

Recent Results from The ATLAS Experiment at the LHC

Spåttind 2012

Nordic Conference on Particle Physics

Skeikampen, 2-7 January, 2012

A. Read (U.Oslo/LAL)

Introduction

- **Some** of the most recent ATLAS results
- **Not** a survey of ALL ATLAS results
 - E.g. heavy ions run just ended
- Summary of 2011 data-taking conditions
- SM results (e.g. “Candles” for searches)
- Observation of new b-resonance
- SUSY searches
- Searches for “exotic” new physics

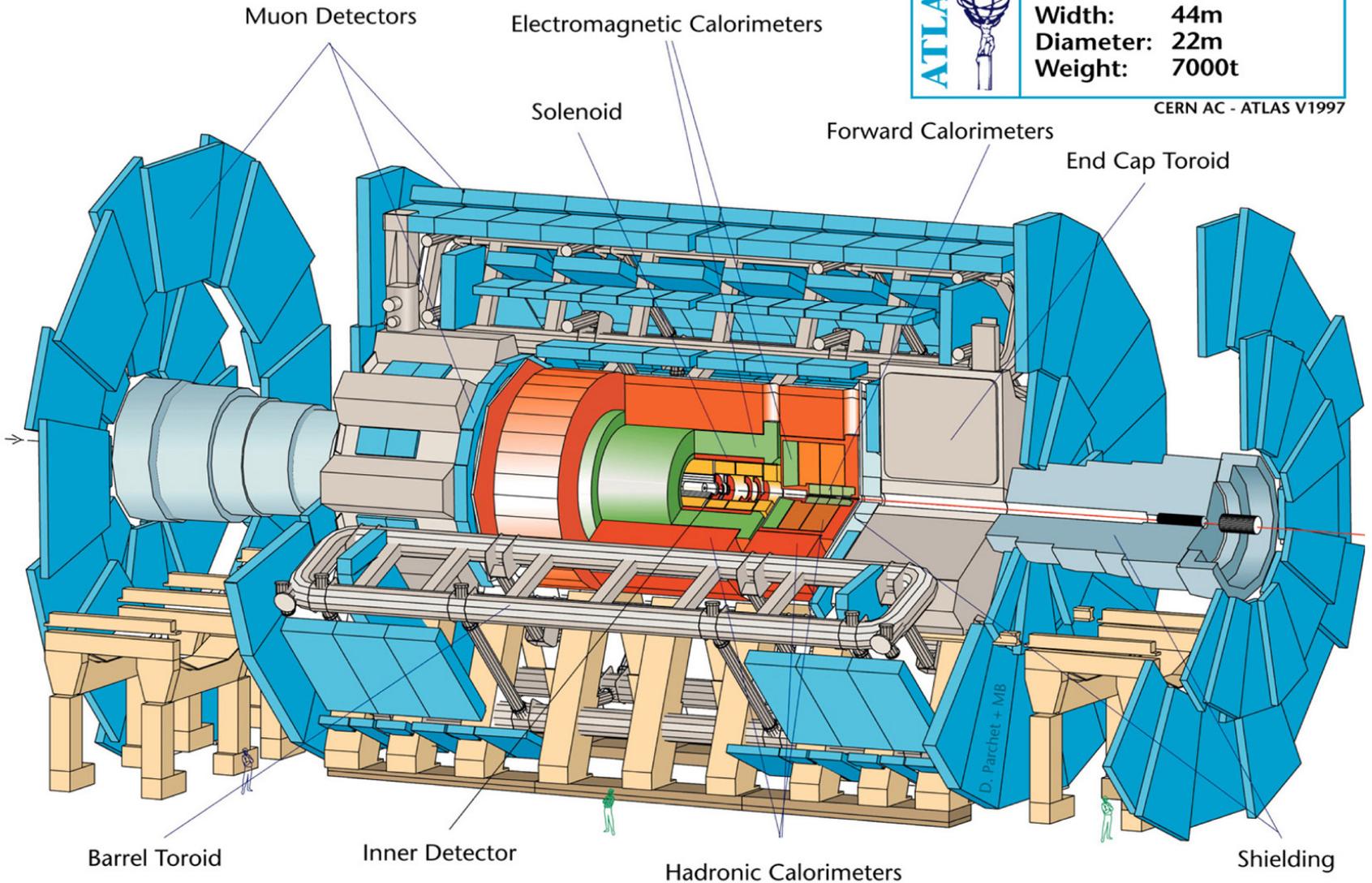
- SM Higgs searches and (**ATLAS**) combination in separate lecture

2011 Data-taking

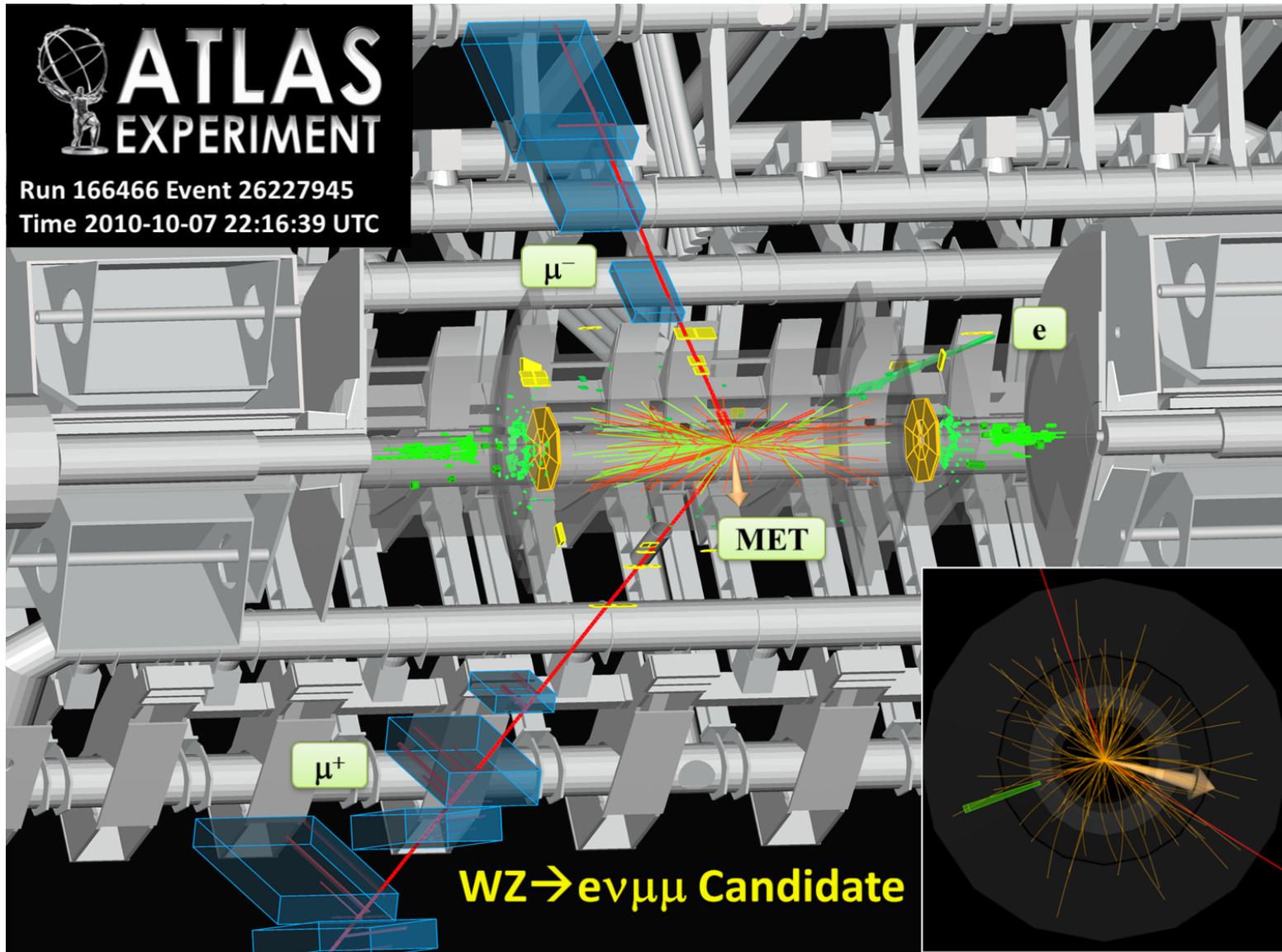
ATLAS Detector

	Detector characteristics	
	Width:	44m
	Diameter:	22m
	Weight:	7000t

CERN AC - ATLAS V1997



Electrons and muons

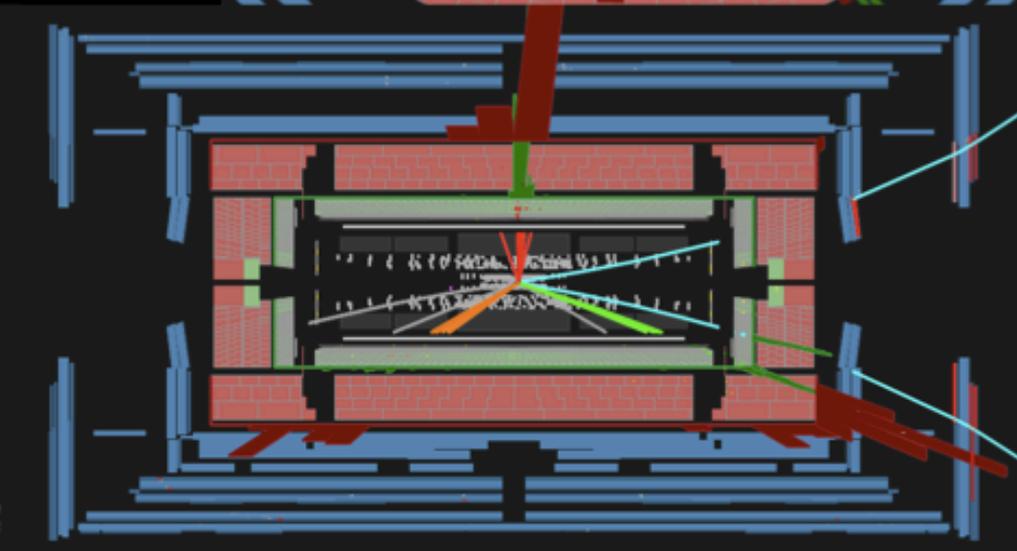
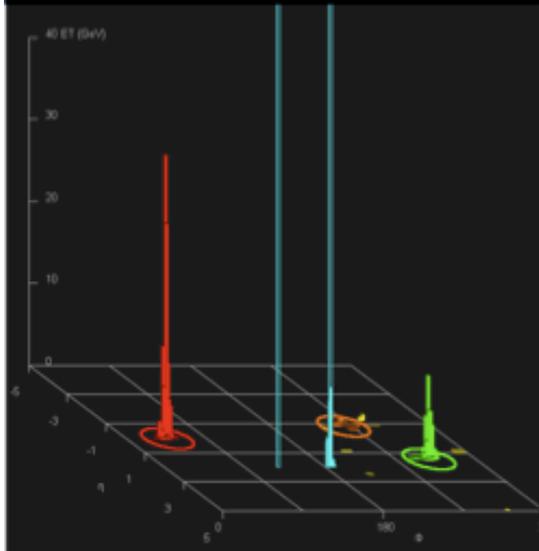
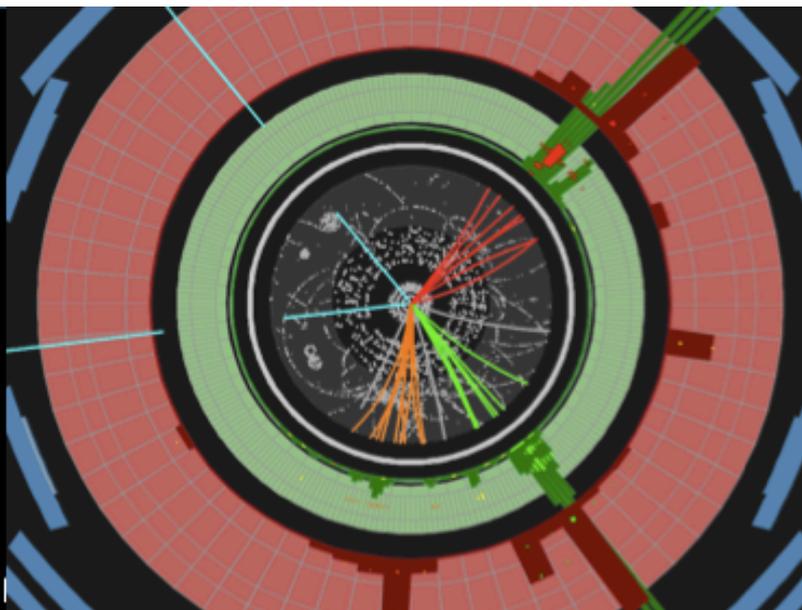


