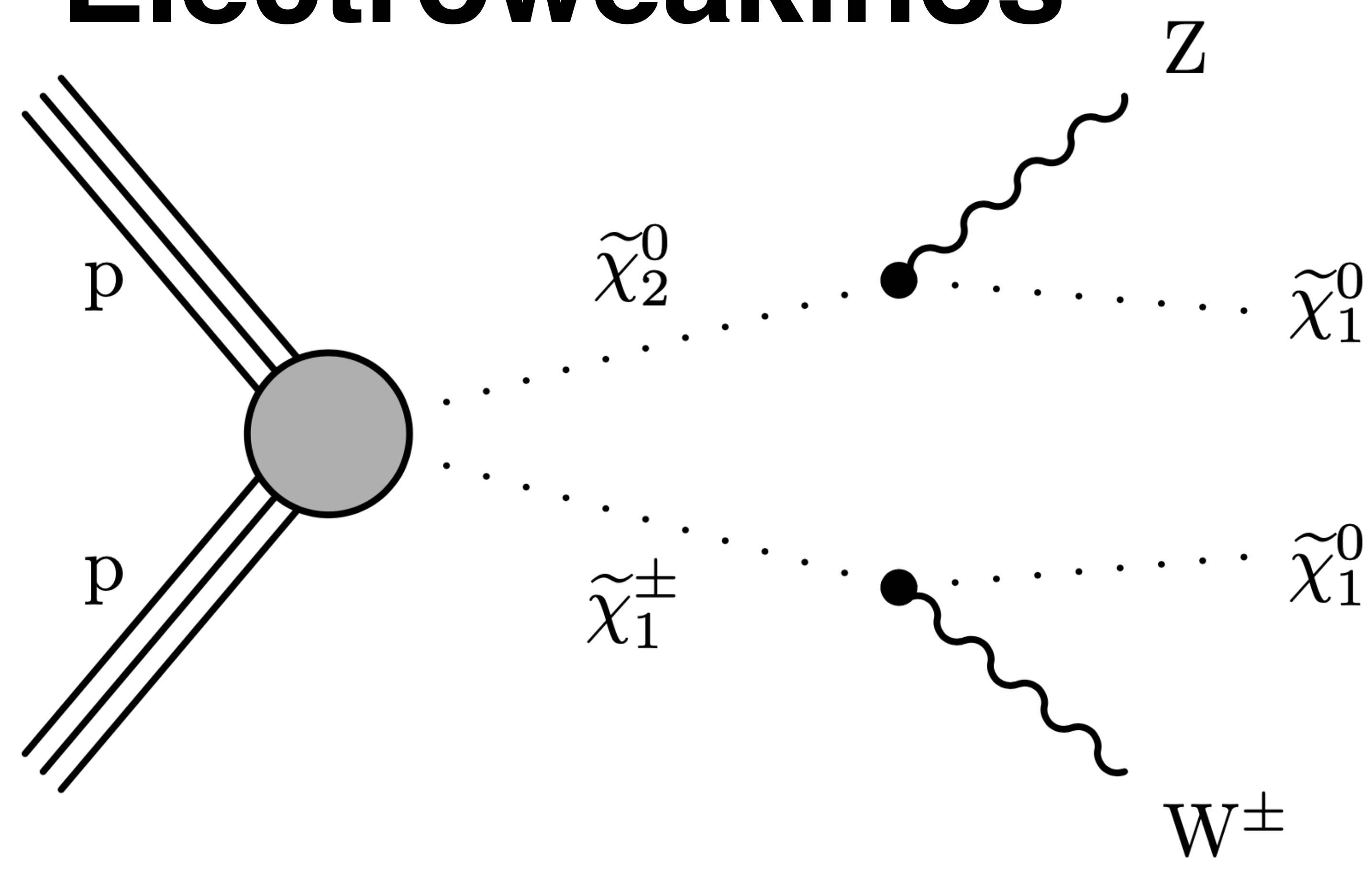




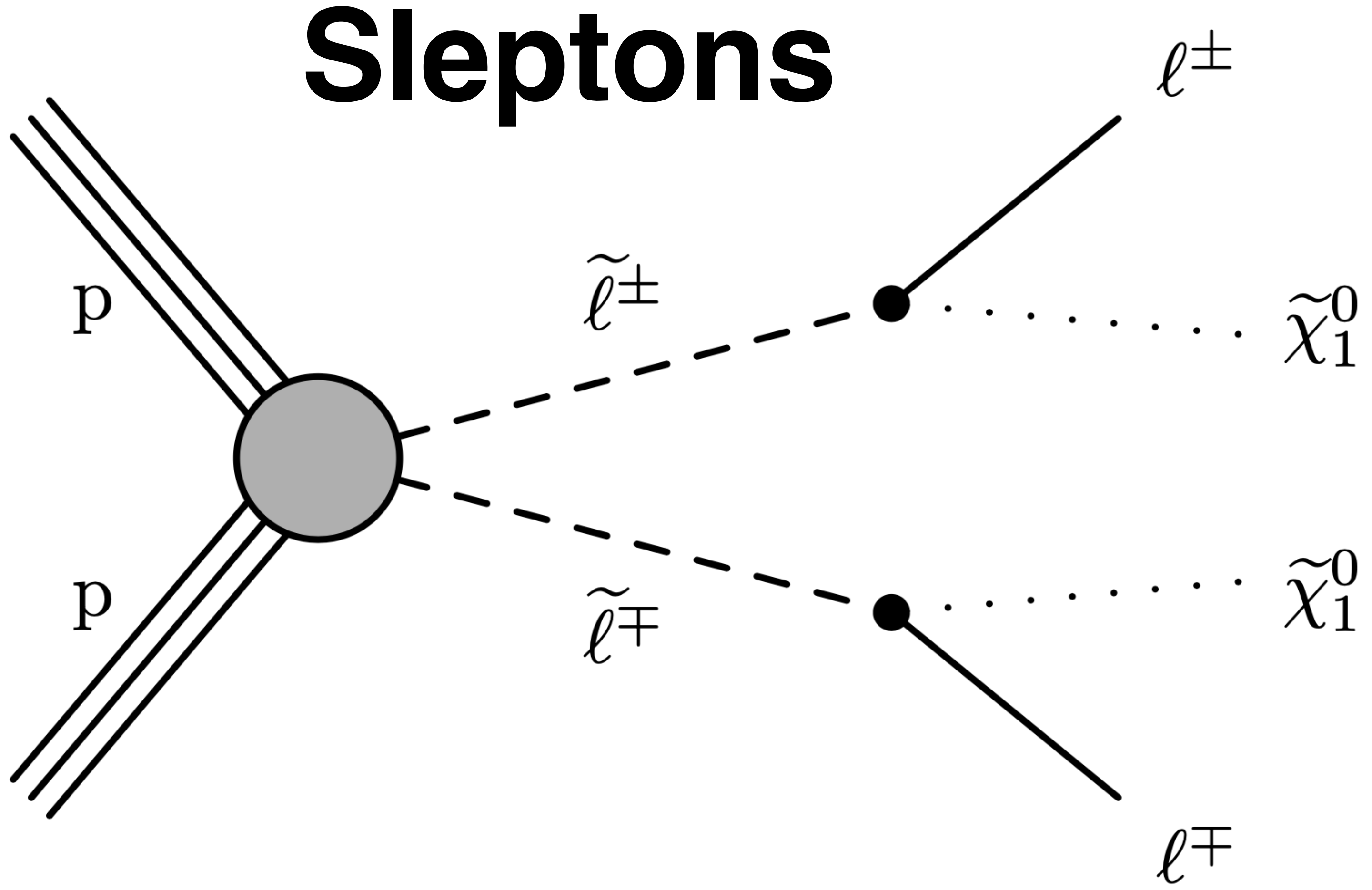


Combined Search For Electroweak SUSY

Electroweakinos



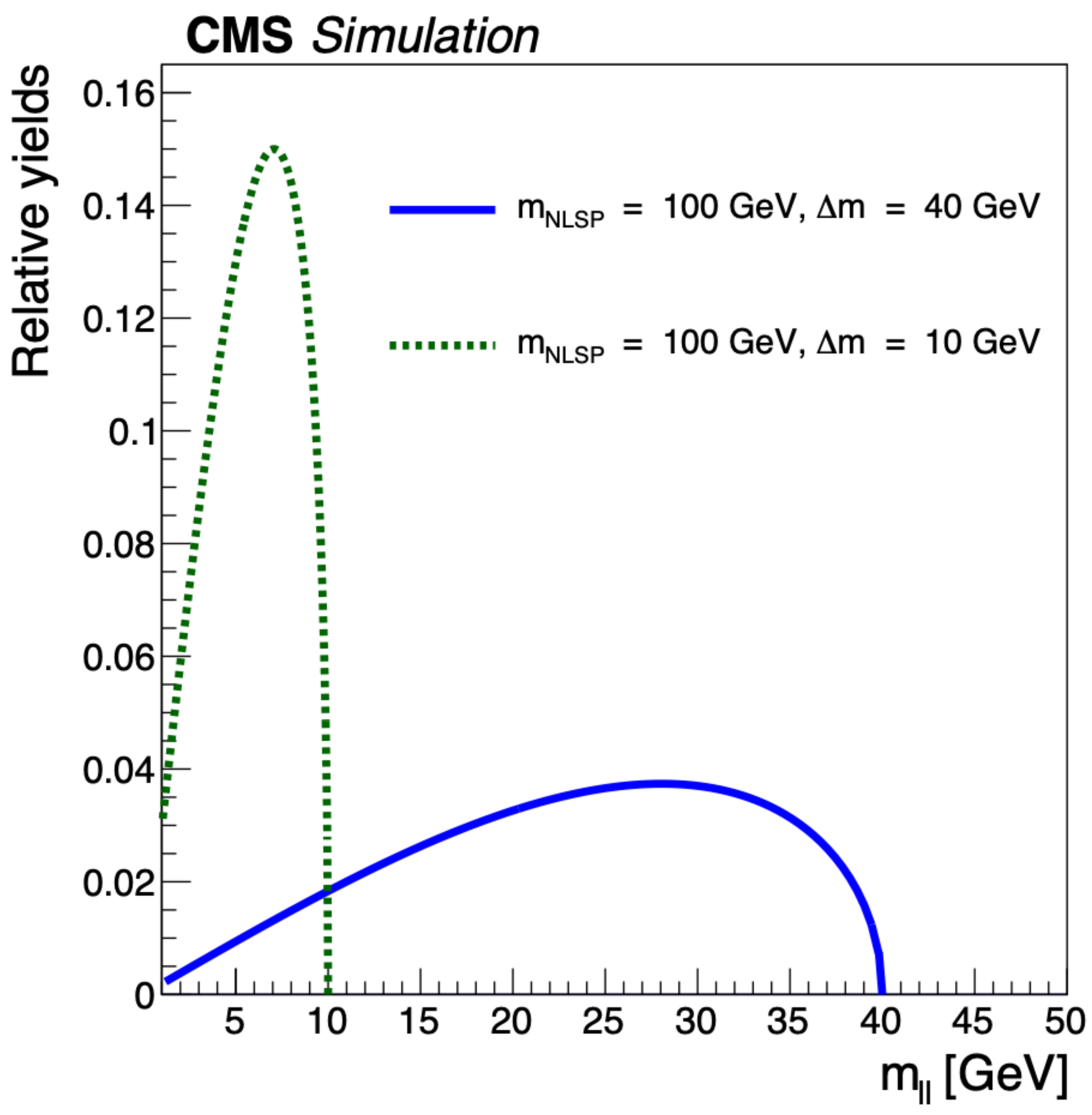
Sleptons



SUS-21-008
arXiv:2402.01888

- Combination of several searches of **electroweak SUSY** in different final states.
- Targets both **compressed and uncompressed SUSY**.
- Example final states included:
  - One lepton, 2 b jets and p_T^{miss}.
  - Oppositely charged same-flavor lepton pair and p_T^{miss}.
  - **2 or 3 soft leptons and jets**.

Search for 2 or 3 Soft Leptons - Strategy

