

The search for new physics (at the LHC)

*Paris Sphicas
CERN & University of Athens
CERN Summer Student program
July 28 - 30, 2014*

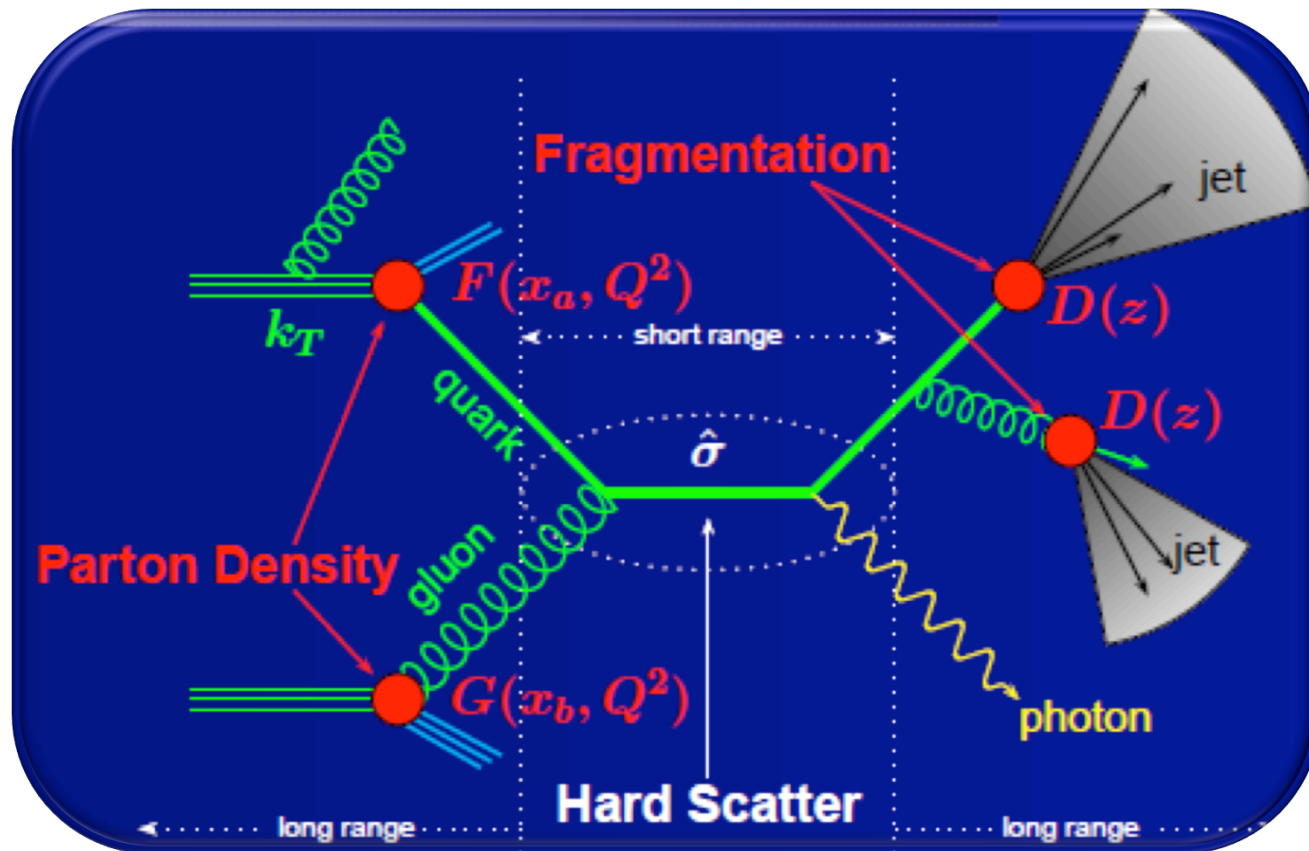
- **Prelude – reminder of the prerequisites**
 - ◆ Why we believe there should be new physics BSM
 - ◆ Proving that there is “new physics”; main prerequisites: understanding the detector, understanding (measuring) Standard Model physics at 7 and 8 TeV
 - ◆ What happens when we do not find a new signal [limits]
- **Searching for New Physics**
 - ◆ Searching for substructure, new interactions
 - ◆ Searches for extra dimensions and other Exotica
 - ◆ Supersymmetry [SUSY]
- **Summary**

So what new physics?

Many (many) possibilities

- **New strong interactions?**
 - ◆ Technicolor; excited quarks; compositeness; new “contact” interactions
- **Exotica:**
 - ◆ Weird stuff: leptoquarks?
 - ◆ New “forces”?
 - New resonances (W-Z-like)
 - ◆ More generations?
 - Fourth generation (b')
 - ◆ Gravity descending at the TeV scale?
 - New resonances; missing stuff; black holes; SUSY-like signatures [Universal Extra dimensions]
- **Supersymmetry (SUSY)**
 - ◆ (super) partners to all that we have in the SM
 - production of squarks, gluinos, sleptons, gauginos,...
- **SUSY-inspired exotica:**
 - ◆ Long-lived massive (new) particles?
- **Some true inspirations: “hidden valleys”?**

parton-parton scattering and QCD



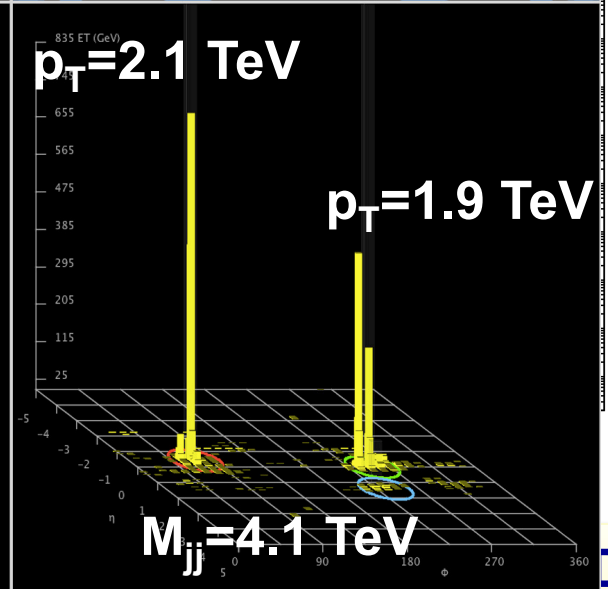
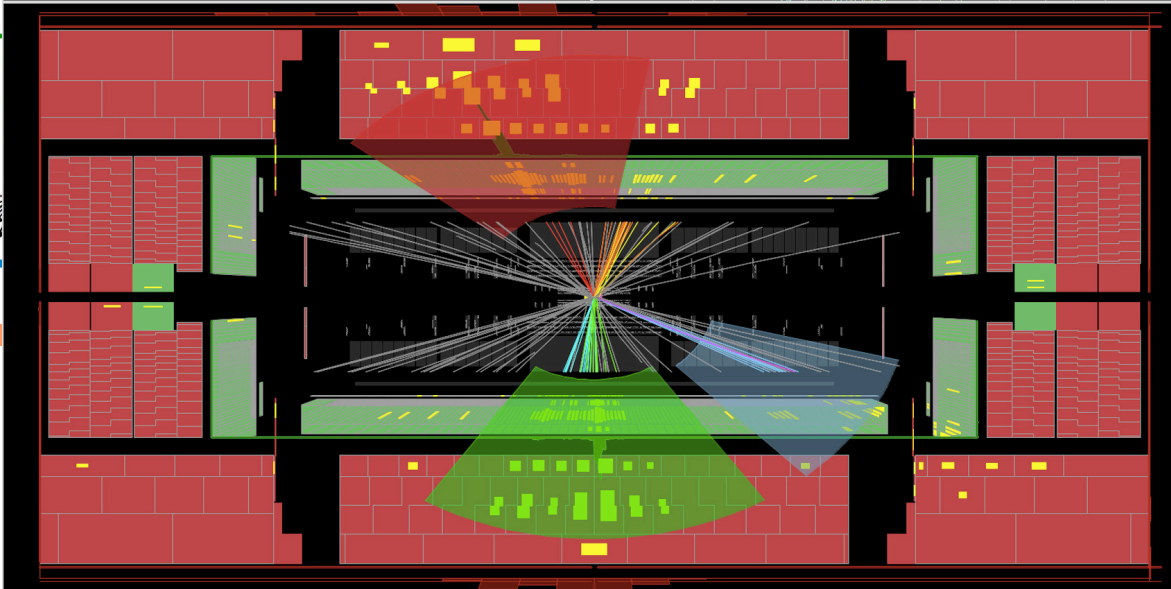
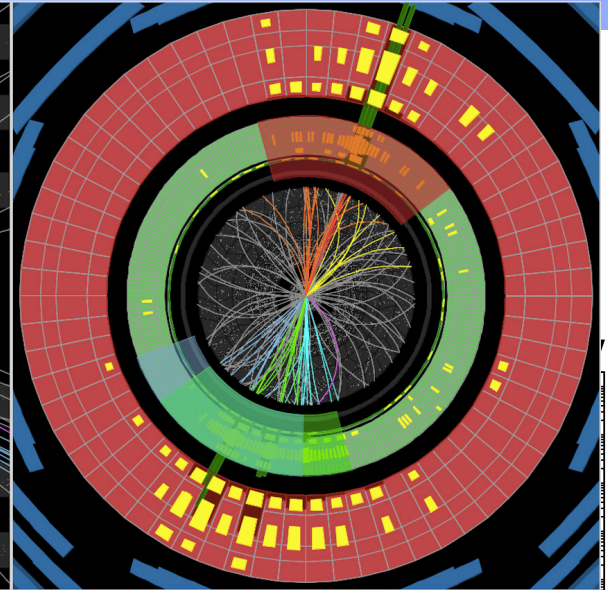
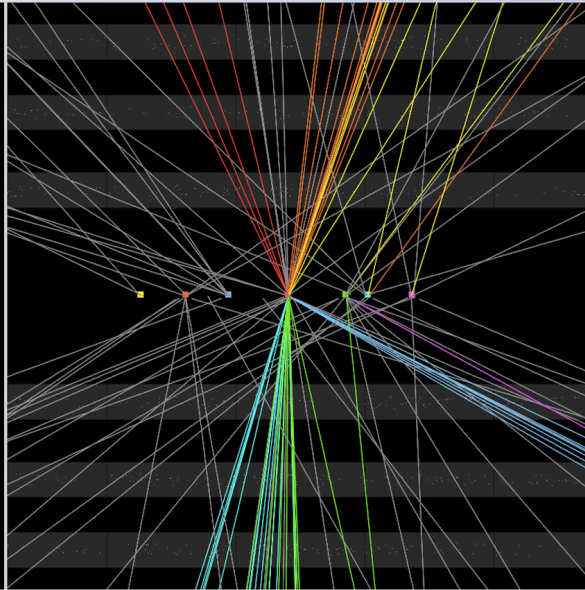
Jets



ATLAS EXPERIMENT

Run Number: 205113, Event Number: 34879440

Date: 2012-06-18 12:25:45 CEST

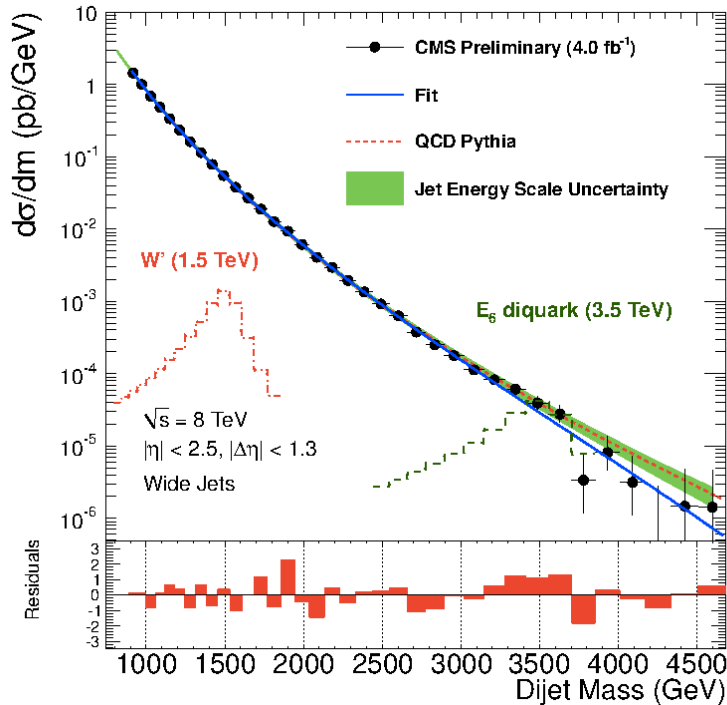
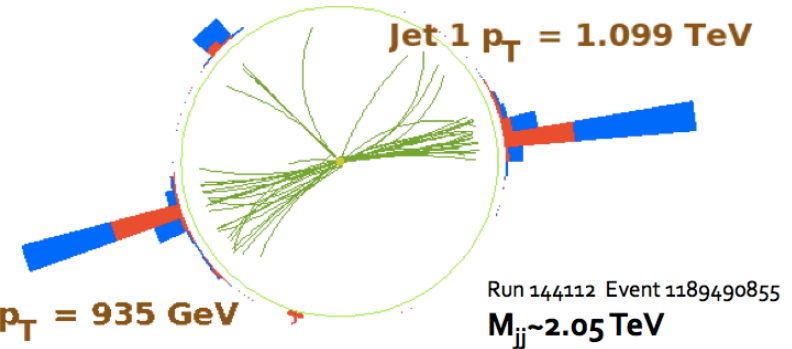


How would new structure show up?

- **If quarks are composite, i.e. they are made of other “stuff”, then there will be excited states, q^* , which would decay to a quark and a neutral boson (gluon, photon or Z)**
 - ◆ **Look for following decays: $q^* \rightarrow qg$; $q^* \rightarrow q\gamma$, $q^* \rightarrow qZ$**
 - ◆ **Signature: resonance in di-jet, photon+jet or Z+jet mass spectrum**
- **The scattering of two quarks (and gluons, and quarks against gluons) will not follow QCD but will show deviations from the exchange of a new boson**
 - ◆ **Signature: the angular distribution of two-jet events will look different from “Rutherford scattering with scaling violations”**

Dijet mass (and search)

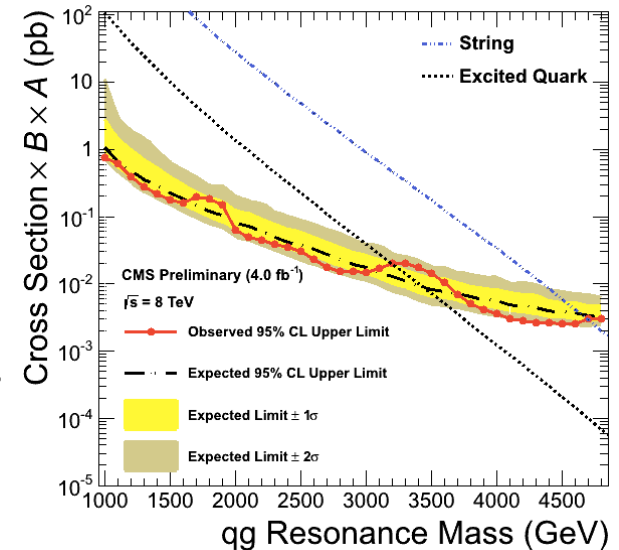
- Very early search for numerous resonances BSM: string resonance, excited quarks, axi-gluons, colorons, E6 diquarks, W' & Z' , RS gravitons



Four-parameter fit to describe QCD shape

$$\frac{d\sigma}{dm} = p_0 \frac{\left(1 - \frac{m}{\sqrt{s}}\right)^{p_1}}{\left(\frac{m}{\sqrt{s}}\right)^B};$$

$$B = p_2 + p_3 \left(m / \sqrt{s}\right)$$



$M(q^*) > 3.1 \text{ TeV}$

Excited quarks (continued)

Decays into quark and photon?

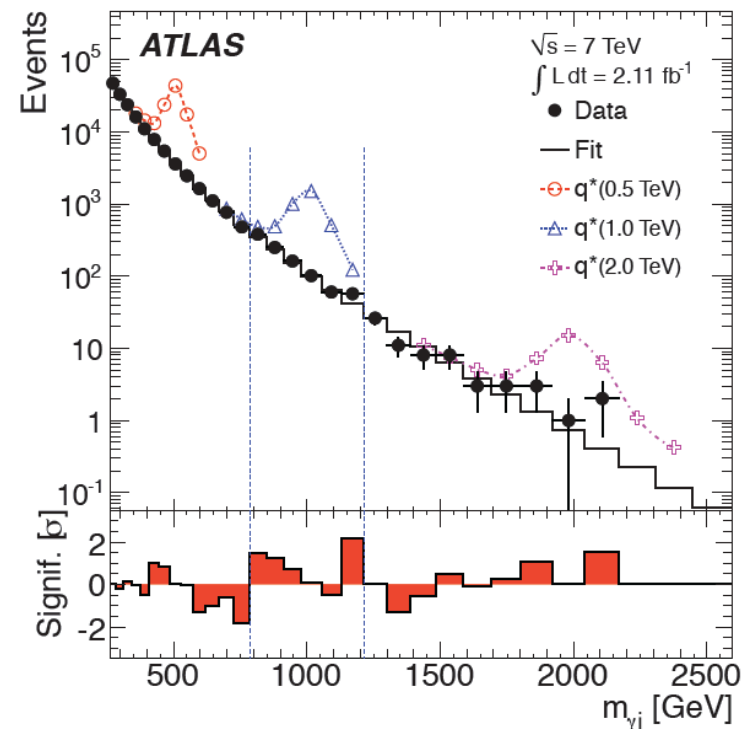
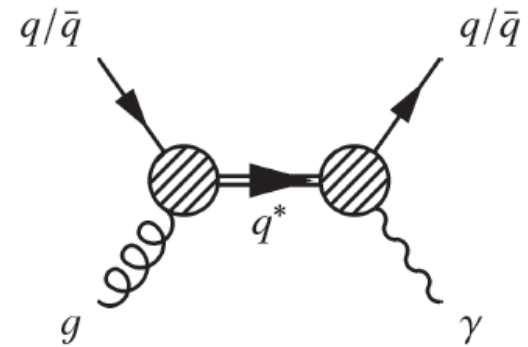
Kinematic selection

(acceptance)

- $p_{T\gamma} > 85$ GeV
- $p_{Tjet} > 30$ GeV
- $m_{\gamma j} > 260$ GeV
- $\Delta R(\gamma, j) > 0.4$
j is any jet w $p_T > 30$ GeV

Background: by fit to data across all bins (same form as for dijets)

- ◆ Run “BumpHunter”: most significant excess in $784 < M_{\gamma j} < 1212$ GeV (p -value = 0.20)



Excited quarks (continued)

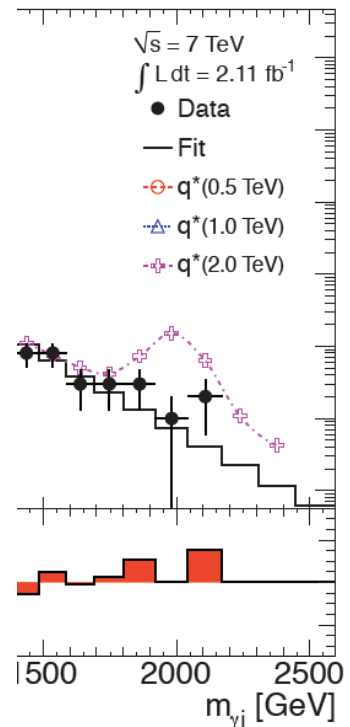
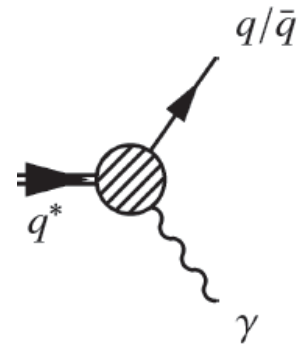
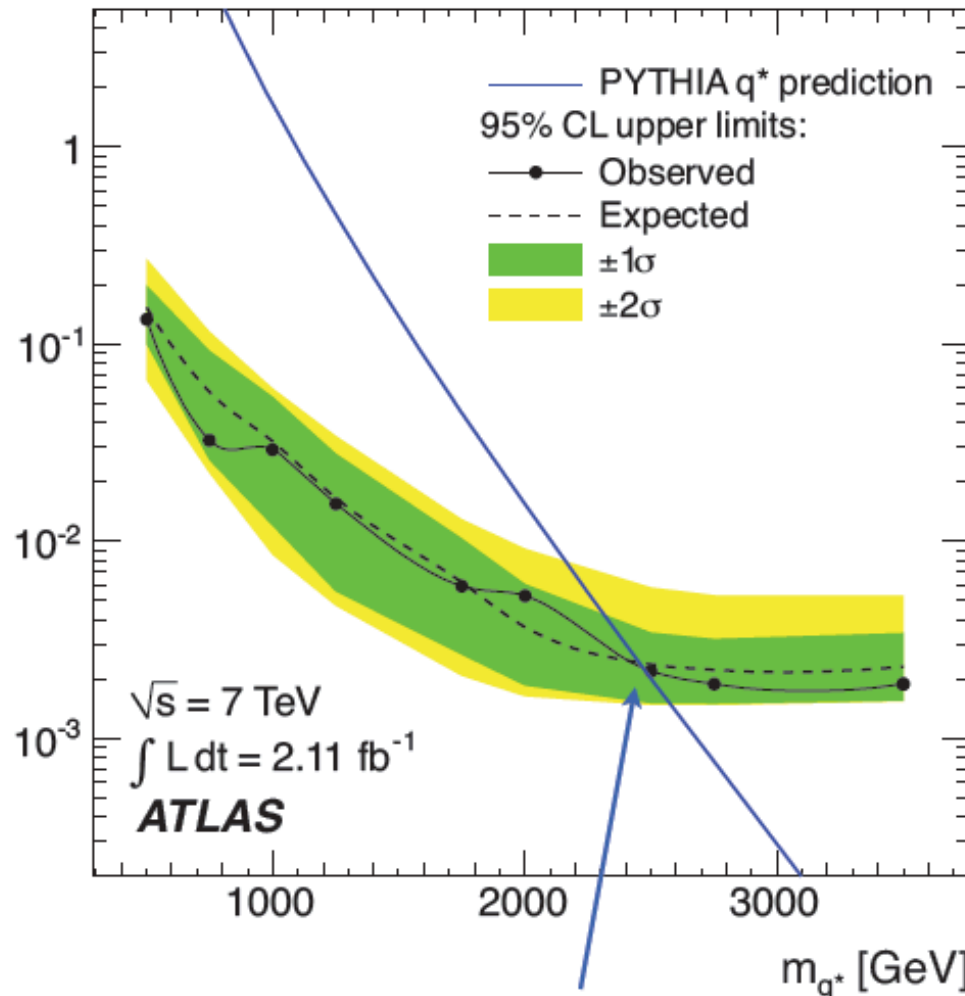
Decays in

