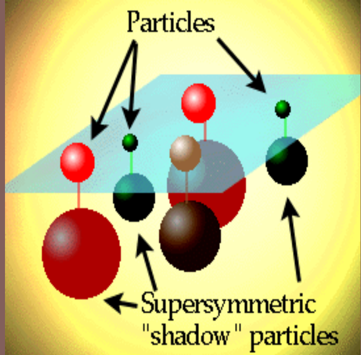


SUSY SEARCHES IN ATLAS

Xuai Zhuang

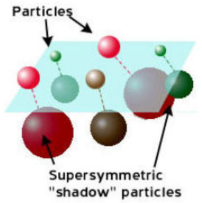
On behalf of ATLAS Collaboration

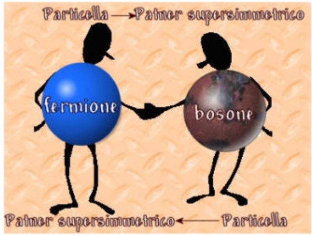
IHEP, Beijing, China
CPPM, Marseille, France

Dec. 8 2014

Outline

- SUSY Introduction
- The LHC and ATLAS
- Overview of SUSY search results on run-1 data
- Outlook and Summary



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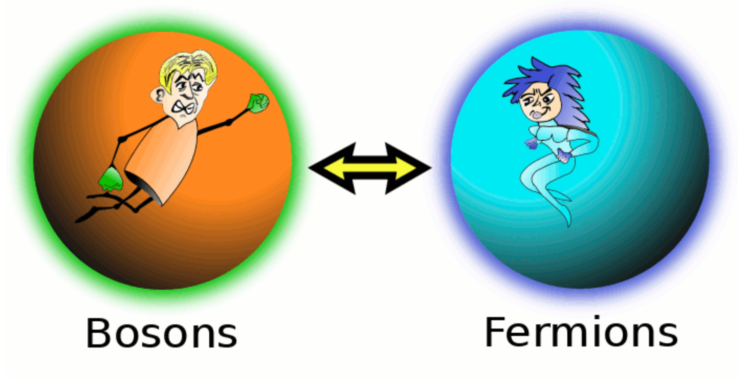


SM and Beyond

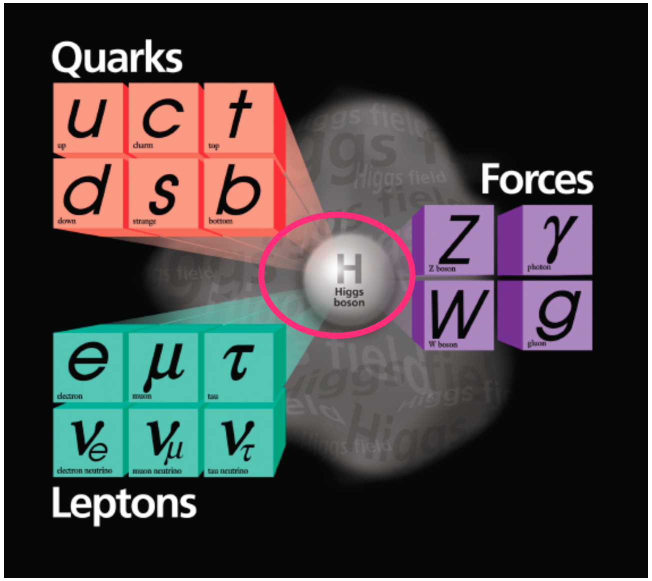


Photo: A. Mahmoud

François Englert

Photo: A. Mahmoud

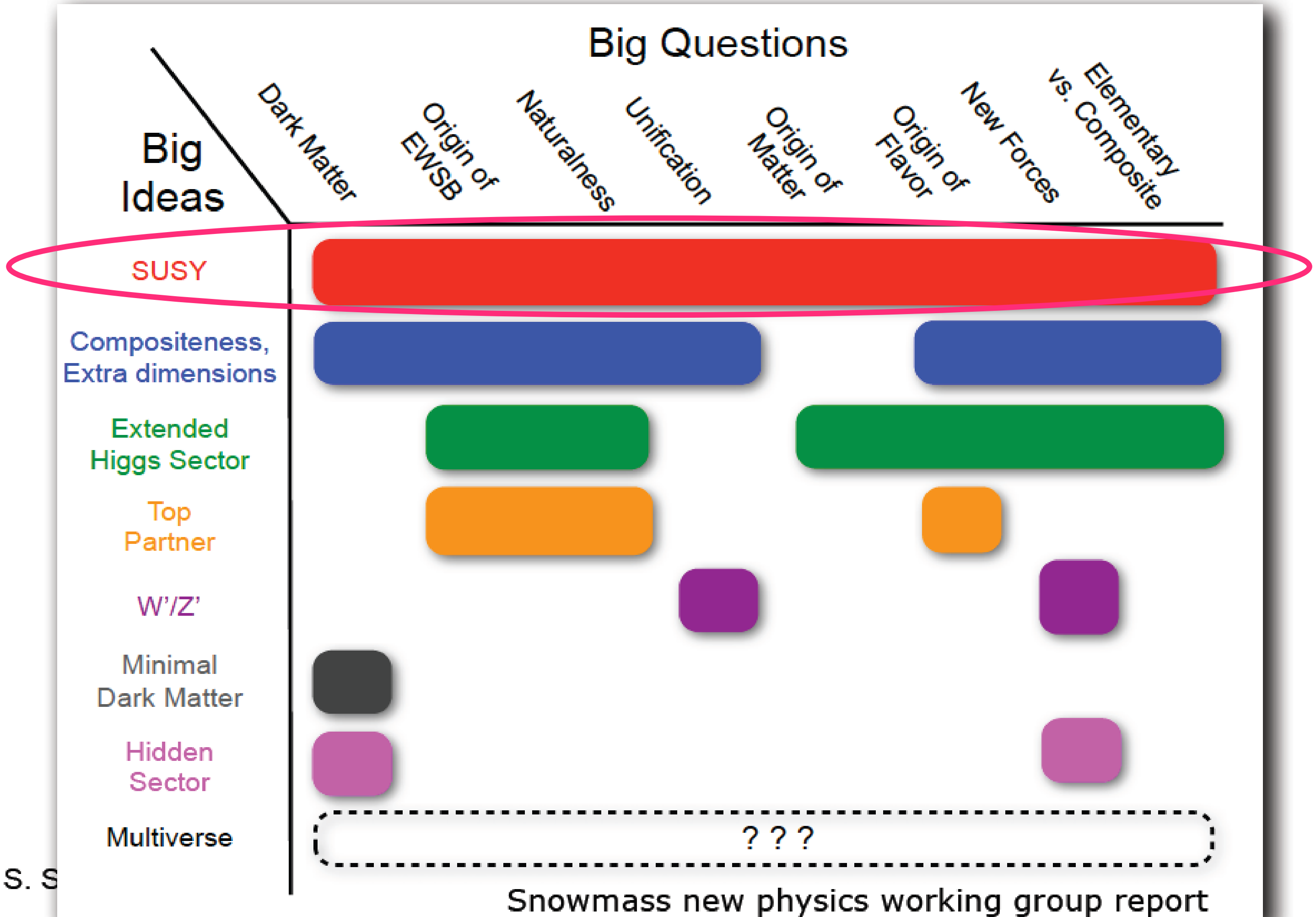
Peter W. Higgs

The Nobel Prize in Physics 2013

François Englert, Peter Higgs

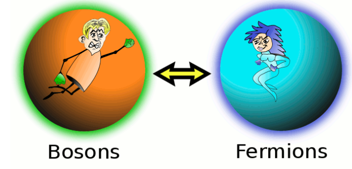
- Higgs boson observed, SM fits the experimental data very well ➔ big success in EW scale
- While has problem in Planck scale:
  - Naturalness and "hierarchy" problem
  - Unification of gauge coupling
  - Dark Matter
  - ……
- Need a more fundamental theory of which SM is only a low-energy approximation ➔ **New Physics**

New Physics beyond the SM



S. S

SUSY Introduction

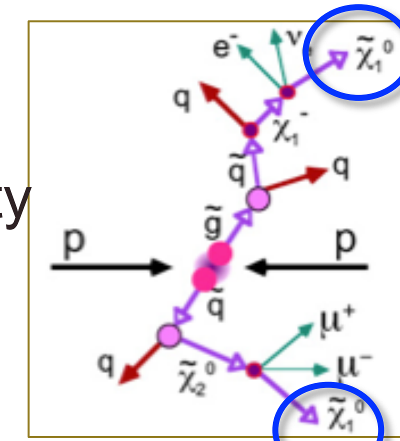


- **A symmetry which unified fermions (mater) and bosons (forces)** -> A fundamental theory
- **<u>Conserved R parity</u>** (originally introduced for stability of proton)

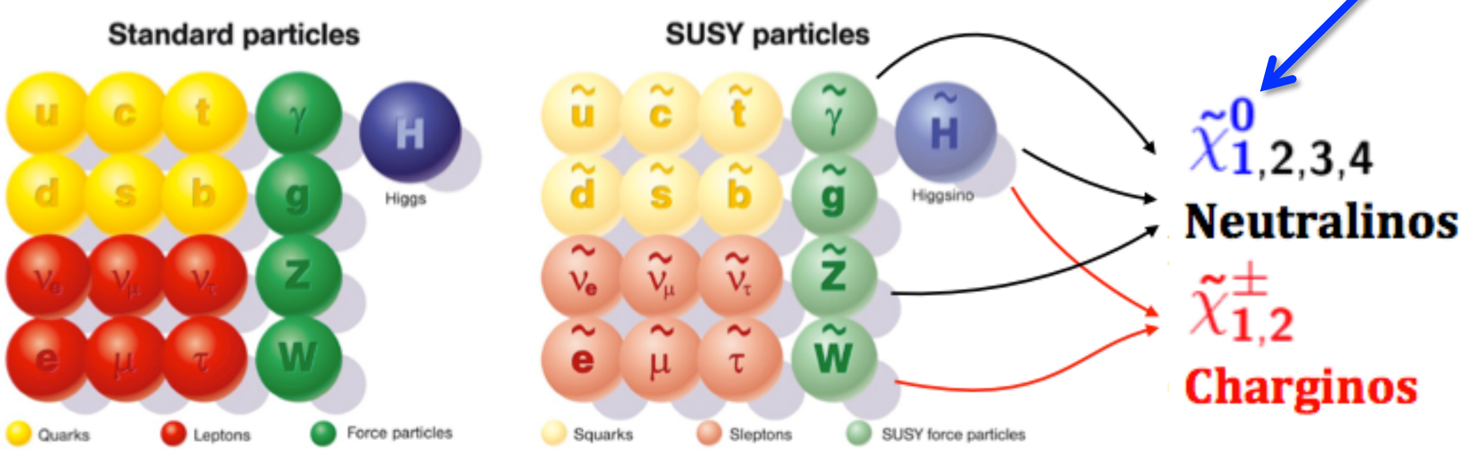
$$R = (-1)^{3(B-L)+2S}$$

R=+1 (SM)
R=-1 (SUSY)

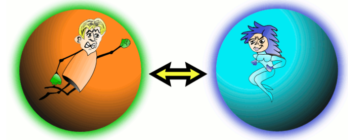
  - SUSY particles produced/annihilated in pairs
  - Lightest SUSY particle (LSP) stable (DM candidate)
  - Typical signature: <u>jets/leptons/photons + **MET**</u>



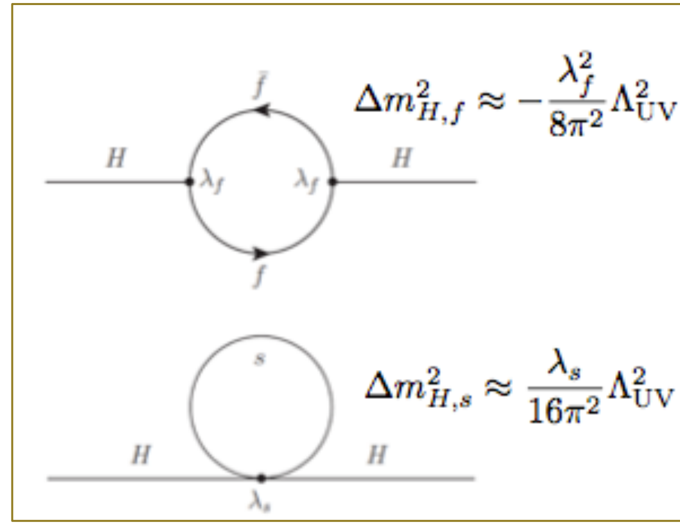
- Violated R parity (RPV): not mentioned in the talk

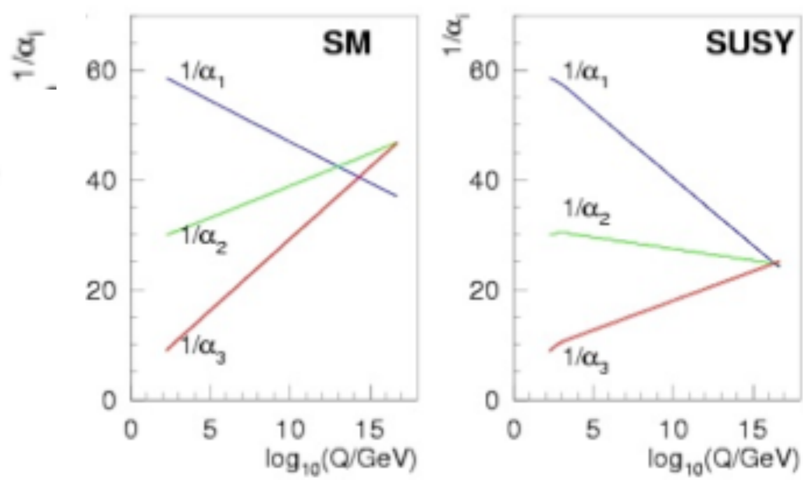


SUSY Introduction



- **Solve hierarchy problem** without "fine tuning"
  - SUSY contributions to Higgs mass cancel SM contributions
- **Unification of gauge couplings**
  - New particle content changes running of couplings
- **Provide Dark Matter candidate**
  - Lightest SUSY particle (LSP) can be stable and only weekly interacting





Some of the arguments are most convincing for SUSY particles at ~TeV scale

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ATLAS and CMS detector @ LHC

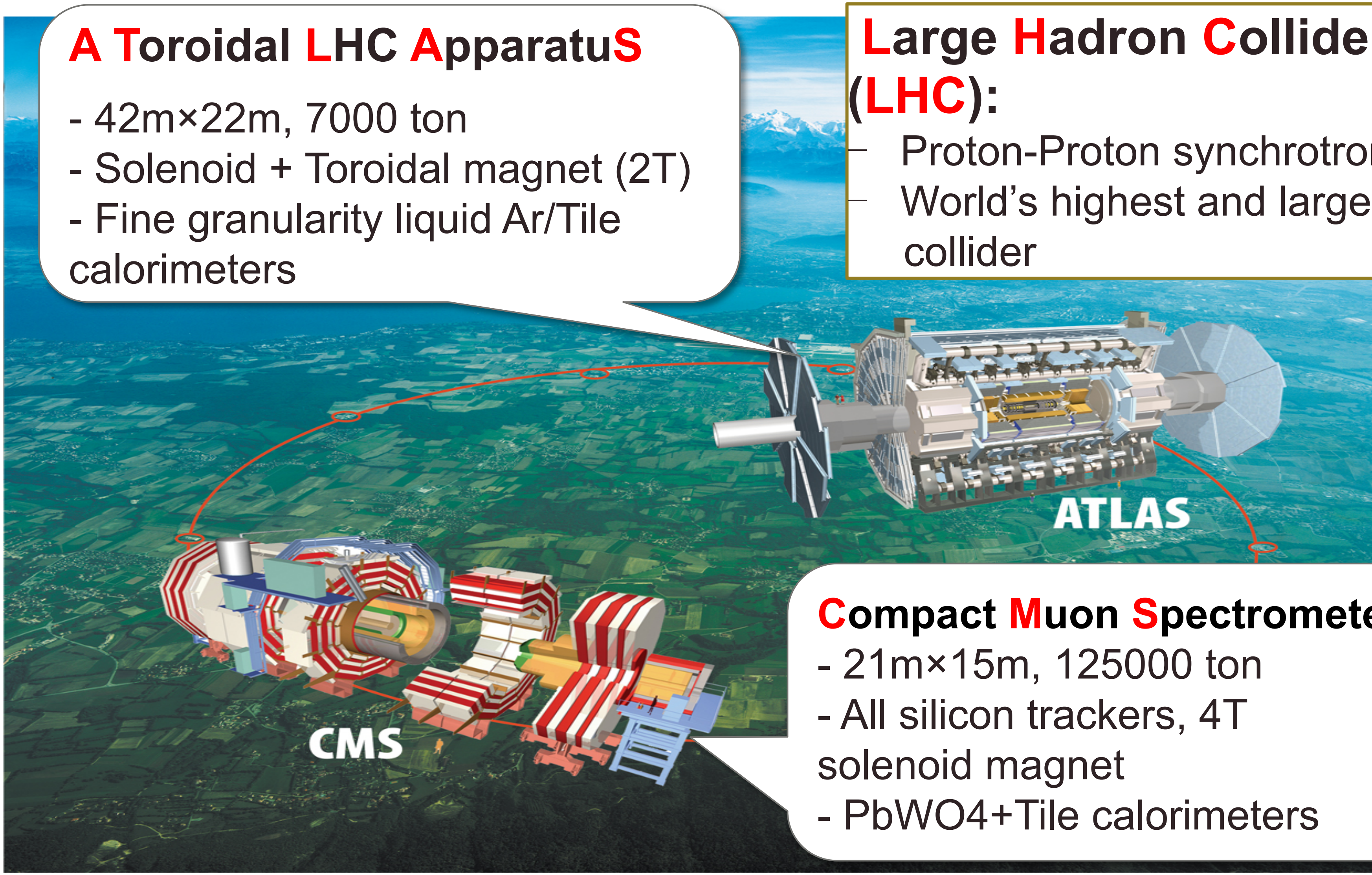
ATLAS and CMS: two multi-purpose detectors @LHC

A Toroidal LHC ApparatuS

- 42m×22m, 7000 ton
- Solenoid + Toroidal magnet (2T)
- Fine granularity liquid Ar/Tile calorimeters

Large Hadron Collider (LHC):

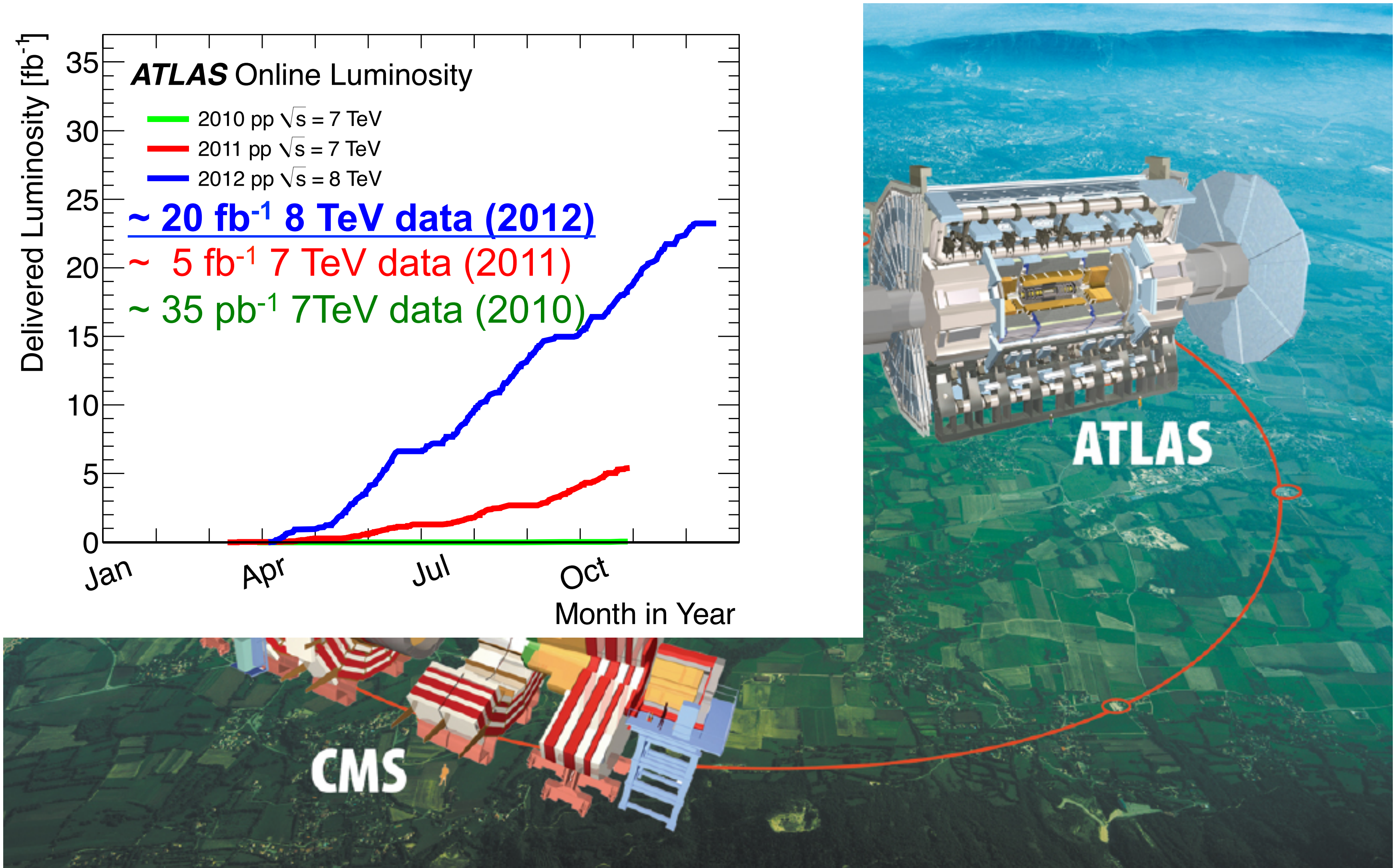
- Proton-Proton synchrotron
- World's highest and largest collider



Compact Muon Spectrometer

- 21m×15m, 125000 ton
- All silicon trackers, 4T solenoid magnet
- PbWO4+Tile calorimeters

Since 2010, ATLAS&CMS have invested huge efforts in SUSY search @LHC : Great Luminosity recorded



Outline

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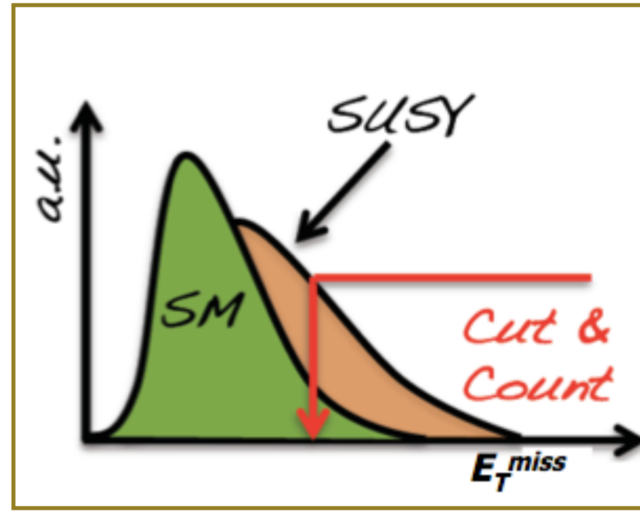
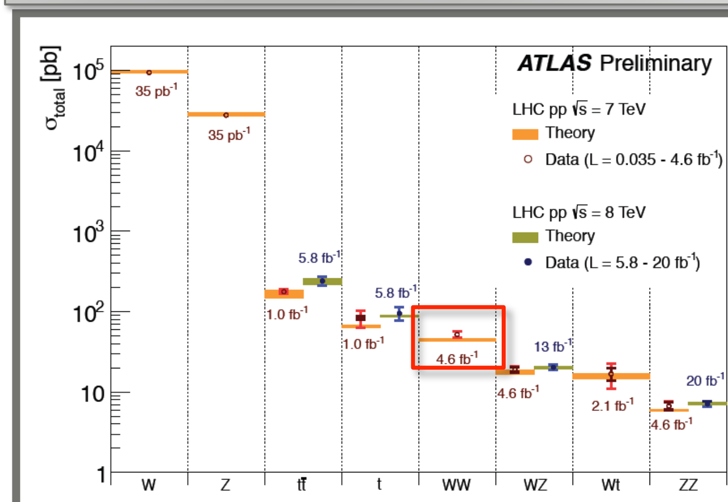
SUSY Search Strategy

- **SUSY search strategy:** search for <u>**deviation from SM**</u>
- **SUSY sensitive variables:** Try to establish excess of events in some sensitive kinematic distribution
- **SM background:** the discovery of new physics can only be claimed when SM backgrounds are understood well or under control
  - SM bgs understood very well ☺
  - No hints for new physics ☹
  - Slightly overshoot in WW cross section, but consistent with NNLO xsec.