Muons and jets

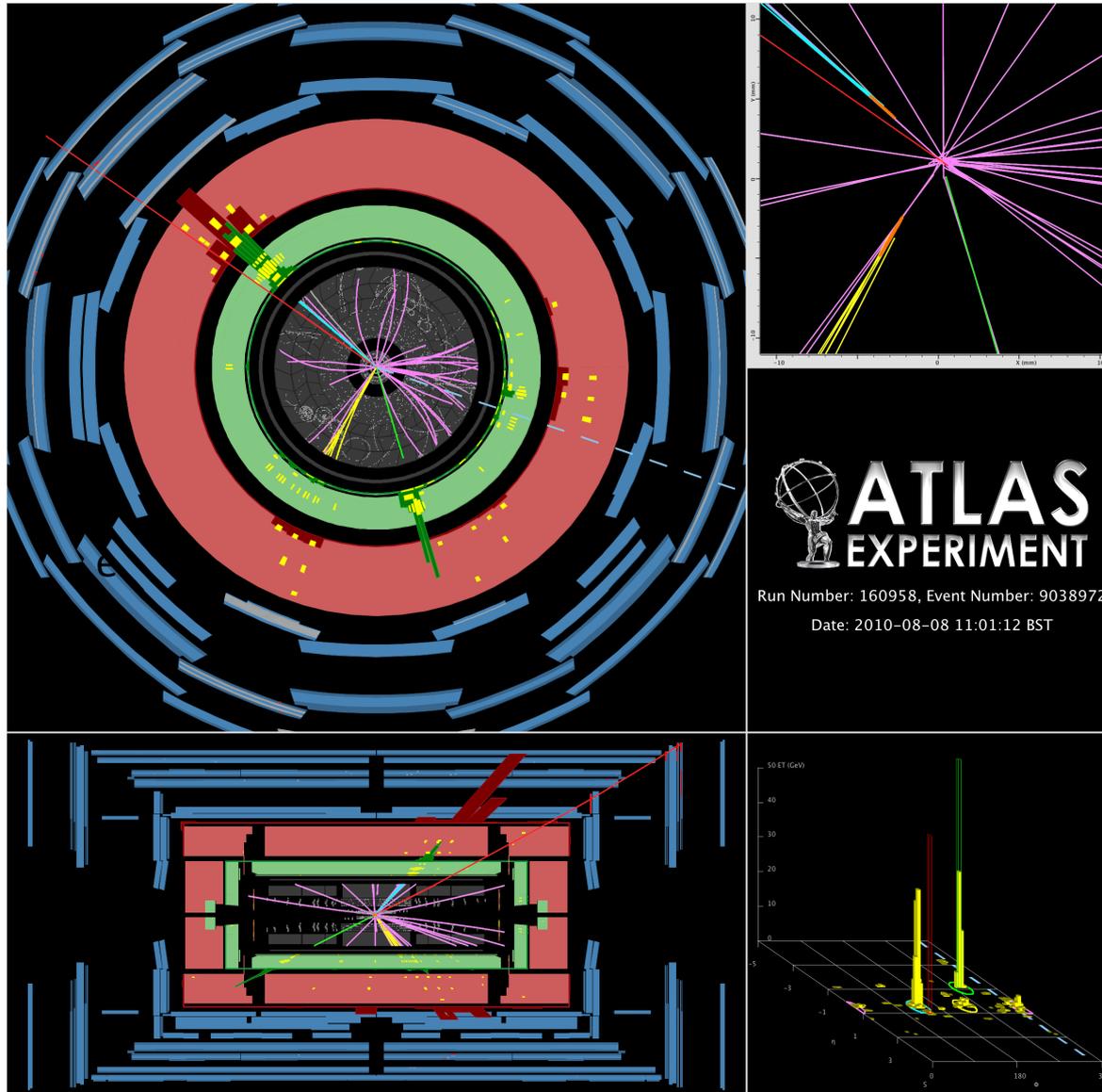
 **ATLAS**
EXPERIMENT

$Z \rightarrow \mu^- \mu^+ + 3 \text{ jets}$

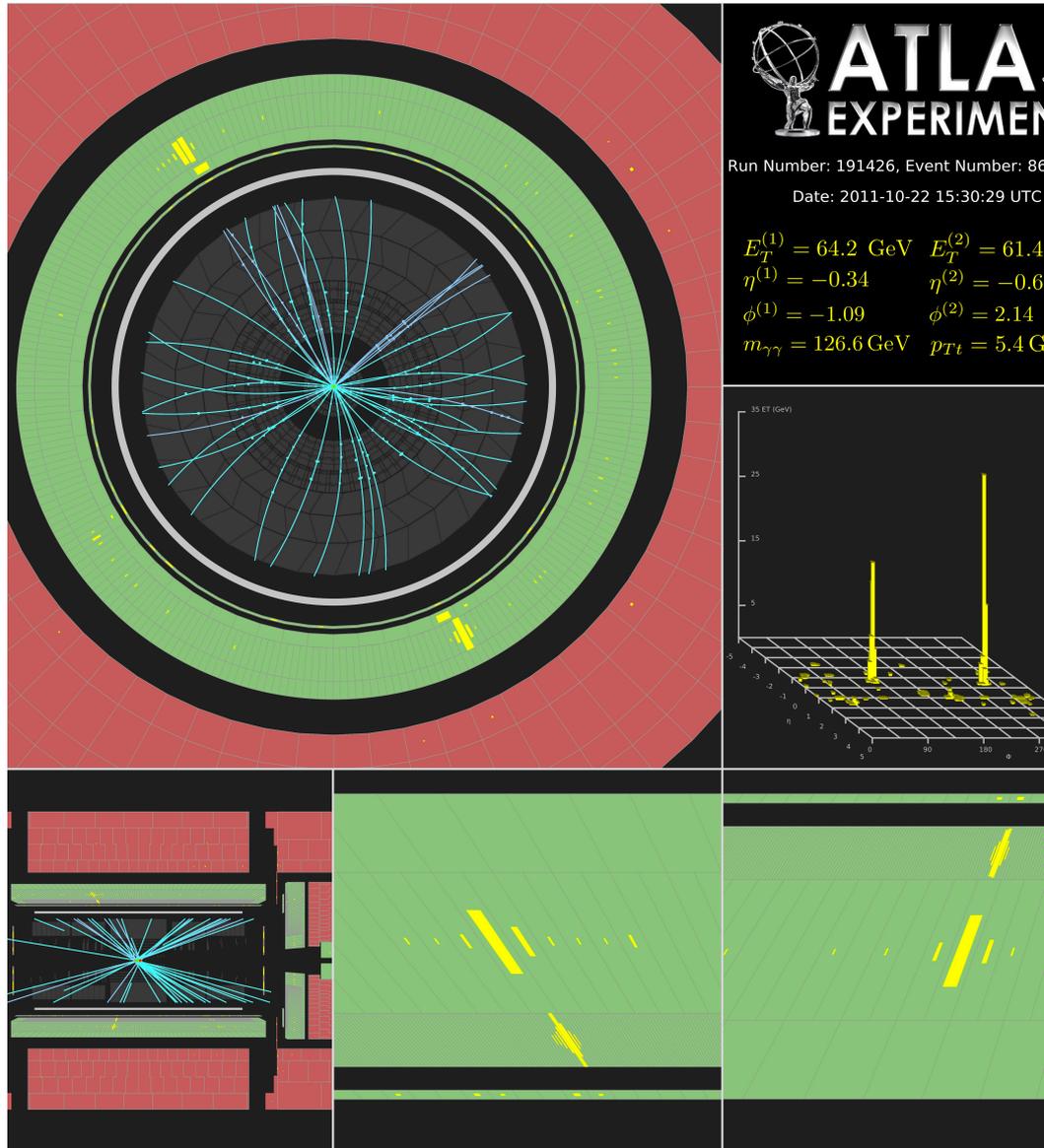
Run Number 158466, Event Number 4174272
Date: 2010-07-02 17:49:13 CEST



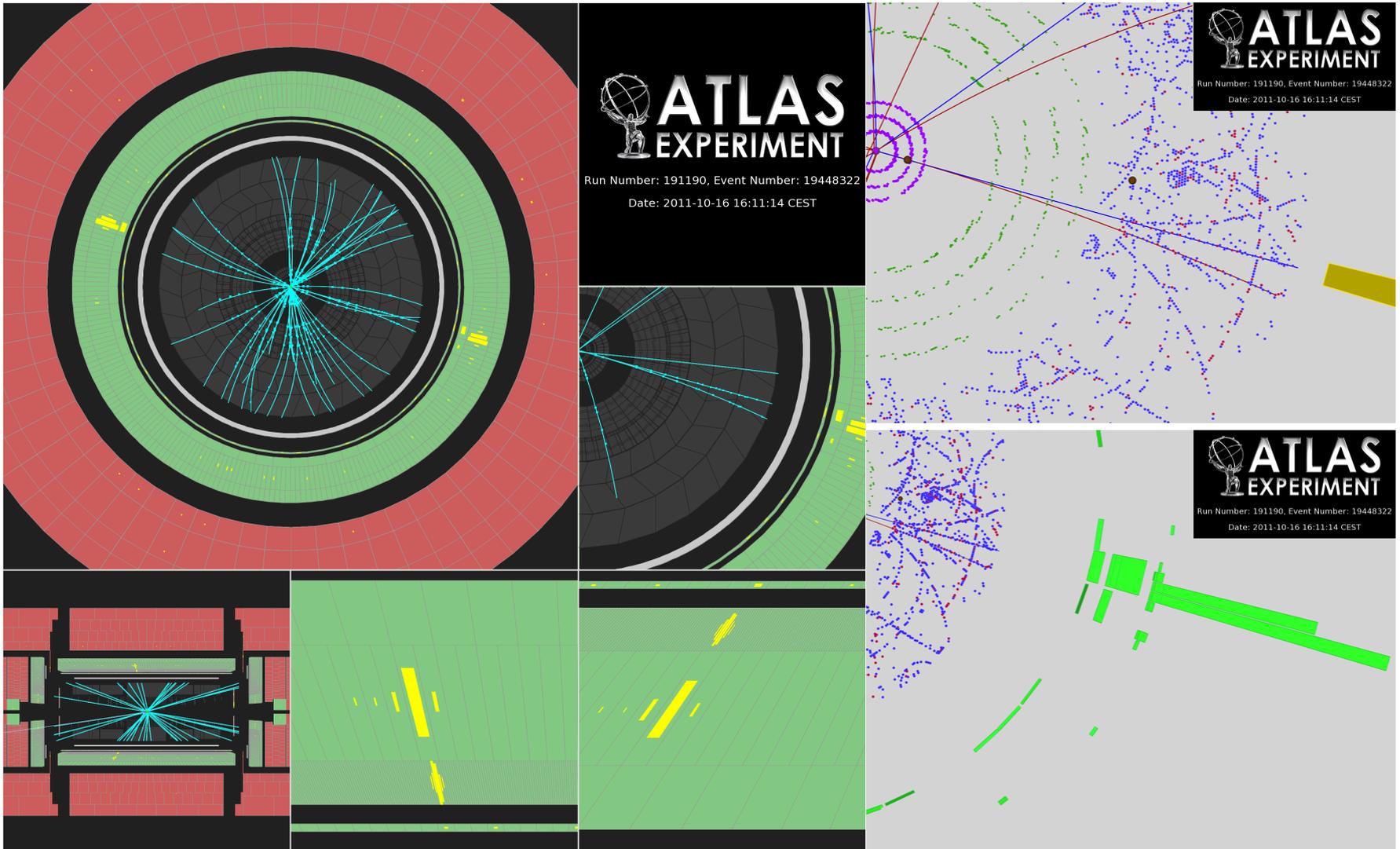
b-jets (top-pair candidate)



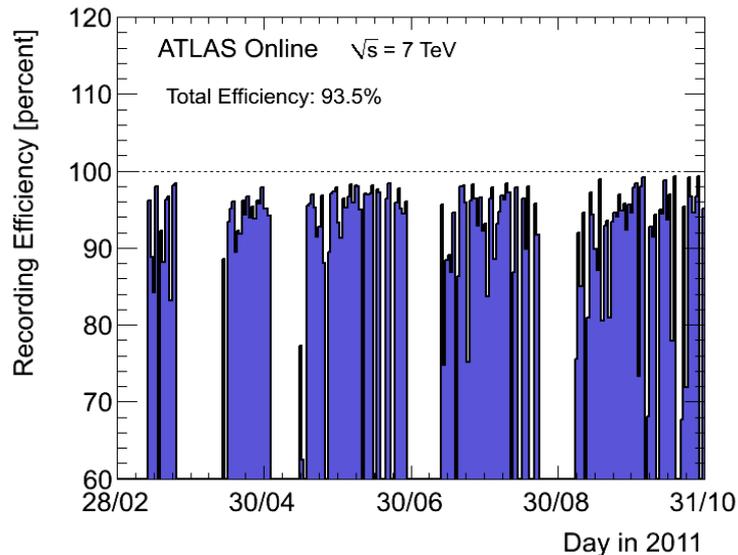
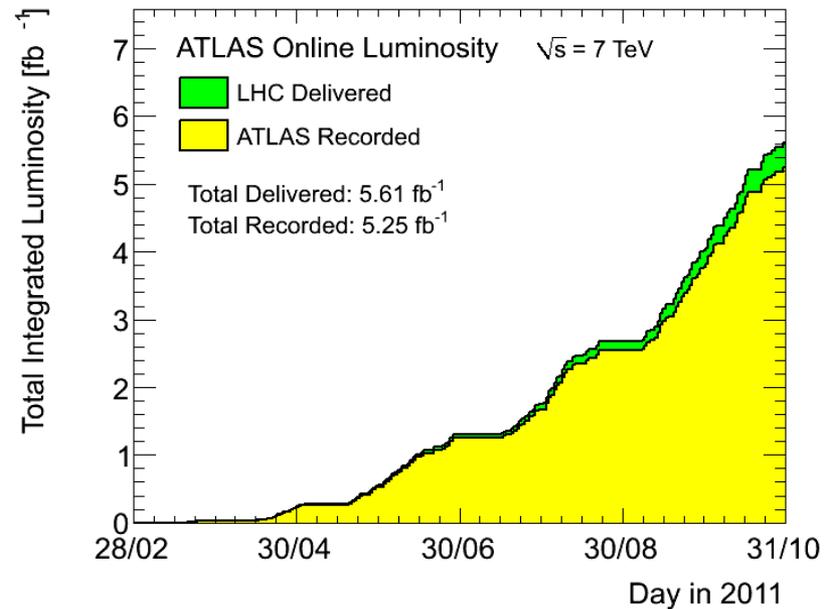
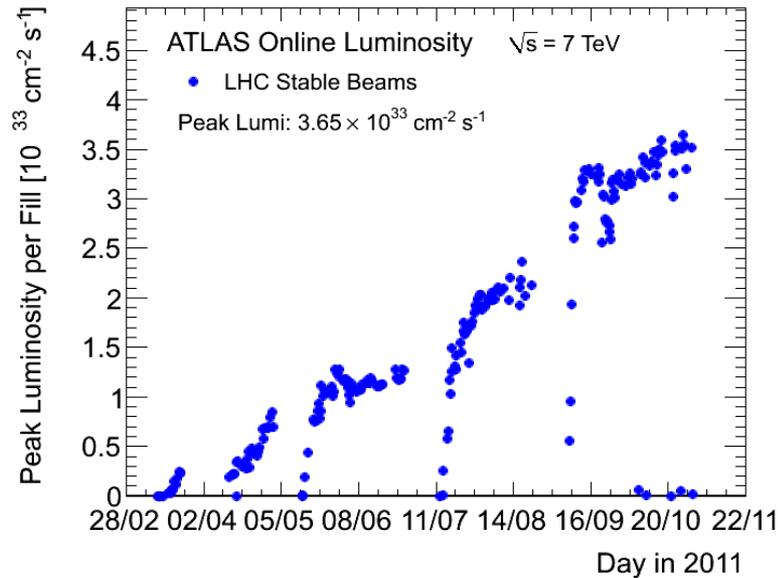
Photons



Converted photons



Luminosity 2011



- 2011 peak lumi $0.36 \times 10^{34} / \text{cm}^2 \cdot \text{s}$
 - 40% of design!
- 5.25/fb recorded (2010 X ~150!)
 - Expected 1-2/fb

Data quality 2011

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

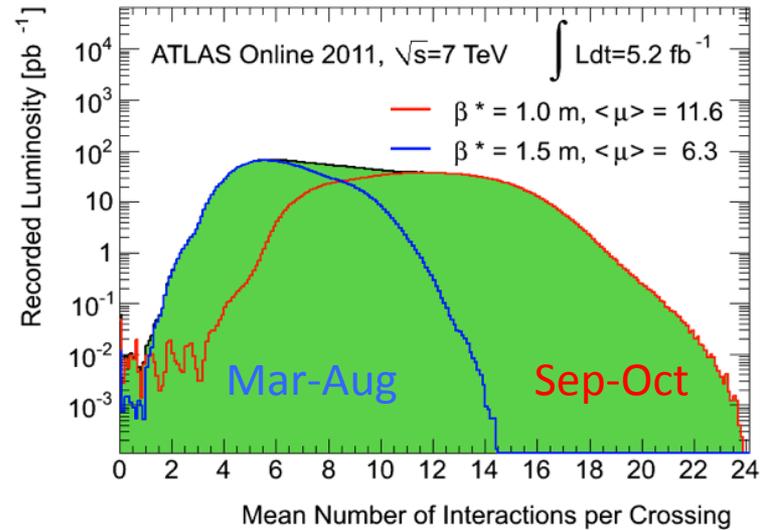
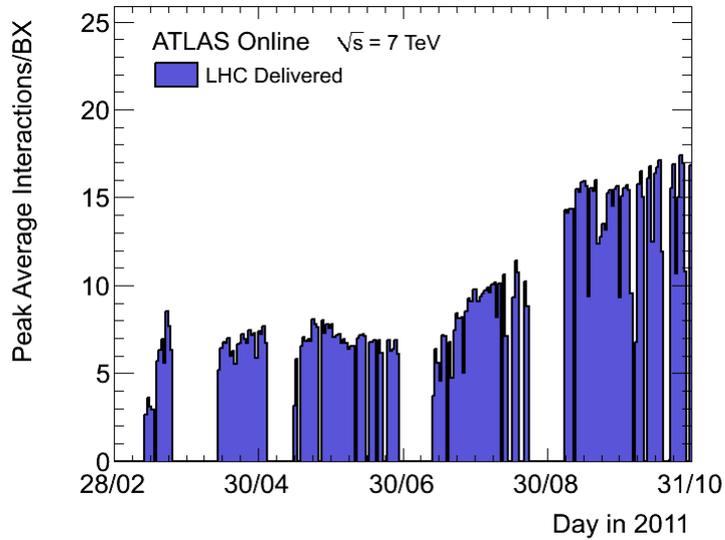
Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at $\sqrt{s}=7$ TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

L1			HLT						
Muon	Calo	CTP	electron	photon	muon	tau	jet	b-jet	missing E_T
99.0	100	99.8	99.3	99.3	100	99.9	98.6	99.9	99.3

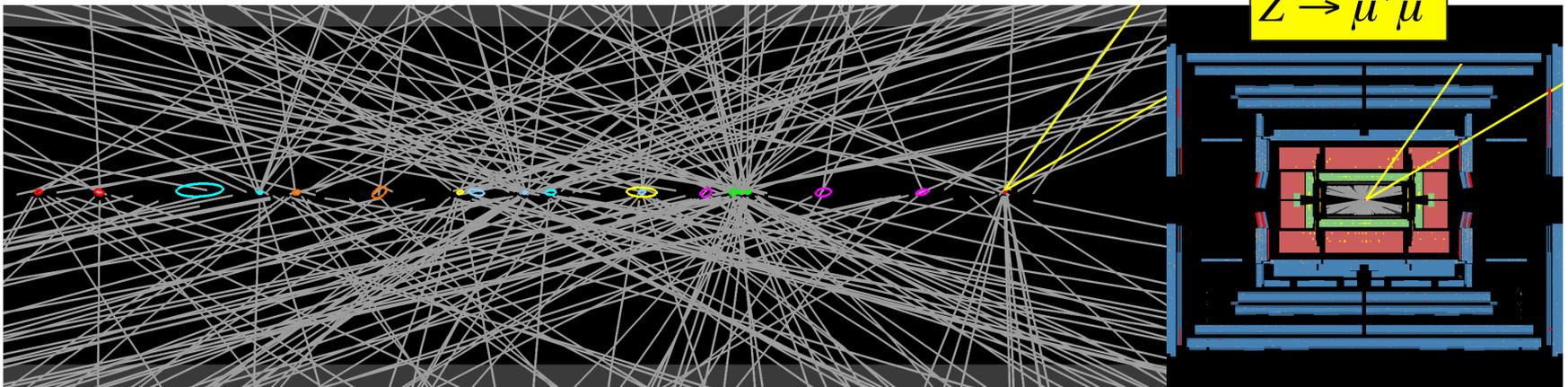
Luminosity weighted relative relative fraction of good trigger data quality delivery during 2011 stable beams in pp collisions at $\sqrt{s}=7$ TeV between 13 March and 30 October (in %).

