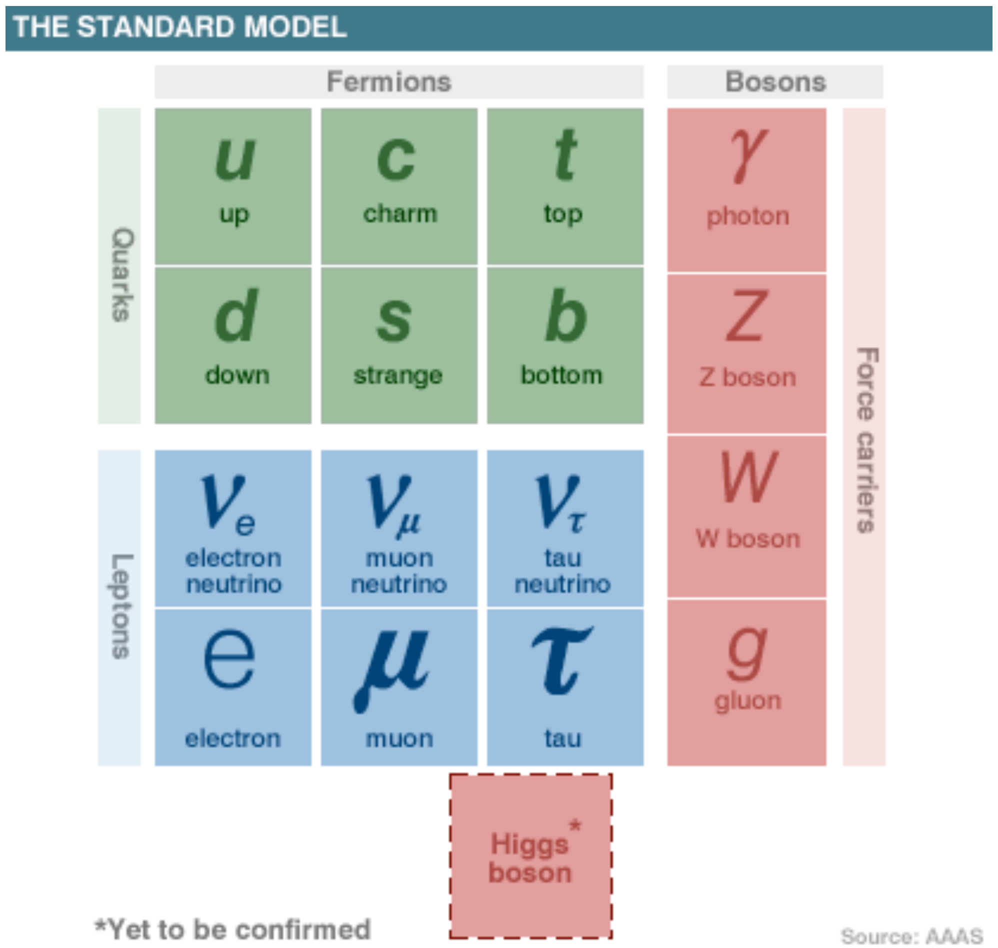
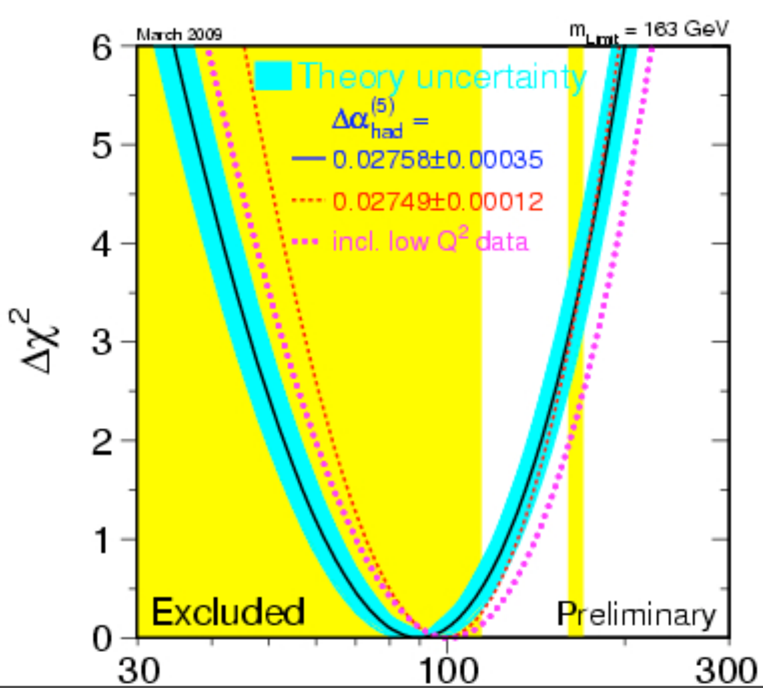
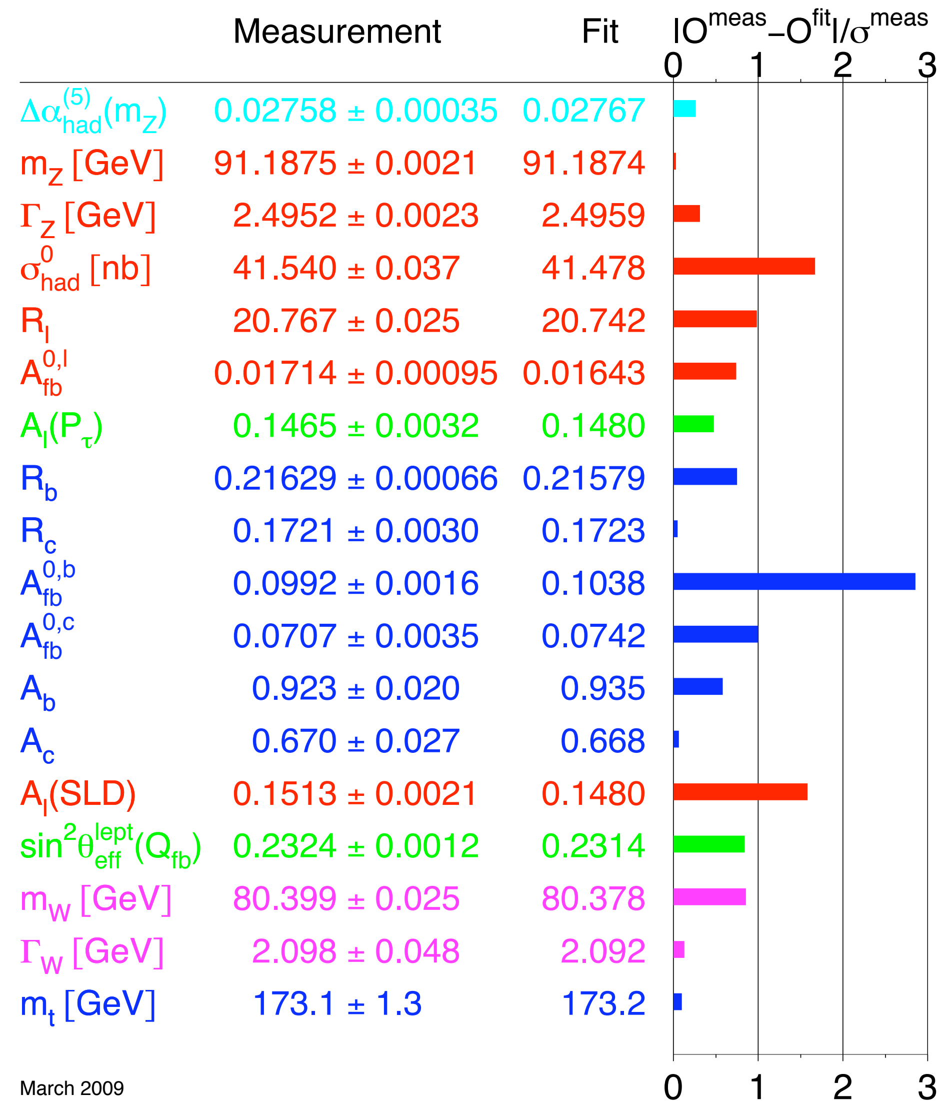
BSM Searches with Leptons and Jets at the LHC

Kevin Black
Harvard University

Standard Model



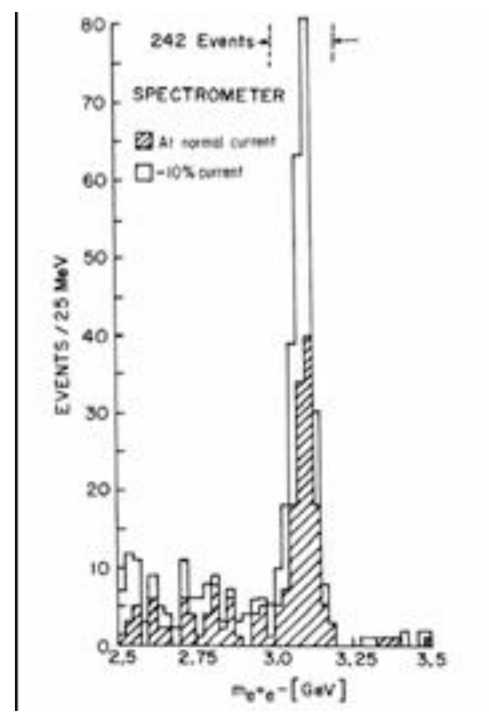




Filling in the final details or awaiting revolution?

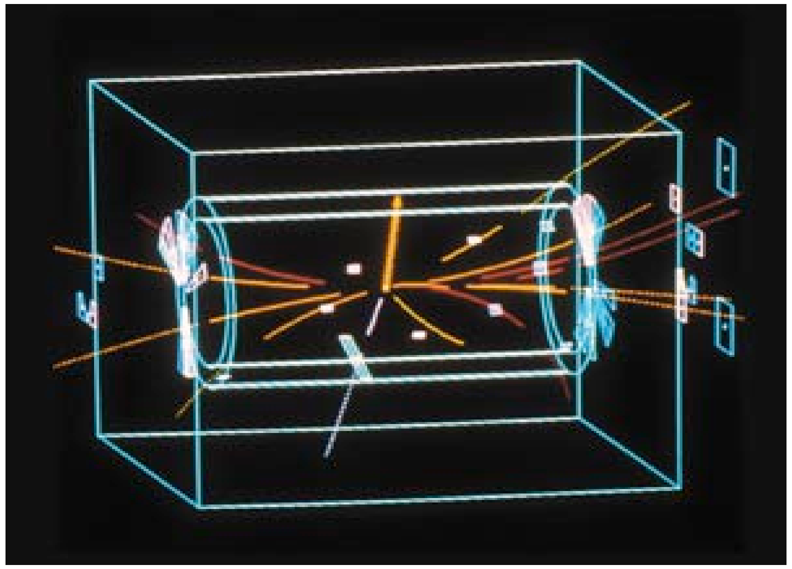
New Energy Regimes

- Previous experiments quickly found new particles which were inaccessible with previous energies
- In most (but not all) cases these were found in simple final states
    - J/Psi, W, Z, tau
- Will the first year LHC data hold the same surprise?

