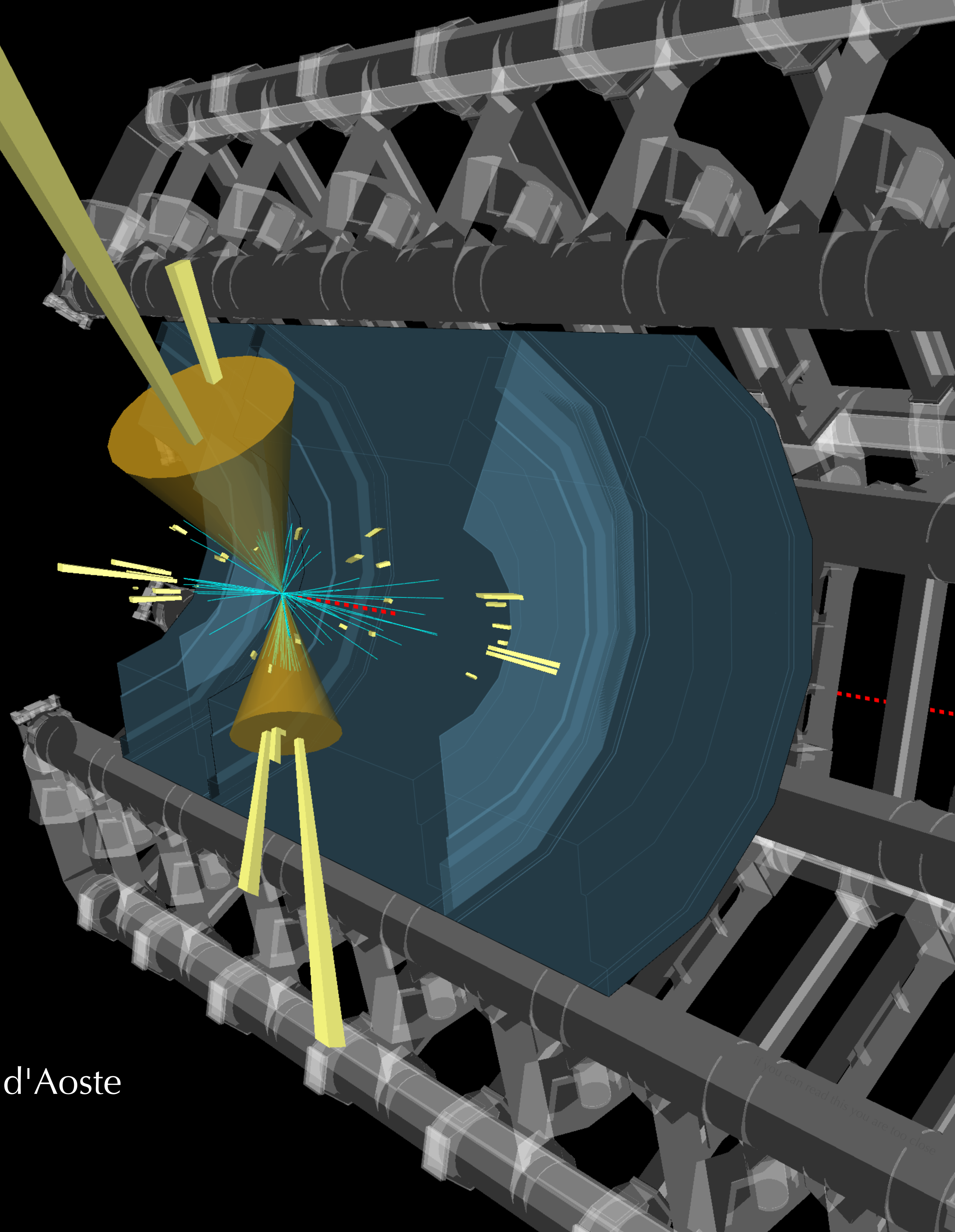
# SUSY Searches at LHC



**Shion Chen (UTokyo/ICEPP)**

o.b.o ATLAS and CMS Collaboration

La Thuile 2022
Les Rencontres de Physique de la Vallée d'Aoste

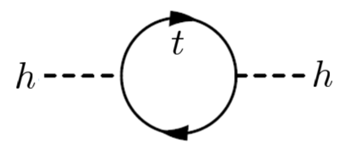
11 Mar 2022

# Why SUSY?

## Hierarchy problem

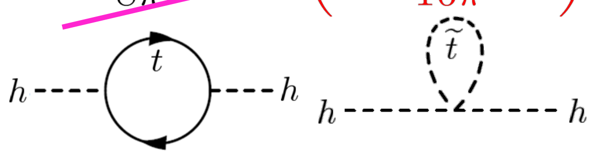
$$\mathrm{SM}:\ \Delta m^2_{\mathrm{higgs}} \sim -\frac{3|\lambda|^2}{8\pi^2}\Lambda^2 + \mathrm{finite}$$

**$10^{38}$?**



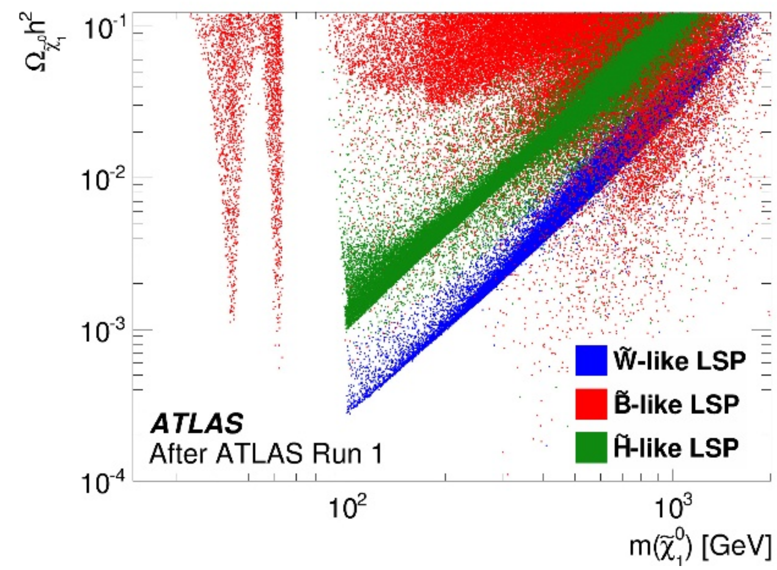
CANCEL

$$\mathrm{MSSM}:\ \Delta m^2_{\mathrm{higgs}} \sim -\frac{3|\lambda|^2}{8\pi^2}\Lambda^2 + \left(2\times\frac{3|\lambda|^2}{16\pi^2}\Lambda^2\right) + \mathrm{O}(\log\Lambda)$$



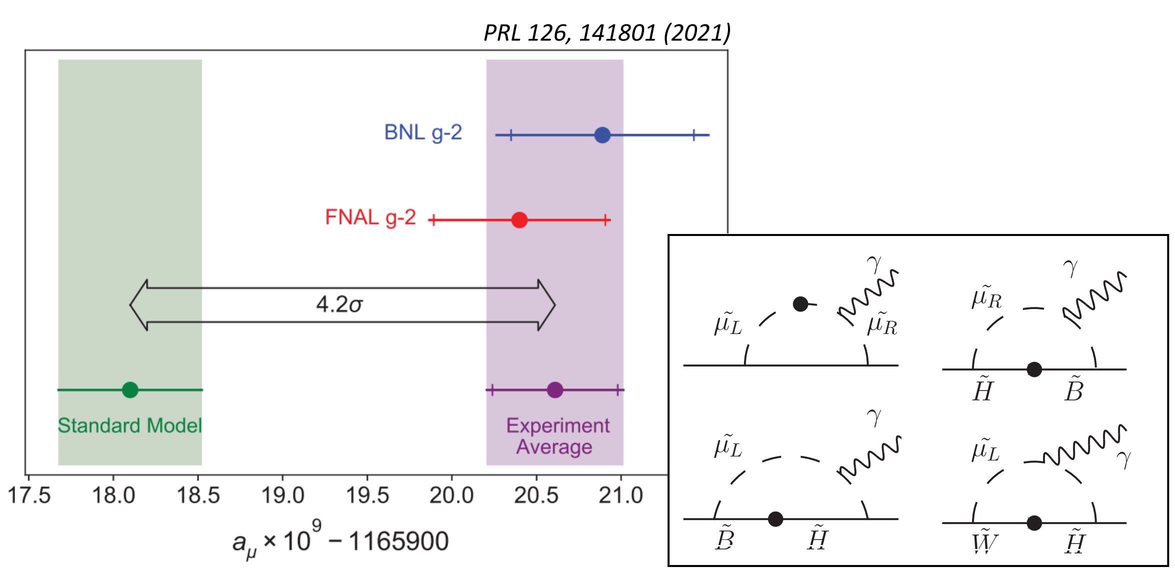
Super top = Scalar top ("stop")

## Dark matter




**Lightest SUSY particle (LSP) → DM candidate**

## Muon g-2

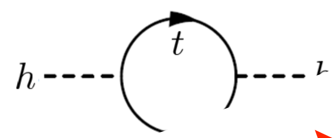



# Why SUSY?

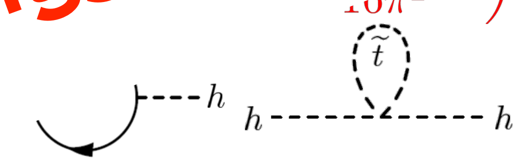
## Hierarchy problem

$$\mathrm{SM}: \Delta m^2_{\mathrm{higgs}} \sim -\frac{3|\lambda|^2}{8\pi^2}\Lambda^2 + \mathrm{finite}$$

$10^{38}$?



$\mathrm{MSSM}: \Lambda$ ... $8\pi^2 \Lambda^2 \big) + \mathrm{O}(\log \Lambda)$

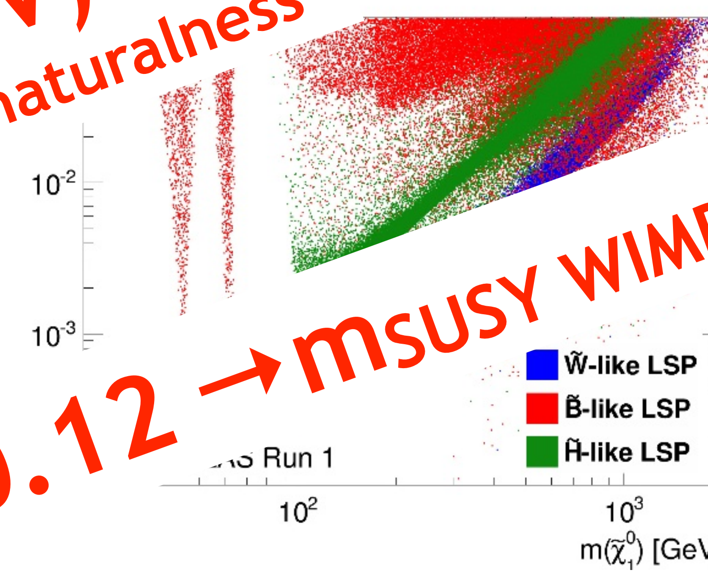


Super top = Scalar top ("stop")

125GeV higgs → mstop ~ O(1-10TeV)

※lighter if with "naturalness"

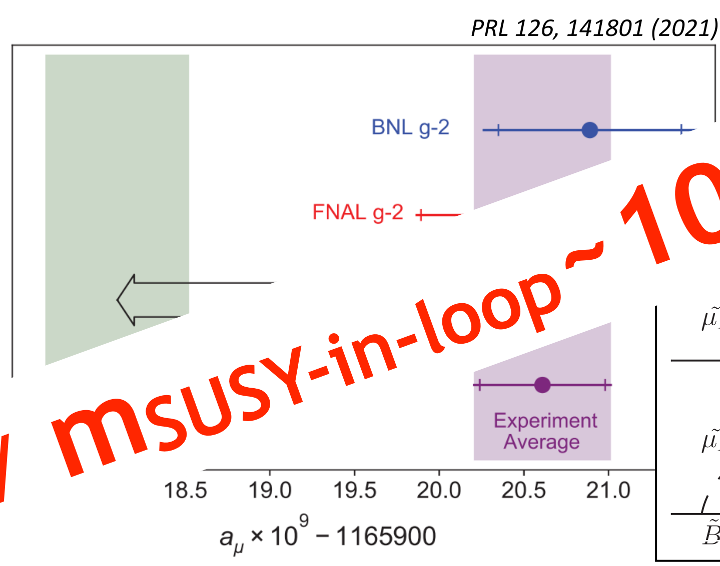
## Dark matter

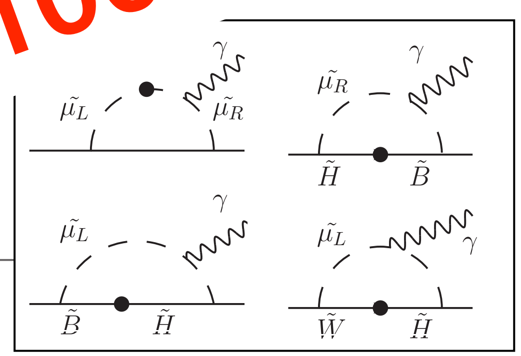



Lightest SUSY particle (LSP) → DM candidate

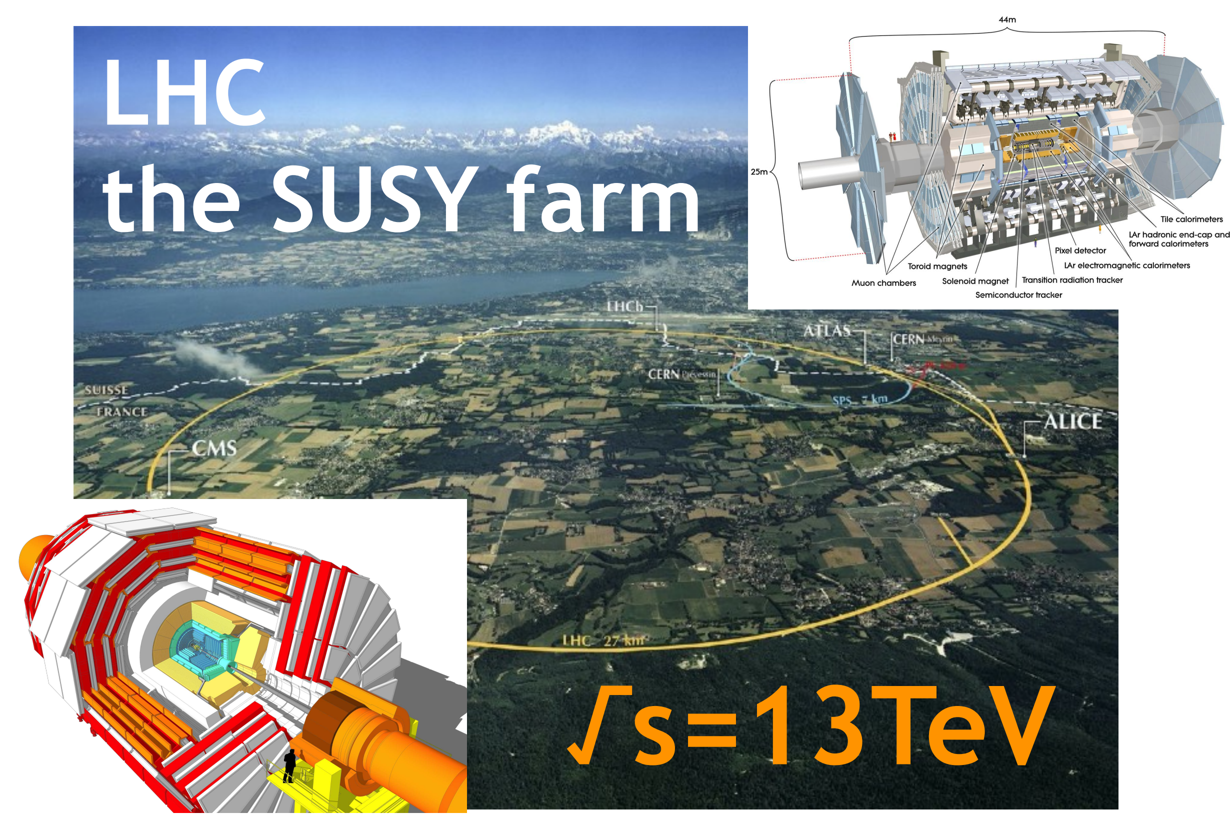
$\Omega h^2$=0.12 → mSUSY WIMP < 3TeV

## Muon g-2



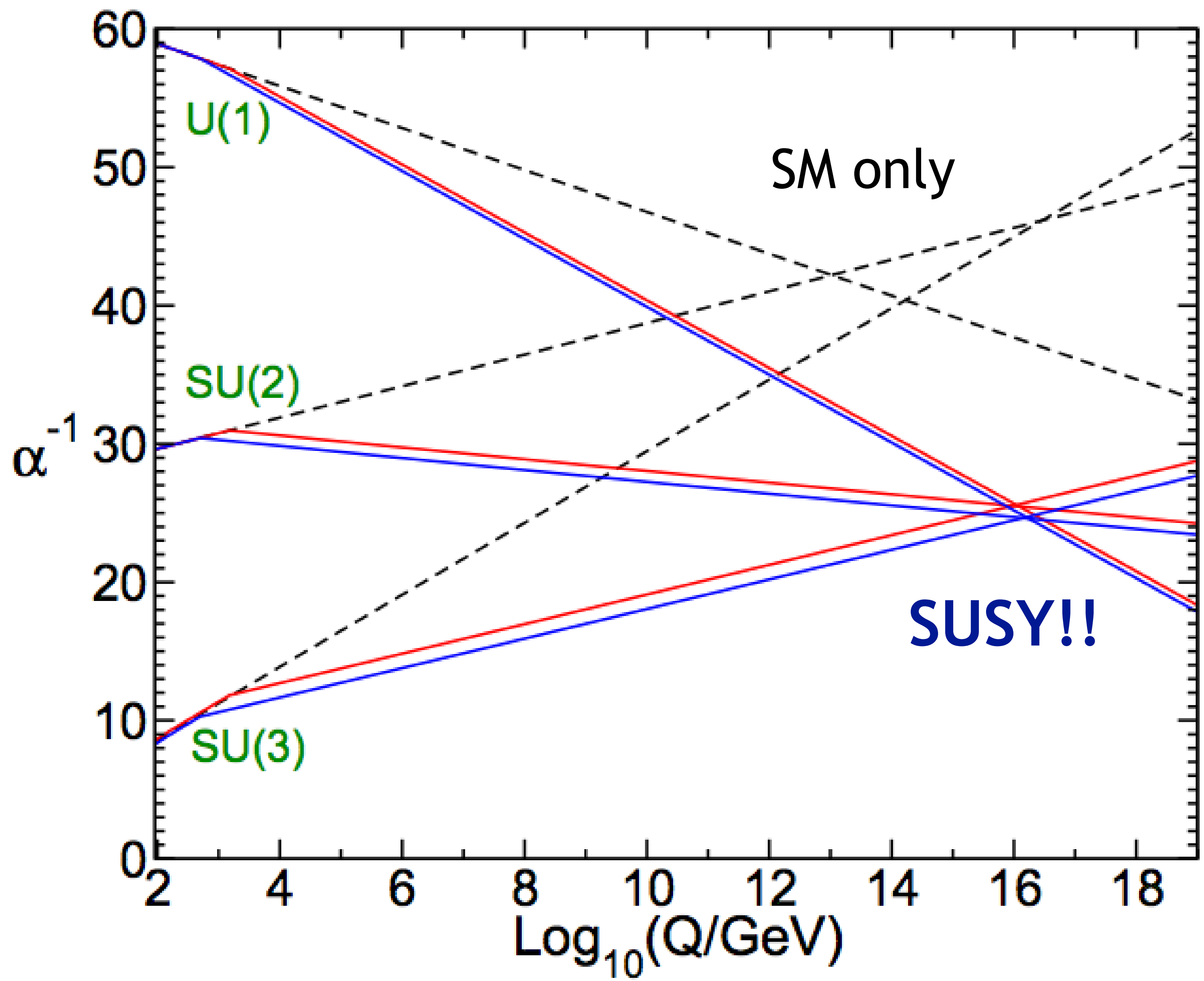




∀ mSUSY-in-loop ~100GeV-1TeV

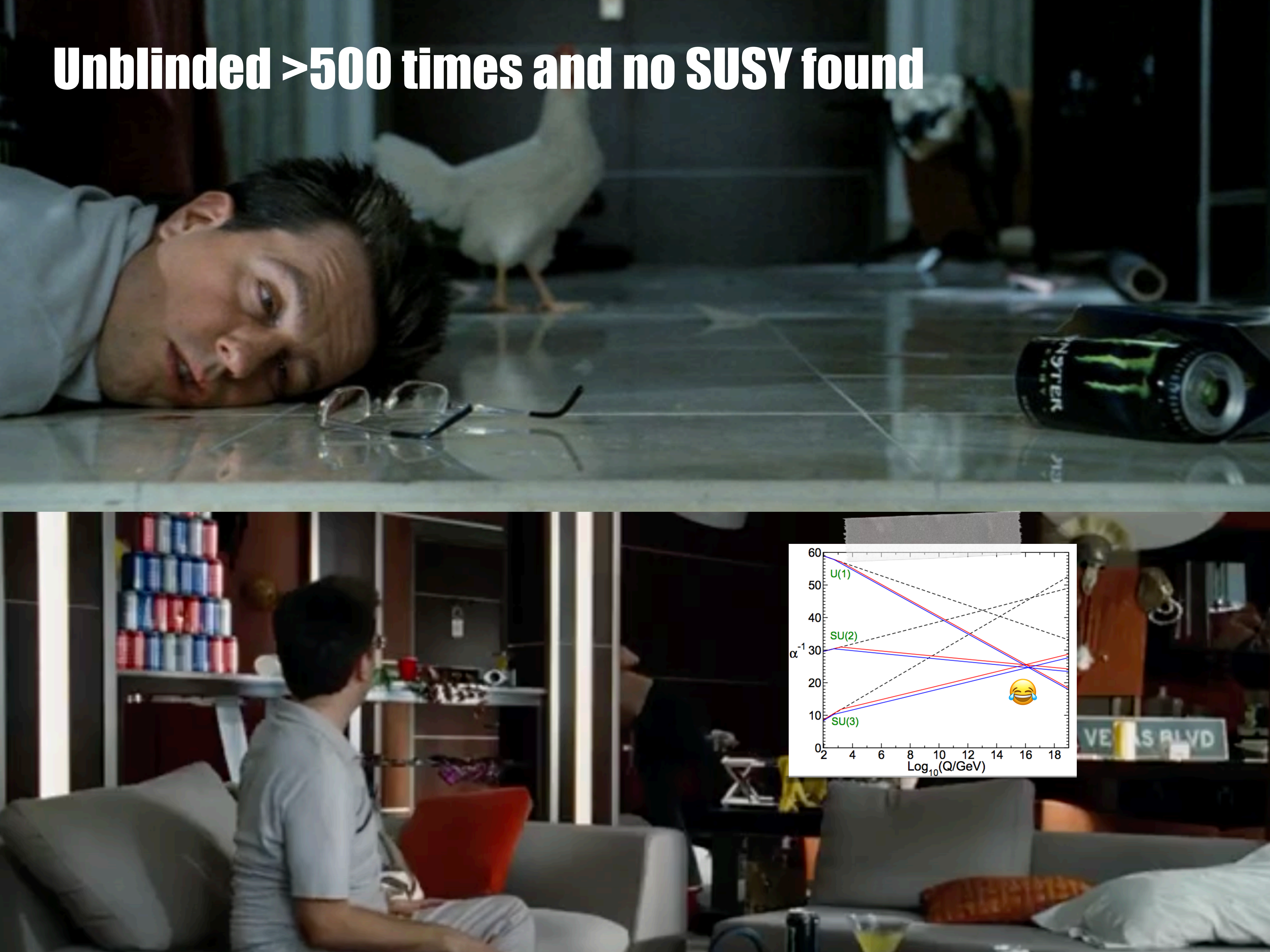


## Why SUSY is a big deal among many? → GUT

No other problem-solving models have this kind of 'coincidence'




Although this doesn't motivate light SUSY (e.g. all 10TeV is fine)


Unblinded >500 times and no SUSY found
U(1)
SU(2)
SU(3)
$\alpha^{-1}$
0
10
20
30
40
50
60
2
4
6
8
10
12
14
16
18
$\text{Log}_{10}(Q/\text{GeV})$

# Search Strategy - Signature-based analyses

$p_T^{miss}$ := transverse momentum imbalance in the event

Large σ

Low σ

## Prod. mode

- $\tilde{g}\tilde{g}$
- $\tilde{q}\tilde{q}$
- $\tilde{t}\tilde{t}$
- $\tilde{b}\tilde{b}$
- $\tilde{\chi}\tilde{\chi}$
- $\tilde{\ell}\tilde{\ell}$

