Recent SUSY results from ATLAS

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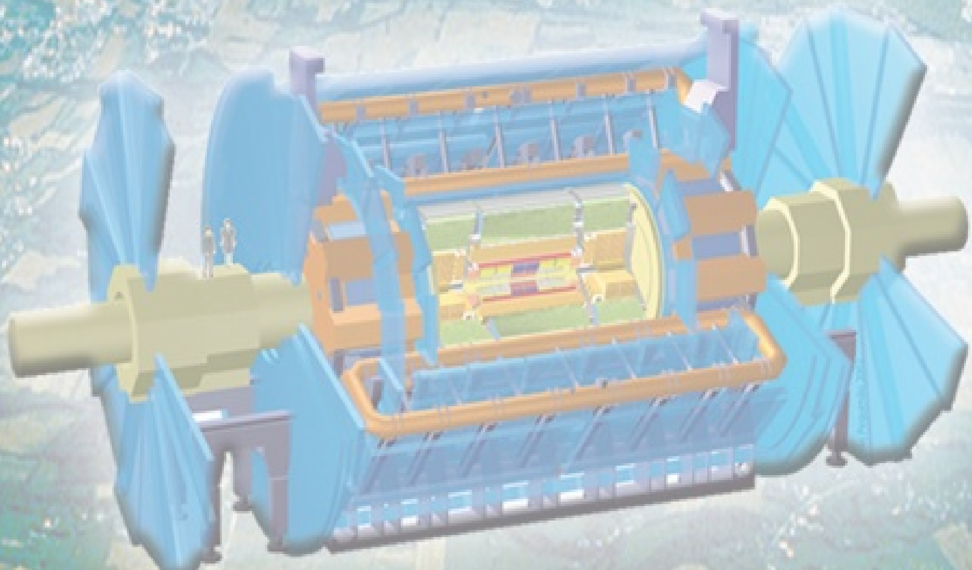


BNL HEP seminar

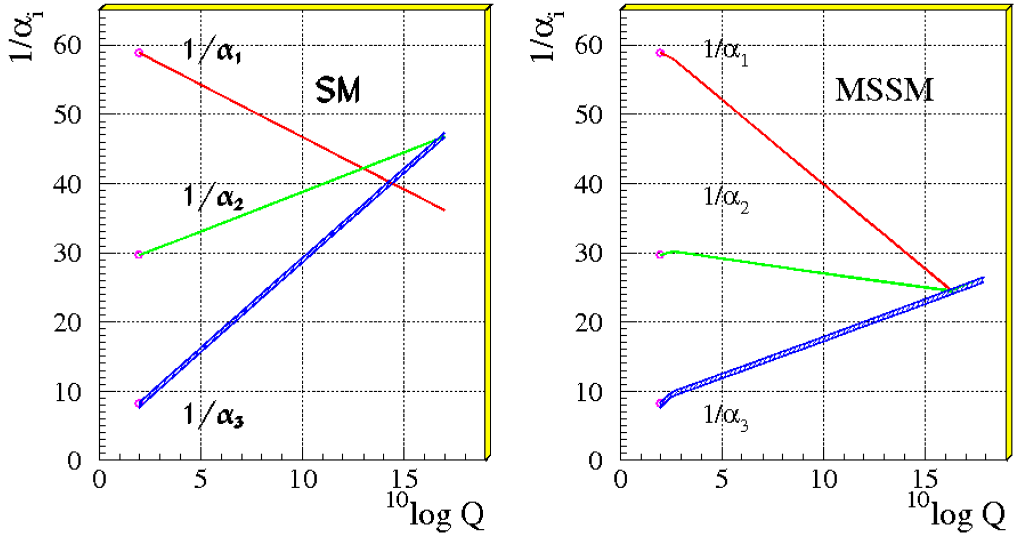
21 Apr 2011

Outline

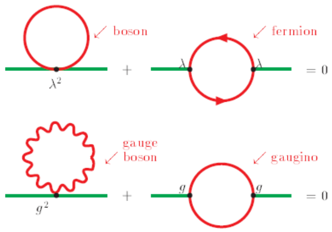
- Why SUSY?
- 2010 run
  - Basic performance of ATLAS
  - Selected SUSY analyses from ATLAS
- Conclusion

SUSY at the TeV scale

Unification of gauge couplings:
$M_{SUSY} = 10^{3.4\pm0.9\pm0.4}$ GeV

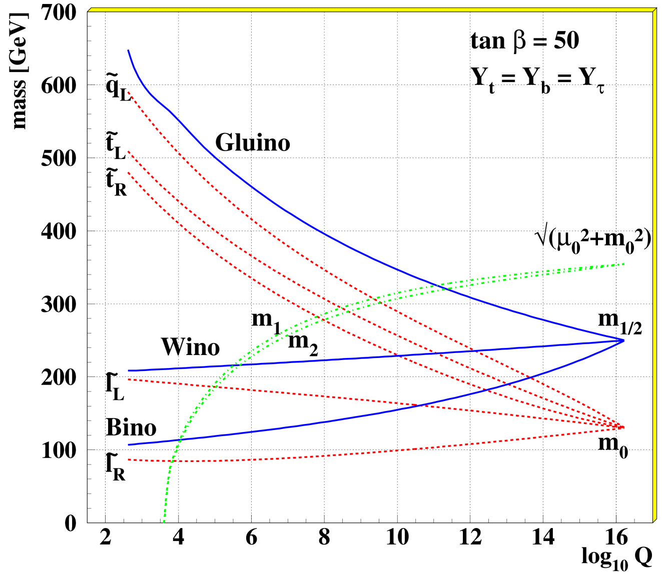


Stabilization of Higgs mass to radiative corrections.
Requires $M_{SUSY} \approx 1$ TeV



Dynamical generation of EWK symmetry breaking works when $M_{SUSY} \approx 0.1$-1 TeV (and top is heavy)

Dark matter density: $M_{wimp} \approx 100$ GeV with weak couplings ("WIMP miracle")



SUSY as unifying principle

SUSY generally tames divergences - “would be a shame if Nature did not take advantage of it”

Unified treatment of matter (fermions) with force carriers (bosons)

SUSY seems to be the only allowed way to connect spacetime symmetry with internal (e.g. gauge) symmetries in a non-trivial way. Extension of space-time to include additional degrees of freedom (“superspace”)

Making SUSY a local symmetry, one can obtain General Relativity (supergravity)

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For these reasons, “true believers” will probably never give up on SUSY

40th anniversary of the birth of SUSY

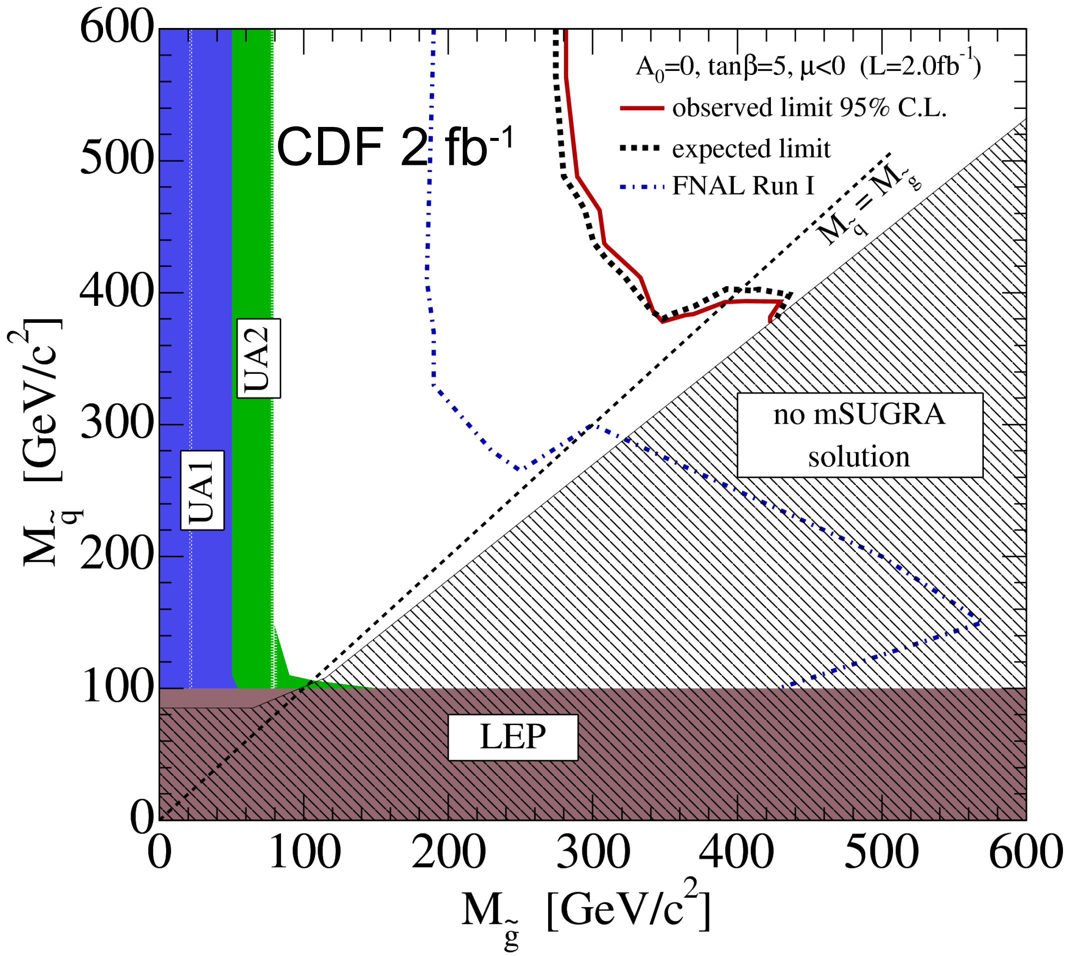
EXTENSION OF THE ALGEBRA OF POINCARE GROUP GENERATORS AND VIOLATION OF P INVARIANCE

Yu.A. Gol'fand and E.P. Likhtman
Physics Institute, USSR Academy of Sciences
Submitted 10 March 1971
ZhETF Pis. Red. 13, No. 8, 452 - 455 (20 April 1971)

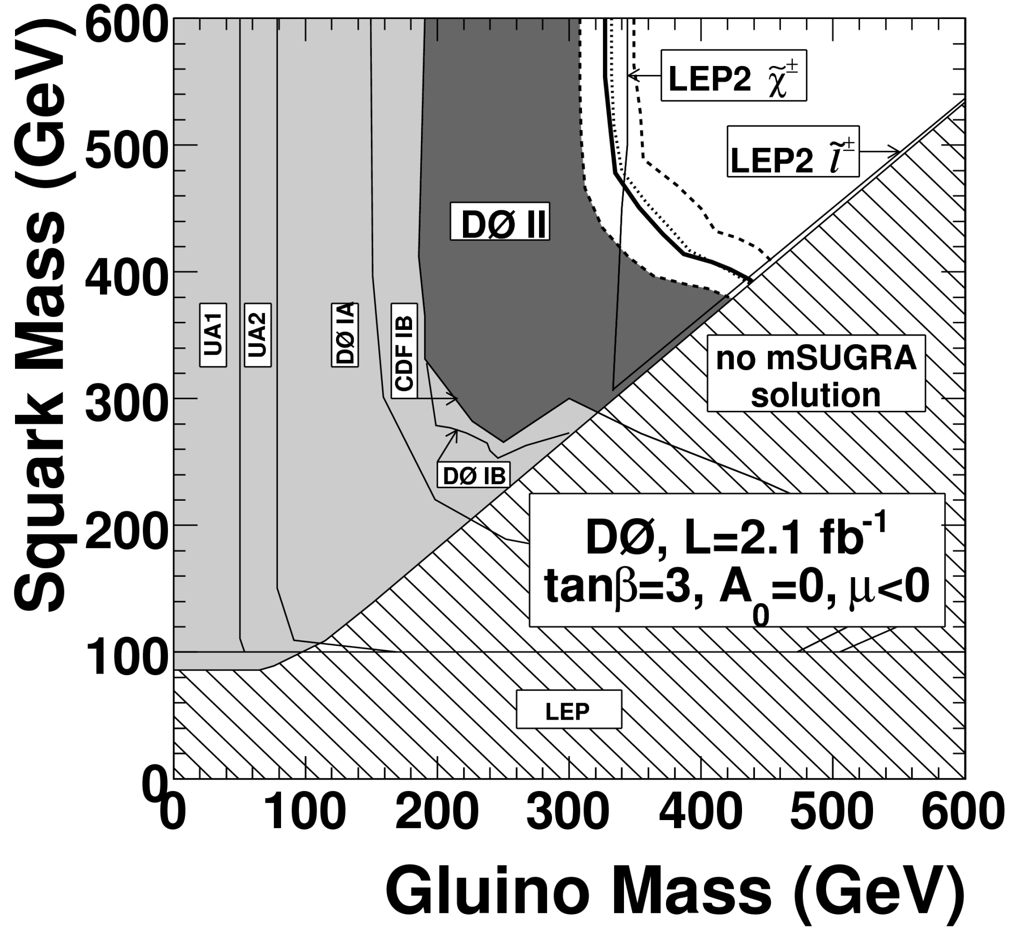
One of the main requirements imposed on quantum field theory is invariance of the theory to the Poincare group [1]. However, only a fraction of the interactions satisfying this requirement is realized in nature. It is possible that these interactions, unlike others, have a higher degree of symmetry. It is therefore of interest to study different algebras and groups, the invariance with respect to which imposes limitations on the form of the elementary particle interaction. In the present paper we propose, in constructing the Hamiltonian formulation of the quantum field theory, to use as the basis a special algebra $\mathcal{R}$, which is an extension of the algebra $\mathcal{P}$ of the Poincare group generators. The purpose of the paper is to find such a realization of the algebra $\mathcal{R}$, in which the Hamiltonian operator describes the interaction of quantized fields.

Golfand and Likhtman, JETP Lett 13 (1971) 323

Tevatron squark/gluino limits



[arXiv:0811.2512]



[arXiv:0712.3805]

The New York Times

February 9, 2001

Tiniest of Particles Pokes Big Hole in Physics Theory

By JAMES GLANZ

UPTON, N.Y., Feb. 8— New observations of subatomic particles do not appear to fit into the standard theories explaining the matter and forces that shape the universe, scientists at Brookhaven National Laboratory reported today.

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"The most natural meaning of this kind of indication," Dr. Marciano said, "would be supersymmetry." The observed change in the frequency, he said, "fits supersymmetry like a glove."

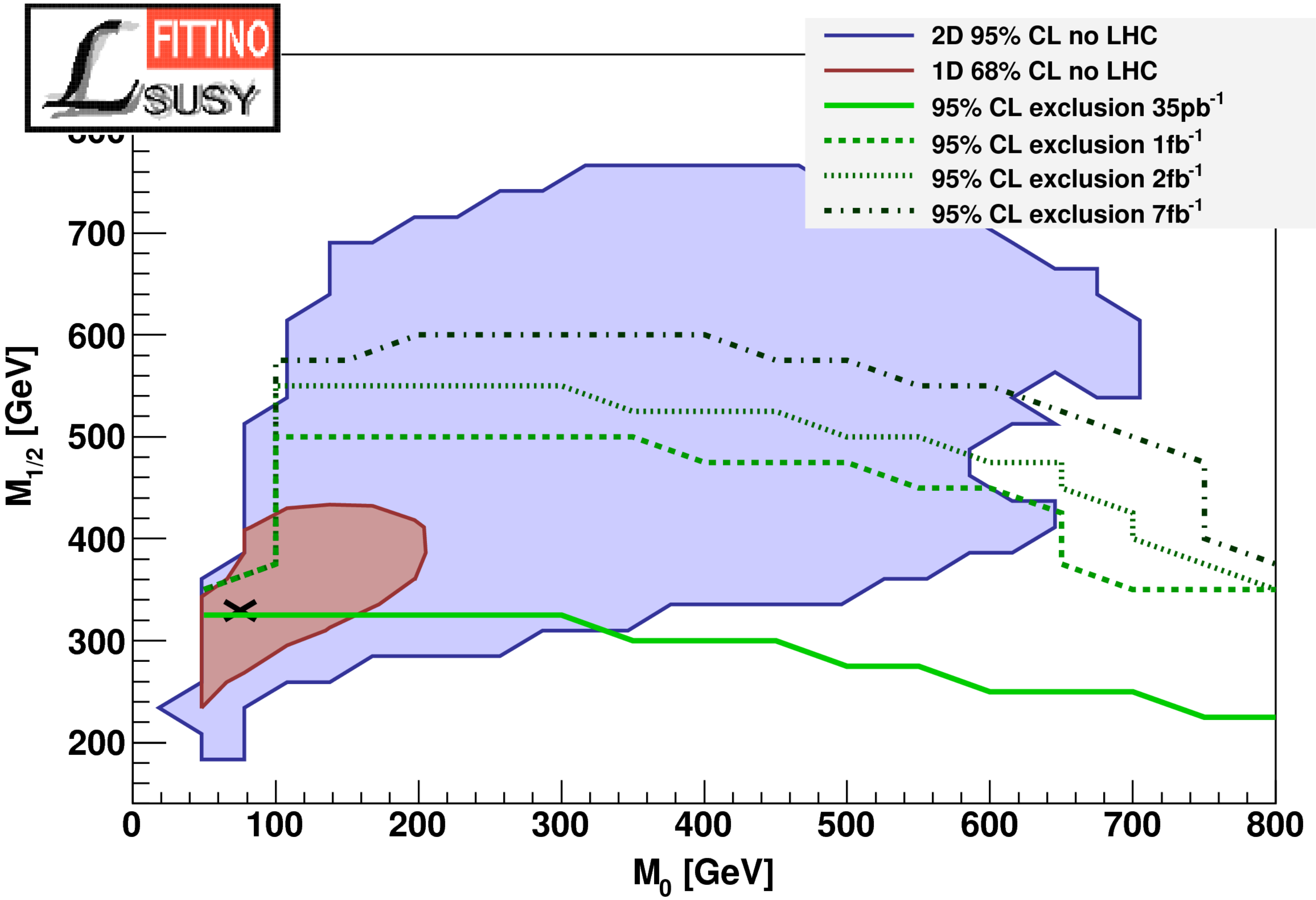
Dr. Frank Wilczek, a physics professor at the Massachusetts Institute of Technology, said that the new result, though not statistically airtight, did mesh with what he called other indirect suggestions that supersymmetry might be the correct way to extend and shore up the Standard Model.

$a_\mu(\text{exp}) = 116592089(63) \times 10^{-11}$ (hep-ex/0401008)

$a_\mu(\text{SM}) = 116591834(49) \times 10^{-11}$ (arXiv:0908.4300)

$\Delta a_\mu = (255 \pm 80) \times 10^{-11}$

arXiv:1102.4693



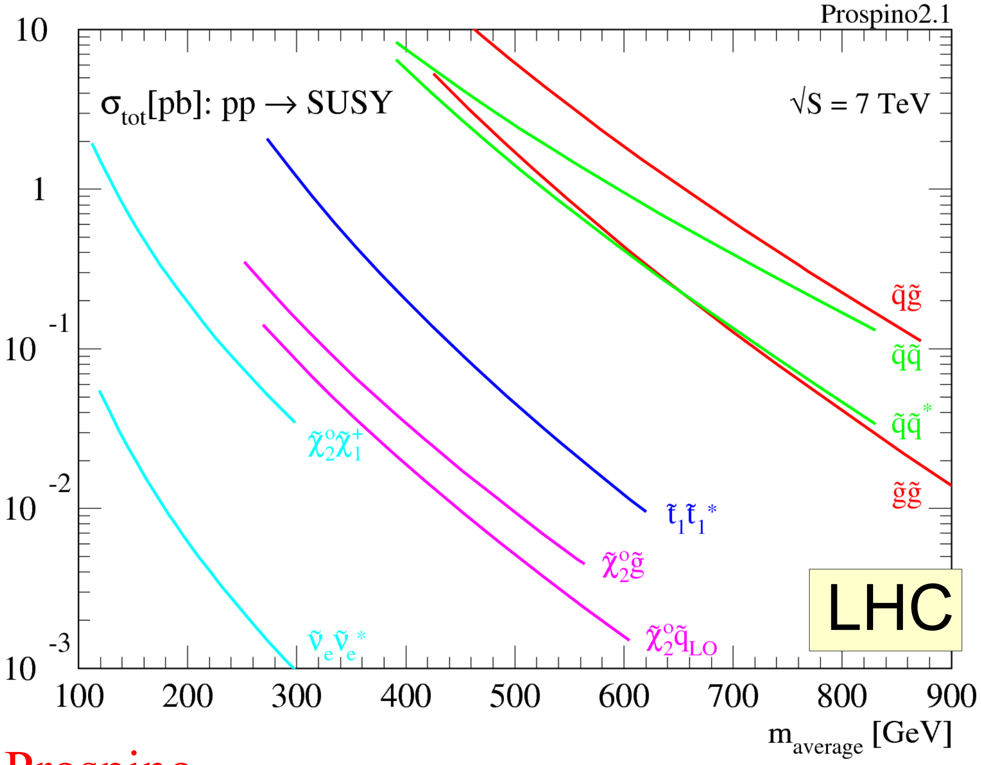
Fit to:

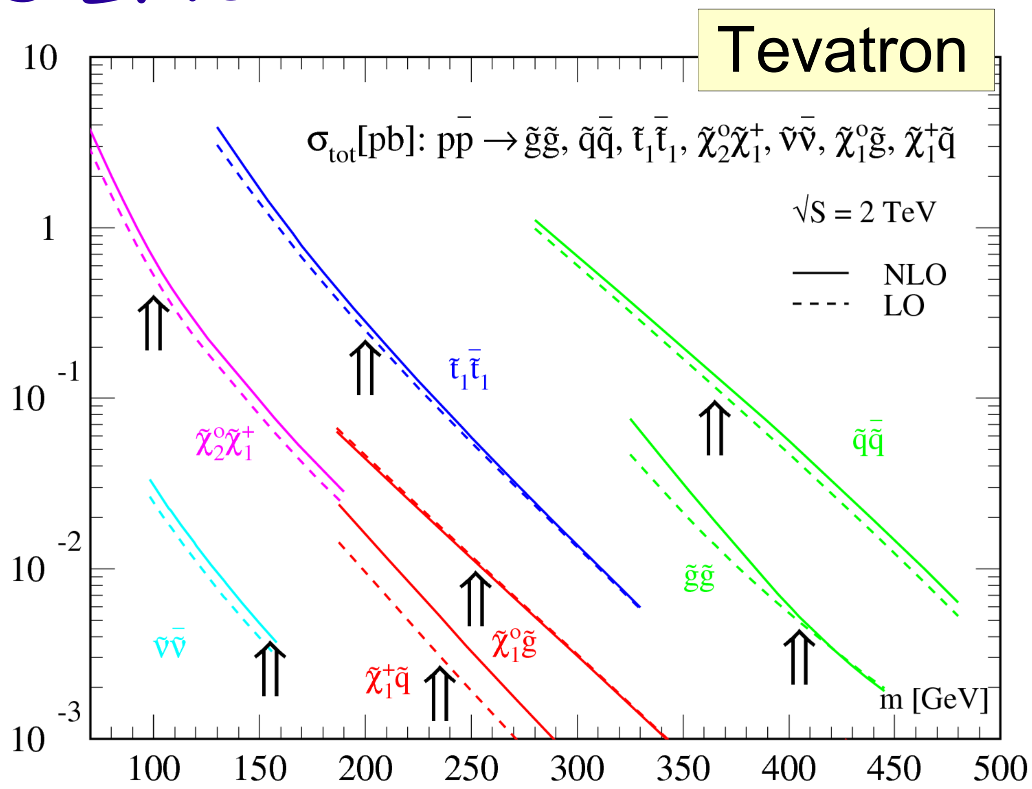
- rare K and B decays
- muon g-2
- EWK meas. from SLC,LEP,Tevatron
- LEP Higgs mass limit
- dark matter relic density

best fit: $M_0 = 75\ ^{+115}_{-29}$ GeV $M_{1/2} = 329\ ^{+92}_{-83}$ GeV

corresponds to m(gl) ~ 780 GeV, m(sq)~700 GeV, m(χ_1^0) ~ 130 GeV

SUSY xsec: Tevatron vs LHC





Prospino

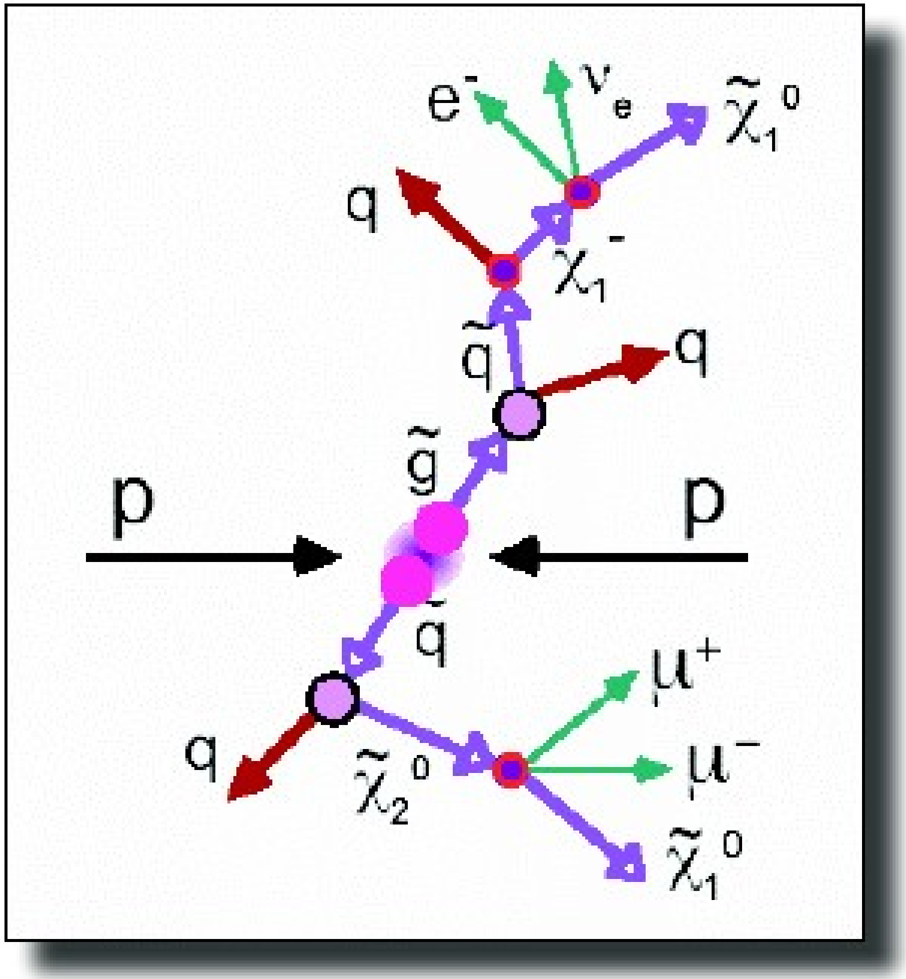
Low mass (~400 GeV) gluino production cross section:

- 4×10^{-3} pb at the Tevatron
- O(10 pb) at the LHC (7 TeV)

Inclusive searches: general considerations

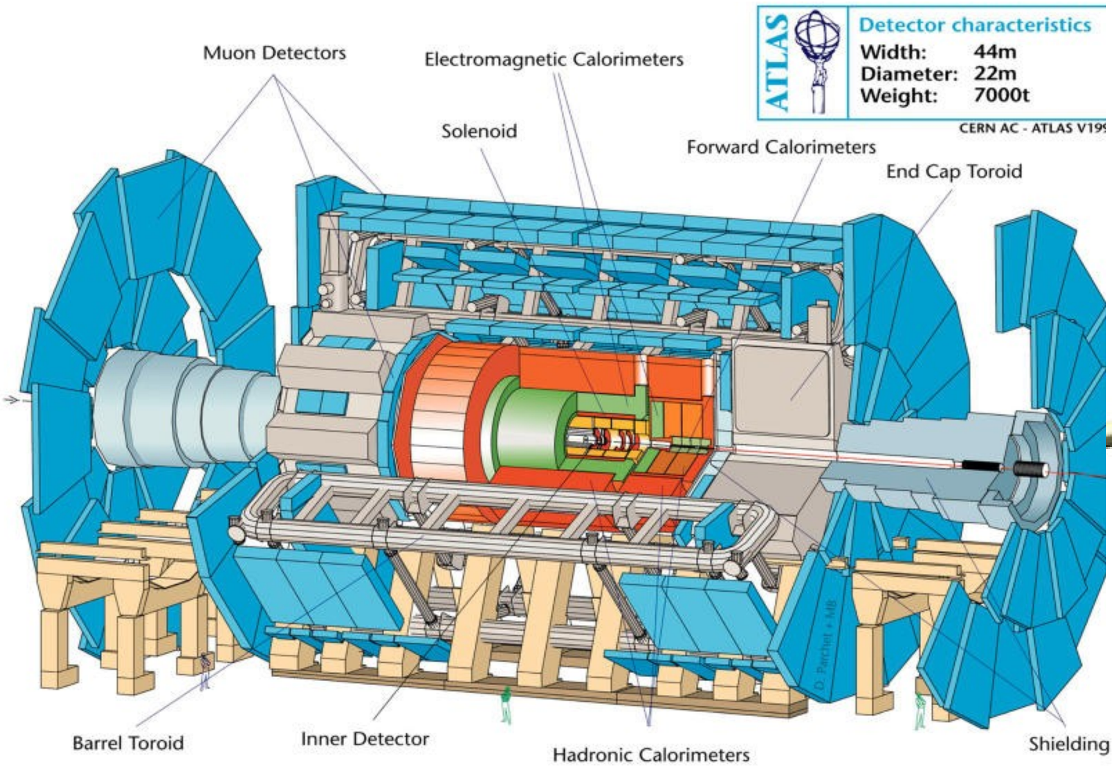
Inclusive SUSY search strategy relies on fairly generic features:

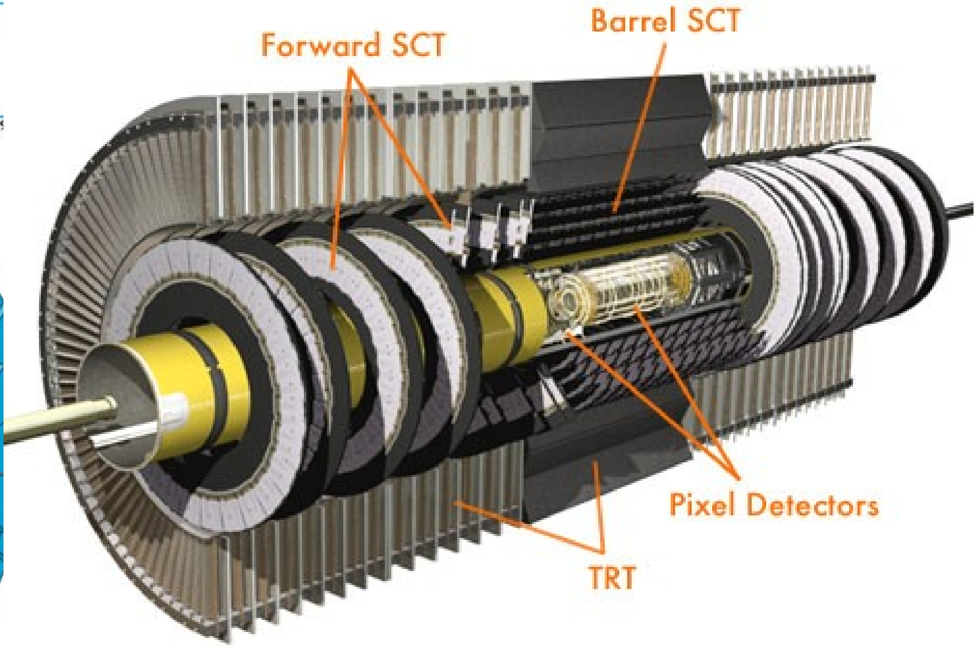
- SUSY production cross section can be calculated in the MSSM (xsec depends mainly on sparticle mass)
- gluinos/squarks are the heaviest sparticles
- gluino/squark decays give rise to (high pt) jets
- neutralinos/charginos often decay via emission of leptons
- LSP is stable (R-parity conservation) and neutral, escaping detector.

