SEARCHES FOR R-PARITY CONSERVING SUPERSYMMETRY WITH THE ATLAS DETECTOR

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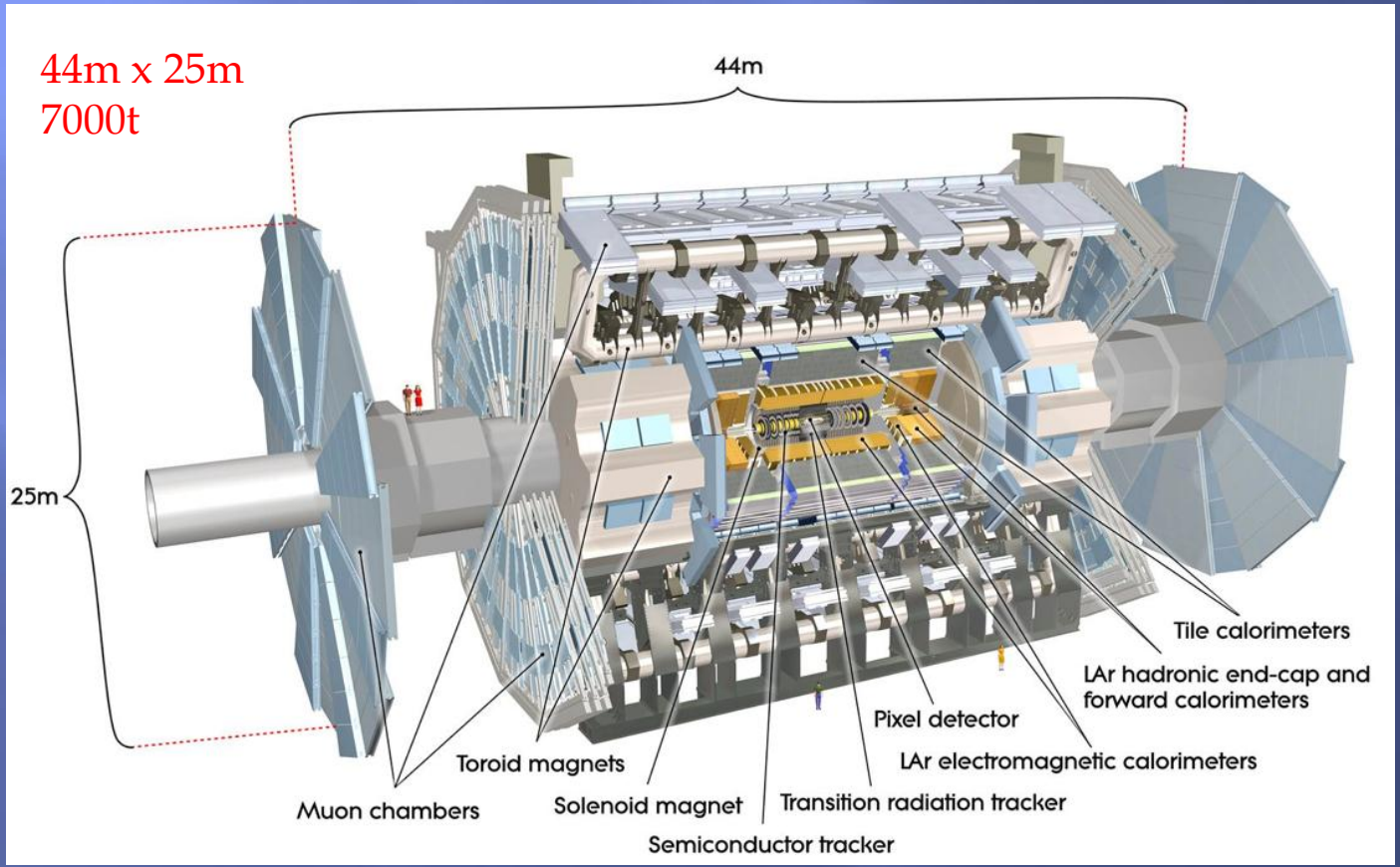
On behalf of ATLAS collaboration

Outline

- Introduction
  ATLAS, search strategy
- Inclusive search
  squark / gluino production
- Exclusive search
  3rd generation (stop/sbottom)
  direct gaugino and slepton
- Summary

The ATLAS Detector

General purpose, high resolution, hermetic detector in LHC
Inner Detector: Pixel, Silicon, Transition Radiation Tracker
Calorimeter: EM(LAr), Had(Tile) Cal
Muon: Trigger(RPC,TGC) + Precision chambers(MDT,CSC)
Magnetic: Central Solenoid(2T) + Barrel and Endcap Toroids

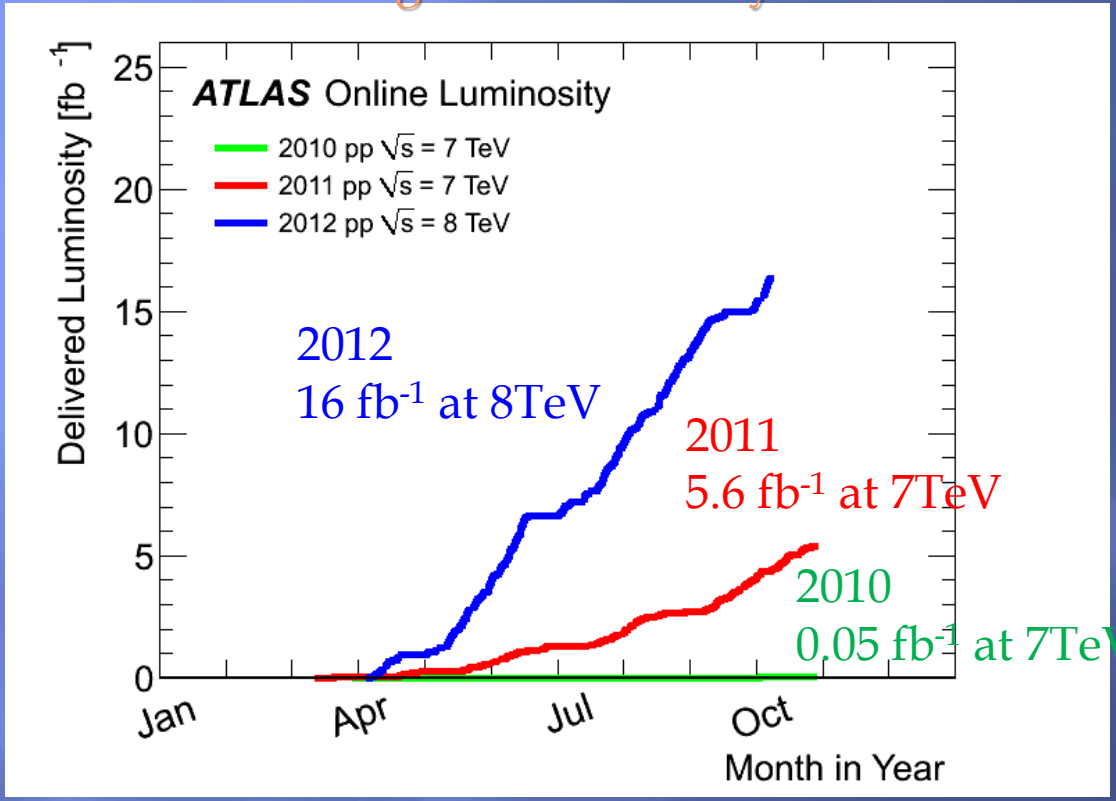


Reconstructed objects
- Lepton (e,μ,τ)
- Photon
- Jet (with b-tagging)
- Missing ET(MET)

Kinematic variables
$pT = p \sin\theta$
$\eta = -\ln \tan(\theta/2)$

Data taking

Integrated luminosity



Peak luminosity

7.7×10^{33} cm^{-2} s^{-1}
(~ 30 pile up events)

Integrated luminosity

2012 Oct: 16 fb^{-1} at 8TeV
2011: 5.6 fb^{-1} at 7TeV
2010: 0.05 fb^{-1} at 7TeV

Data quality

93.7% ready for Physics

ATLAS p-p run: April-Sept. 2012

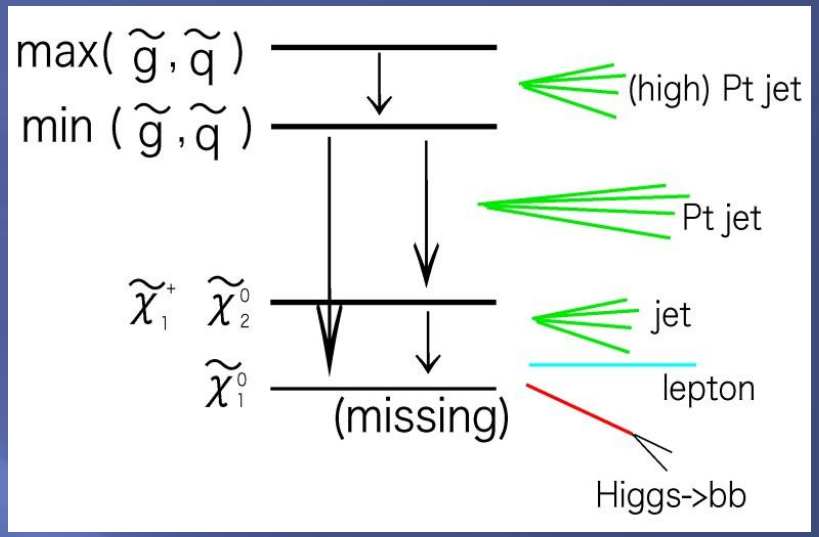
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2

All good for physics: 93.7%

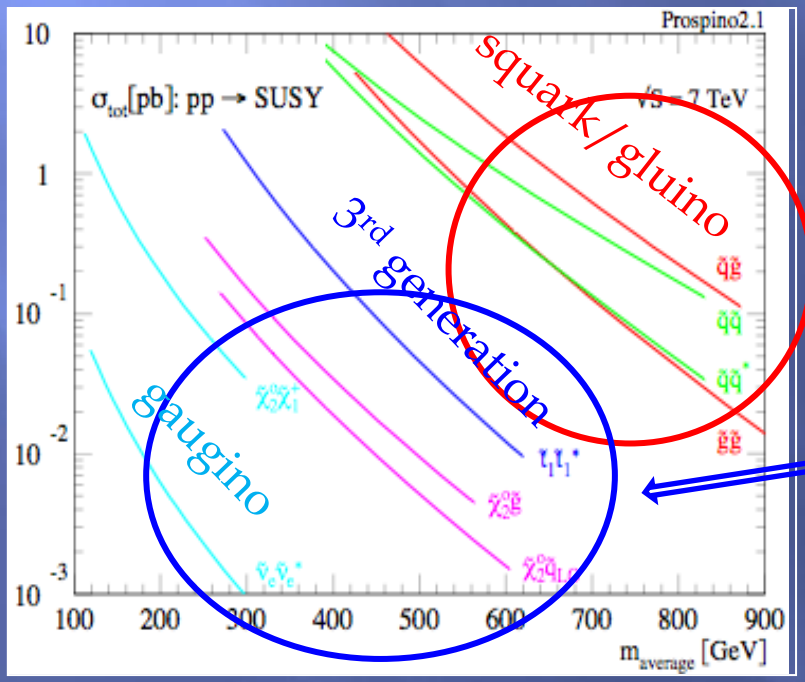
SUSY in ATLAS

Generic phenomenology

- Strongly interacting particle (squark, gluino) dominates
- Several high-pT jets in decay chain
- LSP is stable (R-parity), escape from detector (Missing ET)



cross section of SUSY



Search strategy

1. Inclusive search

   multi-jets + MET + (0~4leptons)
   + (photon, b-jets)

2. Dedicated exclusive chanels

   3rd generation, gaugino sector, etc

Public results

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

8TeV

channel	date	√s(TeV)	L (fb-1)	ATLAS-CONF-	arXiv	paper
0 lepton + >=2-6jets + MET	08/2012	8	5.8	2012-109		
0 lepton + >=6-9jets + MET	08/2012	8	5.8	2012-103		
1 lepton + >=4jets + MET	08/2012	8	5.8	2012-104		
2 same-sign leps + >=4jets + MET	08/2012	8	5.8	2012-105		