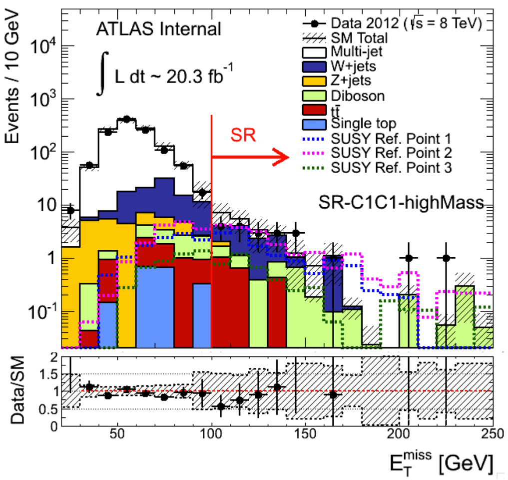


SM "backgrounds"– the big picture

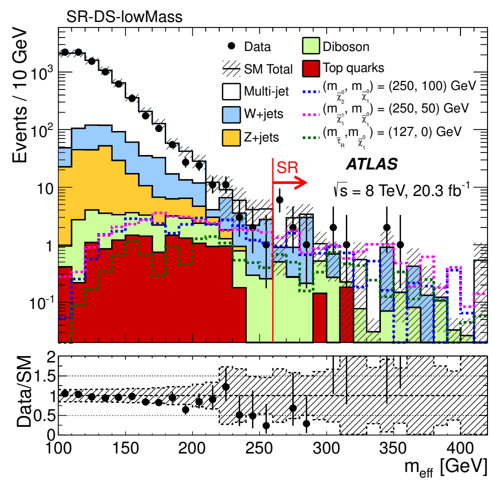


SUSY Sensitive Variables

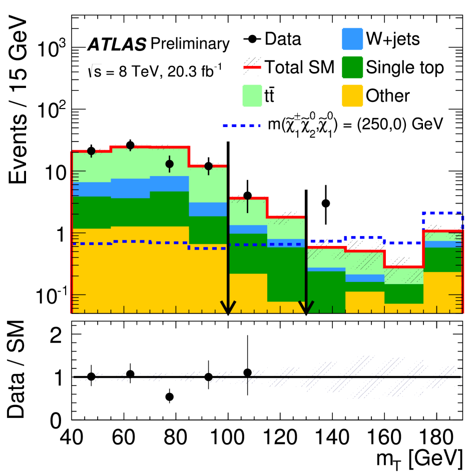
E_T^{miss}



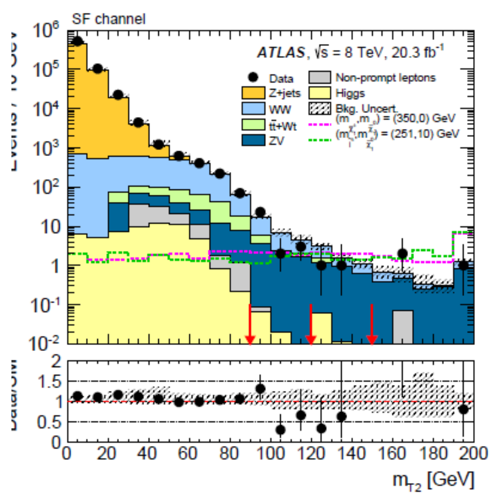
M_{eff}



mT



mT2



- E_T^{miss} from escaping LSP, to suppress bg from mis-measured jets and oth. SM BG
- Related to the sparticle mass scale, like effective mass (**M_{eff}**)

$$M_{\text{eff}} \equiv \sum_{i=1}^{N_{\text{jets}}} p_T^{\text{jet},i} + \sum_{j=1}^{N_{\text{lep}}} p_T^{\text{lep},j} + E_T^{\text{miss}}$$

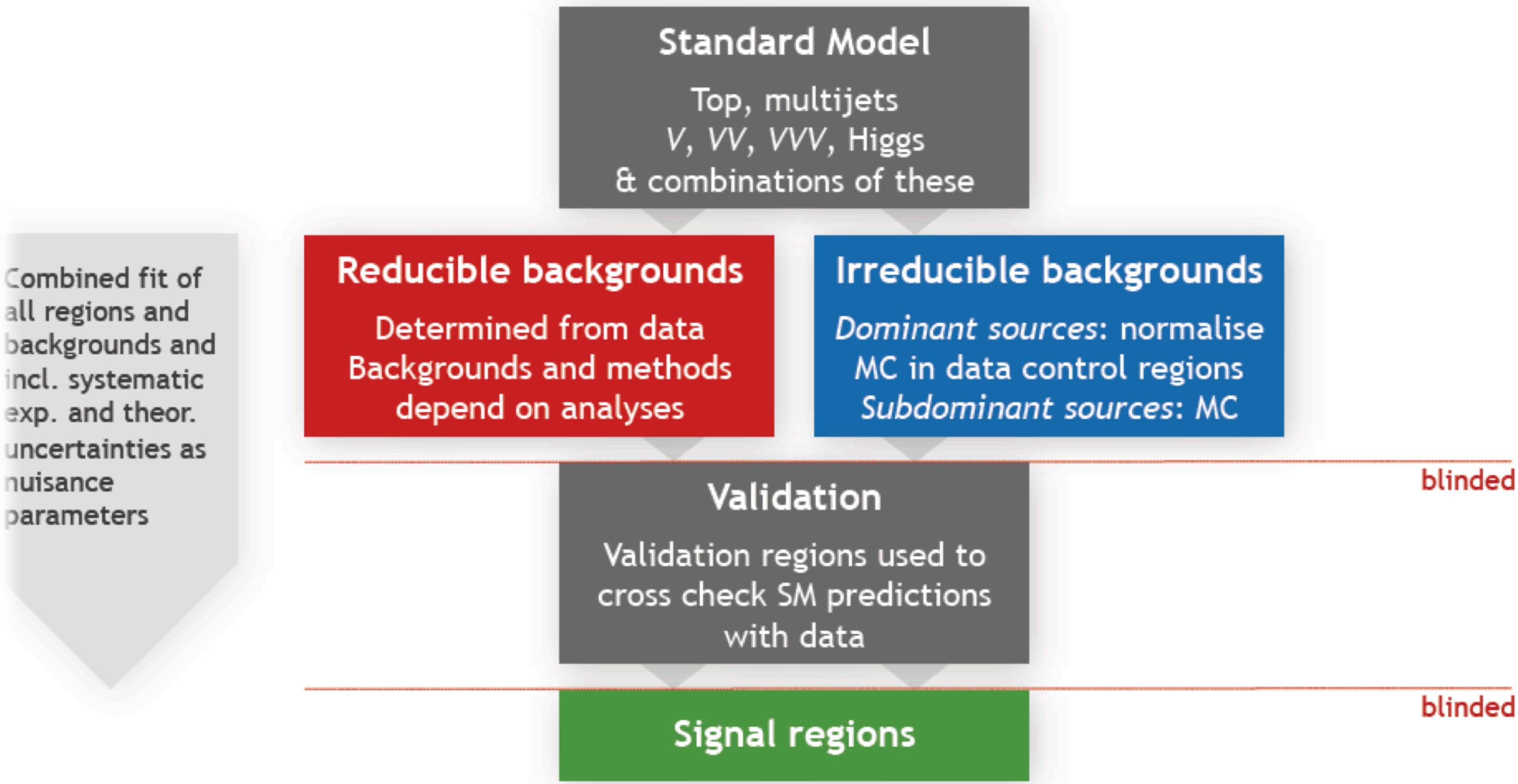
- **mT, mT2** (stransverse mass): suppress BG with Ws

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

- Many others …

SM Background Modeling

- **SUSY searches rely on accurate modeling of the Standard Model backgrounds**



SUSY models: good sale in market

- Simplified Models:
  - Not really a model (Br~100%, most masses fixed at high scales)
  - Important tool for interpretation
- Phenomenological models:
  - pMSSM: captures "most" of phenomenologic features of R-parity conserving MSSM
    - 19 free parameters: M1,M2,M3 ; tan β, μ and $m_{A;}$ 10 sfermion mass parameters; A_t, A_b and A_τ
    - Comprehensive and computationally realistic approximation of the MSSM with neutralino LSP
  - GGM (gravitino)
- Complete SUSY models: mSUGRA, GMSB …

SUSY Search @ LHC

Strong production: gluino pair, gluino-squark and squark pair (include **3rd generation**) production

1） Generic signatures :

Multi -jets + n_lepton/n_photon(n=0,1, ≥2) + large E_T^{miss} **(0L,1 L, >=2L)**

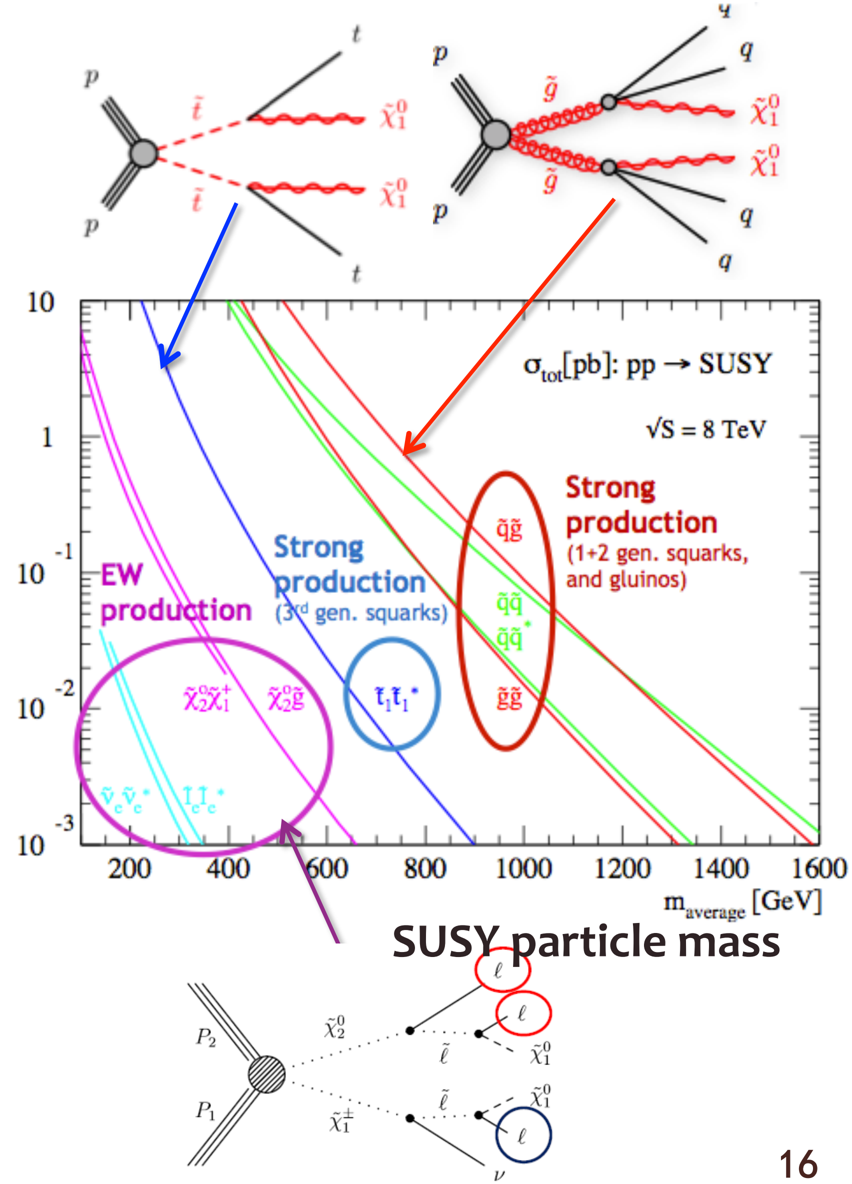
2） large xs, but heavy SUSY mass scale

Weak production: direct gaugino/slepton production

1） Generic signatures:

low–jet multiplicity + ≥ 2leptons + large E_T^{miss} (2/3/4L, **>=2tau**)

2） low xs, but small SUSY mass scale



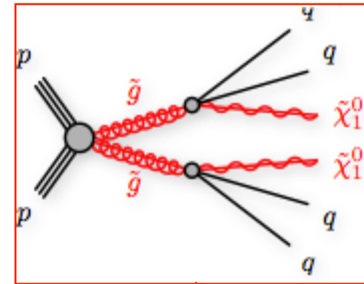
Inclusive Search with strong prod.

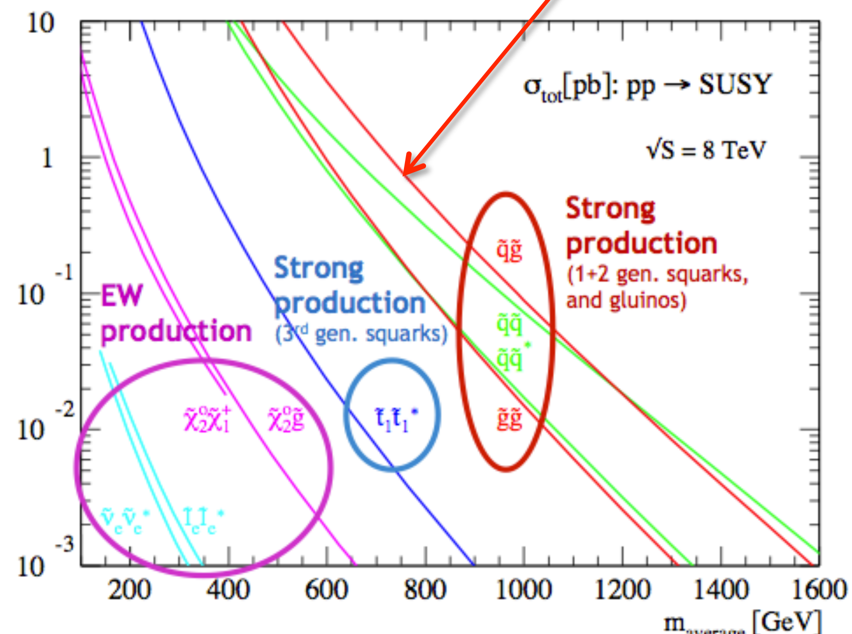
Strong production: gluino pair, gluino-squark and squark pair (include **3rd generation**) production

1）Generic signatures :

Multi -jets + n_lepton/n_photon(n=0,1, ≥2) + large E_T^{miss} **(0L,1 L, >=2L)**

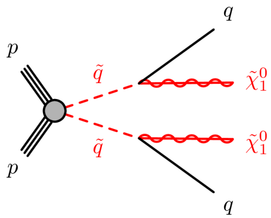
2）large xs, but heavy SUSY mass scale



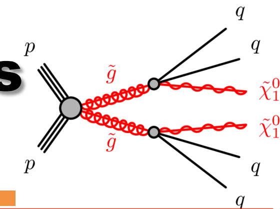


SUSY particle mass

- **0l +jets(2-6)+MET: JHEP 09 (2014) 176**
- 0l +jets(7-10)+MET: JHEP 10 (2013) 130
- **0-1 l + >=3 b-jets + MET: JHEP 10 (2014) 024**
- **1-2l +jets + MET: ATLAS-SUSY-2013-20**
- 2 SS/ 3 l+ 0-3 b-jets + MET: JHEP 06 (2014) 035
- 1-2 taus + 0-1 l + jets + MET: JHEP 09 (2014) 103

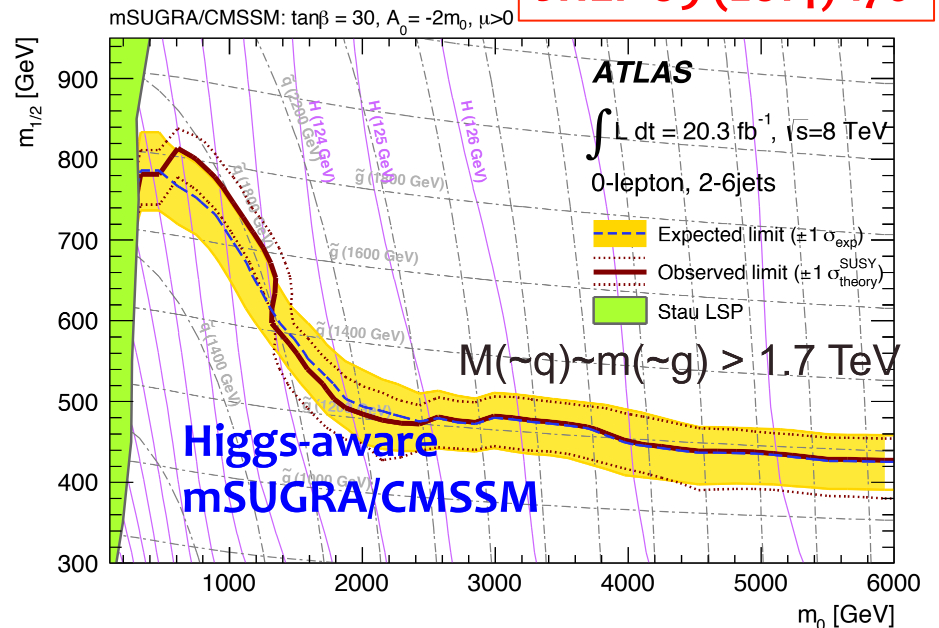


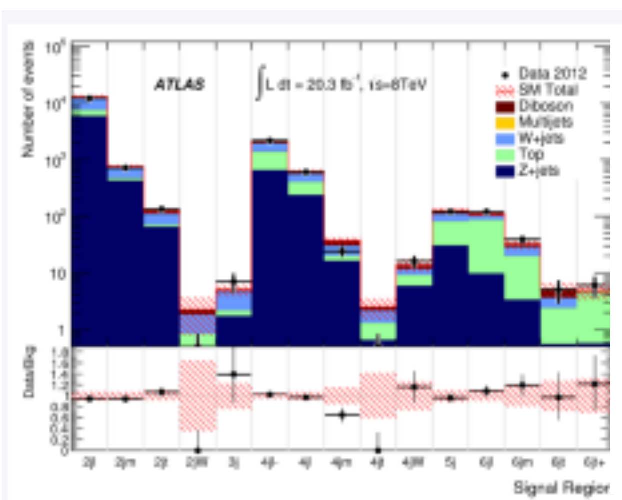
Searches for pair prod. of light-flavor squarks or gluinos decaying via virtual squarks

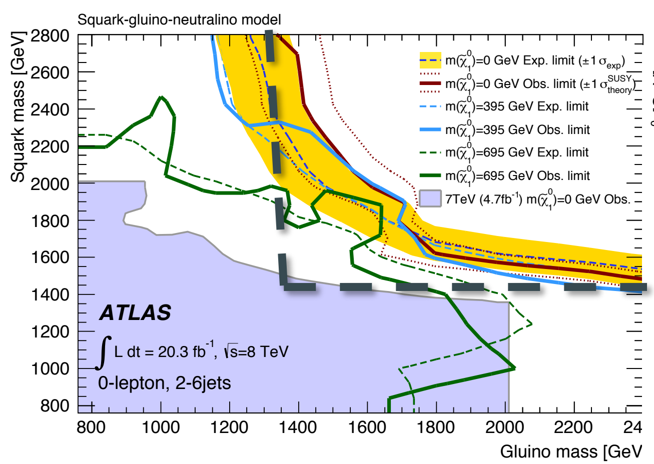


JHEP 09 (2014) 176

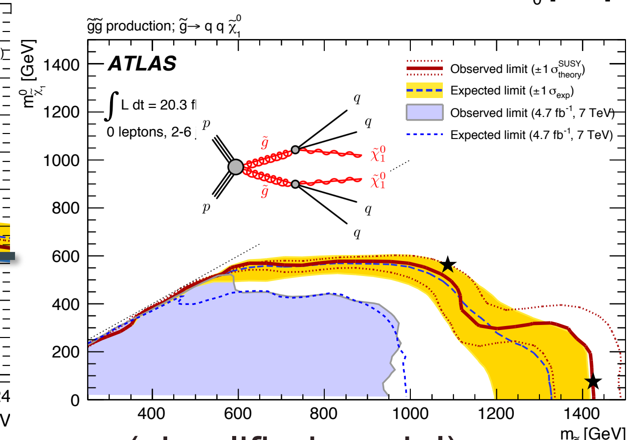
- **Very powerful inclusive search**
- **0l + 2-6 jets + MET** (jet + MET trigger)
- Main discriminating variable: **Meff**
- **15 SRs** from 2 to 6 jets to achive maximum reach on (m_~q, m_~g) -plane
- Backgrounds taken from dedicated data CRs (and validated)





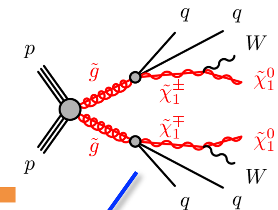


(simplified pMSSM)
m(~q)~m(~g) > 1.65 TeV



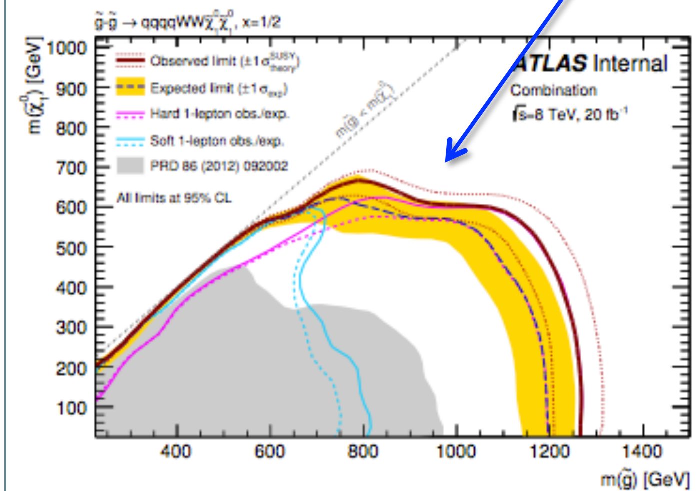
(simplified model)
m(~g) > 1.33 TeV

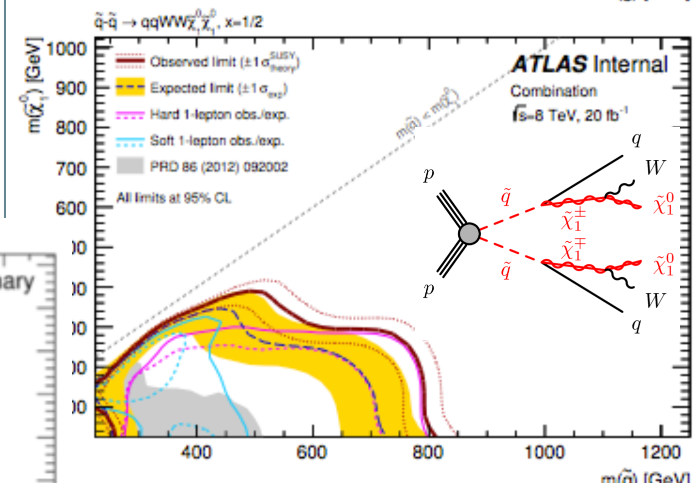
Searches for pair prod. of light-flavor squarks or gluinos decaying via charginos and sleptons

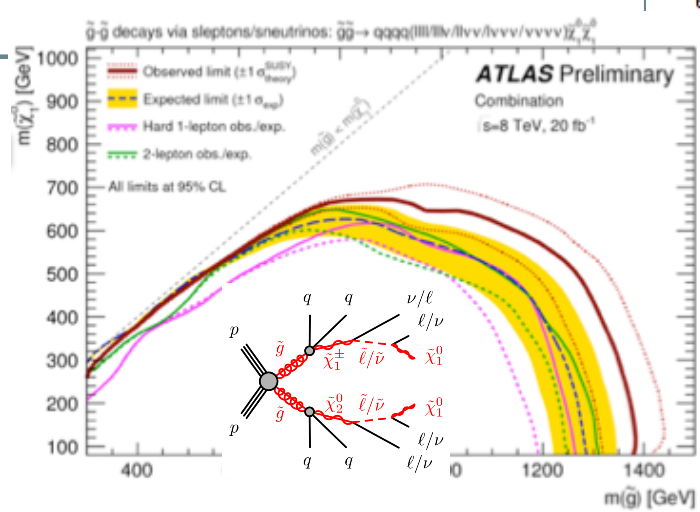


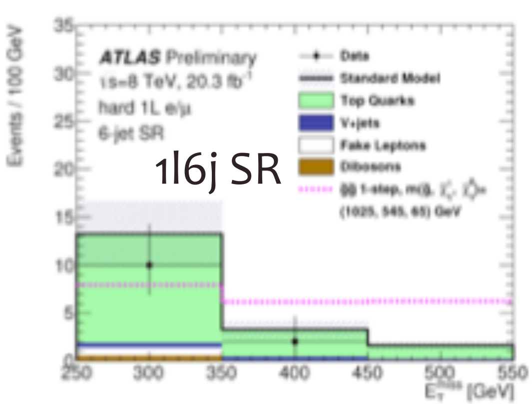
- Search for gluinos/squarks via long decay chain through chargino or sleptons
- **≥1l + jets + MET** (lepton trigger)
- 3 searches targeting:
  - Scenarios with medium to large mass splitting (**"hard lepton"**)
  - Compressed scenarios (**"soft leptons"**, pt in 6-7 to 25 GeV) **(IHEP)**
  - Scenarios with long decay chains (**"hard di-lepton"**, pt>14/10)
- Signal to BG discrimination based on: **Meff, MET, mT…**

New







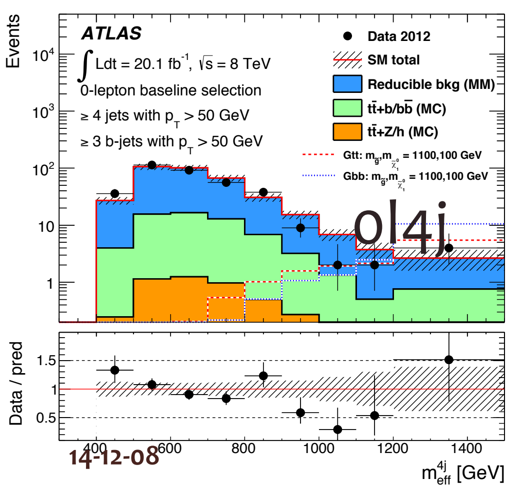


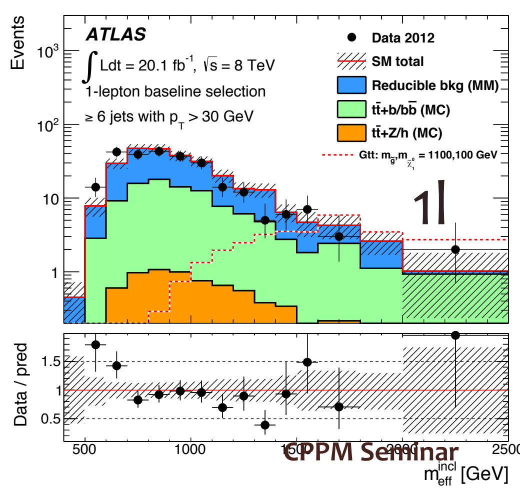
- Gluino mass > 1.2 TeV for massless LSP, independently on decay mode.