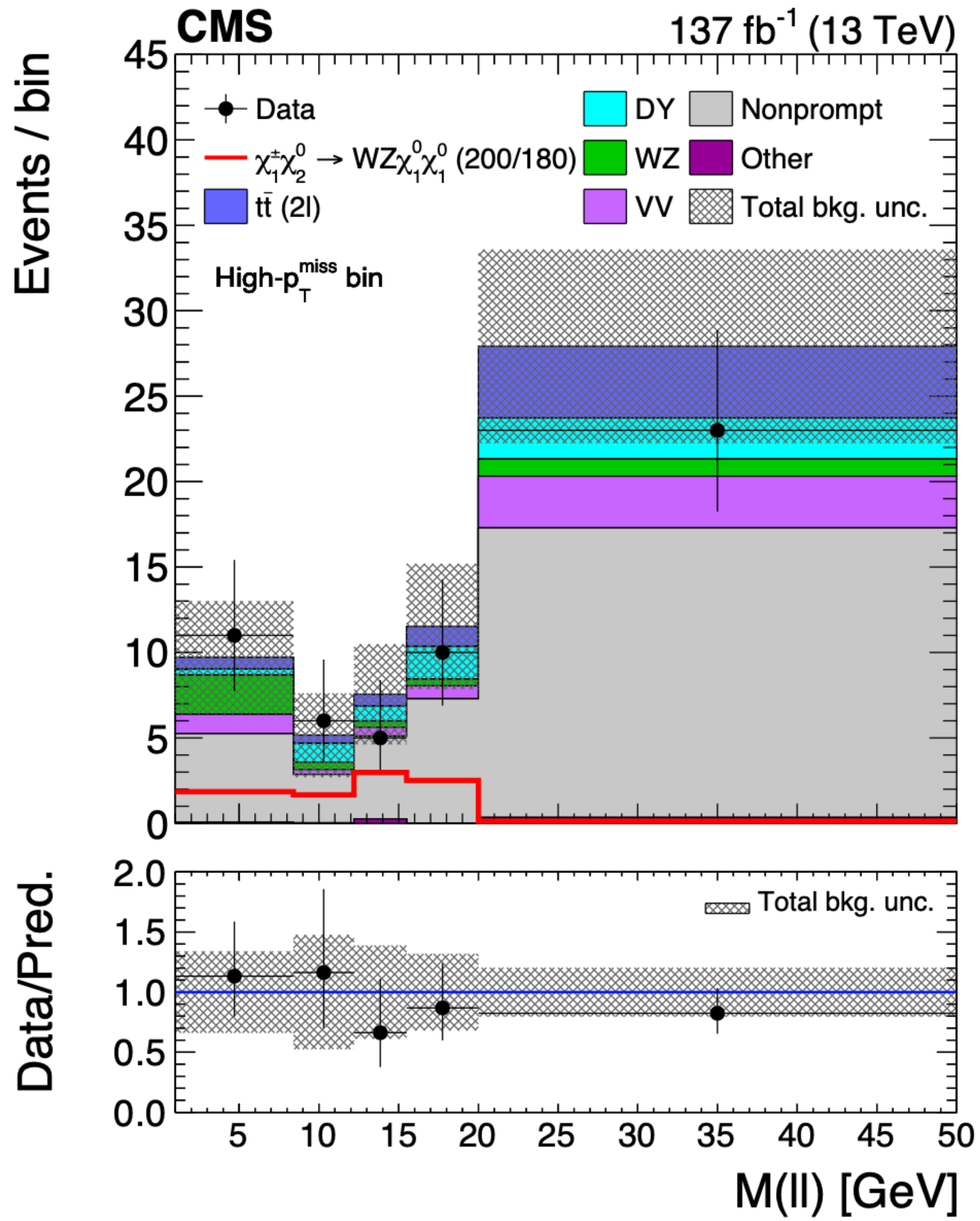


$$M_{\mathrm{T2}}(m_{\tilde{\chi}}) = \min_{\vec{p}_{\mathrm{T}}^{\tilde{\chi}(1)} + \vec{p}_{\mathrm{T}}^{\tilde{\chi}(2)} = \vec{p}_{\mathrm{T}}^{\mathrm{miss}}} \left[\max \left(M_{\mathrm{T}}^{(1)}, M_{\mathrm{T}}^{(2)} \right) \right]$$

- At least one OSSF lepton pair, jets and p_T^{miss}:
  - $p_T < 30$ GeV, with min value at 3.5 (5) GeV for muons (electrons).
- Discriminating Variables: $m_{\ell\ell}$ (electroweakino) and m_{T2} (sleptons).
- Background Suppression: Exclude specific $m_{\ell\ell}$ ranges to veto J/Ψ and Υ.

