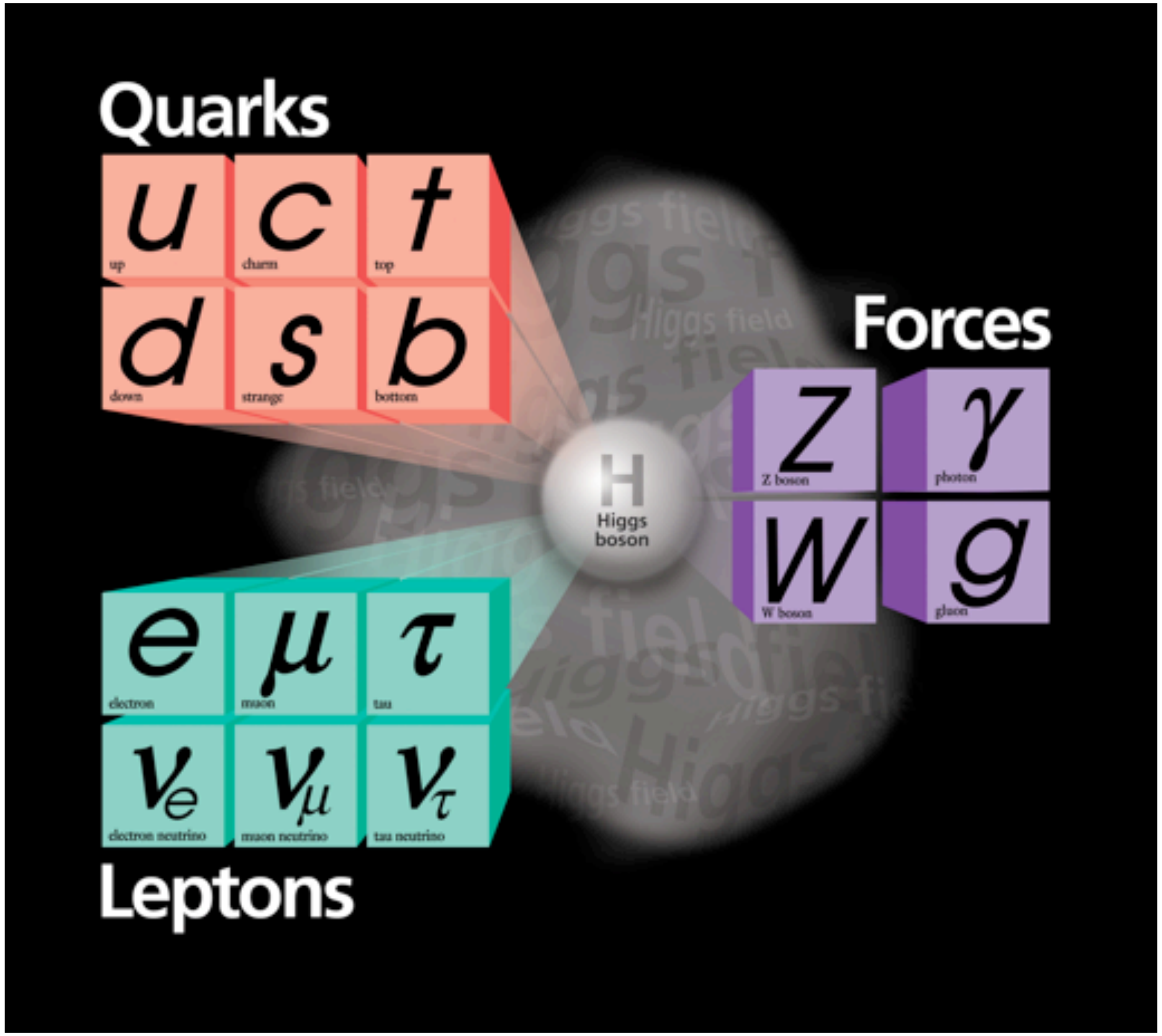
Search for new physics with jets in ATLAS

Belen Salvachua
for the ATLAS Collaboration
Argonne National Laboratory

Workshop on Jet Reconstruction and Spectroscopy at Hadron Colliders
Pisa (Italy) 18-19 April 2011

Physics Beyond the Standard Model



But Higgs seems to be very shy...

... and many other open questions:

- Neutrino oscillations
- Matter/Antimatter asymmetry
- Unification of gravity
- etc...

New physics should appear at the LHC

Outline

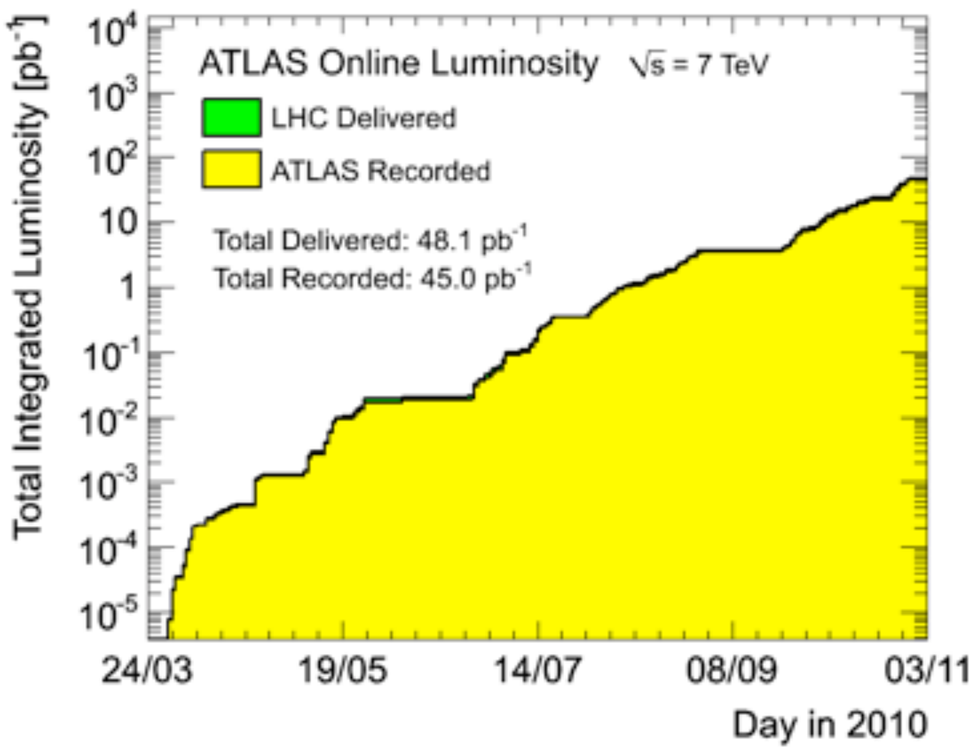
LHC data will offer sensitivity to a mass range beyond that probed by other accelerators...

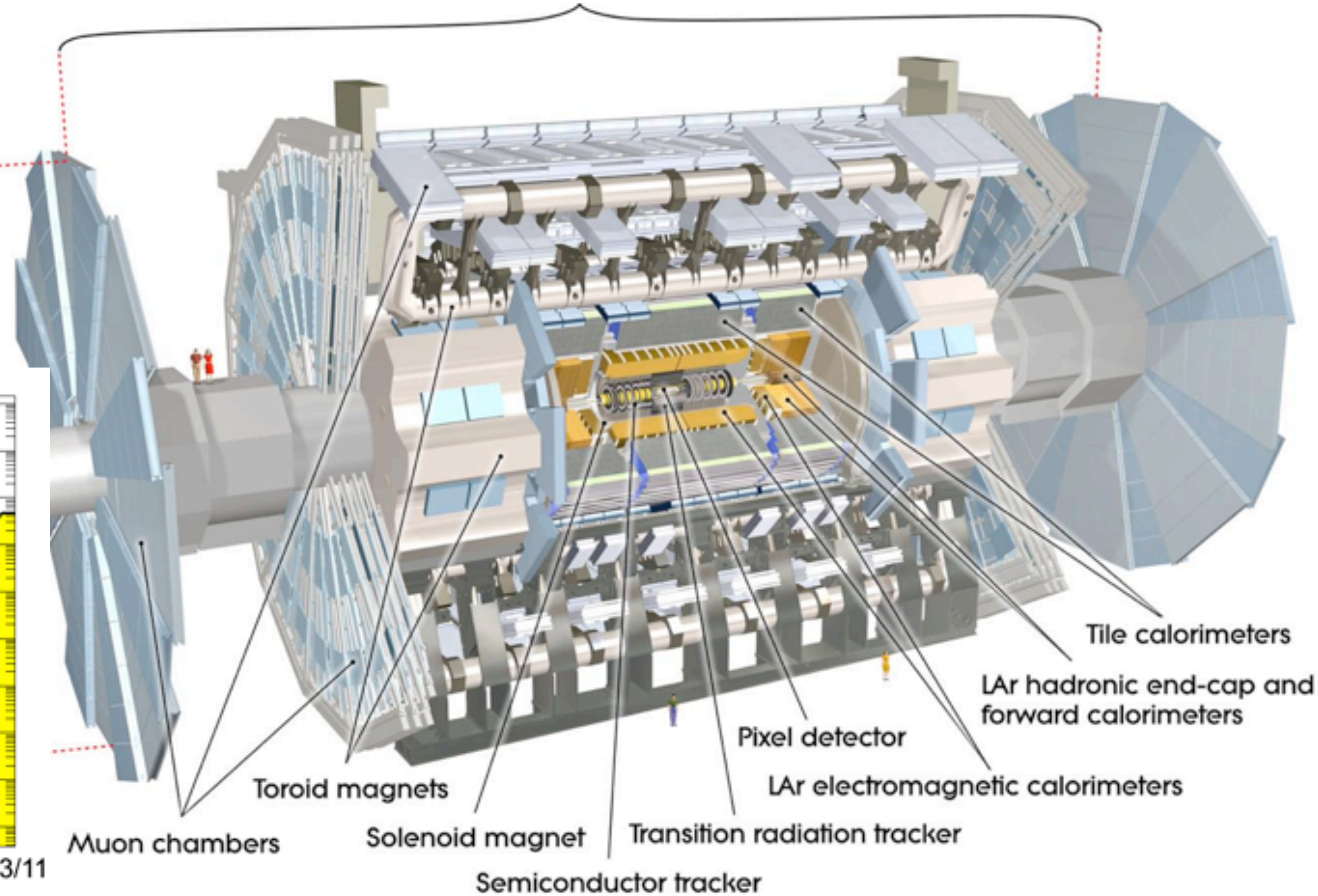
- Dijet signatures:
  - Invariant mass distributions: search for new resonances
  - Angular distributions: search for new interactions
- WWjj signatures:
  - Search for a 4th heavy quark generation
- Leptons and jets signatures:
  - Lepto-quark searches

