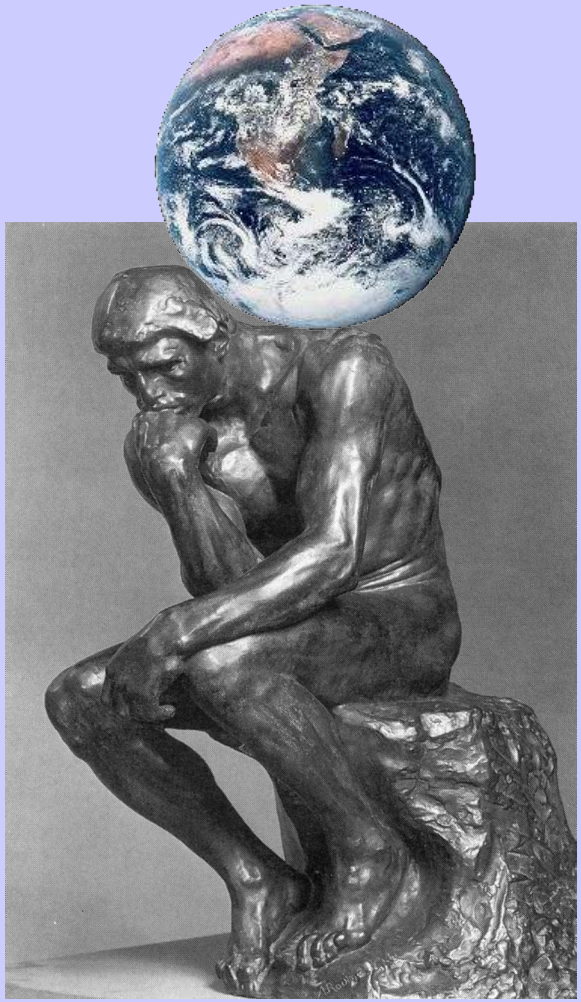
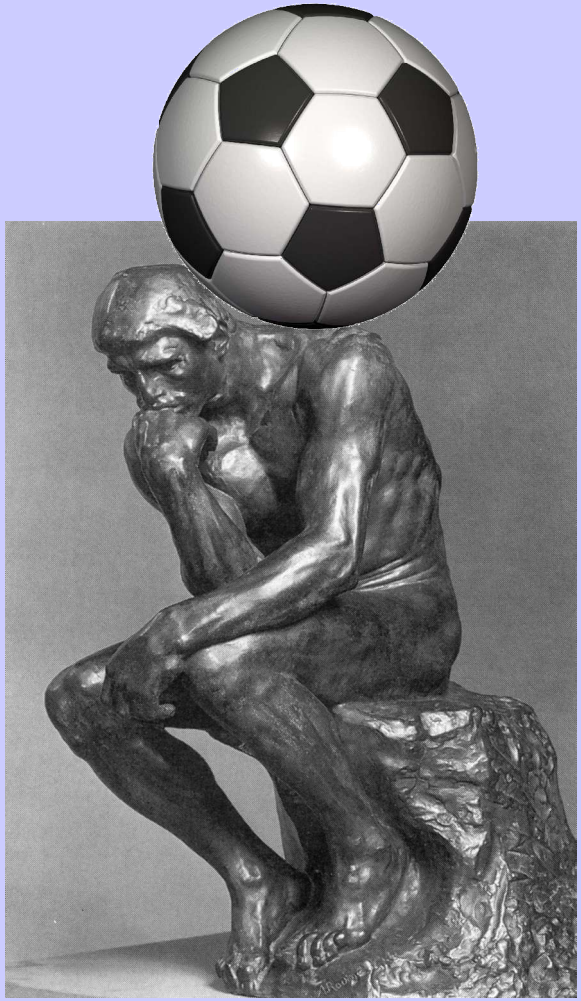
ATLAS New Physics Searches at High p_T



All results are preliminary!

Tobias Golling (LBL)
On behalf of the ATLAS collaboration

ATLAS New Physics Searches at High p_T



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Overview

- First time we have a virtually complete set of realistic studies with full simulation, realistic detector description (geometry, alignment), trigger menus, data-driven background determinations, complete assessment of systematic effects,...

- All results are preliminary, but will be published shortly in the context of the ATLAS "Computing System Commissioning" (CSC) effort

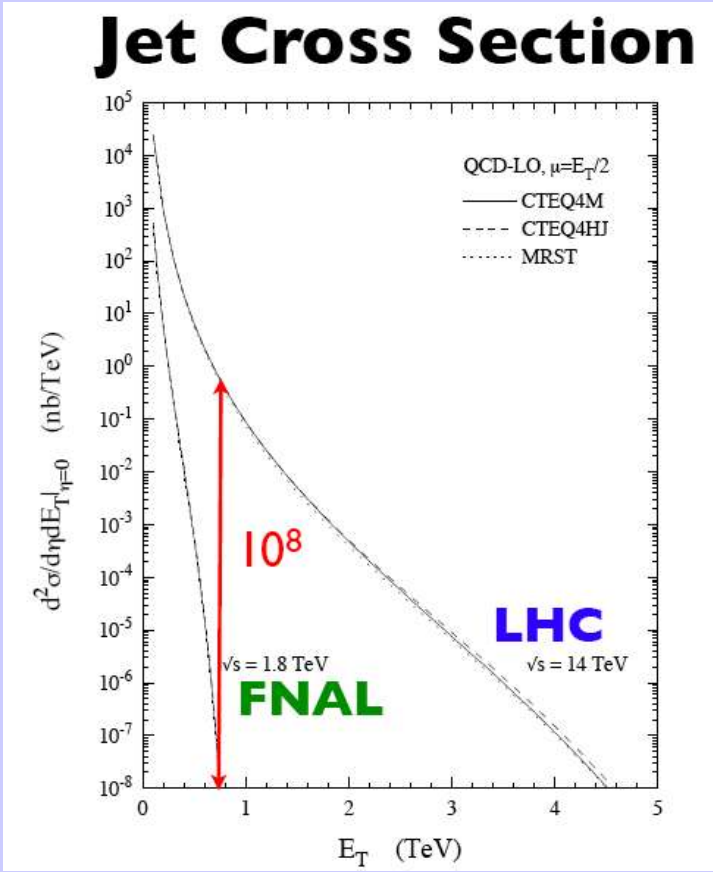
- Most analyses for 1 fb^{-1} (some 100 pb^{-1} or 10 fb^{-1})

Can't show you ALL ATLAS NP searches in 30 min, focus on

- SUSY
- FCNC in top decay, ttbar resonances
- Z'
- Leptoquarks

Physics Reach Overview

Cross Sections of Physics Processes (pb)			
	Tevatron	LHC	Ratio
$W^{\pm}\to l\nu$(80 GeV)	2600	20000	10
$t\bar{t}$ (2x172 GeV)	7	800	100
$gg\to H$ (120 GeV)	1	40	40
$\tilde{\chi}^{+}_{1}\tilde{\chi}^{2}_{0}$ (2x150 GeV)	0.1	1	10
$\tilde{q}\tilde{q}$ (2x400 GeV)	0.05	60	1000
$\tilde{g}\tilde{g}$ (2x400 GeV)	0.005	100	20000
Z′ (1 TeV)	0.1	30	300



Sample size with 100 pb^{-1} similar to Tevatron today:

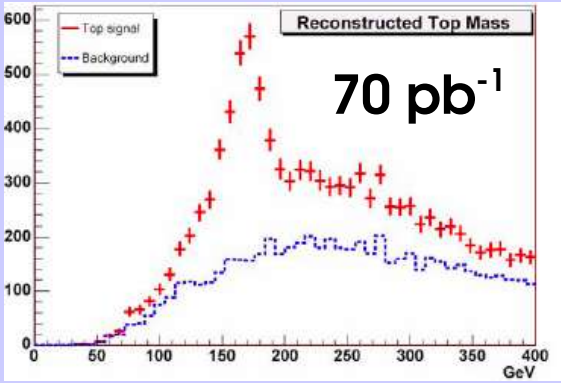
2.000.000 $W\to l\nu$

200.000 $Z\to ll$

20.000 $t\bar{t}\to l\nu+X$

At 10^{33} cm^{-2}s^{-1}:

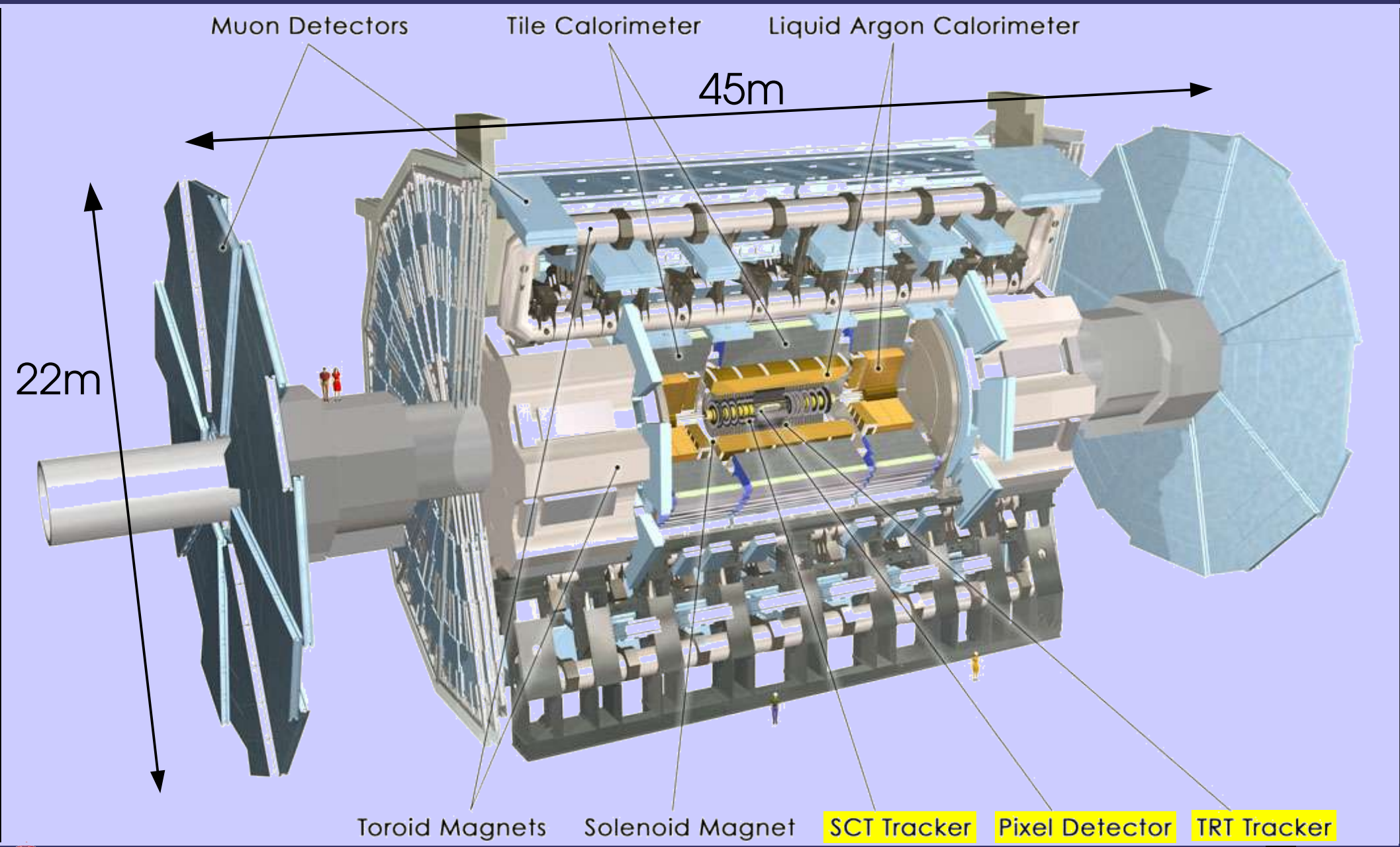
$W\to l\nu$	: 20	Hz
$Z\to ll$	: 2	Hz
$t\bar{t}\to l\nu+X$	: 0.2	Hz
$\tilde{g}\tilde{g}$(400GeV)	: 0.1	Hz
SM Higgs	: ~10^{-2}	Hz



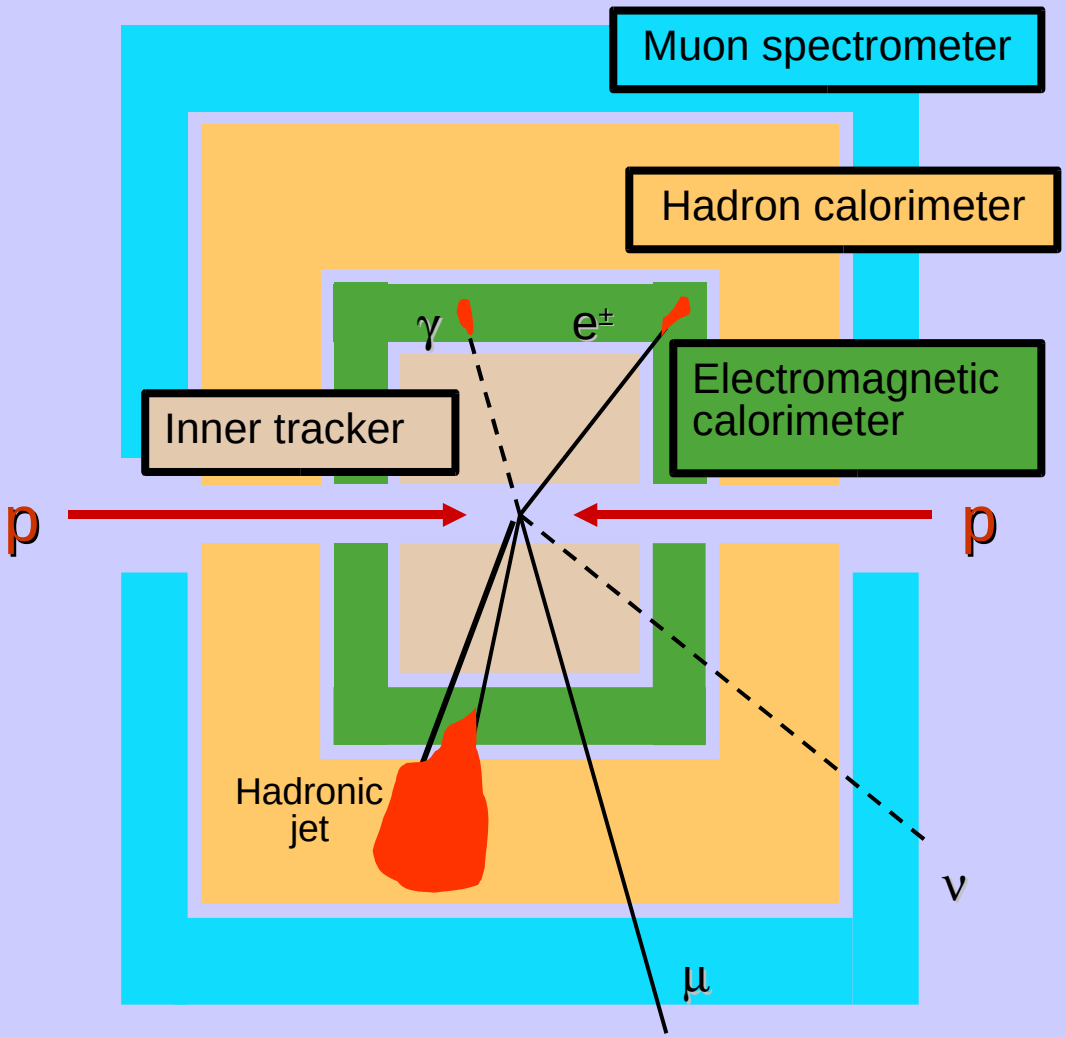
Re-discovery of top after few pb^{-1}

- **Amazing increase in cross section**
- **Excellent disovery potential with early data**

ATLAS – Multi-purpose Experiment

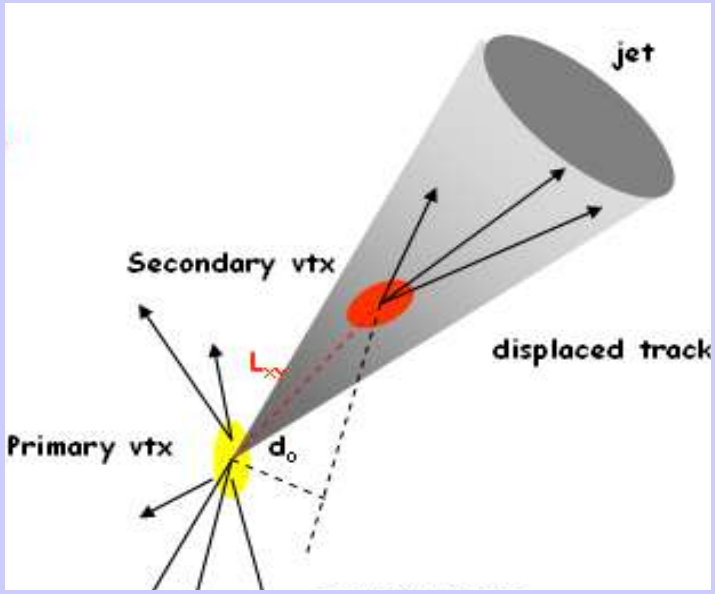


Object Reconstruction



Excellent performance over unprecedented energy range:
few GeV – few TeV

Lifetime b-tagging with Pixel detector



Non-standard reconstruction:

- Non-pointing photons
- long-lived heavy particles

Overview: ATLAS SUSY Studies

All studies for $1fb^{-1}$

(~2 weeks @ 10^{33} $cm^{-2}s^{-1}$)

Focus on :

- **mSUGRA** (gravity-mediated, LSP=lightest neutralino)
- **R-parity conserving** ⇒ MET from stable/undetected LSP
- **Few points in full simulation, complemented by scan over SUSY parameter space in fast simulation**

