Searches for Jet + X at ATLAS

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on behalf of the ATLAS Collaboration

19 March 2012

Jet+X signatures

Searches at ATLAS for (non-SUSY) new physics involving final states with one or more jets as the most prominent signatures

Probe new physics that carries baryon number, strongly-coupled

- *Cross sections for colored processes typically much larger than for uncolored processes*
- *Highest energies directly accessible by LHC*

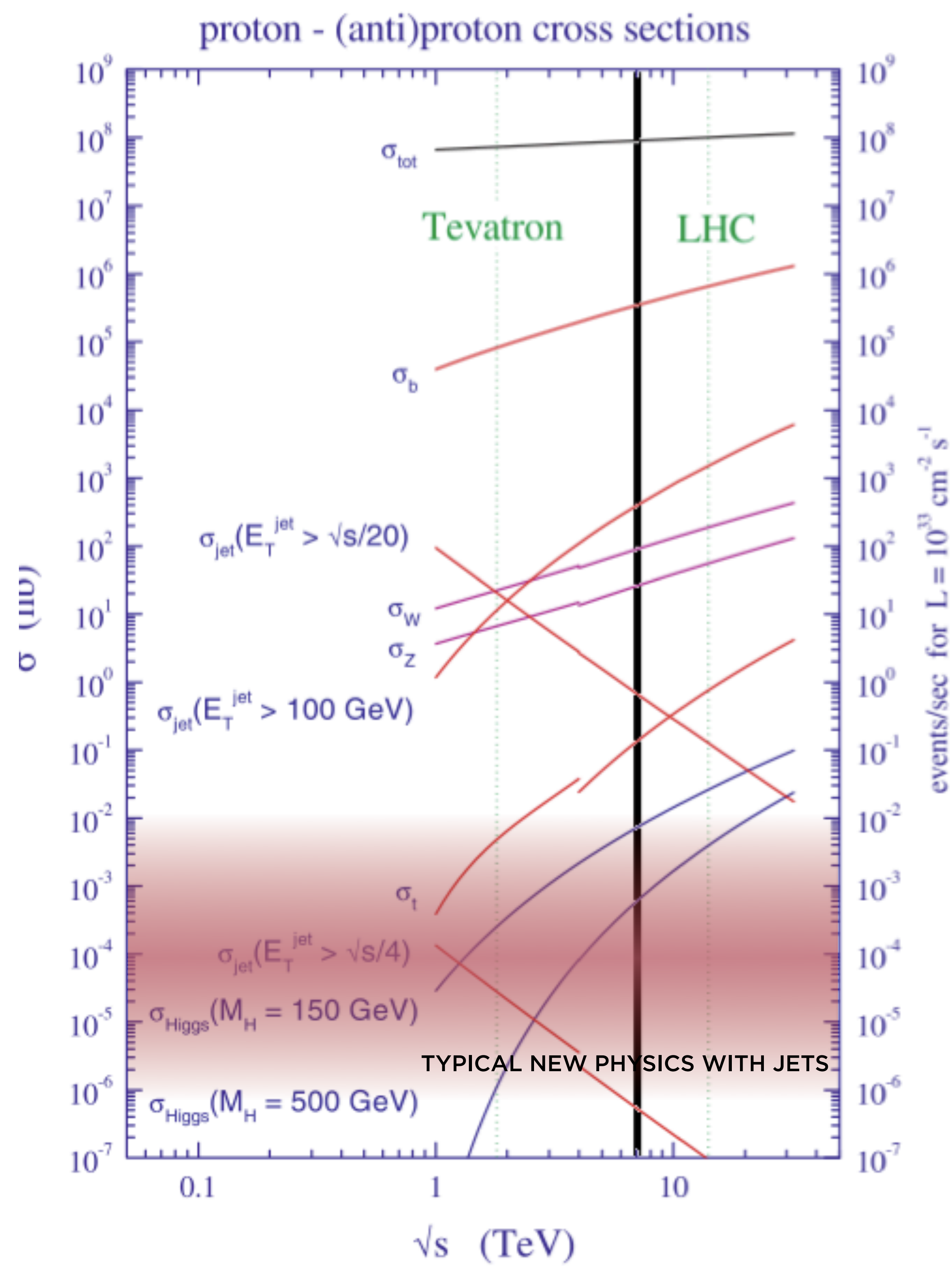
Background is also large!

Today:

Jet + MET
Jet + Photon
Multi-jets + Lepton
Jet + Jet

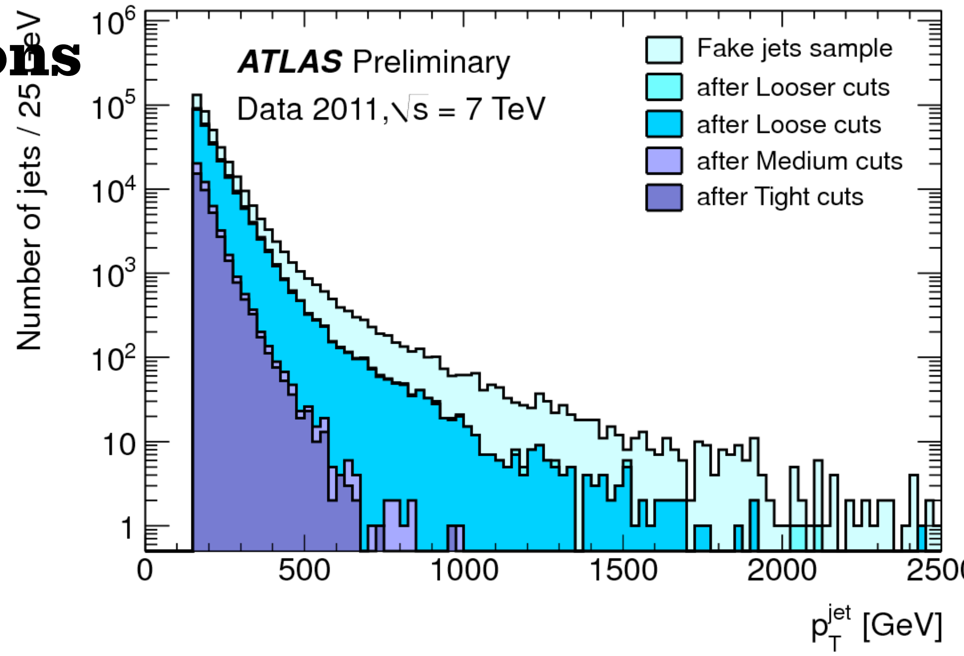
Datasets from 1–4.8/fb

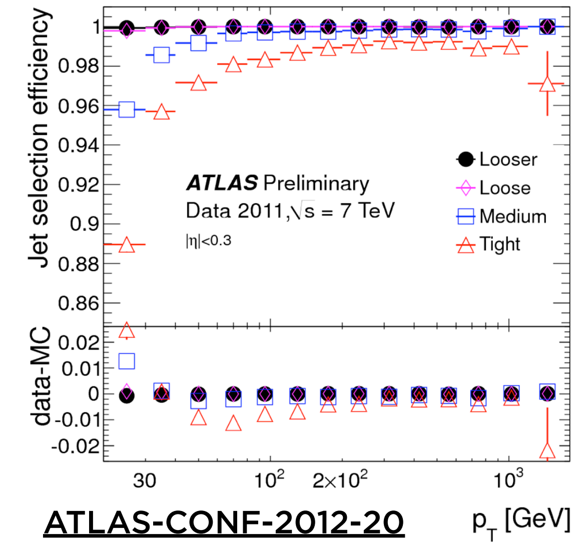
Not discussed: many SM measurements that could also be used to constrain NP



Jet and MET, Quality and Calibrations

(covered in more detail in Stephanie's talk on Saturday)

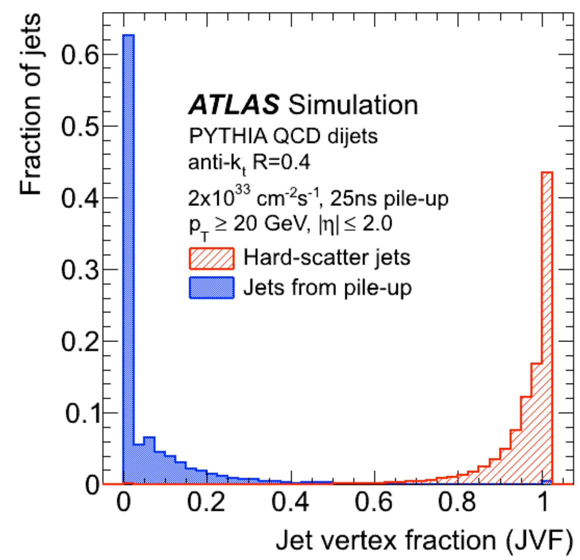




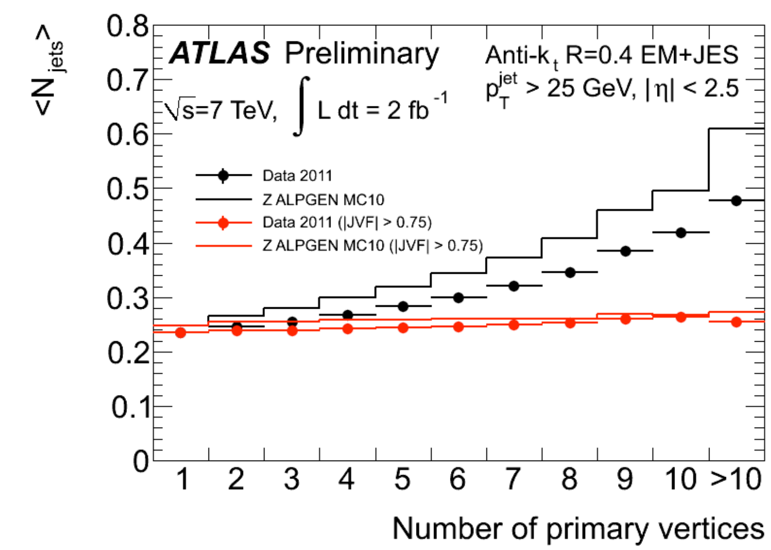
Criteria such as number of cells, EM fraction, and timing of jet used to reject fake jets

- *Selection efficiency for real jets measured in-situ using dijet tag-probe*

"Jet Vertex Fraction" sometimes used to suppress pile-up



2011PileupOffsetAndJVF

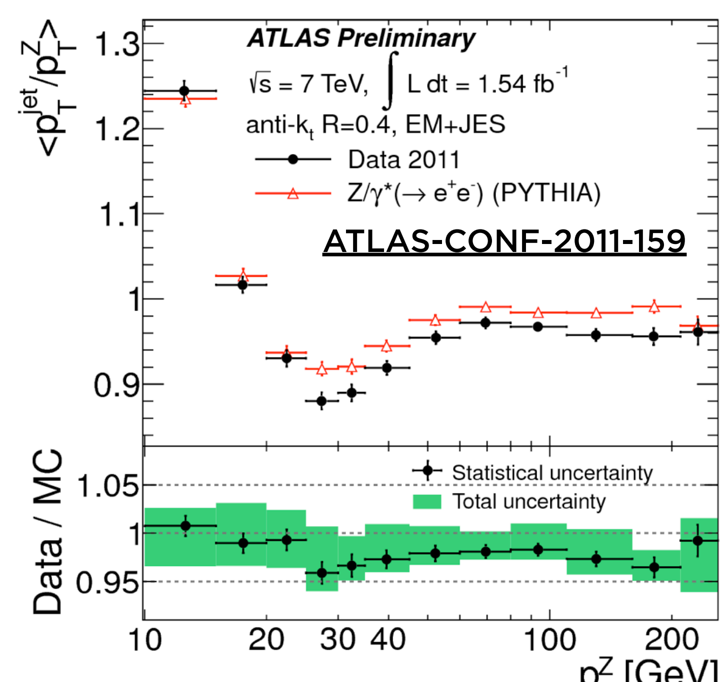


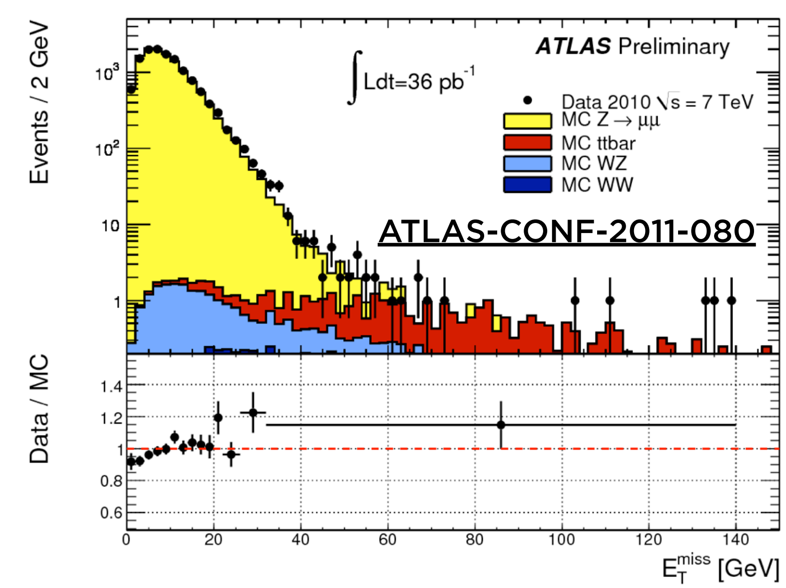
Criteria are very efficient for normal jets, (check if your model predicts abnormal jets)

- *Slow/high EM fraction/low prompt track multiplicity*

Monte Carlo-based jet energy calibration

- *Pile-up correction: energy offset per pile-up interaction*
- *Jet origin (vertex) correction*
- *Energy correction to hadronic scale as a function of jet p_T and η*
- *Correction for calorimeter non-compensation, non-uniform response, etc.*



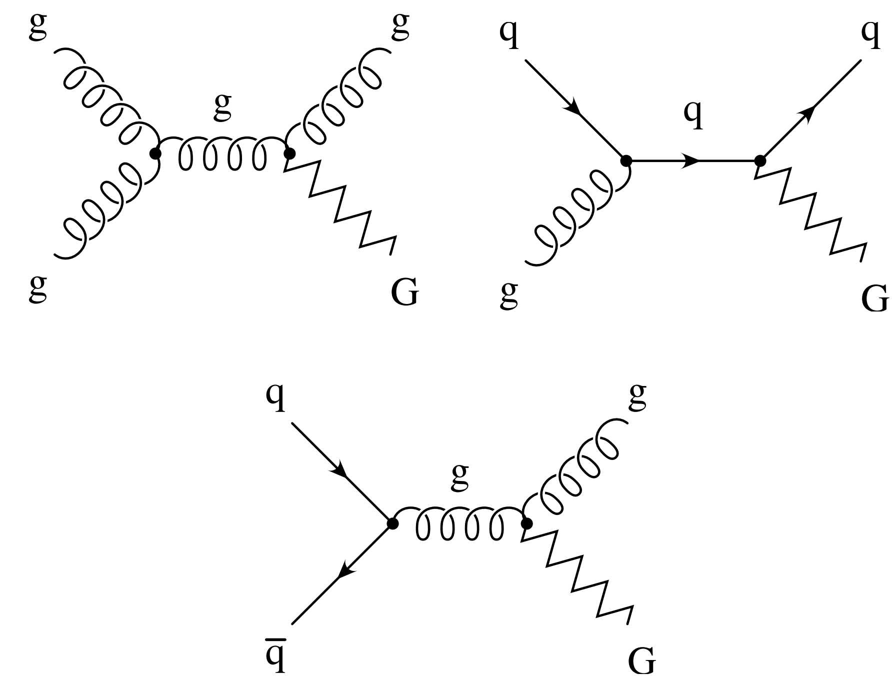


Search for Jet + Missing E_T

ATLAS-CONF-2011-096, 1 fb^{-1}

Many possible signals: graviton emission, unparticles, wimps, (SUSY) ...

Backgrounds: Z/γ/W + jets, multijets, top*



Selection:
- *Events with large missing E_T, exactly one high p_T jet*
- *No second jet*
- *No electrons or muons*
- *$\Delta\varphi(\text{jet}, E_T^{\text{miss}}) > 0.5$ rad*

Trigger:
- *Missing E_T > 60 GeV (fully efficient by 120 GeV)*

	low p_T (GeV)	high p_T (GeV)	very high p_T (GeV)
Jet p_T >	120	250	350
E_T^{miss} >	120	220	300
Second Jet p_T <	30	60	60

Search for Jet + Missing E_T

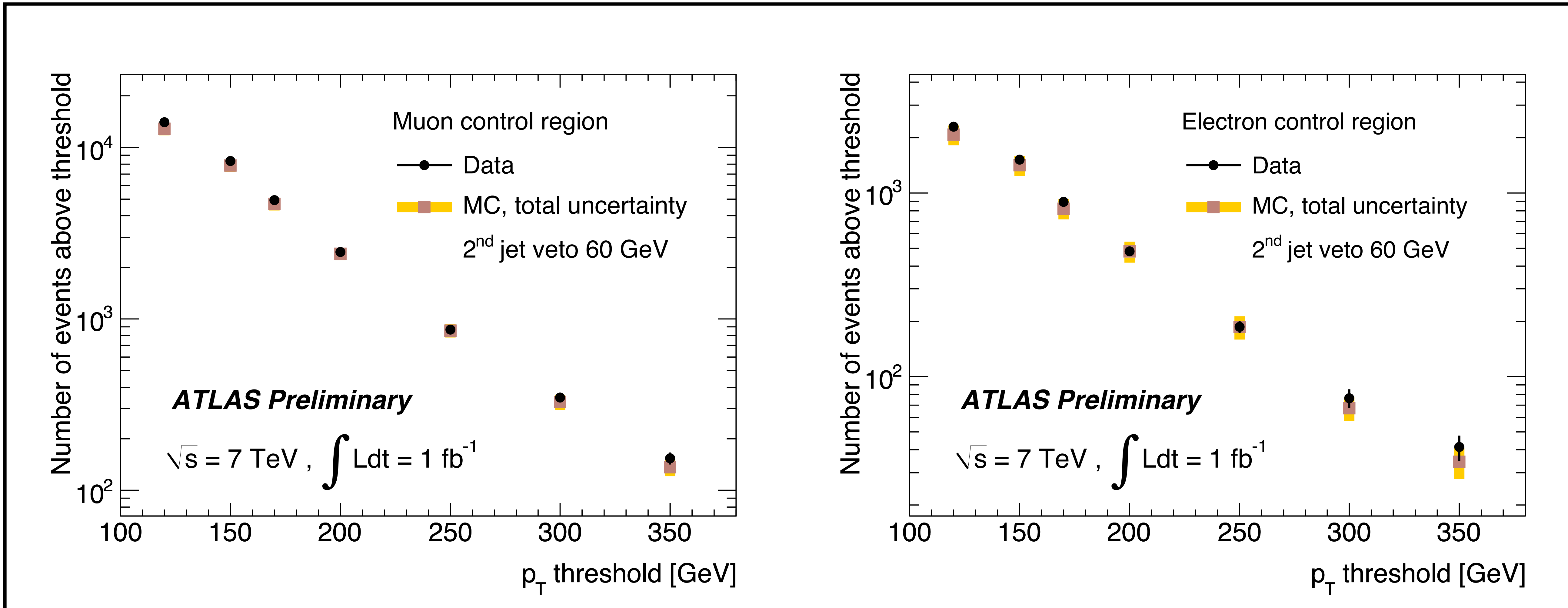
normalization from events with electrons or muons, otherwise passing analysis selection

	Background Predictions ± (stat.) ± (syst.)		
	LowPt Selection	HighPt Selection	veryHighPt selection
$Z\ (\rightarrow \nu\nu)$+jets	$7700 \pm 90 \pm 400$	$610 \pm 27 \pm 47$	$124 \pm 12 \pm 15$
$W (\rightarrow \tau\nu)$+jets	$3300 \pm 90 \pm 220$	$180 \pm 16 \pm 22$	$36 \pm 7 \pm 8$
$W (\rightarrow e\nu)$+jets	$1370 \pm 60 \pm 90$	$68 \pm 10 \pm 8$	$8 \pm 1 \pm 2$
$W (\rightarrow \mu\nu)$+jets	$1890 \pm 70 \pm 100$	$113 \pm 14 \pm 9$	$18 \pm 4 \pm 2$
Multi-jets	$360 \pm 20 \pm 290$	$30 \pm 6 \pm 11$	$3 \pm 2 \pm 2$
$Z/\gamma^* (\rightarrow \tau^+\tau^-)$+jets	$59 \pm 3 \pm 4$	$2.0 \pm 0.6 \pm 0.2$	-
$Z/\gamma^* (\rightarrow \mu^+\mu^-)$+jets	$45 \pm 3 \pm 2$	$2.0 \pm 0.6 \pm 0.1$	-
tt	$17 \pm 1 \pm 3$	$1.7 \pm 0.3 \pm 0.3$	-
γ+jet	-	-	-
$Z/\gamma^* (\rightarrow e^+e^-)$+jets	-	-	-
Non-collision Background	$370 \pm 40 \pm 170$	$8.0 \pm 3.3 \pm 4.1$	$4.0 \pm 3.2 \pm 2.1$
Total Background	$15100 \pm 170 \pm 680$	$1010 \pm 37 \pm 65$	$193 \pm 15 \pm 20$
Events in Data (1.00 fb^{-1})	15740	965	167

from events with MET pointing toward second jet above threshold

from events in empty, unpaired bunches

Search for Jet + Missing E_T



γ+jet	-	-	-
$Z/\gamma^*(\rightarrow e^+e^-)$+jets	-	-	-
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Search for Jet + Missing E_T

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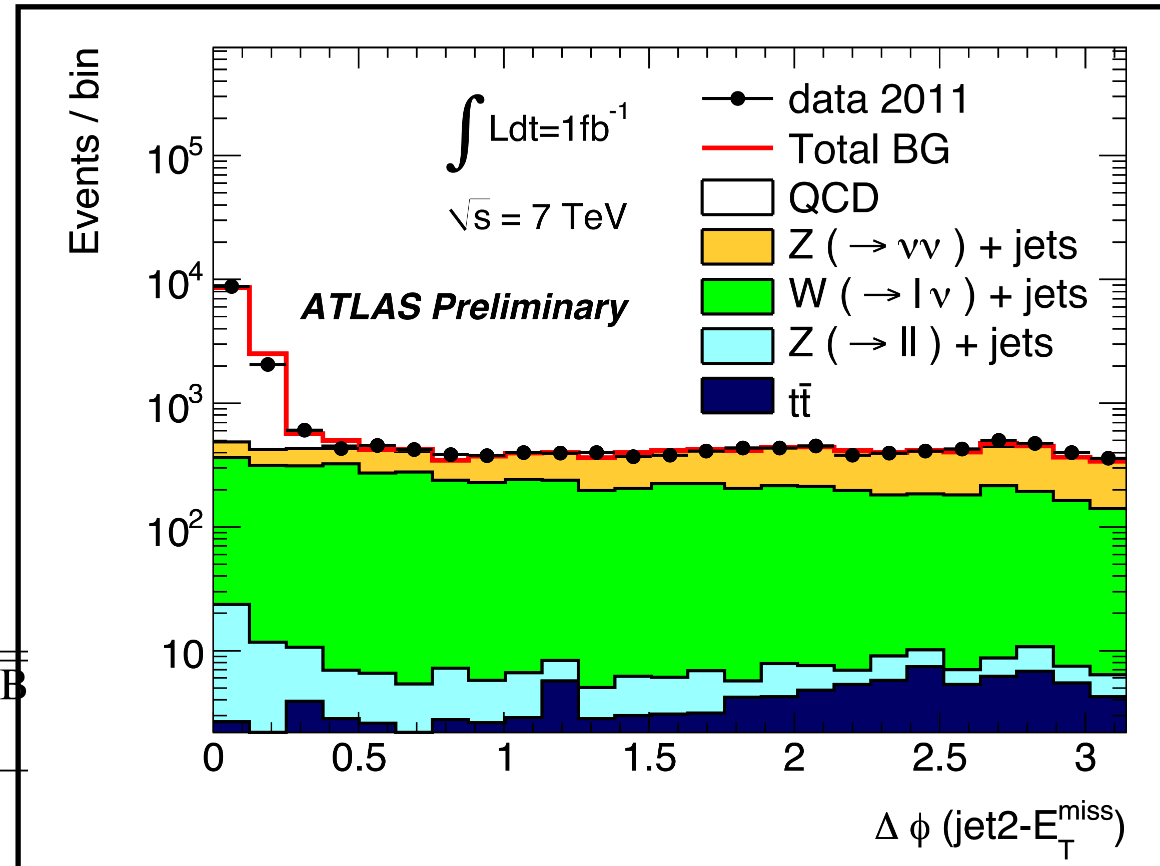
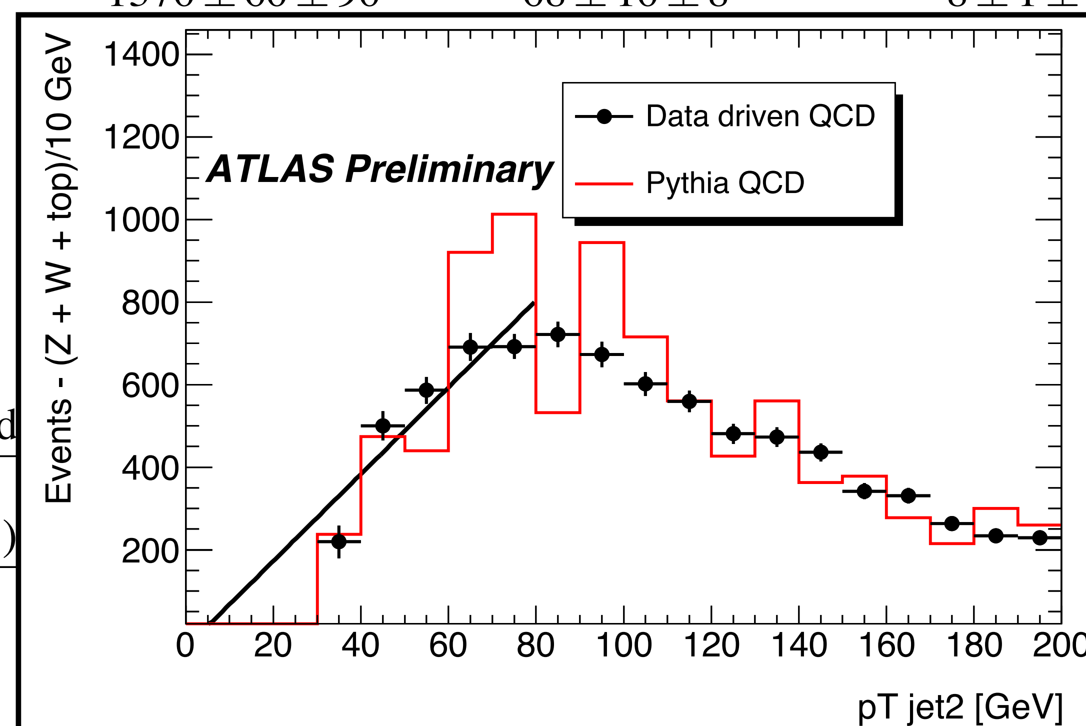
B			on
$Z(\rightarrow \nu\nu)$+jets			
$W(\rightarrow \tau\nu)$+jets			
$W(\rightarrow e\nu)$+jets	$1370 \pm 60 \pm 90$	$68 \pm 10 \pm 8$	$8 \pm 1 \pm 2$
$W(\rightarrow \mu\nu)$+jets			2
Multi-jets			
$Z/\gamma^*(\rightarrow \tau^+\tau^-)$+jets			
$Z/\gamma^*(\rightarrow \mu^+\mu^-)$+jets			
tt			
γ+jet			
$Z/\gamma^*(\rightarrow e^+e^-)$+jets			
Non-collision Background			2.1
Total Background			20
Events in Data (1.00 fb^{-1})			



