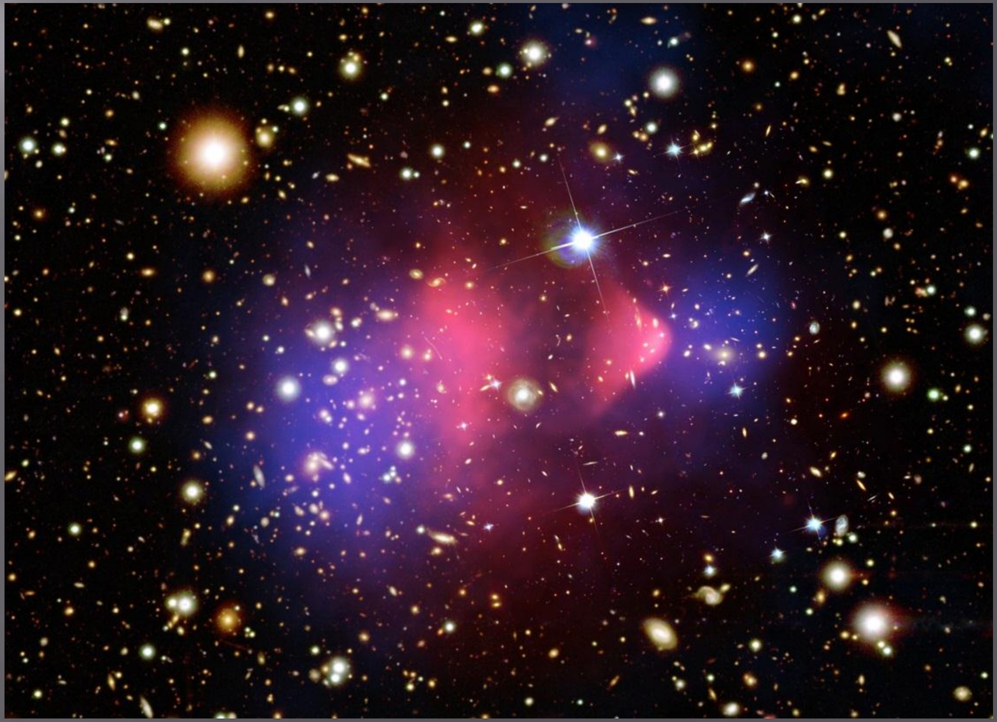
MICHIGAN STATE UNIVERSITY

HIGH MASS RESONANCES AT ATLAS

W. Fedorko
for the ATLAS collaboration

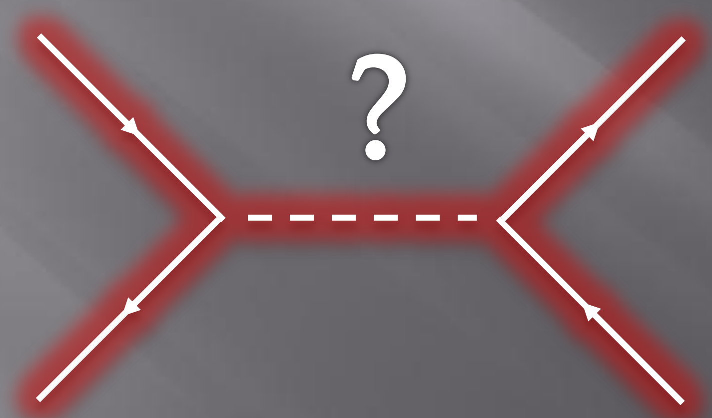
Why should we search?

- The Standard Model very well tested BUT:
- No way to incorporate gravity
- No viable dark matter candidate
- Hierarchy problem



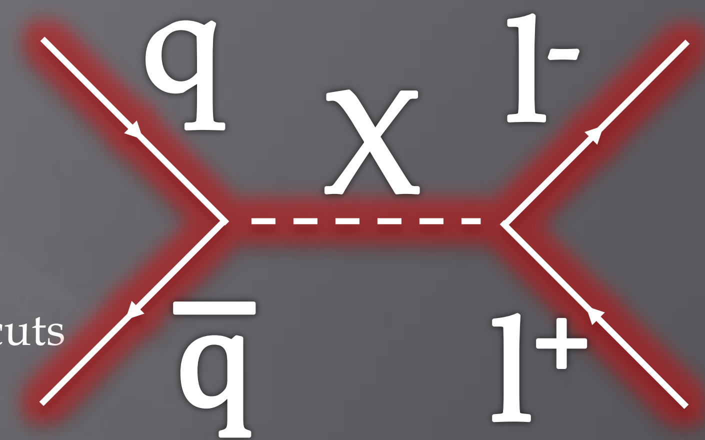
What could we find in a resonance search?

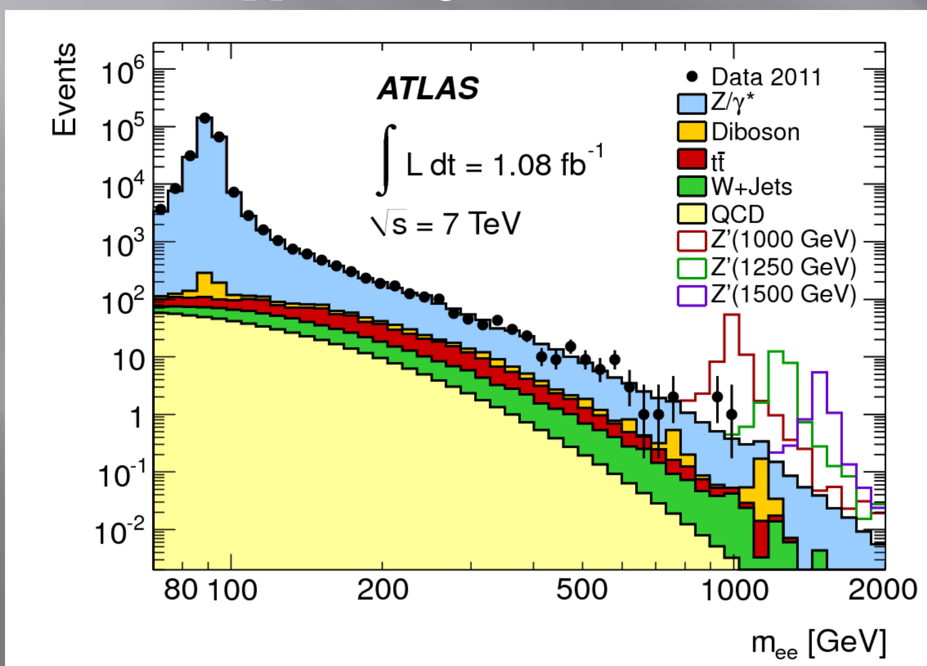
- New symmetries
- Extra dimensions
- Technicolor
- …

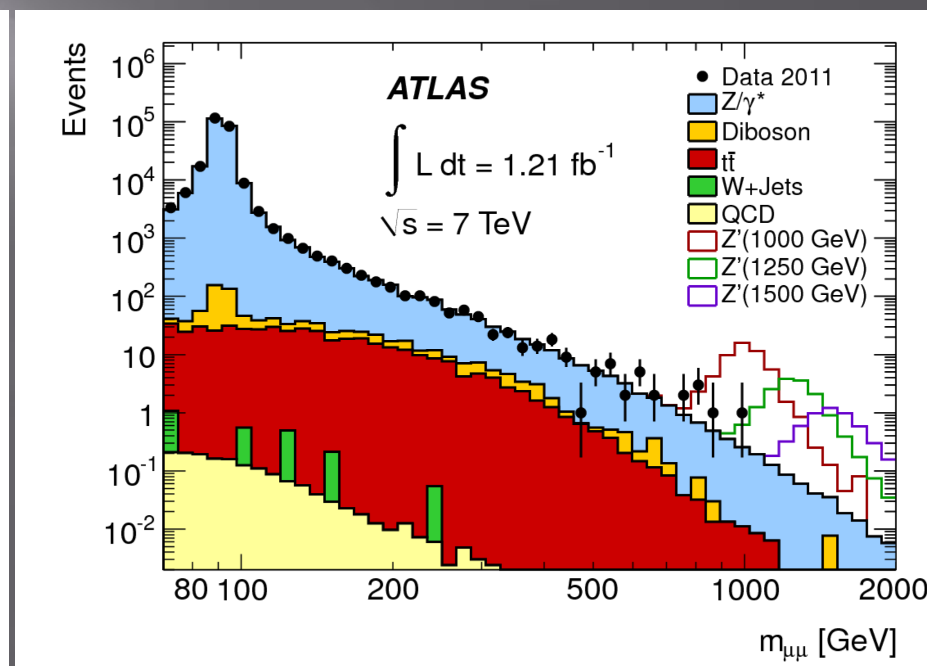


Dilepton resonance search

- Electrons:
  - Shower shape, leakage, tracking quality
  - Leading electron isolated
- Muons:
  - Inner detector and Muon Spectrometer quality cuts
  - Impact parameter and distance from PV
  - Opposite sign







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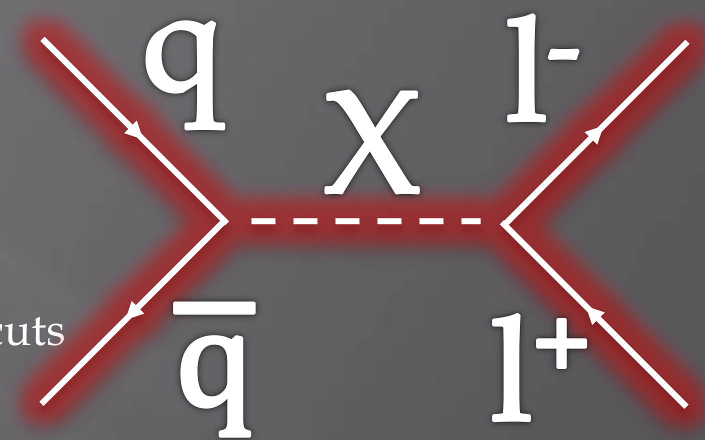
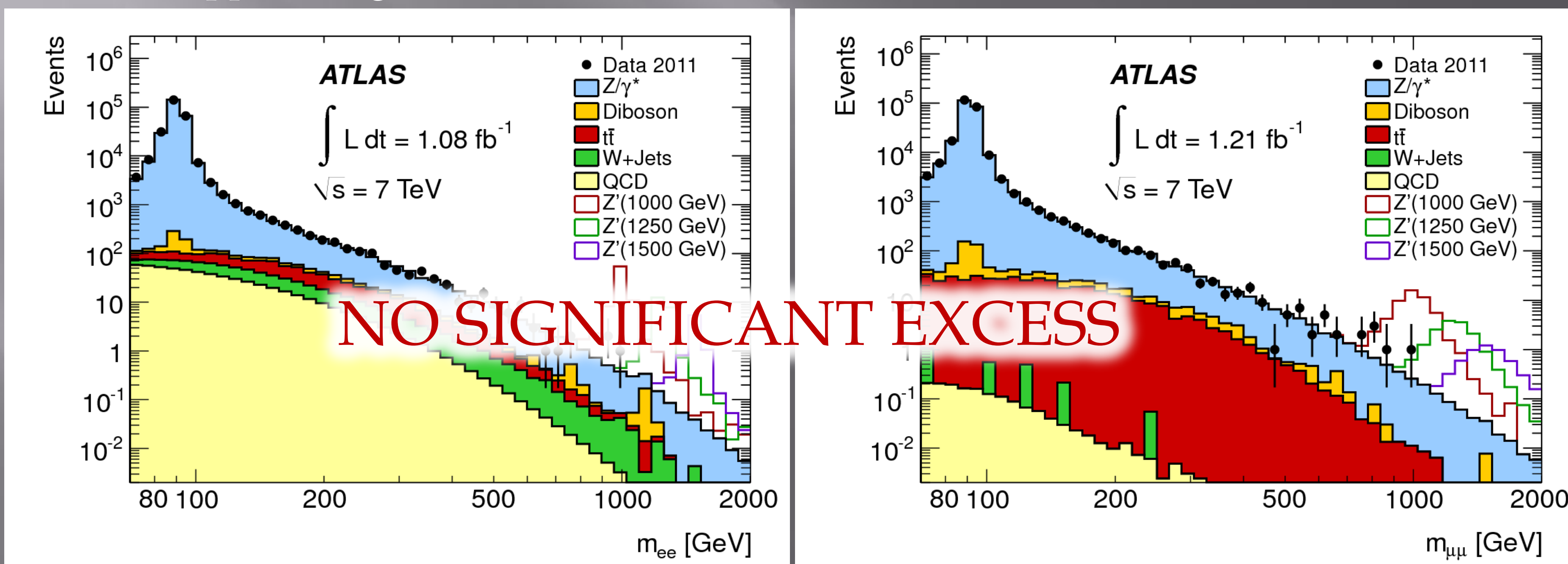
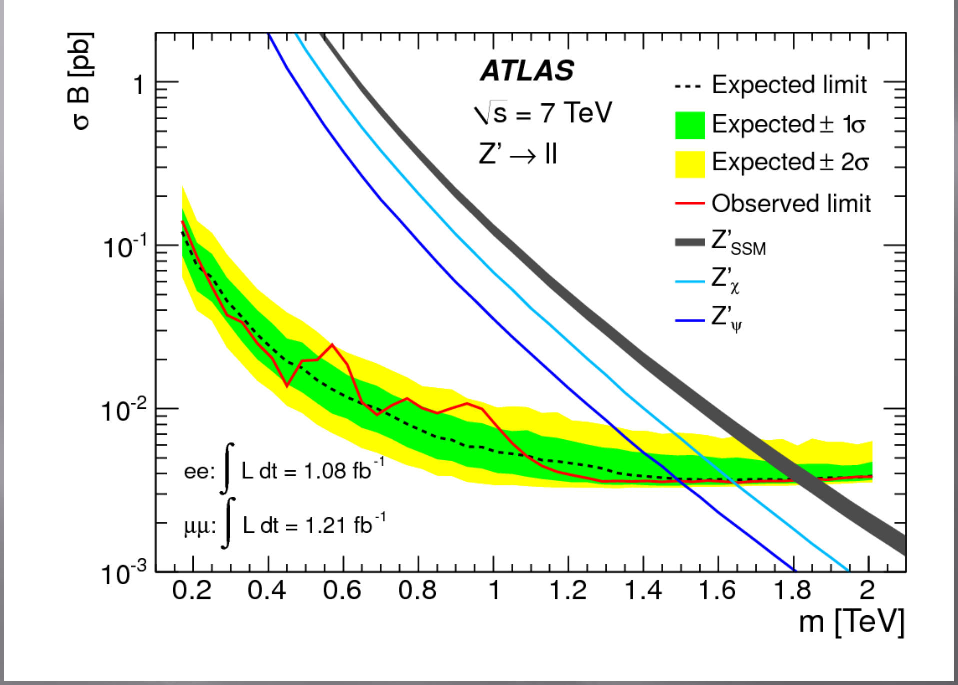




