SUSY/BSM II

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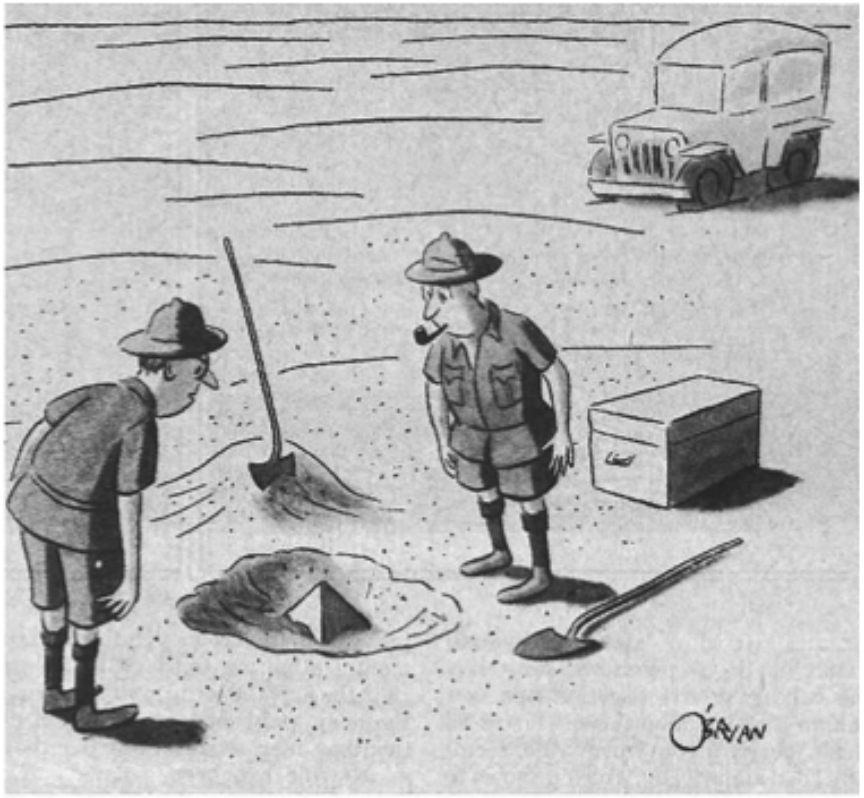
HASCO SUMMER SCHOOL 2016

Outline for Part II

- **How to do/read a search**
- **Statistical facts**

Overview of SUSY searches

- **Inclusive Searches**
- **3rd Generation Squarks**
- **EWK Searches**
- **SUSY Higgs**
- **Bs → μμ**
- **GMSB SUSY**
- **RVP Searches**



"This could be the discovery of the century. Depending, of course, on how far down it goes."

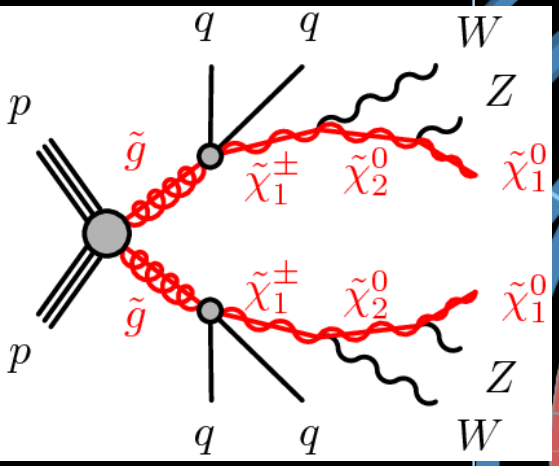
Disclaimer: completely unbalanced set of results from CMS and ATLAS
No attempt to have latest results everywhere

Basic Guidelines on how to perform a Search

Object reconstruction

Background Estimation

Likelihood Fits



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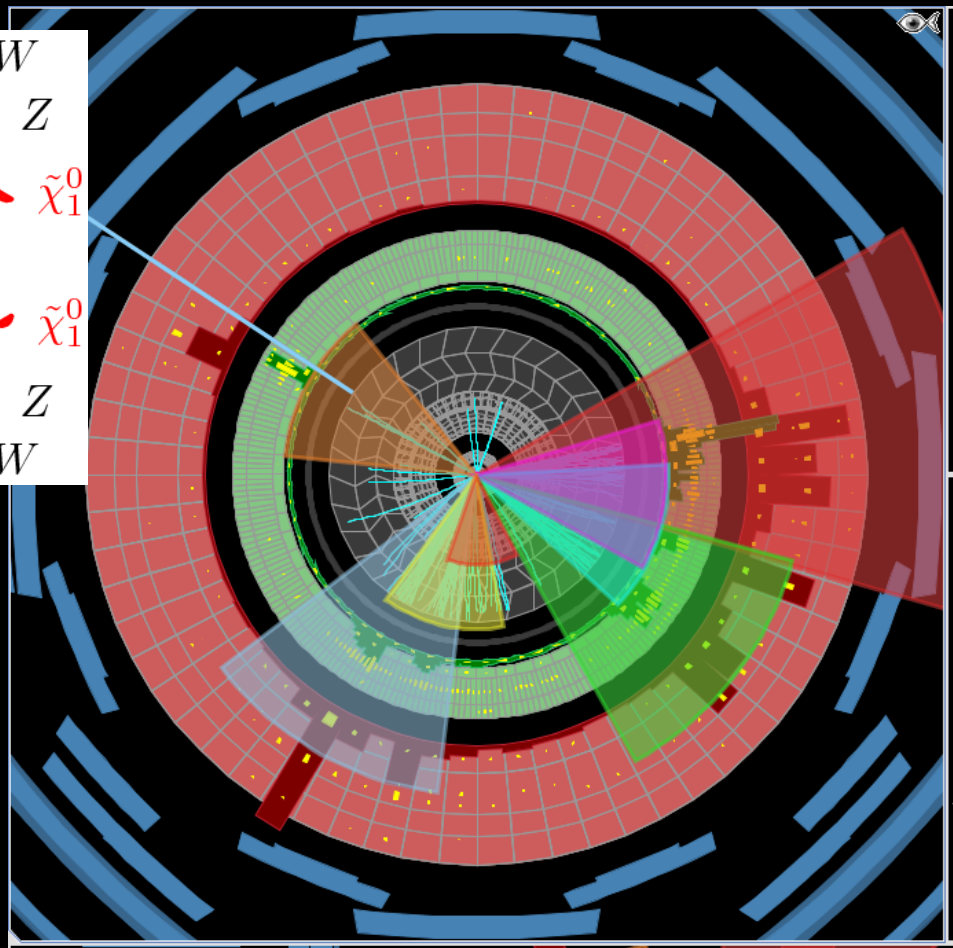
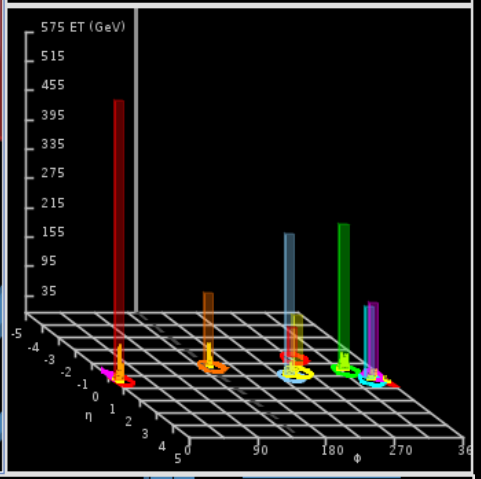
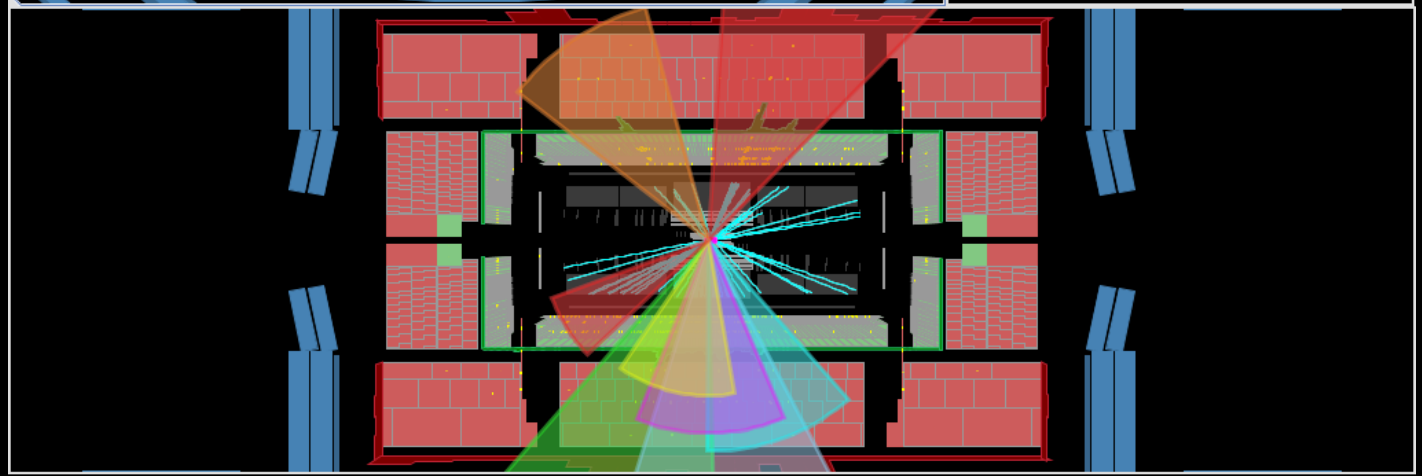


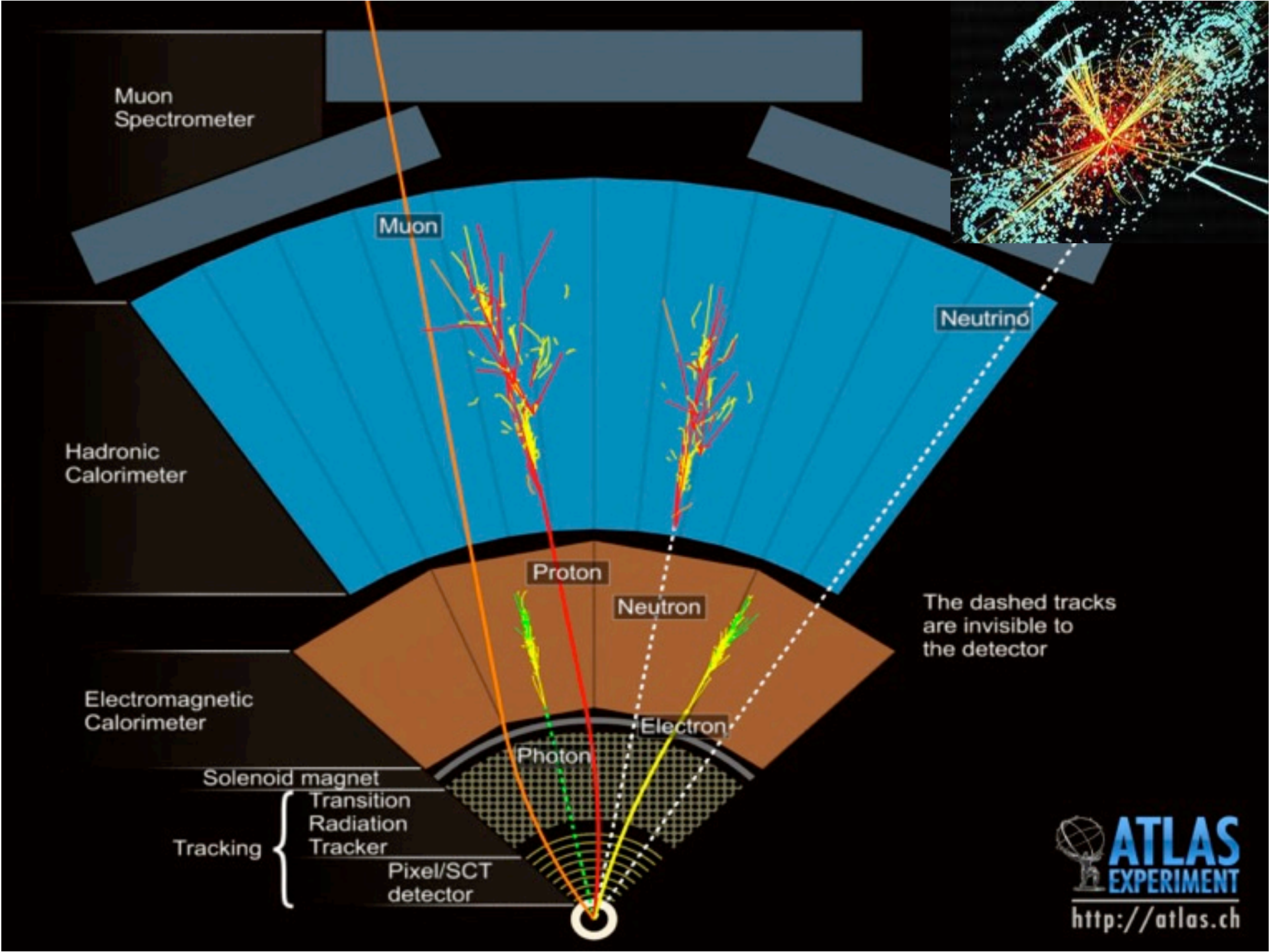
ATLAS EXPERIMENT

Run Number: 278880, Event Number: 101104356

Date: 2015-09-08 12:27:21 CEST

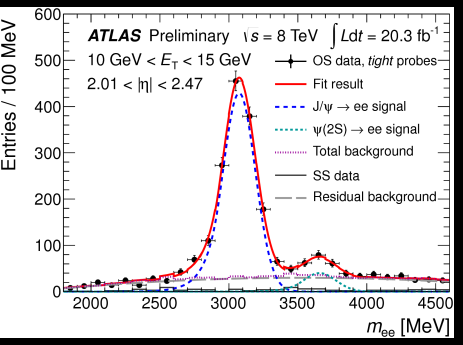


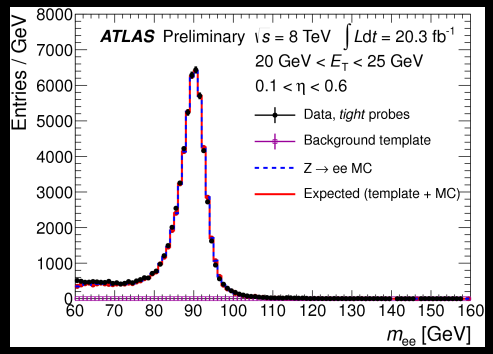



Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch

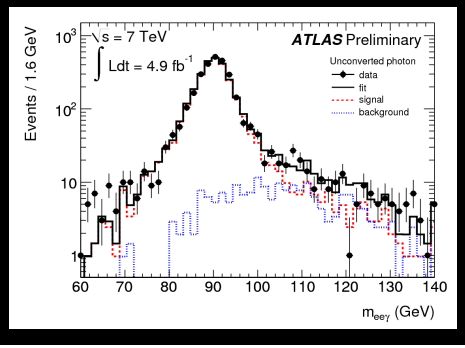
Building Blocks

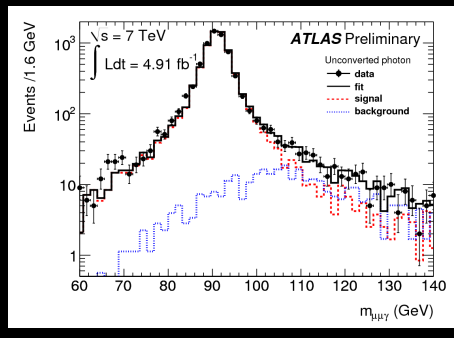
Z → ee , J/Psi → ee .....

