



Heavy resonance searches in ATLAS

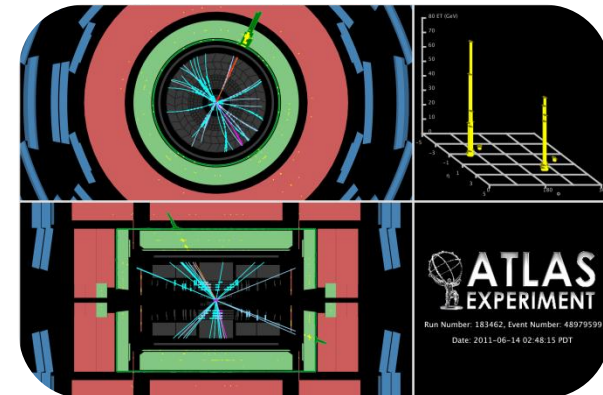
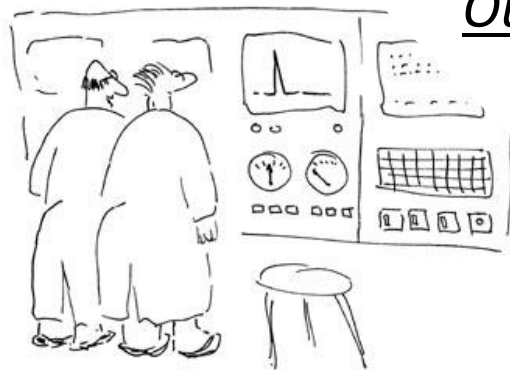
Emmanuel Laisné

LPSC Grenoble / Université Joseph Fourier

On behalf of the ATLAS collaboration

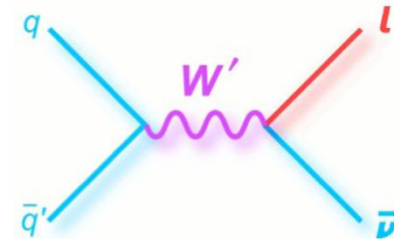
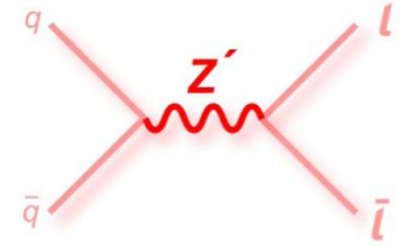
Outline

- Motivations
- Lepton reconstruction
- Heavy resonance searches
 - Z'
 - W'
- Perspectives

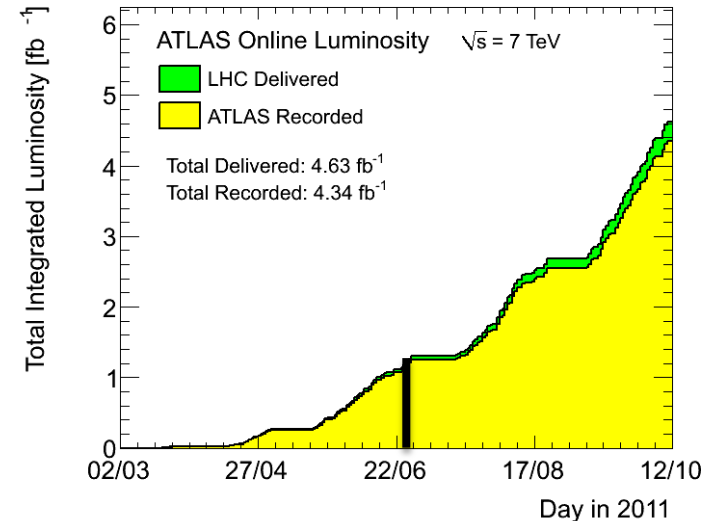


High mass resonances

- High mass resonances predicted in SM extensions ...
 - GUT -> New gauge bosons Z' , W'
 - Extra dimensions -> Randall-Sundrum Graviton : G^*
 - Technicolor -> Low Scale Technicolor : ρ_T/ω_T
 - Benchmark models -> Z'_{SSM} & W'_{SSM}



- ... imply ll or $l\nu$ signatures
analysed $\sim 1 \text{ fb}^{-1}$
 - **Dileptonic** final states
 - **Lepton + MET** final states



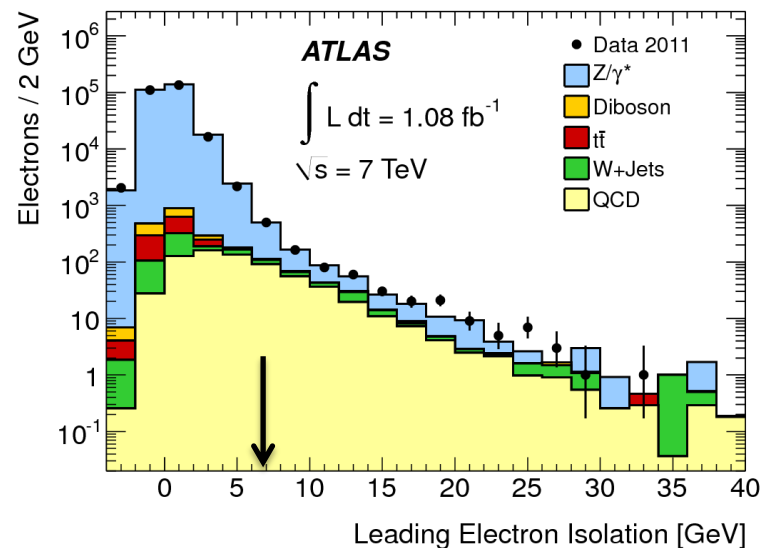
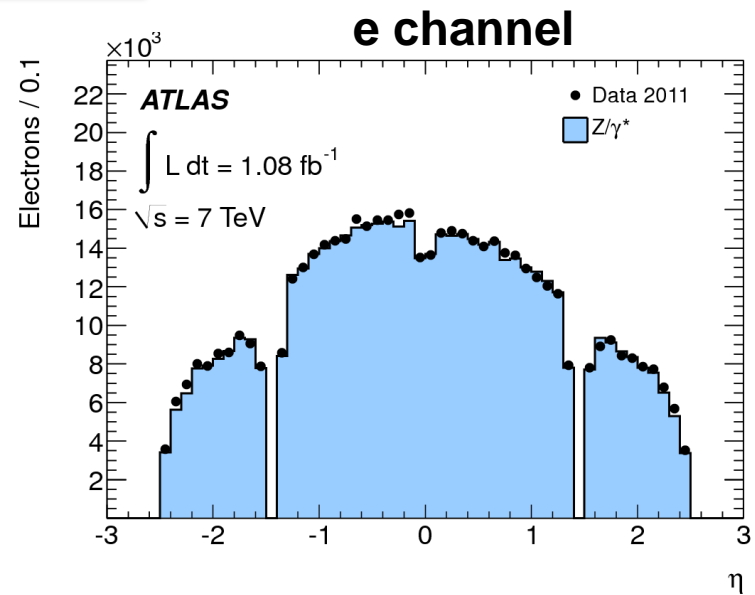
➤ Main challenge : Reconstruct and identify **very** high p_T leptons

- Reconstruction
 - Isolated energy deposit in EM calorimeter matched to an Inner Detector track
 - $|\eta| < 2.47$
 - exclusion of barrel-endcap transition region


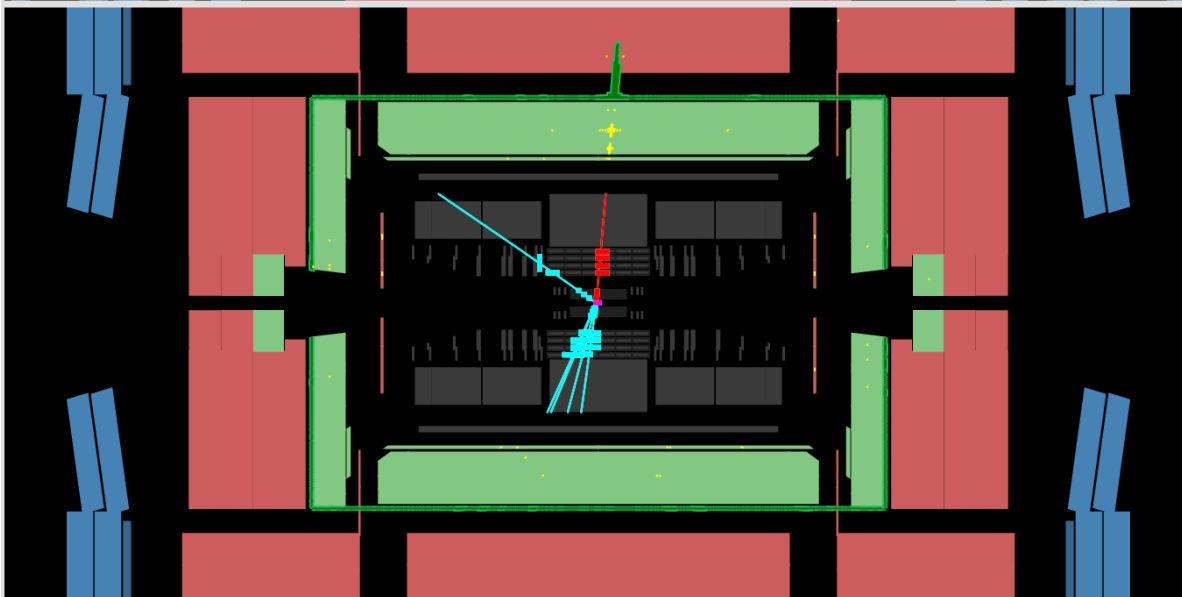
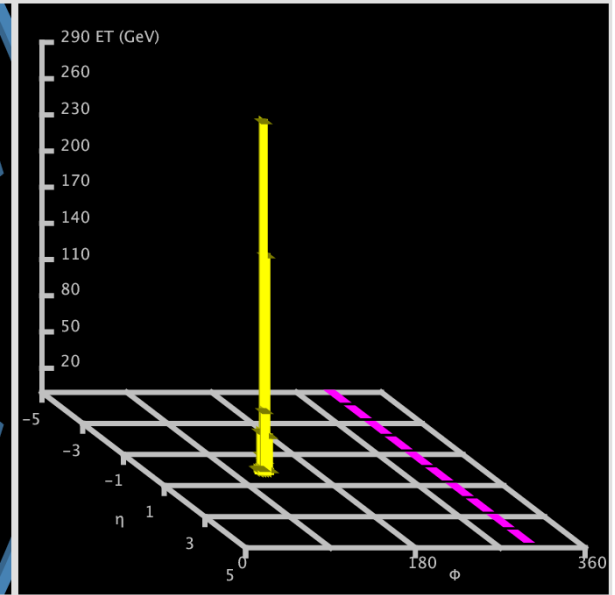
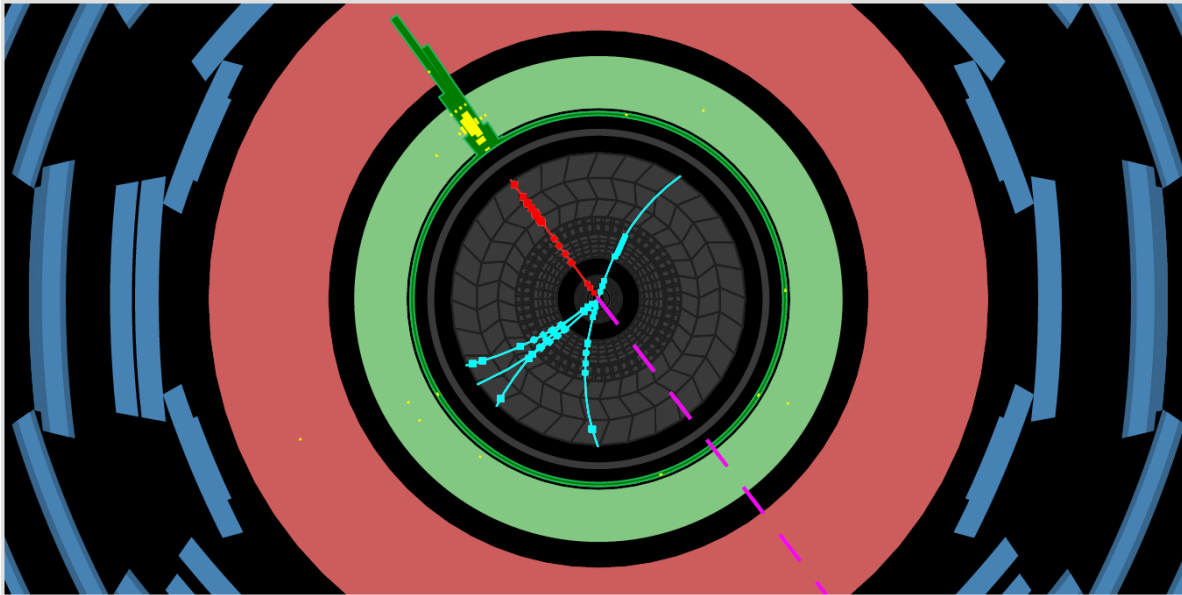
Energy resolution :

$$\sigma(E)/E = 1.1\% \text{ (barrel)}$$
$$1.8\% \text{ (endcap)}$$

- Identification criteria
 - Shower shape, leakage into the hadronic calorimeter, track quality
 - $E_T > 25$ GeV
 - Hit in 1st pixel layer
 - Calorimeter isolation
 - Highest p_T electron only (ee)