Dilepton resonance search

- Limit setting: Bayesian approach using m_{ll} template
- Normalization under Z peak



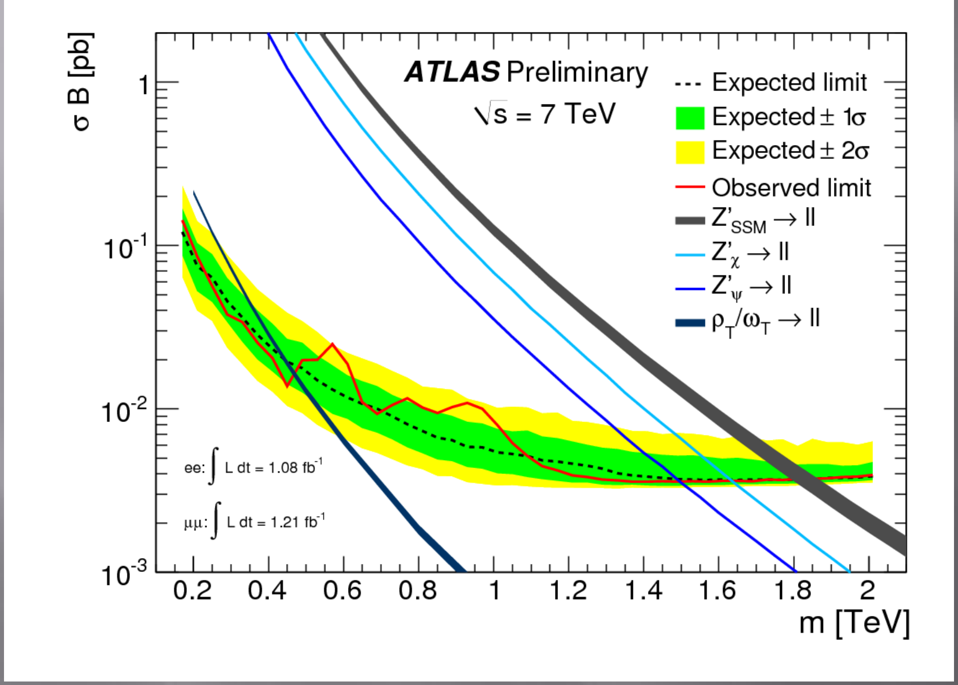
- SSM Z' limits:
  - $M_{Z'}$>1.83 (1.83 exp) TeV
- E6 models:

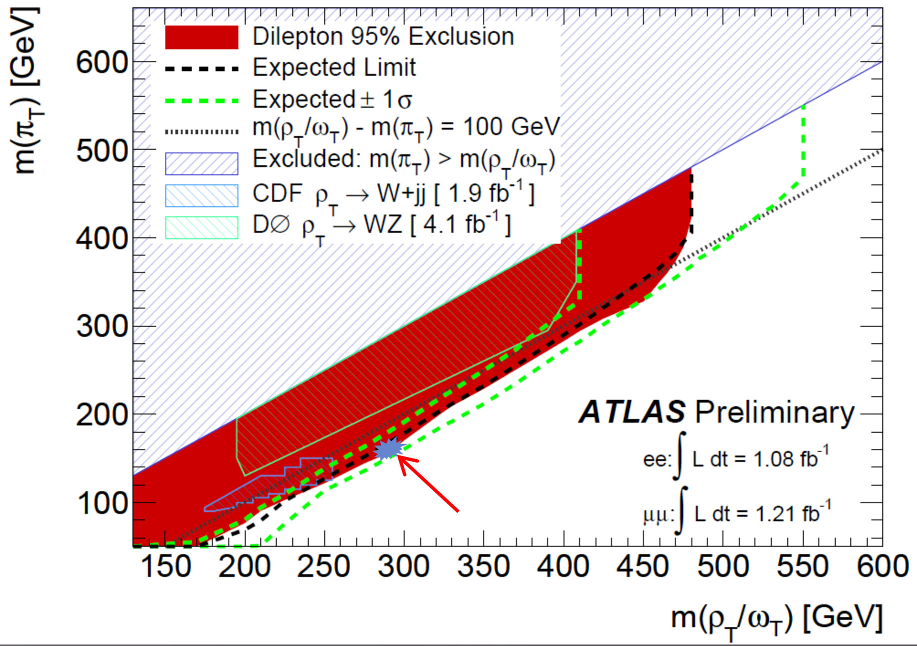
	E_6 Z' Models					
Model	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit [TeV]	1.49	1.52	1.54	1.56	1.60	1.64

Most stringent published SSM limit

Dilepton resonance search: technihadron interpretation

- 'Low Scale Technicolor' limits assuming 100 GeV splitting in $m_{\rho/\omega_T} - m_{\pi_T}$: m_ρ <470 GeV

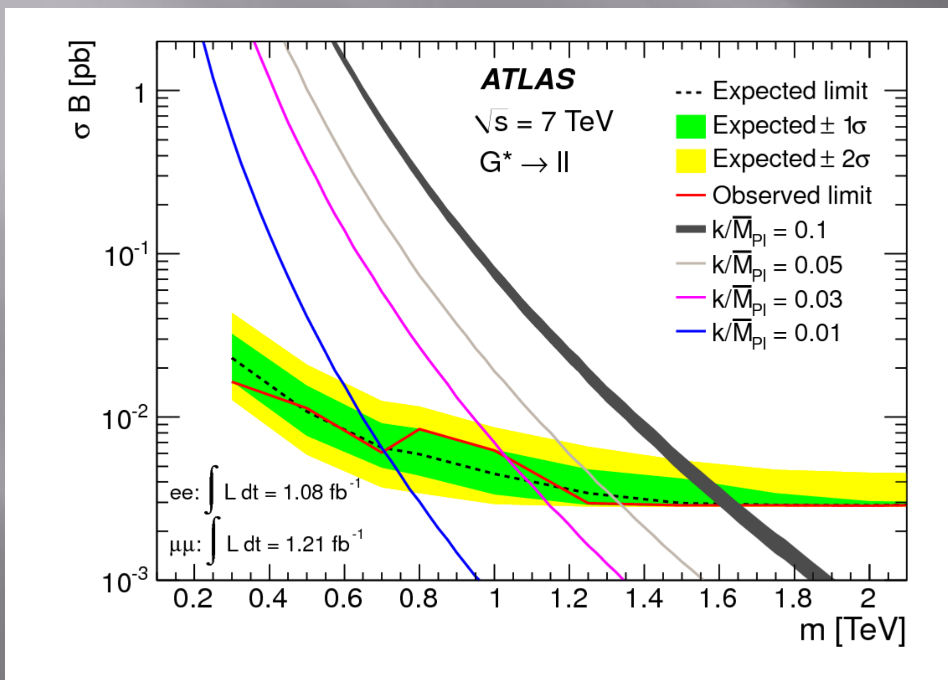


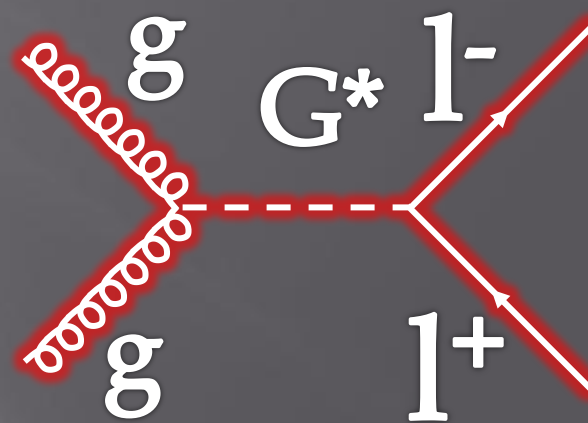


- Technicolor interpretation of CDF Wjj excess excluded

Dilepton resonance search: Spin 2

- Acceptance and width different for G*

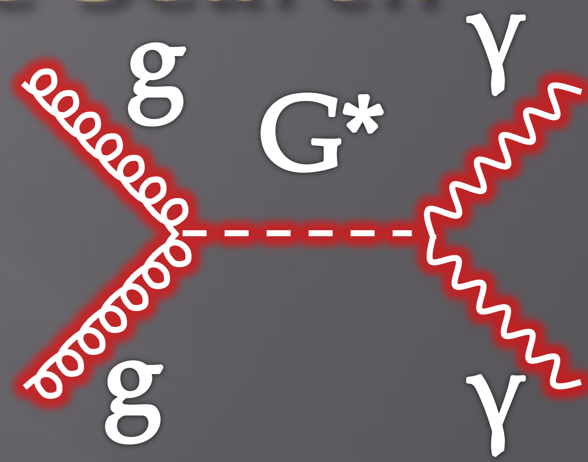




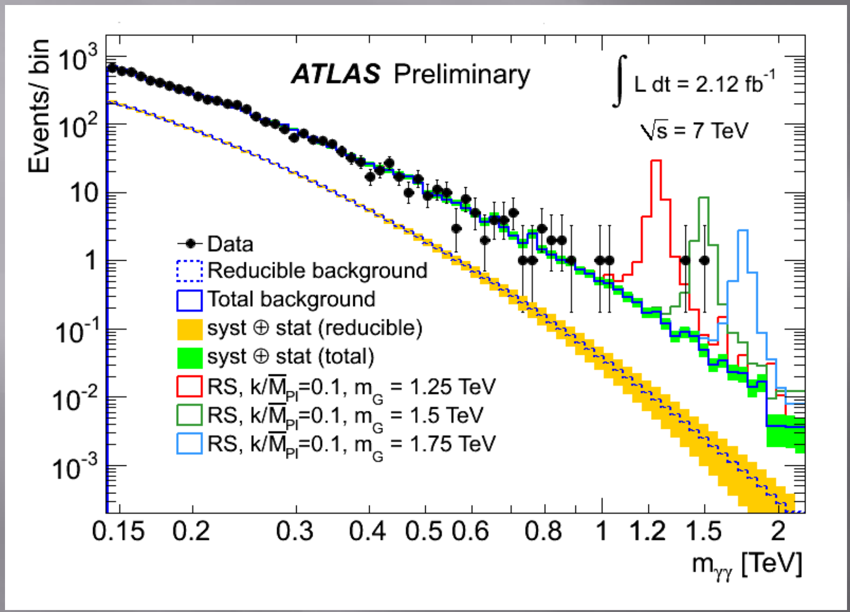
	RS Graviton			
Coupling	0.01	0.03	0.05	0.1
Mass limit [TeV]	0.71	1.03	1.33	1.63

Diphoton Resonance Search

NEW!!

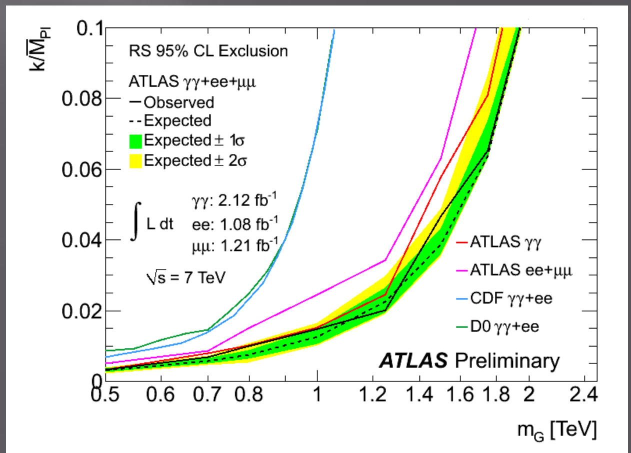


- No excess in the $m_{\gamma\gamma}$ spectrum



- ADD interpretation (non-resonant):
  - M_S>2.27-3.53 TeV
  - Depending on n_D and formalism used

- Bayesian approach using templates
- RS G* limits (γγ+ll):
  - m_{G^*}>1.95 TeV (k/$\bar{M}_{PL}$=0.1)
  - m_{G^*}>0.8 TeV (k/$\bar{M}_{PL}$=0.01)



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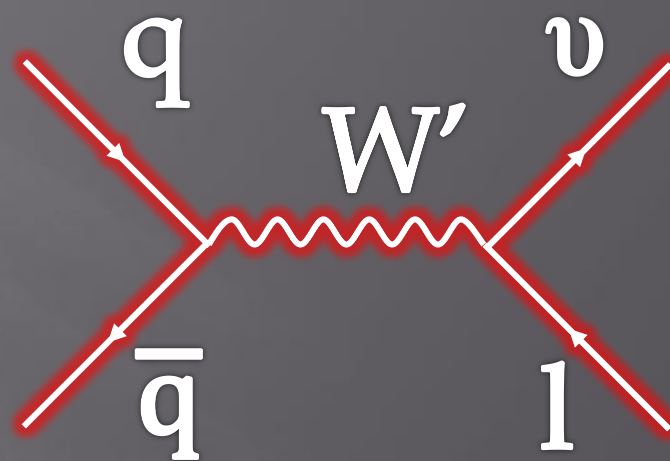
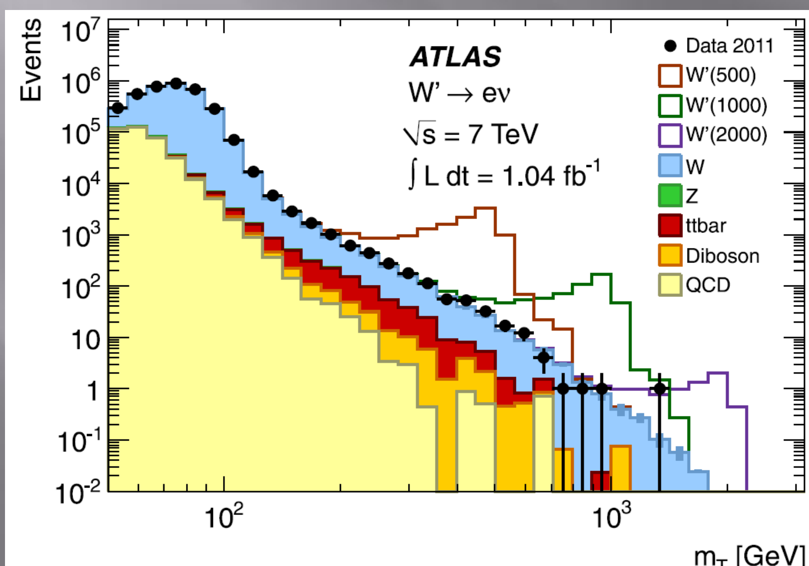
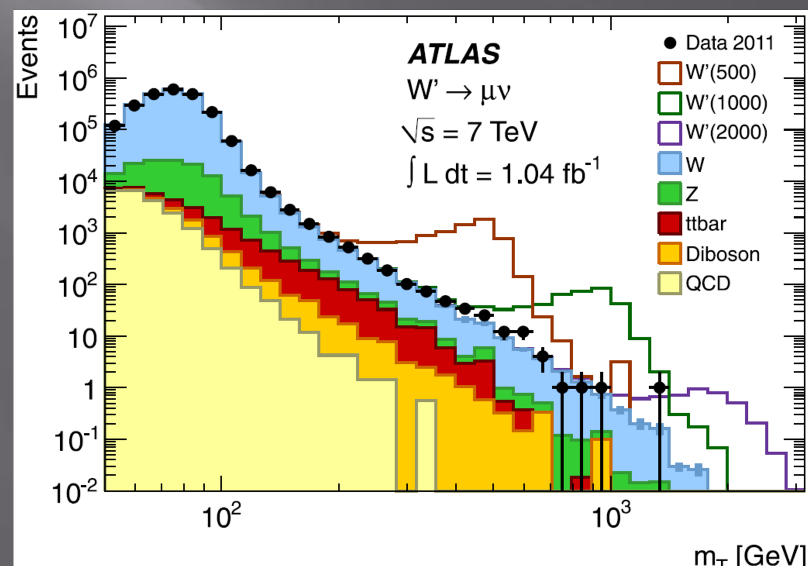
Lepton + missing energy search

