RECENT RESULTS FROM NEW PHYSICS SEARCHES AT ATLAS

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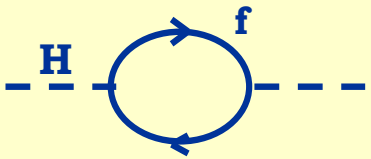
INFN Milano
On behalf of the ATLAS Collaboration

Physics At LHC
Perugia, 6-11 june 2011

WHY WE NEED NEW PHYSICS
(AND THINK WILL FIND SOME AT LHC)

Even if we find the Higgs, many questions unanswered by Standard Model

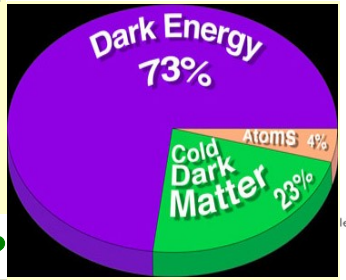


$\Delta m_H^2 \sim \Lambda^2$

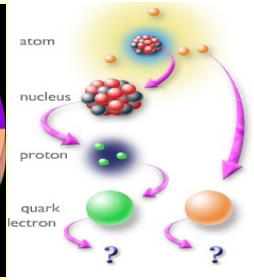
$\Lambda = M_{pl}$?

Stability of EW scale?

Dark Matter and Dark Energy?

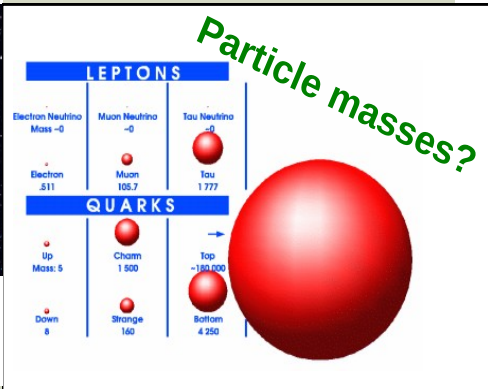


quark and leptons really elementary?

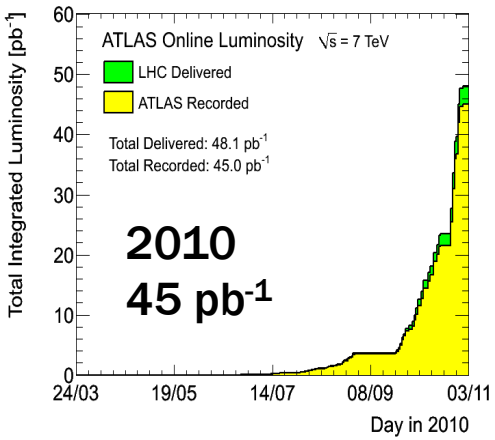


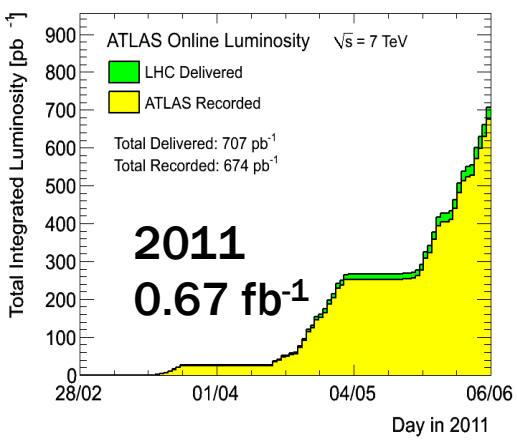
Matter/antimatter asymmetry ?

Particle masses?



Extensions of SM generally foresee new phenomena at TeV scale to tackle the hierarchy problem. If true, we should find them at LHC





The excellent performances of LHC allow us to probe new territory already

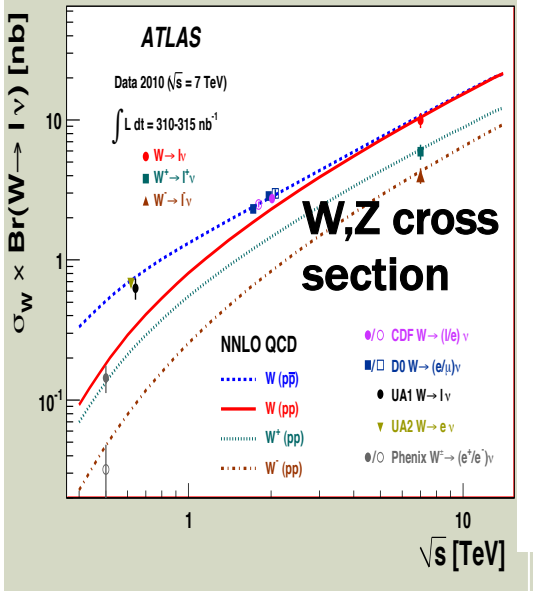
OUTLINE

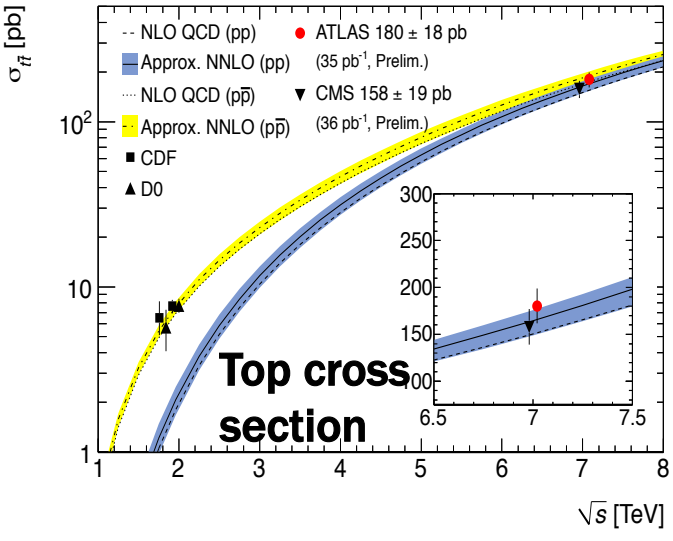
I can not possibly cover all searches for new phenomena in ATLAS in the time of my talk.. I will show some highlights

- Searches in etmiss+jets (sensitive to supersymmetry)
  - 0 lepton+jets+etmiss
  - 1 lepton+jets+etmiss
  - 2+ leptons+etmiss
  - b-jets+etmiss
- Searches for new long-lived particles
- Searches in other final states (possible new phenomena)
  - Searches in di-jet final state (excited quarks, contact interactions, …)
  - Searches for multi-jet final state (black hole production)
  - Searches for heavy di-lepton and lepton-neutrino resonances (Z', W')
  - Searches in lepton+jets final states (leptoquark)
- Other searches,summary, conclusions

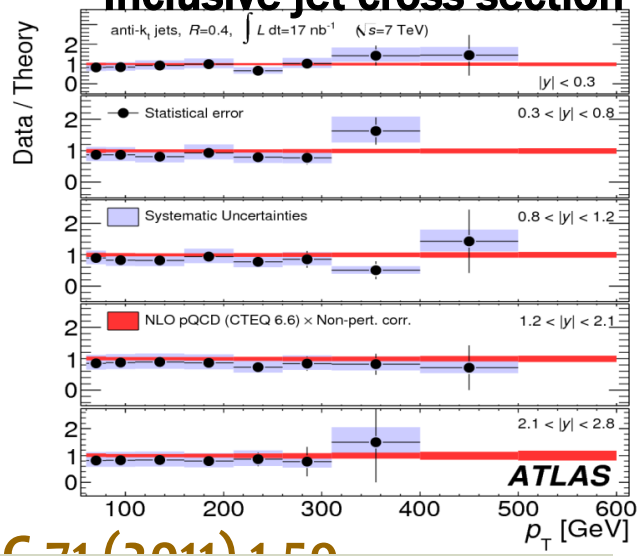
Results <2 weeks old will be marked with

STANDARD MODEL MEASUREMENTS

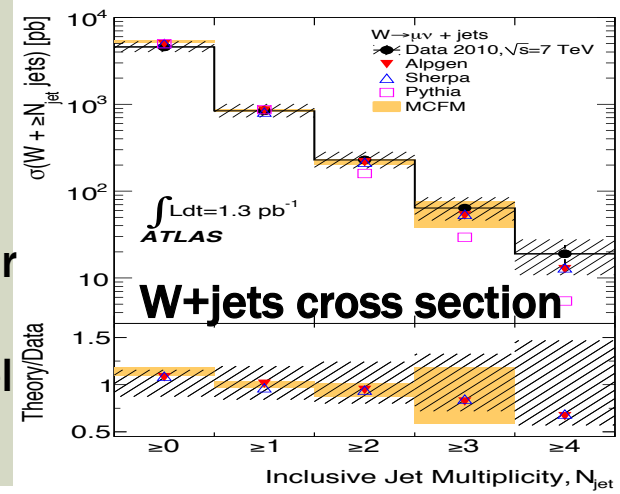


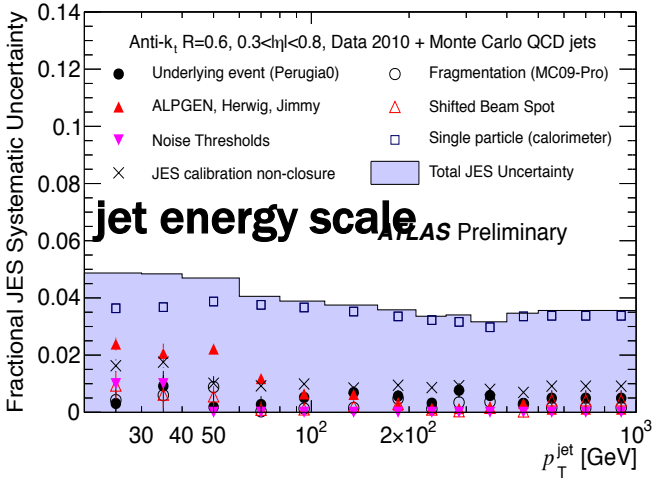


Inclusive jet cross section

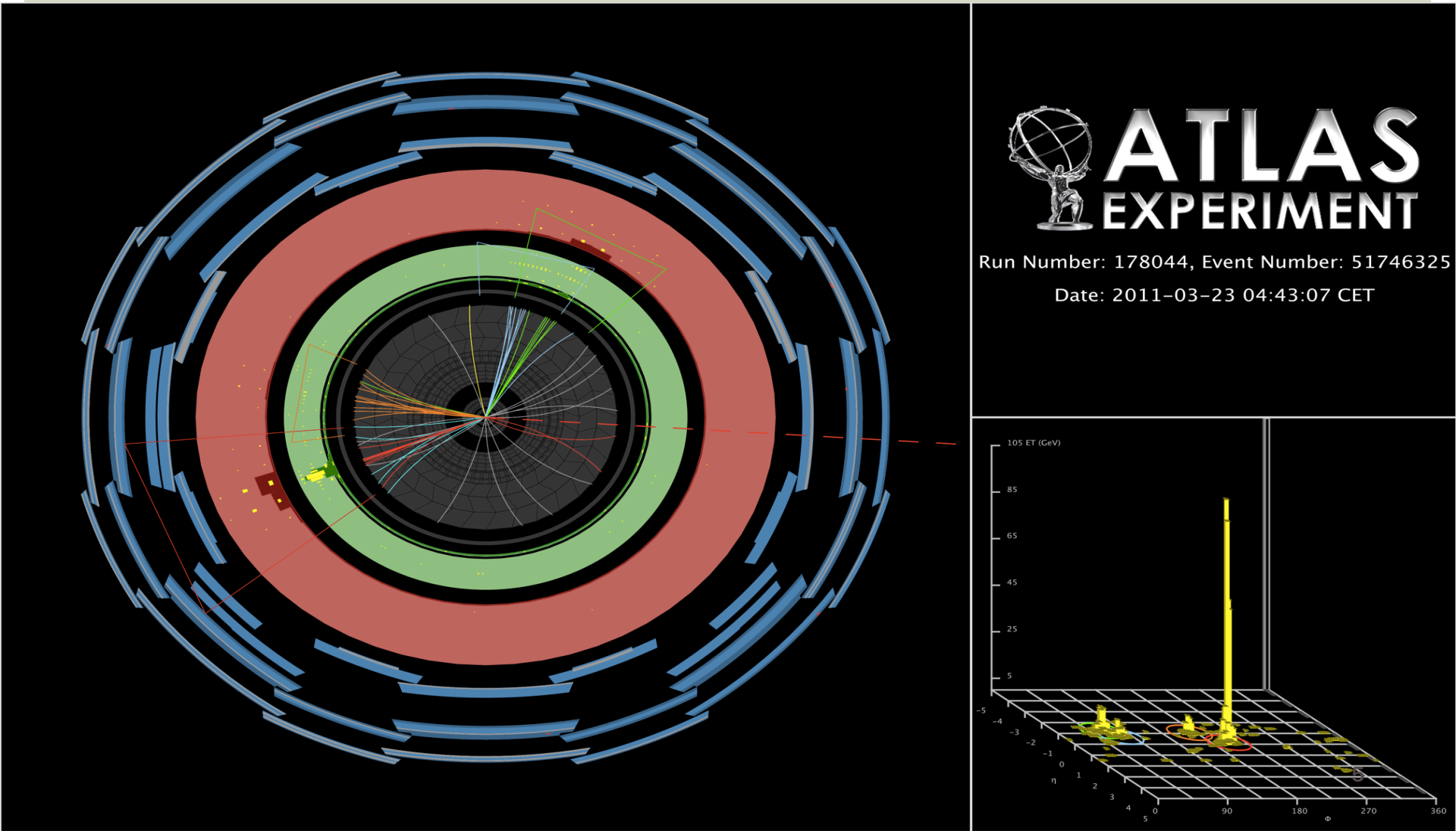


The new physics searches I will present are possible because of the excellent performance of our detector and the understanding we achieved of Standard Model processes



