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Searches for **Supersymmetry**

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Lepton Photon 2021 Manchester

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ATLAS EXPERIMENT

Run: 300800

Event: 2418777995

2016-06-04 03:47:03 CE

if you can read this, you're too close

indico.cern.ch/e/949705/

"SUSY is just around the corner."
— Carlos Wagner

https://indico.cern.ch/event/813884/contributions/3394791

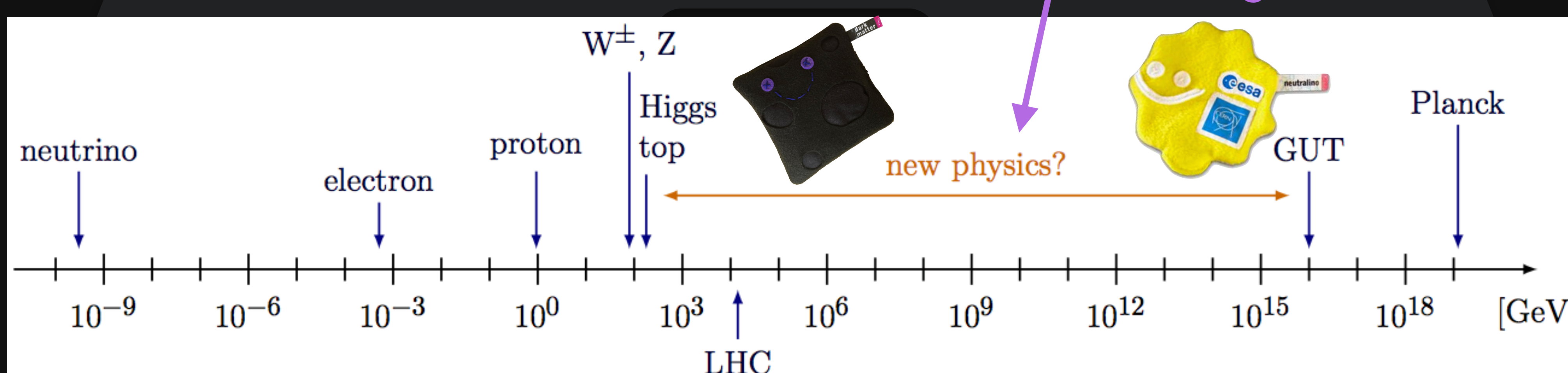
Overview of Today

- A highlight of searches for **new physics inspired by SUSY** across R-Parity Conserving (**RPC**) R-Parity Violating (**RPV**) scenarios
  - Strong,
  - 3rd Generation (**3G**),
  - Electroweak (**EWK**), and
  - Long-Lived Particles (**LL** or **LLP**)
- and how these results fit into a global picture

KEY

PRODUCTION	**Strong** ($\tilde{g}$)
	3G ($\tilde{t}$,$\tilde{b}$)
	EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^{\pm}$)
	RPVLL (λ',λ'')
LUMI	**36 fb^{-1}**
	80 fb^{-1}
	139 fb^{-1}
FIT	**cut and count**
	multi-bin

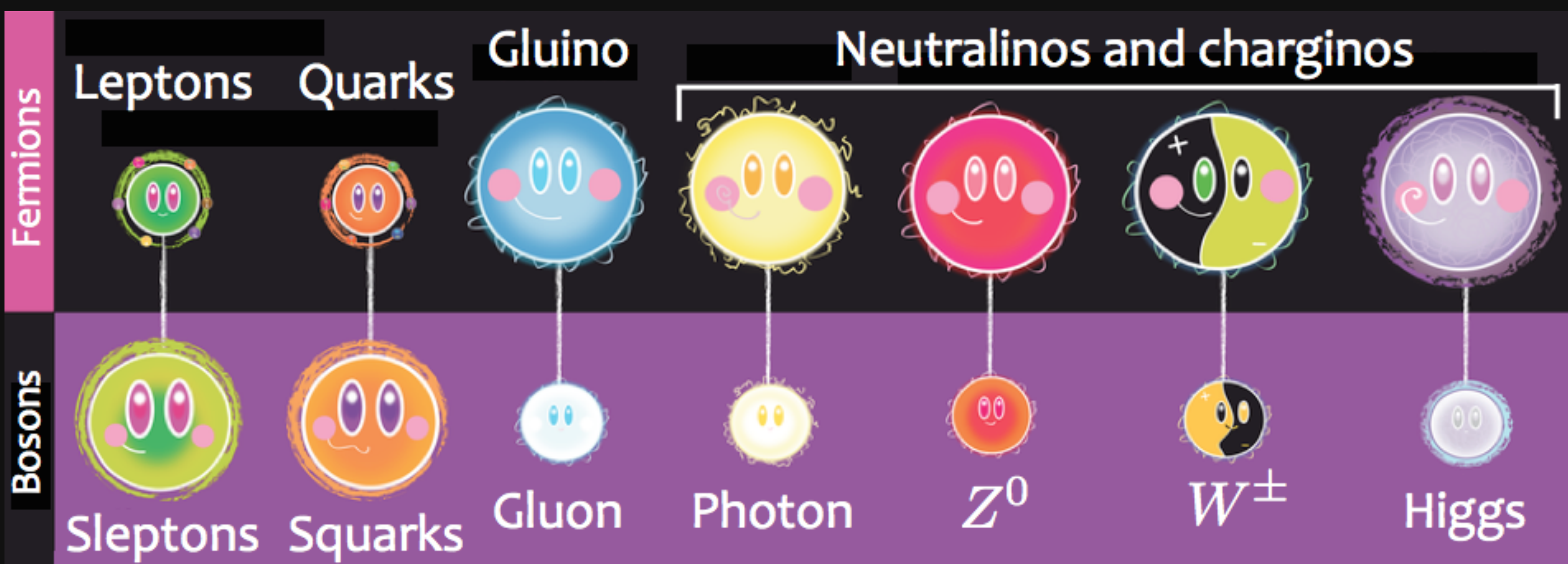
Where is SUSY hiding?



Symmetry between fermions and bosons

What is supersymmetry?

- **A set of theories** that predicts new boson (fermionic) partners for the fermions (bosons) of the Standard Model — each with spin differing by 1/2 unit
  - Stable lightest supersymmetric particle (LSP) in R-parity conserving SUSY theories are possible dark matter candidates, Higgs boson mass stabilized, and possible unification of inverse gauge couplings
- When undergoing electroweak symmetry breaking, the higgsinos and electroweak gauginos mix (binos, winos, higgsinos)
  - neutral higgsinos and neutral electroweak gauginos mix to form **neutralinos**
  - charged higgsinos and charged electroweak gauginos mix to form **charginos**

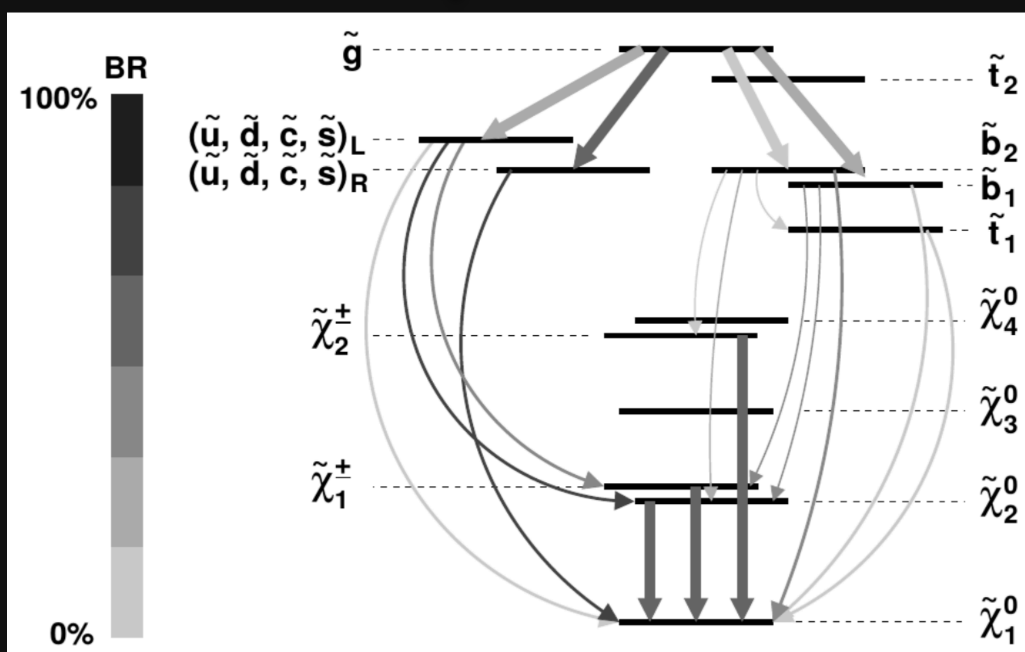


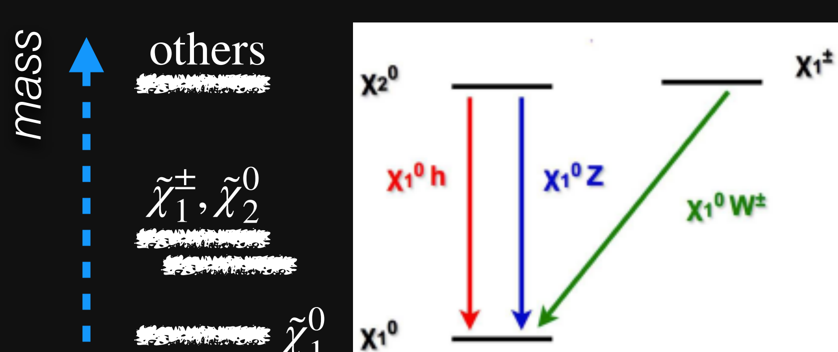
https://indico.cern.ch/event/724564/contributions/2982187/

https://arxiv.org/abs/1309.5966

SUSY "Simple" Models

124 free parameters!

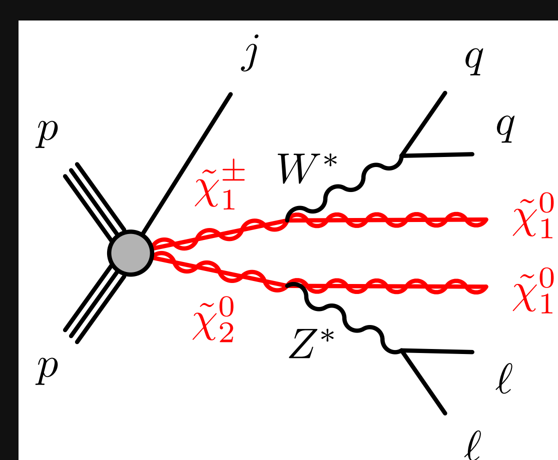




e.g. Bino-Like LSP

$|M_1| < |M_2|, |\mu|$

- Make some assumptions to reduce phase-space and focus on specific decay chains or specific simplified models (typically 3 or 4 parameters)
- **Pro**: (mostly) orthogonal searches for simplified models are easy to combine and re-interpret with alternative models
- **Con**: not physically realizable in the sense that nature won't give us clean, 100% decays



(this is just one example model, there's many others!)
https://feynman.docs.cern.ch/

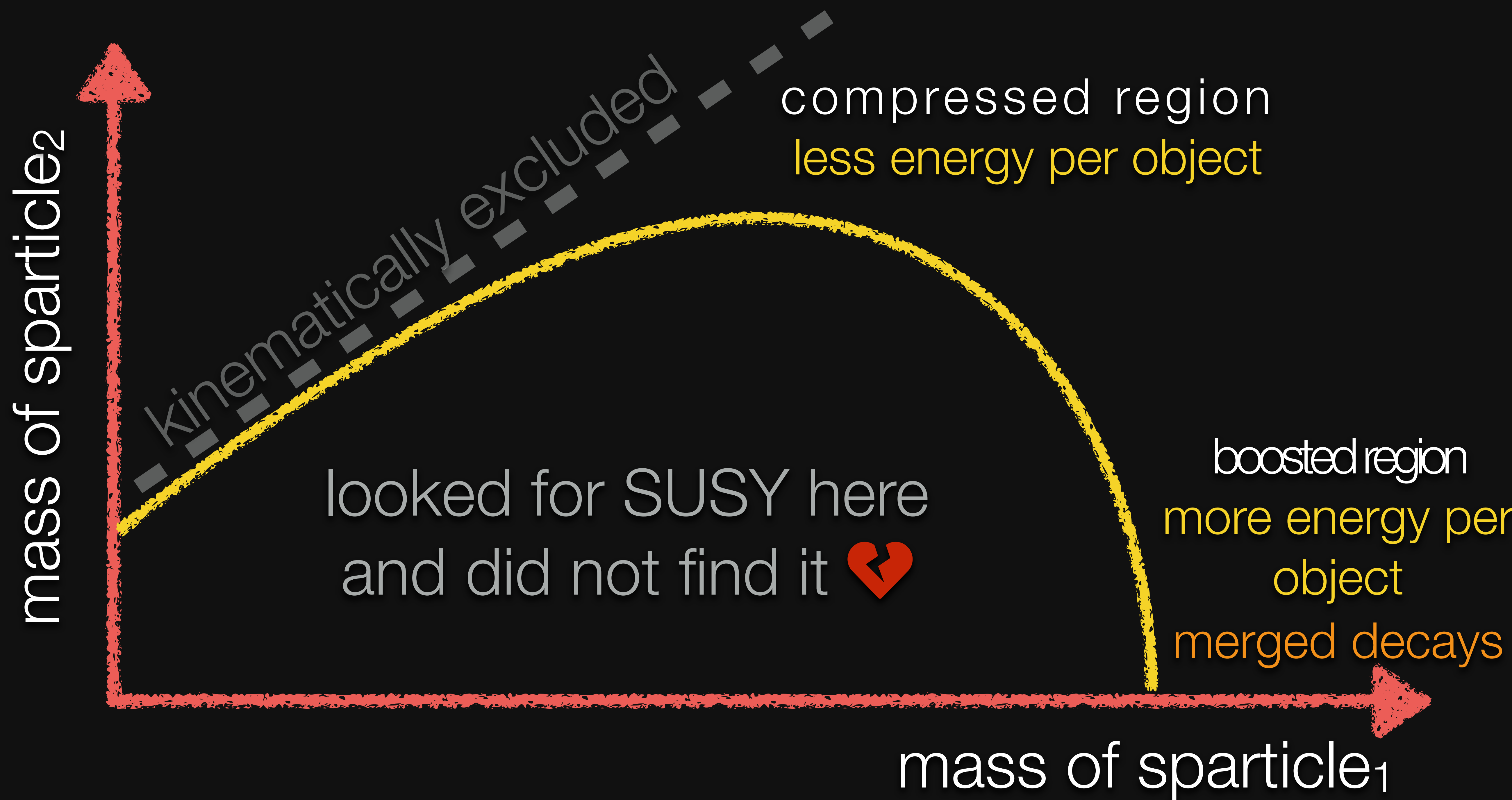
https://arxiv.org/abs/1605.01416

Favorite Discriminating Variables

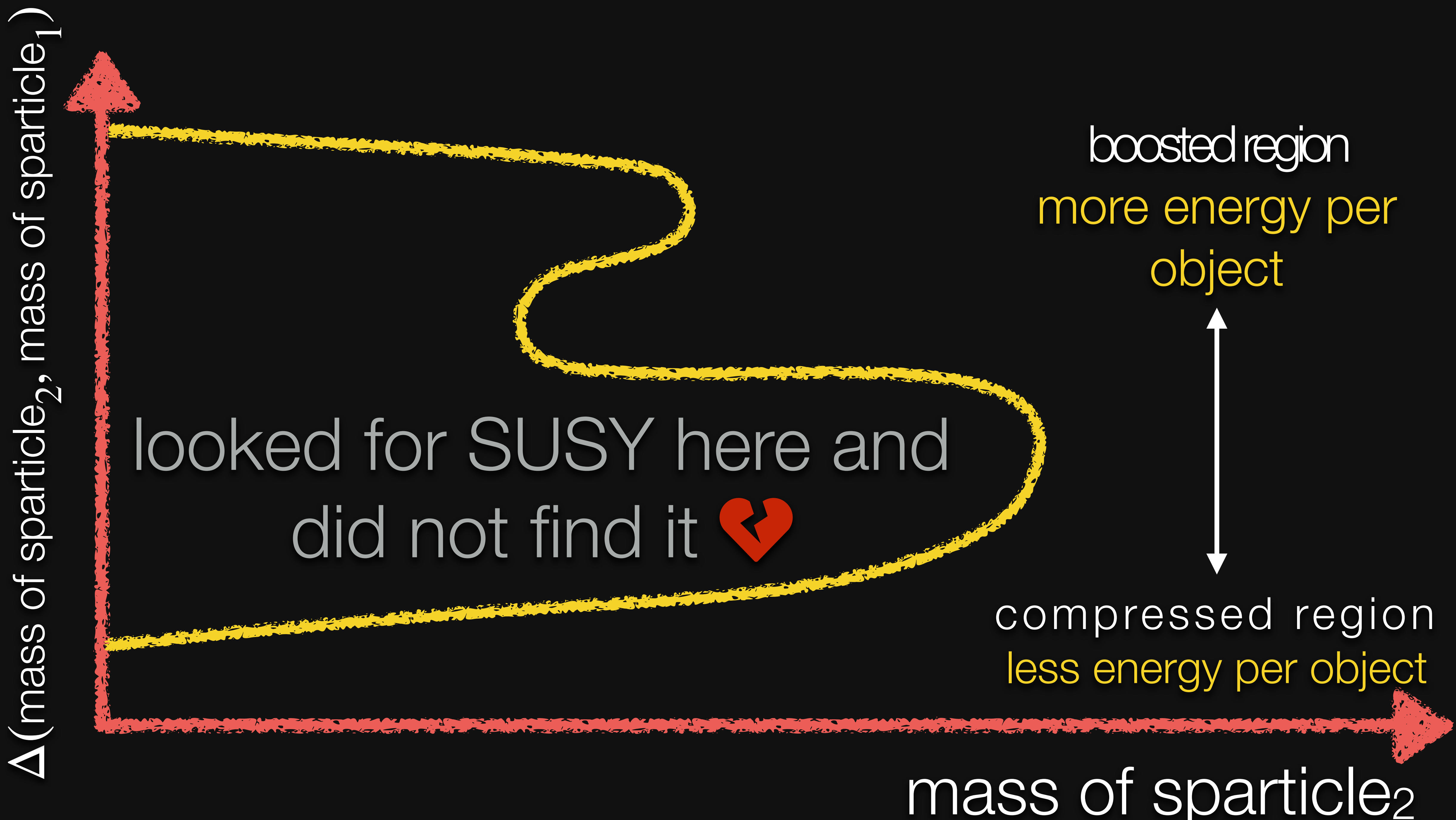
Event selection observables sensitive to features of supersymmetry models are classified as:

- **Missing momentum-type**: sensitive to the properties of the invisible states
  - ❓ **how many neutralinos in the event? (*RPC: LSP escapes detection*)**
- **Energy scale-type**: sensitive to the overall energy scale of the event
  - ❓ **what is the mass of the gluino? (*Strong: can reach high mass scales*)**
- **Energy structure-type**: sensitive to the structure of the visible energy
  - ❓ **how is the energy of the decay partitioned across the final state visible/invisible objects? *(e.g. decay angle between LSP and jets)***

Interpreting Results



Interpreting Results ("dM")



Searching for SUSY

2L0J, W/Z 3L, soft 2L

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2018-32/

regions with different/same flavor electrons/muons

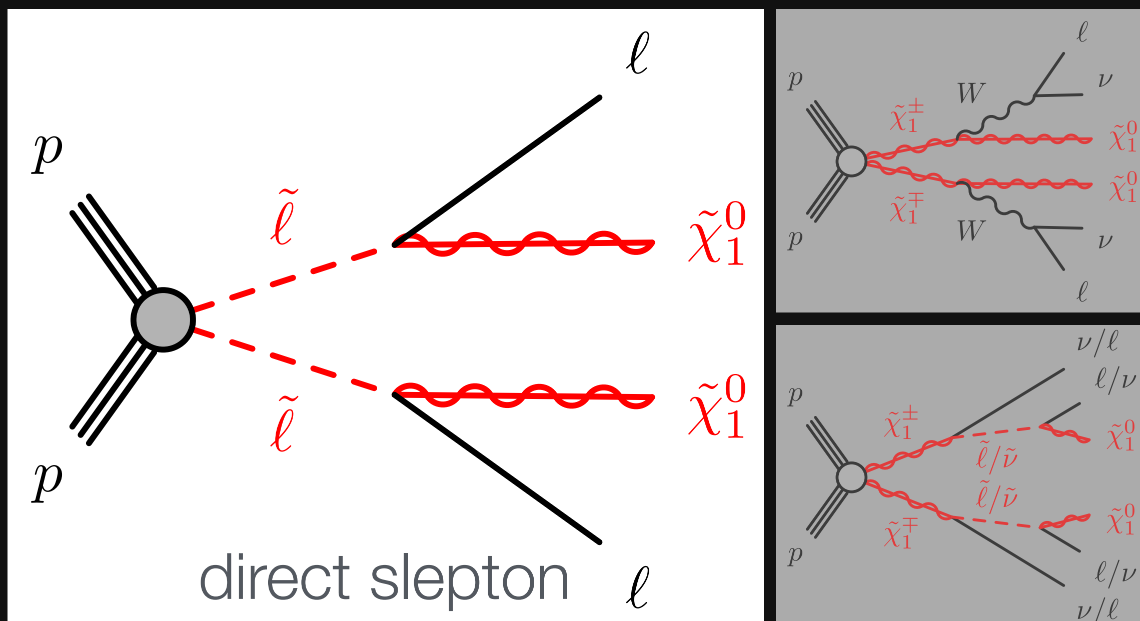
EWK ($\tilde{\ell}$, $\tilde{\nu}$, $\tilde{\chi}_1^{\pm}$)