Strategy:

Searches and inclusive studies

⇒ **Establish SUSY discovery: initial discovery flavor-blind**

Exclusive measurements

⇒ **Measure properties, derive parameters of model**

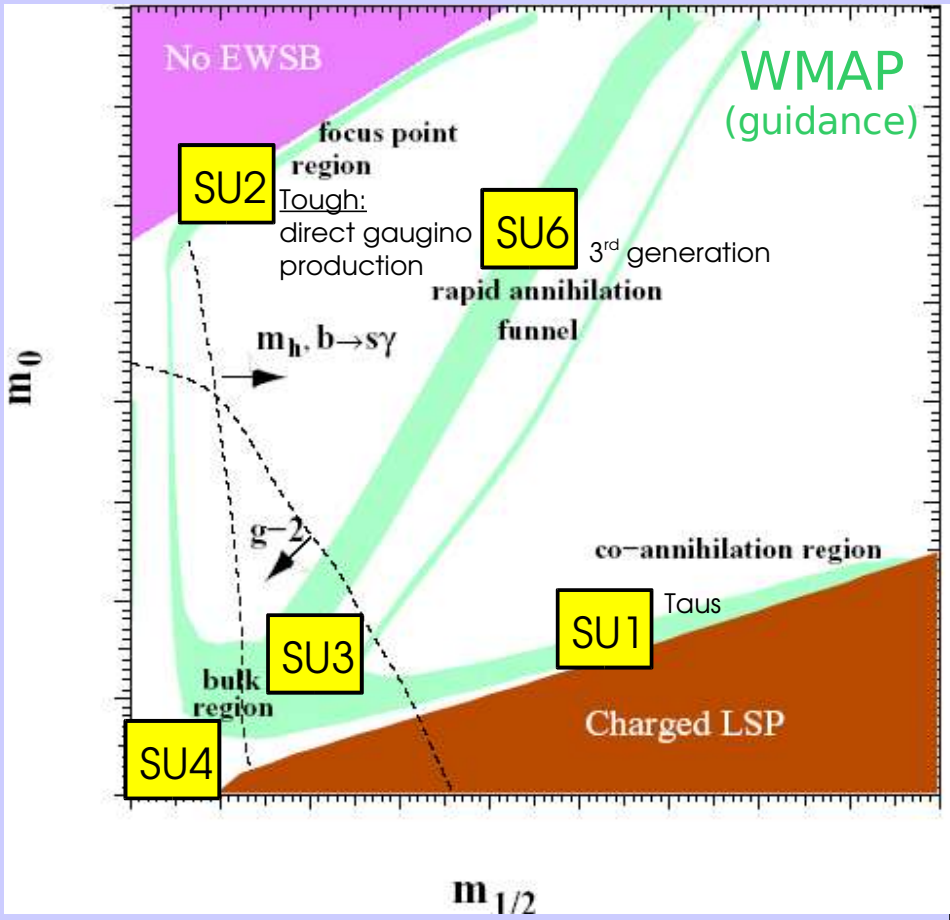
- **Direct gaugino production: Tri-lepton**
- **Photonic & long-lived signatutes**

⇒ **Specific signatures**
⇒ **GMSB & Split-SUSY...**

Specific mSUGRA Points considered

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
SU8.1	6.48	8.70	50 K

— ~1.35 —>



	SU1	SU2	SU3	SU4	SU6
	Coannihilation point	Focus point	Bulk region	Low mass point	Funnel point
	Small ~l mass splitting	Mainly ~g & ~chi production	No special degeneracies	In RunII reach	Taus/b dominate
M0 [GeV]	70	3550	100	200	320
M1/2 [GeV]	350	300	300	160	375
A0	0	0	-300	-400	0
Tanβ	10	10	6	10	50
Sgn(μ)	+	+	+	+	+

mSUGRA Signature

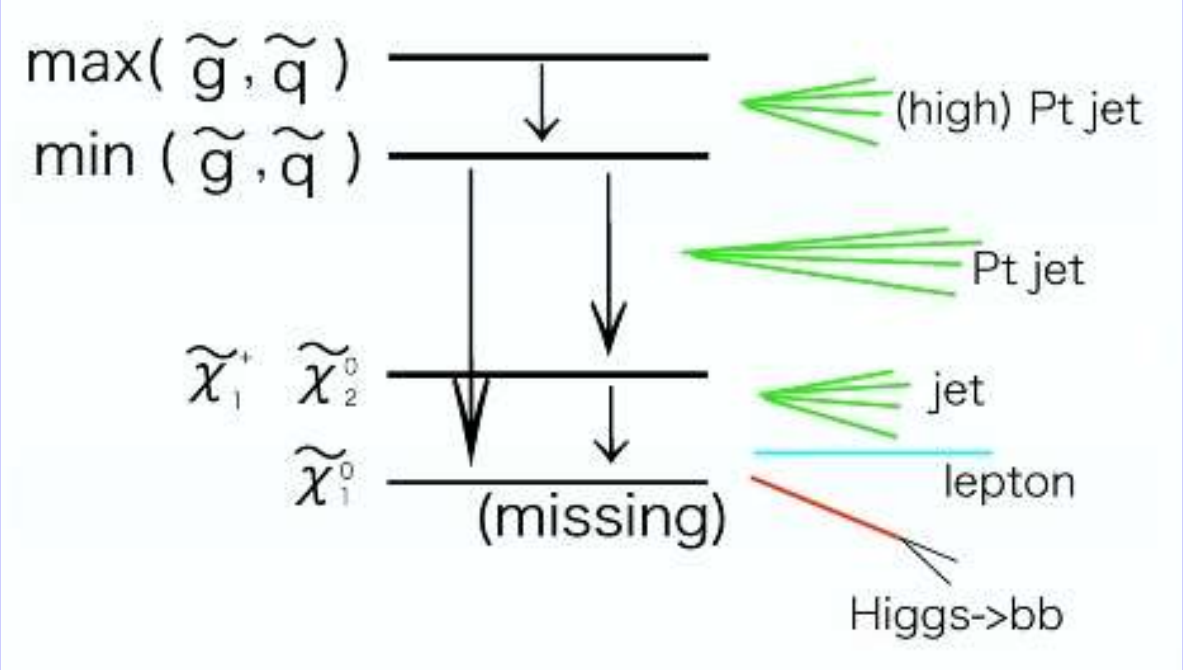
Production:

- Dominantly strong
- squark/gluino pair production

Decay/Topology:

(depending on mass spectrum)

- Missing E_T
- High p_T jets
- High p_T leptons



Jets:
≥ 2, 3, 4
> 50, 100, 150 GeV

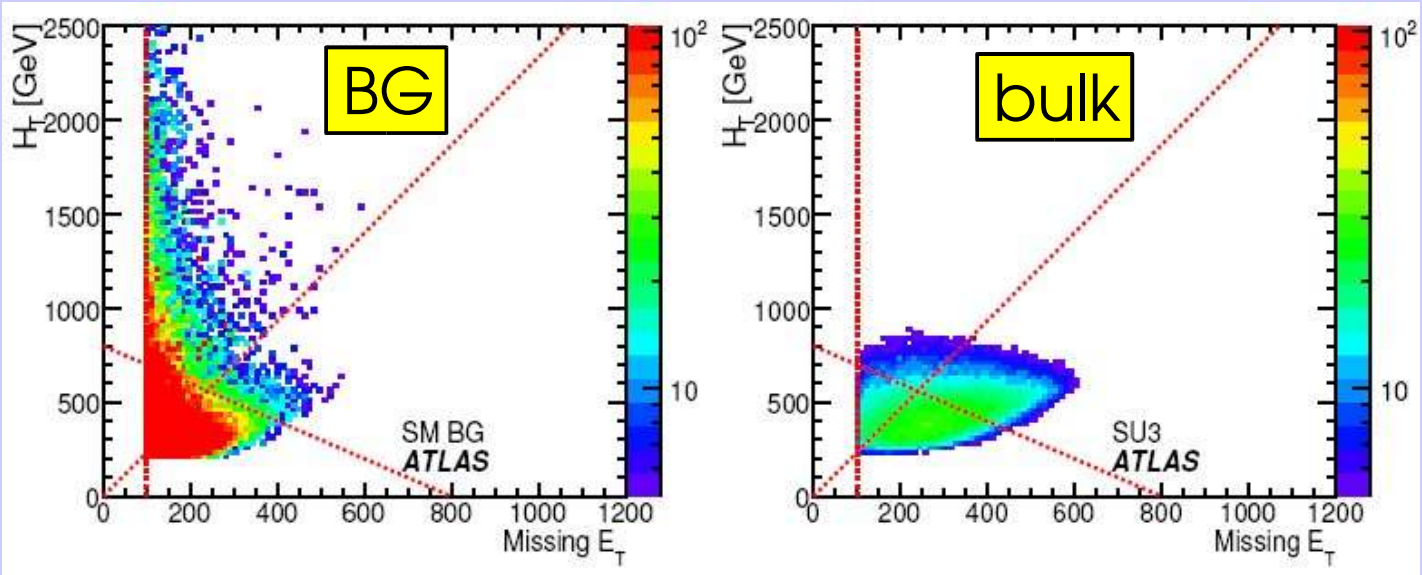
Leptons:
0, 1, 2, 3
> 10, 20 GeV

LSP = MET:
missing transverse energy > 100 GeV

3. Generation:
taus
b-jets

≥N jets + M leptons + MET + taus/b-jets

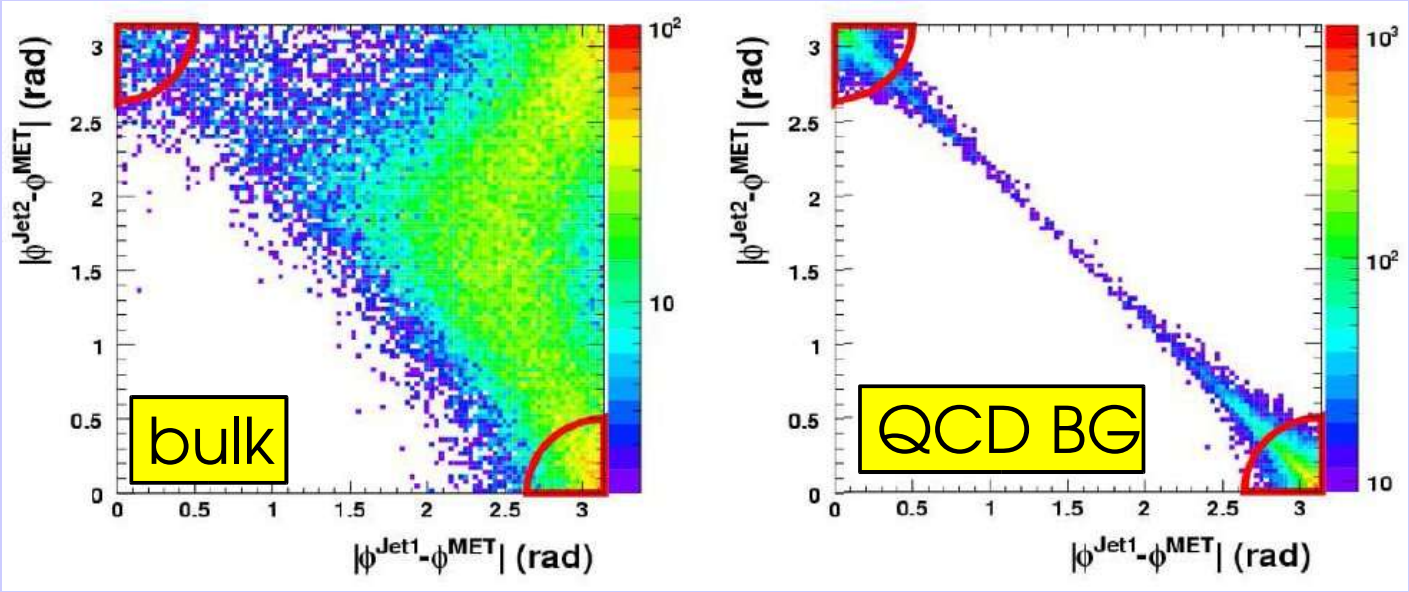
Typical SUSY Selection



High SUSY mass scale:
many jets with high p_T
(> 50-150 GeV)

LSP escapes undetected:
MET > 100 GeV

Reject high p_T QCD:
$\Delta\phi$ cuts between MET and leading jets



MET + ≥4 Jets + 0 Leptons

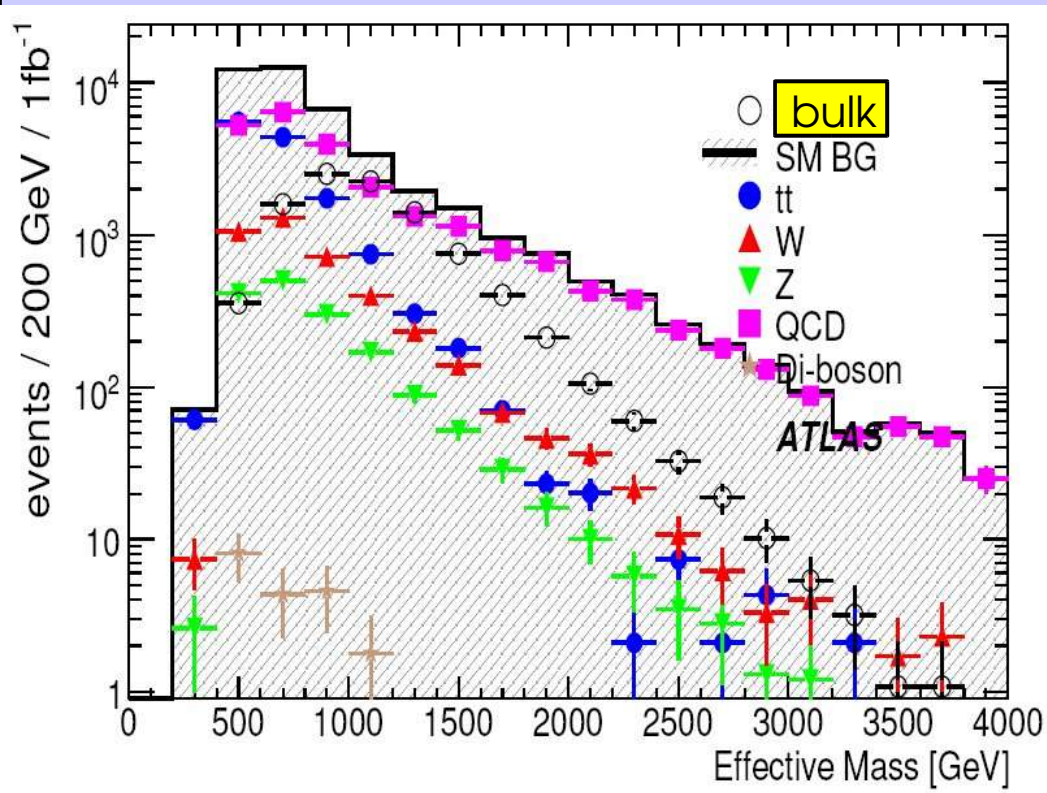
$1 fb^{-1}$

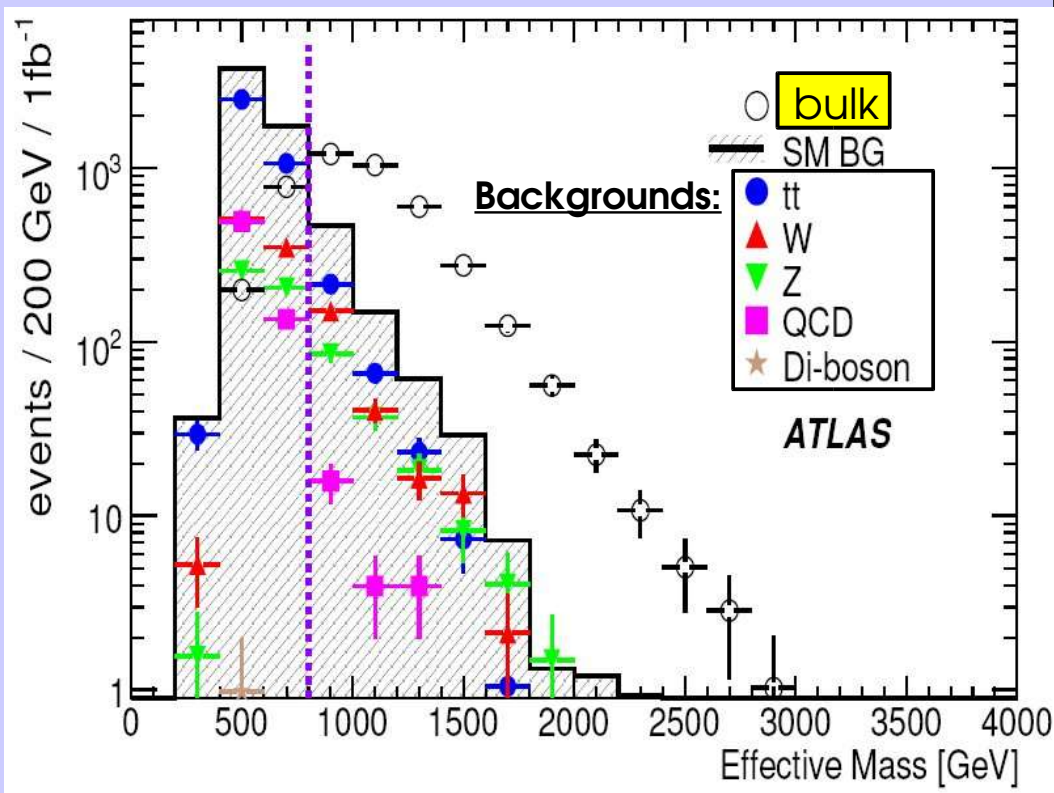
Best discriminating variables:

- MET
- $M_{eff} = \Sigma_{jets, leptons}\, p_T + MET$

Data-driven background determination

Before selection ⇨ **After selection**



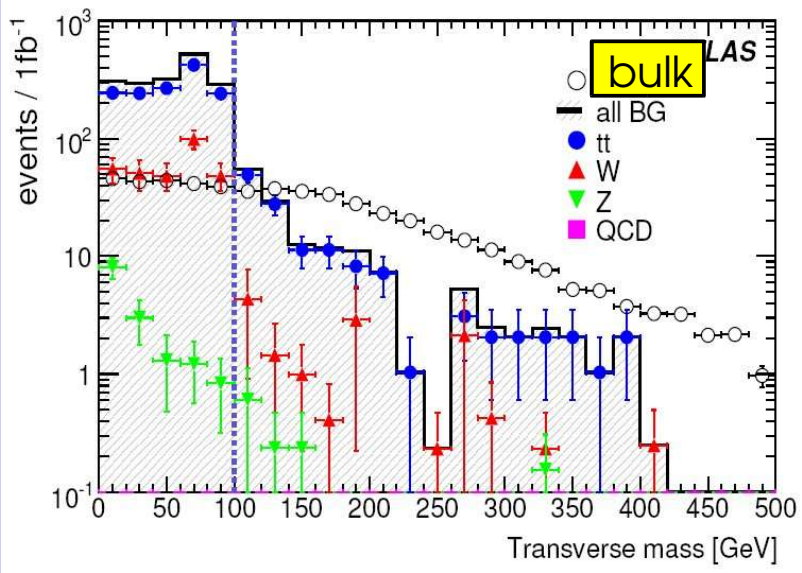


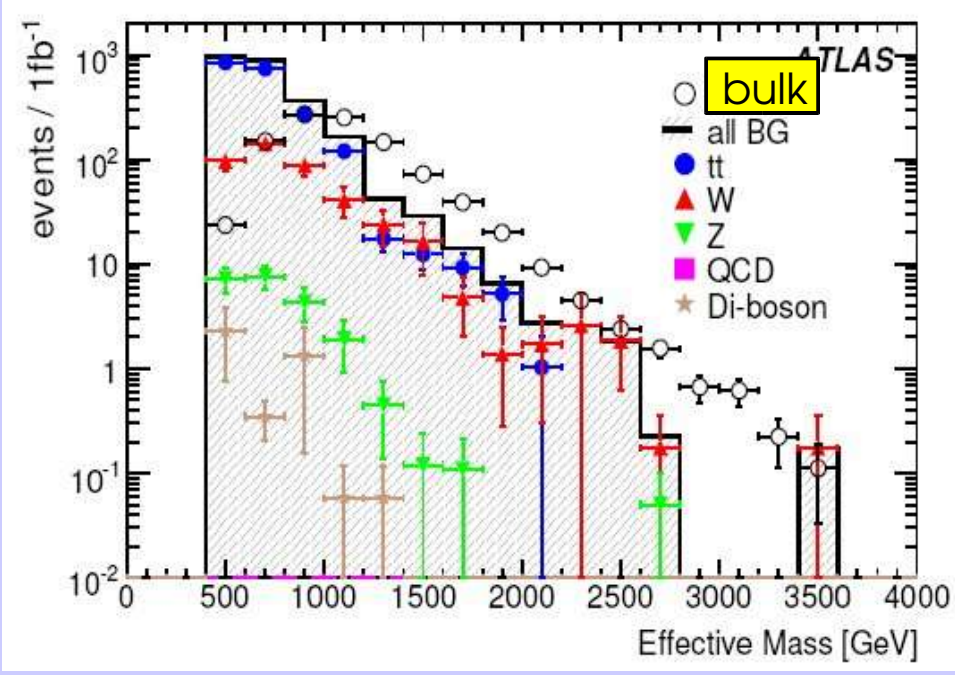
MET + Jets + 1 Lepton

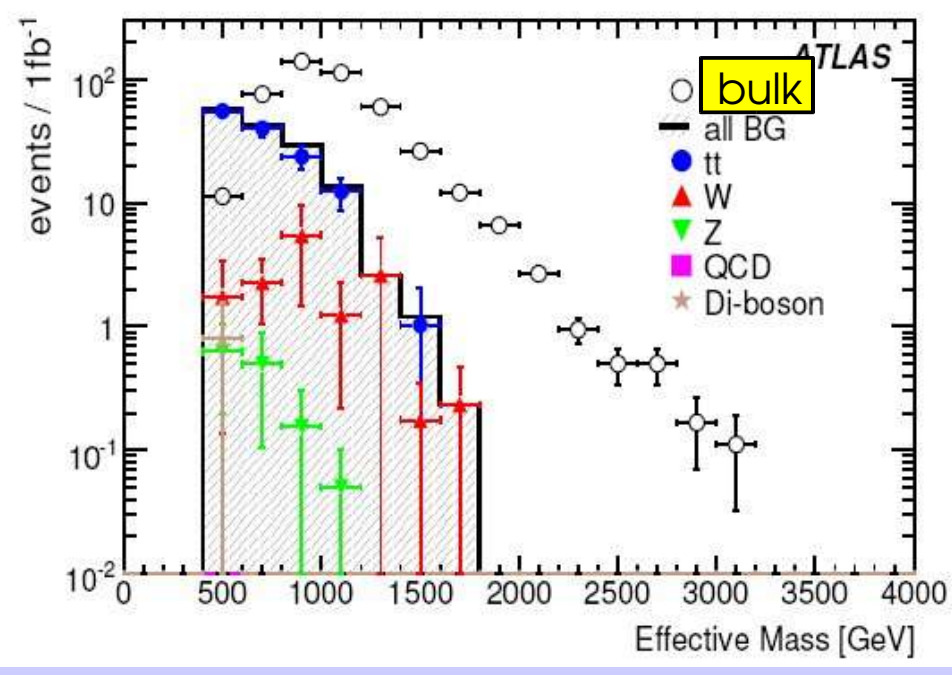
$1fb^{-1}$

BG rejection:

Transverse mass > 100 GeV







3rd Generation

$1fb^{-1}$

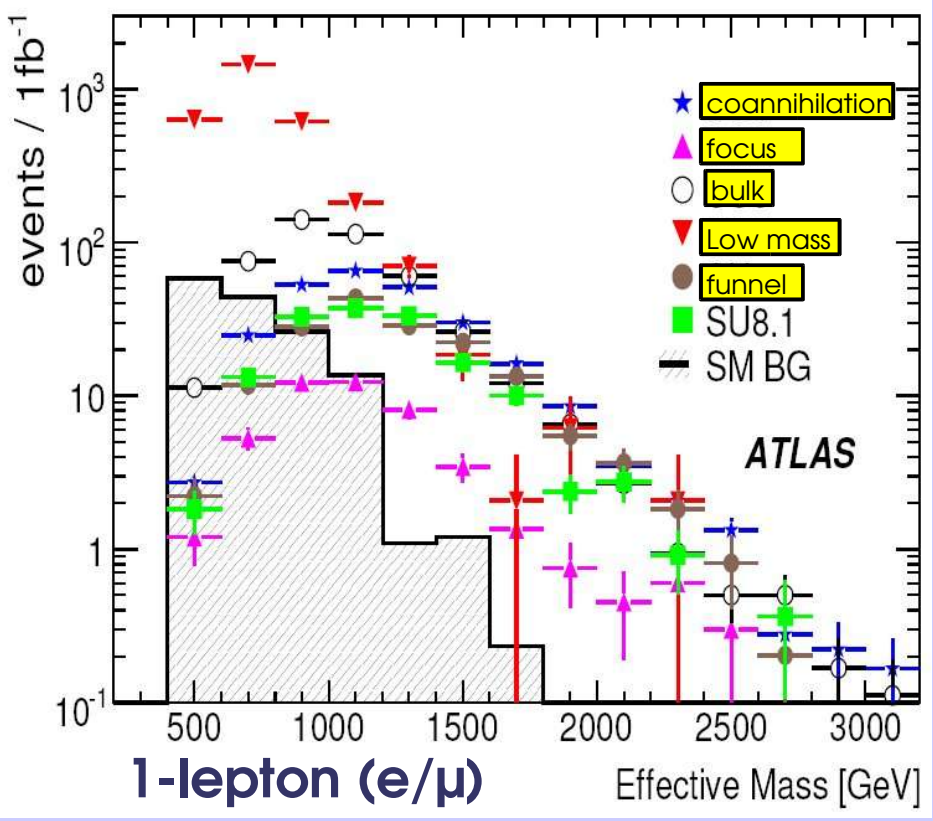
Important when 3rd generation sparticles prodcued abundantly (high tanβ)

- improve S/B: requiring either tau or b-jet ⇒ in particular suppress QCD
- lower efficiency vs. higher purity/better understood backgrounds

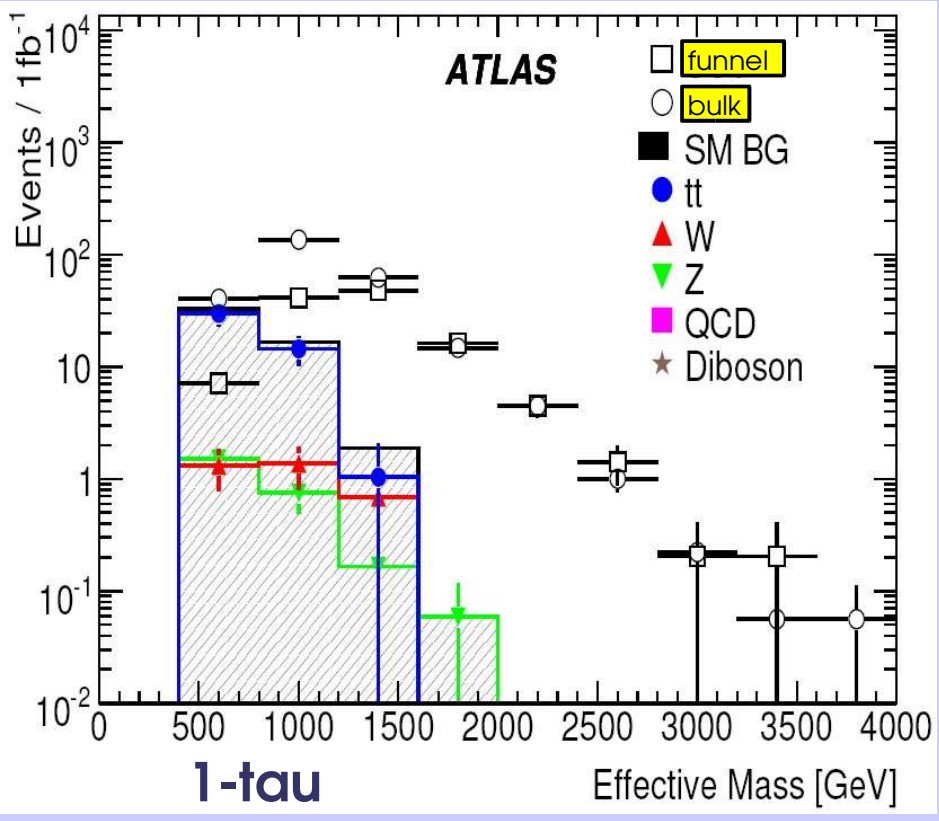
staus decaying to taus

- consider only hadronic taus (leptonic taus indistinguishable from e, μ)
- transverse mass cut

Both have similar significance 10-20σ



1-lepton (e/μ)



1-tau

High tau multiplicity for RPV with a stau LSP (no prelimininary results)

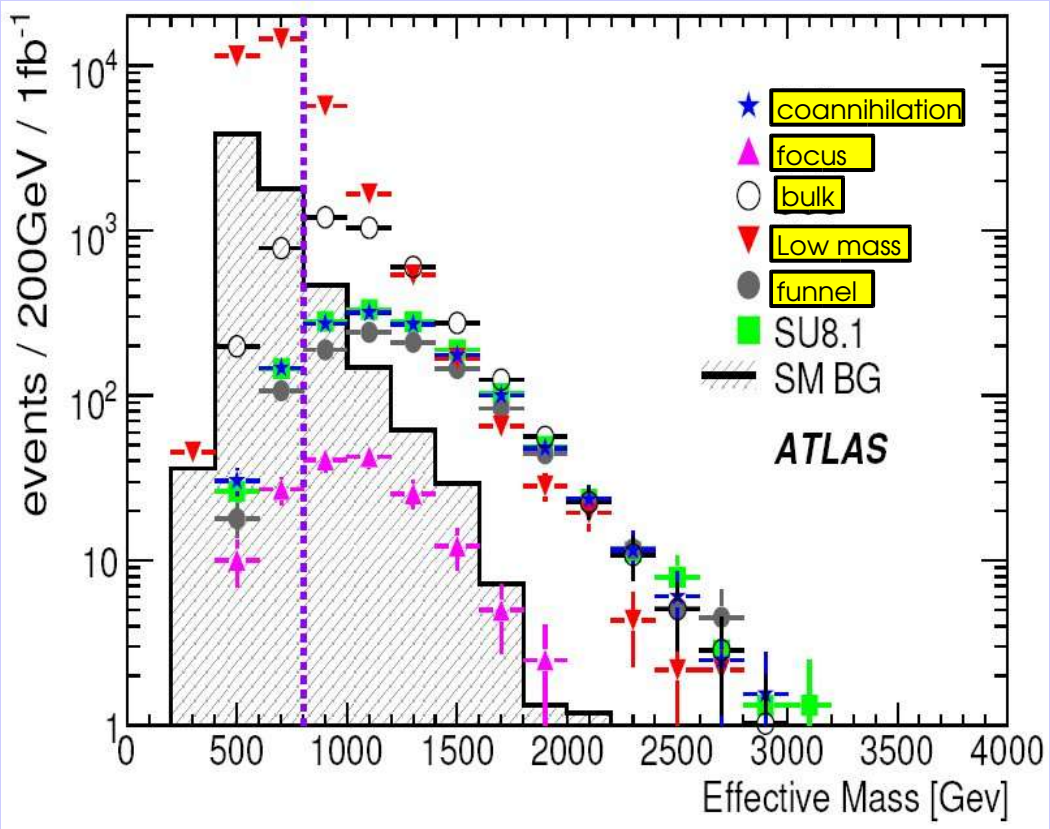
3rd Generation: b-jets

$1fb^{-1}$

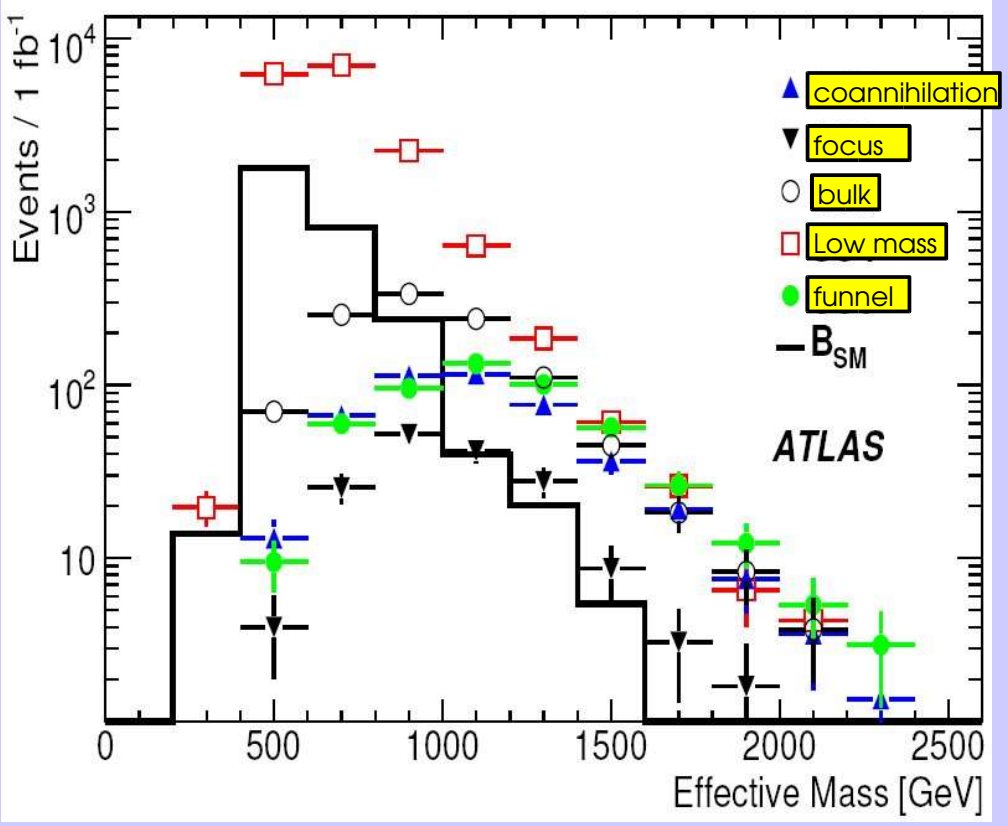
sbottoms/stops: decaying to b-jets

- Light stops and sbottoms ⇒ rich in b-jets
- Lifetime b-tagging (eff = 60%, rejection = 100)

Both have similar significance 10-20σ



0-lepton



≥ 2 b-jets

Light stop with many tops in final state (no preliminary results)