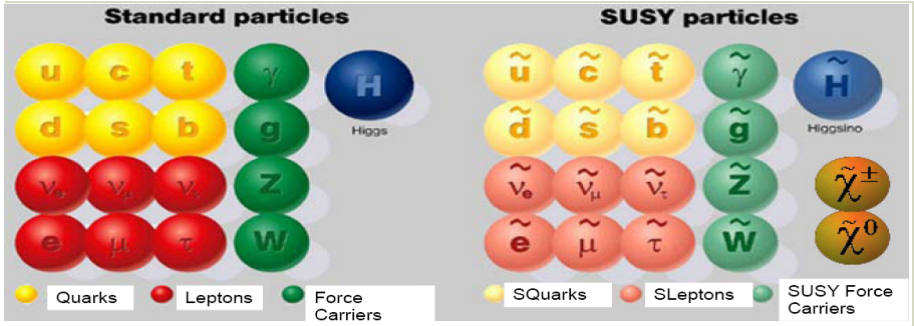


JETS+E_T^{MISS}+X SEARCHES FOR SUPERSYMMETRY



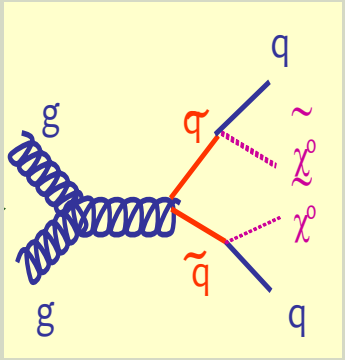
JETS+E_T^{MISS} AND NO LEPTONS

POSSIBLE SIGNAL: SUPERSYMMETRY

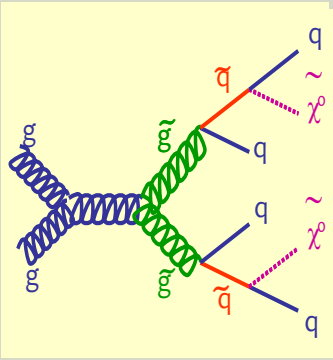


- **Jets+E_T^{Miss}: Targeting the pair production of scalar quarks and/or gluinos decaying into an undetected particle**
  - **In R-parity conserving SUSY models the lightest susy particle is stable, providing a good dark matter candidate**
- **Three signal regions giving good sensitivity to different scenarios**

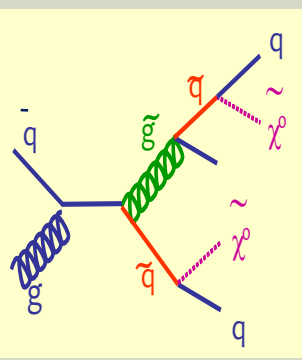
Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000



2 jets



4 jets



3 jets

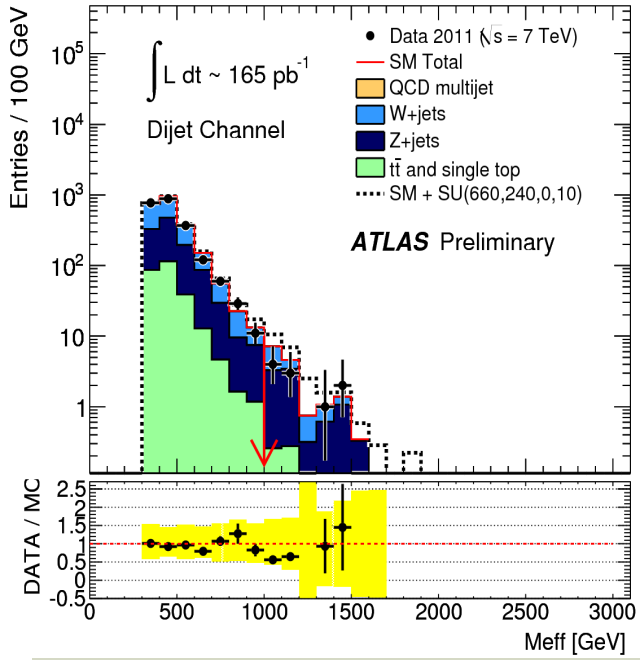
2010 data analysis: arXiv:1102.5290, accepted by PLB
Update with 165 pb^{-1}: ATL-CONF-2011-086

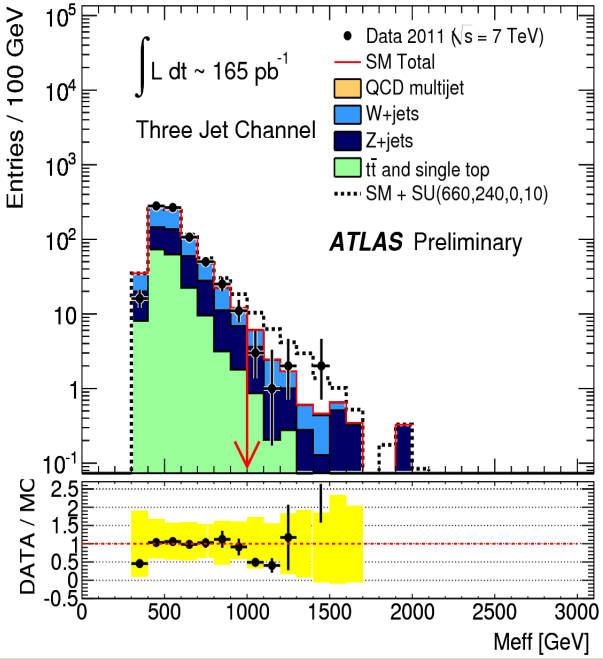
JETS+E_T^{MISS} AND NO LEPTONS

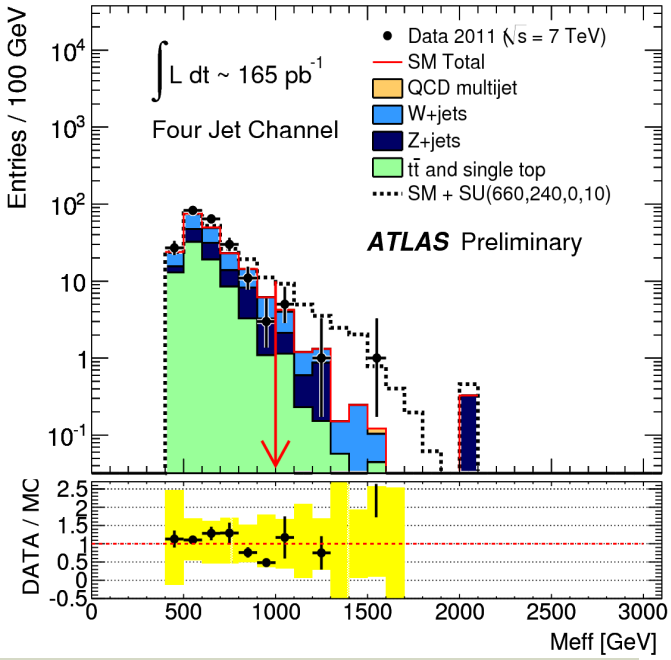
POSSIBLE SIGNAL: SUPERSYMMETRY

165 pb^{-1}

NEW







All distributions found to be consistent with background expectations

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
Total	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7

Cross section times acceptance limits (95% C.L.) for the three signal regions:

σAε < 35 fb (2-jet), 30 fb (3-jet), 35 fb (4-jet)

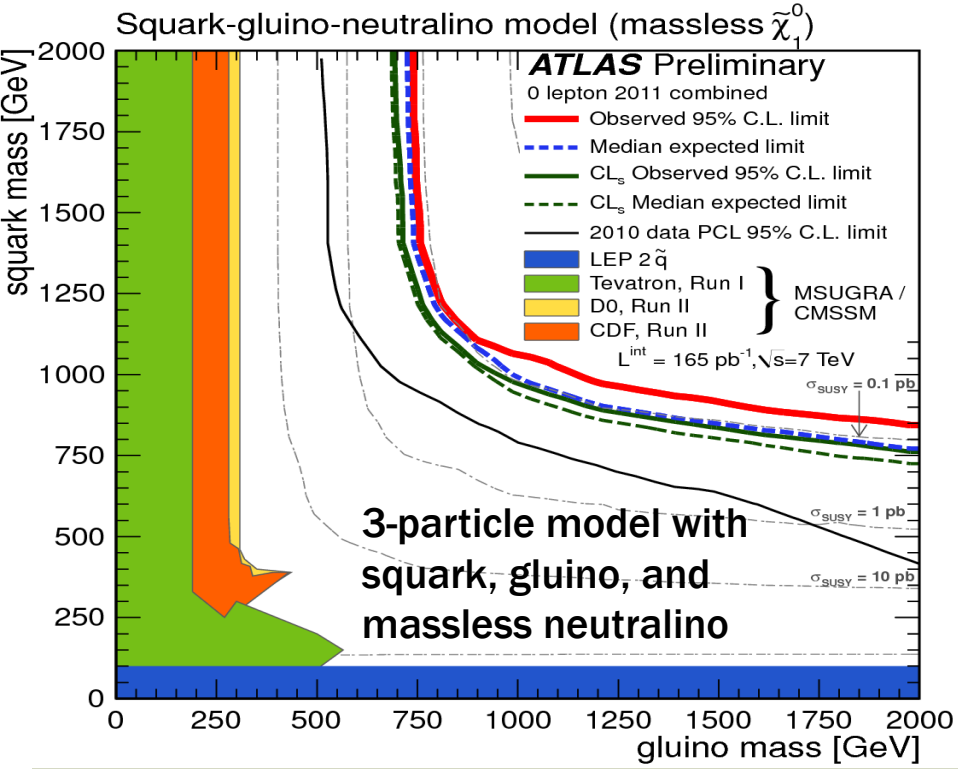
JETS+E_T^{MISS} AND NO LEPTONS

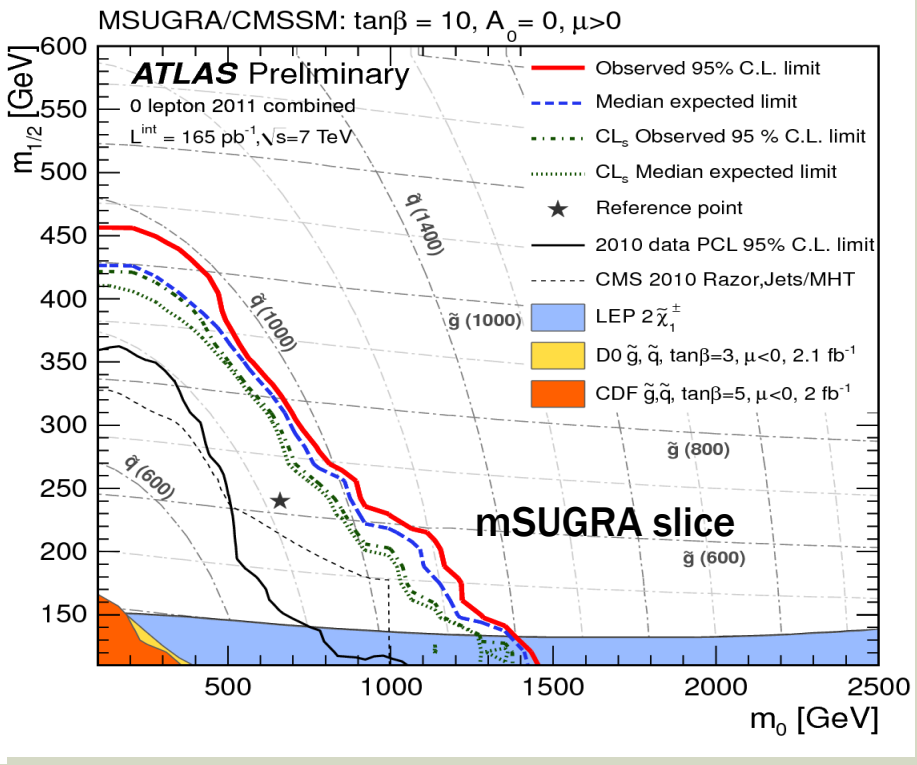
POSSIBLE SIGNAL: SUPERSYMMETRY

165 pb^{-1}

NEW

For exclusion plots, the SR with the best *expected* sensitivity is used





For equal-mass squark and gluino the limit is 950 GeV (mSUGRA slice) or 1025 GeV (simplified MSSM). Best limits to date!

See the talk of M. Rammensee in the parallel session for more details on this analysis

PRL 106, 131802 (2011)

JETS+E_T^{MISS} AND ONE LEPTON

POSSIBLE SIGNAL: SUPERSYMMETRY

- **Signal candidates:**

1 electron or muon with p_T>20 GeV

3 jets with p_T > 60,30,30 GeV

E_T^{MISS} > 125 GeV, E_T^{MISS} > 0.25 M_{eff}

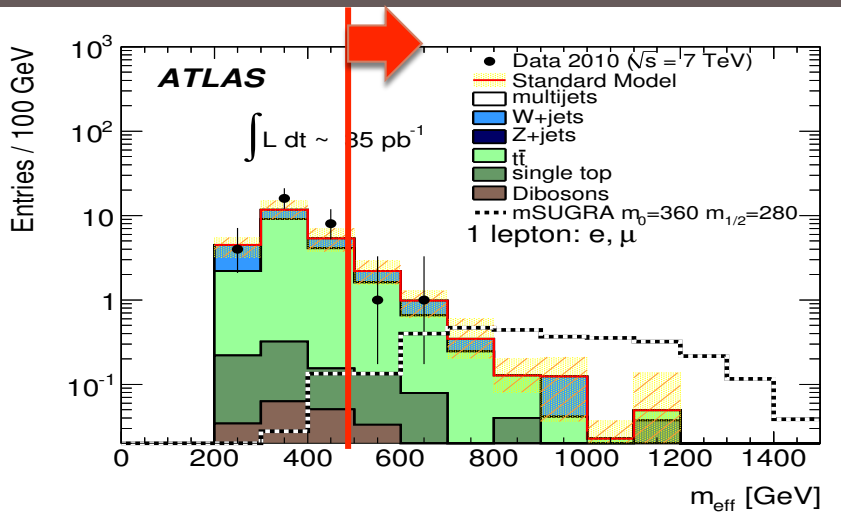
M_T(lep,E_T^{MISS}) > 100 GeV

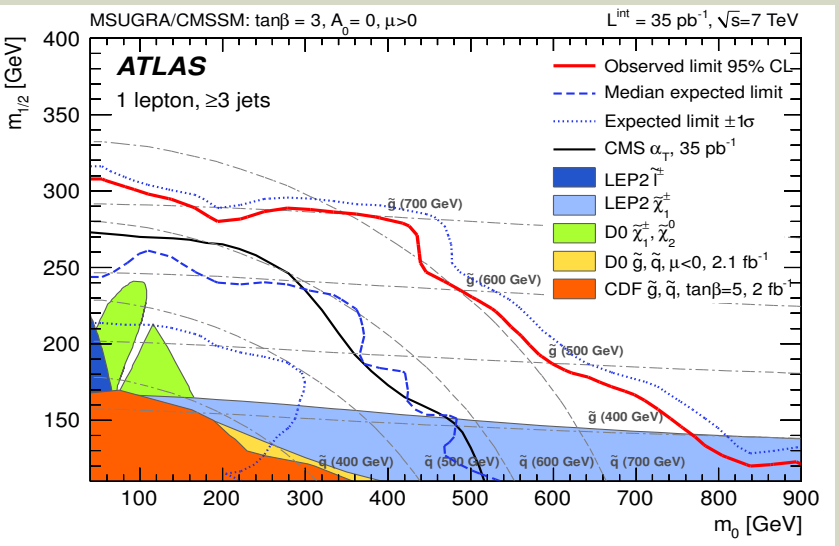
M_{eff} > 500 GeV

- **Constrain backgrounds with data observed in control regions with lower E_T^{MISS} and M_T. Several cross checks with alternative control regions.**

One electron and one muon event in signal selection, in agreement with background prediction

σAε < 65 fb (e-channel) and 73 fb (μ-channel)