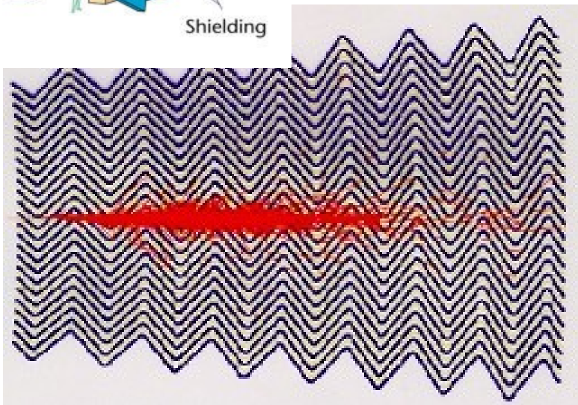


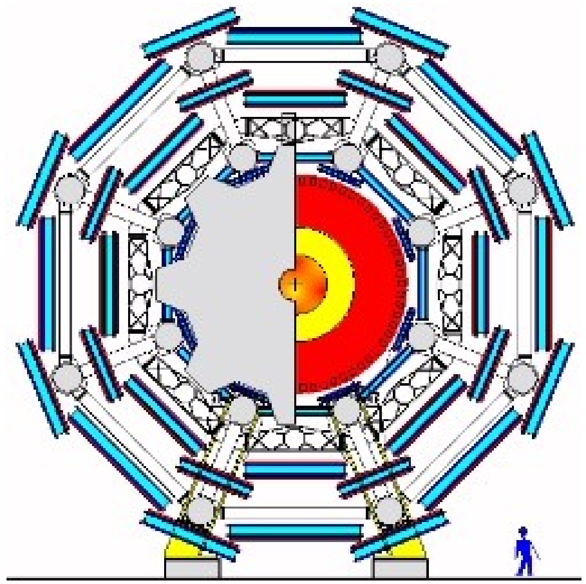
Generic signature is therefore:

- multiple jets, often energetic
- possibly some leptons (lower pt)
- missing Et (no mass peak!)









ID: $\sigma/p_T \approx 5 \times 10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.013$

$\sigma(d_0) \approx 15\ \mu m$ at 20GeV

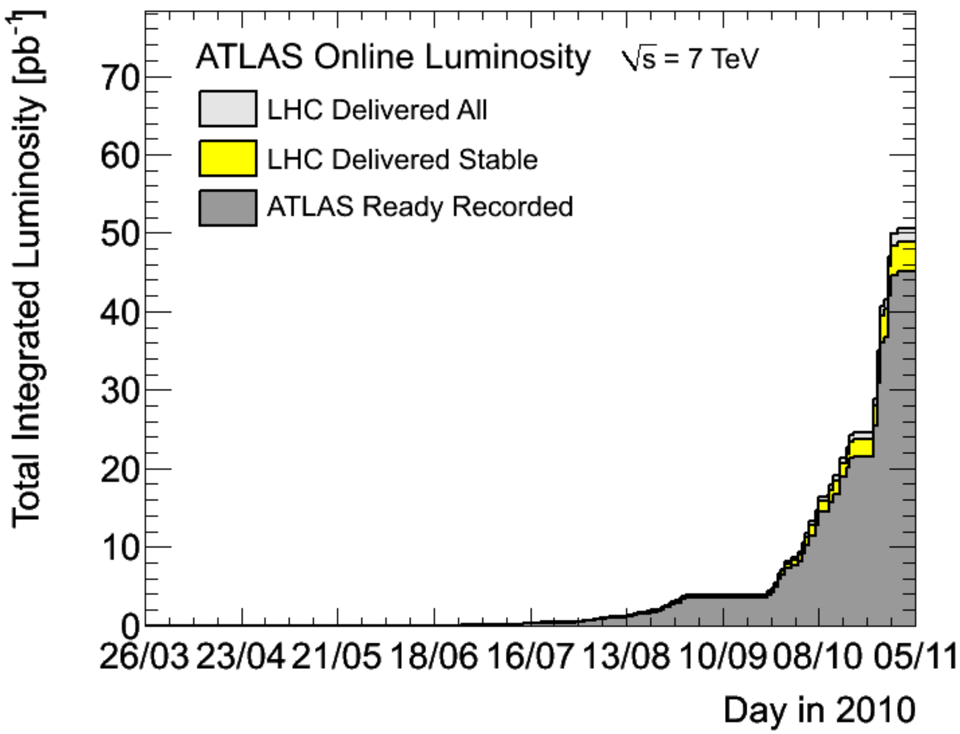
ECAL: $\sigma/E \approx 10\%/\sqrt{E(\mathrm{GeV})} \oplus 0.7\%$

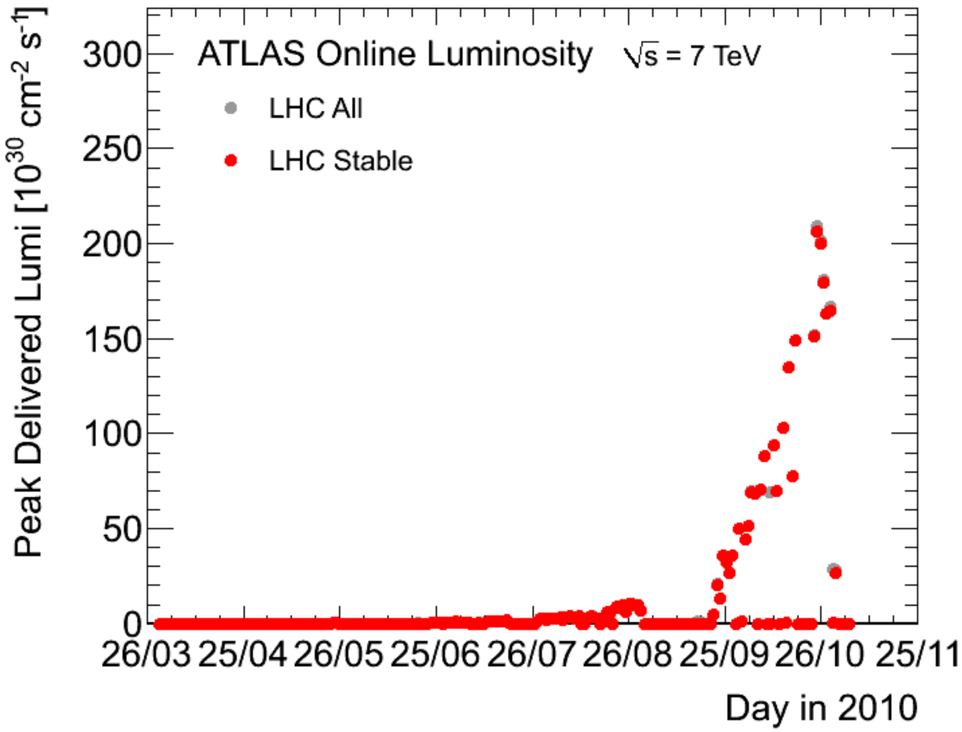
HCAL: $\sigma/E \approx 50\% / \sqrt{E(\mathrm{GeV})} \oplus 3\%$

$(|\eta| < 3.2)$

Muon: $\sigma/p_T \approx 10\%$ at 1 TeV/c

2010 LHC pp run

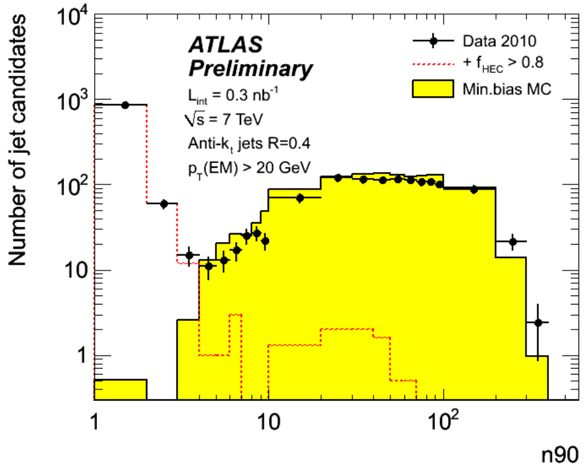


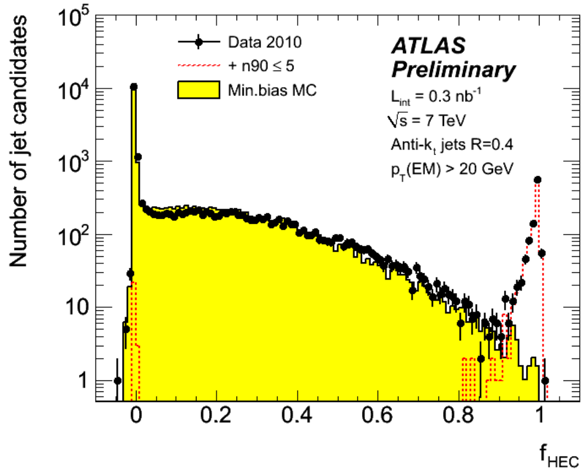


Peak stable luminosity = 2 x 10^{32} cm^{-2} sec^{-1}

Stable beams: 48.9 pb^{-1}
ATLAS stable: 46.7 pb^{-1} (95.6%)
ATLAS ready: 45.0 pb^{-1} (92.1%)

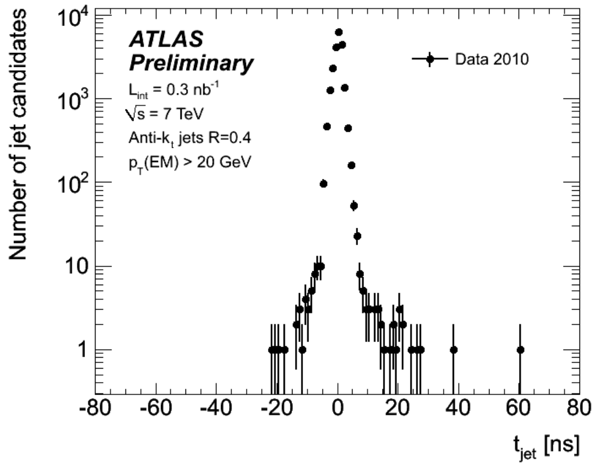
Jet cleaning



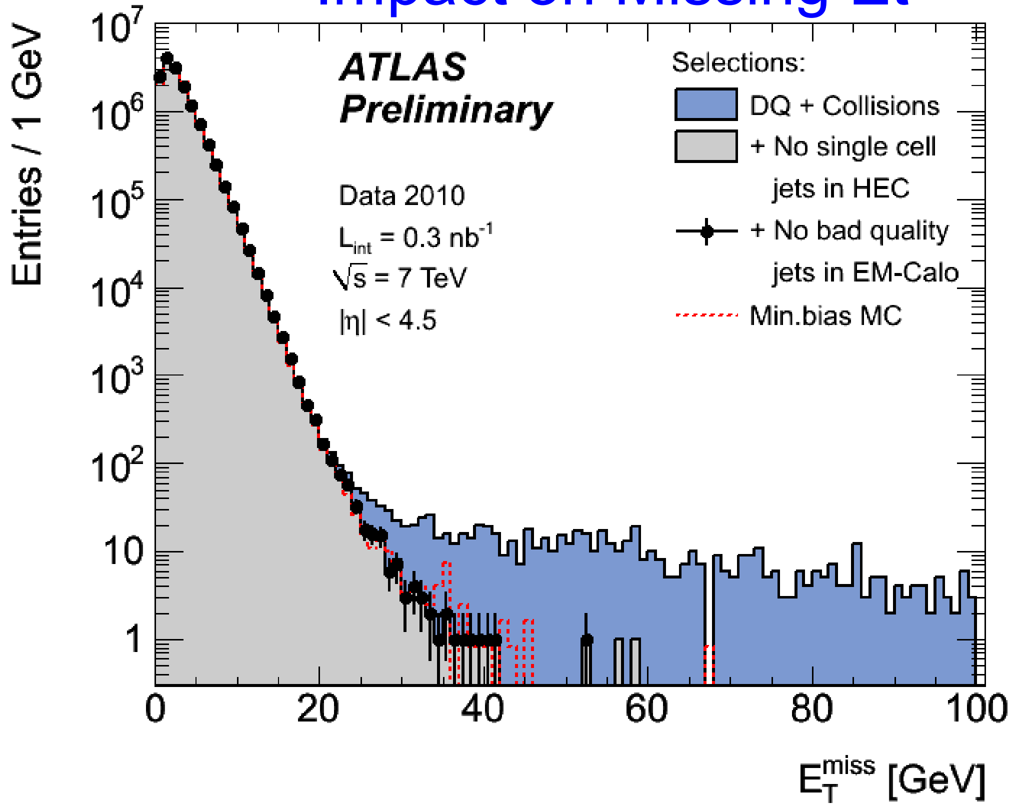


Cuts on:

- fraction of energy in HEC
- # of cells containing 90% of the energy
- jet timing



Impact on Missing Et



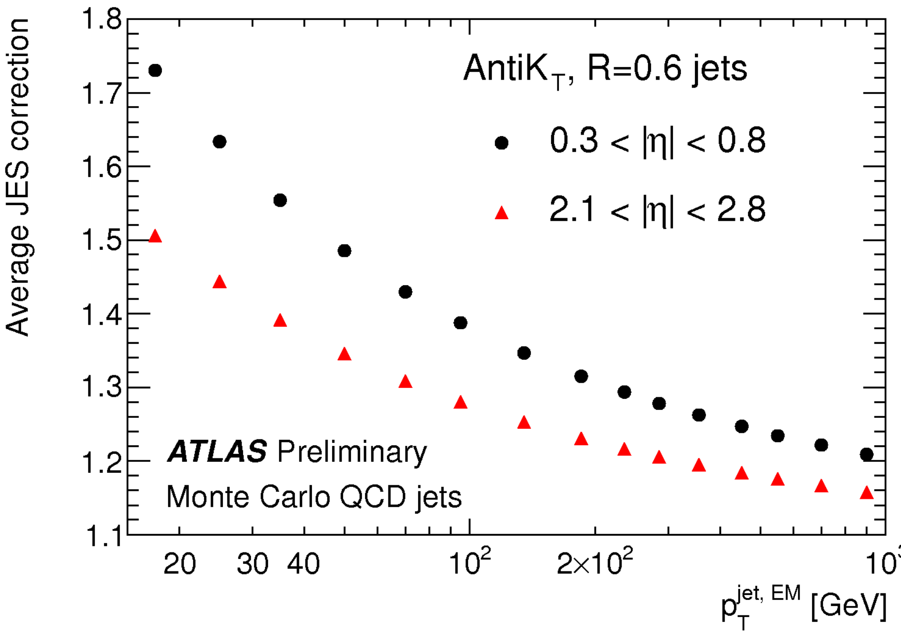
ATLAS-CONF-2010-038

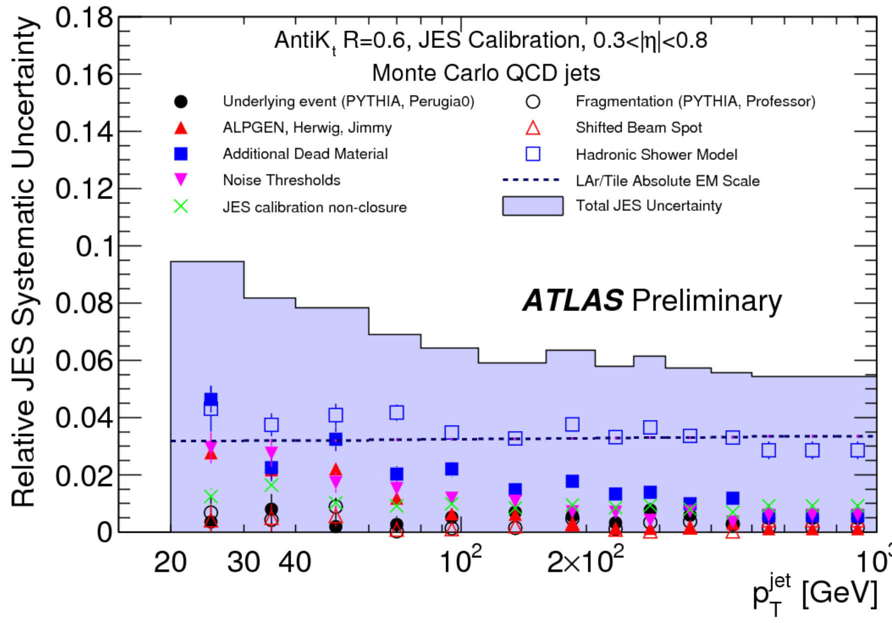
Jet energy calibration

Monte Carlo based calibration

- Correction factors as a function of pt and η of the jet. Restore (on average) the kinematics of reconstructed jets to the MC truth kinematics.
- Systematic uncertainty based on comparisons to MC with different detector configurations, hadronic shower and physics models, and by comparing relative response of jets across η between data and MC

Cross checked with single charged particle response.





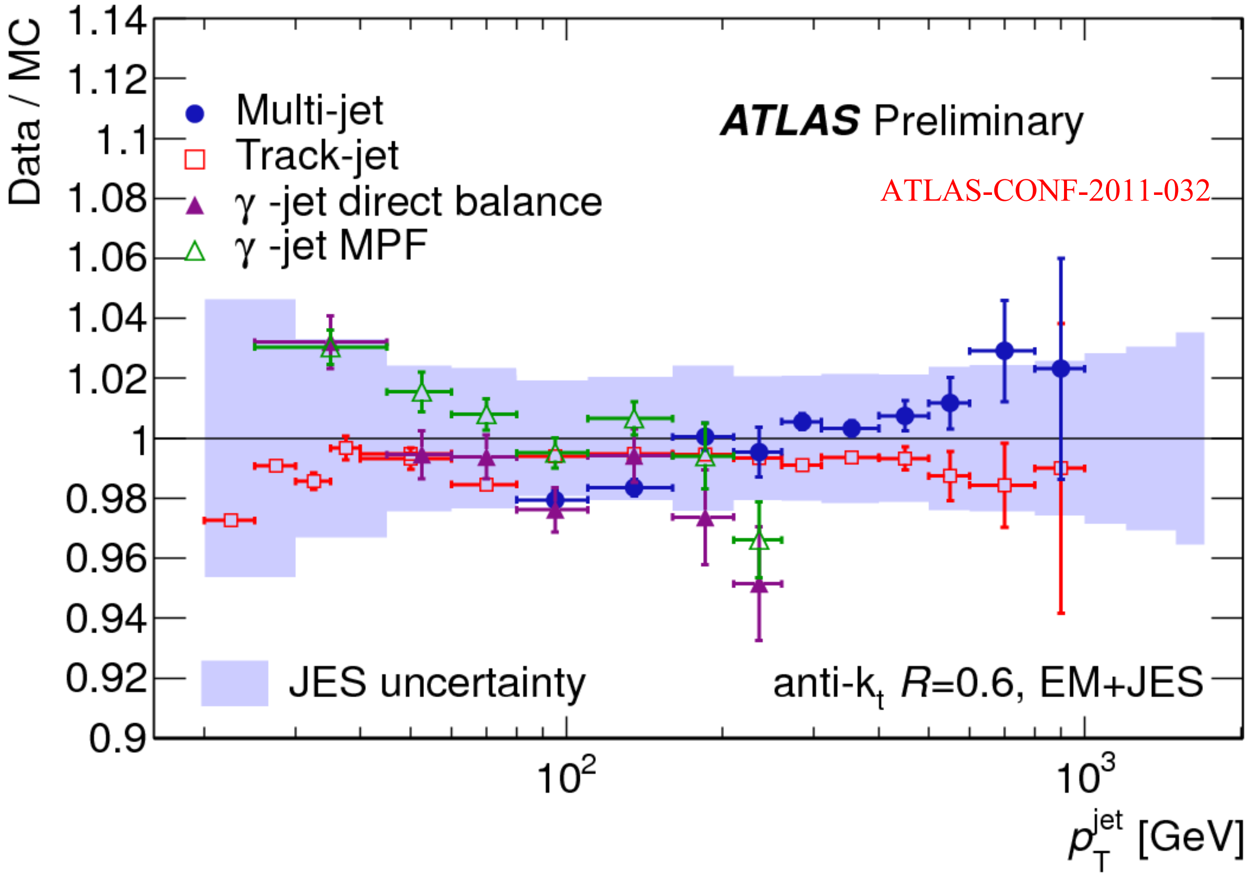
ATLAS-CONF-2010-056

(Improved uncertainties now available, but not used for 2010 SUSY analyses.)

Jet energy calibration (2)

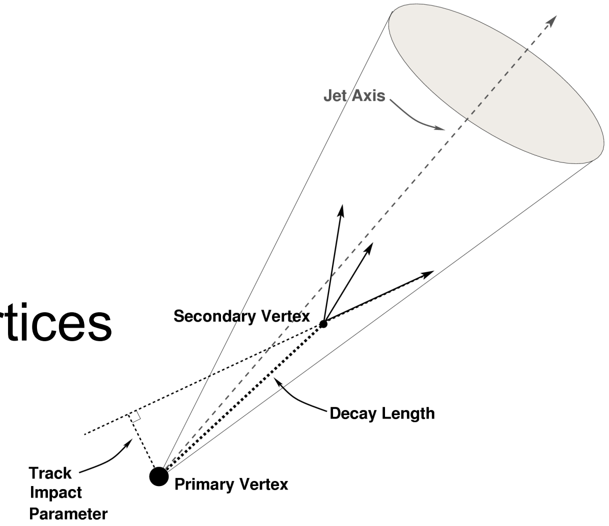
Jet energy scale verified with in-situ techniques

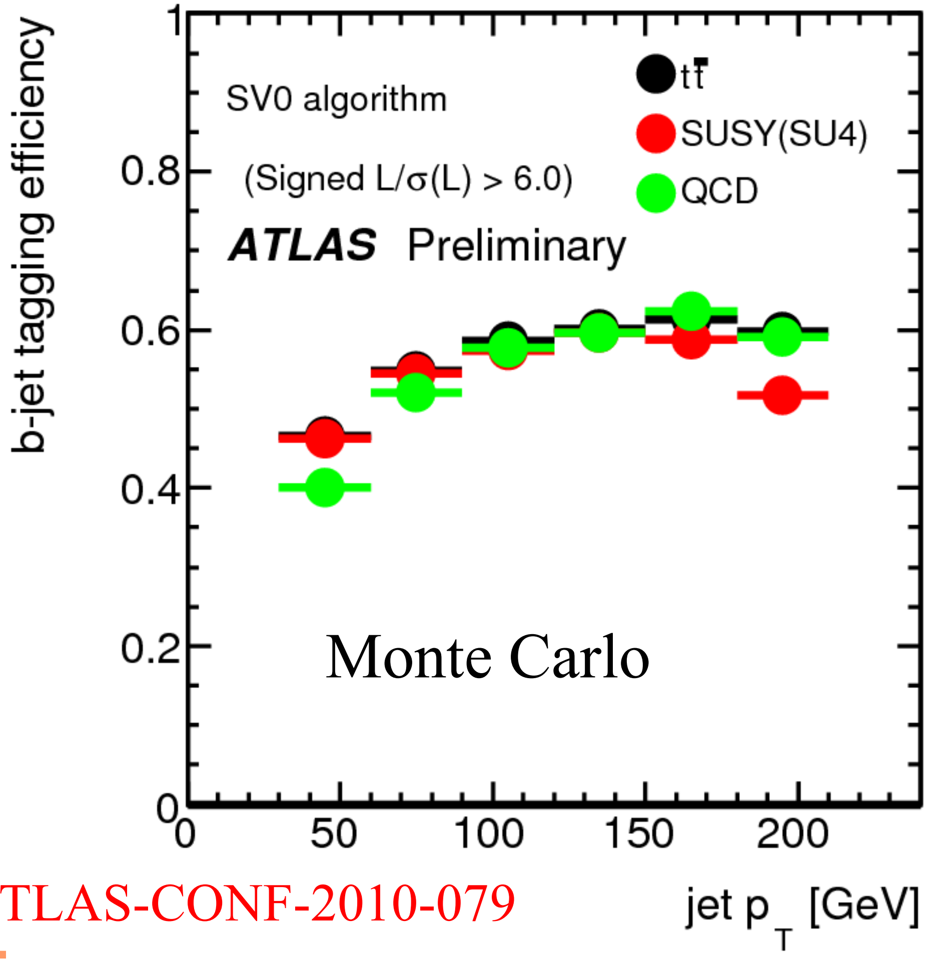
- Multijet pt balance
- photon-jet pt balance
- track pt vs calo pt

