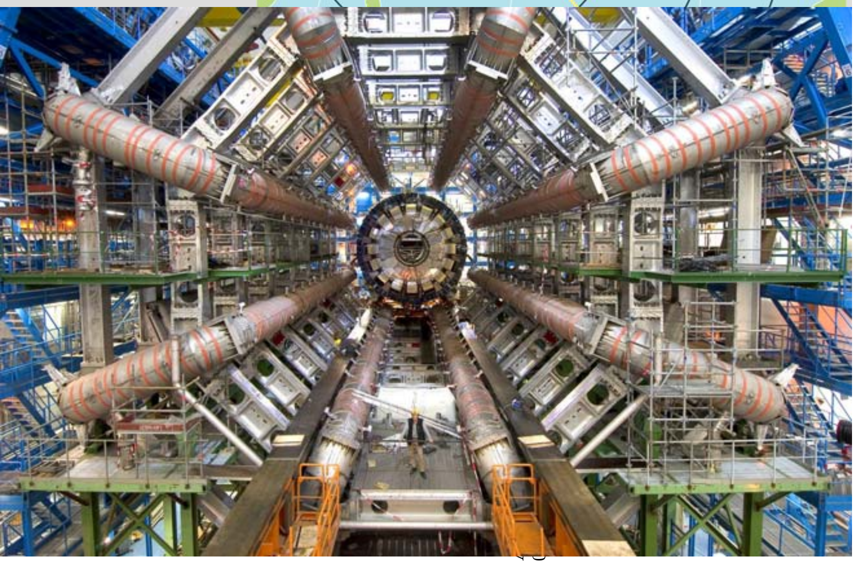
BSM signatures at ATLAS



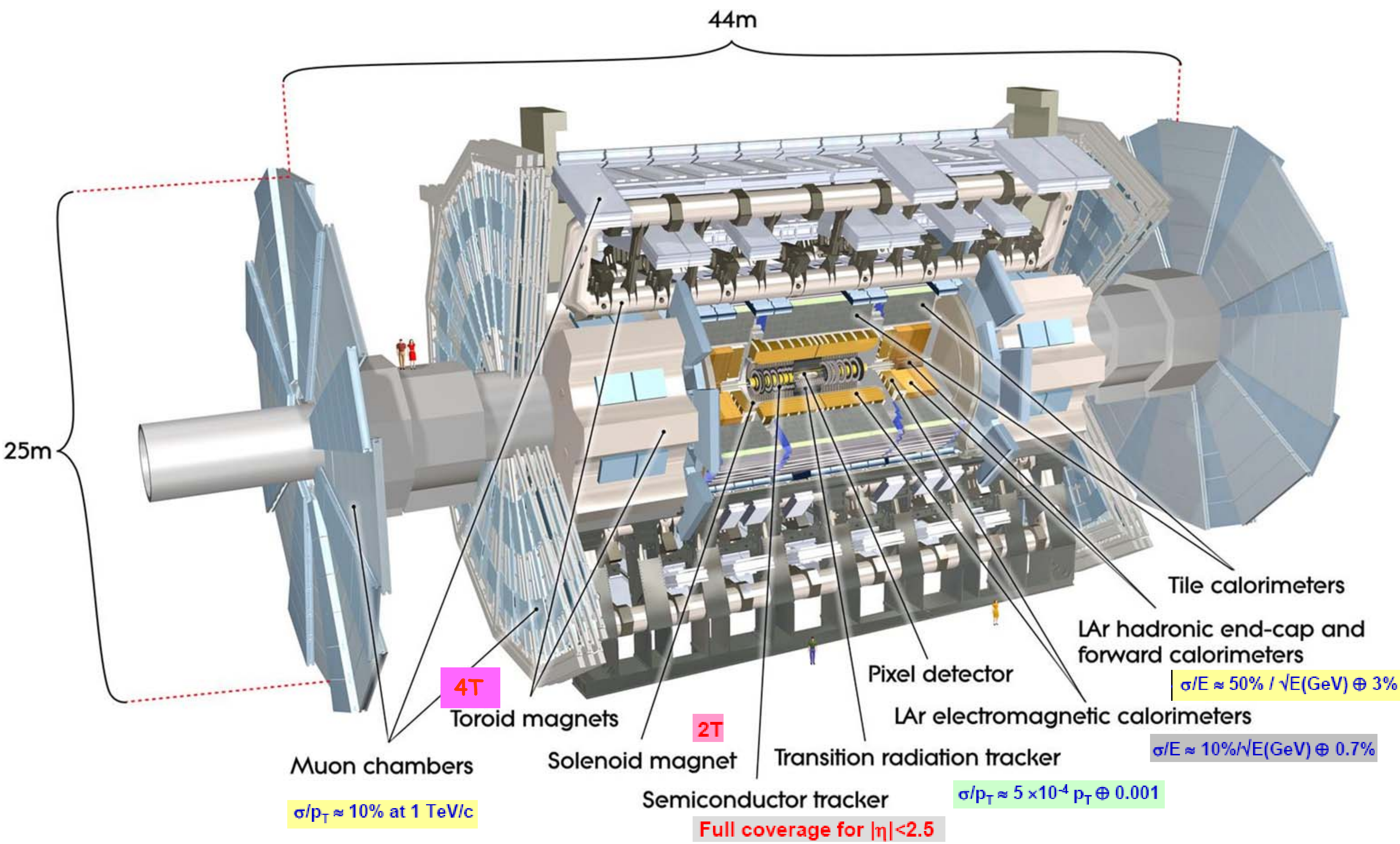
- ATLAS
- Supersymmetry
- Exotics
- Outlook

Fabienne Ledroit

on behalf of the **ATLAS** collaboration

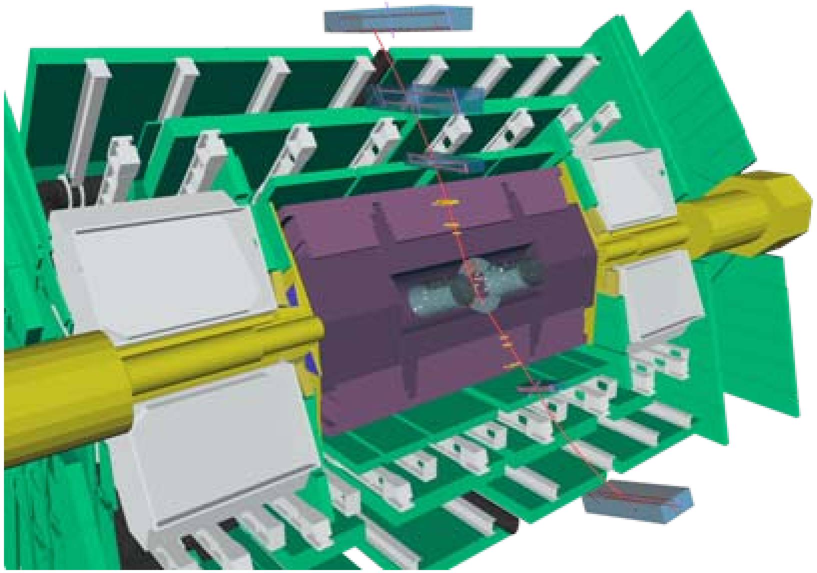
BSM-LHC 09, Northeastern U. (Boston)

ATLAS detector



ATLAS status

After cosmic ray data taking campaign (>200 Mevents recorded)

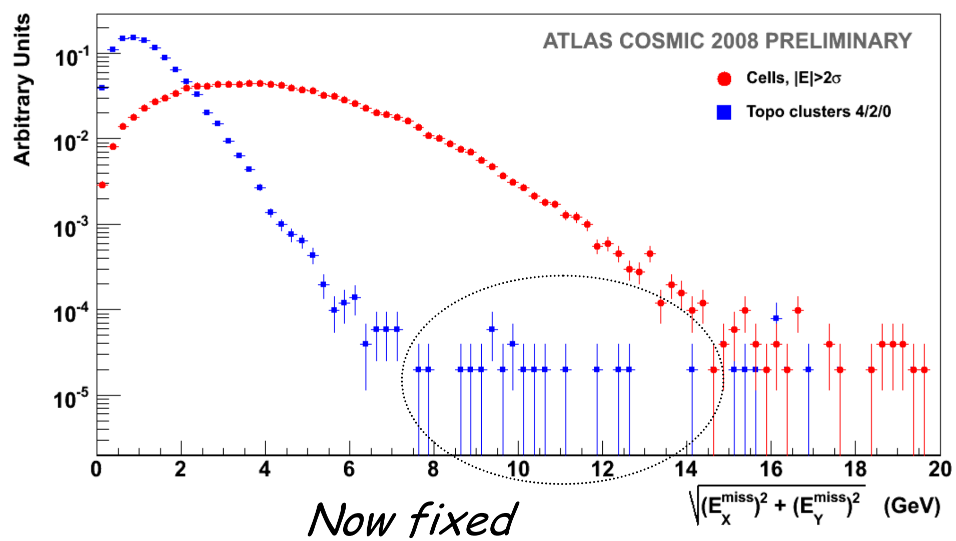


ATLAS will enter the 2009/2010 running period with

- very few dead channel (~ 1%)
- low and well understood noise

Missing E_T performance on random triggers

For *all* cells/clusters with $E>2\sigma_{noise}$ sum E_x and E_y



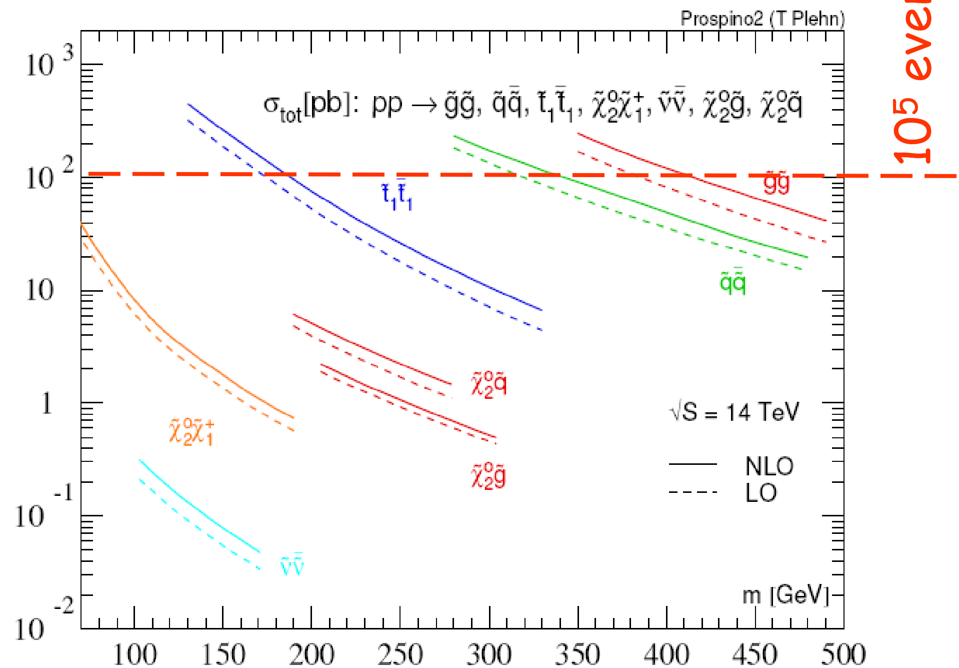
SUSY

Breaking mechanism

- mSUGRA Neutralino LSP
- GMSB Gravitino LSP
- AMSB
- Split SUSY
- ...

