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# **Searches for Resonances at ATLAS**

**Implications of LHC results for TeV-scale physics**

**CERN, 03.29.2012**

**Sarah Heim, Michigan State University**

**on behalf of the ATLAS collaboration**

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# Why are we looking for Physics beyond the SM?<sup>2</sup>

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**The Standard Model of Particle Physics is a very successful theory, but cannot be the end of the story...**

**For example, it doesn't**

- have a dark matter candidate**
- explain, why gravity is so weak compared to the other fundamental forces**



**Also: Before we find the Higgs, we cannot be sure of how electroweak symmetry is broken**



# This talk: Searches for resonances

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in the following final states

- dielectron, dimuon
- dijet  
(angular distributions)
- ZZ
- WZ

focusing on the following models

- Z', RS graviton, Technicolor
- Excited quarks, color octet scalar
- CI, Quantum Black Holes
- RS graviton
- W', Technicolor

**Advantages of signature searches (see Erez's talk on Monday):**

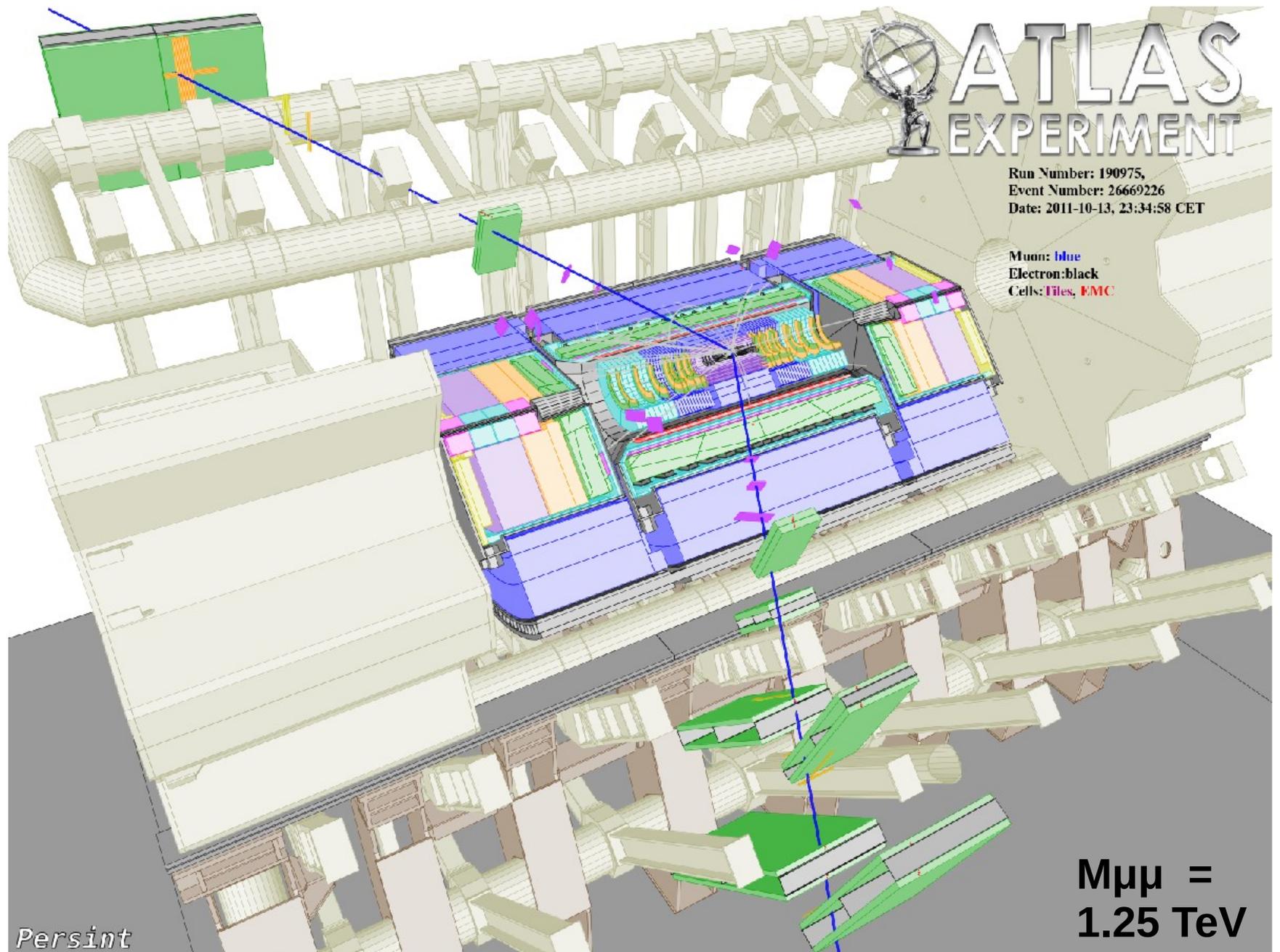
- same final states can probe various models
- allows to find new physics independent of exact model



# Search for resonances in dilepton final states

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$\sim 5 \text{ fb}^{-1}$





# Dileptons: Models

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**Dilepton resonances could be a signature of**

- **new heavy gauge boson in the E6 model (Grand Unified Theory model)**

$$E_6 \rightarrow SO(10) \times U(1) \rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$$

$$Z'(E_6) = Z'_\psi \cos(\theta_{E6}) + Z'_\chi \sin(\theta_{E6})$$

- **excited Kaluza-Klein modes of the Randall Sundrum graviton**

**1 extra dimension, gravitons propagate to extra brane**

**Kaluza-Klein tower of massive graviton states**

- **technivector mesons in one of the Technicolor models**

**Low Scale Technicolor model (Lane, Eichten)**

**QCD-like spectrum: near-degenerate  $\rho_T, \omega_T, a_T$**

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**Benchmark model: Sequential Standard Model  $Z'$  (same couplings as  $Z$  boson), not theoretically motivated**



2 good quality electrons:

-  $E_T > 25$  GeV,  $|\eta| < 2.47$ ,  $1.37 > |\eta| > 1.52$

- cuts on shower shapes, hadronic leakage, tracking hits

- leading electron isolated

- resolution at high  $E_T$ : 1-2%

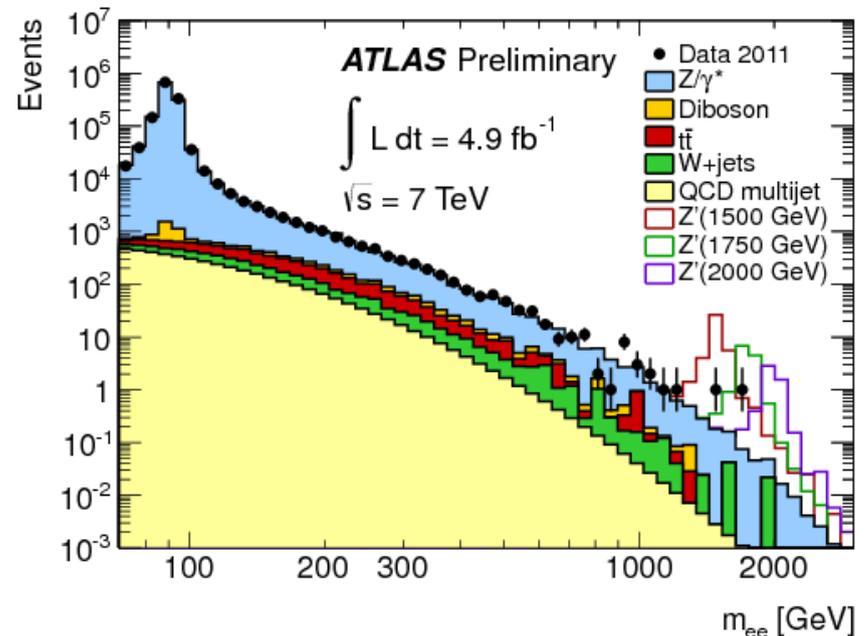
Acceptance \* efficiency

for Z' (2 TeV): ~70%

Dominant background: DY

(Pythia LO simulation corrected to higher orders  
by mass-dependent k-factors)