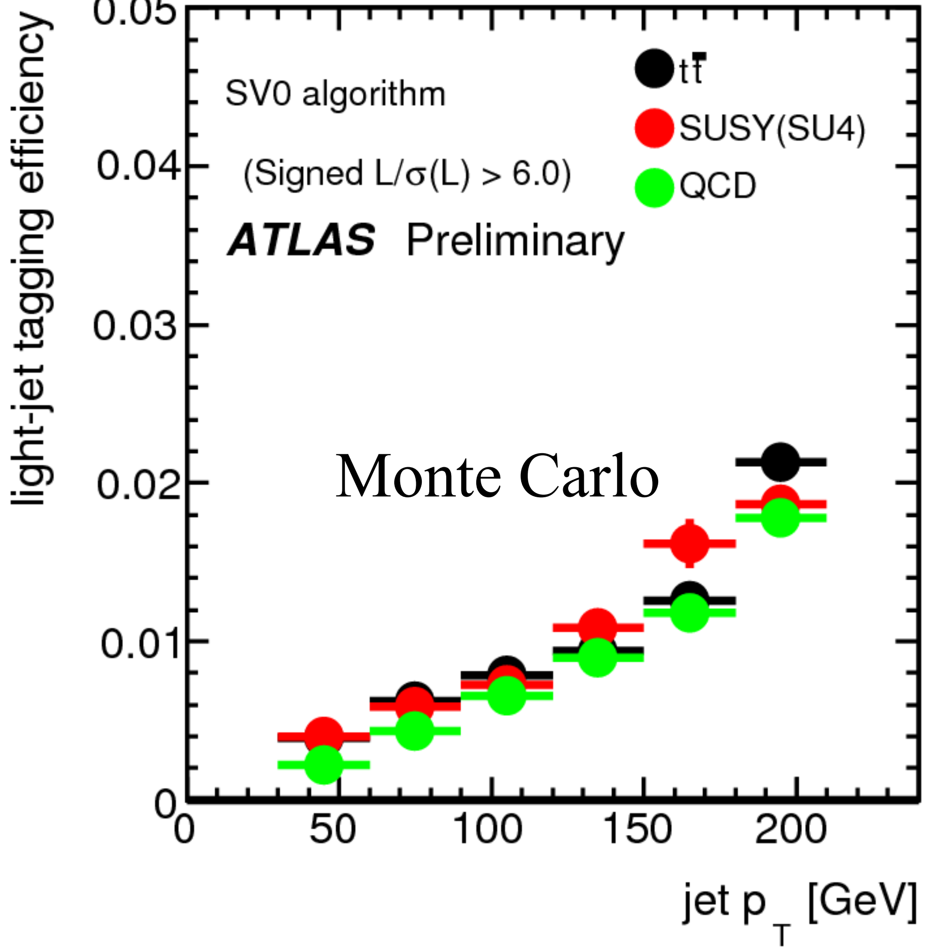


b-tagging

Based on decay-length significance of secondary vertices







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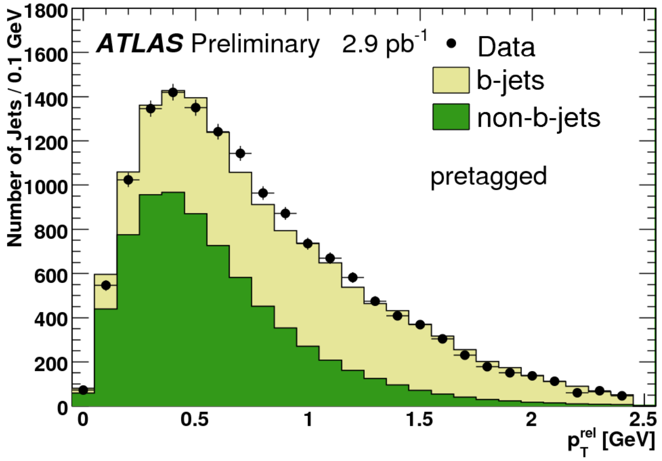
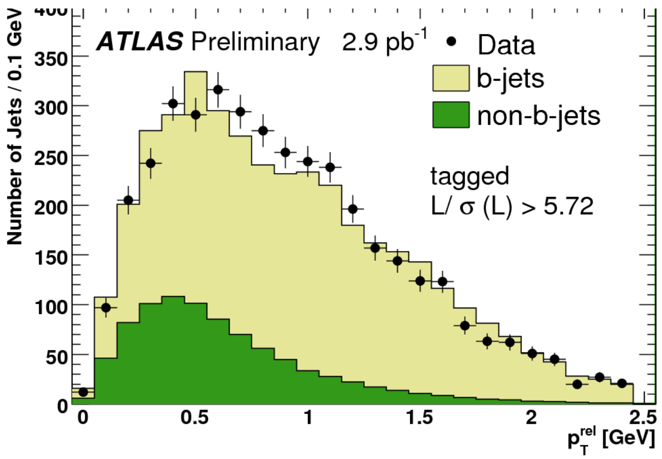
b-tagging (2)

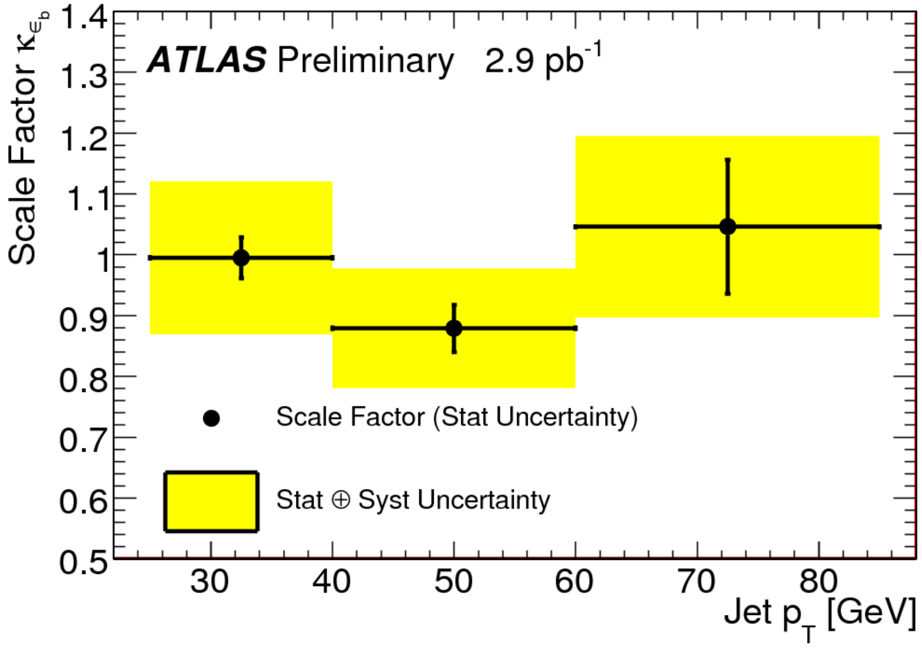
Efficiency and mistag rate estimated from data

Efficiency measured in events witih muons, using pt(rel) to separate b from light flavors





$\varepsilon^{data} / \varepsilon^{MC}$



Main sources of uncertainty:
- Modeling of b-hadron direction
- Non-b templates

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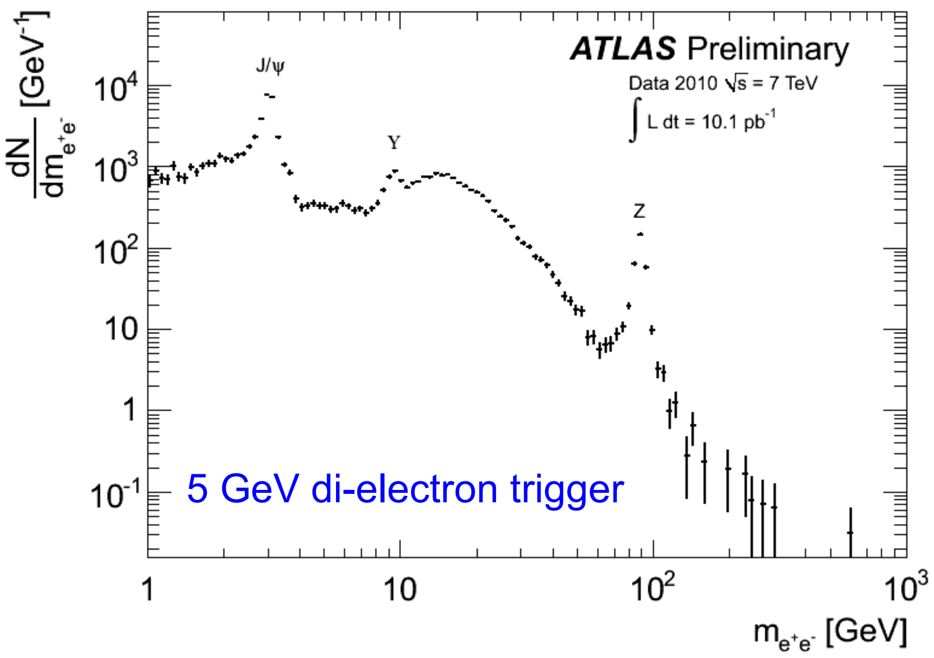
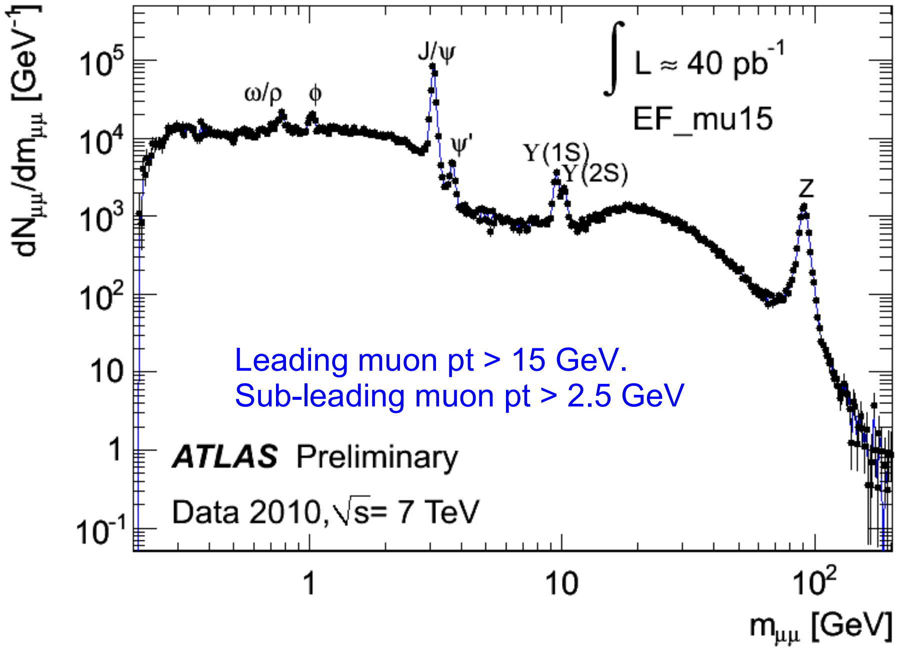
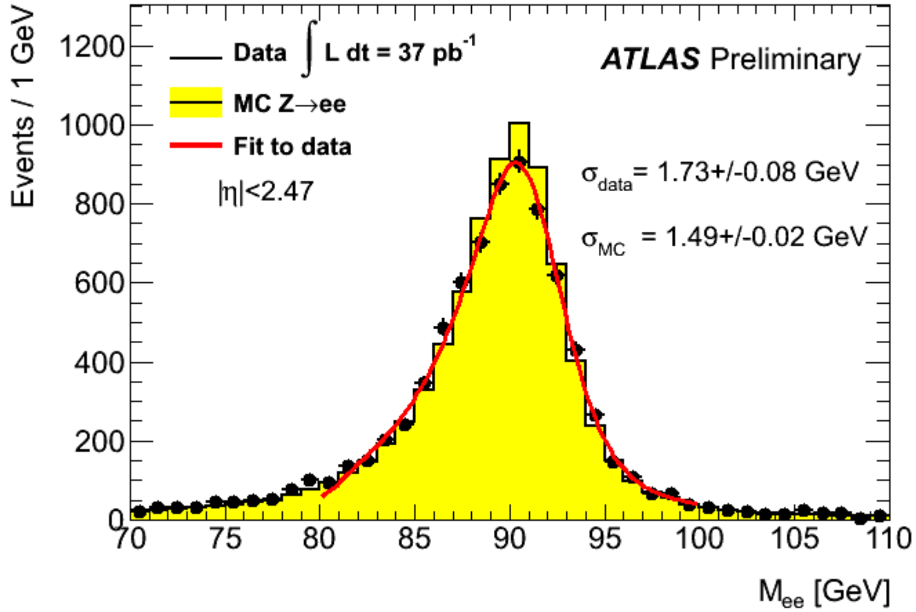
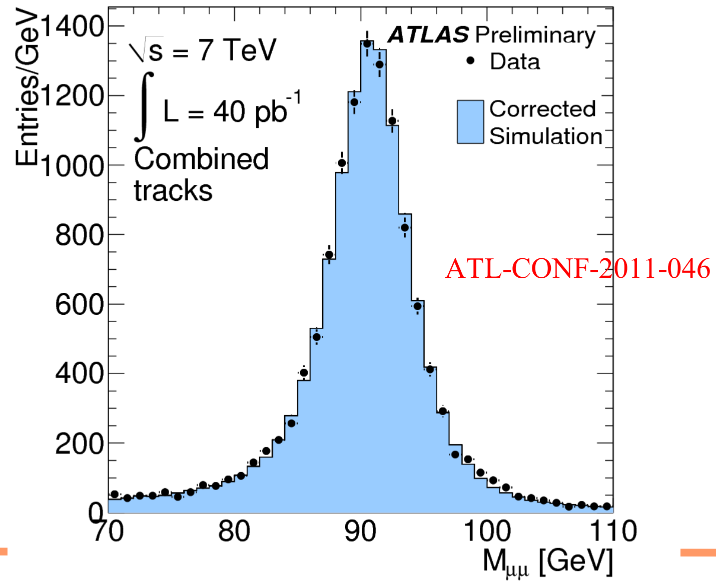
Electrons and muons







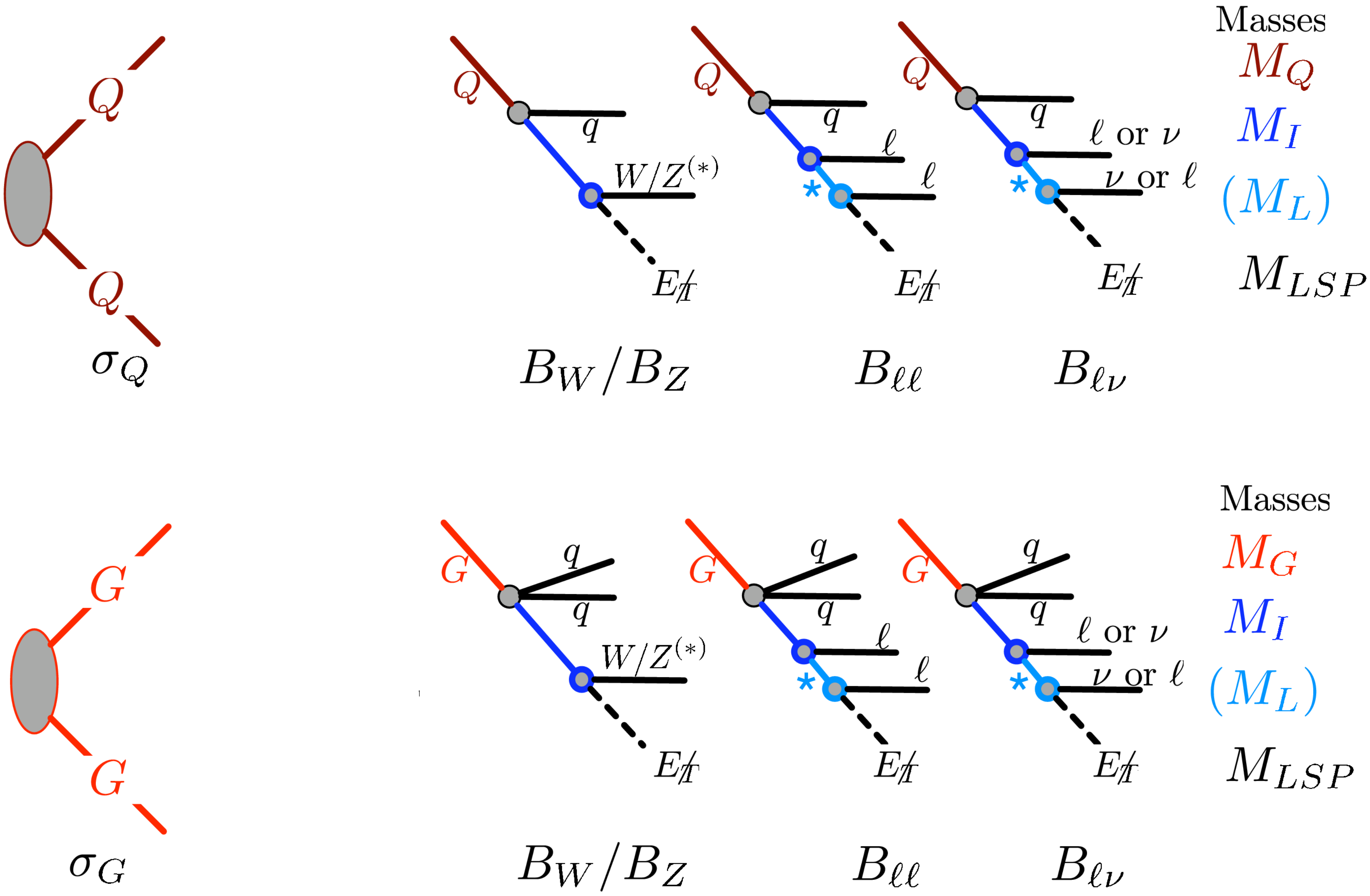


Selected ATLAS SUSY results from the 2010 run

more material can be found at
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Inclusive search in lepton (e/μ) + jets + MET

figures from arXiv:0810.3921



Event selection

arXiv:1102.2357

Trigger on single e or μ

Exactly one reconstructed e or μ with pt > 20 GeV, |η| < 2.47 (e), 2.4 (μ)

Muon isolation: Σpt(trk) < 1.8 GeV in a cone of ΔR<0.2

≥ 3 jets, pt > (60,30,30) GeV

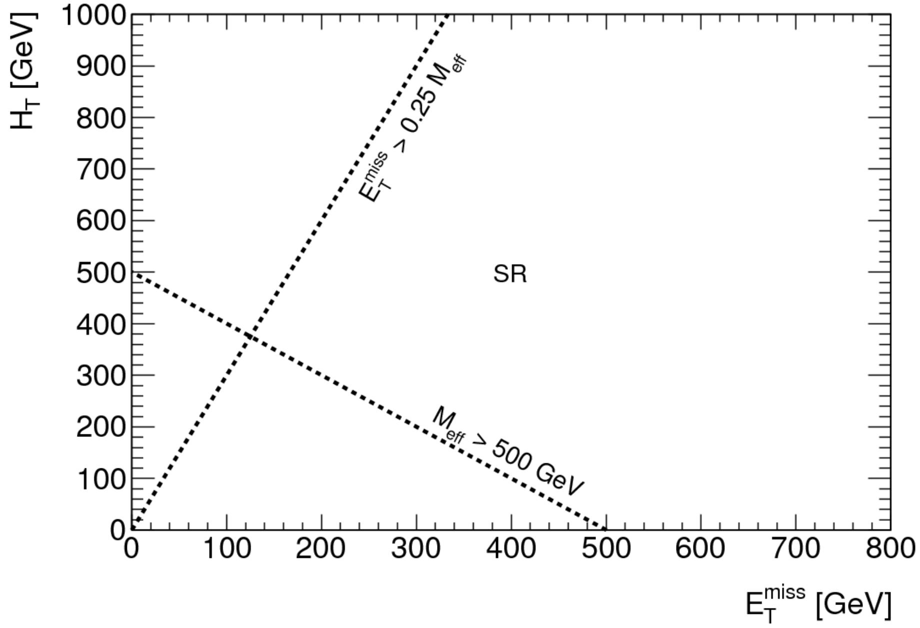
Δφ (jet,MET) > 0.2

Transverse mass (e/μ, MET) > 100 GeV

MET > 125 GeV

MET > 0.25 Meff

Meff > 500 GeV

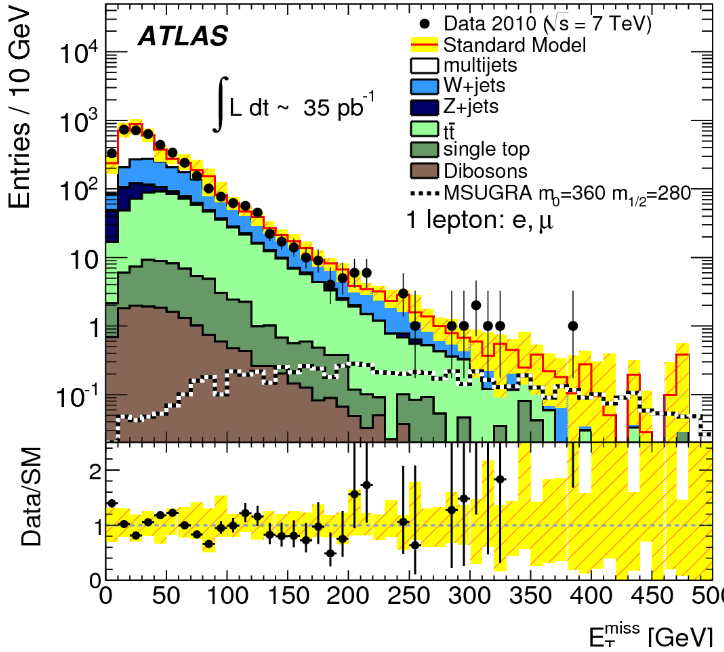


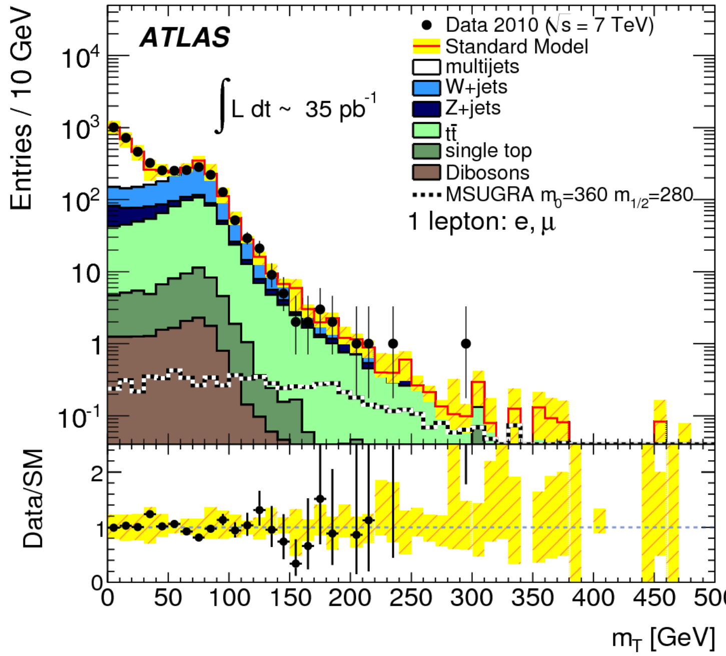
$$m_{\mathrm{eff}} = H_T + E_{\mathrm{T}}^{\mathrm{miss}}$$

$H_T = p_T^\ell + \sum_{i=1}^{3} p_T^{jet_i}$, where $p_T^{jet_i}$ are the 3 leading jets.

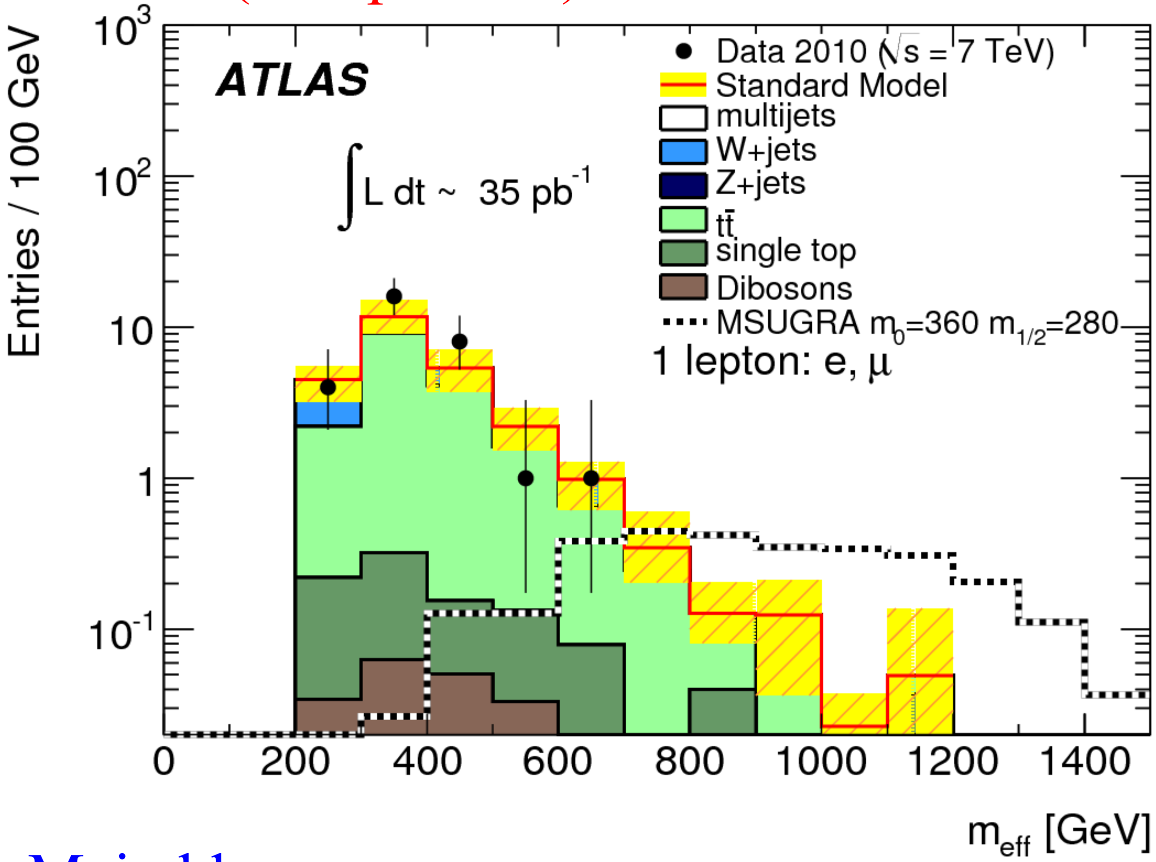
Event selection (2)

after e/μ and jet cuts





after all (except Meff) cuts



Main bkg:

- dileptonic ttbar (one lepton lost)
- W+ jets

MSUGRA point for illustration

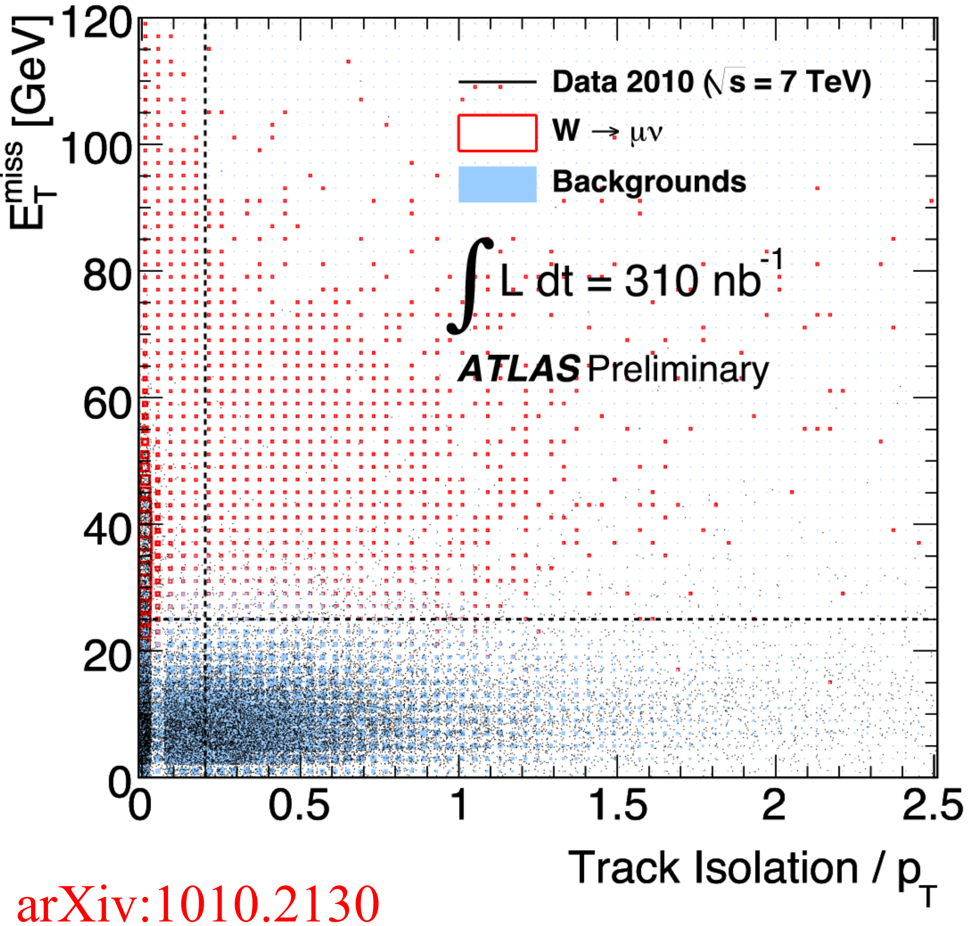
- $M_0 = 360$ GeV, $M_{1/2} = 280$ GeV, $A_0 = 0$, $\tan\beta = 3$, $\mu > 0$ $\rightarrow$ ~ 700 GeV gluinos/squarks

