Search For High-Mass States with Lepton Plus Missing E_T Using ATLAS

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on behalf of the ATLAS Collaboration

DPF

Brown University August, 2011

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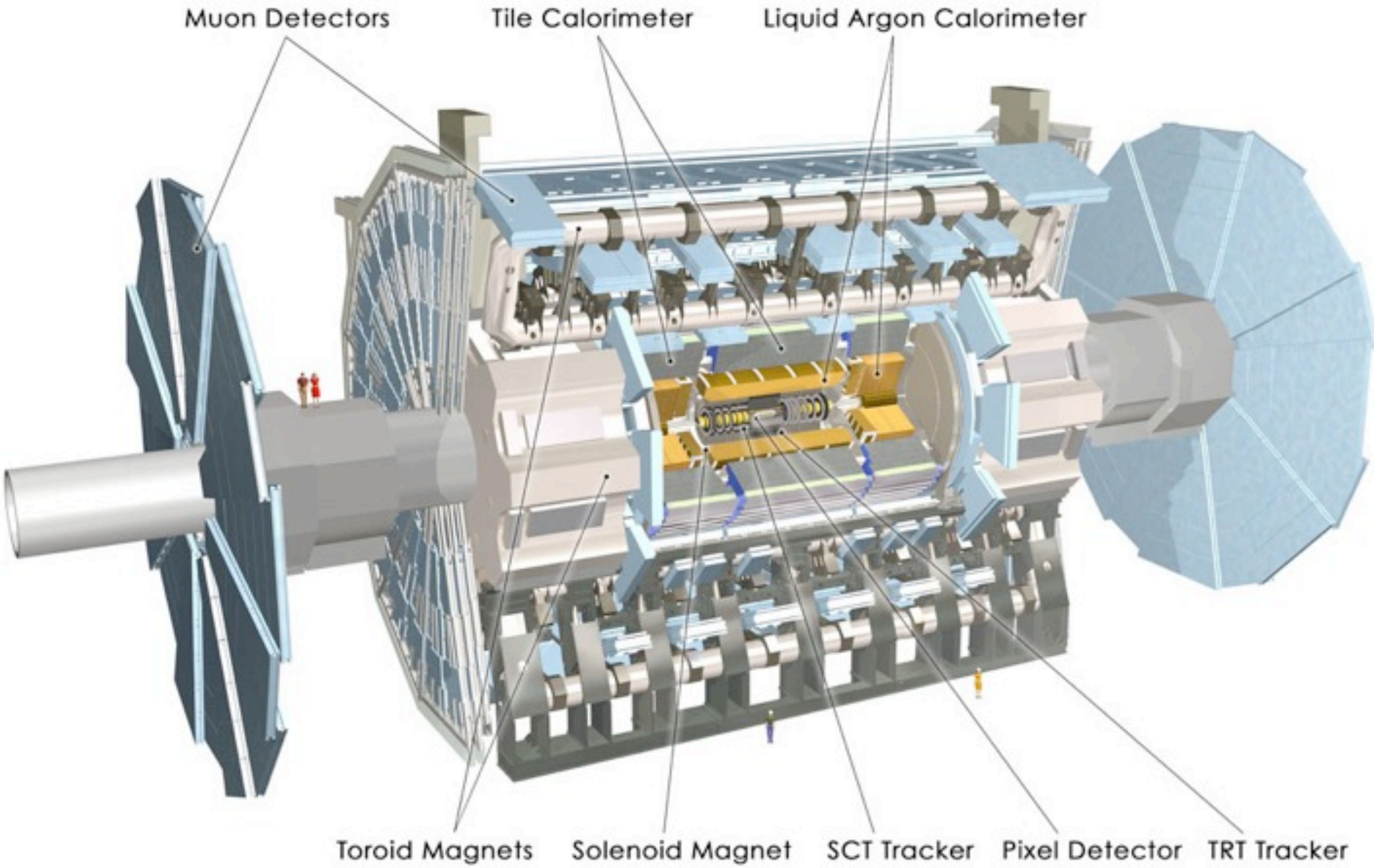
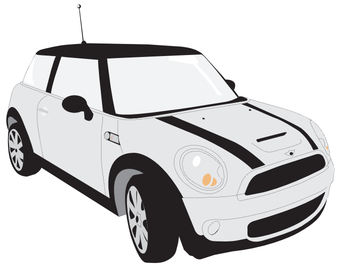
Introduction

- Many BSM theories (i.e. $SU(2)_1 \times SU(2)_2 \times U(1)$) predict additional heavy bosons that will decay to a lepton (electron or muon) and neutrino.
- Use the Sequential Standard Model (SSM) W Prime as a benchmark model.
- LHC, with its high energy center of mass provides a unique opportunity to extend searches for W Prime into new energy regime.
- Previous search has been performed with 36 pb^{-1}, set limits at 1.35 TeV. Phys. Lett. B, 701:50-69,2011, arXiv: 1103.1391
- With > 1 fb^{-1} of data recorded, ATLAS has performed a search for large transverse mass resonances of a lepton and a neutrino from pp collisions at a center-of-mass energy of 7 TeV.

ATLAS

$$\langle\frac{\delta p_{\mathrm{T}}(\mu)}{p_{\mathrm{T}}(\mu)}\rangle \approx 15\% \text{ at } 1 \text{ TeV}$$



=  x 2971

$$\frac{\delta E_{\mathrm{T}}(e)}{E_{\mathrm{T}}(e)} \approx 1\% \text{ at } E_{\mathrm{T}} >> 50 \text{ GeV}$$

Search Strategy

- Select events with high pt leptons and large missing E_T.
- Use m_T as the observable to perform our search with.

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}(l)E_{\mathrm{T}}^{\mathrm{miss}}\cos(1-\phi_{l\nu})}$$

- Look for a significant excess above background expectations using bayesian analysis.
- If no excess is observed, then place limits on the σ*BR production using a bayesian method.

Backgrounds

- SM W production is the largest background and is irreducible.
- Z boson production, where one lepton is not reconstructed, mimicking real missing E_T.
- Dibosons + top pair production are the next largest that have real missing E_T and isolated leptons. These are estimated from MC samples.
- QCD is estimated from data using an ABCD method.
- Cosmics are a function of live detector time and are considered negligible for the current data set.

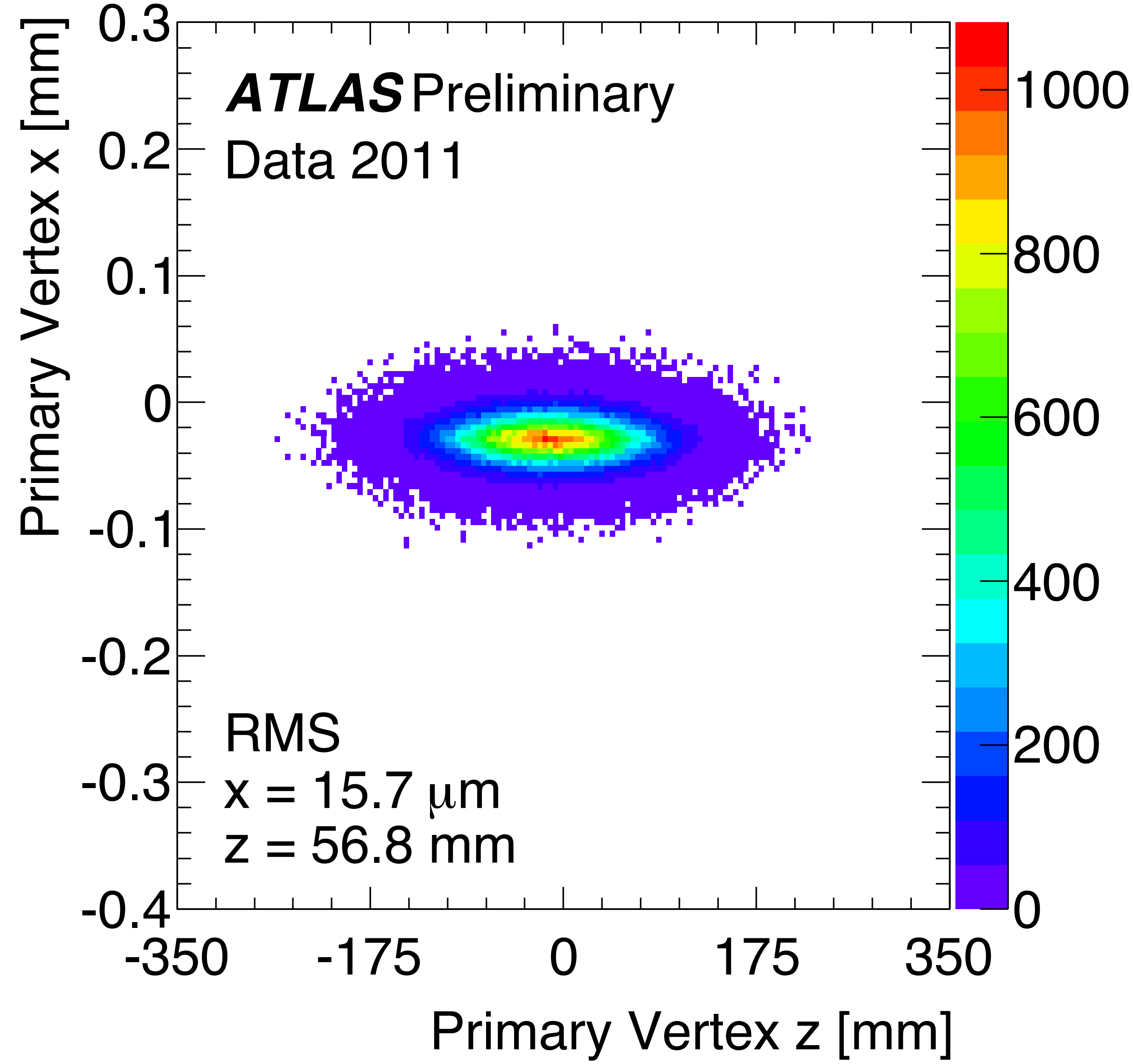
Process	σ*BR [pb]	Order
$W \rightarrow l\nu$	10460	NNLO
$Z/\gamma^* \rightarrow ll$ (m_{Z/γ^*} > 60 GeV)	989	NNLO
$t\bar{t} \rightarrow l+X$ ($m_{t\bar{t}}$ = 172.5 GeV)	89.4	approx - NNLO

Dibosons x-sections using LO

Event Selection

- Require only events where all of the sub-systems used in the analysis were fully operational.
- Require that events do not contain poorly reconstructed jets.
- Require a primary vertex with at least three reconstructed tracks, and is within 200 mm of the center of the interaction region.
- Require the impact parameters of the selected leptons to be associated with the primary vertex.

