Searches for Physics beyond the Standard Model with ATLAS

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(on behalf of the ATLAS Collaboration)

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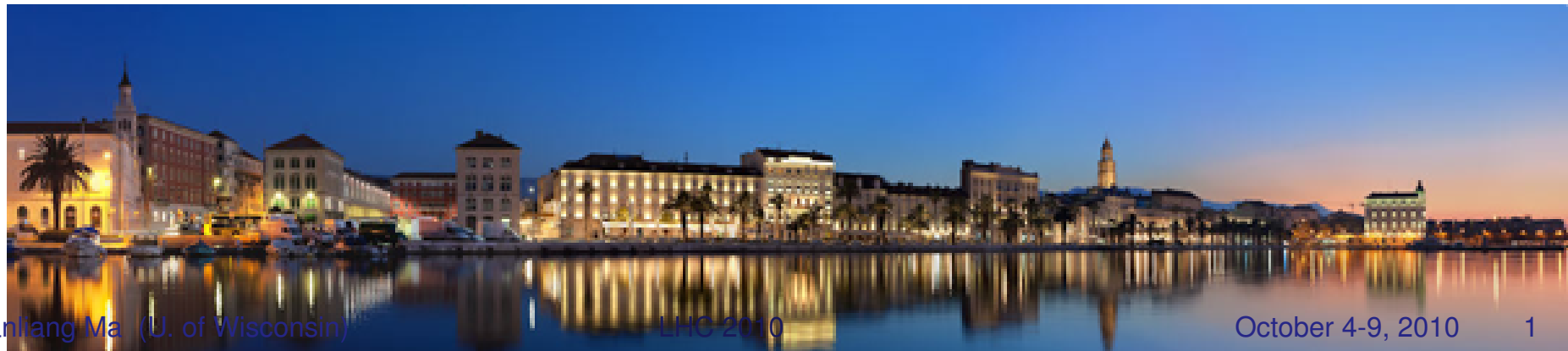


Outline

This talk reports the status of early searches for new physics beyond SM (a few pb^{-1}):

1. Dijet resonance
2. Dijet non-resonance using angular distributions
3. High invariant mass states in multi-object final state
4. Lepton + $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ (W')

There are also other analyses ongoing (not covered):

- Universal Extra Dimension (UED),
- Dilepton (Z'),
- Leptoquark pairs,
- Majorana neutrinos,
- Resonances in $t\bar{t}$ and vector boson scattering,
- and etc. More: https://twiki.cern.ch/twiki/bin/view/Atlas/ExoticsPublicResults

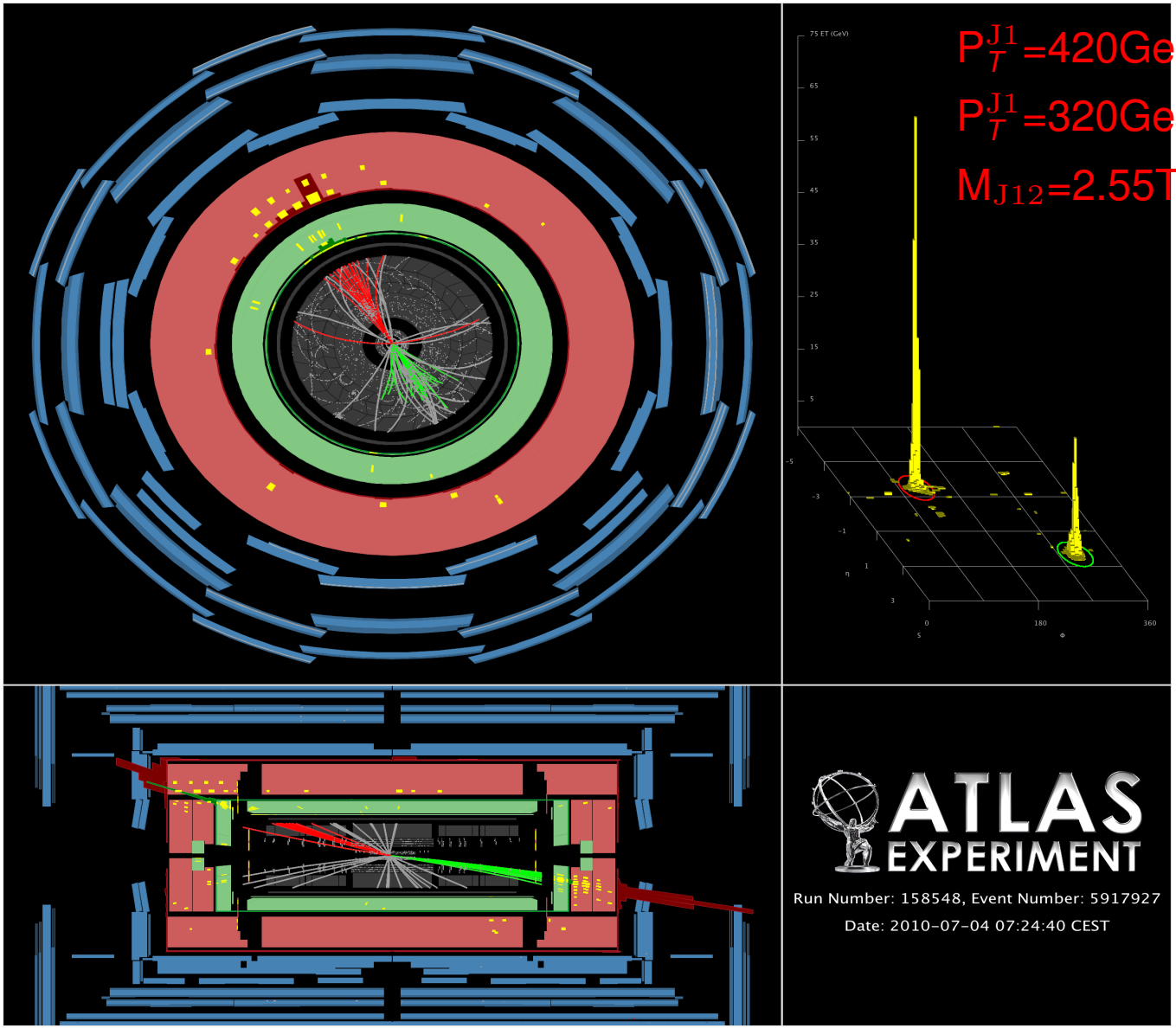
Search for Dijet Resonance (1)

- Possible resonances decaying into dijet :
  - Excited quarks ($qg \rightarrow q^*$)
  - Axigluons in chiral color models
  - W' or Z' in grand unified theories
  - ...
- Observable : dijet mass spectrum in the inclusive dijet final state

$$M_{jj} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

  - Probe new kinematic region
  - Sensitive to the above new models.
- Benchmark signal : excited quark q^*
  - Current limit from Tevatron : $m_{q*} > 870$GeV at 95% CL
    [CDF collaboration, PRD 79 (2009) 112002]

Search for Di-jet Resonance (2)