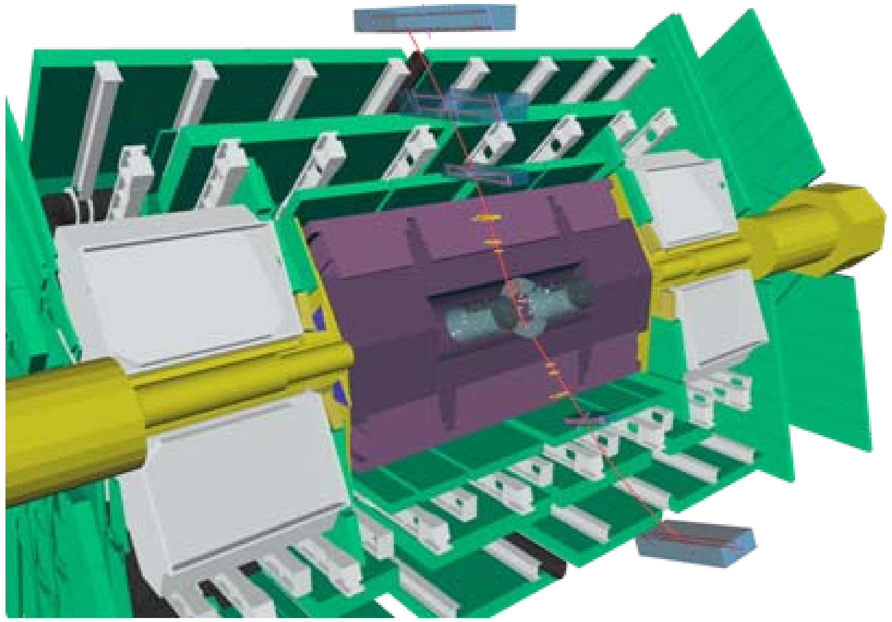


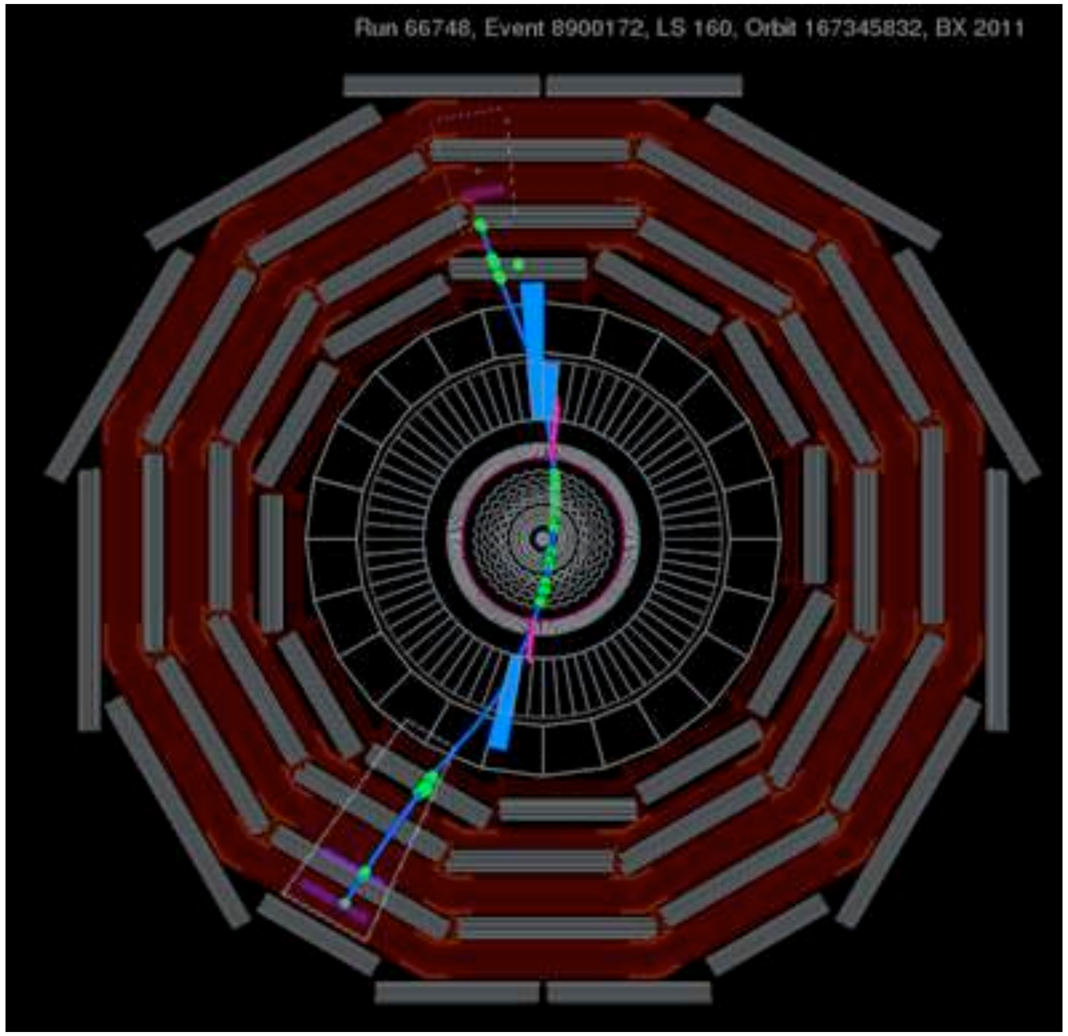
J/Psi
Discovery
1974

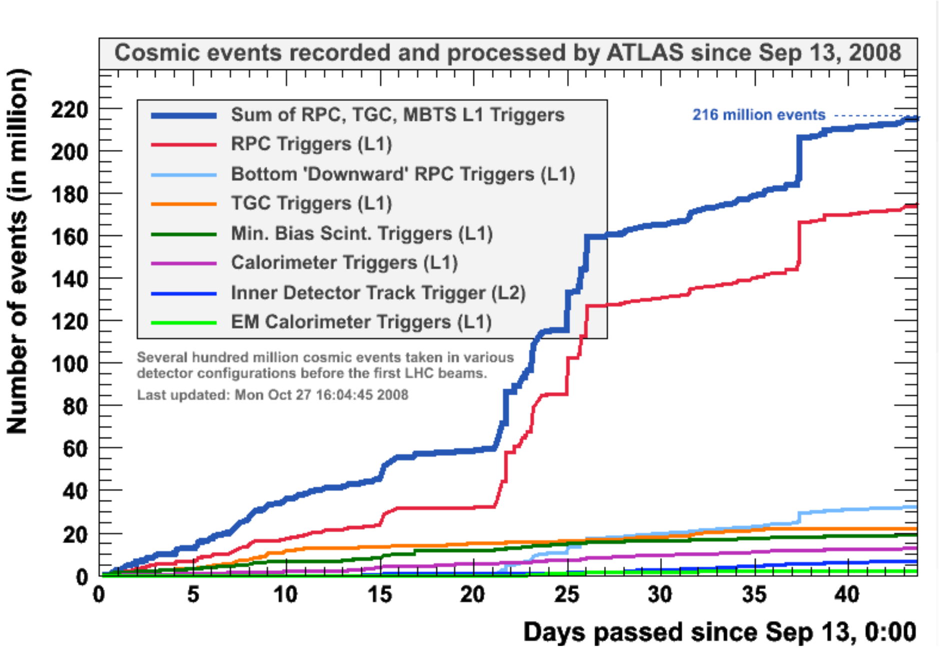
W Boson
Discovery
1983



Detector Status: Operational and taking cosmics..

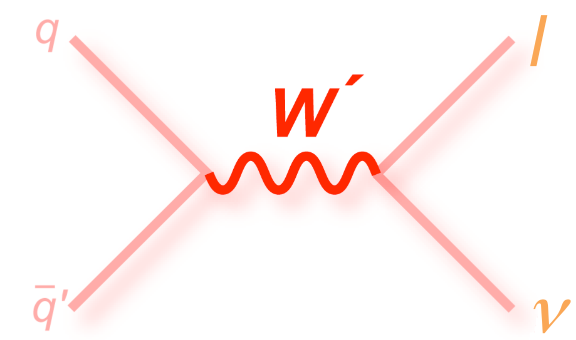




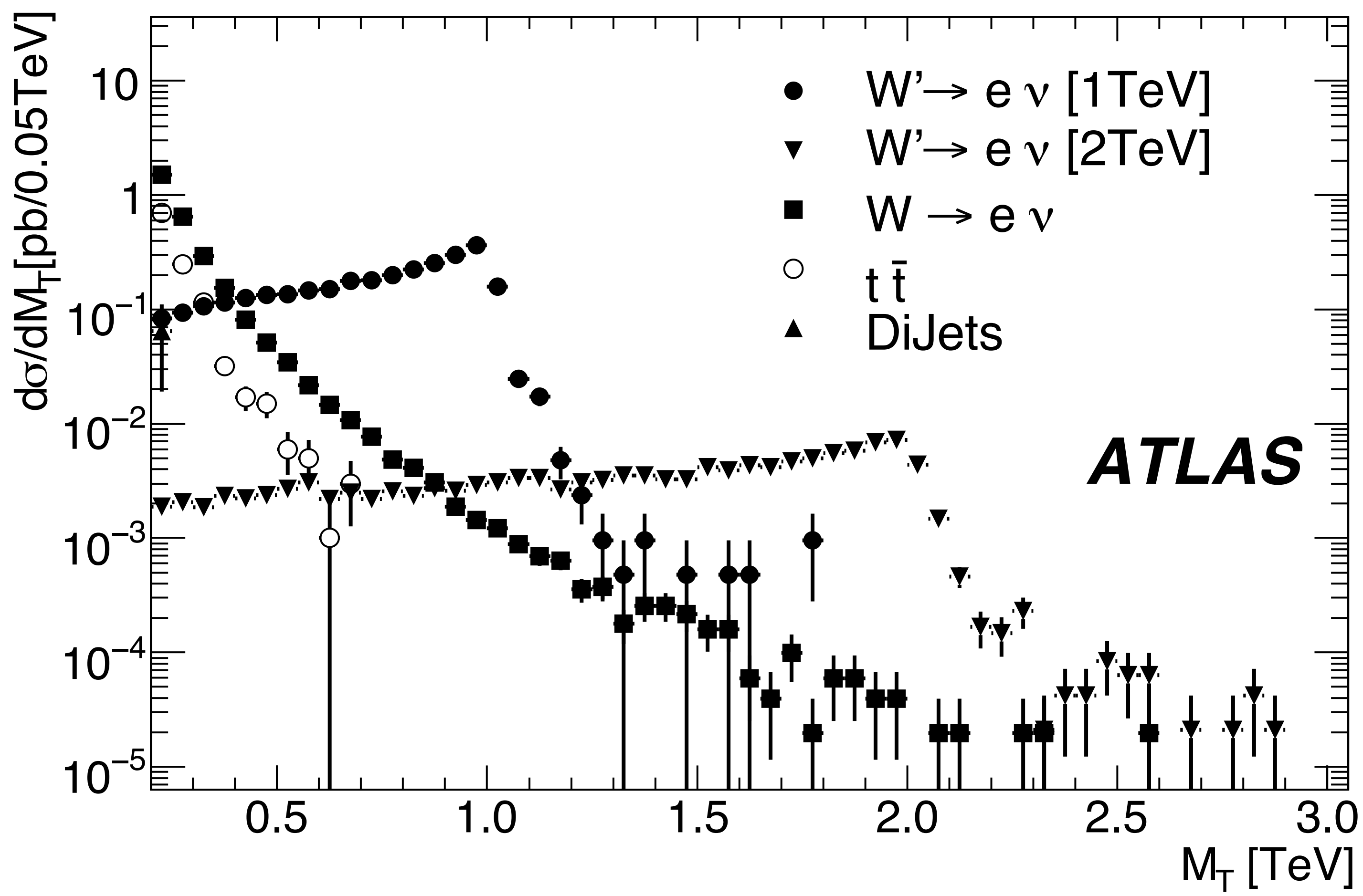


Heavy Gauge Bosons

- New Heavy Gauge bosons - heavier cousins to W,Z
- With couplings 'like' SM gauge couplings most promising search in the leptonic channels
- Analysis is 'scaled up' version of W,Z physics
- Event Selection:
  - 1 high pt Lepton
  - Missing Et
  - Jet Veto (reject tt, high mass dijets)

