# Searches for new physics in Monojet and Dijet final states with ATLAS

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  - Introduction
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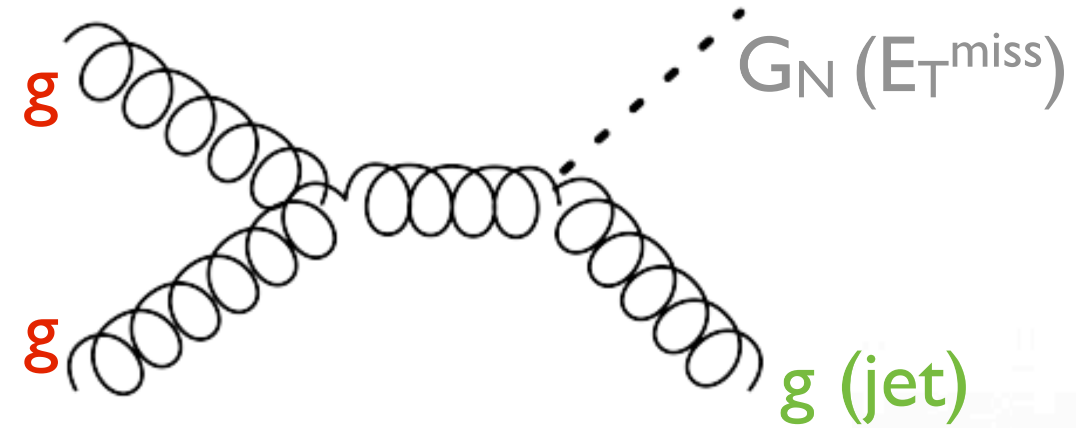
# Introduction : Monojet

✳ Monojet + $E_T^{miss}$ is a promising signature for several BSM scenarios




✳ Extra dimensions:
- provides insight into the hierarchy problem
- compactified on a small radius R (eg. ADD,UXD)

✳ ADD paradigm [N.Arkani-Hamed,S.Dimopoulos, and G.R Dvali , Phys.Lett. **B429**,(1998)263]
- Fundamental scale can be (much) lower than the Planck scale

✳ Planck mass($M_{pl}$) in (3+1)D related to the fundamental mass $M_D$ in 4+d:

$$\boxed{M_{pl}^2 \sim M_D^{2+d} R^d}$$

✳ Signature: Graviton ($G_N$) - $E_T^{miss}$ + jet production
Signal sample : PYTHIA ExoGraviton with CTEQ6.6 PDF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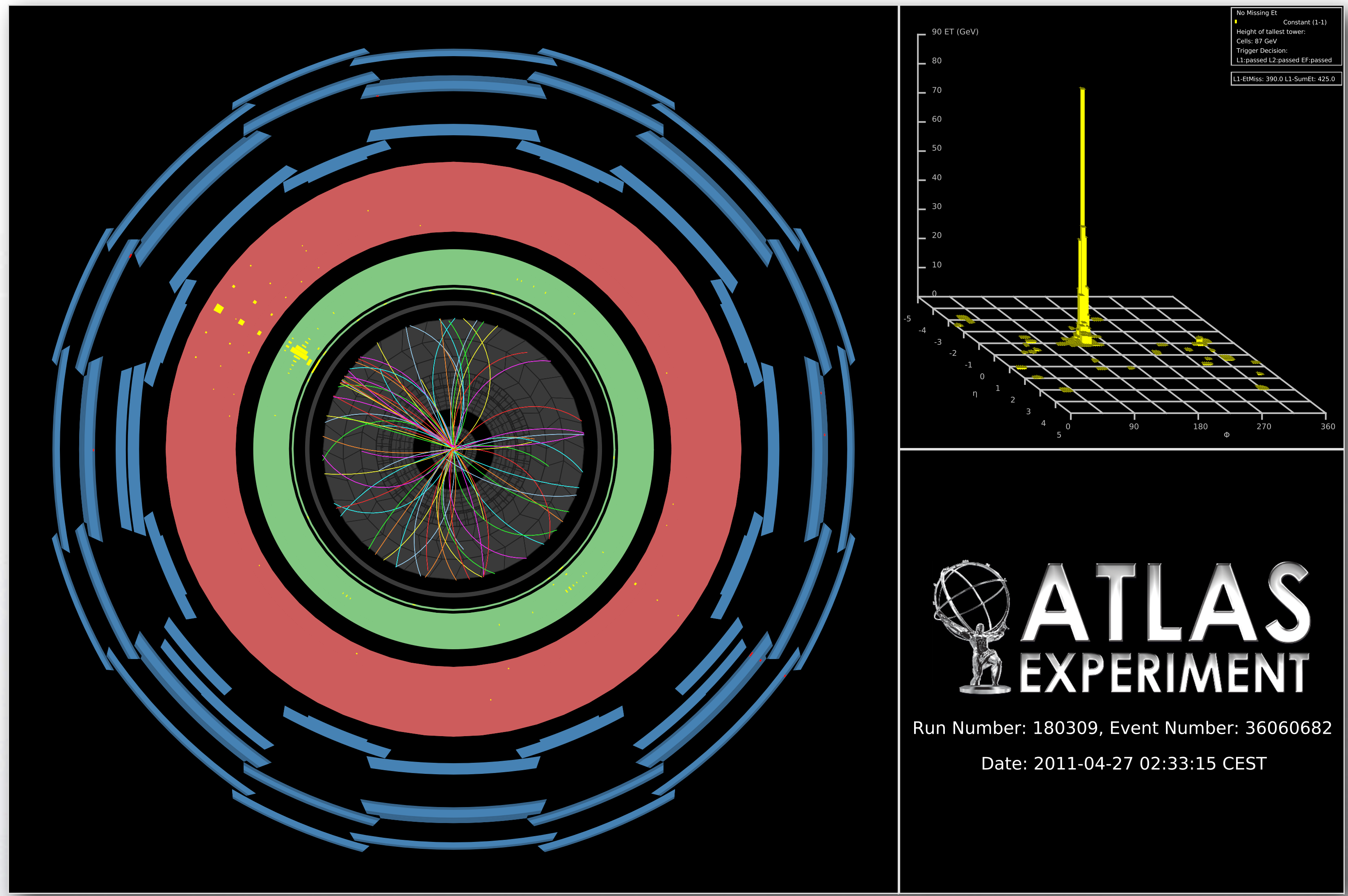
# Part 1: Monojet

*" a typical Monojet event recorded by ATLAS"*

✳ leading jet:
$p_T$ = 602 GeV
$\eta$ = -1; $\Phi$ = 2.6

✳ $E_T^{miss}$ = 523 GeV

✳ no additional jet with $p_T$ > 30 GeV



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# Monojet : Event Selection

- ✴ Lowest threshold unprescaled $E_T^{miss}$ trigger
- ✴ 1 primary vertex with more than 2 tracks
- ✴ Cleaning cut: reject detector noise
- ✴ Lepton veto (electron: $p_T > 20$ GeV, muon: $p_T > 10$ GeV)
- ✴ 3 sets of cuts defining 3 kinematic signal regions

| Region | $E_T^{miss}$ | 1st jet | 2nd jet | $\Delta\Phi$(2nd jet, $E_T^{miss}$) |
|---|---|---|---|---|
| low $p_T$ | > 120 GeV | > 120 GeV | < 30 GeV | ---- |
| high $p_T$ | > 220 GeV | > 250 GeV | < 60 GeV | > 0.5 |
| very high $p_T$ | > 300 GeV | > 350 GeV | < 60 GeV | > 0.5 |

1fb$^{-1}$ (±3.7%) of 2011 data is analysed



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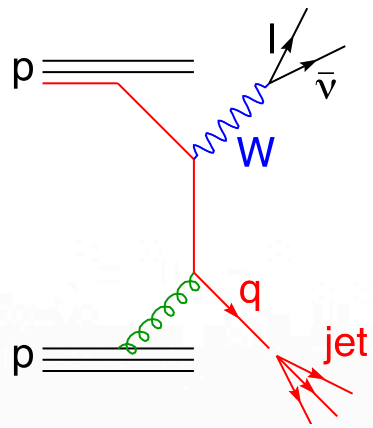
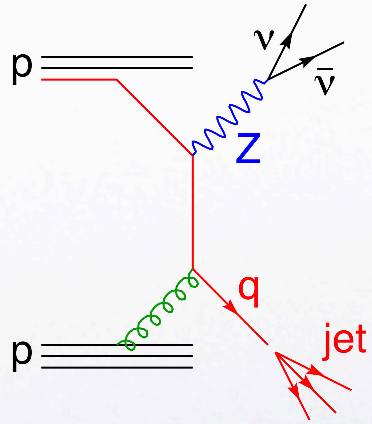
# Monojet : EW background estimation - I

✷ Z/W+ jets constitute the dominant contribution to the background.

1. W->lν+ jet -> misidentification of leptons.




2. Z-> νν + jet is irreducible. Same signature as the signal.




✷ Estimated using ALPGEN MC (NNLO cross sections) and rescaled using data control samples