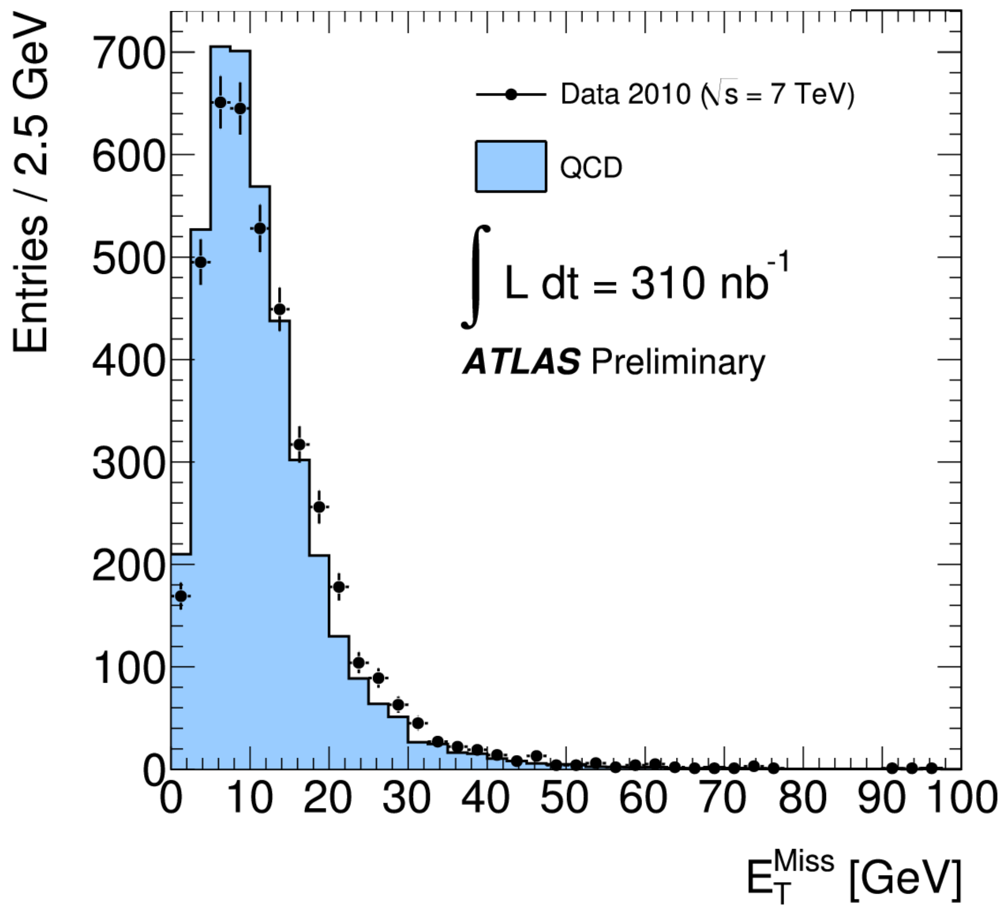
QCD background (muon channel)

To illustrate the method: plots taken from the inclusive W cross section analysis

"Matrix method" (a la Tevatron)

$$N_{\rm loose} = N_{\rm nonQCD} + N_{\rm QCD}$$
$$N_{\rm iso} = \varepsilon^{\rm iso}_{\rm nonQCD} N_{\rm nonQCD} + \varepsilon^{\rm iso}_{\rm QCD} N_{\rm QCD},$$

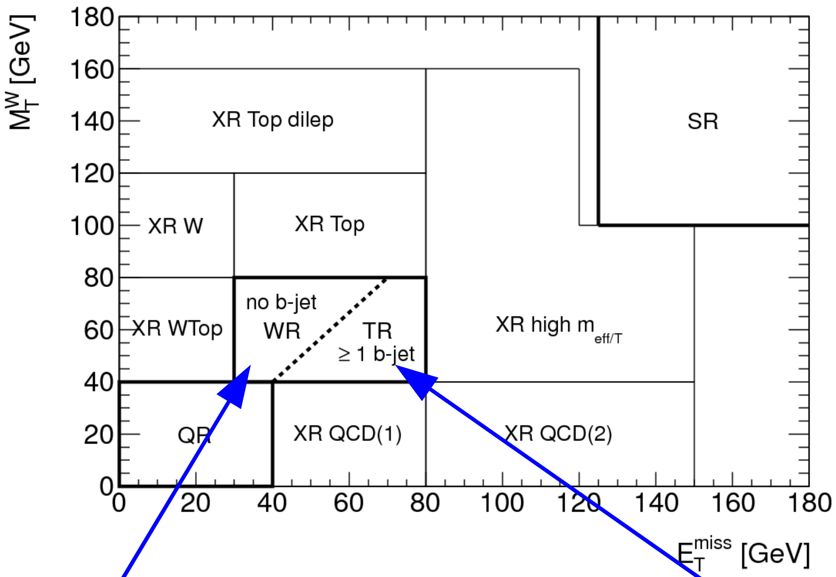


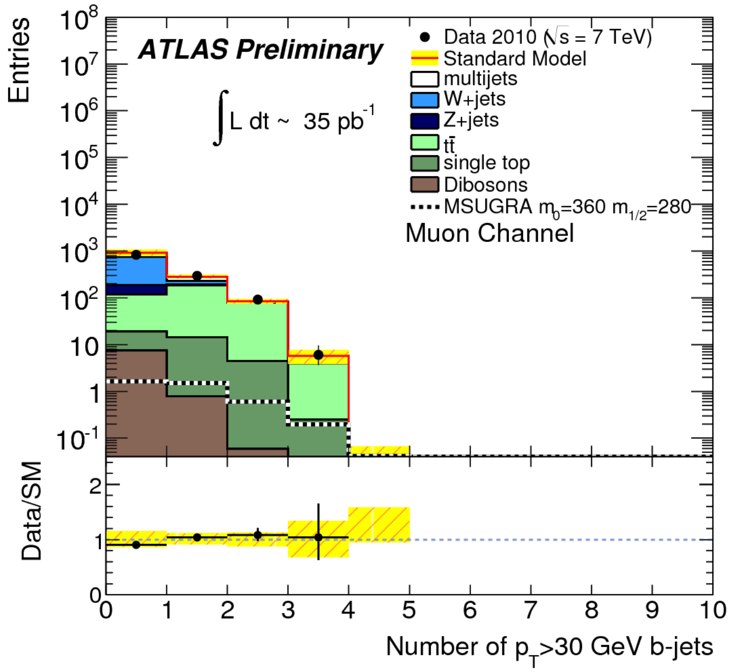


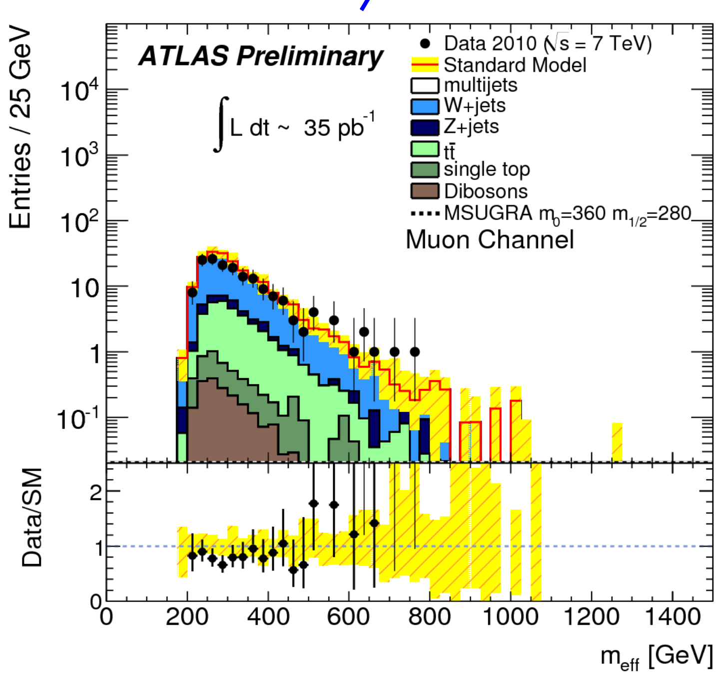
arXiv:1010.2130

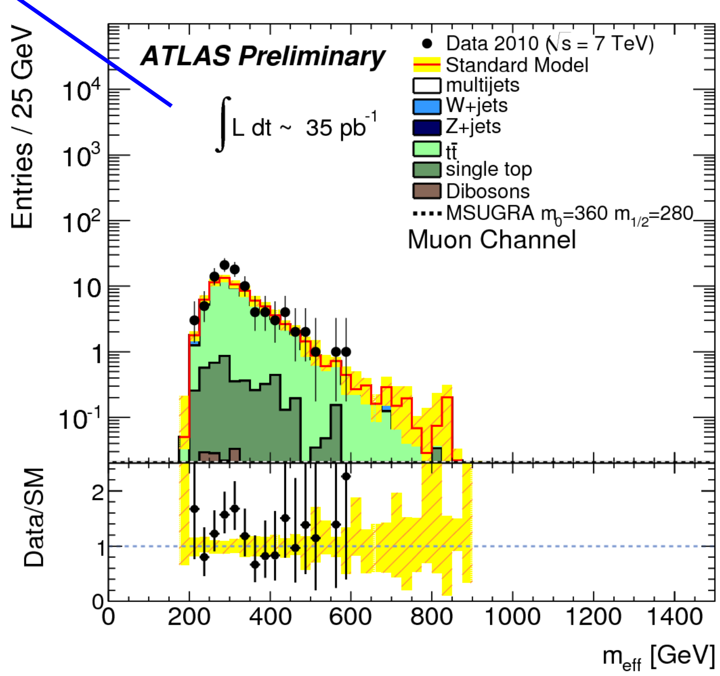
W/top background estimation

MC normalized to data in control regions and extrapolated to signal region









Background fit

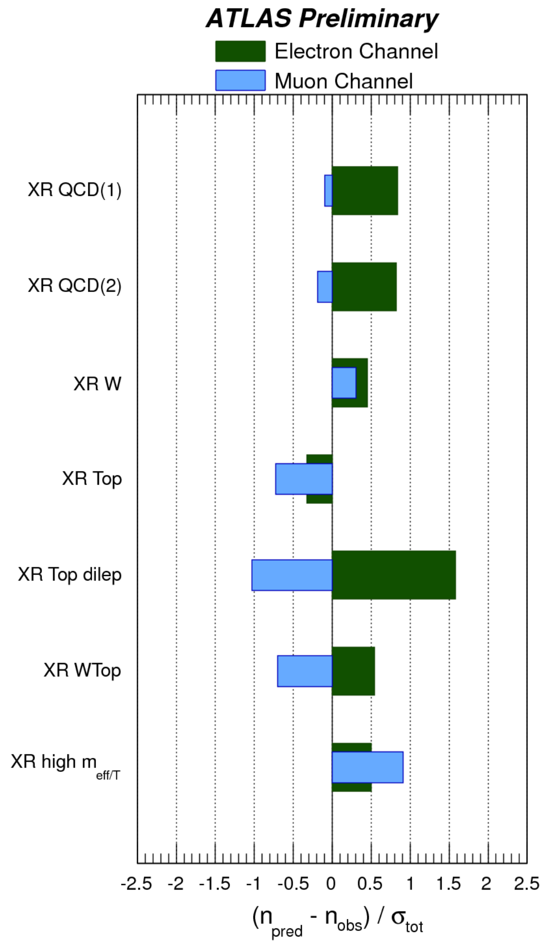
Maximum likelihood to event counts in the QCD, W, ttbar control regions

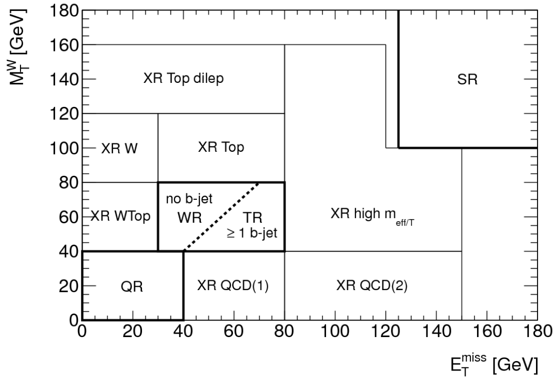
$$L(\vec{n}|\mu, \vec{b}, \vec{\theta}) = P_{SR} \times P_{WR} \times P_{TR} \times P_{QR} \times C_{Syst}.$$

Poisson factor for each control region

Gaussian systematic uncertainties

$$C_{Syst}(\vec{\theta}^0, \vec{\theta}) = \prod_{j \in SU} G(\theta_j^0, \theta_j)$$

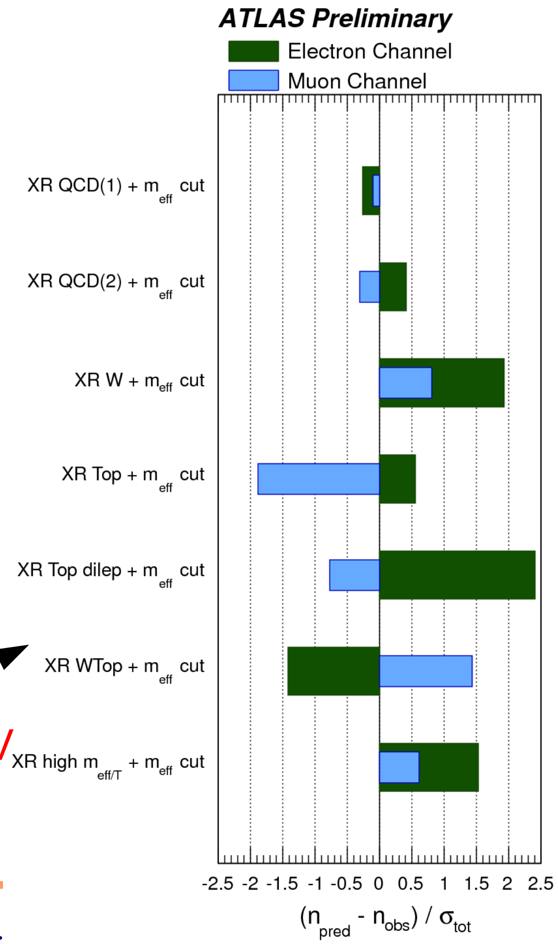




Observed vs predicted background in additional control regions (XR)

No Meff cut

Meff > 500 GeV



Background fit

Electron channel	Signal region	Top region	W region	QCD region
Observed events	1	80	202	1464
Fitted top events	1.34 ± 0.52 (1.29)	65 ± 12 (63)	32 ± 16 (31)	40 ± 11
Fitted W/Z events	0.47 ± 0.40 (0.46)	11.2 ± 4.6 (10.2)	161 ± 27 (146)	170 ± 34
Fitted QCD events	$0.0^{+0.3}_{-0.0}$	3.7 ± 7.6	9 ± 20	1254 ± 51
Fitted sum of background events	1.81 ± 0.75	80 ± 9	202 ± 14	1464 ± 38

agree by construction

Muon channel	Signal region	Top region	W region	QCD region
Observed events	1	93	165	346
Fitted top events	1.76 ± 0.67 (1.39)	85 ± 11 (67)	42 ± 19 (33)	50 ± 10
Fitted W/Z events	0.49 ± 0.36 (0.71)	7.7 ± 3.3 (11.6)	120 ± 26 (166)	71 ± 16
Fitted QCD events	$0.0^{+0.5}_{-0.0}$	0.3 ± 1.2	3 ± 12	225 ± 22
Fitted sum of background events	2.25 ± 0.94	93 ± 10	165 ± 13	346 ± 19

Pure MC estimate, absolutely normalized, in paren

Main systematic uncertainties:

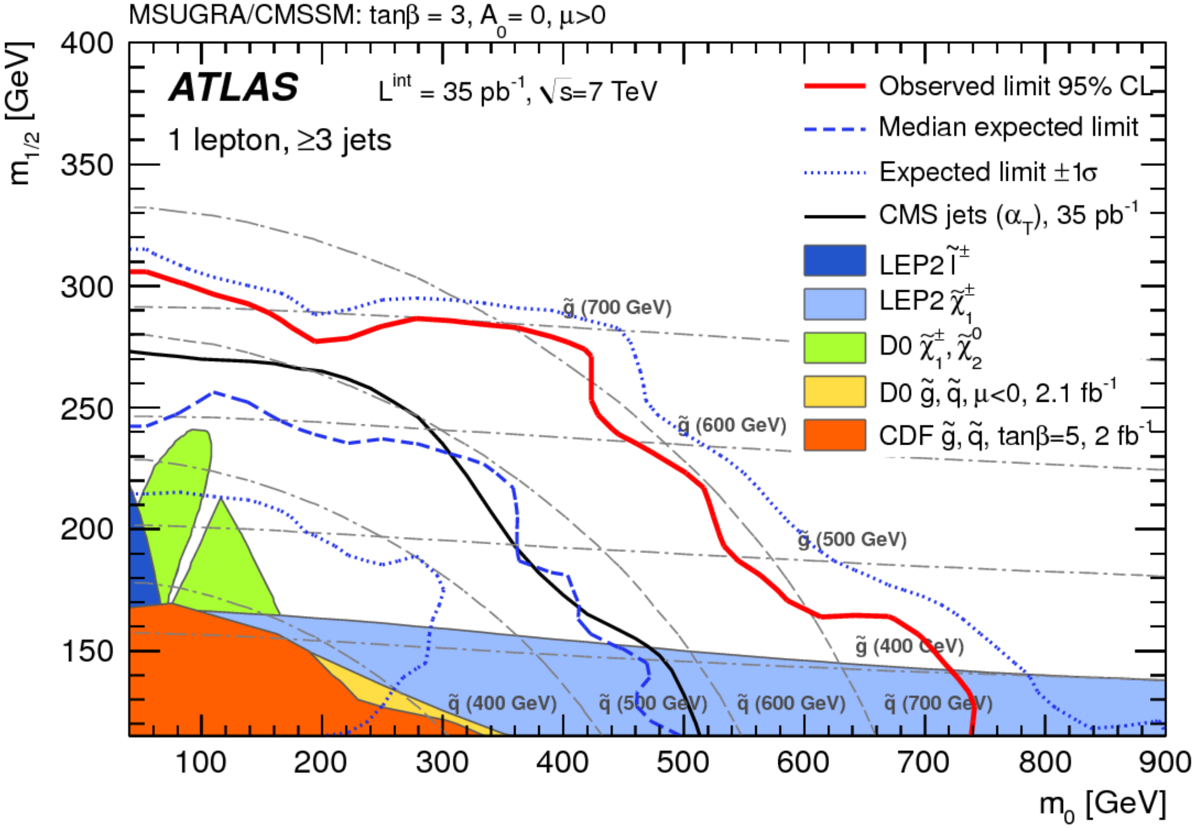
- Limited statistics in W/top control regions
- MC shape uncertainties
- B-tagging efficiency

Final result: 1-lepton channel

One-sided 95% CL upper limit on the number of events from new physics:

- Limits obtained using pseudo-experiments
- 2.2 events (e), 2.5 events (μ)
- corresponding limits on σ▪A▪ε < 0.065 pb (e), 0.073 pb (μ)
  (can be compared to any model if you know A; ε is close to 1)

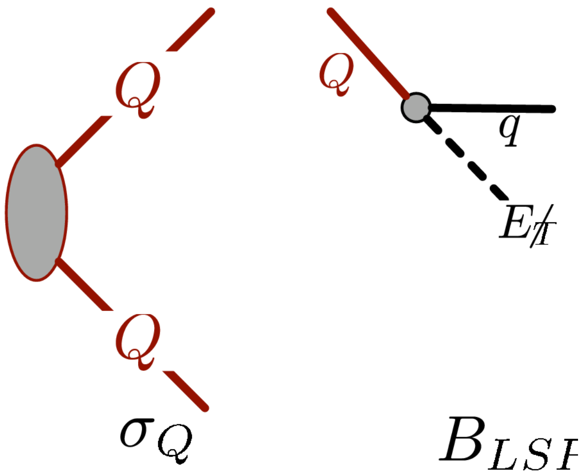
Results also interpreted in MSUGRA/CMSSM model for comparison to Tevatron results



Electron and muon channels combined

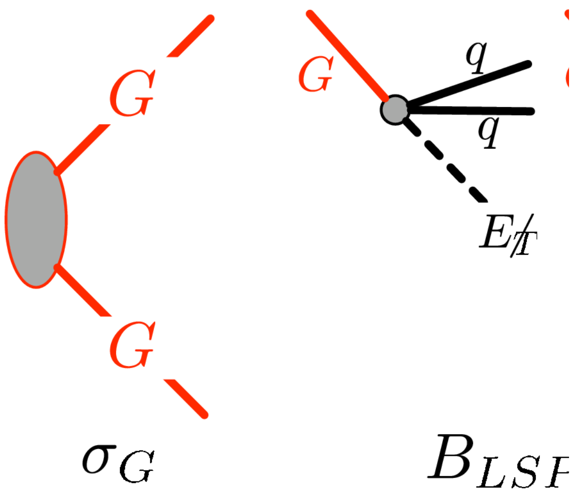
Along the m(sq)=m(gl) line, masses below 700 GeV excluded at 95% CL

Inclusive search in jets + MET



2jets + MET

squark-gluino production gives 3 jets + MET



4 jets + MET

Event selection

Jet multiplcity cuts are inclusive

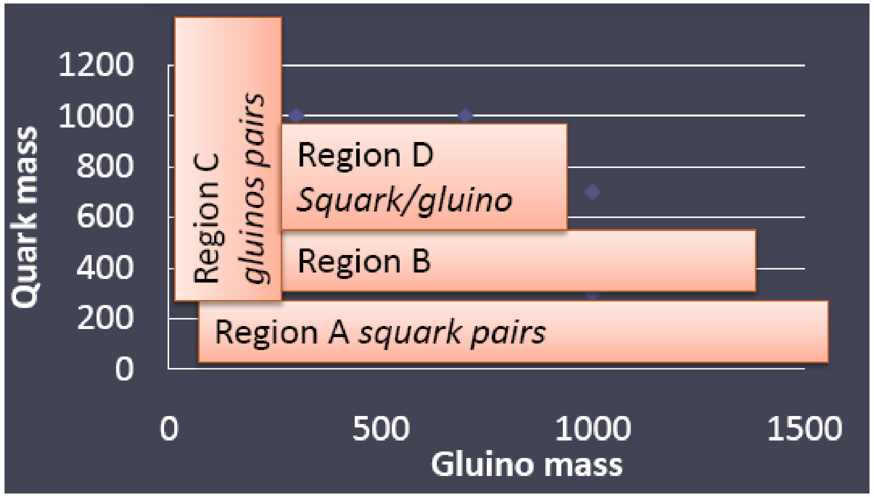
		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

Set by the trigger

Discard events with ≥ 1 isolated e or μ (with pt > 10 GeV, |η| < ~2.4)

$$m_{T2}\left(\mathbf{p}_T^{(1)}, \mathbf{p}_T^{(2)}, \not{\mathbf{p}}_T\right) \equiv \min_{\not{\mathbf{q}}_T^{(1)} + \not{\mathbf{q}}_T^{(2)} = \not{E}_T^{miss}} \left\{\max\left(m_T\left(\mathbf{p}_T^{(1)}, \not{\mathbf{q}}_T^{(1)}\right), m_T\left(\mathbf{p}_T^{(2)}, \not{\mathbf{q}}_T^{(2)}\right)\right)\right\}$$

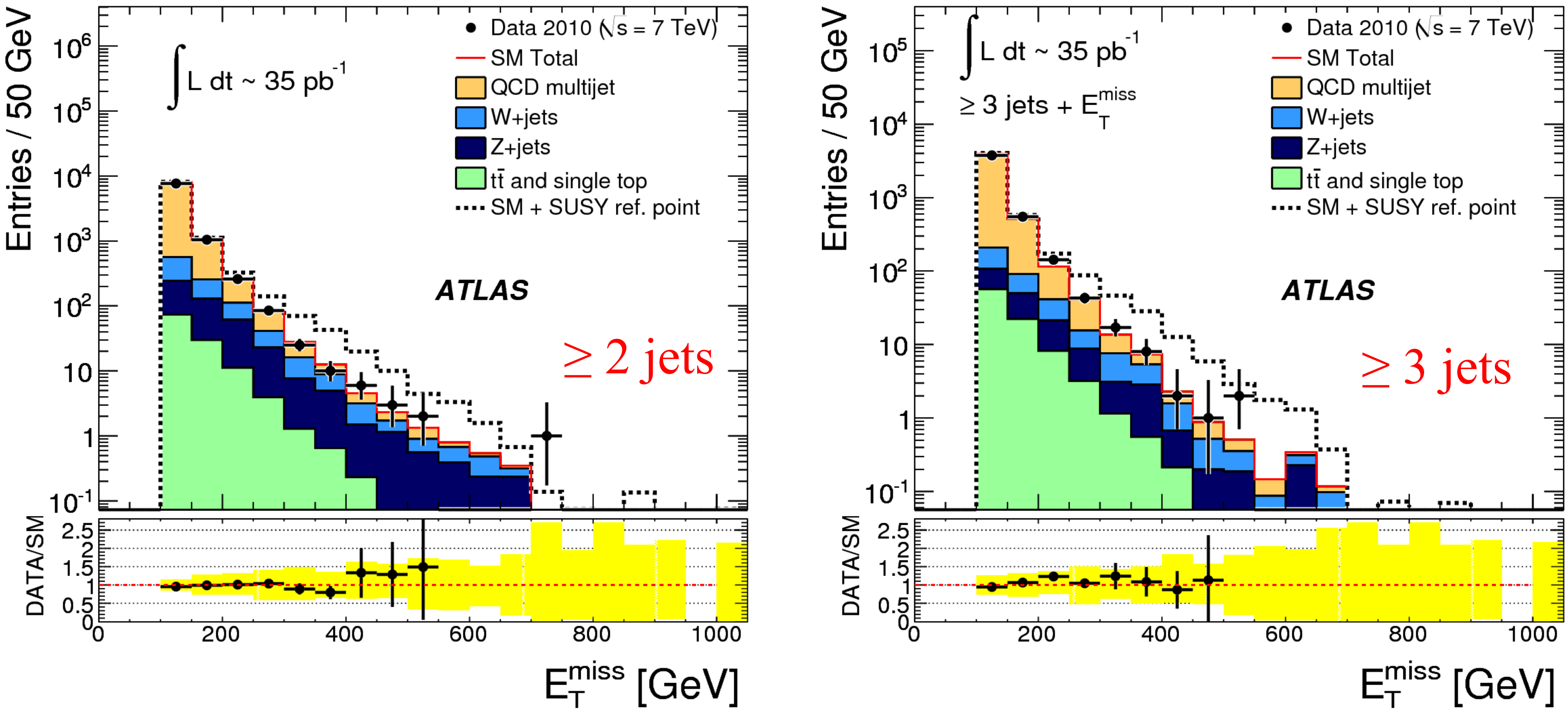
$$m_{eff} \equiv \sum_{i=1}^{n} |\mathbf{p}_T^{(i)}| + E_T^{miss}$$



(fig courtesy S.Caron)

Event selection (2)

after pre-selection cuts



MSUGRA point for illustration

- M_0 = 200 GeV, $M_{1/2}$ = 190 GeV, A_0 = 0, tan β = 3, μ > 0 → ~ 480 GeV gluinos/squarks

QCD background

Primarily from mis-measurement of jets

Estimated using several methods

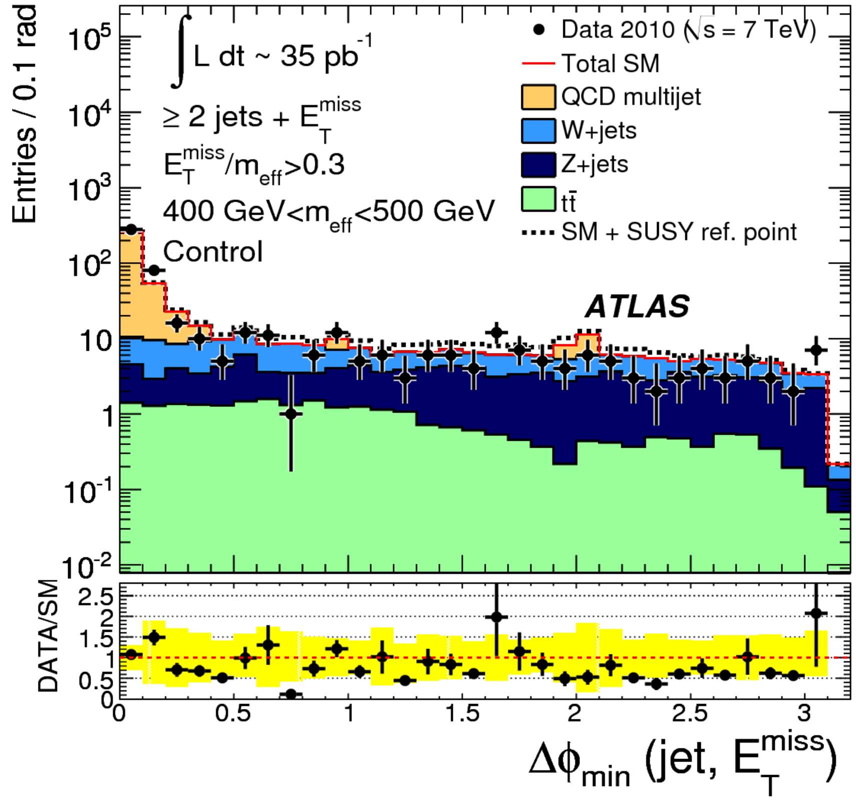
- Isolate a control sample in the data by inverting the Δφ(jet,MET) cut; extrapolate to signal region using MC shape
- Cross check with fully data-driven estimate by smearing well-measured multijets with a jet response function obtained from the data
- Cross check # 2: isolate a control sample in the data by inverting the MET/Meff cut (but with the Δφ(jet,MET) cut applied); extrapolate to signal region using MC shape

