
New Phenomena
at ATLAS & CMS
NExT Meeting, RAL

Introduction

- LHC exotica searches offer real possibilities of exciting discoveries in 2011 !

I will:

1. Summarize UK interests

2. Review *most* the public CMS/ATLAS exotica (but not SUSY) results, emphasising those with UK involvement.

   (but not black-holes, as covered in Eram's talk)

3. Illustrate what we can expect in 2011.

UK Exotica Interests

The UK has provided both ATLAS & CMS exotica conveners:

- ATLAS: Cigdem Issever (Oxford)
- CMS: Chris Hill (formally Bristol)

and is pursuing many experimental analyses:

CMS: Stopped Gluinos (Bristol), Z' → e+e- (Bristol/RAL/Soton) ,
Displaced Fermions (RAL/Soton), Boosted Z from q*... (RAL)

ATLAS: Black holes & Extra Dimensions (Cambridge/Oxford),
Z' → e+e- (RHUL), q* → dijets (Oxford/Glasgow) ,
G→γγ (Liverpool), Boosted Top from Z' (Oxford/UCL) ...

+ those I missed !

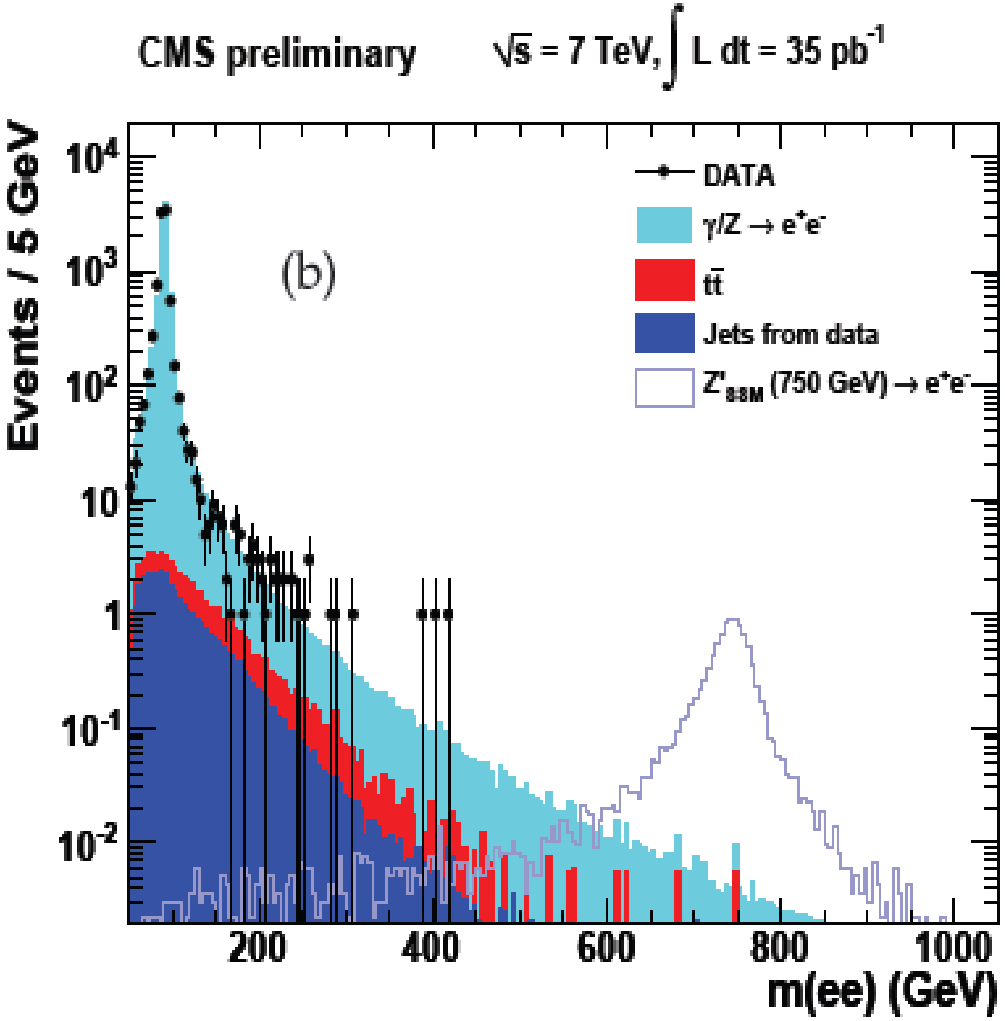
Public Exotica Results with LHC Data

- Areas with UK involvement in pink.

	ATLAS	CMS
$Z' \rightarrow l\,l$		√
Heavy Stable Charged Particles		√
Stopped Gluinos		√
$q^* \rightarrow$ dijets	√	√
Dijet contact interactions	√	√
Black holes	√	√
$LQ \rightarrow l$ + jet		√
$W' \rightarrow e\,\nu$	√	√
UED KK $\gamma^*\gamma^* \rightarrow \gamma\gamma + ET_{miss}$	√	

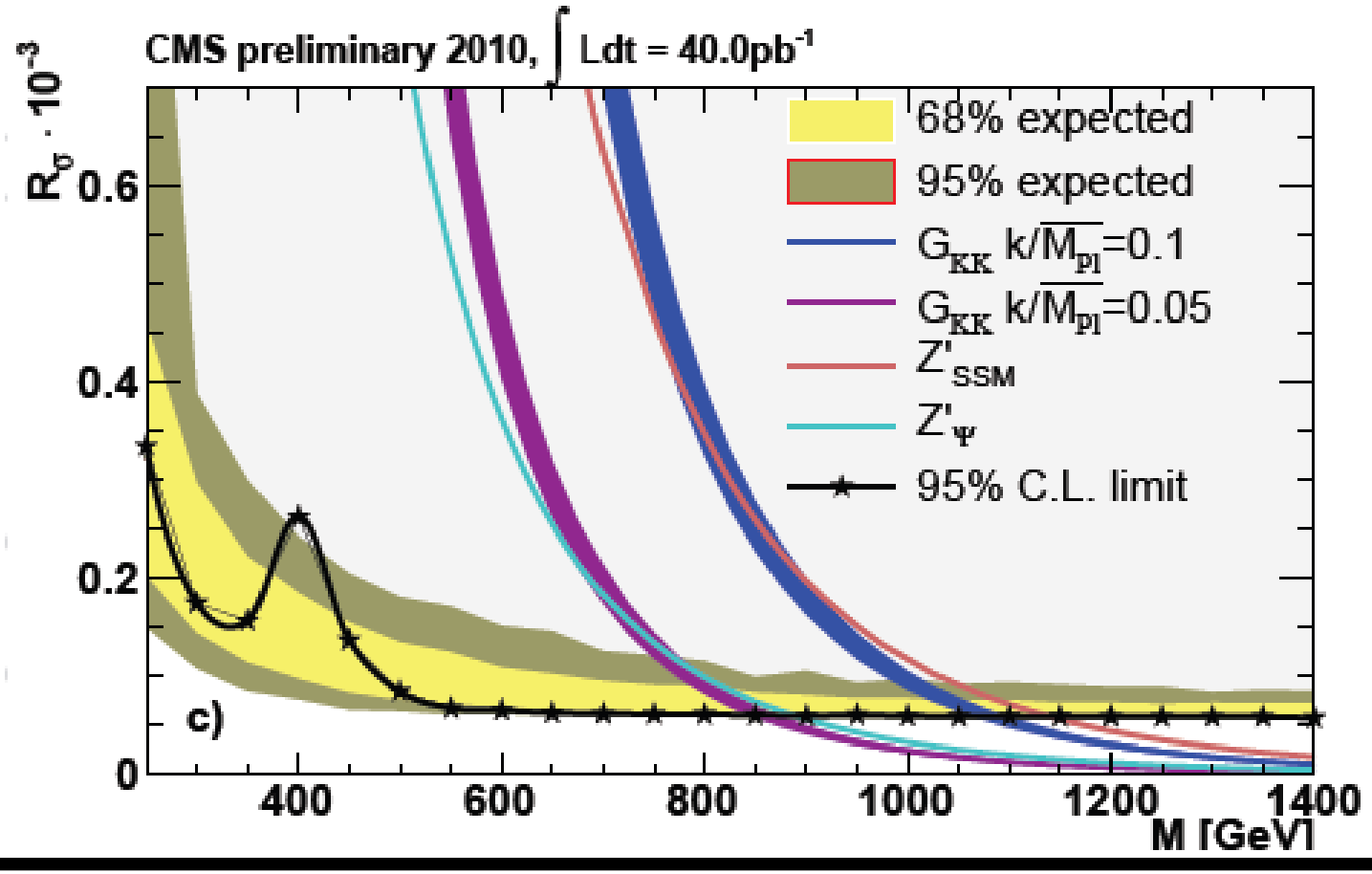
Z' → l+l- (CMS)

- Electron/Muon efficiency measured in data using $Z^0 \rightarrow l^+l^-$.
- Muon momentum scale checked using cosmics.
- Background zero in signal region.



Z' → l+l- (CMS)

Limits obtained by combining electron and muon channels.
M(SSM Z') > 1.14 TeV (similar to Tevatron)



Search for Heavy Stable Charged Particles (CMS)

Theoretical Models

- Gluino in Split-SUSY. (Squarks very heavy, so gluino can only decay via virtual squarks).

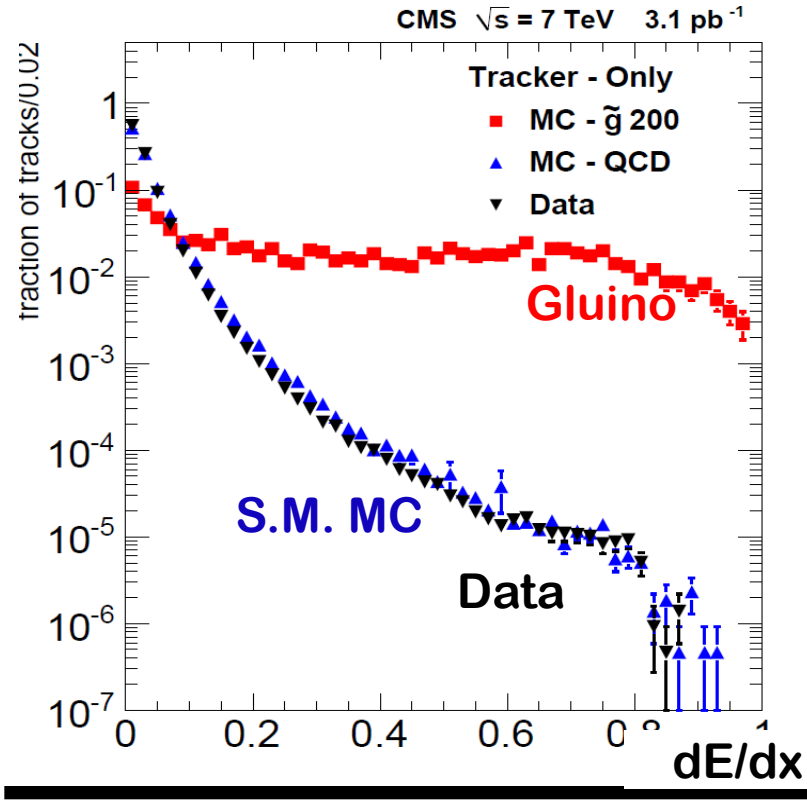
Hadronizes to R-hadrons. These are highly ionizing in the Tracker and look like muons in the calorimeters. They can flip charge whilst Traversing CMS !