SR	Low-$p_{\mathrm{T}}^{\mathrm{miss}}$	Med-$p_{\mathrm{T}}^{\mathrm{miss}}$	High-$p_{\mathrm{T}}^{\mathrm{miss}}$	Ultrahigh-$p_{\mathrm{T}}^{\mathrm{miss}}$
	$p_{\mathrm{T}}^{\mathrm{miss,\ corr}}$	$p_{\mathrm{T}}^{\mathrm{miss,\ corr}}$	$p_{\mathrm{T}}^{\mathrm{miss,\ corr}}$	$p_{\mathrm{T}}^{\mathrm{miss,\ corr}}$
2ℓ soft	$[125, 200]$	$[200, 240]$	$[240, 290]$	>290
3ℓ soft	$[125, 200]$		>200	

Search for 2 or 3 Soft Leptons - Strategy



- At least one OSSF lepton pair, jets and p_T^{miss}:
  - $p_T < 30$ GeV, with min value at 3.5 (5) GeV for muons (electrons).
- Discriminating Variables: $m_{\ell\ell}$ (electroweakino) and m_{T2} (sleptons).
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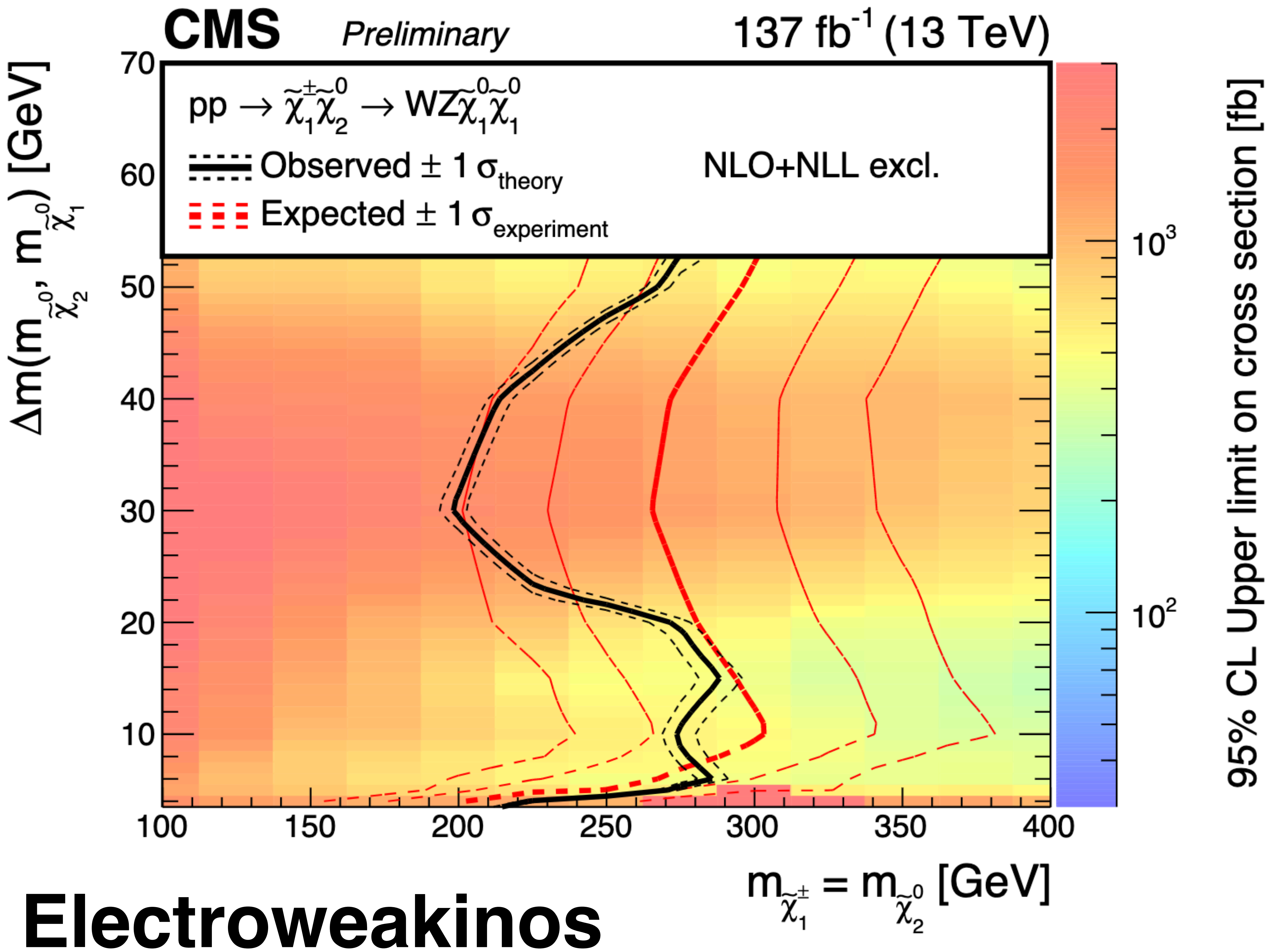
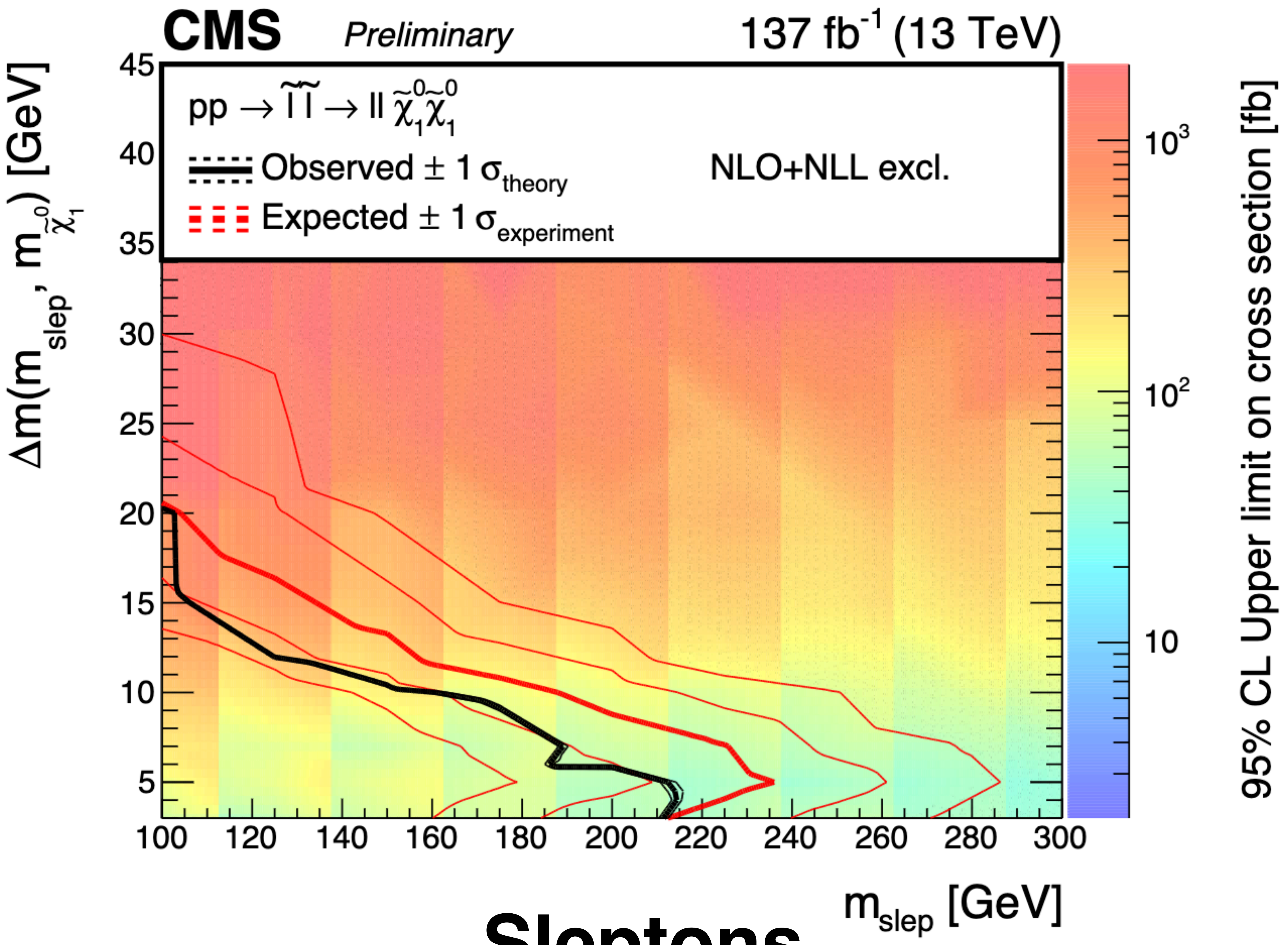
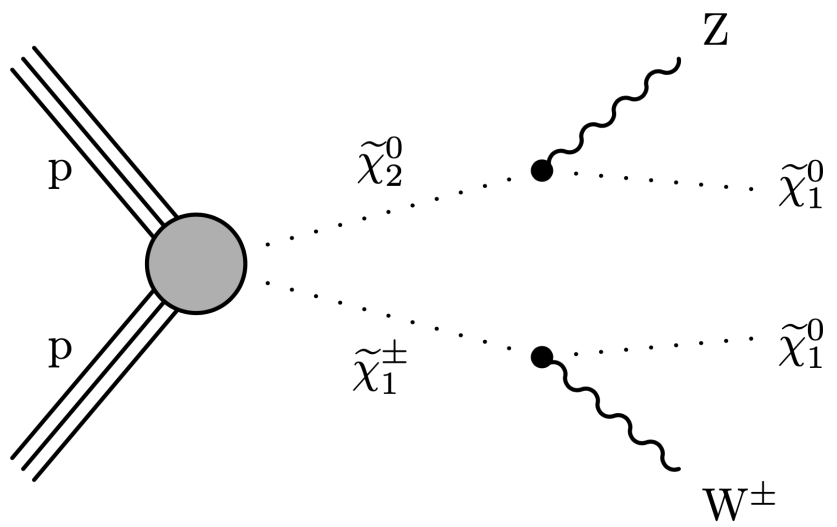
SR	Low-p_T^{miss}	Med-p_T^{miss}	High-p_T^{miss}	Ultrahigh-p_T^{miss}
	$p_T^{miss, corr}$	$p_T^{miss, corr}$	$p_T^{miss, corr}$	$p_T^{miss, corr}$
2ℓ soft	$[125, 200]$	$[200, 240]$	$[240, 290]$	>290
3ℓ soft	$[125, 200]$		>200	