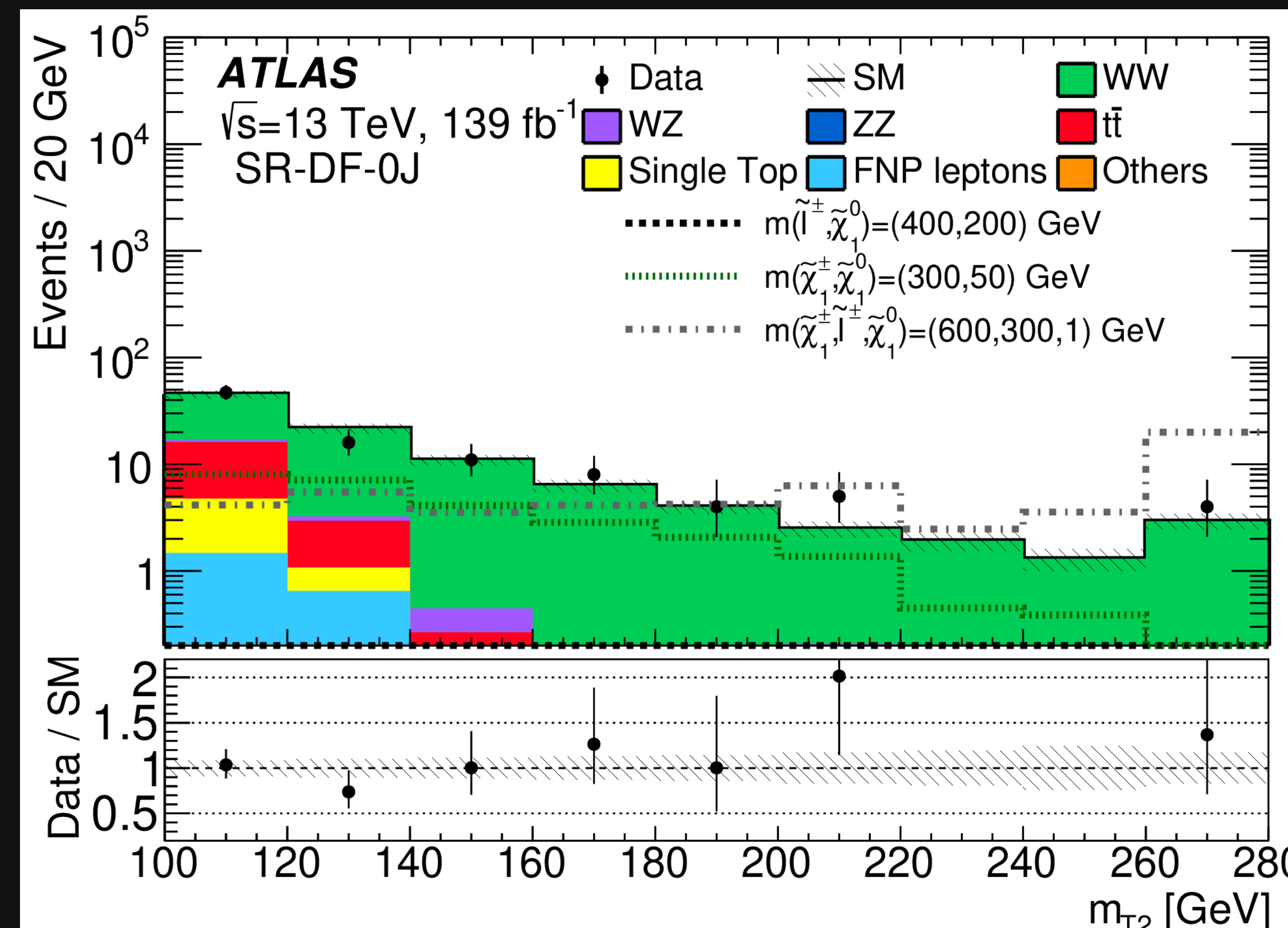
139 fb^{-1}

cut and count

multi-bin

Sleptons: 2 lepton, 0 jet





different-flavor, 0-jet signal region

- MODEL PARAMETERS: $\tilde{\ell}$, $\tilde{\nu}$, $\tilde{\chi}_1^0$, $\tilde{\chi}_1^{\pm}$
- FINAL STATE: =2 leptons (OS), MET
- THREE SIGNAL SCENARIOS (9 exclusion regions):
  - $\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$, $\ell \in [e,\mu]$ (direct slepton)
  - $\tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0$
  - $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\ell}\nu/\tilde{\nu}\ell$, $\tilde{\ell}/\tilde{\nu} \rightarrow \tilde{\chi}_1^0\, \ell/\nu$
- DOMINANT BACKGROUNDS: $t\bar{t}$, Wt, WW, WZ, ZZ
- CHALLENGE: theory uncertainties of diboson, top

OS: Opposite-Sign (electric charge)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2018-32/
https://arxiv.org/abs/1403.5294

EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)
139 fb^{-1}
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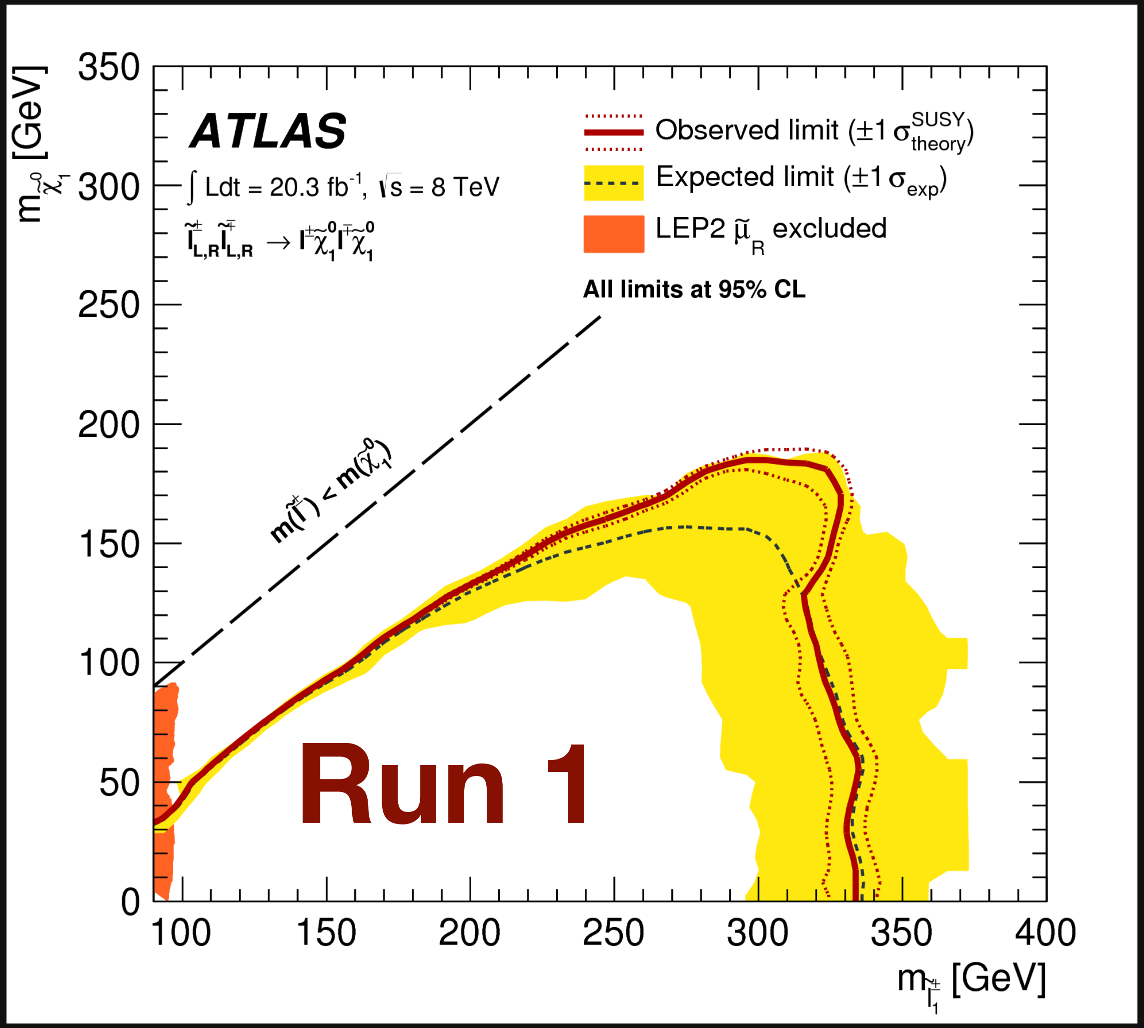
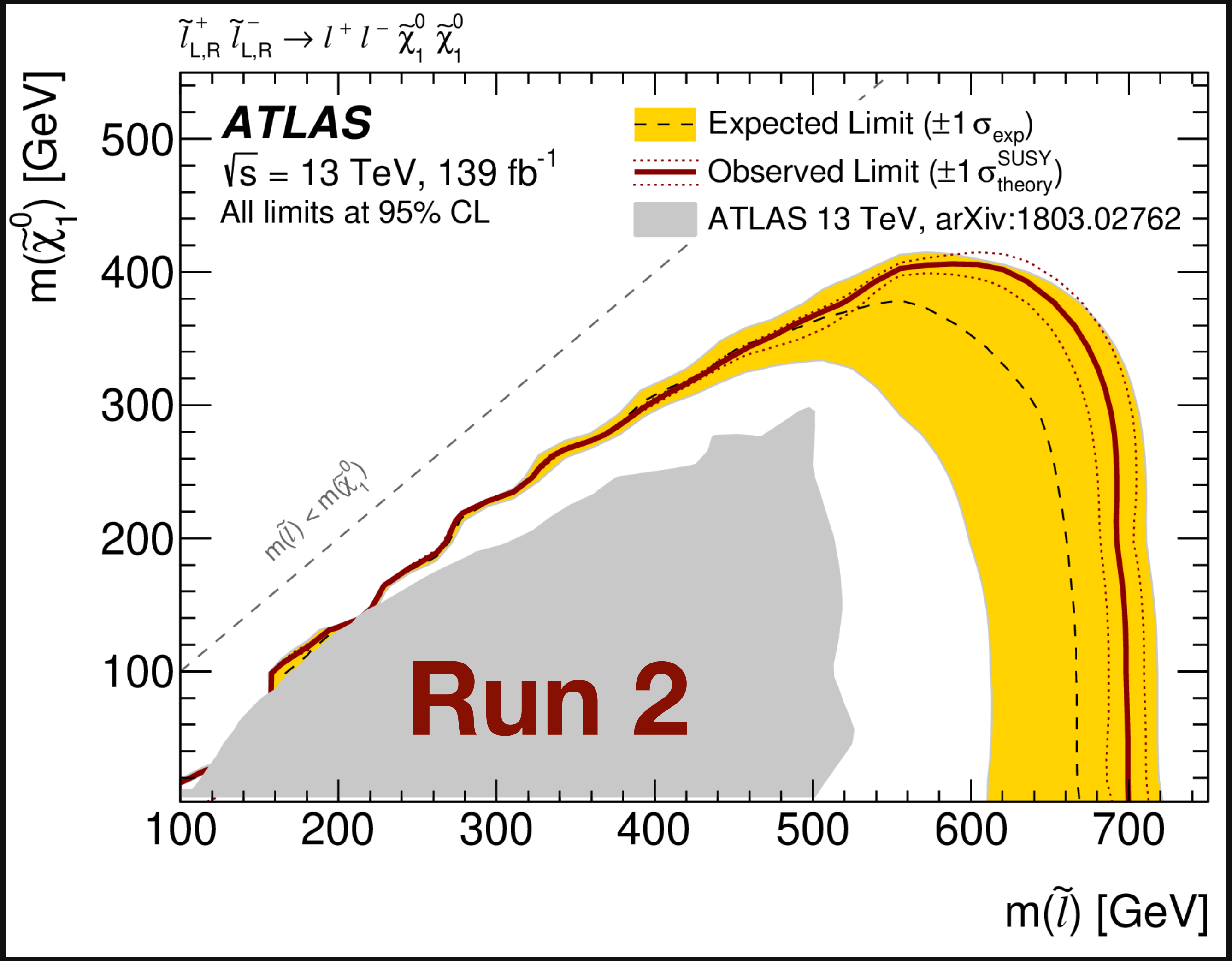
multi-bin

Sleptons: 2 lepton, 0 jet





Optimized for direct sleptons
(used in g-2 global fit)

Sensitivity increased from 350 to 700 GeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2019-09/
https://atlas.cern/updates/briefing/new-higgsino-limits

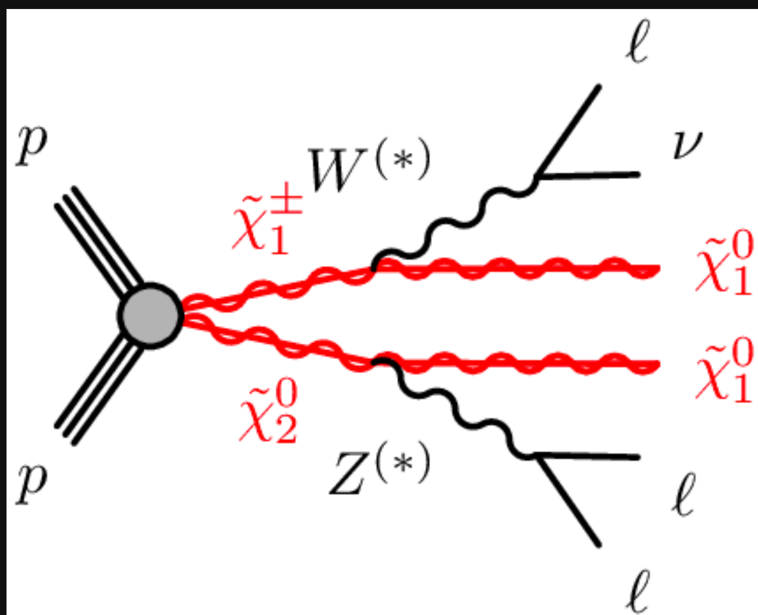
EWK $(\tilde\ell,\tilde\nu,\tilde\chi_1^\pm)$

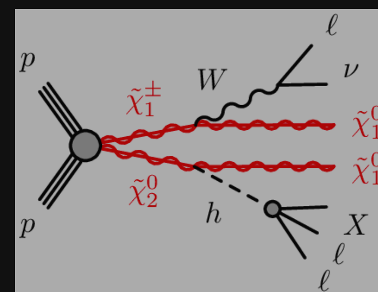
139 fb^{-1}

cut and count

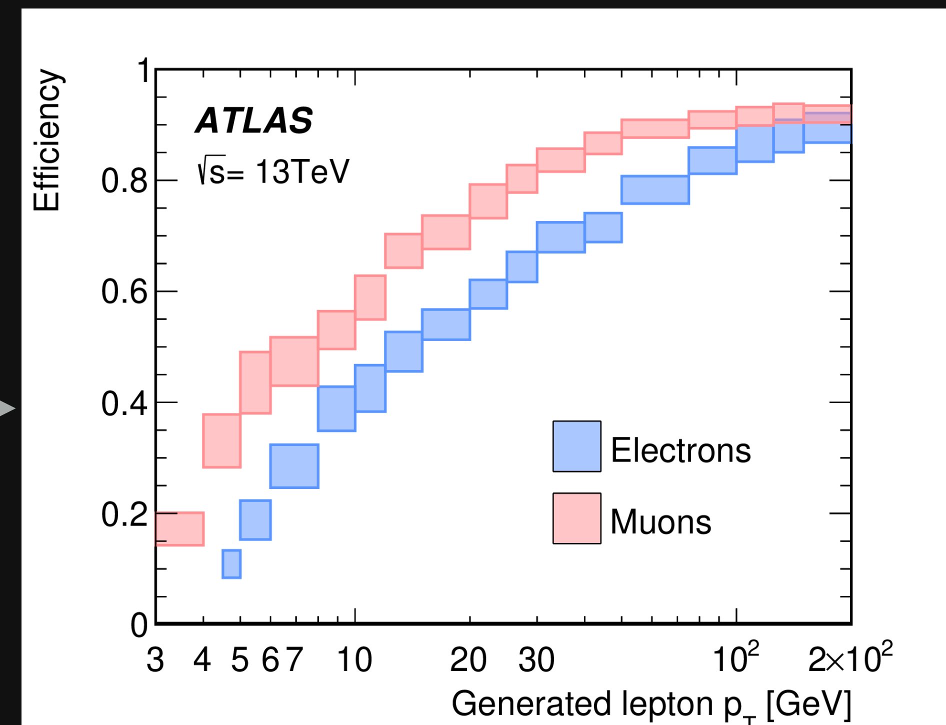
multi-bin

W/Z 3-leptonic

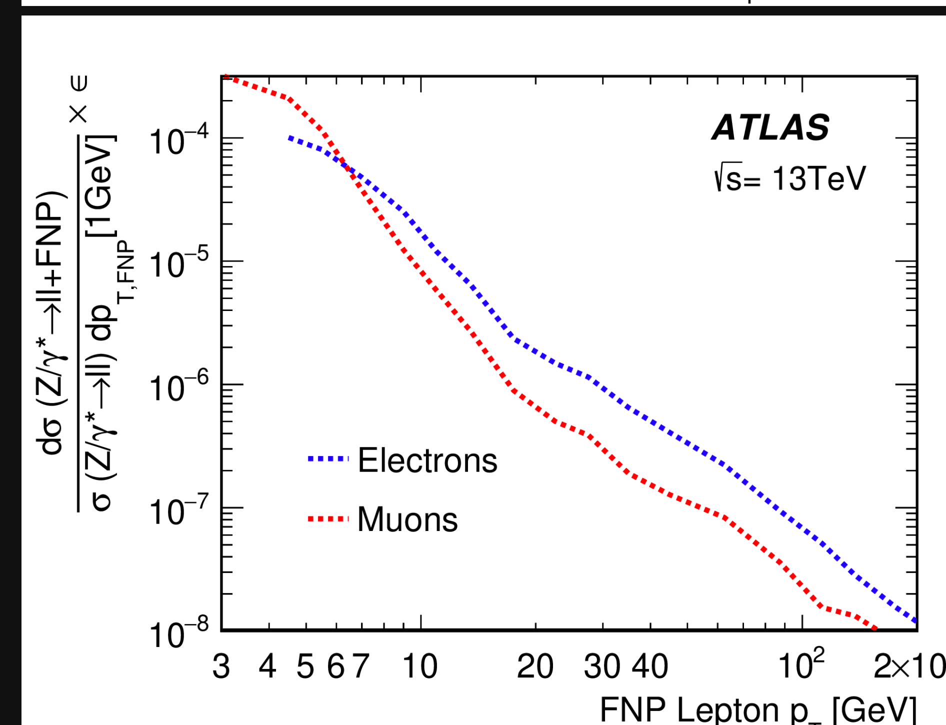




- Model parameters: $\tilde\chi_1^\pm, \tilde\chi_2^0, \tilde\chi_1^0$
- Final state: 3 leptons (OS-SF) + MET
- Three signal scenarios (9 exclusion regions):
  - $|M_1| < |M_2| \ll |\mu|, m(\tilde\chi_1^\pm) = m(\tilde\chi_2^0)$
    - wino/bino(+) with $|M_1| \times |M_2| > 0$
  - $|M_1| < |M_2| \ll |\mu|, m(\tilde\chi_1^\pm) = m(\tilde\chi_2^0)$
    - wino/bino(-) with $|M_1| \times |M_2| < 0$
  - $(\tilde\chi_2^0, \tilde\chi_1^\pm, \tilde\chi_1^0), m(\tilde\chi_1^\pm = \frac{1}{2}\left[m(\tilde\chi_2^0 + m(\tilde\chi_1^0)\right]$
  - *all of the above split up into on-shell W/Z or off-shell W*/Z**
- Dominant backgrounds: SM W/Z, $t\bar t$, $Z +$ jets with FNP lepton
- Challenge: suppressing FNP leptons (dedicated BDT)



signal efficiency



Z+jets(+FNP) efficiency

OS-SF: Opposite-Sign, Same-Flavor *FNP: Fake or Non-Prompt*

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2019-09/
https://atlas.cern/updates/briefing/new-higgsino-limits

EWK $(\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm})$

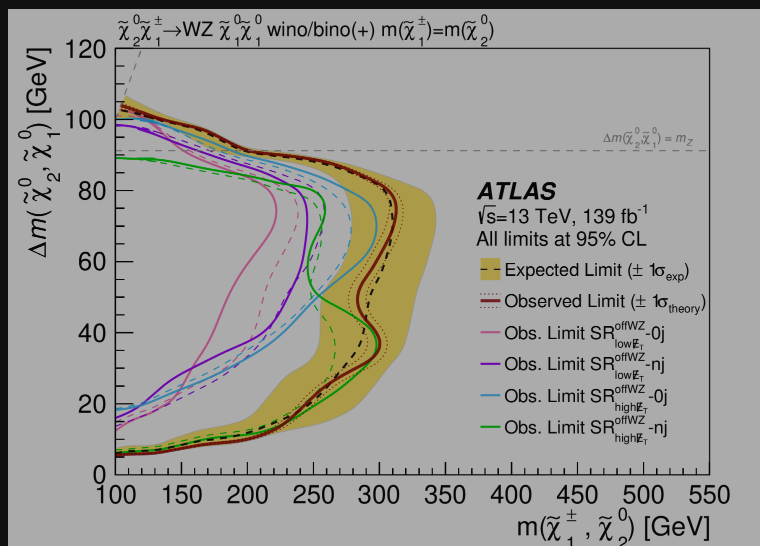
139 fb^{-1}

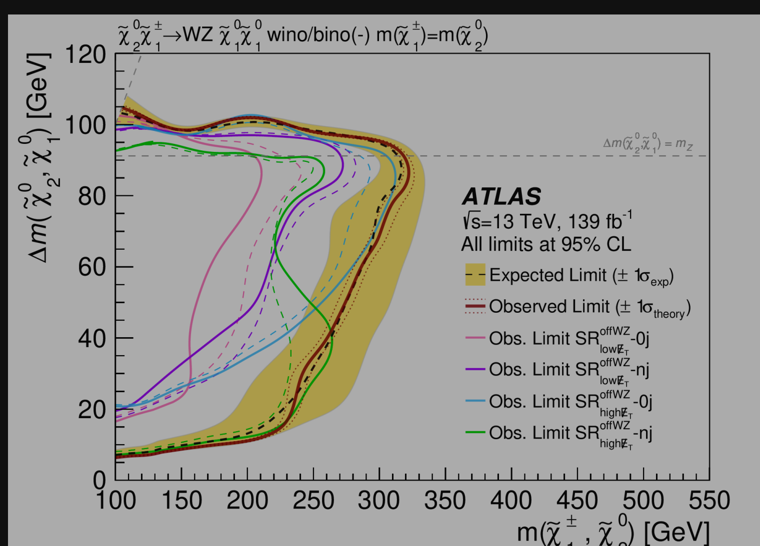
cut and count

multi-bin

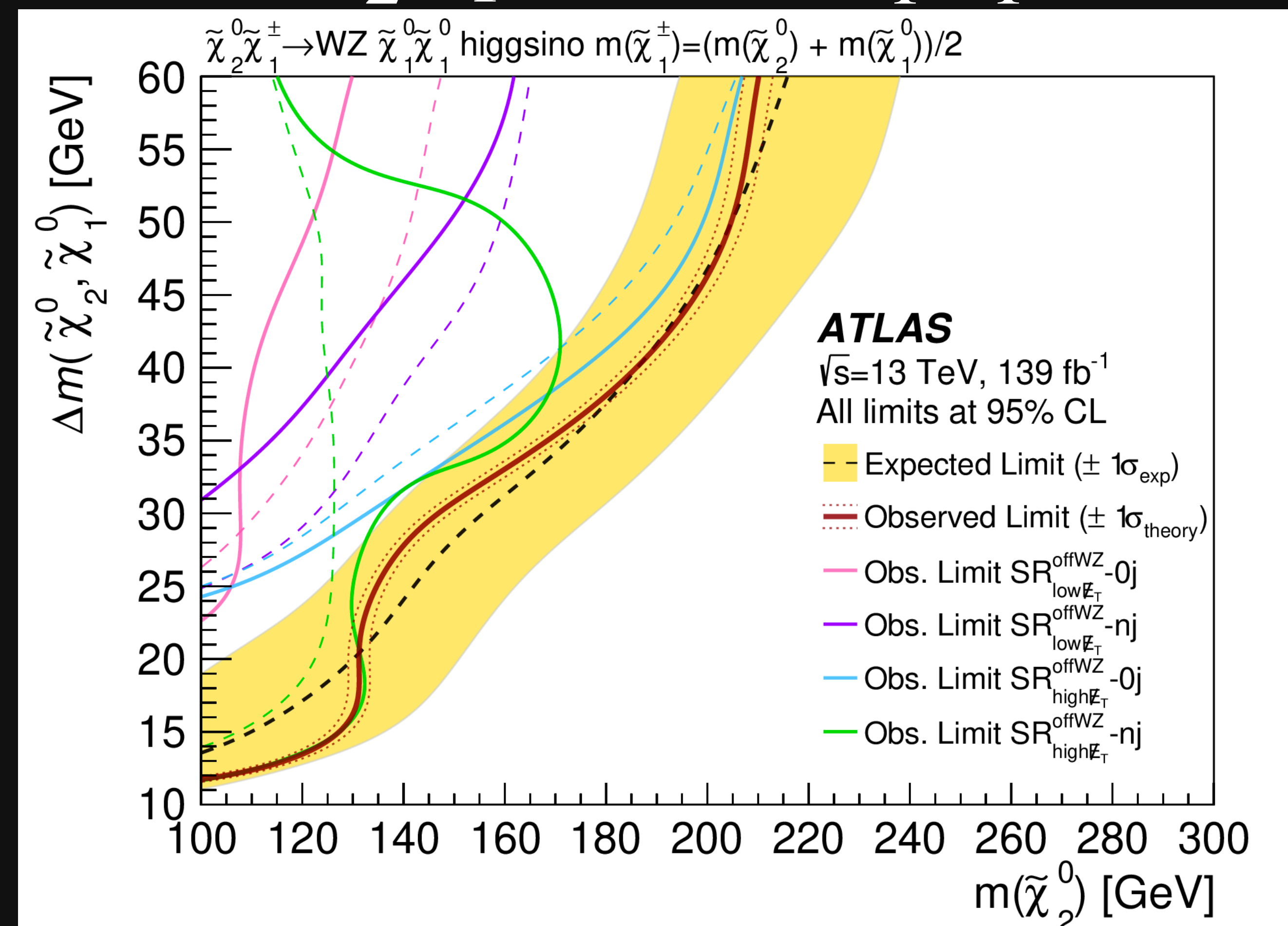
W/Z 3-leptonic

$$\tilde{\chi}_2^0 \tilde{\chi}_1^{\pm} \rightarrow WZ \tilde{\chi}_1^0 \tilde{\chi}_1^0$$





