Searches for Supersymmetry
current results and future prespectives

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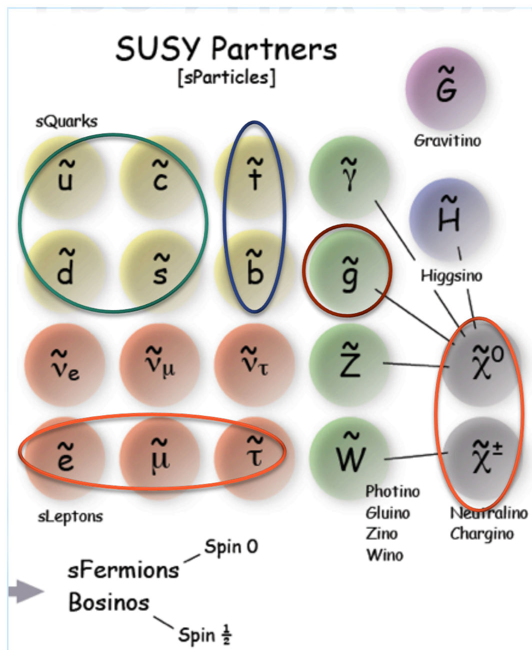


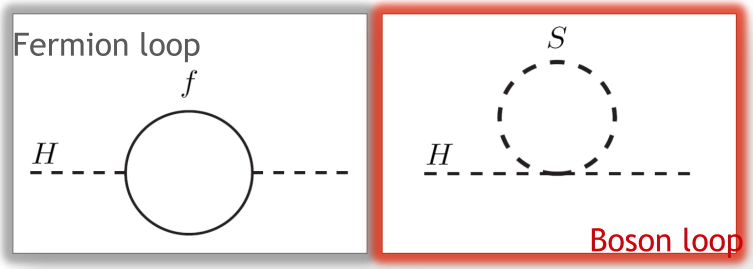
ICFA2014, Bejing – 28/10/2014

Supersymmetry (SUSY) in a nutshell

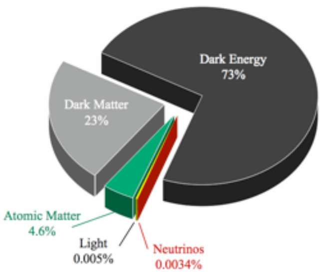
New spin-based symmetry relating fermions and bosons

→ more than doubles the particle spectrum w.r.t. the Standard Model.

- **Naturally solves the gauge hierarchy problem**
  - Fermion and boson loops contribute with different signs to the Higgs radiative corrections.

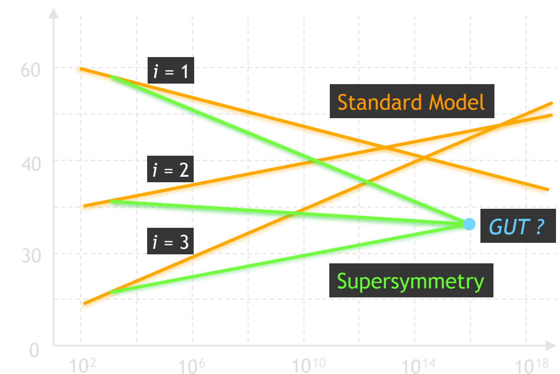


- **SUSY with R-parity conservation predicts a suitable Dark Matter candidate**
  - R-parity = $(-1)^{3(B-L)+2S}$
  - Lightest SUSY particle (LSP) is stable



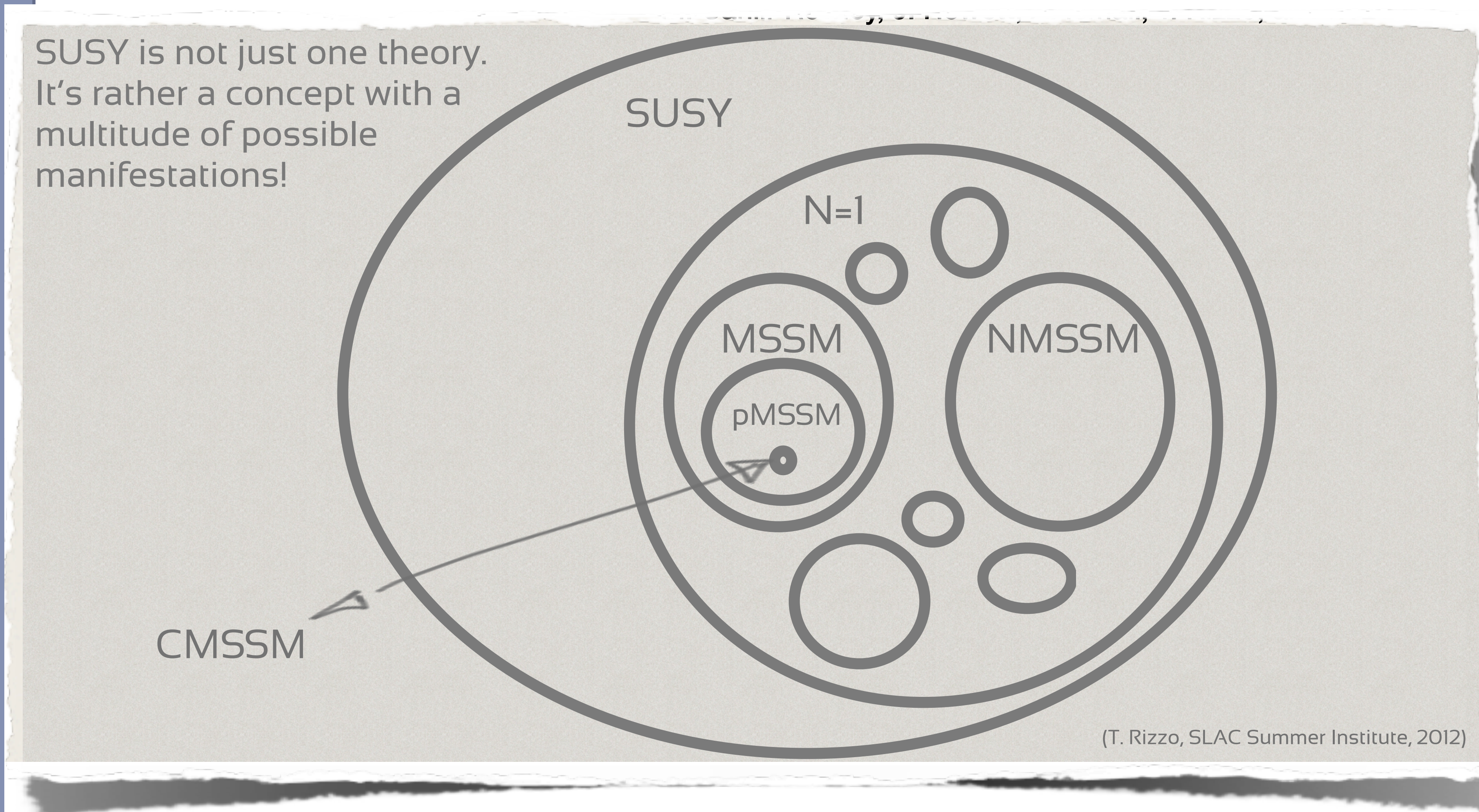
- **Grand unification of forces**
- **Predicts an elementary Higgs scalar …**
  - 'intriguing' SM-like limit

→ mass below 135 GeV (in the MSSM)



SUSY widely considered to remain the chief amongst BSM proposals - although the most simplistic versions tightly constrained by experimental results!

SUSY: framework VS model



T.Rizzo (copied by many others)

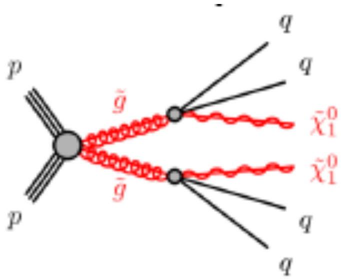
Phenomenology

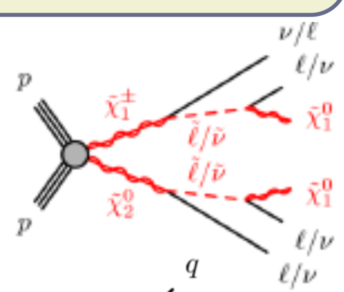
SUSY as theoretical framework

SUSY breaking mechanism and R-parity determines the phenomenology → *sparticle decay modes, nature of the Lightest SUSY Particle, lifetime…*

If R-parity is conserved (RPC)

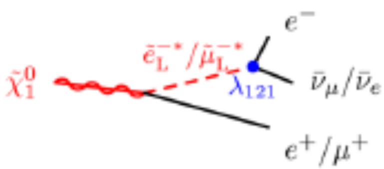
→ sparticles produced in pairs at colliders
→ Lightest Supersymmetric Particle lead to high missing transverse momentum (E_T^{Miss}) final states
Typical LSP: lightest neutralino ($\tilde{\chi}_1^0$), gravitino ($\tilde{G}$)

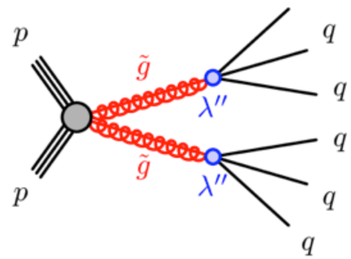




If R-parity is violated (RPV)

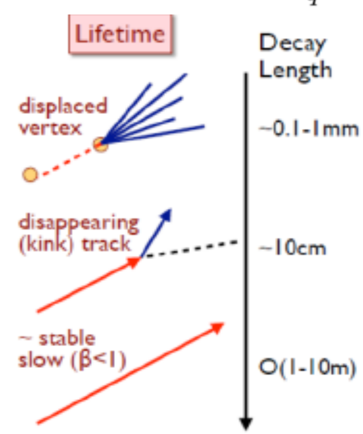
→ LSP no longer stable, rich and diverse phenomenology depending on the involved parameters (λ, λ',λ'')





Prompt or Long Lived (LL) particles could be produced in RPV and RPC scenarios. Few examples of LL:

- **In RPV**: if lambda couplings are very small
- **In RPC:** If very heavy squarks mediate gluinos decay (strong virtuality):
  - Long-lived gluinos → R-hadrons (eg. Split SUSY)

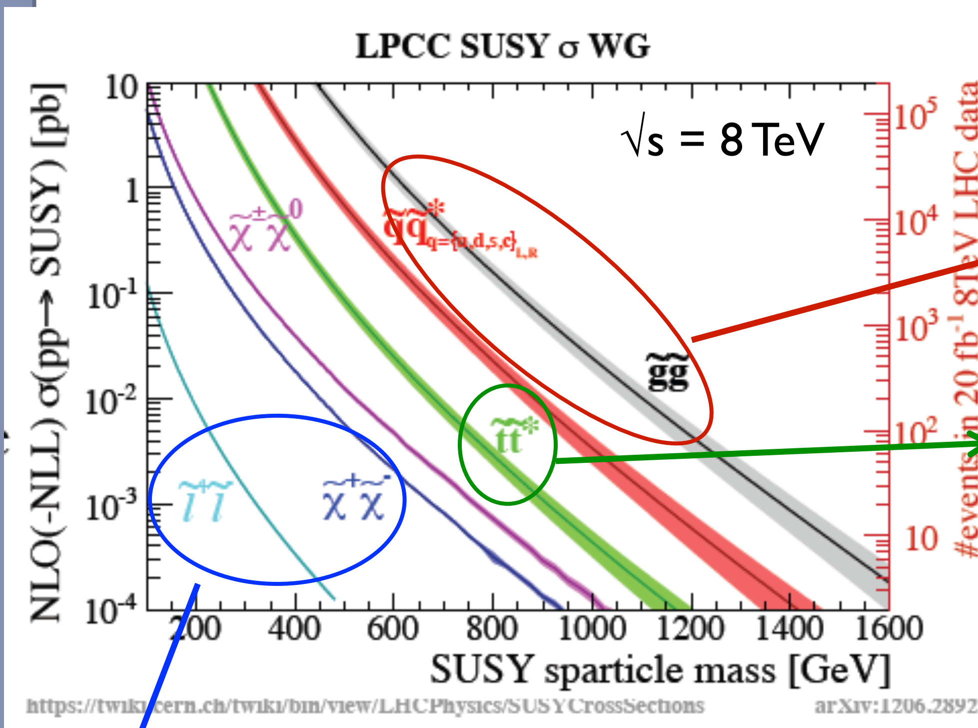


Outline

- Recent results and constraints:
  - ATLAS and CMS experiments (*)
    - Mostly reporting examples of searches for R-parity conserving scenarios (**).
    - Indirect constraints (***)
      - $B_s \rightarrow \mu\mu$, electron dipole moment, g-2
- Prospects for SUSY searches in the next decades:
  - High Luminosity LHC
  - Future Colliders potential
- Conclusion: The last word about SUSY?

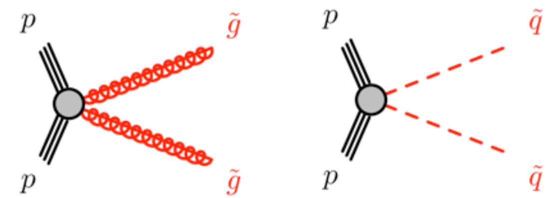
(*) Other hadron-based collider results (Tevatron, HERA) no longer competitive aside for some complementarity studies - example in back-up
(**) Higgs in SUSY: vast program of searches at ATLAS, CMS, B-factories - few examples, also on prospects, in Kerstin Tackmann's talk
(***) Impact of constraints on Dark Matter relic density not directly discussed although taken into account (see dedicated session)

SUSY@LHC: production and search strategy



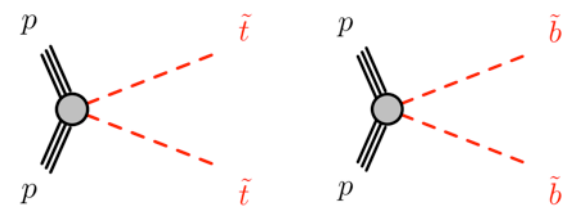
Gluinos and 1st, 2nd generation squarks:

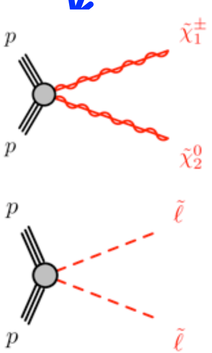
- high cross section up to ~ 1 TeV mass



Top and bottom squarks

- high cross section up to ~ 0.5 TeV





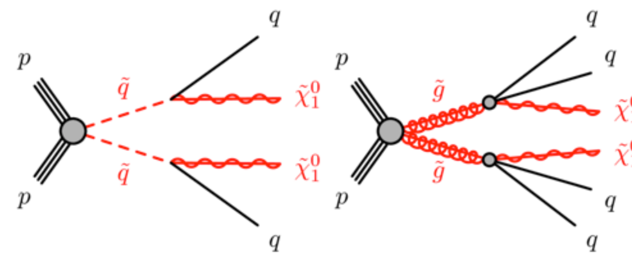
Charginos, neutralinos, sleptons:

- overall small cross section, feasible with current dataset

- **ATLAS&CMS search strategies: designed to provide coverage for a broad class of SUSY models**
- **For each search, a number of signal regions is optimized based on a variety of them ..**

highlights on RPC strong production

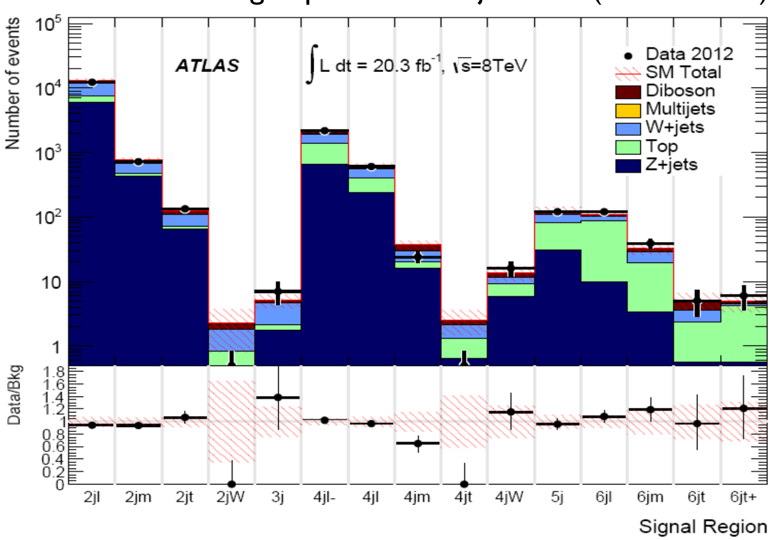
- 1st / 2nd generation squarks and gluinos
- Possibly complex final states, great variety of signatures → main target of inclusive searches with several jets, possibly leptons and large E_T^{Miss}



- *Example:* Inclusive jets+E_T^{Miss} analyses:

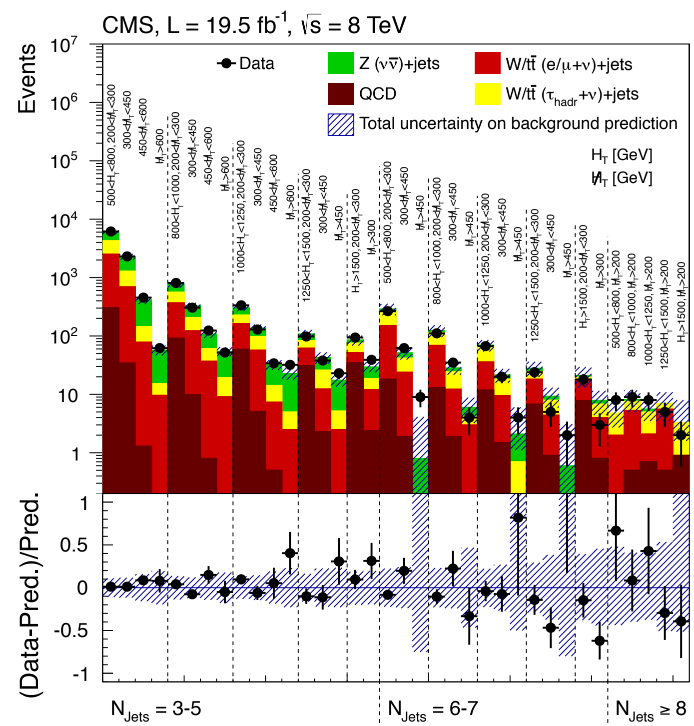
ATLAS: 1405.7875

- Minimum Jet multiplicity (2 to >=6j)
- Use **Effective Mass** (M_{eff}= E_T^{Miss} +Sum p_T jets)
  - Thresholds from 800 GeV to 2.2 TeV
- But also: presence of boosted W→qq'
  - Also merged products → jet mass (60-100 GeV)