- Data-fraction used for analysis typically 90-96%

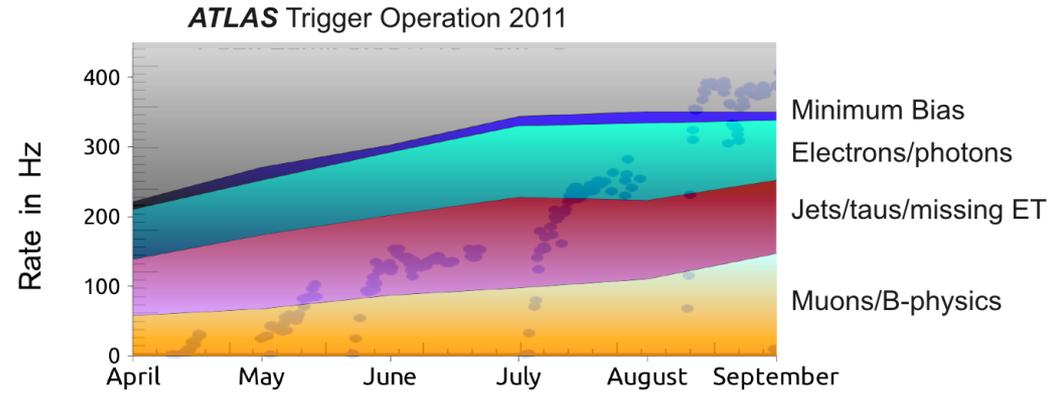
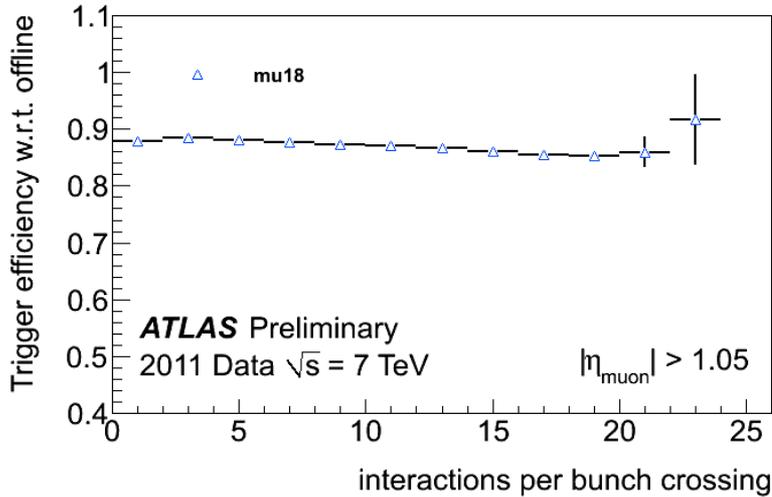
Pileup



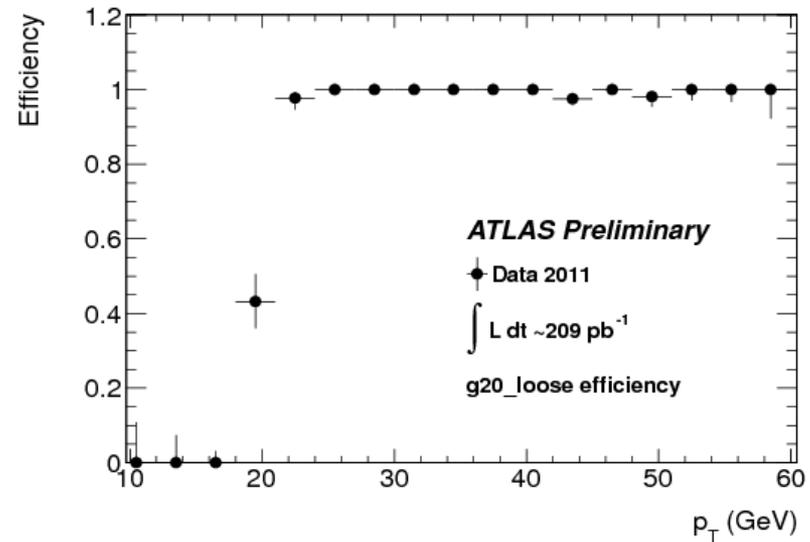
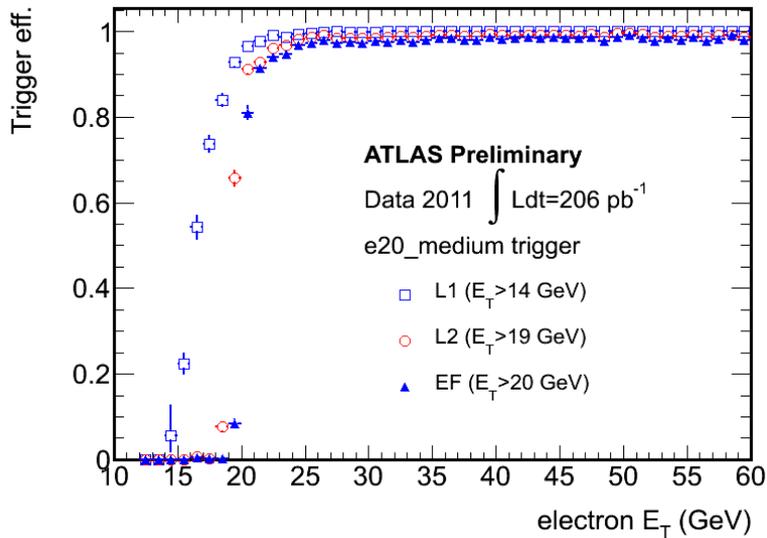
Vertex error ellipses x20 for illustration



Trigger

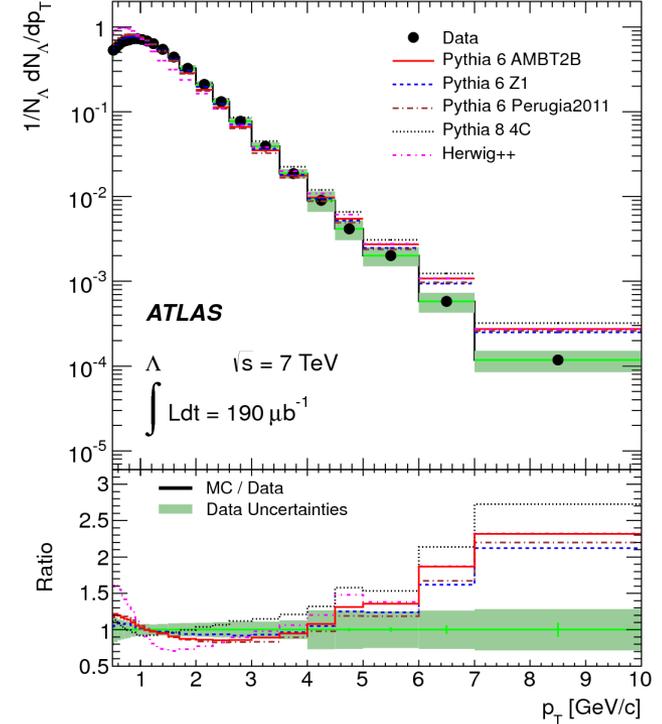
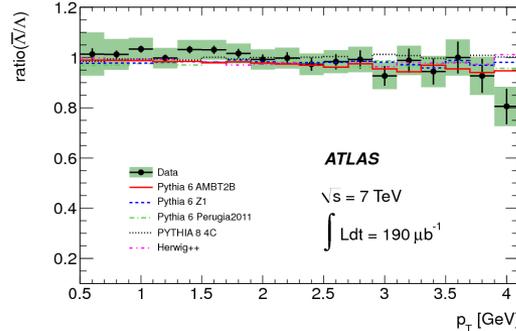
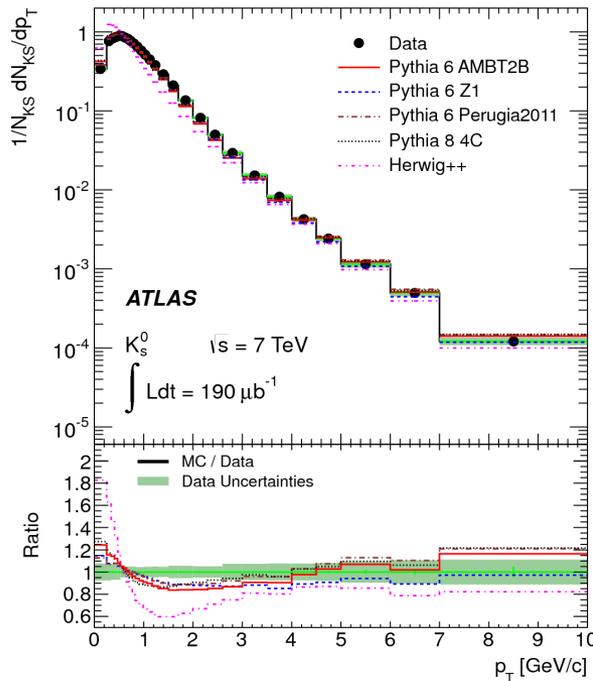
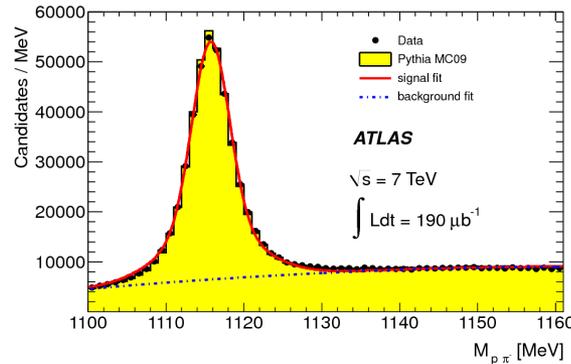
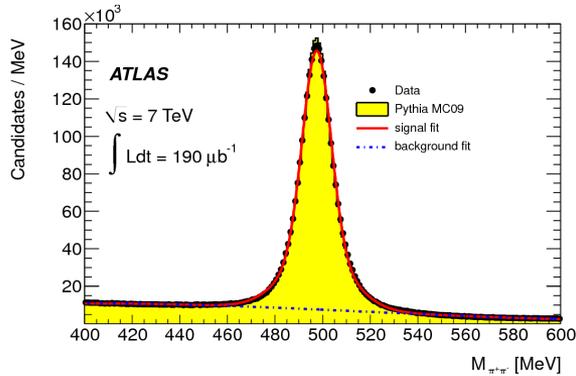


With modest tuning of inclusive triggers, rates increased much less than inst. lumi.



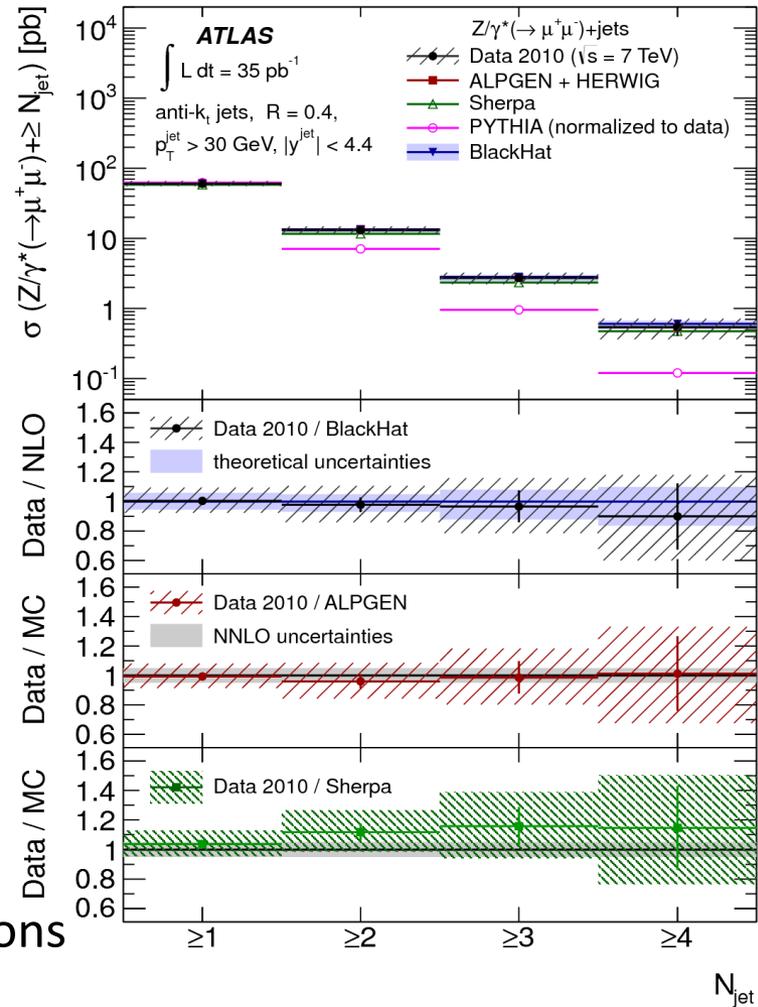
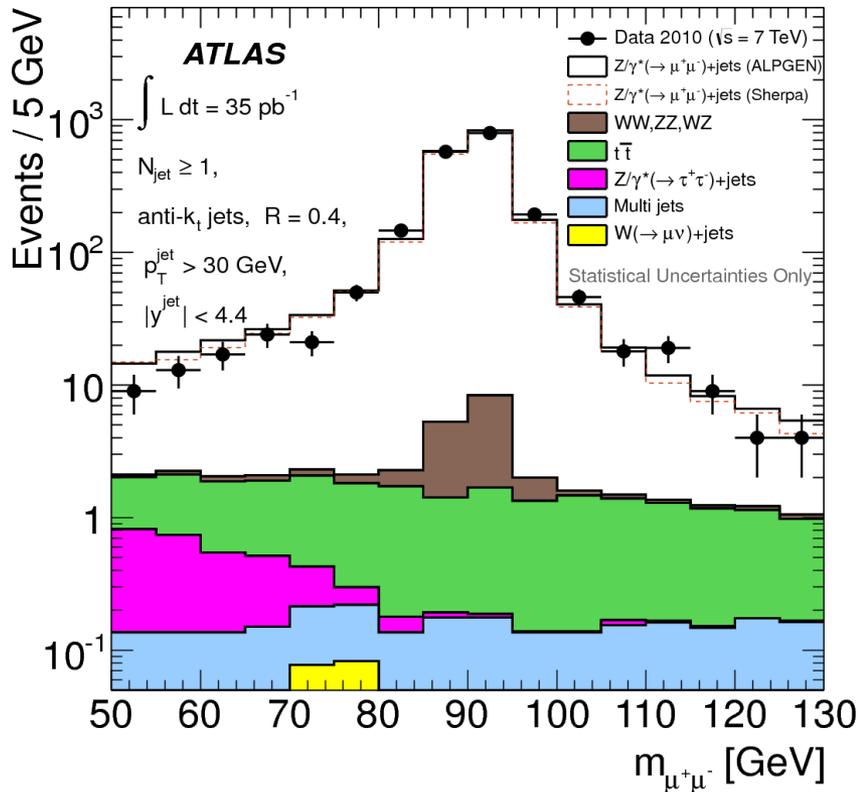
Recent SM Results