- Benchmark :
  Sequential Standard Model W′
- Observable:

$$m_T = \sqrt{2 p_T\, E_T{}^{miss}\, (1 - \cos(\varphi_{l\,\upsilon}))}$$







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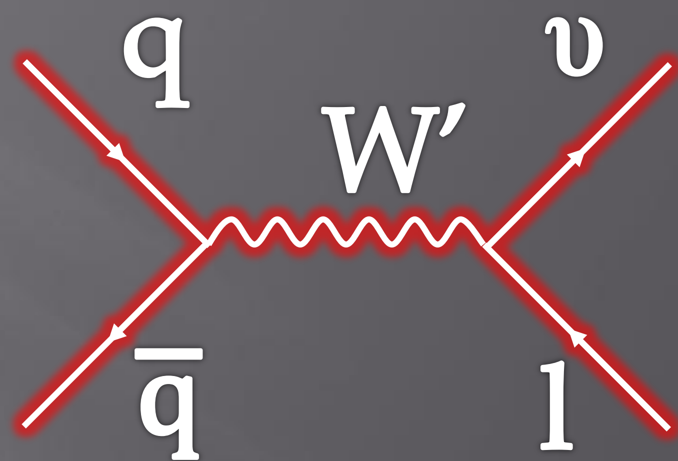
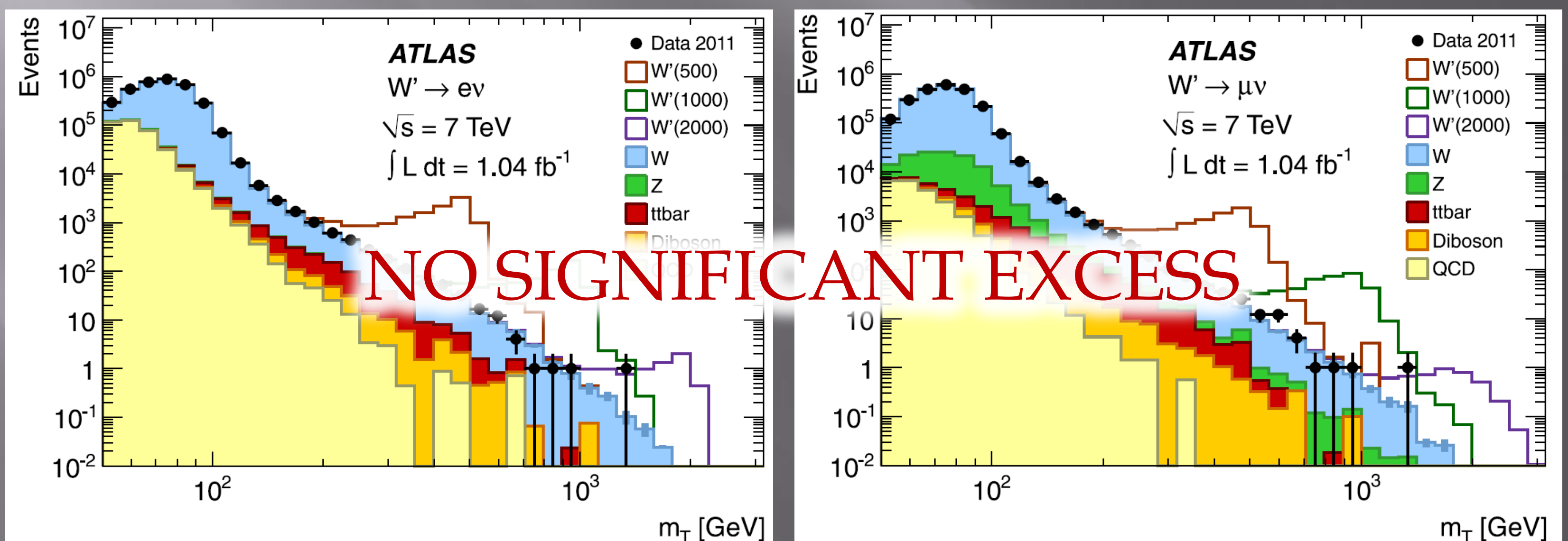
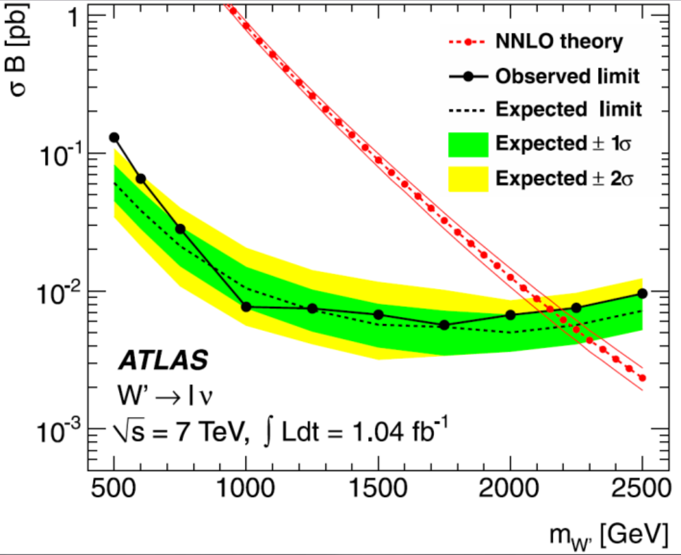




NO SIGNIFICANT EXCESS

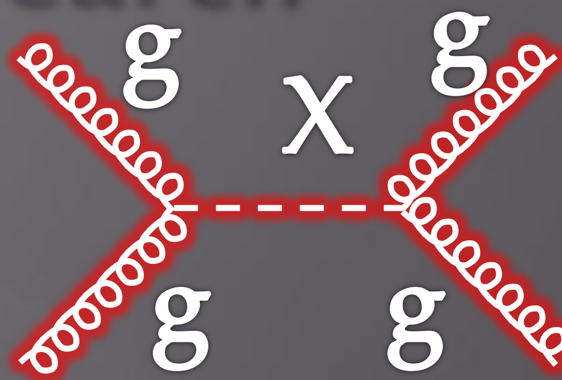
Lepton + missing energy search

- Limit setting:
  - Bayesian
  - Using count of events above $m_{T,min}$ tuned depending on the W′ mass probed

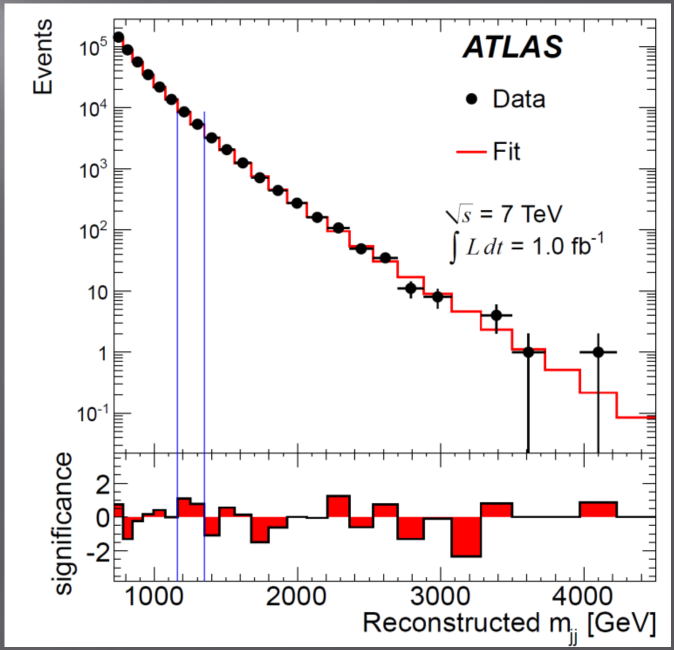


- $m_{W',SSM}$> 2.15 (2.23 exp) TeV
- Electron channel only: $m_{W',SSM}$> 2.08 (2.17 exp) TeV
- Muon channel only: $m_{W',SSM}$> 1.98 (2.08 exp) TeV

Dijet resonance search

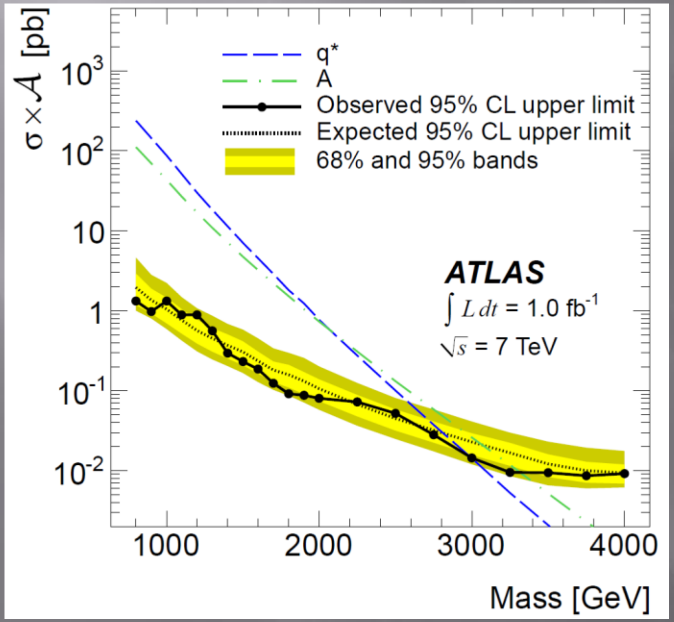


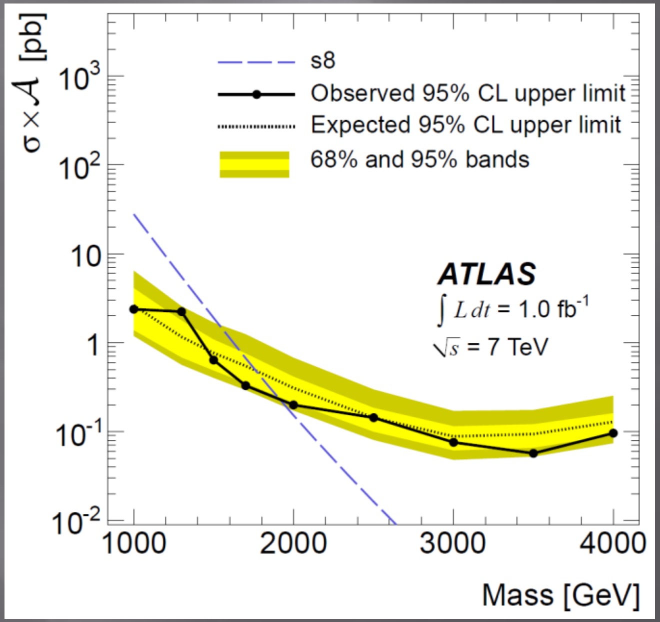
- Di-jet invariant mass
- Anti k_T R=0.6 jets ($|\eta|<2.8$ $|y^*|<0.6$)
- BumpHunter search against a parametrized shape
  - Sensitive to resonance of any width
  - Trials factor accounted
  - No excess found



Dijet resonance search

- Benchmark model interpretation
  - q* (qg→q* production)
  - Axigluon ($q\bar{q}$)
  - Color octet scalar ($gg \rightarrow S_8$)
- Limit setting: templates, Bayesian approach

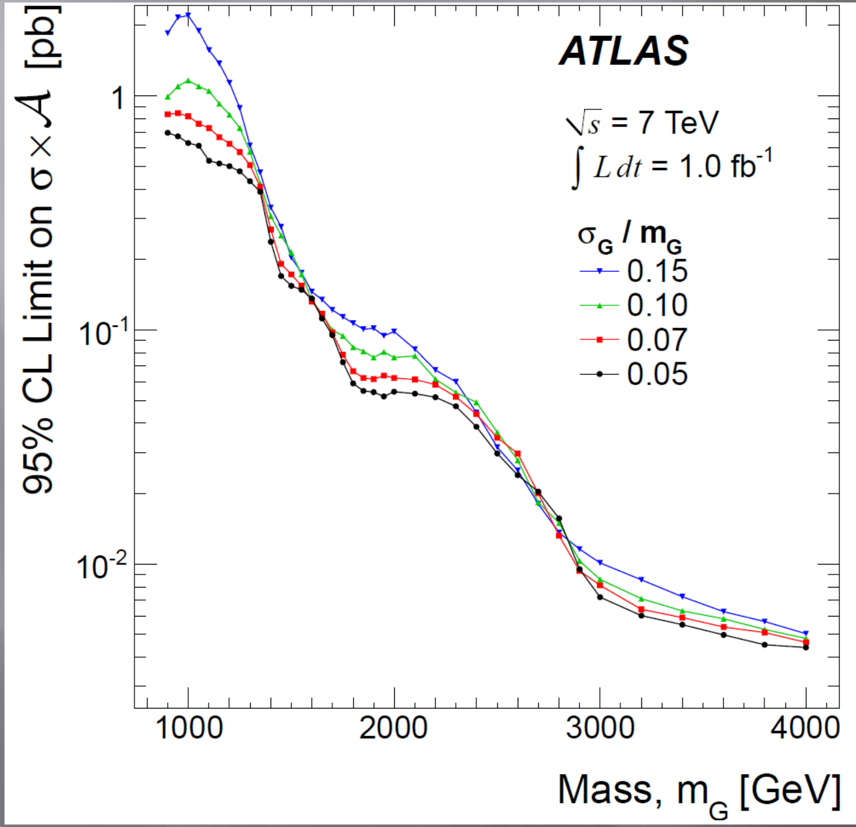




m_{q^*}>2.99 (2.81 exp) TeV
m_A>3.32 (3.07 exp) TeV
m_{S8}>1.92 (1.77 exp) TeV

Dijet resonance search

- Model independent limits
  - Set limit on a presence of Gaussian resonance.
  - Several relative widths probed