Wino/Bino



Higgsino

Sensitivity for $\Delta m > 12$ GeV

(see next few slides for statistical combination)

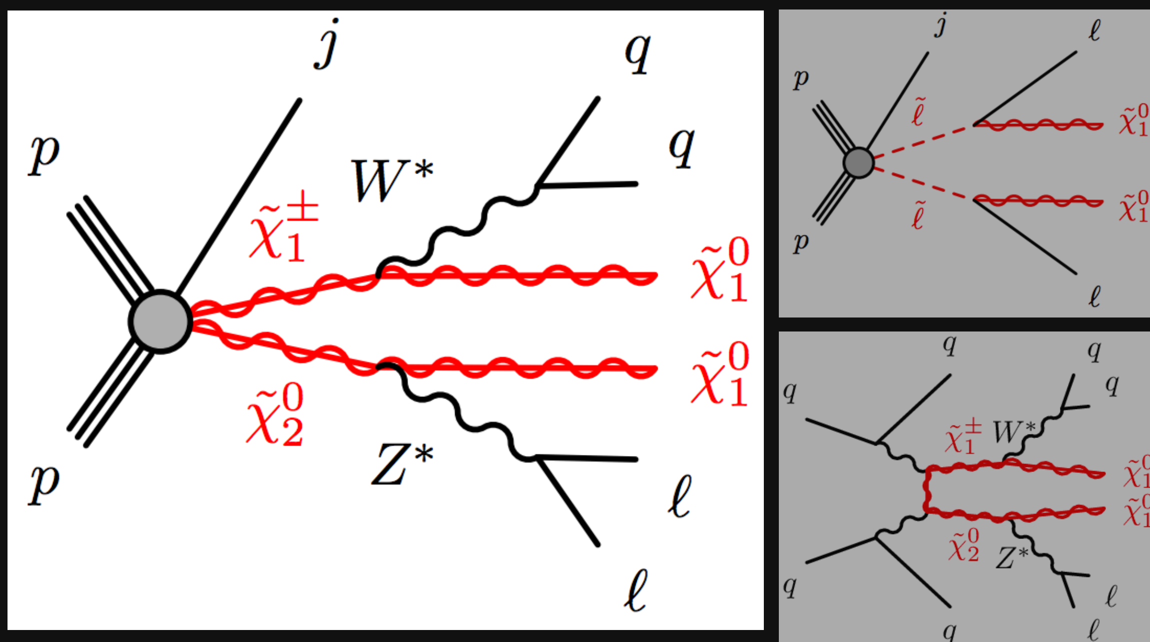
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2018-16/

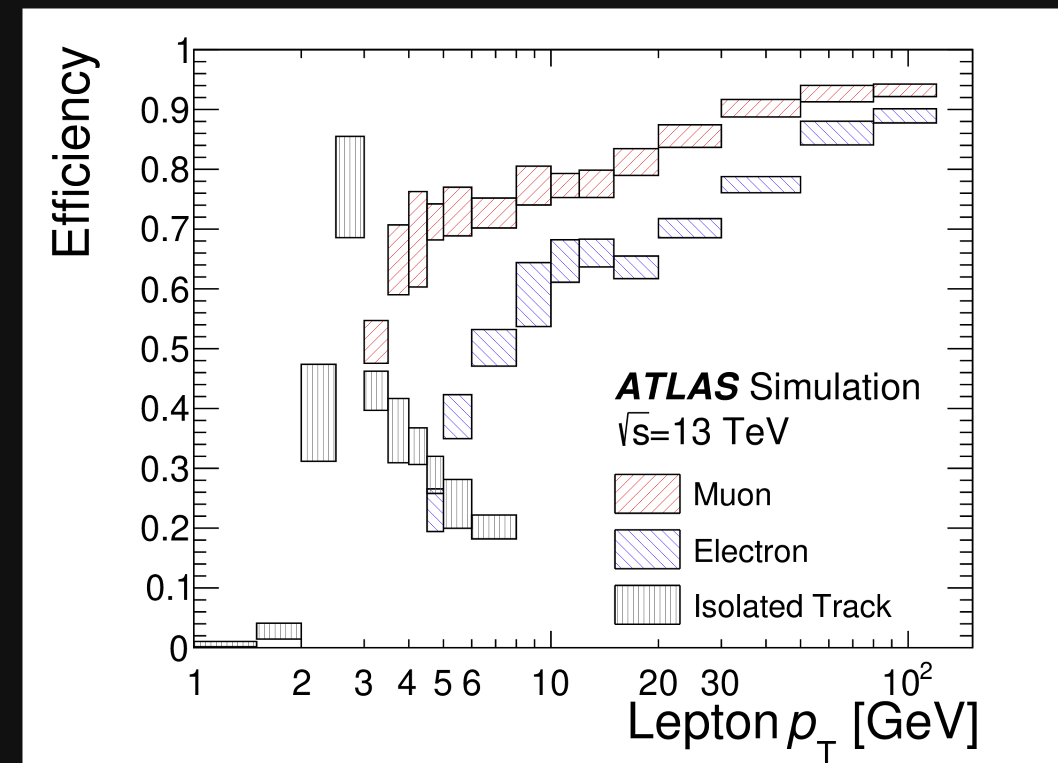
EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)

139 fb^{-1}

multi-bin

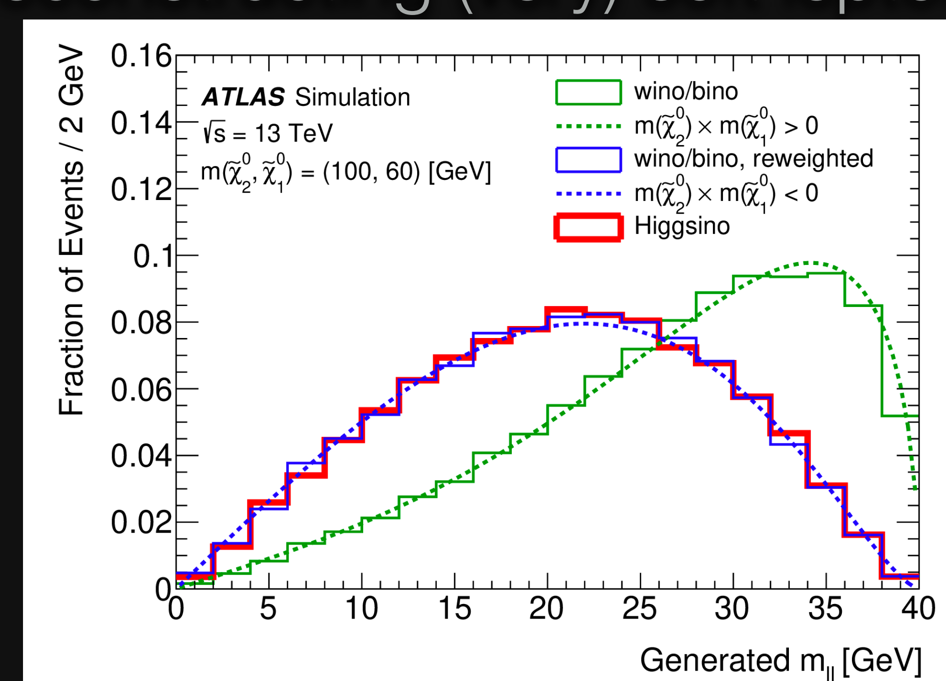
Soft 2-leptonic





reconstructing (very) soft leptons

- MODEL PARAMETERS: $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$, $\tilde{\chi}_1^{\pm}$, $\tilde{\ell}$
- FINAL STATE: =2 leptons [or 1 lepton+1 track] (OS-SF), MET, ISR jet
- FOUR SIGNAL SCENARIOS (6 multi-bin regions):
  - $\tilde{\chi}_2^0 \to Z^* \tilde{\chi}_1^0, \tilde{\chi}_1^{\pm} \to W^* \tilde{\chi}_1^0$ (with ISR or VBF)
    - here similar to W/Z 3-leptonic [three scenarios]
  - $\tilde{\ell} \to \ell \tilde{\chi}_1^0, \ell \in [e, \mu]$ (sleptons, bino-like LSP)
- DOMINANT BACKGROUNDS: $t\bar{t}$, singletop, $Z(\to \tau\tau)$ + jets, diboson, multi-jet fake/nonprompt leptons
- CHALLENGE: compressed-mass search, fake/non-prompt lepton background



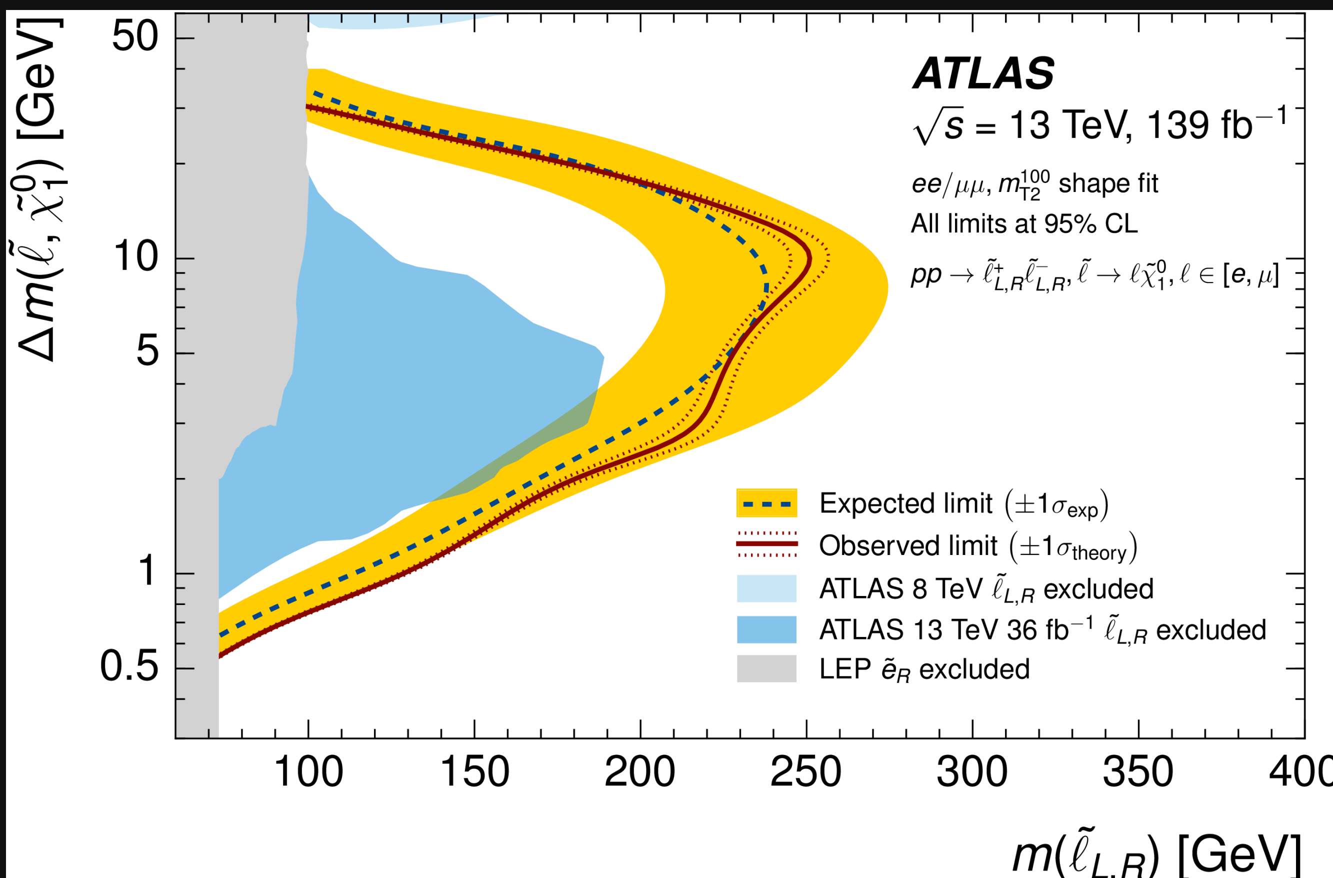
OS-SF: Opposite-Sign, Same-Flavor

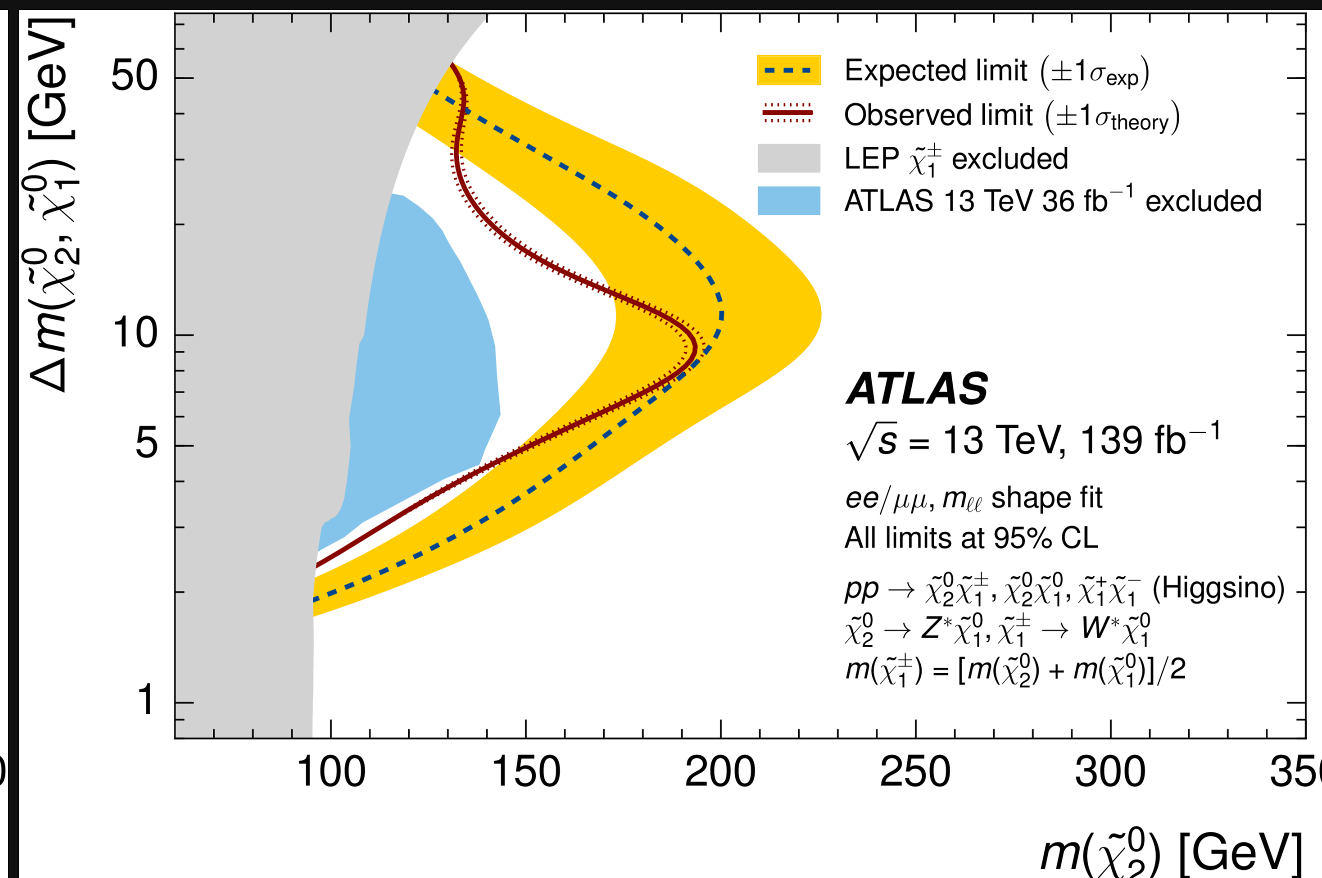
EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)

139 fb^{-1}

multi-bin

Soft 2-leptonic





Mass-degenerate Sleptons
Useful in a g-2 global fit

Higgsinos
Useful in a statistical combination

Sensitive to 200 GeV Higgsinos at mass splitting of 10 GeV

Statistical Reinterpretations

Combinations and global fits

EWK $(\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^\pm)$

139 fb^{-1}

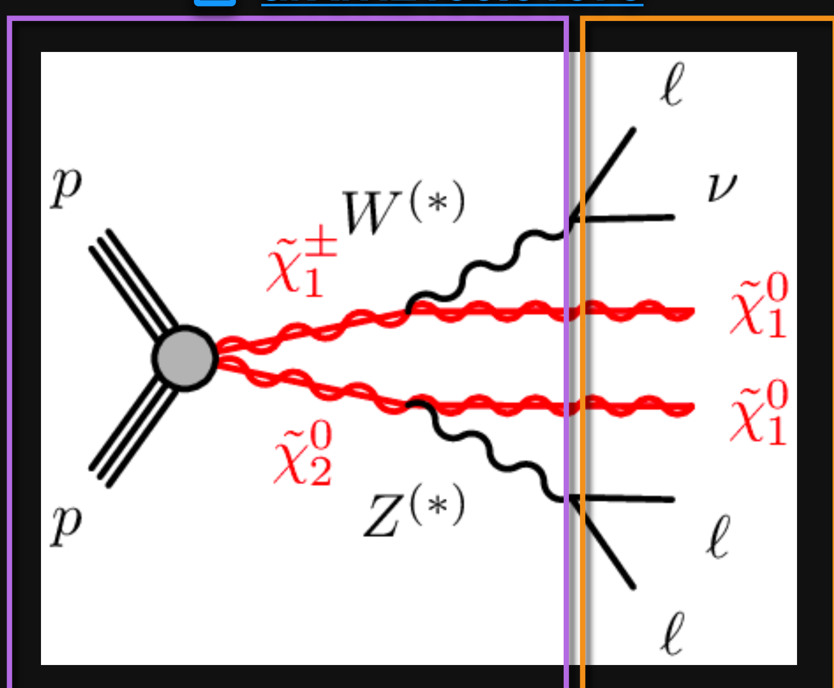
multi-bin

E.G.: Stat. Combination (I)

- Multiple analyses with different **signatures** can still target the same **model**
  - See Zach Marshall's talk on differences between signature and model: https://indico.cern.ch/event/1023573/contributions/4400586/
- Goal: combine multiple searches to paint a tapestry of our sensitivity to Higgsino/Wino-Bino models (production) which decay to on-shell/off-shell Standard Model bosons (W/Z)

ATLAS-CONF-2020-015
arXiv:2106.01676

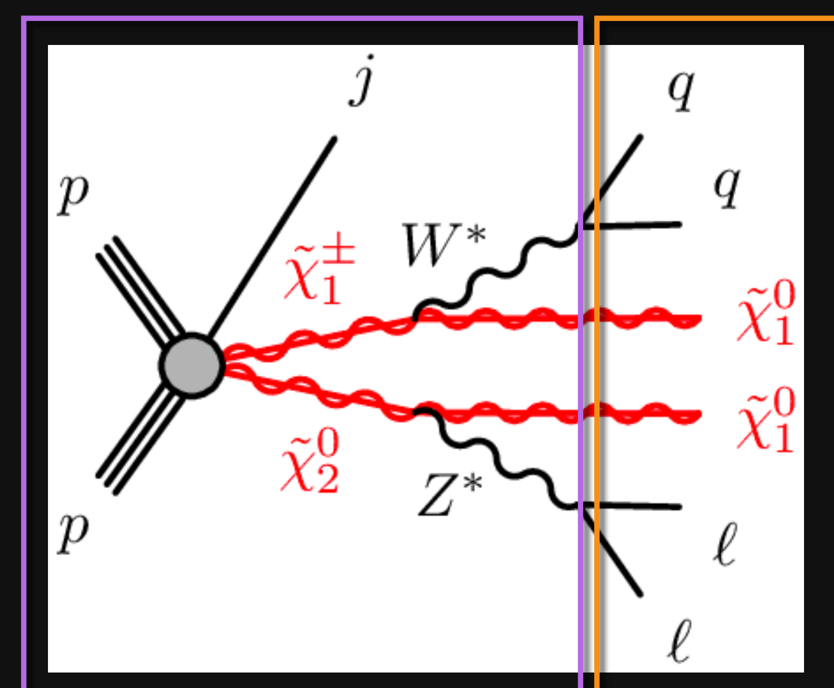
W/Z 3-leptonic



off-shell: $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) \in [5{,}90]$ GeV
on-shell: $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) \geq 90$ GeV
signature: $3\ell + 0j + E_T^{miss}$

arXiv:1911.12606

soft 2L



soft 2L: $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) \in [1{,}60]$ GeV

signature: $2\ell + 3j + E_T^{miss}$

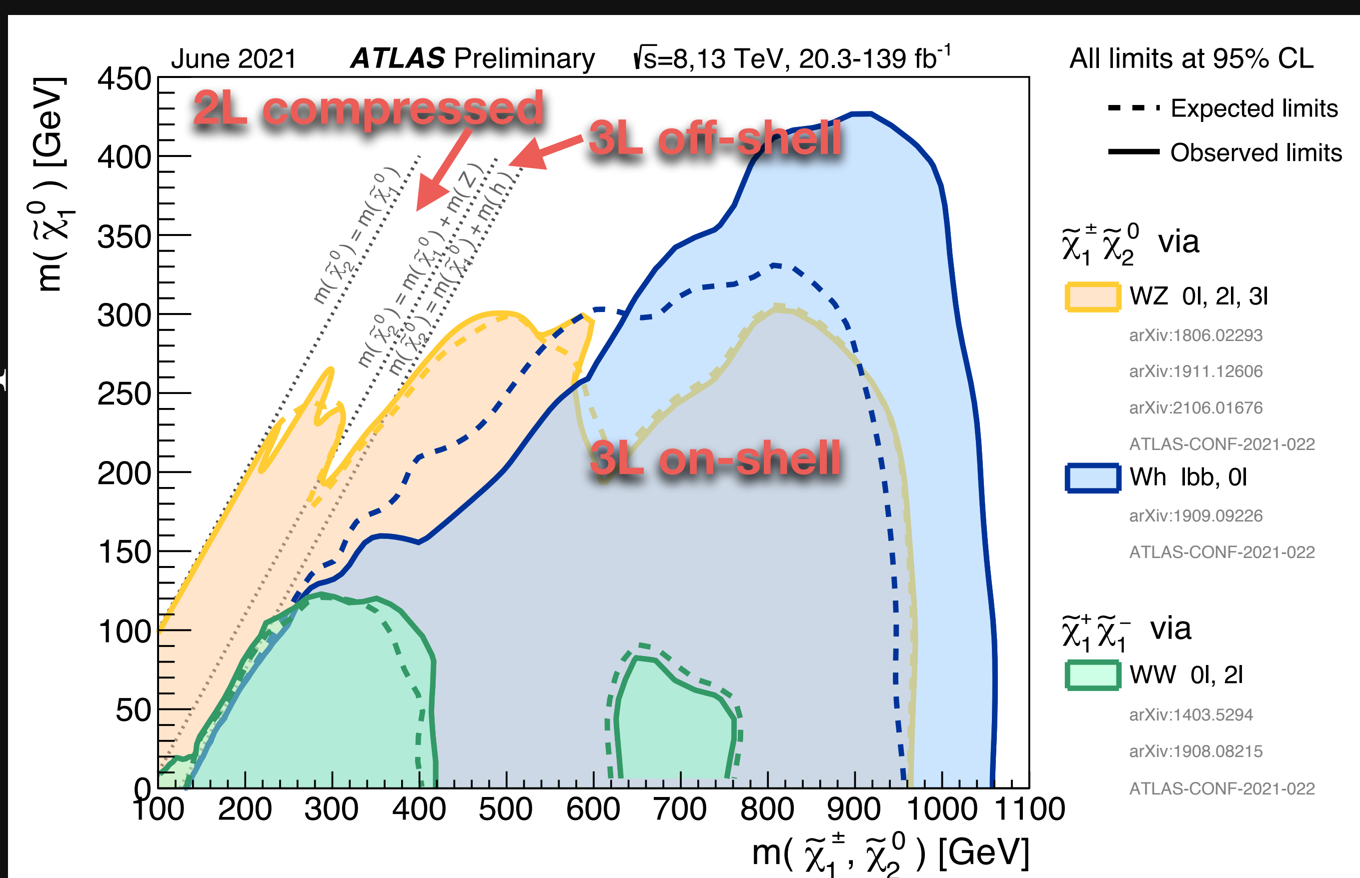
arXiv:1911.12606 ATLAS-CONF-2020-015 arXiv:2106.01676
ATL-PHYS-PUB-2021-019 atlas.cern/updates/briefing/new-higgsino-limits