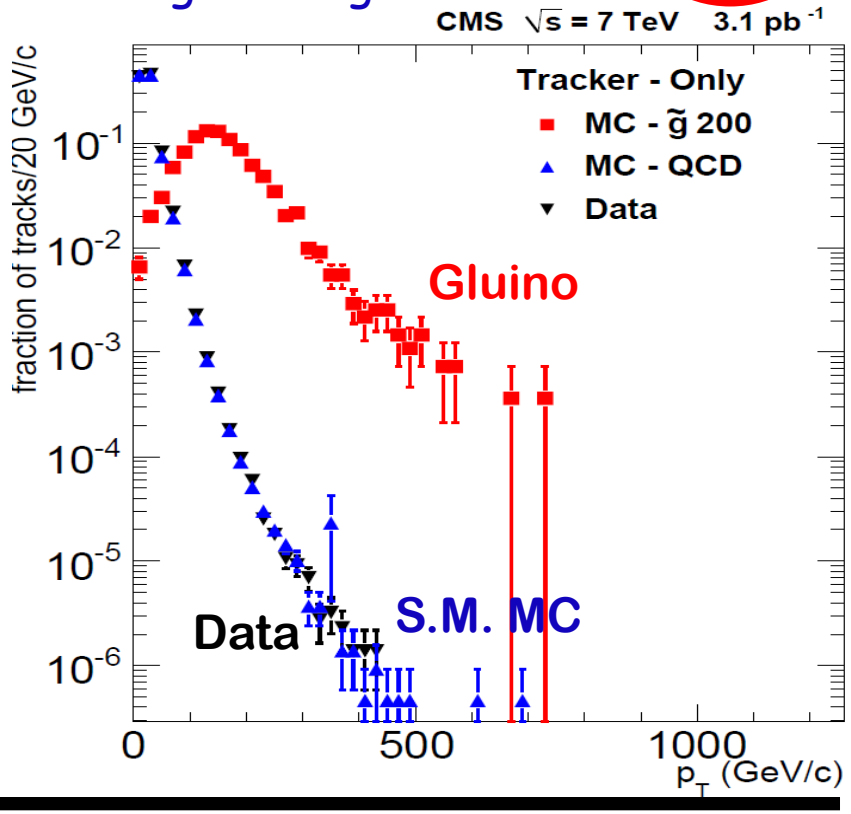
Selection

- Select high Pt track with large dE/dx in Tracker, optionally also requiring muon ID.

Search for Heavy Stable Charged Particles (CMS)

- dE/dx was calibrated module to module using relativistic particles.
- dE/dx & Pt agree well in data and MC. As uncorrelated, can use to estimate background from data alone.
- Both variables offer clear separation for gluino signal.

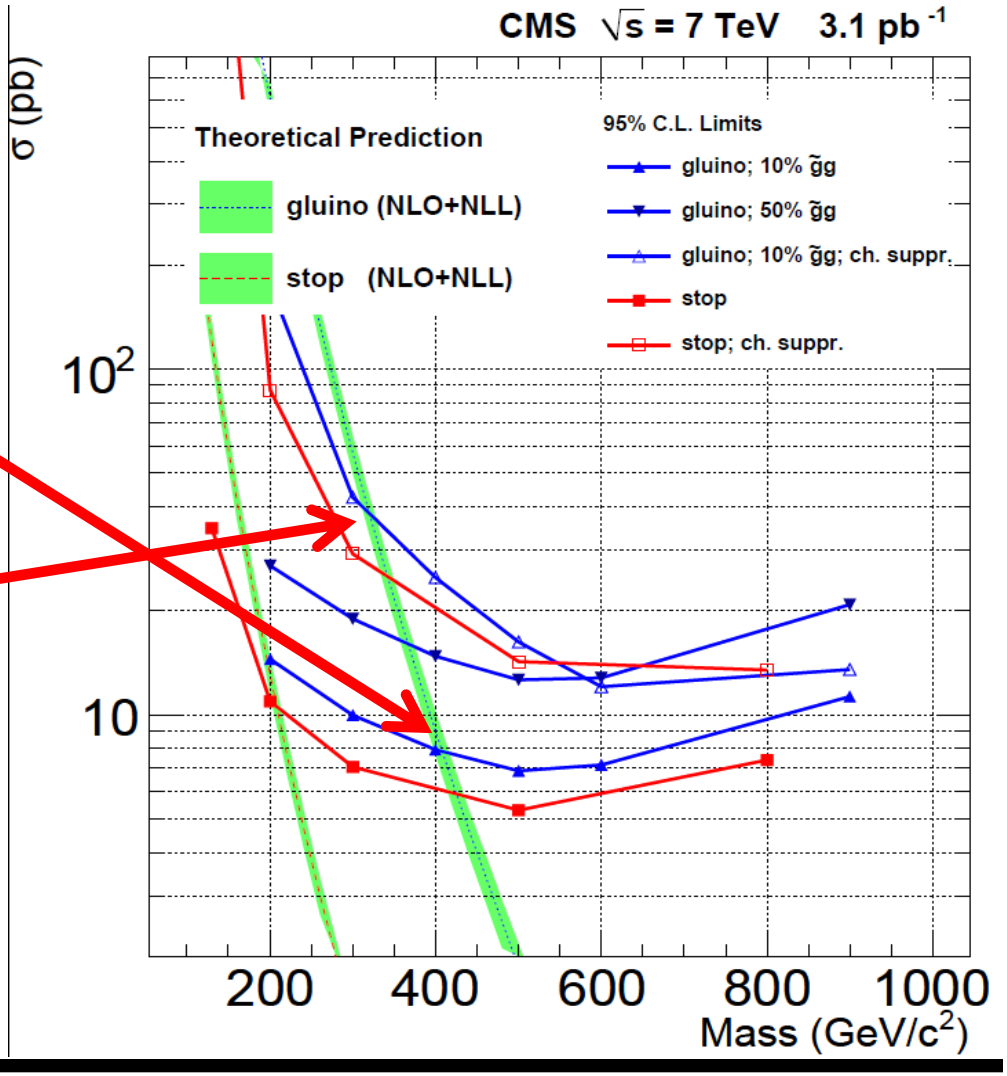




Search for Heavy Stable Charged Particles (CMS)

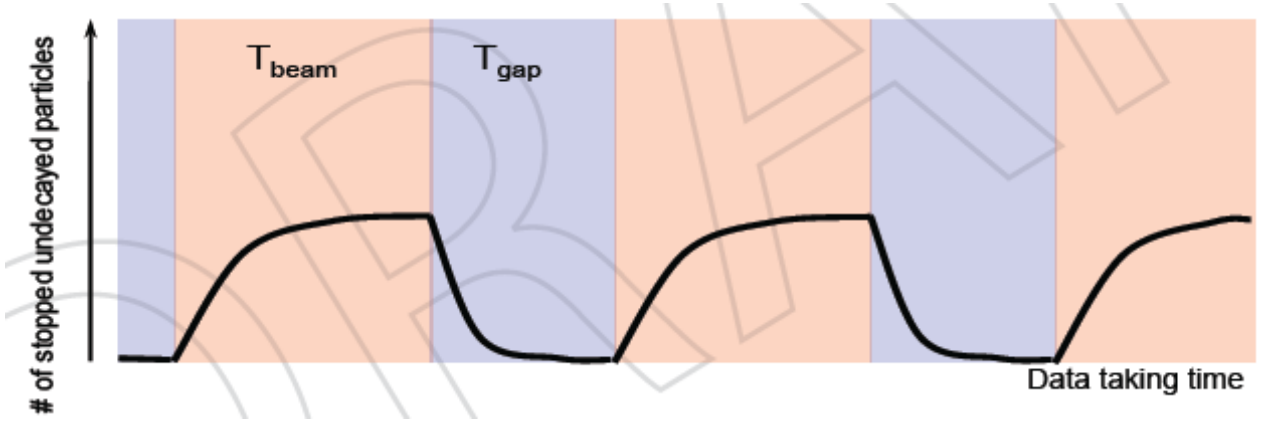
- No events pass cuts !
- M(gluino) > 398 GeV/c^2
- Limit reduces to 311 GeV/c^2 if R-hadron becomes neutral before muon chambers.

(Limits better than Tevatron)



Stopped Gluinos (CMS)

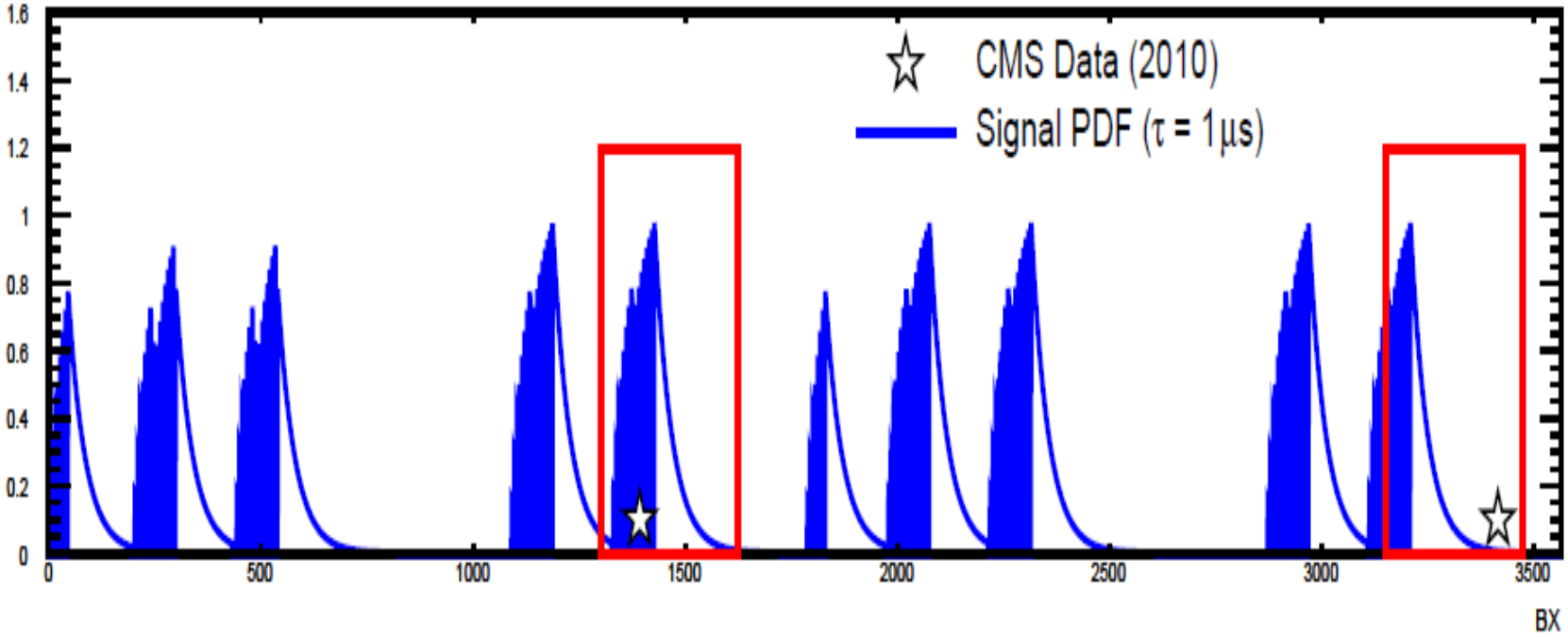
- If the `Split SUSY' gluino is very non-relativistic, it will lose so much energy by ionization that it will stop before leaving CMS.
- Decay to gluon/quarks + neutralino can take micro-seconds → days. Observe it during beam-gaps or shutdowns !