Kinem

- $p_{T\gamma} > \epsilon$
 - $p_{Tjet} > \epsilon$
 - $m_{\gamma j} > \epsilon$
 - $\Delta R(\gamma, j) > \epsilon$
- $\sigma \times \mathcal{B} \times A \times \epsilon$ [pb]
- (a)
- j is any

Background across all for dijets)

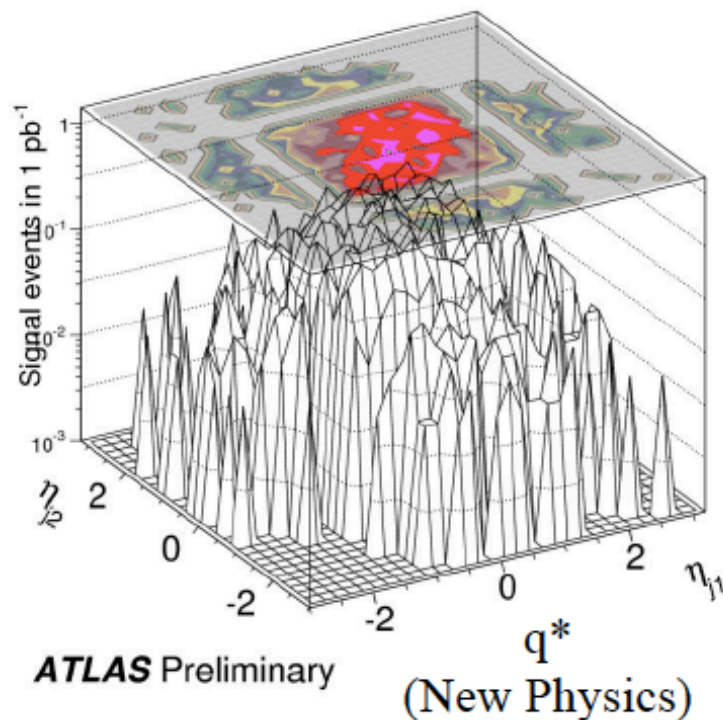
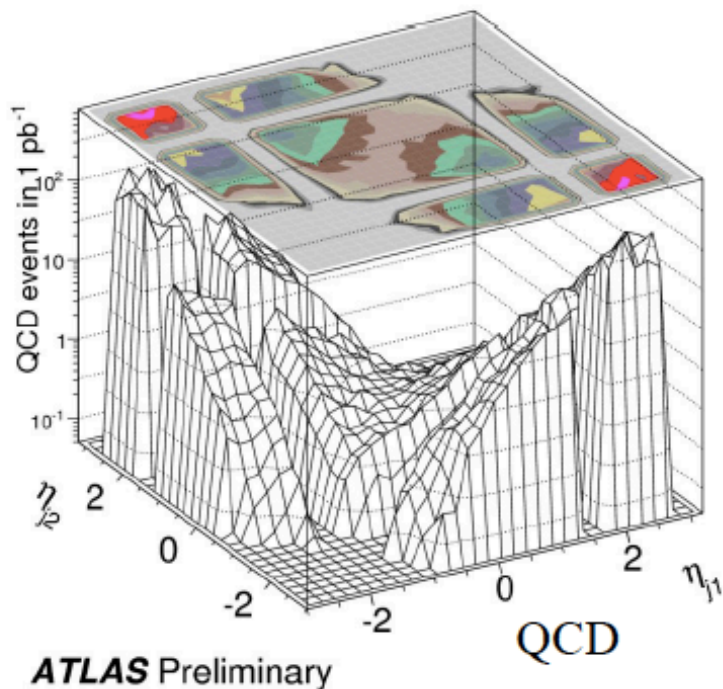
- ◆ Run “Bu significance <1212 G



*Excited quark cross section limit:
 2.46 TeV @ 95% CL*

Angular distributions

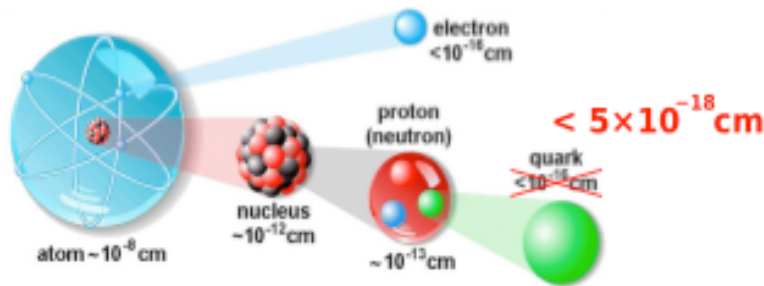
- **New physics: presumably high-mass; so not boosted along z-axis; so more “central”!**
 - ◆ Angular distribution in QCD background different than that from various signals [e.g. an excited quark, decaying to two jets; or jets from “stronger scattering”]



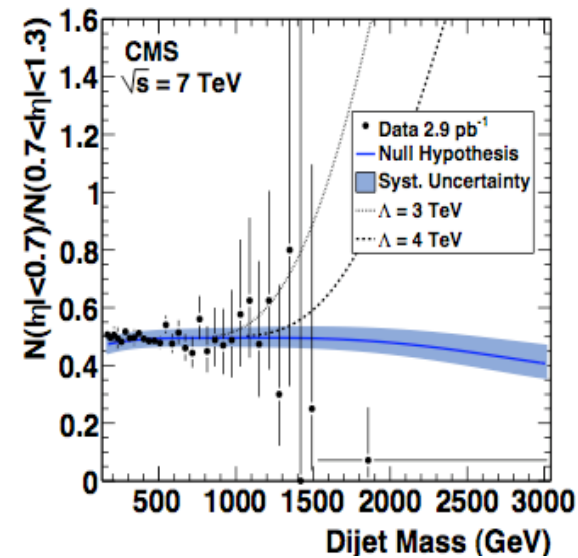
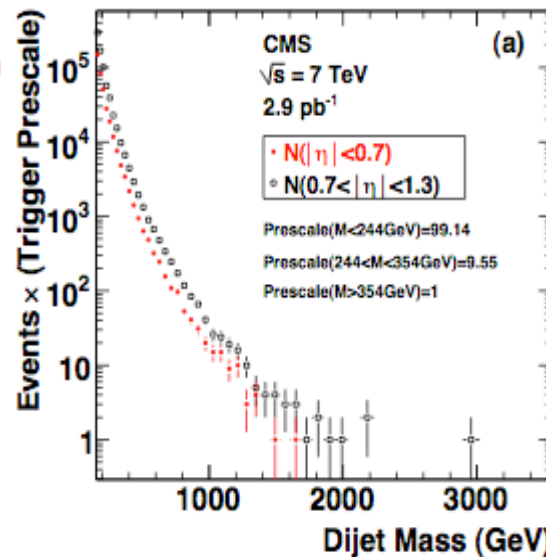
Quark compositeness

- **Centrality ratio: events with two central leading jets to events with both leading jets**
 - ◆ Sensitive to deviations from the SM from quark sub-structure.

$$R_\eta = \frac{\sum_{|\eta| < 0.7} Dijets}{\sum_{0.7 < |\eta| < 1.3} Dijets}$$



arXiv:1010.4439

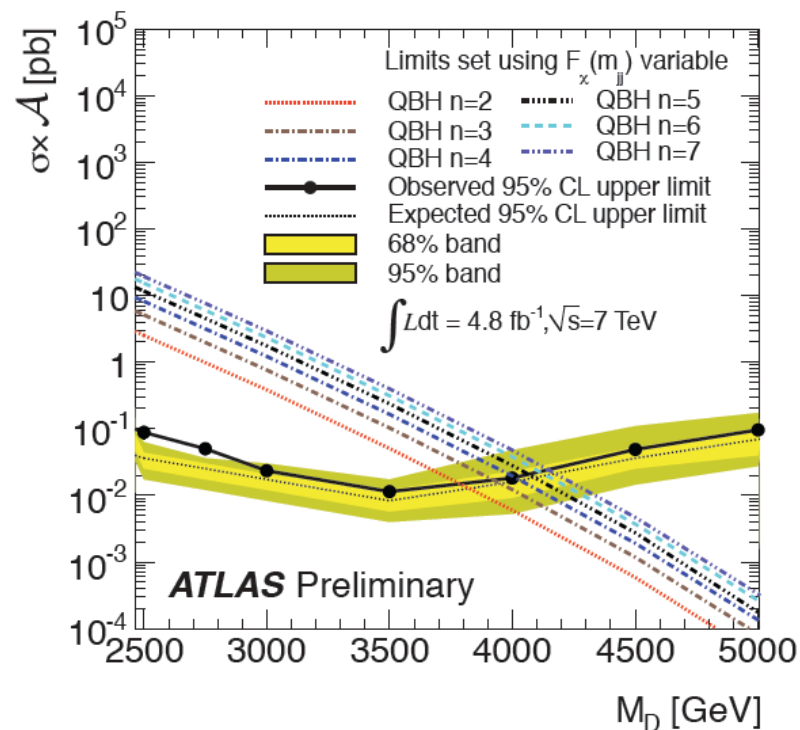
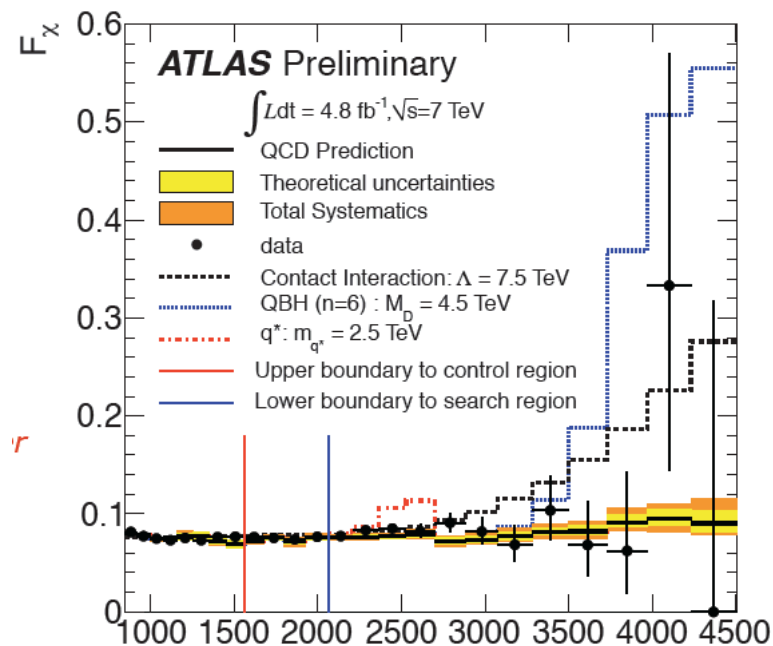


Very small dependence of ratio on m_{jj} . Agreement with QCD.
Exclude (95%CL) quark compositeness for $\Lambda < 4.0 \text{ TeV}$.

Search for quark compositeness

■ ATLAS at 4.8 fb^{-1} , at 7 TeV

$$F_\chi = N(|y^*| < 0.6) / N(|y^*| < 1.7)$$

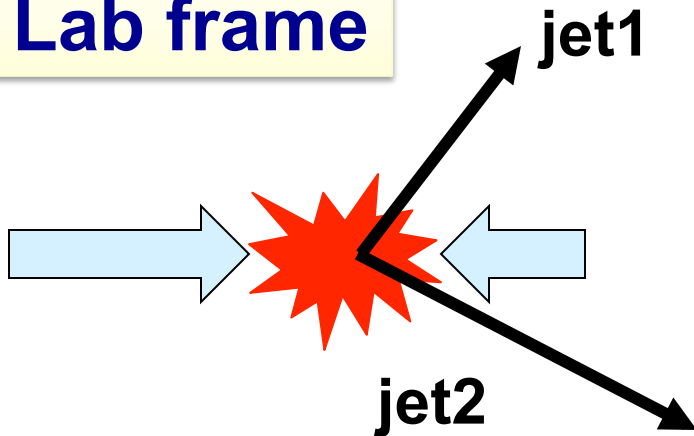


Quark Contact Interaction:
 $\Lambda > 8.2 \text{ TeV}$.

Limits in extra dimensions:
 (n=2) $M_D > 3.8 \text{ TeV}$;
 (n=6) $M_D > 4.1 \text{ TeV}$

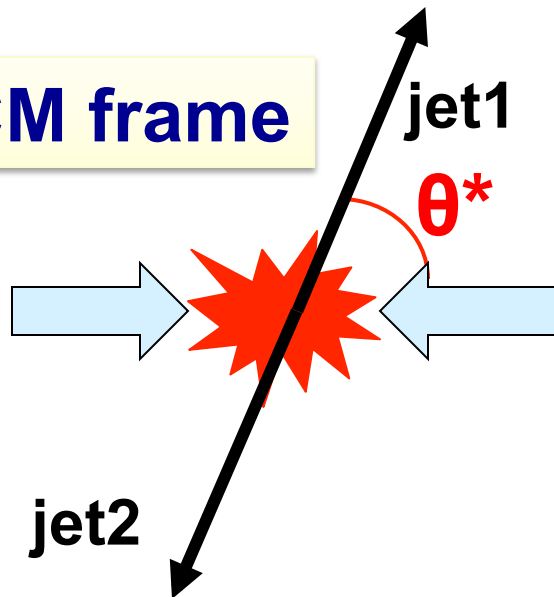
Parton-parton scattering (“2 to 2 process”)

Lab frame



$$y_{boost} = \frac{1}{2}(y_1 + y_2) = \frac{1}{2} \ln \frac{x_1}{x_2}$$

CM frame



$$x_1 = (2p_T/\sqrt{s}) e^{y_{boost}} \cosh y^*$$
$$x_2 = (2p_T/\sqrt{s}) e^{-y_{boost}} \cosh y^*$$

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

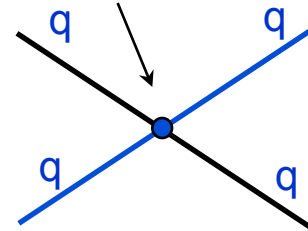
Contact interactions & Dijet Angular Distributions

$$d\sigma \sim [\text{QCD} + \text{Interference} + \text{Compositeness}]$$

$$\alpha_s^2(\mu^2) \frac{1}{\hat{t}^2}$$

$$\alpha_s(\mu^2) \frac{1}{\hat{t}} \cdot \frac{\hat{u}^2}{\Lambda^2}$$

$$\left(\frac{\hat{u}}{\Lambda^2} \right)^2$$



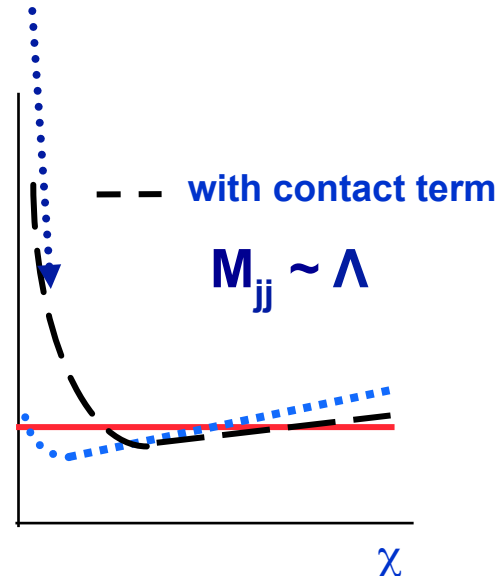
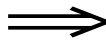
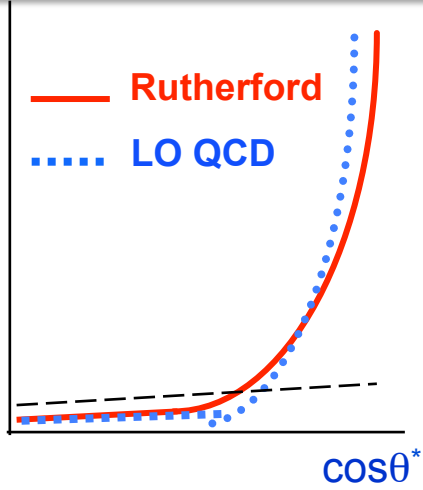
$$\sqrt{\hat{s}} \ll \Lambda$$

$$d\sigma \sim 1/(1-\cos\theta^*)^2$$

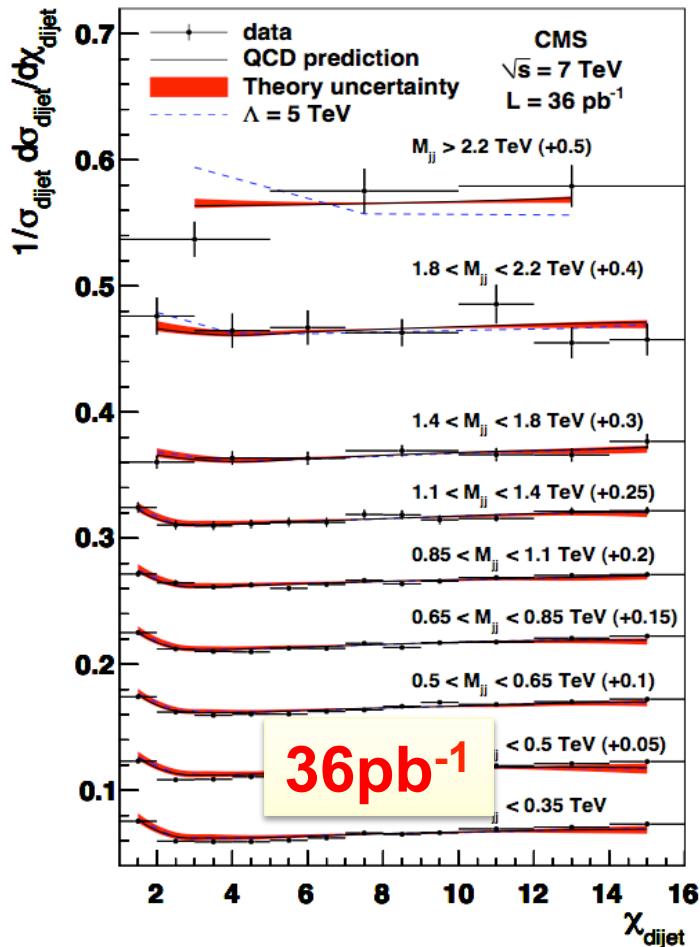
$$d\sigma \sim (1+\cos\theta^*)^2$$

Instead of $\cos\theta^*$, use:
 $dN/d\chi$ sensitive to
 contact interactions

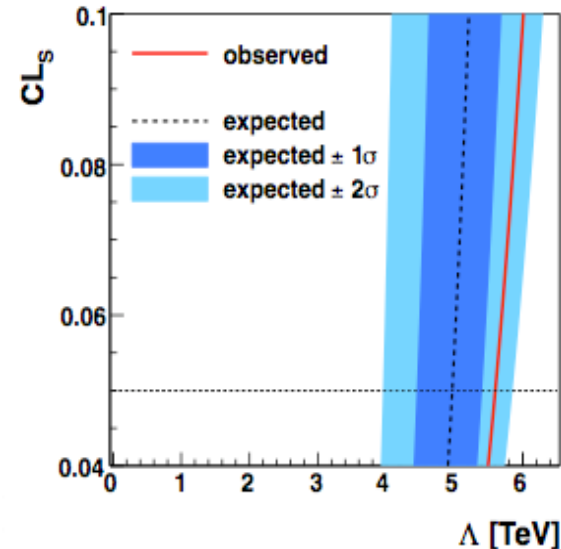
$$\chi = \frac{1 + \cos\theta^*}{1 - \cos\theta^*} = \exp(2|y^*|)$$



Contact interactions



- The χ distributions do not exhibit any excess at low χ . Good description by QCD.
- Lower limit on scale of contact interaction $\Lambda = 5.6 \text{ TeV}$ (95% CL)

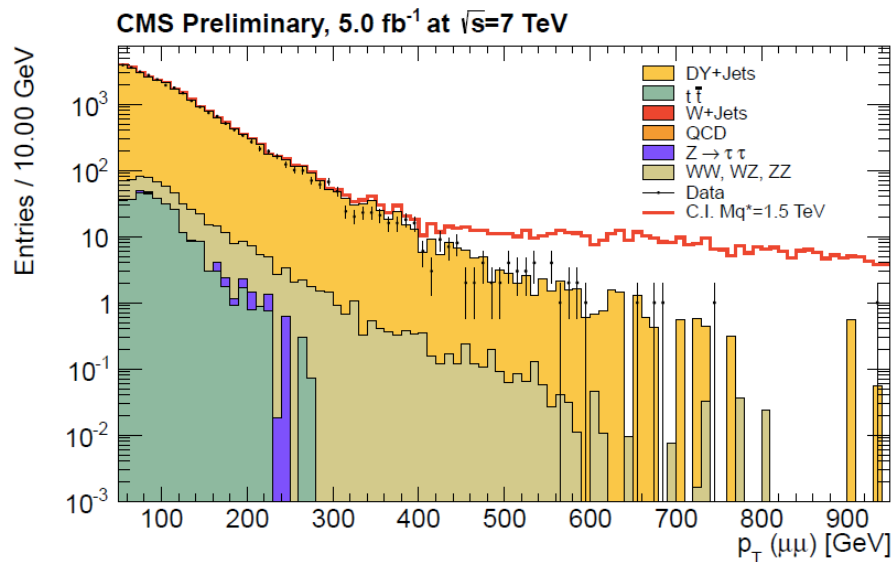


- Most recent results from 7 TeV: **7.8 TeV**

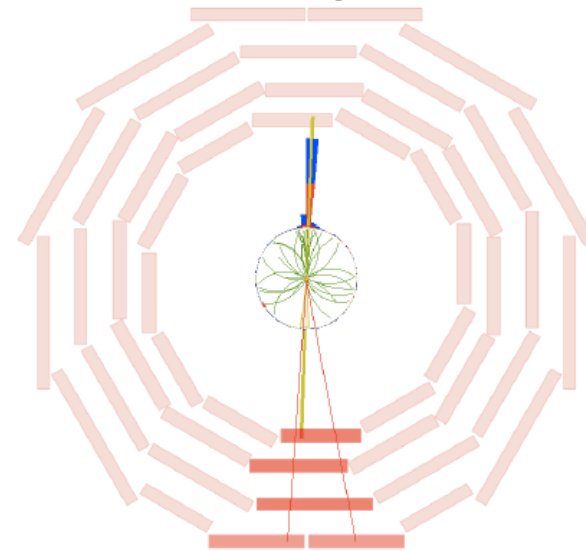
Quark compositeness

■ Decay to jet + Z?