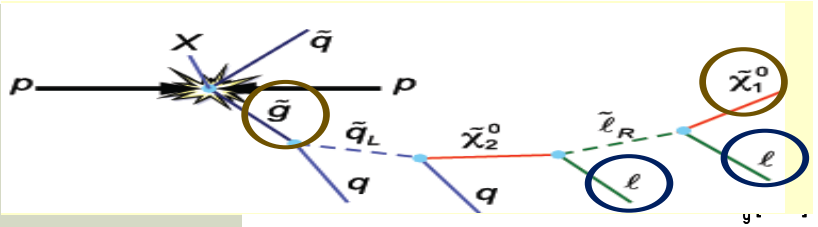


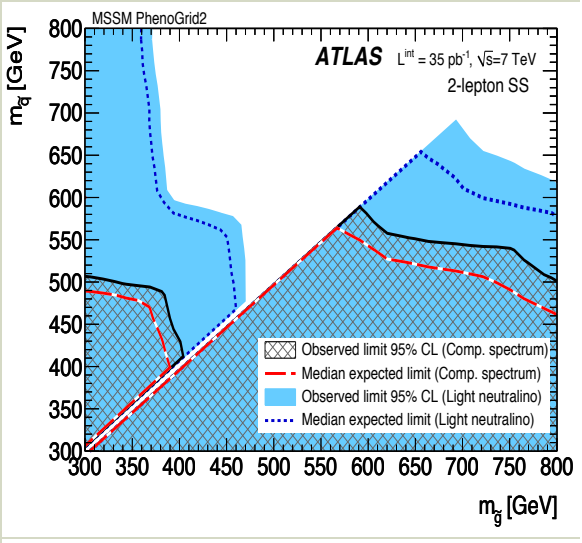


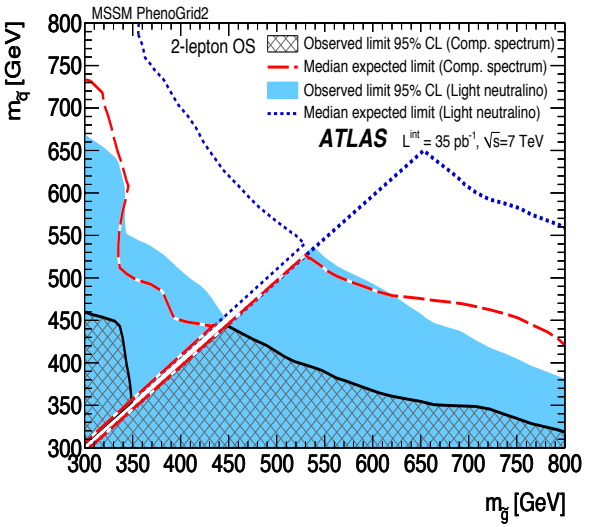
JETS+E_T^{MISS}+(≥2)LEPTONS
POSSIBLE SIGNAL: SUPERSYMMETRY

- Three channels:
  - 2 opposite sign leptons
  - 2 same sign leptons
  - ≥3 leptons
- Sensitive to models with high branching ratios into leptons in decay chain (depends on mass hierarchies in model)

Nine opposite sign, no same sign, no 3-lepton events in signal selections, all consistent with background.







Limits on squark and gluino masses if scalar lepton lighter than second neutralino (high BR in leptons)
Light neutralino: 100 GeV neutralino (light blue)
Compr. spectrum: ΔM = 50 GeV between lightest neutralino and colored particle (hashed)

arXiv:1103.6208, accepted by EPJ letters
arXiv:1103.6214, submitted to EPJ letters
ATL-CONF-2011-064

arXiv:1103.4344, submitted to PLB

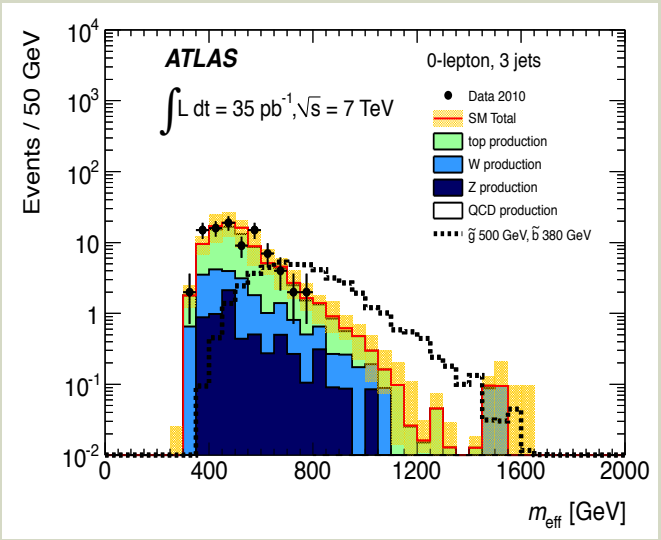
B-JETS+E_T^{MISS}

POSSIBLE SIGNAL: SUPERSYMMETRY

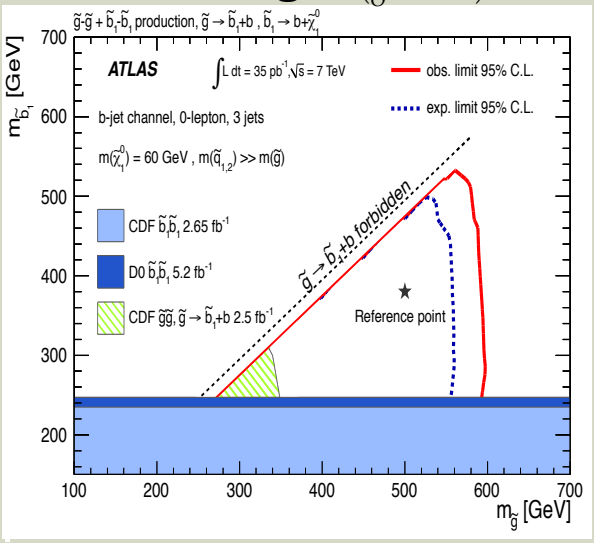
- Look for production of scalar top and bottom pairs, either directly or in from gluino decay

$$pp \to \tilde{g}\tilde{g} \to t\tilde{t}t\tilde{t} \to bWb\tilde{\chi}_1^{\pm}bWb\tilde{\chi}_1^{\pm} \qquad pp \to \tilde{g}\tilde{g} \to b\tilde{b}b\tilde{b} \to bb\tilde{\chi}_1^0 bb\tilde{\chi}_1^0$$

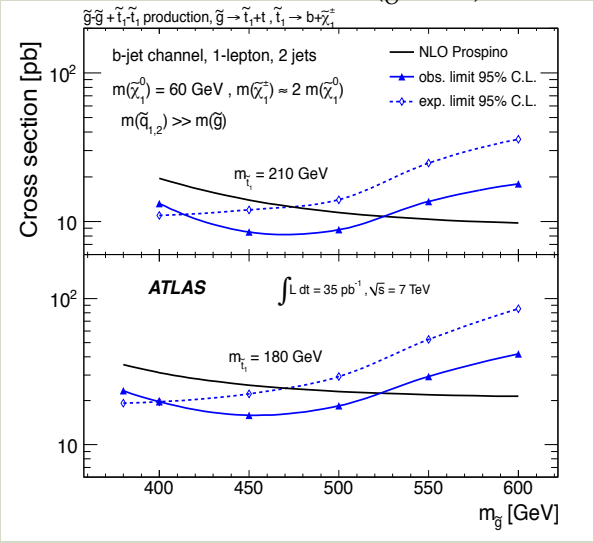
Assuming $BR(\tilde{g} \to \tilde{b}b) = 100\%$ **Assuming** $BR(\tilde{g} \to \tilde{t}t) = 100\%$



No significant excess seen..



M(gluino) > 590 GeV if sbottom lighter than gluino



M(gluino) > 520 GeV if stop mass in 160-240 GeV range

SEARCHES FOR SLOW PARTICLES DETECTED BY MUON SPECTROMETER

NEW

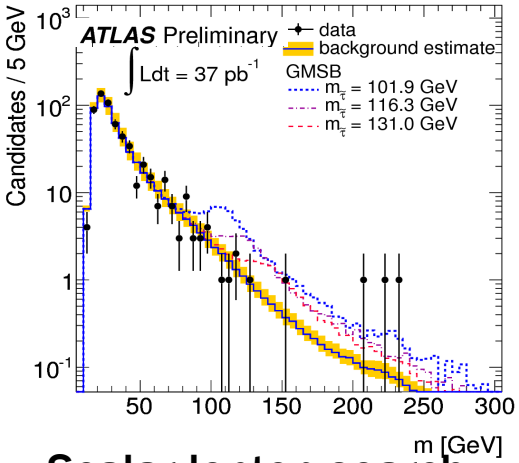
New long lived particles predicted by various models.

Signature: speed $\beta = v/c < 1$. Mass can be reconstructed from measured β and momentum.

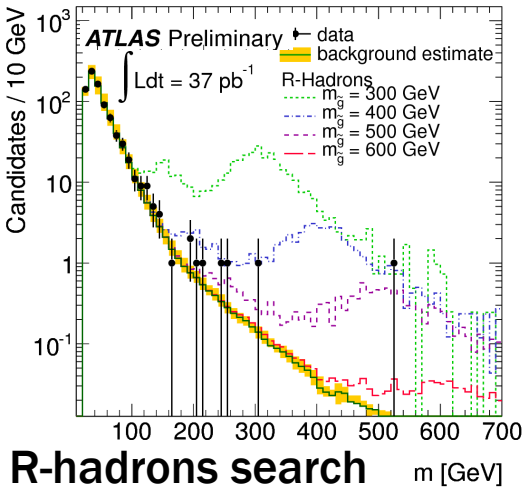
Two searches were performed for particles detected by the muon spectrometer, using timing measurements in the muon system and hadron calorimeters:

- Long lived scalar leptons
- Long lived gluinos. These hadronize (R-hadrons).

See the talk of S. Owen in the parallel session for more details on this analysis



Scalar lepton search



R-hadrons search

particle	Mass limit
Scalar lepton, GMSB	136 GeV
Scalar lepton (direct prod.)	110 GeV
gluino	530-544 GeV

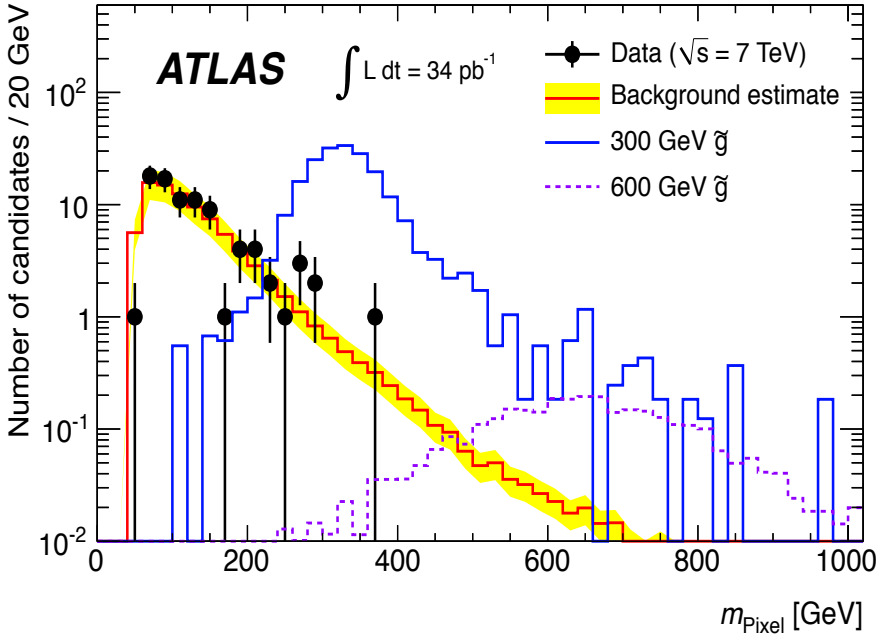
arXiv:1103.1984, accepted by PLB

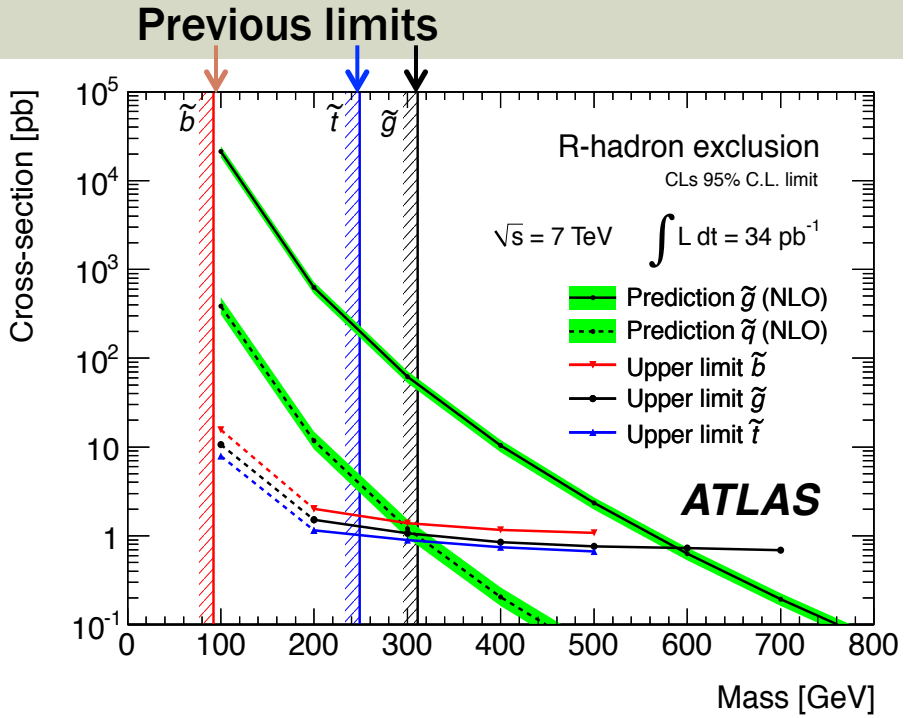
SEARCHES FOR SLOW PARTICLES MUON-AGNOSTIC

An other search for R-hadrons does not use the muon spectrometer

Sensitive also to R-hadrons which becomes neutral when interacting in the calorimeter

Uses dE/dx in pixel and timing from hadron calorimeter to measure β





Limits on masses of long-lived scalar bottom (294 GeV), scalar top (309 GeV) gluino (562-584 GeV), all of them the best to date

