Поиск тяжелых векторных бозонов W’ и W* в эксперименте ATLAS

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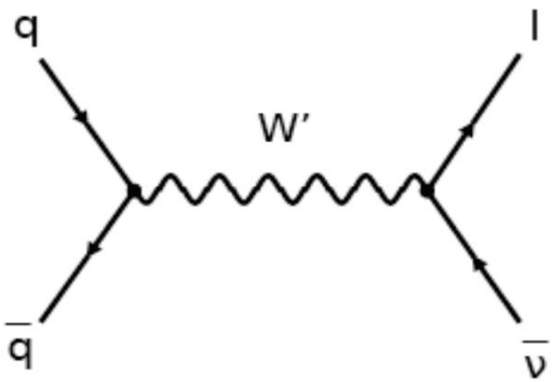
ОФВЭ, ПИЯФ

Outline

- Introduction
- Search strategy
- ATLAS detector overview (Inner Detector, Calorimeter, Muon System)
- Signal and Background
- Common Event selection
- Electron event selection
- Muon event selection
- Data-driven QCD background estimate
- Results with 2011 data
- Summary

Introduction

- Many models predict the existence of heavy gauge bosons
- Search for a new charge ±1, spin 1 gauge boson
- Use Sequential Standard Model (SSM) W’ as a benchmark model



- W’ has the same couplings to fermions as SM W
- Use lepton decay mode for analysis: electron (or muon) and neutrino

Introduction

- Many models predict the existence of states decaying to lepton and neutrino

- One of such models is excited boson W* *[M. Chizhov, G. Dvali , Phys.Lett. B703 (2011) 593-598]* .

- W* has also charge ±1 and spin 1.

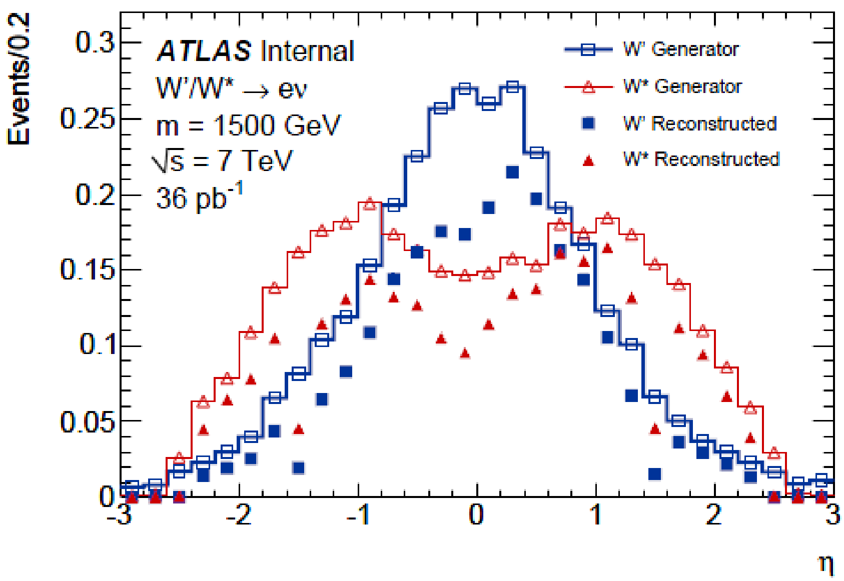
- It has different interactions than W'. It is coupled to fermions tensor currents which mix both left-handed and right-handed fermions.