Consistent estimates from all methods

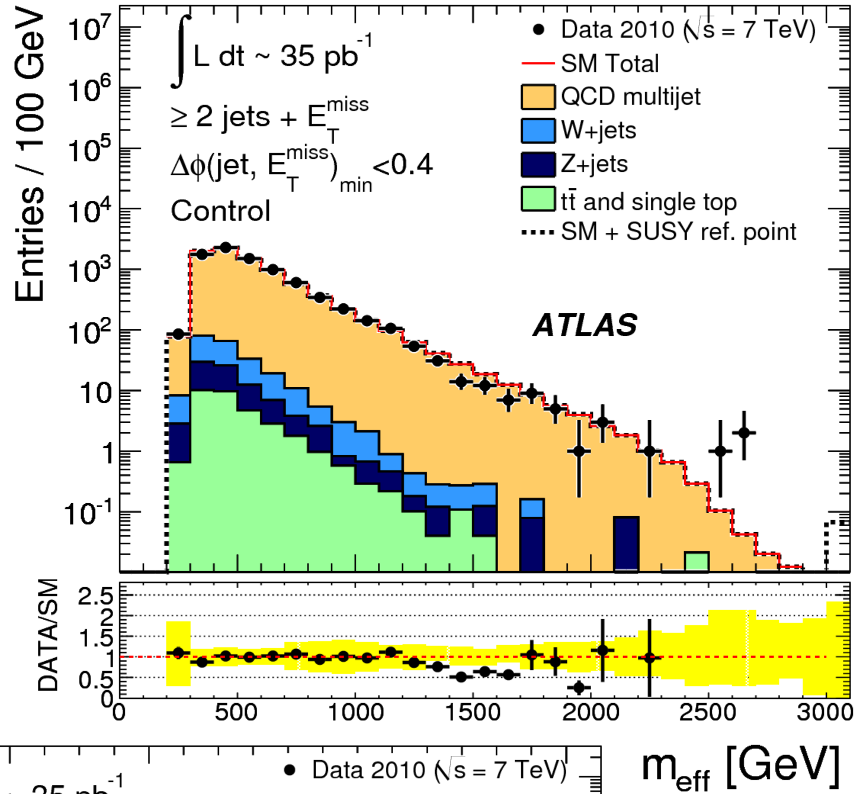
At the end, QCD bkg is very small (by construction)

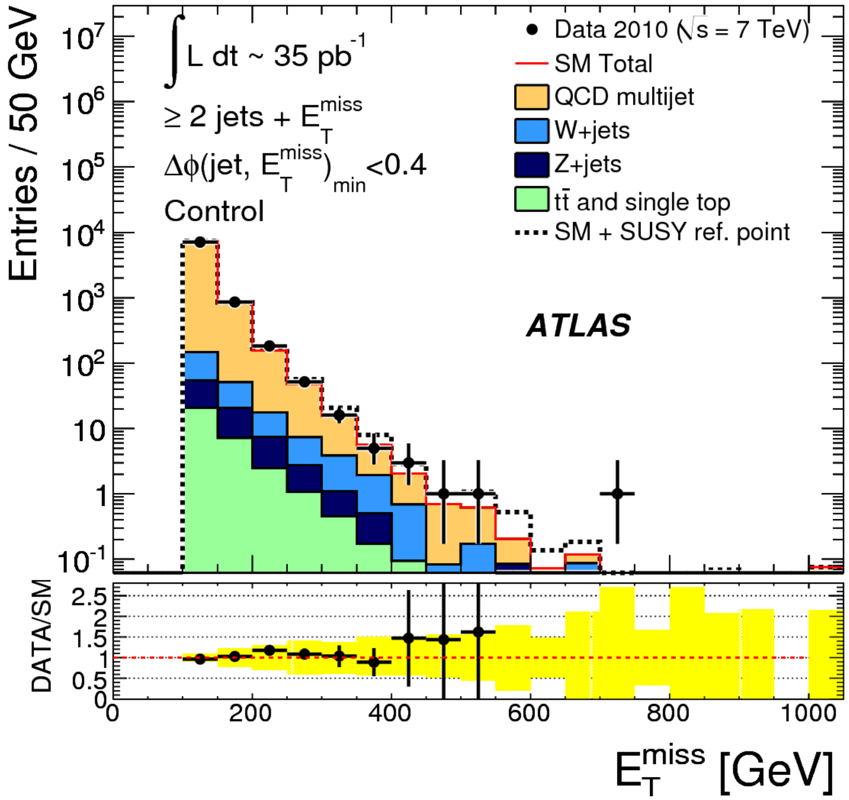
	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\ ^{+8}_{-7}$[u+j]	$0.6\ ^{+0.7}_{-0.6}$[u+j]	$9\ ^{+10}_{-9}$[u+j]	$0.2\ ^{+0.4}_{-0.2}$[u+j]
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] ± 12[$\mathcal{L}$]	10.0 ± 4.3[u] $^{+4.0}_{-1.9}$[j] ± 1.0[$\mathcal{L}$]	88 ± 18[u] $^{+26}_{-18}$[j] ± 9[$\mathcal{L}$]	2.5 ± 1.0[u] $^{+1.0}_{-0.4}$[j] ± 0.2[$\mathcal{L}$]

QCD bkg: Δφ(j,MET)

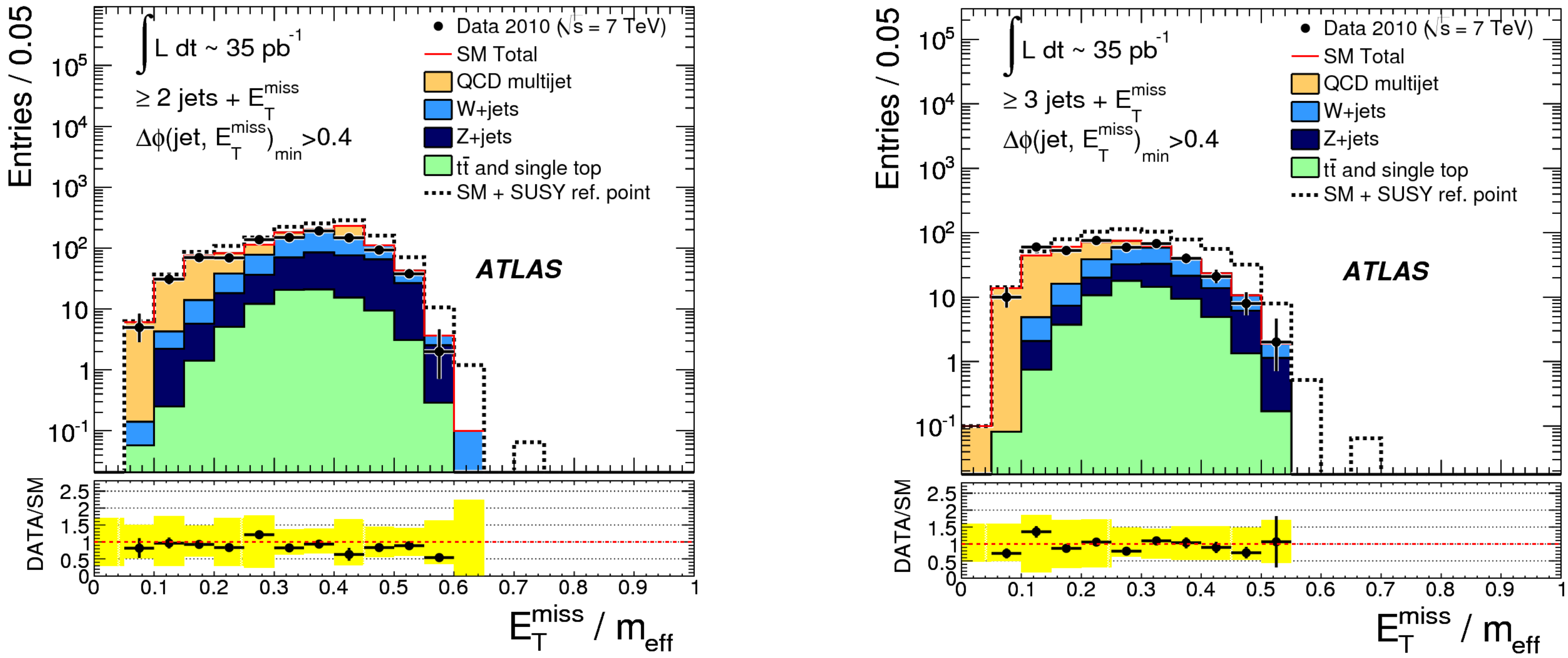


2jet channel after pre-selection
and MET, MET/Meff cuts





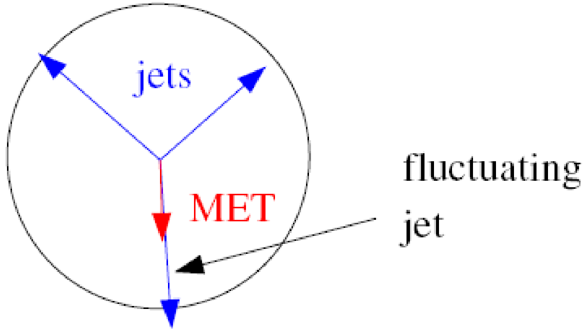
QCD background: MET/Meff



Jet smearing of data with data

Method:
arXiv:0901.0512
p.1513-1694

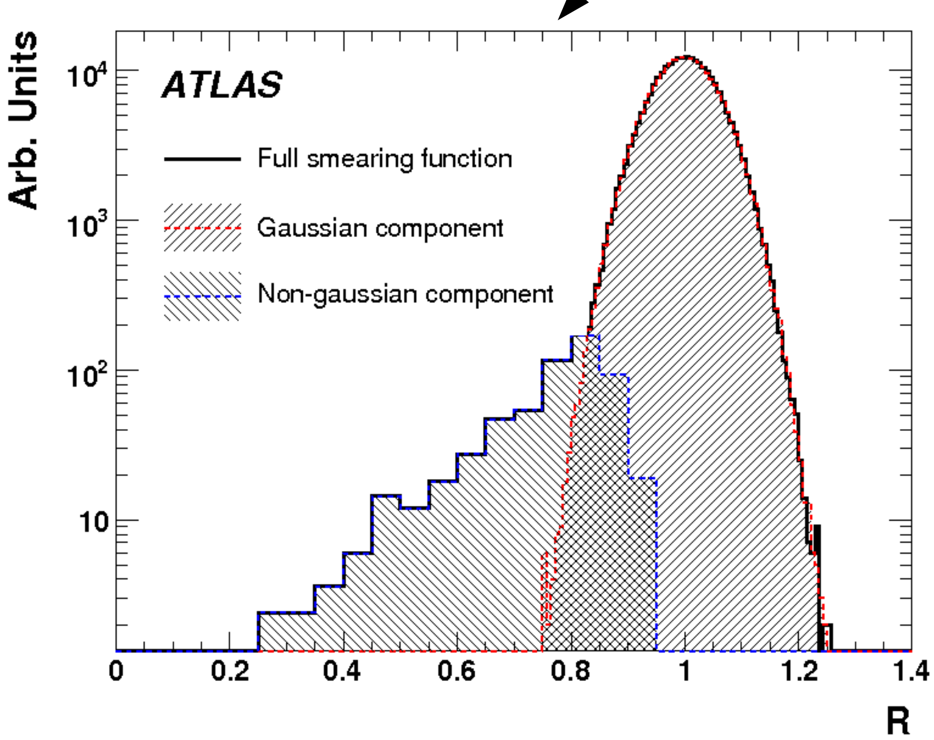
Sensitive to both real and fake MET (if associated with jets).

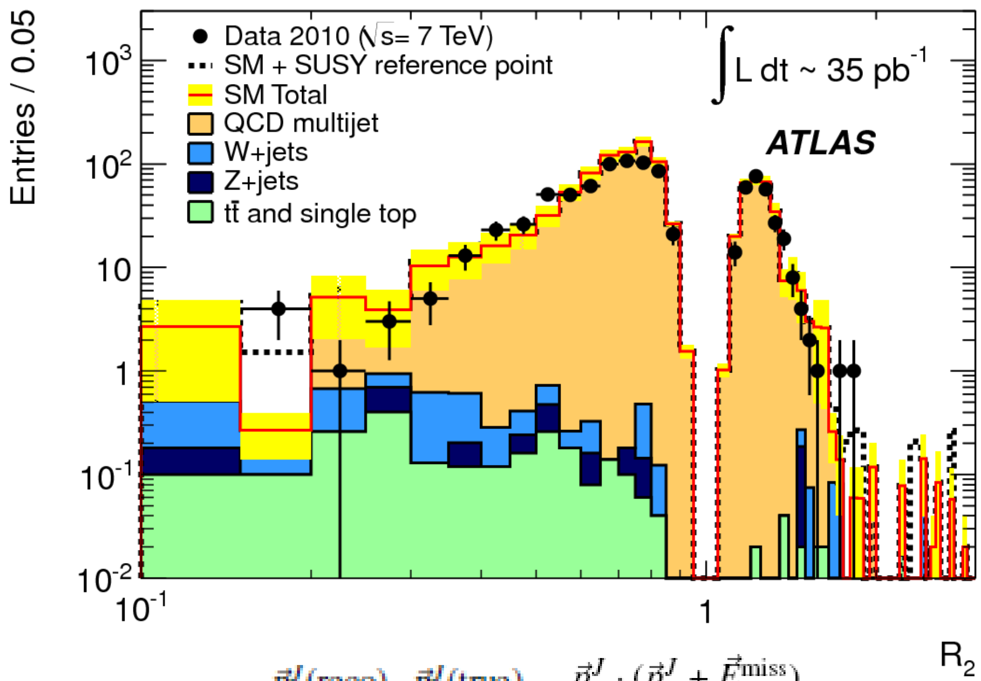


Jet response function:

- "Core" from γ+jet balance
- "Tail" from "Mercedes" type events
- Core/tail ratio from dijet balance

applied to "seed" events



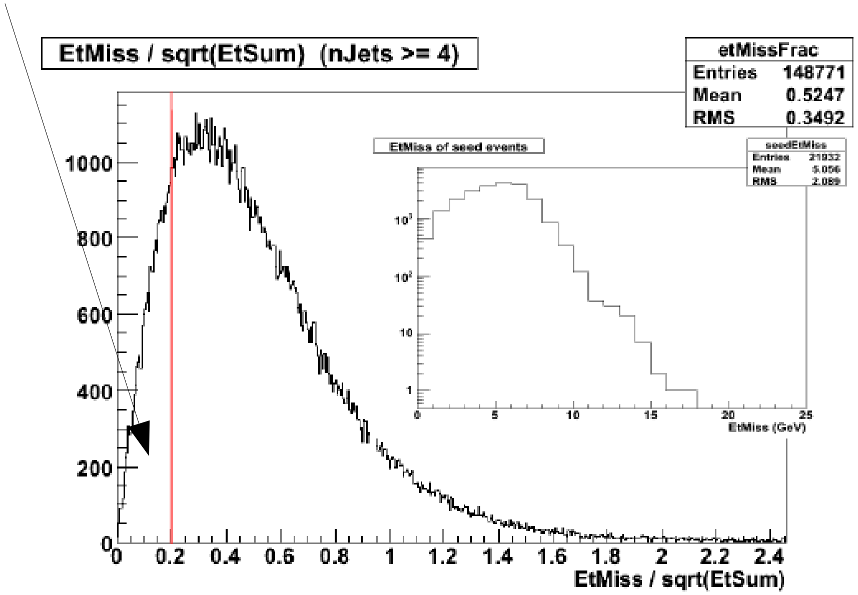


$$R = \frac{\vec{p}_{\mathrm{T}}^{J}(\mathrm{reco}) \cdot \vec{p}_{\mathrm{T}}^{J}(\mathrm{true})}{|\vec{p}_{\mathrm{T}}^{J}(\mathrm{true})|^2} \simeq \frac{\vec{p}_{\mathrm{T}}^{J} \cdot (\vec{p}_{\mathrm{T}}^{J} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}})}{|\vec{p}_{\mathrm{T}}^{J} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}|^2},$$

Jet smearing (2)

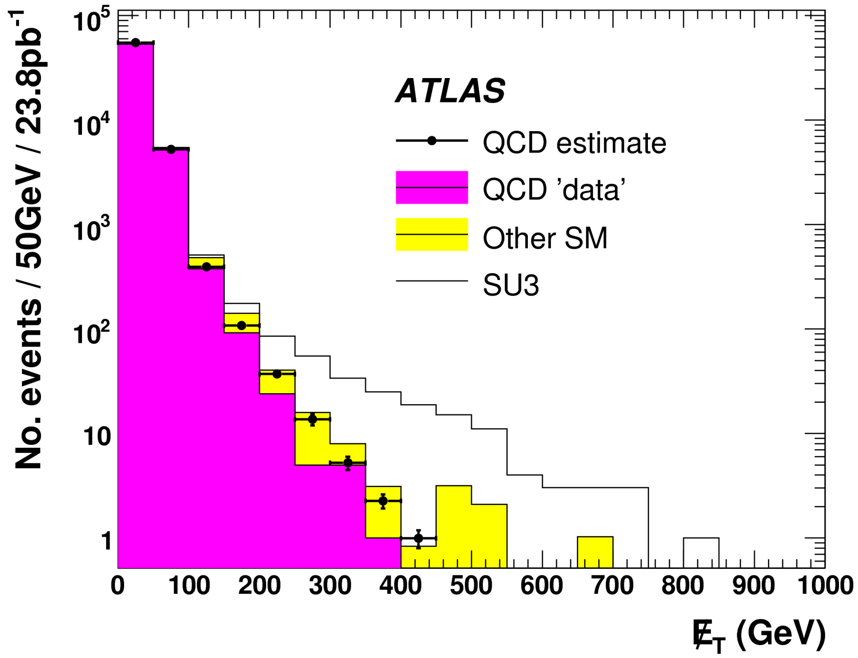
Method:
arXiv:0901.0512 p.1513-1694

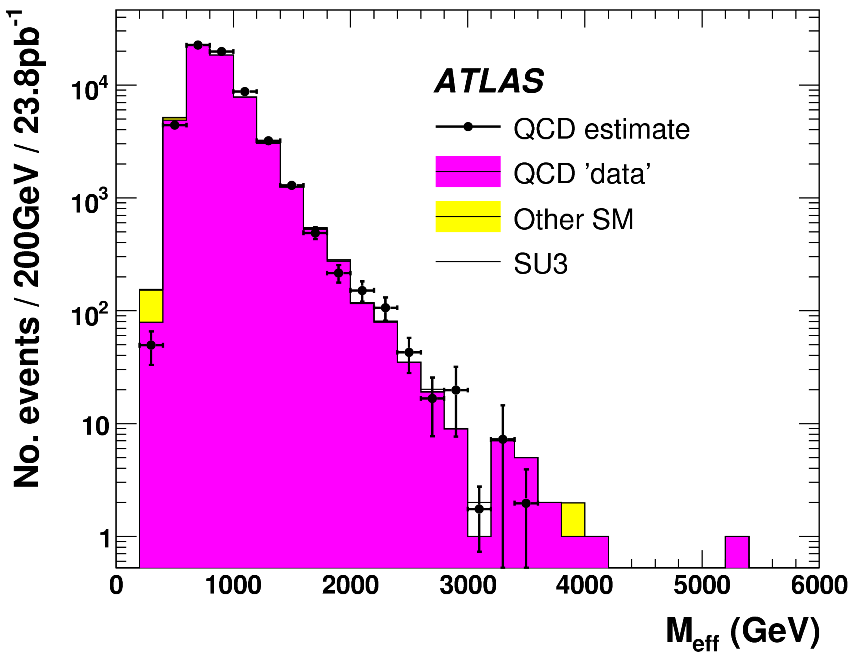
Seed events



≥ 4 jets with pt > (100,50,50,50) GeV

Closure test with Monte Carlo





W/Z + jets bkg

Primary bkg mechanisms are:

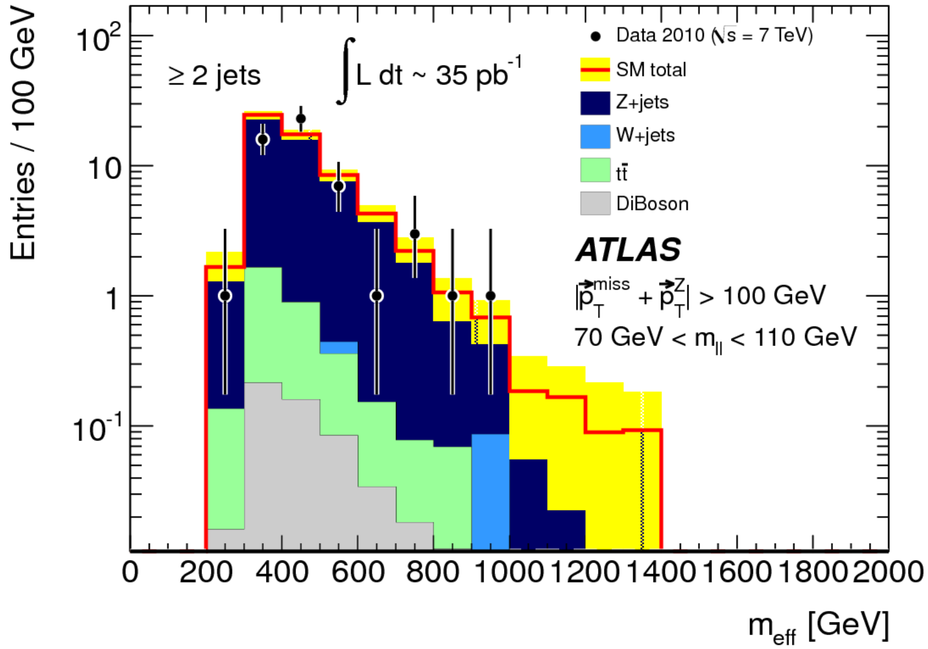
- W(τν)+jets, W(ℓν)+jets with lepton missed
- Z(νν)+jets

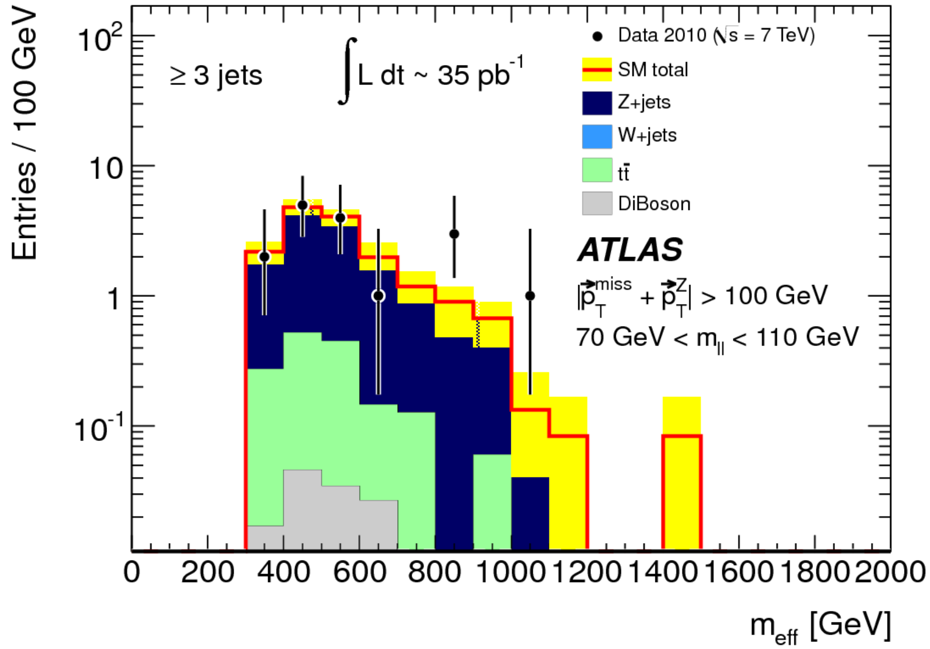
Background estimate	Baseline Method	Control Method	Alternative Methods
Z + jets	Alpgen Monte Carlo	$Z \to \mu\mu$ and $Z \to ee$ control regions	Z + jets from W + jets quasi data driven Z scale factors Z+jets from gamma+jets
W + jets	Alpgen Monte Carlo	$W \to \mu\nu$ and $W \to e\nu$ control regions	W + jets quasi data driven W scale factors ($W \to \tau\nu$ and top via embedding)

uncertainties estimated from data/MC comparisons in control regions

Z(ee+μμ) + jets control samples

after "neutrino-ification" of the leptons





Statistical uncertainty on the data/MC comparison for Z(ee+μμ)+jets is taken as the systematic uncertainty on the MC prediction for VB+jets bkg

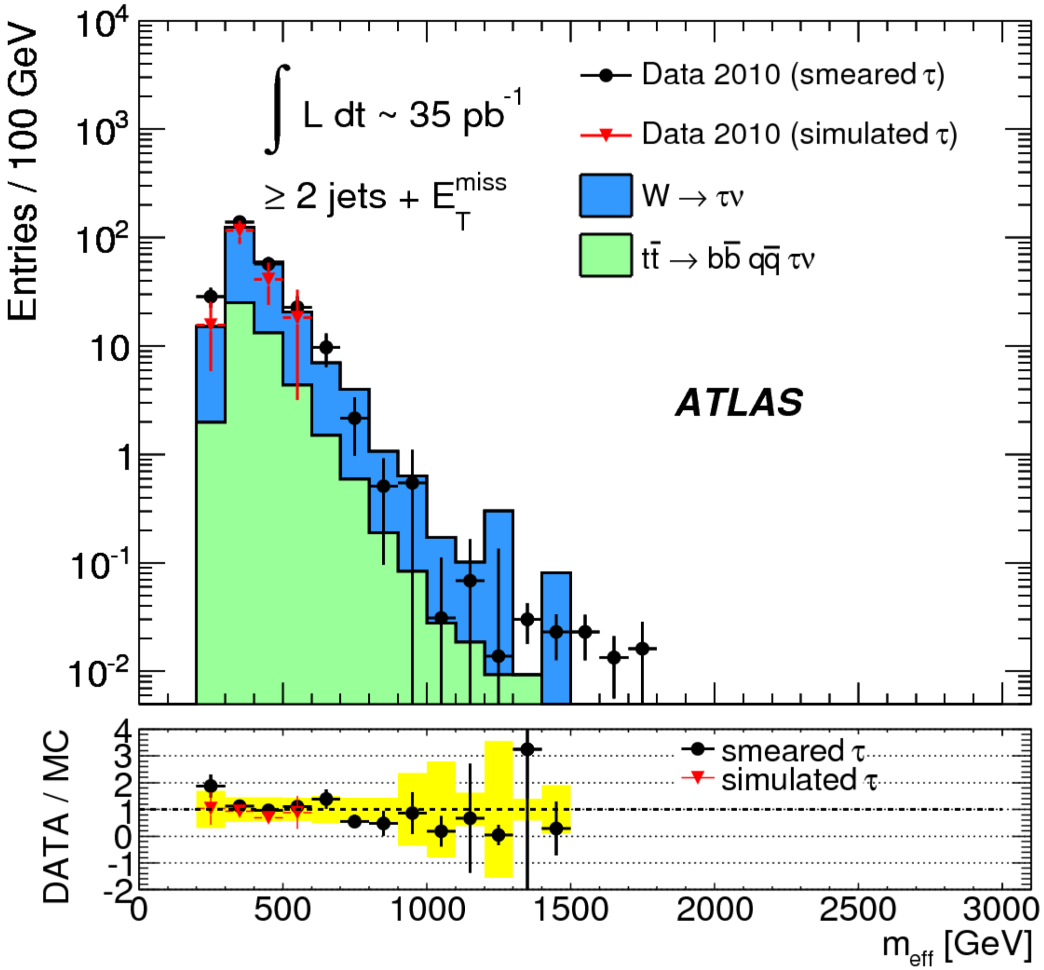
Crosscheck: W(τν)+jets bkg

Isolate a sample enriched in W(μν)+jets and tt → bbτνjj

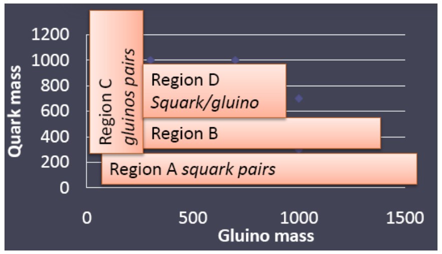
- isolated μ with pt > 20 GeV
- MET > 20 GeV