R-parity:

conserved or not



▪**Production** dominated at LHC by ***strongly interacting particles:*** q̃,g̃

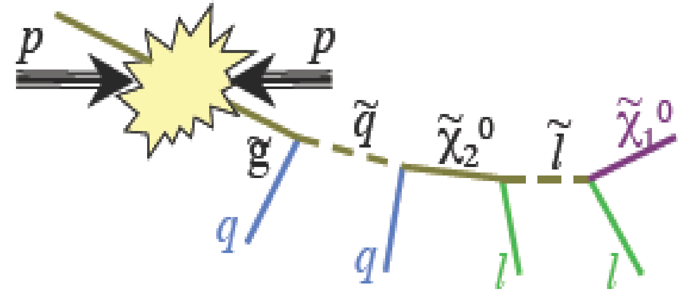
▪**Cross sections** depend primarily ***on masses***

All SUSY results at 14 TeV CM energy

ATLAS baseline strategy

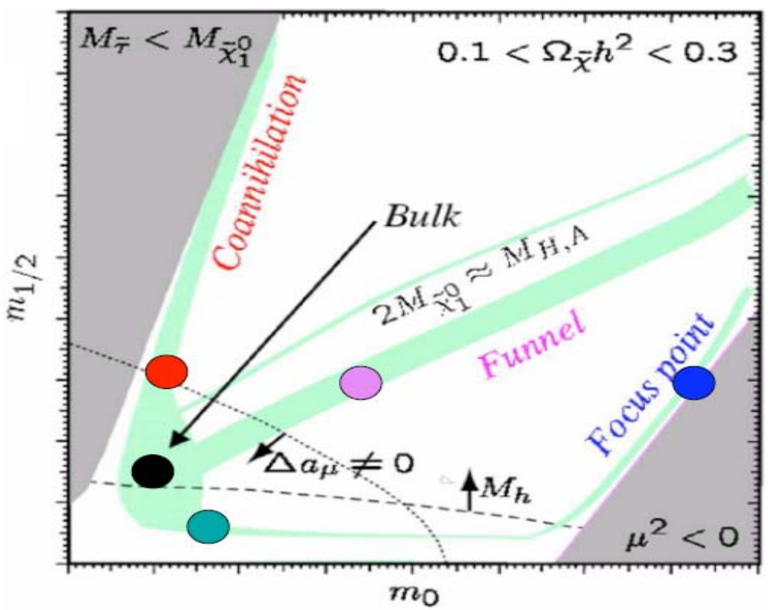
$\tilde{q}$ and $\tilde{g}$ typically heaviest

$\Rightarrow$ *complex cascades to LSP*



RpC SIGNATURE = E_T^{miss} + high E_T jets + leptons

Search for ***inclusive*** topologies $\Rightarrow$ **coverage!**



Use **mSUGRA/RpC** as benchmark

Span broad parameter space

SU1 m($\tilde{g}$)~830 GeV, m($\tilde{q}$)~750 GeV, σ~11 pb

SU2 m($\tilde{g}$)~860 GeV, m($\tilde{q}$)~3500 GeV, σ~7 pb

SU3 m($\tilde{g}$)~720 GeV, m($\tilde{q}$)~620 GeV, σ~28 pb

SU4 m($\tilde{g}$)~410 GeV, m($\tilde{q}$)~410 GeV, σ~402 pb

SU6 m($\tilde{g}$)~900 GeV, m($\tilde{q}$)~850 GeV, σ~6 pb

Inclusive analysis

Baseline selection:

- $\geq$4 jets, E_T^{miss} >100 GeV,
  E_T^{miss}> 0.2 M_{eff}, S_T > 0.2
- exactly 0 *or* 1 *or* 2 leptons (e or μ)
- $\Delta\phi$(j, E_T^{miss})>0.2 *or* M_T (ℓ, E_T^{miss})>100 GeV

$M_{eff}=\Sigma_i|p_T(j_i)|+ E_T^{miss}$ [+ Σ_j $|p_T(\ell_j)|$]
S_T=transverse sphericity

Background-like: $\Delta\phi$(jet, E_T^{miss})~0

Signal-like: $\Delta\phi$(jet, E_T^{miss})>>0

Backgrounds

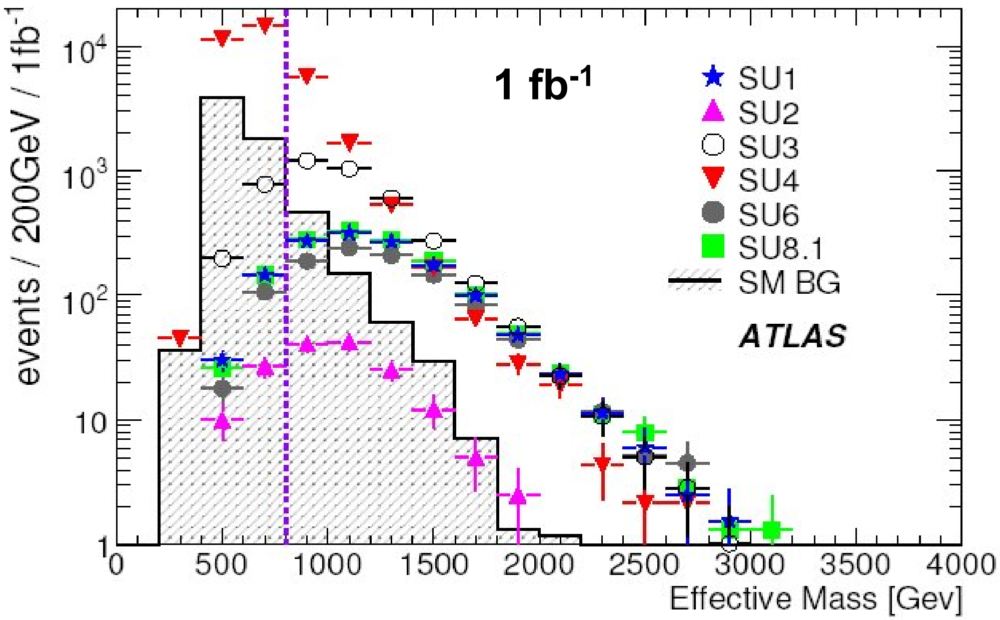
QCD multi-jets — *instrumental fake E_T^{miss}*

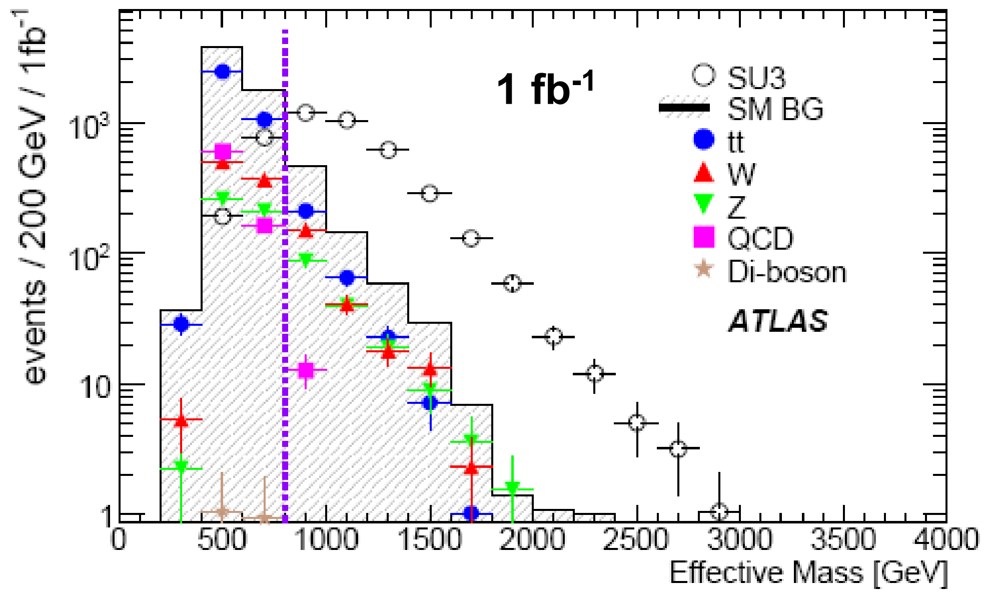
Top quark pairs
W, Z with additional jets
WW/WZ/ZZ/single top

} *real E_T^{miss}*

ATLAS emphasis: data driven estimates

Inclusive 0 lepton analysis





High sensitivity!

All results for 1 fb^{-1} integrated luminosity: need confidence in detector performance, trigger, reconstruction, backgrounds…

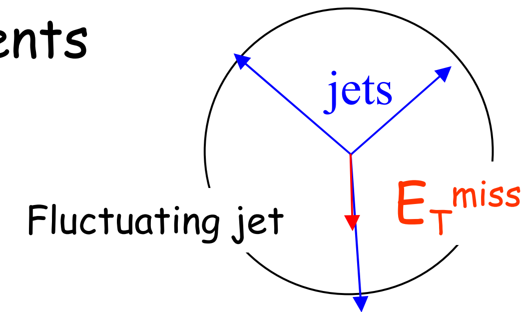
[sensitivity to SUSY beyond the Tevatron already with 10 pb^{-1}]

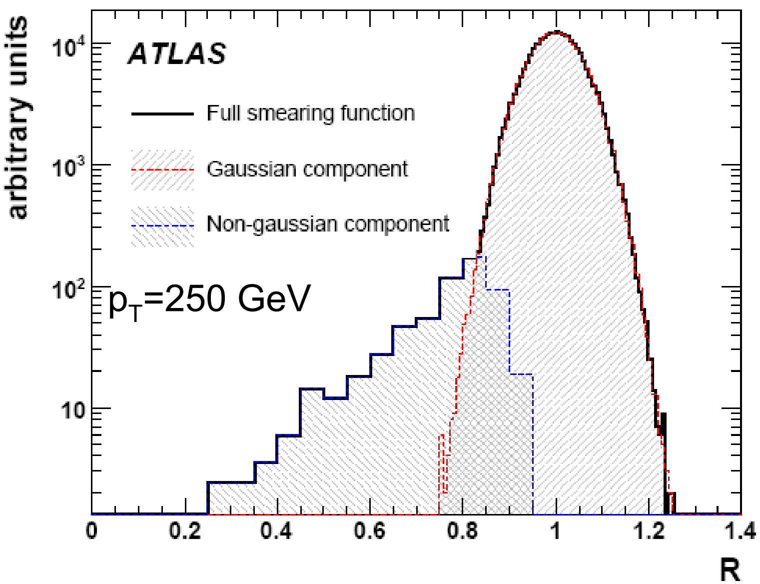
QCD multi-jet background

Step 1: Measure Gaussian response function *balance* in γ+jet events

$$R_1 = 1 + \frac{\mathbf{p}_T^{\rm miss} \cdot \mathbf{p}_T(\gamma)}{|\mathbf{p}_T(\gamma)|^2}$$

Step 2: Measure non-Gaussian response in "Mercedes" events





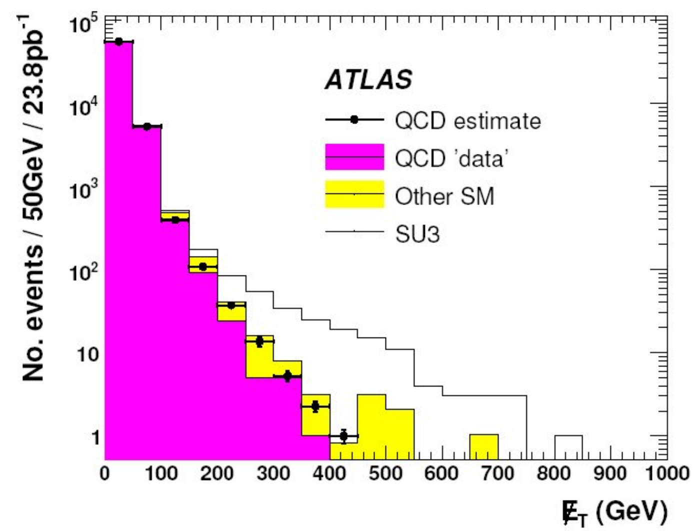
$\vec{p}_T(j,\text{true}) \approx \vec{p}_T(j) + \vec{E}_T^{miss}$

$R = p_T(j)/p_T(j,\text{true})$

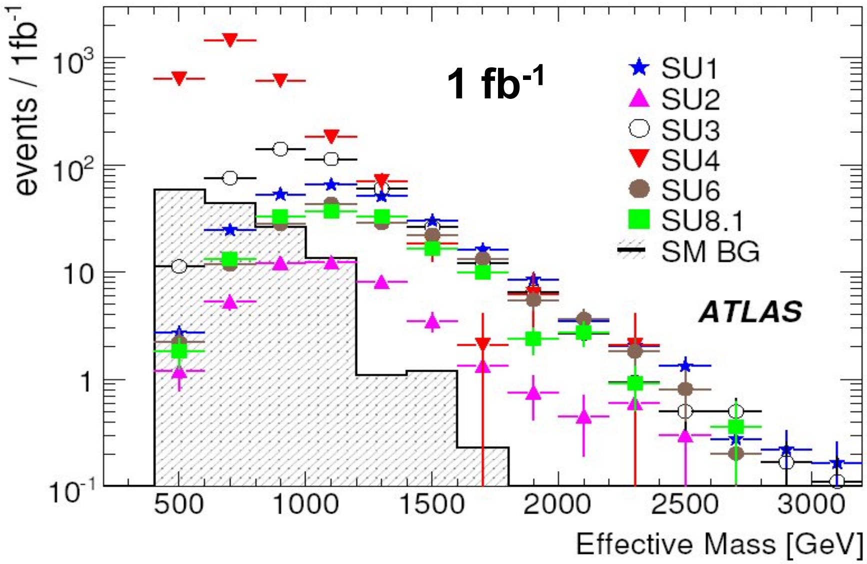
Normalize with *balance* in dijet events

$$R_3(j) = 1 + \frac{\mathbf{p}_T^{\rm miss} \cdot \mathbf{p}_T(j')}{|\mathbf{p}_T(j')|^2}$$