7TeV

1-2 taus + 0-1 leptons + jets + MET [GMSB]	10/2012	7	4.7		1210.1314	submitted to EPJC
2 leptons + jets + MET [Mediium stop]	09/2012	7	4.7		1209.4186	submitted to JHEP
1-2 b-jets + 1-2 leps + jets + MET [Light stop]	09/2012	7	4.7		1209.2102	submitted to PLB
2 photons + >=2-4jets + MET	09/2012	7	4.7		1209.0753	submitted to PLB
1-2 leptons + >= 2-4jets + MET	08/2012	7	4.7		1208.4688	accepted by PRD
2 leptons + >= 1jet + MET [very light stop]	08/2012	7	4.7		1208.4305	submitted to EPJC
3 leptons + MET [Direct gauginos]	08/2012	7	4.7		1208.3144	submitted to PLB
2 leptons + MET [Direct gausinos/sleptons]	08/2012	7	4.7		1208.2884	submitted to PLB
1 lepton + >=4jets (>=1b) + MET [heavy stop]	08/2012	7	4.7		1208.2590	accepted by PRL
0 lepton + 1-2 b + 5-4 jets + MET [heavy stop]	08/2012	7	4.7		1208.1447	accepted by PRL
0 lepton + >=2-6jets + MET	08/2012	7	4.7		1208.0949	submitted to PRD
0 lepton +>=3b + >=1-3j + MET [GM, stop,sb]	07/2012	7	4.7		1207.4686	EPJC
0 lepton +>= 6-9jets + MET	06/2012	7	4.7		1206.1760	JHEP 1207 (2012) 167
Z+ll + bjet + jets + MET [direct stop in GMSB]	04/2012	7	2.05		1204.6736	PLB 715 (2012) 44
1 lepton + >= 7 jets + MET	10/2012	7	4.7	2012-140		
3 lepton + jets + MET	08/2012	7	4.7	2012-108		
2 b-jets + MET [Directo sbottom]	08/2012	7	4.7	2012-106		
General new phenomena	08/2012	7	4.7	2012-107		
4-leptons + MET	01/2012	7	2.05	2012-001		
Z→ll + jets + MET [GGM]	04/2012	7	1.04	2012-046		

Only the most recent result for topics listed

Inclusive searches

(squark / gluino production)

Search channels

channels

generally, look for

multi-jets + MET + (e,μ,τ,γ)

LSP = neutralino (mSugra)

- Squark/gluino → multi-jets + LSP
  → 0 lepton + 2-9 jets + MET
- with leptonic gaugino/slepton decay
  → 1/2 lepton + jets + MET
- with 3rd generation
  → b-jets + MET

LSP = gravitino (GMSB,etc)

topology depend on NLSP

- squark/gluino
  with stau/neutralino →LSP
  → 2 taus/leptons + jets + MET
  → 2 photons + MET

variables

discriminating variable for SUSY

- Missing ET (MET)
  = - Σ **visible energy** (Calo, muon)
- Effective Mass (Meff) =
  MET + Σ pT of jets + (leptons)
- Missing ET significance =
  MET/ sqrt(HT) : HT= ΣpT of jets

for simple topology 2-body decay (visible and invisible)

- Contransverse mass (MCT)
- MT2

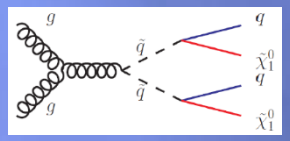
discriminating variable for W→ l ν

- Transverse mass (MT) =
  sqrt[2 x pT(l) x MET x {1-cos(Δφ(l,MET))}]

Event Selection

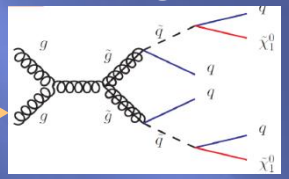
0 lepton mode event selection

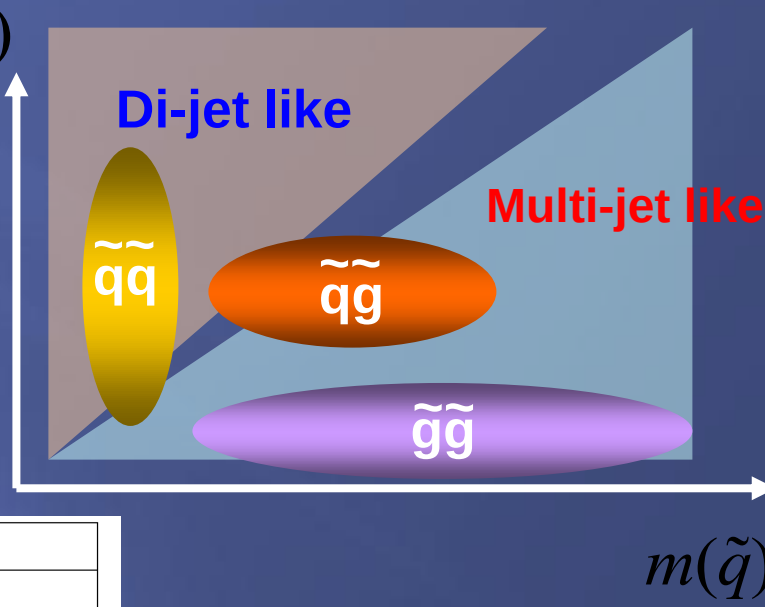
squark/squark



N jets depend on initial production

gluino/gluino





Requirement	Channel				
	A 2-jets	B 3-jets	C 4-jets	D 5-jets	E 6-jets
E_T^{miss}[GeV] >	160				
$p_T(j_1)$ [GeV] >	130				
$p_T(j_2)$ [GeV] >	60				
$p_T(j_3)$ [GeV] >	–	60	60	60	60
$p_T(j_4)$ [GeV] >	–	–	60	60	60
$p_T(j_5)$ [GeV] >	–	–	–	60	60
$p_T(j_6)$ [GeV] >	–	–	–	–	60
$\Delta\phi$(jet, $\mathbf{E}_T^{miss}$)$_{min}$ [rad] >	0.4 (i = {1, 2, (3)})		0.4 (i = {1, 2, 3}), 0.2 (p_T > 40 GeV jets)		
$E_T^{miss}/m_{eff}(N\,j)$ >	0.3/0.4/0.4 (2j)	0.25/0.3/– (3j)	0.25/0.3/0.3 (4j)	0.15 (5j)	0.15/0.25/0.3 (6j)
m_{eff}(incl.) [GeV] >	1900/1300/1000	1900/1300/–	1900/1300/1000	1700/–/–	1400/1300/1000

~~multi jets (>60GeV)~~

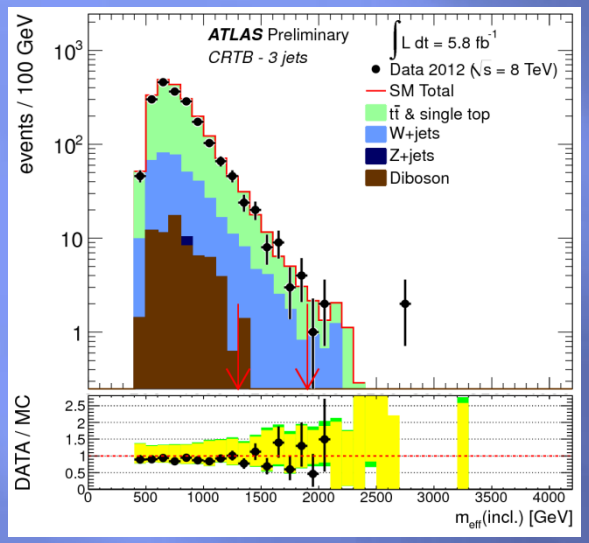
multi jets N=2~6(>60GeV)

MET cut (300~400GeV)

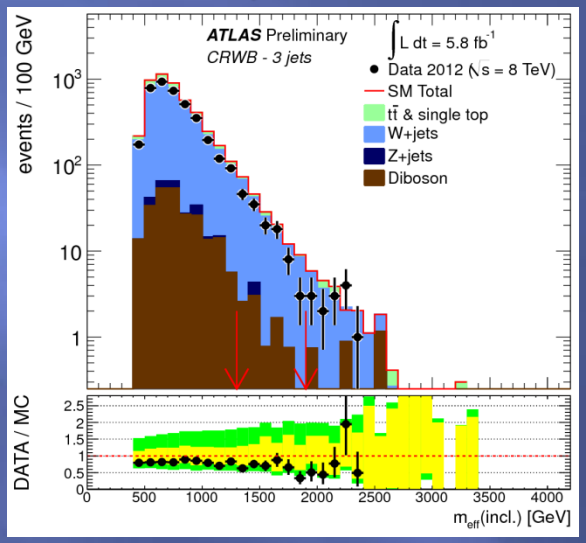
Effective Mass cut (1TeV~2TeV)

SM Backgrounds

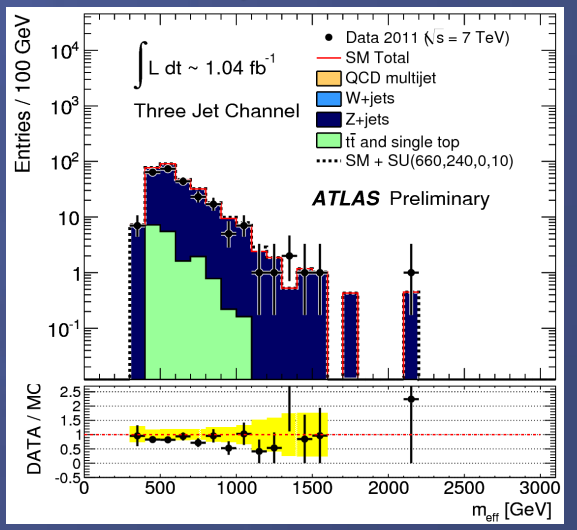
ttbar + multi-jets



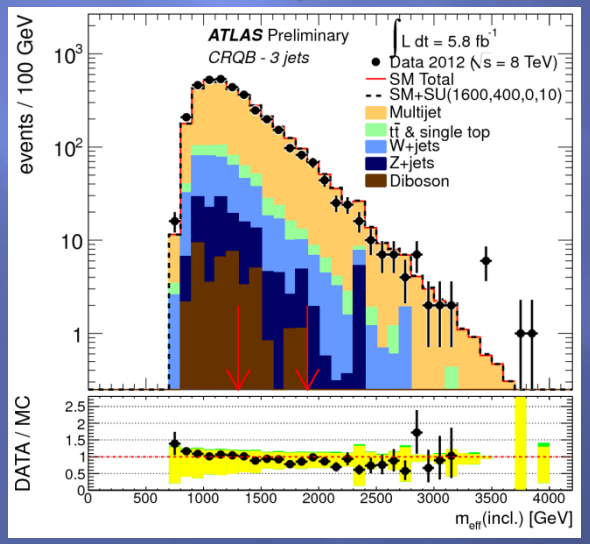
W + multi-jets



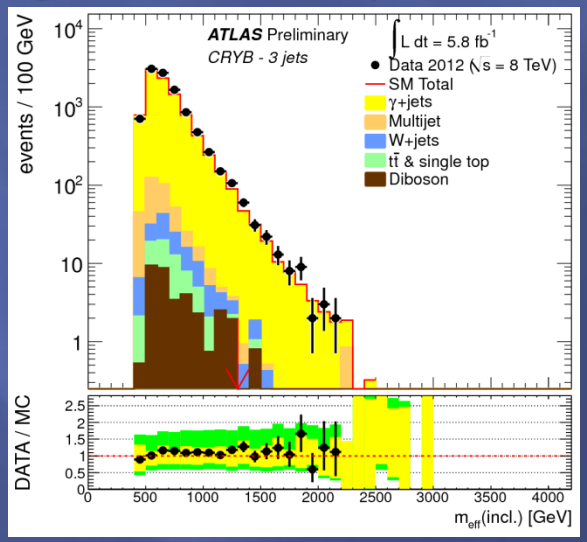
Z + multi-jets



QCD (multi-jets)