Highest mass candidate (ev searches)



ATLAS
EXPERIMENT

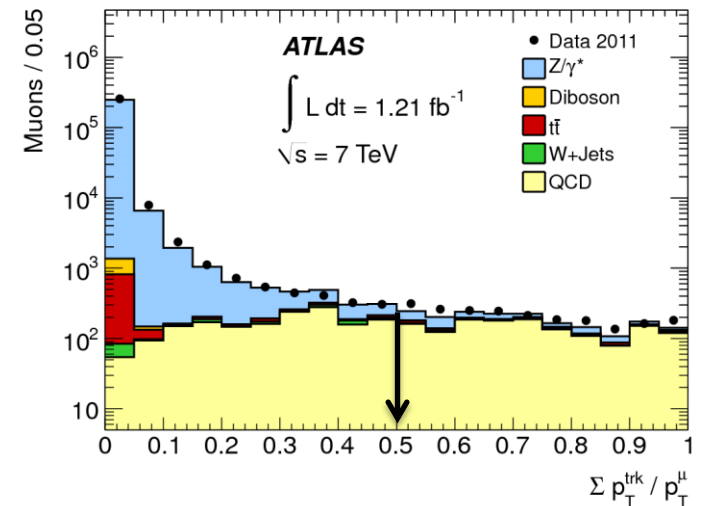
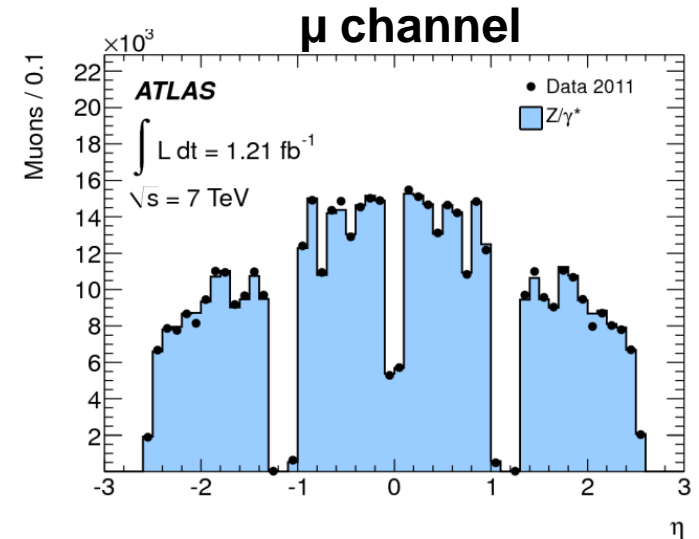
Run Number: 183462, Event Number: 139735410
Date: 2011-06-14 20:10:35 CEST

Muons reconstruction

- Reconstruction
 - Combined track from Muon Spectrometer and Inner Detector
 - η coverage
 - Removed misaligned chambers
 - No barrel-endcap chamber overlapp
 - $|\eta| < 2.0$ ($\mu\nu$ only)

Average momentum resolution
20% @ 1 TeV

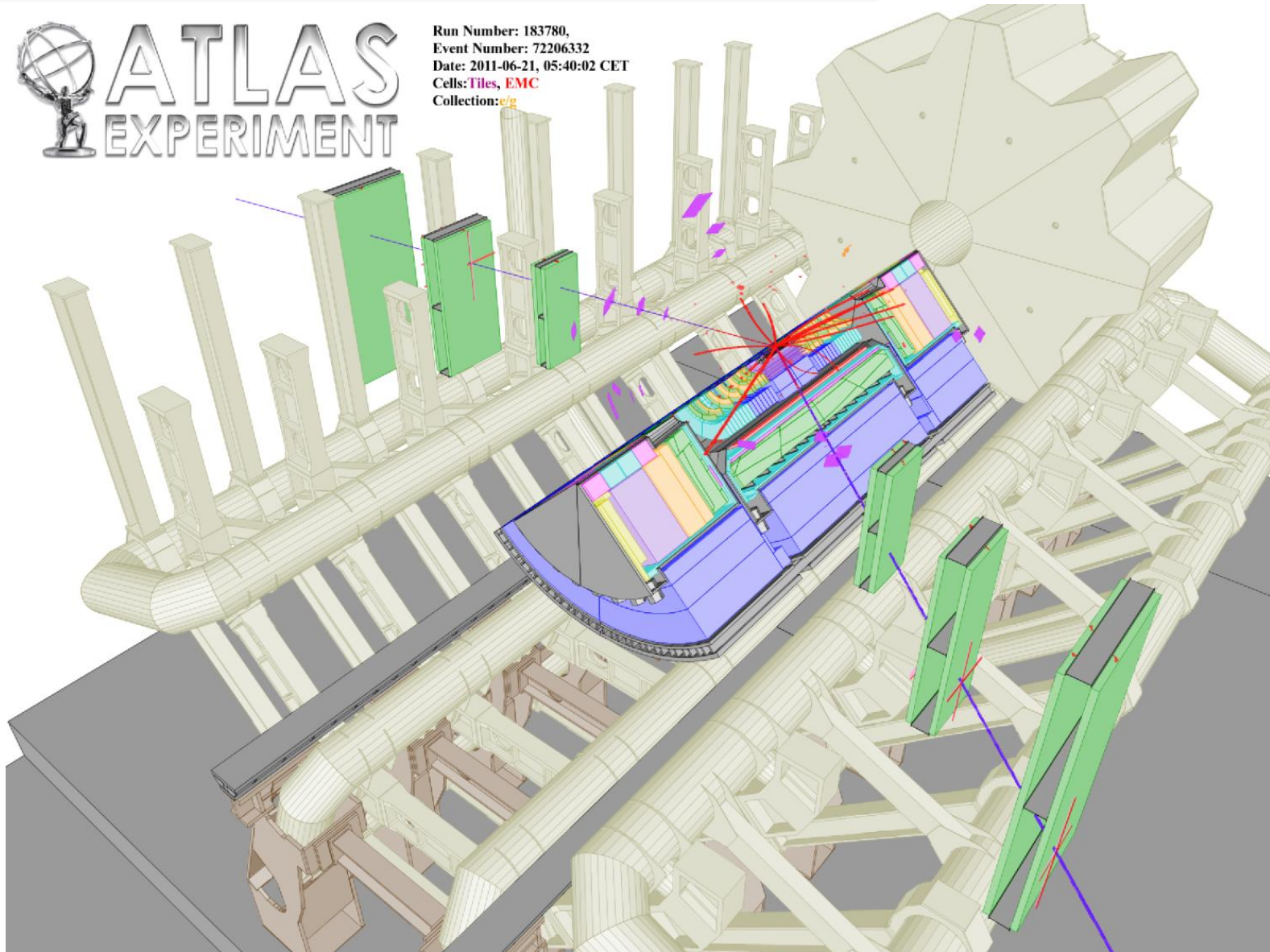
- Selection criteria
 - Hit requirements in ID and MS
 - Criteria on impact parameter (d_0, z_0) w.r.t PV
 - Track isolation



Highest mass candidate ($\mu\mu$ searches)



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



$\ell\ell$ analysis strategy

- Main observable :

$$m_{\ell\ell} = \sqrt{E_{\ell\ell}^2 - |p_{\ell\ell}|^2}$$

- Event selection

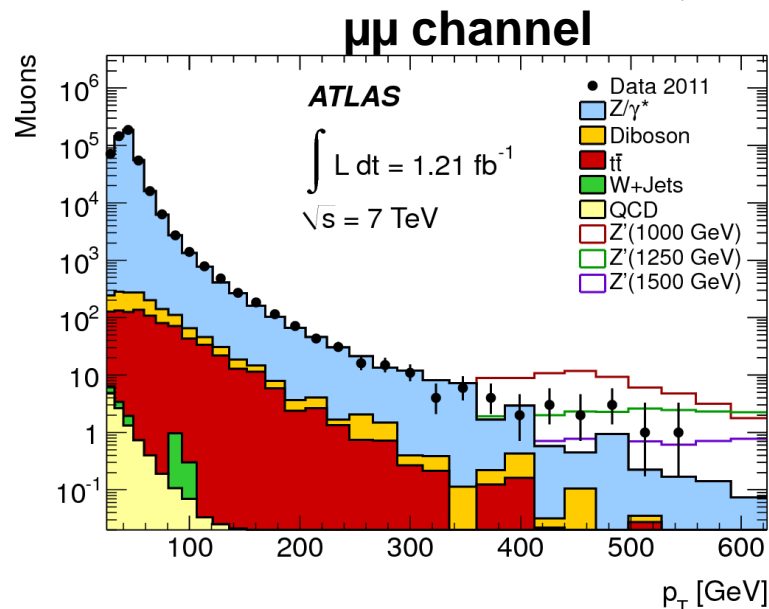
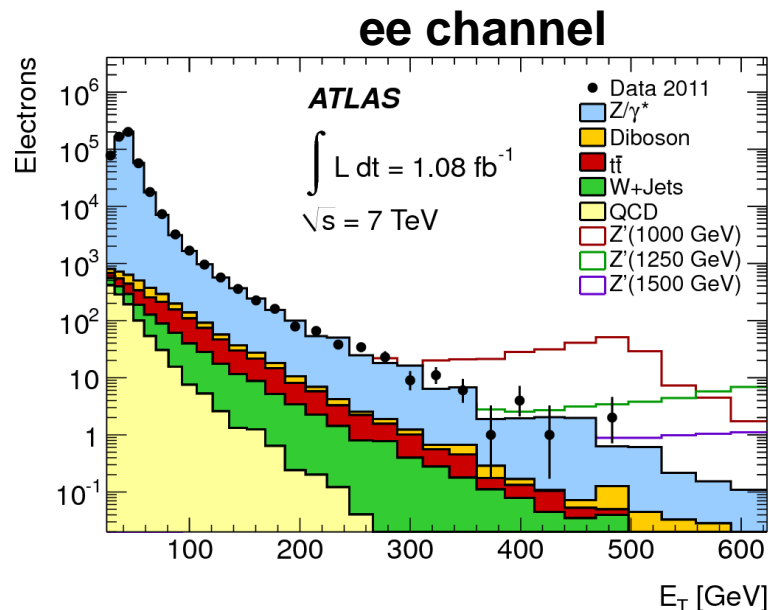
- Single lepton trigger
- Primary vertex with >2 tracks
- **At least 2 leptons**
- *Opposite charge (only for muons)*

- Backgrounds taken from simulation

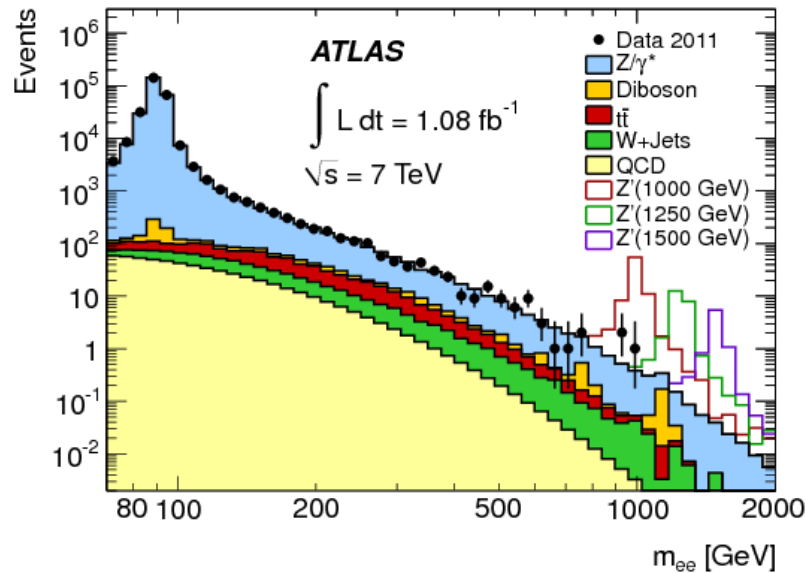
- Z/γ^*
- W+jets
- Diboson : WW, ZZ, WZ
- tt

- Data driven background

- QCD
- *Cosmics (only for muons) -> negligible*



ee channel



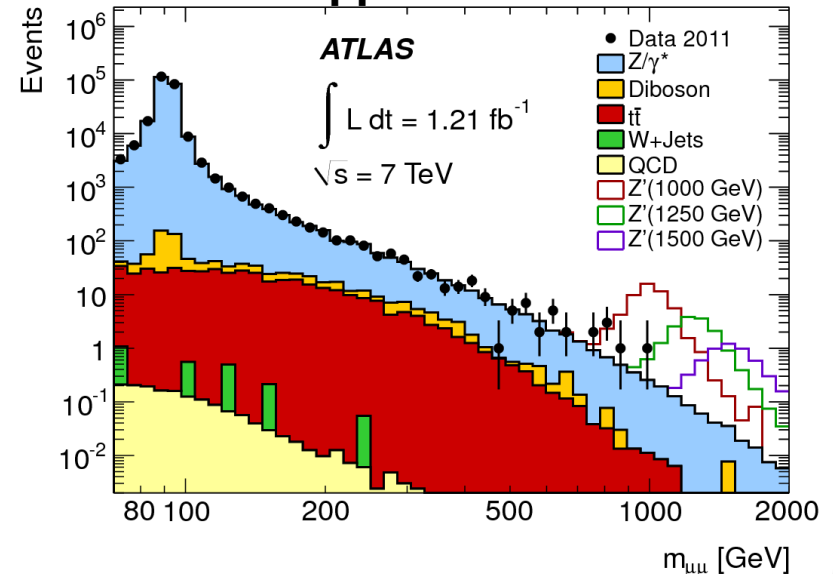
- Normalise background to data in Z peak region 70-110 GeV
 - Cancels out mass independent systematics
 - *Remaining systematics* :