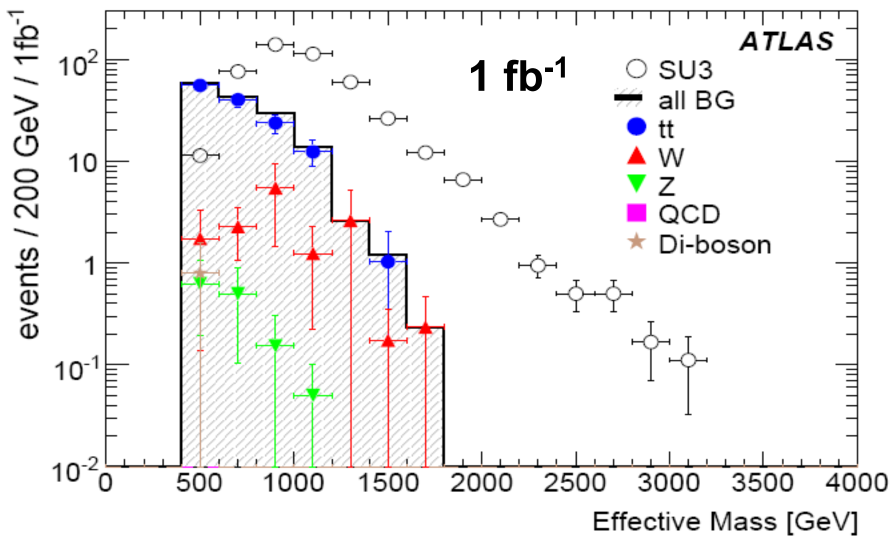
Step 3: Apply response function on 'seed' events (low E_T^{miss} multijet)
⇒ smear all jets, recompute E_T^{miss},
normalize at low E_T^{miss}



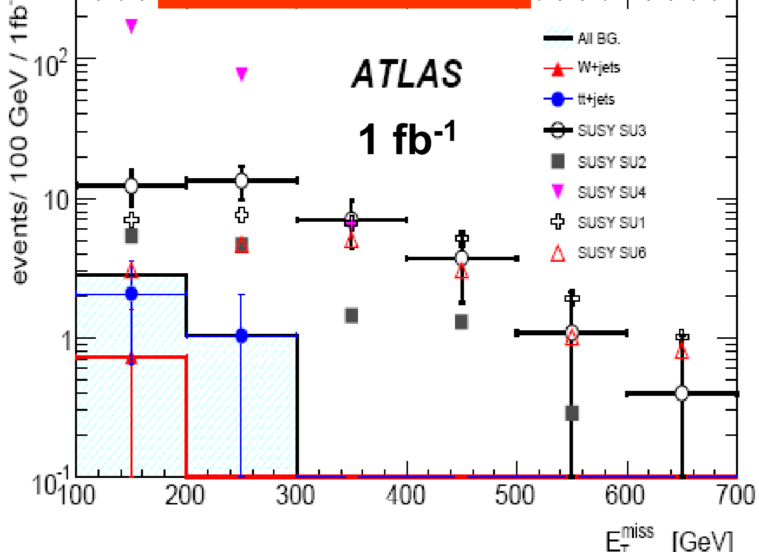
Inclusive 1 or 2 lepton analyses



1 lepton



2 SS leptons



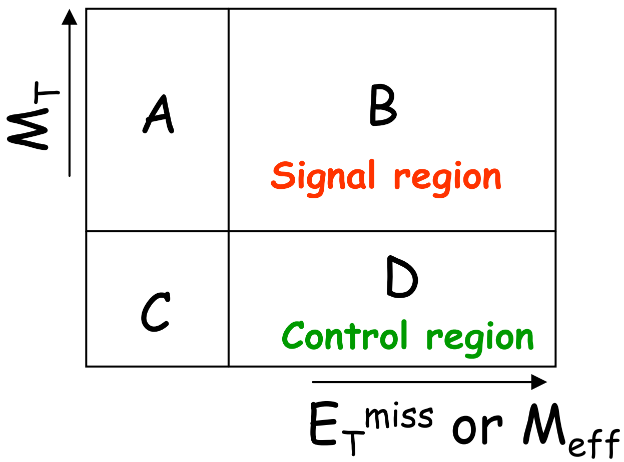
Several other inclusive topologies studied:
2 opposite sign dilepton, trilepton, tau-leptons, b-jets,...

Top and W+jets background

M_T (ℓ, E_T^{miss}) discriminates well top and W+jets

If E_T^{miss} (or M_{eff}) shape **independent** of M_T (MC):

can use low M_T region as *control sample:*

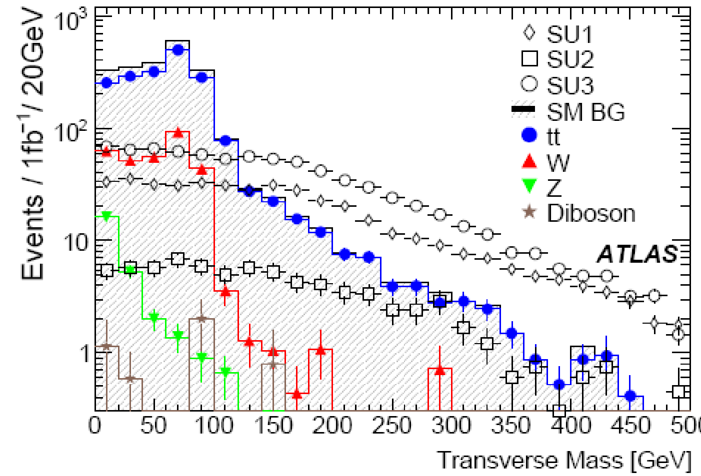


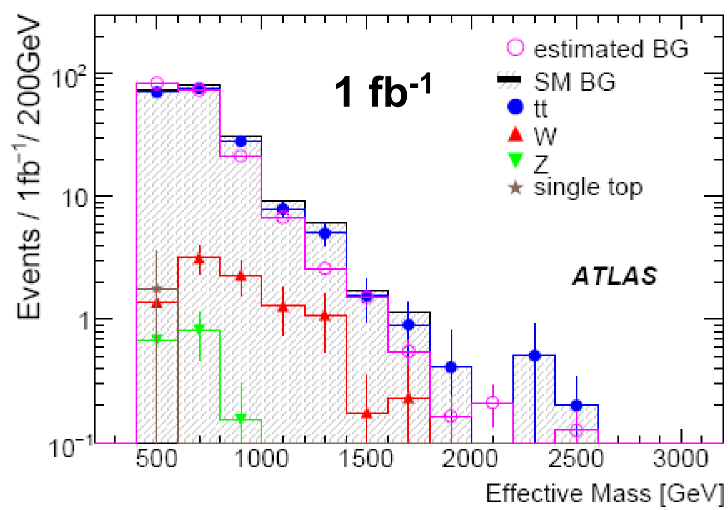
Extrapolate number of background events N from control to signal region:

$$N(B) = N(D) \times N(A) / N(C)$$

Contamination by SUSY ⇒ need to iterate!

Very active field





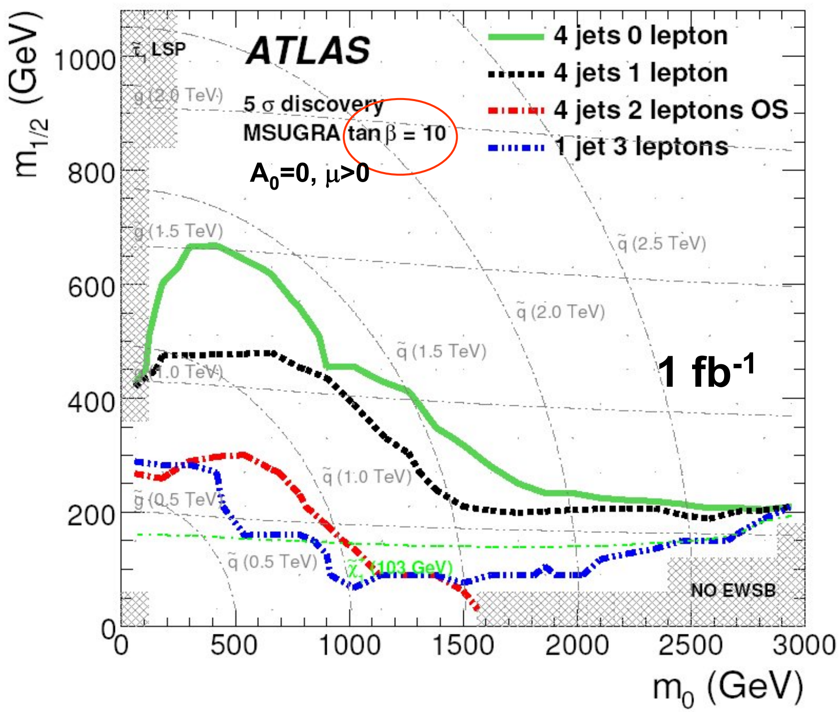
Many other methods studied

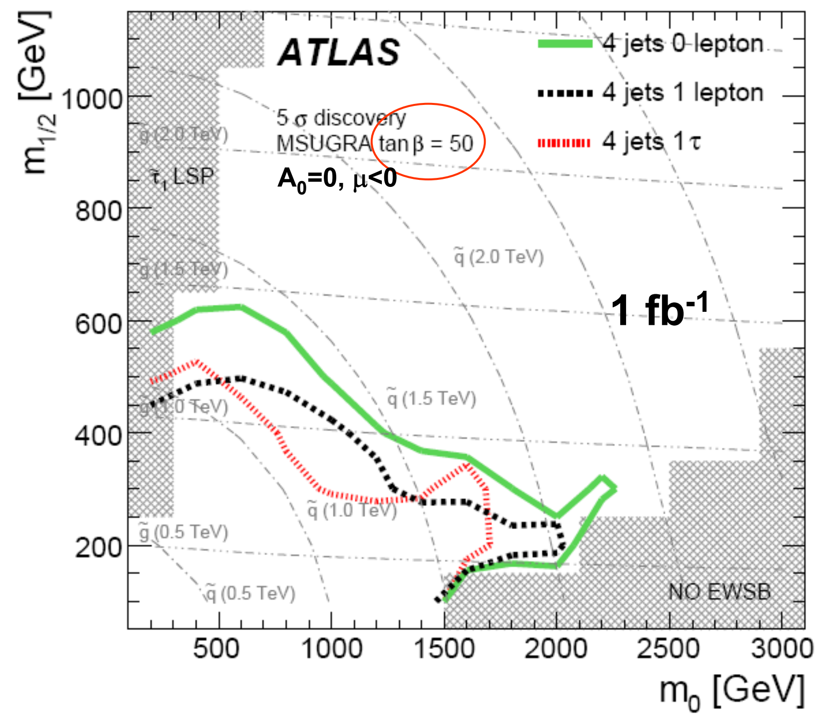
Inclusive analysis: discovery reach

Scan mSUGRA parameter space, optimize M_{eff} cut

Use LO signal cross sections and fast simulation

Background systematic uncertainty with 1 fb^{-1}: **QCD 50%, W/Z/top 20%**





Reach dominated by E_T^{miss}+jets, multiple signatures over most of phase space

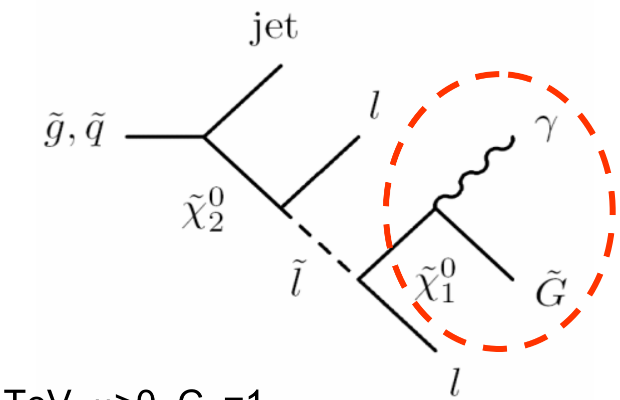
With 1 fb^{-1}: reach $m(\tilde{g})$~ 0.5-1.5 TeV [Tevatron: $m(\tilde{g})$>300-400 GeV]