QCD multijet estimated from data



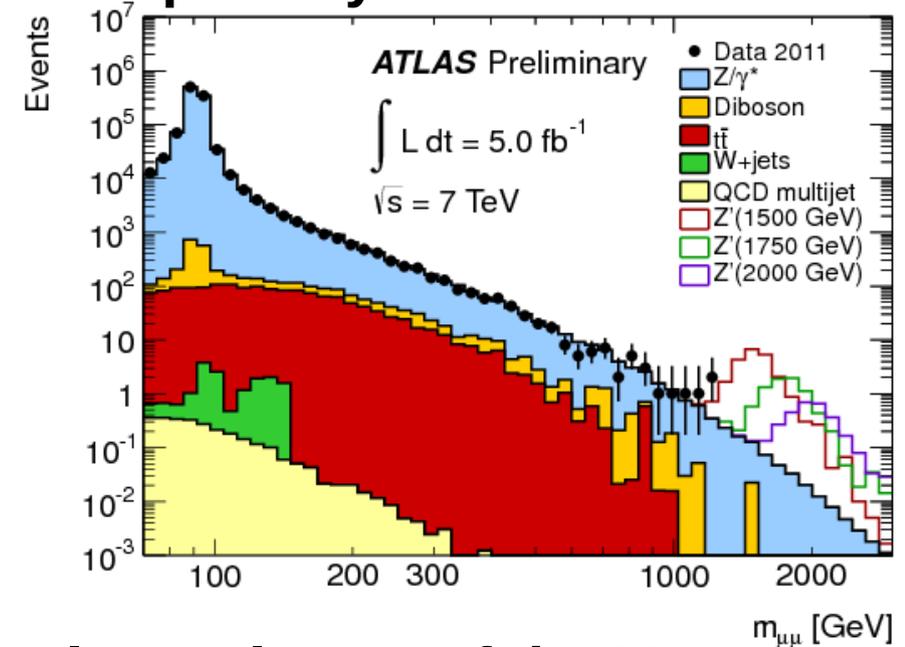


2 good quality muons:

- $p_T > 25 \text{ GeV}$
- Inner Detector and Muon Spectrometer cuts
- impact parameter and distance from primary vertex
- opposite sign
- resolution (1 TeV): 10-25%

Acceptance \* efficiency

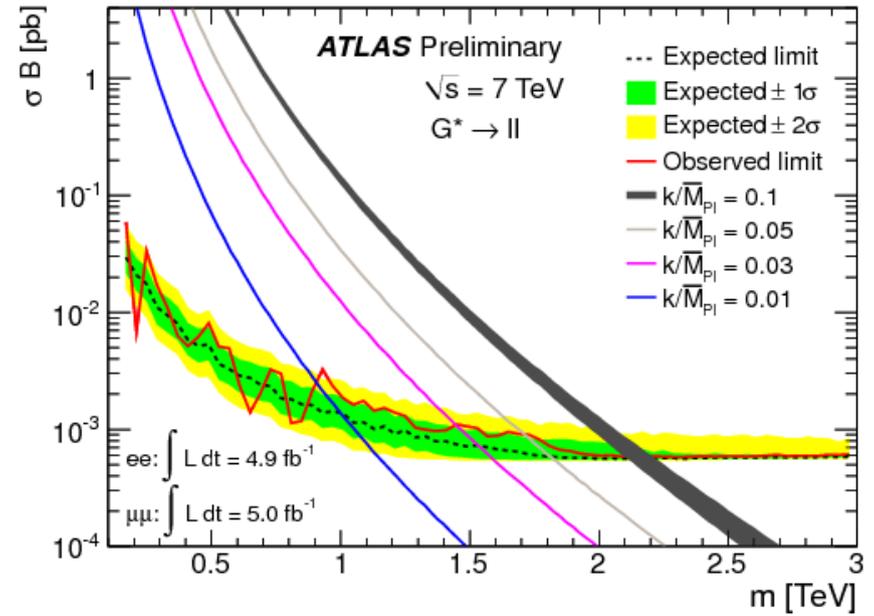
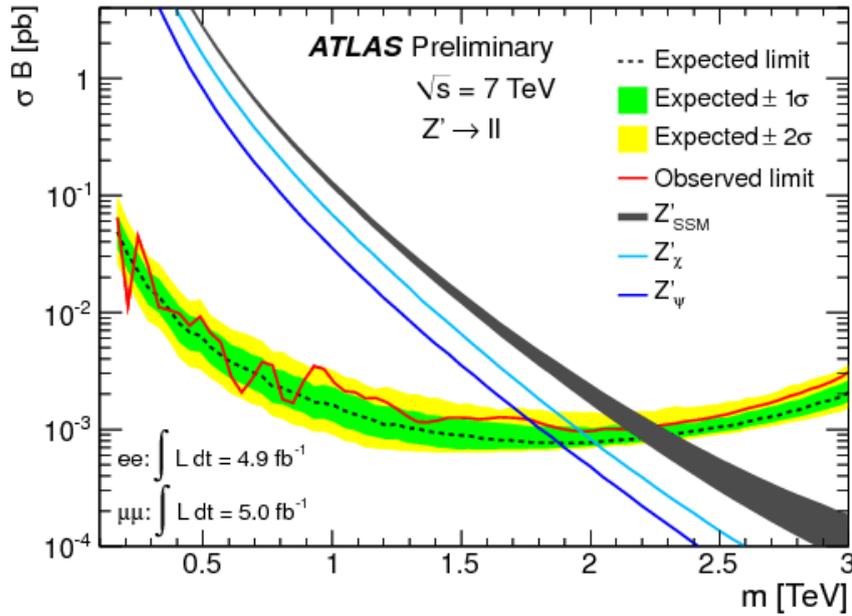
for  $Z'$  (2 TeV):  $\sim 45\%$



Now including muons which hit only two layers of the Muon Spectrometer in well understood regions of the detector



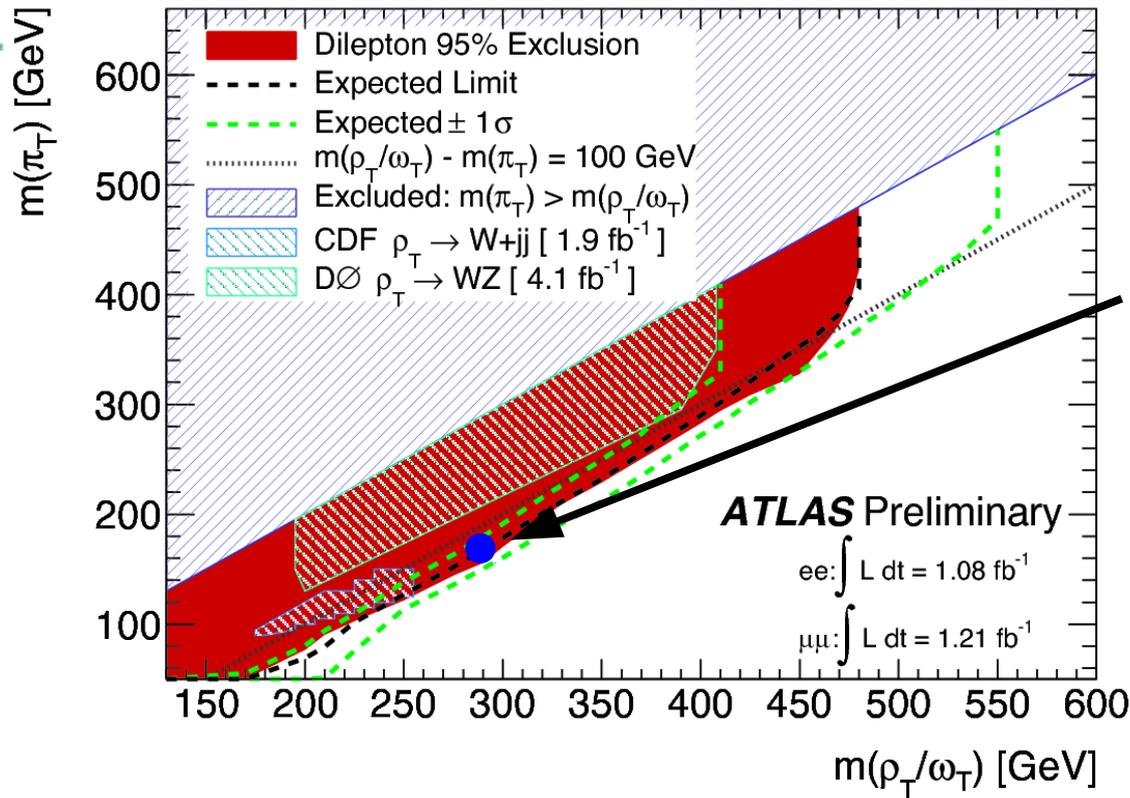
- compare data to SM background + signal templates
- p-value: fraction of pseudo-experiments with excess at least as significant as the one found in data  
(using log-likelihood ratio (sig+bkg)/(bkg only) and BumpHunter algorithm)
- > No significant excess found
- > Setting limits at 95% C.L. (Bayesian, flat prior in  $\sigma_B$ )



**95% C.L. lower mass limits on reference models:**

	Observed dilepton limit [TeV]
SSM Z'	2.21
G* (k/M <sub>PI</sub> = 0.1)	2.16

ATLAS-CONF-2012-007



**Low Scale technicolor interpretation of CDF Wjj excess**  
(Phys. Rev. Lett. 106 (2011) 171801)

## 95% C.L. limits on reference model:

	Observed dilepton limit [TeV]
$\rho_T/\omega_T$ ( $m(\rho_T/\omega_T) - m(\pi_T) = 100$ GeV)	0.47