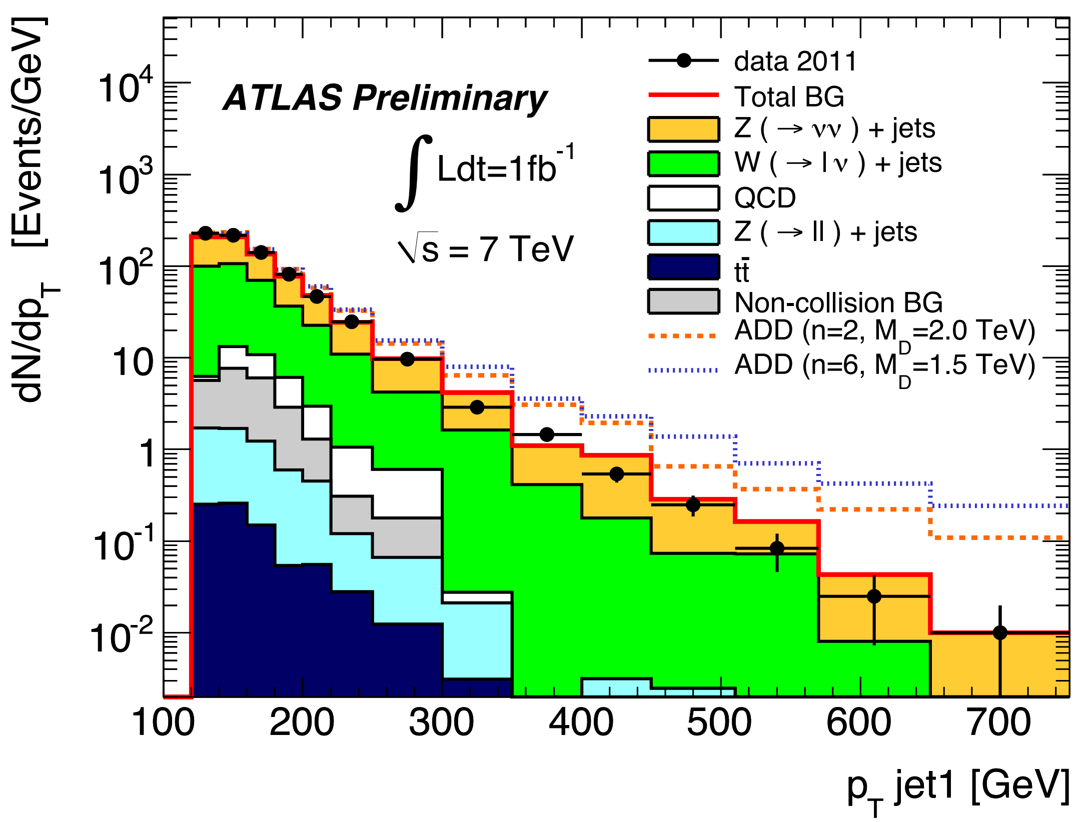


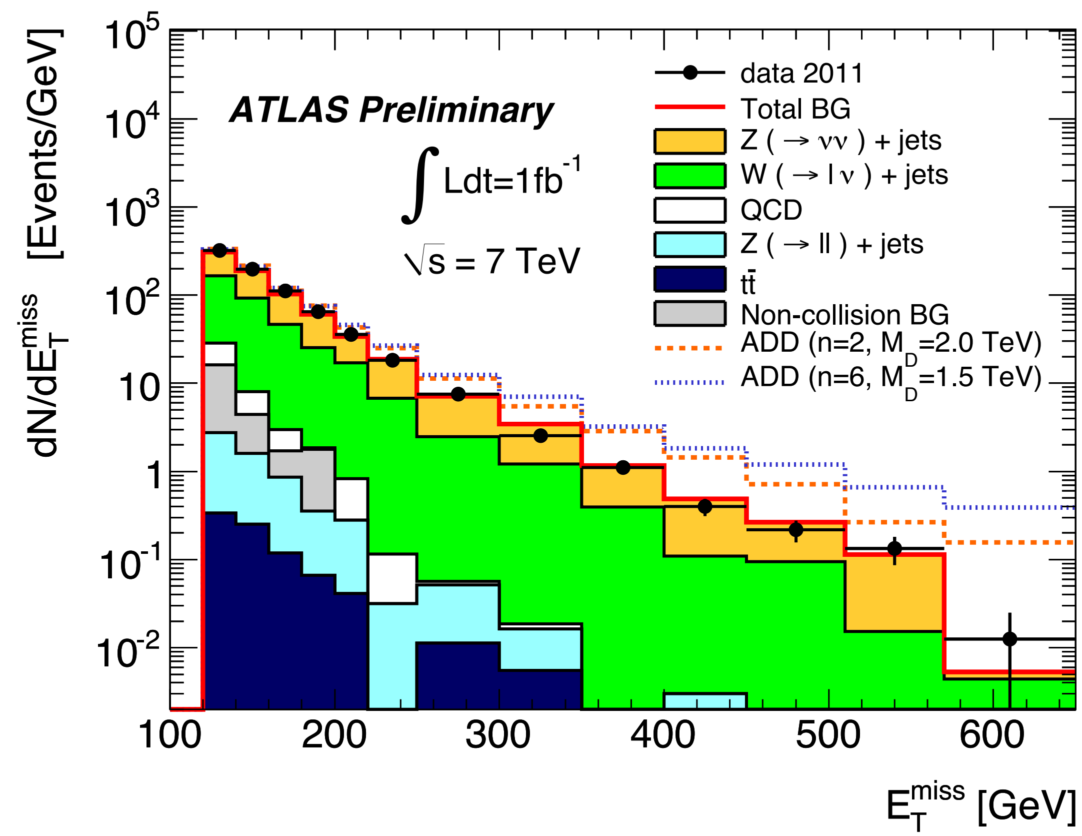
from events with MET pointing toward second jet above threshold

from events in empty, unpaired bunches

Search for Jet + Missing E_T

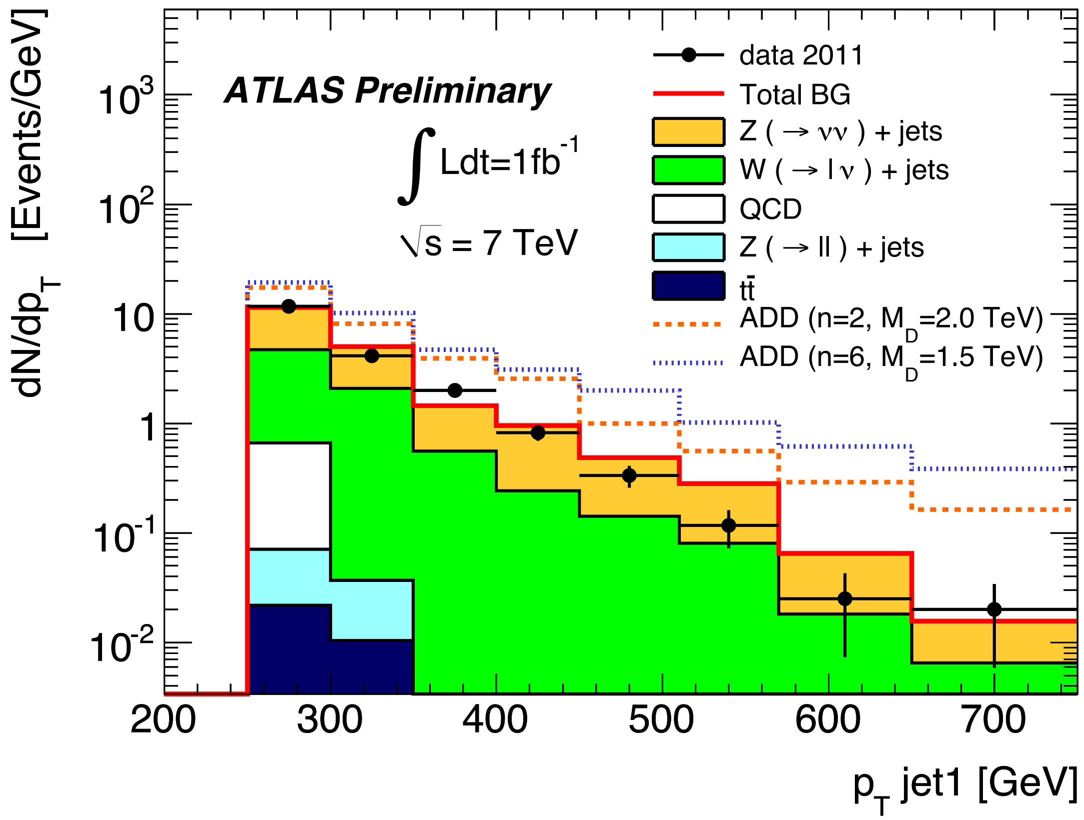
Low p_T Results

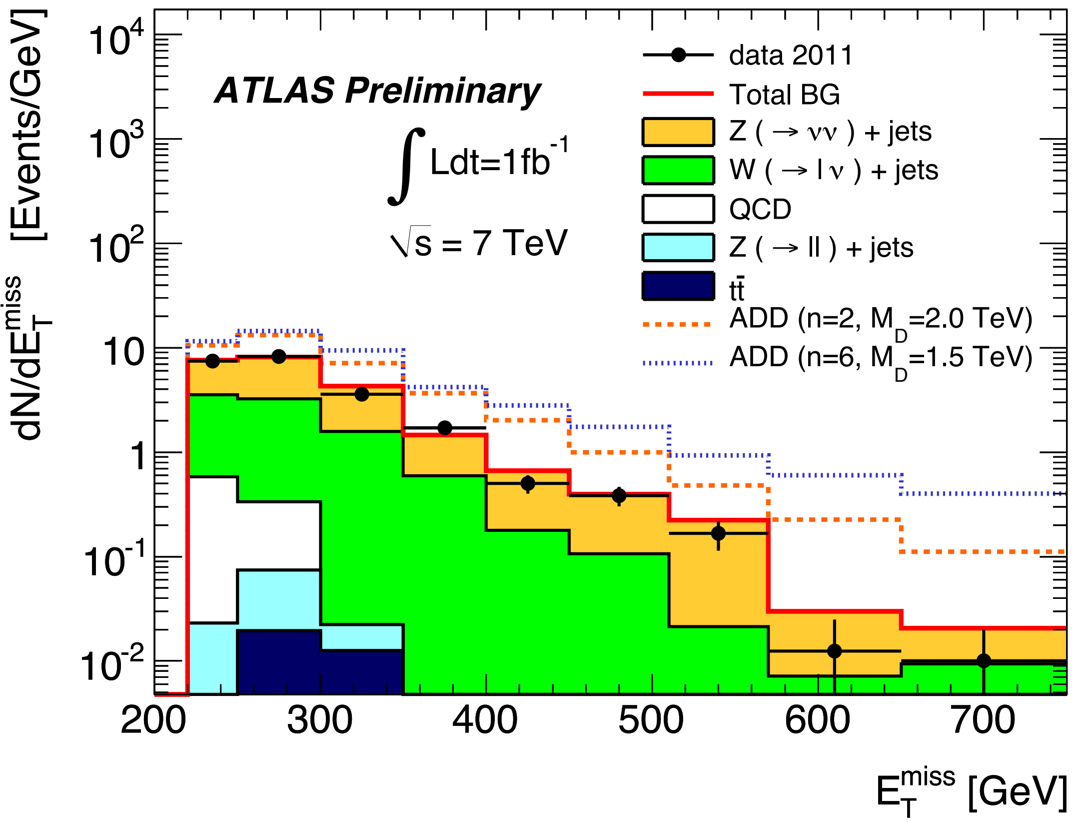




Search for Jet + Missing E_T

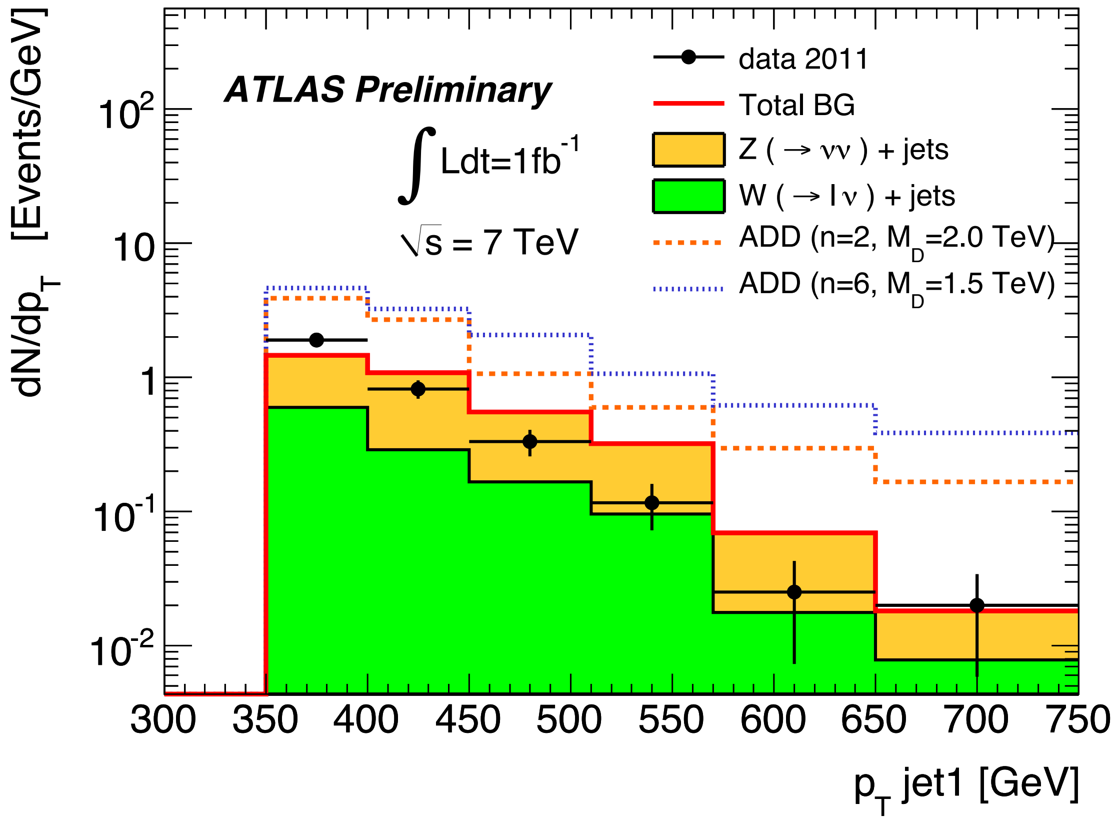
High p_T Results

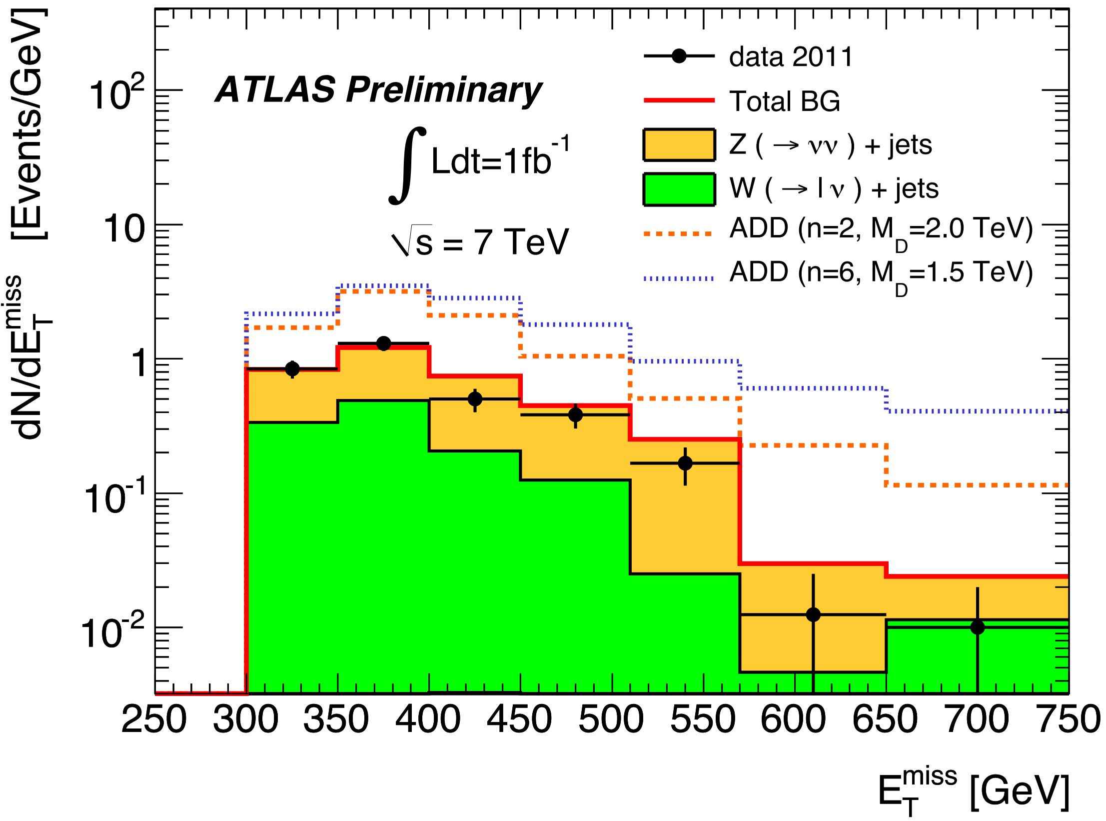




Search for Jet + Missing E_T

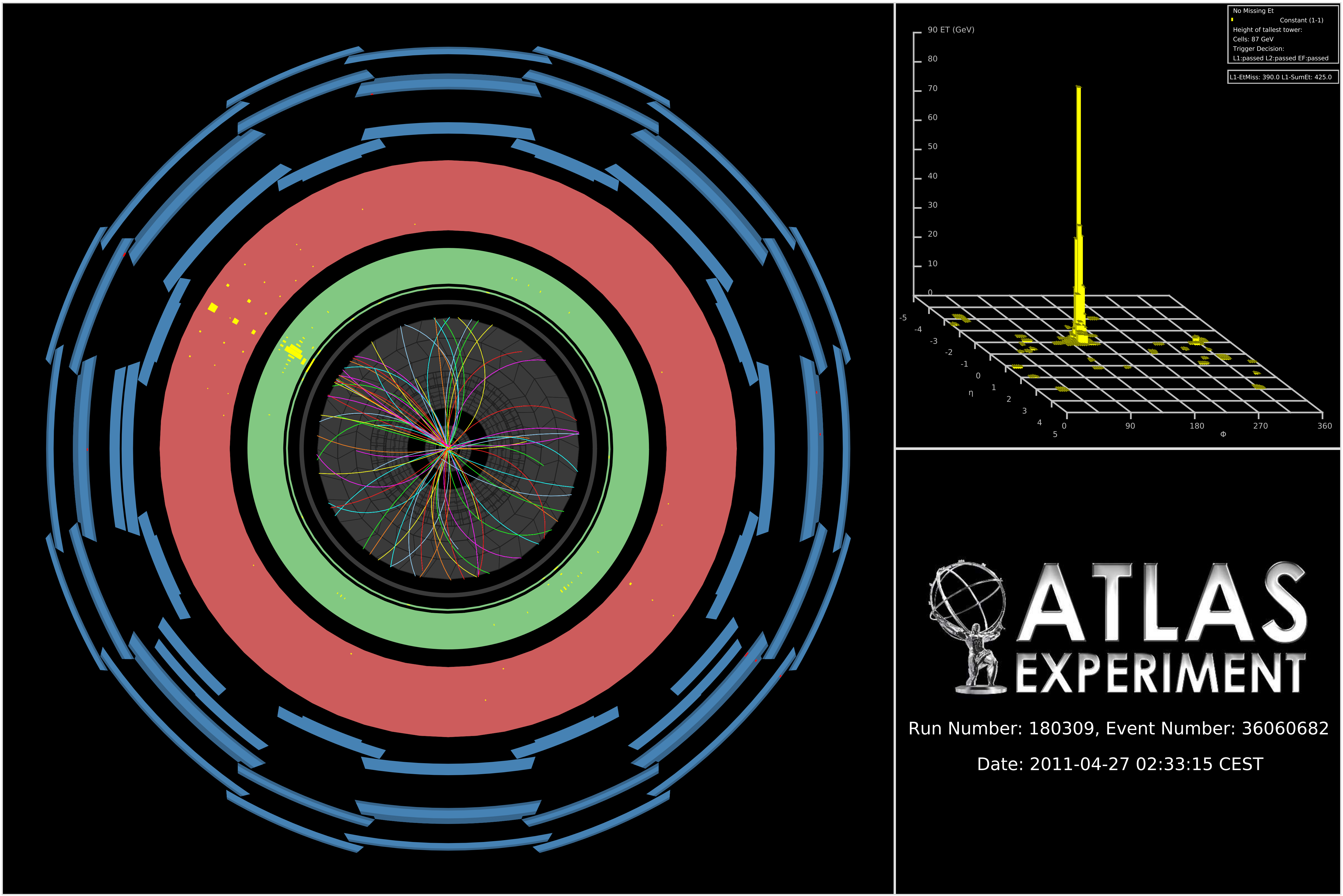
Very High p_T Results





Search for Jet + Missing E_T

Candidate Event

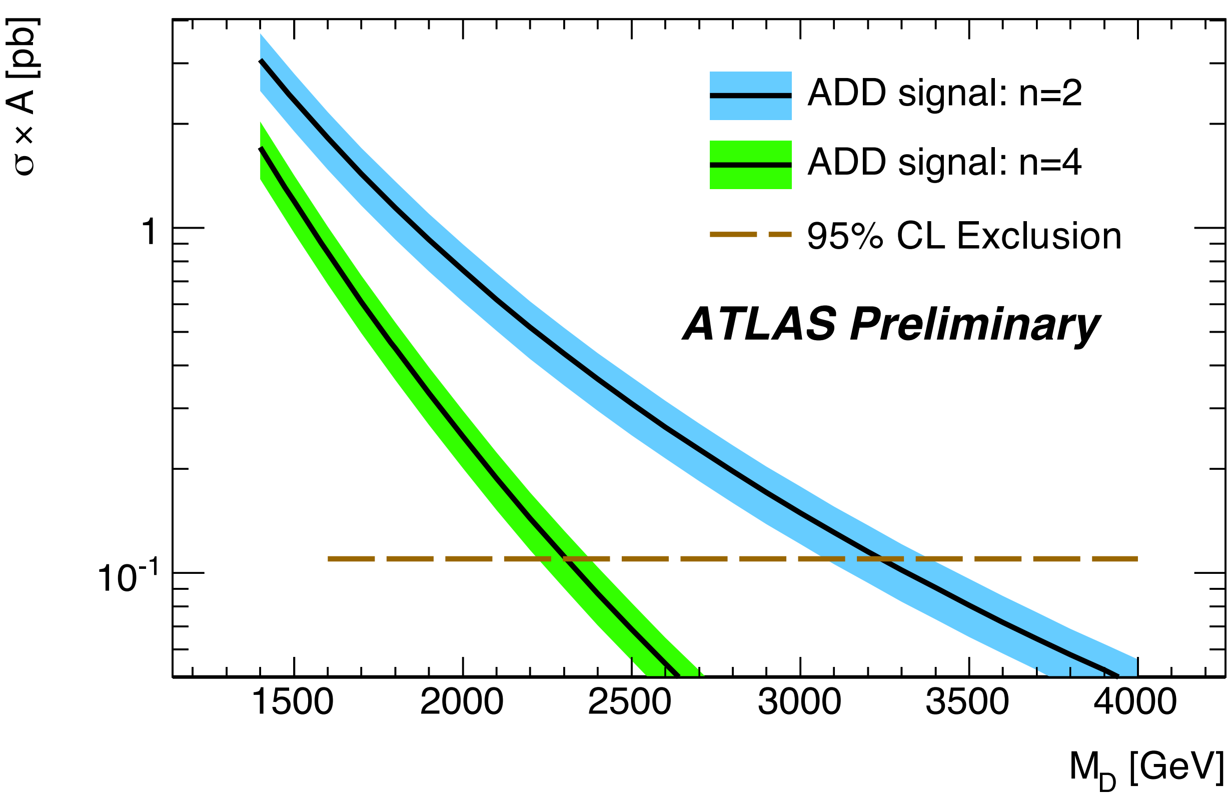


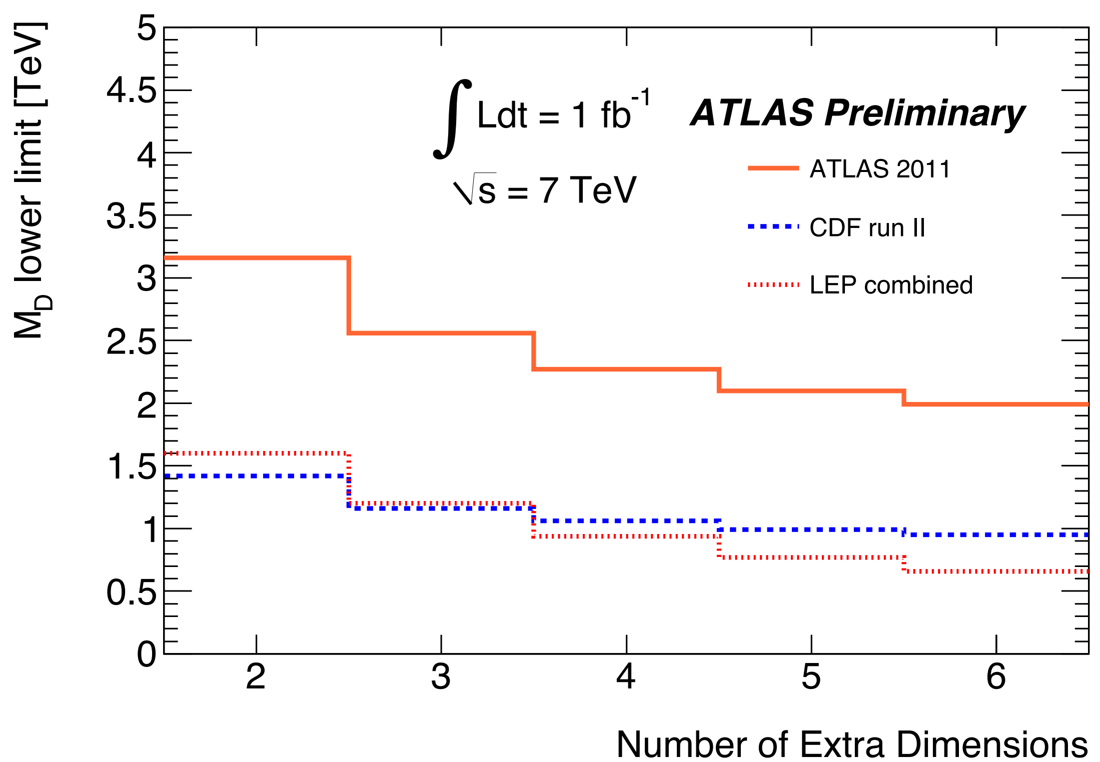
Jet + Missing E_T Limits

No excess observed => set model-independent 95% CL limits on the effective cross section (product of cross section and acceptance) of the signal:

Low p_T: 1.7 pb
High p_T: 110 fb
Very High p_T: 35 fb

High p_T limits in the context of ADD models:





Search for Black Holes in Leptons+jets

ATLAS-CONF-2011-147, 1.04 fb-1
(also searched for in multijet and same-sign dimuon events)

Signals: low-scale gravity models (extra dimensions; BH, string balls)
High multiplicity BH decay
Benchmark: BlackMax, Charybdis

Backgrounds: QCD multijets (Pythia), top (MC@NLO), V+jets (Alpgen), dibosons (Alpgen)

Trigger: single electron/muon (p_T > 20/18 GeV)

Selection:

Events with at least three electrons/muons/jets with p_T > 100 GeV
(including at least one lepton)