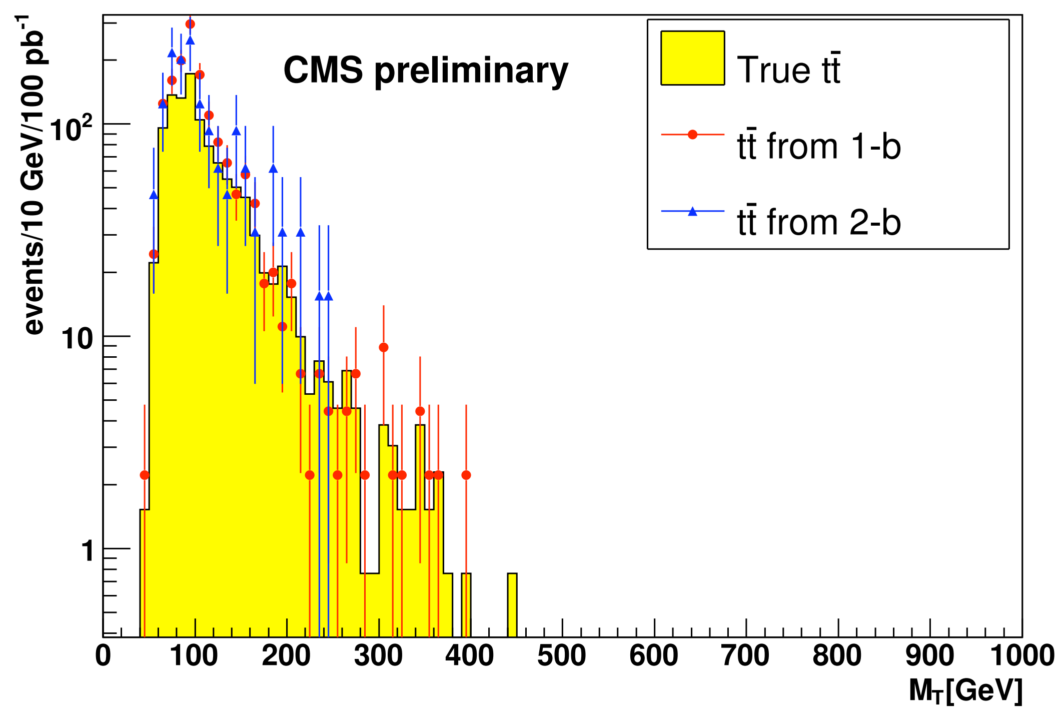


$$m_T = \sqrt{2 p_T \not{E}_T (1 - cos\Delta\phi_{\ell,\not{E}_T})}$$



W' Backgrounds - new for the LHC

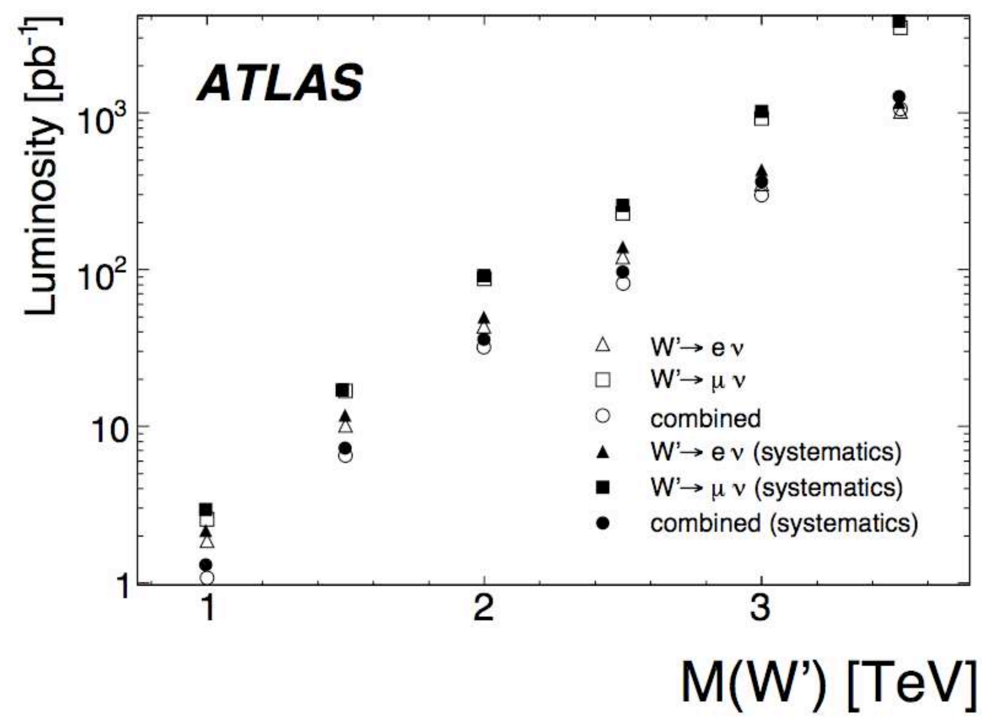
- At Tevatron : W production + dijets dominate background
  - Dijets estimated looking at low transverse mass region (dominated by QCD dijets)
- At LHC tt is non-negligible (cross-section is ~100 times bigger at 14 TeV)
- Data Driven method to estimate based on measured number of b-tags and btagging efficiency

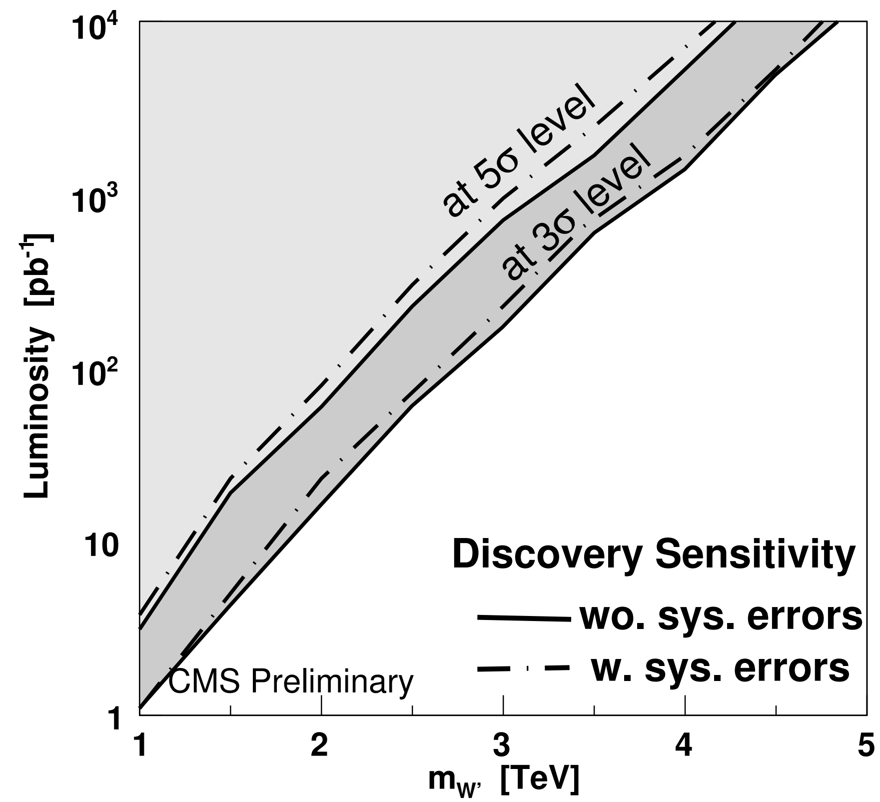


Jet Veto to reduce contribution from tt

Leptonic Channel Sensitivity

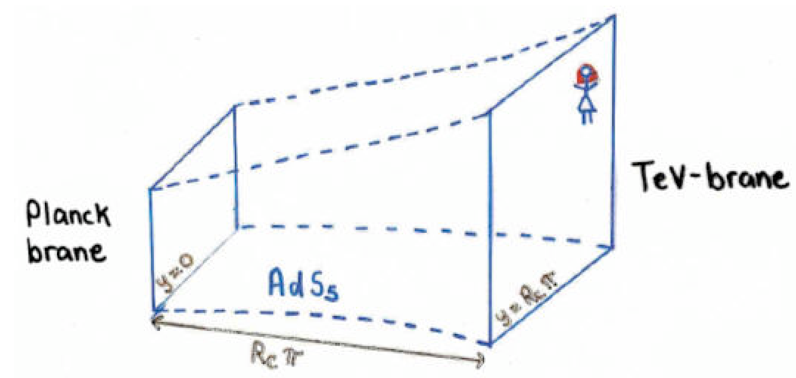
- Tevatron Limits around 1 TeV assuming SSM
- At 14 TeV, can discover W' with relatively modest amounts of data (up to ~2 TeV with ~100 pb-1 of data).
- Set limits up to ~3 TeV with same data set (95% CL)
- At 10 TeV cross-section drops by a ~ factor of 2

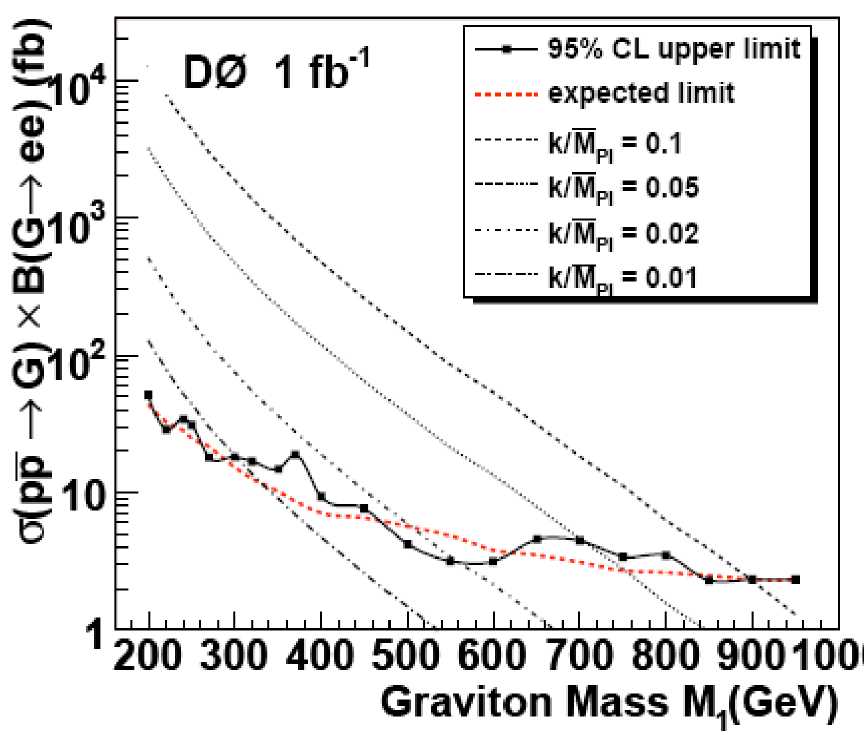




Graviton

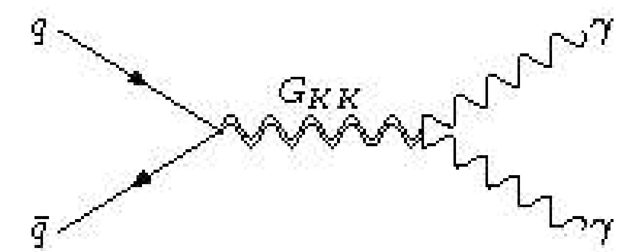
- SM fields on one of two 4-dimensional brane in a 5-D spacetime
- Graviton can propagate in the bulk
- Kaluza-Klein States on the order of TeV
- Main parameters:
    - mass of Graviton
    - curvature parameter





Graviton

- Besides Dilepton channel - Gravition (spin 2) decays into diphotons
  - Spin 1 resonances do not
  - Graviton to diphoton channel has twice dilepton branching ratio
- Backgrounds :
  - direct diphoton production, gamma+jet, dijet, Drell-Yan



$$\bar{M}_{Pl}^2 = \frac{M_5^3}{k}(1 - e^{-2kr_c\pi}).$$

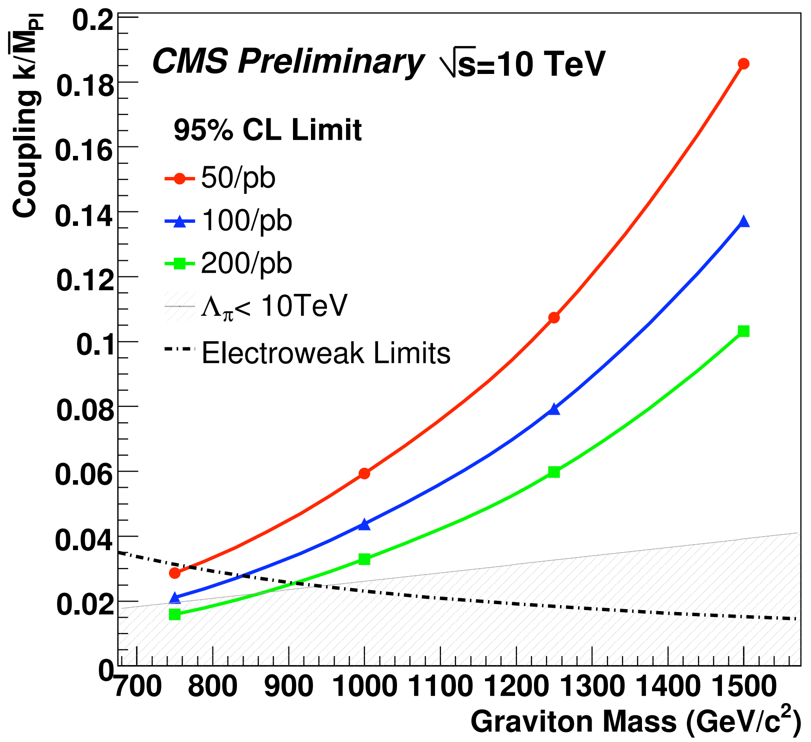
$$\tilde{k} = k/\bar{M}_{Pl}$$

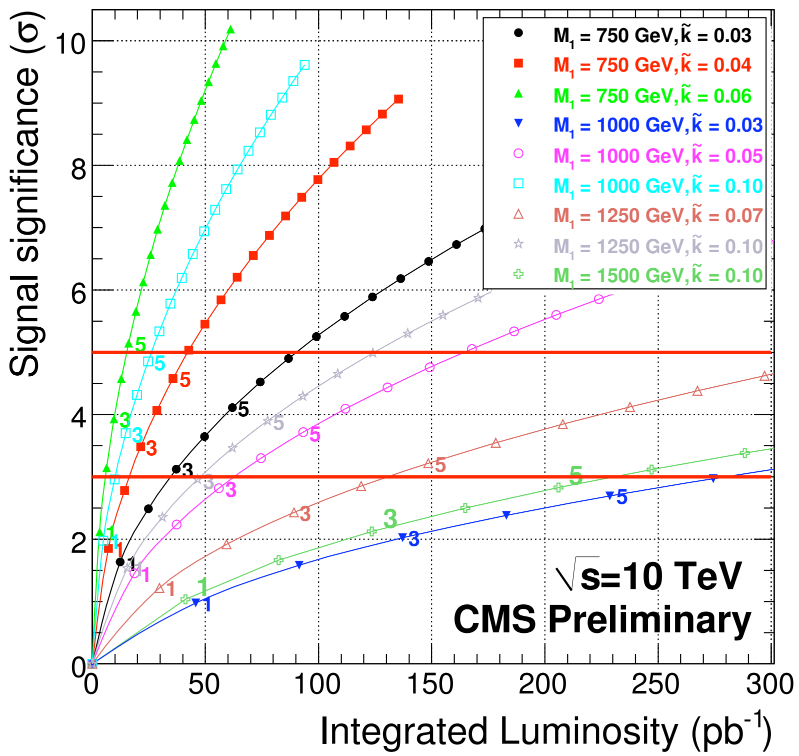
- Photon $p_T > 50\,\mathrm{GeV}$
- Photon $|\eta| < 1.5$
- $M_{\gamma\gamma} > 700\,\mathrm{GeV}$