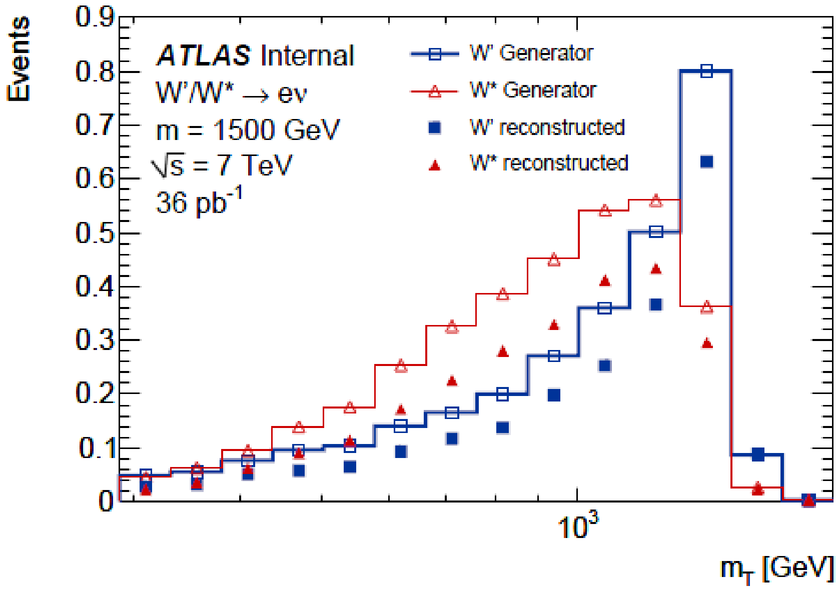
$$\mathcal{L}_{W'} = \bar{\psi}\gamma^{\mu}(g_V + g_A\gamma^5)\psi \cdot W'_{\mu} \qquad \mathcal{L}_{W*} = \frac{g}{2\Lambda}\bar{\psi}\sigma^{\mu\nu}\psi \cdot (\partial_{\mu}W^*_{\nu} - \partial_{\nu}W^*_{\mu})$$

- Introduction of such bosons helps to solve the Hierarchy Problem

Introduction

- W' and W* has significantly different kinematic distributions





- It can be used in future for model-dependent analysis

Search strategy

- Search for high mass states with lepton+MET

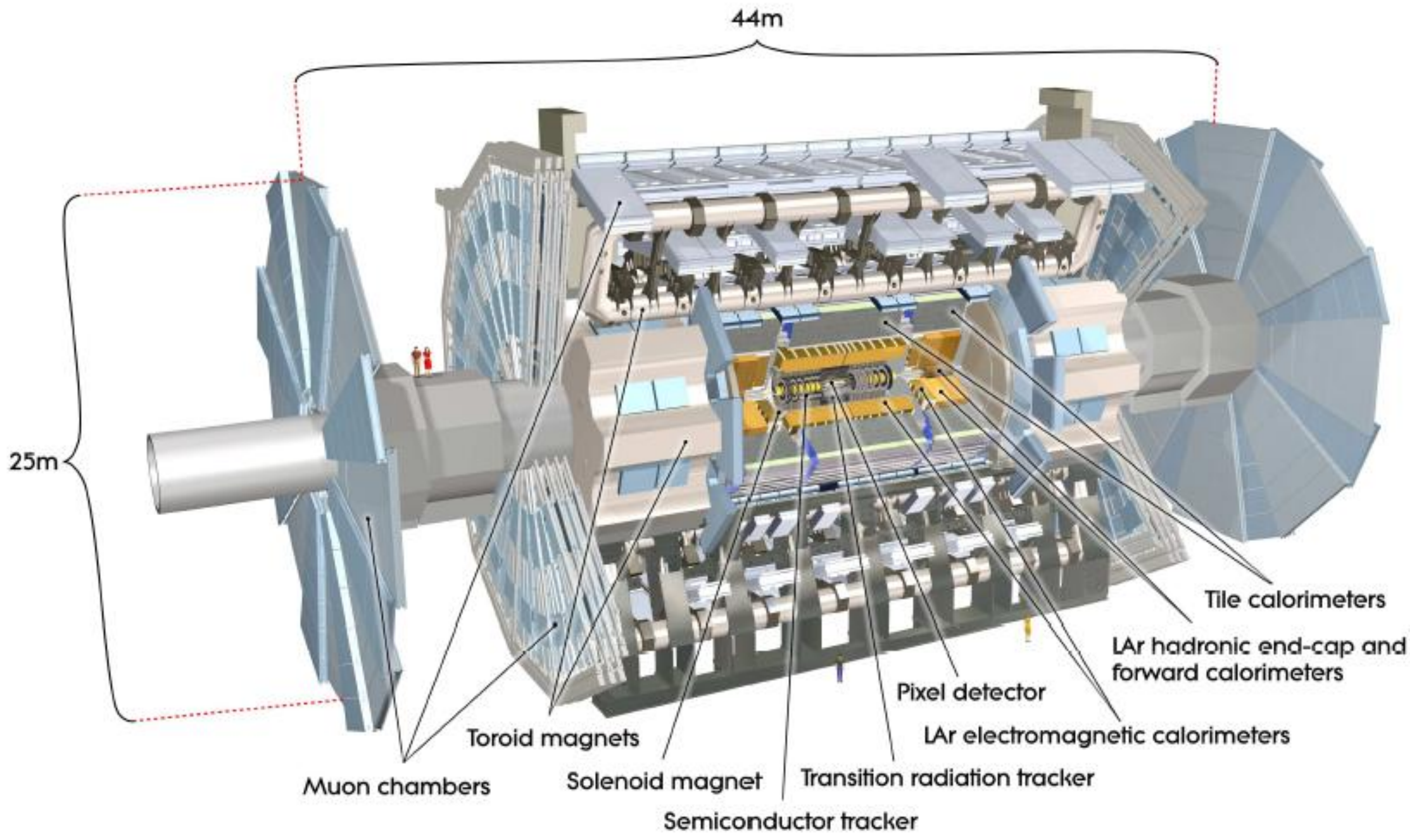
- The observable is transverse mass:

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

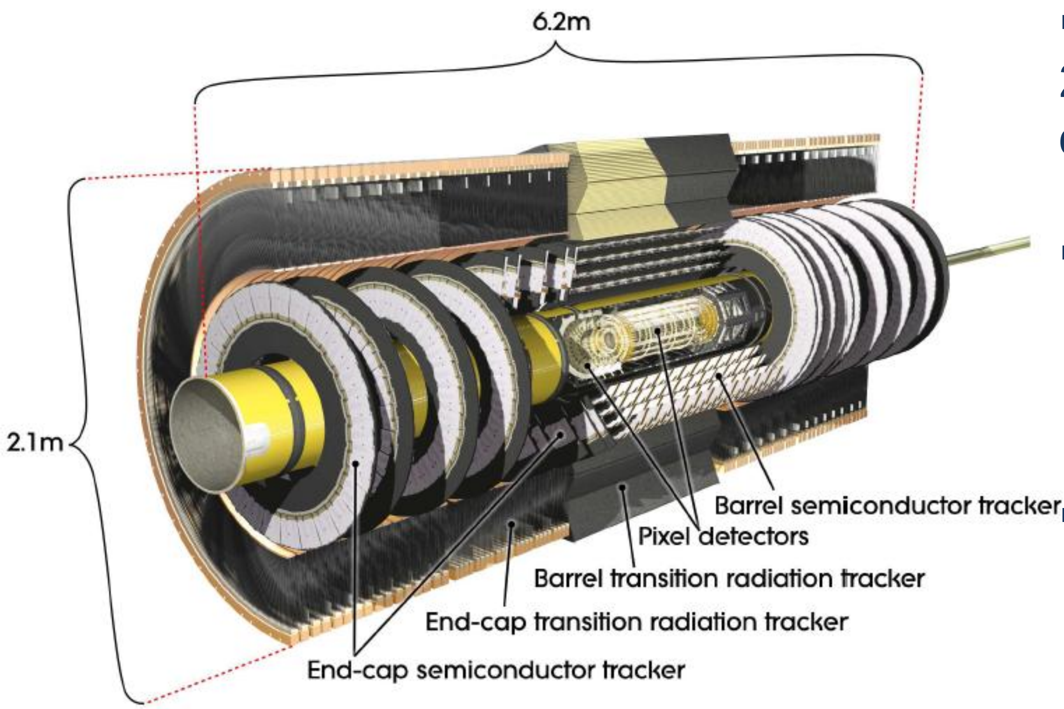
- Look for significant excess above background expectations

