SEARCHES AT ATLAS

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Physics at the Dawn of the LHC Era

January 27-29 2011

TRIUMF, Vancouver, BC

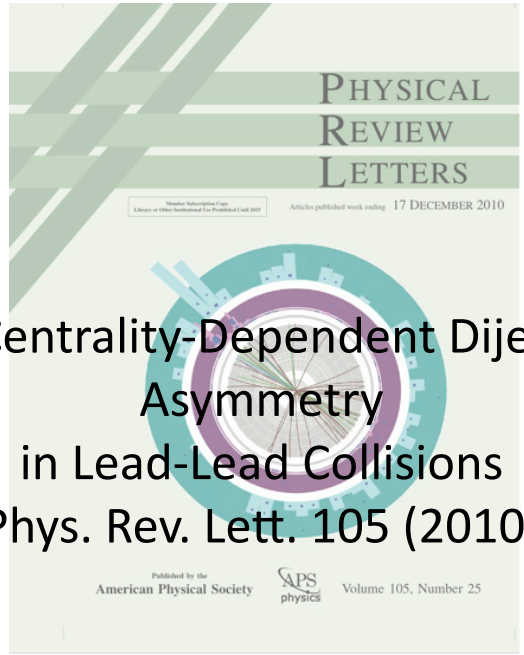
OUTLINE

- Excited Quarks and Contact Interactions
- Extra-Dimensions
- SUSY
- Black Holes
- W'
- Expected sensitivity for 2011 run
- Summary

Disclaimer

I'll focus on searches with proton data!

Many more results : twiki.cern.ch/twiki/bin/view/AtlasPublic



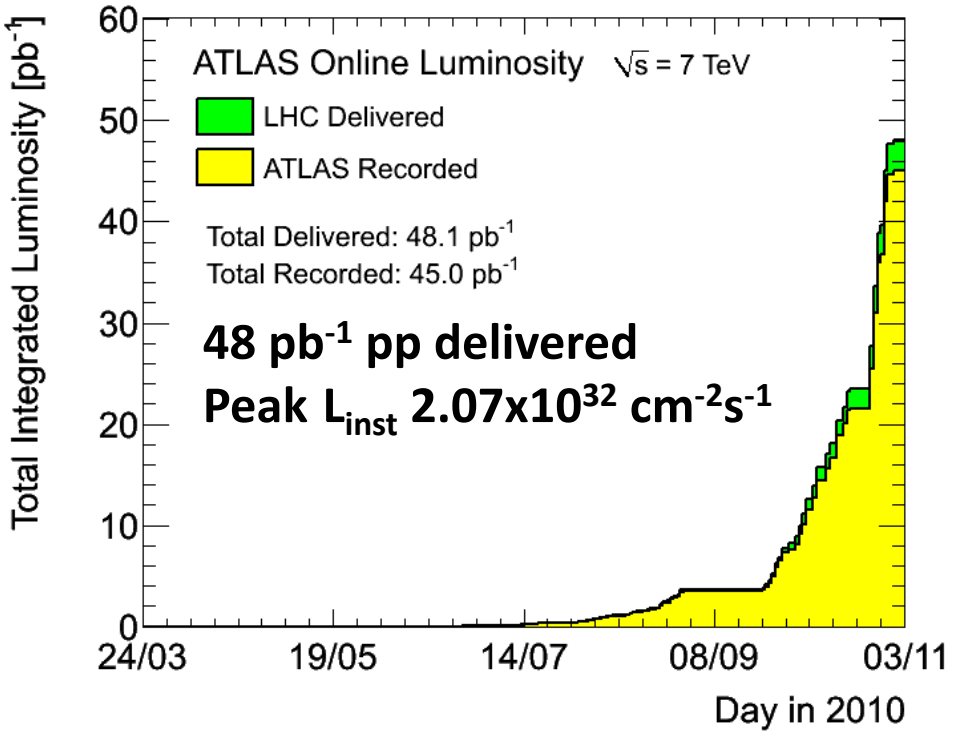
Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions
Phys. Rev. Lett. 105 (2010)

LHC in 2010

EXCELLENT PERFORMANCE!

- March 30th, start of the 7 TeV pp program
- Spring, x1000 increase of L_{inst}
- Summer, stable operations
- October, $L_{inst}>10^{32}$ $cm^{-2}s^{-1}$

At the end of the proton run, LHC had 368 (348) nominal (colliding) bunches, with 150 ns separation, and at β* of 3.5m



Machine achieved all of its milestones either on time or ahead of the 2010 schedule

ATLAS in 2010

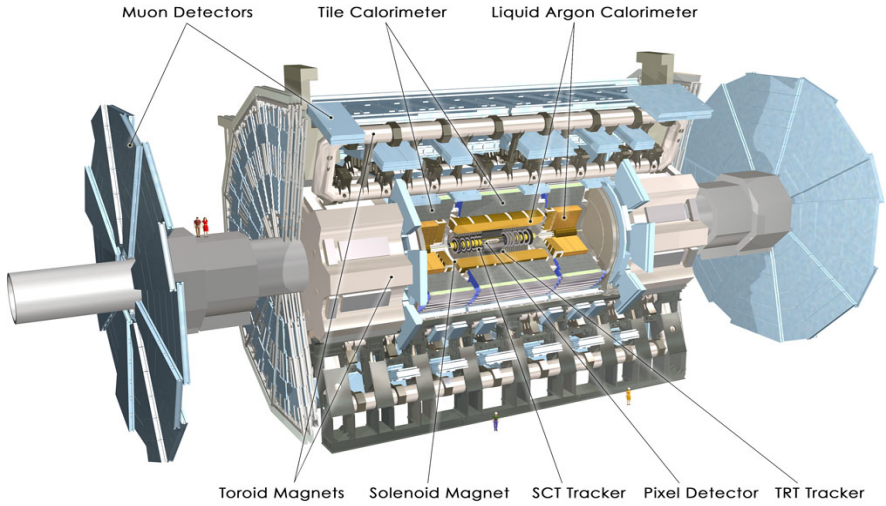
Muon spectrometer ($|\eta|<2.7$):
$\sigma/p_T < 10\%$ (1TeV)

HAD calorimeter ($|\eta|<4.9$):
scintillator Tiles (central),
LAr (fwd). $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

EM calorimeter ($|\eta|<4.9$):
LAr.$\sigma/E \sim 10\%/\sqrt{E}$

Inner Detector
($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation (straws)
e/π separation.
$\sigma/p_T \sim 3.8\text{x}10^{-4}\ p_T\ (\text{GeV}) \oplus 0.015$

TDAQ SYSTEM
3-level trigger reducing the rate from 40 MHz to ~200 Hz



- Data taking efficiency is
  - Above 90% (high quality fraction is 97%)
  - Giving a recorded luminosity of 45.03/pb
- Two milestones were achieved by the GRID
  - 1 million job/day and 10 PB transferred/6 months

Search strategy (I)

- Naturalness arguments support the existence of New Physics at the TeV scale

➲ The LHC has the potential to explore this new territory in coming year(s)

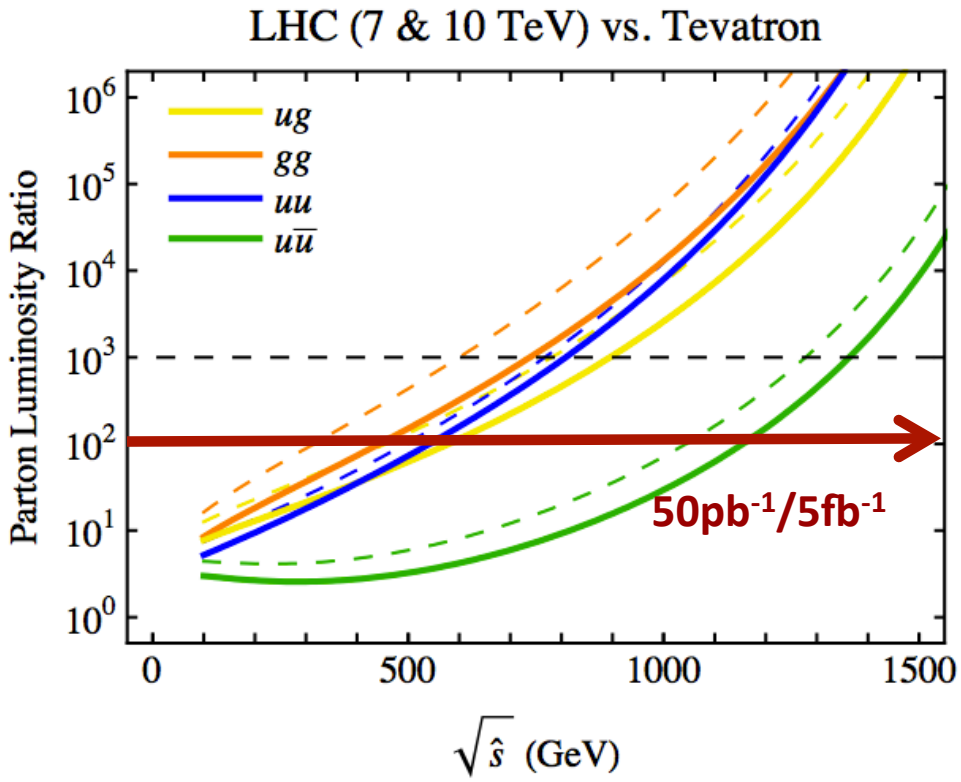
How do we extract most information from the LHC data?

- Theoretical landscape is very articulate!
- ATLAS' strategy is based on selecting 'topologies' that are in common to various theoretical models or loosely dependent on the parameters of a given theory

SUSY, in what flavor, and with or without R-parity conservation? Extra dimensions, black holes? Leptoquarks? New gauge bosons, with which properties? Majorana Neutrinos? Fourth generation? Contact interactions?

Search strategy (II)

- How is the bottom-up strategy implemented for early discoveries?
  - Processes with large cross sections at the LHC but that might have evaded the Tevatron searches are identified
  - Consistency with other existing bounds is imposed



Bauer *et all*.
Phys. Lett. B 690, 280 (2010)

- Mass range < TeV
  - production of colored objects in g-g, q-g, or q-q
- Mass range > TeV
  - production in q-qbar

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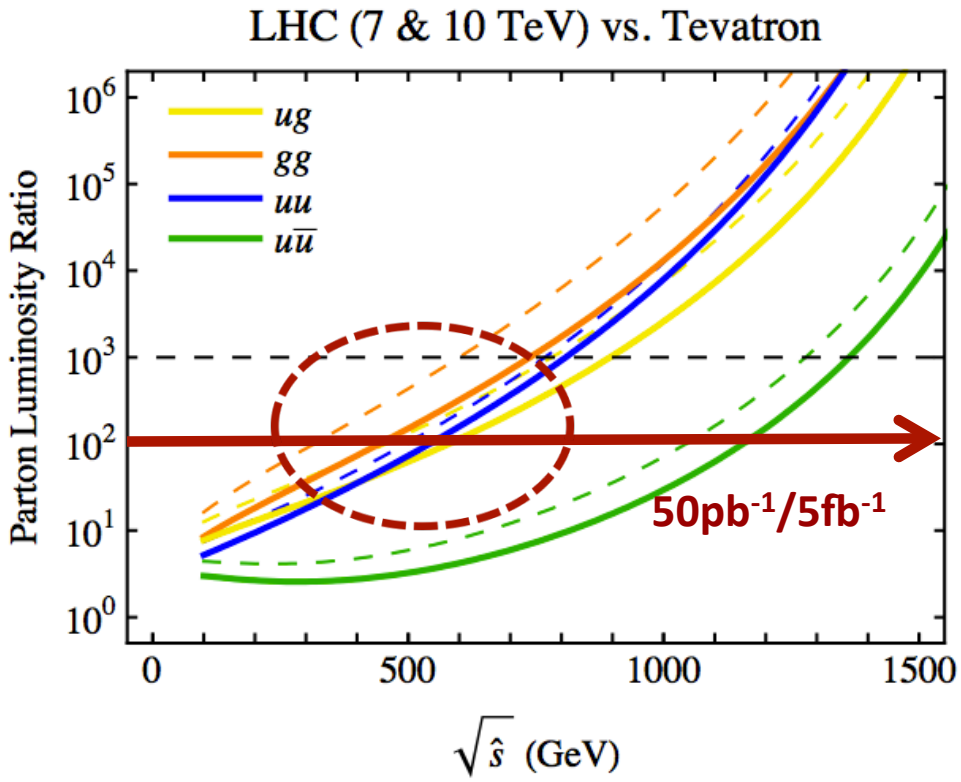