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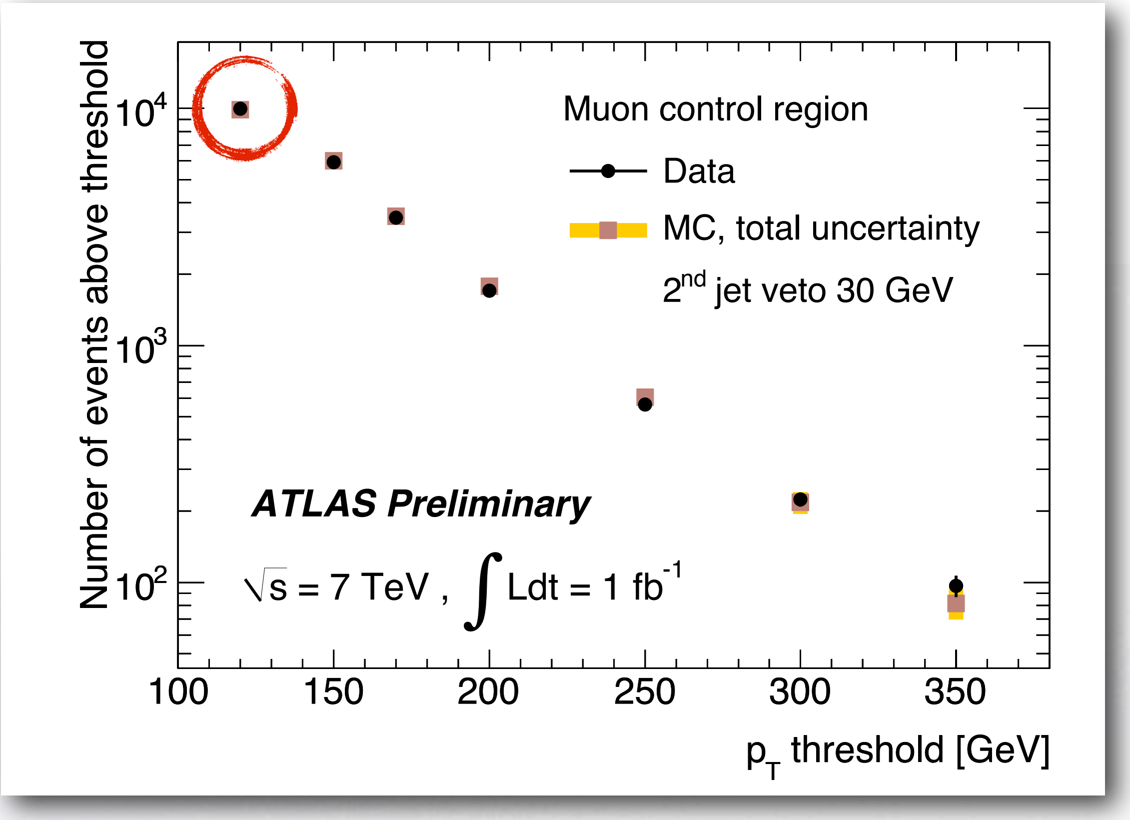
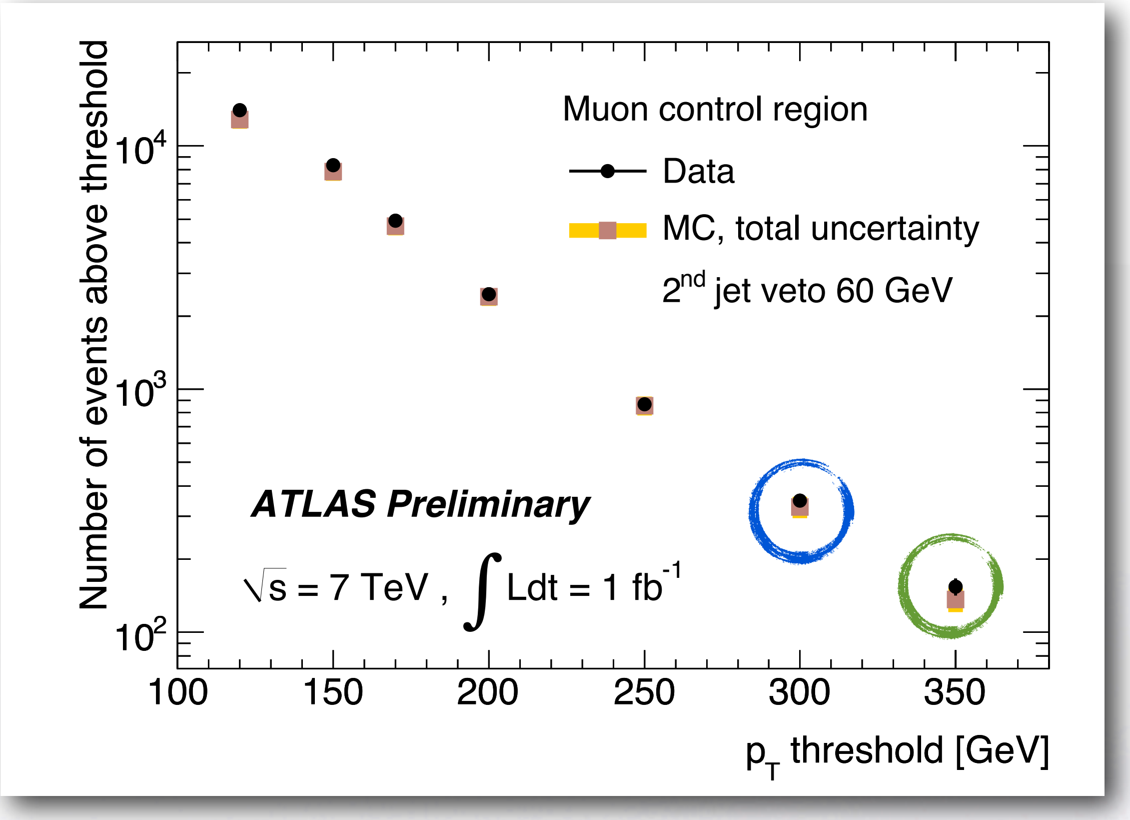
# Monojet : EW background estimation - II

Determined by inverting the lepton veto to define a control region and scale the simulation in the CR to data.




| Scale Factor | low $p_T$ | high $p_T$ | very high $p_T$ |
|---|---|---|---|
| muon control region | 0.95 ± 0.02 | 0.87 ± 0.05 | 0.97 ± 0.11 |
| electron control region | 0.90 ± 0.04 | 0.81 ± .009 | 0.98 ± 0.21 |



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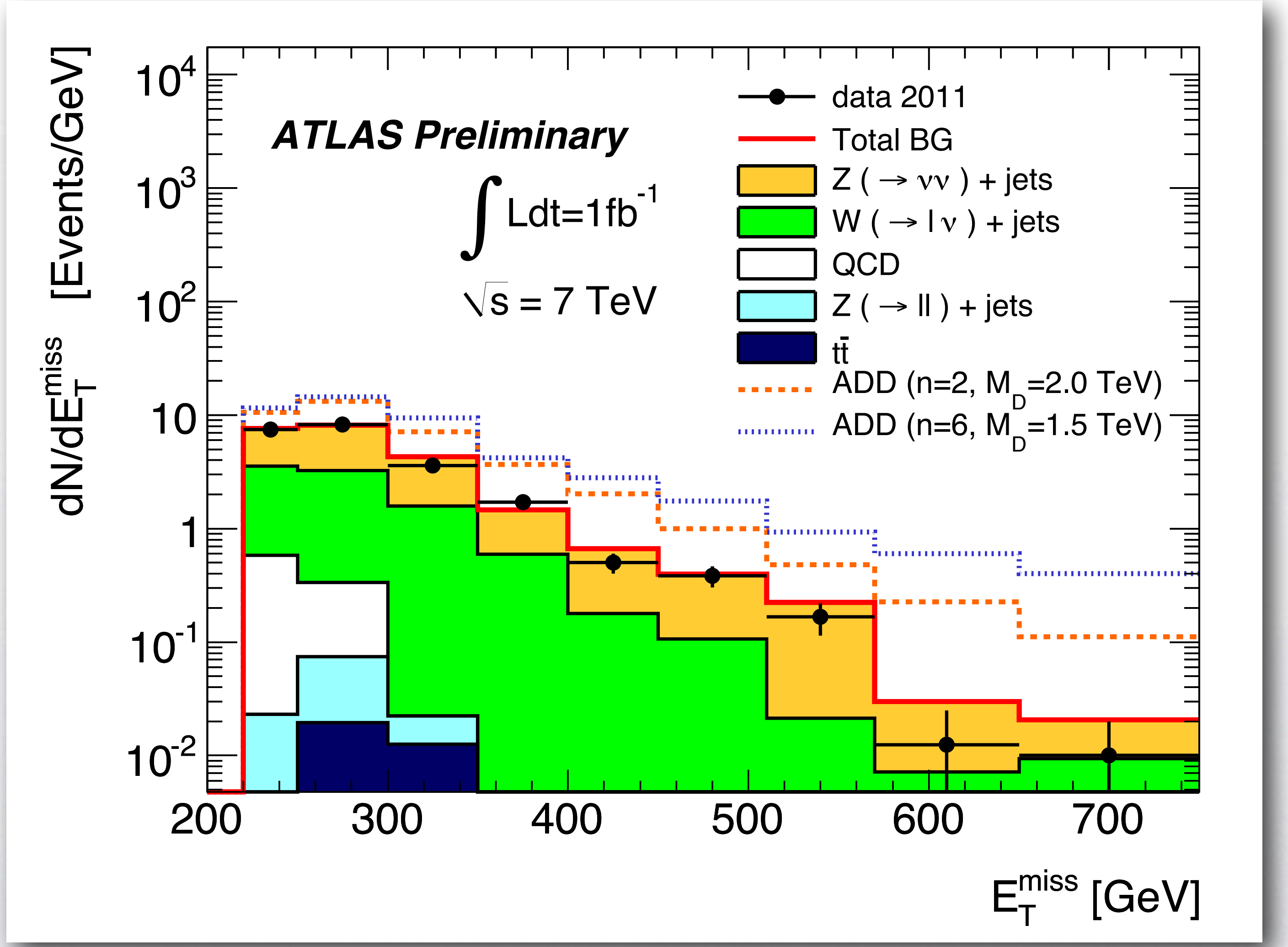
# Monojet : Results

| | low $p_T$ | high $p_T$ | very high $p_T$ |
|---|---|---|---|
| Total background ± (stat) ± (syst.) | 15100 ± 170 ± 680 | 1010 ± 37 ± 65 | 193 ± 15 ± 20 |
| Events in Data ($1 fb^{-1}$) | 15740 | 965 | 167 |



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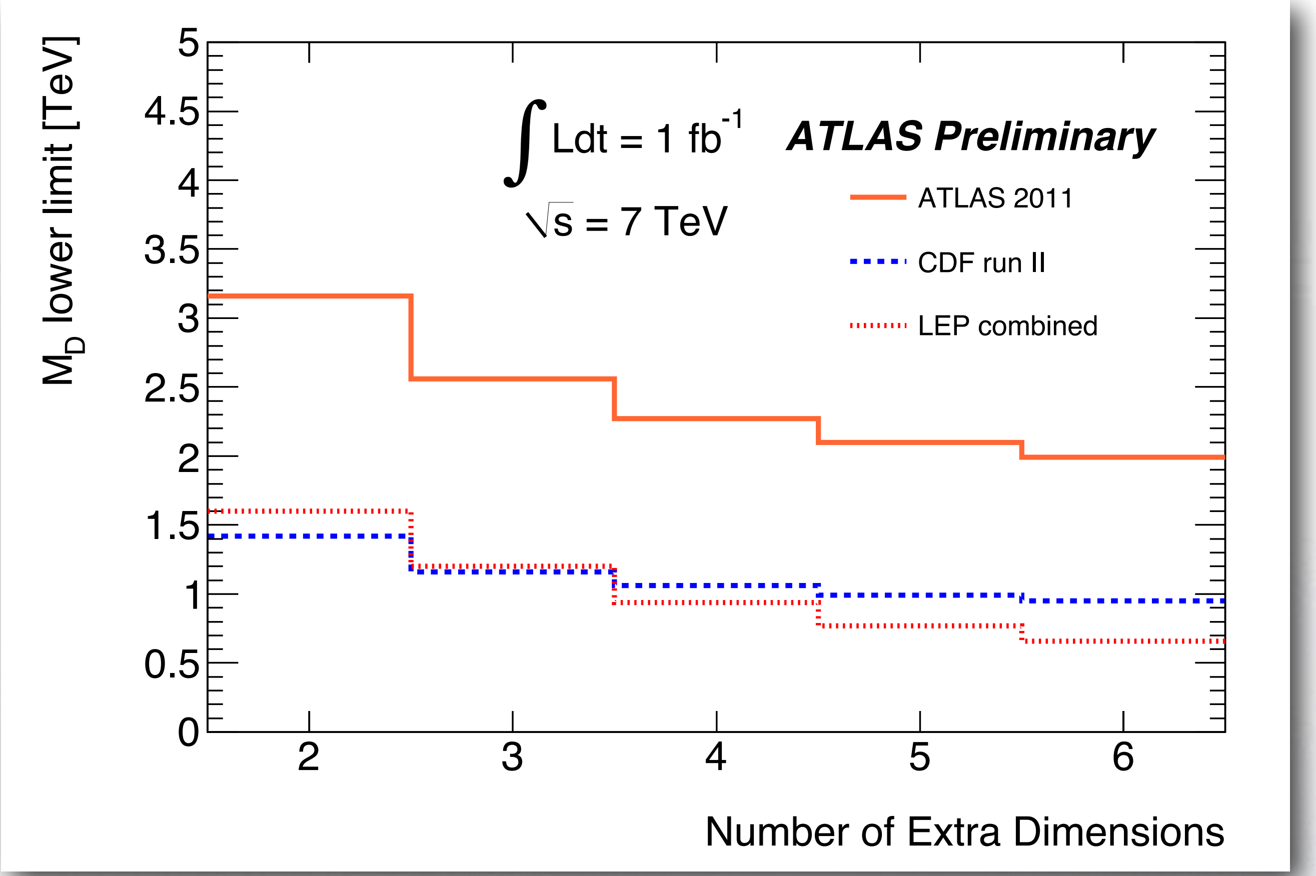
# Monojet : ADD Exclusion limits