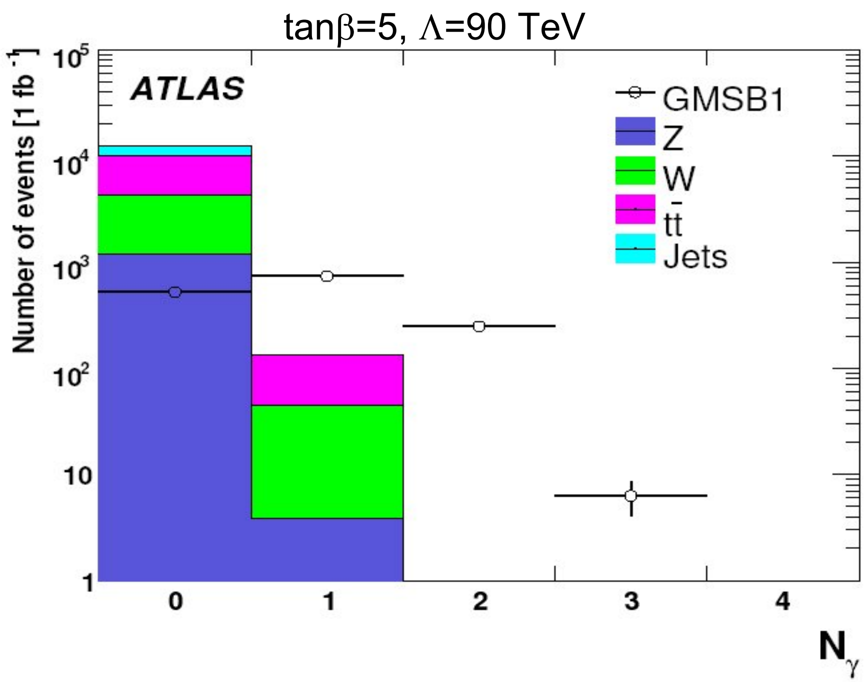
Final states with photons

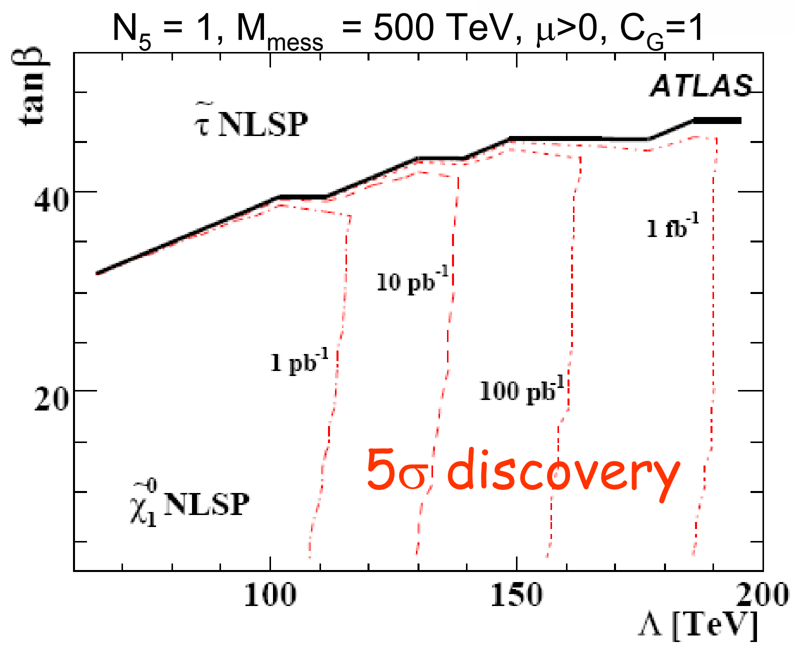
GMSB with *neutralino NLSP* *(N_5=1)*:

high p_T (prompt) photons

Usual inclusive preselection + **≥ 1 photon**







Scan

tanβ, Λ

Use fast simulation

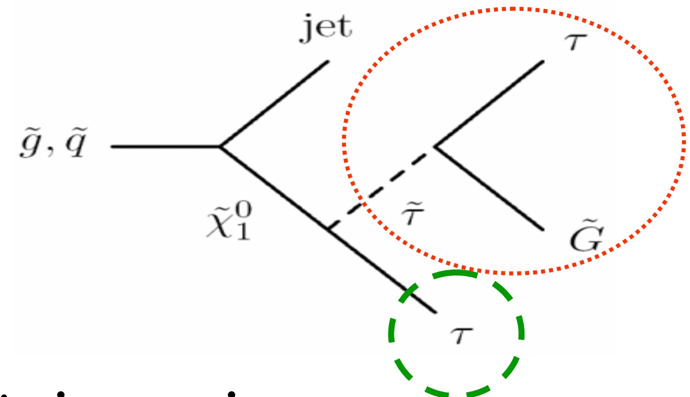
C_G>1: non-pointing photons

*⇒ **neutralino lifetime** determination*

See talk by H. Hadavand

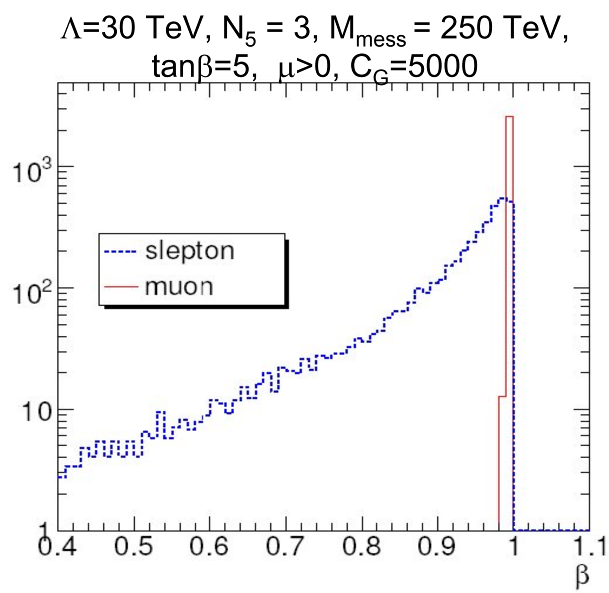
Long lived charged particles

GMSB with *slepton NLSP* *($N_5 \geq 2$)*:
high p_T prompt leptons,
(long lived) sleptons

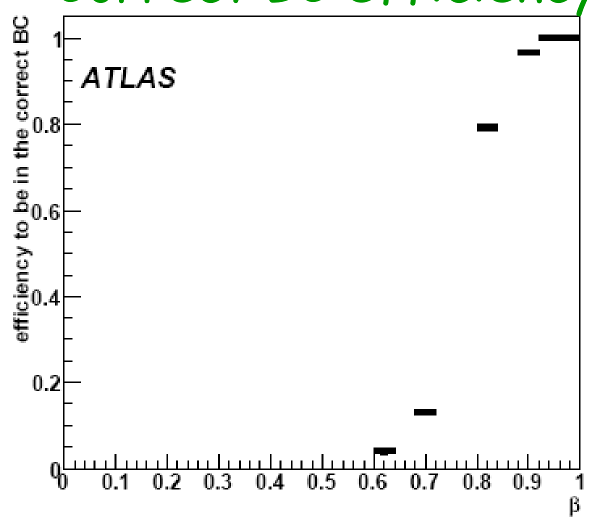


At β=1, 25 ns ↔ 7.5 m
at β=0.8, +15 ns wrt μ

⇒ timing/trigger issues:
need to process more than 1 beam crossing



Correct BC efficiency

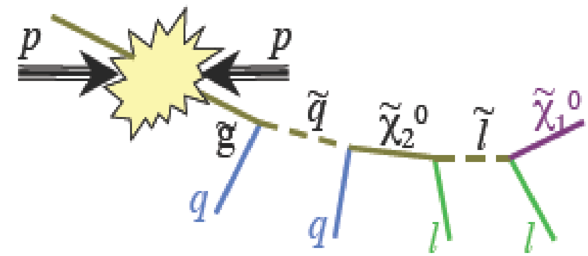


After muon trigger-chambers time calibration, discovery potential follows production cross section

Also R-hadrons in Split SUSY

After discovery

What kind of SUSY is it?



⇒ edges and thresholds in dilepton, lepton-jet, dijet invariant mass distributions

- Mass values

⇒ rate of tau leptons

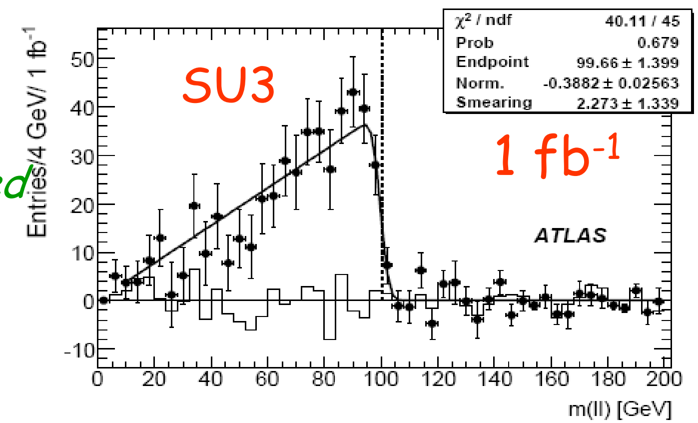
- $\tan\beta$

⇒ trileptons

- chargino/neutralino couplings

…

Flavour subtracted

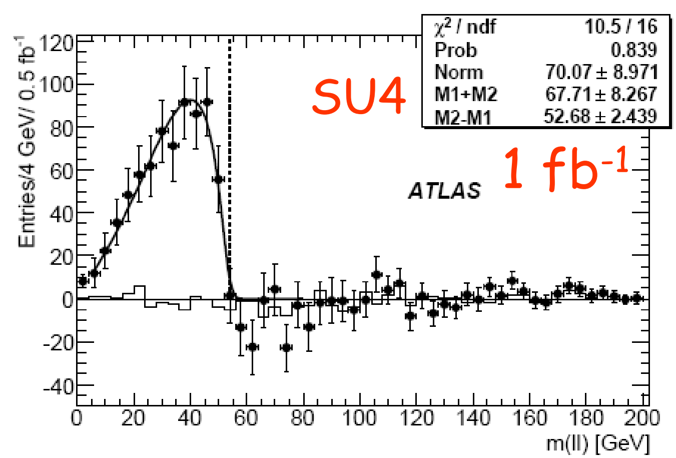


$\tilde{\chi}_2^0$ *2-body decay*

Is it SUSY at all? *(or UED, LH with T-parity,…)*

⇒ spin measurements

« Inverse LHC problem »



$\tilde{\chi}_2^0$ *3-body decay*

see talks by A. Barr, D. Zerwas

Exotics

Numerous BSM theories!

GUTs → Z′, W′, leptoquarks, heavy fermions, H^{++},...

Compositness → q*, ℓ*

Technicolor → technimesons (ρ_T, π_T, ω_T),...

Extra-dimensions → Z_{KK}, W_{KK}, g_{KK}, G*, radion, black holes,...

Little Higgs, Twin Higgs → Z_H, W_H, A_H, T,...

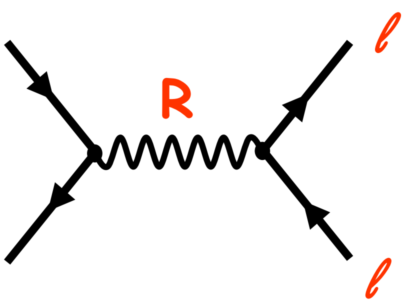
Hidden Valley → $\pi_V{}^0$,...

...