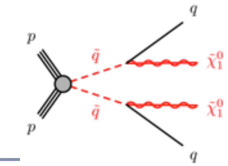


CMS: 1402.4770

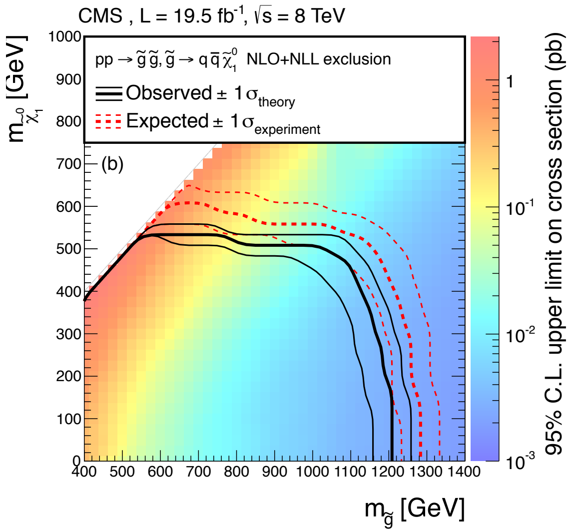
- Three jet multiplicity categories:(3–5, 6–7, and 8 jets)
- Selections in E_T^{Miss} and HT (Sum p_T jets)

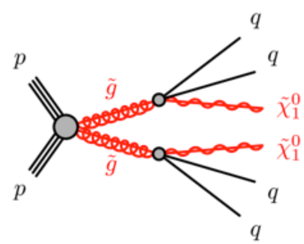


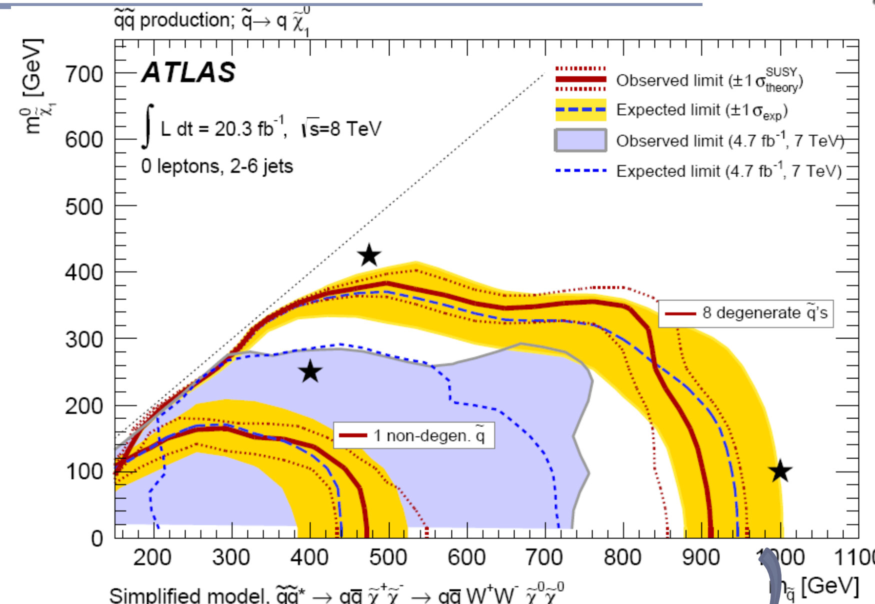
highlights on RPC strong production (II)

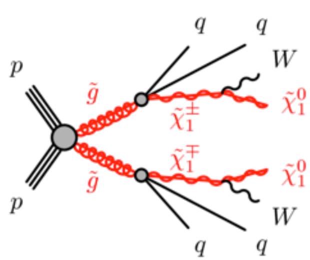


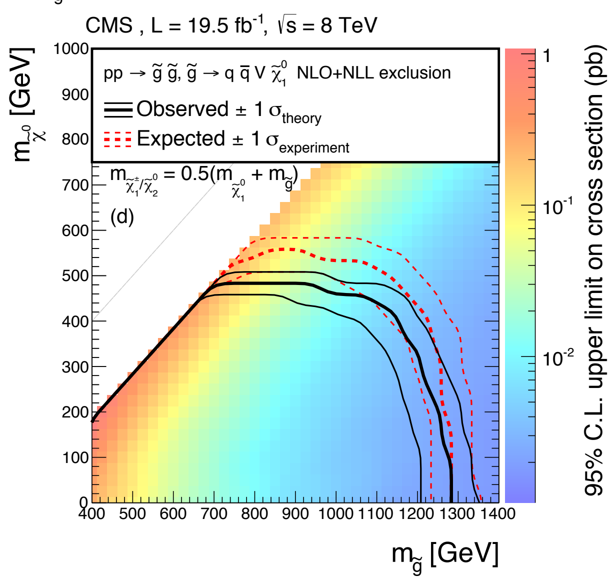
- Exclusions on gluino and squark masses

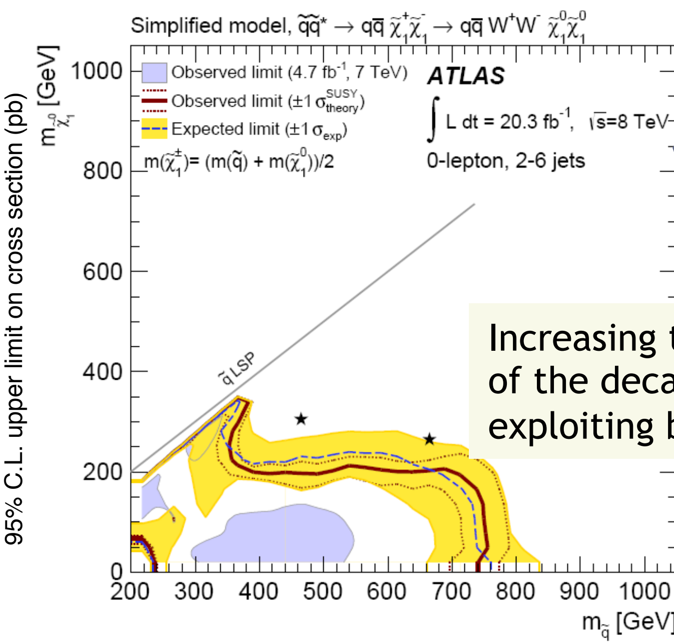


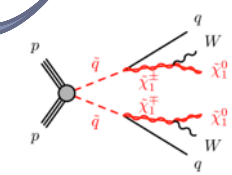










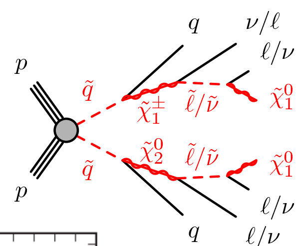


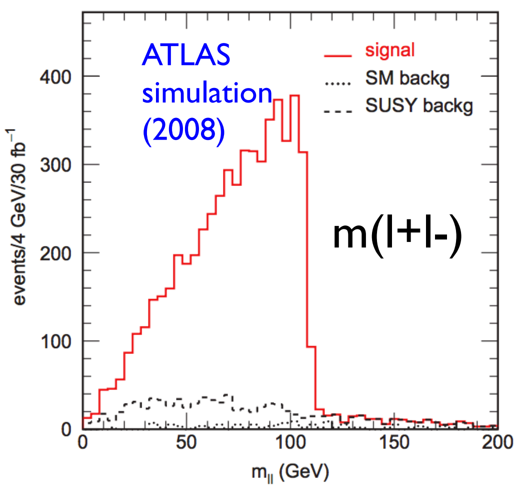
Increasing the complexity of the decay chain, exploiting boosted W

Study of di-lepton 'edges'

- Not only 'cut-and-count' searches
- Various interesting kinematic variables proposed before beginning of Run1 to characterize 'SUSY' signal (some used as discriminating quantities)
- **Di-lepton mass:**
  - end-point expected for some SUSY processes

$$\tilde{\chi}_2^0 \rightarrow \ell^+\ell^-\tilde{\chi}_1^0$$

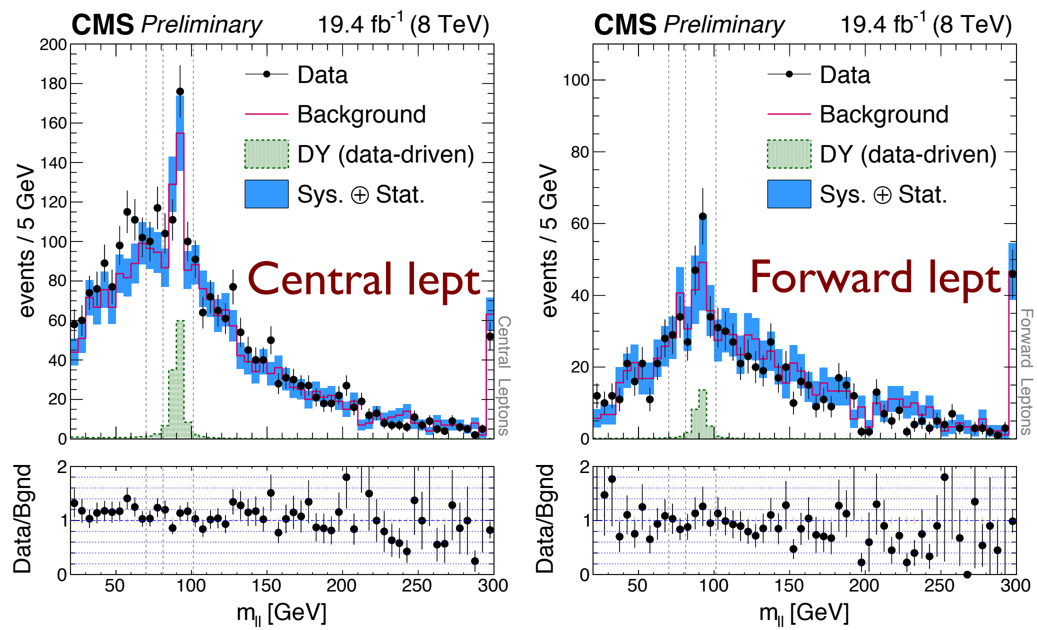




CMS search:

PAS-SUS-12-019

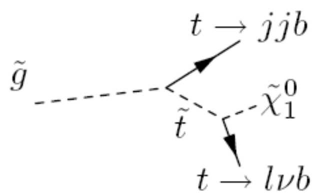
- Opposite sign leptons (ee,eμ,μμ)
- Signal and background estimates: kinematic fit



Interest raised by discrepancy for central region ..

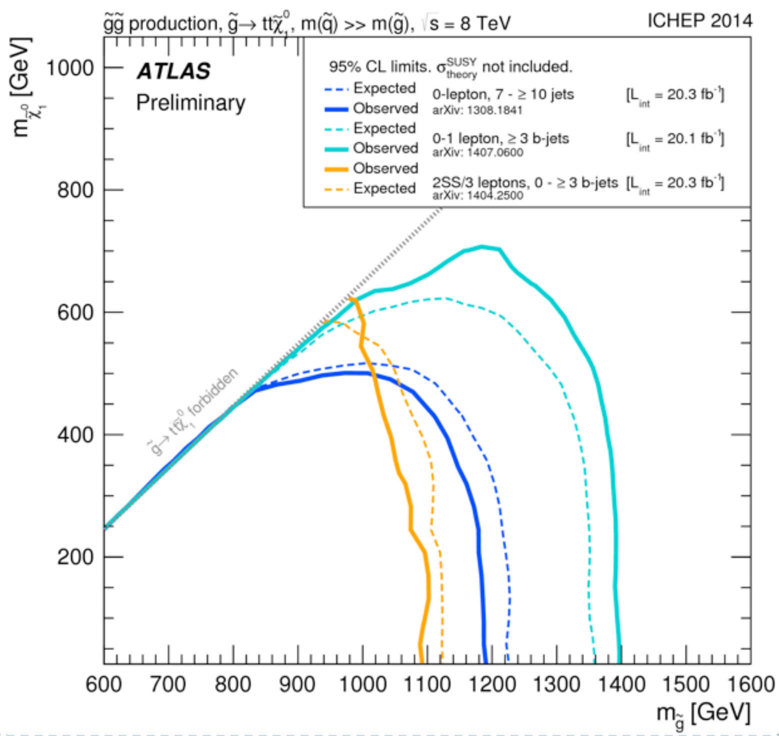
Third generation squarks

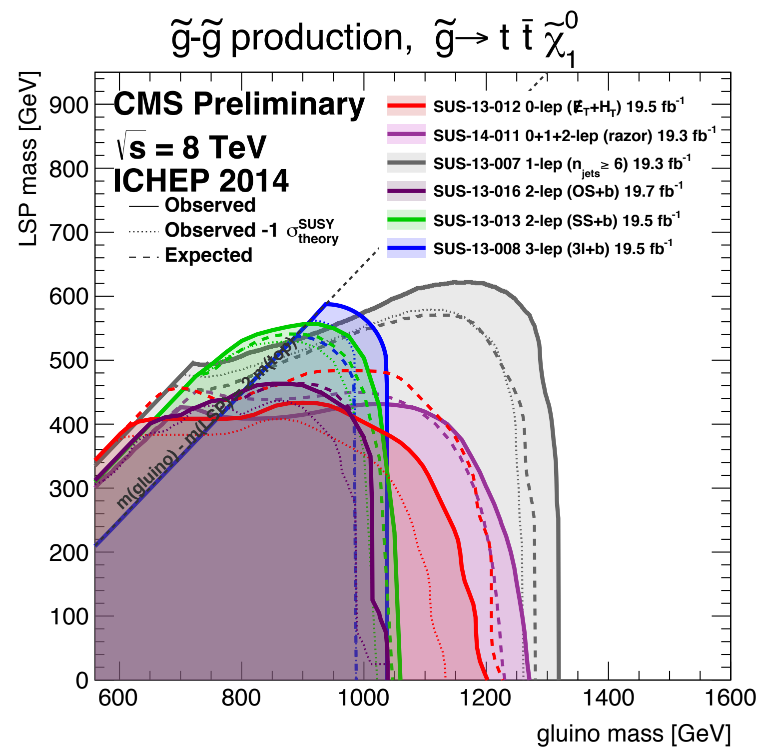
- In ‘Natural’ SUSY, bottom and top squarks most likely O(100-1TeV)
  - Gluinos enter in the higgs mass calculation at 2-loop level → < 2-3 TeV
- Searched for in gluino-mediated and direct pair production. E.g.: **Gluino-mediated stop:**



Various analyses exploiting the complexity of the final states including up to 4 tops.

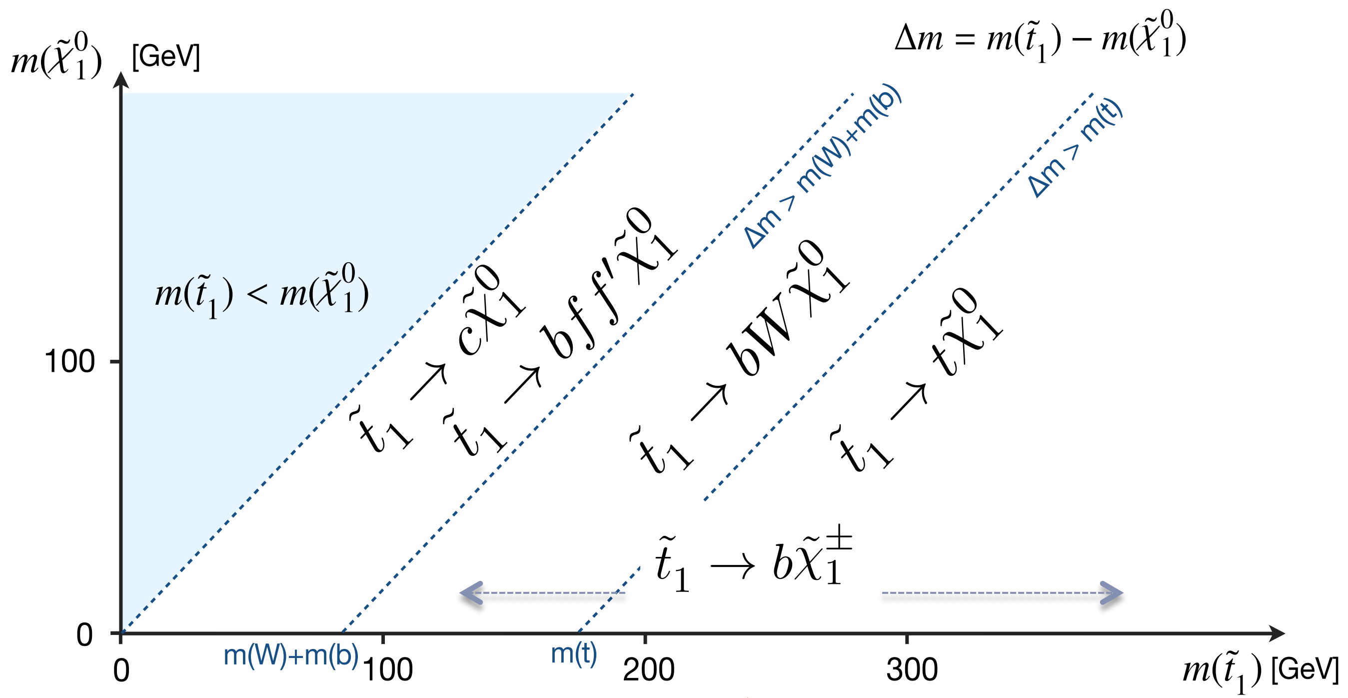
0 lepton + multijets (7-10j)
Same-sign /3 leptons + jets (b-jets)
0/1 or 2 leptons + 3- or 4bjets ..