- If no excess is observed then set limit on the σ*BR using bayesian analysis

ATLAS detector overview



Inner detector



- The Inner Detector is immersed in a 2 T magnetic field generated by the central solenoid

- Pixel detector:
  - barrel – 3 layers
  - end-cap – 2x3 discs
  - ~80.4 million channels
  - resolution: 10 μm(rϕ), 115 μm(r,z)
- Semiconductor tracker (SCT):
  - barrel – 4 layers
  - end-cap – 2x9 discs
  - ~6.3 million channels
  - resolution: 17 μm(rϕ), 580 μm(r,z)
- Transition Radiation Tracker (TRT):
  - barrel – 73 straw planes
  - end-cap – 160 straw planes
  - ~351000 channels
  - resolution: 130 μm(r,z)

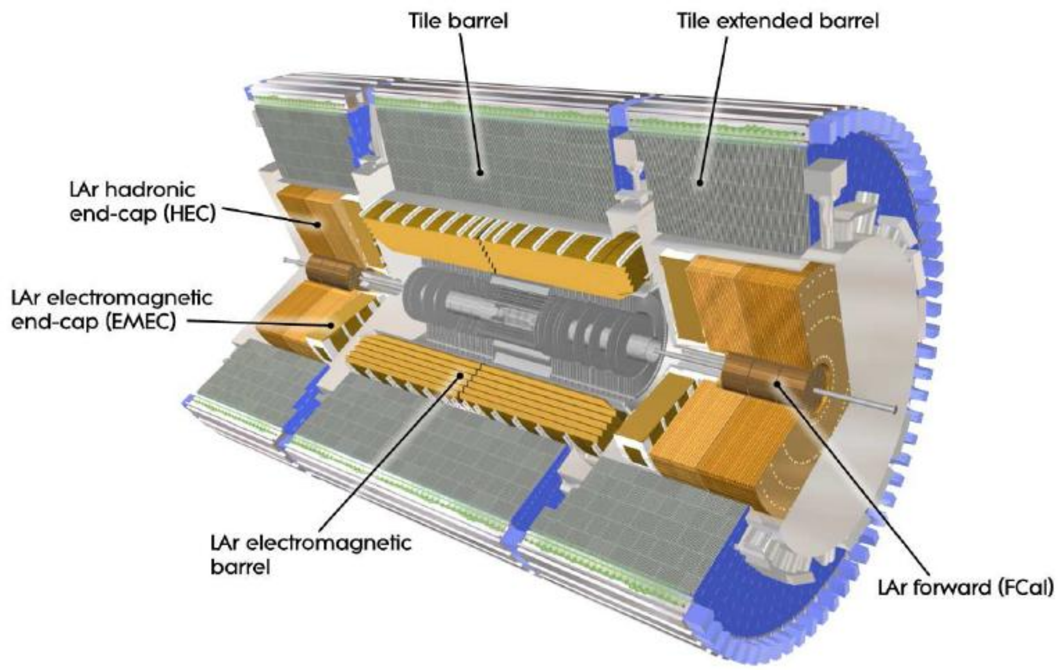
- Pixels and SCT cover the region |η| < 2.5
- TRT covers the region |η| < 2.0
- precision measurement of charged particle trajectories.