### R-parity conserving (RPC) → LSP is DM

- multi-jets
- multi-leptons
- lepton(s) + jets
- tau(s)
- photon(s)
- ⋮

**Large $p_T^{miss}$ signature**

### R-partity violating (RPV) → SUSY decays into SM

- multi-jets
- lepton(s) + jets
- multi-leptons
- ⋮

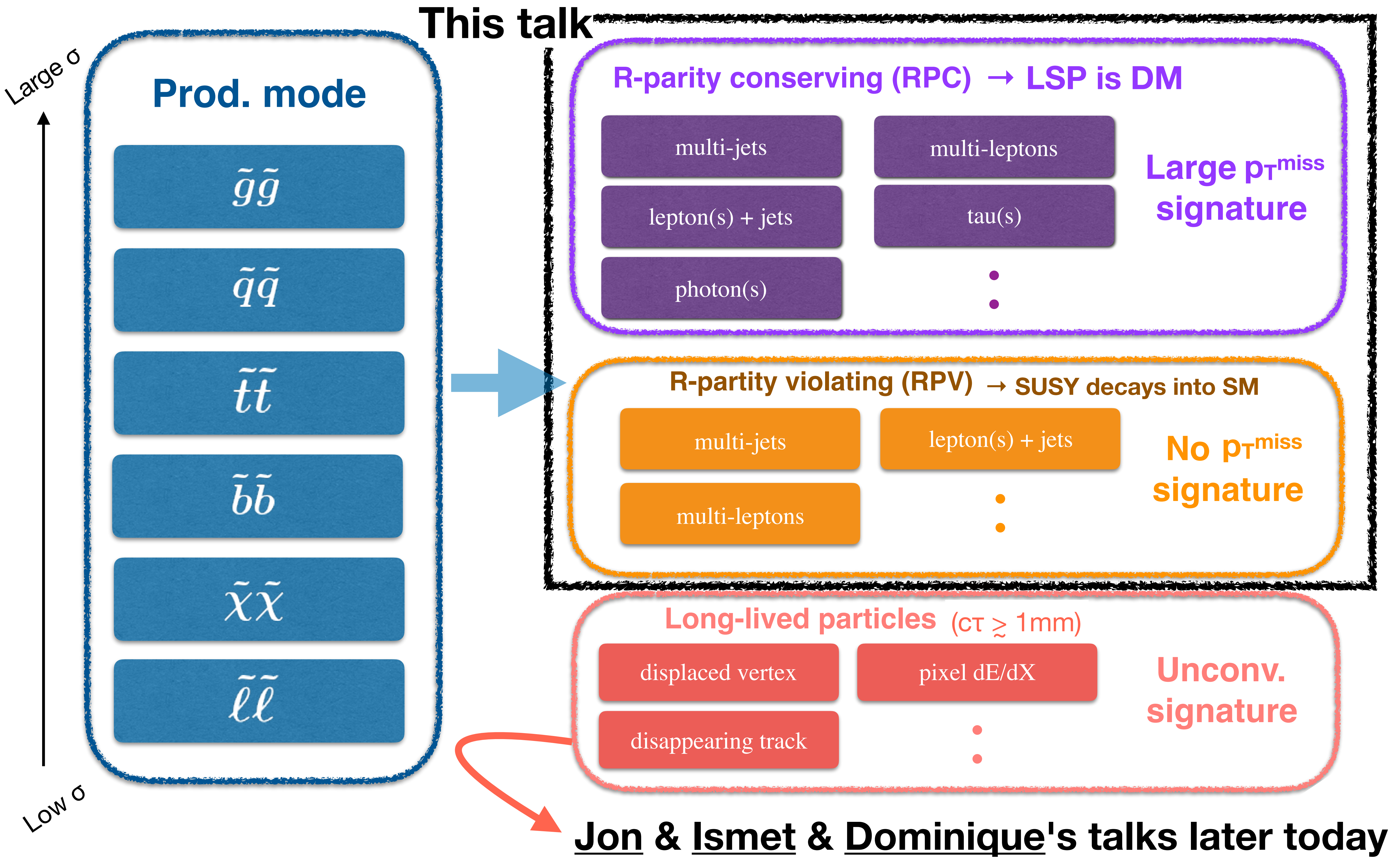
**No $p_T^{miss}$ signature**

### Long-lived particles (cτ $\gtrsim$ 1mm)

- displaced vertex
- pixel dE/dX
- disappearing track
- ⋮

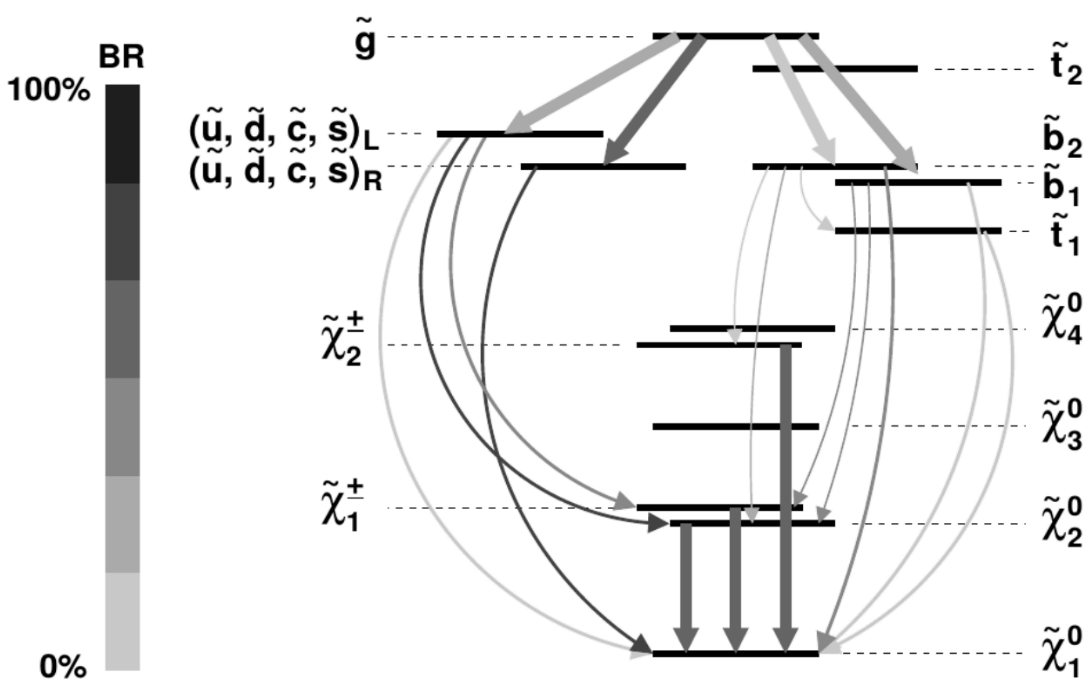
**Unconv. signature**

# Search Strategy - Signature-based analyses

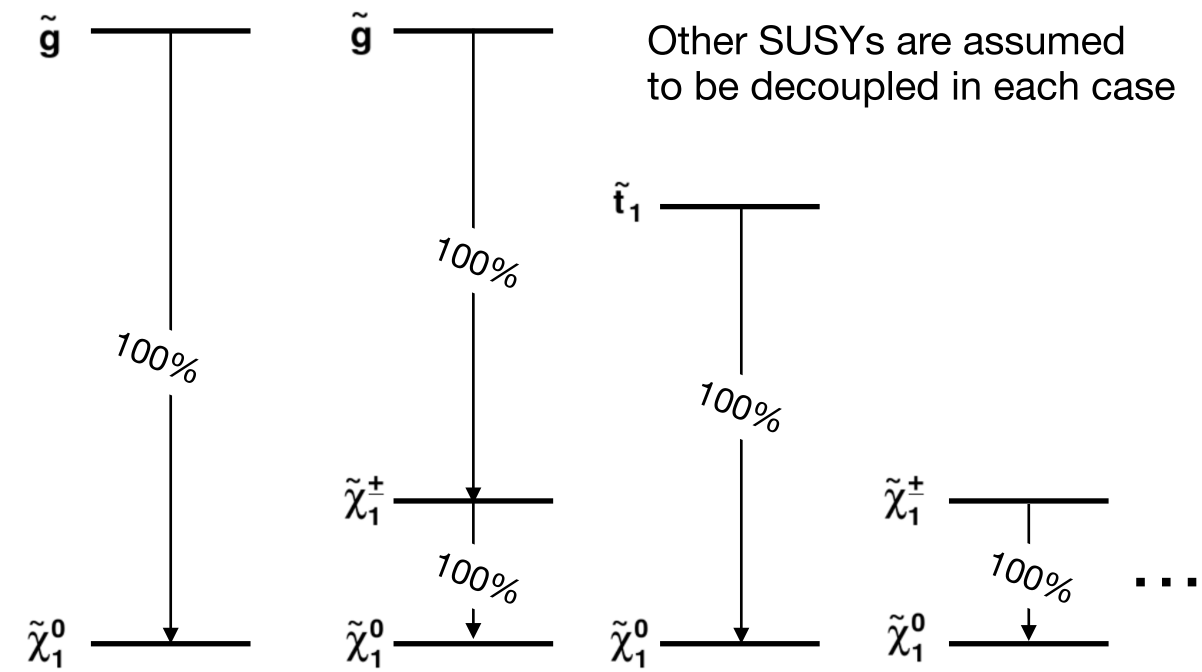


# Signal characterization → Simplified model approach

**Full model** O(100) parameters, O(10) free masses



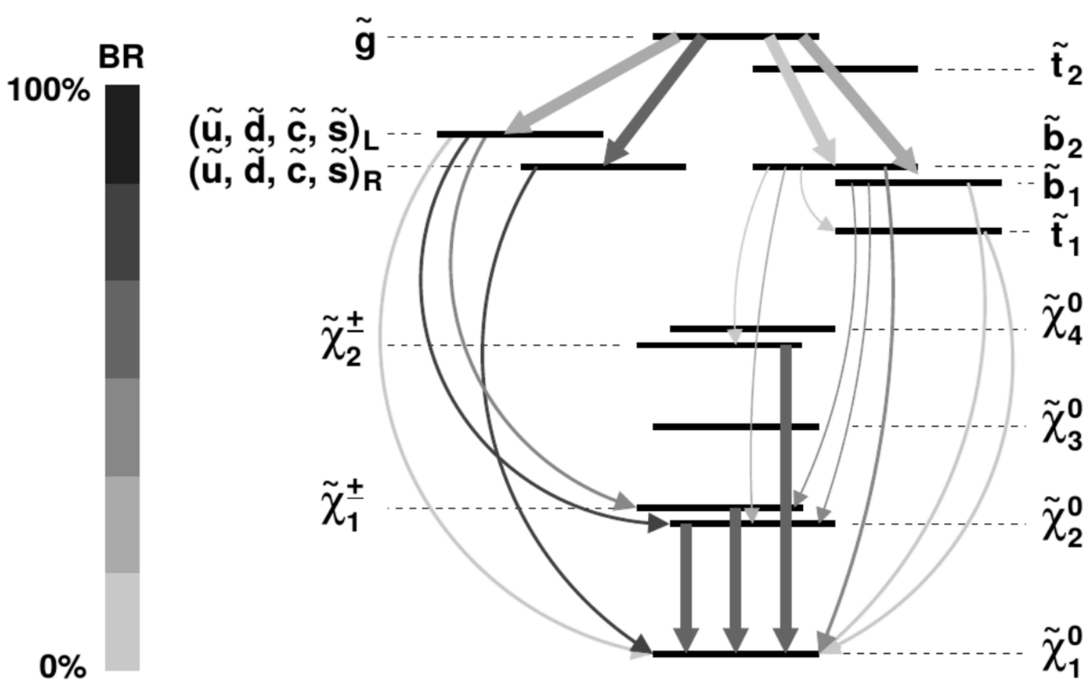

**“Simplified models”** 2-3 free mass parameters



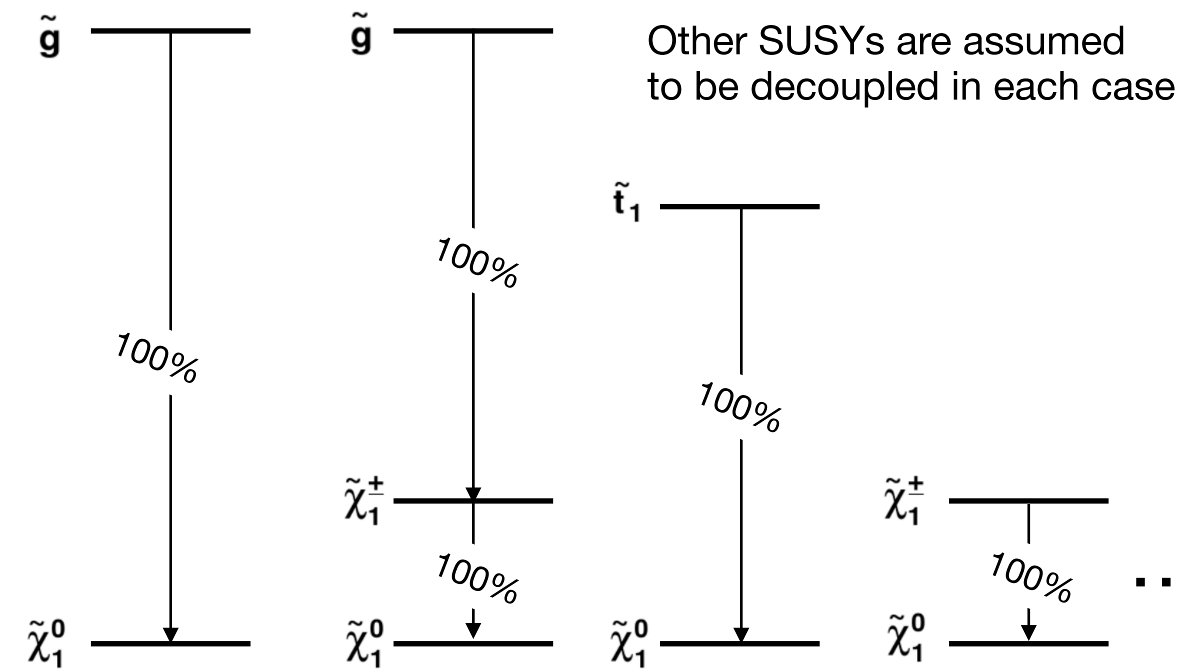

| | |
|---|---|
| **Floating masses** | **Floating masses** |
| **Floating mass hierarchy** | **Fixed mass hierarchy** |
| **Floating BRs** | **100% BRs** |
| **Multiple production modes at the same time** | **Only one production mode considered** |

# Signal characterization → Simplified model approach

**Full model** O(100) parameters, O(10) free masses




**"Simplified models"** 2-3 free mass parameters

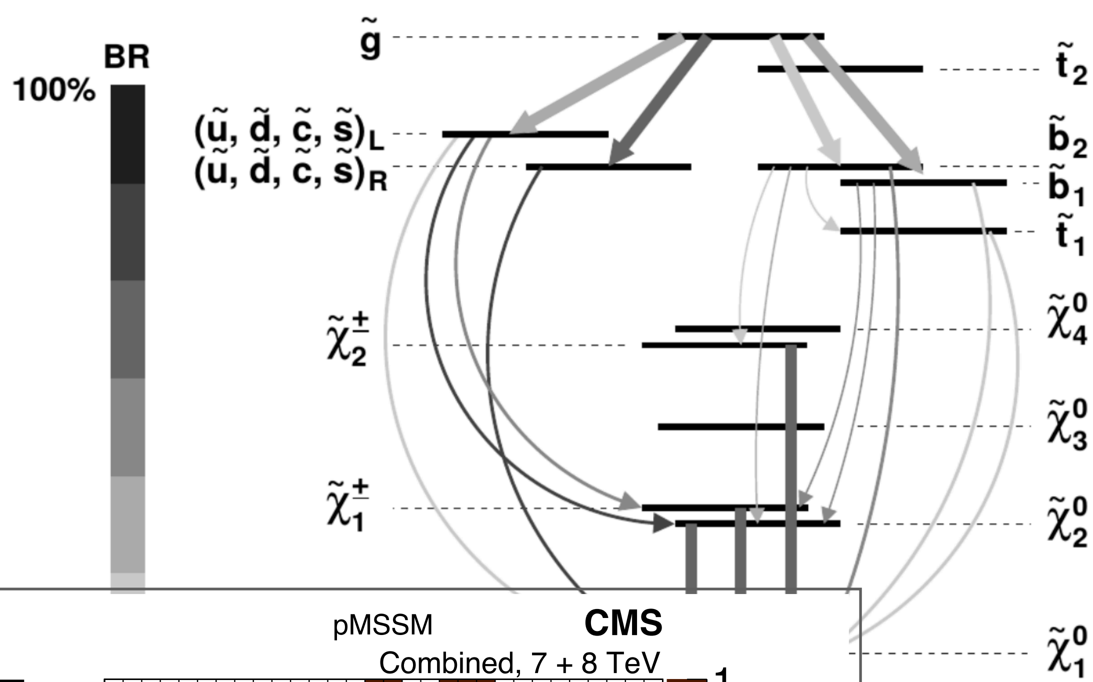


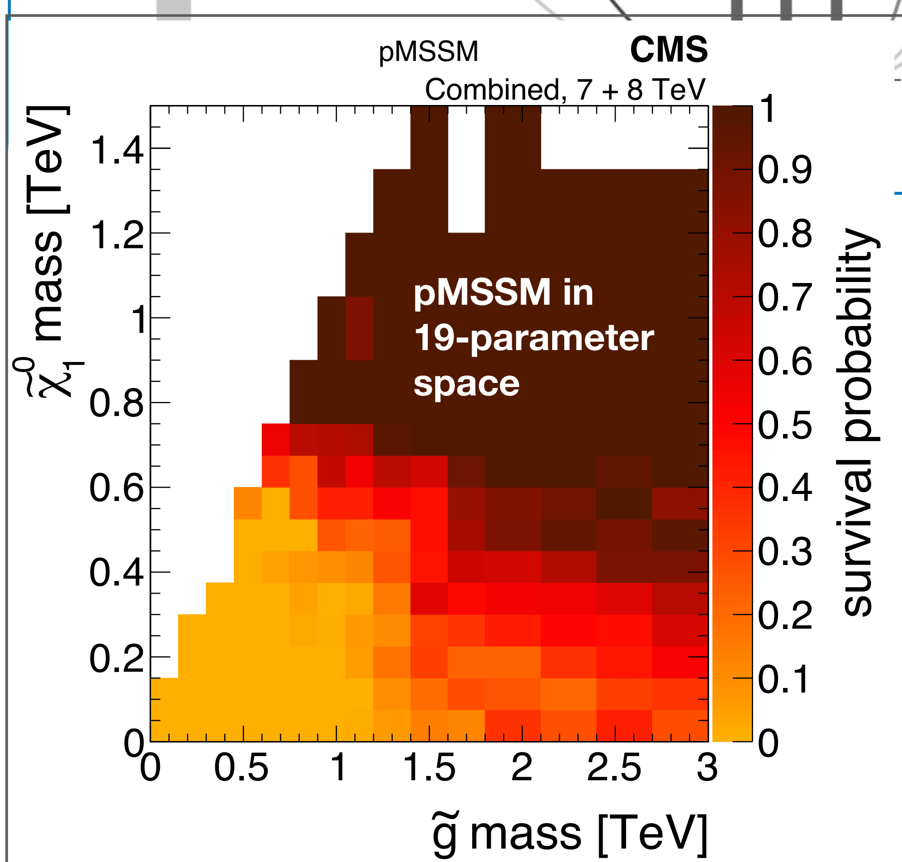

- 😃 General & realistic
- 😞 Hard to define benchmarks
  Visualize results etc.

- 😃 Easy & systematic design of analyses
- 😃 Can draw exclusion limits on "mass planes"
- 😞 Obtained limits tend to be conditional
  (i.e. **many caveats**!)

# Signal characterization → Simplified model approach

**Full model** O(100) parameters, O(10) free masses

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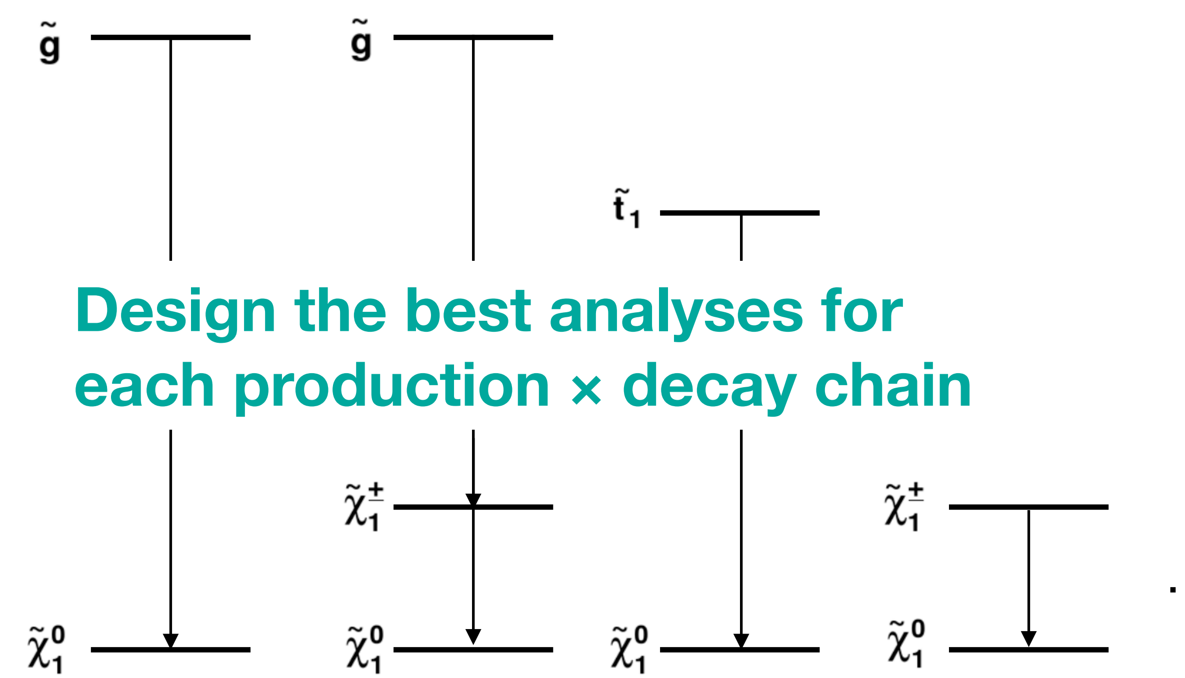



**Design the best analyses for each production × decay chain**

If no excess found

**Examine the exclusion in the (pseudo-)full model space**

Technically intense. Don't do very often.

ATLAS Run1 pMSSM
ATLAS Run1 pMSSM (WIMP DM topical)
CMS Run1 pMSSM

# Recent Results

'Recent' = First conference appearance after winter 2021

| Name | Target Signature | Ref. | Experiment |
|---|---|---|---|
| **RPC searches** | | | |
| **EWK all-hadronic** | Generic EWKino pair production | Phys. Rev. D 104 112010 (2021) (arXiv: 2108.07586) | ATLAS |
| | | CMS-PAS-SUS-21-002 | CMS |
| **EWK di-higgs 4b** | (Higgsino→h+Gravitino LSP)$^2$ etc. | arXiv: 2201.04206 | CMS |
| Stau all-hadronic | (Stau → $\tau + \tilde{\chi}_1^0$)$^2$ | CMS-PAS-SUS-21-001 | CMS |
| Photon + $p_T^{miss}$ | (Gluino→ $\tilde{\chi}_1^0$ → (γ/Z/h)+Gravitino LSP)$^2$ | ATLAS-CONF-2021-028 | ATLAS |
| Zh→2L+2b+$p_T^{miss}$ | h→ $\tilde{\chi}_1^0\tilde{\chi}_2^0$→ a$\tilde{\chi}_1^0\tilde{\chi}_1^0$ @NMSSM | JHEP 01 063 (2022) (arXiv: 2109.02447) | ATLAS |
| **RPV searches** | | | |
| **eμ-asymmetry** | RPV smuon single-prod. | arXiv: 2112.08090 | ATLAS |

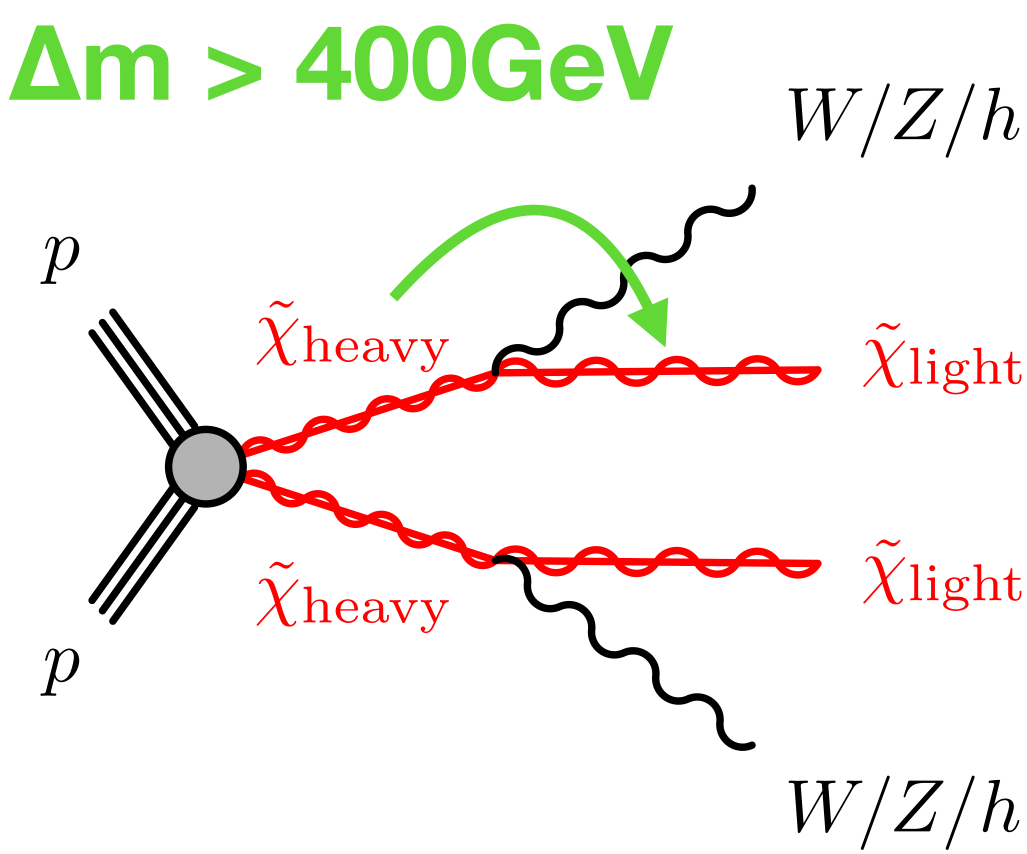
Full list of the results

ATLAS: Publication / Preliminary / Summary
CMS: Publication / Preliminary / Summary