M_1 (GeV/c^2)	$\tilde{k}$	$\sigma_{tot} \times$BR (pb)
750	0.01	0.02083
1000	0.01	0.004285
1250	0.01	0.001262
1500	0.01	0.0003947

Graviton

- Possibility to discover ‘low’ mass graviton with relatively modest amount of data
- Strongly dependent upon coupling and mass
- One way of disentangling new resonance (spin 1 objects cannot decay into diphoton final state)



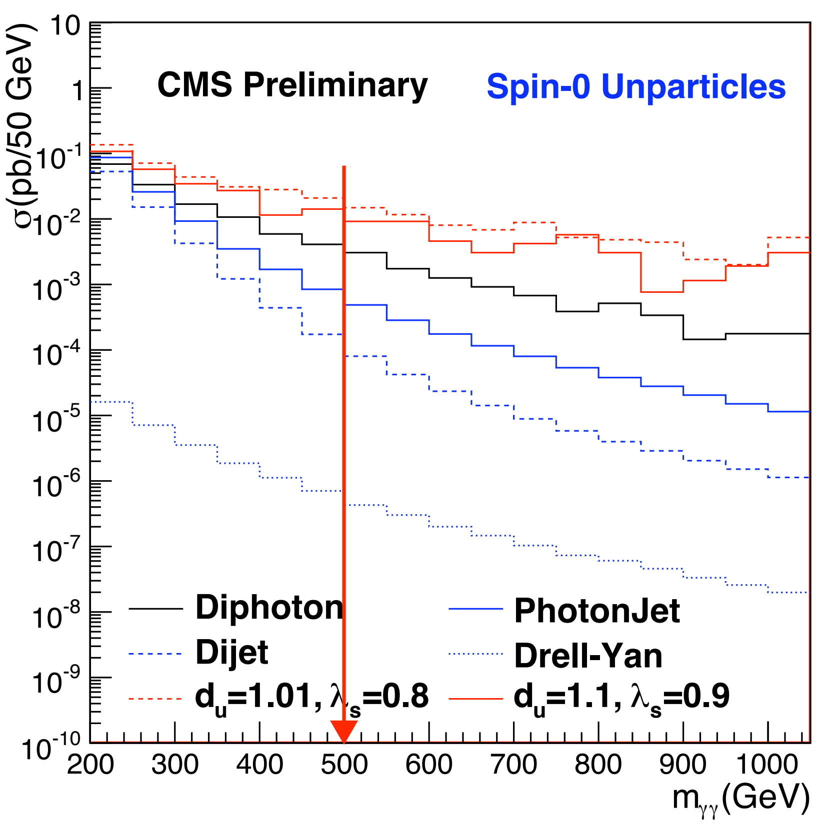


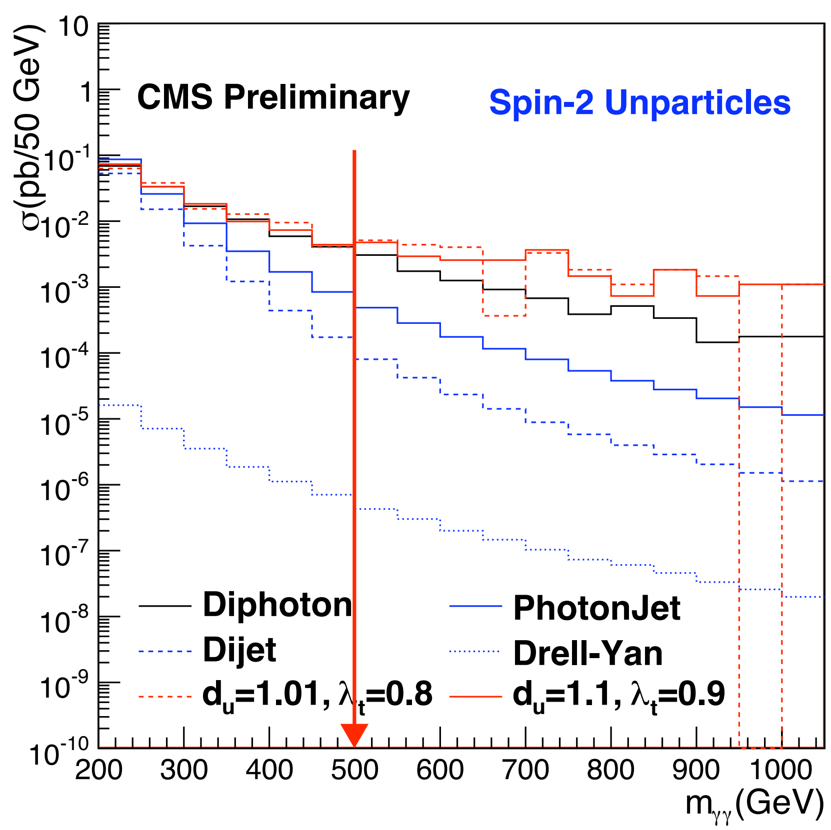
Tuesday, July 28, 2009

Unparticles

- SM diphoton production from quark anti-quark annihilation (Born diagram);
- SM diphoton production from gluon fusion (Box diagram);
- Photon+Jets;
- QCD multijets;
- Drell-Yan e^+e^-.

similar to Graviton search,
but no bump...