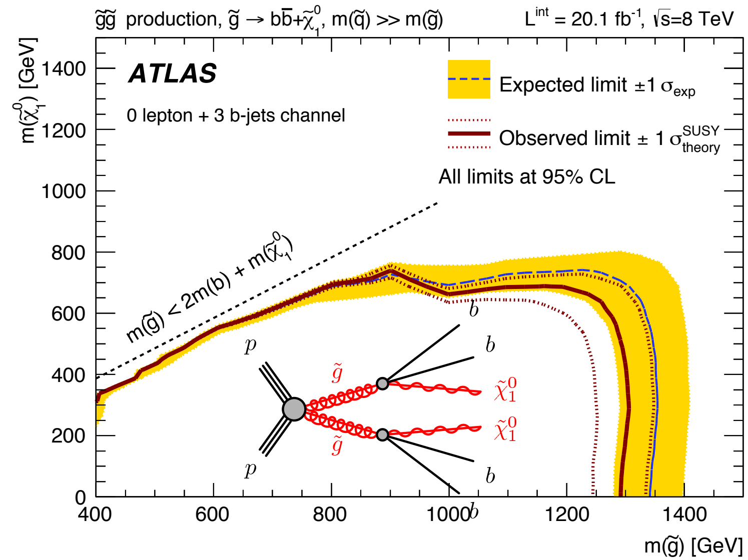
Search for squarks/gluinos via stop/ sbottom decay

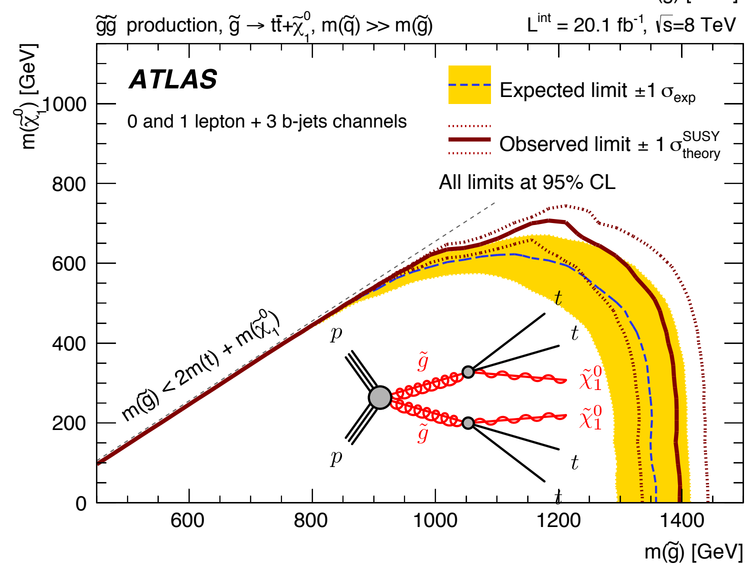
JHEP 10 (2014) 024

- **2 channels** with ≥3b-jets to search for gluino-mediated sbottom or stop production (**0-1l + 3 b-jet +MET**)
  - 0 lepton, ≥4 or 7 jets
  - ≥1 lepton, ≥6 jets
- **Most powerful search for high ~g mass**
- Discriminating variable: **Meff, MET**
- Reducible bkg (tt+fake b's) from MM
- Irreducible bkg (tt+b/bb) from normalizing MC to data in a CR







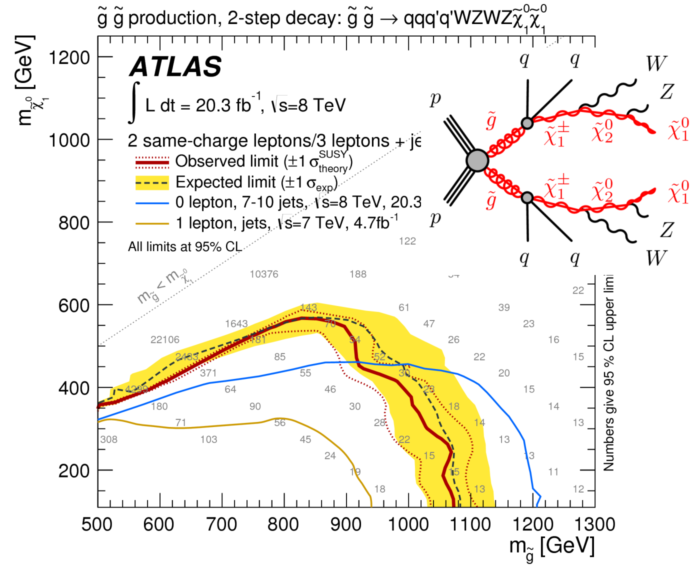


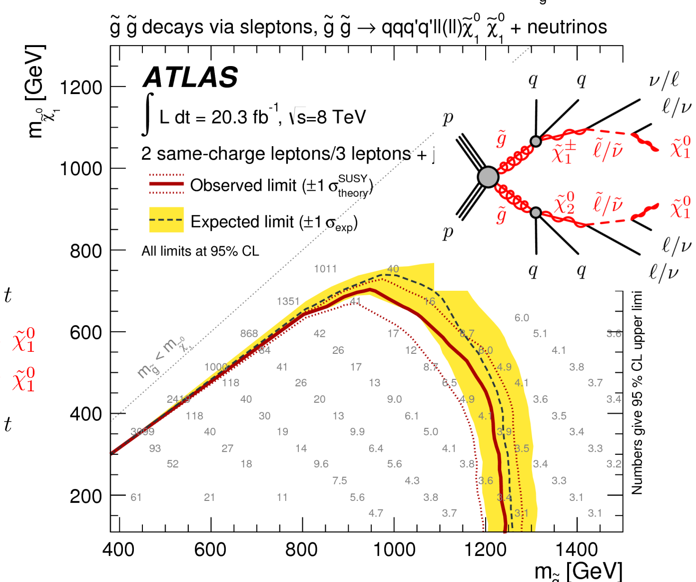
CPPM /IHEP

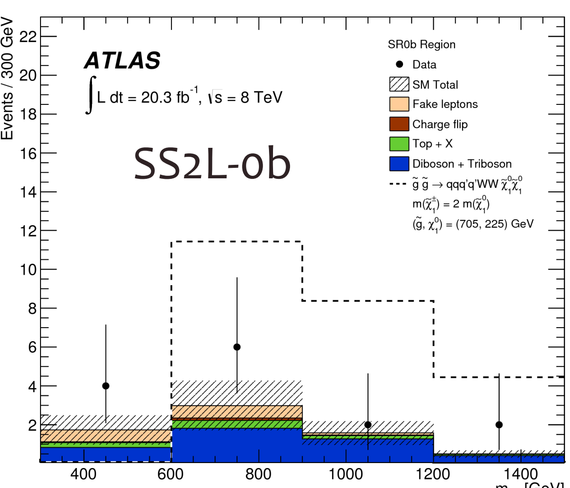
Search for squarks/gluinos via long decay chain (SS2L/3L)

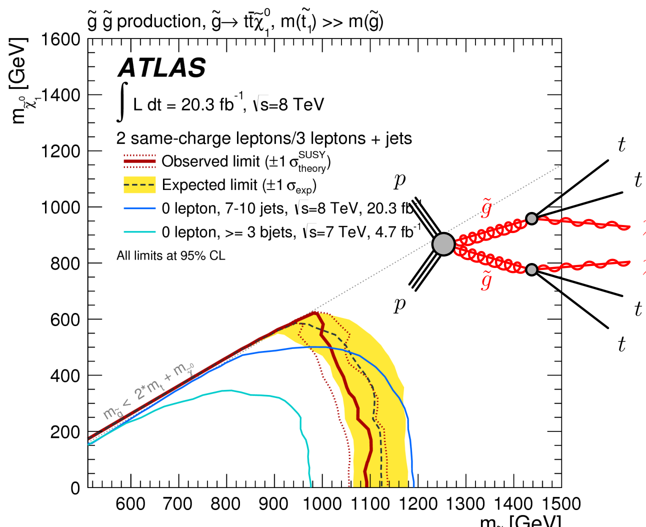
JHEP 06 (2014) 035

- **Target signals with gluino pair or guino-squark pair production resulting 2l SS or 3l final states (5 SRs with SS2L + 0 or 1 or 3 bjets, or 3L)**
- Very clean channels with only tiny SM bg (mainly top+V, diboson, triboson)
- Discriminating variable: **Meff, MET**
- These SRs increase sensitivity to **longer decay cascades**, compressed mass spectra, 3rd generation squarks …



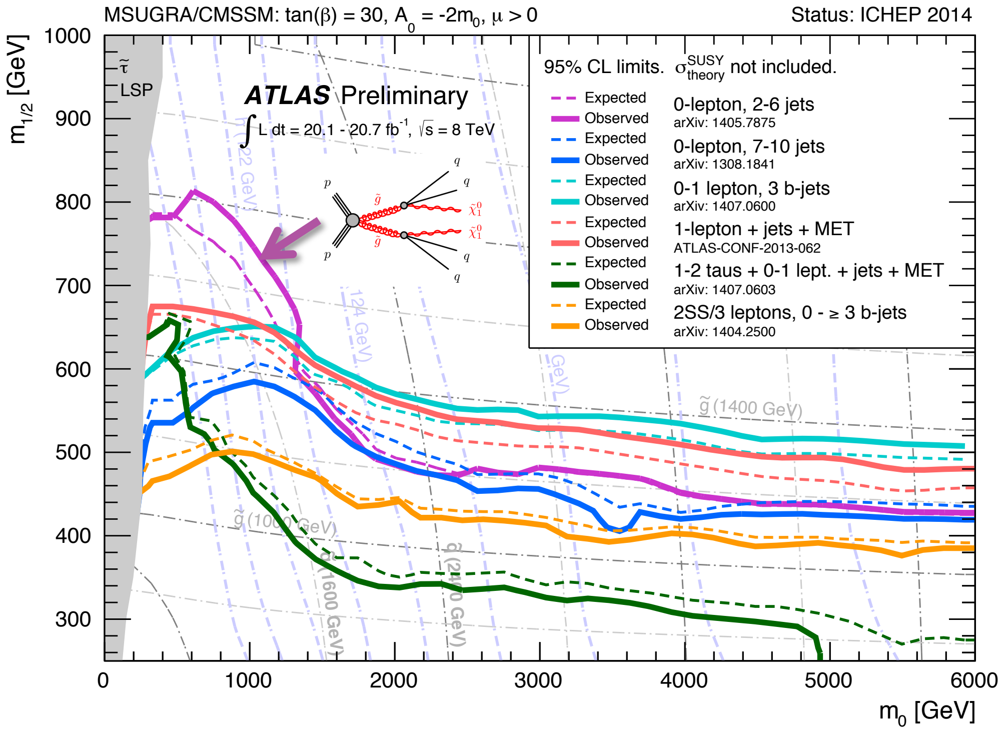




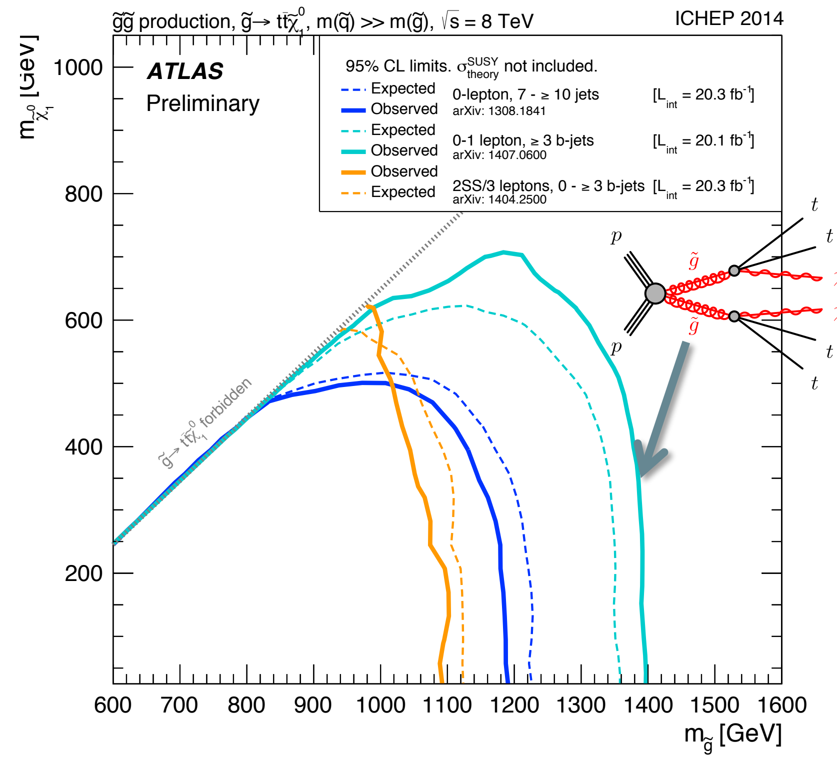


Inclusive search for squark and gluino production Summary

m_0 .vs. $m_{1/2}$ (mSUGRA/cMSSM)



M(~g) .vs. m(LSP)

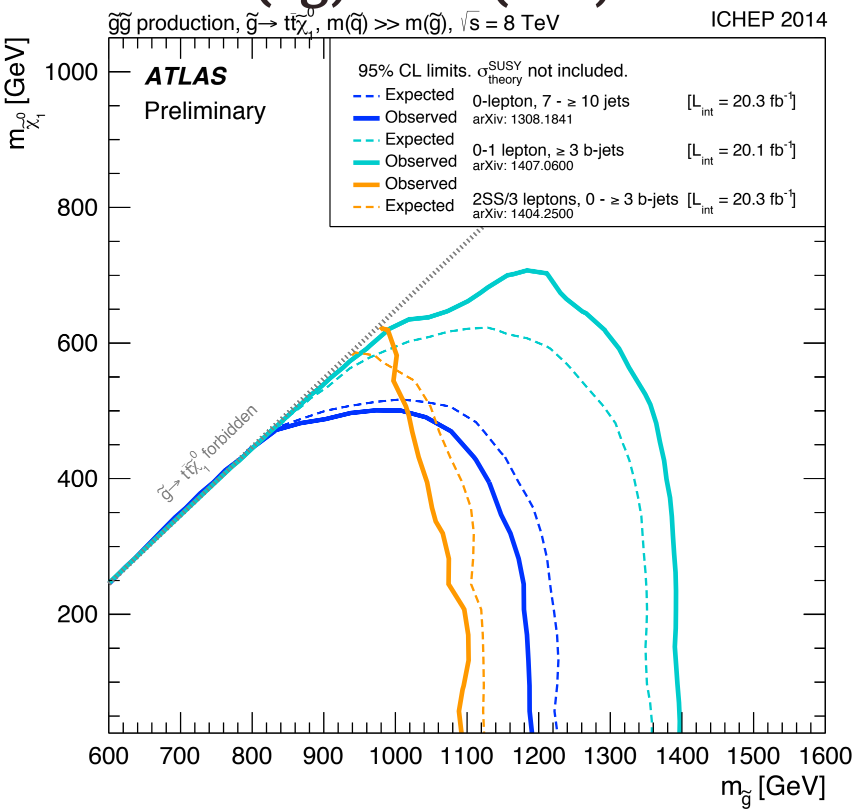


- m(~q) ~m(~g): m(~g) > 1.7 TeV
- M(~q) >> m(~g): m(~g)>1.35 TeV
- Conditional/indirect limit on LSP: m> 200-300 GeV

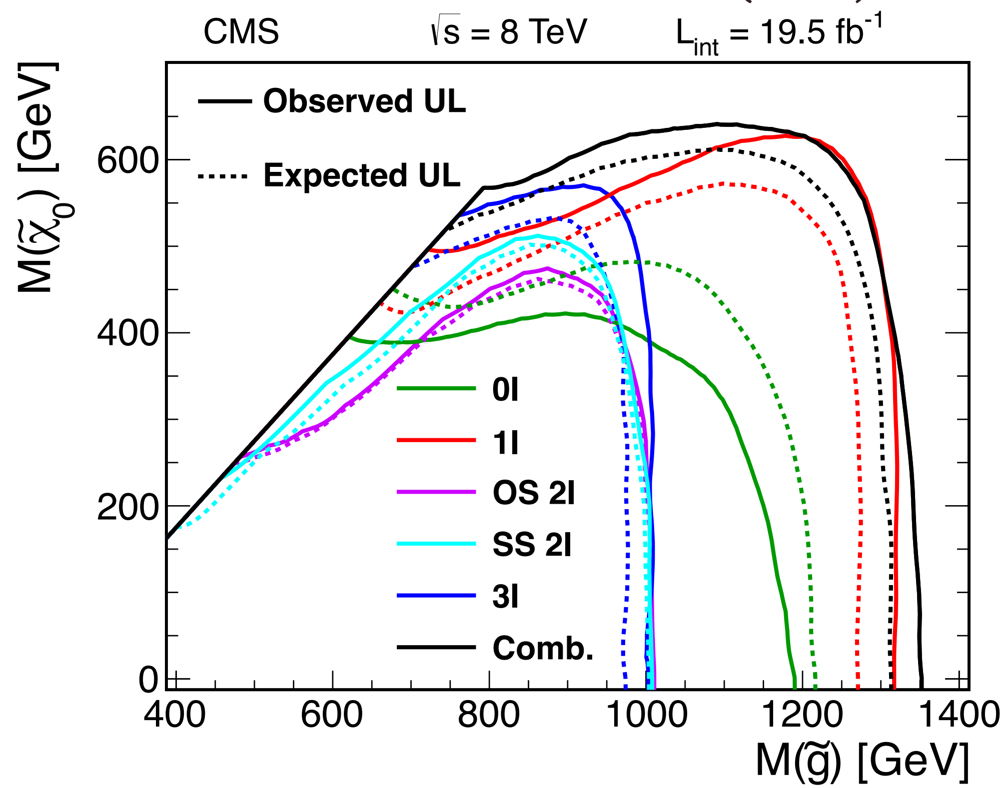
- No exclusion for M(LSP) ≥ 700 GeV
- Strongest limit: m(~g) ≥ 1400 GeV

Inclusive search for squark and gluino production Summary

M(~g) .vs. m(LSP)

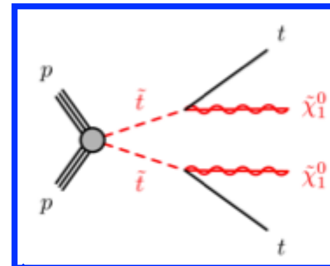


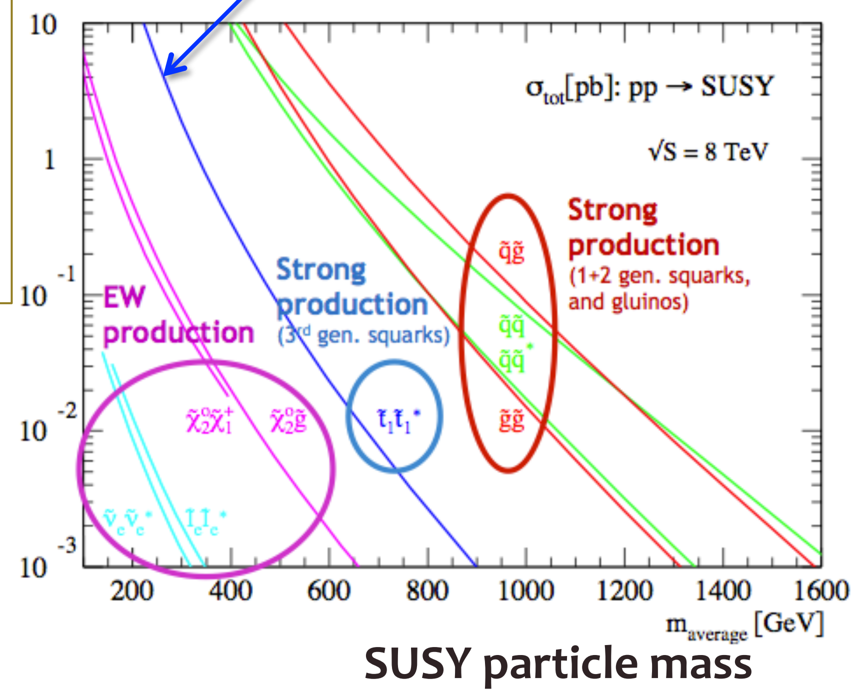
CMS: PAS-SUS-14-010(NEW)



Direct stop/sbottom search

- **Light stop and sbottom is motivated by nature SUSY**
  - **strong physics case for third generation squarks.**
- **Generic signatures:**
  - n_lepton(n=0,1, ≥2) + multi-jets **(≥ 1 b-jets)** + large MET

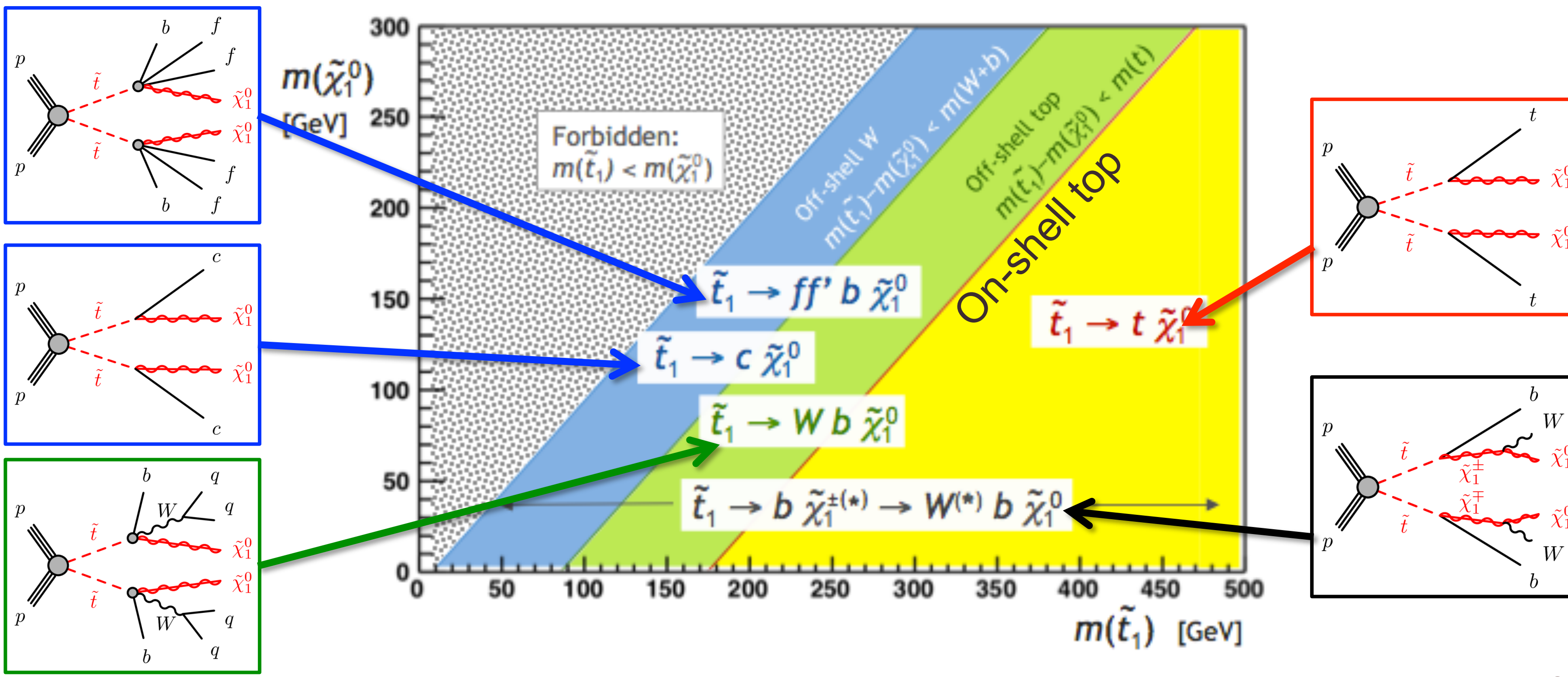




- 1 l + 4(1 b-)jets + MET(medium/heavy stop) : 1407.0583
- 0 l + 6 (2 b-)jets + MET(heavy stop) : JHEP 09 (2014) 015
- Z search (stop in GMSB, stop2): Eur. Phys. J.C(2014)74:2883
- Light stop: Eur. Phys. J.C(2014)74:3109
- Charm search: Phys. Rev. D. 90, 052008 (2014)
- 2 leptons + (b)jets + MET (stop): JHEP 06 (2014) 124
- 0 leptons + 2 b-jets + MET (~b/~t) : JHEP 10 (2013) 189
- 0-1lelptons+≥3bjets+MET(3rd gen. ~q):JHEP 10 (2014) 024

Direct stop/sbottom pair production

- Dedicated effort to search for **direct stop/sbottom pair** production
- Large spectrum of possible stop/sbottom decays
- Effort concentrated on simplified models with 100% BRs to chosen final state

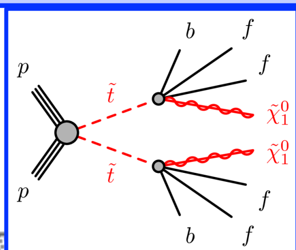


1-lepton stop search: 2/3/4-body decay to LSP

JHEP 11 (2014) 118

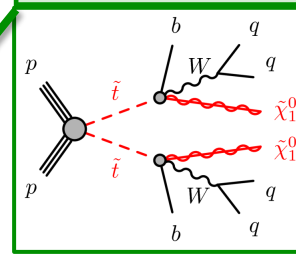
Stop 4-body decay:

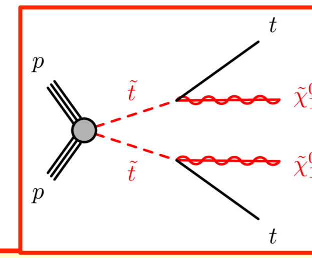
- **1 soft lepton** (6/7 GeV mu/e), **hard ISR jet**, ≥ 1 b-jet, MET cut
- Shape fit in lepton p_T

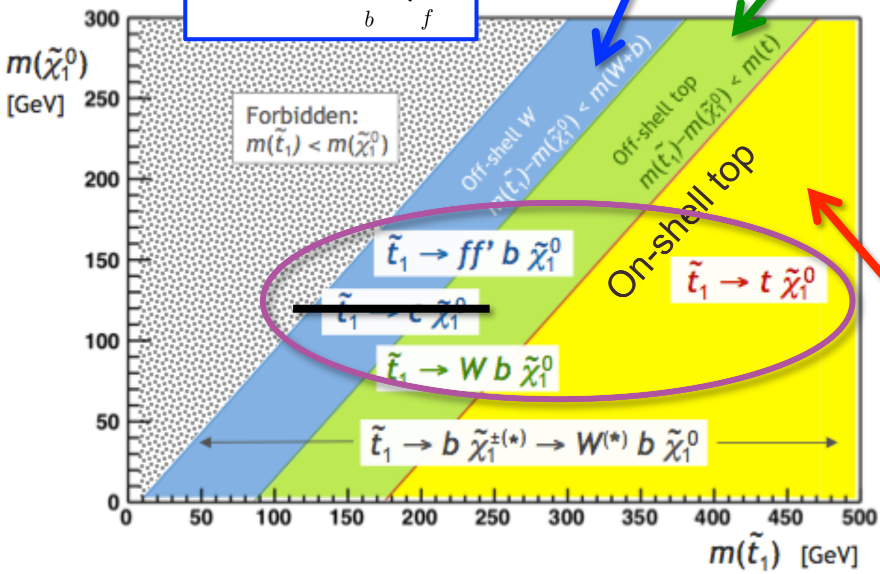


Stop 3-body decay:

- 1 lepton, ≥ 4 jets, ≥ 1 b-jet, MET cut
- Softer thresholds on MET, MT…
- 2-D shape fit in m_T and m_{T2}







Stop→top+neutralino decay:

- 1 lepton, ≥ 4 jets, ≥ 1 b-jet, MET cut
- Large-R jets (collect decay products of boosted top in heavy stop search)
- Shape fit for diagonal

Dominant BG: tt, W (MC normlized to data)

1-lepton stop search: 2/3/4-body decay to LSP

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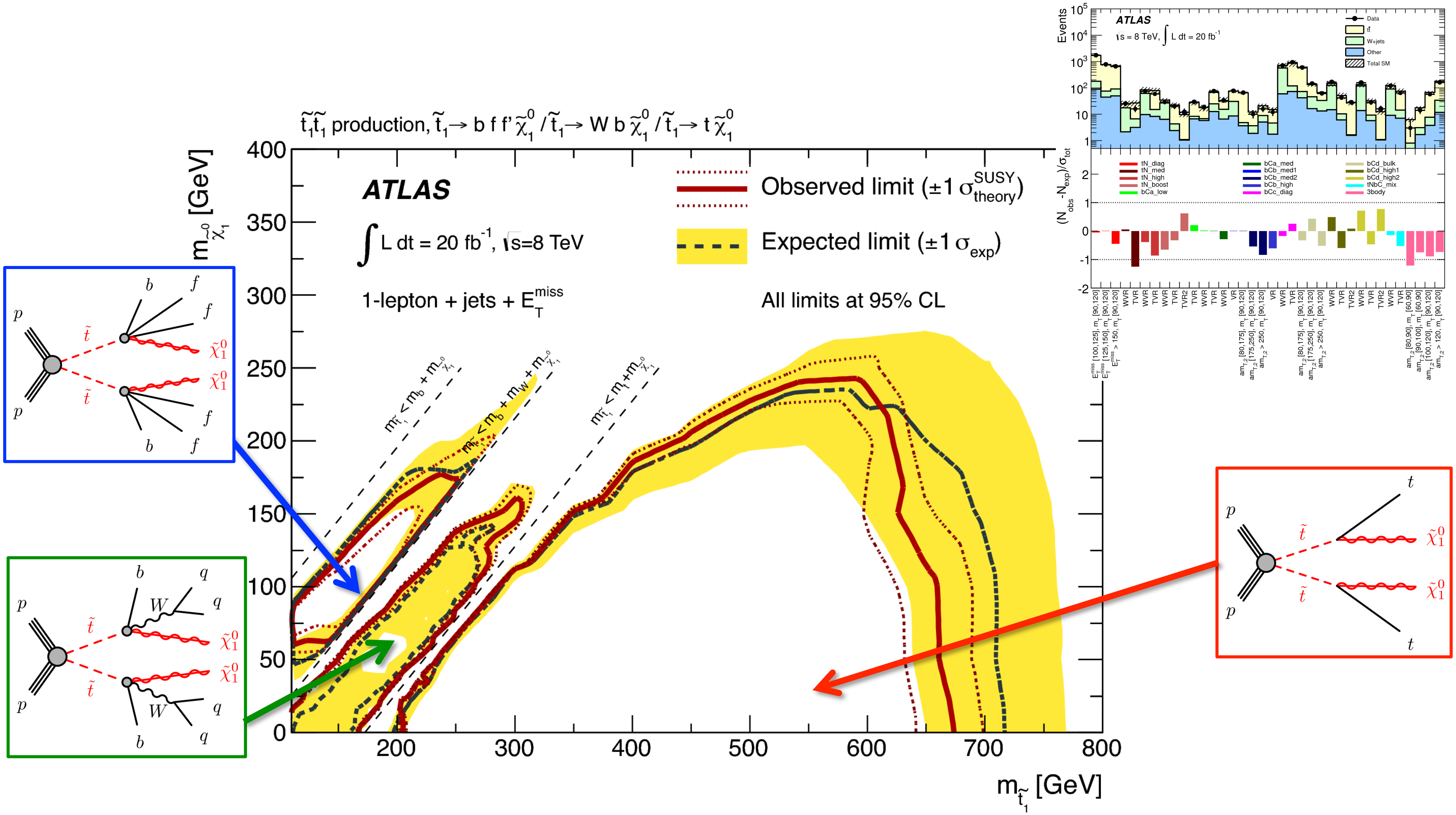