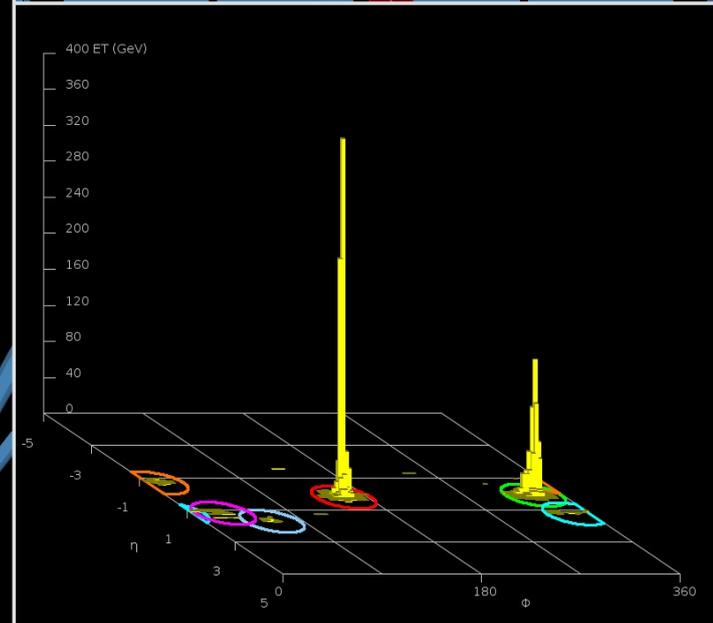
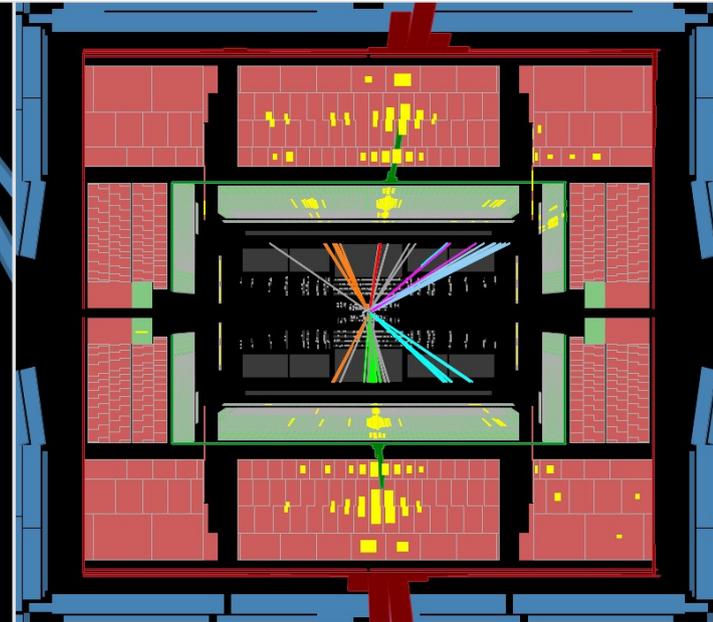
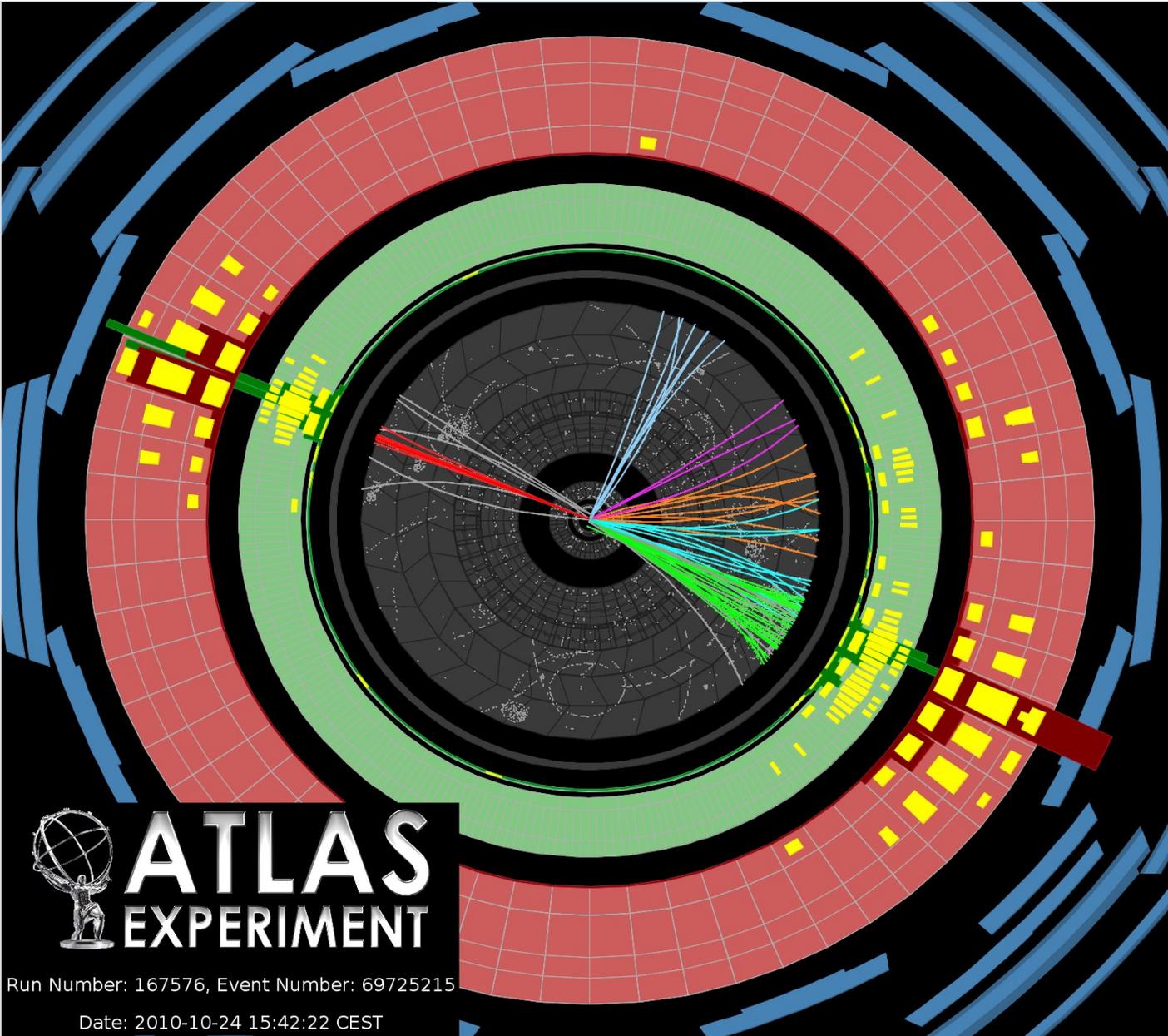
**ATLAS-CONF-2011-125**



# Searches in dijet final states

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$\sim 5 \text{ fb}^{-1}$



 **ATLAS**  
EXPERIMENT

Run Number: 167576, Event Number: 69725215

Date: 2010-10-24 15:42:22 CEST

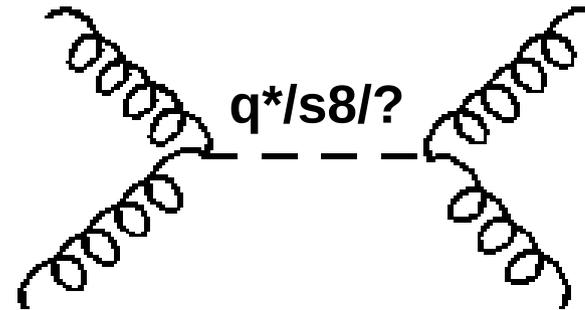


# Dijets: Models

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## Resonances

- Excited quarks
  - composite
- Color octet scalars
  - colored resonance, decaying into two gluons



## Deviation in angular distributions (jets from NP more central than in SM)

- Quantum black holes
  - due to extra dimensions:  $M_{Pl} \triangleright M_D$
  - assume classical relativity for production
- Quark contact interaction
  - quark compositeness (compositeness scale  $\Lambda$ )
  - interference with QCD (here: destructive)