EWK $(\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm})$
139 fb^{-1}
multi-bin

E.G.: Stat. Combination (II)

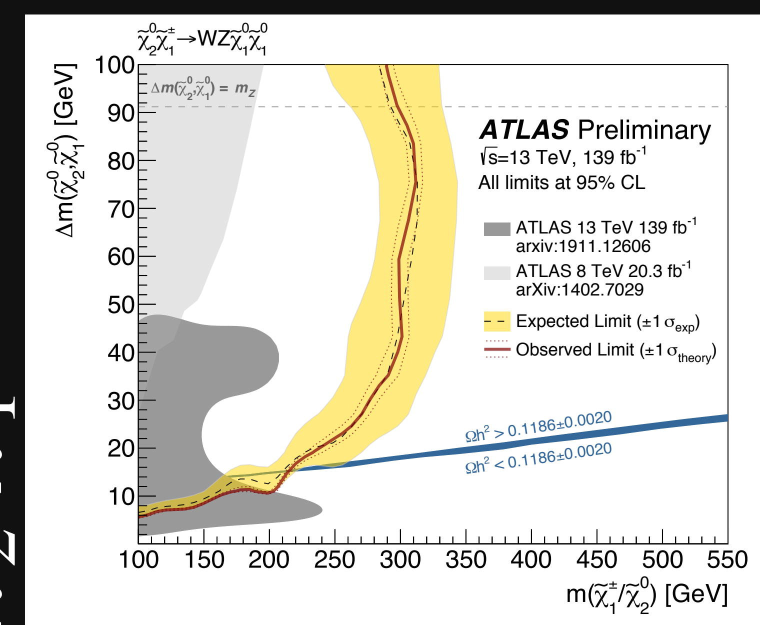
- Multiple analyses with different **signatures** can still target the same **model**
  - See Zach Marshall's talk on differences between signature and model: https://indico.cern.ch/event/1023573/contributions/4400586/
- Goal: combine multiple searches to paint a tapestry of our sensitivity to Higgsino/Wino-Bino models (production) which decay to on-shell/off-shell Standard Model bosons (W/Z)

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

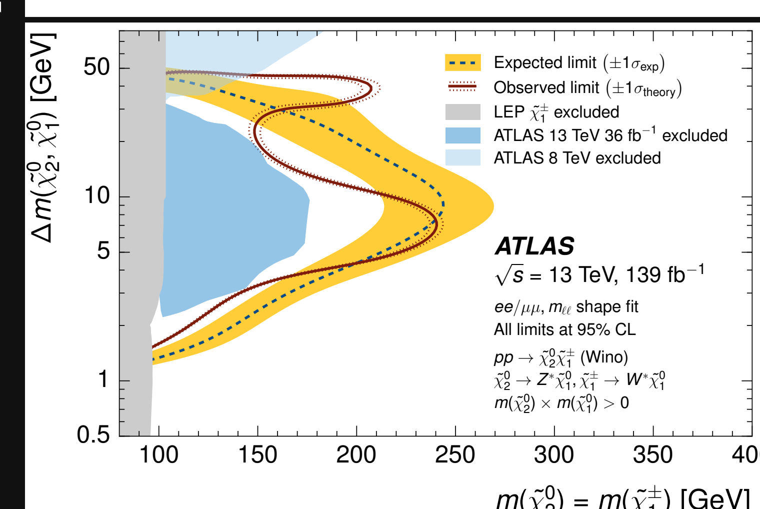


$m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0)$

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$



3L



2L

arXiv:1911.12606 ATLAS-CONF-2020-015 arXiv:2106.01676
ATL-PHYS-PUB-2021-019 atlas.cern/updates/briefing/new-higgsino-limits

EWK $(\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm})$

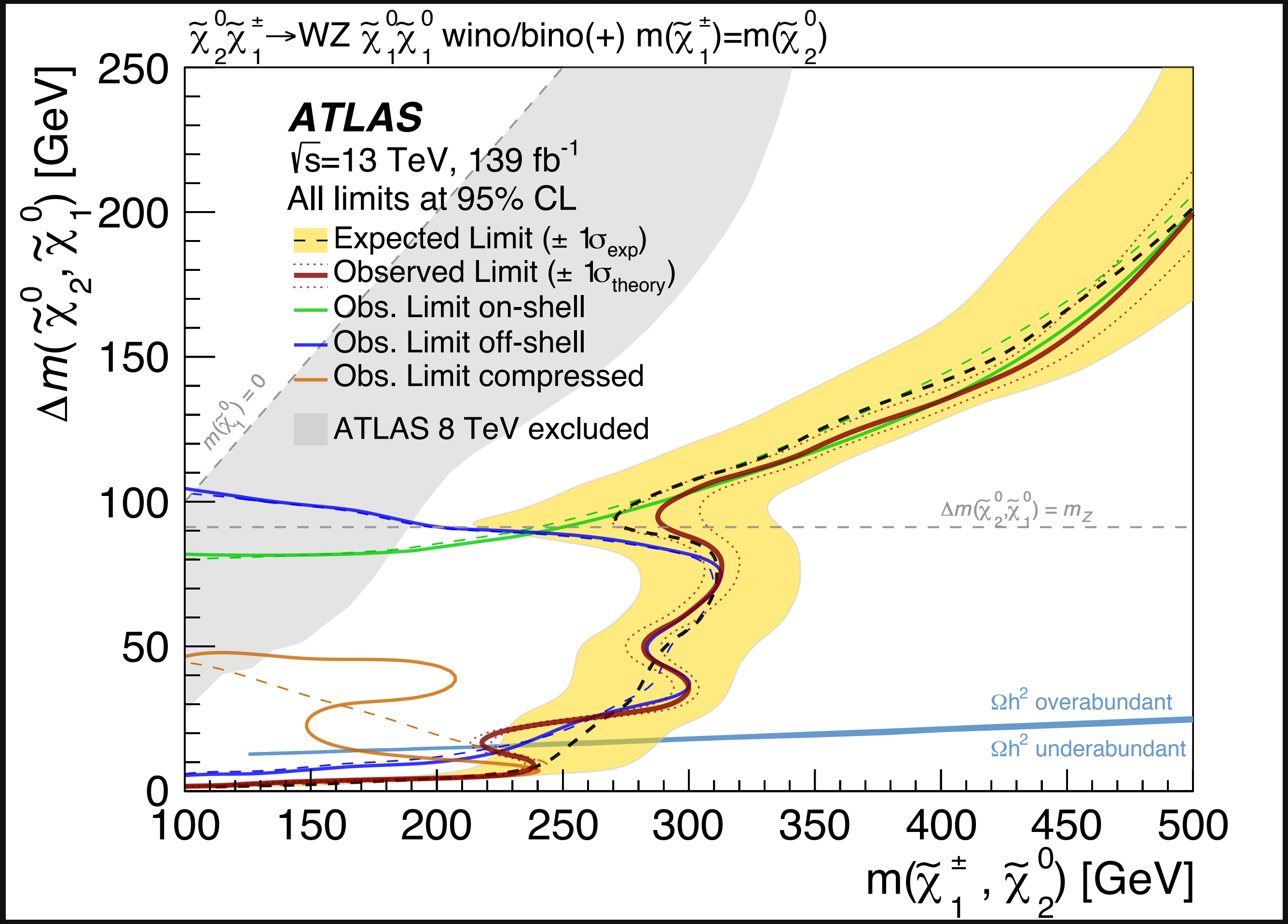
139 fb^{-1}

multi-bin

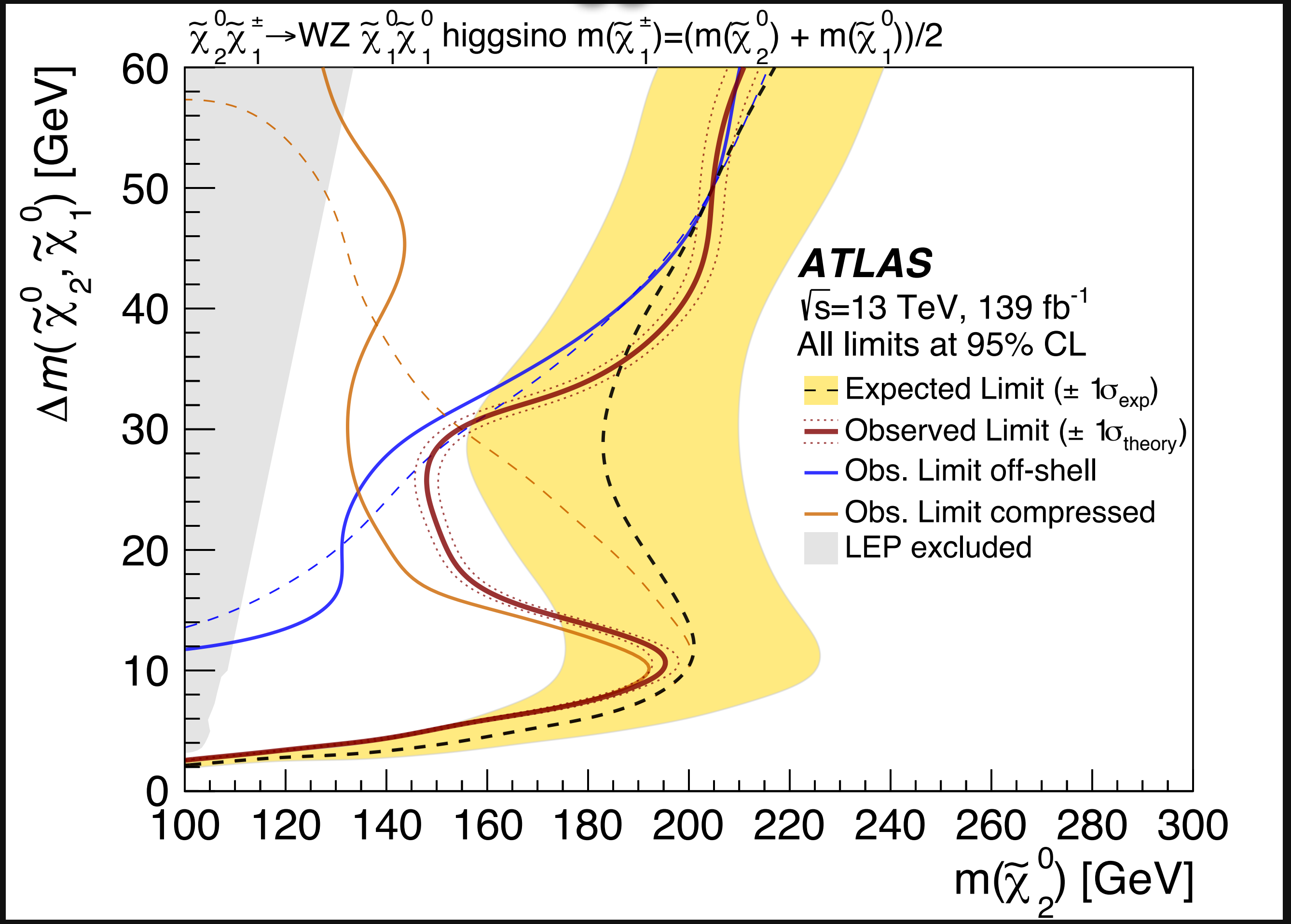
E.G.: Stat. Combination (III)

- Experimental uncertainties were correlated if both analyses used the same object definitions
- Modeling uncertainties were correlated if both analyses used the same background and estimation procedure
- Scale factors (e.g. data-driven normalization) are not correlated as they probe different phase spaces

Wino-Bino



Higgsino

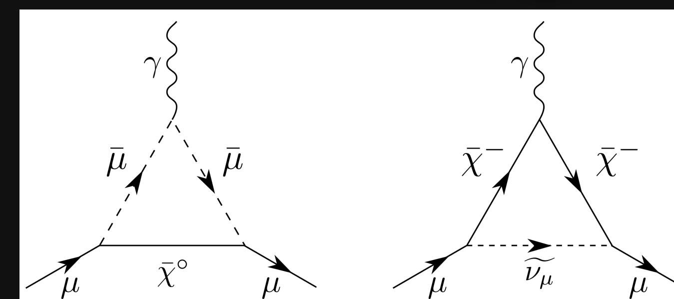


! Statistical combination increases our coverage in this phase-space

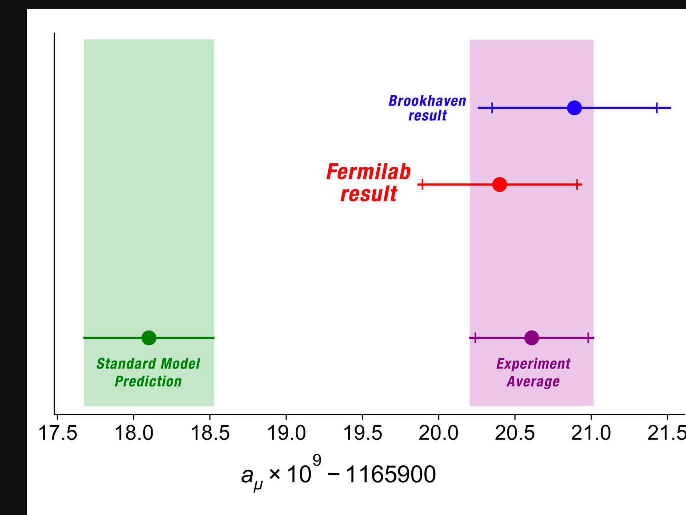
ATL-PHYS-PUB-2021-019 arXiv:1403.5294 arXiv:1908.08215 arXiv:1911.12606
10.1103/PhysRevLett.126.141801

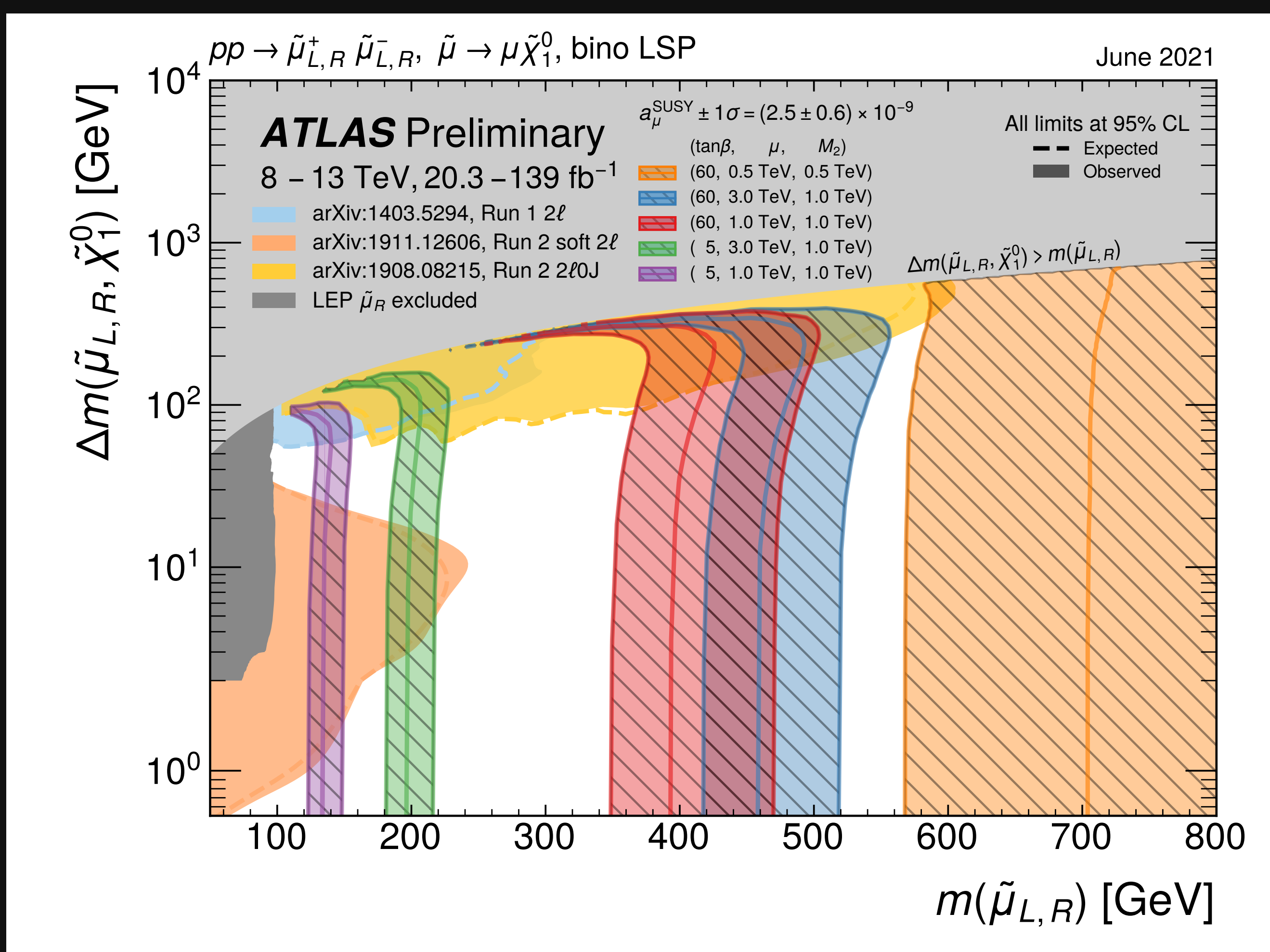
Example: global fit (g-2)

- Can measurements performed by other experiments be used to constrain or inform our search programme?
  - ✅ Yes!