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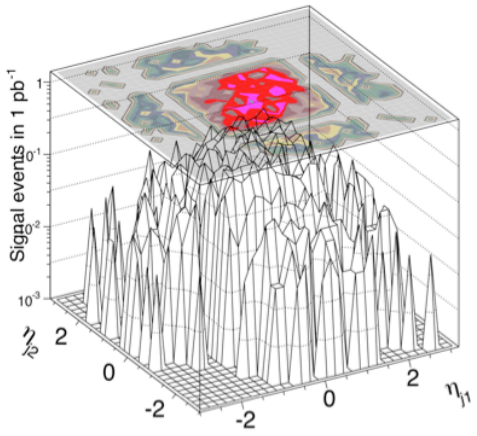
Search in the di-jet final state

- Strong production of colored objects predicted by ➔ **EXCITED QUARKS, GENERIC COMPOSITENESS, AXIGLUONS, COLORONS, etc.**

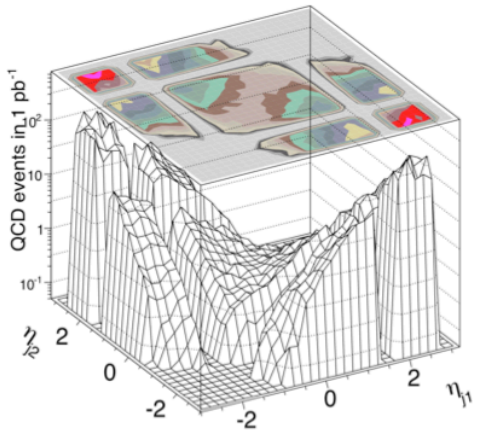
- Excited quark with spin=1/2 and quark like couplings
- are singly produced via qg ➔ **q***
- can decay **q*** ➔ qg, qW, qZ, qγ
- Compositeness scale is set at q* mass

- Main SM background is steeply falling in di-jet invariant mass and is mainly forward
- The signal can be produced in the s-channel (resonance) and is mainly central

q*(1TeV) signal



QCD,
875 < m^{jj} < 1020 GeV



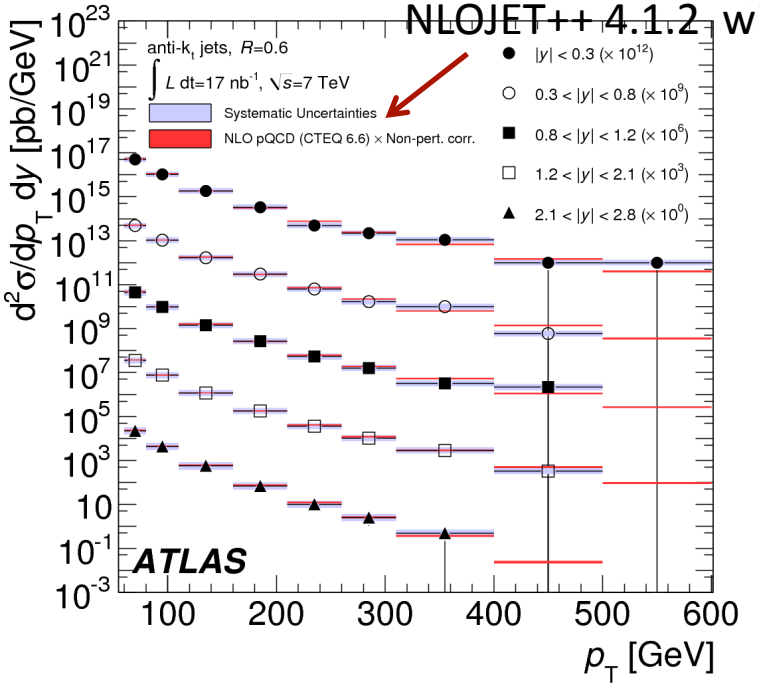
➔ Mass analysis (resonance)

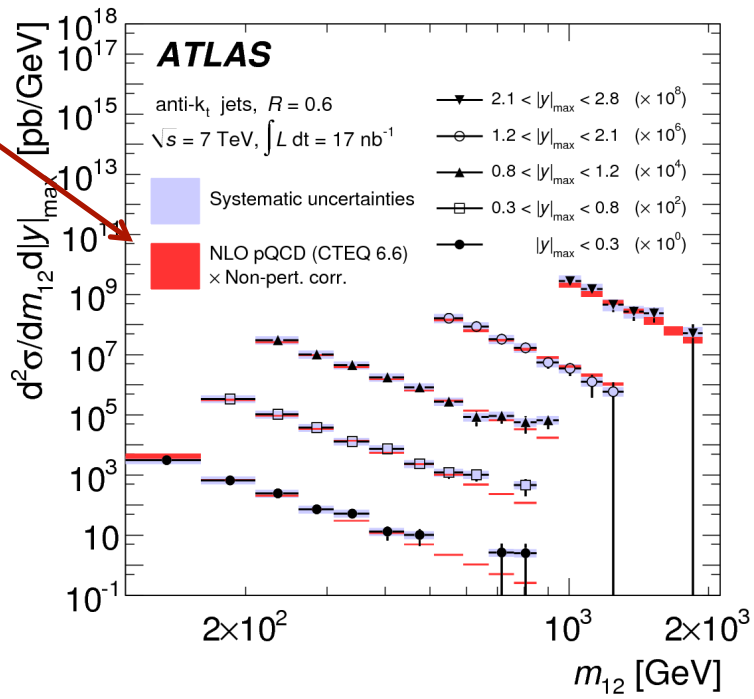
➔ Angular analysis (resonance & compositeness)

Di-jet SM x-section

Accepted by EPJC
arXiv:1009.5908

NLOJET++ 4.1.2 with CQTE6



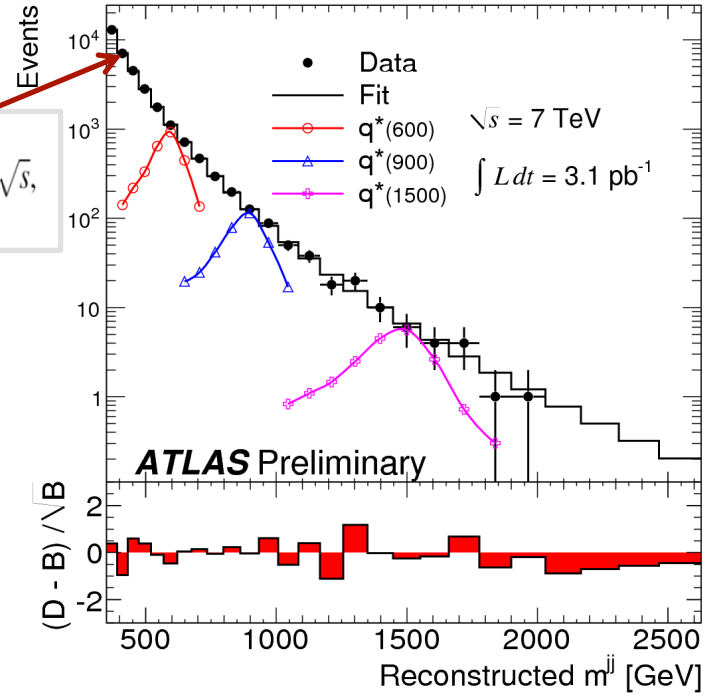


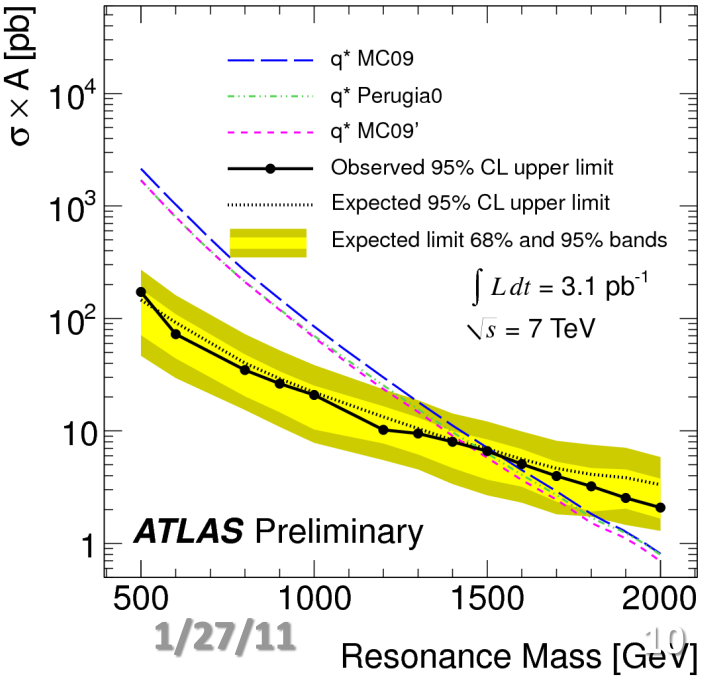
- Jets reconstructed with anti-kt algorithm (from noise suppressed 3D clusters)
- Measured jets are corrected to particle level with parton-shower MC
- Main experimental uncertainty from JES (7% for p_T>60 GeV)
- Agreement data-theory over 5 orders of magnitude over wide range of p_T and η

Mass analysis

$$f(x) = p_0 \frac{(1-x)^{p_1}}{x^{(p_2+p_3 \ln(x))}} \qquad x \equiv m^{jj}/\sqrt{s},$$

- Event selection:
  - p_T > 80/30 GeV & |η|<2.5 & |Δη|<1.3
- Measured di-jet mass distribution is used to estimate the background
- Syst. uncert. are dominated by JES (6-9%)
- No significant deviations from predictions is seen
  - p-value of the background-only hypothesis is > 48%
- Signal and bkg. are simultaneously fit to data
  - PYTHIA (MRST2007 PDFs)





Excluded: 0.5 TeV < mq* < 1.53 TeV with 3.1/pb (ATLAS-CONF-2010-093)

Phys. Rev. Lett. 105 (0.315/pb)

CDF's result mq* < 0.87 (1.13/fb)

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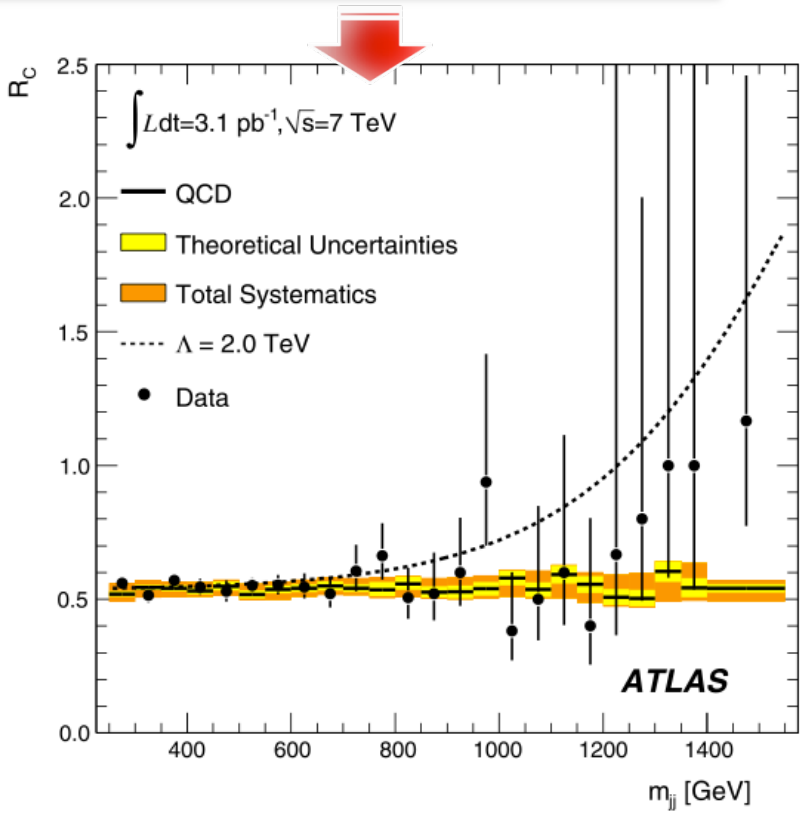
Angular analysis