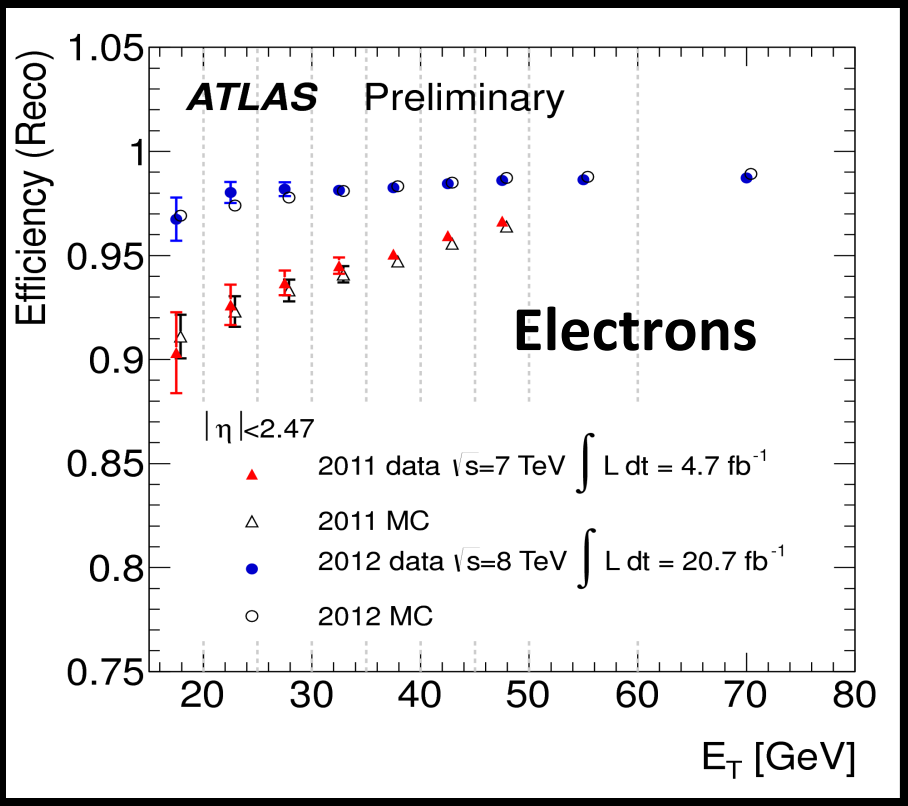


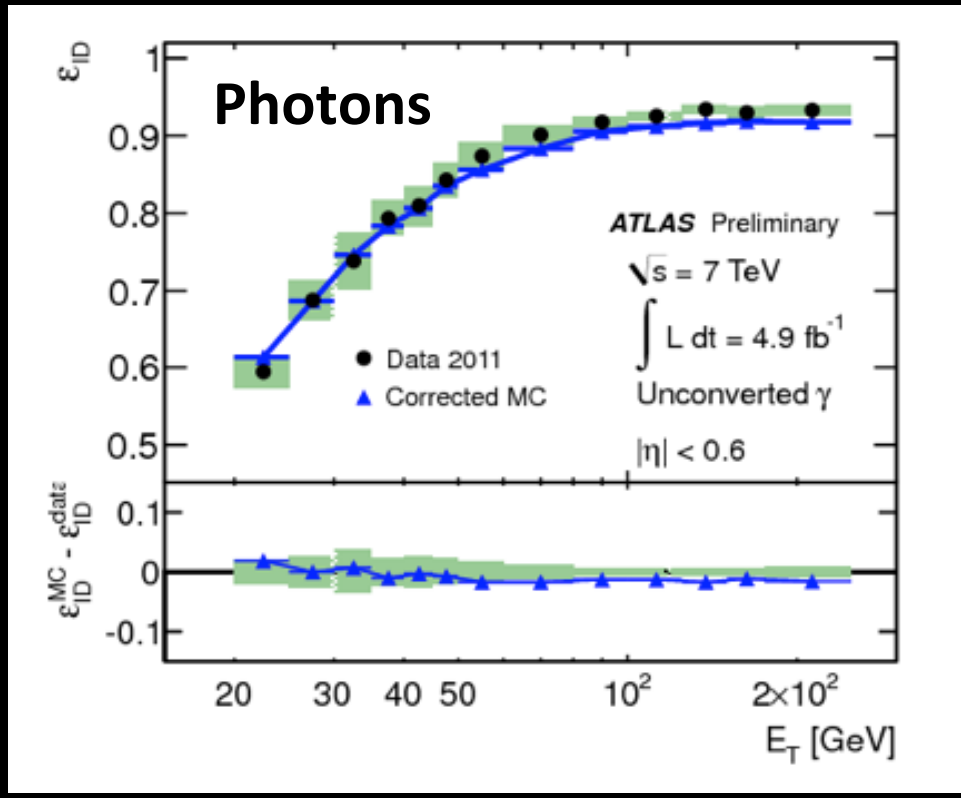


eeγ and μμγ



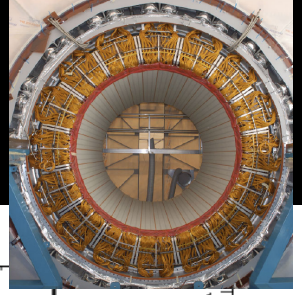


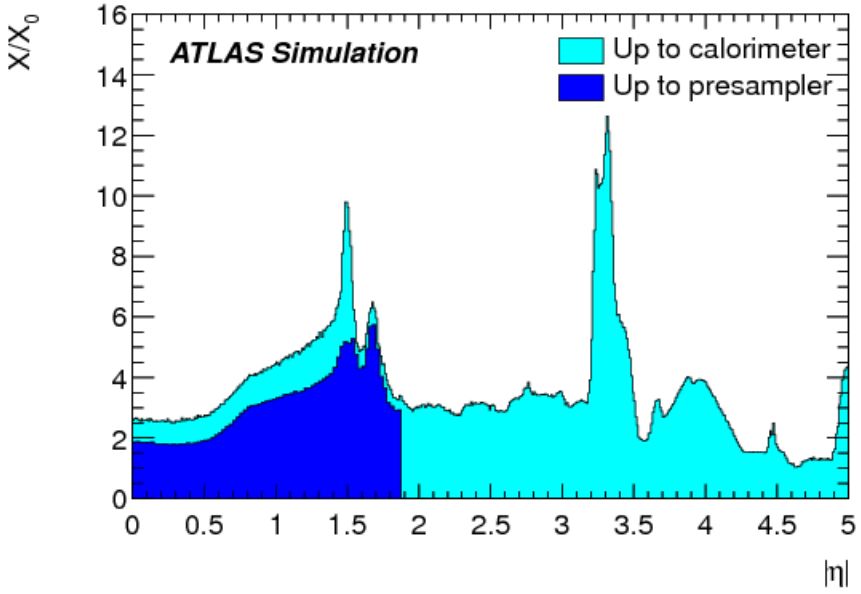




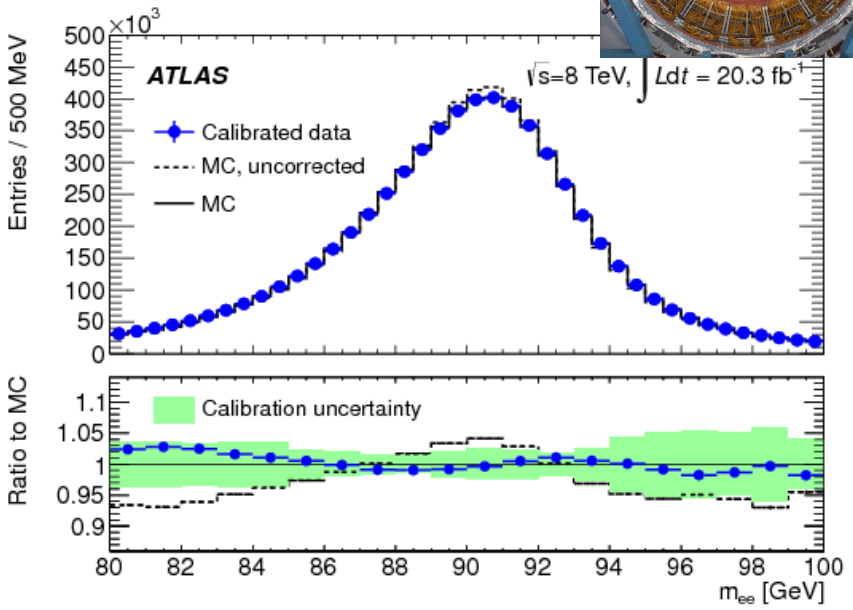
Building Blocks

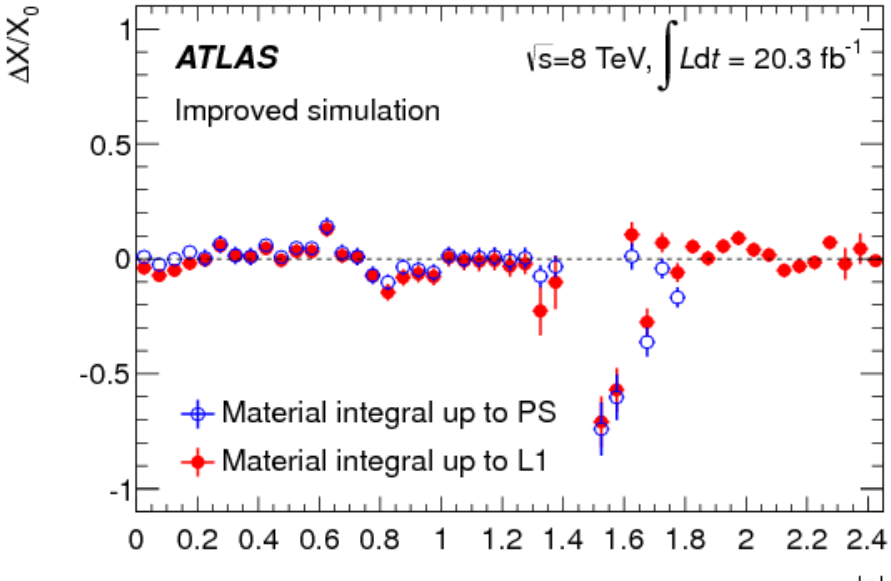
Detector Material

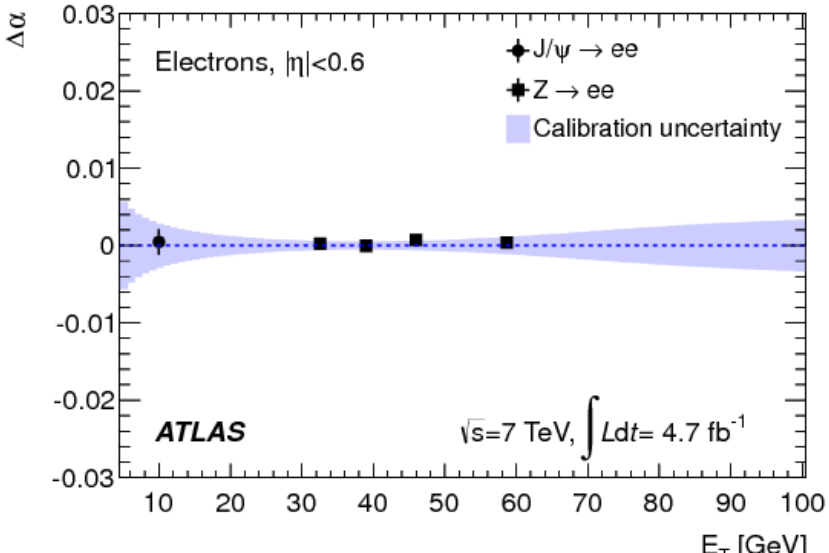




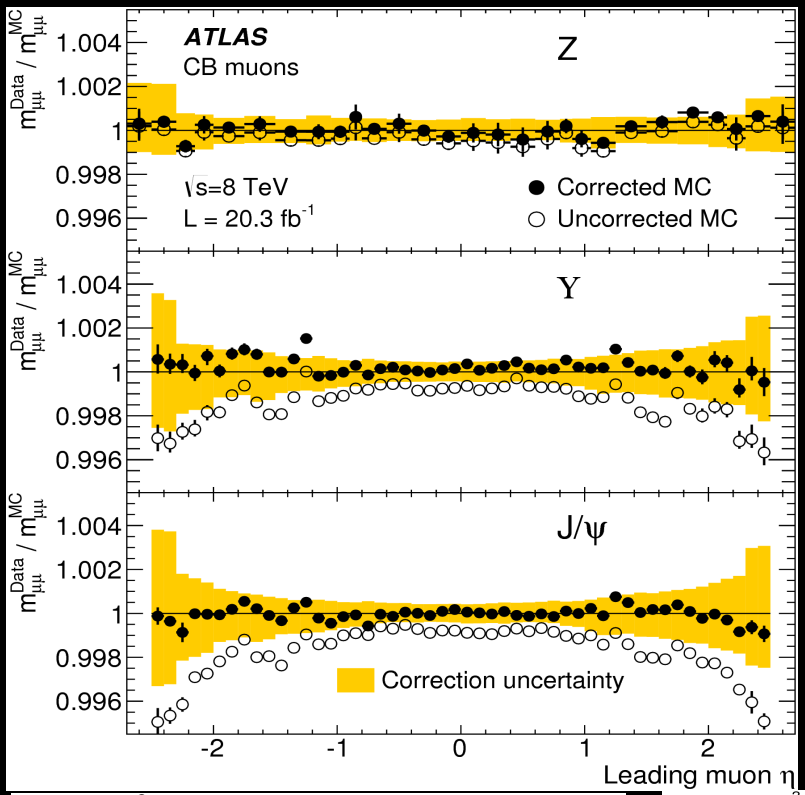
EM absolute scale



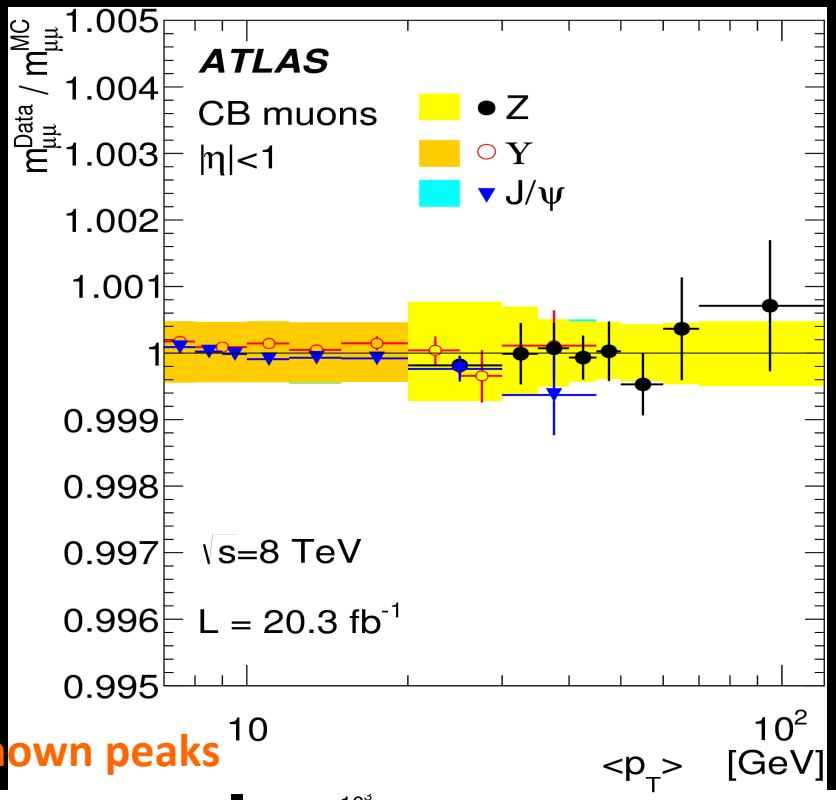




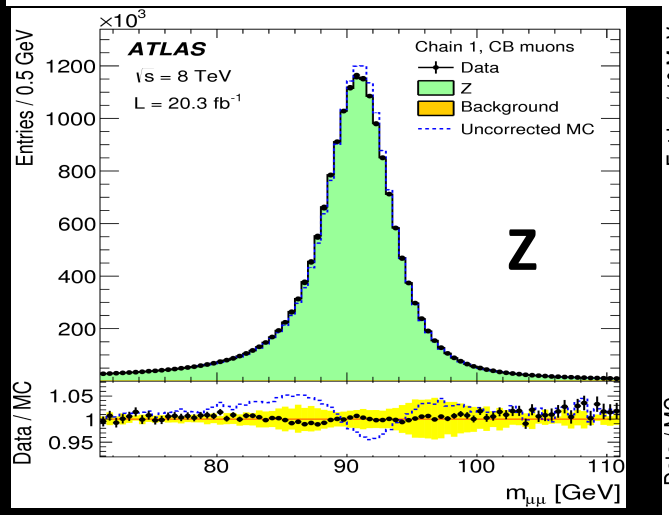
Building Blocks

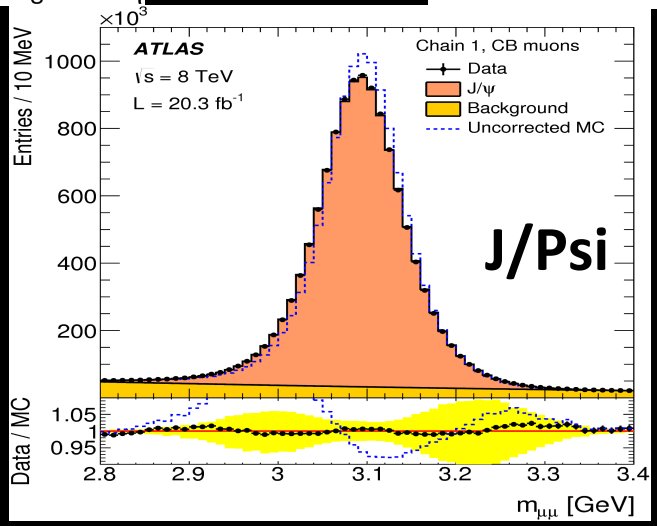


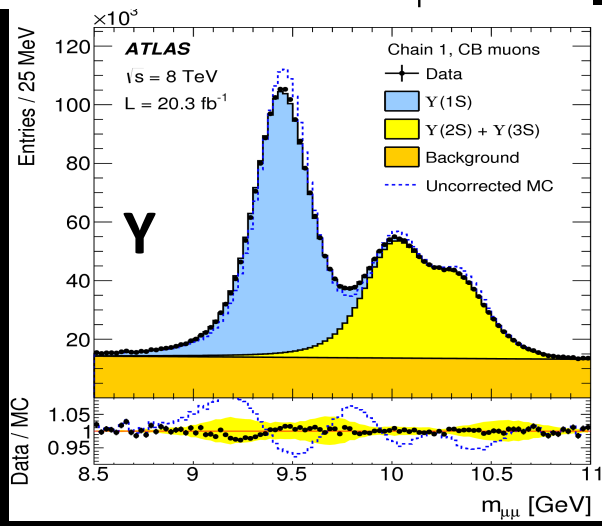
Alignment of trackers and muon chambers



Using well-known peaks

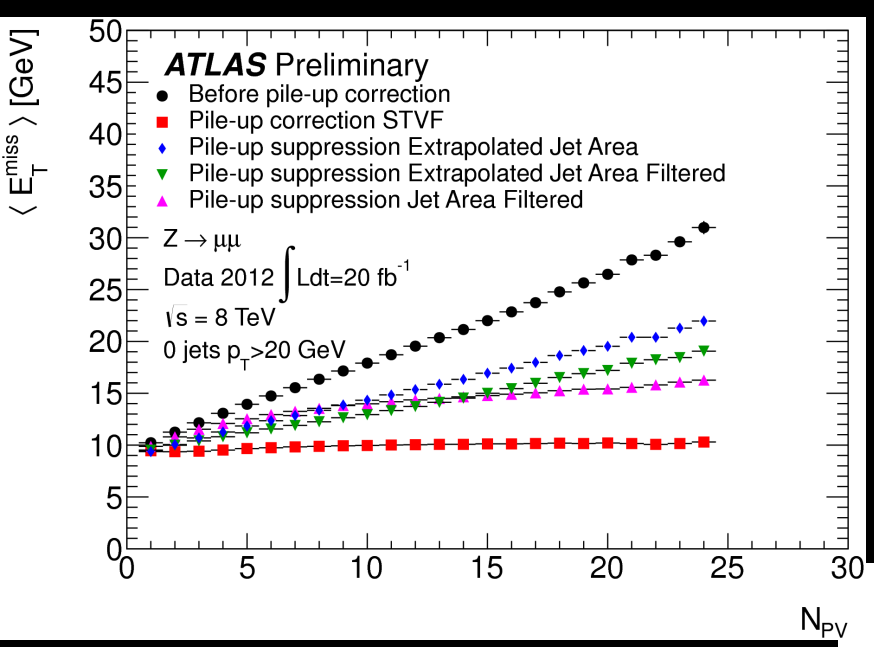




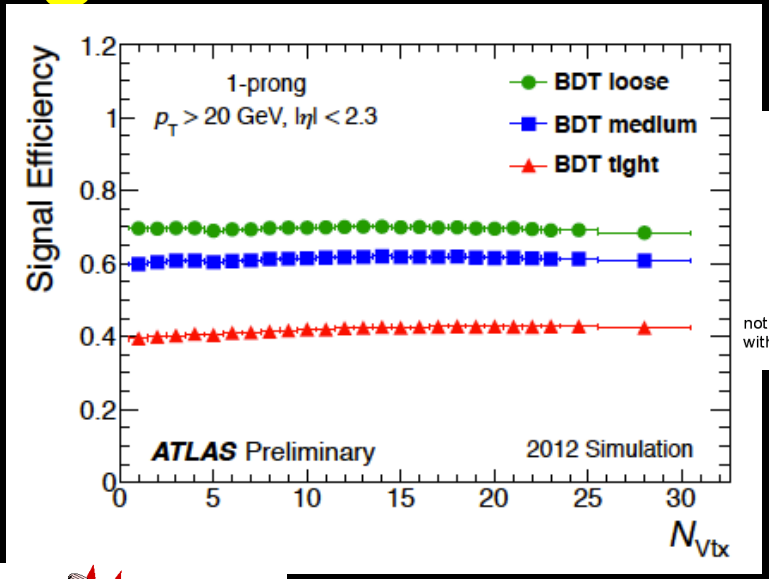


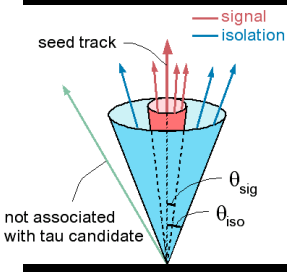
Building Blocks

Missing E_T vs PILEUP

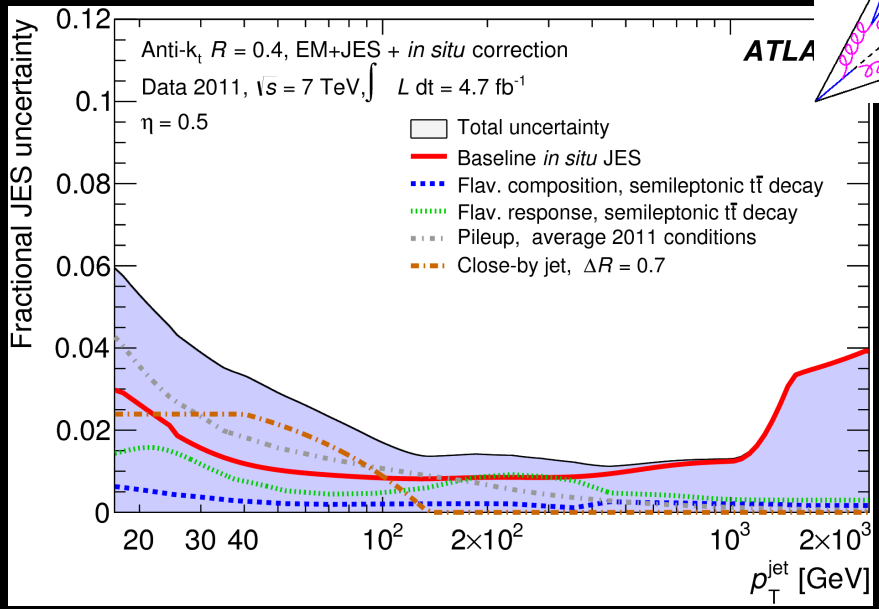


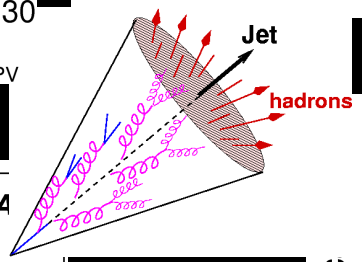
TAU ID vs PILEUP



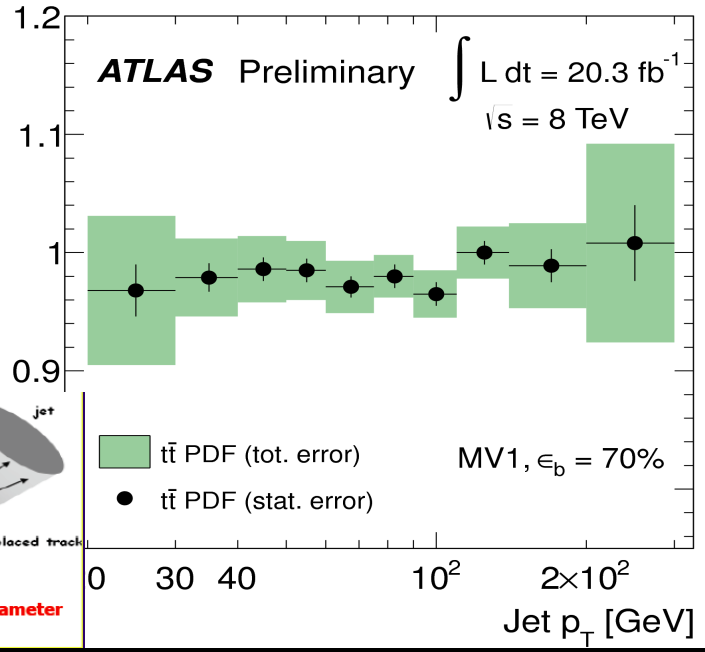


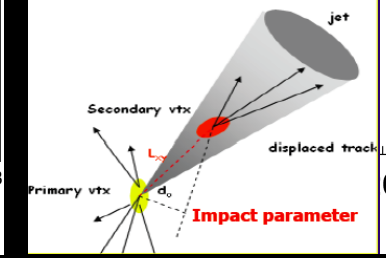
JET ENERGY SCALE UNCERTAINTY



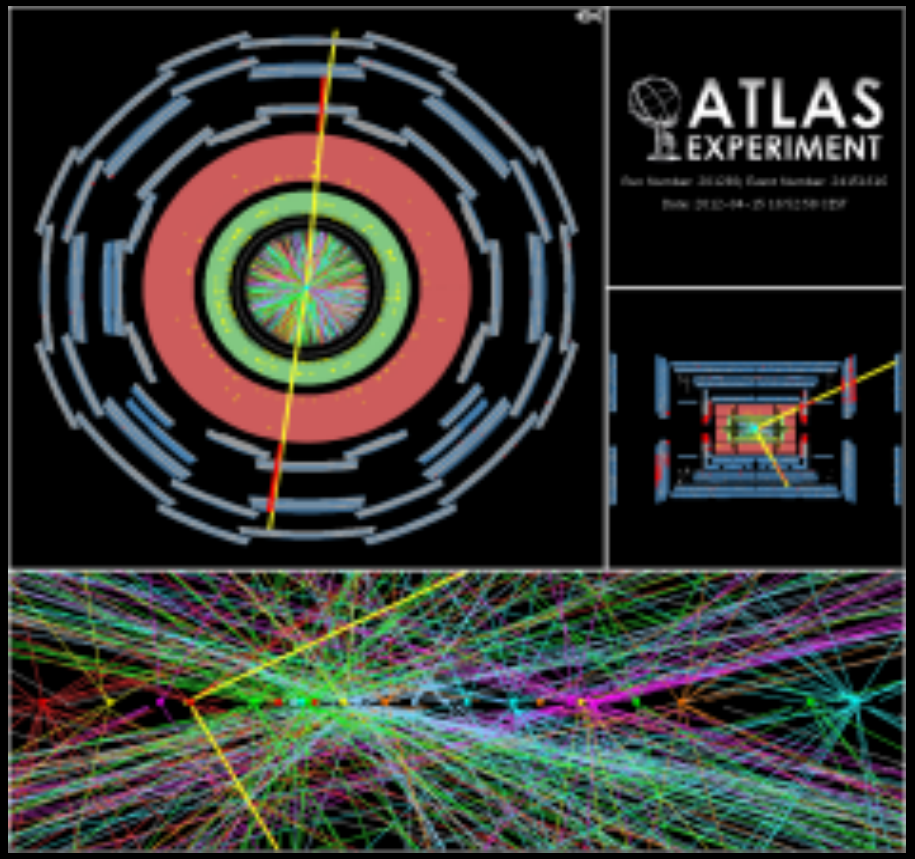


B-JET TAGGING EFFICIENCY





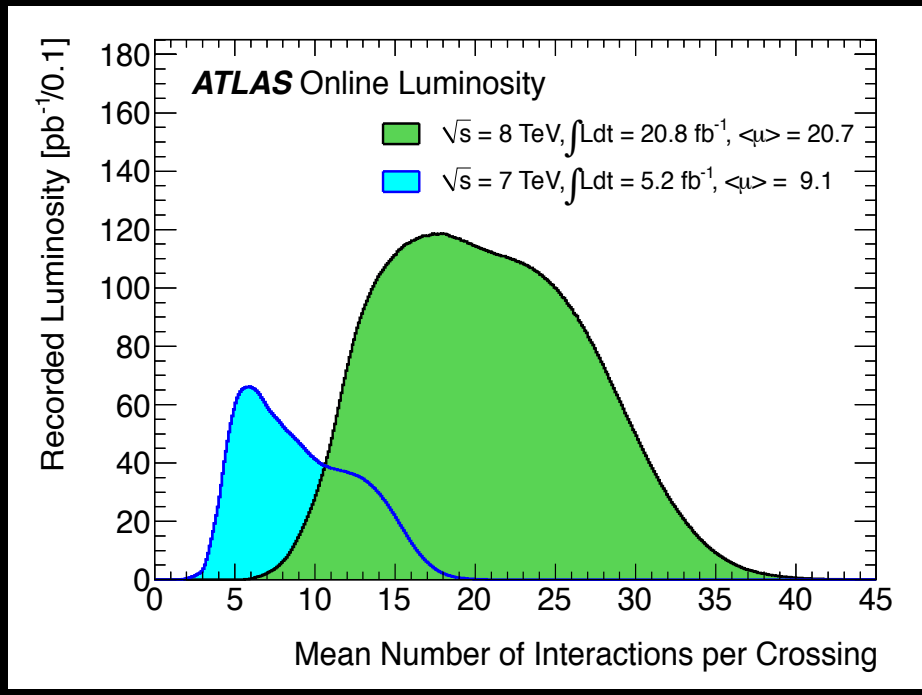
Multiple Interactions



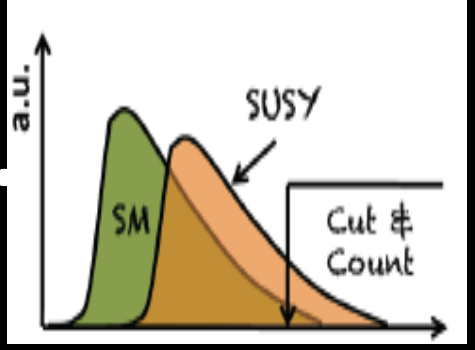
Z → μμ events with
20 interactions on top

Up to 40 interactions / crossing

(requires enormous efforts to understand the reconstruction of the physics objects…)

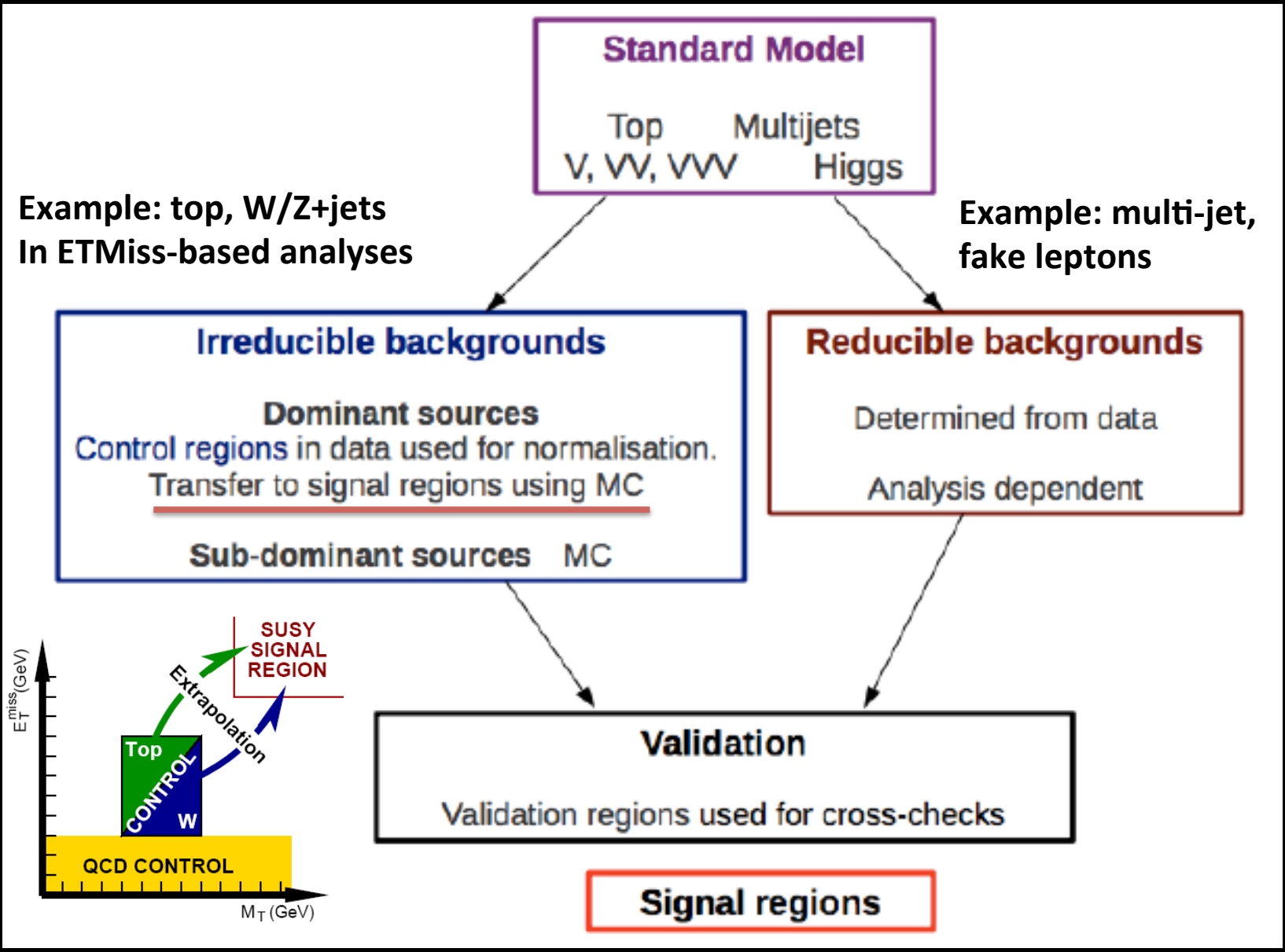


How to make your search…



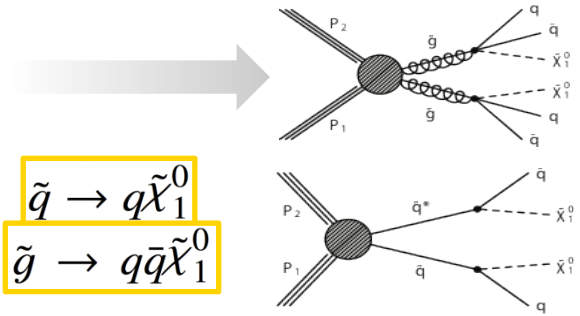
1. Find good discriminant(s) → signal region (blind it!)
2. Determine your SM background + related systematics
    1. As much as possible from data
    2. If taken from theory/simulations → define control regions in data (orthogonal to your signal regions) to constrain the predictions with data (and to reduce systematics from models)
    3. Validate your predictions in regions close to the signal region (similar kinematics) where you do not expect new physics
    4. Convince your collaborators all is under control and open box
3. Use a sophisticated Likelihood fit to determine whether your data is statistically consistent with a background only hypothesis in the signal region taking into account correlations of systematic uncertainties, etc..
    1. Buy a ticket to Stockholm or compute exclusion limits @ 95% CL

Background strategy



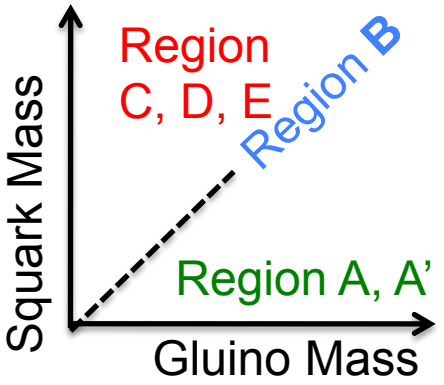
An example: 0-lepton signature

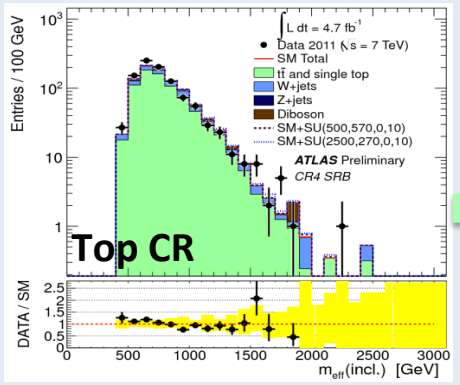
- Searches in inclusive jets + E_t^{miss} events
  - **from 2 (A) to 6 (E) jets**

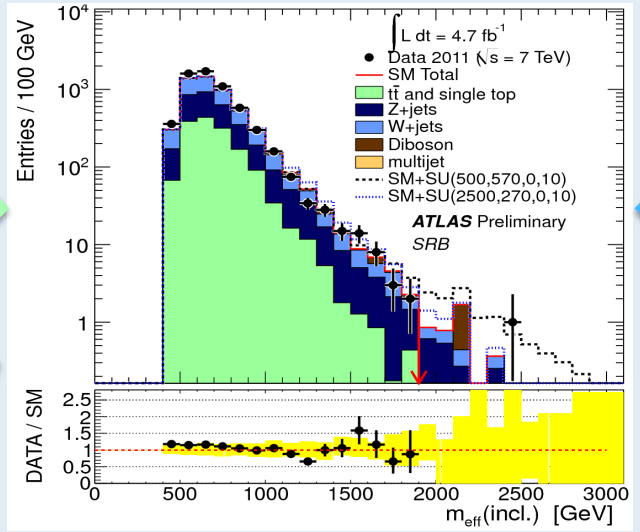


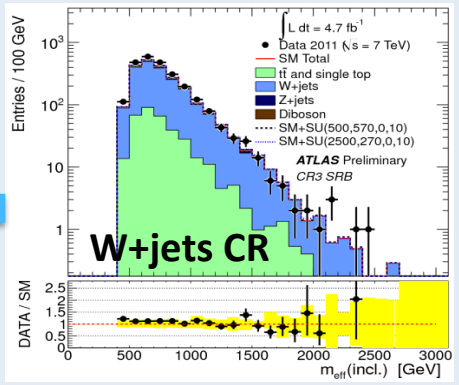
Expect significant "effective mass"

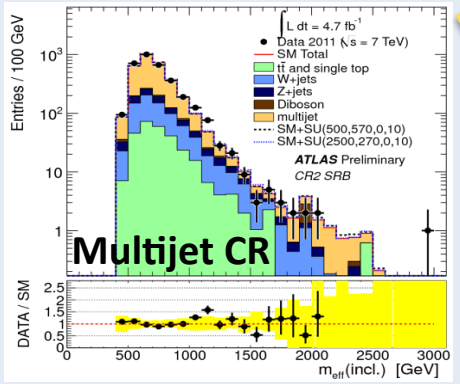
$$\sum_{jet} E_{T,jet} + E_T^{miss}$$

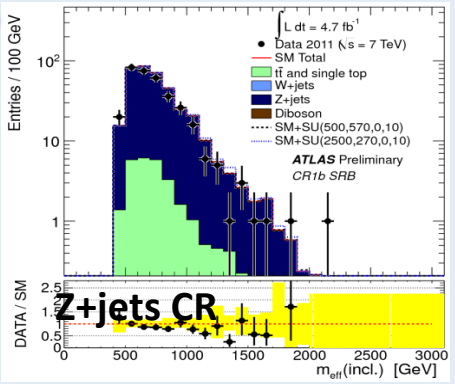












Normalizations obtained in all CR and extrapolated to signal regions simultaneously by combined maximum likelihood fit

The mother of all fits…

- Combine all info in a global fit. Likelihood based on CR and SR (mutually exclusive)

$$L(n \mid \mu, b, \theta) = P_{SR} \times P_Z \times P_W \times P_{Top} \times P_{QCD} \times C_{syst}$$

b=background
θ= systematics treated as nuisance parameters with Gaussian
n=Number of observed events in data
μ= SUSY signal strength to be tested

- Each region described with a **Poisson p.d.f**
- Statistical and systematic uncertainties on the expected values included in the fit as nuisance parameters → typically constrained by a **Gaussian function** with width corresponding to the size of the uncertainty considered
  - correlations between these parameters are taken into account
- **Inputs:** Transfer factors (c), N events for data in SR(s) and CRj(bj)

$$P_{SR} = P(n \mid \lambda_S(\mu, b, \theta)) = \mu \bullet c_{sR->SR}(\theta) \bullet s + \sum_j c_{jR->SR}(\theta) \bullet \mathrm{b_j}$$

$$P_i = P(n \mid \lambda_i(\mu, b, \theta)) = \mu \bullet c_{sR->iR}(\theta) \bullet s + \sum_j c_{jR->iR}(\theta) \bullet \mathrm{b_j}$$

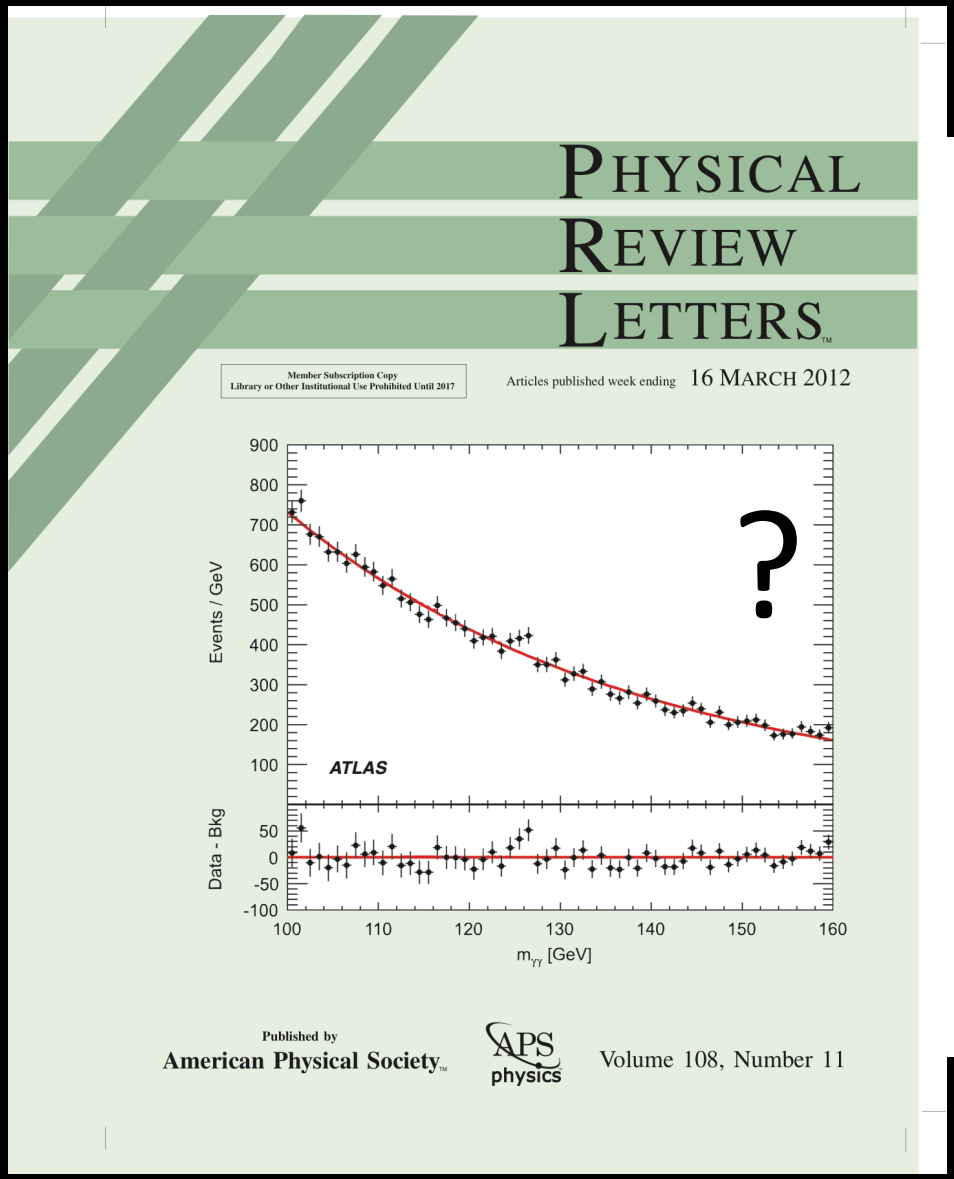
λ (μ, b, θ) = expected number of events

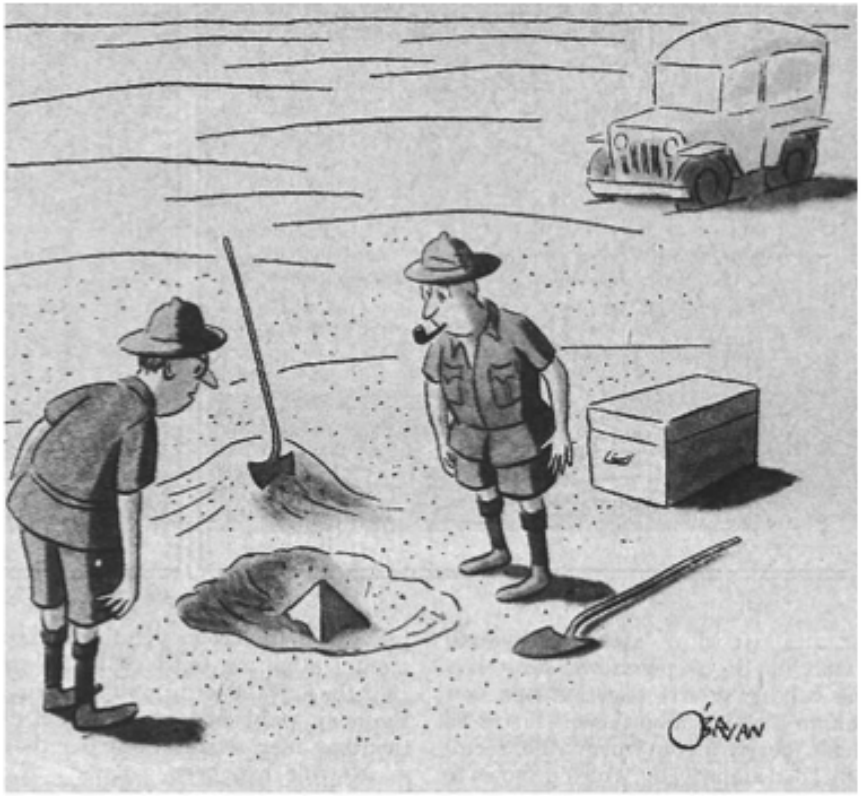
Statistical facts

Notes on statistics

Using Higgs discovery for illustration

Notes on Statistical Significance





"This could be the discovery of the century. Depending, of course, on how far down it goes."

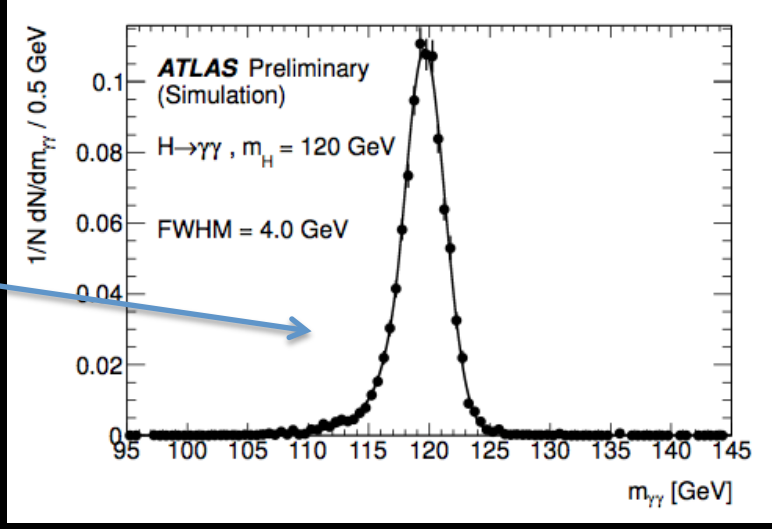
Likelihood ratio

$$L(\mu,\theta) = f_b \phi_b(m_{\gamma\gamma}) + f_s \phi_s(m_{\gamma\gamma})$$

$$f_s \propto \mu$$

$$n_s = \mu \sigma_s^{visible}$$

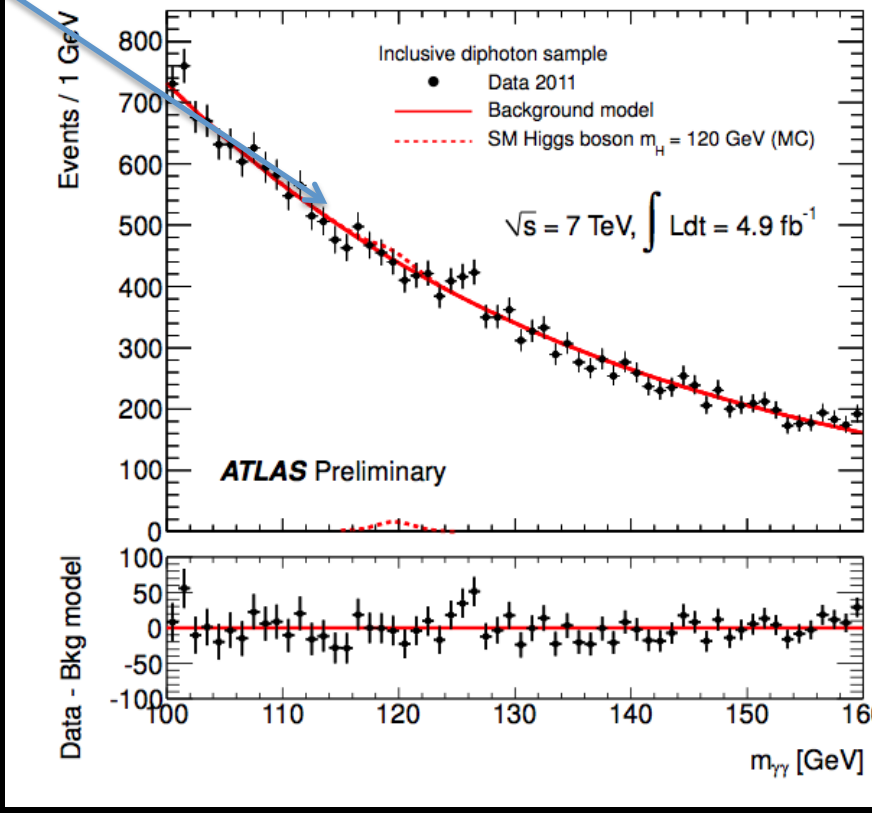
Nuisance parameters



$$\lambda_\mu = \lambda(\mu,\theta) = \frac{L(\mu,\hat{\hat{\theta}}(\mu))}{L(\hat{\mu},\hat{\theta})}$$

$$q_\mu = -2 \ln \lambda_\mu$$

$$p_\mu = \int_{q_{obs}}^{\infty} f(q_\mu \mid \mu) dq_\mu$$



Only background ?