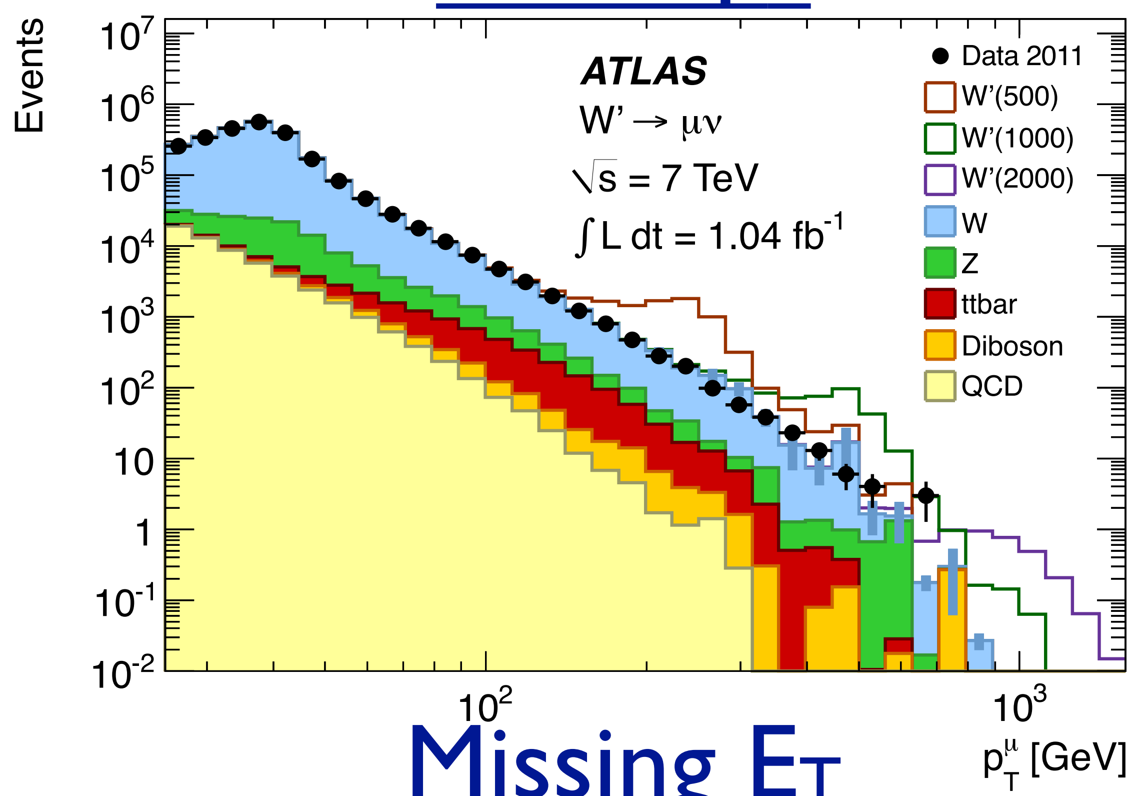
Primary Vertex Position



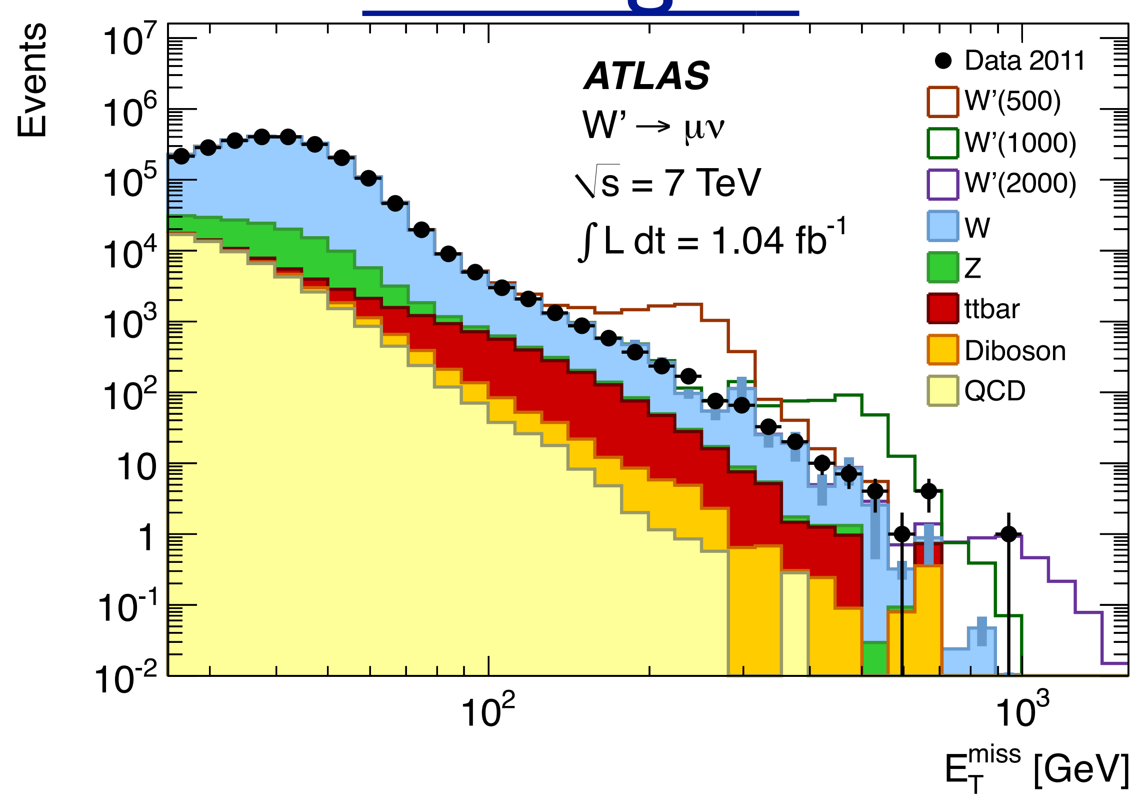
Muon Event Selection

- Single Muon Trigger with p_T > 20 GeV.
- Well reconstructed combined muon with:
  - p_T > 25 GeV
  - $|\eta| < 1.0$ or $1.3 < |\eta| < 2.0$
  - Demand three stations crossed by the muon to ensure good momentum measurement.
  - Require the difference between the ID and MS q/p measurements to be within 5σ of their fit errors.
  - Track isolation: $\Sigma\, p_T(\text{tracks}, R<0.3) < 0.05\, p_T$ (muon).
- Require large missing E_T > 25 GeV.
- Veto additional high pt muons.

Muon p_T



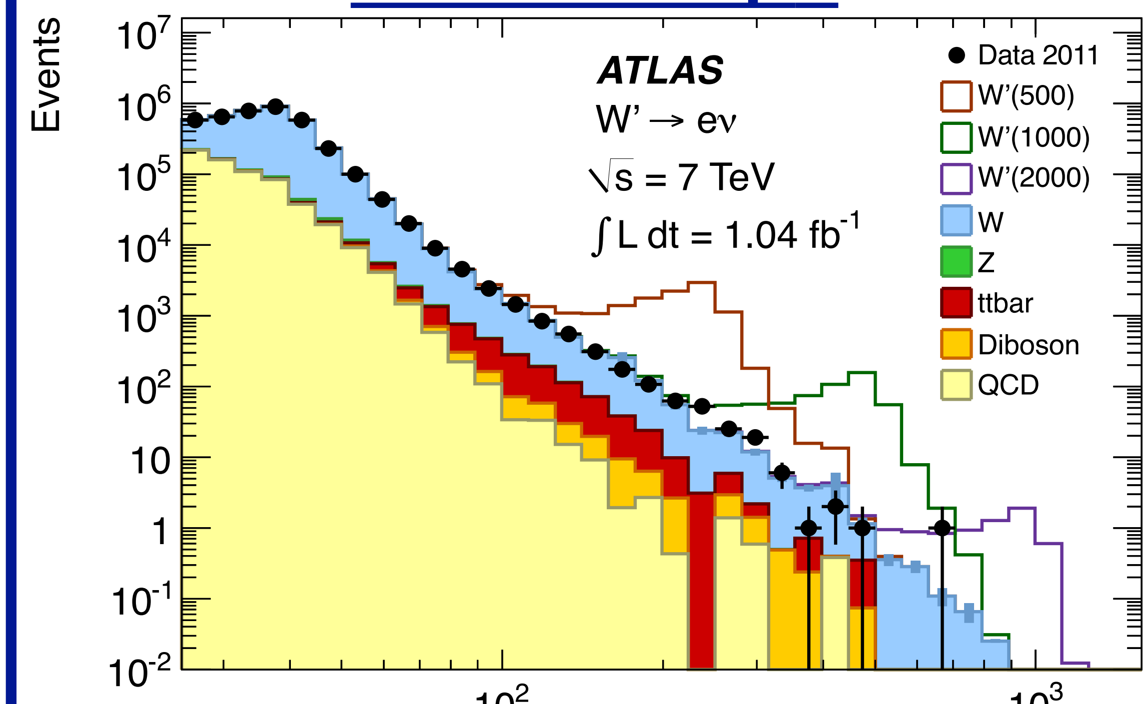
Missing E_T



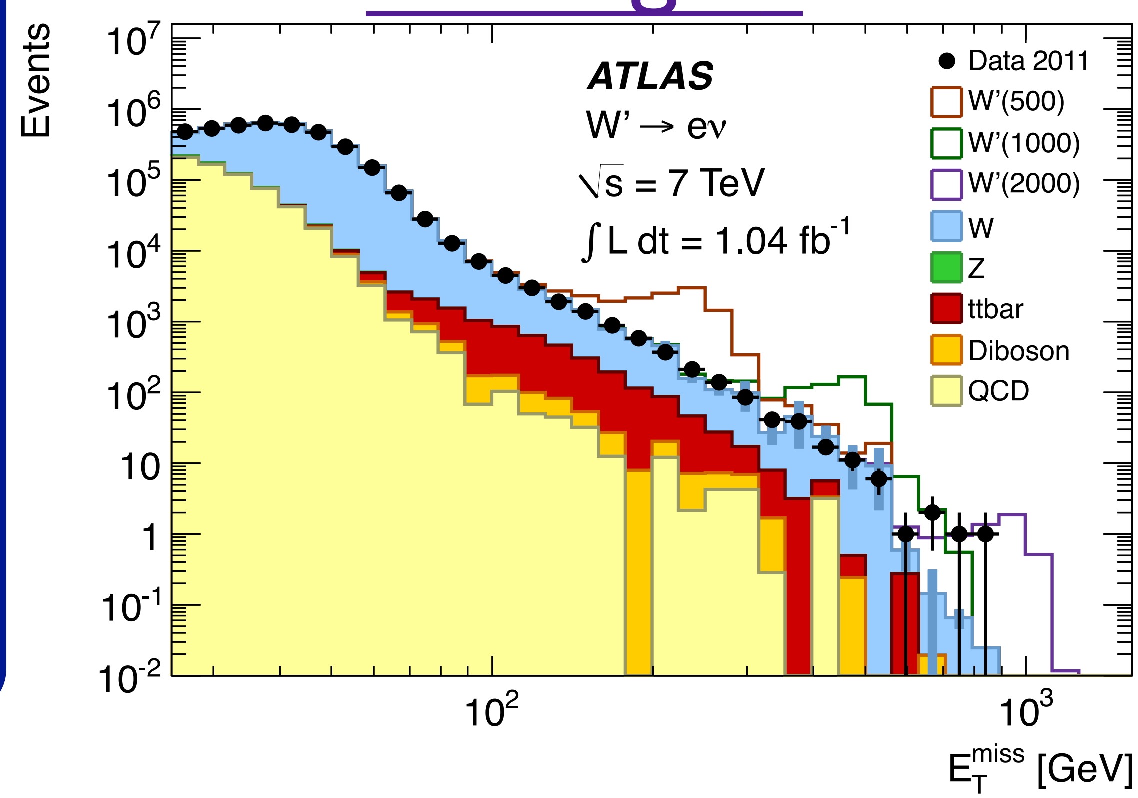
Electron Event Selection

- Require a single electron trigger with E_T > 22 GeV.
- Reconstructed electron requirements:
  - E_T(electron) > 25 GeV
  - $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$
  - A well reconstructed energy cluster with a shape consistent the an electron that is also matched to a track.
  - Calorimeter Isolation, $\Sigma E_{TCalo}(R<0.4) < 9$ GeV
  - a b-layer hit
- Require large missing E_T > 25 GeV.
- The ratio of the missing $E_T > 0.6\ E_T$ (electron).
- Veto additional electrons.