1-lepton stop search: decay to b + chargino

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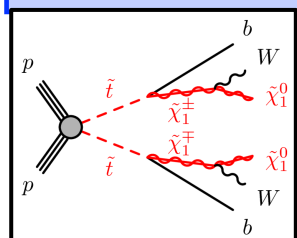
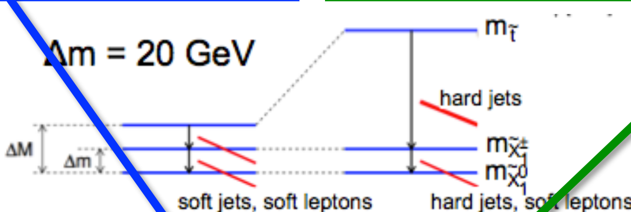
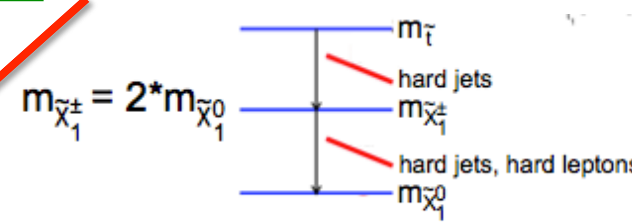
Fully compressed:
- **1 soft lepton** (6/7 GeV mu/e), **hard ISR jet**, ≥ 1 b-jet, MET
- Shape fit in lepton p_T

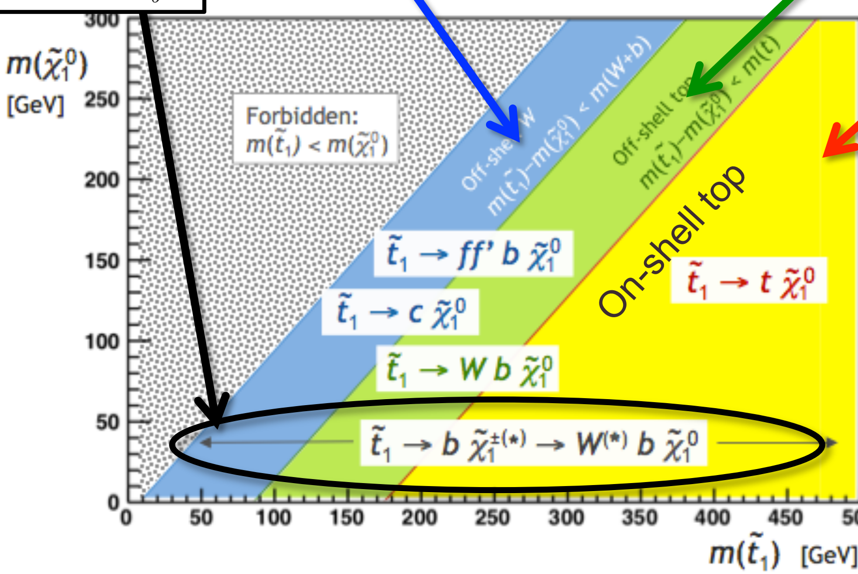
Partially compressed:
- **1 soft lepton** (6/7 GeV mu/e), ≥ 2 b-jet, MET
- Shape fit in am_{T2}

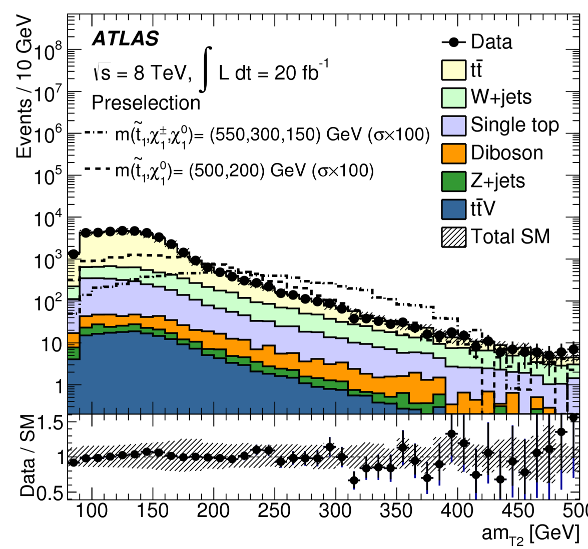
Bulk area:
- 1 hard lepton, ≥ 4 jets, ≥ 1 b-jet, MET
- Shape fit in m_T and am_{T2}











Dominant BG: tt, W (MC normlized to data)

1-lepton stop search: decay to b + chargino

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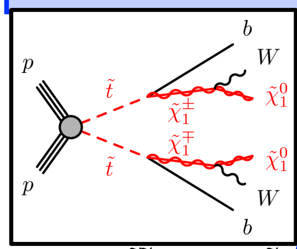
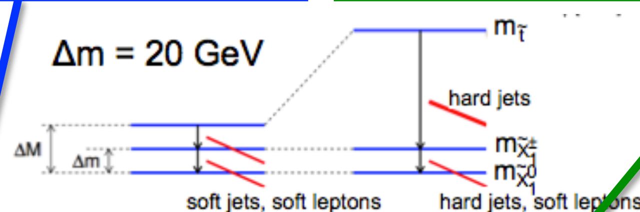
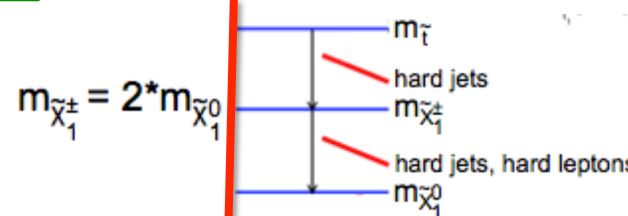
Fully compressed:
- **1 soft lepton** (6/7 GeV mu/e), **hard ISR jet**, ≥ 1 b-jet, MET
- Shape fit in lepton p_T

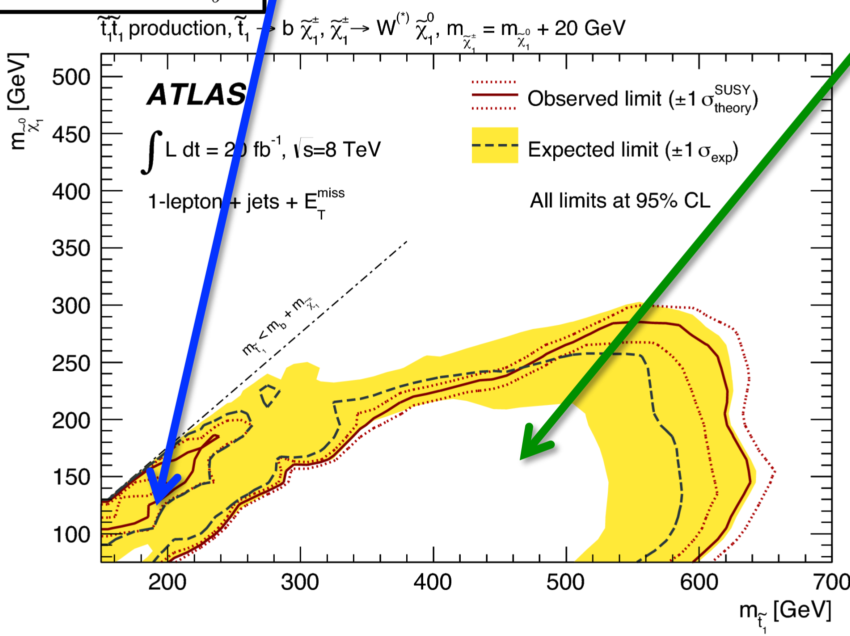
Partially compressed:
- **1 soft lepton** (6/7 GeV mu/e), ≥ 2 b-jet, MET
- Shape fit in am_{T2}

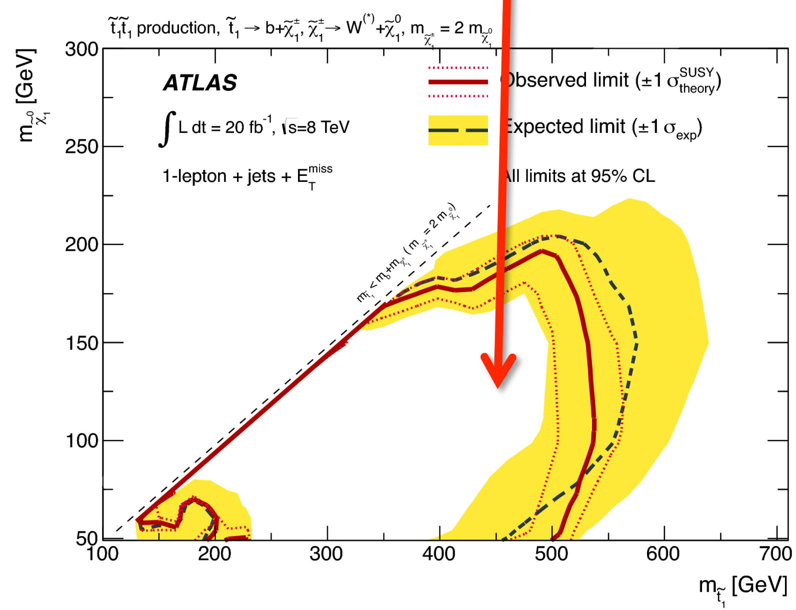
Bulk area:
- 1 hard lepton, ≥ 4 jets, ≥ 1 b-jet, MET
- Shape fit in m_T and am_{T2}







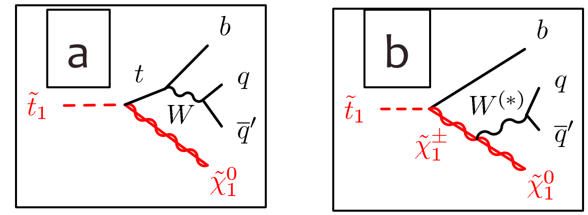


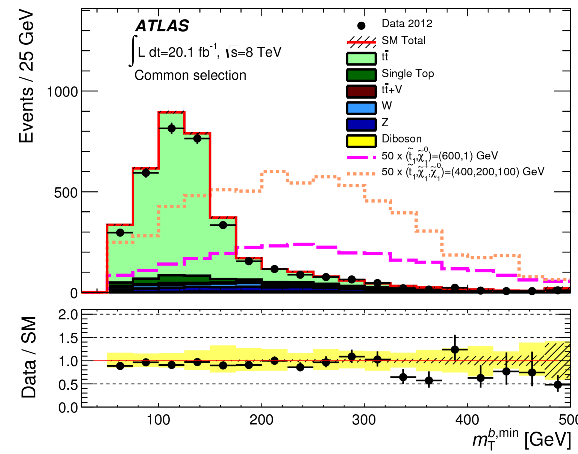


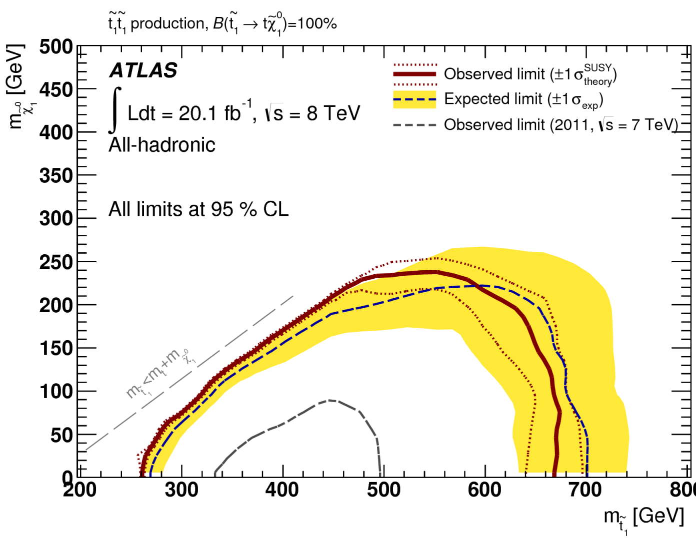
All Hadronic Stop Search (0l)

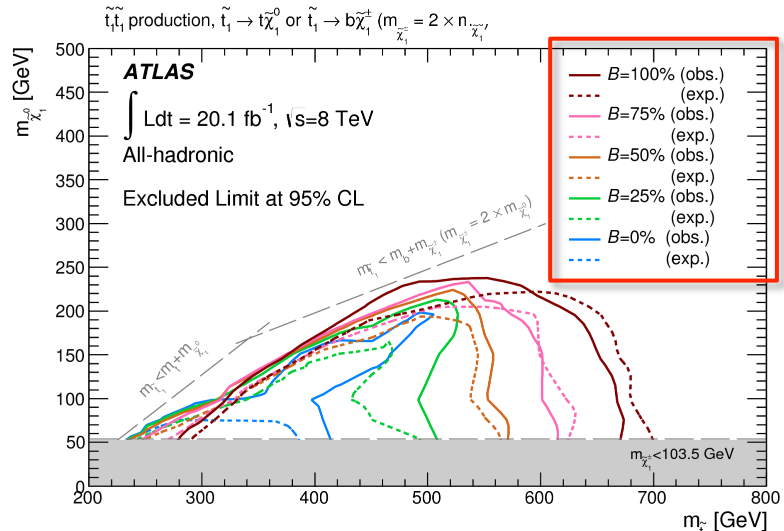
JHEP 09 (2014) 015

- Direct stop production search targeting:
- 3 type of targeting medium and heavy stops
  - **"Full resolved" channel**: ≥6 jets, ≥2 b-jets (all jets reconstructed in a,b)
  - **"Partially resolved" channel**: ≥4-5 large-R jets(targeting boosted regime in a)
  - **≥5 jets, ≥2 b-jets** (targeting mixed decays of a and b with 1 soft jet due to low Δm)
- Common discriminating variables:
  - m_T^{min}(b,MET): suppress ttbar
  - $\Delta\Phi^{min}$(j,MET): suppress fake background

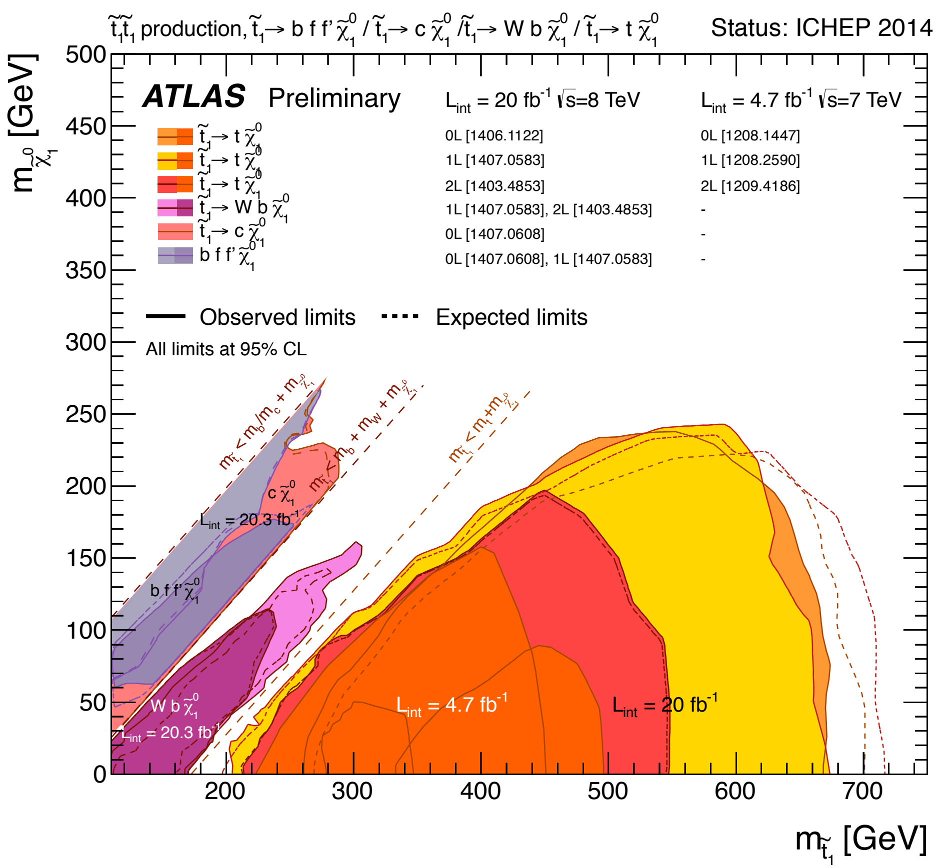


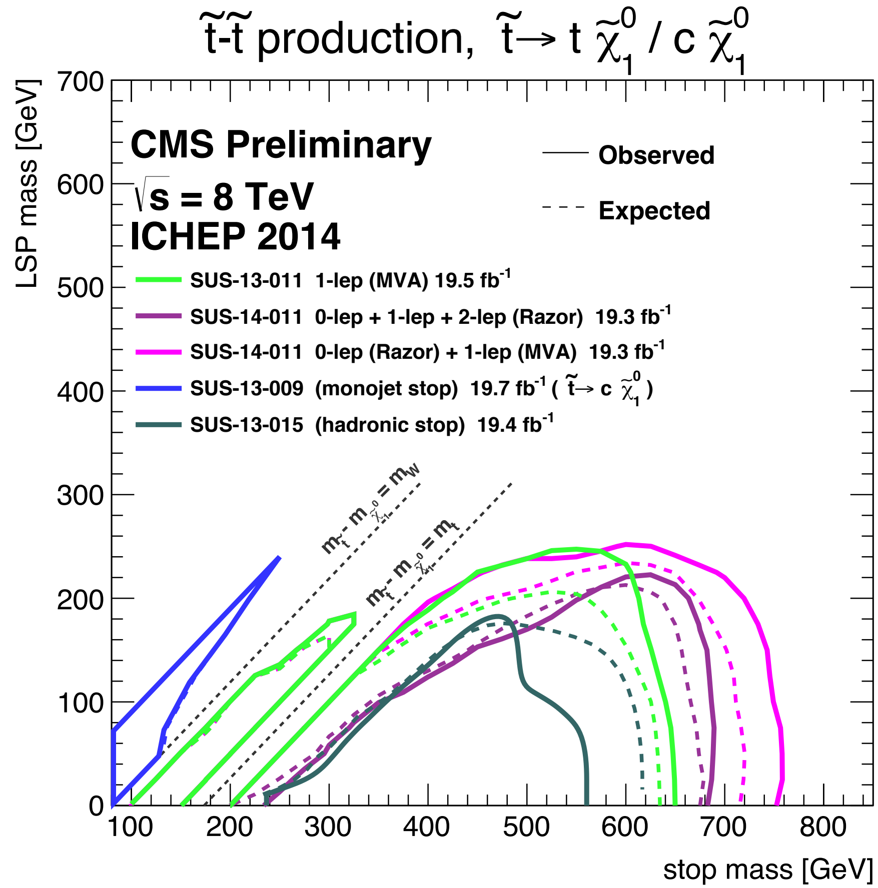






Direct stop pair production Summary



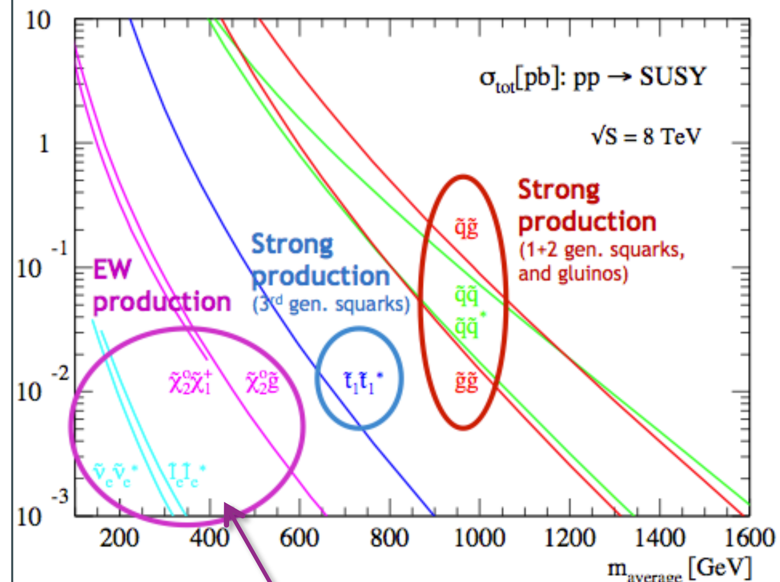


- Strong search program on stop, covering range from low to heavy stop mass, various decay modes.
- Exclusion for m(~t1) < ~660GeV for massless LSP, exclusion up to m(LSP) ~250 GeV

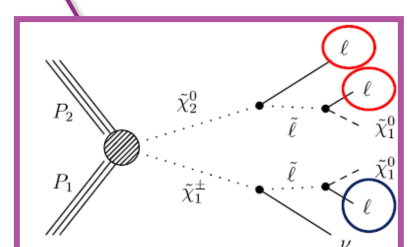
Direct EWK-ino Search

- Search for electroweak (EWK) SUSY below the TeV scale is motivated by naturalness arguments.
- EWK production has a low cross-section compared to strong production
  - Very challenging searches
  - But leads to multi-lepton signatures with very low SM background.
- If strong production is suppressed, EWK processes could be the dominant SUSY production at the LHC. (EWKino < 1 TeV)

- 2l (e/mu) + MET: JHEP 05 (2014) 071
- 3l + MET: JHEP 04 (2014)169
- 2tau + MET: JHEP 10 (2014) 096
- 1l+bb+MET : *ATLAS-CONF-2013-093*
- 4l + Etmiss: Phys. Rev. D. 90, 052001 (2014)



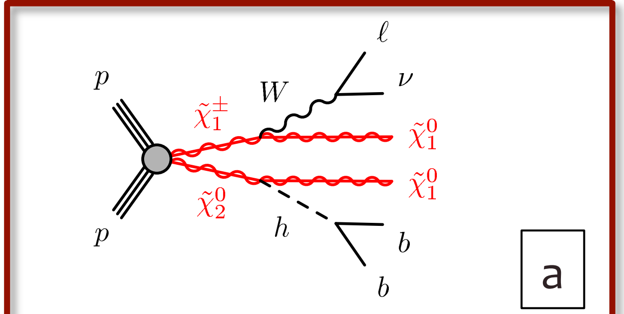
SUSY particle mass



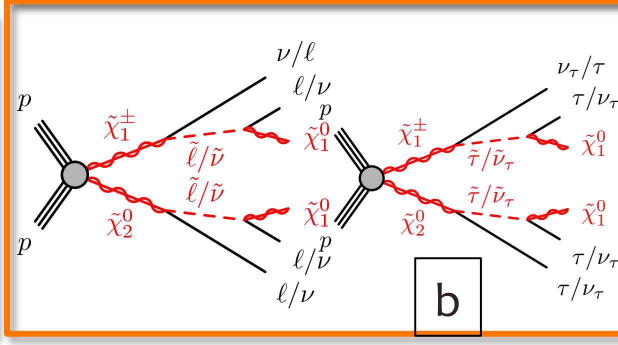
<u>Generic signature</u>: >=1 lepton(s) in the final state arising from the decay of charginos/neutralinos via sleptons/sneutrinos, gauge bosons or Higgs.

ElectroWeak production
(direct C/N and slepton production)

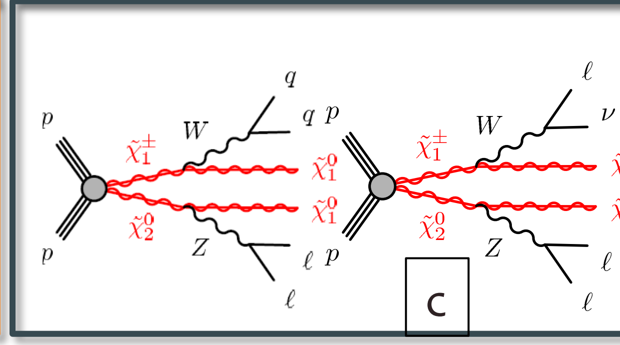
C1N2 via Wh,
w→lν,h→bb,γγ,ll
FS: 1l +bb/γγ or 3l +MET
(ATLAS-CONF-2014-062)



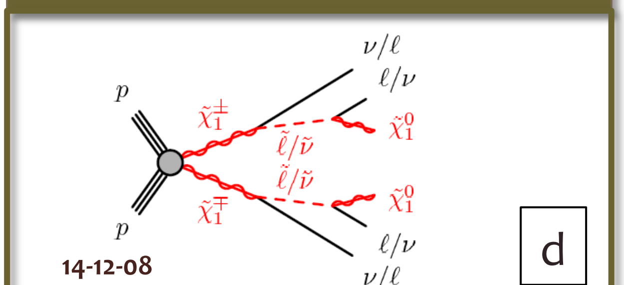
C1N2 via slepton,
FS: 3l + MET (l=e/μ/τ)
3l (e/μ): JHEP 04 (2014)169
⩾2 τ : JHEP 10 (2014) 096



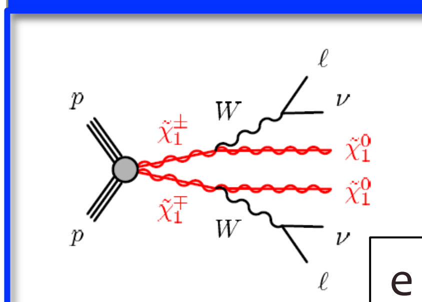
C1N2 via WZ
FS: 2/3l+MET
2l: JHEP 05 (2014) 071
3l: JHEP 04 (2014)169



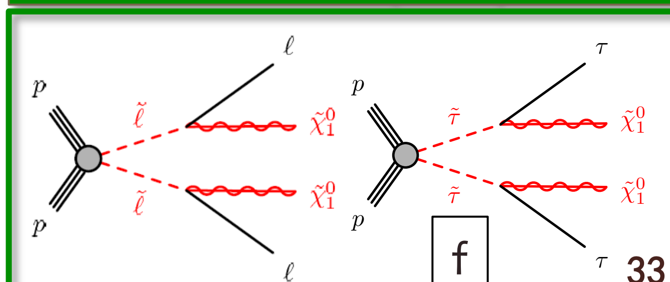
C1C1 via slepton
FS: 2L+MET(l=e/μ/τ)
2l (e/μ): JHEP 05 (2014)071
2 τ : JHEP 10 (2014) 096



C1C1 via WW
FS: 2L+MET
2l (e/μ): JHEP 05 (2014)071



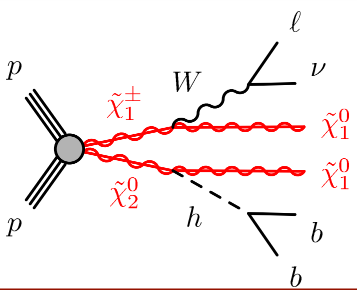
Direct slepton pair
FS: 2L+MET (l=e/μ/τ)
2l (e/μ): JHEP 05 (2014)071
2 τ : JHEP 10 (2014) 096



Electroweak production – Wh

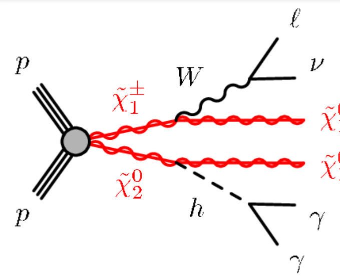
[direct C1N2 production via higgs]

C1N2 via Wh, 1Lbb



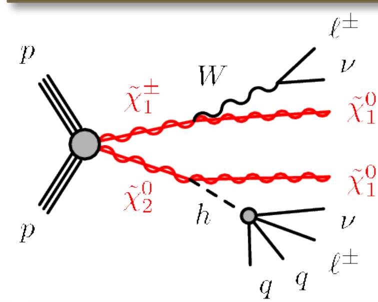
- Search based on events with 1L and two b-tagged jets
- Signal from background discrimination based on MET, mT, and mCT observables and by binning in mbb (2SR)

C1N2 via Wh, 1Lγγ



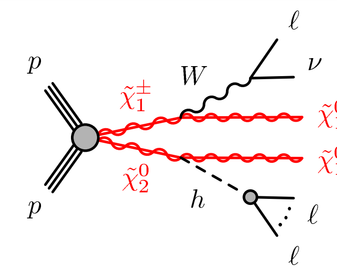
- Search based on events with 1L and two photons
- Signal from background discrimination based on MET, ΔΦ(Wh) and **mT(Wγ$_i$)** (2SR)

C1N2 via Wh, SS2L



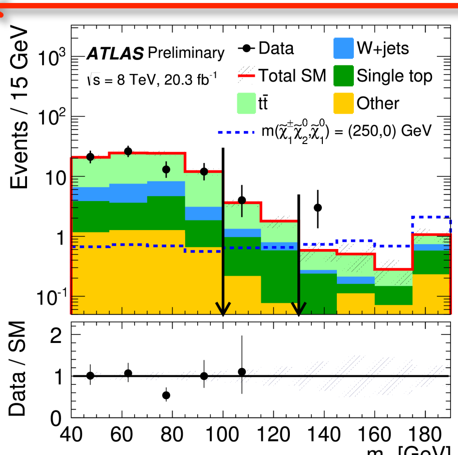
- Search based on events with SS2L
- Signal from bg discrimination based on MET, meff, mTmax, mlj,mljj (6SR)