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%

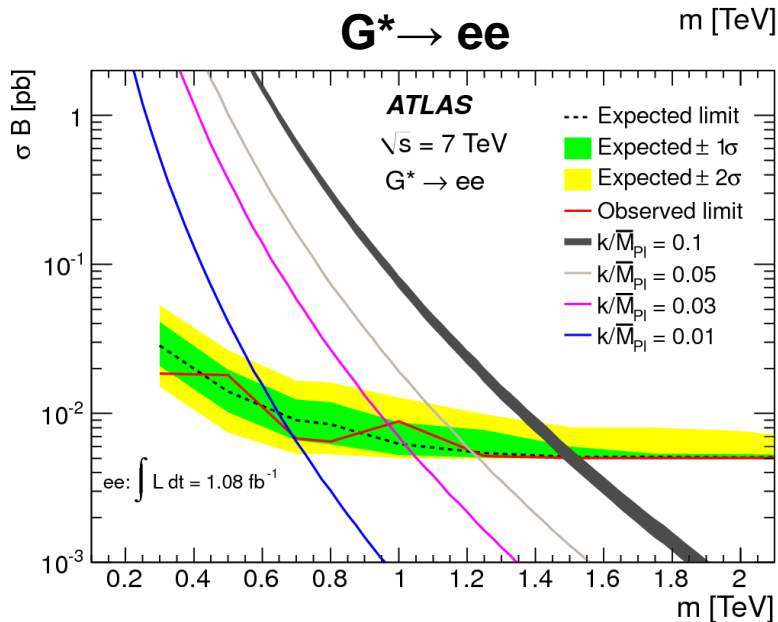
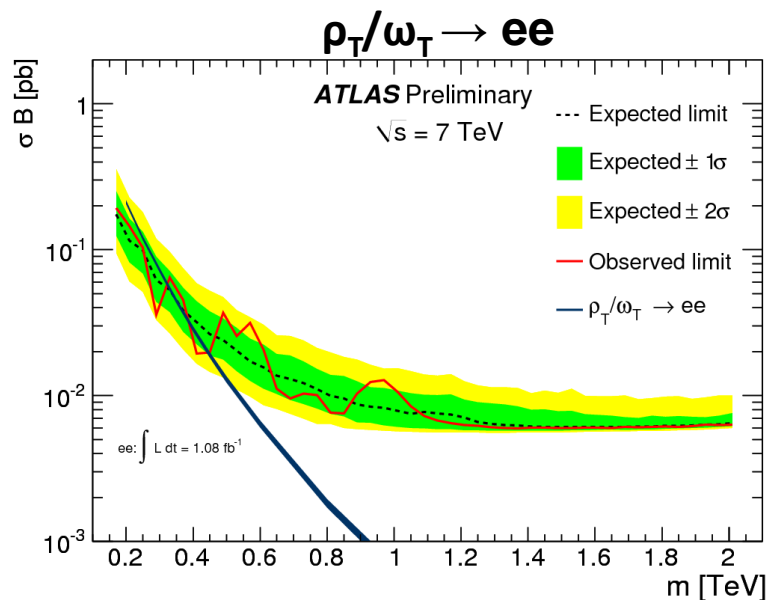
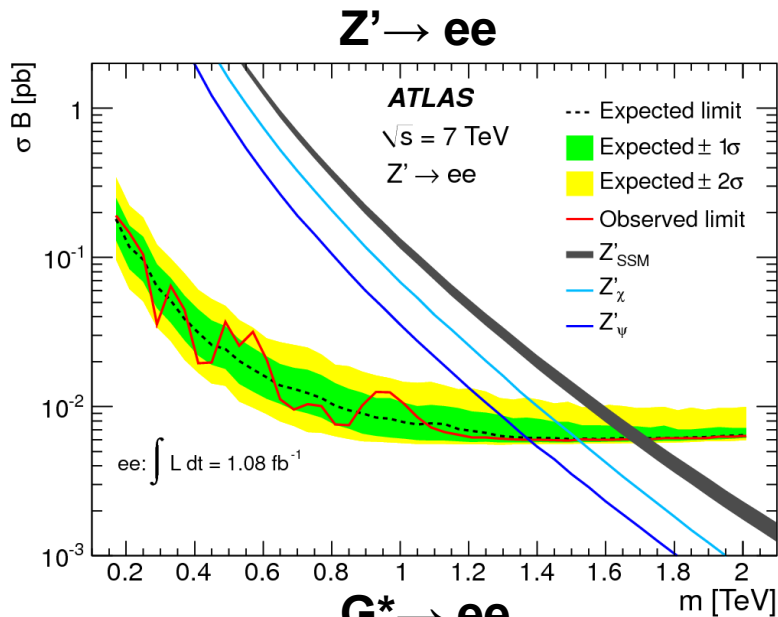
- Discovery statistics (*Bayesian*)
 - 2D maximum likelihood fit for $M(Z')$ and $N(Z')$
 - p-value : 54% (ee) 24% ($\mu\mu$)
- No significant excess
 - 95% CL limits on $N(Z')$
 - Converted into 95% CL limits on $\sigma \cdot B(Z')$

Z' could be replaced by G^* or ρ_T/ω_T all along the slide

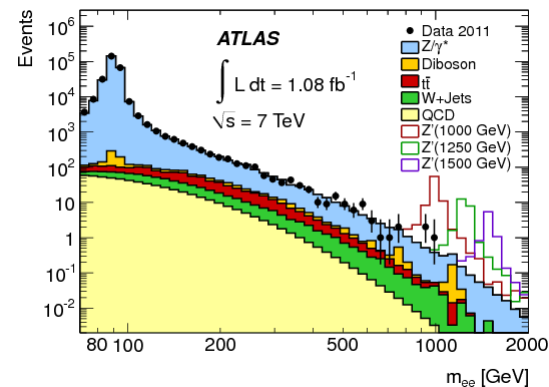
$\mu\mu$ channel



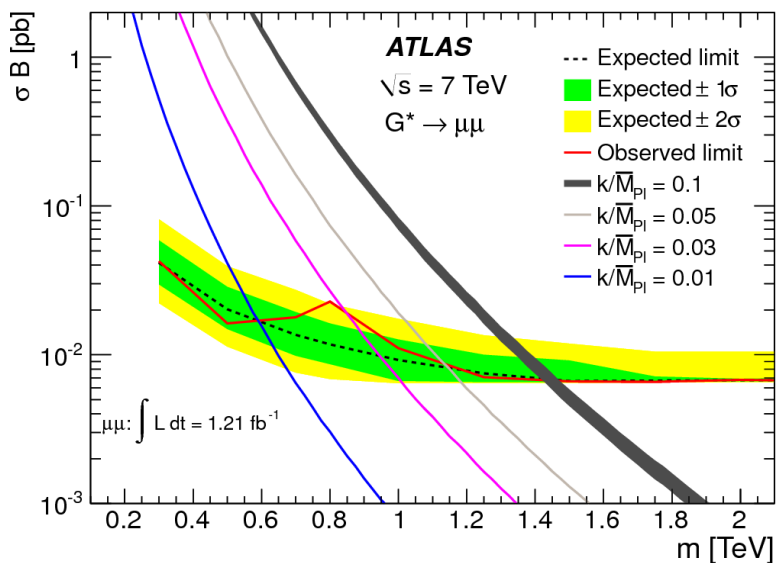
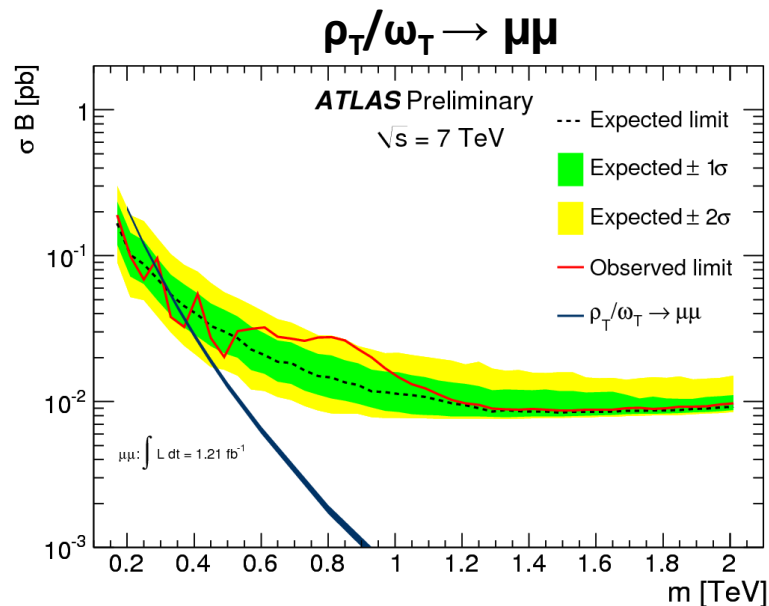
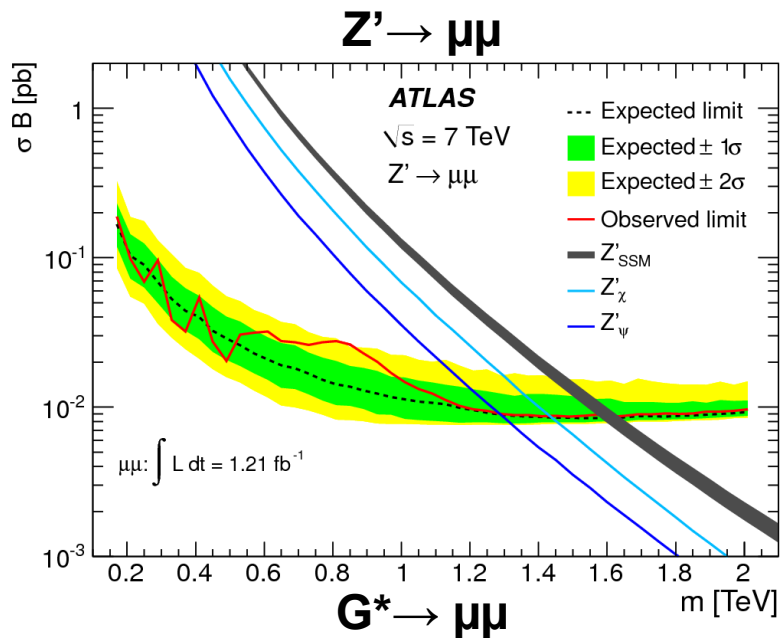
σ_B 95% CL limits - ee channel



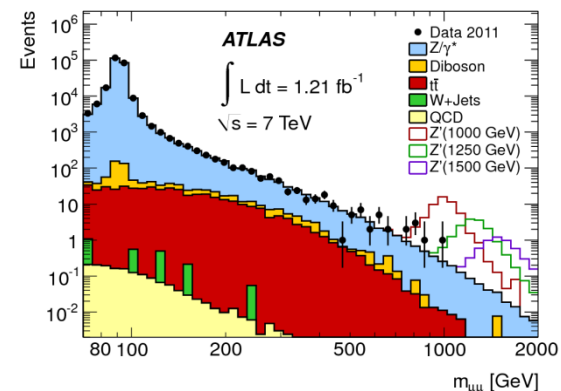
- Limits on Z' like resonances
 - Z'_{SSM} & E_6 models Z'
 - LSTC ρ_T/ω_T
 - G*