Electron p_T



Missing E_T



Systematics

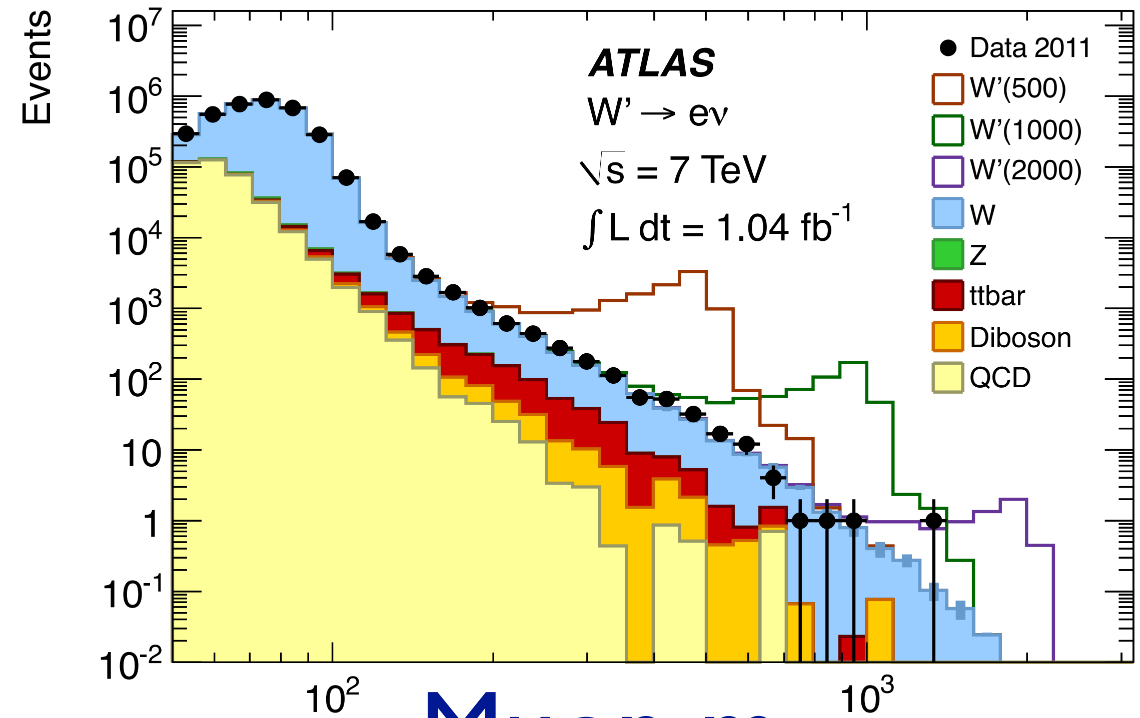
- Both channels have a correlated systematic uncertainties from Luminosity and MC generators.
- Other correlations are treated as negligible.
- Relative uncertainties at the 1500 GeV mass point.

	ε_{sig}		N_{bg}	
Source	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
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%

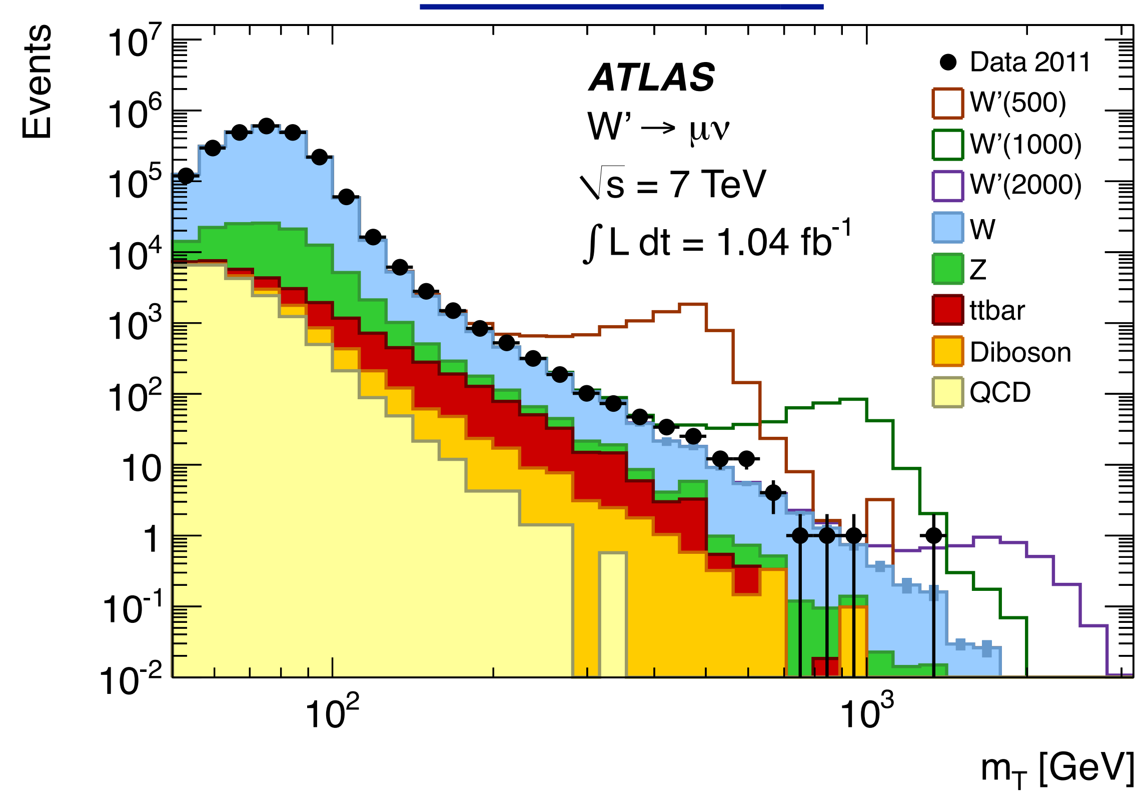
Results

- The m_T distributions of the electron and muon channel is shown.
- No excess with a significance above 3 σ (0.00135) is observed, in either channel, nor in the combination.
- 95% CL limits are set using a Bayesian analysis method.
- Bayesian results are identical to CLs results.