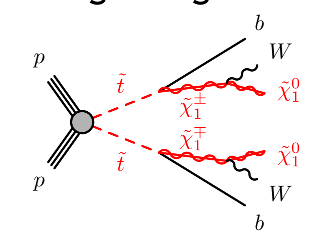


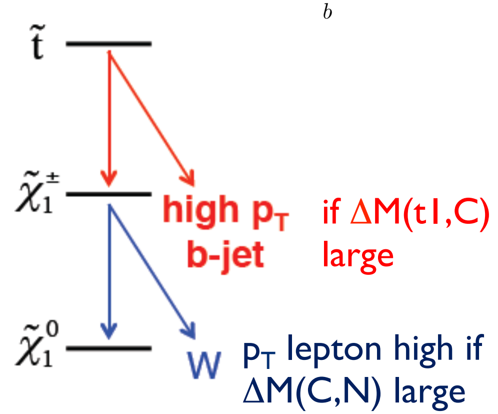
Direct top squark pair production

- Several complex decay modes possible



For decay modes involving charginos:

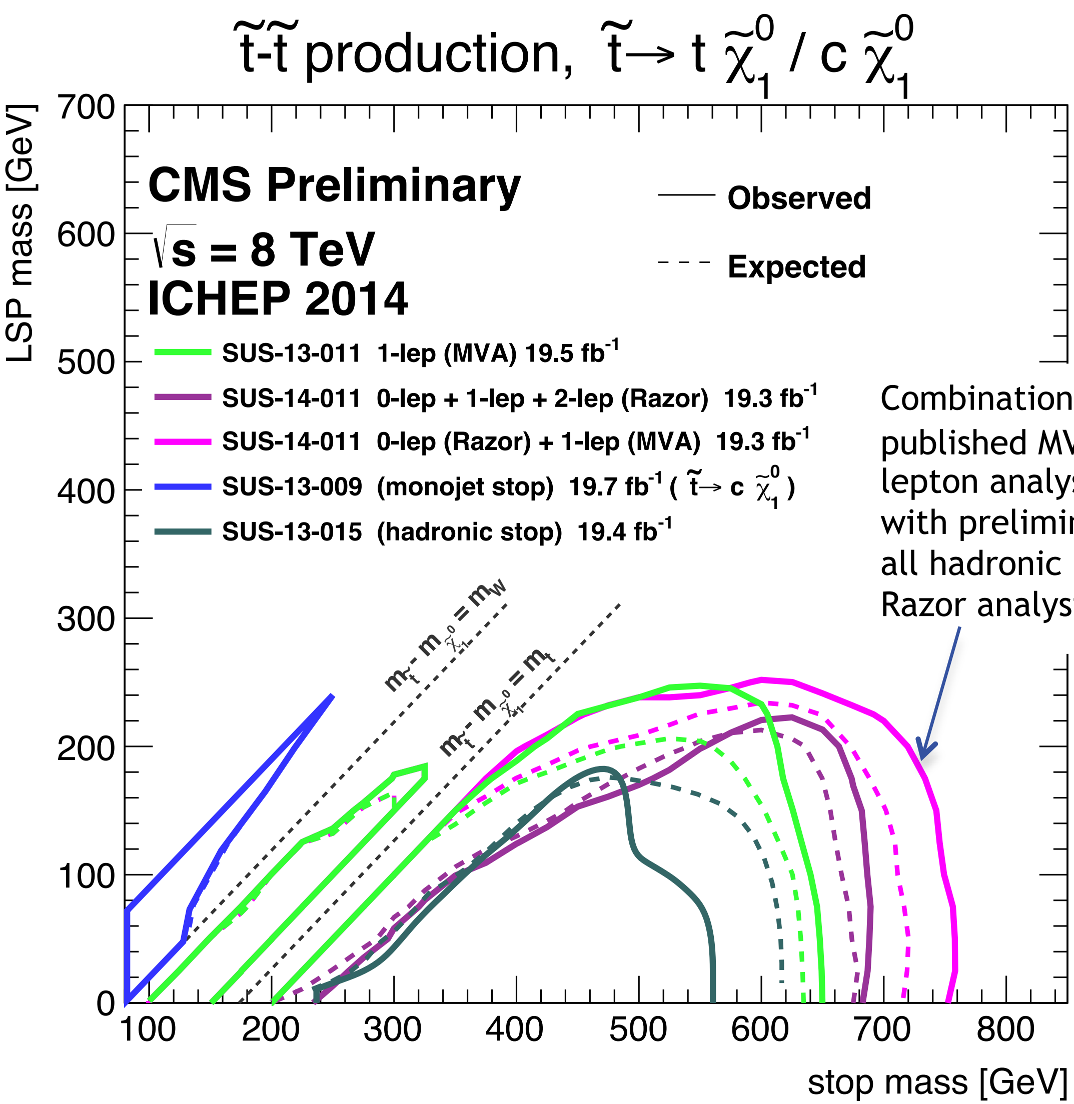




“Compressed” scenarios:
- mono-jet
- Soft-leptons

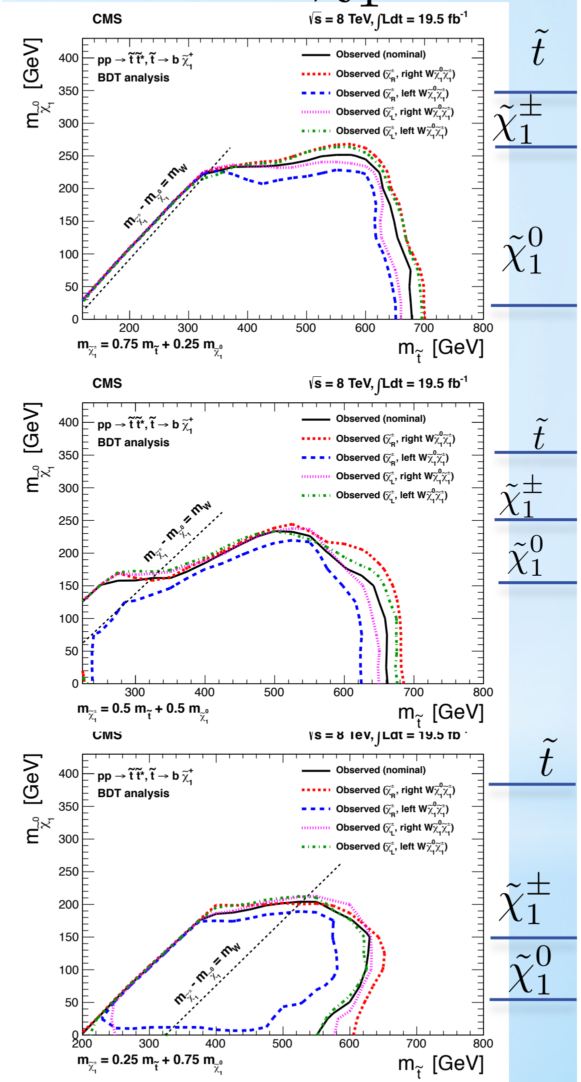
Exploit 0,1,2 leptons final states
Complex discriminating variables
Use boosted objects to reject SM top background

Top squark summary: CMS

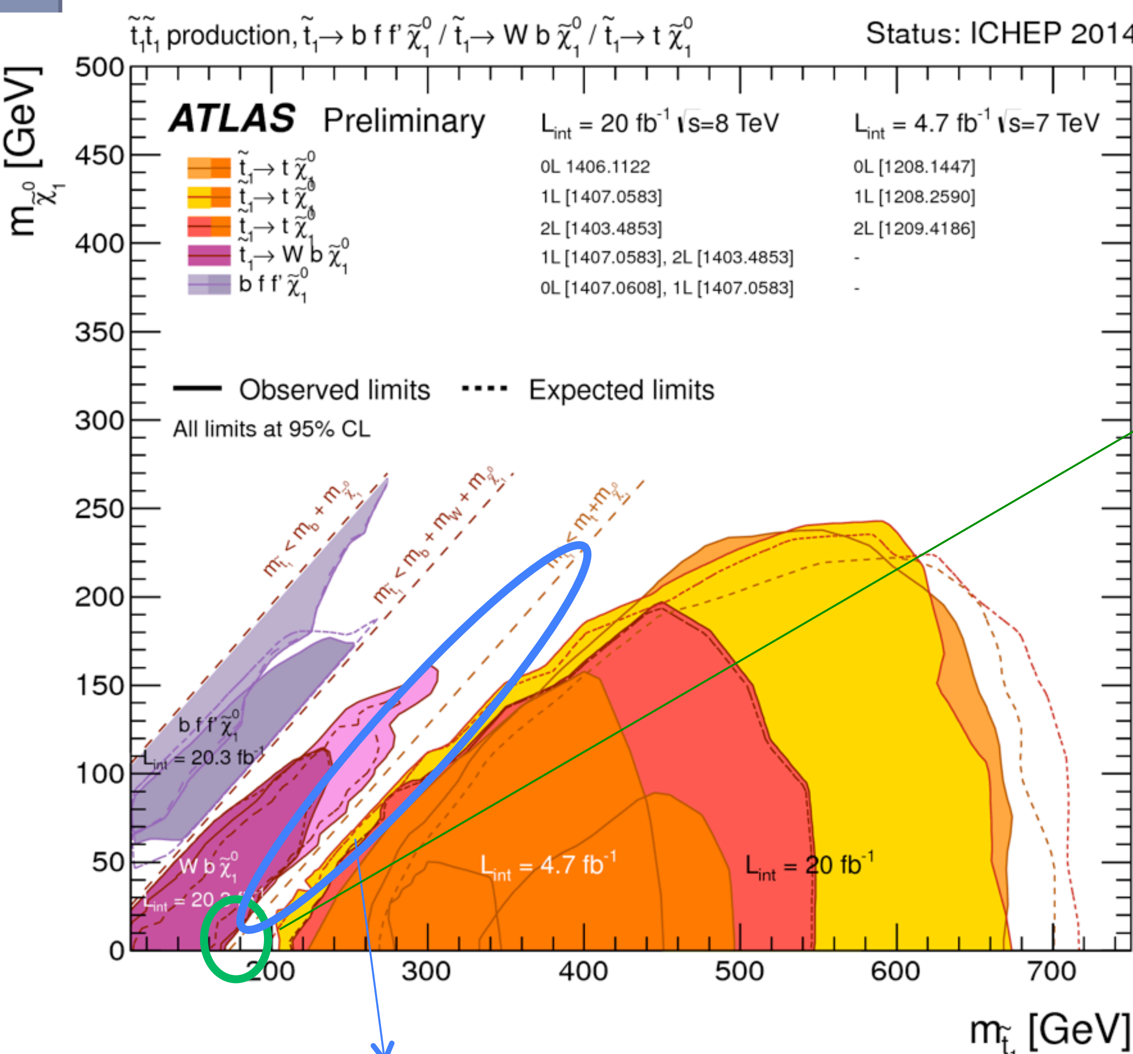


Combination of published MVA 1-lepton analysis with preliminary all hadronic Razor analysis.

$\tilde{t} \to b\tilde{\chi}_1^\pm$

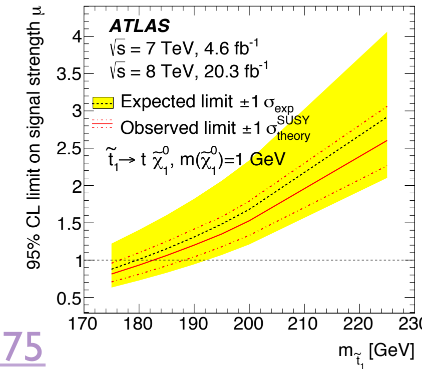


Top squark summary: ATLAS



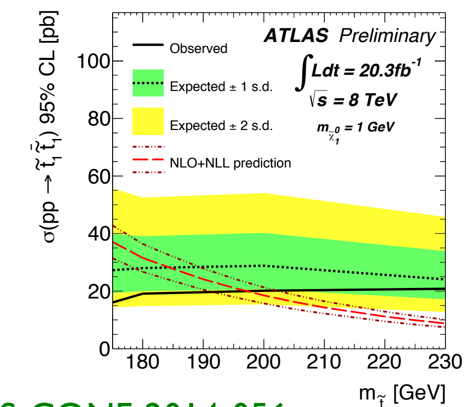
M(stop) ~ m(top):

- Constraints from $\sigma(t\bar{t})$ measurement



1406.5375

- Constraints from top-antitop spin correlations (exploit that stop is scalar)



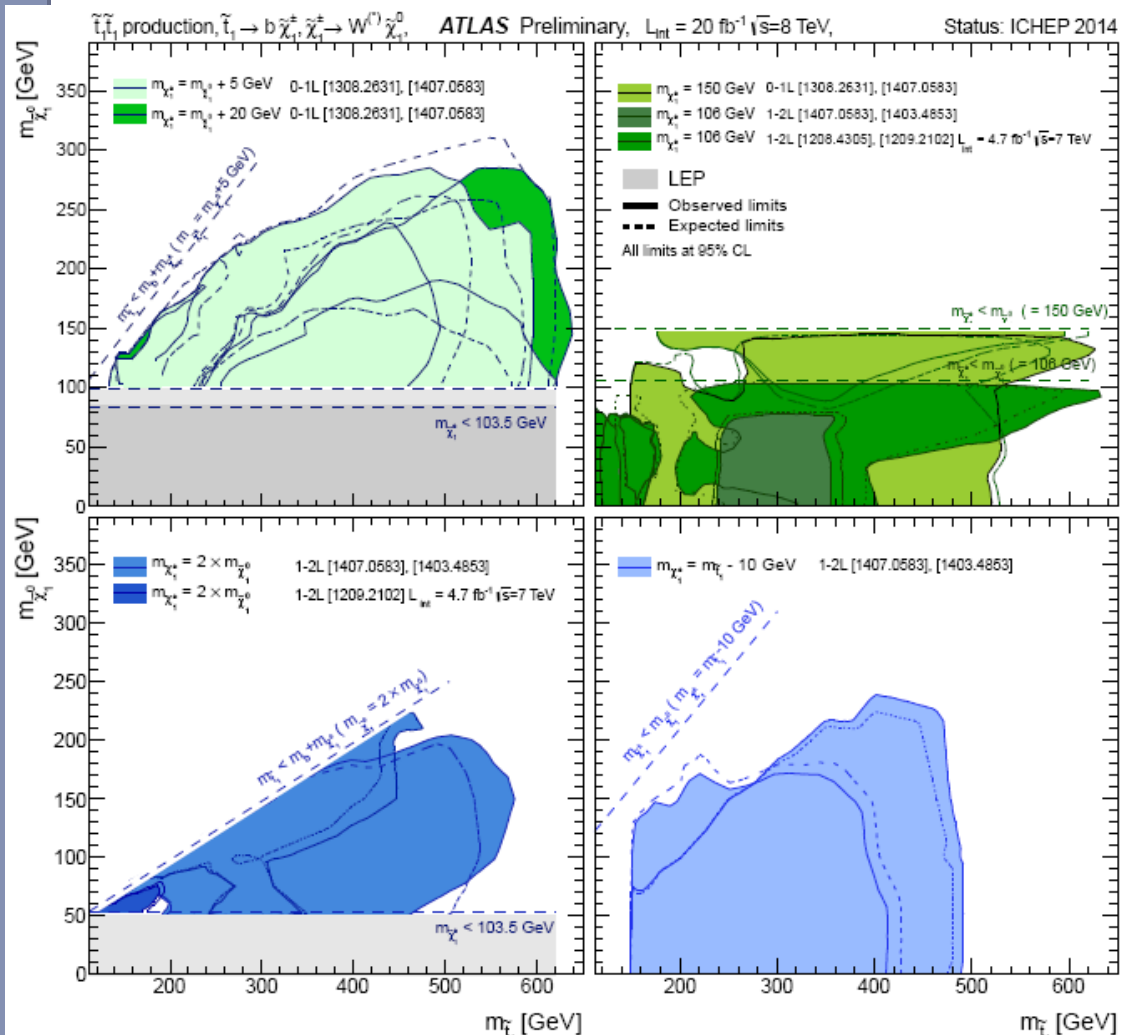
ATLAS-CONF-2014-056

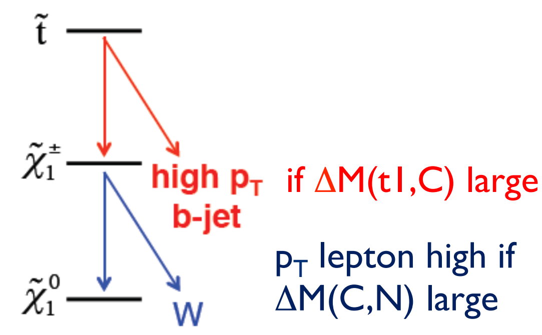
Also: M(stop) ~ m(top)+m(neut1): Compressed regions indirectly accessed via stop2 searches: Stop2 → stop1 + Z/higgs, Stop1 → t + Neut1

ATLAS: 1403.5222 (Z-mode)
CMS:1405.3886 (Z/H modes)

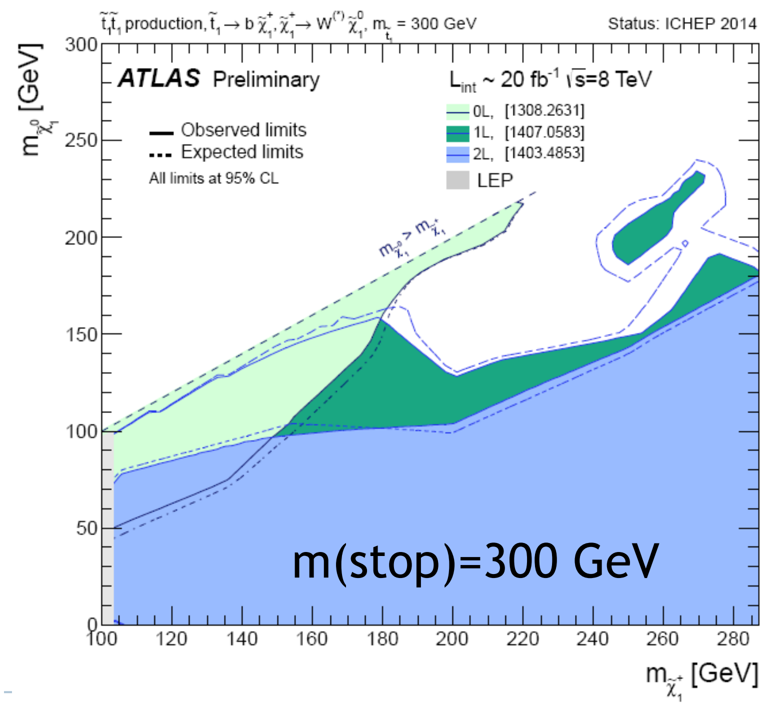
Top squark summary: ATLAS (II)

- Various assumptions of ΔM(stop-chargino) and ΔM(chargino-neutralino)



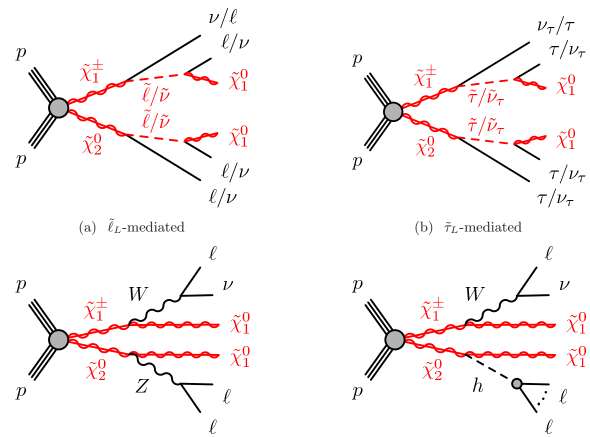


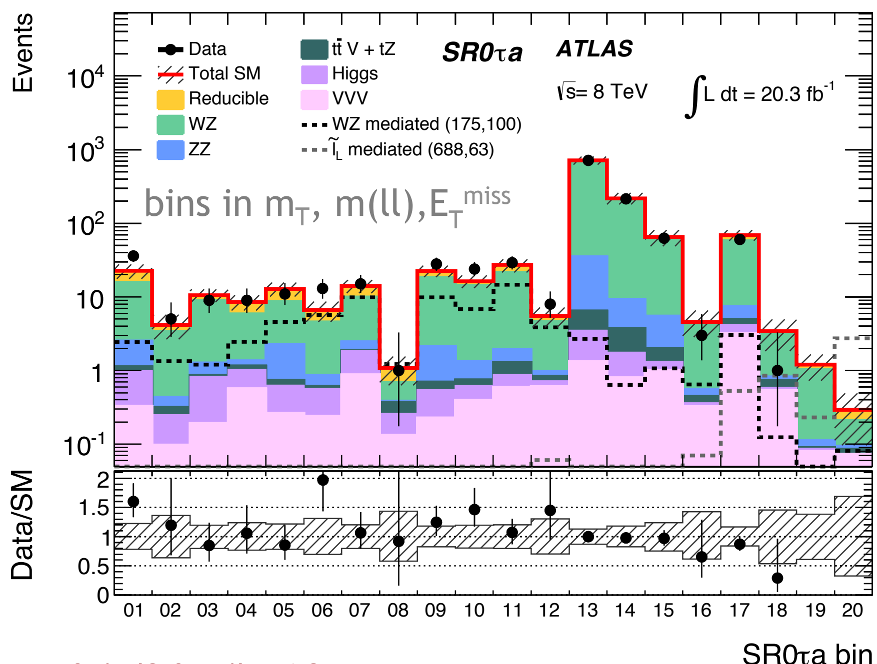
Fixed mass stop, function of chargino-neutralino mass