- Trigger using jet-trigger + beam veto (using orbit monitors).
- Select requiring calorimeter energy cluster > 50 GeV.
  N.B. So only sensitive if M(gluino) – M(neutralino) > 100 GeV.
- Many cuts to suppress calorimeter noise. Optimised before LHC switched on !

Stopped Gluinos (CMS)

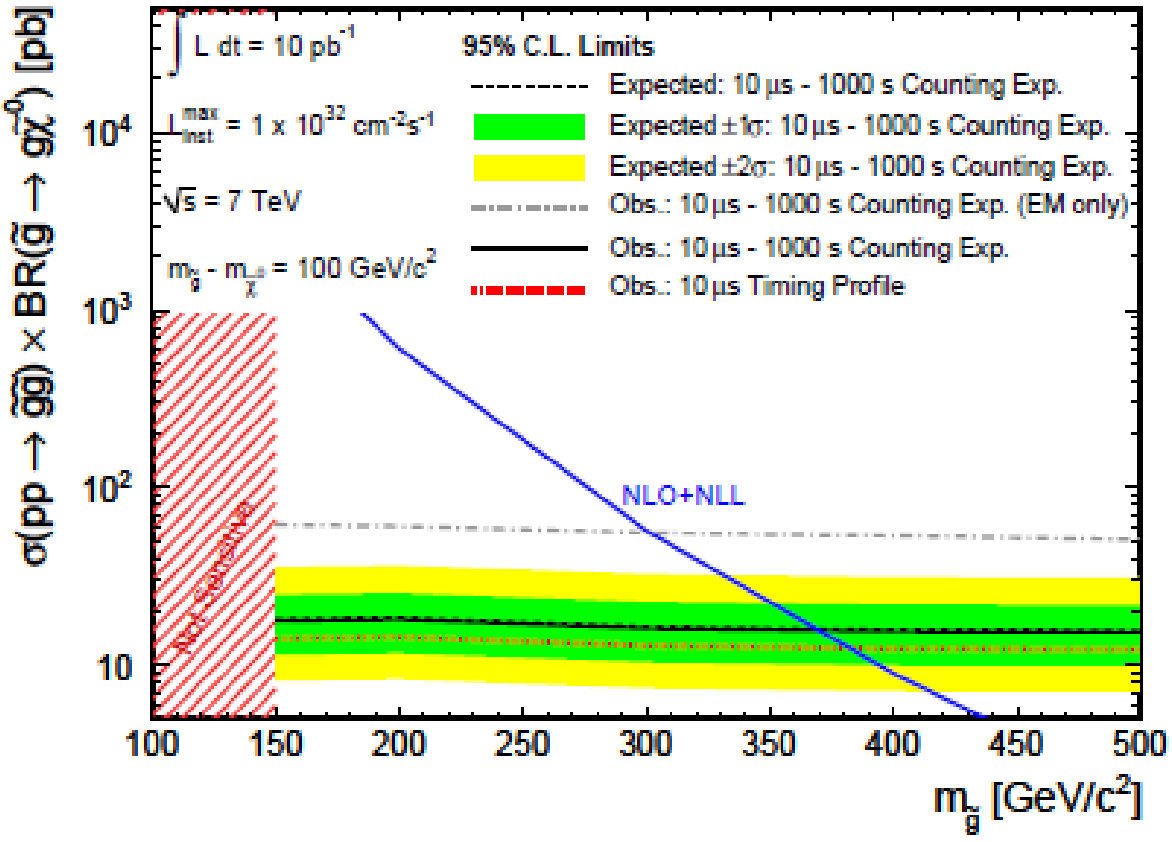
2-5 events pass cuts, compatible with background expectations.
This plot compares their time distribution with that expected for gluino with τ = 1 μs.



Stopped Gluinos (CMS)

- For gluino mass of < 370 GeV/c^2 exclude gluino lifetimes of 10 μs – 1000 s, not previously covered by Tevatron.

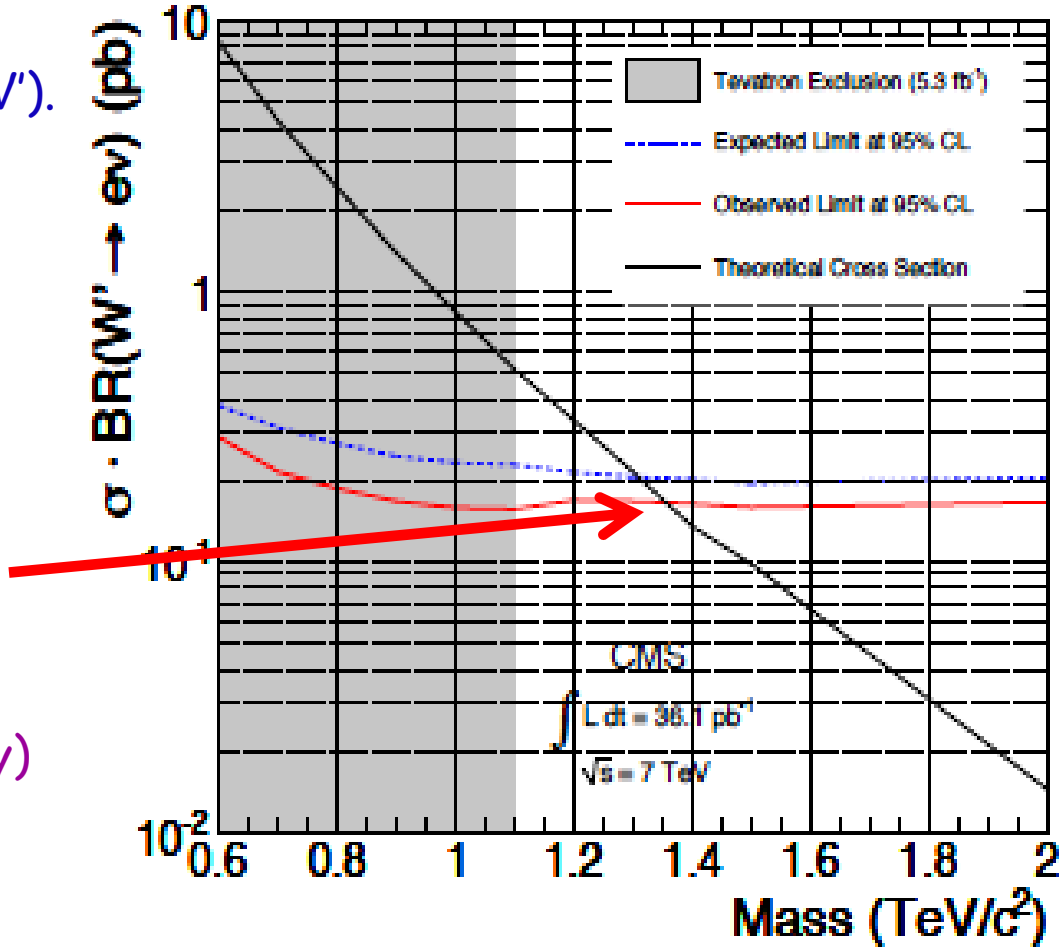
N.B. More stringent limits currently set by HSCP search.



W' → e ν (ATLAS & CMS)

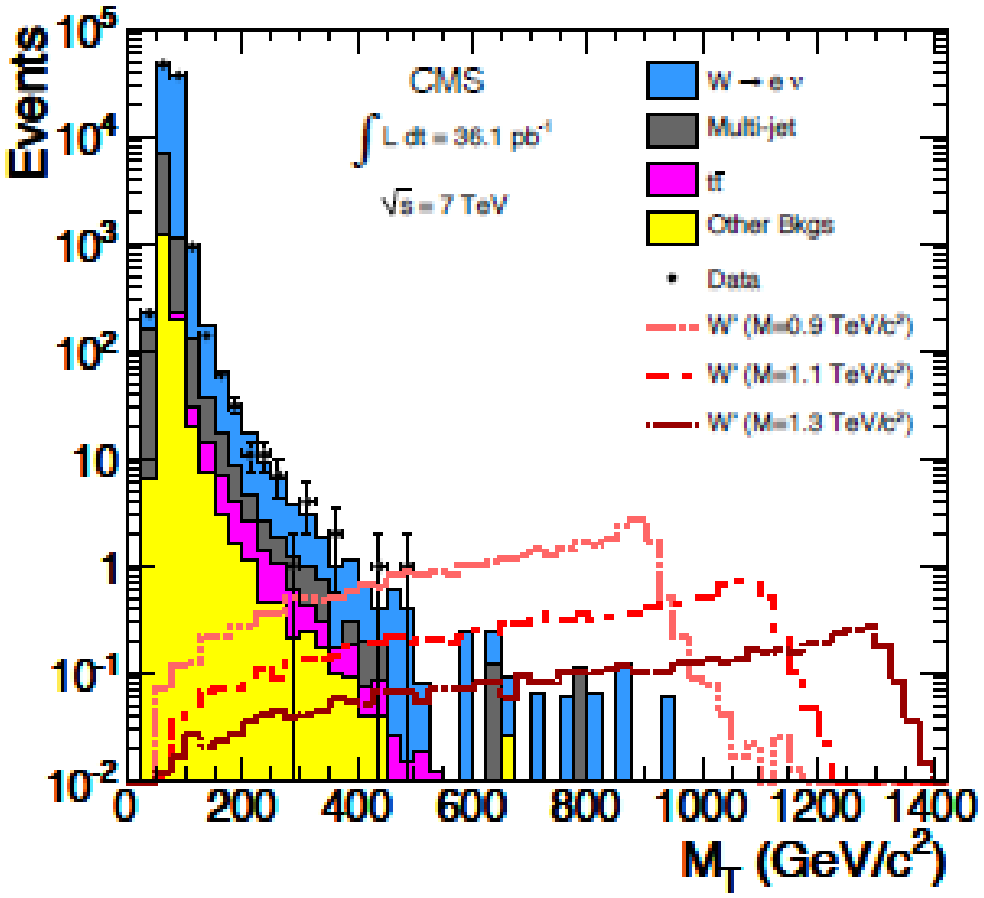
- Get limit at M(W') by counting events with M_T > a fraction of M(W').
- No events pass cuts in signal region.
- M(W') > 1.36 GeV with 36/pb of CMS data.