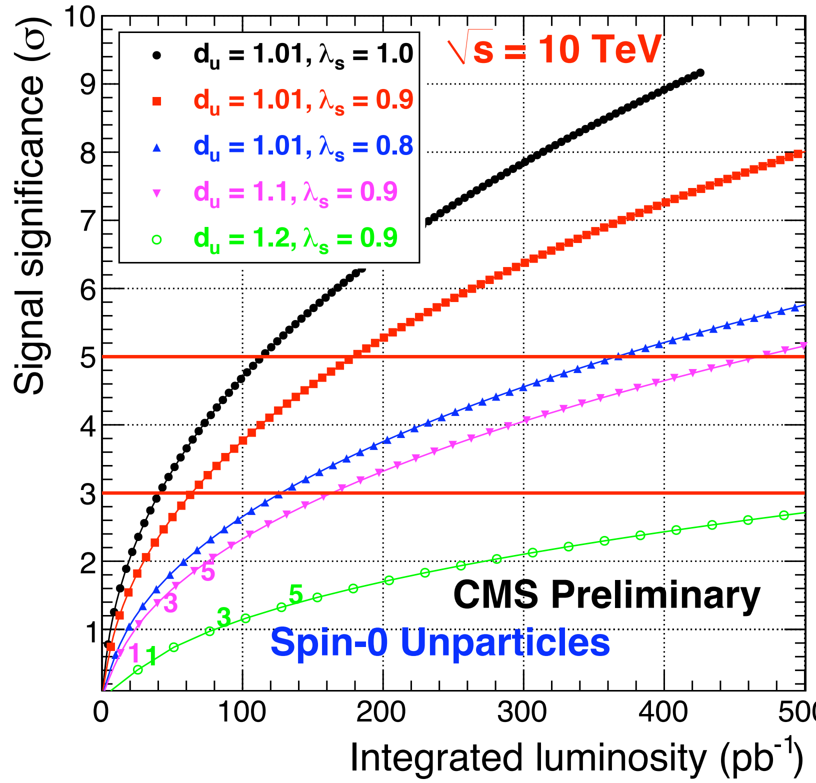


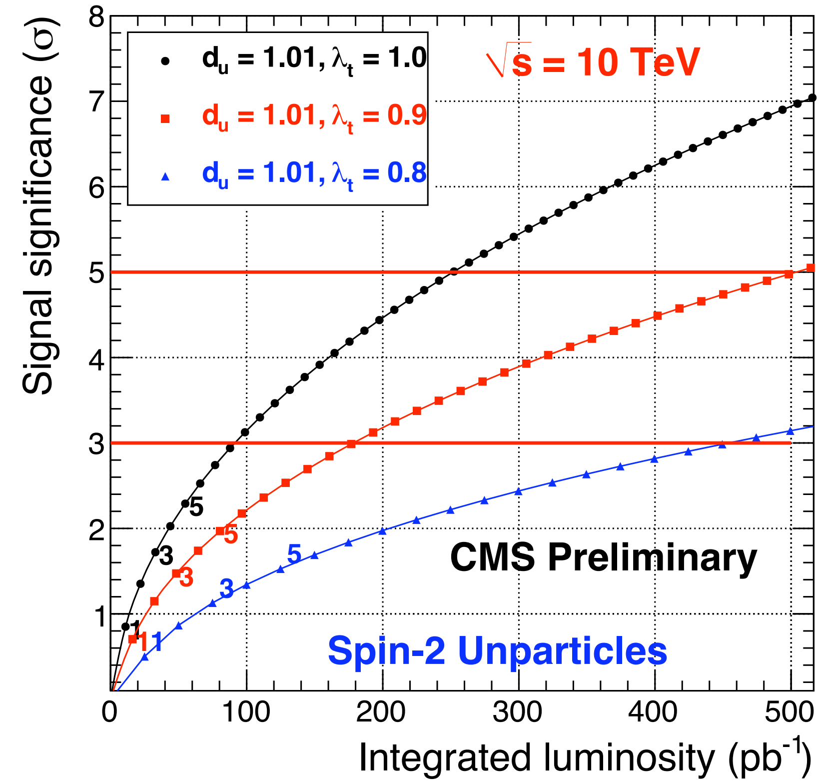


$d_{\mathcal{U}}$ scale parameter

λ coupling

Unparticles

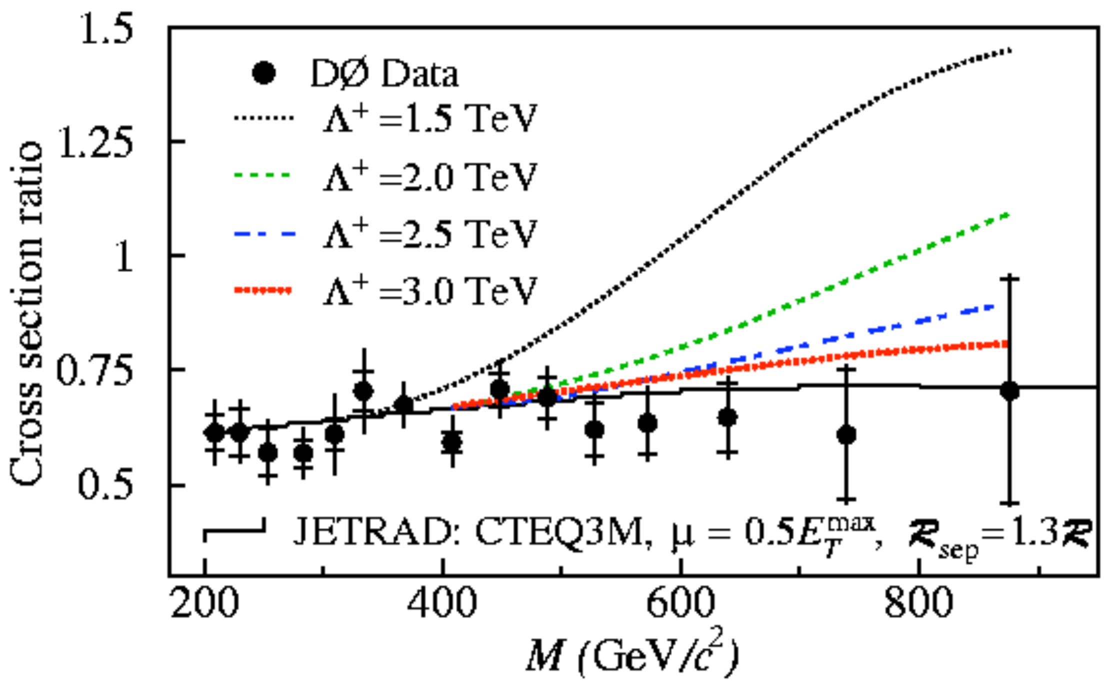


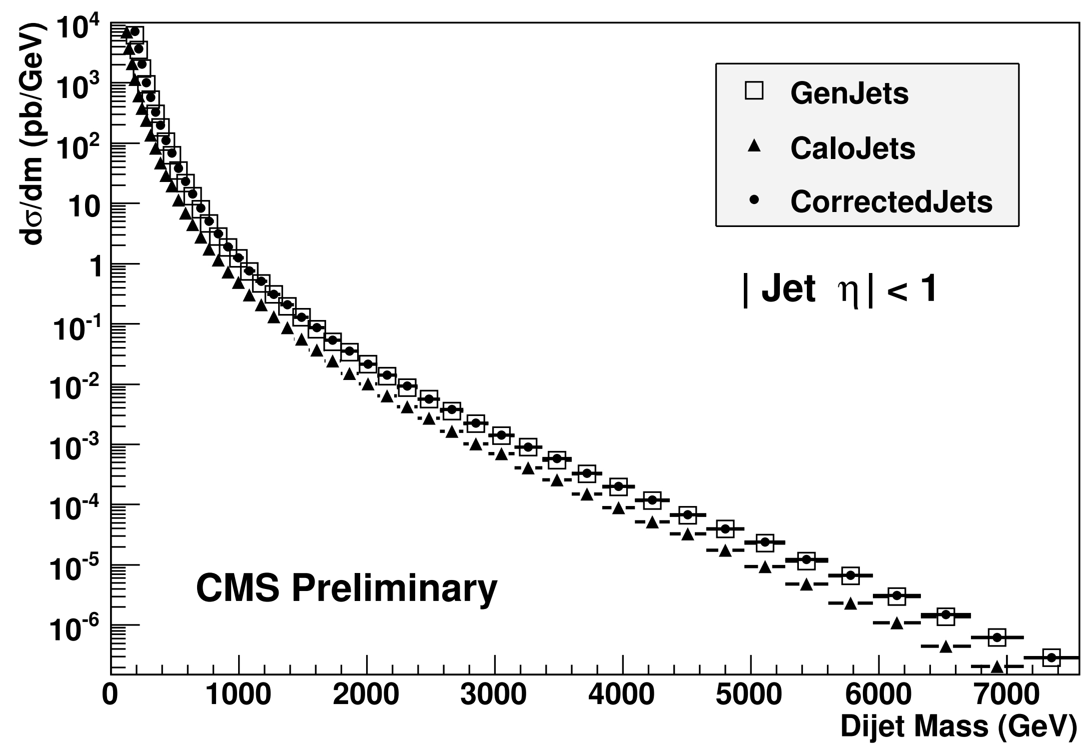


- Should be able to see unparticle production with few hundred inverse pb of data
- Dependence on details of model as usual

Dijet Signatures

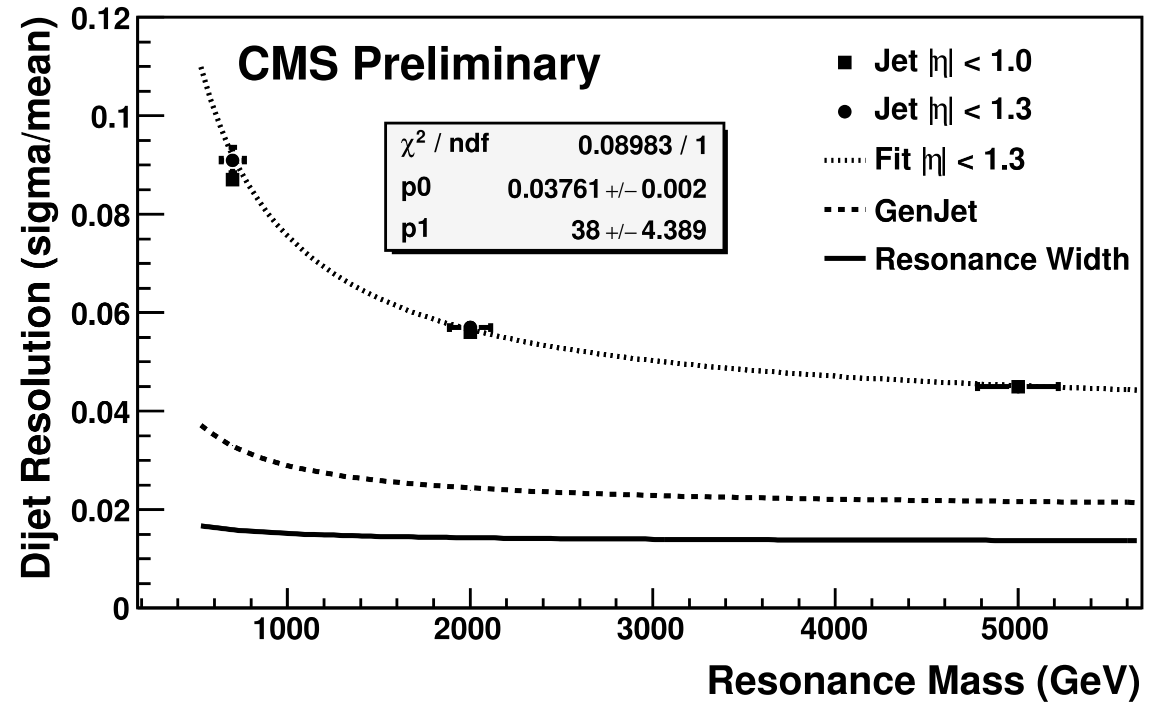
- Obvious place to look is multilepton signatures - but maybe 'new' physics couples more to quarks
- Resonances
- Contact Interactions
- Larger backgrounds - but still just as promising channels...

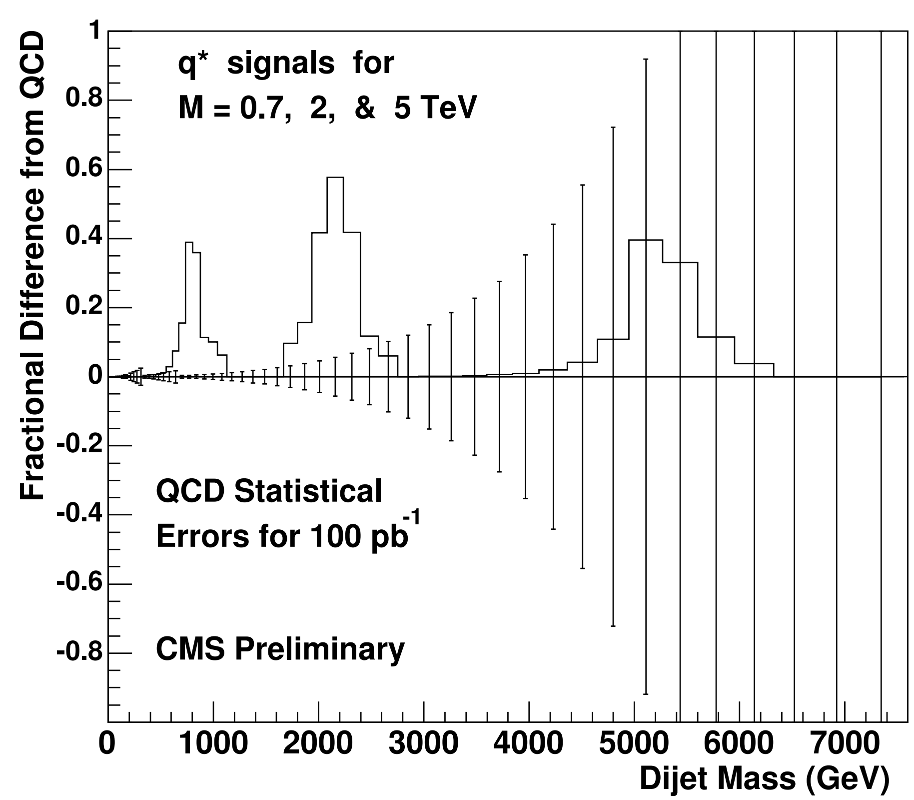




Dijet Resonances

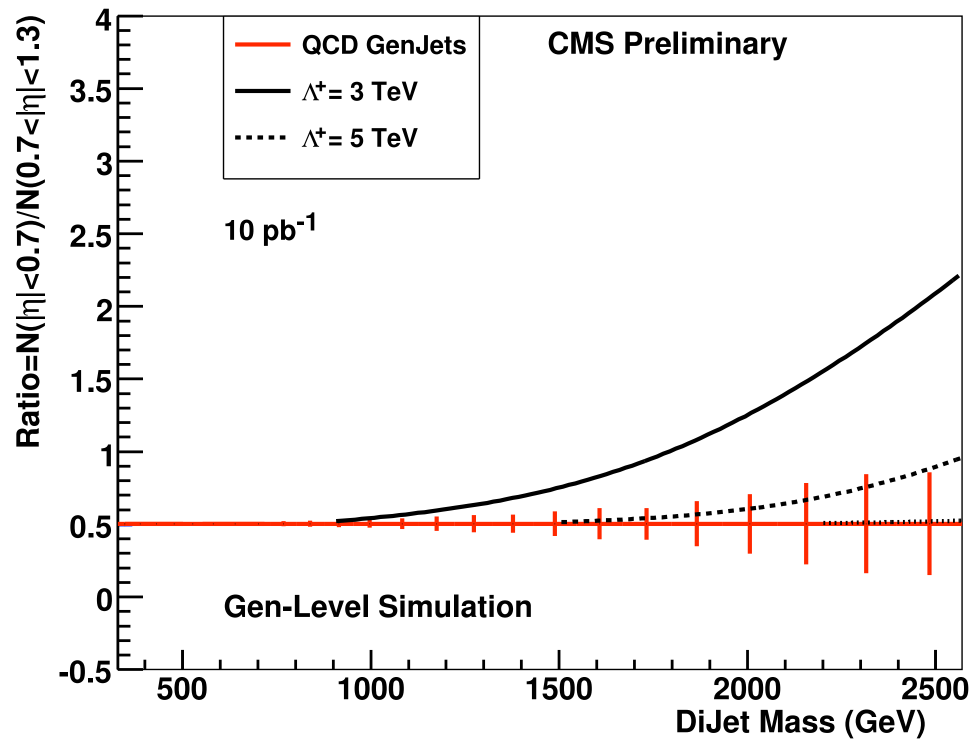
- For high mass resonances dijet resolution ~ 5-10%
- Measure the QCD dijet distribution and extrapolate to the high mass region
- Errors grow with invariant mass (will improve with larger data sets)
- Should be able to see clear signal for area just out of Tevatron reach