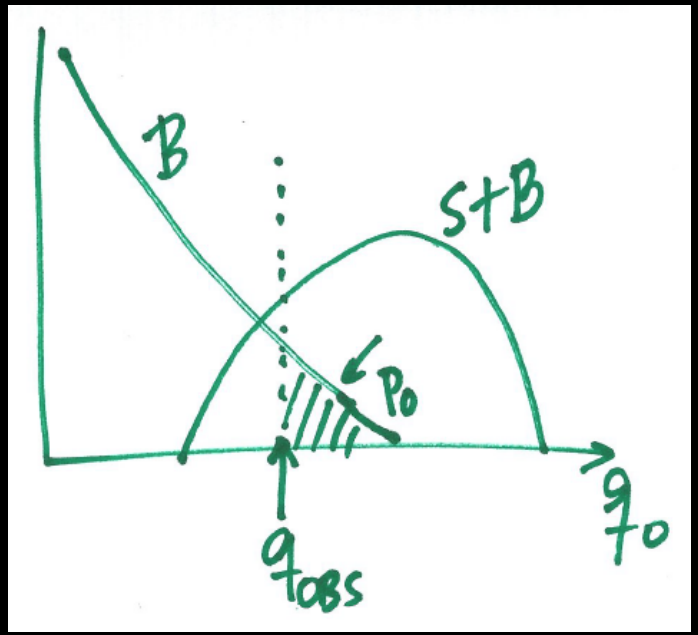
Test of “null” hypothesis of no signal

If a real signal appears … $p_0 \rightarrow 0$
(once $p_0 < 2.87 \times 10^{-7} \rightarrow$ Discovery)

$$\lambda_0 = \lambda(0,\theta) = \frac{L(0,\hat{\hat{\theta}}(0))}{L(\hat{\mu},\hat{\theta})}$$

$$q_0 = -2\ln\lambda_0$$

$$p_0 = \int_{q_{obs}}^{\infty} f(q_0 \mid 0)\, dq_0$$



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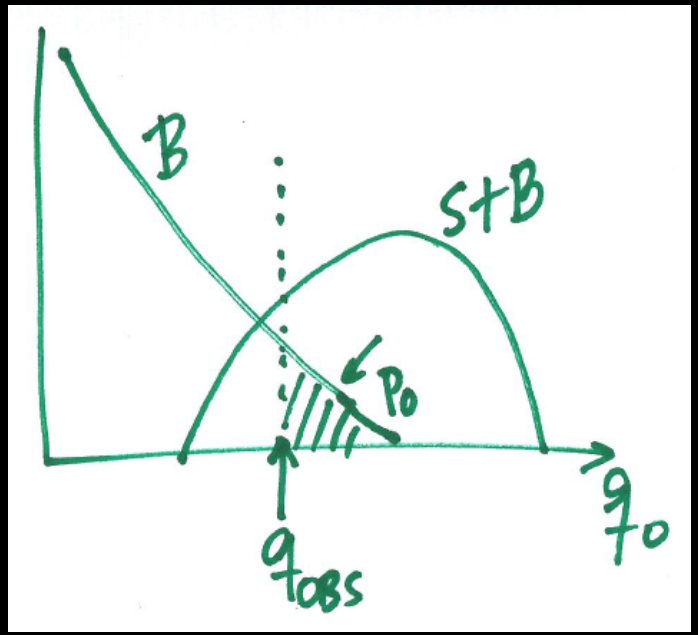


CL_s

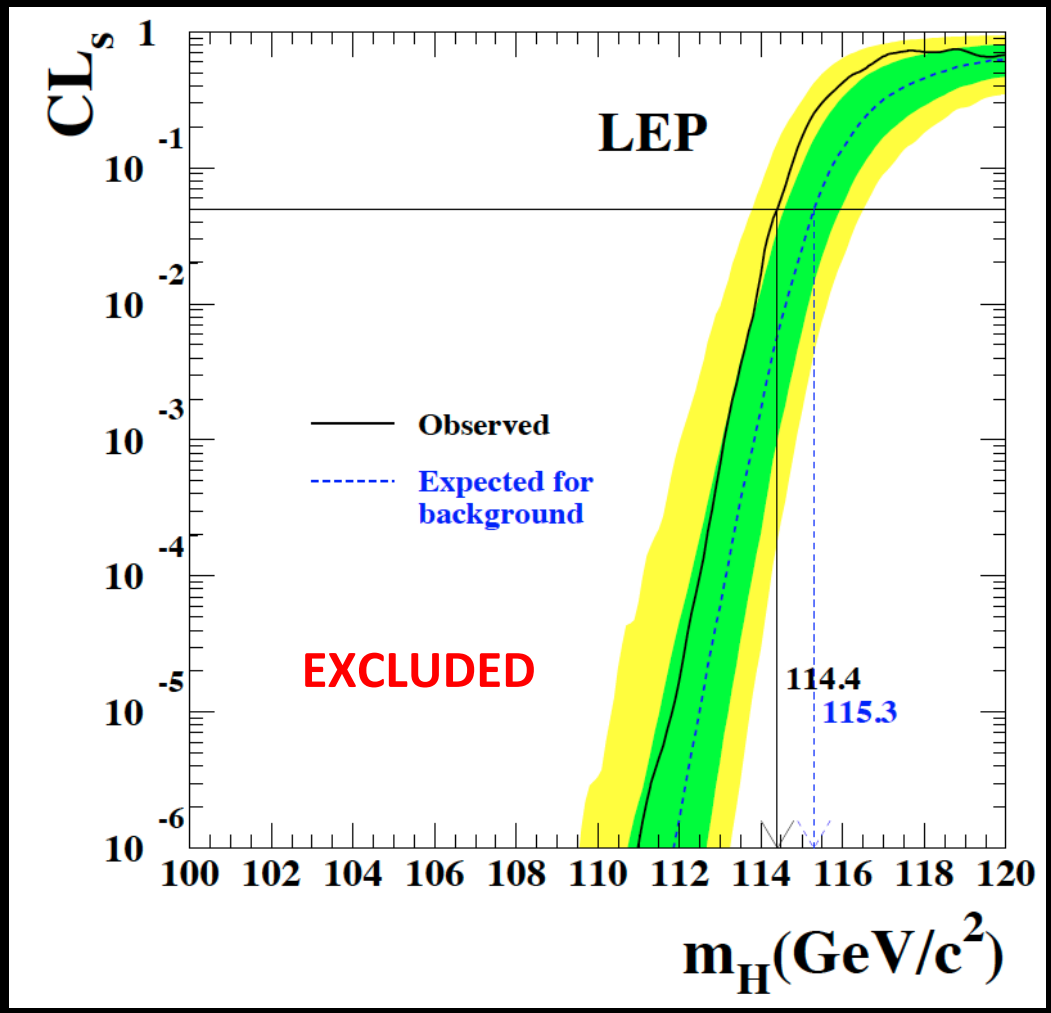
(do not exclude your signal…)

$$CL_S = \frac{p_s}{1 - p_b}$$

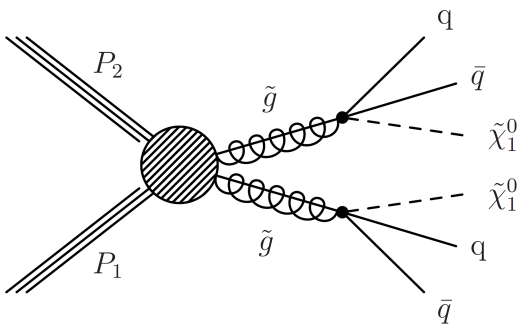
In the case of very small signals (limited sensitivity) the use of p_s to exclude signals can lead to false exclusions if the data fluctuates down….

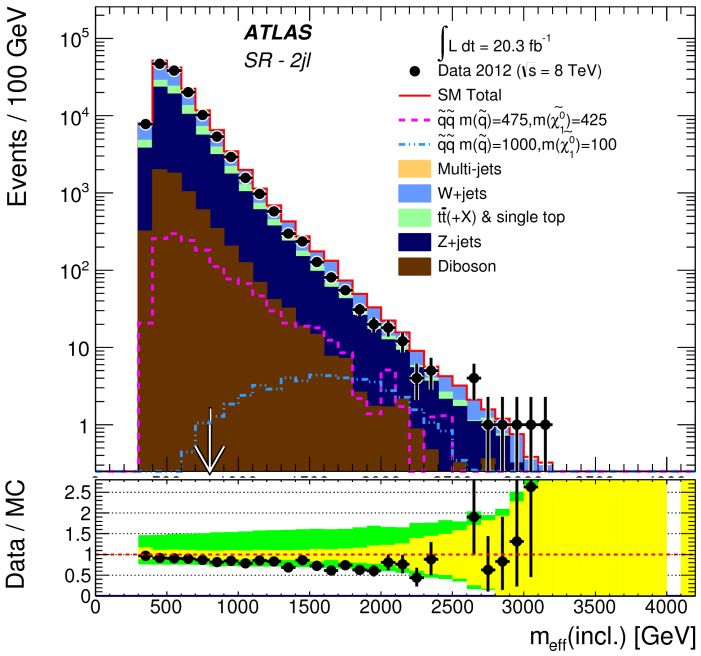
In these cases it is better to use CLs … which is conservative in the exclusion

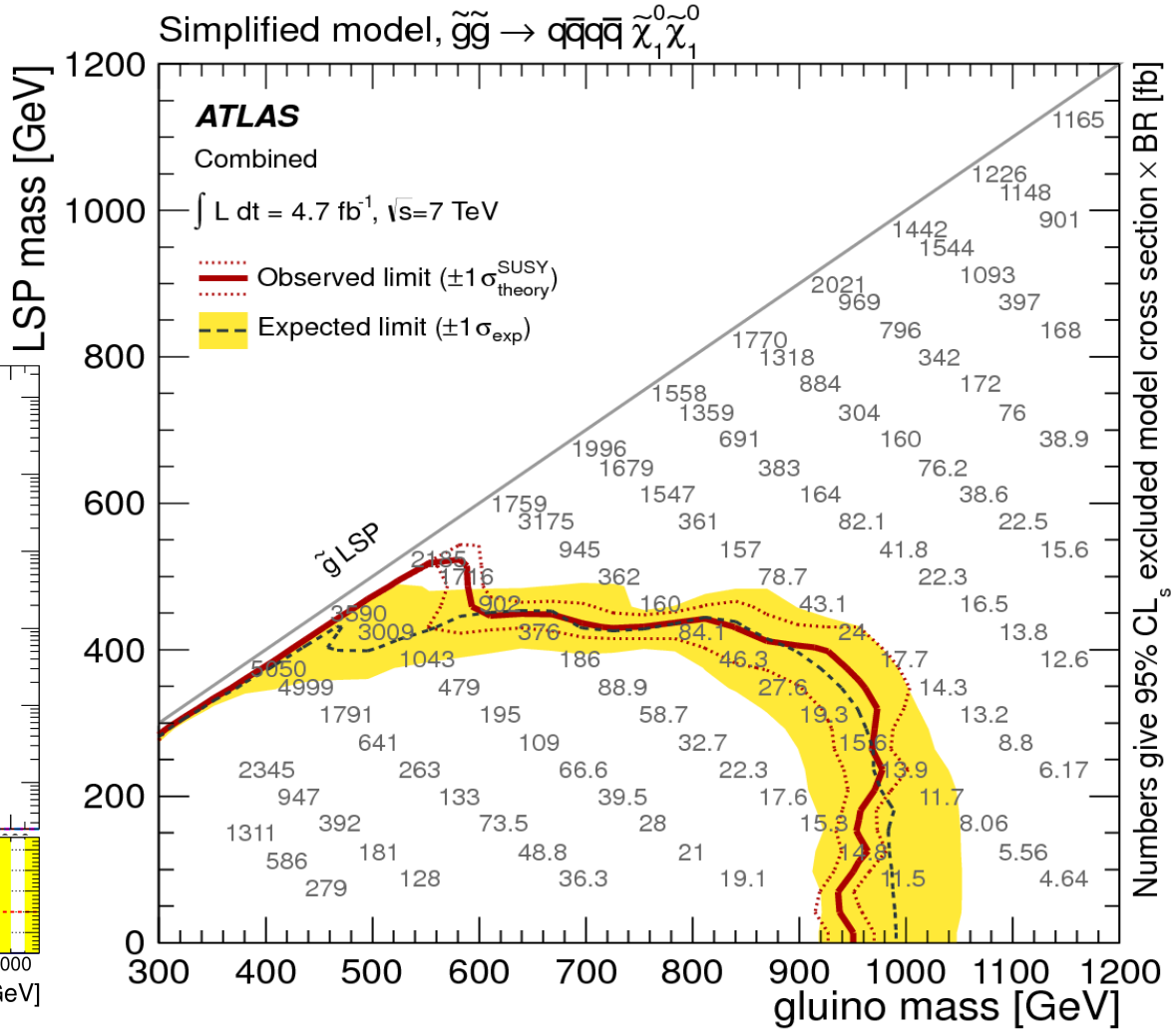
If CLs < 0.05 → excluded at 95% CL



Typical SUSY exclusion plot..

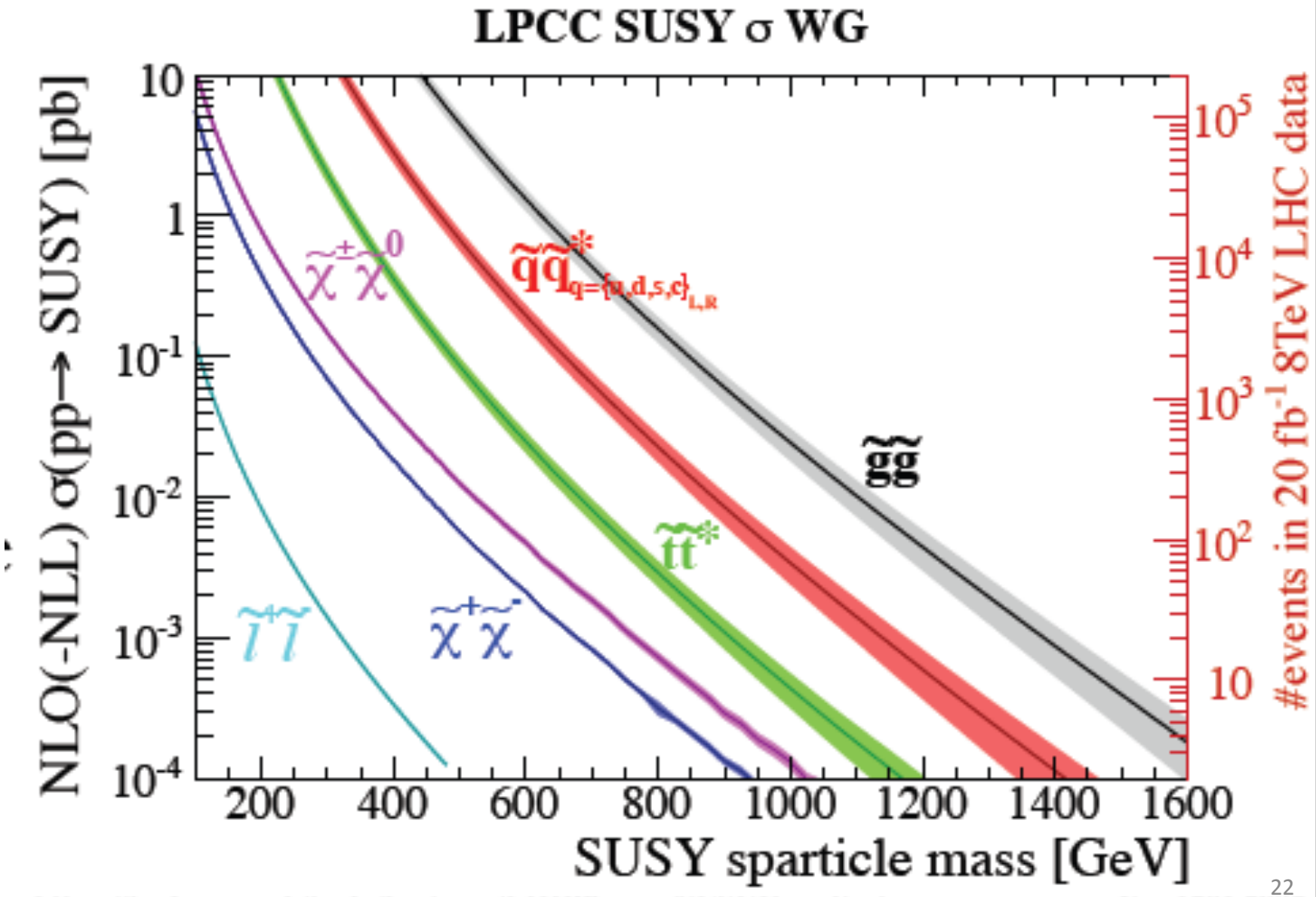




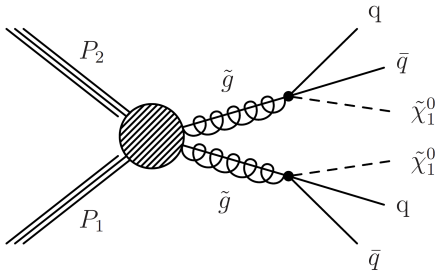


Expected: use SM prediction as data (yellow band reflects uncertainties in SM prediction)
Observed: what the data tells you (dashed band depends on the model uncertainties)
Numbers inside: 95% CL signal exclusion (if your signal is larger than this.. You excluded it)

SUSY Cross Sections @ LHC (8 TeV)



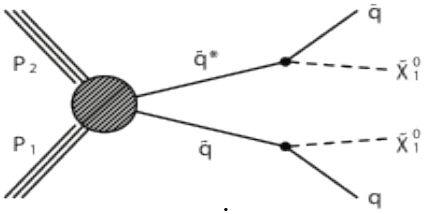
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892



Inclusive Searches

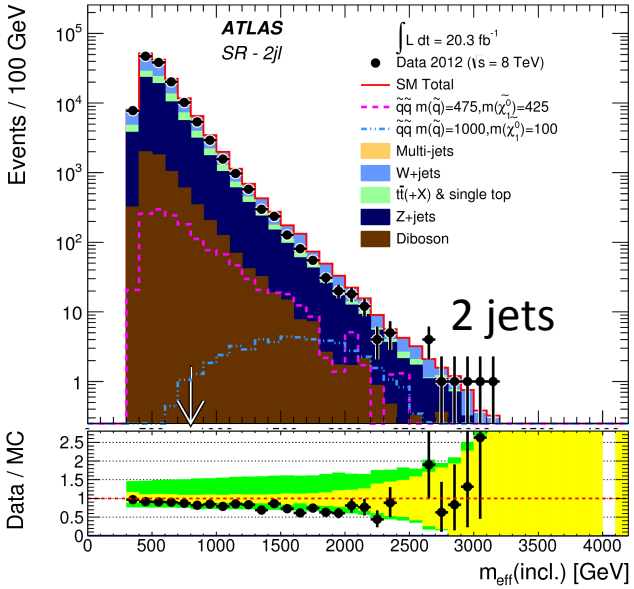
Multiple-jets and large E_T^{miss}

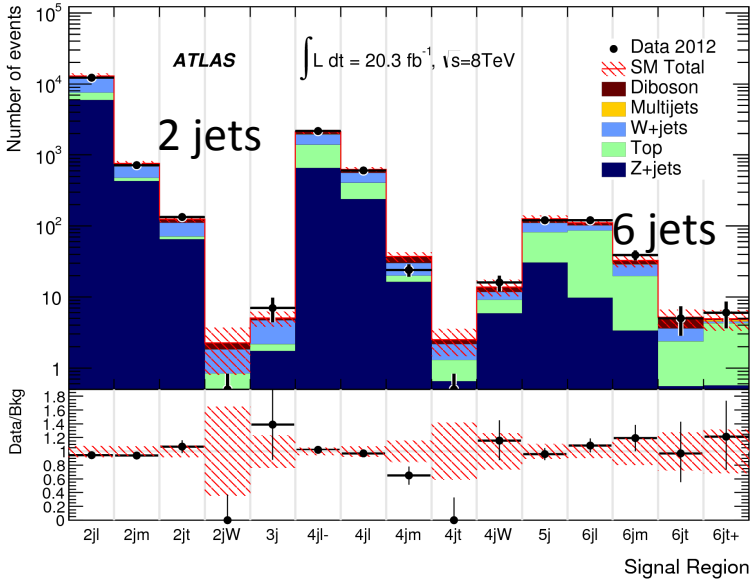
[JHEP09(2014)176](#)



$$m_{eff} = E_T^{miss} + H_T$$

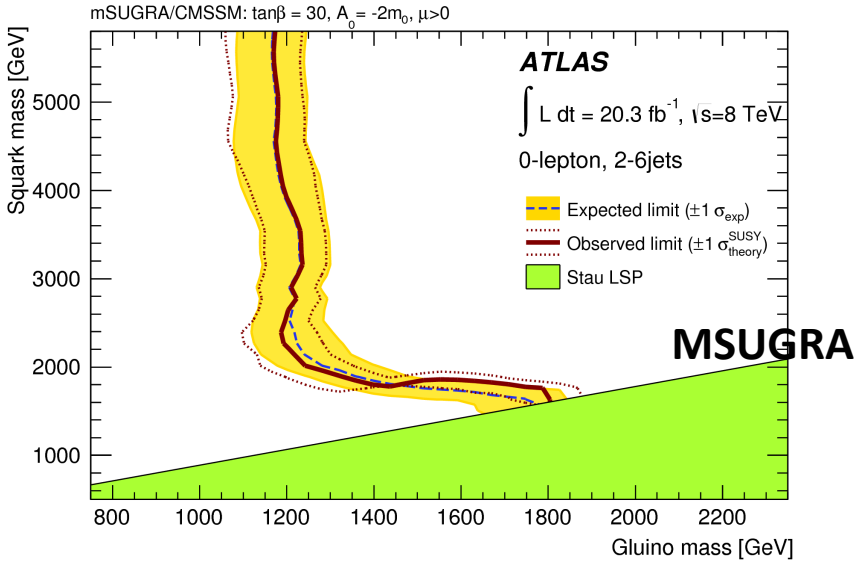
$$H_T = \sum_{jets} p_T$$

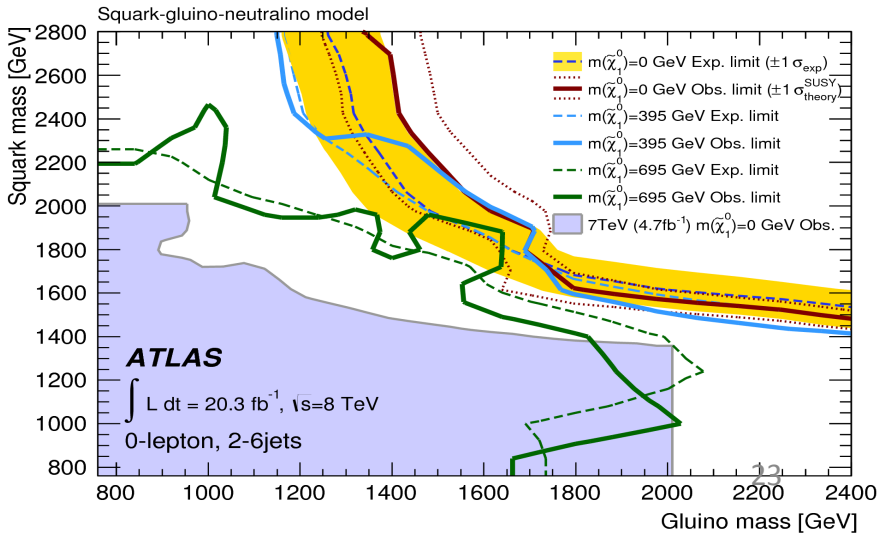


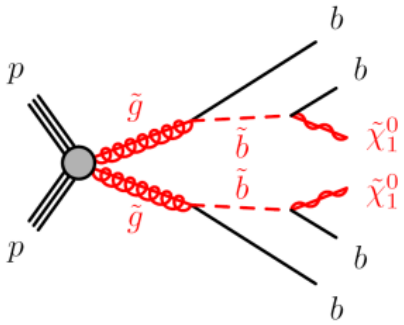


Background from 1 lepton b-tag/veto & photon CRs with similar jet and kinematic selections as in SRs

SIMPLIFIED SCENARIO







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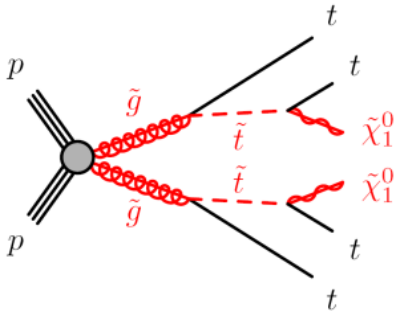
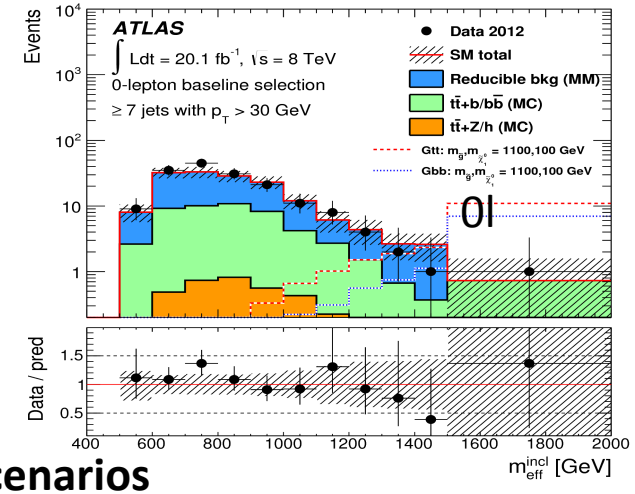
Gluino-mediated
Stop/Sbottom Production

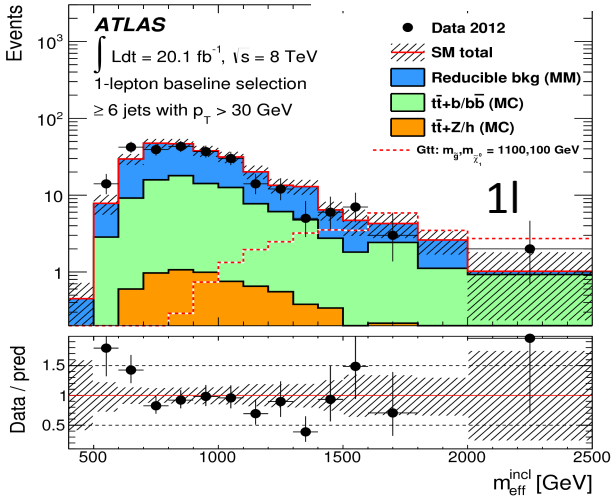


0/1 lepton + 3b-jets + E_t^{miss}

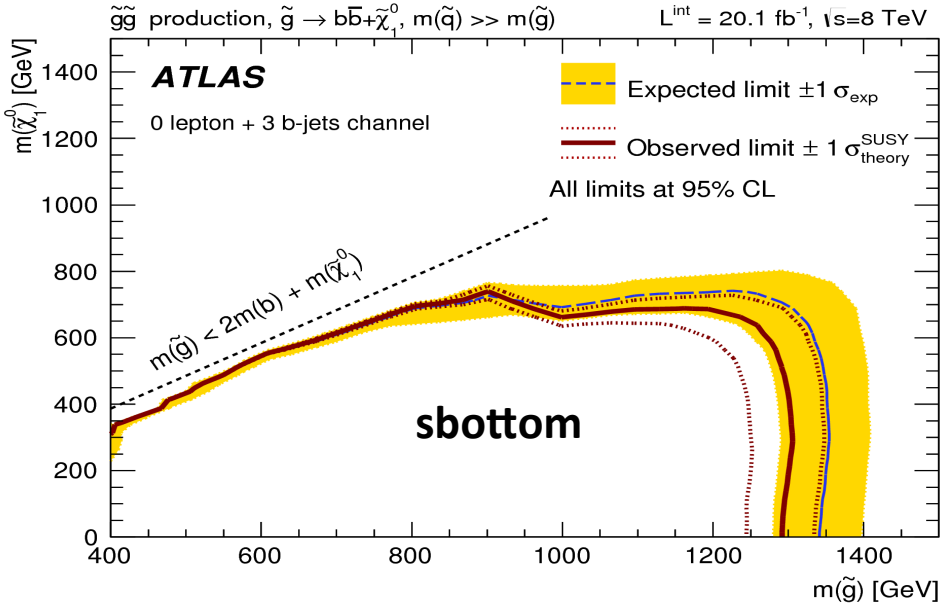
Background dominated by tt+bb, tt+V and tt+fakes

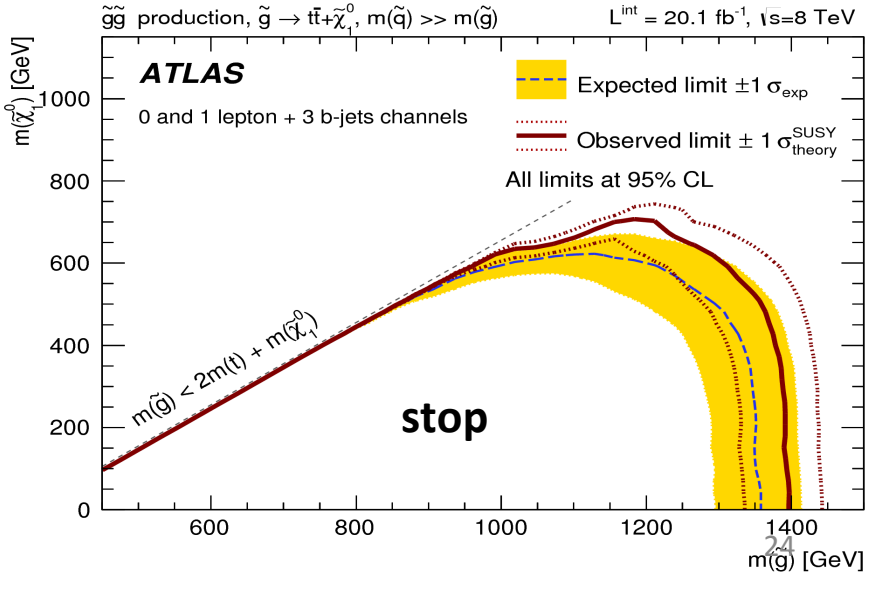
most powerful for very heavy gluinos





Interpreted in simplified scenarios

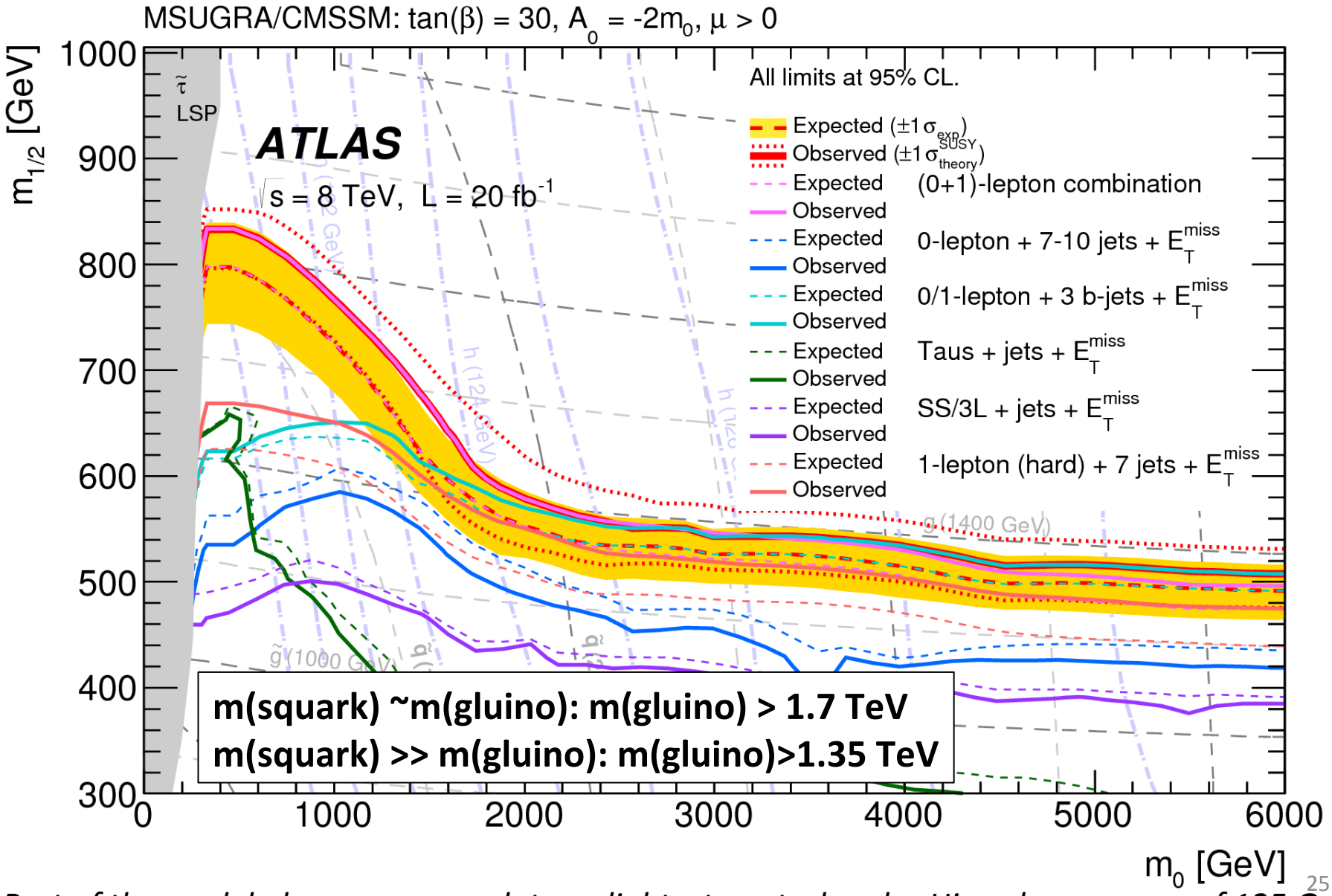




MSUGRA Scenario

arXiv:1507.05525

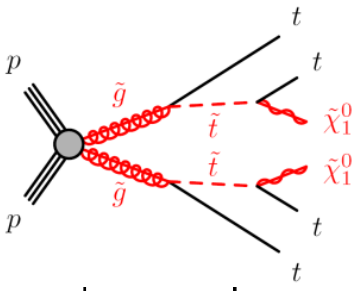
Run-1 summary on inclusive squark and gluino searches



Part of the model plane accommodates a lightest neutral scalar Higgs boson mass of 125 GeV

Simplified model

arXiv:1507.05525



g̃g̃ production, g̃→ tt(*)χ̃⁰₁; m(t̃) >> m(g̃), including up to five-body decays

All limits at 95% CL.