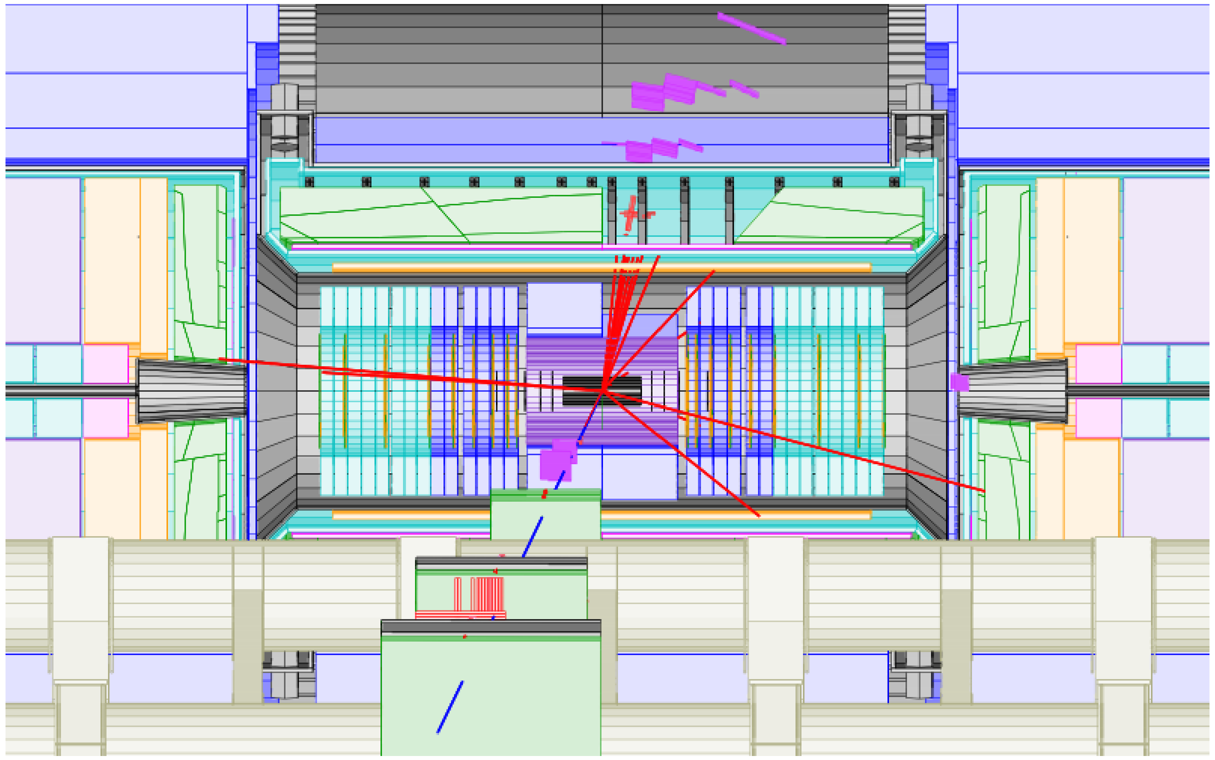
Electron m_T



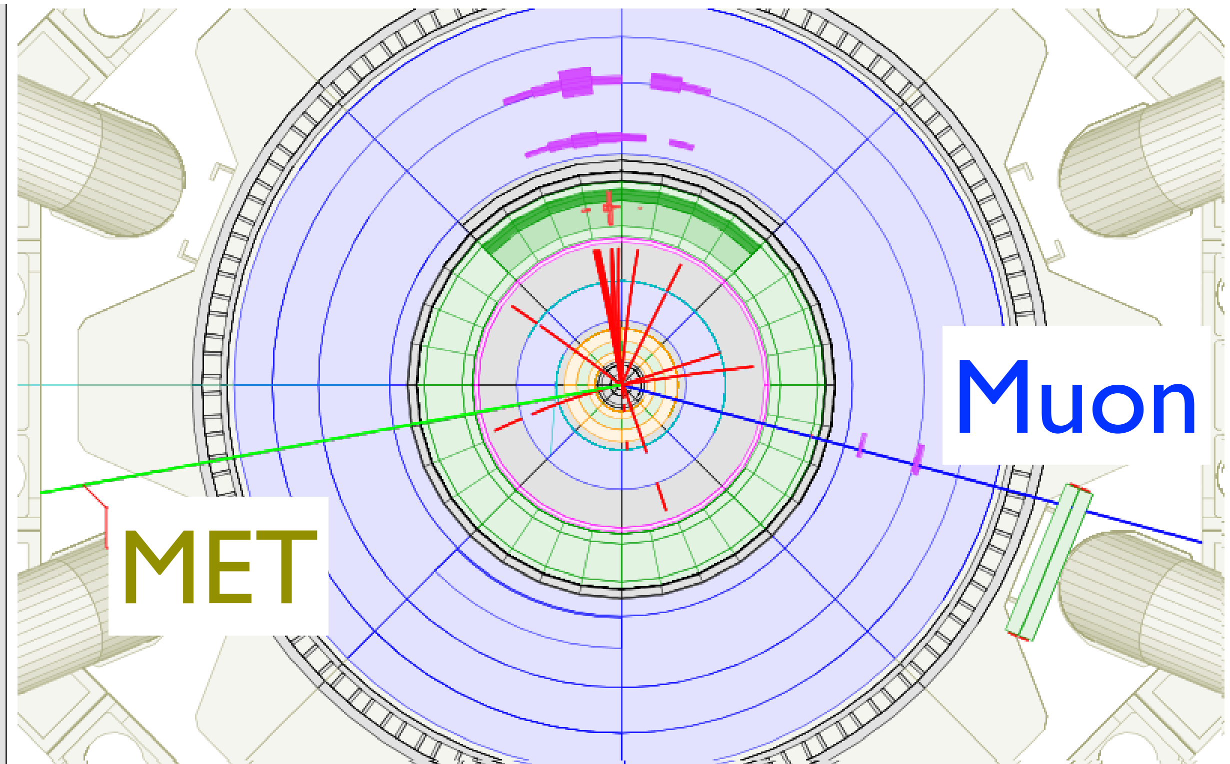
Muon m_T



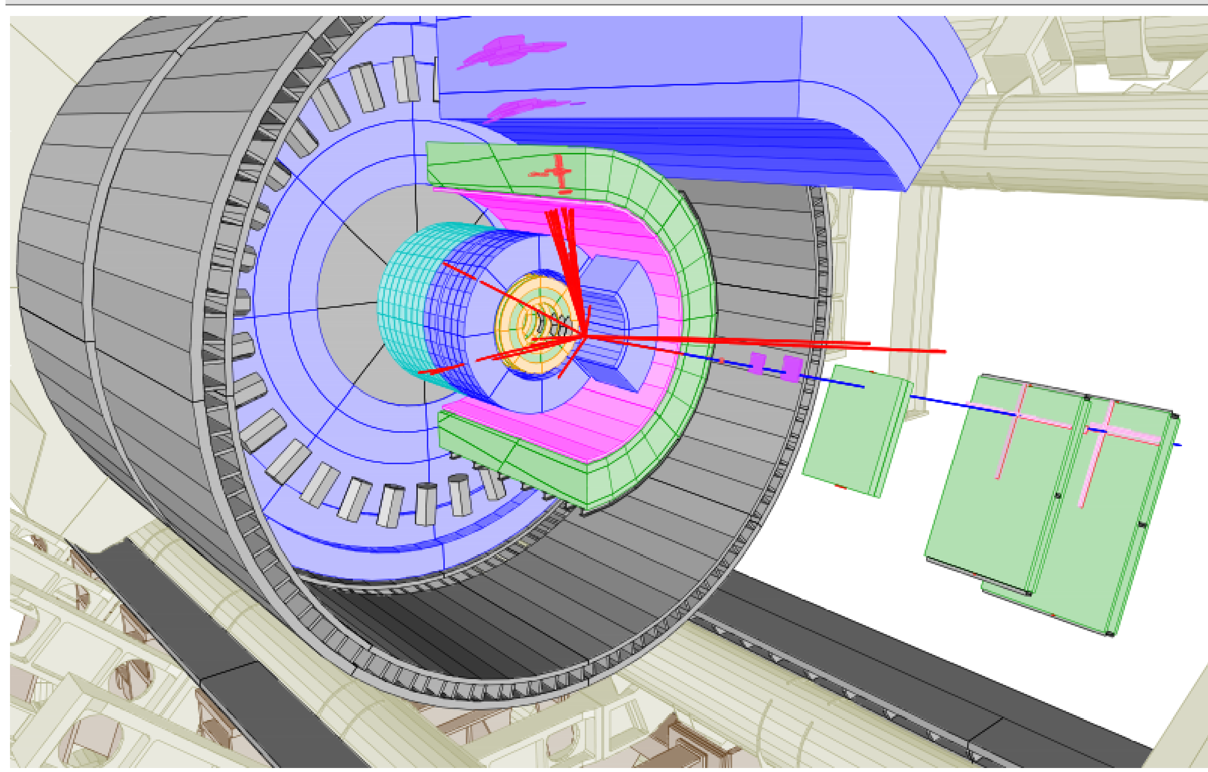
Highest m_T Muon Event



YZ view



XY view



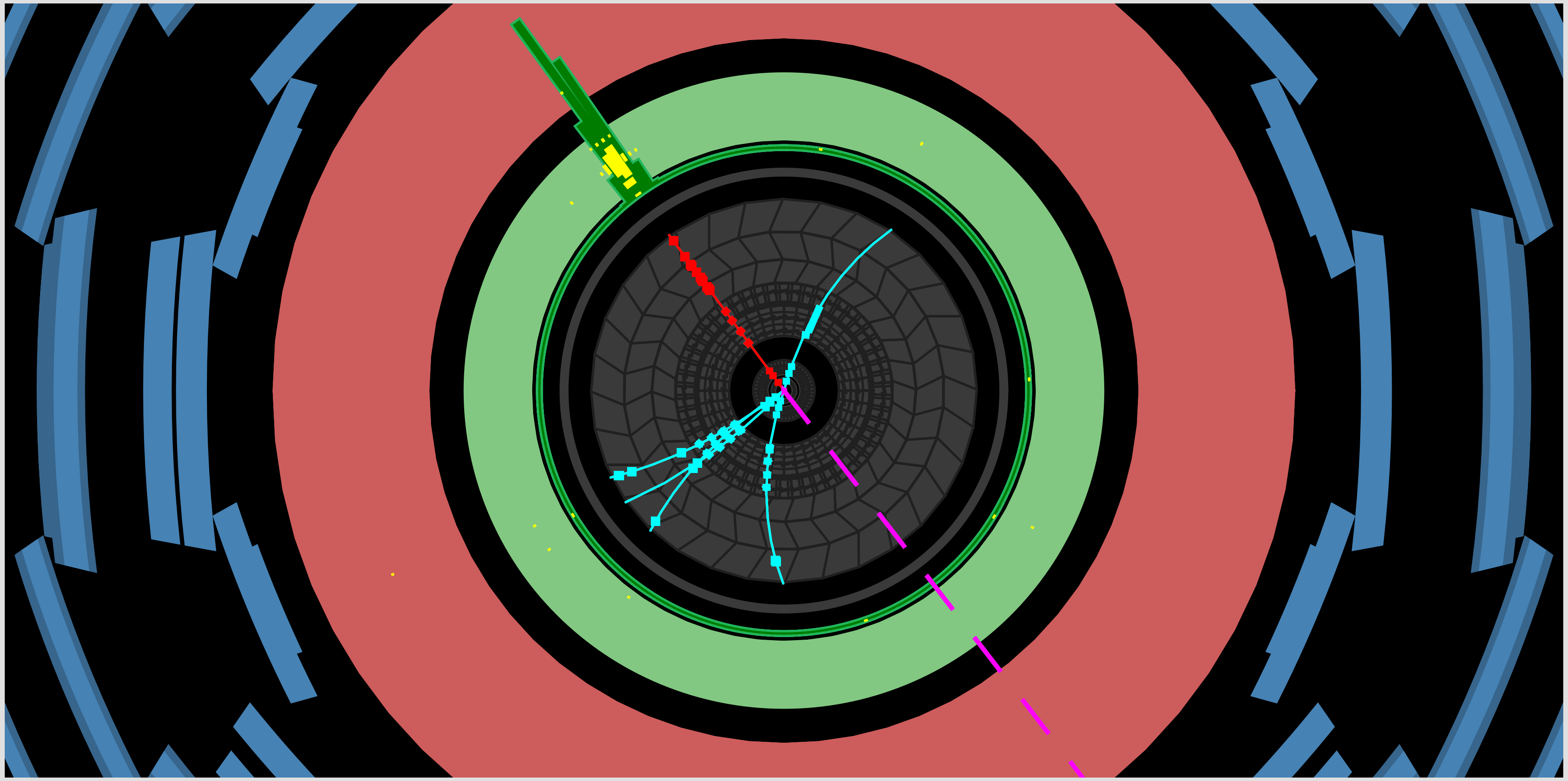
ATLAS EXPERIMENT

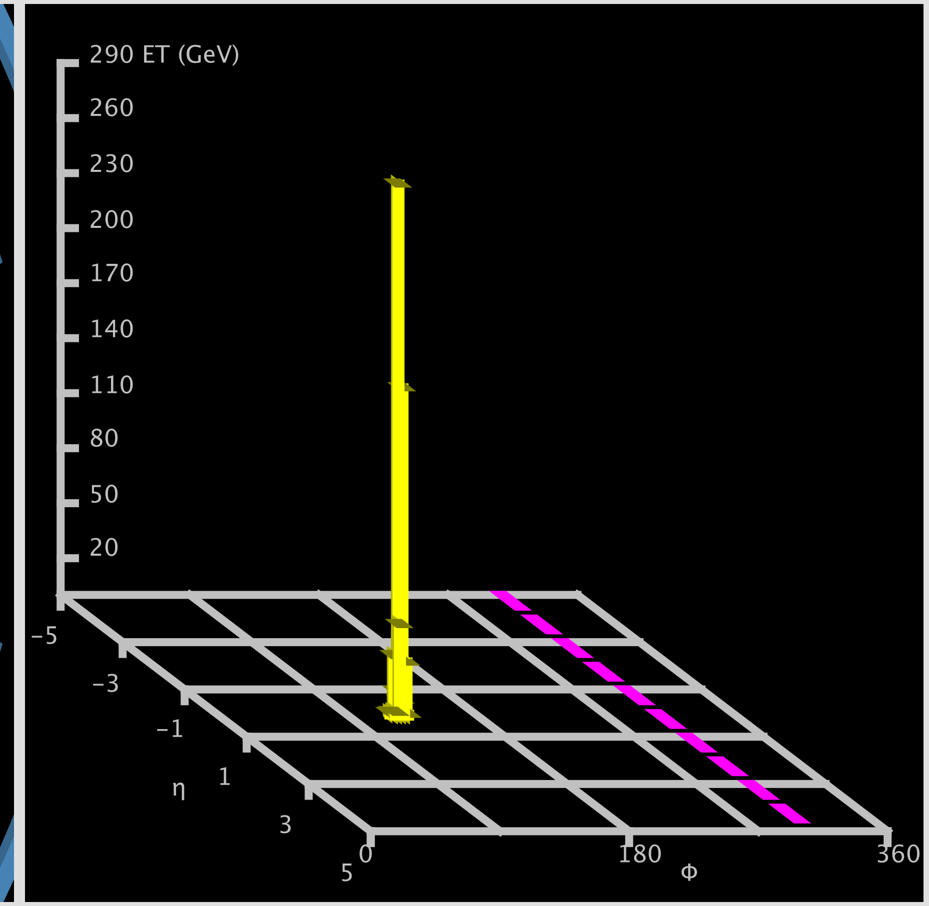
Run Number: 180149,
Event Number: 25360846
Date: 2011-04-22, 20:17:34 CET