- high $p_T$ region used to set limits
- Limits set on $\sigma \times A$ (acceptance)
- Acceptance includes all reconstruction, trigger and selection cuts
- Interpreted in terms of $M_D$

| 95% CL limits on $M_D$ for the ADD model | | |
|---|---|---|
| High $p_T$ selection | | |
| no. of extra dim | expected [TeV] | observed [TeV] |
| 2 | 2.98 | 3.16 |
| 3 | 2.44 | 2.56 |
| 4 | 2.18 | 2.27 |
| 5 | 2.03 | 2.10 |
| 6 | 1.92 | 1.99 |



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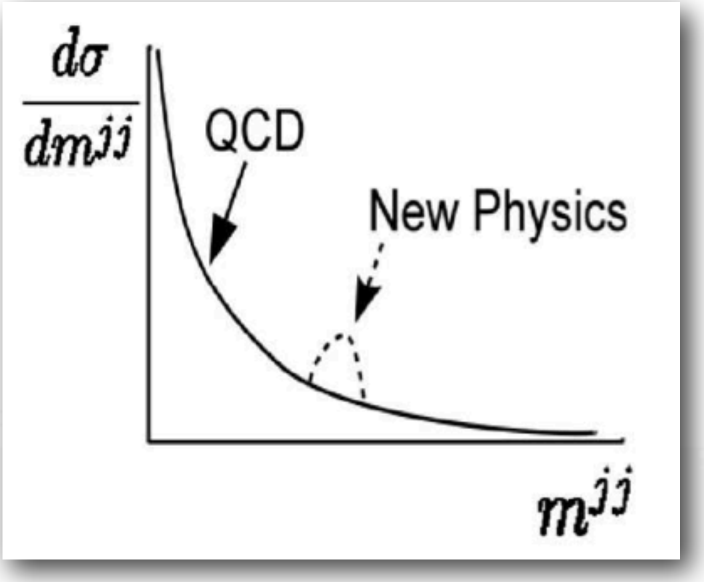
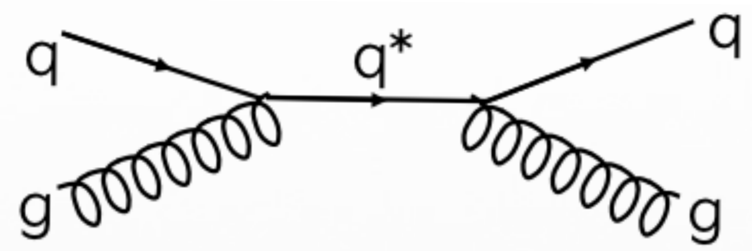
# Introduction : Dijets

BSM scenarios with a dijet final state:




1. excited quarks -




[U. Baur, I. Hinchliffe and D. Zeppenfeld, Int. J. Mod. Phys. **A2**,1285 (1987)]

Signal sample: PYTHIA MC generator with MRST2007LO* PDF

2. Axigluon -

existence of a massive, color octet gauge boson : Axigluon->$q\bar{q}$

[P. Frampton and S. Glashow, Phys. Lett. B **190**,157 (1987)

J. Bagger, C.Schmidt and S.King, Phys. Rev. D **37**, 1188 (1988)]

Signal sample: CalcHEP MC generator with MRST2007LO* PDF

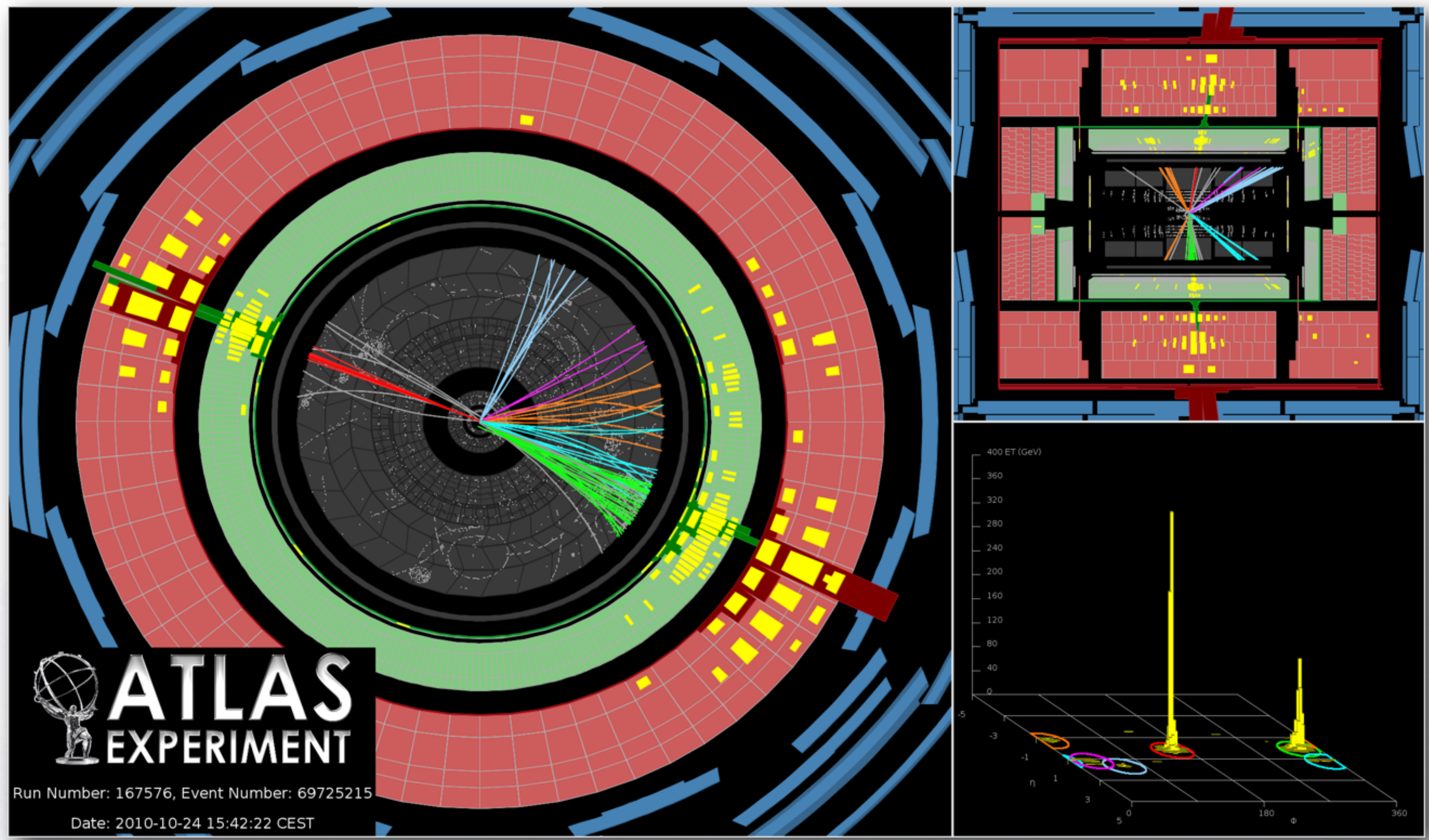
# Part 2 : Dijets

*" a typical high mass dijet event recorded by ATLAS"*

- ✳ leading jet:
  $p_T = 1.3$ TeV
  $\eta = -0.2$; $\Phi = 2.8$

- ✳ sub-leading jet:
  $p_T = 1.2$ TeV
  $\eta = 0.0$; $\Phi = -0.5$

- ✳ $m_{jj} = 2.6$ TeV



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# Dijets : Event Selection

- ✴ Lowest threshold unprescaled jet trigger
- ✴ 1 primary vertex with more than 4 tracks
- ✴ cleaning cut: reject detector noise
- ✴ Jet kinematics:

  $p_T$ ($jet_1$ and $jet_2$) > 30 GeV, $|\eta| < 2.8$

  $|y_{12}| < 1.2$ (rapidity in parton CM frame)
- ✴ No treatment for leptons -> EW backgrounds negligible

$1 fb^{-1}$ (±3.7%) of 2011 data is analysed

# Dijets : Resonances

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

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

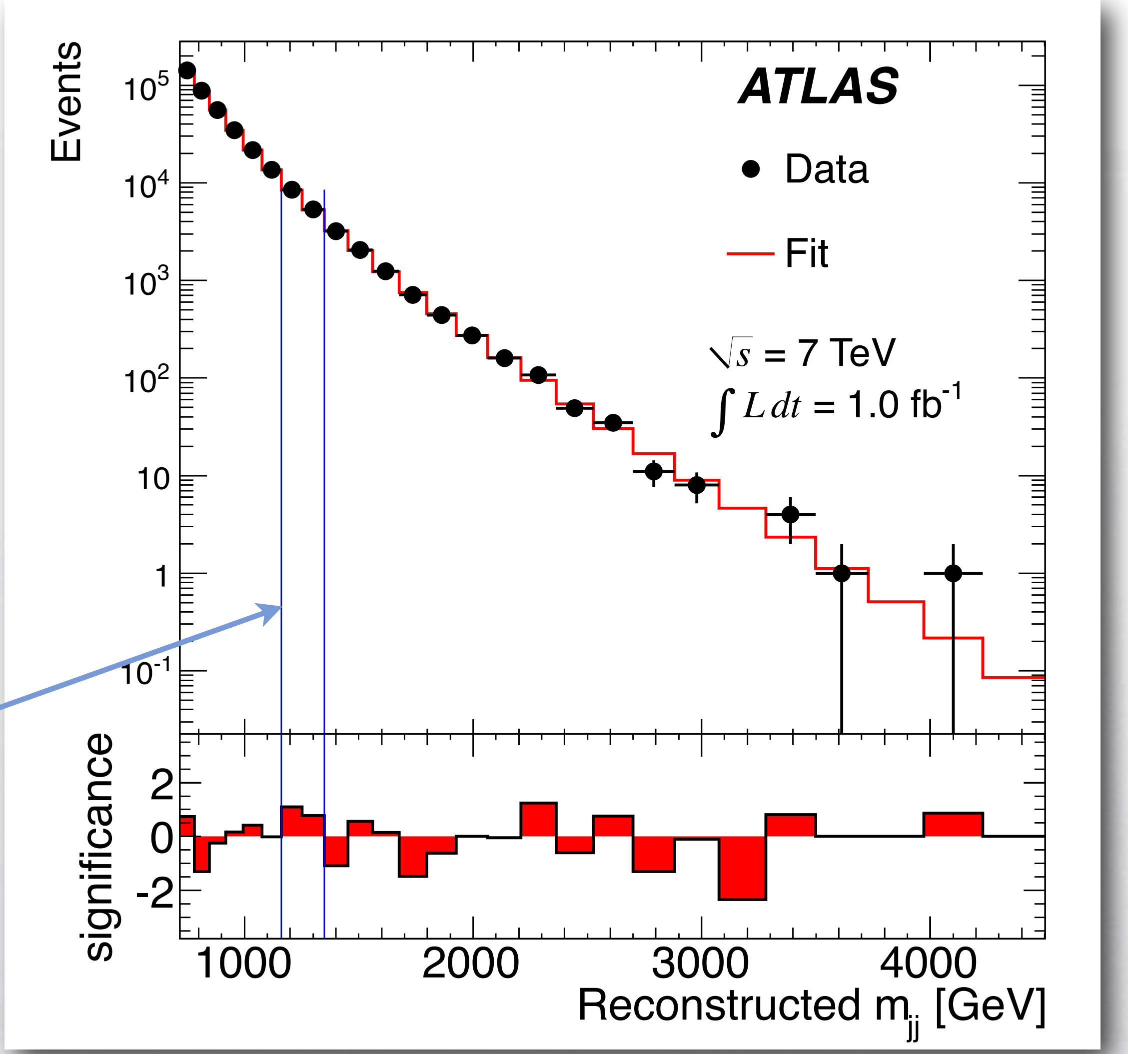
$p_i$ *are fit parameters*

✳ Data is fit to a function which accurately models the QCD dijet mass spectrum [T.Aaltonen *et al.* (CDF collaboration),Phys Rev.D **79**, 112002(2009)]