Sum p_T of leptons and jets > 700 GeV

Search variable: sum p_T of electrons, muons, jets

Lepton+jets background techniques

Pure QCD contribution from jet mis-identified as a lepton

Fake electron estimate from in-situ extrapolation from background-enhanced data sample (loosened electron selection)

$$N_{\text{pass}} = \epsilon_{\text{real}} N_{\text{real}} + \epsilon_{\text{fake}} N_{\text{fake}},$$

$$N_{\text{fail}} = (1 - \epsilon_{\text{real}}) N_{\text{real}} + (1 - \epsilon_{\text{fake}}) N_{\text{fake}}$$

Muon contribution is negligible

Lepton+jets background techniques

DY, W, and top background contributions from MC

Normalized to data in control regions

DY:

- $80 < m_{ll} < 100$ GeV
- *opposite sign leptons*
- $300 < \text{sum } p_T < 700$ GeV

SF (muons): 0.85 ± 0.04 (stat) ± 0.14 (syst)
SF (electrons):0.93 ± 0.03 (stat) ± 0.08 (syst)

W/top:

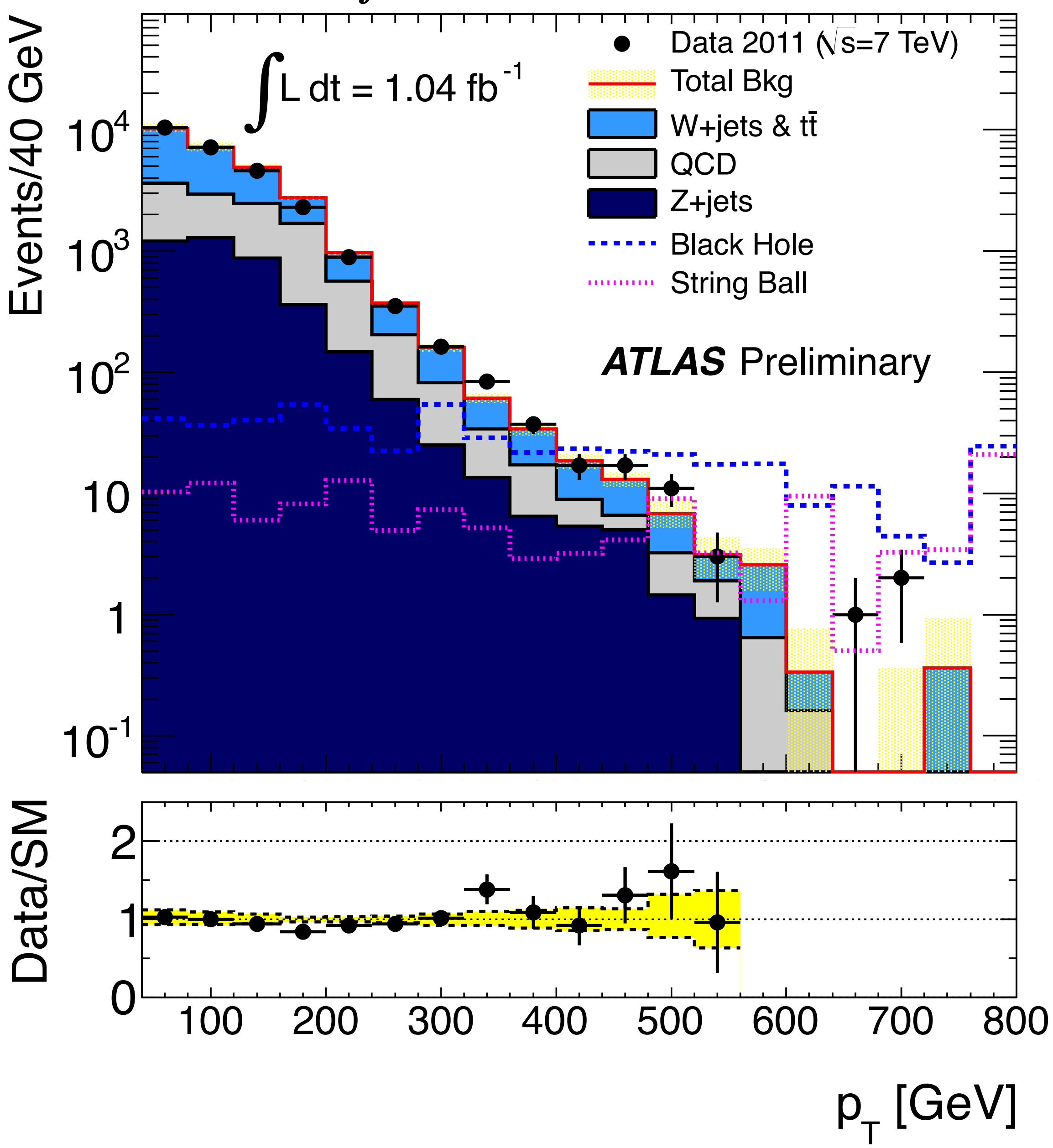
- $40 < M_T < 100$ GeV
- $30 < MET < 60$ GeV
- $300 < \text{sum } p_T < 700$ GeV

SF (muons): 1.05 ± 0.02 (stat) ± 0.12 (syst)
SF (electrons): 0.93 ± 0.02 (stat) ± 0.14 (syst)

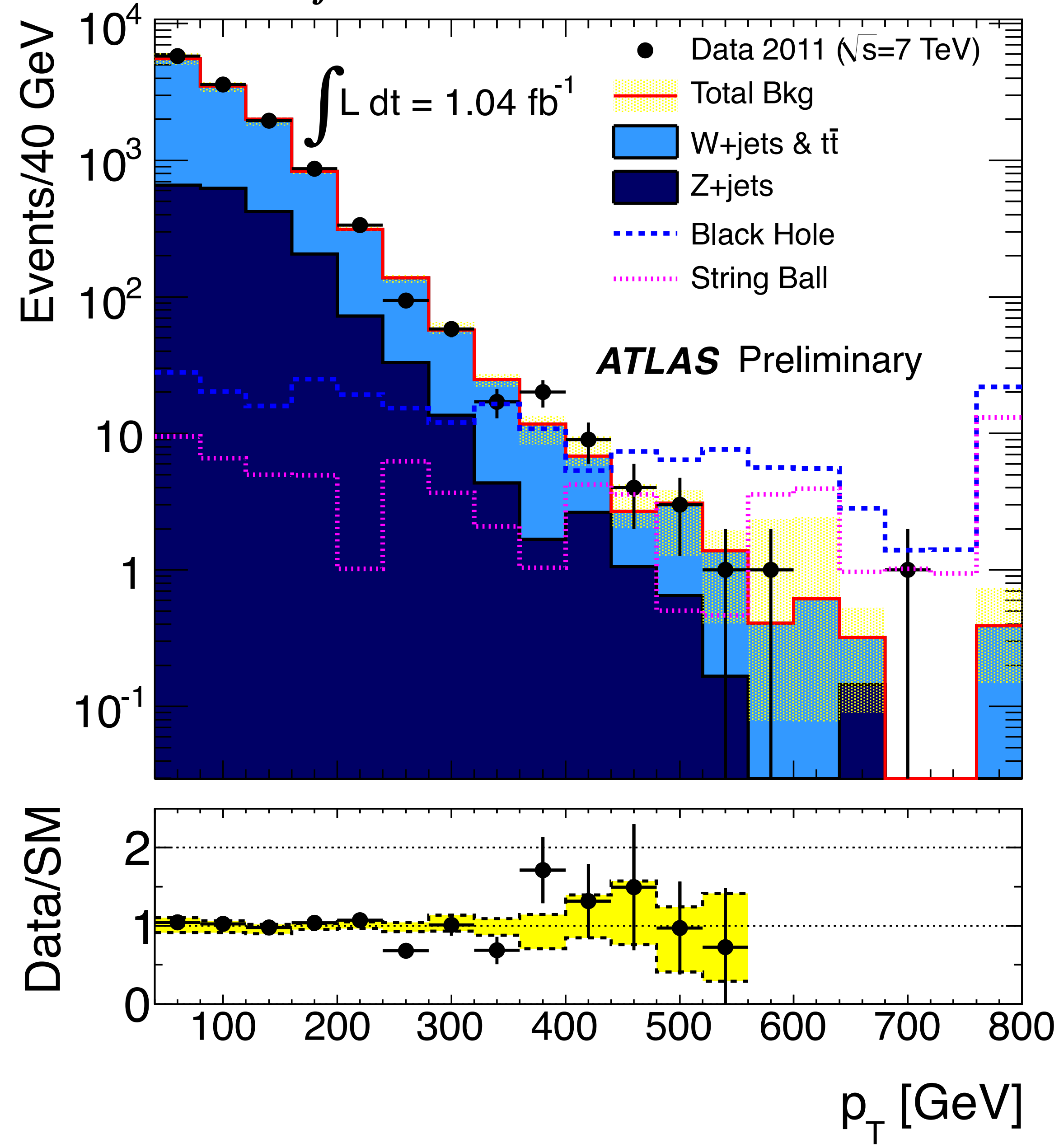
Lepton+jets background validation

Leading lepton p_T distributions in background-enhanced 'preselected' sample before final background rejection.

Electron+jets



Muon+jets



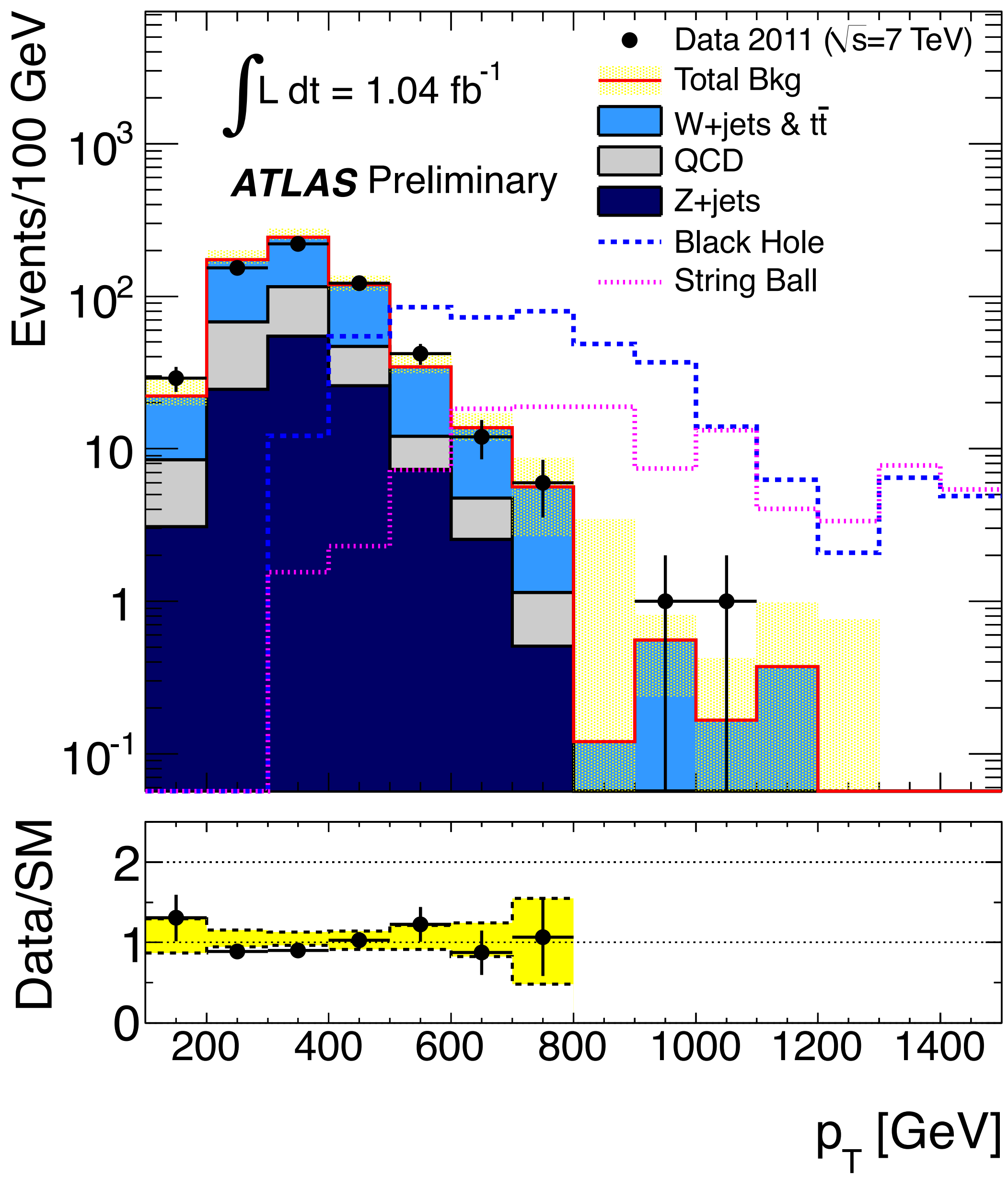
Shown for pre-selection:

Events with at least three electrons/muons/jets with p_T >40 GeV (including at least one lepton)

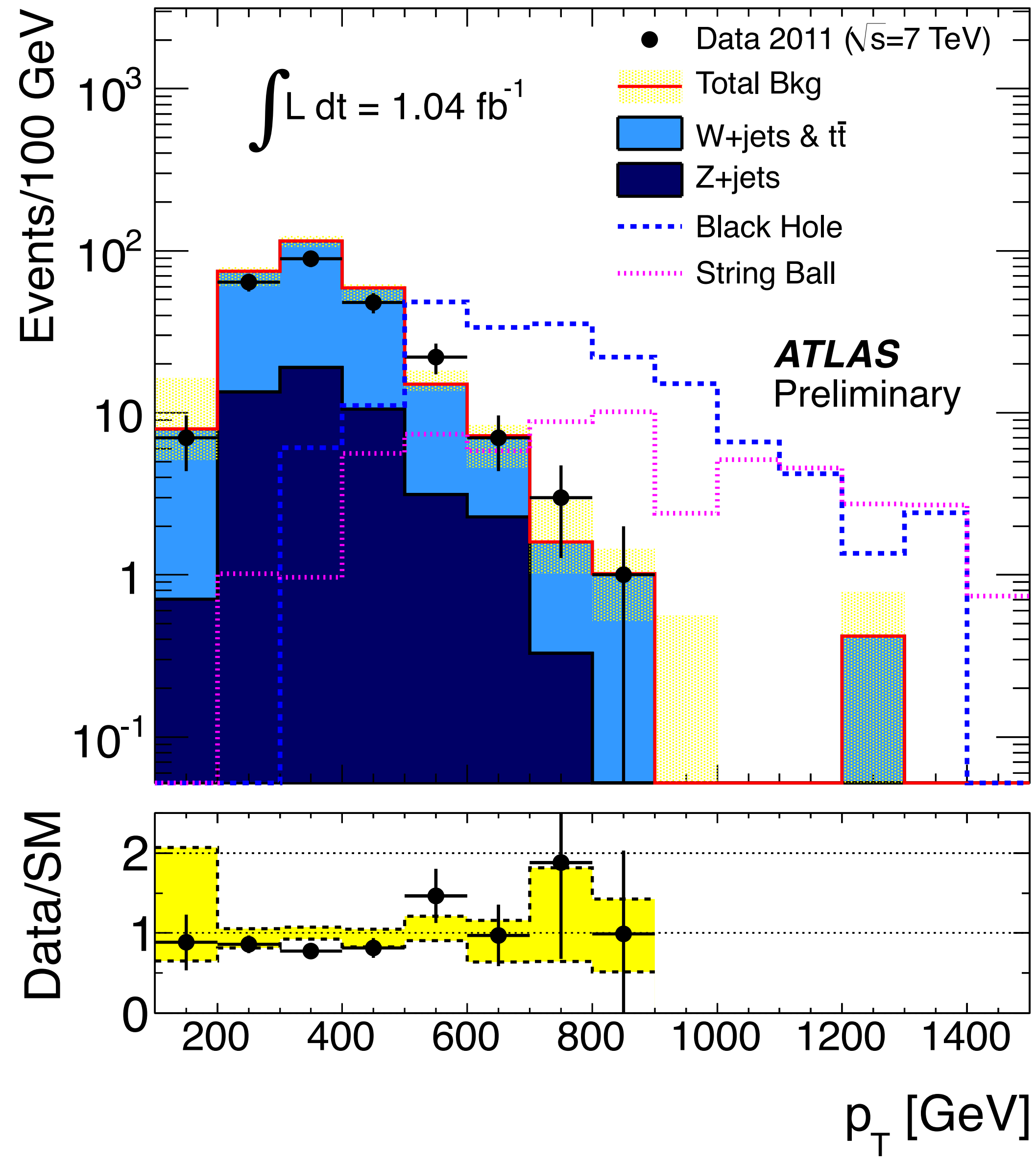
Sum p_T of leptons and jets > 300 GeV

Lepton+jets results

Electron+jets



Muon+jets



Good agreement between data and background prediction observed (p-values 0.43–0.47).

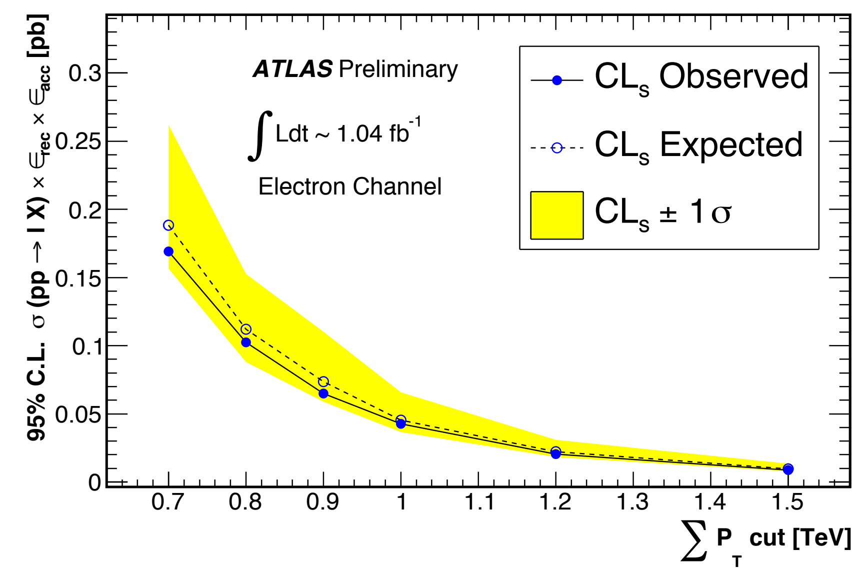
Lepton+jets results

Set 95% CL limits on effective black hole production cross section.

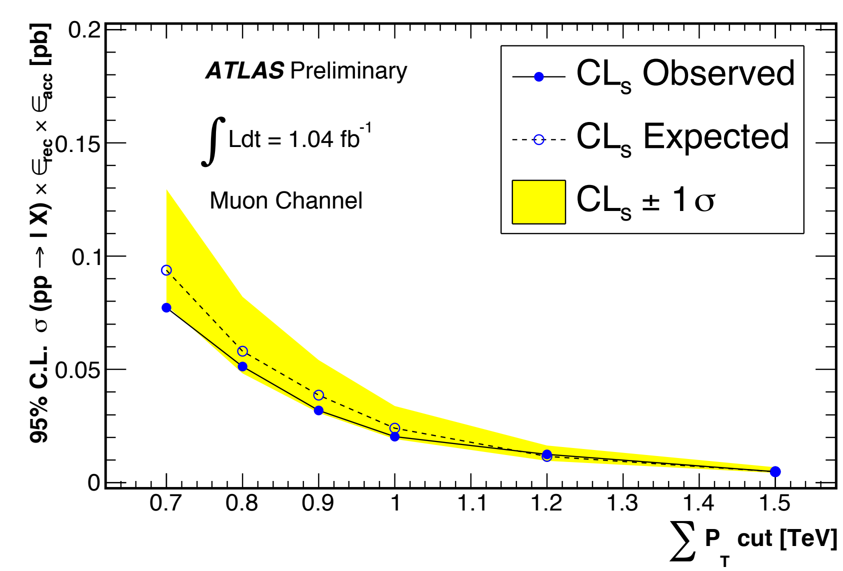
$\sum p_T$ (GeV)	σ_{eff} 95% C.L. Upper Limit (fb) Observed (Expected)	
	Muon Channel	Electron Channel
> 700	77 (94)	169 (188)
> 800	51 (58)	102 (112)
> 900	32 (39)	65 (73)
> 1000	20 (24)	43 (45)
> 1200	13 (12)	20 (22)
> 1500	4.8 (4.8)	8.7 (9.7)

$$\sigma_{eff} = \sigma\,(pp \to lX) \cdot eff_{rec} \cdot eff_{acc},$$

$\sigma\,(pp \to lX)$ is the production cross section for a high-sum-pT multi-object state containing a high-p_T (> 100 GeV) isolated lepton inside experimental acceptance.

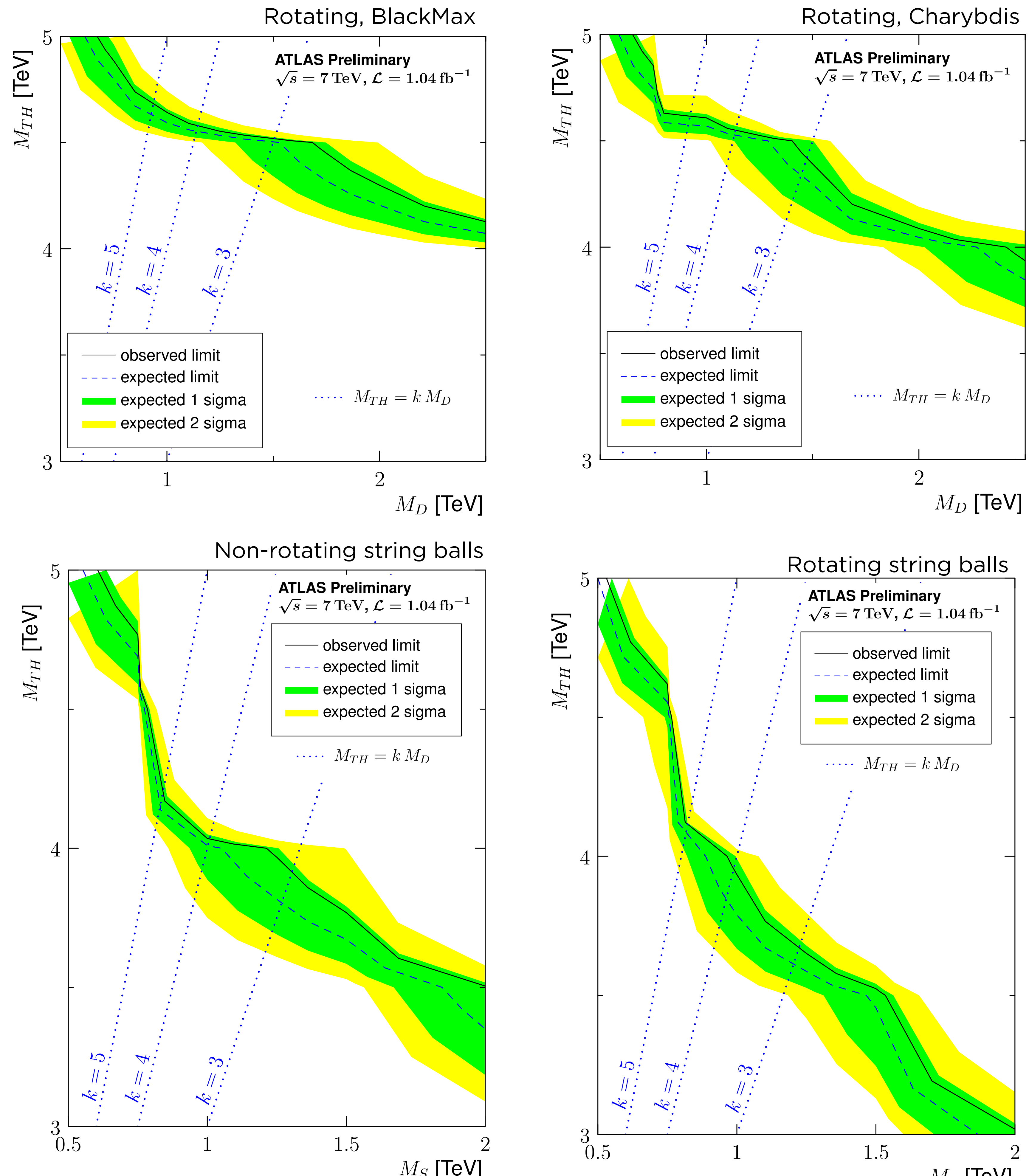


For sum-p_T > 1.5 TeV, the upper limits on the cross section are 8.7 fb for the electron channel and 4.8 fb for the muon channel, at 95% C.L.



Lepton+jets results

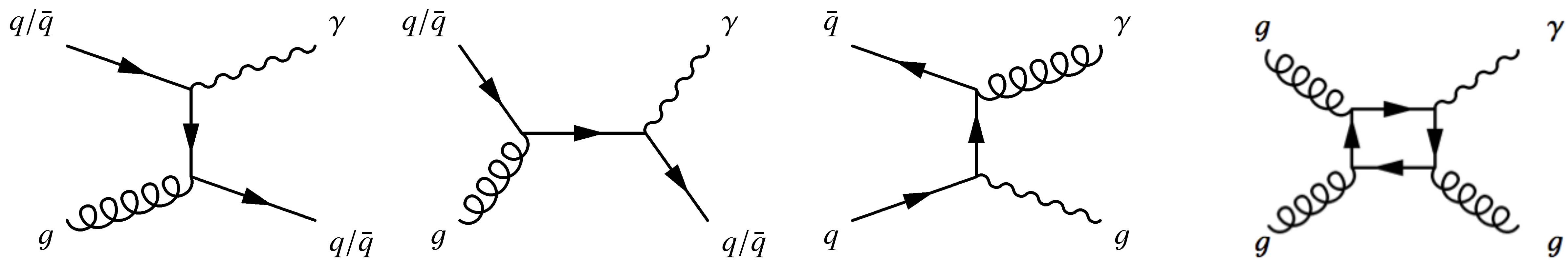
Set 95% CL limits limits on effective production cross section.