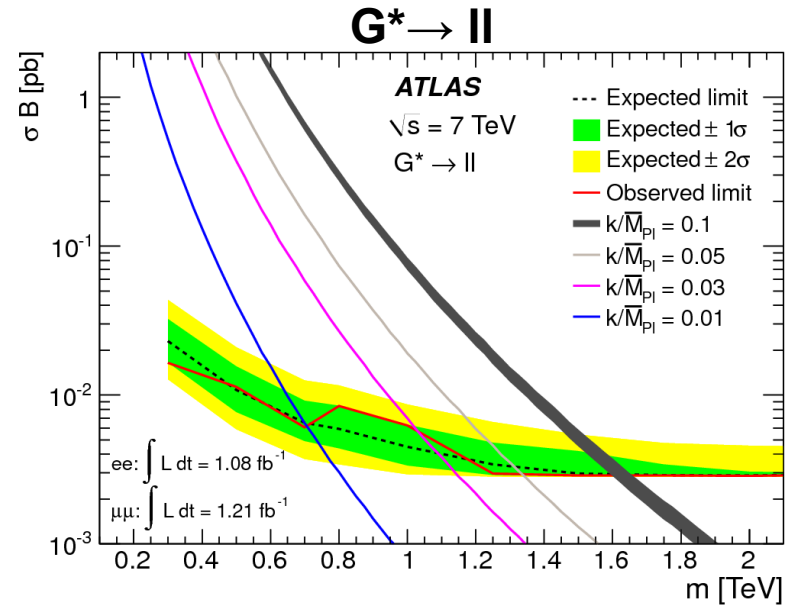
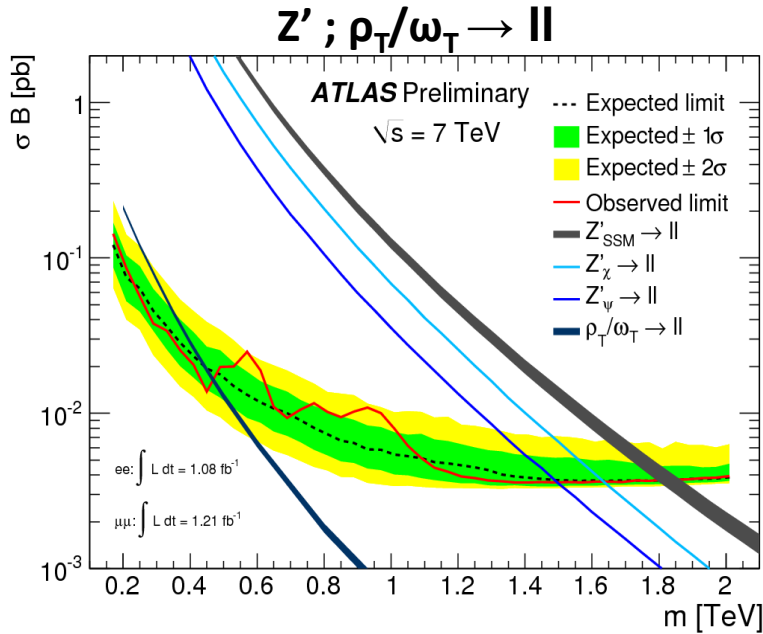


σ_B 95% CL limits - $\mu\mu$ channel



- Limits on Z' like resonances
 - Z'_{SSM} & E_6 models Z'
 - LSTC ρ_T/ω_T
 - G^*





- $M_{Z'(SSM)} > 1.83 \text{ TeV}$ (1.82 TeV exp.)

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

Tevatron (CDF $\mu\mu$) : 1.071 TeV

LEP indirect searches : 1.787 TeV

- $M_{\rho_T/\omega_T} > 470 \text{ GeV}$ (442 GeV exp.)
with $m(\rho_T/\omega_T) - m(\pi_T) = 100 \text{ GeV}$ (LSTC)

- $M_{G^*(k/M_{PI} = 0.1)} > 1.63 \text{ TeV}$ (1.61 TeV exp.)

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

Tevatron : 1.058 TeV

$\ell\nu$ analysis strategy

- Main observable :

$$m_T = \sqrt{2p_T E_T^{\text{miss}} (1 - \cos \varphi_{\ell\nu})}$$

- Event selection

- Single lepton trigger
- Primary vertex with >2 tracks
- **Exactly one lepton**
- **Missing $E_T > 25$ GeV**
- **Missing $E_T > 0.6 * E_T$ (only for electrons)**

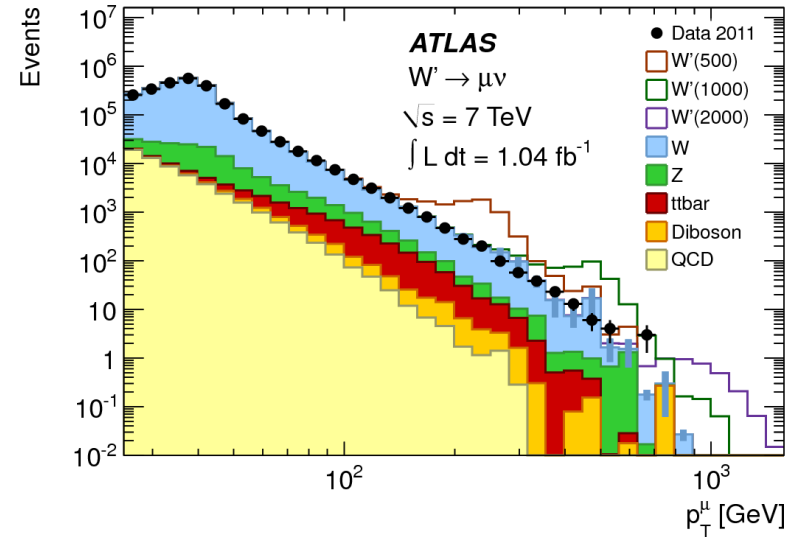
- Backgrounds taken from *full simulation*

- $Z/\gamma^*, W$
- Diboson : WW, ZZ, WZ
- tt

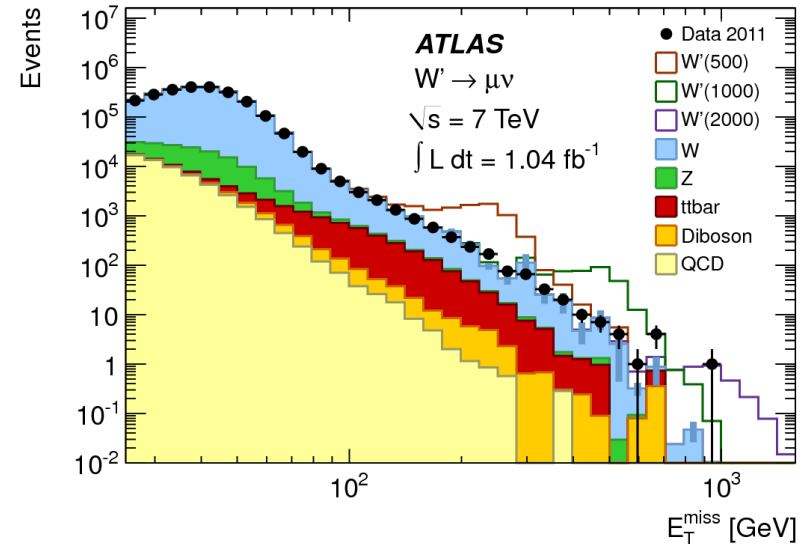
- Data driven background

- QCD

$\mu\nu$ channel

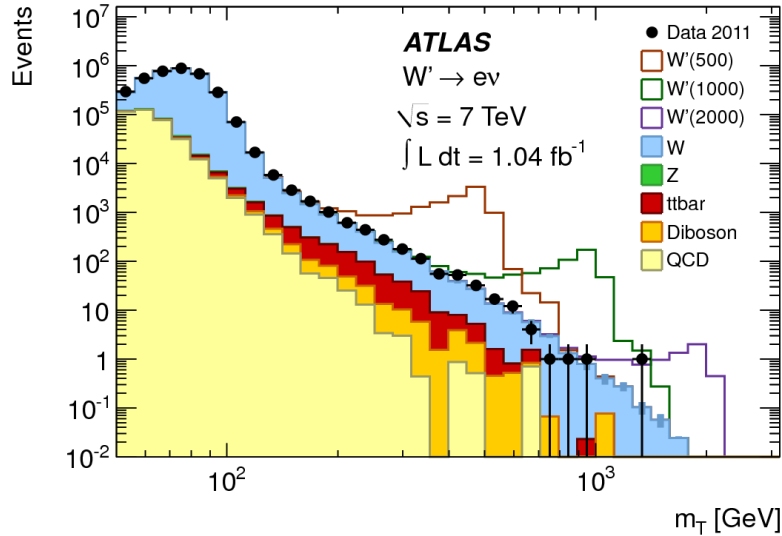


$\mu\nu$ channel



$\int v$ results

$W' \rightarrow e\nu$



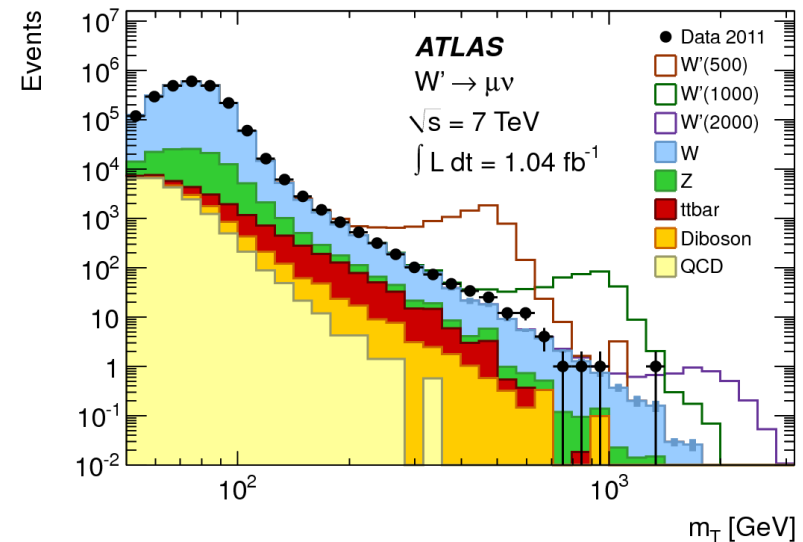
- Background normalized with σ_B to data luminosity

– Systematics :

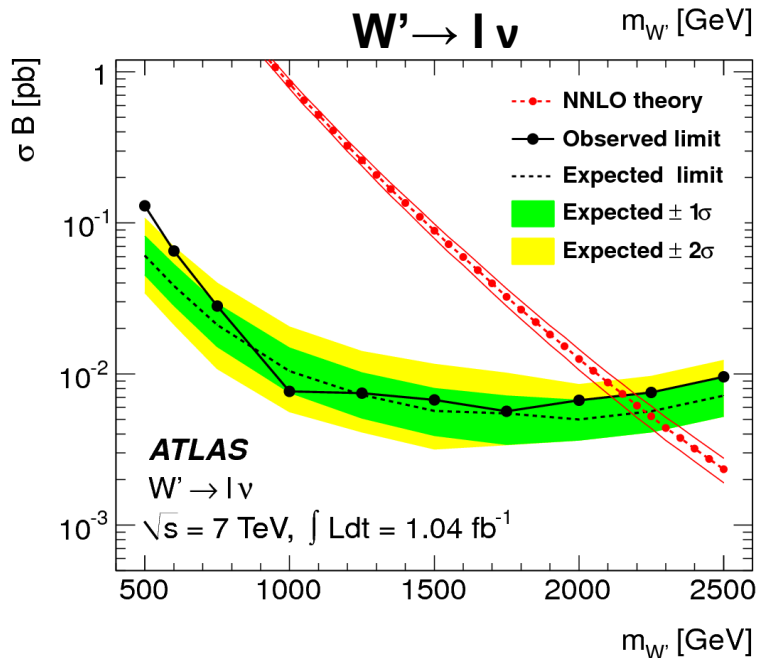
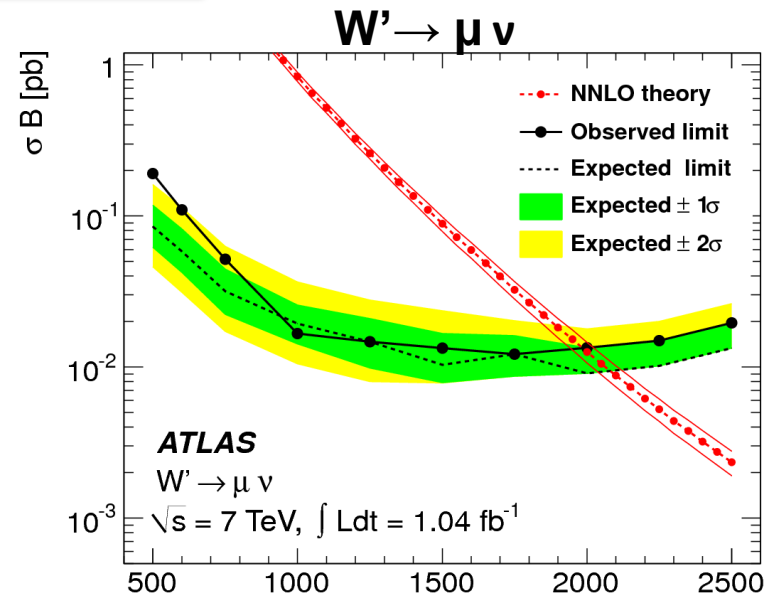
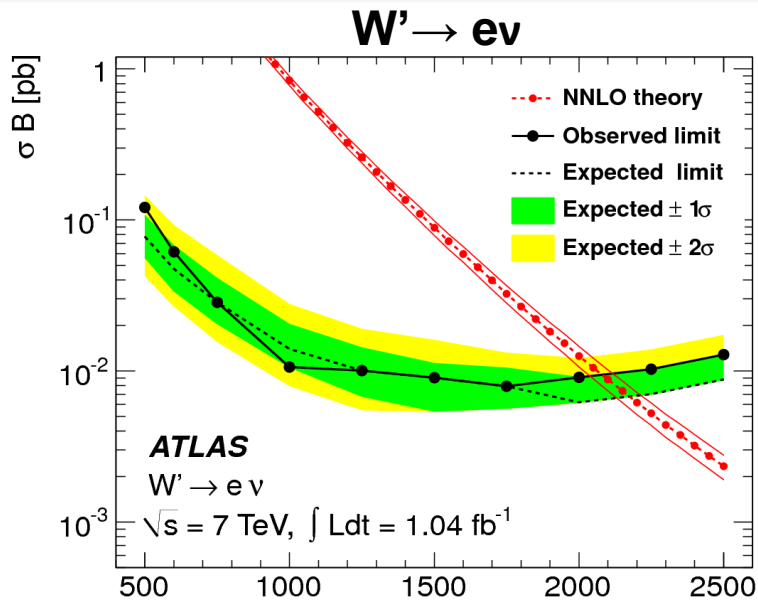
Source	ε_{sig}		N_{bg}	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Efficiency	2.7%	3.9%	2.7%	3.8%
Energy/momentum resolution	0.3%	2.3%	2.9%	0.6%
Energy/momentum scale	0.5%	1.3%	5.2%	3.0%
QCD background	-	-	10.0%	1.3%
Monte Carlo statistics	2.5%	3.1%	9.4%	9.9%
Cross section (shape/level)	3.0%	3.0%	9.5%	9.5%
All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