(ATLAS study used much lower luminosity)



W' → e ν (ATLAS & CMS)

- From electron + MET, reconstruct transverse mass.



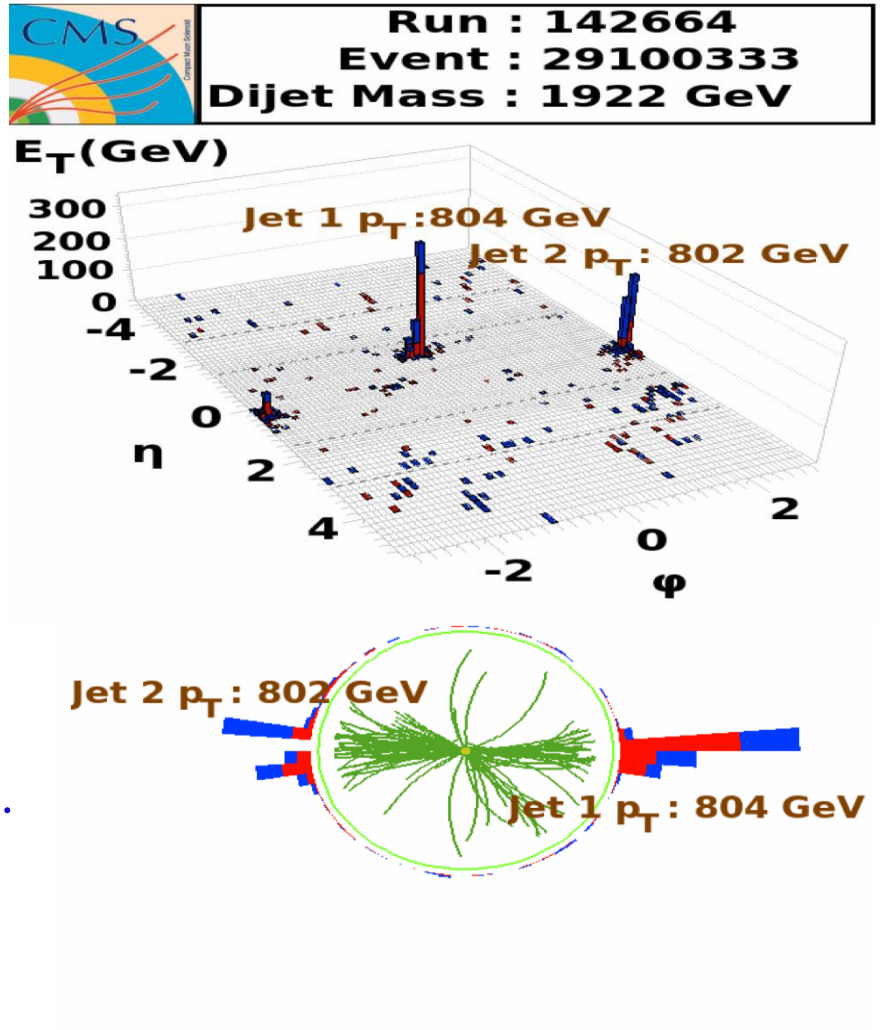
Dijet Mass Resonances (ATLAS & CMS)

Theoretical Models

- Excited quarks: q* → qg
- Z′ → q qbar
- RS Gravitons → q qbar

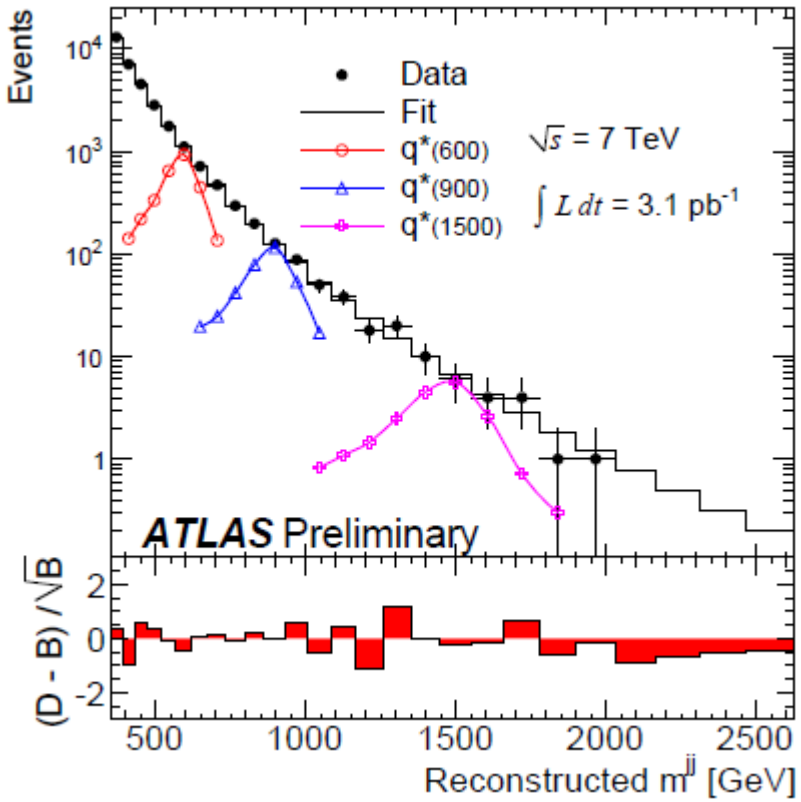
Selection

- ❑ Use anti-Kt jet algorithm
- ❑ Plot dijet mass of 2 leading jets.



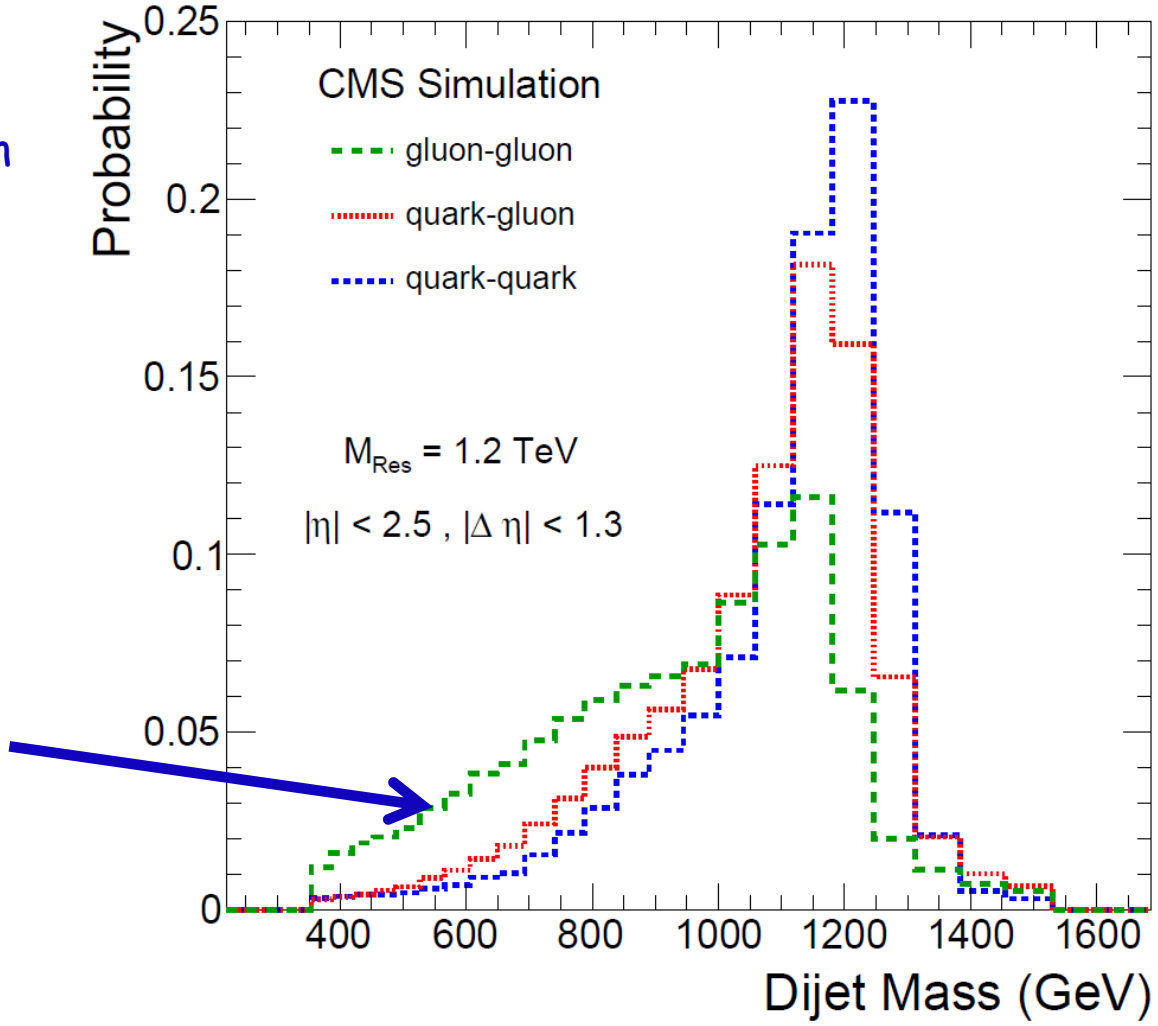
Dijet Mass Resonances (ATLAS & CMS)

- Dijet spectrum fitted with smooth function to describe background.