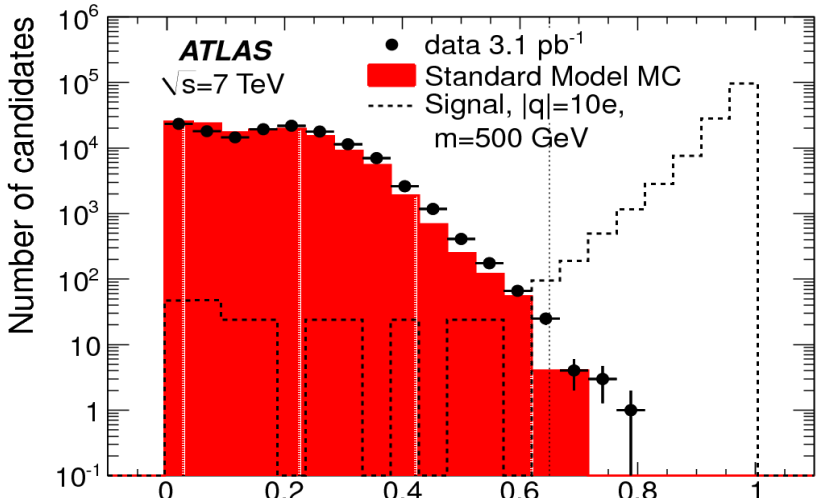
arXiv:1102.0459v3, Phys. Lett. B698, 353

HEAVILY IONIZING PARTICLE SEARCHES

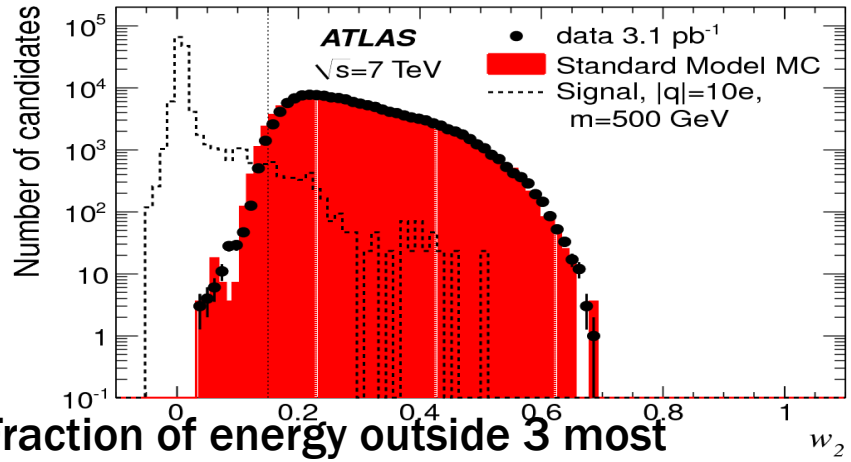
- Look for long lived particles with charge >> e
  - Q-balls, stable micro black-holes, …
- Signature high ionization in tracker, narrow deposit in calorimeter
- Sensitivity to 6e < q < 17e, m<1000 GeV, lifetime > 100 ns

m[GeV]	|q|=6e	|q|=10e	|q|=17e
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3

Limits on production cross section (pb)

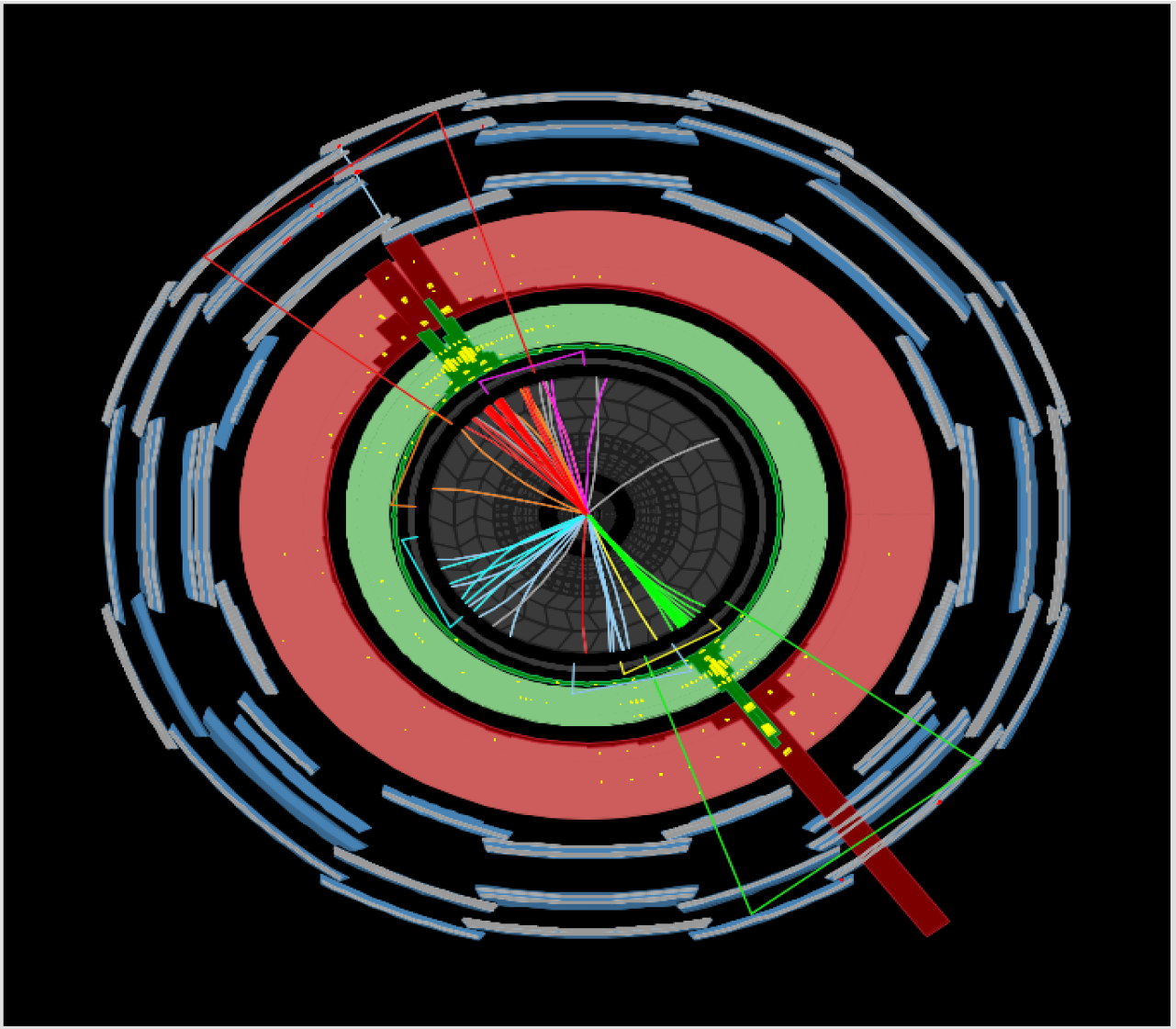


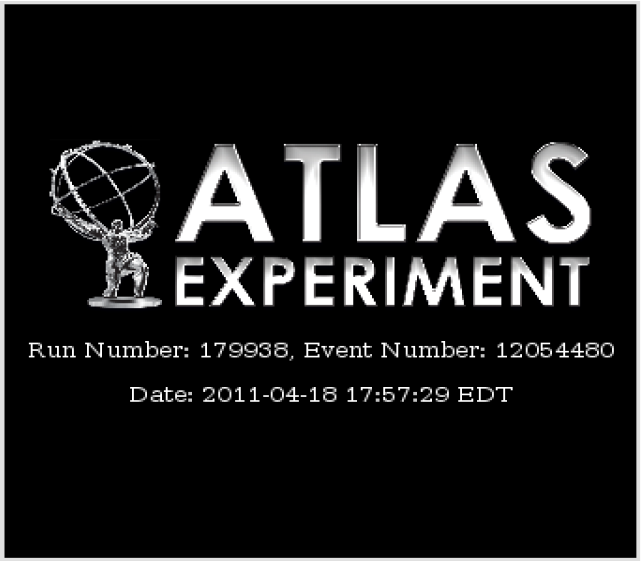
Fraction high-ionization hits in transition radiation tracker

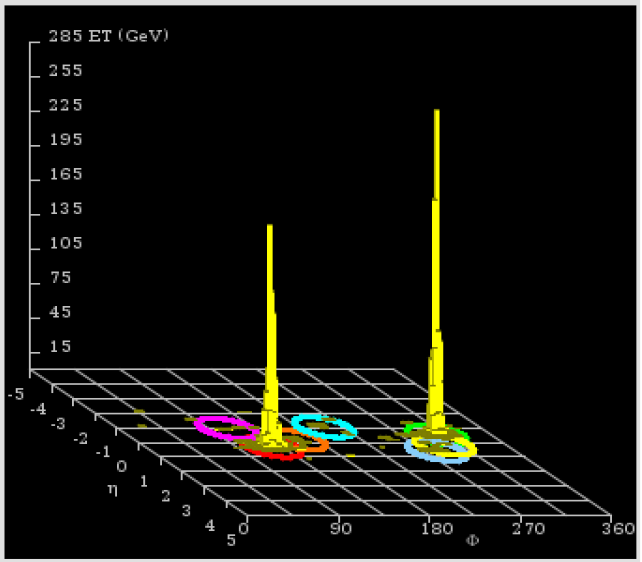


Fraction of energy outside 3 most energetic cells in 2nd layer of EM calorimeter

SEARCHES IN JET FINAL STATES







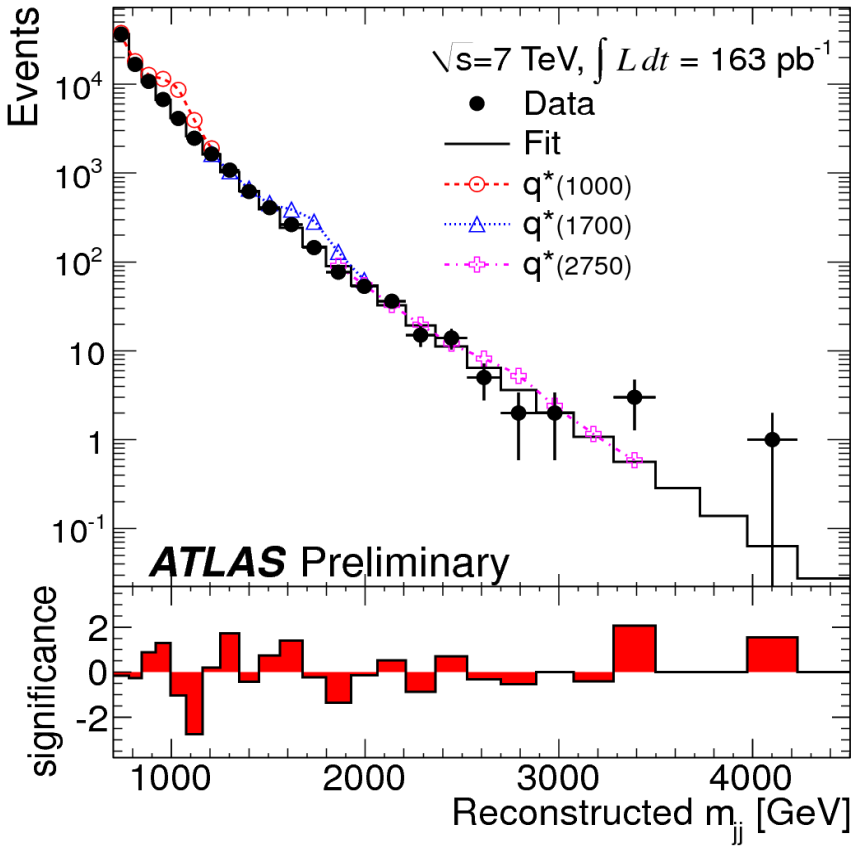
DIJET RESONANCE SEARCH

163 pb^{-1}

NEW

- Look for a peak in di-jet invariant mass
- No evidence found…

Best limits to date!



95% C.L. Limits observed (expected)
Excited quarks (q*): M > 2.49 (2.40) TeV
Axigluons: M > 2.67 (2.48) TeV

See the talk of R. M. Buckingham in the parallel session for more details on di-jet analysis

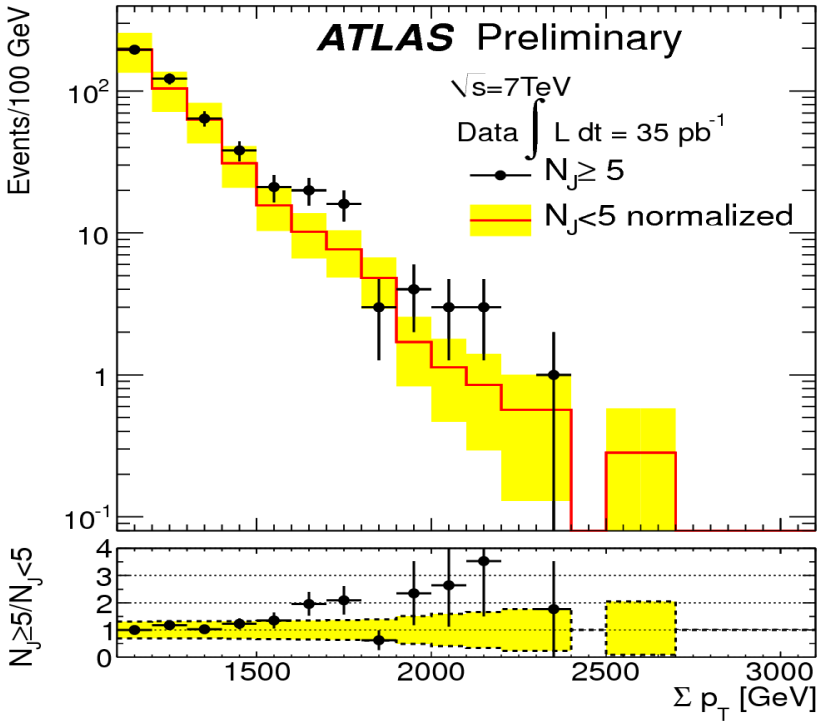
Published 2010 analysis:
arXiv:1103.3864, New J.Phys. 13 (2011) 053044
2011 update: ATL-CONF-2011-081