Search for 2 or 3 "Soft" Leptons - Results

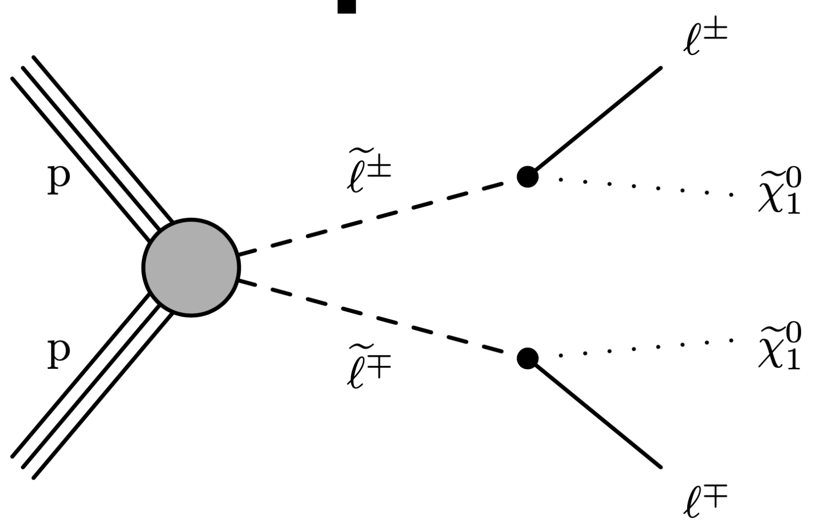




Electroweakinos



Sleptons



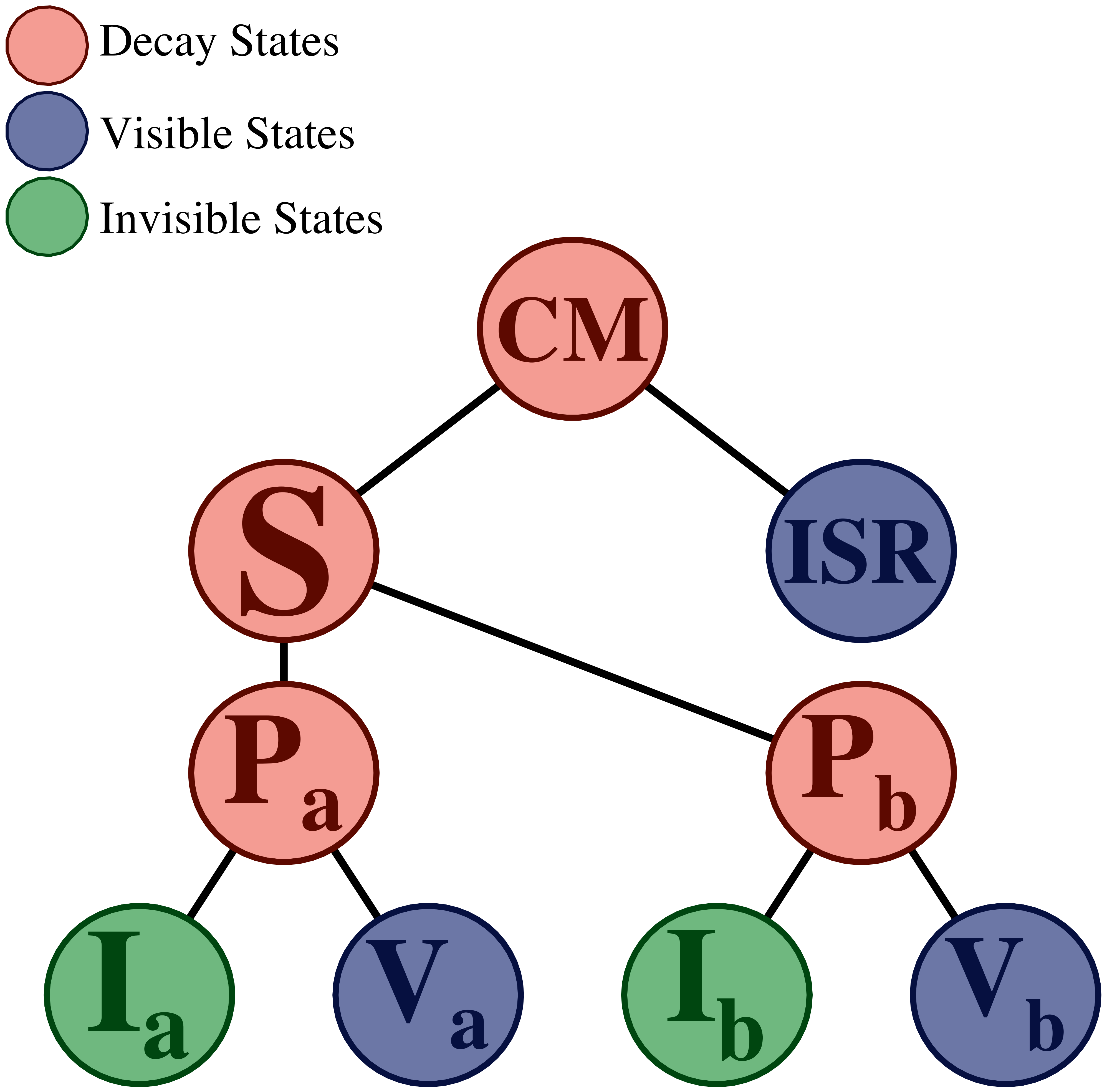
New Analysis Strategy on CMS Using RJR

Results not yet available

General Search For SUSY With RJR

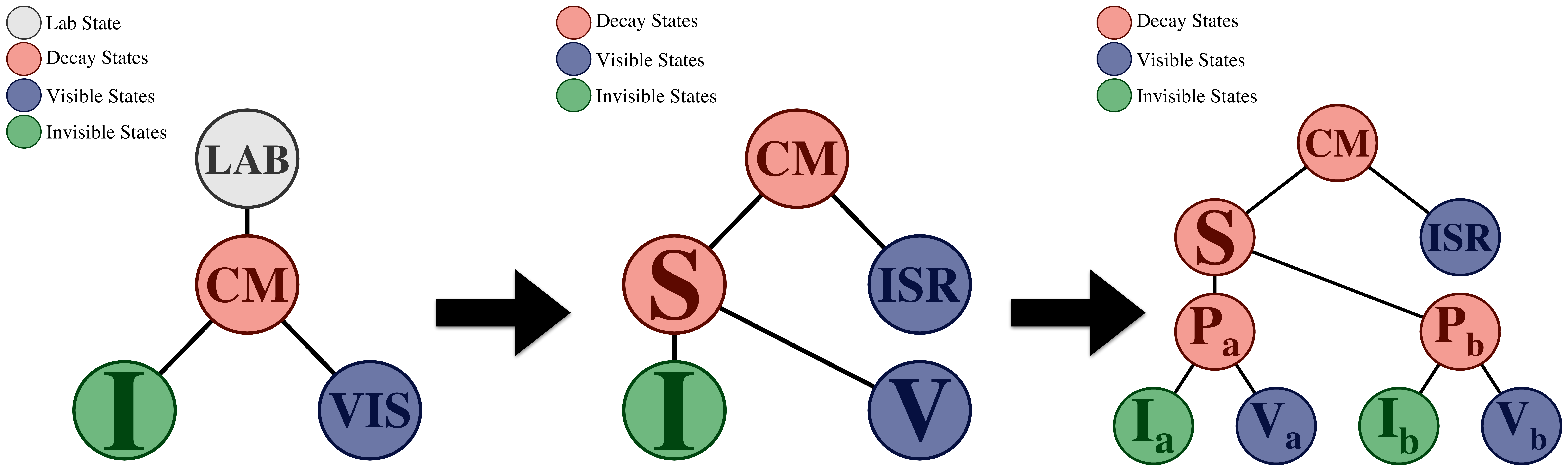
- General search for compressed SUSY using **recursive jigsaw reconstruction** (**RJR**):
  - **Novel analysis strategy** on CMS:
    - Simultaneous search for **many signal models in any final state** (0, 1, 2 and 3 leptons + jets).
    - Allows for definition of signal variables that **exploit compressed SUSY characteristics**.
  - Relevant objects (**soft visible objects and p_T^{miss}**):
    - **leptons** (p_T as low as 3 GeV for muons), **b-tagged jets** and **soft secondary-vertices** (uses **custom made NN** to tag SVs with $2 \leq p_T < 20$ GeV).

General Search For SUSY With RJR



- **General signal template** with compressed SUSY characteristics:
  - Viewed from **center-of-mass system**.
  - **Sparticle system** (S) recoiling from ISR radiation.
  - Sparticle system decays into **pair of sparticles** (**$P_{a/b}$**).
  - Each **parent** decays into an **invisible** ($I_{a/b}$) and a **visible** ($V_{a/b}$) system.
- Set of **kinematic** and **combinatoric unknowns** resolved with **RJR**.