✳ Comparing: $\chi^2$ from data and pseudo experiments gives a p-value = 0.96

✳ Good agreement between data and functional form

✳ To increase sensitivity BumpHunter algorithm is used [T.Aaltonen *et al.* (CDF collaboration),Phys Rev.D **79**, 011101(2009)]







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# Dijets : Model Dependent Limit Setting

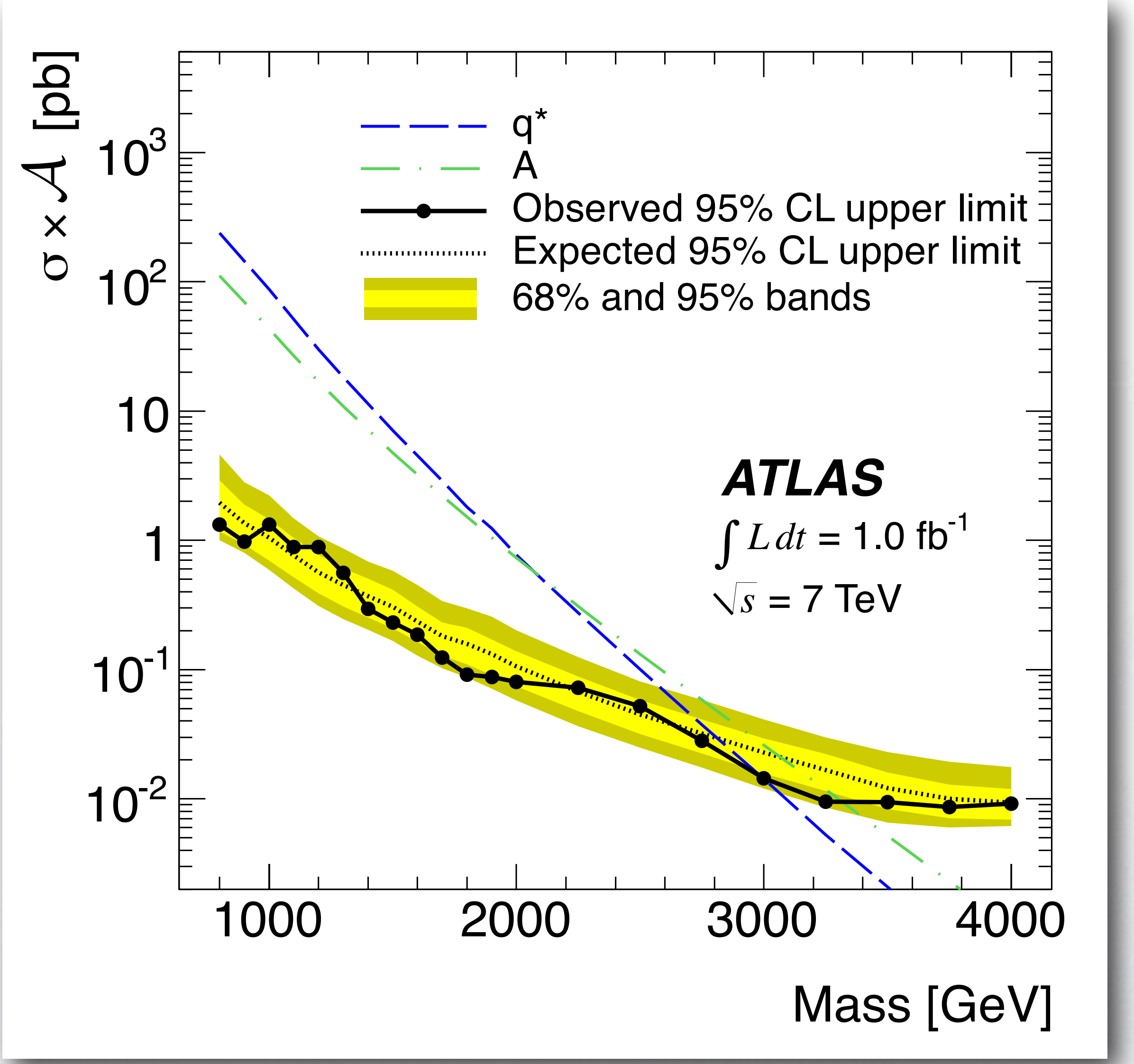
The limit setting incorporates:

✳ Effects of systematic uncertainties (luminosity, JES)

✳ Effect of JER which is negligible

✳ Reweighting of simulation to account for *in-time* and *out-of-time* "pile-up"

✳ New physics model is a benchmark i.e. no theoretical uncertainty (fixed MC tune and PDF set)




| Model | 95% CL Limits (TeV) Expected | Observed |
|---|---|---|
| Excited Quark q* | 2.81 | 2.99 |
| Axigluon | 3.07 | 3.32 |



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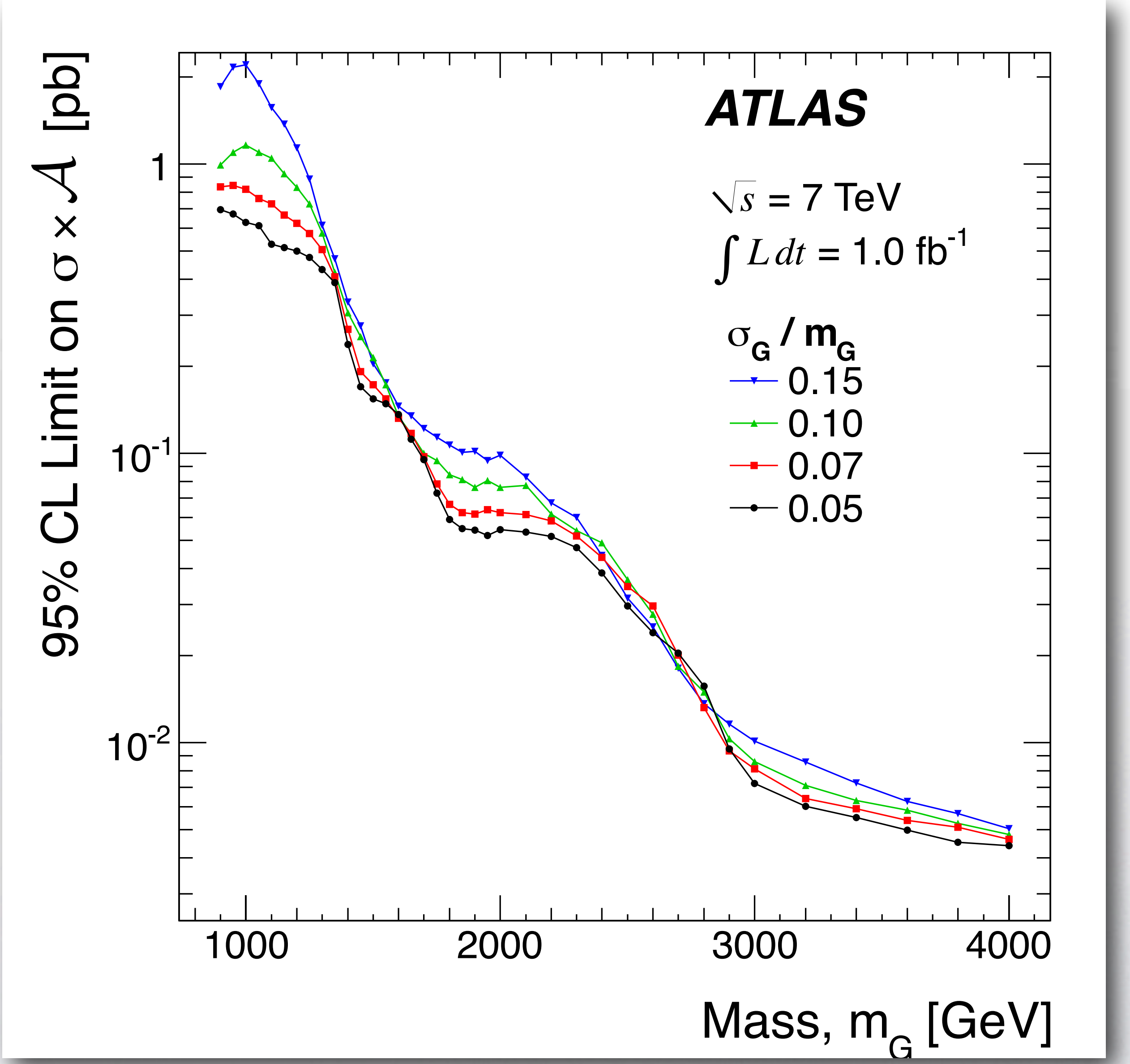
# Dijets : Model Independent Exclusion Limits

✴ Results can be utilized to set model independent limits

✴ Hypothetical signal:
Assumptions,
1. Gaussian distributed with mean ($m_G$) in [0.9,4.0] TeV.
2. Standard deviation ($\sigma_G$) from 5% to 15% of mean

Systematics: same as in the model dependent limits







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# Summary

✳ ATLAS searches for new physics with Monojet or Dijet final states is presented with 1$fb^{-1}$ of 2011 data.

✳ No hints of new physics found yet...

✳ Limits for models with Extra Dimensions, Excited Quarks or Axigluons.

✳ Model independent limits

✳ Apart from dijet resonance search efforts also ongoing in dijet angular distribution analysis. [G.Aad *et.al*, The ATLAS Collaboration, New Journal of Physics **13** (2011) 053044]

✳ The search is still on .... about 5$fb^{-1}$ of data collected in 2011.



