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Status of searches for EW-scale supersymmetry after LHC Run 2

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University of Birmingham, 28/09/2022

Run 2 is a good moment to summarise

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- No large increase of centre-of-mass energy or luminosity expected for a while.
  - Results will not be superseded quickly
- Role of the authors in Run 2 SUSY search programme.

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International Journal of Modern Physics A | VOL. 37, NO. 02

Status of searches for electroweak-scale supersymmetry after LHC Run 2

Wolfgang Adam and Iacopo Vivarelli

https://doi.org/10.1142/S0217751X21300222

https://arxiv.org/abs/2111.10180, https://doi.org/10.1142/S0217751X21300222

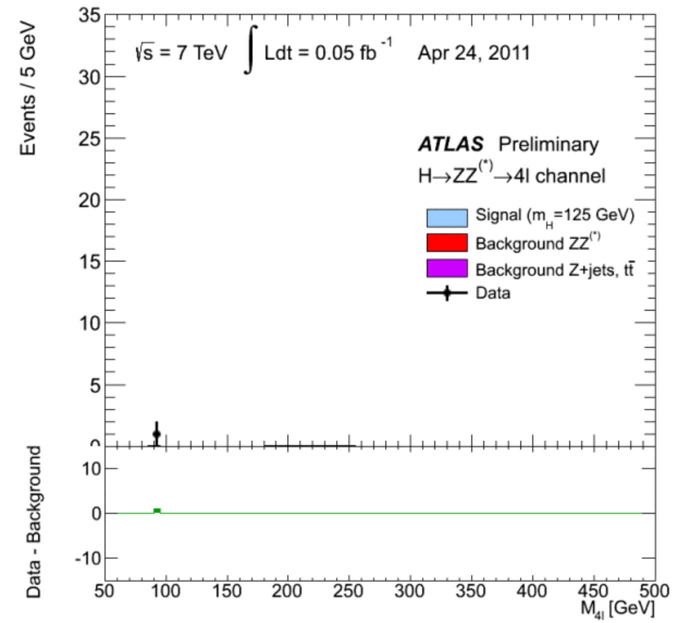
Has LHC achieved its mission?

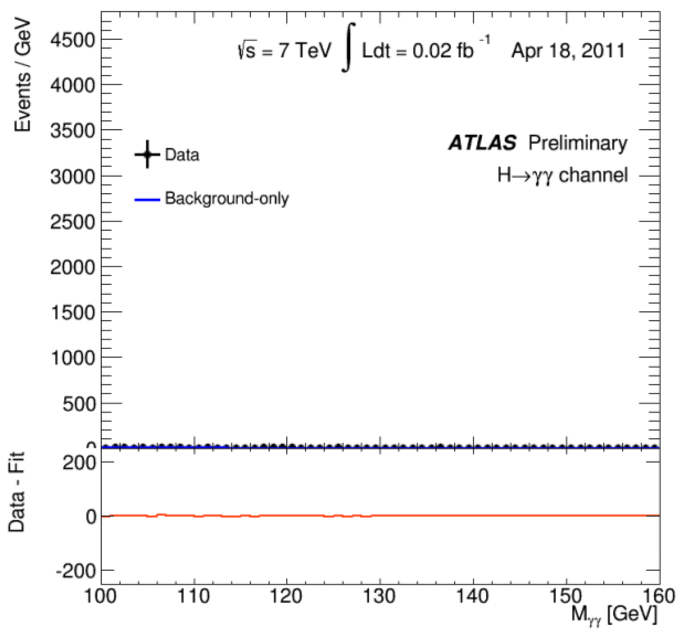
- From "ATLAS - A 25 years Insider Story of the LHC Experiment", (with reference to the Losanne meeting in **1984)**

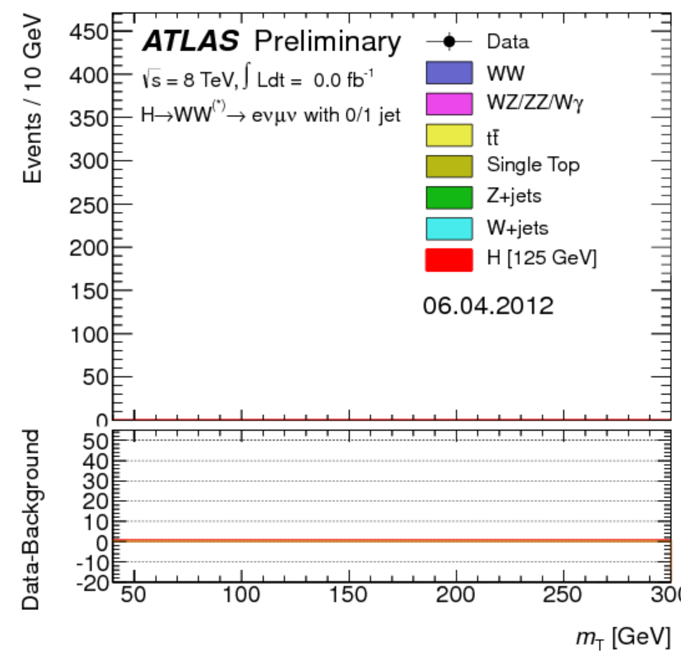
In this context, it appeared for the first time that it was possible to quantitatively compare the potentials of vastly different accelerators, in terms of answering some of the fundamental questions at the time. These included questions on the existence (or not) of the following: (i) a Higgs boson responsible for the mechanism of the electroweak symmetry breaking, (ii) heavier quarks, including the missing third-generation top quark, and (iii) supersymmetry (see Chap. 9).

- LHC successfully completed (i), (ii) and (iii)

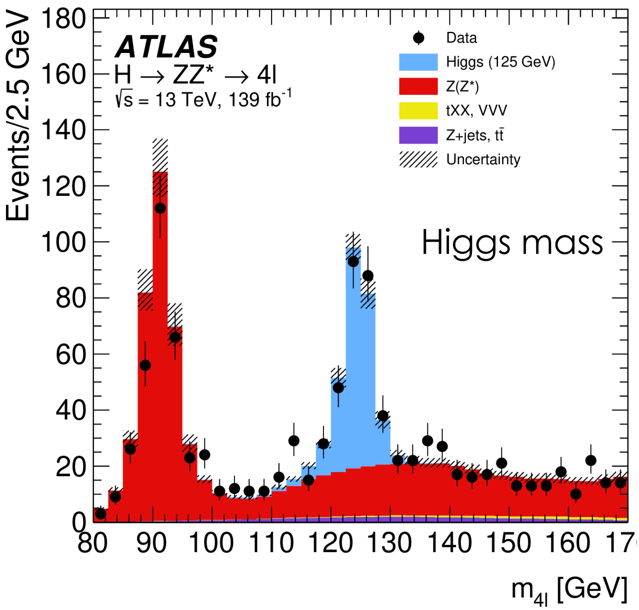
(i) A Higgs boson.....

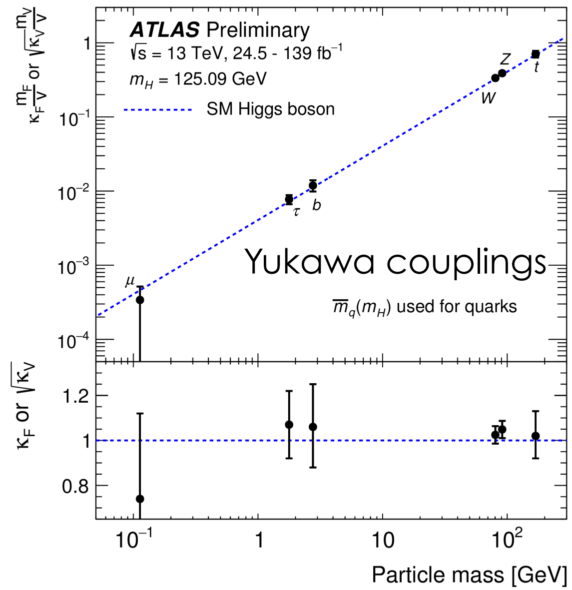




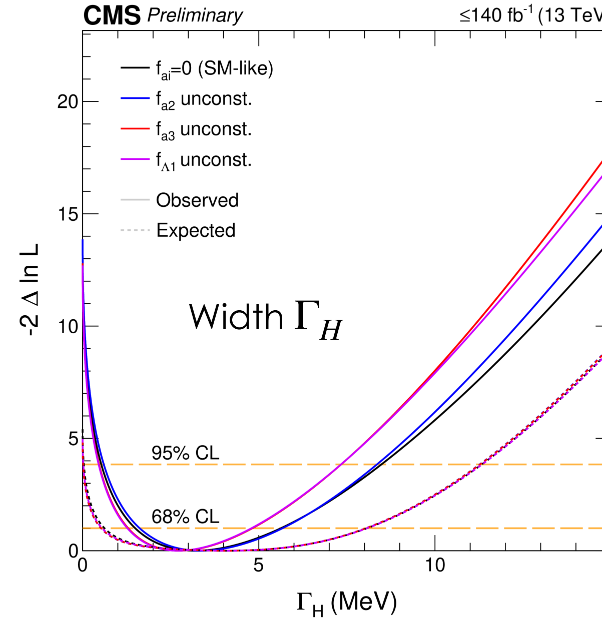


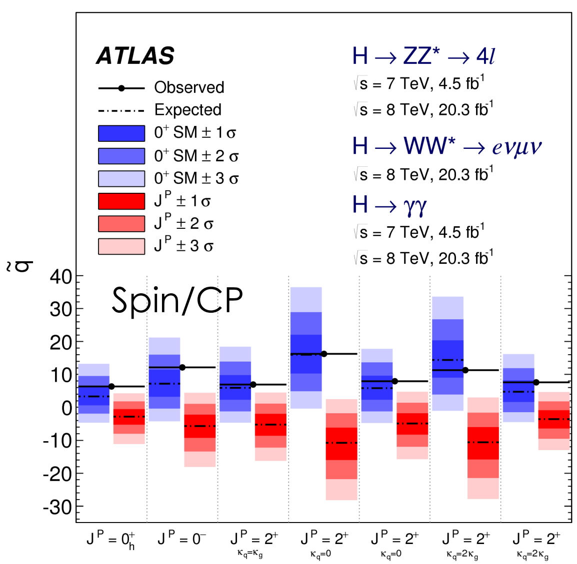
(i)…responsible for the mechanism of electroweak symmetry breaking

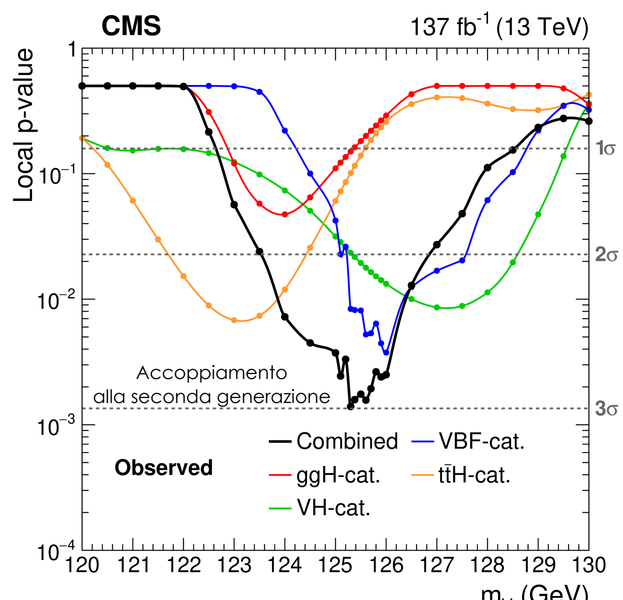




CMS PAS HIG-21-013







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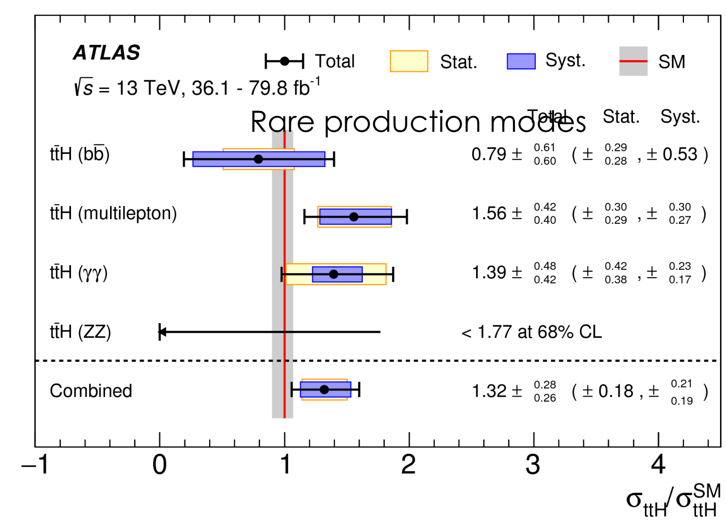
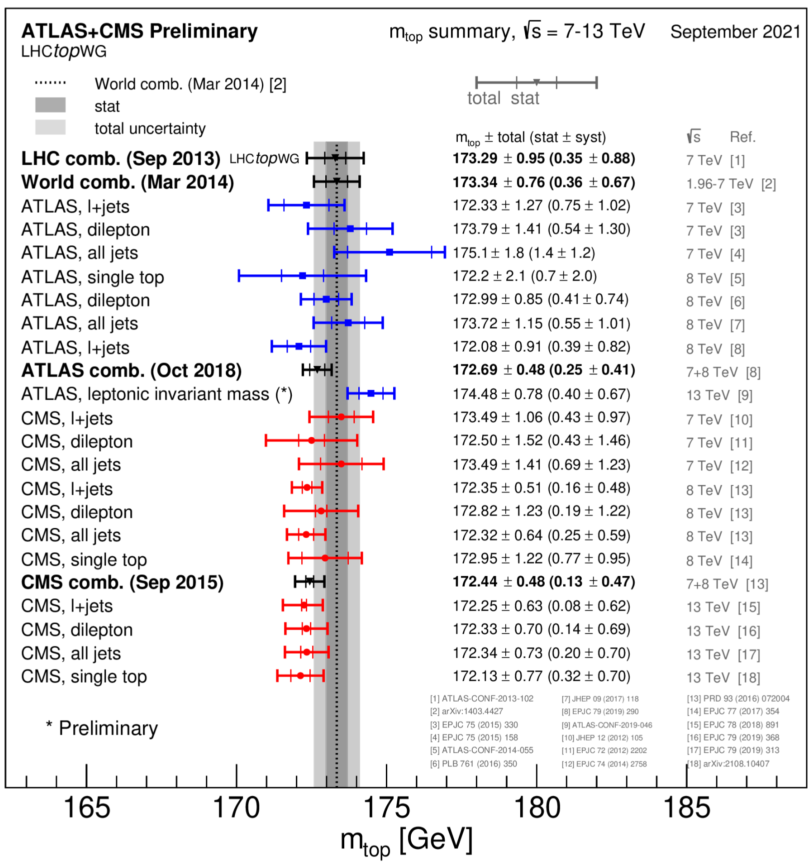
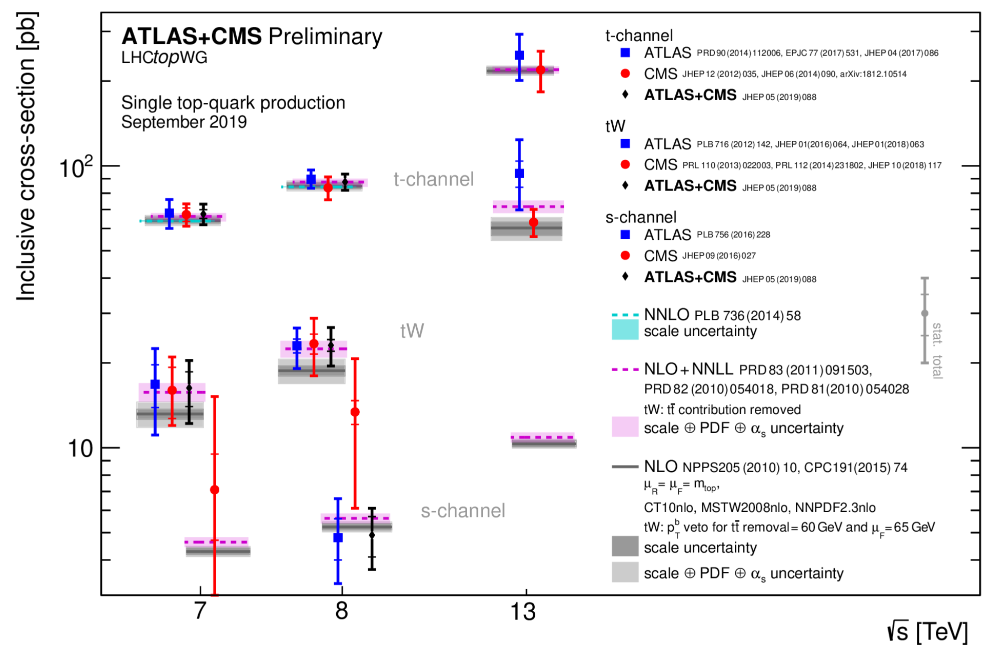


(ii)…third generation top quark…

- LHC transformed top quark measurement into **precision physics**.
  - … including rare processes, some of which observed for the first time.





(iii)Supersymmetry

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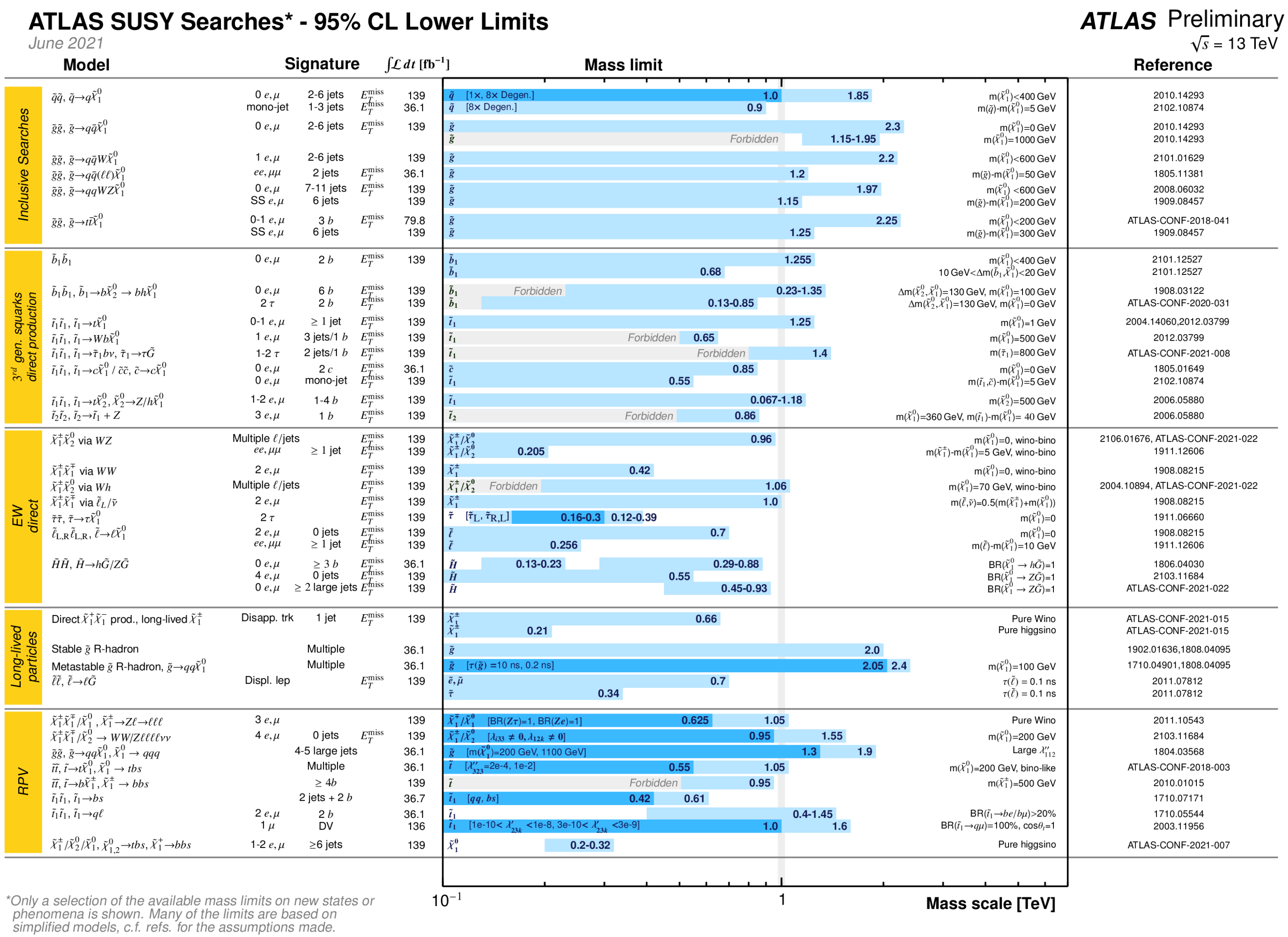
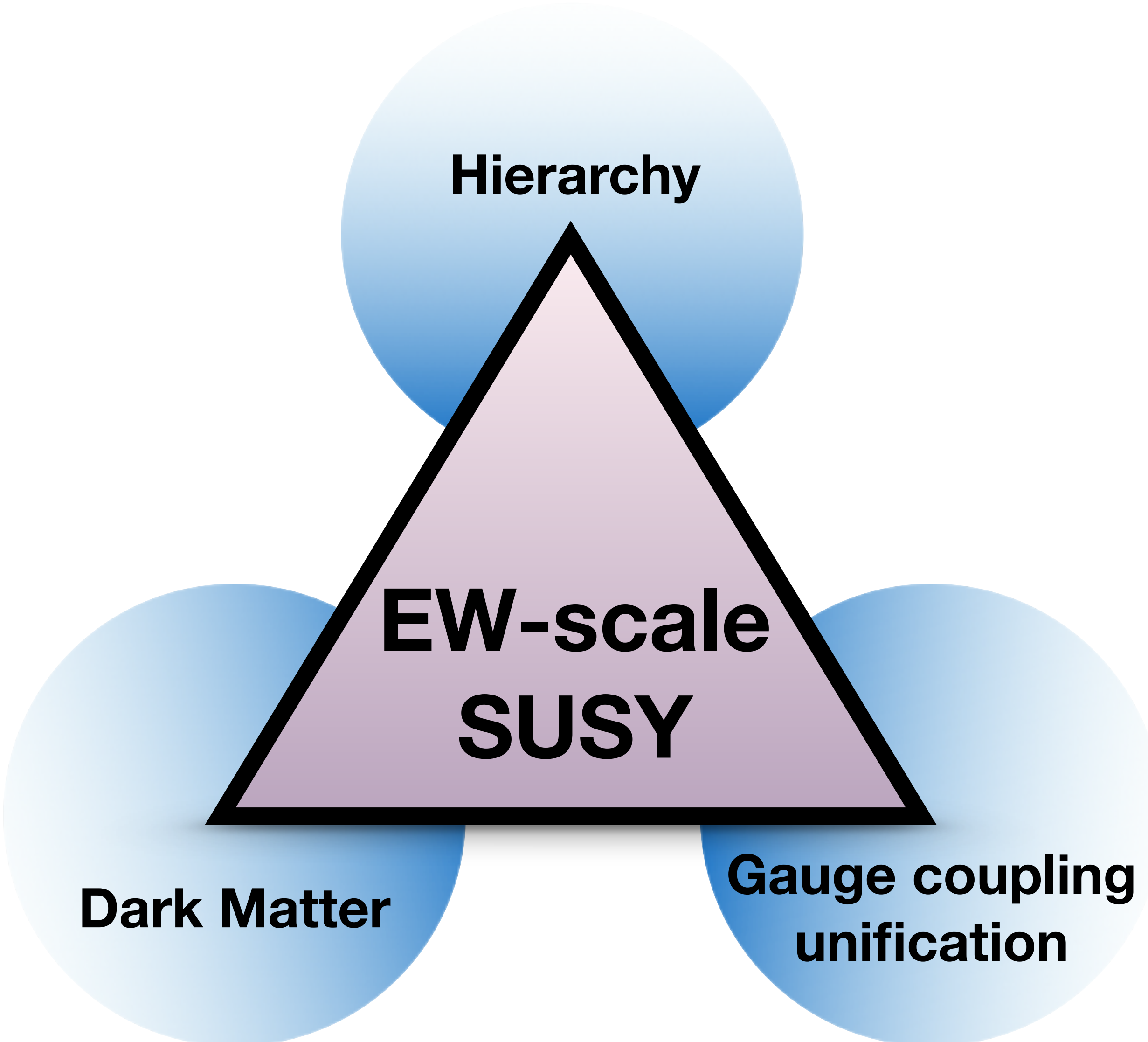
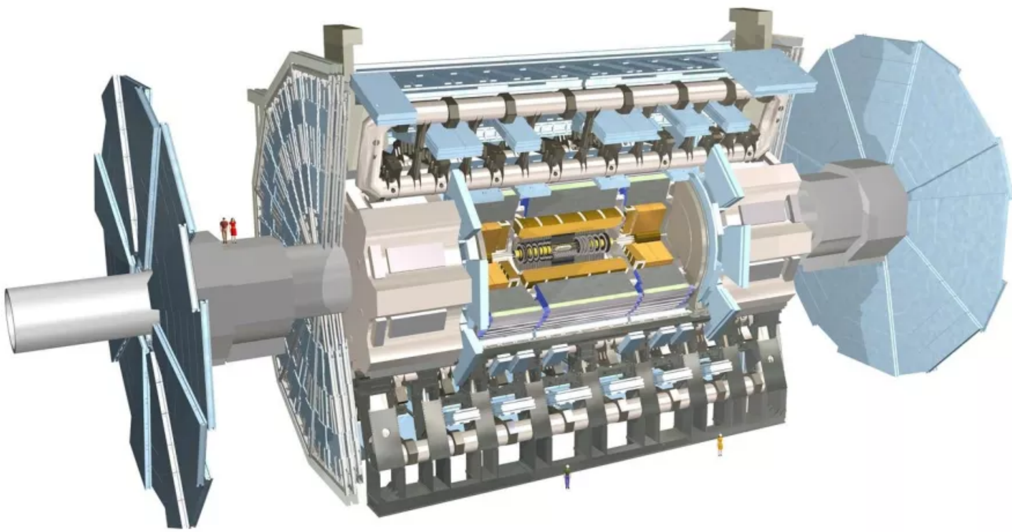
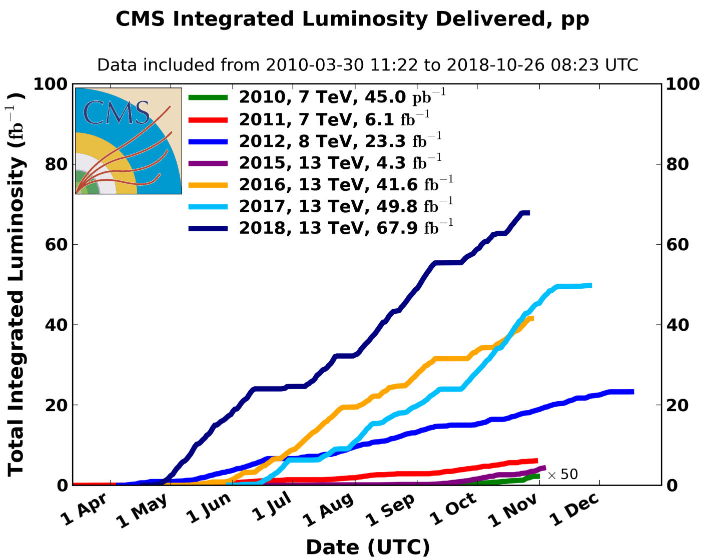