◆ High mass $q^* \rightarrow Z$ with large boost (p_T)



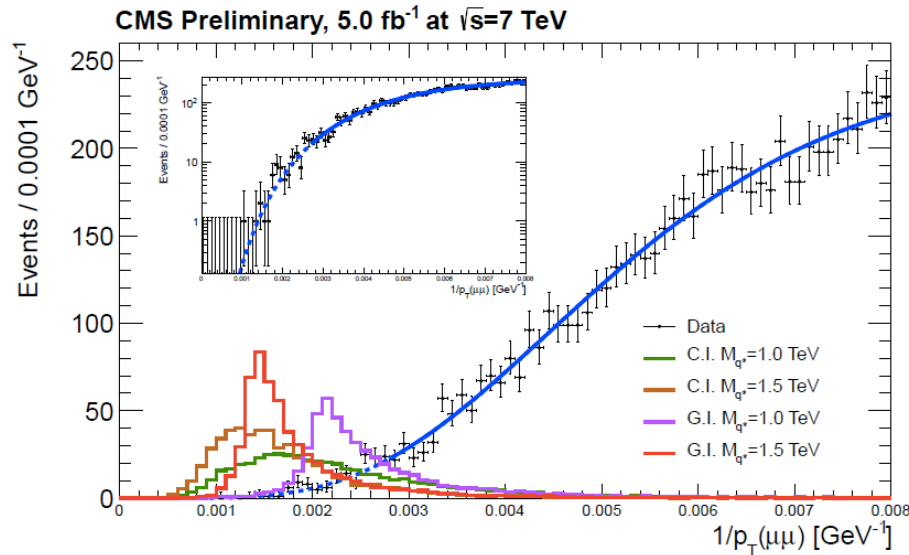
CMS Experiment at LHC, CERN
Data recorded: Sat Apr 23 01:37:06 2011 CEST
Run/Event: 163300 / 101936668
Lumi section: 187
Orbit/Crossing: 48997136 / 57



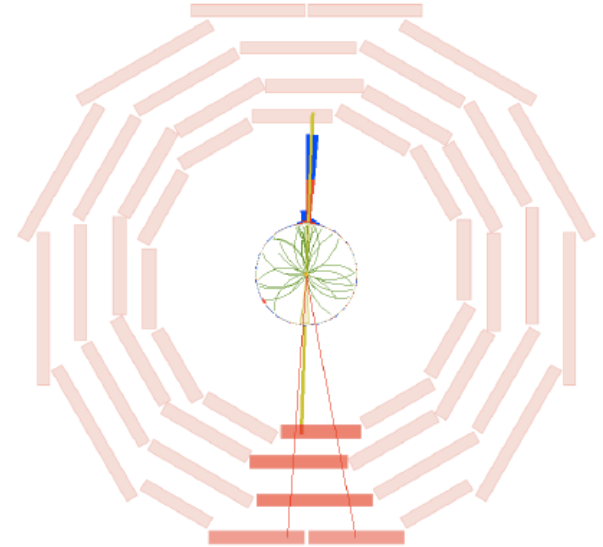
Quark compositeness

■ Decay to jet + Z?

◆ High mass $q^* \rightarrow Z$ with large boost (p_T)



CMS Experiment at LHC, CERN
Data recorded: Sat Apr 23 01:37:06 2011 CEST
Run/Event: 163300 / 101936668
Lumi section: 187
Orbit/Crossing: 48997136 / 57



Main background: DY+jets. Bkg estimate:

(a) template fit to high stats, signal-free region in $1/p_T$: [125-360] GeV

(b) extrapolation to high p_T

Signal efficiency X acceptance $\sim 50-70\%$ (increasing with q^* mass)

Contact Interactions (CI)

- **Cis: low-energy manifestation of “true” phenomena, e.g.**

- ◆ Quark-lepton compositeness
- ◆ Large Extra Dimension (ADD) model

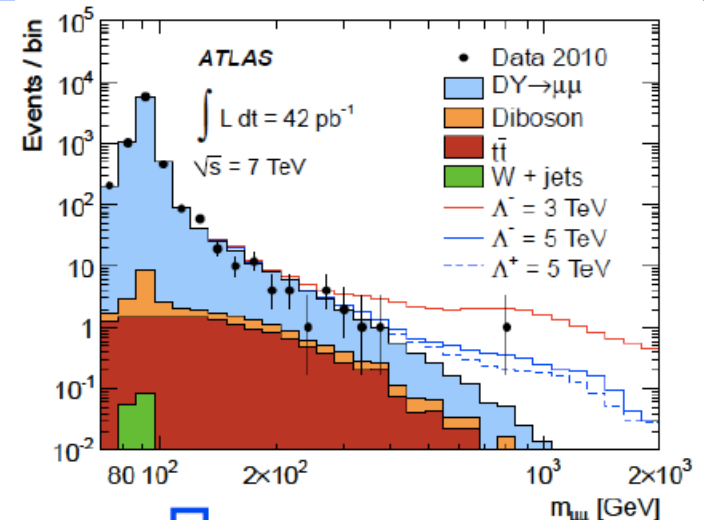
- **Deviations in dimuon mass:**

$$\frac{d\sigma}{dm_{\mu\mu}} = \frac{d\sigma_{DY}}{dm_{\mu\mu}} - \eta_{LL} \frac{F_I(m_{\mu\mu})}{\Lambda^2} + \frac{F_C(m_{\mu\mu})}{\Lambda^4}$$

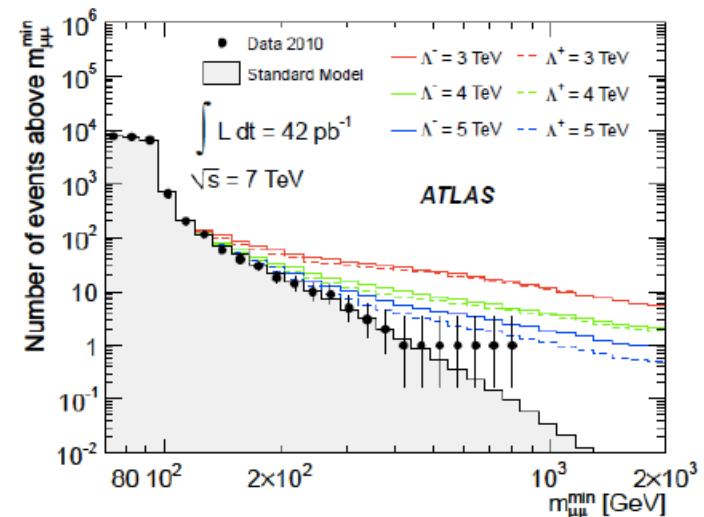
- ◆ F_I and F_C : interference terms
- ◆ Λ : energy of “new binding”

- **Mass spectrum agrees, so set limits instead:**

- ◆ For Constr Interf: $\Lambda_C > 4.9$ TeV
- ◆ For Destr Interf: $\Lambda_I > 4.5$ TeV



↓ Taking an integral...



Searches for signs of exotic New Physics

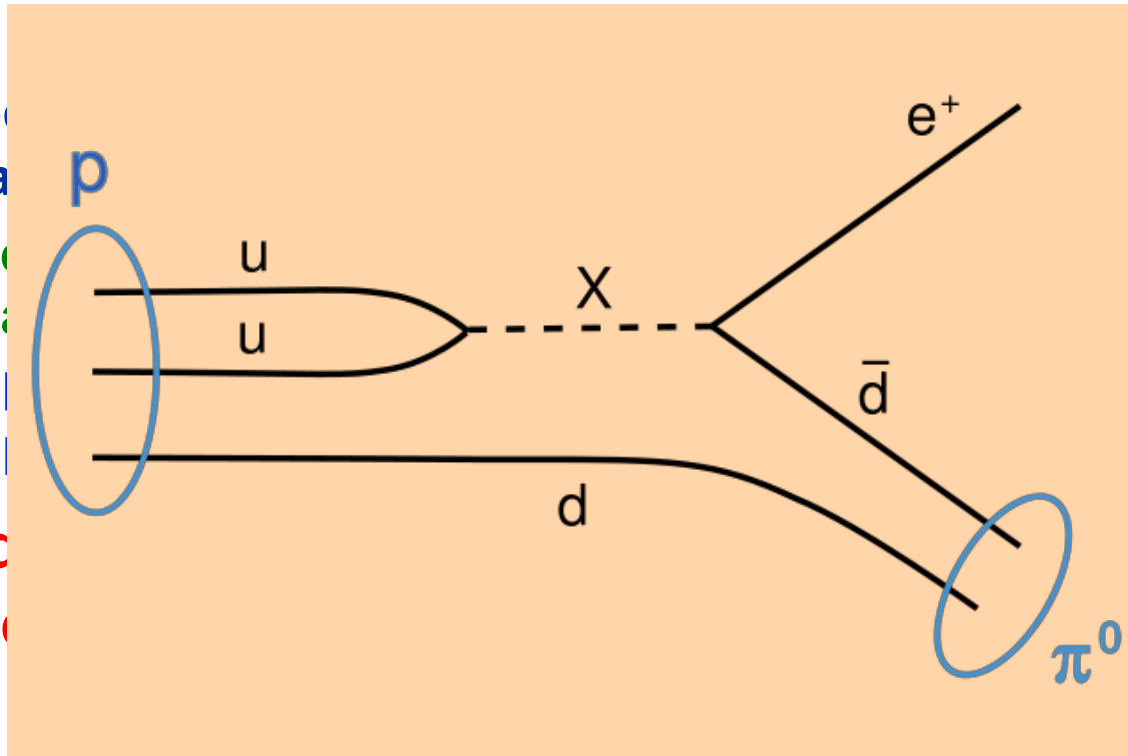
Leptoquarks (I)

- As name implies, they are both “leptons” and “quarks”: i.e. carry baryon and lepton number – & color (large σ !)
 - ◆ GUT-inspired models, with (hypothetical) proton decay acting as one of the main motivations

- ◆ Decay:
- ◆ A lepto
- ◆ constr

- In ge
- usu
-

- Pair-proc
- final stat
- look for:



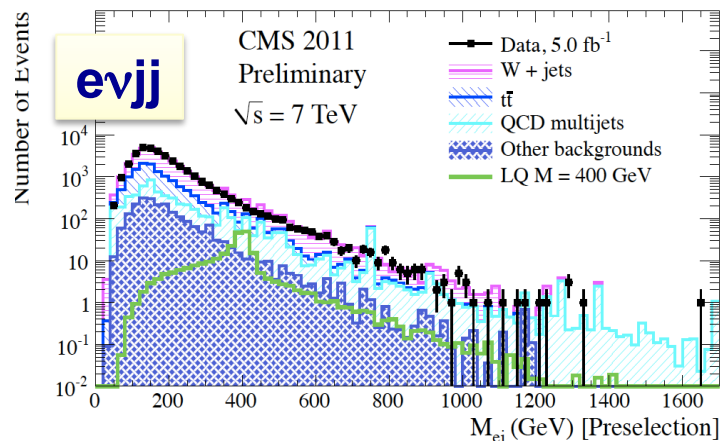
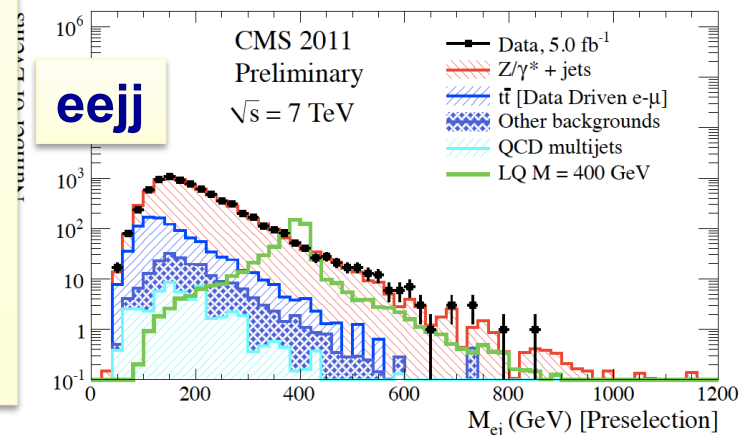
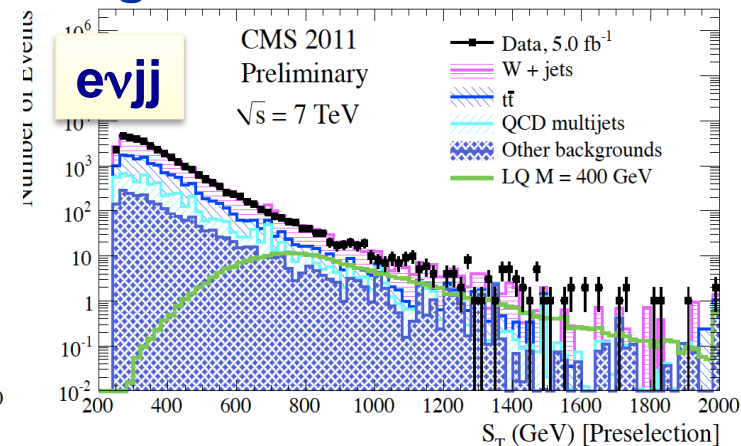
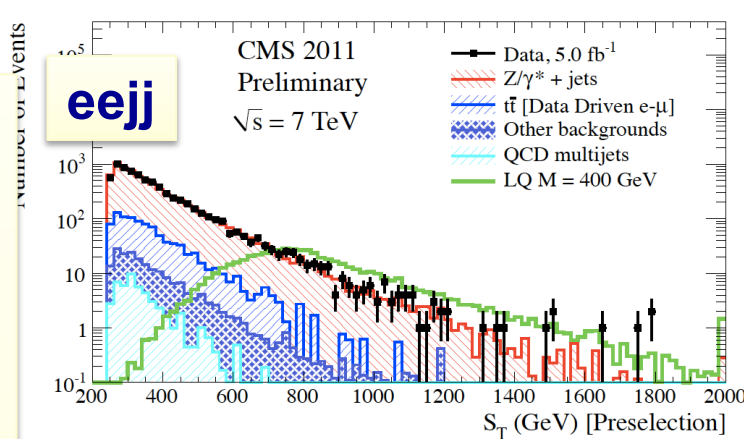
CNC
 searches
 ation
 Q1 and

Leptoquarks (II)

■ Main irreducible bkg: DY+jets; 2nd: top production

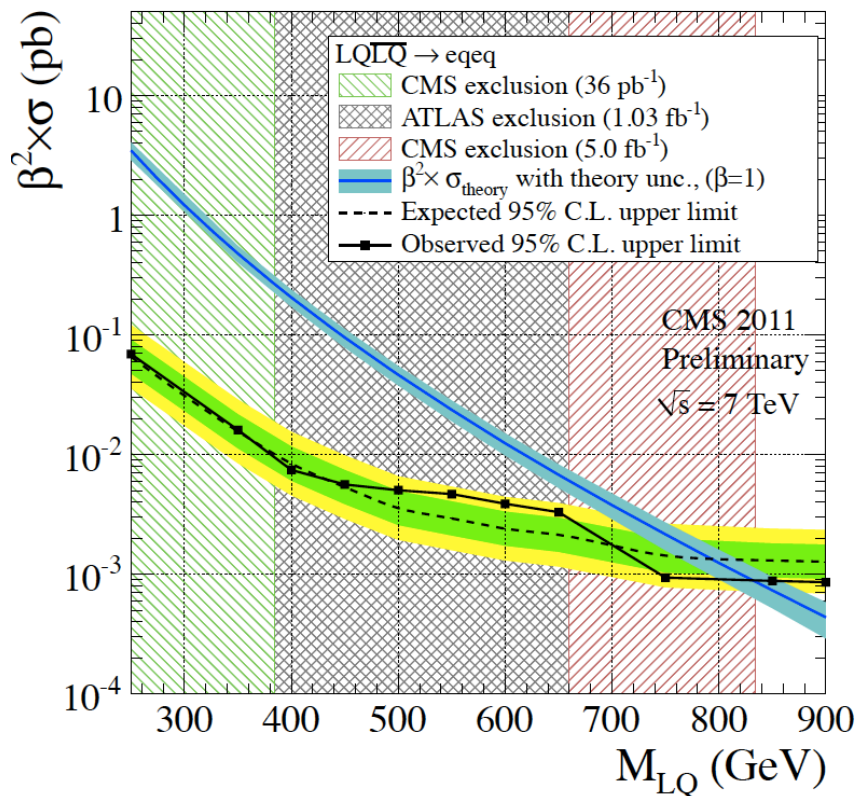
- ◆ In situ Z+jets measurement + measured top cross section in the dilepton channel to estimate both bkg

- DY+jets normalized to Z+jets (control region)
- anti-Z cut
- optimize S_T cut (mass-dependent)