The ATLAS detector

For these analysis:
Muon Spectrometer, Calorimeters and Inner detector

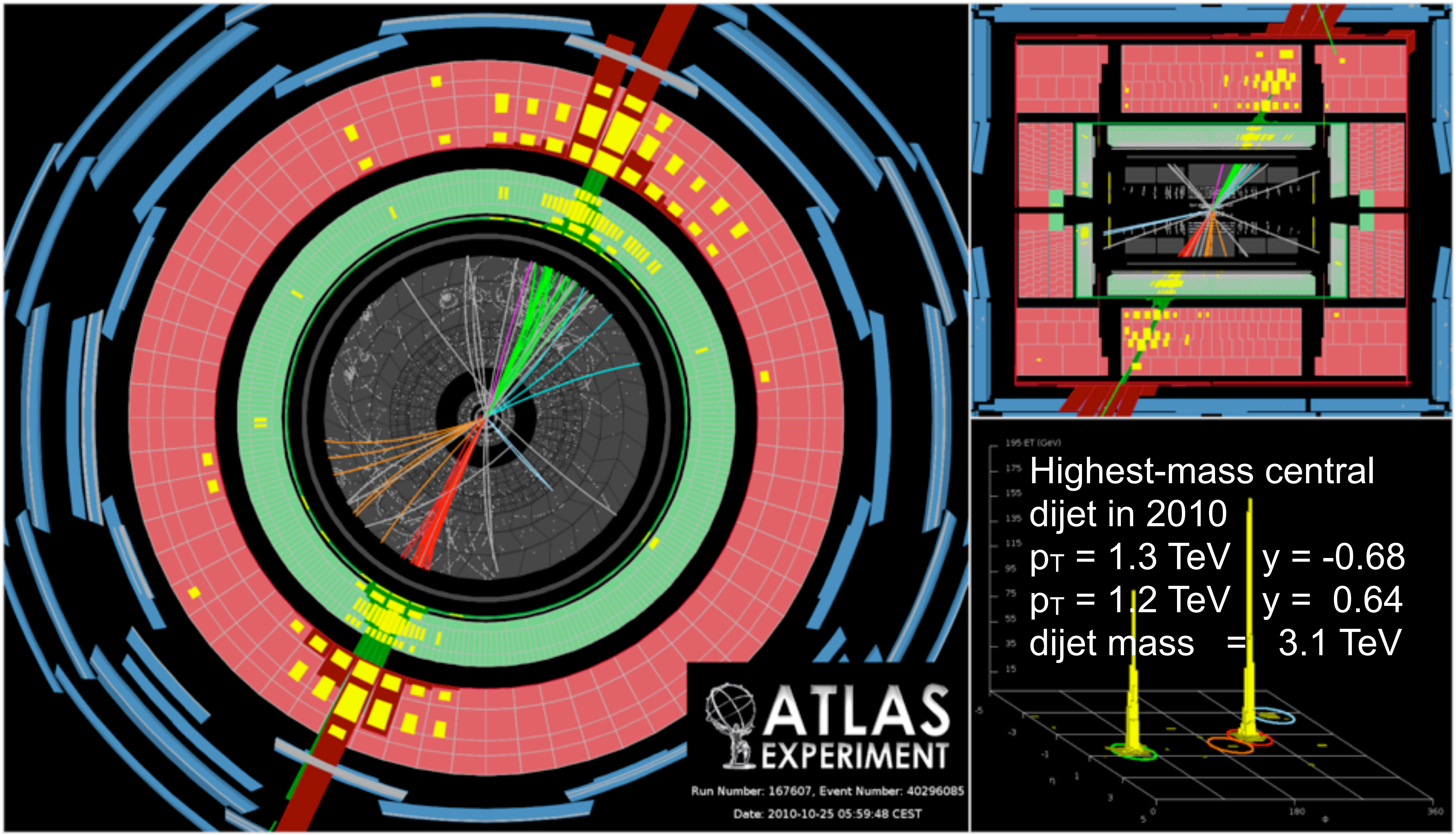
Integrated Luminosity used:
33-37 pb^{-1}





Dijet analysis

ATLAS-CONF-2011-047



Previous ATLAS results use $3.1 pb^{-1}$, now $36 pb^{-1}$ integrated luminosity

Dijet analysis

- Search for massive objects and new interactions
- At high p_T, '2 → 2' scattering. We are testing the Standard Model in a new unexplored regime
- Discrepancies could indicate new physics:
  - Quark substructure: excited composite quark q*
  - Chiral color models: axigluon
  - Quark contact interactions...

Search

dijet invariant mass
dijet angular distributions

Event pre-selection:

✤ 2 jets p_{T1} > 60 GeV and p_{T2} > 30 GeV

Dijet-mass analysis

mjj sensitive to new phenomena

Data-driven model of the QCD bkg shape, χ^2 test:

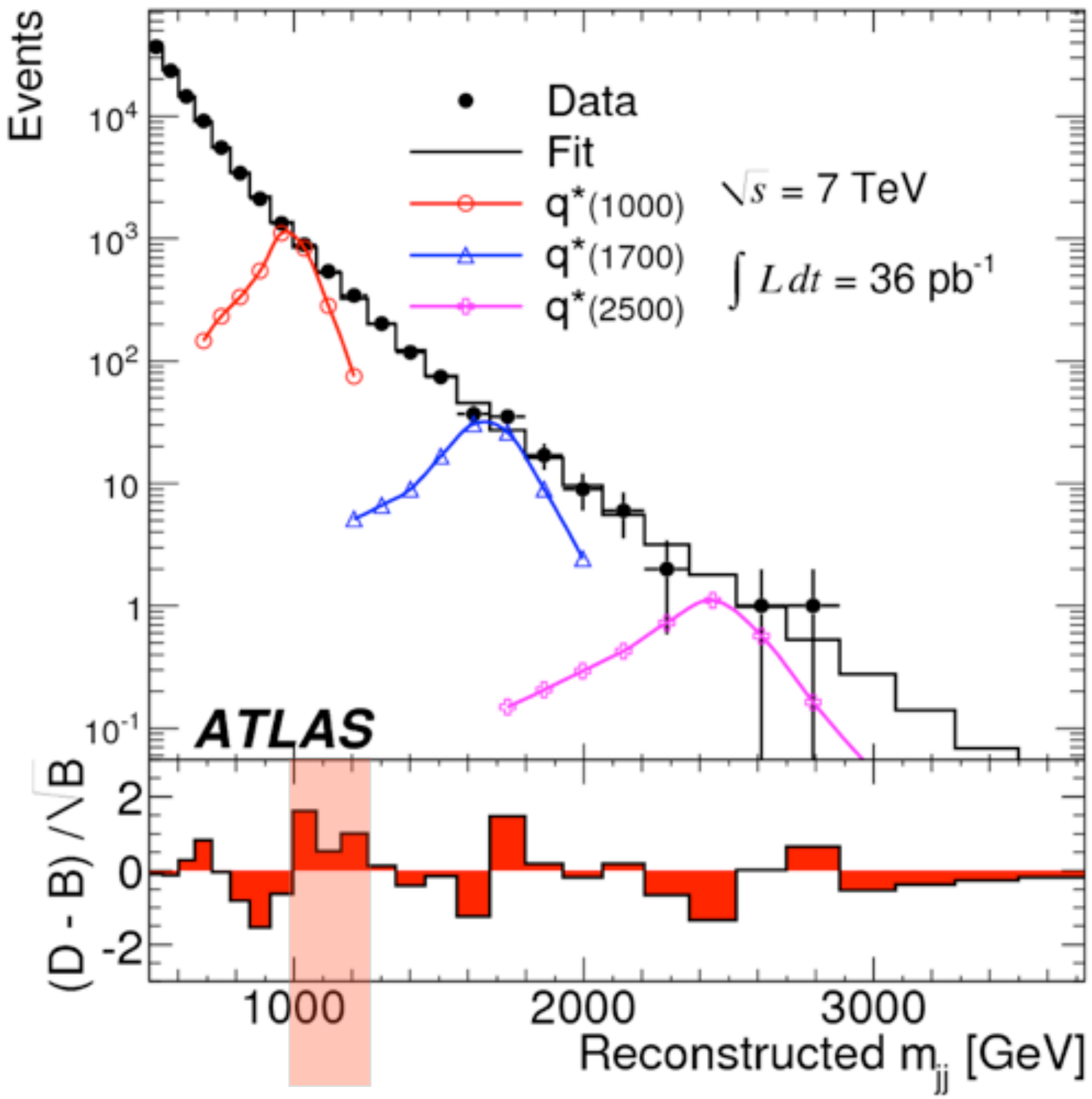
$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

$$x \equiv m_{jj}/\sqrt{s}$$

p-value of fit is 0.88→ good agreement between fit and data

Additional test using: BUMPHUNTER algorithm

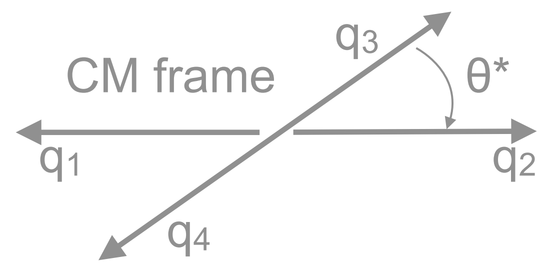
Observed spectrum consistent with rapidly falling, smooth distribution



Most significant discrepancy, p-value of 0.39: still good agreement between fit and data

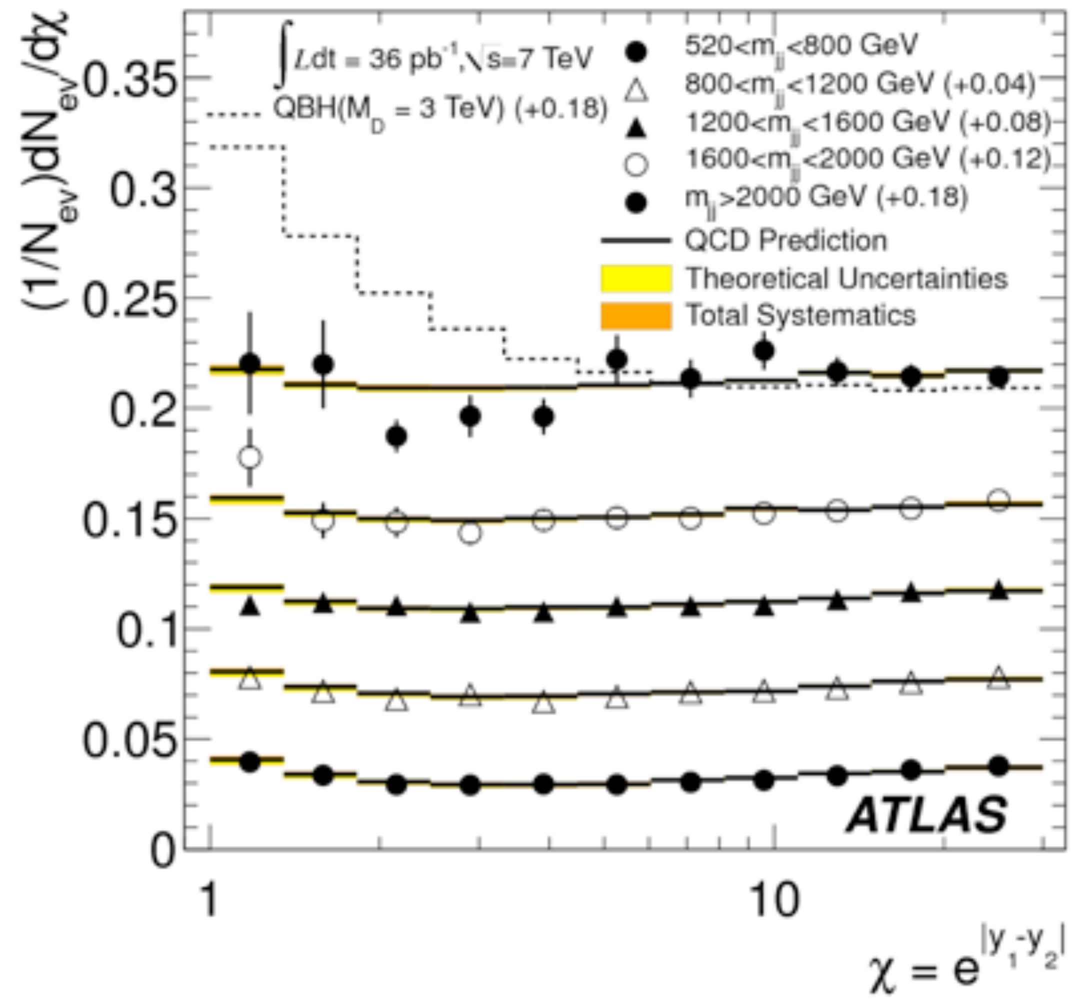
Dijet angular distributions

$$y^* = \frac{1}{2}\ln\left(\frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}\right)$$