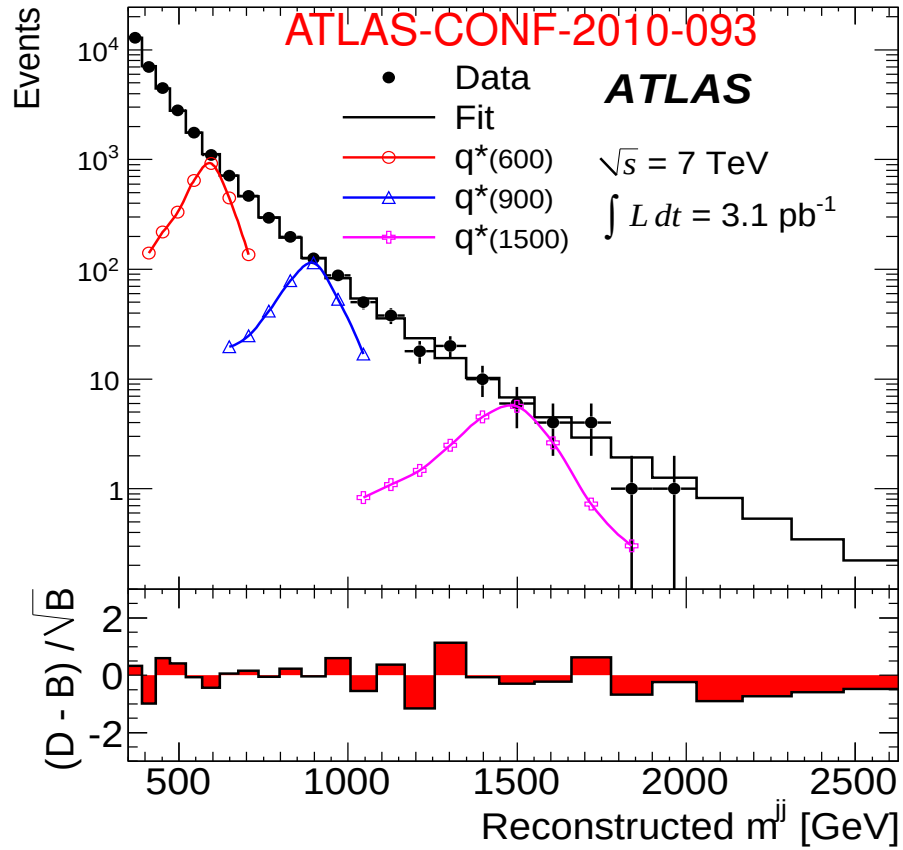
Search for Di-jet Resonance (3)

- Anti-Kt jet with R=0.6
- Jet selection:
  - $p_T^{jet1} > 150$ GeV, $p_T^{jet2} > 30$ GeV
  - $|\eta^{jet}| < 2.5$; excluding $1.3 < |\eta^{jet}| < 1.8$
  - $|\Delta\eta| < 1.3$
- Background shape as:

$$f(x) = p_0 \frac{(1-x)^{p_1}}{x^{[p_2+p_3 \ln(x)]}},$$

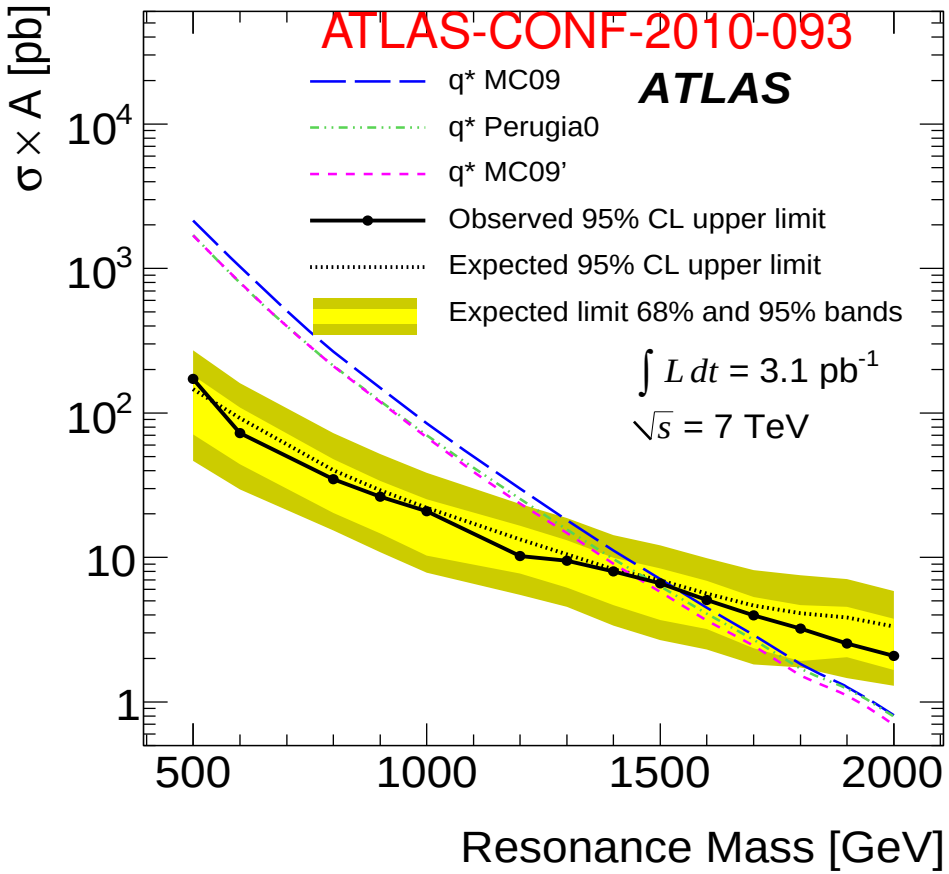
$$x = M_{jj}/\sqrt{s}$$

$p_{0,1,2,3}$: free parameters to constrain $f(1) = 0$, and $f(0) \to \infty$. The $x^{[p_3 ln(x)]}$ for the high-m^{jj} part. (Also used in PRD 79 (2009) 112002).



Multiple statistical tests indicate an agreement between data and smooth monotonically decreasing function.

Search for Di-jet Resonance (4)



Excluded at 95% CL :

- 0.5 TeV$<m_{q^*}<$1.53 TeV, ATLAS default MC settings with MRST2007 LO
- First world best limit published from ATLAS.

Search for Quark Contact Interaction (1)

If quarks are made of constituents, then at the scale of the compositeness scale (Λ), new interactions among quarks should appear.
Benchmark: *qq* contact interaction.

- Exotic signal: mainly *s*-channel; QCD process: mainly *t*-channel
- Observables:

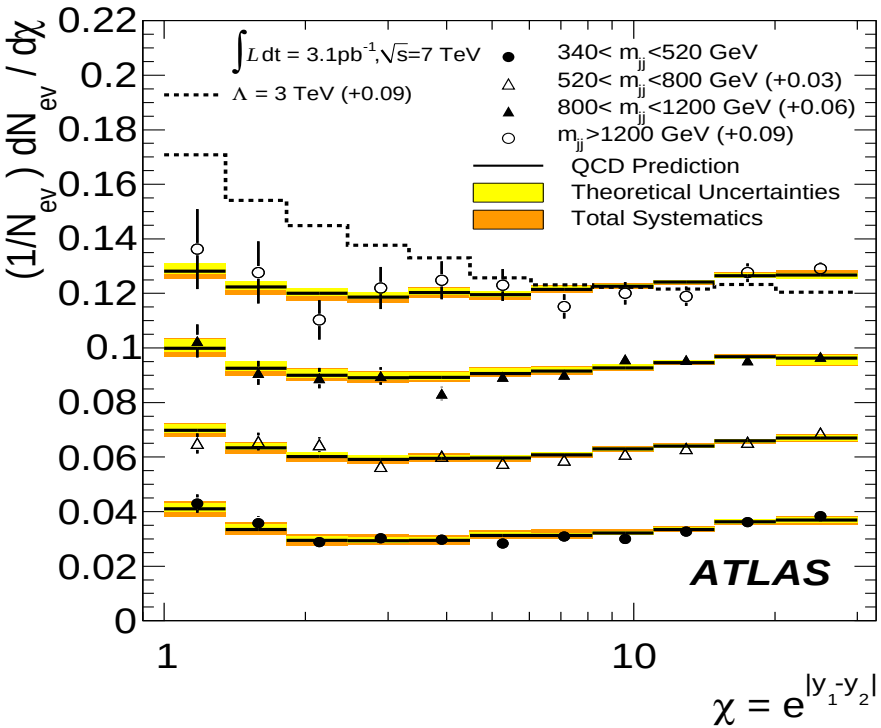
$$\chi = \exp(|y_1 - y_2|), \quad \text{Centrality ratio } R_C = \frac{\mathrm{N}(|\eta_{1,2}| < 0.7)}{\mathrm{N}(0.7 < |\eta_{1,2}| < 1.3)}$$