- Discovery statistics (*Bayesian*)
 - Single bin counting likelihood fit
 - Counting events for $m_T > m_{T\text{min}}$
 - $m_{T\text{min}}$ chosen to maximise sensitivity
- No significant excess
 - 95% CL limits on $N(W')$
 - Converted into 95% CL limits on $\sigma \cdot B(W')$

$W' \rightarrow \mu\nu$



W' σ_B 95% CL limits



- $M_{W'(SSM)} > 2.15 \text{ TeV} (2.23 \text{ TeV } exp.)$

Tevatron (*CDF* $e\nu$) : 800 GeV

Conclusion

- A search for heavy resonances has been performed in ATLAS
 - LHC results have now surpassed results from Tevatron and LEP
 - Still no significant excess beyond the Standard Model expectations
 - Cross section limits set and converted into mass limits

$M_{Z'(SSM)} > 1.83 \text{ TeV}$; $M_{G^*(k/M_{Pl} = 0.1)} > 1.63 \text{ TeV}$; $M_{\rho_T/\omega_T} > 470 \text{ GeV}$; $M_{W'(SSM)} > 2.15 \text{ TeV}$

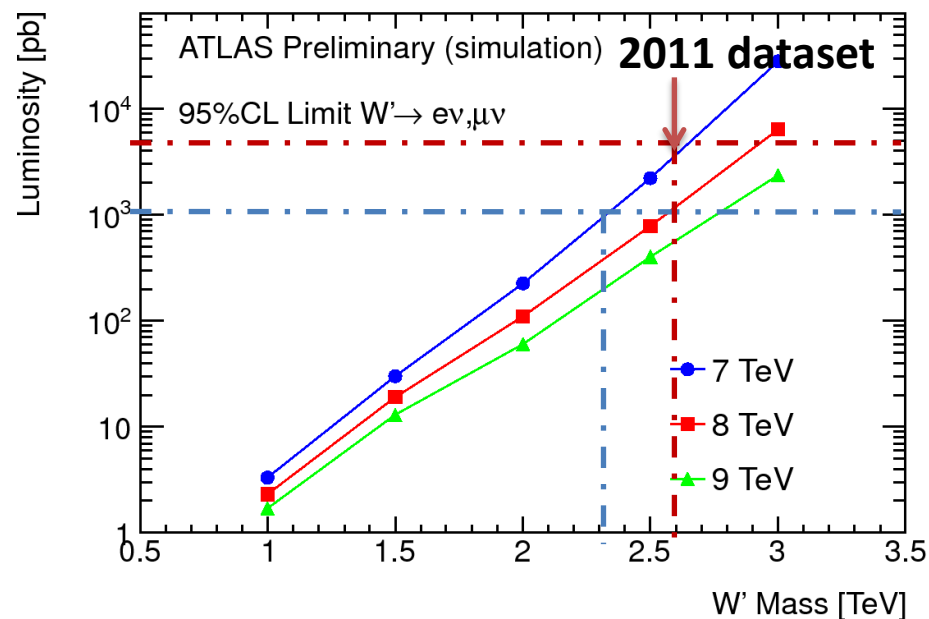
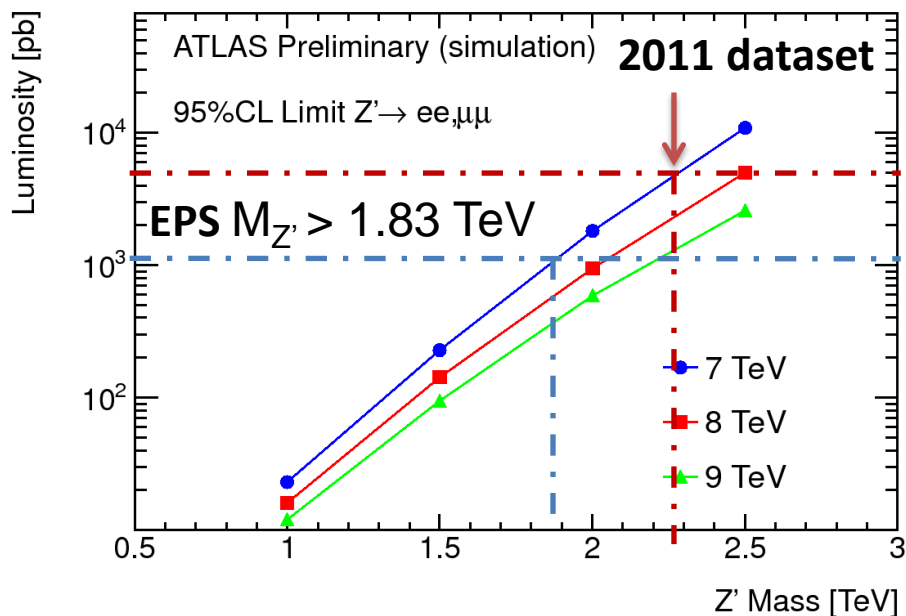
[arXiv:1108.1582v1](https://arxiv.org/abs/1108.1582v1)

[arXiv:1108.1316v1](https://arxiv.org/abs/1108.1316v1)

- Data still being recorded
 - 4x times the analysed dataset on tape
 - ~5 fb⁻¹ by this winter
- Perspectives
 - More BSM models interpretation to be included/updated
 - Non resonant : contact interaction
 - Improvement of analyses

Perspectives ('d)

- Expected limit reach : Z'_{SSM}, W'_{SSM}
 - Last year results show accurate expectations (ATL-PHYS-PUB-2011-002)



- **Full 2011 dataset ($\sim 5 \text{ fb}^{-1}$) :**
 - **Discovery ?**
 - **$M_{Z'(SSM)} > 2.3 \text{ TeV}$, $M_{W'(SSM)} > 2.6 \text{ TeV}$?**

Backup slides

Data - MC comparison (\mathcal{L})

- Expected number of background events vs data count

$m_{e^+e^-}$ [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

- Backgrounds
 - Z/ γ^* , dibosons, W+jets, tt from **MC** -> normalised to each others
 - **QCD shape** evaluated from **data** (3 methods)
- M_{ee} fit to data
 - 2 components : QCD + MC bkg (fit $70 < M_{ee} < 200$ GeV)
 - **QCD proportion** + normalisation to luminosity $70 < M_{ee} < 110$ GeV
 - Normalisation factor : ~ 0.99

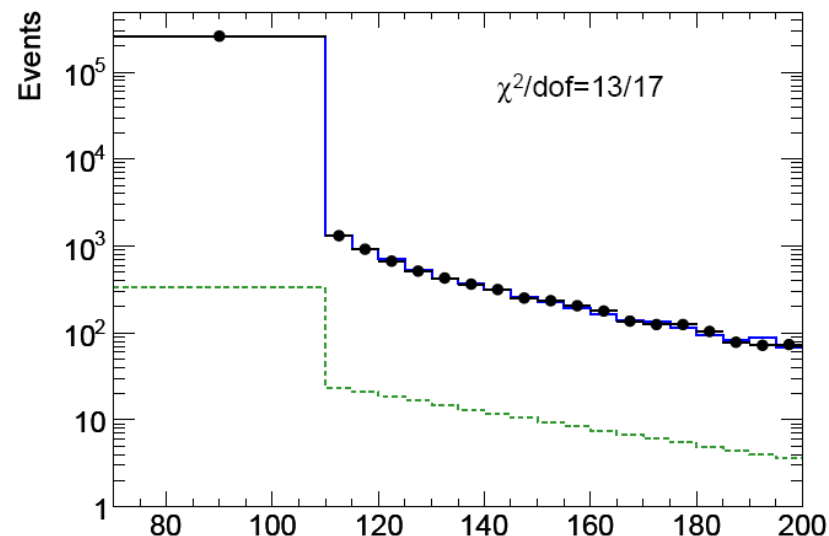
Methods

1. Reverse id template

- 2g20_loose trigger
- electron selection reversing isEM id cuts
 - Loose $!(\Delta E_{\max_{S1}} \& w_{\text{stot}})$
- Extrapolated to high M_{ee} $f(x) = p_0 x^{p_1} x^{p_2 * \text{Log}x}$
 - « dijet » function fit :

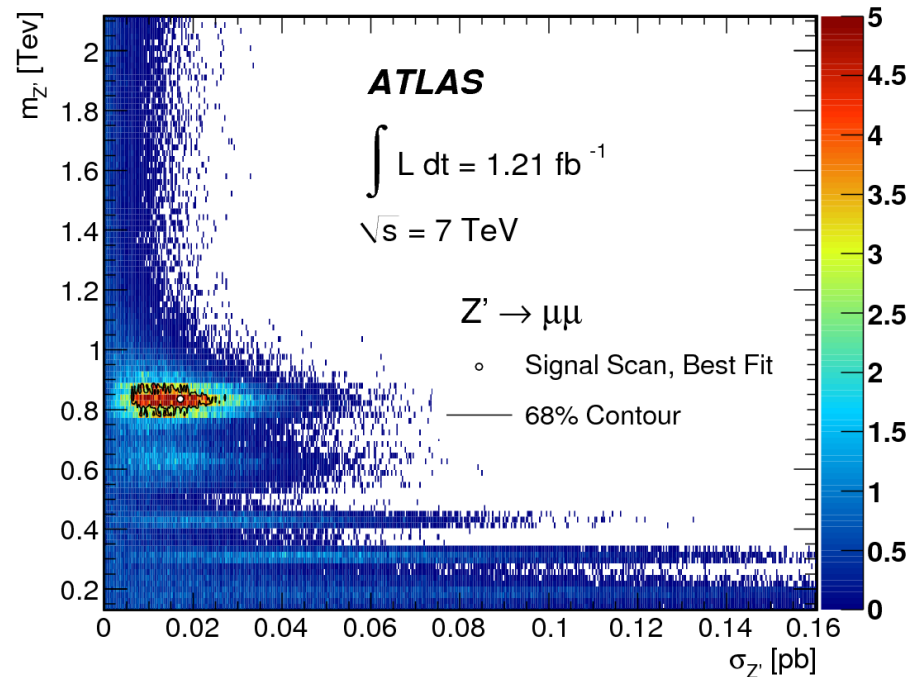
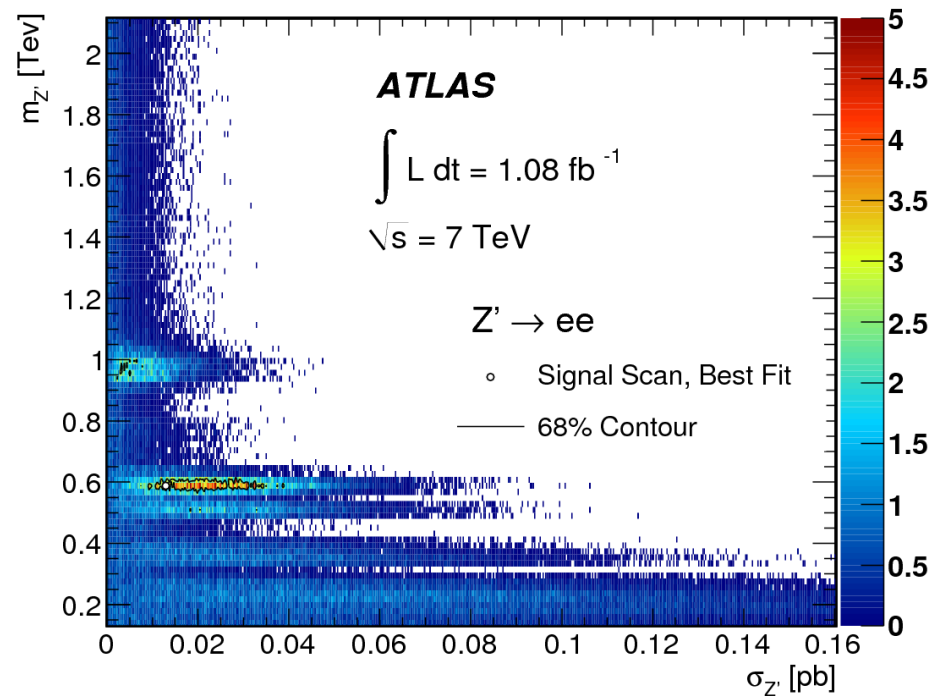
2. Isolation fit