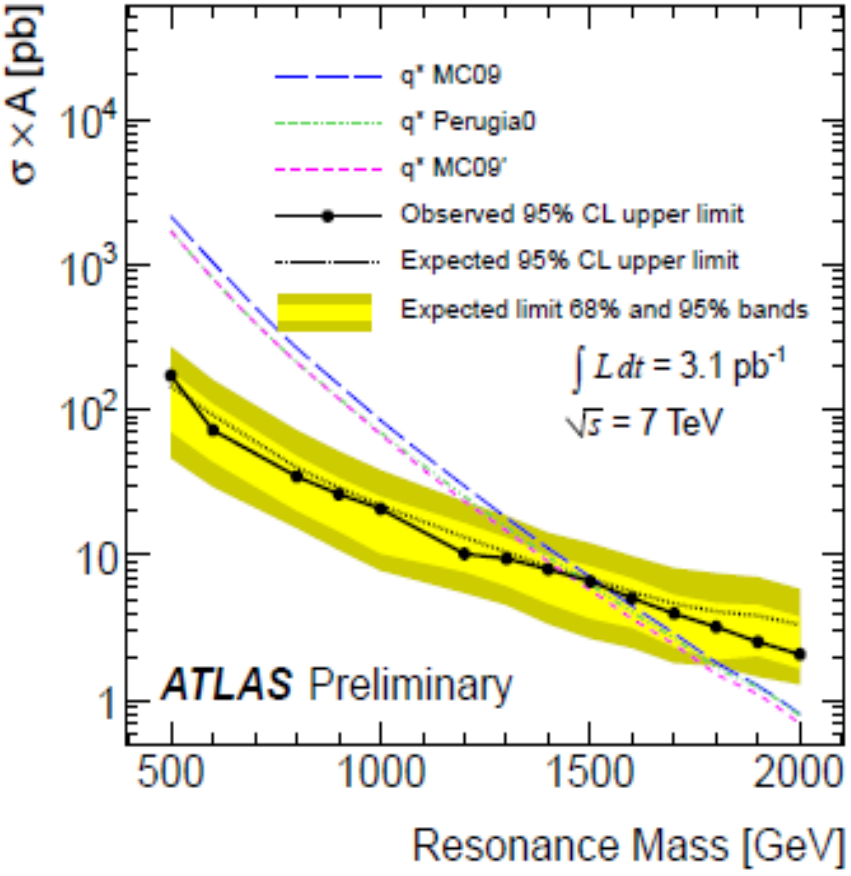
Dijet Mass Resonances (ATLAS & CMS)

- Signal shape taken from MC.
- Its position depends on uncertainty in jet energy scale.
- CMS noted that spectrum broader for gluon states, so quotes separate limits for these.



Dijet Mass Resonances (ATLAS & CMS)

- ATLAS excludes excited quarks with 500 < M < 1530 GeV.
- CMS excludes those with M < 1580 GeV using 2.9/pb.
- Both surpass Tevatron limit of 870 GeV.



Dijet Angular Distribution (ATLAS & CMS)

Motivation

- Z' etc. whose mass exceeds the $\sqrt{s}$ of the partons will not be seen as a resonance, but will modify the dijet spectra.
- The effect can be parametrized as `contact interaction'.

- Changes to the dijet mass spectrum hard to distinguish from systematics.

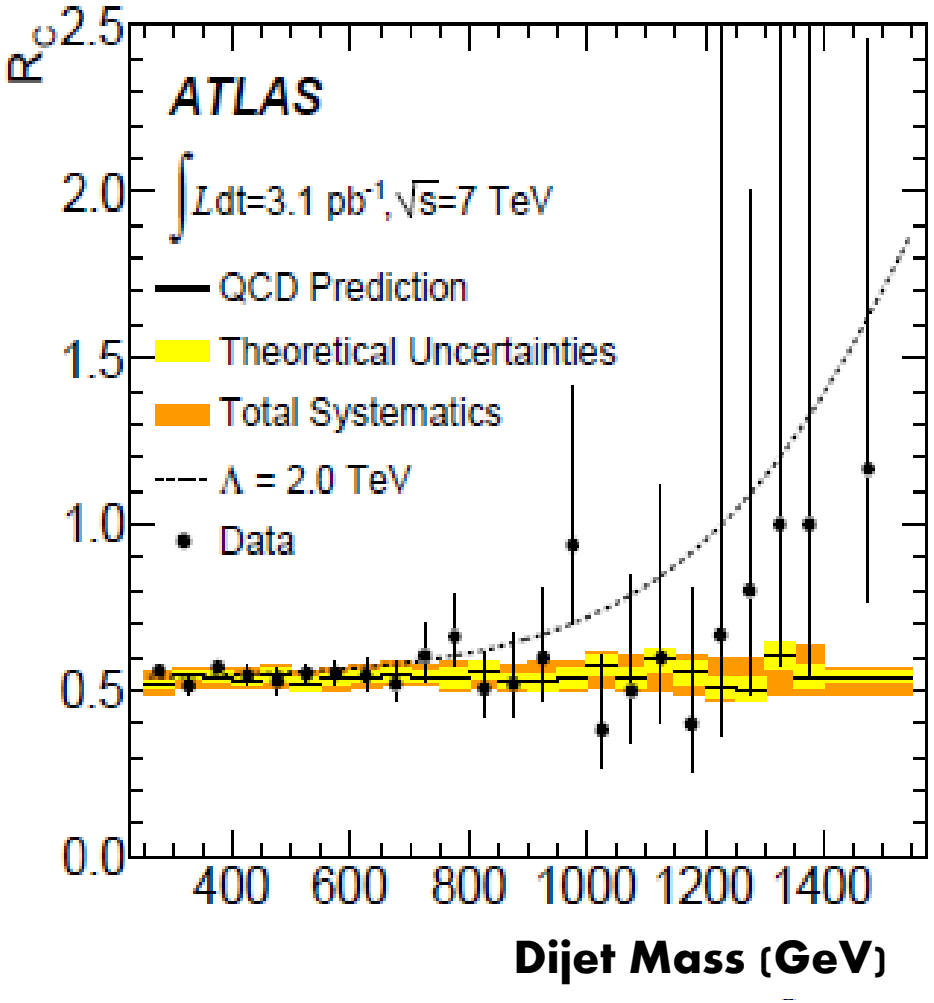
- Better to study jet angular distributions as a function of dijet mass, e.g. using` dijet centrality ratio' so systematics cancel:

$$N\_dijets(|\eta| < 0.7) / N\_dijets(0.7 < |\eta| < 1.3)$$

Flat for QCD, whereas exotica produced mainly in central η region.

Dijet Angular Distribution (ATLAS & CMS)

- Dijet centrality ratio compared with predictions in low mass region, where no signal expected.
- Very good agreement with QCD.

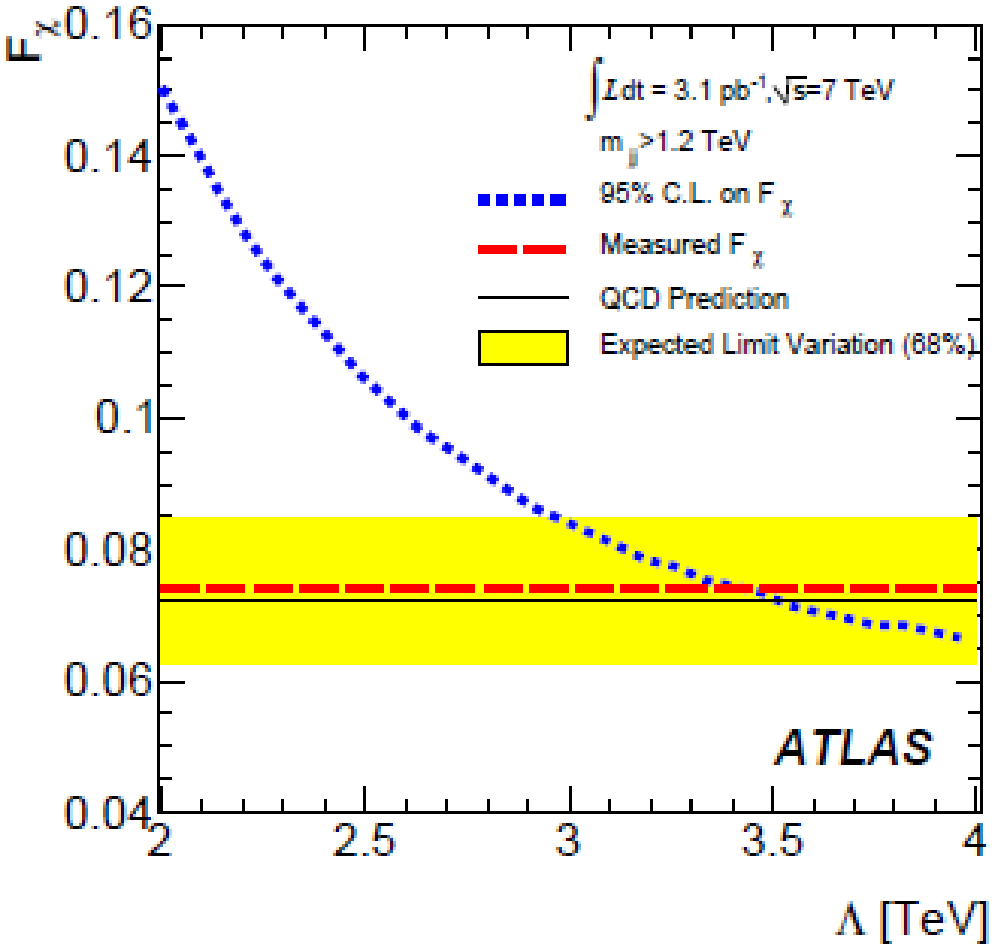


Dijet Angular Distribution (ATLAS & CMS)

- Limits placed on 4-quark contact interactions $\Lambda > 3.2$ TeV. (ATLAS)
- CMS Limit is $\Lambda > 4.0$ TeV from 2.9/pb

c.f. Current Tevatron limit

L = 2.8 TeV



Leptoquarks (CMS)