$\tilde{\mu}^{\pm}/\tilde{\chi}^{0}$ or $\tilde{\chi}^{\pm}/\tilde{\nu}_{\mu}$





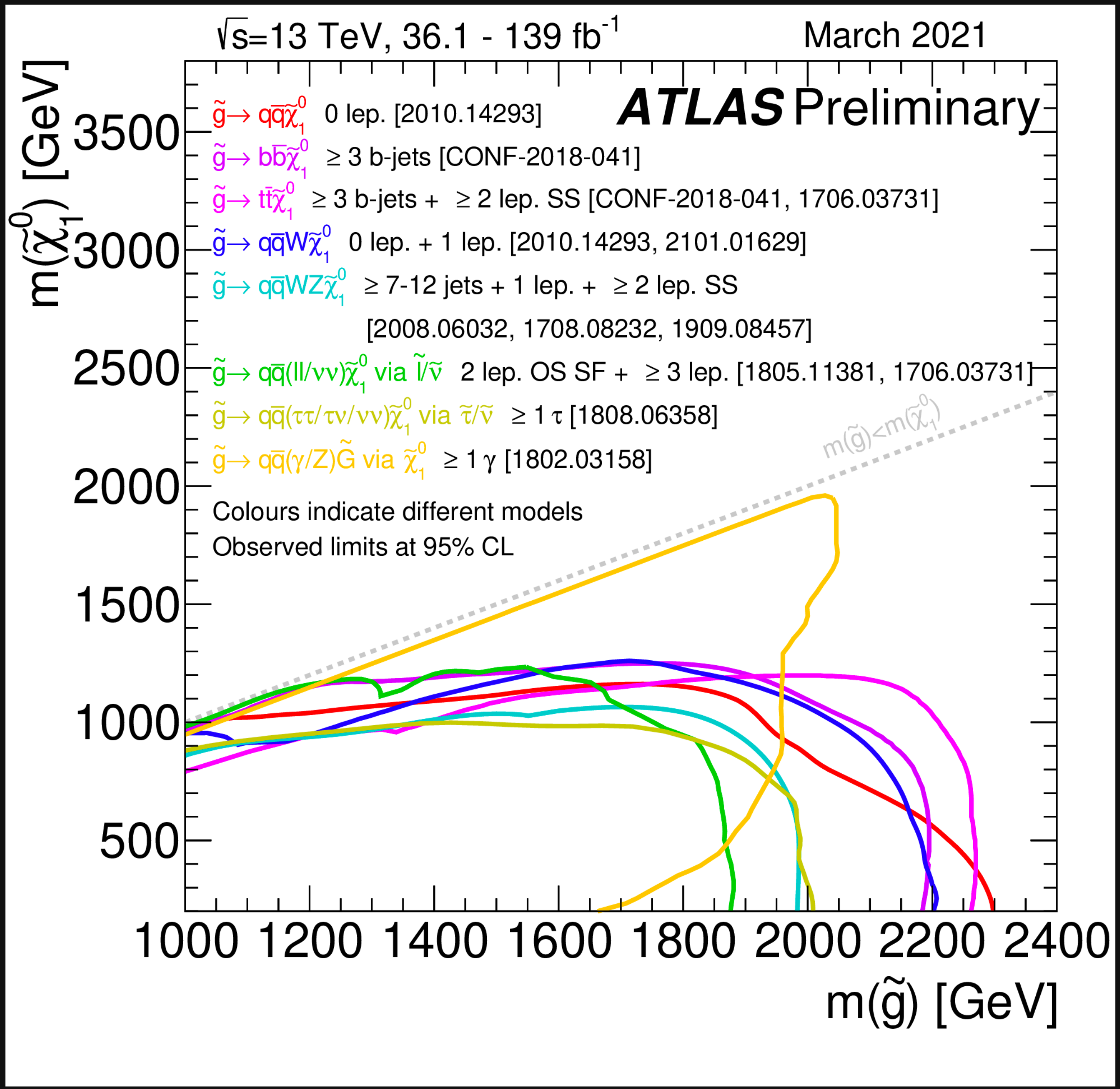
📢 April 27th, 2021

- Compute exclusion limits in the $(\tilde{\mu}, \tilde{\chi}_1^0)$ mass plane for different analyses that are sensitive to the smuon model with muon/bino-like $\tilde{\chi}_1^0$ signature
- Hatched bands are compatible with the observed g-2 anomaly measured by Fermilab and BNL experiments to $\pm 1\sigma$, for a variety of pMSSM parameters

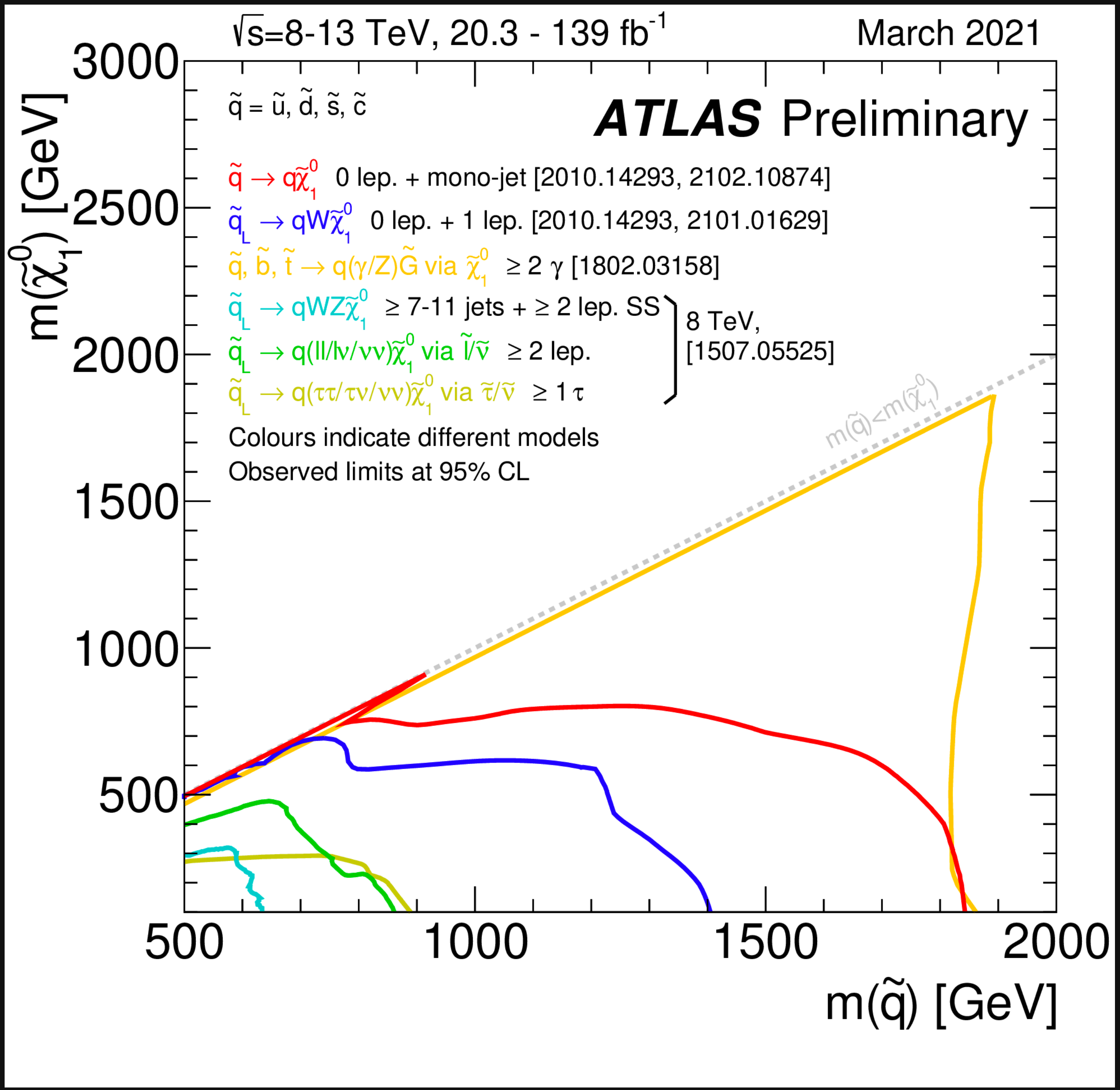
❗ Light smuon/light neutralino needed!

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-019/

Gluino/Squark Summary



$\tilde{g} \rightarrow \text{LSP or } \tilde{G}$



$\tilde{q} \rightarrow \text{LSP or } \tilde{G}$

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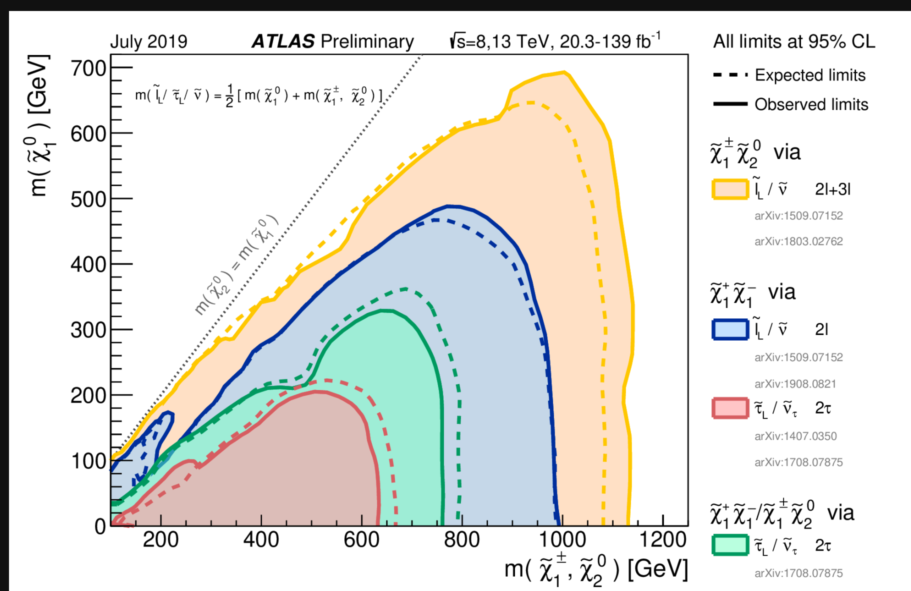
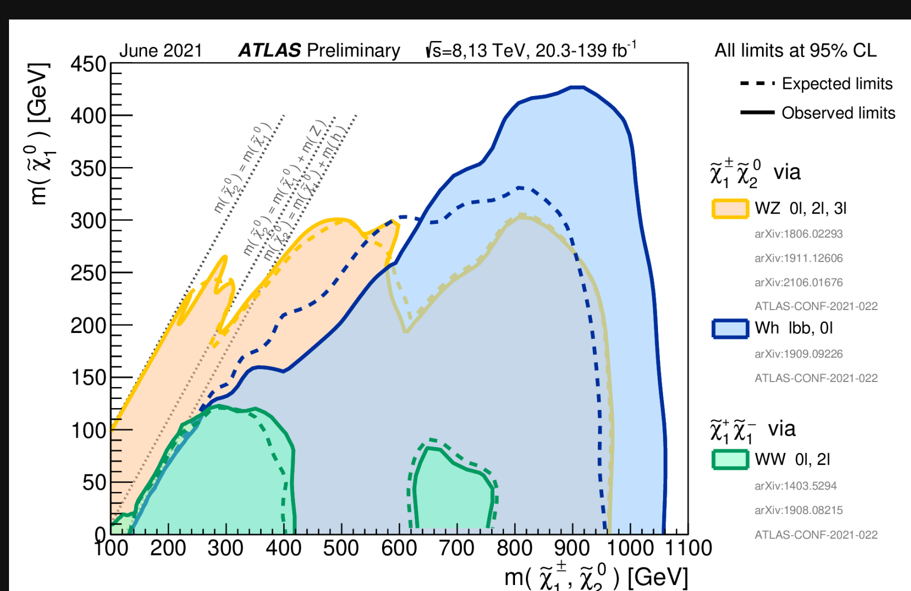
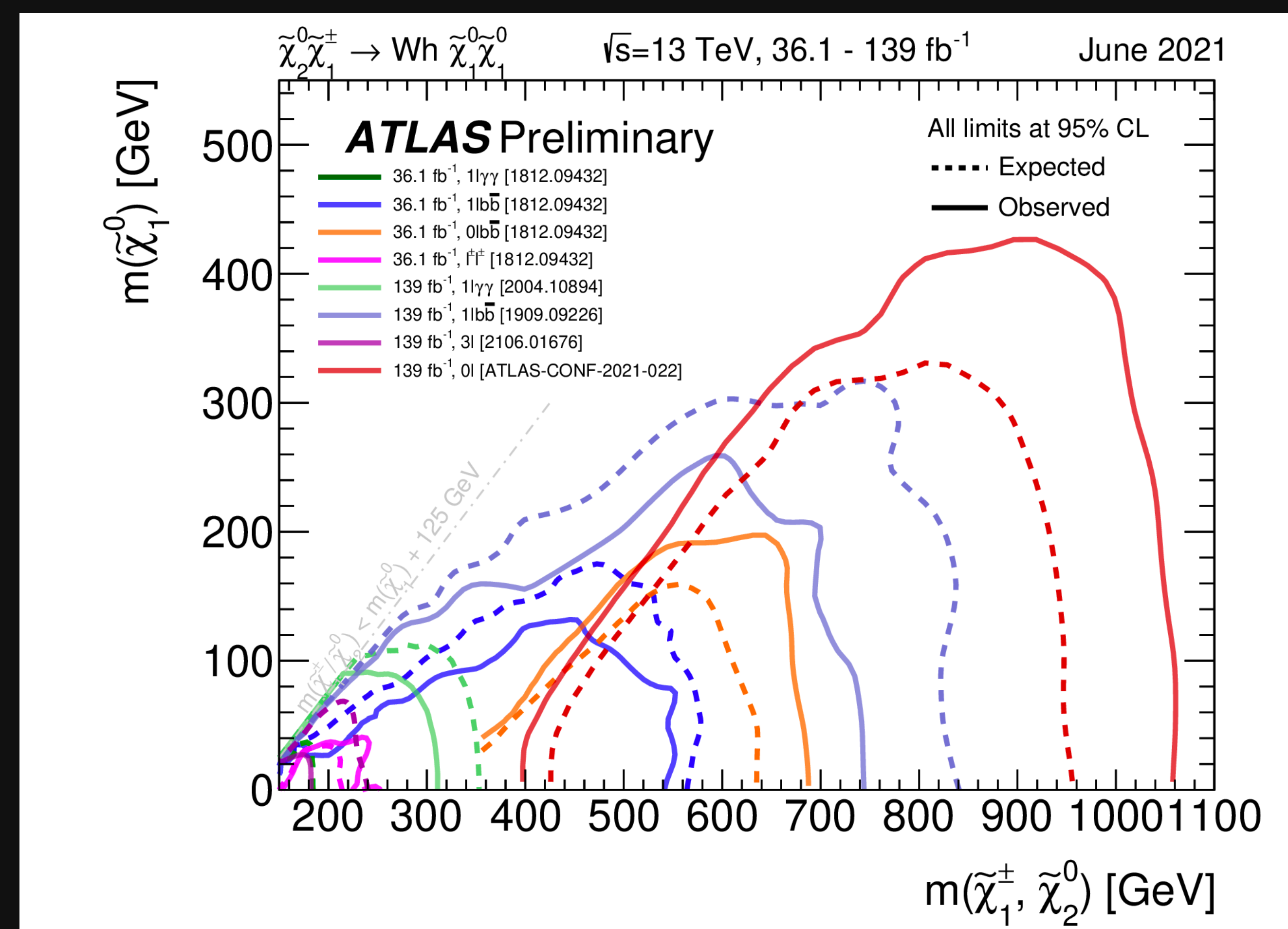
C1N2/C1C1 Summary



$\tilde{\chi} \to \ell$

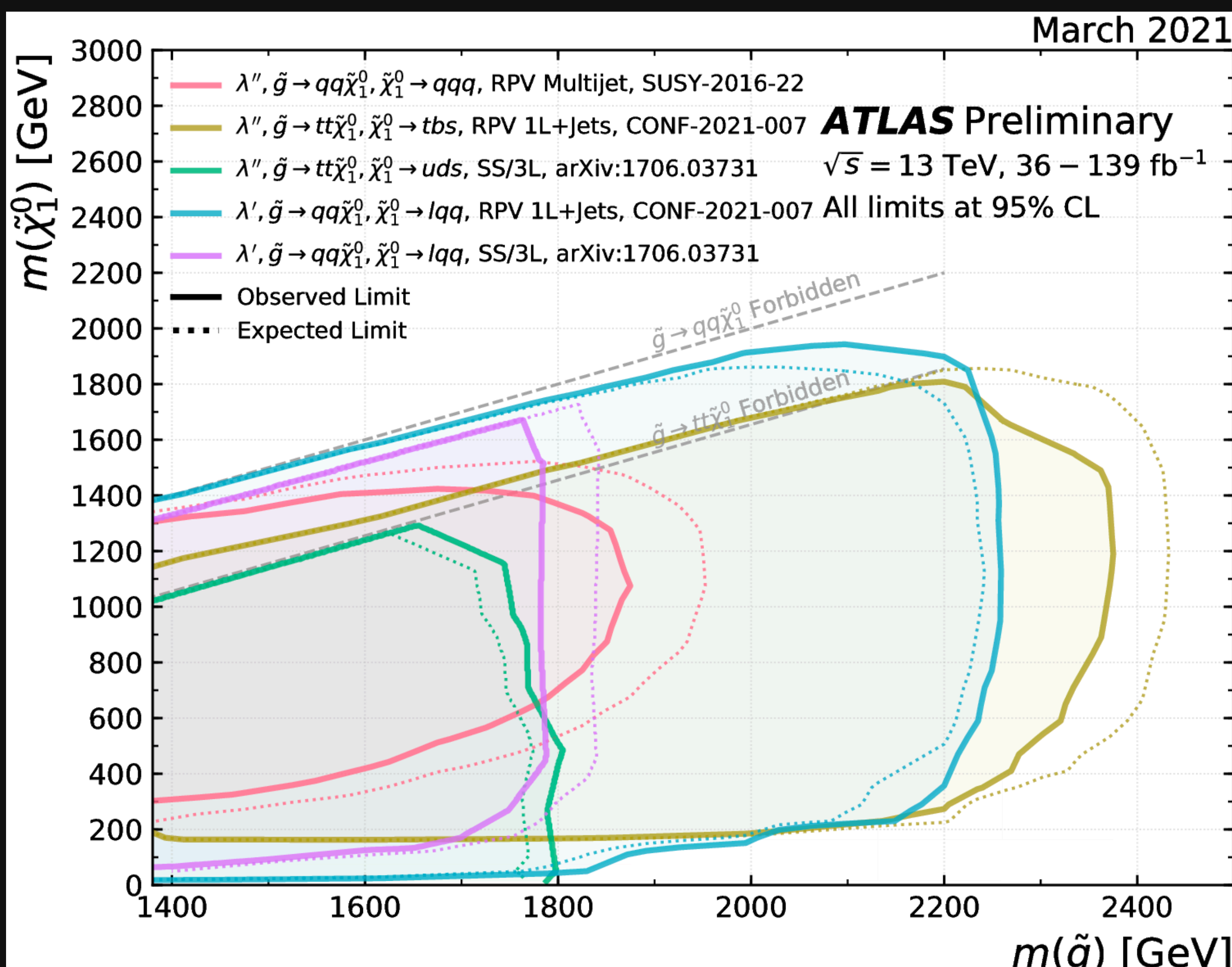


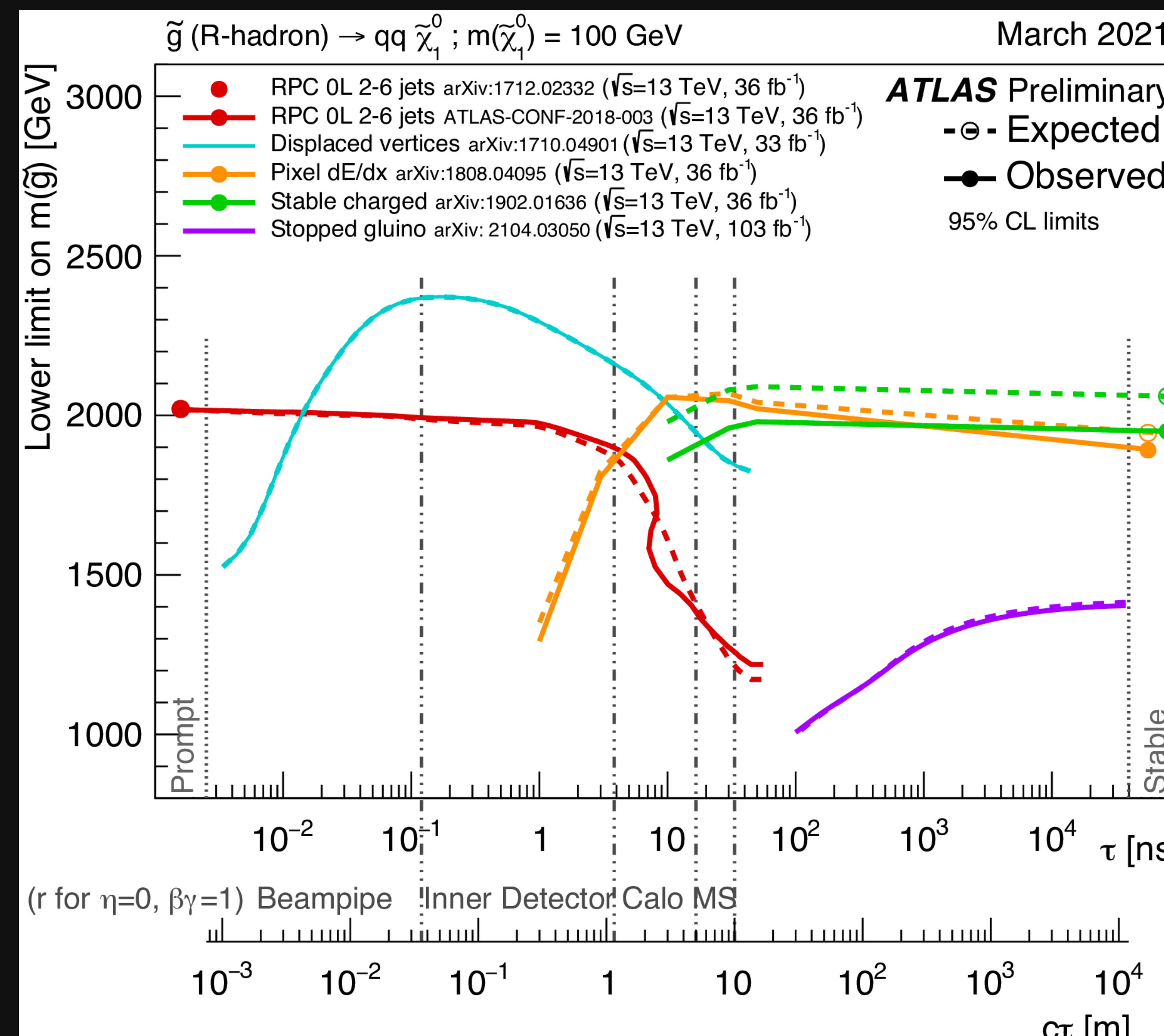
$\tilde{\chi} \to W/Z/h$



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-019/

Gluino (II) Summary





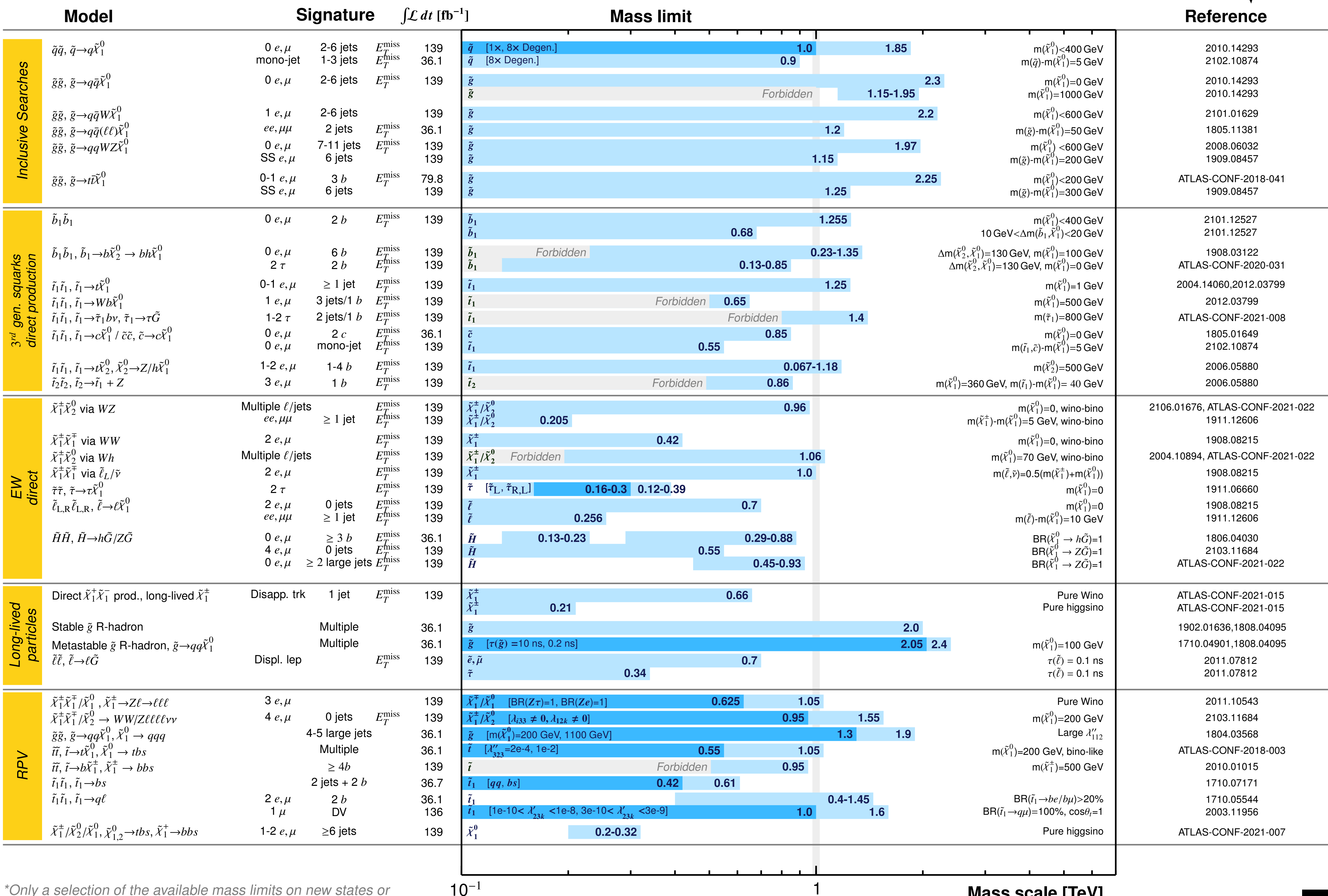
$\tilde{g} \rightarrow \text{LSP} \rightarrow \text{SM}$