The angular observable χ is defined such that QCD is flat whilst the signal is peaking

$$\chi = e^{2y^*} = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

$$\text{Centrality ratio } R_C = \frac{N(|\eta_{1,2}| < 0.7)}{N(0.7 < |\eta_{1,2}| < 1.3)}$$

- Event selection:
  - p_T > 60/30 GeV & |η|<2.8
  - For χ analysis, events are rejected if $|y_B|$>0.75 or |y*|> 1.7. The combined criteria limit the rapidity range of both jets to |y| < 2.45.
- QCD is estimated from PYTHIA (MRST2007) with bin-by-bin k factors from NLOJET++ (CTEQ6.6)
- The impact of JES systematic is reduced, but remains the dominant uncertainty
  - bin-wise uncertainties are up to 9% for the χ observable, and up to 7% for the R_C observable



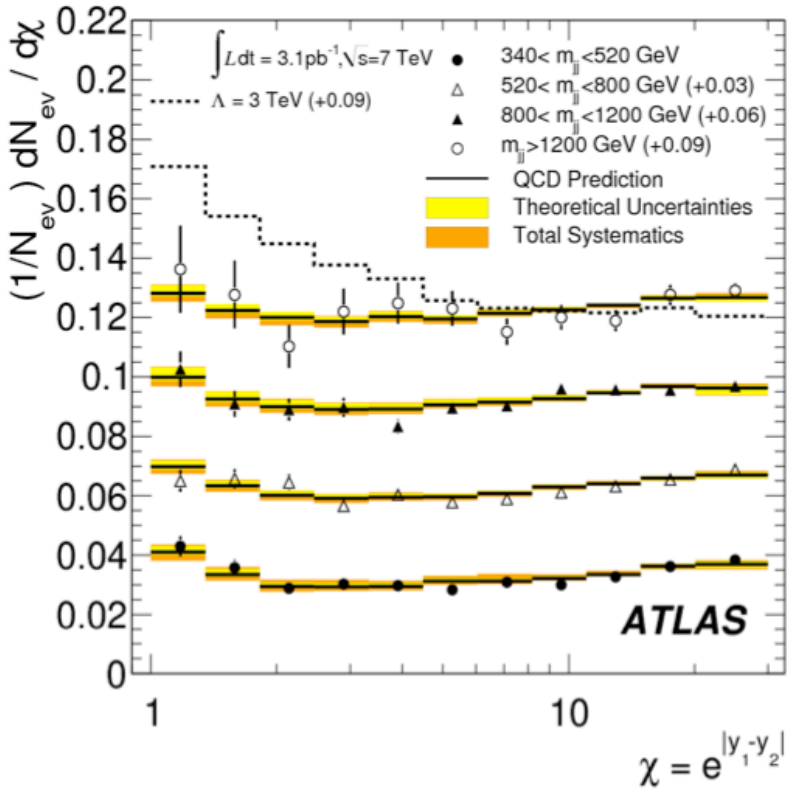
Angular analysis

The angular observable v is defined such that QCD is flat whilst the signal is peaking

$$\chi = e^{2y^*} = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

$$\text{Centrality ratio } R_C = \frac{N(|\eta_{1,2}| < 0.7)}{N(0.7 < |\eta_{1,2}| < 1.3)}$$

- Since no signal from new physics processes is apparent
- limits have been obtained on the compositeness scale Λ of quark contact interactions based on χ analysis



excluded scales Λ below 3.4 TeV at the 95% CL with 3.1/pb

Physics Letters B 694 (2011)

D0's result Λ < 2.84-3.06 TeV (0.7/fb)

Search in the diphoton-met final state

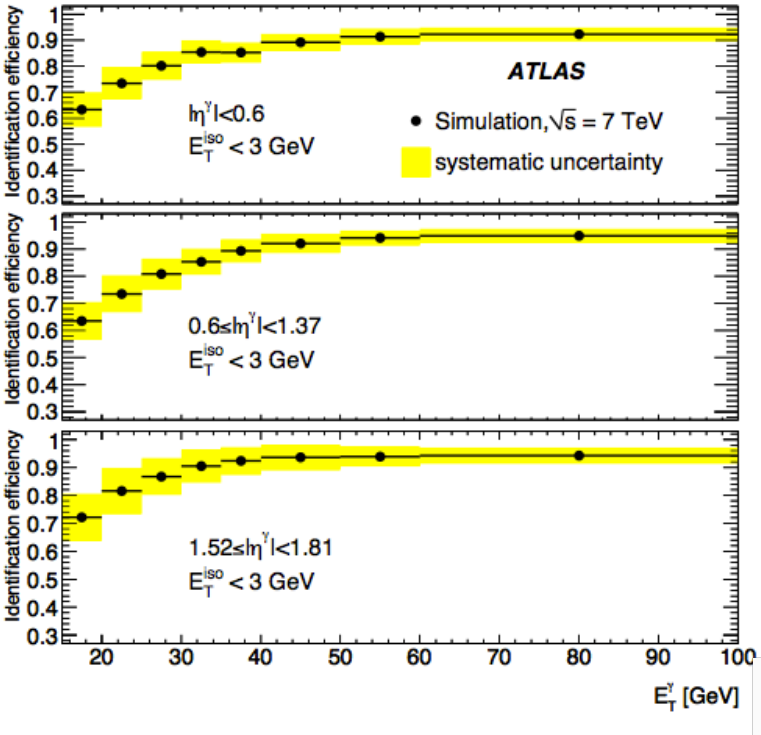
- SM cross sections are of order of femtobarns, whilst models for New Physics can predict larger rates ➔ **UNIVERSAL EXTRA-DIMENSIONS**

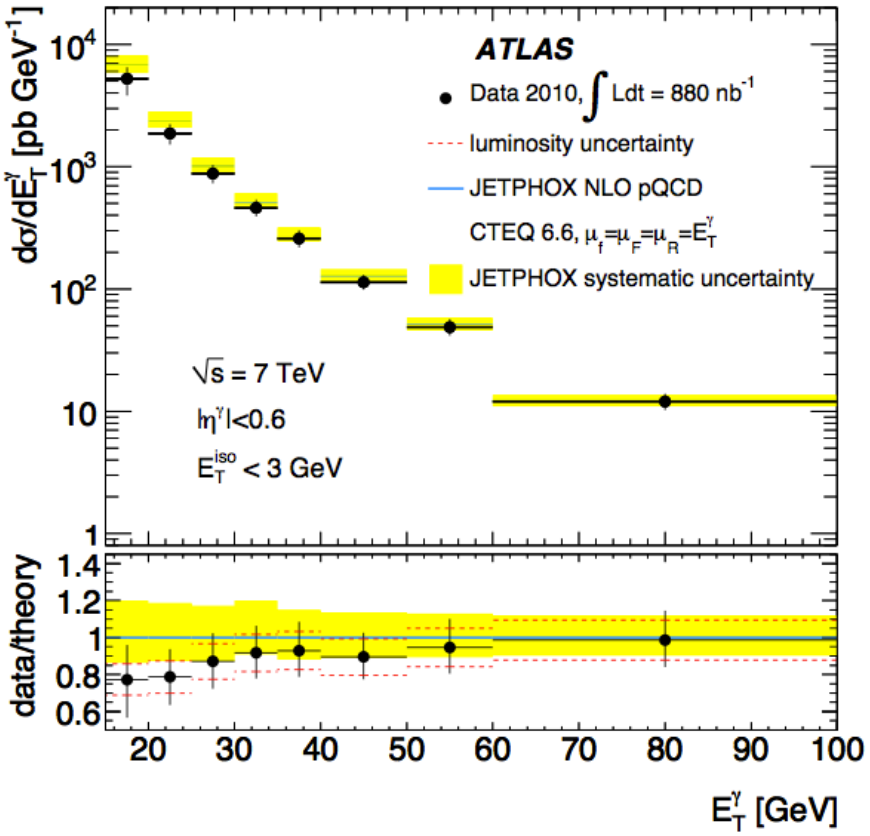
- KK towers of partners to SM due to curled-up ED (R~1/TeV)
- Mass splitting ~ TeV (stable lightest KK is γ*)

- Main UED process, KK gluon/quark **pair production**
- If UED embedded in larger space with N additional 1/eV sized dimensions accessible only to gravity **γ*➔ γG**

Prompt photon SM x-section

- Inclusive Isolated prompt photon cross section x30 (10^5) compared to Tevatron (HERA)
- Good agreement with NLO pQCD predictions by JETPHOX for $E_T > 25$ GeV





Submitted to Phys. Rev. D
arxiv.org/abs/1012.4389

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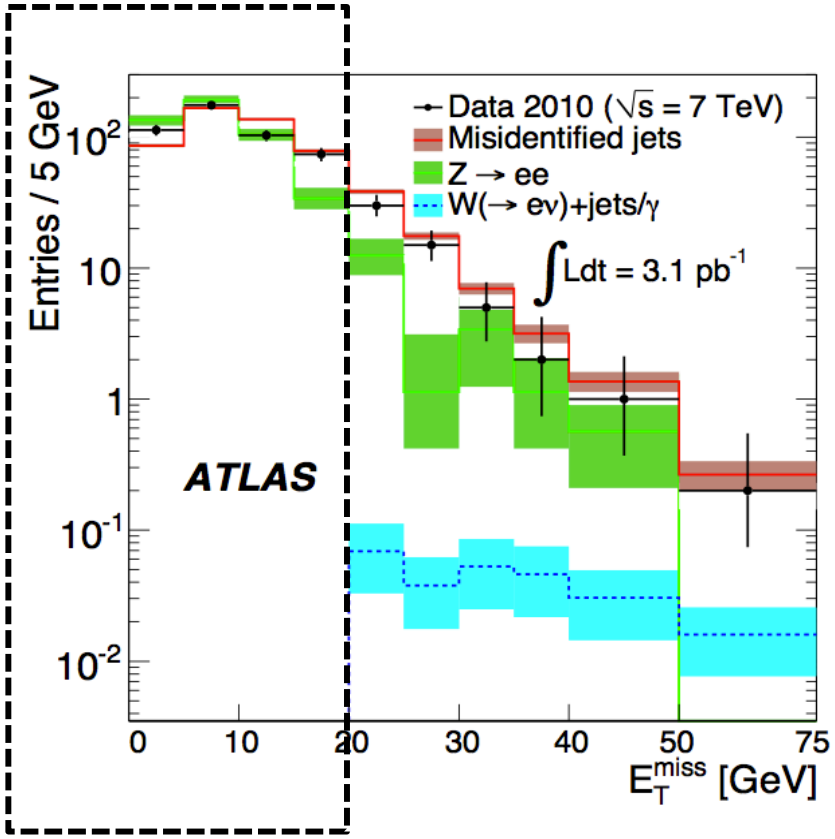
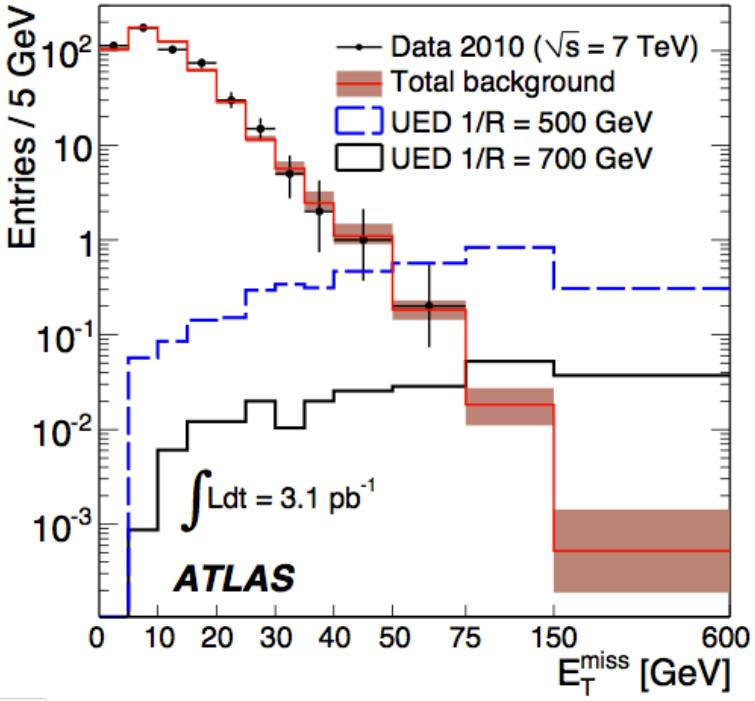
Search in the diphoton-met final state