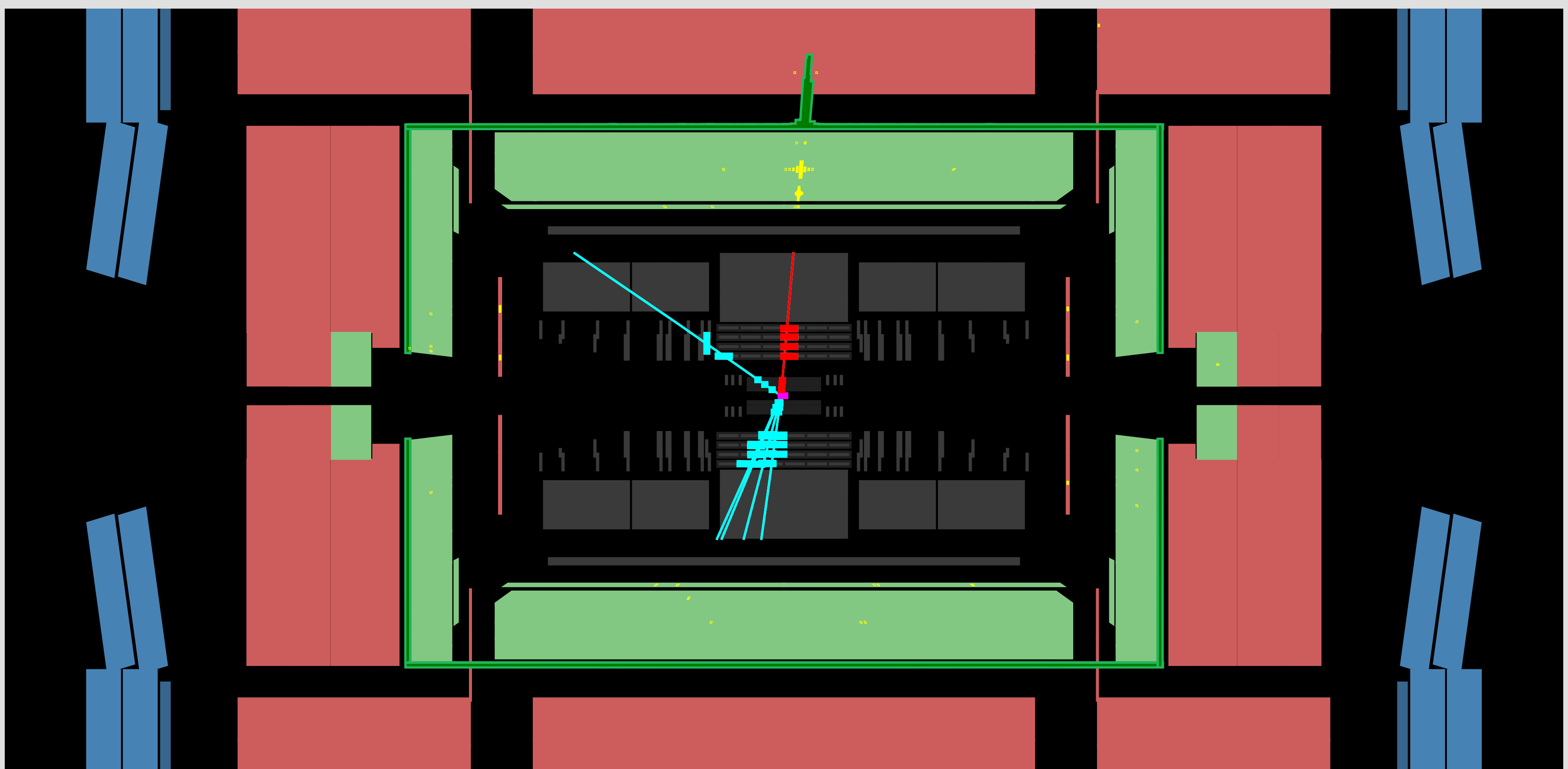
Cells:Tiles, EMC

m_T = 1.3 TeV
$p_T(\mu)$ = 690 GeV
missing E_T = 680 GeV

Highest m_T Electron Event







m_T = 1.3 TeV

$E_T(e)$ = 670 GeV

missing E_T = 670 GeV

Determining Signal Significance

- For each mass point the number of events above $m_{T\ min}$ is compared with the expected background.
- $m_{T\ min}$ is optimized on the expected significance of a given mass.
- Using Poisson statistics a likelihood is constructed comparing the expected number of events with the observed number of events.
- Systematic uncertainties are treated as gaussian nuisance parameters.
- Only the luminosity and generator MC uncertainties are treated as correlated, other correlations are considered negligible.

$$N_{\rm exp} = \epsilon_{\rm sig} L_{\rm int} \sigma B + N_{\rm bg}$$

$$\mathcal{L}(\sigma B) = \frac{N_{\rm exp}^{N_{\rm obs}} e^{-N_{\rm exp}}}{N_{\rm obs}!}$$

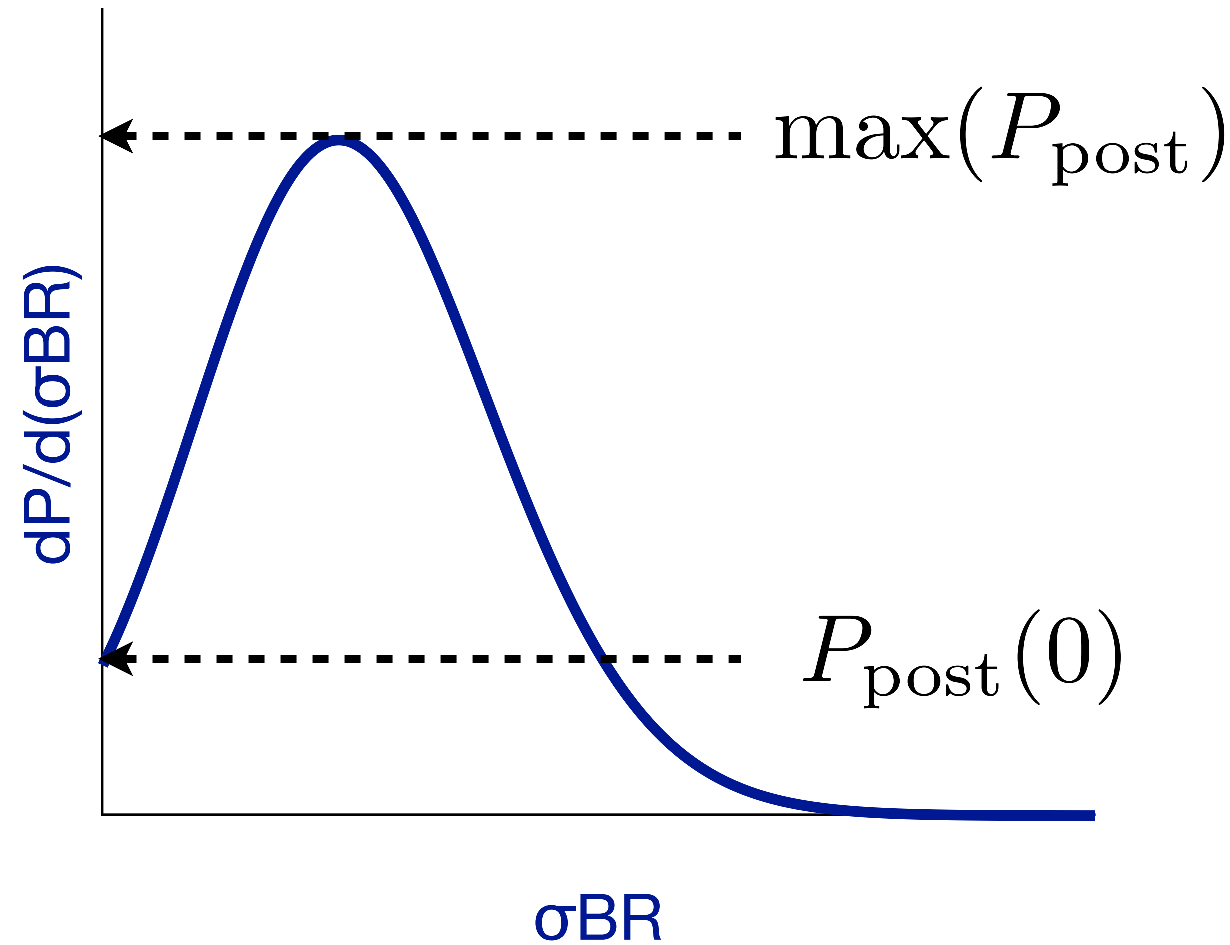
Determining Limits

- Using Bayes theorem a posterior probability is determined from the likelihood and assuming a flat prior.
- A discriminant is then constructed using the ratio of the maximum posterior probability to the posterior probability for no signal.
- A p-value is determined from this discriminant by seeing how often a background only hypothesis will give this outcome (or higher).
- Limits for 95% CL exclusion are determined by finding the smallest value of σ*BR for which the p-value of the posterior probability is 0.05.

$$P_{\text{post}}(\sigma B) = N\mathcal{L}(\sigma B)P_{\text{prior}}(\sigma B)$$

$$B_{\text{disc}} = \max(P_{\text{post}})/P_{\text{post}}(0)$$

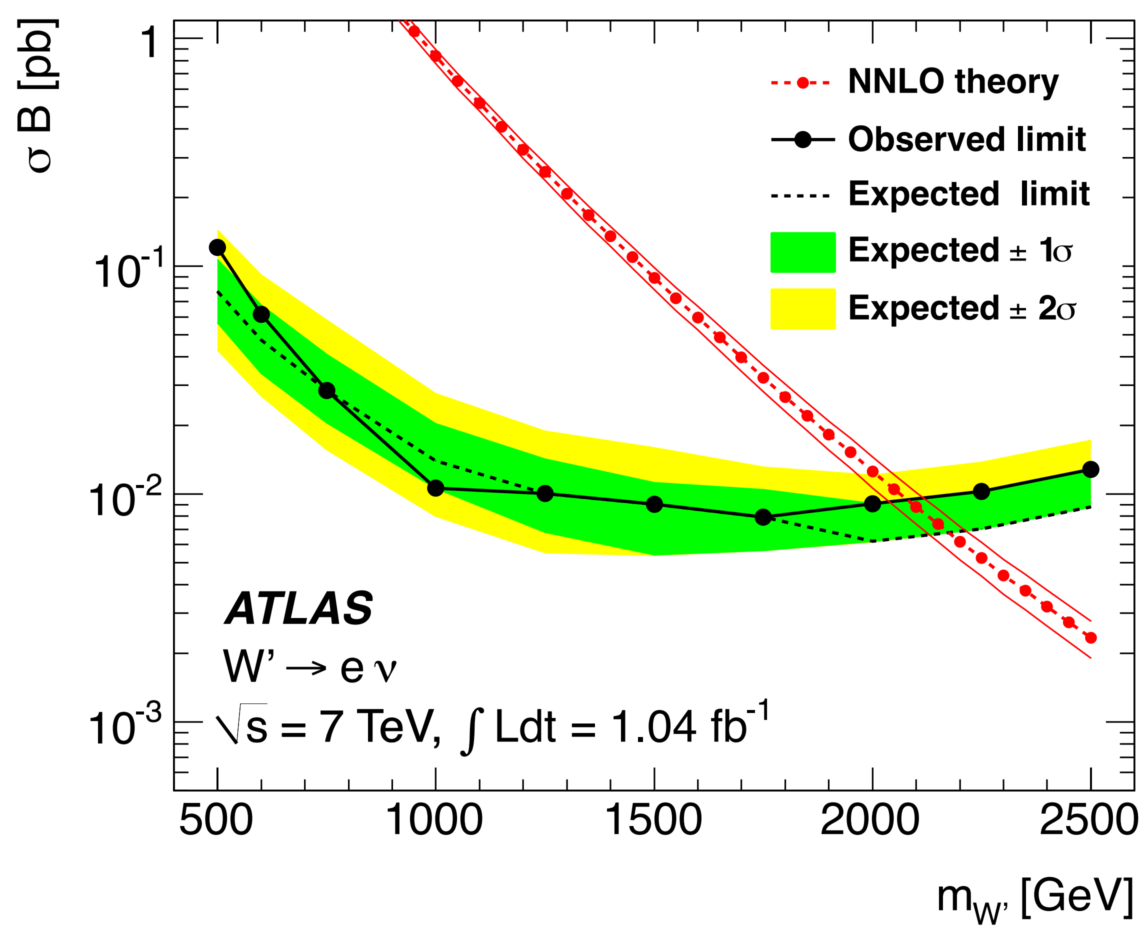
$$CL_{\text{bayes}} = \int_0^{\sigma B} P_{\text{post}}(x)dx$$