# Dijets: Signal Search (invariant mass)

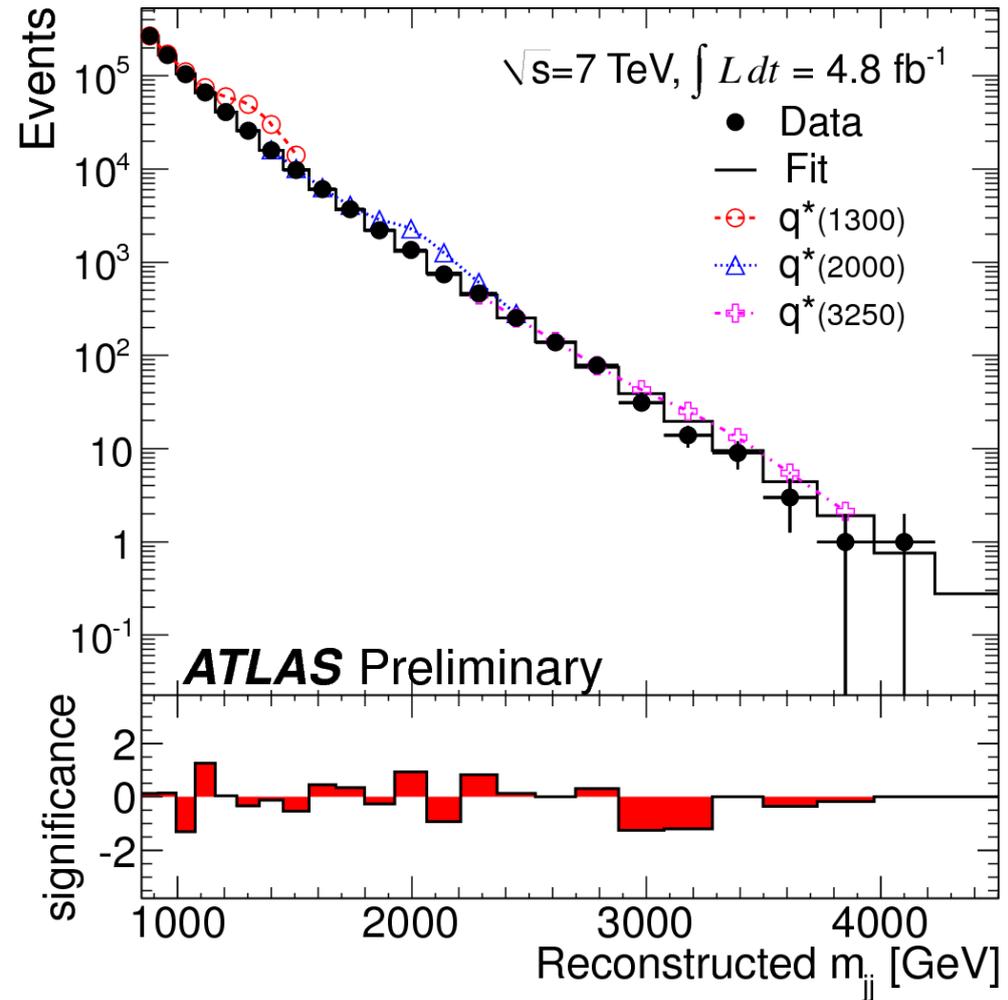
$\sim 5 \text{ fb}^{-1}$

## - Event selection:

- events with two jets
- anti  $k_T$ ,  $R = 0.6$
- $|y| < 2.8$ ,  $0.5*|y_1-y_2| < 0.6$

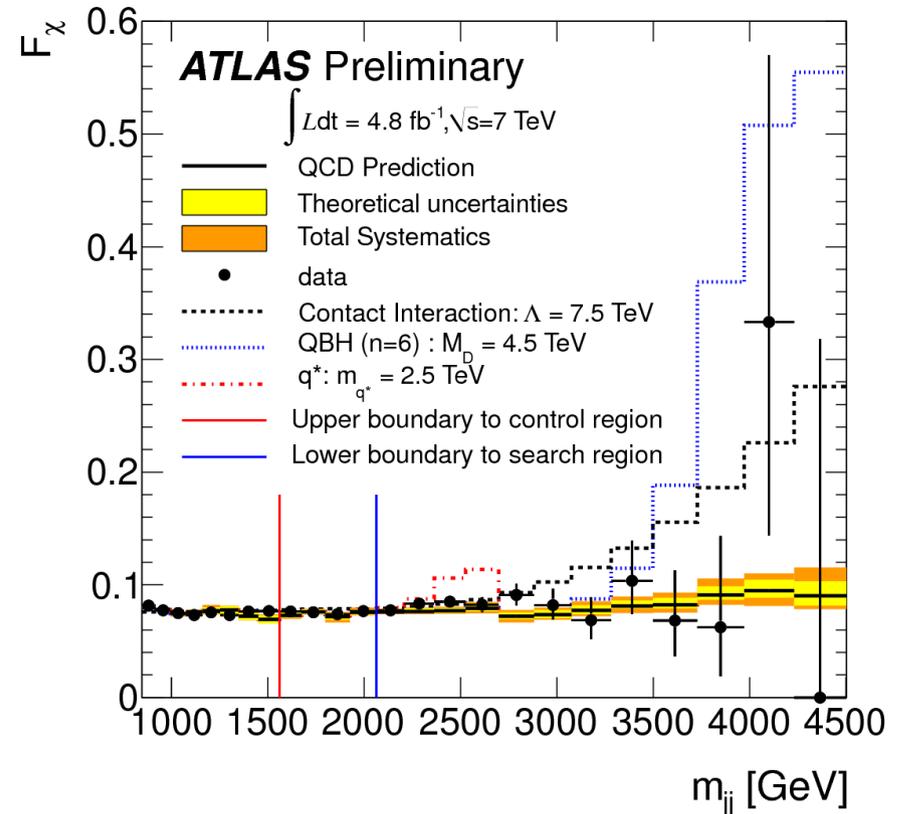
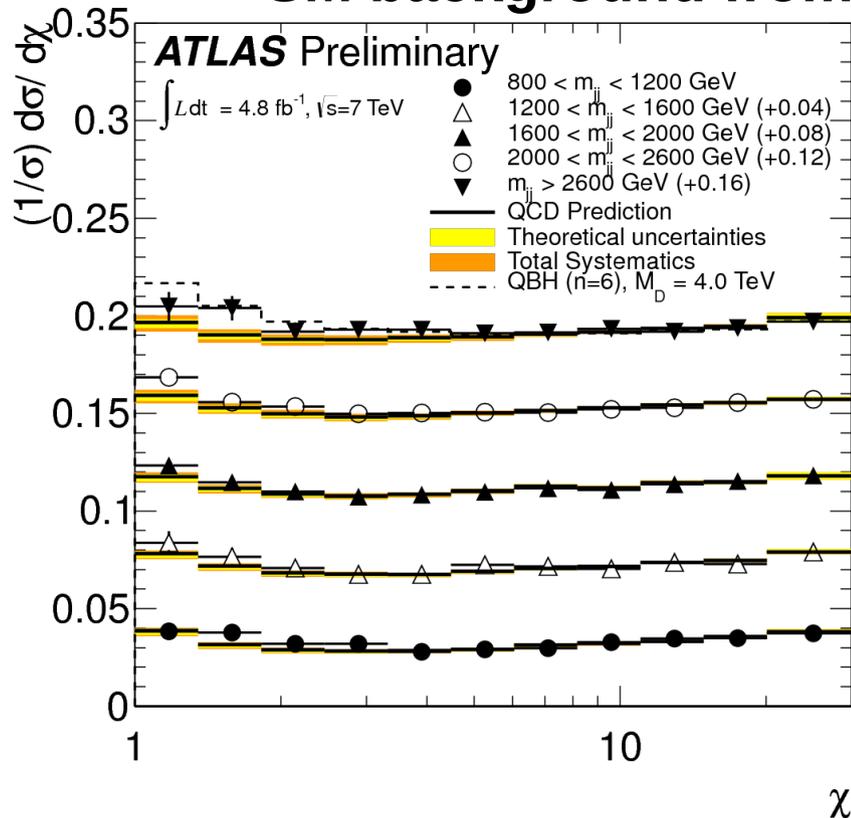
- fit dijet spectrum with a function to estimate SM background

- check fit quality and search for peak-like excesses with BumpHunter tool (variable width, trials factors) ---> no significant excess found