3. QCD fake rates from inclusive jet samples

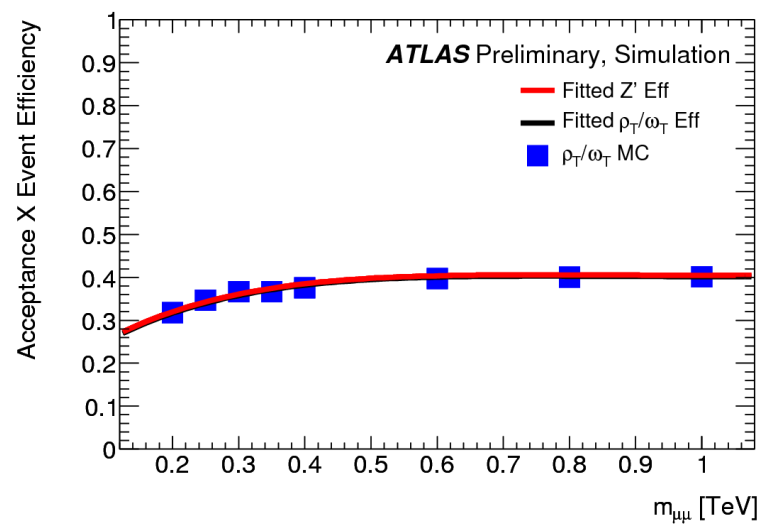
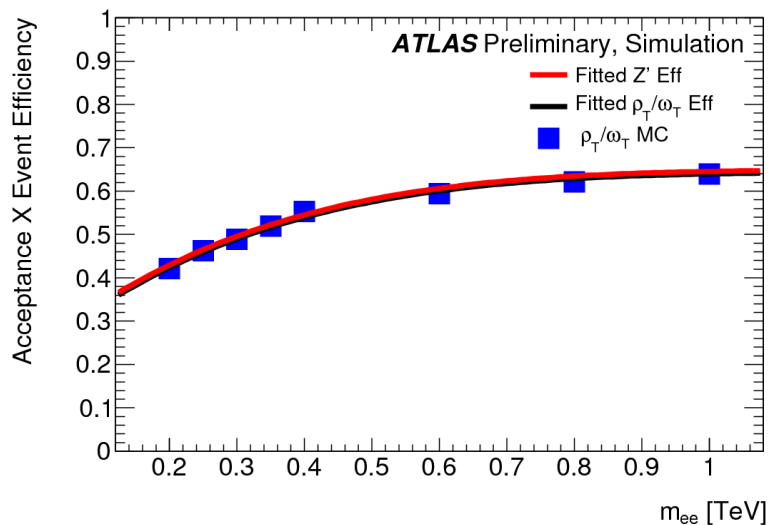


Results taken as systematics

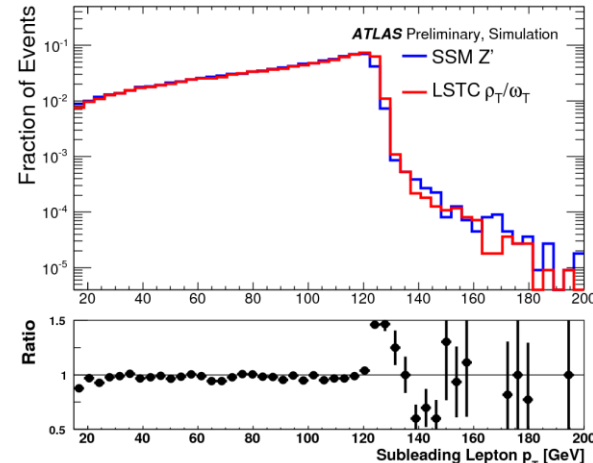
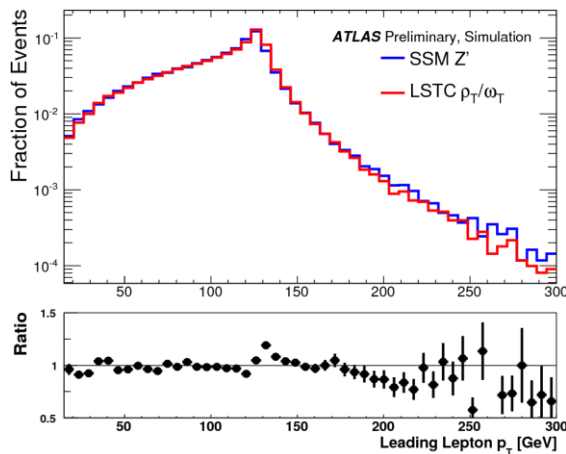
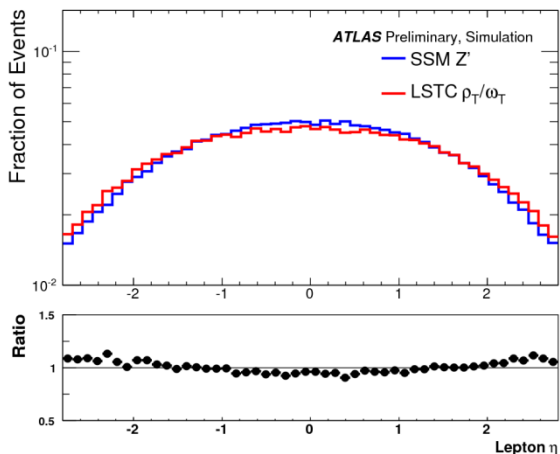
- Marginalized 2D posterior probability

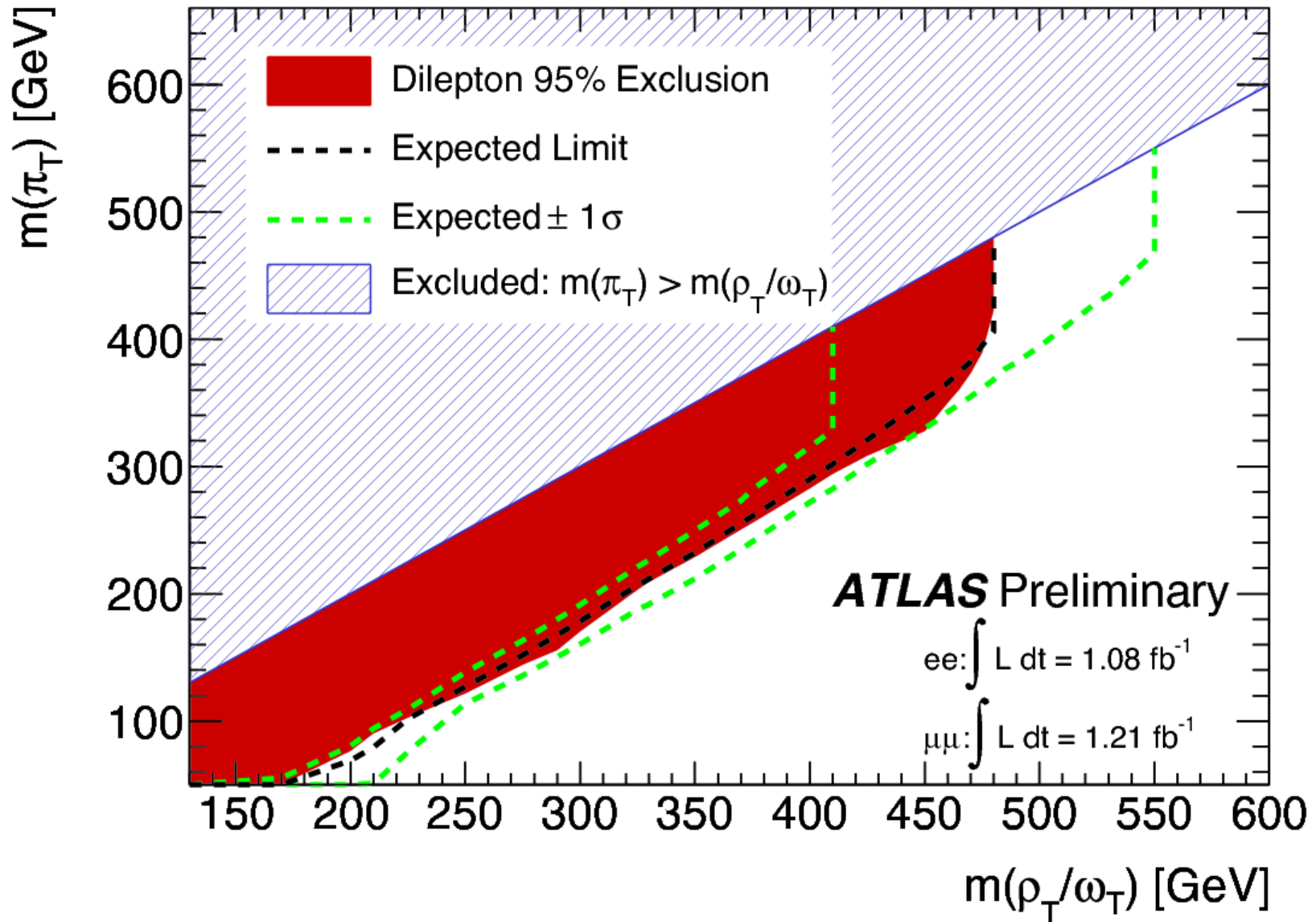


- Acceptance x efficiency vs resonance mass


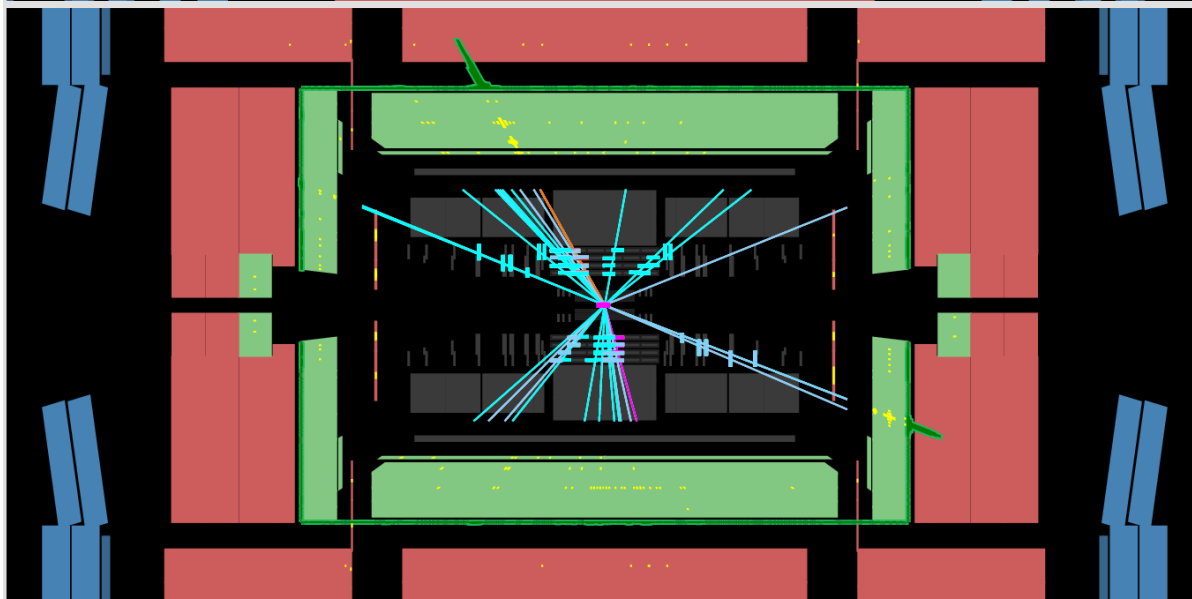
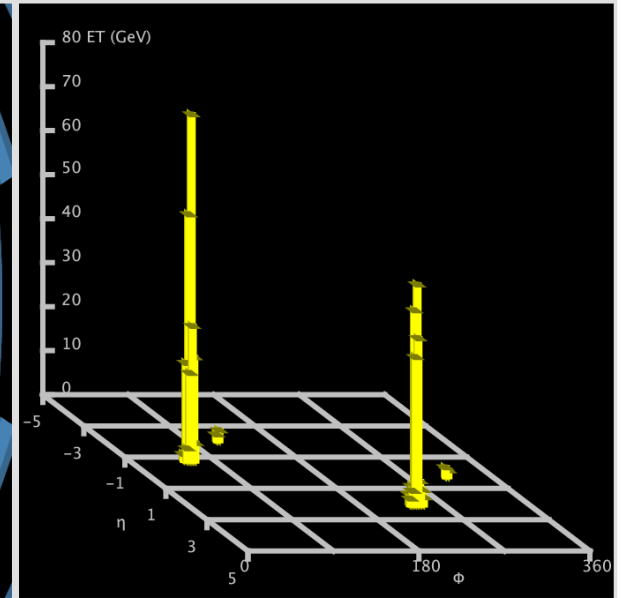
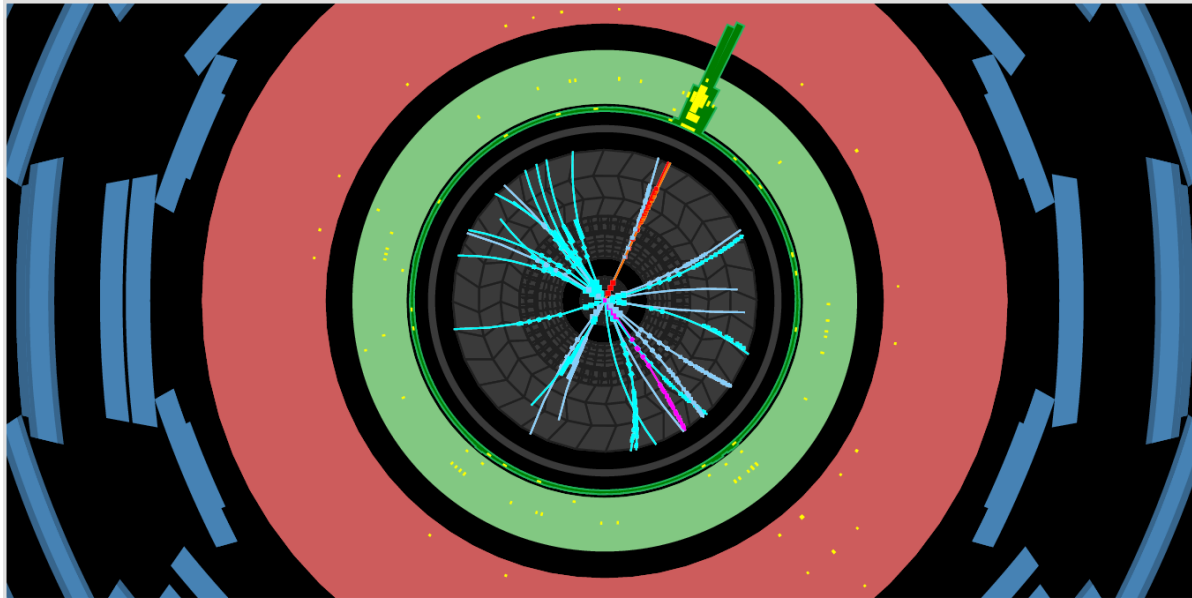