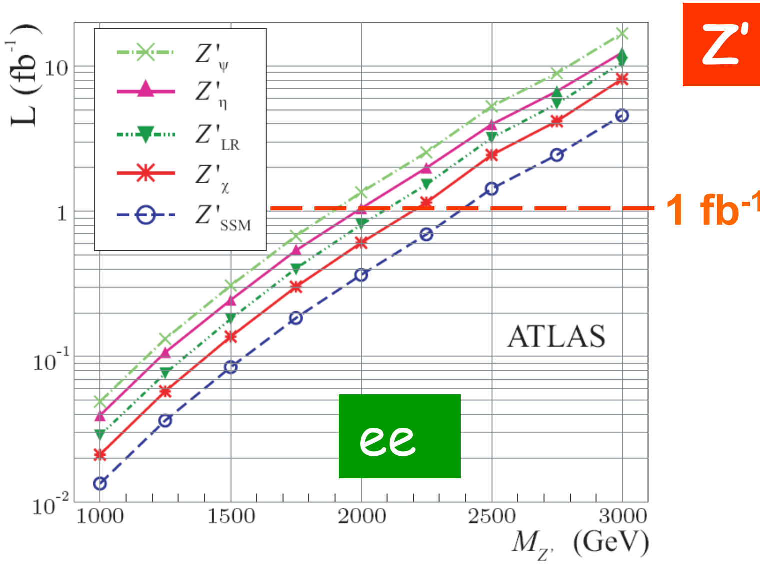
ATLAS strategy: final state approach

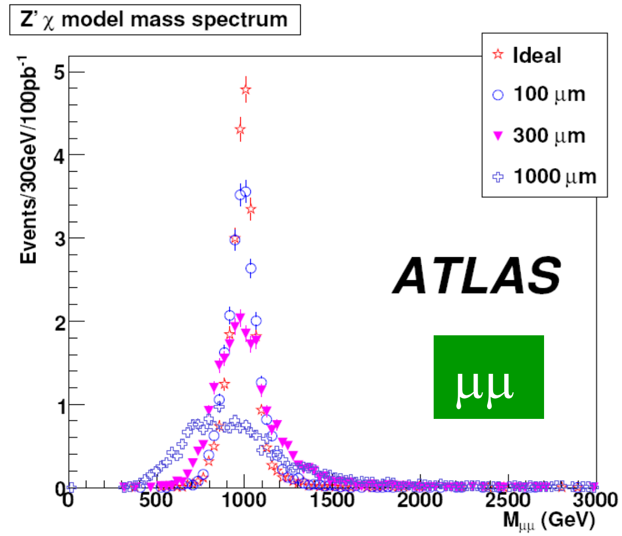
Lepton+X, Jet+X, Long Lived Particles, Dibosons, « Busy events »

Dilepton resonances



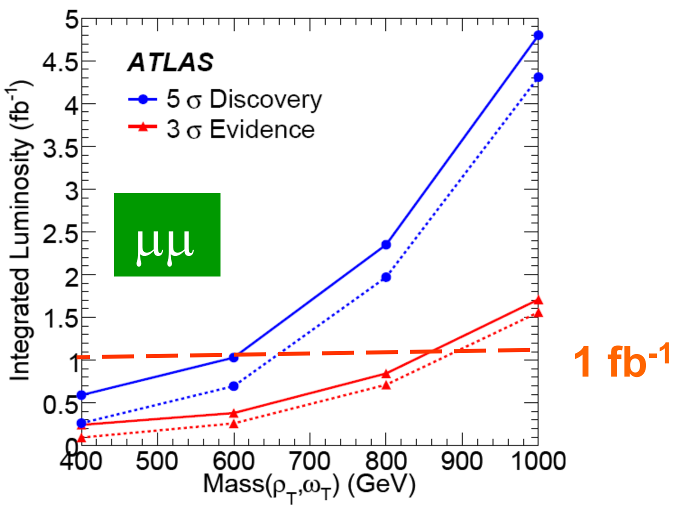
Z'

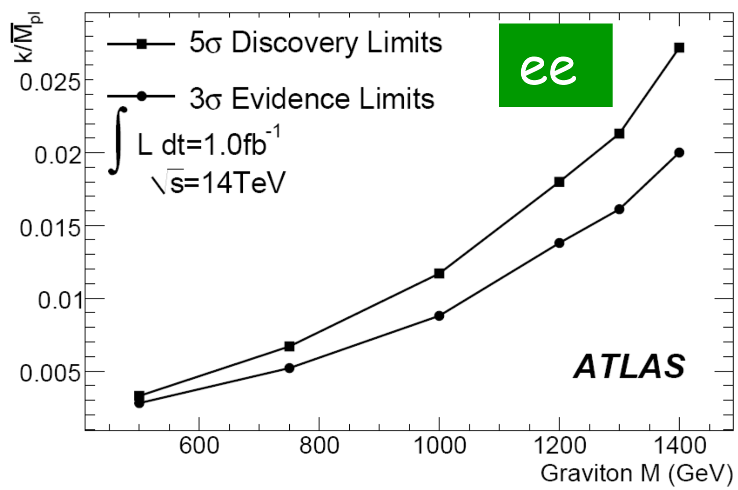




TCSM

ω_T, ρ_T





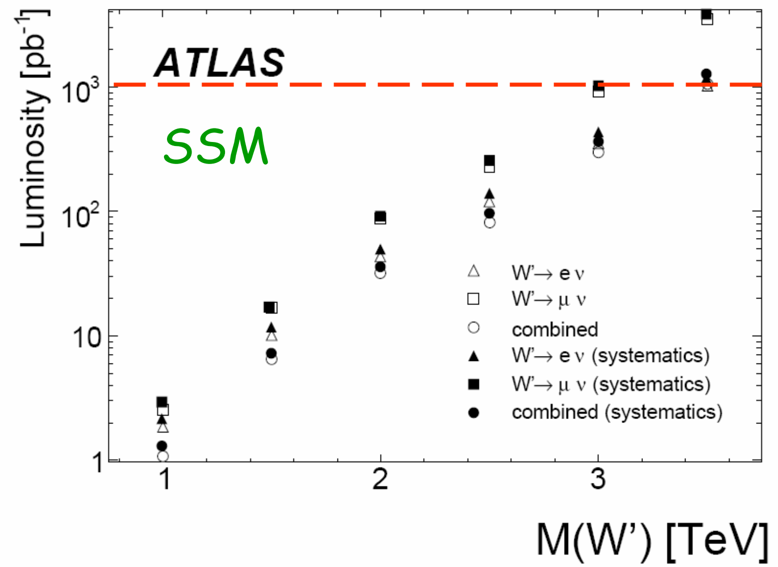
RS

G*

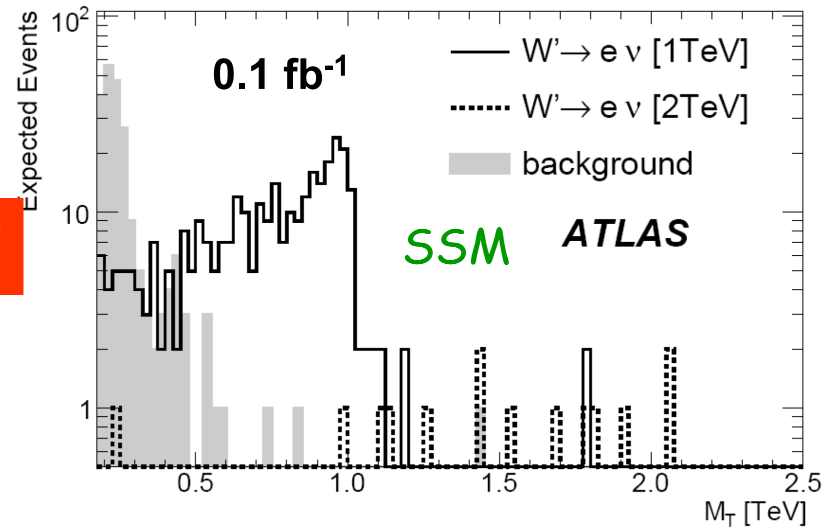
Probe TeV range with low luminosity!

See talk by L. Flores

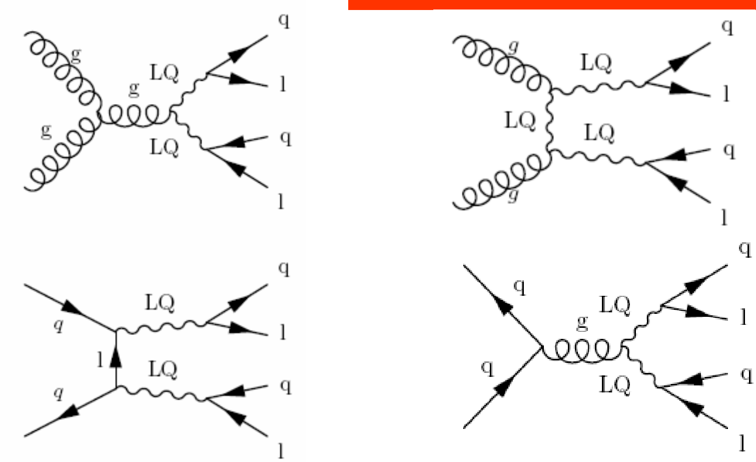
Lepton+X resonances

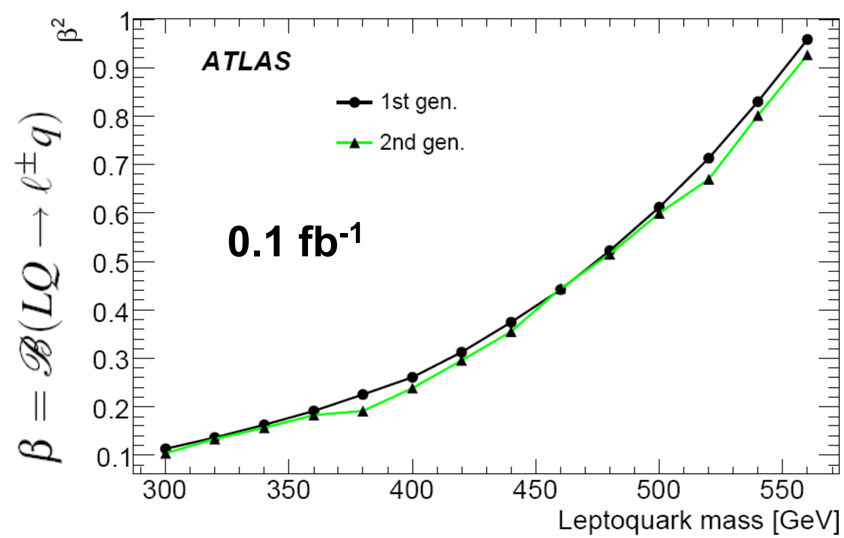


ℓ + E_T^{miss}: W'



ℓ+jet: leptoquark





See talk by L. Flores

Long lived *neutral* particles

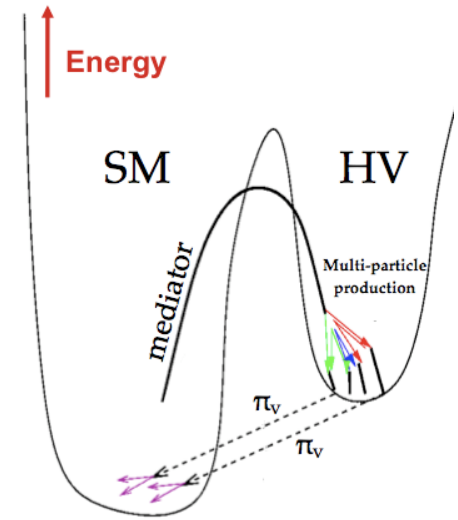
Hidden Valley model:

Hidden sector (« v-sector ») + communicator

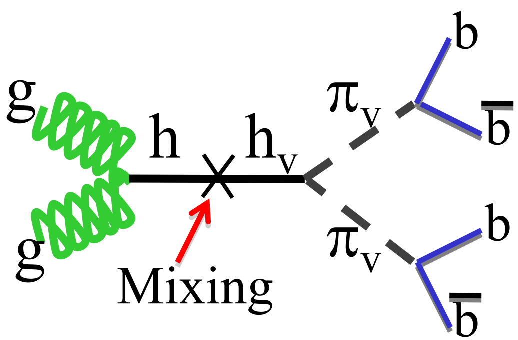
Barrier ⇒ need high E to produce v-particles

Lightest v-particle = π^0_V

π^0_V decay helicity suppressed ⇒ **displaced vertices**



Studied channel: Higgs production

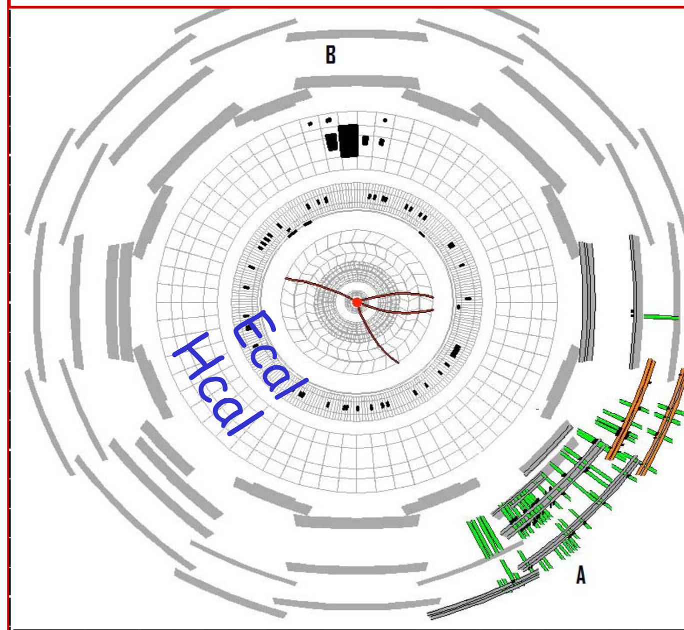


$M(h)$ = 140 GeV

$M(\pi_V)$ = 40 GeV

$c\tau$ = 1.5 m

“Atlantis” ATLAS event display



Challenges to the trigger!