Relatively flat for QCD

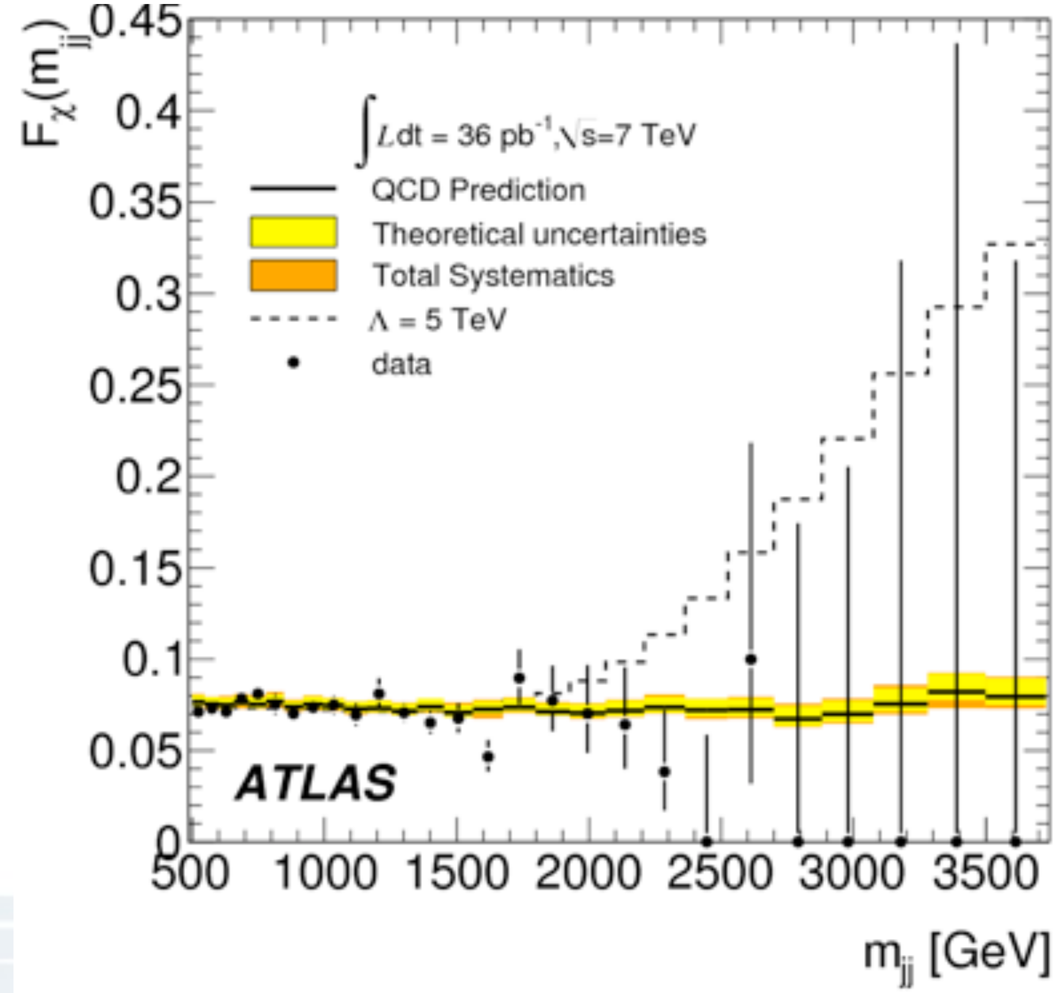
$$\chi \equiv \exp(|y_1 - y_2|)$$



Fraction of dijets produced centrally versus the total number of observed dijets for a specified dijet mass range

$$F_\chi\left(\left[m_{jj}^{min} + m_{jj}^{max}\right]/2\right) \equiv \frac{N_{events}(|y^*| < 0.6, m_{jj}^{min}, m_{jj}^{max})}{N_{events}(|y^*| < 1.7, m_{jj}^{min}, m_{jj}^{max})}$$

Sensitive to mass-dependent changes



$$y^* = \frac{1}{2}(y_1 - y_2) \quad y_B = \frac{1}{2}(y_1 + y_2)$$

Dijet mass resonance search limits

Exclude production of q*

Observed 0.6< m(q*) < 2.15 TeV

Expected m(q*) < 2.07 TeV

Exclude production of Axigluon

Observed 0.6< m(A) < 2.10 TeV

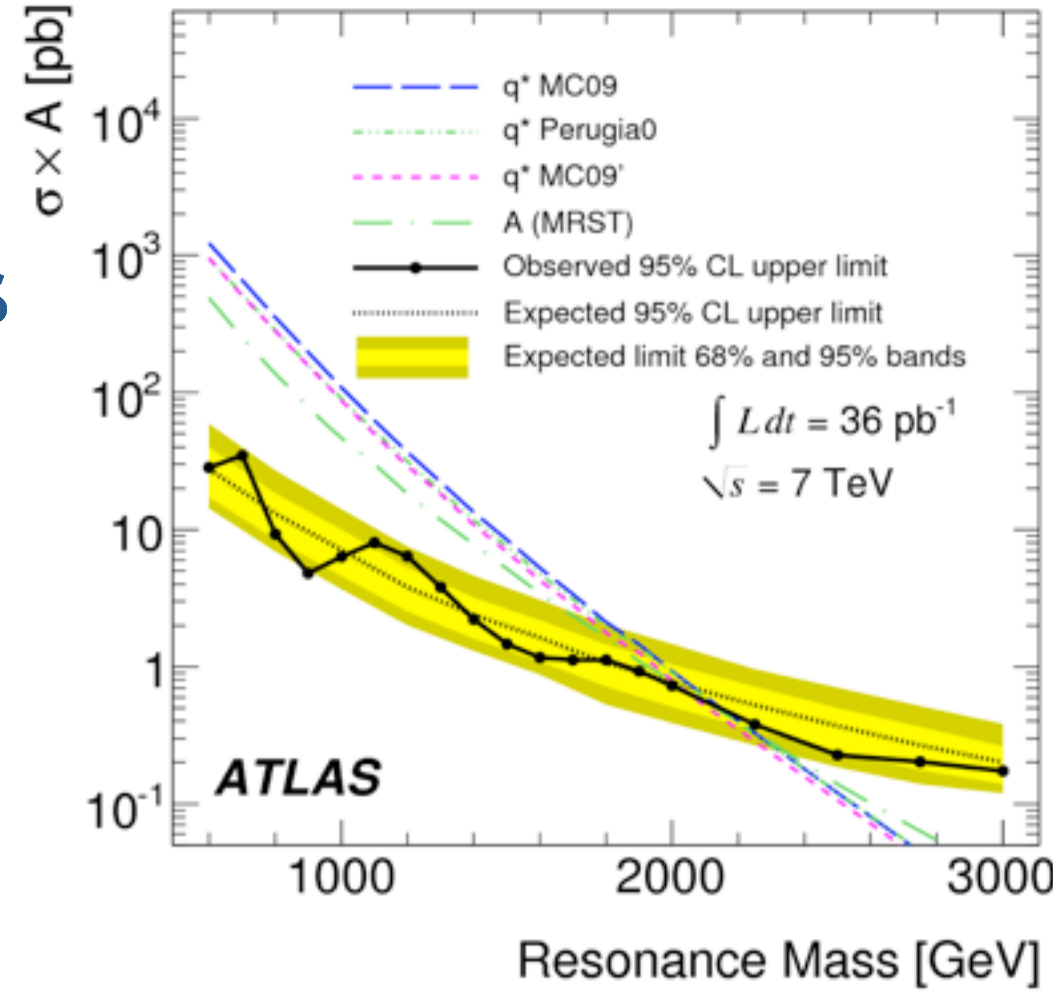
Expected m(A) < 2.01 TeV

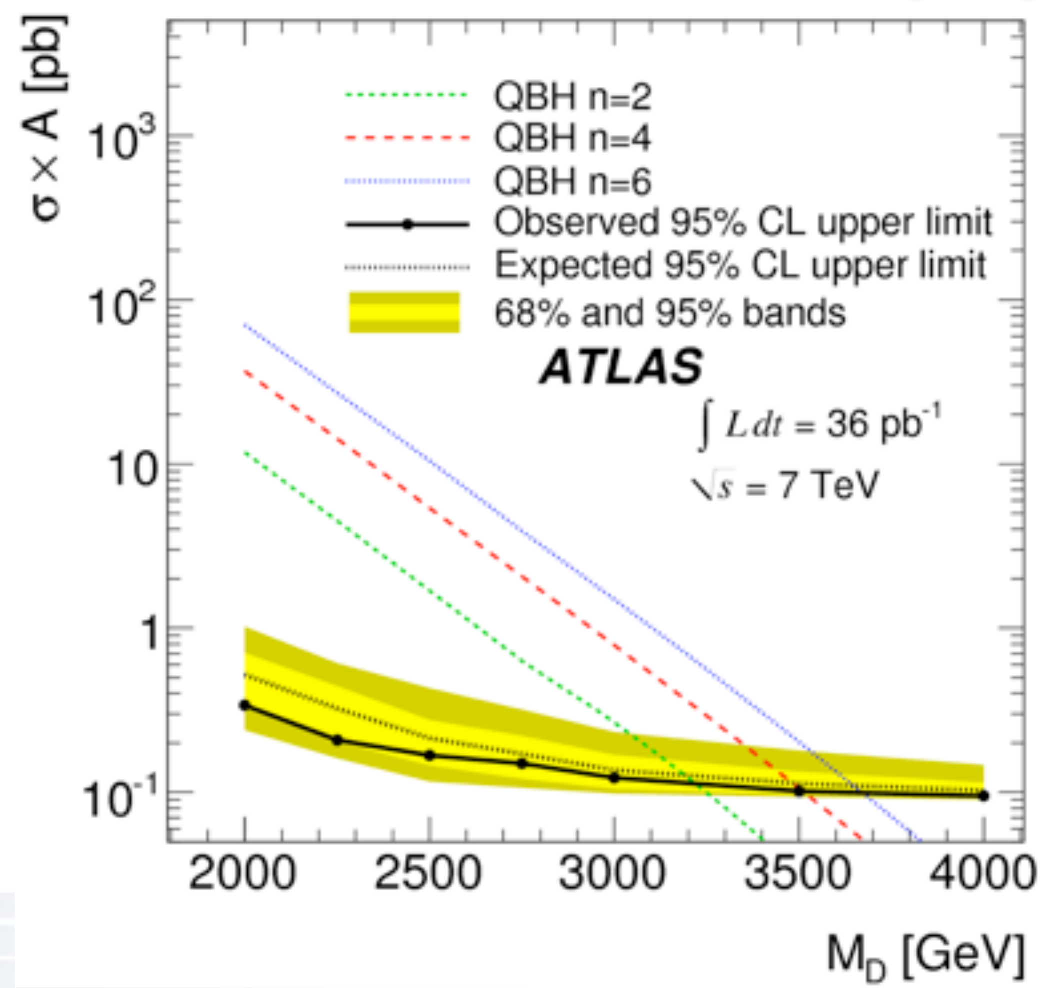
Exclude Quantum Black Hole Production

for Number of Extra-dim = 6

Observed M_D < 3.67 TeV

Expected M_D < 3.64 TeV





Dijet mass resonance limits

New technique:

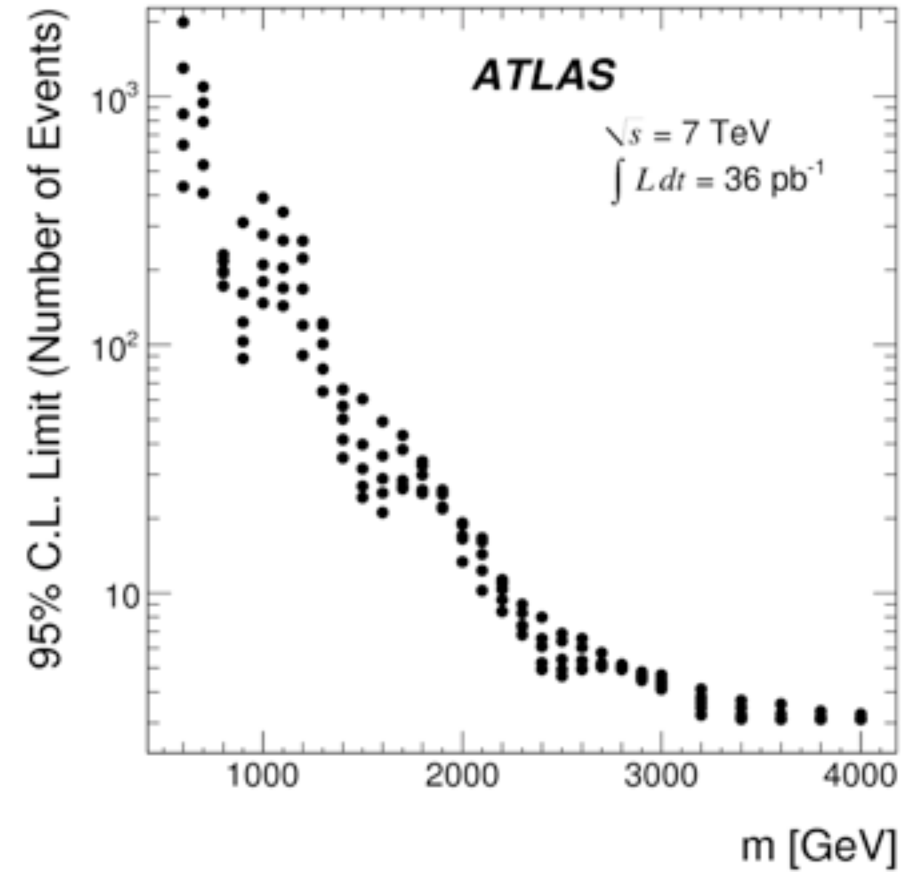
Simplified Gaussian model limits

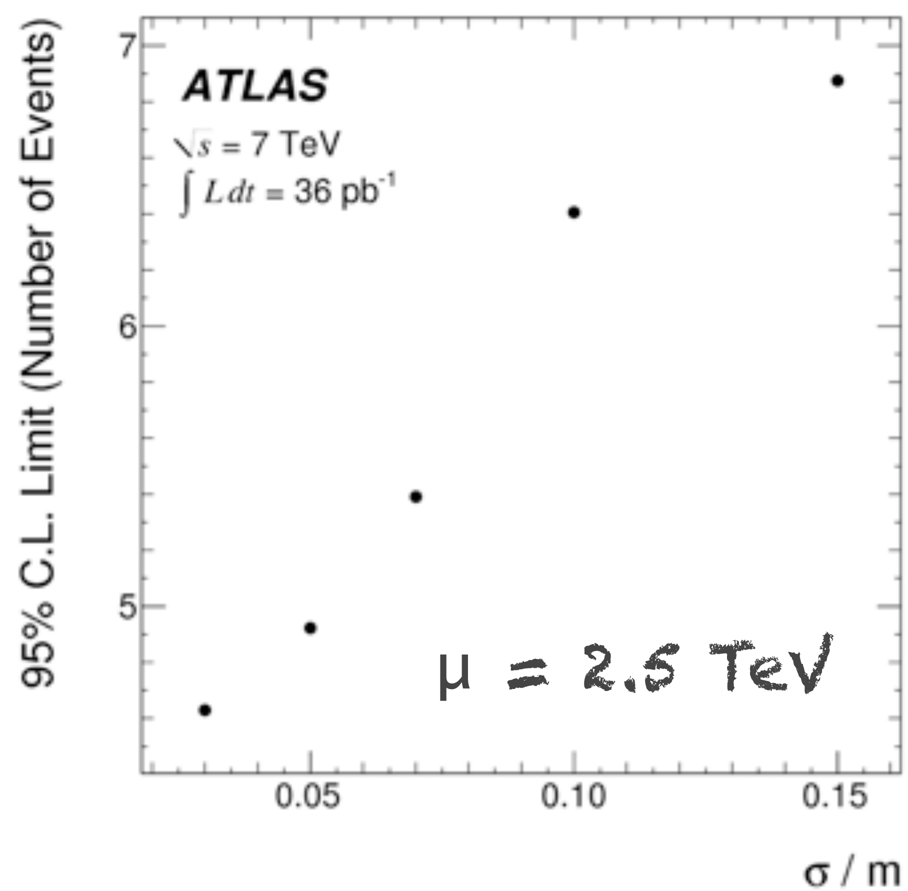
Model independent limits

Our signal template is a Gaussian:

- μ mean: between 600GeV and 4000GeV
- σ sigma: between 3% and 15% of mean

We set production cross section limits as a function of dijet mass to facilitate comparisons with other hypotheses





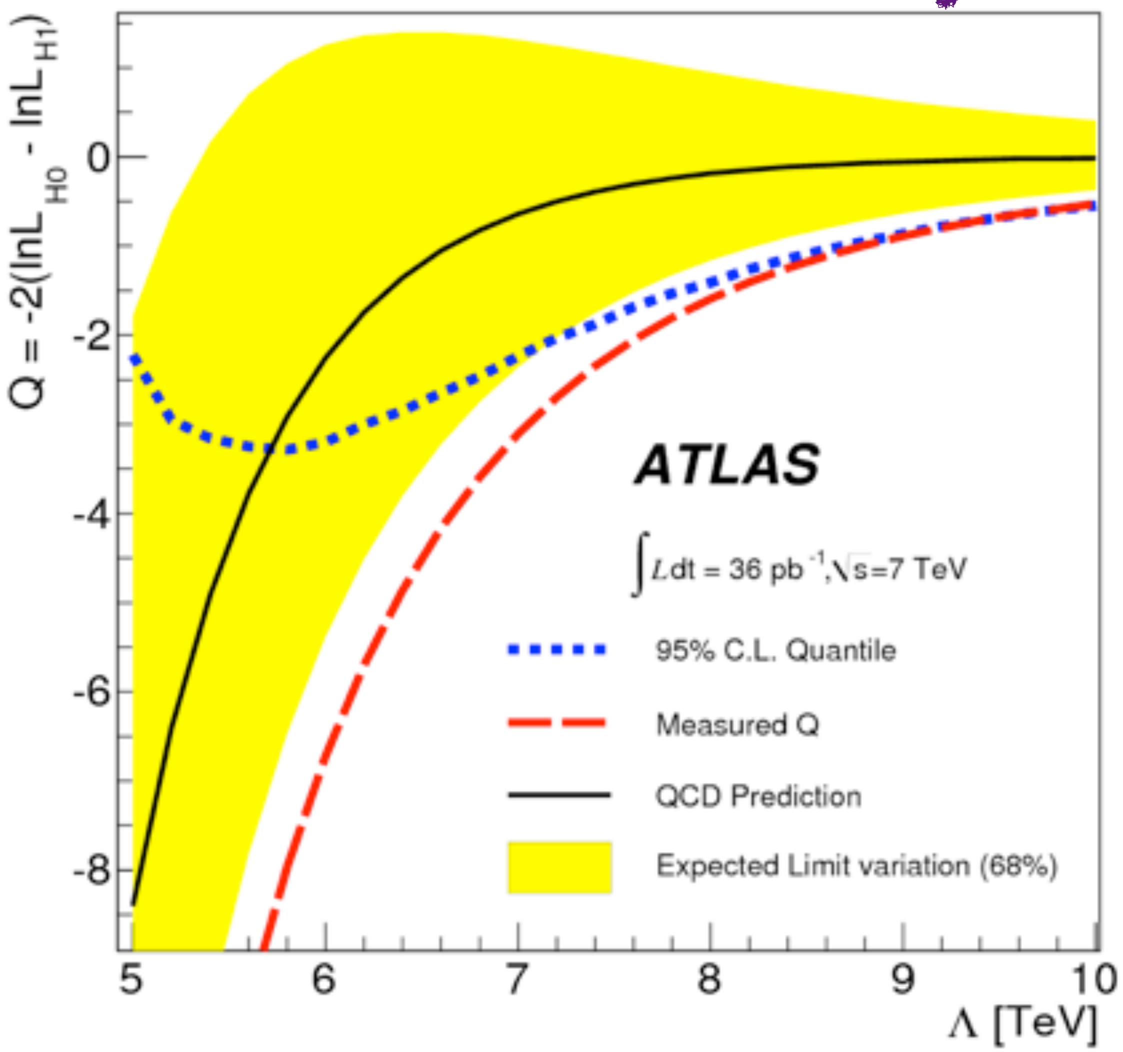
Dijet angular distribution limits

Exclude contact interaction

Observed Λ < 9.5 TeV

Expected Λ < 5.7 TeV

Observed Λ < 6.7 TeV (Bayesian)

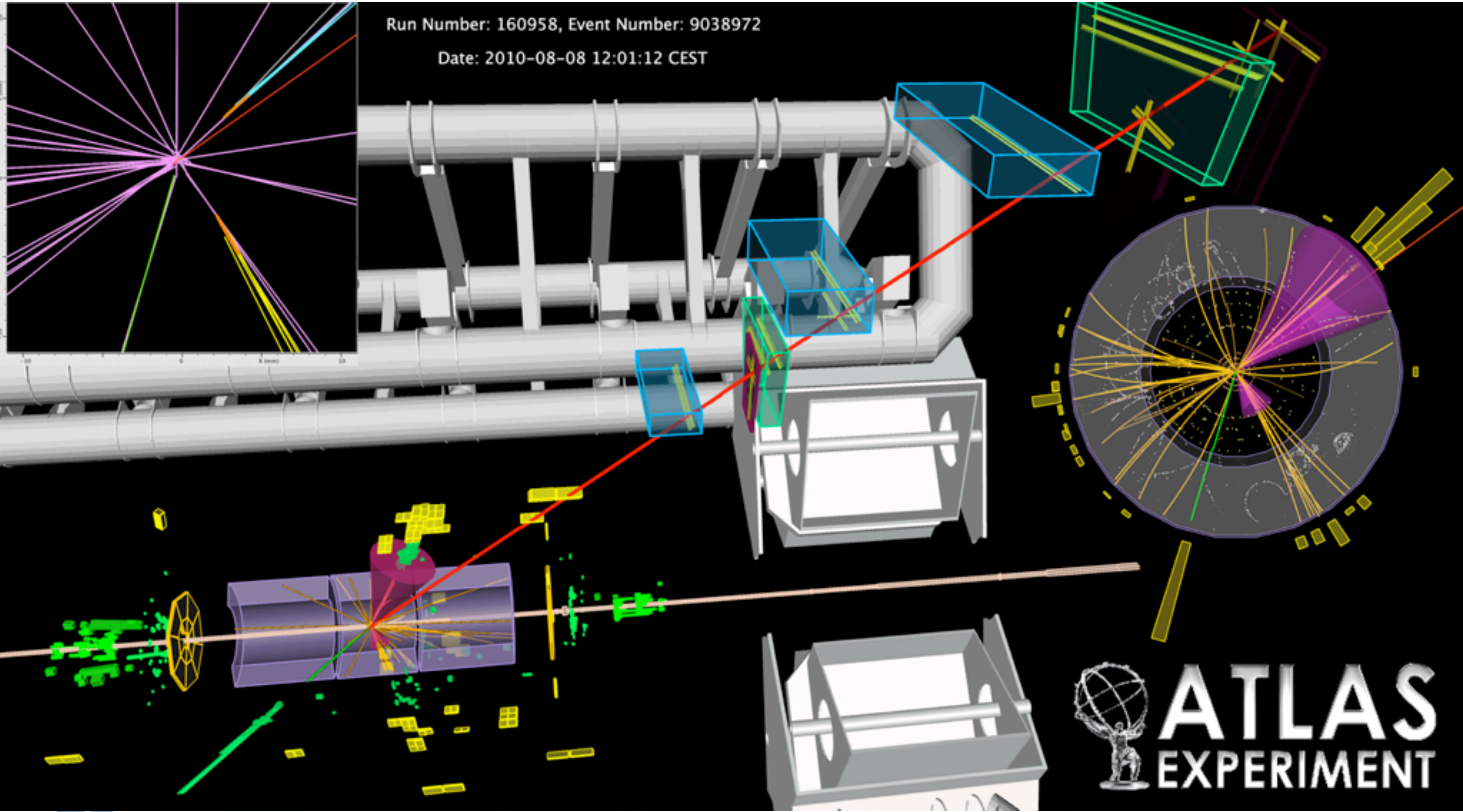


Summary dijet mass and angular distribution limits

Model and Analysis Strategy	95% C.L. Limits (TeV) Expected	Observed
Excited Quark q^*		
Resonance in m_{jj}	2.07	2.15
$F_\chi(m_{jj})$	**2.12**	**2.64**
Randall-Meade Quantum Black Hole for $n = 6$		
Resonance in m_{jj}	**3.64**	**3.67**
$F_\chi(m_{jj})$	3.49	3.78
θ_{np} Parameter for $m_{jj} > 2$ TeV	3.37	3.69
11-bin χ Distribution for $m_{jj} > 2$ TeV	3.36	3.49
Axigluon		
Resonance in m_{jj}	**2.01**	**2.10**
Contact Interaction Λ		
$F_\chi(m_{jj})$	**5.7**	**9.5**
F_χ for $m_{jj} > 2$ TeV	5.2	6.8
11-bin χ Distribution for $m_{jj} > 2$ TeV	5.4	6.6

WWjj analysis

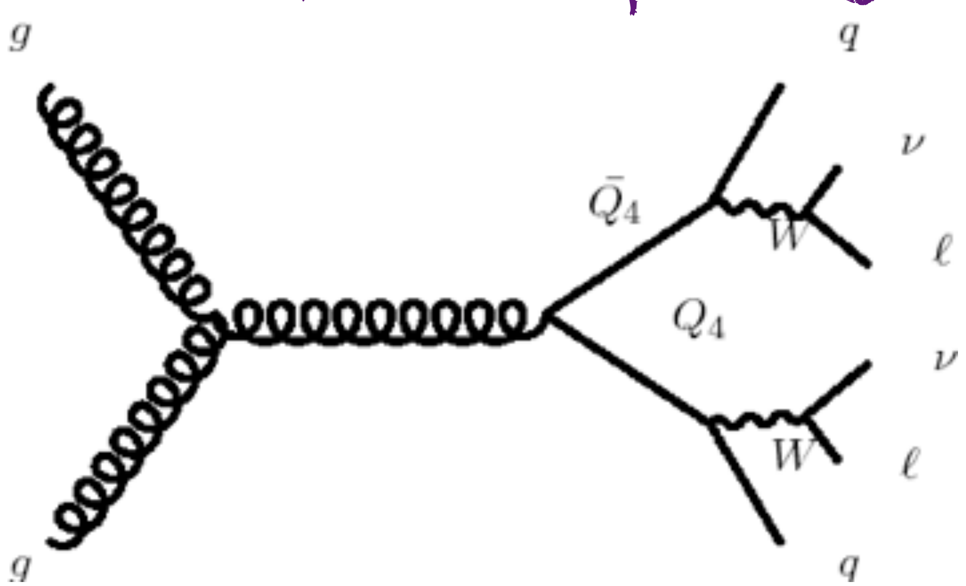
t t-bar candidate (main background)