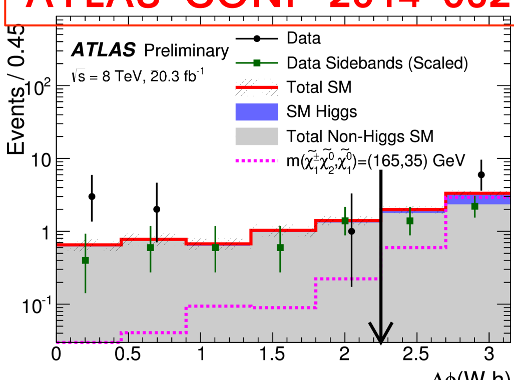
C1N2 via Wh,3L

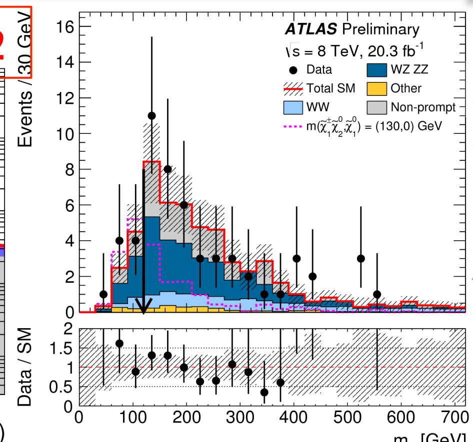


- Search based on events with 3L
- **3 SRs: 0,1,2 taus + light leptons**

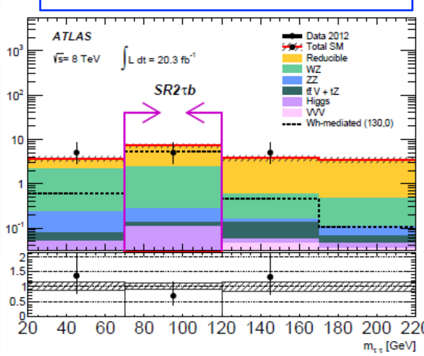
ATLAS-CONF-2014-062







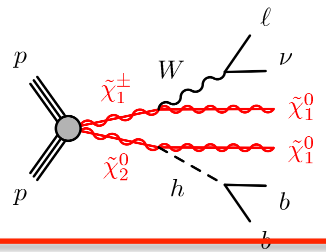
JHEP 04 (2014) 169

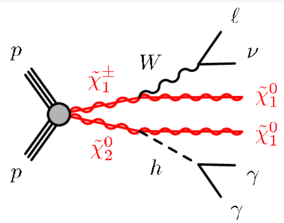


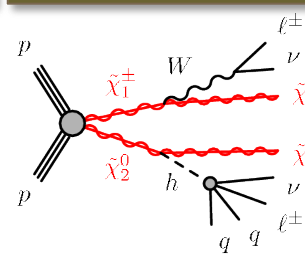
Electroweak production – Wh

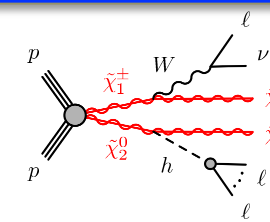
[direct C1N2 production via higgs]

C1N2 via Wh, 1Lbb	C1N2 via Wh, 1Lγγ	C1N2 via Wh, SS2L	C1N2 via Wh,3L









ATLAS-CONF-2014-062

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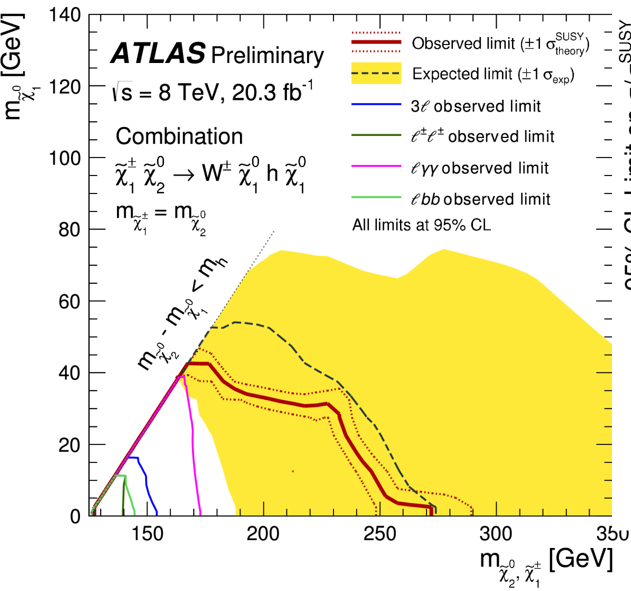
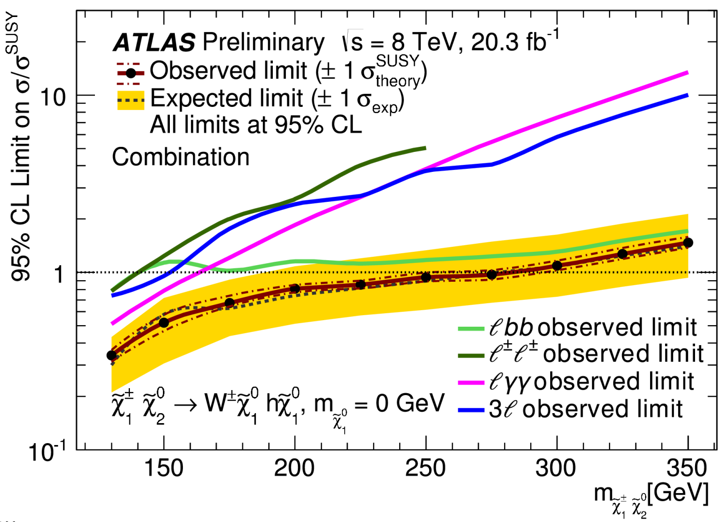




- For chargino mass < 170 GeV all channels contribute
- For chargino mass > 170 1L+bb channel dominates
- 1L+bb sensitivity varies slowly due to decreasing XS

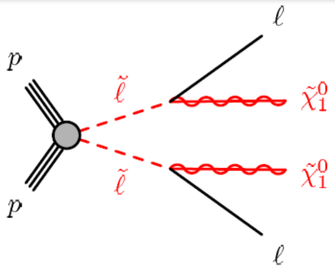
- Electroweakino mass > 250 GeV for massless LSP in models with higgs in decay

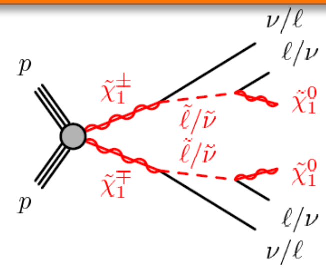
Electroweak production – 2L

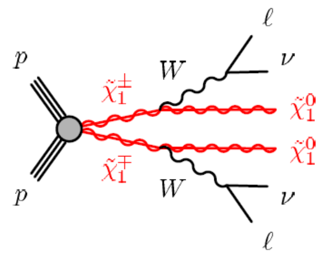
[direct C1/ sl production]

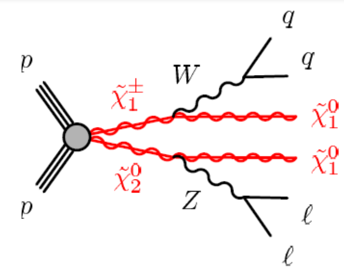
JHEP 05 (2014) 071

Direct slepton pair	C1C1 via slepton/ sneutrino	C1C1 via WW	C1N2 via WZ









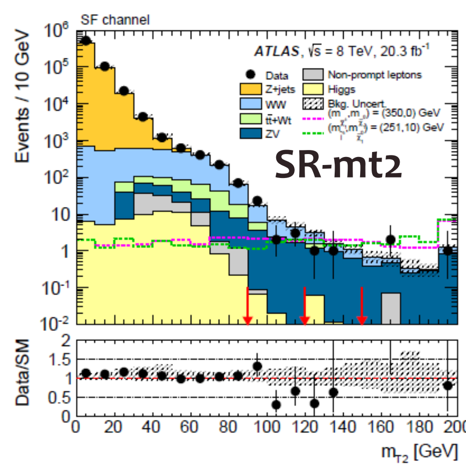
[SR-mt2]
3SRs: slepton mediated

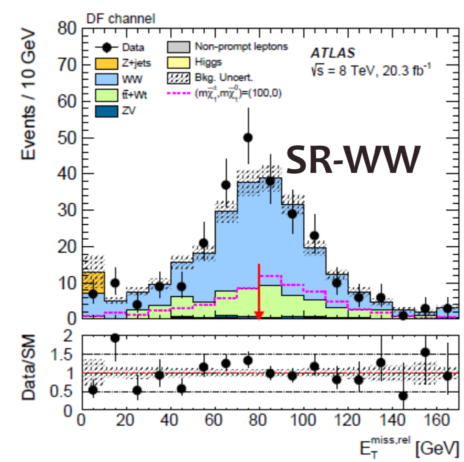
[SR-WW]
3SRs: WW mediated

[SR-WZ]
1SRs:WZ mediated

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\rm miss} - \mathbf{q}_T)\right)\right]$$

- **7 SRs designed targeting different models.**
  - **The same flavor and different flavor are considered separately in each SR.**
- **Main backgrounds: top-quark(ttbar and Wt) and dibosons.**
  - **For SM ttbar and WW: mt2 has an upper end-point at the W mass.**



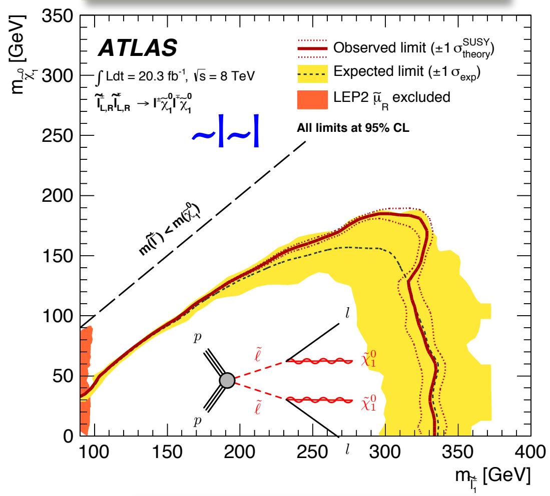


Electroweak production – 2L

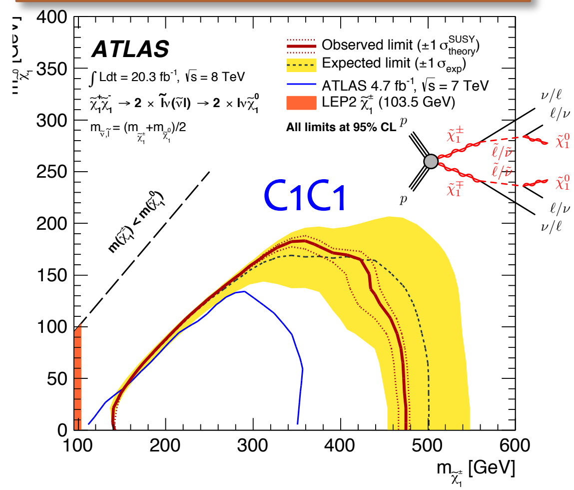
[direct C1/ sl production]

JHEP 05 (2014) 071

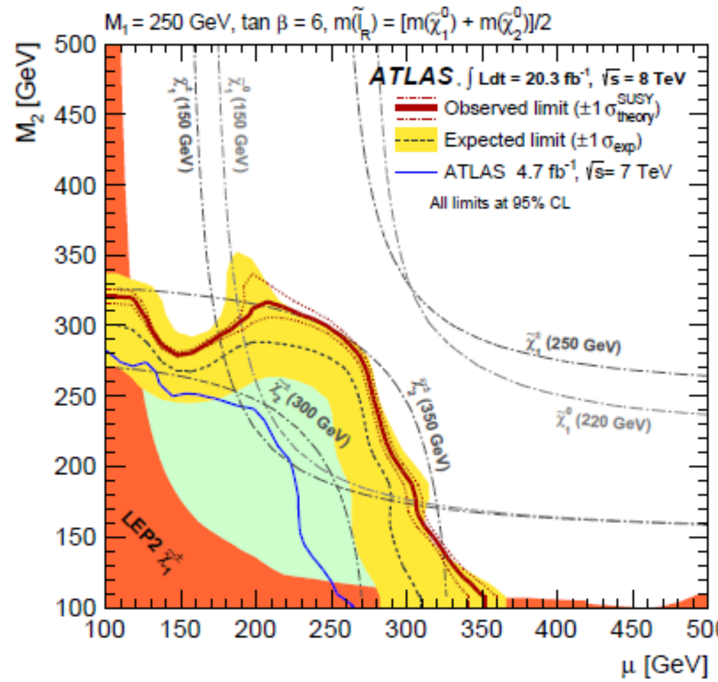
Direct slepton pair



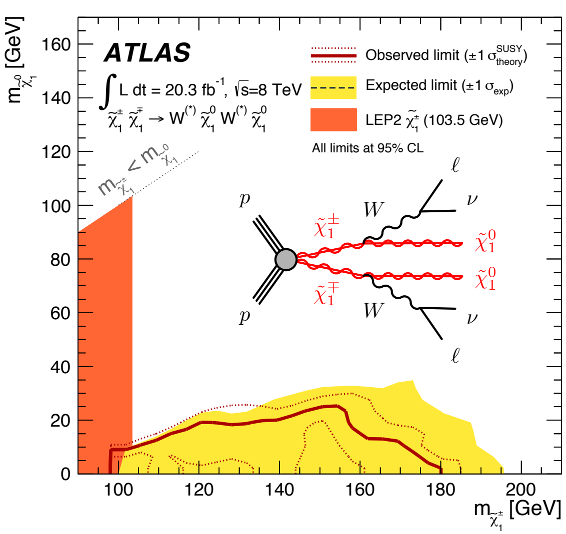
C1C1 via slepton/sneutrino



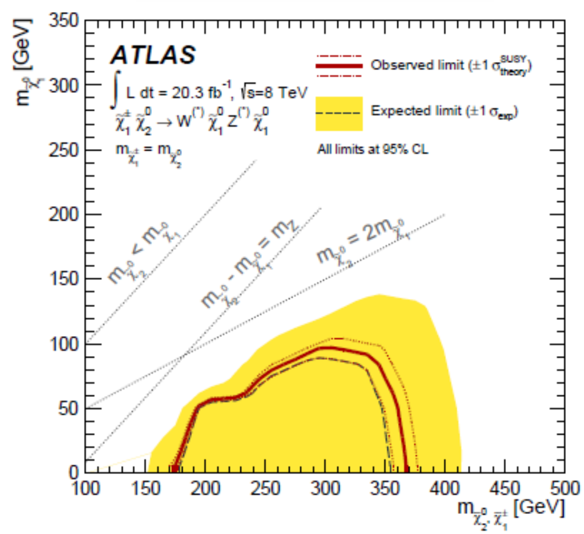
pMSSM decay via slepton



C1C1 via WW



C1N2 via WZ



ElectroWeak production – 3L

[direct C1N2 production]

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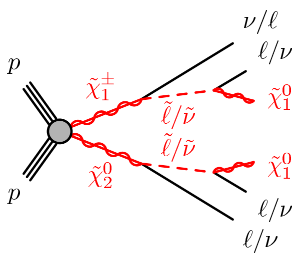
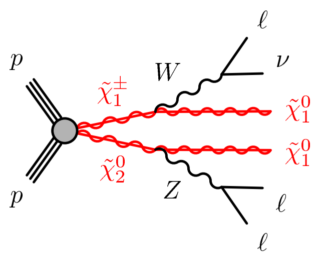
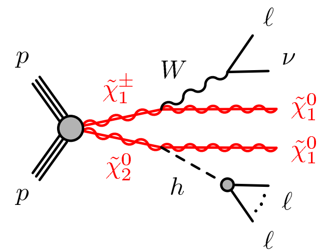
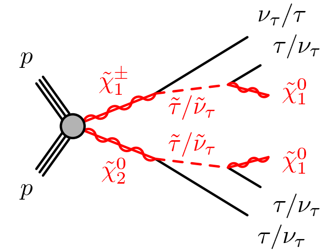
C1N2 via stlepton/sneutrino	C1N2 via WZ	C1N2 via Wh	C1N2 via stau/sneutrino







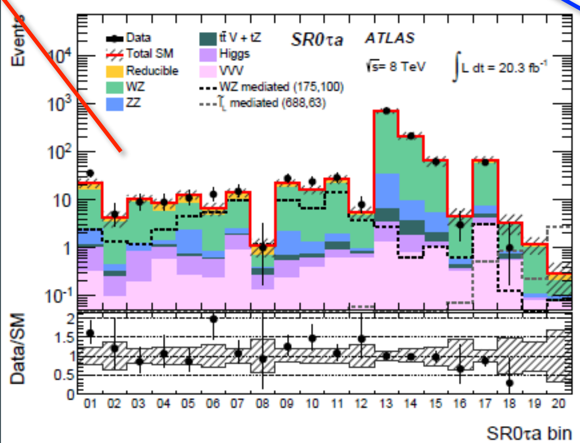


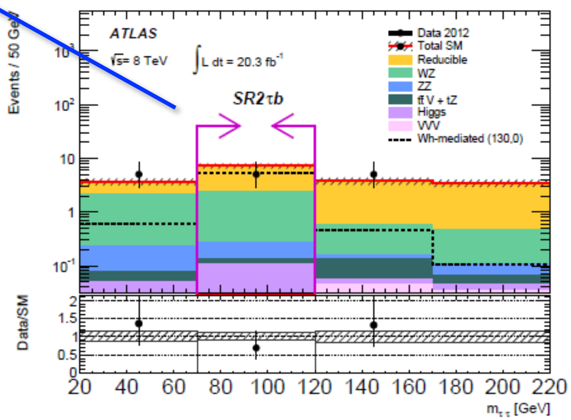
1 SR: 0 tau + light leptons
characterized by 20 independent bins

3 SRs: 0,1,2 taus + light leptons

1 SR: 2 taus + light lepton

- **Analysis includes up to 2 hadronic taus.**
- **5 SRs are defined according to the flavor and charge of the leptons, targeting different models.**
- **Main backgrounds: diboson, triboson**

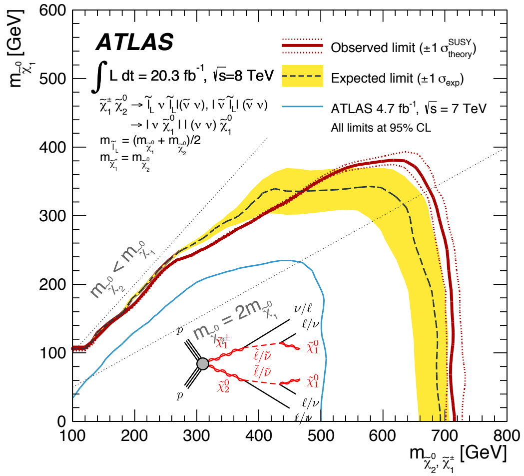




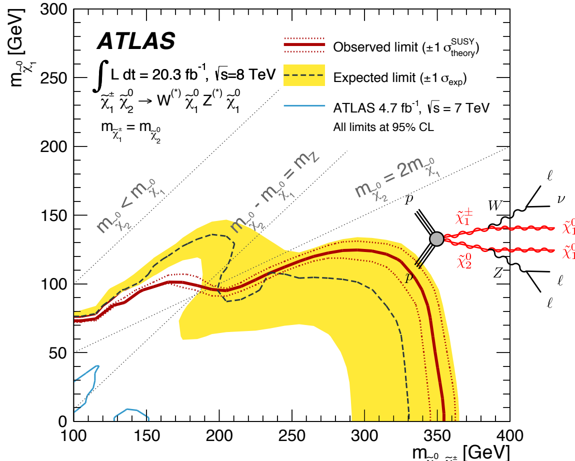
ElectroWeak production – 3L

[direct C1N2 production]

C1N2 via stlepton/sneutrino



C1N2 via WZ



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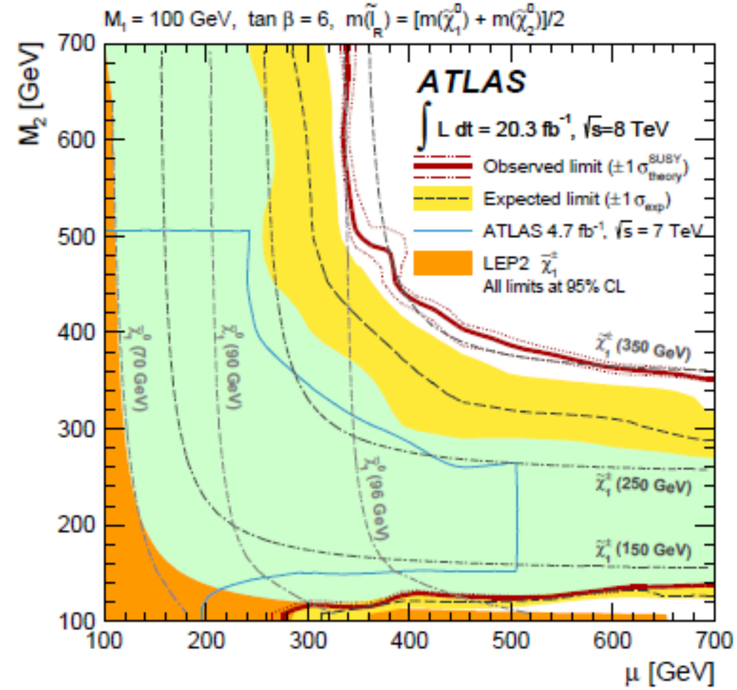
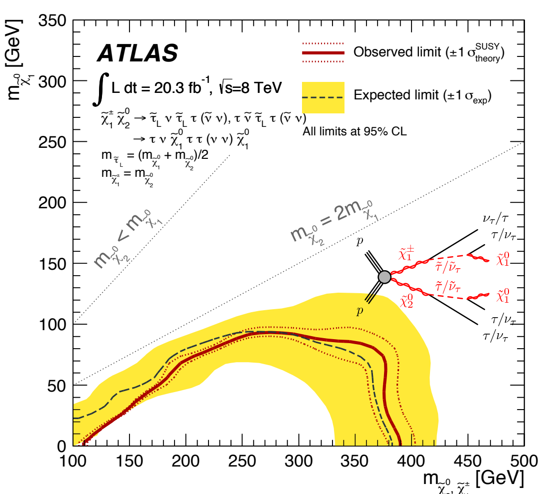
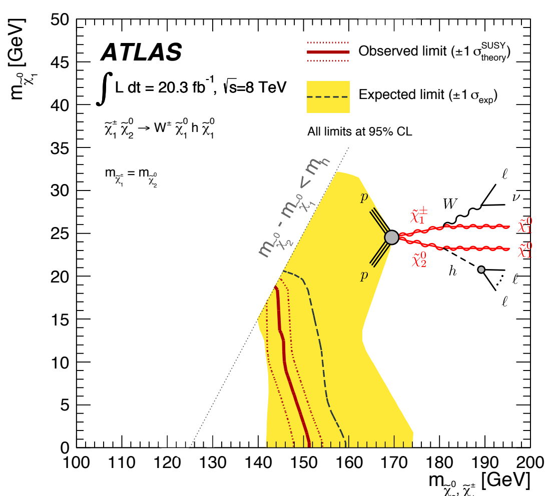
pMSSM
decay via slepton



C1N2 via stau/sneutrino



C1N2 via Wh

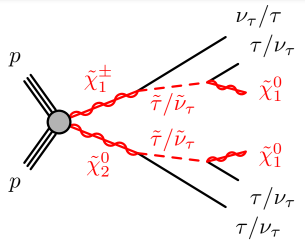


Electroweak production – 2tau

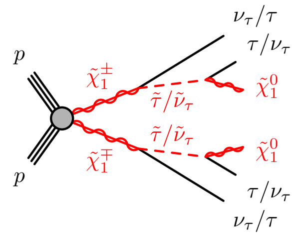
[direct C1(N2)/ sl production]

IHEP

C1N2 via stau/sneutrino



C1C1 via Stau/sneutrino



Direct stau pair

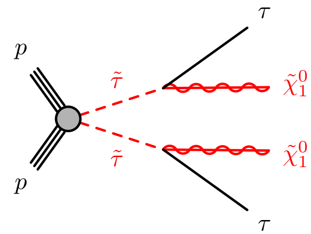


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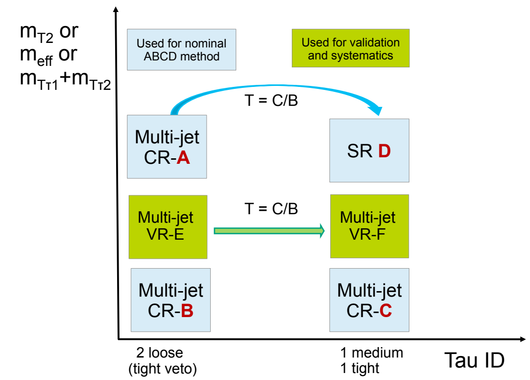
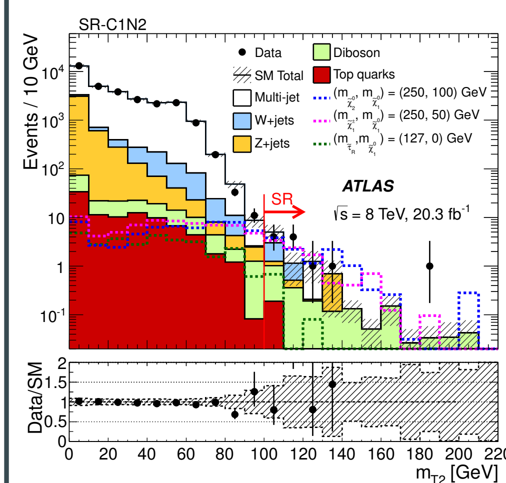
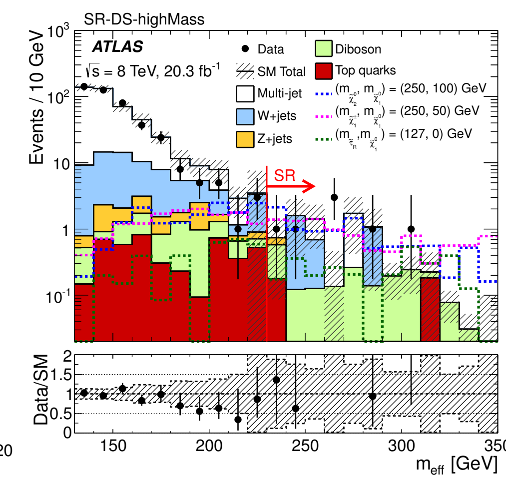
Illustration of "ABCD" method



First search for production of C1C1 and Dstau with hardronic tau decays from the LHC !