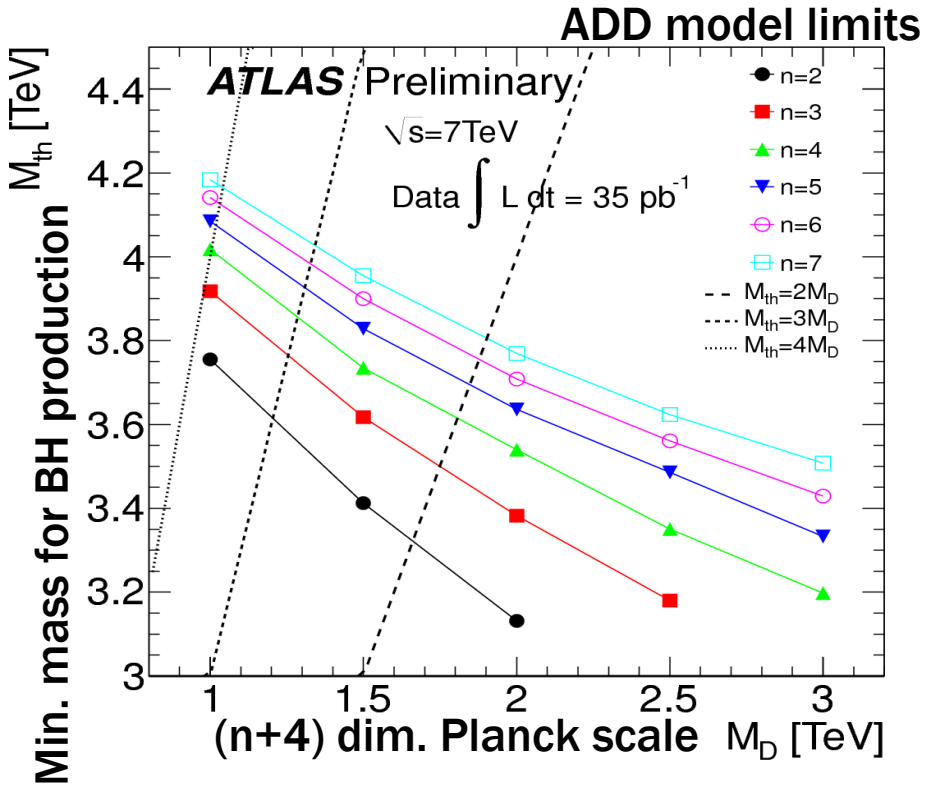
ATL-CONF-2011-068

MULTI-JET SEARCH

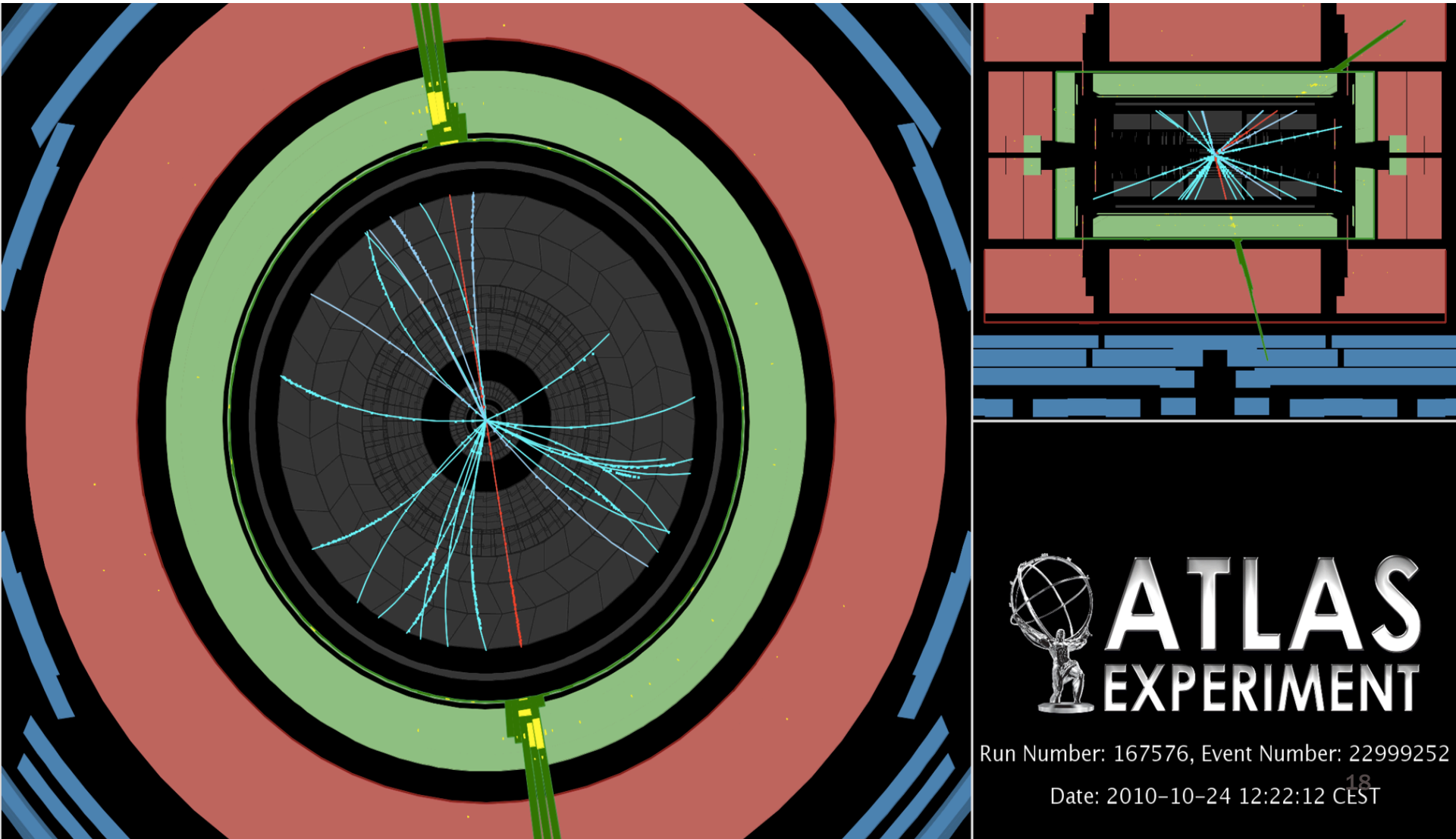
POSSIBLE SIGNAL: BLACK HOLES!

- Expect multi-jet events with high multiplicity and ΣpT from black hole production in models with extra dimensions
- Background Σp_T shape invariant with jet multiplicity – measured in data for Njet < 5 (jets with p_T > 50 GeV, η< 2.8 considered)





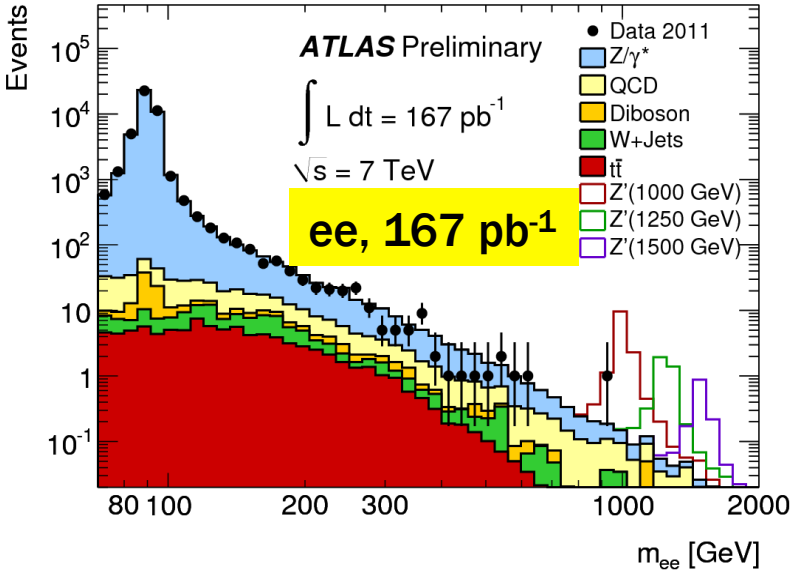
SEARCHES IN LEPTON FINAL STATES

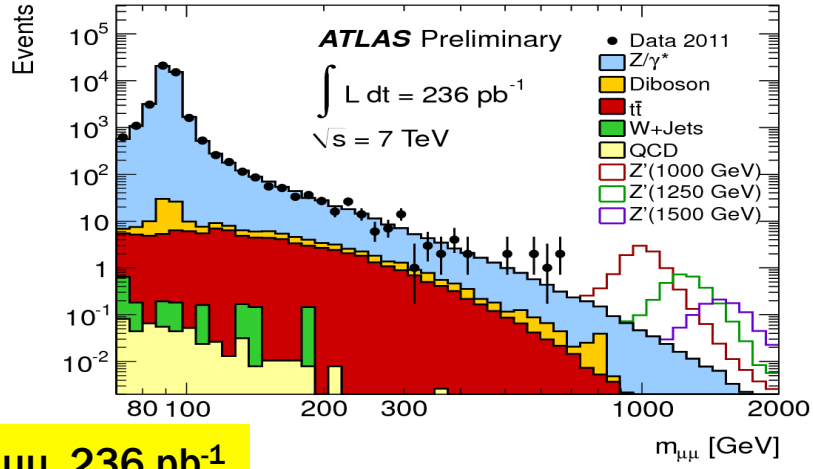


DI-LEPTON HIGH MASS PAIRS

POSSIBLE SIGNAL: Z-LIKE HEAVY BOSONS

NEW





Distributions consistent with DY spectrum.

Limits on new gauge bosons (best to date)

SSM Z': 1.407 TeV

E6 model Z': 1.116-1.259 TeV

$$\mathcal{L} = \frac{g^2}{2\Lambda^2}\,\eta_{LL}\;\;\overline{\psi}_L\gamma_\mu\psi_L\,\overline{\psi}_L\gamma^\mu\psi_L$$

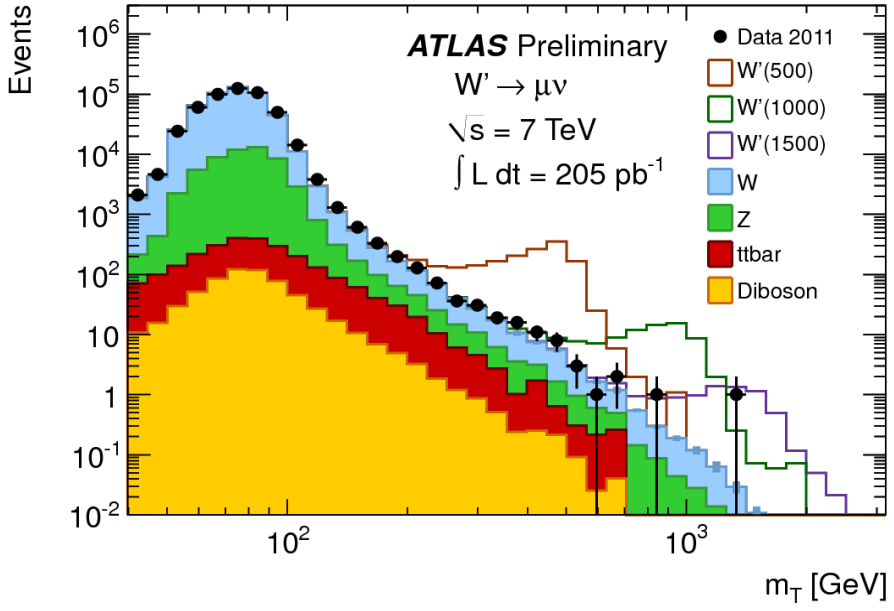
Published analysis with 2010 data:
arXiv:1103.6218, accepted by PLB
arXiv:1104.4398, accepted by PRD
2011 update: ATL-CONF-2011-083

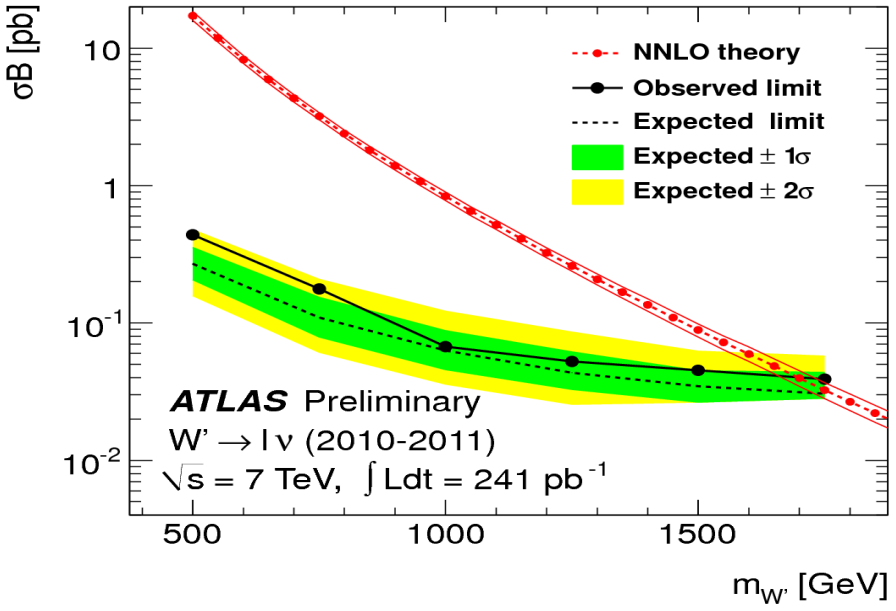
LEPTON-NEUTRINO RESONANCE

POSSIBLE SIGNAL: W-LIKE HEAVY BOSONS

205 pb^{-1}

NEW





Signal would appear at high values of transverse mass. None found, limit on SSM W': from combination of 2010 (e+μ) and 2011 (μ):

M > 1.70 TeV 95% C.L.

Published analysis of 2010 data:
arXiv:1103.1391, accepted by PLB
2011 update:ATL-CONF-2011-082

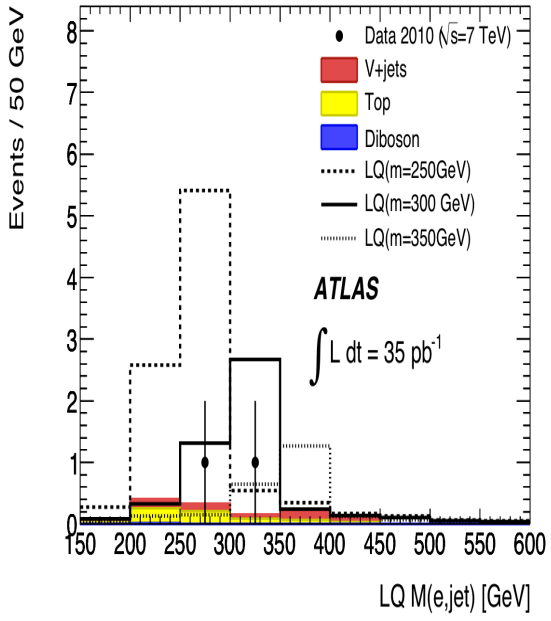
See the talk of D. J. Olivito in the parallel sessions for more details on W', Z' searches

arXiv:1104.4481, accepted by PRD

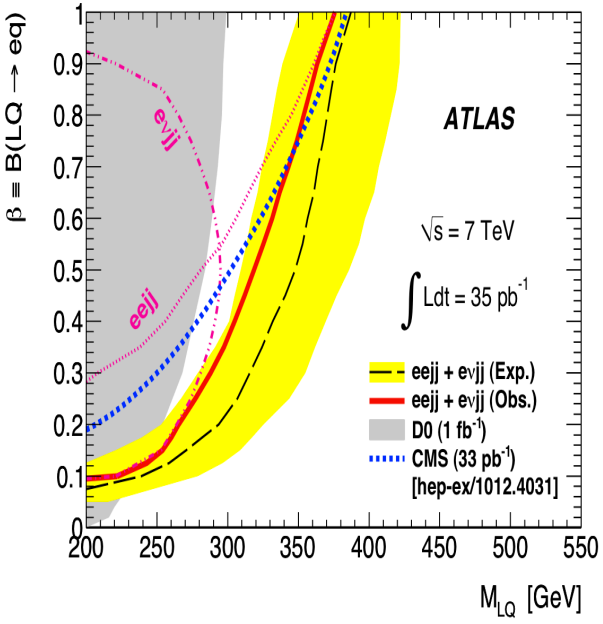
LEPTON+JETS RESONANCES

POSSIBLE SIGNAL: LEPTOQUARKS

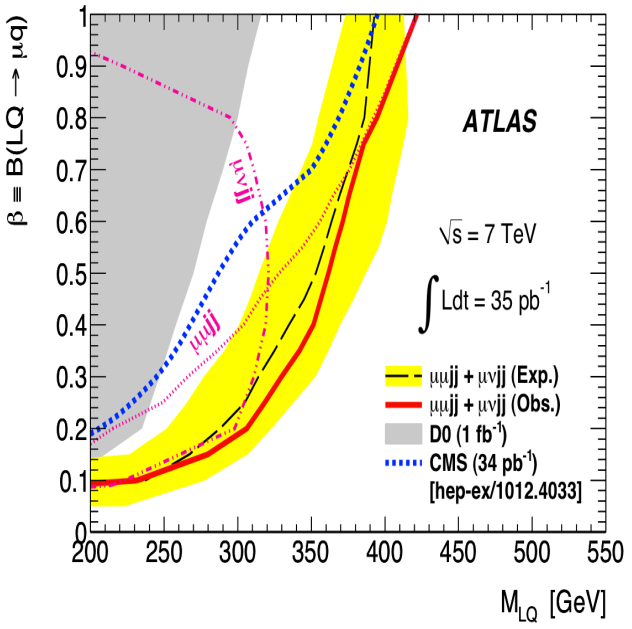
- Look for pair production of particles possessing both lepton and baryon quantum numbers
- Consider **2 lepton + 2 jets** and **lepton+ 2 jets + E_T^{Miss}** final states



ejej final state: average (e,j) inv.mass



1st generation limits



2nd generation limits (**best to date**)