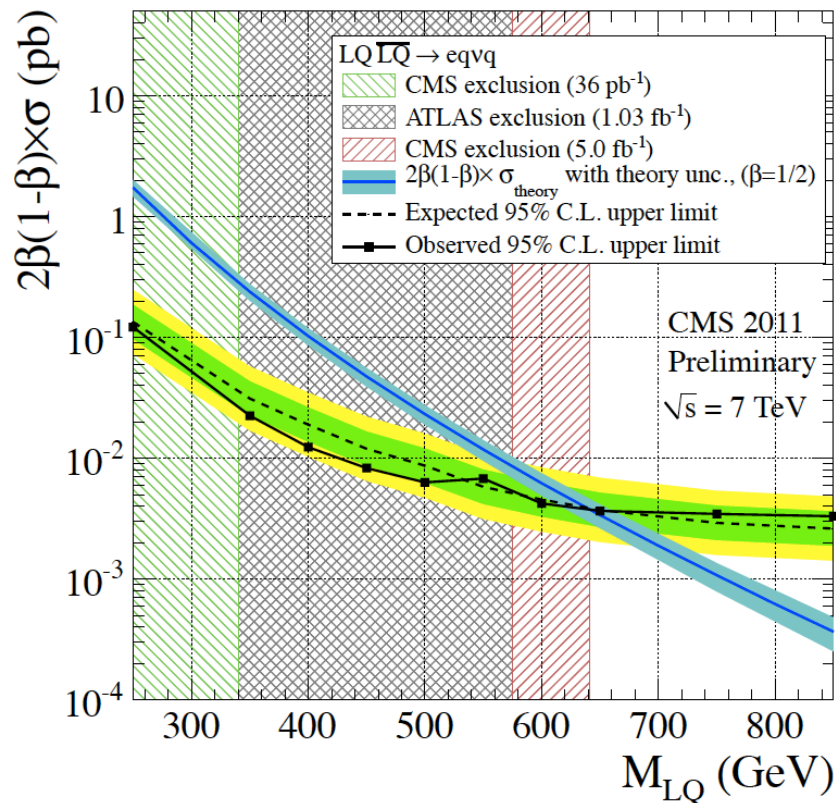


Leptoquarks: limits

■ $\beta=1$

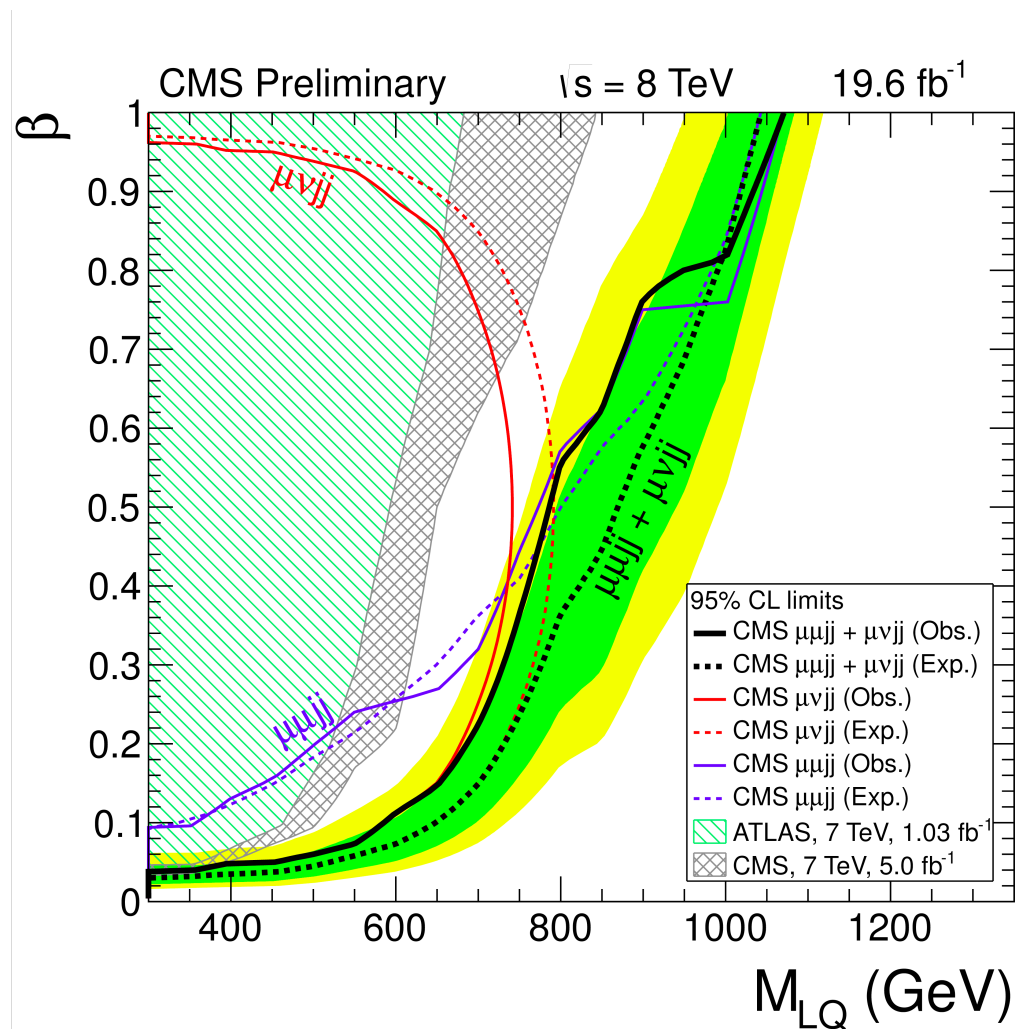


■ $\beta=0.5$



Leptoquarks: limits

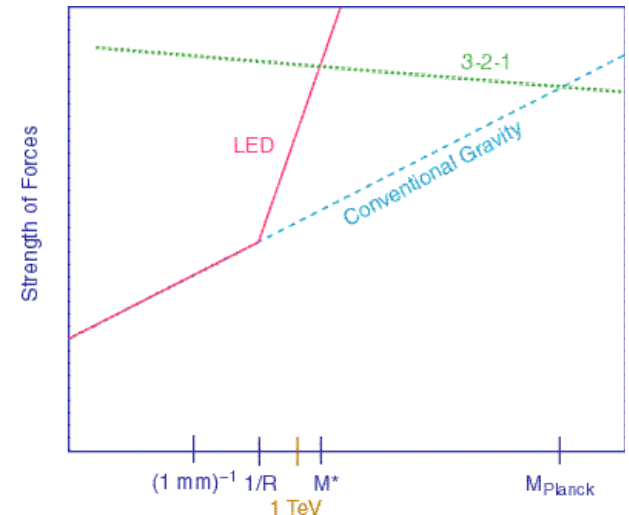
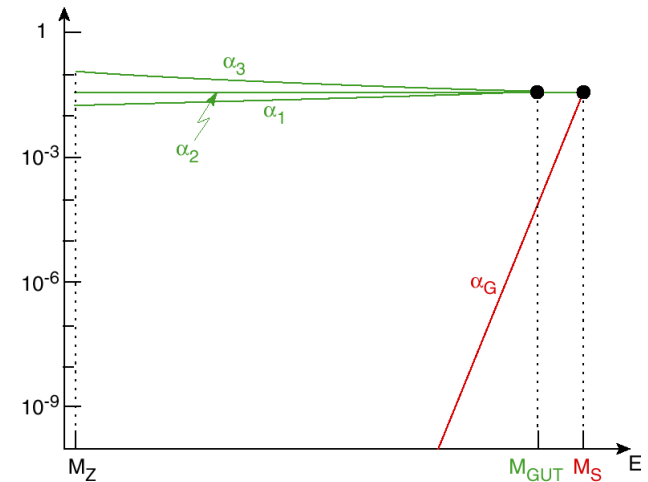
■ Combined limit



Extra Dimensions (?!?)

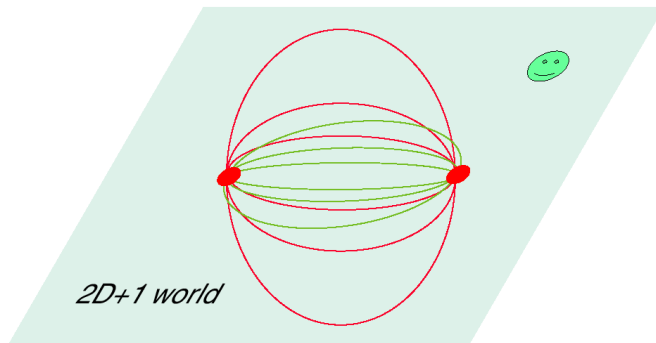
TeV-scale gravity

- **The idea of our times: that the scale of gravity is actually not given by M_{PL} but by M_W**
 - ◆ **Strings live in >4 dimensions. Compactification \rightarrow 4D “SM”. M_{PL-4} related to $M_{PL-(4+d)}$ via volume of xtra dimensions:**
 - $M_{PL-4}^2 \sim V_d M_{PL-(4+d)}^{2+d}$ - ◆ **Conventional compactification: very small curled up dims, $M_{PL-4} \sim M_{PL-(4+d)}$**
 - $V_d \sim (M_{PL-4})^{-d}$
 - ◆ **Alternative: volume is large; large enough that $V_d \gg (M_{PL-(4+d)})^{-d}$**
 - **Then $M_{PL-(4+d)}$ can be \sim TeV (!)**
 - **“our” Planck mass at $\log(\Lambda) \sim 19$: an artifact of the extrapolation**

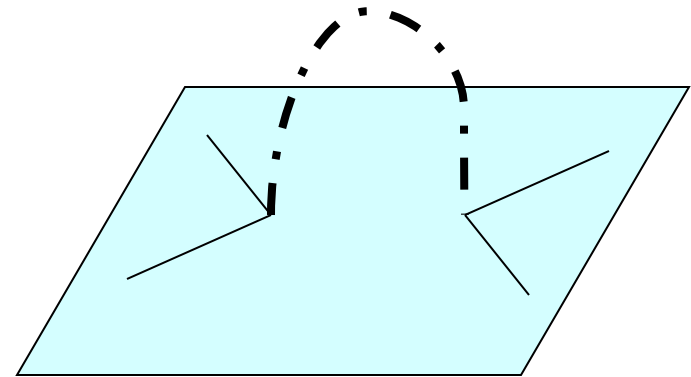


Forces and number of dimensions

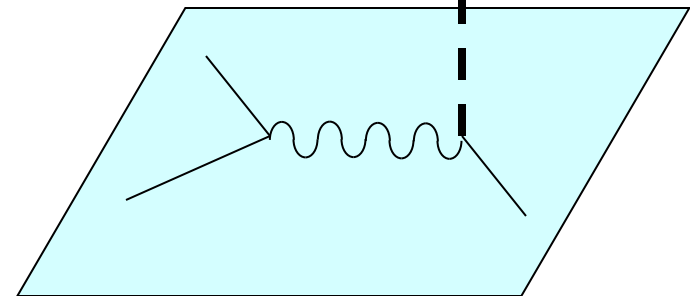
- **Number (D) of space-time dimensions → form of force observed**
 - ◆ E+M: $F \sim 1/r^2$ because $D=3+1$
 - ◆ For “ants” living in $D=2+1$ dimensions, E+M is actually a $F \sim 1/r$ force
- **Propagation into the other dimensions:**
 - ◆ Resonances!



- **Tabletop experiments: look for deviations from $1/r^2$ law**



- ◆ **Missing energy!**



Different types of extra dimensions

- The “traditional” image of a circular extra dimension



$$\phi(x) = \phi(x + k2\pi R)$$

$$(k = 0, 1, 2, \dots)$$

$$p = k/R$$

- Randal-Sundrum

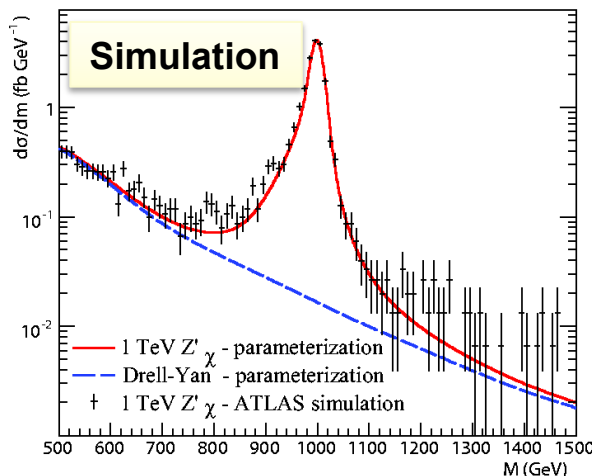
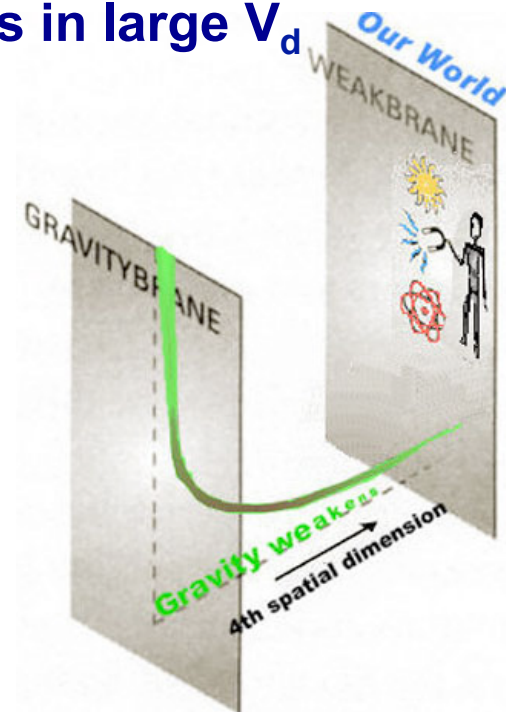
$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu + g_{mn}(y) dy^m dy^n$$

(x: SM coordinates; y: d extra ones)
Generalize: dependence on location in extra dimension

$$ds^2 = e^{2A(y)} g_{\mu\nu} dx^\mu dx^\nu + g_{mn}(y) dy^m dy^n$$

Large $\exp(A(y))$ results in large V_d

As an example (RS model), two 4-D branes, one for SM, one for gravity, “cover” a 5-D space – with an extra dimension in between

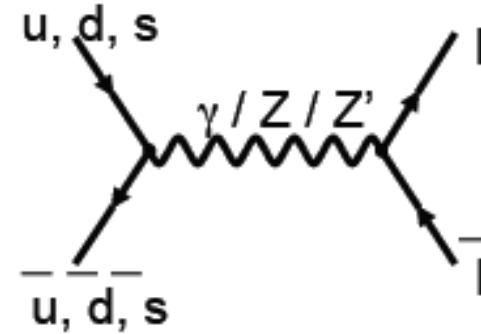
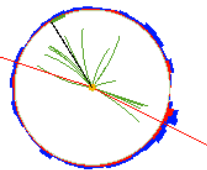


Search for Z'

- **Di-muon event, $M(\mu\mu)=1379$ GeV**



CMS Experiment at LHC, CERN
Data recorded: Sun Oct 23 20:23:31 2011 CEST
Run/Event: 179547 / 505584390
Lumi section: 319

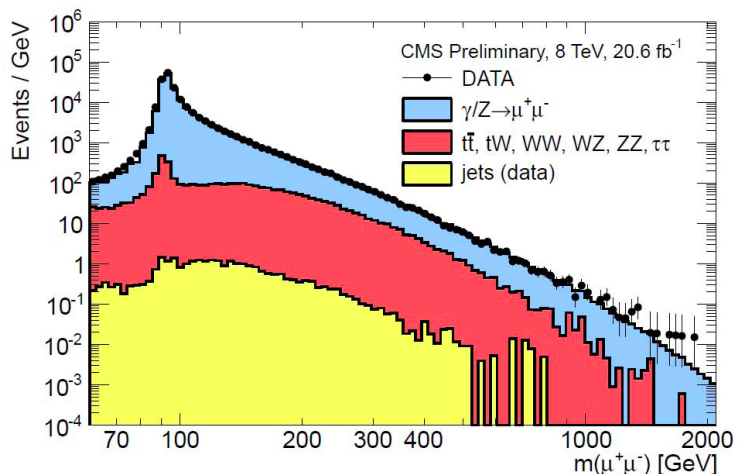
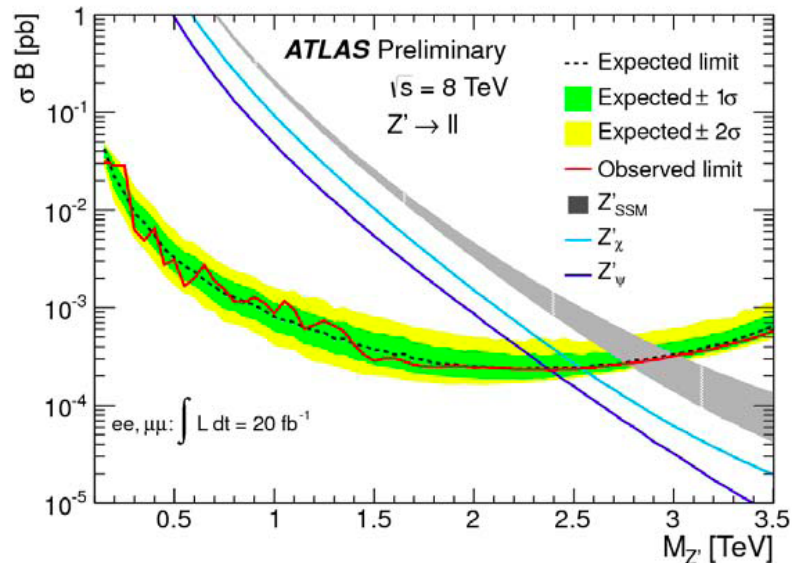
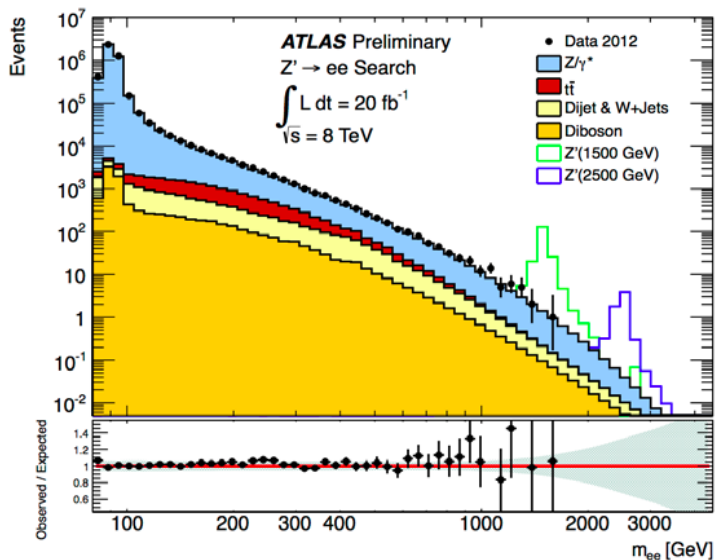


Nice, clean signature (but SM tails)

Experimental issues:

- **detector resolution: for muons deteriorates with mass; for electrons the opposite**
- **reconstruction of E and p reconstruction with > 1 TeV can be tricky business...**

Search for a $Z' \rightarrow ee$ and/or $\mu\mu$



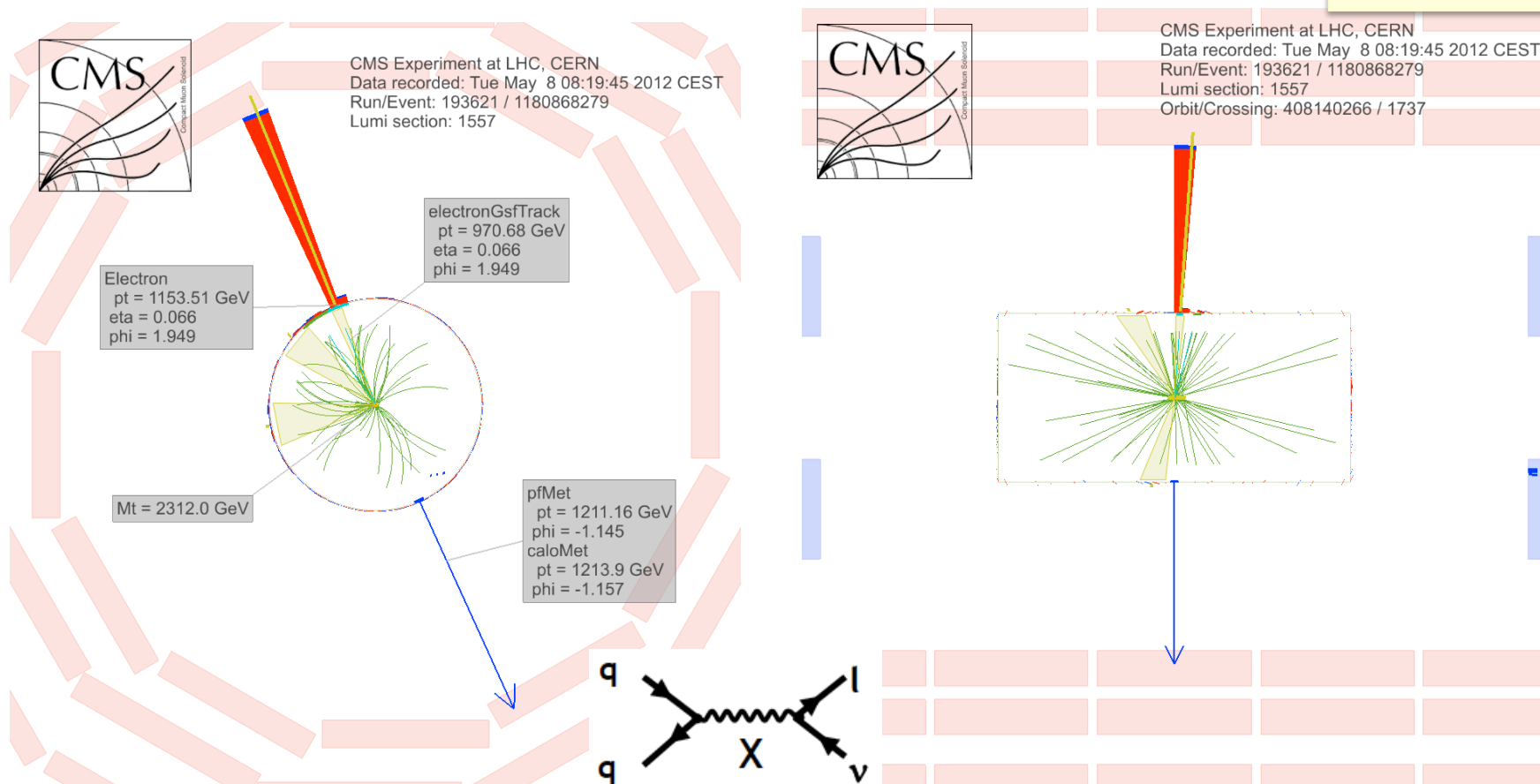
Model	ATLAS	CMS
SSM Z'	2.86	2.96
$E_6 Z'_{\psi}$	2.38	2.60
RS G^* ($k/\bar{M}_{Pl}=0.1$)	2.47	

SSM: Sequential SM
 RS: Randall-Sundrum

Search for W' : example from CMS

- Events are equally spectacular; a very high- p_T lepton, and little, very little else!