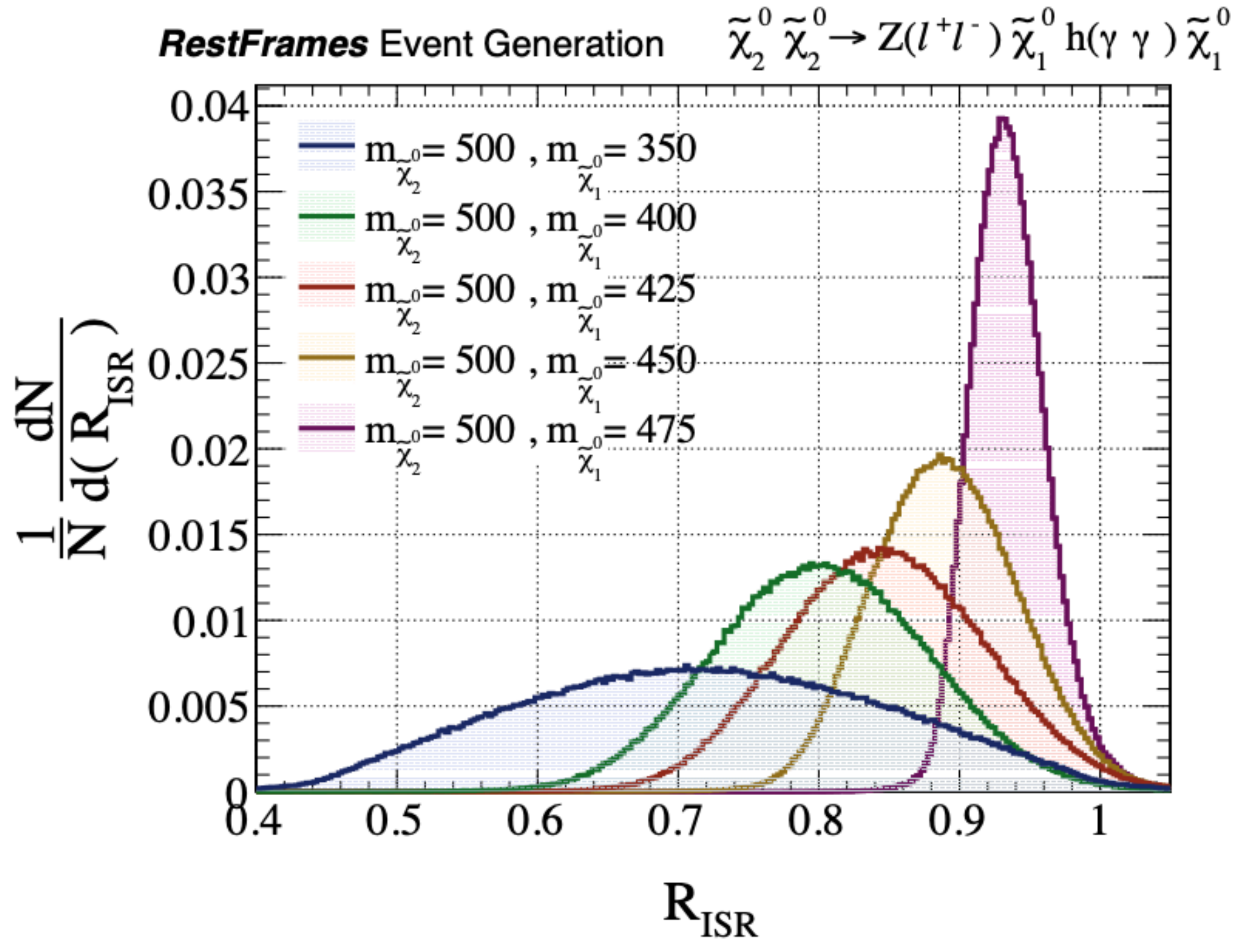
Event Model: The RJR Algorithm

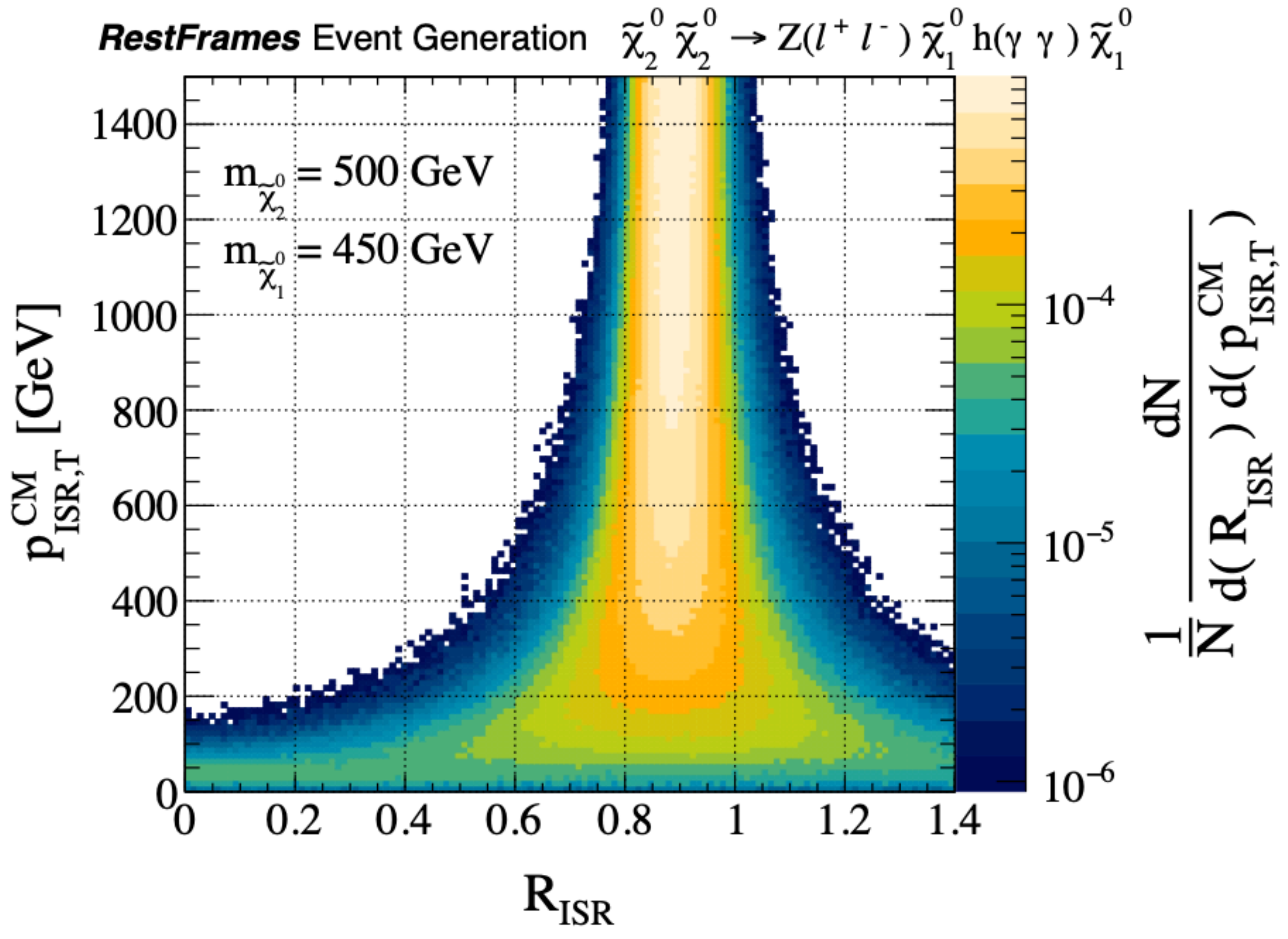


Transform from lab to CM frame

Distribute visible objects between ISR and S

Assign visible objects to $V_{a/b}$ systems