K_s^0 and Λ production



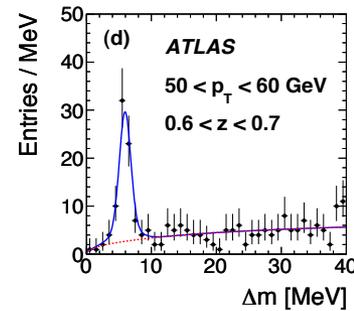
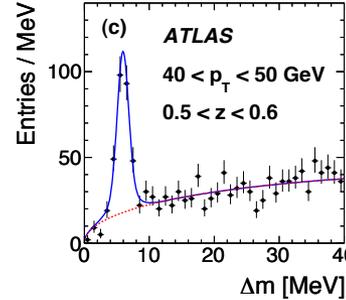
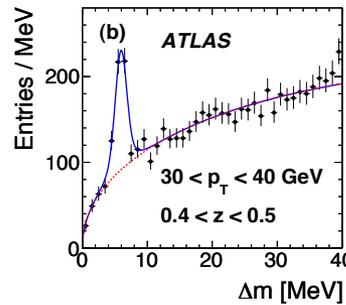
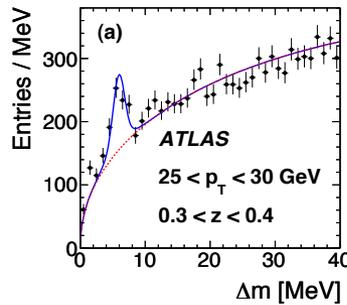
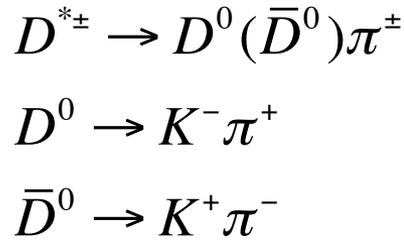
- The first 190/ μb in 2011 (7 TeV MINBIAS)
- K_s^0 production modeled fairly well ($\sim 15\%$)
- Λ production at high p_T not understood
- $\Lambda / \bar{\Lambda}$ consistent with unity, earlier measurements, SM expectations

Z + jets

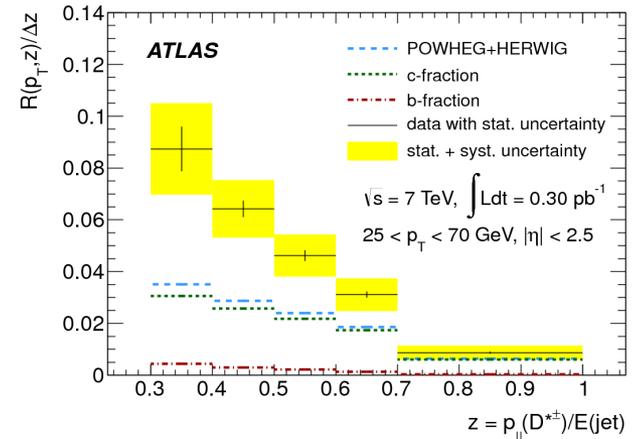
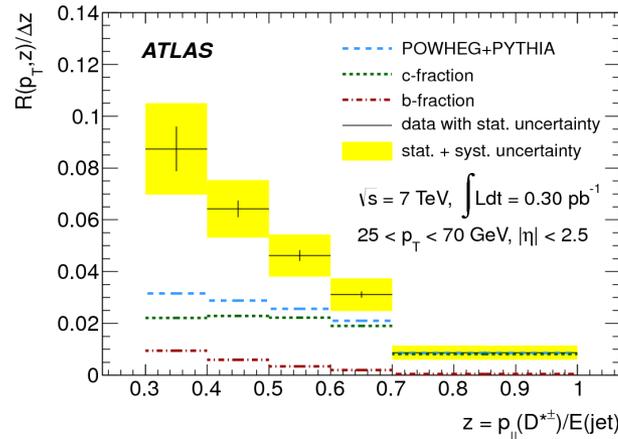


- 2010 data
- Data reproduced by several calculations
 - NLO pQCD (BLACKHAT)
 - LO matrix element plus parton-shower (ALPGEN, SHERPA)

D*± production in jets

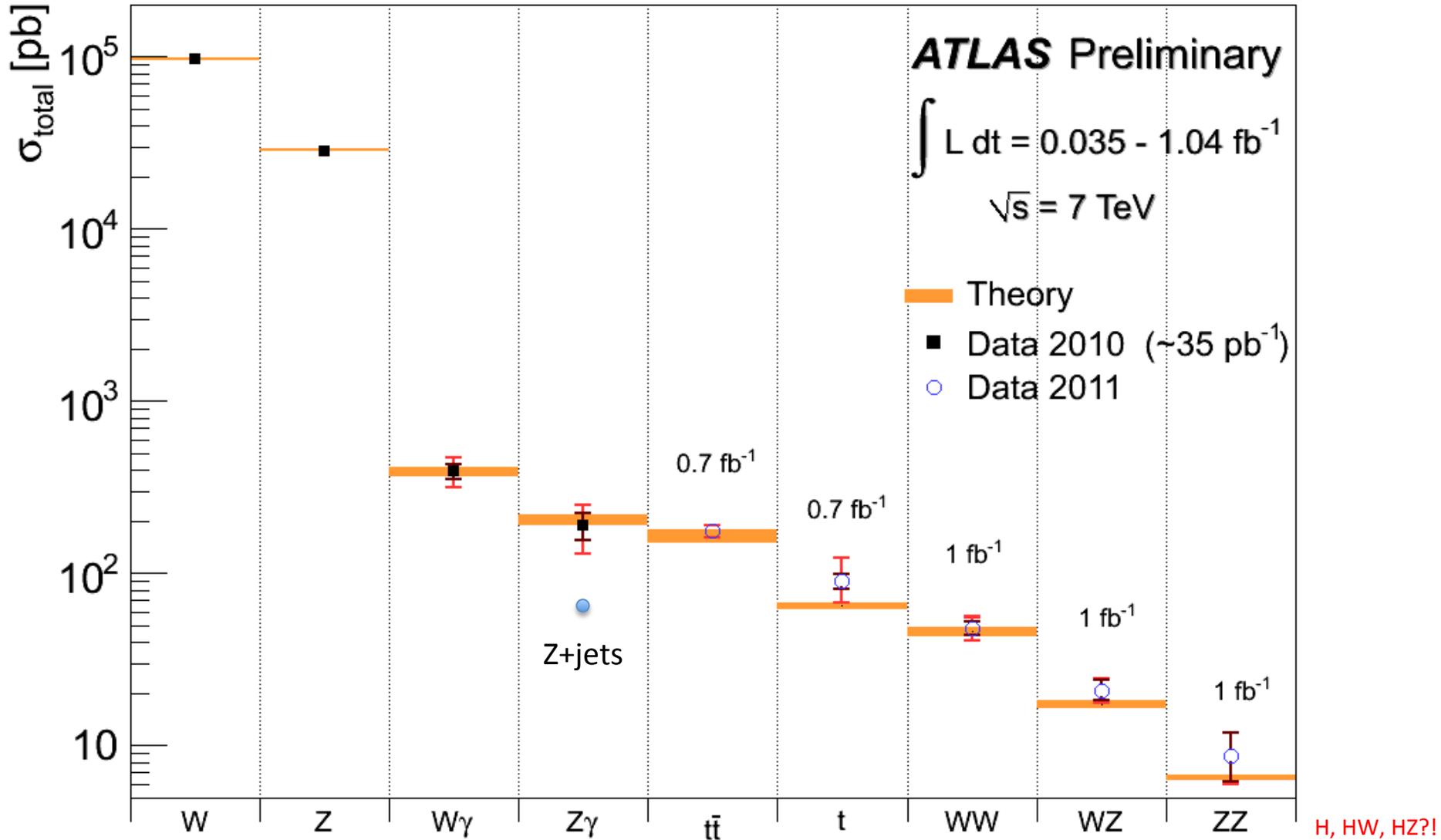


- Opposite charged pairs, closest to D⁰ mass
- Add charged track (Δm)
- Require decay length > 0
 - 89% eff.
 - Reject 50% comb. bg.



- Anti-kt jets with R=0.6, D* within 0.6 of jet center
- D* momentum along jet axis $z = p_{\parallel}(D^{*\pm}) / E(\text{jet})$
- Ratio of D*-jet to inclusive jet $\mathfrak{R}(p_T, z) = N_{D^{*\pm}}(p_T, z) / N_{\text{jet}}(p_T)$
- Neither Pythia nor Herwig anywhere close at low z

Standard Model total production cross sections



Recent B-physics result

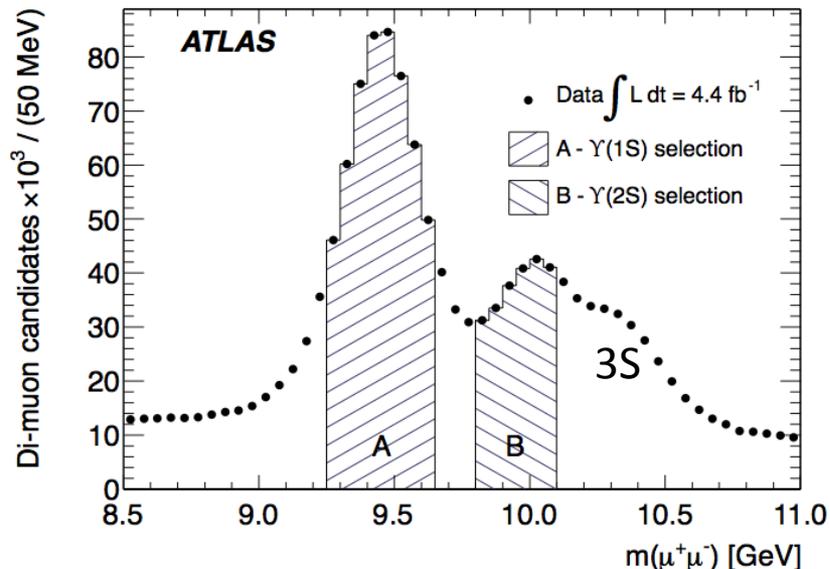
Observation of a New χ_b State

- Quarkonium physics, test of QCD
- $\chi_b(1P)$, $\chi_b(2P)$ seen and measured by CUSB, CLEO, ARGUS, CDF 1982-2004
- Radiative decays

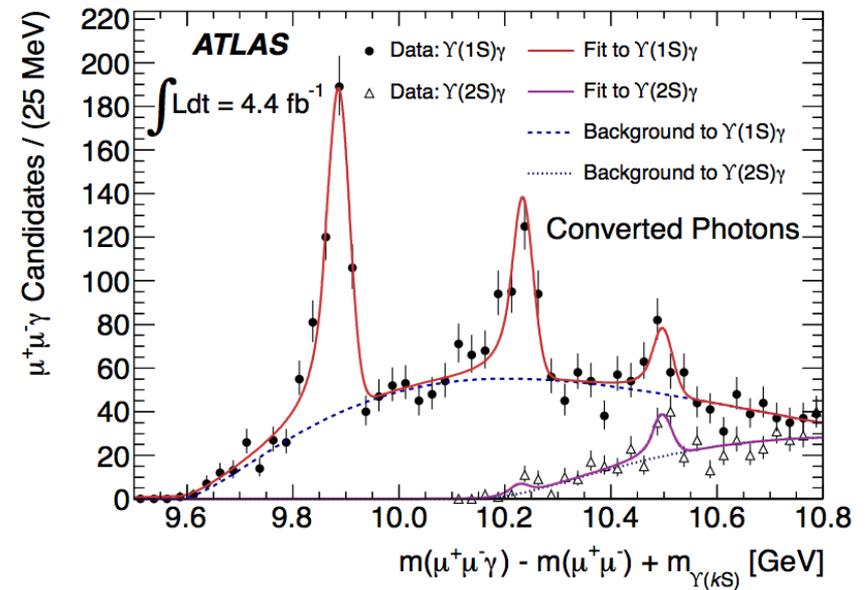
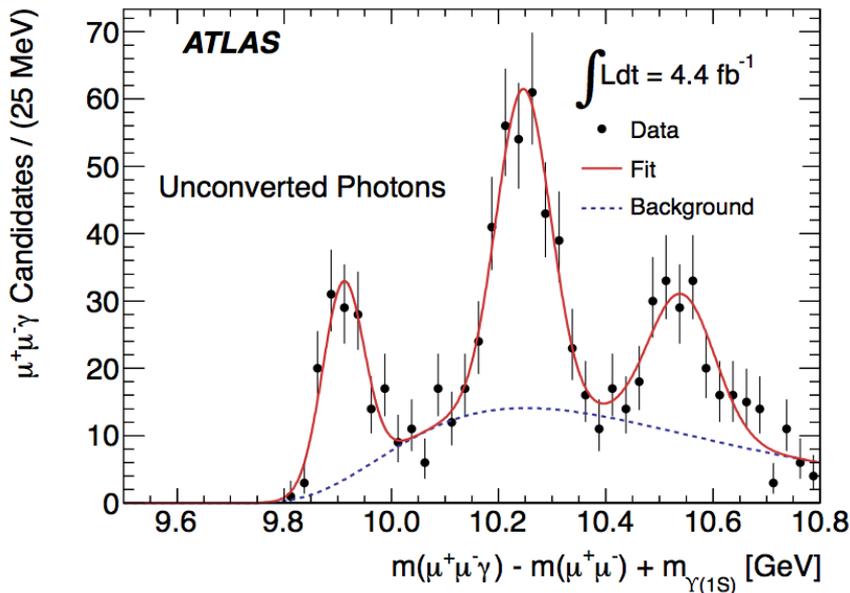
$$\chi_b(nP) \rightarrow \Upsilon(1,2S) \gamma$$

$$\Upsilon(1,2S) \rightarrow \mu^+ \mu^-$$

- “Loose” muons $\eta < 2.3$, $p_T > 4$ GeV
- $p_T(\mu^+ \mu^-) > 12$ (20) GeV converted (unconv.) Υ 's
- “Loose” Υ 's from shower shape, little in HCAL or e^+e^- pairs with vertex $P(\chi^2) > 1\%$ and 40 mm from beam



“ATLAS Discovers its first new particle”



- Hyperfine splittings taken from previous experiments for $\chi_b(1P)$ and $\chi_b(2P)$
 - Taken from theory (12 MeV) for previously undetected $\chi_b(3P)$
- Over 6σ (!) in each converted/unconverted category (log-likelihood ratio)
- Mass barycenter (GeV):
 - Unconverted: 10.541 ± 0.011 (stat) ± 0.030 (syst)
 - Converted : 10.539 ± 0.004 (stat) ± 0.008 (syst) ← Taken as final result
 - Converted systematics dominated by signal and background model assumptions

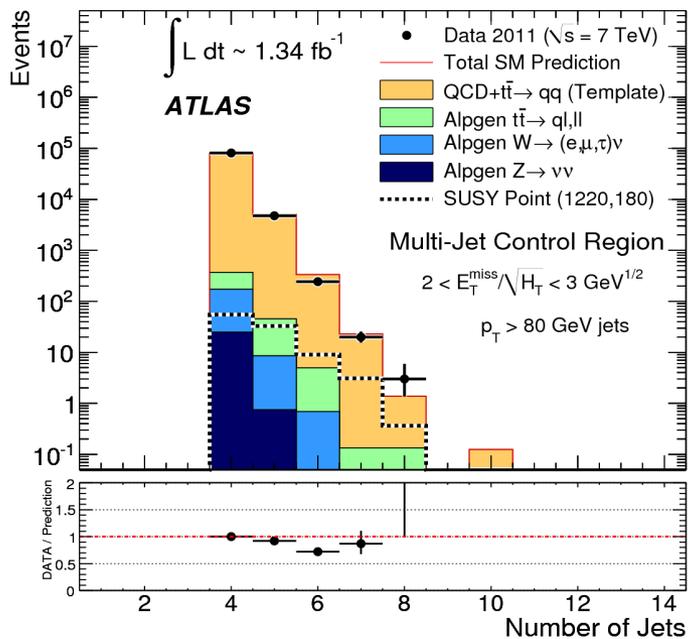
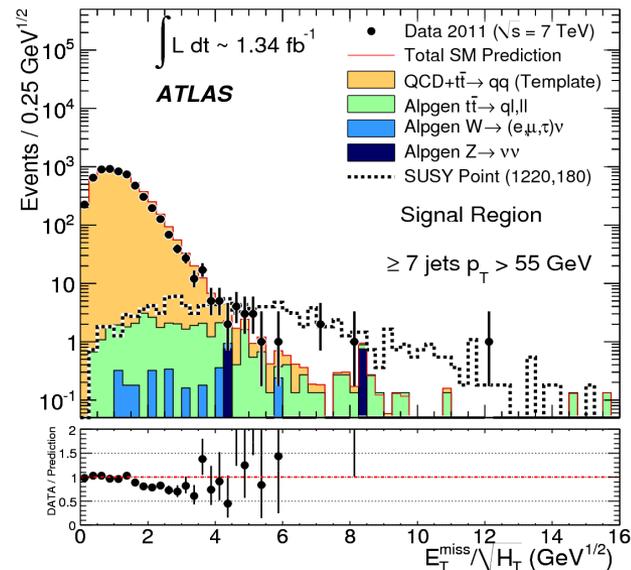
Recent SUSY results