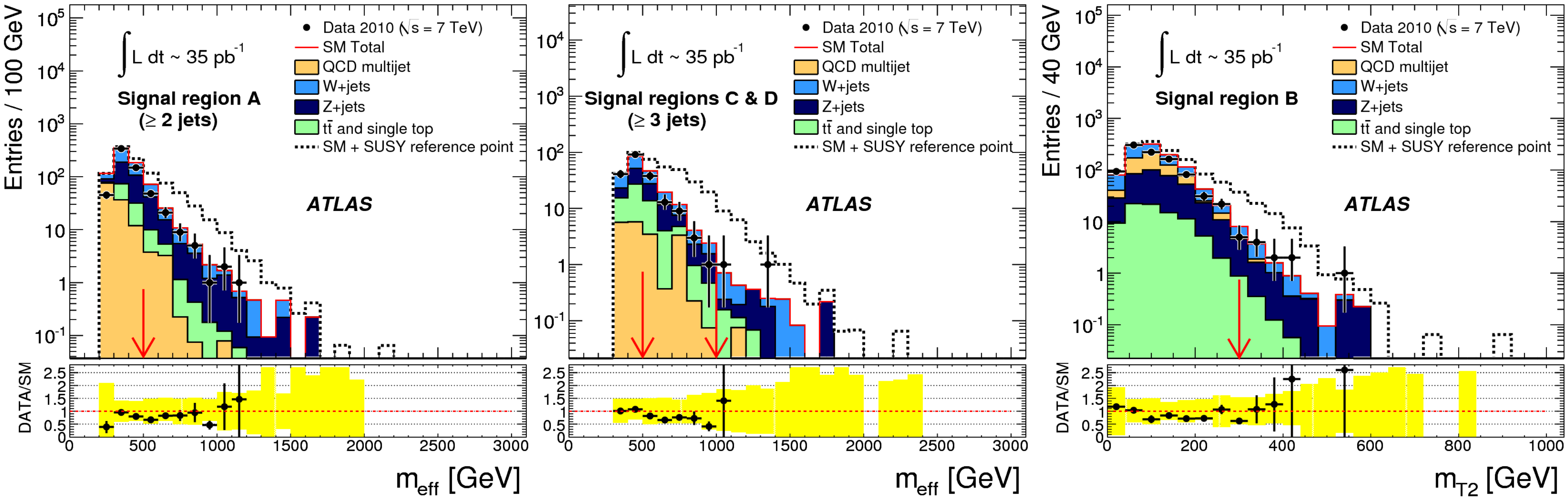
Remove μ and replace with either

- MC tau smeared with MC-based detector response functions
- Embed a MC tau at the detector hit level (from full simulation) into the data



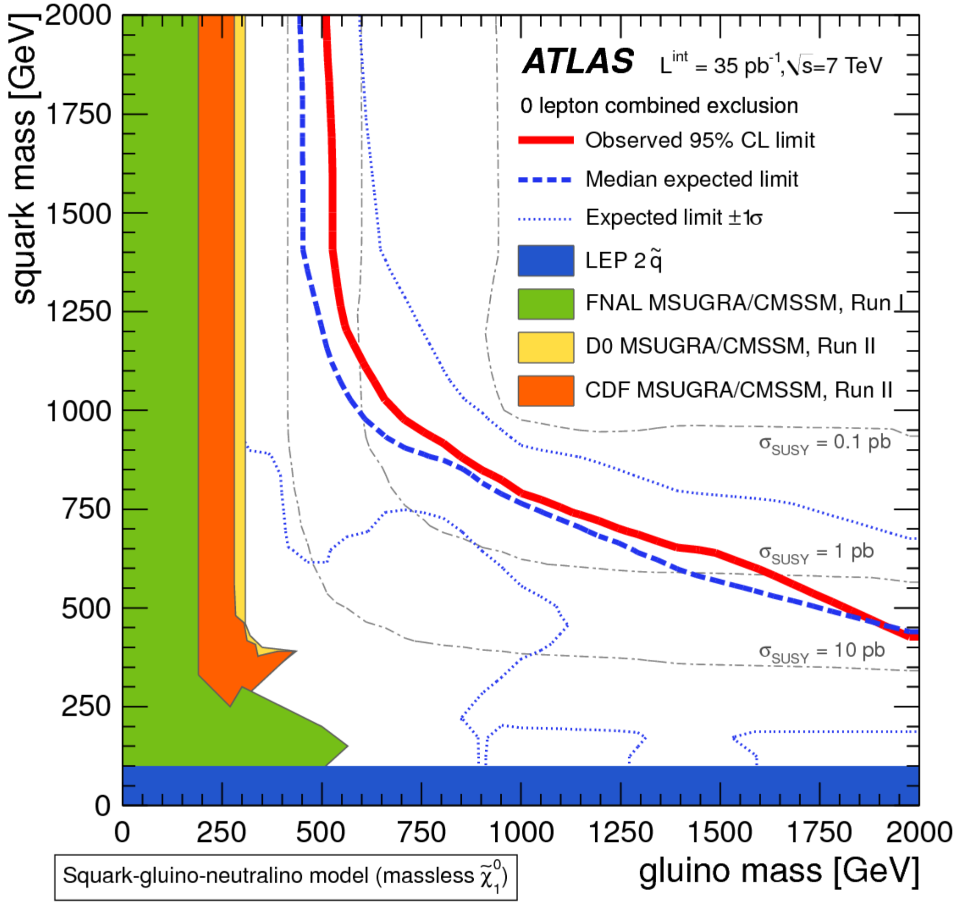
Results of the jets+MET analysis





	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\ ^{+8}_{-7}$[u+j]	$0.6\ ^{+0.7}_{-0.6}$[u+j]	$9\ ^{+10}_{-9}$[u+j]	$0.2\ ^{+0.4}_{-0.2}$[u+j]
W+jets	50 ± 11[u] $^{+14}_{-10}$[j] $\pm$ 5[$\mathcal{L}$]	4.4 ± 3.2[u] $^{+1.5}_{-0.8}$[j] $\pm$ 0.5[$\mathcal{L}$]	35 ± 9[u] $^{+10}_{-8}$[j] $\pm$ 4[$\mathcal{L}$]	1.1 ± 0.7[u] $^{+0.2}_{-0.3}$[j] $\pm$ 0.1[$\mathcal{L}$]
Z+jets	52 ± 21[u] $^{+15}_{-11}$[j] $\pm$ 6[$\mathcal{L}$]	4.1 ± 2.9[u] $^{+2.1}_{-0.8}$[j] $\pm$ 0.5[$\mathcal{L}$]	27 ± 12[u] $^{+10}_{-6}$[j] $\pm$ 3[$\mathcal{L}$]	0.8 ± 0.7[u] $^{+0.6}_{-0.0}$[j] $\pm$ 0.1[$\mathcal{L}$]
$t\bar{t}$ and t	10 ± 0[u] $^{+3}_{-2}$[j] $\pm$ 1[$\mathcal{L}$]	0.9 ± 0.1[u] $^{+0.4}_{-0.3}$[j] $\pm$ 0.1[$\mathcal{L}$]	17 ± 1[u] $^{+6}_{-4}$[j] $\pm$ 2[$\mathcal{L}$]	0.3 ± 0.1[u] $^{+0.2}_{-0.1}$[j] $\pm$ 0.0[$\mathcal{L}$]
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] $\pm$ 12[$\mathcal{L}$]	10.0 ± 4.3[u] $^{+4.0}_{-1.9}$[j] $\pm$ 1.0[$\mathcal{L}$]	88 ± 18[u] $^{+26}_{-18}$[j] $\pm$ 9[$\mathcal{L}$]	2.5 ± 1.0[u] $^{+1.0}_{-0.4}$[j] $\pm$ 0.2[$\mathcal{L}$]
Data	87	11	66	2

Results of the jets+MET analysis



Simplified MSSM model containing only gluino, squarks of the 1st and 2nd generation and massless χ_1^0

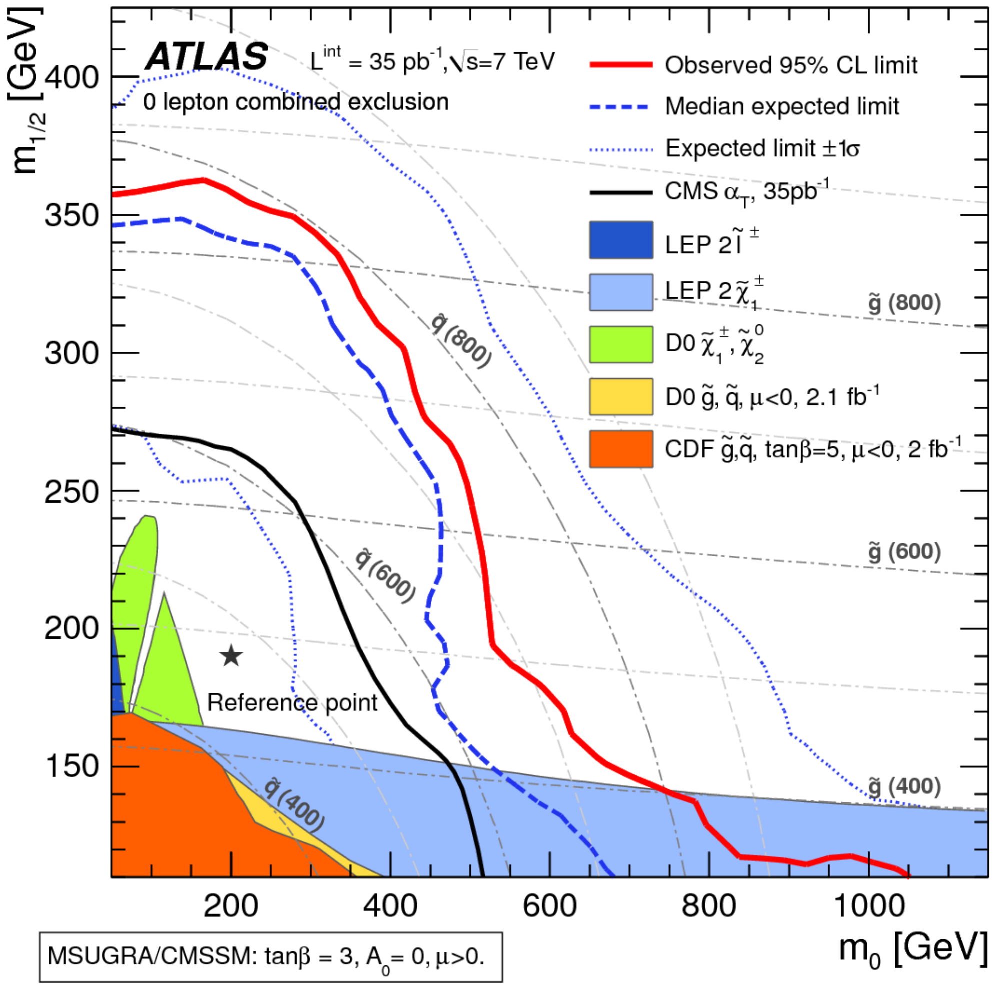
All other SUSY particles assigned a mass of 5 TeV

For each model point, choose a priori the signal region with the **best expected sensitivity**

M(gl) < 500 GeV excluded at 95% CL
M < 870 excluded for M(gl)=M(sq)

95% CL limits on σ·A·ε from new physics:
1.3, 0.35, 1.1, 0.11 pb (regions A,B,C,D)

Results of the jets+MET analysis (2)

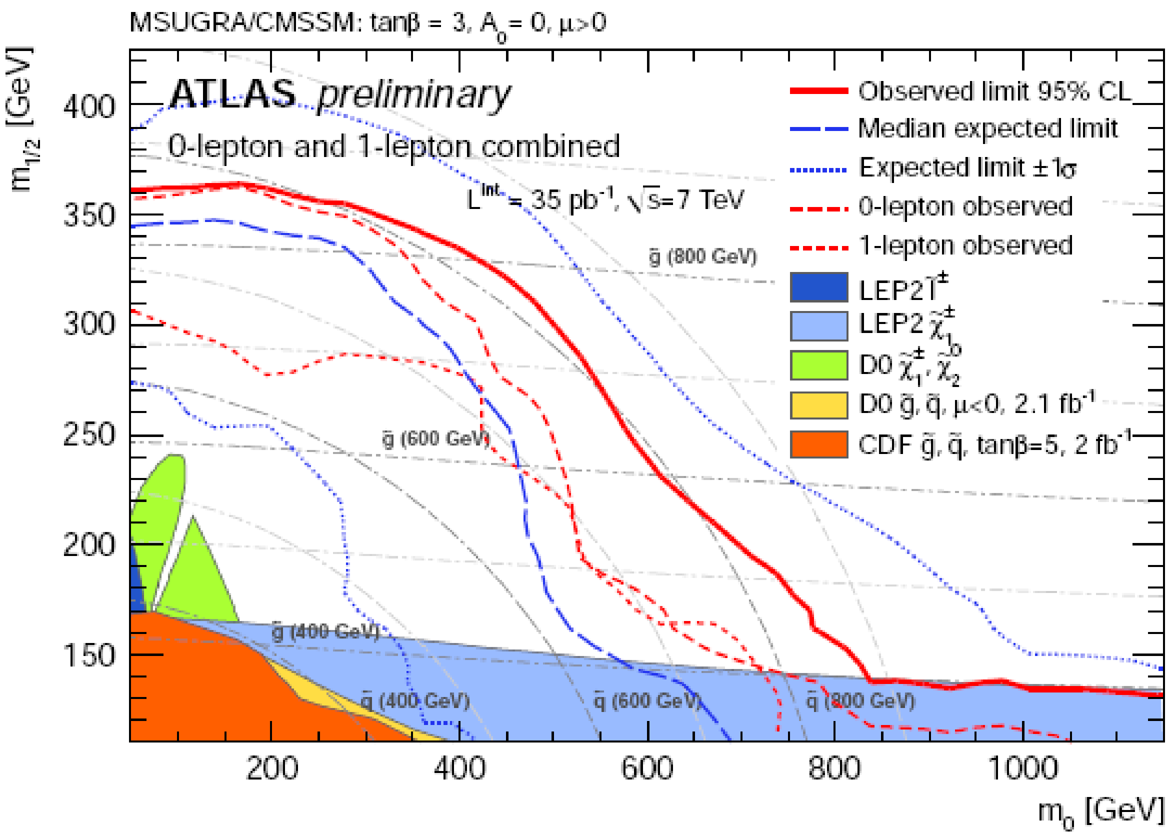


MSUGRA/CMSSM model

For each model point, choose a priori the signal region with the **best expected sensitivity**

M < 775 GeV excluded at 95% CL along the M(gl)=M(sq) line

Combined limit from 0- and 1-lepton channels



MSUGRA/CMSSM model

For each model point in the 0-lepton channel, choose a priori the signal region with the **best expected sensitivity**

Systematic uncertainties common to 0- and 1-lepton channels:

- Jet energy scale
- Signal xsec uncertainty
- Luminosity uncertainty

M < 815 GeV excluded at 95% CL along the M(gl)=M(sq) line

Expected 95% CL upper limit: 745 GeV

Long-lived massive particle search

LLP's are a generic feature of SUSY models

Complements MET-based searches

arXiv:1103.1697 (pMSSM scan) "SUSY without prejudice"

- ATLAS jets+MET analysis can fail to find high xsec pMSSM points when long-lived massive particles are produced at the end of the decay chain
- Low MET!

hep-ph/0611040

SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg |\mu|$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll |\mu|$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{GS} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Table 1
Brief overview of possible SUSY SMP states considered in the literature. Classified by SMP, LSP, scenario, and typical conditions for this case to materialise in the given scenario. See text for details.

Event selection

"Muon agnostic" search → do not rely on the muon system (analysis based on muon system coming soon...)

Retain sensitivity to R-hadrons which can interact in the calorimeter

But difficult to trigger. Rely on ISR to trigger → "monojet" topology

MET trigger: > 40 GeV uncalibrated

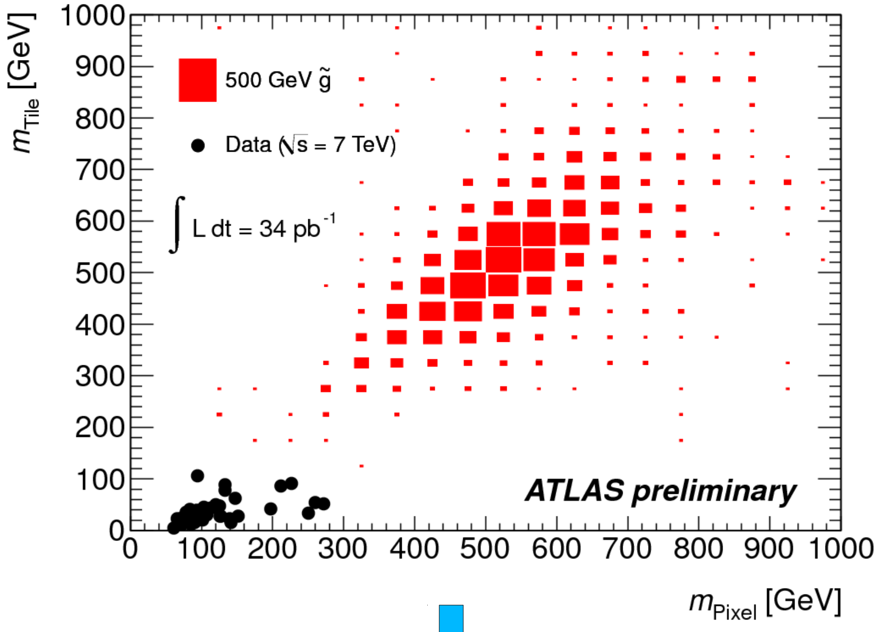
≥ 1 charged track with pt > 50 GeV and $\Delta R > 0.5$ to any jet with Et > 40 GeV

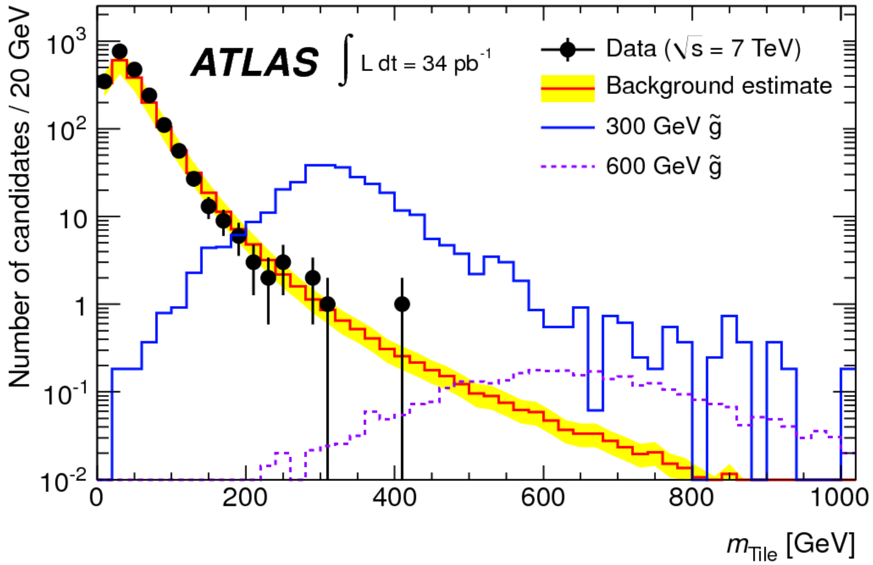
Reconstruct the particle velocity based on

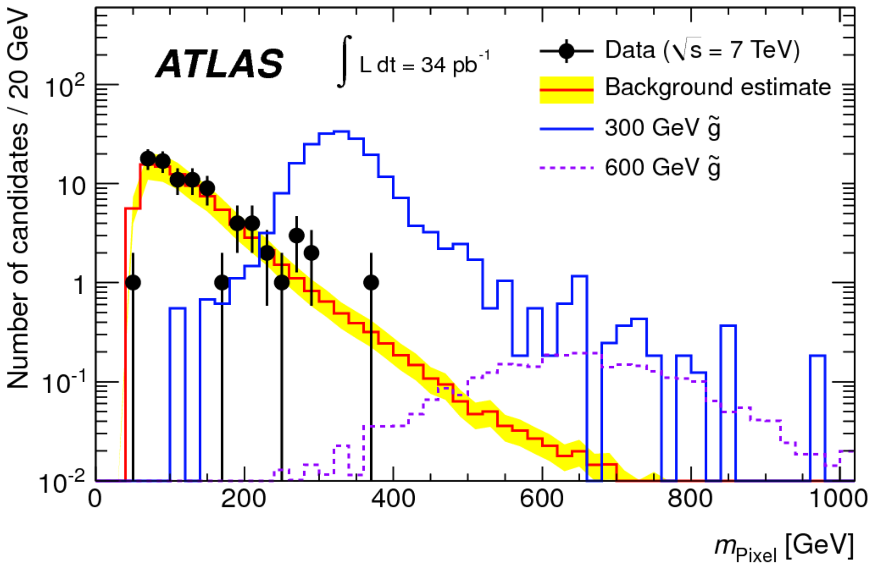
- dE/dx in pixel detector
- TOF in hadron calorimeter

Combine with momentum measurement to get the particle mass

Mass from dE/dx and TOF



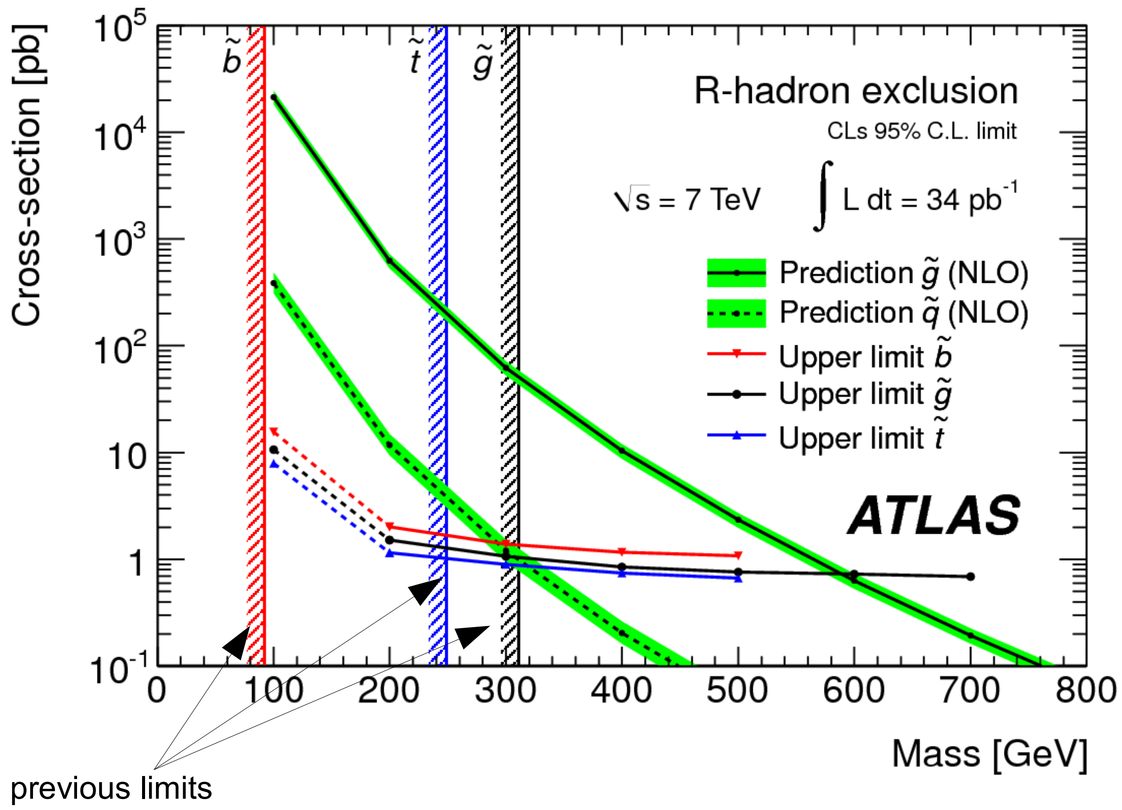




Bkg shape estimated from the data:

- Combine random momentum values with random measurements of dE/dx or β_{tile}

Results from the long-lived particle search



Results interpreted as limits on R-hadron masses:

- Stable sbottom
- Stable stop
- Stable gluino

95% CL upper limits:

M > ~300 GeV (sbottom,stop) and ~560 GeV (gluino)

(using most conservative hadronic interaction models)

Other SUSY results

Opposite-sign and same-sign dileptons + MET: arXiv:1103.6214

Same-sign, same-flavor dileptons + MET: arXiv:1103.6208

e+μ resonance (RPV sneutrino): arXiv:1103.5559

≥3 leptons + jets + MET: ATLAS-CONF-2011-039

B-jets (+ ≥ 1 lepton) + MET: arXiv:1103.4344

Other results in the pipeline:

- diphotons + MET
- long-lived massive particle search (muon spectrometer based)
- jets with displaced vertices
- stopped gluino
- monojet

Conclusion

Very successful 2010 run at the LHC: ~40 pb^{-1} of data collected

ATLAS is performing very well
Remarkable agreement between data and Monte Carlo

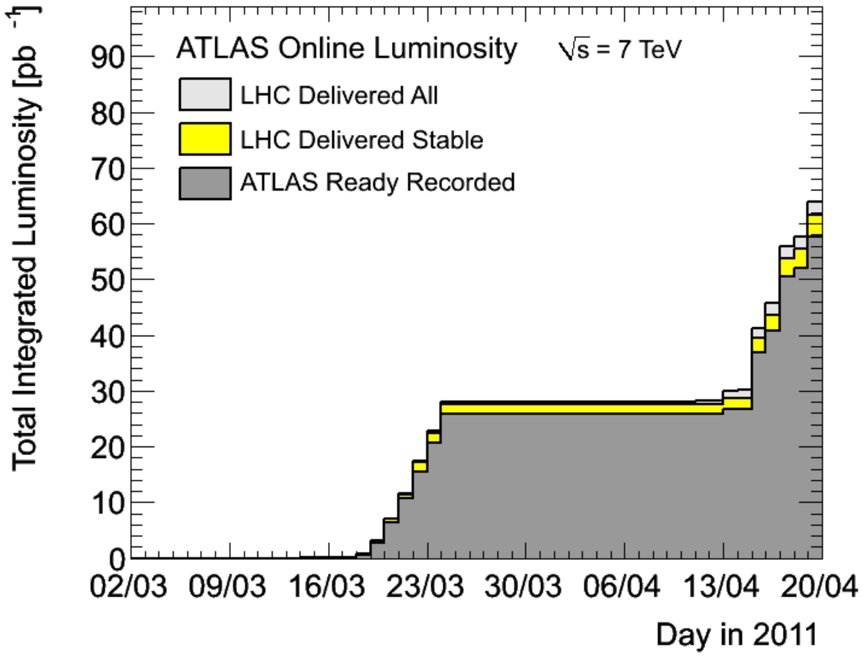
ATLAS SUSY searches are just getting started.
No sign of new physics yet. It seems that SUSY was not “just around the corner”

2011 run has started

~ 60 pb^{-1} collected so far

Rough projections:

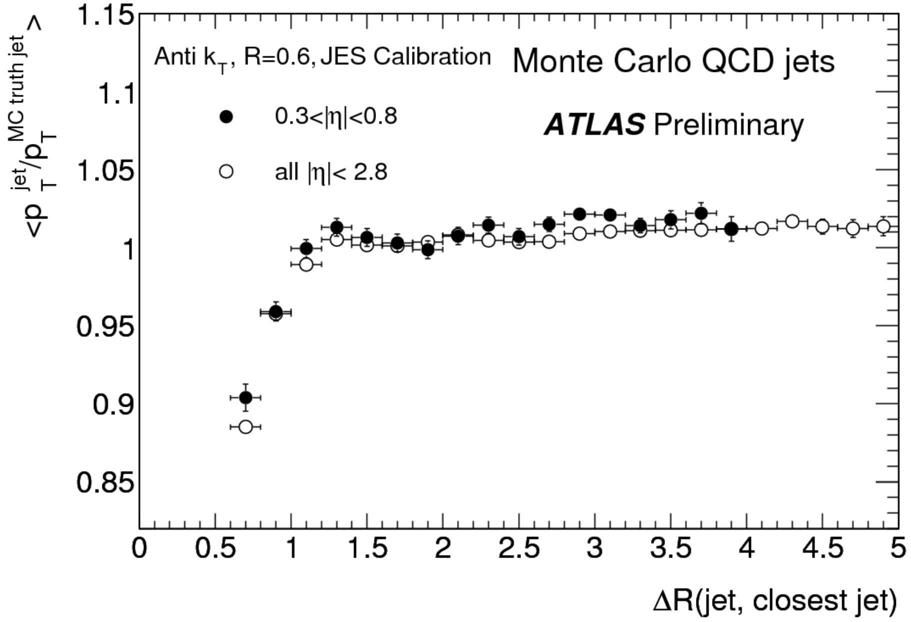
- 1 fb^{-1} by summer
- 3 fb^{-1} by end 2011
- 10 fb^{-1} (??) by end 2012

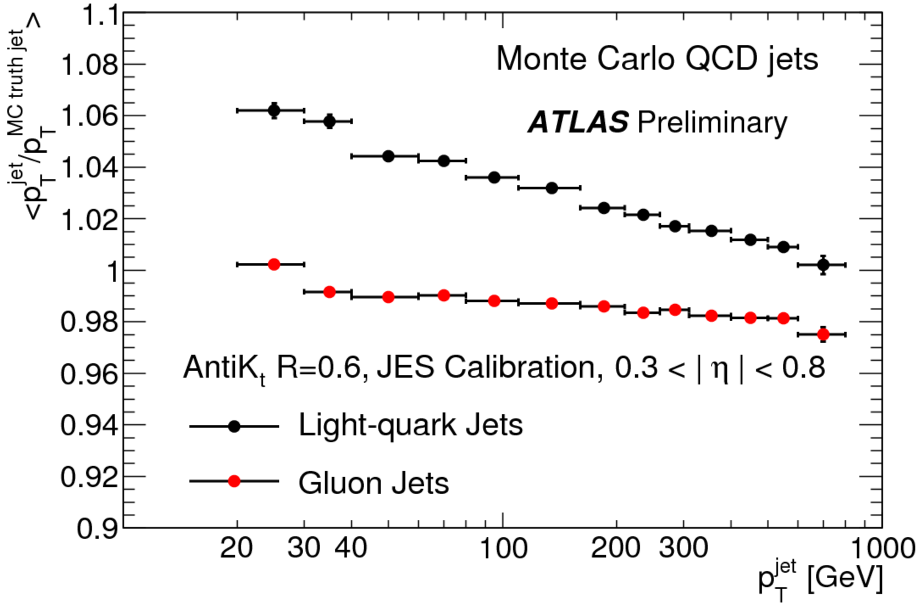


Backup material

Jet energy calibration (2)

Topology and flavor dependence. Impact is analysis dependent.