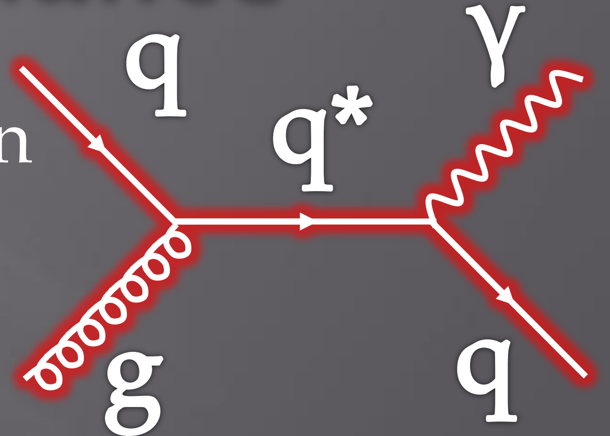


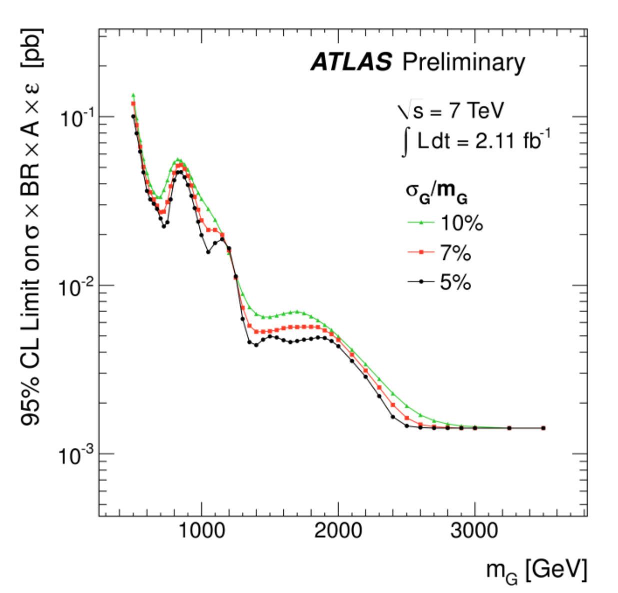
- Can be interpreted in context of any model
  - Need to know acceptance

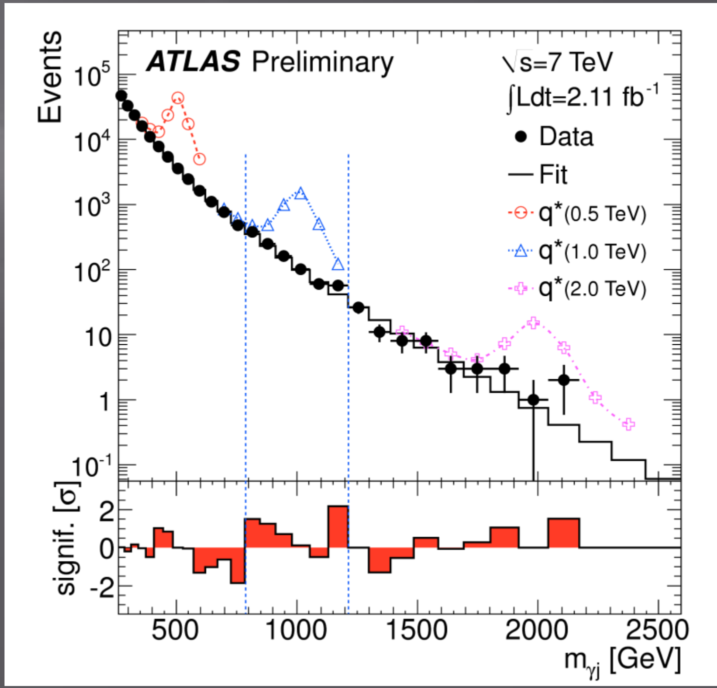
Gamma+jet resonance

NEW!!

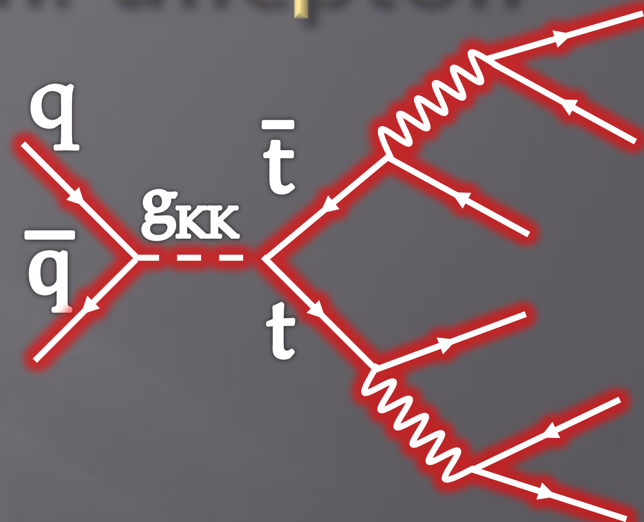
- Anti k_T R=0.6 jet + isolated photon
- Central photons only ($|\eta|<1.37$)
- BumpHunter search – no excess
- q* interpretation $m_{q*}>2.46$TeV



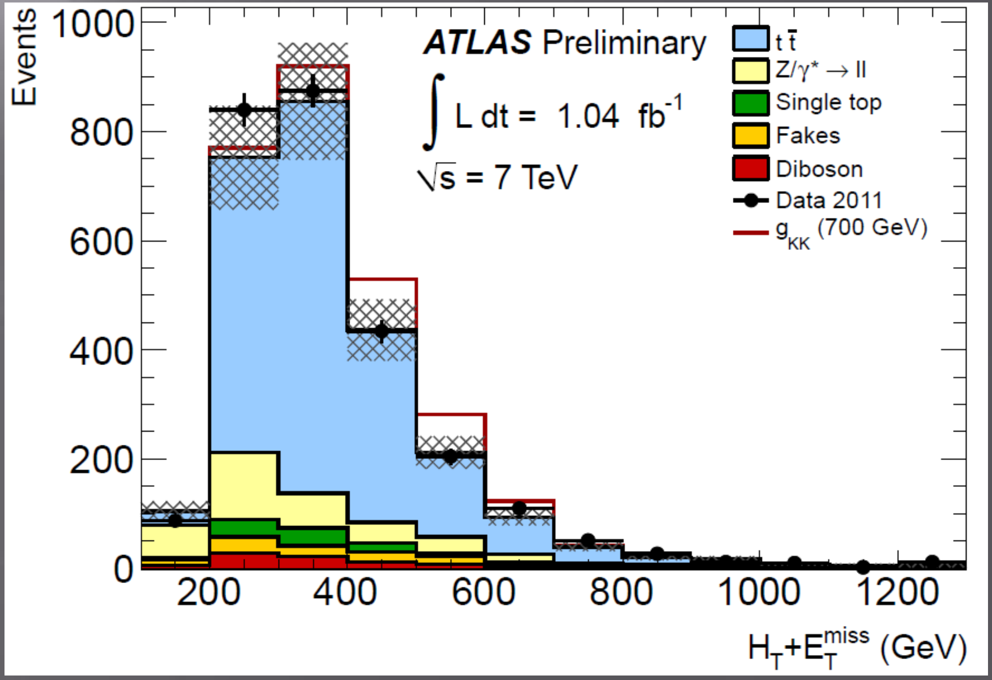




$t\bar{t}$ resonance search: dilepton channel



- Sensitive to models with enhanced coupling
  - Topcolor, top see-saw, SUSY, extra dimensions
  - g_{KK} benchmark
- Search in $H_T + E_t^{miss}$ using signal templates

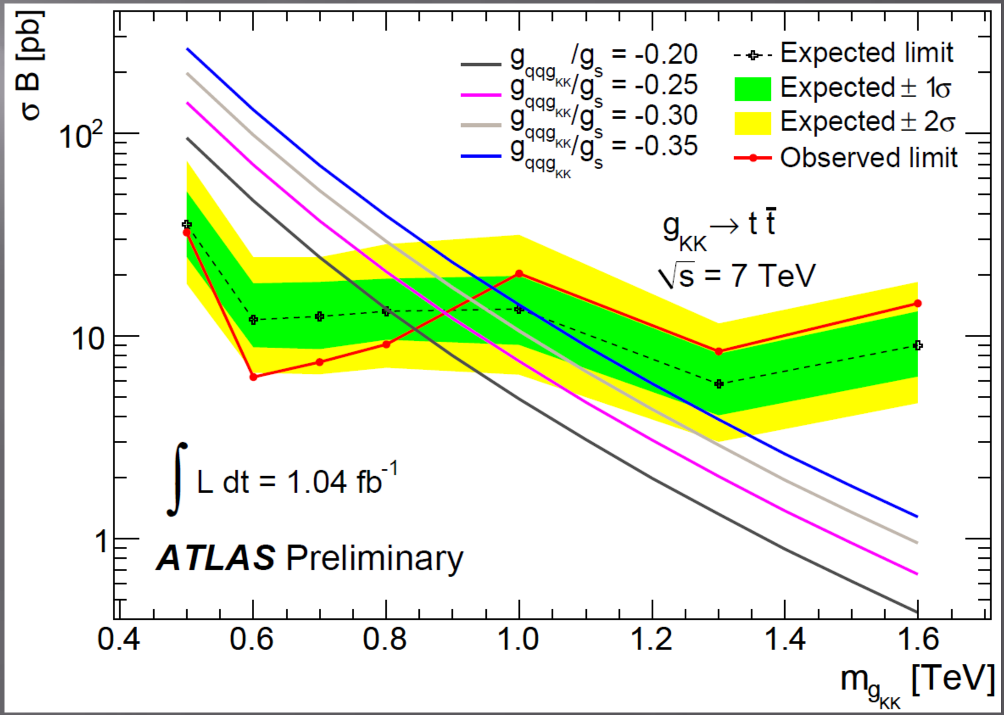


(H_T= linear sum of p_T of leptons and jets)

$t\bar{t}$ resonance search: dilepton channel

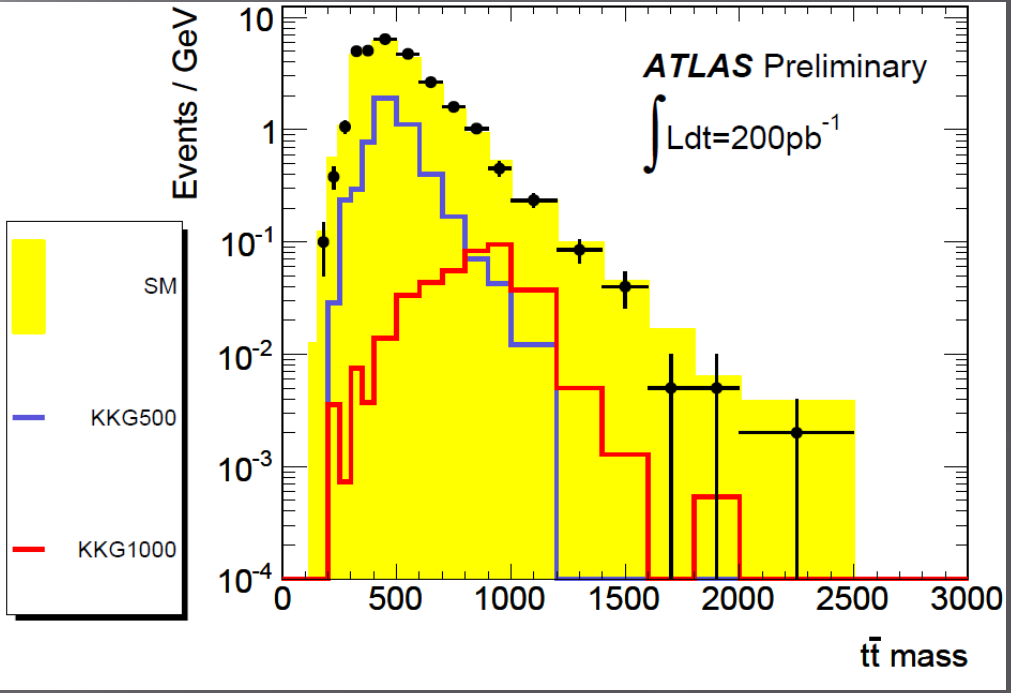
- Limit setting: Bayesian approach

	Mass Limit (TeV)	
$g_{qqg_{KK}}/g_s$	Expected	Observed
-0.20	0.80	0.84
-0.25	0.88	0.88
-0.30	0.95	0.92
-0.35	1.02	0.96



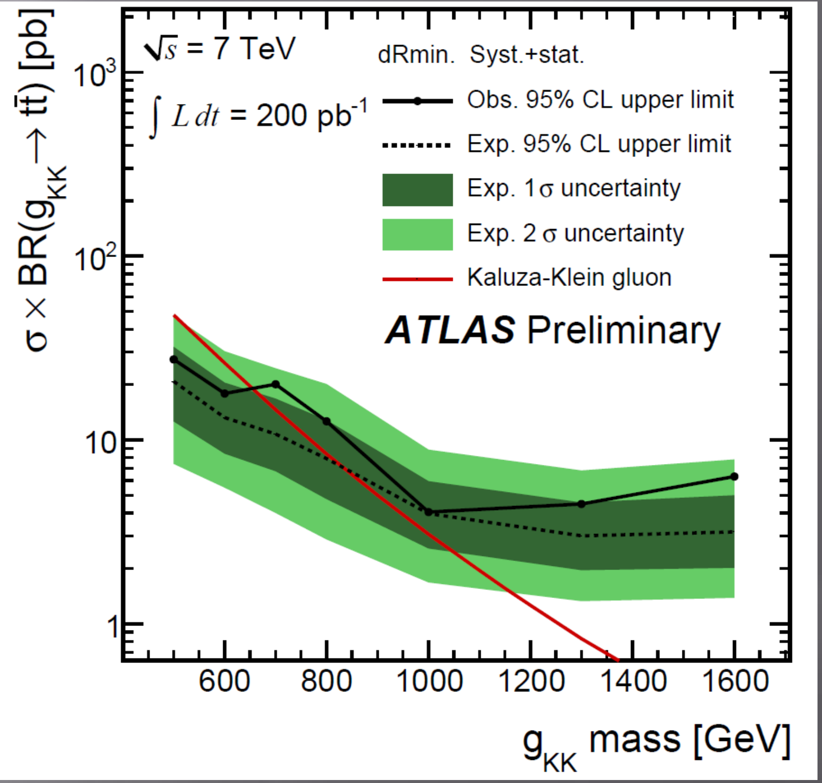
$t\bar{t}$ resonance search: lepton+jets channel