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# BACKUP MATERIAL





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# Monojet : Object definition

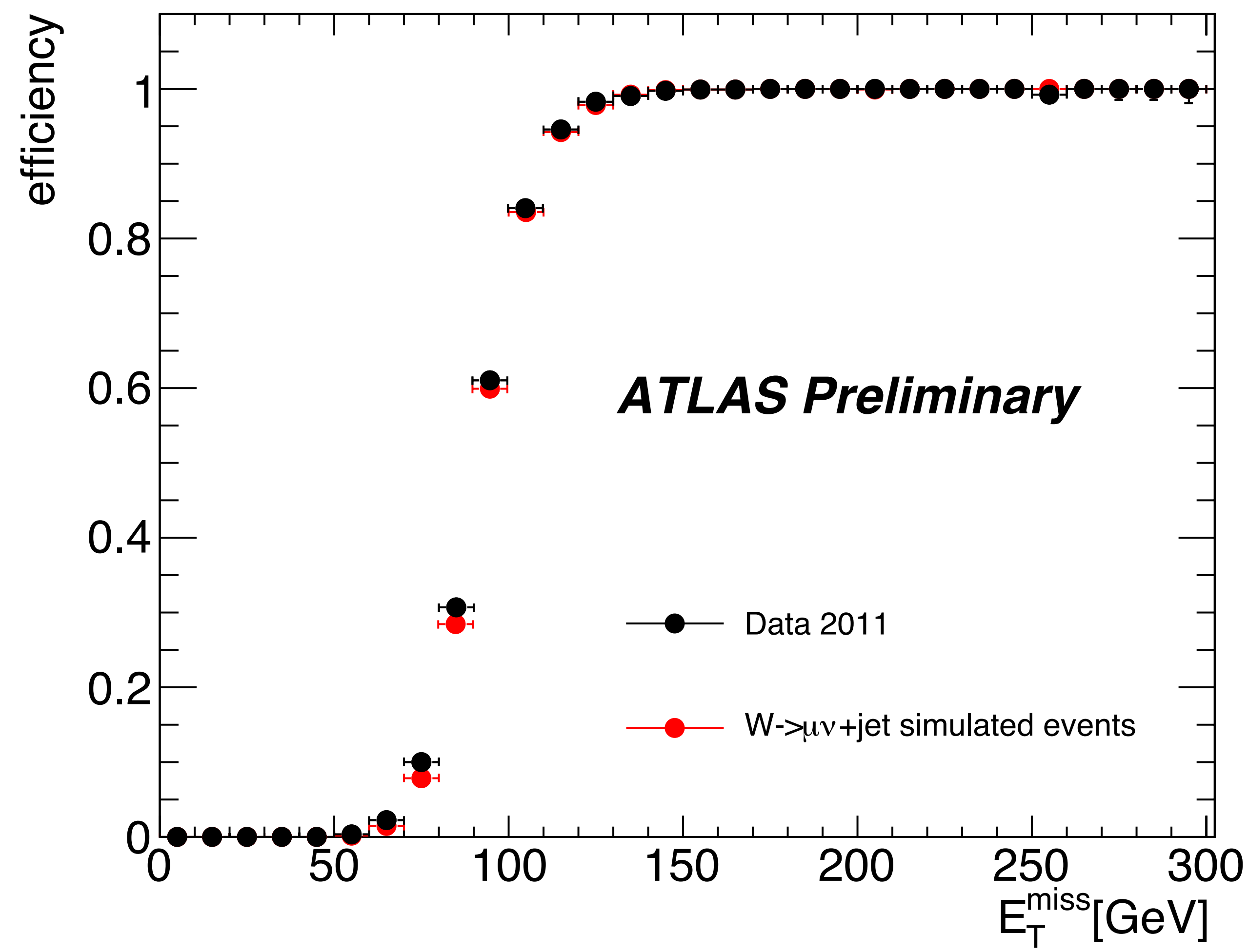
Jets:
- reconstructed using AntiK$_T$ (R=0.4)
- input are topological clusters
- calibrated to hadronic scale
- $p_T > 30$ GeV
- $|\eta| < 4.5$

Muons:
- $p_T > 10$ GeV
- $|\eta| < 2.4$
- isolation criteria

$E_T^{miss}$:
- Calorimeter based
- topological clusters within $|\eta| < 4.5$

Electrons:
- $p_T > 20$ GeV
- $|\eta| < 2.47$

# Monojet: Trigger selection



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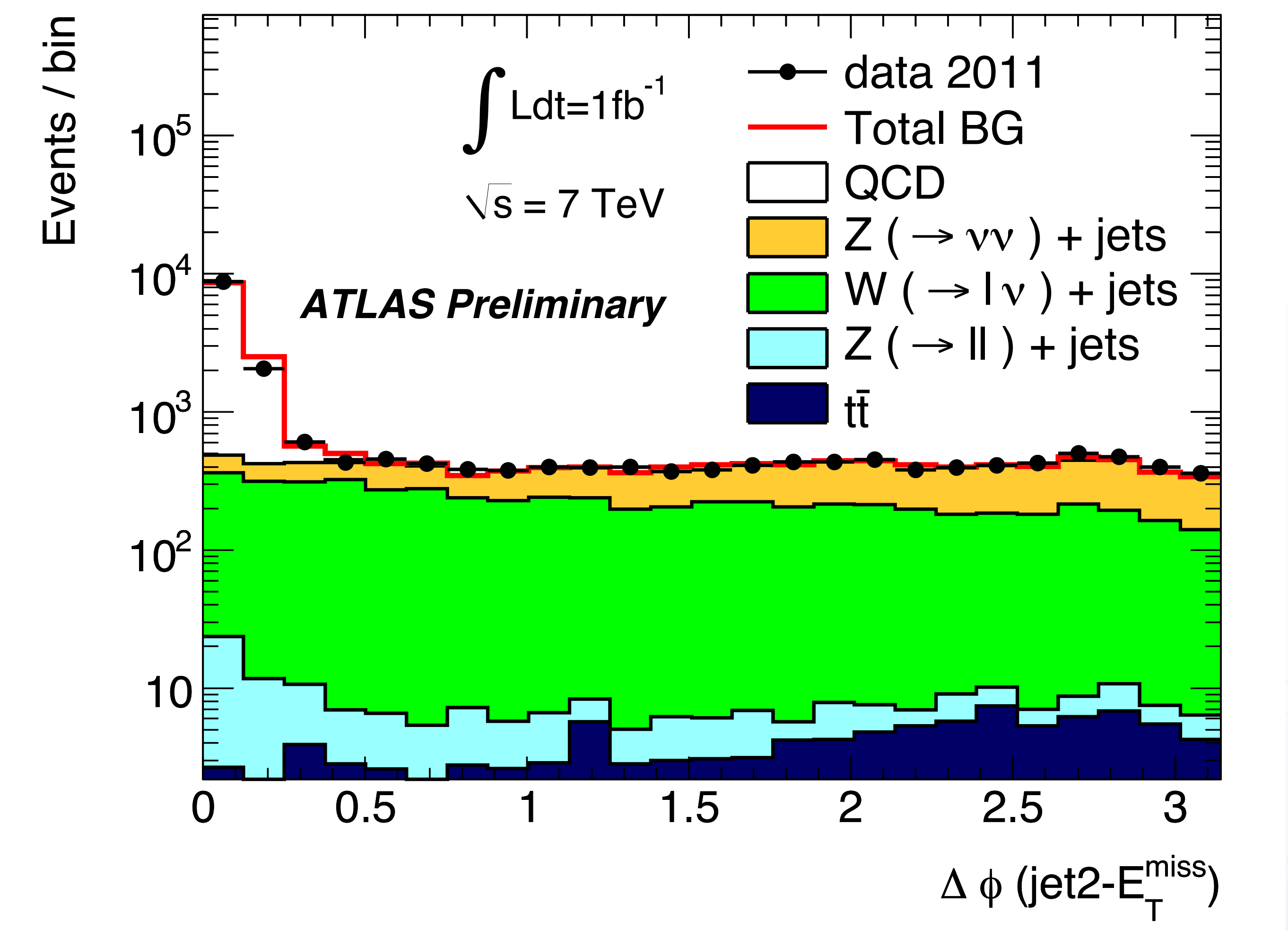
# Monojet: QCD background estimation



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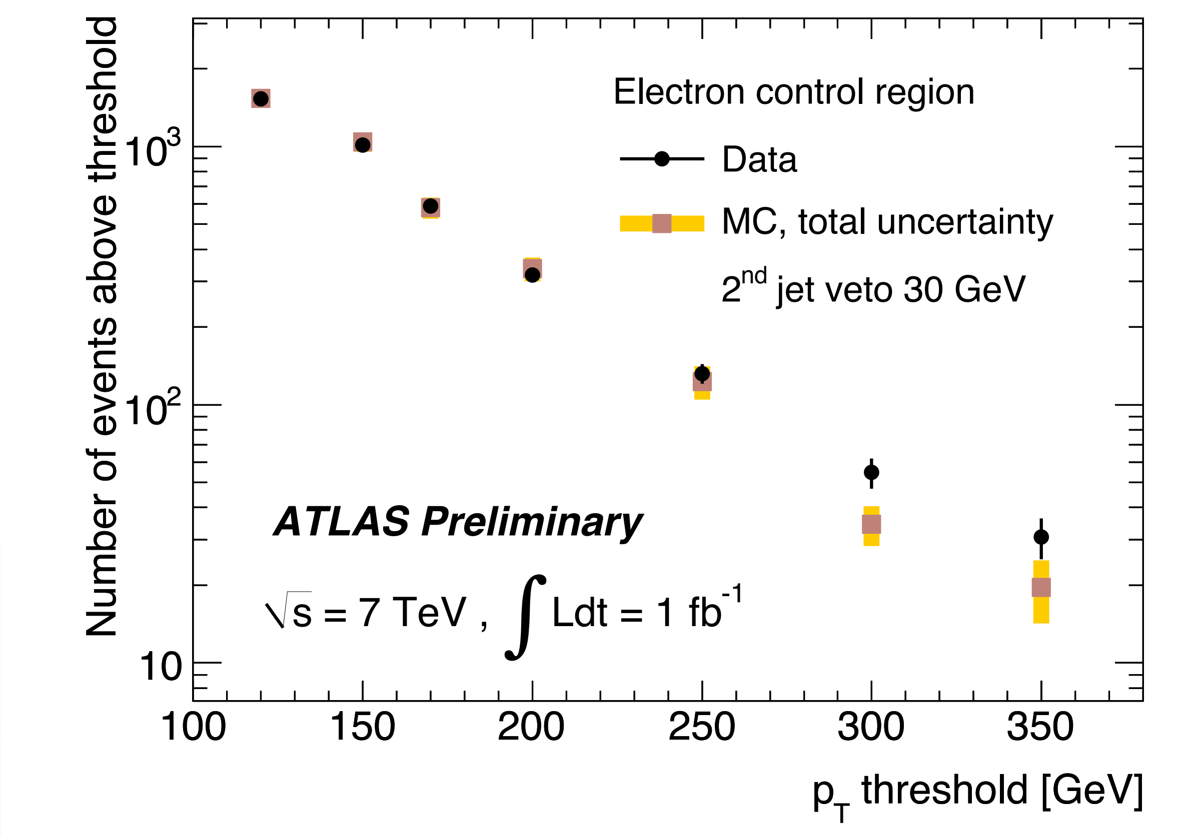
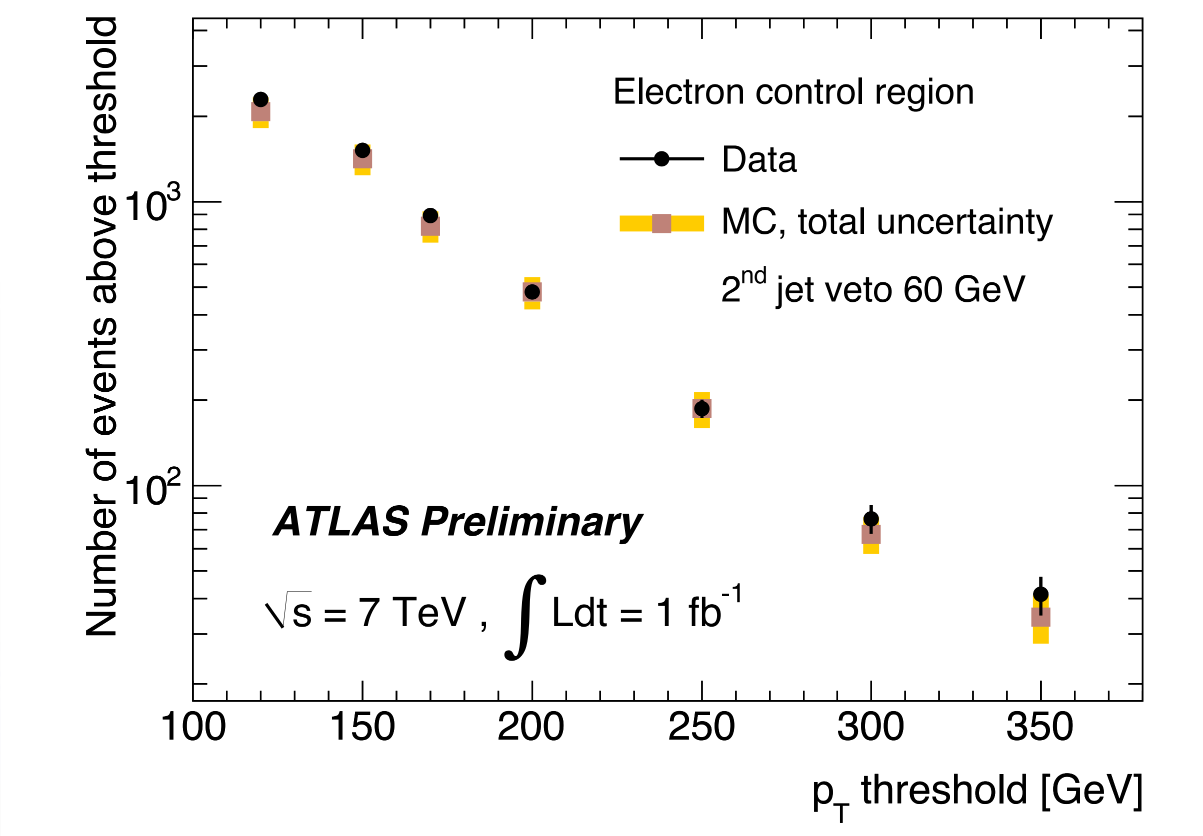
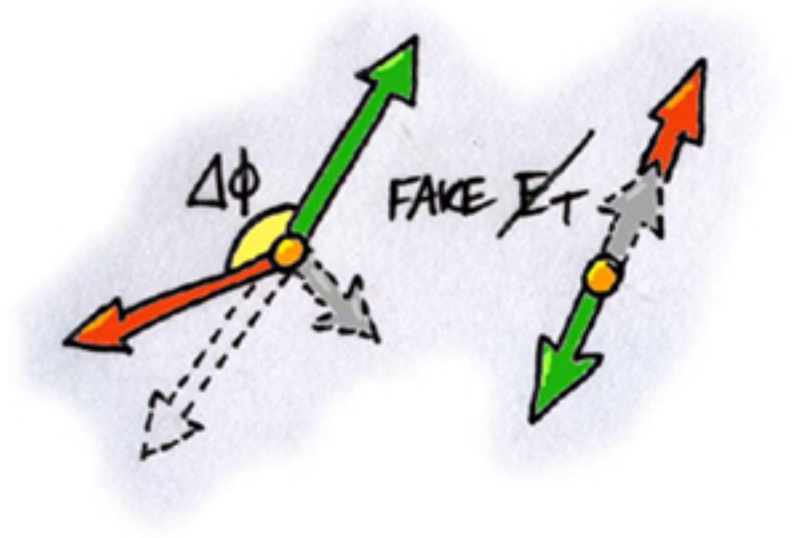
# Monojet: EW background estimation - electron



