# New Physics Signal:
# Simplest Topology and Largest Rate

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Topologies for Early LHC Searches

SLAC, Sept. 22, 2010

*with Ian Lewis, Zhen Liu, to appear.

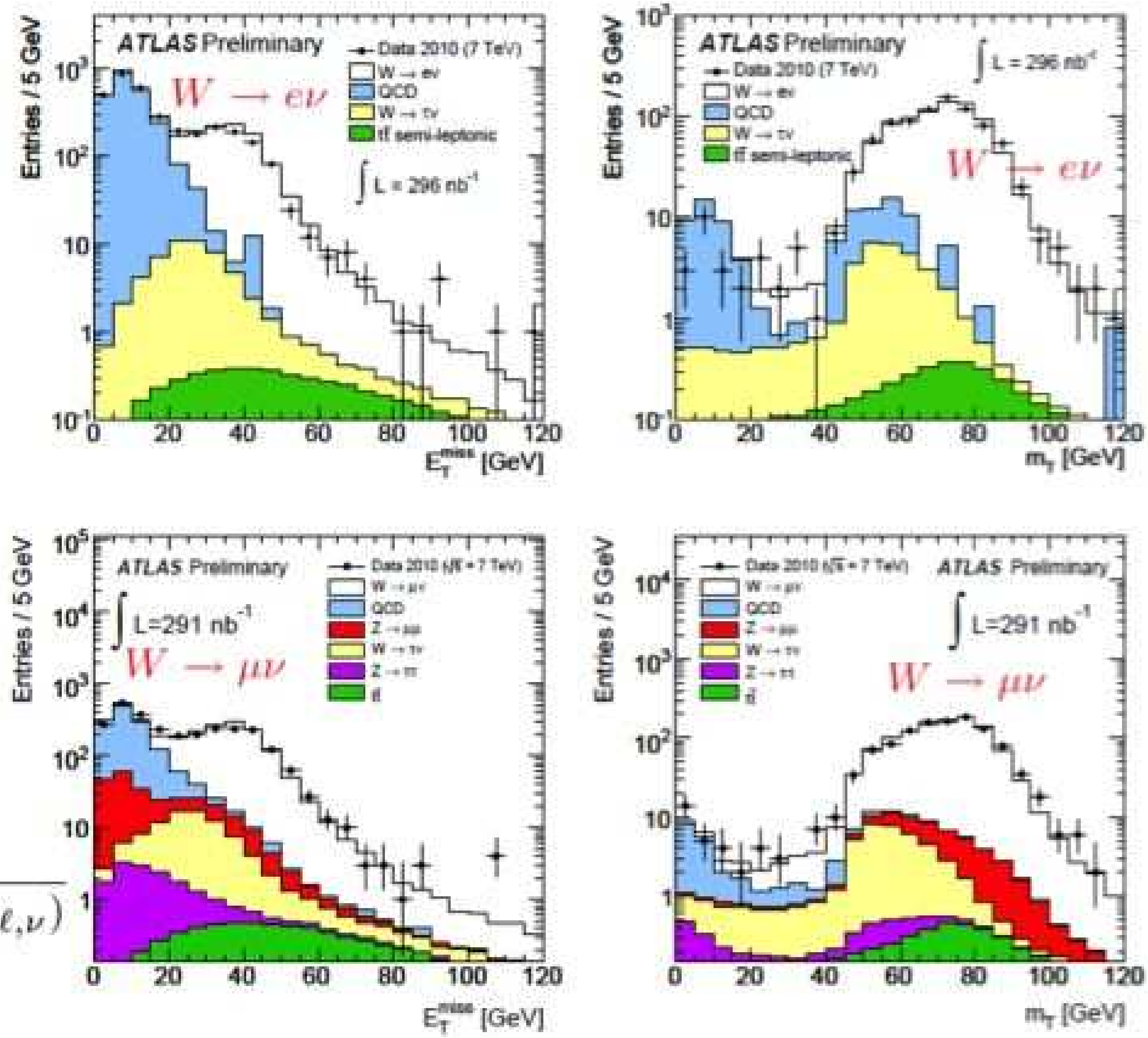
# It IS the LHC era !

ATLAS $W$ re-discovery:

## W Selection

- Tight electron.
- Muon with $p_T > 20$ GeV.
- Muon isolation $\sum_{\Delta R<0.4} p_T^{trk}/p_T^{\mu} < 0.2$
- $\not{E}_T > 25$ GeV.
- $m_T > 40$ GeV.

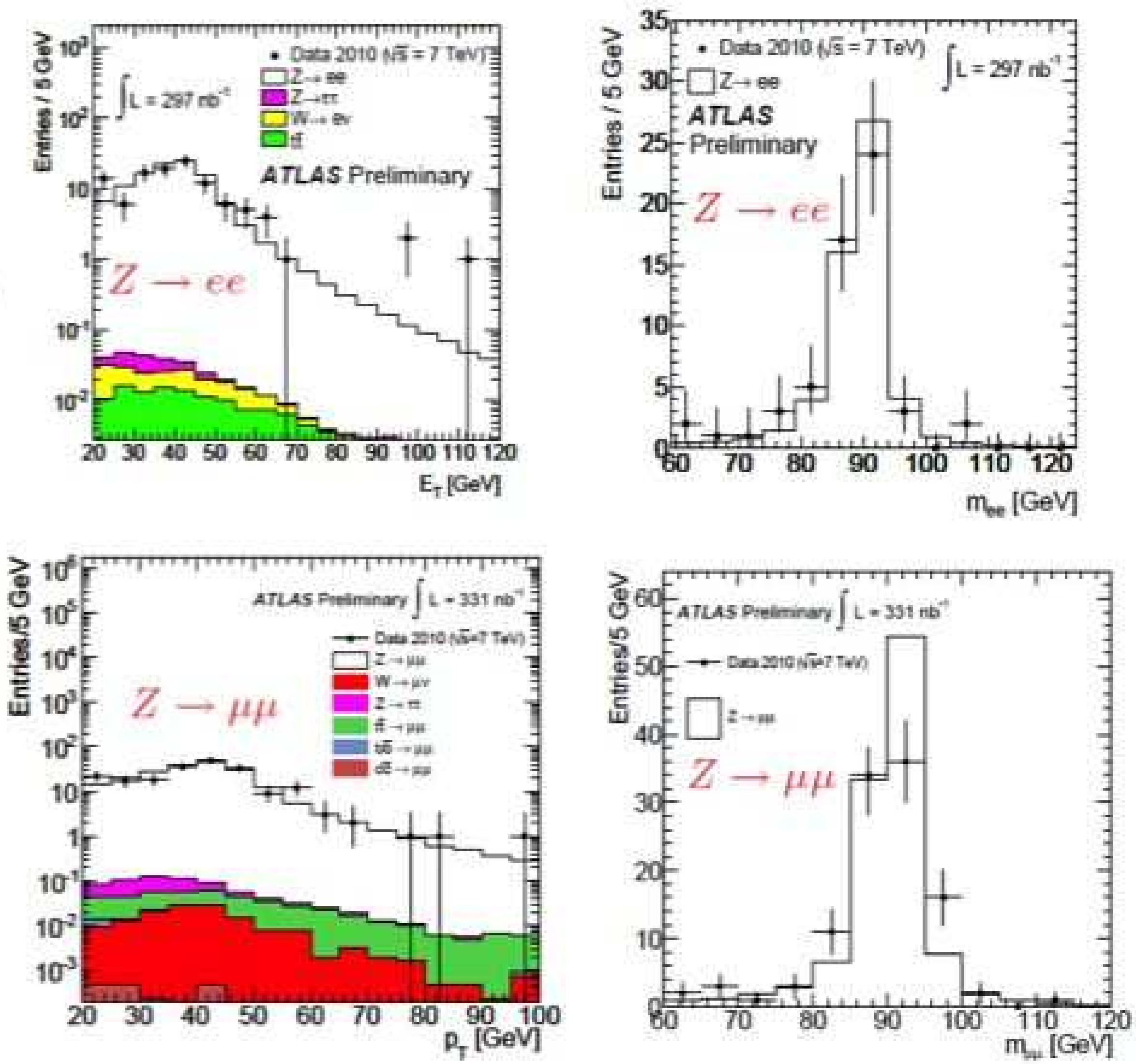
$$m_T = \sqrt{2p_T^{\ell}p_T^{\nu}(1-\cos(\Delta\phi_{\ell,\nu}))}$$