- Mass reconstructed using M_W constraint
- BumpHunter search
  - No excess



$t\bar{t}$ resonance search: lepton+jets channel

- Bayesian limit setting: $m_{g_{KK}} > 650$ GeV

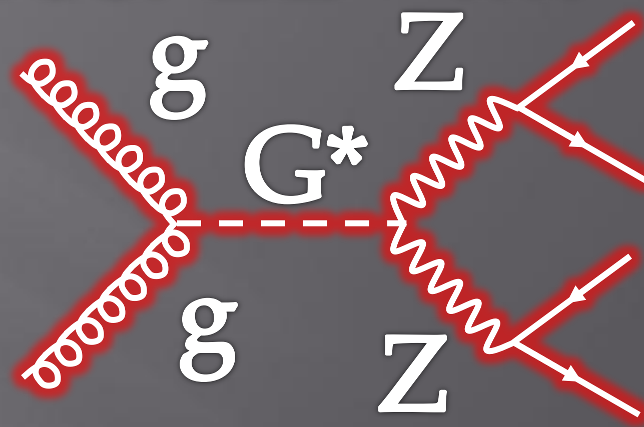


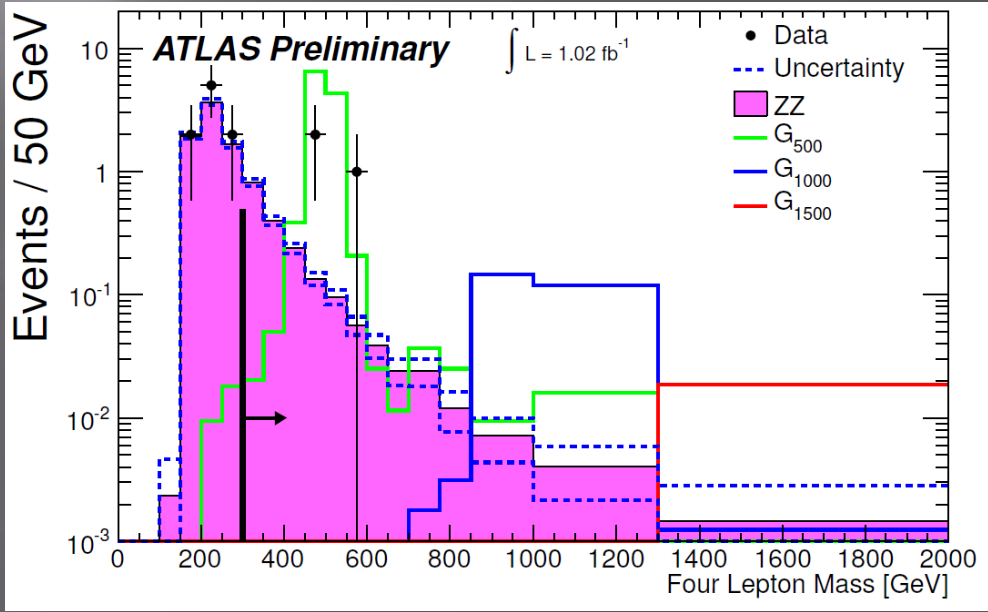
- Limits on leptophobic Z' σxB 38-3.2 pb for $m_{Z'}$ 500-100GeV

Diboson resonance: ZZ->llll

NEW!!

- Sensitive to warped extra dimensions, technicolor, grand unified theories
- Two pairs of opposite sign same flavor leptons each in Z mass window.

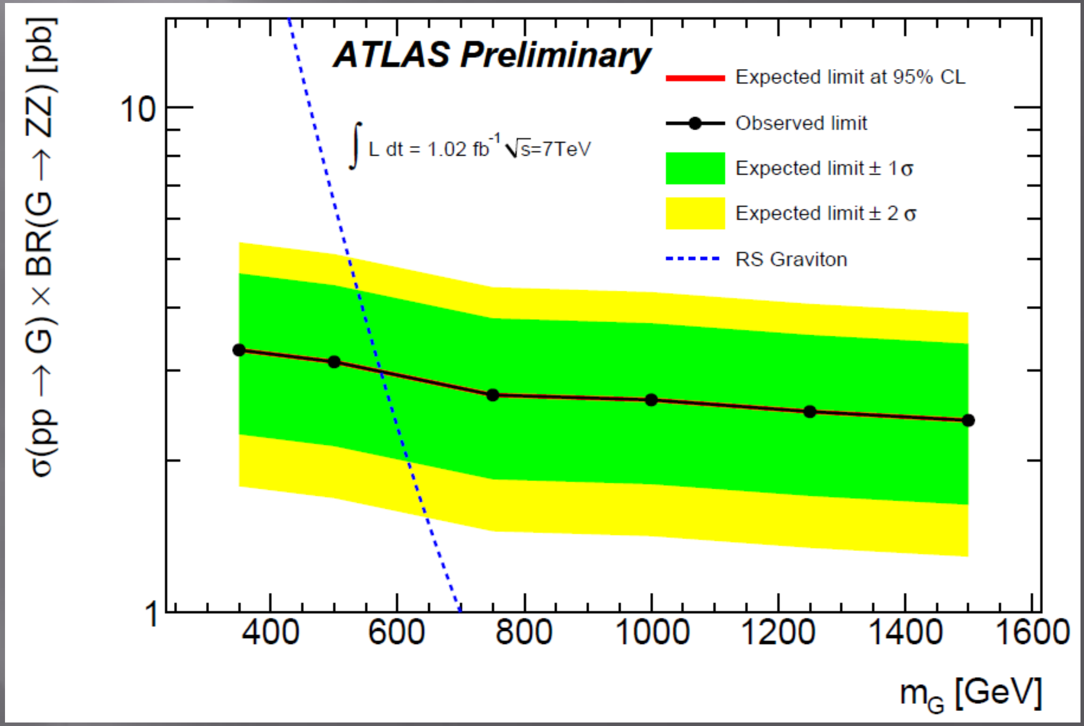




No excess at 327GeV (c.f. CDF)

Diboson resonance ZZ->llll

- CLs limit setting
  - single bin counting experiment
- m_{G*}>575GeV
- Results may be used to constrain models with different BR



Conclusions

- Exciting and productive year for ATLAS
- Resonance searches in many final states
- Passed 1 TeV Milestone
  - 2-3 TeV in simpler topologies
  - Approaching 1TeV in more complicated ones
  - Didn't find anything
- Most searches here $\int L$=1fb^{-1} >5fb^{-1} recorded
- Stay tuned!

References

- Dilepton: arXiv:1108.1582, accepted by PRL
- Diphoton: watch: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- Dijet: arXiv:1108.6311, submitted to PLB
- Gamma+jet: watch: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- L+met arXiv:1108.1316, accepted by PLB
- ttbar, dilepton: ATLAS-CONF-2011-123
- ttbar, l+jets: ATLAS-CONF-2011-087
- Diboson, ZZ→4l: ATLAS-CONF-2011-144
- CDF ZZ resonance search: CDF/PUB/EXOTICS/PUBLIC/10603

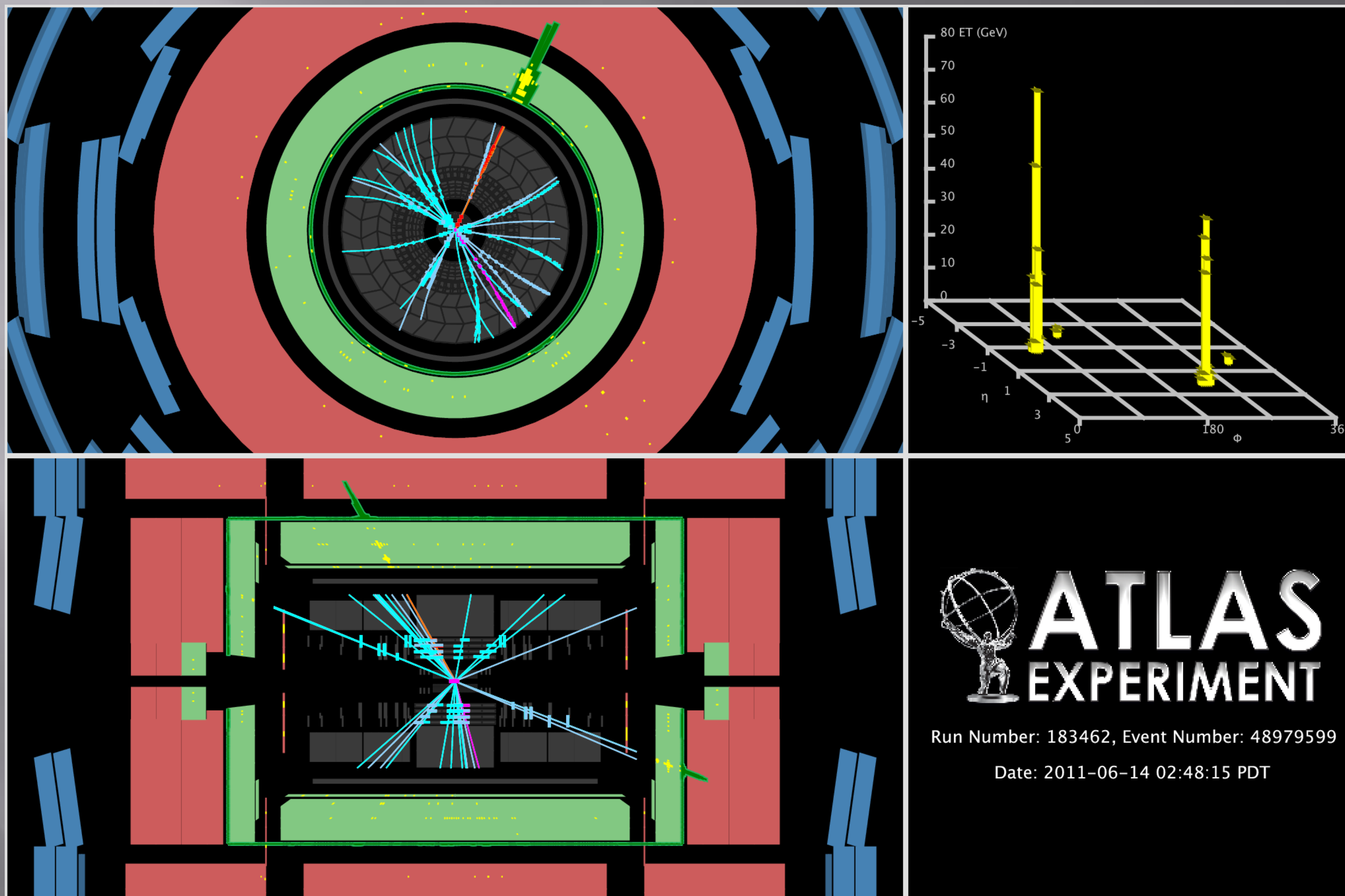
Backup

Dilepton: systematics

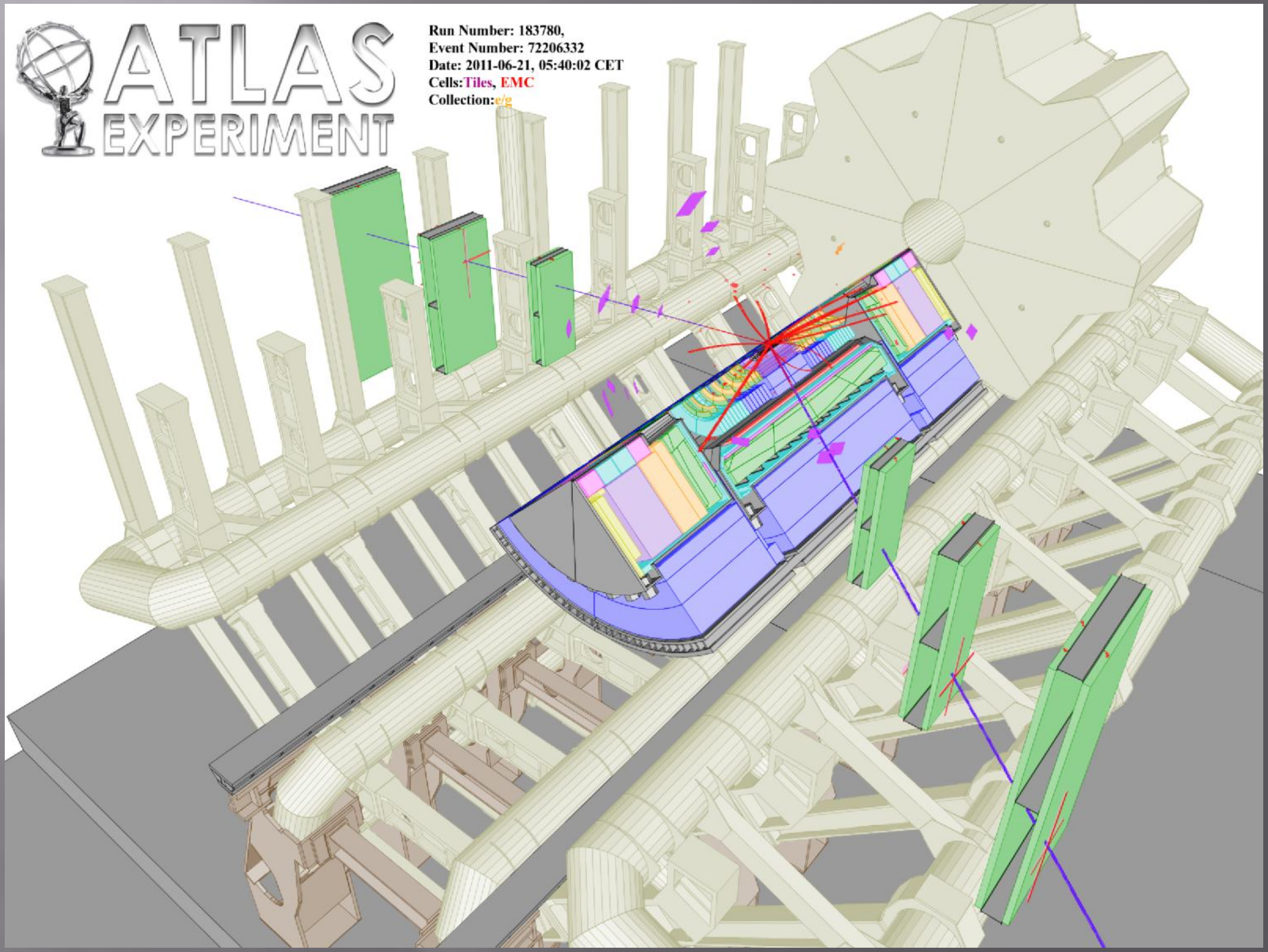
TABLE II: Summary of the dominant systematic uncertainties on the expected signal and background yields at $m_{\ell^+\ell^-} = 1.5$ TeV for the Z' (G^*) analysis. NA means not applicable.