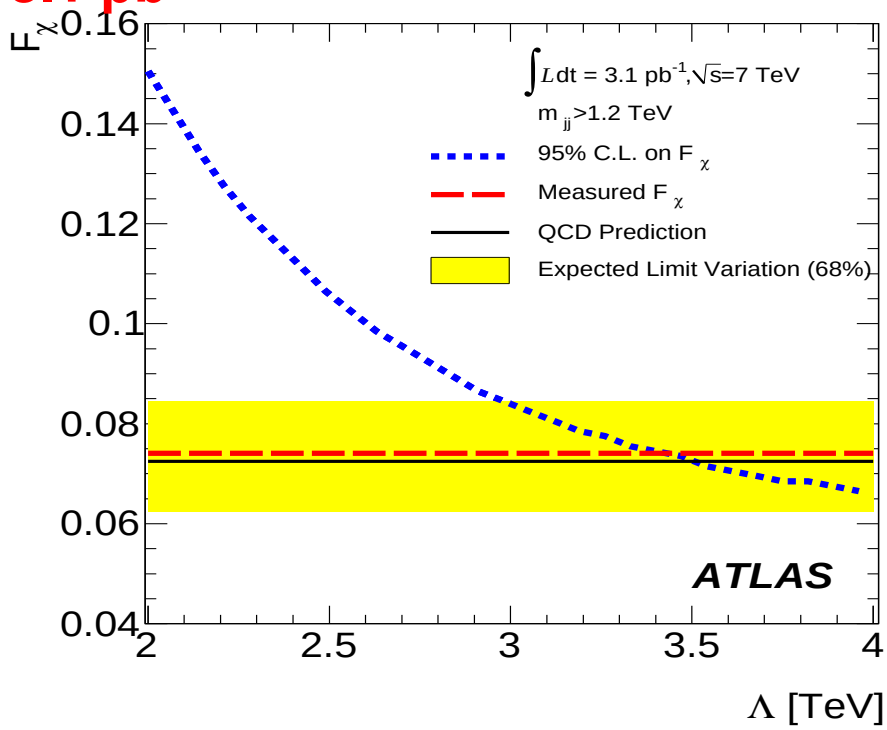
  - Flat distributions for QCD processes on both observables
  - New physics signals: excess of events at low χ, or larger R_C value at high dijet masses.

- Events selection:
  - Anti-Kt with R=0.6: $p_T^{j1} > 60$GeV, $p_T^{j2} > 30$GeV, $|\eta_1| < 2.8$, $|\eta_2| < 2.8$
  - $|y_1 + y_2| < 1.5$ to reduce impact of PDF uncertainties

Search for Quark Contact Interaction (2)

Lumi = 3.1 pb^{-1}



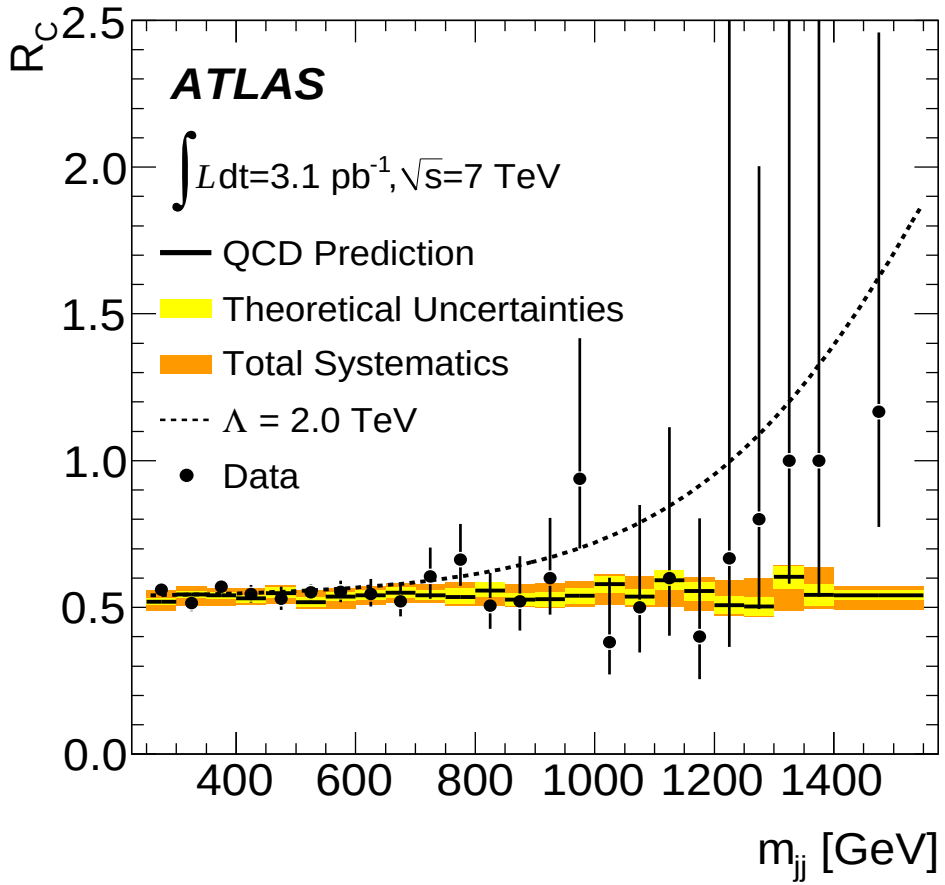


- Data agrees with SM prediction within errors
- F_χ: ratio of the number of events in the first 4 χ bins to that in all χ bins.
- Exclude the compositeness scale Λ below 3.4 TeV at 95% CL, corresponding to a distance scale of 6×10^{-5} fm
- Surpasses the best published limit 2.8 TeV (D0 Collaboration, PRL 103:191803, 2009)

Search for Quark Contact Interaction (3)

Lumi = 3.1 pb^{-1}

- Centrality ratio
  $R_C = \frac{\mathrm{N}(|\eta_{1,2}|<0.7)}{\mathrm{N}(0.7<|\eta_{1,2}|<1.3)}$
- Good agreement between data and QCD prediction with χ^2/NDF=0.61
- Limit on compositeness scale Λ at 2.0 TeV at 95% CL
- The weaker limit than the result from the χ analysis, expected to be due to the lower η acceptance