# ATLAS $Z$ re-discovery:

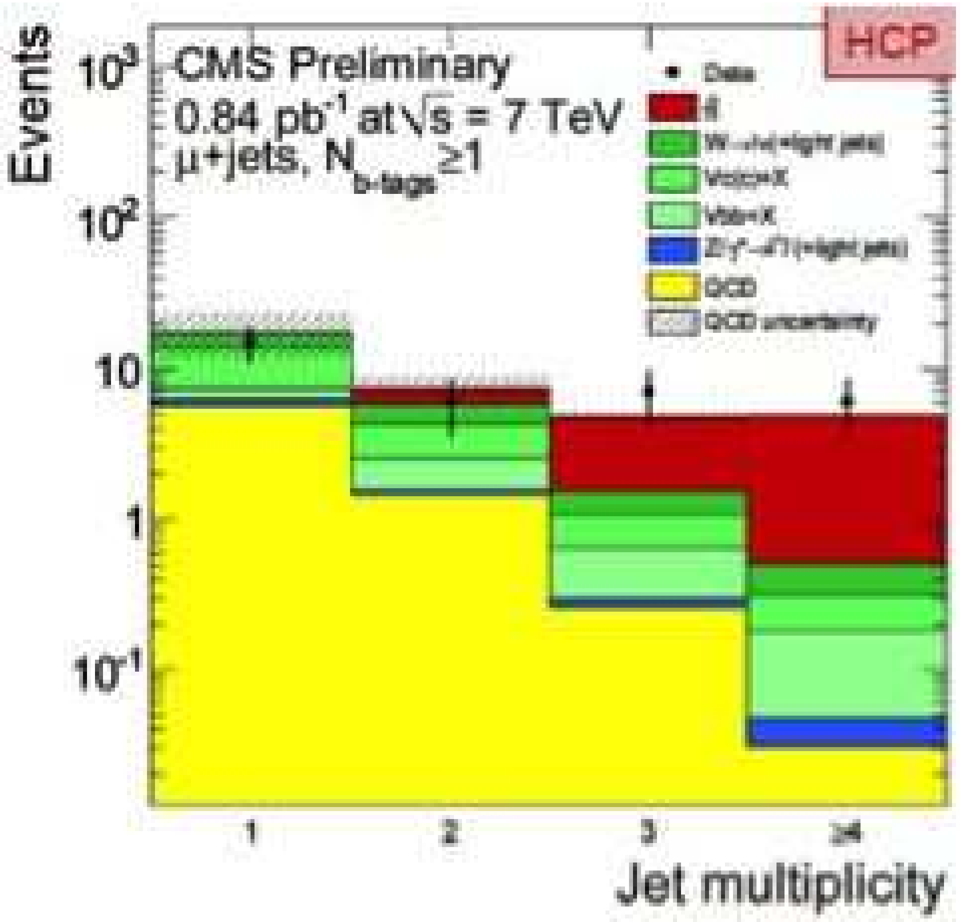
## Z Selection

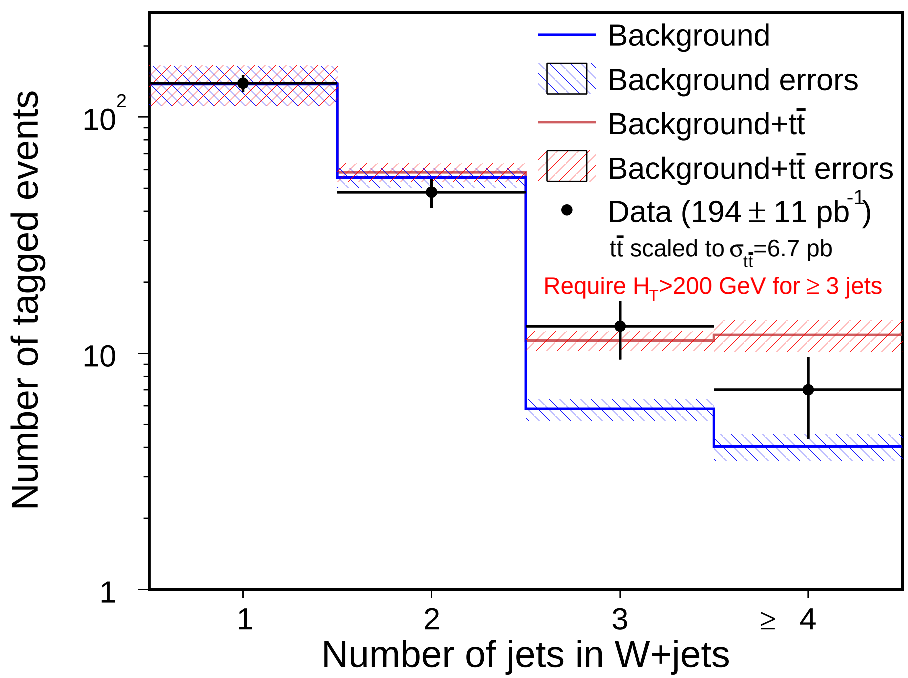
- Two oppositely charged leptons ($e/\mu$).
- Same lepton selection as $W$ analysis except medium electrons.
- Invariant mass $66 < m_Z < 116$ GeV.



CMS $W$+jets and top events

CDF $W$+jets and top



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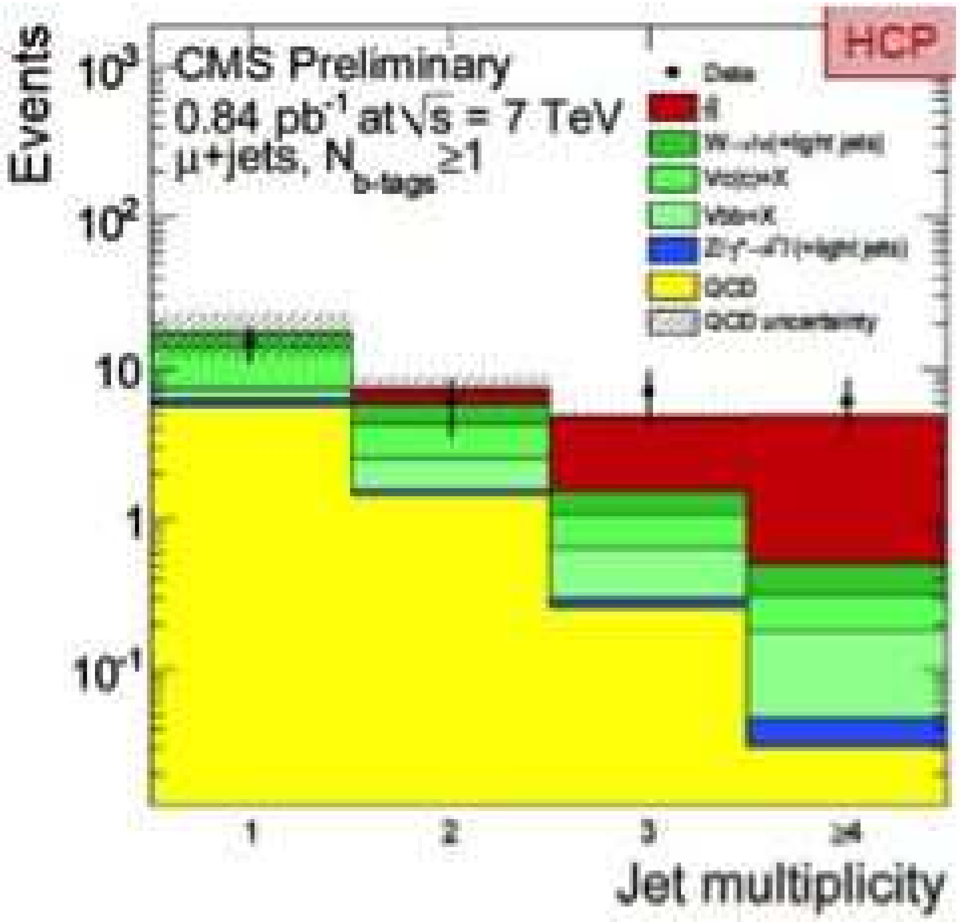