Source	dielectrons		dimuons	
	signal	background	signal	background
Normalization	5%	NA	5%	NA
PDFs/α_S	NA	10%	NA	10%
QCD K-factor	NA	3%	NA	3%
Weak K-factor	NA	4.5%	NA	4.5%
Trigger/Reconstruction	negligible	negligible	4.5%	4.5%
Total	5%	11%	7%	12%

Dilepton: ee


80 ET (GeV)
70
60
50
40
30
20
10
0
-5
-3
-1
η
1
3
5
0
180
Φ
360
ATLAS
EXPERIMENT
Run Number: 183462, Event Number: 48979599
Date: 2011-06-14 02:48:15 PDT

Dilepton μμ


ATLAS
EXPERIMENT
Run Number: 183780,
Event Number: 72206332
Date: 2011-06-21, 05:40:02 CET
Cells:Tiles, EMC
Collection:e/g

Z' Production Spin 1

- SSM – benchmark same couplings as the SM
- E6 model:
  - $E_6 \rightarrow SO(10) \times U(1)_\psi$
    $\rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$
    $\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_\chi \times U(1)_\psi$
    $\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)'$
    $\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y$
- Assume EWK- scale U(1)′ is a linear combination of $U(1)_Y \times U(1)_\chi$
  - Generic U(1)′ can be expressed in terms of θ
  - $Z'(\theta)=Z'_\psi \cos(\theta)+ Z'_\chi \sin(\theta)$
  - 6 Z′ s

Dilepton: expectation and data

TABLE I: Expected and observed number of events in the dielectron (top) and dimuon (bottom) channels for an integrated luminosity of 1.08 fb^{-1} and 1.21 fb^{-1} respectively. The first bin is used to normalize the total background to the data. The errors quoted include both statistical and systematic uncertainties, except the error on the total background in the normalization region which is given by the square root of the number of observed events. The systematic uncertainties are correlated across bins and are discussed in the text.

$m_{e^+e^-}$[GeV]	70-110	110-200	200-400	400-800	800-3000
DY	258482 ± 410	5449 ± 180	613 ± 26	53.8 ± 3.1	2.8 ± 0.1
$t\bar{t}$	218 ± 36	253 ± 10	82 ± 3	5.4 ± 0.3	0.1 ± 0.0
Diboson	368 ± 19	85 ± 5	29 ± 2	3.1 ± 0.5	0.3 ± 0.1
W+jets	150 ± 100	150 ± 26	43 ± 10	4.6 ± 1.8	0.2 ± 0.4
QCD	332 ± 59	191 ± 75	36 ± 29	1.8 ± 1.4	< 0.05
Total	259550 ± 510	6128 ± 200	803 ± 40	68.8 ± 3.9	3.4 ± 0.4
Data	259550	6117	808	65	3

$m_{\mu^+\mu^-}$ [GeV]	70-110	110-200	200-400	400-800	800-3000
DY	236319 ± 320	5171 ± 150	483 ± 22	40.3 ± 2.5	2.0 ± 0.3
$t\bar{t}$	193 ± 21	193 ± 20	63 ± 6	4.2 ± 0.4	0.1 ± 0.0
Diboson	307 ± 16	69 ± 5	25 ± 2	1.7 ± 0.5	< 0.05
W+jets	1 ± 1	1 ± 1	< 0.5	< 0.05	< 0.05
QCD	1 ± 1	< 0.5	< 0.5	< 0.05	< 0.05
Total	236821 ± 487	5434 ± 150	571 ± 23	46.1 ± 2.6	2.1 ± 0.3
Data	236821	5406	557	51	5

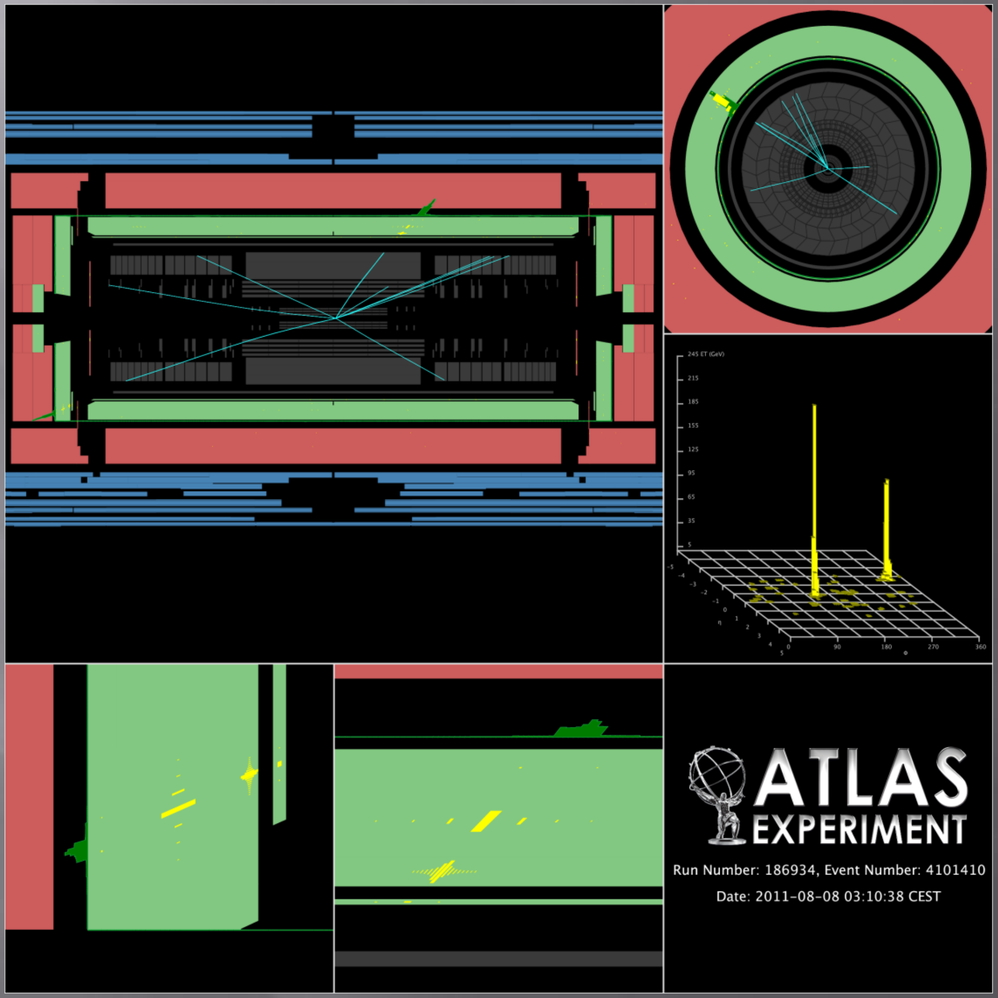
Diphoton: details

- Photons: E_T>25 GeV, had leakage+shower shape cuts, calo isolation< 5GeV in R=0.4
- $m_{\gamma\gamma}$ resolution ~1%
- Photon efficiency: ~85% barrel 75% endcap
- RS G* A x ε 53-60%
- RS G* width: 8-30 GeV between 0.8 and 2.2 TeV for k/MPL=0.1
- Irreducible SM γγ production:
  - PYTHIA reweighted by DIPHOX NLO
- Reducible:
  - γ+jet, jet+jet
  - $m_{\gamma\gamma}$ template from reverse i.d., fit in range <400GeV using also DIPHOX shape
  - 2D template fit to the isolation distribution
- Background uncertainties 2% at $m_{\gamma\gamma}$ =140 GeV - 20% at 2 TeV, Signal 6.7% largest photon efficiency, lumi.

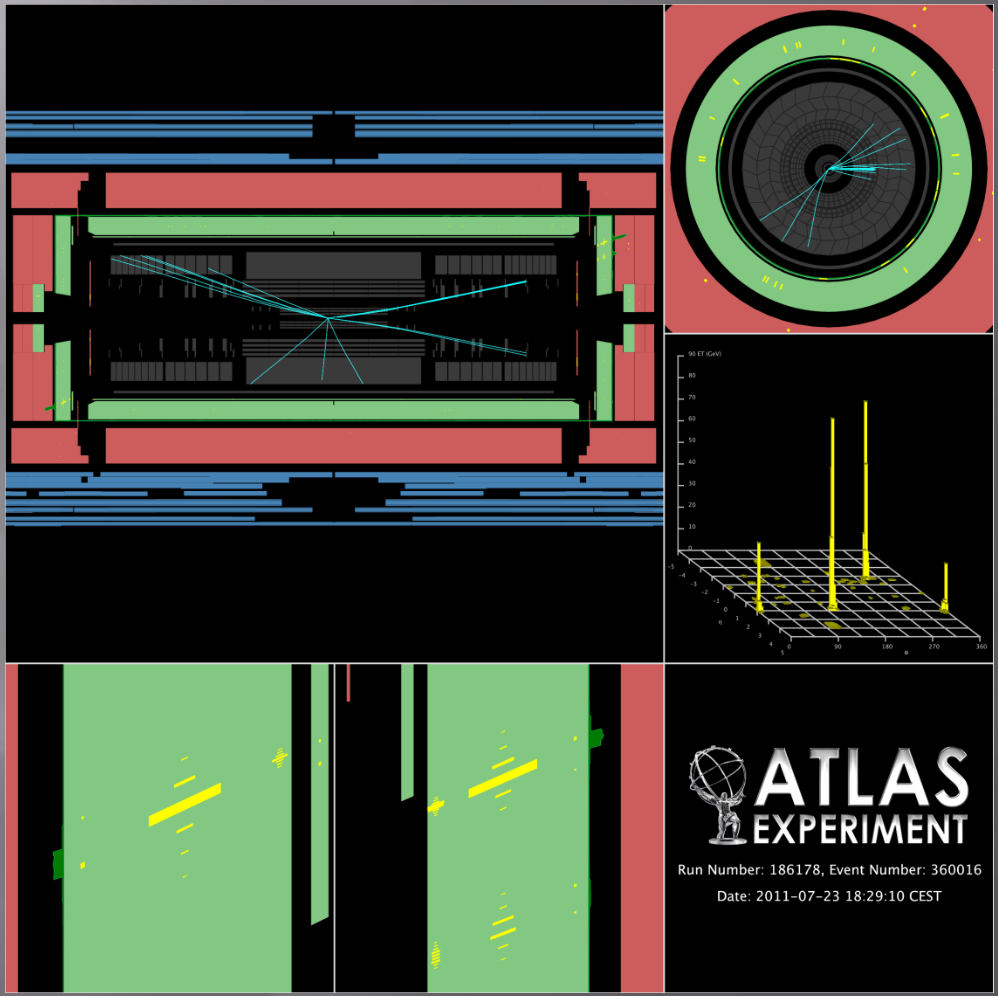
Diphoton: expectation and data

Mass Range (GeV)	Background Expectation Irreducible	Reducible	Total	Observed Events
[140, 400]	4738 ± 180	1935 ± 97	6674 ± 0	6674
[400, 500]	90.0 ± 8.5	19.9 ± 1.8	109.9 ± 9.2	102
[500, 600]	31.1 ± 4.0	5.8 ± 0.8	37.0 ± 4.2	36
[600, 700]	13.7 ± 2.3	2.0 ± 0.4	15.7 ± 2.4	16
[700, 800]	6.2 ± 1.2	0.8 ± 0.2	6.9 ± 1.3	9
[800, 900]	3.1 ± 0.4	0.3 ± 0.1	3.4 ± 0.5	5
[900, 1000]	1.6 ± 0.2	0.14 ± 0.05	1.8 ± 0.3	1
[1000, 1100]	1.0 ± 0.2	0.07 ± 0.03	1.0 ± 0.2	1
[1100, 1200]	0.50 ± 0.09	0.03 ± 0.02	0.54 ± 0.11	0
[1200, 1300]	0.29 ± 0.07	0.02 ± 0.01	0.31 ± 0.07	0
[1300, 1400]	0.14 ± 0.04	0.010 ± 0.005	0.15 ± 0.04	1
[1400, 1500]	0.13 ± 0.04	0.005 ± 0.003	0.14 ± 0.04	1
> 1500	0.18 ± 0.09	0.009 ± 0.006	0.19 ± 0.09	0

Diphoton: highest mass



Diphoton: 2nd highest mass



W' search

- W′ (no interference), W/Z PYTHIA MRST LO* ttbar MC@NLO
- W W′ reweighted to NNLO QCD with ZWPROD
- FEWZ, HORACE ewk corrections (18% reduction at $m_{l\upsilon}$=2TeV)
- Electron: Medium >25 GeV, calo isolated R=0.4 9 GeV
- Muon: >25 GeV, track isolation <%5 R=0.3
- MET: topological clusters, local hadronic calibration
  - Electron channel- use electron calibrated E_T
  - Muon channel- corrected for energy loss of the muon
  - >25 GeV, in e channel >0.6 electron E_T
- QCD: electron channel ABCD in isolation and MET

W' yields

Table 2: Expected numbers of events from the various background sources in each decay channel for $m_T > 891$ GeV, the region used to search for a W' with a mass of 1500 GeV. The $W \to \ell\nu$ and $Z \to \ell\ell$ entries include the expected contributions from the τ-lepton. No muon events are found in the $t\bar{t}$ sample above this m_T threshold. The uncertainties are statistical.