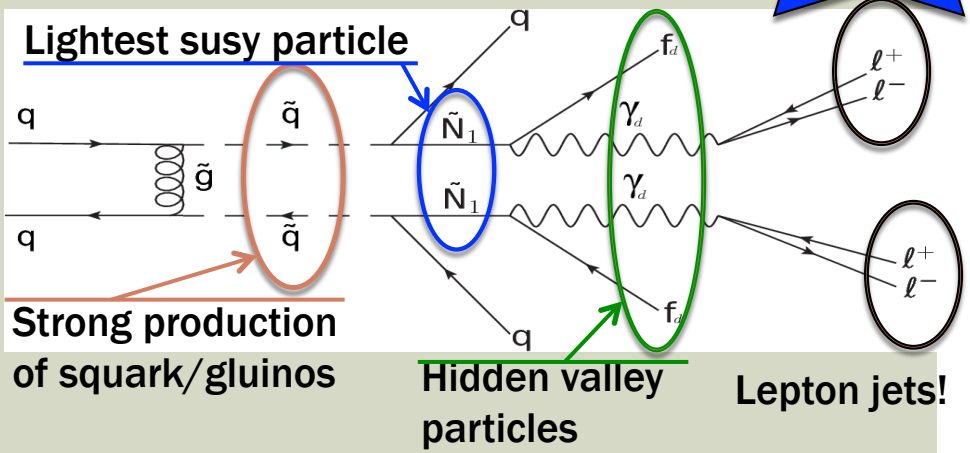
ATL-CONF-2011-076

SEARCH FOR LEPTON JETS

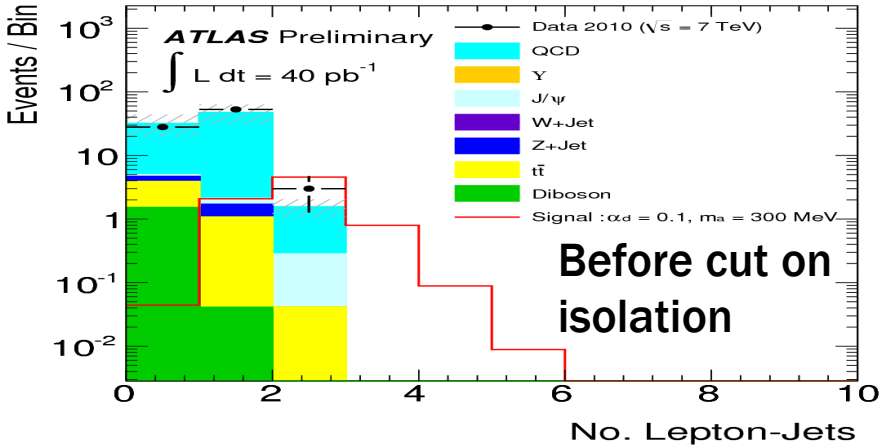
POSSIBLE SIGNAL: SUSY PLUS HIDDEN VALLEY SECTOR

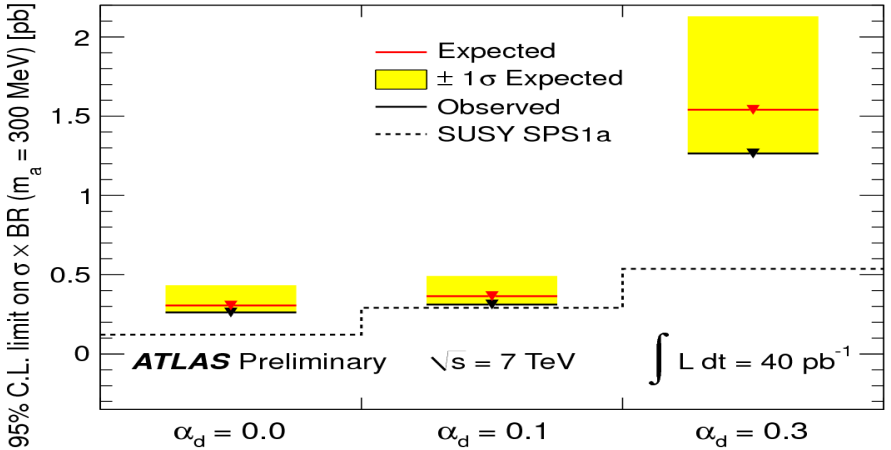
NEW

- Looking for light boosted bosons decaying in muons. Example: dark photons from SUSY decays produce dark photons.
- Looking for two isolated "lepton jets", with ≥2 muons each
- Estimated background 0.20 ± 0.19. 0 events observed



	≥ 2 muon	≥ 4 muons	≥ 4 muons w/ ≥ 3 HQ	2 LJets	2 Isolated LJets
data	174450	246	84	3	0
all bkg	200000 ± 15000	200 ± 50	81 ± 20	1.74 ± 0.48	0.20 ± 0.19





OTHER SEARCHES NOT COVERED IN THIS TALK

- A search for high-mass phenomena producing top quarks with the ATLAS experiment ATLAS-CONF-2011-010
- A search for ttbar resonances in the lepton plus jets channel in 200 pb^{-1} of pp collisions at sqrt(s)=7 TeV ATLAS-CONF-2011-087

See the talk of D. Cinca in the parallel sessions for the ttbar resonance search

- Search for Diphoton events with large missing transverse energy in 7 TeV proton-proton collisions with the ATLAS detector, arXiv:1012.4272v2, PRL 106 (2011) 121803

See the talk of S. Owen in the parallel sessions for γγ+MET with 35 pb^{-1}

- A search for Randall-Sundrum gravitons decaying to photon pairs in 7 TeV pp collisions, ATLAS-CONF-2011-044
- Search for strong gravity effects in same-sign dimuon final states, ATLAS-CONF-2011-065
- Search for 4^{th} generation quarks decaying to WqWq ➔ lvqlvq in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector, ATLAS-CONF-2011-022

See also the talks of M.Escalier and Y.Zhu for Higgs searches (not covered in this talk)

ATLAS public results for exotic and supersymmetry searches can be found in
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

SUMMARY OF MASS LIMITS

Several table entries: to be updated if approved

channel	particle	Limits [TeV]
jet+MET+X	mSUGRA g, q	0.950* if m(g)=m(q)
bjets+MET	gluino	0.590* if m(b)<m(g)
Long lived particles	gluino	0.562-0.584*
	stop	0.309*
	sbottom	0.294*
	slepton	0.110-0.136
di-jets	Excited quarks	2.49*
	axigluons	2.67*
di-leptons	SSM Z'	1.407
	E6 Z'	1.116-1.259
Lep+MET	SSM W'	1.70

channel	Model/particles	Limits [TeV]
Lep+jets +MET	1^{st} gen. LQ(β=1)	0.376
	2^{nd} gen. LQ(β=1)	0.422*
γγ+MET	UED(1/R)	0.961
	Gluino (GGM)	0.560
γγ	RS graviton	0.920 (k/M_{Pl}=0.1)
lqvlqv	4^{th} gen. u	0.270

* World's best limit

2010 data already allowed us to set better limits than Tevatron/LEP searches In most channels

50-100 times more data expected by the end of 2011!

CONCLUSIONS

- Results of searches for new phenomena with 2010 and first 2011 ATLAS data have been presented
- New physics was not found "just behind the corner" of previous searches
  - All distributions found consistent with SM expectations
  - Previous limits considerably improved
- We keep looking for new phenomena, taking advantage of the excellent performances of LHC (and of our detector)
  - 2011 luminosity expected to be 50-100 times larger than 2010: we will explore again far beyond current limits

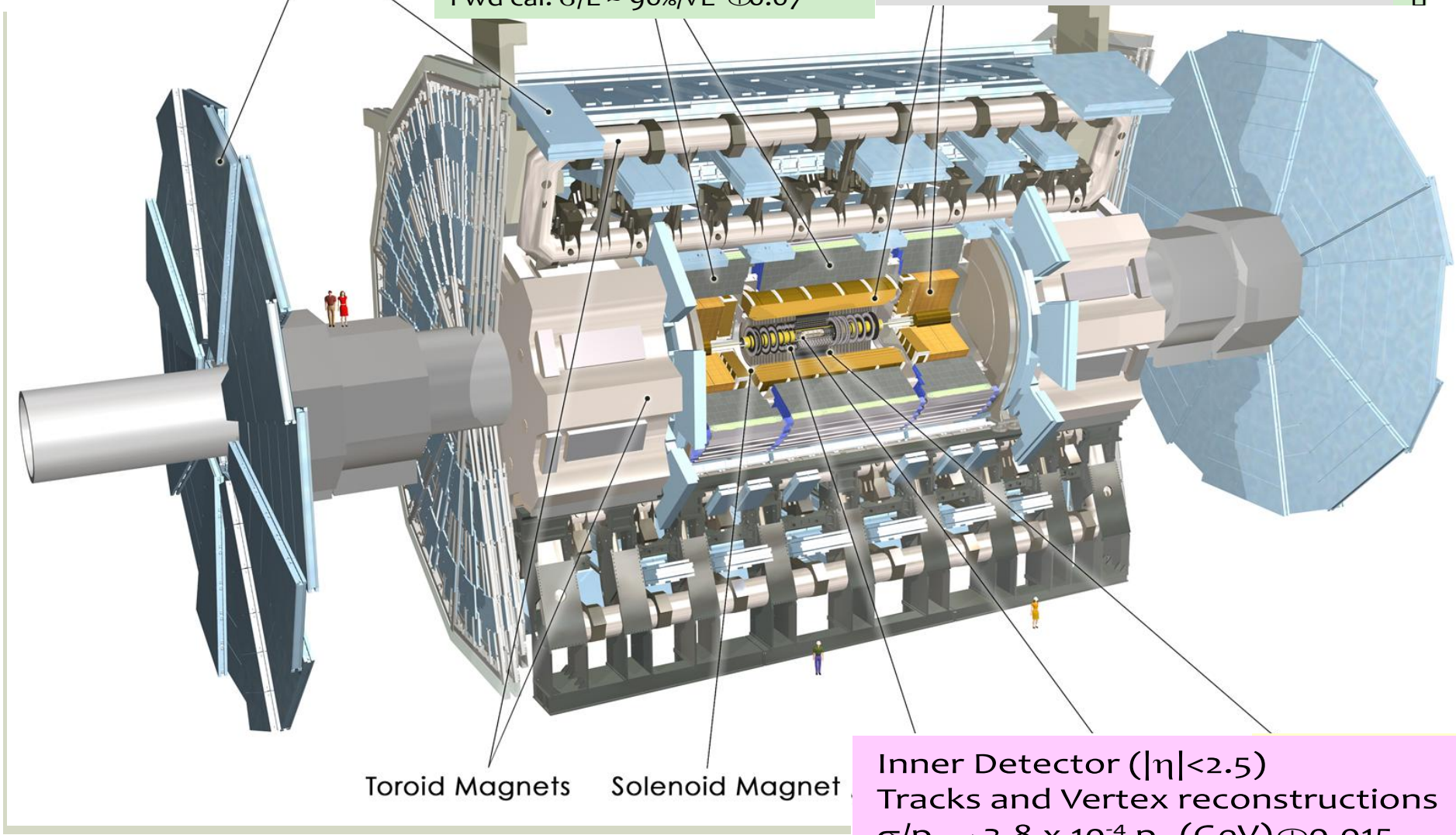
BACKUP SLIDES

A ToroidaL ApparatuS

Spectrometer coverage up to $|\eta|<2.7$
Trigger and measurement for μ with momentum resolution < 10% up to $E_\mu \sim 1$ TeV

HAD calorimeter (jets, MET)
Tiles(central), Cu/W-Lar (fwd)
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
Fwd cal: $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$

EM calorimeter, e/γ trigger, ID, measurement
Resolution: $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.007$



Inner Detector ($|\eta|<2.5$)
Tracks and Vertex reconstructions
$\sigma/p_T \sim 3.8 \times 10^{-4}\ p_T$ (GeV) $\oplus 0.015$

FREQUENTLY USED OBJECTS

- Electrons: energy measured with EM calorimeter, direction from track. Coverage $|\eta| < 2.5$. Isolation from jets within a cone in $\Delta R = (\Delta\varphi^2 + \Delta\eta^2)^{1/2}$ measured with either calorimeter or tracks

Muons: from combined inner tracker and muon spectrometer up to $\eta = 2.5$

Jets: IR-safe AntiKt algorithm, $\eta<5$. b-tagging (up to $\eta = 2.5$) using displaced secondary vertices. Typical working point has ~50% efficiency (depends on pT, η)

Missing transverse energy from energy deposited in calorimeter (with calibrations depending on the identified objects they belong to) and muons

STATISTICS AND LIMITS

Systematics introduced as nuisance parameter in the likelihood function

$$\mathcal{L}(\sigma B, \theta_1, \ldots, \theta_N) = \mathcal{L}(\sigma B) \prod g_i(\theta_i)$$

When combining channels, they are usually treated as 100% correlated (for example, luminosity, MC based backgrounds) or uncorrelated (for example, MC statistics)