- Kinematics





Highest mass candidate (ee searches)

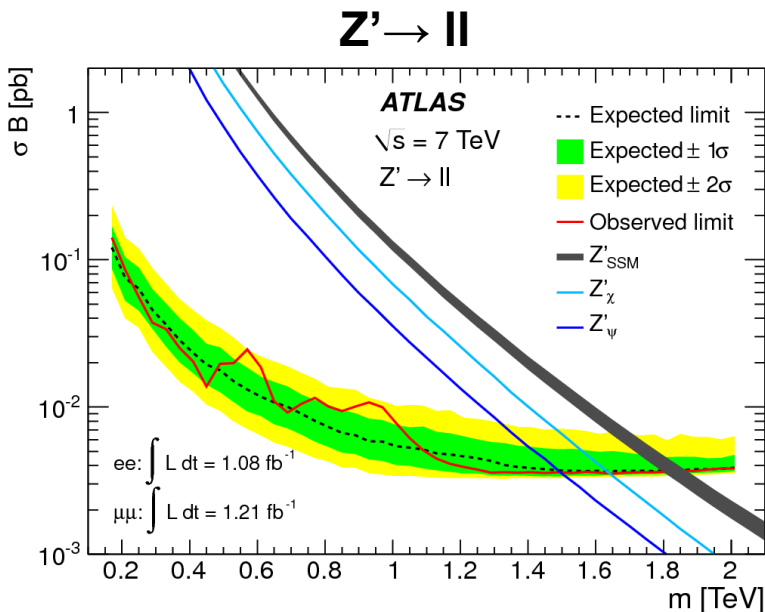
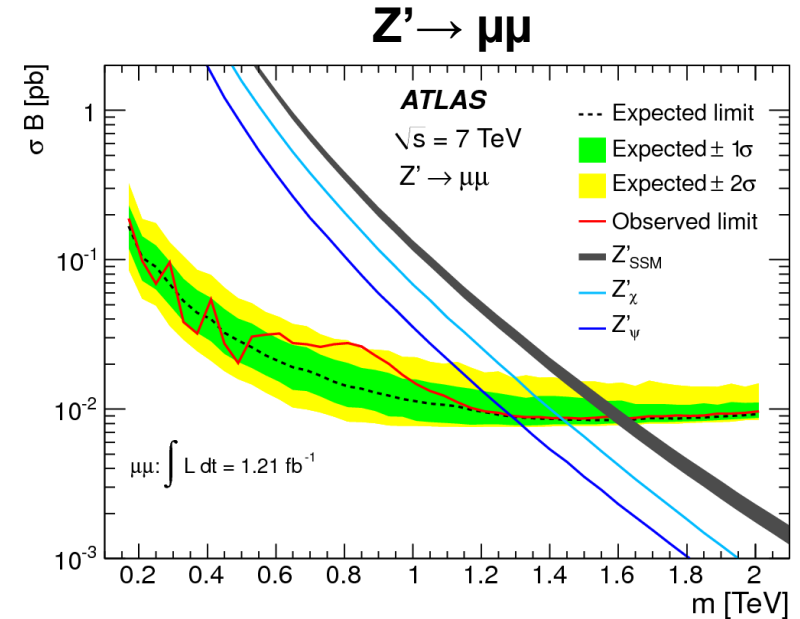
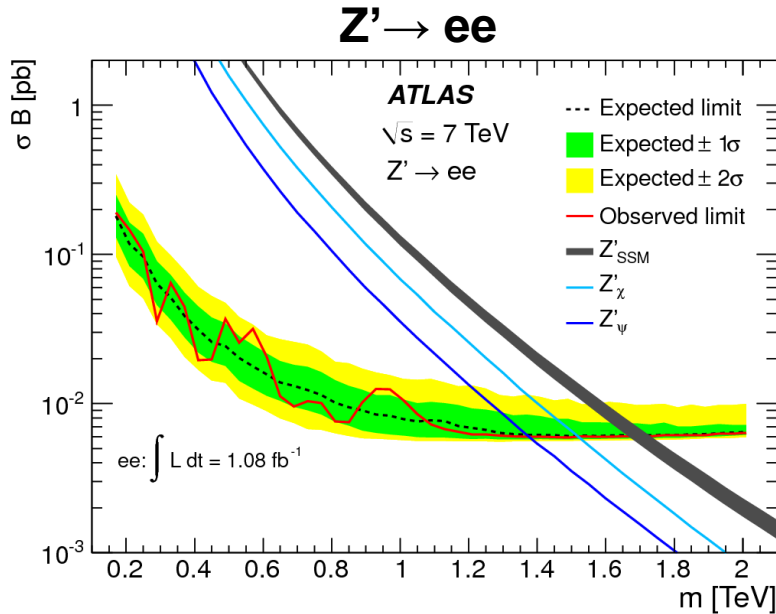


**ATLAS
EXPERIMENT**

Run Number: 183462, Event Number: 48979599

Date: 2011-06-14 02:48:15 PDT

Z' σ_B 95% CL limits



- $M_{Z'(SSM)} > 1.83 \text{ TeV}$ (1.82 TeV exp.)

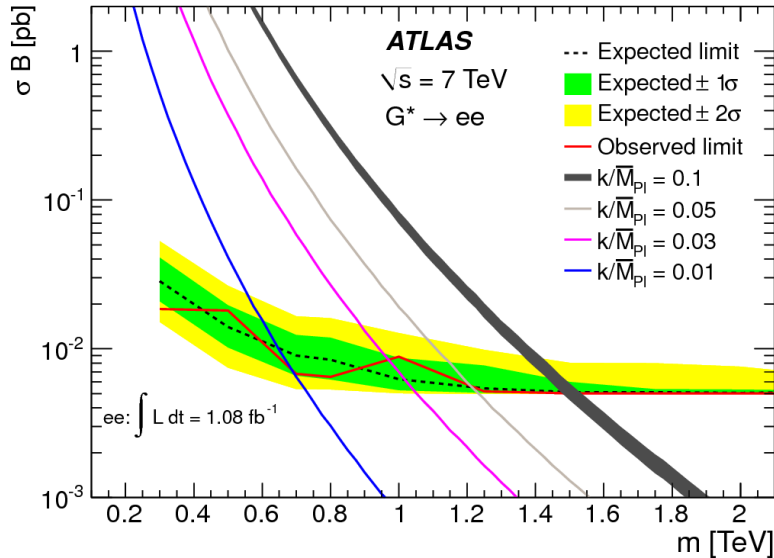
	E_6 Z' Models					
Model/Coupling	Z'_{ψ}	Z'_{N}	Z'_{η}	Z'_{I}	Z'_{S}	Z'_{χ}
Mass limit [TeV]	1.49	1.52	1.54	1.56	1.60	1.64