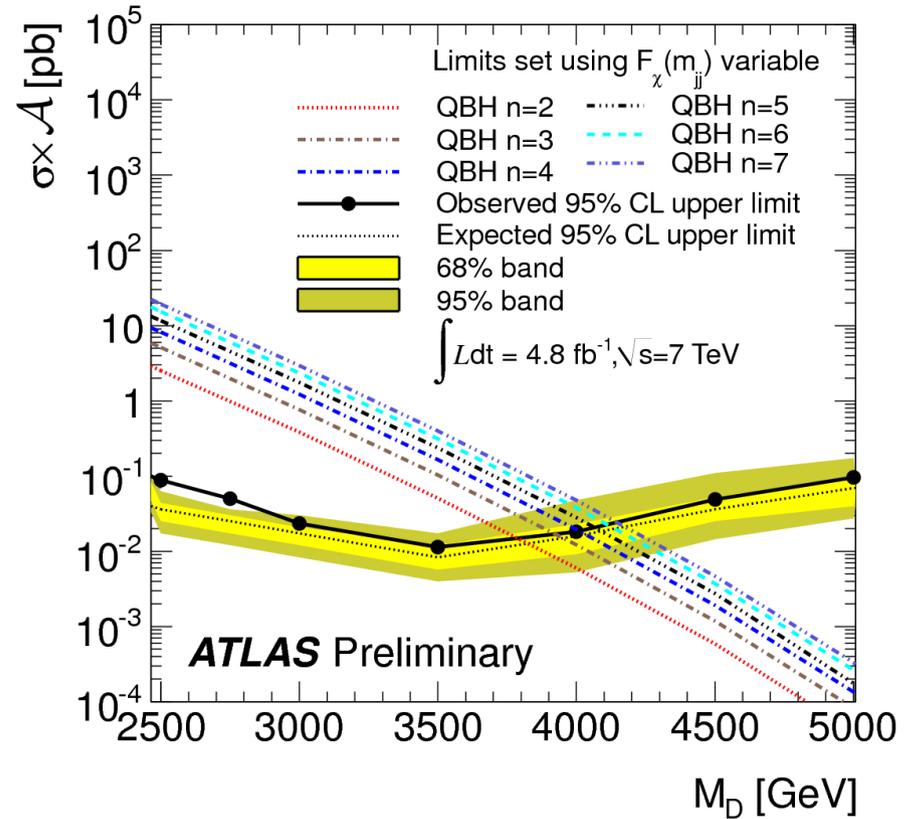
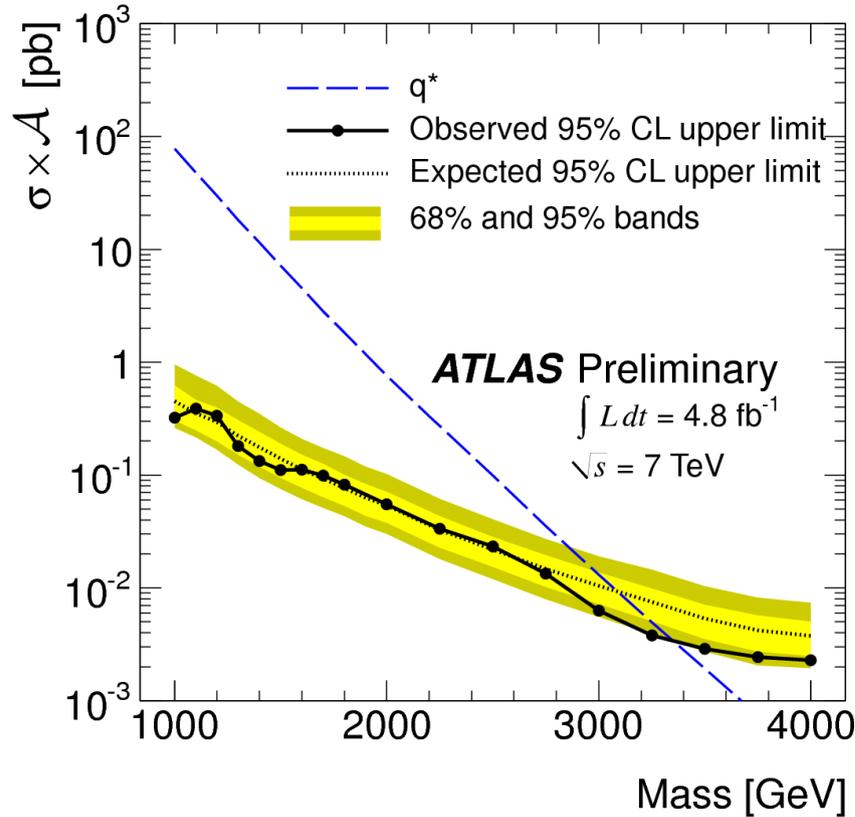




- Here,  $0.5 \cdot |y_1 - y_2| < 1.7$ ,  $|y_B| < 1.1$
- Used distributions:  $\chi = \exp(|y_1 - y_2|)$ ,  $F_\chi = N(\chi < 0.6) / N(\chi < 1.7)$  (binned in dijet mass)
- signal usually more central than QCD multijet background
- SM background from simulation



---> no significant deviation from SM background



## 95% C.L. limits on reference models:

	Limit on	Observed limit [TeV]
Excited quarks $q^*$	mass	3.35
Color octet scalars $s_8$	mass	1.94
Mini Quantum Black Holes ( $n = 6$ )	Gravity scale	3.96
Quark contact interaction	Compositeness scale	7.8



# Search for resonances in ZZ final states

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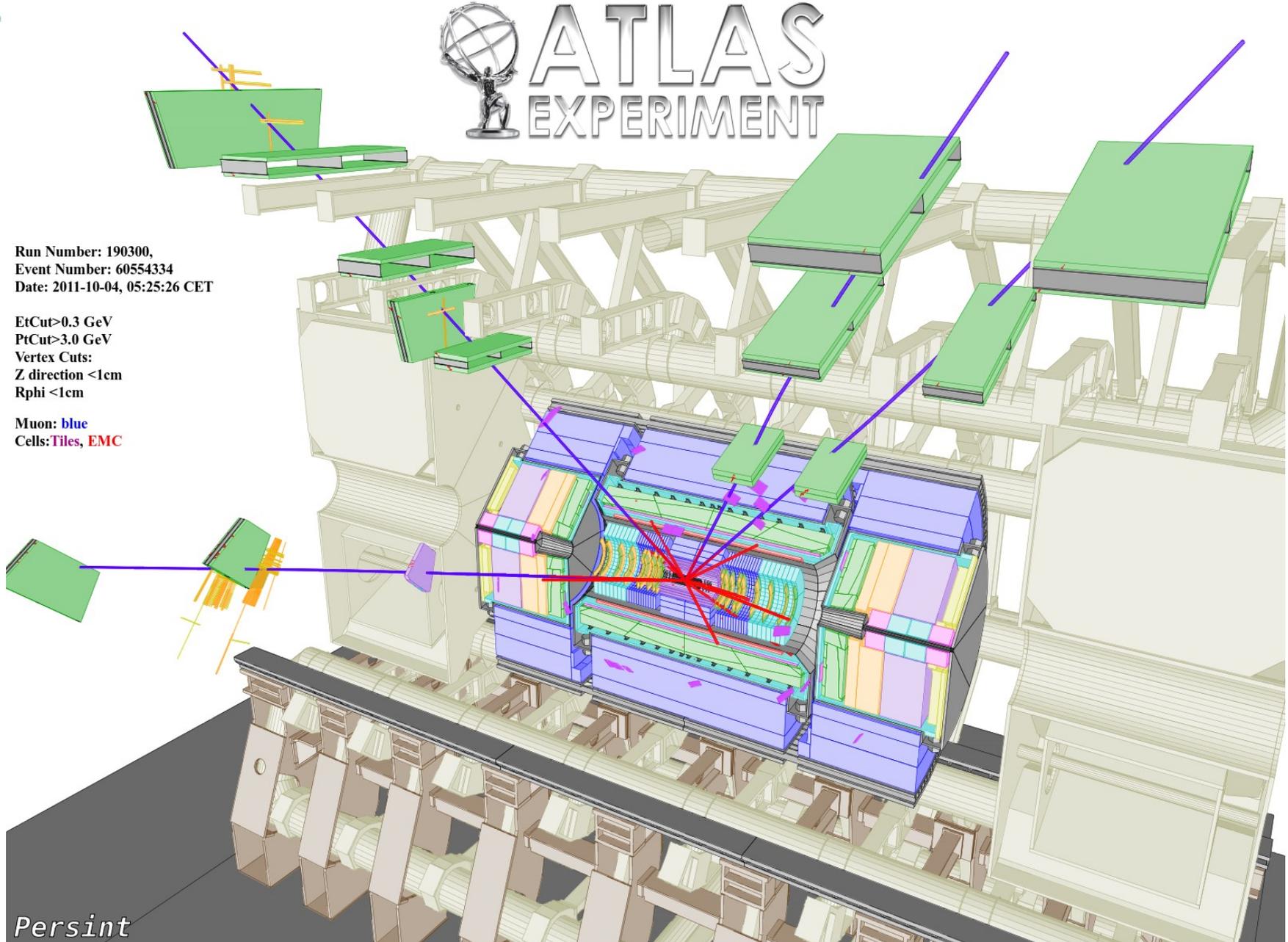
$\sim 1 \text{ fb}^{-1}$