- Event selection is based on 2 isolated photons with p_T>25 GeV $|\eta|$<1.81 (except 1.37<$|\eta|$<1.52)
- The background is evaluated entirely using data
  - Shapes for QCD jj and QCD γj are obtained from events with one ID photon and one anti-ID photon
  - Shape for QCD γγ is extracted from Zee
  - QCD is normalized to data in the low Etmiss region (Etmiss < 20 GeV)
  - Shape for Wγ from Wj events but normalized to the expected Wγ



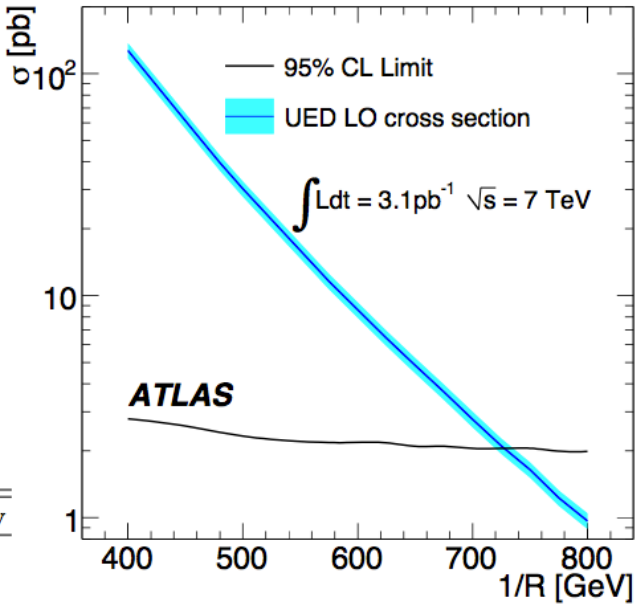
Limits on UED

- The signal region is optimized to achieve the best sensitivity: Etmiss > 75 GeV
- Acceptance determined from PYTHIA to vary from 43 to 48% (1/R form 500 to 700) mainly due to eh Etmiss requirements



Source of uncertainty	Uncertainty
Integrated luminosity	11%
Photon reconstruction and identification	4%
Effect of pileup	2%
E_T^{miss} reconstruction and scale	1%
Signal MC statistics	1%
Total	12%

Background	UED (1/R=500GeV)	UED (1/R=700GeV)
0.32±0.16	40.45±0.64	4.21±0.06



1/R < 728 GeV are excluded at 95% C.L with 3.1/pb

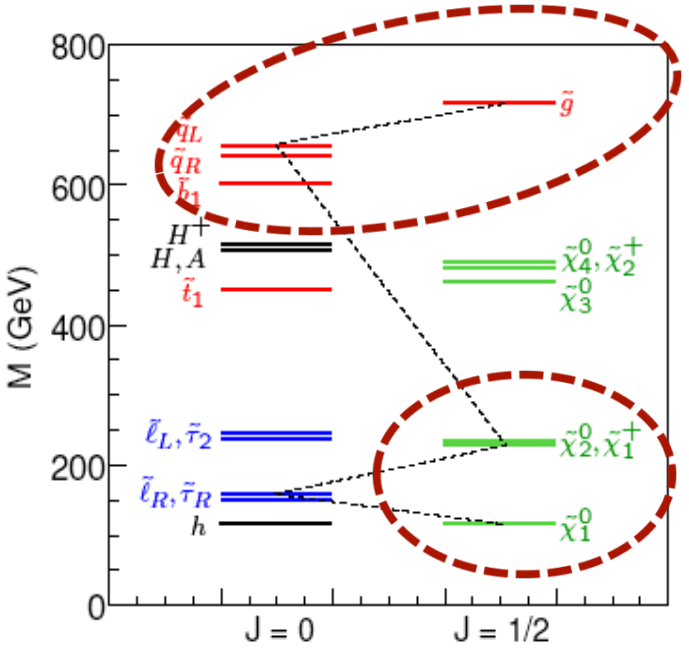
arXiv:1012.4272, Submitted to Phys. Rev. Lett.

D0's result 1/R < 477 GeV (6.3/fb)
1/27/11

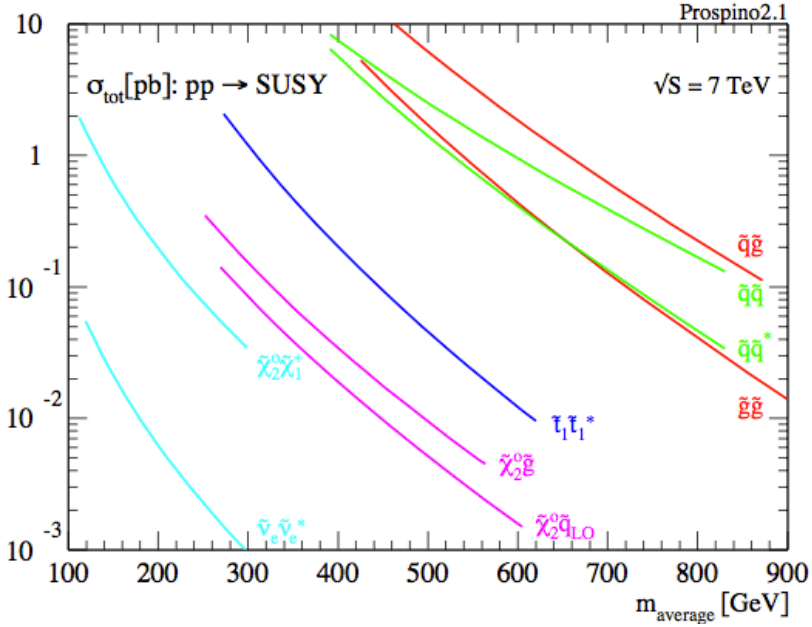
SUSY spectra

$[u, d, c, s, t, b]$	$[e, \mu, \tau]$	$[\nu_{e,\mu,\tau}]$	Spin $\frac{1}{2}$
$[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}]$	$[\tilde{e}, \tilde{\mu}, \tilde{\tau}]$	$[\tilde{\nu}_{e,\mu,\tau}]$	Spin 0
g	$W^{\pm}, H^{\pm}$	$\gamma, Z, H_1^0 H_2^0$	Spin1/Spin 0
$\tilde{g}$	$\tilde{\chi}^{\pm}_{1,2}$	$\tilde{\chi}^0_{1,2,3,4}$	Spin $\frac{1}{2}$

But SUSY is a broken symmetry and the breaking mechanism is not known!

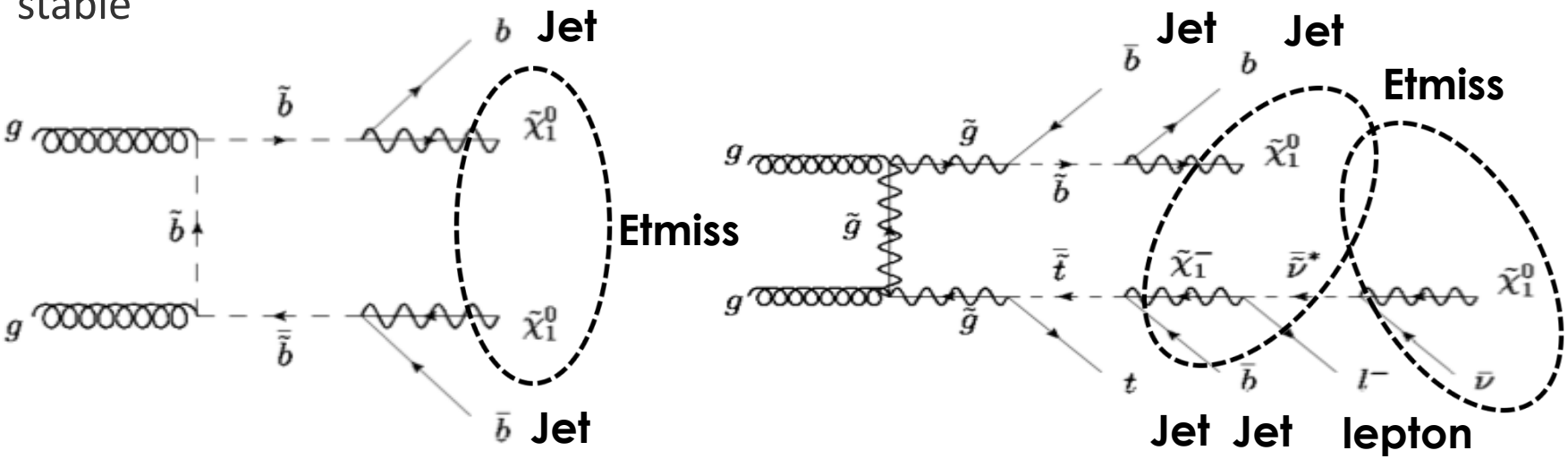


- SOFT BREAKING: MSSM, $L_{susy} \rightarrow L_{susy} + L_{soft}$
  - more than 100 free parameters
- BENCHMARK BREAKING SCENARIO:
  - New superfields in "hidden" sector
  - mSUGRA: Unified gaugino mass $m_{1/2}$, Unified scalar mass m_0 , **Ratio of H_1, H_2 vevs tanβ,** trilinear coupling A_0 , Higgs mass term sgn(μ)



SUSY final states

- With the assumption of R-parity conservation that implies lightest neutralino be stable



- 1, ≥2, ≥3, ≥4 Jets & Etmiss & 0 lepton
- ≥2 Jets & Etmiss & ≥1 leptons
- ≥3 Jets & Etmiss & 0 lepton. At least 1 b-tag jet
- ≥2 Jets & Etmiss & 1 lepton. At least 1 b-tag jet

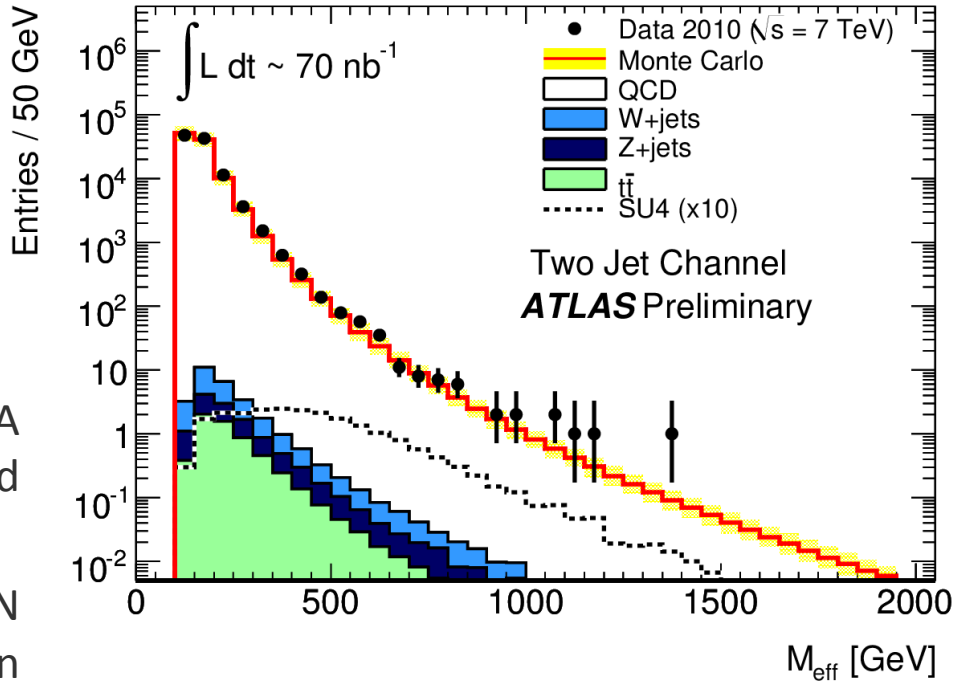
Enhanced sensitivity for large tanβ scenarios with large splitting in the third generation

Jet-Etmiss & 0 lepton (I)

ATLAS-CONF-2010-065

$$M_{\text{eff}} \equiv \sum_{i=1}^{n} |\mathbf{p}_{\text{T}}^{(i)}| + E_{\text{T}}^{\text{miss}}$$