Theory

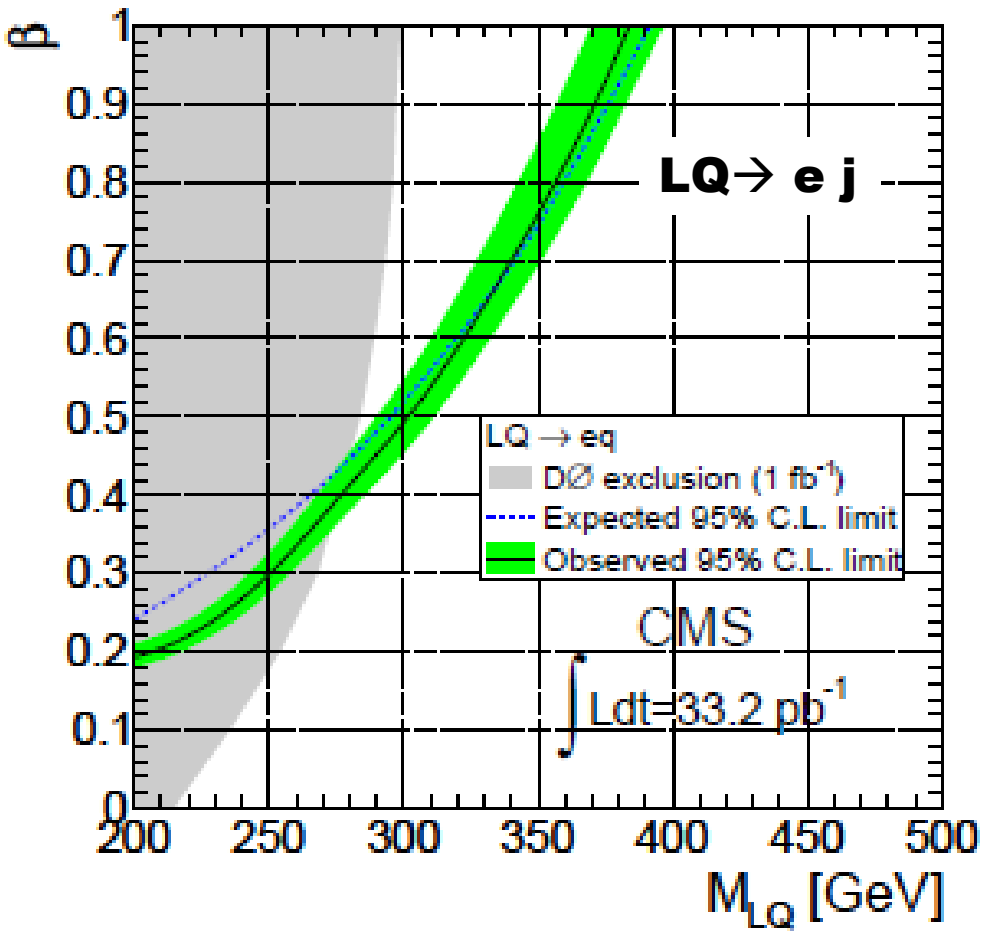
- gluon → LQ pair has high cross-section.
- Each (1^{st}/2^{nd} generation) LQ decays to electron/muon + jet.

Selection

- Require at least 2 electrons/muons & 2 jets.
- Cut on their Sum |Pt|.
- Require M(l+l-) > 125 GeV/c^2 to suppress main background (Z + jets) (& measure background by reversing this cut ...)

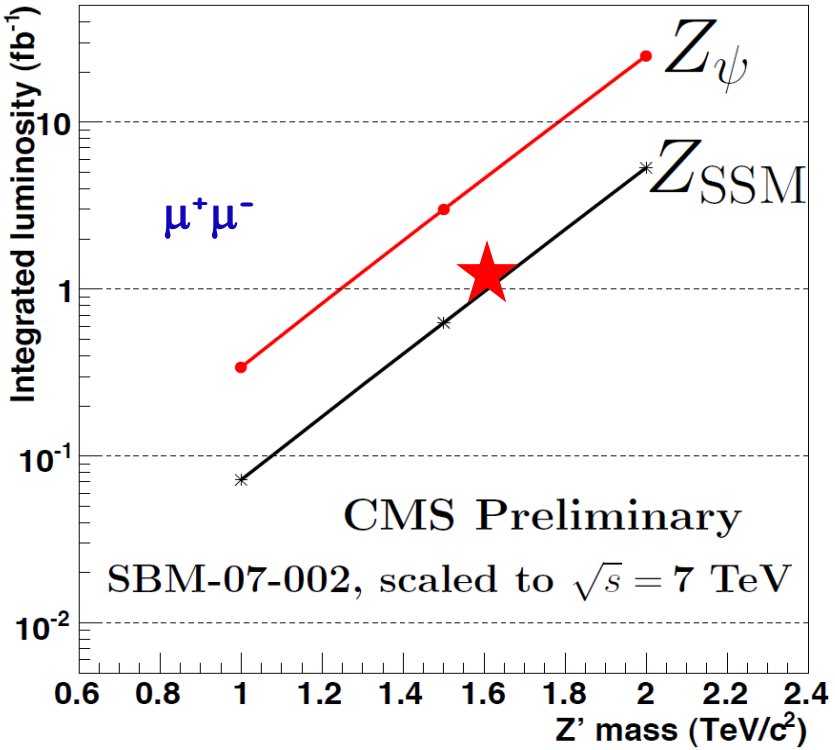
Leptoquarks (CMS)

- 7 events found in signal region with 33/pb. Compatible with background.
- Limit M(LQ) > 384 GeV for BR(LQ → e j) = 1
- Limit M(LQ) > 394 GeV for BR(LQ → μ j) = 1
- Exceed Tevatron limits.



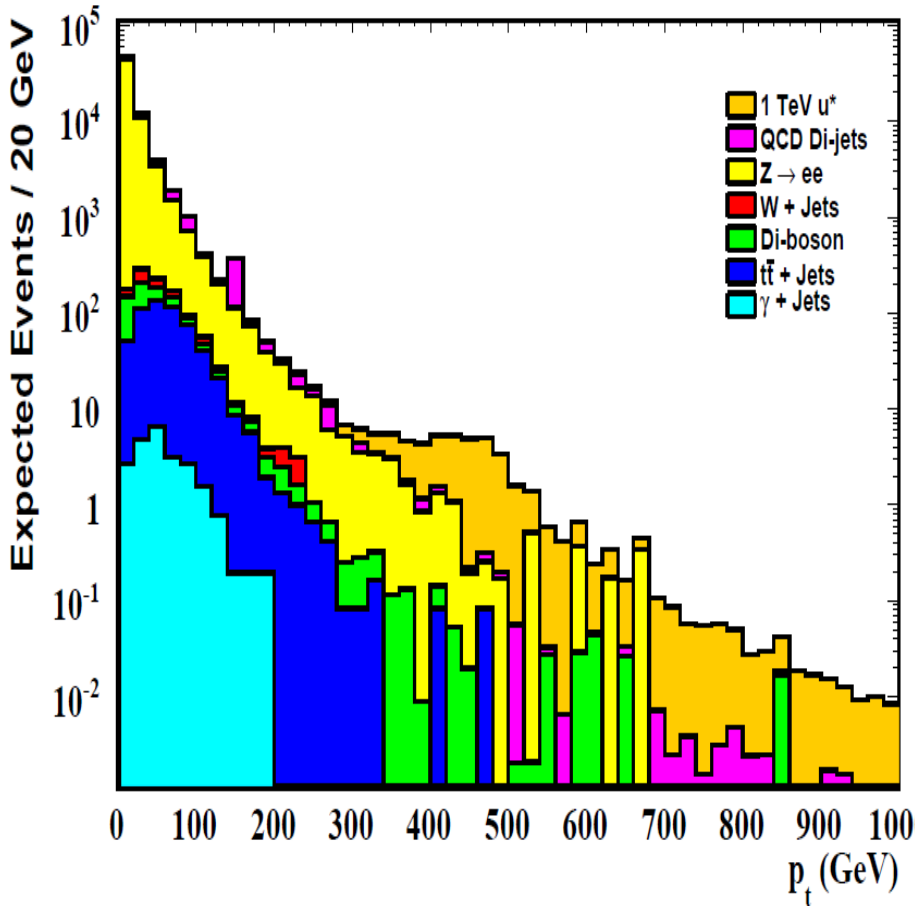
Future Prospects
Expected Z' → l^+l^- Reach (CMS)

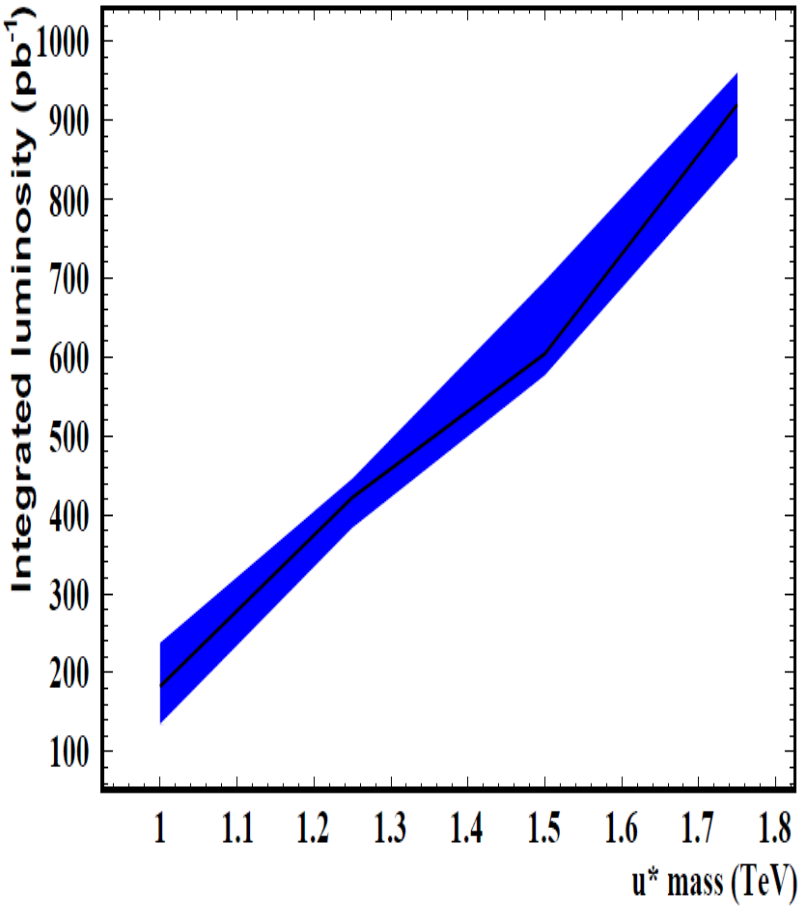
- For SSM Z', expect limits in each of e^+e^- & $\mu^+\mu^-$ channels of ~1.7 TeV/c^2 by end 2011 !
- Both CMS and ATLAS UK working on e^+e^- channel.



Future Prospects: q* → Boosted Z0
(James Jackson PhD Thesis)

Interesting limits (M(q*) ~ 1.8 TeV) expected from 2011 data …





Conclusions

- LHC already sets the World's best limits for heavy stable charged exotica, stopped gluinos, Z'→ jets/leptons, W'->e ν & leptoquarks !
- Good chances to make a discovery in 2011 !