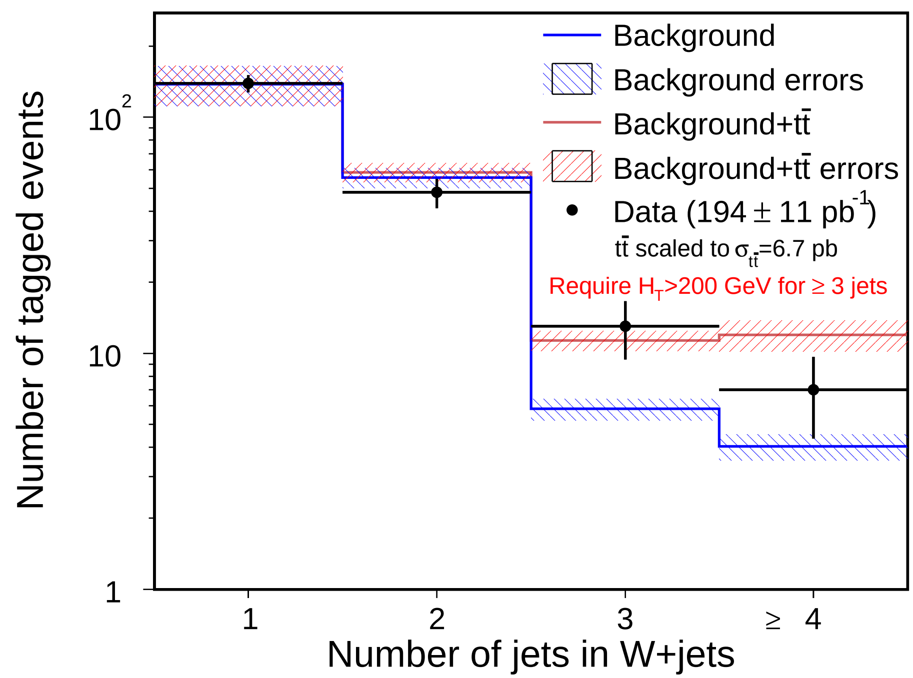


LHC top studies catching up !

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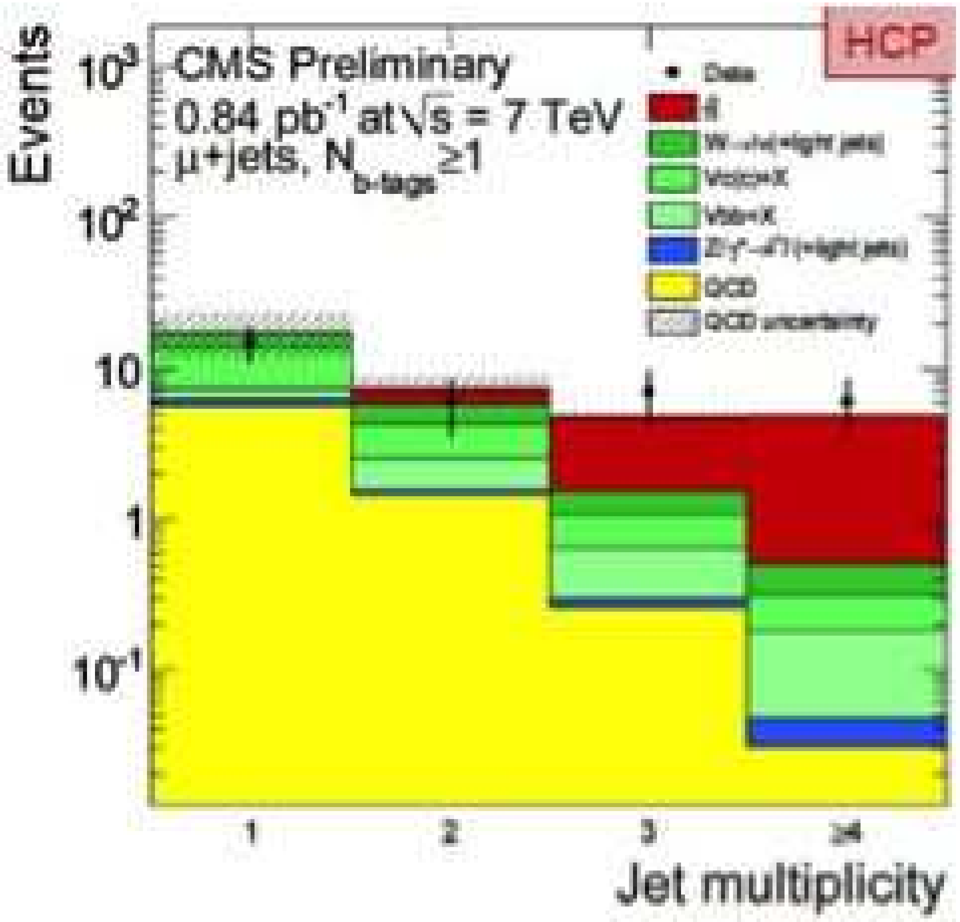
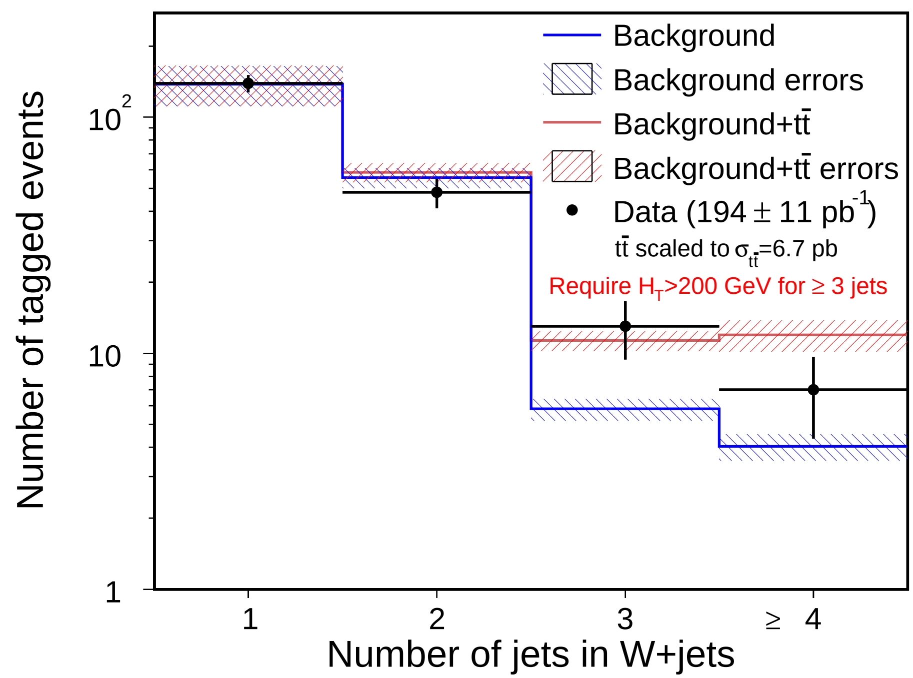
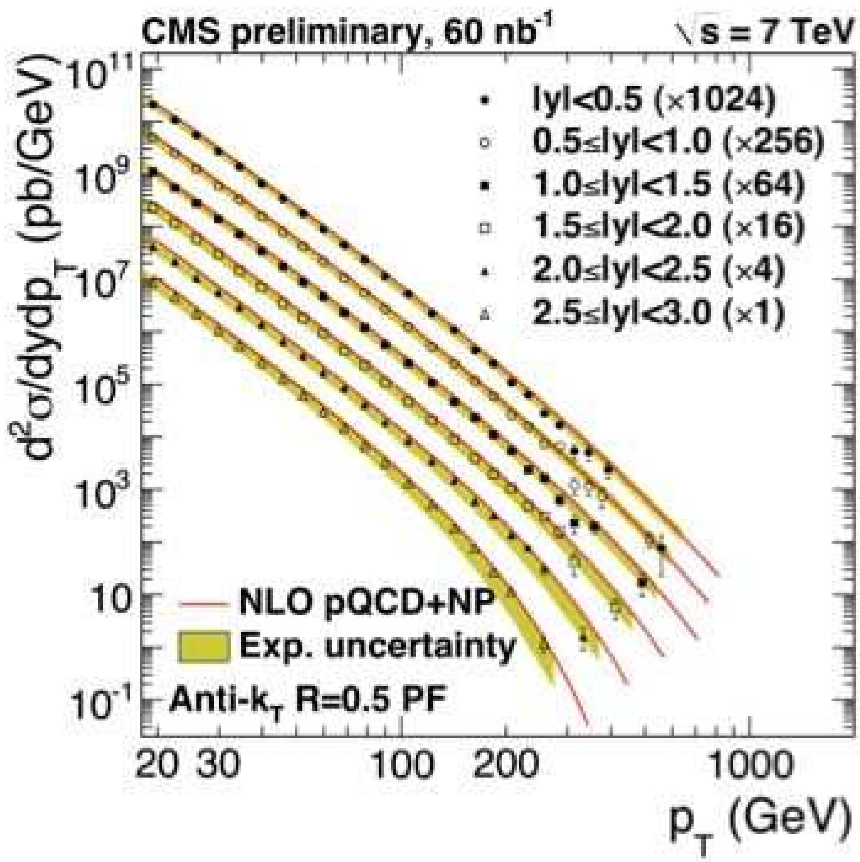