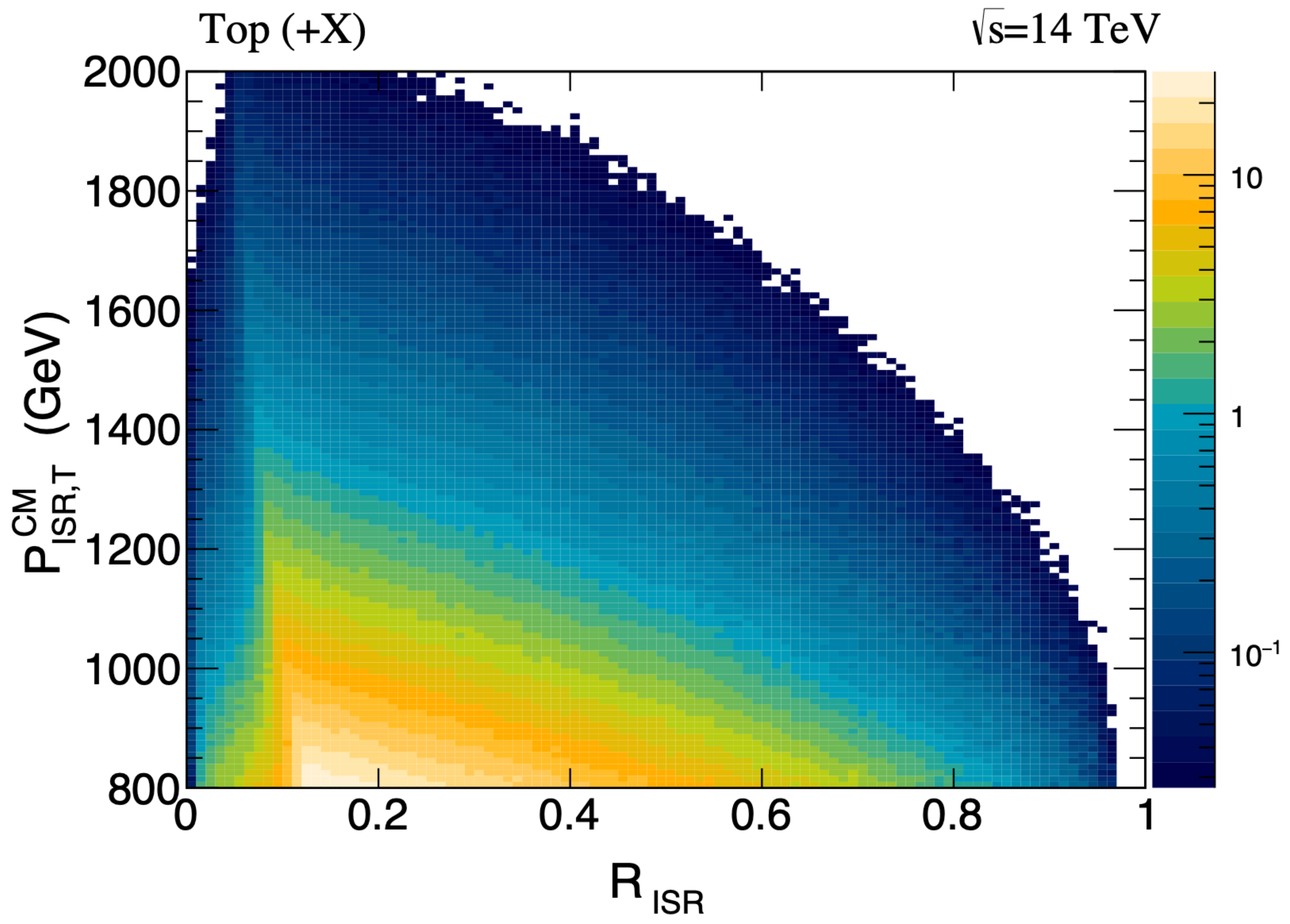




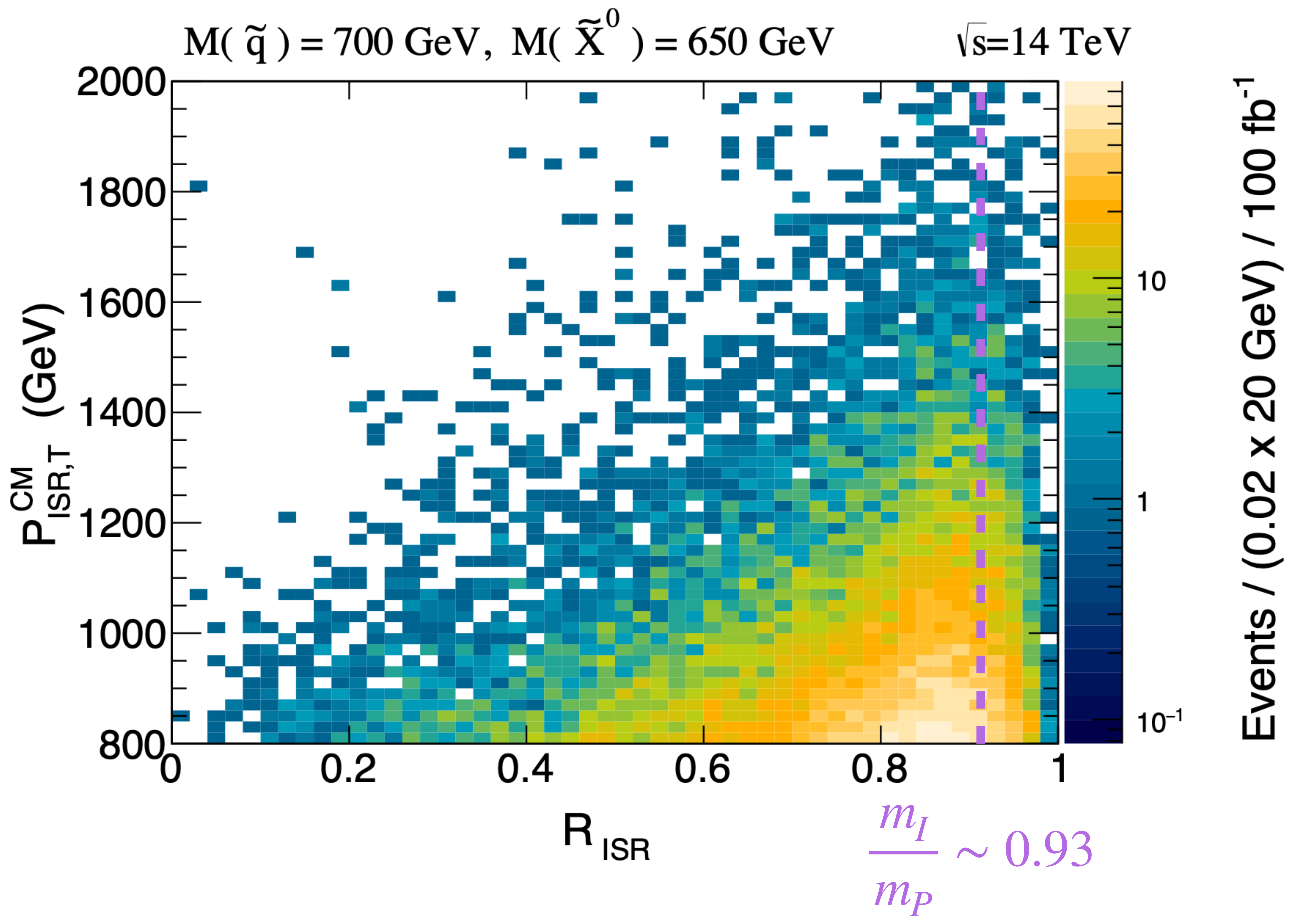
- Take advantage of **features of compressed SUSY** at the CM frame:
  - **Correlation between the ISR system and the** $\vec{p}_T^{\,miss}$ of the event:

$$\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} \sim \frac{m_{\mathbf{I}}}{m_{\mathbf{P}}} \vec{p}_{\mathrm{T}}^{\,\mathrm{ISR}} \quad \rightarrow \quad R_{\mathrm{ISR}} = \frac{\left|\vec{p}_{\mathbf{I}}^{\,\mathbf{CM}} \cdot \hat{p}_{\mathbf{ISR}}^{\,\mathbf{CM}}\right|}{\left|\vec{p}_{\mathbf{ISR}}^{\,\mathbf{CM}}\right|} \sim \frac{m_{\mathbf{I}}}{m_{\mathbf{P}}}$$

Phys. Rev. D 95, 035031 (2017)



Background



Signal

Summary

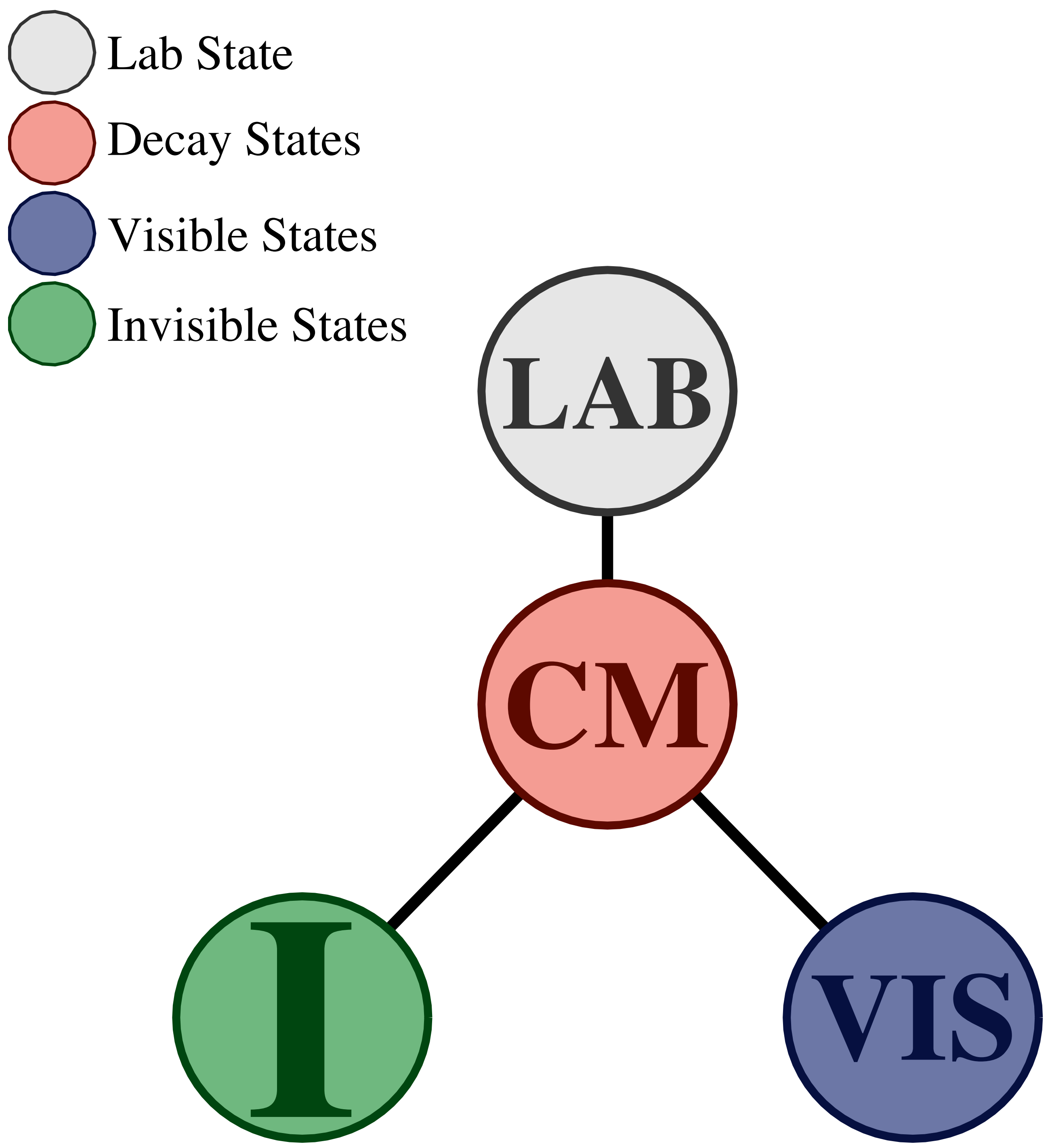
- Compressed SUSY is compelling and **theoretically well-motivated**.
- **Difficulties** associated with compressed SUSY **can be mitigated**:
  - Require **ISR radiation** in the event.
  - Use specialized **soft b/SV tagging algorithms**.
- **RJR Analysis**: Generically sensitive for many signal models, in every final state:
  - Analysis On CMS Data Underway!