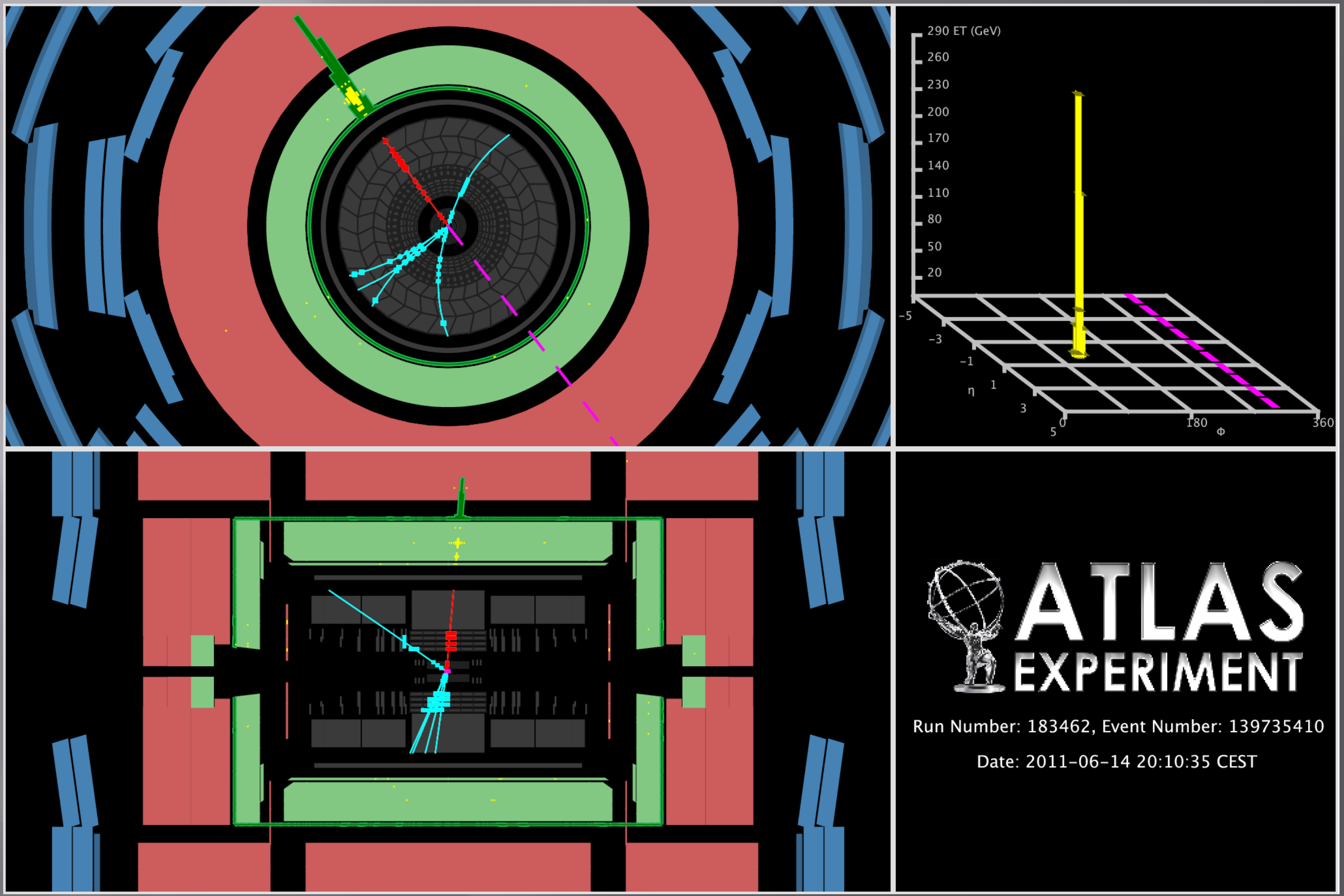
	$e\nu$	$\mu\nu$
$W \to \ell\nu$	1.59 ± 0.13	1.36 ± 0.13
$Z \to \ell\ell$	0.00010 ± 0.00004	0.095 ± 0.005
diboson	0.08 ± 0.08	0.11 ± 0.08
$t\bar{t}$	0.08 ± 0.08	0
QCD	$0\ ^{+0.17}_{-0}$	$0.01\ ^{+0.02}_{-0.01}$
Total	$1.75\ ^{+0.24}_{-0.18}$	1.57 ± 0.15

W' systematics

- $M_{W'}$=1.5 TeV:

Source	$\varepsilon_{\mathrm{sig}}$ $e\nu$	$\varepsilon_{\mathrm{sig}}$ $\mu\nu$	N_{bg} $e\nu$	N_{bg} $\mu\nu$
Efficiency	2.7%	3.9%	2.7%	3.8%
Energy/momentum resolution	0.3%	2.3%	2.9%	0.6%
Energy/momentum scale	0.5%	1.3%	5.2%	3.0%
QCD background	-	-	10.0%	1.3%
Monte Carlo statistics	2.5%	3.1%	9.4%	9.9%
Cross section (shape/level)	3.0%	3.0%	9.5%	9.5%
All	4.7%	6.3%	18%	15%

W' highest m_T event



Dijet- some details

- $y = 1/2 \ln((E+p_Z)/(E-p_Z))$ $y^* = 1/2\,(y_1 - y_2)$
- Jets corrected: hadronic shower response and detector material
- $\frac{\sigma_{jj}}{m_{jj}}$=5% at m_{jj}=1 TeV → 4%at 5 TeV
- Trigger p_T threshold 180 GeV
- m_{jj}>717 GeV (trigger 99% efficient)
- events with poorly measured jets with p_T >30% of the subleading jet – rejected
- Parametrization: $f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln(x)}$ $x = m_{jj}/\sqrt{s}$
- q* acceptance 37-51% in 0.8-5TeV range
- Systematics: JES shifts signal peaks by 4%, luminosity 3.7%

Dijet search

- q*
  - spin 1/2 , SM couplings, Compositeness scale Λ set to q* mass
  - PYTHIA MRST2007LO*
- Axigluon: $\mathcal{L}_{Aq\bar{q}} = g_{QCD}\bar{q}A^a_\mu \frac{\lambda^a}{2}\gamma^\mu\gamma_5\, q$
  - Parity conservation: no coupling to gluons
  - CalcHEP MRST2007LO*
- Color octet scalar: $\mathcal{L}_{gg8} = g_{QCD}d^{ABC}\frac{\kappa_s}{\Lambda_s}S^A_8 F^B_{\mu\nu}F^{C,\mu\nu}$
  - κ_s-coupling assumed unity, Λ_s – new physics scale set to resonance mass
  - gg→s8→gg
  - Pythia CTEQ6L1

Ttbar dilepton details

- SM : MC@NLO CTEQ6.6, HERWIG shower, Jimmy UE
- Z, diboson – Alpgen +Herwig,Jimmy
- W+jets, QCD – data
- KK gluon Pythia MRST 2007 LO*
- Leptons:
  - Electrons: tight, E_T >25GeV calo isolation R=0.2 <3.5GeV
  - Muons: combined p_T>20GeV calo and track isolation R=0.3 <4GeV, R=0.4 away from jets
- Jets
  - anti kT R=0.4
  - calibrated to hadronic energy scale
  - p_T>25GeV $|\eta|$<2.5, no b-tagging
- MET>40 GeV + Z window cut in ee μμ channel
- H_T>130GeV in eμ channel
- Backgrounds:
  - DY: CR: Z window, ratio gives Z in signal region
  - QCD, W+jets, Matrix Method
  - EW: MC

Ttbar dilepton: expectation and data

Table 1: Background composition in the signal region. Both statistical and systematic uncertainties are included.

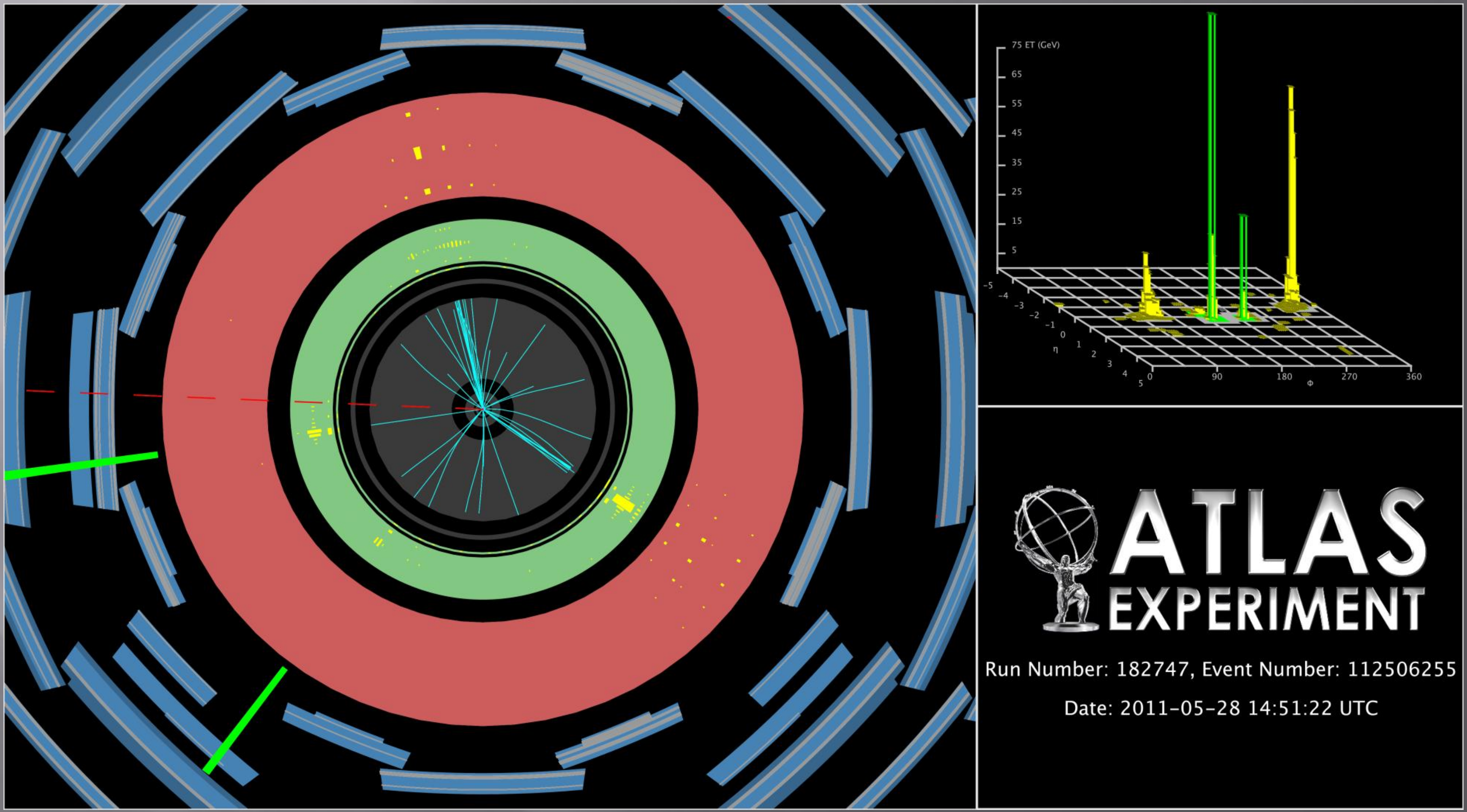
Process	Predicted number of background events
$t\bar{t}$	1920^{+230}_{-220}
$Z/\gamma^* \to ee$ + jets	130^{+72}_{-49}
$Z/\gamma^* \to \mu\mu$ + jets	140^{+27}_{-21}
$Z/\gamma^* \to \tau\tau$ + jets	85^{+12}_{-10}
Diboson	83^{+13}_{-12}
Single top	98^{+14}_{-13}
Fakes	96^{+94}_{-51}
Total background	2550^{+330}_{-300}
Data	2659

Ttbar dilepton: systematics

Table 2: Change in acceptance due to various sources of systematic uncertainties. Positive and negative acceptance variations are listed in [%]. All signal systematic uncertainties have been symmetrized. The total systematic uncertainty for Standard Model background also includes luminosity (3.7%) and the cross-section uncertainties.

	SM background (+)	SM background (-)	m_{KK}=700 GeV	m_{KK}=1000 GeV
Lepton ID / Trigger	3.4	4.5	4.2	4.7
Jet energy scale	7.4	6.7	3.5	4.0
Jet energy resolution	2.3	-	2.5	6.8
ISR/FSR	0	2.3	2.5	4.5
Parton Shower	1.4	1.4	-	-
Generator	4.8	4.8	-	-
PDF	2.7	2.7	1.2	1.2
Total Systematic	12.8	11.5	6.6	10.3

Ttbar dilepton : example event



Ttbar l+jets

- Topcolour Z′ boson, strong ewk symmetry breaking with top condensation, leptophobic scenario IV f_1=1, f_2=0, 1.2% width, Pythia
- g_{KK}: ‘standard’ couplings: g_L=g_R=-0.2 for light quarks, Madgraph+Pythia
- Ttbar: MC@NLO + Herwig, Jimmy UE, σ corrected to approximate NNLO
- W,Z + jets Alpgen + Herwig, Jimmy
- Diboson: Herwig+Jimmy

Ttbar l+jets

- Electrons:
  - Tight p_T>25 GeV
  - Calo isolated <4 GeV, R=0.2
- Muons:
  - Combined p_T>25 GeV $|\eta|$<2.5
  - Calo isolation <3 GeV, R=0.3; track isolation <2.5 GeV R=0.3
  - R=0.4 away from jets
- 4 Jets anti kT R=0.4, hadronic energy scale,E_T>25 GeV, $|\eta|$<2.5,
  - SV0 – at least 1 b-tagged
- MET: >35 GeV M_T(lepton, MET)>25 GeV

Ttbar l+jets- yields

	Electron channel	Muon channel
$t\bar{t}$	724	988
Single top	36	50
W+jets	93	172
Z+jets	6	8
Diboson	2	2
Total MC Background	861	1220
QCD Background	35	105
Total Expected	896	1325
Data observed	935	1396
Z', m = 500 GeV	15	21
g_{KK}, m = 700 GeV	68	93