ATLAS

√s = 8 TeV, L = 20 fb^{-1}

Expected ($\pm1\sigma_{exp}$)

Observed ($\pm1\sigma^{SUSY}_{theory}$)

Expected 0-lepton + 7-10 jets + E_T^{miss}

Observed

Expected SS/3L + jets + E_T^{miss}

Observed

Expected 1-lepton (soft+hard) + jets + E_T^{miss}

Observed

Expected 0/1-lepton + 3 b-jets + E_T^{miss}

Observed

Off-shell region

On-shell region

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

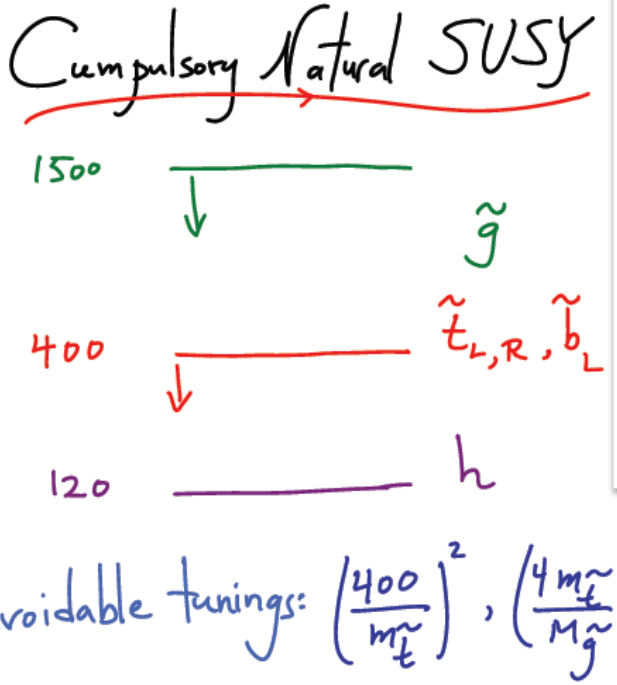
$m_{\tilde{\chi}^0_1}$ [GeV]

1200
1000
800
600
400
200

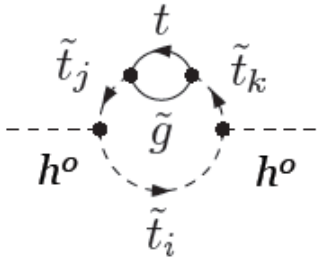
500 600 700 800 900 1000 1100 1200 1300 1400 1500

$m_{\tilde{g}}$ [GeV]

"Natural SUSY 2012"



N. Arkani-Hamed talk at CERN Oct. 2012



$$\frac{m_H^2}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

$$\delta m_H^2\big|_{stop} \cong -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2\right)\ln\left(\frac{\Lambda}{TeV}\right)$$

$$\delta m_H^2\big|_{gluino} \cong -\frac{2y_t^2}{\pi^2}\left(\frac{\alpha_s}{\pi}\right)|M_3|^2 \ln^2\left(\frac{\Lambda}{TeV}\right)$$

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_t & \sin\theta_t \\ -\sin\theta_t & \cos\theta_t \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

→ Light higgsinos

→ Light stop (t_1 < 1 TeV)

→ Light gluinos (< 1-2 TeV)

One light stop and sbotton ….rest of sparticles can be decoupled….

$$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix} \quad \tilde{t}_R \quad \tilde{b}_R$$

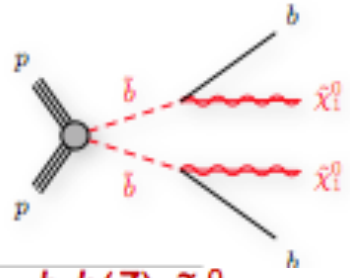
(same weak isospin multiplet)

Direct Stop/Sbottom

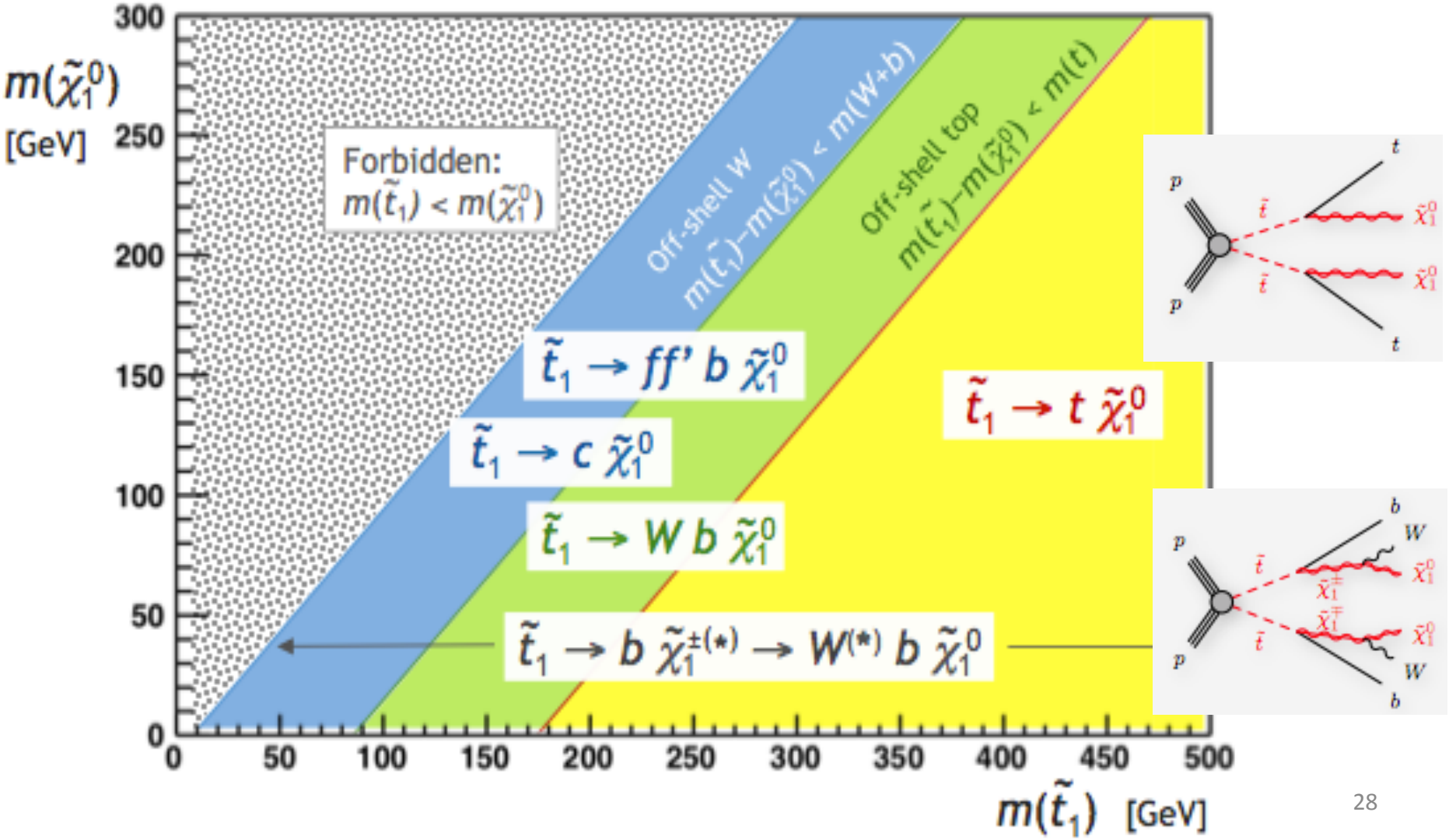
$\tilde{b}_1 \to b\,\tilde{\chi}_1^0$

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

$\tilde{b}_1 \to b\,\tilde{\chi}_2^0 \to b\,h(Z)\,\tilde{\chi}_1^0$

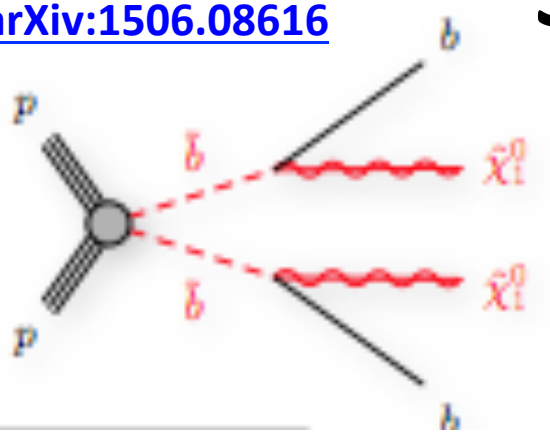


In the scenario with TeV gluinos / squarks (1st/2nd generations)
All the attention is put now in searches for stop/sbottom
Multiple channels according to the decays



JHEP 10 (2013) 189
arXiv:1506.08616

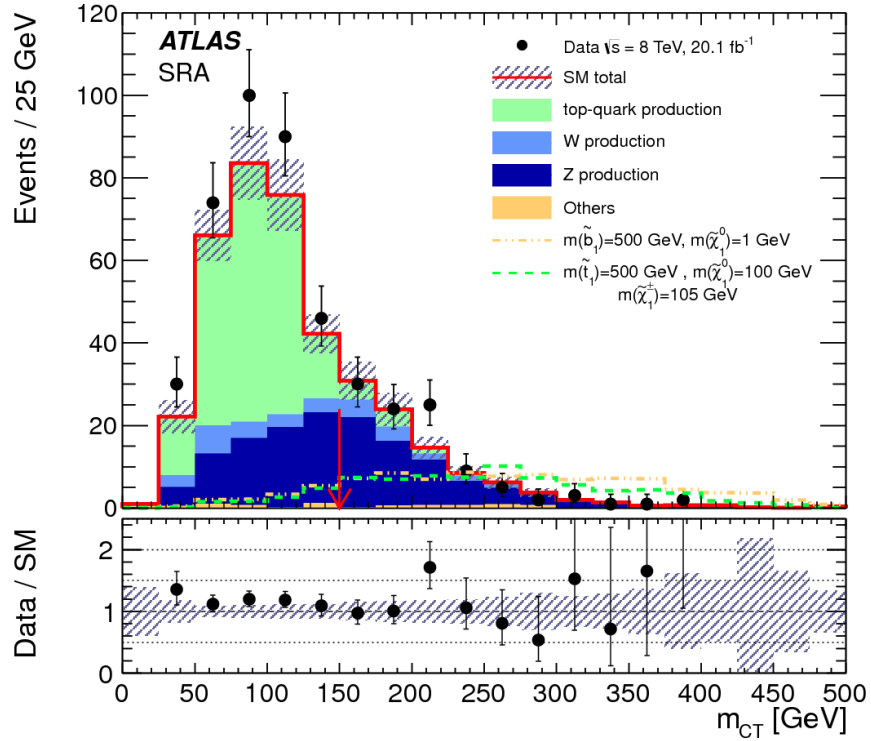
Sbottom Direct Production

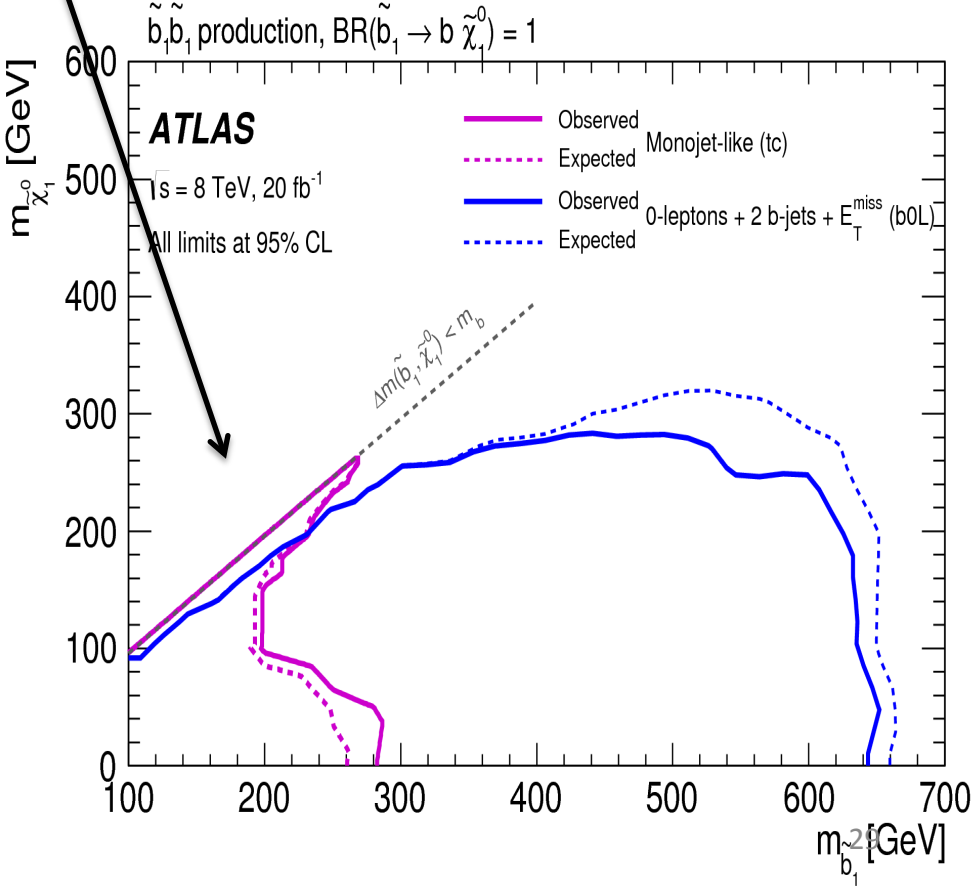


Large E_T^{miss} and 2 b-jets
Discriminating variable MCT

Additional selections to target also compressed scenarios (assisted with ISR jets)

$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [\boldsymbol{p}_T(v_1) - \boldsymbol{p}_T(v_2)]^2$$

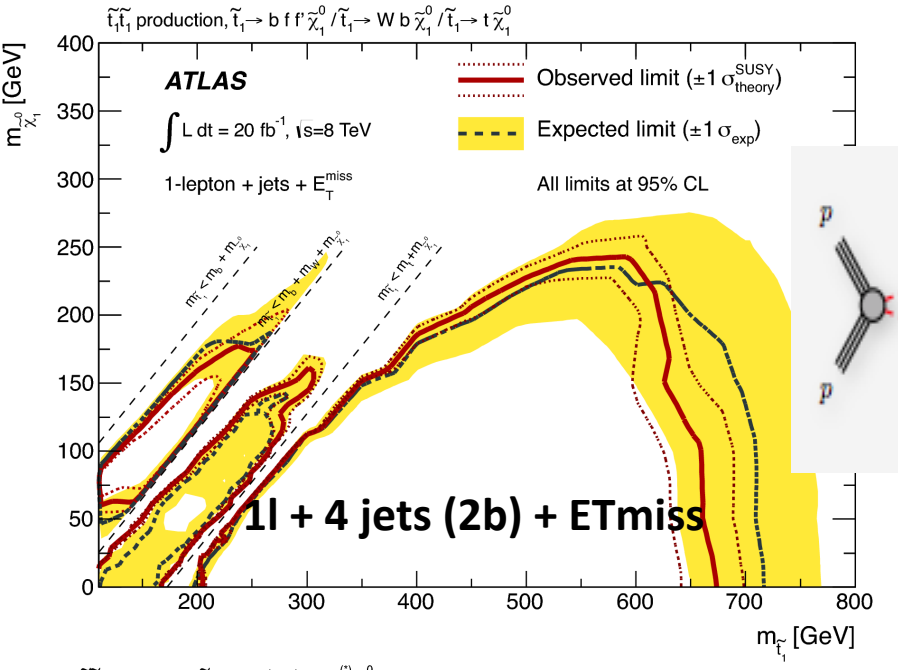


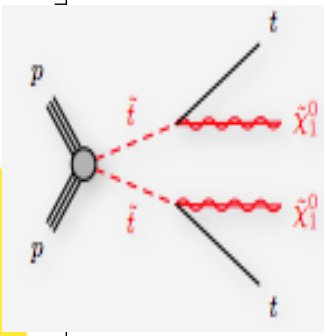


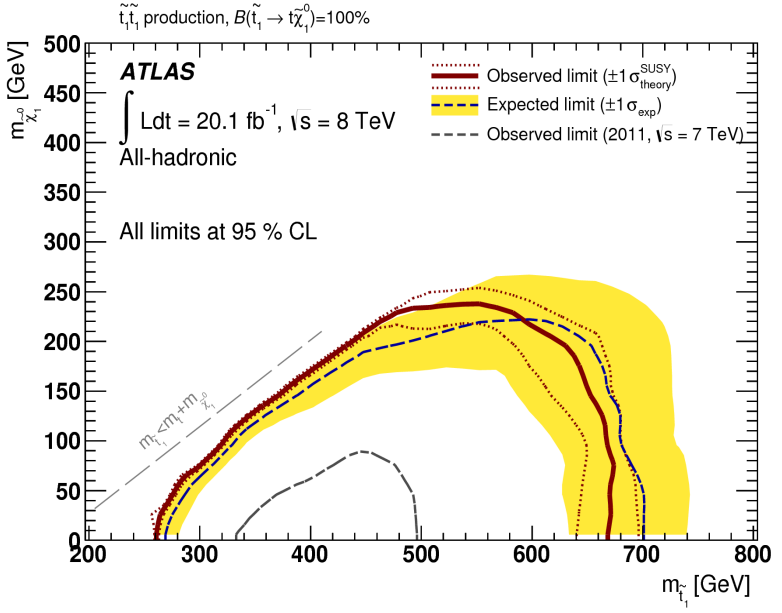
Direct Stop

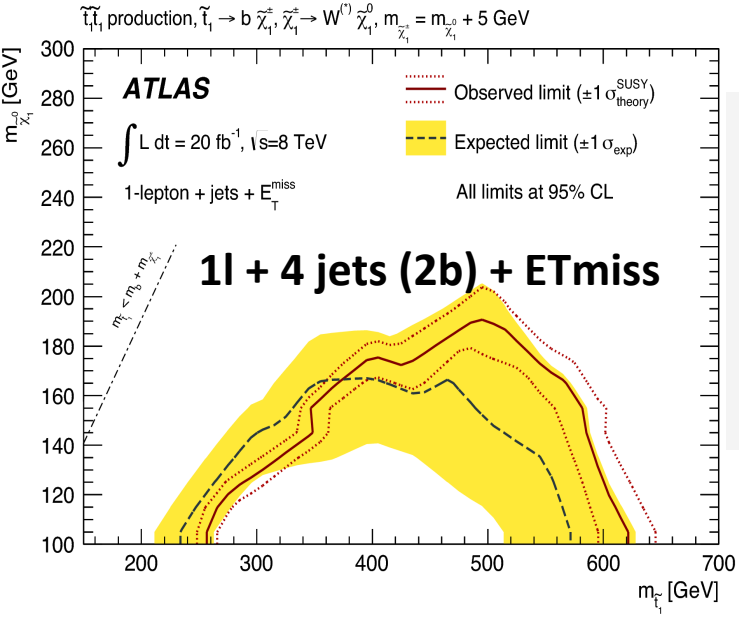
JHEP11(2014)118

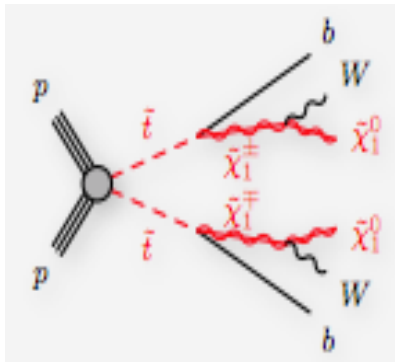
JHEP 09 (2014) 015

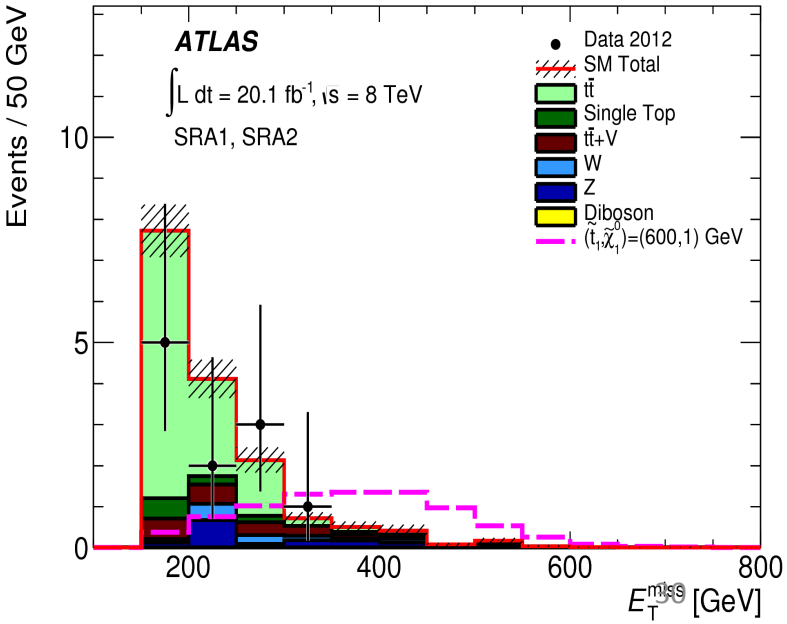












Phys. Rev. D. 90, 052008 (2014)

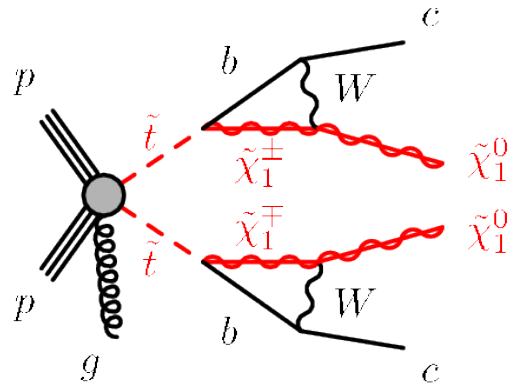
Direct Stop

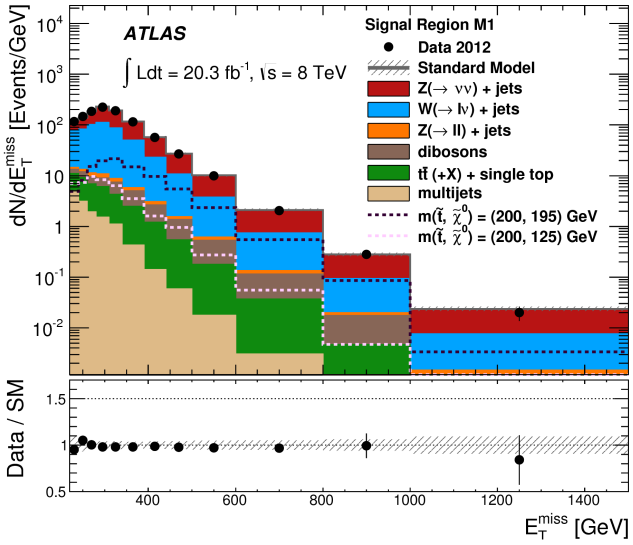
Two selections:

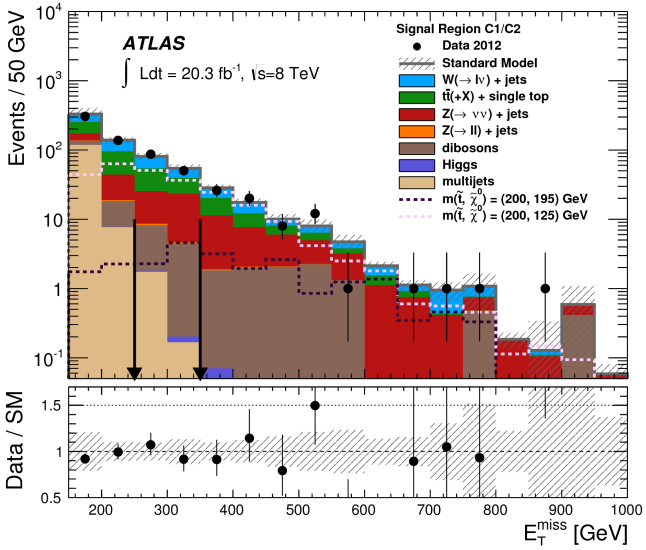
Monojet for compressed scenario

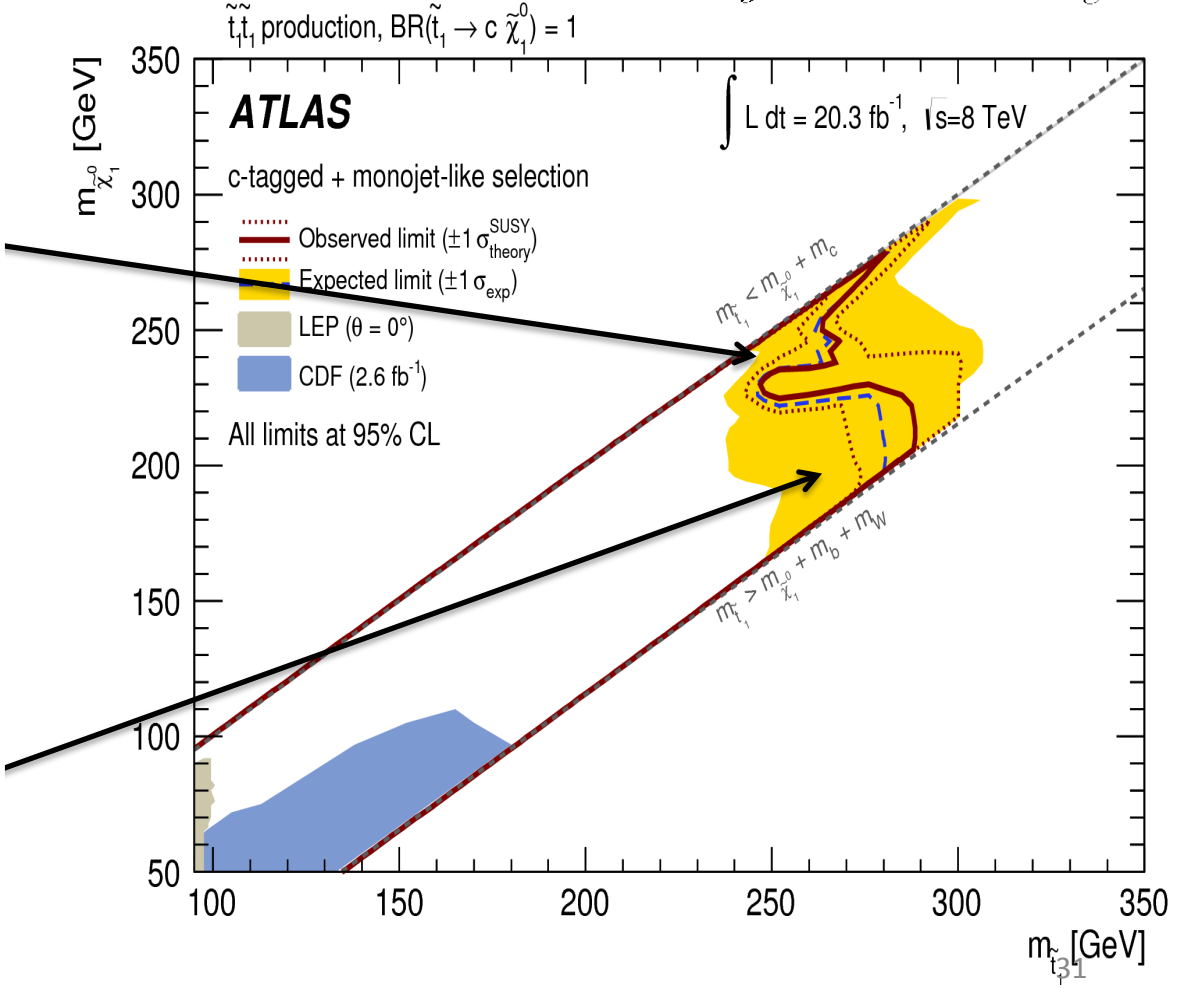
Large E_T^{miss} and c-jets

Very light stop





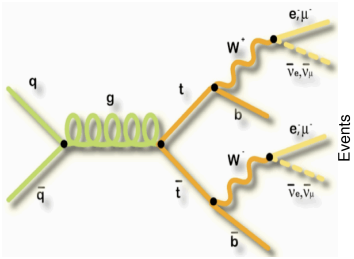


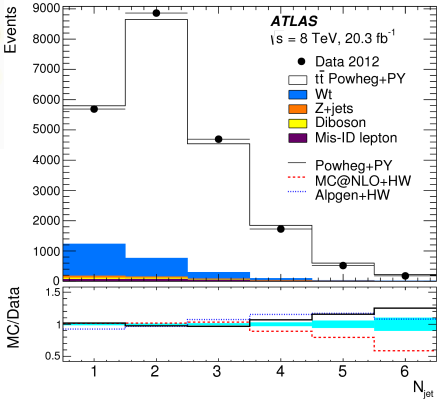


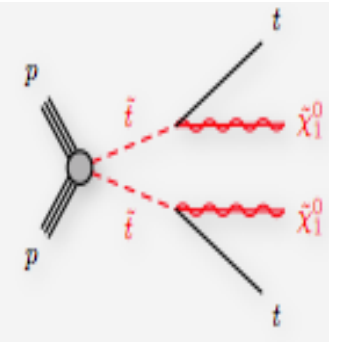
Eur. Phys. J. C74 (2014) 3109

Further stop constrains

(using the top cross section measurements)

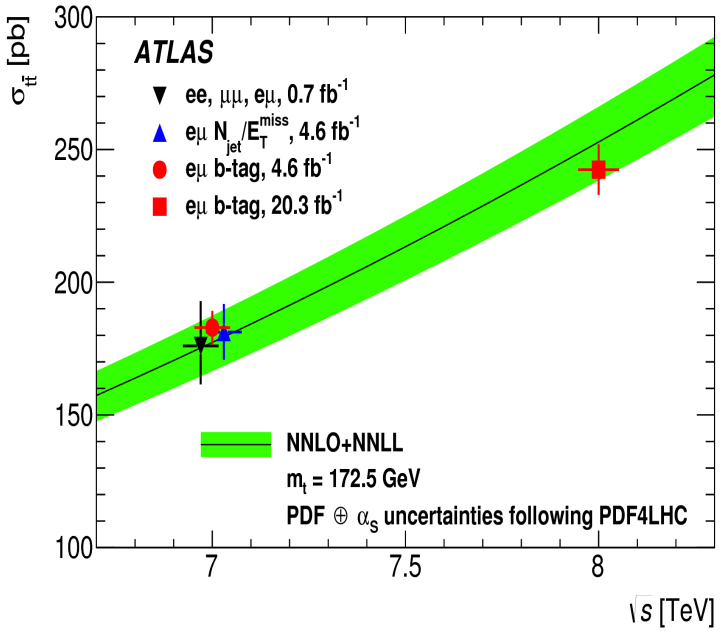


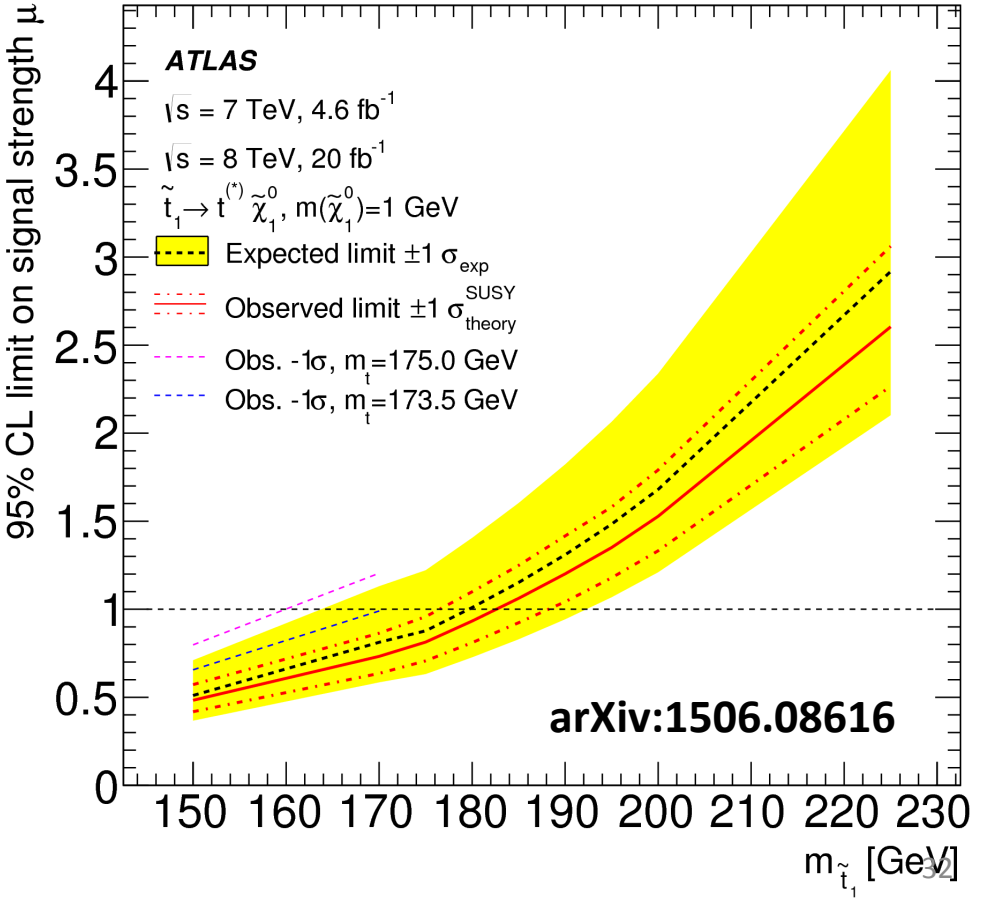




For stop masses close to the top mass the separation of SUSY signal and background is very challenging → use top cross section

Dilepton (e-μ) channel with exactly one and two b-jets

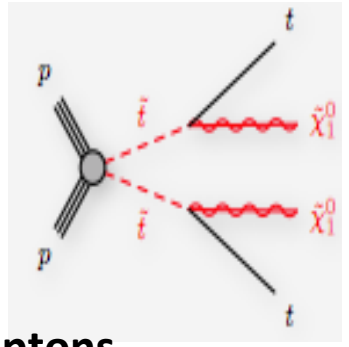


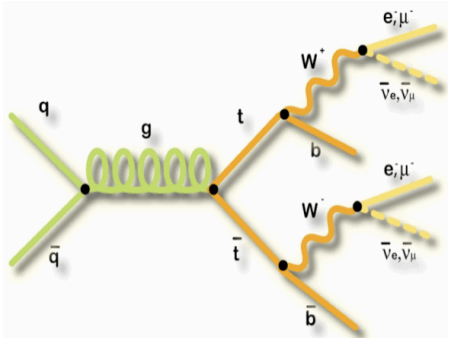


Phys. Rev. Lett. 114. 142001 (2015)