$\tilde{g}$ R-hadron $\rightarrow$ LSP

ATLAS SUSY Searches* - 95% CL Lower Limits

June 2021

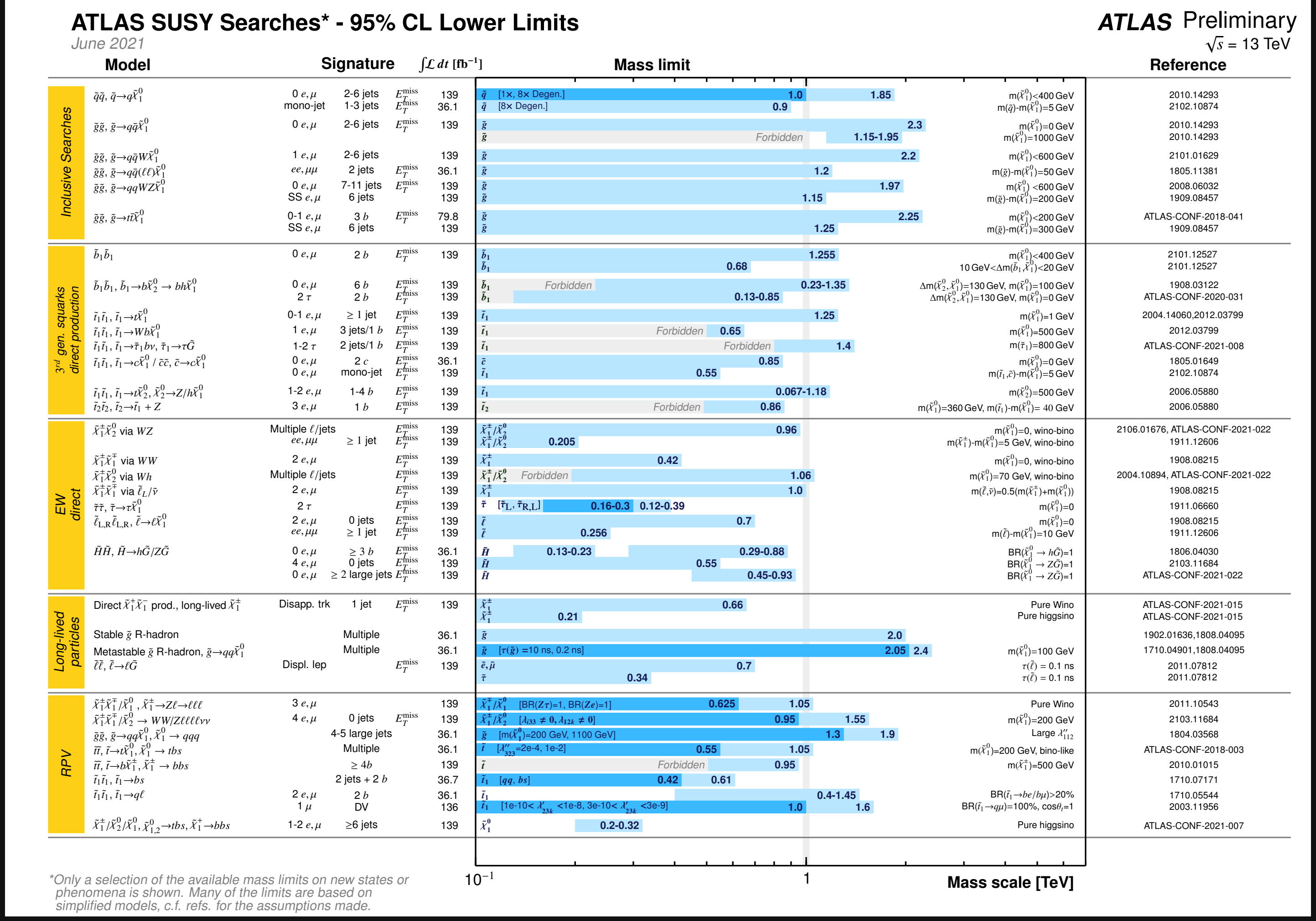
ATLAS Preliminary $\sqrt{s}$ = 13 TeV



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

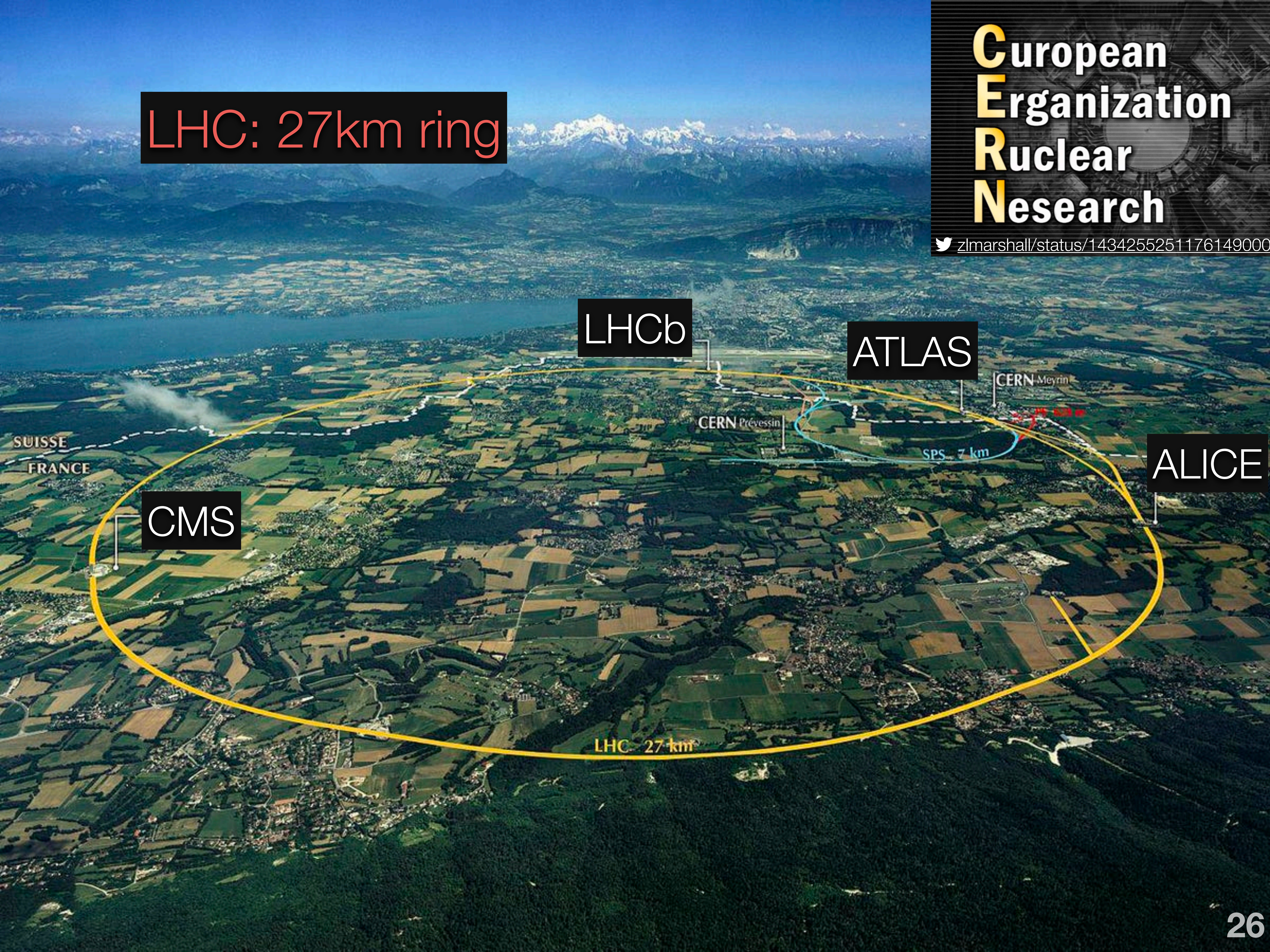
Conclusion

- Gearing up for the 3rd operation of the LHC and the ATLAS detector in March 2022
- ATLAS has a robust SUSY search programme
  - Take advantage of likelihood preservation and reinterpretation to expand coverage
- Identify uncovered areas and find new rocks to look under for SUSY



Backup

Rama lama lama ka dinga da dinga dong

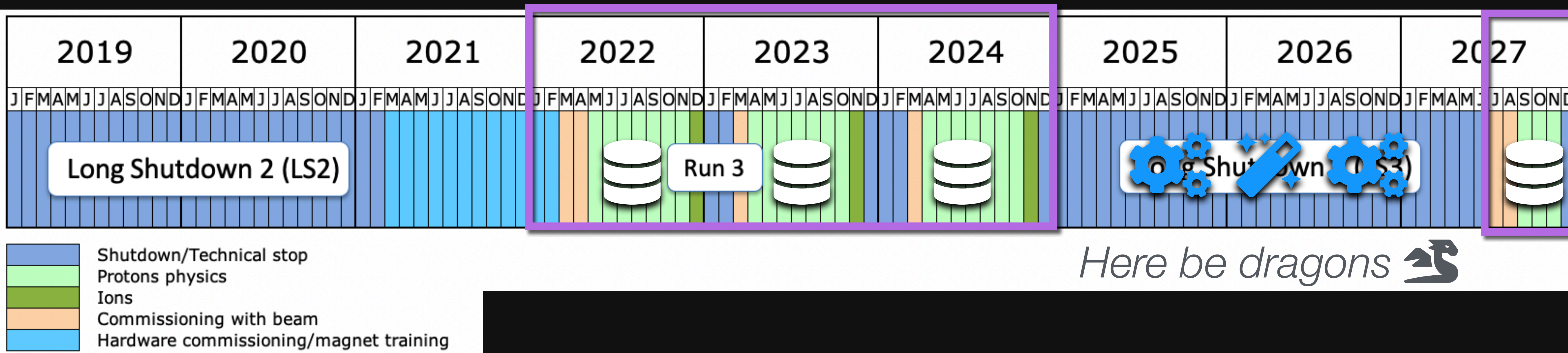

LHC: 27km ring
Curopean
Erganization
Ruclear
Nesearch
zlmarshall/status/1434255251176149000
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

LHC Schedule

No data collection

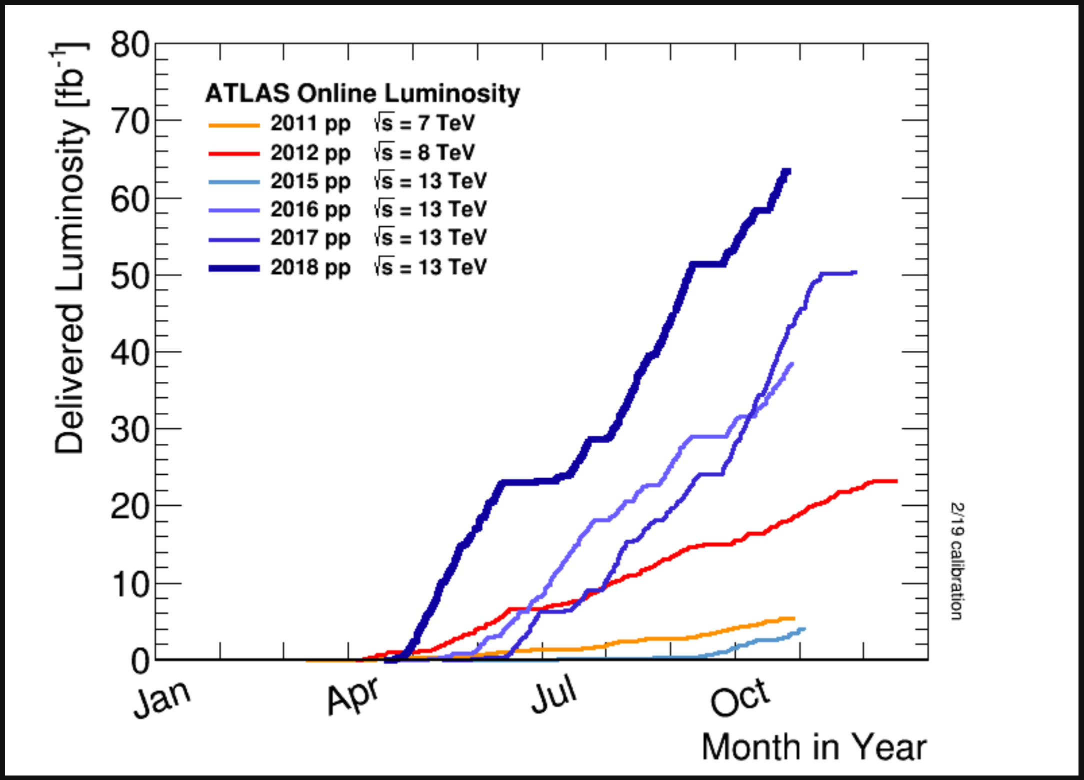
Run 3 **Run 4+**

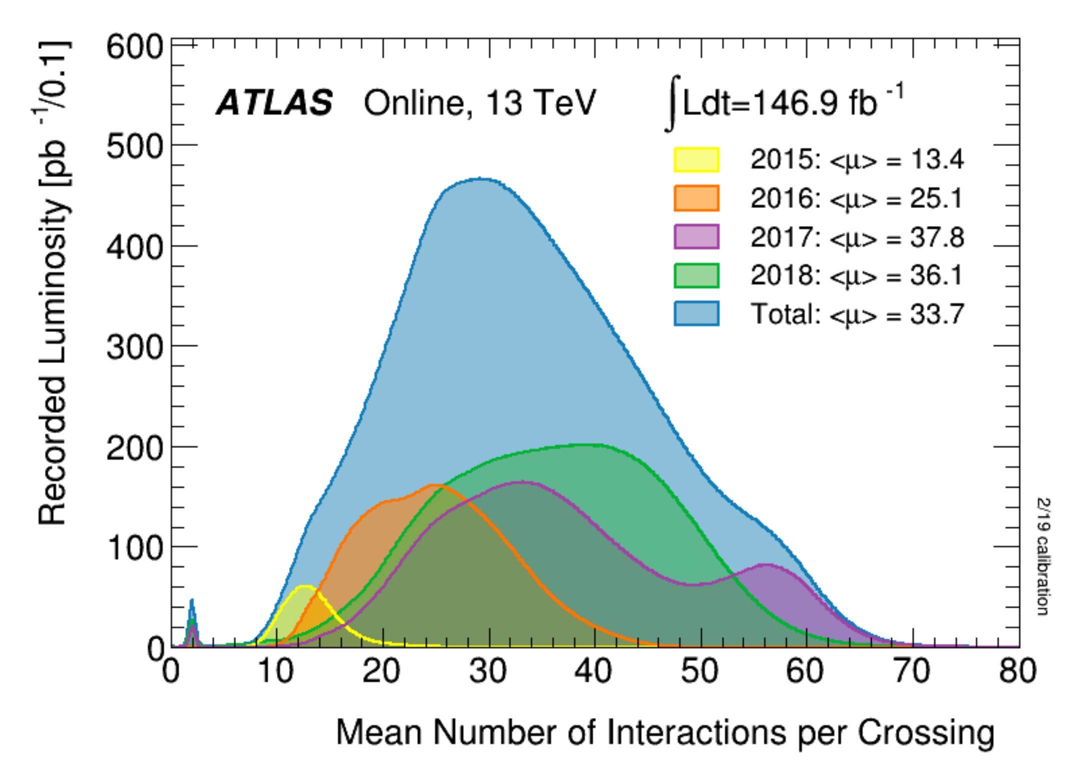


Experiments currently shutdown, **no new data** until early 2022!

- Focus on doing more with what we have
  - clever techniques to find new physics (SUSY?) in existing data
  - **global fits and large scale combinations to determine future directions**
- **Finalized calibrations** on physics objects (electrons, muons, jets, photons) and pushed **object definitions to lower energies**

The Large Hadron Collider





A proton-proton collider at 13 TeV center-of-mass energy

- For 2015-2018 operation:
  - Operating peak luminosity: 2.10×10^{34} cm^{-2} s^{-1}
  - Proton bunch spacing: **25 ns** — 40 million crossings per second
  - 2808 bunches colliding in ATLAS
  - **146.9 ifb of data delivered**
  - Up to 70 collisions per bunch crossing **(pileup!)** — billions of collisions per second!

? ***Why that peak at low <μ>? ATLAS does many special runs. This one was for precision W-physics.***

Beyond the Standard Model

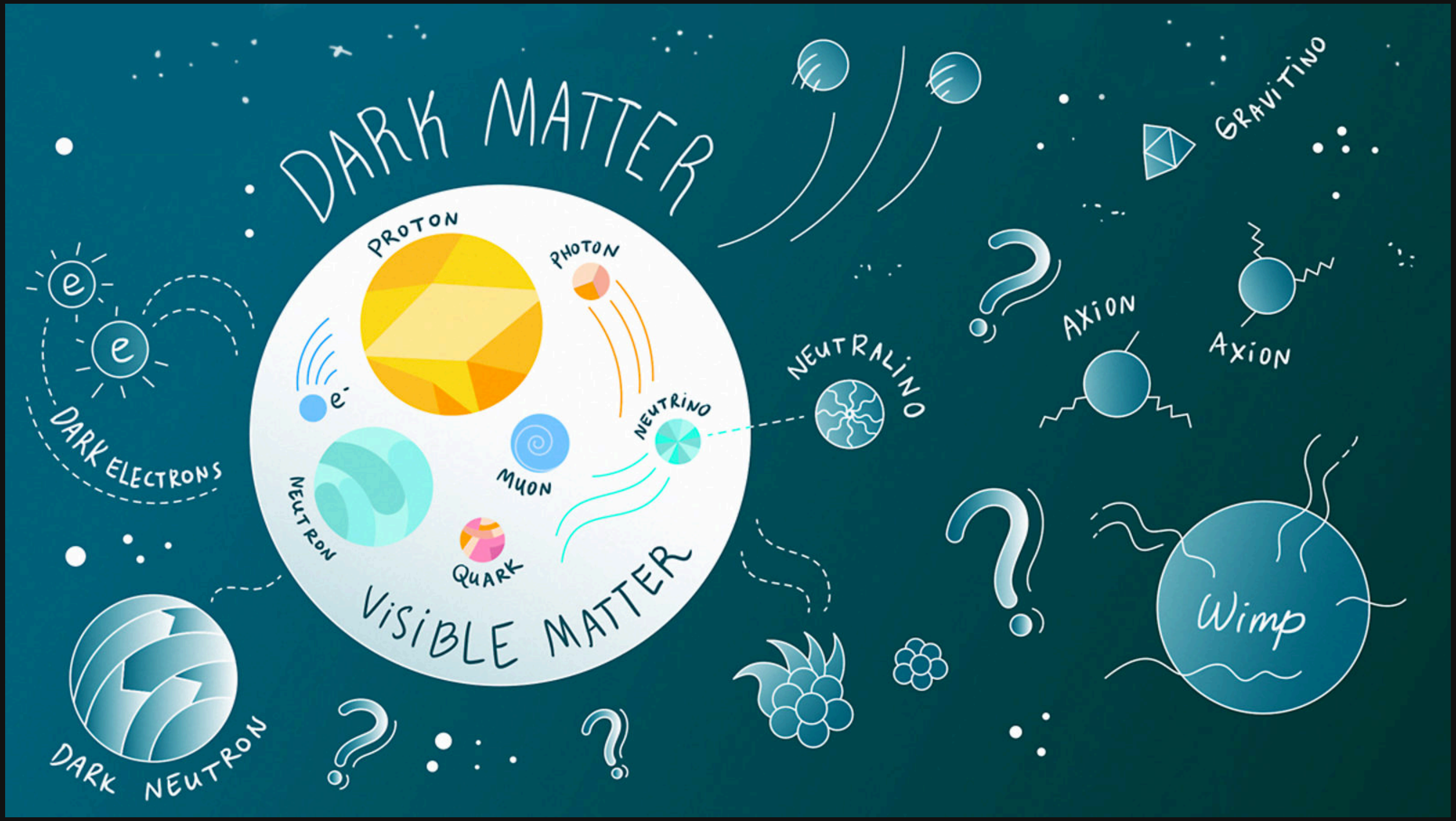
What *is* dark matter?

Where did all the antimatter go?

Why does the standard model look the way it does?

Why is the weak force so much stronger than gravity? (Hierarchy problem)

Supersymmetry (SUSY) is a framework with good theoretical motivations in which theorists can study BSM physics

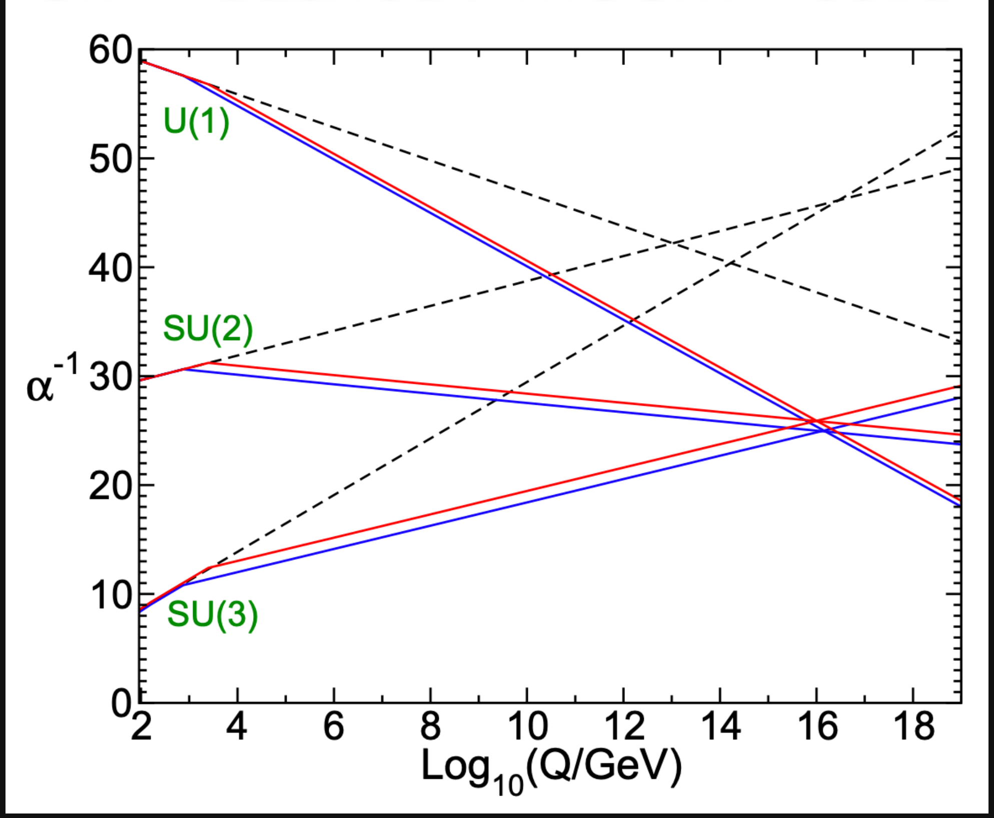


Supersymmetry (SUSY) is a set of benchmark models to help experimentalists answer these questions!