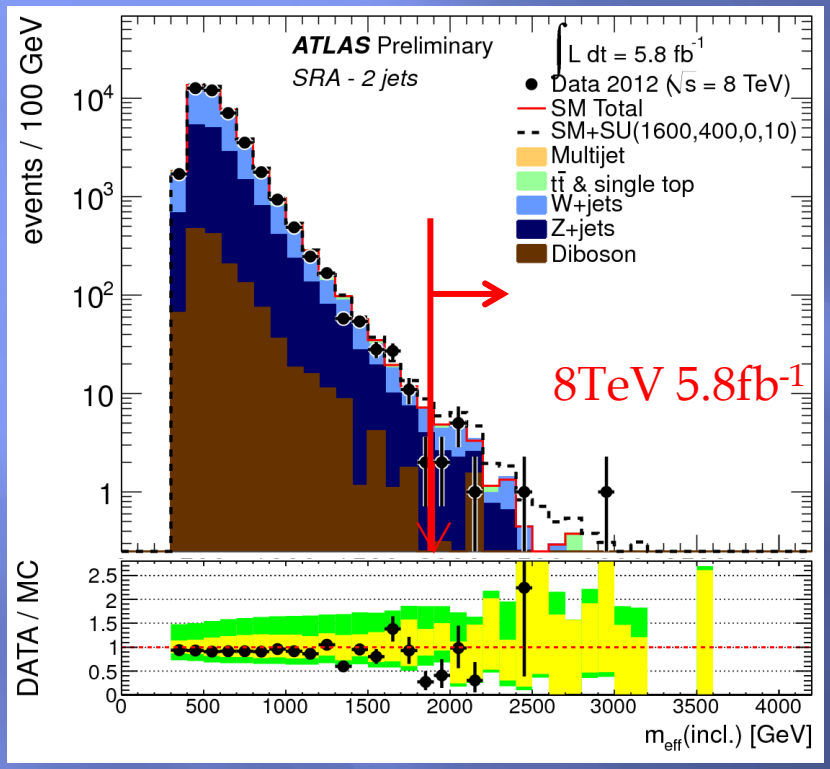
gamma + multi-jets



- understand BGs in control regions
  ~ signal depleted
  ~ pure as possible
- normalize MC, extrapolate to signal region using MC

Signal regions

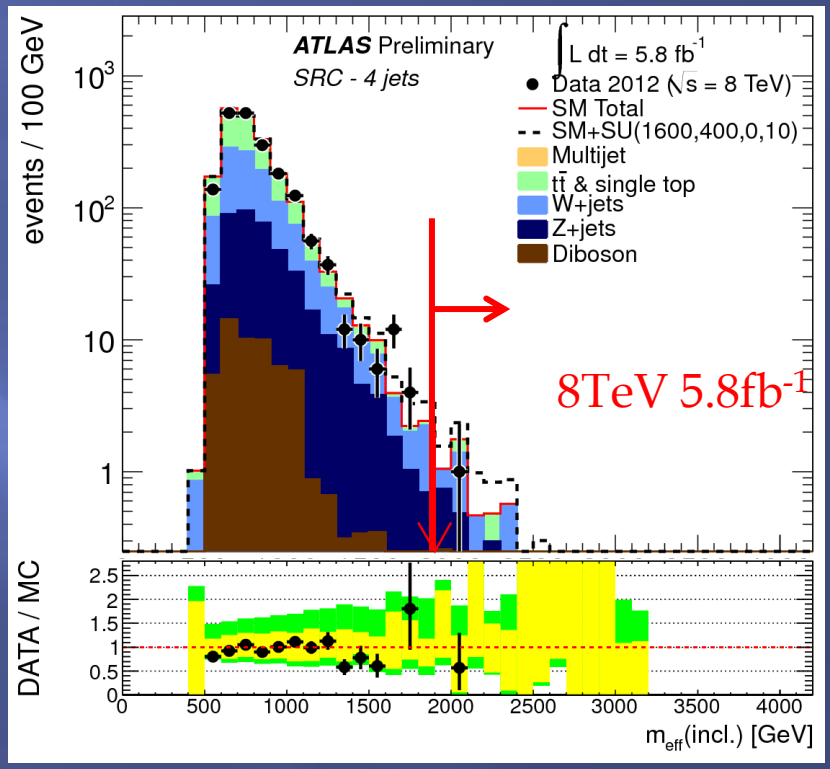
0 lepton + >=2 jets + MET



Effective Mass

Meff>1900 GeV
Data 10
MC 14+-5
(W:3,Z:7,tt:1:Di:3)

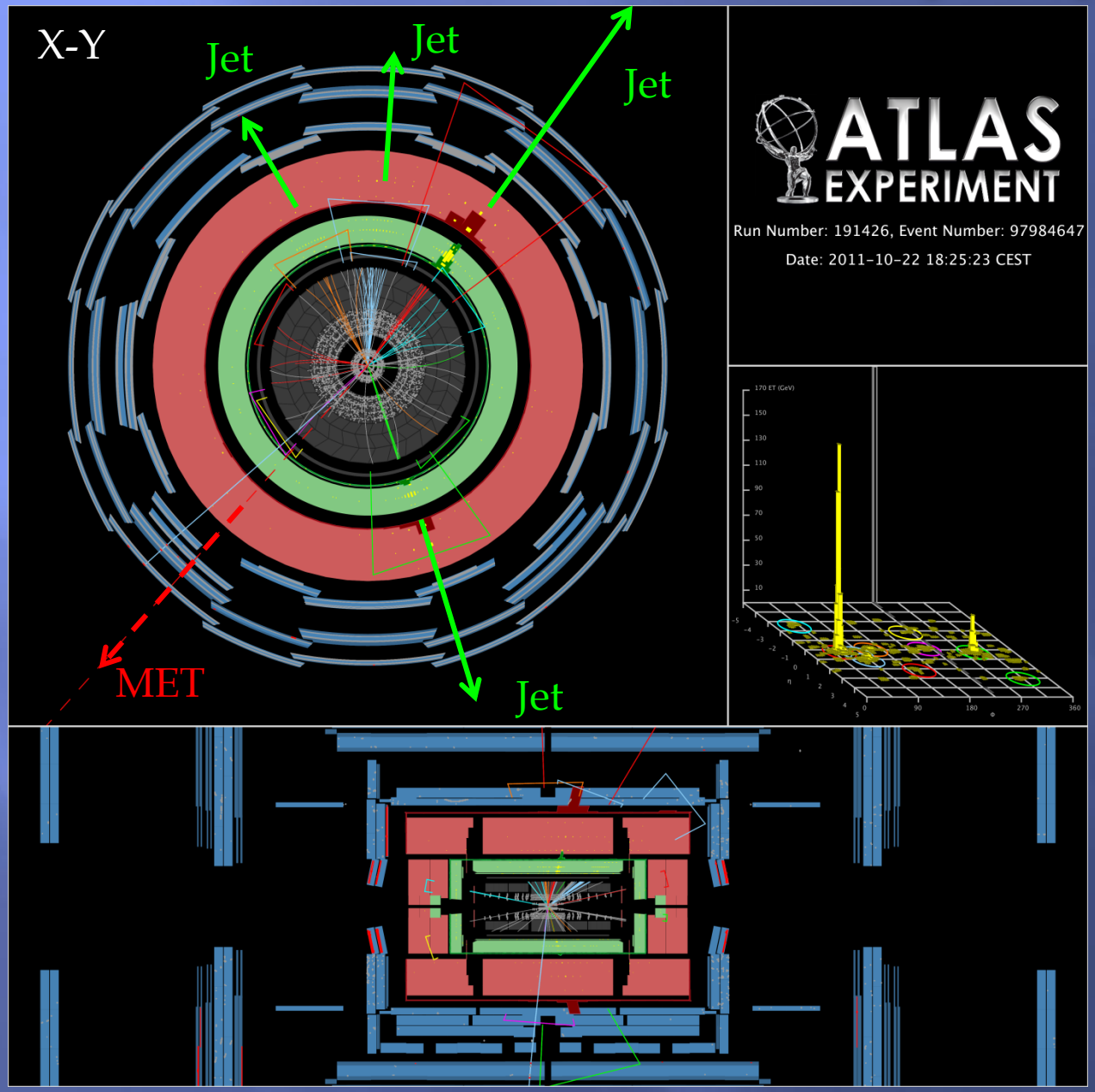
0 lepton + >=4 jets + MET



Effective Mass

Meff>1900 GeV
Data 1
MC 2.8+-1.2
(W:0.3,Z:2.0,tt:0.6,Di:--)

Event display



Run:191426 #97984647
(7TeV 2011)

Effective Mass
2441 GeV

MET
984 GeV

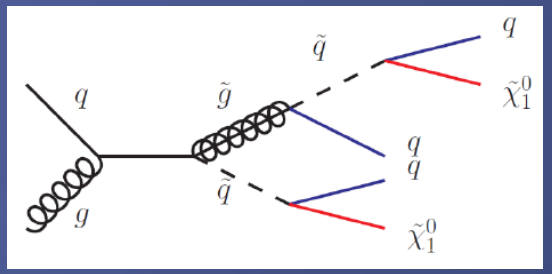
Jets (>40GeV)
974, 276, 146, 61 GeV

Leptons (e,μ)
No (>10GeV)

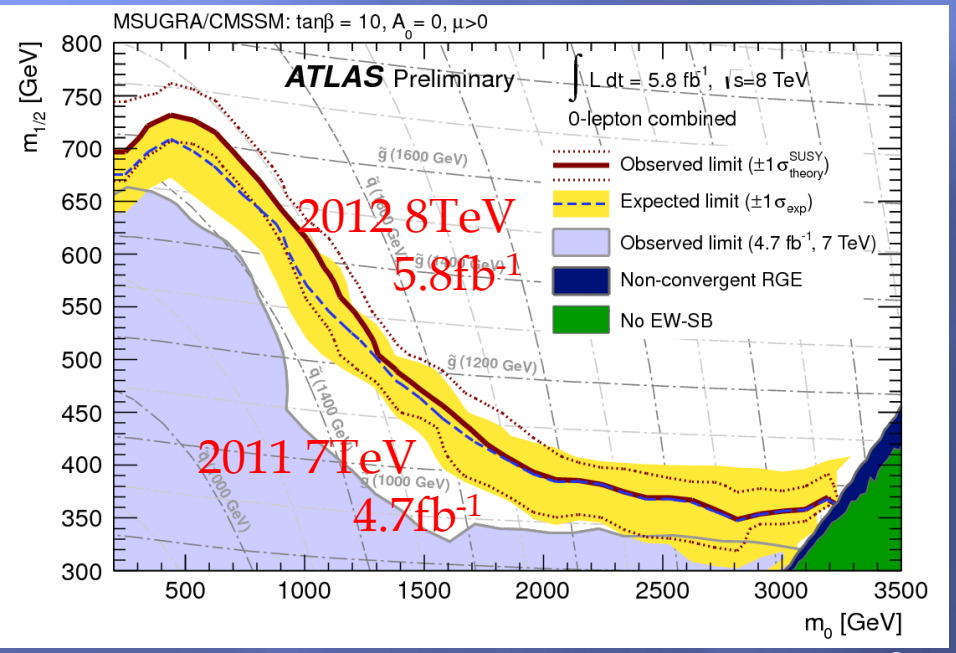
Exclusion region

0 lepton + 2-6 jets + MET (most sensitive)

- no evidence so far (at 5.8fb^{-1}, 8TeV)
- exclude ~1.5TeV for Msquark~Mgluino,
  ~1TeV for Msquark>>Mgluino
- widely extended at 8TeV (cross section x2~5)

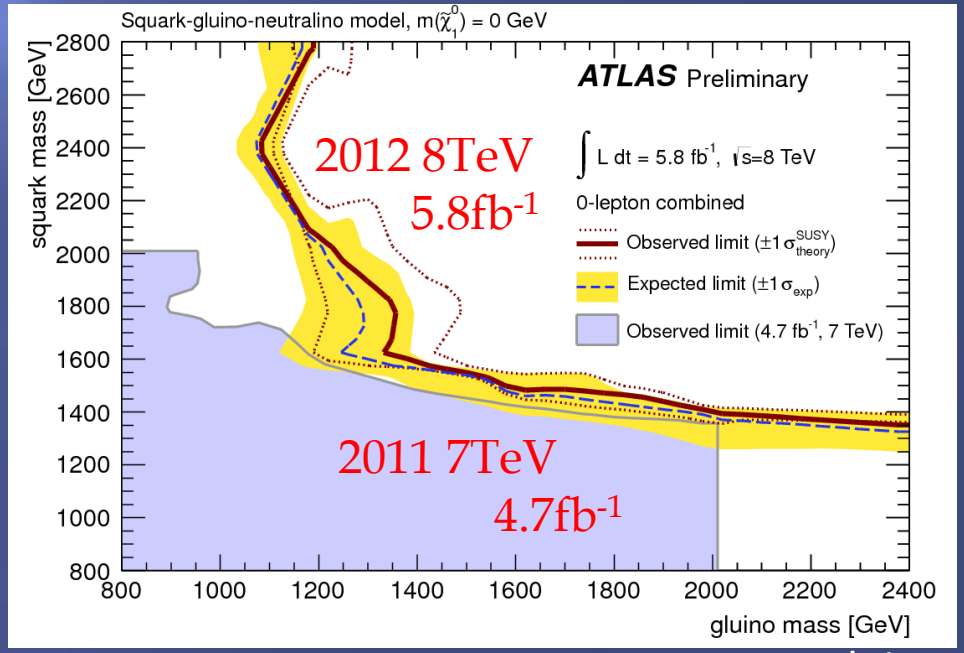


M1/2 MSUGRA (tanb=10,A=0,mu>0)