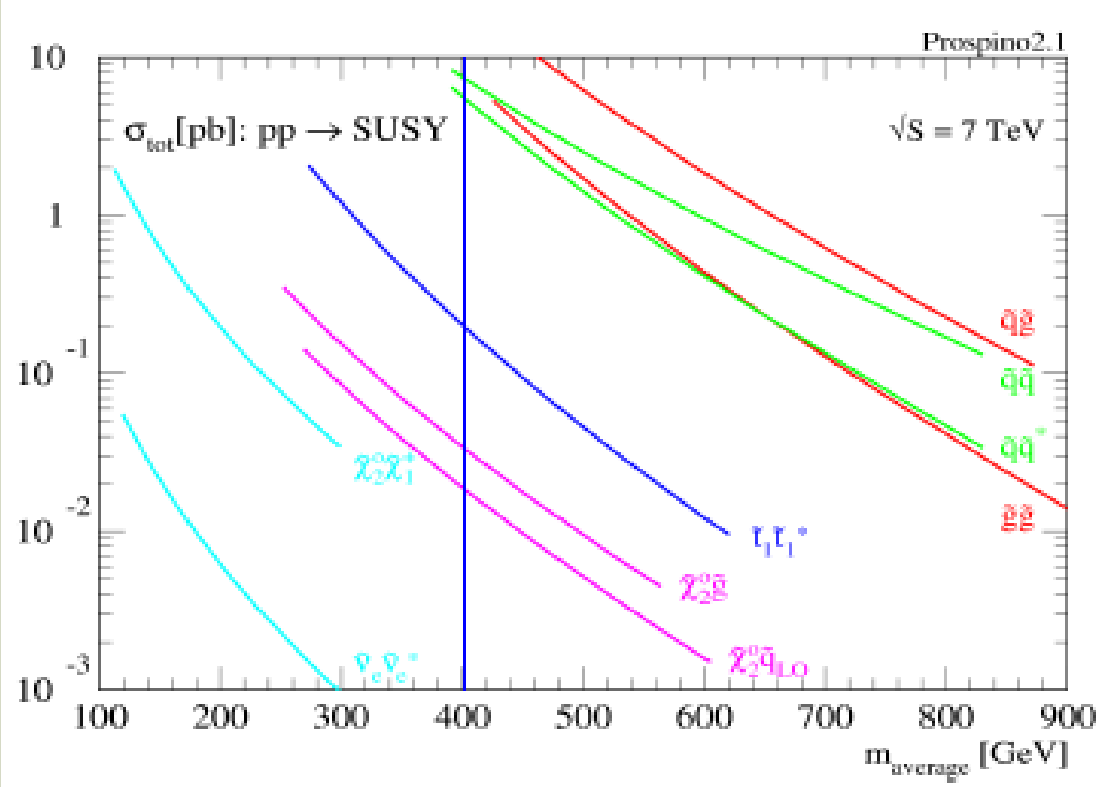
Some analysis used Bayesan inference, in particular when there is a tradition of Bayesian limits for that kind of searches in the community.

The preferred ATLAS method is **PCL**

- Use the frequentist profiled likelihood ratio $L(H_s)/L_{best}$, where H_s is the signal hypothesis, and find the minimum σ x BR for which $CL_{s+b} = P(\text{data} \mid H_s) < 0.05$.
- Protect against downward fluctuations of the background (SM and any signal would be excluded in 5% of measurements…) by setting the observed number of events to B-1σ for the limit calculation if lower than this.

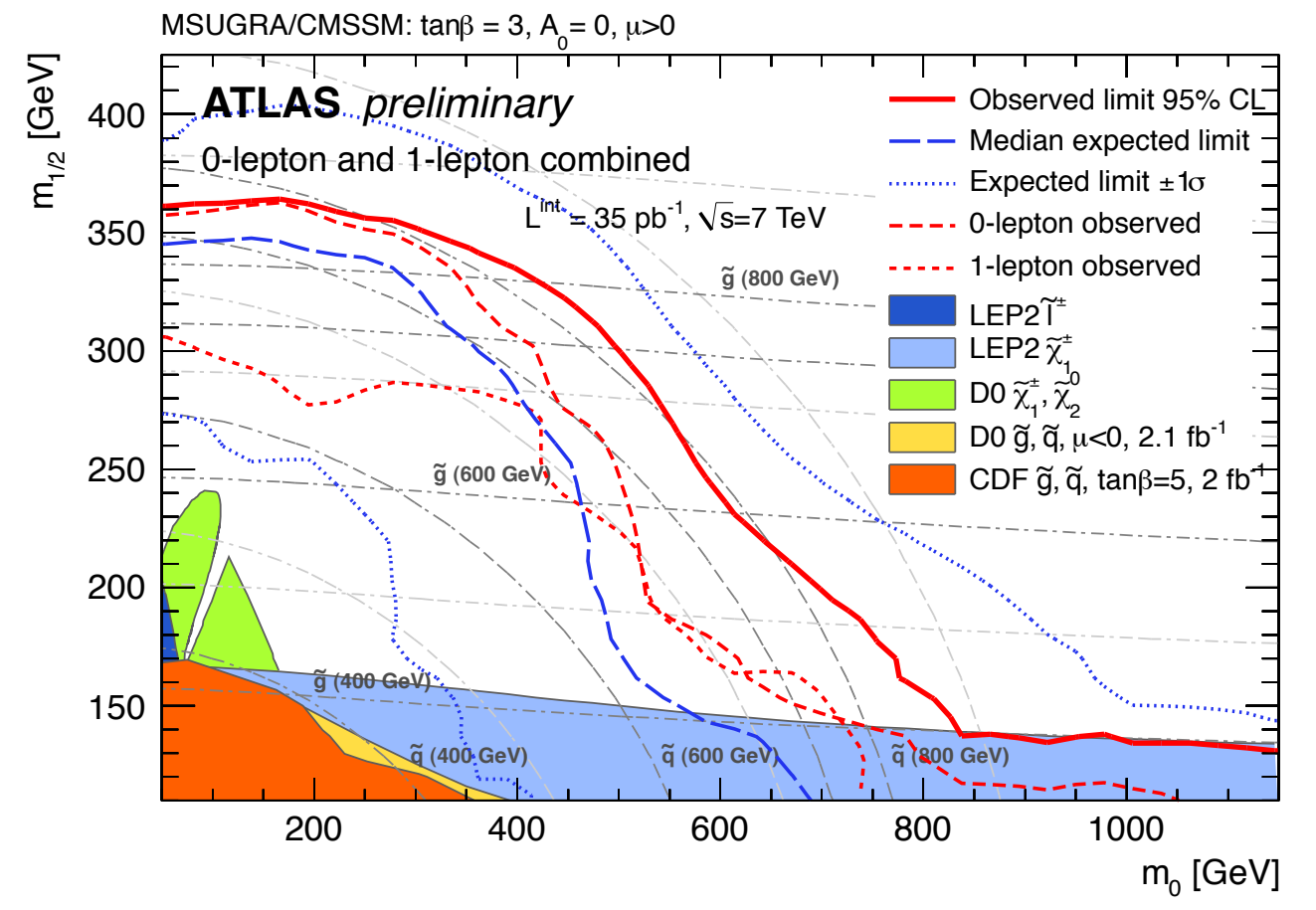
The ratio CL_{s+b}/CL_b used by LEP experiments is also used by some analysis, and also always quoted along with PCL in order to ease comparison with other experiments

SUSY PARTICLE CROSS SECTIONS



JETS+E_T^{MISS}, 0+1 LEPTON COMBINATION

POSSIBLE SIGNAL: SUPERSYMMETRY

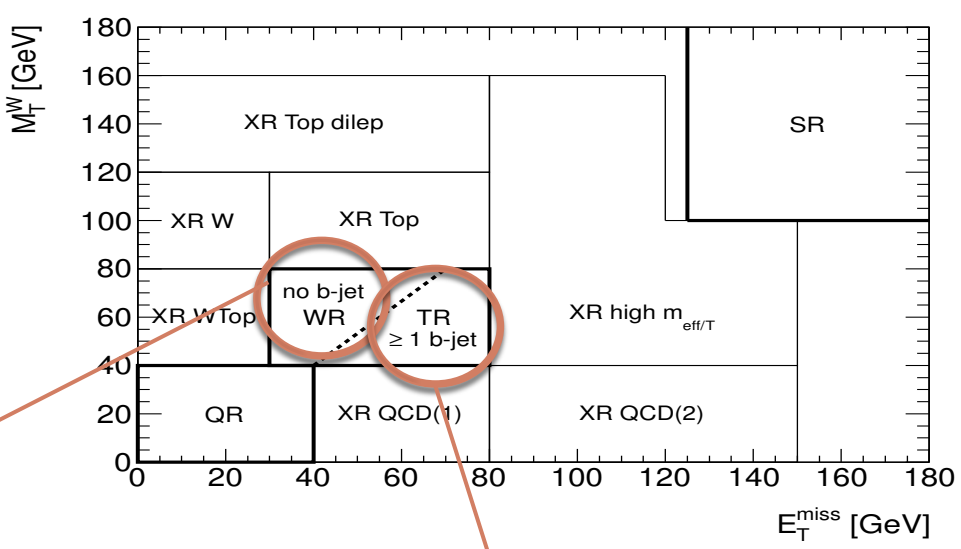


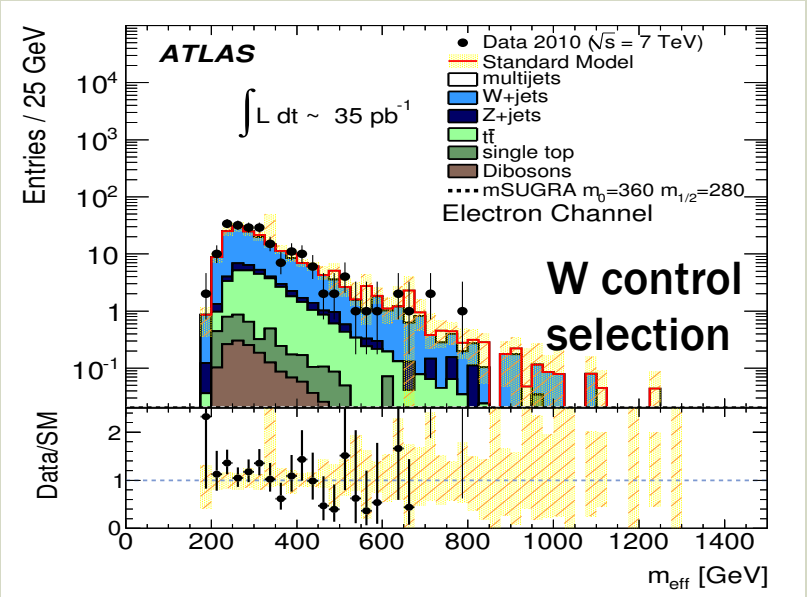
Combined limit significantly better than each channel at large m_0

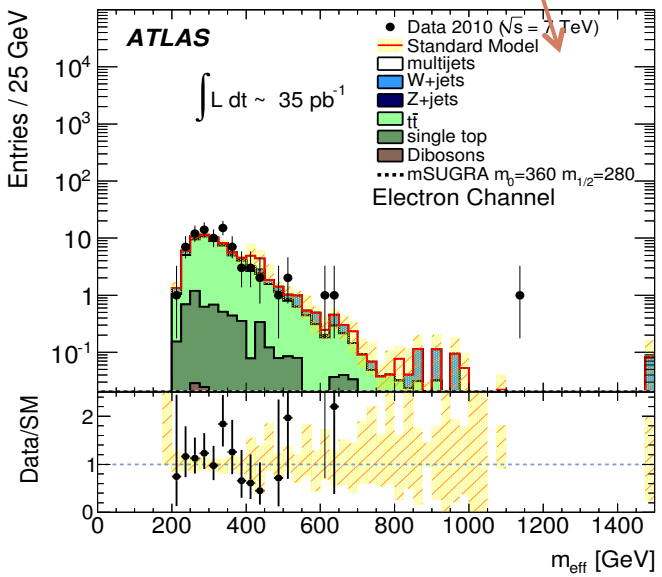
For equal squark and gluino masses, the limit is 815 GeV (most stringent to date)

Etmiss+jets+1 lepton: background estimate

Background predicted with a fit to control regions data, extrapolating to signal region (SR) with MC.
Several cross checks with alternative control regions.





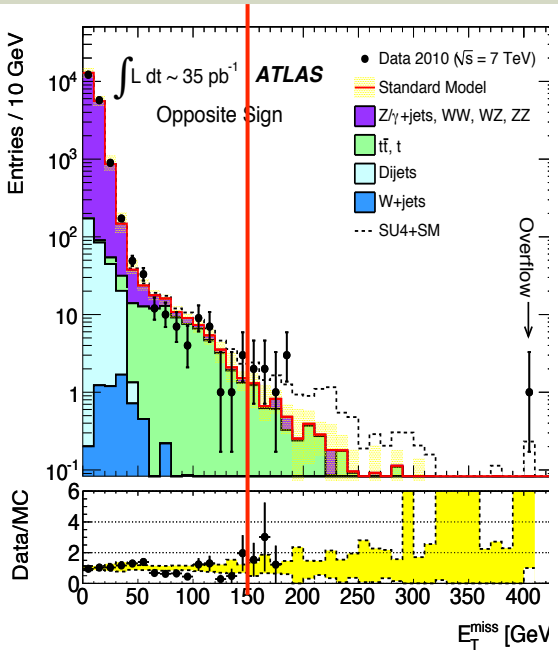


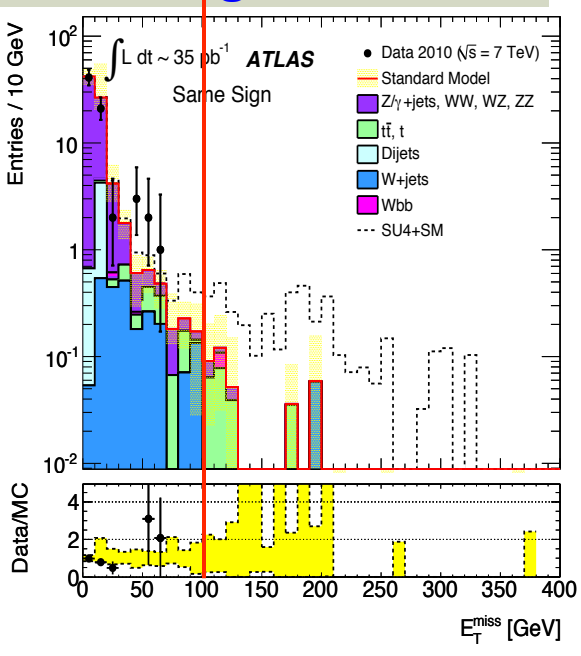
top control selection

E_T^{MISS}+2LEPTONS SELECTION

- **Opposite sign leptons.**
  - **Selection: 2 electron or muons, EtMiss > 150 GeV**
  - **Main background** $t\bar{t} \rightarrow bl\nu\bar{b}l\bar{\nu}$
- **Same sign leptons**
  - **Selection: 2 electrons or muons, EtMiss > 100 GeV**
  - **Very small Standard Model left:**
  - **WZ, ZZ (small x-section), leptons from jets, opposite sign with charge mismeasurement.**