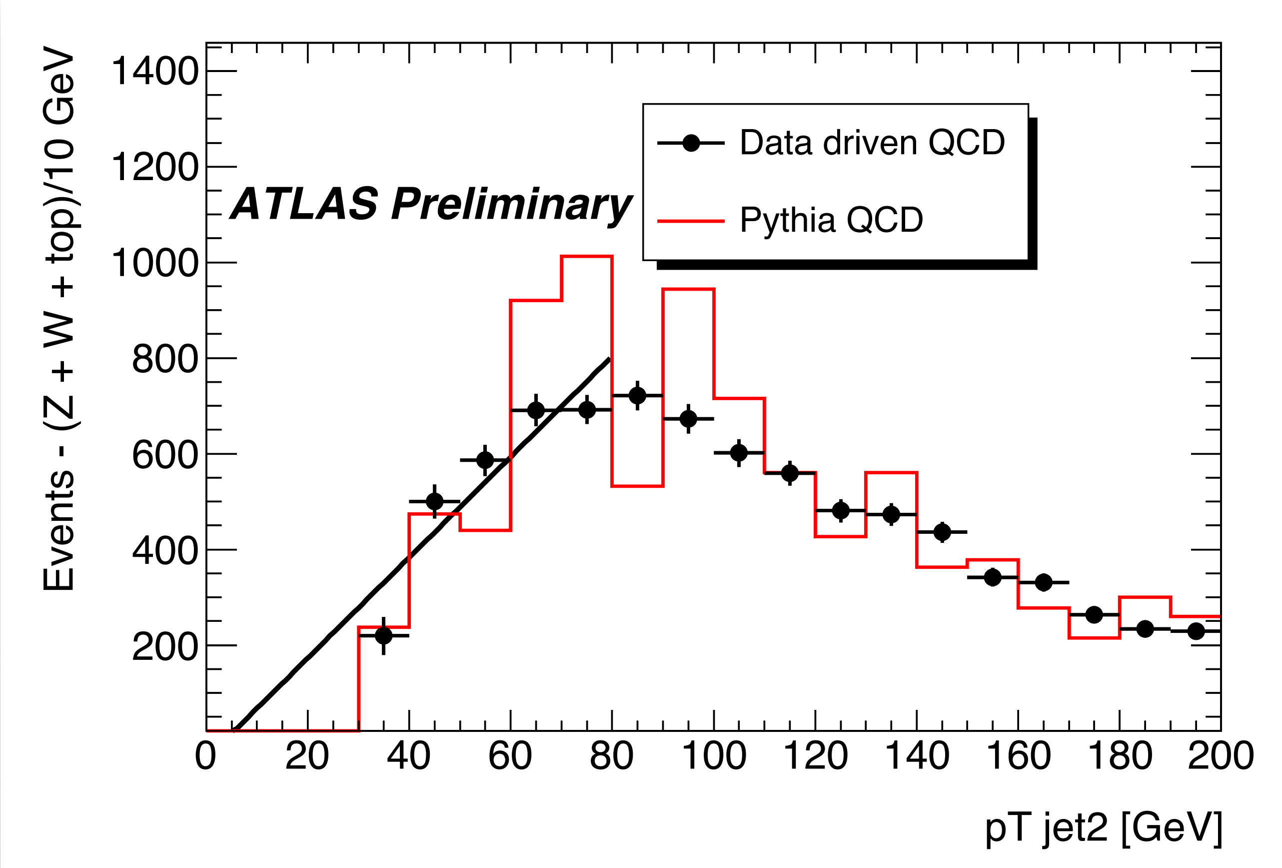



# Monojet : QCD background estimation




Multi or dijet events can constitute QCD background due to mismeasurement of next-to-leading jet -> *fake* $E_T^{miss}$

Invert the second jet veto to obtain a dijet enriched sample and extrapolate the shape of next-to-leading jet in lower $p_T$ bins using a linear fit.







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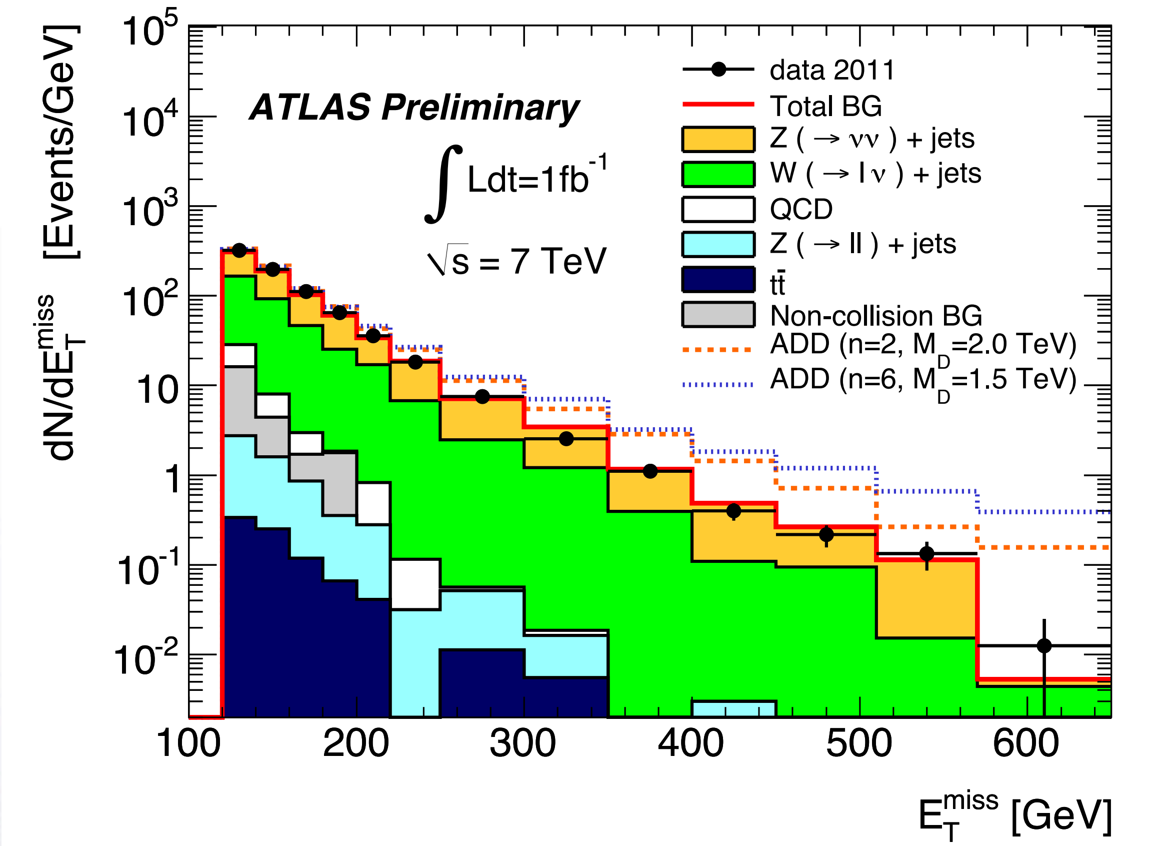
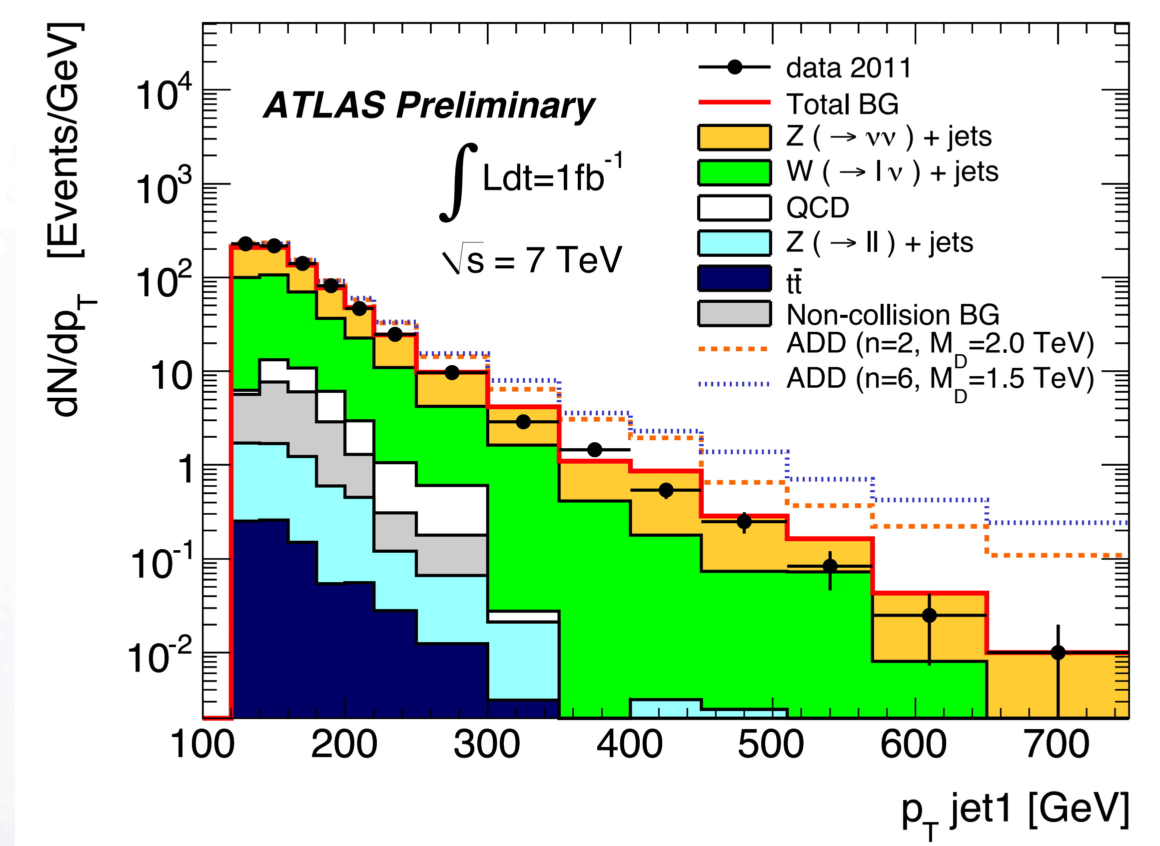
# Monojet: Low $p_T$ distributions