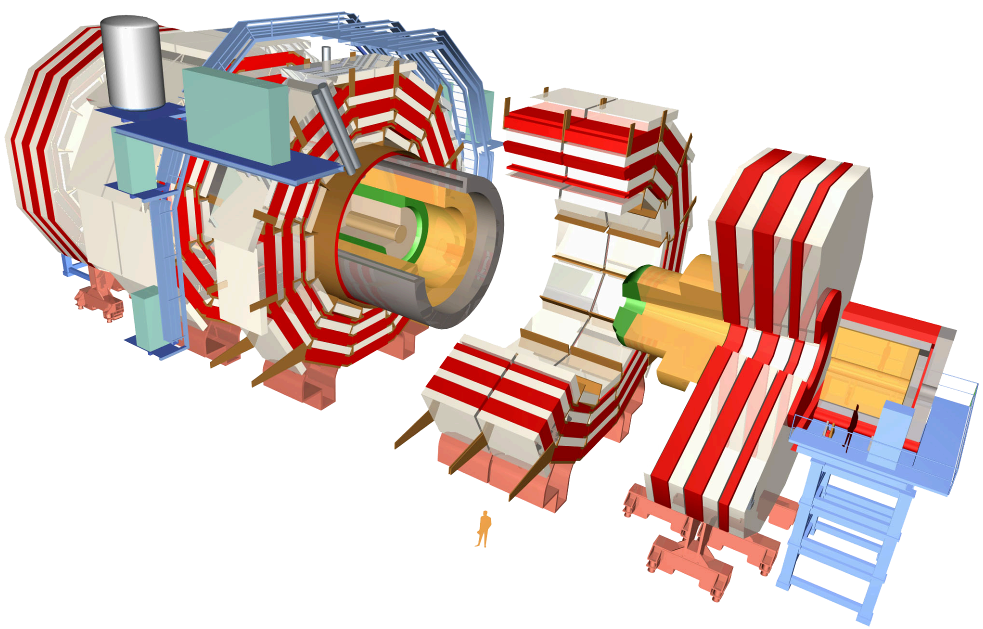
(iii)Supersymmetry

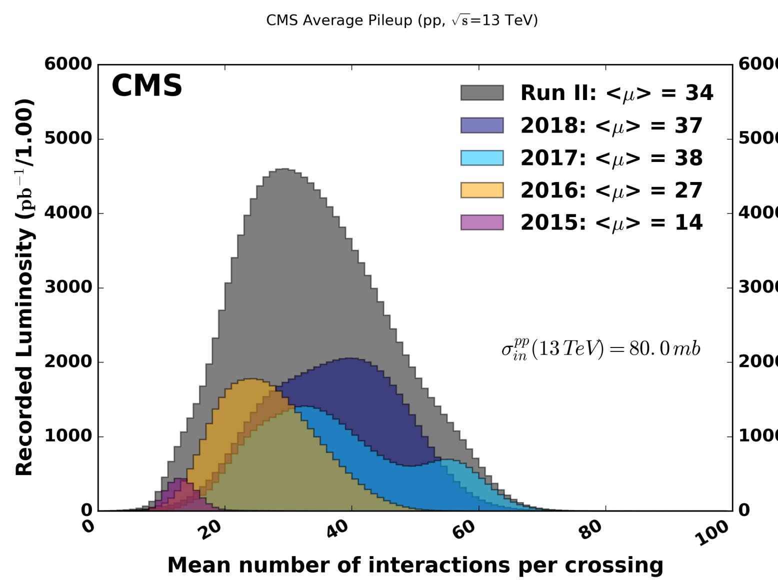


ATLAS and CMS





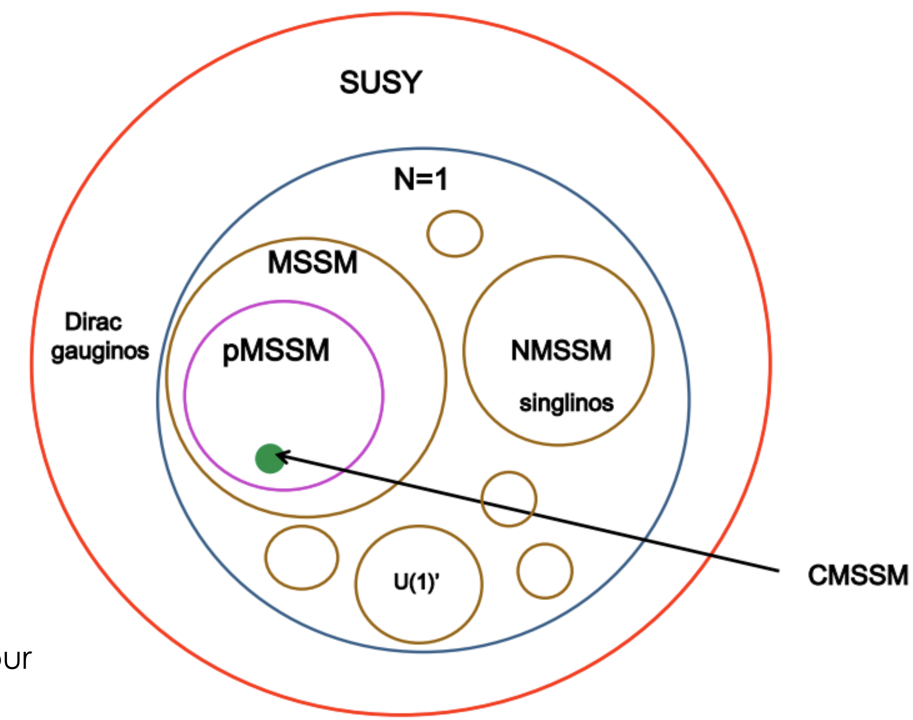




Complexity of SUSY parameter space

- The **minimal supersymmetric extension of the Standard Model (MSSM)** contains 124 new parameters.
- Even hypotheses well backed-up by experimental results[1], one ends up with a **19-dimension parameter space**.
- Approach:
  - Use **simplified models.**
  - Then **combine** these results to **make statements on SUSY model** (and particle masses) exclusions.

SUSY conserving sector	SUSY breaking sector
3 coupling constants for SU(3)xSU(2)sU(1)	5 3x3 hermitian mass matrices (one per EW multiplet)
4 Yukawa couplings per generation	3 complex 3x3 matrices (Higgs trilinear couplings to sfermions)
	3 mass terms for the Higgs sector + 2 additional off-diagonal terms
	Higgs VEV expectation angle β



[1]These are: absence of new sources of CP violation, absence of flavour changing neutral currents, universality of 1st and 2nd generation.

Complete Vs Simplified models

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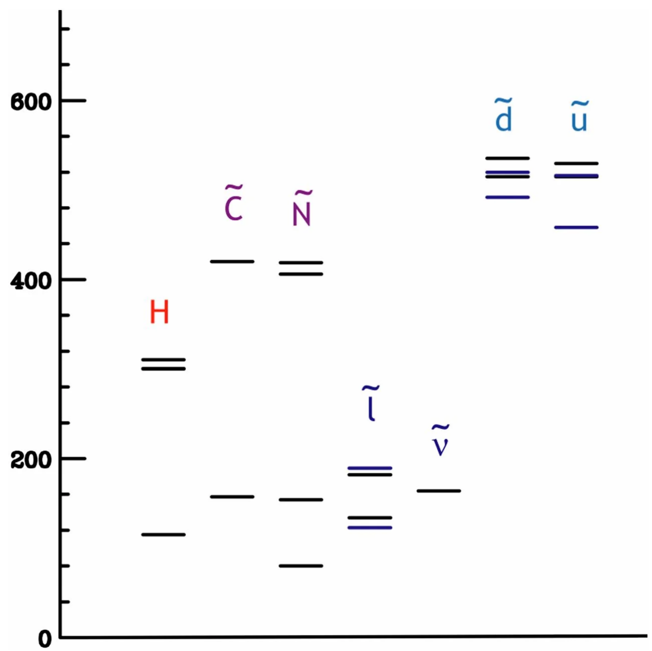
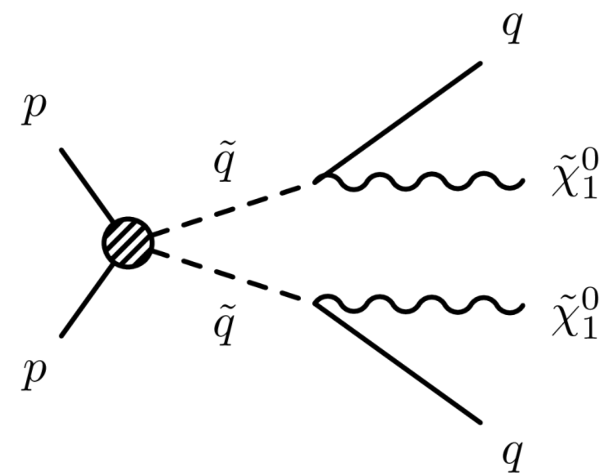




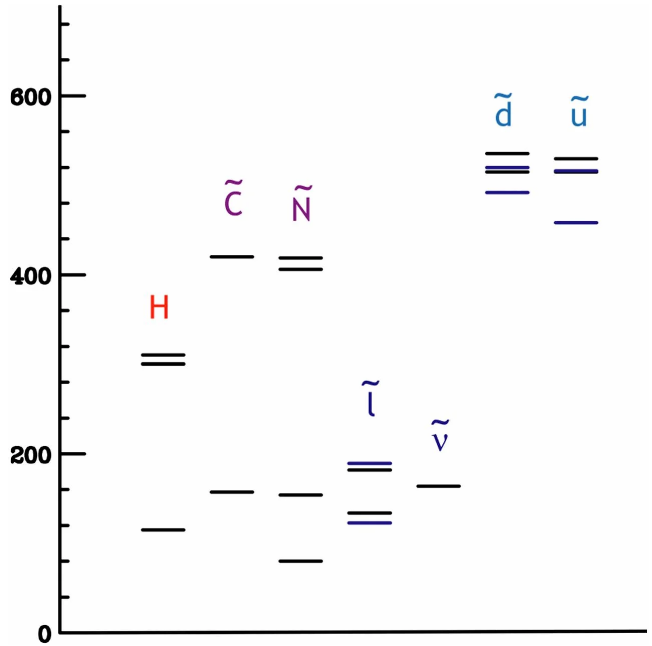
Real SUSY model

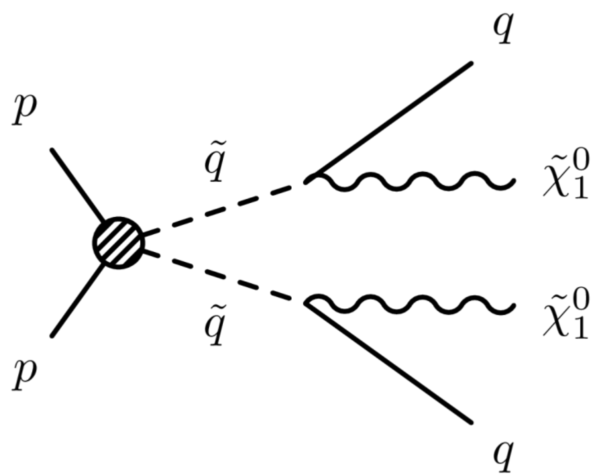
- Many concurrent production processes.
- Many different decay modes for SUSY particles.
- Many diagrams to target.

Simplified model

- Very few production processes (often only one).
- Very few decay modes (often only one).
- One (or few) diagrams to target.

Complete Vs Simplified models





Real SUSY model

- Pros:
  - Direct connection to physics.
  - Direct statement on UV completion.
- Cons:
  - Analysis strategy very model dependent.

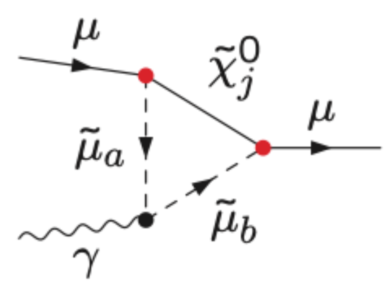
Simplified model

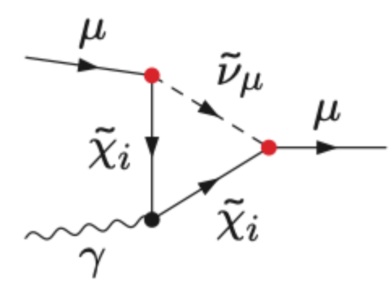
- Pros:
  - Analysis strategy closely connected to event topology.
  - "Model independent" constraints: they apply whenever the signature considered is realised in a model.
- Cons:
  - Mass limits do not extend automatically to complete scenarios.

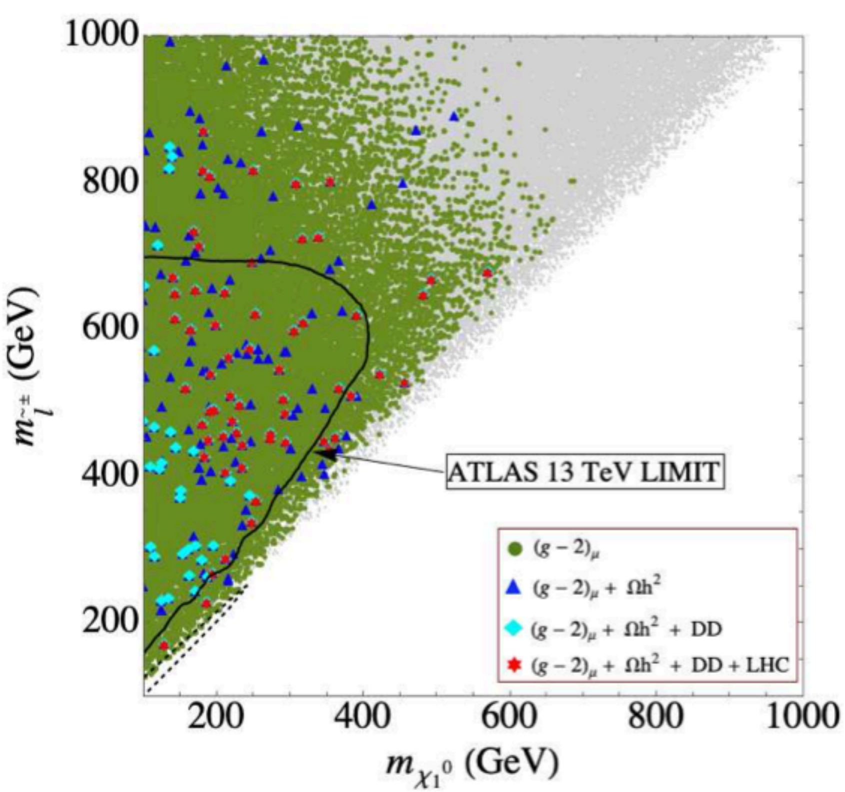
Example 1 - SUSY "fixing" g-2

Taken from M. Chakraborti et al., Eur. Phys. J. C 80, 984 (2020)

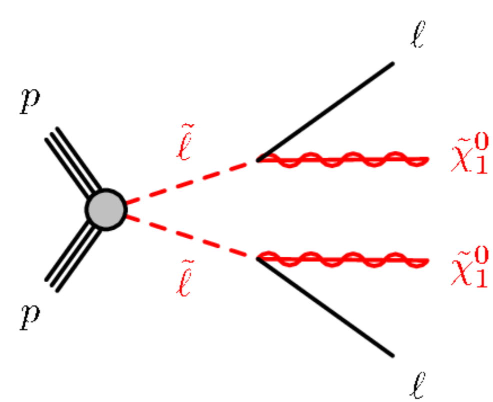
- A class of models **fixing muon g-2** and **satisfying DM constraints** has $\tilde{\chi}_1^0$ almost degenerate with $\tilde{\chi}_1^{\pm}$.
- Are these excluded by the LHC?

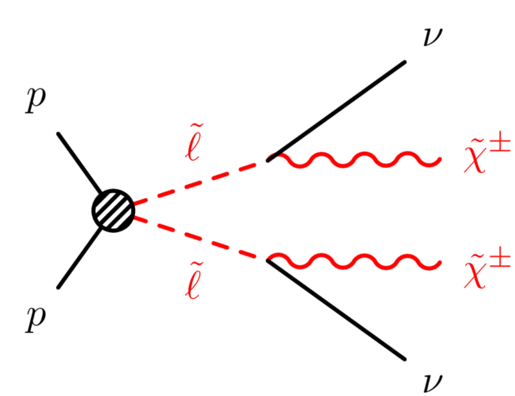






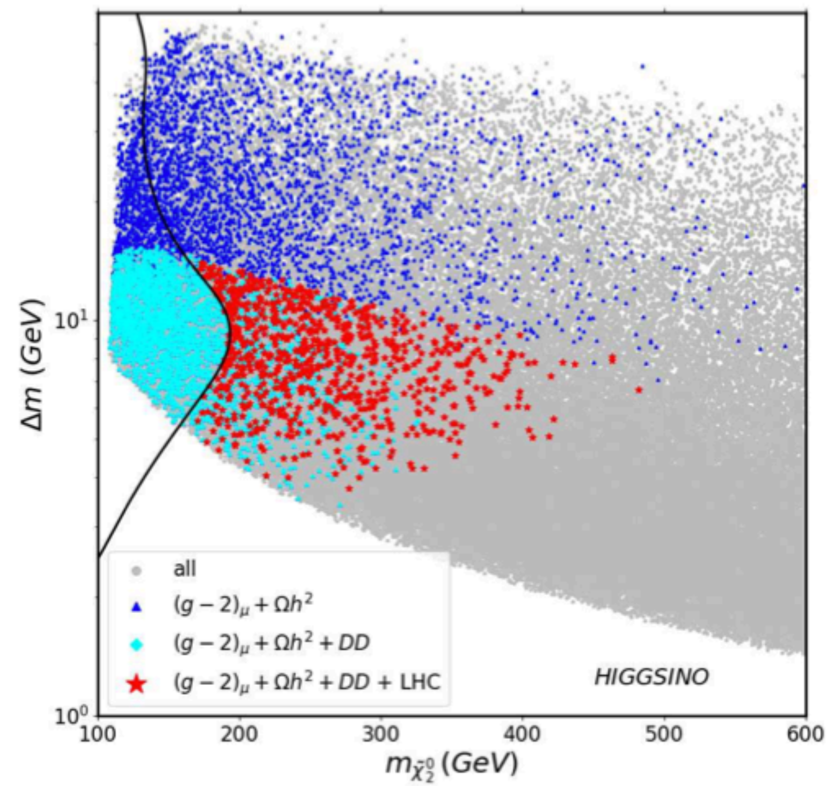
The LHC limit is based on $\tilde{\ell} \rightarrow \tilde{\chi}_1^0 \ell$, but here $\tilde{\ell} \rightarrow \nu \tilde{\chi}_1^{\pm} \rightarrow \nu \ell \nu \tilde{\chi}_1^0$ is relevant (and in this case ℓ is very soft).

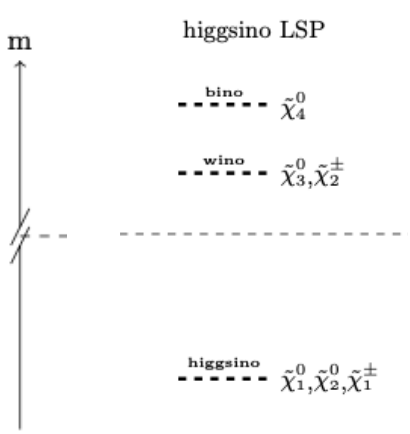




Example 2 - Nearly degenerate states

- A class of models **fixing muon g-2** and satisfying **dark matter constraints**.
- Dark matter could be composed by the **lightest neutral Higgsino state**.
- Is this excluded by the LHC?