ATLAS SUSY Searches 2011

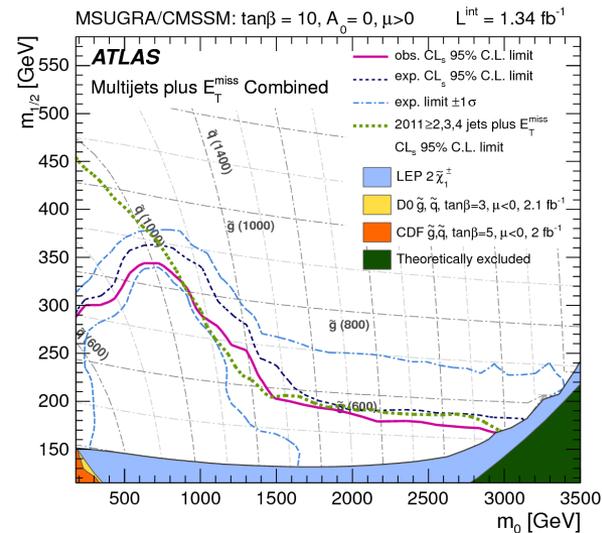
Search	Date	Lumi (1/fb)
Jets and Emiss	June	0.16
One lepton, jets, and Emiss	June	0.16
B-jets and Emiss	July	0.83
B-jets, 1-lepton and Emiss	August	1.03
Electron-muon resonance	September	1.07
Jet and Emiss (update)	September	1.04
One lepton, jets and Emiss (update)	September	1.03
Large jet multiplicity and Emiss	October	1.34
2 leptons	October	1.04
Additional interp. jets+Emiss	November	1.04
Additional interp. 2 leptons, jets and Emiss	November	1.04
Diphoton and Emiss	November	1.07
Direct sbottom search	December	2.05

Large jet multiplicity and E_Tmiss

Signal region	7j55	8j55	6j80	7j80
Multi-jets	26 ± 5.2	2.3 ± 0.7	19 ± 4	1.3 ± 0.4
$t\bar{t} \rightarrow q\ell, \ell\ell$	10.8 ± 6.7	0 ^{+4.3}	6.0 ± 4.6	0 ^{+0.13}
W + jets	0.95 ± 0.45	0 ^{+0.13}	0.34 ± 0.24	0 ^{+0.13}
Z + jets	1.5 ^{+1.8} _{-1.5}	0 ^{+0.75}	0 ^{+0.75}	0 ^{+0.75}
Total Standard Model	39 ± 9	2.3 ^{+4.4} _{-0.7}	26 ± 6	1.3 ^{+0.9} _{-0.4}
Data	45	4	26	3
$N_{\text{BSM,max}}^{95\%}$	26.0	11.2	16.3	6.0
$\sigma_{\text{BSM,max}}^{95\%} \times \epsilon/\text{fb}$	19.4	8.4	12.2	4.5
p_{SM}	0.30	0.36	0.49	0.16



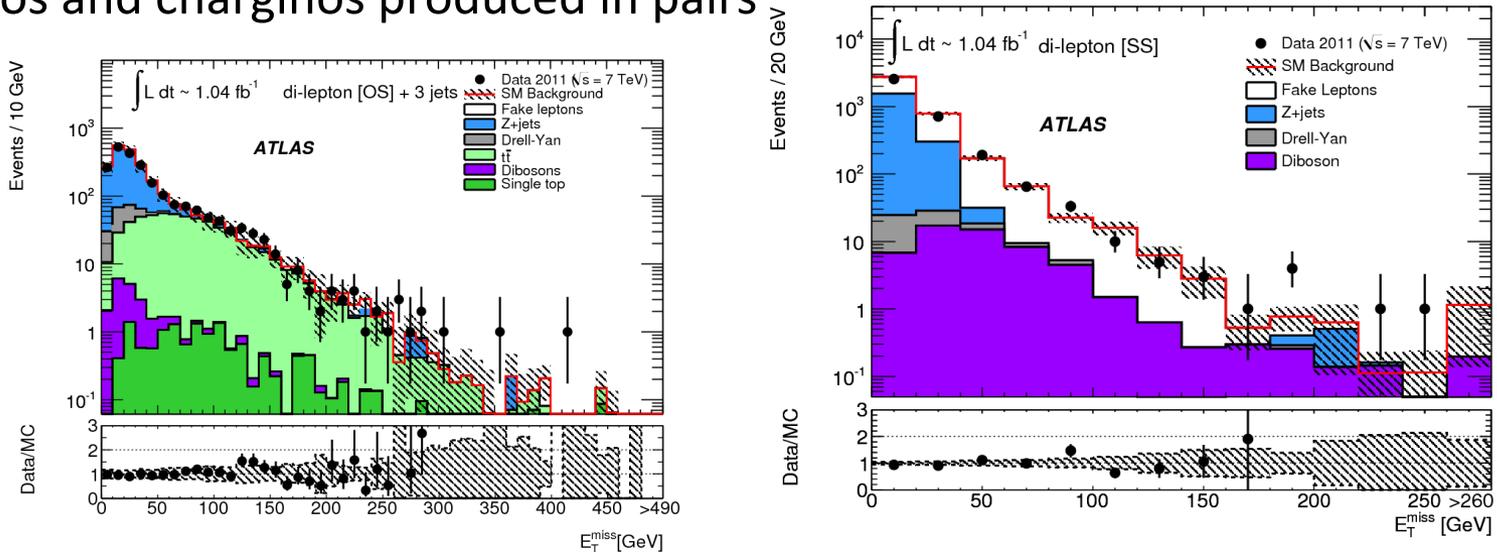
- H_T = scalar sum of transverse momentum of jets with $\eta < 2.8$ and $p_T > 40$ GeV
- In MSUGRA/CMSSM $m_{\text{gluino}} < 520$ GeV, < 680 for $m_{\text{squark}} = 2 * m_{\text{gluino}}$ excluded @ 95% CL



2 leptons (e,μ)

Signal Region	OS-SR1	OS-SR2	OS-SR3	SS-SR1	SS-SR2	FS-SR1	FS-SR2	FS-SR3
E_T^{miss} [GeV]	250	220	100	100	80	80	80	250
Leading jet p_T [GeV]	-	80	100	-	50	-	-	-
Second jet p_T [GeV]	-	40	70	-	50	-	-	-
Third jet p_T [GeV]	-	40	70	-	-	-	-	-
Fourth jet p_T [GeV]	-	-	70	-	-	-	-	-
Number of jets	-	≥ 3	≥ 4	-	≥ 2	-	≥ 2	-
m_{ll} veto [GeV]	-	-	-	-	-	80-100	-	-

- Opposite and same-sign (OS, SS), and same-flavor (OSSF, OF-subtracted) lepton pairs plus missing energy, sensitive to cascade decays of neutralinos and charginos produced in pairs

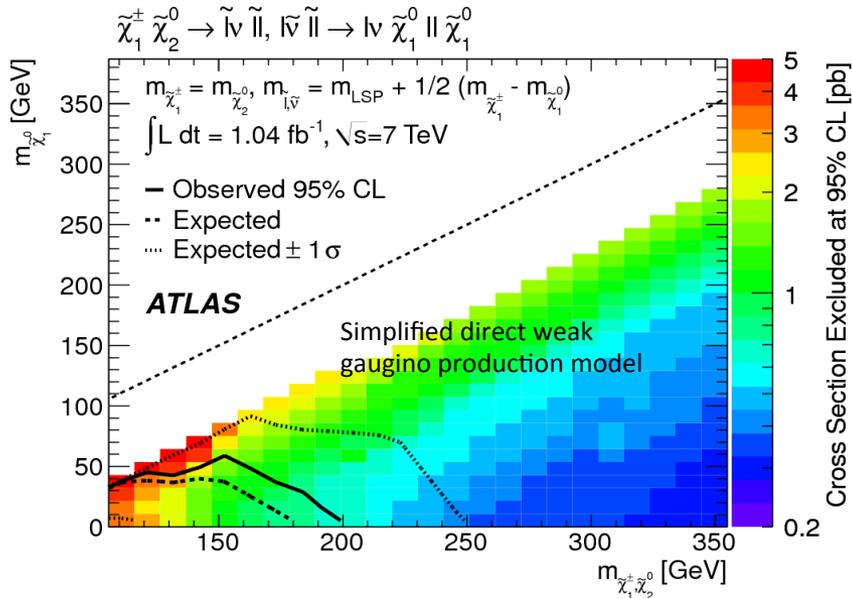


2 leptons (e,μ)

$$S = \frac{N(e^\pm e^\mp)}{\beta(1 - (1 - \tau_e)^2)} + \frac{\beta N(\mu^\pm \mu^\mp)}{(1 - (1 - \tau_\mu)^2)} - \frac{N(e^\pm \mu^\mp)}{1 - (1 - \tau_e)(1 - \tau_\mu)}$$

	$S > S_{obs}$ (%)	Limit \bar{S}_s (95% CL)
FS-SR1	39	94
FS-SR2	6	158
FS-SR3	79	4.5

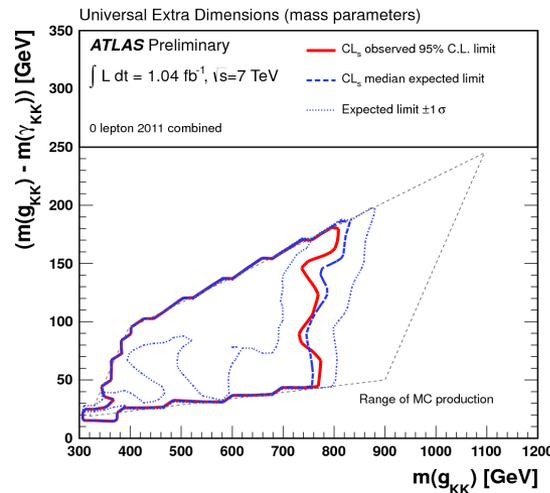
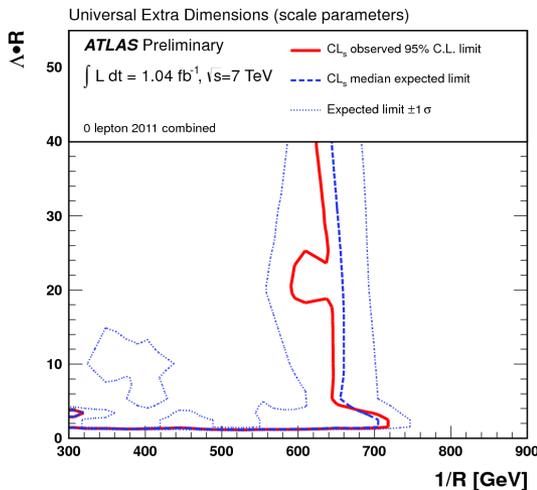
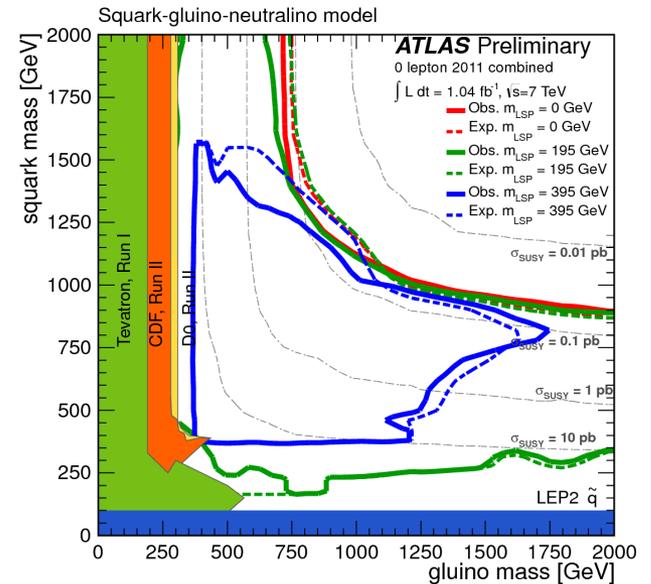
	Background	Obs.	95% CL
OS-SR1	15.5 ± 4.0	13	9.9 fb
OS-SR2	13.0 ± 4.0	17	14.4 fb
OS-SR3	5.7 ± 3.6	2	6.4 fb
SS-SR1	32.6 ± 7.9	25	14.8 fb
SS-SR2	24.9 ± 5.9	28	17.7 fb



- Model-independent limits
 - OS $E_{\text{tmiss}} > 250 \text{ GeV}$: $\sigma_{\text{eff}} = \sigma_X A_X \epsilon > 9.5 \text{ fb}$ excluded @ 95% CL
 - SS $E_{\text{tmiss}} > 100 \text{ GeV}$: $\sigma_{\text{eff}} > 10.2 \text{ fb}$
 - SF $E_{\text{tmiss}} > 250 \text{ GeV}$: exclude $N > 4.5$ events
- Simplified direct weak gaugino production model limits extended

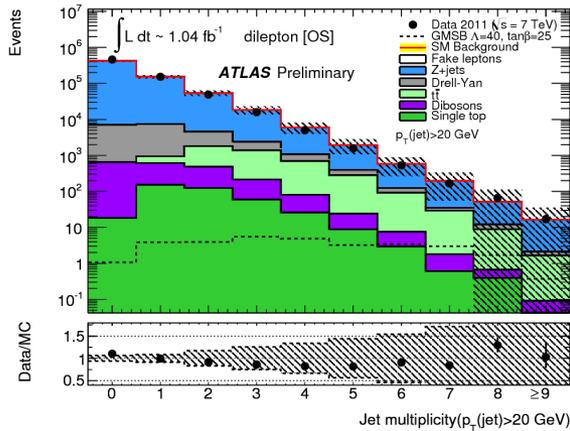
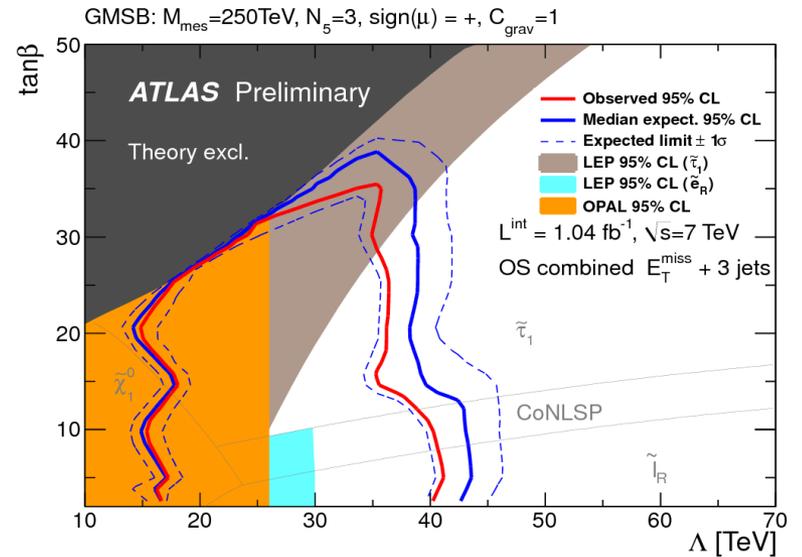
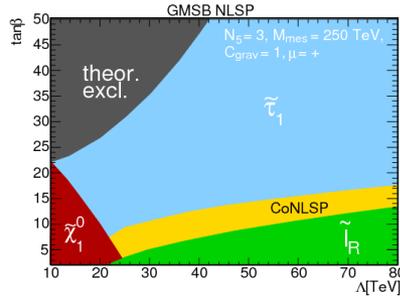
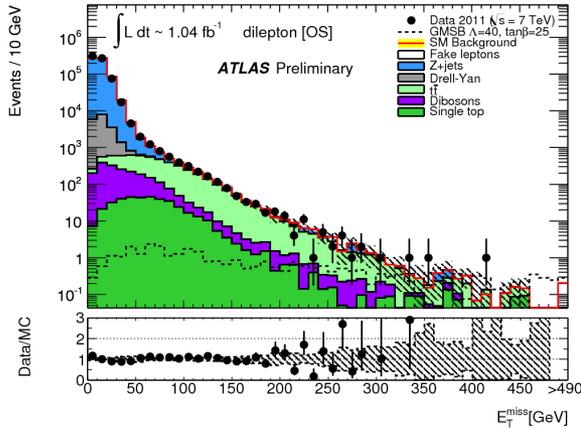
Jets+Emmiss additional interpretation