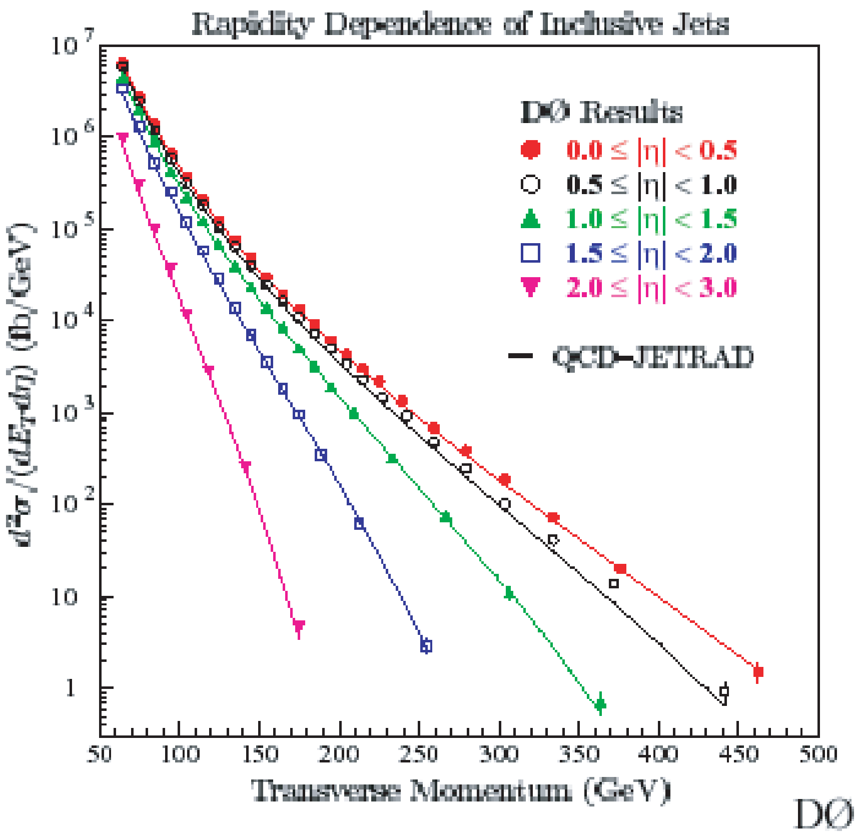

LHC top studies catching up !

LHC achieved the first crucial step:
The Standard Model rediscovered !

CMS 1-jet in different rapidities:




D0 1-jet in rapidity ranges:



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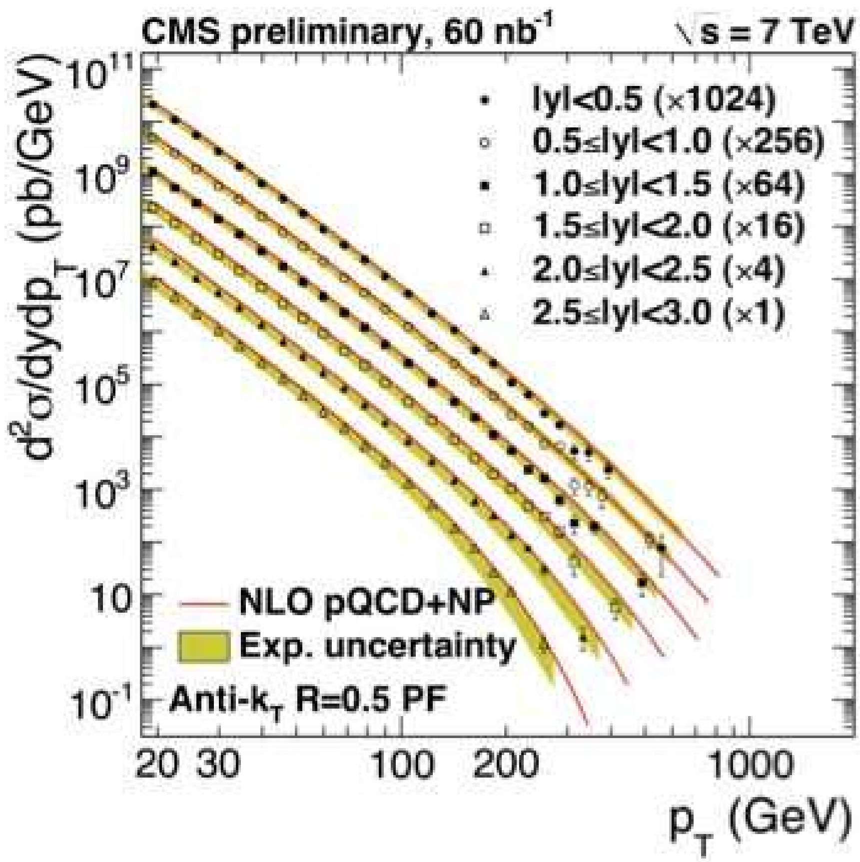
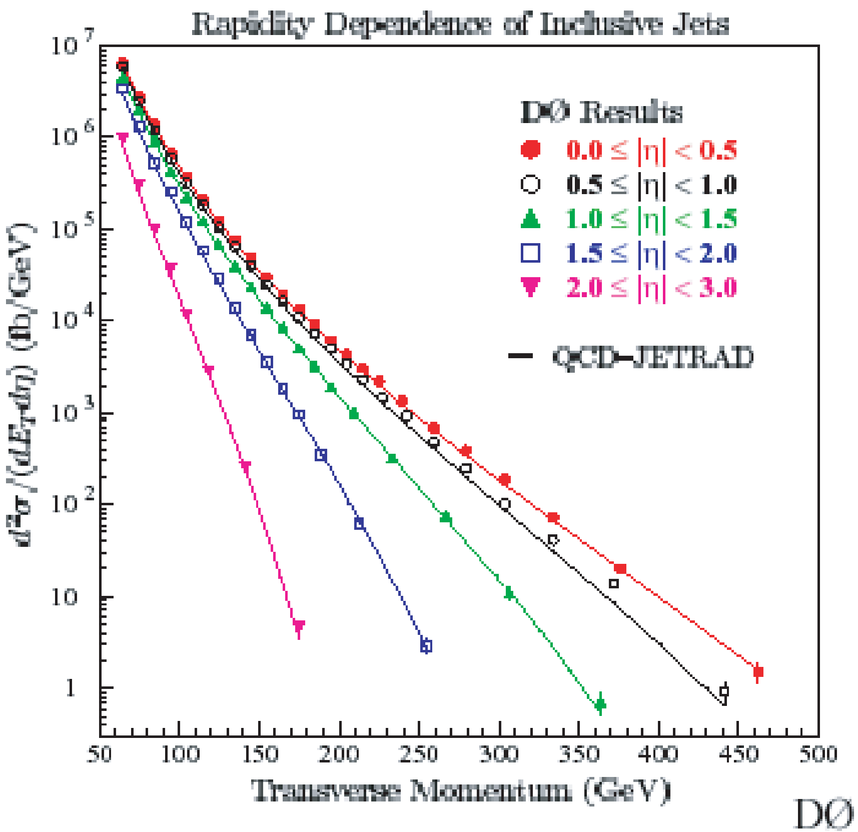
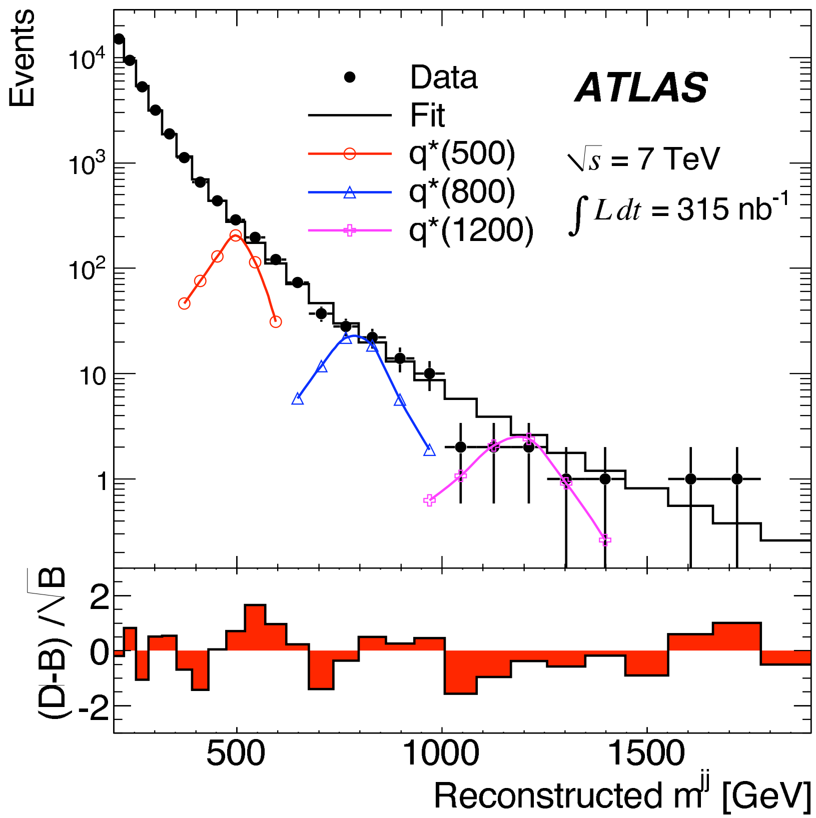
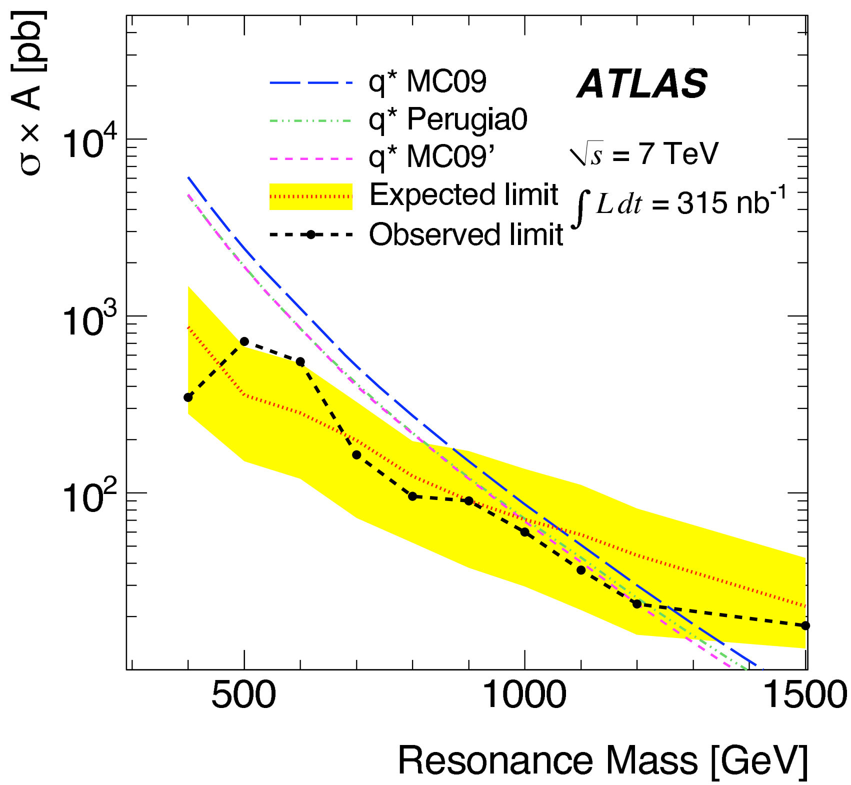