Long lived *neutral* particles

Initial **trigger** efficiency 2-3%:

jets at both Level-1 and-2 (low p_T), muons at Level-2 (no ID track)

New triggers implemented:

10 TeV 100 pb^{-1}

Decays in the Muon Spectrometer

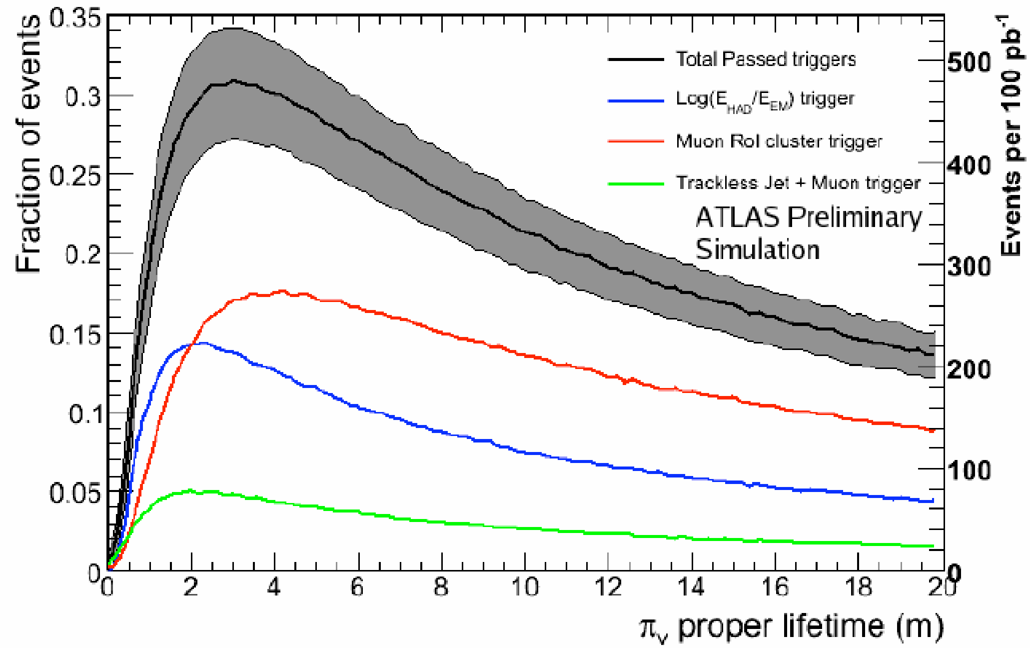
≥3 Level-1 Regions-of-Interest in $\Delta R=0.4$
+ no Level-2 jet nor ID track

Decays in the Hadronic calorimeter

A Level-2 jet: $E_T \geq 35$ GeV, $\mathrm{Log}(E_H/E_{EM}) \geq 1$
+ no ID track

Decays in the Inner Detector (ID)

Trackless jet + muon; ongoing study



Timing issues OK. Backgrounds OK (0.1-0.4 Hz at $L=10^{31}\ cm^{-2}s^{-1}$ on QCD dijet p_T= 35-70 GeV)

TeV scale gravity signatures

Extra dimensions ⇒ low *effective* Planck scale M_D (TeV order)

Black Hole production
general relativity

Threshold
~5 M_D

String Ball production
quantum gravity

[Dimopoulos, Emparan hep-ph/0108060]

Parameters: number of Xdim *n*, M_D, string scale M_S, string coupling g_S

$$M_S < M_D < M_S/g_S < M_S/g_S^2 \sim 5\ M_D$$

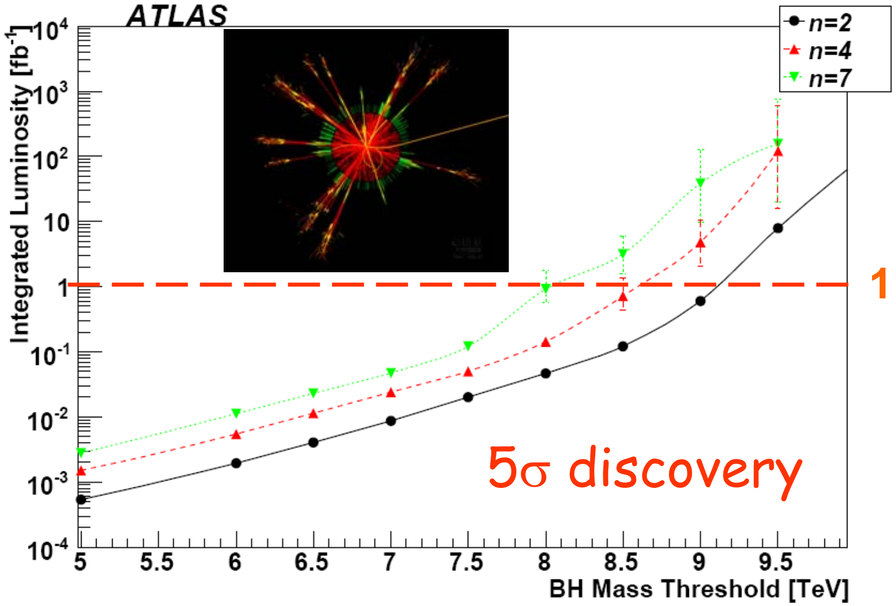
Comparable (large, but uncertain) cross sections:

$$\hat{\sigma}_{ab\to \mathrm{BH}} = \pi r_h^2 \qquad \hat{\sigma}_{ab\to \mathrm{StringBall}} = \begin{cases} \dfrac{g_s^2 M^2}{M_s^4} & M_s \ll M \le \dfrac{M_s}{g_s} \\ \dfrac{1}{M_s^2} & \dfrac{M_s}{g_s} \le M \le \dfrac{M_s}{g_s^2} \end{cases}$$

Then thermal decays on the brane

⇒ multiple jets, leptons and photons! (« busy » events)

TeV scale gravity signatures



Black Holes

$\Sigma|p_T|$ > 2.5 TeV

≥ 1 lepton with p_T>50 GeV

String balls

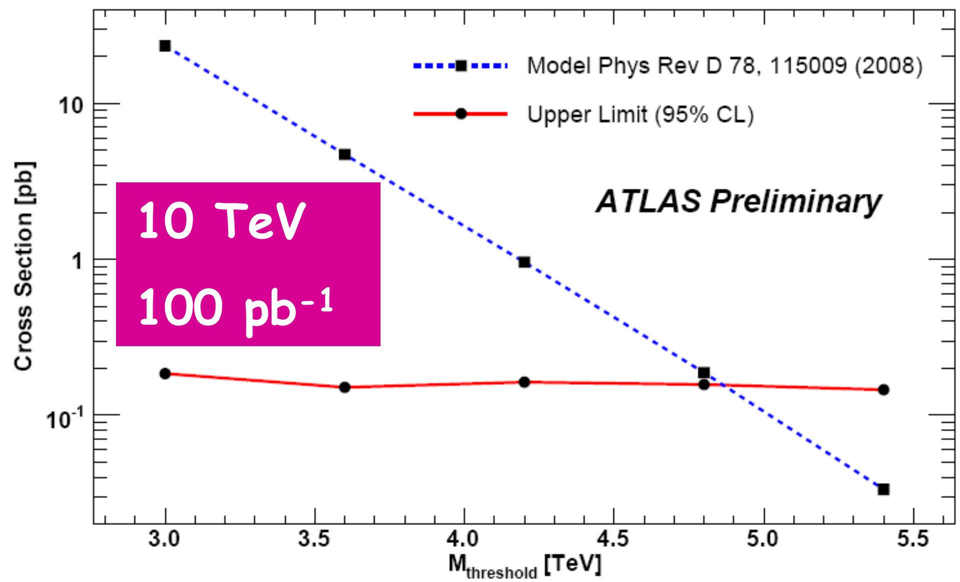
NEW

$\Sigma|p_T|$ + E_T^{miss} > ~ 0.8 M_{thresh}

≥ 1 lepton with p_T > 50-100 GeV

Sensitive to 185 fb

M_S > 1.6 TeV, M_D > 2.4 TeV limits



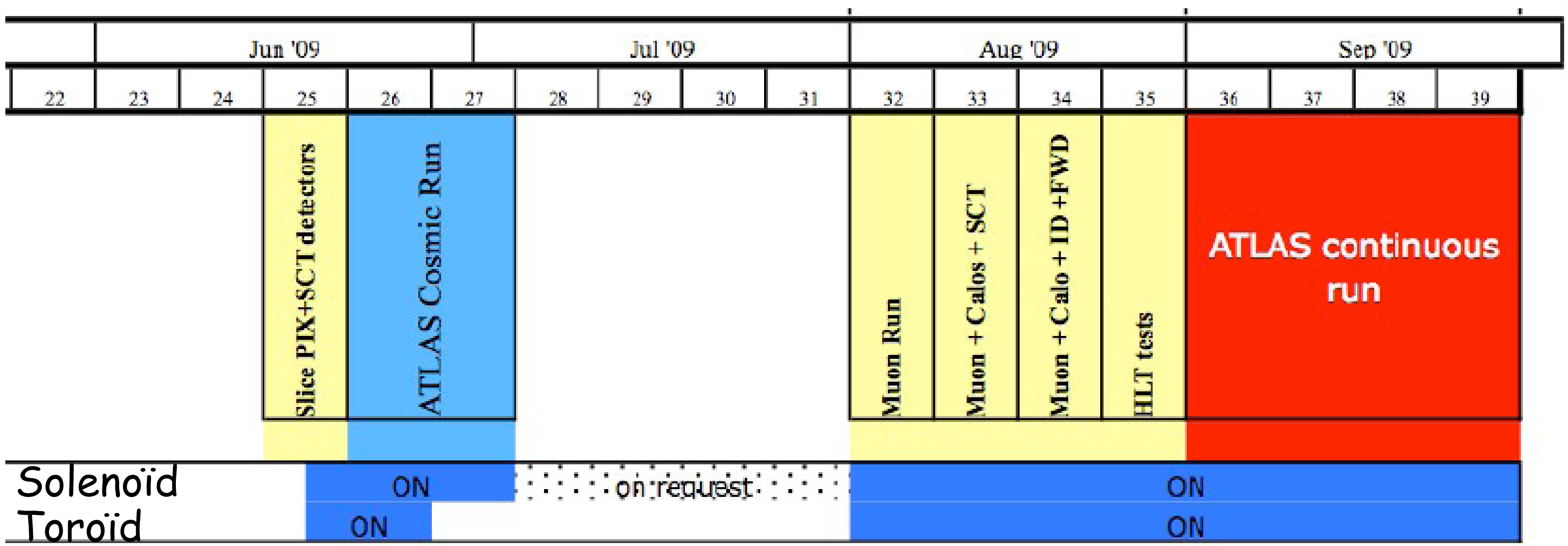
Conclusion and outlook

ATLAS is ready for all types of BSM signatures and topologies

With ~1 fb^{-1} at 14 TeV: (10 TeV cross sections ~50% lower)

- Sensitive to a very interesting region of SUSY parameter space
  gluinos @ m~500-1000 GeV
- Sensitive to many other new theories
  Z' @ ~2 TeV, W' @ ~3 TeV, G* @ 0.5-1.5 TeV, BH @ 8-9 TeV,...