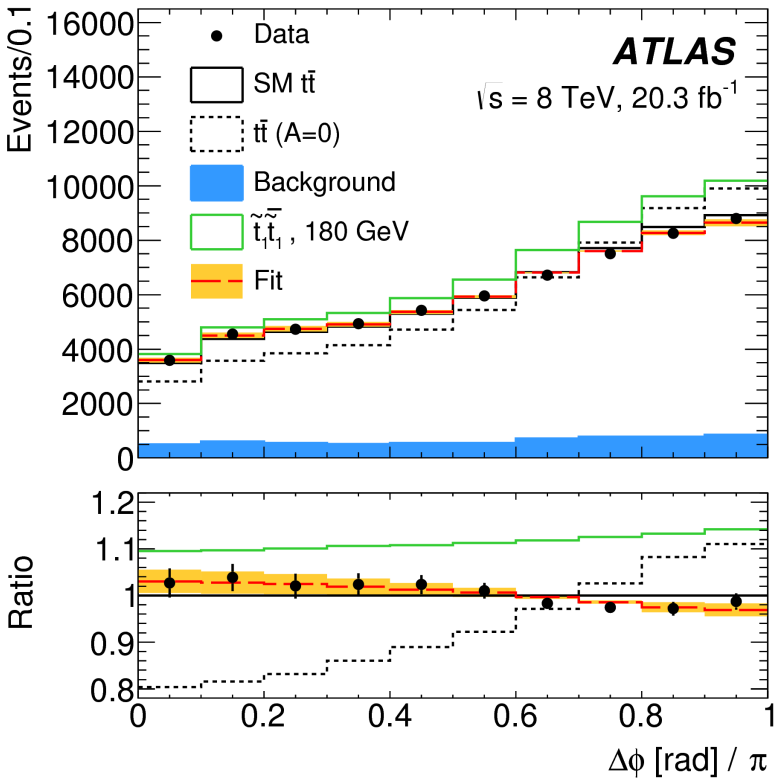
Further stop constrains

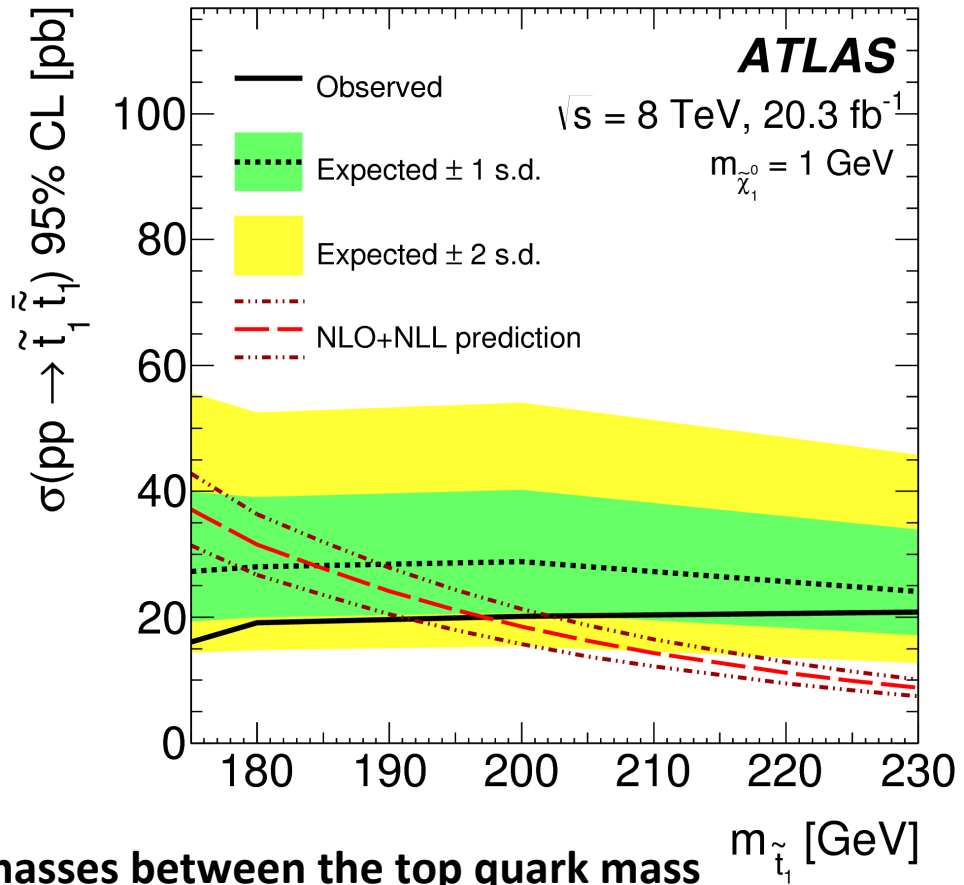
(using the top-(anti)top spin correlations)





using azimuthal separation of leptons from top-(anti)top decays in the final state



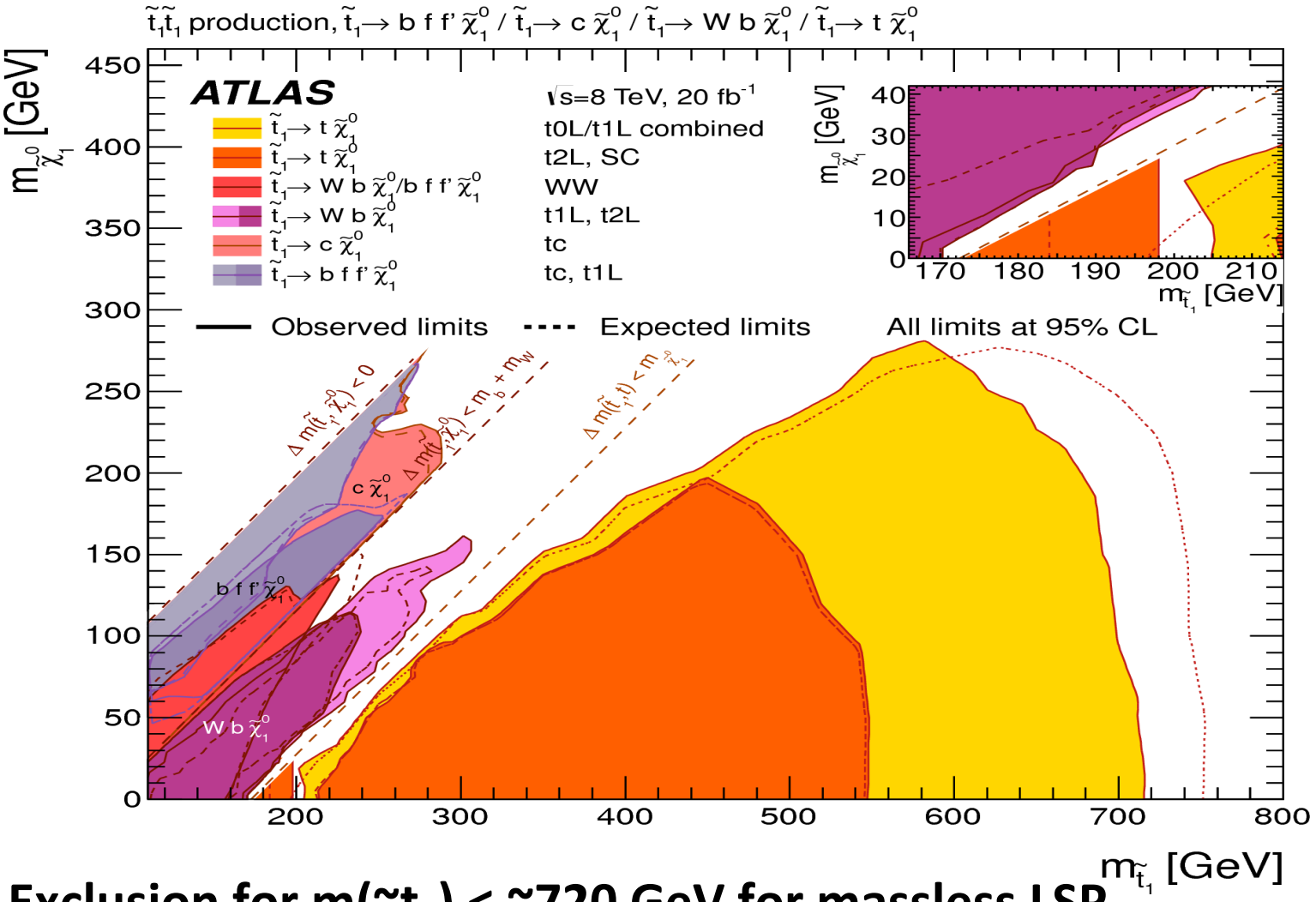


masses between the top quark mass and 191 GeV are excluded

arXiv:1506.08616

Summary Searches for Stop

(different mass hierarchies, simplified models)



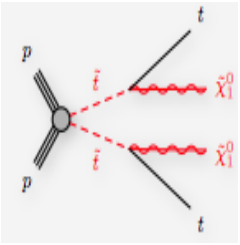
Exclusion for m(~t_1) < ~720 GeV for massless LSP

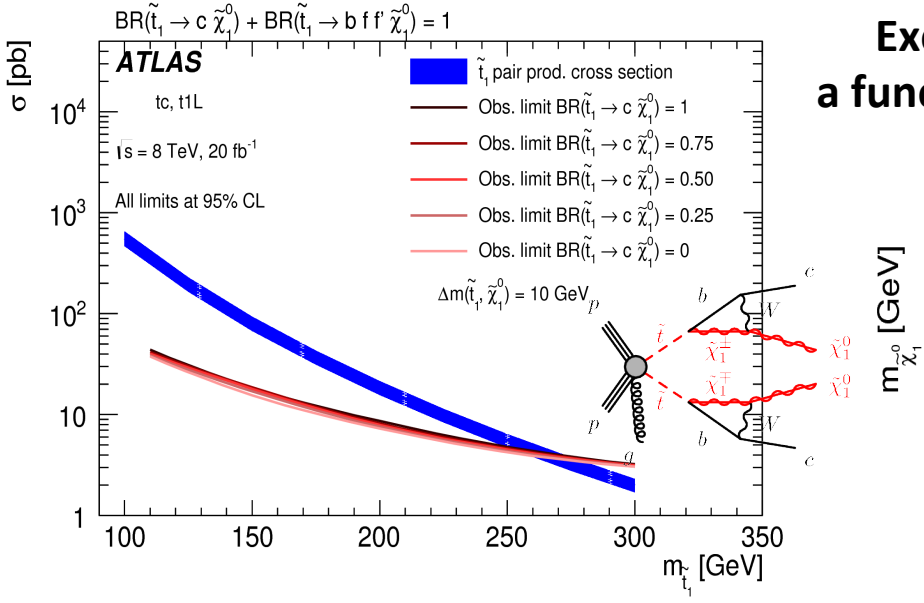
Exclusion up to m(LSP) ~280 GeV

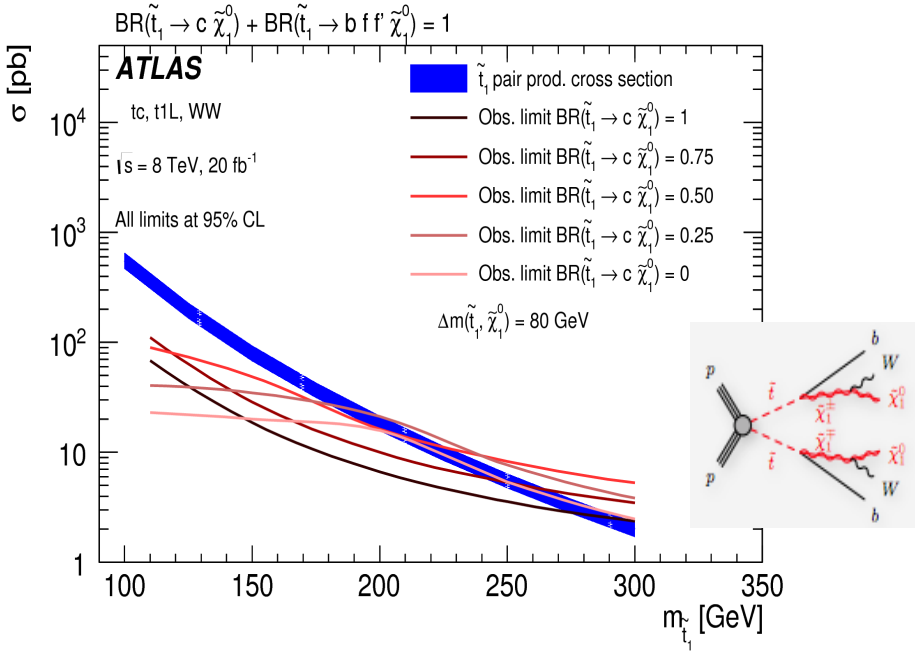
arXiv:1506.08616

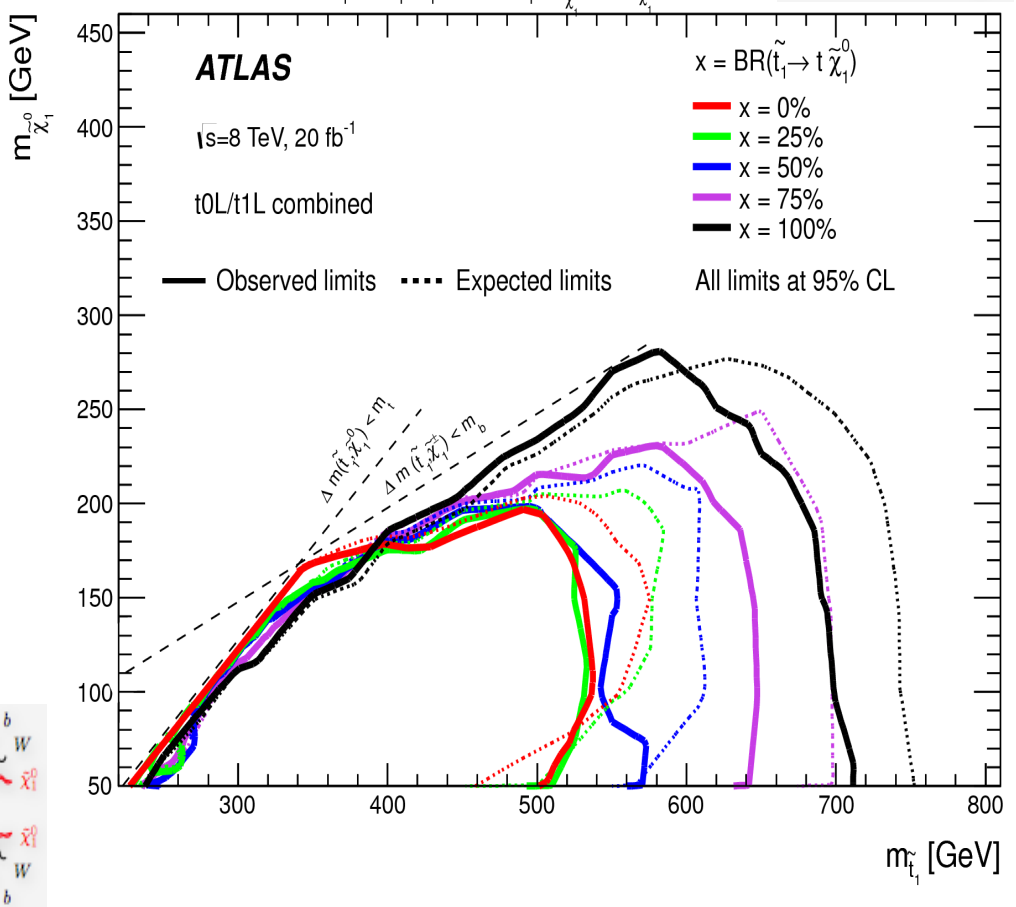
Branching Ratio Dependence

Exclusion limits are computed as a function of the decay Br for the stop









As expected, large variations are observed (not in the case of compressed scenario)

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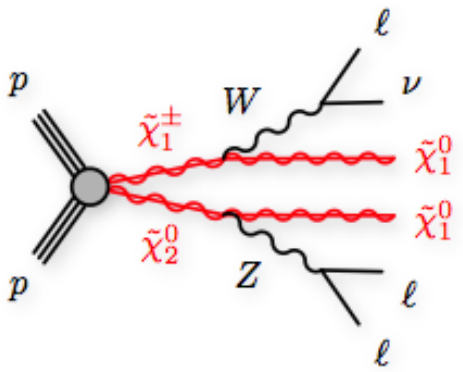
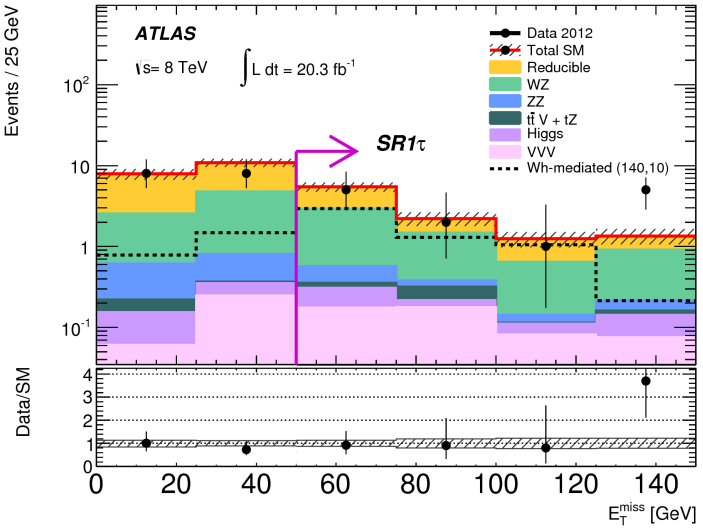
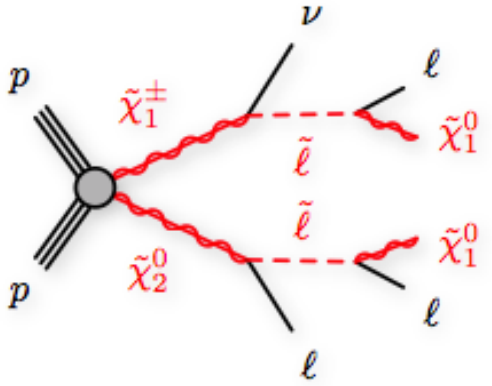
Chargino/Neutralino

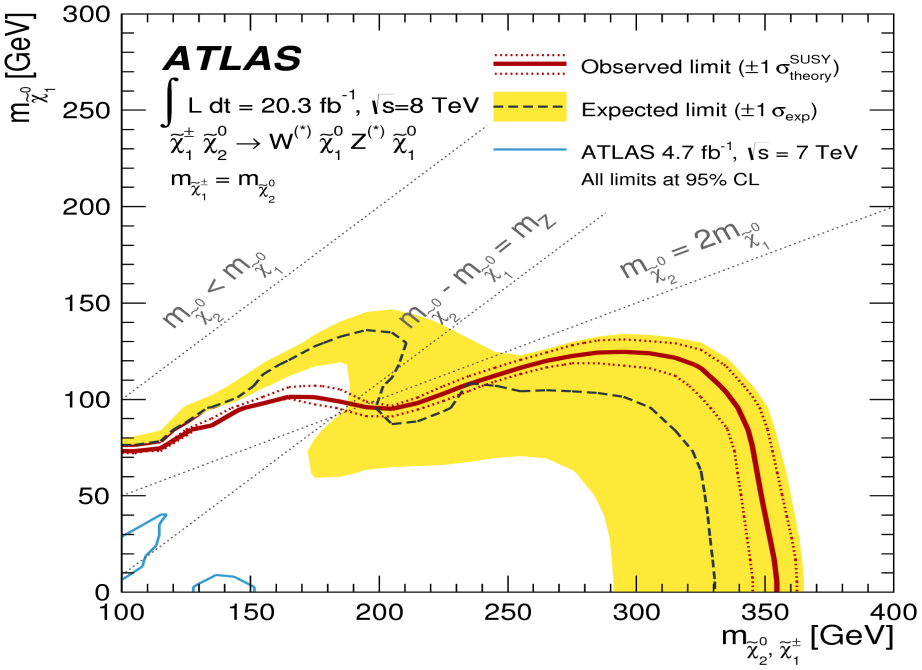
3 leptons + E_T^{miss}

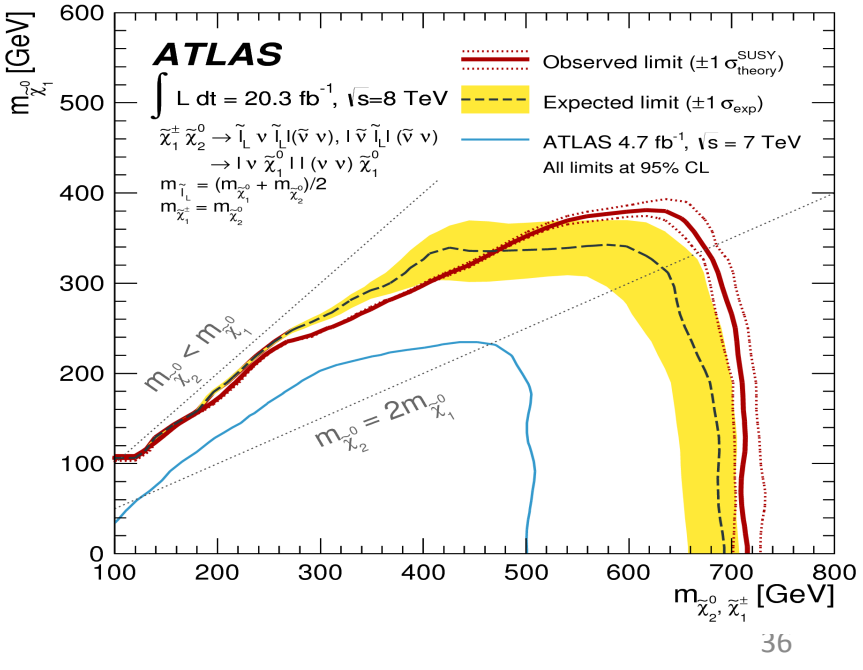




Background mostly WZ, ZZ followed by ttV and tribosons

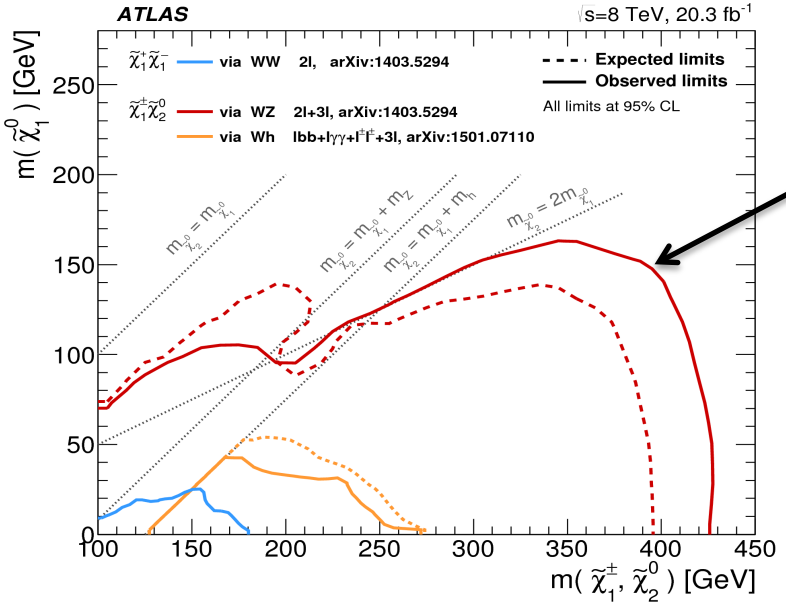


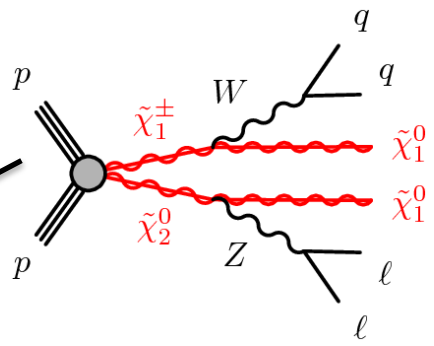




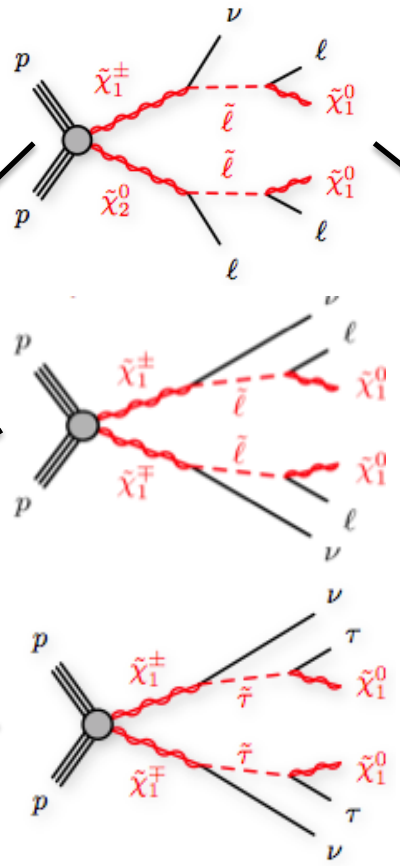
EWK production

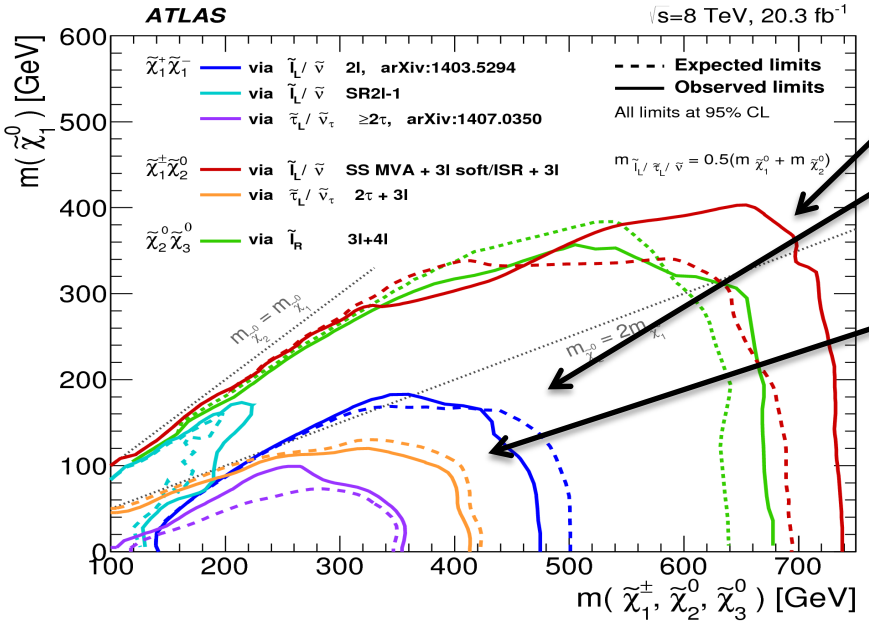
arXiv:1509.07152





2 or 3 leptons + E_T^{miss}





Chargino mass > ~700 GeV
Neutralino mass > ~380 GeV

Very sensitive to the details of the scenario considered

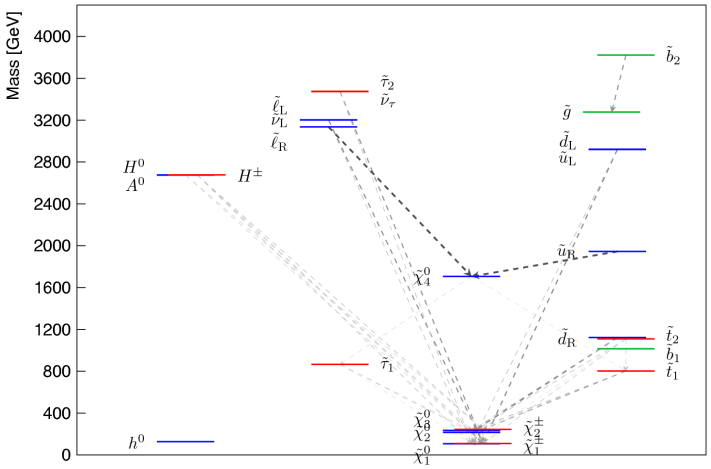
arXiv:1508.06608

pMSSM

Up to 22 different ATLAS searches considered

Analysis	Ref.	Category
0-lepton + 2–6 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[57]	Inclusive
0-lepton + 7–10 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[58]	
1-lepton + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[59]	
$\tau(\tau/\ell)$ + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[60]	
SS/3-leptons + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[61]	
0/1-lepton + 3b-jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[62]	
Monojet	[63]	
0-lepton stop	[64]	Third generation
1-lepton stop	[55]	
2-leptons stop	[65]	
Monojet stop	[66]	
Stop with Z boson	[67]	
2b-jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	[68]	
tb+$E_{\mathrm{T}}^{\mathrm{miss}}$, stop	[56]	
ℓh	[69]	Electroweak
2-leptons	[53]	
2-τ	[54]	
3-leptons	[52]	
4-leptons	[70]	
Disappearing Track	[71]	
Long-lived particle	[72,73]	Other
$H/A \to \tau^+\tau^-$	[74]	

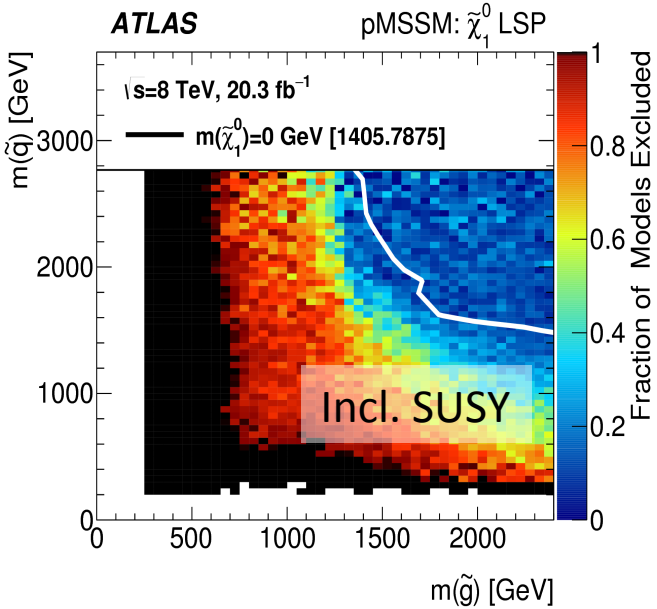
One example of particle spectra

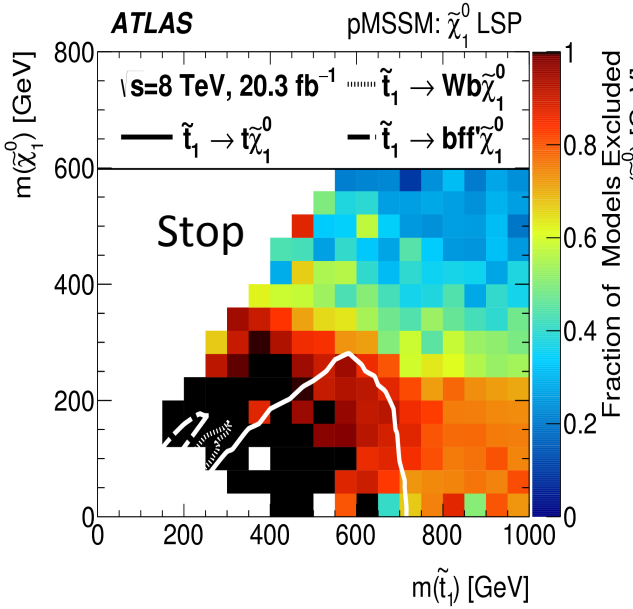


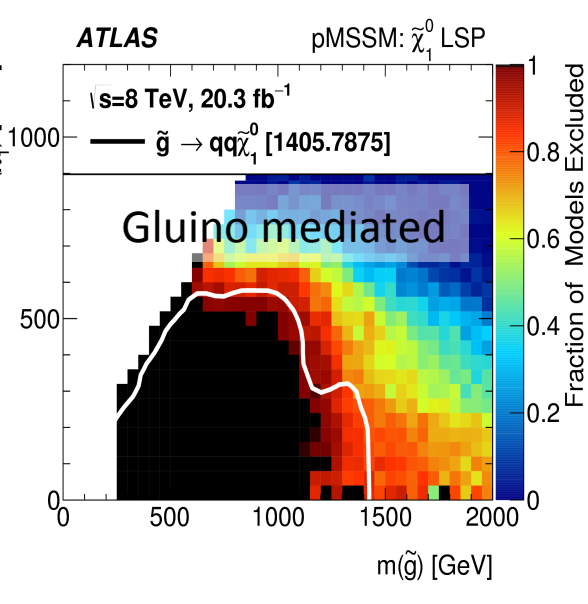
The results are interpreted in the context of 19-parameter

Parameter	Min value	Max value	Note
$m_{\tilde{L}_1}(=m_{\tilde{L}_2})$	90 GeV	4 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1}(=m_{\tilde{e}_2})$	90 GeV	4 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	90 GeV	4 TeV	Left-handed stau doublet mass
$m_{\tilde{e}_3}$	90 GeV	4 TeV	Right-handed stau mass
$m_{\tilde{Q}_1}(=m_{\tilde{Q}_2})$	200 GeV	4 TeV	Left-handed squark (first two gens.) mass
$m_{\tilde{u}_1}(=m_{\tilde{u}_2})$	200 GeV	4 TeV	Right-handed up-type squark (first two gens.) mass
$m_{\tilde{d}_1}(=m_{\tilde{d}_2})$	200 GeV	4 TeV	Right-handed down-type squark (first two gens.) mass
$m_{\tilde{Q}_3}$	100 GeV	4 TeV	Left-handed squark (third gen.) mass
$m_{\tilde{u}_3}$	100 GeV	4 TeV	Right-handed top squark mass
$m_{\tilde{d}_3}$	100 GeV	4 TeV	Right-handed bottom squark mass
$\lvert M_1\rvert$	0 GeV	4 TeV	Bino mass parameter
$\lvert M_2\rvert$	70 GeV	4 TeV	Wino mass parameter
$\lvert\mu\rvert$	80 GeV	4 TeV	Bilinear Higgs mass parameter
M_3	200 GeV	4 TeV	Gluino mass parameter
$\lvert A_t\rvert$	0 GeV	8 TeV	Trilinear top coupling
$\lvert A_b\rvert$	0 GeV	4 TeV	Trilinear bottom coupling
$\lvert A_\tau\rvert$	0 GeV	4 TeV	Trilinear τ lepton coupling
M_A	100 GeV	4 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

Fraction of pMSSM models excluded (in general, similar to simplified models)







Hard to believe in SUSY if the Higgs sector stays with just h_0

…Looking for extra Higgs particles ….