# EWK all-had - Overview

ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002

**Target:** Generic EWKino pair production w/ large Δm(heavy, light)



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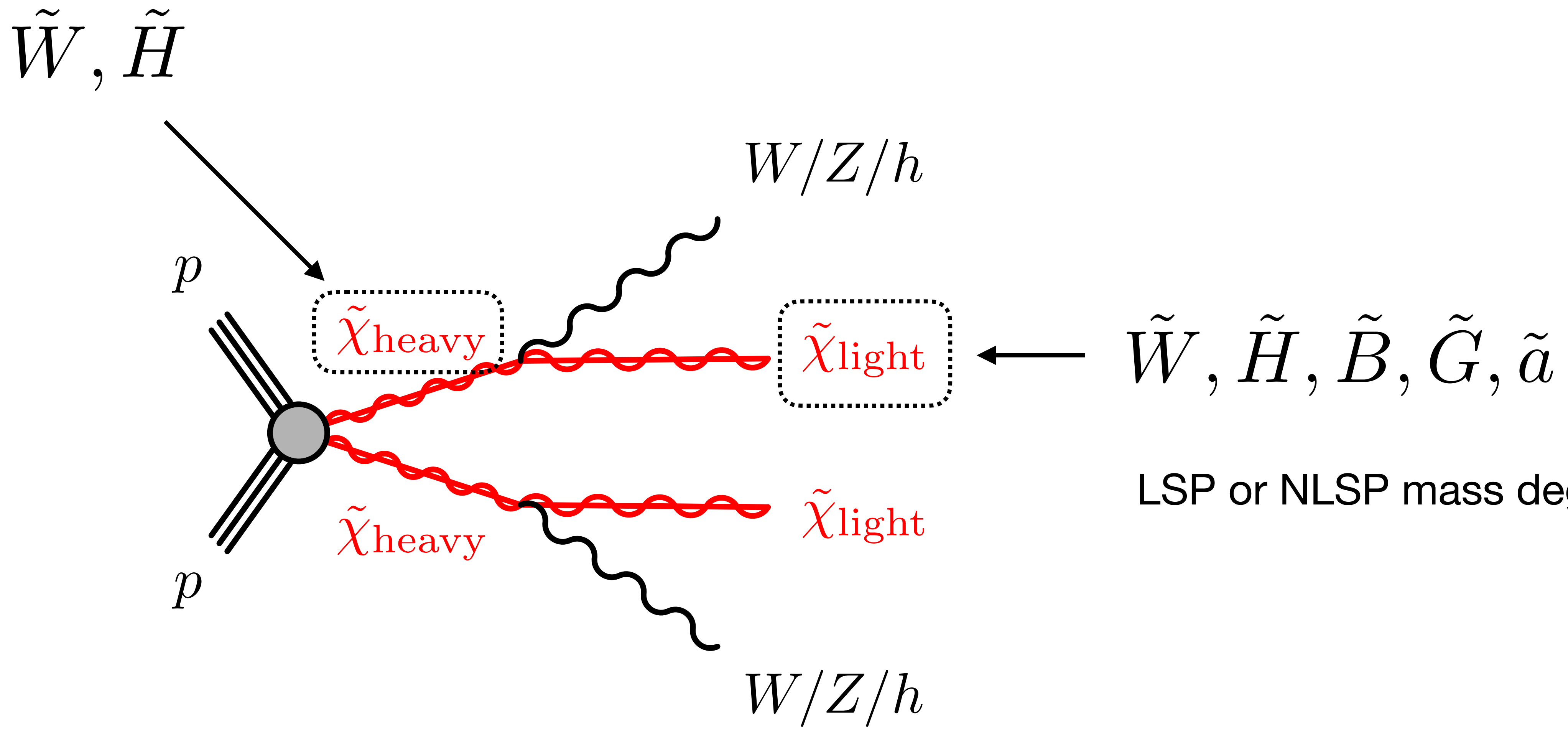
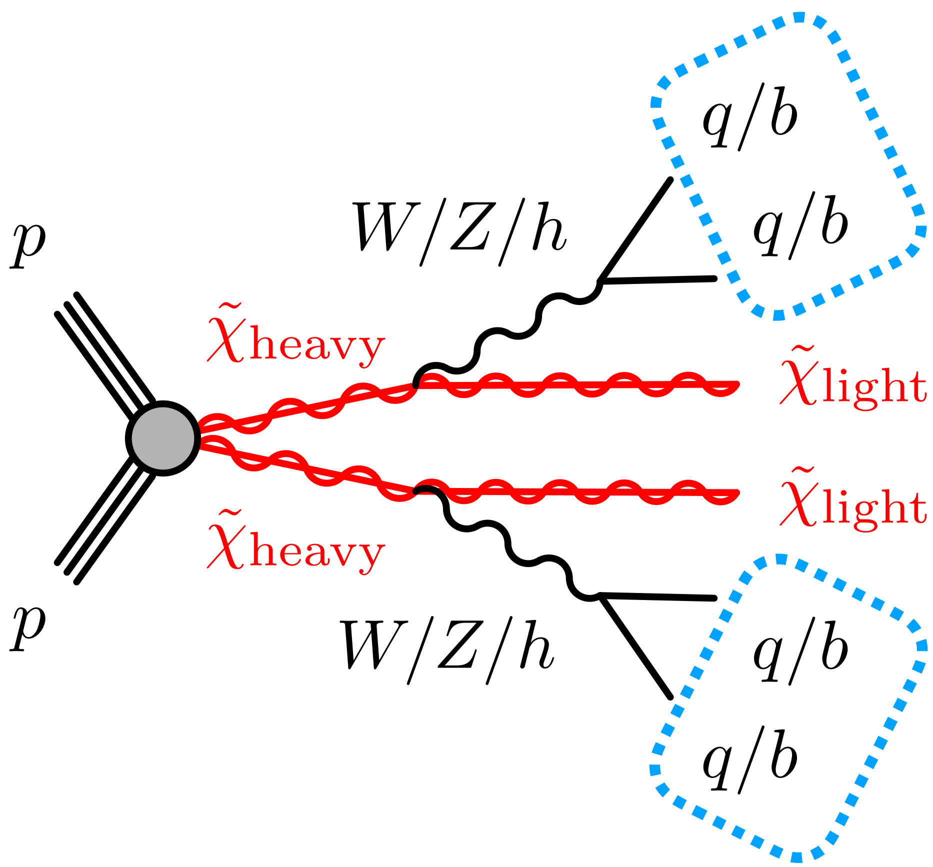


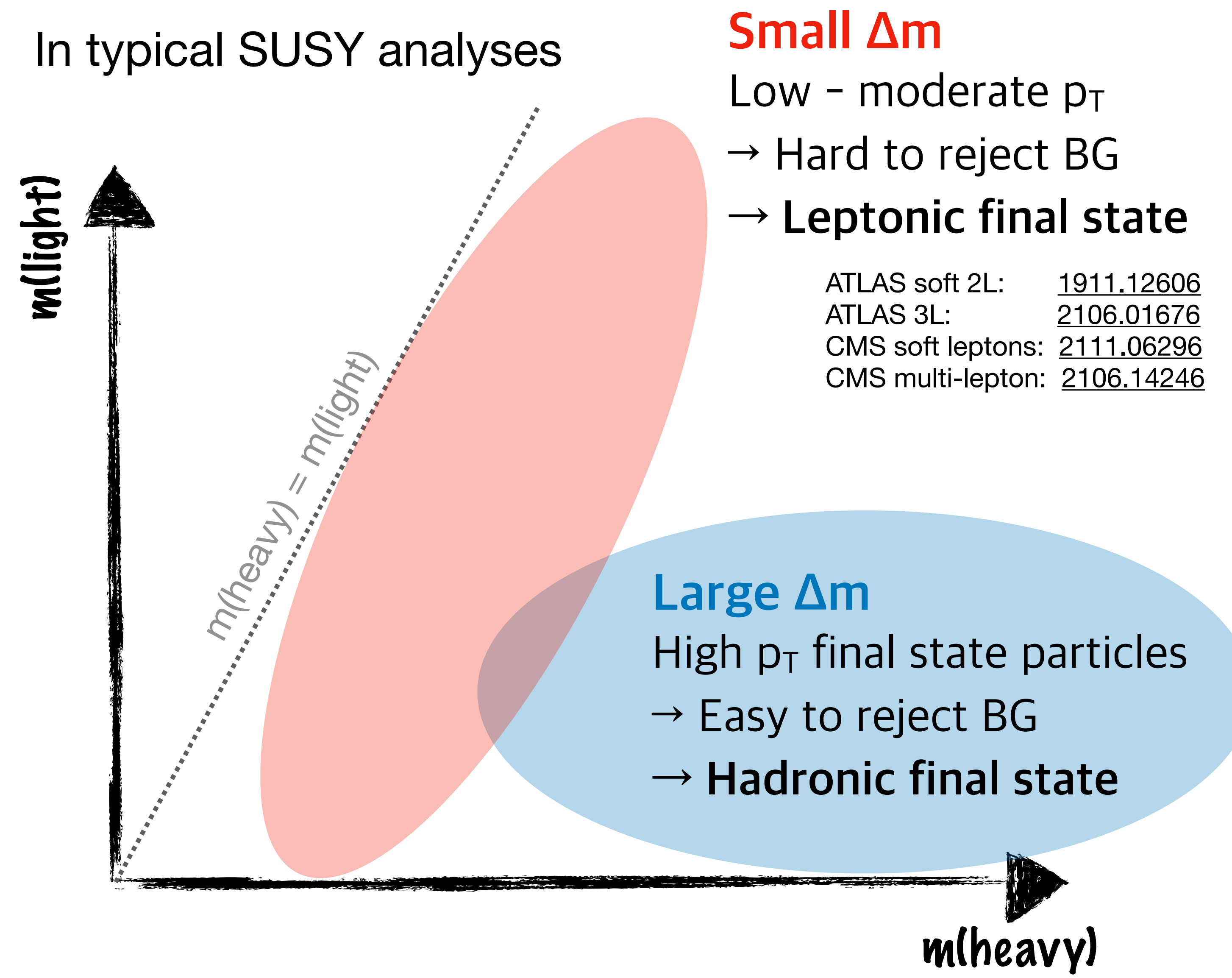

LSP or NLSP mass degenerate with it

Large Δm(heavy, light) → charginos/neutralinos don't mix much

ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002




In typical SUSY analyses




## Hadronic final state = More signals & More BGs

Usually promising at large-Δm as it can afford tight cuts to cope with the BG.

# EWK all-had - Overview

ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002

## Curse of low signal 👻

**Low signal**

**Have to look at lower mass**
(more σ)

**Can only probe smaller Δm**
(Δm < $m_{heavy}$)

**Poor BG rejection**

**Need tighter cuts**
(or give up & look at leptonic final states)

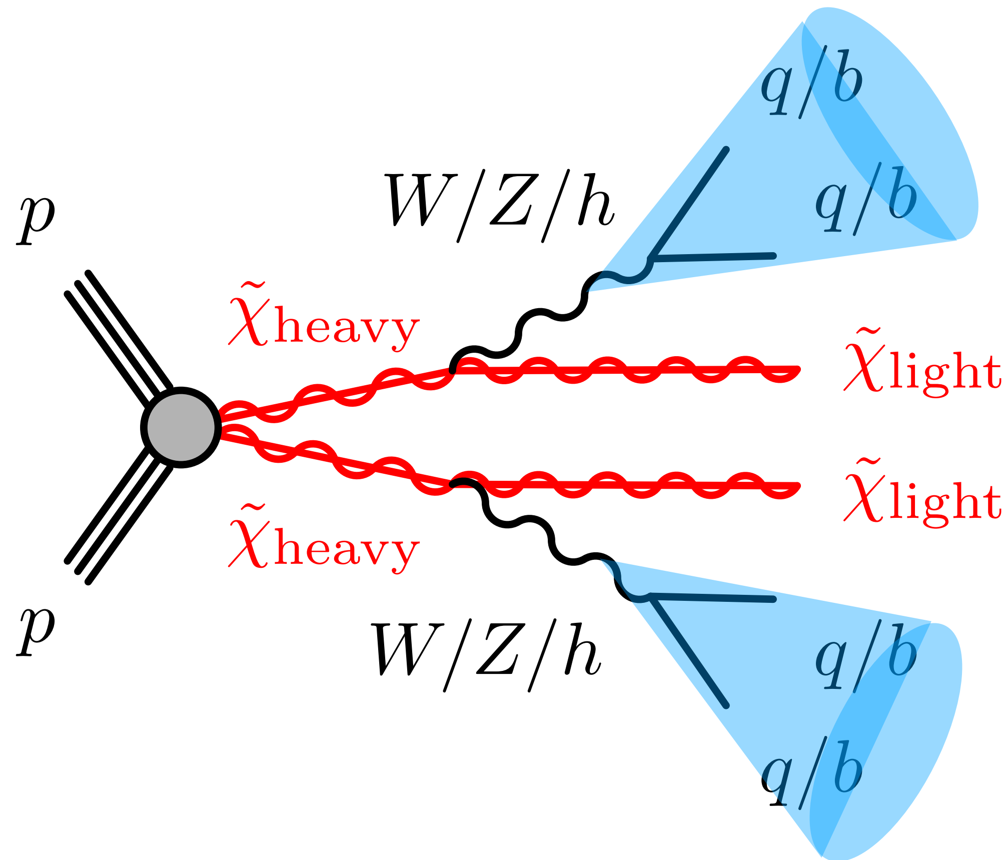
**BUT! Wasn't the case for the EWK production for a long time!**

due to the small xsec at high mass

# EWK all-had - Overview

ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002

Identify the two quark cores in a “fat” jet




No more 👻

**Sufficient amount of signals**

~~Low signal~~ → have to look at lower mass → can only probe smaller Δm → poor BG rejection → need tighter cuts → ~~Low signal~~

**Only feasible recently thanks to**

**Large full-Run2 datasets** + **boosted boson jet tagging.**

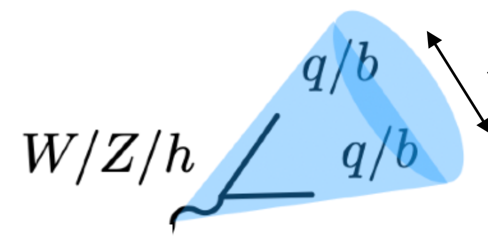
**First EWKino search using “qqqq” final state at LHC!**

# Boosted boson jet tagging

ATLAS:
W/Z→qq: ATL-PHYS-PUB-2020-017
Z/h→bb: ATL-PHYS-PUB-2017-010

CMS:
JINST 15 (2020) P06005

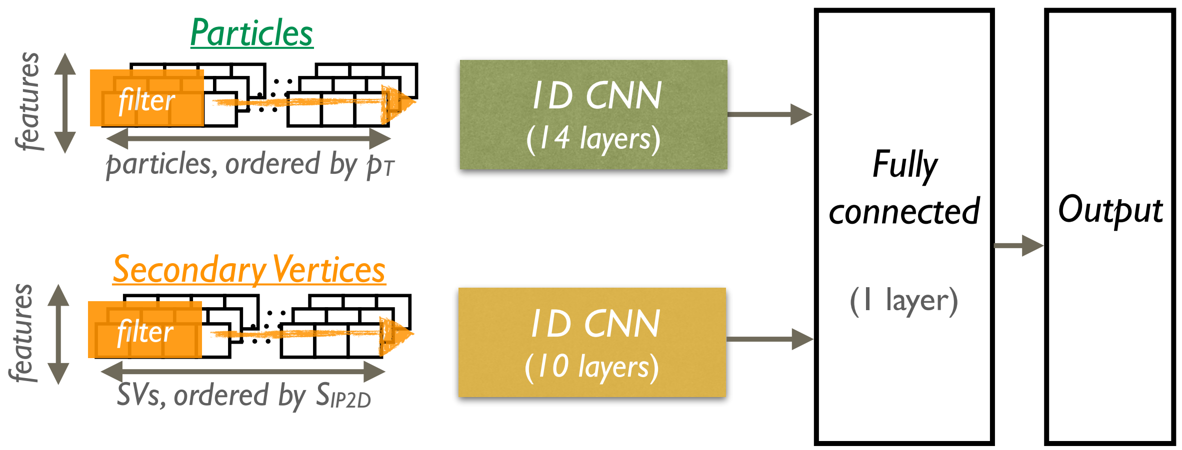
## e.g. CMS: Anti-kt R=0.8 + DNN

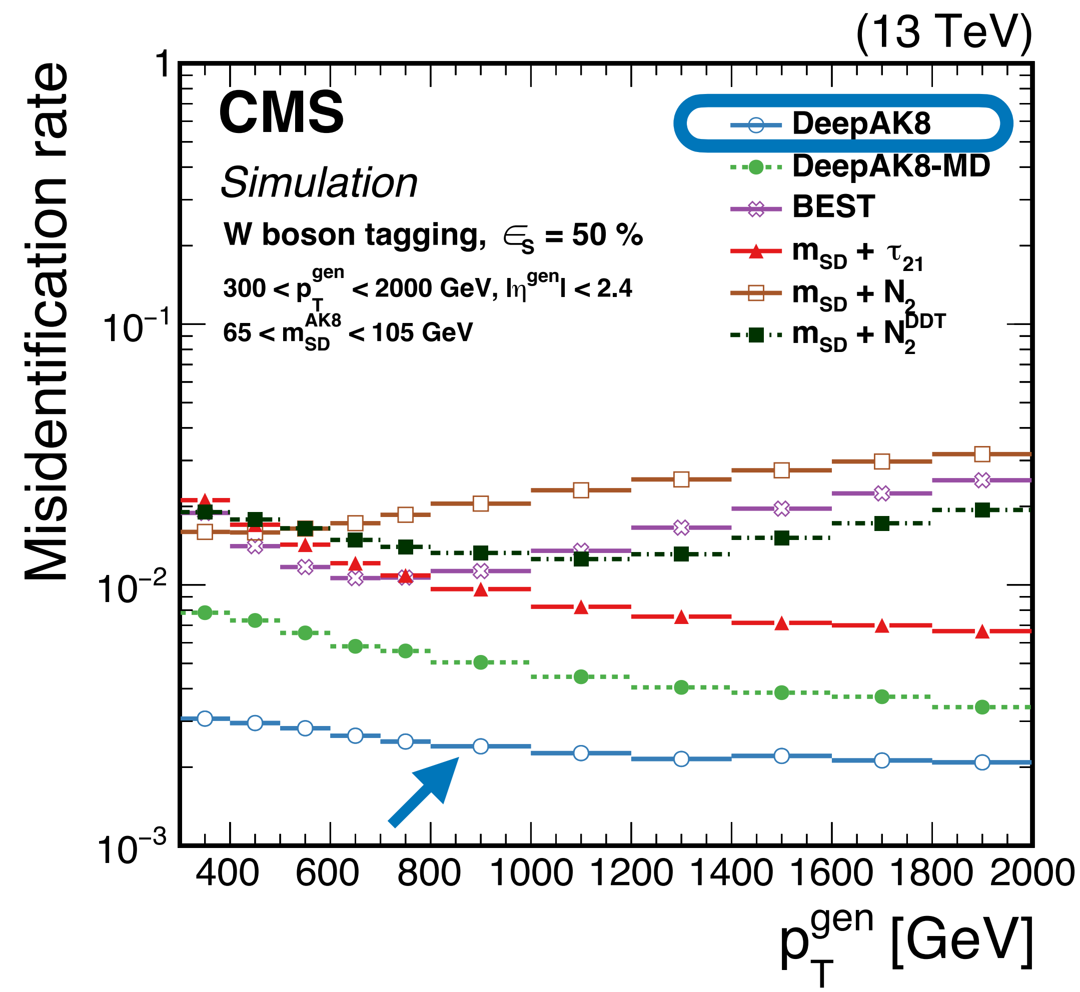



$$R := \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

c.f. normal jets: R=0.4

*"DeepAK8"*




**CNN1: Extract jet substructure → 1-/2-/3-subjet "cores"**

Input: jet particle level features

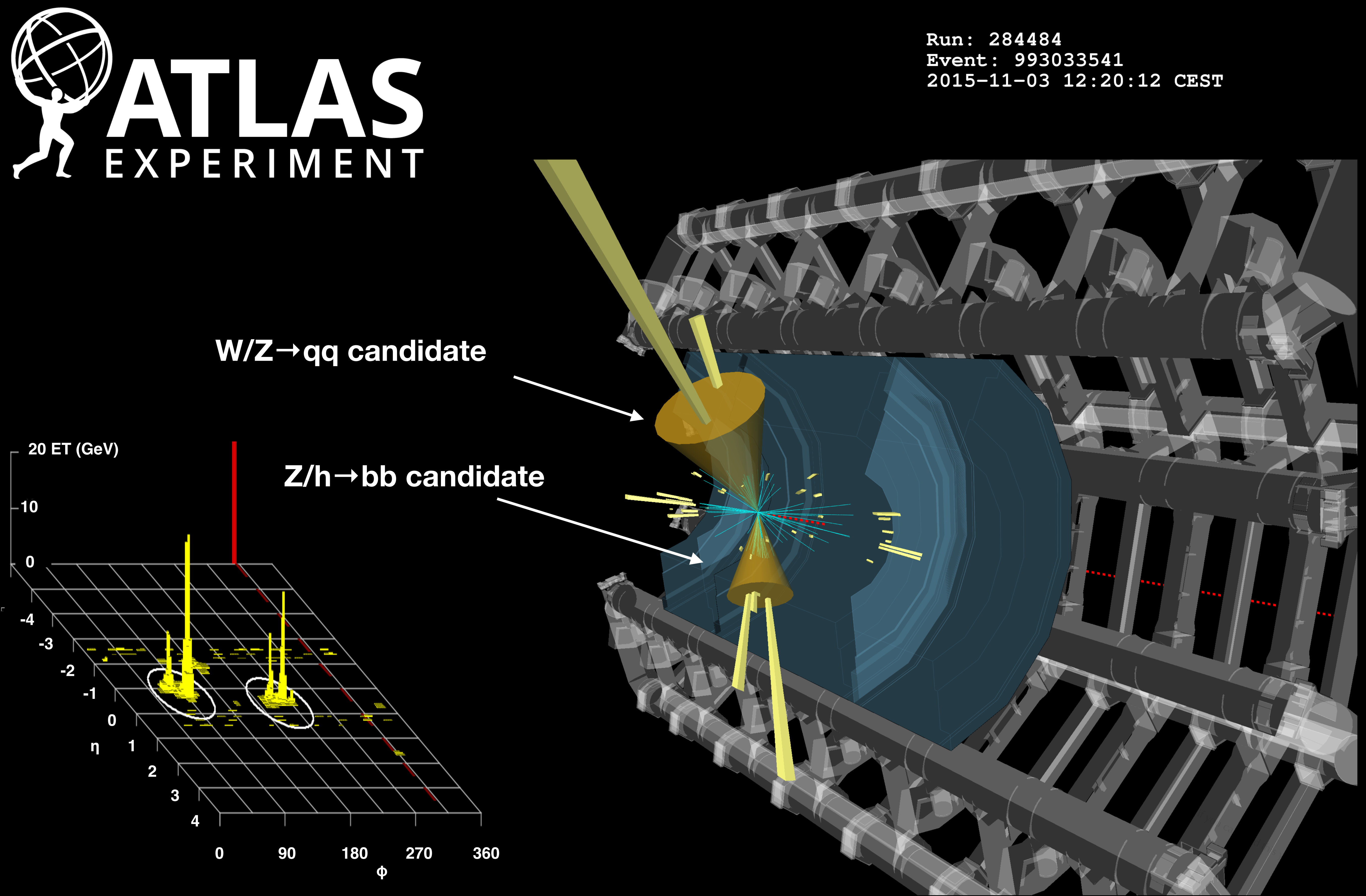
Multi-class output: W,Z,h

**CNN2: Flavor-tagging at the same time (Z→qq vs bb etc.)**

Small ~ moderate pileup dependency (very cool)

**Typical efficiency** Signal: 40~50% BG: 0.1%-1% per jet

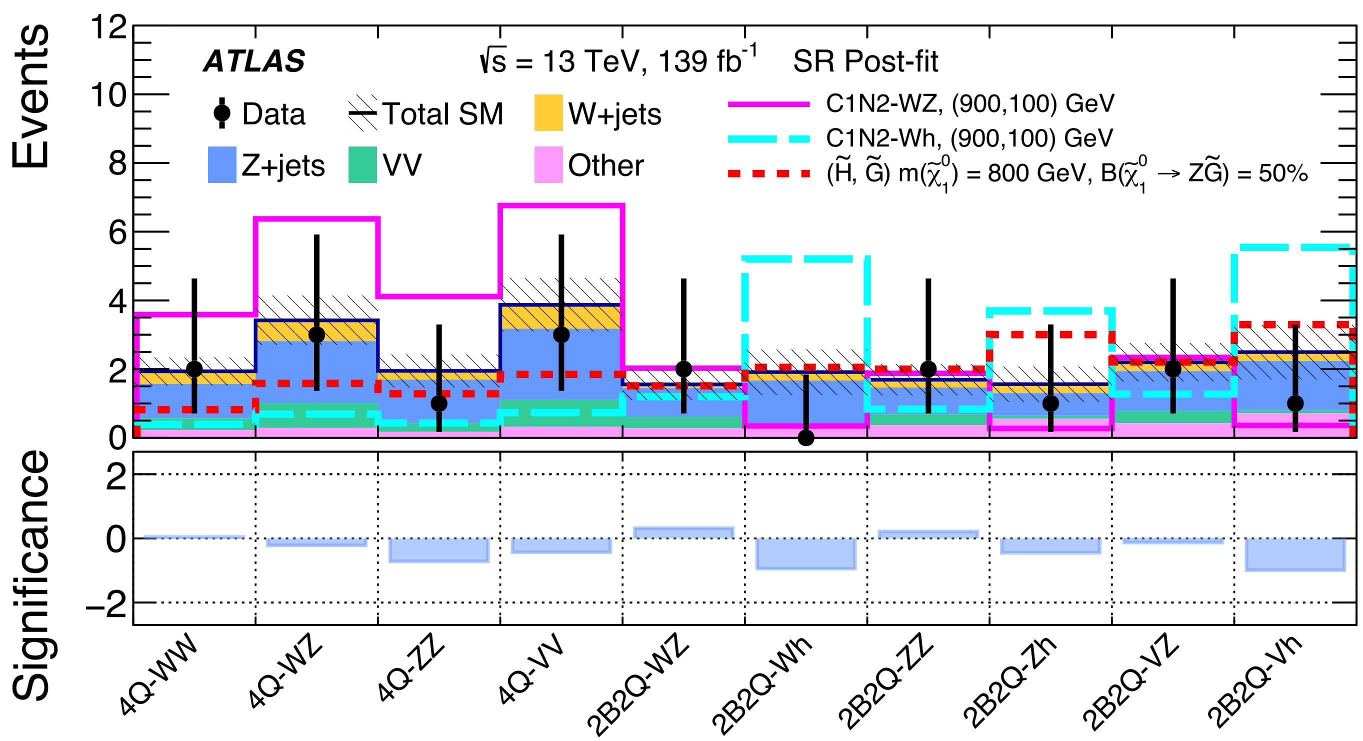
**→ O($10^3$-$10^5$) improvement in S/N with 2 jets tagged**