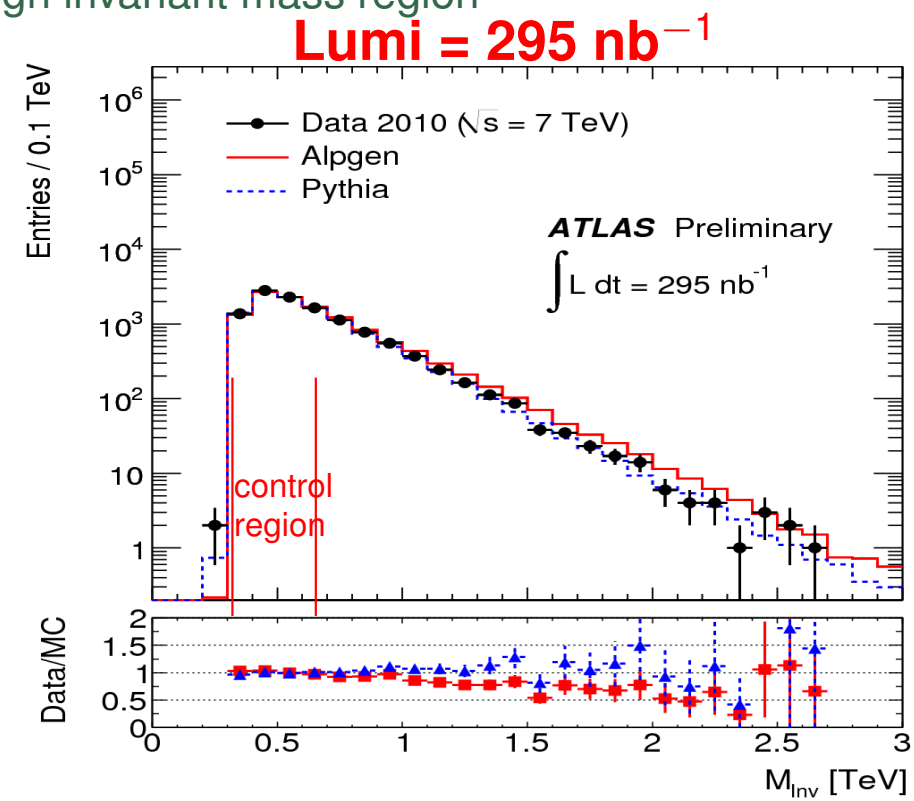


Submitted to PLB, and available at [arXiv:1009.5069]

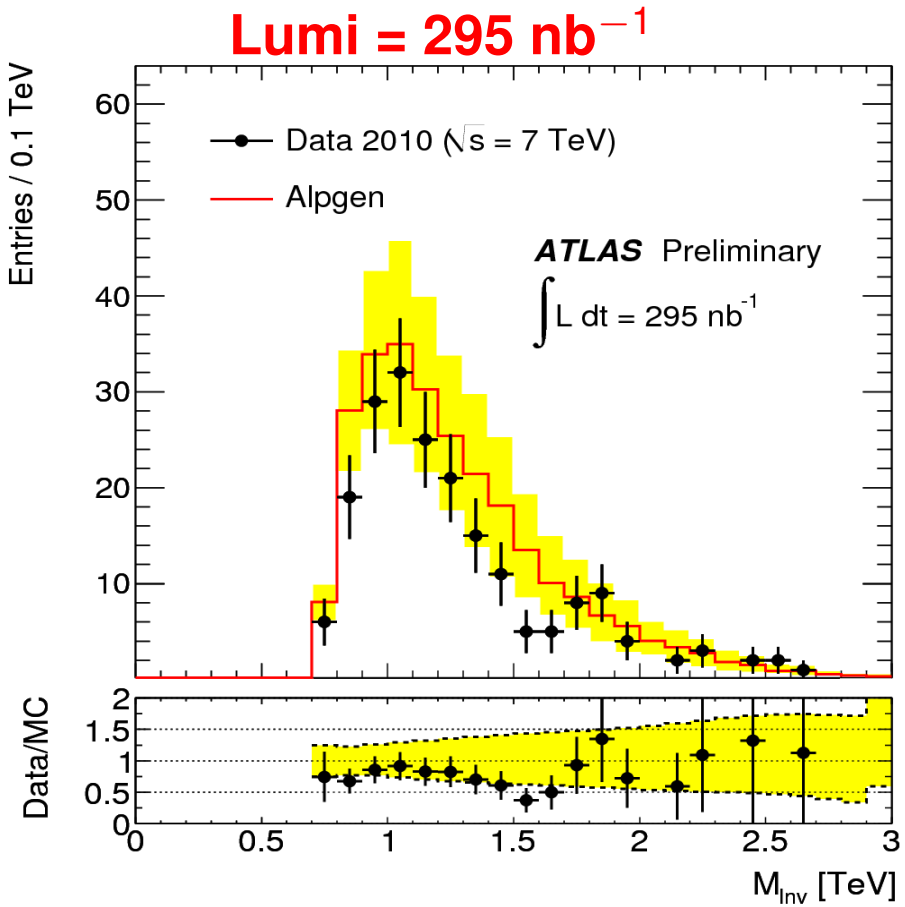
Search for New Physics with Multi High-p_T Objects

- The fundamental scale of gravity M_D in TeV scale in extra dimensions model
- Basic assumptions for gravitational states :
  - Decays democratic to all degrees of freedom in SM
  - Detector signature: several high-pt objects: *e*, γ, μ, jet
  - Deviation from SM in the high invariant mass region

- Benchmark : TeV Gravity models (e.g. Black holes, string balls)
- Observables : No. of obj $\geq$3
  - $M_{inv} = \sqrt{\sum E_i^2 - \sum \vec{P}_i^2}$
  - sumPt = $\sum P_{Ti}$
- Control region :
  - sumPt>300GeV
  - 300GeV<M_{inv} <700GeV



Search for New Physics with Multi High-p_T Objects



Signal region :

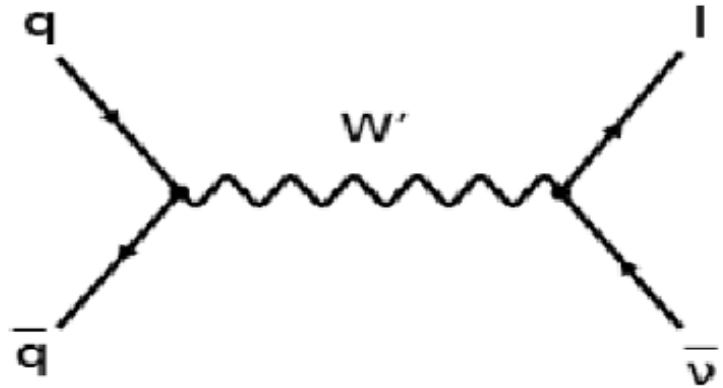
- sumPt$>$ 700GeV
- M_{inv} $>$800GeV

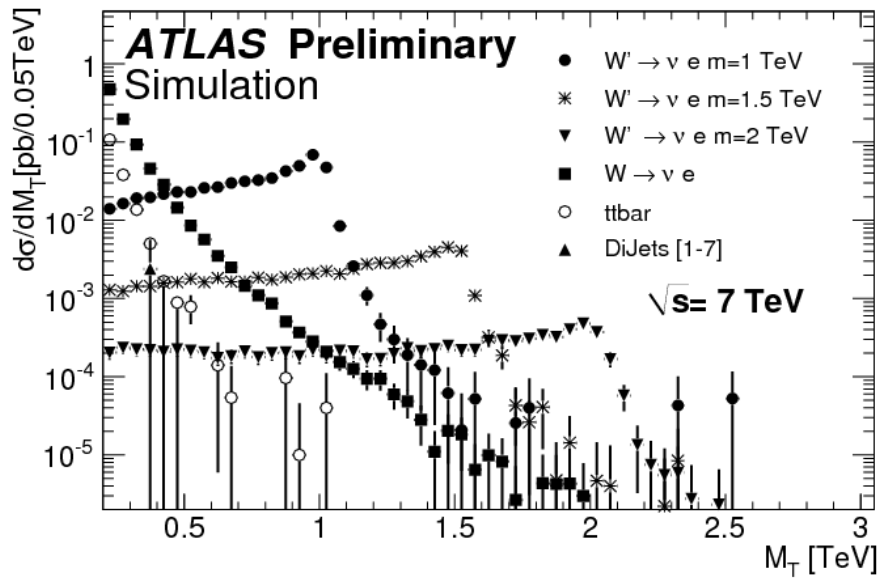
Results :

- Observe 193 events in the SR
- Consistent with the estimated background $254 \pm 18 \pm 84(sys.)$
- An upper limit of 0.34 nb on $\sigma \times$Acceptance at 95% C.L.