- Direct gaugino/stau production with final state: **2tau + MET**
- 4 SRs designed targeting different scenarios: one for C1N2, one for C1C1 and two for Dstau
- Main backgrounds:
  - W+jets (1real+1fake): normalized MC to data in WCR
  - Multi-jet (2fake): ABCD data-driven estimation





Electroweak production – 2tau

[direct C1(N2)/ sl production]

C1N2+C1C1 via stau/sneutrino

C1C1 via Stau/sneutrino

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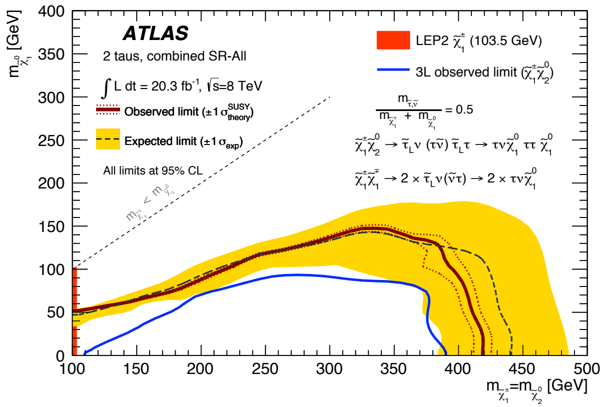
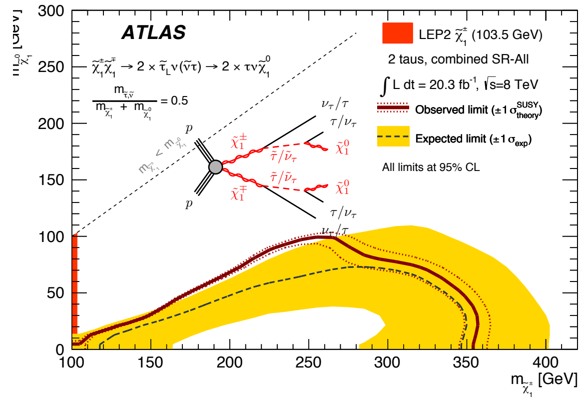
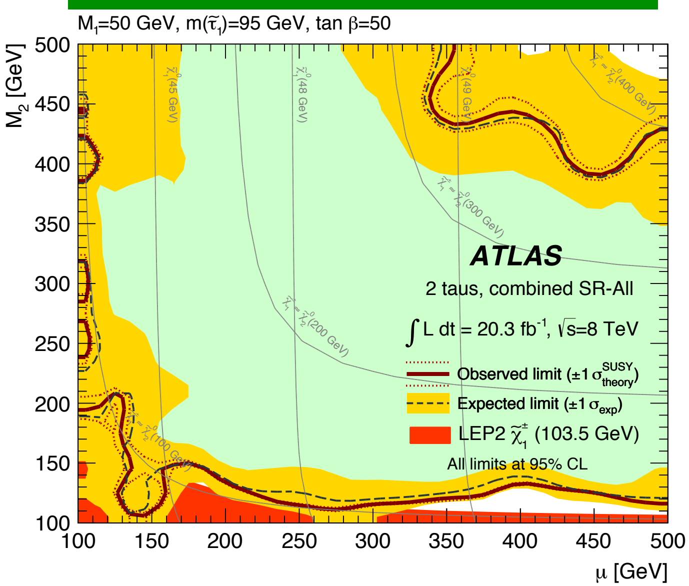


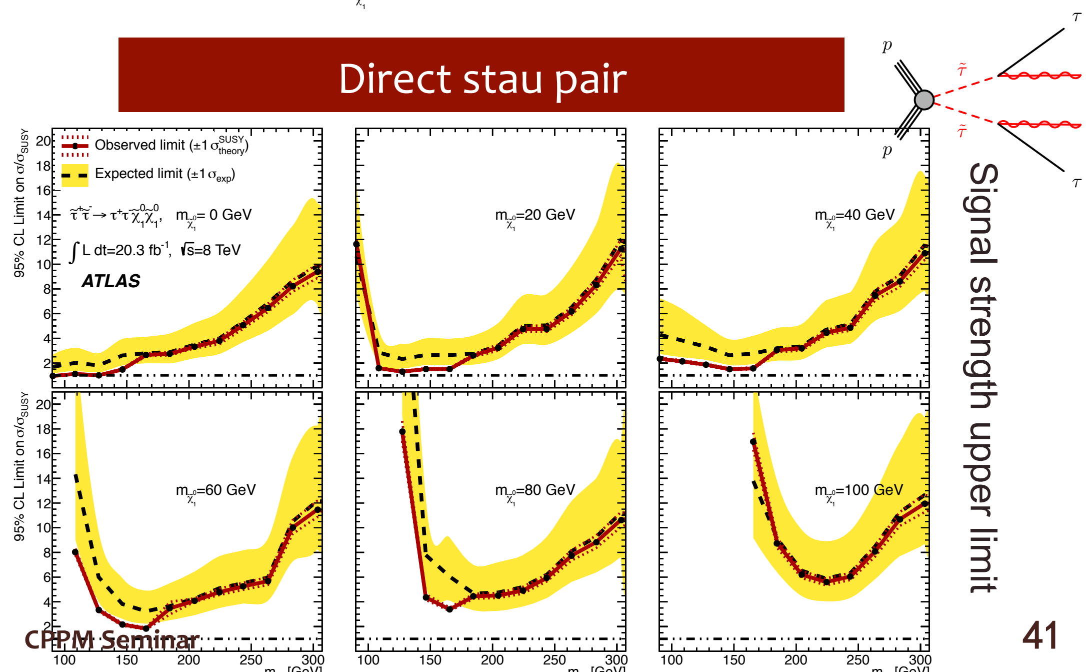


Multivariate analysis technique (MVA) has been used **for direct stau search** by HUAN, which will be published in a legacy paper before Moriond 2016.

pMSSM stau-enriched

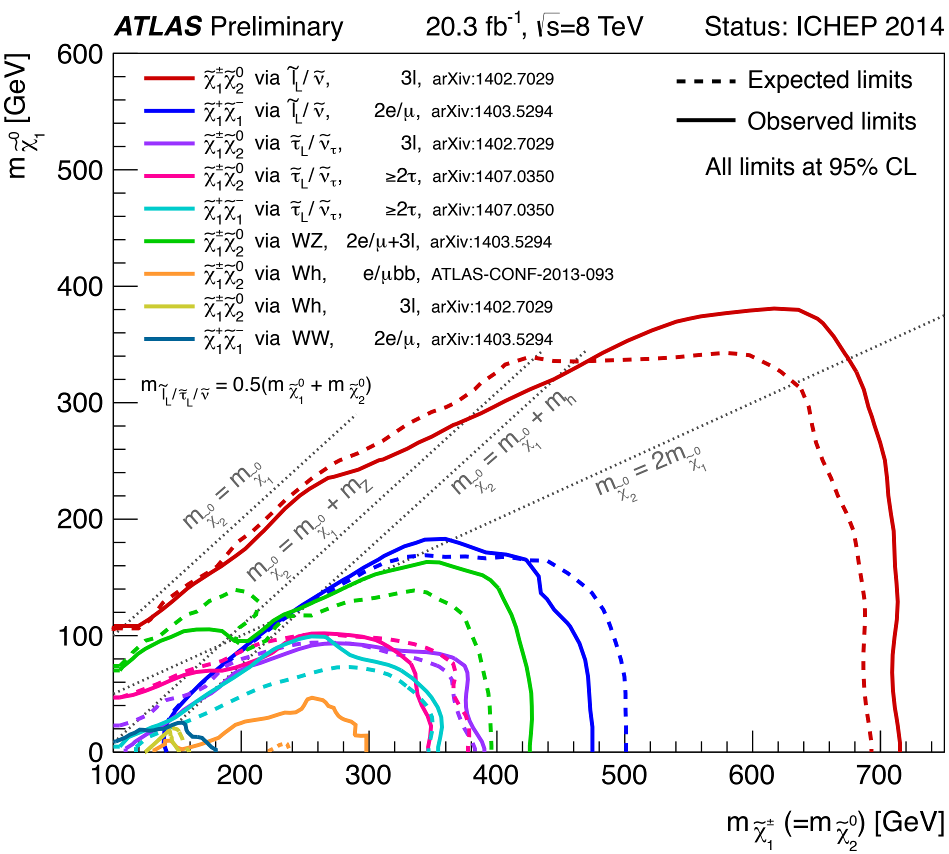


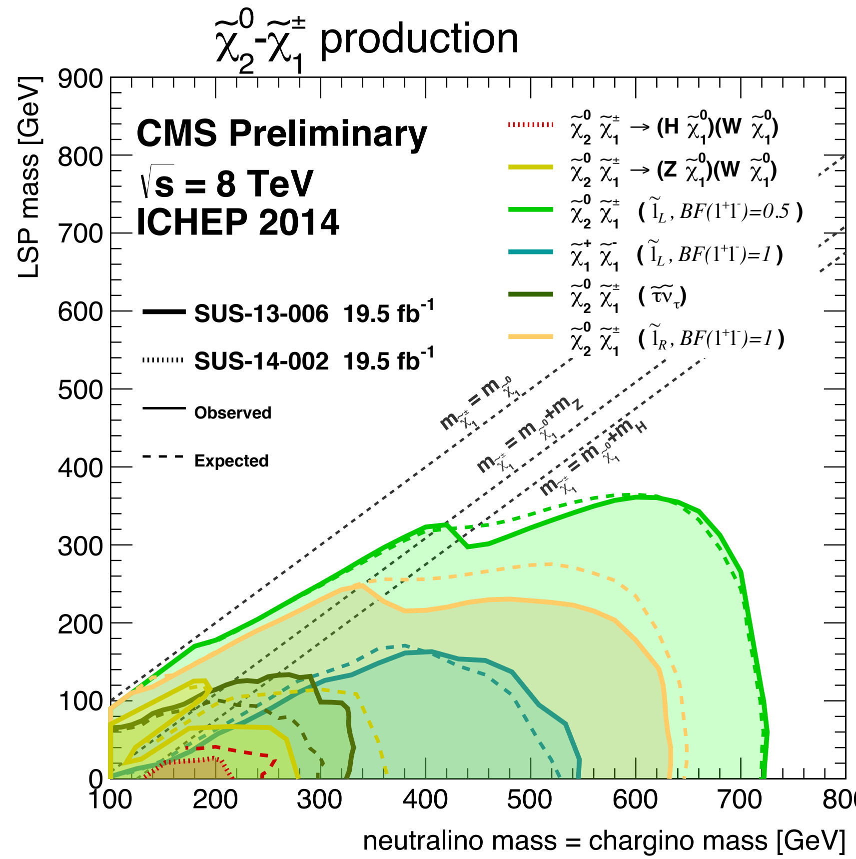
Direct stau pair



Signal strength upper limit

ElectroWeak Production Summary





- Comparable for C1N2 via slepton
- CMS: SS improvement in compressed region; no results on C1C1 via stau and WW
- ATLAS: more results for compressed scenario will be ready soon

Outline

- SUSY Introduction
- The LHC and ATLAS
- Overview of SUSY search results on run-1 data
- *Outlook and Summary*

Outlook and Summary

- **ATLAS developed a vast program to search for SUSY**
  - No significant excess seen so far
  - All public results:

    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

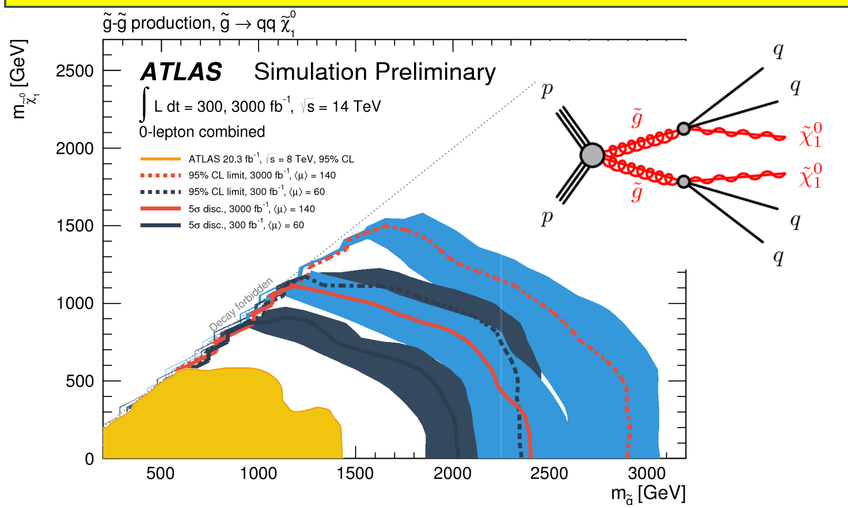
- **In canonical scenarios, sensitivity is achieved to ~1.2 TeV gluinos, ~700 GeV stops and ~400 GeV for EWK-inos**

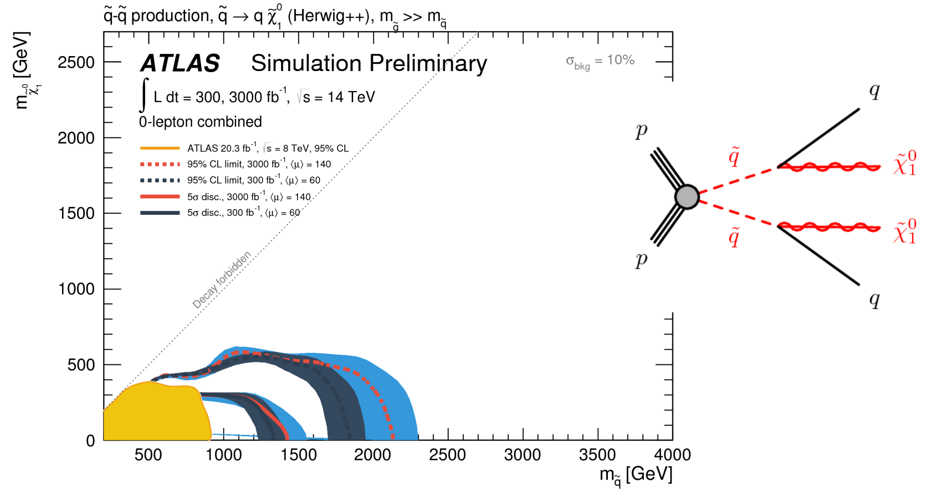
- **The reach with SUSY is expected to increase significantly at run2 and run3**

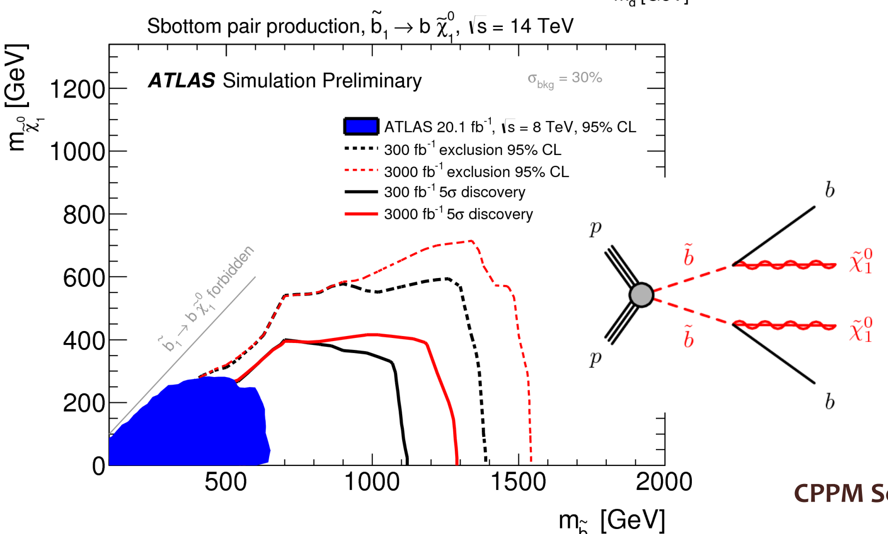
Long term prospects

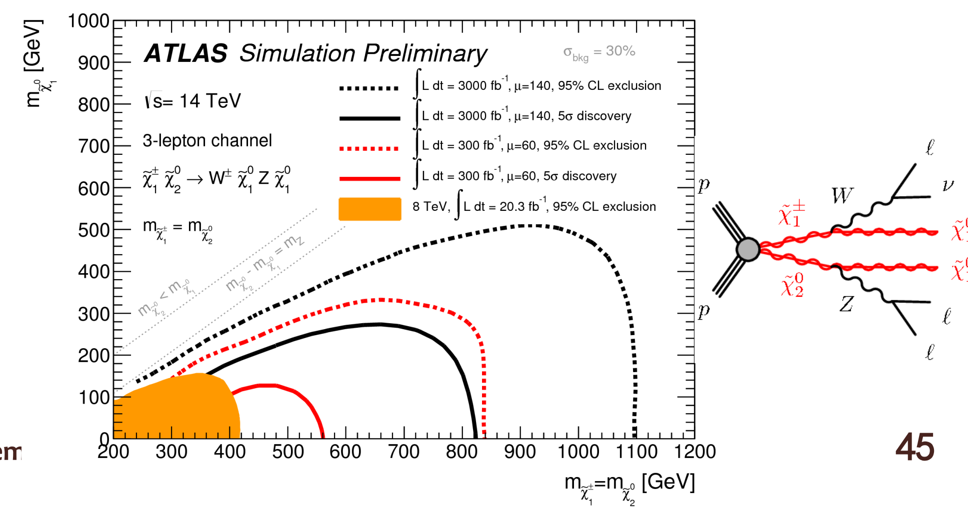
ATL-PHYS-PUB-2014-010

- ATLAS studied long term prospects for the (HL-)LHC with 300, 3000 fb^{-1}@14 TeV
- Discovery potential up **to 2.5 TeV gluinos, 1.3 TeV squarks/sbottom and 800 GeV Electroweakinos**

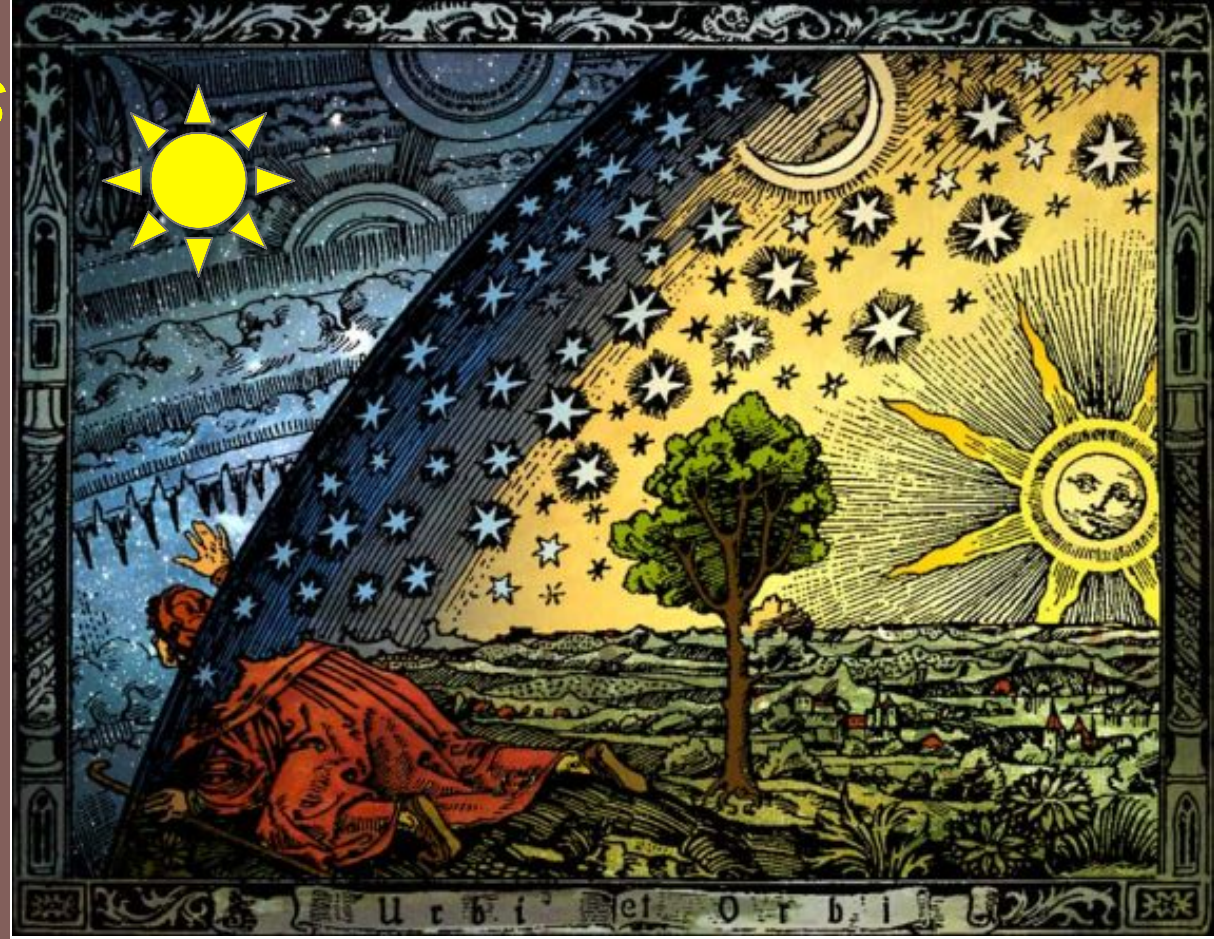








Exciting times are ahead of us !



THANKS FOR YOUR ATTENTION!

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	$\tan\beta$ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{G})>10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-210 GeV	$m(\tilde{\chi}_1^0)$ =$m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)$<<$m(\tilde{\chi}_1^\pm)$	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$ 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$ 260-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	10<$\tan\beta$<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^\pm)$, $\lambda_{121}\neq 0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e, μ (SS)	2 b	Yes	14.3	sgluon 350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

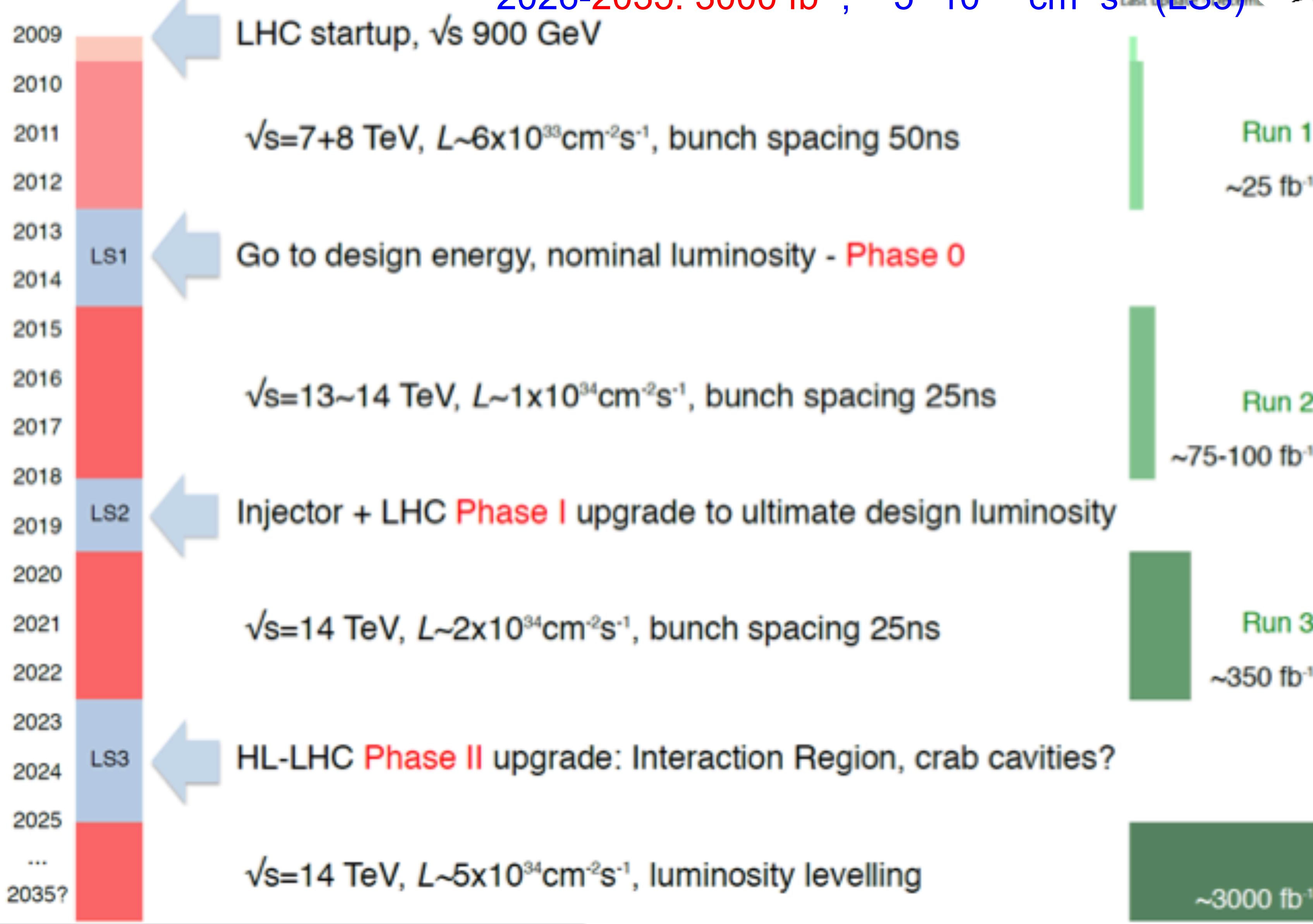
$\sqrt{s}$ = 7 TeV full data; $\sqrt{s}$ = 8 TeV partial data; $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

LHC roadmap

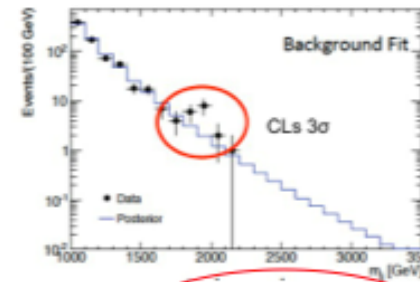
2015-2017: 100 fb^{-1}, ~ 1* 10 ^{34} $cm^{-1}s^{-1}$ (LS1)
2020-2022: 300 fb^{-1}, ~ 2* 10 ^{34} $cm^{-1}s^{-1}$ (LS2)
2026-2035: 3000 fb^{-1}, ~ 5* 10 ^{34} $cm^{-1}s^{-1}$ (LS3)



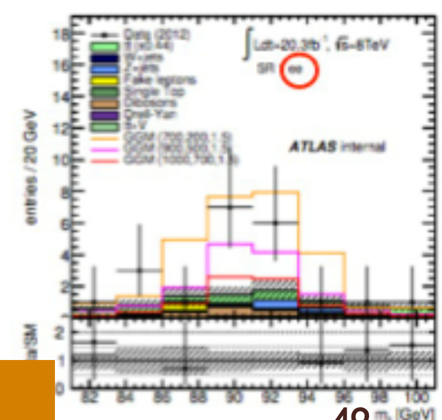
From LHCC Open meeting, 03.12.2013

Excesses seen so far (Exotics, SUSY)

- **For a more detailed review, see the** [physics plenary talk (July 18th) by T. Golling](#)
- **Mono-jet** [CDS link](#)
  - ~1.7σ / 2.4σ excess above BG in the two highest MET SRs
  - High MET SRs dropped for paper (very low stat in CR)
- **VV→JJ** [CDS link](#)
  - Mass of fat jets each consistent with W,Z mass
  - No issue found in cross checks
- **Same-sign leptons / 3-leptons + b-jets** [CDS link](#)
  - No issue found in cross checks, being made public
- **3-leptons + 3 b-jets** [CDS link](#)
  - ~3.5σ in a validation region of the 3-lepton search
  - No issue found, but will not be made public as not a SR
  - Plan a dedicated SR for run2
- **Z+jets + MET** [CDS link](#)
  - Peaking at Z mass, BG dominated by non-Z (tt)
  - No issue found in cross checks, to be made public soon



RVLQ5/SR4t2	SRVLQ6/SR4t3	SRVLQ7/SR4t4
6 ± 0.73 ± 0.87	4.25 ± 0.46 ± 0.85	1.12 ± 0.30 ± 0.23
6	12	6
0.430	0.00952	0.00734



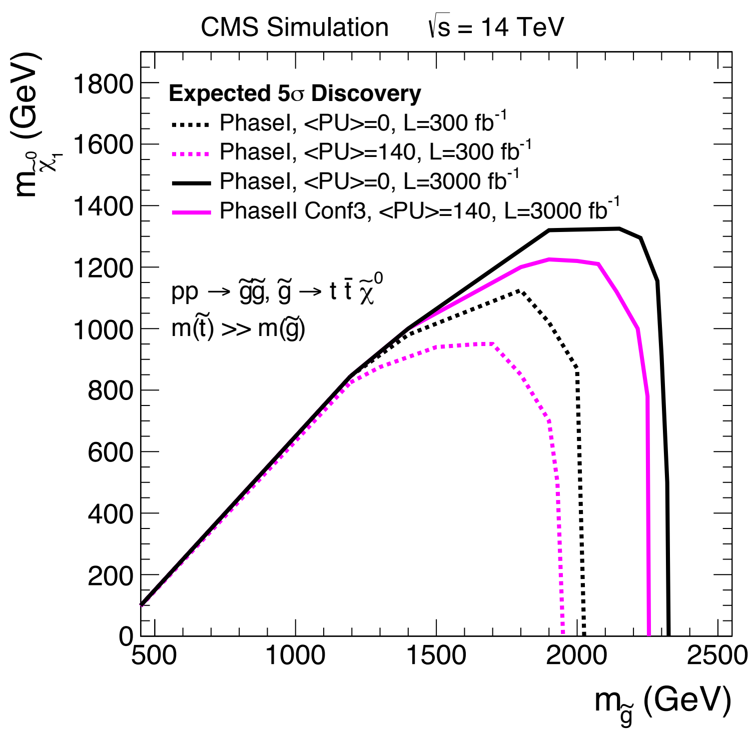
SUS Y: https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/SusyDiscrepancies
Exotics: https://twiki.cern.ch/twiki/bin/view/AtlasProtected/ExoticsExcessSummary

Long-term prospects

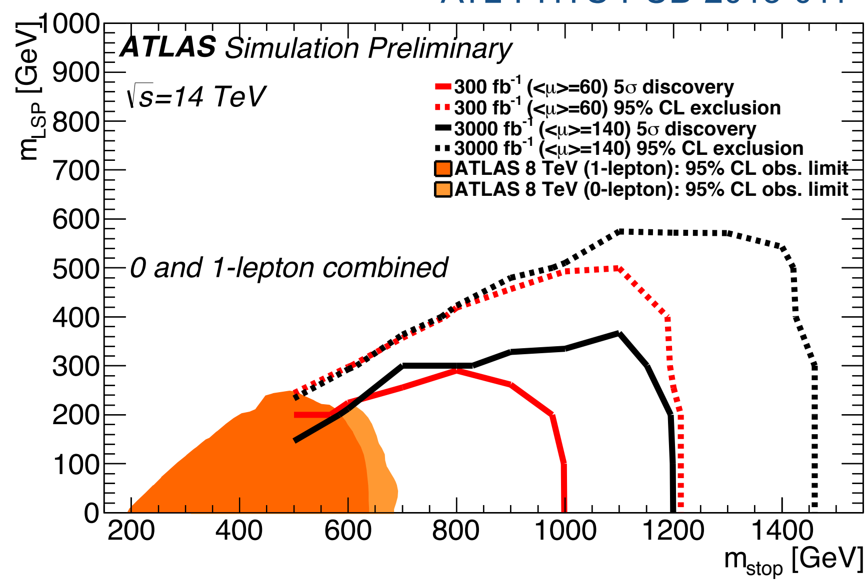
CMS and ATLAS studied long-term prospects for the (HL) LHC.