Run Number: 190300,  
Event Number: 60554334  
Date: 2011-10-04, 05:25:26 CET

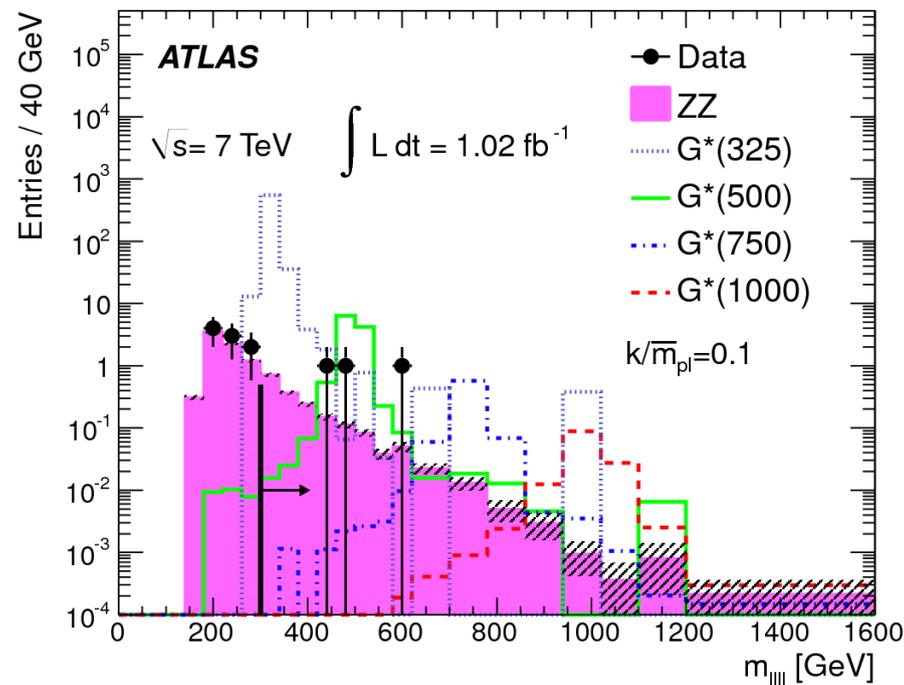
EtCut > 0.3 GeV  
PtCut > 3.0 GeV  
Vertex Cuts:  
Z direction < 1cm  
Rphi < 1cm

Muon: blue  
Cells: Tiles, EMC



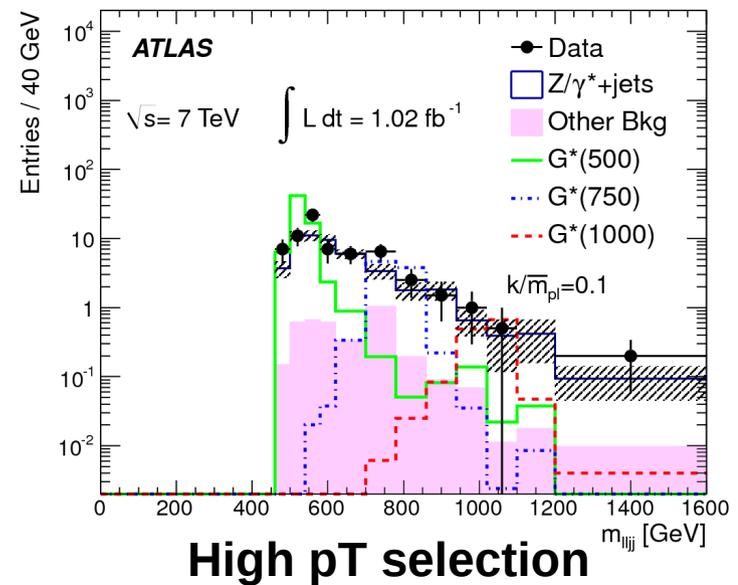
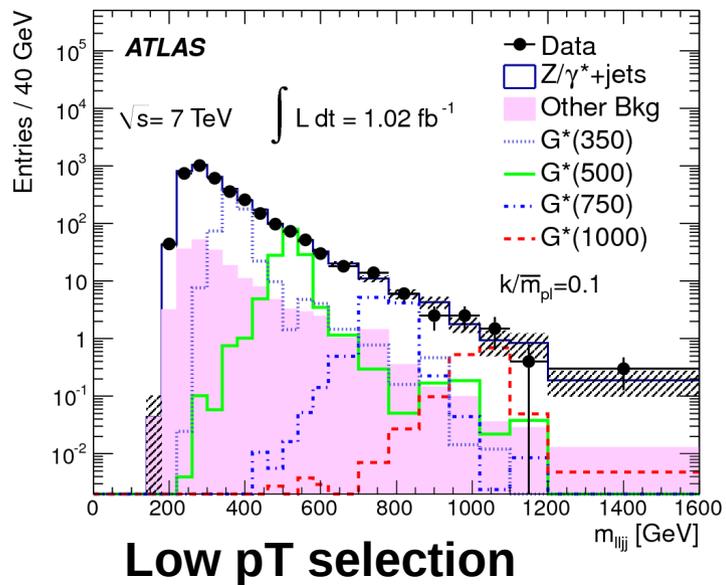
# ZZ: Event selection - IIII channel

- 2 pairs of isolated electrons/muons
  - electrons:  $|\eta| < 2.47, 1.37 > |\eta| > 1.52$ , muons:  $|\eta| < 2.7$
  - opposite charges,  $66 < m_{ll} [\text{GeV}] < 116$
  - dominant background: SM ZZ (simulated with Herwig, scaled to NLO)
  - background from misidentified leptons estimated from data
- > very small





- exactly two isolated electrons/muons
- $66 < m_{ll} [\text{GeV}] < 116$
- jet pair, anti kT,  $R = 0.4$
- $65 < m_{jj} [\text{GeV}] < 115$
- 2 regions (optimized for low and high mass RS graviton search):  
pT of dilepton system and highest pT jet pair  $> 50(200) \text{ GeV}$
- dominant background: DY+jets (ALPGEN simulation, scaled to data)





**BumpHunter: no significant excess found**

Submitted to PLB

arXiv:1203.0718

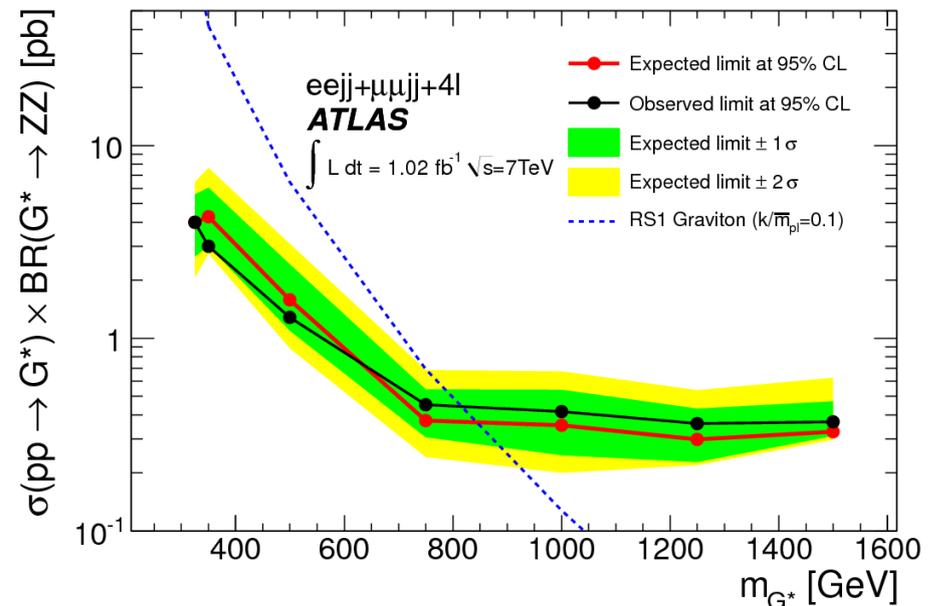
**---> 95% C.L. limits using Cls**

**(single bin for III, sliding window for IIjj)**

**---> Limits on the cross-section times branching ratio  
of the RS graviton ( $k/M_{\text{Pl}} = 0.1$ )**

**- RS graviton ( $k/M_{\text{Pl}} = 0.1$ )  
excluded for 325-845 GeV**

**- for III, also limits on  
fiducial cross section  
for any new ZZ physics: 0.92 pb  
( $p_T > 15 \text{ GeV}$ ,  $\eta < 2.5$ ,  $66 < m_{\text{II}} [\text{GeV}] < 116$ ,  $m_{\text{III}} [\text{GeV}] > 300$ )**