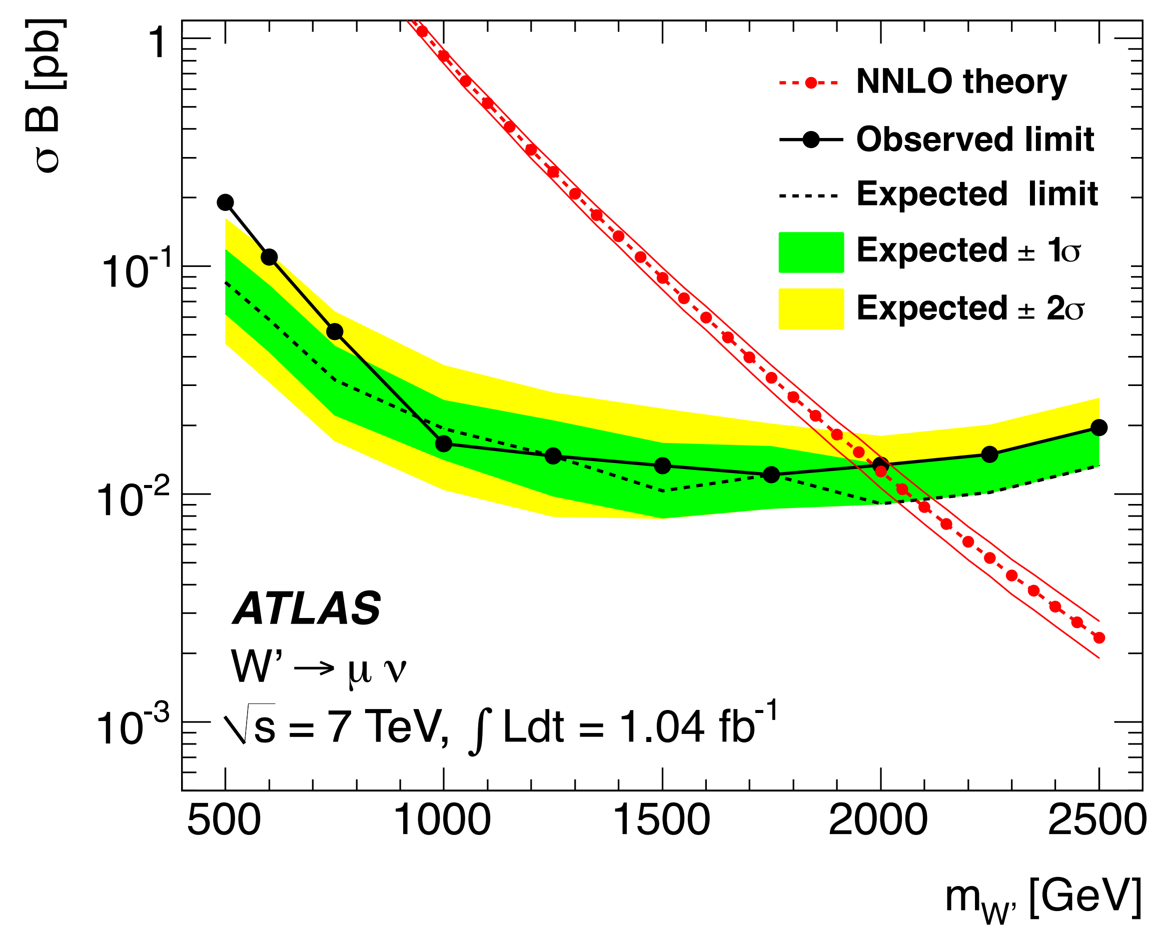
Individual Limits

- The individual σ*BR limits for several mass points.
- The most discrepant point is the 500 GeV mass point in both channels.
  - Future analysis will include lower mass points as well as higher mass points.

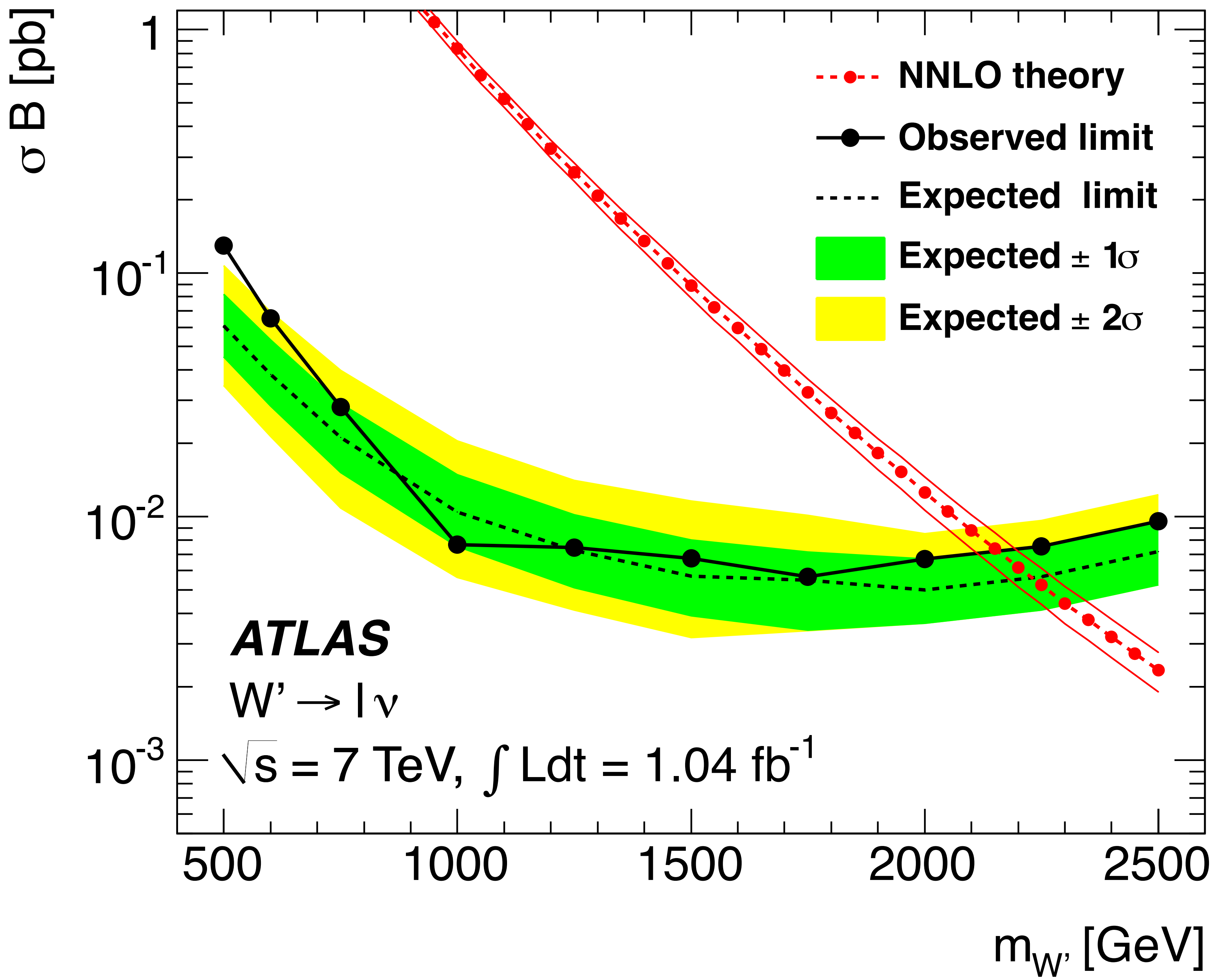
95% CL Limits for W Prime Electron Channel



95% CL Limits for W Prime Muon Channel



Combined Limits

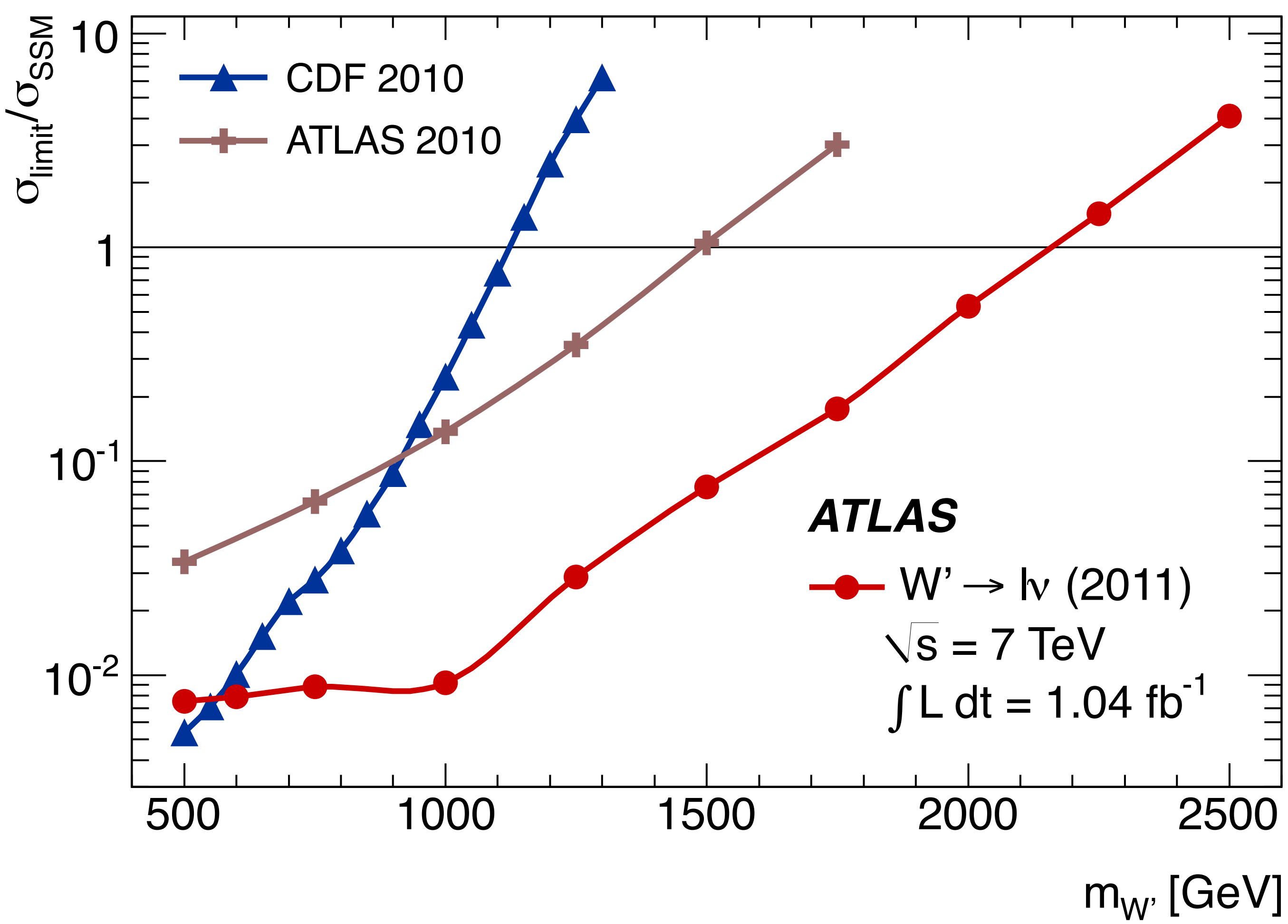


	$m_{W'}$ [TeV] Exp.	Obs.
$e\nu$	2.17	2.08
$\mu\nu$	2.08	1.98
both	2.23	2.15

Comparison with Previous Publications

- In 2010 ATLAS Published with 36 pb^{-1}.
- CDF has a better exclusion at low mass.
- CMS 2010 not shown because they are presenting newer limits at this conference.