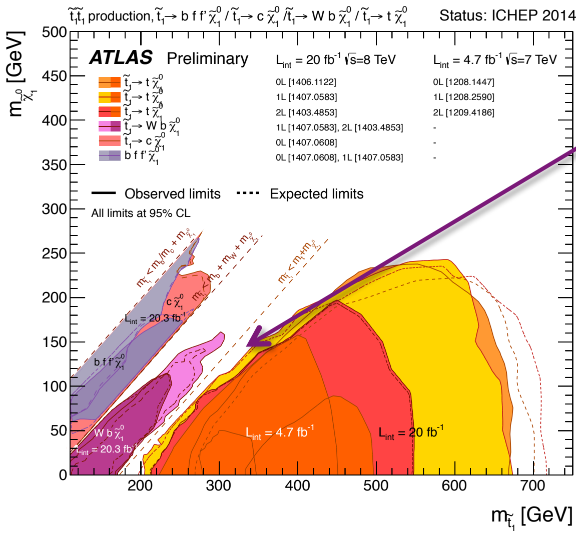
- with 300 and 3000 /fb at 14 TeV
- searches for gluino-mediated stop production reach beyond 2 TeV
- searches for direct stop production reach well beyond 1 TeV

CMS PAS FTR-13-014



ATL-PHYS-PUB-2013-011





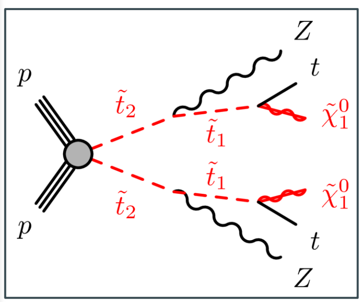
Challenge: **"Stealth" stop**

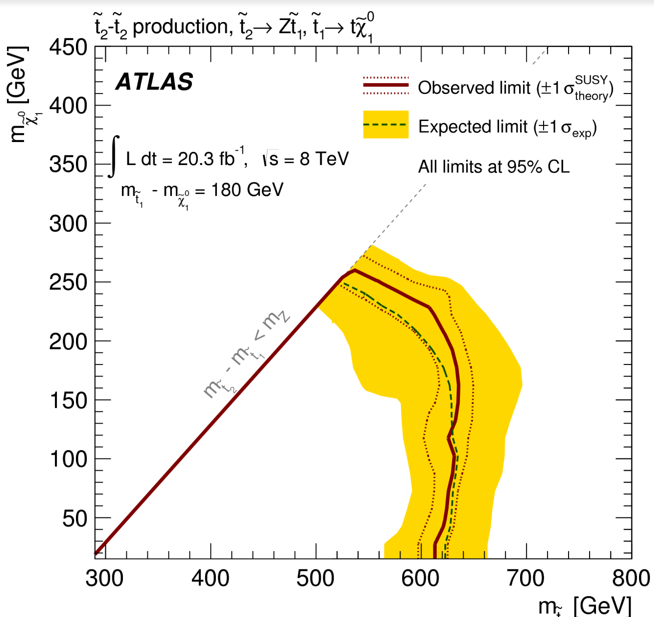
- **Close to gap**: m(stop1)-m(N1) ≈ m(top), signal similar to tt backgrounds, general kinematic Variables not discriminating (MET, mT, …)
- **Small signal xsec**: ~ 15% SM ttbar for same mass

■ Try use new technique: shape fit, MVA, top meas.

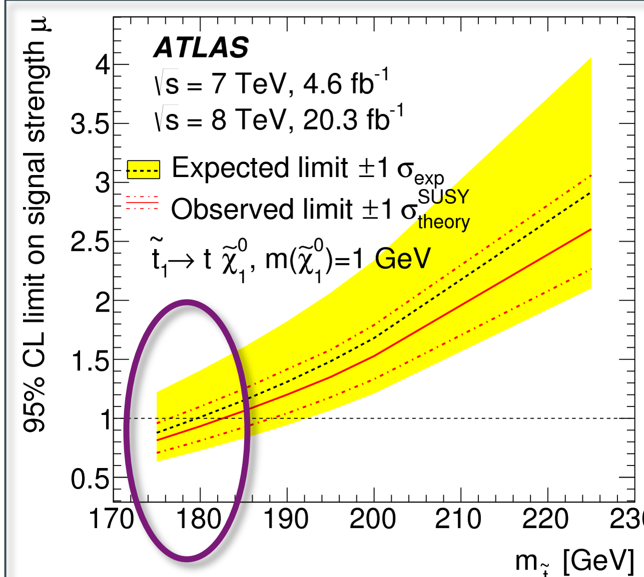
■ Search for heavier SUSY production with subsequent decay via stop1: gluino to stop1+t, or stop2 to stop1+Z/H

Search for Stop2 with Z in final state to cover gap region: Eur. Phys. J.C(2014)74:2883

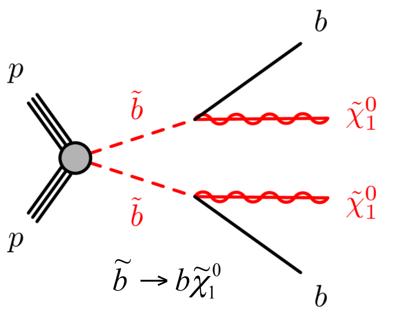


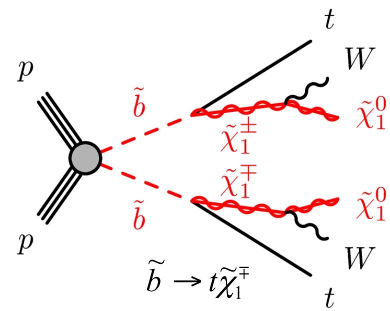


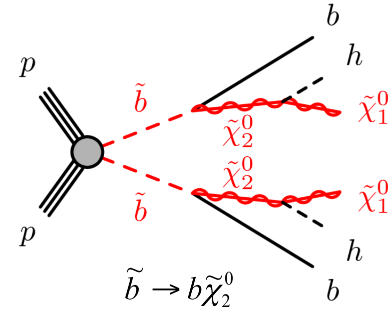
For mStop ~ mTop, constrains from XS measurement: Eur. Phys. J.C(2014)74:3109



Direct production of sbottom pairs



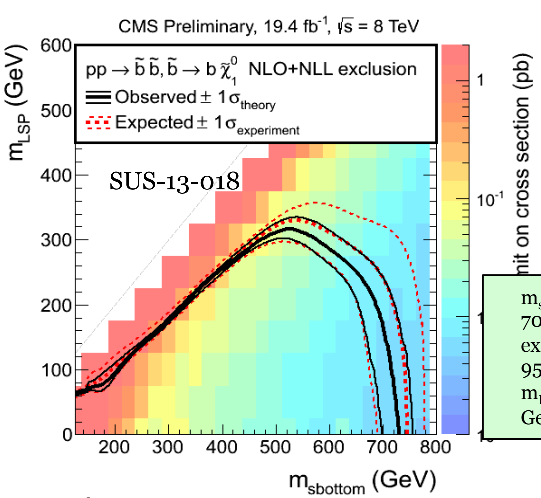




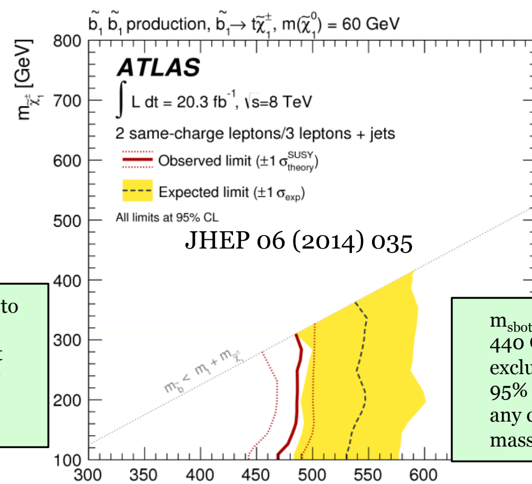
- bjet # =1 or 2, 0 lepton
- Signal discriminant is M_{CT} (8 exclusive SRs)

- bjet # =0-2
- 2 same-sign (SS) or 3 leptons
- SRs based on E_T^{miss}, N_{jets}, $M_T(\ell_1\text{-}E_t^{miss})$, $m_{eff} = E_t^{miss} + \Sigma_{jet} p_T + \Sigma_{\ell} p_T$

- bjet # >=3, 0 lepton
- $\tilde{\chi}_2^0$ can decay (BR=100%) to the lightest neutral Higgs boson (or Z), h->$b\bar{b}$(same BRs than the SM Higgs)
- SRs based on E_T^{miss} and m_{eff}

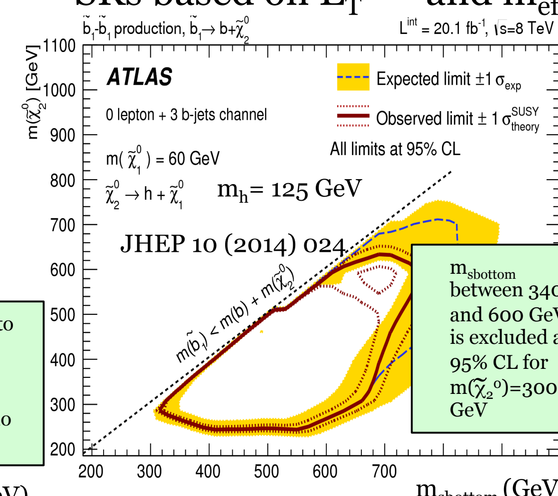


$m_{sbottom}$ up to 700 GeV is excluded at 95% CL for m_{LSP} < 50 GeV.



$m_{sbottom}$ up to 440 GeV is excluded at 95% CL for any chargino mass

$m_{sbottom}$ (GeV)



$m_{sbottom}$ between 340 and 600 GeV is excluded at 95% CL for m($\tilde{\chi}_2^0$)=300 GeV

$m_{sbottom}$ (GeV)

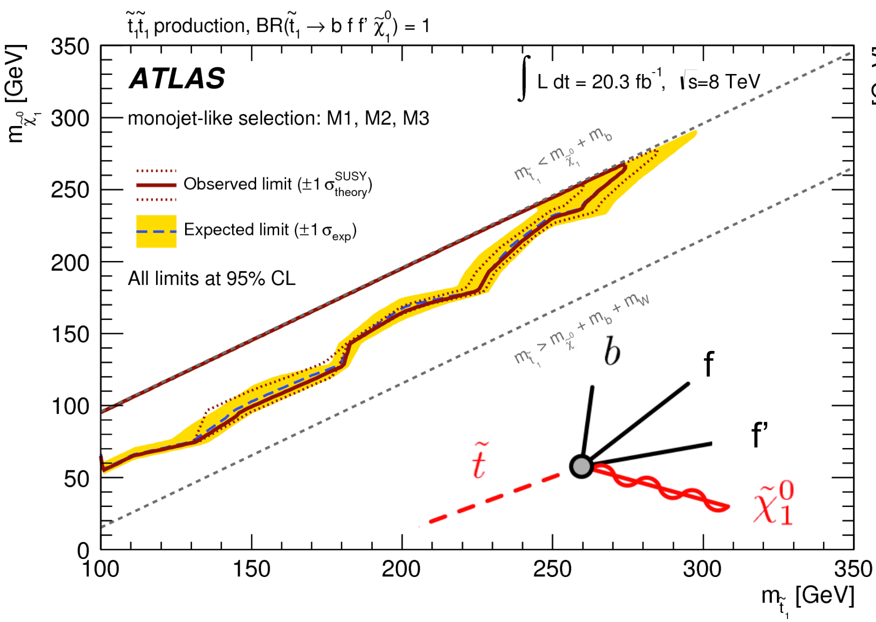
Stop Charm Search

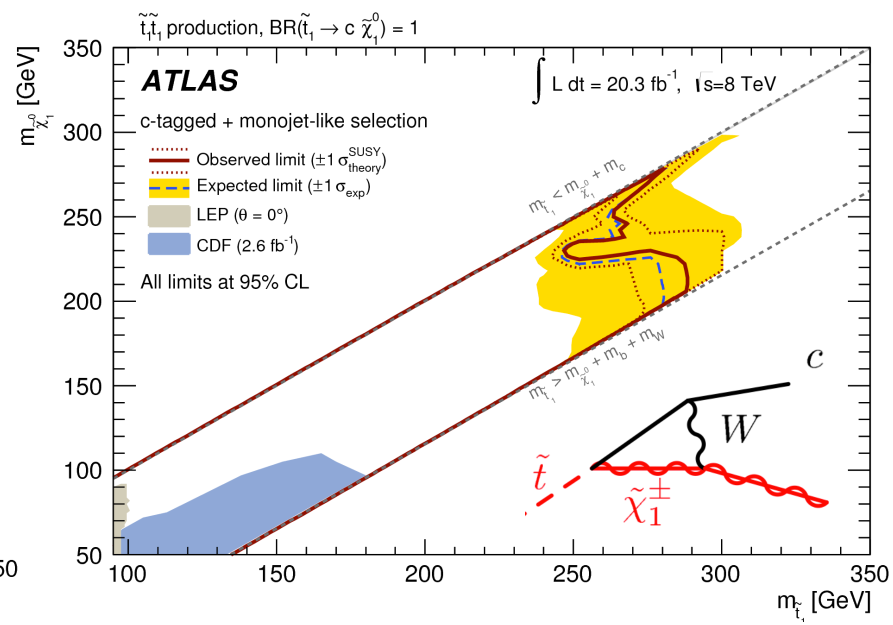
- **Direct stop production search targeting the region:** $\Delta m \equiv m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_W + m_b$
  - 4-body decay
  - Decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0$

Phys. Rev. D. 90, 052008 (2014)

arXiv:1407.0608

- **ISR based search strategies:**
  - Monojet-like selection (Δm < 20 GeV): ≤ 3 jets, 1 hard ISR jet, large $E_{T,miss}$
  - c-tagged selection (Δm > 20 GeV): ≥ 4 jets, 1 hard ISR jet, ≥ 1 c-tagged jet, large $E_{T,miss}$
- **Background estimation**
  - Data-driven multi-jet estimate, W/Z + jets & $t\bar{t}$ (charm-tagged) normalized with data-driven scale factors

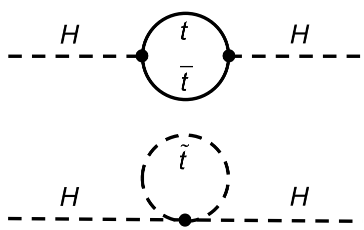




Natural SUSY

What are the minimal requirements for `natural' (low level of fine-tuning) SUSY?

Recall: **Top loop** is the most important contribution in Higgs virtual corrections:



While inclusive LHC searches set O(TeV) limits mostly on 1st and 2nd generation squarks and gluinos, which are less relevant in Higgs corrections.

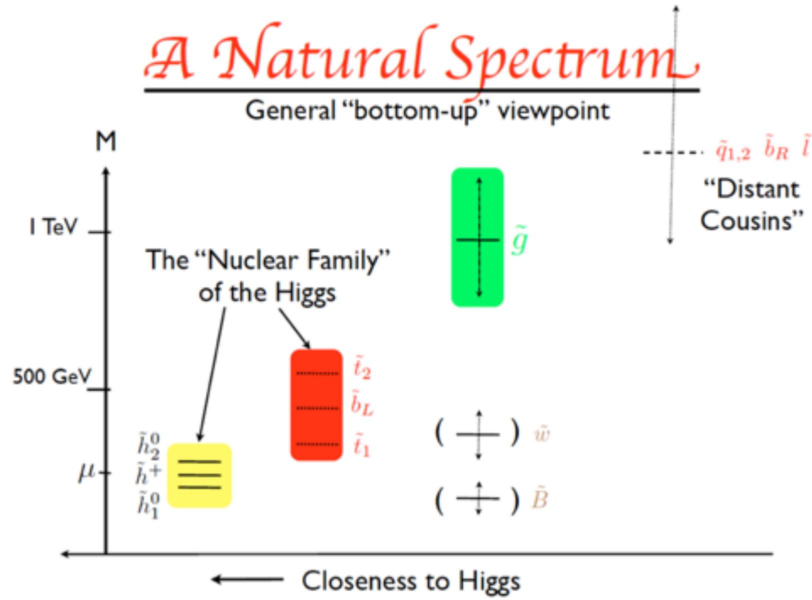


Illustration taken from: L. Hall, LBNL workshop, Oct-2011

For **natural SUSY** need:

- light higgsinos
- light top and bottom squarks (stop, sbottom, respectively)
- not-too-heavy gluinos

➡ strong physics case for **third generation squarks**

2 leptons razor

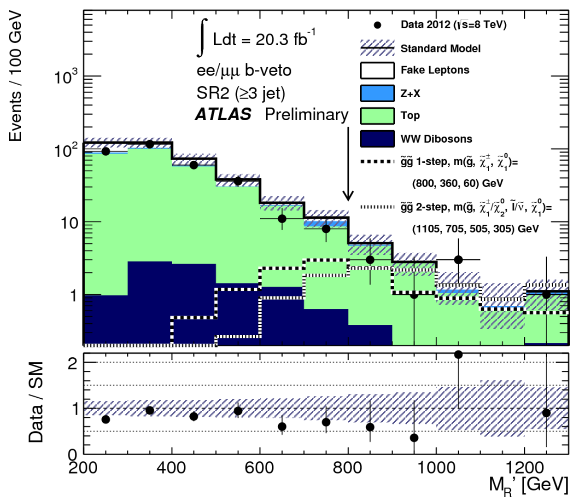
- **Target signals:** strong production simplified models, direct sbottom production
- Exploits transverse and longitudinal event information (razor variable $R = M^R_T / M'_R$):

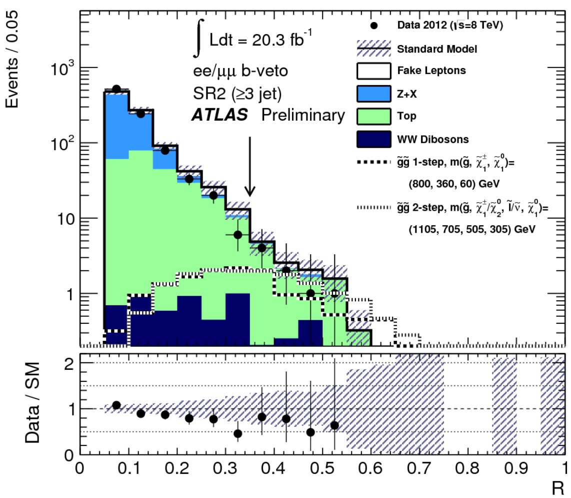
	SR1		SR2	
leptons	eμ	ee/μμ	eμ	ee/μμ
M'_R [GeV]	>400		>800	
R	>0.5		>0.35	
N(jet)	<3		>=3	

$$M'_R = \sqrt{(j_{1,E} + j_{2,E})^2 - (j_{1,L} + j_{2,L})^2}$$

Measures how longitudinally splitted the events are

$$M^R_T = \sqrt{\frac{|\vec{E}_T^{\text{miss}}|(|\vec{j}_{1,T}| + |\vec{j}_{2,T}|) - \vec{E}_T^{\text{miss}} \cdot (\vec{j}_{1,T} + \vec{j}_{2,T})}{2}}$$





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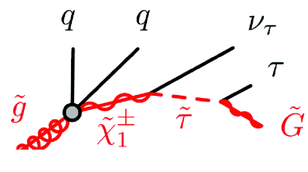
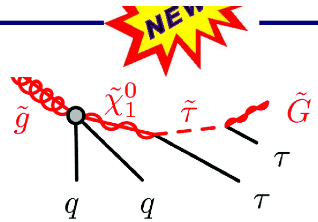
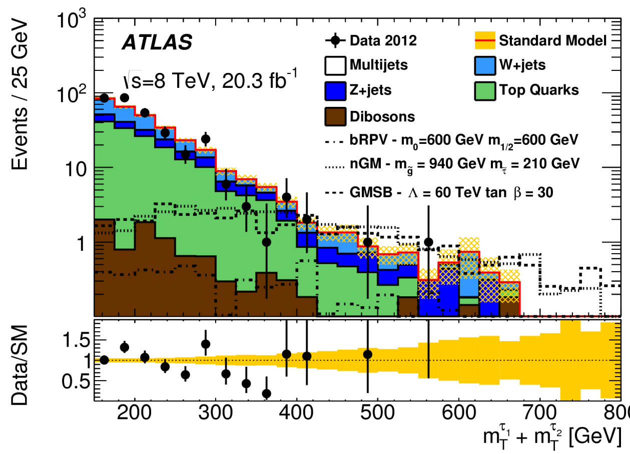
taus + jets + MET

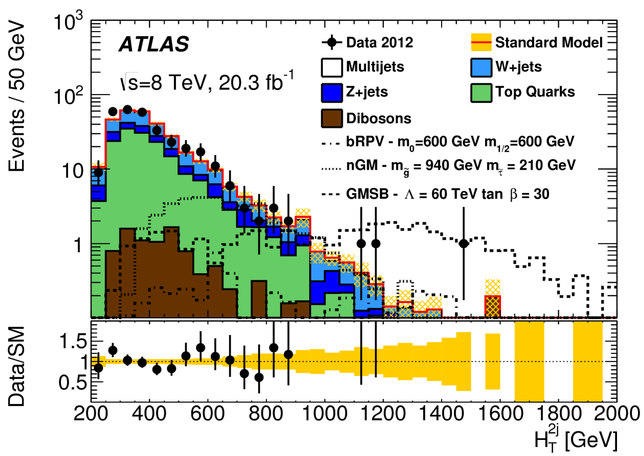




- **Target signals:** GMSB, natural gauge mediated nGM model (tuned version of GGM to avoid fine tuning in Higgs sector) with stau as NLSP
- Hadronically decaying taus (with veto on e/μ in pure τ-channels)
- Data driven estimate of fake taus events

	1τ SR	2τ GMSB SR	2τ nGM	τ+l nGM SR
m_T [GeV]	$m_T^{\tau}>140$	$m_T^{\tau1} + m_T^{\tau2}>250$		$m_T^{l}>100$
H_T^{2j} [GeV]	>800	>900	>600	
MET [GeV]	>200			>350
N(jet)		>=4	>=4	>=3



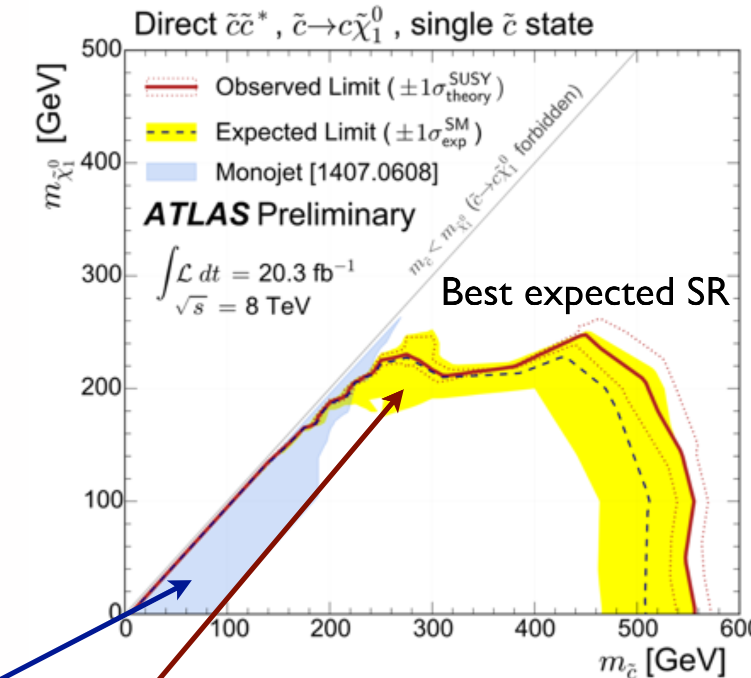


Search for Charm Squark, Results

New

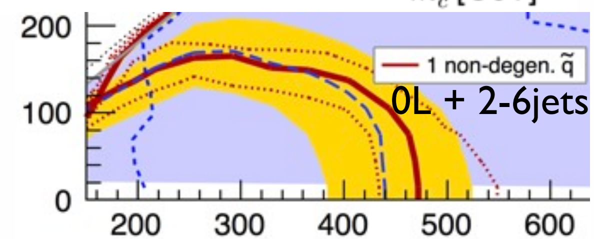
- Dominant uncertainties originate from the limited number of events in the CRs ~20%, jet tagging and mis-tagging ~20%, jet energy scale ~10%

m_{CT} (GeV)	>150	>200	>250
Top	7.4 ± 2.7 (7.1)	3.9 ± 1.6 (3.7)	1.6 ± 0.7 (1.5)
Z+jets	14 ± 3 (13)	7.7 ± 1.7 (7.0)	4.3 ± 1.2 (3.9)
W+jets	7.2 ± 4.5 (7.4)	4.1 ± 2.6 (4.2)	1.9 ± 1.2 (1.9)
Multijets	0.3 ± 0.3	0.2 ± 0.2	0.05 ± 0.05
Others	0.5 ± 0.3	0.4 ± 0.3	0.4 ± 0.3
Total	30 ± 6	16 ± 3	8.2 ± 1.9
Data	**19**	**11**	**4**