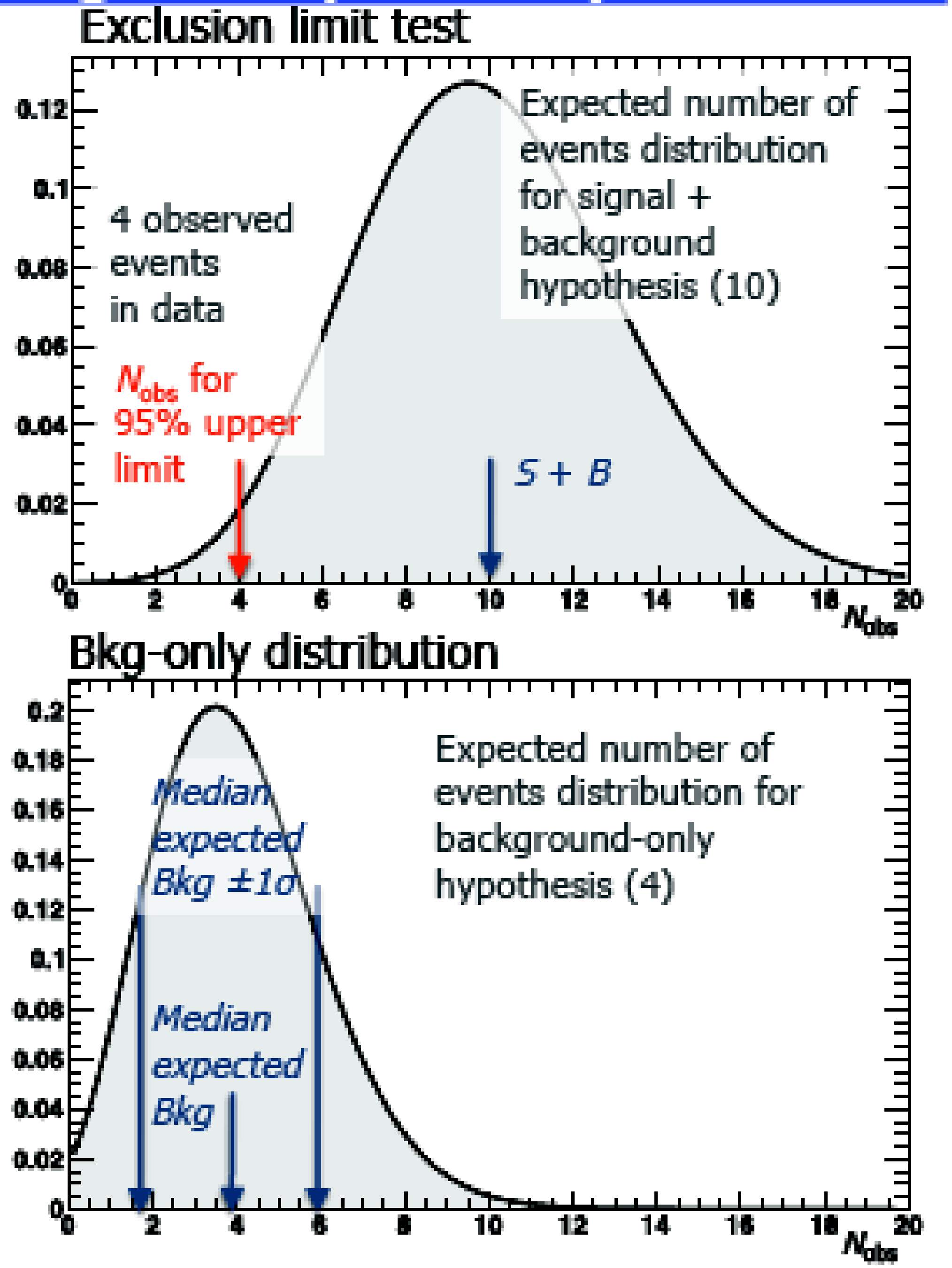




Gluon jets: softer fragmentation
→ lower energy response
particles more likely to fail to reach the calorimeter

The exclusion goal (sofar)

- Typical exclusion test
  - Bkg-only estimate B + uncertainty obtained from control samples.
- Observed limit:
  - Find S for which 5% of S+B toy distribution is equal or lower than observed number of of events.
- Expected limit (S^{95}) + uncertainty:
  - Same idea: find S for which 5% of S+B toy distribution is equal or lower than expected bkg events, or events for bkg $\pm 1\sigma$



QCD multijet background

QCD multijet bkg is small in all inclusive search channels (in Monte Carlo!).
Suppression due to:

- Etmiss cut
- Isolated lepton requirement (not available in 0-lepton channel, obviously)
- $\Delta\varphi$ cut between jets and Etmiss vector

However.... Big uncertainties.

Sensitive to rare effects in large cross section process. Difficult to model in Monte Carlo.

Depends critically on detector performance and suppression of instrumental pathologies.

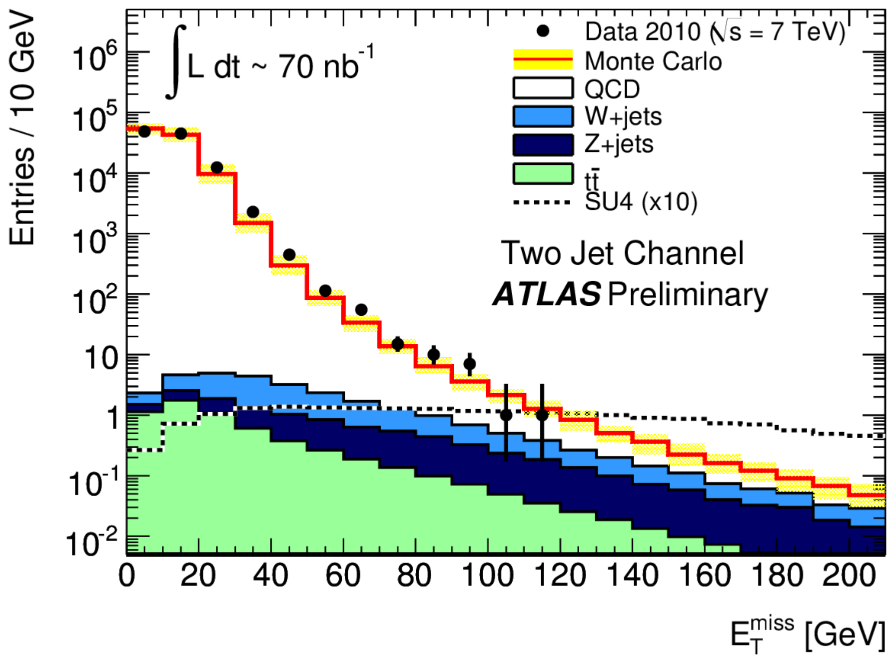
Must understand QCD multijet bkg to some level before data-driven studies of other SUSY backgrounds can begin sensibly.

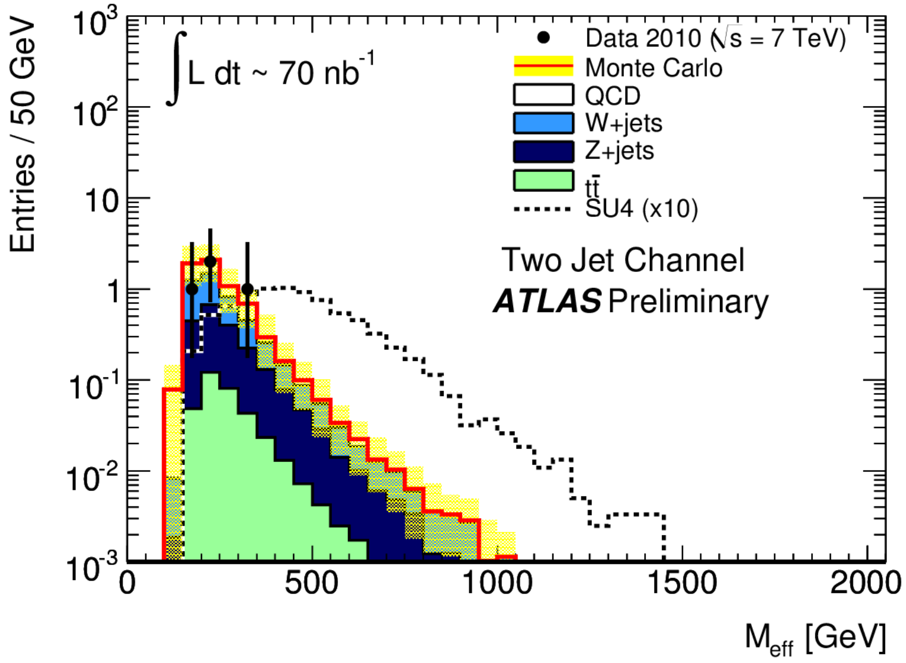
SUSY search in jets+MET (70 nb^{-1})

Soft cuts on jets and MET

Number of jets	Monojets	$\geq$ 2 jets	$\geq$ 3 jets	$\geq$ 4 jets
Leading jet p_T (GeV)	> 70	> 70	> 70	> 70
Subsequent jets p_T (GeV)	veto if > 30	> 30	> 30 (Jets 2 and 3)	> 30 (Jets 2 to 4)
E_T^{miss}	> 40 GeV	> 40 GeV	> 40 GeV	> 40 GeV
$\Delta\phi(\text{jet}_i, \vec{E}_T^{miss})$	no cut	$[> 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2, > 0]$
$E_T^{miss} > f \times M_{eff}$	no cut	$f = 0.3$	$f = 0.25$	$f = 0.2$

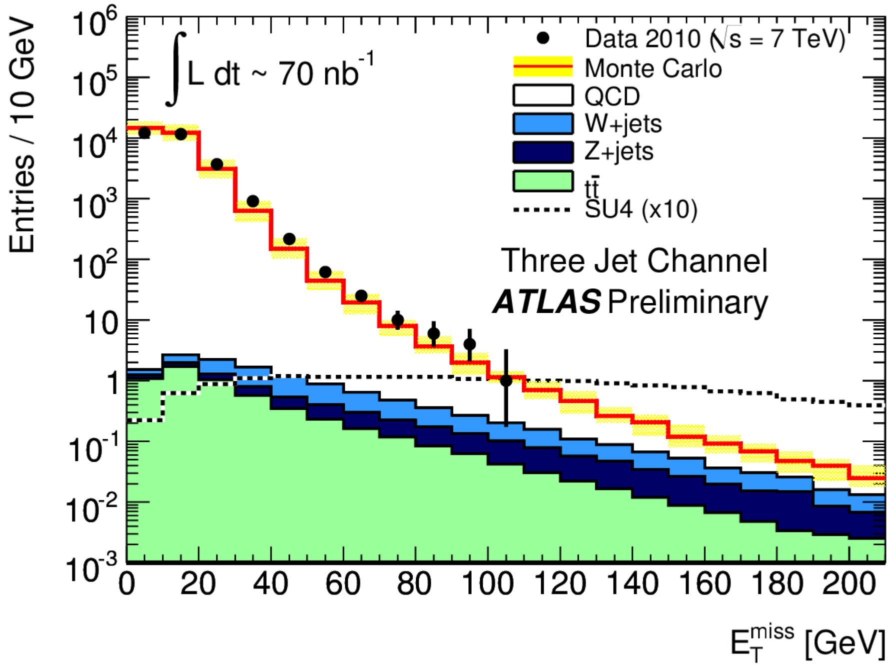
Veto events with ≥ 1 leptons with pt > 10 GeV

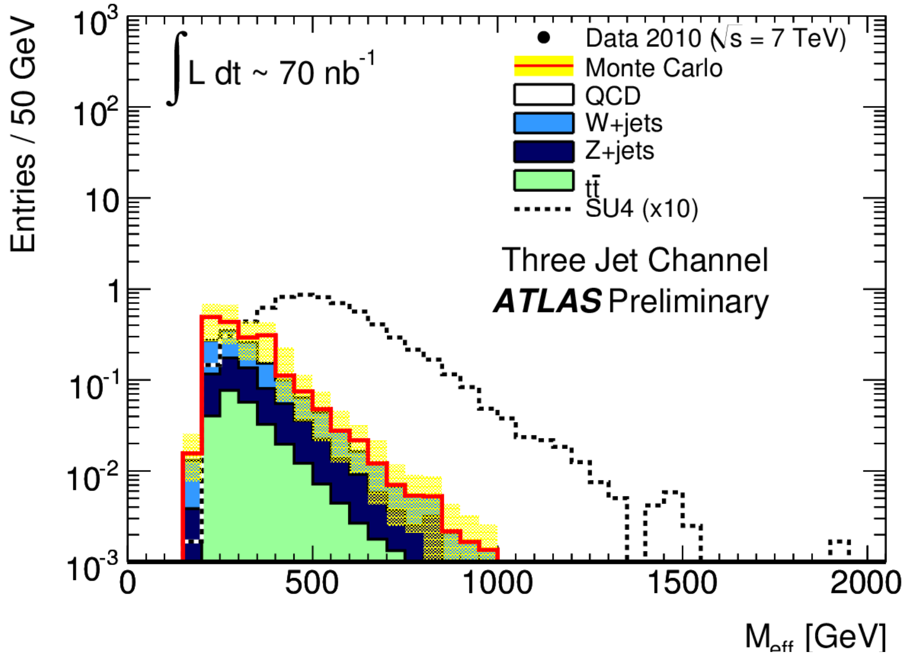




ATL-CONF-2010-065

SUSY search in jets+MET (70 nb^{-1})





ATL-CONF-2010-065

	Monojet		≥ 2 jets		≥ 3 jets		≥ 4 jets	
	Data	Monte Carlo	Data	Monte Carlo	Data	Monte Carlo	Data	Monte Carlo
After jet cuts	21 227	$23\,000^{+7000}_{-6000}$	108 239	$108\,000^{+31\,000}_{-25\,000}$	28 697	$31\,000^{+10\,000}_{-8000}$	5329	5600^{+2300}_{-1600}
$\cap\ E_T^{miss}$ cut	73	46^{+22}_{-14}	650	450^{+190}_{-120}	325	230^{+100}_{-70}	116	84^{+45}_{-30}
$\cap\ \Delta\phi$ and E_T^{miss} cuts	–	–	280	200^{+110}_{-65}	136	100^{+55}_{-30}	54	43^{+26}_{-16}
$\cap\ E_T^{miss}/M_{eff}$, $\Delta\phi$ and E_T^{miss} cuts	–	–	4	6.6 ± 3	0	1.9 ± 0.9	1	1.0 ± 0.6

New SUSY limits with 70 nb^{-1}

SLAC-PUB-14219
arXiv:1008.0407

It's On: Early Interpretations of ATLAS Results in Jets and Missing Energy Searches

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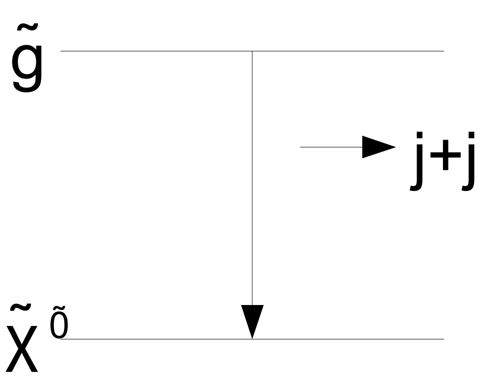
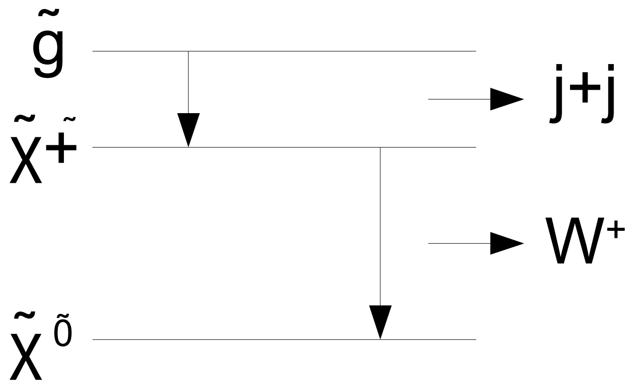
The first search for supersymmetry from ATLAS with 70 nb^{-1} of integrated luminosity extends the Tevatron' s reach for colored particles that decay into jets plus missing transverse energy. For gluinos that decay directly or through a one step cascade into the LSP and two jets, the mass range $m_{\tilde{g}} \leq 205$ GeV is disfavored by the ATLAS searches, regardless of the mass of the LSP. In some cases the coverage extends up to $m_{\tilde{g}} \simeq 295$ GeV, already surpassing the Tevatron's reach for compressed supersymmetry spectra.





Soft MET cut gives access to compressed decay spectra.
Detailed study underway inside ATLAS.

Towards SUSY with 40 pb^{-1}

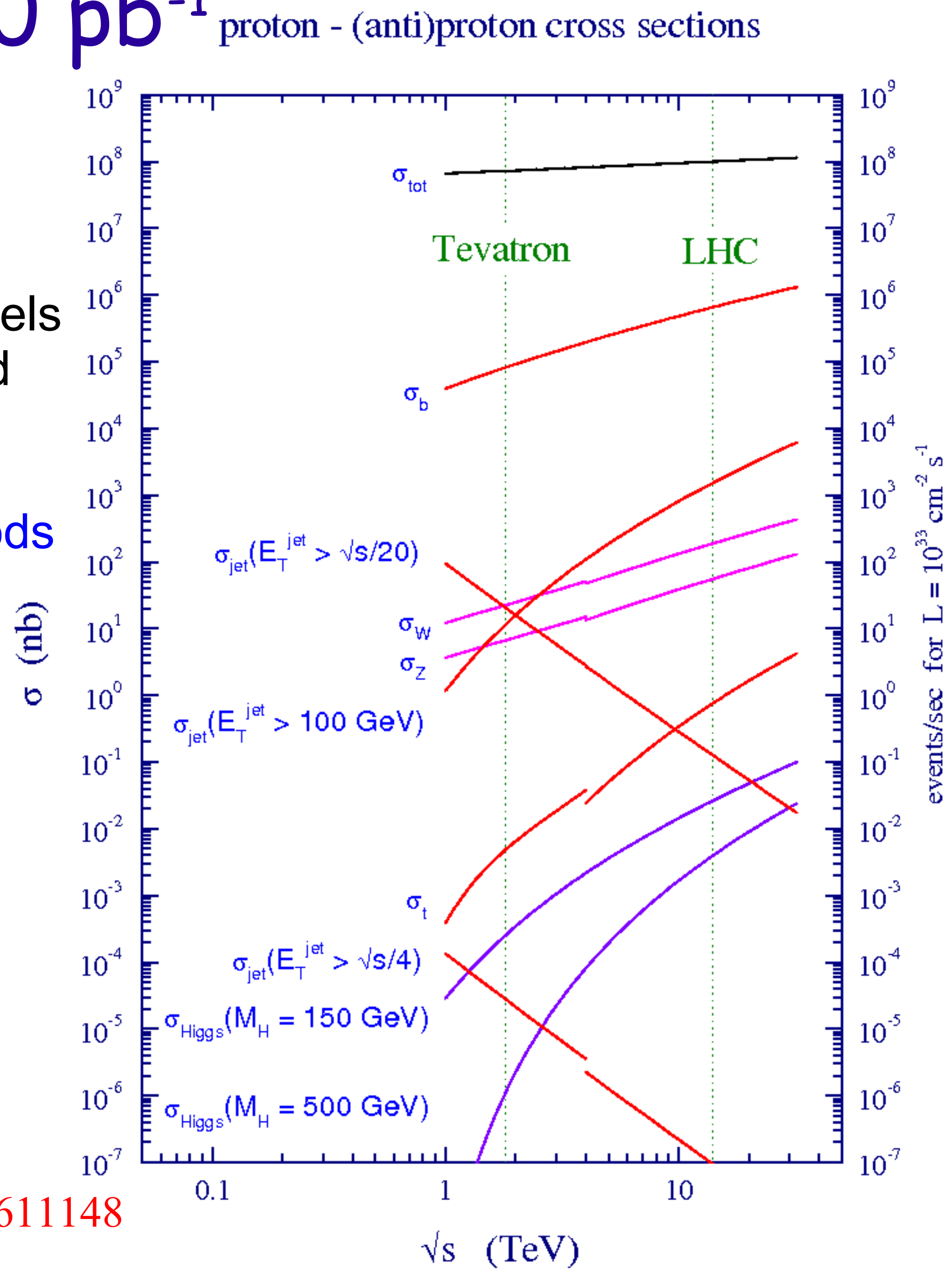
We are working our way down in cross section

SUSY searches in 1- and 2-lepton channels build on measurements of W/Z(+jets) and top

Many similarities in bkg estimation methods for QCD and use of btag to separate W from top

Validation of MC by comparison to SM measurements

In 0-lepton channel, W and top bkg are normalized using measurements in leptonic channels. (QCD bkg requires dedicated estimation methods.)



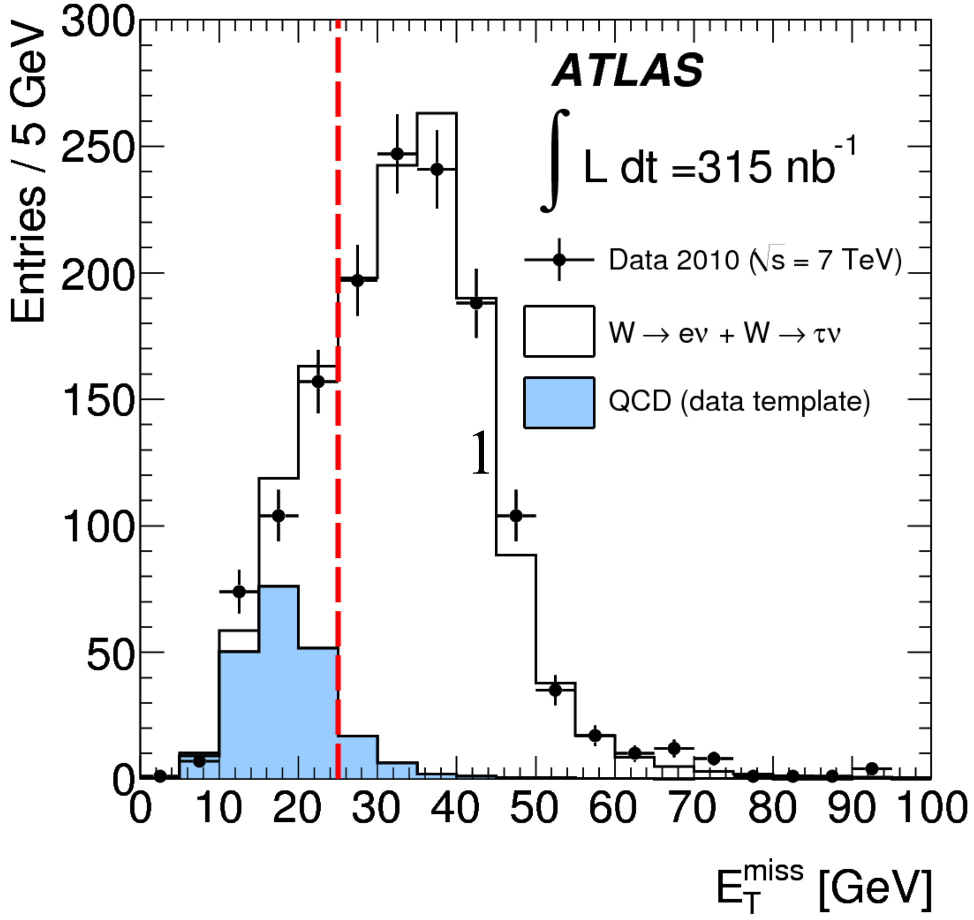
hep-ph/0611148

W cross section

Requirement	Number of candidates	
	$W \to e\nu$	$W \to \mu\nu$
Trigger	6.5×10^6	5.1×10^6
Lepton: e with $E_T > 20$ GeV or μ with $p_T > 20$ GeV	4003	7052
Muon isolation: $\sum p_T^{ID} / p_T < 0.2$	–	2920
$E_T^{miss} > 25$ GeV	1116	1220
$m_T > 40$ GeV	1069	1181

arXiv:1010.2130

QCD bkg (electron channel)



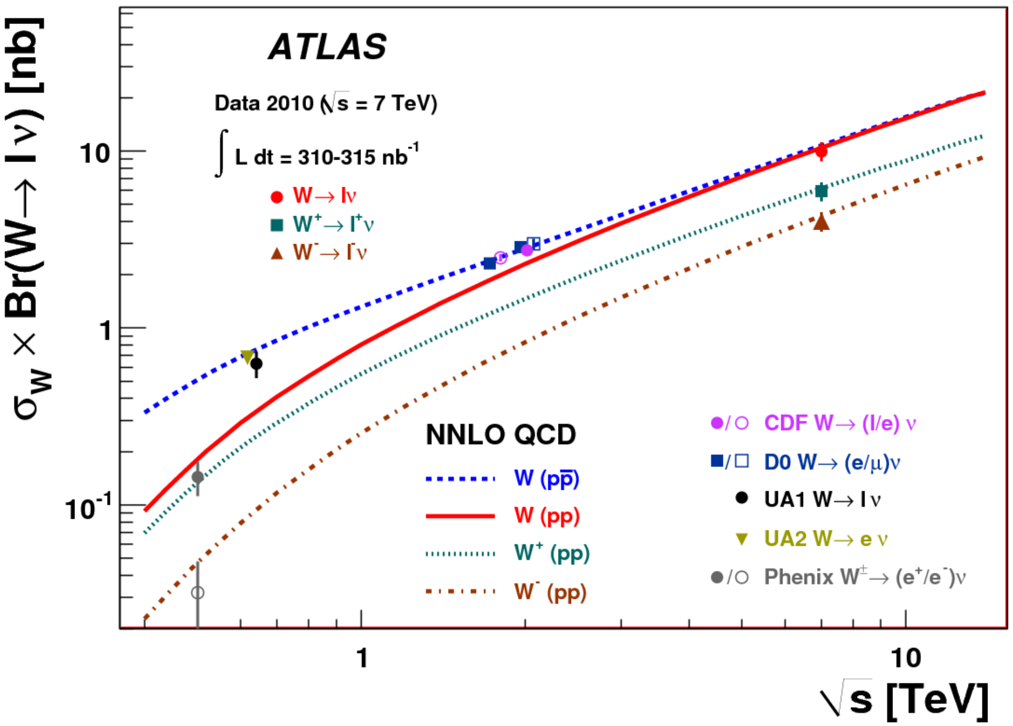
Derive a MET template for QCD bkg using a sample obtained by reversing some of the electron selction cuts