- Event pre-selection is based on
  - Jet E_T (>70GeV, 30GeV) and E_{tmiss} (40GeV)
  - $\Delta\Phi_{\text{ j-Etmiss}}$ and $E_{tmiss} > f \times M_{eff}$
  - Lepton vetoed (10GeV)
- Main backgrounds are:
  - **QCD**; shape is obtained from PYTHIA (with MRST 2007 LO*); yield normalized to the data in a di-jet control region
  - **W/Z+jets**; shape comes from ALPGEN and the overall normalization is based on the (NNLO) QCD corrections estimated from FEWZ
  - **tt**; MC@NLO (CTEQ6)



mSUGRA Benchmark point SU4

Low mass, close to the Tevatron limits

m_0=200 GeV, $m_{1/2}$=160GeV, A_0=-400 GeV, tanβ=10, μ>0
Spectrum from ISAJET (MRST2007 LO*)
LO (NLO) xs from HERWIG++ (PROSPINO)

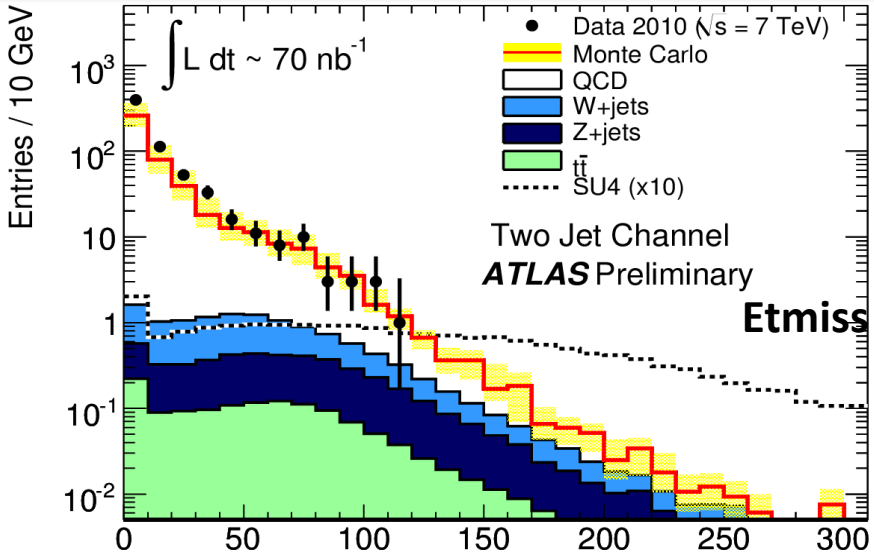
Jet-Etmiss & 0 lepton (II)

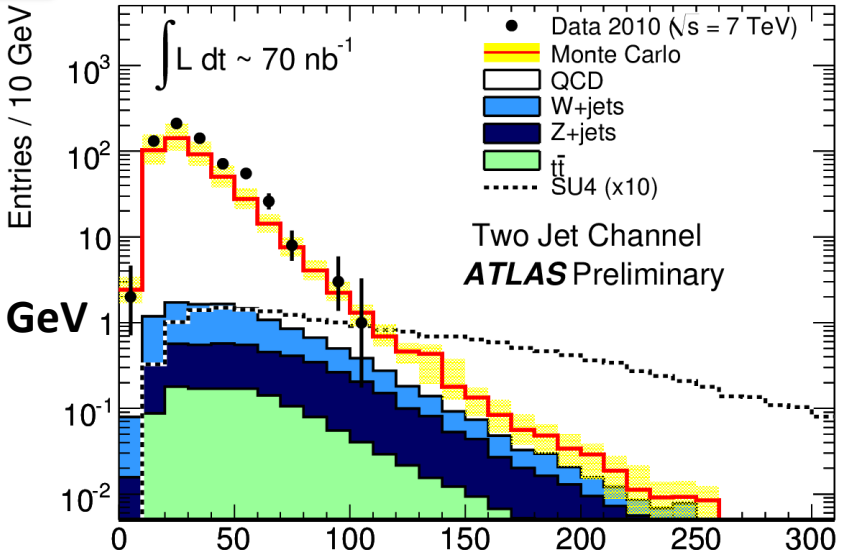
ATLAS-CONF-2010-065

- Observations is in agreement with the predictions within the systematic uncertainties (JES 25-50%; Luminosity 11%)

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

$$m_{CT}^2\left(j^{(1)}, j^{(2)}\right) \equiv 2E_T^{(1)}E_T^{(2)} + 2\mathbf{p}_T^{(1)} \cdot \mathbf{p}_T^{(2)}.$$





Sensitivity optimization is based on Etmiss/M_{eff}

	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

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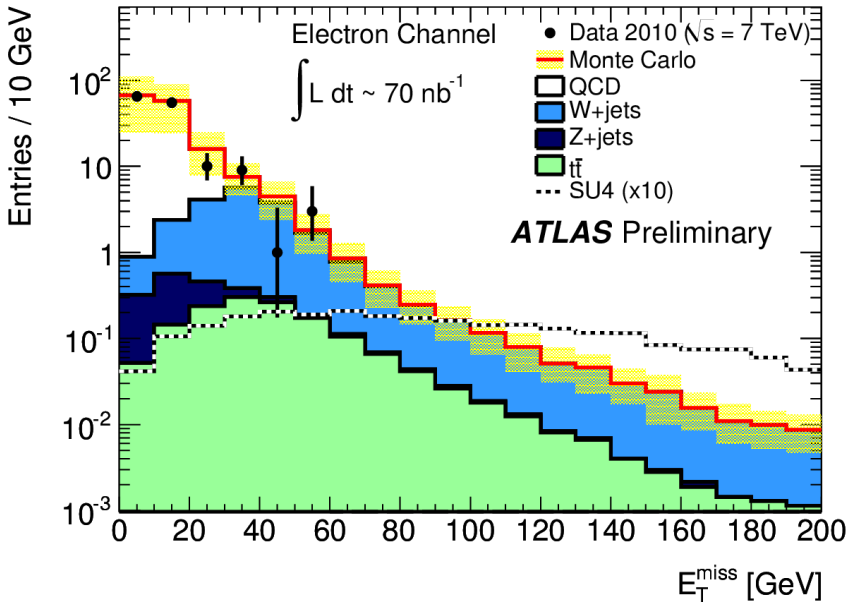
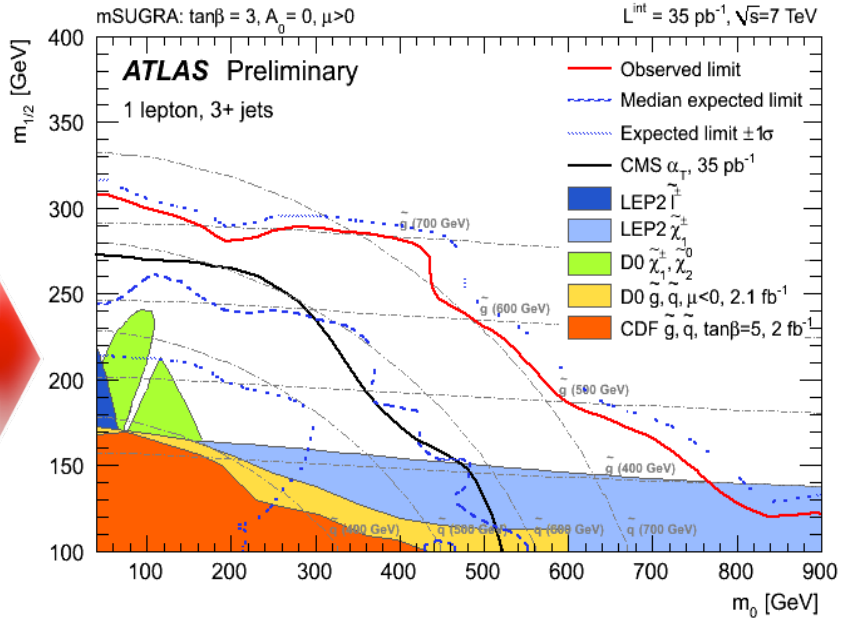
Jet-Etmiss & ≥1 lepton

ATLAS-CONF-2010-066

- Event selection:
  - Jet E_T (>30GeV, 30GeV) and E_{tmiss} (30GeV)
  - At least 1 lepton (20/10GeV)
  - m_T > 100GeV or m_{ll} > 5 Gev
- QCD is suppressed due to lepton cut
  - normalized to data in control regions
- **W-jet becomes dominant**
  - normalized in control region defined as 30 GeV < Emiss < 50 GeV and 40 GeV < m_T < 80 GeV
- No excess is observed when comparing the data with the expected background (systematics are included)



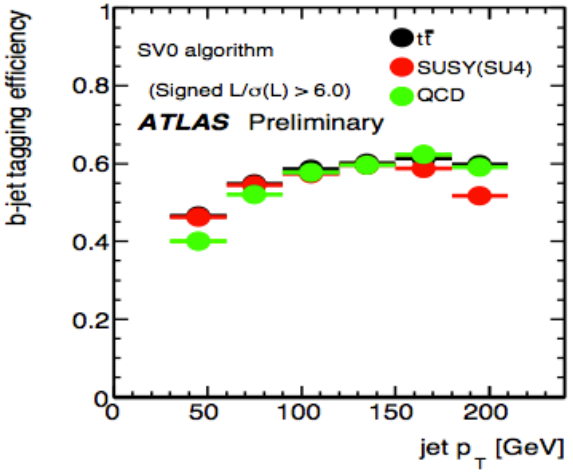


TRIUMF

Jet-Etmiss & ≥0 lepton with bs

ATLAS-CONF-2010-079

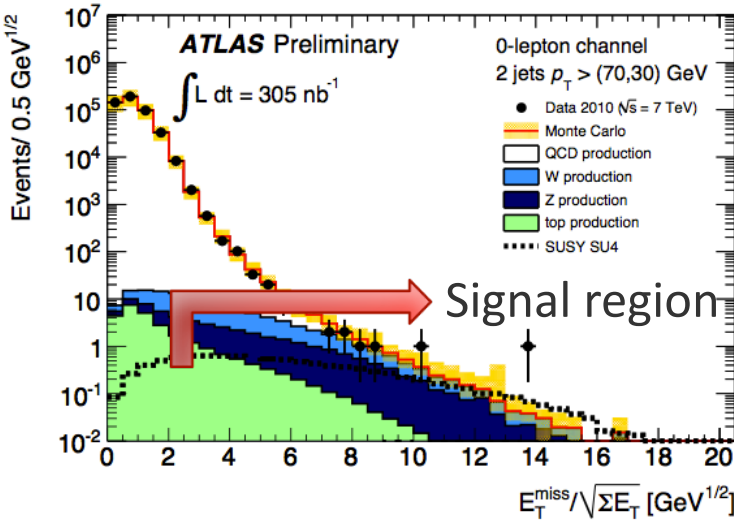
- Enhanced sbottom production is predicted for large tanβ
- Jets from Bs are tagged with lifetime-based tagger
  - reconstructs secondary vertices from tracks associated with a jet
  - the sign of L/σ(L) -> projection of the decay length on the jet axis
- The low MetSig region is used for normalization of QCD to data (in the 1 lepton channel additional cut on m_T is imposed to suppress real Ws)

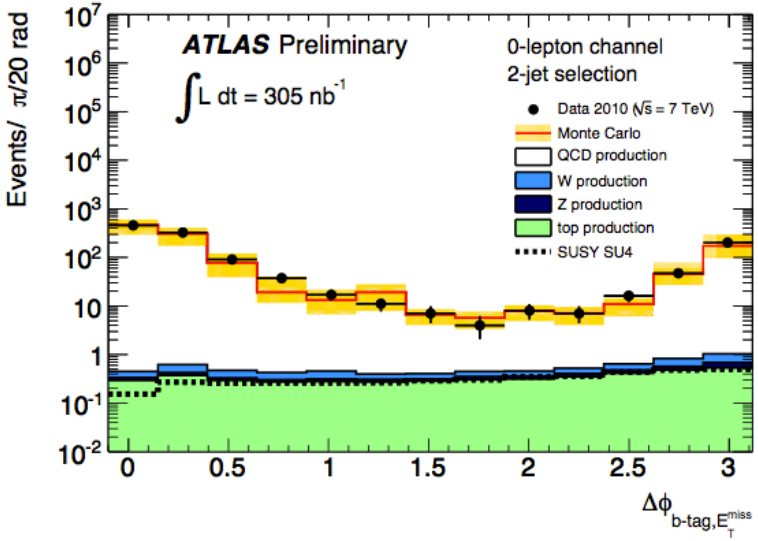


Selection	data	QCD	data/QCD
MetSig < 2 GeV$^{1/2}$ (inclusive)	463180	752913	0.61
MetSig < 2 GeV$^{1/2}$ (≥ 1 b-tag jet)	28638	42562	0.67