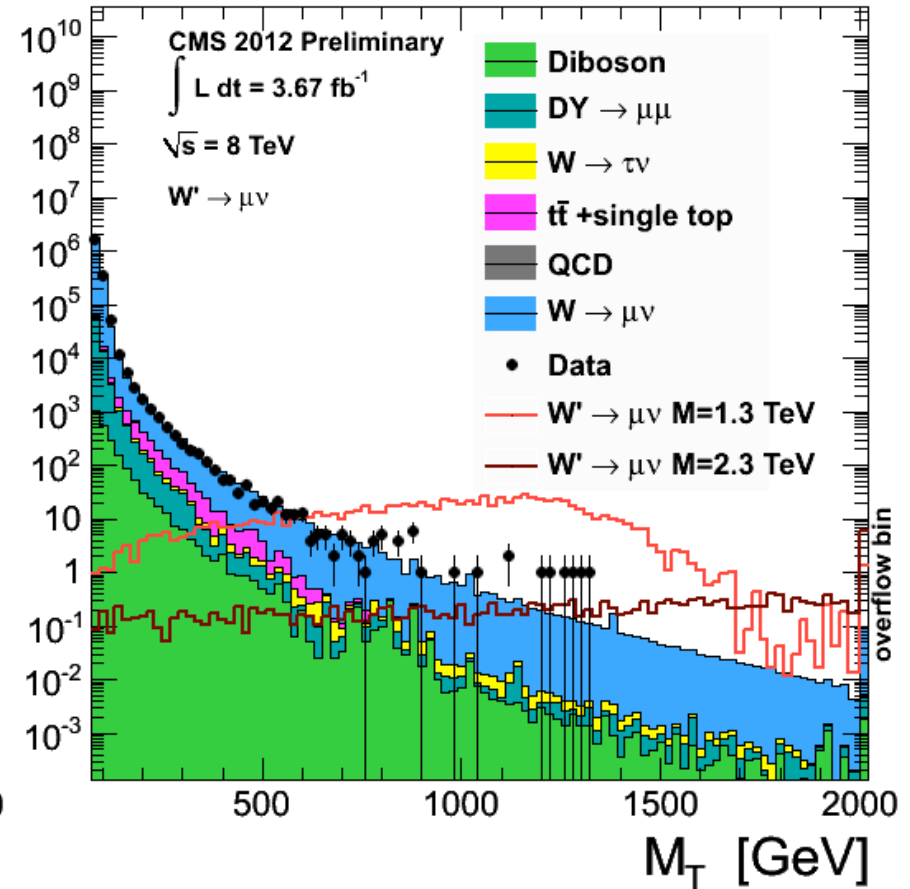
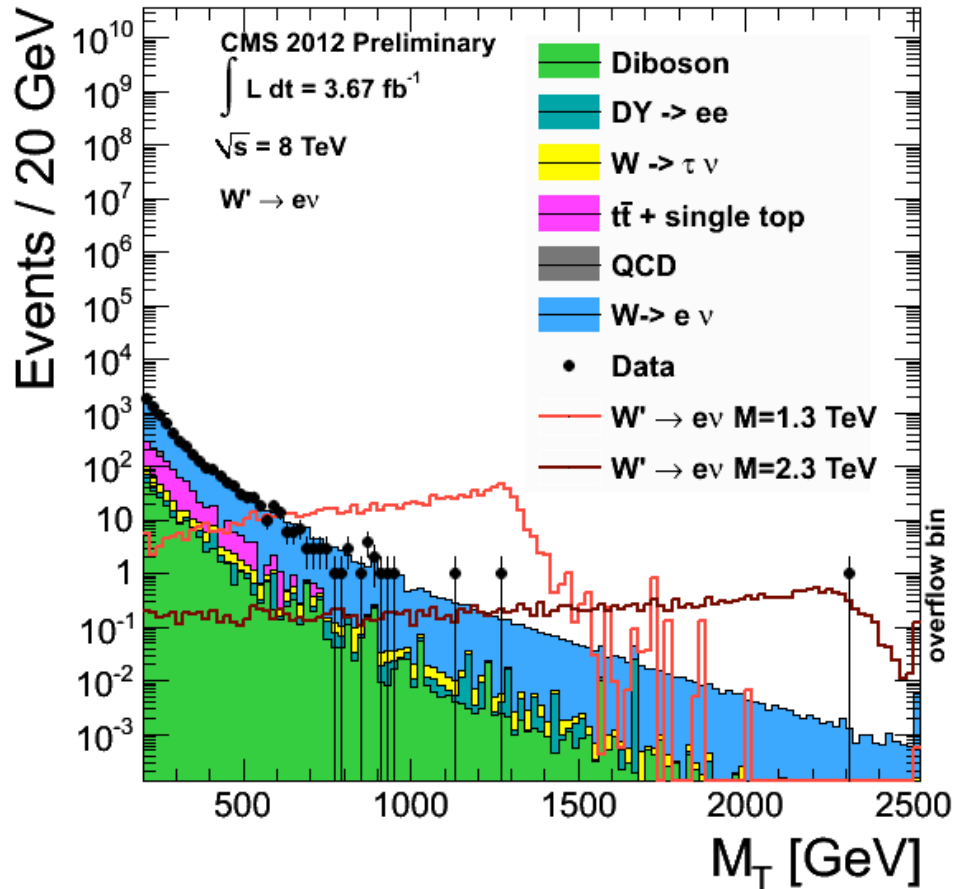
8 TeV



Search for W' : example from CMS

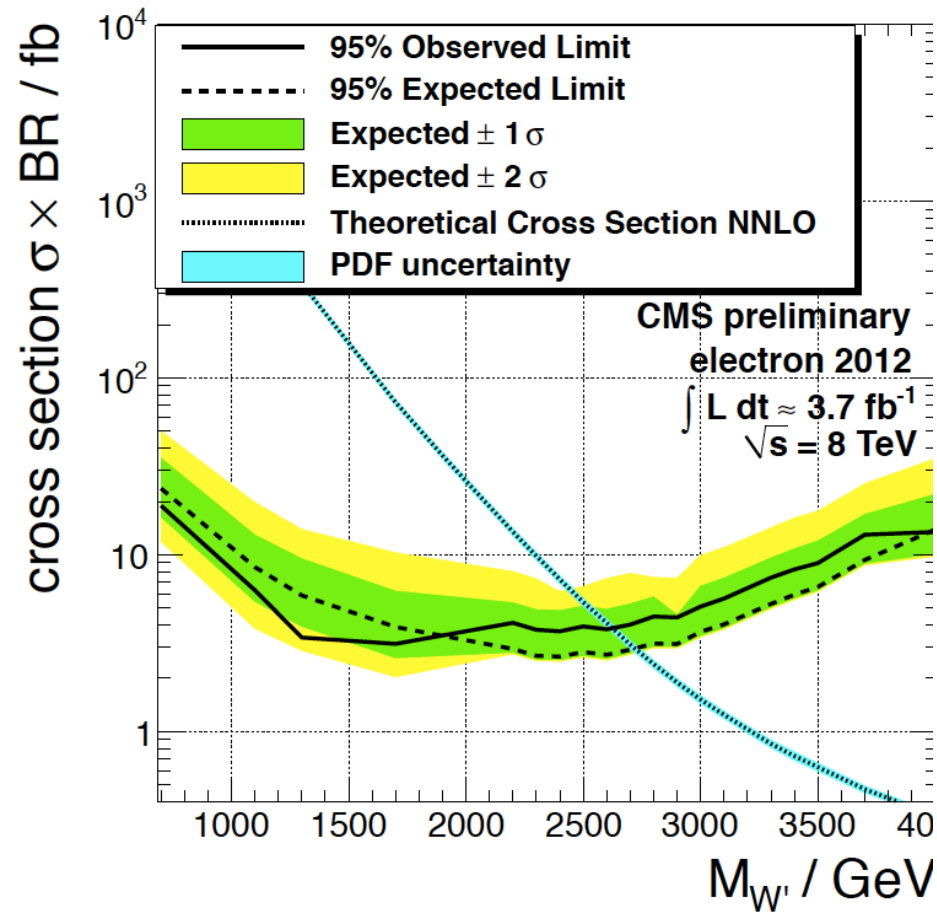
Electrons

Muons

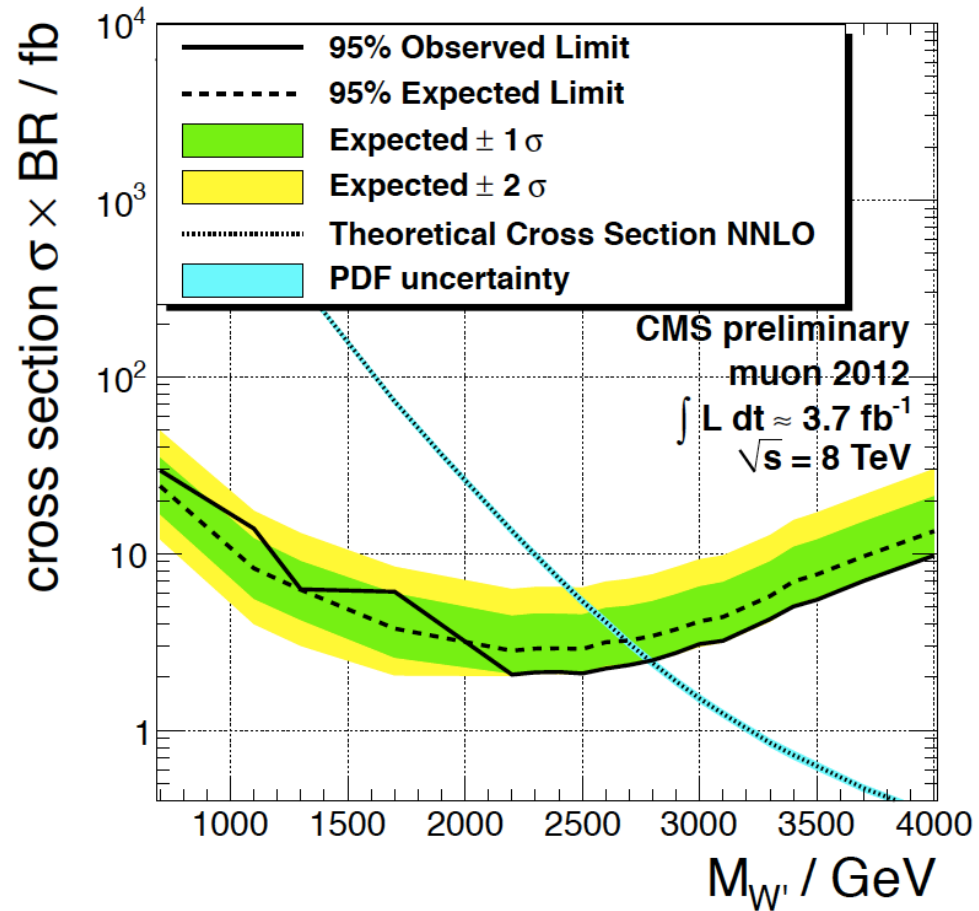


Search for W' : example from CMS

Electrons

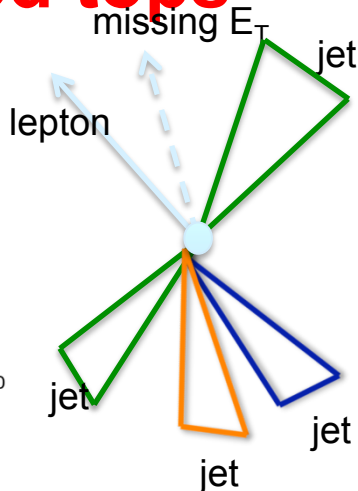
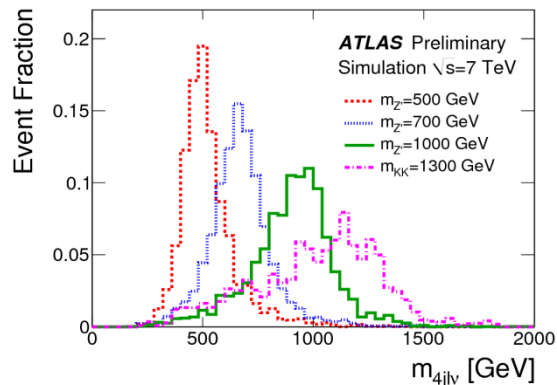


Muons

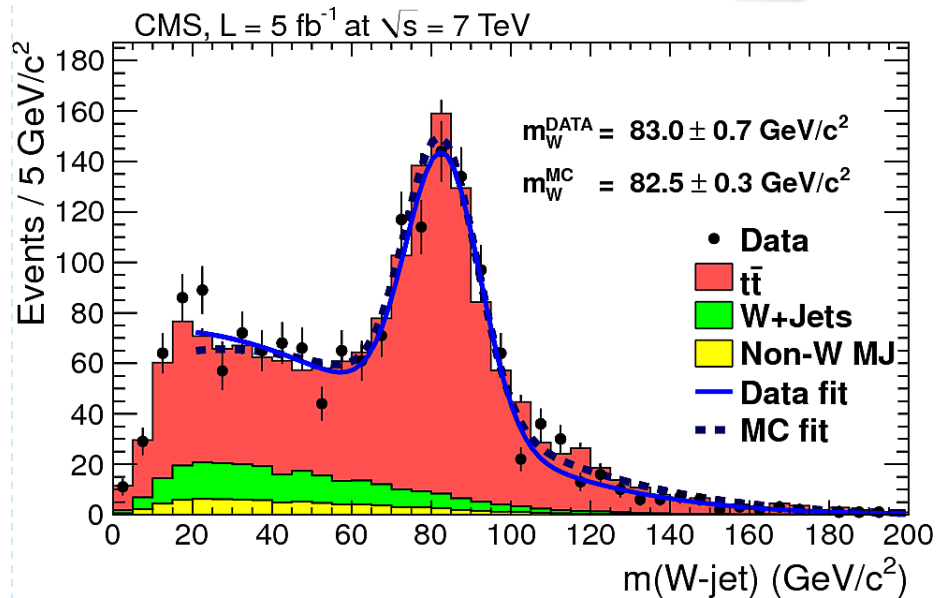
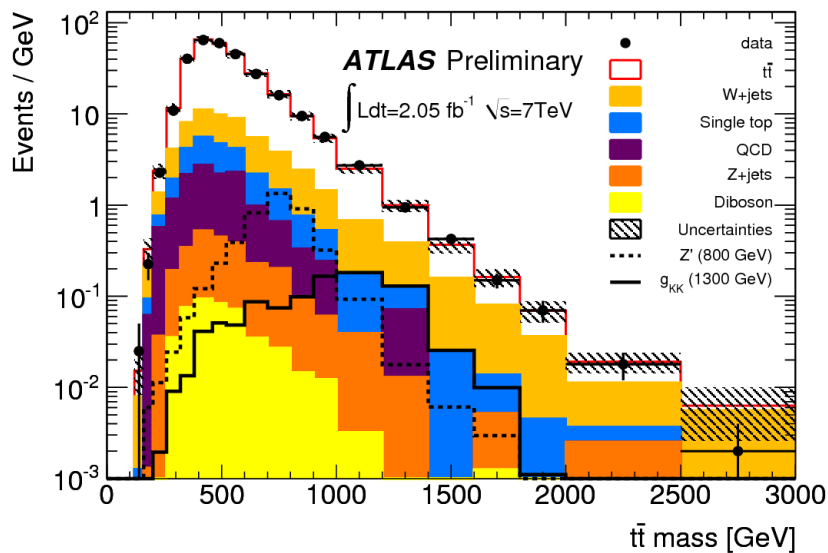
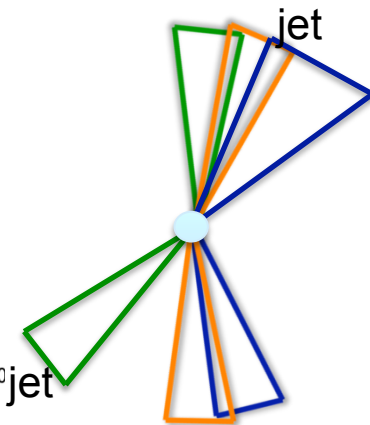
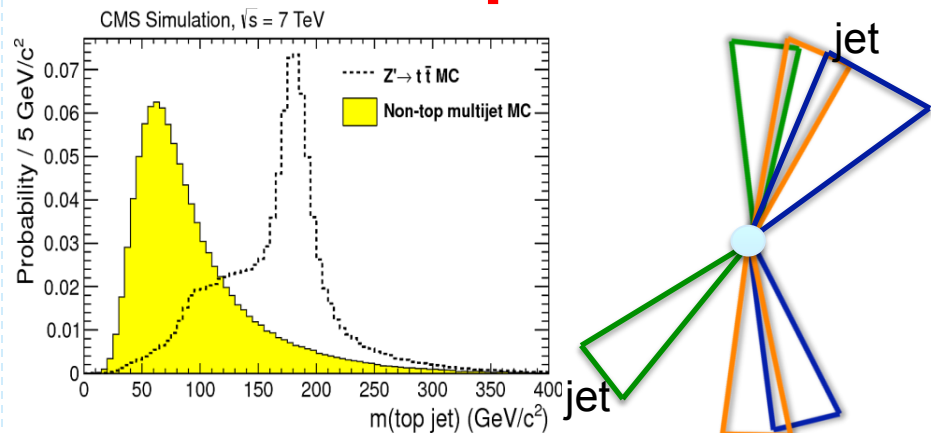


Search for a resonance decaying to t-tbar

non-boosted tops

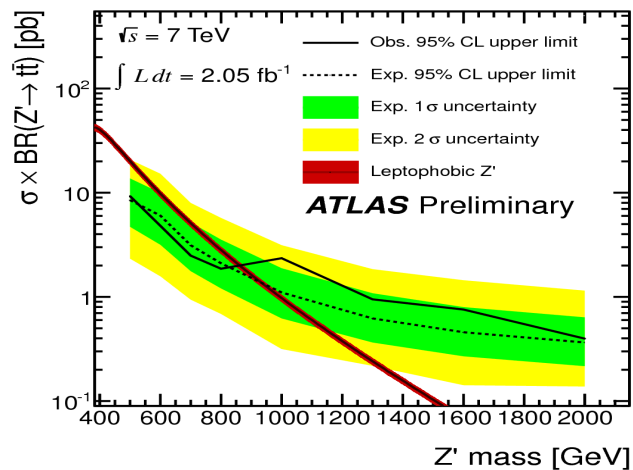
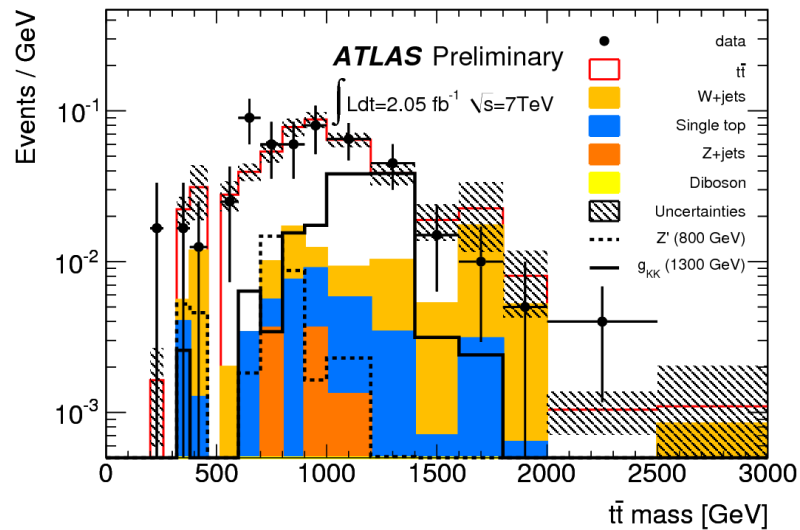


boosted tops

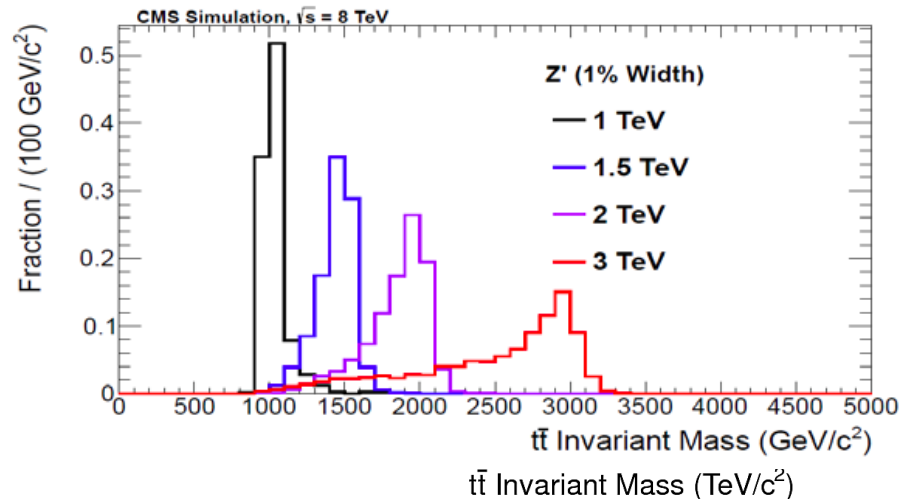
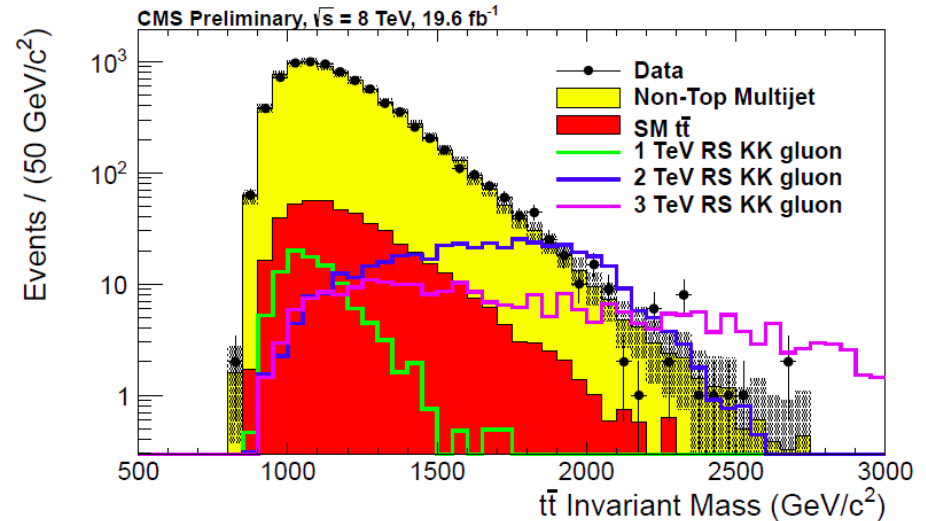