MSSM Higgs Sector

Two Higgs doublets are required in supersymmetric theories to generate mass for both "up" type and "down" type quarks and charged leptons.

$$H_d = \begin{pmatrix} (v_d + \phi_d^0 + i\chi_d^0)/\sqrt{2} \\ \phi_d^- \end{pmatrix} \quad H_u = \begin{pmatrix} \phi_u^+ \\ (v_u + \phi_u^0 + i\chi_u^0)/\sqrt{2} \end{pmatrix}$$

normalization: $v^2 \equiv v_d^2 + v_u^2 = 4m_W^2/g^2 = (246\,\mathrm{GeV})^2$

$$\frac{v_u}{v_d} = \tan\beta, \quad \beta\epsilon(0, \tfrac{\pi}{2})$$

Two parameter : M_A and tanβ

$$m_{H^\pm}^2 = m_A^2 + m_W^2$$

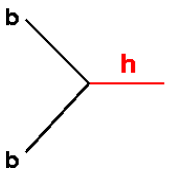
$$m_{h^0,H^0}^2 = \tfrac{1}{2}\left(m_{A^0}^2 + m_Z^2 \mp \sqrt{(m_{A^0}^2 + m_Z^2)^2 - 4m_Z^2 m_{A^0}^2 \cos^2 2\beta}\right)$$

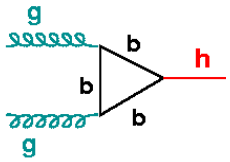
MSSM Higgs

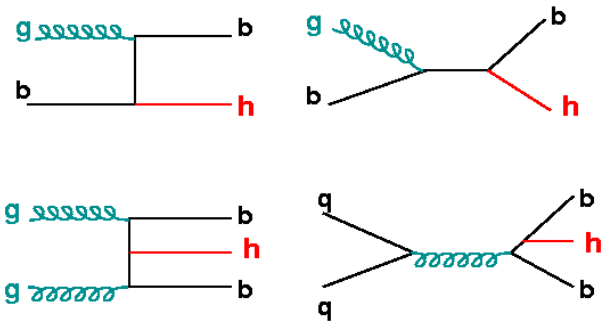
$H_U, H_D \longrightarrow$ h,H,A and $H^{\pm}$

$\tan\beta = < H_U > / < H_D >$

$M(h) < 135$ GeV





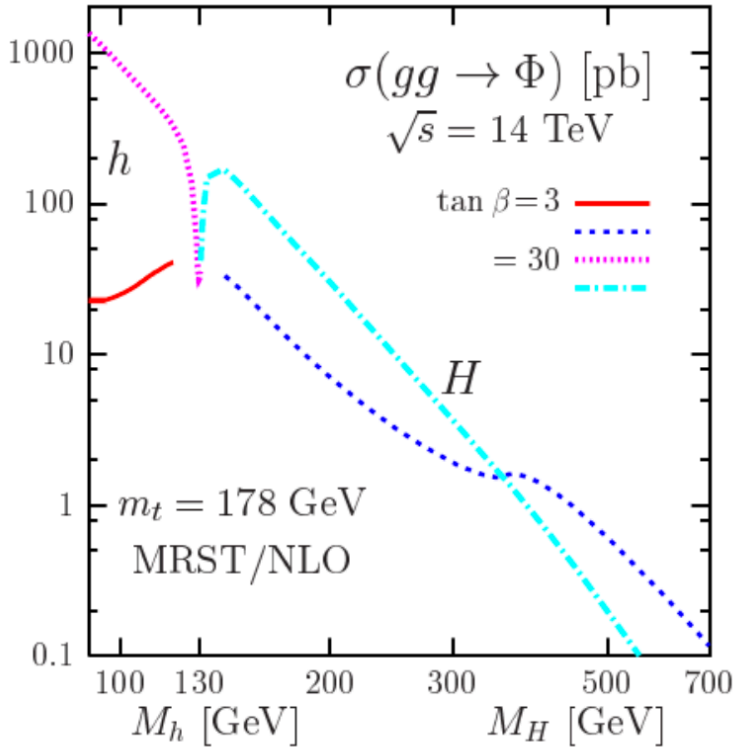


Tree level : M_A and $\tan\beta$ as parameters

MSSM Higgs production cross section boosted compared to SM at large tanβ

$$\sigma(b\bar{b}A) \times \mathrm{BR}(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

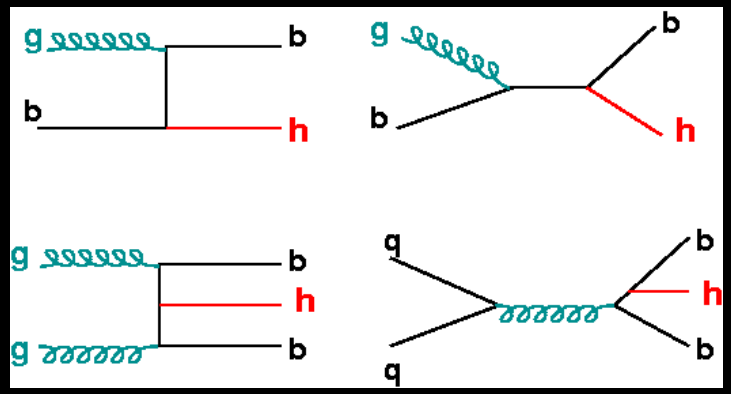
$$\sigma(gg, b\bar{b} \to A) \times \mathrm{BR}(A \to \tau^+\tau^-) \simeq \sigma(gg, b\bar{b} \to A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2+9},$$

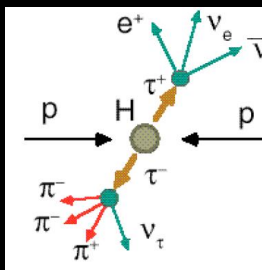


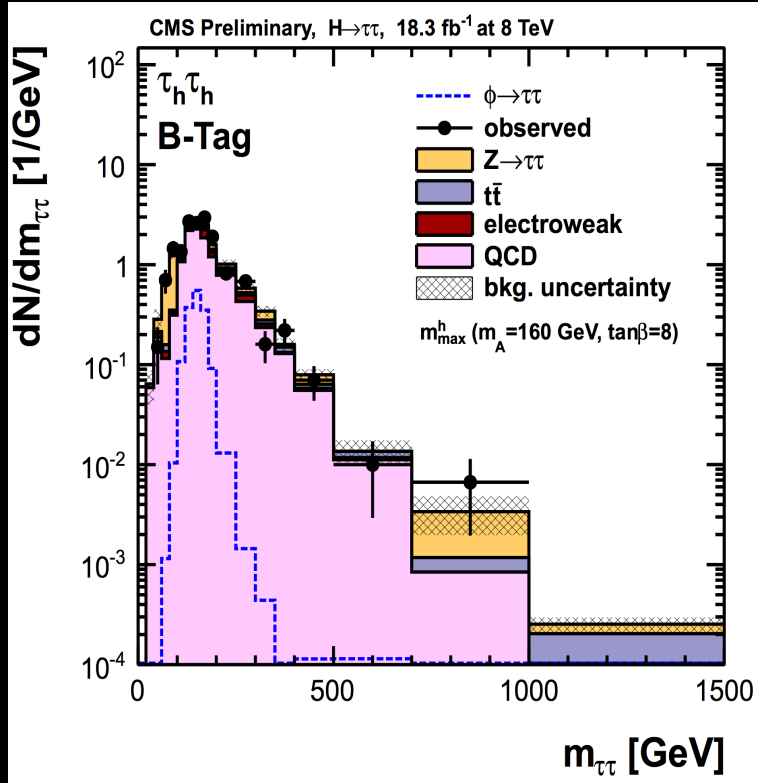
At low masses

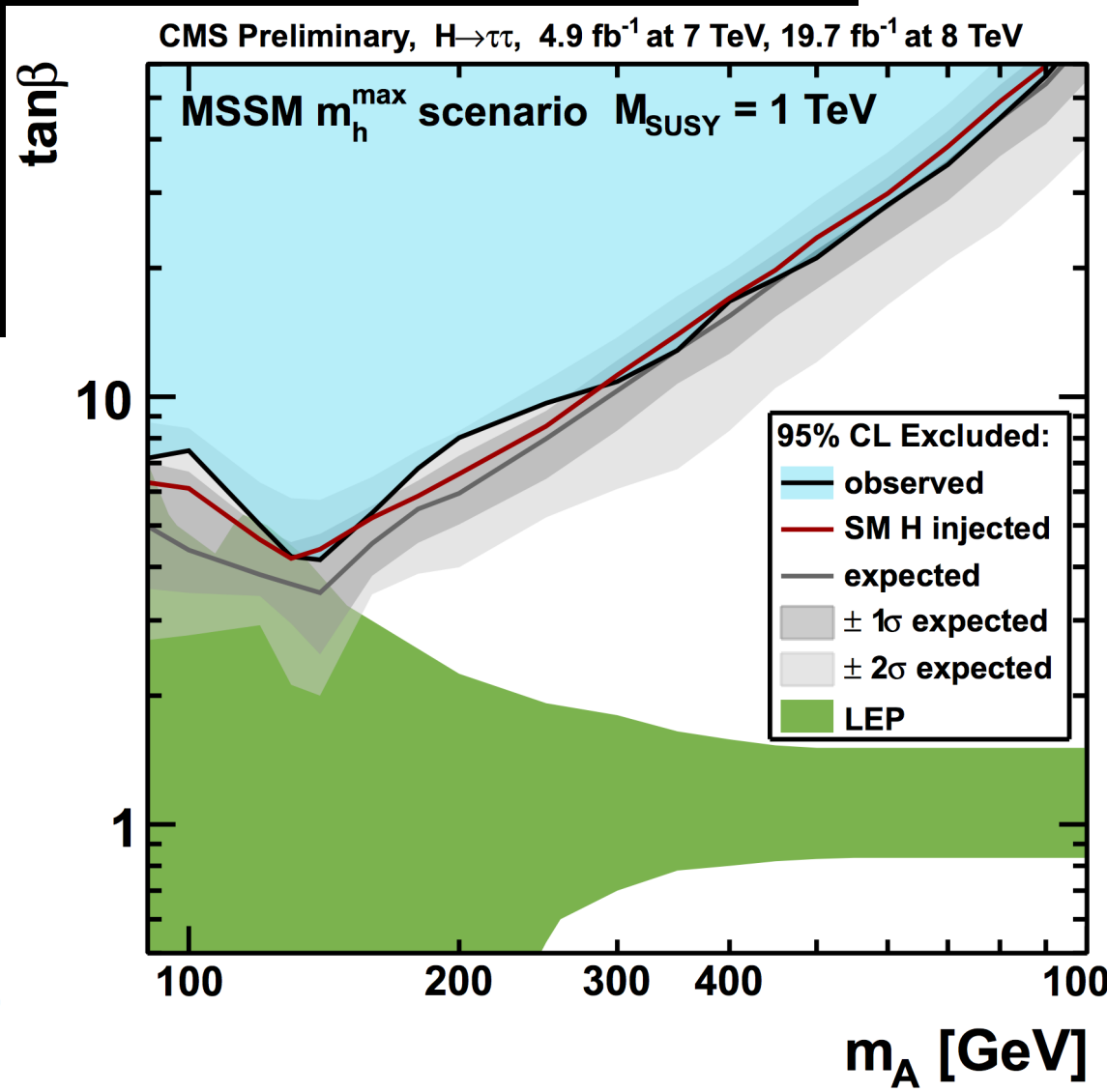
Br(h → bb) ~ 90% , Br(h → ττ) ~ 10%

MSSM Neutral Higgs

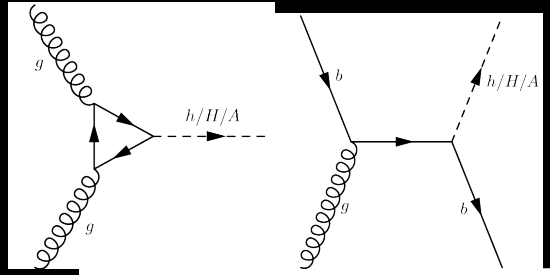


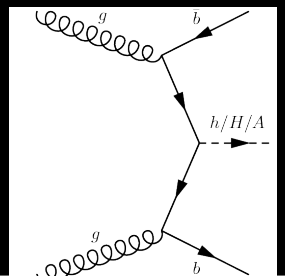


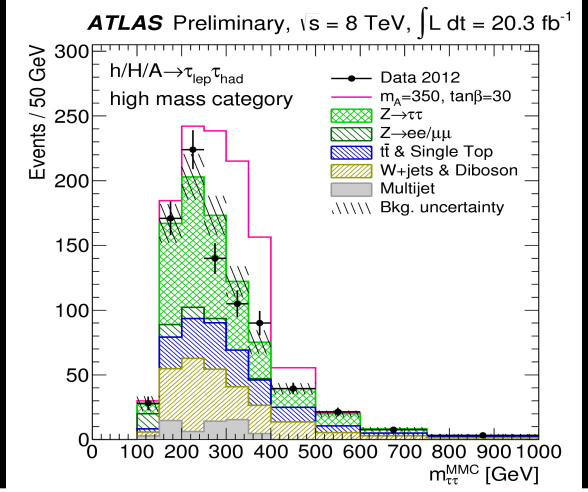


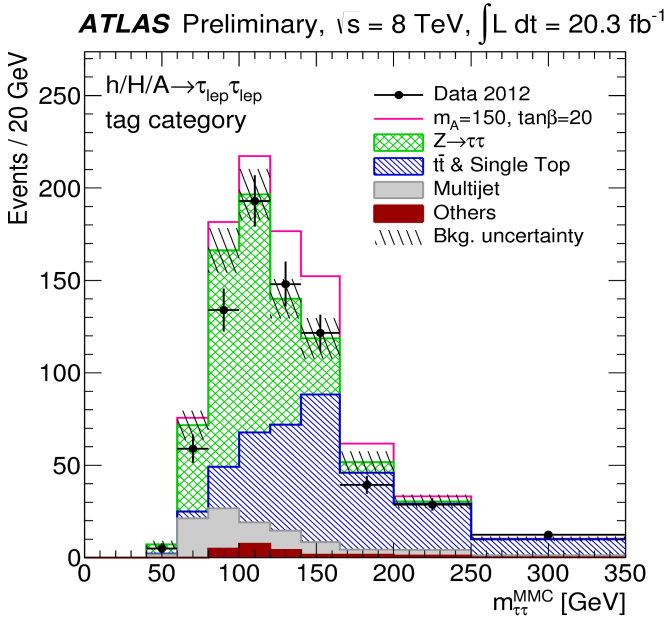


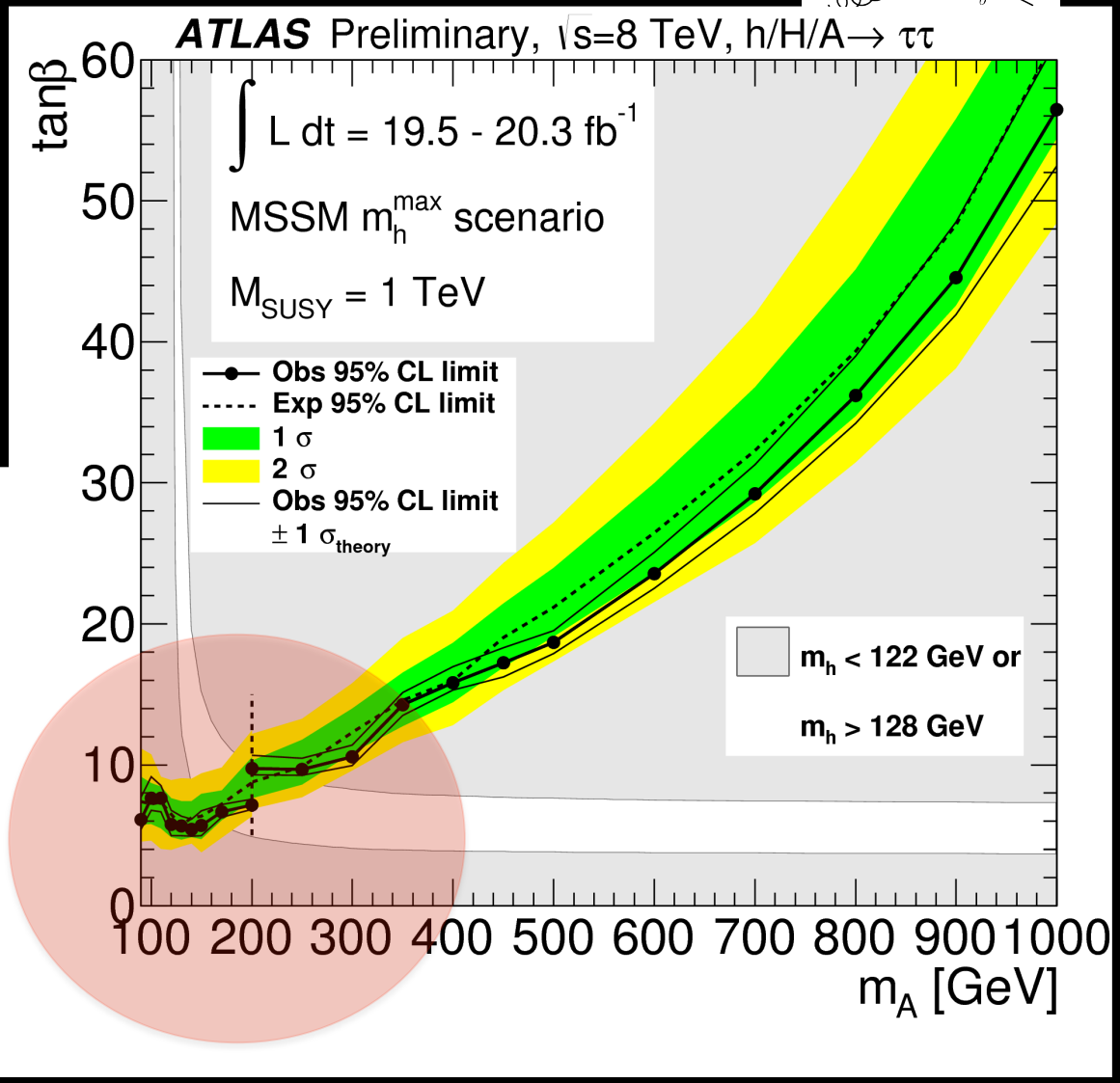
MSSM Neutral Higgs



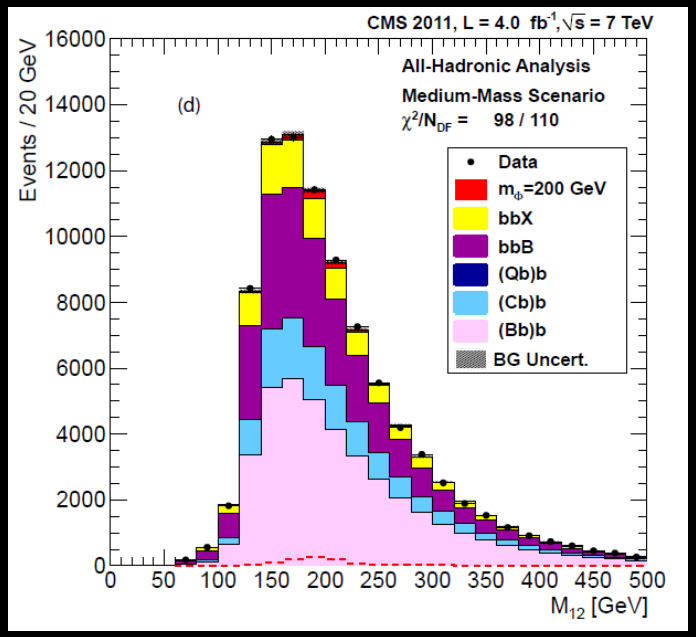




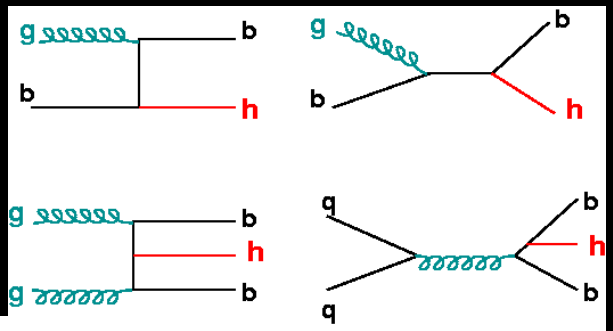


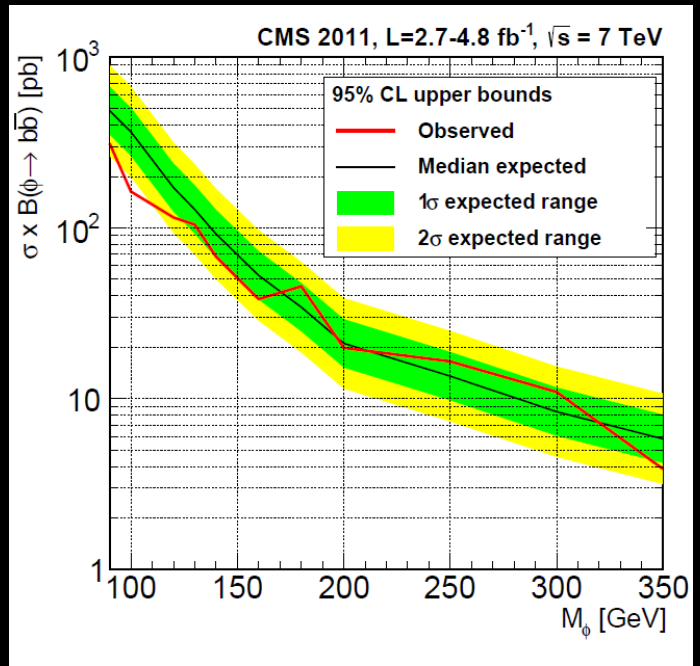


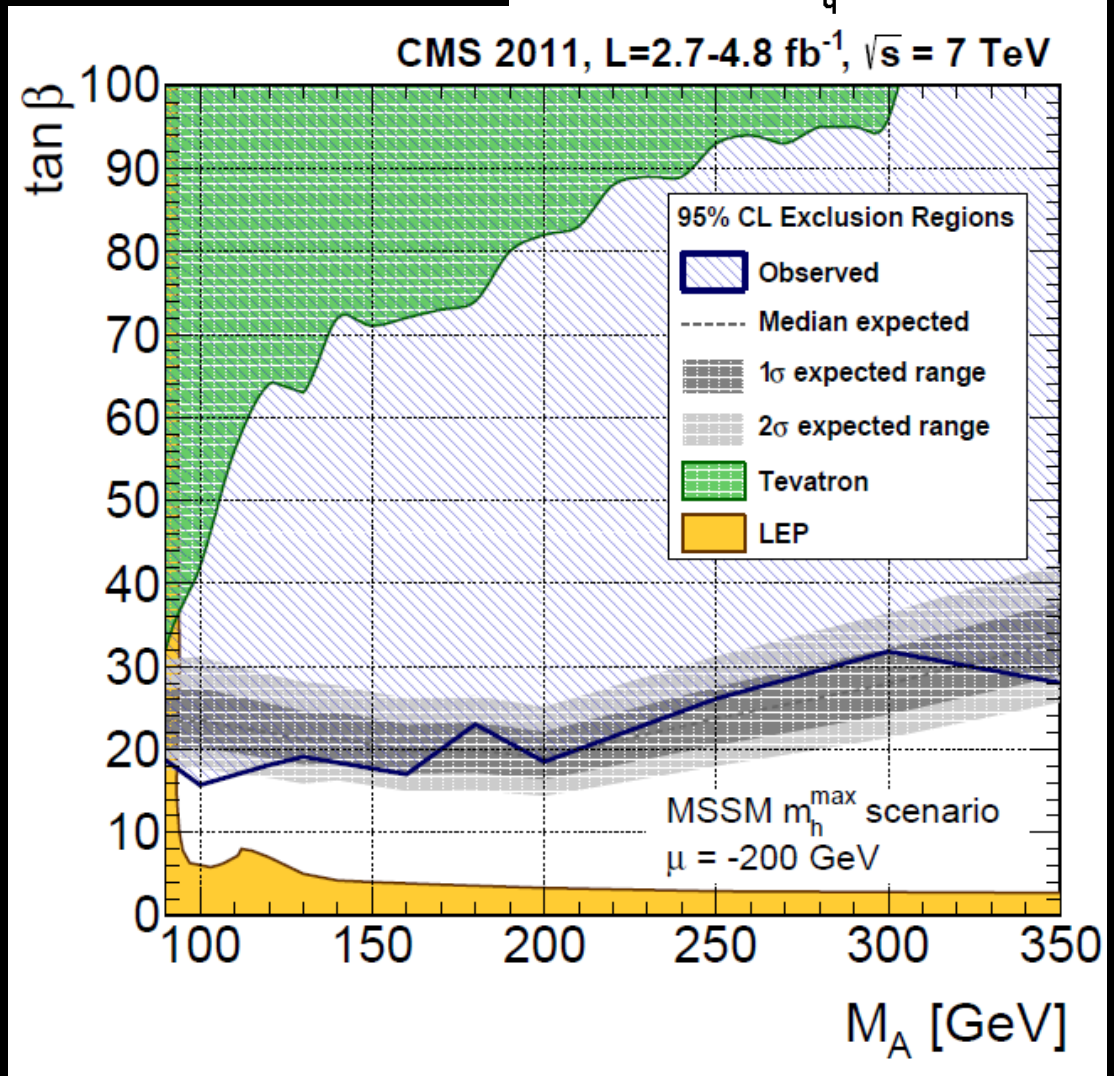
MSSM Higgs



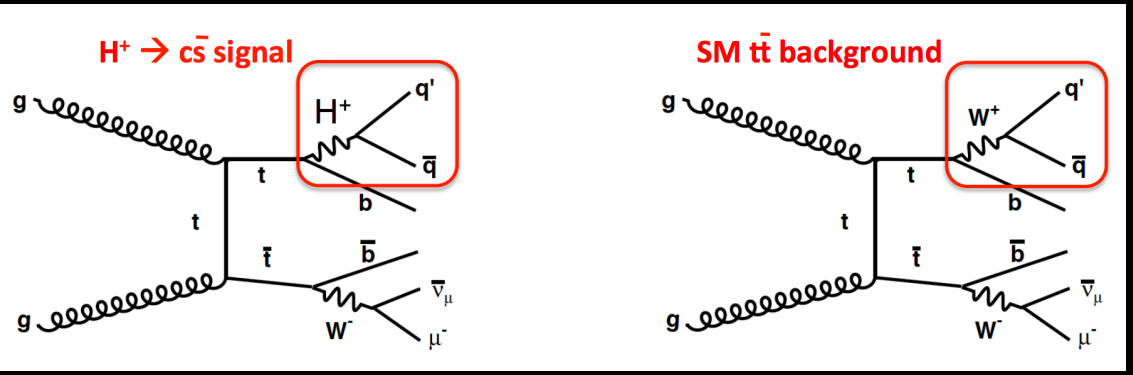
h → bb



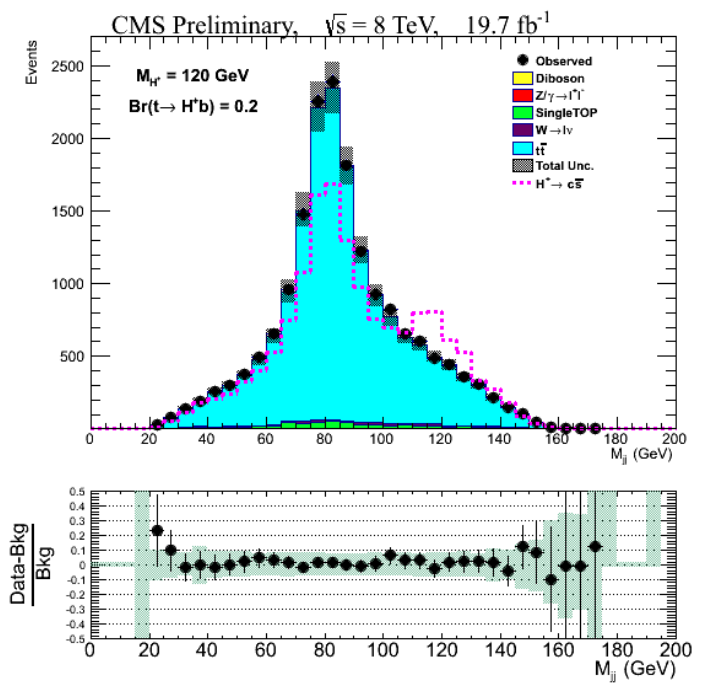


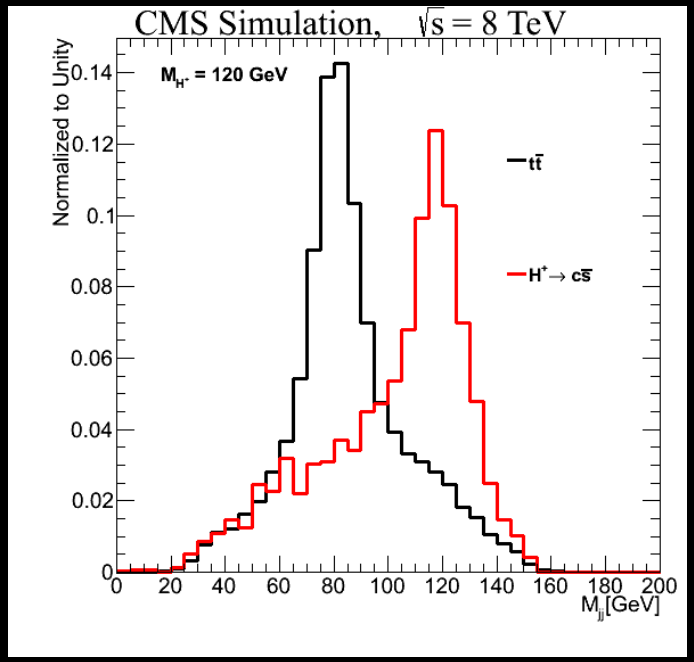


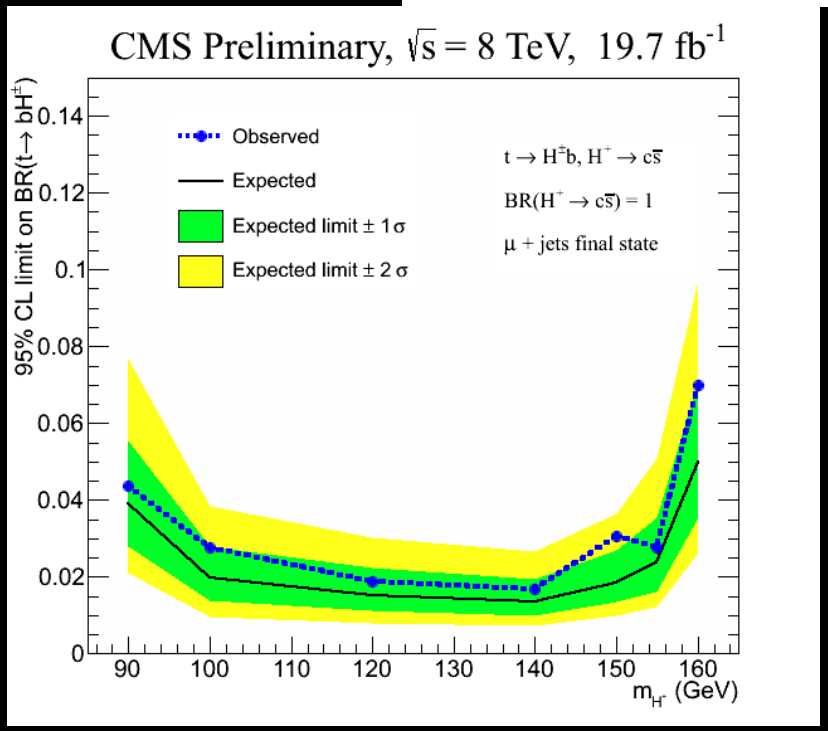
$H^+ \rightarrow c\bar{s}$

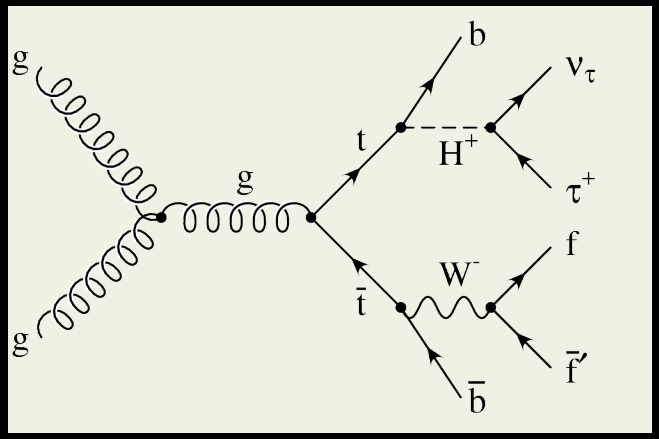


Expressed in terms of limits on BR in top decays

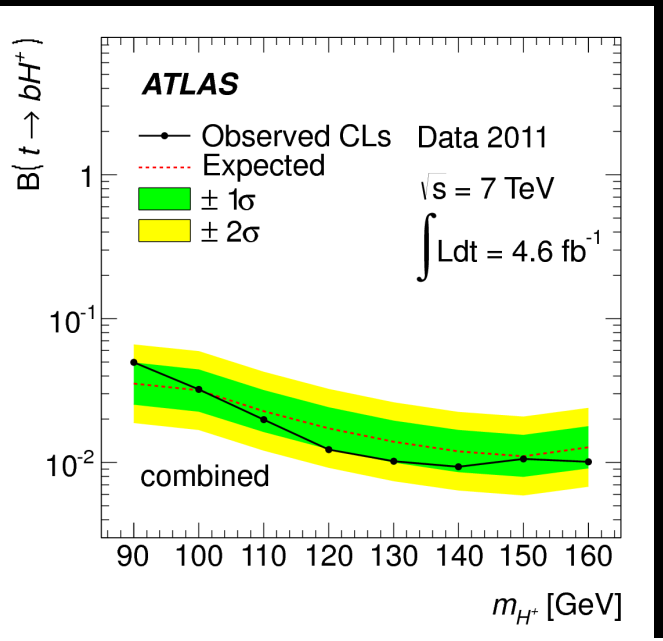






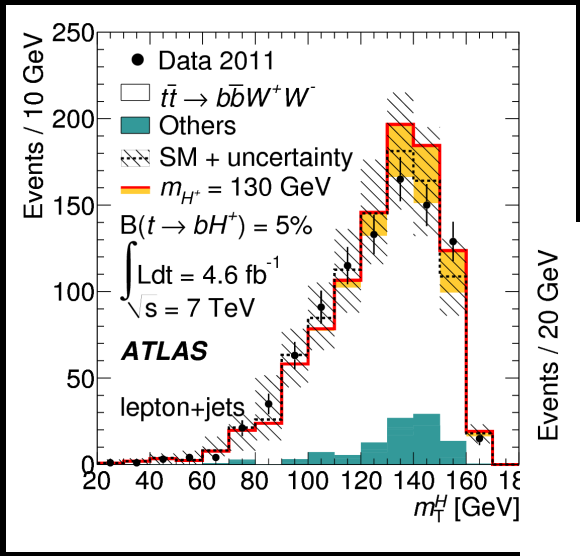


$H^+ \rightarrow \tau\nu$

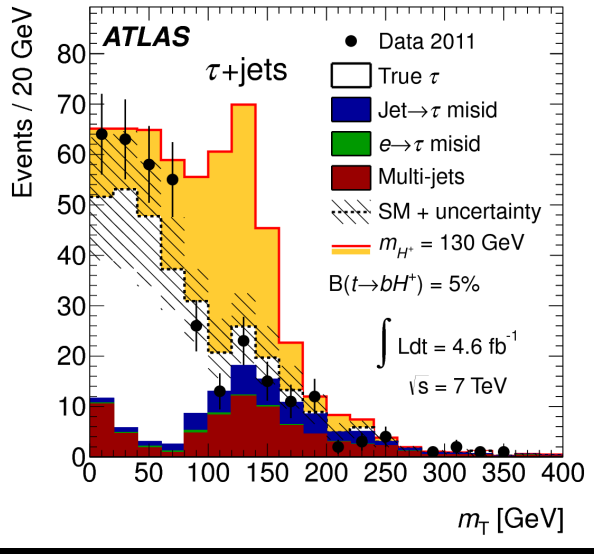


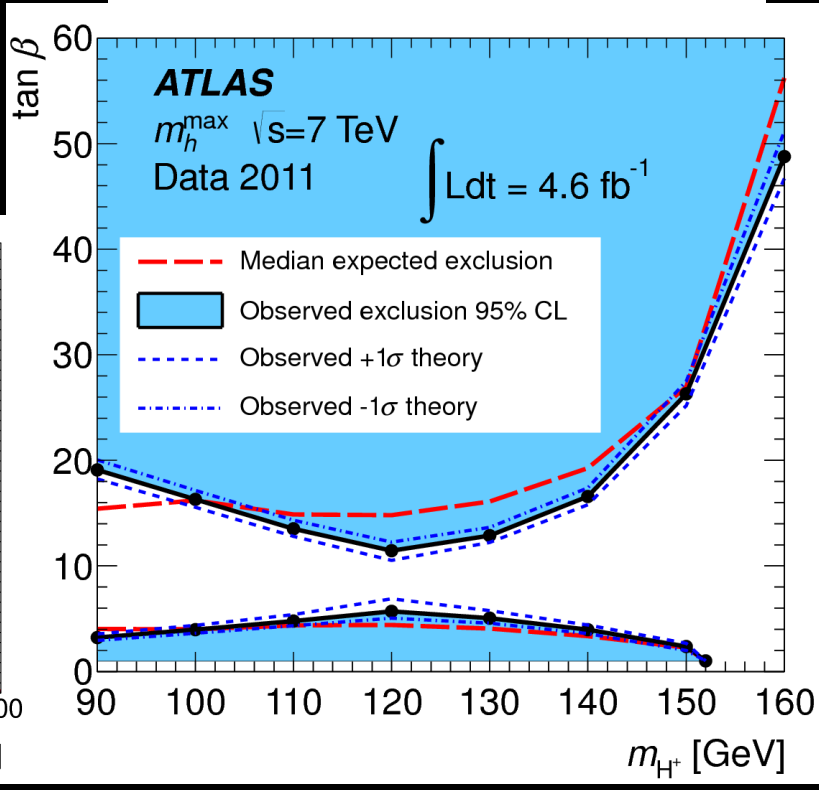
Limits on top BR and SUSY MSSM parameters