LHC QCD results have gone BEYOND the Tevatron, entering the discovery era !

# ... And have gone on to the physics BSM :

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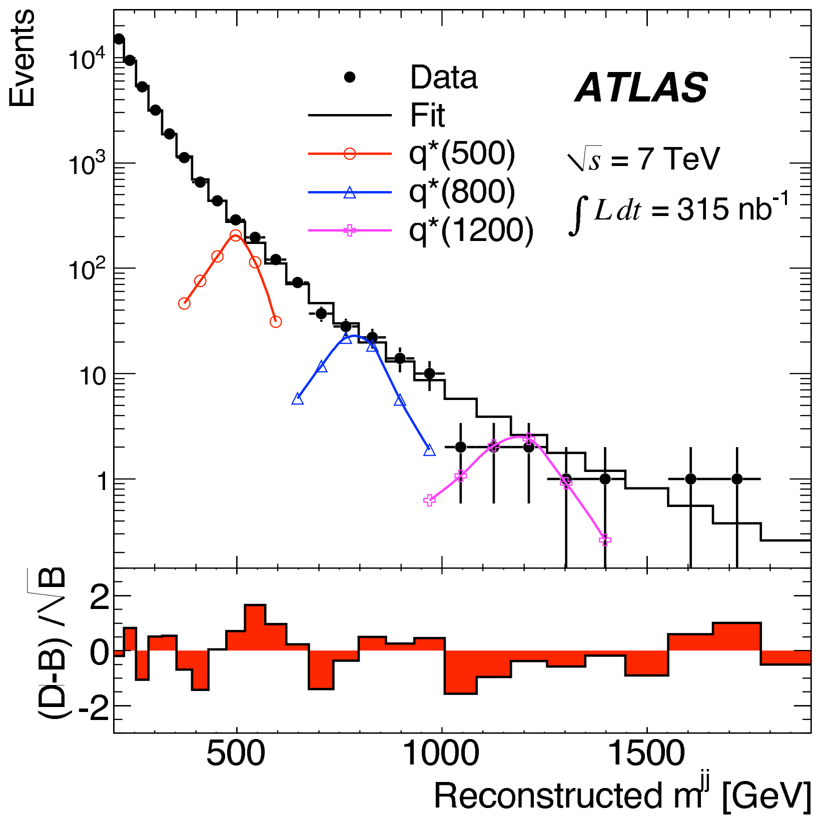


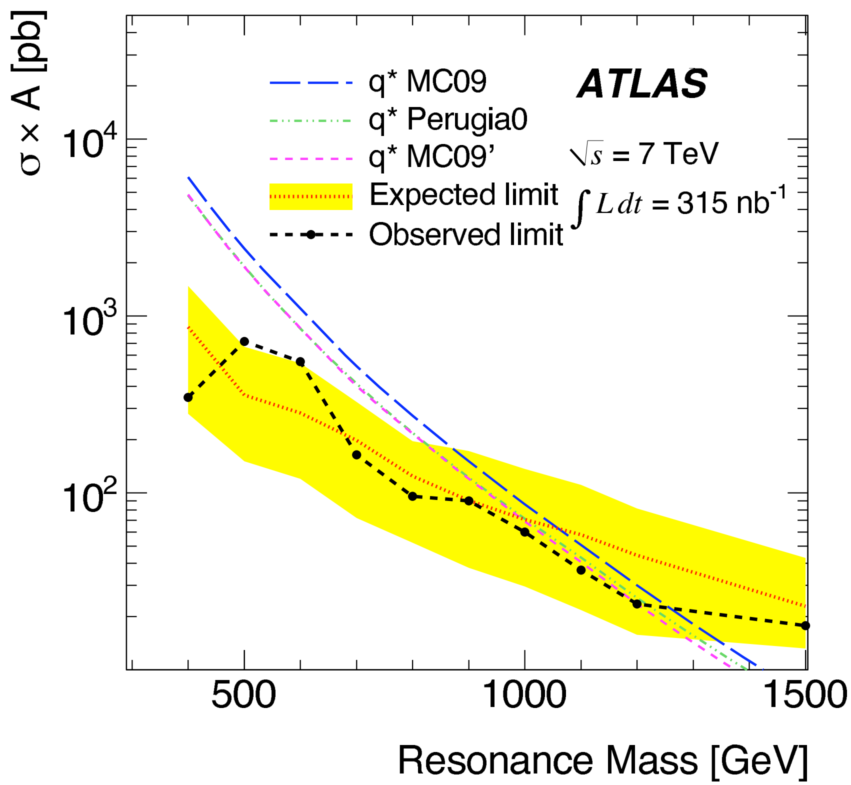


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First BSM physics search beyond the Tevatron reach !

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$$R \to jj,\ \ell^+\ell^-,\ \ell j,\ \dots$$

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- color octet scalar/vector: $\pi_{TC},\ \rho_{TC},\ S_2,\ g_{KK}$, axigluon ...