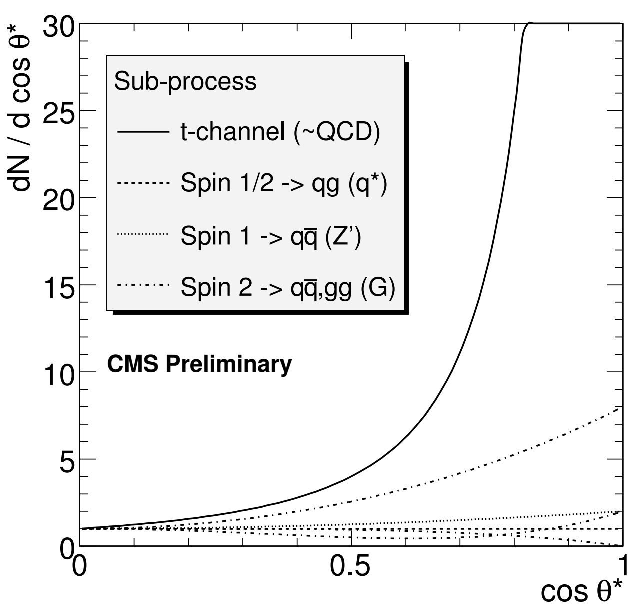


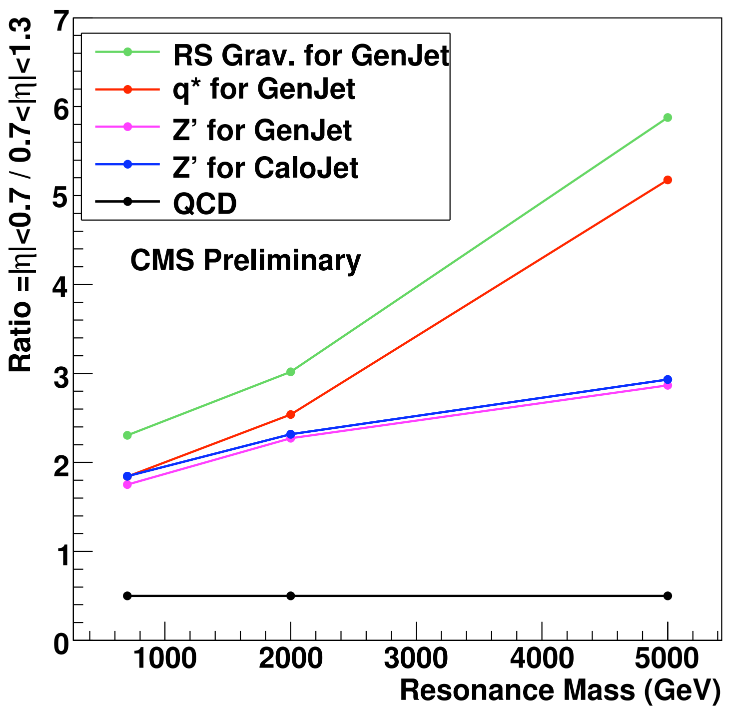


Dijet Ratio Method

- Compare ratio of dijet events in central to forward region as a function of dijet mass.
- New interactions/particles modify this ratio
- Look at angular distribution to see spin of new particle

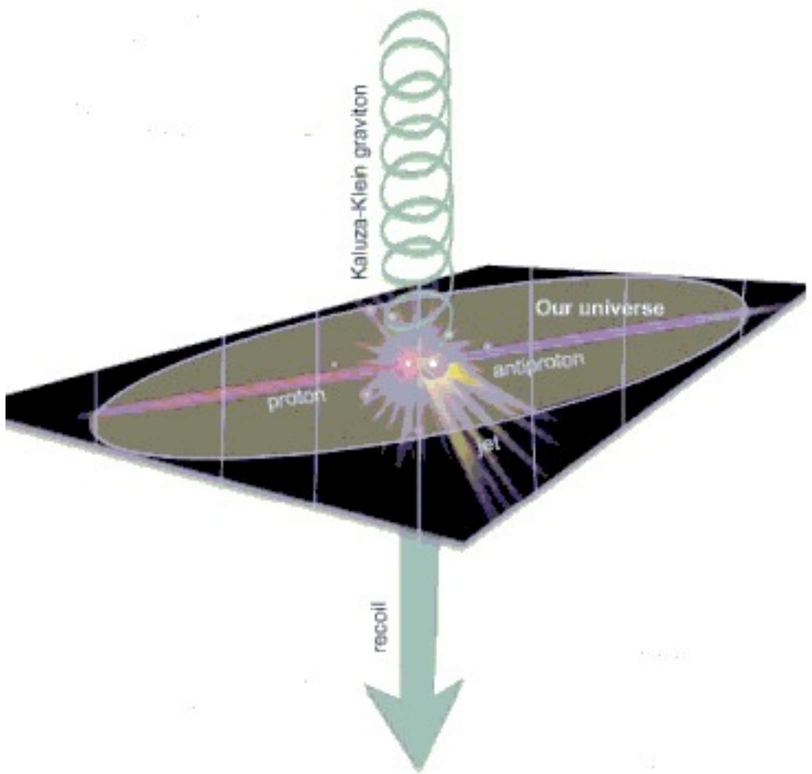






Monojets

- Real Graviton Production that escapes detection (weakly coupled)
- Recoils against one or more high energy jets
- Background
  - Z->vv
  - W+jets (miss lepton)
  - ttbar (mis-measure jets or miss lepton)
  - Dijets (mis-measure jet)



Extra Dimensions

	$\delta = 2$	$\delta = 4$
$M_D = 2$ TeV	49.246 ± 0.056	18.914 ± 0.022
$M_D = 4$ TeV	4.253 ± 0.005	0.998 ± 0.001
$M_D = 6$ TeV	0.862 ± 0.001	0.109 ± 0.001

Cross-section in pb

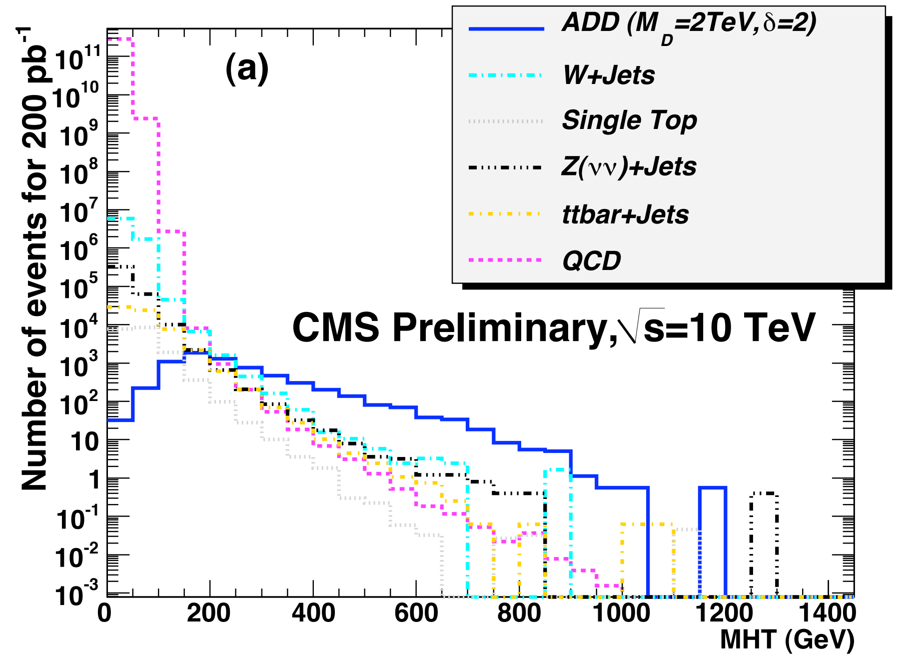
Monojets

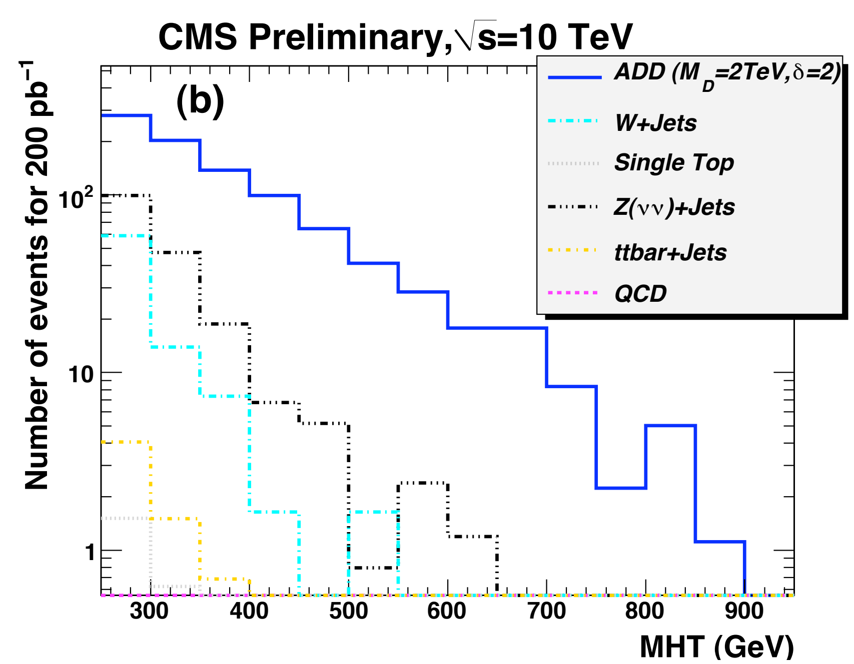
- Analysis done with Ht distribution

- Clean background by additional cuts on Jet quality (reduce lepton->jet rate)

- Reduce remaining multijet data by exploiting shape of events

$$MHT = \left| \sum_{p_T(\text{jet})_i > p_T^0} \vec{p}_T(\text{jet})_i \right|$$



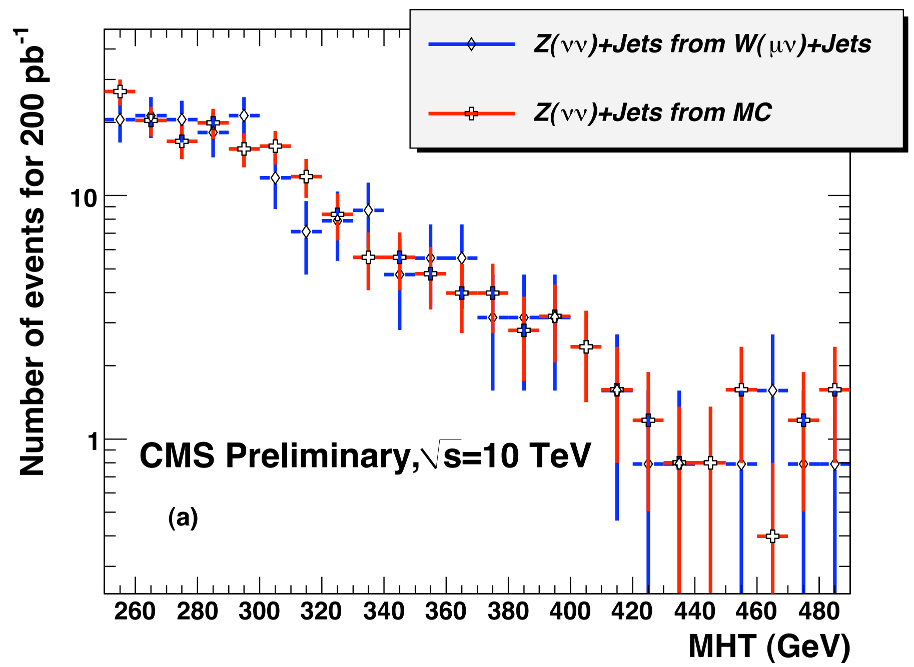


	$t\bar{t}$	$Z(\nu\nu)$+j	QCD	$W(e\nu)$+j	$W(\mu\nu)$+j	$W(\tau\nu)$+j	single-t
Trigger	28,970	11,390	$143 \cdot 10^6$	31,320	19,320	20,600	4460
MHT >250 GeV	318	358	288	90	391	230	44
$0.1 < JEMF < 0.9$ TIV >0.1	52.5	305	214	31.9	38.5	90.9	7.2
$p_T(\text{jet}\,1) > 200$ GeV $\lvert\eta(\text{jet}\,1)\rvert$ <1.7	37.4	245	187	24.6	24.6	72.1	4.5
numb. jets<3	8.2	205.6	70.9	18.8	22.9	59.8	2.8
$\Delta\phi(\text{jet}\,1, MHT)$ >2.8 $\Delta\phi(\text{jet}\,2, MHT) > 0.5$	6.4	182.5	0.2	17.2	19.7	46.7	2.3

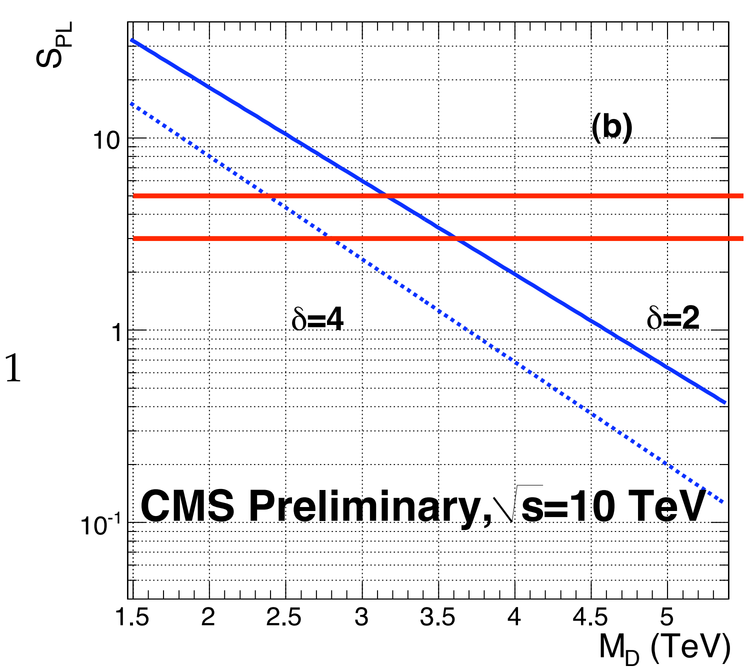
$$\text{TIV} = \quad \Sigma_{0.02<R<0.35}\, p_T) \,/\, p_T(\text{trk}\,1)$$

Monojets

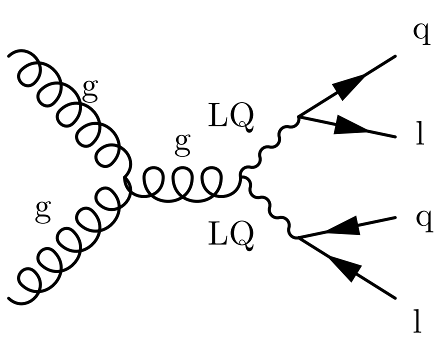
- Largest backgrounds can be derived from data
  - Dijets (lower mass control region)
  - Z->neutrinos (W->mu nu +jets removing muon)
- Should be able to discover Gravitons in to the few TeV range with nominal 2009/2010 datasets...