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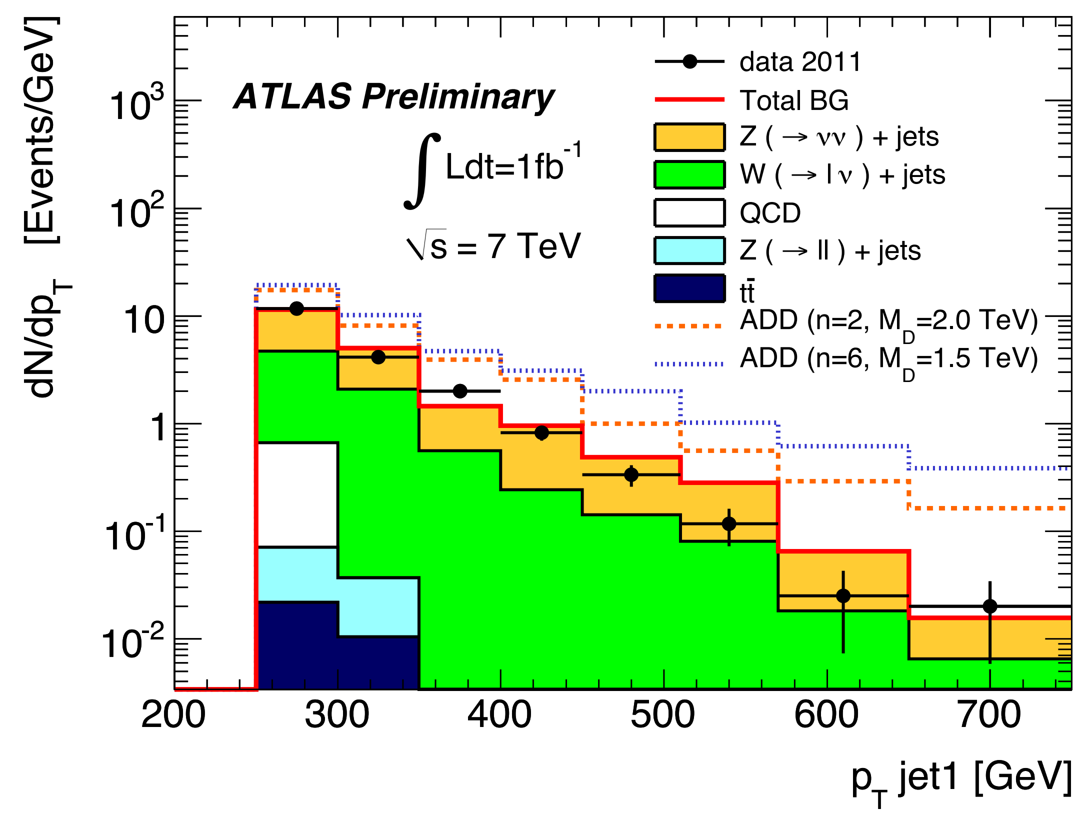
# Monojet: High $p_T$ distributions

| | Background Predictions ± (stat.) ± (syst.) | | |
|---|---|---|---|
| | LowPt Selection | HighPt Selection | veryHighPt selection |
| $Z(\to \nu\bar{\nu})$+jets | $7700 \pm 90 \pm 400$ | $610 \pm 27 \pm 47$ | $124 \pm 12 \pm 15$ |
| $W(\to \tau\nu)$+jets | $3300 \pm 90 \pm 220$ | $180 \pm 16 \pm 22$ | $36 \pm 7 \pm 8$ |
| $W(\to e\nu)$+jets | $1370 \pm 60 \pm 90$ | $68 \pm 10 \pm 8$ | $8 \pm 1 \pm 2$ |
| $W(\to \mu\nu)$+jets | $1890 \pm 70 \pm 100$ | $113 \pm 14 \pm 9$ | $18 \pm 4 \pm 2$ |
| Multi-jets | $360 \pm 20 \pm 290$ | $30 \pm 6 \pm 11$ | $3 \pm 2 \pm 2$ |
| $Z/\gamma^*(\to \tau^+\tau^-)$+jets | $59 \pm 3 \pm 4$ | $2.0 \pm 0.6 \pm 0.2$ | - |
| $Z/\gamma^*(\to \mu^+\mu^-)$+jets | $45 \pm 3 \pm 2$ | $2.0 \pm 0.6 \pm 0.1$ | - |
| $t\bar{t}$ | $17 \pm 1 \pm 3$ | $1.7 \pm 0.3 \pm 0.3$ | - |
| $\gamma$+jet | - | - | - |
| $Z/\gamma^*(\to e^+e^-)$+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 |







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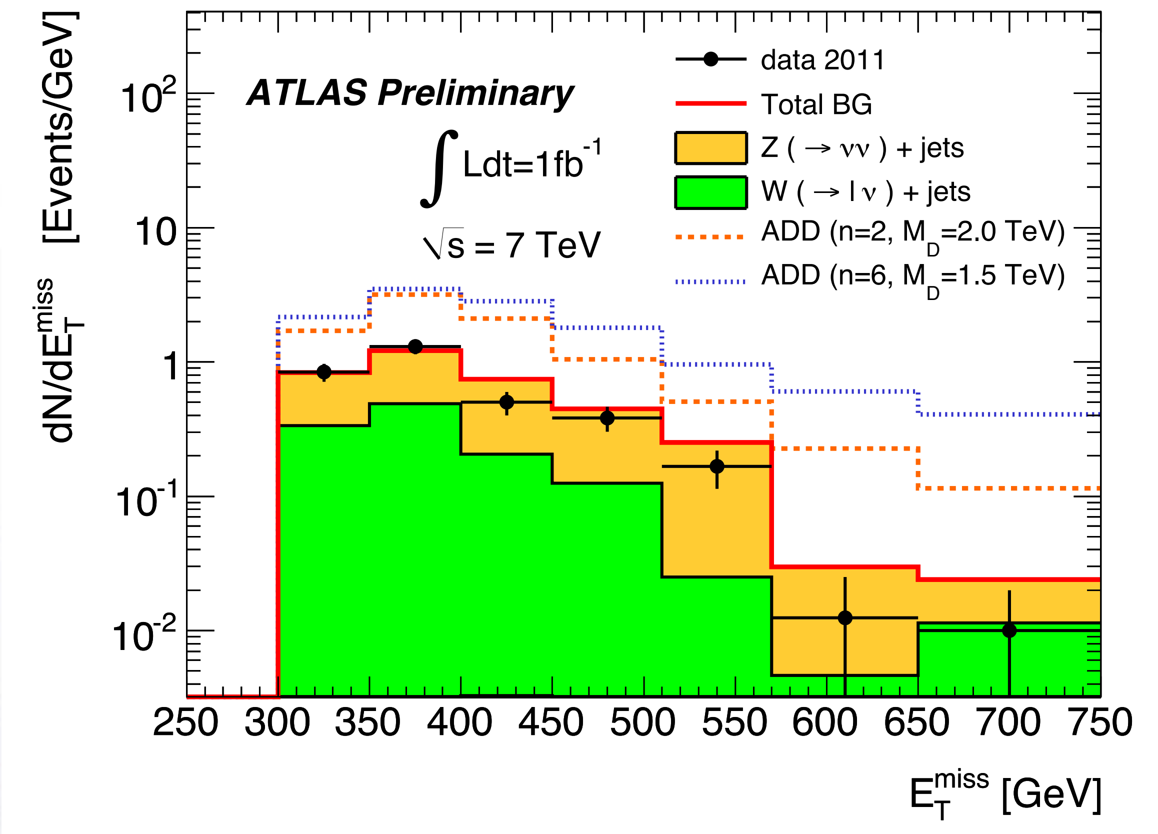
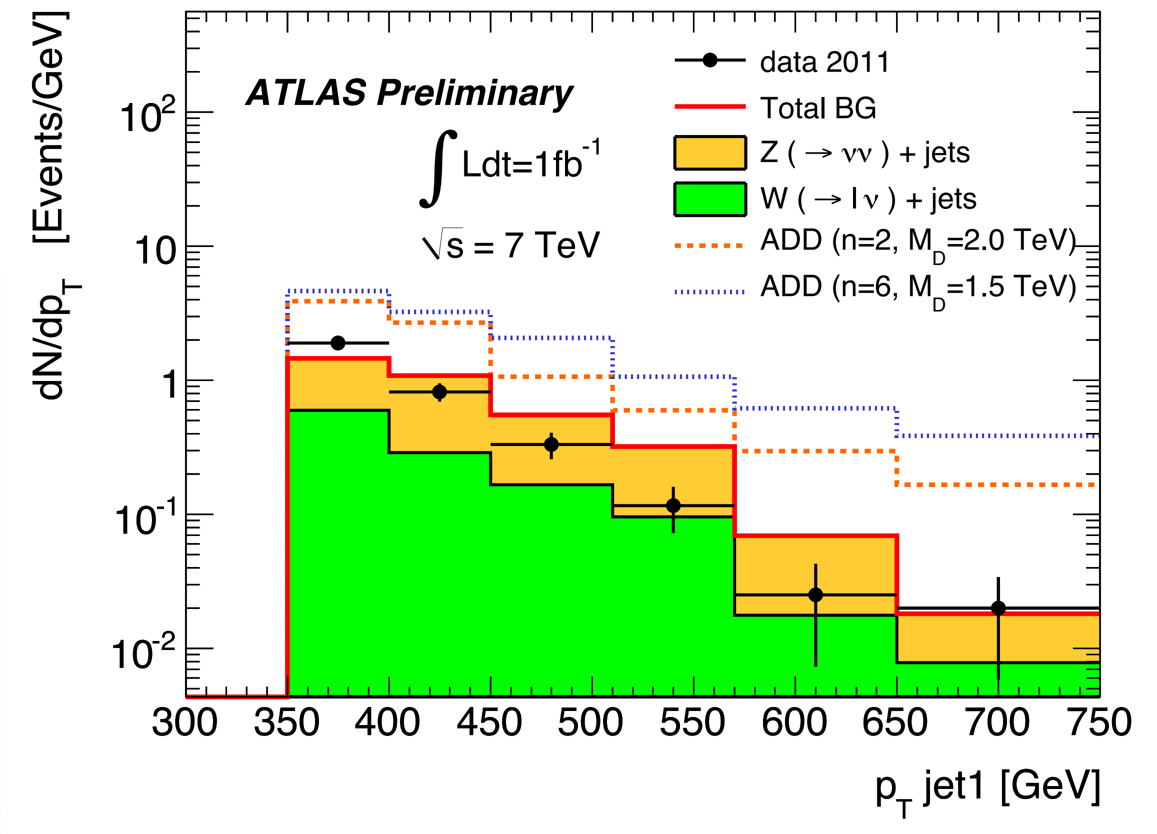
# Monojet: very high $p_T$ distributions