# Search for resonances in WZ final states

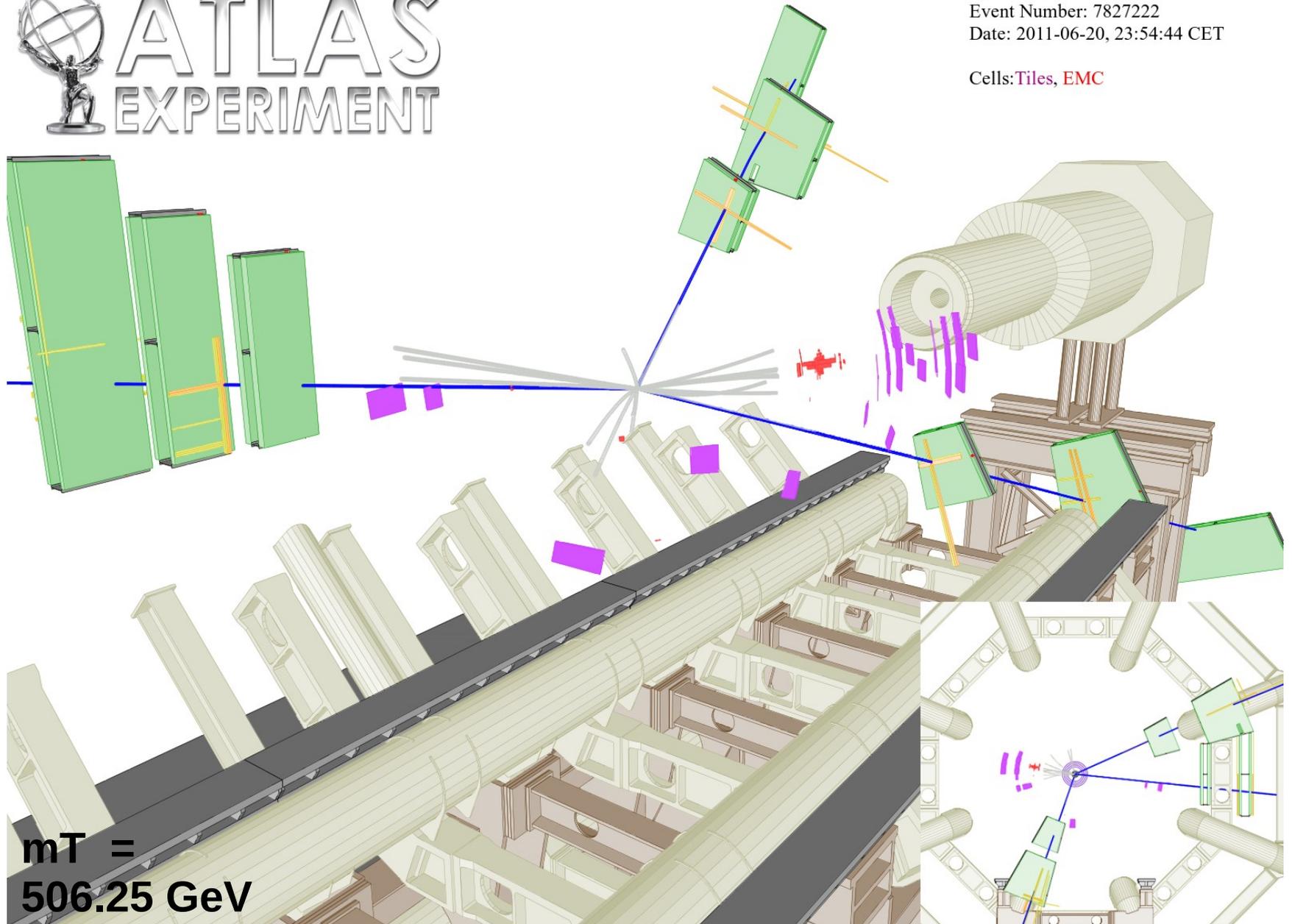
20

$\sim 1 \text{ fb}^{-1}$



Run Number: 183780,  
Event Number: 7827222  
Date: 2011-06-20, 23:54:44 CET

Cells: Tiles, EMC

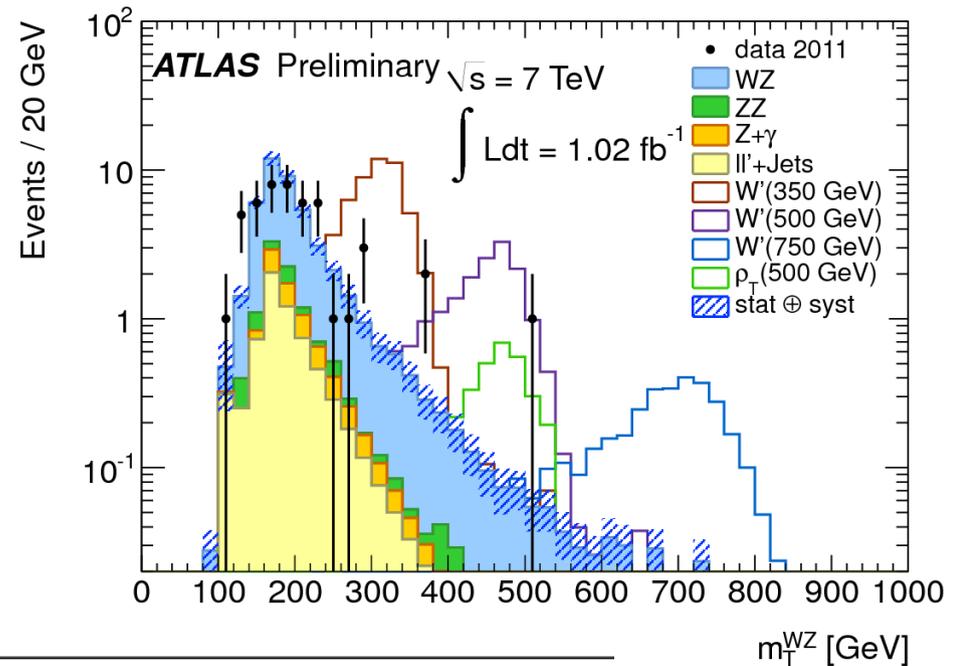


$m_T =$   
**506.25 GeV**



- Z- $\rightarrow$  ee,  $\mu\mu$  and W- $\rightarrow$ ve,  $\nu\mu$
- > two oppositely charged, same flavor leptons,  
exactly one additional lepton, MET > 25 GeV
- electrons:  $|\eta| < 2.47$ ,  $1.37 > |\eta| > 1.52$ , muons:  $|\eta| < 2.4$
- $71 < m_{ll} [\text{GeV}] < 111$ ,  $m_T(W) > 15 \text{ GeV}$

- dominant background:  
SM WZ production  
(simulated with MCatNLO)
- $ll'+\text{jets}$  estimated from data
- discriminating variable:



$$m_T^{WZ} = \sqrt{(E_T^Z + E_T^W)^2 - (p_x^Z + p_x^W)^2 - (p_y^Z + p_y^W)^2}$$



- comparison of mT distribution in data and simulation
- log-likelihood ratio test-statistics
- > no significant excess found
- > set 95% C.L. limits with CLs

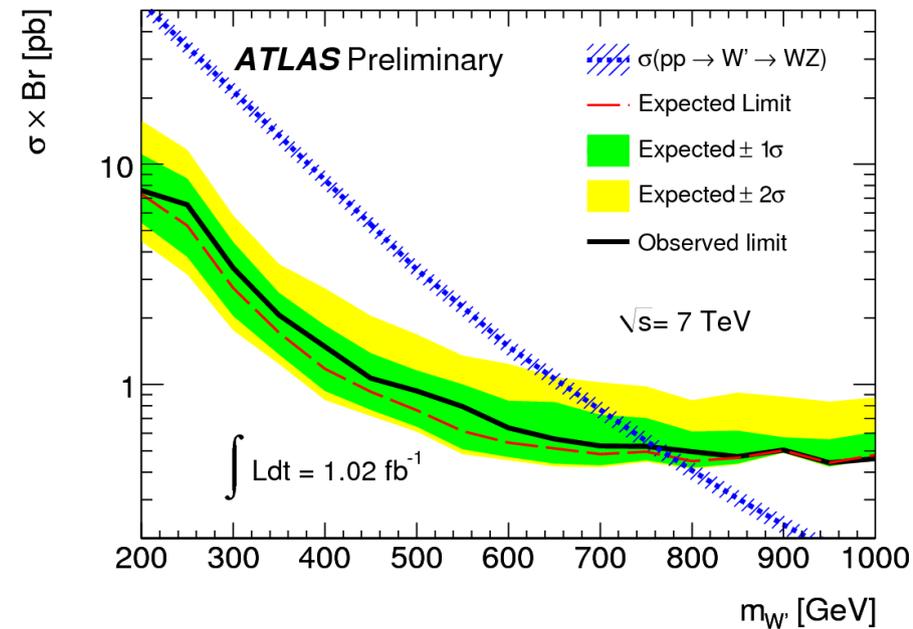
**Limits on  $W'$   
in extended Gauge model**