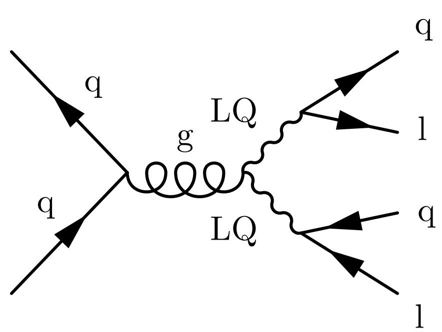


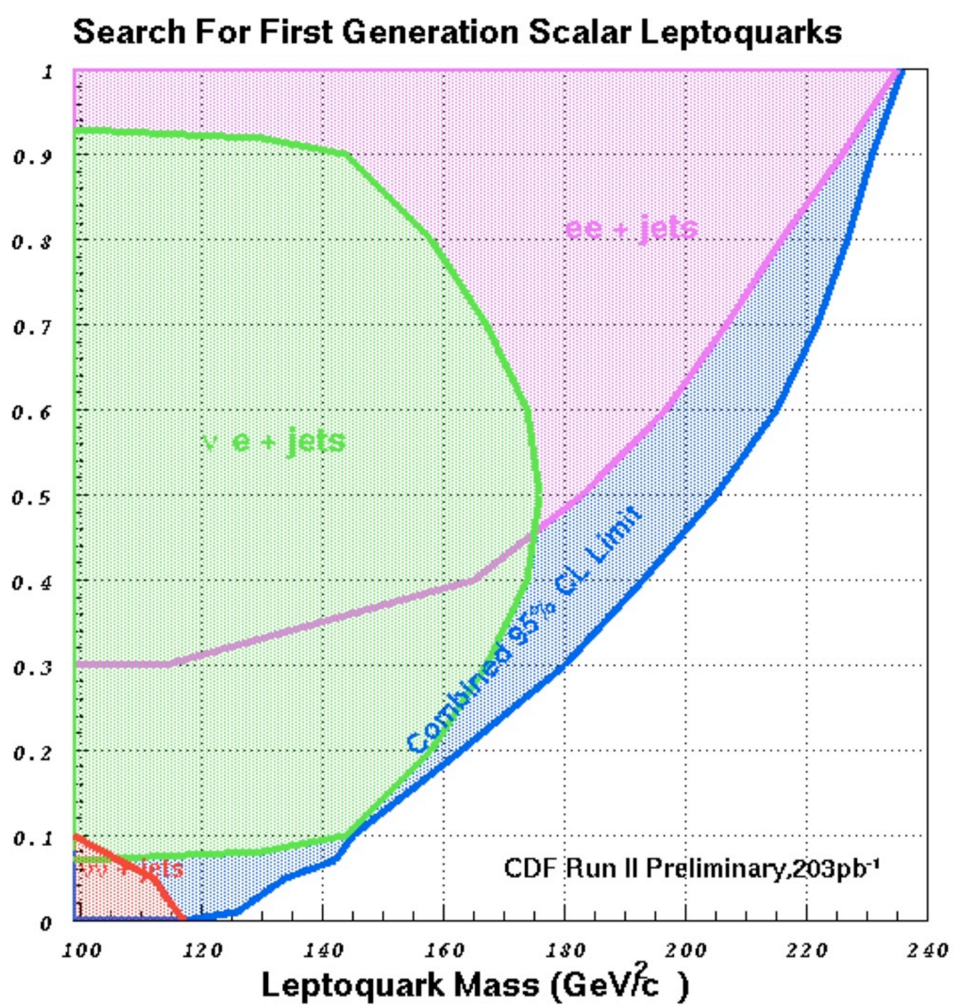
$200\ pb^{-1}$



Leptoquarks

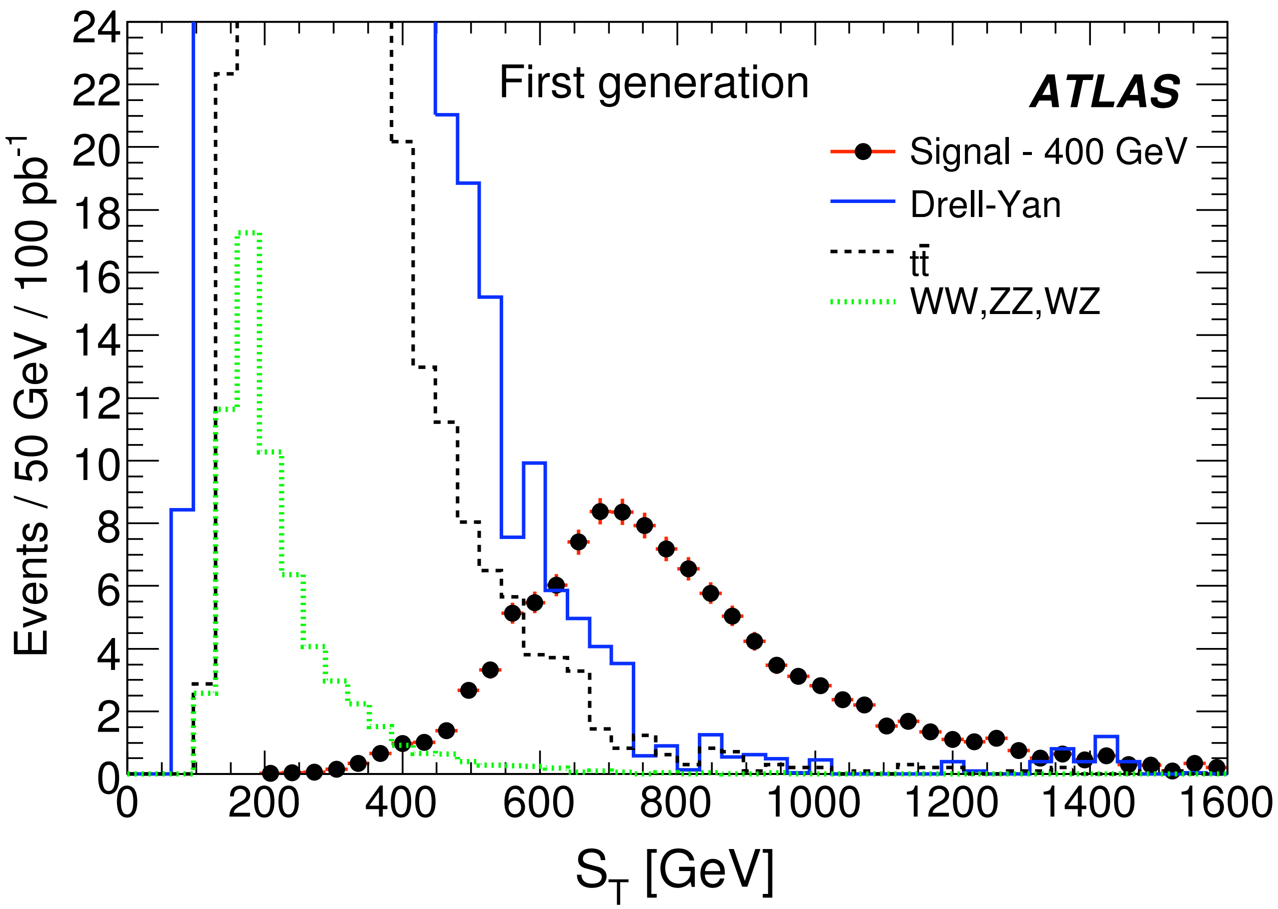






- New heavy particles which carry both lepton and color charge
- Predicted to explain complex SM symmetries and 3 generations
- Dilepton+Dijet Final State
- Main backgrounds
    - DY+jets, ttbar, diboson

Leptoquarks



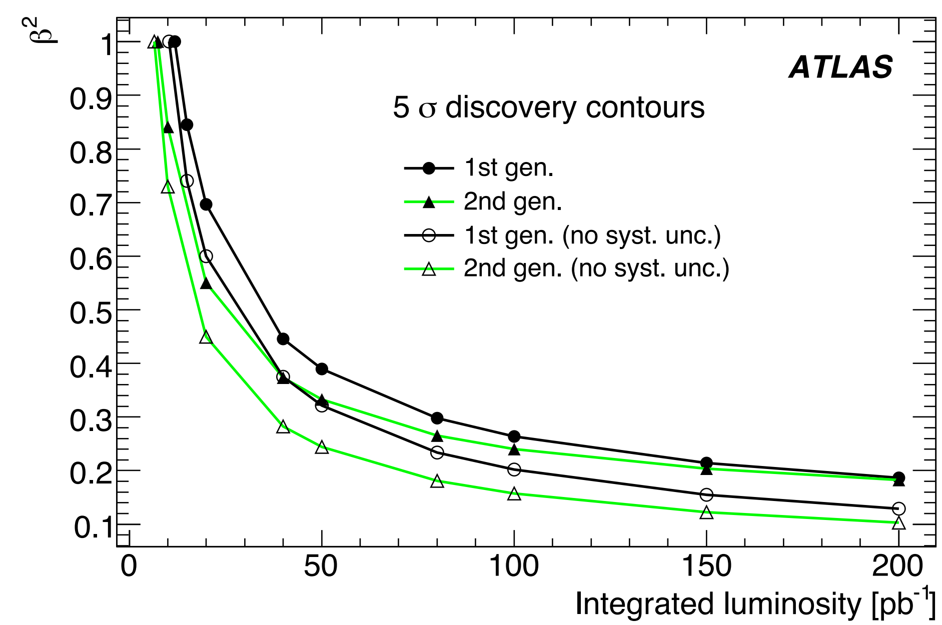
- Take advantage of hard decay products of leptoquarks
  - high invariant mass dileptons
  - Two or more hard jets
- Produced in pairs (mass constraint)

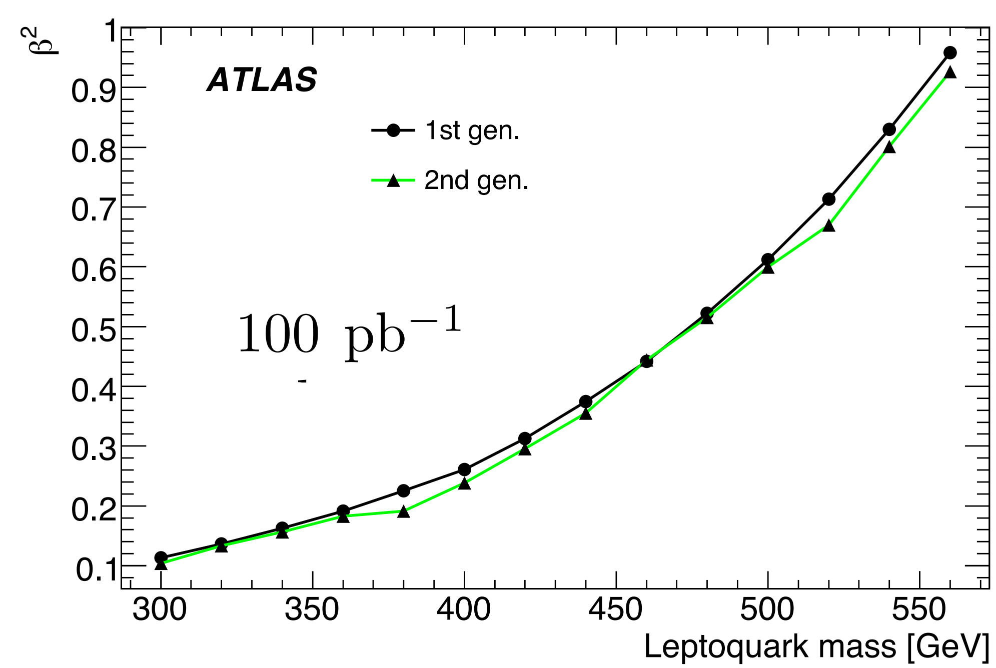
$$S_T = \sum |\vec{p}_T|_{jet} + \sum |\vec{p}_T|_{lep}$$