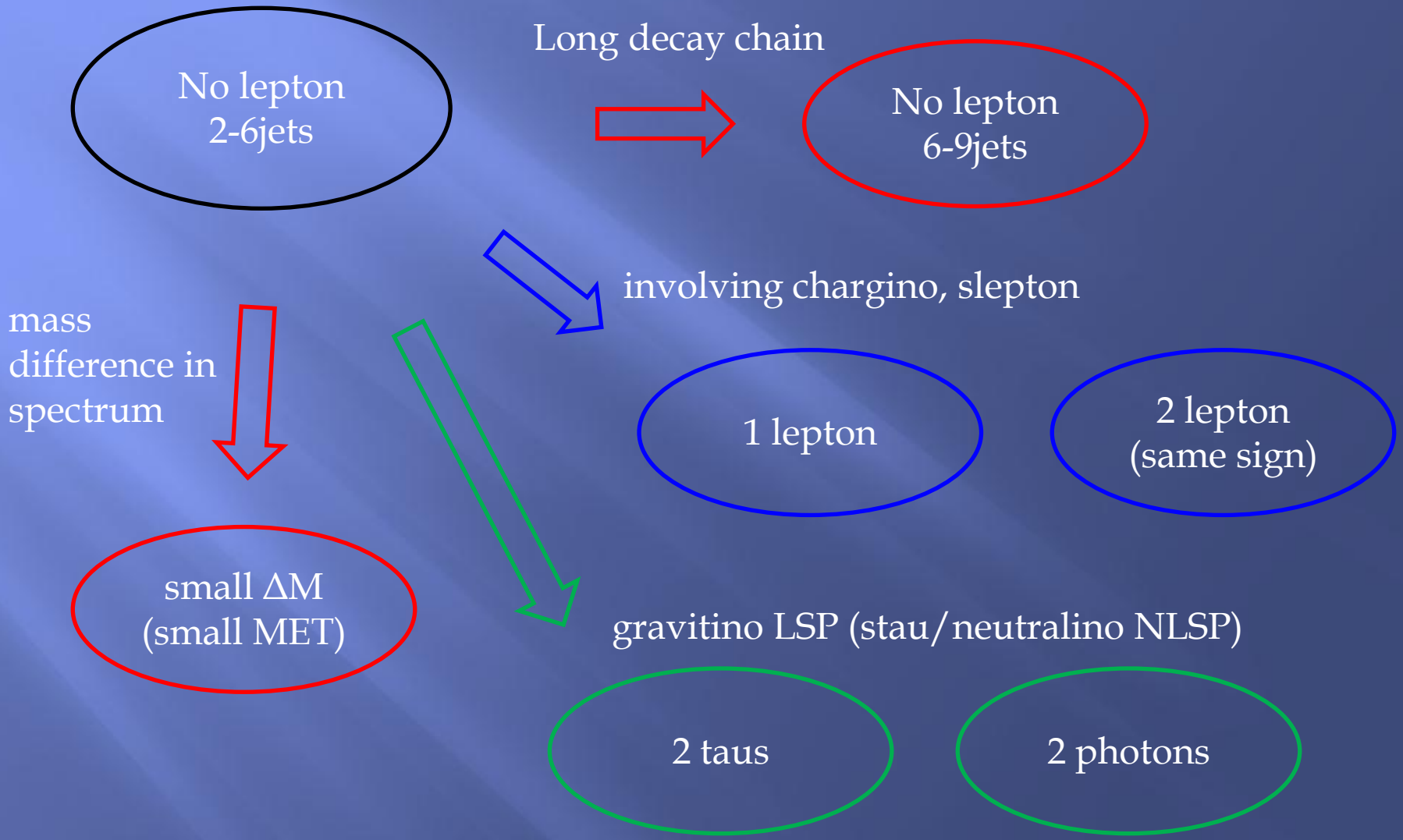
M0

Msquark Simplified squark/gluino model



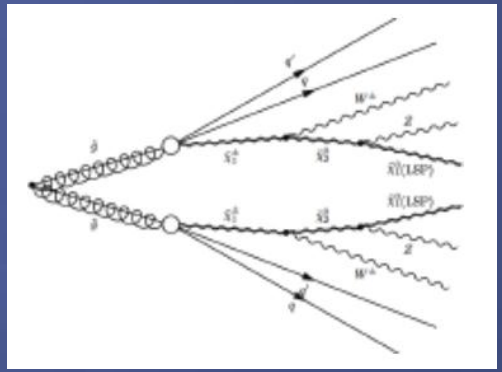
Mgluino

Relaxing constraints

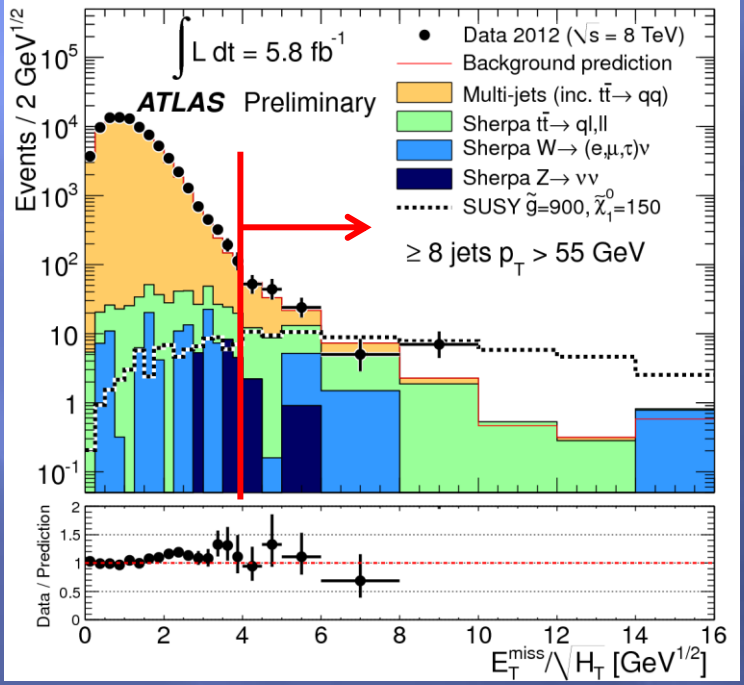


Long decay chain

- target for gluino pair production,
  (especially involving stop, higher gaugino, etc)
  0 lepton + >=6-9 jets + MET
- change BG composition: QCD, ttbar (hadronic)
  MET significance = MET/ sqrt(HT)

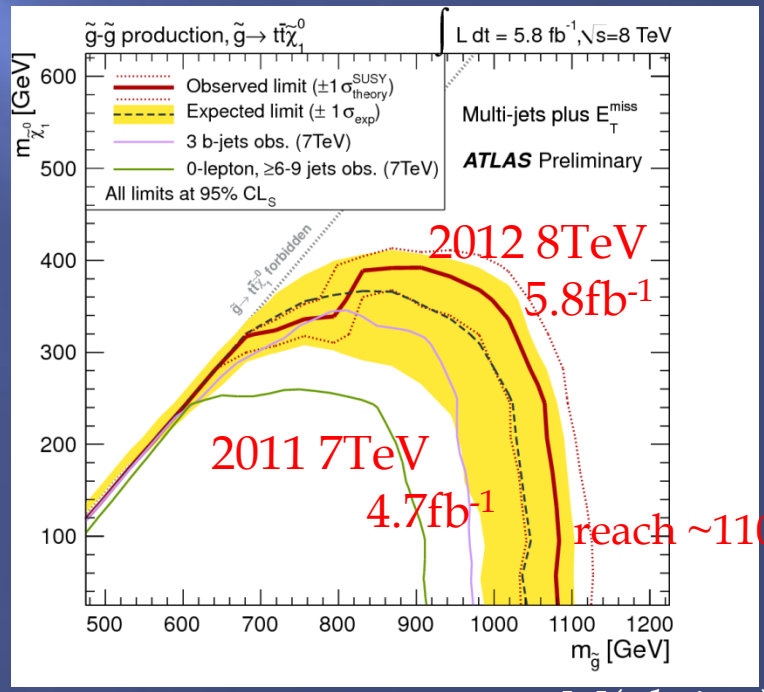


Simplifed: gluino → stop + top → 2 top + LSP



MET significance

LSP

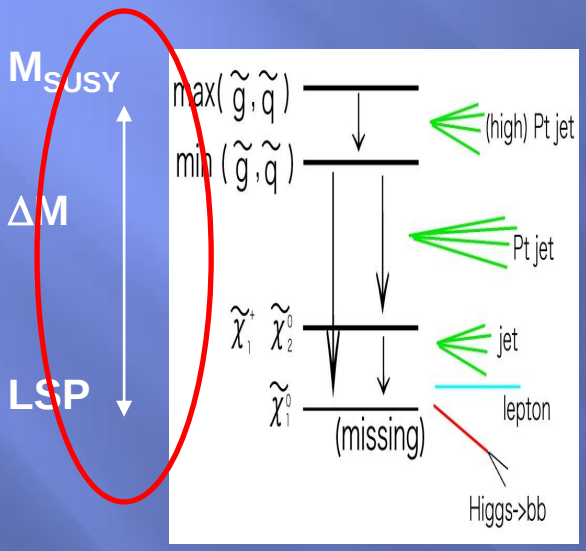


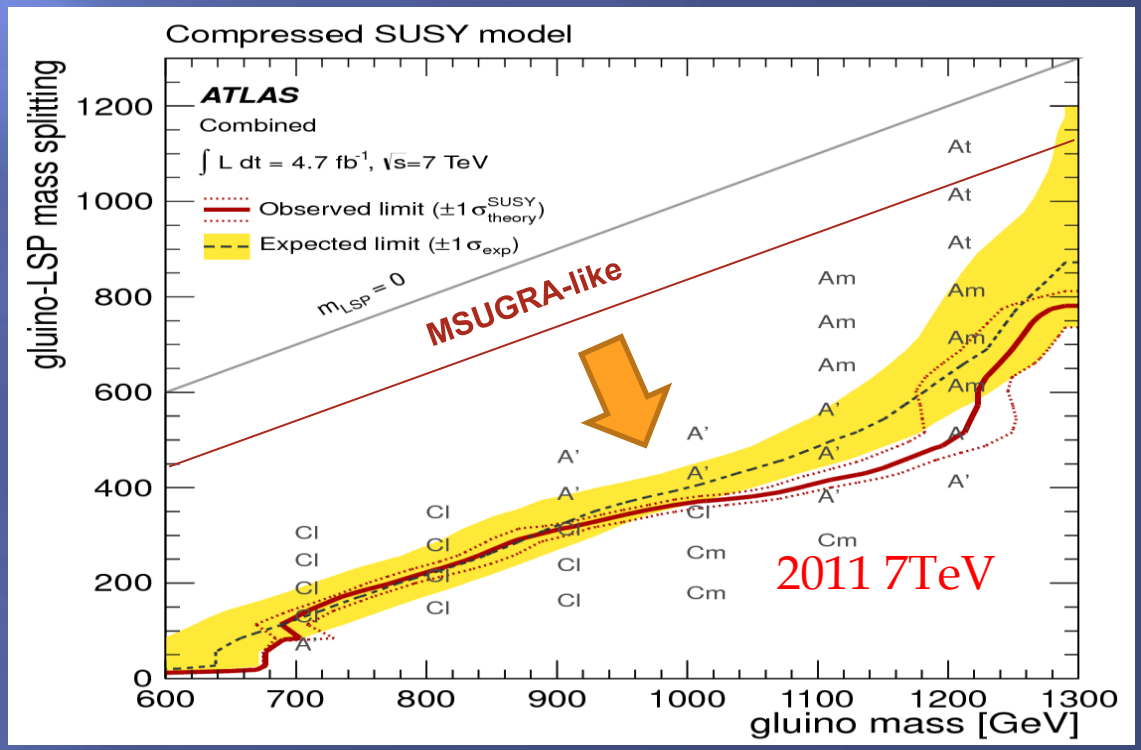
M(gluino)

Small mass difference

- mSugra-like spectrum
  large ΔM (M(squark) - LSP) ~ 0.85
- explore to small ΔM region by using simplified model

ΔM (Msusy - LSP)