**Coupling to WZ:**

$$g_{W'WZ} = g_{WWZ} \times m_W m_Z / m_{W'}^2$$

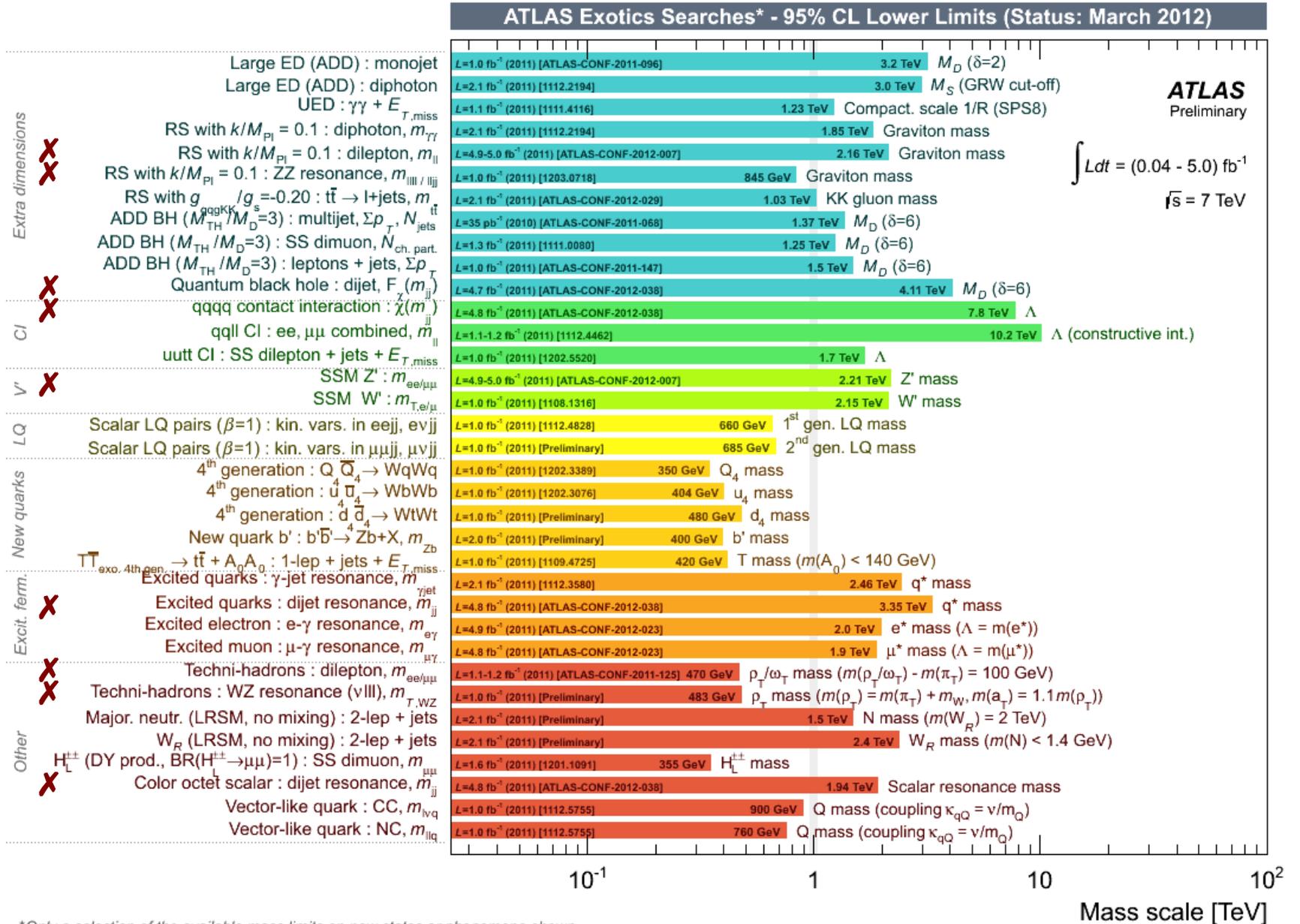
**Masses excluded up to 760 GeV**

**(also limits on  $\rho_T$ , see backup slides)**





# Summary





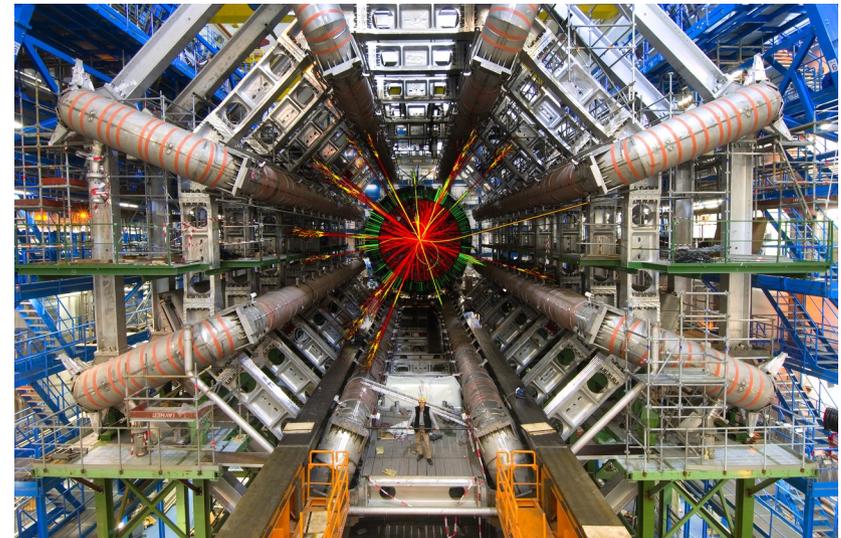
**Presented results of resonance searches at ATLAS  
in dilepton, dijet, ZZ, WZ final states**

- no hint of new physics found so far**
- extended exclusion ranges for many models**

**Looking forward to 2012 data!**

- resonance searches  
benefit directly from  
higher CM energy**

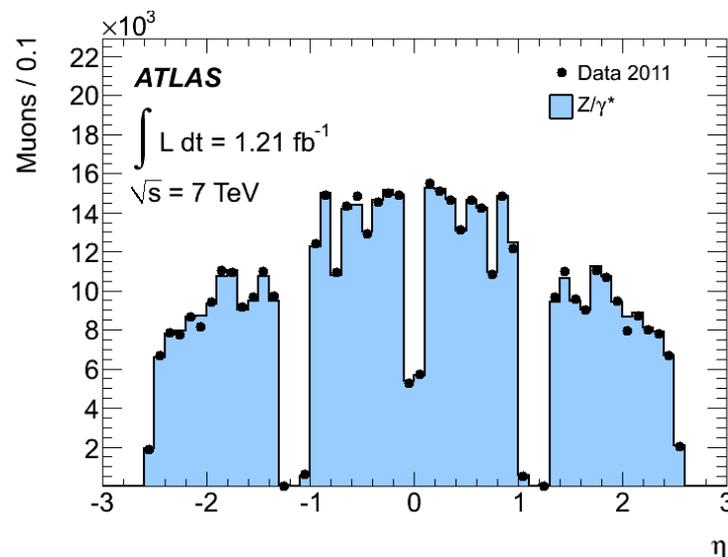
Simulated black hole event superimposed  
over image of ATLAS detector



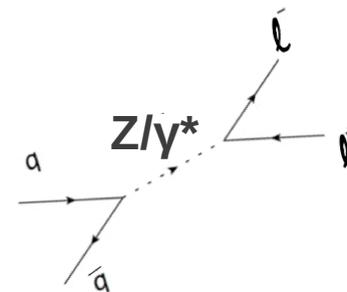


# Backup: Event Selection – muons

- ATLAS data quality (stable beam, functioning subdetectors etc.)
- pick two standard combined muons,  $p_T > 25$  GeV
- require 3 hits in 3 muon spectrometer layers,  
no overlap barrel-endcap, veto misaligned chambers
- distance from primary vertex needs to be small
- require tracks to be isolated
- muons must have opposite charge
- form invariant mass, require mass  $> 70$  GeV



Main background:



Acceptance ( $Z'$ , 1.5 TeV): 42%



## Backup: 2-station muons

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**Low acceptance in muon channel due to strict cuts on the hits in the muon spectrometer (inner, middle, outer layer)**

**----> decent momentum resolution**

**----> but three layers not available for every region of the detector**

**Inclusion of 2-station muons**

**- 1 leg 3 stations, 1 leg 2 stations**

**- combined muons (inner detector and spectrometer)**

**- require 5 hits in each of the inner and outer layer**

**- veto regions with misalignments**

**- significance cut (ID-MS):  $3\sigma$  (instead of 5 like for 3-station muons)**

**---> acceptance increase by ~4% (absolute)**

**---> resolution ~25% (dominated by inner detector)**

# Backup: WZ Limits

## Limits on $\rho_T$ in Low Scale Technicolor Model

- depend on  $m(\pi_T)$  and  $m(a_T)$ ,  
and  $\pi_T$  mixing with EW gauge bosons
- assume  $\sin(\chi) = 1/3$
- consider two scenarios:  $m(a_T) = 1.1 m(\rho_T)$ ,  $m(a_T) \gg m(\rho_T)$
- signal template modeled without spin correlations  
---> affects acceptance, use  $W'$  acceptance as check