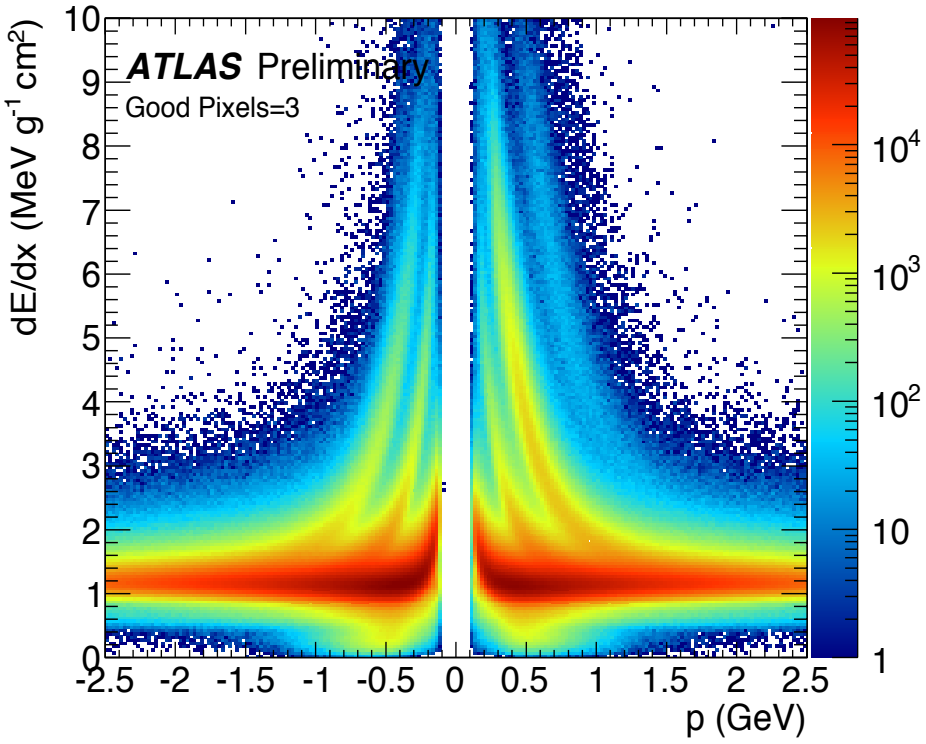
Same Sign, $E_T^{miss} > 100$ GeV			
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Data	0	0	0
Fakes	0.12 ± 0.13	0.030 ± 0.026	0.014 ± 0.010
Di-bosons	0.015 ± 0.005	0.035 ± 0.012	0.021 ± 0.009
Charge-flip	0.019 ± 0.008	0.026 ± 0.011	-
Cosmics	-	$0^{+1.17}_{-0}$	-
Total	0.15 ± 0.13	$0.09^{+1.17}_{-0.03}$	0.04 ± 0.01
Opposite Sign, $E_T^{miss} > 150$ GeV			
	$e^{+}e^{-}$	$e^{\pm}\mu^{\mp}$	$\mu^{+}\mu^{-}$
Data	1	4	4
$t\bar{t}$	$0.62^{+0.31}_{-0.28}$	$1.24^{+0.62}_{-0.56}$	$1.00^{+0.50}_{-0.45}$
Z+jets	0.19 ± 0.15	0.08 ± 0.08	0.14 ± 0.17
Fakes	-0.02 ± 0.02	-0.05 ± 0.04	-
Single top	0.03 ± 0.05	0.06 ± 0.08	0.10 ± 0.07
Di-bosons	0.09 ± 0.03	0.06 ± 0.03	0.15 ± 0.03
Cosmics	-	-0.2 ± 1.18	-0.43 ± 1.27
Total	$0.92^{+0.42}_{-0.40}$	$1.43^{+1.45}_{-0.59}$	$1.39^{+1.41}_{-0.53}$



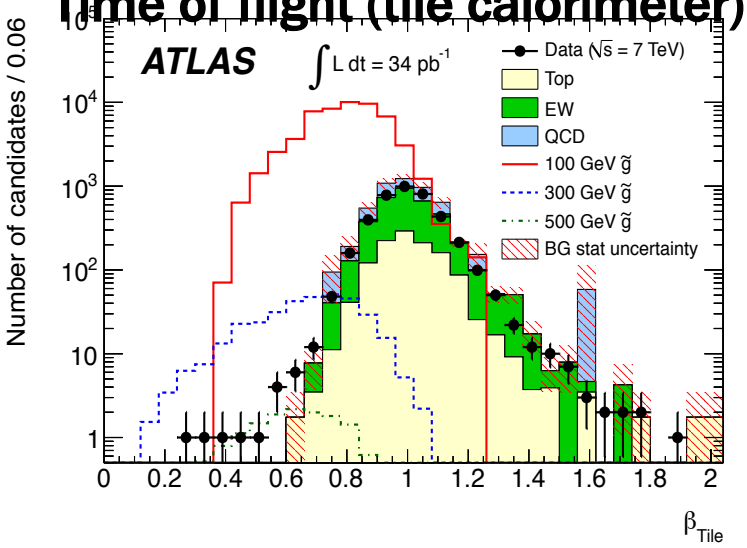


Stable massive hadron searches

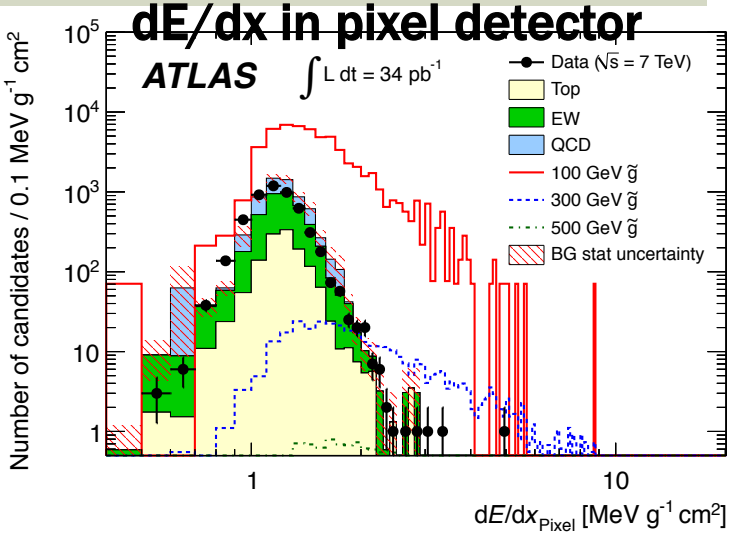
- Signature is a slow (v < c) moving object loosing energy mainly by ionization
- Selection: E_T^{MISS} > 40 GeV, ID track with



Time of flight (tile calorimeter)

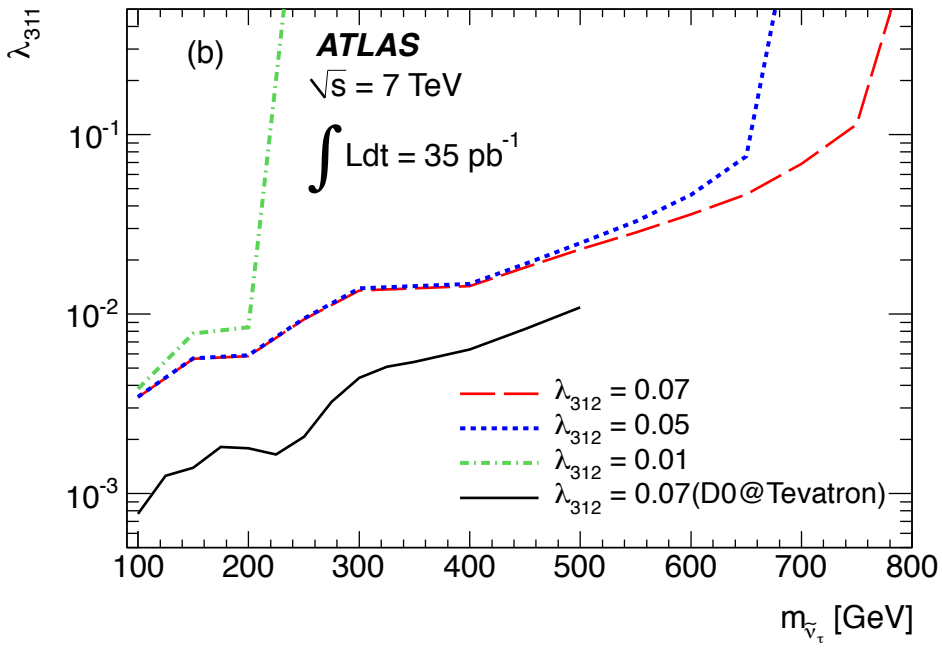


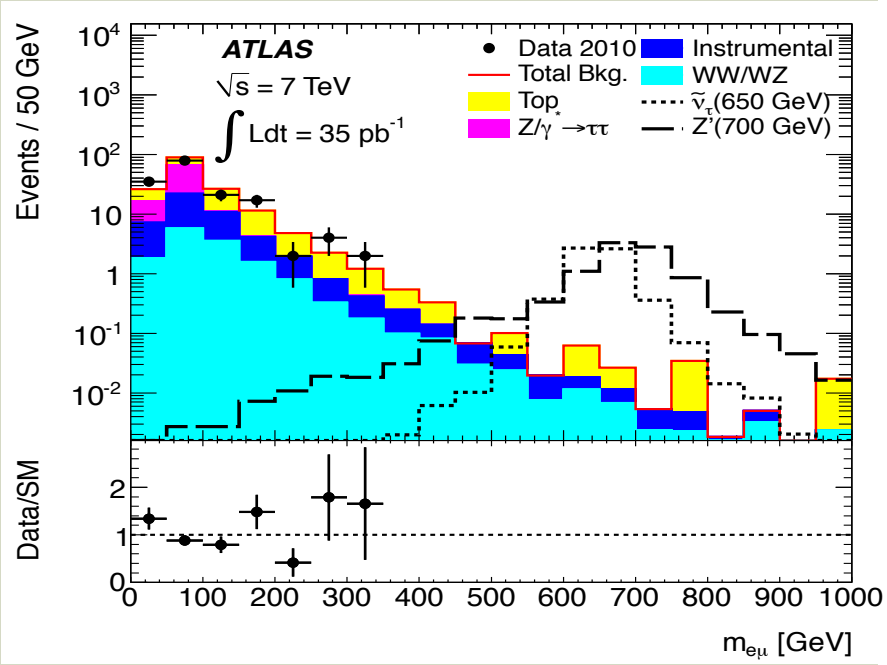
dE/dx in pixel detector



eμ resonance

- Search for a generic electron muon resonance
- Ask two leptons of pt > 20 GeV. No E_T^{MISS} cut.





Extending previous searches for R-parity violating ν_τ production at larger masses

$$\tilde{\nu}_\tau \rightarrow e\mu$$

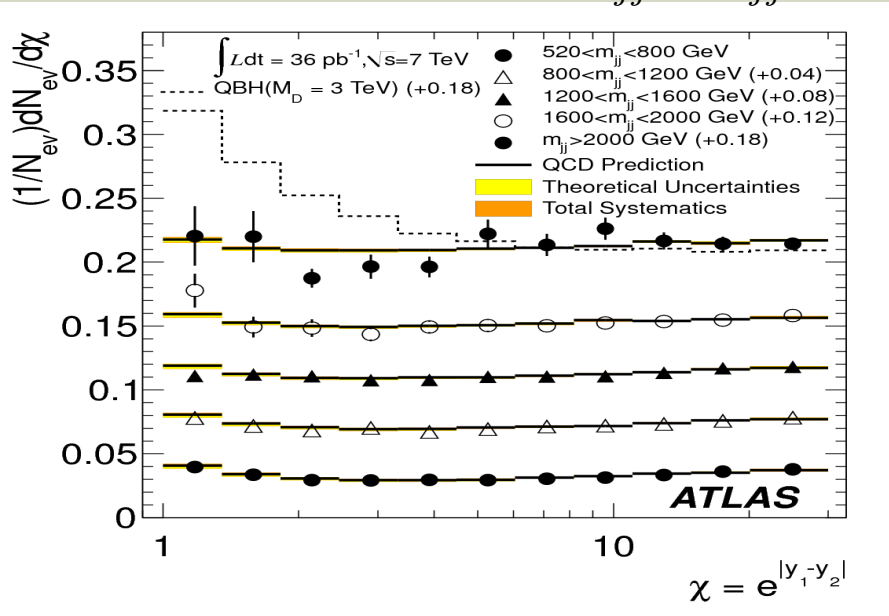
DIJET – ANGULAR DISTRIBUTIONS

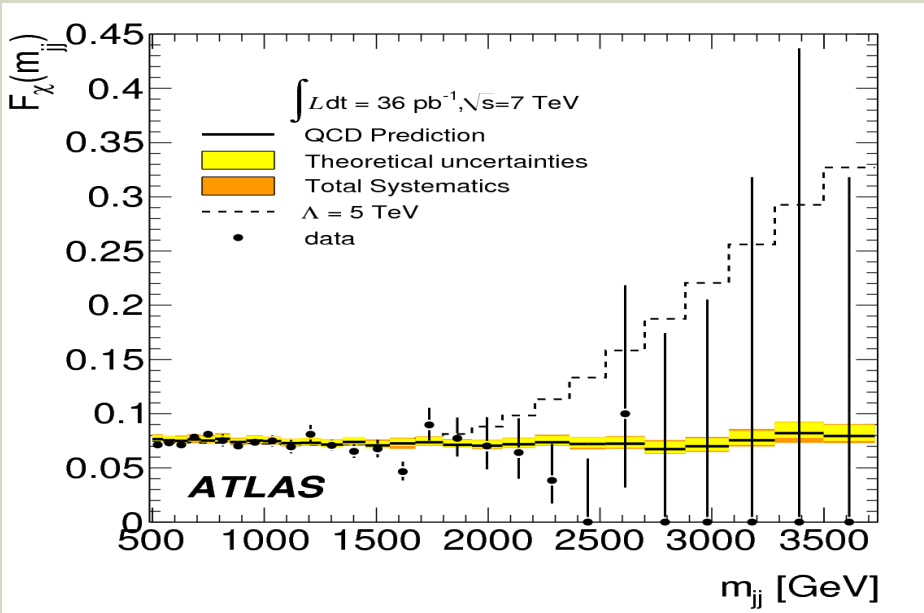
POSSIBLE SIGNAL: CONTACT INTERACTIONS

$y^* = \frac{1}{2}\ln\left(\frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}\right)$ **Rapidity in the two jet center of mass frame**

$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$ **Flat for QCD, peak at small values for signals**

$$F_\chi \equiv \frac{N_{events}(|y^*| < 0.6, m_{jj}^{min}, m_{jj}^{max})}{N_{events}(|y^*| < 1.7, m_{jj}^{min}, m_{jj}^{max})}$$ **Systematics cancel in the ratio**





Sensitive also to non-resonant signals.

Λ > 9.5 TeV limit placed on contact interactions