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C.W. Bauer, Z. Ligeti, M Schmaltz, J. Thaler, D.G.E. Walker

arXiv:0909.5213 [hep-ph]

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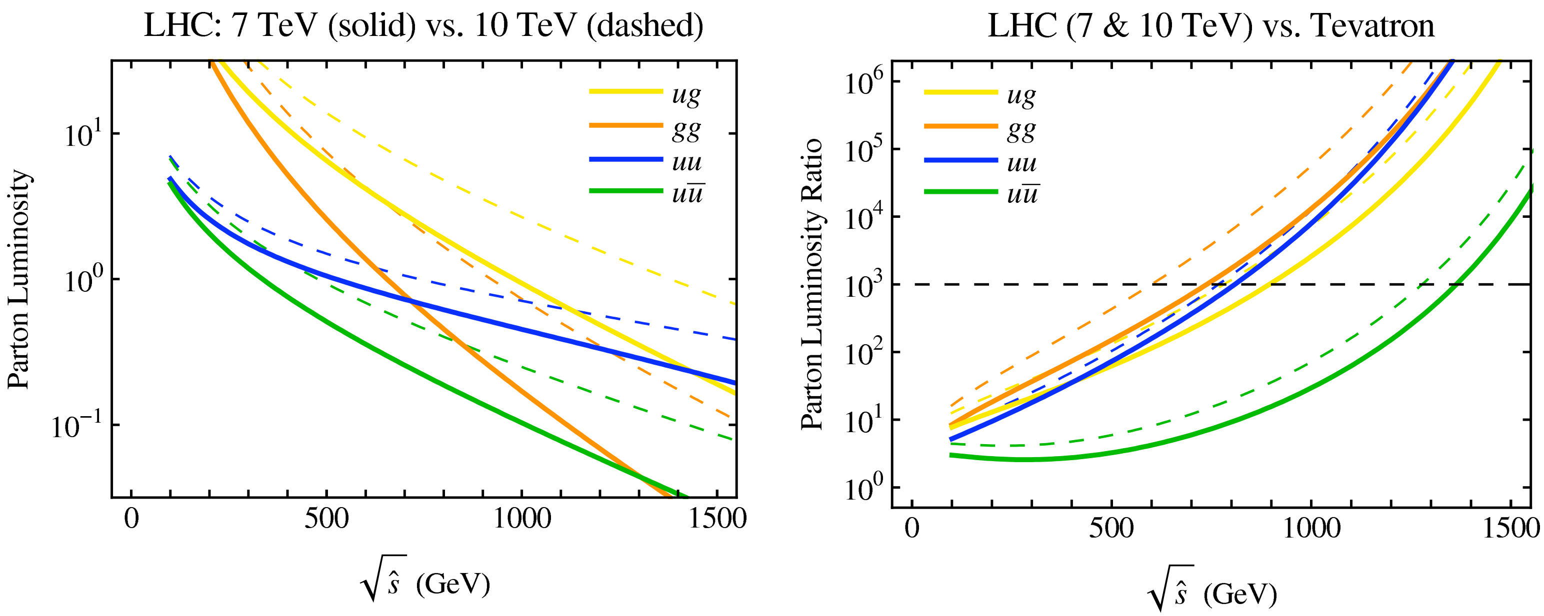
that give large, easy, early signals:



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" ... Among many possibilities, I regard the discovery of a diquark resonance [Bauer:2009cc] (for which the $pp$ collisions of the LHC offer higher sensitivity than the $\bar{p}p$ collisions of the Tevatron) as not so plausible, but the early observation of a fourth-generation quark [soni,...] as not so implausible. "

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We take an “anti-model” measure *

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# "Simplified Models"

## Quantum numbers $(SU_3, SU_2)^J_{Q_e}$

| | | |
|---|---|---|
| $Q$ | $(\mathbf{3},\mathbf{2})^{1/2}_{2/3,-1/3}$ | Left – handed doublet |
| $U$ | $(\mathbf{3},\mathbf{1})^{1/2}_{2/3}$ | Right – handed singlet |
| $D$ | $(\mathbf{3},\mathbf{1})^{1/2}_{-1/3}$ | Right – handed singlet |
| $A$ | $(\mathbf{8},\mathbf{1})^{1}_{0}$ | vector |

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| initial state | $J$ | $SU_C(3)$ | $SU(2)_L$ | $U(1)_Y$ | $\lvert Q_e\rvert$ | $B$ |
|---|---|---|---|---|---|---|
| $QQ$ | 0 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{1} \oplus \mathbf{3}$ | $\frac{1}{3}$ | $\frac{4}{3}, \frac{2}{3}, \frac{1}{3}$ | $\frac{2}{3}$ |
| $QU$ | 1 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{2}$ | $\frac{5}{6}$ | $\frac{4}{3}, \frac{1}{3}$ | $\frac{2}{3}$ |
| $QD$ | 1 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{2}$ | $-\frac{1}{6}$ | $\frac{2}{3}, \frac{1}{3}$ | $\frac{2}{3}$ |
| $UU$ | 0 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{1}$ | $\frac{4}{3}$ | $\frac{4}{3}$ | $\frac{2}{3}$ |
| $DD$ | 0 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{1}$ | $\frac{2}{3}$ | $\frac{2}{3}$ | $\frac{2}{3}$ |
| $UD$ | 0 | $\bar{\mathbf{3}} \oplus \mathbf{6}$ | $\mathbf{1}$ | $\frac{1}{3}$ | $\frac{1}{3}$ | $\frac{2}{3}$ |
| $QA$ | $\frac{1}{2}, \frac{3}{2}$ | $\mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$ | $\mathbf{2}$ | $\frac{1}{6}$ | $\frac{2}{3}, \frac{1}{3}$ | $\frac{1}{3}$ |
| $UA$ | $\frac{1}{2}, \frac{3}{2}$ | $\mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$ | $\mathbf{1}$ | $\frac{2}{3}$ | $\frac{2}{3}$ | $\frac{1}{3}$ |
| $DA$ | $\frac{1}{2}, \frac{3}{2}$ | $\mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$ | $\mathbf{1}$ | $\frac{1}{3}$ | $\frac{1}{3}$ | $\frac{1}{3}$ |
| $AA$ | 0, 1, 2 | $\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \bar{\mathbf{10}} \oplus \mathbf{27}$ | $\mathbf{1}$ | 0 | 0 | 0 |
| $Q\bar{Q}$ | 1 | $\mathbf{1} \oplus \mathbf{8}$ | $\mathbf{1} \oplus \mathbf{3}$ | 0 | 1, 0 | 0 |
| $Q\bar{U}$ | 0 | $\mathbf{1} \oplus \mathbf{8}$ | $\mathbf{2}$ | $-\frac{1}{2}$ | 1, 0 | 0 |
| $Q\bar{D}$ | 0 | $\mathbf{1} \oplus \mathbf{8}$ | $\mathbf{2}$ | $\frac{1}{2}$ | 1, 0 | 0 |
| $U\bar{U},\ D\bar{D}$ | 1 | $\mathbf{1} \oplus \mathbf{8}$ | $\mathbf{1}$ | 0 | 0 | 0 |
| $U\bar{D}$ | 1 | $\mathbf{1} \oplus \mathbf{8}$ | $\mathbf{1}$ | 1 | 1 | 0 |

# Gauge-invariant interactions:

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There are 7 (EW) states:

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$$V^\mu_U \sim \mathbf{(\bar{3} \oplus 6, 2)^1_{4/3,1/3}} \quad \mathbf{V^\mu_D \sim (\bar{3} \oplus 6, 2)^1_{1/3,-2/3}}.$$

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$$V_U^\mu \sim (\bar{\mathbf{3}} \oplus \mathbf{6}, \mathbf{2})^{\mathbf{1}}_{\mathbf{4/3,1/3}} \quad \mathbf{V}^\mu_{\mathbf{D}} \sim (\bar{\mathbf{3}} \oplus \mathbf{6}, \mathbf{2})^{\mathbf{1}}_{\mathbf{1/3,-2/3}}.$$