Search for a resonance decaying to t-tbar

■ non-boosted tops



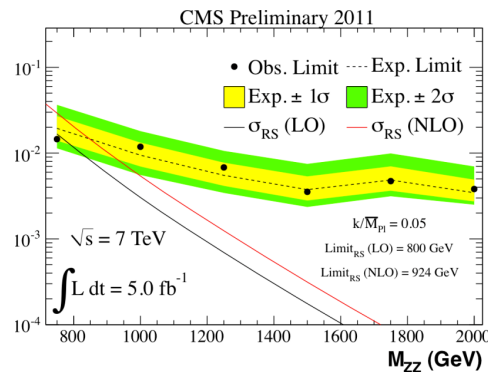
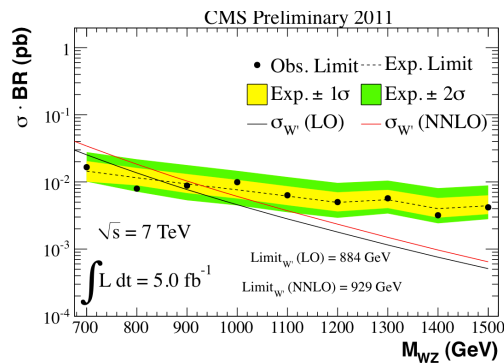
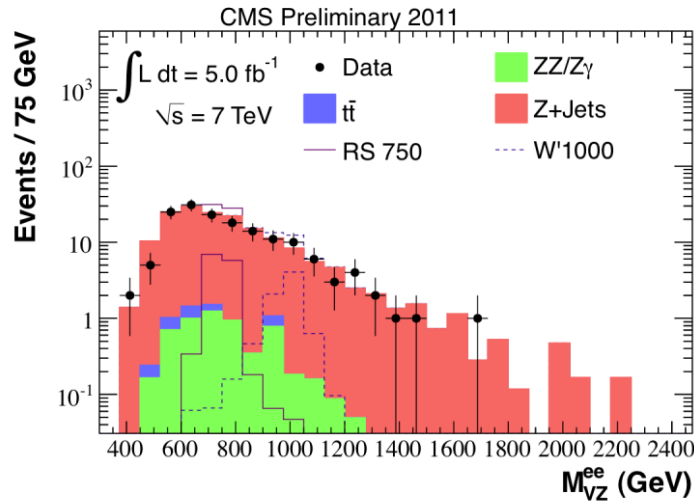
■ boosted tops



Search for diboson resonances

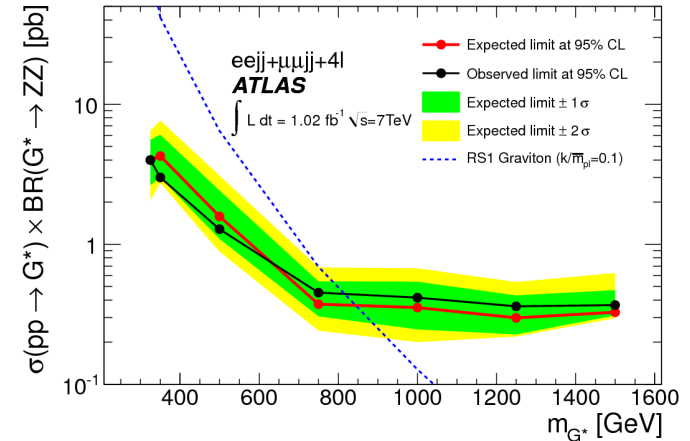
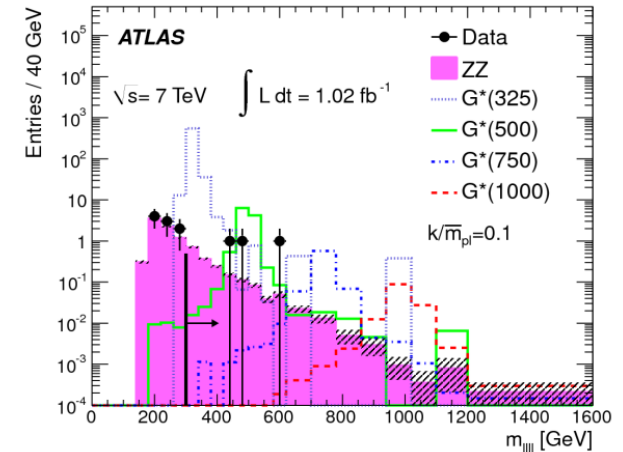
X → WZ

◆ Dilepton+ jets

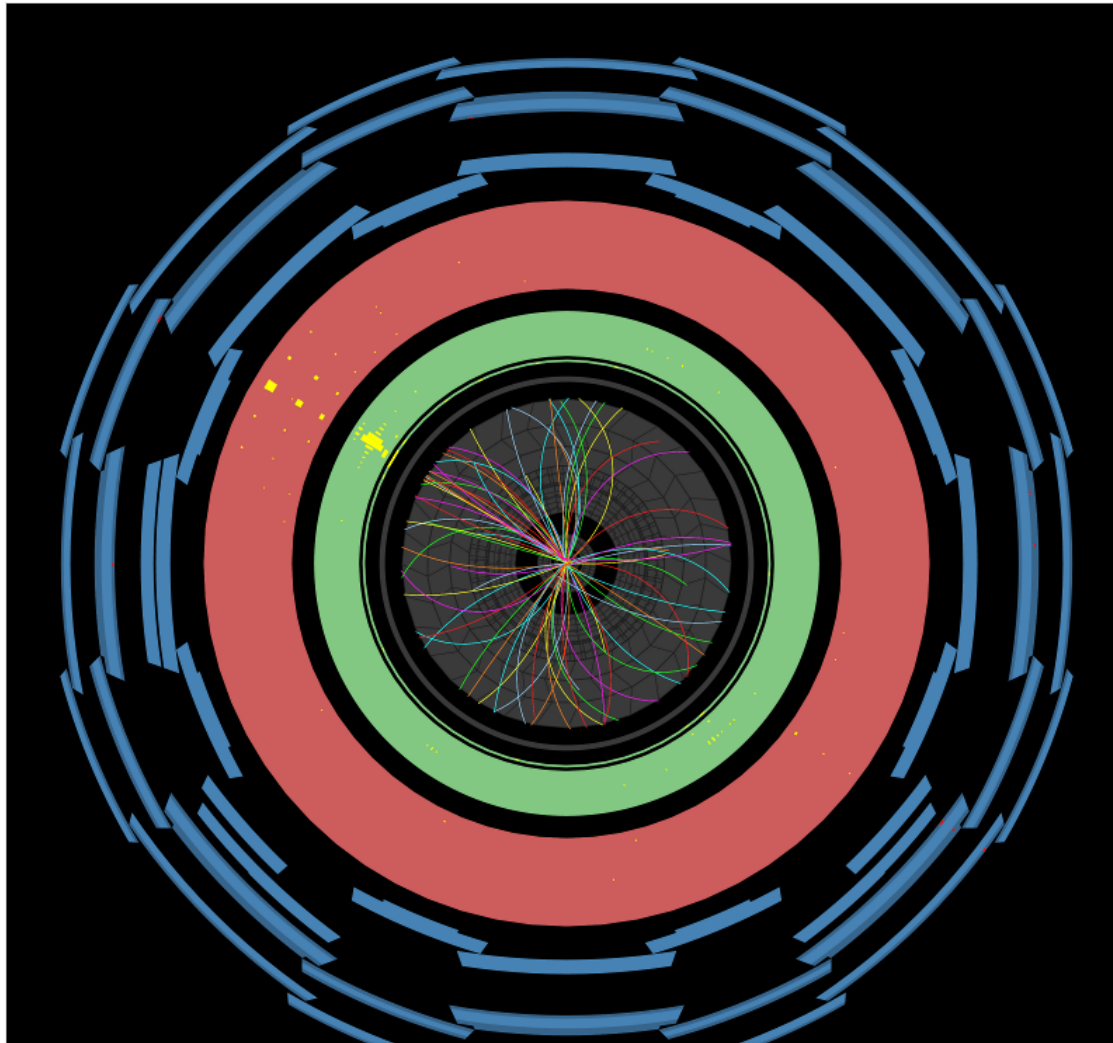


X → ZZ

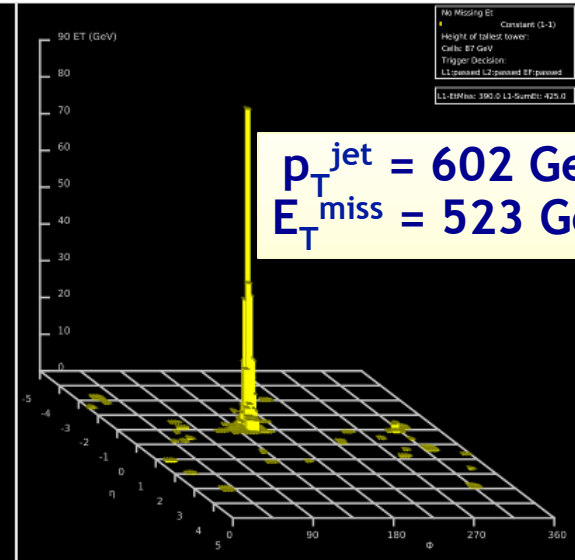
◆ 2lep+jets; 4lep



Monojets?



SM interpretation: $Z \rightarrow \nu\nu + \text{jet}$

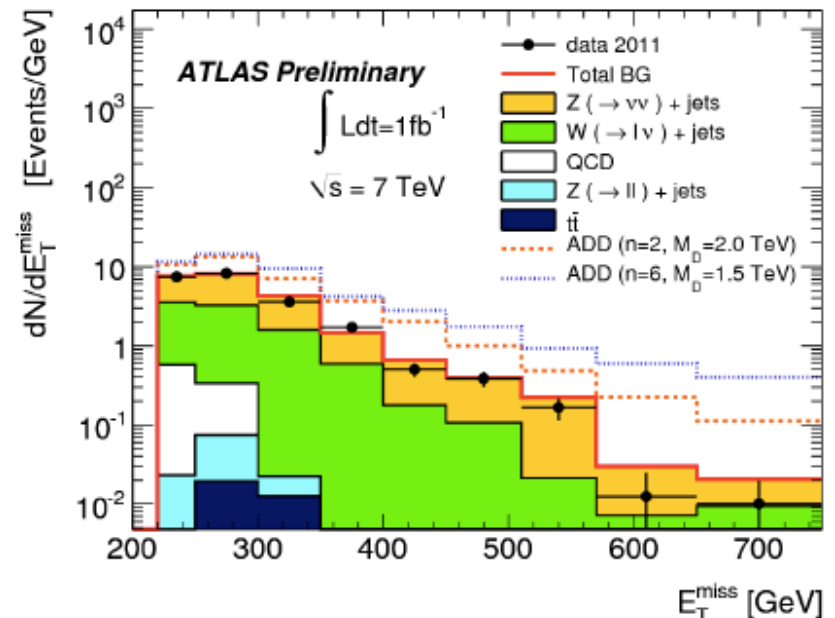
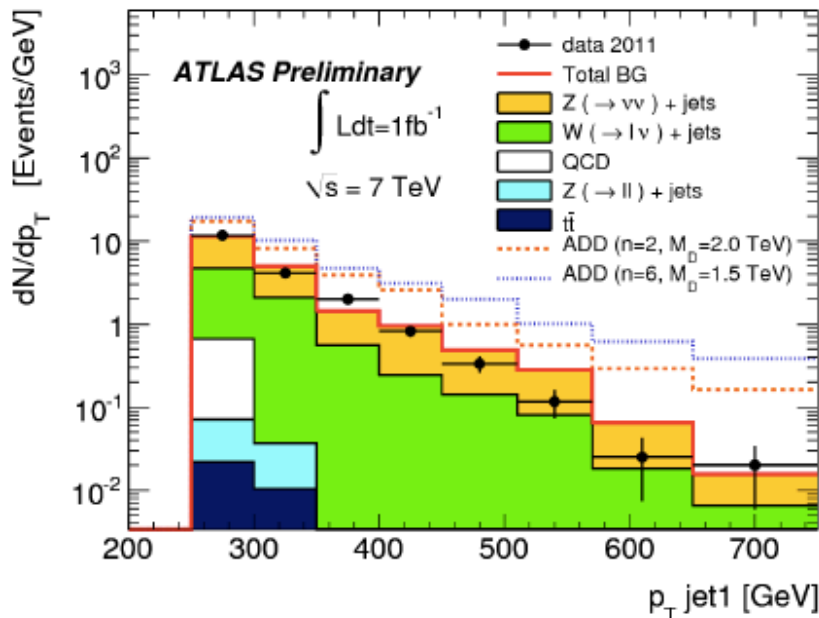


Run Number: 180309, Event Number: 36060682

Date: 2011-04-27 02:33:15 CEST

Monojets (I)

- **Extra dimensions: hard scatter leads to a jet plus an invisible particle [e.g. a graviton]; signal region:**
 - ◆ $P_T(\text{jet1}) > 250 \text{ GeV}$, $ME_T > 220 \text{ GeV}$
 - ◆ $P_T(\text{jet2}) < 60 \text{ GeV}$, $\Delta\phi(\text{jet2}, ME_T) > 0.5$
 - ◆ No “reasonable” electrons or muons

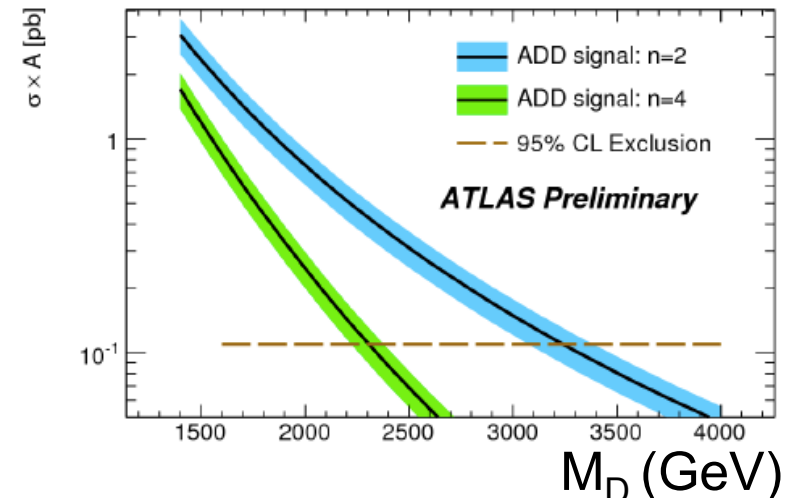
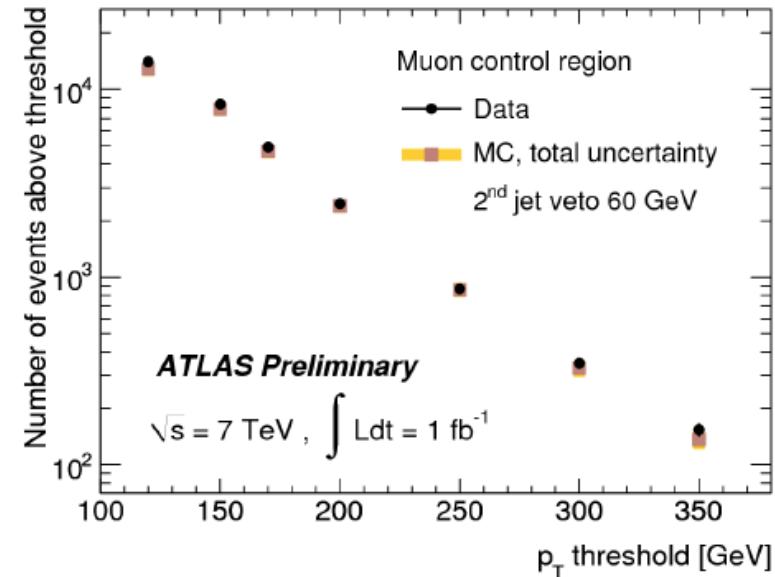


Monojets (II)

- **Main bkg: EWK**
 - ◆ Irreducible: $Z(\rightarrow\nu\nu)+\text{jets}$ & $W(\rightarrow l\nu)+\text{jets}$
 - ◆ Get normalization from data, then apply to Monte Carlo samples
- **QCD (multijet) bkg: reverse $\Delta\phi$ cut and allow 2nd jet!**
- **Data agree with sum of bkg:**
 - ◆ Bkg est: $1010 \pm 37(\text{stat}) \pm 65(\text{syst})$
 - ◆ Data: 965 events
- **Model-independent limit on cross section \times acceptance: “0.11 pb at 95% CL”**

95 out of 100 experiments [with 0.11 pb] would have observed a larger number of events

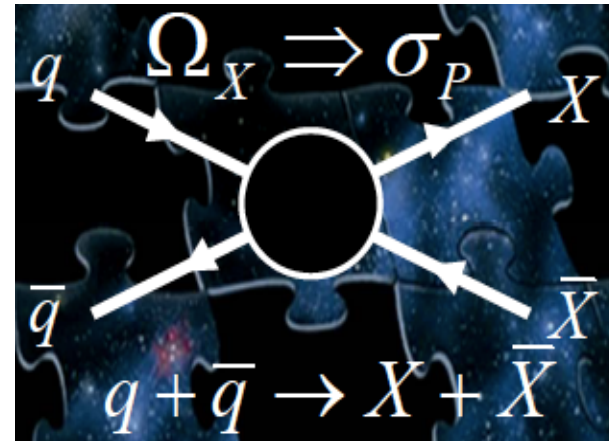
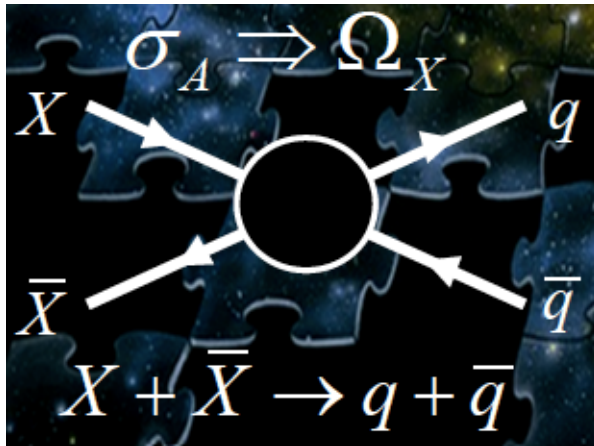
No “magic” to “95%” – only a norm.



Dark Matter?