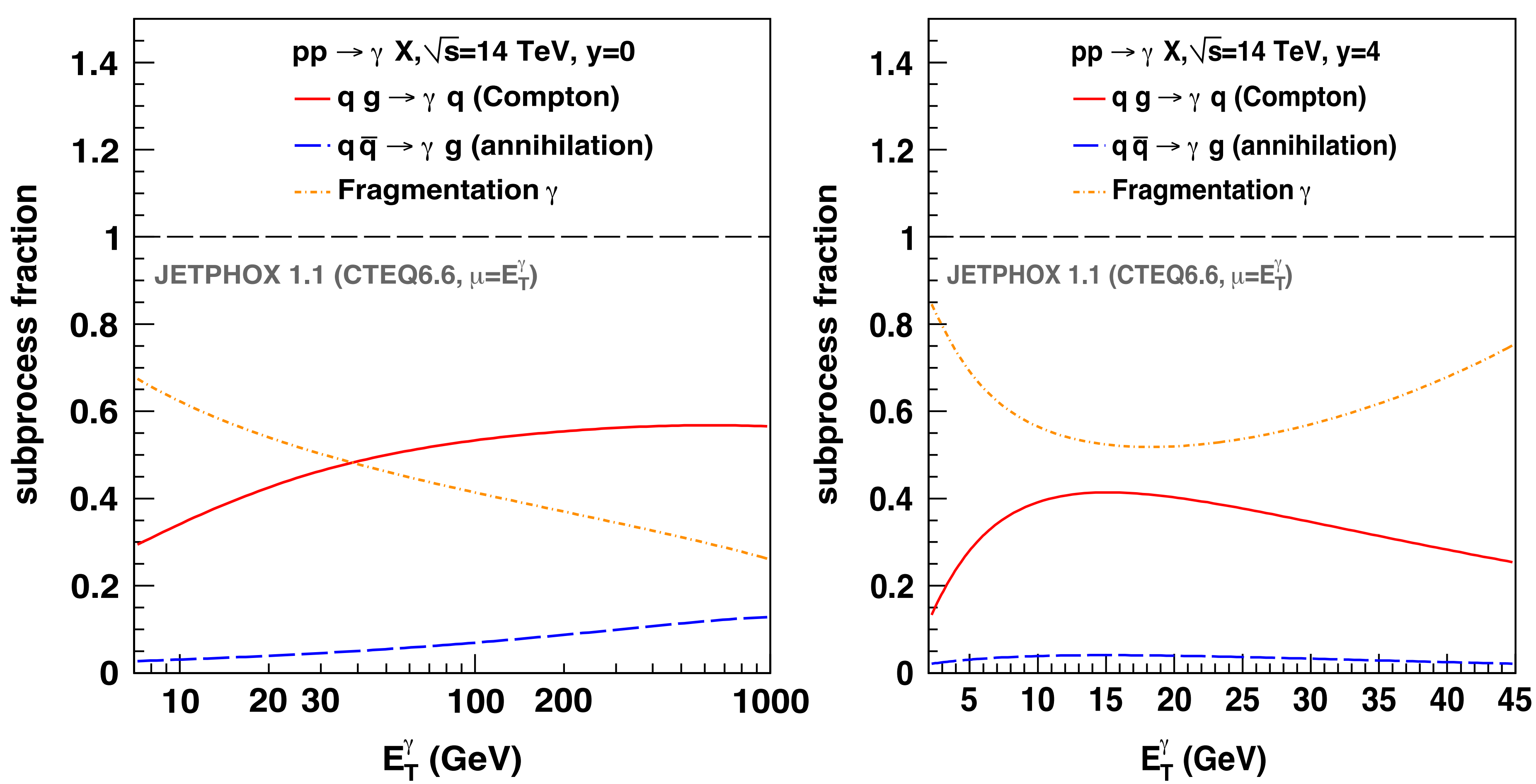
Search in the Photon+Jet Mass Distribution

arXiv:1112.3580, submitted to PRL, 2.1 fb^{-1}

- *Backgrounds: SM photon+jet, dijet with fragmentation photons*



RAPHAËLLE ICHOU AND DAVID D'ENTERRIA PHYSICAL REVIEW D 82, 014015 (2010)



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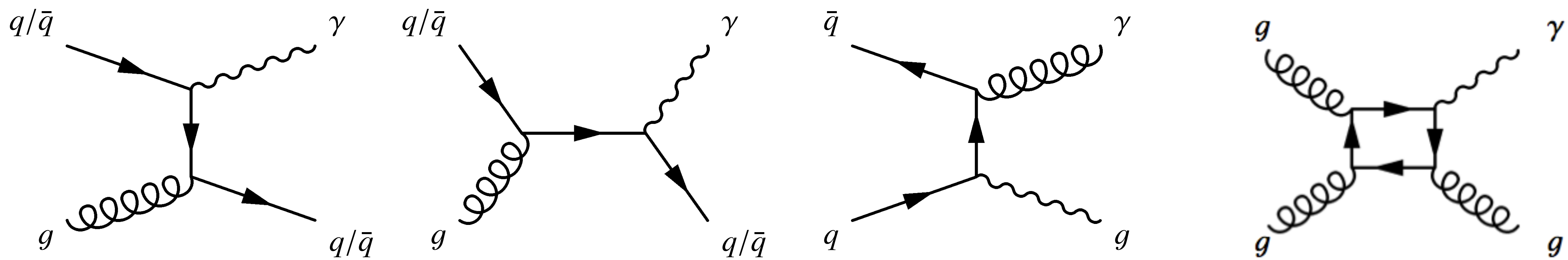
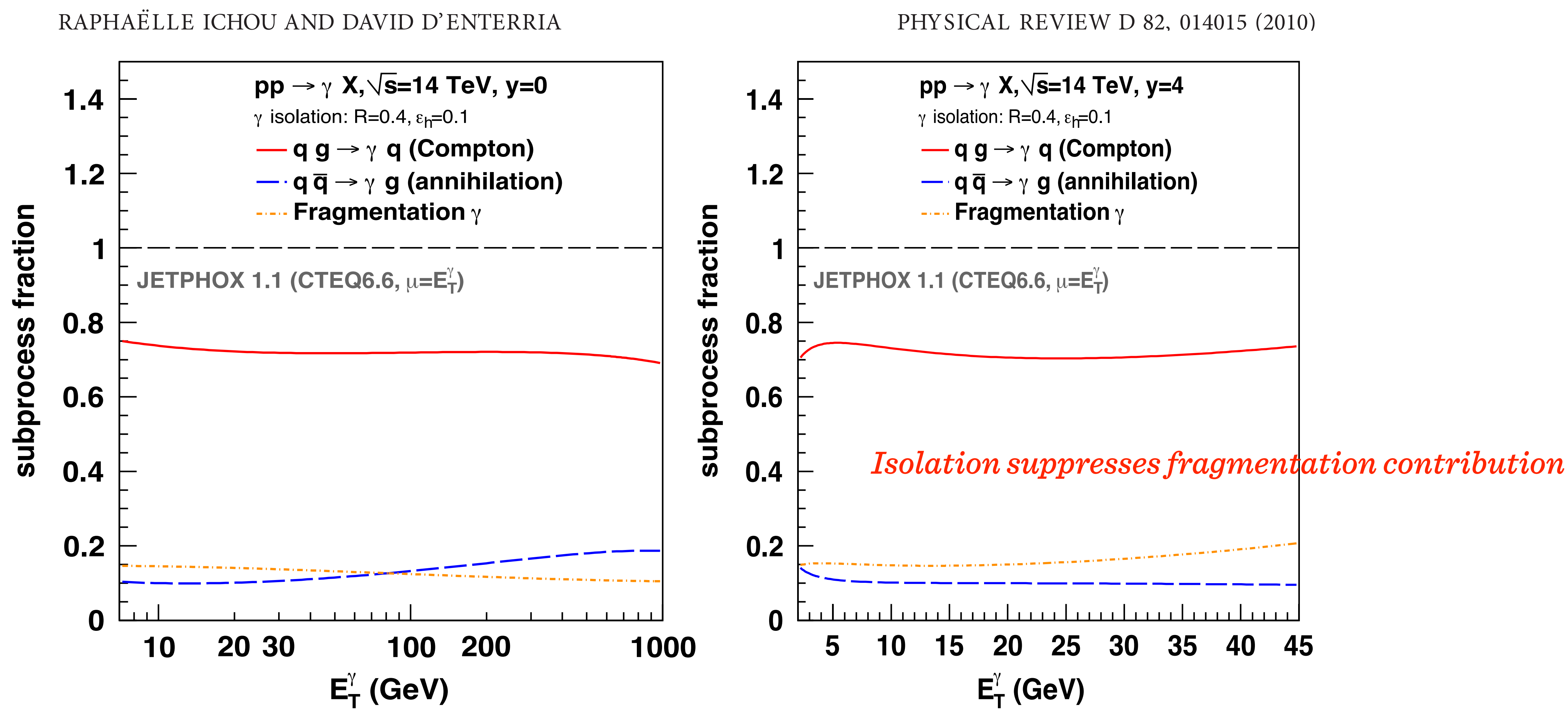




Photon+Jet Resonance Models

Photon+jet sensitive to many models: excited quarks, Regge recurrences, topological pions
Complementary to dijet searches for some models (e.g. excited quarks)

Few searches published

- *Much tighter constraint possible with LHC data*

Excited quark model used as benchmark model

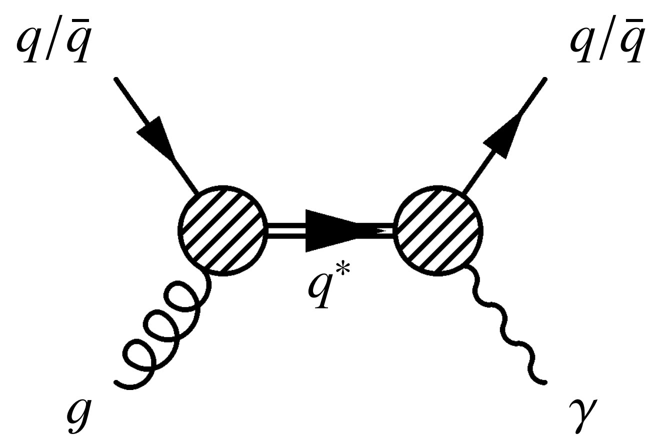


TABLE II. Relative branching ratios $B_G = \Gamma(f^* \to fV) / \sum_V \Gamma(f^* \to fV)$ for decays of excited fermions into gauge bosons for $m^* = \Lambda$, $f_s = f = f' = 1$, and $\alpha_s = 0.11$.

Decay mode	B_G	Decay mode	B_G
		$e^* \to e\gamma$	0.28
$\nu^* \to \nu Z$	0.39	$e^* \to eZ$	0.11
$\nu^* \to eW$	0.61	$e^* \to \nu W$	0.61
$u^* \to ug$	0.85	$d^* \to dg$	0.85
$u^* \to u\gamma$	0.02	$d^* \to d\gamma$	0.005
$u^* \to uZ$	0.03	$d^* \to dZ$	0.05
$u^* \to dW$	0.10	$d^* \to uW$	0.10

PRD 42 (815)

Search in the Photon+Jet Mass Distribution

- *Previous most sensitive direct search published in 1994 (CDF)*
- *Excludes 80 < m_{q^*} < 460 GeV*

PRL 72 (3004)

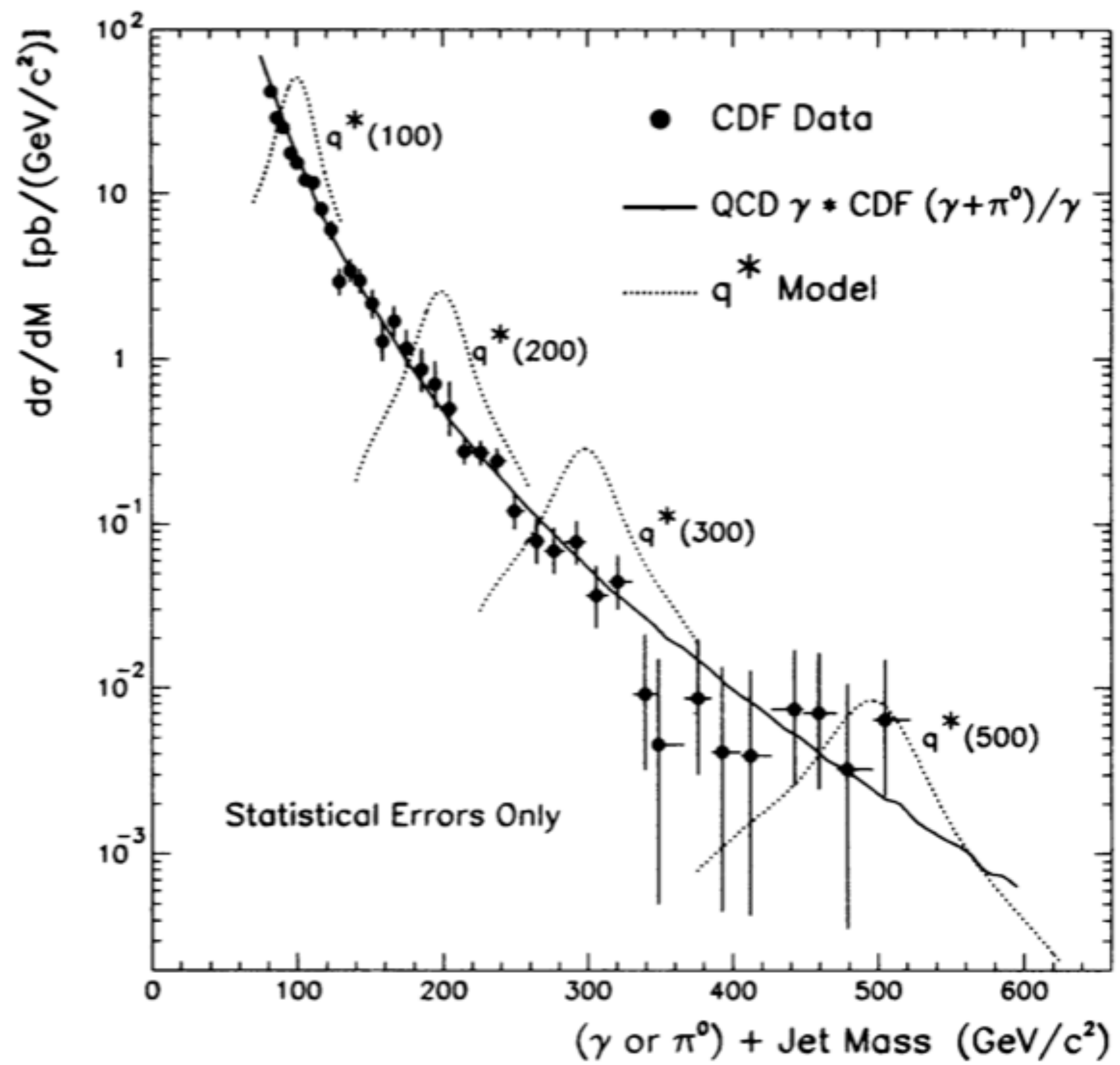


FIG. 1. The photon candidate+leading jet invariant mass distribution (points) compared to an estimate of the QCD background (solid curve) and excited quark signal at four different q^* mass values (dotted curves). Corrected for acceptance and efficiency except for the cuts $|\eta_\gamma| < 0.9$ and $|\cos\theta^*| < \frac{2}{3}$.

Photon+Jet Resonance Models

Example: LHC is sensitive to Regge excitations of fundamental strings at "string disk" (tree) level

PRD 78 016005

$$|\mathcal{M}(gg \to g\gamma)|^2 \approx g^4 Q^2 C(N) \frac{\pi^4}{4}(s^4 + t^4 + u^4) \qquad (s, t, u \ll 1)\,.$$

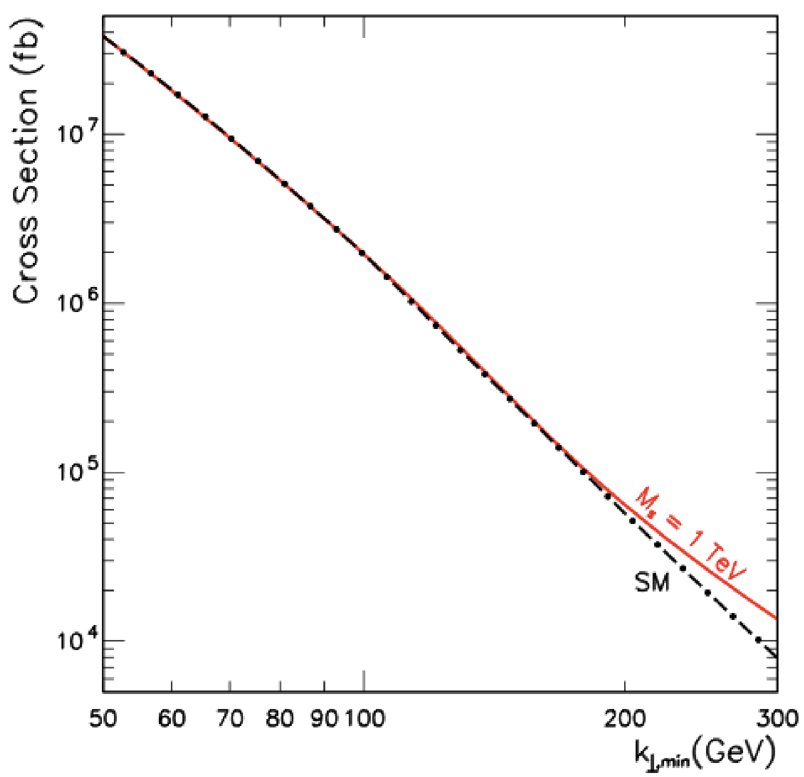


FIG. 2: Behavior of the QCD cross section for $pp \to \gamma + \text{jet}$ (dot-dashed line) as a functio $k_{\perp,\text{min}}$. The string cross section overlying the QCD background is also shown as a solid line $M_s = 1$ TeV.

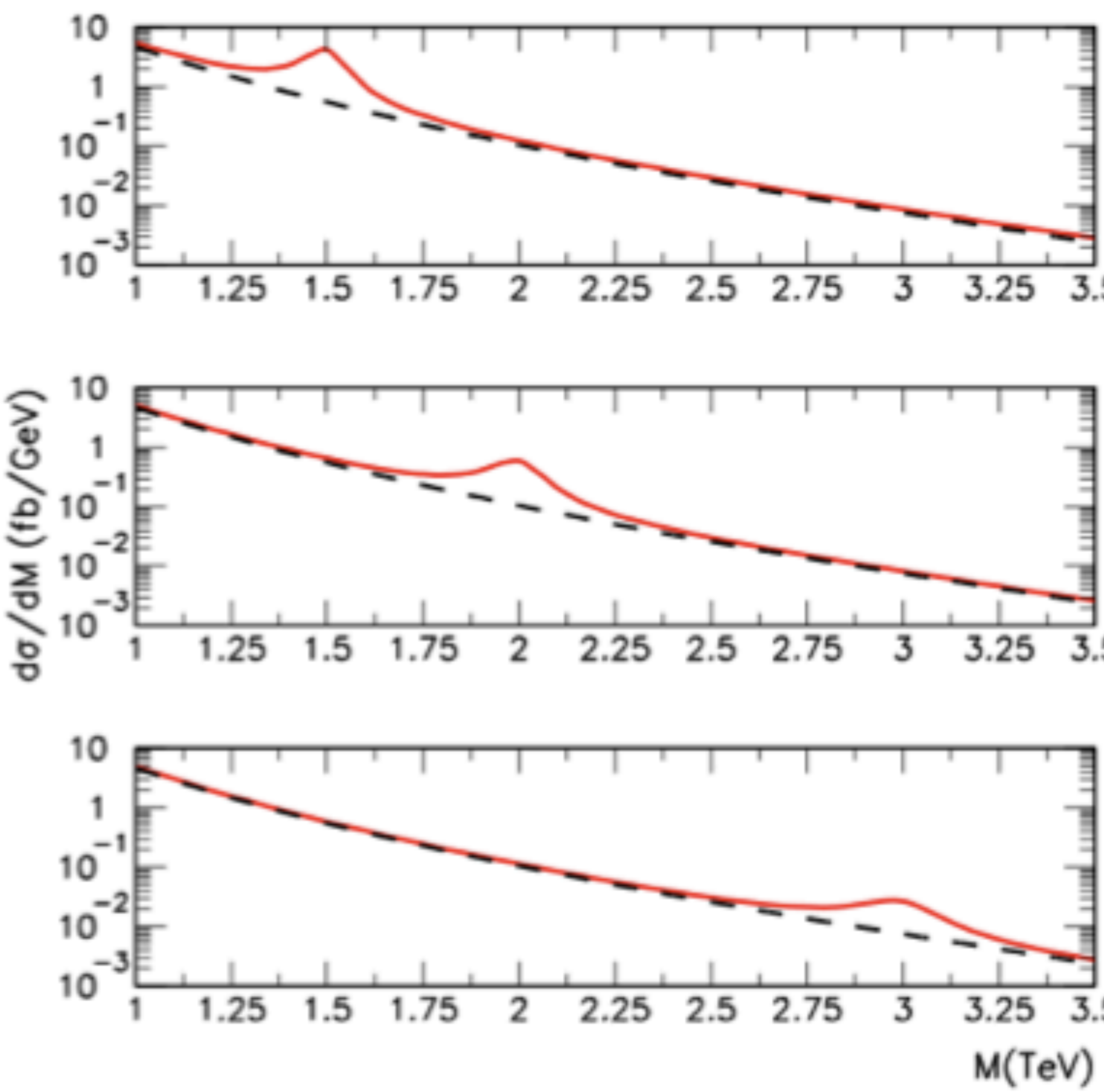


FIG. 5: $d\sigma/dM$ (units of fb/GeV) *vs.* M (TeV) is plotted for the case of SM QCD background (dashed) and (first resonance) string signal + background (solid).

Search in the Photon+Jet Mass Distribution

Selection:

At least one photon with E_T>85 GeV

At least one jet with E_T>30 GeV

Photon isolation E_T (0.4 cone) < 7 GeV

Delta R (eta–phi) > 0.4 between leading photon and any jet

Invariant mass of photon and jet pair $m_{\gamma j}$ *> 260 GeV*

Background estimate:

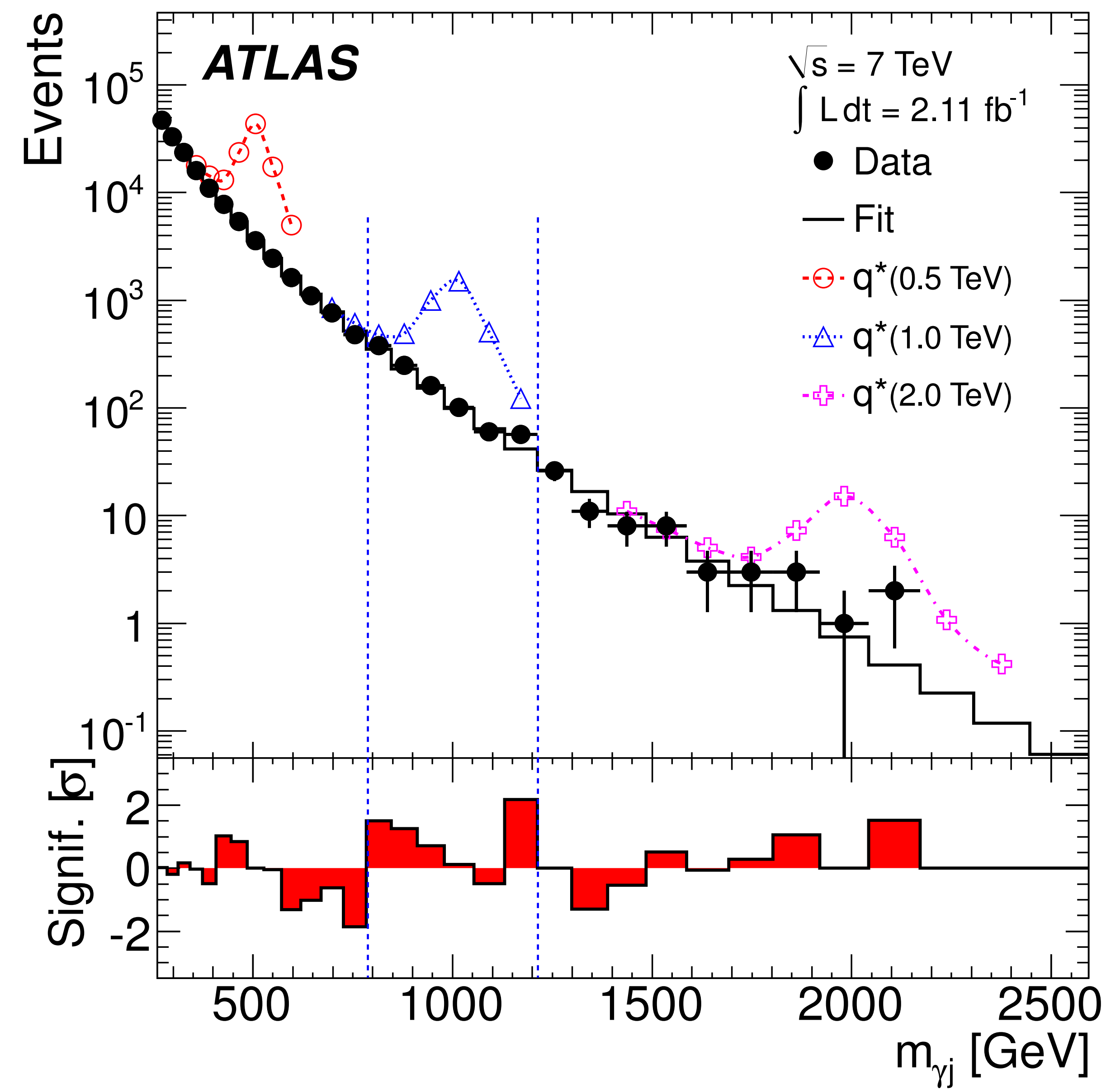
Fit mass distribution to an ansatz motivated by massless 2->2 scattering formulae

$$f(x \equiv m_{\gamma j}/\sqrt{s}) = p_1(1-x)^{p_2} x^{-p_3-p_4 \ln x}$$

BumpHunter:

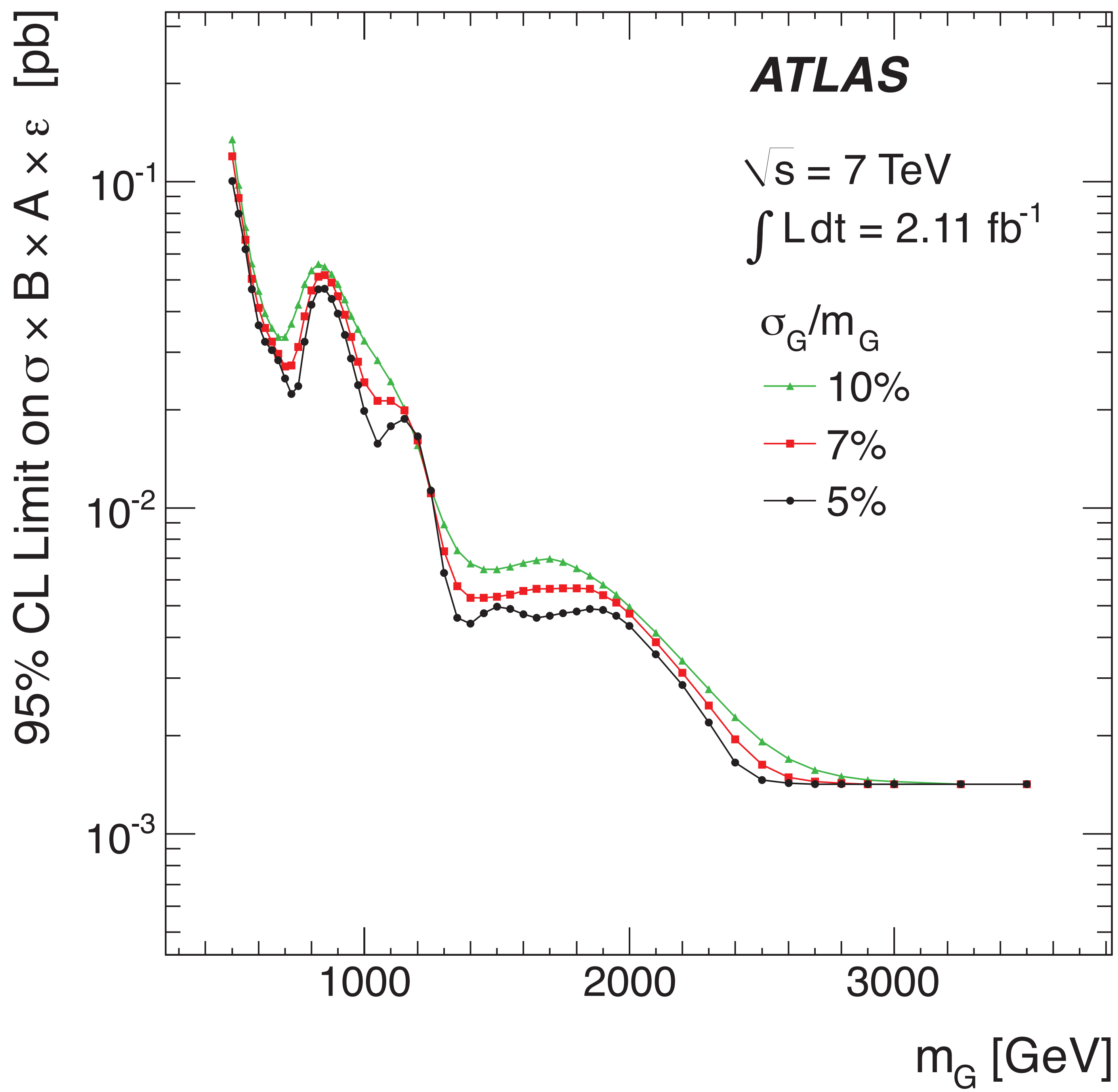
Most significant excess appears in the interval 784–1212 GeV

p-value of 0.20



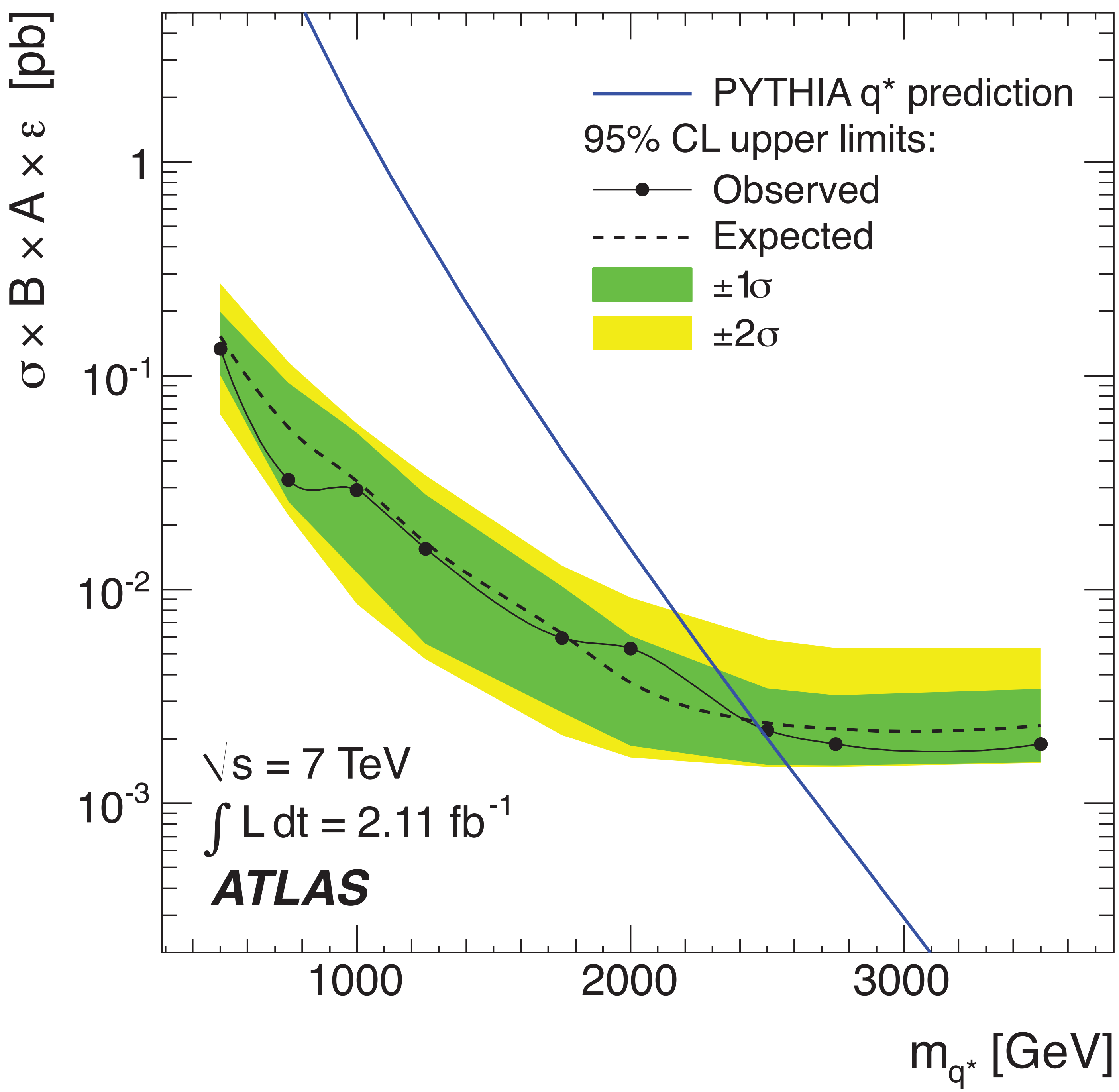
Photon+Jet Model-Independent Limits

Set 95% CL Bayesian limits on Gaussian-shaped resonances.



Photon+Jet Excited Quark Limits

Set 95% CL Bayesian limits on excited quark model.
Compare $M_{q^*} > 2.46$ TeV with ~3 TeV from 1/fb dijet search.



Search for New Phenomena in Dijet Mass and Angular Distributions

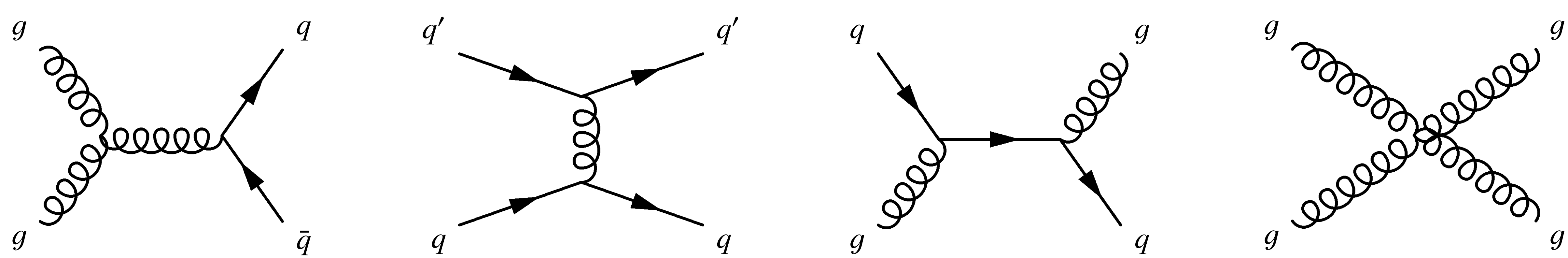
ATLAS-CONF-2012-038 (just updated), 4.8 fb^{-1}

- *Bump search in dijet mass distribution*
- *Shape comparison in $\chi \equiv exp(|y_1 - y_2|)$*

- *Many many models predict resonances with two-body decays to jets: Z', excited quarks, chiral color, axigluons, black holes, KK gravitons, ...*

- *New physics tends to prefer central production (s-channel)*
- *QCD multijets has strong t-channel component*

- *Some new physics will not produce a peak in the dijet mass distribution but could appear in angular distribution*
  - *e.g., effective contact interaction due to NP at higher energy*
  - *angular search also benefits from cancellation of systematic effects in numerator/denominator*



+ ...

Search for New Phenomena in Dijet Mass and Angular Distributions

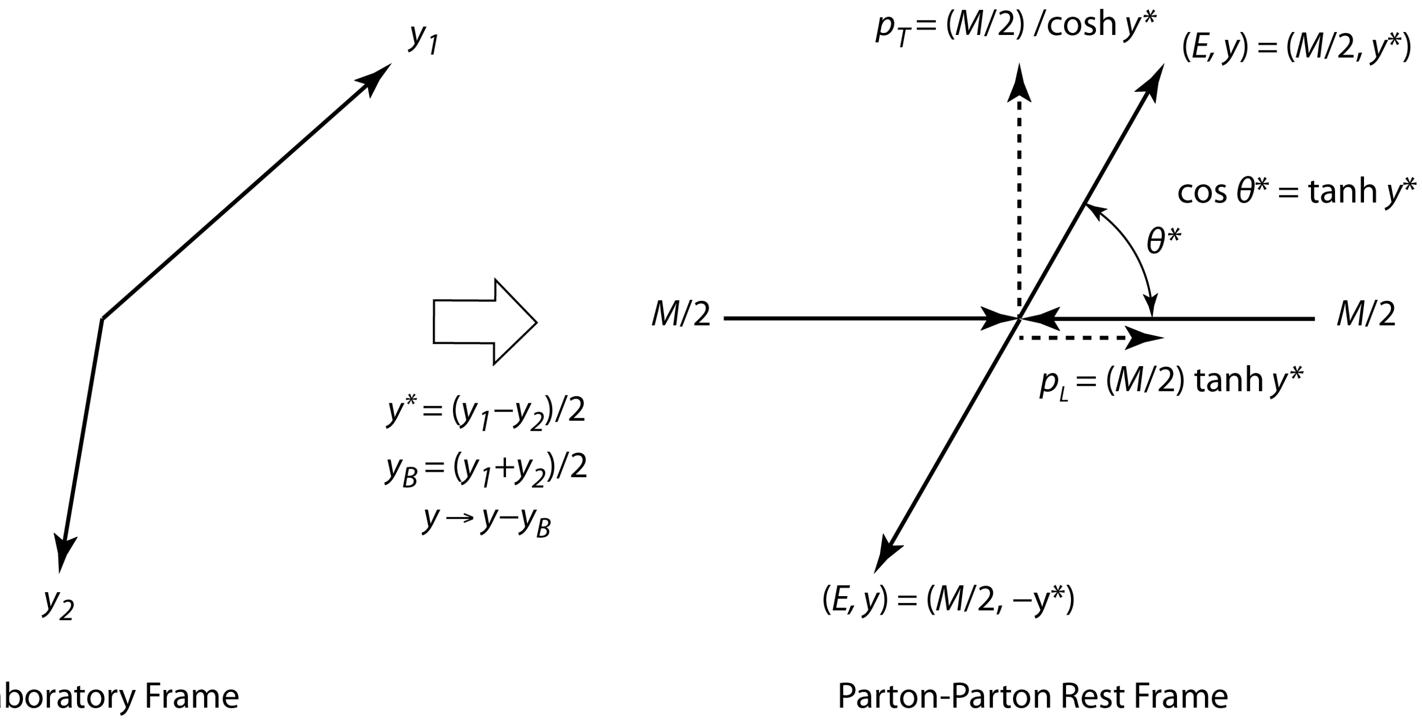
- *Selection common to mass and angular analyses:*
  At least two jets (p_T > 80 GeV)
  $|y_{1,2}| < 2.8$
  $|y^*| < 0.6$
  $m_{jj} > 850$ *GeV*

$$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$$

$$y \equiv \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

- *Mass analysis:*
  - *Single high p_T jet trigger*

- *Angular analysis:*
  - *Different high p_T jet trigger for each χ distribution*
  - $|y^*| < 1.7 \Leftrightarrow \chi < 30.0$
  - $F_\chi = N_{central}/N_{total}$
    - $N_{central}$: $|y^*| < 0.6 \Leftrightarrow \chi < 3.32$
  - F_χ *divided into 11 bins of m_{jj}*



Search in the Dijet Mass Distribution

Background estimate:

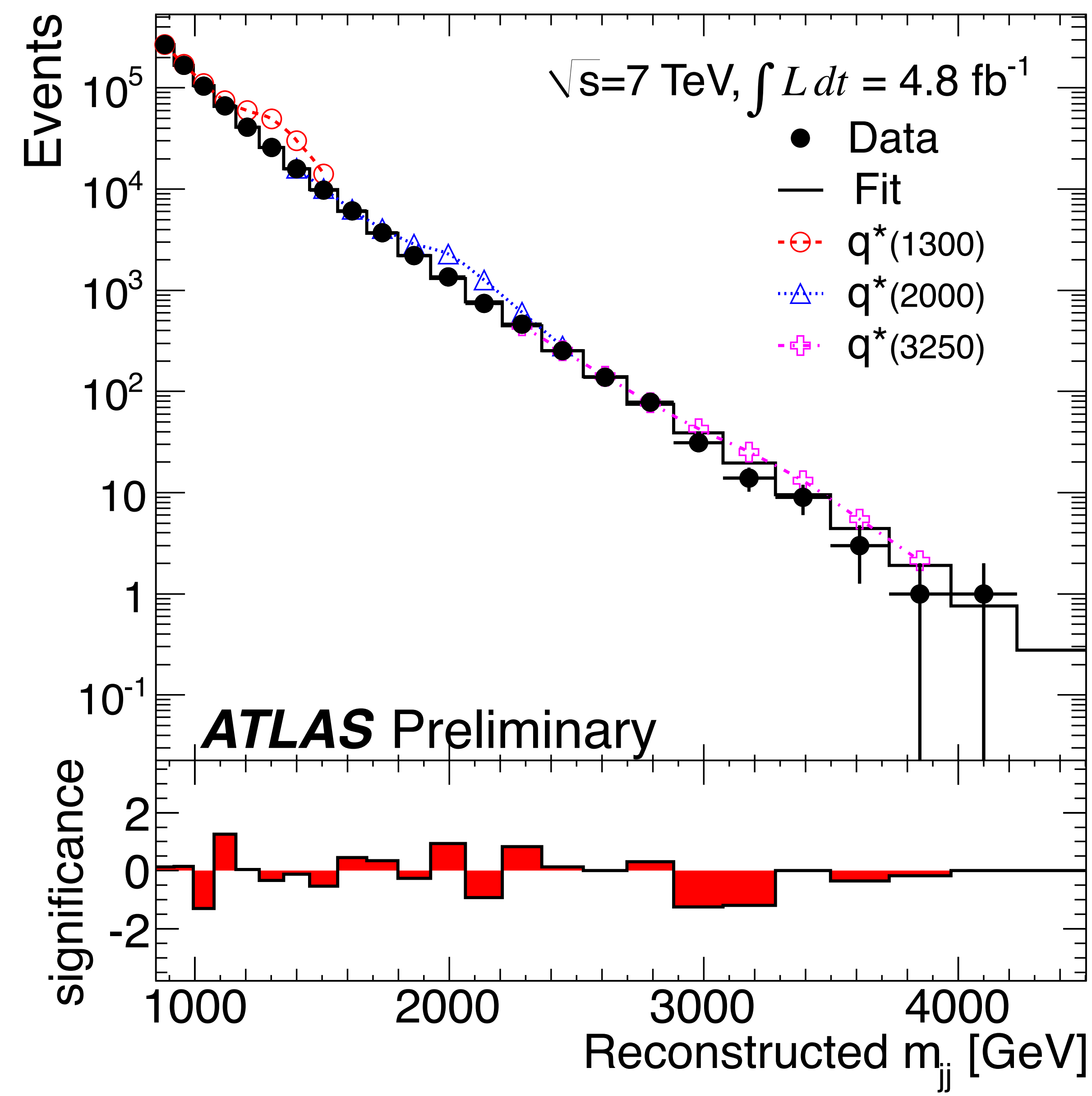
Fit mass distribution to an ansatz motivated by massless 2->2 scattering formulae

Perform BumpHunter search for bin range with most significant deviation from background

Most significant discrepancy appears in the two bins spanning 1.08–1.25 TeV.

Probability of observing an upward fluctuation of background at least as large anywhere in the spectrum is 0.96.

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



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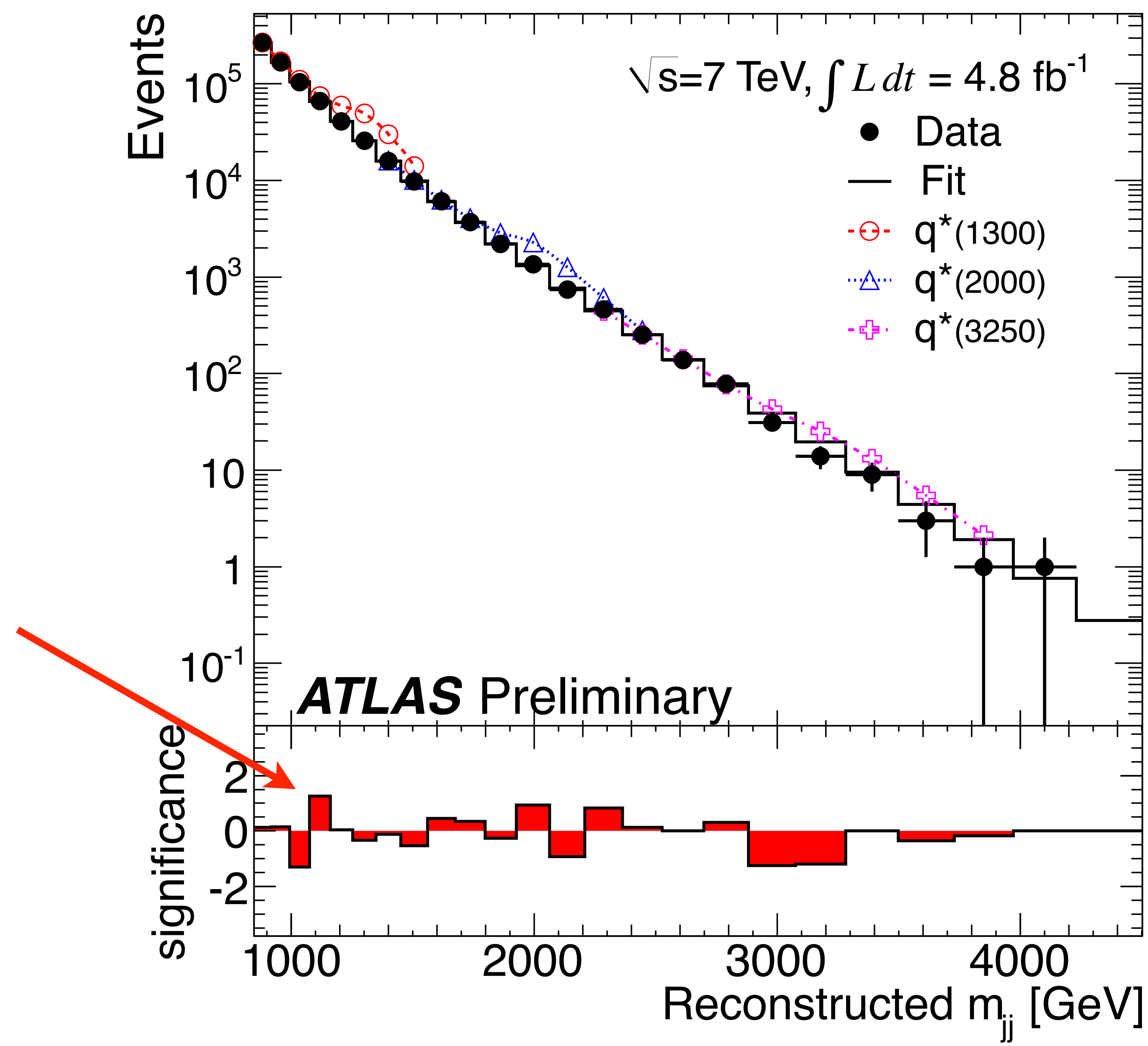
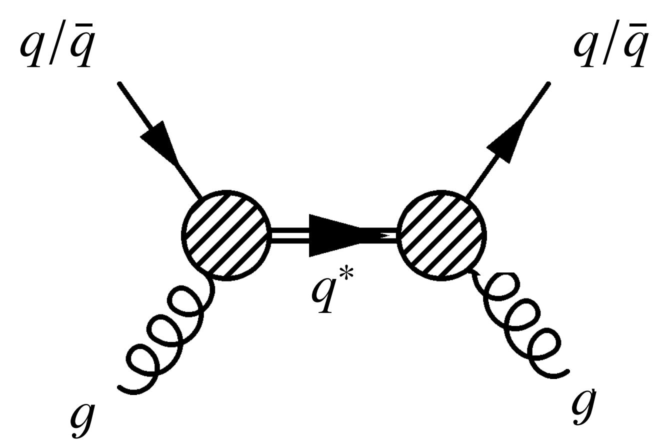
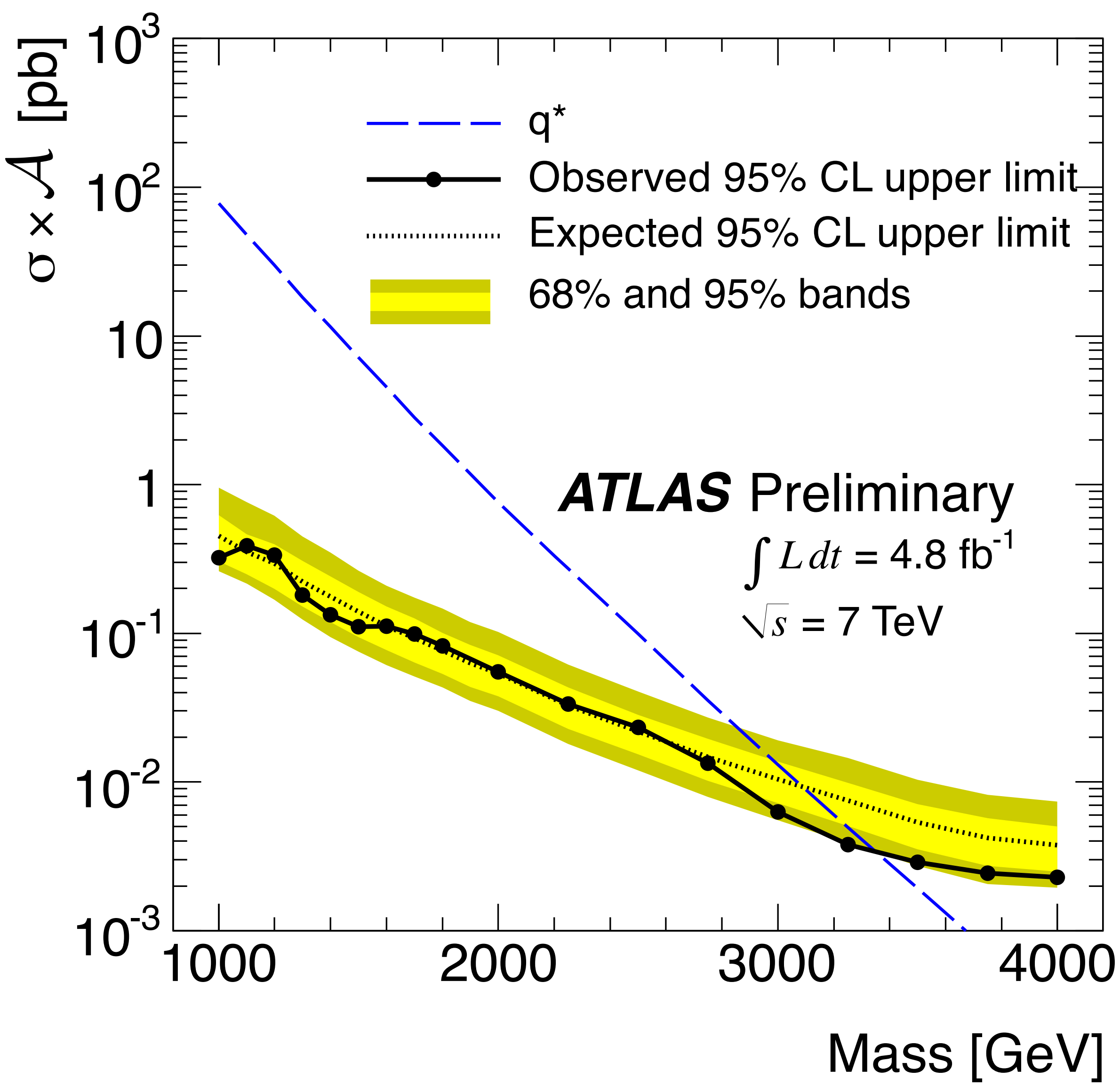


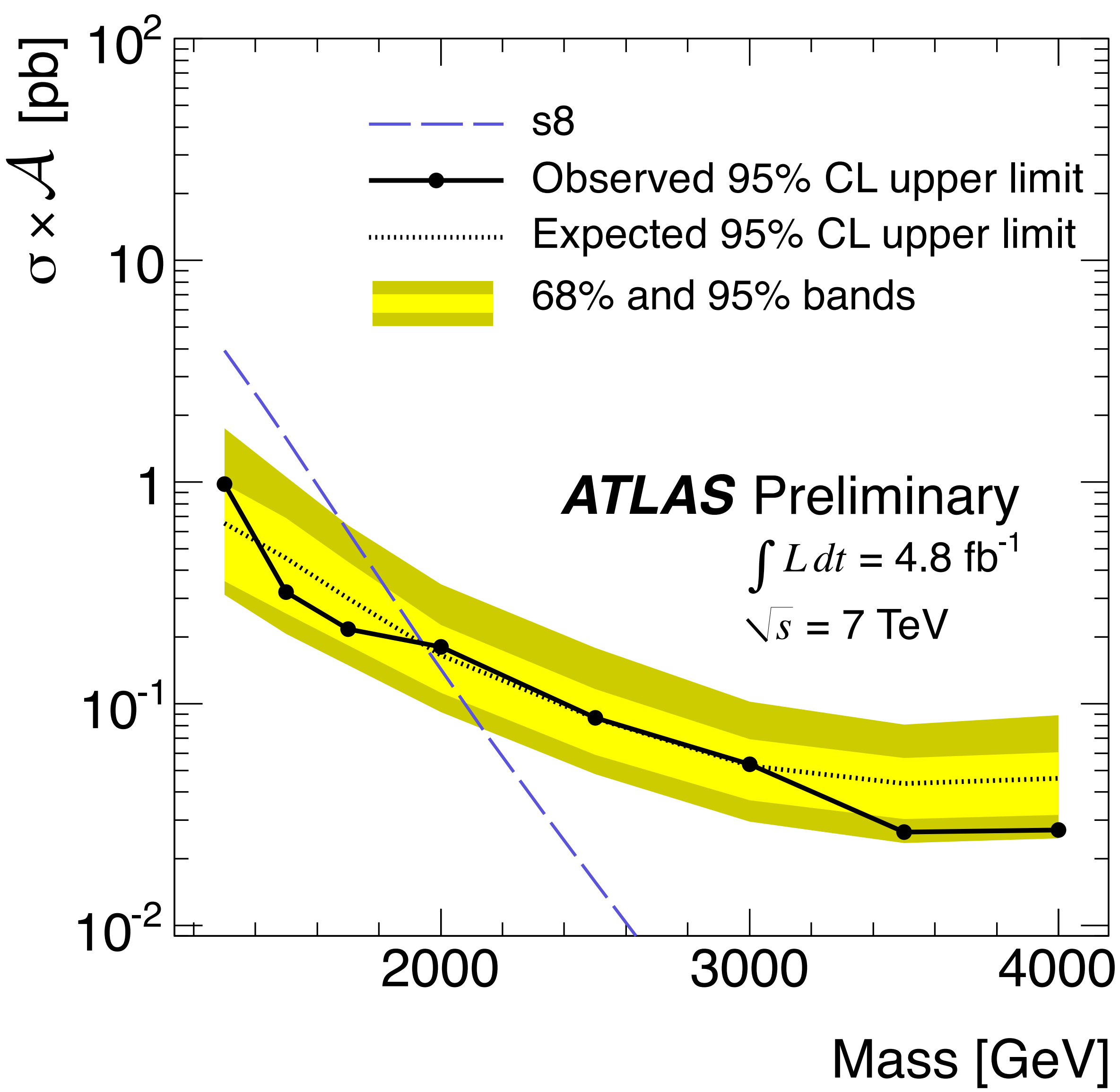
Search in the Dijet Mass Distribution



Limits using the mass distribution:

Set specific limits on excited quark and color octet models.