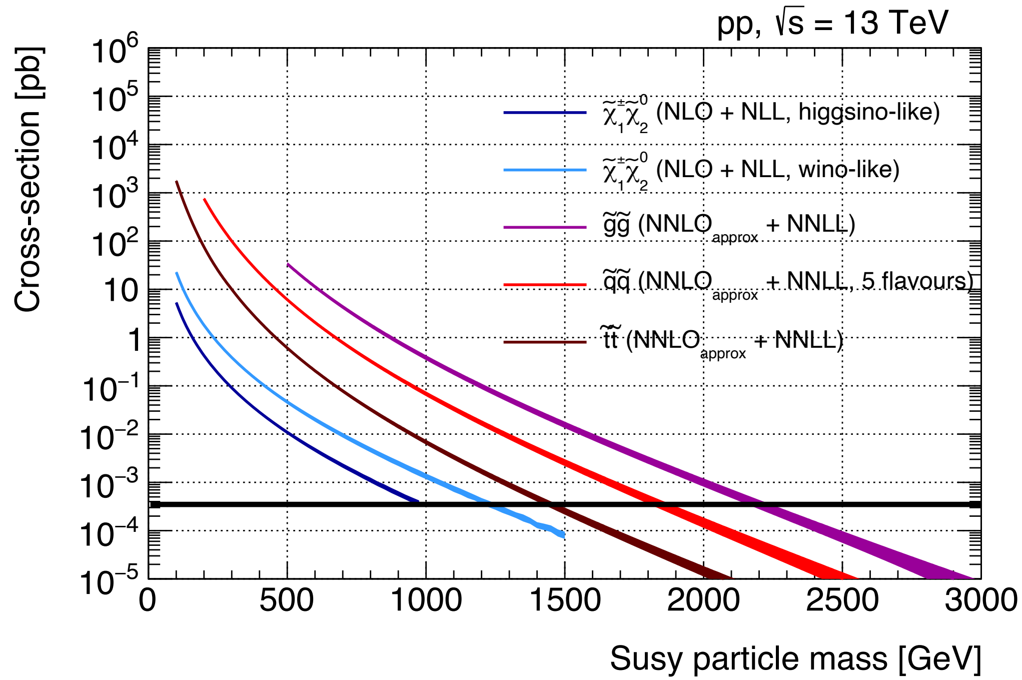




LHC simplified models map directly into this phase space

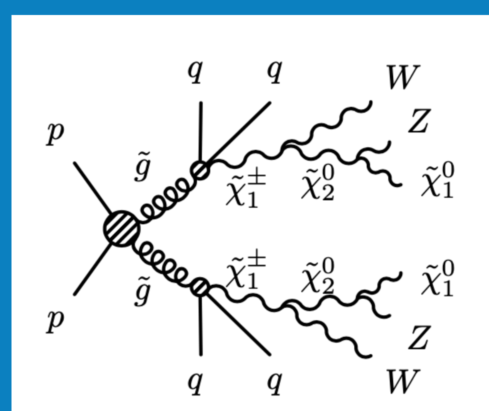
Production and decay

- Simplified model **production cross sections** determined by Standard Model physics (for a 2HDM model) + mixing.
- Thumb rule for sensitivity (works well for simple scenarios): ~ 50 events are enough for discovery.

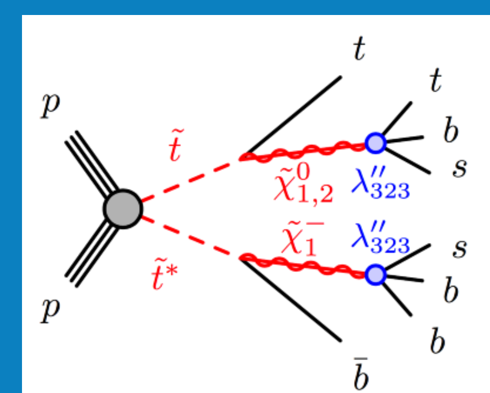


Example decay - R-parity conserving gluino decay.

Signature: $p_{\mathrm{T}}^{\mathrm{miss}}$ + stuff



Example decay - R-parity violating stop decay. Signature: depends on the topology



The electroweak sector

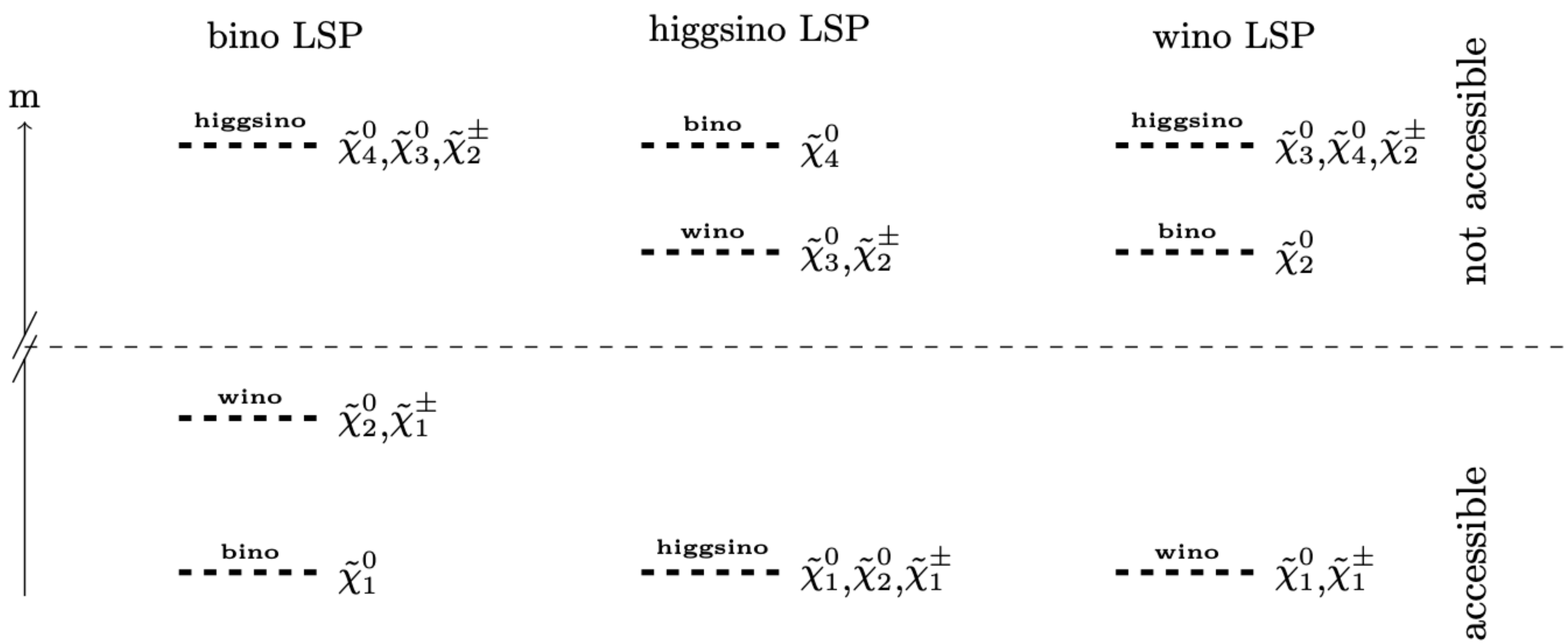
- The mass hierarchy and couplings of the neutralinos and charginos depend on the mixture in terms of the superpartners of the **standard model B and W fields**, and of the **two Higgs doublets**. The mixing matrices are

$$M_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & \text{SMALL-ISH} & \\ 0 & M_2 & \text{STUFF} & \\ \text{SMALL-ISH} & & 0 & \mu \\ \text{STUFF} & & \mu & 0 \end{pmatrix} \qquad \begin{pmatrix} \tilde{\chi}_1^0 \\ \tilde{\chi}_2^0 \\ \tilde{\chi}_3^0 \\ \tilde{\chi}_4^0 \end{pmatrix} = M_{\tilde{N}} \begin{pmatrix} \tilde{B} \\ \tilde{W}^0 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix}$$

$$M_{\tilde{C}} = \begin{pmatrix} M_2 & \text{SMALL-ISH STUFF} \\ \text{SMALL-ISH STUFF} & \mu \end{pmatrix} \qquad \begin{pmatrix} \tilde{\chi}_1^\pm \\ \tilde{\chi}_2^\pm \end{pmatrix} = M_{\tilde{C}} \begin{pmatrix} \tilde{W} \\ \tilde{H} \end{pmatrix}$$

The electroweak sector

$M_1 < M_2 \ll \mu$ $\mu \ll M_1, M_2$ $M_2 \ll \mu, M_1$



…or gravitino LSP (in which case the phenomenology is determined by the NLSP)

mSUGRA/ CMSSM, dark matter density typically too high

Natural scenarios, dark matter density typically too low

AMSB-like scenarios, dark matter density typically too low

GGM-like scenarios, dark matter difficult to get right.

Why so many SUSY searches?

- Each of ATLAS and CMS has tens of different SUSY searches performed.

$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

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

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

GGM/GMSB

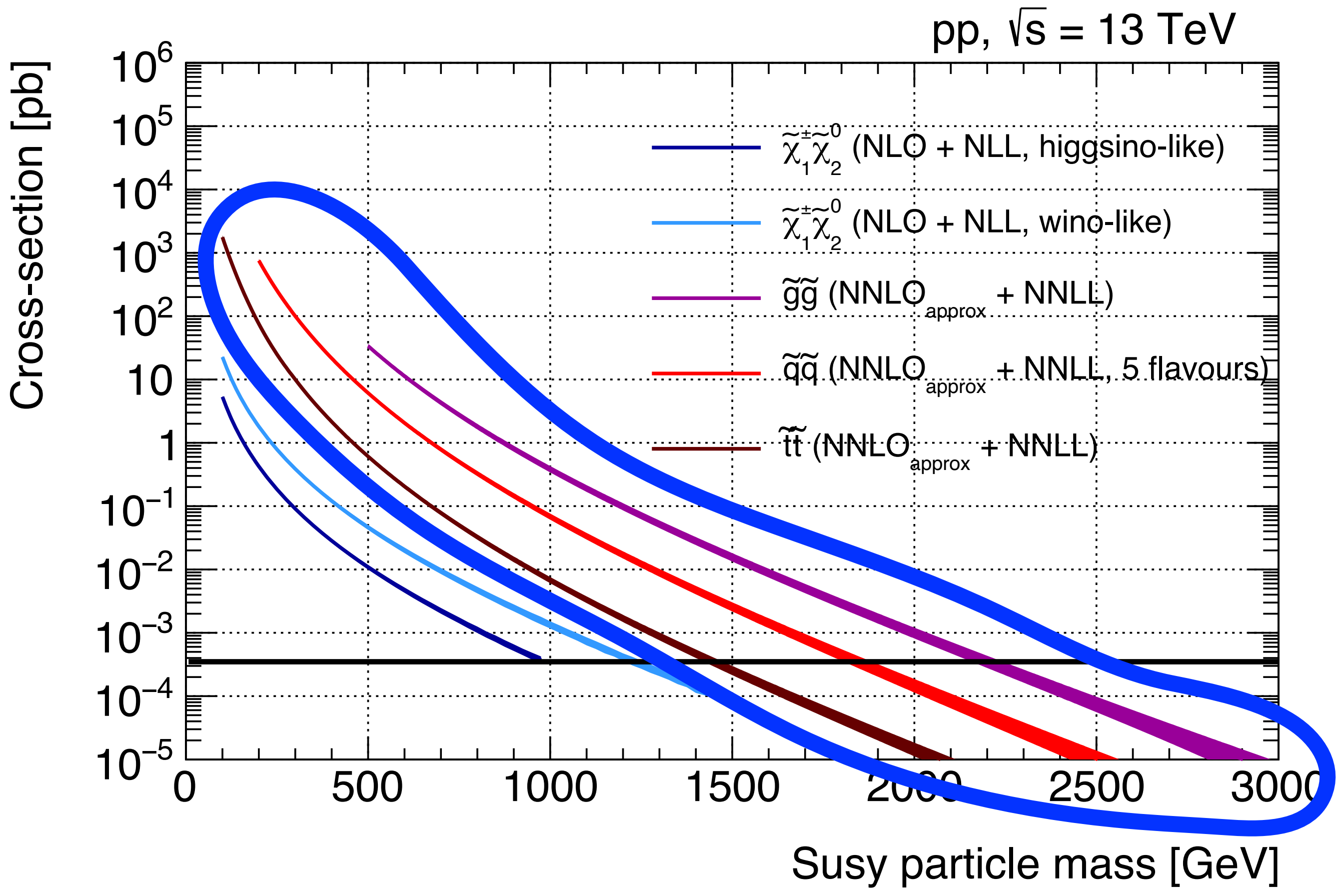
$\otimes$

RPC

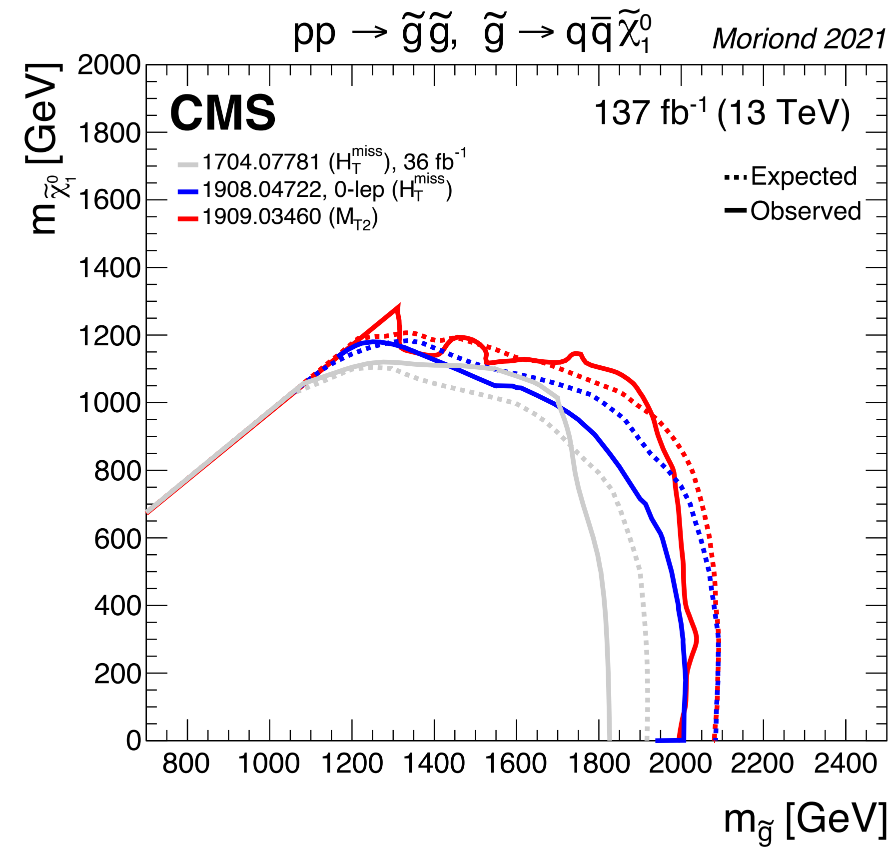
RPV

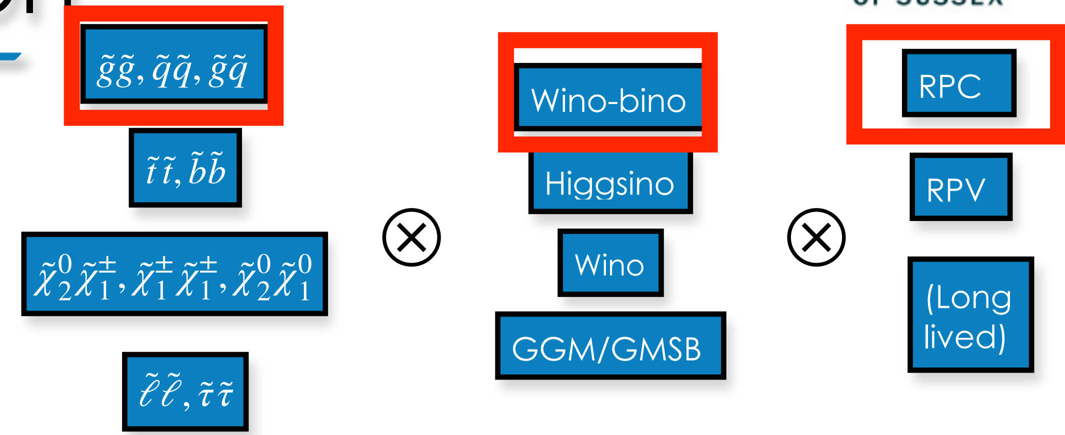
(Long lived)

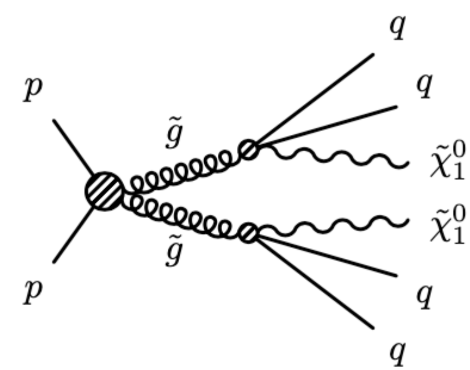
Strong production



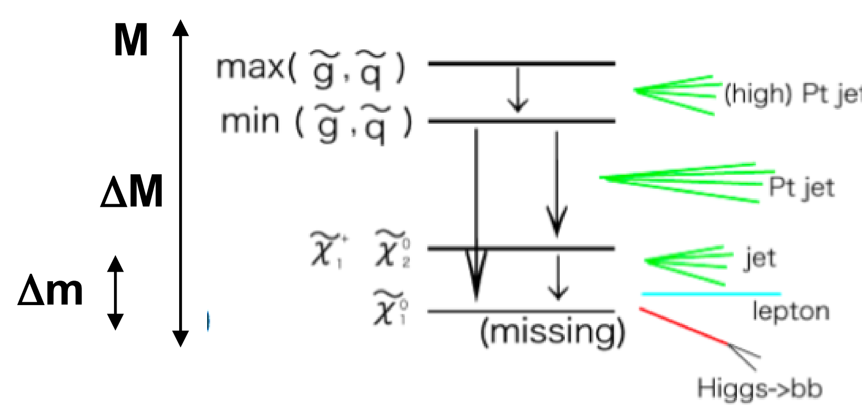
Gluino pair-production



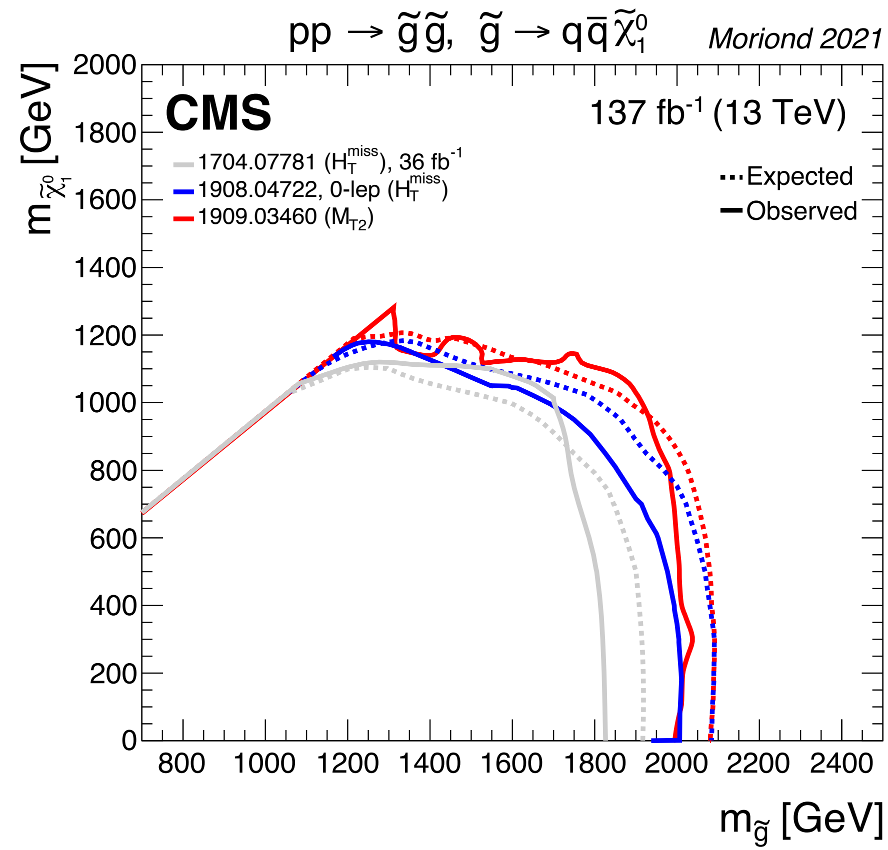


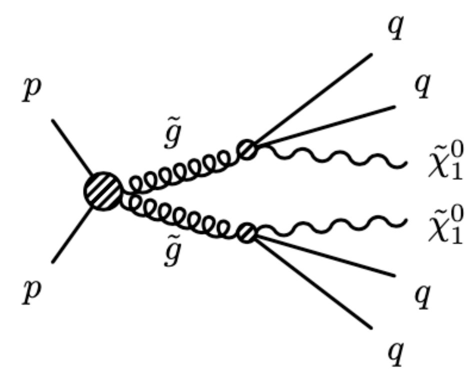


RPC simplified model inspired by a bino-like EW sector. It assumes squarks are too heavy to be relevant, and only a bino state in the EW sector.



Gluino pair-production





Signature:

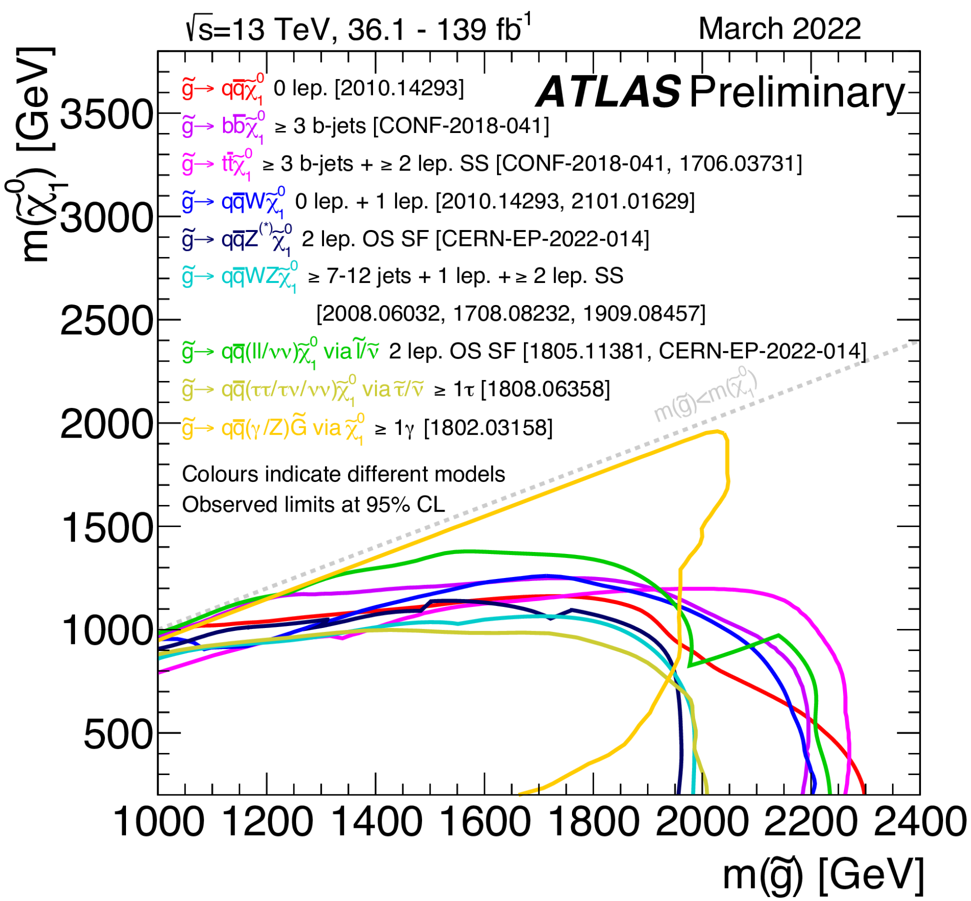
- jets
- missing transverse momentum

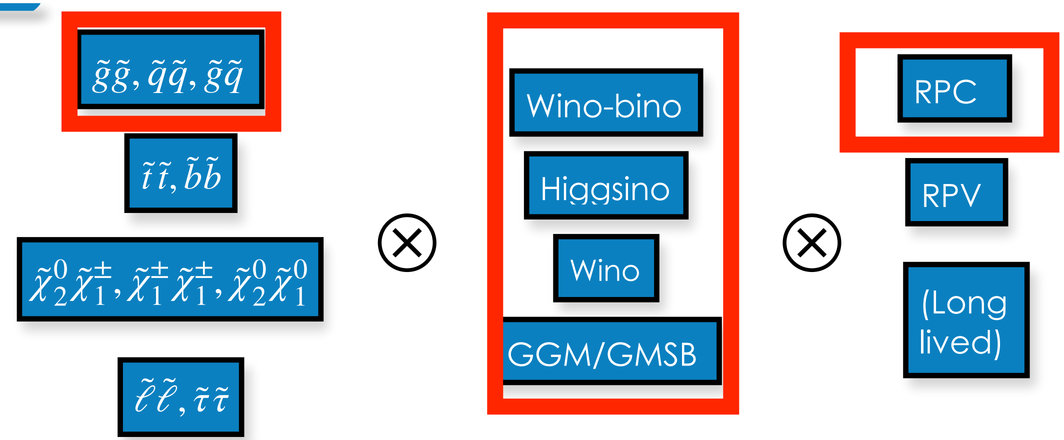
Main background processes:

- $Z \rightarrow \nu\nu + jets$
- $W \rightarrow \ell\nu + jets, t\bar{t} \rightarrow \ell\nu + jets$ where the lepton is lost or is a τ_{had}
- Multijet (but it is typically very well suppressed)

- For example, the blue line is obtained by a 0-lepton analysis categorising events based on: $H_T = \sum p_T^{jets}, H_T^{miss}, N_{jets}, N_b$

Gluino pair-production





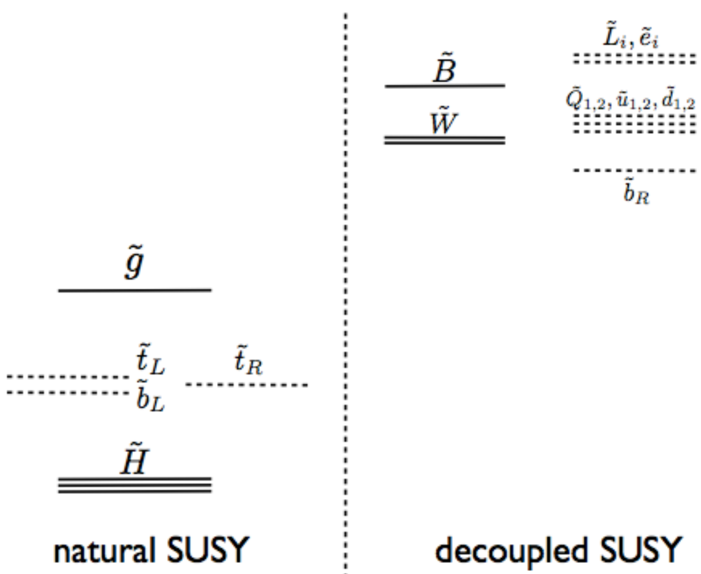
- This plot includes many different scenarios - each with 100% branching ratio.
- $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0, \tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ relevant for naturalness.
- $\tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0, \tilde{g} \rightarrow q\bar{q}Z\tilde{\chi}_1^0$ are an example of electroweak sector with a wino-bino electroweak sector.
- Etc…

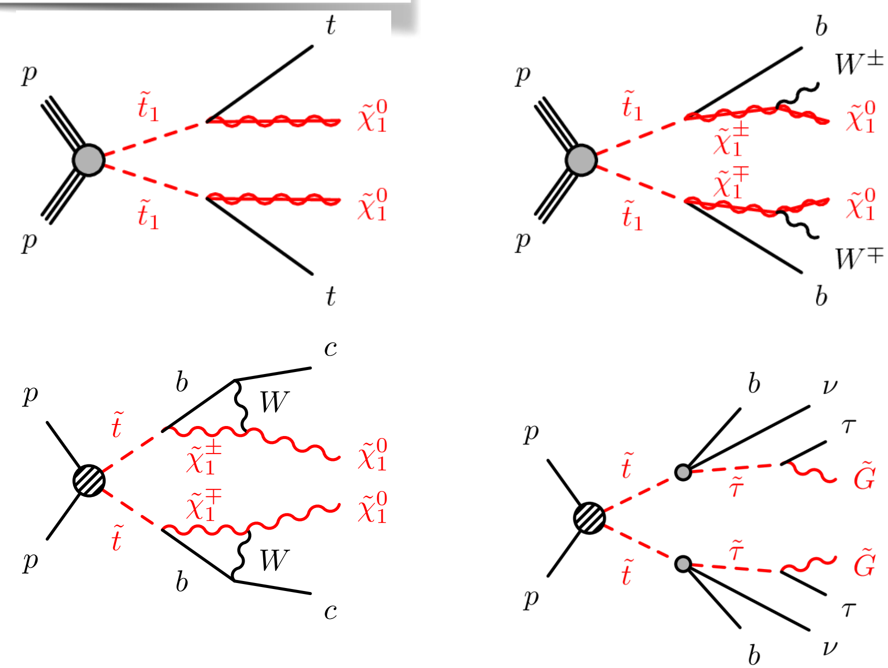
- Some dependence on the exclusion power on the topology.
- The combination of the analyses gives a nice overall exclusion

Naturalness wants light stops

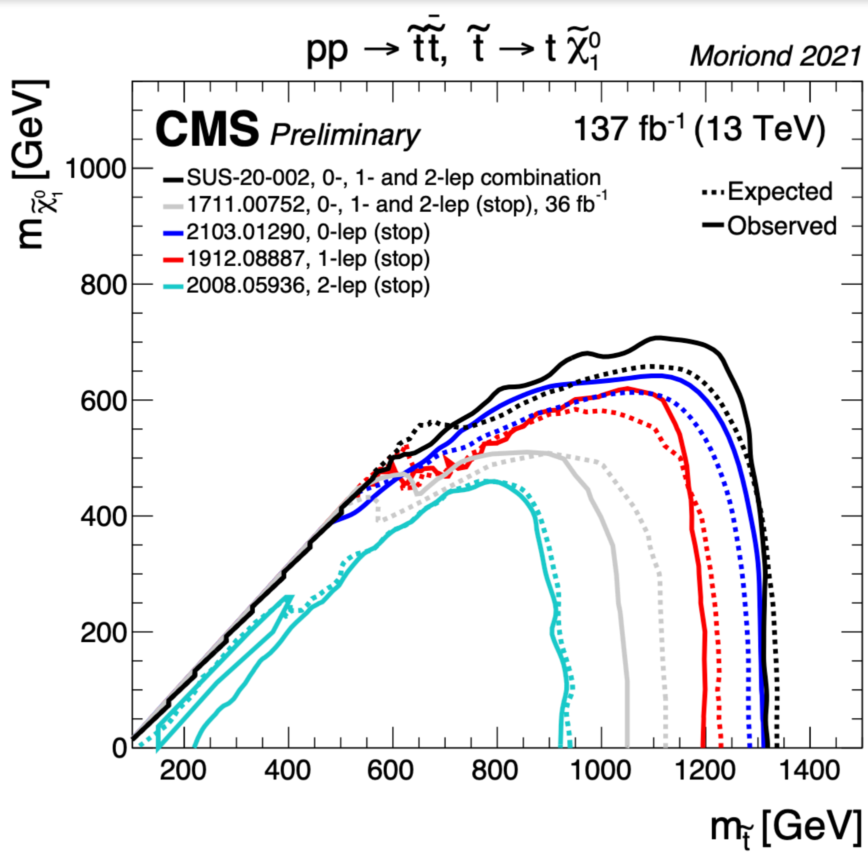
- The naturalness of the Higgs boson mass requires:
  - A **Higgsino mass** of maximum few hundred GeV.
  - A **top partner** mass at the TeV scale.
  - A **gluino mass** of maximum few TeV.

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3y_t^2 m_t^2}{4\pi^2}\left[\log\left(\frac{m_S^2}{m_t^2}\right) + X_t^2\left(1 - \frac{X_t^2}{12}\right)\right] + \cdots$$





Naturalness wants light stops



$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

$\tilde{\chi}^0_2\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1, \tilde{\chi}^0_2\tilde{\chi}^0_1$

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

GGM/GMSB

$\otimes$

RPC

RPV

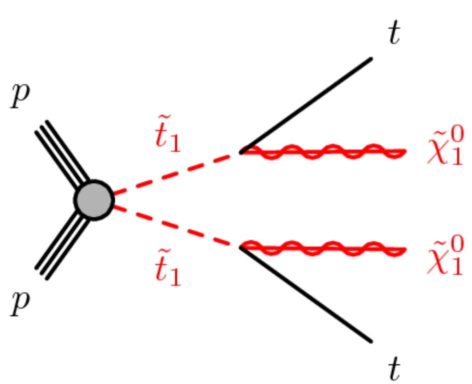
(Long lived)

Signature:

- jets
- B-jets
- Top quarks (possibly boosted)
- missing transverse momentum
- Possibly leptons
- Etc…

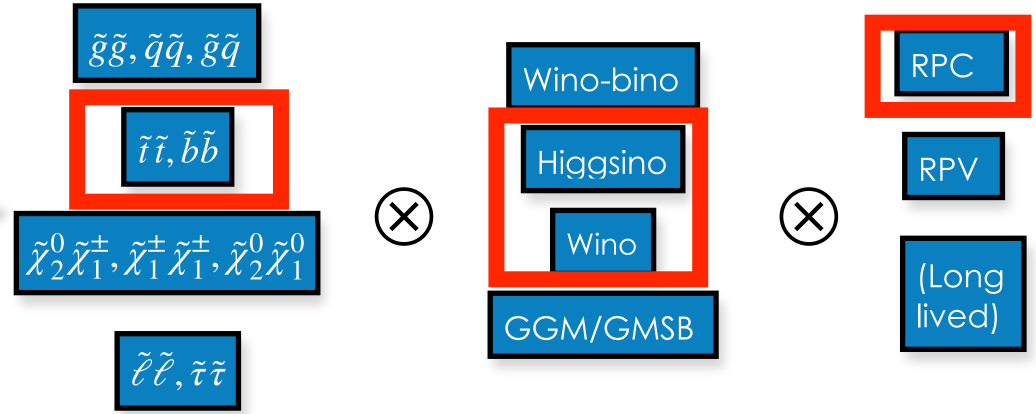
Main background processes:

- $t\bar{t}, t\bar{t}V$
- $W + \text{heavy flavours}, Z + HF$
- Multiboson production



- The bino scenario.
- Different regions in the plane characterised by hierarchy between $\tilde{t}_1, t, W$.

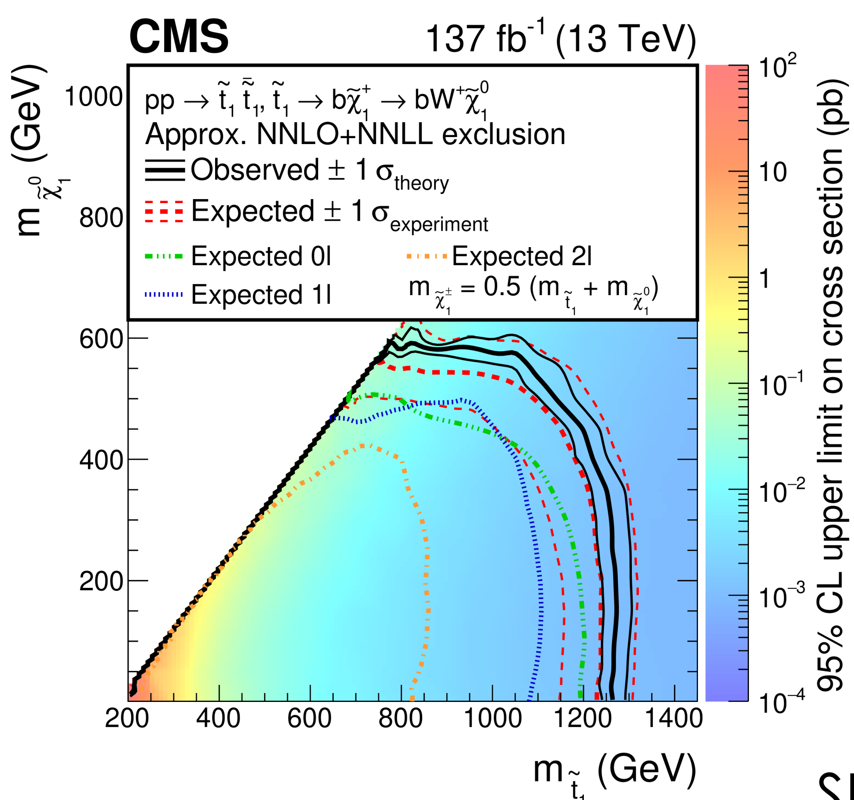
Stop constraints

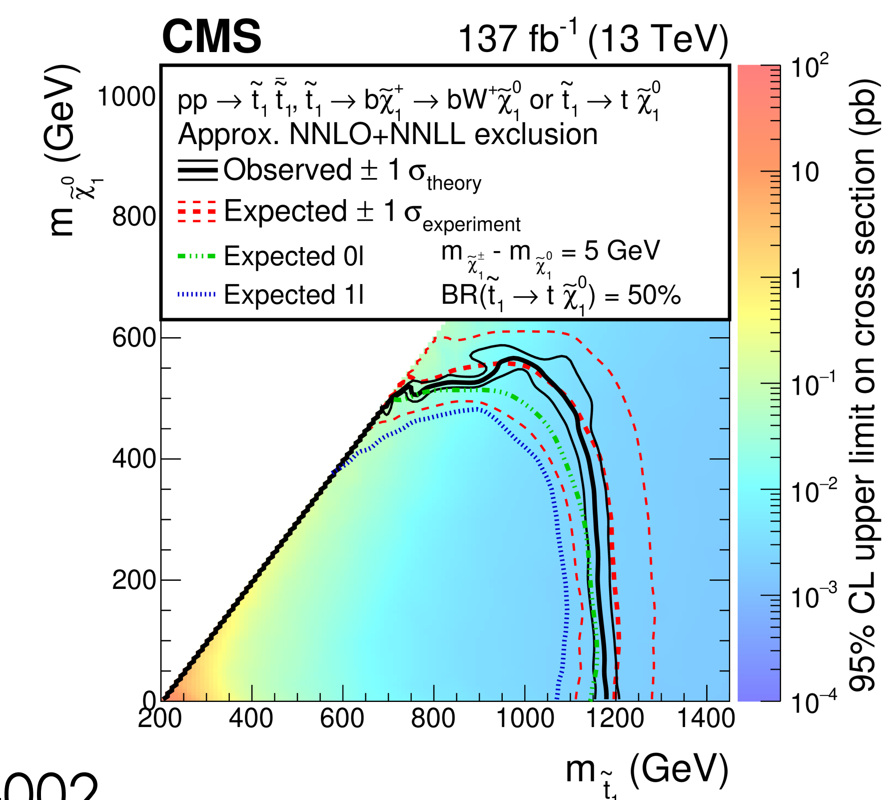


- Moving away from the bino scenario

Bino-wino scenario

With compressed EW sector (wino or higgsino)





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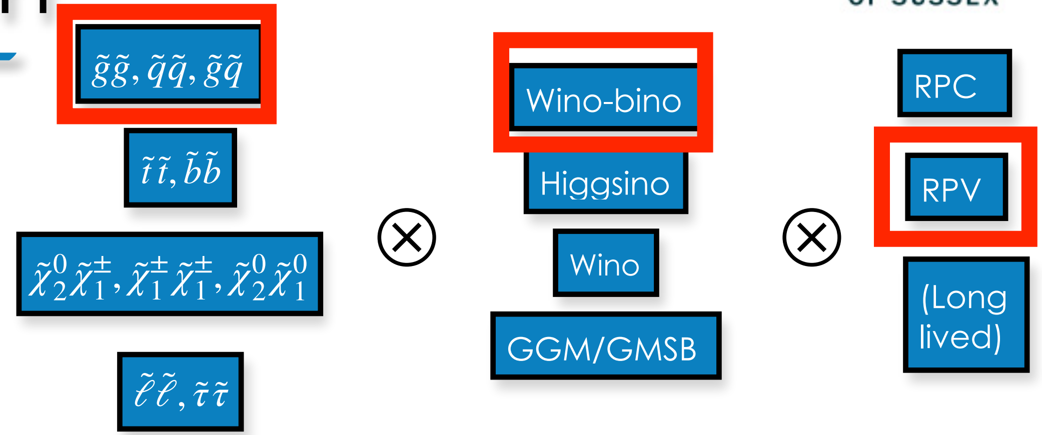
RPV strong production

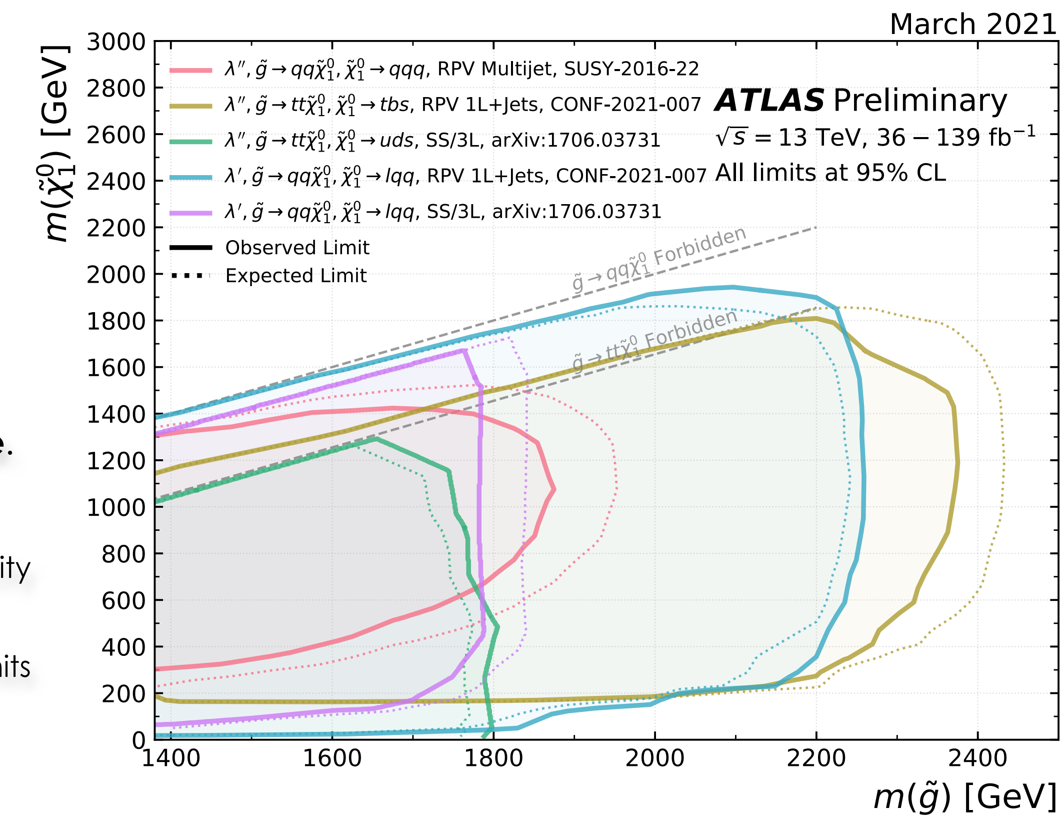


Signature:

- Jets (and leptons depending on which RPV coupling is on)
- Possibly b-jets

Main background processes:

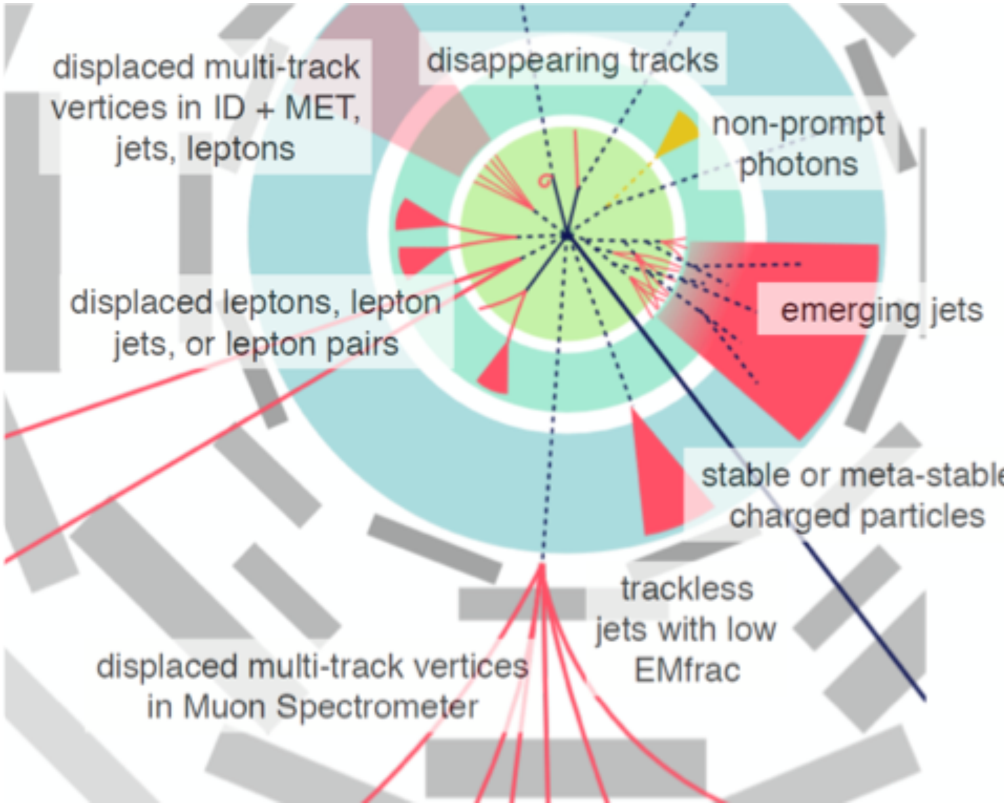
- Depends on the signature
- Typically multijet, $t\bar{t}$, $t\bar{t}bb$, etc.



- If **R-parity is not conserved**, the LSP is **not stable anymore**.
- RPV 1L + jets in the plot:
  - Data driven background estimation for high-jet multiplicity configurations of ttbar.
  - Different EW sector configurations considered, higgsino limits weaker by ~200 GeV.
- Limits are **at least on a par** with RPC scenarios.

Long-lived strong production

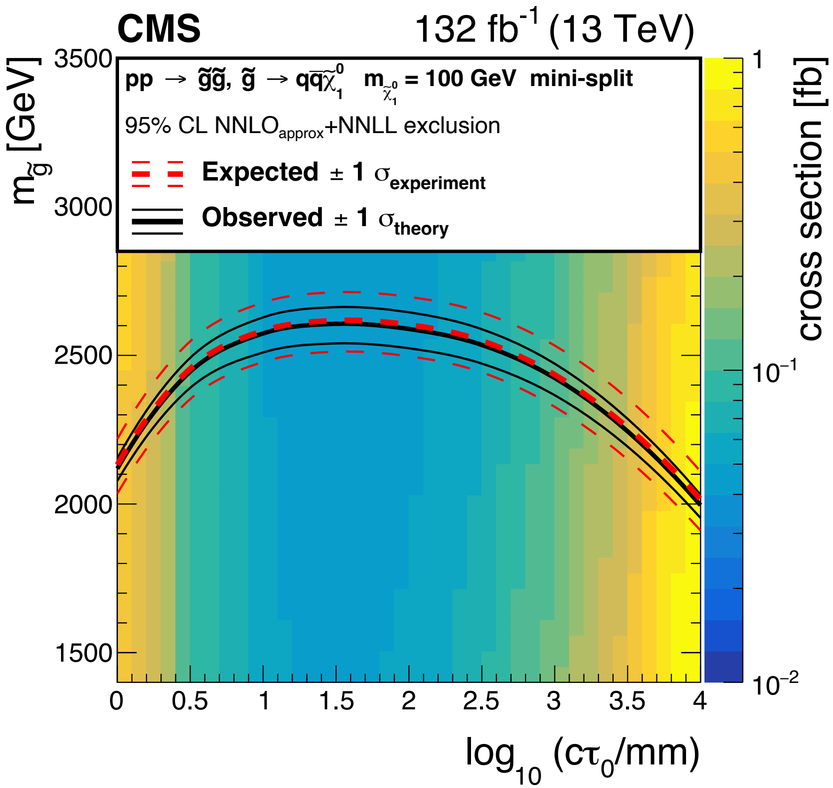
- Sparticles become long-lived if:
  - Decay **mediator largely off-shell** (for example $\tilde{g} \to \tilde{q}^* q \to qq\tilde{\chi}_1^0$, but the $\tilde{q}^*$ has very large mass - This is the split SUSY scenario).
  - **Small phase space** available in the decay (compressed states, e.g. pure wino EW sector).
  - **Small couplings** in the decay.