Searches for EWK SUSY production

- Low mass EWK SUSY particles (charginos, neutralinos, possibly sleptons) foreseen by several SUSY models
- Again very comprehensive search program covering various possible final states: high p_T leptons, WW,ZZ,WZ,Wh,Zh,hh + MET final states
- *Examples*:
  - ATLAS: 3 leptons (e, μ,τ), SFOS pair + E_T^{miss}





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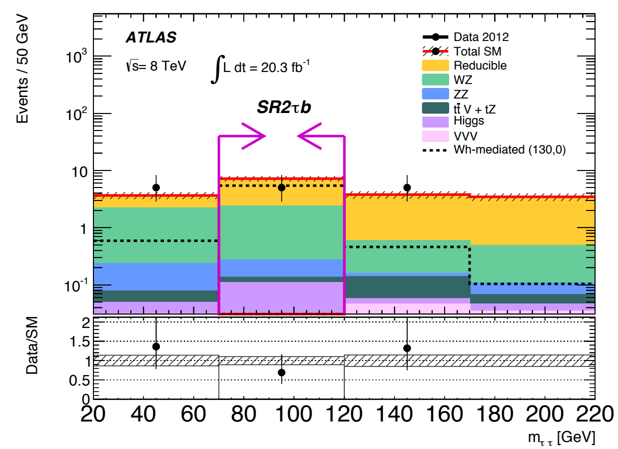
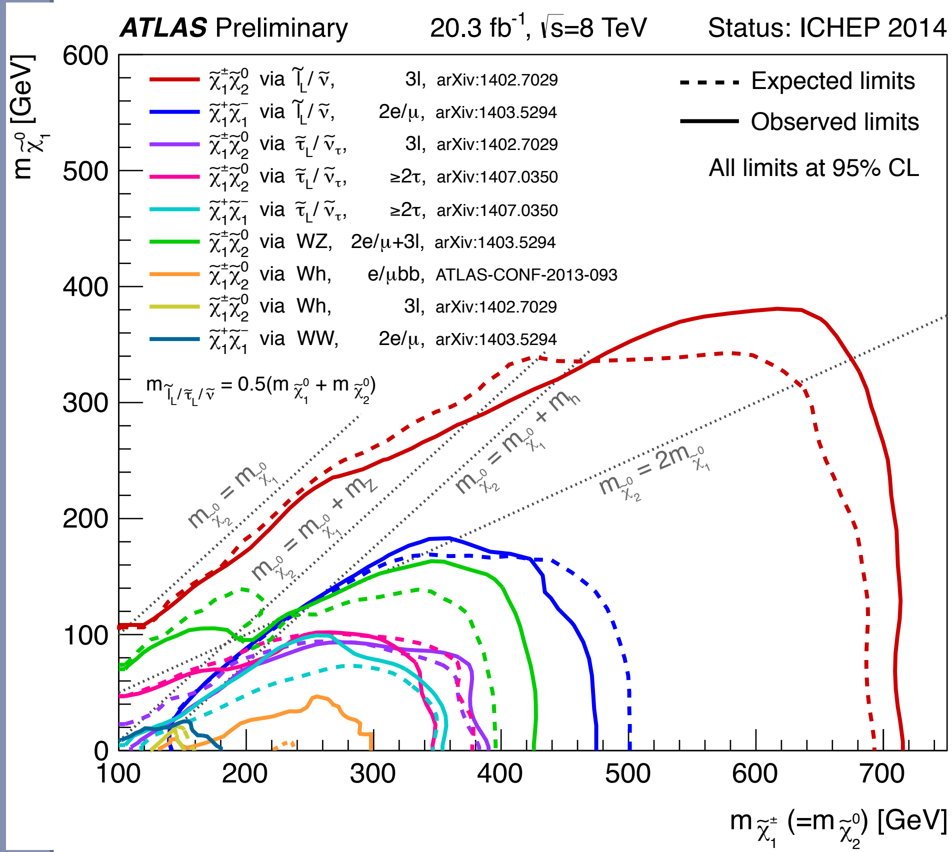
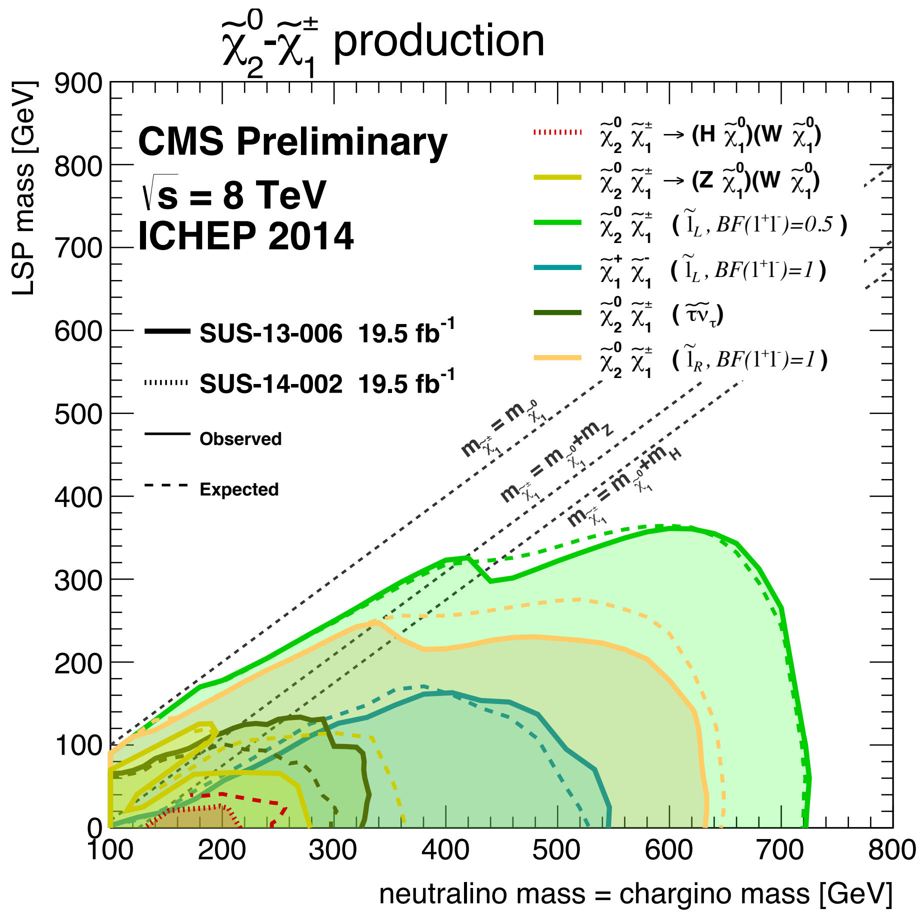


H→ττ in decay chain

Summary for chargino-neutralino production





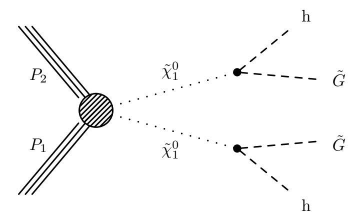
- Constraints on chargino/next-to-lightest neutralinos up to 720 GeV (if decays are mediated by sleptons); up to ~ 450 GeV for WZ-decays; little or no constraints for compressed scenarios
- **Great emphasis** on decay channels involving the higgs boson →

Searches for EWK SUSY with higgs

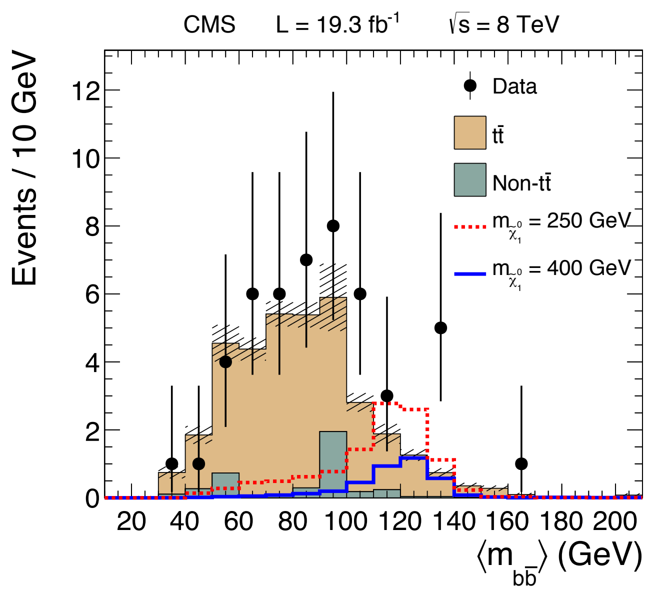
Higgs discovery opens up new branches of searches:

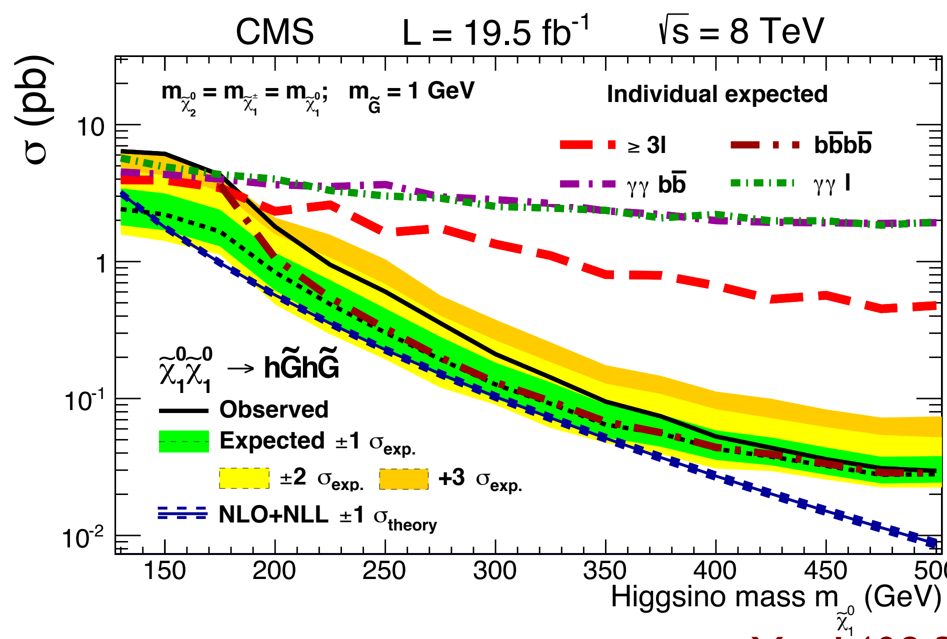
- Lightest neutral CP-even higgs expected to be SM-like, if others are heavy
- Charginos and neutralinos can decay to h+LSP

- CMS: Comprehensive set of searches for Zh, hh and hW final states
  - higgs in γγ, bb, ZZ* and WW*
  - Example for neutralino pair production in Gauge Mediated Models:



hh→bbbb mode



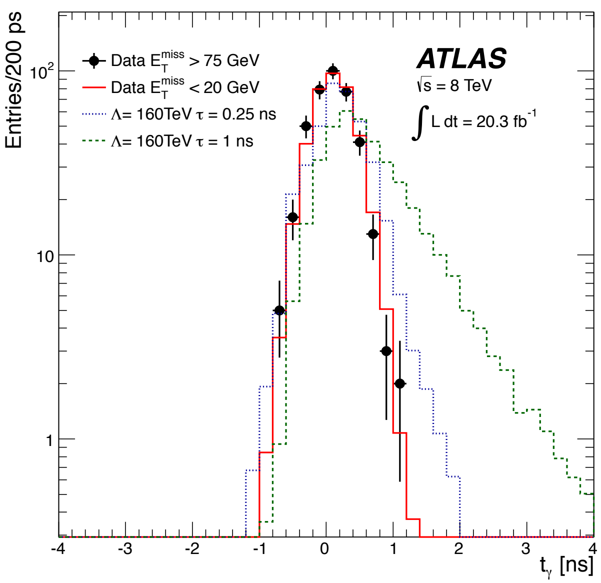


arXiv:1409.3168

Searches for long-lived (s)particles

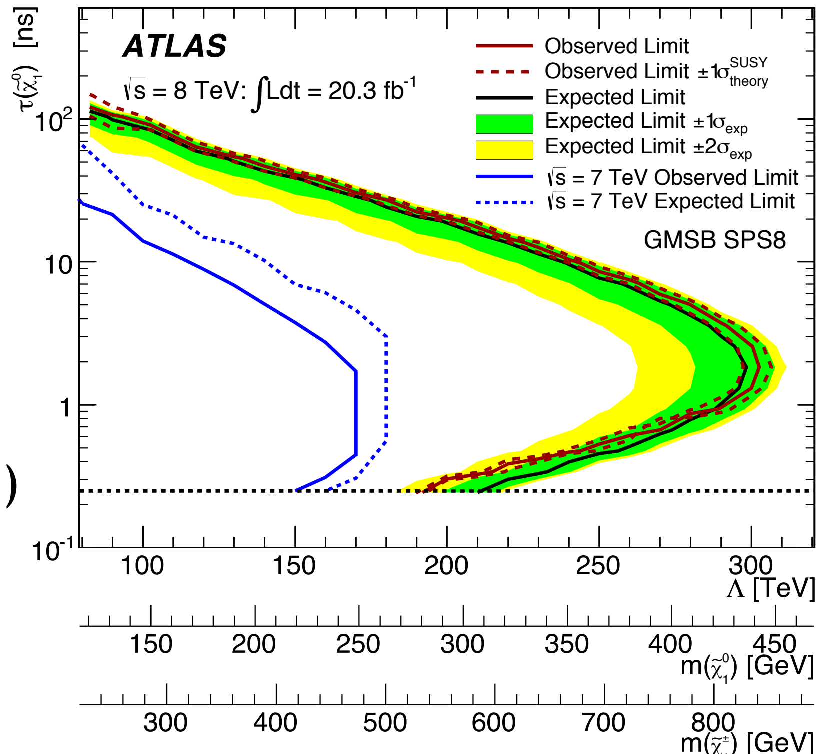
- Long Lived (LL) particles could be produced in RPV and RPC scenarios.
  - Several specific searches for displaced vertex, stable massive particles and more
- An example: delayed photons (ATLAS)
  - Di-photon + Missing E_T final states: one prompt, one non-prompt photon
  - Exploit ATLAS capability to make precise measurements of **flight direction and time**

arXiV:1409.5542



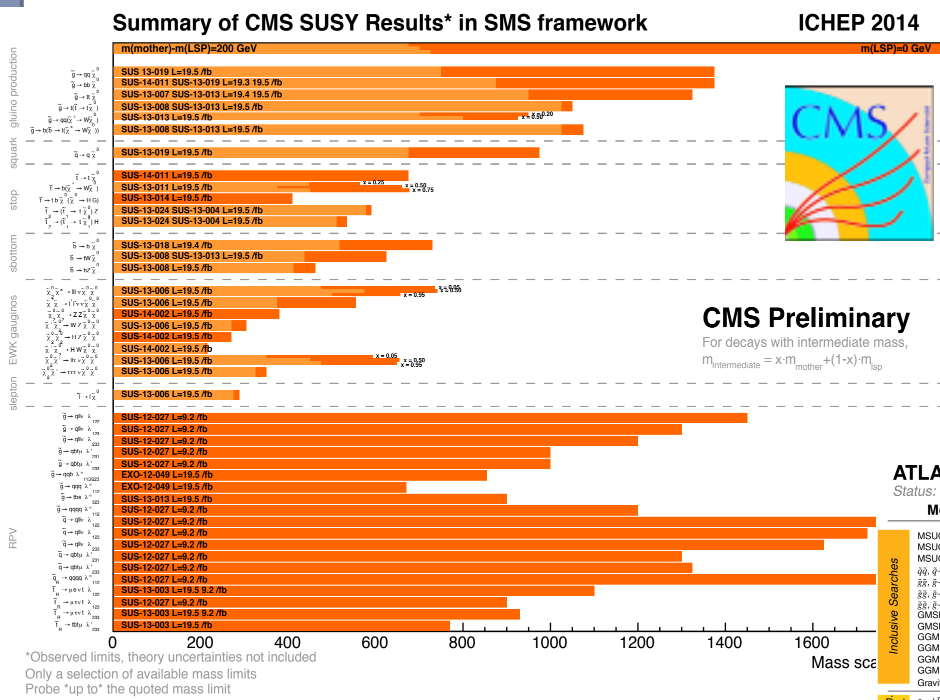
Target:
Strong and EWK production in Gauge Mediated Scenarios (GMSB)

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

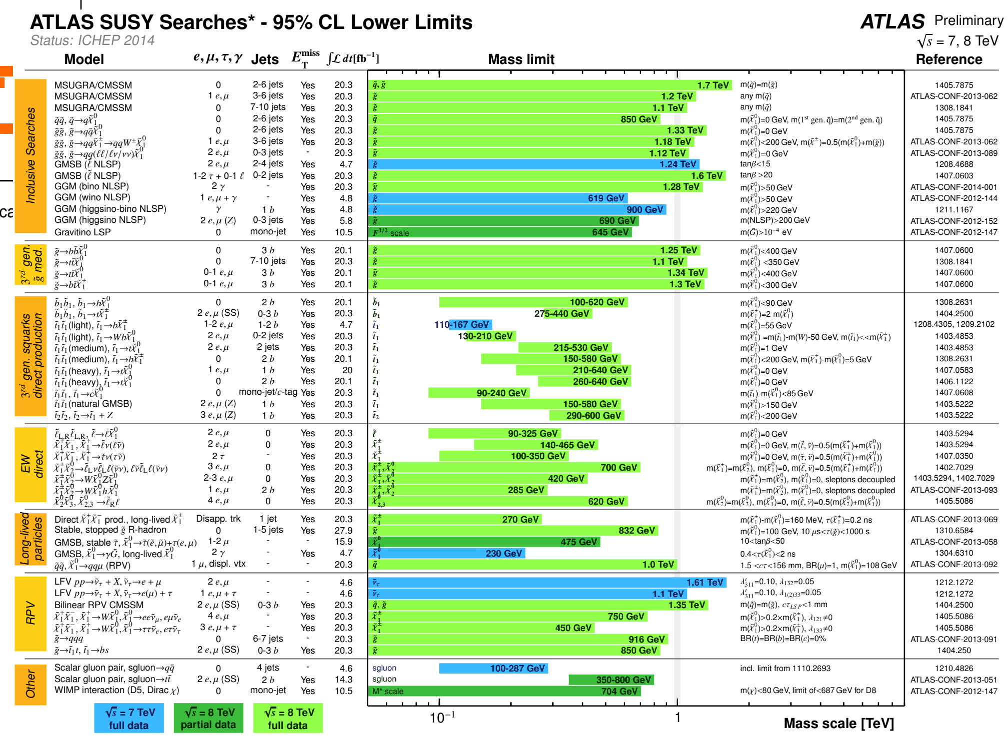


CDF:1307.0474 *(see back-up)*
Complementary search for delayed photons in exclusive $\gamma+E_T^{Miss}$

Grand summary for exclusion of SUSY



Stringent constraints beyond TeV-scale BUT ….