Scans & Optimization

$1fb^{-1}$

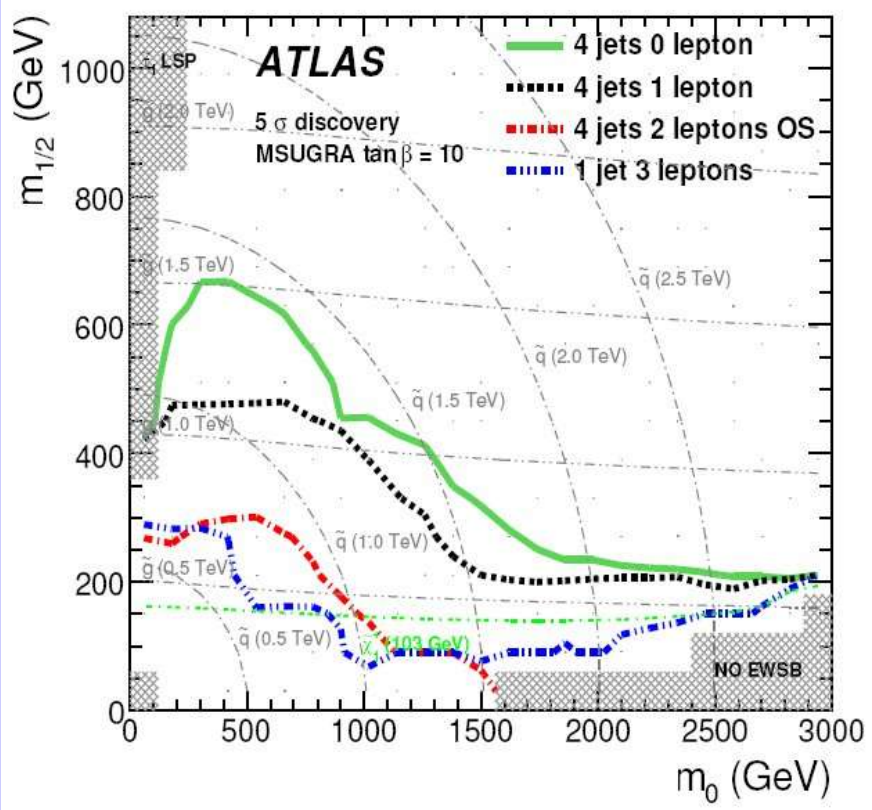
Evaluation of discovery reach in early ATLAS data

- **Less model dependent discovery strategies - explore LHC signatures**
  - Scan over constrained models (points generated in SUSY parameter space) mSUGRA w/ and w/o DM & other constraints, NUHM, GMSB, AMSB,...
- **FastSim, corrected to FullSim**

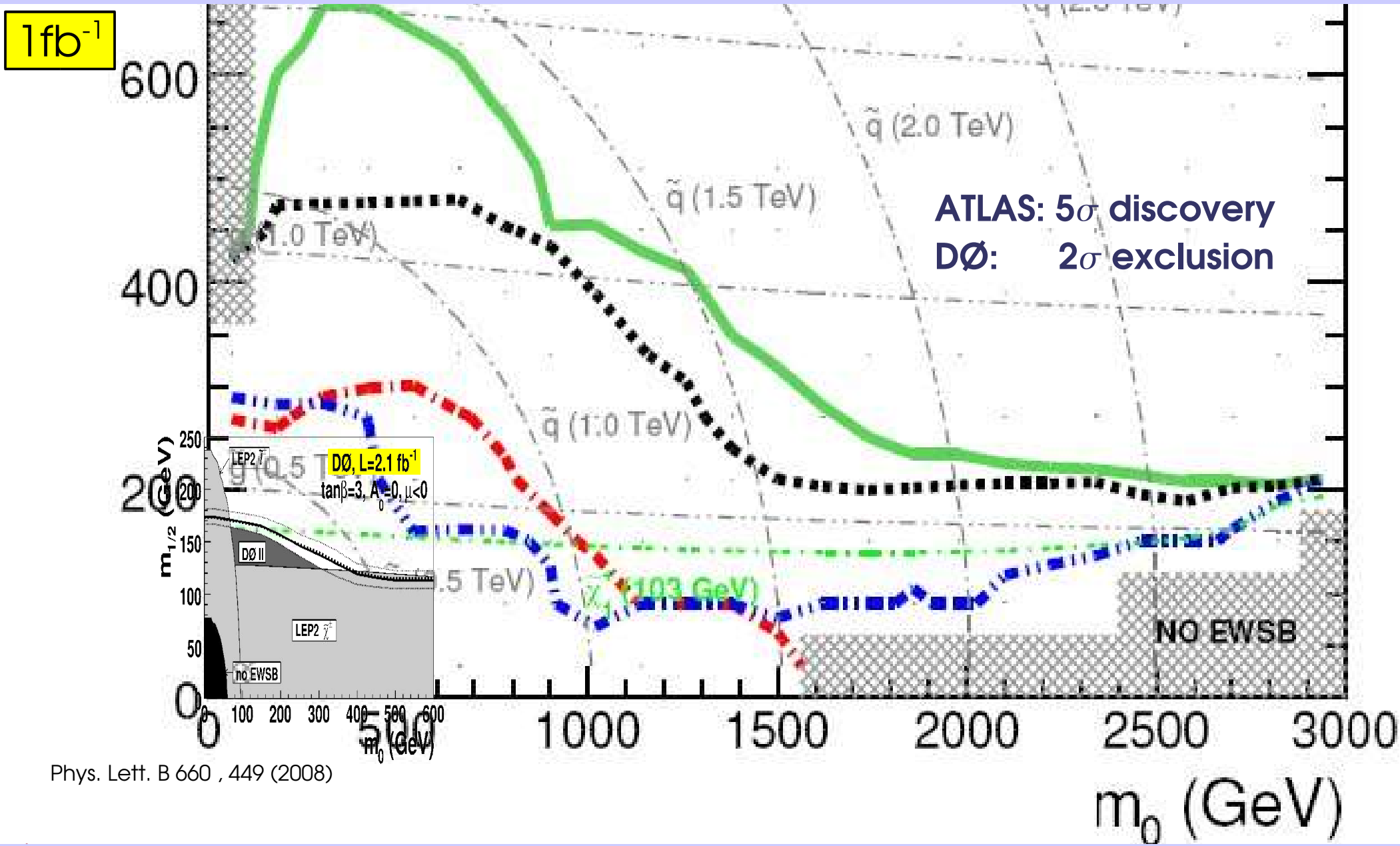
- **Optimisation: scan Meff cut to maximize significance** (corrected for multiple cuts)

- Improved one-τ reach for tanβ=50

Establish SUSY: need discovery in all channels
Comparable reach for mSUGRA, AMSB etc
(cross section driven by gluino/squark mass)



Qualitative Comparison with Tevatron



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Exclusive Measurements

<u>After discovery:</u> Mass spectrum, model parameters

<u>No mass peak reconstruction possible</u>

- R-parity conservation: sparticles eventually decay into undetected LSP's

<u>Instead:</u> endpoints are measured in invariant mass distributions of sparticle decay products

<u>System of equations:</u>

- Endpoint is function of masses of particles involved in decay
- often sparticle mass differences are mearsured

Flavor Subtraction

Particulary promising:

BR≃30% BR≃10-20%

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{\chi}_1^0 \boxed{l^\mp l^\pm} q$$

2-body decay (SU3): $\tilde{\chi}_2^0 \rightarrow l\tilde{l}_{LR} \rightarrow ll\tilde{\chi}_1^0$

3-body decay (SU4): $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$

(depending on model / mass spectrum)

Flavor subtraction:

signal: OSSF (opposite sign same flavor)

BG is random flavor and cancels:

- SUSY combinatorical BG
- SM BG

$$N(e^+e^-) + \beta^2 N(\mu^+\mu^-) - \beta N(e^\pm\mu^\mp)$$

efficiency correction

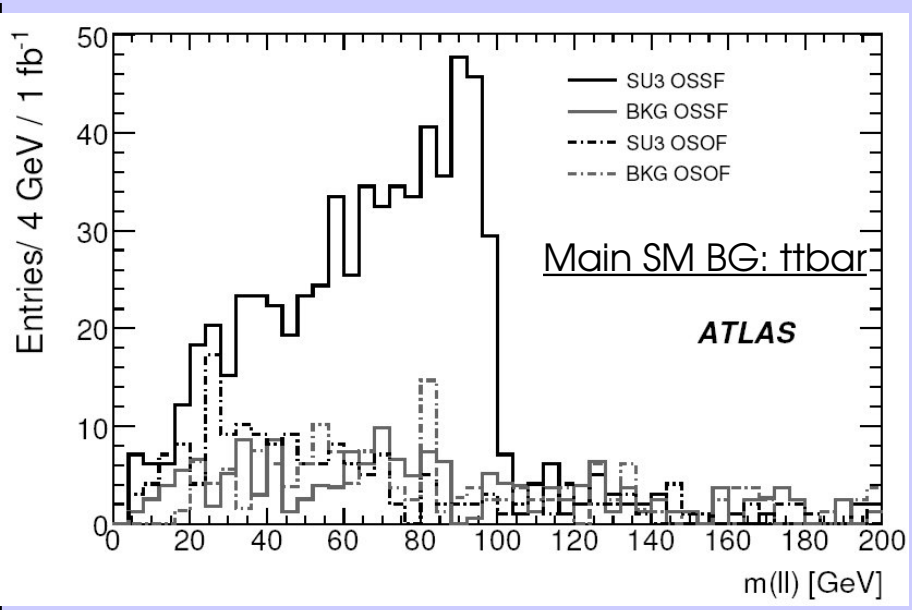
Excess of OSSF over OSOF would be clear indication of NP!

One step further: Optimize cut selection by maximizing:

$$S \equiv (N(OSSF) - N(OSOF)) / \sqrt{N(OSSF) + N(OSOF)}$$

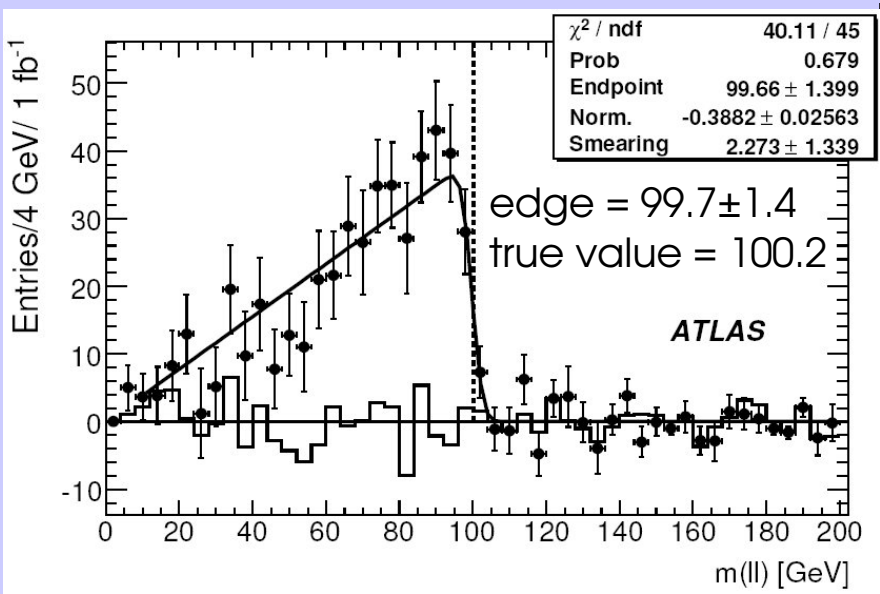
maximize selection efficiency while suppressing SM and SUSY combinatorics

Dilepton Edges



Flavor subtraction →

bulk, 1fb^{-1}



Triangle smeared with gaussian

2 edges if both sleptons lighter than $\tilde{\chi}_2$

Add in the quark ⇒ 4 more llq endpoint measurements:

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\chi}_1^0 \boxed{l^\mp l^\pm q}$$

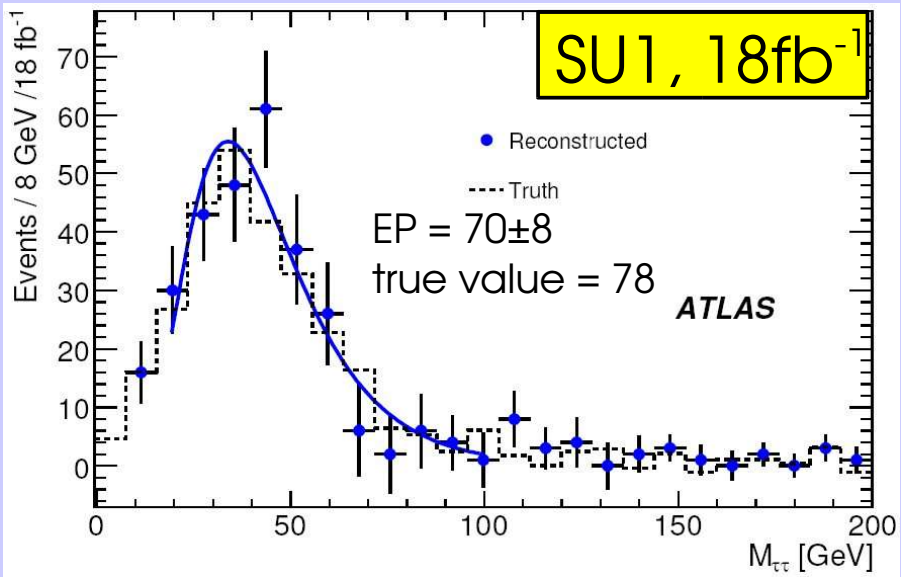
Tau Signatures

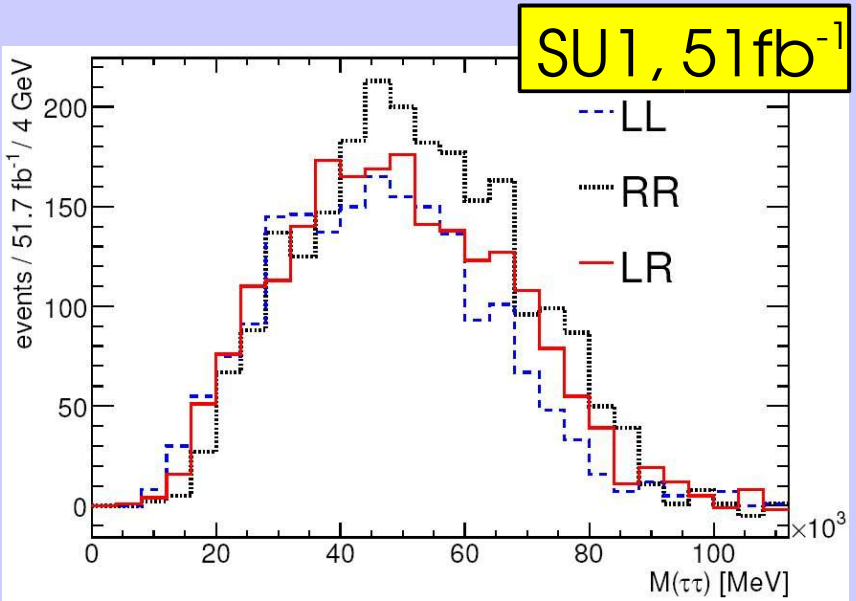
SU1: coannihilation point

$$\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau \to \tilde{\chi}_1^0 \tau^{\pm} \tau^{\mp}$$

- enhanced wrt e & μ if large L-R-mixing and $\tilde{\chi}_2$ mostly wino (stau often lightest slepton)
  - ➔ obtain $\tilde{\tau}$ mass parameter
- no sharp edge due to ν_τ
- Derive endpoint (EP) from calibration curve

Use charge subtraction: OS-SS





tau polarisation: $\tilde{\tau}_1^{\pm} \to \tau^{\pm} \tilde{\chi}_1^0$

- **sensitive to wino, bino & higgsino composition of $\tilde{\chi}_1$**
- **Polarisation ⇒ shift in endpoint (largest systematics!)**

Light Stop Signature

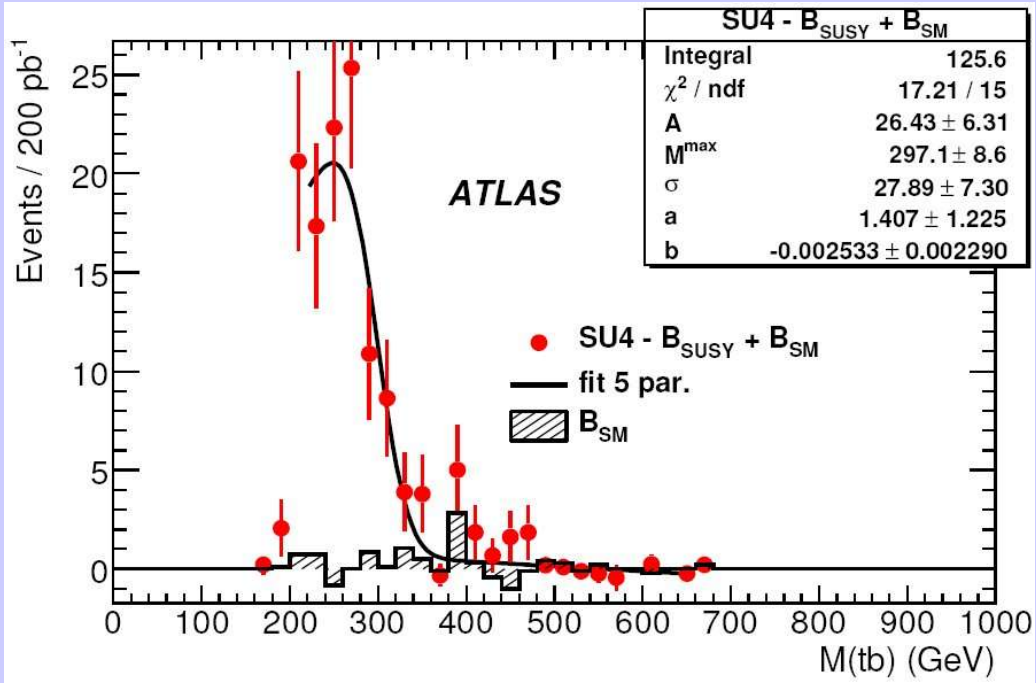
Low mass SUSY model, e.g. SU4, has large BR for: $\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1^{\pm} tb$

tb invariant mass has upper kinematic endpoint:

$$M^{max}(tb) = \left[m_t^2 + \frac{m_{\tilde{t}_1}^2 - m_{\tilde{\chi}_1^{\pm}}^2}{2m_{\tilde{t}_1}^2} \left((m_{\tilde{g}}^2 - m_{\tilde{t}_1}^2 - m_t^2) + \sqrt{(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} - m_t)^2)(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} + m_t)^2)} \right) \right]^{1/2}$$