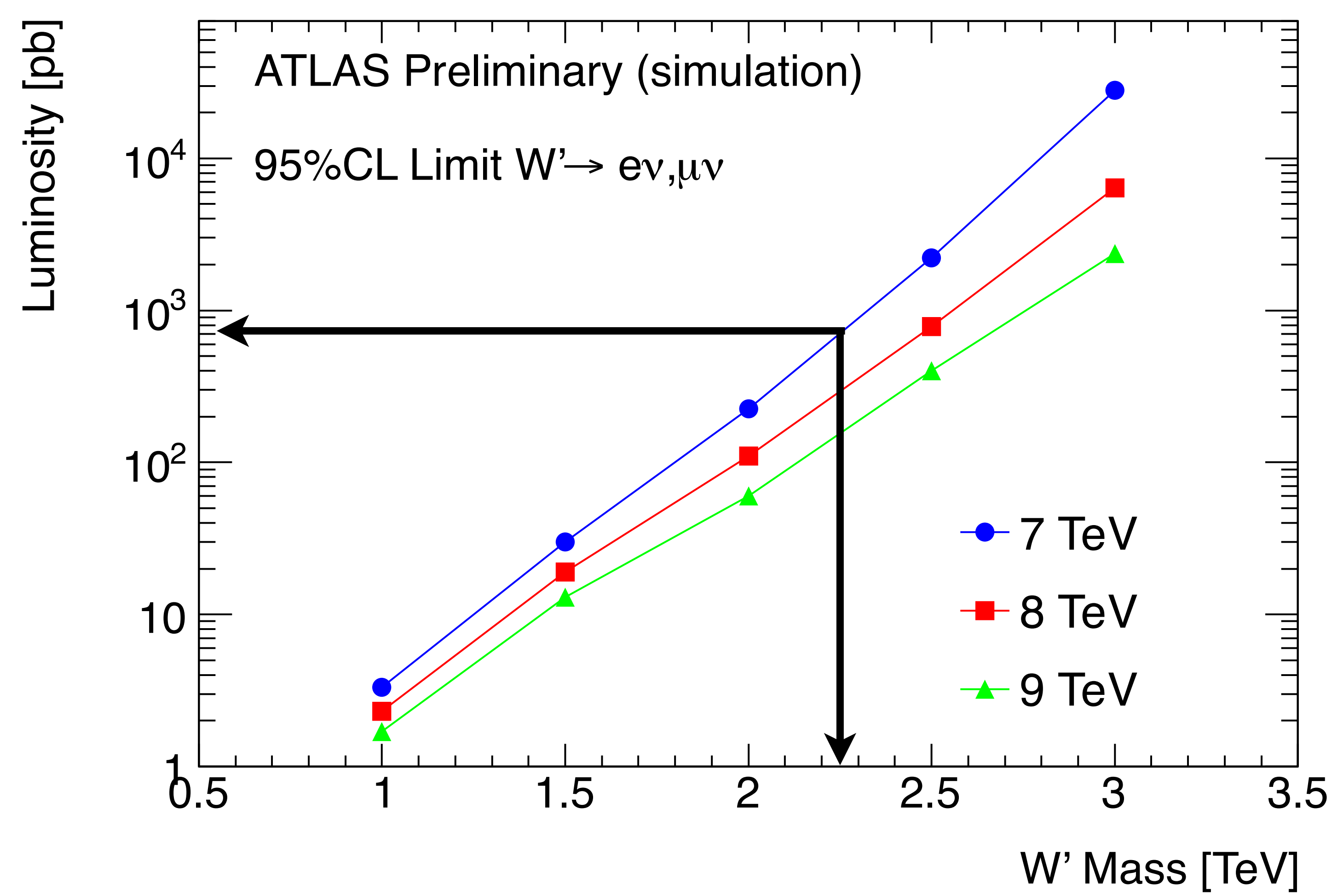
Normalized Production Limits (σ_{Limit} / σ_{SSM}) vs. Mass



Conclusion

- ATLAS has completed an update to its search for high m_T resonances from a lepton and missing E_T.
- No significant excess has been observed yet.
- 95% CL limits have been set on σ*BR for W Prime production to l+ν at 2.15 TeV.
- Analysis is submitted to PLB.
- arXiv: 1108.1316v1

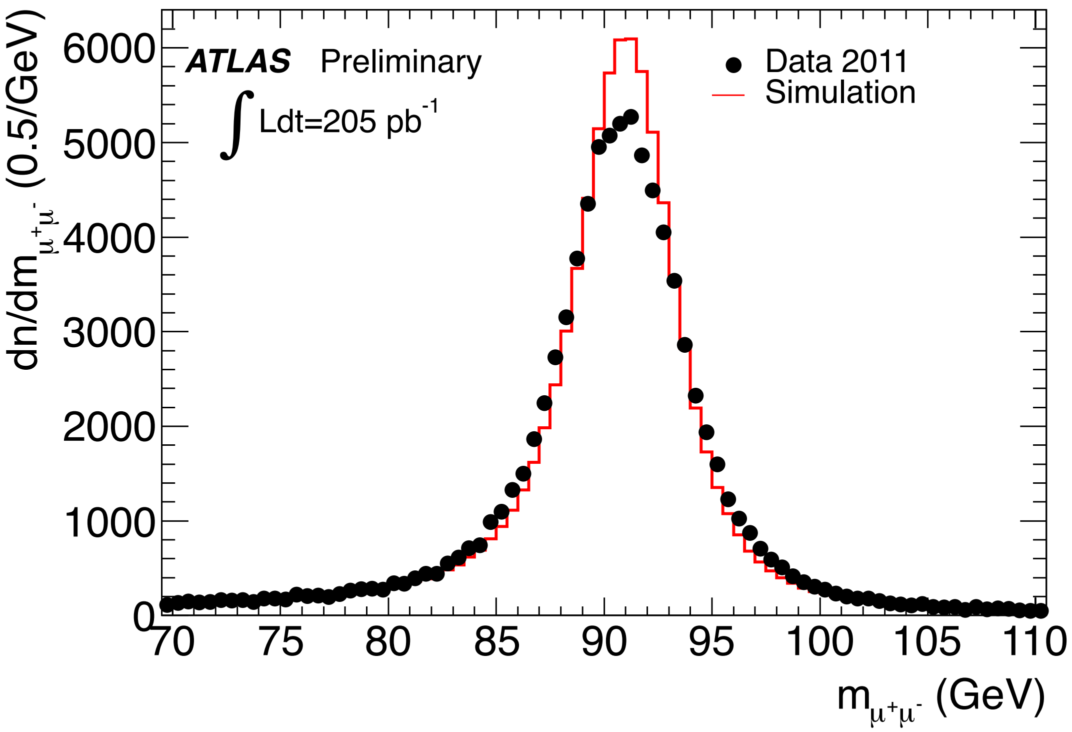
Expected Sensitivity vs. Center-of-Mass Energy

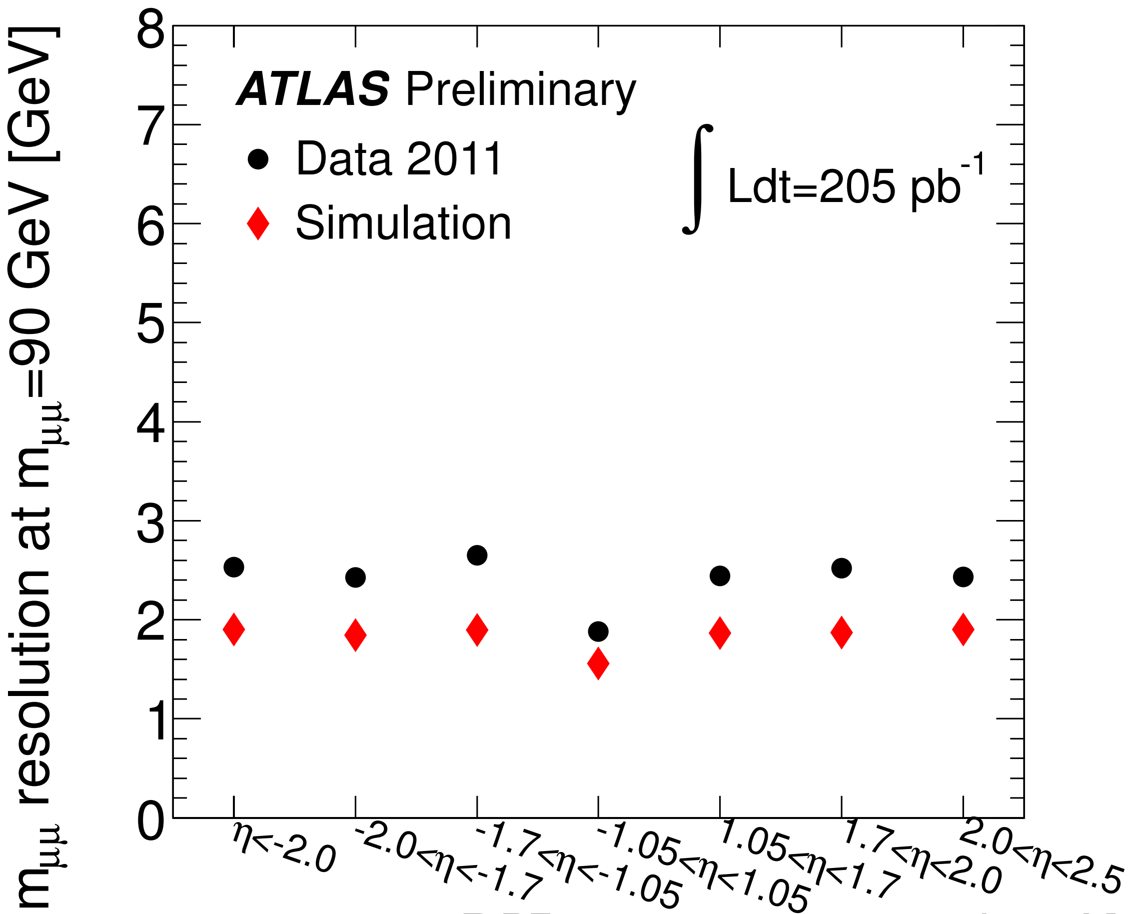


Backups

Muon Resolution

- Muon transverse momentum resolution is about 15% at 1 TeV.
- Already near design resolution.
- Alignment efforts are continually improving the resolution at high momentum.



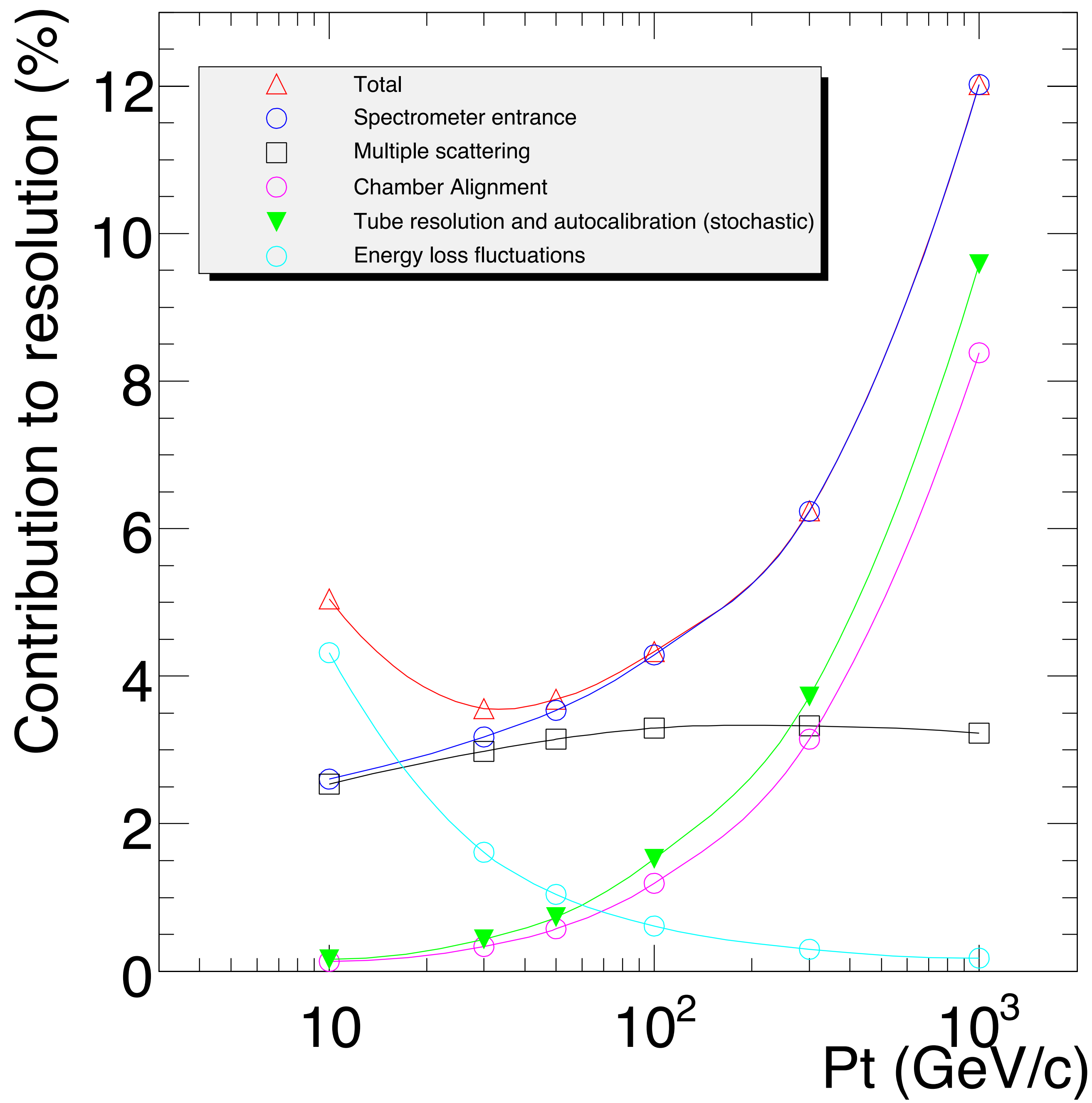


Muon Resolution

- Contributions to muon resolution at high transverse momentum from the muon spectrometer only.