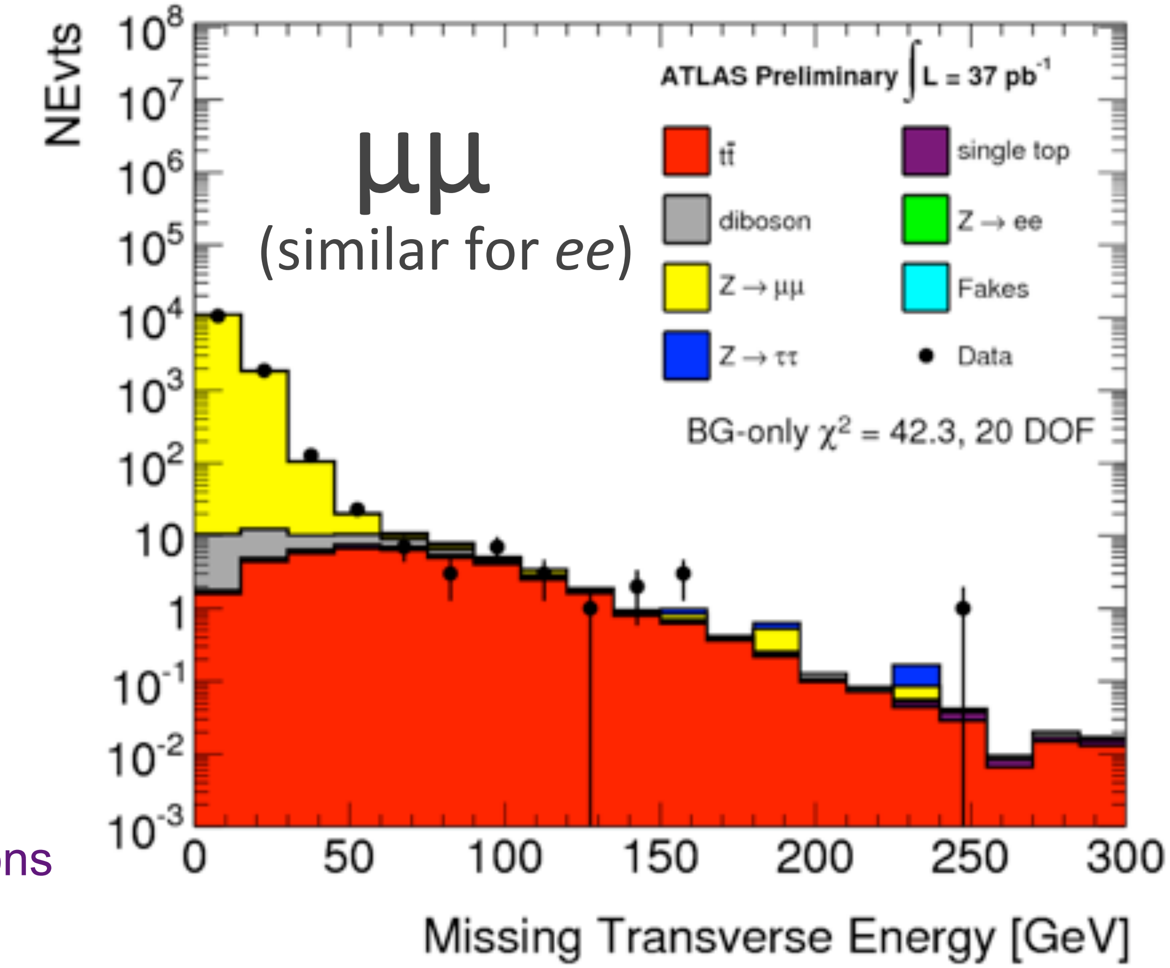
Integrated luminosity $37pb^{-1}$

WWjj

Search for 4th quark generation

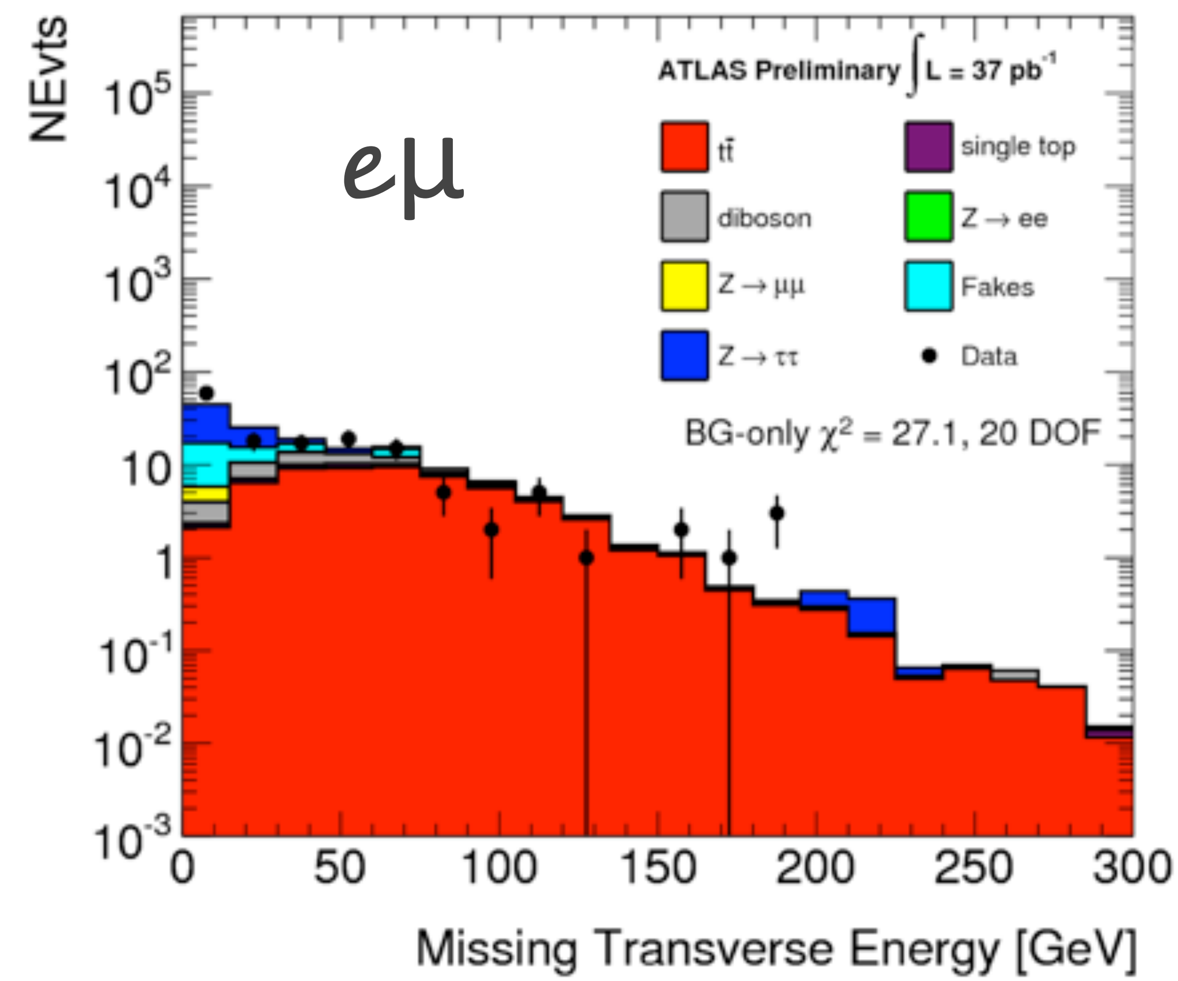


all leptonic
(e and μ)
opposite sign leptons



Reduce Z background main selection:

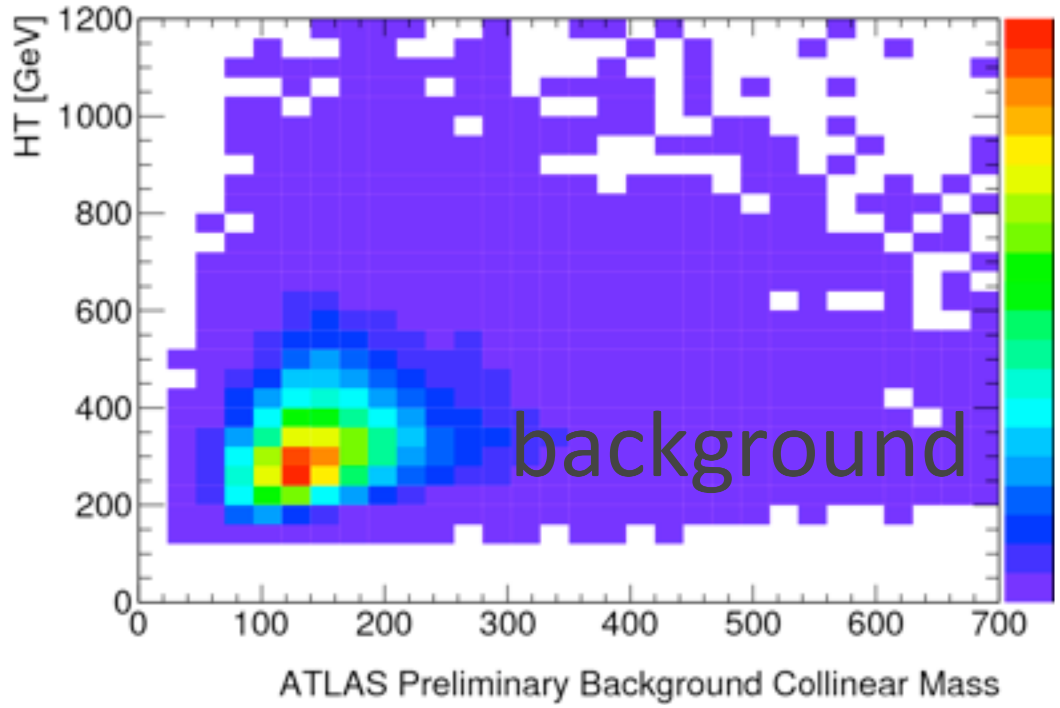
- Same flavor events (ee and μμ) :
  - E_T^{miss} > 40 GeV
  - Dilepton inv. mass > 15 GeV
  - Dilepton inv. mass outside Z-mass window
- Opposite flavor events (eμ) :
  - Sum E_T > 130 GeV