only consider decay: $t \to Wb \to qqb$

Low mass point, 0.2fb^{-1}



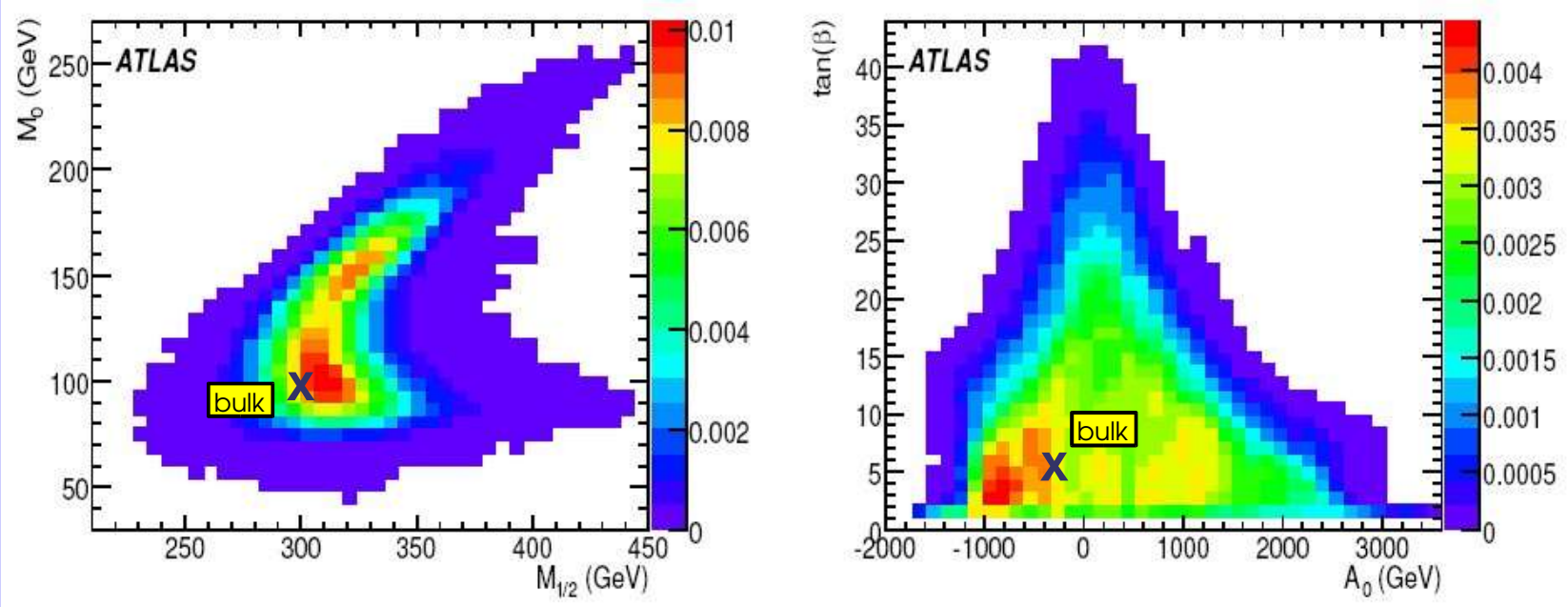
Selection:

- require exactly 2 b-jets
- W and top mass window cuts
- W sideband subtraction to reject SUSY combinatorical BG

endpoint = 297±9
true value = 300

Extract Model Parameters

$1 fb^{-1}$



Input data: kinematic edges

- **Scan of mSUGRA parameter space**
- **Pseudo experiments & fit**

M_0 and $M_{1/2}$ much better constrained than A_0, sign(μ) ambiguity

Parameter	bulk value	fitted value	exp. unc.	theo. + exp. unc.
		$\mathrm{sign}(\mu) = +1$		
$\tan\beta$	6	7.4	4.6	–
M_0	100 GeV	98.5 GeV	±9.3 GeV	±9.5 GeV
$M_{1/2}$	300 GeV	317.7 GeV	±6.9 GeV	±7.8 GeV
A_0	−300 GeV	445 GeV	±408 GeV	–
		$\mathrm{sign}(\mu) = -1$		
$\tan\beta$		13.9	±2.8	–
M_0		104 GeV	±18 GeV	–
$M_{1/2}$		309.6 GeV	±5.9 GeV	–
A_0		489 GeV	±189 GeV	–

Long-Lived Heavy Particles

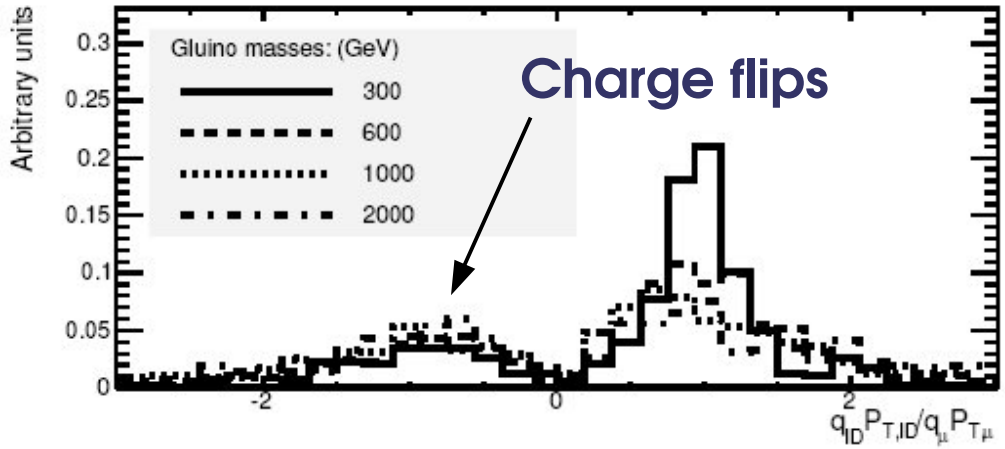
$1 fb^{-1}$

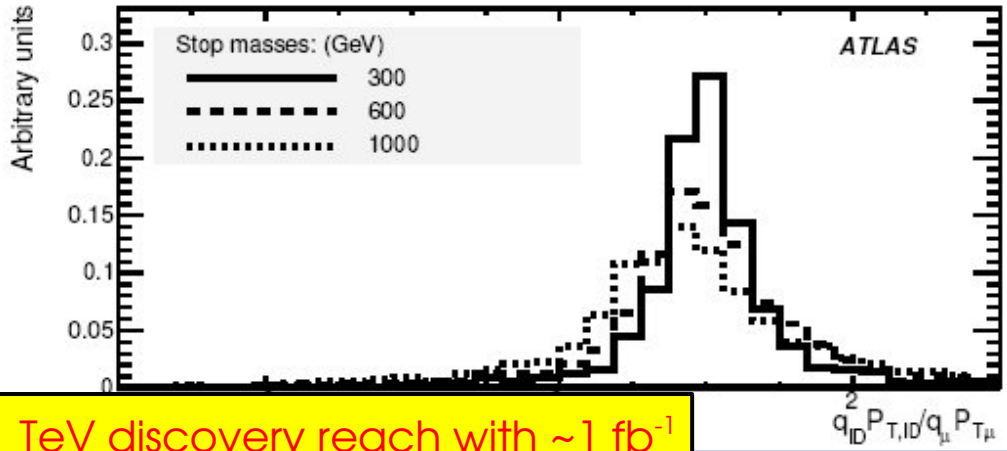
Meta-stable charged sleptons in GMSB, R-hadrons in Split-SUSY/stop-NLSP SUGRA:
muon-like signature, higher energy deposition, longer ToF (0.7 ns res.), charge-flip

Timing: ATLAS extends up to 20m from interaction point
⇒ **three separate bunch crossings co-exist in the detector at the same time**
event fragments assembled using beam crossing ID (assuming speed of light)

Muon system triggers on slow particles:
- need Inner Detector data from previous BC (feasibility to be assessed)
- need muon data from next BC for complete reconstruction (possible)

Topology = challenge for trigger & reconstruction vs useful discovery observables





1 TeV discovery reach with ~1 fb^{-1}

FCNC – Rare Top Decays

$1 fb^{-1}$

- **FCNC strongly suppressed in SM due to GIM mechanism**
- **SM contributions only at one-loop level ⇒ BR(t→qX, X=Z,γ,g) < 10^{-10}**

<u>SUSY, multi-Higgs doublet models, exotic (vector-like) quarks:</u>

FCNC contributions at tree level ⇒ predicted BR ~10^{-4} - 10^{-8}

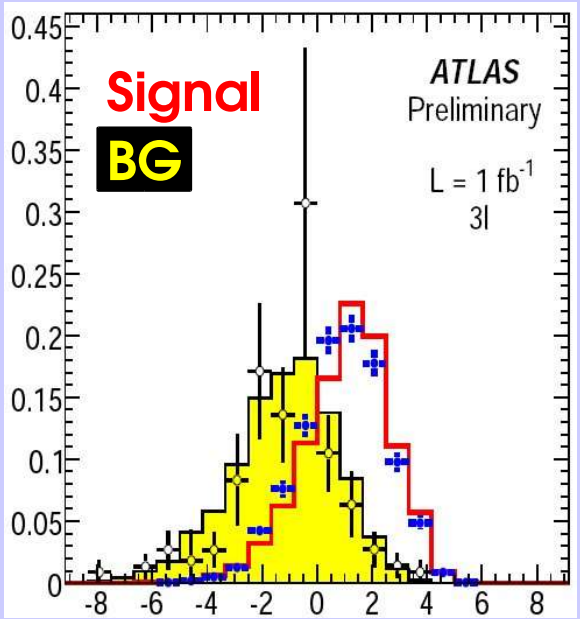
(Tevatron searches limited by statistics, current BR limits ~ 10^{-2})

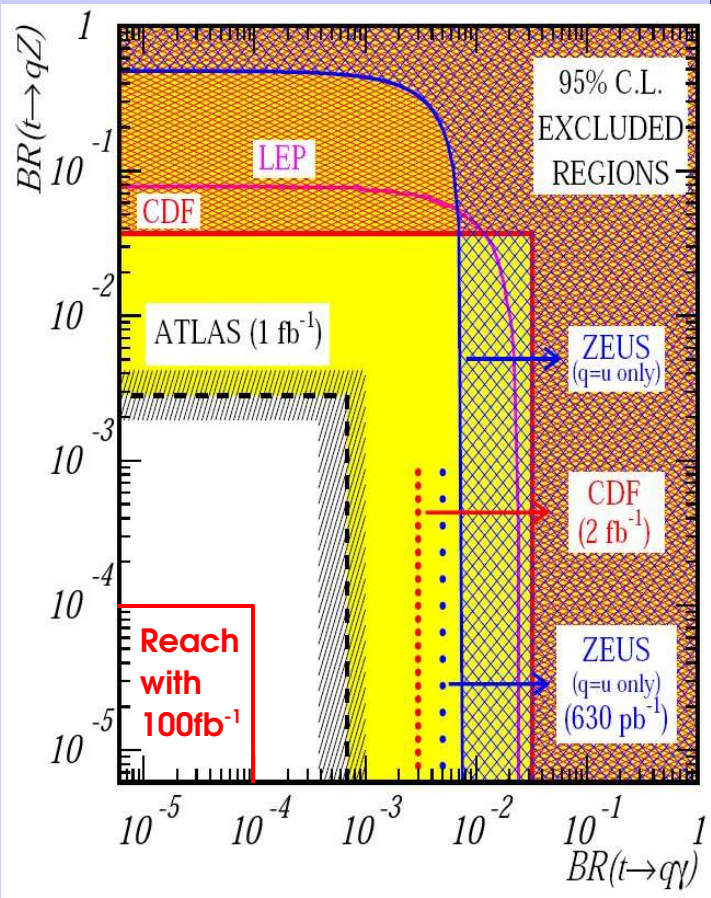
<u>ttbar event selection:</u>

- SM decay for one top
  FCNC decay for other top
- consider only lepton decays of W, Z
- no b-tagging

likelihood-based analysis with invariant mass and transverse momentum inputs

t→qZ





Ttbar Resonances

$1 fb^{-1}$

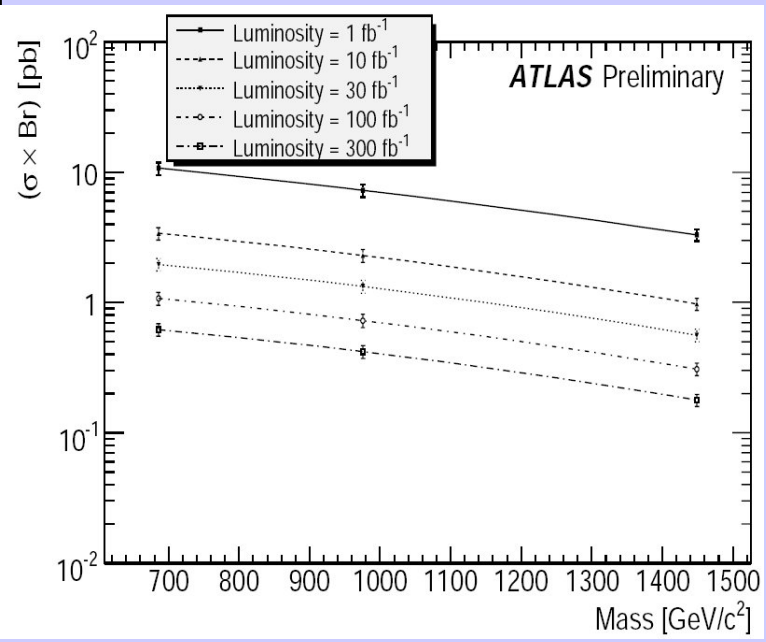
Large variety of models:

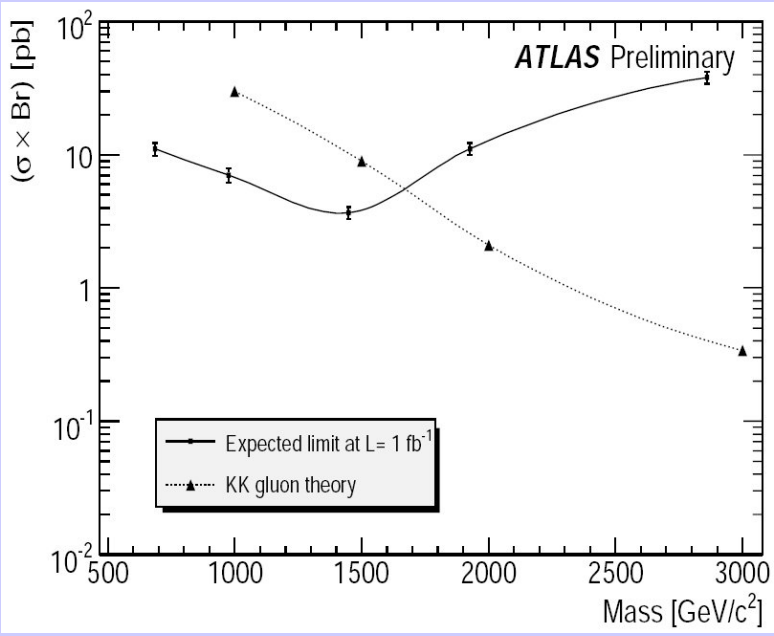
new resonances or gauge bosons strongly coupled to top quark

⇒ **generic, model-independent search for narrow resonance: Z'→ttbar**

- Simple cut-based lepton+jet ttbar selection
- W and top mass cuts

Degraded resolution & efficiency with invariant ttbar mass, objects start overlapping ⇒ need modified selection for m > 2 TeV





5σ discovery potential

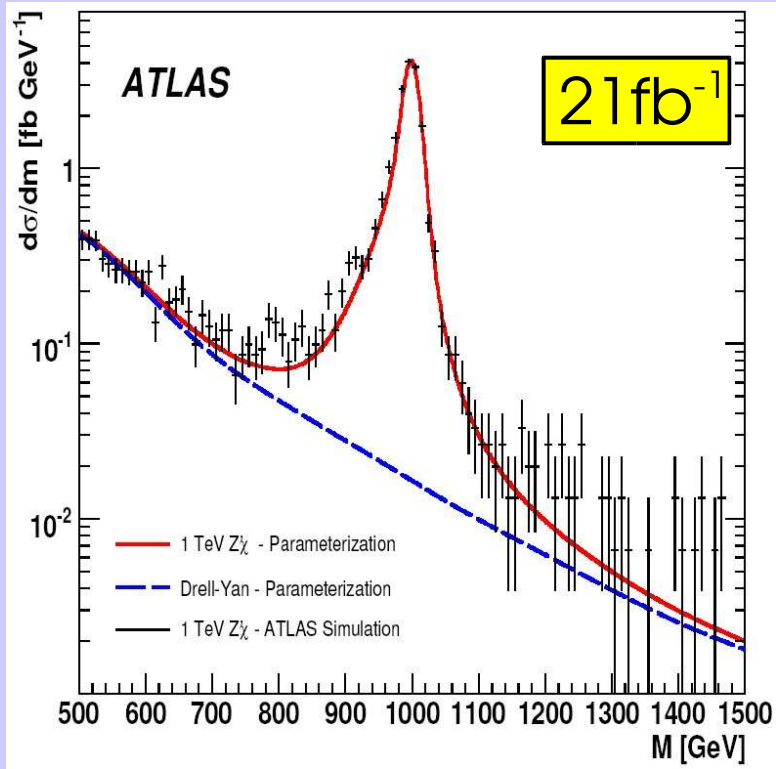
KK gluon large BR into ttbar (flavor non-universality)