Current run plan over next few months

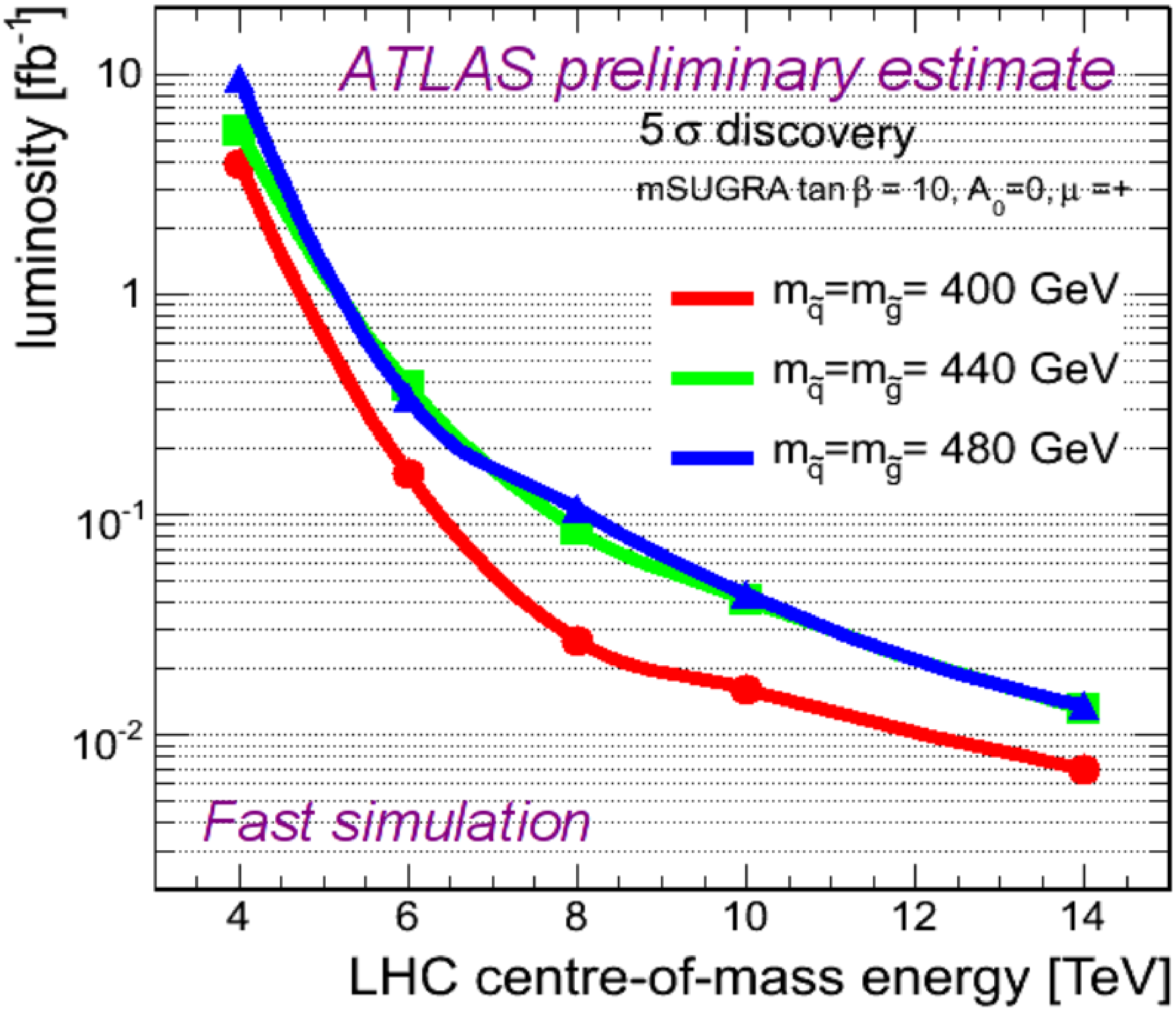


Many thanks to the organizers!

References:
The ATLAS Collaboration, CERN-OPEN-2008-020
G. Ciapetti et al., ATL-COM-PHYS-2009-233
D. Gingrich, ATL-PHYS-PUB-2009-011

Extra slides

mSUGRA below 14 TeV

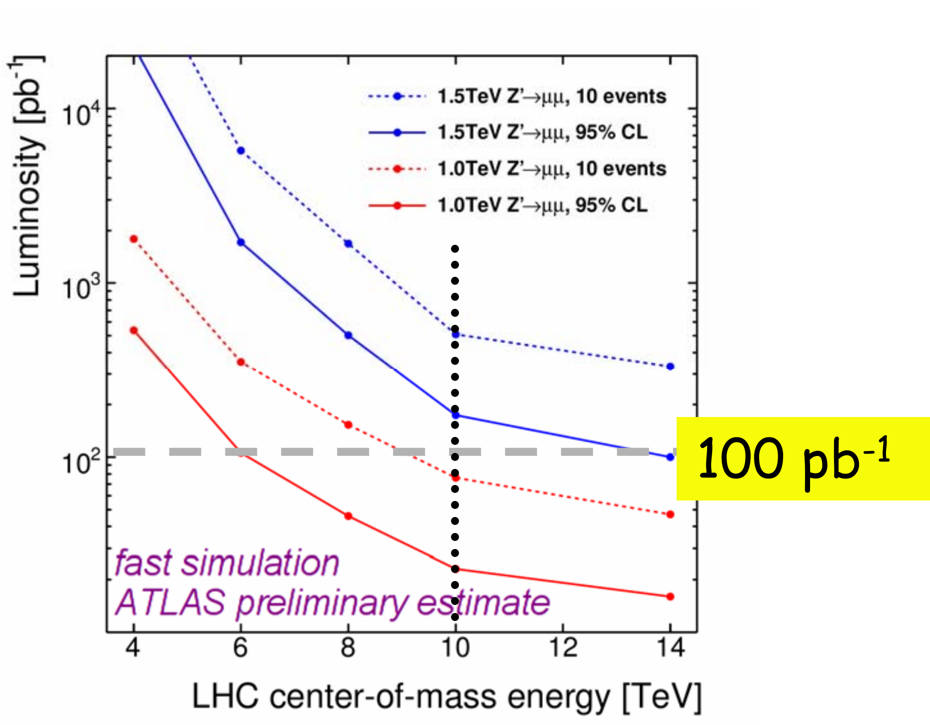


1 lepton channel

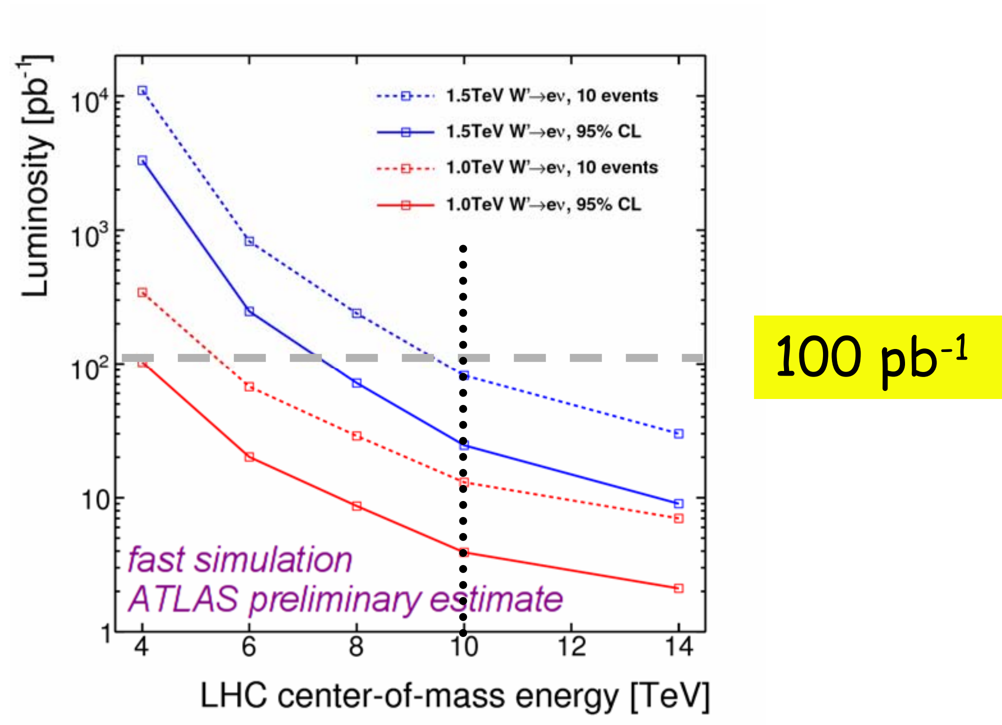
LHC Chamonix 2009 meeting (2-6 February 2009)

Z', W' below 14 TeV

Z'→μμ, SSM, fast simulation:



W' →eν, SSM, fast simulation:



LHC Chamonix 2009 meeting (2-6 February 2009)

Parameters and cross-sections of benchmark Points

SU1: $m_0 = 70\,\text{GeV},\ m_{1/2} = 350\,\text{GeV},\ A_0 = 0,\ \tan\beta = 10,\ \mu > 0.$

SU2: $m_0 = 3550\,\text{GeV},\ m_{1/2} = 300\,\text{GeV},\ A_0 = 0,\ \tan\beta = 10,\ \mu > 0.$

SU3: $m_0 = 100\,\text{GeV},\ m_{1/2} = 300\,\text{GeV},\ A_0 = -300\,\text{GeV},\ \tan\beta = 6,\ \mu > 0.$

SU4: $m_0 = 200\,\text{GeV},\ m_{1/2} = 160\,\text{GeV},\ A_0 = -400\,\text{GeV},\ \tan\beta = 10,\ \mu > 0.$

SU6: $m_0 = 320\,\text{GeV},\ m_{1/2} = 375\,\text{GeV},\ A_0 = 0,\ \tan\beta = 50,\ \mu > 0.$

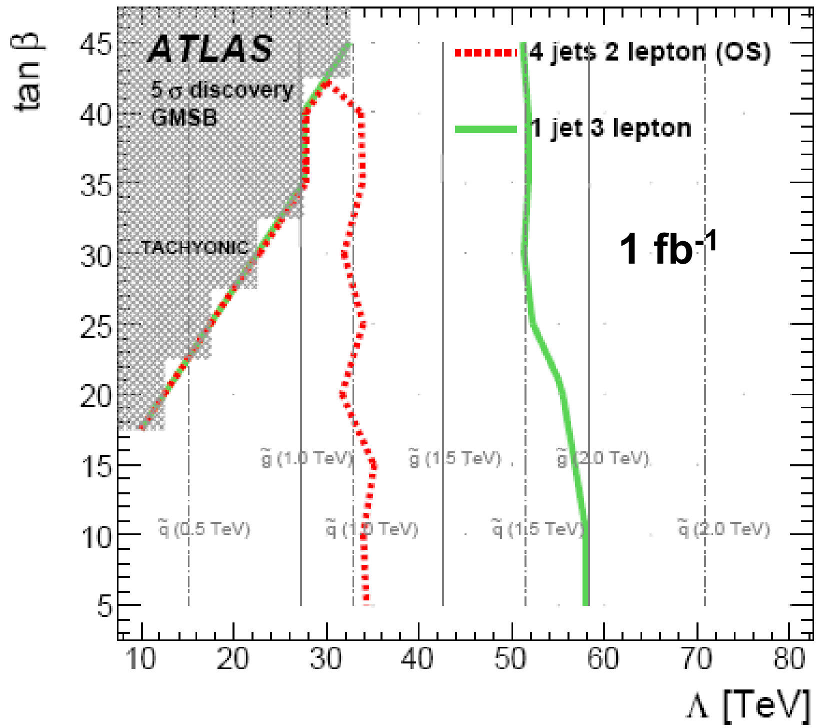
Signal	σ^{LO} (pb)	σ^{NLO} (pb)	N
SU1	8.15	10.86	200 K
SU2	5.17	7.18	50 K
SU3	20.85	27.68	500 K
SU4	294.46	402.19	200 K
SU6	4.47	6.07	30 K

Particle	SU1	SU2	SU3	SU4	SU6
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42

Interpretations in other models (1 fb^{-1}):

Par.	Description
Λ	SUSY breaking scale
M_m	Messenger mass scale
tanβ	Ratio of Higgs vev
N_m	Number of SU(5) messenger multiplets
sign(μ)	μ from Higgs sector
C_{grav}	Sets NLSP lifetime