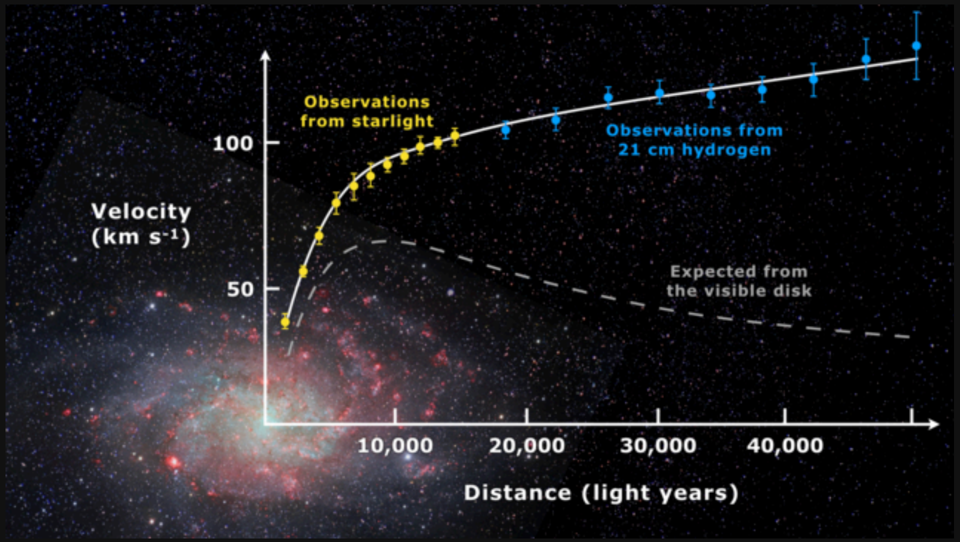
https://arxiv.org/abs/hep-ph/9709356
https://en.wikipedia.org/wiki/Galaxy_rotation_curve

Beyond the Standard Model

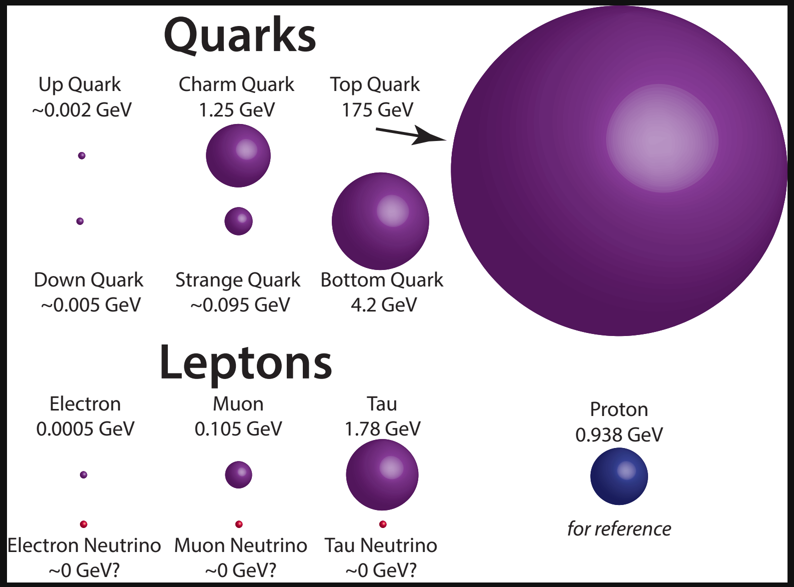
SM - dashed / MSSM - solid



Unification of couplings at LHC energy scale?



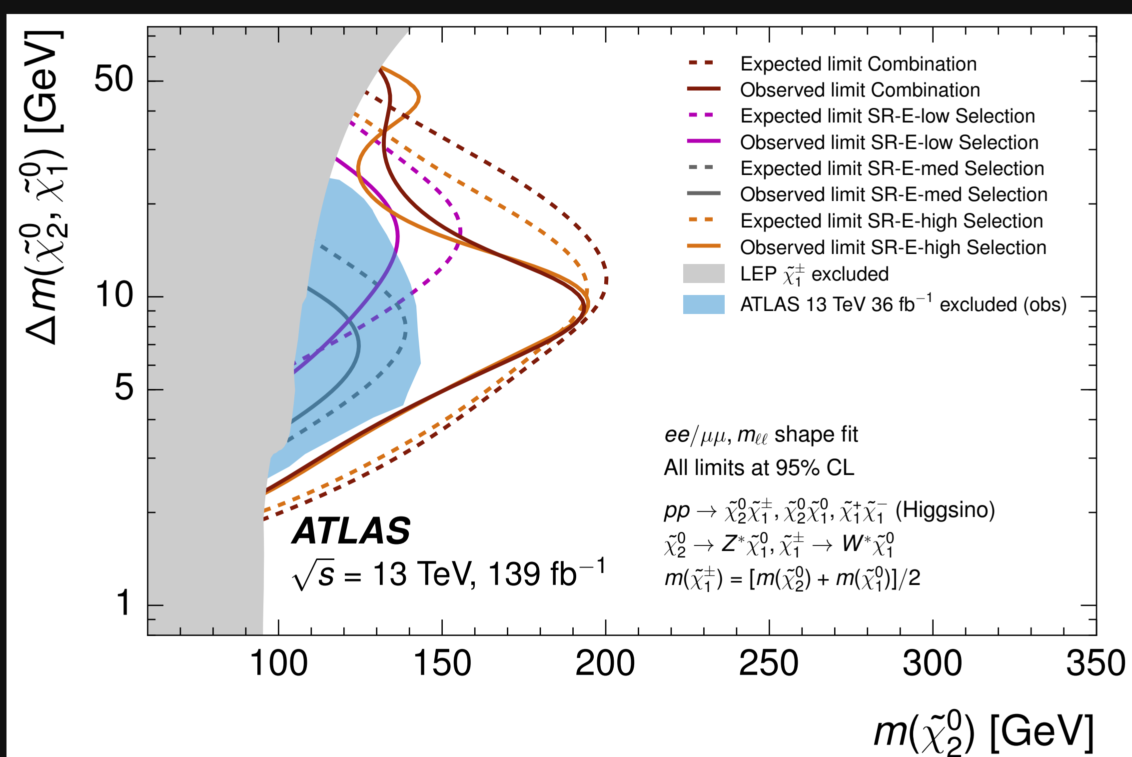
Cold Dark Matter candidates?

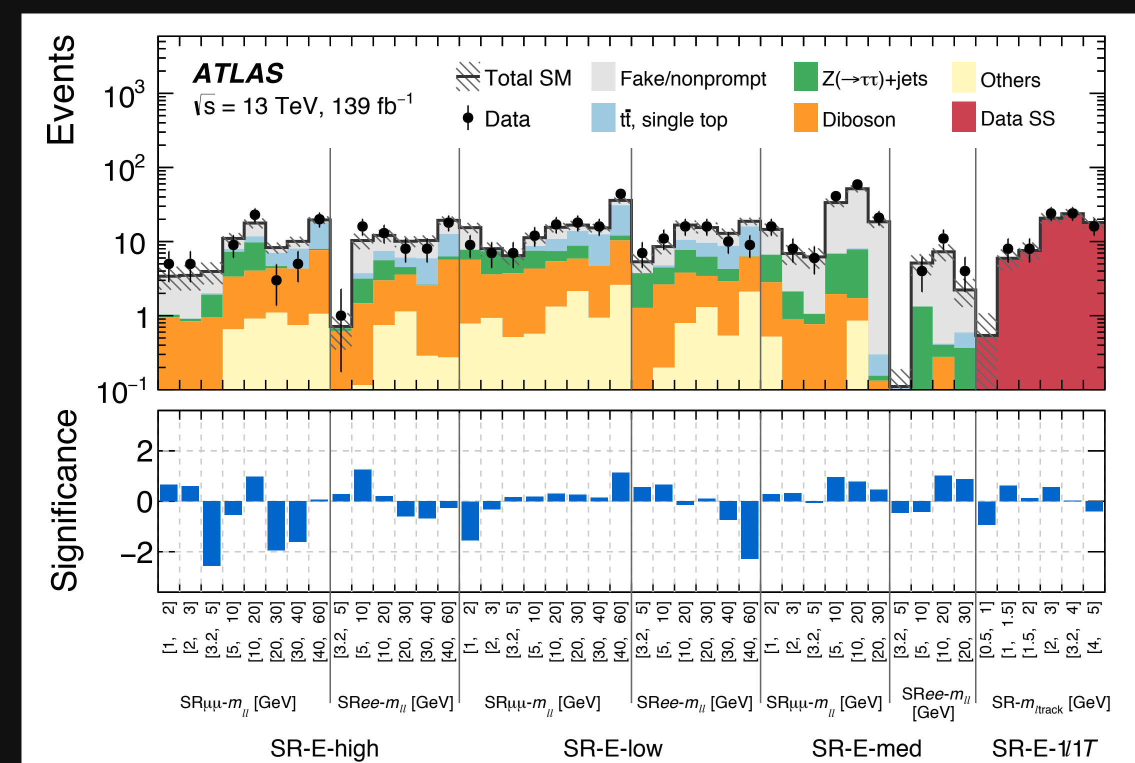


Hierarchy Problem

Higgsino combination

- Why is the observed weaker than the expected?
- SR-E-high and SR-E-low both have worse observed than predicted in that region. $\Delta m \approx 20$ GeV corresponds with $m_{\ell\ell} \approx 10$ GeV and there are some correlated (small) excesses across the bins in that phase-space.





https://cds.cern.ch/record/2040684/

RPC-RPV Spectrum

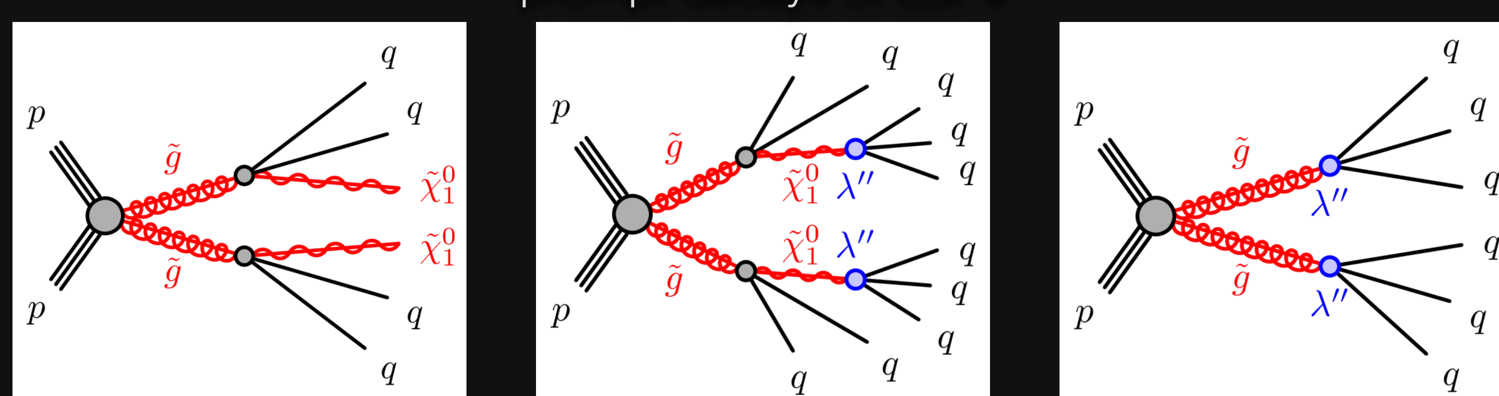
$$\mathcal{W}_{\text{RPV}} = \frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_u,$$

RPV terms in the SUSY superpotential

- All simplified models fall somewhere on the RPC-RPV spectrum… either
  - set all terms large or …
  - set all terms to 0 (conserve “SUSYness”, RPC) and require the lightest SUSY particle (LSP) to be stable → dark matter candidates?

prompt decays of LSPs

long-lived LSPs displaced decays?



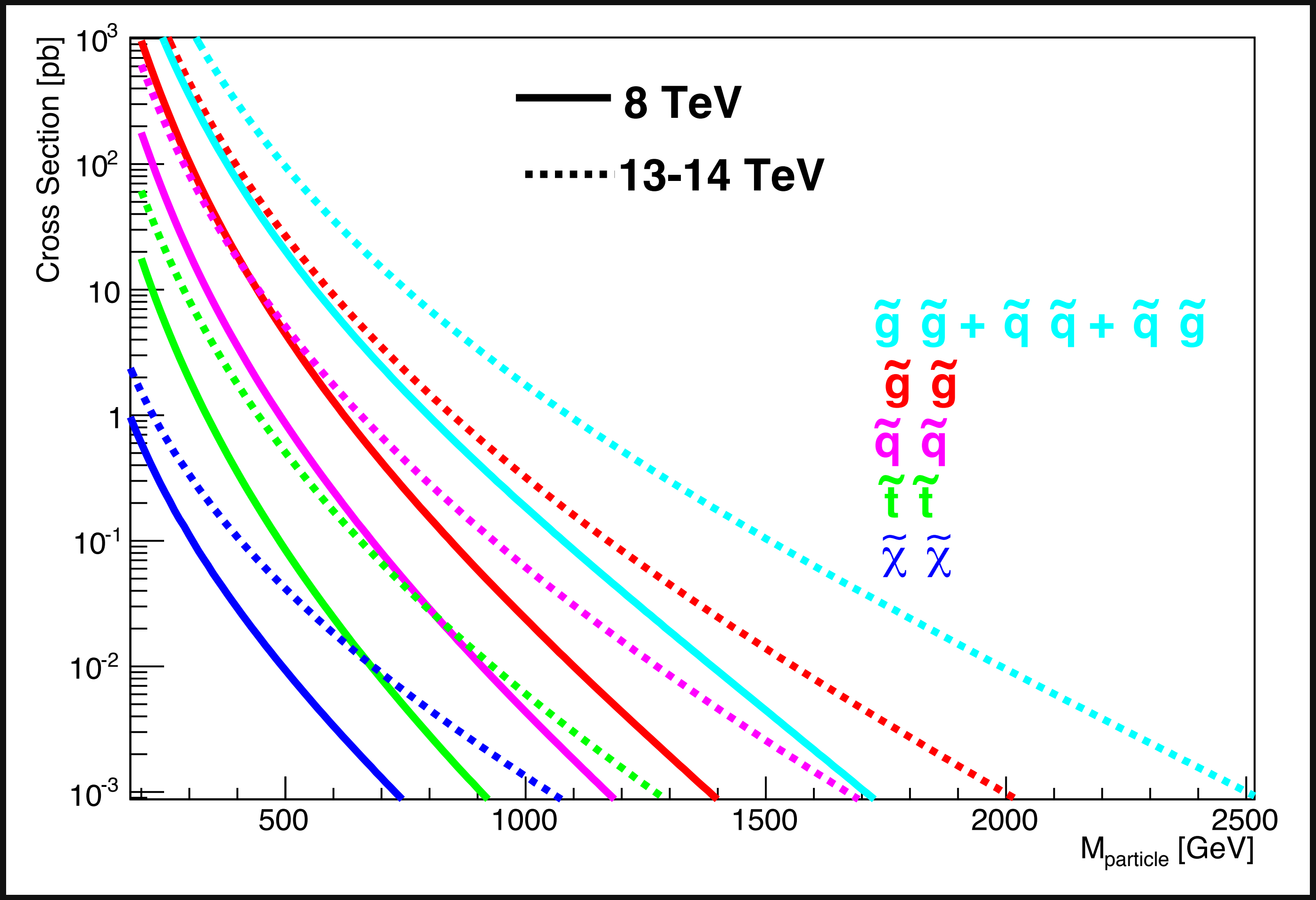
prompt decays of gluinos

increasing λ'' →

Naturalness motivates light gluinos and stops

Searching for SUSY

- Gluinos, because of their strong color coupling, have the highest theoretical cross-section of the sparticles found at the LHC
  - The upgrade of LHC from 8 TeV to 13 TeV also provides an order of magnitude increase in the theoretical cross-section
- Theoretical cross-sections are shown for:
  - **total strong production**
  - **gluino production**
  - **total squark production**
  - **heavy squark**
  - **electroweak**



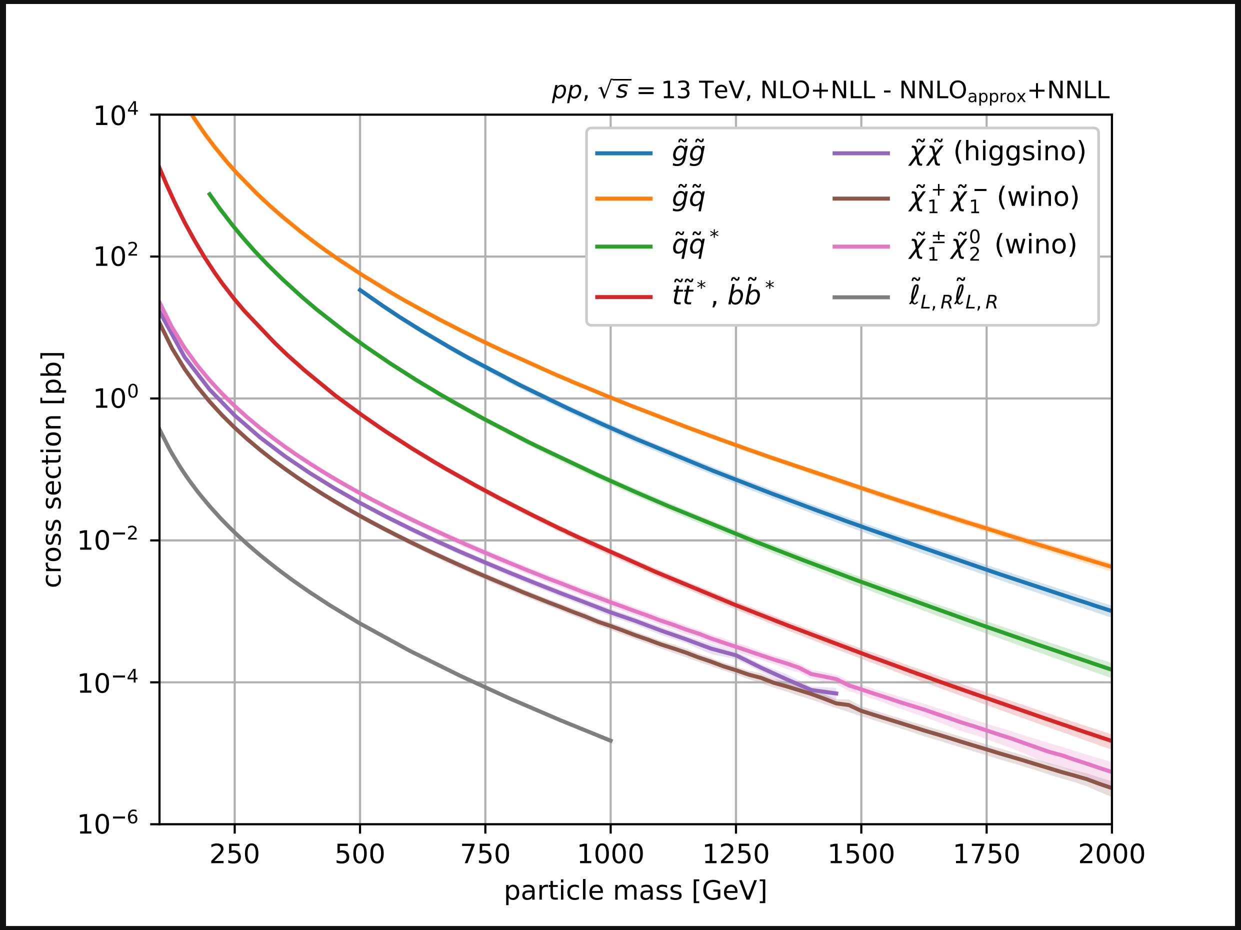
[1407.5066] [1206.2892]

Search for strongly-produced sparticles!

(electroweak states may be first detected if high mass limits on strong production)

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

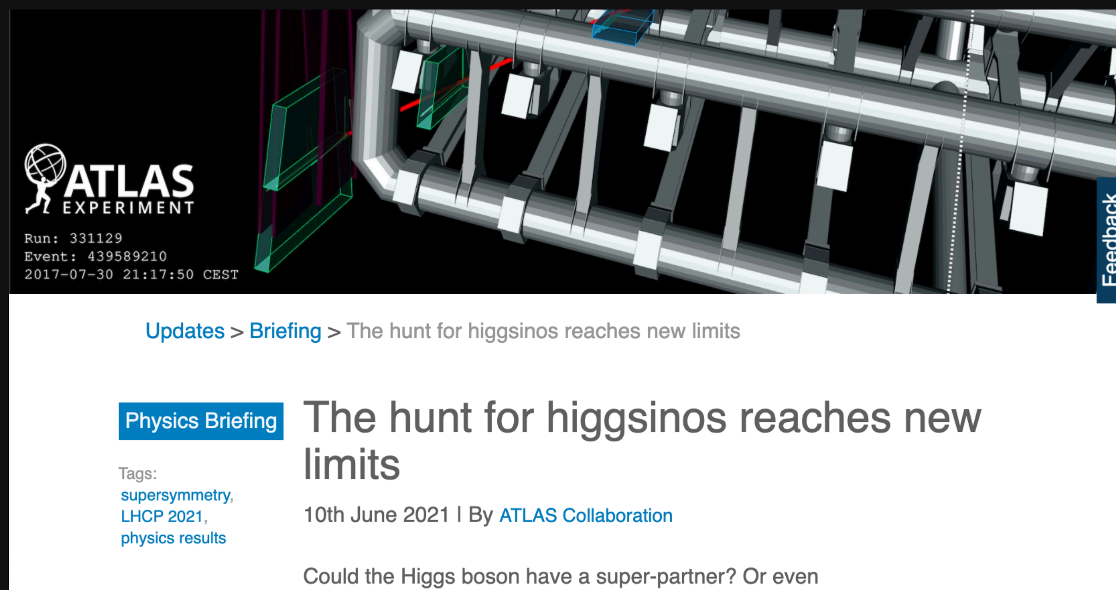
Cross Sections



- LHC 13 TeV well-motivated to search for SUSY (some searches are possible for the first time!)
- Typically: Strong/3G will have larger cross-sections than electroweak (EWK)

Motivate: search for light sparticles

Technical: combine… how?