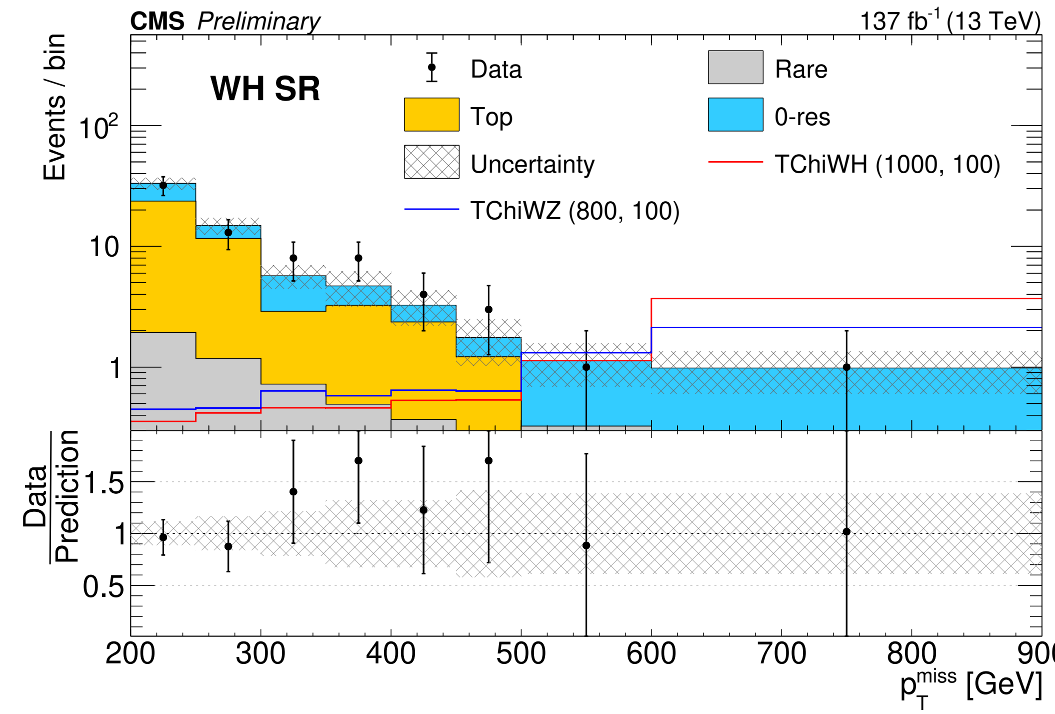



An event in the ATLAS search signal region

# EWK all-had - Selection & BG

ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002




**Selection:** $p_T^{miss}$ >200GeV, $\Delta\phi(E_T^{miss}$, jets)>0.3-1.5, hard jet kinematics etc.

**ATLAS:** SRs segmented based on di-boson species (WW, WZ, Wh, ZZ, Zh, OR of them)

**CMS:** + binned in $E_T^{miss}$

**BG:** W(→ℓν)/Z(→νν)+jets ("0 resonance", 70-90%)

V(→ℓν)V(→qq)+jets, ttbar etc. ("1 resonance", 10-25%)

Z(→νν)VV(→qqqq), ttbar+X etc. ("irreducible", <10%)

**>=1 "Fake boson jets"**
Semi-data-driven.
CR = boson tagging inverted

**=2 real boson jets**
Directly estimated from MC

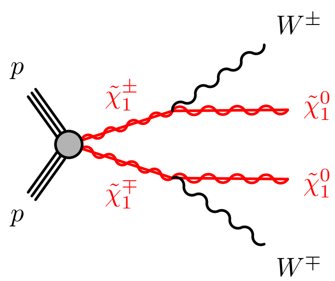
**ATLAS:** VRs in 1-lepton & 1-photon regions

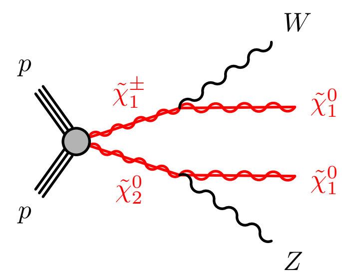
**CMS:** VRs defined by loosening the boson tagging

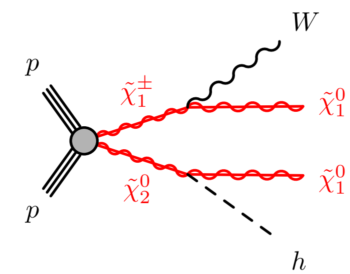
**No significant excess found**

# EWK all-had - Simplified model limits

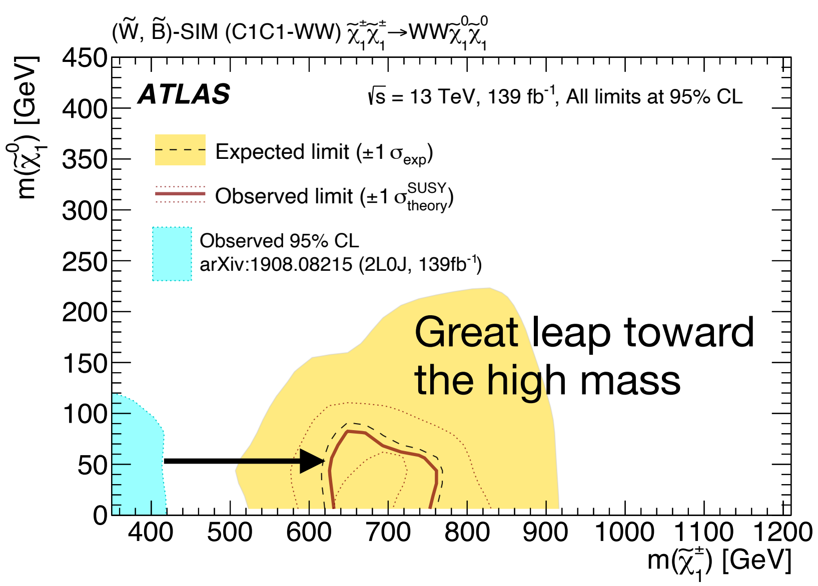
ATLAS: Phys. Rev. D 104 112010 (2021)
CMS: CMS-PAS-SUS-21-002

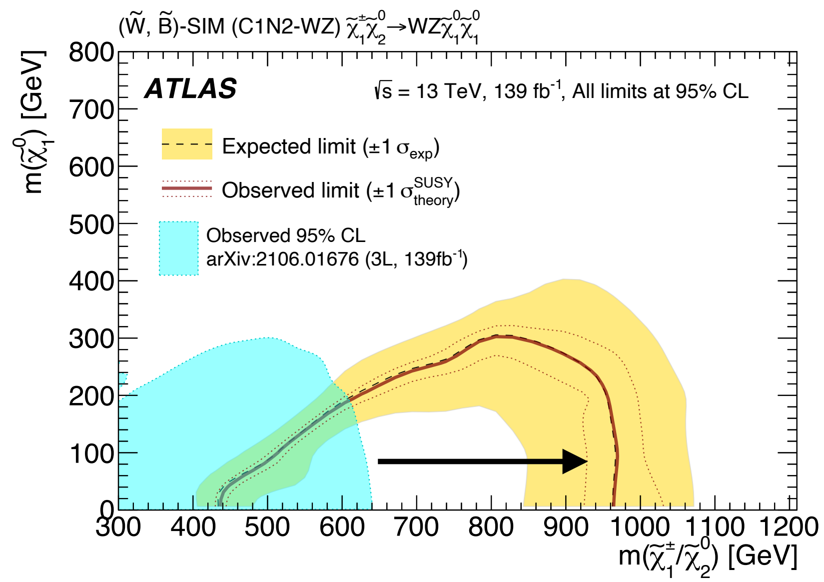


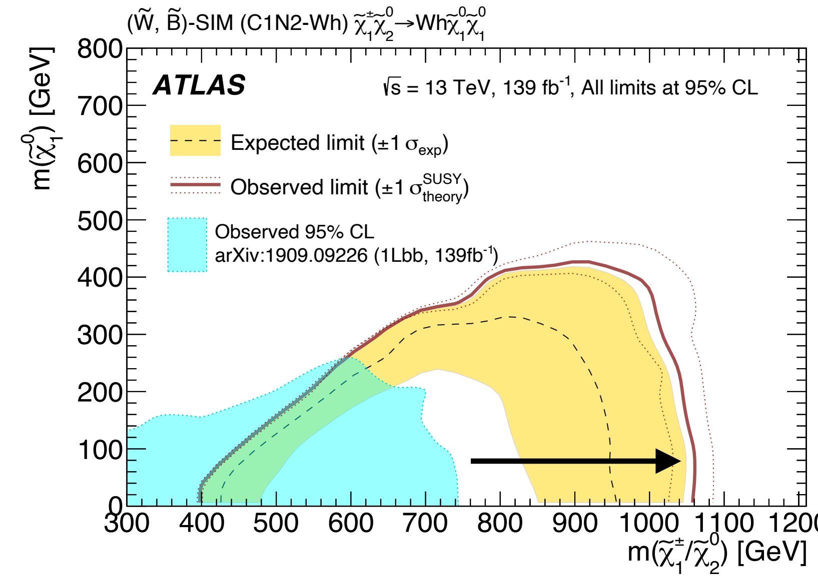


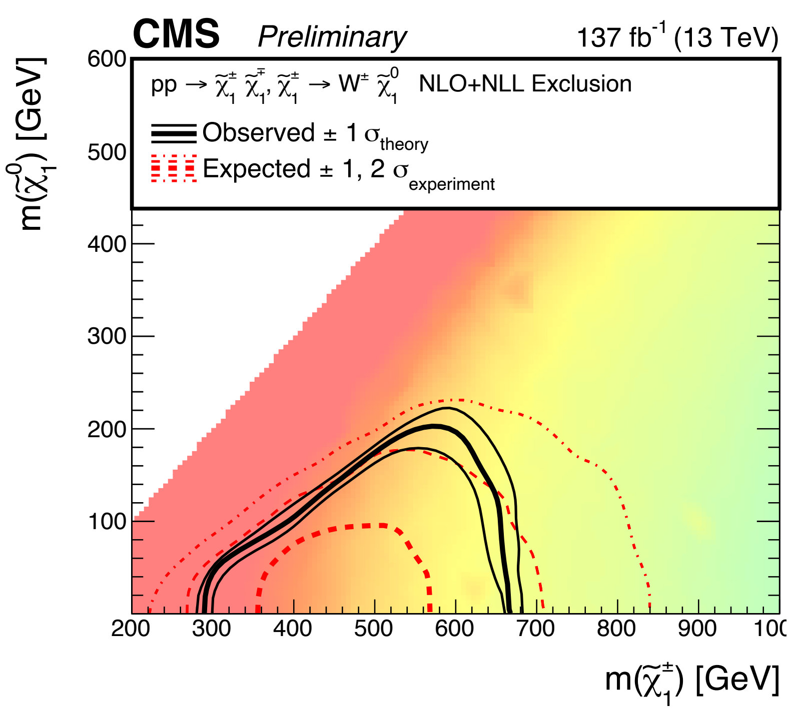


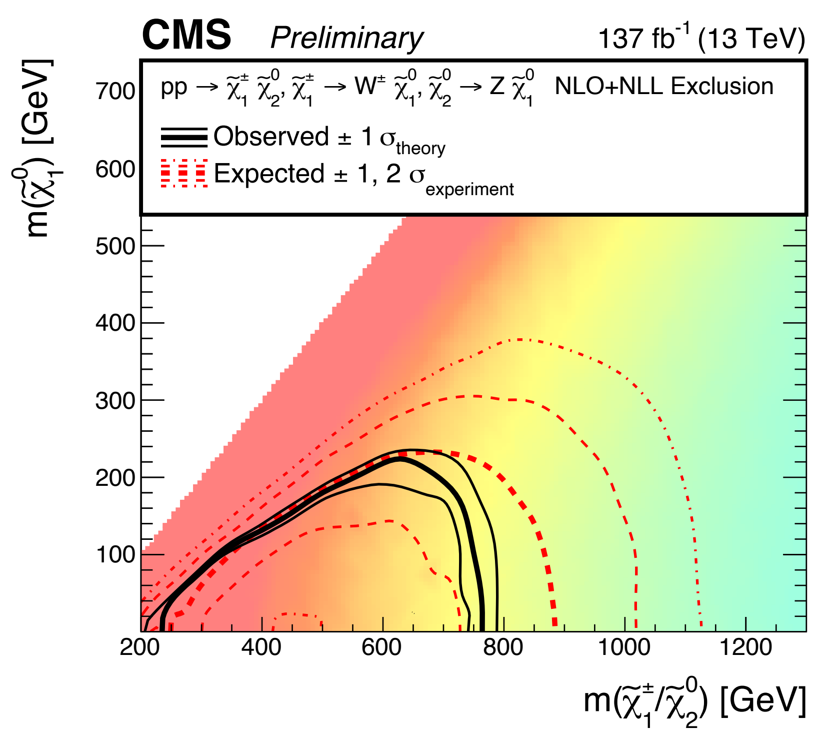
**ATLAS vs CMS:**
**Similar or complementary**

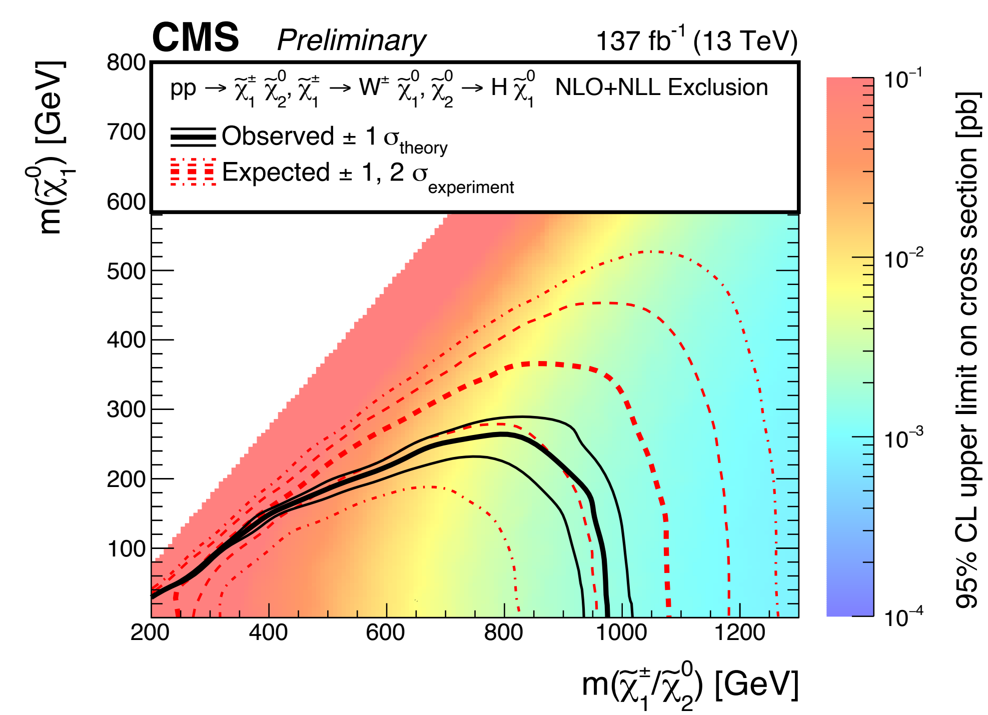


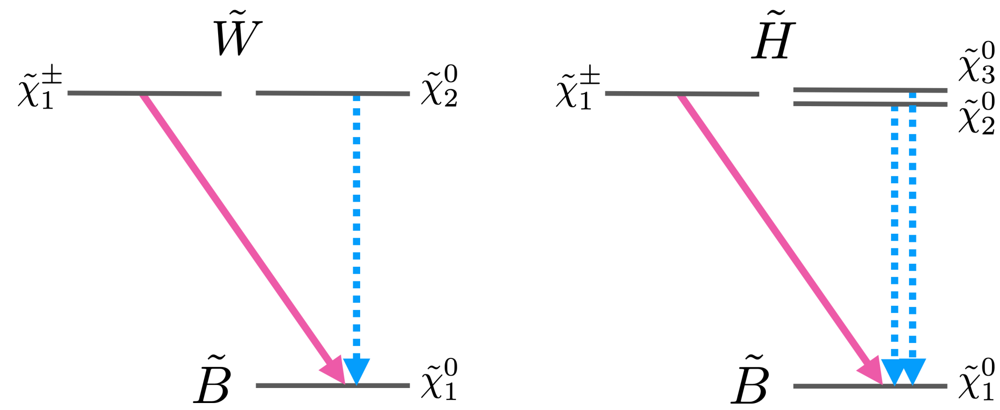



# EWK all-had - “Less-simplified” model limits

Phys. Rev. D 104 112010 (2021)

e.g. Bino LSP




| Model | Production | Final states | Branching ratio |
|---|---|---|---|
| $(\widetilde{W},\widetilde{B})$ | $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^{\mp}$, $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$ | $WW, WZ, Wh$ | $\mathcal{B}(\widetilde{\chi}_1^{\pm} \rightarrow W\widetilde{\chi}_1^0) = 1$<br>$\mathcal{B}(\widetilde{\chi}_2^0 \rightarrow Z\widetilde{\chi}_1^0)$ scanned |
| $(\widetilde{H},\widetilde{B})$ | $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^{\mp}$, $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$,<br>$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_3^0$, $\widetilde{\chi}_2^0\widetilde{\chi}_3^0$ | $WW, WZ, Wh,$<br>$ZZ, Zh, hh$ | $\mathcal{B}(\widetilde{\chi}_1^{\pm} \rightarrow W\widetilde{\chi}_1^0) = 1$<br>$\mathcal{B}(\widetilde{\chi}_2^0 \rightarrow Z\widetilde{\chi}_1^0)$ scanned<br>$\mathcal{B}(\widetilde{\chi}_3^0 \rightarrow Z\widetilde{\chi}_1^0) = 1 - \mathcal{B}(\widetilde{\chi}_2^0 \rightarrow Z\widetilde{\chi}_1^0)$ |

Consider all the prod. modes

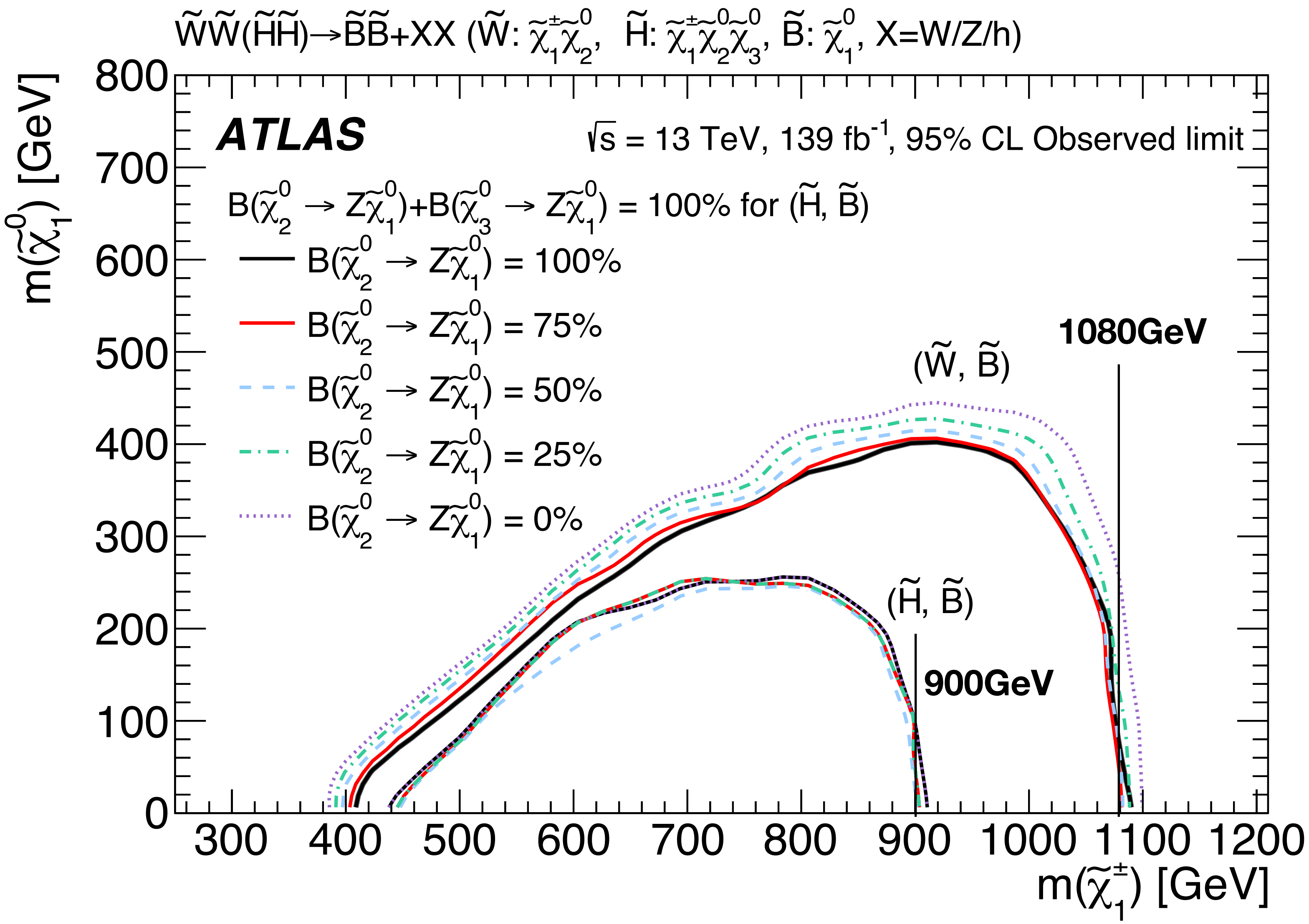
Simultaneously target different di-boson signals

**Scan the floating BRs**

(or the MSSM parameters dictating them)

# EWK all-had - “Less-simplified” model limits

Phys. Rev. D 104 112010 (2021)

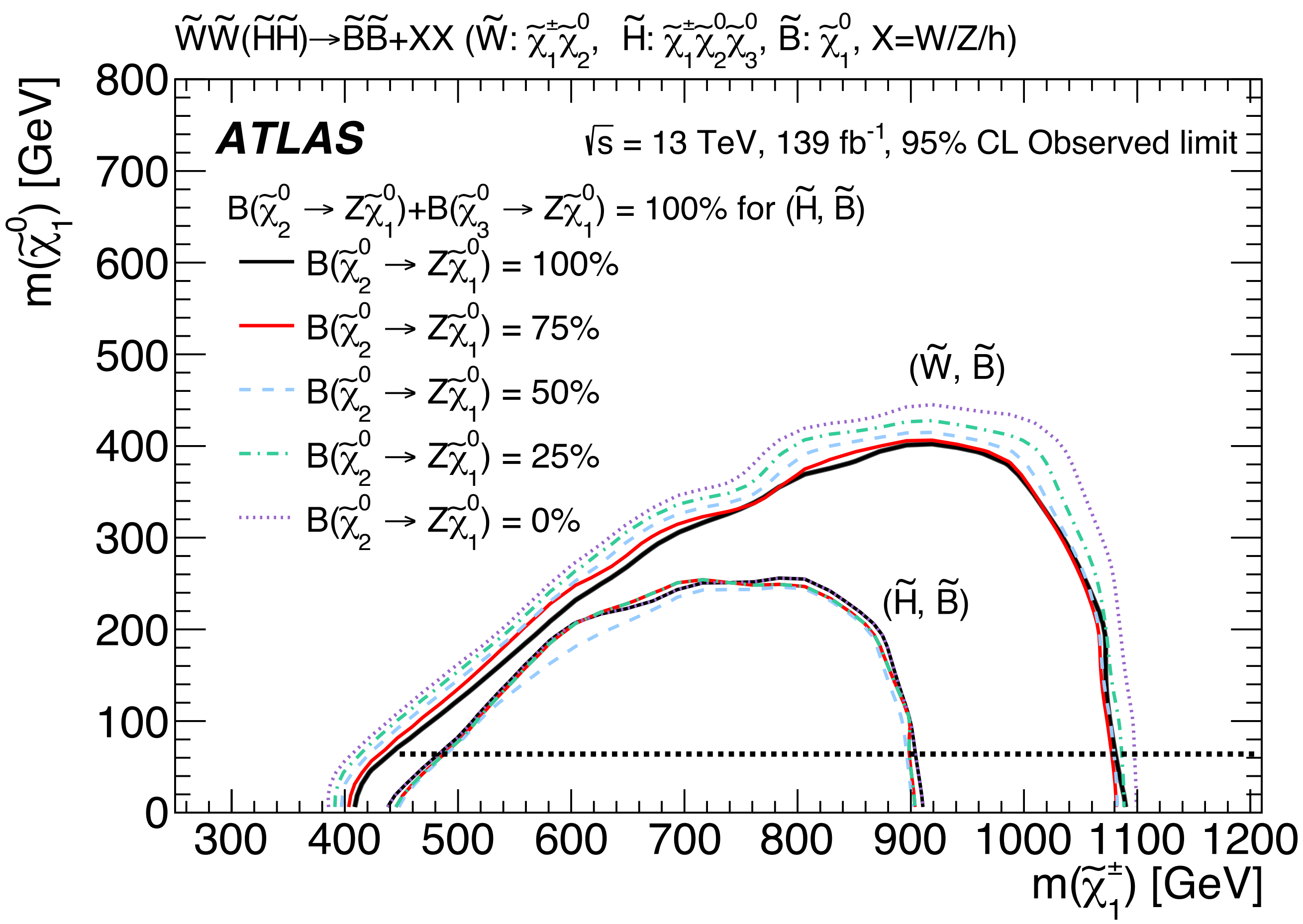



✔ **Realistic limit for these particular mass hierarchies**

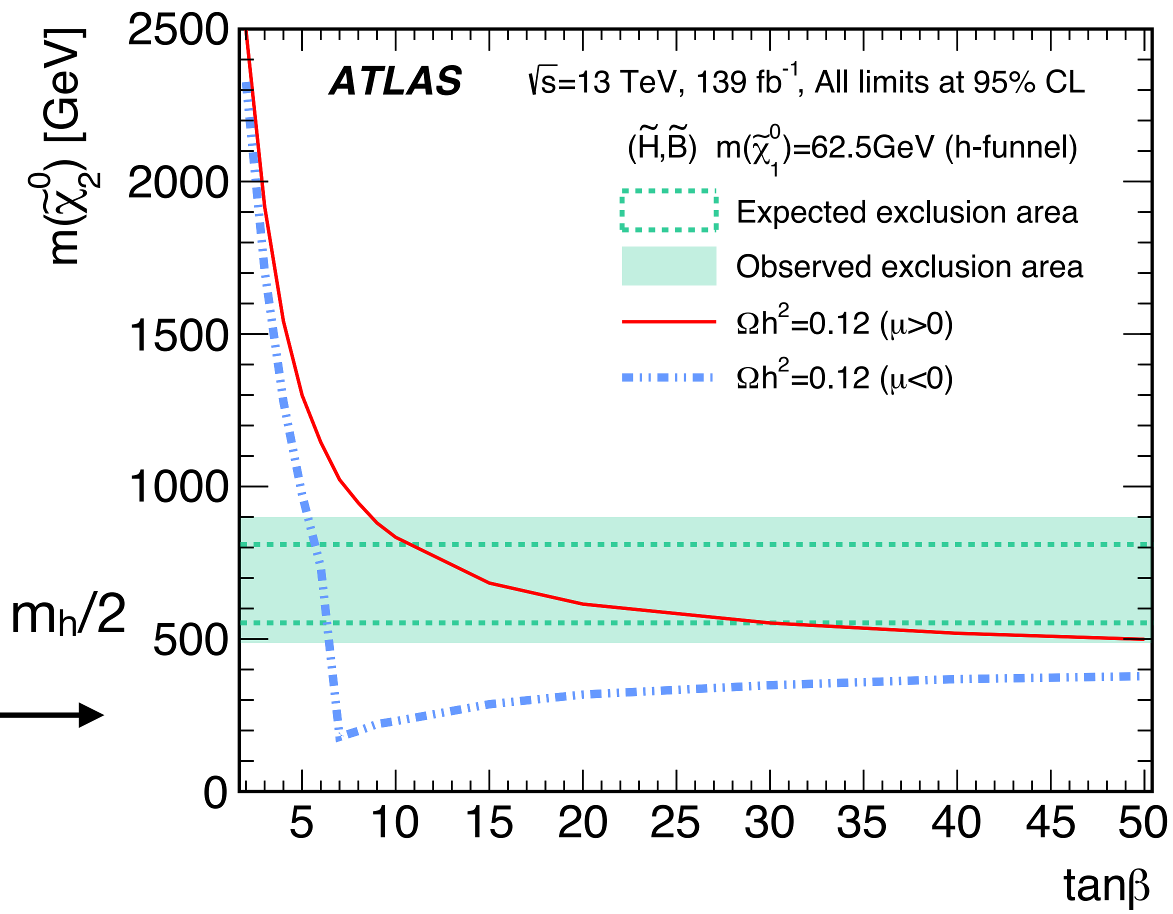
✔ Small BR(→Z) vs BR(→h) dependency thanks to that W/Z/h could be treated inclusively in the analysis.