Search in the Dijet Angular Distribution

Background estimate:

2->2 Pythia 6 with NLOJet++

k-factor in each m_{jj} bin

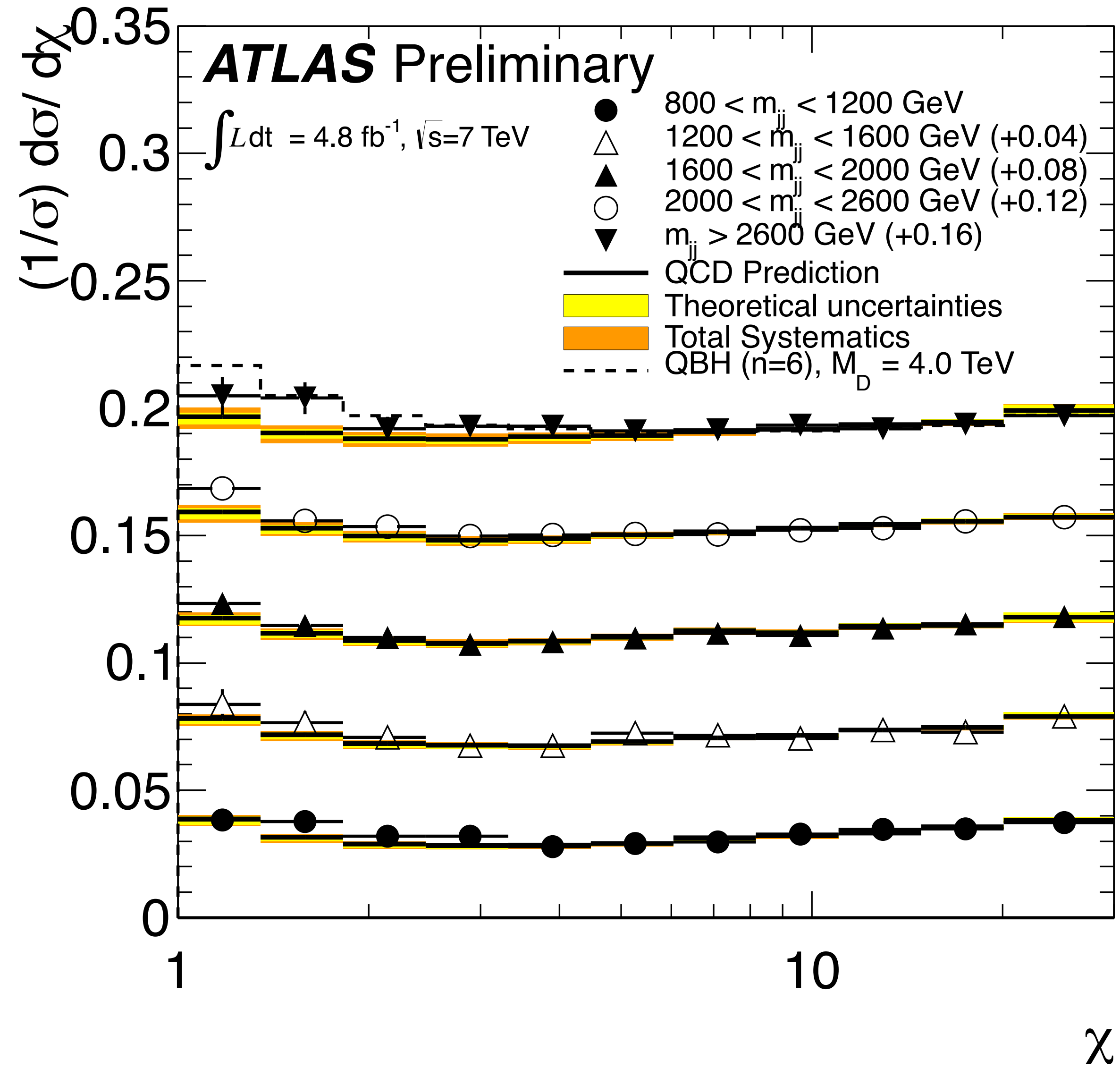
Two statistical tests:

p-value with binned likelihood: 0.052

BumpHunter and TailHunter:

most discrepant range 2209–3498 GeV

p-value of 0.082, corresponding to 1.39σ



Search in the Dijet Angular Distribution

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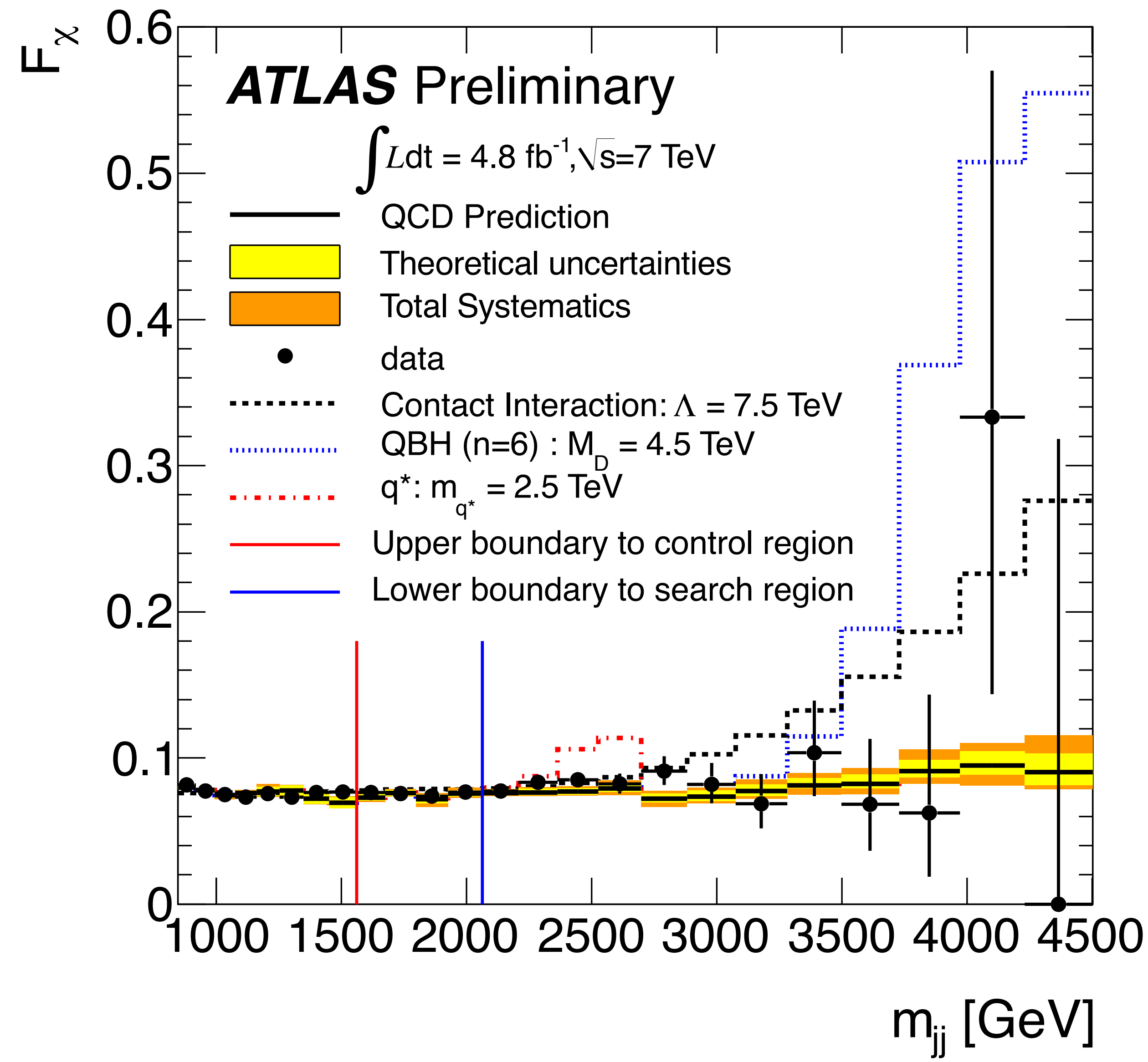
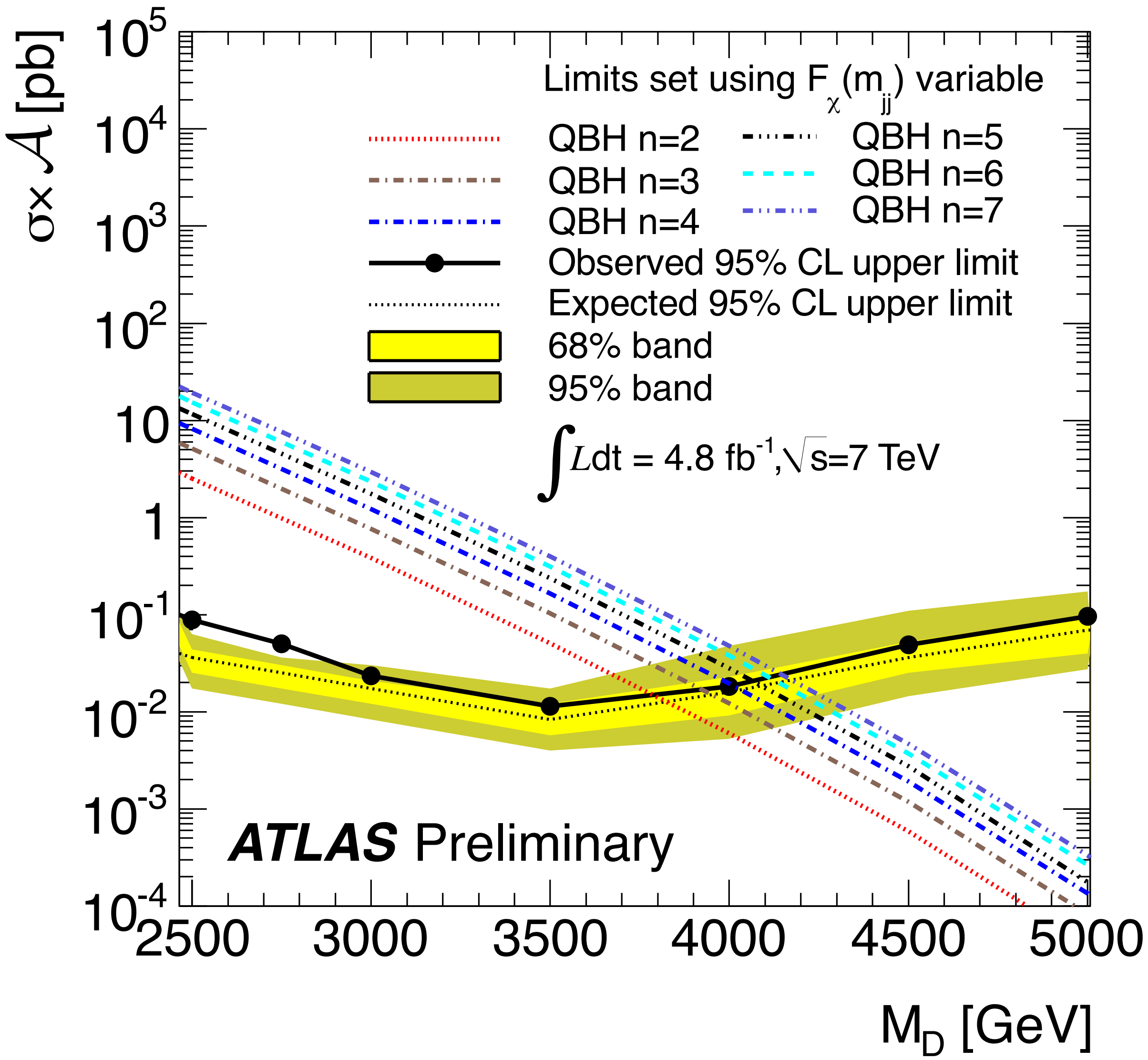


Search in the Dijet Angular Distribution



Limits using the angular distribution:

Using F_χ (m_{jj}):

New physics that does not interfere with QCD (semi-model independent), quantum black holes

Contact interactions: Λ > at 7.6 TeV with an expected limit of 8.2 TeV

Also set separate limits on QBH and contact interactions using the 11 χ distributions

Lower limits at 95% C.L. on M_D of the QBH model with n=2 to 7 extra dimensions.

n extra dimensions	Expected limit (TeV)	Observed limit (TeV)
2	3.82	3.79
3	3.95	3.93
4	4.03	4.01
5	4.09	4.06
6	4.14	4.11
7	4.18	4.15

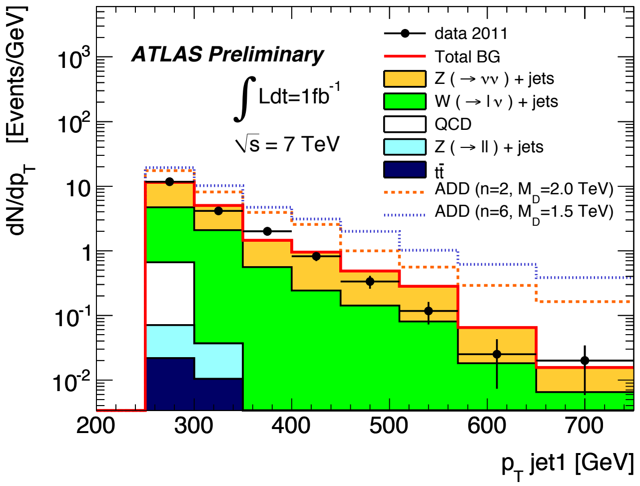
Summary of dijet limits

Table 3: The 95% C.L. lower limits on the masses and energy scales of the models examined in this study. All limit analyses are Bayesian, with statistical and systematic uncertainties included. For each NP hypothesis, the result corresponding to the highest expected limit is the result quoted in the abstract.

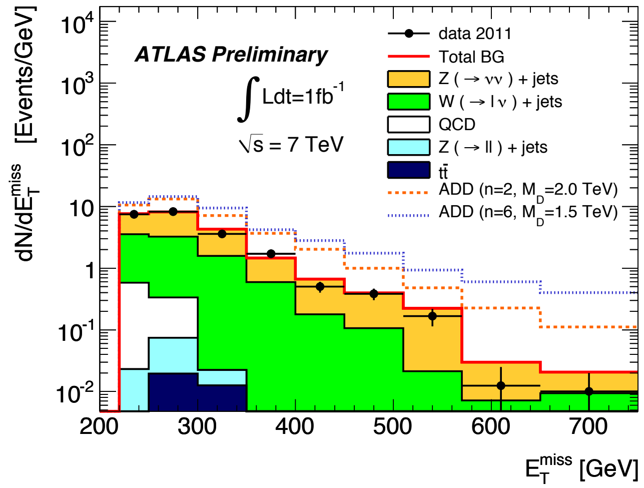
Model, and Analysis Strategy	95% C.L. Limits (TeV)	
	Expected	Observed
Excited quark, mass of q^*		
Resonance in m_{jj}	3.09	3.35
Resonance in $F_\chi(m_{jj})$	2.97	2.58
Colour octet scalar, mass of s8		
Resonance in m_{jj}	1.95	1.94
Quantum Black Hole for $n = 6$, M_D		
$F_\chi(m_{jj})$	4.14	4.11
11-bin χ , $m_{jj} > 2.6$ TeV	4.23	3.96
Contact interaction, Λ, destructive interference		
$F_\chi(m_{jj})$	8.2	7.6
11-bin χ , $m_{jj} > 2.6$ TeV	8.7	7.8