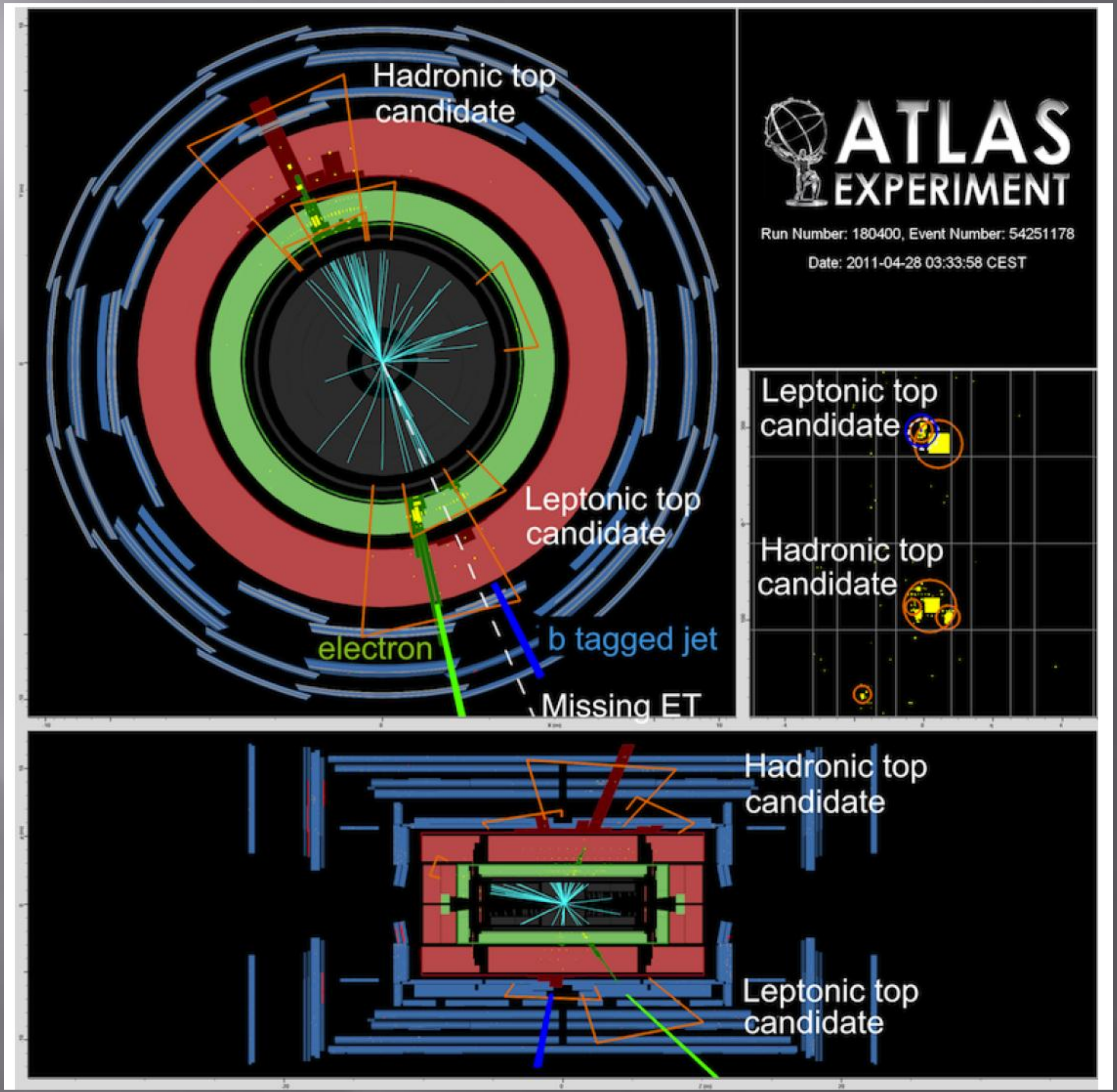
Ttbar l+jets dRmin algorithm

- Designed to reduce long tails in the reconstructed mass distribution caused by picking up I/FSR jet.
- Exclude a jet if distance to lepton or closest jet $\Delta R > 2.5 - 0.015 \times m_j$
- If more then 3 jets remain – iterate again.

Ttbar l+jets systematics

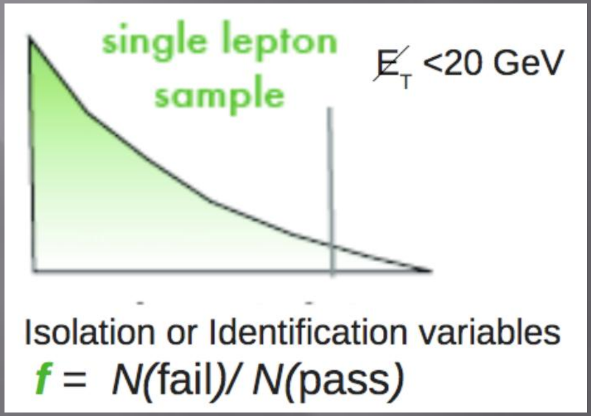
- Rate:
  - Luminosity 4.5%
  - Background normalization (QCD 30% (e) 50% (μ))
  - Trigger + reco efficiencies <1.5%
- Shape:
  - B-tagging efficiency (11% on yield)
  - JES+pileup (9% on yield)
  - ISR FSR modeling (7% on yield)

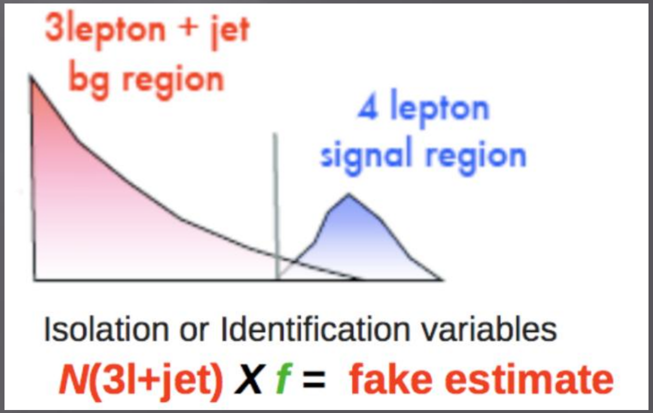
Ttbar l+jets example event



ZZ some details

- SM: Pythia MRST LO* corrected to NLO with MCFM 2008 NLO
- Graviton: Pythia
- 4 leptons p_T>15GeV 15% track isolation R=0.2
- Resolve ambiguity by sum of the differences of mass of pairs to the Z mass
- Data driven fake estimate: $N(\mathrm{BG}) = N(\ell\ell\ell j) \times f - N(\ell\ell jj) \times f^2 - N(\mathrm{ZZ}).$





ZZ yields

Table 5: Background estimates in 1.02 fb^{-1} of data in the high mass $m_{ZZ} > 300$ GeV signal region. Also shown are expected yields for $G \to ZZ$ samples for a coupling of $k/\bar{M}_{pl} = 0.1$. The first quoted uncertainty is statistical; the second systematic. See Section 4 for discussion of the fake background uncertainty.

Process	**Total**
ZZ	$1.85 \pm 0.11 \pm 0.09$
Fakes	$0.02^{+1.03}_{-0.01}{}^{+0.75}_{-0.02}$
Total Bkg.	$1.87^{+1.04}_{-0.11}{}^{+0.75}_{-0.09}$
Data	3
G(350 GeV)	$71 \pm 3 \pm 4$
G(500 GeV)	$12 \pm 0.5 \pm 0.6$
G(750 GeV)	$1.5 \pm 0.08 \pm 0.07$
G(1000 GeV)	$(2.7 \pm 0.2 \pm 0.1) \times 10^{-1}$
G(1250 GeV)	$(6.6 \pm 0.4 \pm 0.3) \times 10^{-2}$
G(1500 GeV)	$(1.9 \pm 0.1 \pm 0.1) \times 10^{-2}$

Process	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\mu^+\mu^-e^+e^-$
ZZ	$0.32 \pm 0.03 \pm 0.01$	$0.63 \pm 0.04 \pm 0.03$	$0.53 \pm 0.04 \pm 0.03$	$0.37 \pm 0.03 \pm 0.02$
Fakes	$0.00^{+0.04}_{-0.00}{}^{+0.03}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.02 \pm 0.02 \pm 0.02$
Total Bkg.	$0.32^{+0.05}_{-0.03}{}^{+0.03}_{-0.01}$	$0.63^{+1.03}_{-0.04}{}^{+0.75}_{-0.03}$	$0.54^{+1.03}_{-0.04}{}^{+0.75}_{-0.03}$	$0.39 \pm 0.04 \pm 0.03$
Data	0	2	1	0
G(350 GeV)	$12 \pm 1 \pm 1$	$23 \pm 2 \pm 1$	$20 \pm 2 \pm 1$	$16 \pm 1 \pm 1$
G(500 GeV)	$2.1 \pm 0.2 \pm 0.1$	$4.0 \pm 0.3 \pm 0.2$	$3.2 \pm 0.2 \pm 0.2$	$2.3 \pm 0.2 \pm 0.1$
G(750 GeV)	$0.30 \pm 0.02 \pm 0.01$	$0.46 \pm 0.03 \pm 0.01$	$0.43 \pm 0.03 \pm 0.01$	$0.26 \pm 0.02 \pm 0.01$
G(1000 GeV)	$(6.0 \pm 0.5 \pm 0.5) \times 10^{-1}$	$(8.5 \pm 0.6 \pm 0.5) \times 10^{-1}$	$(8.6 \pm 0.6 \pm 0.6) \times 10^{-1}$	$(4.3 \pm 0.4 \pm 0.5) \times 10^{-1}$
G(1250 GeV)	$(1.3 \pm 0.1 \pm 0.1) \times 10^{-2}$	$(2.0 \pm 0.1 \pm 0.1) \times 10^{-2}$	$(2.4 \pm 0.2 \pm 0.1) \times 10^{-2}$	$(0.9 \pm 0.1 \pm 0.1) \times 10^{-2}$
G(1500 GeV)	$(4.1 \pm 0.3 \pm 0.2) \times 10^{-3}$	$(5.6 \pm 0.4 \pm 0.2) \times 10^{-3}$	$(7.0 \pm 0.5 \pm 0.3) \times 10^{-2}$	$(2.6 \pm 0.2 \pm 0.2) \times 10^{-3}$

ZZ systematics

- Electron and muon identification:
  - ee ee: 6.6%
  - ee μμ: 3.1%
  - μμ μμ: 2.0%
  - μμ ee: 1.0%
- Fake rate f: difference in MC and data calculation when same procedure applied

ZZ efficiencies

Graviton Mass [GeV]	Theory [pb]	Fiducial Acceptance	Selection Efficiency	Expected Limit [pb]	Observed Limit [pb]
350	41.70	27%	61%	3.3	3.3
500	6.45	28%	63%	3.2	3.2
750	0.69	31%	66%	2.9	2.9
1000	0.13	32%	66%	2.8	2.8
1250	0.03	33%	67%	2.7	2.7
1500	0.01	35%	66%	2.6	2.6

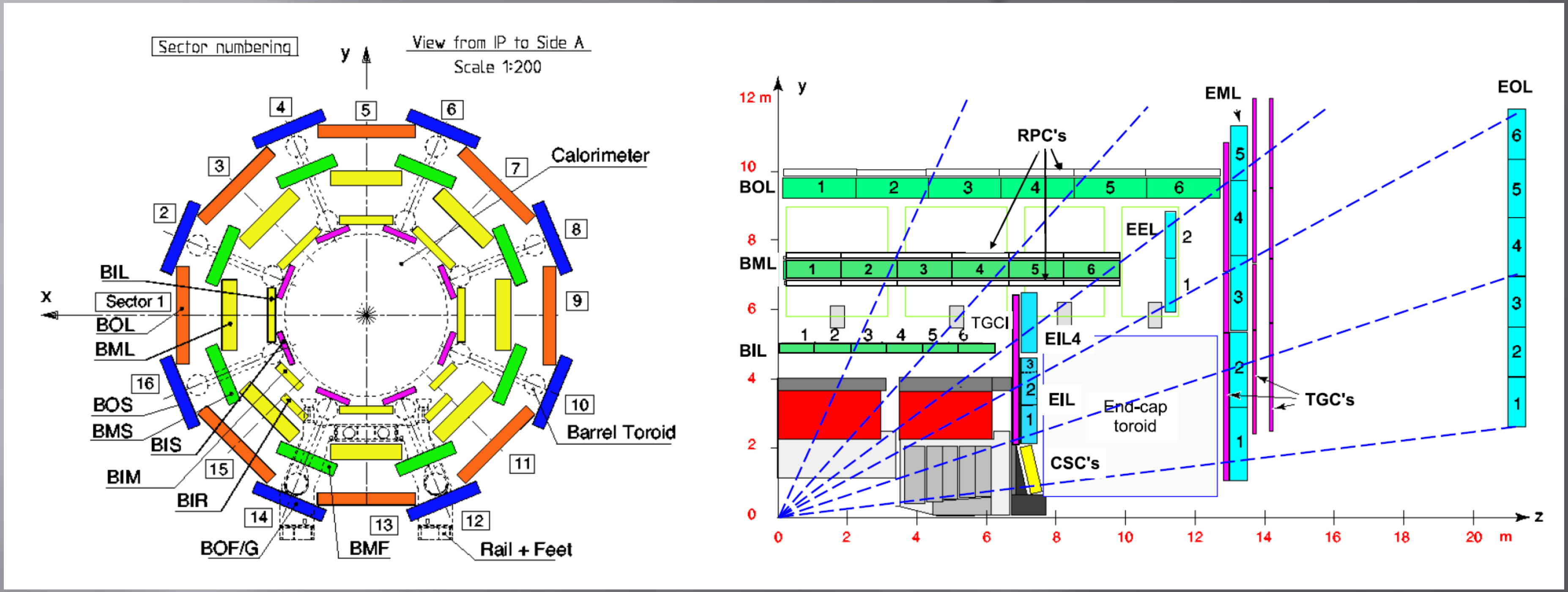
High p_T Resolution

- Electron/Photon:
  - Isolated energy in EM calo

$$\frac{\sigma(E)}{E} = \frac{k_1}{\sqrt{E}} + k_2$$

  - For high energy electrons k_2 in barrel 1.2% 1.8% in endcap
- Muons:
  - At high p_T curvature resolution dominated by intrinsic/misalignment 0.15 TeV^{-1} to 0.44 TeV^{-1} (for $|\eta|>2$)
- Jets: $q/p_T \rightarrow (q/p_T)_{ini} + S_1\,(q/p_T)_{ini} + S_2$
  - JES:2.5-8% in barrel, 3.5-14% endcap +up to 5-7% from pileup (mostly at low p_T

ATLAS Muon system



- Coverage $|\eta|<2.7$,
  - CSC $2<|\eta|<2.7$
- Triggering $|\eta|<2.4$
  - RPC $|\eta|<1.05$, TGC $1.05<|\eta|<2.4$

QCD k-factor DY