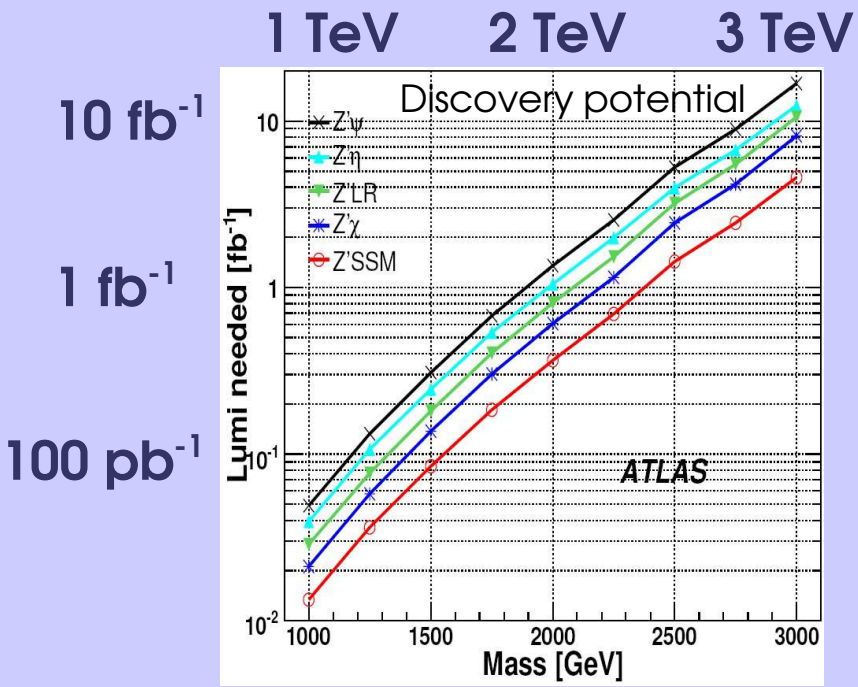
KK discovery potential up to 4 TeV with full luminosity

Dilepton Resonances

Many models, all give very similar signature:
narrow resonance with natural width~1% of mass

Irreducibal dominant BG: Drell-Yan
jet rejection = 10^4





for 1 TeV Z' – complementarity of e and μ:

- 5% lepton charge mis-identification

Electrons: larger jet fakes, jet-e overlaps, 1% dielectron mass resolution

Muons: higher efficiency & purity, misalignment dominant systematic, 5-10% dimuon mass resolution

ultimate reach with 300 fb^{-1}: 5-6 TeV

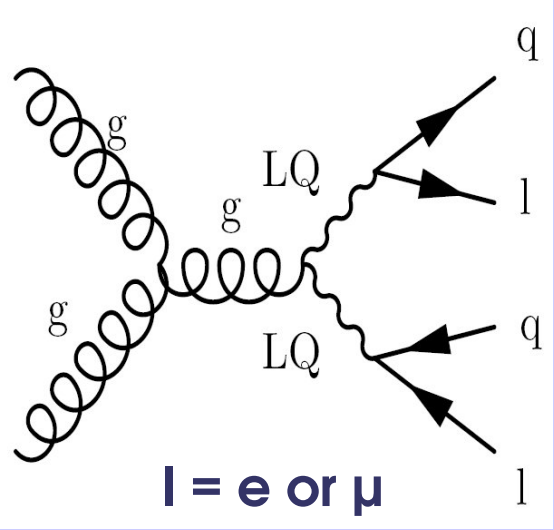
Dilepton-Jets Final States w/o MET

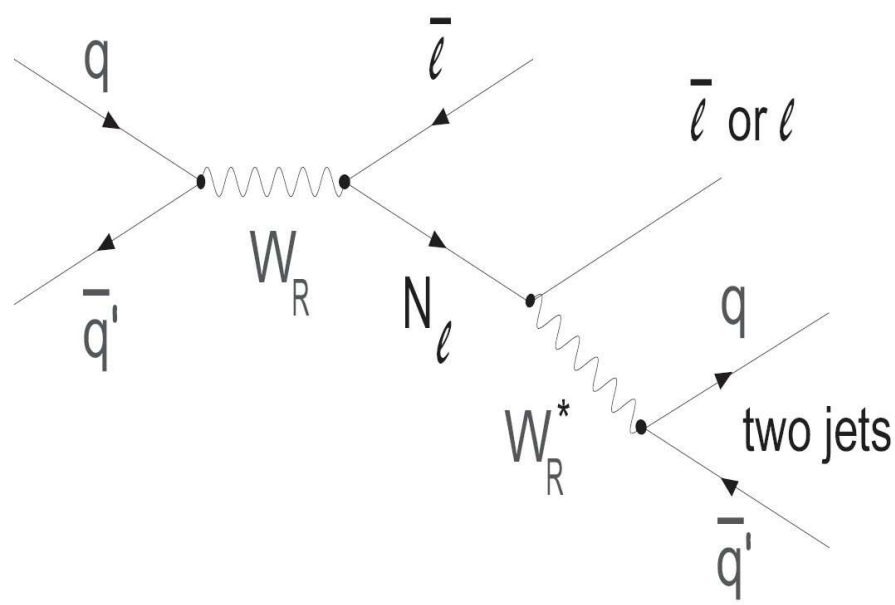
2 models considered:

- Leptoquarks (with 3 generations)
- Left-Right Symmetric Models with new intermediate vector bosons and Majorana neutrinos

Dominant backgrounds:

ttbar, Z+jets, QCD multijet production, diboson production





High-mass objects:

Require high pT & high scalar sum pT of leptons/jets

LQ: lq combination which gives smallest mass difference between two LQ's

LRSM: lqq combination which gives smallest Majorana mass (99% correct for $W_R >> N_l$).

- For $W_R > \sim 2\ N_e$ e-jet objects overlap ⇒ use only jets
- Future improvement: same sign dileptons

Dilepton-Jets w/o MET Results

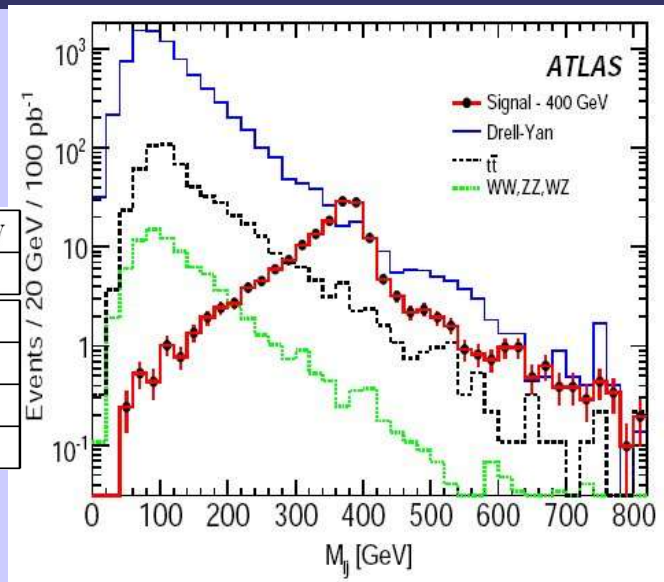
100pb^{-1}

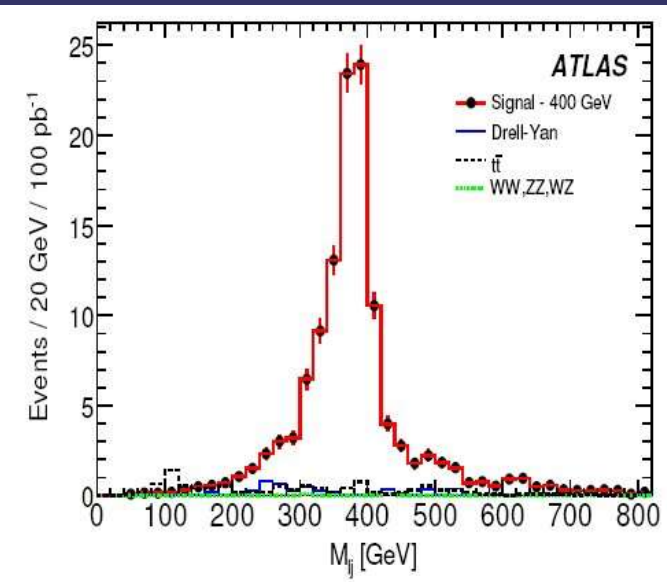
2nd generation shown, similar for 1st

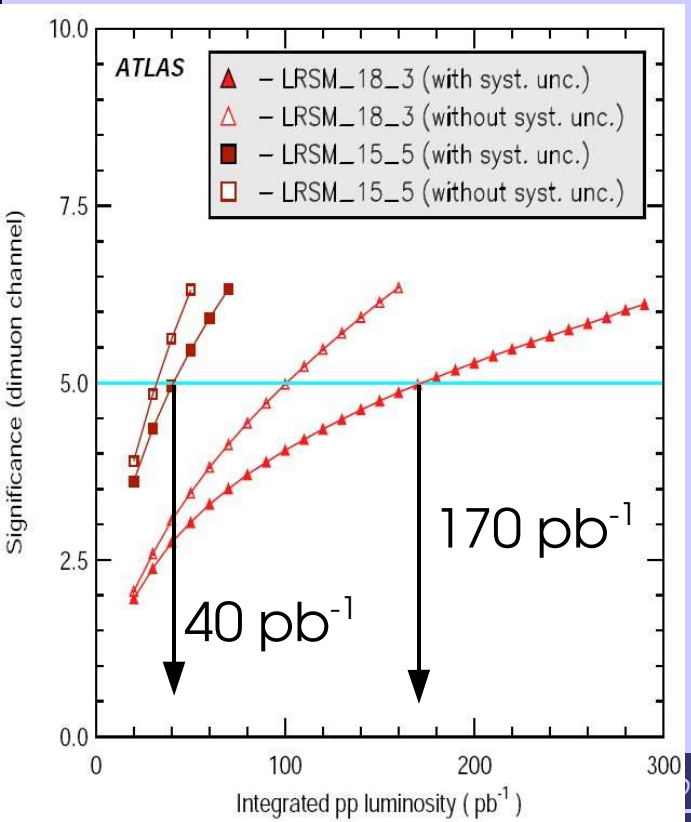
LQ

550-600 GeV discovery reach with 100 pb^{-1} assuming 100% BR(LQ→lq)

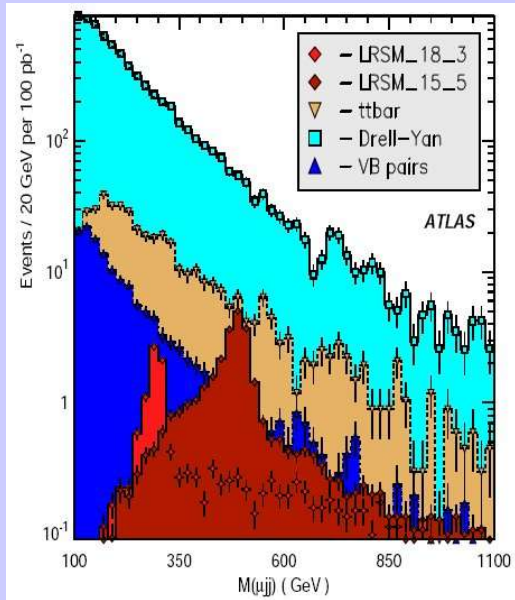
Leptoquark mass	Expected luminosity needed for a 5σ discovery	
	1st gen.	2nd gen.
300 GeV	2.8 pb^{-1}	1.6 pb^{-1}
400 GeV	11.8 pb^{-1}	7.7 pb^{-1}
600 GeV	123 pb^{-1}	103 pb^{-1}
800 GeV	1094 pb^{-1}	664 pb^{-1}

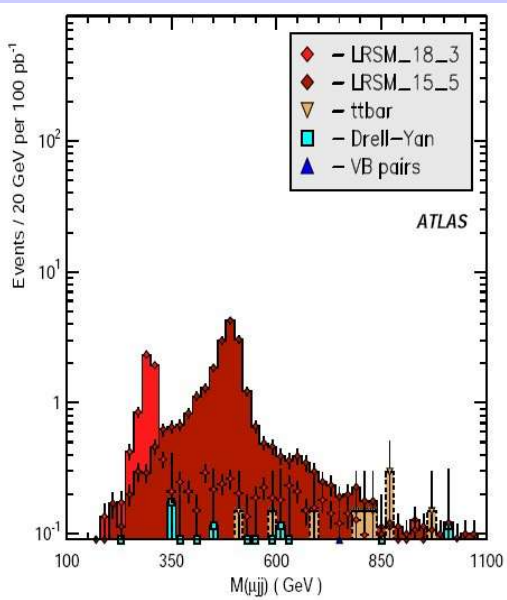






LRSM: N_μ mass





Before selection ⇨ After selection

Summary

Broad range of ATLAS searches for New Physics with realistic detector description confirming TDR results

<u>Left out many NP searches:</u> GMSB photon searches, stopped R-hadrons, black holes, W', technihadrons,...

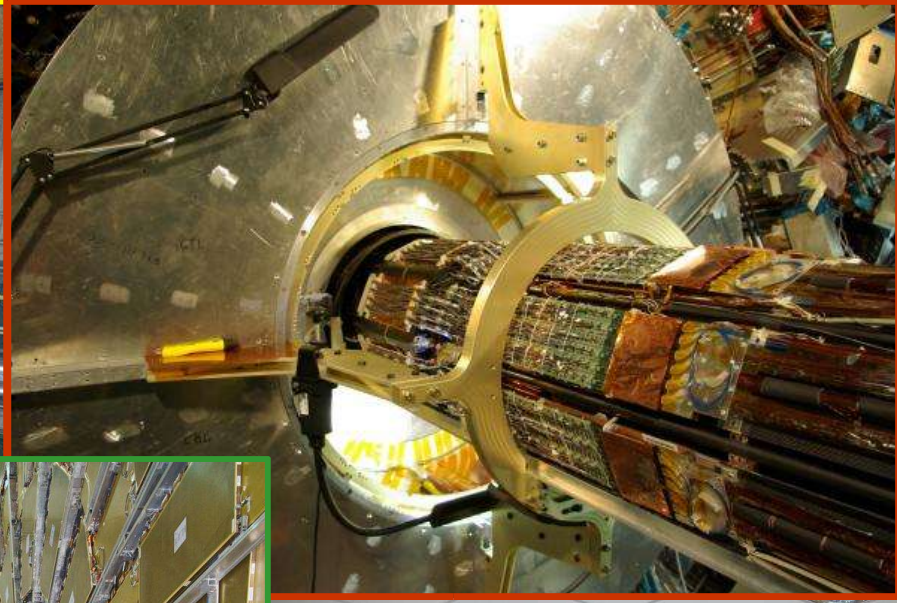
- model-independent searches
- complemented by detailed studies of specific models

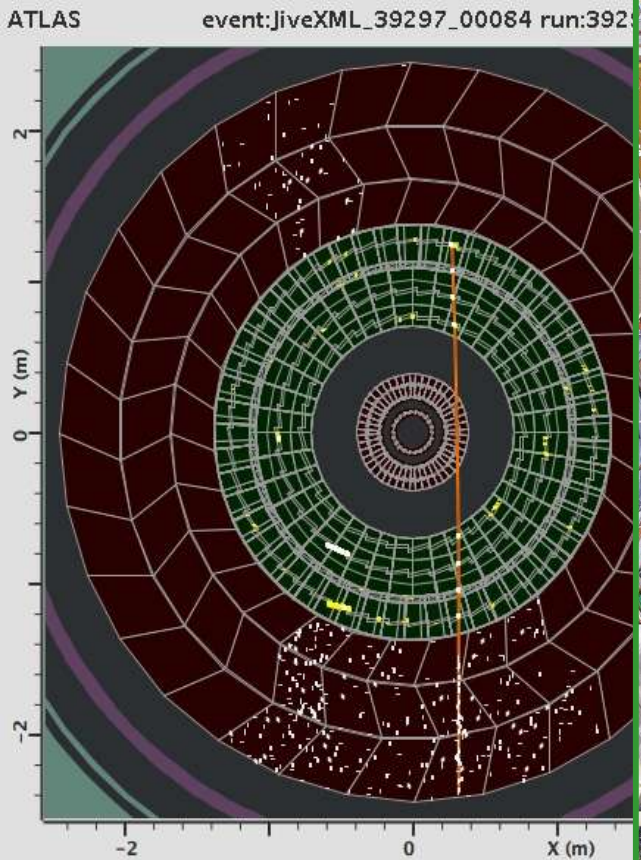
- use flavor to enhance S/B
- understand flavor content of New Physics

⇒ **Eagerly awaiting first data!**

Backup


SCALES




ATLAS
event:JiveXML_39297_00084 run:392
2
0
-2
Y (m)
-2
0
X (m)

Trigger (Online Event Selection System)

- **40 MHz collision rate**
- **200 Hz written to storage, given technology and budget**

Multi-level system:

- Level 1: calorimeter and muon system, hardware-based (40 MHz → 40 kHz)
- High-Level Trigger: fast reconstruction (40 kHz → 200 Hz)

At design luminosity:

- 25 interactions / per bunch crossing
- collect 36 pb^{-1} / hour

Trigger = f (detector performance, physics, physics program)

ATLAS defines the physics program: **optimise trigger for all possible NP signatures**

"Easy" since high mass objects ⇒ trigger on:

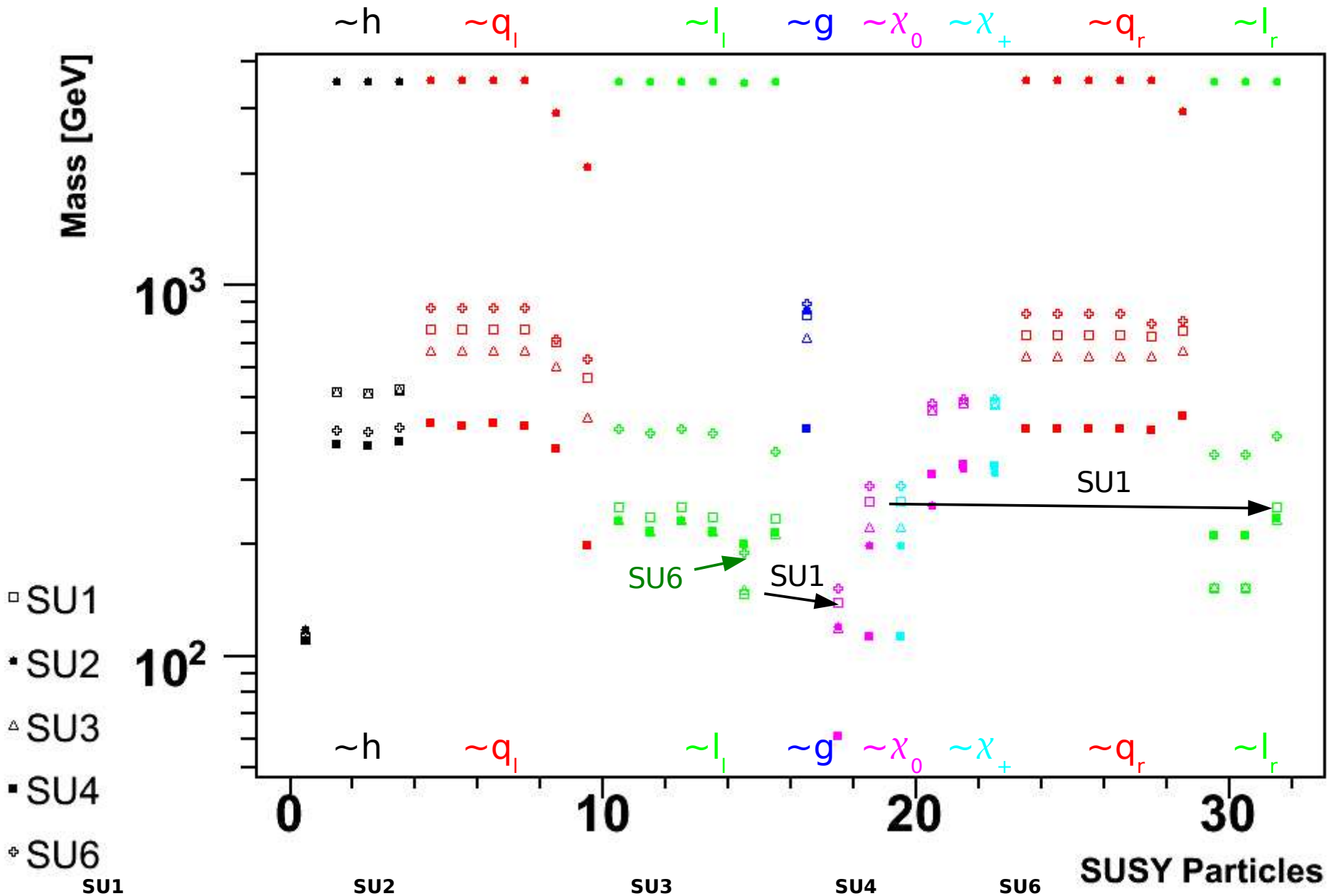
- high-pT jets
- high-pT leptons
- MET (commissioning!)

Simulation

Full simulation for SUSY:

- **Background (generated with filter cuts on leading jets and missing ET):**
  - MC@NLO for ttbar
  - Alpgen for W+jets, Z+jets
  - Pythia for QCD (J4-J8)
- **Signal:** Isajet & Herwig

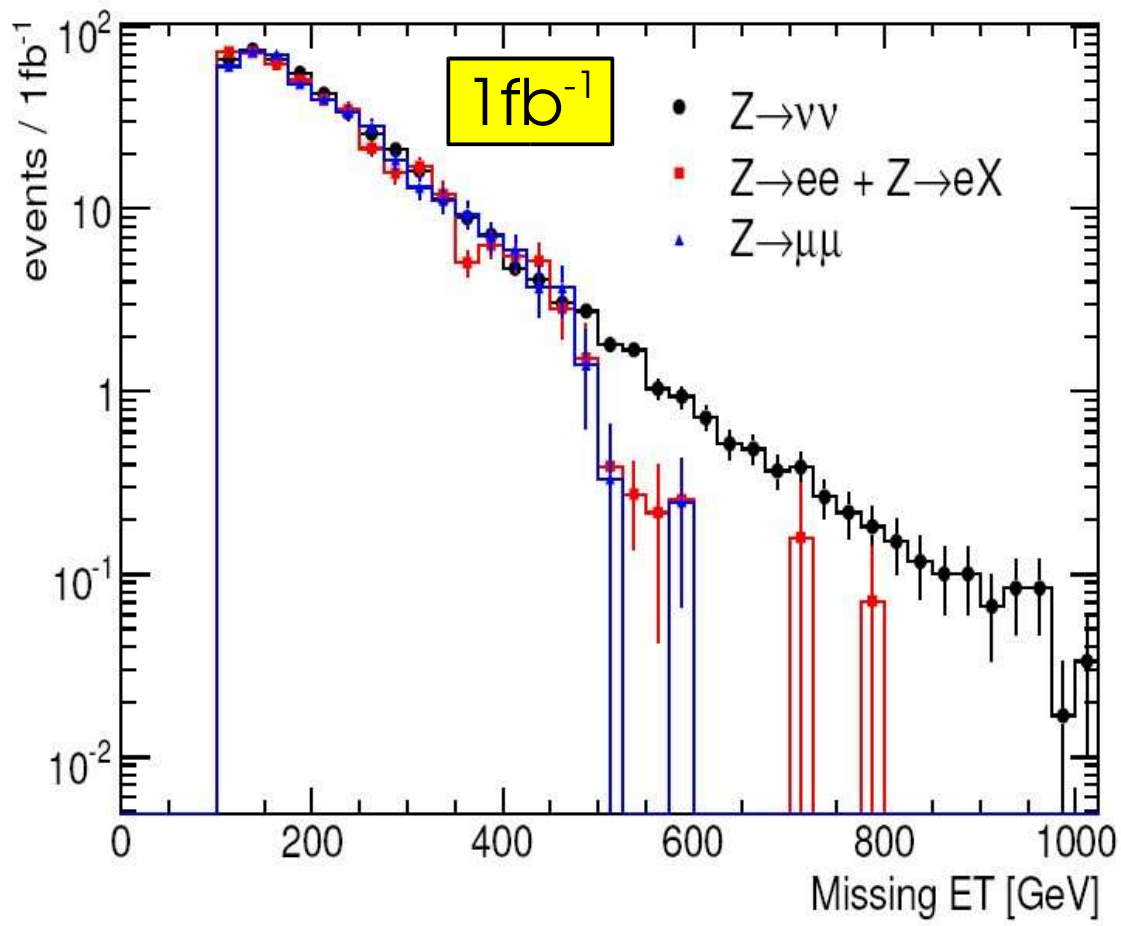
Signal Points in more Detail



SU1	SU2	SU3	SU4	SU6
Coannihilation point	Focus point	Bulk region	Low mass point	Funnel point
Small ~l mass splitting	Mainly ~g & ~chi production	No special degeneracies	In RunII reach	Taus dominate

Data-driven Background Determination

Z->$\nu\nu$ from Z->ll



Main idea:
Select Z→ll and replace charged leptons by neutrinos

Corrections applied to Z→ll:

- **Fiducial $|\eta|$ correction** (from MC)
- **Kinematics correction**
  Z selection cuts (from MC)
- **Lepton ID efficiency** (from data)

13%(stat.) @1fb^{-1}
8%(sys.)
15%(total)

Method limited by statistics:

- small Br(Z→ll)/Br(Z→$\nu\nu$) ~ 1/6, other inefficiencies

⇒ fitting / extrapolation / MC shape

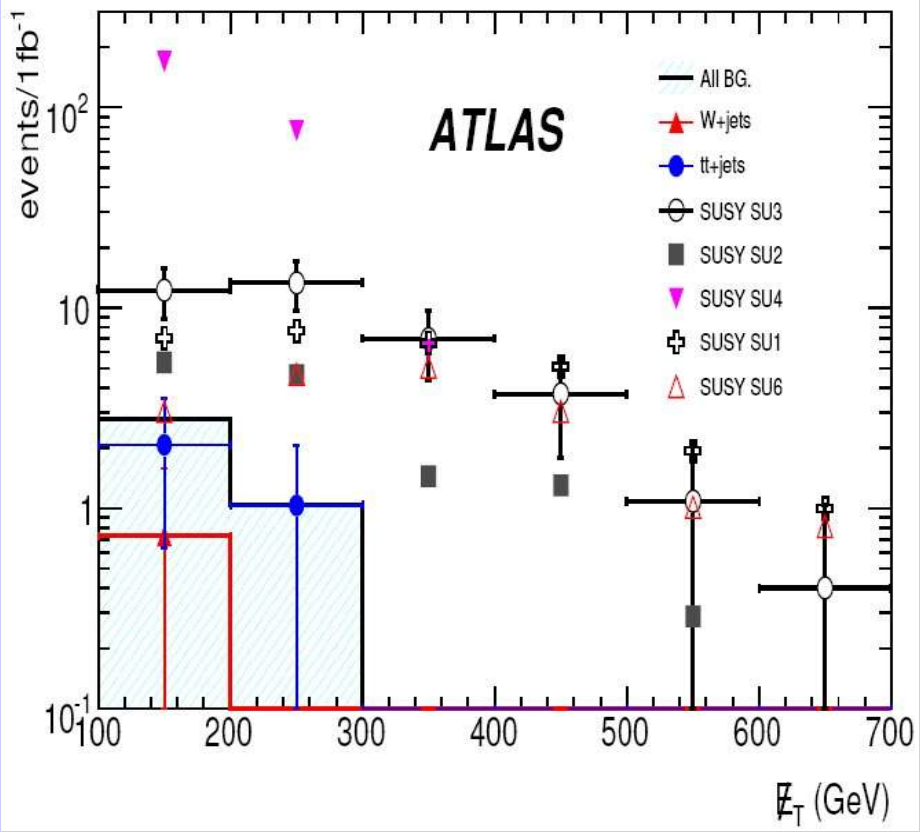
MET + Jets + 2 Leptons

$1 fb^{-1}$

Opposite sign:

- Flavor subtraction:
  excess of OSSF over OSOF would be clear indication of NP!

Sample	$\not{E}_T$ cut	Leading jet cut	N_{SF}	N_{OF}	Significance
SU1	220 GeV	100 GeV	90.69	58.53	2.63
SU2	140 GeV	100 GeV	31.64	29.95	0.22
SU3	160 GeV	160 GeV	93.75	38.58	4.80
SU4	120 GeV	100 GeV	392.45	281.55	4.27



Same sign: (gluino is self-conjugate Majorana)

- low statistics, very clean

3 Leptons

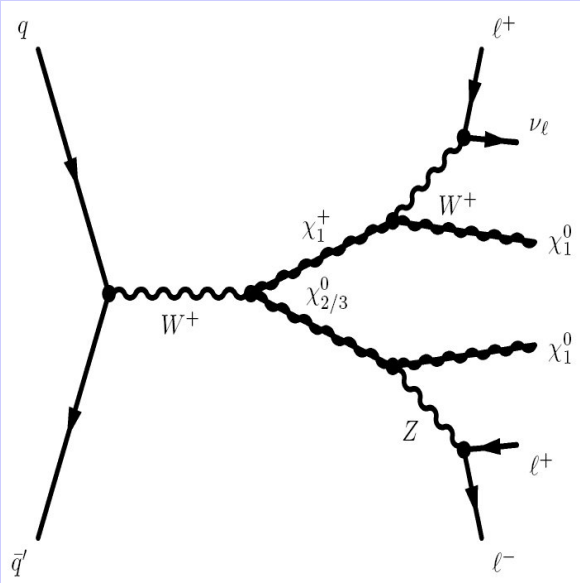
10fb^{-1}

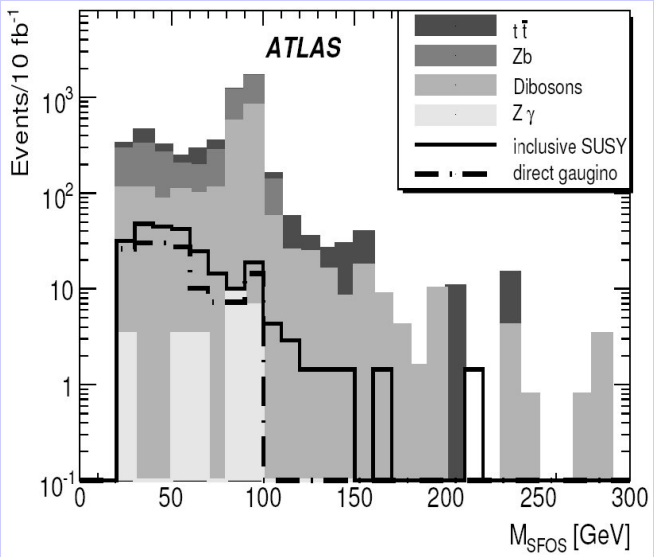
2 complementary approaches
to cover wide range of scenarios:

Jet + 3 leptons: higher statistical significance

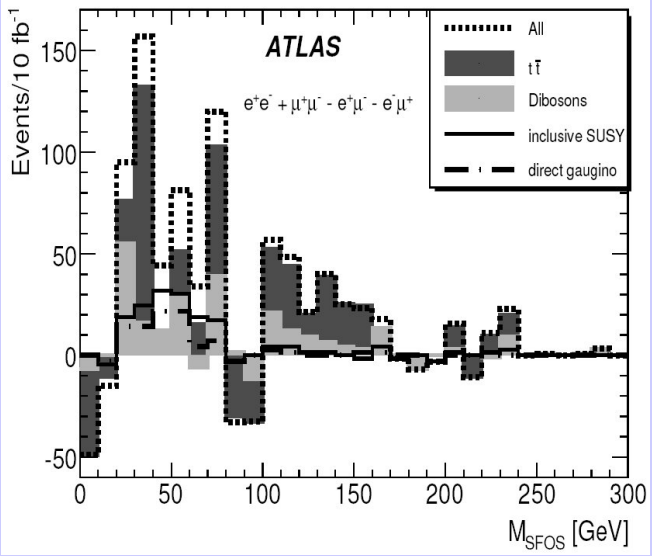
MET + 3 leptons:

- **direct gaugino production (focus point)**
  lepton isolation ⇔ fakes from heavy quarks





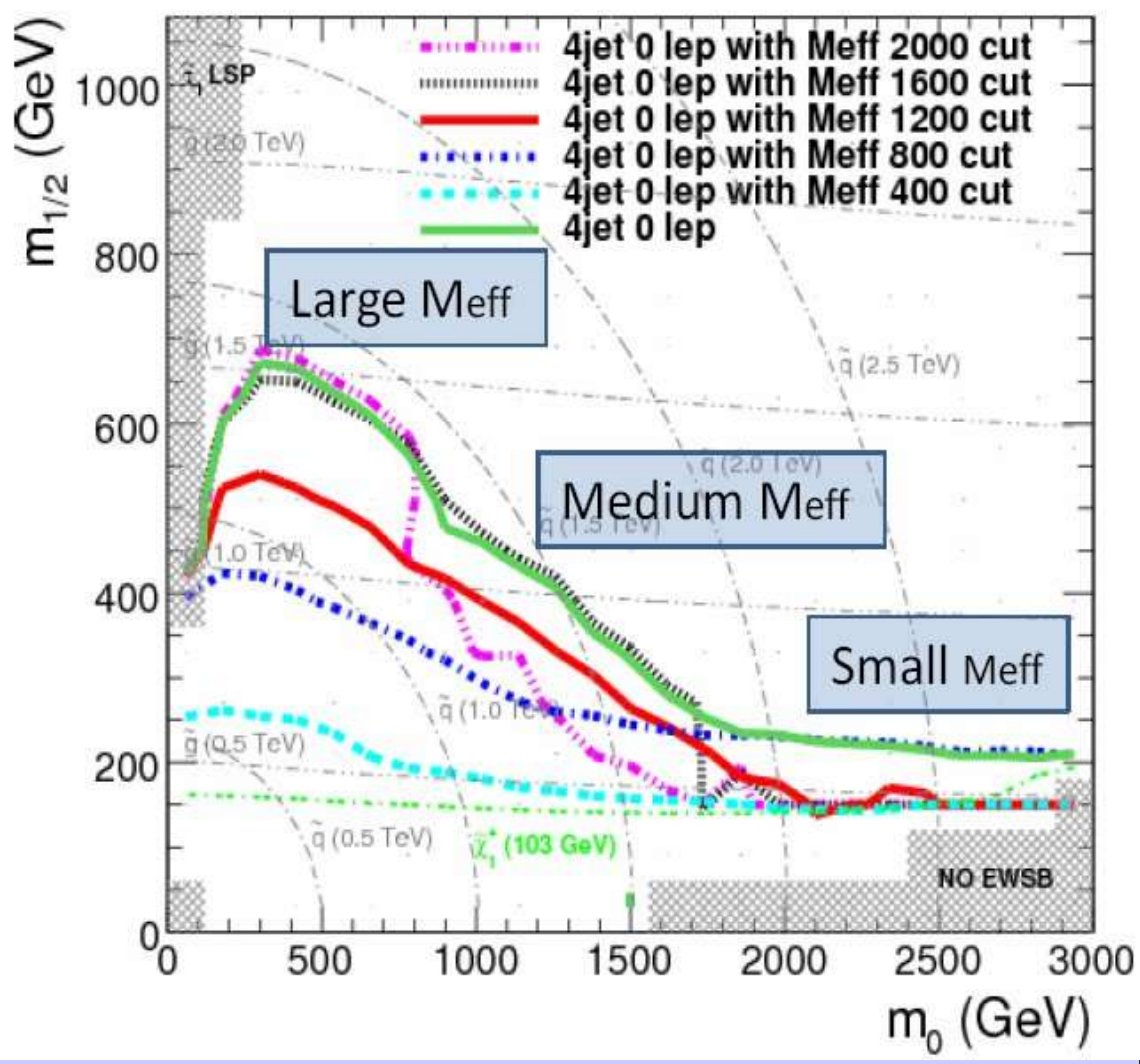
- Z mass window
- flavour subtraction



SU2

Scans & Optimization

$1 fb^{-1}$



Other cut optimization:

- Define FoM, e.g. "number of SUSY points that can be discovered at 5 sigma"
- Maximize FoM, on various grids, for a single and for multiple analyses

Leptons+Jets Edges

Same decay chain:

BR≃30% BR≃10-20%

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{\chi}_1^0 \boxed{l^\mp l^\pm q}$$

4 endpoints = 4 equations

m_{llq}^{max}: smaller

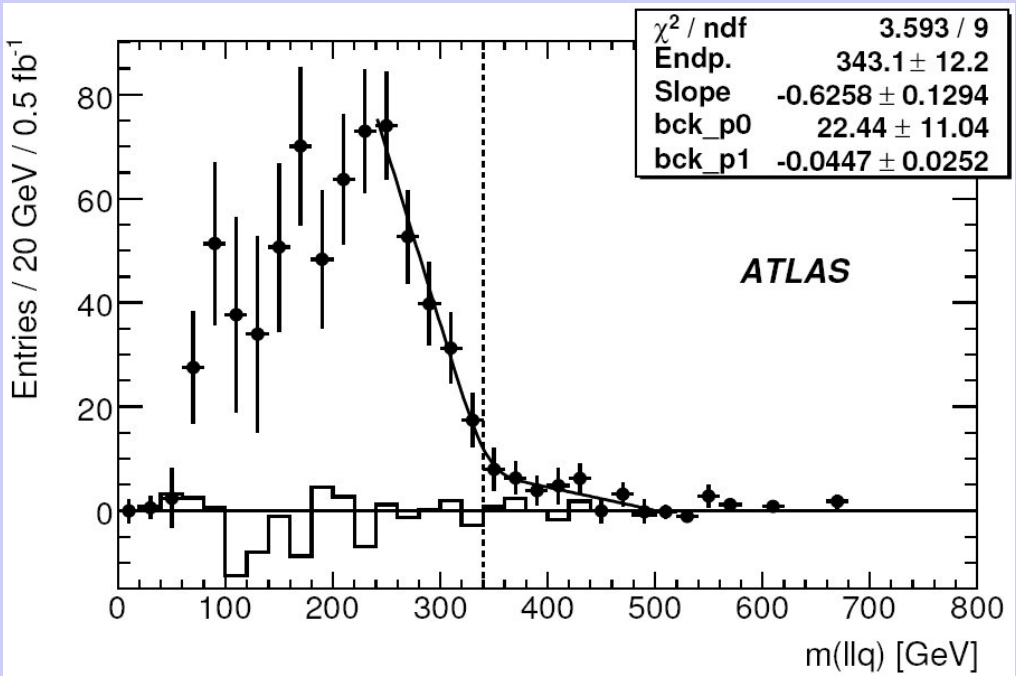
m_{llq}^{min}: larger

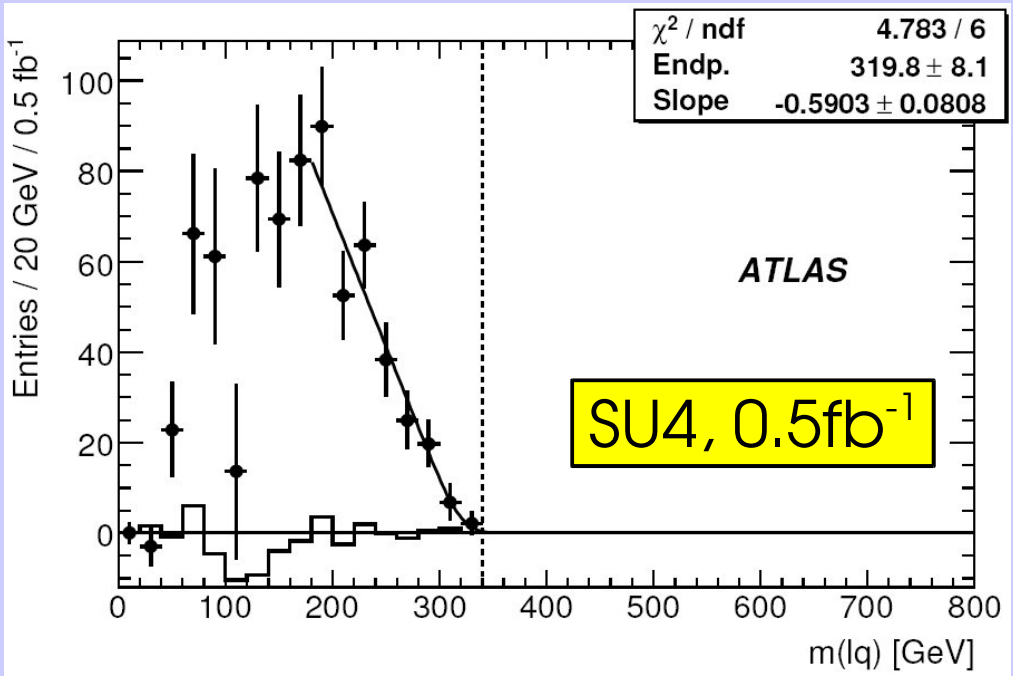
combination with 2 hardest jets

$m_{lq(low)} = \min(m_{l^+q}, m_{l^-q})$

$m_{lq(high)} = \max(m_{l^+q}, m_{l^-q})$

Use flavor subtraction





Stransverse Mass Endpoint

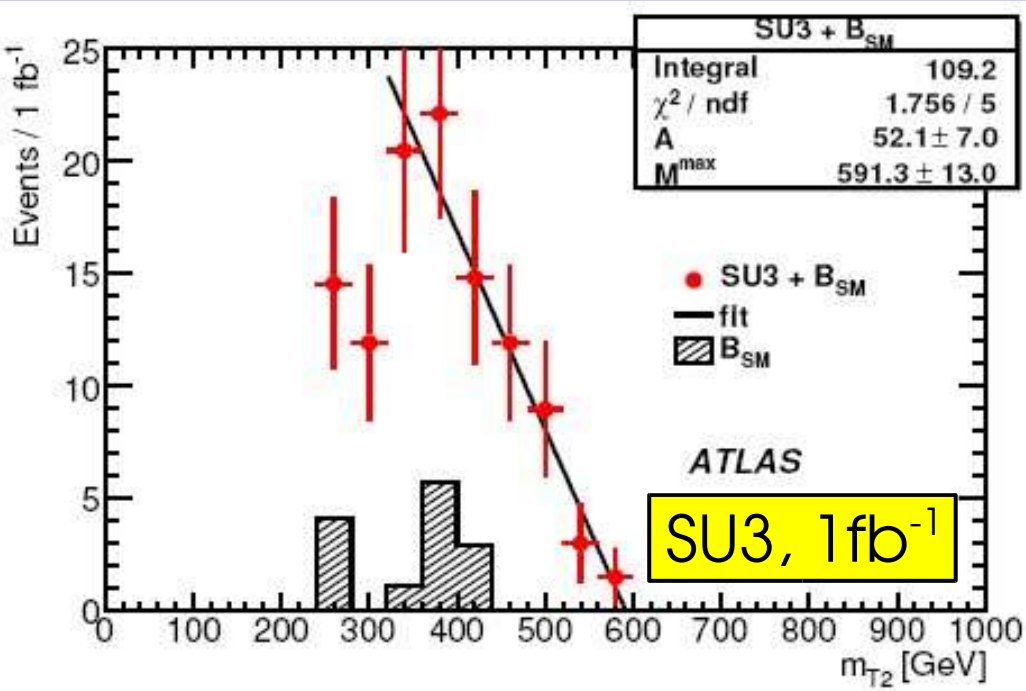
m_{T2}: stransverse mass defined for events with 2 undetectable decay products, applied to $\tilde{q}_R\tilde{q}_R$ events where:

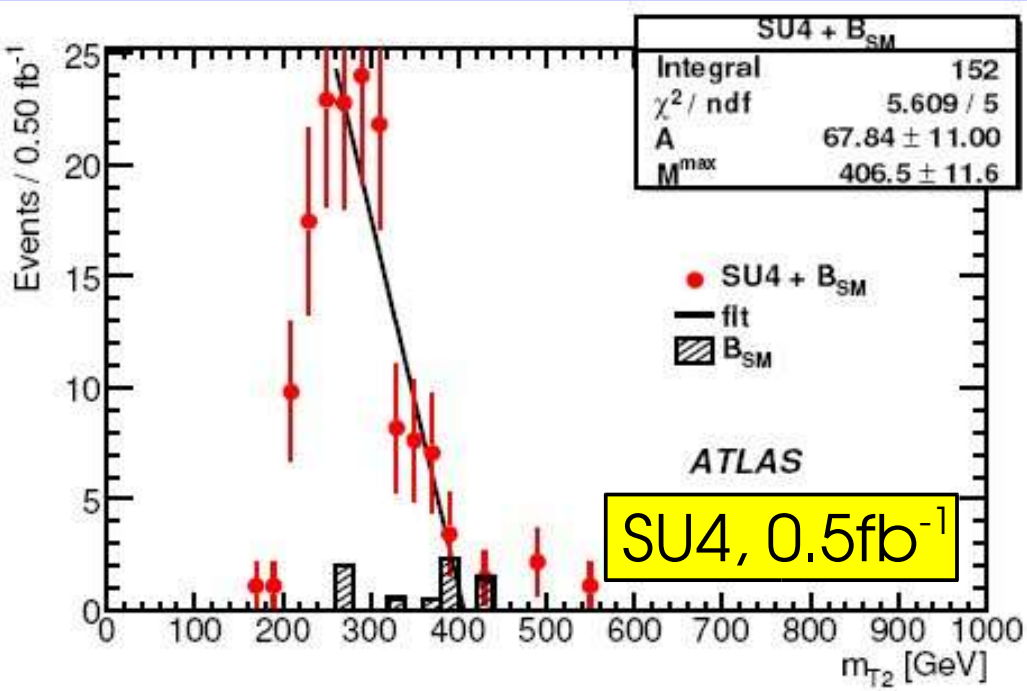
$$\tilde{q}_R \rightarrow \tilde{\chi}_1^0 q$$

upper kinematical endpoint = mass of the decaying particle ($\tilde{q}_R$ in this case)

endpoint = 591±15
$\tilde{q}_R$ mass = 637

endpoint = 407±12
$\tilde{q}_R$ mass = 405





Higgs Signature

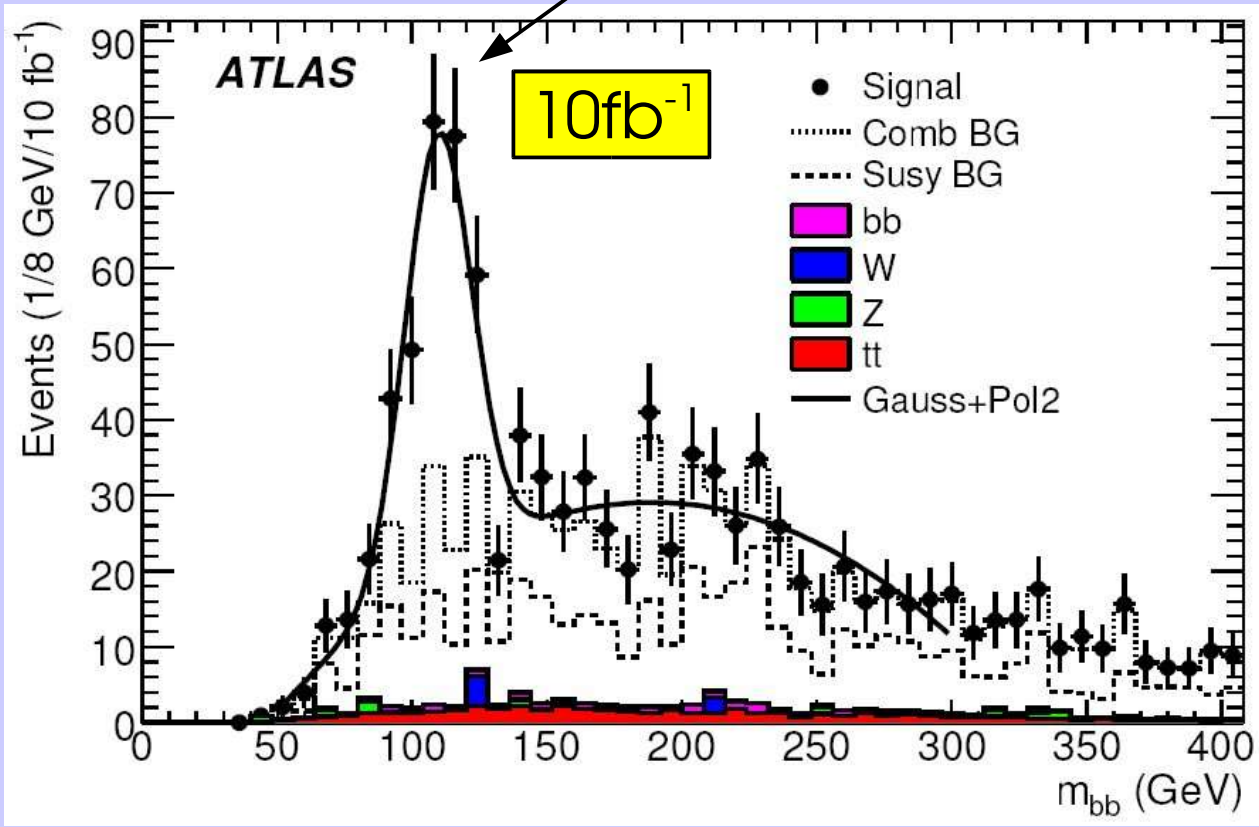
Search of lightest CP-even higgs boson in: $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$

14 sigma significance

Thanks to MET signature:

dominant decay channel h→bb can be used

(otherwise swamped by QCD)



Complementary to Higgs to dilepton search: $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$

Long-Lived Heavy Particles

Stable charged sleptons in GMSB:

- high tanβ, slepton is NLSP, couples weakly to gravitino (LSP) $\Rightarrow$ long-lived, $\beta < 1$
- muon-like signature with higher energy deposition and longer time of flight
- excellent muon time resolution (0.7 ns) $\Rightarrow$ mass measurement for slow particles

Stable R-hadrons in Split-SUSY/gravitino LSP scenario in SUGRA:

- signature similar to stable sleptons with additional multiple nuclear interactions
- possible charge flip, or neutral in Inner Detector
- phenomenology fully determined by stable sparticle masses
- signature ~independent of energy loss and scattering model
- analysis sensitive to generic search for stable heavy exotic hadrons

Split-SUSY:

- gauginos, higgsinos ~ weak scale
- squarks ~ GUT scale $\Rightarrow$ meta-stable gluino forms bound state (R-hadron)

gravitino LSP, stop NLSP in SUGRA:

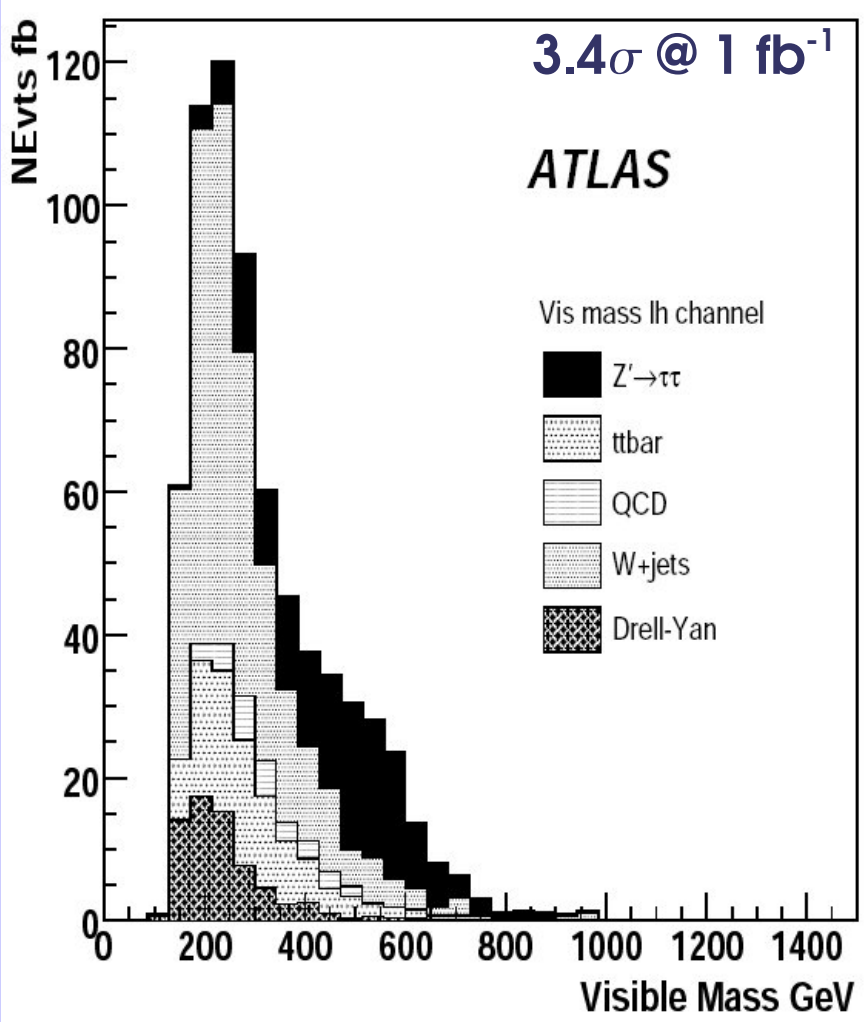
- meta-stable stop forms bound state (R-hadron)
- R-hadrons with masses below 1 TeV discoverable with ~1 fb^{-1}

Dilepton Resonances with Taus

$1 fb^{-1}$

Many models with preferred coupling to 3rd generation

- "hadron-lepton" final states considered here
- much larger reducible backgrounds, much lower selection efficiency



600 GeV Z'→ττ with Sequential SM cross section