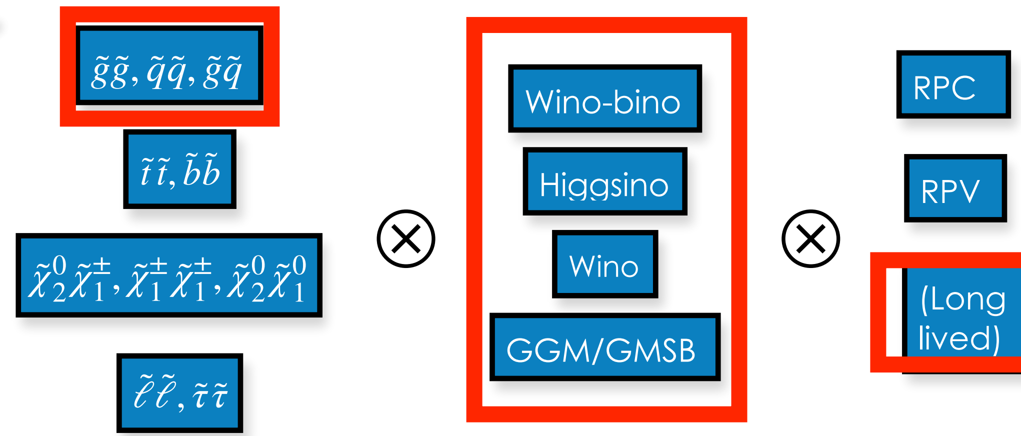


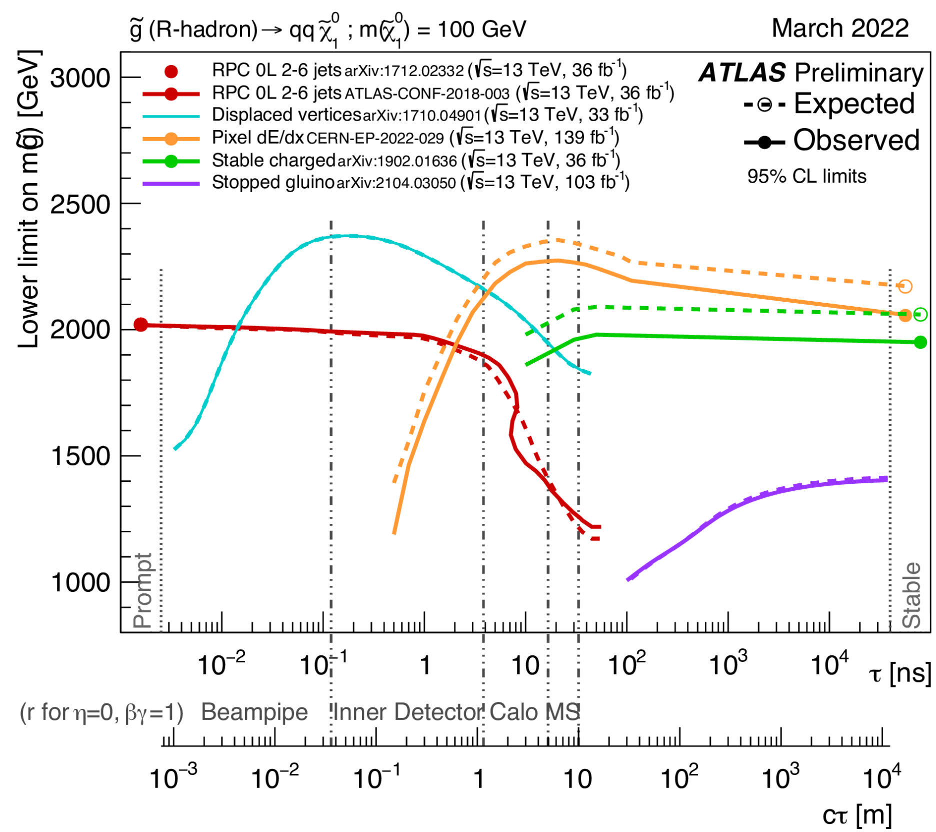
- A plethora of experimental techniques (and a lot of fun).
- Sometimes challenging for the detector configuration.
- One of the areas where the gain from run 1 has been more visible.

Long-lived strong production

EXO-19-021



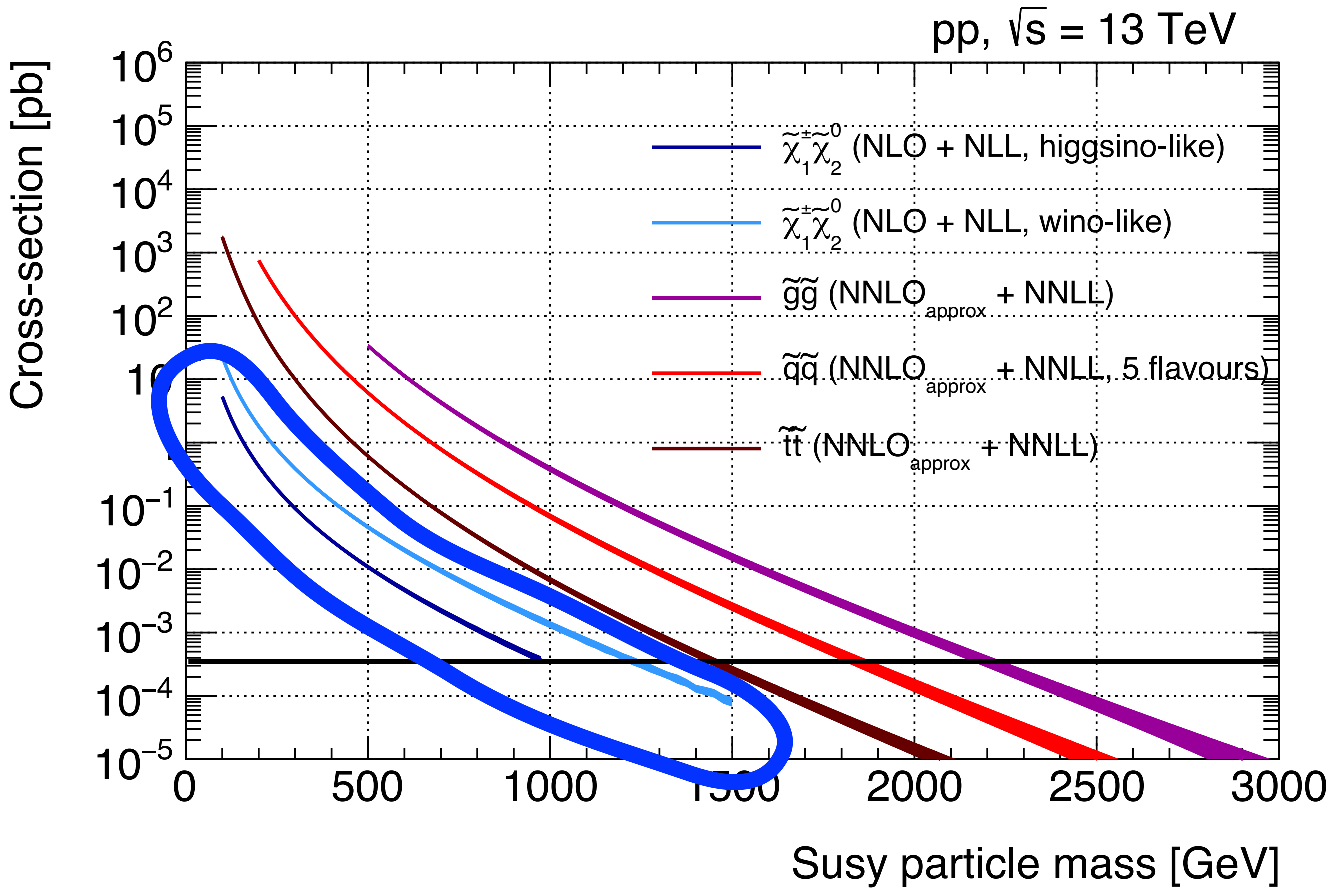




Displaced jets in CMS:
- looking at dijet events where a secondary vertex from displaced tracks can be reconstructed

Electroweak production

(Where Run 2 really made huge difference)



Electroweak production

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- The core of SUSY searches in Run 2.
- Directly probing the dark matter sector.

$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

$\tilde{\chi}_2^0\tilde{\chi}_1^\pm, \tilde{\chi}_1^\mp\tilde{\chi}_1^\pm, \tilde{\chi}_2^0\tilde{\chi}_1^0$

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

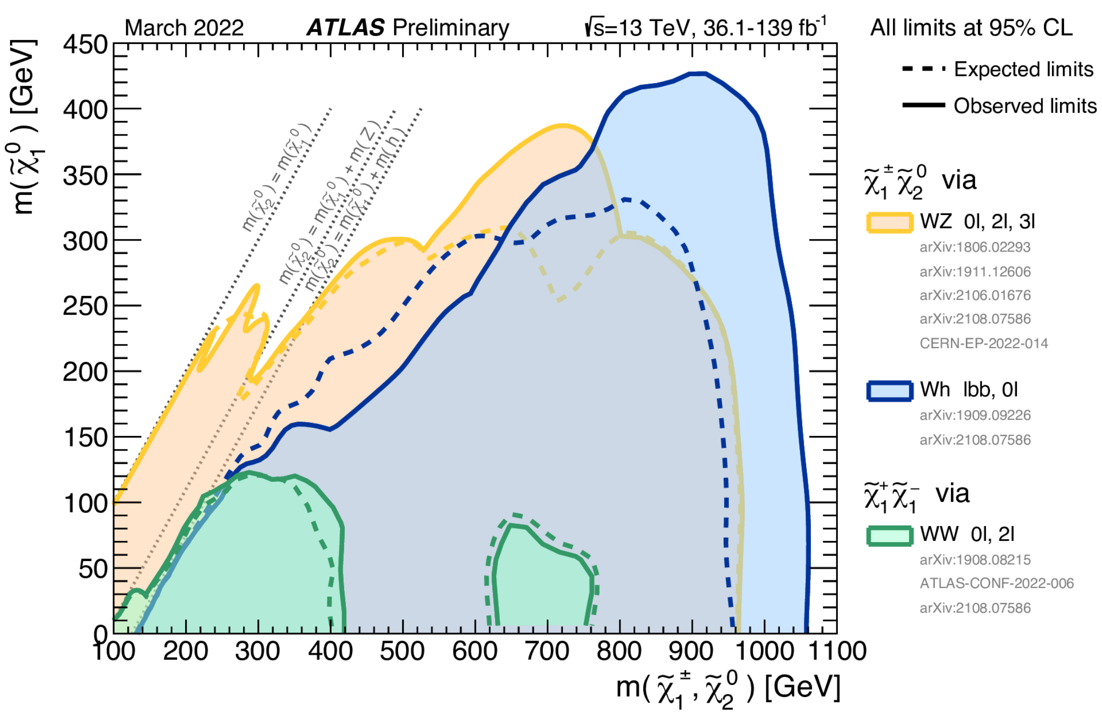
GGM/GMSB

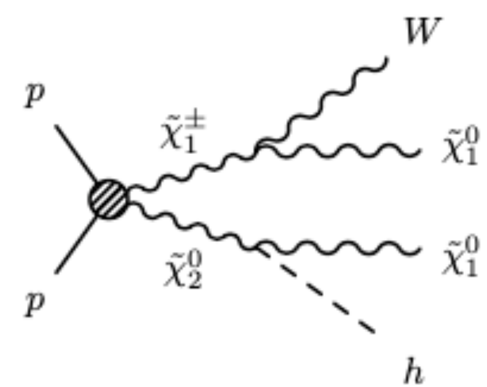
$\otimes$

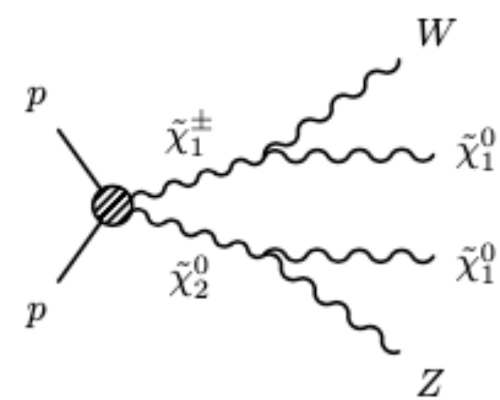
RPC

RPV

(Long lived)







Full hadronic final states

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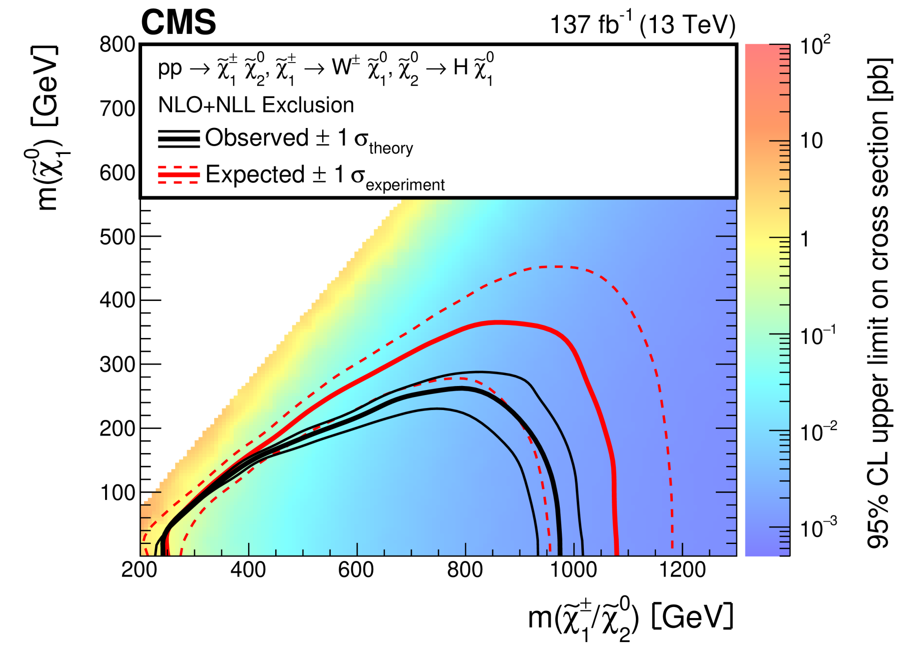
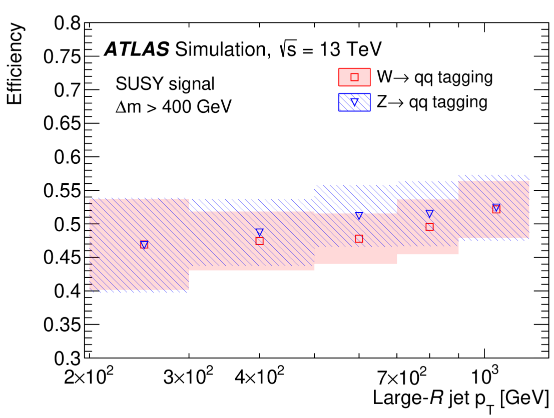
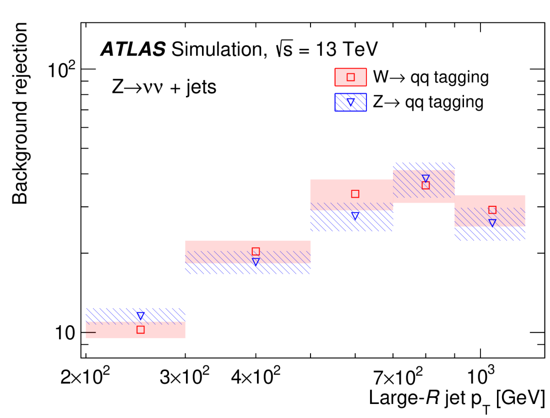
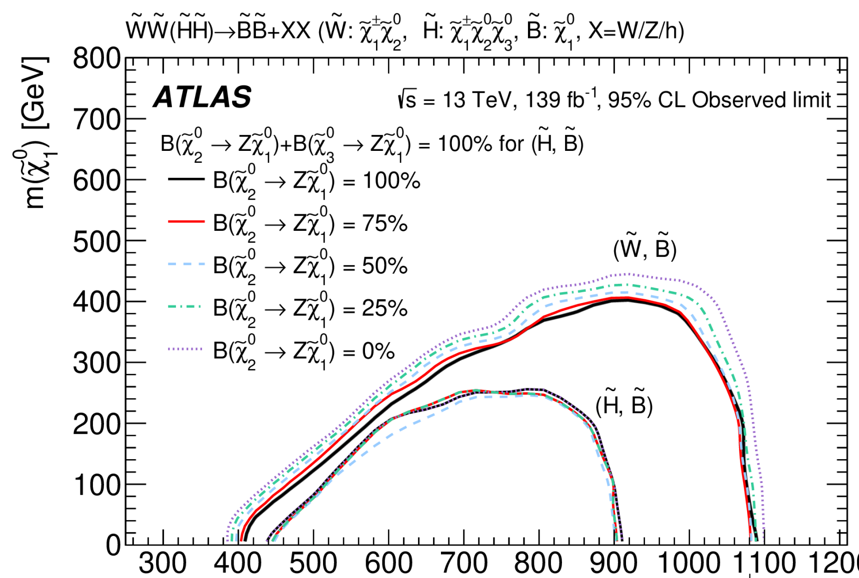
- Run 2: access to **higher boson boost** in $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm} \rightarrow X\tilde{\chi}_1^0$ (X generic boson).
- **Full hadronic final states**: heavily relying in the ability of **tagging** $W, Z \rightarrow qq$ and $h \rightarrow bb$ using **jet substructure techniques.**

SUS-21-002









SUSY-2018-41

Higgsino

$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

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

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

GGM/GMSB

$\otimes$

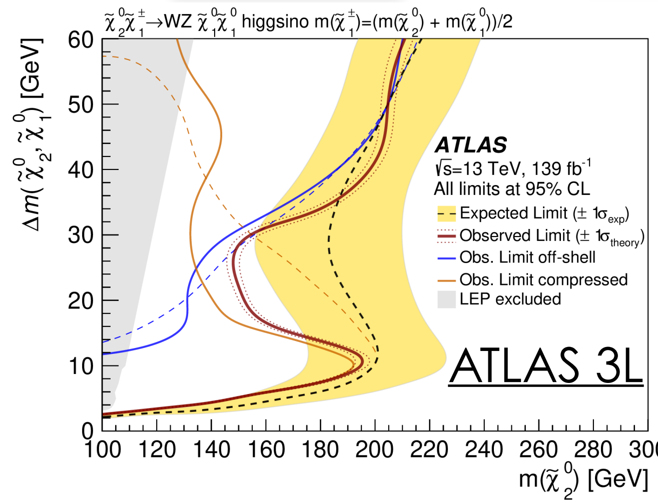
RPC

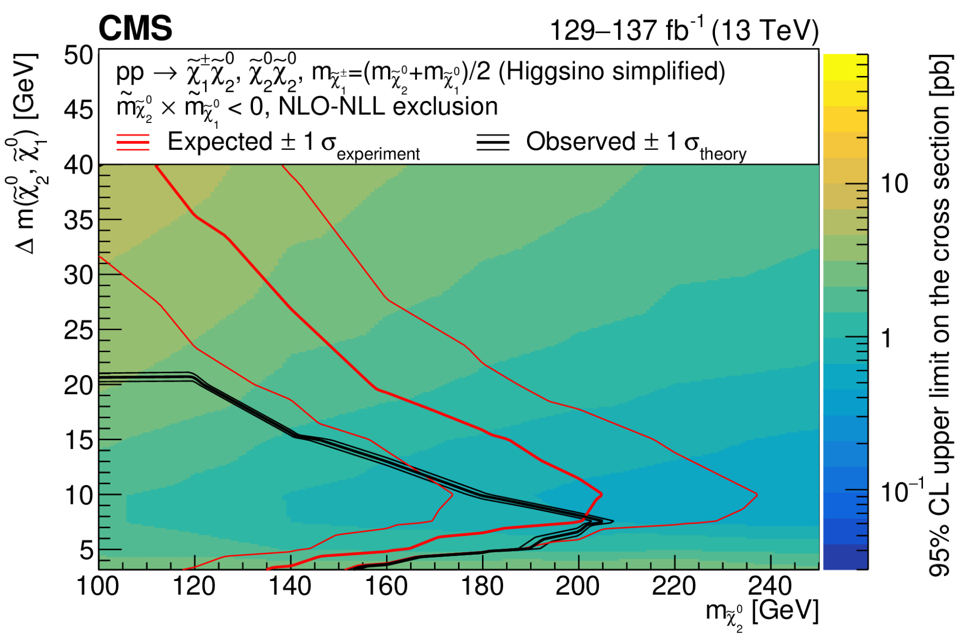
RPV

(Long lived)

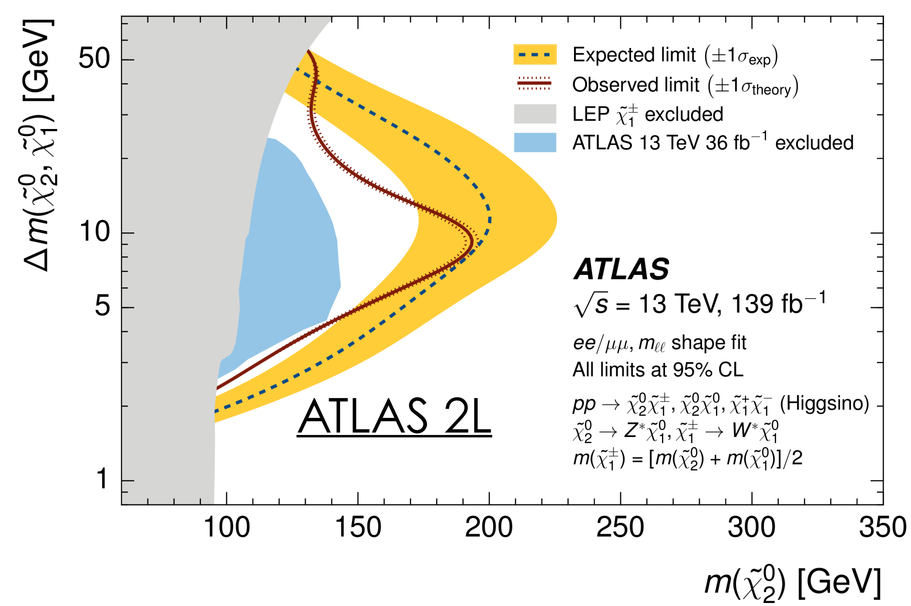
- Light Higgsinos are needed in **natural SUSY scenarios**.
- Higgsinos (maybe with a bino component) are a **good dark matter candidate**.
- Typical **mass splittings** in the Higgsino multiplet: **o(10 GeV) or less**.
- Pair produced Higgsino will decay to the lightest neutralino **emitting soft objects** (leptons).

Now the mass split (rather tahn the neutralino mass) is on the y-axis!