Search for New Physics in Lepton + E_T^{miss}

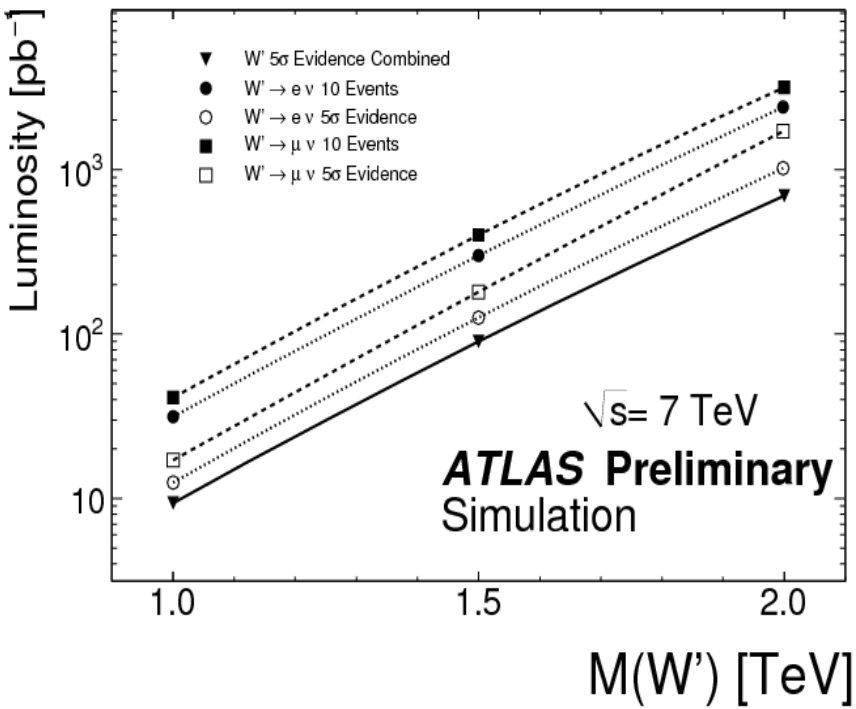
- Benchmark signal: W' decaying into lepton + neutrino
- Current limit: $M_{W'} > 1.0$ TeV at 95% C.L. (D0 Collaboration, PRL **100** (2008) 31804)
- Main backgrounds:
  - High m_T tail of SM W
  - Reducible backgrounds: $t\bar{t}$, dijets, Drell-Yan
- Main systematics:
  - Integrated luminosity
  - Background estimation
  - Lepton ID efficiencies





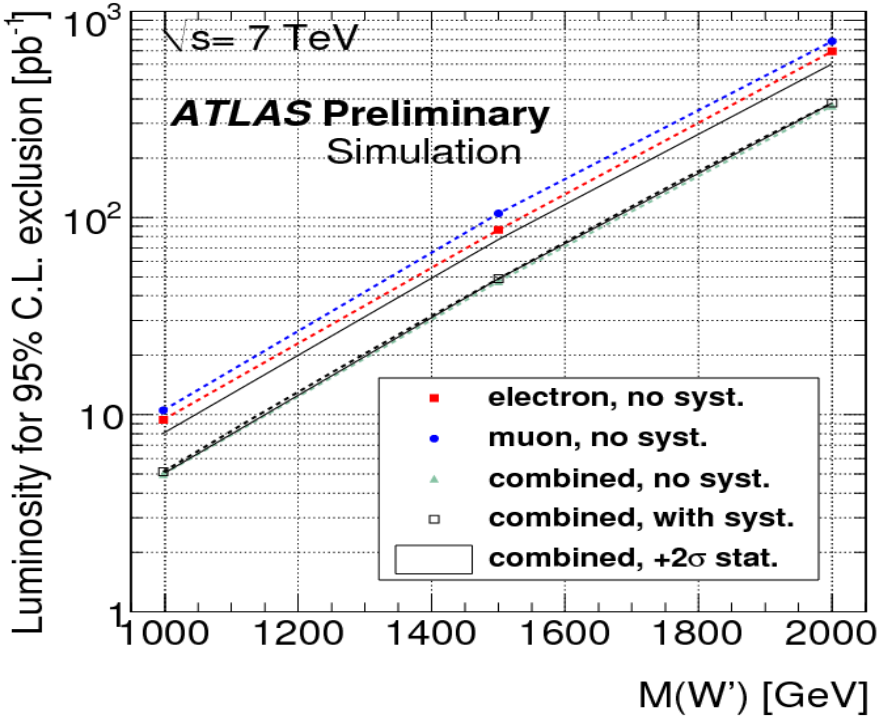
W' Prospects at $\sqrt{s} = 7$ TeV

Discovery



Discovery potential with $\sim$ 10-20 pb^{-1}

Limit on the mass at 95% C.L.



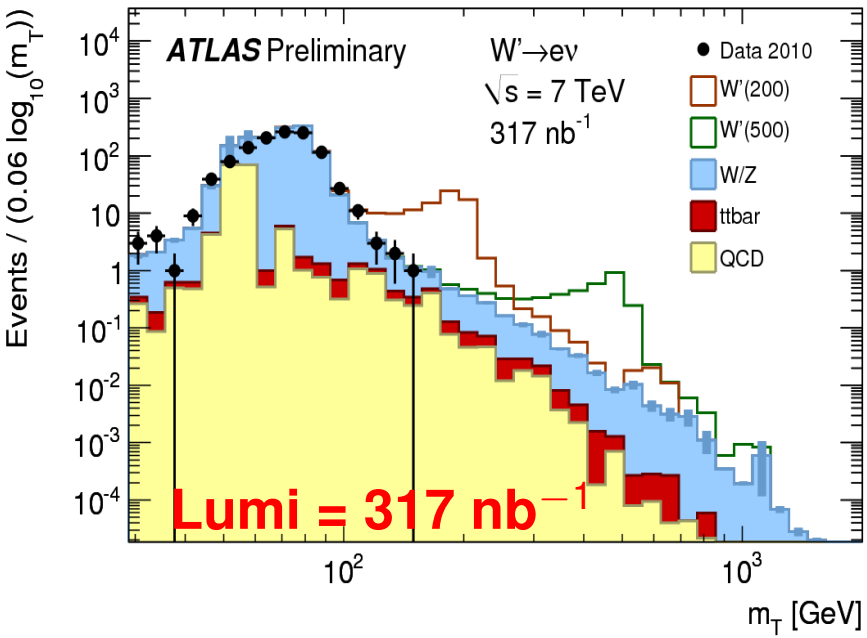
Improve current limits with $\sim$ 5 pb^{-1}