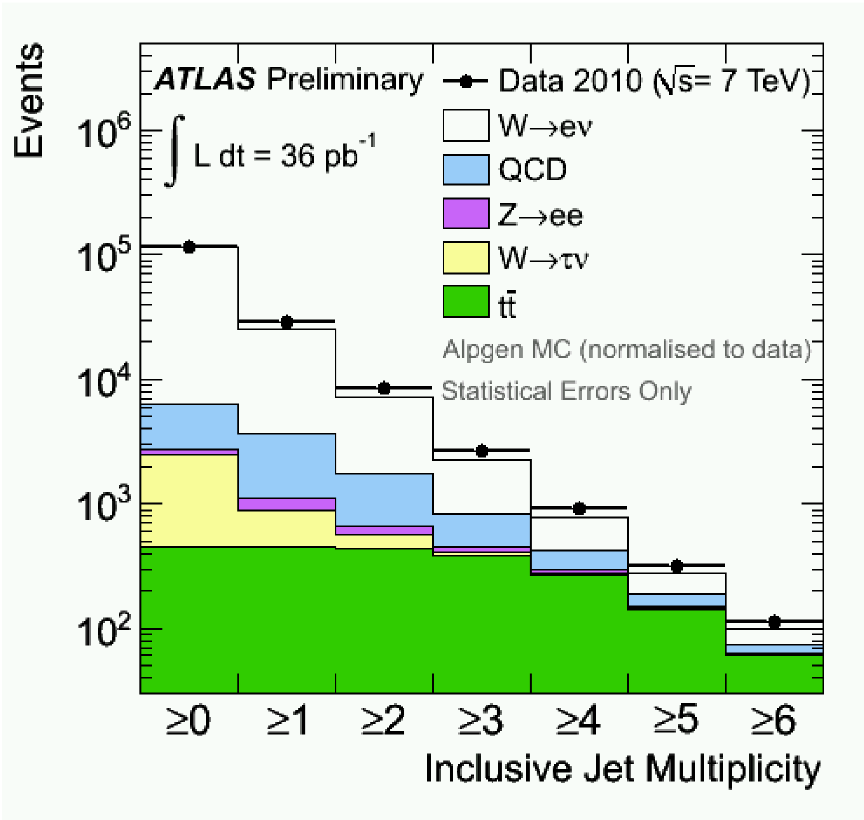
Transverse mass cut is applied here

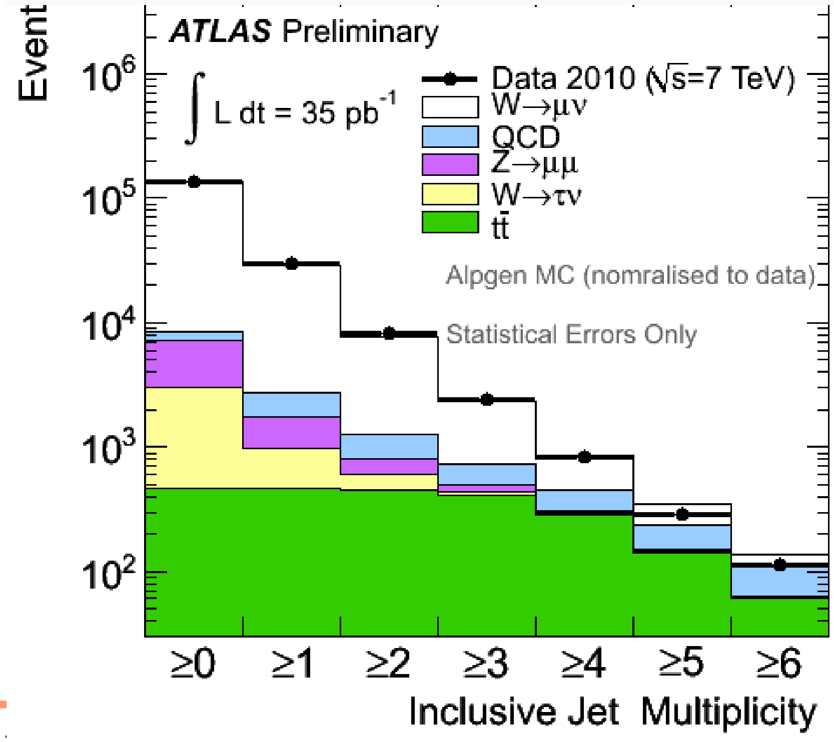
arXiv:1010.2130

W (+jets)

W cross section







ttbar cross section

Lepton+jets selection

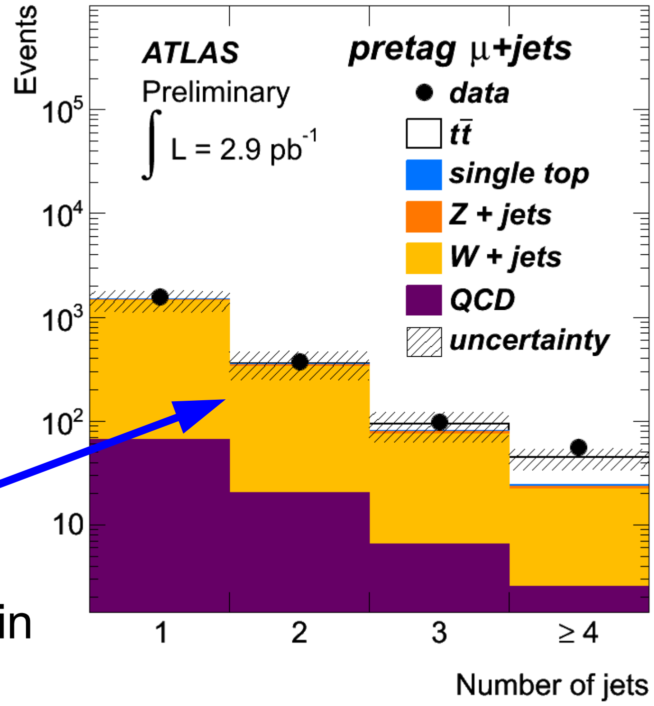
- Lepton trigger, pt > 10 GeV
- Exactly one offline lepton, pt > 20 GeV, matching to trigger object
- MET > 20 GeV, MET+MT > 60 GeV
- ≥ 1 jet with pt > 25 GeV and $|\eta| < 2.5$

Dilepton selection

- Exactly two (OS) leptons (ee,μμ,eμ), each with pt > 20 GeV
- ≥ 2 jets with pt > 25 GeV and $|\eta| < 2.5$
- MET > 40 GeV (ee), 30 GeV (μμ)
- Z mass veto for ee and μμ
- HT > 150 GeV (eμ channel)
- Cosmic ray veto

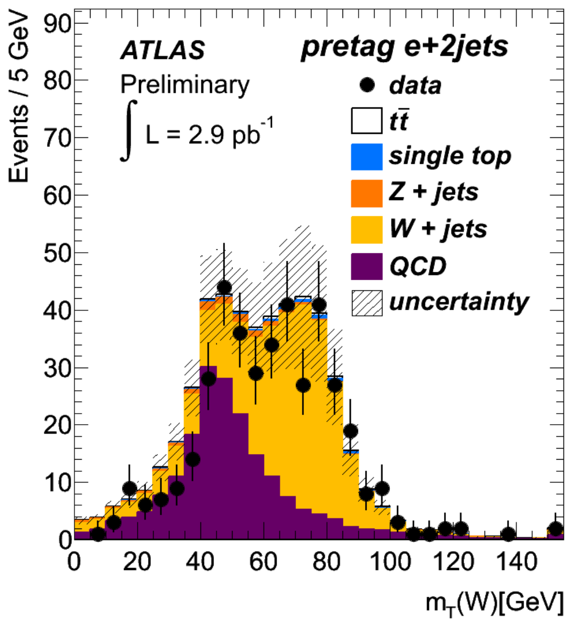
W +jets bkg (lepton+jets)

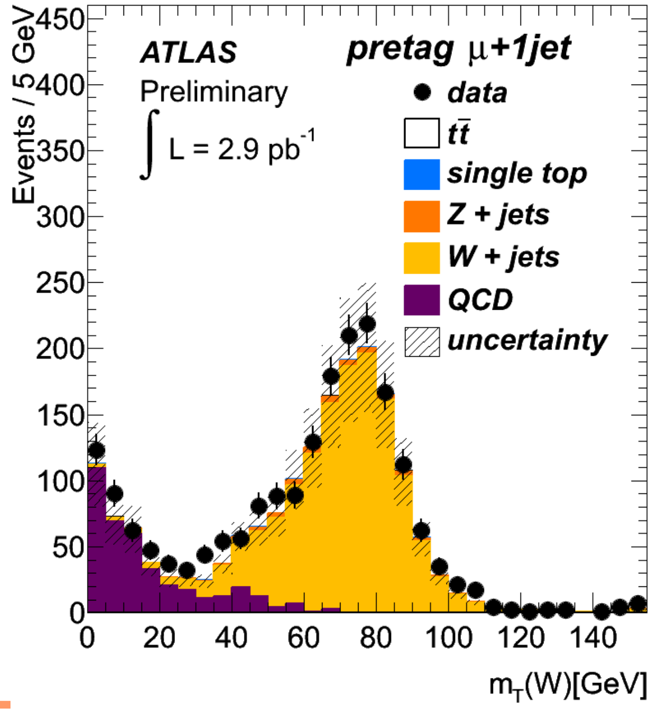
Estimated in the muon channel only because of better control of QCD bkg. Assume W+jets bkg is independent of μ vs e

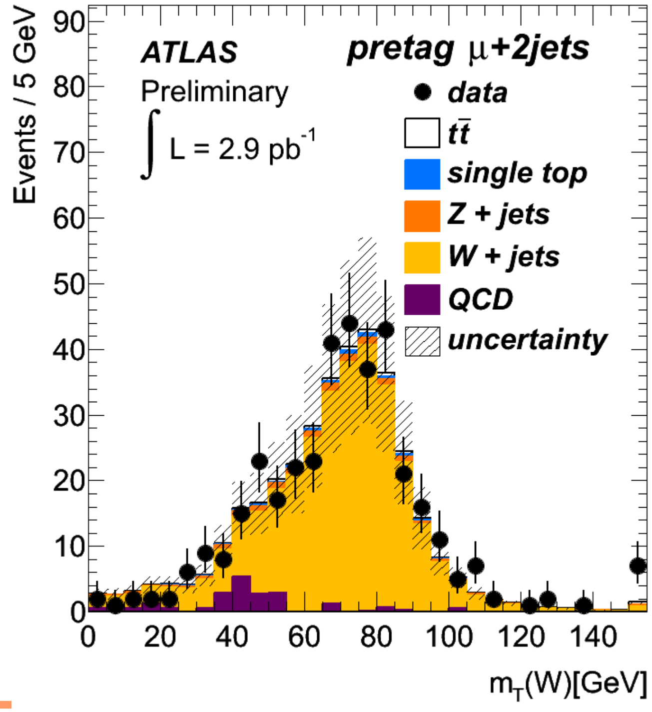


Exploit Berends scaling in the 2jet:1jet ratio

Extrapolate to the ≥ 4jet bin



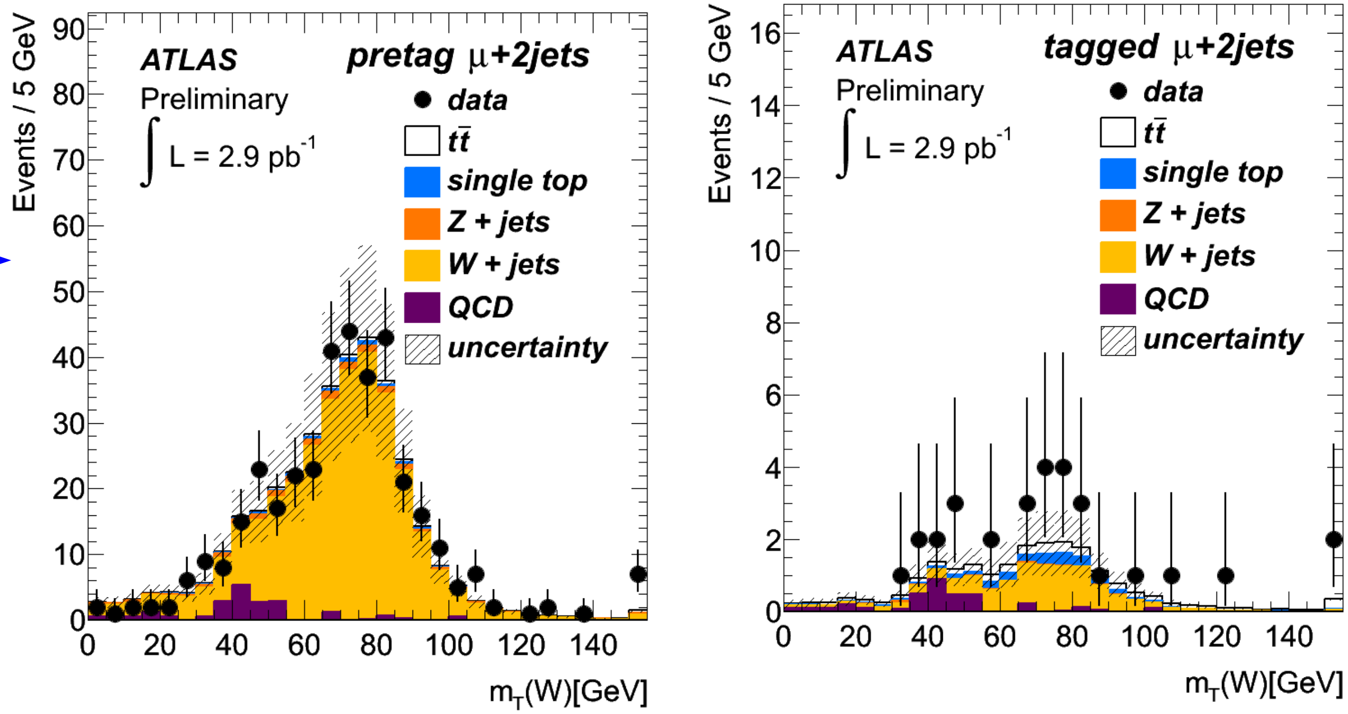




W +jets background (2)

Must correct $W^{\geq 4jet}_{pre\text{-}tag}$ for the fraction of events that are b-tagged

Measure the fraction in the 2-jet bin

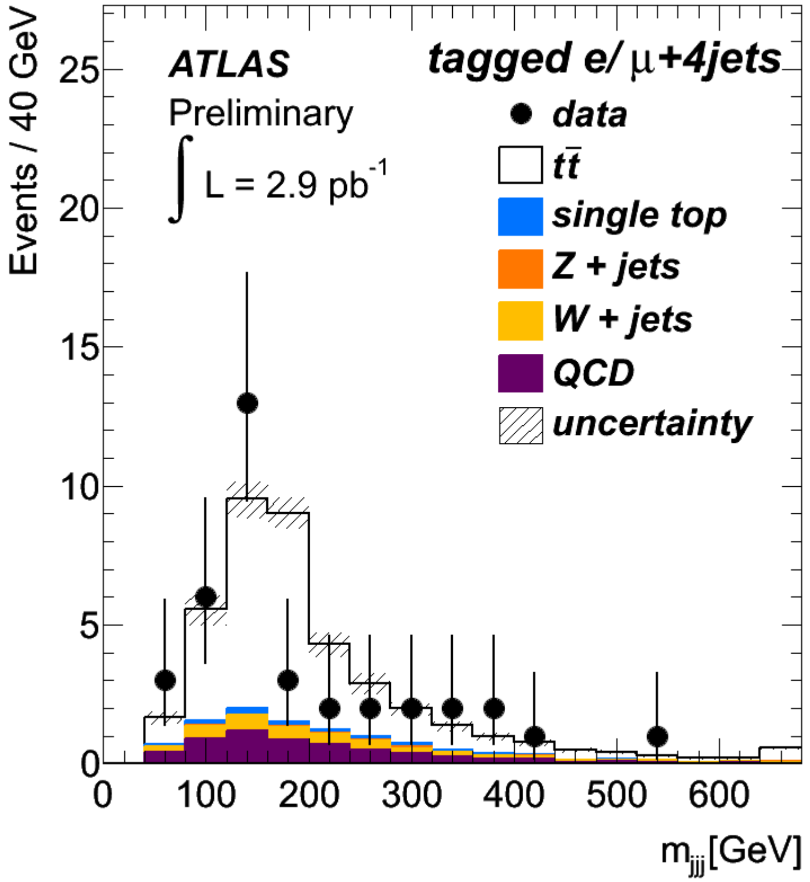


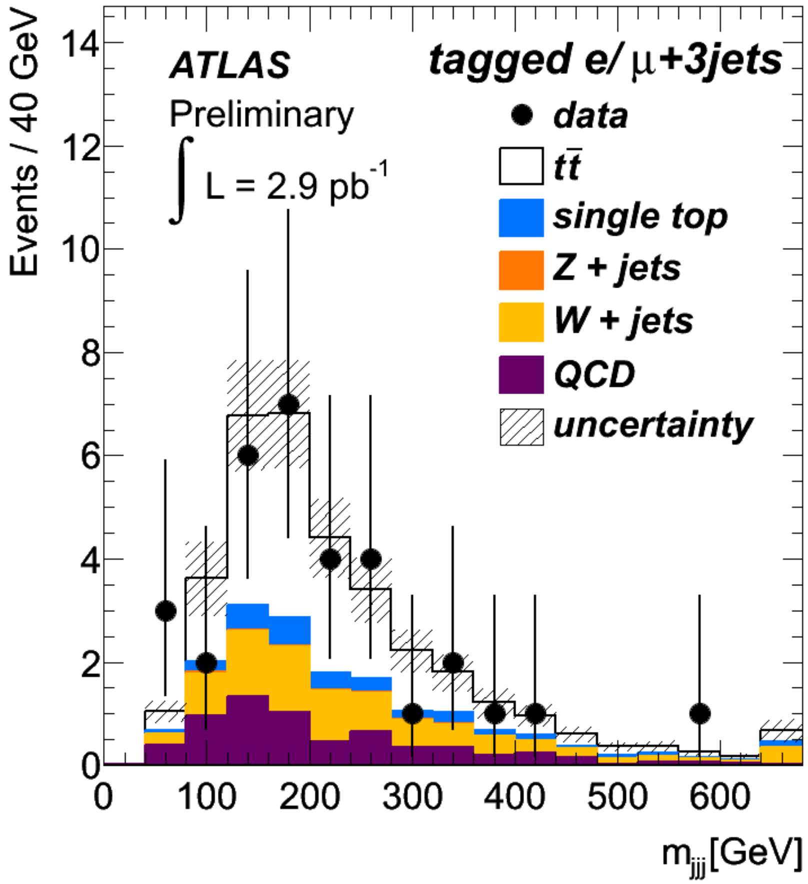
Correct the fraction for the difference in b-jet content as a function of jet multiplicity.

From ALPGEN: $f^{corr}_{2\to 4} = 2.8 \pm 0.8$ (sys)

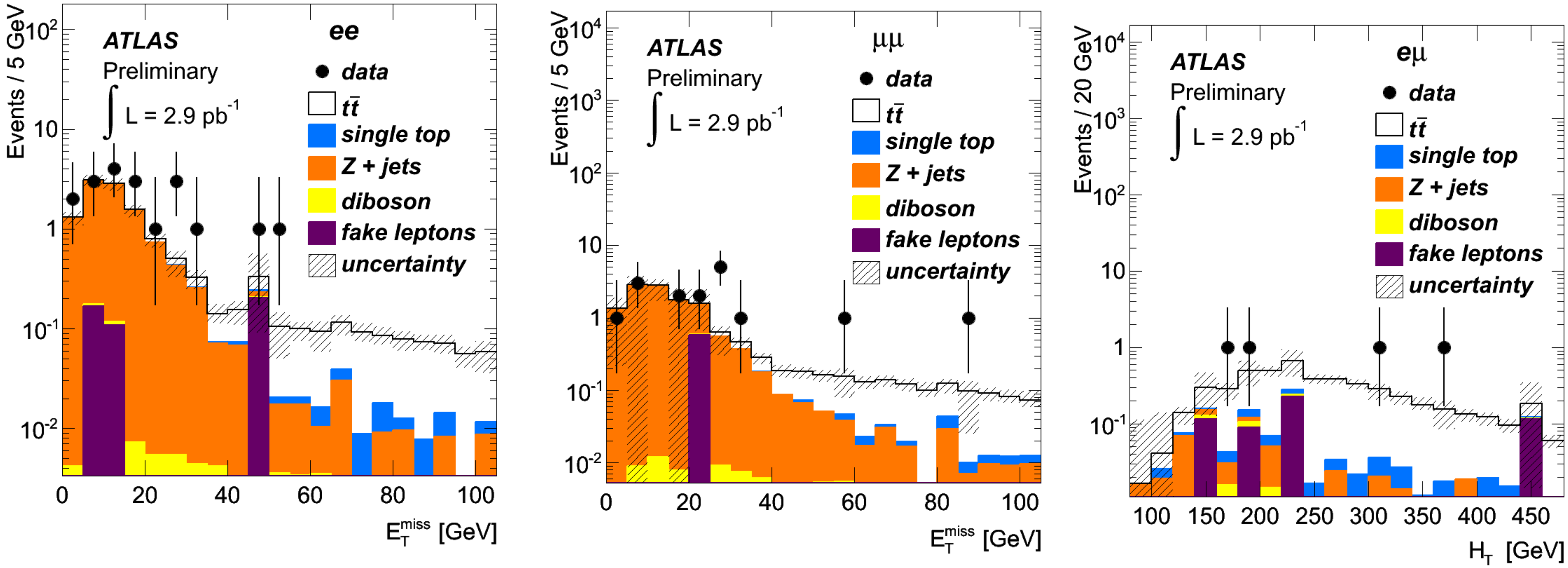
Main uncertainty from relative rates (in 2 and ≥4 jet bins) for W+bb+jets, W+cc+jets and W+c+jets

3-jet invariant mass

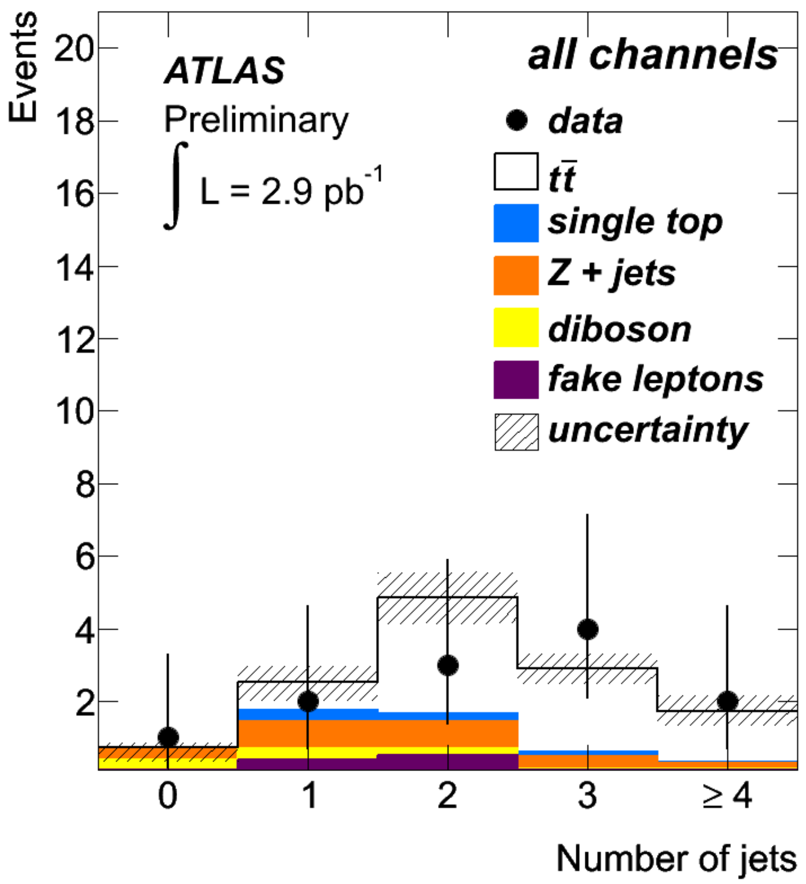


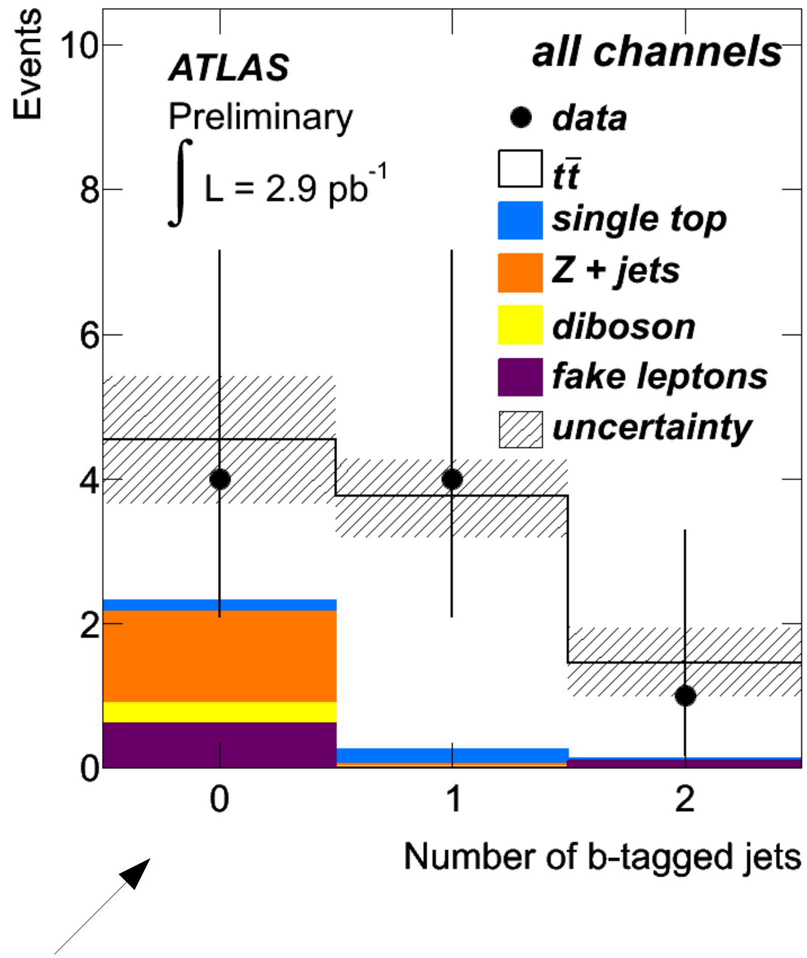


Dilepton channel



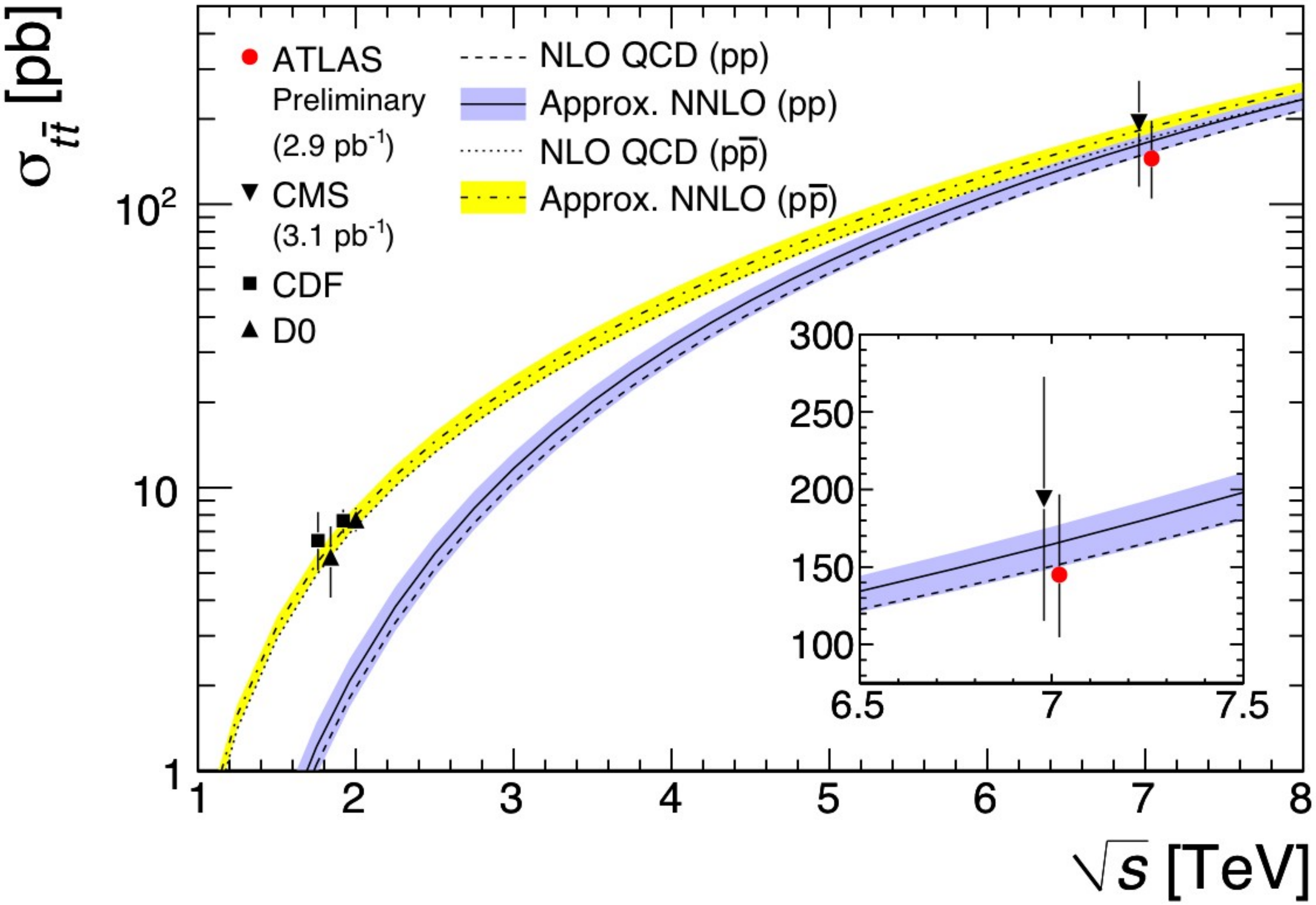
Jet multiplicity, dilepton channel





Crosscheck with btag

ttbar cross section



Theoretical predictions from HATHOR (arXiv:1007.1327)

$\sigma(pp \rightarrow \text{ttbar } X) = 145 \pm 31 \text{ (stat)} ^{+42}_{-27} \text{ (sys) pb}$

Jets+MET: signal regions used for the limits