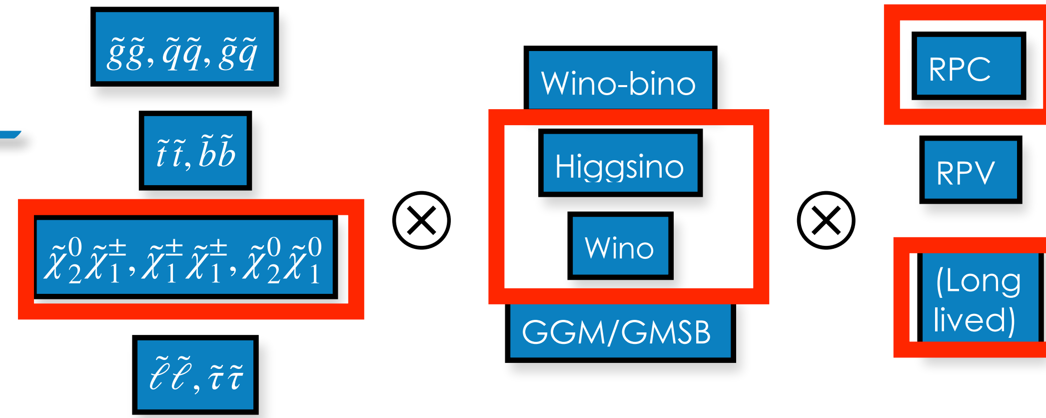


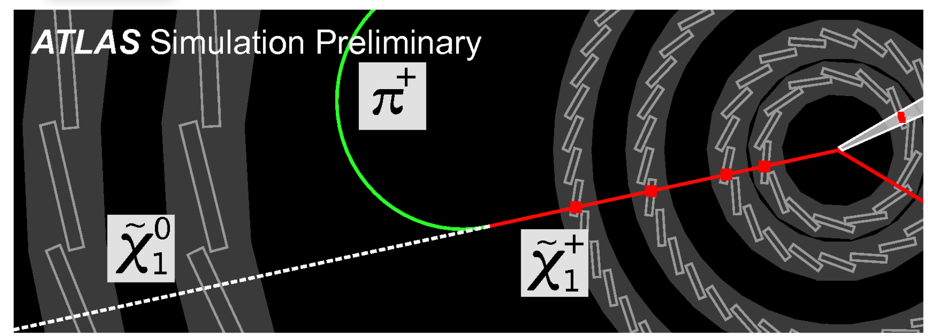
SUS-18-004

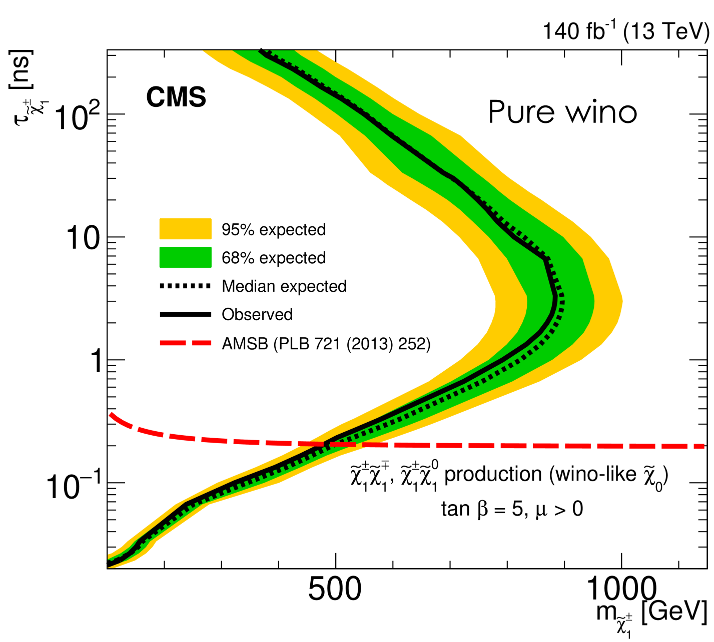


Wino

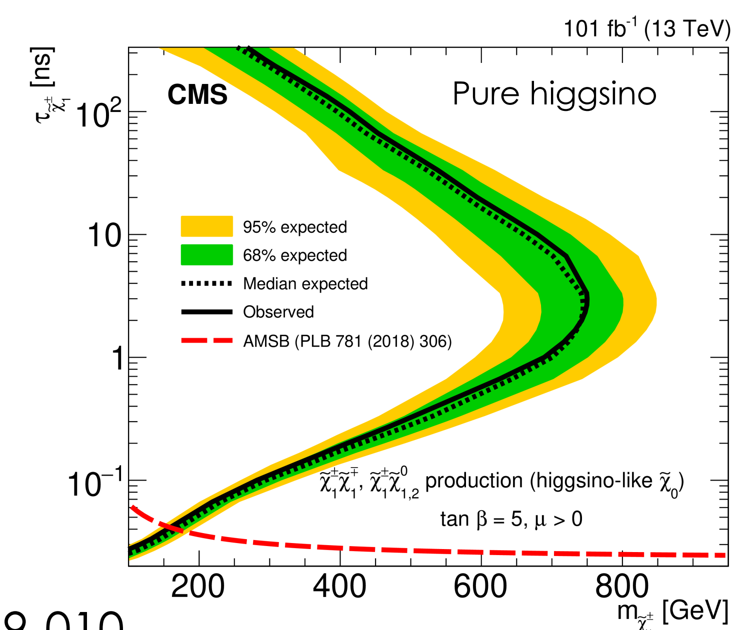
- If **Higgsino mass split very small** (300 MeV), then the chargino becomes **long-lived**.
- This is in common with the **pure Wino scenario**, where the mass plit can go down to ~160 MeV.
- Experimental signature: **disappearing track** in the detector.







EXO-19-010



Sleptons (and g-2)

$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

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

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

GGM/GMSB

$\otimes$

RPC

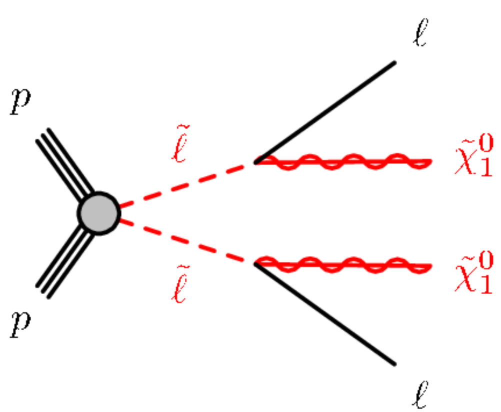
RPV

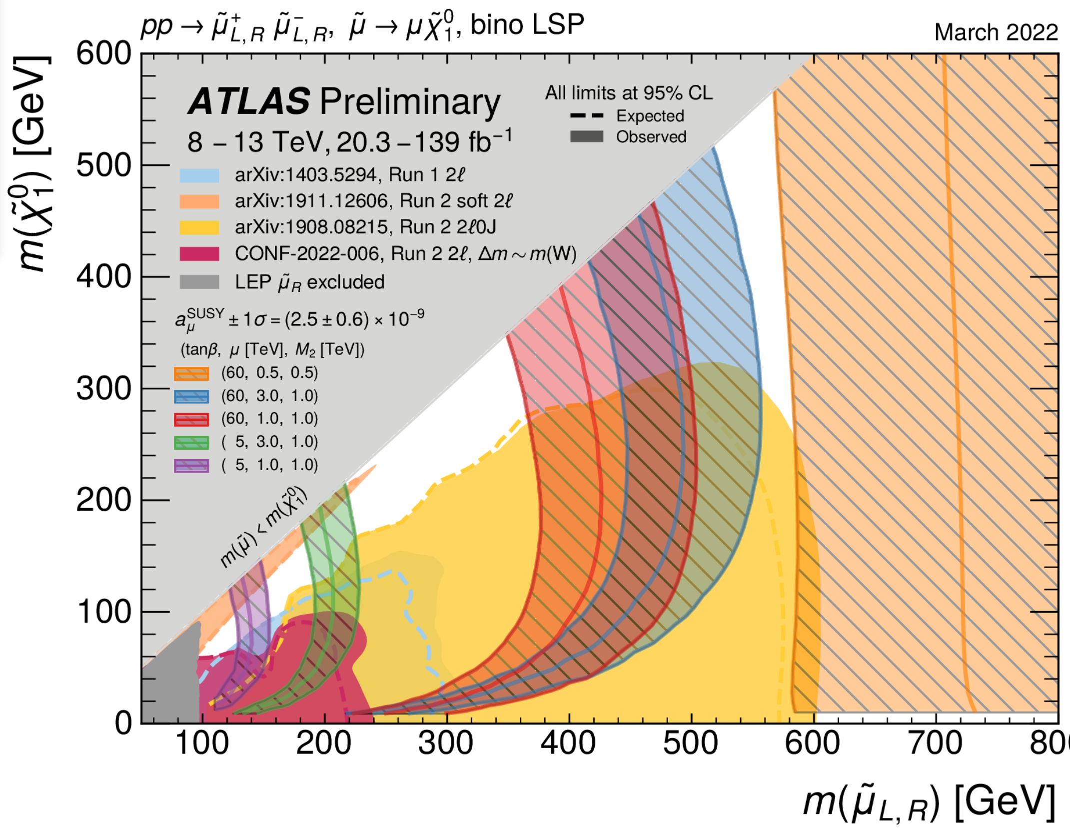
(Long lived)

Signature:
- Two opposite sign, same flavour leptons.

Main background processes:
- Di-boson production.

Results have direct impact on g-2 anomaly possible explanations.



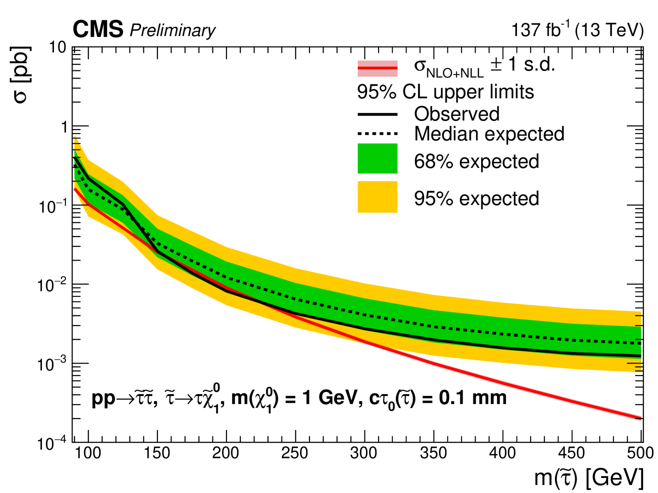


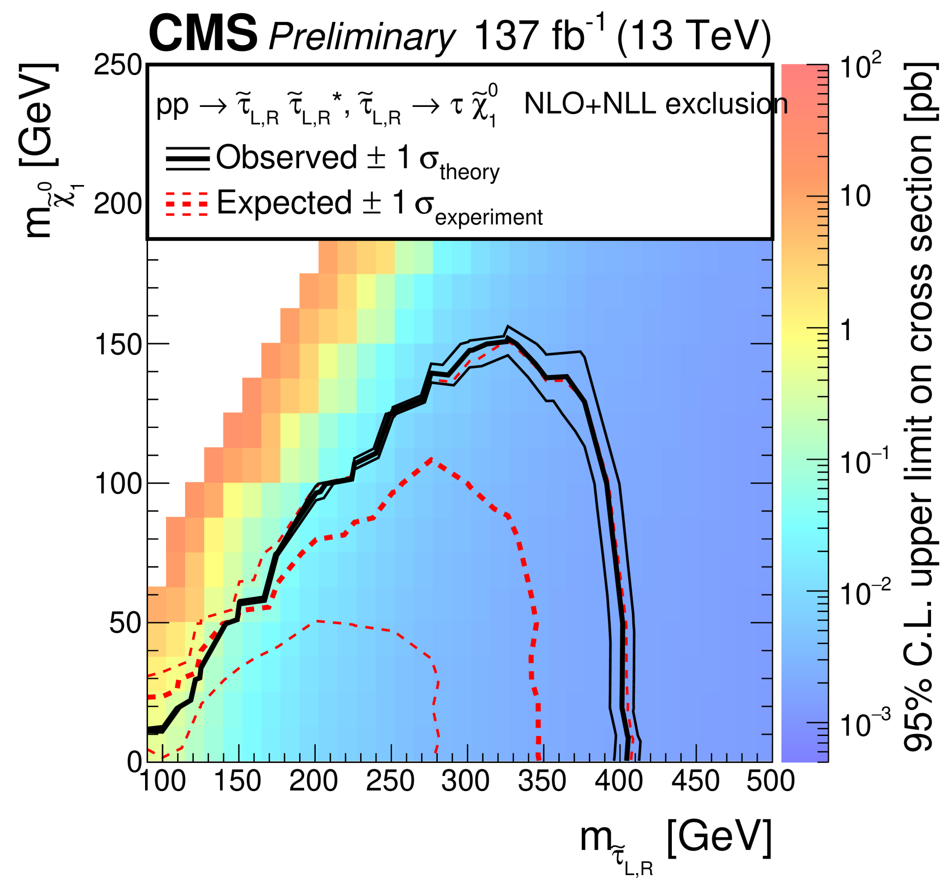
Staus

- Direct staus are of interest mainly because of their role in possible dark matter scenarios (stau co-annihilation)

Signature:
- Two tau leptons (hh and hl final states of interest).
- Possibly displaced taus.

Main background processes:
- Fake taus, $Z \to \tau\tau$.

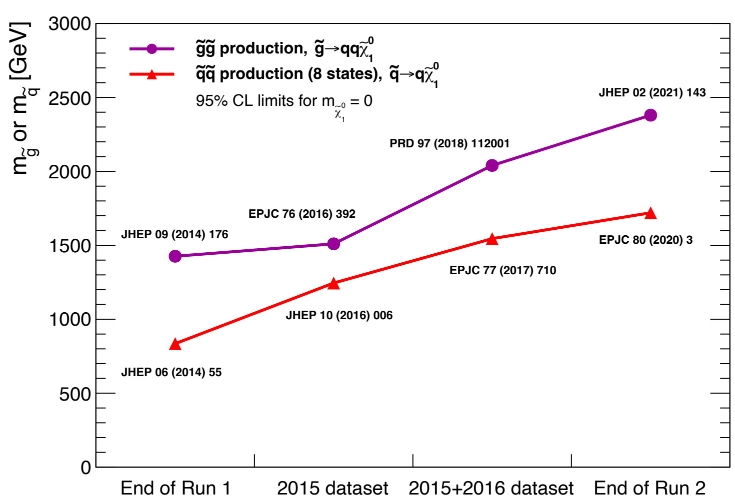


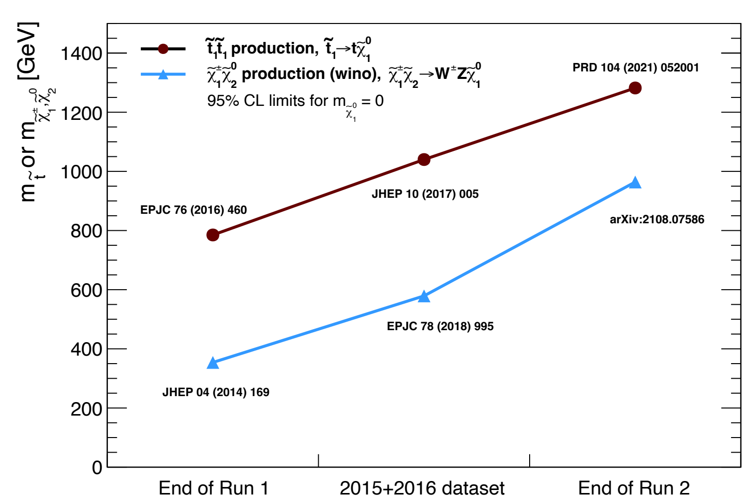


SUS-18-006

Wrapping up

	Pre-LHC	Post-LHC
"Losanne 1984" SUSY	Simple realisations of SUSY (mSUGRA/CMSSM) viable.	Simple realisations of SUSY excluded.
Naturalness	Expected m(gluino) ~ m(squark) ~ m(stop) ~ hundreds of GeV.	Classical naturalness arguments need m(gluino) < few TeV, m(stop) < 1 TeV under severe stress. More modern arguments relax these constraints. However consensus on m(Higgsino) < hundreds of GeV (and not fully explored).
Dark Matter	Stop/chargino/stau cohannihilations as favourite regularisation mechanism for a bino-like DM candidate.	Bino-like dark matter strongly constrained by electroweak SUSY searches. Higgsino- and wino-like dark matter still largely allowed.
Muon g-2	Can be fully (and easily) incorporated in EW-Scale SUSY.	Can be fully (and easily) incorporated in EW-Scale SUSY (on a much restricted parameter space).



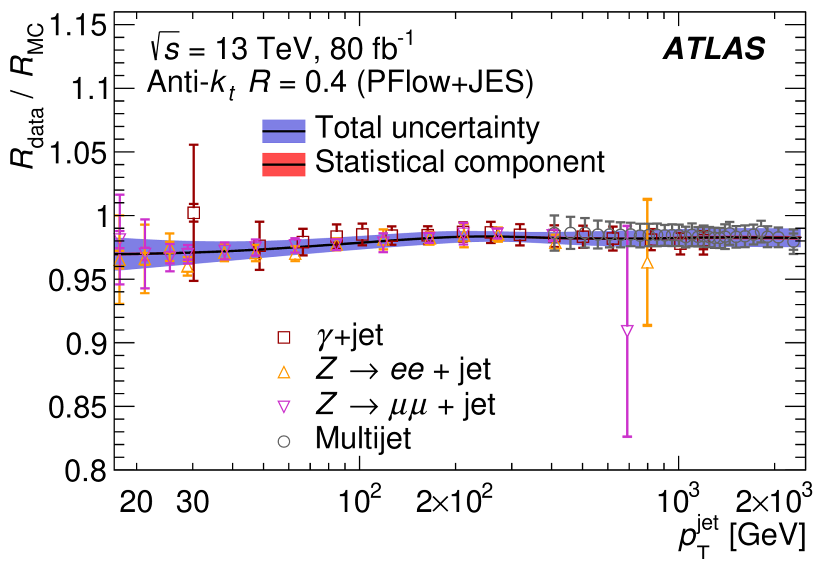


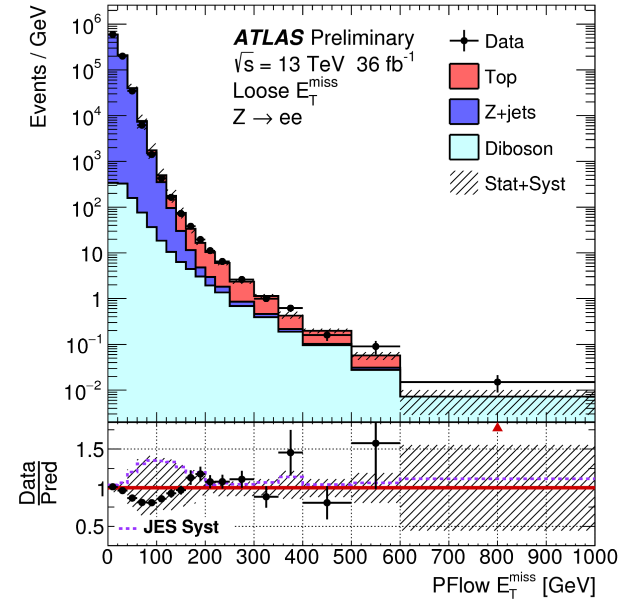
Summary

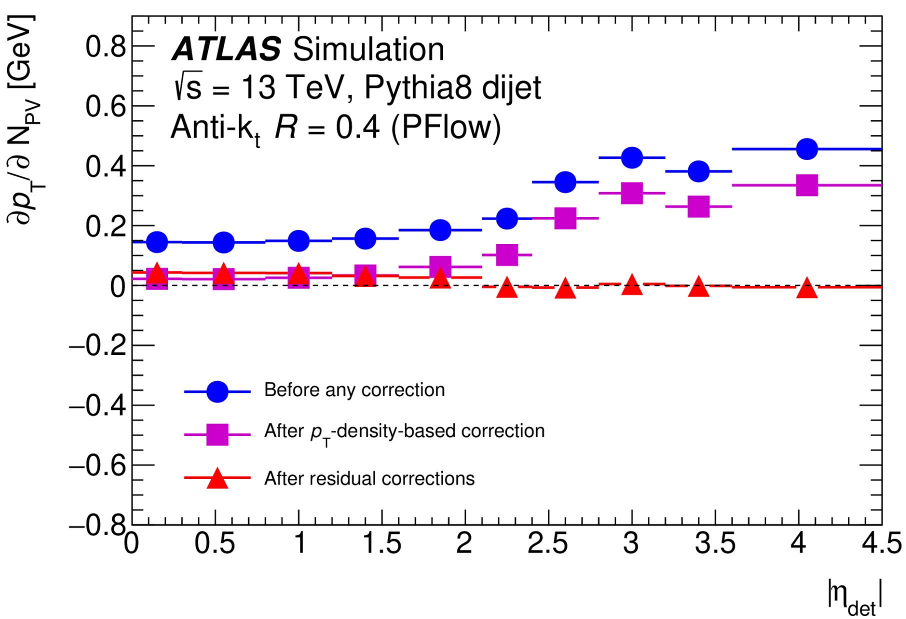
- Tried to deliver **reasons and principles** to navigate the **body of SUSY searches** from ATLAS and CMS.
  - And I highlighted some of the crucial limits.
- Full statement on the **state of the art** will be done by ATLAS and CMS with the **analyses combination and MSSM scans.**
- It is hard to identify another sector of HEP where **LHC had such a dramatic impact**.
- After 14 years of LHC (and other HEP enterprises), the questions of **naturalness and dark matter** haven't yet found an answer.
- No significant BSM excess at the LHC **may be frustrating**. At the same time, **anomalies start to appear** (not necessarily connected with SUSY) and LHC has till to collect >95% of its expected luminosity. **Exciting (but also strange) times for HEP**.