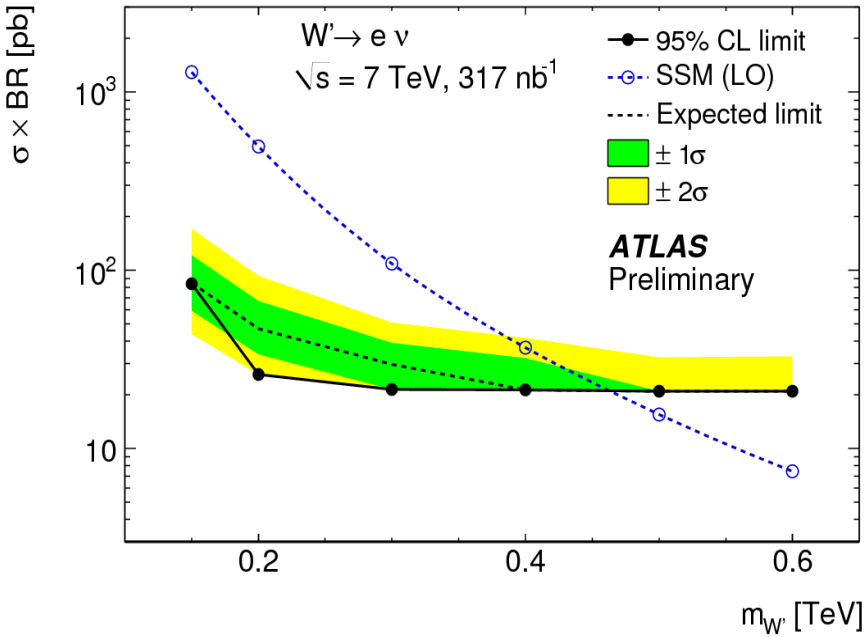
Status of W' with Data (Electron + $\mathrm{E_T^{miss}}$)

Observable :

$$\mathrm{M_T} = \sqrt{2\mathrm{p_T^l}\mathrm{E_T^{miss}}(1 - \cos\Delta\phi_{\mathrm{l,E_T^{miss}}})}$$

- High pt isolated electron (> 25 GeV)
- Large $\mathrm{E_T^{miss}}$ (> 25 GeV)





- Data is consistent with SM predictions.
- Limit at 95% C.L. is set $>$ 465 GeV for SSM W'.
- Expect to surpass the current best limits on W' (1 TeV) with 5 pb^{-1} data

Conclusions

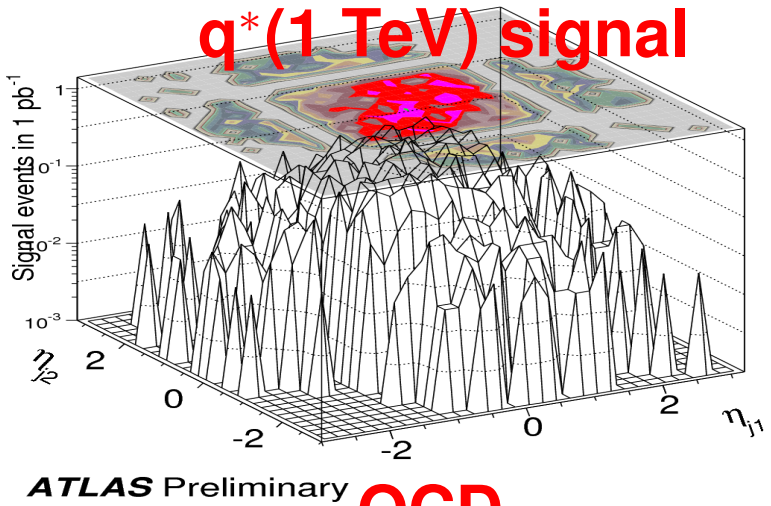
- ATLAS has started to explore physics in new territory!
  - Preliminary results show that data is consistent with SM predictions.
  - Dijet resonance (3.1 pb^{-1}) :
    - Exclude 0.5 TeV$<m_q^*<$1.53 TeV
    - Surpassed the world's best limit, paper accepted by PRL (arXiv:1008.2461).
  - Dijet angle distribution (3.1 pb^{-1}) :
    - Limit on compositeness scale $\Lambda > 3.4$ TeV
    - Surpassed the world's best limit, submitted to PLB
  - High invariant mass in Multi-object final state (295 nb^{-1}) :
    - The upper limit of 0.34 nb with $M_{inv} > 800 GeV$, sumPt>700GeV
  - Lepton + E_T^{miss} 317 nb^{-1}:
    - Exclude SM-like W' $<$ 465 GeV with only electron channel
    - Expect 5 pb^{-1} to surpass the current best limit

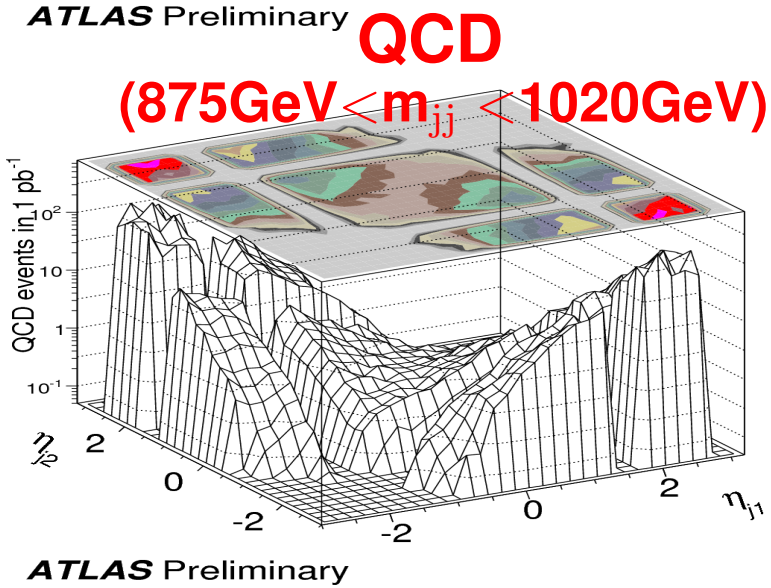
More data on the way, more exciting results from ATLAS!

Extra slides

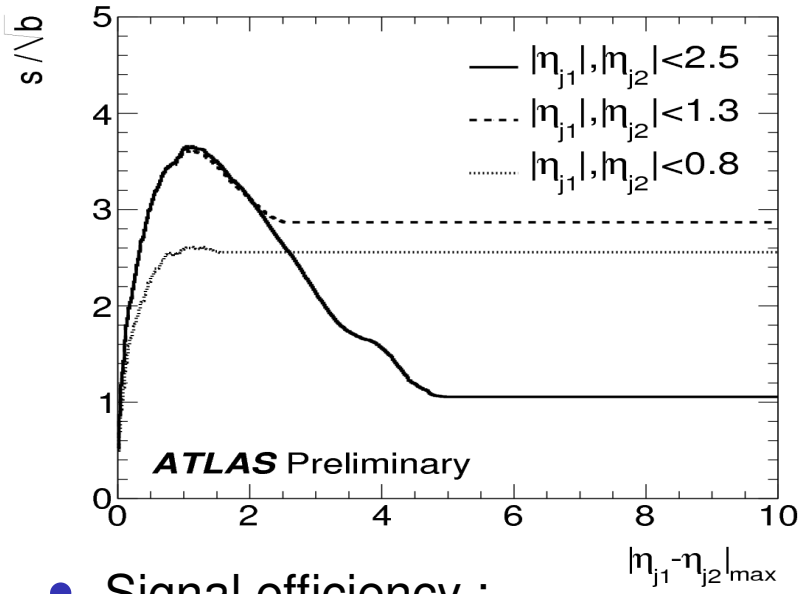
Search for Dijet Resonance

- Jet reconstruction algorithm : Anti-Kt with R=0.6
- Events accepted by single jet trigger
- Jet1 : P_T >150GeV, Jet2 : P_T >30GeV
- Remove event if leading or next leading jet in 1.3< $|\eta|$ <1.8
- Jet1 : $|\eta|$ <2.5 Jet2 : $|\eta|$ <2.5
- $\Delta\eta$ <1.3, QCD jets are forward(large $|\Delta\eta|$), signal is more central