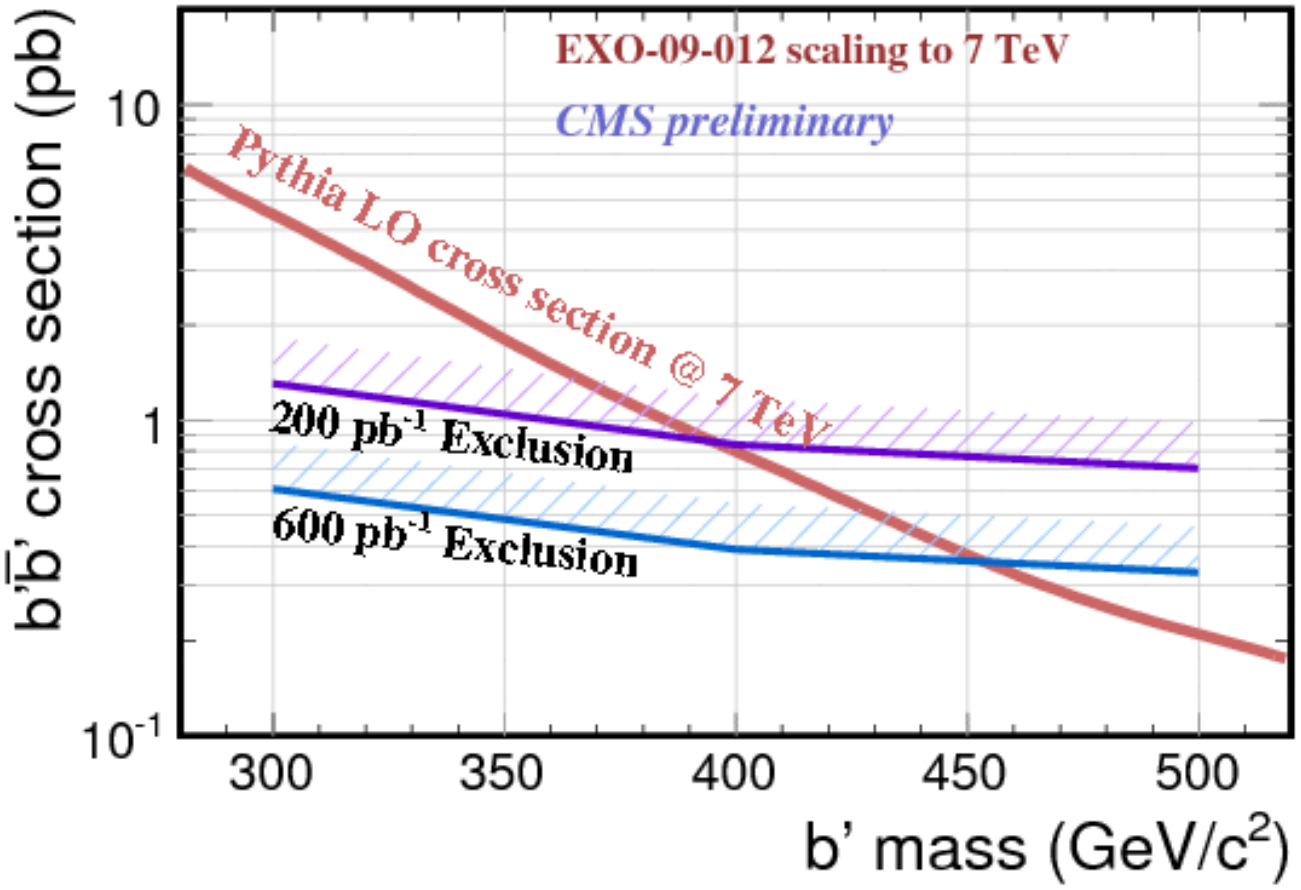
Backup

Future Prospects (CMS, but ATLAS similar)

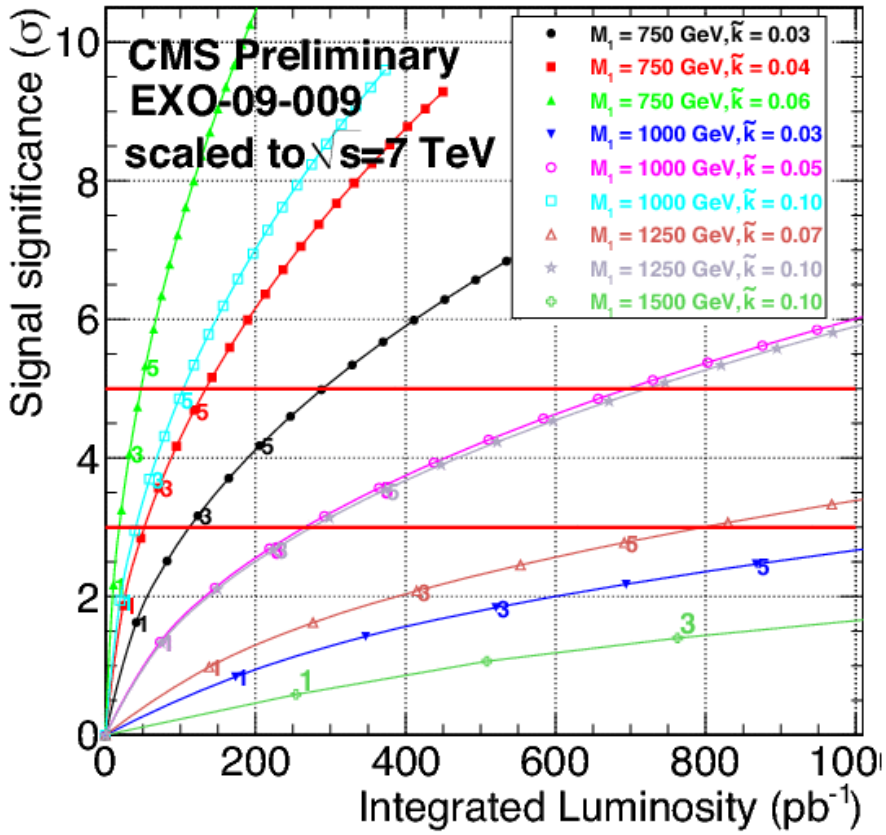
We expect ~ 1/fb in 2011. This table shows some of the limits (or discoveries ...) we should get. All surpass Tevatron limits.

	Limit
b′ → tW	M(b′) > 450 GeV (for 600 /pb)
Z′ → ee or μμ	M(SSM Z′) > 1.7 TeV
q* → boosted Z0	M(q*) > 1.8 TeV
HSCP (stable gluino)	M(gluino) > 0.6 TeV
RS/ADD KK Graviton → γ γ	complicated limits ...

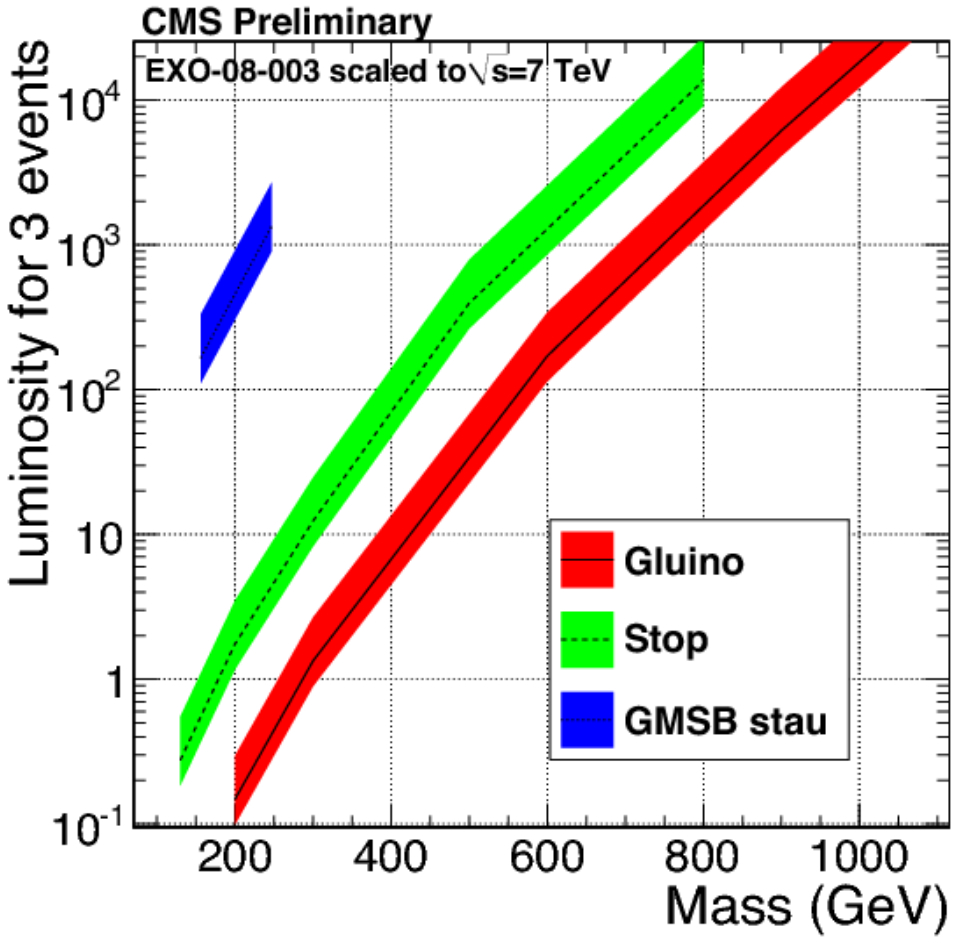
Future Prospects: B' → tW



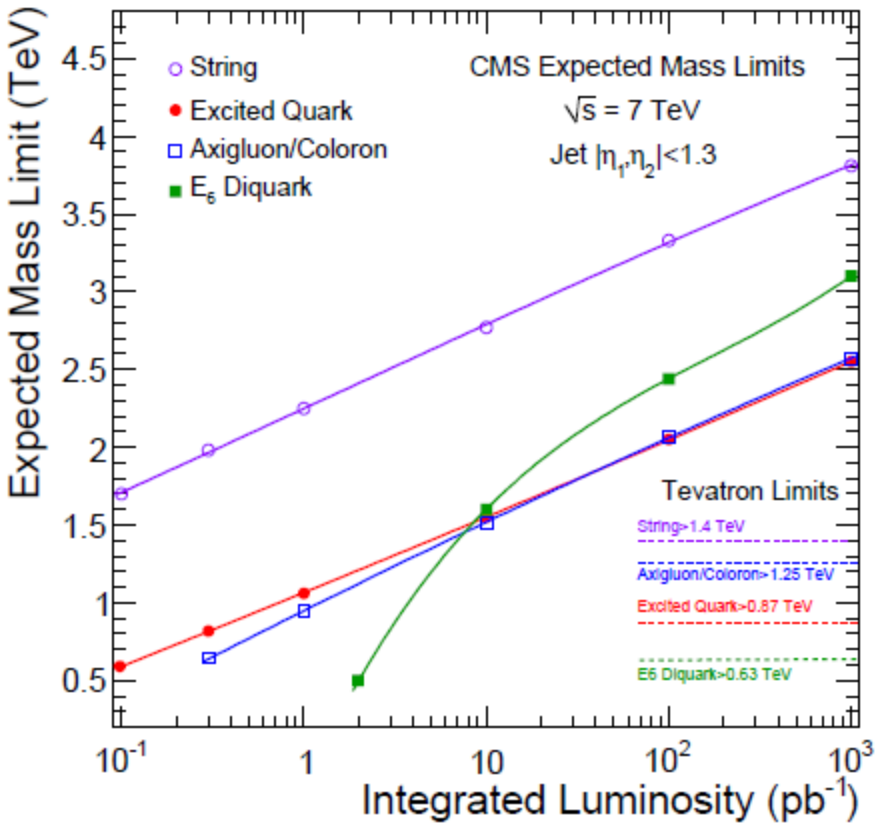
Future Prospects
RS Gravition → gamma gamma