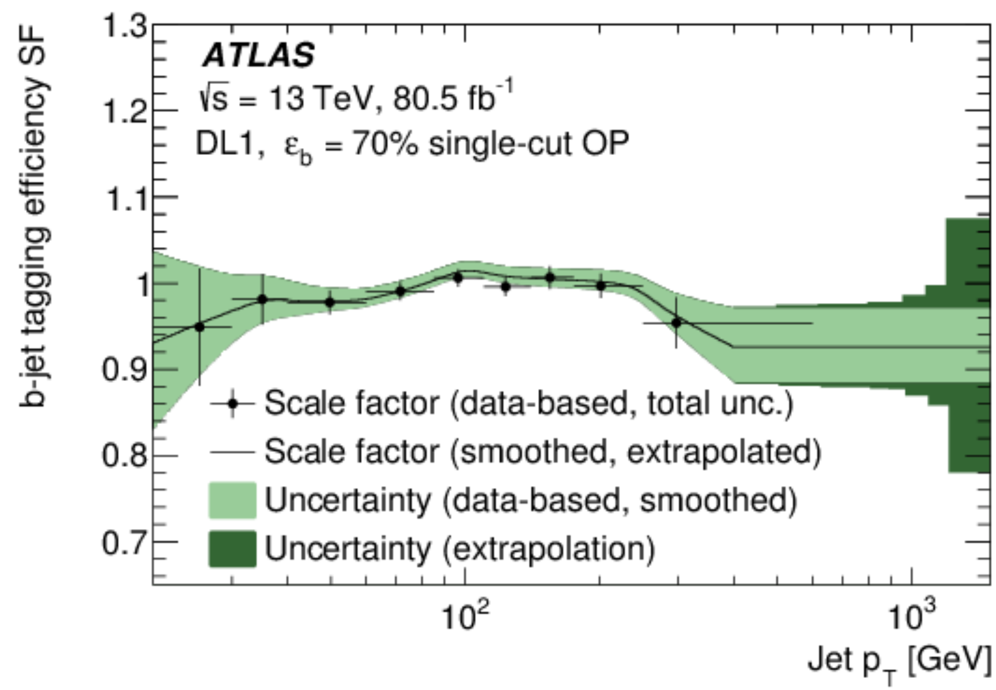
Backup

Affinare gli strumenti

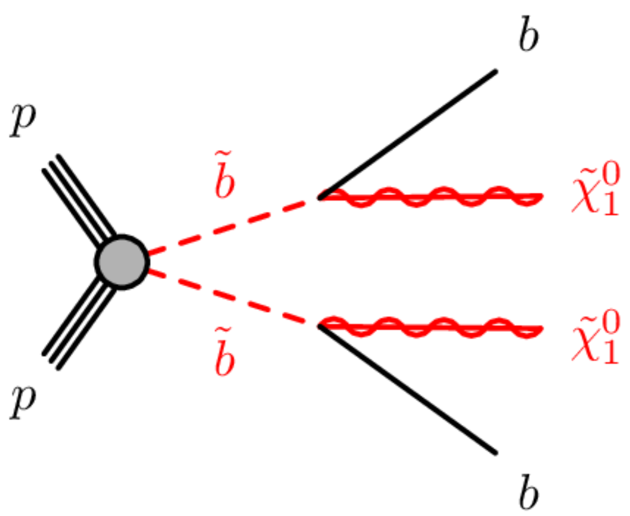


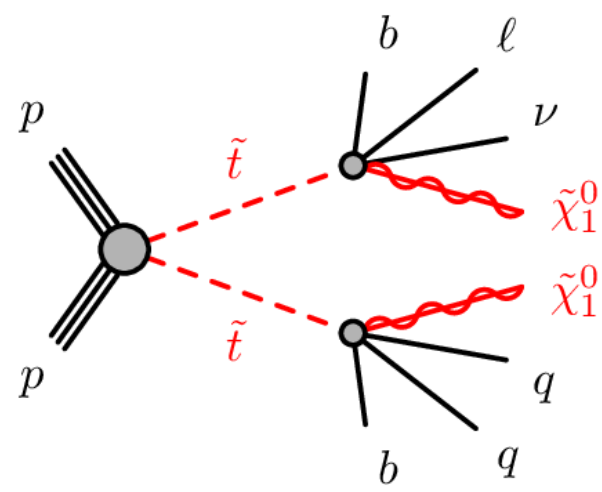


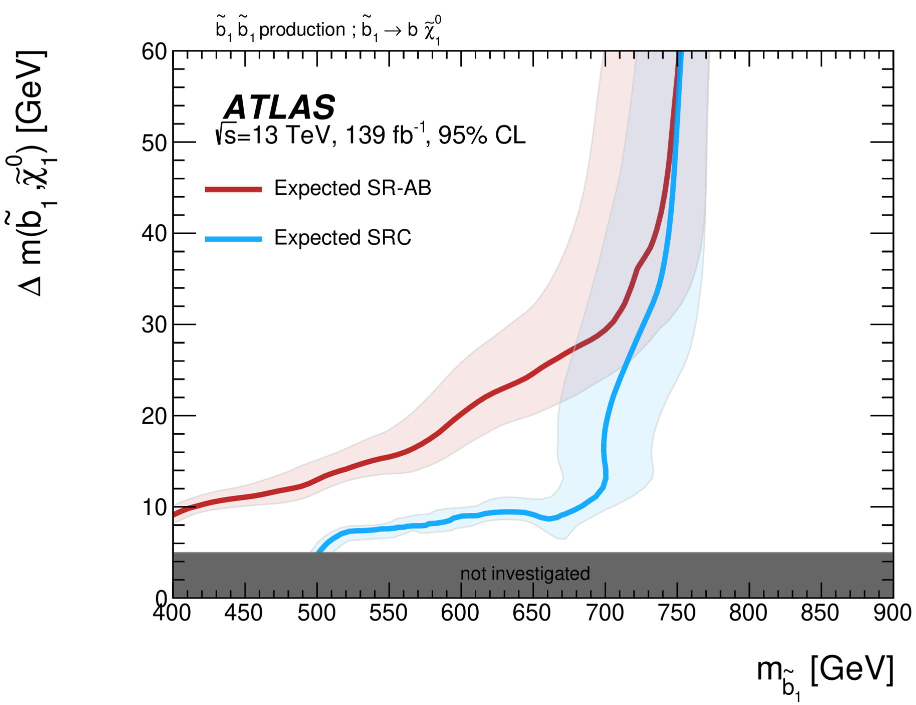


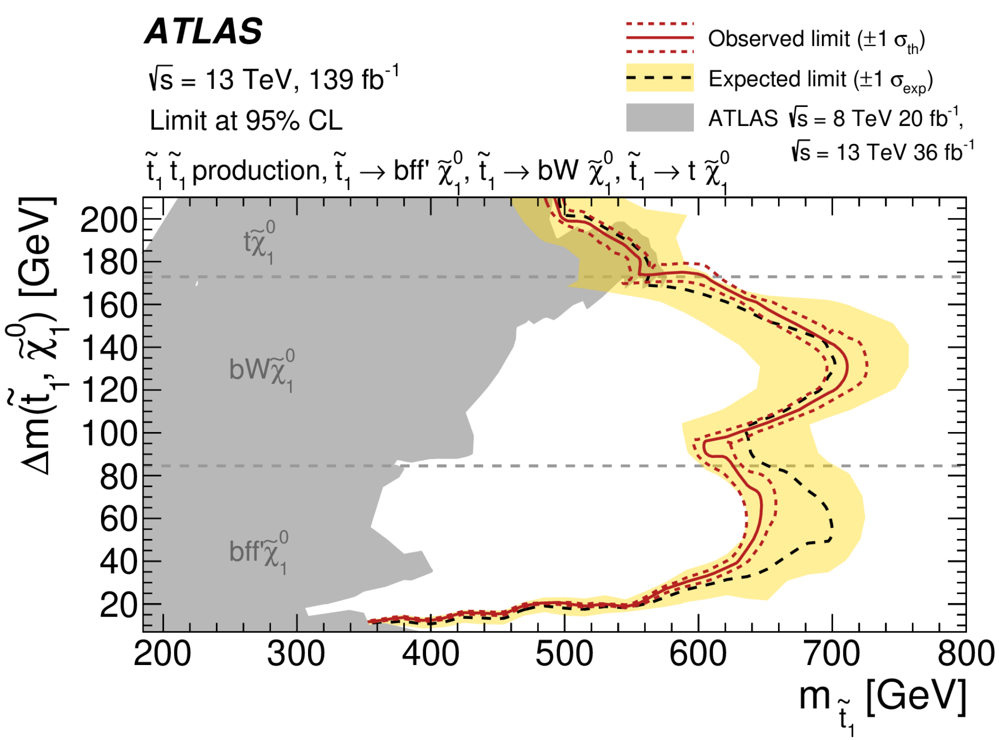


Funziona?


p
p
$\tilde{b}$
$\tilde{b}$
b
b
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$

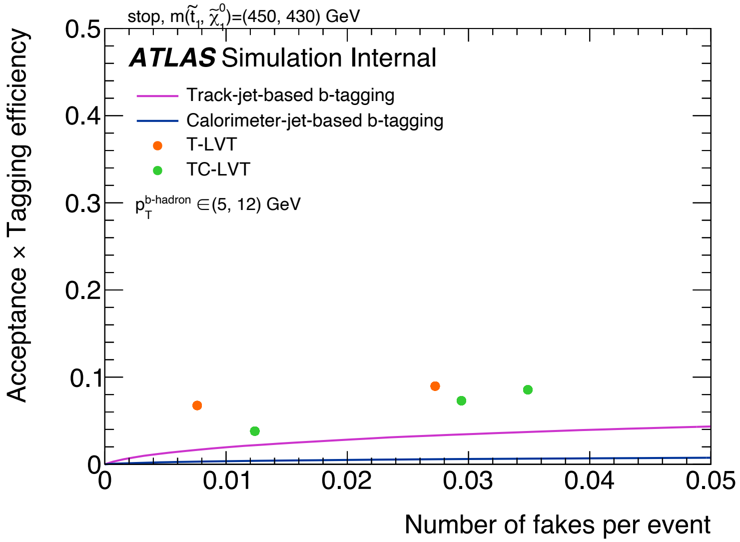

p
p
$\tilde{t}$
$\tilde{t}$
b
ℓ
ν
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
q
q
b

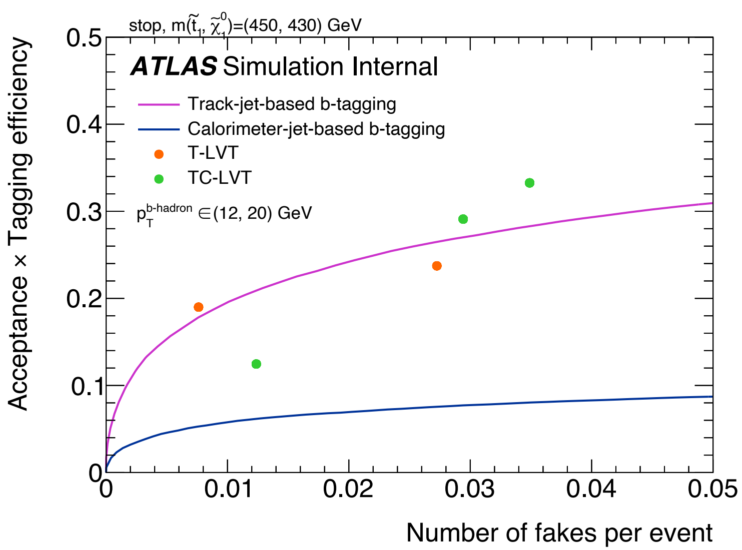

$\tilde{b}_1\tilde{b}_1$ production ; $\tilde{b}_1 \to b\,\tilde{\chi}_1^0$
ATLAS
$\sqrt{s}$=13 TeV, 139 fb^{-1}, 95% CL
Expected SR-AB
Expected SRC
not investigated
$\Delta\,m(\tilde{b}_1,\tilde{\chi}_1^0)$ [GeV]
$m_{\tilde{b}_1}$ [GeV]

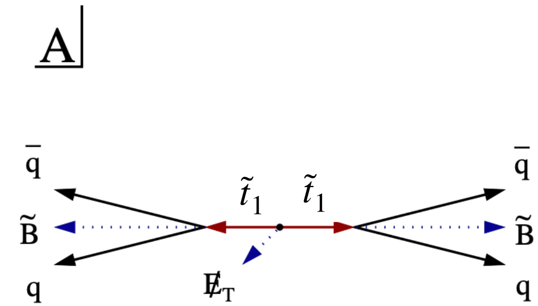

ATLAS
$\sqrt{s}$ = 13 TeV, 139 fb^{-1}
Limit at 95% CL
Observed limit ($\pm 1\,\sigma_{th}$)
Expected limit ($\pm 1\,\sigma_{exp}$)
ATLAS $\sqrt{s}$ = 8 TeV 20 fb^{-1}, $\sqrt{s}$ = 13 TeV 36 fb^{-1}
$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to bff'\,\tilde{\chi}_1^0$, $\tilde{t}_1 \to bW\,\tilde{\chi}_1^0$, $\tilde{t}_1 \to t\,\tilde{\chi}_1^0$
$t\tilde{\chi}_1^0$
$bW\tilde{\chi}_1^0$
$bff'\tilde{\chi}_1^0$
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0)$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

L'idea

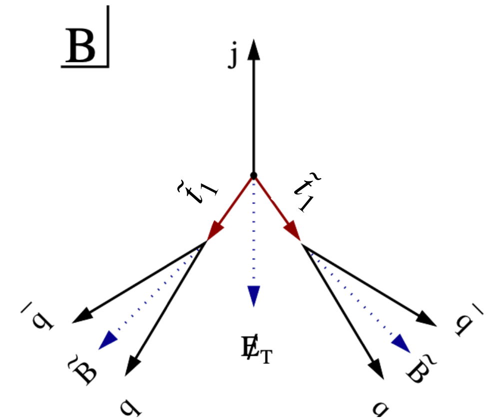
- Scordarsi del jet e <u>cercare un vertice secondario isolato</u>:



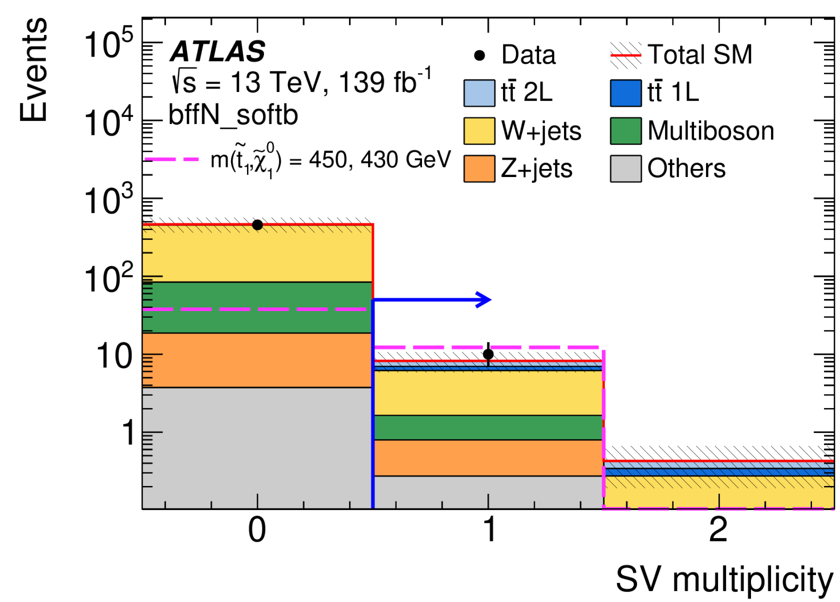




In stop CMS, basso $E_{\mathrm{T}}^{\mathrm{miss}}, p_T^b$



In lab, alto $E_{\mathrm{T}}^{\mathrm{miss}}$, ma basso p_T^b



Supersymmetry and the LHC

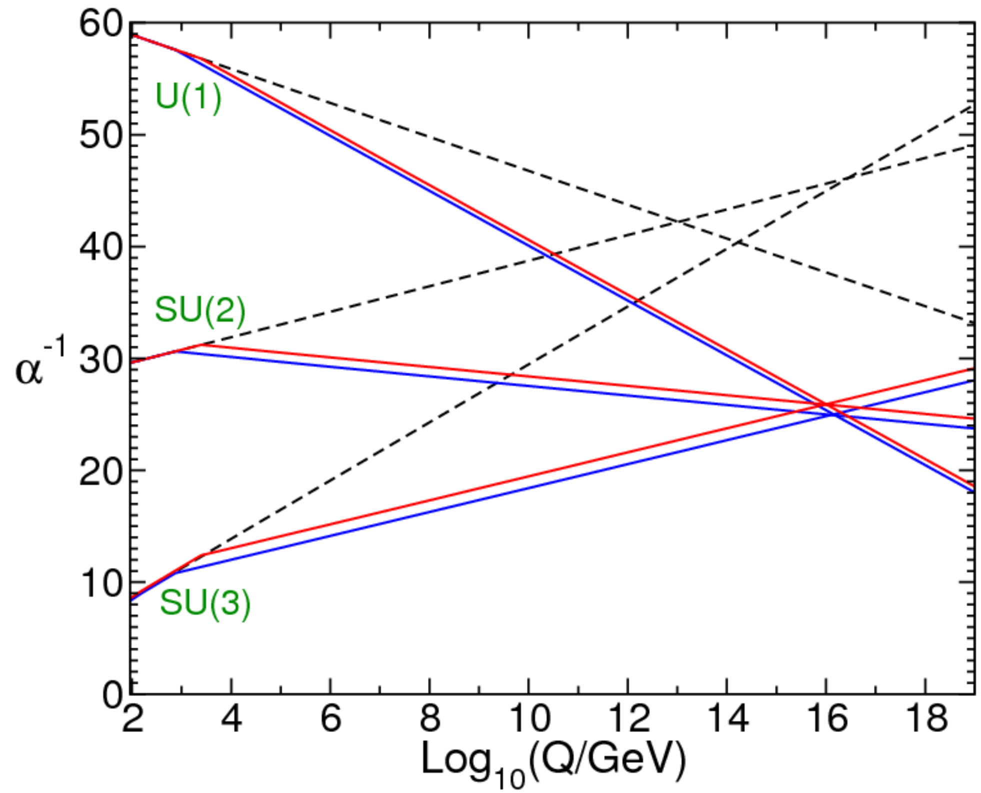
$$\beta_{g_a} \equiv \frac{d}{dt} g_a = \frac{1}{16\pi^2} b_a g_a^3, \qquad (b_1, b_2, b_3) = \begin{cases} (41/10,\ -19/6,\ -7) & \text{Standard Model} \\ (33/5,\ 1,\ -3) & \text{MSSM} \end{cases}$$

$$\frac{d}{dt}\alpha_a^{-1} = -\frac{b_a}{2\pi} \qquad (a = 1, 2, 3)$$

Evolution of RGE modified by additional particle content in MSSM

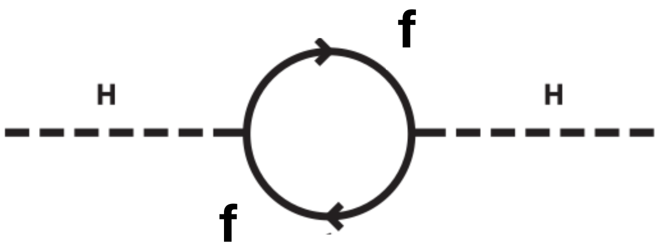
Couplings unify at ~ 10^{16} GeV

from arXiv:hep-ph/9709356



Naturalness

- Why SUSY? Many possible answers.
- But why SUSY at ~ TeV (rather than at 10 or 100 TeV)?
    - Fix hierarchy if sparticles masses < 1 TeV
        - if the Higgs couples to a higher physical scale Λ, then its natural mass is of the order of Λ. Why is the Higgs light?
    - WIMP miracle: weakly interacting DM points to a DM mass of ~ 1 TeV.



$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\rm UV}^2 + \ldots$$

$$\Delta m_H^2 = 2 \times \frac{|\lambda_f|^2}{16\pi^2}\Lambda_{\rm UV}^2 + \ldots$$

With SUSY, **quadratic effects** (big hierarchy) are **cancelled exactly**, one is left with **only logs** (little hierarchy)

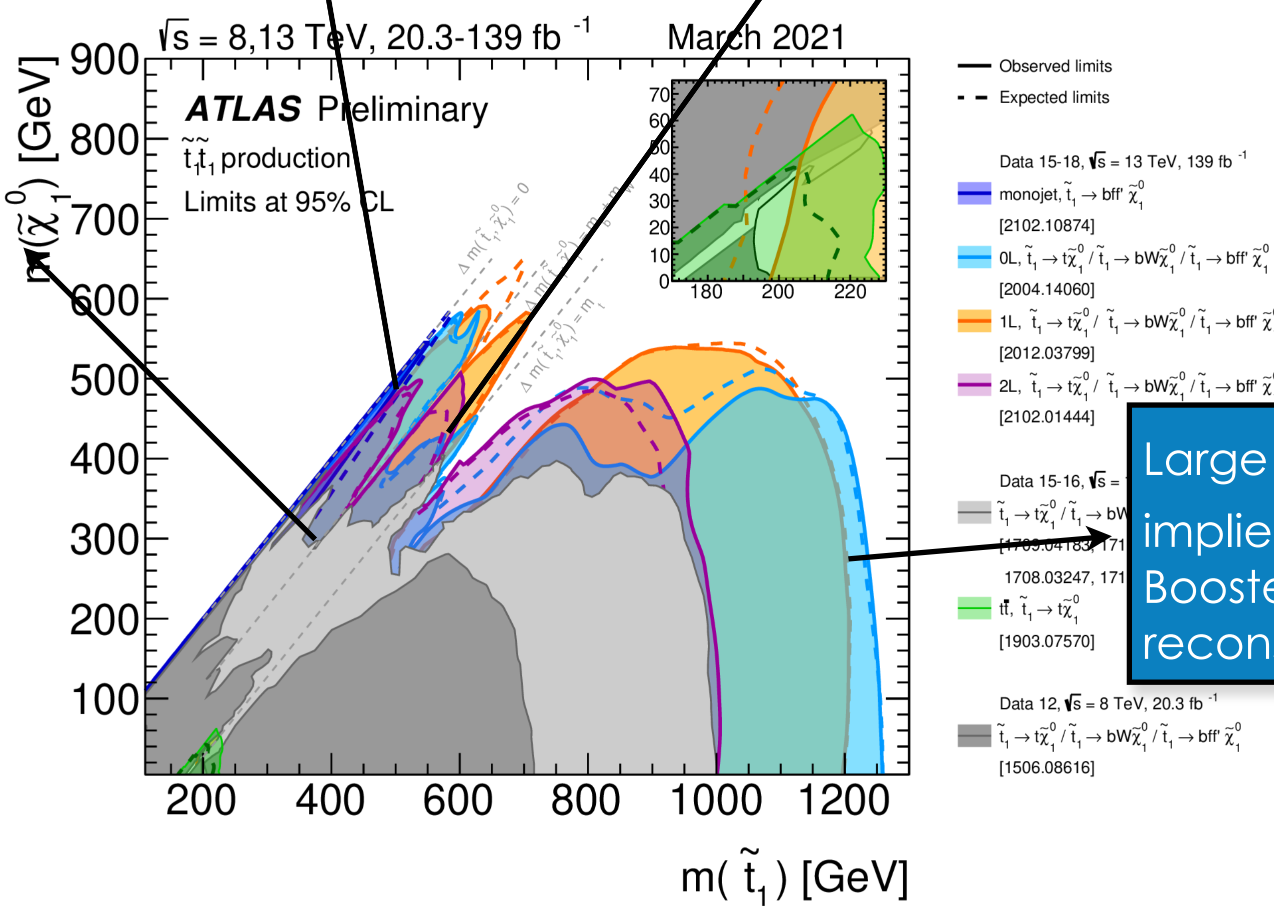
Naturalness wants light stops

$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_0^1} \sim 0$:

Soft b-tagging

$$\frac{E_T^{miss}}{p_T^{\rm ISR}} \sim \frac{m_{\tilde{\chi}_0^1}}{m_{\tilde{t}_1}}$$

c-tagging

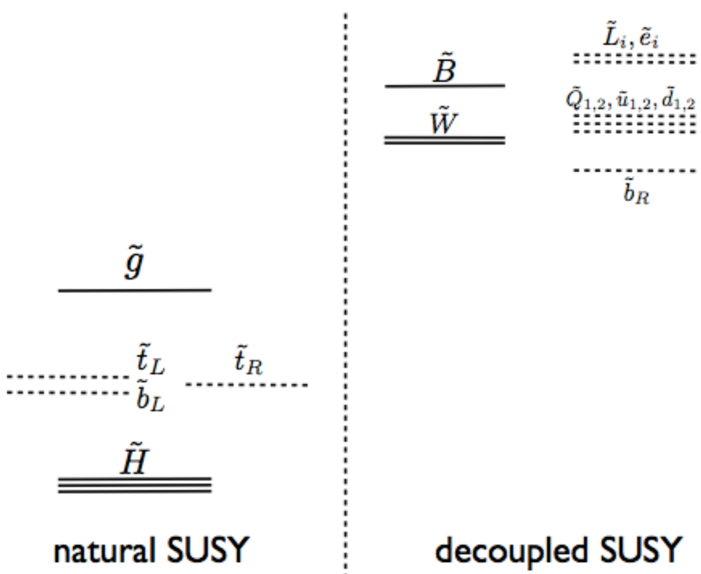


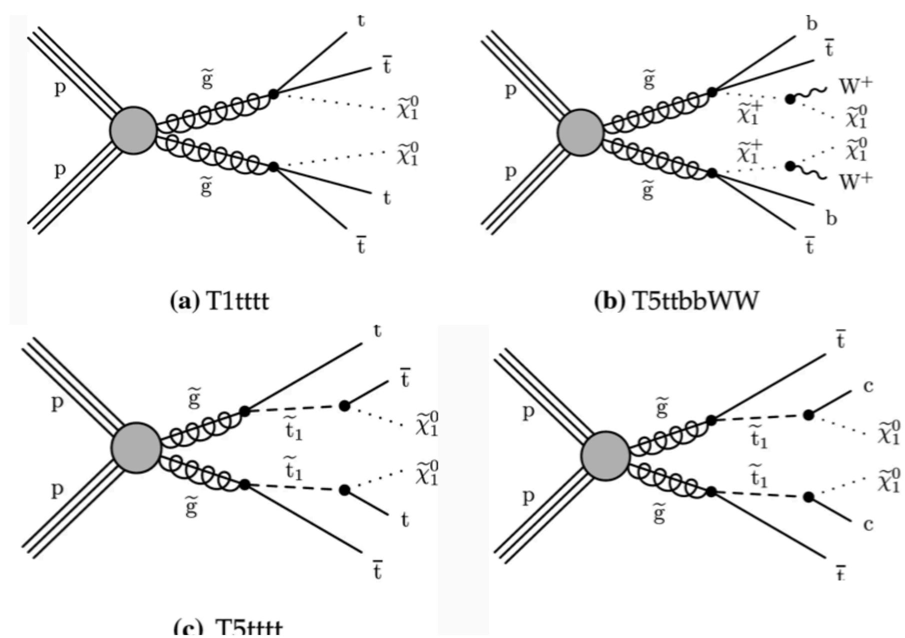
Large $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_0^1}$ implies large top boost. Boosted top reconstruction

The "natural" gluino production scenario

- The naturalness of the Higgs boson mass requires:
  - A Higgsino mass parameter of maximum few hundred GeV
  - A top partner mass at the TeV scale
  - A gluino mass parameter of maximum few TeV

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3y_t^2 m_t^2}{4\pi^2}\left[\log\left(\frac{m_S^2}{m_t^2}\right) + X_t^2\left(1 - \frac{X_t^2}{12}\right)\right] + \cdots$$





(a) T1tttt

(b) T5ttbbWW

(c) T5tttt

Naturalness wants light stops

$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$

$\tilde{t}\tilde{t}, \tilde{b}\tilde{b}$

$\tilde{\chi}^0_2\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1, \tilde{\chi}^0_2\tilde{\chi}^0_1$