- **Create the workspaces: 3L on-shell, 3L off-shell, and 2L**
  - `pyhf patchset apply --name CN_WZ_200_190 bkg_onshell.json onshell_patchset.json --output-file CN_WZ_200_100_onshell.json`
  - `pyhf patchset apply --name CN_WZ_200_190_offshell bkg_offshell.json offshell_patchset.json --output-file CN_WZ_200_190_offshell.json`
  - `pyhf patchset apply --name 200p0_190p0 EWKinos_bkgonly.json EWKinos_patchset.json --output-file CN_WZ_200_190_2L.json`
- **Rename modifiers (“systematics”) in a workspace to (de)correlate nuisance parameters**
  - `pyhf rename -m mu_Ztt_lowmet mu_CMP_Ztt_lowmet -m EG_RESOLUTION_ALL COMB_EG_RESOLUTION_ALL -m …`
- **Combine the workspaces**
  - `pyhf combine --join outer CN_WZ_200_190_onshell.json CN_WZ_200_190_offshell.json --output-file combined_CN_WZ_200_190_3L.json`
  - `pyhf combine --join outer CN_WZ_200_190_3L.json CN_WZ_200_190_2L.json --output-file combined_CN_WZ_200_190L.json`
- **Perform inference**
  - `pyhf cls combined_CN_WZ_200_100.json`

g-2 references

- Some papers on it
  - https://arxiv.org/abs/2104.03302 (pheno)
  - https://arxiv.org/abs/2104.03294 (MSSM)
- RPV with LLE/LQD
  - https://arxiv.org/abs/1511.08874
  - https://arxiv.org/abs/2104.03294

light SUSY particles → g-2 contributions:

$\tilde{\mu}_R$	$\tilde{\mu}_L/\tilde{\nu}_\mu$	$\tilde{B}$	$\tilde{W}$	$\tilde{h}$
	✓		✓	✓
	✓	✓		✓
✓		✓		✓
✓	✓	✓		

$$a_\mu^{\rm WHL} = \frac{\alpha_2}{4\pi}\frac{m_\mu^2}{M_2\mu}\tan\beta\cdot f_C\left(\frac{M_2^2}{m_{\tilde{\nu}_\mu}^2}, \frac{\mu^2}{m_{\tilde{\nu}_\mu}^2}\right) - \frac{\alpha_2}{8\pi}\frac{m_\mu^2}{M_2\mu}\tan\beta\cdot f_N\left(\frac{M_2^2}{m_{\tilde{\mu}_{\rm L}}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{\rm L}}^2}\right)$$

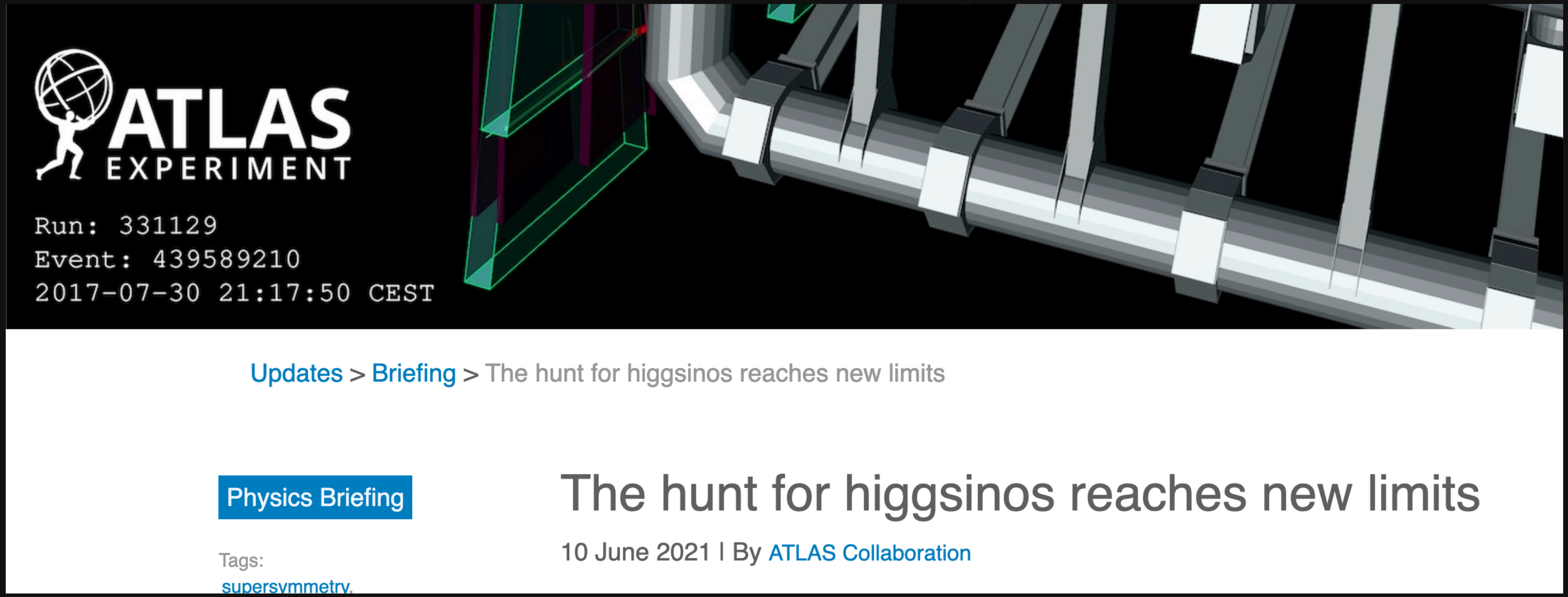
$$a_\mu^{\rm BHL} = \frac{\alpha_Y}{8\pi}\frac{m_\mu^2}{M_1\mu}\tan\beta\cdot f_N\left(\frac{M_1^2}{m_{\tilde{\mu}_{\rm L}}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{\rm L}}^2}\right)$$

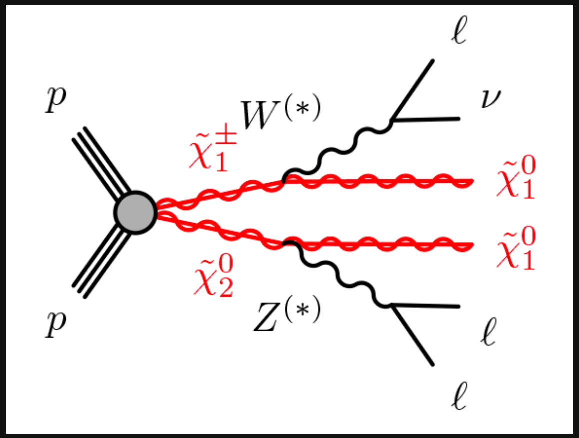
$$a_\mu^{\rm BHR} = -\frac{\alpha_Y}{4\pi}\frac{m_\mu^2}{M_1\mu}\tan\beta\cdot f_N\left(\frac{M_1^2}{m_{\tilde{\mu}_{\rm R}}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{\rm R}}^2}\right)$$

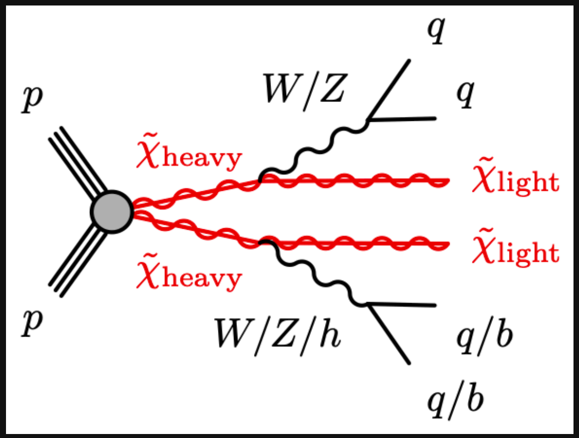
$$a_\mu^{\rm BLR} = \frac{\alpha_Y}{4\pi}\frac{m_\mu^2 M_1\mu}{m_{\tilde{\mu}_{\rm L}}^2 m_{\tilde{\mu}_{\rm R}}^2}\tan\beta\cdot f_N\left(\frac{m_{\tilde{\mu}_{\rm L}}^2}{M_1^2}, \frac{m_{\tilde{\mu}_{\rm R}}^2}{M_1^2}\right),$$

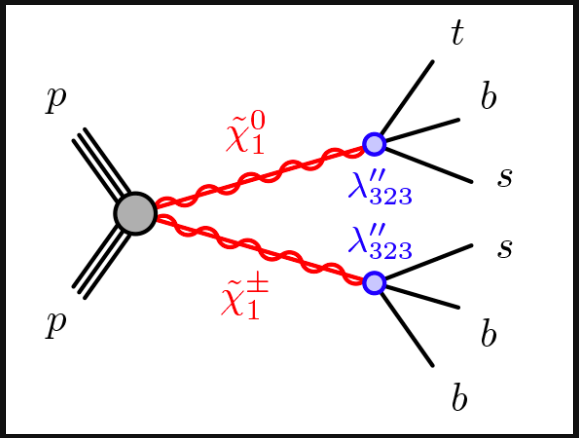
credit: B. Hooberman

Brief sidebar









- If we consider SUSY RPC models with a Higgsino LSP, heavier Higgsinos are theoretically predicted to decay only into the LSP and soft SM particles
- Two different avenues for searching, each with unique challenges:
  - very **heavy** (hadronic) Higgsinos, decay into lighter SUSY particles and **boosted** SM bosons
  - very **light** (leptonic) Higgsinos, decay into **soft** leptons (poor reconstruction efficiency!)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2018-41/
https://atlas.cern/updates/briefing/new-higgsino-limits

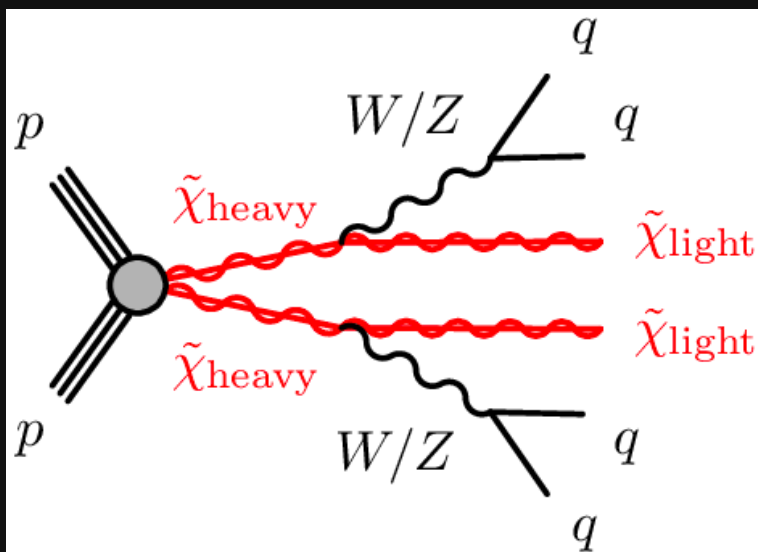
EWK $(\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm})$

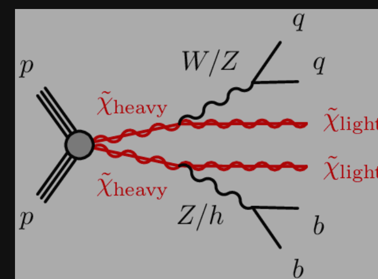
139 fb^{-1}

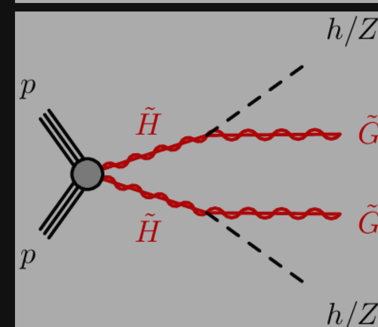
cut and count

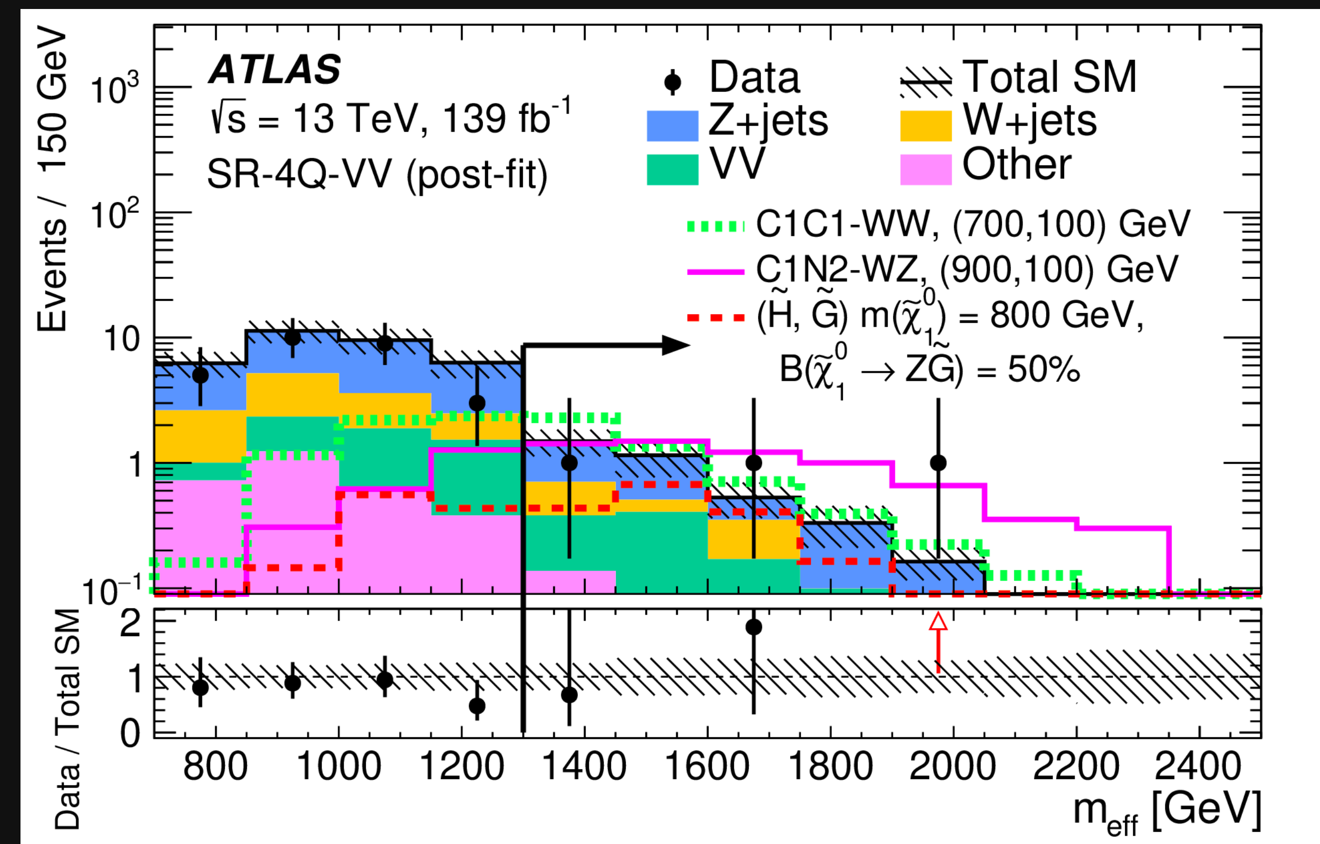
multi-bin

W/Z Hadronic



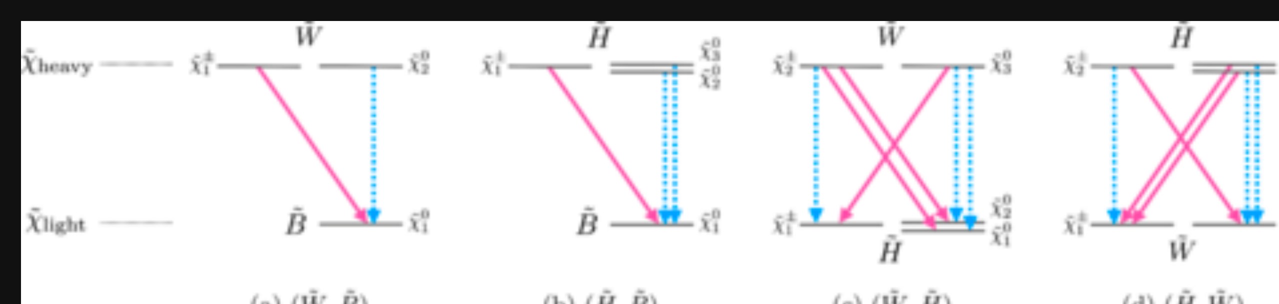






- Model parameters: $\tilde{W}, \tilde{H}, \tilde{B}$
- Final state: boosted jets, MET, no leptons
- Three signal scenarios (10 exclusion regions):
  - $(\tilde{\chi}_h, \tilde{\chi}_l) \in (\tilde{W}, \tilde{H}, \tilde{B})$ (RPC neutralino LSP)
  - $\tilde{H} \to h/Z + \tilde{G}$ (GGM, Gravitino LSP)
  - $\tilde{H} \to h/Z + \tilde{a}$ (Naturalness axino LSP)
- Dominant backgrounds: $Z(\to \nu\nu)$ + jets, $W(\to \ell\nu)$ + jets, VV
- Challenge: "fake boson jet" estimation, semi-data-driven approach, accidental substructure

2 large-R jets with at most 1 *b*-jet to target the qqqq final state (not bbqq)



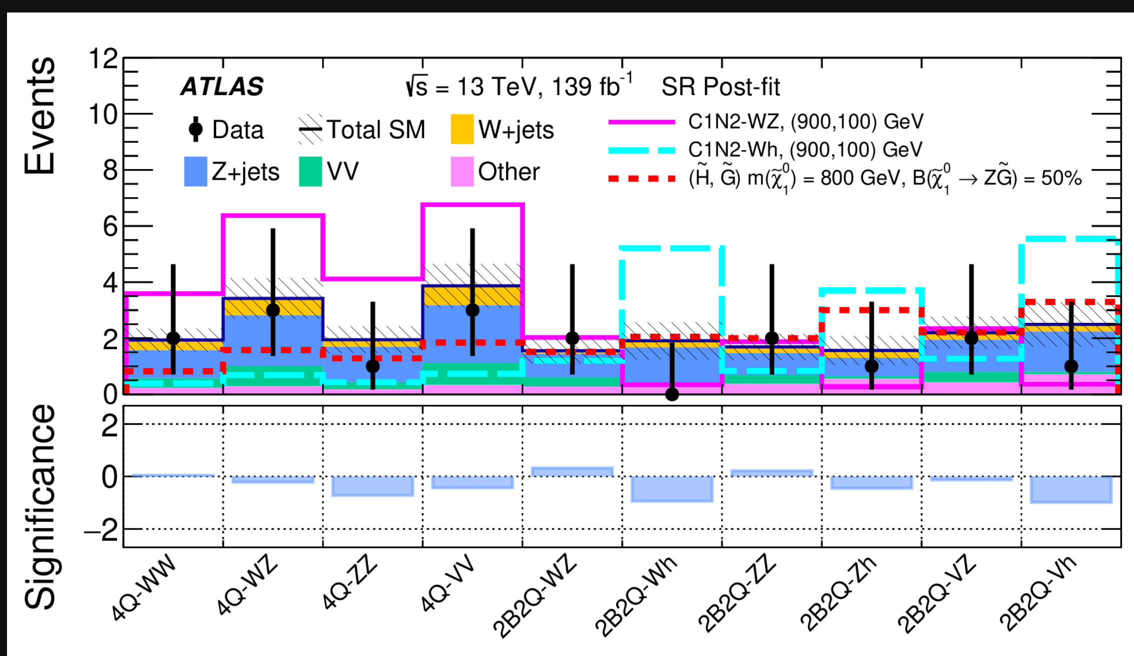
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2018-41/
https://atlas.cern/updates/briefing/new-higgsino-limits

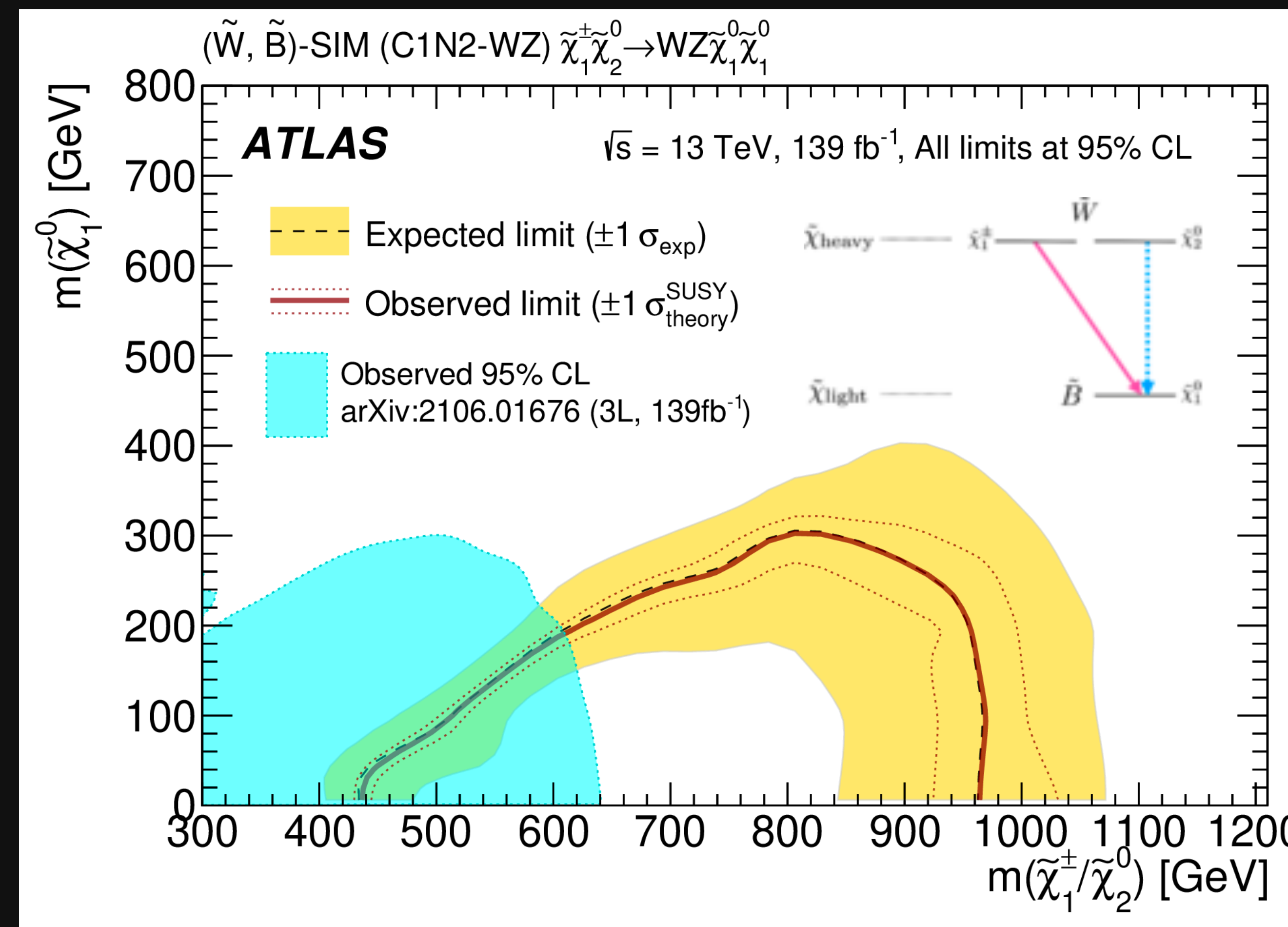
EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)
139 fb^{-1}
cut and count
multi-bin

W/Z Hadronic

$$\tilde{\chi}_2^0 \tilde{\chi}_1^{\pm} \rightarrow WZ \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

No significant excess found in any SR





Significance

$$(\tilde{\chi}_{\text{heavy}}, \tilde{\chi}_{\text{light}}) = (\tilde{W}, \tilde{B})$$

Improve sensitivity from $\Delta m \sim [300{,}600] \rightarrow [450{,}1000]$ GeV

(also did DM global fit, and MSSM reinterpretations)