Summary

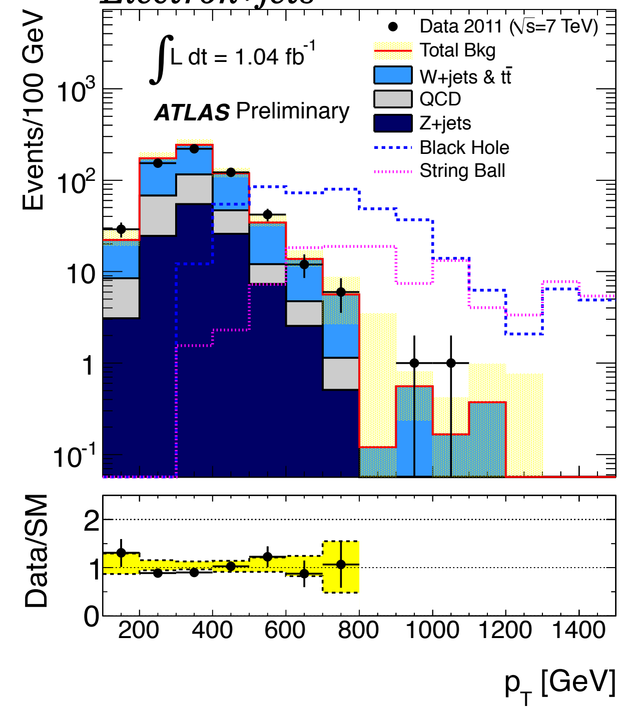
Mono jet



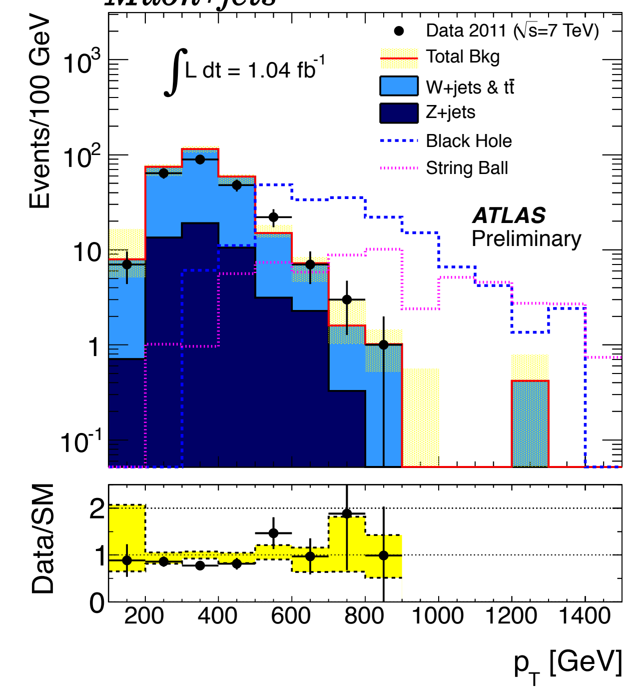
Mono jet



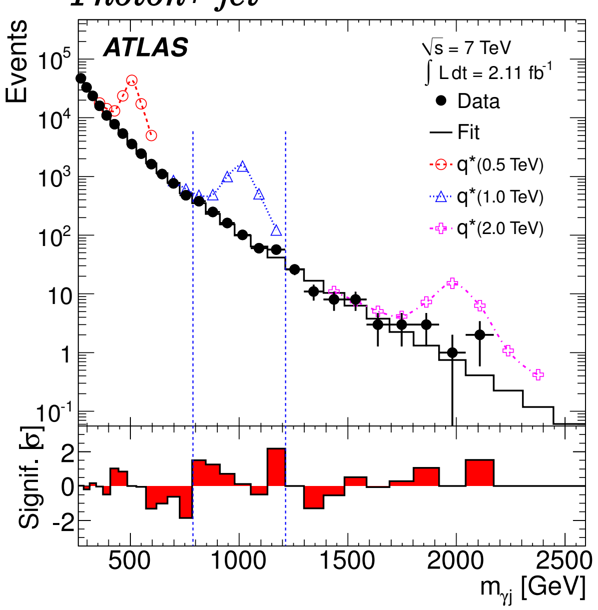
Electron+jets



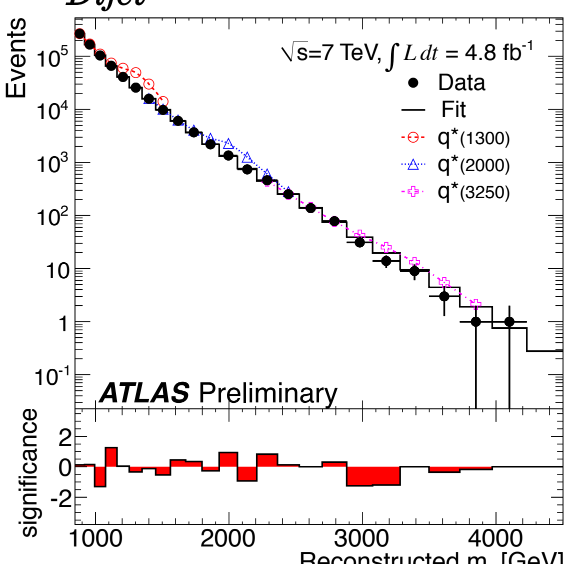
Muon+jets



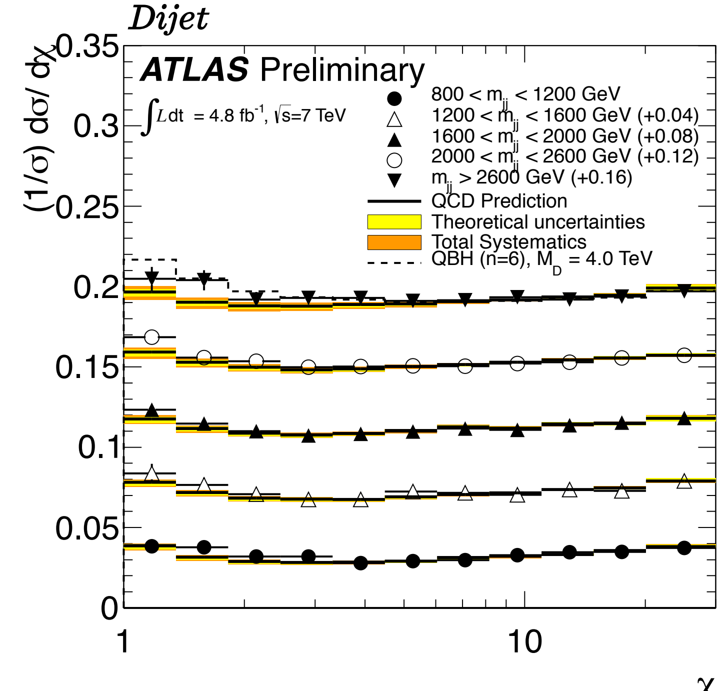
Photon+ jet



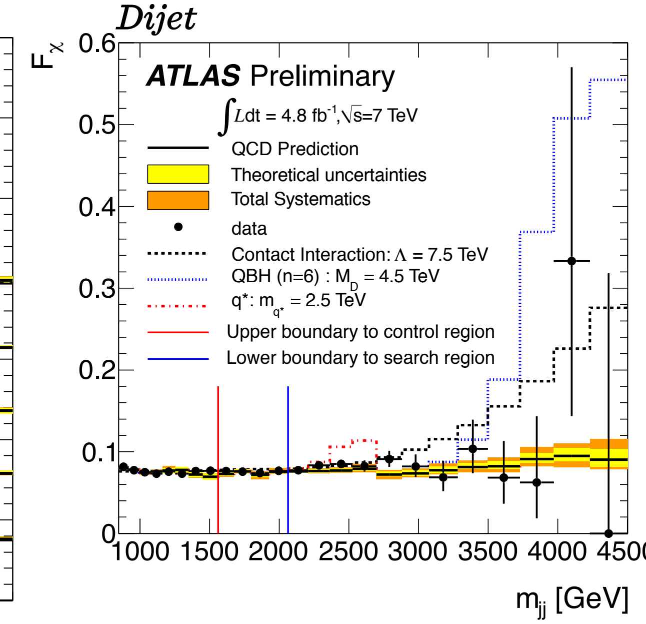
Dijet



Dijet



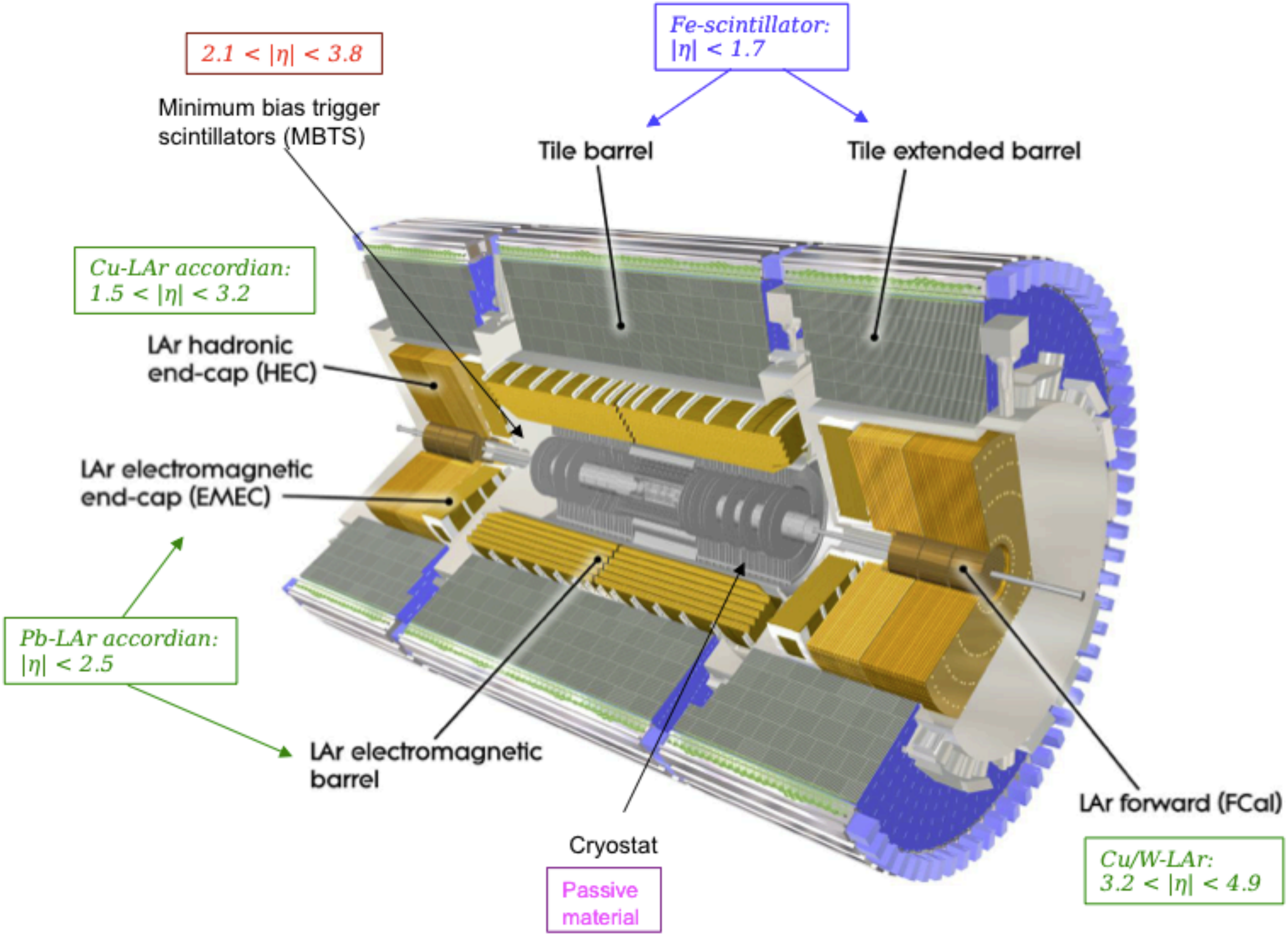
Dijet



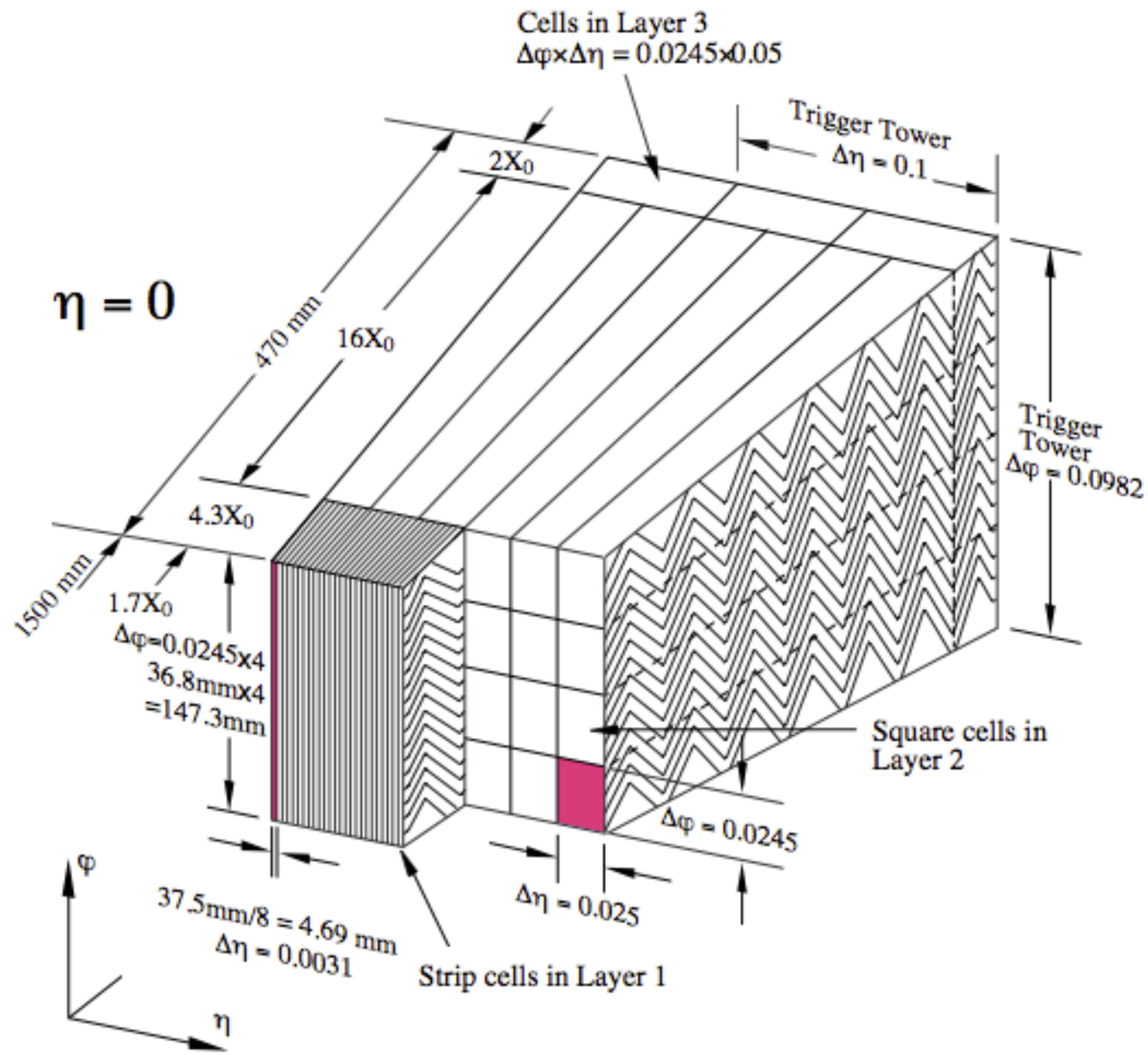
These and other results at

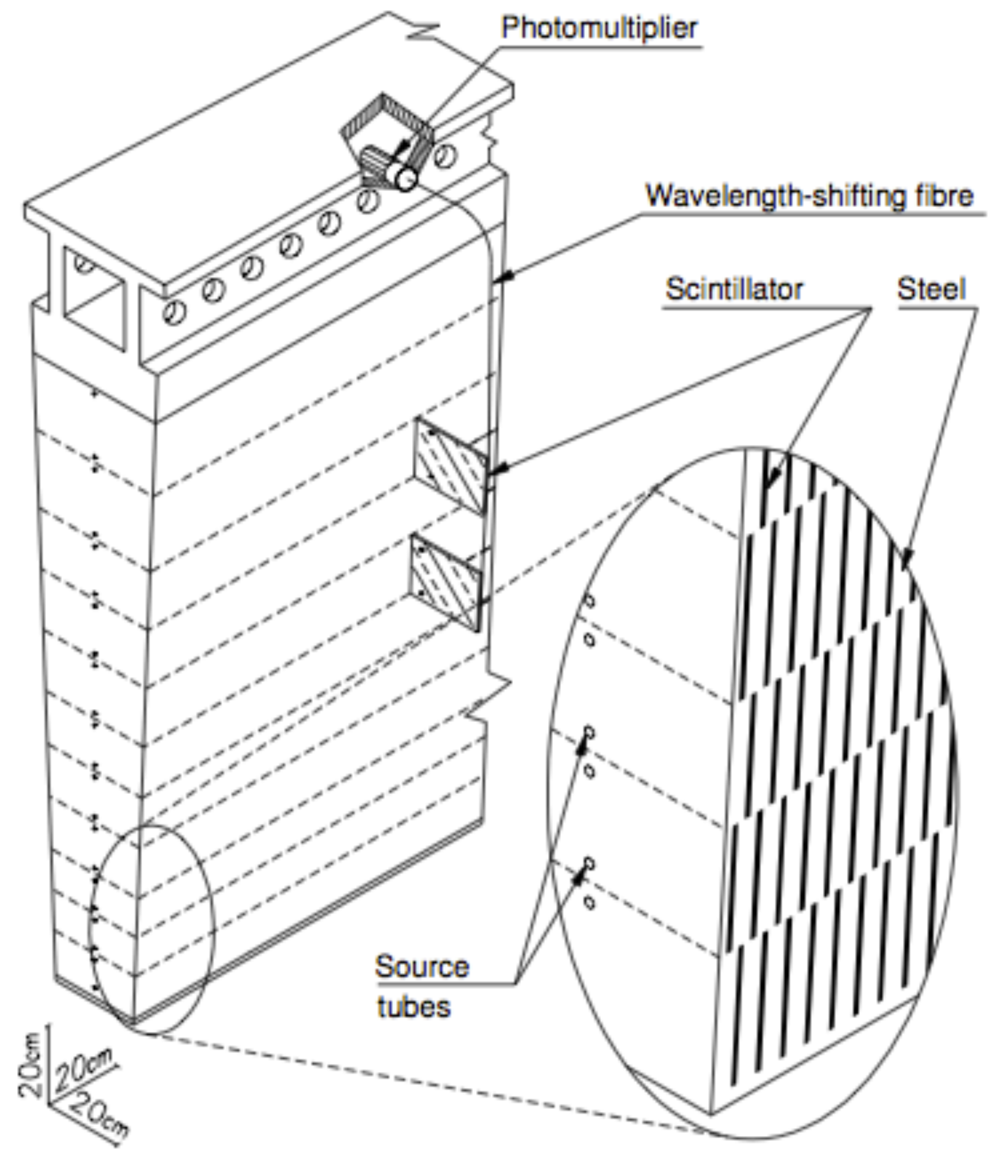
- *ATLAS Exotic Results*
- *ATLAS Public Results*

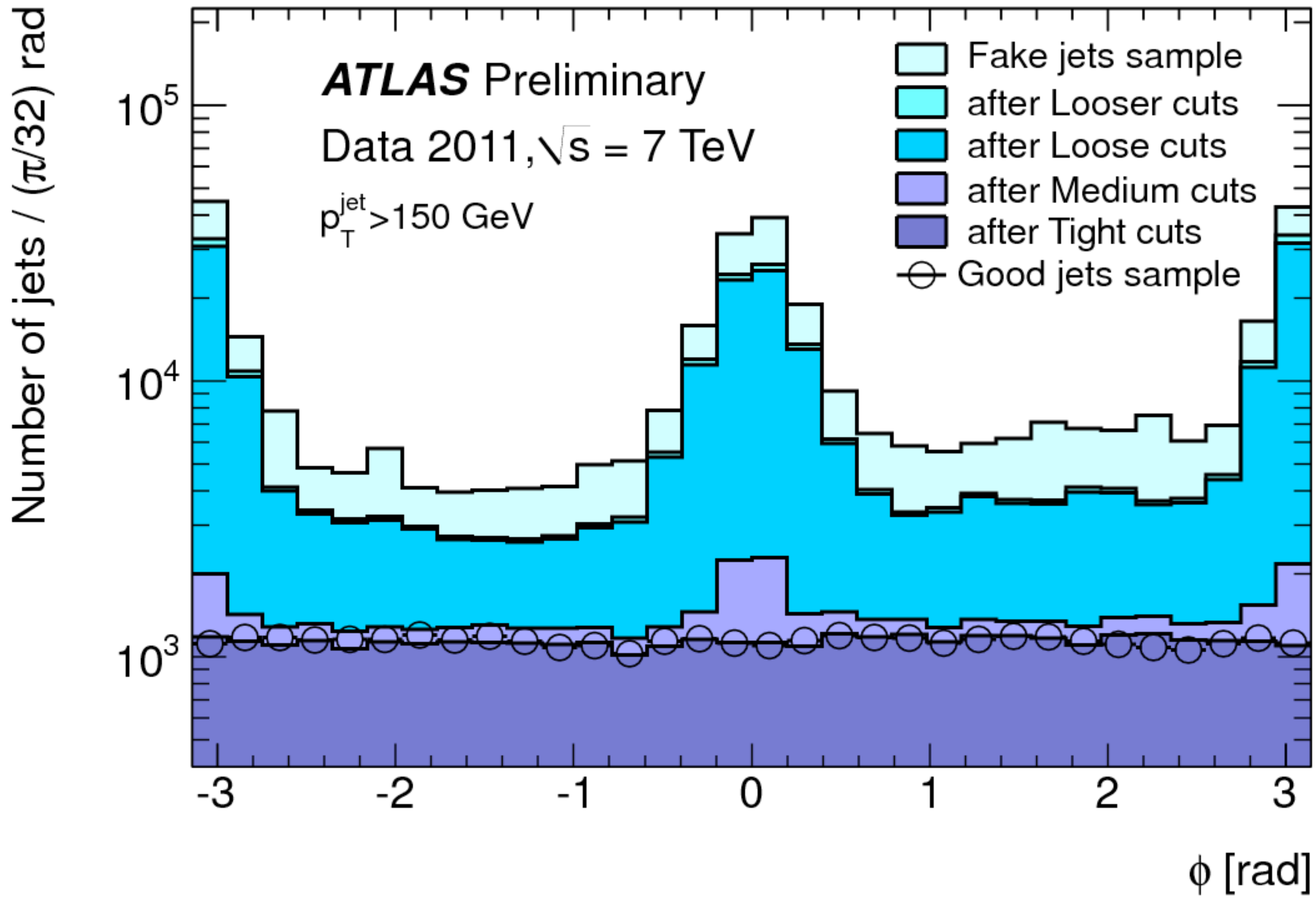
Additional Slides



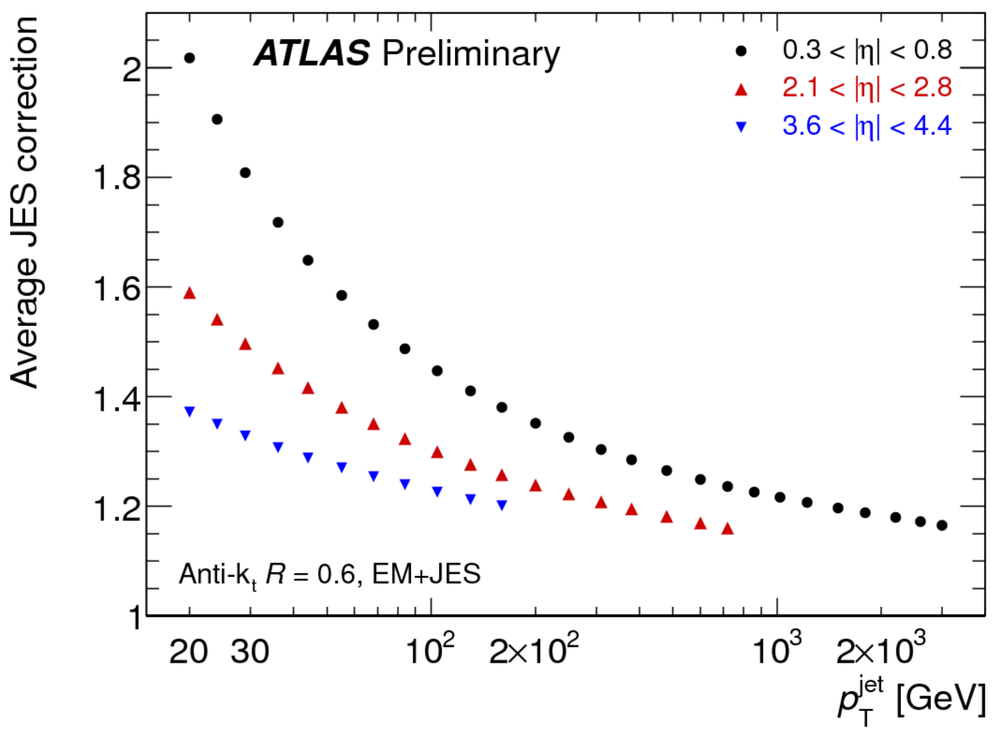
2.1 < |η| < 3.8
Minimum bias trigger scintillators (MBTS)
Fe-scintillator: |η| < 1.7
Tile barrel
Tile extended barrel
Cu-LAr accordian: 1.5 < |η| < 3.2
LAr hadronic end-cap (HEC)
LAr electromagnetic end-cap (EMEC)
Pb-LAr accordian: |η| < 2.5
LAr electromagnetic barrel
Cryostat
Passive material
LAr forward (FCal)
Cu/W-LAr: 3.2 < |η| < 4.9

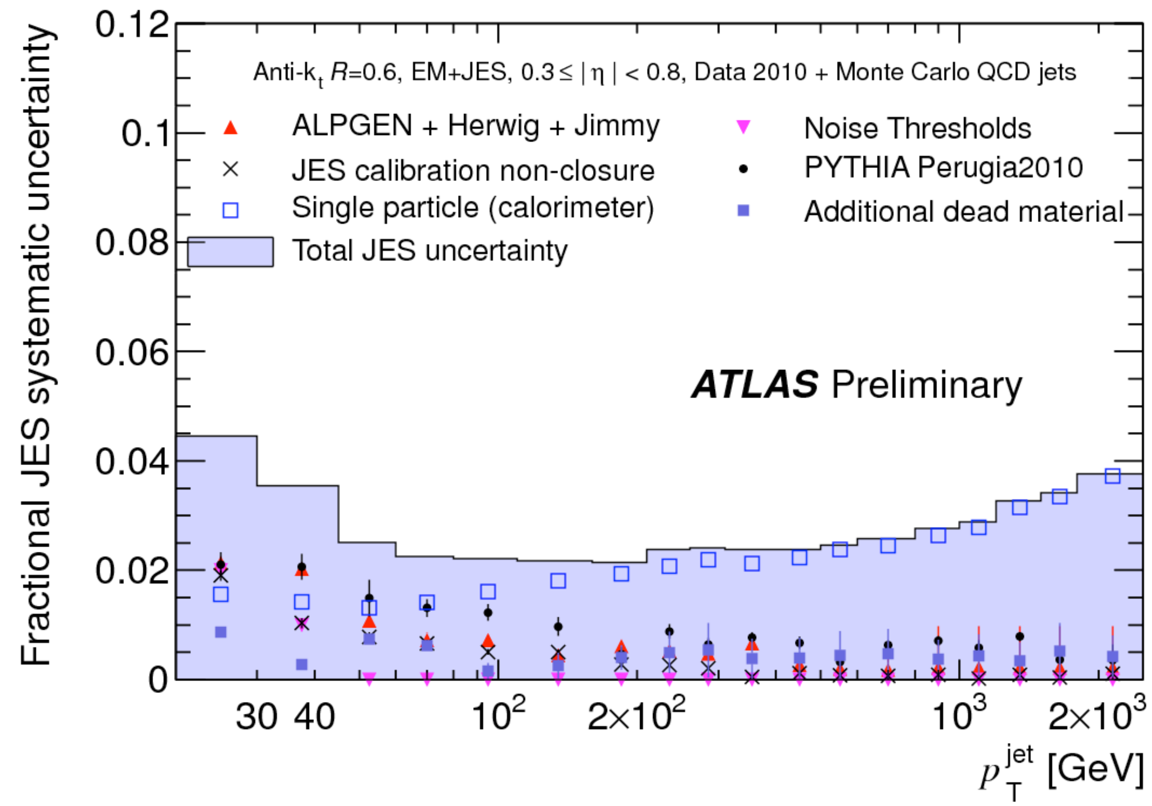

η = 0
Cells in Layer 3
Δφ×Δη = 0.0245×0.05
Trigger Tower
Δη = 0.1
2X0
470 mm
16X0
Trigger
Tower
Δφ = 0.0982
4.3X0
1500 mm
1.7X0
Δφ=0.0245x4
36.8mmx4
=147.3mm
Square cells in
Layer 2
Δφ = 0.0245
Δη = 0.025
37.5mm/8 = 4.69 mm
Δη = 0.0031
Strip cells in Layer 1
φ
η

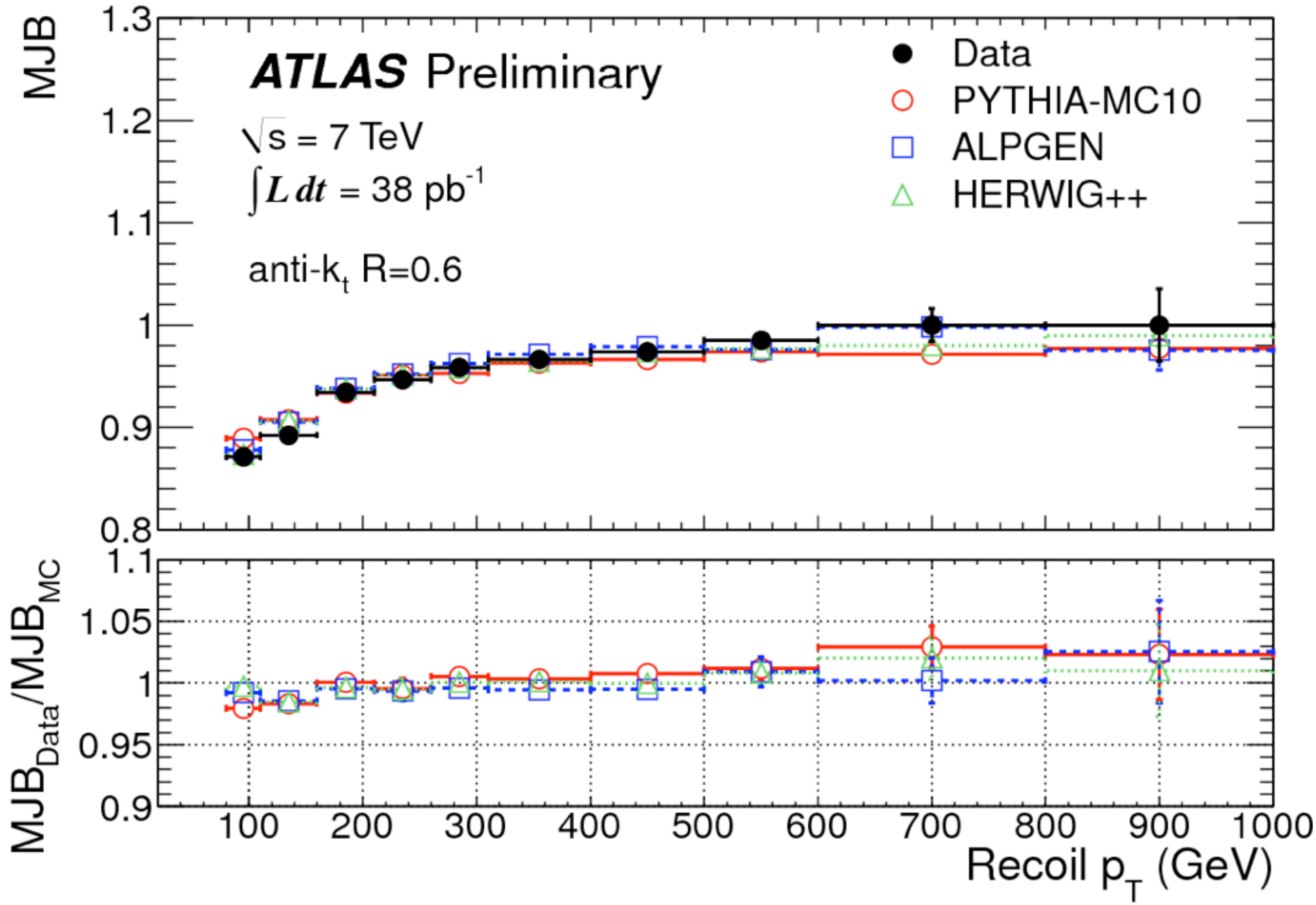

Photomultiplier
Wavelength-shifting fibre
Scintillator
Steel
Source
tubes
20cm
20cm
20cm


ATLAS Preliminary
Data 2011, √s = 7 TeV
p_T^jet >150 GeV
Fake jets sample
after Looser cuts
after Loose cuts
after Medium cuts
after Tight cuts
Good jets sample
Number of jets / (π/32) rad
10^5
10^4
10^3
-3
-2
-1
0
1
2
3
φ [rad]