# EWK all-had - “Less-simplified” model limits

Phys. Rev. D 104 112010 (2021)




$m_{LSP} = m_h/2$

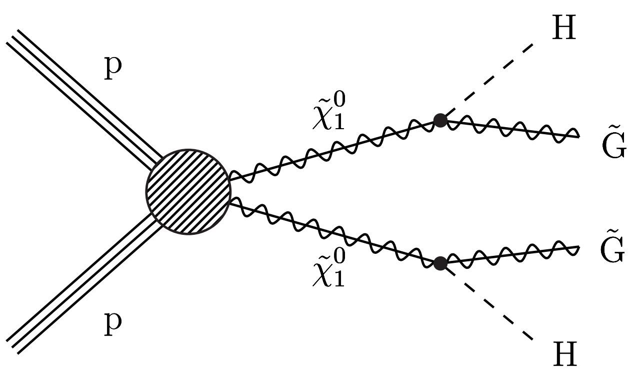



**<u>Bonus:</u>** Re-interpretation on the **“Z/h-funnel”** DM scenarios

**Strongest limit for tanβ>10** including direct experiments

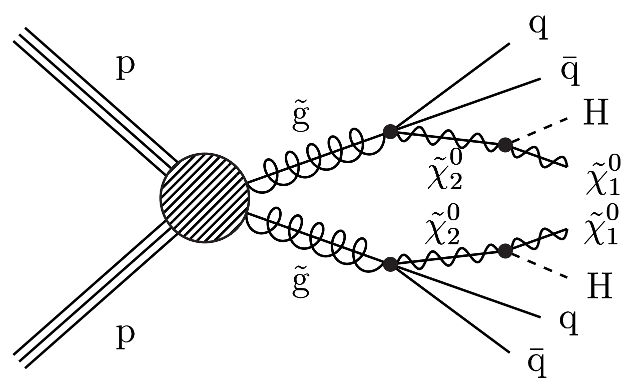
# Di-higgs(→4b) + $p_T^{miss}$

arXiv: 2201.04206

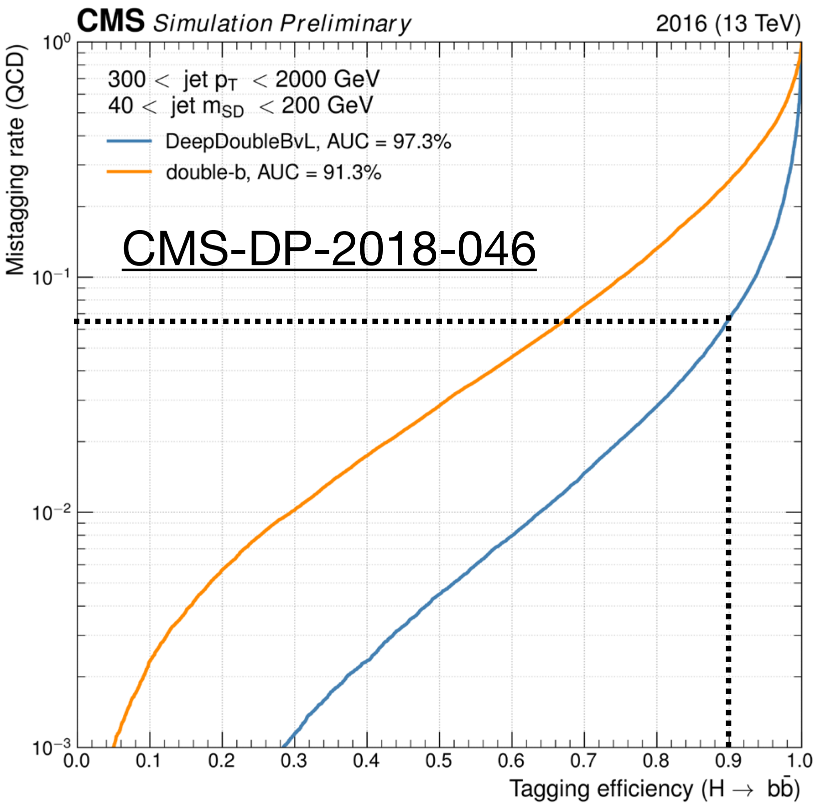



GMSB/naturalness inspired

Higgsino NLSP→Gravitino LSP




Gluino→Wino/Higgsino NLSP→Bino LSP




**Dedicated searches for EWKinos decaying via di-higgs→4b**

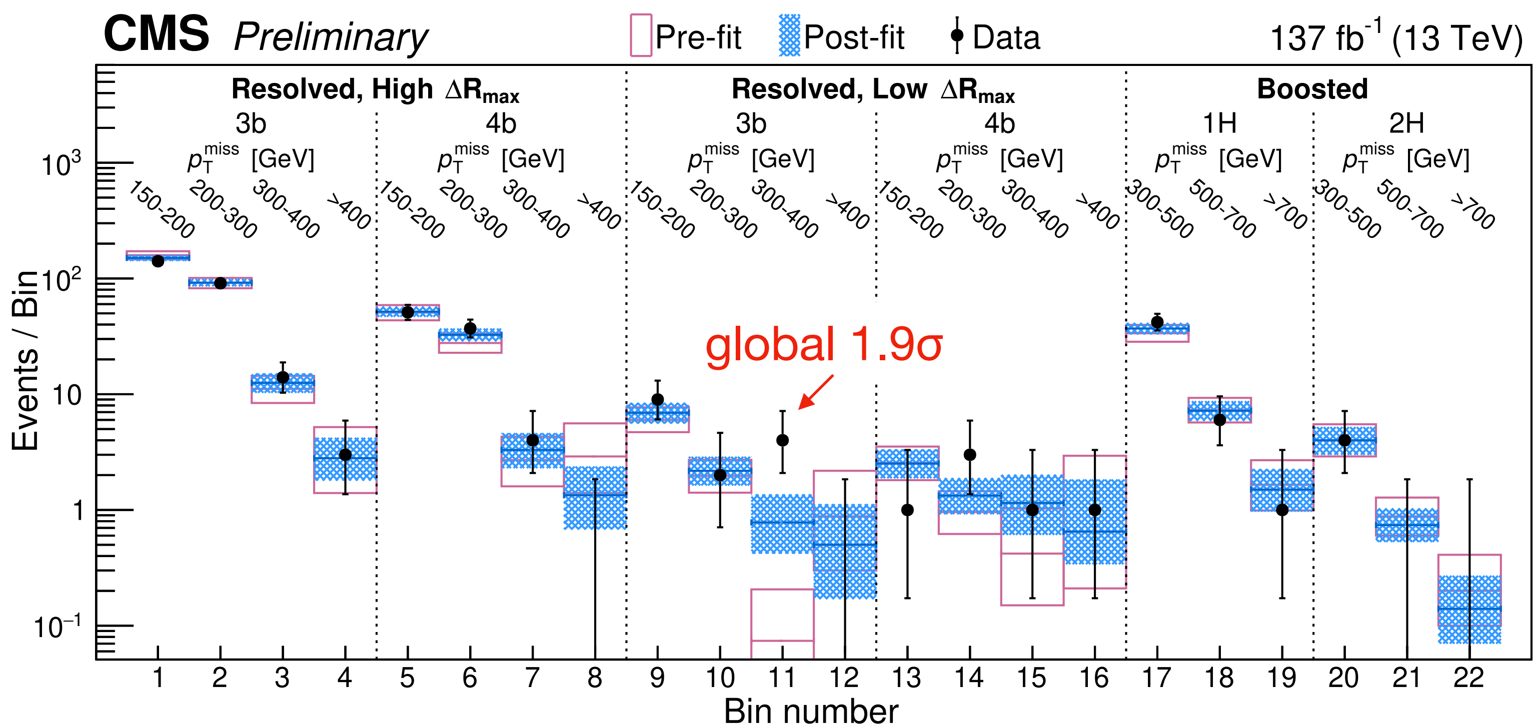
**Selection:** 3 or 4 b-tagged anti-$k_t$ R=0.4 jets, binned in $p_T^{miss}$.

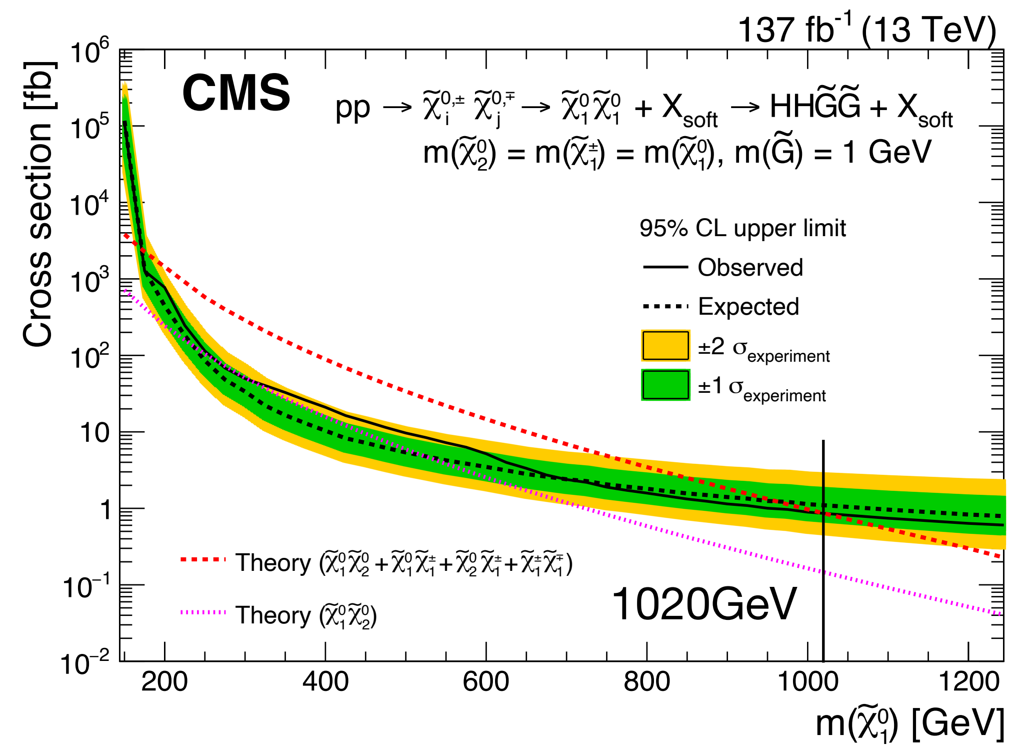
**Two sub-categories:**

- **"Resolved"**: Targeting small Δm, reconstructing h→bb by pairing anti-$k_t$ **R=0.4** jets.
  Based on minimizing the mass diff. between the 2 higgs candidates.
- **"Boosted"**: Targeting larger Δm, reconstructing h→bb by tagging a single anti-$k_t$ **R=0.8** jets.
  Deep learning bb-tagging: **90% efficiency** for h→bb (5% for LF quark jets).
  #(boosted higgs candidate) = 1 or 2.

# Di-higgs(→4b) + $p_T^{miss}$

arXiv: 2201.04206




**BG: ttbar+X, Z(→vv)+jets** estimated by ABCD method

- Resolved: $m_{bb}$ (window vs sideband) vs $n_{b\text{-jet}}$ (2b vs 3-4b)
- Boosted: $m_H$ (window vs sideband) vs $n_H$ (0 vs 1-2)

**No significant excess found.**

✔ Most stringent limit on a few models involving neutralinos with large BR(→h)

GGM Higgsino→h+Gravitino LSP, Gluino→heavy neutralino→h+LSP etc.

# eμ-asymmetry search

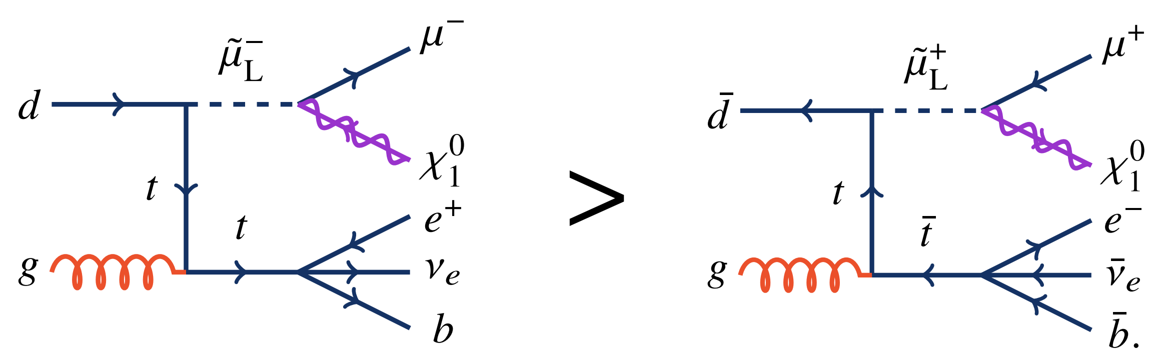
**New analysis at LHC!**
arXiv: 2112.08090

$$\rho := \frac{N(e^+\mu^-)}{N(e^-\mu^+)}$$

**SUSY benchmark:** **RPV smuon single-production**

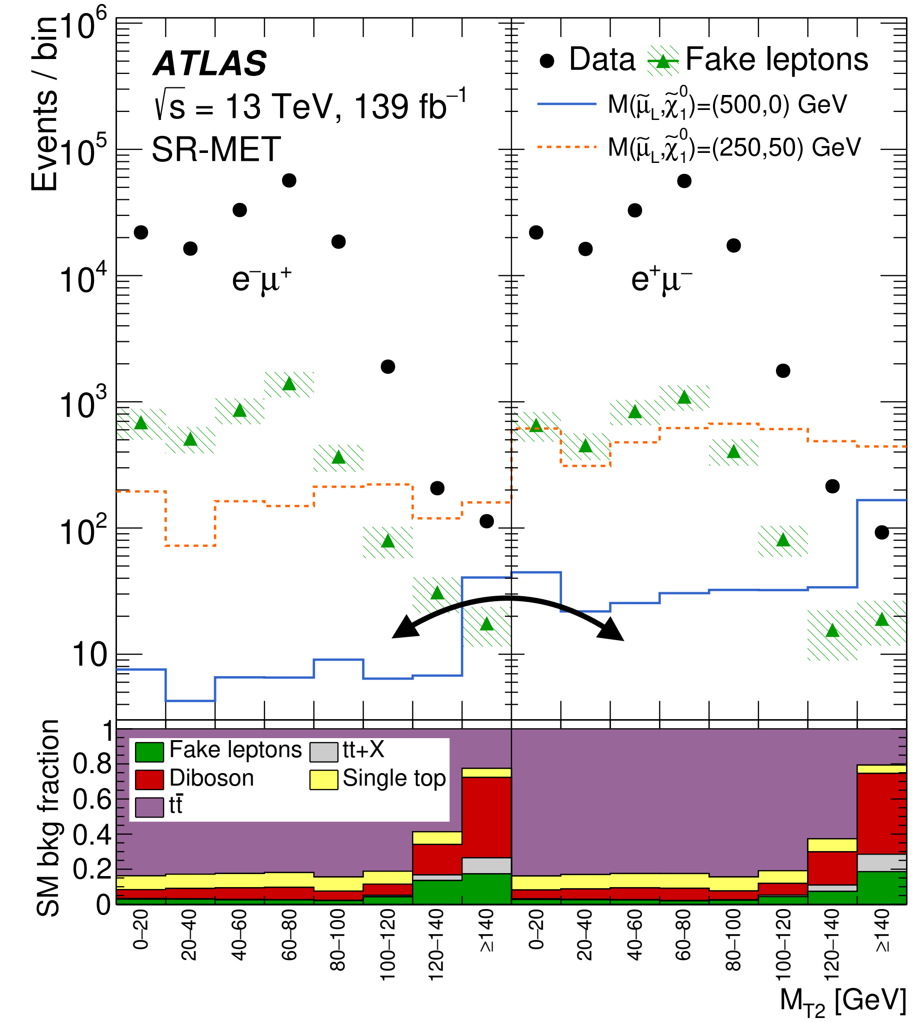
$\lambda'_{231}>0$ → $\mu_L$ production

$\mu_L$ NLSP &
$m_{LSP} < m_{top}$ → no RPV decay




Other target: leptoquarks

$$M_{T2} \equiv \min_{\vec{a}+\vec{b}=\vec{p}_T^{\,miss}} \max\left[m_T(e,\vec{a}), m_T(\mu,\vec{b})\right]$$




**Most of di-leptonic SM process: ρ~1**

- Experimental effects often bias to ρ<1 (e.g. $e_{fake} > \mu_{fake}$) → **Search for ρ>1**
- Test of ρ on top of the cut & count at the SM tail → can differentiate the BSM model.

**Selection:** Large $p_T^{miss}$ & large $\Sigma m_T$ selection → **Measure ρ in each bin of $m_{T2}$ or $H_P$ variable.**

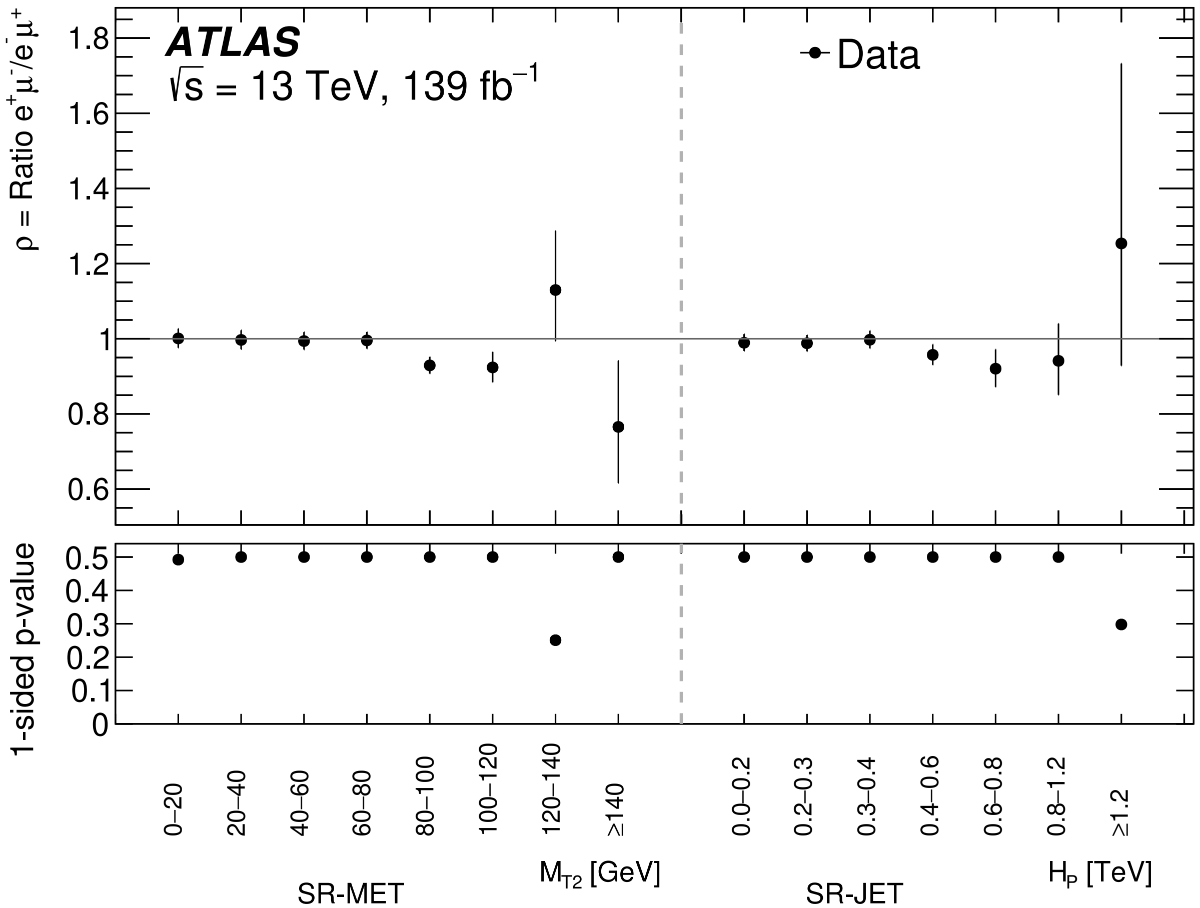
**BG:** ttbar, di-boson

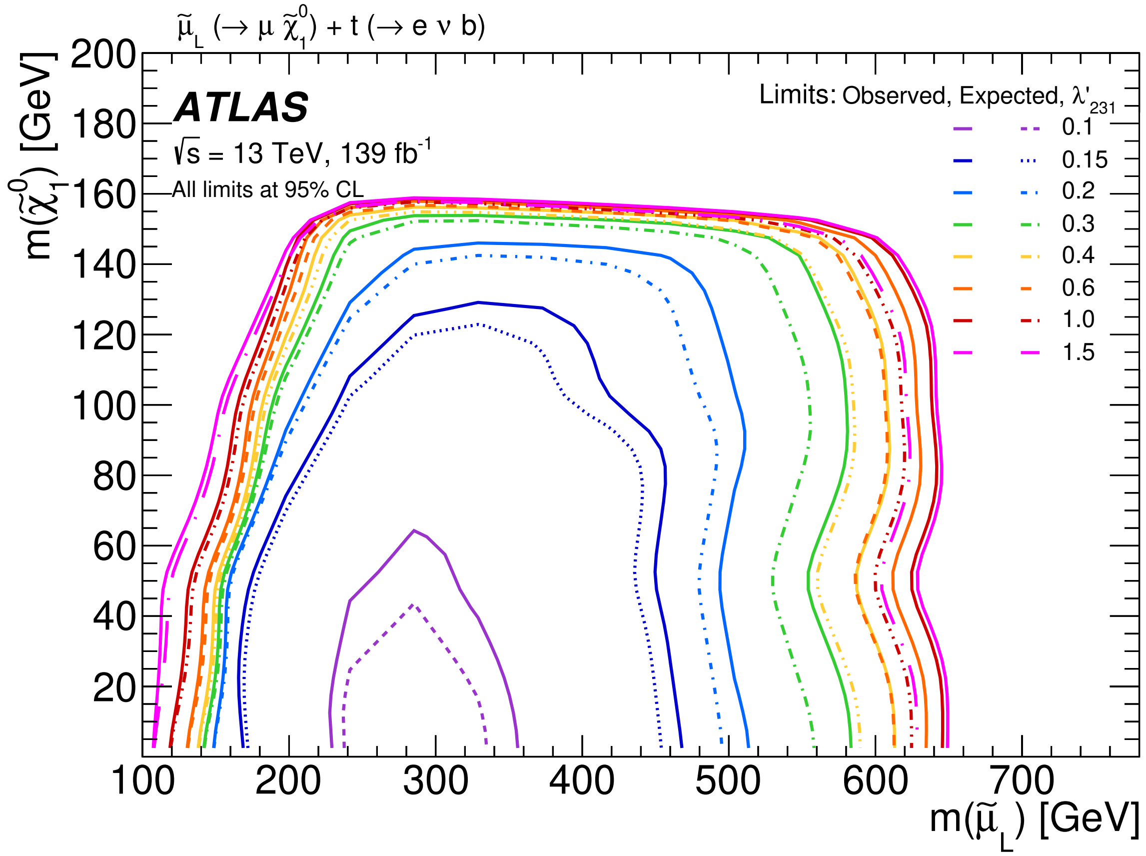
$$H_P \equiv |\vec{p}_T^{\,e}| + |\vec{p}_T^{\,\mu}| + |\vec{p}_T^{\,j_1}|$$

# eμ-asymmetry search

**New analysis at LHC!**

arXiv: 2112.08090




**Known significant detector biases affecting $\rho$ to max. the sensitivity**

- Muon reconstruction/ID efficiency ($\mu^+$ vs $\mu^-$) due to the toroidal magnet geometry
- Fake lepton estimation done separately for e/μ and +/-.
- Validated in the CRs/VRs using both MC and data