lepton + jets



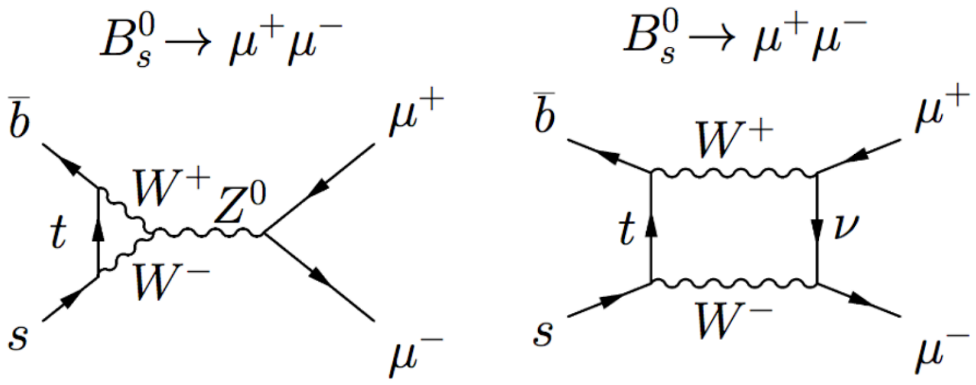
Tau-ID + jets

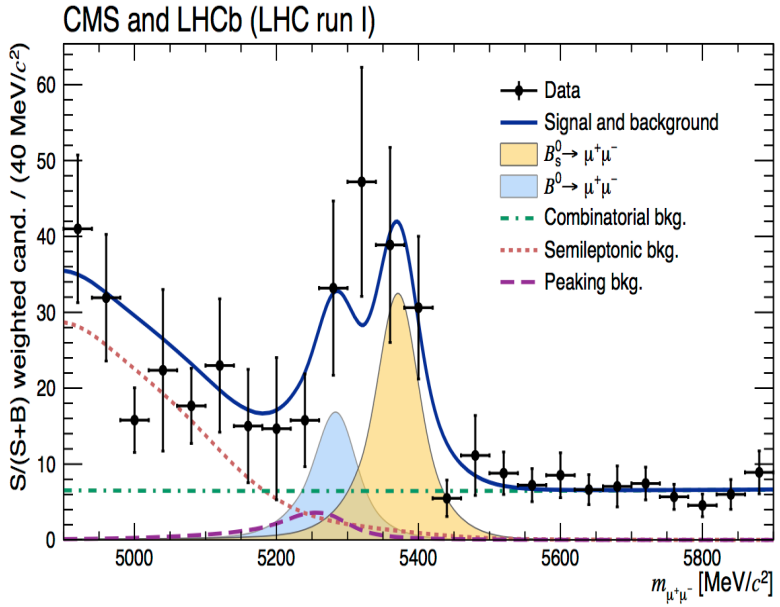




arXiv:1411.4413

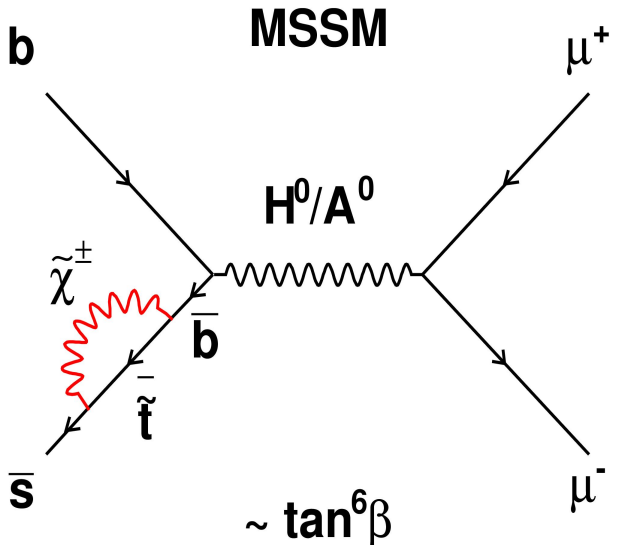
$B_s \rightarrow \mu^+\mu^-$

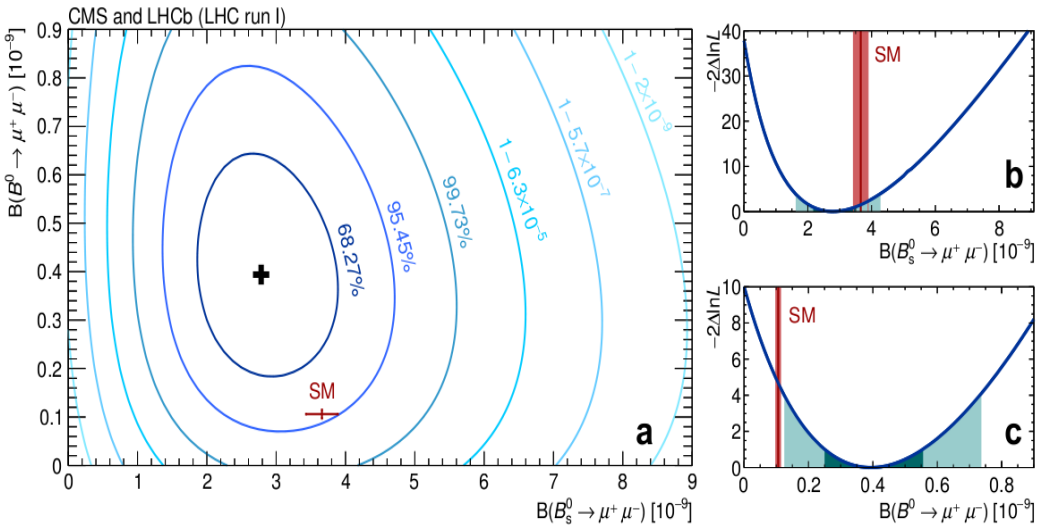




SM prediction $\Rightarrow$ Br($B_s \rightarrow \mu^+\mu^-$) ~ 3.42×10^{-9}

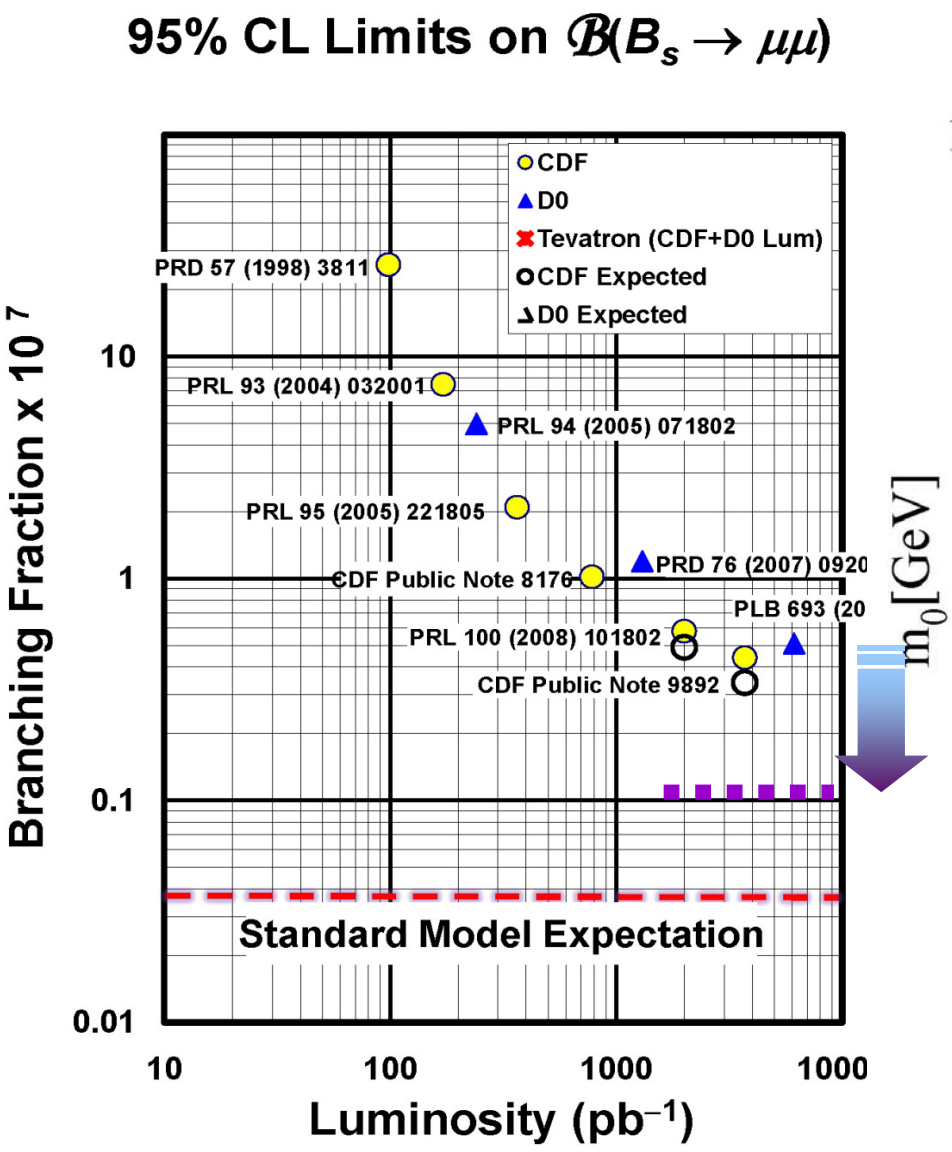
SUSY $\rightarrow$ big enhancement $\rightarrow$ (~ $\tan^6\beta$)

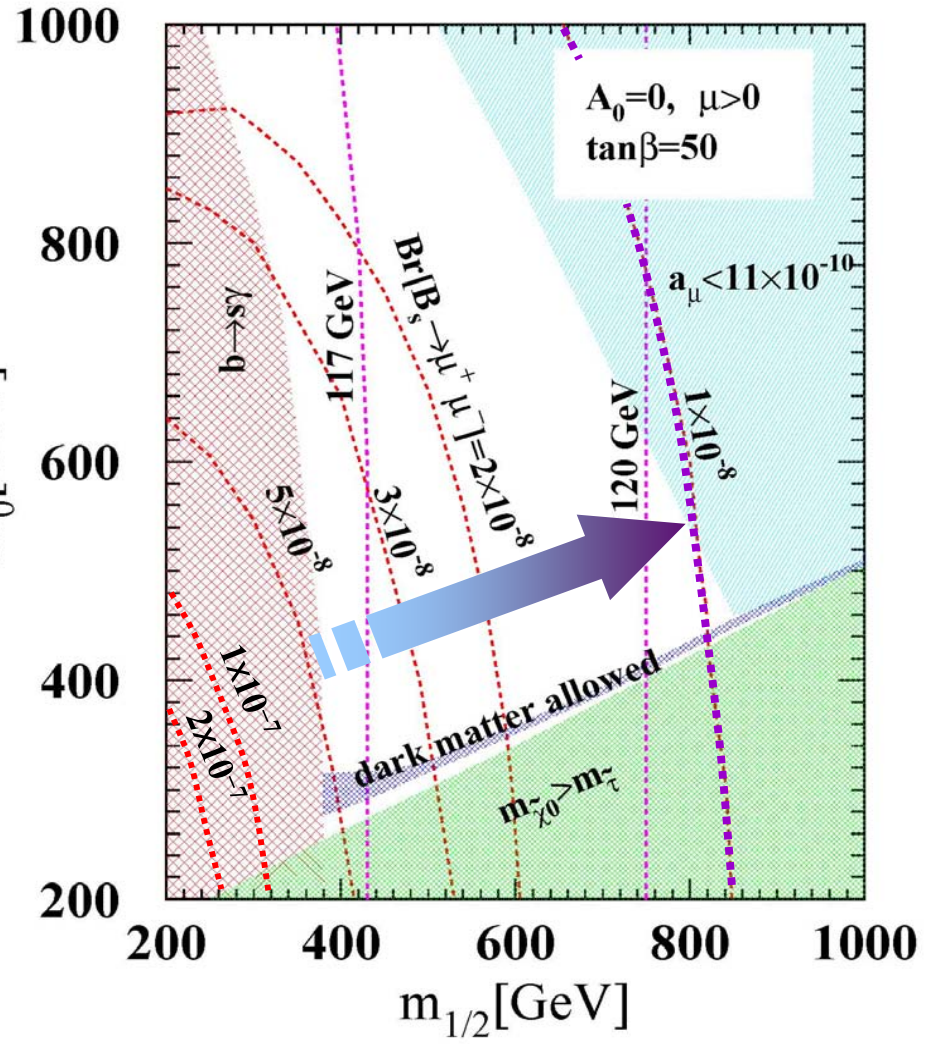


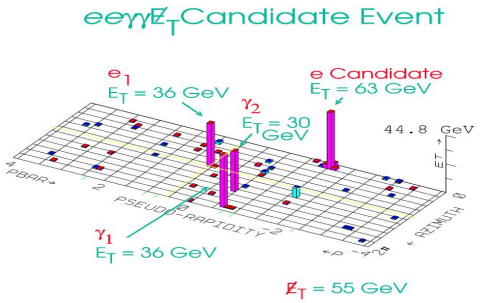


Consistent with SM predictions

$\mathcal{B}(B_s \to \mu\mu)$ and Cosmological Connection







GMSB

(gauge mediated SUSY breaking)

SUSY breaking (hidden sector) → Gauge Fields → MSSM (visible sector)

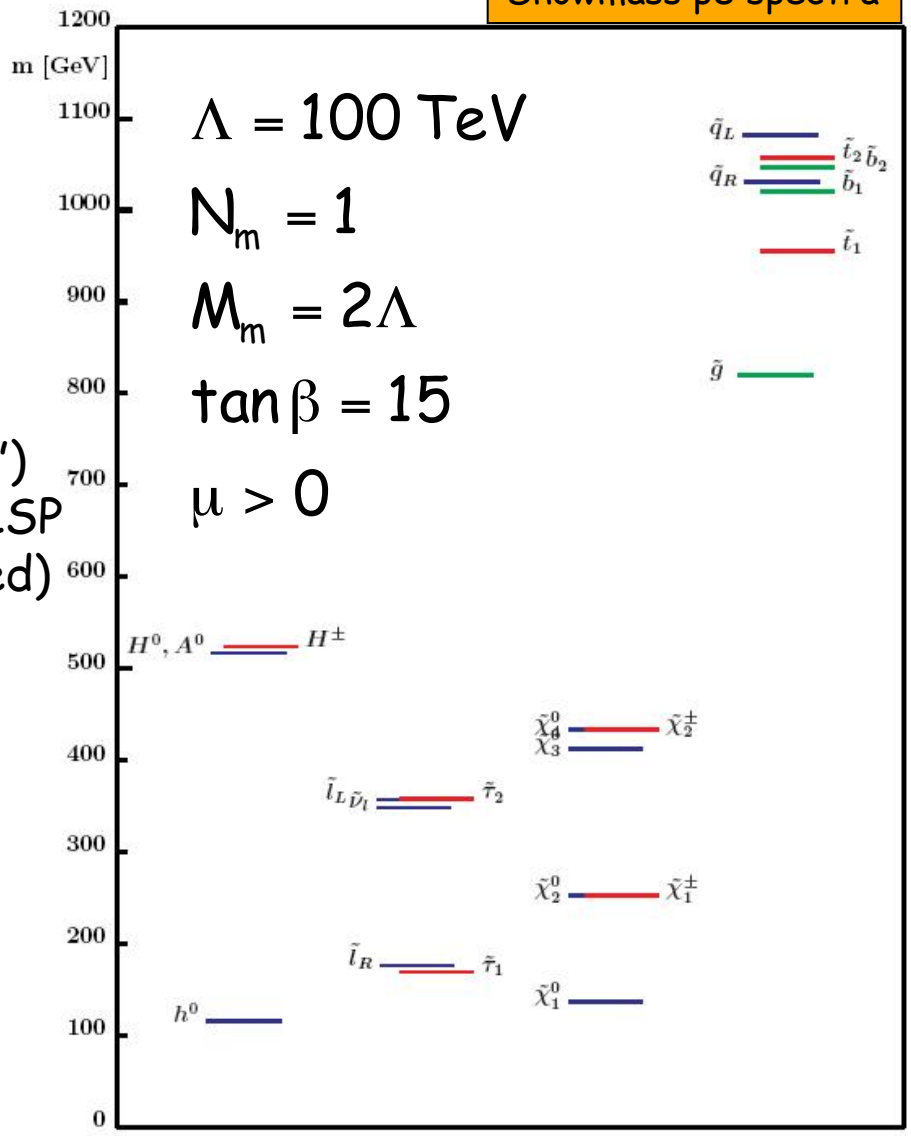
- SUSY breaking at scale Λ (10 -100 TeV)
- Mediated by Gauge Fields ("messengers")
- Gravitino is very light (~ KeV) and the LSP
- Neutralino is NLSP (its lifetime not fixed)

$$\chi_1^0 \rightarrow \tilde{G}\gamma$$

- Rp conservation (2 NLSP in final state)

$$\gamma\gamma + \not{E}_T + X$$

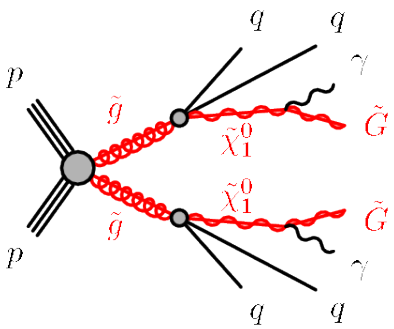
Snowmass p8 spectra

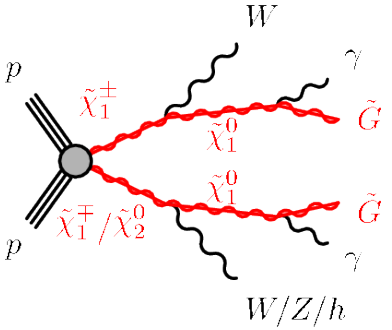


(taken from N. Ghodbane et al., hep-ph/0201233)

Phys. Rev. D 92 (2015) 072001

GMSB

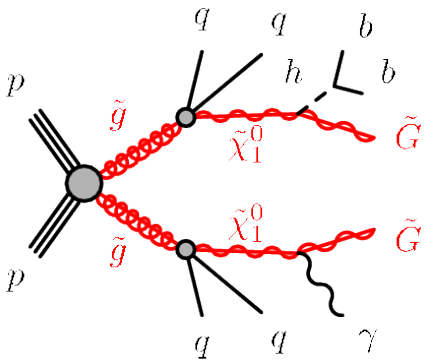


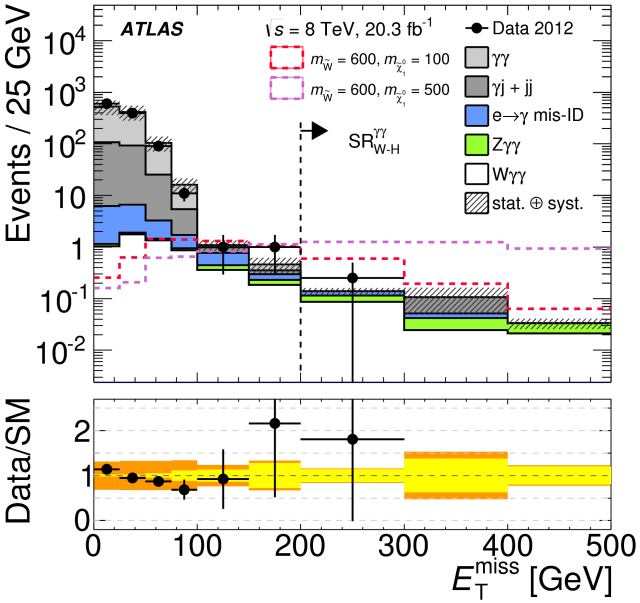


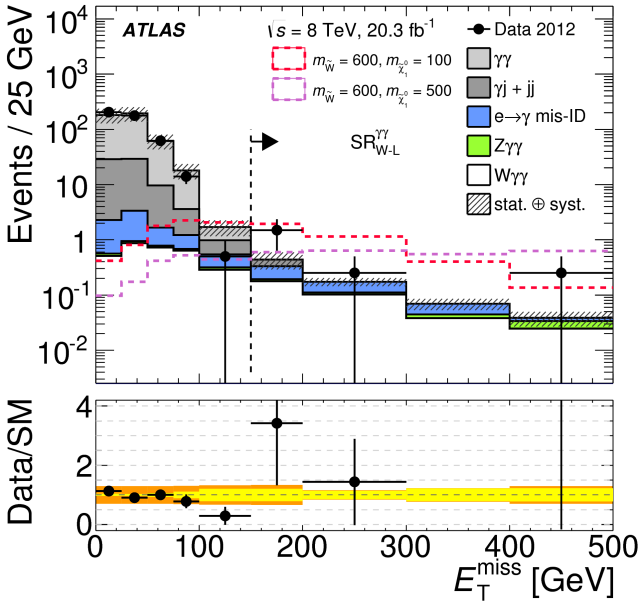
Scenario in which Gravitinos are the LSP

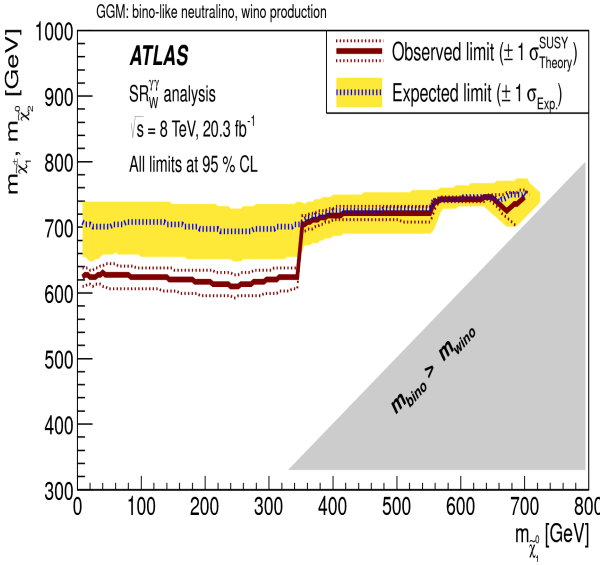
Events with large E_T^{miss} and one or two energetic photons in the final state

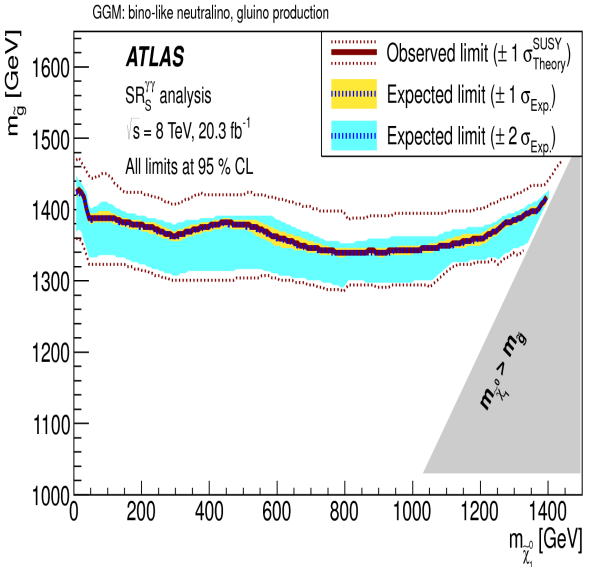
Different topologies with additional leptons, jets and b-jets.











GMSB Gravitino

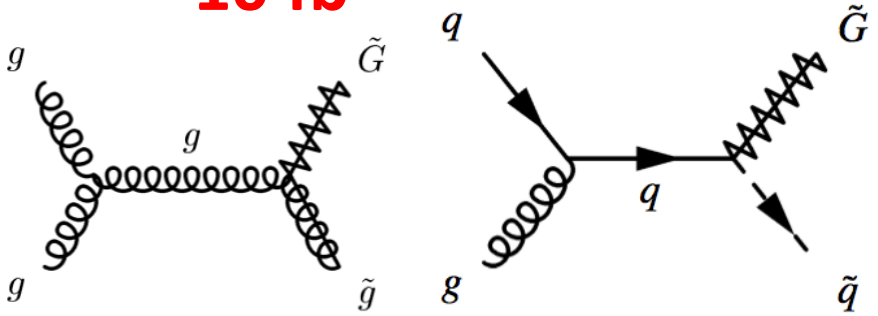
$$m_{3/2} = \langle F \rangle / \sqrt{3}\,\overline{M}_{\rm Pl}$$

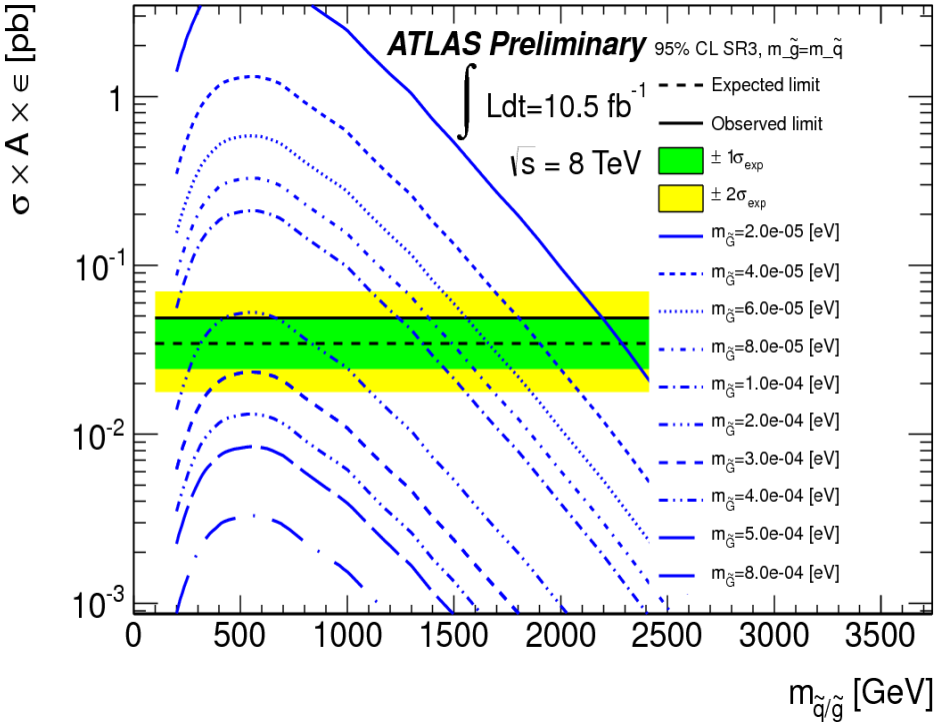
8 TeV
10 fb^{-1}

Monojet analysis
ATLAS-CONF-2012-147

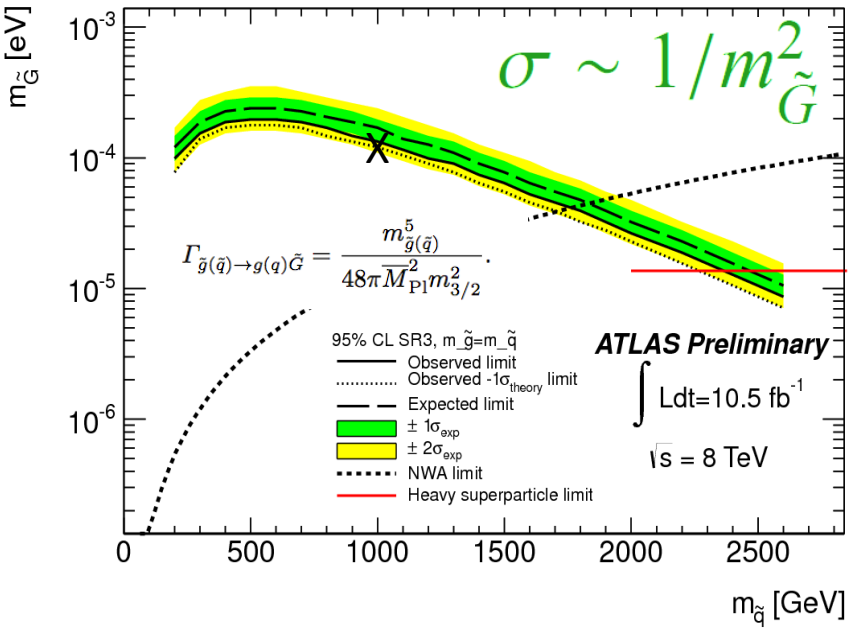
Interpreted in terms of GMSB gravitino+squark/gluino production

gluinos (squarks) decay to gluon (quark) plus Gravitino (100%)





Best limits to date on the gravitino mass



$m_{3/2} > 10^{-4}$ eV → √F > 640 GeV
(LEP limit 240 GeV)