Background	SU4	Data
1190±430	4.23±0.04	1253

- JES: 30%
- B-tag: 20%





TRIUMF

Towards Heavy resonances

- New heavy vector bosons are predicted in many models extending the gauge structure of the SM
  - **LEFT-RIGHT SYMMETRY MODELS –> W'**
  - **E6, LITTLEST HIGGS, CONTACT INTERACTION, EXTRADIMENSIONS, SUSY –> Z'**

- W' → *ev*
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Towards Heavy resonances

JHEP 12 (2010) 060

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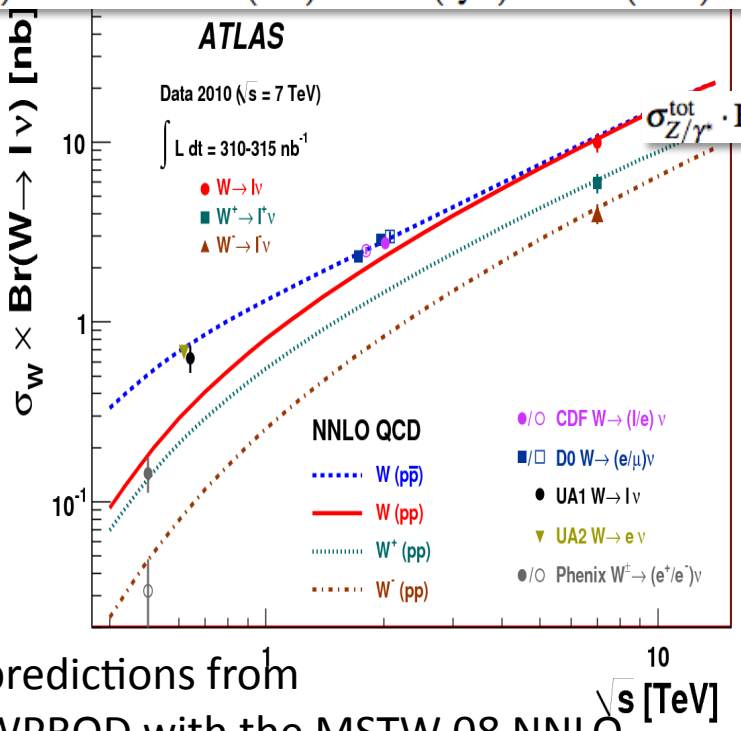
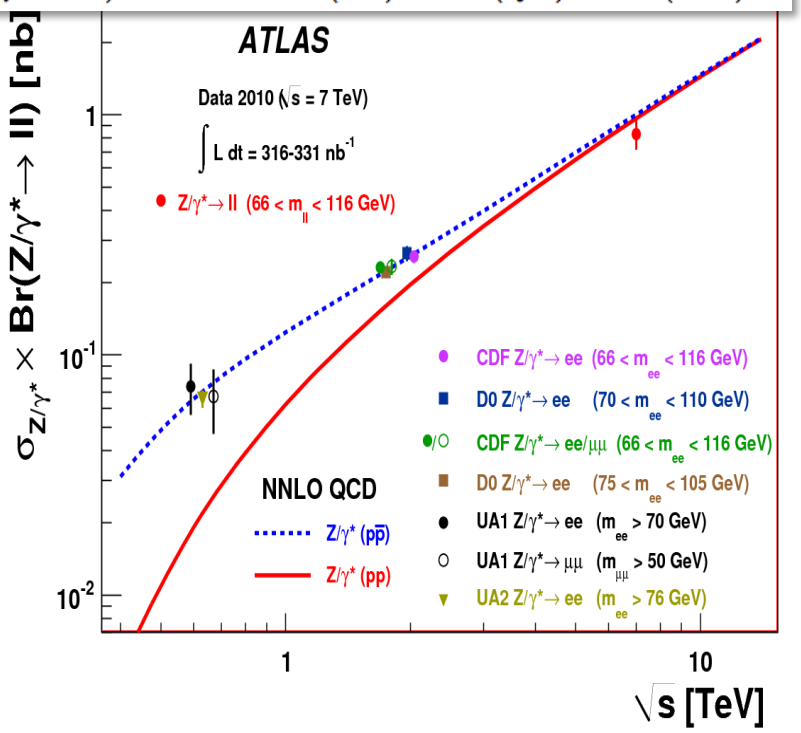
$\sigma_W^{tot} \cdot BR(W \to \ell\nu) = 9.96 \pm 0.23(stat) \pm 0.50(syst) \pm 1.10(lumi)$ nb



$\sigma_{Z/\gamma^*}^{tot} \cdot BR(Z/\gamma^* \to \ell\ell) = 0.82 \pm 0.06(stat) \pm 0.05(syst) \pm 0.09(lumi)$ nb



Theoretical predictions from
FEWZ and ZWPROD with the MSTW 08 NNLO

Towards Heavy resonances

arXiv:1012.1792v2
Submitted to EPJC

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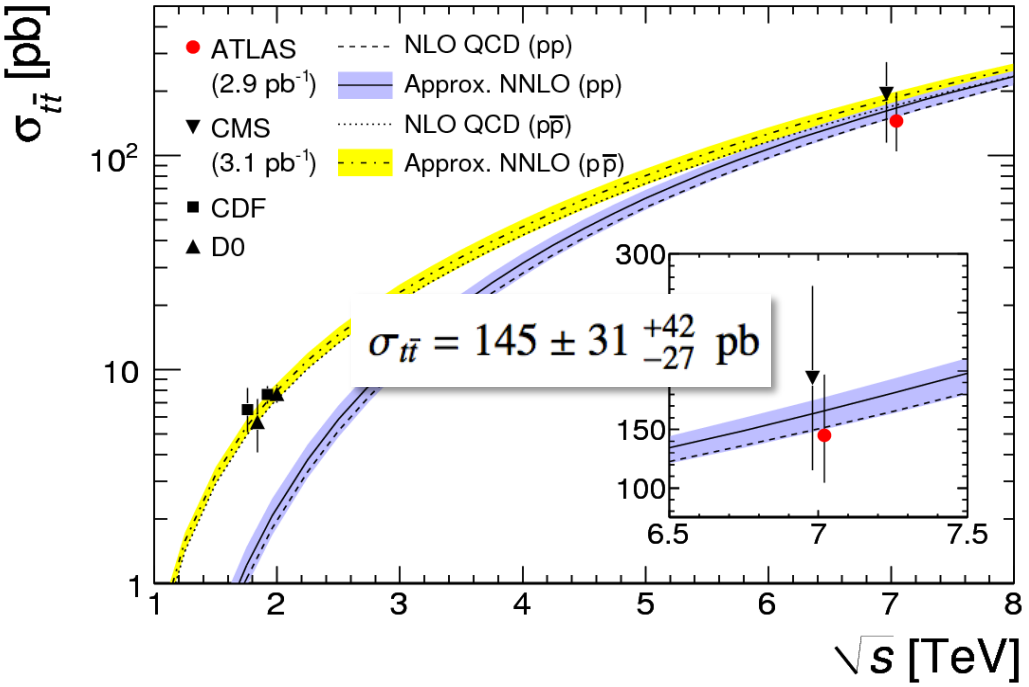
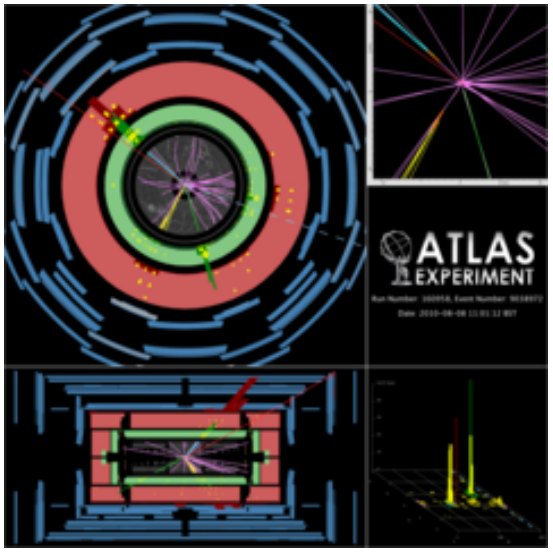




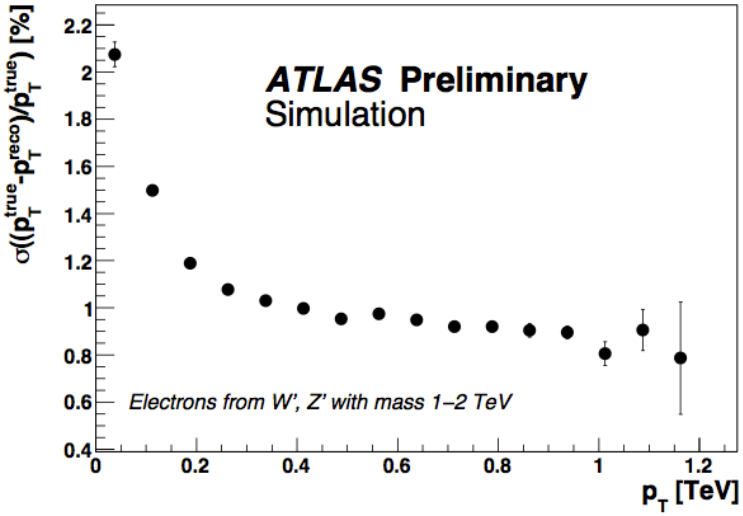
Most precise measurement at 7TeV!

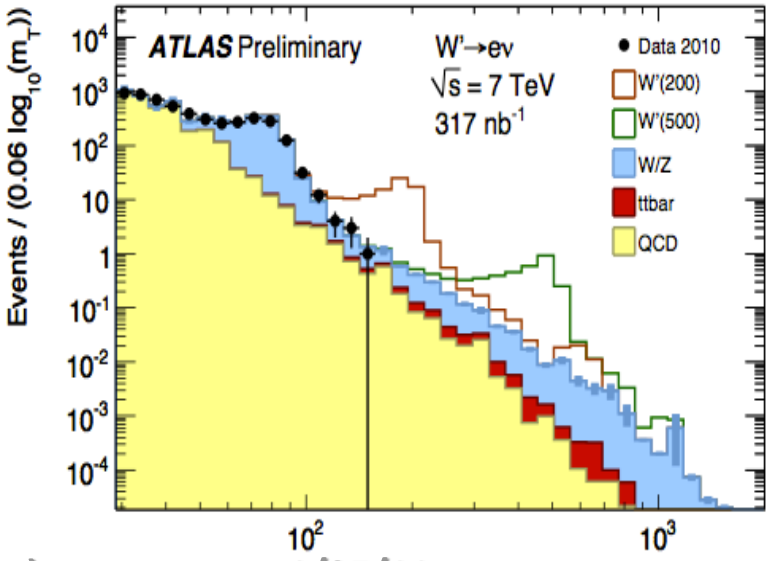
Dominating systematic uncertainties normalization of the QCD background

W' in the electron channel

ATLAS-CONF-2010-089

- Transverse mass is used to select events
- Main backgrounds are:
  - **SM W** (PYTHIA, MRST LO*) with NNLO cross sections from FEWZ (MSTW2008 PDFs). Mass dependence of the cross section corrected based on MCFM predictions
  - **QCD** normalized to low m_T (<20GeV)
- W' signal in Sequential SM (SSM)
- Limit is set using single bin Poisson likelihood (signal region m_T>700 GeV)
- With 317 nb^{-1} an SSM W' with mass less than 465 GeV is excluded at 95% CL.