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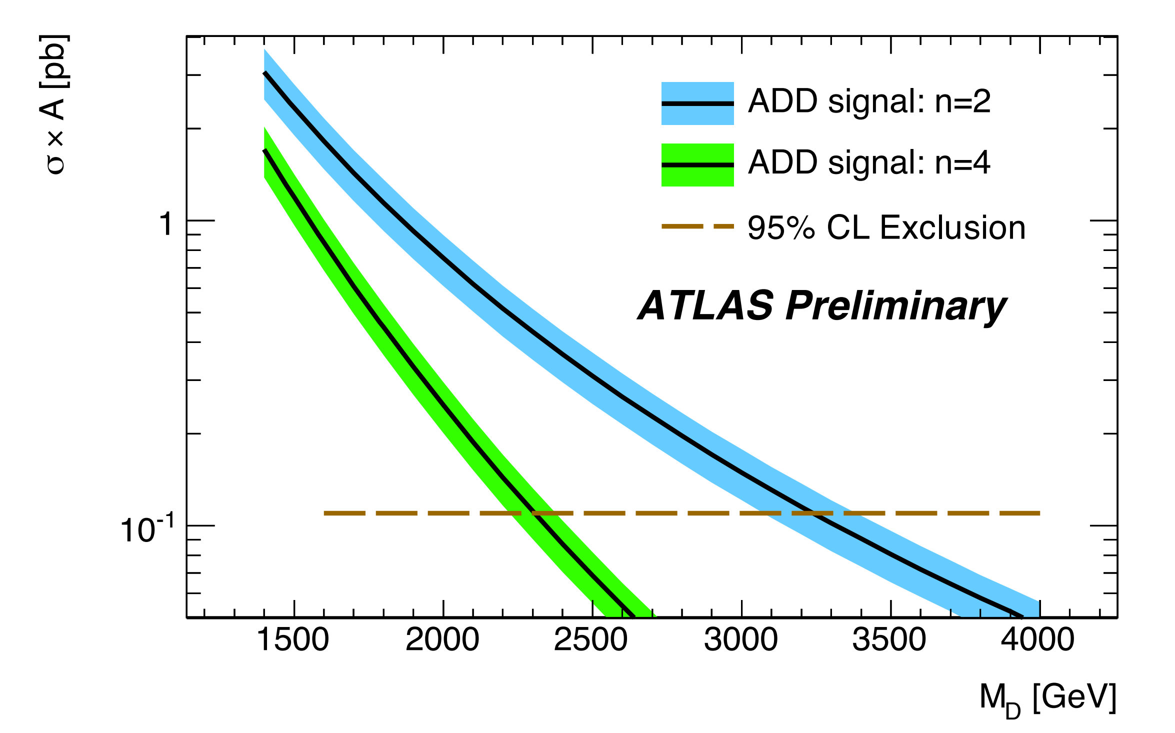
# Monojet: ADD limits

| 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 |




| 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 |

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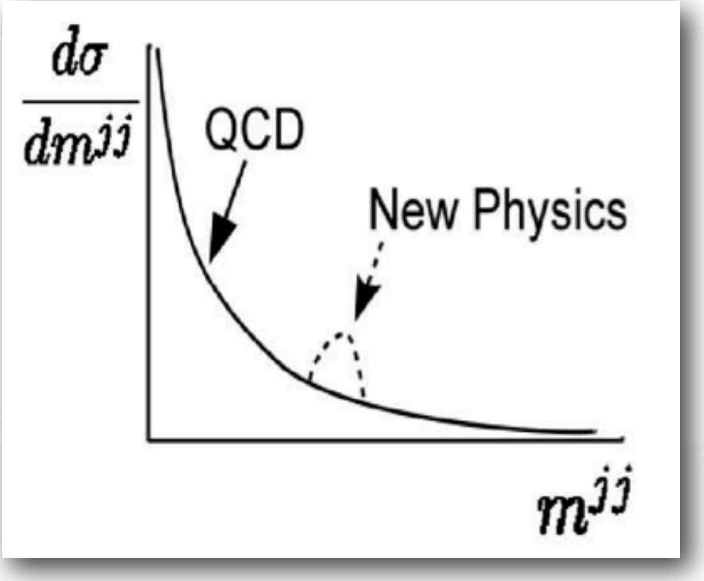
# Monojet: Systematics

| | lowPt (%) | HighPt (%) |
|---|---|---|
| PDFs | 6.3 | 6.3 |
| ISR/FSR | 13 | 13 |
| $Q^2$ scale | 11.2 | 11.2 |
| JES | 5.3 | 5.6 |
| JER | 2.7 | 1.1 |
| Pile-Up | 2.6 | 2.0 |
| Luminosity | 3.7 | 3.7 |
| MC statistics | 5.2 | 5.2 |
| Total sys | 19.7 | 19.8 |

# Introduction : Dijets

BSM scenarios with a dijet final state:




1. excited quarks - qg->q*->qg [1]
   Assumptions: spin 1/2, quark like SM couplings
   Compositeness scale ($\Lambda$) set to q* mass
   [U. Baur, I. Hinchliffe and D. Zeppenfeld, Int. J. Mod. Phys. **A2**,1285 (1987)]
   Signal sample: PYTHIA MC generator with MRST2007LO* PDF

2. Axigluon - Extend the standard color gauge group:

$$SU(3)_L \times SU(3)_R \Rightarrow SU(3)_C$$

   Existence of a massive, color octet gauge boson : Axigluon->qq
   Strong interaction coupling strength same as QCD
   [P. Frampton and S. Glashow, Phys. Lett. B **190**,157 (1987)
   J. Bagger, C.Schmidt and S.King, Phys. Rev. D **37**, 1188 (1988)]
   Signal sample: CalcHEP MC generator with MRST2007LO* PDF



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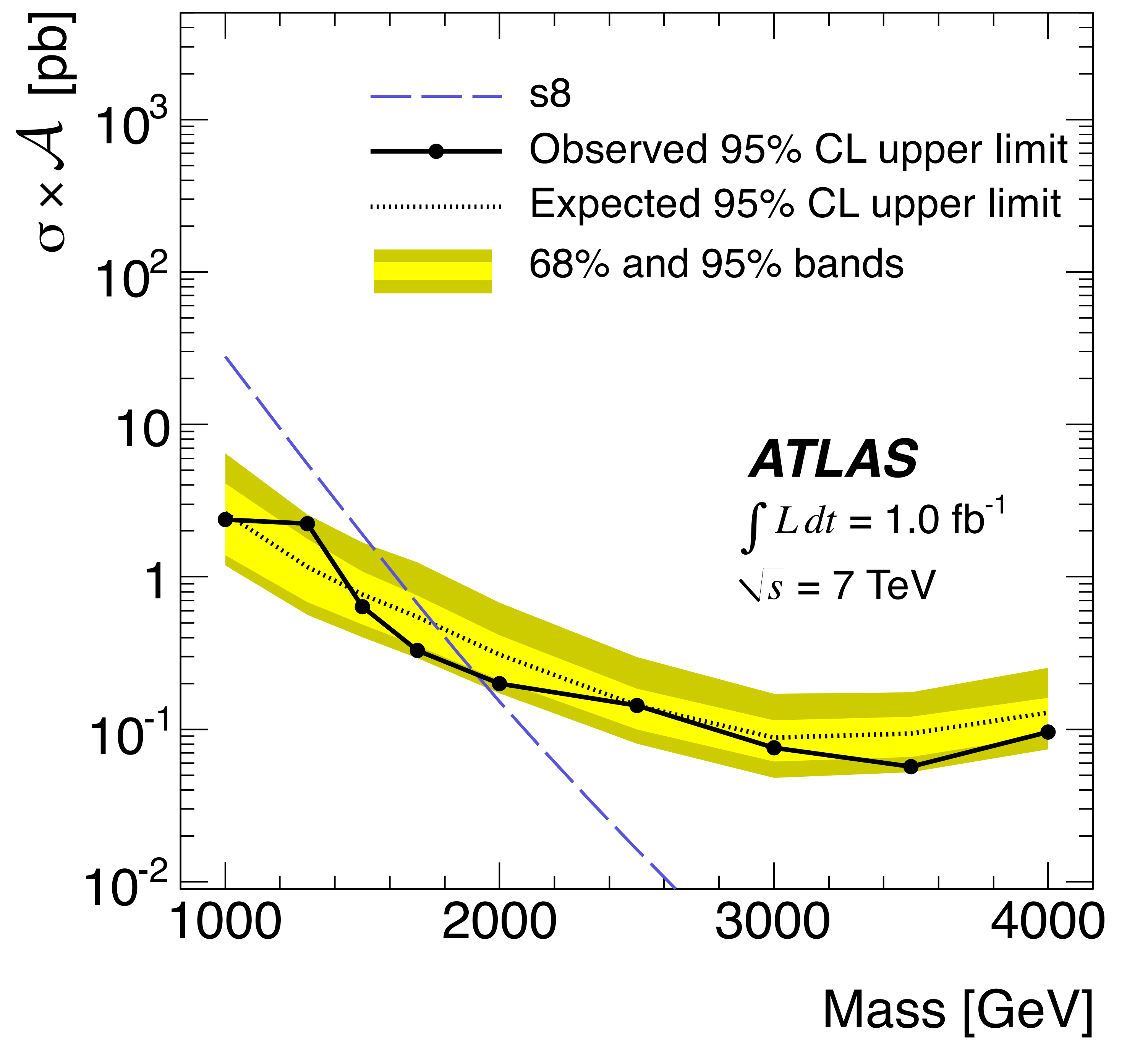
# Dijet : Scalar Octet (S8) limit setting



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