Backup

Search for Top Squarks: Low Δm Search Regions

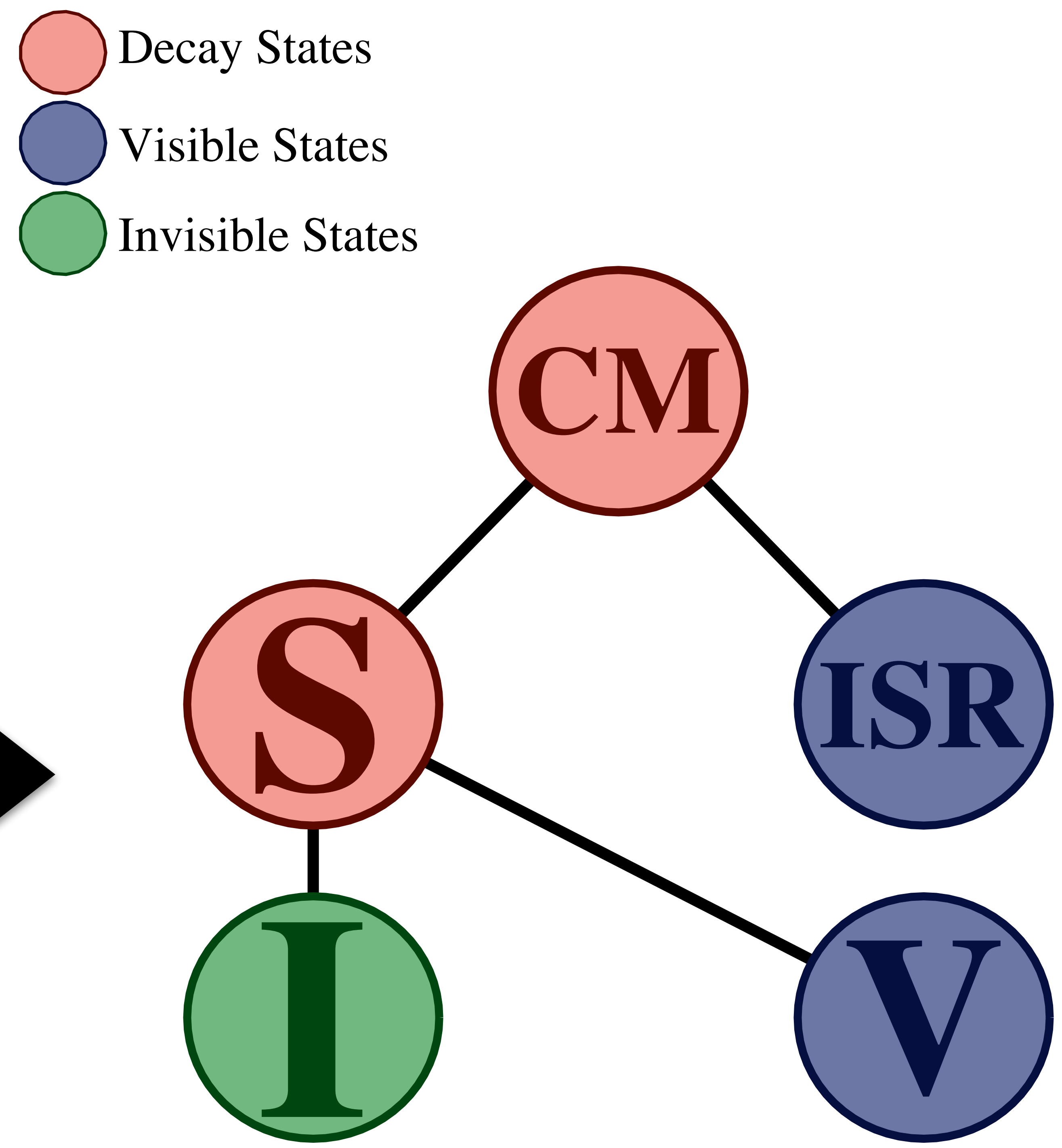
N_j	N_b	N_{SV}	m_T^b [GeV]	p_T^{ISR} [GeV]	p_T^b [GeV]	p_T^{miss} [GeV]	Bin number
2–5	0	0	—	>500	—	[450, 550, 650, 750, ∞]	0–3
≥6	0	0	—	>500	—	[450, 550, 650, 750, ∞]	4–7
2–5	0	≥1	—	>500	—	[450, 550, 650, 750, ∞]	8–11
≥6	0	≥1	—	>500	—	[450, 550, 650, 750, ∞]	12–15
≥2	1	0	<175	300–500	20–40	[300, 400, 500, 600, ∞]	16–19
≥2	1	0	<175	300–500	40–70	[300, 400, 500, 600, ∞]	20–23
≥2	1	0	<175	>500	20–40	[450, 550, 650, 750, ∞]	24–27
≥2	1	0	<175	>500	40–70	[450, 550, 650, 750, ∞]	28–31
≥2	1	≥1	<175	>300	20–40	[300, 400, 500, ∞]	32–34
≥2	≥2	—	<175	300–500	40–80	[300, 400, 500, ∞]	35–37
≥2	≥2	—	<175	300–500	80–140	[300, 400, 500, ∞]	38–40
≥7	≥2	—	<175	300–500	>140	[300, 400, 500, ∞]	41–43
≥2	≥2	—	<175	>500	40–80	[450, 550, 650, ∞]	44–46
≥2	≥2	—	<175	>500	80–140	[450, 550, 650, ∞]	47–49
≥7	≥2	—	<175	>300	>140	[450, 550, 650, ∞]	50–52

Event Model: The RJR Algorithm



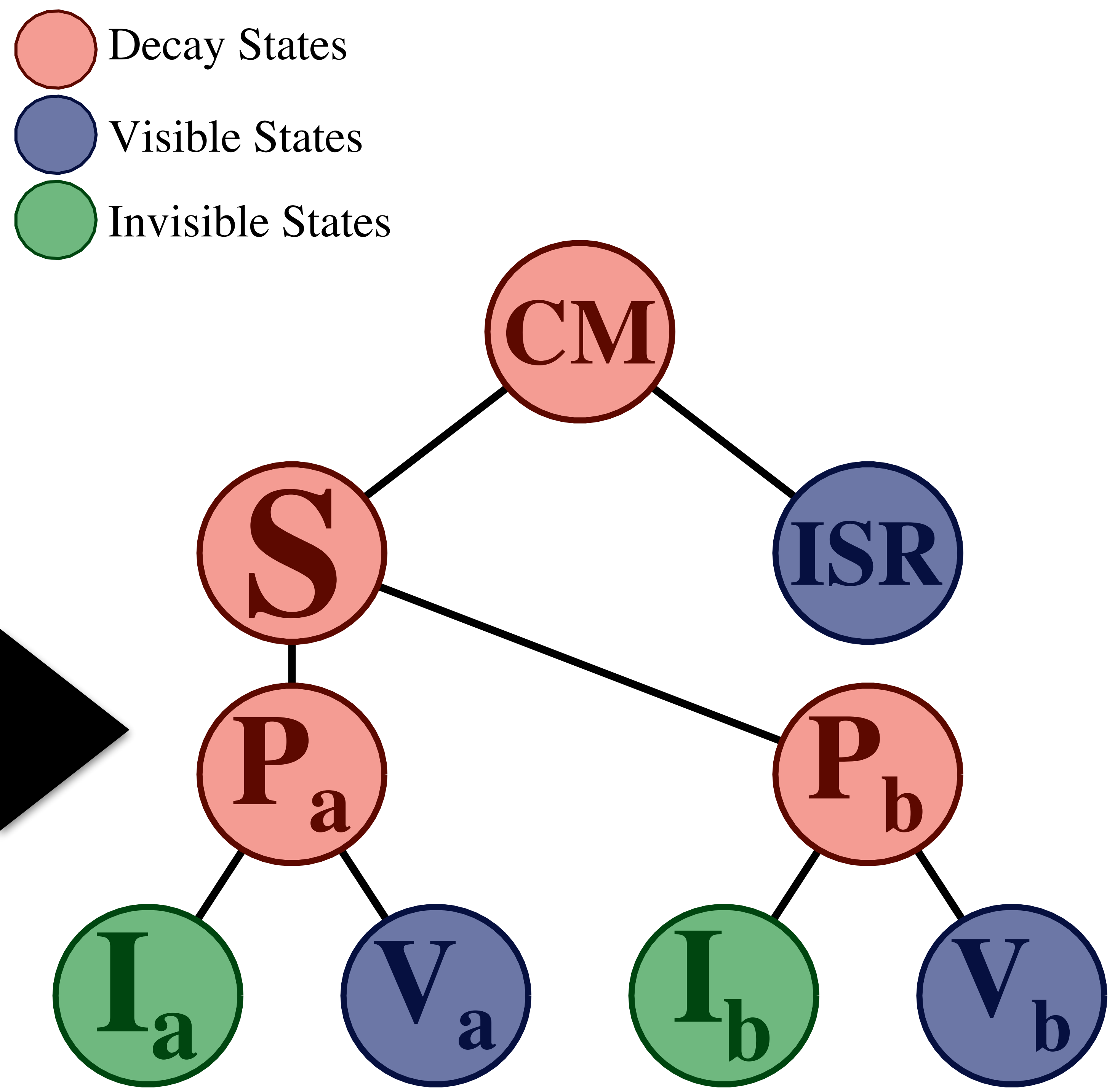
Transform from lab to CM frame

$$\hat{\beta}^{\mathbf{lab}}_{\mathbf{CM},z} = \underset{\beta^{\mathbf{lab}}_{\mathbf{CM},z}}{\text{argmin}}\, M_{\mathbf{CM}}$$



Distribute visible objects between ISR and S

$$\{\mathbf{V},\mathbf{ISR}\} = \underset{\mathbf{V},\mathbf{ISR}}{\text{argmax}}\, p_{\mathbf{S}}^{\mathbf{CM}}$$



Assign visible objects to $V_{a/b}$ systems

$$\{\mathbf{V}_a,\mathbf{V}_b\} = \underset{\mathbf{V}_a,\mathbf{V}_b}{\text{argmin}}\, M_{\mathbf{P}_a}^2 + M_{\mathbf{P}_b}^2$$