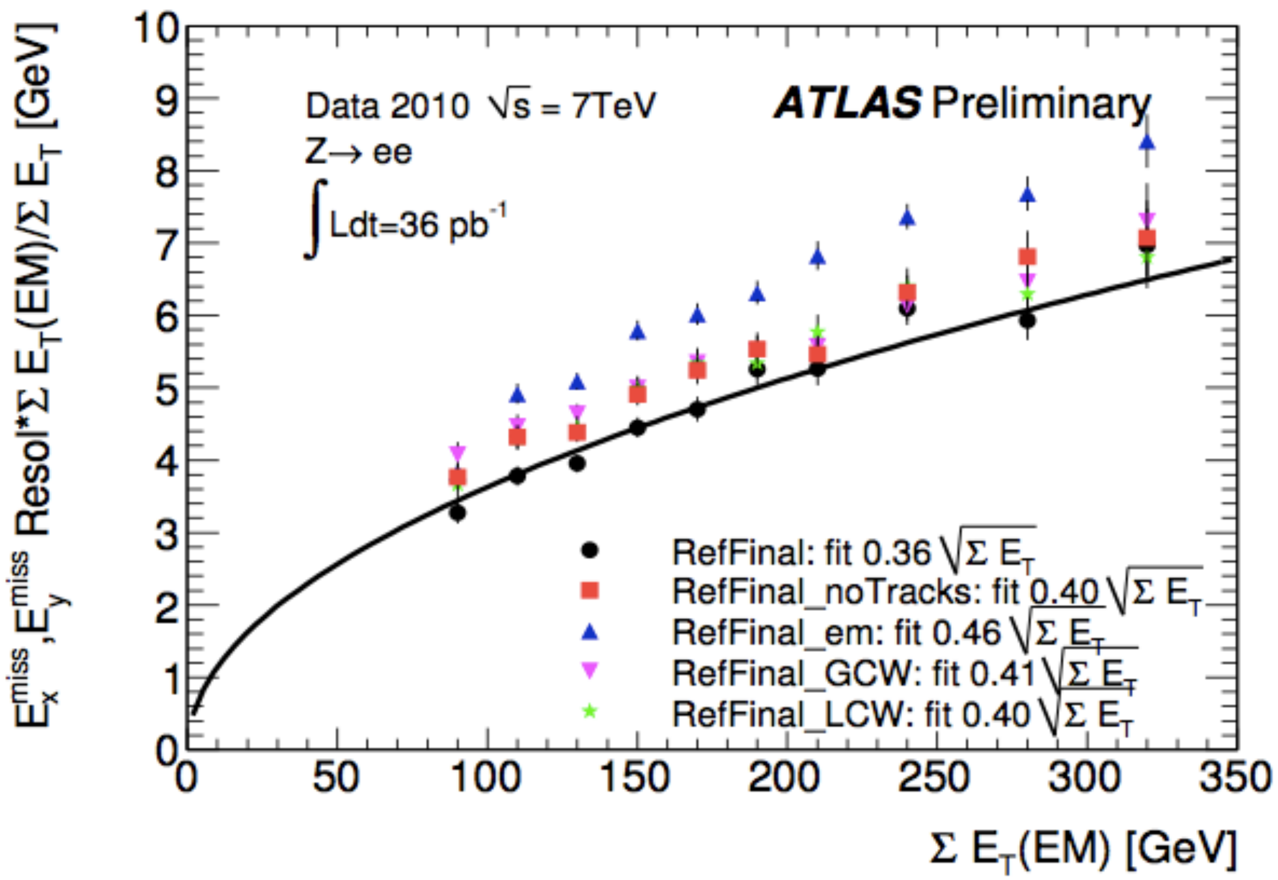
ATLAS-CONF-2011-032

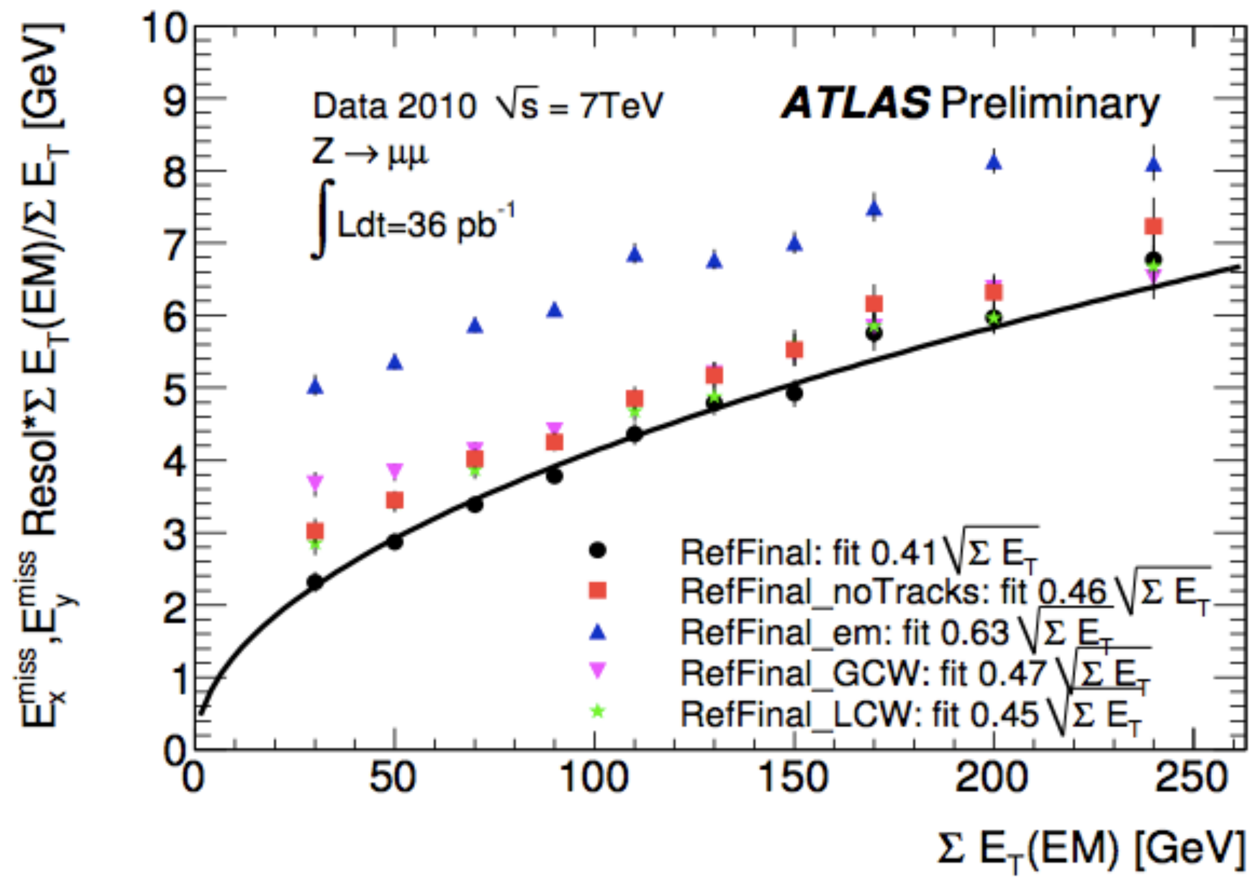


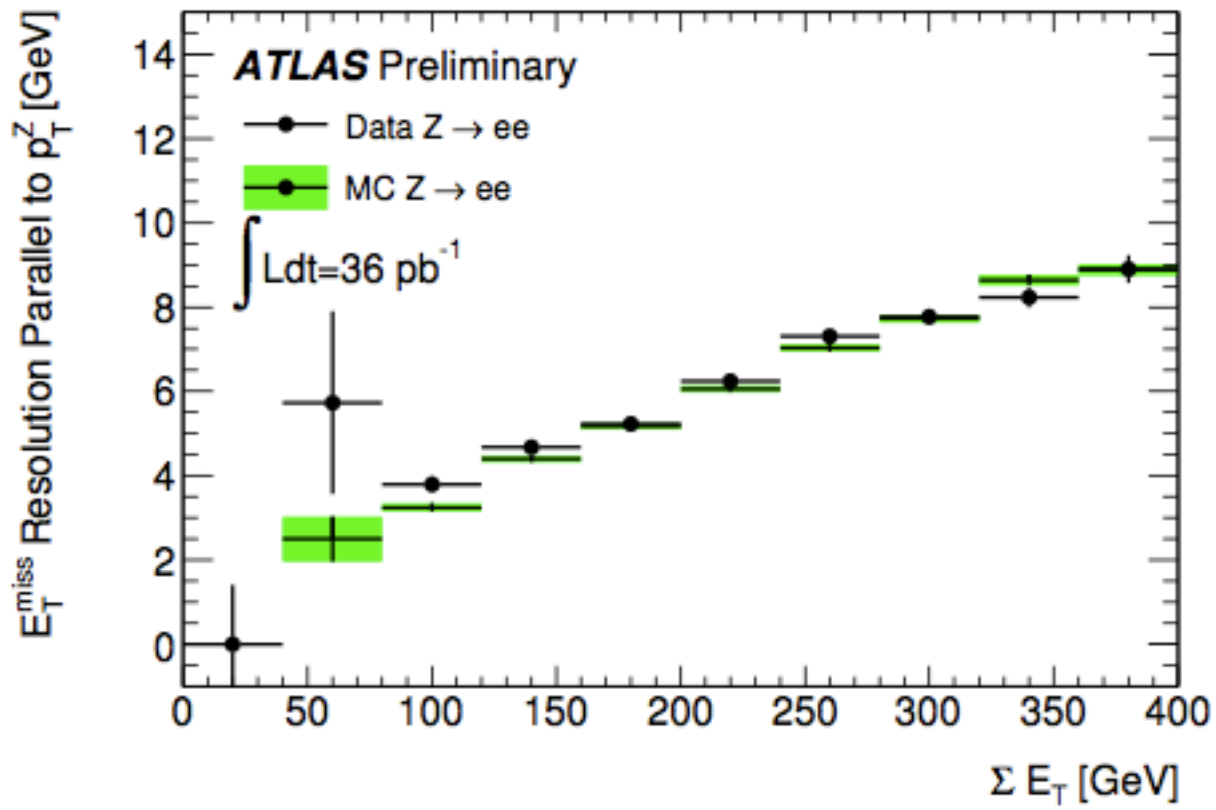


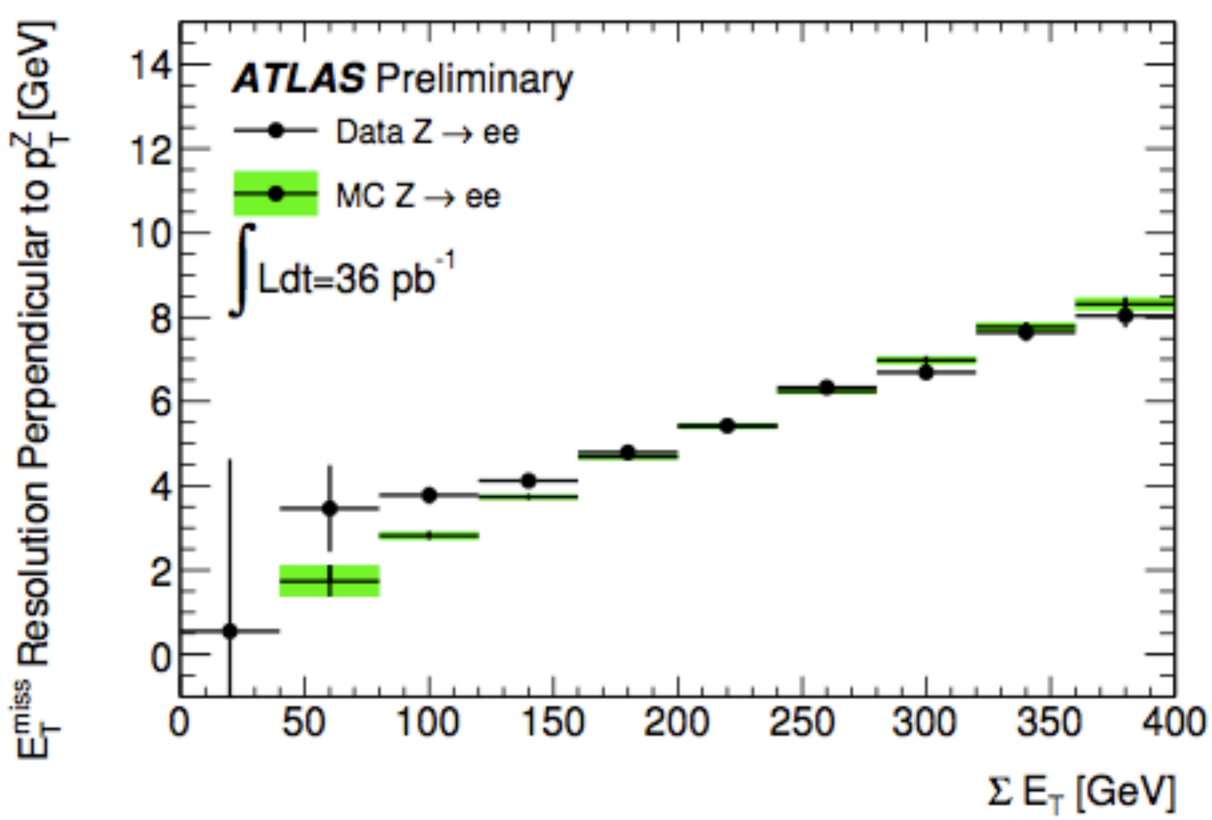


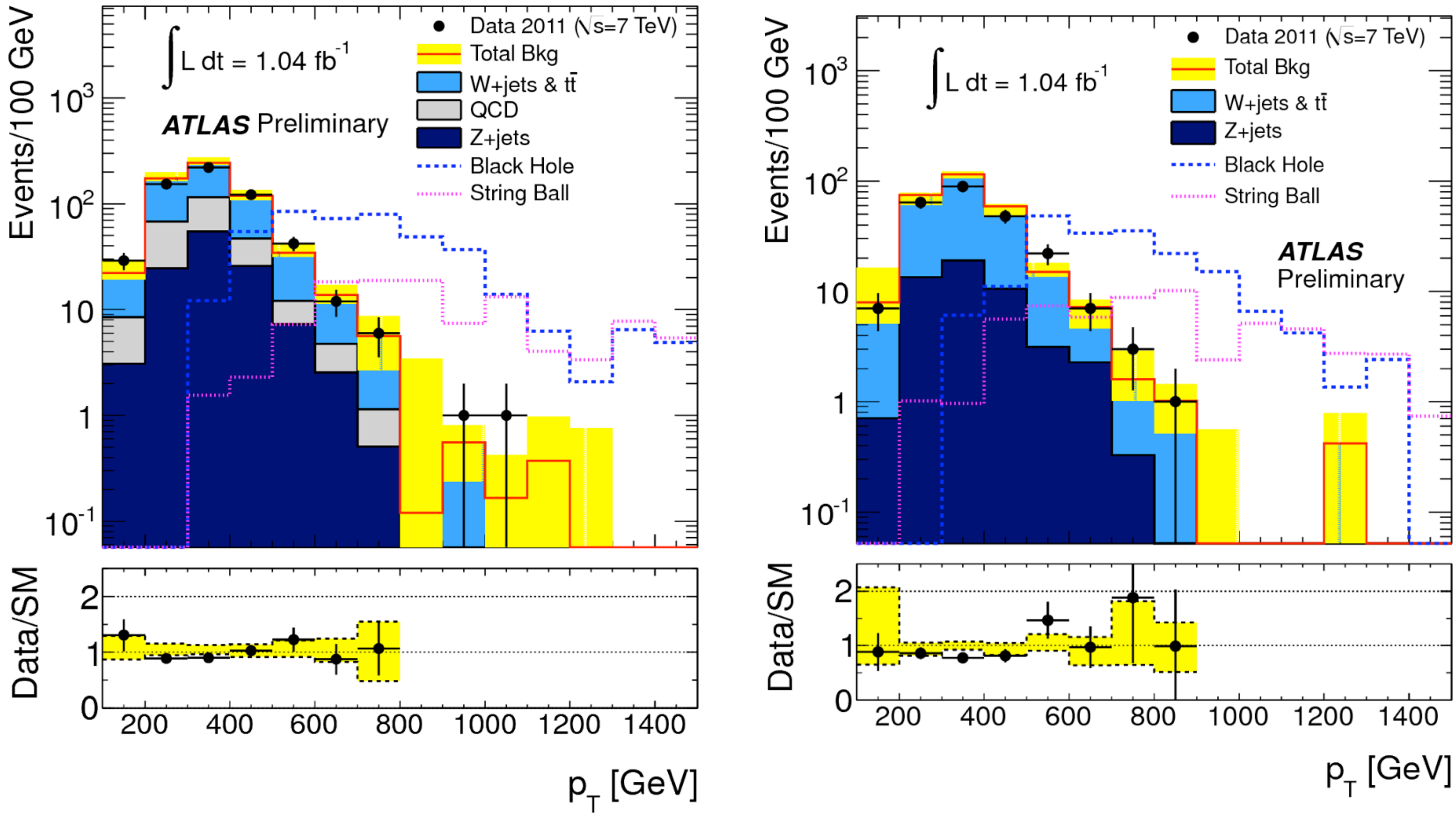
ATLAS Preliminary
√s = 7 TeV
∫L dt = 38 pb⁻¹
anti-k_t R=0.6
Data
PYTHIA-MC10
ALPGEN
HERWIG++
MJB
1.3
1.2
1.1
1
0.9
0.8
MJB_Data/MJB_MC
1.1
1.05
1
0.95
0.9
100
200
300
400
500
600
700
800
900
1000
Recoil p_T (GeV)


Data 2010 √s = 7TeV
ATLAS Preliminary
Z→ ee
∫Ldt=36 pb-1
RefFinal: fit 0.36 √Σ ET
RefFinal_noTracks: fit 0.40 √Σ ET
RefFinal_em: fit 0.46 √Σ ET
RefFinal_GCW: fit 0.41 √Σ ET
RefFinal_LCW: fit 0.40 √Σ ET
Ex miss,Ey miss Resol*Σ ET(EM)/Σ ET [GeV]
Σ ET(EM) [GeV]


Data 2010 √s = 7TeV
ATLAS Preliminary
Z → μμ
∫Ldt=36 pb-1
RefFinal: fit 0.41 √Σ ET
RefFinal_noTracks: fit 0.46 √Σ ET
RefFinal_em: fit 0.63 √Σ ET
RefFinal_GCW: fit 0.47 √Σ ET
RefFinal_LCW: fit 0.45 √Σ ET
Ex miss,Ey miss Resol*Σ ET(EM)/Σ ET [GeV]
Σ ET(EM) [GeV]


ATLAS Preliminary
Data Z → ee
MC Z → ee
∫Ldt=36 pb^-1
E_T^miss Resolution Parallel to p_T^Z [GeV]
Σ E_T [GeV]


ATLAS Preliminary
Data Z → ee
MC Z → ee
∫Ldt=36 pb^-1
E_T^miss Resolution Perpendicular to p_T^Z [GeV]
Σ E_T [GeV]



Data 2011 (√s=7 TeV)
Total Bkg
W+jets & tt̄
QCD
Z+jets
Black Hole
String Ball
∫L dt = 1.04 fb⁻¹
ATLAS Preliminary
Events/100 GeV
Data/SM
p_T [GeV]

95% CL limits on M_D for the ADD model						
	LowPt selection		HighPt selection		veryHighPt selection	
n	expected [TeV]	observed [TeV]	expected [TeV]	observed [TeV]	expected [TeV]	observed [TeV]
2	2.38	2.21	2.98	3.16	3.04	3.39
3	1.94	1.82	2.44	2.56	2.48	2.71
4	1.73	1.64	2.18	2.27	2.25	2.42
5	1.63	1.55	2.03	2.10	2.12	2.26
6	1.55	1.47	1.92	1.99	1.98	2.12

Table 2: Expected and observed 95% lower limits on M_D as a function of the number of extra dimensions in the ADD model for the LowPt, HighPt, and veryHighPt selections.

95% CL limits on M_D for the ADD model ($\hat{s} < M_D^2$)			
	LowPt selection	HighPt selection	veryHighPt selection
n	observed [TeV]	observed [TeV]	observed [TeV]
2	2.20	3.16	3.39
3	1.76	2.50	2.55
4	1.54	2.15	2.26
5	1.37	1.89	1.90
6	1.24	1.68	1.58

Table 3: Observed 95% lower limits on M_D as a function of the number of extra dimensions in the ADD model for the LowPt, HighPt and veryHighPt selections using truncated ($\hat{s} < M_D^2$) cross sections.

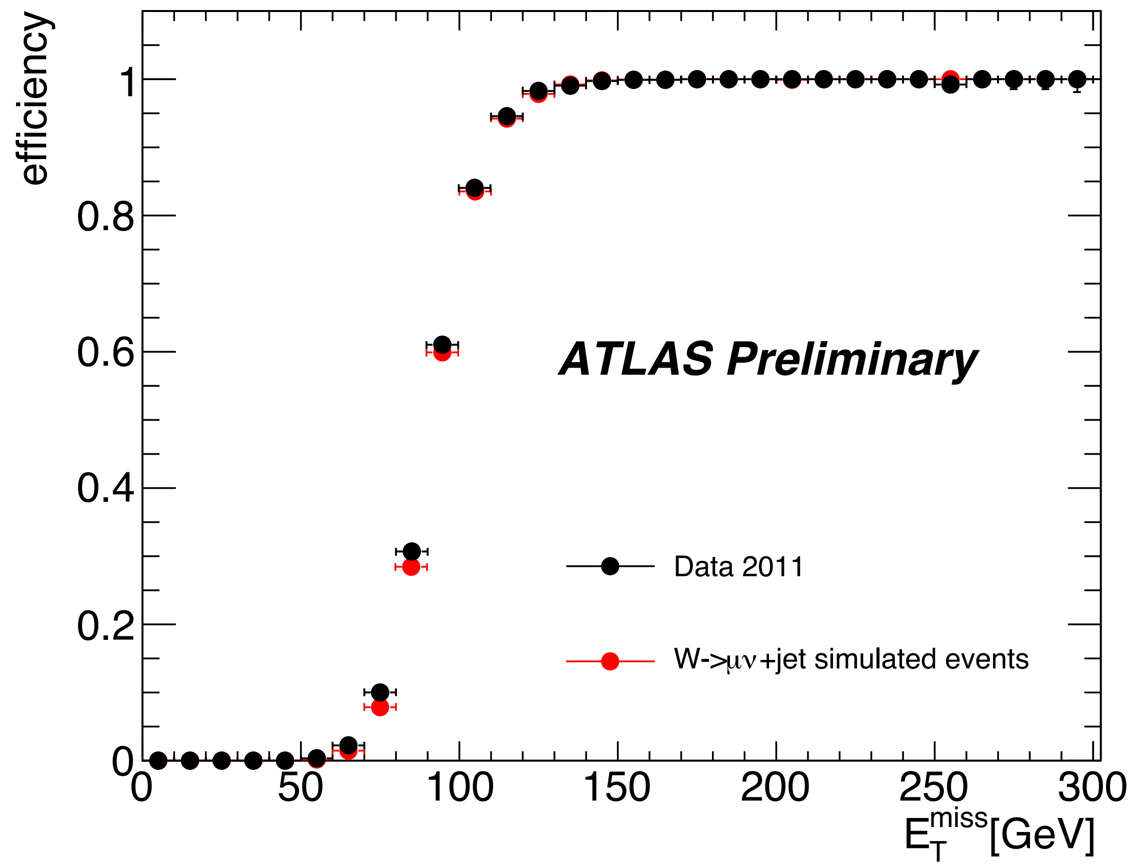


Figure 1: Trigger efficiency curve as a function of the reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ as determined from the data using an unbiased data sample with muons in the final state (black dots). The data are compared to the predictions from a $W(\rightarrow \mu\nu)$+jets MC sample.

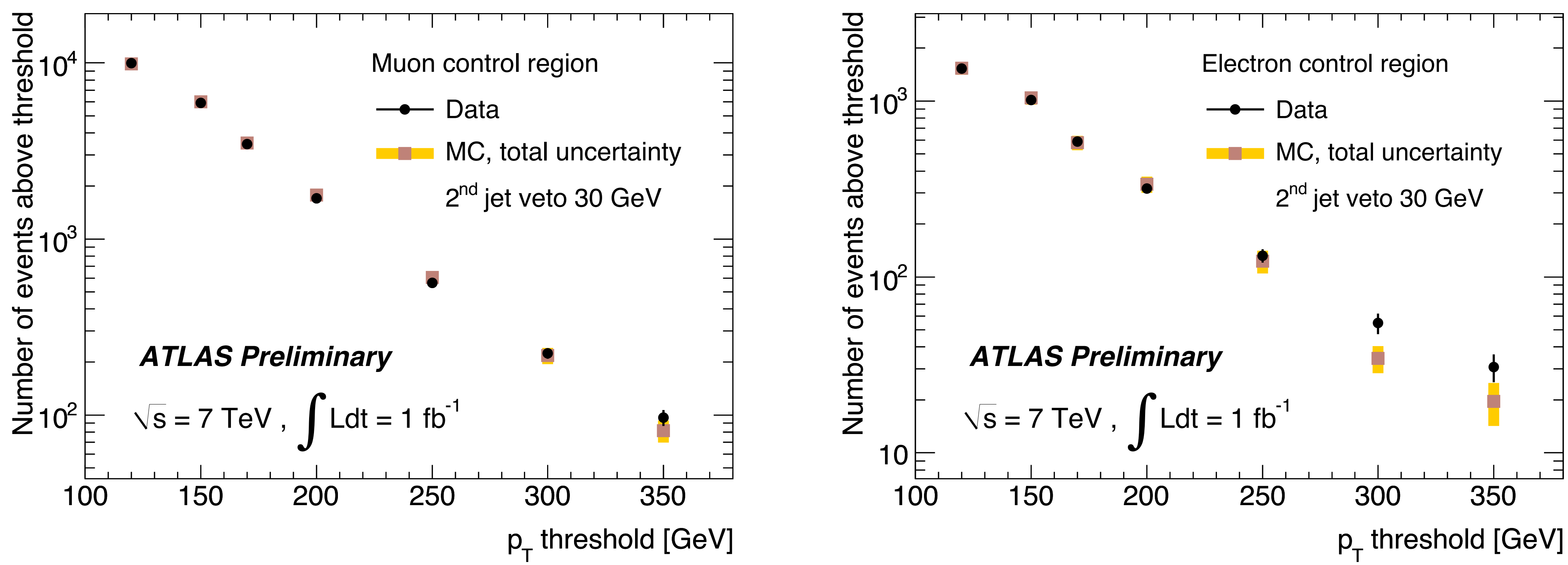


Figure 2: Observed number of events (black circles) in the muon and electron control samples compared to the sum of the different W/Z plus jets predictions (squares) as a function of the highest jet p_T threshold, in events with no second-leading jet with $p_T > 30$ GeV. The MC prediction includes the normalization factors determined in the LowPt region, and the band indicates the total systematic uncertainty.

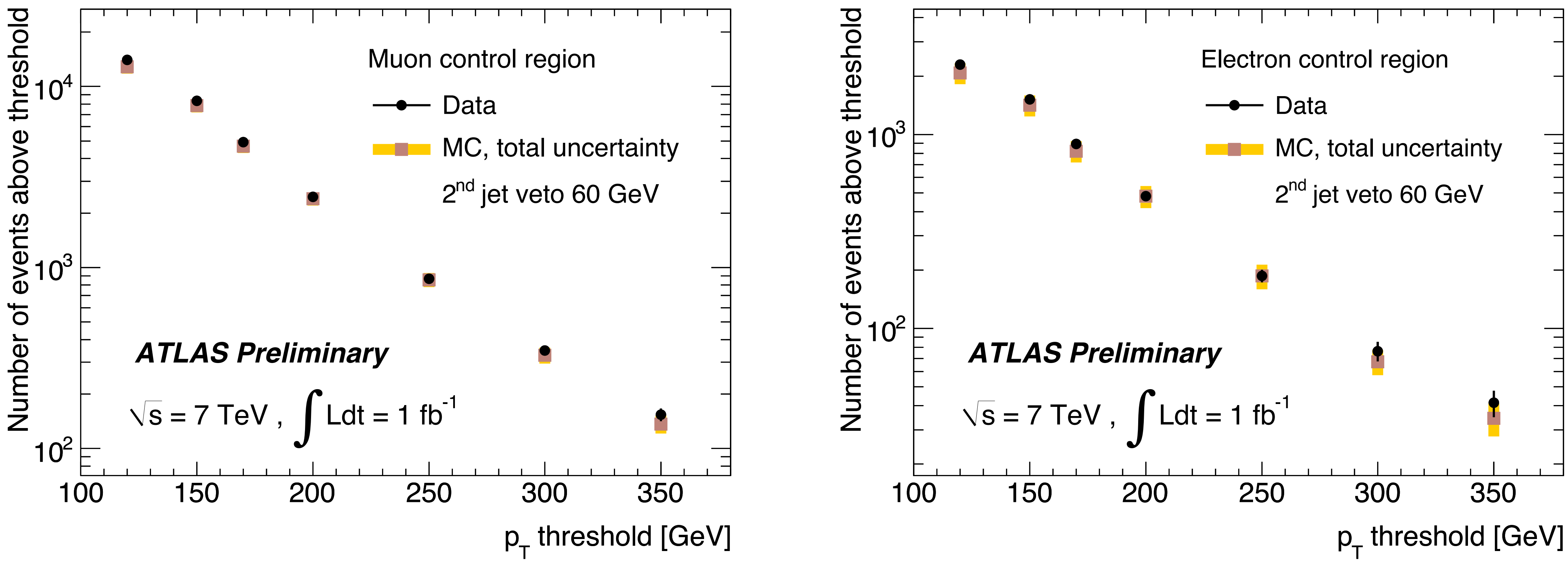


Figure 3: Observed number of events (black circles) in the muon and electron control samples compared to the sum of the different W/Z plus jets predictions (squares) as a function of the highest jet $p_{\rm T}$ threshold, in events with no second-leading jet with $p_{\rm T} > 60$ GeV. The MC prediction includes the normalization factors determined from the average of those extracted in the HighPt and veryHighPt regions, and the band indicates the total systematic uncertainty.

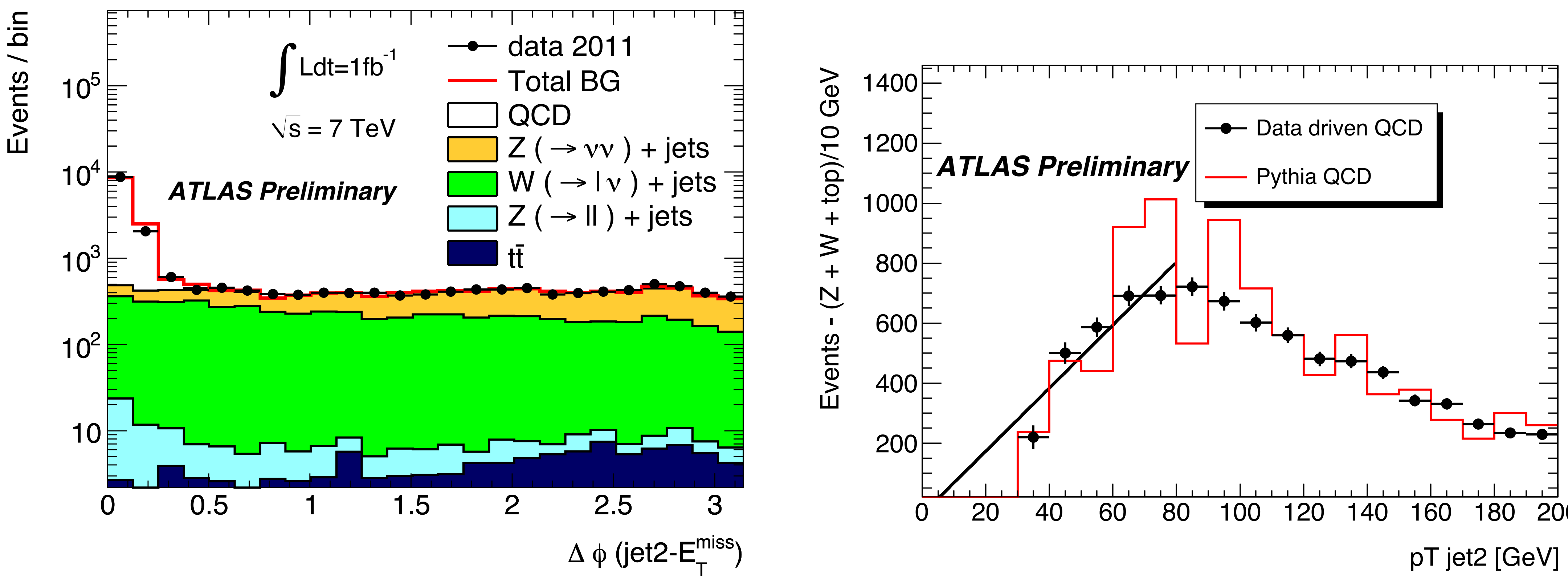


Figure 4: (left) Measured $\Delta\phi(jet2 - E_{\mathrm{T}}^{\mathrm{miss}})$ distribution in the LowPt selection with no veto on the second leading jet p_{T} applied. The data are compared to the SM predictions, as determined by the MC simulation. The QCD jets prediction is determined from PYTHIA and includes a normalization factor 0.94 ± 0.04 that brings the prediction close to the data in the region $\Delta\phi(jet2 - E_{\mathrm{T}}^{\mathrm{miss}}) < 0.5$. The W/Z plus jets MC predictions contain the normalization factors extracted from the electron and muon control samples, as explained in the body of the text. (right) Measured p_{T} distribution of the second leading jet in the LowPt region before the veto is applied and after requiring $\Delta\phi(jet2 - E_{\mathrm{T}}^{\mathrm{miss}}) < 0.5$. The data are compared to QCD jets prediction from PYTHIA. The solid line shows a linear fit to the turn-on part of the measured p_{T} distribution (see text).

Table 1: Comparing χ distributions to QCD predictions. The header symbols in the first line of the table stand for "log-likelihood" (LL), and "BUMPHUNTER" (BH). The second line labels the "p-value" (p-val), the "most discrepant region" (Discrep), the "p-value with statistical uncertainties only" (Stats-only), the "p-value with systematic uncertainties included" (Stats+syst) and the "p-value with the look-elsewhere effect included" (+LEE).

m_{jj} bin GeV	LL p-val	BH Discrep	BH Stat-only	BH Stat+syst	BH +LEE
800-1200	0.25	bin 1-4	0.00034	0.030	0.091 (1.3σ)
1200-1600	0.71	bin 1-7	0.016	0.098	0.21 (0.8σ)
1600-2000	0.44	bin 1-3	1.7E-6	0.070	0.28 (0.6σ)
2000-2600	0.21	bin 1-5	1.0E-8	0.094	0.15 (1.1σ)
2600-7000	0.36	bin 1-5	0.00081	0.049	0.12 (1.2σ)