**No significant R>1 observed**

- First & strongest limit set on the model as the function of $\lambda'_{231}$

# Ways forward

# Loopholes in our searches?

**To our theorist friends: Any final states unexpectedly insensitive to your models?**

More re-interpretation materials/tools are becoming available


```
{
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        {
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            "samples": [
                {
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                    ],
                    "modifiers": [
                        {
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                            ],
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                            "type": "staterror"
                        },
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                            "name": "mu_nonResoBG_0L4Q",
                            "type": "normfactor"
                        }
                    ],
                    "name": "tX_0L4Q"
                },
                {
                    "data": [
                        24.02806854248047
                    ],
                    "modifiers": [
                        {
                            "data": [
                                1.6331842888140888
                            ],
```
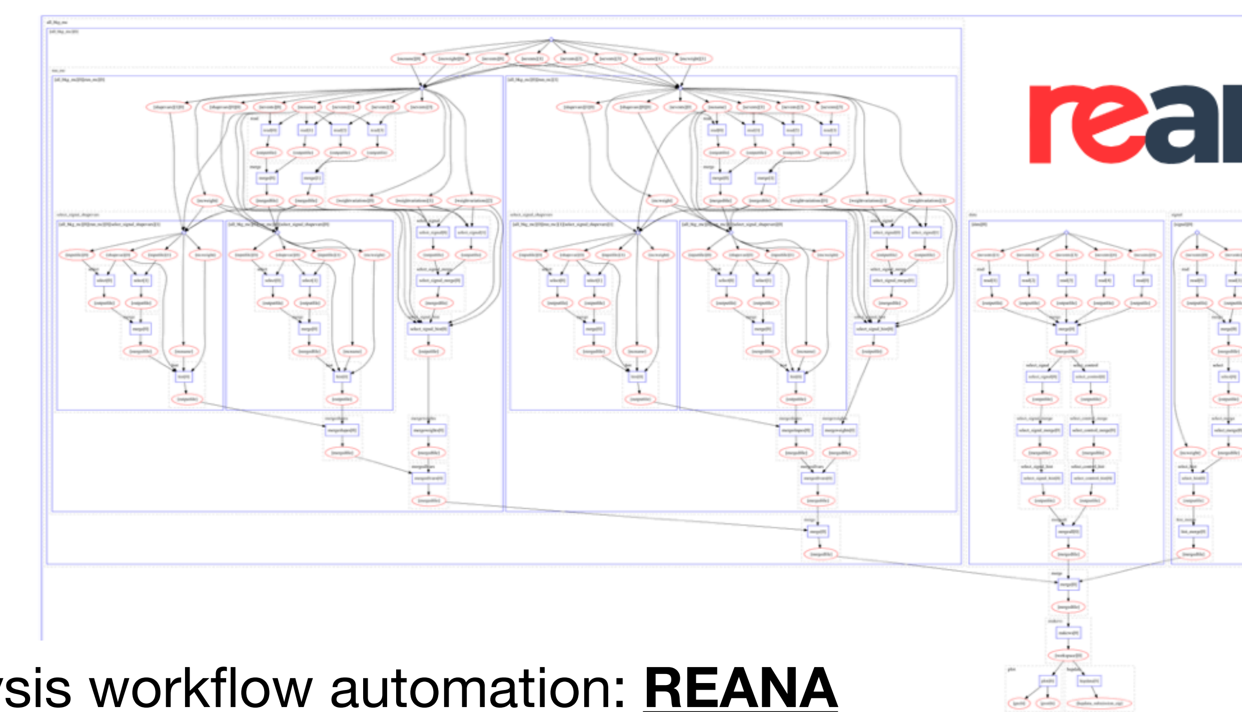


**json likelihood** (example)
easily processable by **pyhf**

```
//==========================================================================================
auto baselineleptons = baselineElectrons + baselineMuons;
int nbaselineleptons = baselineleptons.size();

// signal objects
auto electrons = filterObjects(baselineElectrons, 7, 2.47, ETightLH | ED0Sigma5 | EZ05mm | EIsoFCTight);
auto muons     = filterObjects(baselineMuons, 6, 2.7, MuD0Sigma3 | MuZ05mm | MuIsoFixedCutLoose);
auto photons   = filterObjects(baselinePhotons, 150, 2.37, PhotonIsoFixedCutTight);
auto taus      = event->getTaus(20, 2.5, TauMedium);
auto jets      = filterObjects(baselineJets, 30, 2.8, JVT50Jet);
auto bjets     = filterObjects(jets, 30., 2.8, BTag85MV2c10);
auto btrackjets= filterObjects(trackjets, 20, 2.8, BTag85MV2c10);
auto leptons   = electrons + muons;
```

Selection emulator: **SimpleAnalysis**



Analysis workflow automation: **REANA**

# Comments to a few commonly held connotations about SUSY searches

## Comments to a few commonly held connotations about SUSY searches

- **SUSY is dead → Wrong**

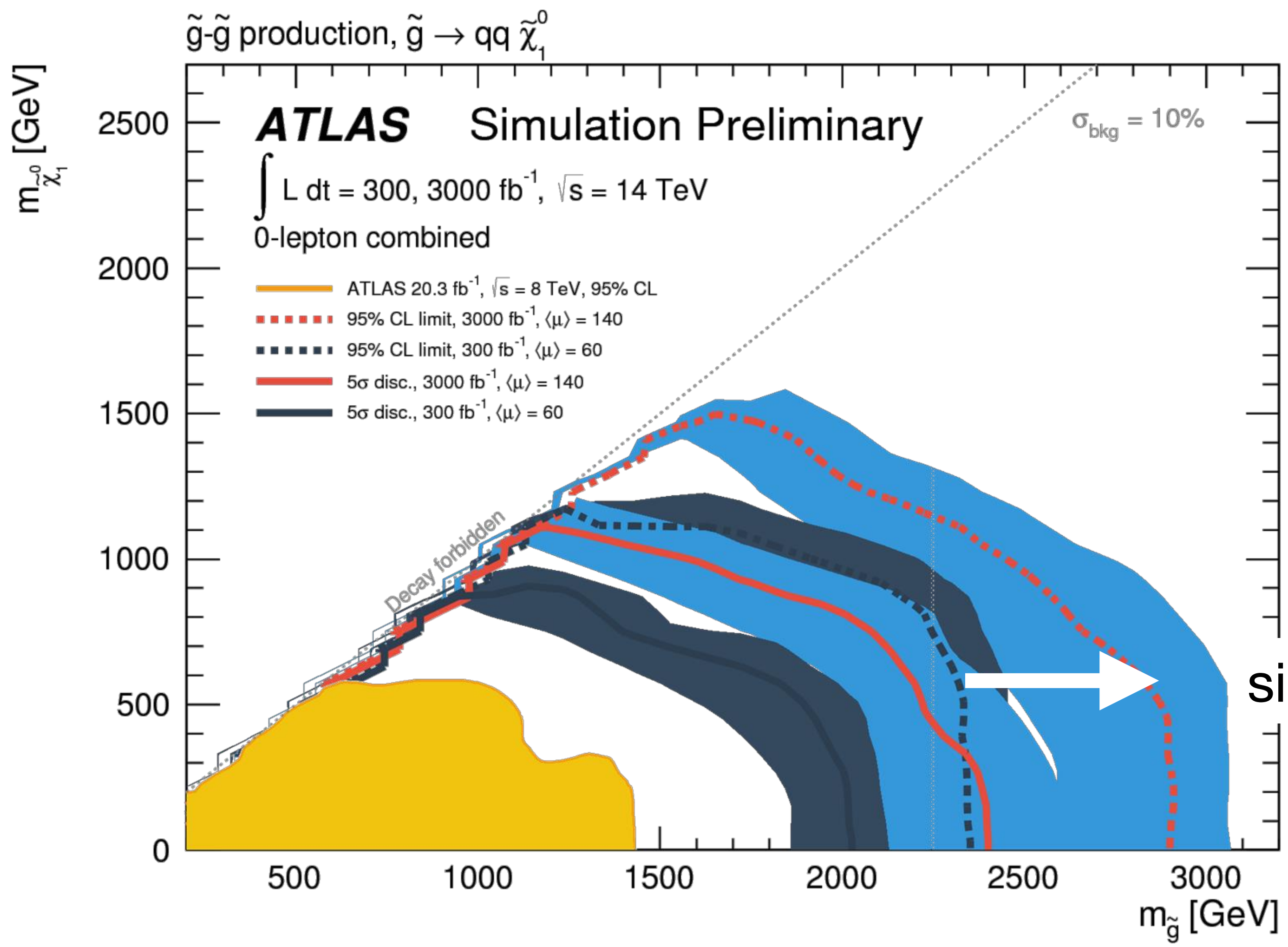
# Comments to a few commonly held connotations about SUSY searches

○ **SUSY is dead → Wrong**

○ **SUSY that can be probed in LHC is dead → Wrong**

Many searches are stat-limited → More data always helps.

But it takes much more time to double the data size (sad but we should be correctly sad).




significant, but take 10 yr

# Comments to a few commonly held connotations about SUSY searches

- **SUSY is dead → Wrong**
- **SUSY that can be probed in LHC is dead → Wrong**

  Many searches are stat-limited → More data always helps.

  But it takes much more time to double the data size (sad but we should be correctly sad).
- **Low-mass SUSY is dead → Wrong**

  Compressed mass spectra in the EWK sector is vibrantly alive.

  Build lepton colliders or we do better (next page).

# Comments to a few commonly held connotations about SUSY searches

- **SUSY is dead → Wrong**
- **SUSY that can be probed in LHC is dead → Wrong**

  Many searches are stat-limited → More data always helps.

  But it takes much more time to double the data size (sad but let's be sad correctly).
- **Low-mass SUSY is dead → Wrong**

  Compressed mass spectra in the EWK sector is vibrantly alive.

  Build lepton colliders or we do better (next page).
- **I don't believe SUSY anymore bc. I searched and didn't find it → Fine, but logically wrong**

  Nobody is this explicit but it seems an underlying mentality across the community recently.

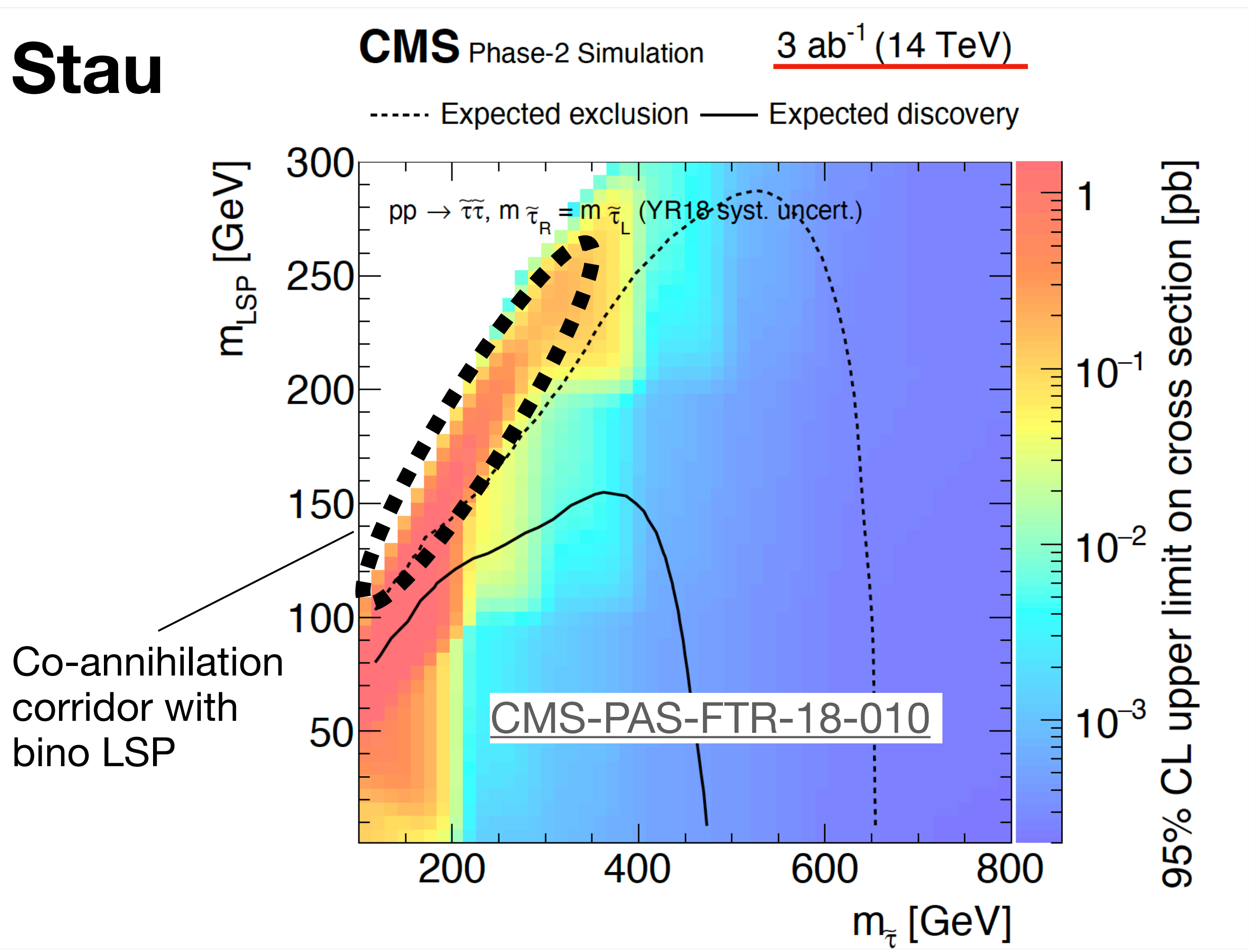
# 150GeV SUSY is viable!

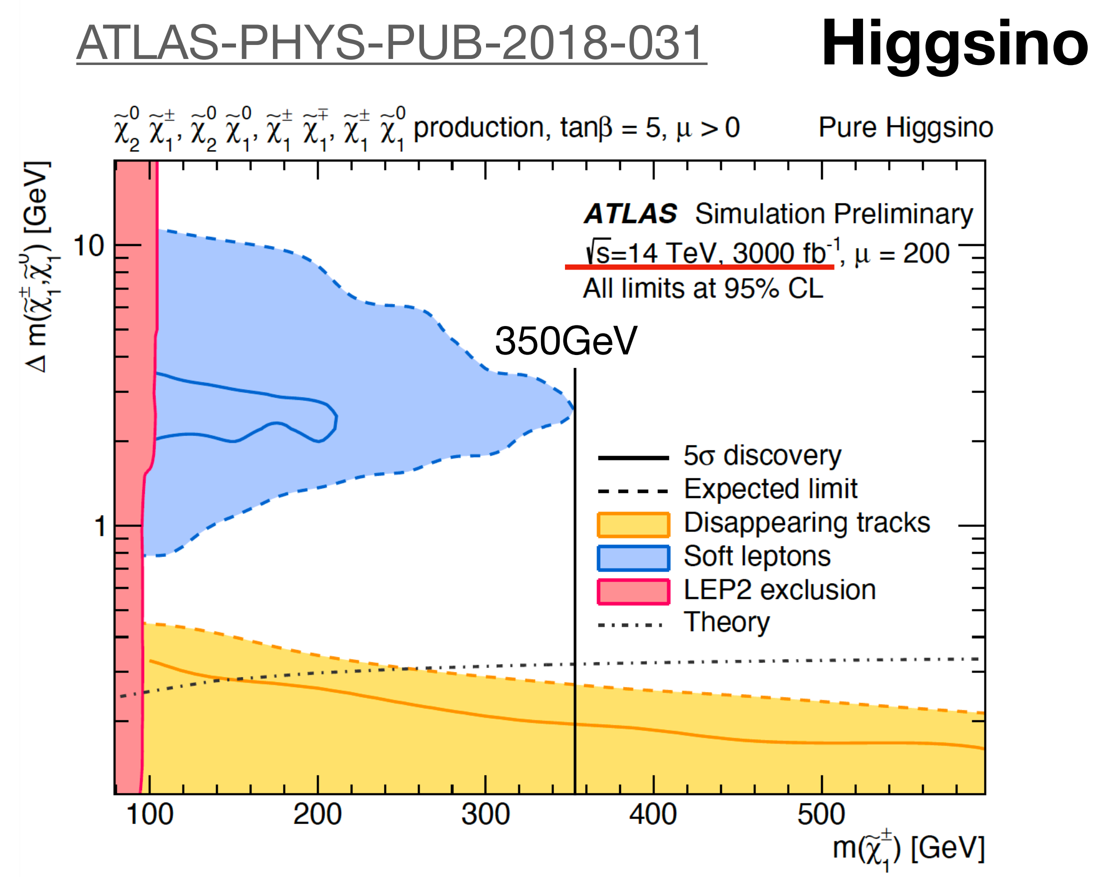
**Not even in a contrived way e.g.**

- (Pseudo-) pure higgsino LSP
- Compressed slepton-/stau-bino (muon g-2, bino DM co-annihilation)

Upcoming LHC-Run3 is exciting but just adding more data won't help much.

**New schemes wanted!** e.g. **γγ-collision**, **semi-long-lived signatures**, loop?, bound-state?




c.f. Need 1TeV to achieve correct DM relic density

# Summary

## The first round of full Run2 results becoming complete

Now most of the Run1 searches have the Run2 updates.

## No sign of promptly decaying SUSY yet

**Stick around the talks today for the long-lived part! J. Burr & I. Siral & D. Trischuk.**

## The search scope has been increasingly extended

New handles: Charge asymmetry, tailored jet tagging technique etc.

More non-minimal models: NMSSM, Stealth SUSY etc.

## LHC Run3 is coming!

Will ~double the data statistics in 3 years, with a bit higher $\sqrt{s}$ (13TeV→13.6TeV),

better detector performance, reconstruction techniques and measurements.

## It's double but only double

Some most appealing & challenging scenarios don't get addressed much by the increased data stats.

Time to think outside of the box to fill those gaps…!

**Reminder: 100GeV higgsino, 150GeV slepton, 1TeV gluino (RPV) are all alive**

# Backup

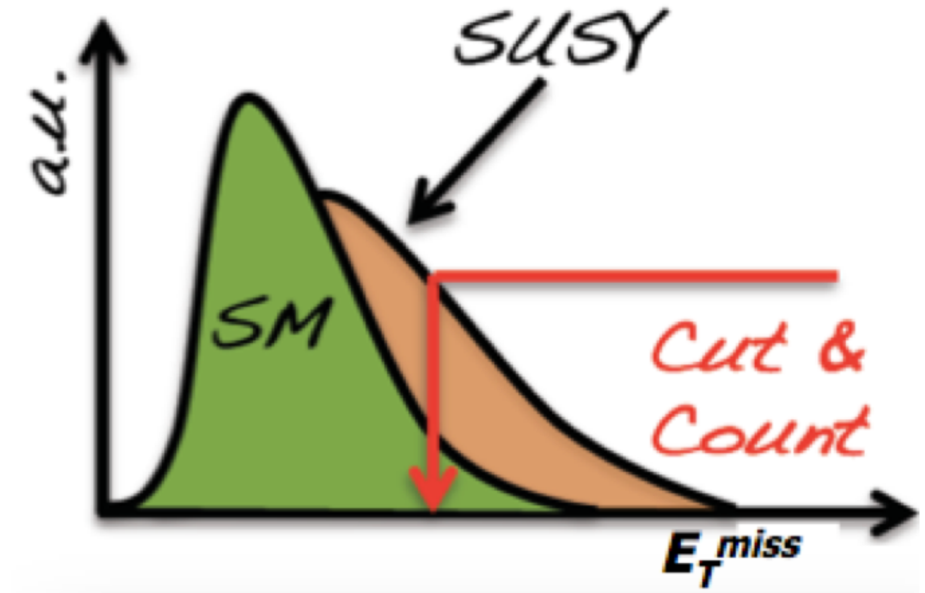
# A Typical SUSY Analysis

**Signal region† (SR):** **Test SM expectation vs data**

- Look for subtile excesses on the SM tail.

  Typpycally $H_T := \Sigma p_T(\mathrm{jet})$, $m_{\mathrm{eff}} := p_T^{\mathrm{miss}} + H_T$, $m_T$, $m_{T2}$ etc.

- Either one-bin or multi-bin.




**BG estimation:**

- **Irreducible BG → "semi-data-driven" method**

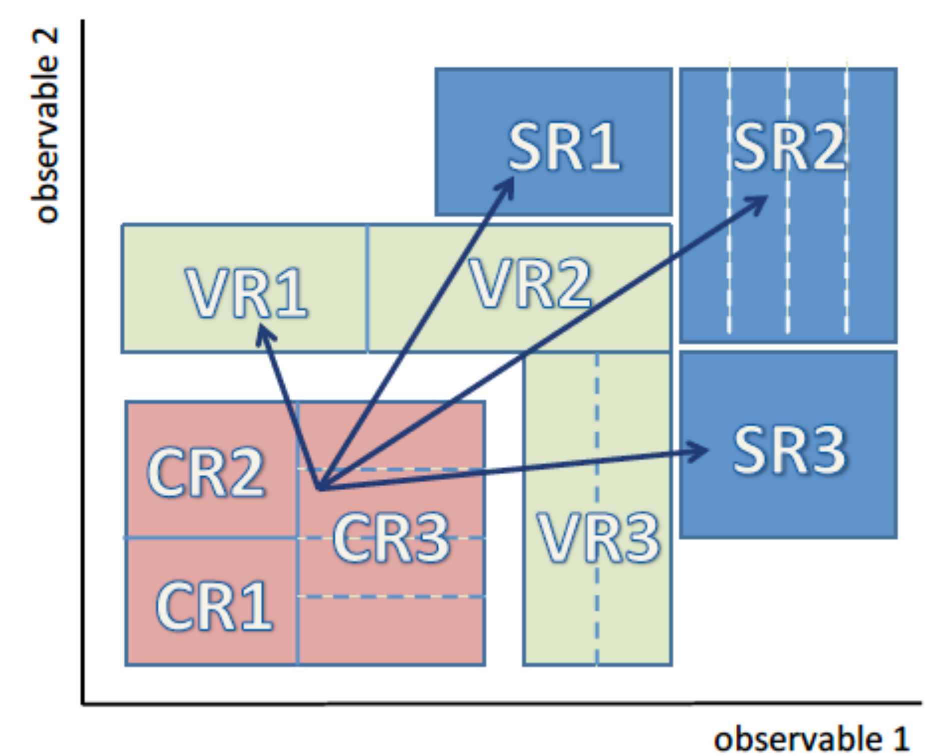
  MC normalized in the control regions (CRs) nearby SRs
  made by inverting cuts of variables well modeled by MC.

- **Reducible BG → fully (or more) data driven method**

  e.g. Fake lepton estimation:
  Measure the "fake rate" in pre-selection regions
  and apply it to the "anti-ID leptons" in the SR.

- **Validation regions (VRs)**

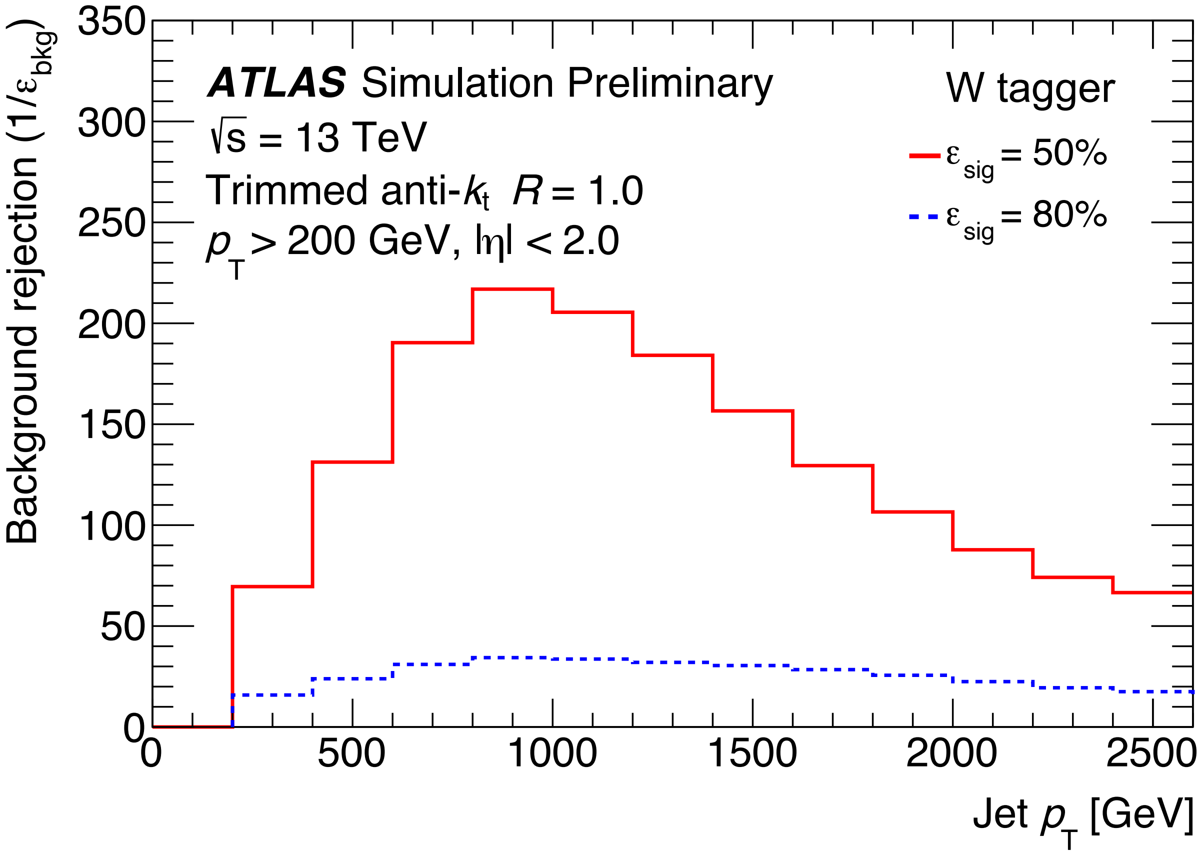
  Testing the methodology and assigned uncertainties.

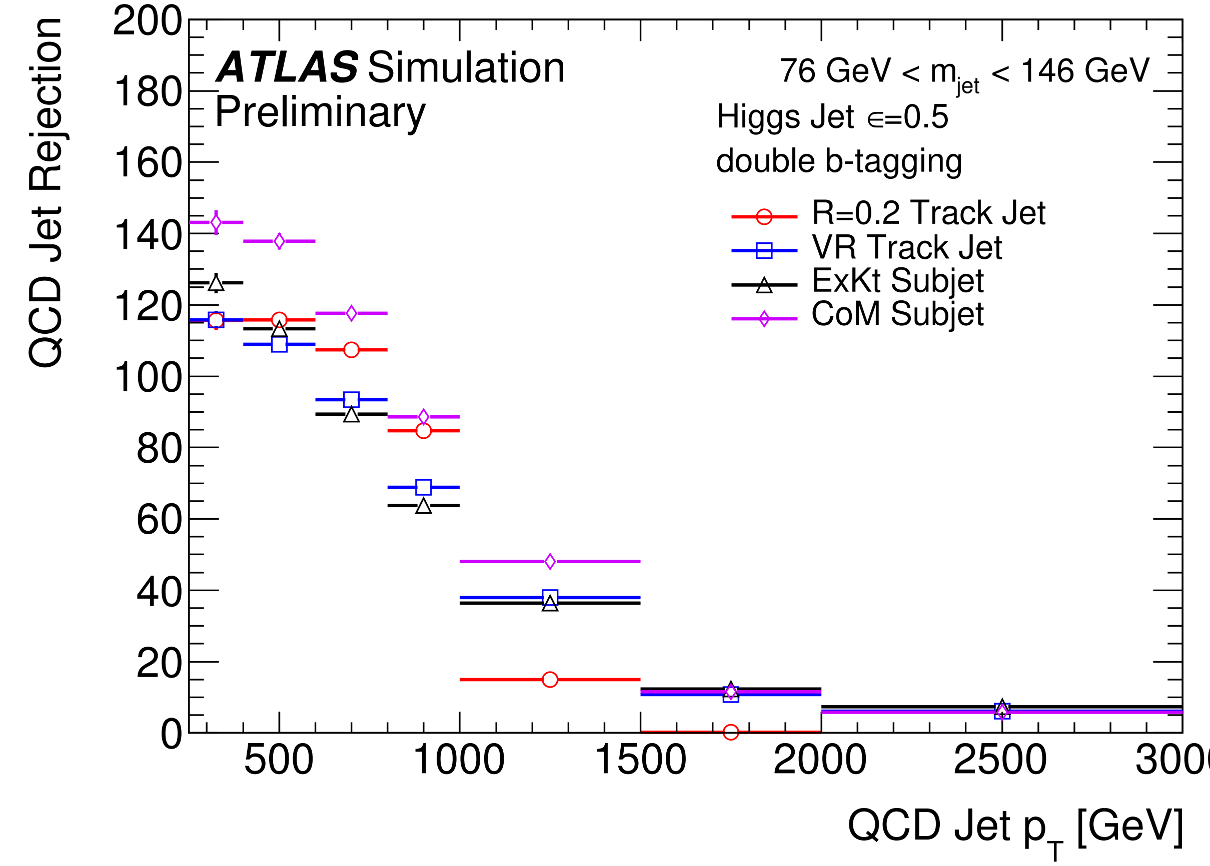



† ATLAS nomenclature. CMS calls "search regions".