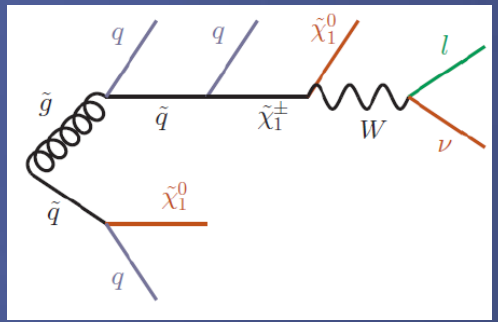


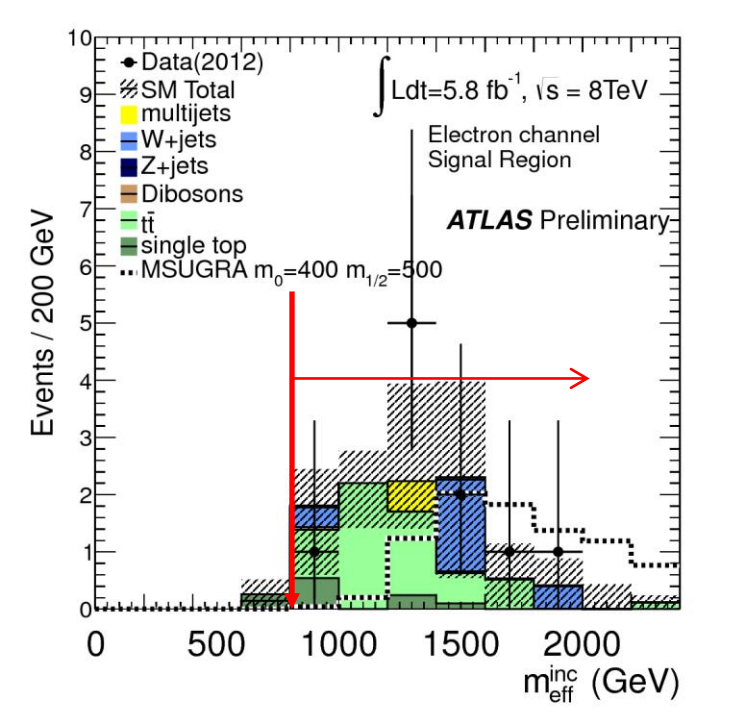


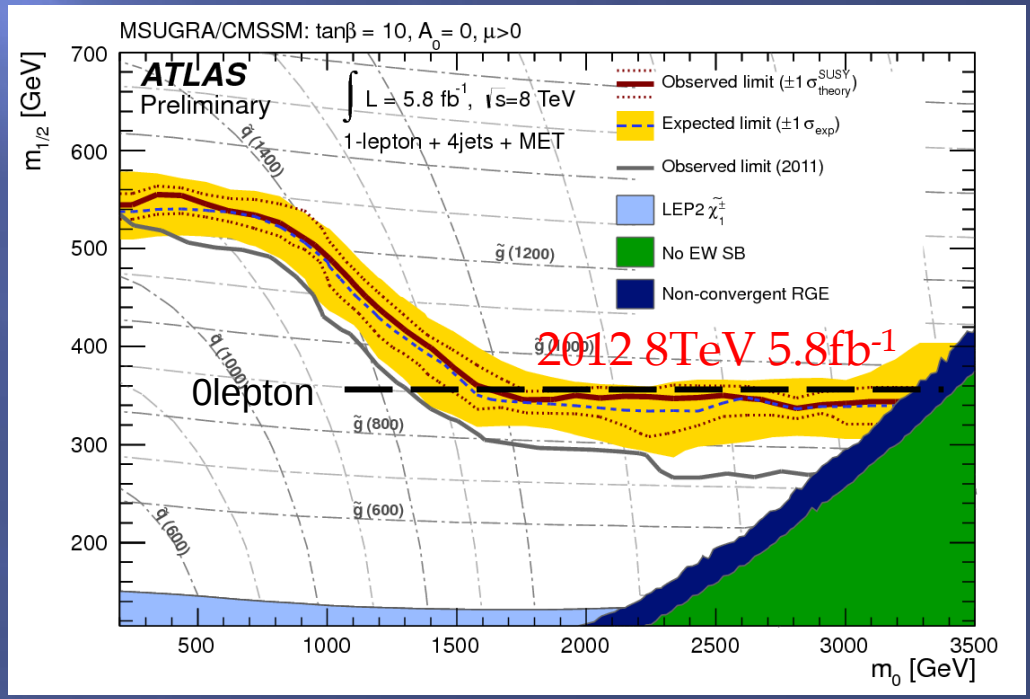
- gluino mass limit depende on ΔM
- exclude ΔM ~ 0.4 at M(gluino)~1TeV

1 lepton mode

- focus on leptonic gaugino / slepton decay
  1 lepton (>25GeV) + 4 jets + MET
- good to control backgrounds
  - eliminate QCD, Z→νν
  - reject W/ tt(→bblνqq) by transverse mass cut



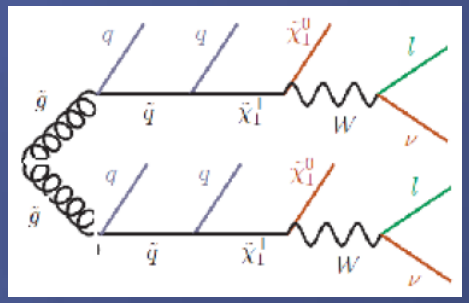


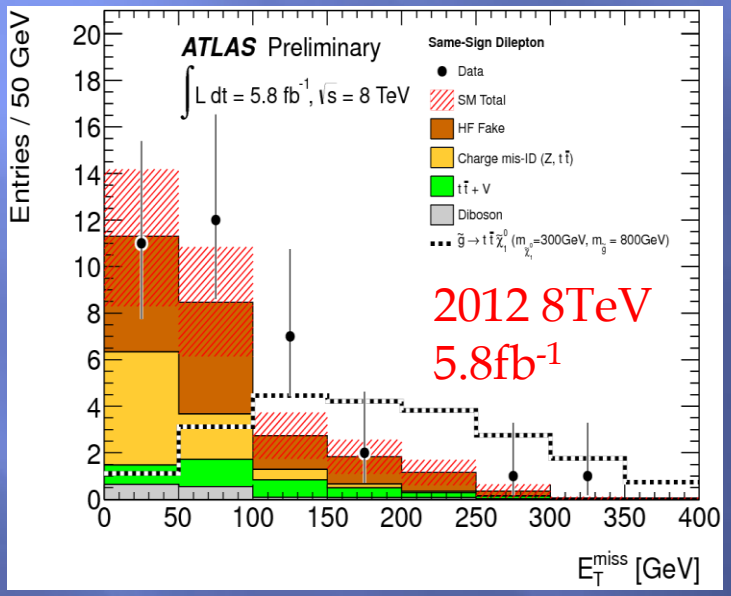


competitive at high M0 (gluino production)

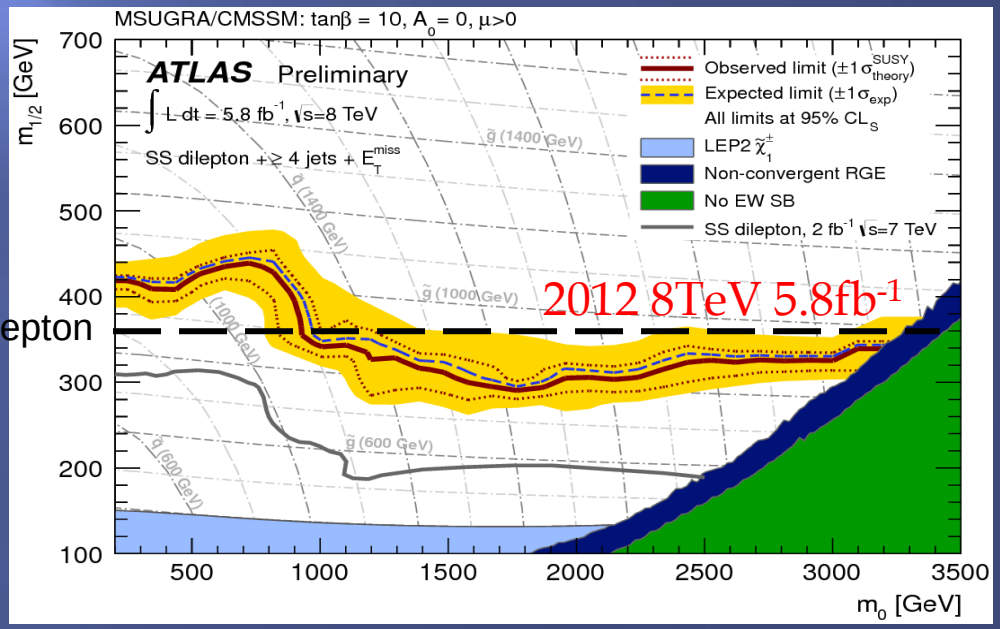
2 lepton (same sign)

- leptonic gaugino / slepton decay
  2 lepton (same sign) + 4 jets + MET
- statistics limited but high rejection to SM BG
  - reject opposite sign SM background (ttbar)
    (1/2 case is same sign in SUSY)





0lepton



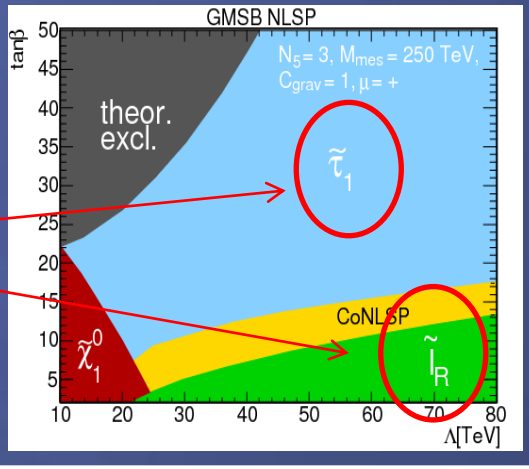
competitive at high M0 (gluino production)

2 taus / 2l (GMSB)

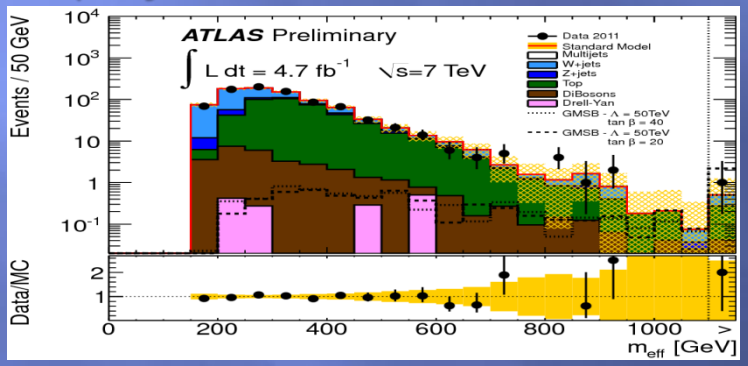
- Gravitino LSP in GMSB
  Topology depend on NLSP
  stau / slepton NLSP enhance tau/leptons

→ 2 taus + jets + MET

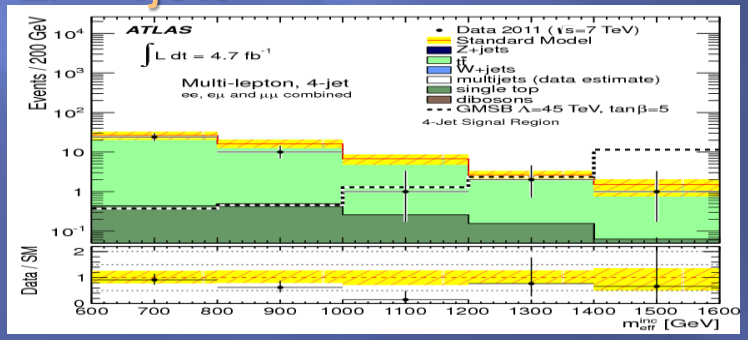
→ 2 opposite sign leptons(e,μ) + jets + MET