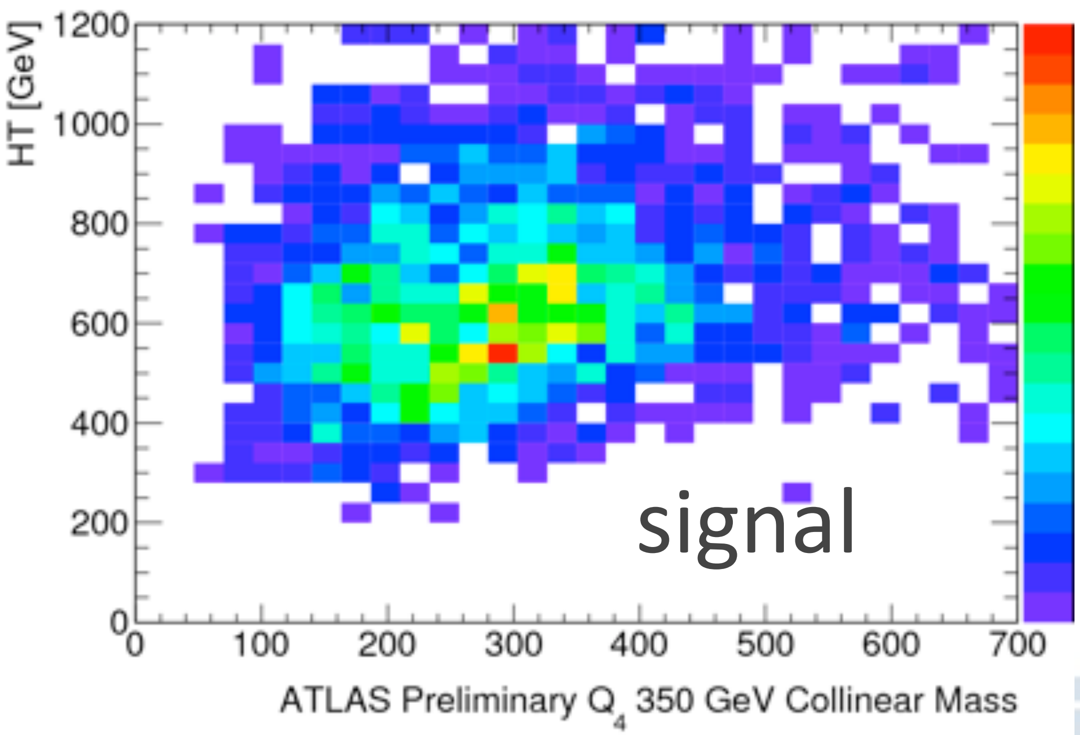


Main background after cuts
t t-bar

WWjj analysis

Reduce t t-bar background

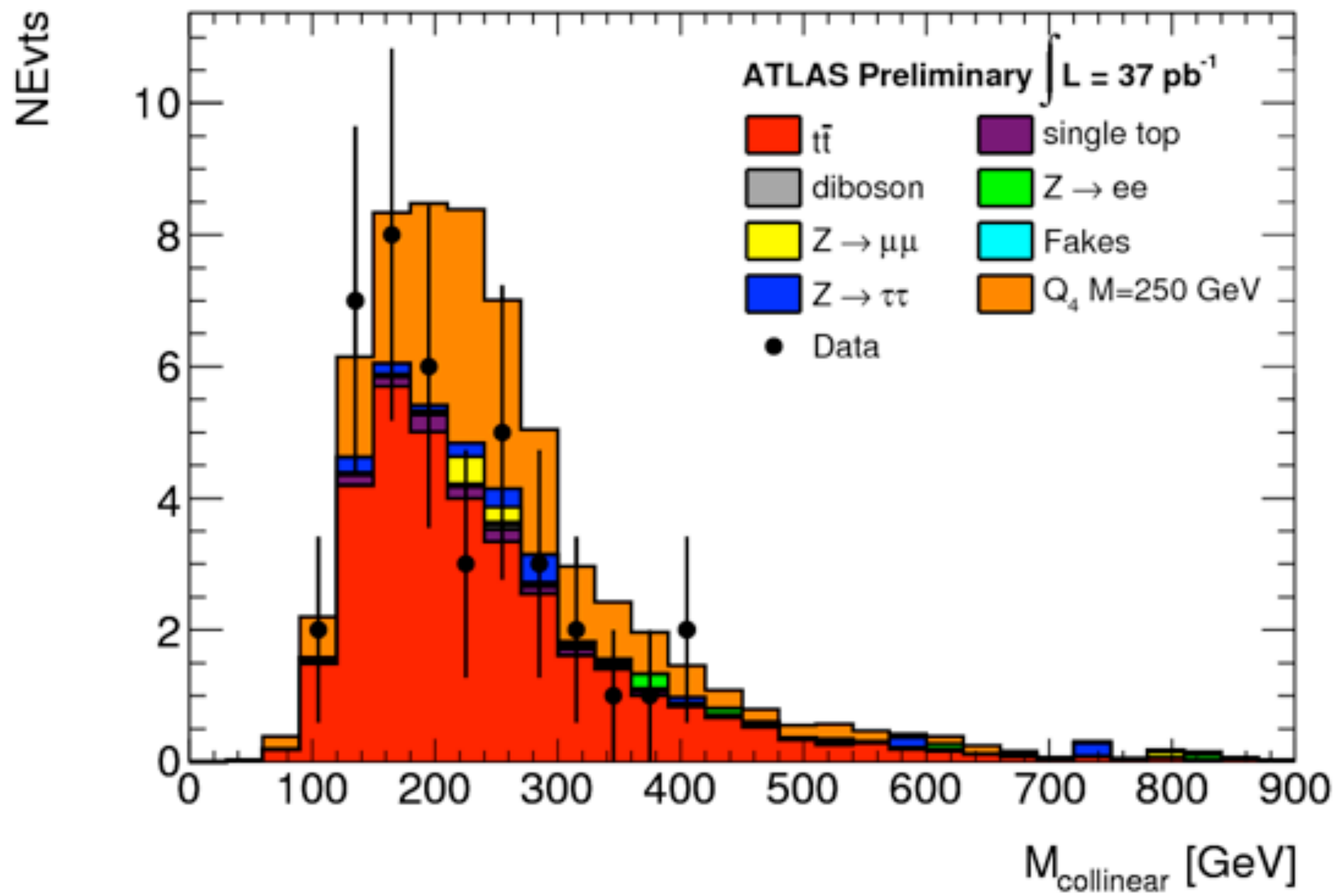




Collinear approximation $\ell\nu$

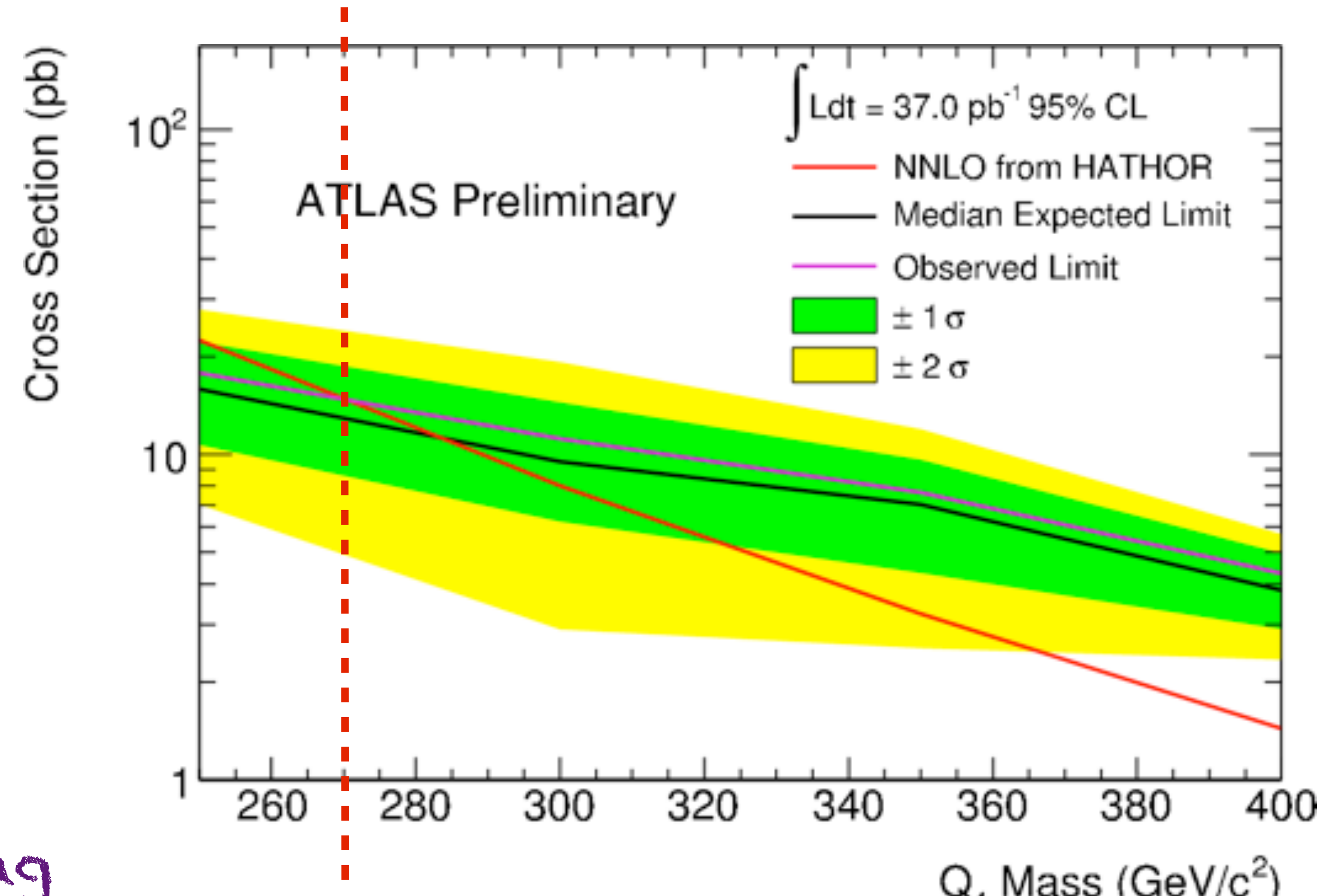
1. Variation $|\Delta\eta(\ell\nu)|<1$ and $|\Delta\phi(\ell\nu)|<1$
2. Calculate $M_{Collinear}$ for each Q4
3. Pick combination that minimizes $\Delta M_{Collinear}$ of 2 heavy quarks
4. Define final $M_{Collinear}$ as the average of the 2 masses

Triangular cut on: $M_{Collinear}$ + $SumE_T$



WWjj: Q_4 mass limit

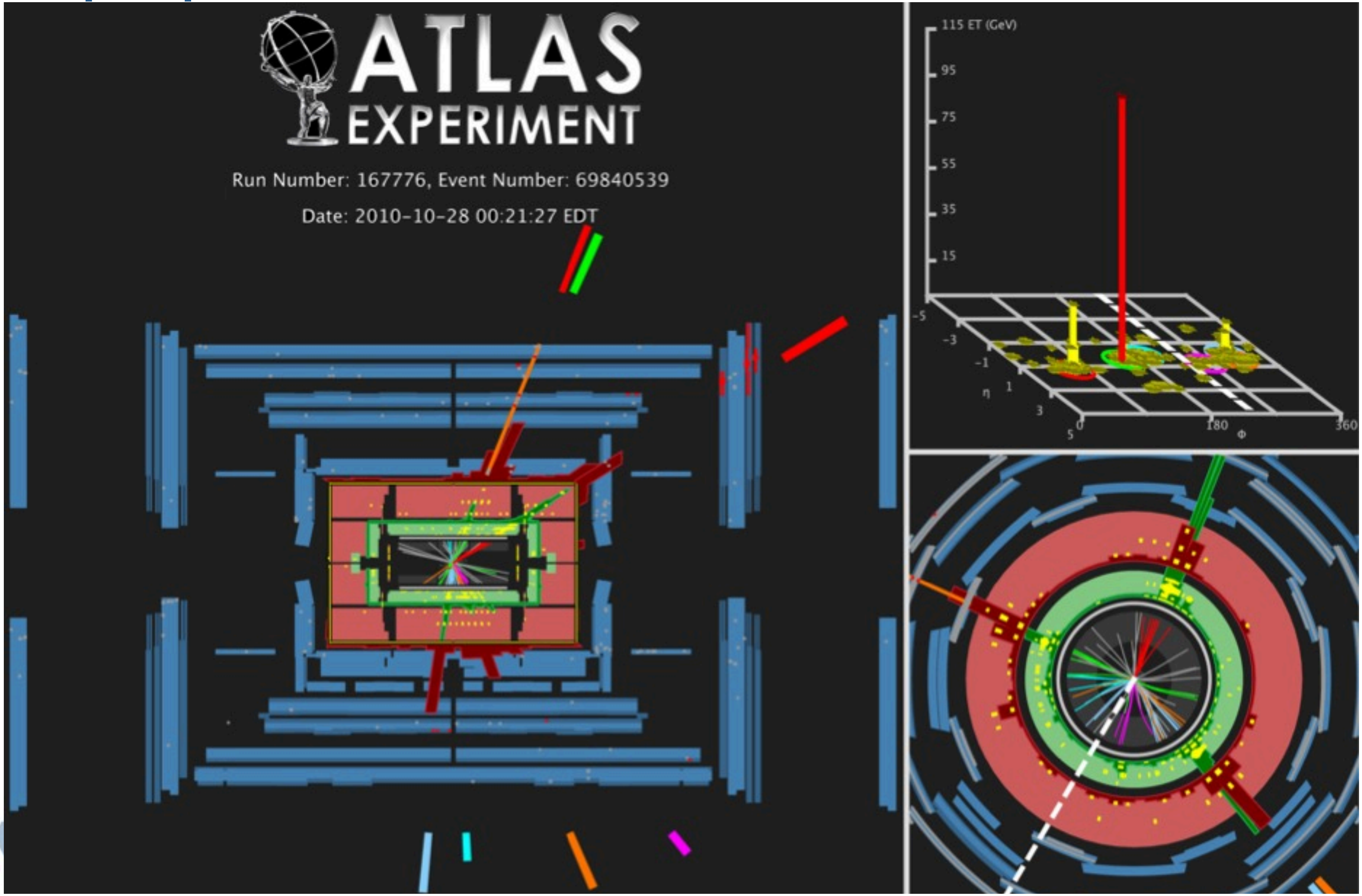
$m_{Q4} > 270$ GeV @ 95% C.L



limit applicable to:

- up-type quark u_4
- down-type quark d_4
- other exotics quarks with charges (-1/3,-4/3) decaying to light quarks $Q_4 \rightarrow Wq$