- Simplified SUSY model: Specific production of gluino, neutralino, squarks
- Everything else moved to higher scale.
- In Minimal Universal Extra Dimension (MUED) SM particles have heavier partners with same spin



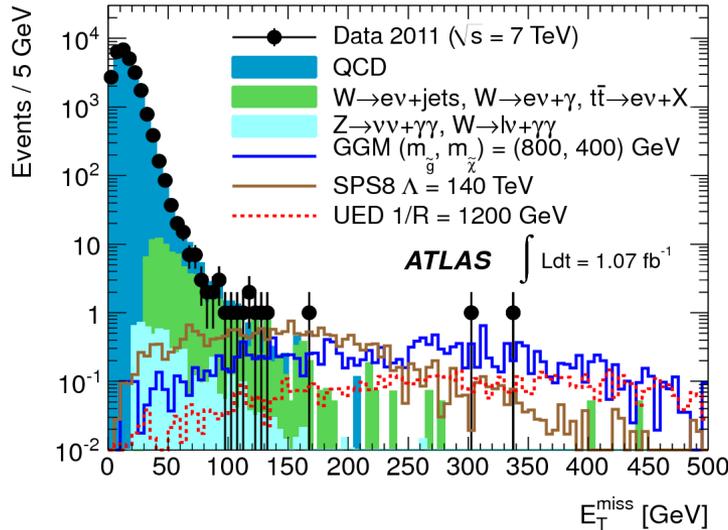
- 1025 GeV limit on degenerate gluino-squark masses with $m_{\text{LSP}} < 400 \text{ GeV}$
- Single universal extra dimension 730 GeV limit on mass of 1st KK gluon

2 leptons GMSB interpretation

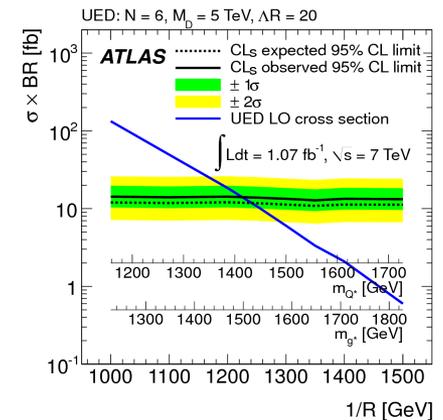
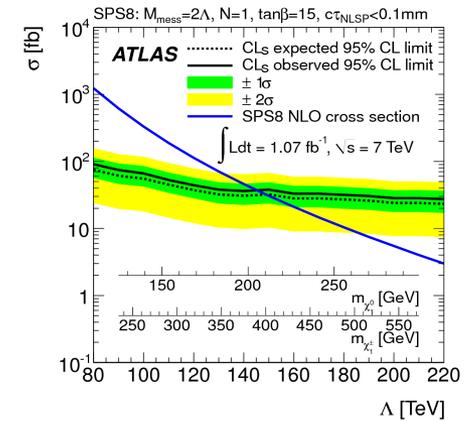
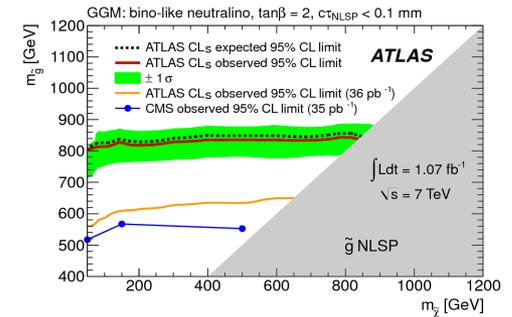


- LSP is \sim massless gravitino
- SU(5) messenger fields transmit SUSY breaking
- Λ is SUSY-breaking scale: up to 40 TeV probed

SUSY search with di-photons and missing transverse momentum



- 5 events $E_T^{\text{miss}} > 125$ GeV
 $b = 4.1 \pm 0.6(\text{stat.}) \pm 1.6(\text{syst.})$
- Model-independent limit on new physics: 7 events
- Also interpreted in terms of 3 models
 - Generalized gauge-mediated SUSY-breaking
 - SPS8 specific gauge-mediated SUSY-breaking
 - 1 Universal Extra Dimension



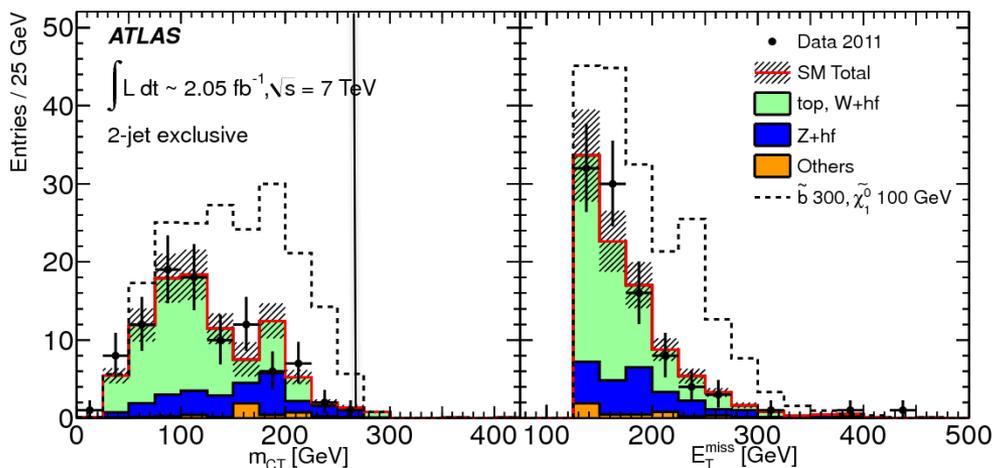
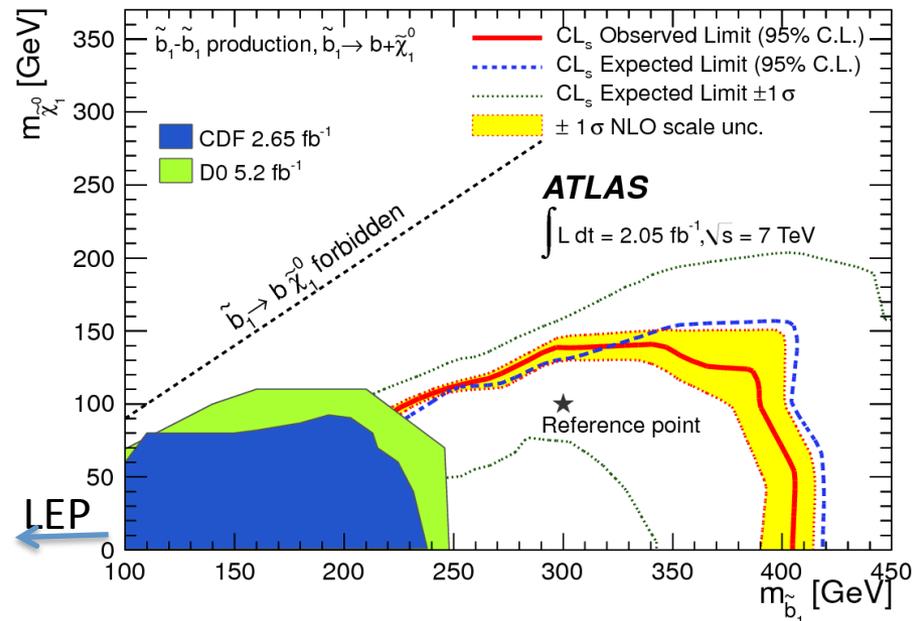
Direct sbottom (pair) search

- Assuming pair-prod. and 100% $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
- co-transverse mass m_{CT} of identical visible decay products 1,2 of identical heavy particles...

$$m_{CT}^2 = (E_{T1} + E_{T2})^2 - (\vec{p}_{T1} - \vec{p}_{T2})^2$$

- ...should have an endpoint at

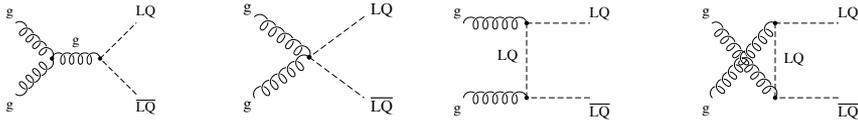
$$(m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2) / m(\tilde{b}_1)$$



- For 100% BR $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$ and neutralino masses less than 60 GeV, sbottom masses less than 390 GeV excluded at 95% CL

Recent “exotics” results

First generation scalar leptoquarks



- New (e.g. GUT) gauge boson with both lepton and baryon numbers
 - Under ~ 1 TeV produced mostly by pairs via gg-fusion
 - couple to single (here 1st) generation to avoid FCNC, B, I-violation

- $e^+e^-jj, evjj$ events
- Likelihood products

- $eejj$ channel:

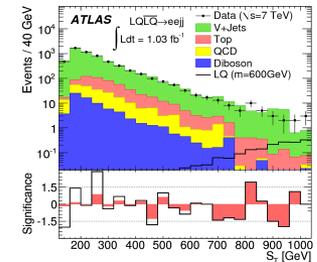
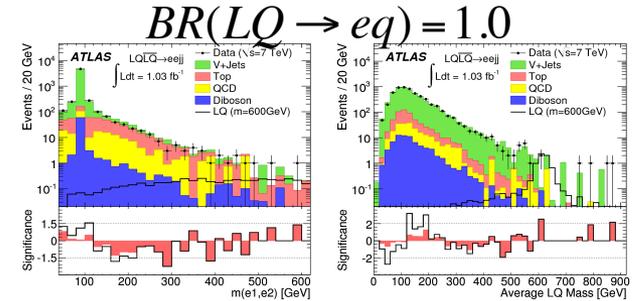
$$m_{ee}, \bar{m}_{ej}$$

$$S_T = E_T^{e1} + E_T^{e2} + p_T^{j1} + p_T^{j2}$$

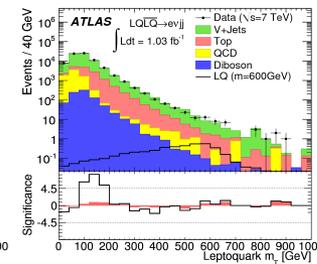
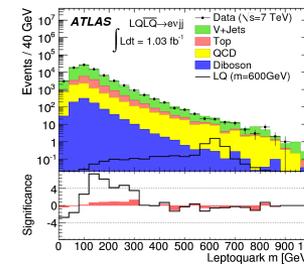
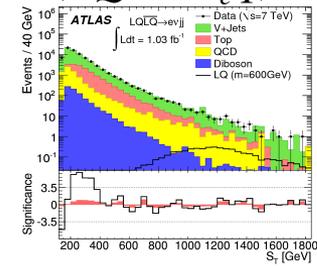
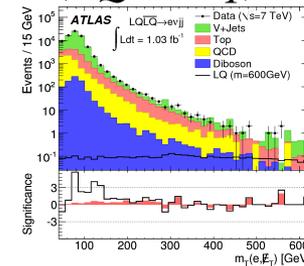
- $evjj$ channel:

$$\min[m(e, j), m_T(e, E_T^{miss}), m_T(j, E_T^{miss})]$$

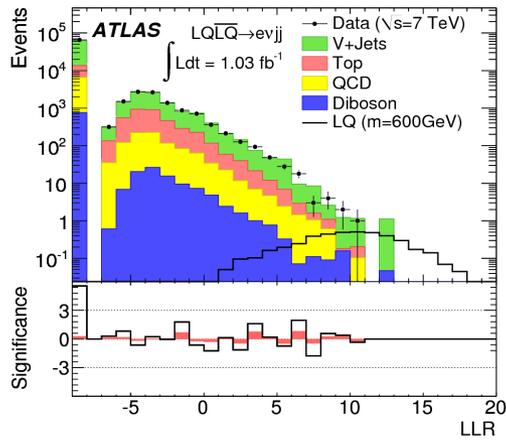
$$S_T = E_T^e + E_T^{miss} + p_T^{j1} + p_T^{j2}$$



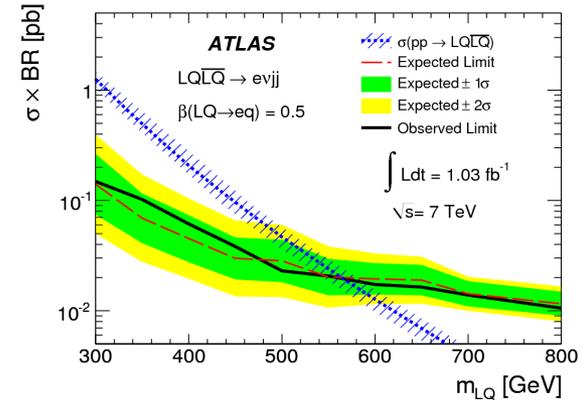
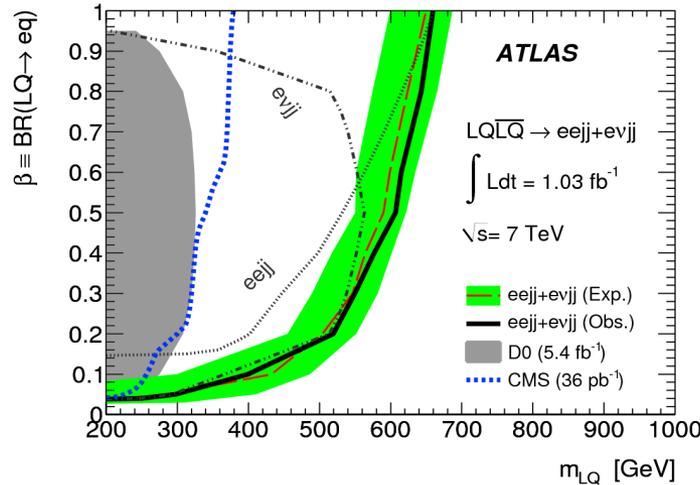
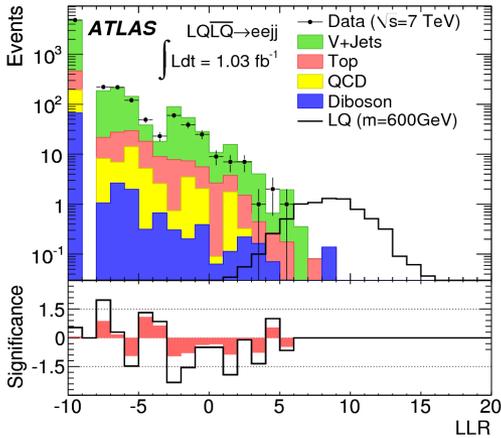
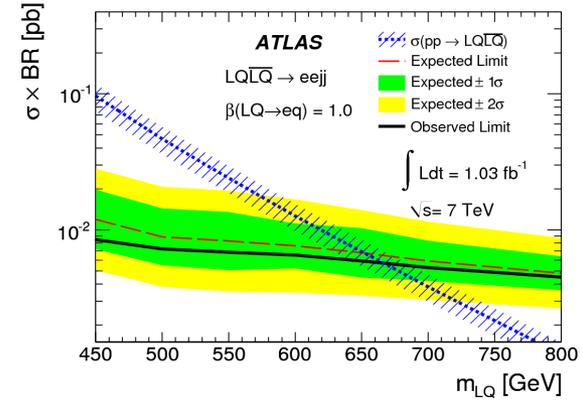
$$BR(LQ \rightarrow eq) = BR(LQ \rightarrow \nu_e q) = 0.5$$