# Boosted boson jet tagging

**ATLAS:** **Anti-kt R=1.0 + multi-dim cuts**




**W/Z→qq:** $p_T$-dependent cuts in jet mass, energy correlation, $n_{Tracks}$

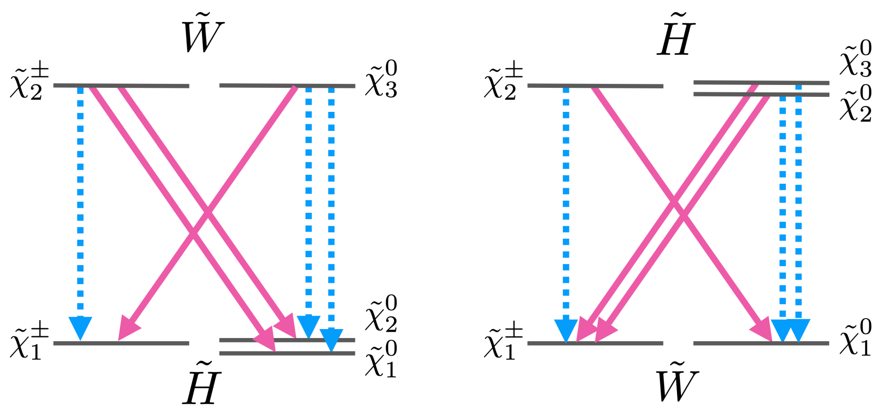
ATL-PHYS-PUB-2020-017

**Z/h→bb:** jet mass cut + sub-track-jet b-tagging

ATL-PHYS-PUB-2017-010

# EWK all-had - “Less-simplified” model limits

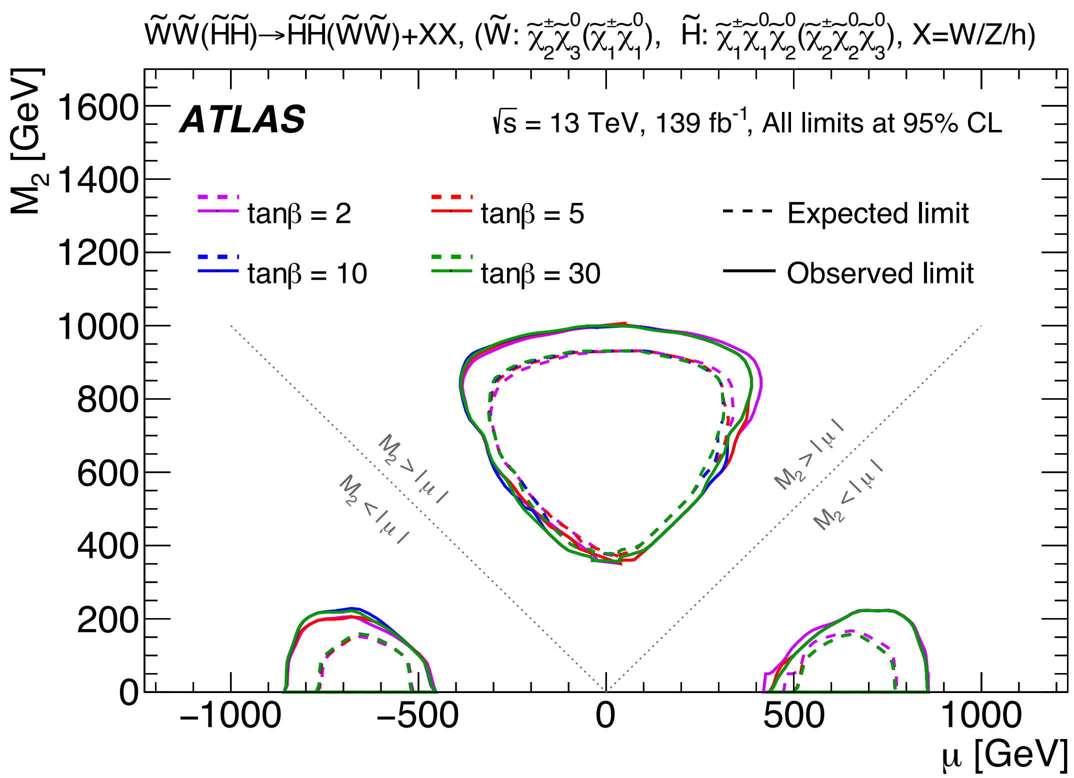
arXiv: 2108.07586



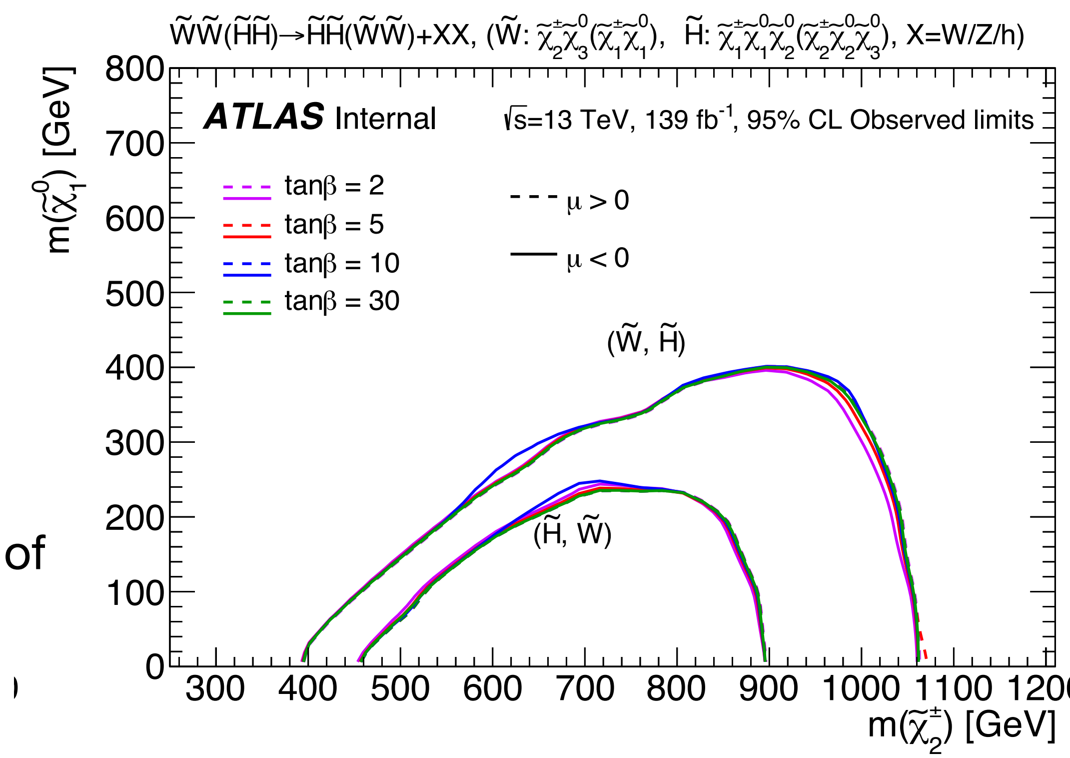

| Model | Production | Final states | Branching ratio |
|---|---|---|---|
| $(\tilde{W},\tilde{H})$ | $\tilde{\chi}_2^\pm\tilde{\chi}_2^\mp$, $\tilde{\chi}_2^\pm\tilde{\chi}_3^0$ | $WW, WZ, Wh, ZZ, Zh, hh$ | Determined from $(M_2, \mu, \tan\beta)$ |
| $(\tilde{H},\tilde{W})$ | $\tilde{\chi}_2^\pm\tilde{\chi}_2^\mp$, $\tilde{\chi}_2^\pm\tilde{\chi}_2^0$, $\tilde{\chi}_2^\pm\tilde{\chi}_3^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$ | $WW, WZ, Wh, ZZ, Zh, hh$ | Determined from $(M_2, \mu, \tan\beta)$ |

**Too many floating BRs.** What do we do?

→ Parameter scan within a pMSSM sub-space: 3D scan in ($M_2$, $\mu$, $\tan\beta$).

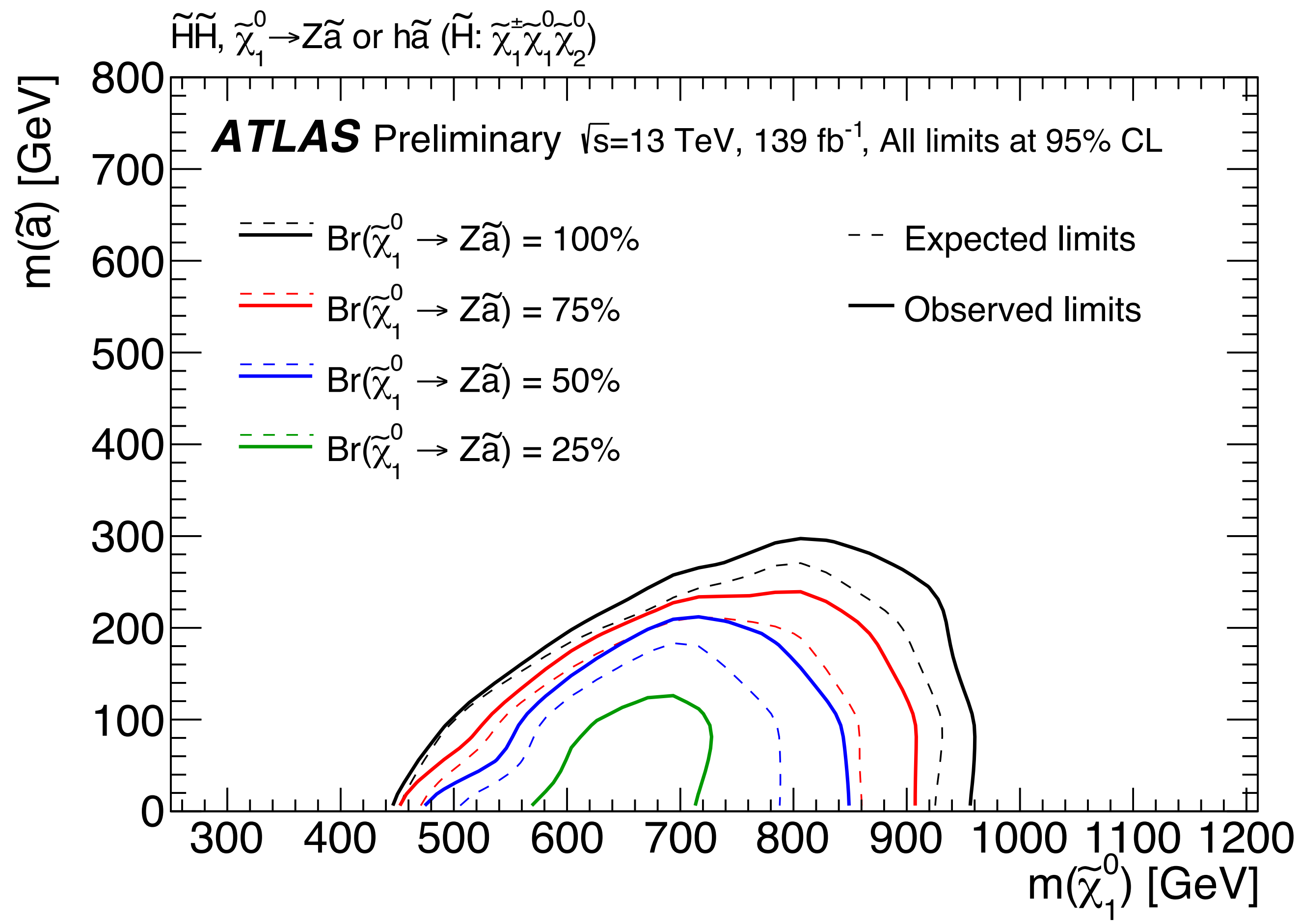


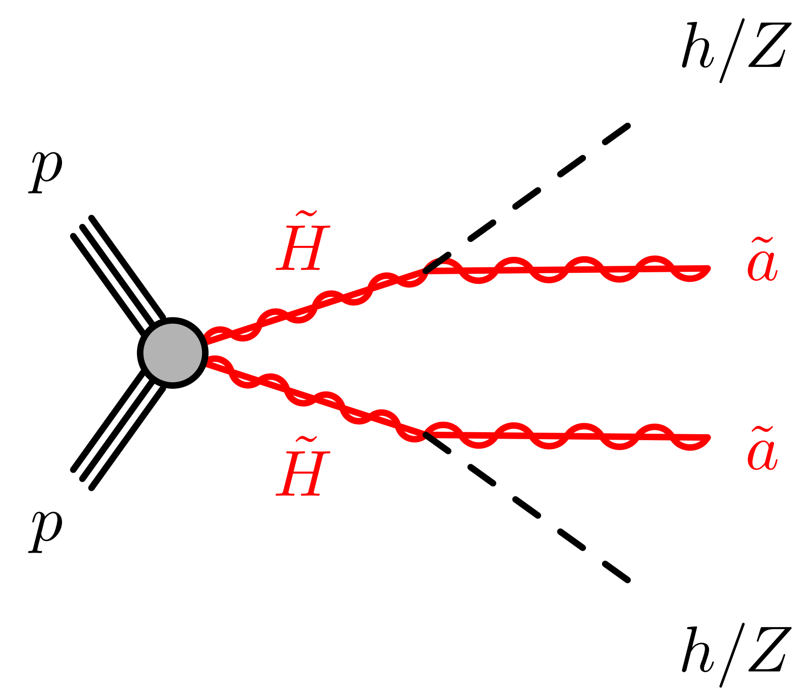

as the function of physical mass



# EWK all-had - Limits on an Axino LSP model

arXiv: 2108.07586




○ **Inspired by a very consistent pursuit for "naturalness"** (arXiv: 1407.1218)

Hierarchy problem → SUSY / EW naturalness → Light higgsino

Strong CP problem → Axion → (SUSY should exist) → Axino

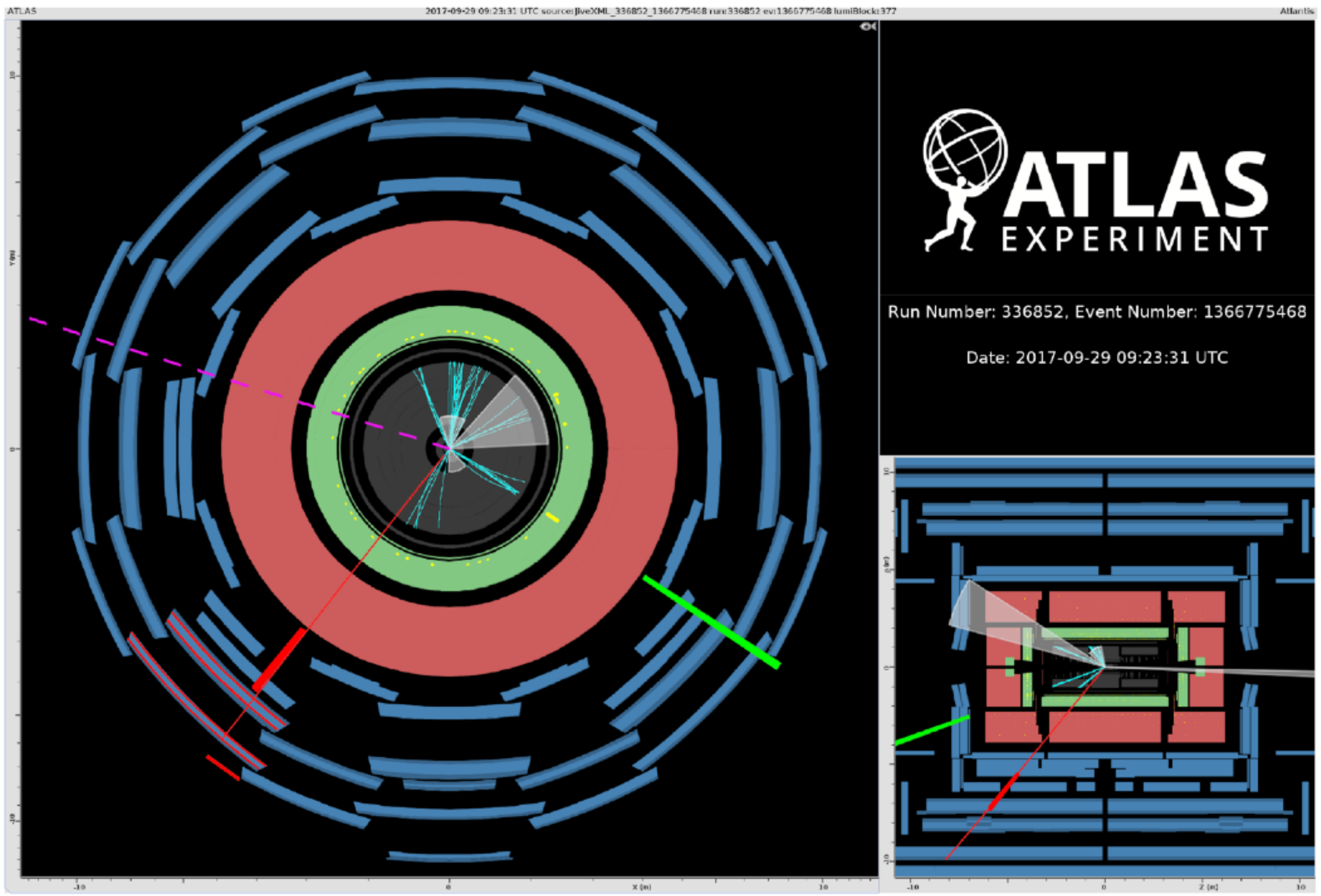
○ Axino LSP: Interesting in the context of DM