Search for Dijet Resonance



- Signal efficiency :
  - 36% ∼ 400GeV, 49%∼ 1.5TeV
- Systematic Uncertainties :
  - Jet energy scale (dominant)
  - Background fit parameters
  - Integrated luminosity
  - Jet energy resolution (small)

- Six statical test :
  - BumpHunter
  - Jeffreys divergence
  - Kolmogorov-Smirnov test
  - Likelihood
  - Pearson χ^2
  - TailHunter statistic
- The results of all six tests are consistent wit the fitted result with *p*-values inexcess of 49%.
- The p-value of the background-only hypothesis is defined as the fracion of the pseudo-experiments that results in a value of given statistics greater than the value of the same statistic found by the fit to the data.

Search for Quark Contact Interaction

If quarks are made of constituents, then at the scale of the constituent binding energy (Λ), new interactions among quarks should appear. If Λ is much larger than $\sqrt{\hat{s}}$, these interactions are suppressed by inverse powers of Λ and the quarks would appear to be point-like. The dominant effect should then come from the lowest dimensional interactions with four fermions (contact terms). The contact interaction model used here is described by the effective Lagrangian:

$$L_{qqqq}(\Lambda) = \frac{\eta g^2}{2(\Lambda^{+}_{LL})^2_q} \bar{\Psi}^L_q \gamma^\mu \Psi^L_q \bar{\Psi}^L_q \gamma^\mu \Psi^L_q,$$

where $\eta = +1$ (destructive interference), $g^2/4\pi = 1$ and the quark fields Ψ^L_q are left-handed (this is the *LL* Model).
The full lagrangian is the sum of the Lagrangian in the above equation and the QCD lagrangian.

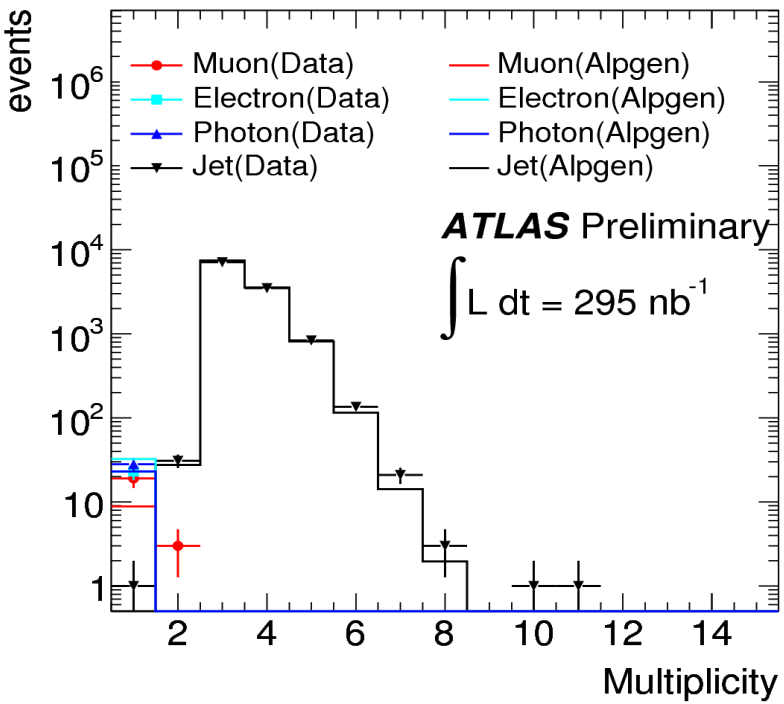
Search for New Physics with Multi High-p_T Objects

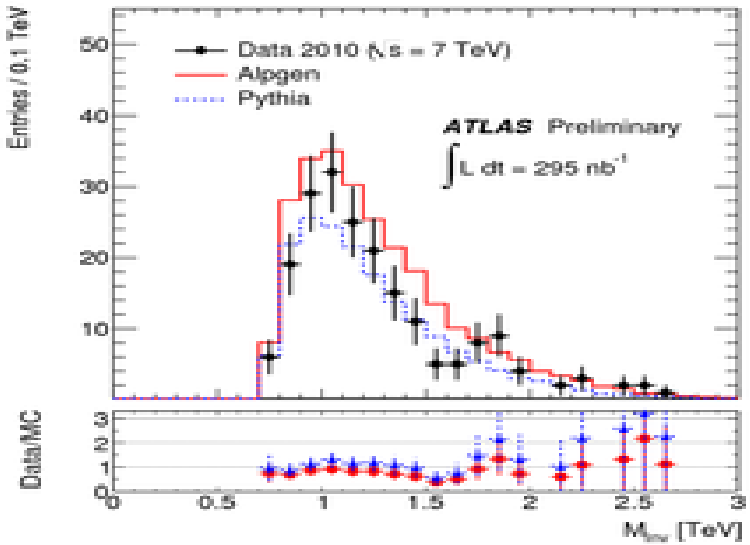
In extra dimensions model, the fundamental scale of gravity, M_D is expected to be in TeV range.

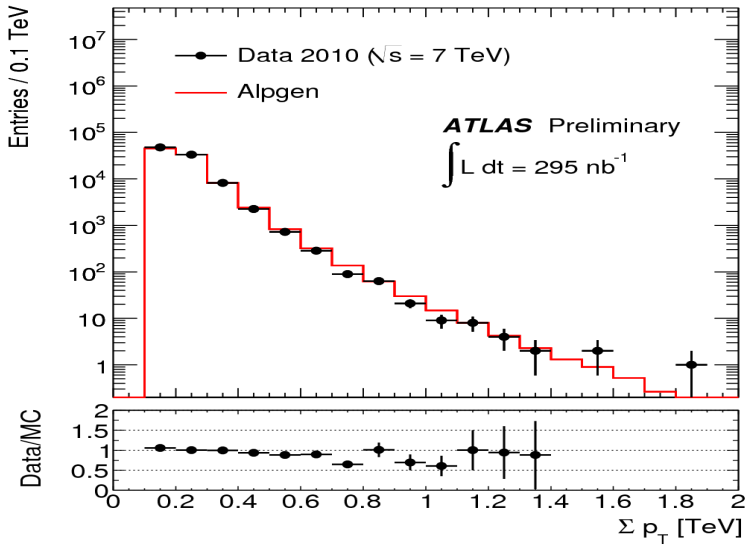
- Some low-scale gravity models predict a continuum production of mon-perturbative gravitational states above the new mass threshold.
- Rely on a few basic assumptions for the behaviour of final states arising from gravity in the quantum regime, we expect deviation from the SM in the high invariant mass distribution of several high-pt objects.
- Since gravity couples only to the energy-momentum content of matter, the decays of strong gravitational objects are approximately democratic to all degrees of freedom in the SM
- Event generator: CHARYBIDS2 and BLACKMAX2. All samples are produced with an energy threshold equal to the Planck scale of 800 GeV and six extra dimensions.