SUSY @ the end of Run 1

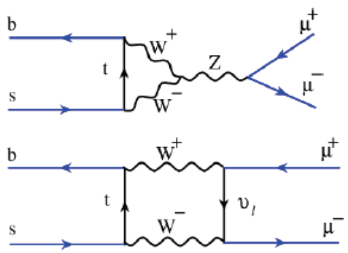
- Most simplistic version of SUSY under stress
  - Partially true also for 'Natural' SUSY, although depends *e.g.* on level of fine-tuning
- Still, lot of open suitable scenarios. A few examples:
  - Generic SUSY models explaining higgs mass indicate top squarks up the TeV range → not yet fully covered
    - If there are such 'light' stops, gluinos might be in the 2-3 TeV range → not yet reached
  - Decays of sparticle in most of SUSY models are complex:
    - Limitations on our limits: often valid only if a sparticle decays 100% in one mode
  - High scalar masses (O(10 TeV)) foreseen in several models (e.g. Split SUSY)
    - Focus on EWK sector, where boundaries are less stringent
  - More on the EWK sector: Low higgsino mass scenarios lead to "compressed" SUSY spectra (low ΔM Next-LSP – LSP) → difficult to corner because of low cross sections + low acceptances
  - R-parity violation scenarios not fully covered:
    - Lack of handles such as missing transverse momentum, complex phenomenology, possibly long-lived particles

Before moving to prospects, see what other (indirect) searches and measurements can tell us about SUSY

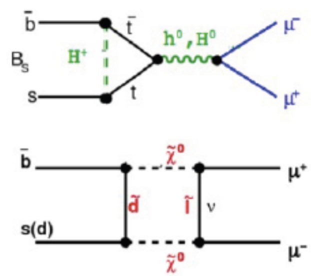
Indirect constraints

- **$B_s \rightarrow \mu\mu$:** constrain MSSM at large tan β
- BR Enhancement from many BSM models

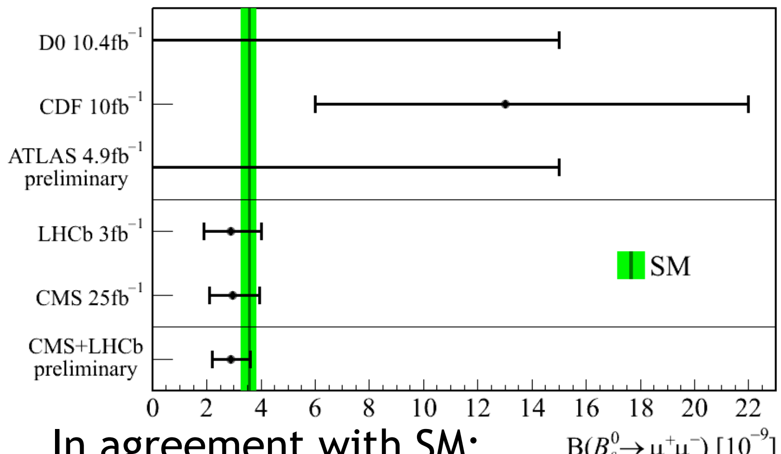
In SM:



In BSM:

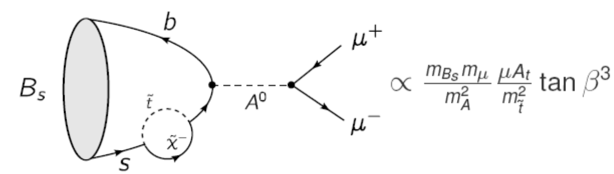


The CMS and the LHCb Collaborations have obtained a combined preliminary value of the Bs→μμ branching fraction of $(2.9 \pm 0.7) \times 10^{-9}$



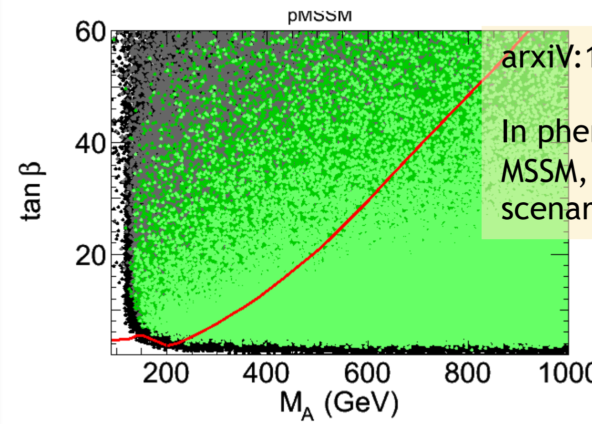
In agreement with SM: BR=$(3.56 \pm 0.30) \times 10^{-9}$

What can this tell us about SUSY?



Large tan β with light pseudoscalar Higgs disfavoured **BUT**
'Natural' (small fine tuning) MSSM scenarios barely affected

- SUSY-BR($B_s \rightarrow \mu\mu$) is ~ to SM-BR or even smaller in some scenarios



arxiV:1212.4887

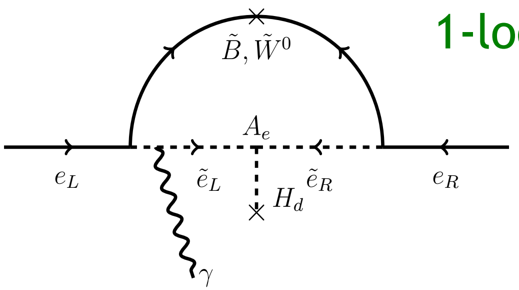
In phenomenological MSSM, only < 20-30% scenarios are excluded

Indirect constraints (II)

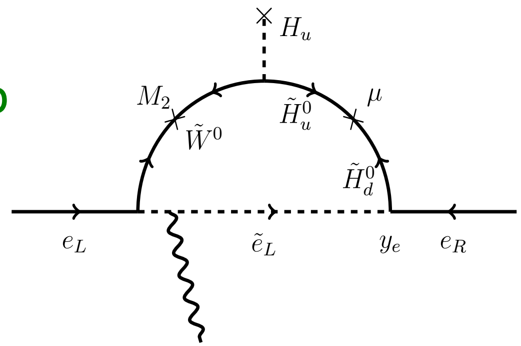
- **EDM:** As other BSM theories, SUSY predict small – yet measurable electron electric dipole moment (d_e)

  (In SM, $d_e \sim 10^{-44}$ *e* cm)

1-loop

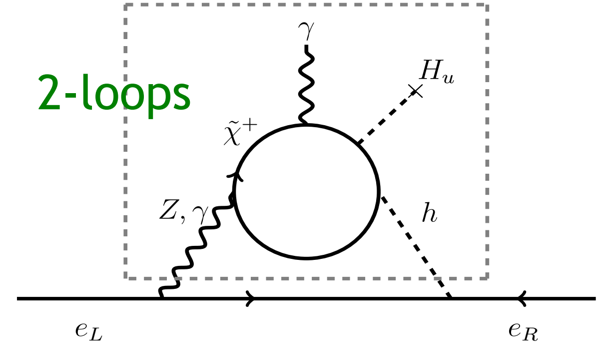


Bino-higgsino/Selectron

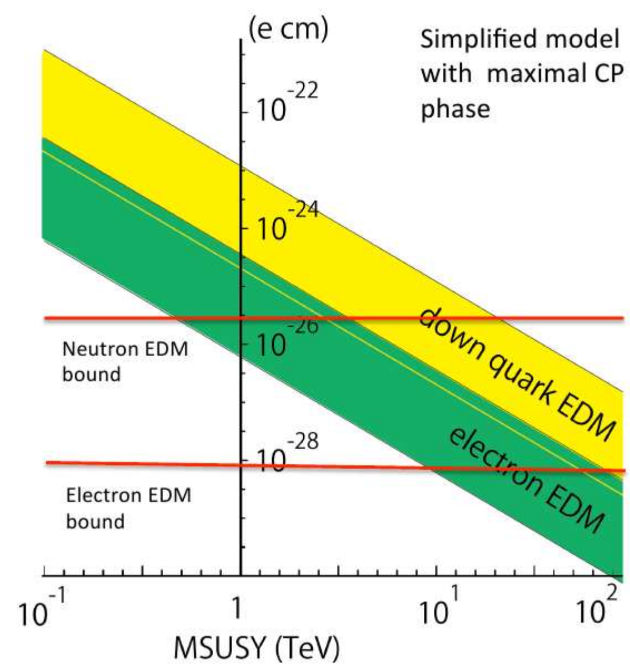


Selectron-electron-higgsino interaction

2-loops



(Hisano @ Moriond EW 2014)



ACME collaboration (arXiV:1310.7534):

- d_e = -2.1±3.7(stat)±2.5(syst) x 10^{-29} *e* cm
- $|d_e| < 8.7 \times 10^{-29}$ *e* cm
  - for models where 1- (2-loop) diagrams produce d_e, bound on CP violation at energy scales **Λ ~ 3(1) TeV**

→ **Small CP phases ←→ decoupling:** Might indicate preference for **Split SUSY** and/or **1st generation squark/slepton masses** at O(10) TeV

(preserves EWK sector / naturalness)

Indirect constraints (III)

$$\left(a_\mu := \frac{g_\mu - 2}{2}\right)$$

- Anomalous magnetic moment: Muon g-2

$$a_\mu^{SM} = (116\,591\,828 \pm 49) \times 10^{-11}$$
$$a_\mu^{exp} = (116\,592\,089 \pm 63) \times 10^{-11}$$

$$\Delta a_\mu \equiv a_\mu(\mathrm{exp}) - a_\mu(\mathrm{SM}) = (26.1 \pm 8.0) \times 10^{-10}$$

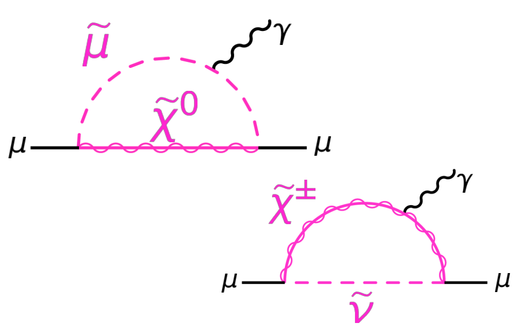
3.3 σ discrepancy → New Physics ? SUSY ?

$$\delta a_\mu \sim (\alpha_{\mathrm{NP}}/4\pi) \times (m_\mu^2/m_{\mathrm{NP}}^2)$$

Coupling constant of new particles to the muon

Typical scale of new particle mass

SUSY contributions to g-2:
neutralino-smuon and chargino-sneutrino loop diagrams

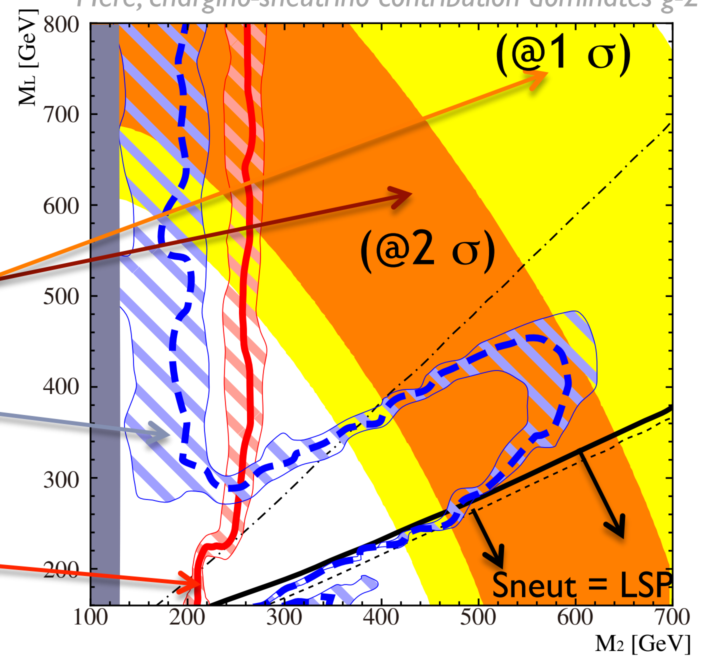


- SUSY explains g-2
- LEP searches
- Excluded by LHC-lepton searches
- Excluded by LHC Jet searches

M_1,M_2=bino,wino masses
μ = higgsino mass
m_L = slepton (LH component) mass

JHEP01(2014)123
LHC and g-2 constraints

Here, chargino-sneutrino contribution dominates g-2

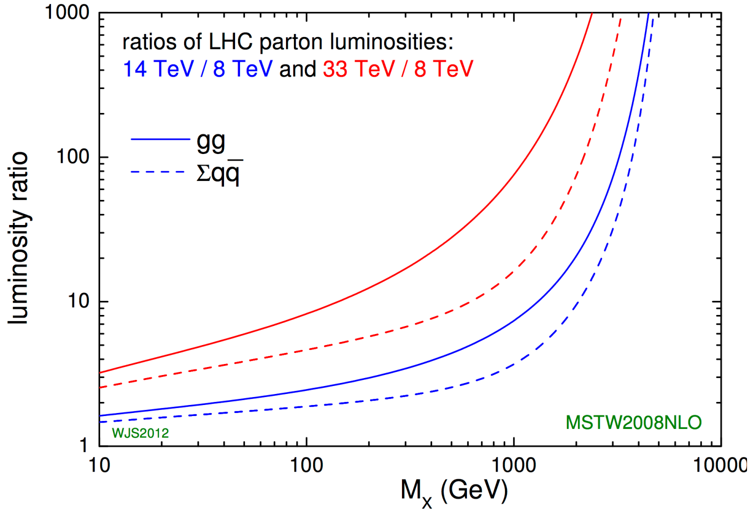


(a) $\mu = M_2$, $m_R = 3\,\mathrm{TeV}$

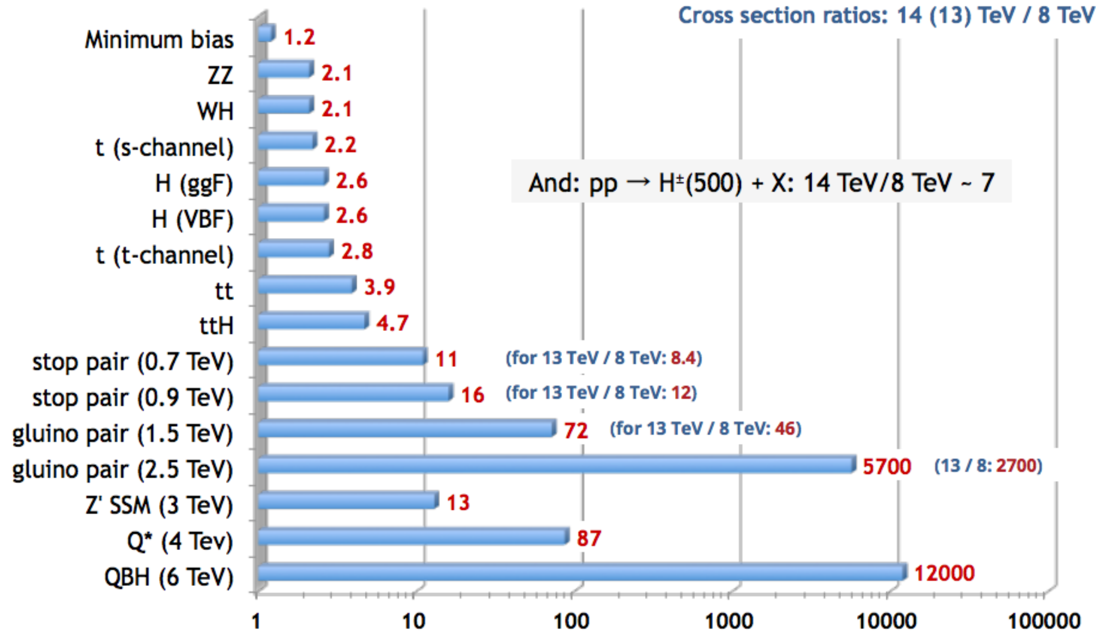
Prospects for discovering SUSY in the next decades

The next steps for the LHC

- **LHC Runs 2 and 3**, up to 300 fb^{-1} at $\sqrt{s}$ = 13/14 TeV
  - Huge increase in sensitivity wrt Run 1 in multi-TeV region



Cross section 14 TeV / 8 TeV	gg	$\Sigma q\bar{q}$
M_X = 2 TeV	~20	~10
M_X = 3 TeV	~70	~30
M_X = 4 TeV	~400	~160

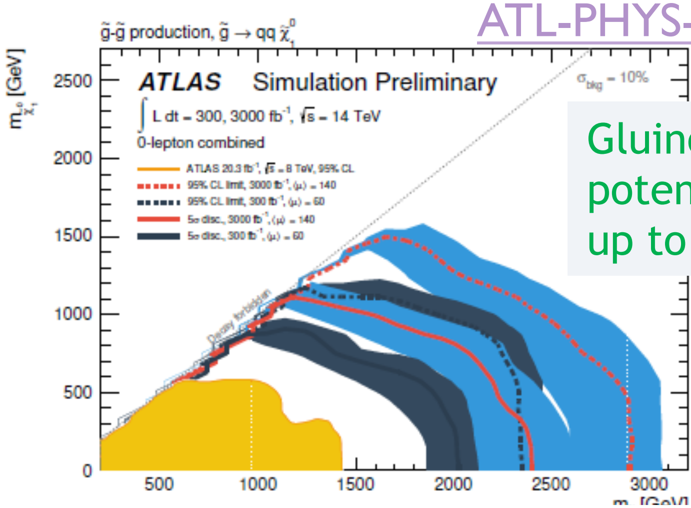


- **High Luminosity (HL)-LHC:**
  - up to 3000 fb^{-1} at $\sqrt{s}$ = 14 TeV → factor of 10 luminosity crucial for new physics processes with low cross section (e.g. EWK SUSY, 3rd generation squarks)