Overlaying observed limit from the monojet-SR,

combining with c-tagged SR of the $\tilde{t} \to c\tilde{\chi}_1^0$ search

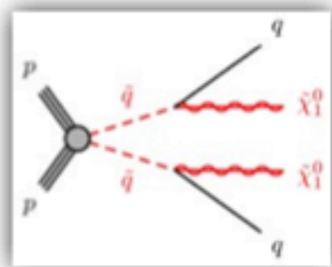


ATLAS-CONF-2014-062

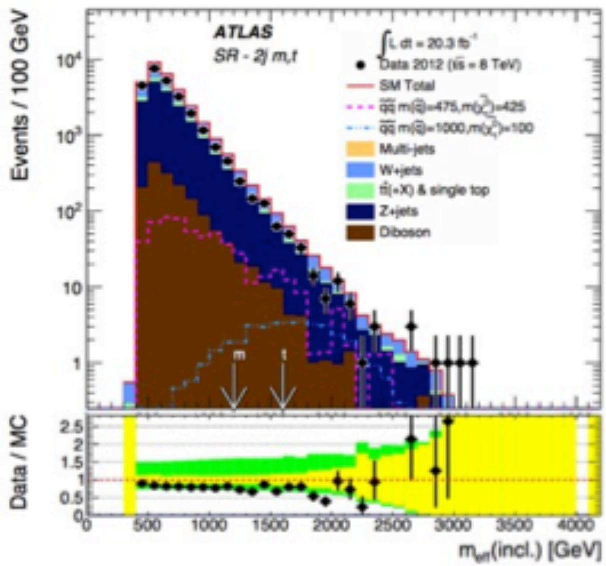
Limit on charm squark mass ~ 540 GeV , for massless LSP
improves significantly on single light flavor squark limit
improved sensitivity for heavier LSP

20

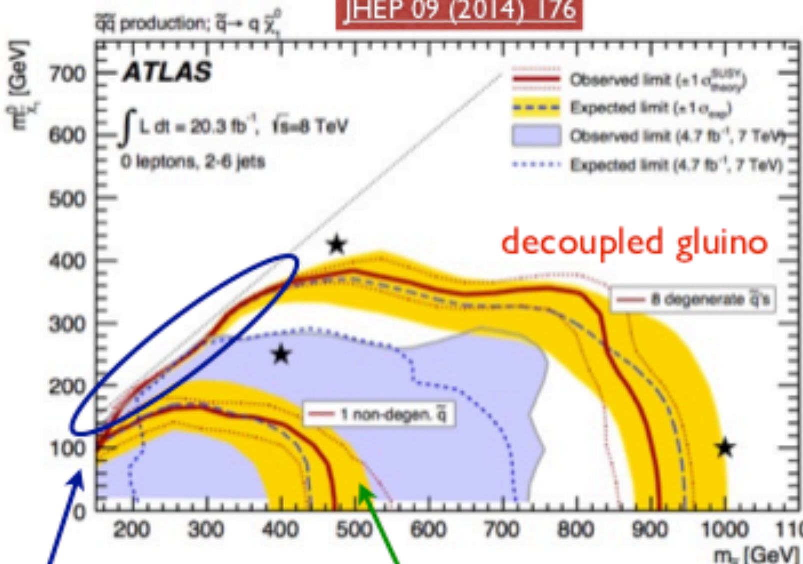
Search for Pair Production of Light-flavor Squarks



- The cross-section for 1st and 2nd generation squarks benefits from 8-fold degeneracy (u, d, c, s) x (left, right)
  - comparable to the gluino pair production cross-section
- Searches using events with 0 leptons, 2-6+ jets



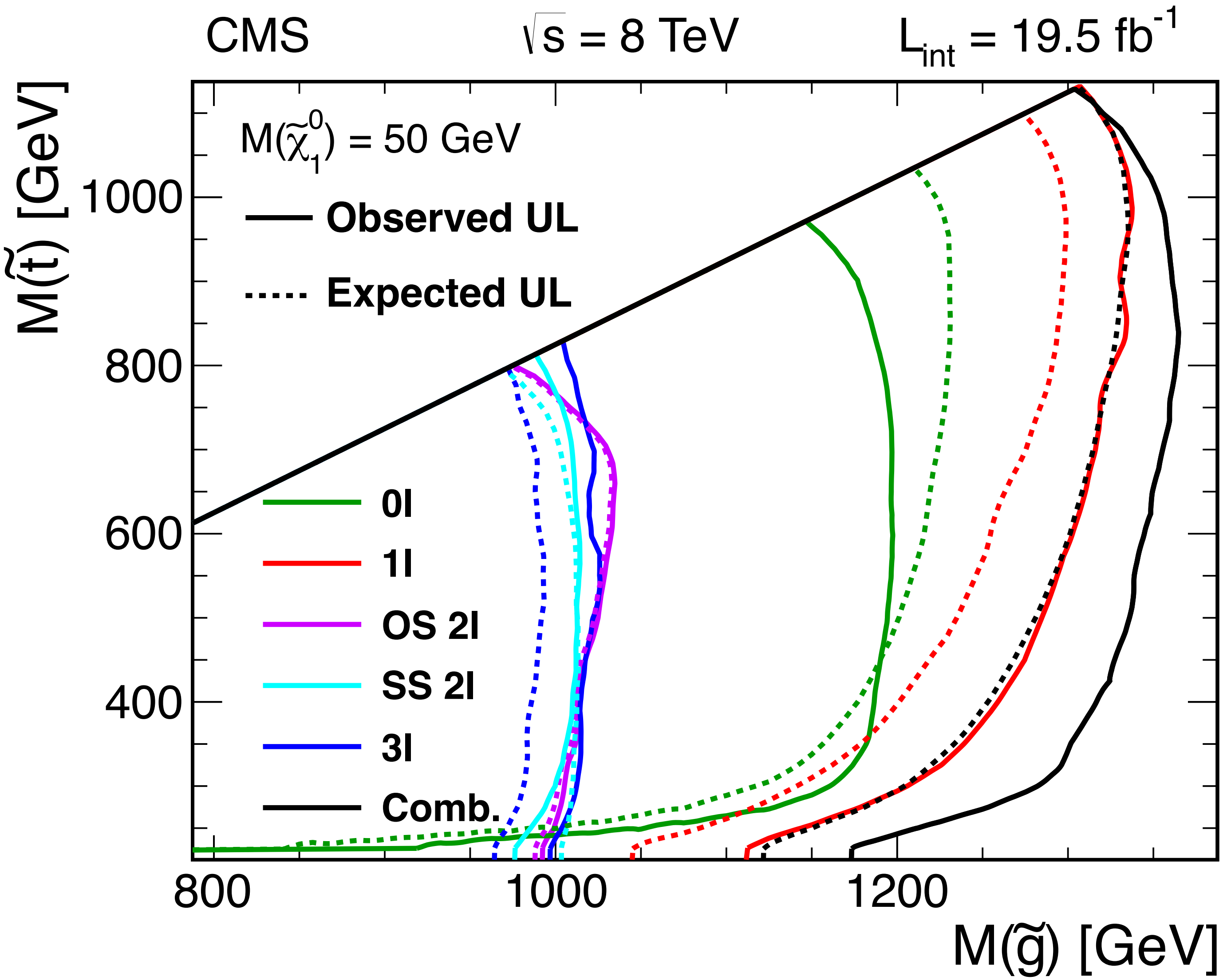
JHEP 09 (2014) 176



Coverage of compressed scenarios is challenging

Significant drop of sensitivity if only 1 squark is accessible!

CMS: PAS-SUS-14-010(NEW)



Discovery and exclusion

- P-value=probability that result is as/less compatible with the hypothesis

DISCOVERY:

- The null hypothesis H_0 describes background only
  - If the *p*-value of H_0 is found below a given threshold, one can consider looking for a better model
  - In HEP, $Z \geq 5$ is conventionally required to claim a discovery
- The alternative hypothesis H_1 describes signal + background
  - The alternative hypothesis is supposed to fit the data very well for claiming a discovery

EXCLUSION:

- The null hypothesis H_0 describes signal + background
  - One is interested into setting an upper limit to the intensity of the signal alone
- The alternative hypothesis H_1 describes background only
  - No real need to test for it
  - The background-only model becomes important only in case of discovery

Interpretation strategy

Based on the number of observed, expected events in all regions with all uncertainties: Probability density function (PDF)

Likelihood function: $L(\mu,\theta)$

μ: signal strength (POI);

θ: nuisance parameters(NP)

Profile Likelihood: constrain uncertainty (NP) as part of a likelihood fit

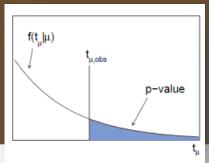
Construct test statistics t_μ based on likelihood ratio λ:

$$\tilde{\lambda}(\mu) = \begin{cases} \frac{L(\mu,\hat{\hat{\theta}}(\mu))}{L(\hat{\mu},\hat{\theta})} & \hat{\mu} \geq 0, \\ \frac{L(\mu,\hat{\hat{\theta}}(\mu))}{L(0,\hat{\hat{\theta}}(0))} & \hat{\mu} < 0 \end{cases}$$

$$t_\mu = -2\ln\lambda(\mu)$$

Find the observed test statistic for tested μ: $t_{\mu,obs}$

Construct the PDF of test statistic t_μ: generate toy Monte Carlo or using asymptotic formula



From the constructed distribution of test statistic for s+b, find the p-value of the observation

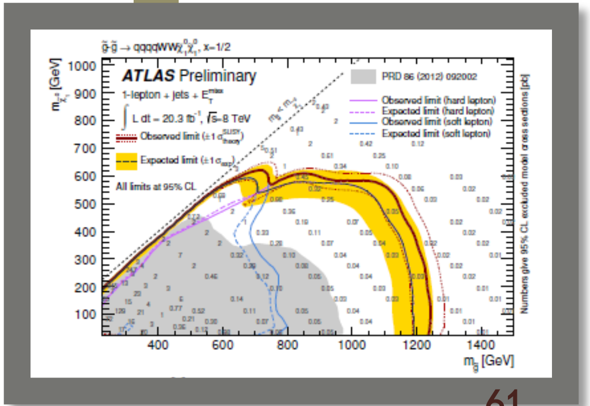
$$p_\mu = \int_{t_{\mu,\mathrm{obs}}}^{\infty} f(t_\mu|\mu)\, dt_\mu$$

If CLs<0.05: the value of signal is excluded at 95% CL……….

$$\mathrm{CL_s} = \frac{\mathrm{CL_{s+b}}}{\mathrm{CL_b}} = \frac{p_{s+b}}{1-p_b}$$

The above check has been done for each signal grid points on the SUSY model.

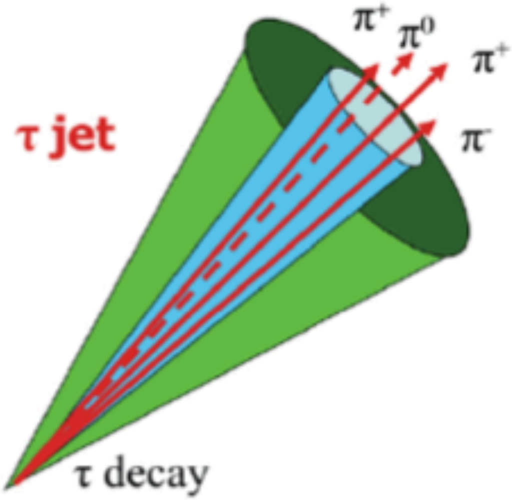
The line can be drawn for the area where points are excluded



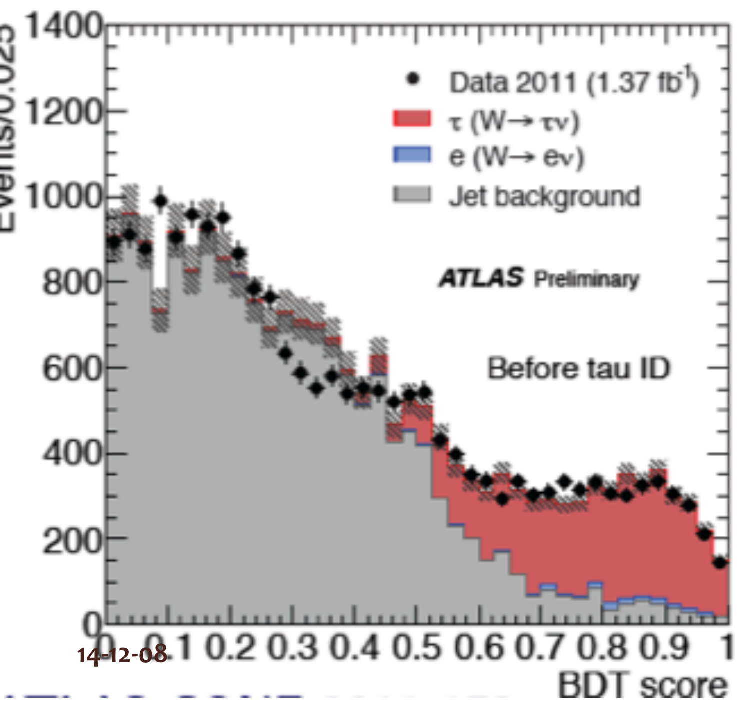
Simultaneous fit

- Background estimates in SRs are obtained by a *simultaneous fit* in each channel based on the profile likelihood method. Three dedicated fit for different purpose…
  - **Background-only fit**
    - Fit for all CRs, excluding SRs.
      - Get background-only estimates.
      - Also extrapolate to VRs (non used in fit, only for cross-check) and SRs.
  - **Discovery fit**
    - Fit for all CRs and SRs.
    - Signal contamination is turned off in CRs and set as a dummy number 1 in SR (so, the fitted non-SM signal strength = the excess in Nevents of SR)
      - Get model-independent upper limit on signal in SR.
  - **Exclusion fit**
    - Fit for all CRs and SRs.
    - Signal is turned on in all regions, according to model-dependent prediction.
      - Got signal model-dependent exclusion from all CRs+SRs →final exclusion contours for SUSY model
- The basic strategy is to share background information in all regions (CR,SR,VR). The background parameters are predominantly constrained by CRs with large statistics, which in turn reduces the impact of uncerts in SR.

Hadronic Taus



- Tau decays:
  - Leptonic (35%): $\tau \to \nu_\tau \ell \bar{\nu}_\ell$
  - Hadronic (65%): decay to one or three charged pions, neutrinos and π^0's
- Need to separate τ's from hadronic jets:
  - τ decay tends to be well collimated
  - Large electromagnetic component from $\pi^0 \to \gamma\gamma$ decay

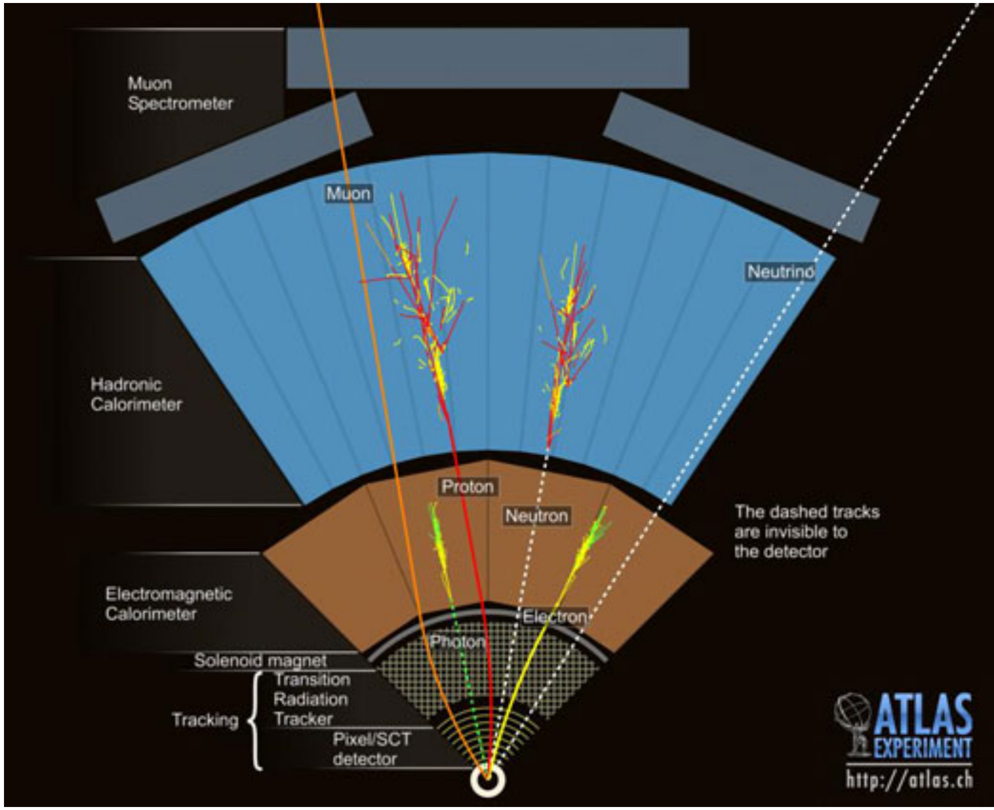


Tau Object

- ▷ $p_T > 20$ GeV, $|\eta| < 2.5$
- ▷ 1 or 3 tracks with total charge ± 1
- ▷ Boosted decision tree (BDT) using variables sensitive to the longitudinal and transverse shower shape
- ▷ Working points:
  - **Loose:** efficiency: 60%; jet rejection: 20-50
  - **Tight:** efficiency: 30-50%; jet rejection: 30-200

Reconstructed Objects

- Photons: no track but energy in el-m (and not in the hadronic) calorimeter
- Electrons: track and energy in el-m (and not in the hadronic) calorimeter
- Muons: track in inner tracker and muon chamber
- Jets: cluster in hadronic calorimeter

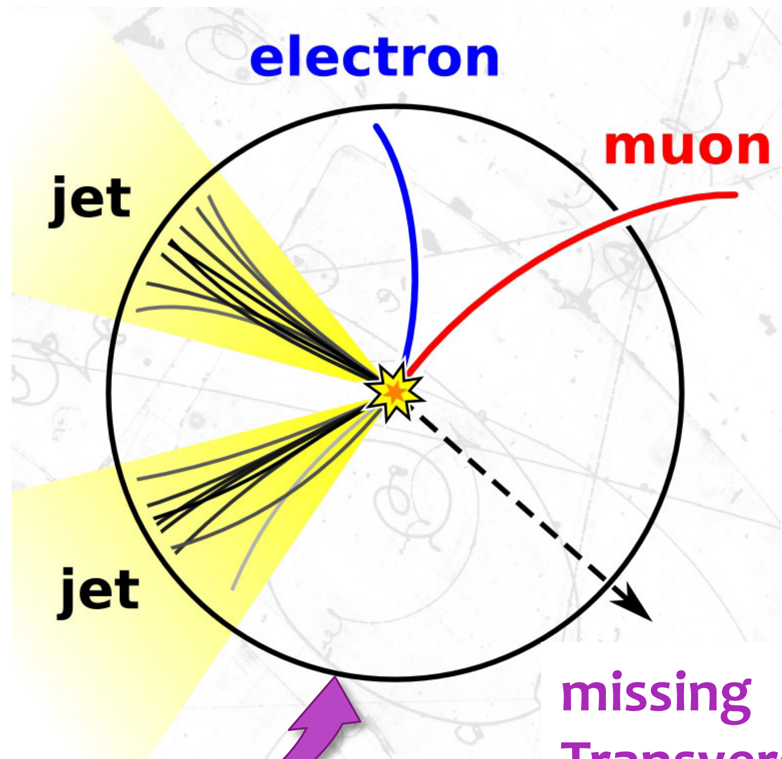


MET: Missing Transverse Energy

- At the LHC an unknown proportion of the energy of the colliding protons escapes down the beam-pipe

- Invisible particles (neutrinos, neutralinos?) are created their momentum can be constrained in **the plane transverse to the beam direction**

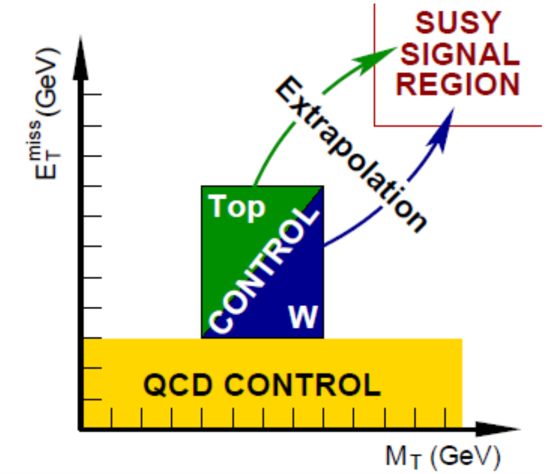
$$E_T^{\text{miss}} = -\sum_i p_T(i)$$



missing Transverse Energy

Data-Driven-Method (simultaneously fit)

- Background estimates in SRs are obtained by a ***simultaneous fit*** in each channel based on the **profile likelihood method**.
  - Fit for all BG-CRs
- Comments:
  - Shape from MC (CR), NF from fit
  - Advantage:
    - Considered correlations between different BG CRs and VRs, SRs;
    - considered correlated syst. from detector
  - Disadvantage: shape is depending on MC (semi-data-driven method)



$$= (N^{CR_i}_{data} - N^{CR_i}_{other\ bkg}) \times \frac{N_{pred}(MC^j, SR)}{N_{pred}(MC^j, CR_i)}$$

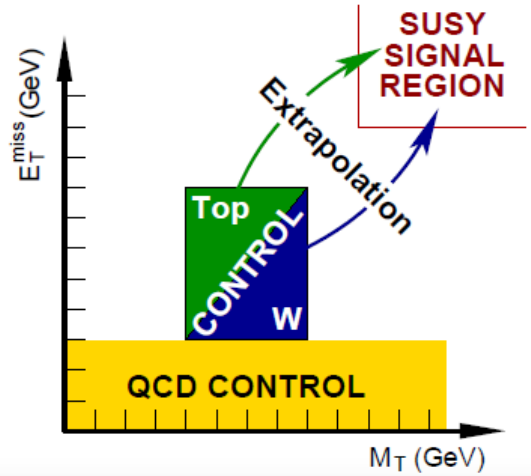
$$= (N^{CR_i}_{data} - N^{CR_i}_{other\ bkg}) \times C^j_{CR_i \to SR}$$

Normalization factor (NF)

Background Estimation Strategy

ATLAS-CONF-2013-062

- **W/Z/ttbar background (dominant)**
- **Semi-data driven approach**
- **Normalize MC to Data in W/T-CR**
- **Extrapolate to SR using MC: assuming shape is described correctly**
- **Extrapolation done in simultaneous fit.**



$$N^{SR}_{pred_j} = (N^{CR_j}_{data} - N^{CR_j}_{other\ bkg}) \times \frac{N_{pred}(MC^j, SR)}{N_{pred}(MC^j, CR_j)}$$
$$= (N^{CR_j}_{data} - N^{CR_j}_{other\ bkg}) \times C^j_{CR_j \to SR}$$

- QCD background (small bg)
- Fullly-data driven approach
- Measure real and fake efficiencies in QCD-CRs
- Apply Matrix Method to get contribution in SR

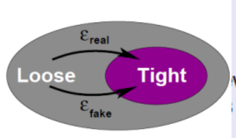
$$\text{QCD BG} = \frac{1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{fail} - \frac{1/\epsilon_{real} - 1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{pass}$$

N_{pass}: Events passing the signal selection cuts (*tight*)

N_{fail}: Events satisfying relaxed lepton isolation criteria but not passing the signal selection cuts (*loose-but-not-tight*)

ϵ_{real}: Probability t... vent passes also...

ϵ_{fake}: Probability that a loose QCD event passes also the tight selection cuts

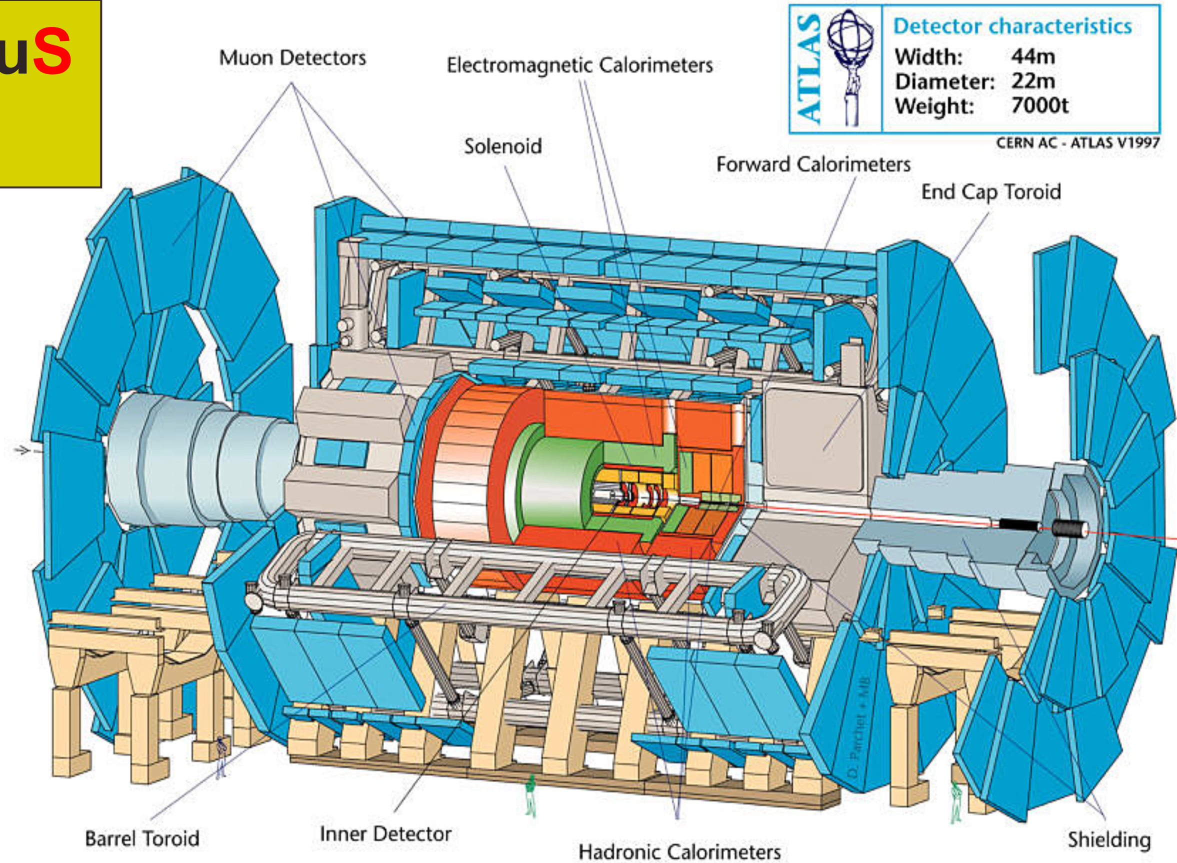


Other small BGs (diboson, single top etc) are directly estimated from MC.

A Toroidal LHC ApparatuS

- 42m×22m, 7000 ton

- **Inner Detector (2T solenoid, |η|<2.5):**
  $\sigma_{p_t}/p_t \square 0.05\%/\mathrm{GeV} \times p_t \oplus 1\%$
- **Calorimetry:**
  - * electromagnetic, |η|<3.2
    $\sigma_E/E \square 10\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 0\%$
  - * hadronic (central, |η|<1.7)
    $\sigma_E/E \square 50\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 3\%$
  - * hadronic (endcaps, 1.7<|η|<3.2)
    $\sigma_E/E \square 60\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 3\%$
  - * hadronic (forward, 3.2<|η|<4.9)
    $\sigma_E/E \square 100\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 5\%$
- **Muon system (~4T toroid, |η|<2.7):**
  $\sigma_{p_t}/p_t \square 10\%$ for $p_t(\mu) \approx 1$ TeV/c



- **Inner Detector:** Highly segmented silicon strips, determine very accurately charged particles trajectories
- **Solenoid Magnet:** Solenoid coil that generates a 2T magnetic field in the region of the Inner Detector
- **Electromagnetic Calorimeter:** Electron and photon energies are measured through electromagnetic showers
- **Hadronic Calorimeter:** Hadrons interact with dense material and produce a shower of charged particles
- **Toroid Magnets:** 8 toroidal coils that create a 0,4T magnetic field in the area of the Muon Spectrometer
- **Muon Spectrometer:** Muons traverse the rest of the detector and are measured in its outer layers