Tevatron (CDF $\mu\mu$) : 1.071 TeV

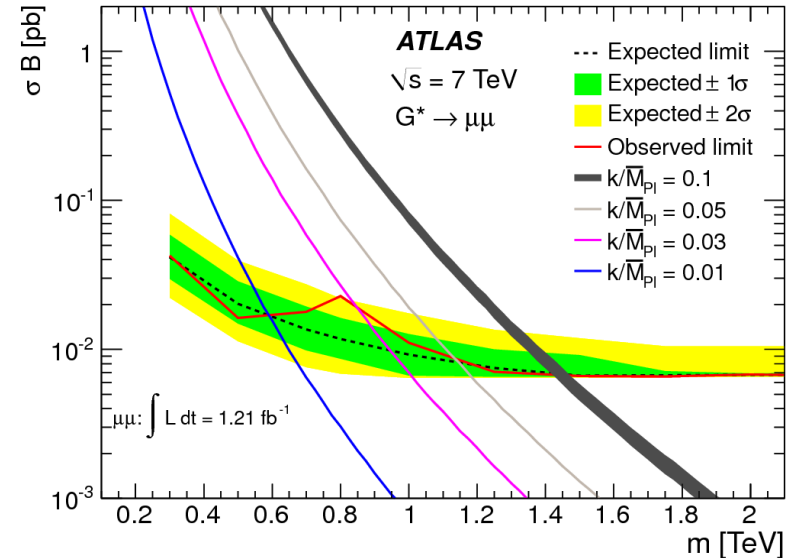
LEP indirect searches : 1.787 TeV

G^* σ_B 95% CL limits

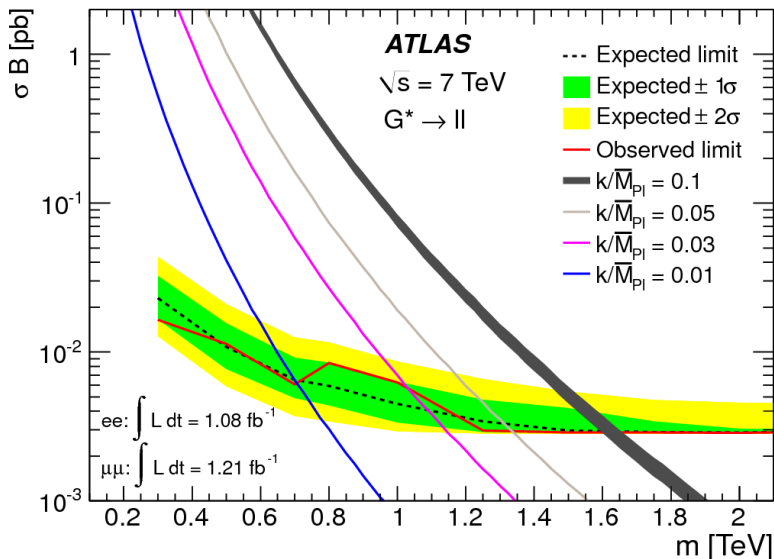
$G^* \rightarrow ee$



$G^* \rightarrow \mu\mu$



$G^* \rightarrow \ell\ell$

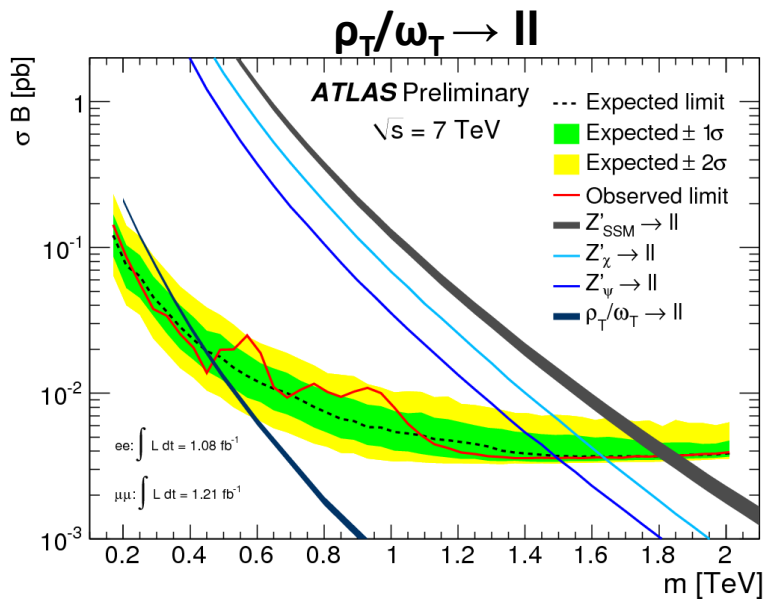
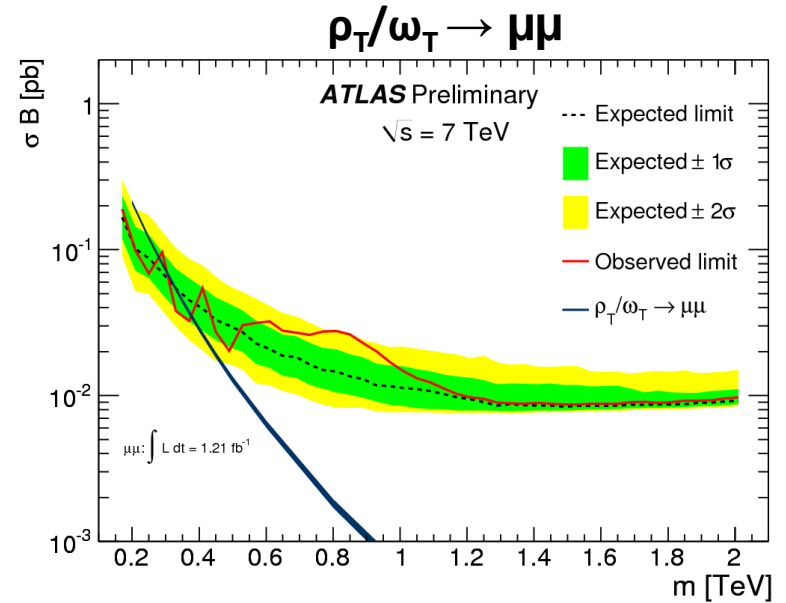
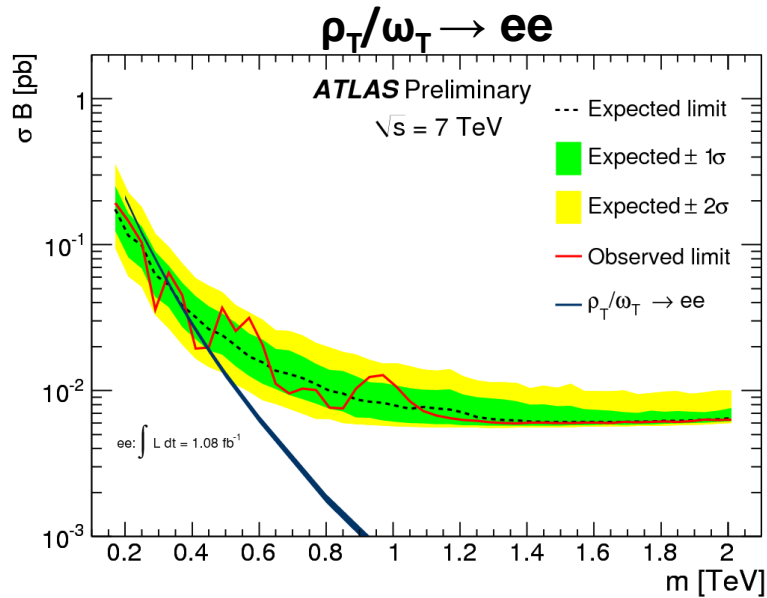


- $M_{G^*(k/M_{PI} = 0.1)} > 1.63 \text{ TeV (1.61 TeV exp.)}$

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

Tevatron : 1.058 TeV

ρ_T/ω_T σ_B 95% CL limits



- $M_{\rho_T/\omega_T} > 470 \text{ GeV}$ (442 GeV *exp.*)
with $m(\rho_T/\omega_T) - m(\pi_T) = 100 \text{ GeV}$

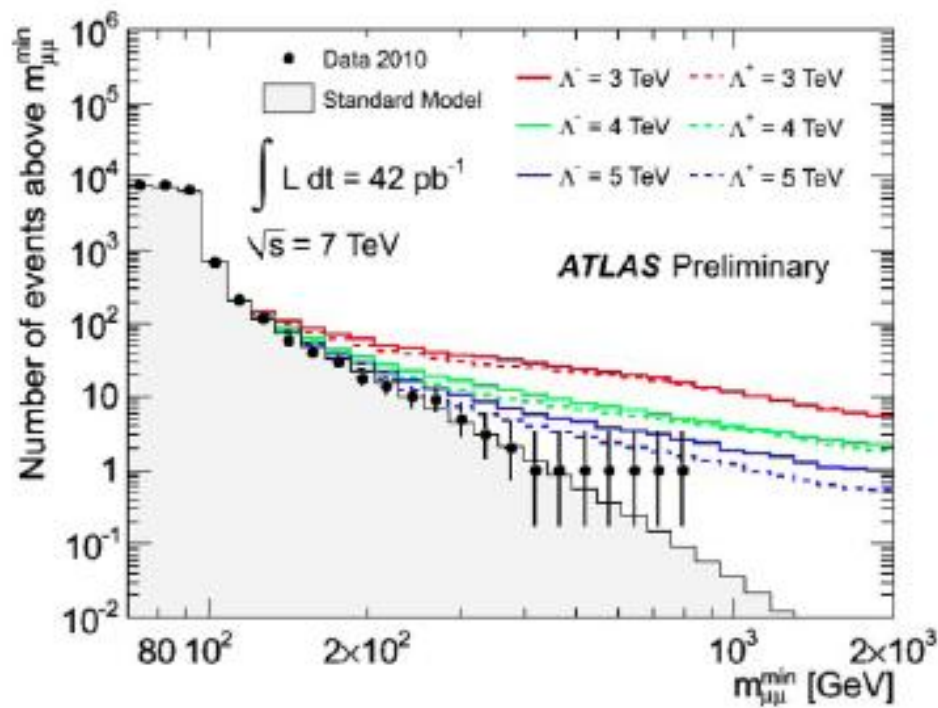
Data - MC comparison (\sqrt{s})

- Expected number of signal and background events vs data count (N_{obs})

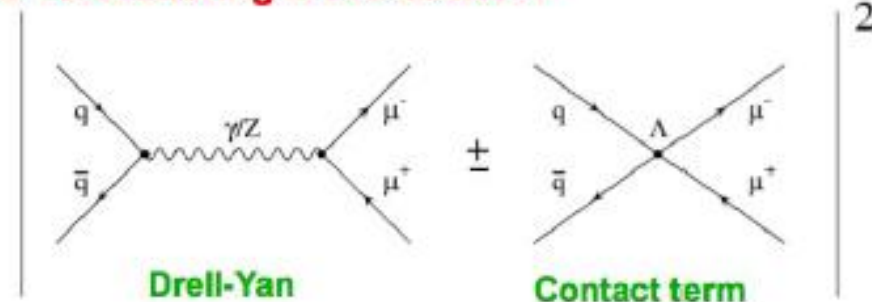
$m_{W'}$ [GeV]	$m_{T\text{min}}$ [GeV]		ϵ_{sig}	N_{sig}	N_{bg}	N_{obs}
500	398	$e\nu$	0.388 ± 0.019	6930 ± 620	101.9 ± 10.8	121
		$\mu\nu$	0.252 ± 0.015	4500 ± 430	63.7 ± 6.5	91
600	447	$e\nu$	0.456 ± 0.022	3910 ± 330	62.1 ± 7.1	69
		$\mu\nu$	0.286 ± 0.016	2450 ± 220	41.8 ± 4.7	57
750	562	$e\nu$	0.429 ± 0.020	1420 ± 110	20.7 ± 3.7	20
		$\mu\nu$	0.293 ± 0.017	970 ± 79	14.3 ± 1.4	20
1000	708	$e\nu$	0.482 ± 0.022	417 ± 35	6.13 ± 0.92	4
		$\mu\nu$	0.326 ± 0.019	282 ± 26	4.98 ± 0.54	4
1250	794	$e\nu$	0.527 ± 0.024	143 ± 14	3.09 ± 0.49	3
		$\mu\nu$	0.367 ± 0.021	99 ± 10	2.87 ± 0.34	3
1500	891	$e\nu$	0.541 ± 0.026	49.6 ± 6.0	1.75 ± 0.32	2
		$\mu\nu$	0.374 ± 0.024	34.4 ± 4.4	1.57 ± 0.23	2
1750	1000	$e\nu$	0.515 ± 0.024	17.3 ± 2.4	0.89 ± 0.20	1
		$\mu\nu$	0.338 ± 0.020	11.4 ± 1.7	0.82 ± 0.14	1
2000	1122	$e\nu$	0.472 ± 0.023	6.16 ± 0.99	0.48 ± 0.10	1
		$\mu\nu$	0.323 ± 0.021	4.21 ± 0.70	0.44 ± 0.09	1
2250	1122	$e\nu$	0.415 ± 0.019	2.84 ± 0.50	0.48 ± 0.10	1
		$\mu\nu$	0.288 ± 0.018	1.97 ± 0.36	0.44 ± 0.09	1
2500	1122	$e\nu$	0.333 ± 0.018	0.81 ± 0.16	0.48 ± 0.10	1
		$\mu\nu$	0.221 ± 0.017	0.53 ± 0.11	0.44 ± 0.09	1

Contact Interactions

- Search for constructive or destructive interference in the Drell-Yan tail, coming from new physics
- Using the exact same Z' selection



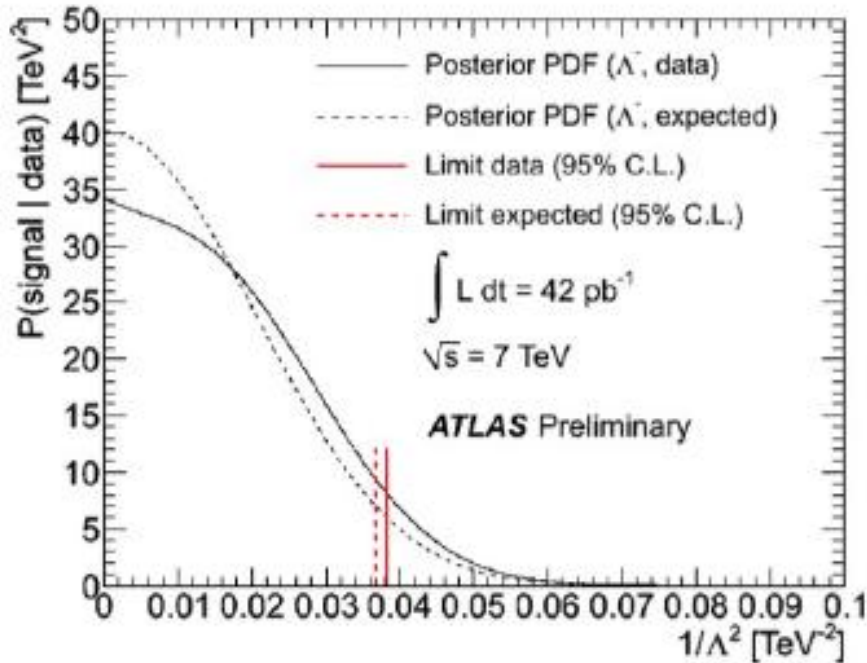
2→2 scattering cross-section:



Slide from S. Viel

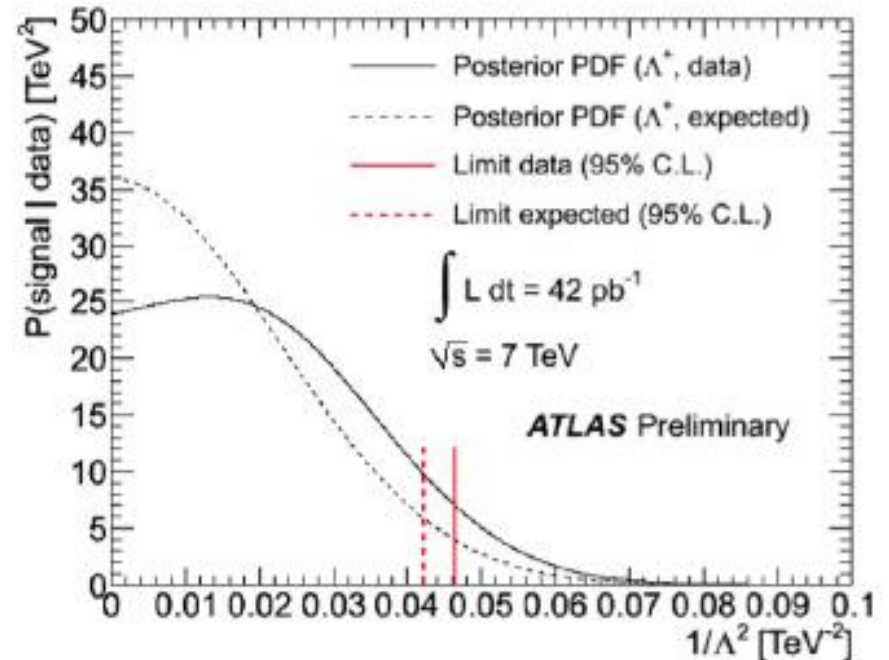
Contact Interactions Limits

Constructive Interference



Λ^- data: 4.9 TeV
 Λ^- expected: 5.1 TeV

Destructive Interference



Λ^+ data: 4.5 TeV
 Λ^+ expected: 4.8 TeV

Slide from S. Viel

Background simulation

Generators and PDF sets:

Z, W: Pythia with MRST2007 LO*

WW, WZ, ZZ: Herwig with MRST2007 LO*

ttbar: MC@NLO + Jimmy + Herwig with CTEQ6

W+jets: Alpgen + Jimmy + Herwig with CTEQ6

Cross sections and PDF sets:

Z, W: NNLO (PHOZPR, FEWZ, MCFMs+HORACE) with MSTW08

WW, WZ, ZZ: NLO

ttbar: approximate NNLO (HATHOR)

W+jets: NLO, rescaled to inclusive σ at NNLO