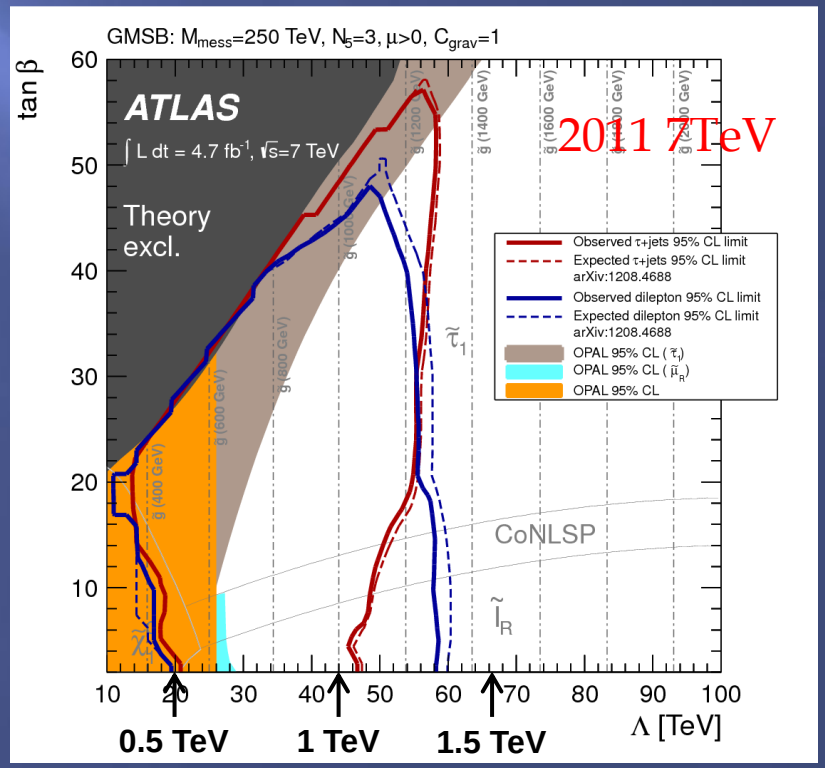


τ+μ +jets



2l + 4jets

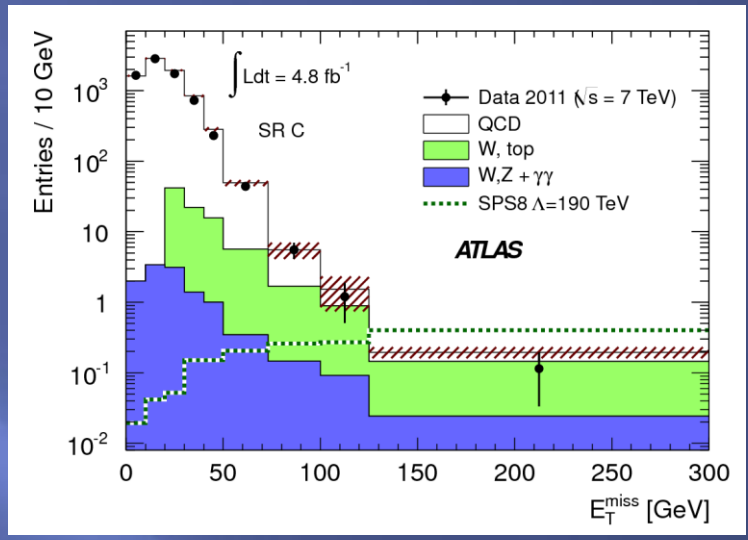




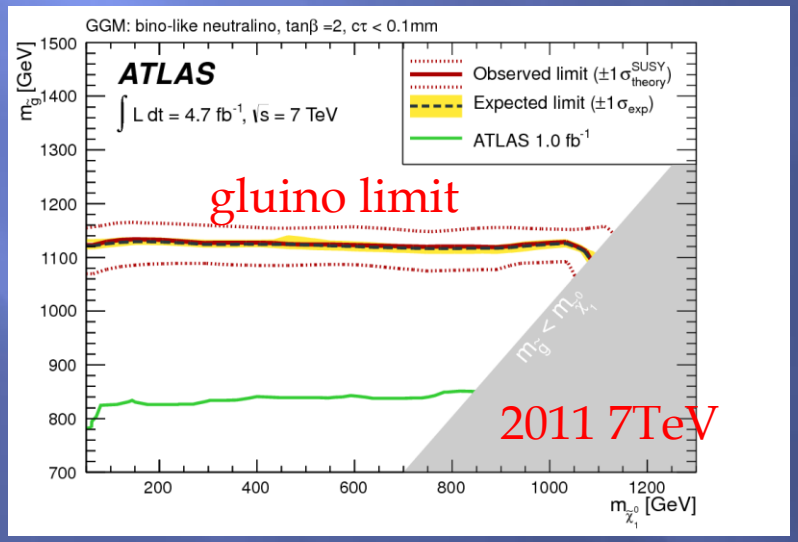
sensitive to gluino up to 1.3TeV

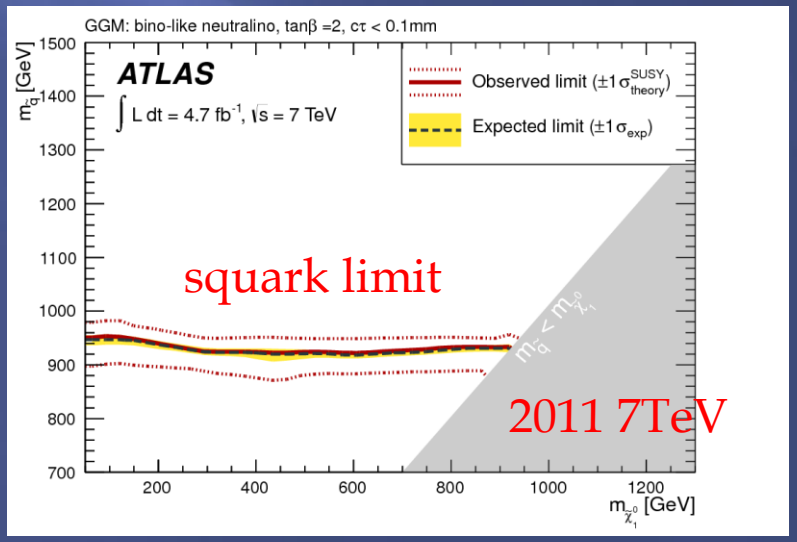
2 photons (GGM)

- Neutralino NLSP case (in GGM) decay into gravitino and photon
  → 2 photons(>50GeV) + jets + MET



2 gamma>50GeV + MET>125GeV





Exclusive search

(3rd generation / gaugino and slepton)

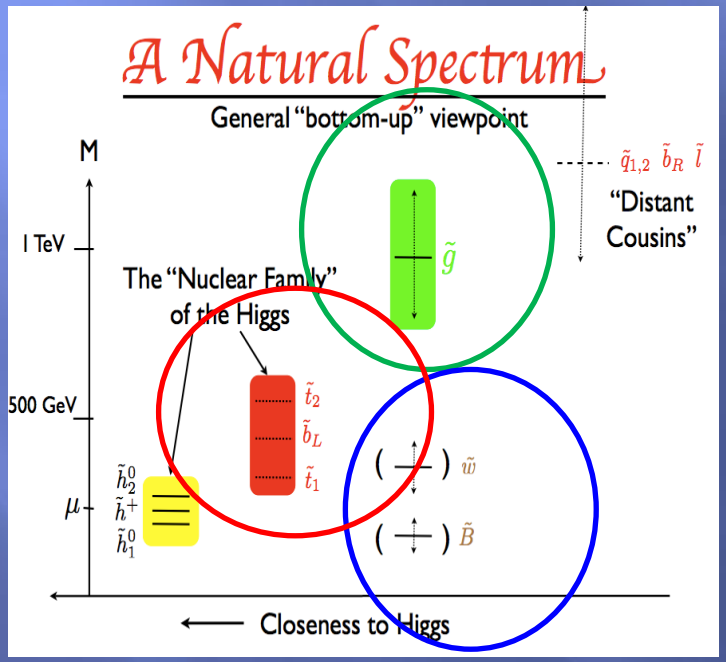
Natural SUSY searches

- Light squarks / Gluino … no evidence so far

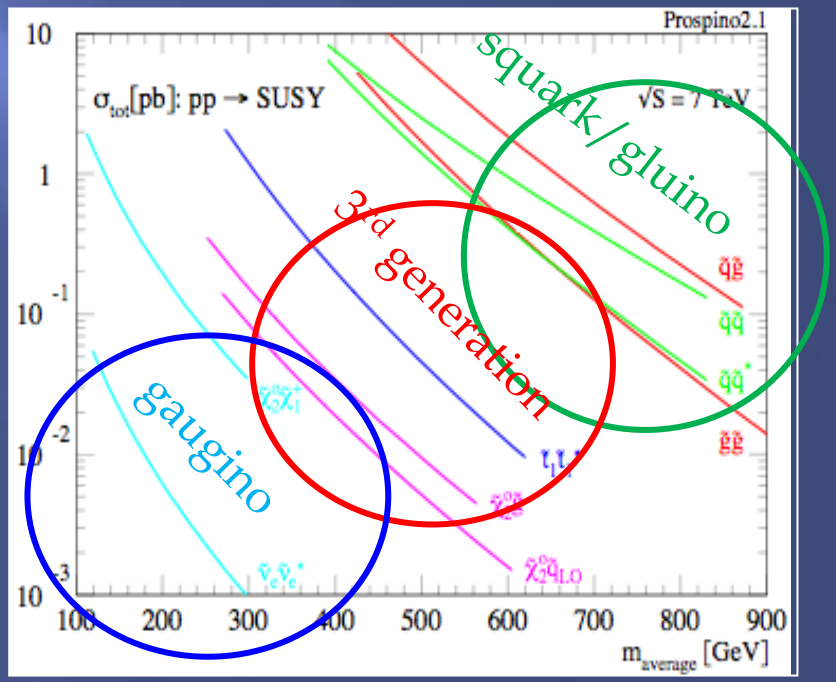
→ 3rd generation (stop, sbottom) direct production

→ gaugino direct production

small cross section but prominent characteristics → dedicated exclusive search

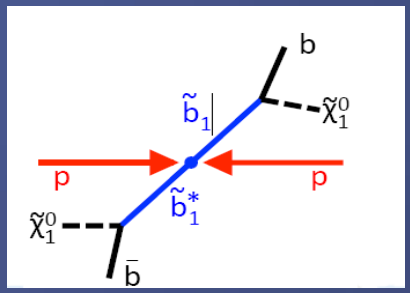


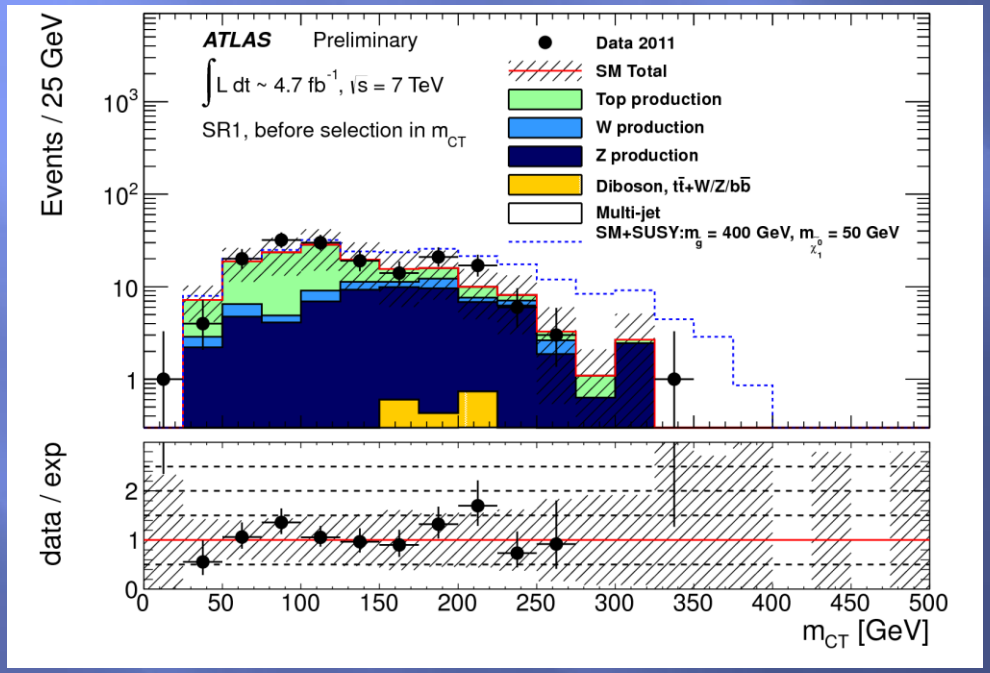
cross section of SUSY

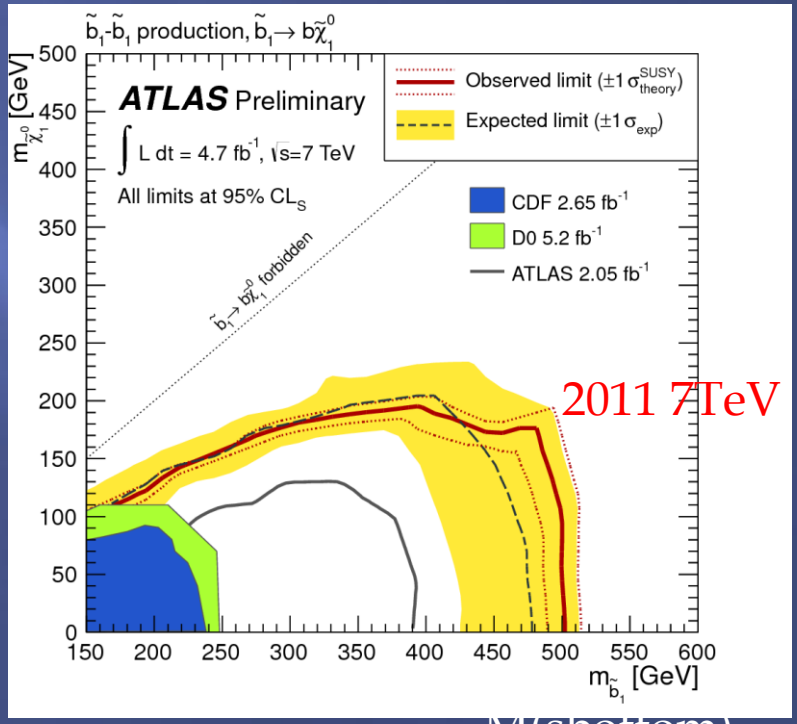


Direct sbottom

- Direct sbottom production, sbottom→ b + LSP (2body decay)
  2 b-jets / 2-bjets + ISR
- cut on M_{CT} (useful for 2 body decay, endpoint related to Msusy)