Black Holes (I)

ATLAS-CONF-2010-088

- Signature of BSM theories with a new gravity scale of ~1TeV
  - Weakness of gravity is due to gravity propagating into higher dimensional space
  - New gravitational states can be produced close to the new mass scale and a continuum of non-perturbative states above it
  - Gravitational collapse occurs when partons approach closer than the Schwarzschild radius: R_s -> M=√s
  - Cross sections are ~ πR_S^2 ; black holes decay via Hawking evaporation emitting a large number of energetic objects

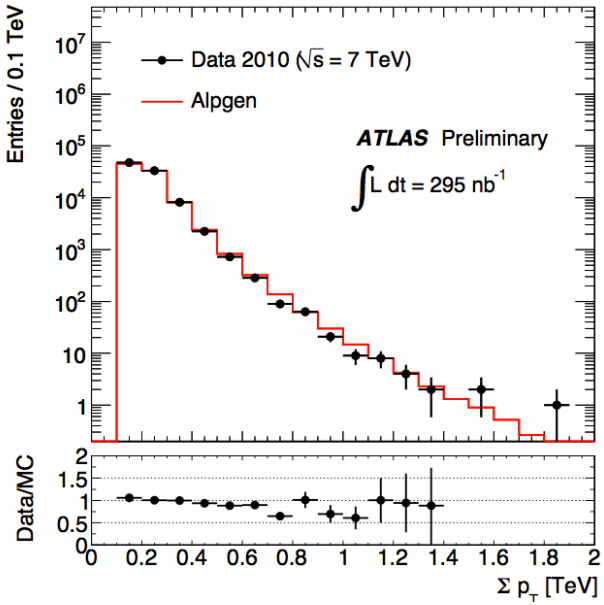
Look for excess in the 'invariant mass':

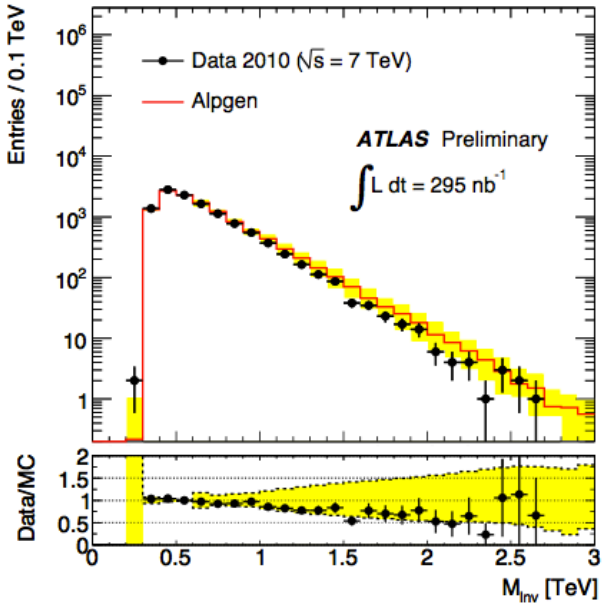
$$M_{\text{inv}} = \sqrt{p^2} \quad \text{and} \quad p = \sum_{i=\text{objects}} p_i + (E_{\text{T}}^{\text{miss}}, E_{\text{T}x}^{\text{miss}}, E_{\text{T}y}^{\text{miss}}, 0)$$

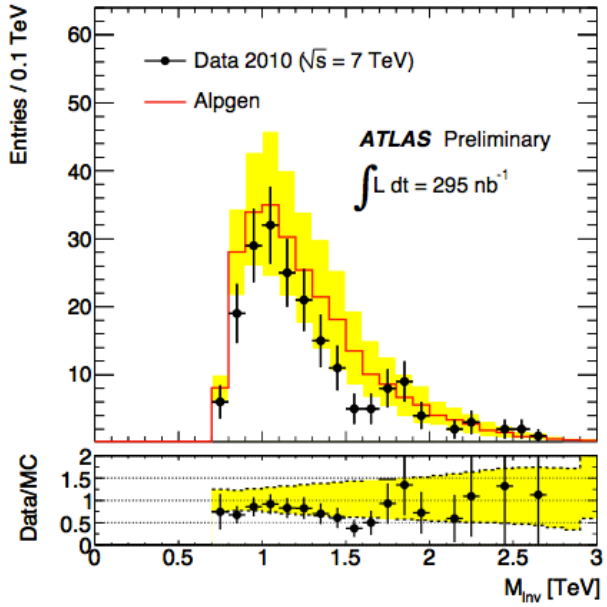
Black Holes (II)

- Data is polluted by multi-jet QCD, suppressed by requiring at least 3 objects in the events and the sum of transverse momentum to be above 300 GeV
- The shape is determined in ALPGEN and the yield normalize to data in control region (∑ pT > 300 GeV and 300 GeV < M < 800 GeV). Dominant syst. (~30%)

ATLAS-CONF-2010-088







- Signal region is:
  - ∑ pT > 700 GeV
  - M > 800 GeV
- 193 events are found; background is 254 ± 18 ± 84
- An upper limit of 0.34 nb at the 95% is set

2011, year of discovery?

Plan for 2011 operations

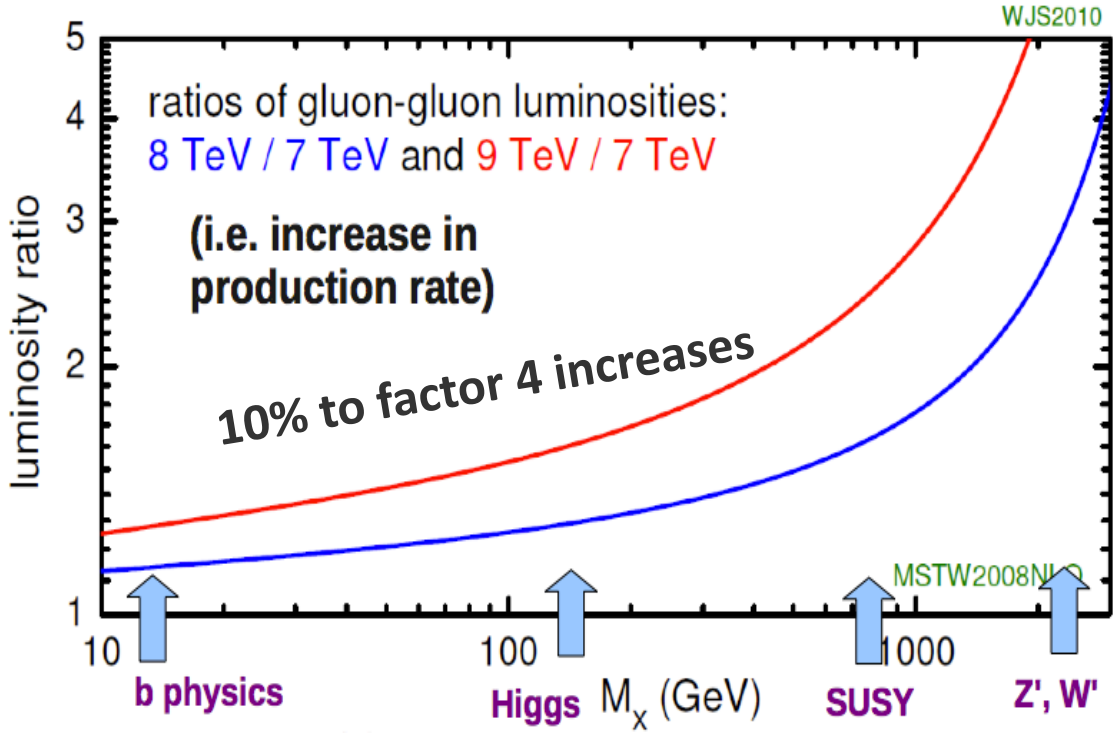
- During the LHCC in November 2010, two sets of machine parameters were presented
- Discussion is on-going at the **Chamonix Workshop**
  - **Monday 24 January to Friday 28 January**

Parameter	'Reasonable'	'Optimistic'
Beam E	4TeV	4TeV
No. bunches	936 (75ns)	1400
Emittance	3um	2.5um
Intensity	1.2 10^{11} p/b	1.5 10^{11} p/b
β*	2.5m	2.0m
200 days	2.2/fb	7.6/fb

Based on the experiments' inputs, machine status, consolidation plans, and final decision about Tevatron run beyond FY11 (*cancelled*), decisions being made on:

- Running at 4 TeV/beam
- Postponing 2012 shutdown to 2013
- Increasing the instantaneous luminosity to e33

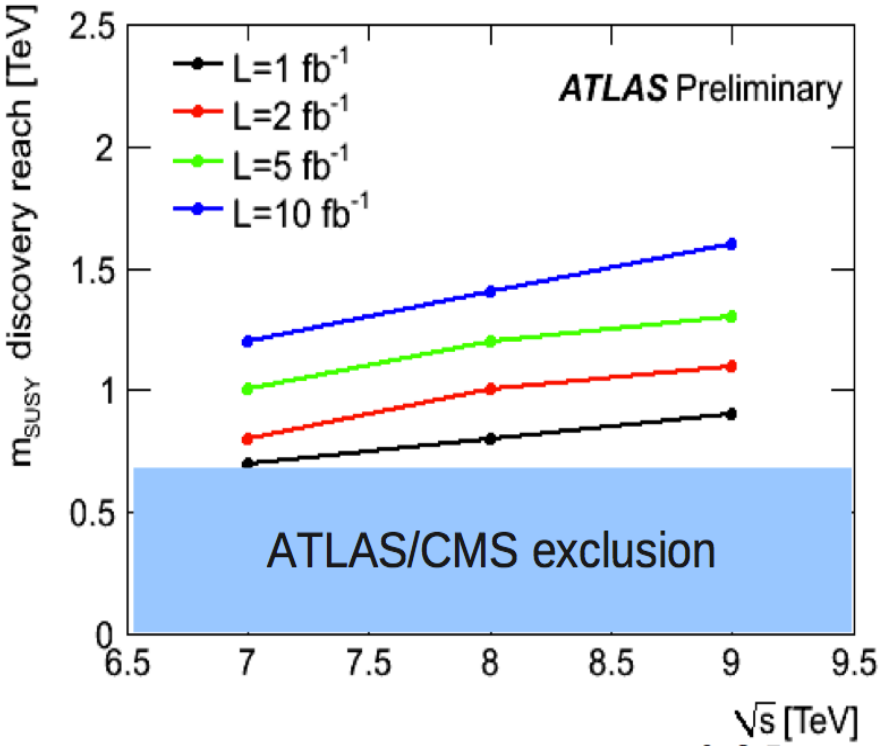
Discovery potential



SUSY potential

- The discovery reach scales as $L^{1/\alpha}$
  - α is the combination of two factors $\alpha 1$ and $\alpha 2$
    - dependence of the production cross-section ($m^{-\alpha 1}$)
    - selection efficiency ($m^{\alpha 2}$)
  - Based on CSC notes, $\alpha \sim 4$

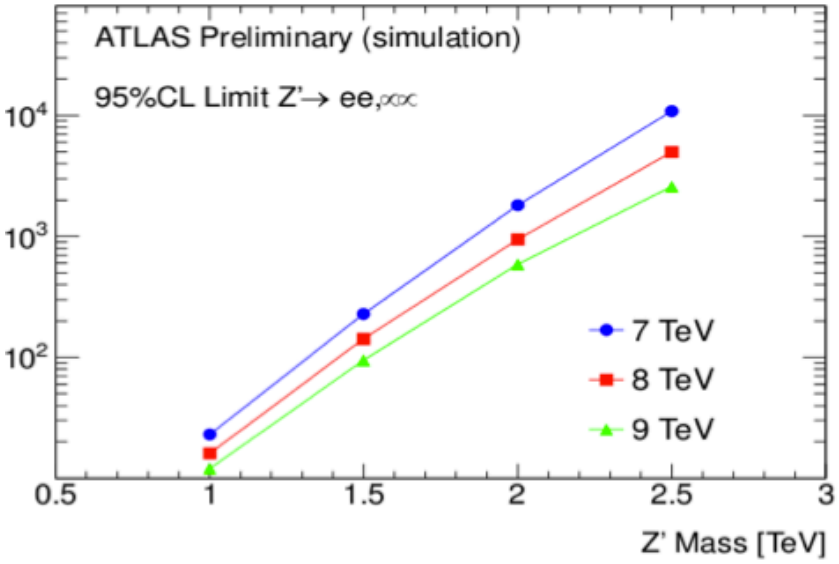
$$m_{SUSY} \sim \sqrt{s}/10 \times \mathcal{L}^{0.25}$$