Dark matter

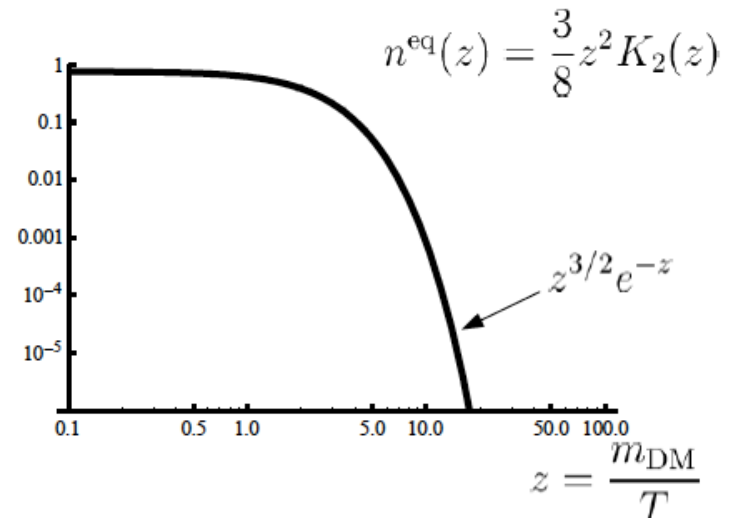
- Early universe: create/destroy dark matter via:



- If the two rates are the same \rightarrow equilibrium; and then, as it cools off...

$$\frac{dn}{dt} = -\langle \sigma_{\text{ann}} v \rangle (n^2 - n_{\text{eq}}^2)$$

But: universe is expanding



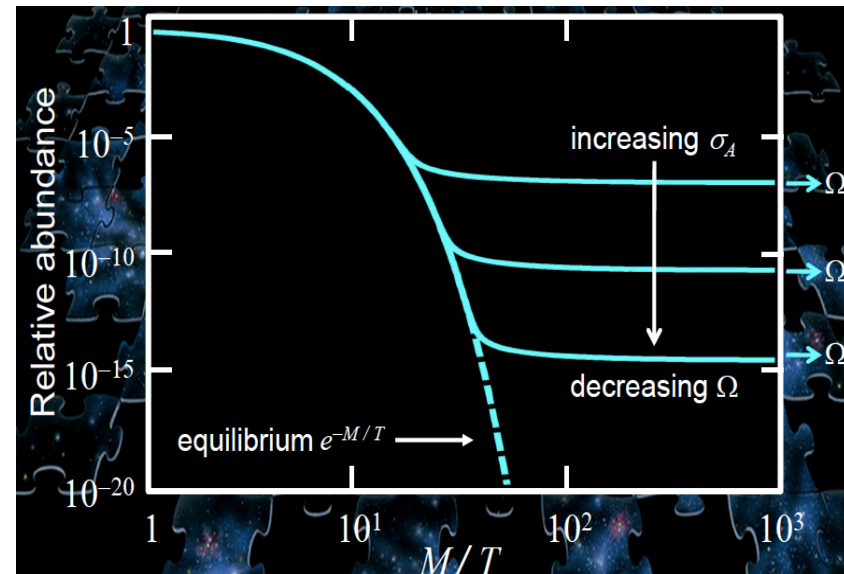
Dark matter (II)

- **If DM production rate large compared to expansion rate**
 - ◆ Essentially a static configuration
 - ◆ DM particles are in thermal equilibrium
- **If DM production rate small compared to expansion rate**
 - ◆ Few DM particles remain
 - ◆ DM particles do not bump into each other (and do not destroy themselves)
 - **Density remains constant (!)**

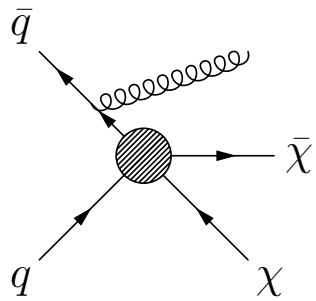
$$\Omega_{\text{DM}} h^2 \simeq \frac{3 \times 10^{-27} \text{ cm}^3 \text{ s}^{-1}}{\langle \sigma v \rangle}$$

$$\Omega_{\text{DM}} h^2 \simeq 0.1$$

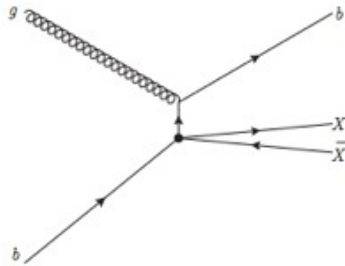
- **Thus: $\sigma \sim 1 \text{ pb!}$**



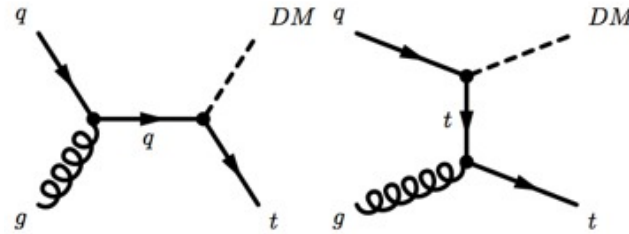
Mono-X signatures



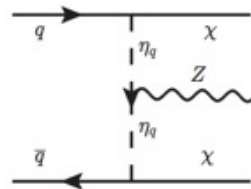
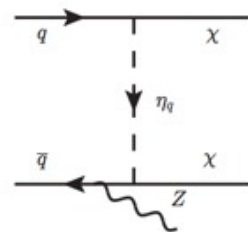
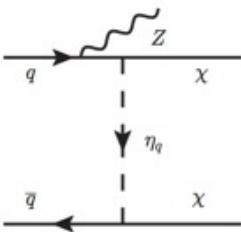
Monojet



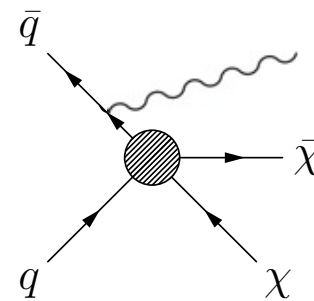
MonoB



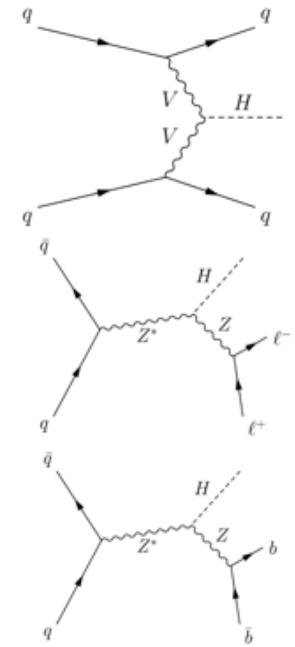
MonoTop



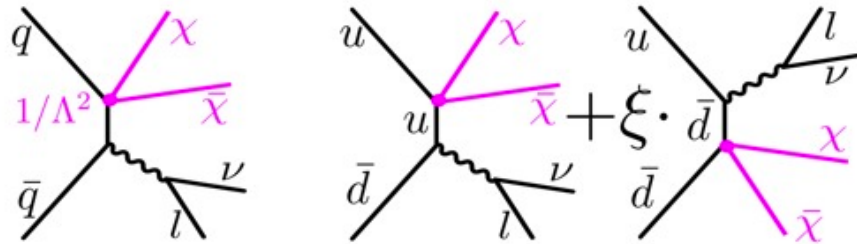
MonoZ



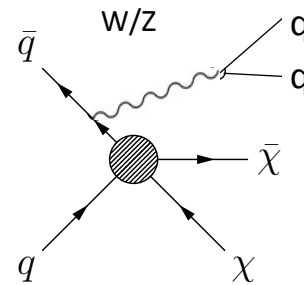
MonoPhoton



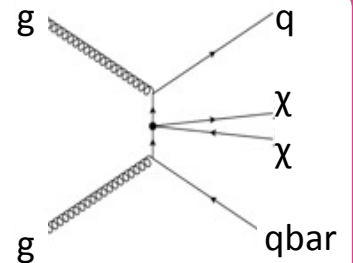
Higgs Portal



MonoW (monoLepton)



MonoW/Z (Hadronic)



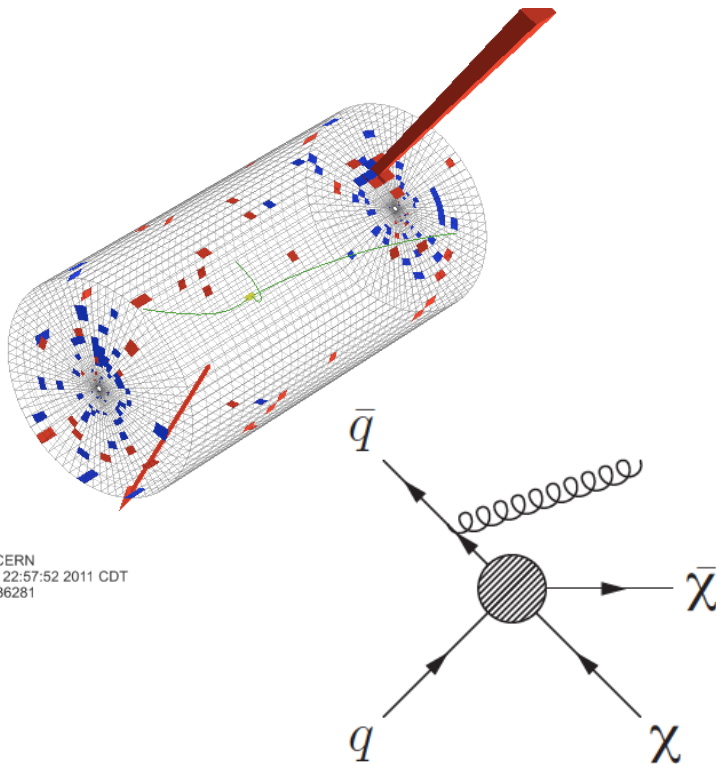
BBbar / TTbar

Search for dark matter: photon/jet+MET

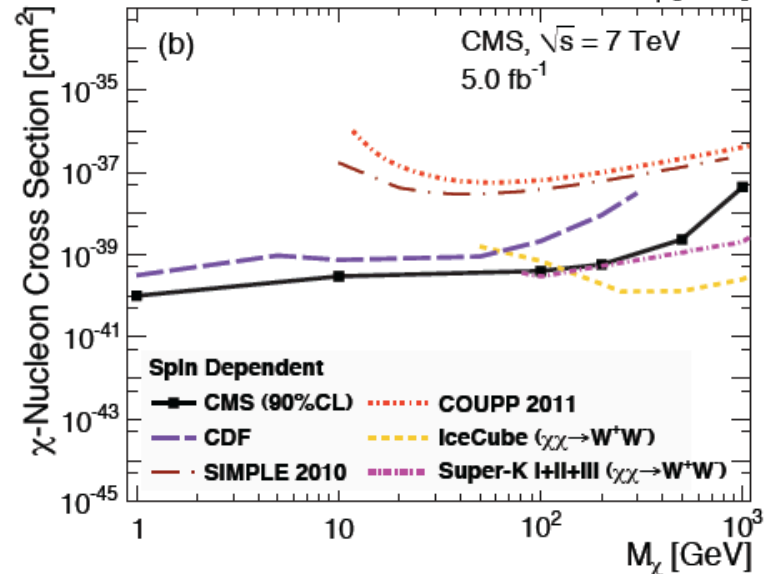
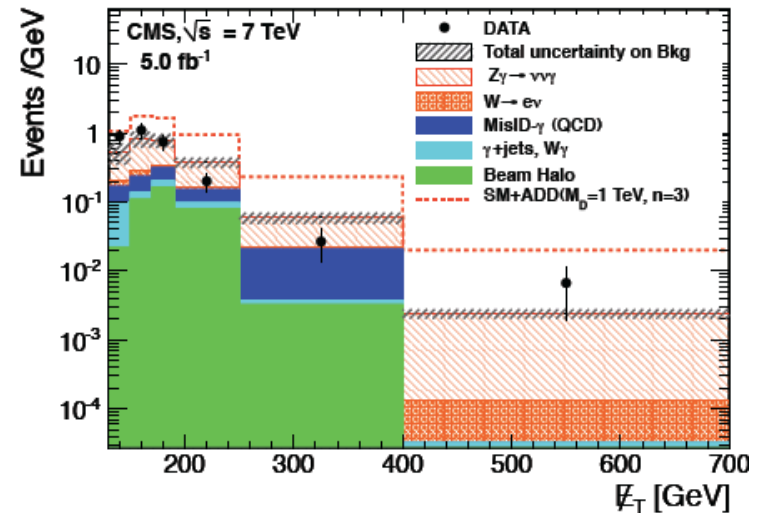
γ +MET signature from:

Extra dimensions $q\bar{q} \rightarrow \gamma G$

Dark matter $q\bar{q} \rightarrow \gamma\chi\bar{\chi}$



CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604



Higgs invisible decays?

$$M_{jj} > 1.1 \text{ TeV}$$

$$\Delta\eta_{jj} > 4.2$$

$$\Delta\Phi_{jj} < 1$$

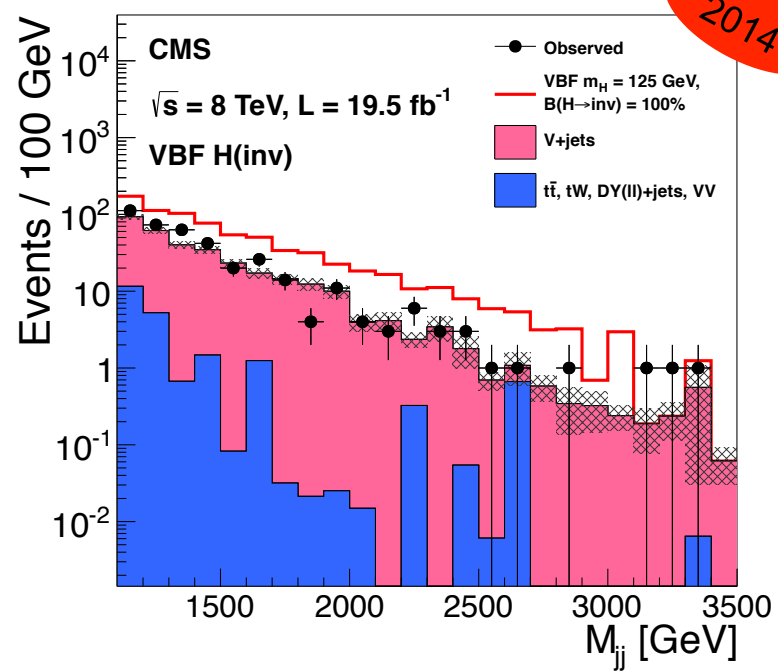
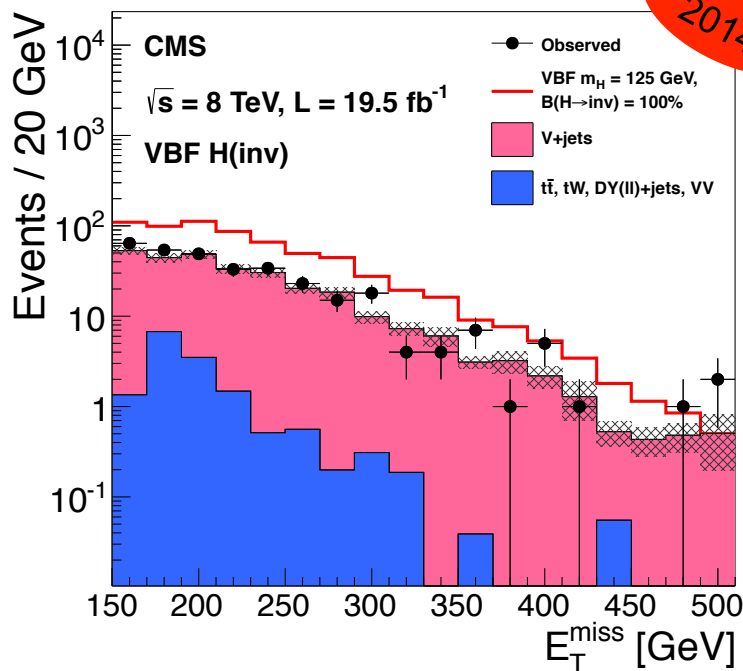
$$\text{MET} > 130 \text{ GeV}$$

$$\text{lepton veto } p_T > 10 \text{ GeV}$$

$$\text{central jet veto } p_T > 30 \text{ GeV}$$

Expected 210 ± 30 evts if $\text{BR} \sim 100\%$
 \Rightarrow Would be clearly visible above bkg

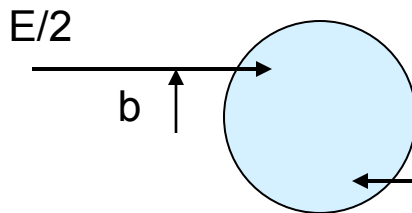
\Rightarrow Proof of principle for VBF to nothing search strategy!



Black Holes?

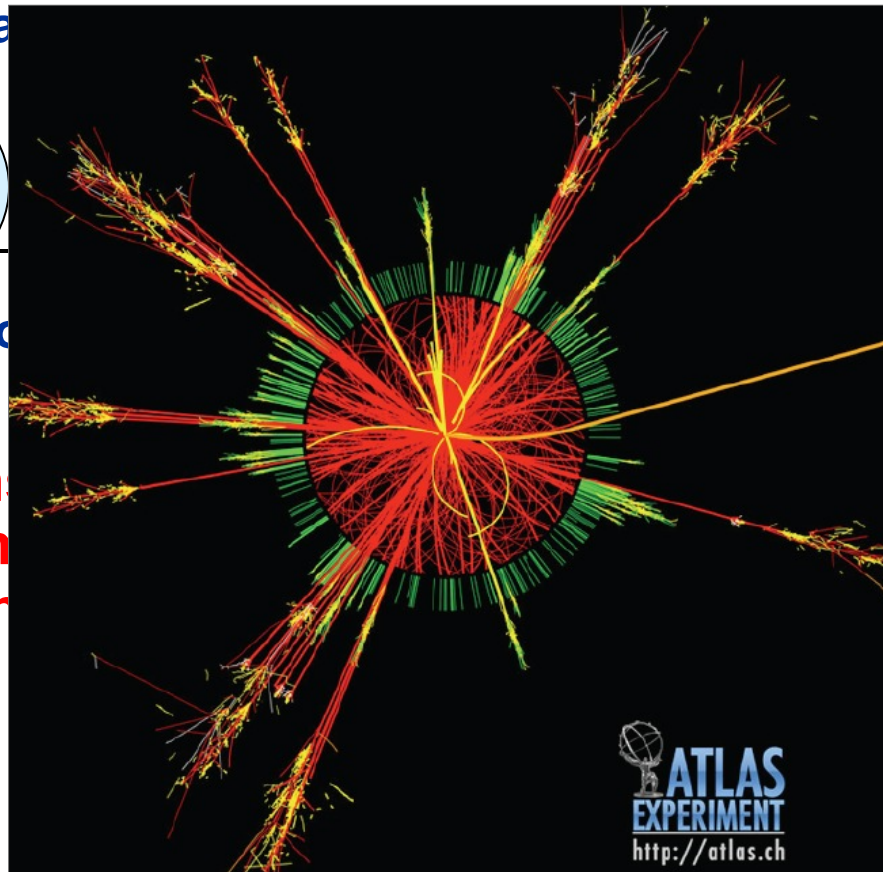
Search for BHs

- **THE signature of low-scale quantum gravity ($M_D \ll M_{Pl}$)**
 - ◆ BH formation when the two colliding partons have distance smaller than $R_{S,}$, the Schwarzschild radius corresponding to their invariant mass



- ◆ Cross section

- **BHs decay in**
emitting “dense
quarks, gluon
 - ◆ Contrary to



$$\left[\frac{\pi^{(n+3)/2}}{\Gamma((n+3)/2)} \frac{M_{BH}}{M_*} \right]^{1/(n+1)}$$

up to ~100 pb!

formation
of energetic

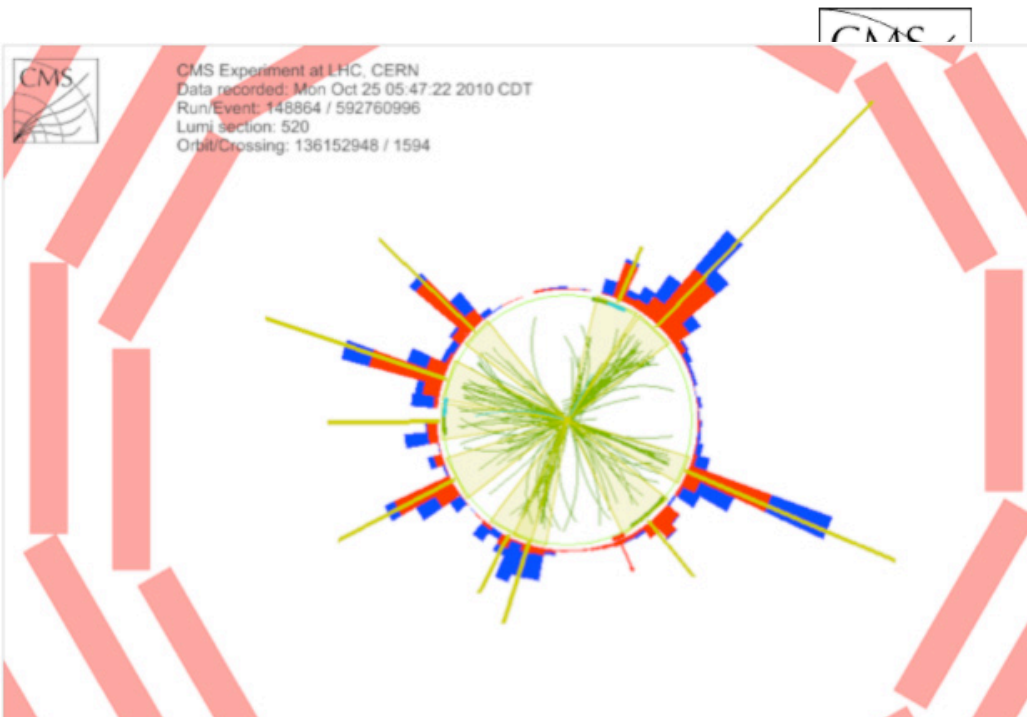
rel-dependent)



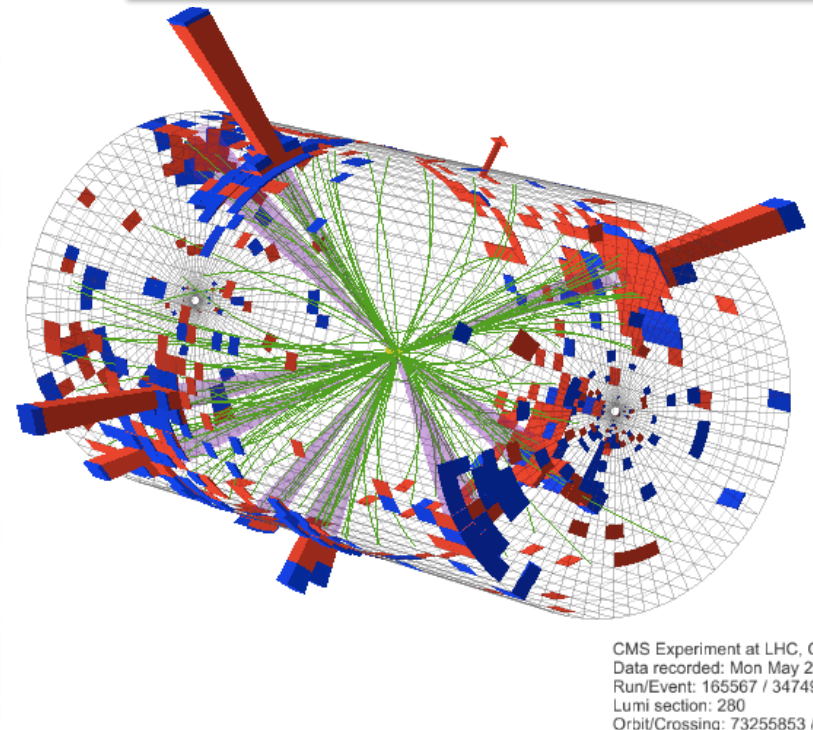
Search for micro-BH

- **Expect lots of activity in the event, so**
 - ◆ Use $S_T = \text{Sum } E_T$ of all objects (including ME_T) with $E_T > 50$ GeV.