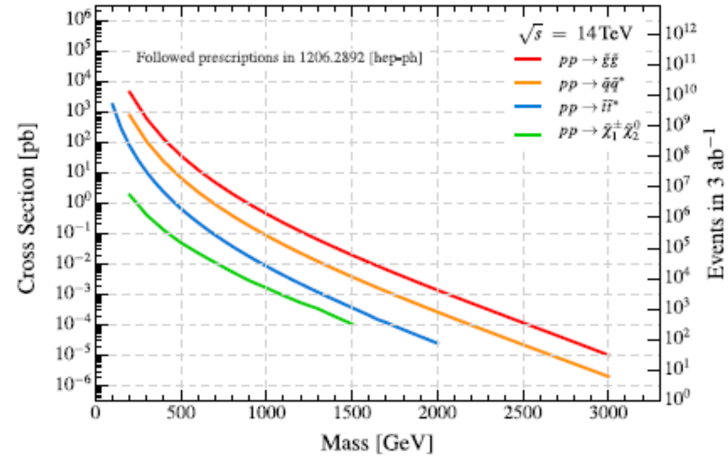
Squark/gluinos reach at HL-LHC

- Compare the search reach with 300 and 3000 /fb at 14 TeV

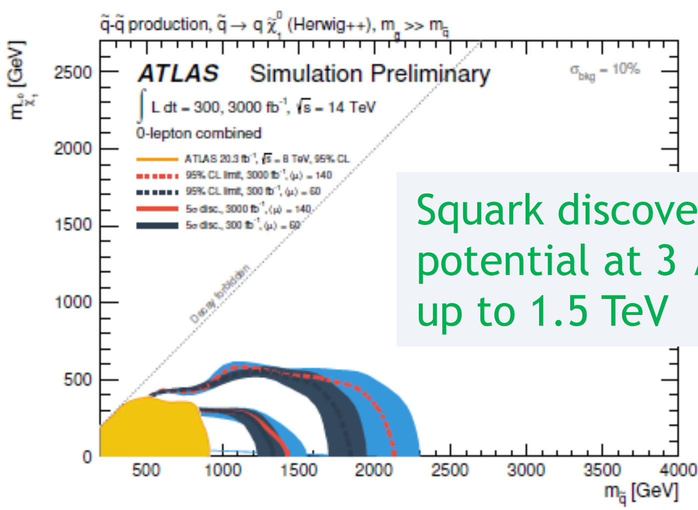
ATL-PHYS-PUB-2014-010



Gluinos discovery potential at 3 /ab up to 2.5 TeV

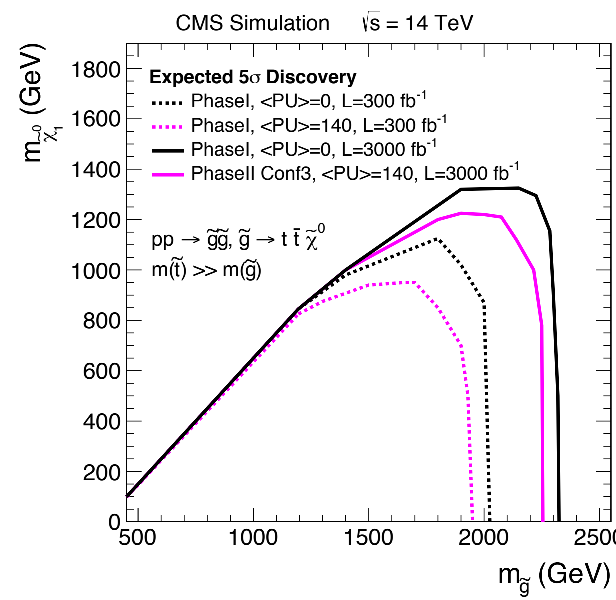


Discovery reach up to 2.5-3 TeV



Squark discovery potential at 3 /ab up to 1.5 TeV

CMS PAS FTR-13-014

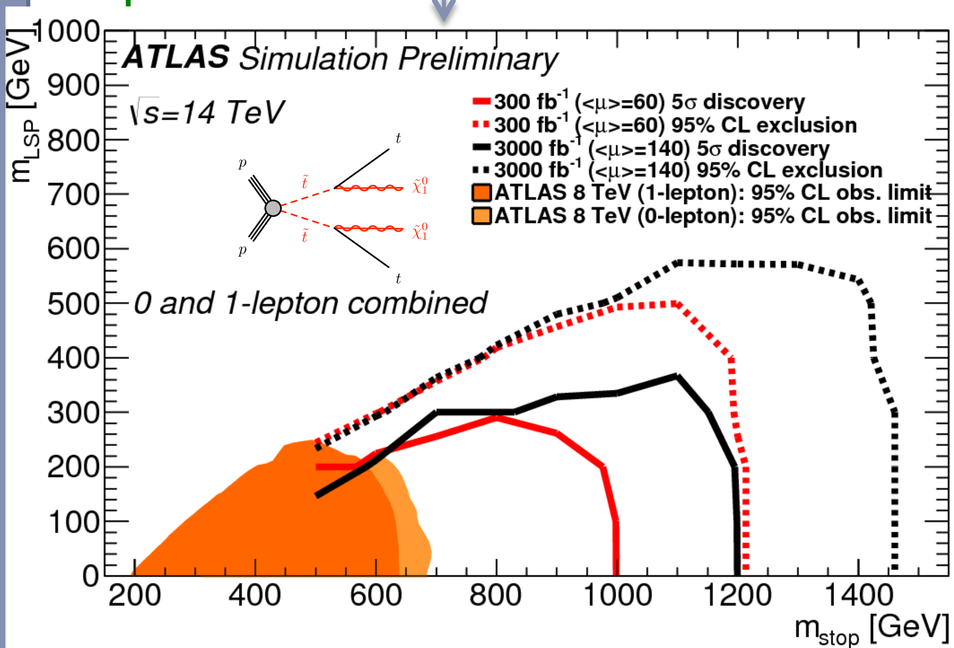


Third generation squarks

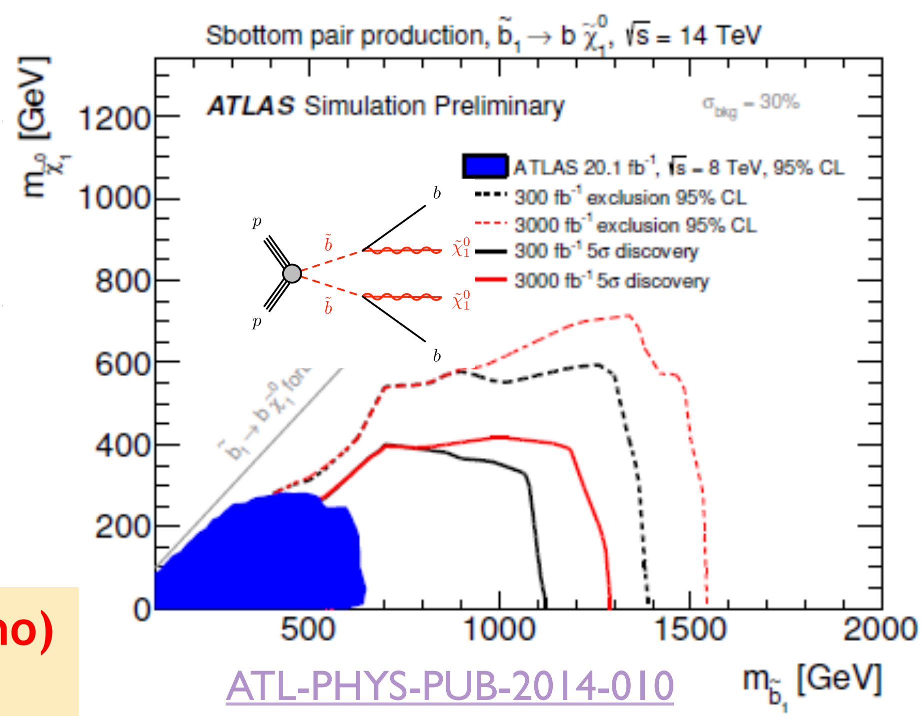
- Top and bottom squarks
  - Direct production, feasibility studies only for standard cases (b/t+LSP)
  - Predictions for 'compressed' scenarios more difficult → need complex analyses, good level of knowledge for systematic uncertainties

stop

ATL-PHYS-PUB-2013-011



sbottom



ATL-PHYS-PUB-2014-010

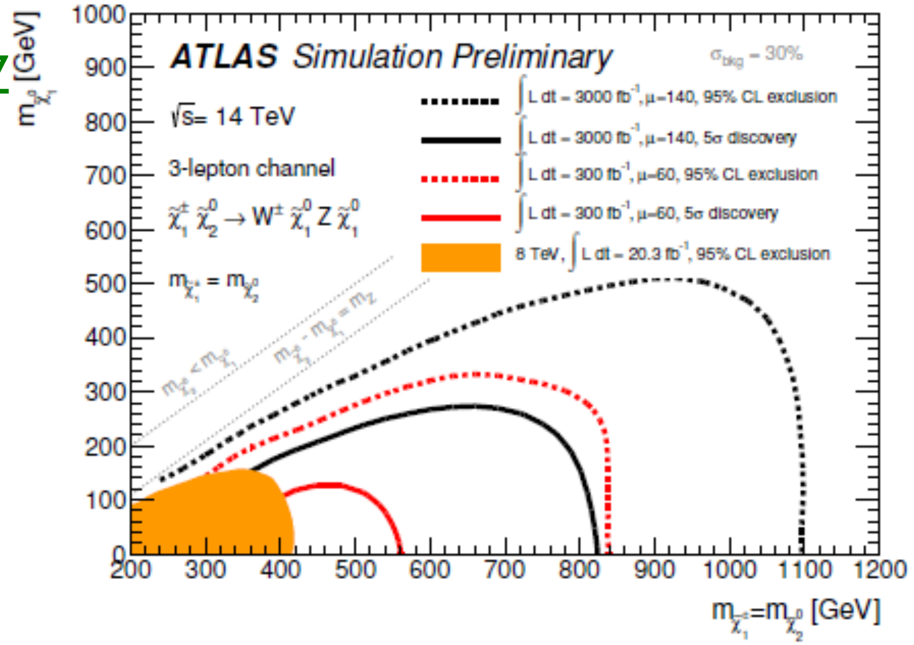
Discovery reach up to 2.5 TeV (gluino) and above 1 TeV (stop/sbottom)

EWK SUSY at the HL-LHC

- Chargino and neutralino production

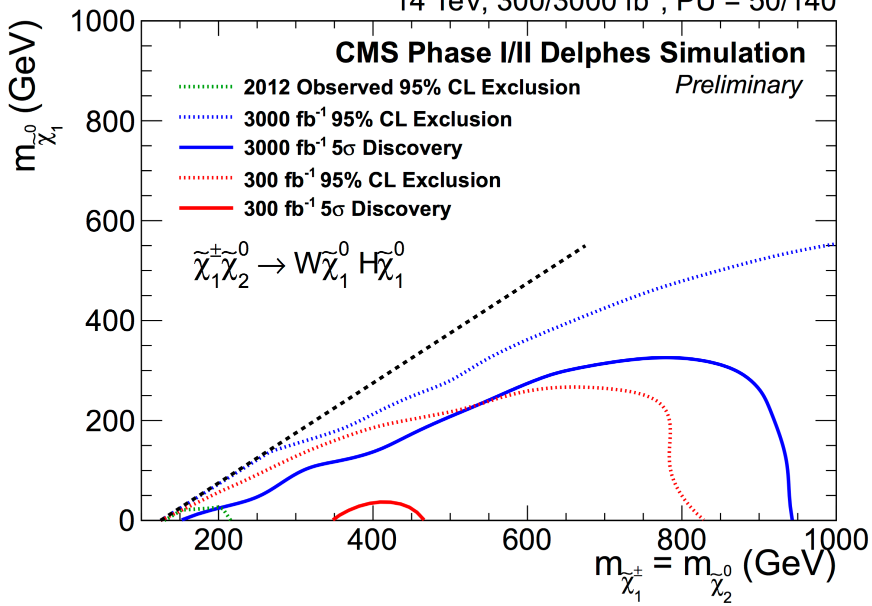
ATL-PHYS-PUB-2014-010

Via WZ



Via WH, with higgs in WW*, ττ

CMS PAS SUS-14-012

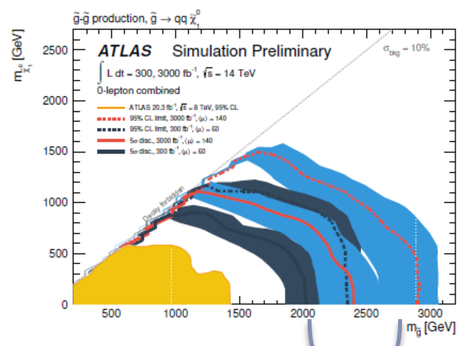


Charginos/Neutralinos discovery potential at 3/ab up to 800(600) GeV depending on decays mode

Very challenging even with 3 /ab

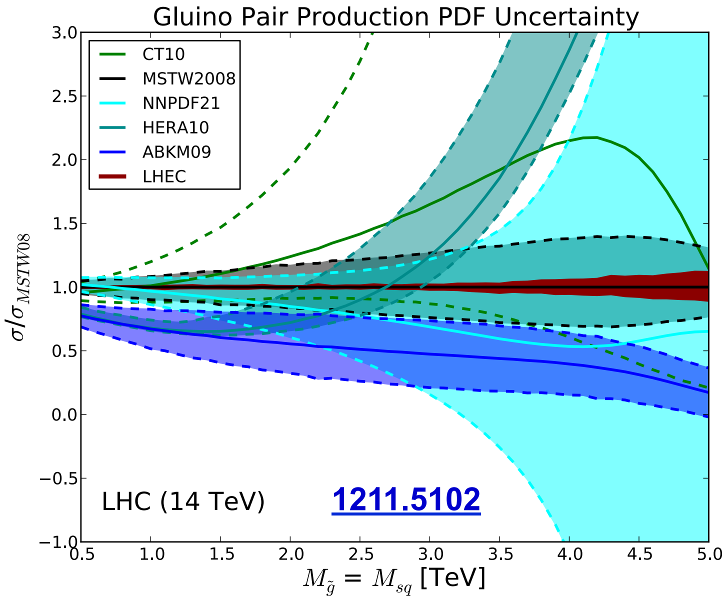
More prospects: the LHeC

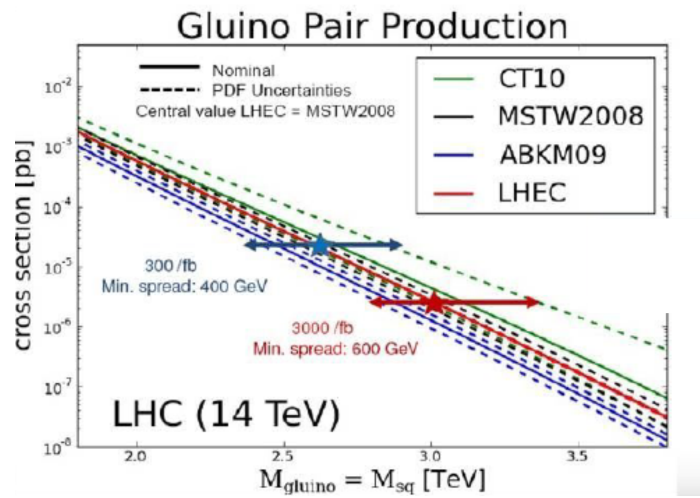
- **Large Hadron-electron collider:** Operations simultaneous with HL-LHC *pp* physics, 60 GeV ele – 7 TeV p, up to 1 ab^{-1} luminosity
- **For SUSY:** Searches near HL-LHC kinematic boundary may ultimately be limited by knowledge of PDFs (especially gluon at x → 1)
  - Example: gluino production at HL-LHC



Effect could be up to 1 TeV

→ >100% PDF uncertainty → Dependency on discovery potential and exclusion limits at 300 and 3000 /fb for 14 TeV c.o.m.



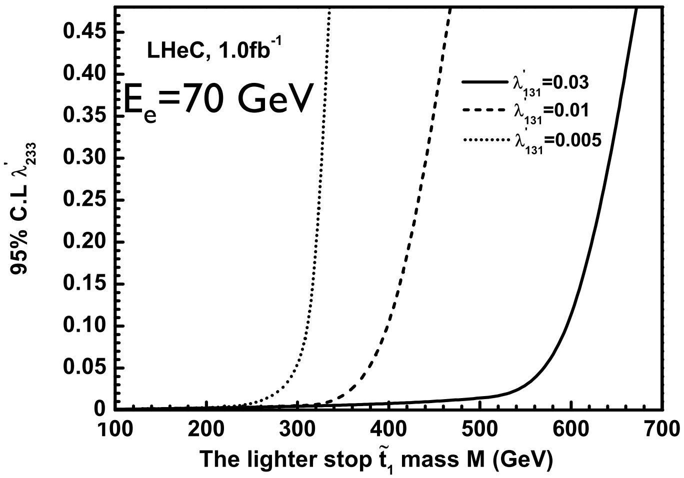


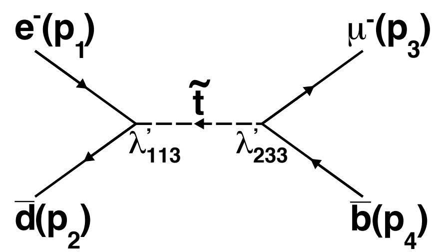
Clear improvement with LHeC data! (<5% uncertainty)

More prospects: the LHeC (II)

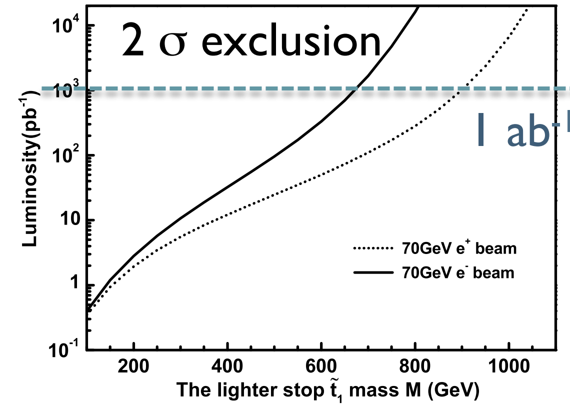
- **Large Hadron-electron collider:** Operations simultaneous with HL-LHC *pp* physics, 60 GeV ele – 7 TeV p, up to 1 ab^{-1} luminosity
- **For SUSY:** Searches for R-parity violating SUSY – often challenging at the LHC
  - Examples: top and sbottom squarks RPV

arXiV: 1107.4461

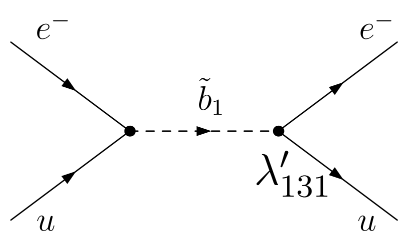




Sensitivity up to 700-800 GeV stop



lepton-flavor-conserving process under single coupling dominance hypothesis



$m_{\tilde{b}_1}$ (GeV)	$E_e = 50$ GeV	
	σ_S (pb)	$\mathcal{L}$ (pb^{-1})
100	5.34	13.5
200	1.32	39.7
...	.....	.....
600	8.24×10^{-2}	451
700	3.83×10^{-2}	956
800	1.49×10^{-2}	2.46×10^{3}
900	4.31×10^{-3}	8.64×10^{3}
1000	7.23×10^{-4}	5.62×10^{4}

arXiV: 1401.4266

< 100 fb^{-1} needed for **1 TeV RPV sbottom 5 σ discovery**

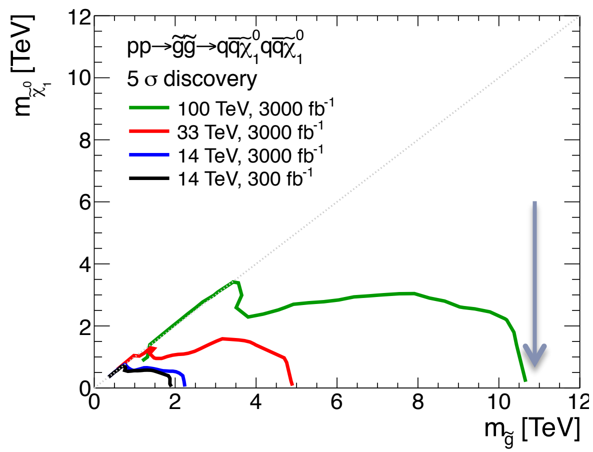
Even more prospects: High Energy colliders