Search for New Physics with Multi High-p_T Objects

- Objects are :
  - certral jets (pt>40GeV)
  - e/γ (pt>20GeV)
  - μ (pt>20GeV)
  - MET, only used in M_{inv}





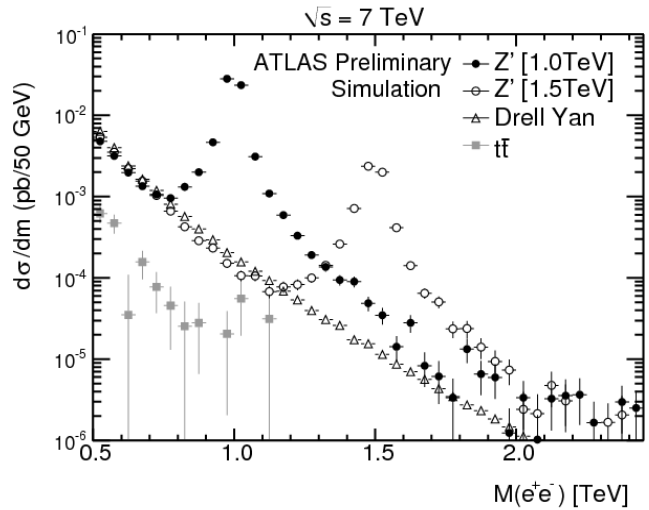


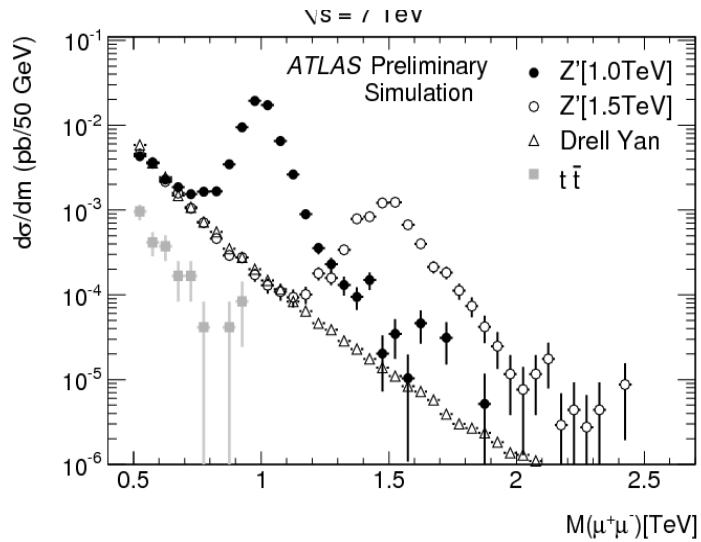
Search for DiLepton Resonance

- Benchmark signal: Z' Boson
  - Current limit from CDF $M_{Z'_{SM}} > 1$TeV (CDF Collaboration, PRL **102** (2009) 091805)
- Observable : Invariant mass

$$M_{l^+l^-} = \sqrt{(E_{l^+} + E_{l^-})^2 - (\tilde{p}_{l^+} + \tilde{p}_{l^-})^2}$$

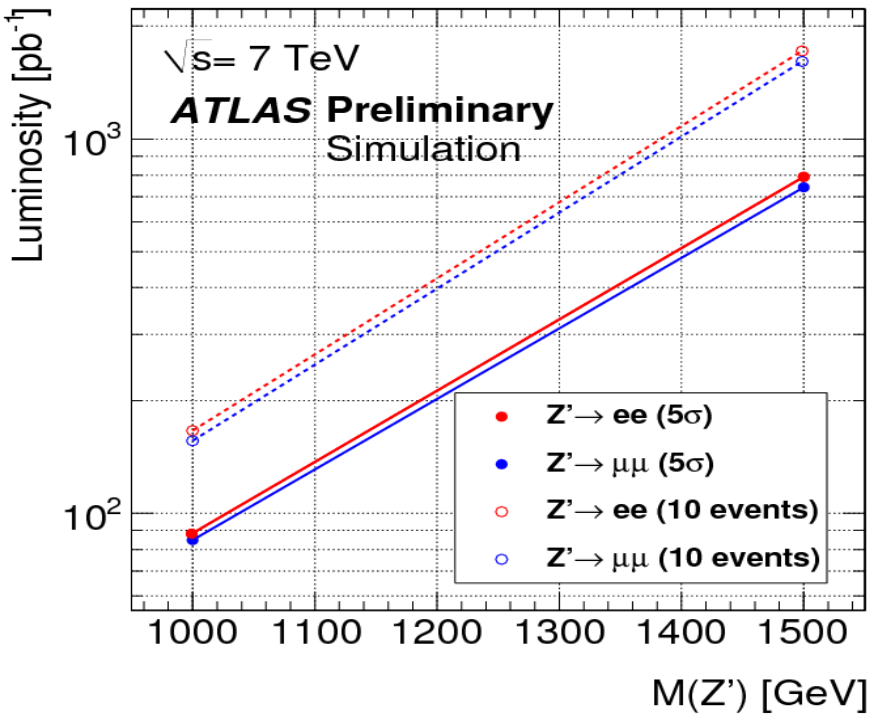
- Event selection :
  - Two high-pt isolated leptons (pt>20GeV)
  - Lepton $|\eta| < 2.5$
- Main background :
  - High mass Drell-Yan





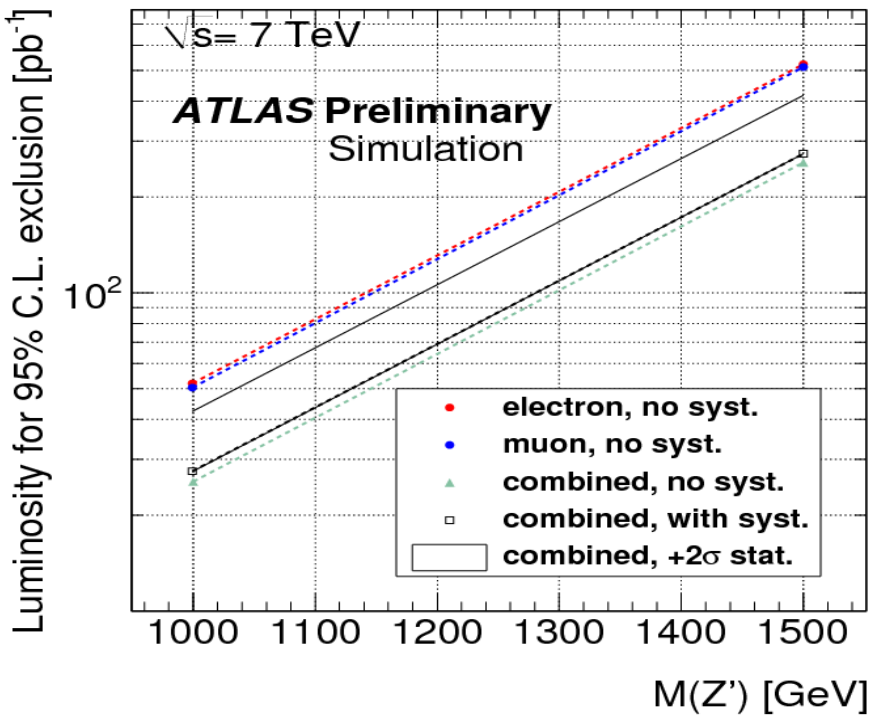
Search for DiLepton Resonance

Discovery



Discovery potential with $\sim 100 pb^{-1}$

95% C.L. mass Limit



Improve limit with $\sim 30 pb^{-1}$