A candidate event with 10 jets and $S_T = 1.3$ TeV



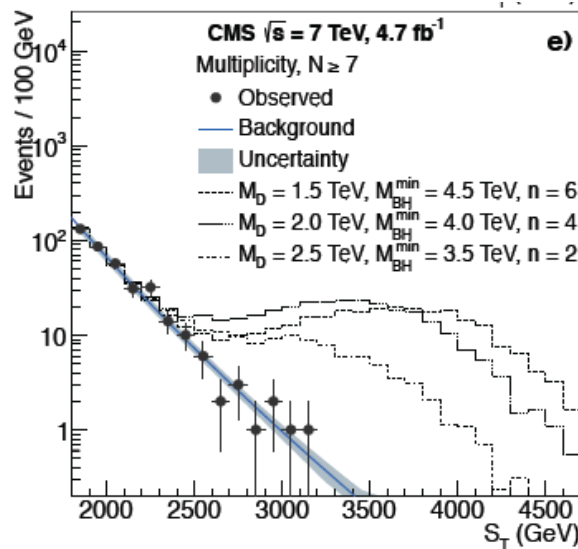
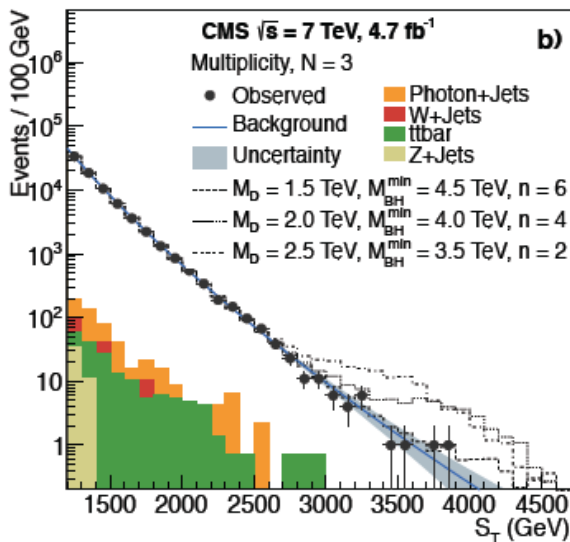
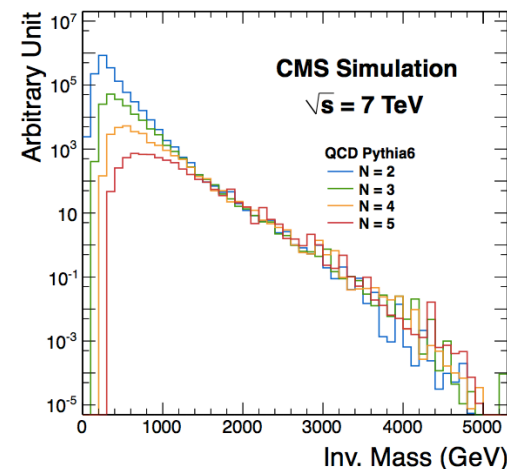
A candidate event with 9 jets and $S_T = 2.6$ TeV



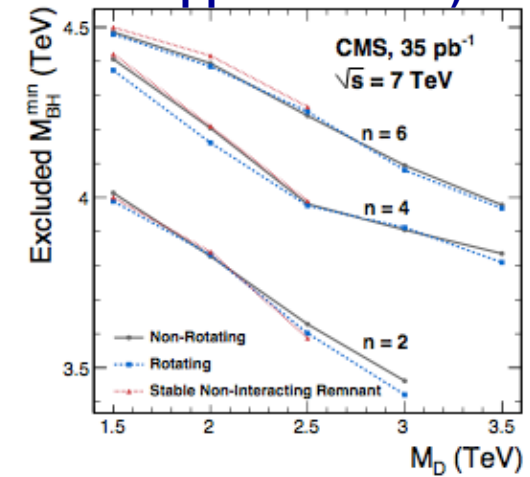
(Null) search for BHs

arXiv:1012.3375

- **Expect lots of activity in the event, so**
 - ◆ Use $S_T = \text{Sum } E_T$ of all objects (including ME_T) with $E_T > 50$ GeV.
 - Great against pileup (in the future as well)
- **Key for search: S_T -invariance of final state multiplicity**
 - ◆ A posteriori wisdom: FSR/ISR collinear do not affect S_T a lot
- **Use $N=2$ shape (with uncertainties) to fit higher multiplicities – where signal more prominent**

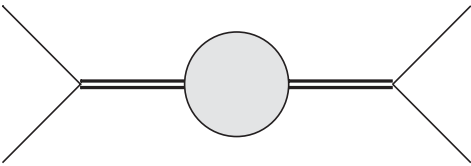


$M_{BH} > 3.8-5.3$ TeV
(semi-classical approximation)

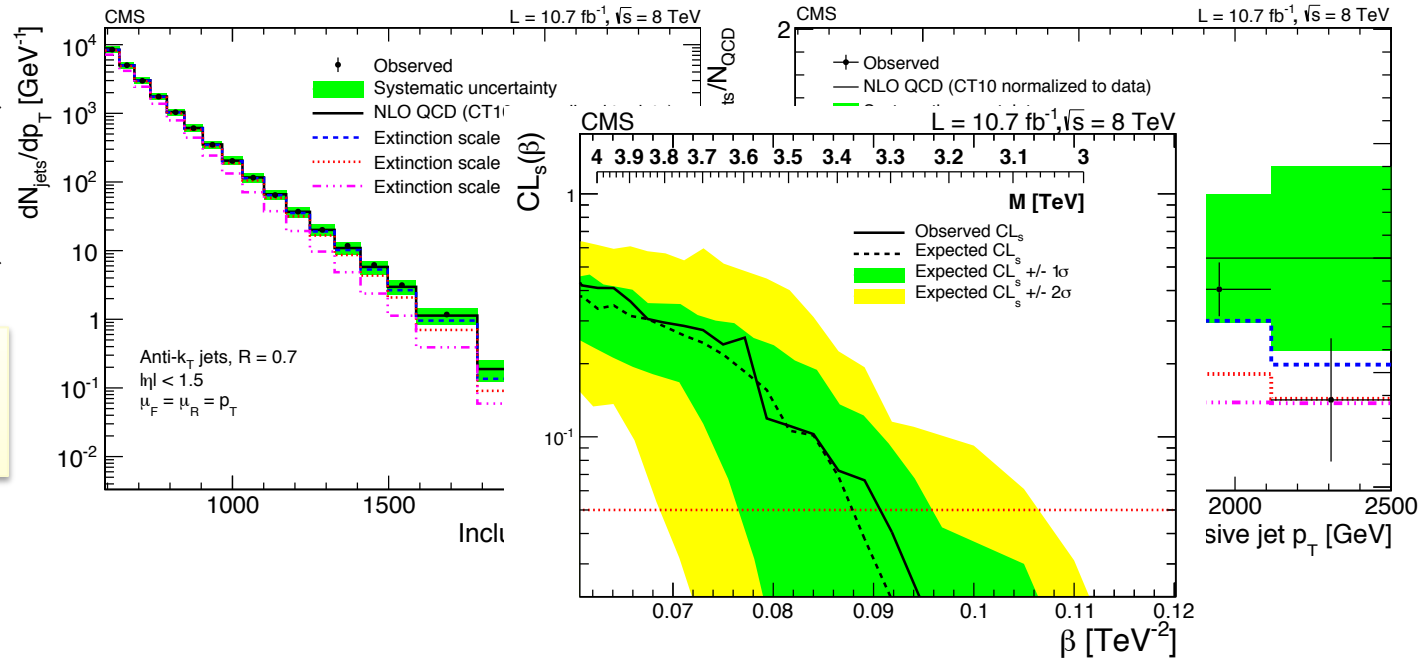


Jet extinction?

- **Production of either black holes or other non-perturbative quantum gravity effects can have rapidly increasing total cross section beyond some scale $\sim \Lambda$**
 - ◆ **Their decay to low-multiplicity final states could be thermally suppressed. Leads to effective extinction of high- p_T SM scattering**



Basic QCD 2→2 process modified



Summary [2/3]

Searches for BSM physics

ATLAS Exotics Searches* - 95% CL Exclusion

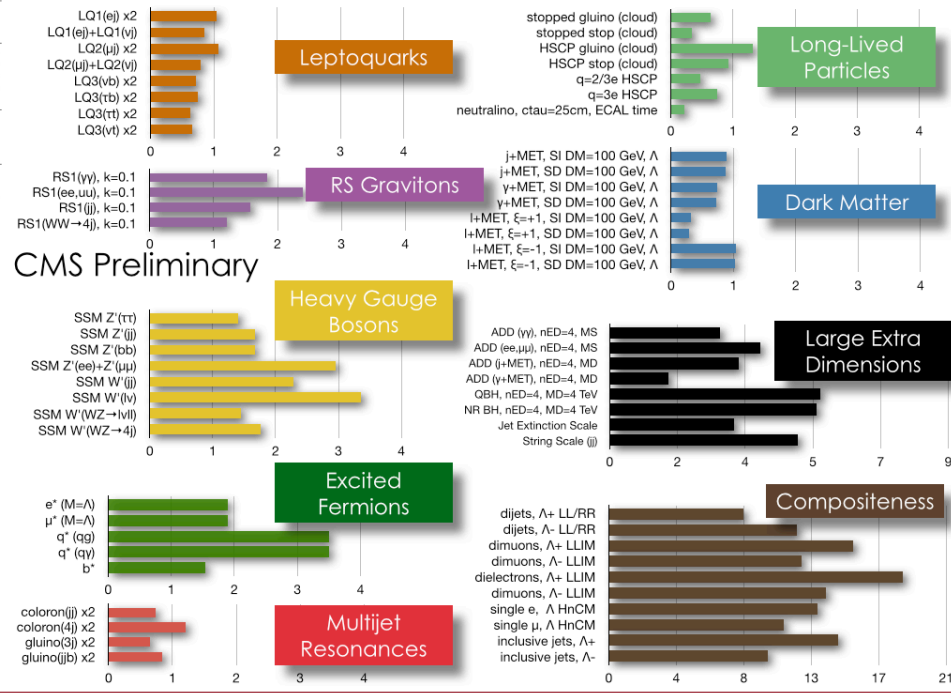
Status: ICHEP 2014

ATLAS Preliminary

$$\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$

Model	L, γ	Jets	E_{T}^{miss}	$[\mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference	
Extra dimensions	ADD $G_{KK} = g/q$	-	1-2j	Yes	4.7	M_{pl} 4.37 TeV	$n=2$ 1210.4491
	ADD non-resonant ll	$2e, \mu$	-	-	20.3	M_{pl} 5.2 TeV	ATLAS-CONF-2014-050
	ADD OBH $\rightarrow qq$	$1e, \mu$	1j	-	20.3	M_{pl} 5.2 TeV	$n=6$ 1311.1200
	ADD OBH	$1e, \mu$	2j	-	20.3	M_{pl} 5.42 TeV	$n=6$ to be submitted to PRD
	ADD BH high M_{KK}	2μ (SS)	-	-	20.3	M_{pl} 5.7 TeV	$n=6, M_{\text{pl}} = 1.5 \text{ TeV, non-rot BH}$ 1308.4075
	ADD BH high Σpr	$\geq 1e, \mu$	$\geq 2j$	-	20.3	M_{pl} 6.2 TeV	1405.4254
	RS1 $G_{KK} \rightarrow ll$	$2e, \mu$	-	-	20.3	$G_{KK} \text{ mass}$ 2.64 TeV	$k/\overline{M}_{\text{pl}} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow WW \rightarrow l\nu l\nu$	$2e, \mu$	-	Yes	4.7	$G_{KK} \text{ mass}$ 1.23 TeV	$k/\overline{M}_{\text{pl}} = 0.1$ 1208.2880
	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow llqq$	$2e, \mu$	2j/1j	-	20.3	$G_{KK} \text{ mass}$ 730 GeV	ATLAS-CONF-2014-039
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbb\bar{b}$	-	4b	-	19.5	$G_{KK} \text{ mass}$ 590-710 GeV	ATLAS-CONF-2014-005
Gauge bosons	Bulk RS $G_{KK} \rightarrow ll$	$1e, \mu$	$\geq 1b, \geq 1l, 0j$	Yes	14.3	$G_{KK} \text{ mass}$ 2.0 TeV	ATLAS-CONF-2013-052
	S^1/Z_2 ED	$2e, \mu$	-	Yes	5.0	$M_{KK} = R^{-1}$ 4.71 TeV	1209.2535
	UED	2γ	-	Yes	4.8	Compact, scale R^{-1} 1.41 TeV	ATLAS-CONF-2010-072
	SSM $Z' \rightarrow ll$	$2e, \mu$	-	-	20.3	$Z' \text{ mass}$ 2.9 TeV	1405.4123
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	19.5	$Z' \text{ mass}$ 1.9 TeV	ATLAS-CONF-2013-066
	SSM $W' \rightarrow l\nu$	$1e, \mu$	-	Yes	20.3	$W' \text{ mass}$ 3.28 TeV	ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow ll'l'l'$	$3e, \mu$	-	Yes	20.3	$W' \text{ mass}$ 1.52 TeV	1405.4452
	EGM $W' \rightarrow WZ \rightarrow qq'll$	$2e, \mu$	2j/1j	-	20.3	$W' \text{ mass}$ 1.59 TeV	ATLAS-CONF-2014-039
	LRSM $W'_\mu \rightarrow r\bar{b}$	$1e, \mu$	2b, 0-1j	Yes	14.3	$W' \text{ mass}$ 1.44 TeV	ATLAS-CONF-2013-050
	LRSM $W'_\mu \rightarrow r\bar{b}$	$0e, \mu$	$\geq 1b, 1j$	-	20.3	$W' \text{ mass}$ 1.77 TeV	to be submitted to EPJG
CI	CI $qqqq$	-	2j	-	4.8	A 7.6 TeV	$\eta = +1$ 1210.1718
	CI $qq'l'l'$	$2e, \mu$	-	-	20.3	A 3.9 TeV	$\eta_{ll} = -1$ ATLAS-CONF-2014-020
DM	CI $cutt$	$2e, \mu$ (SS)	$\geq 1b, \geq 1j$	Yes	14.3	A	ATLAS-CONF-2013-051
	EFT D5 operator (Dirac)	$0e, \mu$	1-2j	Yes	10.5	M_{pl} 731 GeV	at 90% CL for $m(\chi) < 90 \text{ GeV}$
LQ	EFT D9 operator (Dirac)	$0e, \mu$	1j, $\leq 1j$	Yes	20.3	M_{pl} 2.4 TeV	at 90% CL for $m(\chi) < 100 \text{ GeV}$
	Scalar LQ 1 st gen	$2e$	$\geq 2j$	-	1.0	LQ mass 660 GeV	$\beta = 1$ 1112.4628
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	-	1.0	LQ mass 685 GeV	$\beta = 1$ 1203.3172
Heavy quarks	Scalar LQ 3 rd gen	$1e, \mu, 1\tau$	1b, 1j	-	4.7	LQ mass 534 GeV	$\beta = 1$ 1303.0526
	Vector-like quark $TT \rightarrow Ht + X$	$1e, \mu$	$\geq 2b, \geq 4j$	Yes	14.3	T mass 790 GeV	T in (TB) doublet ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	14.3	T mass 870 GeV	isospin singlet ATLAS-CONF-2013-060
	Vector-like quark $TT \rightarrow Zc + X$	$2b, 3\mu$	$\geq 2b, \geq 1j$	-	20.3	T mass 735 GeV	T in (TB) doublet ATLAS-CONF-2014-038
Excited fermions	Vector-like quark $BB \rightarrow Zb + X$	$2b, 3\mu$	$\geq 2b, \geq 1j$	-	20.3	B mass 735 GeV	B in (B) doublet ATLAS-CONF-2014-038
	Vector-like quark $BB \rightarrow Wt + X$	$2e, \mu$ (SS)	$\geq 1b, \geq 1j$	Yes	14.3	B mass 720 GeV	B in (TB) doublet ATLAS-CONF-2013-051
	Excited quark $q^* \rightarrow q\gamma$	1j	1j	-	20.3	$q^* \text{ mass}$ 3.5 TeV	only u' and d' , $A = m(q')$
	Excited quark $q^* \rightarrow qg$	-	2j	-	20.3	$q^* \text{ mass}$ 4.08 TeV	only u' and d' , $A = m(q')$
Other	Excited quark $q^* \rightarrow Wt$	1 or 2 e, μ	1b, 2j or 1j	Yes	4.7	$q^* \text{ mass}$ 870 GeV	to be submitted to PRD 1301.1563
	Excited lepton $l^* \rightarrow l\gamma$	$2e, \mu, 1\tau$	-	-	13.0	$l^* \text{ mass}$ 2.2 TeV	$A = 2.2 \text{ TeV}$ 1308.1664
	LSTC $l^* l^* \rightarrow W\gamma$	$1e, \mu, 1\tau$	-	Yes	20.3	$l^* \text{ mass}$ 968 GeV	to be submitted to PLB 1203.5430
	LRSM Majorana ν	$2e, \mu$	2j	-	2.1	$N^c \text{ mass}$ 1.4 TeV	$m(W_\mu) = 2 \text{ TeV, no mixing}$ ATLAS-CONF-2013-019
	Type III Seesaw	$2e, \mu$	-	-	5.8	$N^c \text{ mass}$ 245 GeV	$(V_\mu)_0 = 0.055, (V_\mu)_\pm = 0.063, (V_\mu)_0 = 0$ 1210.5070
	Higgs triplet $H^{\pm\pm} \rightarrow ll$	$2e, \mu$ (SS)	-	-	4.7	$H^{\pm\pm} \text{ mass}$ 409 GeV	DY production, BR($H^{\pm\pm} \rightarrow ll$)=1 1301.3272
	Multi-charged particles	-	-	-	4.4	Multi-charged particle mass 490 GeV	DY production, $ \eta = 4\mu$ 1207.5411
	Magnetic monopoles	-	-	-	2.0	Monopole mass 862 GeV	DY production, $ \eta = 4\mu$

*Only a selection of the available mass limits on new states or phenomena is shown.



CMS Exotic Physics Group Summary – ICHEP 2014

Summary [2/3]

- **First set of searches today: hadronic channels**
 - ◆ Jet resonances, jet angular distributions, probing compositeness [nope]
 - ◆ New contact interactions [nope]
- **Second set of searches today: “exotica” channels**
 - ◆ Searches for new gauge bosons [nope]
 - ◆ Searches for other signs of extra dimensions [nope]
 - ◆ Searches for leptoquarks [nope]
 - ◆ Mono-objects, for a signature from “extra dimension physics” or dark matter [nope]
- **Next [and final for these lectures] stop: SUSY searches**