Gauge-invariant operators:

$$\begin{aligned}\mathcal{L}_{qqD} \sim \ & \bar{K}_j^{ab}\Big[y_{\alpha\beta}\bar{Q}_{\alpha a} i\sigma_2 \Phi^j Q^C_{\beta b} + \kappa_{\alpha\beta}\Phi^j_{1/3}\bar{Q}_{\alpha a} i\sigma_2 Q^C_{\beta b} \\ & + \lambda^{1/3}_{\alpha\beta}\Phi^j_{1/3}\bar{U}_{\alpha a} D^C_{\beta b} + \lambda^{2/3}_{\alpha\beta}\Phi^j_{-2/3}\bar{D}_{\alpha a} D^C_{\beta b} + \lambda^{4/3}_{\alpha\beta}\Phi^j_{4/3}\bar{U}_{\alpha a} U^C_{\beta b} \\ & + \lambda^U_{\alpha\beta}\bar{U}_{\alpha a} V_U^{j\dagger\mu}\gamma_\mu Q^C_{\beta b} + \lambda^D_{\alpha\beta}\bar{D}_{\alpha a} V_D^{j\dagger\mu}\gamma_\mu Q^C_{\beta b}\Big] + \text{h.c.},\end{aligned}$$

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After EWSB: $E^j_{(\mu)}, U^j_{(\mu)}, D^j_{(\mu)}$ (color $j = \mathbf{\bar{3}},\ \mathbf{6}$ and charges $4/3,\ -2/3,\ 1/3$)

$$\begin{aligned}\mathcal{L}_{qqD} \ =\ & \bar{K}^{ab}_j \big[ \lambda^E_{\alpha\beta} E^j\ \bar{u}_{\alpha a} P_L C \bar{u}^T_{\beta b} + \lambda^U_{\alpha\beta} U^j\ \bar{d}_{\alpha a} P_L C \bar{d}^T_{\beta b} + \lambda^D_{\alpha\beta} D^j\ \bar{u}_{\alpha a} P_L C \bar{d}^T_{\beta b} \\ & + \lambda^{E'}_{\alpha\beta} E^{j\mu}\ \bar{u}_{\alpha a} \gamma_\mu C P_R \bar{u}^T_{\beta b} + \lambda^{U'}_{\alpha\beta} U^{j\mu}\ \bar{d}_{\alpha a} \gamma_\mu C P_R \bar{d}^T_{\beta b} \\ & + \lambda^{D'}_{\alpha\beta} D^{j\mu} (\bar{u}_{\alpha a} \gamma_\mu C P_R \bar{d}^T_{\beta b} + \bar{d}_{\alpha a} \gamma_\mu C P_R \bar{u}^T_{\beta b}) \big] + \text{h.c.}\end{aligned}$$

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They are: $\tilde{q},\ D_{qq},\ ...$

(Must adopt Minimal Flavor Violation.)

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There are 4 (EW) states:

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(Not consider fermion higher dim. representations.)

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Gauge-invariant operators at dim-5:

$$\mathcal{L}_{qgF} \sim \frac{g_s}{\Lambda} G^{a\mu\nu} \left[\lambda^L \bar{Q} \bar{K}_a \sigma_{\mu\nu} \rho + \lambda^U \bar{U} \bar{K}_a \sigma_{\mu\nu} \rho_U + \lambda^D \bar{D} \bar{K}_a \sigma_{\mu\nu} \rho_D\right] + \text{h.c.}$$

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(Not consider fermion higher dim. representations.)

Gauge-invariant operators at dim-5:

$$\mathcal{L}_{qgF} \sim \frac{g_s}{\Lambda} G^{a\mu\nu} \left[ \lambda^L \bar{Q} \bar{K}_a \sigma_{\mu\nu} \rho + \lambda^U \bar{U} \bar{K}_a \sigma_{\mu\nu} \rho_U + \lambda^D \bar{D} \bar{K}_a \sigma_{\mu\nu} \rho_D \right] + \text{h.c.}$$

After EWSB: $d^*_j$, $u^*_j$ (color $j = \mathbf{3}$, $\bar{\mathbf{6}}$ and charges $-1/3$, $2/3$)

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## (3). $\underline{\mathbf{8} \otimes \mathbf{8} = \mathbf{1} \oplus \mathbf{8} \oplus \ldots}$

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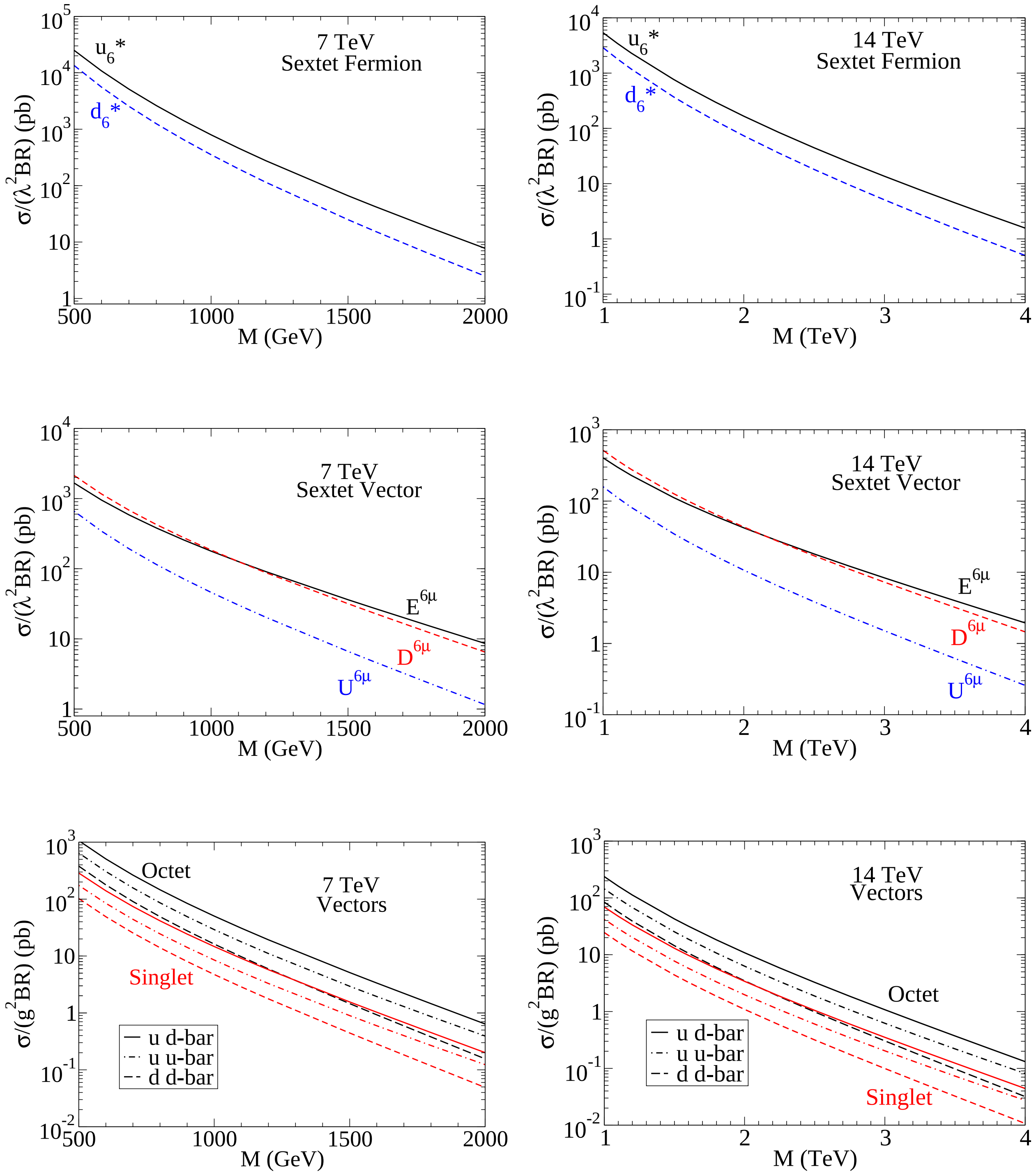
skipped here.