$\tilde{\ell}\tilde{\ell}, \tilde{\tau}\tilde{\tau}$

$\otimes$

Wino-bino

Higgsino

Wino

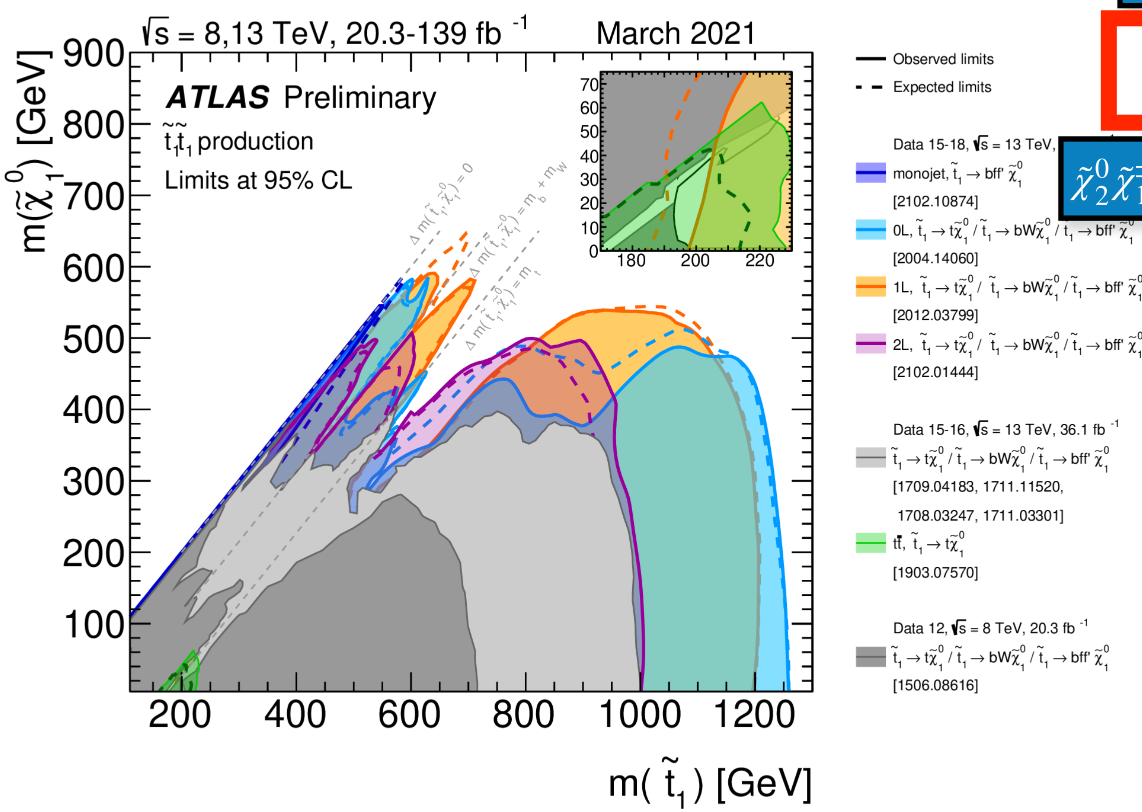
GGM/GMSB

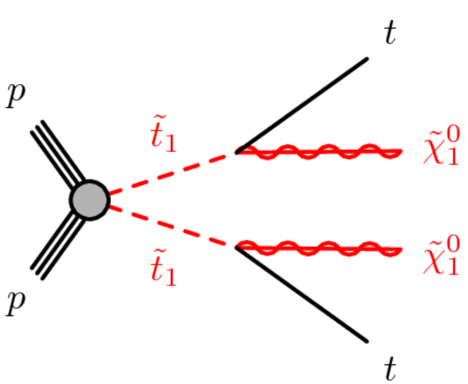
$\otimes$

RPC

RPV

(Long lived)





- The bino scenario.
- Different regions in the plane characterised by hierarchy between $\tilde{t}_1, t, W$

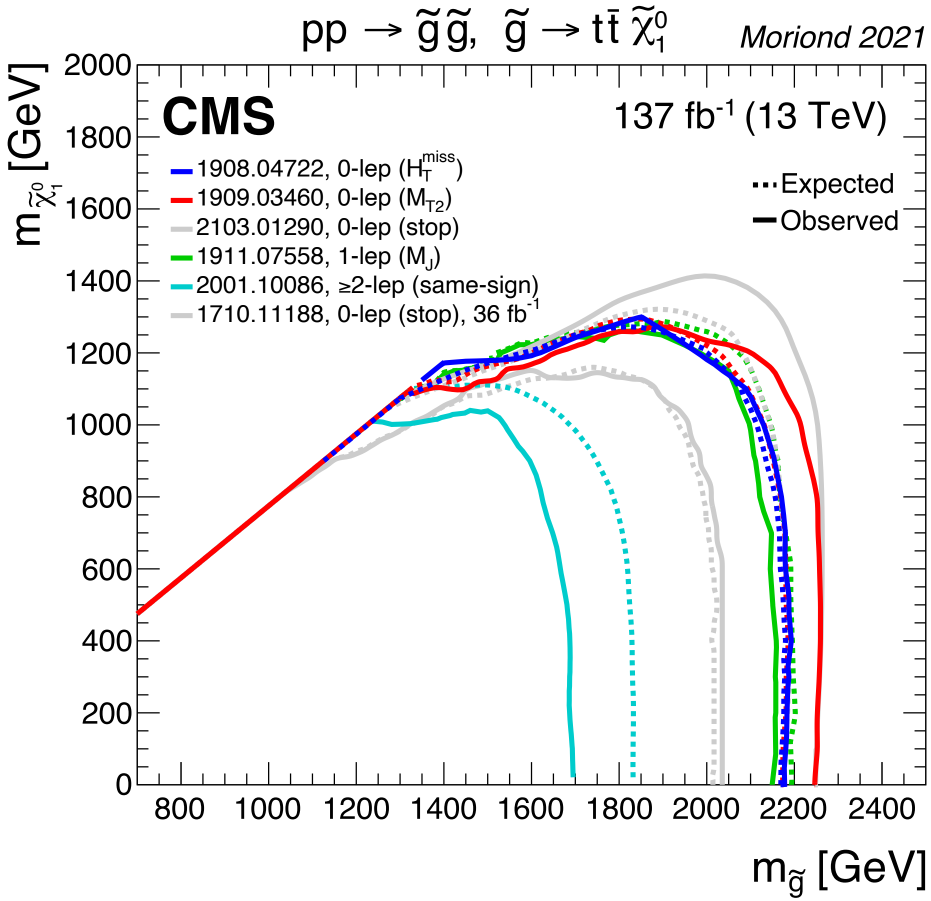
Signature:

- jets
- B-jets
- Top quarks (possibly boosted)
- missing transverse momentum
- Possibly leptons
- Etc…

Main background processes:

- $t\bar{t}, t\bar{t}bb$
- W + heavy flavours, $Z + HF$
- Multiboson production

The "natural" gluino production scenario



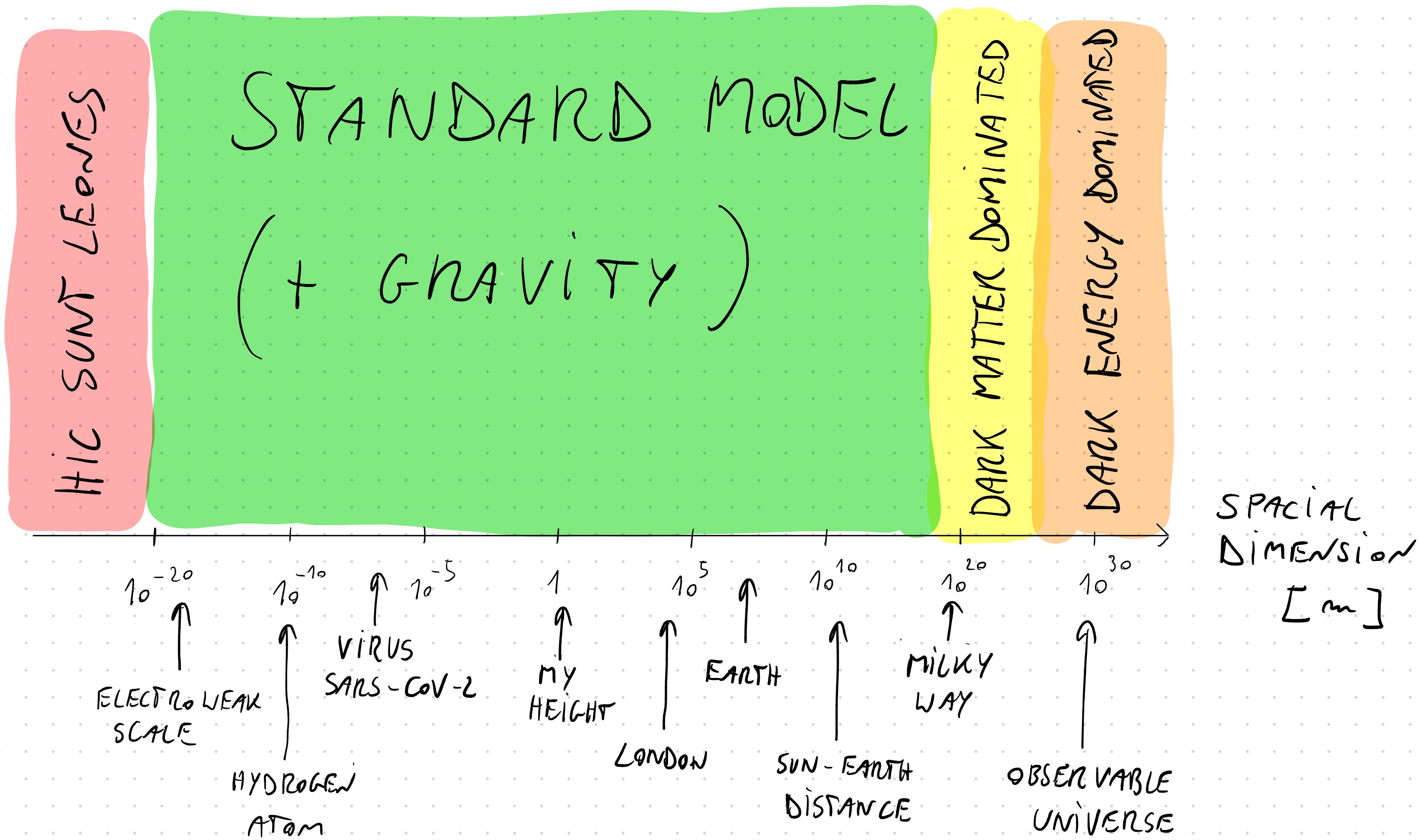
Signature:

- jets
- B-jets
- Top quarks (possibly boosted)
- missing transverse momentum
- Possibly leptons and multileptons
- Etc…

Main background processes:

- $t\bar{t}, t\bar{t}bb$
- $W +$ heavy flavours, $Z + HF$
- Multiboson production

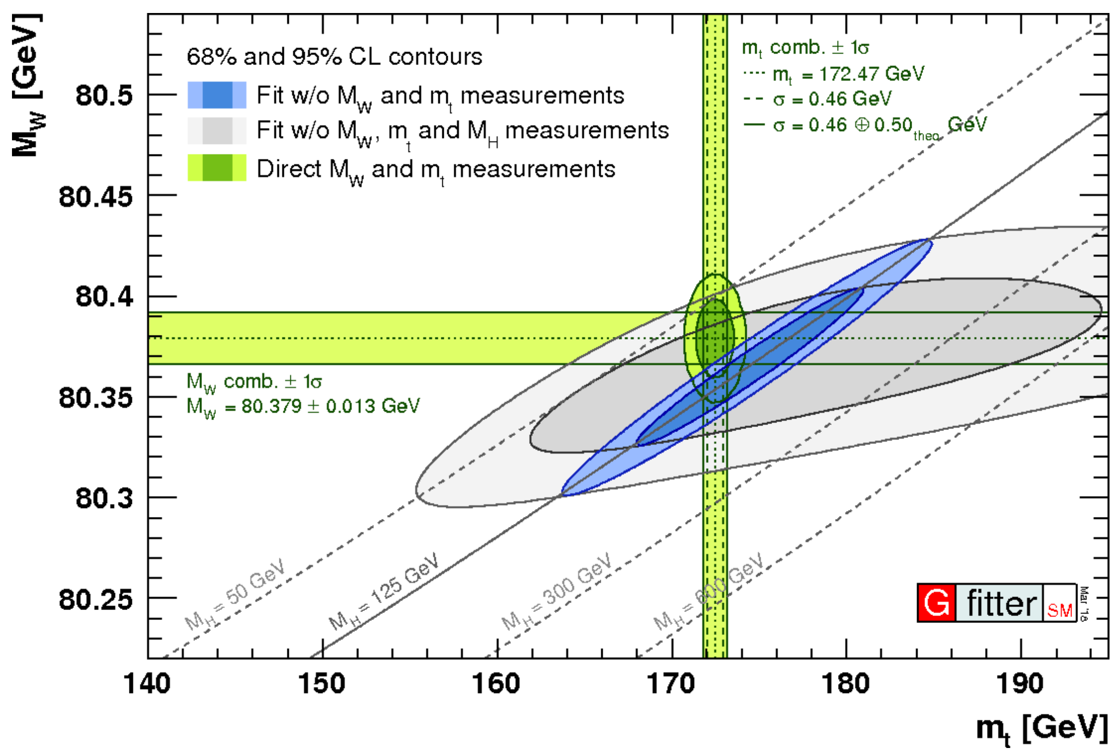
Standard Model - Joys and pains



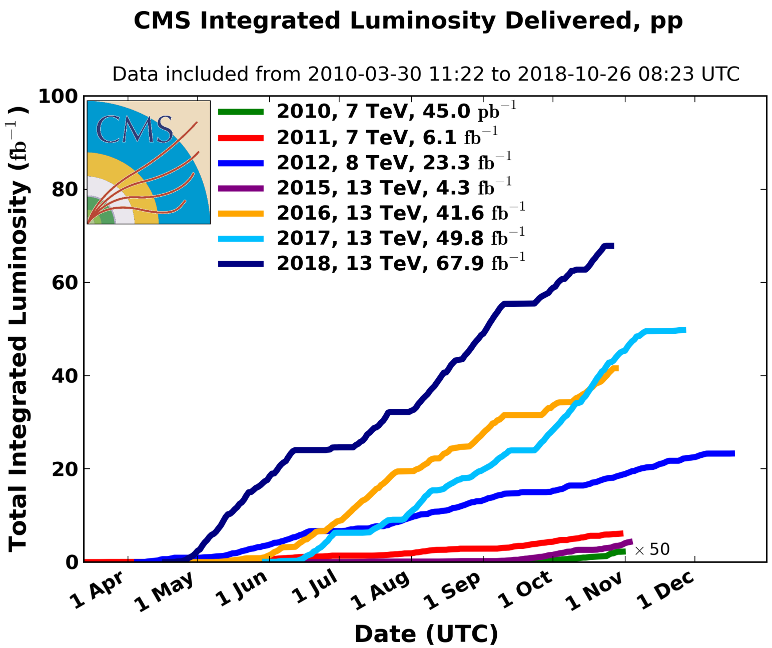
The role of colliders

- Colliders are **the only experimental tool** to access the EW scale **directly**.
- The Standard Model predictions **agree with data** over the board.

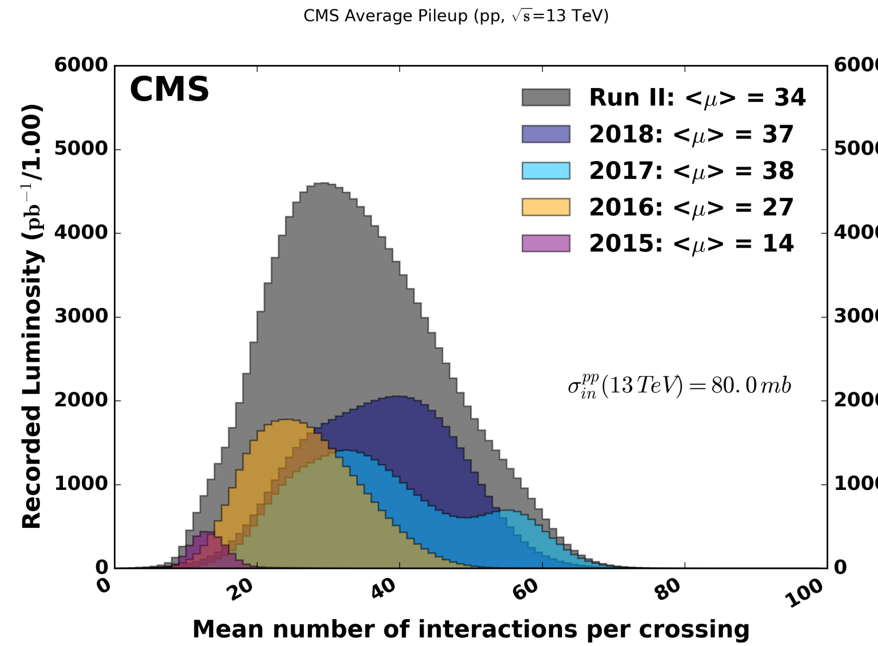
Parameter	Input value	Free in fit	Fit Result	w/o exp. input in line	w/o exp. input in line, no theo. unc
M_H [GeV]	125.1 ± 0.2	yes	$125.1^{+0.2}_{-0.2}$	$100.2^{+24.4}_{-20.6}$	$100.3^{+23.5}_{-19.9}$
M_W [GeV]	80.379 ± 0.013	–	80.363 ± 0.007	80.356 ± 0.008	80.356 ± 0.007
Γ_W [GeV]	2.085 ± 0.042	–	2.091 ± 0.001	2.091 ± 0.001	2.091 ± 0.001
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1879 ± 0.0020	91.1967 ± 0.0099	91.1969 ± 0.0096
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4950 ± 0.0014	2.4945 ± 0.0016	2.4945 ± 0.0016
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–	41.483 ± 0.015	41.474 ± 0.016	41.474 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.744 ± 0.017	20.725 ± 0.026	20.724 ± 0.026
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–	0.01623 ± 0.0001	0.01622 ± 0.0001	0.01624 ± 0.0001
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	0.1471 ± 0.0005	0.1471 ± 0.0005	0.1472 ± 0.0004
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–	0.23151 ± 0.00006	0.23151 ± 0.00006	0.23150 ± 0.00005
$\sin^2\theta^\ell_{\rm eff}({\rm TEV})$	0.2318 ± 0.0003	–	0.23151 ± 0.00006	0.23150 ± 0.00006	0.23150 ± 0.00005
A_c	0.670 ± 0.027	–	0.6679 ± 0.00022	0.6679 ± 0.00022	0.6680 ± 0.00016
A_b	0.923 ± 0.020	–	0.93475 ± 0.00004	0.93475 ± 0.00004	0.93475 ± 0.00003
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–	0.0737 ± 0.0003	0.0737 ± 0.0003	0.0737 ± 0.0002
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–	0.1031 ± 0.0003	0.1033 ± 0.0004	0.1033 ± 0.0003
R^0_c	0.1721 ± 0.0030	–	$0.17226^{+0.00009}_{-0.00008}$	0.17226 ± 0.00008	0.17226 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21579 ± 0.00011	0.21578 ± 0.00012	0.21577 ± 0.00004
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes	$1.27^{+0.07}_{-0.11}$	–	–
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes	$4.20^{+0.17}_{-0.07}$	–	–
m_t [GeV]$^{(\nabla)}$	173.06 ± 0.94	yes	173.54 ± 0.86	$175.97^{+2.11}_{-2.12}$	$176.00^{+2.03}_{-2.04}$
$\Delta\alpha^{(5)}_{\rm had}(M^2_Z)$ $^{(\dagger\triangle)}$	2758 ± 10	yes	2756 ± 10	2738 ± 41	2739 ± 39
$\alpha_s(M^2_Z)$	–	yes	$0.1197^{+0.0030}_{-0.0029}$	0.1197 ± 0.0030	0.1198 ± 0.0028



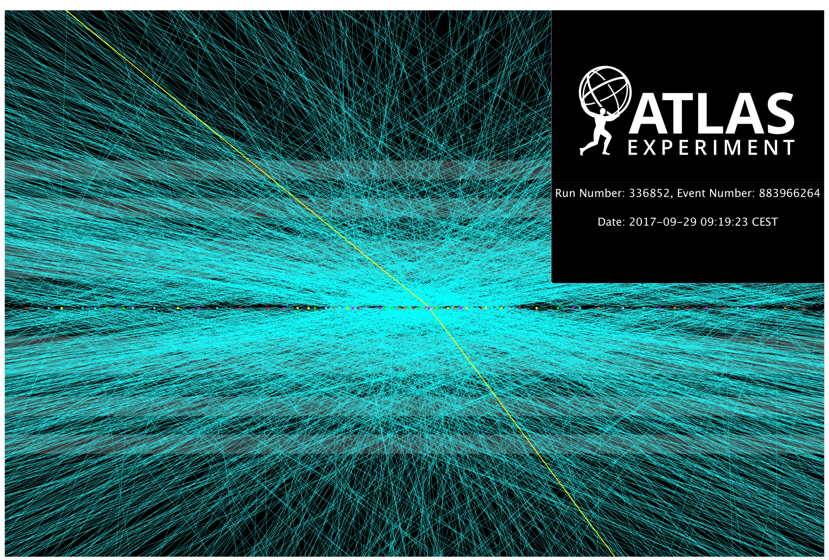
The LHC Run 2



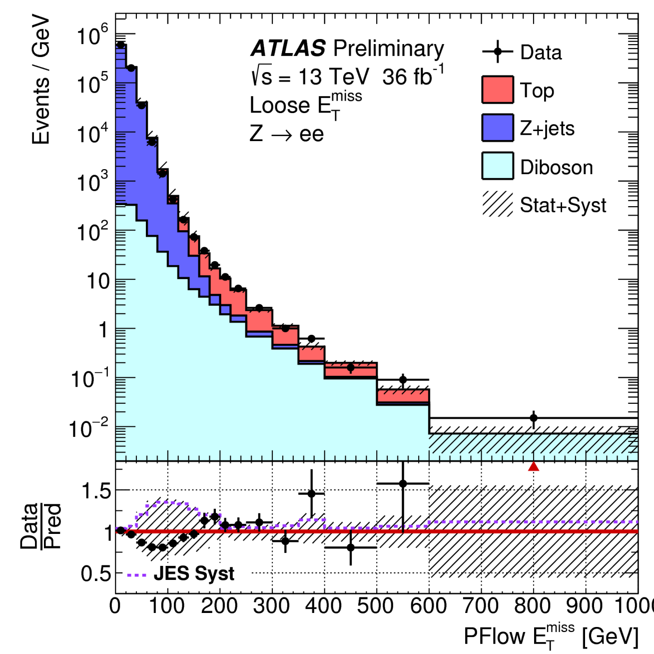
CMS Integrated Luminosity Delivered, pp
Data included from 2010-03-30 11:22 to 2018-10-26 08:23 UTC
2010, 7 TeV, 45.0 pb⁻¹
2011, 7 TeV, 6.1 fb⁻¹
2012, 8 TeV, 23.3 fb⁻¹
2015, 13 TeV, 4.3 fb⁻¹
2016, 13 TeV, 41.6 fb⁻¹
2017, 13 TeV, 49.8 fb⁻¹
2018, 13 TeV, 67.9 fb⁻¹
× 50
Total Integrated Luminosity (fb⁻¹)
Date (UTC)
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec



CMS Average Pileup (pp, √s=13 TeV)
CMS
Run II: <μ> = 34
2018: <μ> = 37
2017: <μ> = 38
2016: <μ> = 27
2015: <μ> = 14
σ_in^pp(13 TeV) = 80.0 mb
Recorded Luminosity (pb⁻¹/1.00)
Mean number of interactions per crossing



ATLAS
EXPERIMENT
Run Number: 336852, Event Number: 883966264
Date: 2017-09-29 09:19:23 CEST



ATLAS Preliminary
√s = 13 TeV 36 fb⁻¹
Loose E_T^miss
Z → ee
Data
Top
Z+jets
Diboson
Stat+Syst
Events / GeV
Data/Pred
JES Syst
PFlow E_T^miss [GeV]