2011 7TeV

M(sbottom)

sensitive up to M(sbottom) ~500GeV

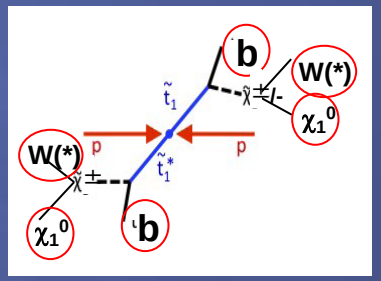
Direct stop

- Direct stop production

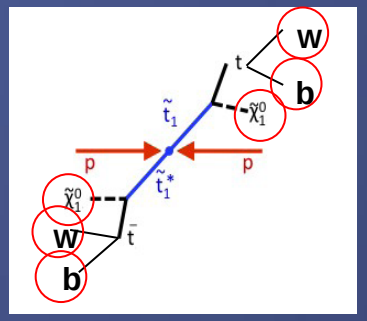
1. M(Stop) < m(top)
   stop → chargino + b
2. M(Stop) > m(top)
   stop → top + neutralino

→ exclusive channels for final states

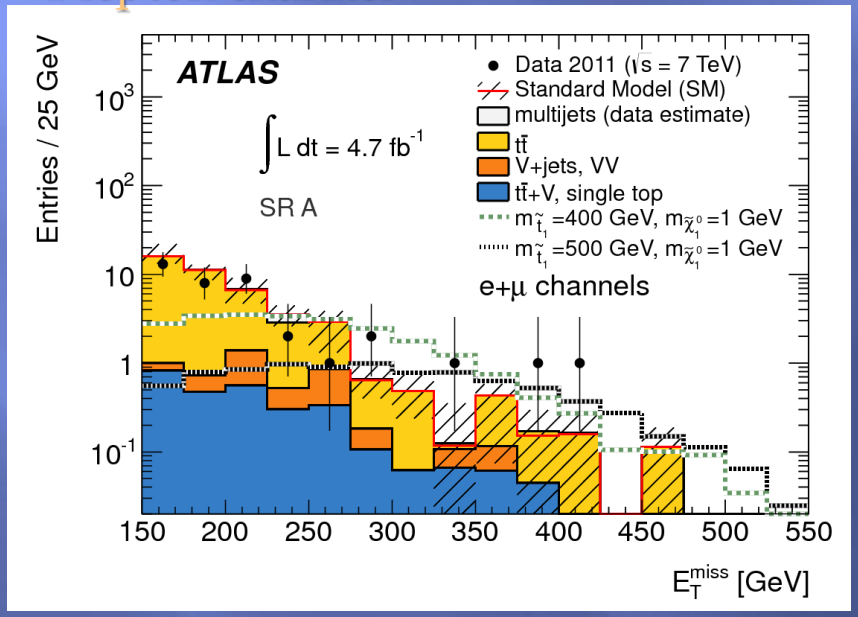
M(Stop) < m (top)

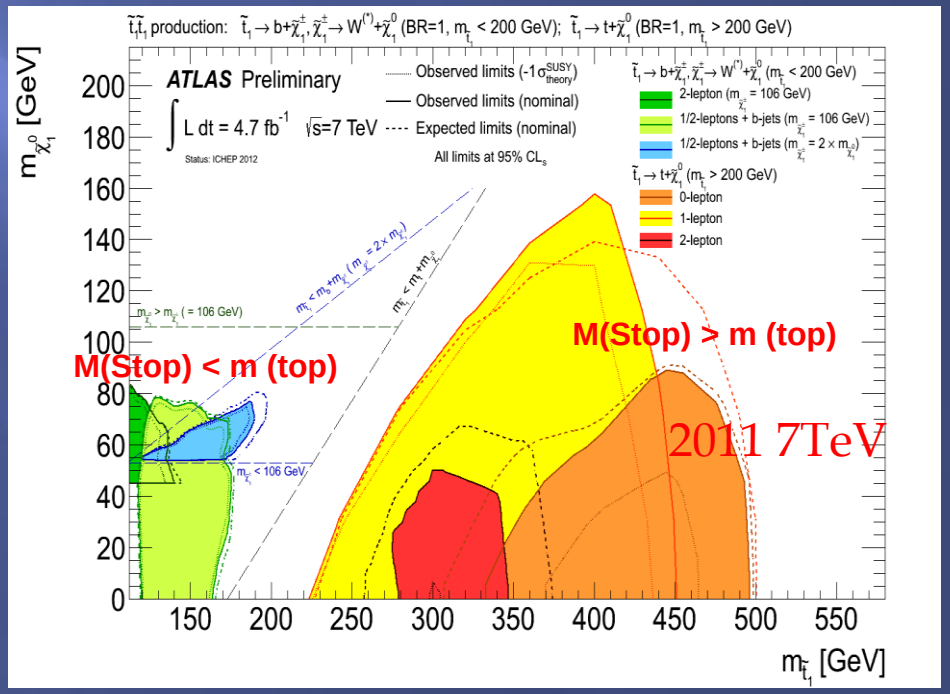


M(Stop) > m (top)



1 lepton channel



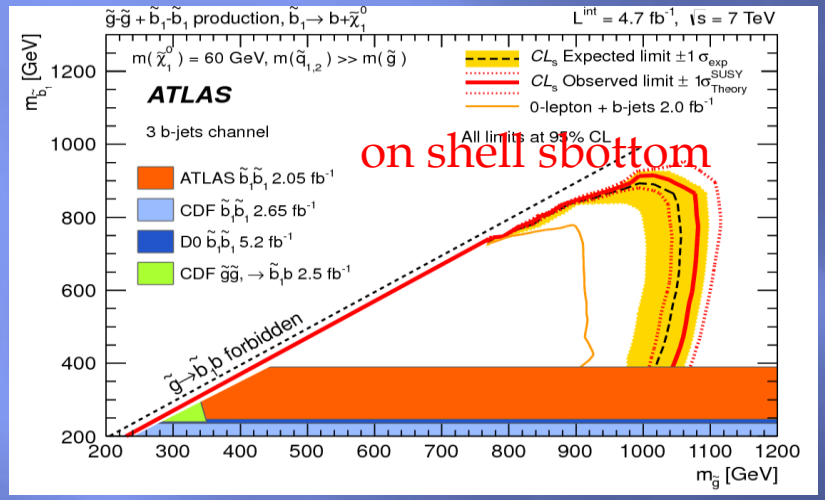


sensitive up to M(stop) ~500GeV

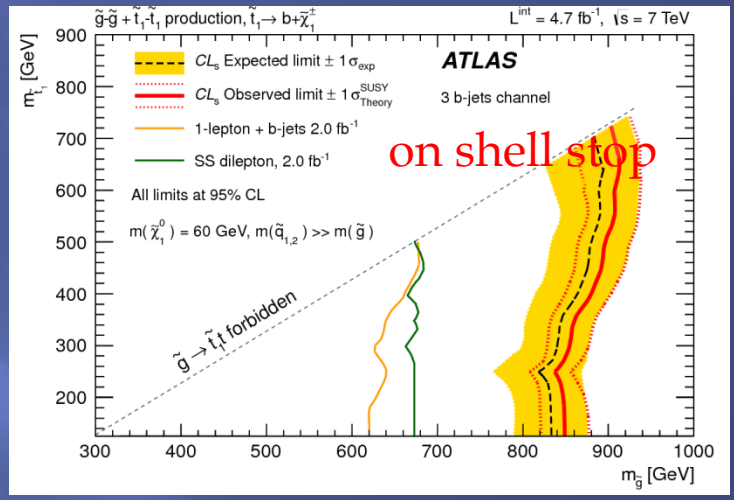
Gluino mediated sbottom/stop

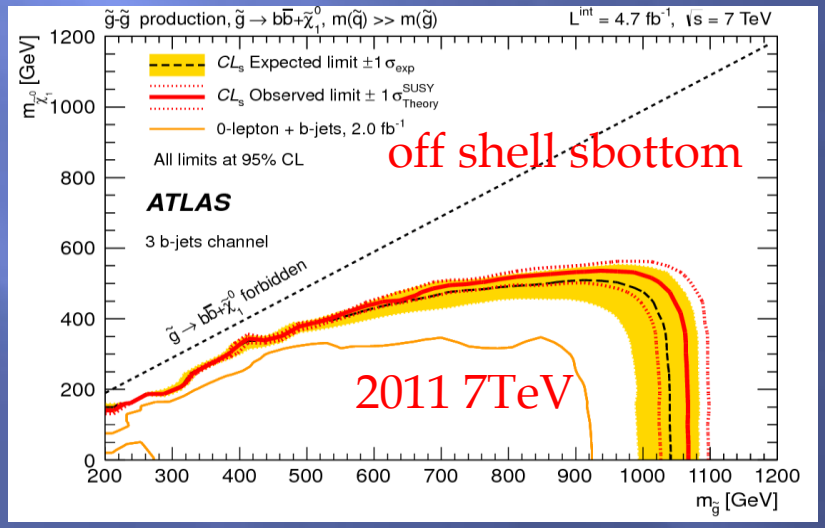
- sbottom/stop search in gluino decay chain

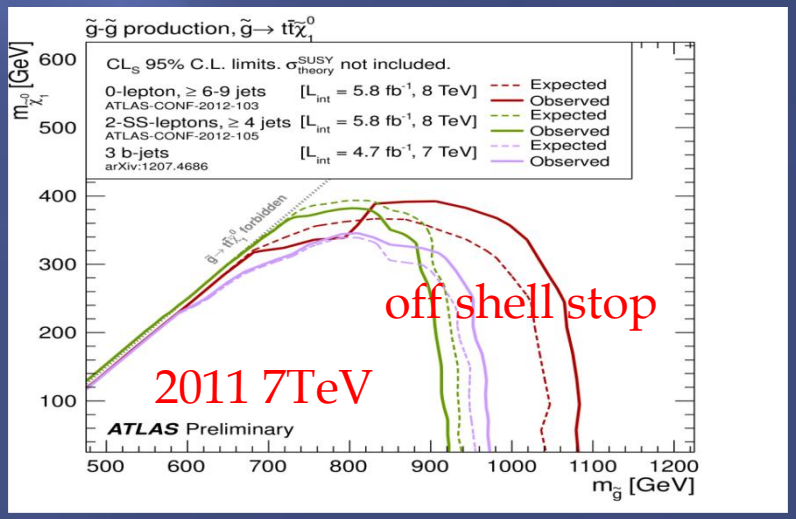
gluino → (sbottom + b) → 2b + LSP



gluino → (stop + top) → 2top + LSP







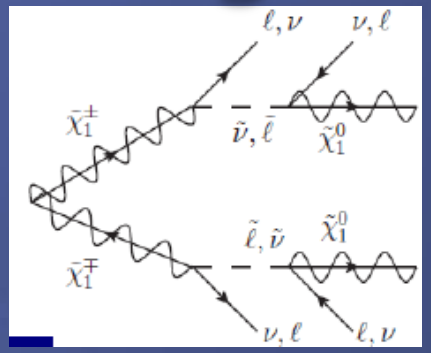
M(gluino)<1TeV for LSP<500GeV

M(gluino)<1TeV for LSP<380GeV

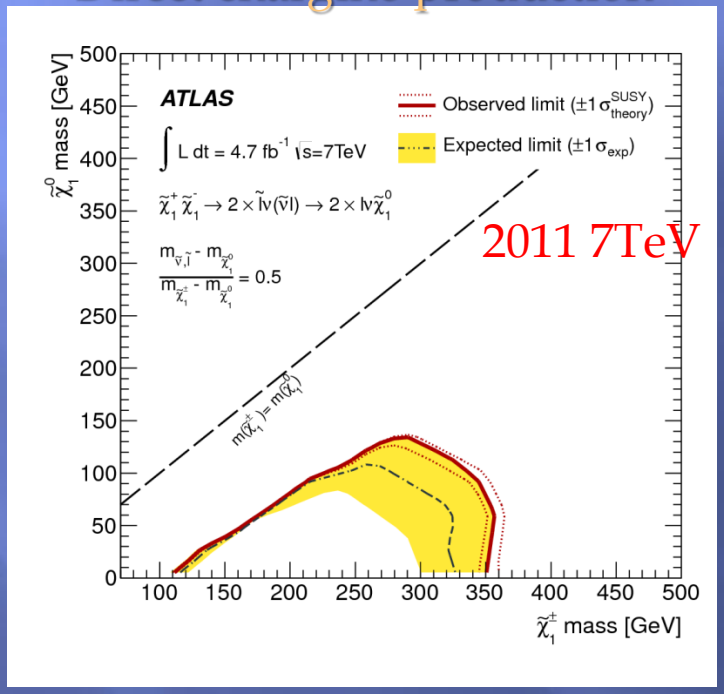
Direct slepton, Direct chargino

- direct slepton or chargino production
  - chargino → lepton + ν + neutralino
  - slepton → lepton + neutralino