Physics sample	Before selection	Baseline selection	$S_T \geq$ 490 GeV	$m_{ee} \geq$ 120 GeV	m^1_{lj} - m^2_{lj} window (GeV) [320-480] - [320-480]	[700-900] - [700-900]
LQ (m = 400 GeV)	2.24	1.12	1.07	1.00	0.534	-
LQ (m = 800 GeV)	0.0378	0.0177	0.0177	0.0174	-	0.0075
$Z/\gamma^* \geq$ 60 GeV	1808.	49.77	0.722	0.0664	0.0036	0.00045
$t\bar{t}$	450.	3.23	0.298	0.215	0.0144	$<$ 0.0012
Vector Boson pairs	60.9	0.610	0.0174	0.00384	$<$ 0.002	$<$ 0.0014
Multijet	10^8	20.51	0.229	0.184	0.0	0.0

Leptoquarks

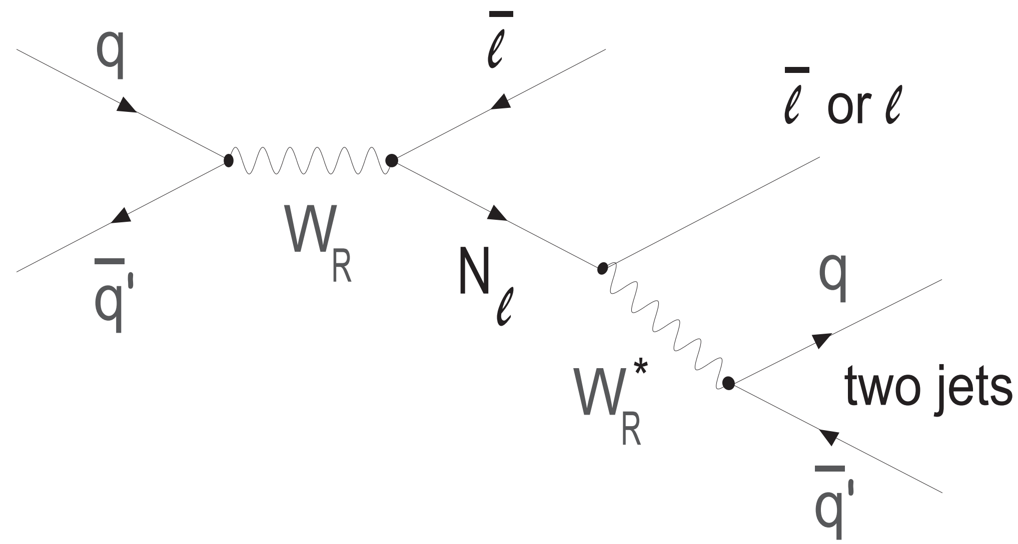
- Significant discovery potential over Tevatron (studies here assume 14 TeV)
- Signal cross-sections ~ 2 smaller at 10 TeV
- Roughly same sensitivity to 1st/ 2nd generation (slightly better in case of electrons)





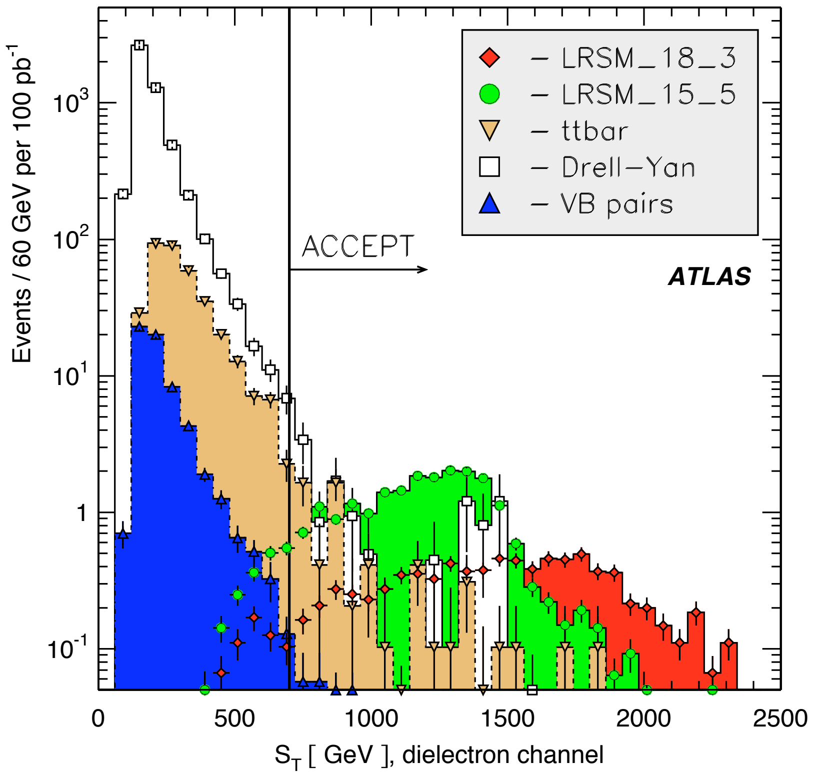
Heavy Neutrinos

- Heavy Right handed W and heavy neutrino
- Final State - dilepton+dijets
- Can be same or opposite sign dileptons
- Similar final state/ backgrounds to leptoquarks
- Suppress background utilizing excellent charge ID of LHC detectors

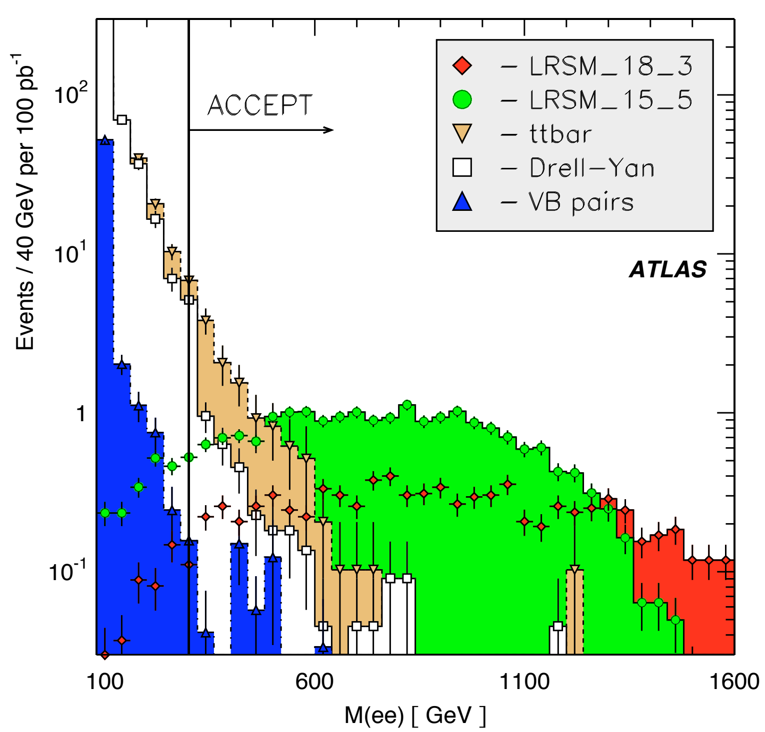


Heavy Neutrinos

- Similar analysis to leptoquarks
- High Mass DY and tt expected to be largest backgrounds
- Major difference is one can look at both opposite/sign dileptons

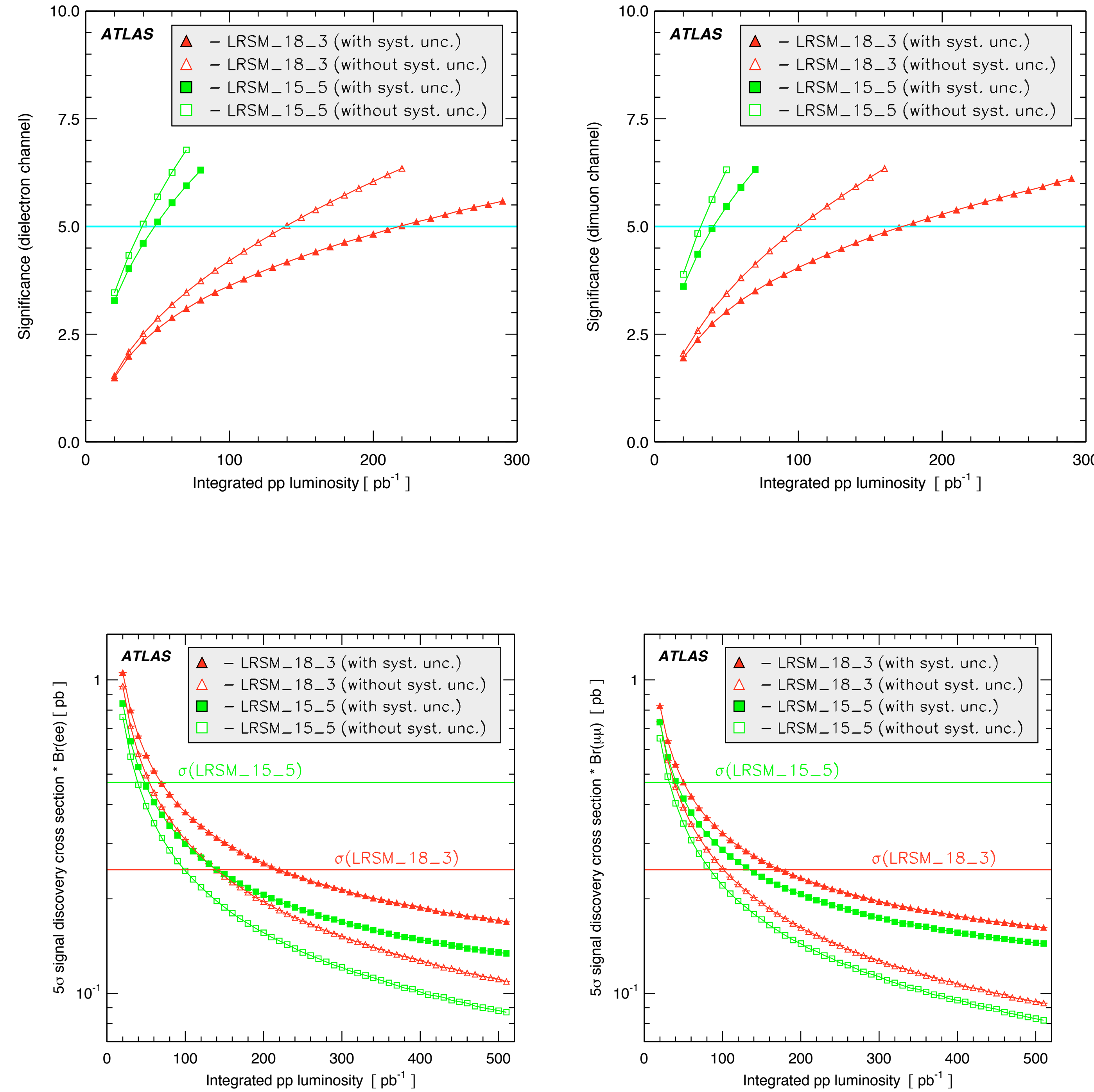


Physics sample	Before selection	Baseline selection	m_{ejj} ≥ 100 GeV	m_{eejj} ≥ 1000 GeV	m_{ee} ≥ 300 GeV	S_T ≥ 700 GeV
LRSM_18_3	0.248	0.0882	0.0882	0.0861	0.0828	0.0786
LRSM_15_5	0.470	0.220	0.220	0.215	0.196	0.184
$Z/\gamma^*, m \geq 60$ GeV	1808.	49.77	43.36	0.801	0.0132	0.0064
$t\bar{t}$	450.	3.23	3.13	0.215	0.0422	0.0165
VB pairs	60.9	0.610	0.522	0.0160	0.0016	0.0002
Multijet	10^8	20.51	19.67	0.0490	0.0444	0.0444



Heavy Neutrinos

- Should be able to probe region inaccessible at Tevatron with ‘first year’ data
- Cross-sections for signal down by ~2 at 10 TeV
- Systematics taken to be conservative - still fairly modest reduction on sensitivity



Summary

- Many exciting possibilities for exotics even in early running
- Production of new states above the Tevatron limits do not require that much luminosity or ultimate precision of detectors
- Do require sensible and understood systematics
- Lets hope for start up soon!