- **Higher Energy hadron colliders** of course provide an exciting playground for SUSY with possibility of reaching high sparticle masses!
  - 50-70 TeV *pp* collider (SppC)
  - 100 TeV *pp* collider (FCC-hh)

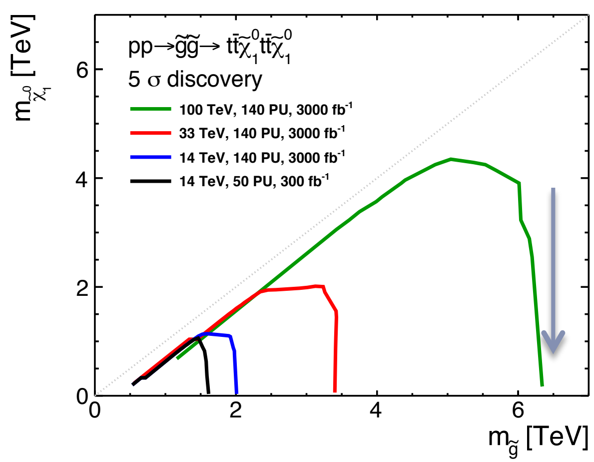
Rule of thumb: at fixed Lumi, discovery reach scales as 2/3 E_{beam}
X 5 from 14 to 100 TeV

Gluino pair production @ 100 TeV

Simple feasibility studies: several jets + ETMiss searches

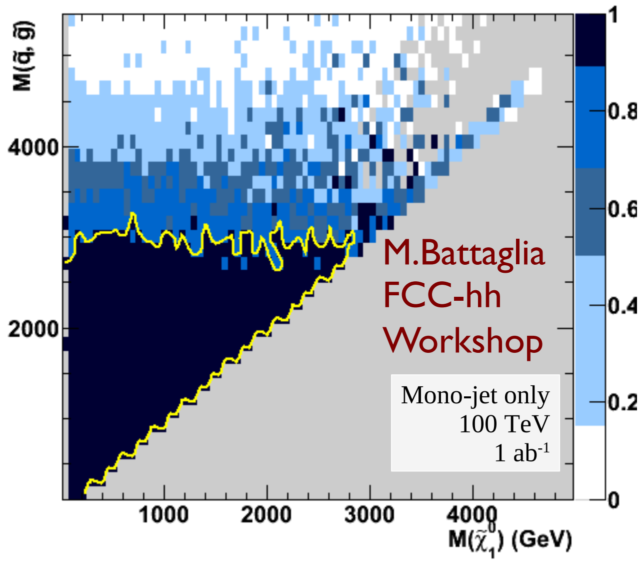


→ Discovery reach up to 11(6) TeV depending on decay mode



arXiV:1310.0077
(Snowmass '13 studies)

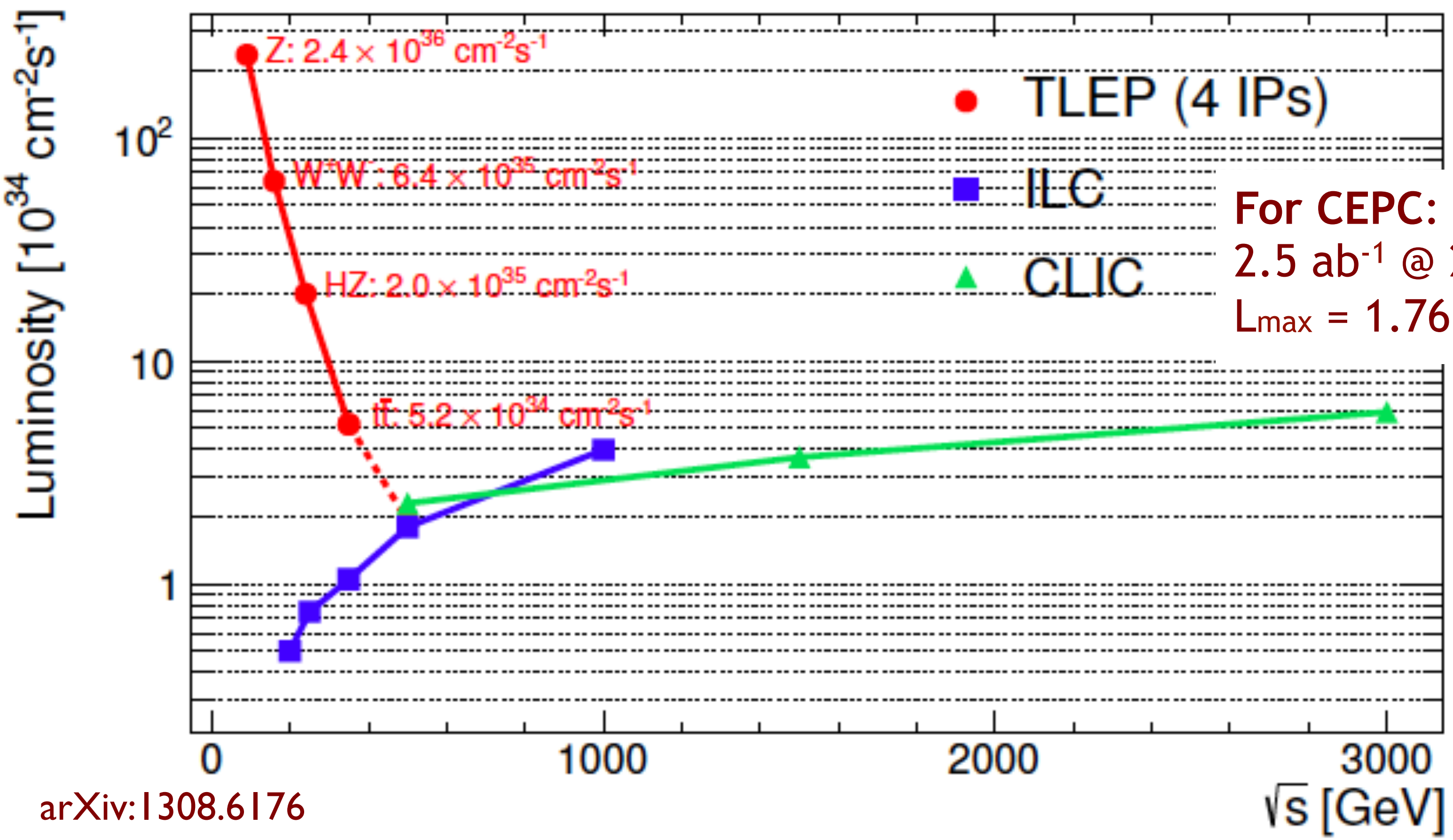
Feasibility studies: mono-jet searches (relevant for compressed scenarios)



FCC-hh to operate **at the same time of FCC-he and FCC-ee: great complementarity**

electron-positron machines

- Various proposals under study (at different stages):
  - Linear e+e- colliders: ILC, CLIC
  - Circular e+e- colliders: FCC-ee (was TLEP), CEPC

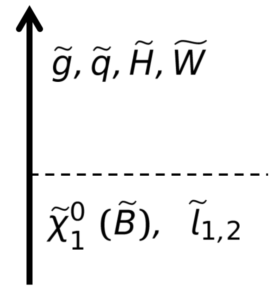


For CEPC:
2.5 ab^{-1} @ 250 GeV
$L_{max} = 1.76\times10^{34}\ cm^{-2}s^{-1}$

arXiv:1308.6176

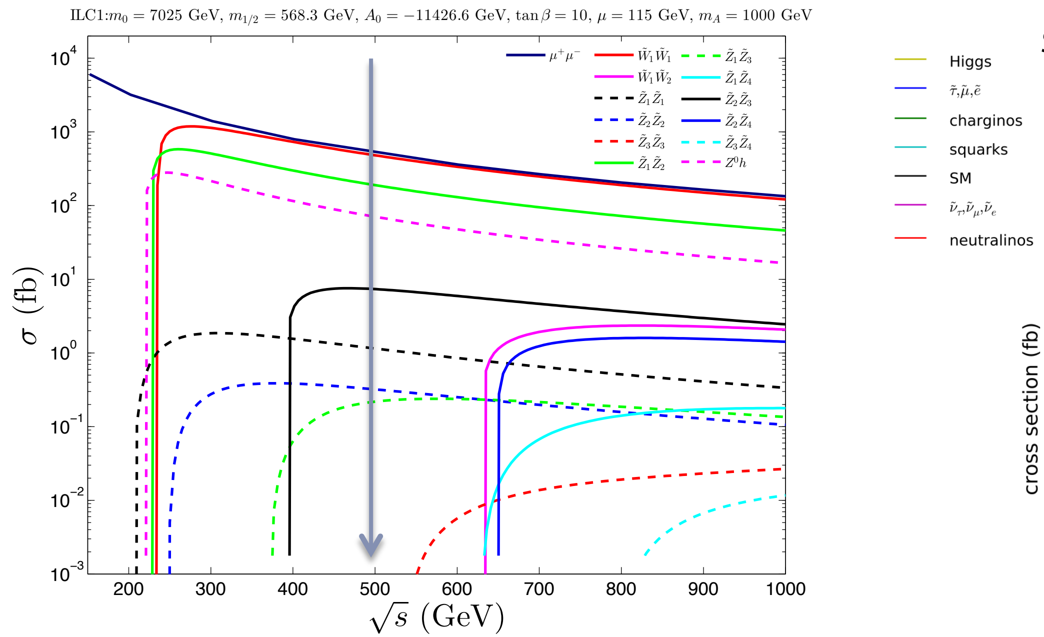
electron-positron machines

- Various proposals under study:
  - Linear e+e- colliders: ILC, CLIC
  - Circular e+e- colliders: FCC-ee (was TLEP), CEPC
- Why are they interesting for SUSY ?

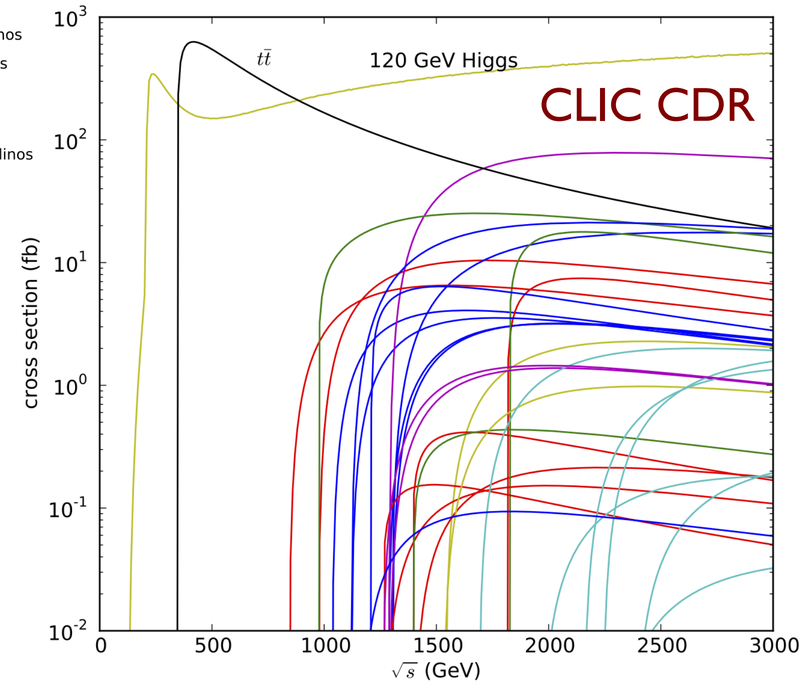


Sensitive to EWK process
Compressed scenarios in 'Natural' SUSY

Sparticle σ for unpolarized beams at e+e- for ILC benchmark



Sparticle σ at e+e- for one CLIC benchmark point

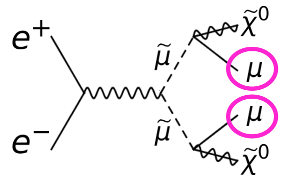


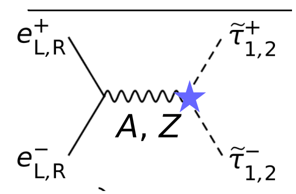
arXiV:1404.7510

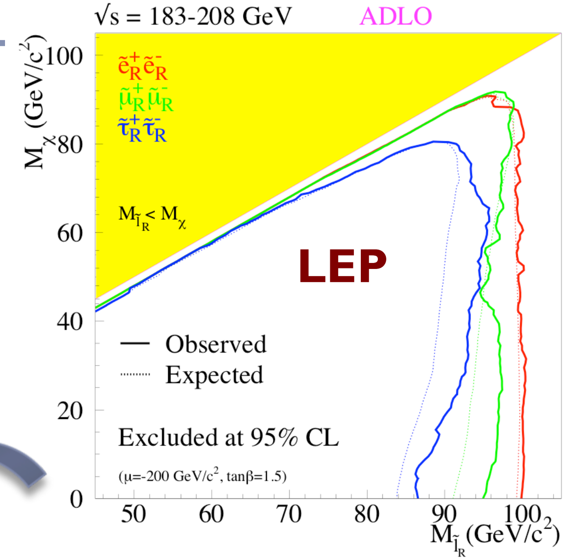
High cross section for $\chi^{\pm}_1$ and χ_0 production and sleptons: clean environment to access very compressed scenarios

electron-positron machines (II)

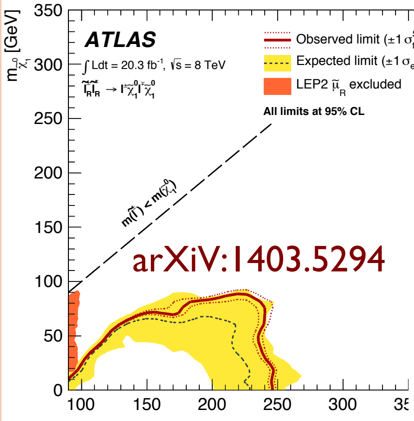
- In EWK SUSY sector, some of the LEP limits are still the most stringent up to date.
- *Example:*
  - slepton pair production





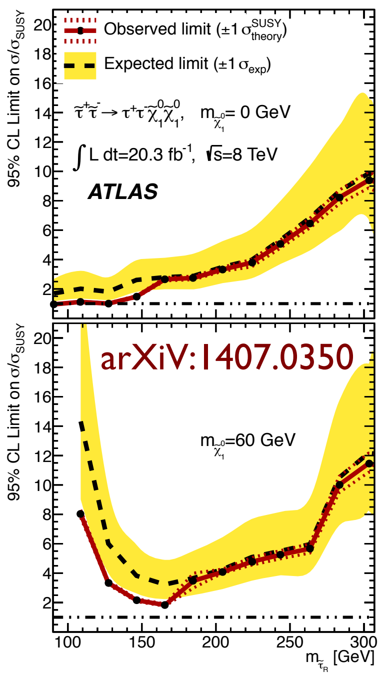


LHC current results



$\tilde{e}/\tilde{\mu}_R$ mass

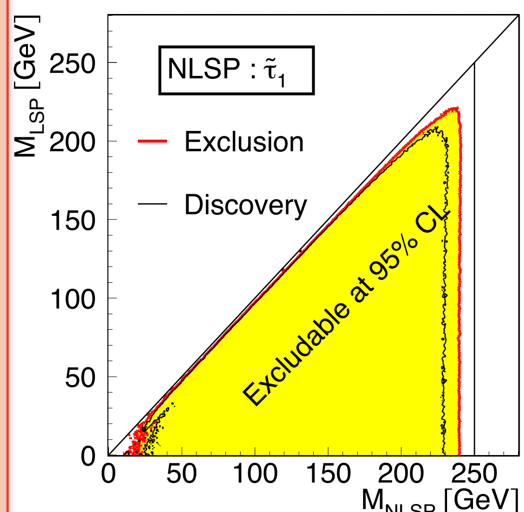
$\tilde{\tau}_1$ mass

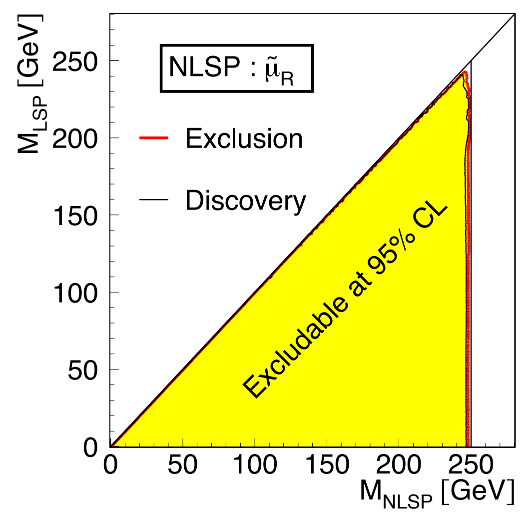


Difficult to probe regions with ΔM(Next LSP-LSP)<100 GeV

ILC (500 GeV)

arXiV:1307.5248



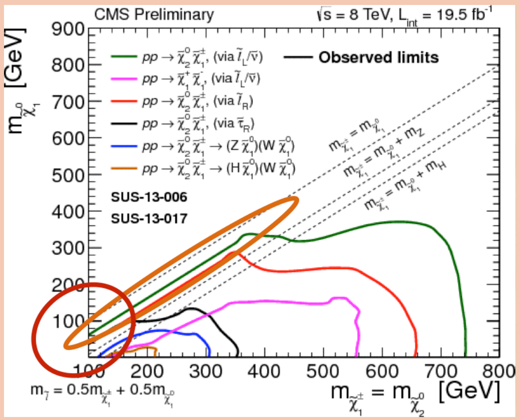


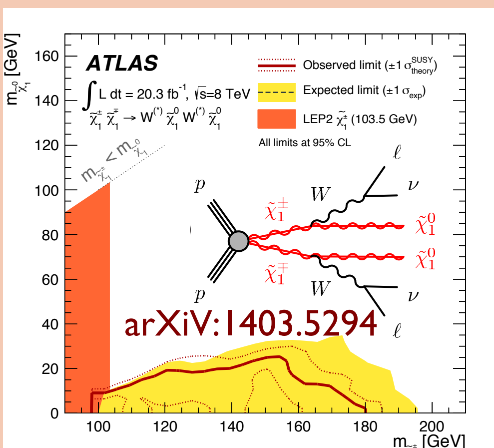
Similar studies in progress for circular colliders

electron-positron machines (III)

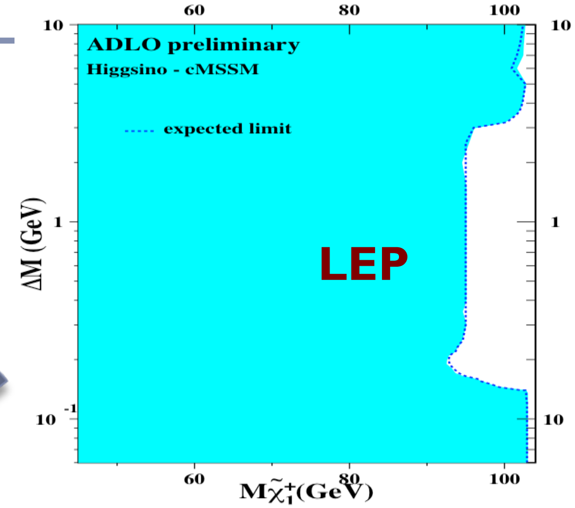
- **Chargino/neutralino pair production**
- Very challenging at hadron colliders if no intermediate sleptons and/or in compressed scenarios

LHC current results

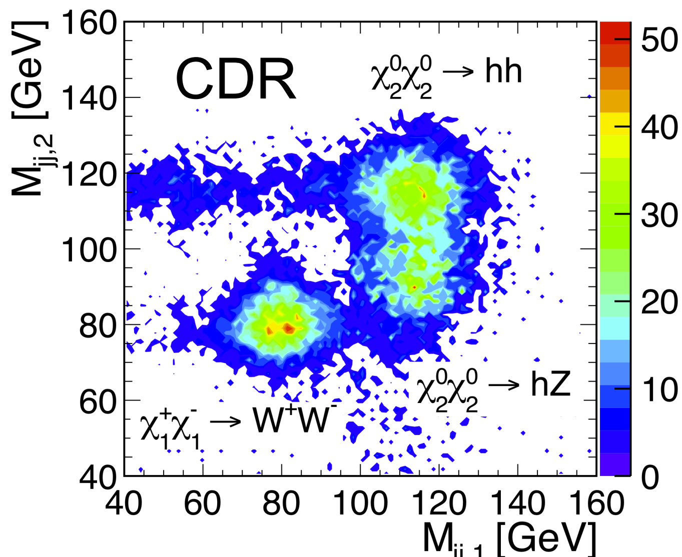




→ LEP limits are still the most stringent for model- independent chargino mass!