Leptoquarks



Leptoquarks

Quark and lepton substructure theories

Grand unification theories

Extended technicolor theories

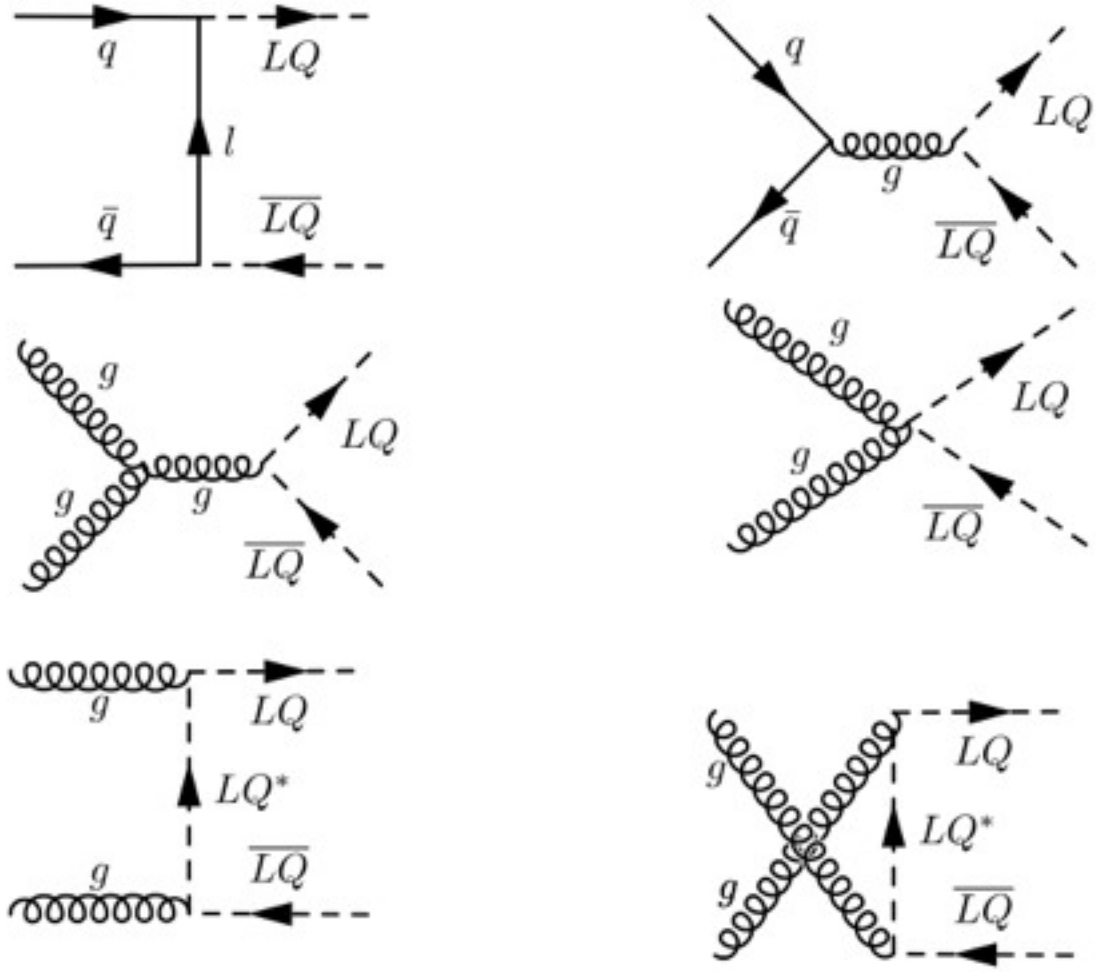
$$\sigma(pp \to lljj) = \sigma_{LQ} \times \beta^2$$
$$\sigma(pp \to l\nu jj) = \sigma_{LQ} \times 2\beta(1-\beta)$$

$\beta(LQ \to \ell + X) \equiv$ Branching Fraction

$M_{LQ} \equiv$ LQ mass

theory-dependent

for scalar LQ, production rates depend strongly on M_{LQ}



Integrated Luminosity $35pb^{-1}$

Leptoquarks

- LQ pair production
  - ℓℓjj
  - ℓνjj
  - ννjj

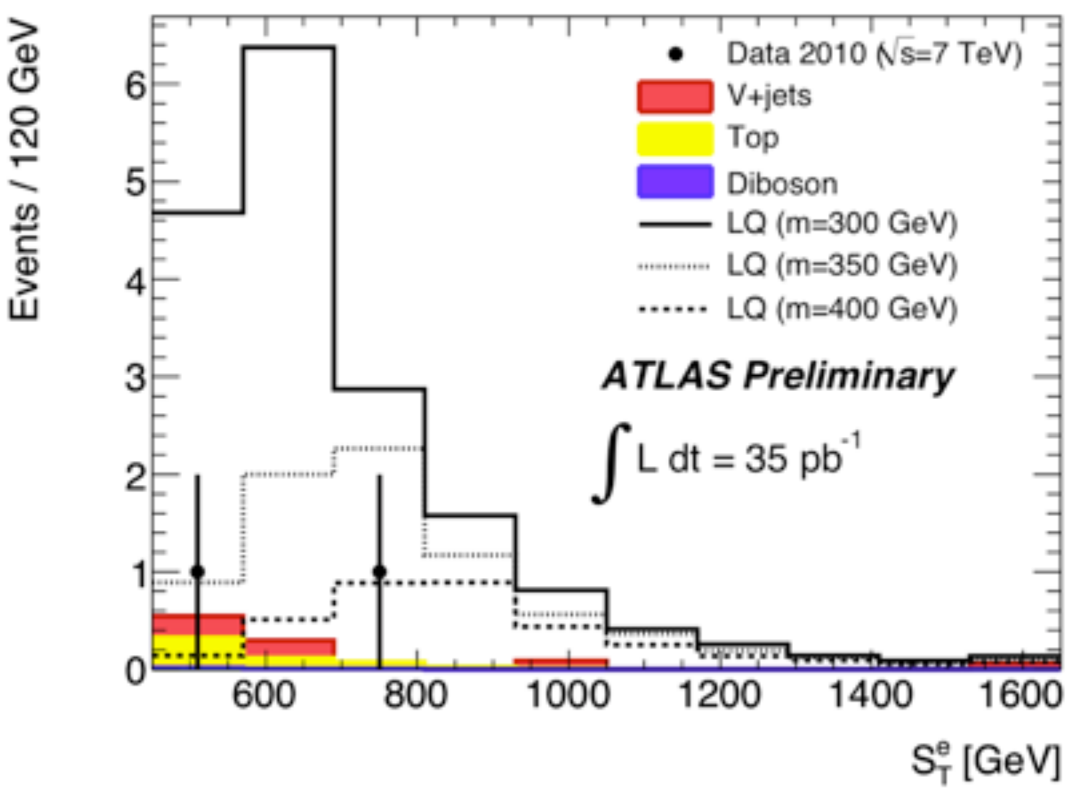
e/μ for 1st/2nd LQ generation

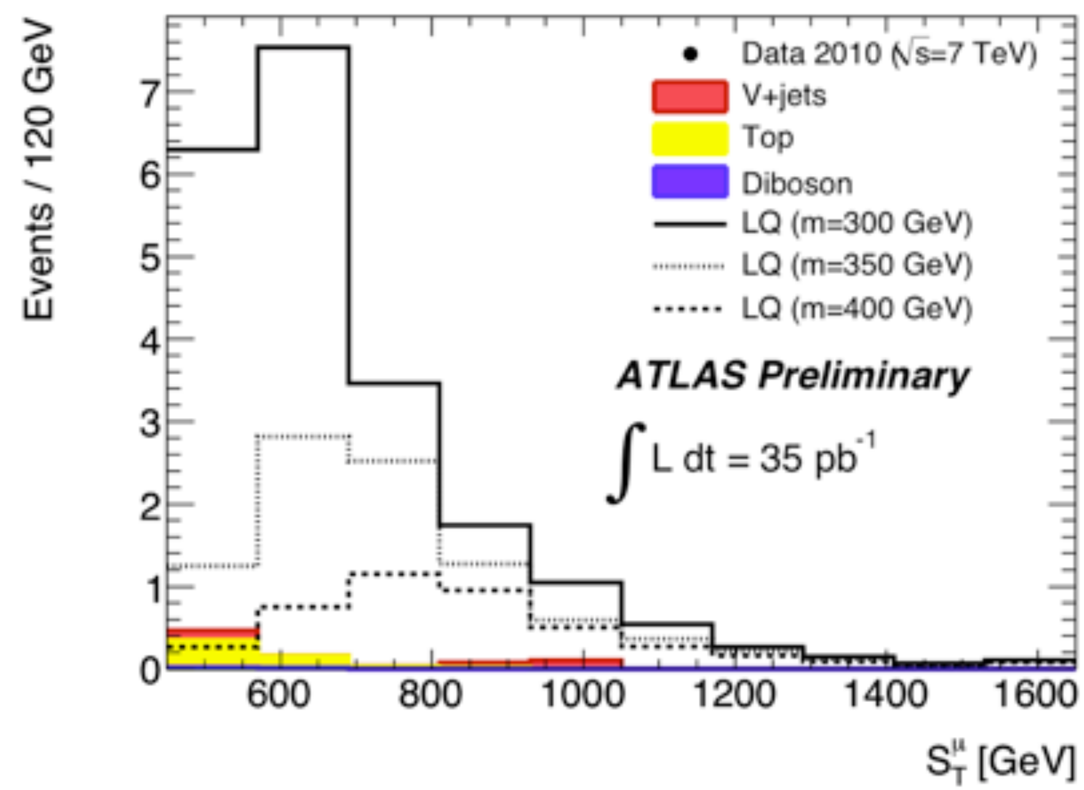
Peak of signal in invariant mass jet-lepton (jet-neutrino) pairs