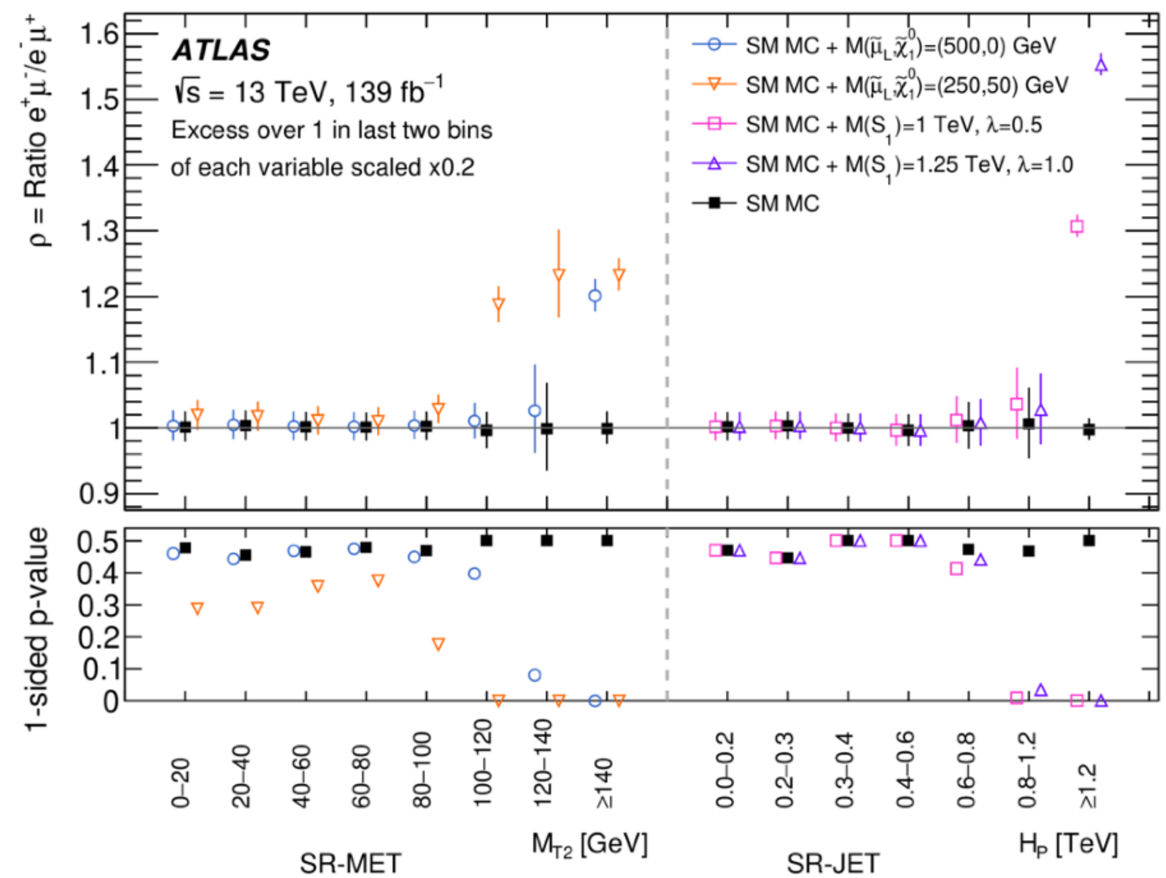
○ Large Δm favors short-lived higgsino

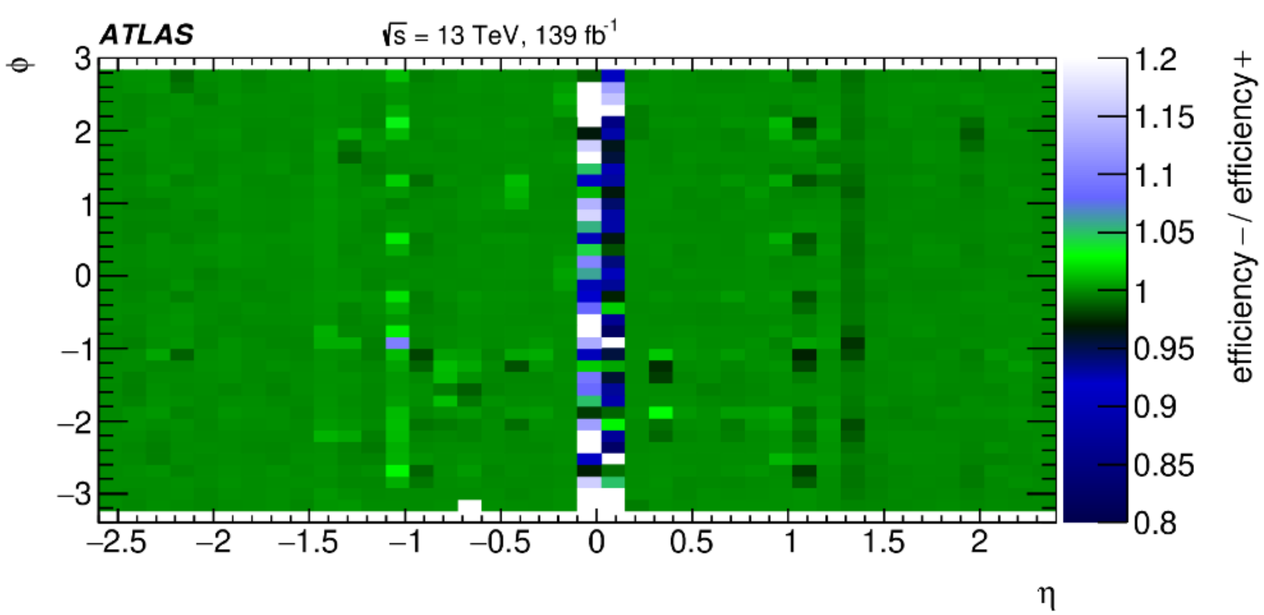
**First dedicatedly probed at LHC**

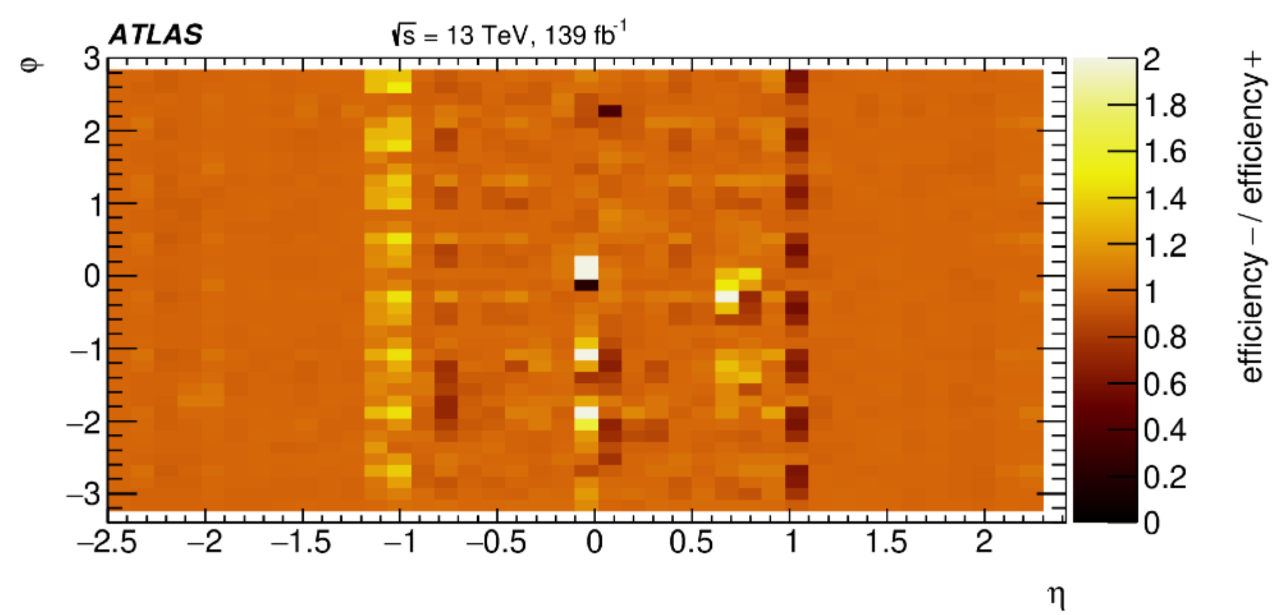
**Excluded up to max. 950GeV**

# eμ-asymmetry search (more plots)



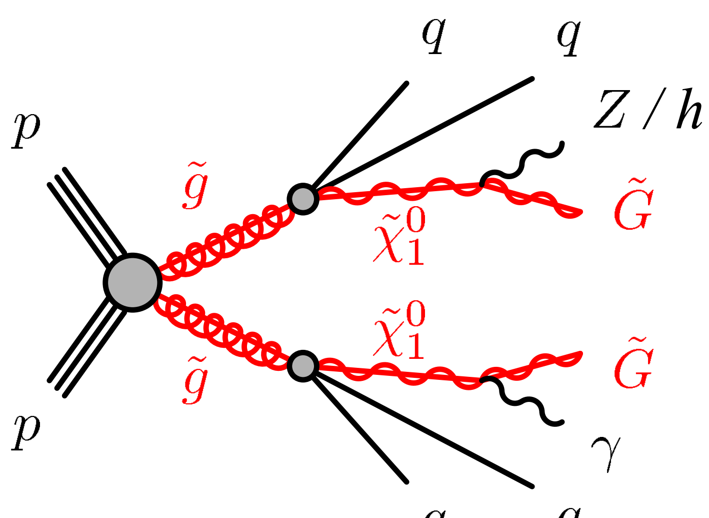



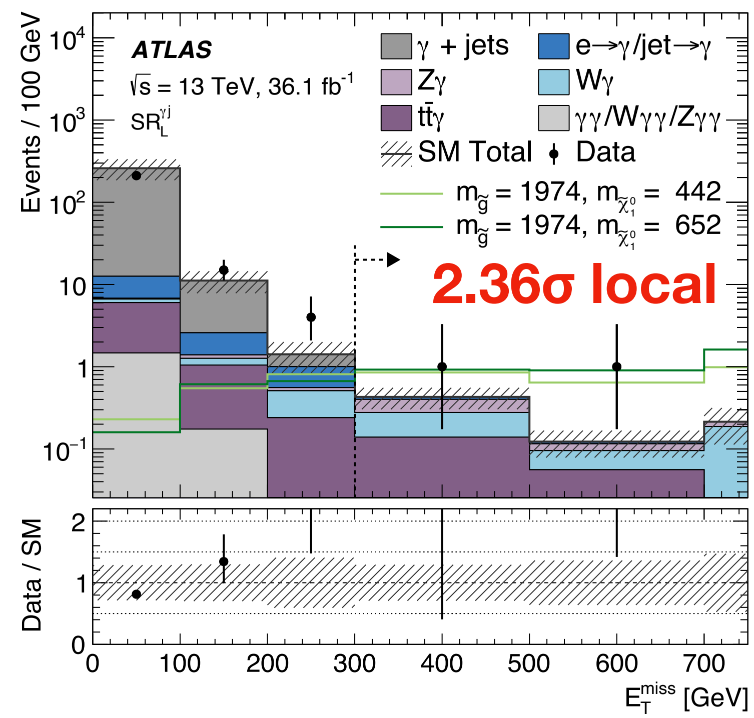
# Photon+Jets+$p_T^{miss}$

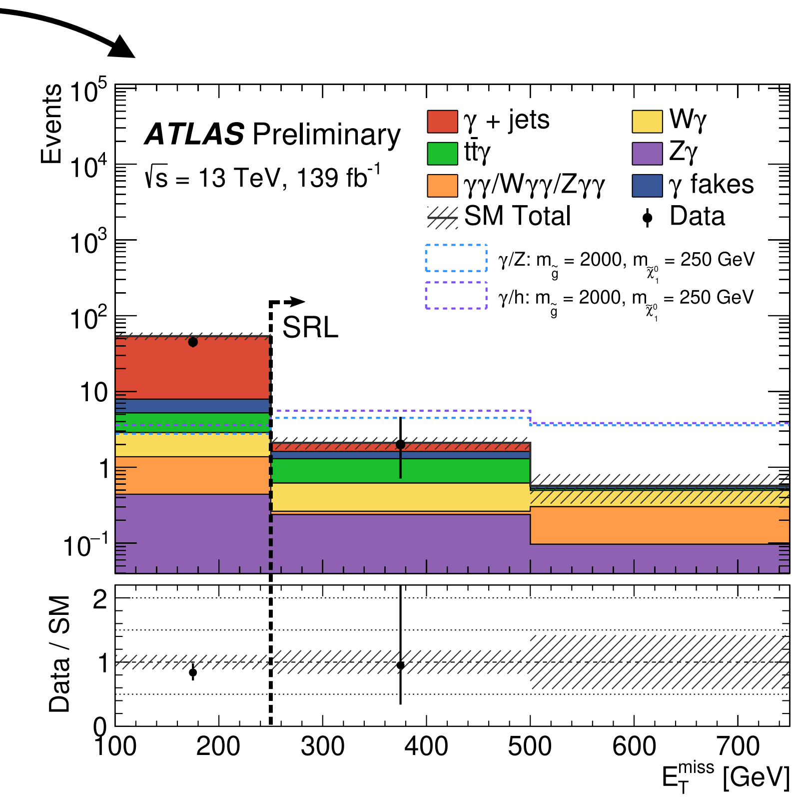
[ATLAS-CONF-2021-028](ATLAS-CONF-2021-028)




GMSB-inspired

Gluino → neutralino → γ/Z/h + Gravitino




**Selection:** Photon trigger ($p_T$>145GeV)

$E_T^{miss}$>250GeV, $H_T$>1.6TeV

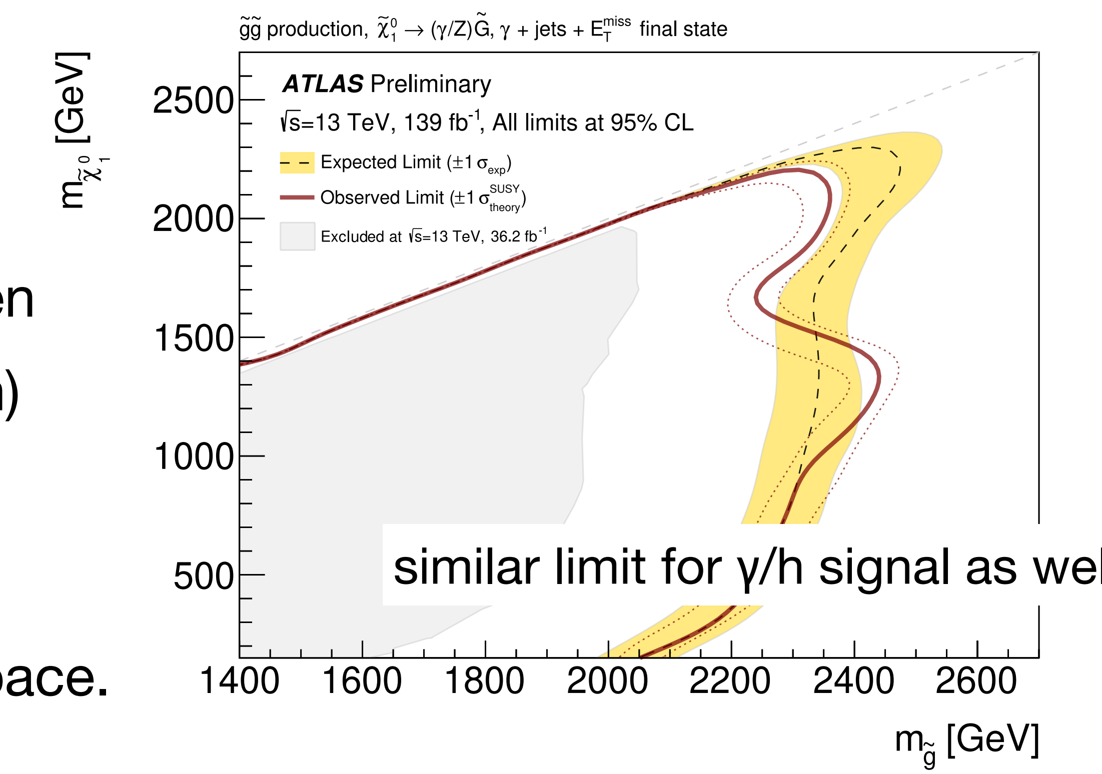
**BG:** Real photon BGs (γ+jets etc.) → semi-data-driven

Fake photon BGs → ABCD method (ID×isolation)

**Results:** No excess.

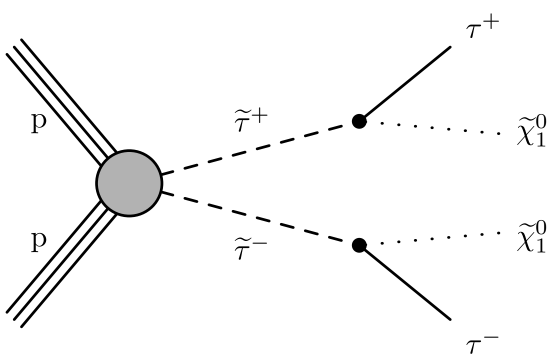
Mild excess seen in the previous analysis @36fb⁻¹

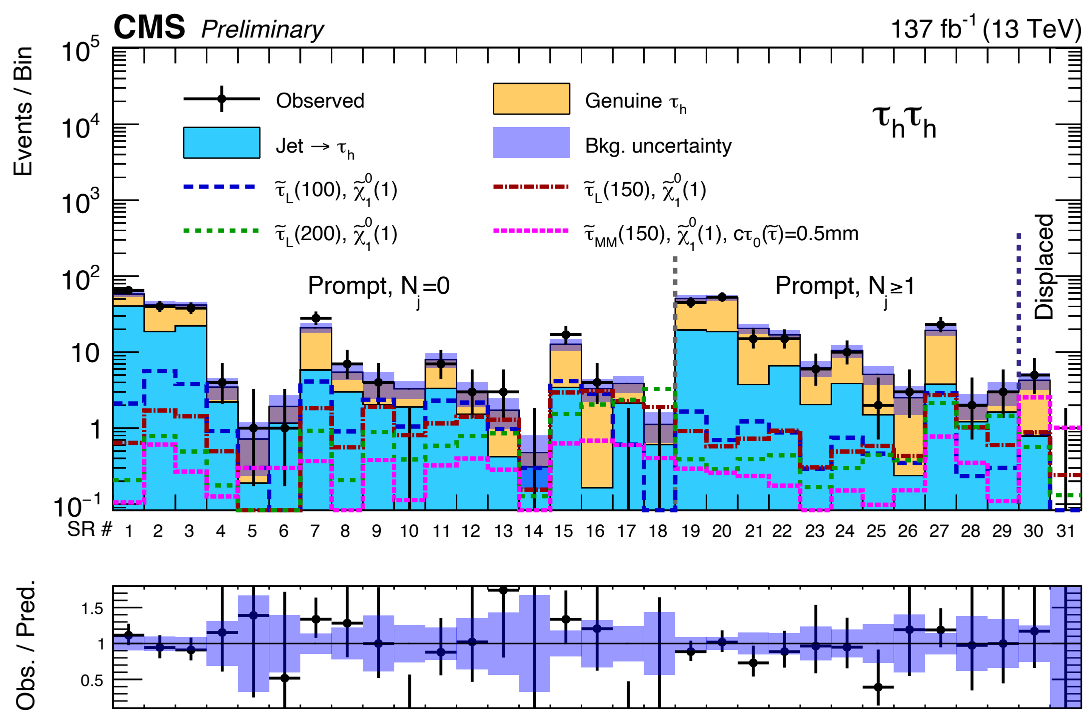
→ Not confirmed @139fb⁻¹ in the similar phase space.

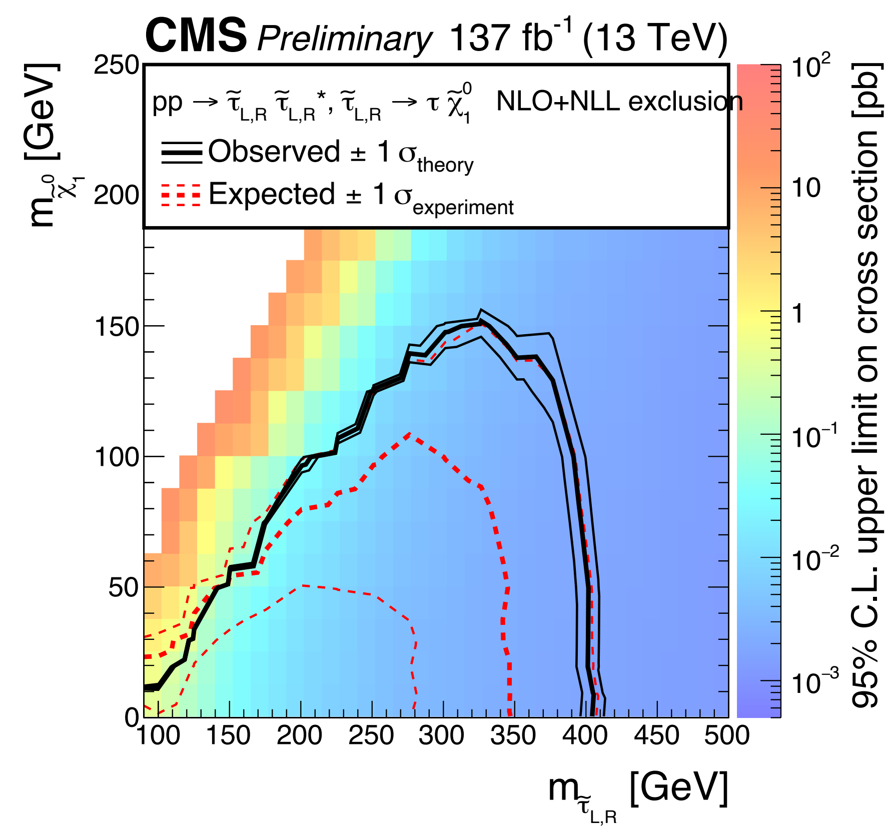


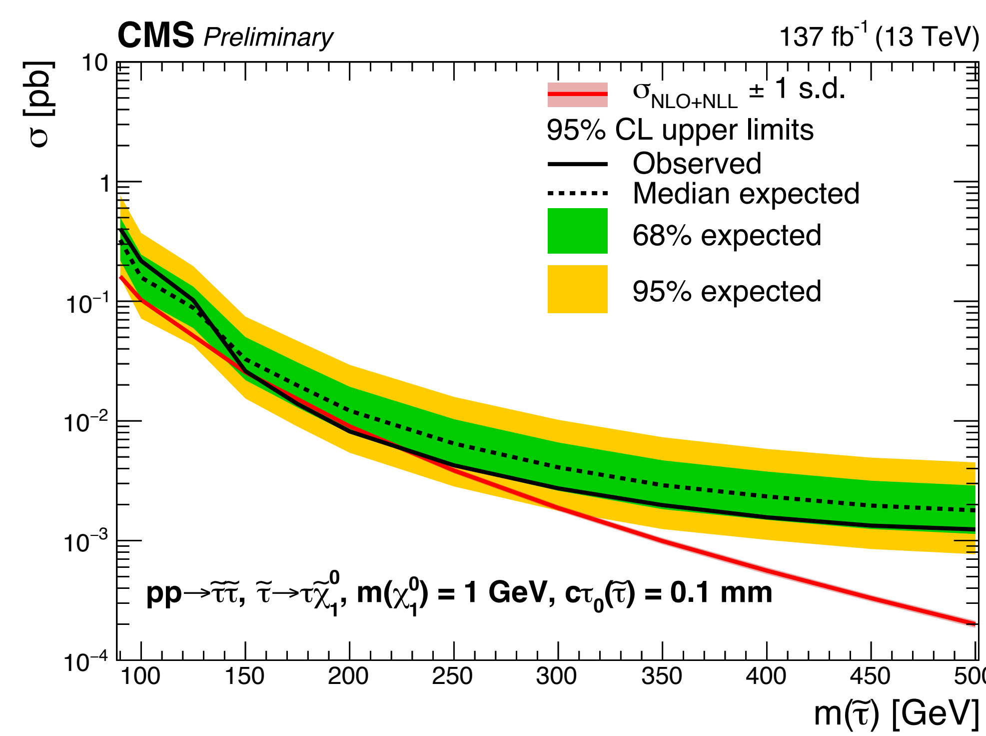
# Stau all-hadronic

CMS-PAS-SUS-21-001




- **Target:** Stau (L/R/L+R) → Bino (prompt decay)

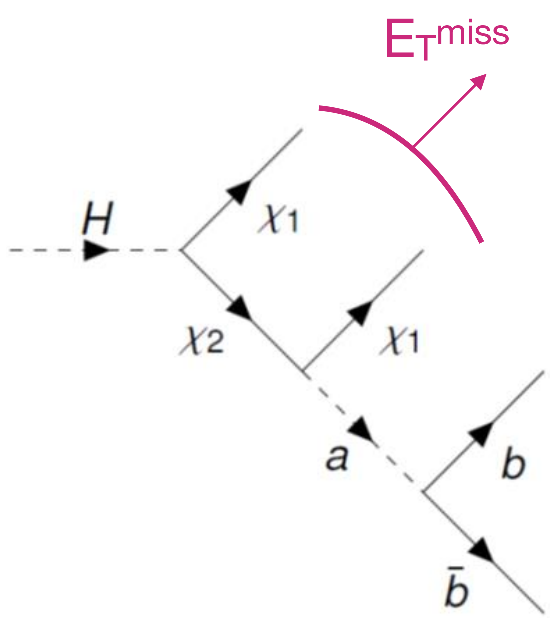
  Stau (L-R mixed) → Gravitino (long-lived)

  † Often NLSP & weak coupling to G~ in GMSB.
- **SR:** Binned in $m_{T2}$, $\Sigma m_T$, $n_{Jets}$ etc.
- **Main BG: Z→ττ**

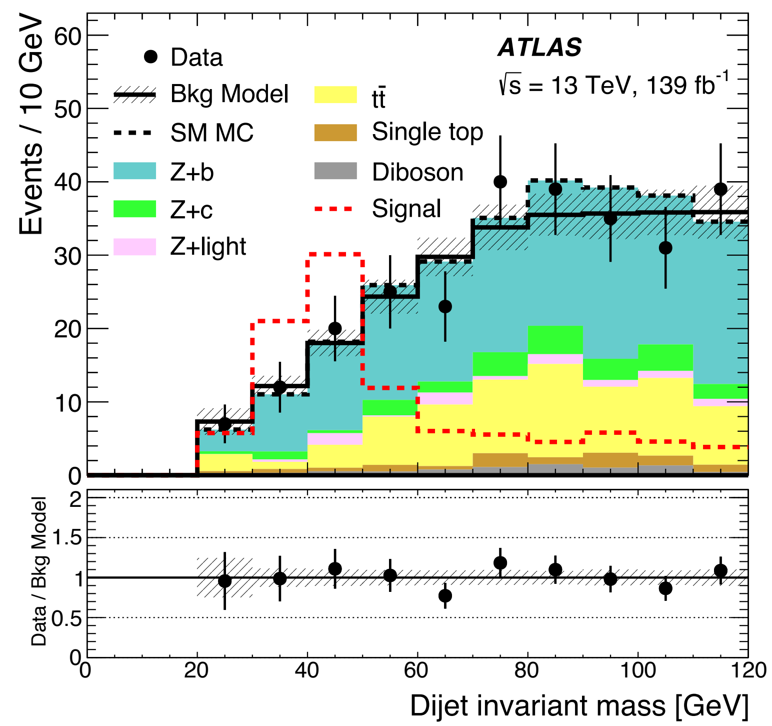
  Estimated using the **"embedding"** method i.e. replace the μ to simulated τ in Z→μμ data.
- **Fake $\tau_h$ BG:** data-driven estimation.

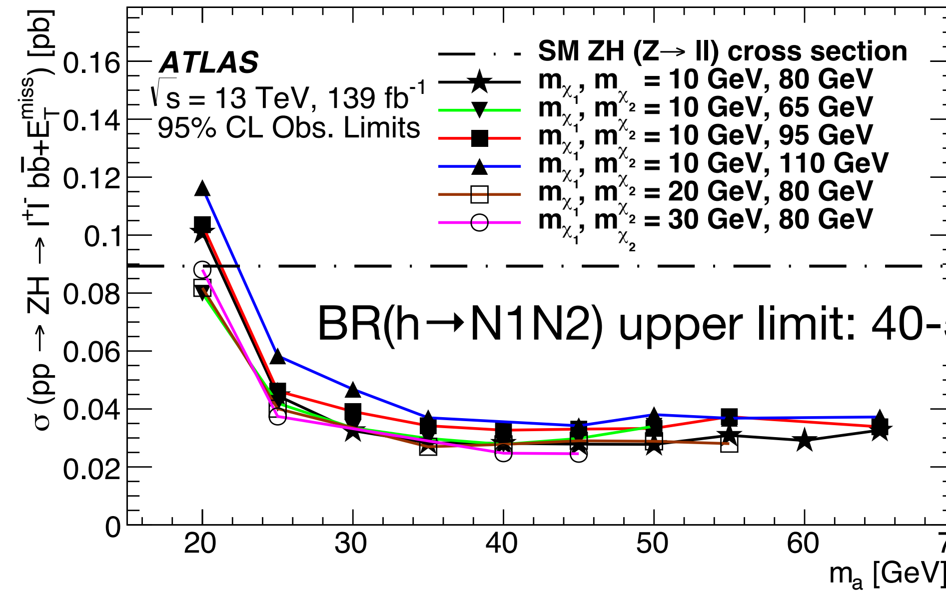
# Higgs decay into NMSSM singlet (2L+2b+$p_T^{miss}$)

arXiv: 2109.02447




signal: $(m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}) = (45\text{ GeV}, 10\text{ GeV}, 80\text{ GeV})$



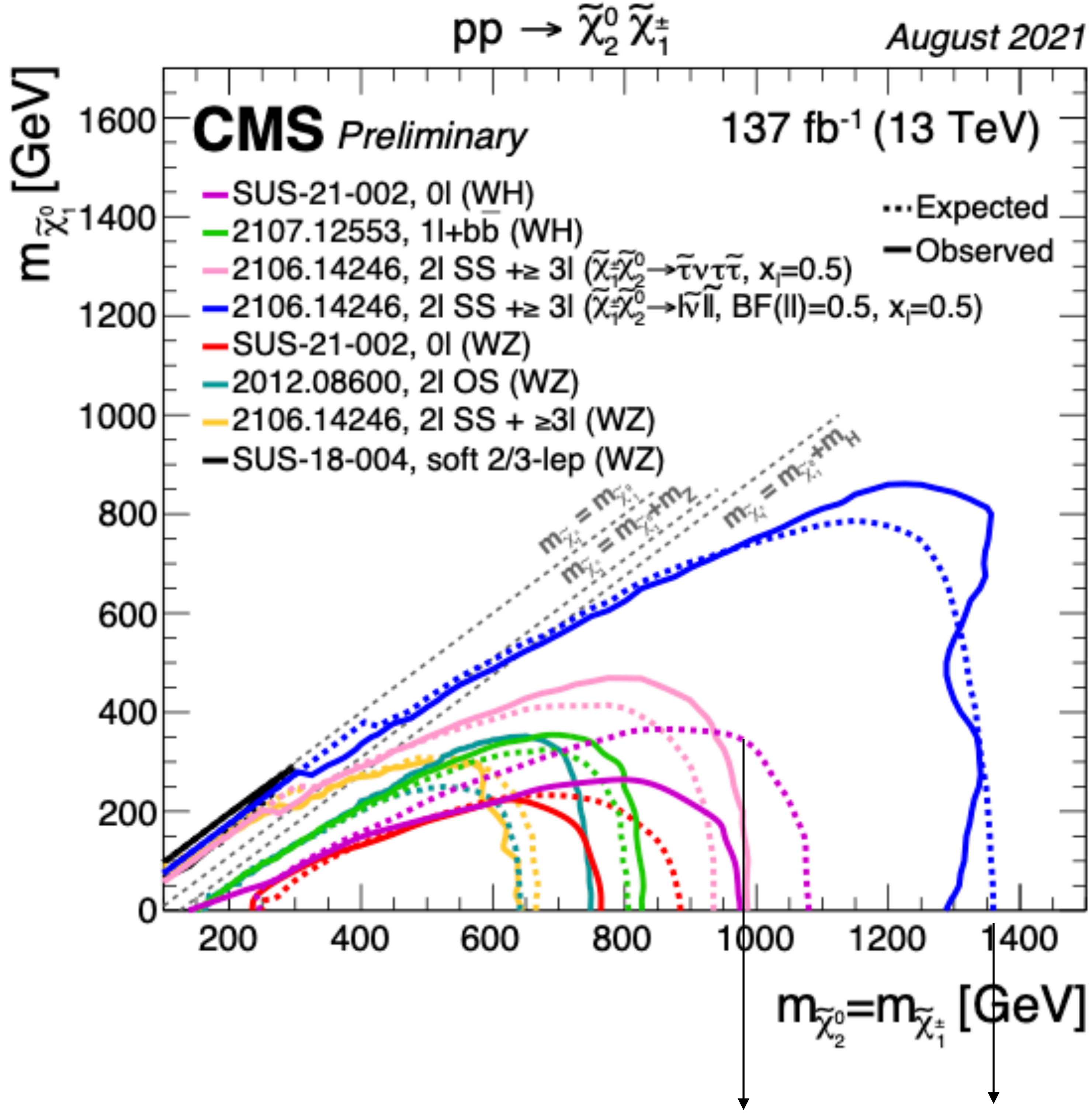




BR(h→N1N2) upper limit: 40-50%

- **"a": additional higgs in the SM sector in NMSSM.** $m(\tilde{\chi}_2^0) < m(a) < m(\tilde{\chi}_1^0)$.
- Zh production, $Z \to \ell\ell$, $h \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$
- Di-bjet resonance peaking at m(a).
- Main BG: $Z(\to \ell\ell)$ + b-jets, ttbar

  $m_{jj}$ template derived using CR data + normalized using MC
- **No significant excess found.**

# How to read the summary plots




These numbers are derived for very specific conditions!

Be sure what they are when quoting "~GeV is excluded"!

e.g. When finding the $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ limits

**This is about:**

**Wino NLSP→ (stable) bino LSP**

σ is ~1/4 if Higgsino

**Simplified model**

BR($\tilde{\chi}_2^0 \to Z\, \tilde{\chi}_1^0$)=100% assumption is unrealistic when $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) > m_h$

**950GeV** **(if sleptons are not relevant)** **1.35 TeV** **(if $m_{slepton}$ is exactly between $m_{LSP}$ and $m(\tilde{\chi}_2^0)$)**