First generation scalar leptoquarks



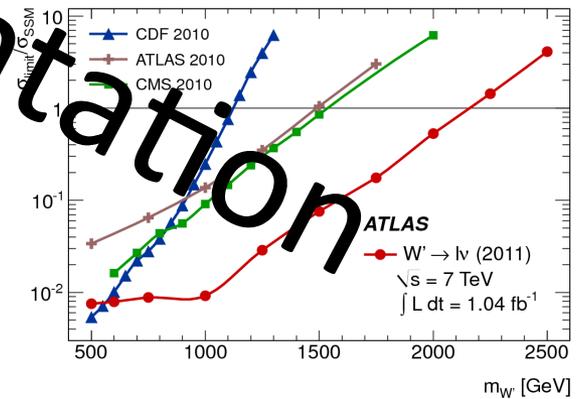
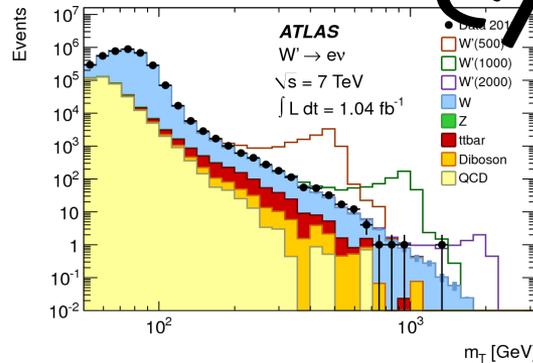
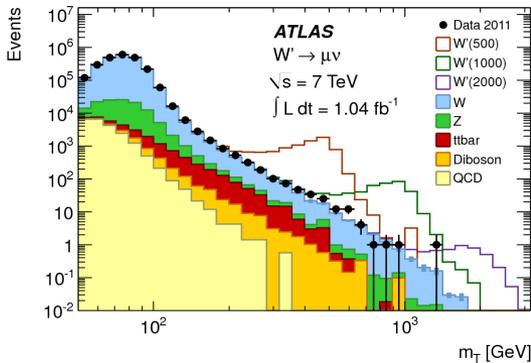
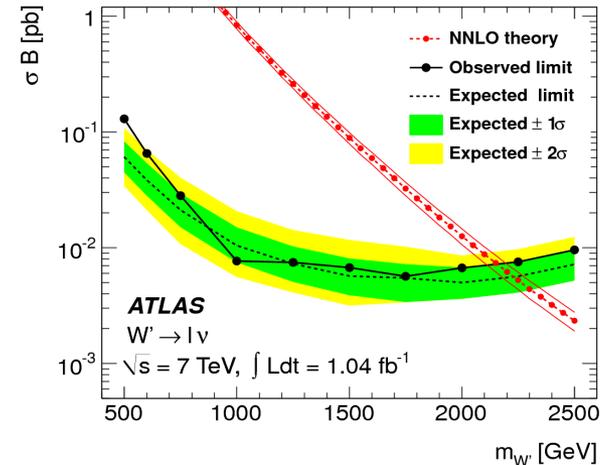
Source	$eejj$ Channel		$evjj$ Channel	
	400 GeV	600 GeV	400 GeV	600 GeV
W+jets	—	—	1500 ± 670	670 ± 210
Z+jets	98 ± 53	26 ± 14	45 ± 41	18 ± 19
$t\bar{t}$	15 ± 9	4.6 ± 2.2	430 ± 180	150 ± 38
Single t	1.4 ± 0.9	0.7 ± 0.4	53 ± 19	23 ± 4
Dibosons	1.5 ± 0.8	0.7 ± 0.3	25 ± 11	11 ± 2
MJ	9.2 ± 4.5	2.3 ± 1.5	170 ± 35	75 ± 15
Total	120 ± 55	34 ± 14	2200 ± 690	950 ± 220
Data	82	22	2207	900
LQ	120 ± 8	7.5 ± 0.5	69 ± 4	4.5 ± 0.2



$m_{LQ} > 660$ (607) GeV for $BR(LQ \rightarrow eq) = 1.0$ (0.5)

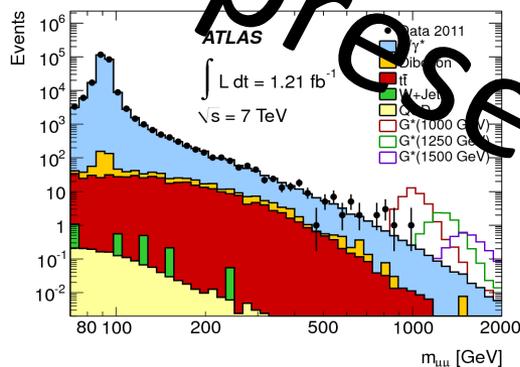
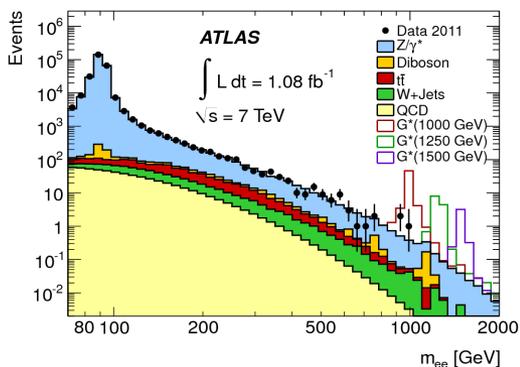
Heavy gauge boson->lepton+neutrino

- High p_T lepton, missing T-momentum
- Counting experiment, sliding m_T window
- $m_T^2 = 2p_T E_T^{miss} (1 - \cos \Delta\phi_{lv})$
- For $m_{W'}=1500$, 2 events each in e, μ observed, 1.8, 1.6 background estimated
- Baseline SSM $m_{W'} > 2.15$ TeV



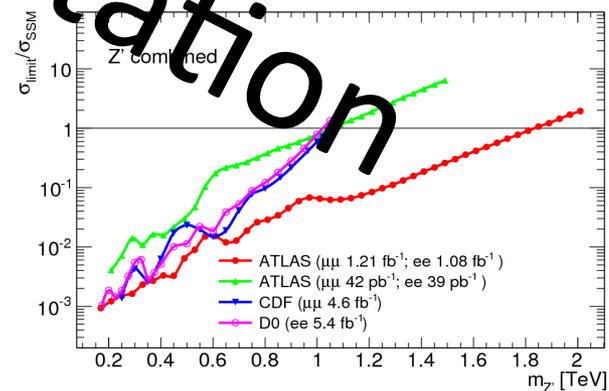
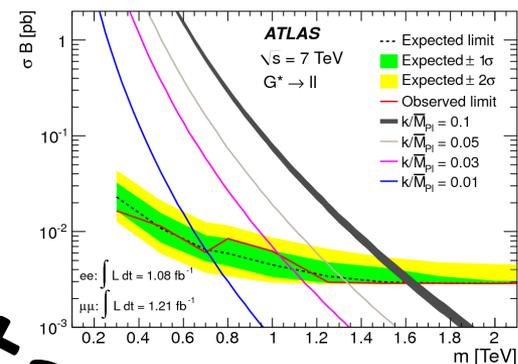
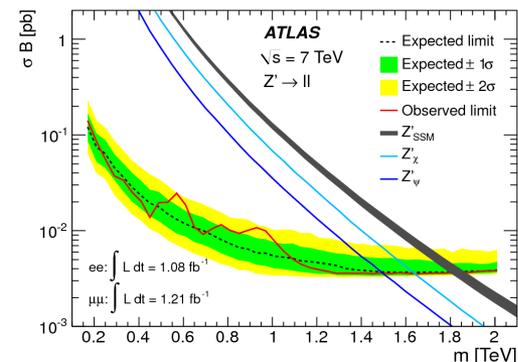
High-mass dilepton resonances

- SSM Z' , technipions, Randall-Sundrum graviton resonances
- For $m_{\text{res}} = 0.8-3$ TeV 3, 5 events observed in e^+e^- , $\mu^+\mu^-$ channels with estimated $bg \approx 34, 2.1$ events ($p_0=54, 24\%$)

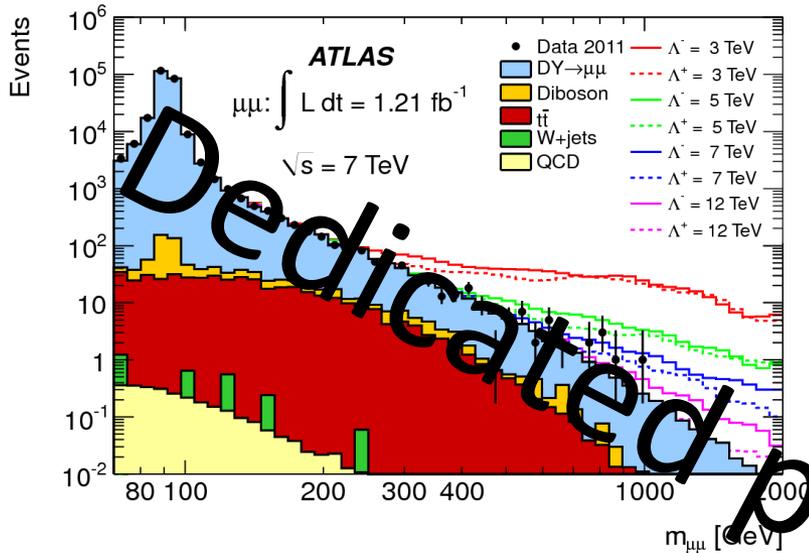


Model	e^+e^-	$\mu^+\mu^-$	l^+l^-
Z'_{SSM}	1.70 (1.70)	1.61 (1.61)	1.83 (1.83)
G^*	1.51 (1.50)	1.45 (1.44)	1.63 (1.63)

95% CL limits (TeV)

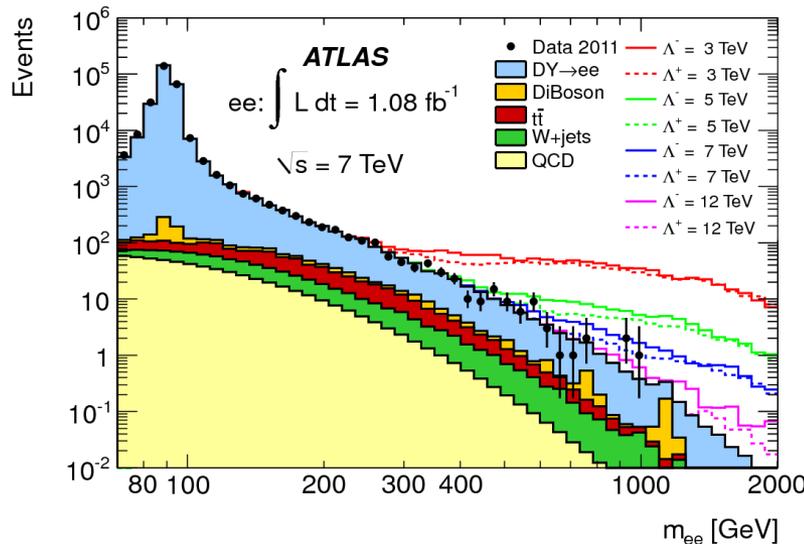


Contact interactions w/ dilepton events



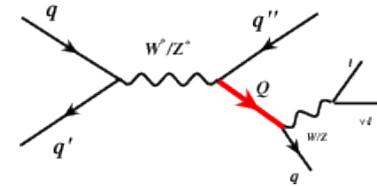
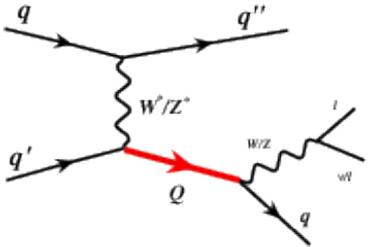
$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta_{LL} \frac{F_I(m_{\ell\ell})}{\Lambda^2} + \frac{F_C(m_{\ell\ell})}{\Lambda^4}$$

- Interference:
 - $\eta_{LL} = -1$: Constructive
 - $\eta_{LL} = +1$: Destructive
- For $m_{\ell\ell} > 300$ GeV and $\Lambda > 9$ TeV $F_C/F_I \sim 2/3$

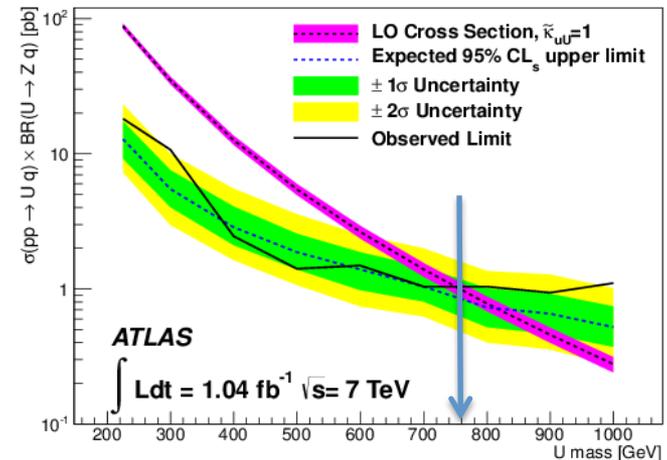


Channel	Prior	Expected limit (TeV)		Observed limit (TeV)	
		Const. r.	Destr.	Const. r.	Destr.
e^+e^-	$1/\Lambda^2$	9.6	8.7	10.1	9.4
	$1/\Lambda^4$	8.9	8.6	9.2	8.6
$\mu^+\mu^-$	$1/\Lambda^2$	8.9	8.6	8.0	7.0
	$1/\Lambda^4$	8.3	7.9	7.6	6.7
Comb.	$1/\Lambda^2$	10.4	10.1	10.2	8.8
	$1/\Lambda^4$	9.6	9.4	9.4	8.4

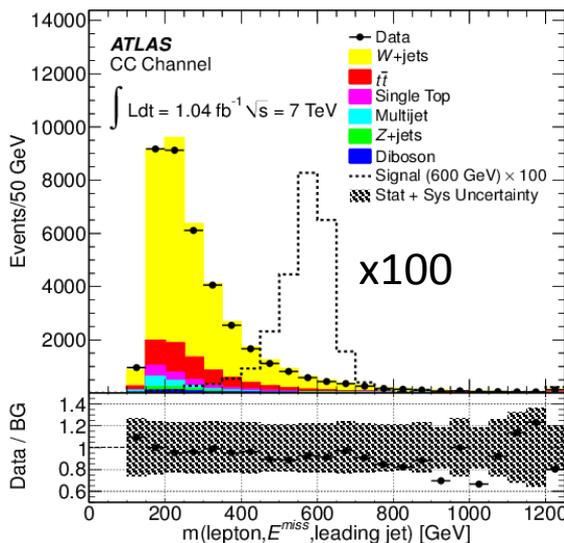
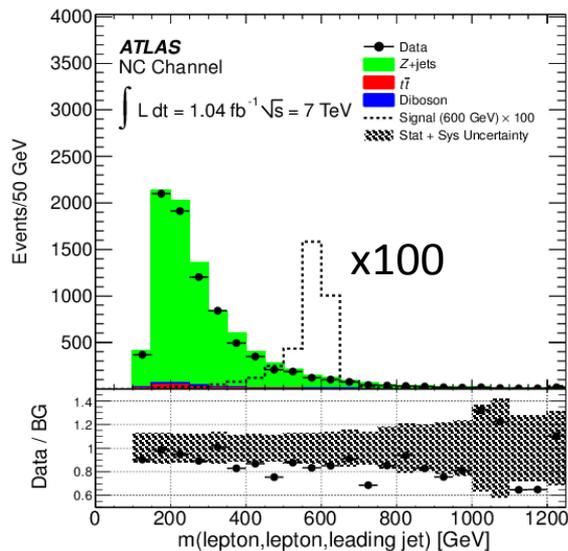
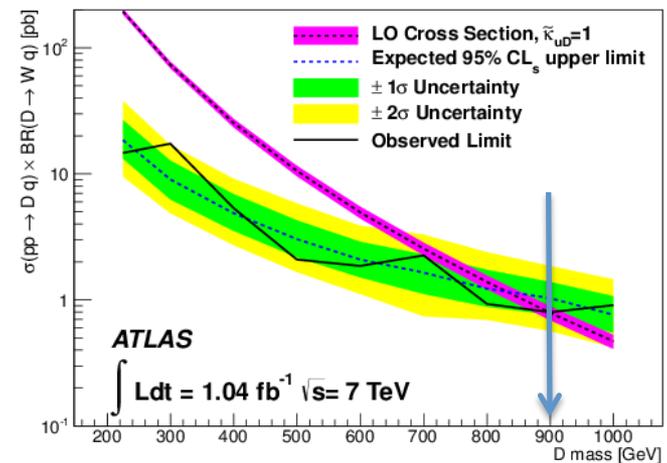
Heavy vector-like quarks