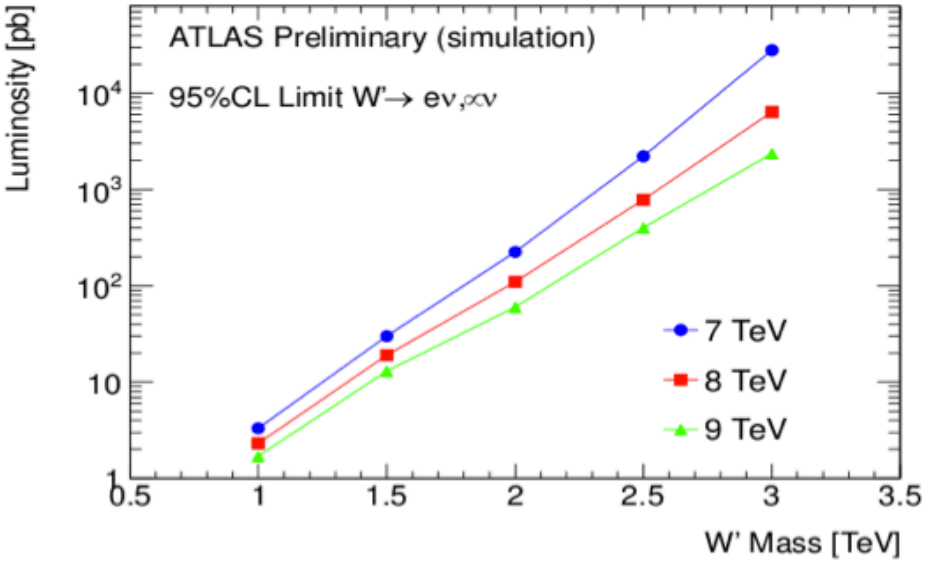


TRIUMF

W'/Z' potential

- Each 1TeV in the center of mass-energy halves the data needed for a discovery of a new gauge boson with SM couplings (SSM)

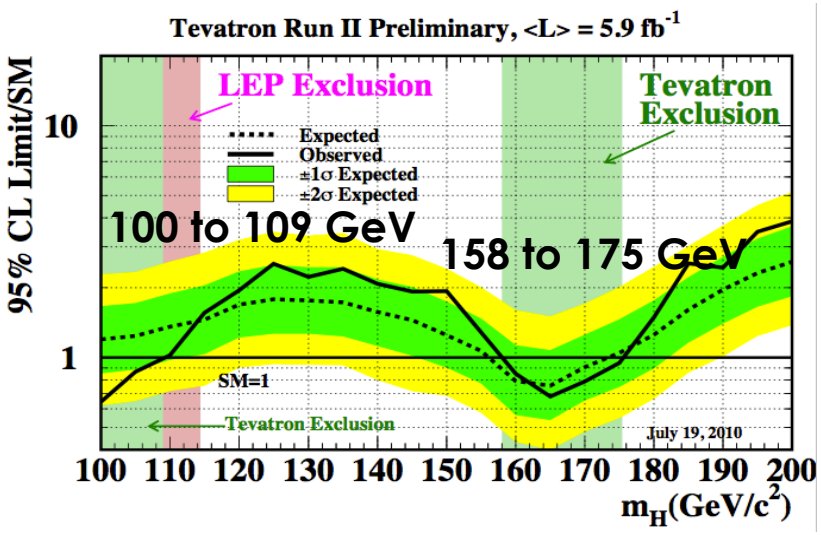


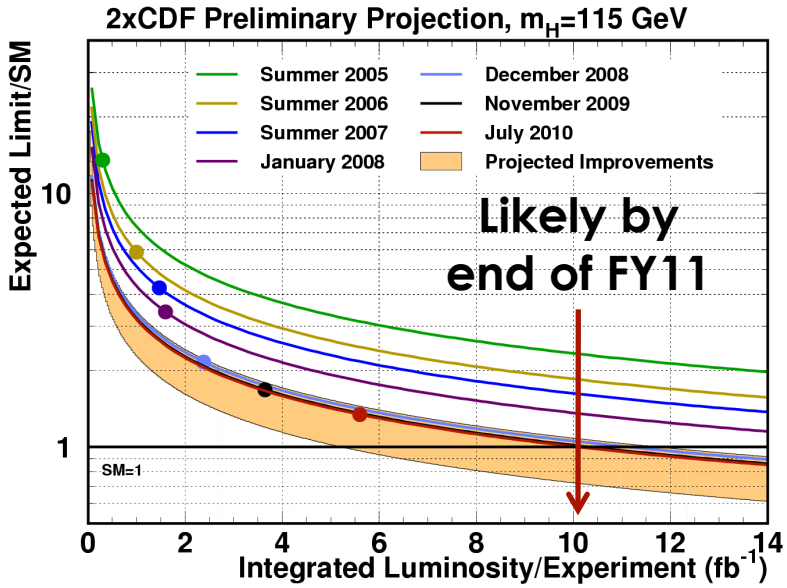


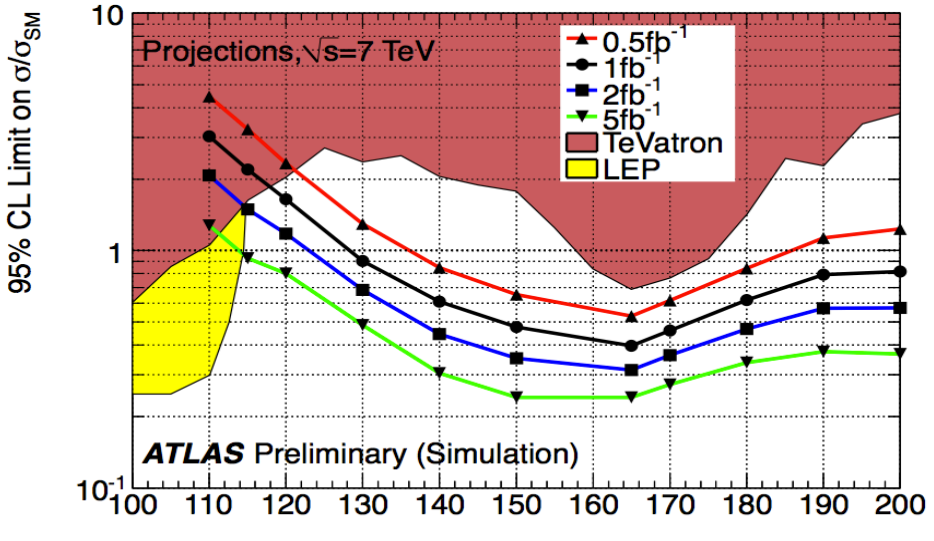
- Tevatron has excluded W' below 1.1 TeV (CDF, 5.3/fb), Z'ee below 1.023 TeV (D0, 5.4/fb), and Z'μμ below 1.071 TeV (CDF, 4.6/fb) at 95% C.L.

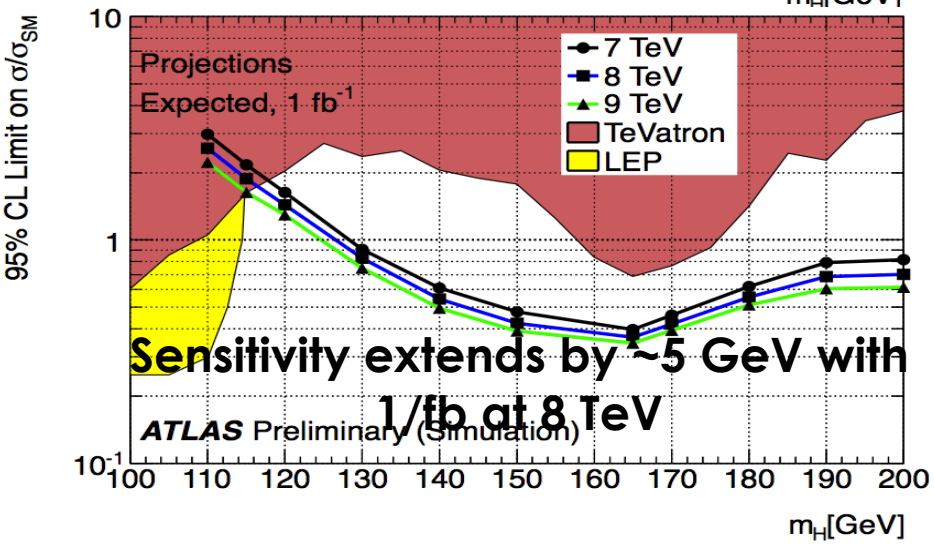
Potential for the Higgs (I)

With 5/fb (1/fb), ATLAS can exclude from 115 (130) to 200 GeV



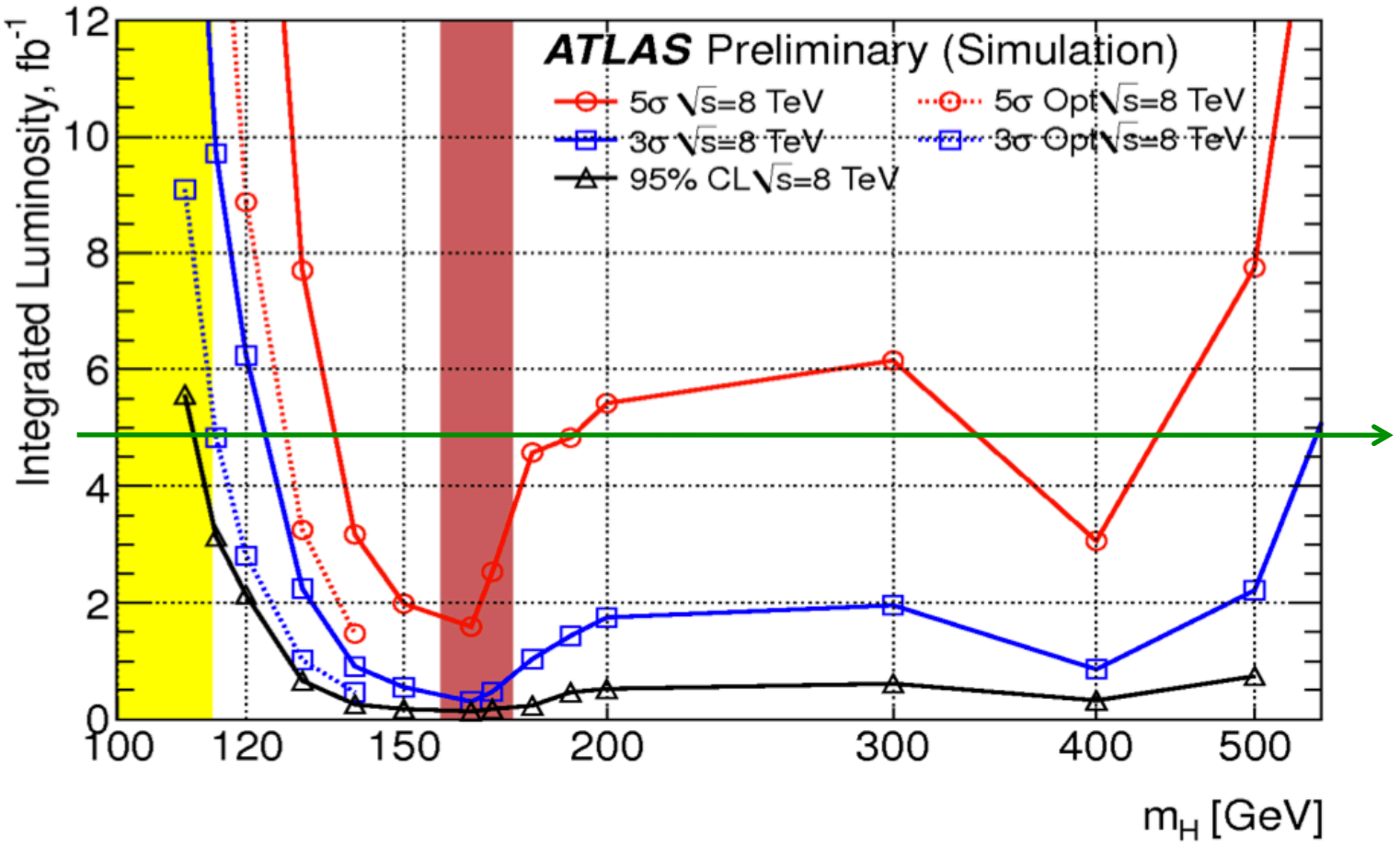






Potential for the Higgs (II)

With 5/fb at 8TeV ATLAS achieves 3σ for a Higgs mass from 114 to >500GeV



Conclusions

- We have entered the LHC era!
- The machine and the experiments are working extremely well
- ATLAS has already explored uncharted territories and set stringent limits on possible new models
- Many many more results are in the pipe line for the Winter Conferences 2011
- Discoveries can occur with the data we have already collected or the one to be delivered in the coming months
- The LHC has the potential to revolutionize our vision of the particle physics!

Additional material

Higgs at the Tevatron