Future Prospects: HSCP



Future Prospects: q* → dijet



Black Holes & High Mass, Many Body Events (ATLAS)

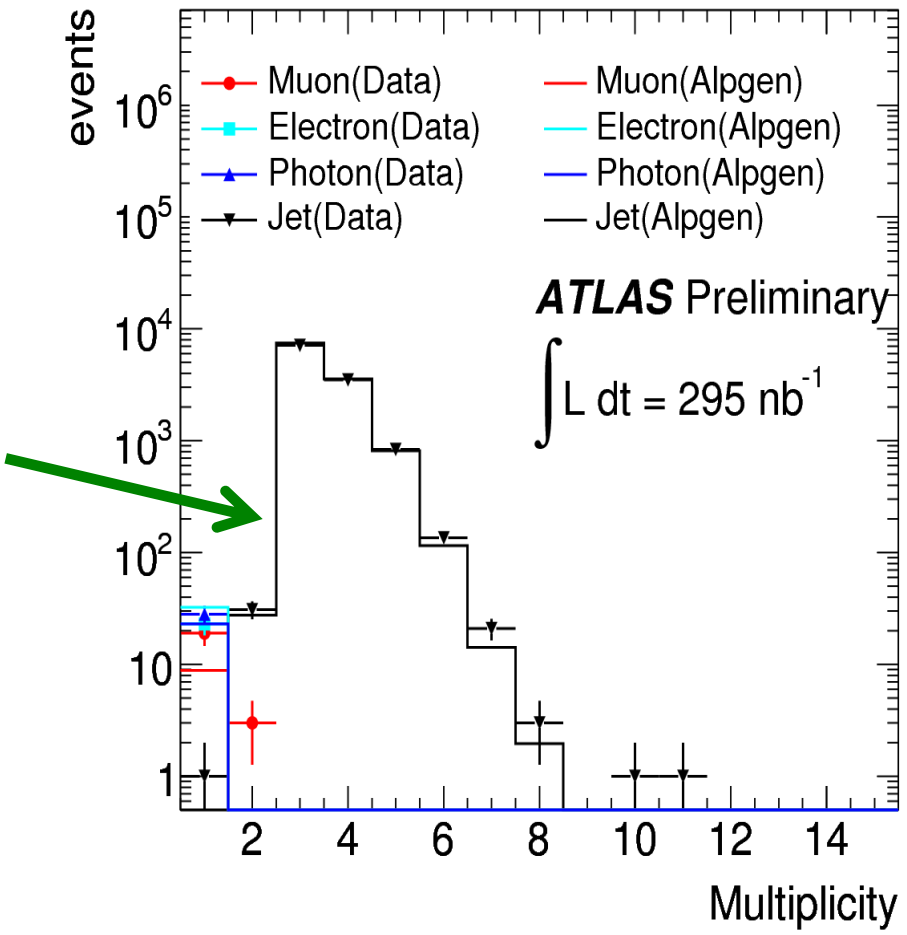
Theory

- In ADD models, gravity propagates in additional spatial dimensions, whose size corresponds to an energy scale M_D.
- Tevatron says $M_D > 800$ GeV
- Above this scale, gravity becomes strong, leading to black hole production.
- As gravity couples to energy (not mass !), black holes evaporate democratically to all fermion/boson species. Many body final state.

- Other exotica will also give many body final state ...

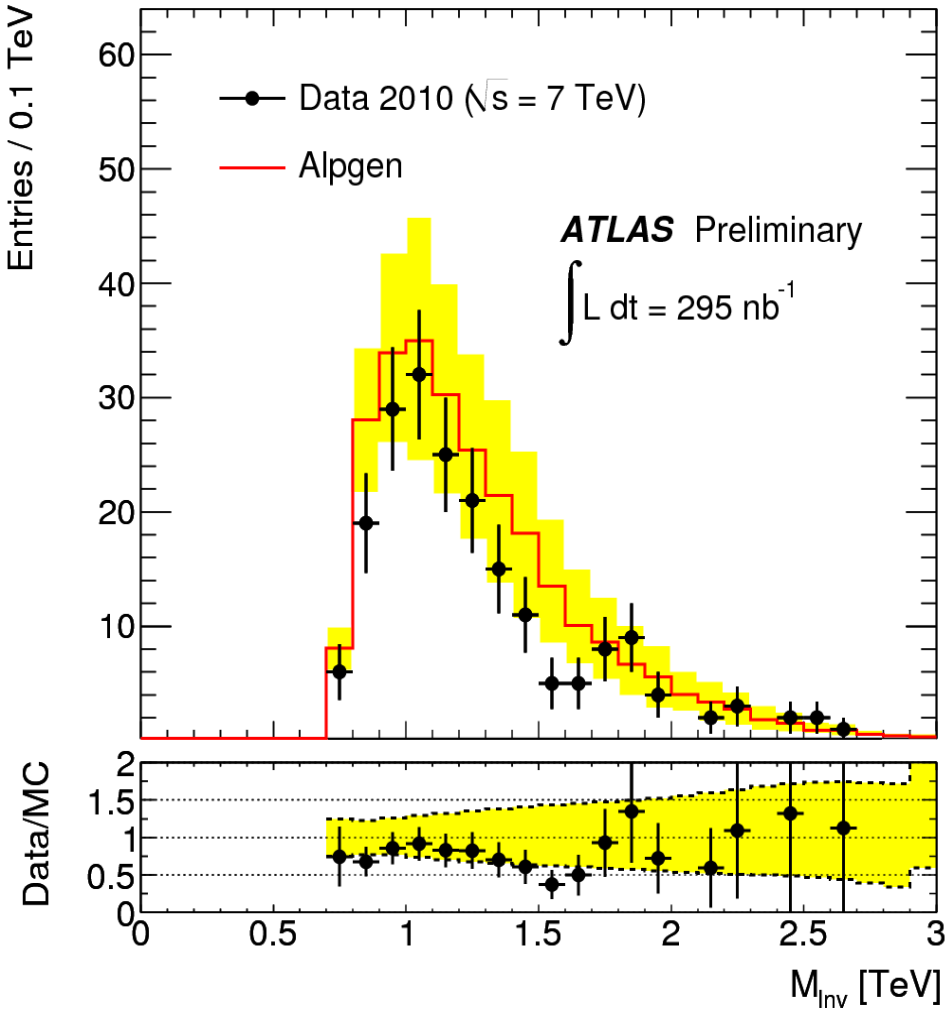
Black Holes & High Mass, Many Body Events (ATLAS)

- Jets, photons, electrons, muons & MET counted.
- Tricky analysis, since must understand all of these …
- S.M. multiplicity dominated by jets. (Could reduce by requiring leptons …)



Black Holes & High Mass, Many Body Events (ATLAS)

- Count events in signal region defined as:
  - $N \geq 3$
  - $M_{inv} > 800\ GeV/c^2$
  - $\Sigma\ |Pt| > 700\ GeV/c$
- For black-holes produced with $M_D = 800\ GeV$ (6 extra dimensions) get interesting limit of 0.6/nb

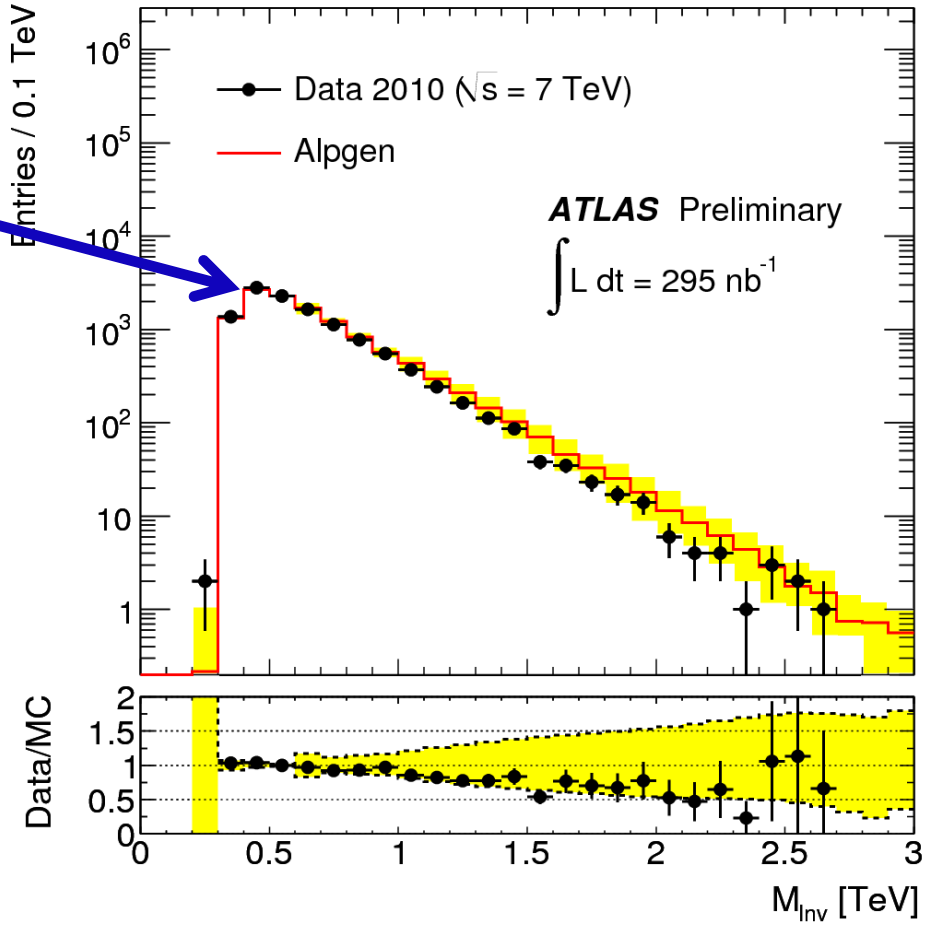


Black Holes & High Mass, Many Body Events (ATLAS)

- Systematics reduced by normalising background in control region. (Low M_{inv} or Σ |Pt|).

- Nonetheless remain large:

1. Simulation of N jet QCD final states (ALPGEN vs. Pythia) (±26%)
2. PDF choice (±12%)



Search for Heavy Stable Charged Particles (CMS)

- Bethe-Bloch ionization curves for K, p, D clearly visible
- Ionization from gluino allows its mass to be determined.