- Main backgrounds

ℓℓjj	ℓνjj
Z + jets	W + jets
t t-bar	t t-bar

large LQ masses give rise to larger total measured transverse energy S_T^{ℓ}

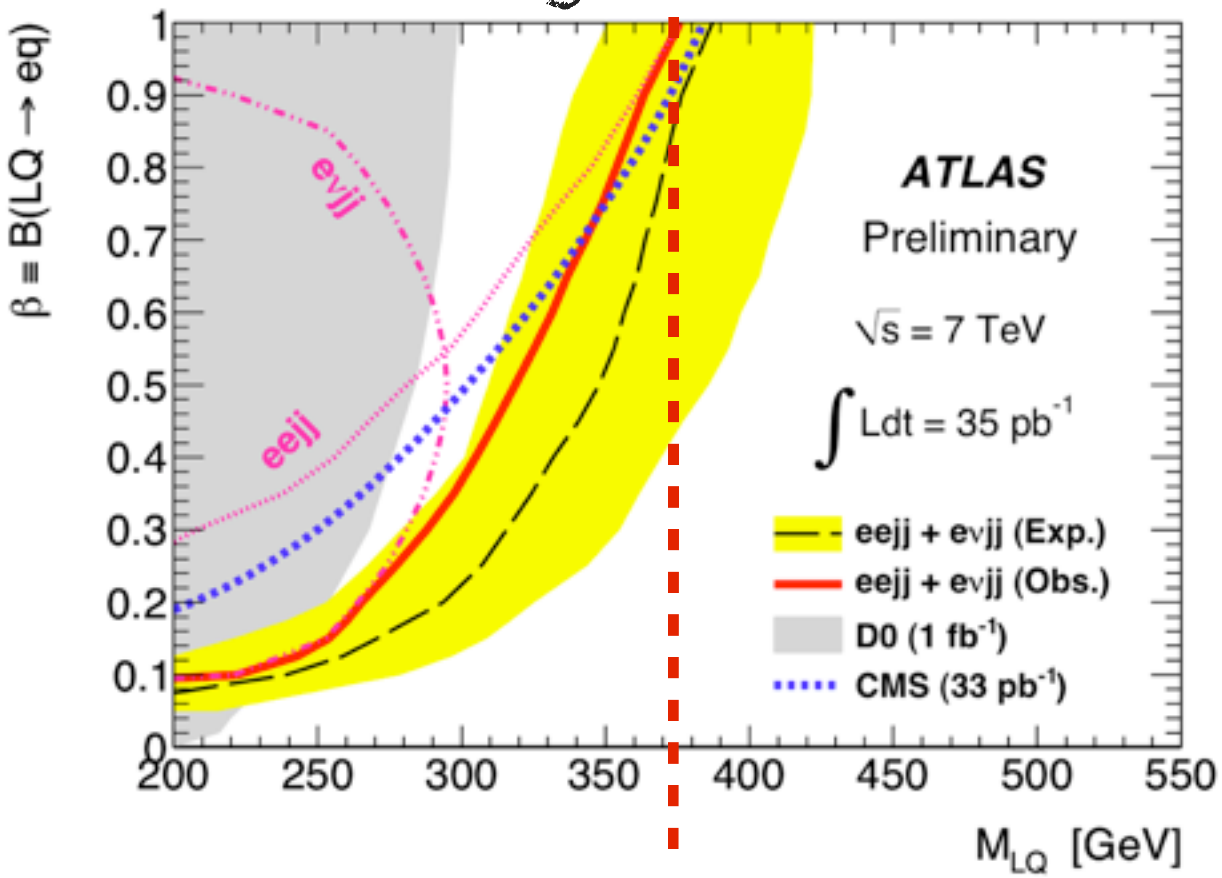




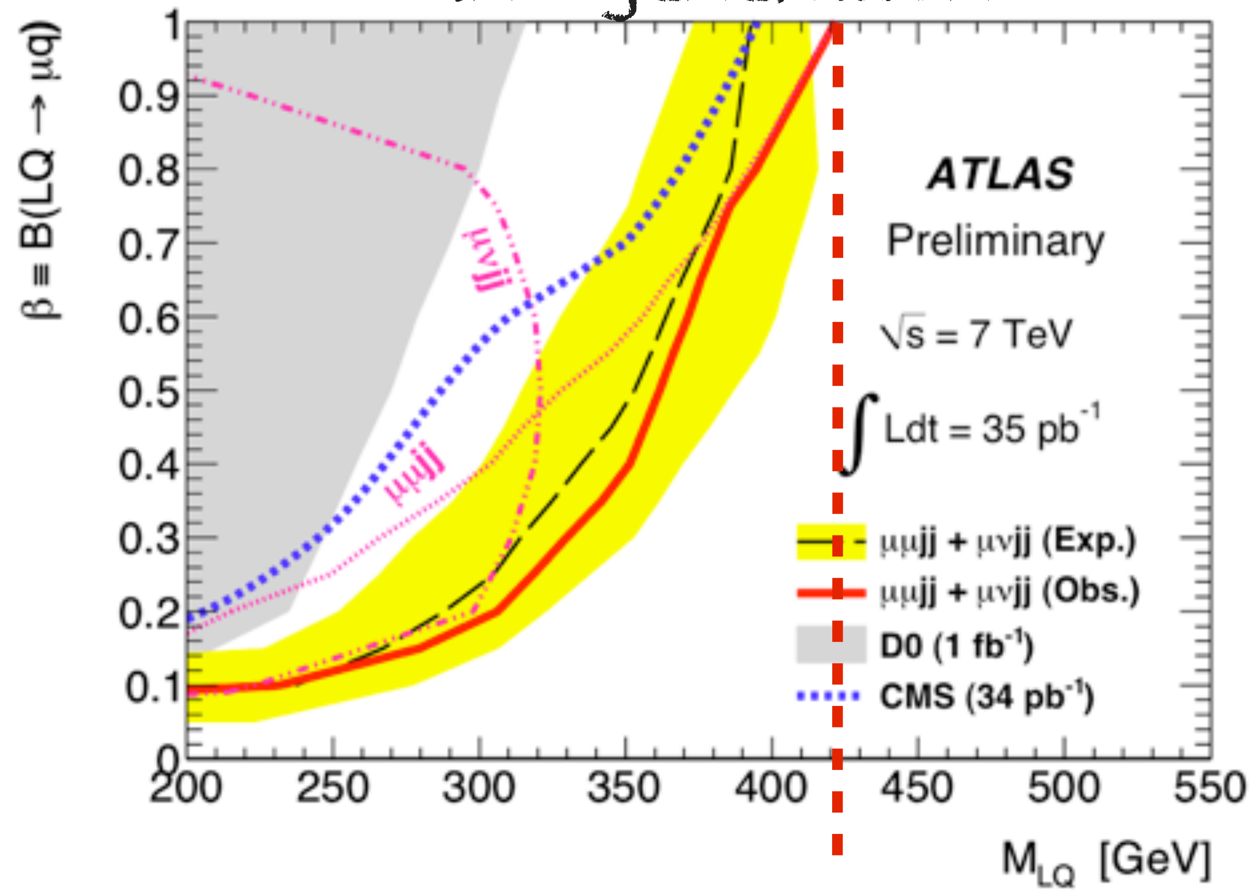
95% C.L. limits

Leptoquarks limits

1st generation



2nd generation



Type (β)	Expected limit (GeV)	Observed limit (GeV)
1st generation (1.0)	387	376
1st generation (0.5)	348	319
2nd generation (1.0)	393	422
2nd generation (0.5)	353	362

Summary and Conclusions

- Search for new physics in final states with jets using 33-37pb^{-1} of LHC data (full 2010)
- We are exploring a new regime at TeV scale
- No discrepancies with the Standard Model were found
- New limits (95% C.L. [TeV]) in several models:

		Tevatron	ATLAS
Dijets	Excited quarks (q*)	0.87	**2.64**
	QBH n = 6	-	**3.67**
	Axigluons	1.25	**2.1**
	Contact Interactions Λ	2.9	**9.5***
WWjj	4th generation heavy quark (Q_4)	m_{u4}> 0.356 m_{d4} > 0.372	**0.270**
Leptons (MET) + jets	1st generation LQ (β=1)	0.299	**0.376**
	2nd generation LQ (β=1)	0.316	**0.422**

* 6.7 TeV (Bayesian limit)

BACK-UP

Dijet analysis: Monte Carlo Generation

- QCD production:
  - For angular correlations:
    - PYTHIA 6.4.21 with the ATLAS MC09 Tune and modified leading-order MRST2007 PDF.
    - Bin-by-bin correction factors (K-factors) applied to angular distributions"
      - account for next-to-leading order corrections calculated with ratio NLOJET++ ME (NLO CTEQ6.6)/ PYTHIA
    - PYTHIA includes the non-perturbative effects and K-factors were designed to retained those effects
    - Maximum change on angular distribution ~6%
- Models for New Physics Phenomena:
  - Excited quark qg->q* with spin 1/2 and quark-like couplings with compositeness scale Λ = mass(q*). Generated with same PYTHIA as QCD productions
  - Axigluons

    $$\mathcal{L}_{Aq\bar{q}} = g_{QCD}\bar{q}A^a_\mu \frac{\lambda^a}{2}\gamma^\mu\gamma_5\, q.$$ CALCHEP MC package
  - Randall-Sundrum (RS) gravitons. Generated with same PYTHIA as QCD.

    $$\kappa/\bar{M}_{Pl} = 0.1$$
  - Non-resonance phenomena: a benchmark quark-contact interactions to model quark compositeness

    $$\mathcal{L}_{qqqq}(\Lambda) = \frac{\xi g^2}{2\Lambda^2}\bar{\Psi}^L_q\gamma^\mu\Psi^L_q\bar{\Psi}^L_q\gamma_\mu\Psi^L_q$$

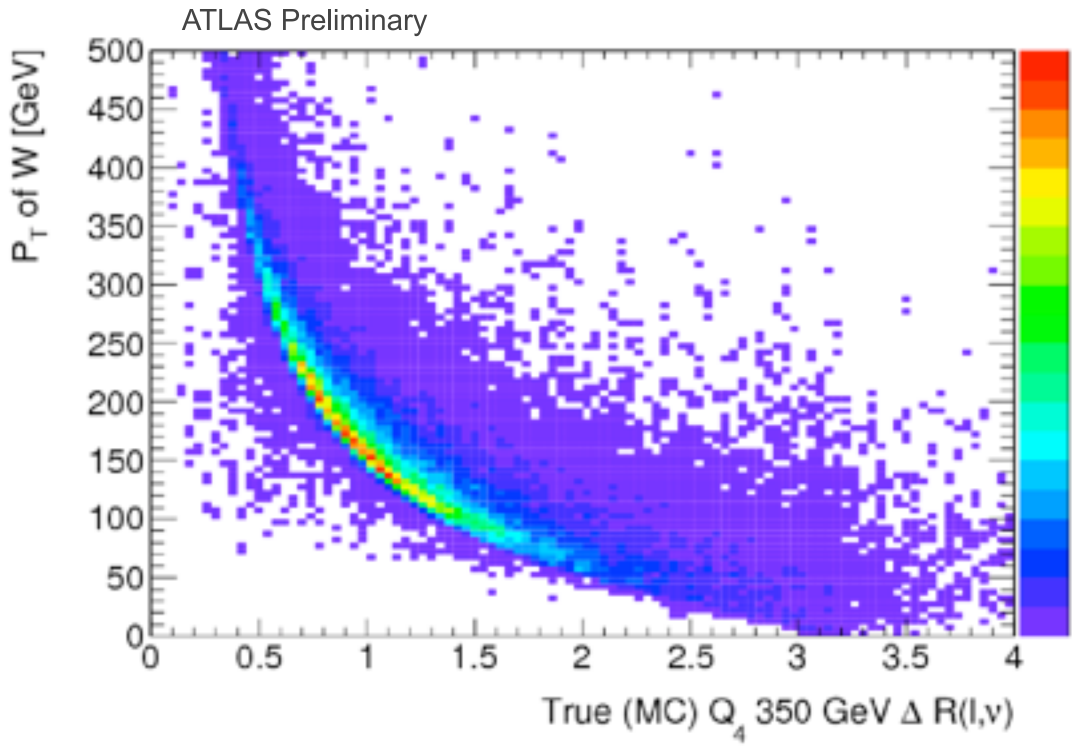
    We use destructive interference for contact interactions, ξ = + 1

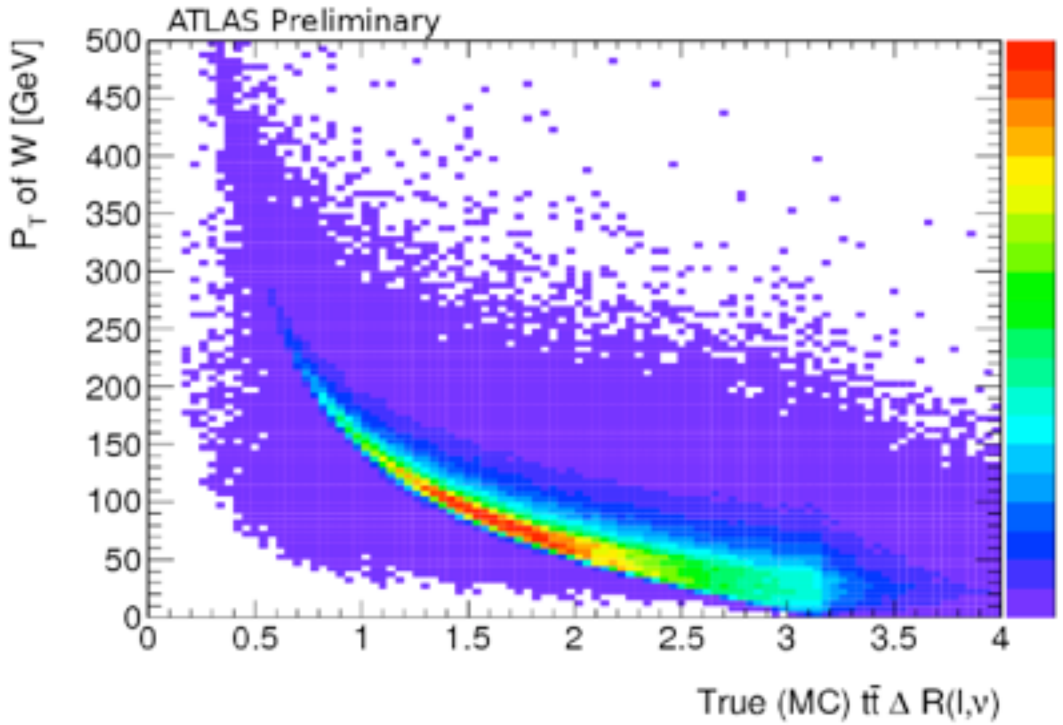
  Non-resonant phenomena: "low multiplicity" quantum black hole QBH BLACKMAX event generator

Leptoquarks

- Previous Limits (assuming $\beta = 1$):
  - D0 @ Tevatron:
    - Limit on existence of 1st and 2nd generation scalar leptoquarks at 95% C.L.
    - 1st generation $M_{LQ} > 299$ GeV
    - 2nd generation $M_{LQ} > 316$ GeV
  - CMS @ LHC:
    - Limit on existence of 1st and 2nd generation scalar leptoquarks at 95% C.L.
    - 1st generation $M_{LQ} > 384$ GeV
    - 2nd generation $M_{LQ} > 394$ GeV

WWjj Collinear approximation





1. Variation $|\Delta\eta(\ell\nu)|<1$ and $|\Delta\phi(\ell\nu)|<1$
2. Calculate $M_{Collinear}$ for each Q4
3. Pick combination that minimizes $\Delta M_{Collinear}$ of 2 heavy quarks
4. Define final $M_{Collinear}$ as the average of the 2 masses