7 TeV
Sextet Fermion
u6*
d6*
σ/(λ2BR) (pb)
M (GeV)
14 TeV
Sextet Fermion
u6*
d6*
σ/(λ2BR) (pb)
M (TeV)
7 TeV
Sextet Vector
E6μ
D6μ
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Singlet
u d-bar
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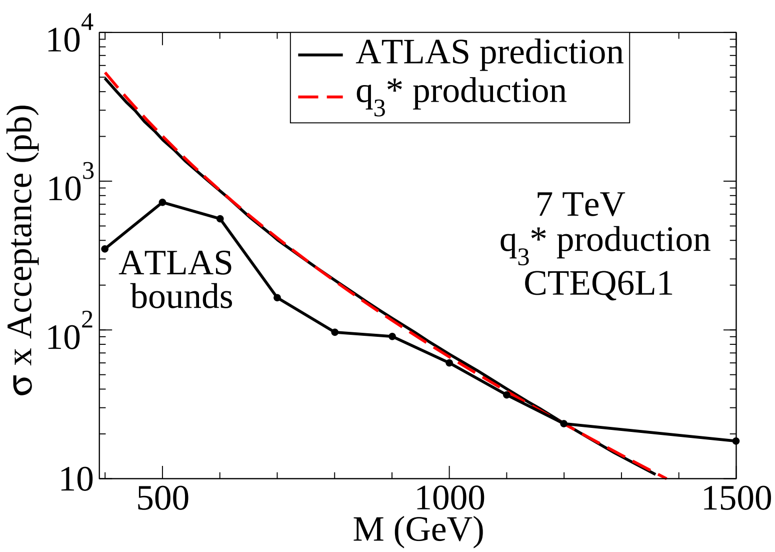
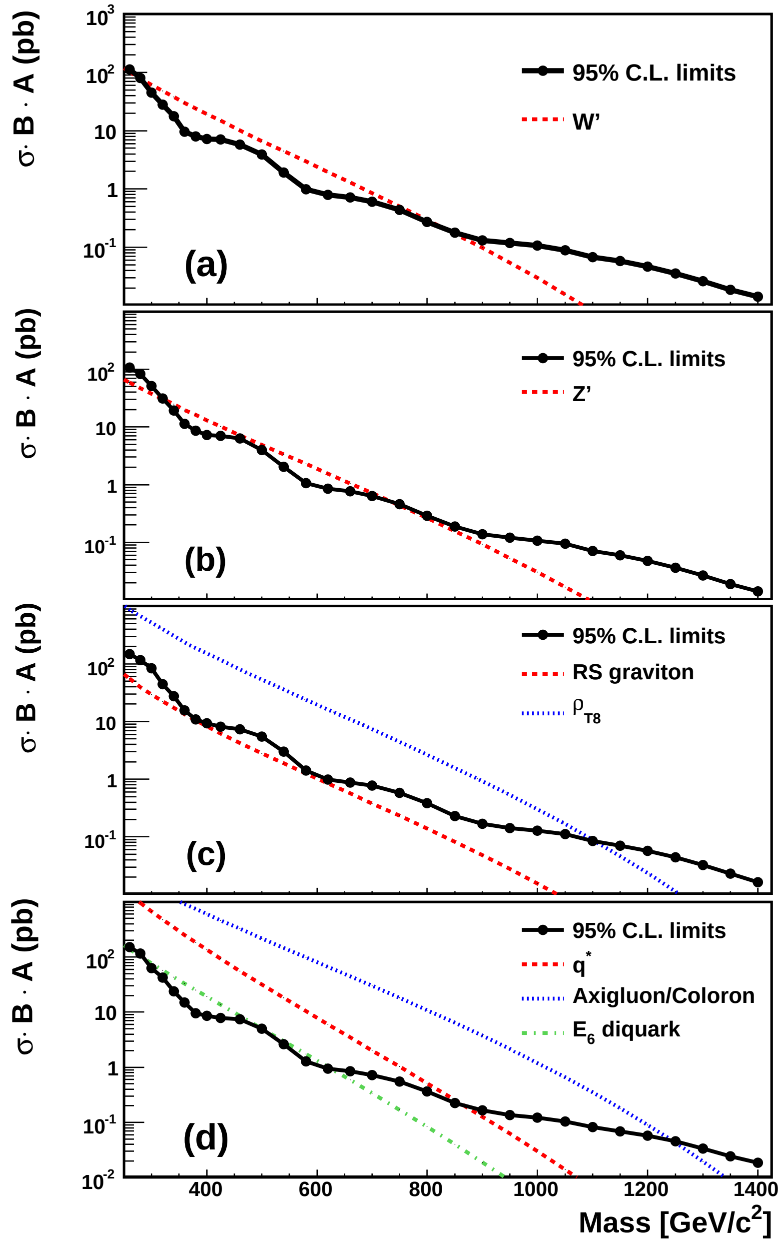
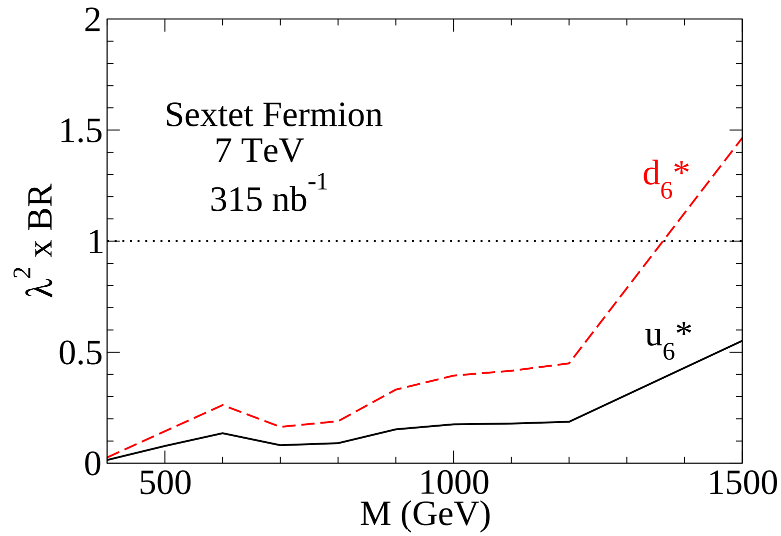
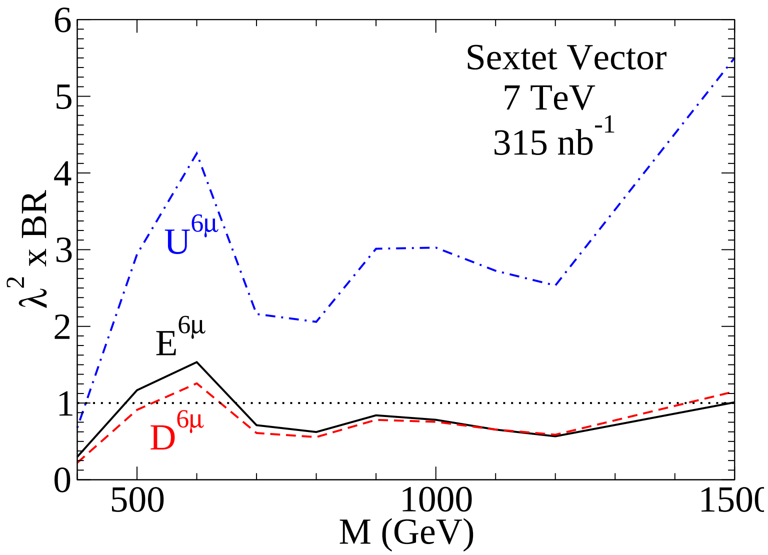
# ATLAS/CDF Bounds from di-jet:

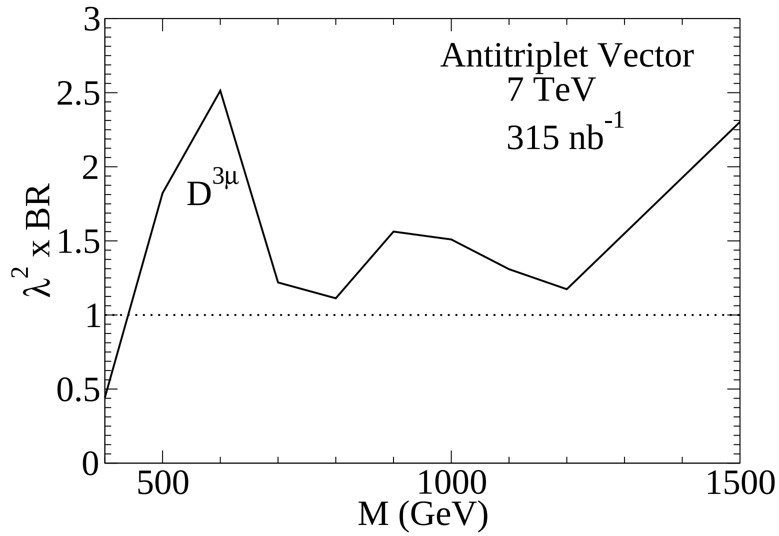


# More bounds from ATLAS di-jet result:



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## Real excitement yet to come !