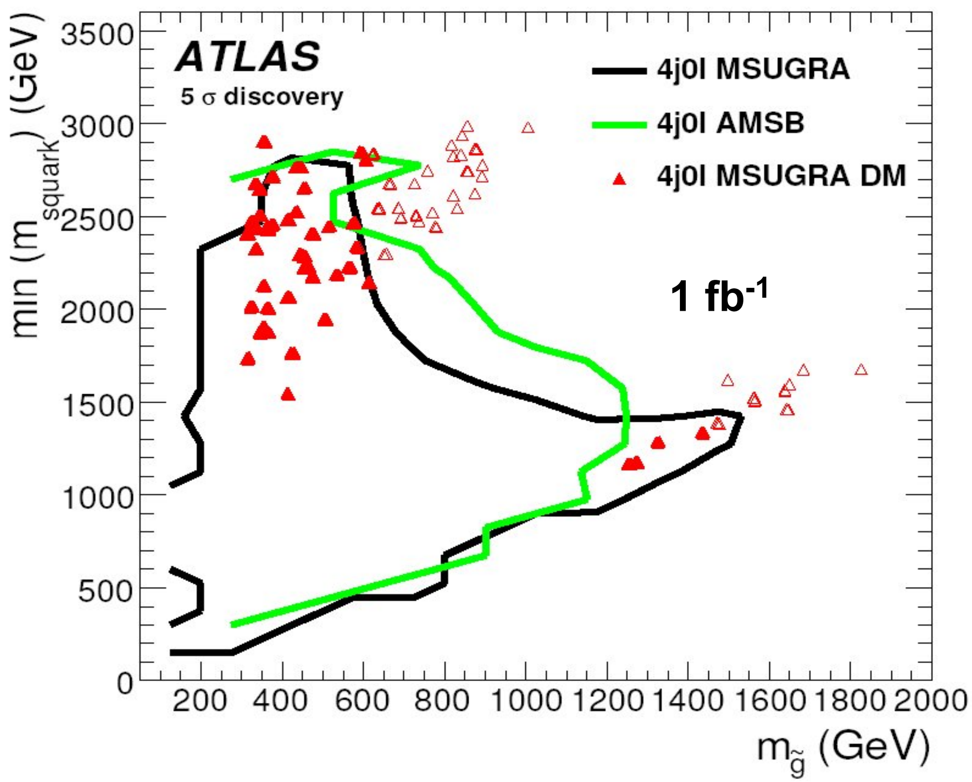
N_5 = 1, M_{mess} = 500 TeV, μ>0, C_G=1



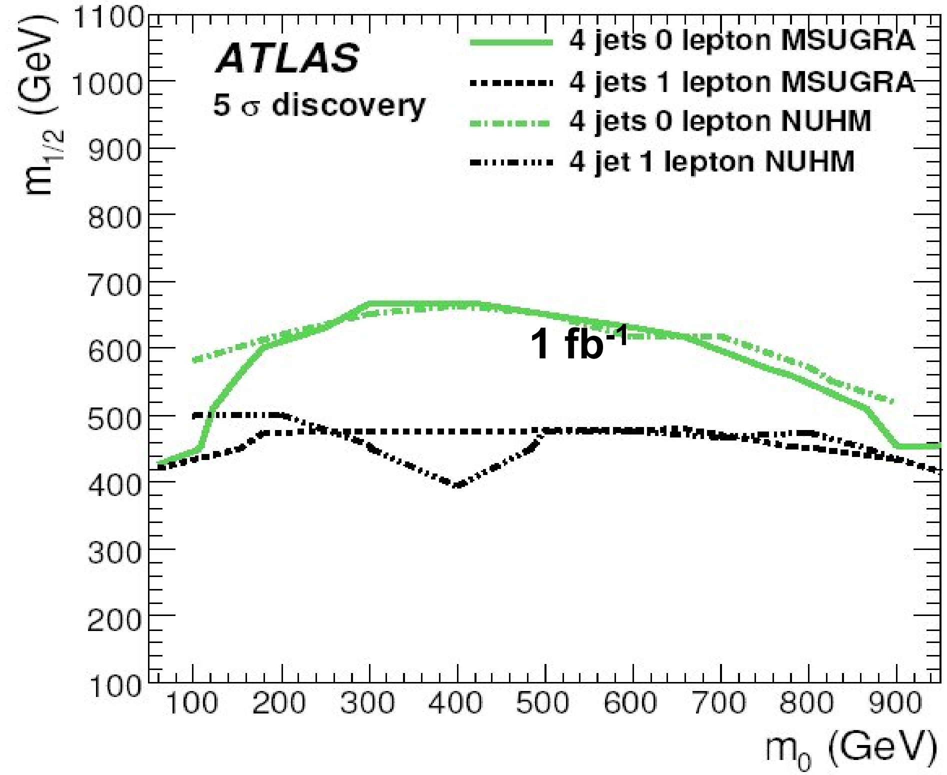
Interpretations in other models (1 fb^{-1}):

``mSUGRA + constraints''
mSUGRA scan, but
satisfying WMAP, a_μ , M_h ,
$b \rightarrow s\gamma$, $B_s \rightarrow \mu\mu$, $\mu>0$

``mSUGRA vs NUHM''
NUHM here: fix M_A and tan β to values
compatible with WMAP constraints



AMSB parameters: m_0, $m_{3/2}$, $\tan\beta$, sgn(μ)

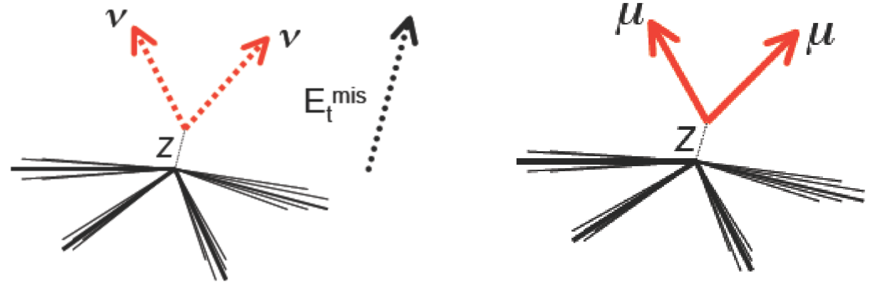


NUHM parameters: m_0, $m_{1/2}$, A_0, $\tan\beta$, sgn(μ)

+m(A), $|\mu|$

Z→νν background

Replace method



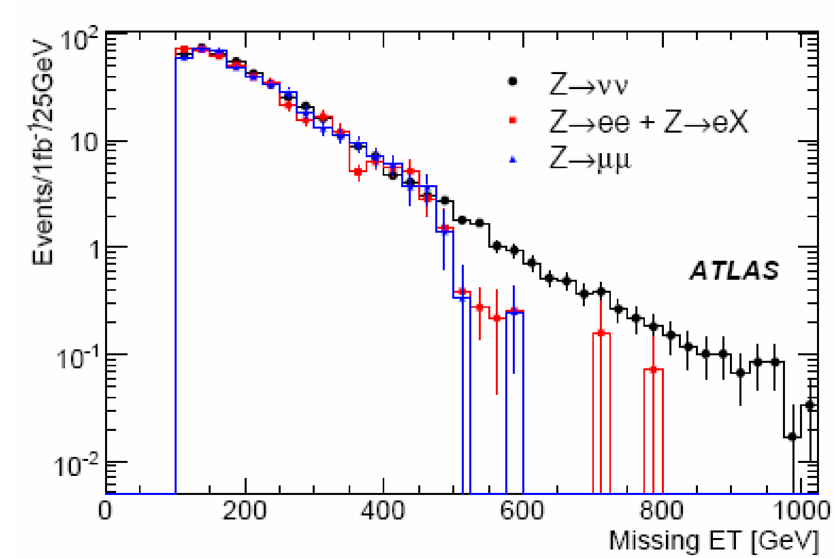
In each E_T^{miss} bin:

$$N_{Z\to\nu\bar{\nu}}(E_T^{\rm miss}) = N_{Z\to\ell^+\ell^-}(p_T(\ell^+\ell^-)) \times c_{\rm Kin}(p_T(Z)) \times c_{\rm Fidu}(p_T(Z)) \times \frac{{\rm Br}(Z\to\nu\bar{\nu})}{{\rm Br}(Z\to\ell^+\ell^-)}$$

Correction factors:

c_{Kin} ⇒ select pure Z sample

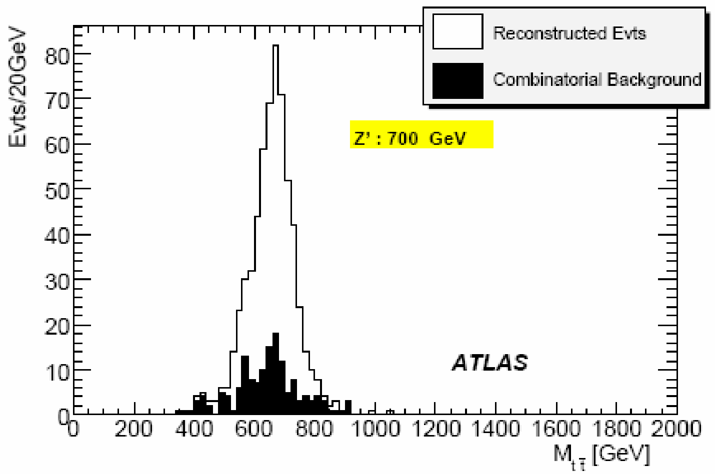
c_{Fidu} ⇒ lepton p_T, η and identification

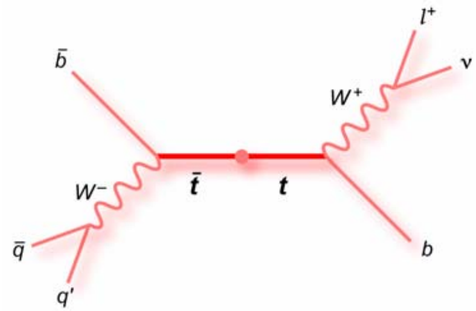


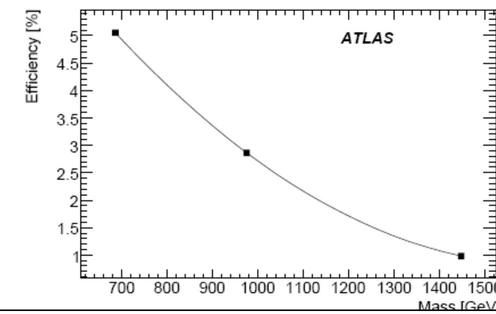
See talk by T. Yetkin

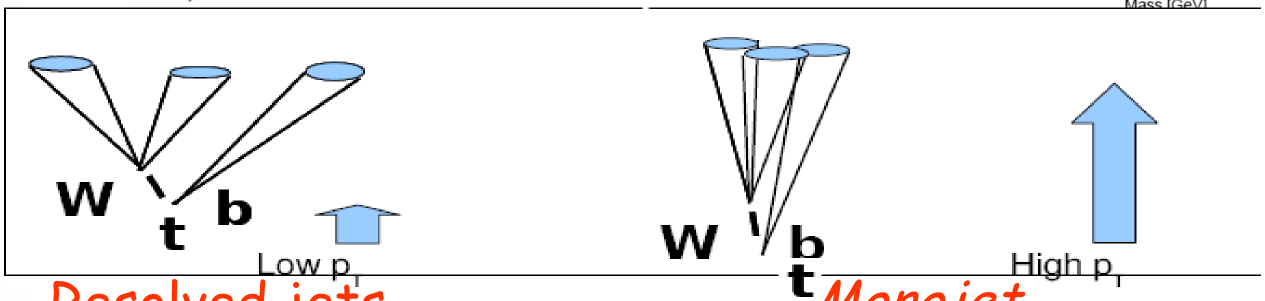
Top pairs

Randall-Sundrum g_{KK}







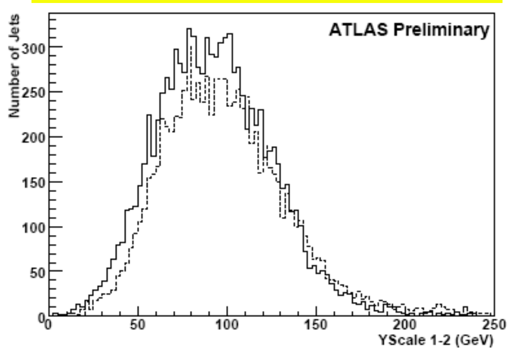


Resolved jets

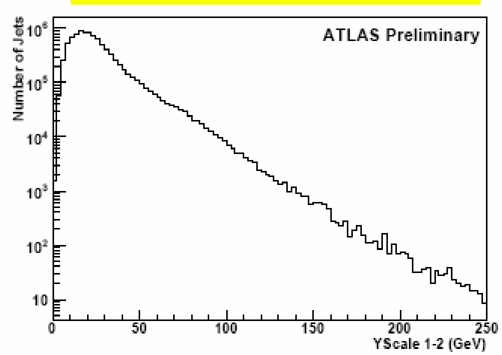
Monojet

Need to identify *monojets* as tops ⇒ jet mass, YSplitter:

Tops from 2,3 TeV Z'



Multijet sample



[J.M. Butterworth, J.R. Ellis, A.R. Raklev, hep-ph/0702150]

k_T scale at which 1 jets splits into 2

See talk by K. Terashi