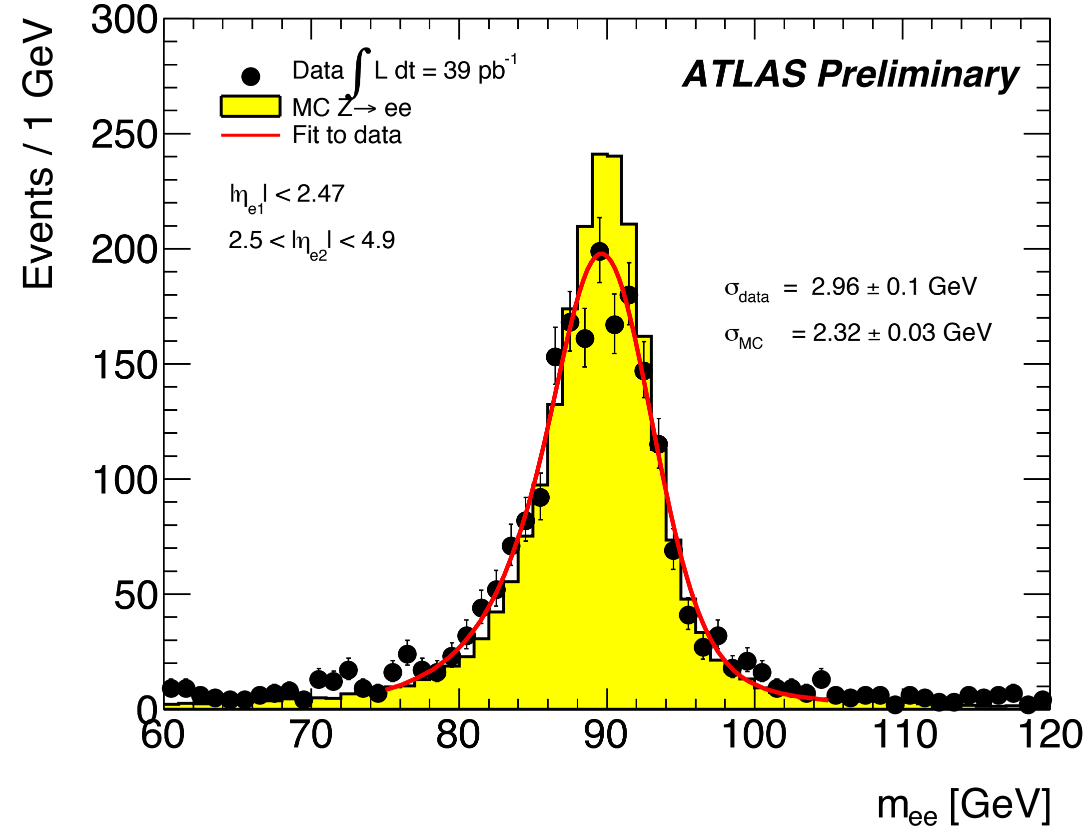
- At large muon momentum the muon spectrometer dominates the combined measurement.

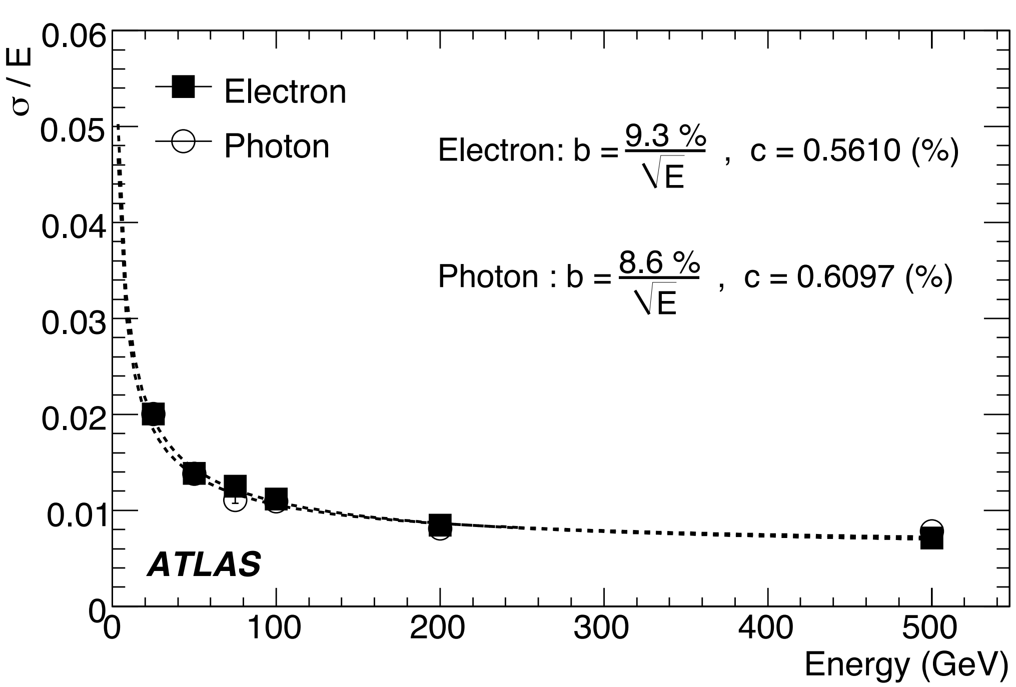
- The inner detector still does improve the momentum at high pt when combined with the MS.

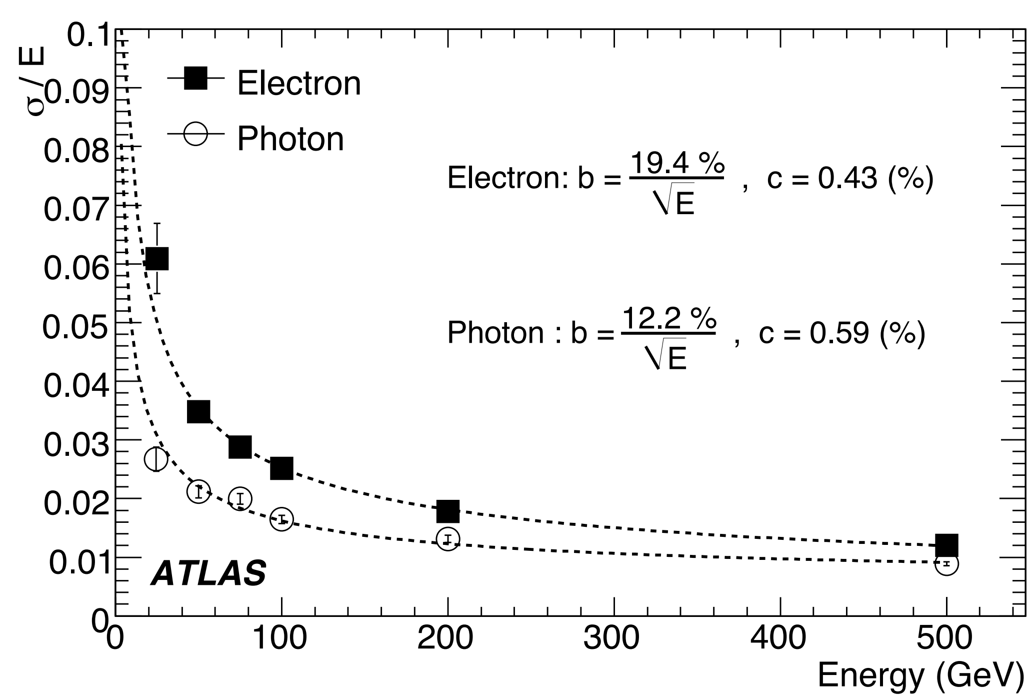


Electron Resolution

- Electron energy resolution varies with eta.
- At |η| of 1.65, resolution at 50 GeV is about 3.5%.
- At |η| of 0.3, resolution at 50 GeV is about 1.3%.







Limit Inputs

- Inputs to the limit calculation at different mass points.
- $m_{T\,min}$ is chosen to minimize the expected σ*BR limit.

$m_{W'}$ [GeV]	m_{Tmin} [GeV]		$\varepsilon_{\mathrm{sig}}$	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

95% CL Limits by Mass Bin

- 95% CL limits on σ*BR for different mass points.
- "S" is selection efficiency uncertainty only.
- "SB" is selection efficiency and background level uncertainties only.
- "SBL" is the final limit with all nuisance parameters (including the luminosity uncertainty).

$m_{W'}$ [GeV]		95% CL limit on σB [fb] none	S	SB	SBL
500	$e\nu$	97	98	117	121
	$\mu\nu$	171	174	186	191
	both	109	110	127	130
600	$e\nu$	49	49	59	61
	$\mu\nu$	99	100	108	110
	both	55	55	64	65
750	$e\nu$	23.0	23.1	28.1	28.5
	$\mu\nu$	49.2	49.8	50.9	51.7
	both	23.7	23.8	27.8	28.1
1000	$e\nu$	10.1	10.2	10.5	10.6
	$\mu\nu$	16.1	16.3	16.5	16.7
	both	7.3	7.3	7.6	7.7
1250	$e\nu$	9.8	9.9	10.0	10.1
	$\mu\nu$	14.4	14.5	14.6	14.7
	both	7.3	7.3	7.4	7.5
1500	$e\nu$	8.8	8.9	9.0	9.0
	$\mu\nu$	13.0	13.2	13.2	13.3
	both	6.6	6.6	6.7	6.7
1750	$e\nu$	7.8	7.9	7.9	7.9
	$\mu\nu$	12.0	12.1	12.1	12.2
	both	5.6	5.6	5.7	5.7
2000	$e\nu$	8.9	9.0	9.0	9.1
	$\mu\nu$	13.2	13.3	13.3	13.4
	both	6.6	6.7	6.7	6.7
2250	$e\nu$	10.2	10.2	10.3	10.3
	$\mu\nu$	14.8	14.9	14.9	15.0
	both	7.5	7.5	7.6	7.6
2500	$e\nu$	12.7	12.8	12.8	12.9
	$\mu\nu$	19.2	19.5	19.6	19.7
	both	9.5	9.6	9.6	9.6