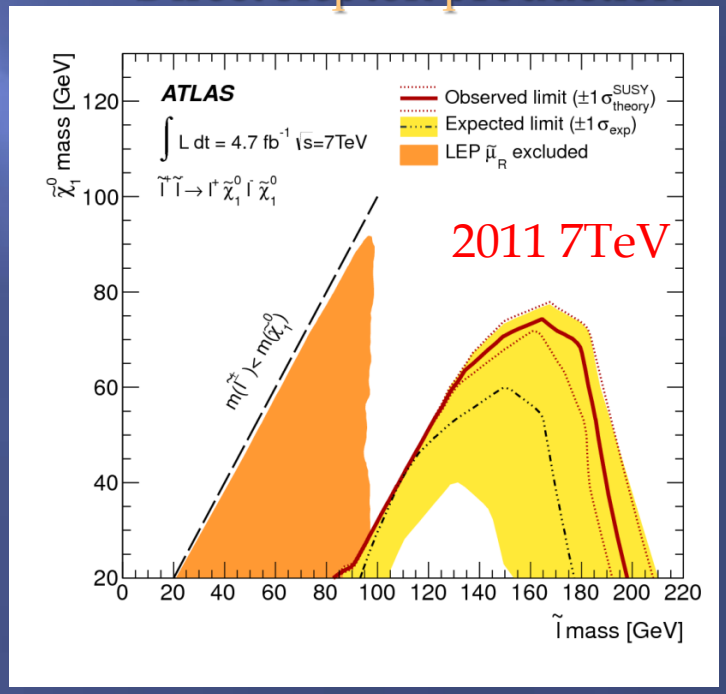
  2 lepton[e,μ] + MET + jet veto
- cut on MT2 (useful for simple topology of 2 objects)



Direct chargino production



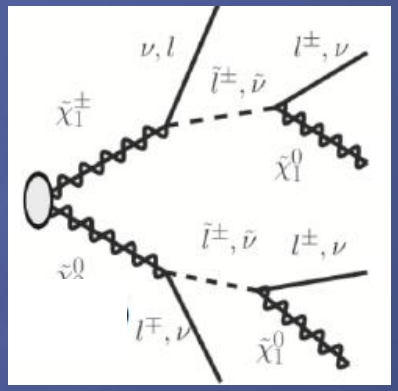
Direct slepton production



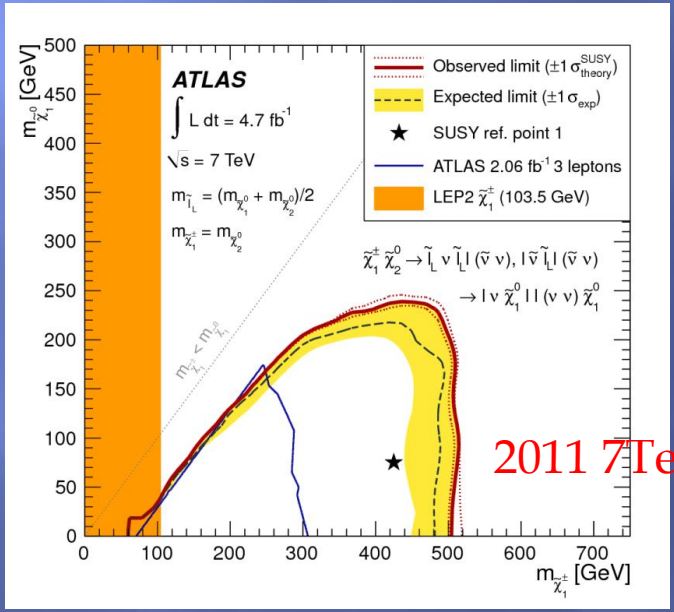
sensitive also to slepton mass

Direct chargino+neutralino

- chargino + neutralino production, decay into 3 leptons [e,μ] + MET

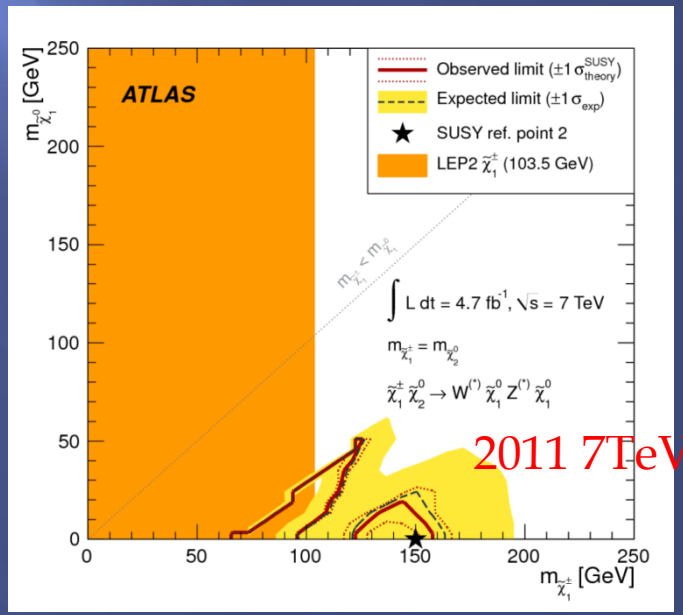


2slepton + lepton + 3ν → 3lep. + MET (intermediate slepton)



2011 7TeV

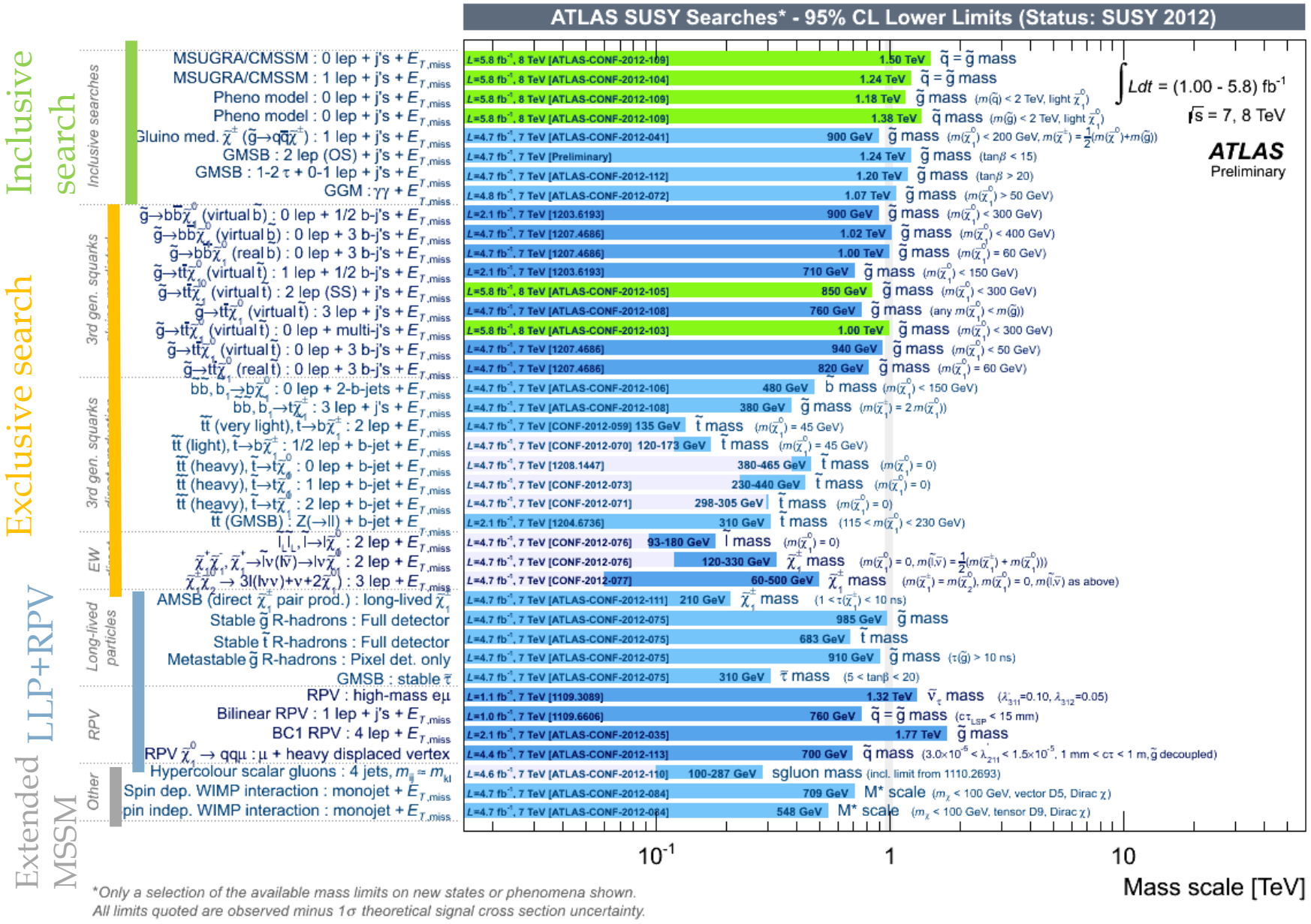
W+Z+2LSP → 3lep. + MET (intermediate W/Z)



2011 7TeV

summary

Mass limit summary



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

Summary

- No evidence so far
  - 4.7 fb^{-1} at 7TeV, and 5.8 fb^{-1} at 8TeV in some analyses
  - Inclusive searches and also dedicated searches for third generation, direct gaugino and sleptons
  - widely as possible (model-independent)
- Prospects
  - We have 16fb^{-1} data already, expect 20~25fb^{-1} by early 2013
  - many analyses for 8TeV in progress

backup

$$(E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{RefFinal}} = (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{RefEle}} + (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{RefGamma}} + (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{RefJet}} + (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{Muons}} + (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{SoftJets}} + (E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{x(y)}}^{\mathrm{CellOut}},$$

$$m_{\mathrm{T}} = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - cos(\Delta\phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}})))},$$

$$H_T = p_T^{\ell} + \sum_{j=1}^{N_{jet}} p_T^{jet_j}$$

$$m_{\mathrm{eff}}^{incl} = H_T + E_{\mathrm{T}}^{\mathrm{miss}} = p_T^{\ell} + \sum_{j=1}^{N_{jet}} p_T^{jet_j} + E_{\mathrm{T}}^{\mathrm{miss}}$$

$$M_{\mathrm{CT}}^2(v_1, v_2) = 2p_T(v_1)p_T(v_2)(1 + \cos\phi_{12}),$$

$$m_{T2}^2(\chi) \equiv \min_{\not{q}_T^{(1)} + \not{q}_T^{(2)} = \not{p}_T} \left[\max \left\{ m_T^2(\mathrm{p}_T^{\pi^{(1)}}, \not{q}_T^{(1)}; \chi),\ m_T^2(\mathrm{p}_T^{\pi^{(2)}}, \not{q}_T^{(2)}; \chi) \right\} \right].$$