- VLQ's predicted in various scenarios of GUTS, Dyn. EWSB, Extra Dim.
- Benchmark model: $\tilde{K}_{uD}^2 = \tilde{K}_{uU}^2 = 1$



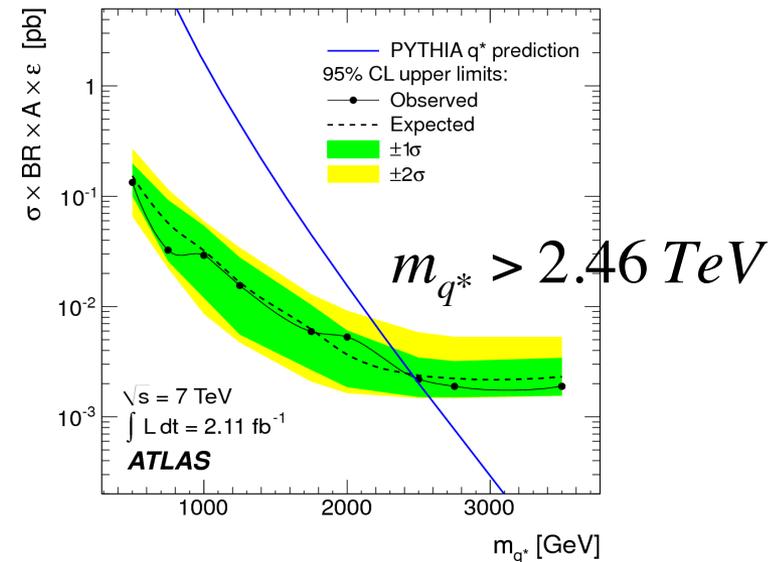
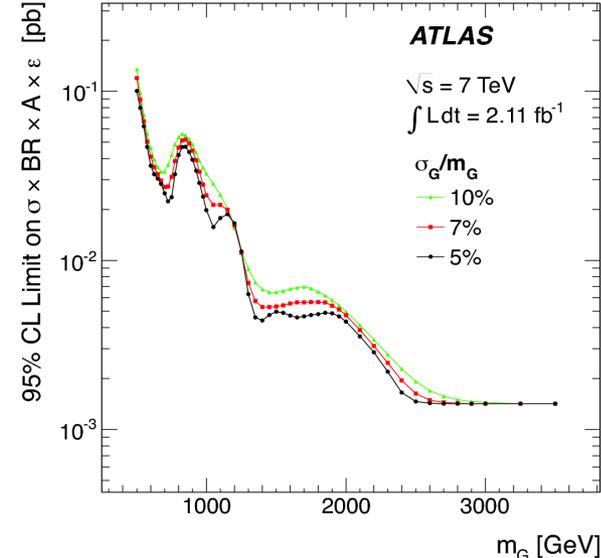
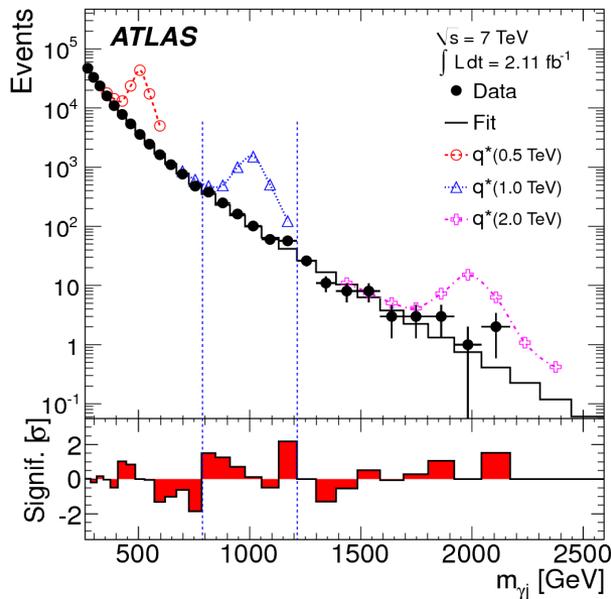
Neutral current limit : 760 GeV
 Charged current limit: 900 GeV



Photon-jet resonances

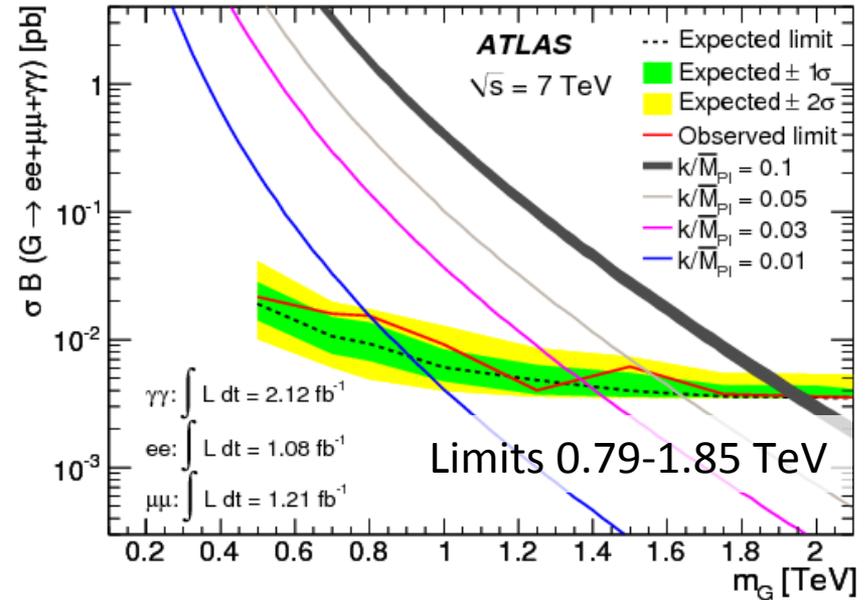
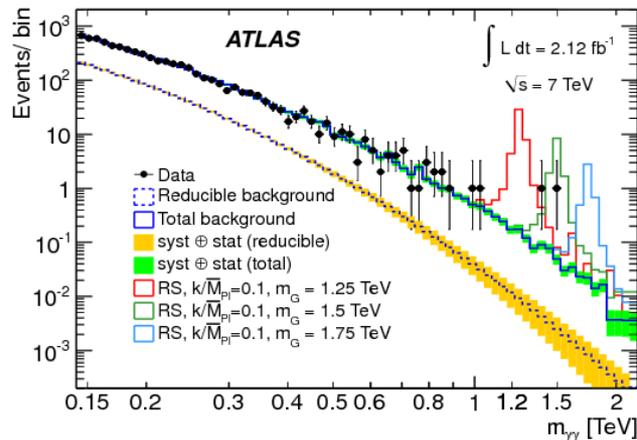
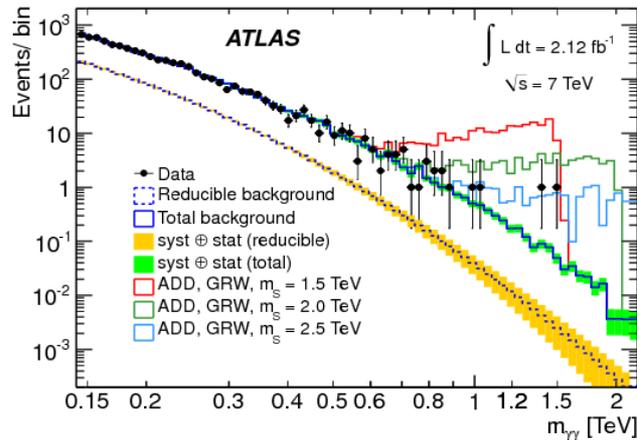
- Generic Gaussian-shaped resonances
- Benchmark excited quark model with compositeness scale = m_{q^*}

$$u^* \rightarrow ug, u\gamma$$
- $\sigma_m/m \sim 3-4\%$ for $m=0.6-2$ TeV



Heavy di-photon resonances

- KK-excitations of gravity in extra dimensions
- ADD ultraviolet cutoff M_S
- RS mass of lightest excitation m_G and dimensionless coupling to SM fields k/M_{PL}



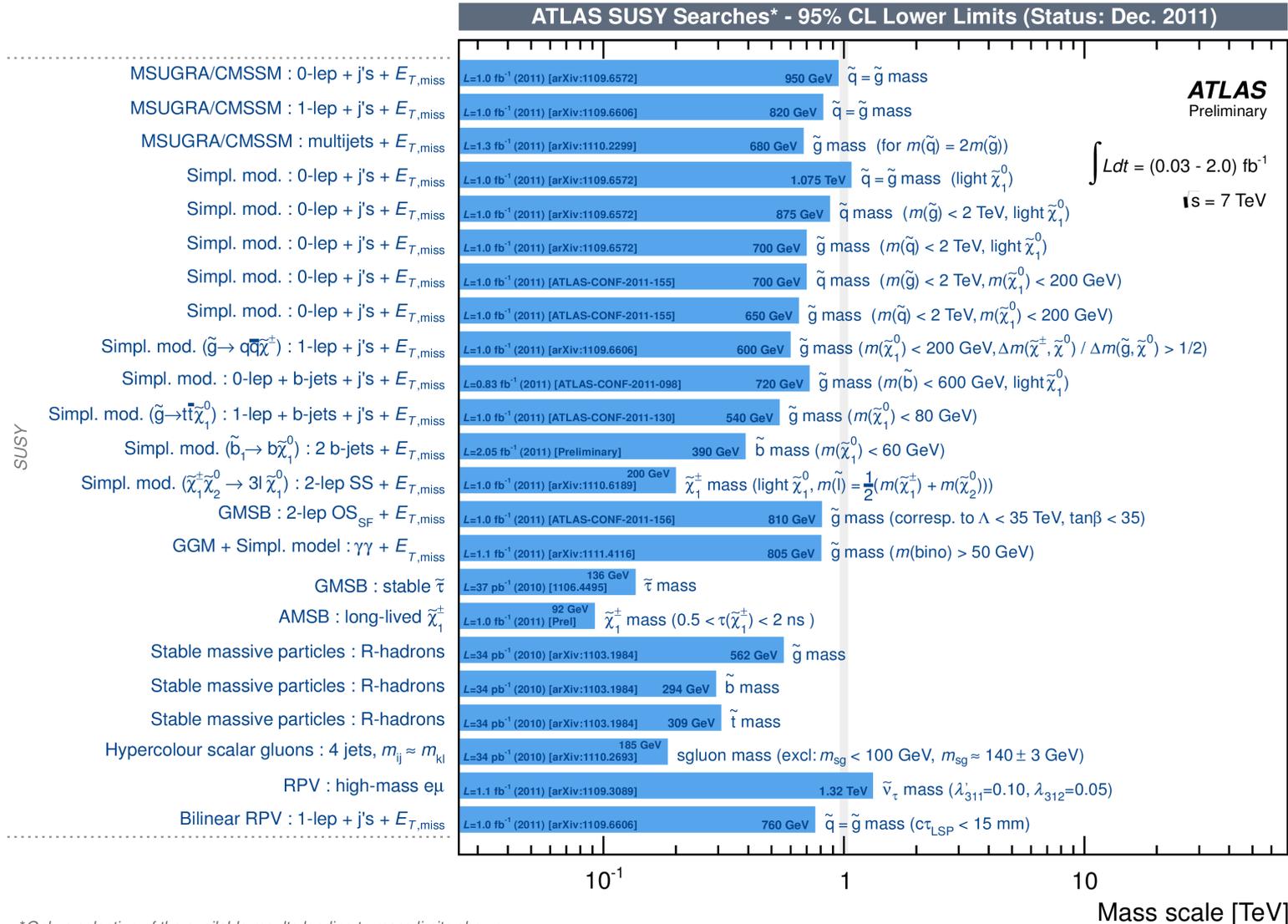
k-factor Value	GRW	Hewett		HLZ				
		Pos	Neg	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
1	2.73	2.44	2.16	3.25	2.73	2.47	2.30	2.17
1.70	2.97	2.66	2.27	3.53	2.97	2.69	2.50	2.36

Limits on M_S (TeV)

Conclusions

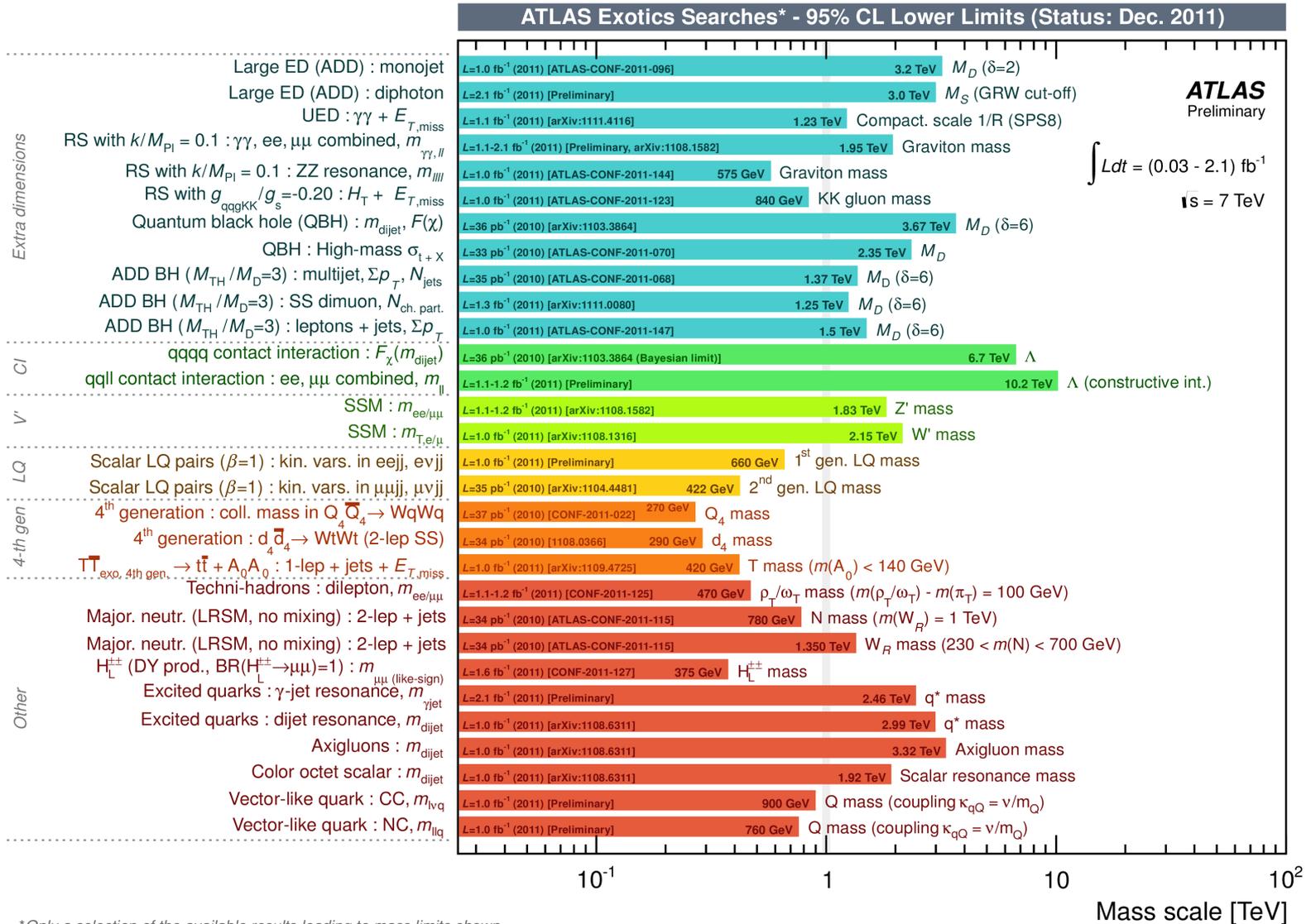
- Typically less than half of 2011 data analysed thus far
- First observation of $\chi_b(3P)$ with $m=10.539 \pm 0.004$ (stat) ± 0.008 (syst)
- Production of D^* , Λ in jets need better understanding
- Production of $W,Z,t\bar{t},VV,V$ +associated consistent with SM so far
- Huge progress in the TeV regime for model-specific, simplified model, model-independent searches for BSM physics...no signs of deviations yet

Summary of SUSY searches (partial!)



*Only a selection of the available results leading to mass limits shown

Summary of Exotics Searches (partial!)



*Only a selection of the available results leading to mass limits shown