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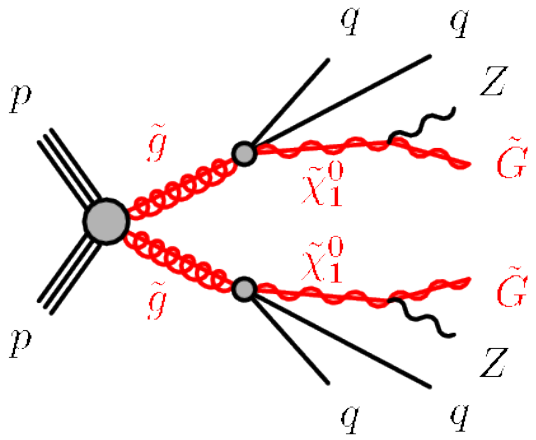
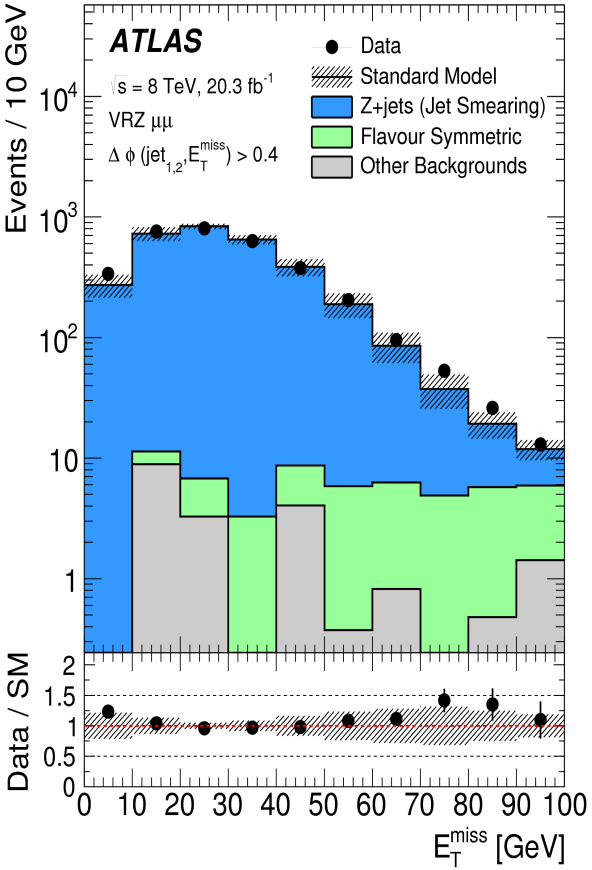
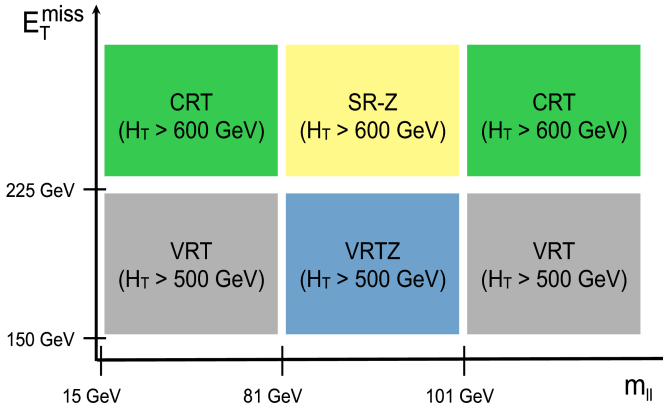
SUSY searches with on-shell Zs

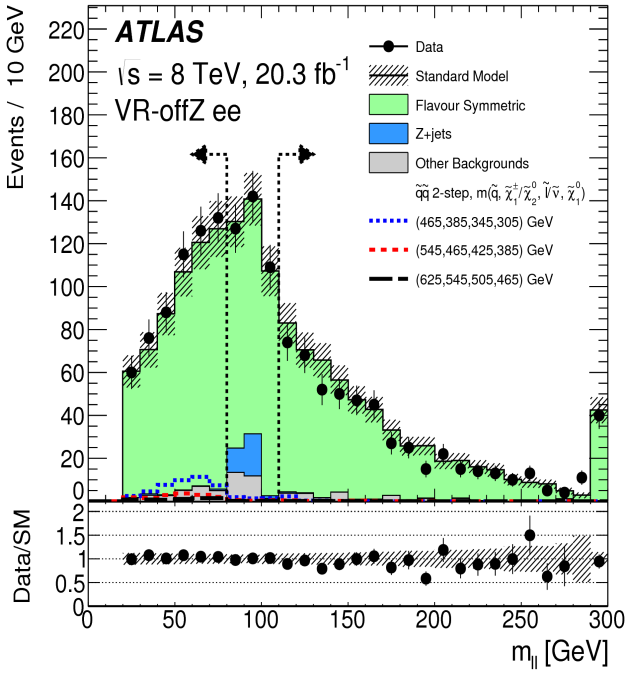


On-shell Z

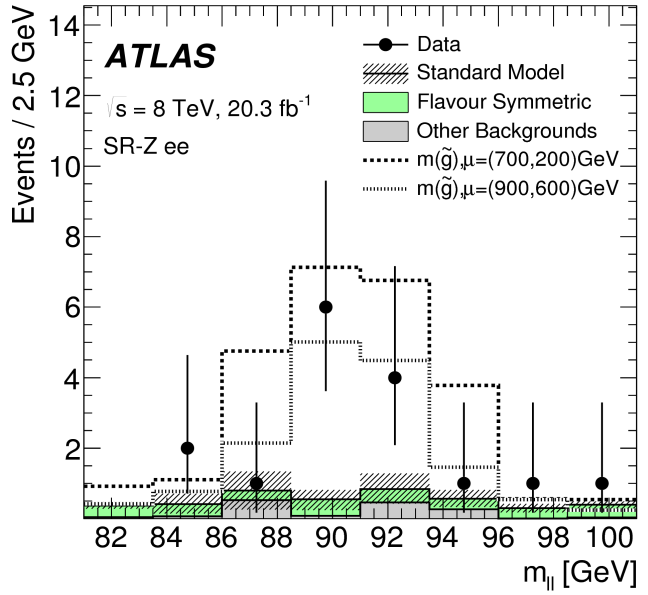
Large H_T and E_T^{miss}







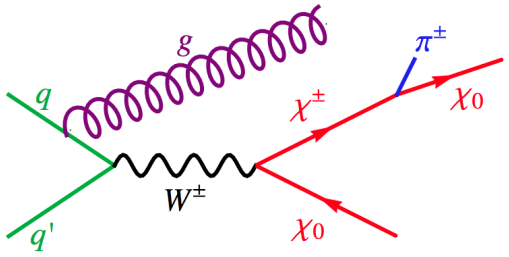
3 sigma effect



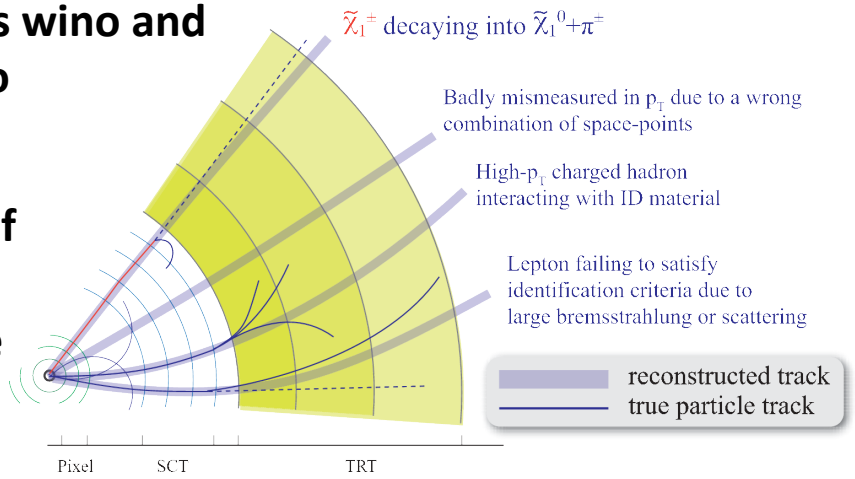
Phys. Rev. D 88 112006 (2013)

Disappearing track

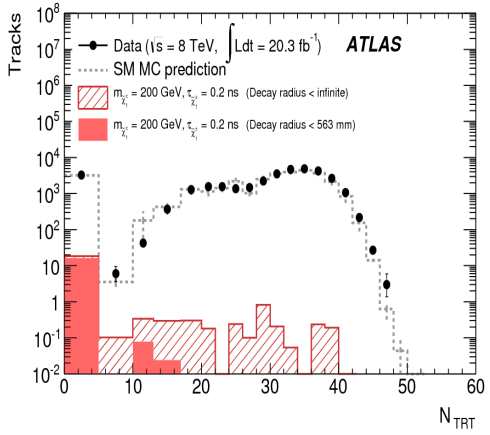
In AMSB model where the lightest chargino (N)LSP is wino and nearly mass-degenerate with the lightest neutralino

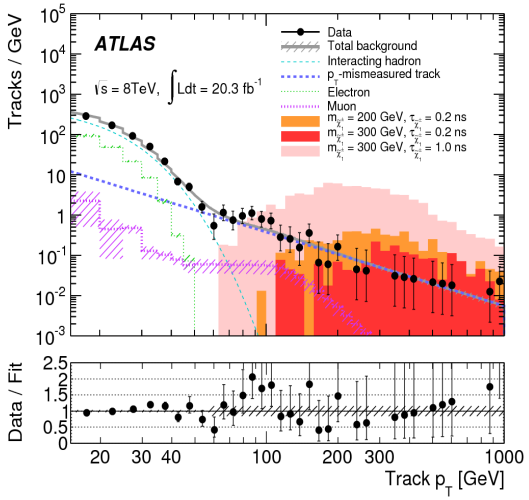


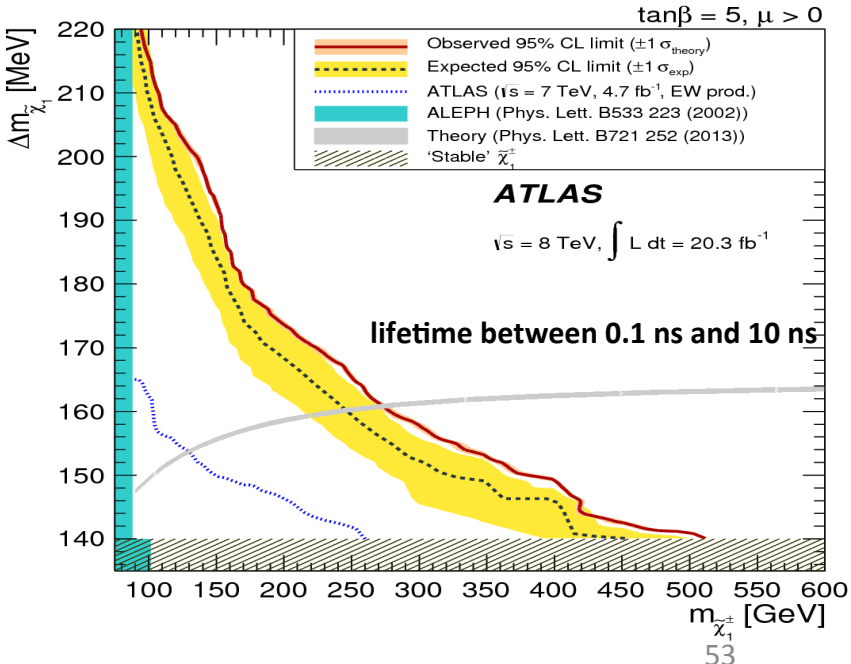
The signal reveals itself as disappearing tracks in the outer ID volume



At least one jet with PT > 90 GeV, Etmiss > 90 GeV
Lepton (electron and muon) vetoes
One good isolated track with pT > 15 GeV
and less than 5 hits in the TRT







A chargino mass below 270 GeV is excluded at 95% CL

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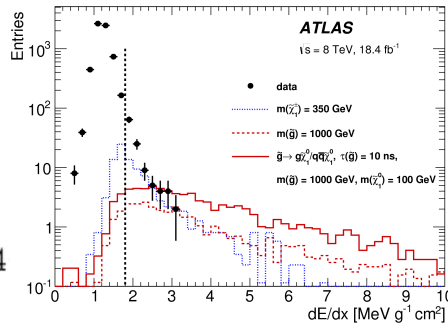
Heavy meta-stable Particles

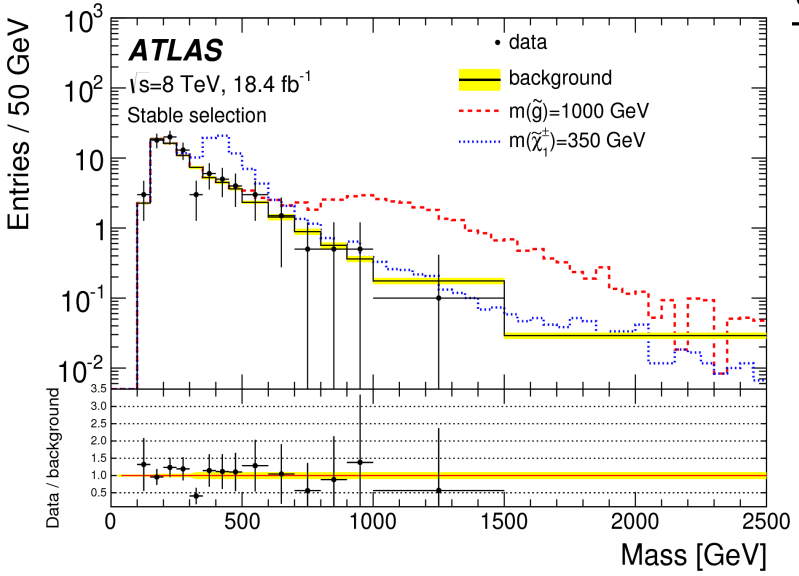
Using dE/dx in pixel detector to extract the mass of the particle

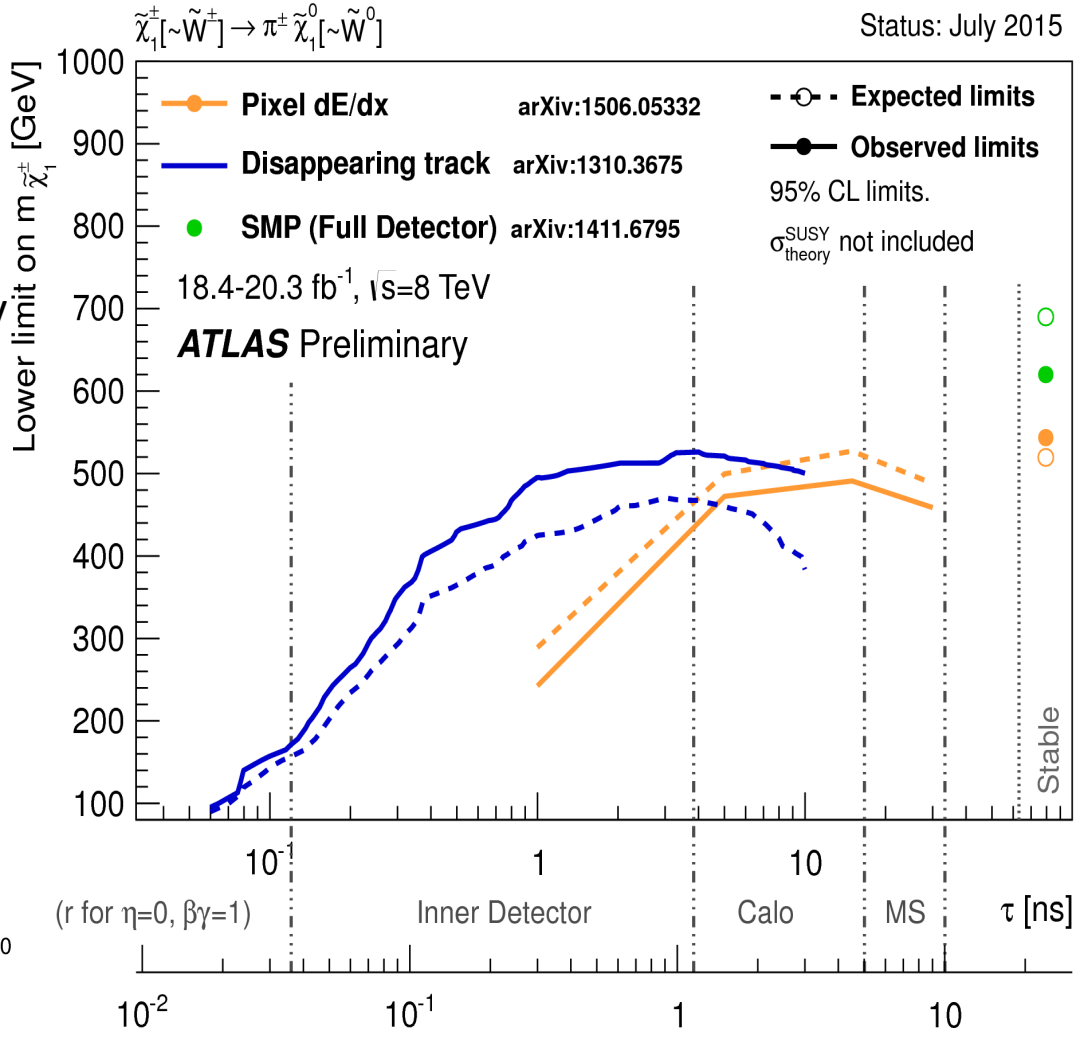
$$dE/dx_{\mathrm{MPV}}(\beta\gamma) = \frac{p_1}{\beta^{p_3}} \ln[1 + (|p_2|\beta\gamma)^{p_5}] - p_4$$

Searching for highly Ionizing particles (R-hadrons, charginos in AMSB)



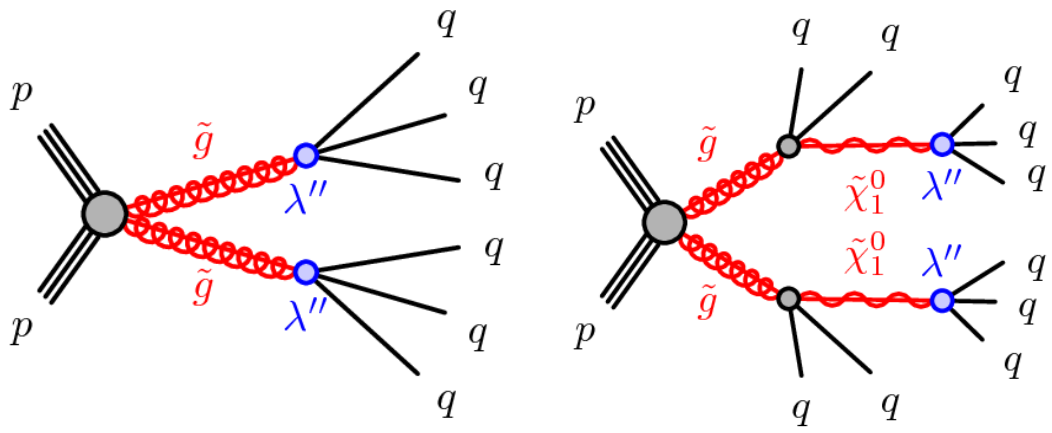
Etmiss > 100 GeV
Lepton (electron and W-muon) vetoes
One good isolated track with pT > 80 GeV
Highly ionizing track





Stable (metastable) charginos with masses smaller than 534 GeV (483 GeV @ 15 ns τ) are excluded

One example of RVP search



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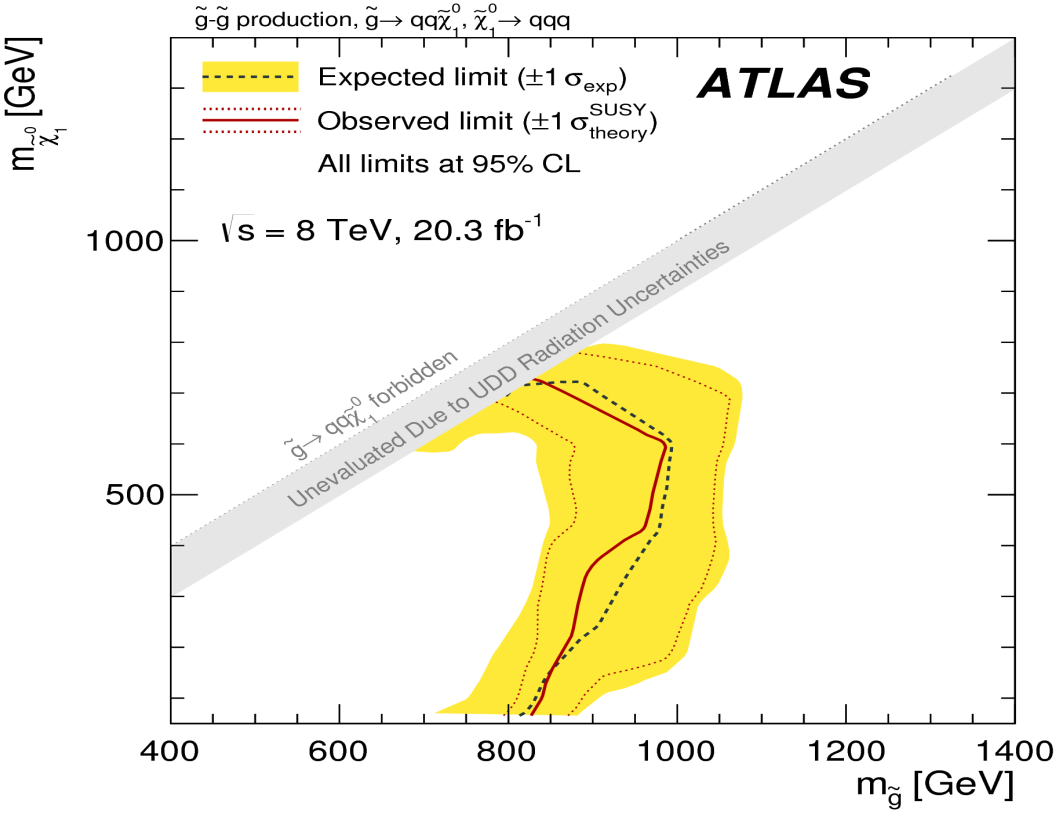
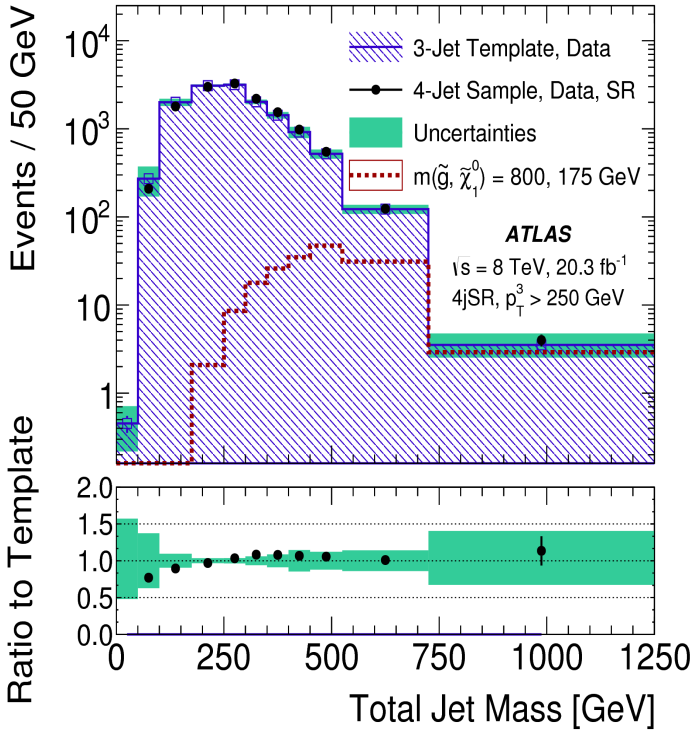
Searching for an excess of events in multijet final states

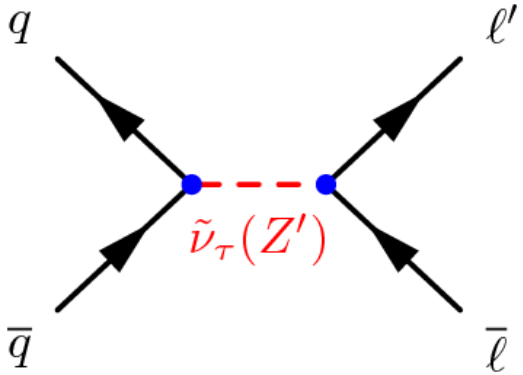
→ Computing the inv. mass of mega jets reflecting the presence of a very massive particle



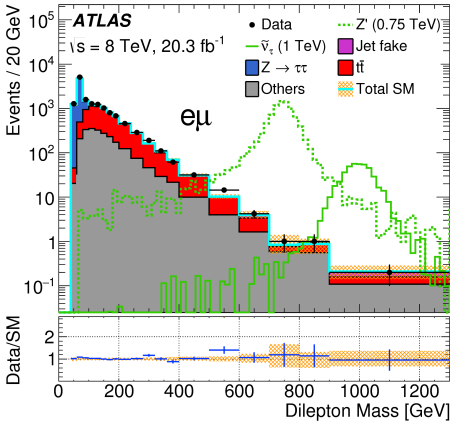


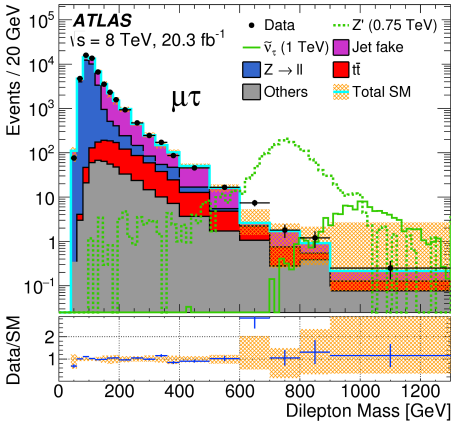
Phys. Rev. Lett. 115, 031801 (2015)

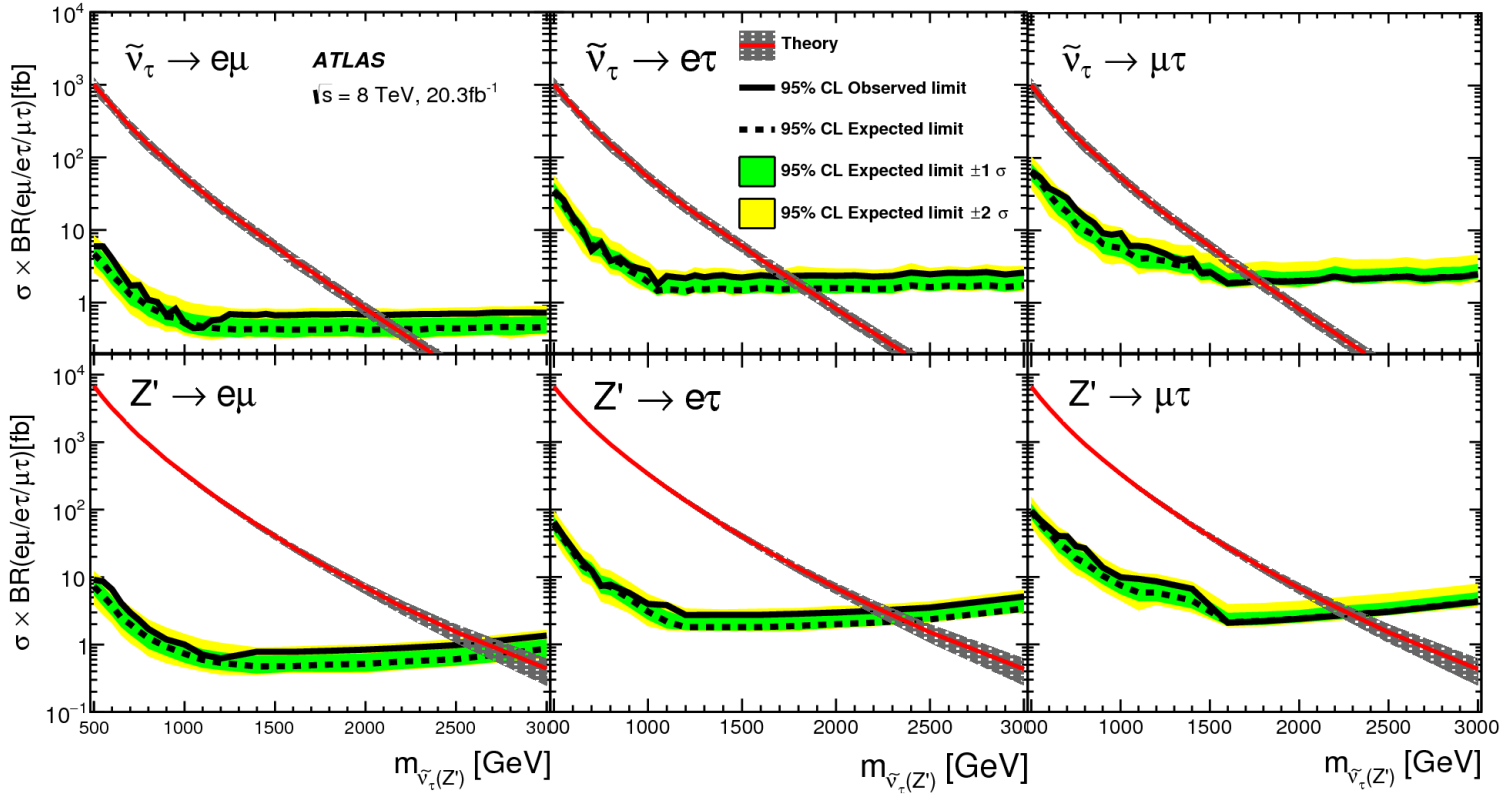
RPV (eμ, eτ, μτ)



Nature does not like this…







ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

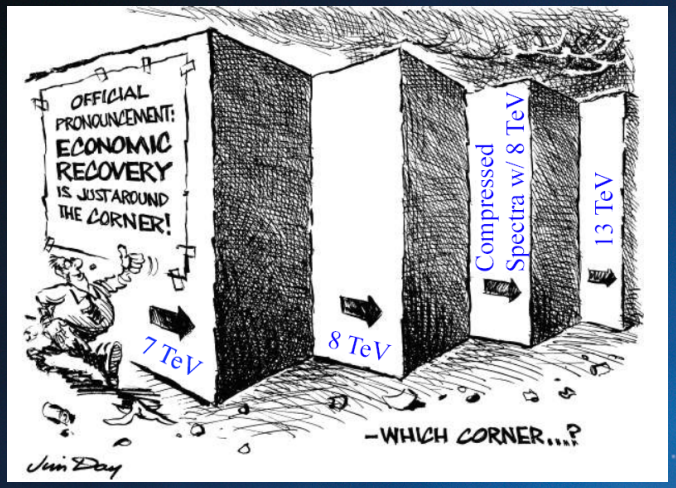
$\sqrt{s}$ = 7, 8 TeV

No hint for SUSY ?

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 8 TeV	Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.8		
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV		
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV		
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV		
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV		
	$\tilde{g}\tilde{g}, \tilde{g}\to qqW^{\pm}\tilde{\chi}_1^0$	0-1 e, μ	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV		
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20	$\tilde{g}$	1.32 TeV		m($\tilde{\chi}_1^0$)=0 GeV
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV		tanβ >20
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.29 TeV		$c\tau$(NLSP)<0.1 mm
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.3 TeV		m($\tilde{\chi}_1^0$)<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV		m($\tilde{\chi}_1^0$)<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV		m(NLSP)>430 GeV
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV		m($\tilde{G}$)>1.8 × 10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV		m($\tilde{\chi}_1^0$)<400 GeV
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV		m($\tilde{\chi}_1^0$) <350 GeV
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV		m($\tilde{\chi}_1^0$)<400 GeV
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV		m($\tilde{\chi}_1^0$)<300 GeV
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
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^+$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV		m($\tilde{\chi}_1^+$)=2 m($\tilde{\chi}_1^0$)
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^+$	1-2 e, μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 110-167 GeV	230-460 GeV		m($\tilde{\chi}_1^+$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-191 GeV	210-700 GeV		m($\tilde{\chi}_1^0$)=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	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
	$\tilde{t}_1\bar{t}_1$(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	$\tilde{\ell}_{LR}\tilde{\ell}_{LR}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	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
	$\tilde{\chi}_1^+\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	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
	$\tilde{\chi}_1^+\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	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
	$\tilde{\chi}_1^+\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$	250 GeV		m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	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
	GGM (wino NLSP) weak prod.	1 e, μ + γ	-	Yes	20.3	$\tilde{W}$	124-361 GeV		$c\tau$<1 mm	1507.05493
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($\tilde{\chi}_1^+$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$	482 GeV		m($\tilde{\chi}_1^+$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)<15 ns	1506.05332
	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<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$	1.27 TeV			1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV		10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	435 GeV		2<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to eev/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV		7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV		6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV		λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	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
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV		BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to q\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	870 GeV		m($\tilde{\chi}_1^0$)=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV			1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$	100-308 GeV			ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e, μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV		BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV		m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

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.*



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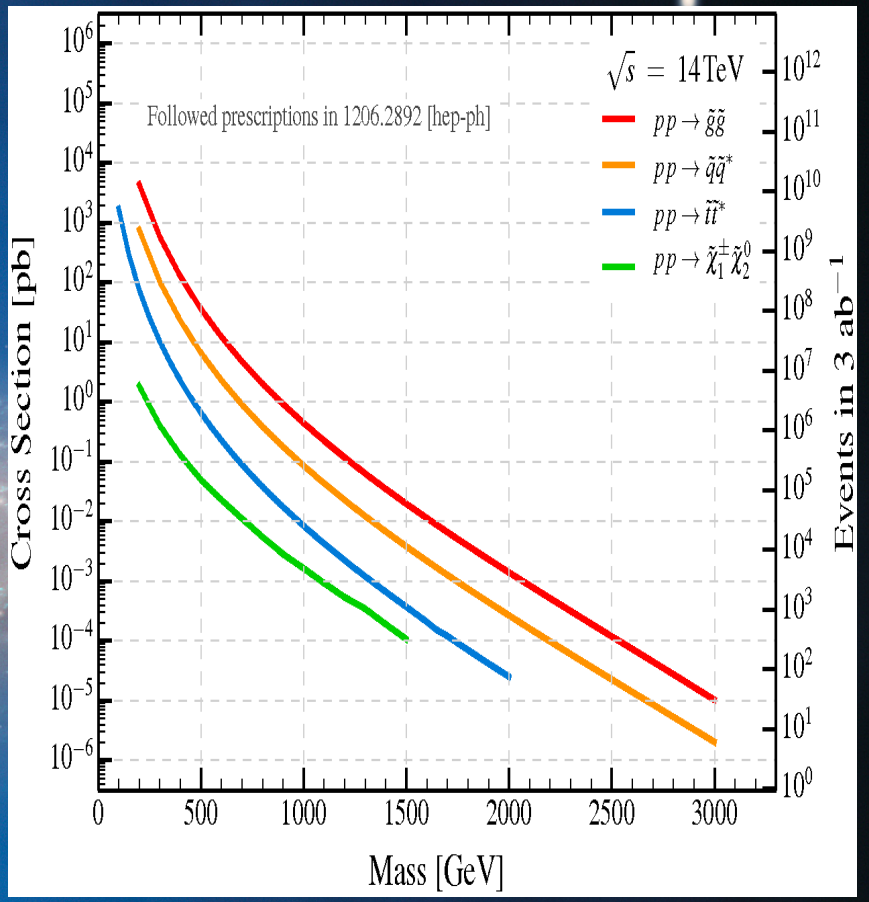

The discovery of New Physics requires more energy and more data ……

End Part II