CLIC (Stage 2: 1.4 TeV)



$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+W^-$$
$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow hh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0$$
$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow Zh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

Precision on the measured chargino/neutralino masses (few hundred GeV): 1 - 1.5%

(M(charg/neut2)=487 GeV)

- *Similar studies in progress for circular colliders*

Summary & conclusions

- Many reasons to be interested in SUSY → *increasingly* the best (or least bad?) solution to hierarchy problem, provide good Dark Matter candidate etc.
- SUSY is a beautiful theoretical framework:
  - Very diverse phenomenology, experiments must have a wide search strategy (while keeping an eye on possible indirect constraints)
- LHC Run 1 has set stringent exclusion limits:
  - Under stress simplest version of SUSY, but with many open points and exciting opportunities → just hitting the 'regimes' indicated by the higgs mass !
  - and, we learned a lot along the way…
- LHC Run2&3, HL-LHC and future hadron/electron colliders will offer the possibility to explore various SUSY scenarios. Hope in a discovery, otherwise:
- *Will we ever exclude SUSY?* Maybe not, and will just loose interest - but before that, we have a long path in front of us…

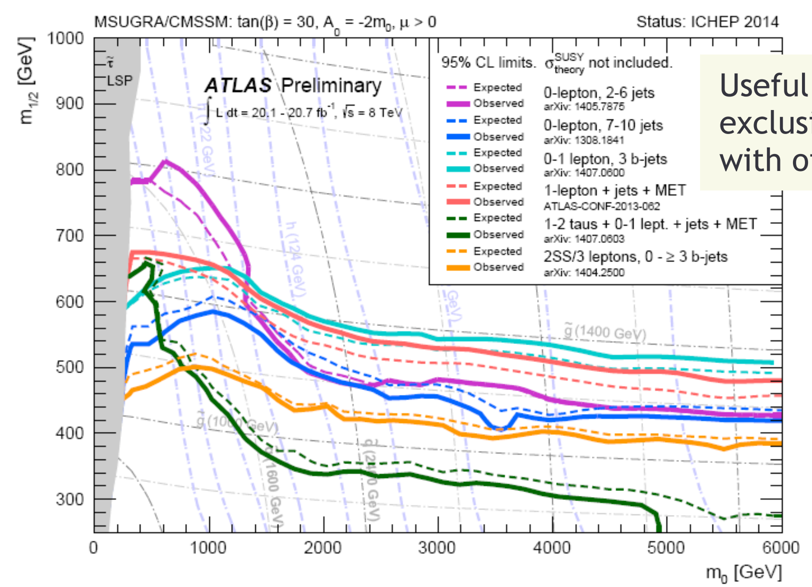
Long time ago, they told us SUSY was just around the corner. It might still be true. We just need to find the right one …

Back-up

Searching for SUSY @ ATLAS & CMS

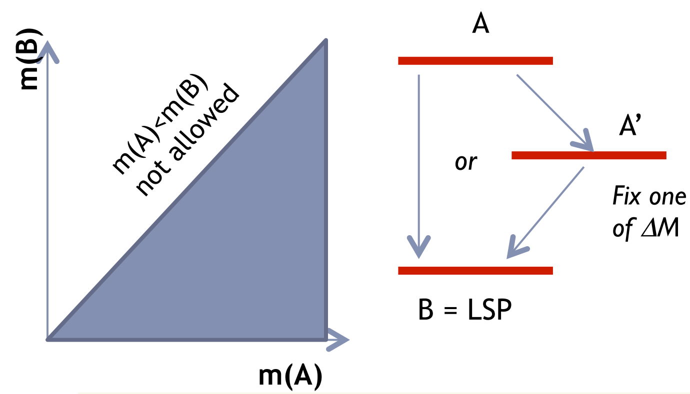
Optimization of signal regions based on:

'Full' Physics models
- SUSY breaking @ high scale → specific spectrum at EWK scale
- mSUGRA, Gauge Mediated Symmetry Breaking, Anomalous MSB, Minimal SUSY (MSSM)



Useful to calibrate our exclusion and compare with other results

Simplified models
- Described by a minimal set of parameters (particle masses, cross section)
- Most models: fixed BR to final state of interest (e.g. 100%)



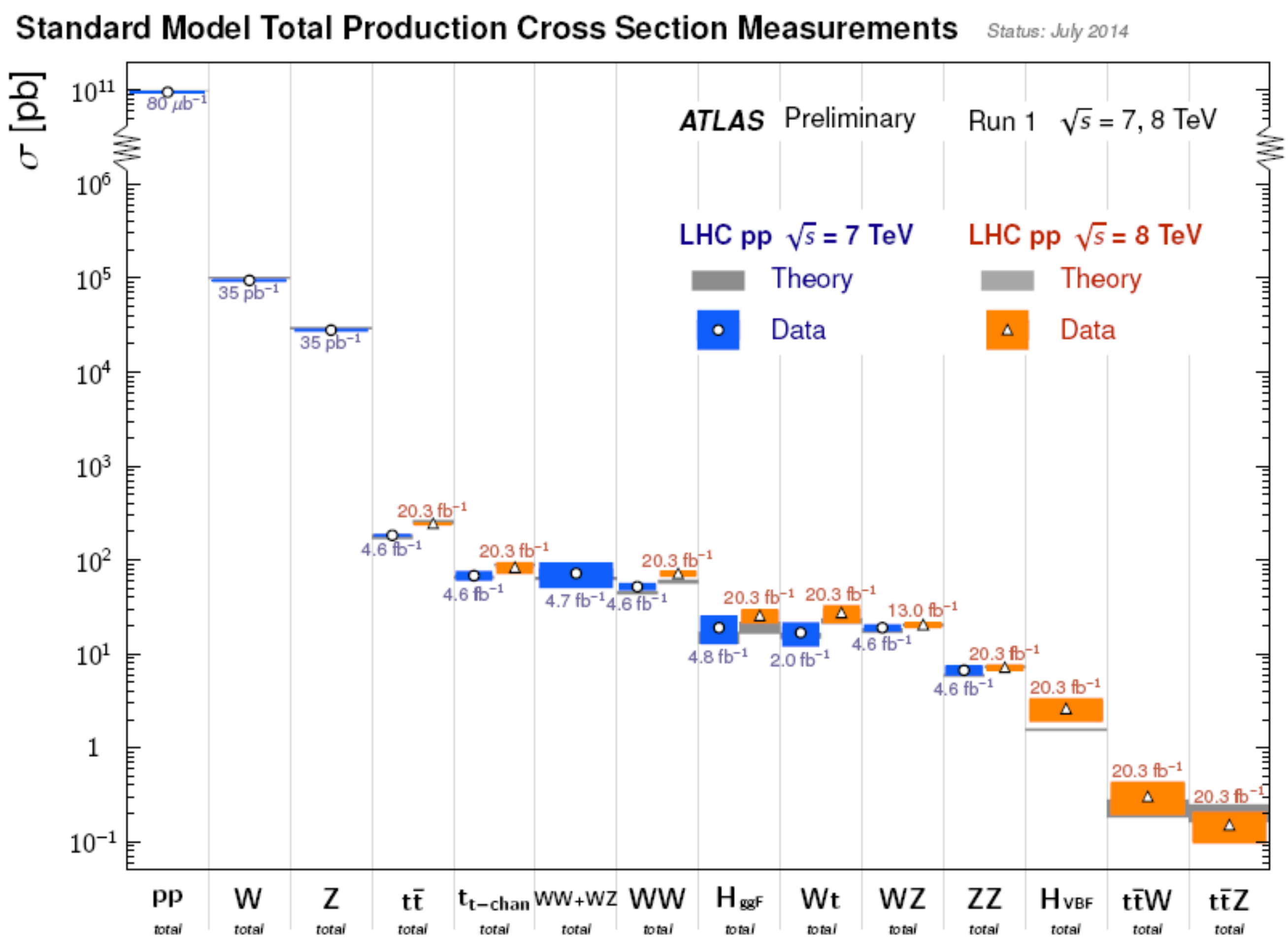
Very helpful to design analyses and understand loop-holes.

Generalized models
- Parameters @ EWK scale → spectrum at EWK scale
  - Set considering also indirect constraints
- pMSSM, General Gauge Mediated …

Searching for SUSY @ ATLAS & CMS

- **Step 1:**
  - understand SM background contributions

SM processes measured at ATLAS with extremely high precision



Searching for SUSY @ ATLAS & CMS

- **Step 1:**
  - understand SM background contributions (*)
  - Search kinematic phase space usually different from SM measurements (tail of distributions at high p_T)

(*) For long-lived particle searches, need more specialized techniques

Irreducible SM backgrounds →

'Semi' data-driven methods

- Normalisation done in dedicated Control Regions (CR) enriched in specific bkg. E.g.: top pair production, W+jets…
- Compromise between closeness to SR, statistics and handling of uncertainties

Reducible SM background →

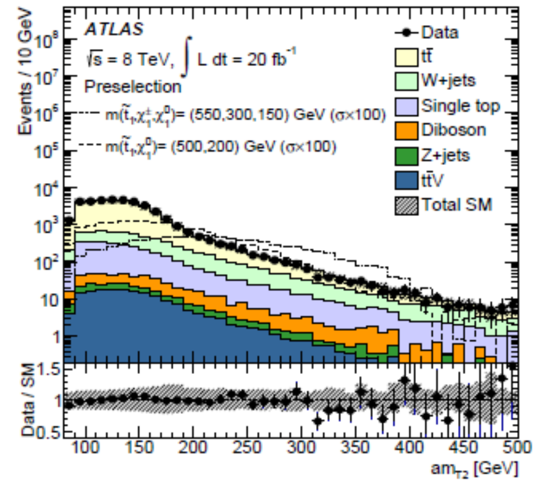
Data-driven methods: E.g.

- 'Jet Smearing' for multijet or Z+jets background due to fake E_T^{Miss}
- 'Matrix Method' for background from misidentified leptons

Validation of Background estimates in dedicated samples (VR)

Searching for SUSY @ ATLAS & CMS

- **Step 3:**
  - Define selections based on various discriminating quantities
    - **Ex: MET, Meff = E_T^{Miss} + Scalar Sum of jets (leptons) p_T, transverse mass m_T, mT2, amT2 ....**



  - Define SRs, which are usually 'blind'
    - **Cut and count analyses or fit on shape of single or multiple discriminating variables (especially for searches with low S/B)**

  - After bkg estimates in CR and validation in VR

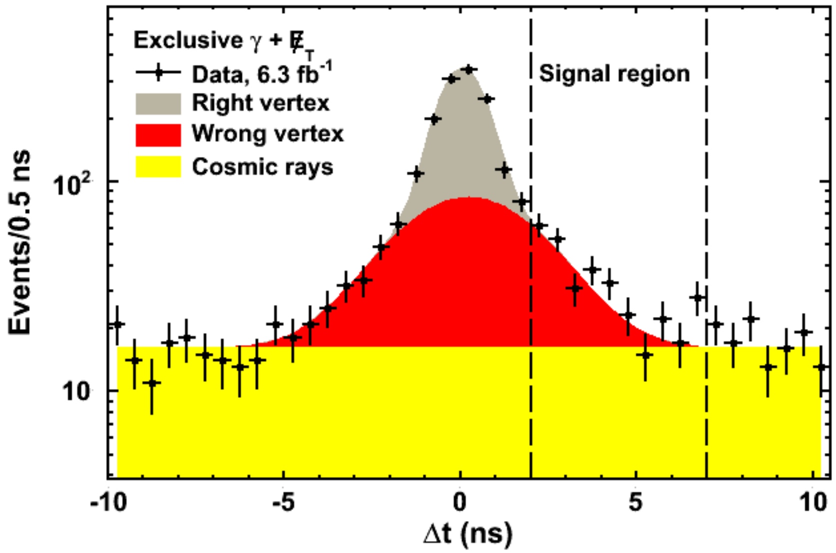
→ Proceed to unblinding data in SR
    - If excess is found, champagne!
    - If not ☹, set 95% Confidence Level limits

SUSY @ Tevatron

- Tevatron experiments, CDF and D0, are no longer competitive with ATLAS or CMS:
  - Limited data-set (~ 10 fb-1 / experiment)
  - Limited center of mass energy (1.96 TeV)
- Few relatively recent results offer some complementarity

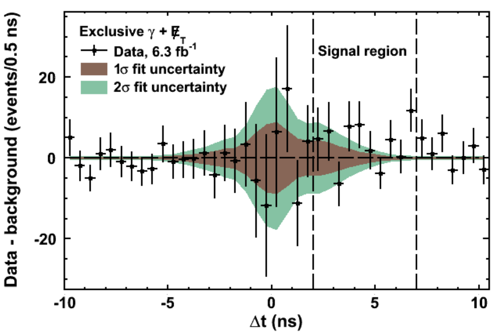
CDF: 1307.0474

Signature-based search for delayed photons in exclusive $\gamma+E_T^{Miss}$



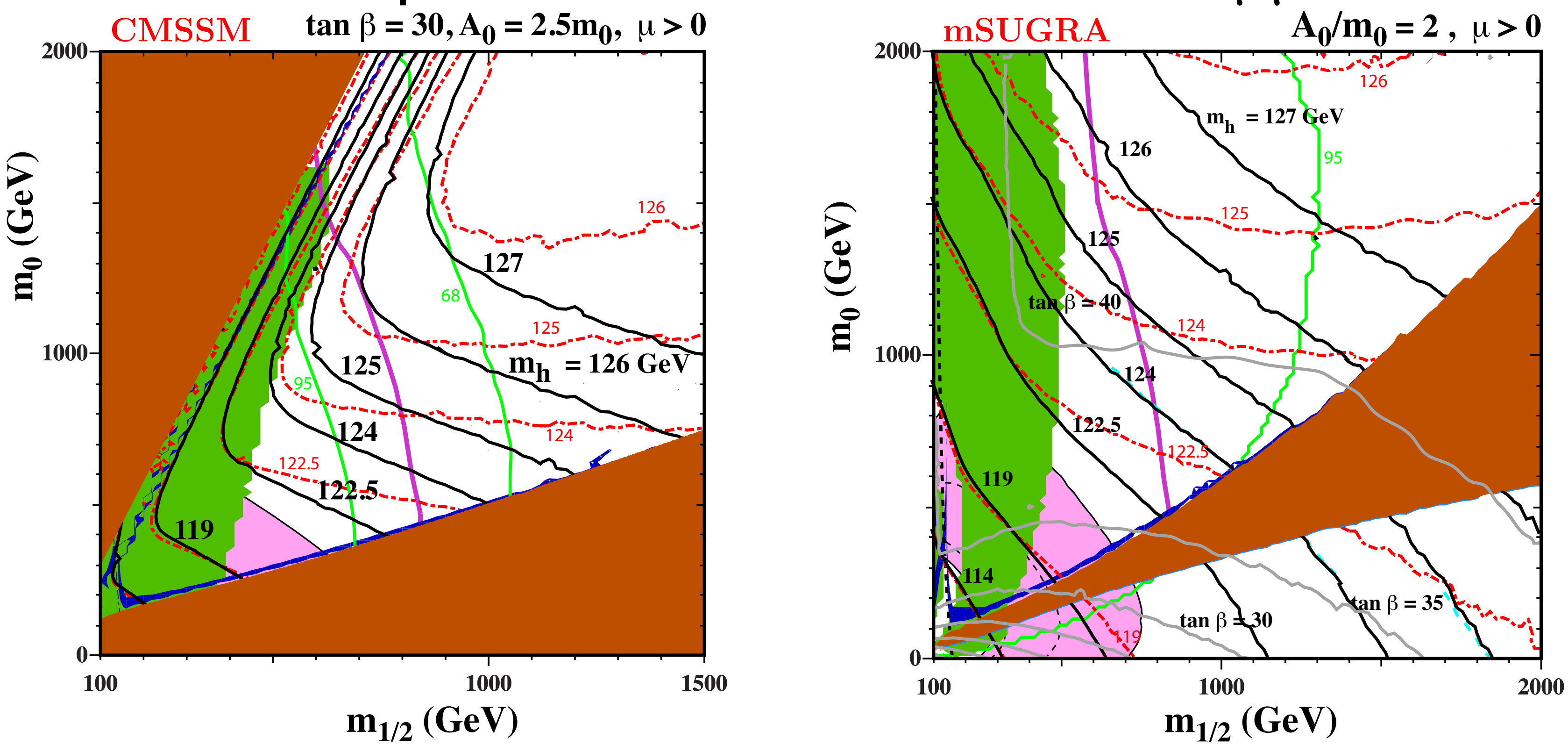
Δt: difference between the observed arrival time of γ in the detector and the time predicted for photons promptly produced in the primary interaction.

- Shifted towards positive values for signal
- Sensitive to delayed decays: $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$



Constraints from Bs

- Other examples of constraints from Bs→μμ



green lines – bounds from $B_s \to \mu^+\mu-$ (CMS & LHCb 2013, exclusion to the left)

purple lines – ATLAS 95%CL bounds from $\not{E}_T +$ jets

green shaded – excluded by $b \to s\gamma$

brown shaded – charged LSP

pink shaded – SUSY helps with $g-2$

blue strips – favoured by Ω_{DM}

arXiv:1312.5426

Current experimental bounds on dipole moments

Wolfgang Altmannshofer

[Griffith et al. 2009 (Hg); Baker et al. 2006 (neutron); Regan et al. 2002 (Tl); Hudson et al. 2011 (YbF); ACME 2013 (ThO)]

$$d_{Hg} < 3.1 \times 10^{-29}\ ecm$$

$$d_n < 2.9 \times 10^{-26}\ ecm$$

$$|d_e| \leq \left\{ \begin{array}{ll} 1.6 & (Tl) \\ 1.05 & (YbF) \\ 0.089 & (ThO) \end{array} \right\} \times 10^{-27} e\,\mathrm{cm}$$

bounds on the electron EDM assume the absence of contributions from CP-odd electron nucleon couplings