$$\frac{\sigma(p_T)}{p_T} = 0.034\% p_T[GeV] \oplus 1.5\%$$

$$\sigma(d_0) = 10\mu m \oplus 140\mu m / p_T[GeV]$$

Calorimeter

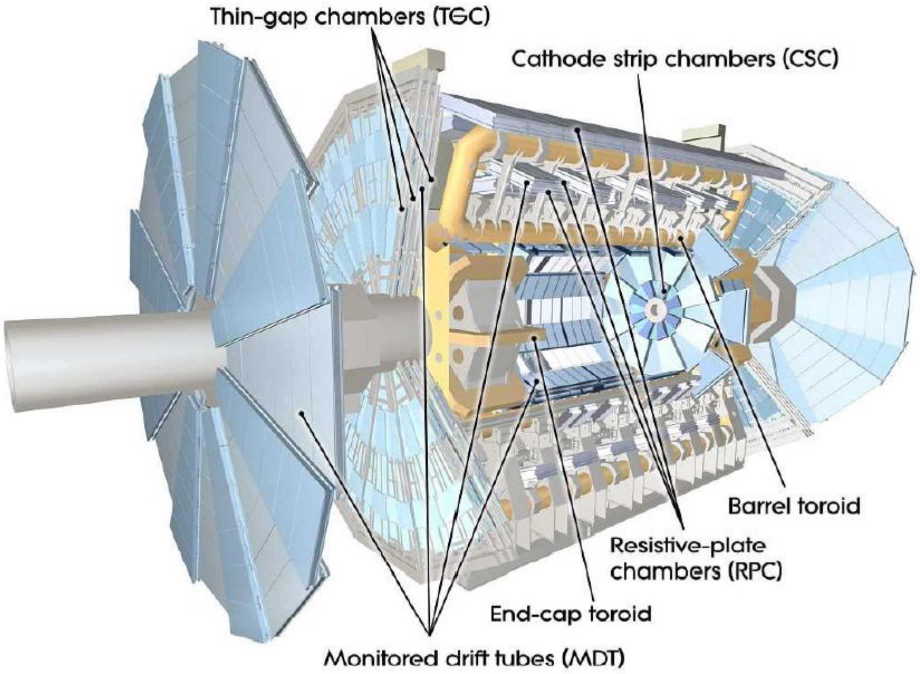
- Covers the range |η| < 4.9
- Liquid Ar electromagnetic calorimeter:
  - lead as absorber
  - accordion structure
  - 3 layers+presampler
  - barrel+endcap covers region |η| < 3.2
- Tile hadronic calorimeter:
  - steel as absorber
  - scintillating tiles as active material
  - barrel |η| < 1.0
  - extended barrel 0.8 < |η| < 1.7
- Liquid Ar hadronic end-cap calorimeter:
  - Copper as absorber
  - covers 1.5 < |η| < 3.2
- Liquid Ar forward calorimeter:
  - copper (1 module) and tungsten (2 modules) as absorbers
  - covers 3.1 < |η| < 4.9



- Energy resolution of LAr electromagnetic calorimeter:

$$\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}} \oplus 0.7\%$$

Muon system



- p_T resolution varies from 4% (for 10 GeV) to 10%(for 1 TeV) as a function of p_T

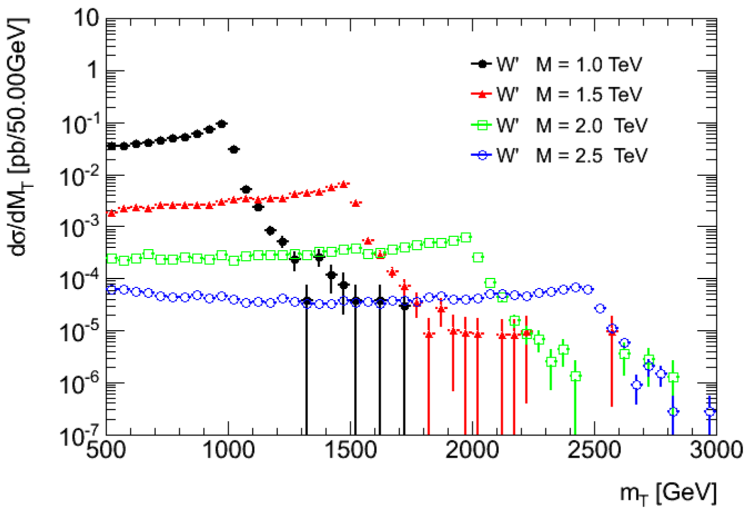
- Measure muon momentum in $|\eta| < 2.7$
- Magnet system: barrel and end-cap toroid magents
- Monitored drift tubes (MDT):
  - consist of three to eight layers of drift tubes
  - cover $|\eta| < 2.7$ range
  - $|\eta| < 2.0$ for innermost end-cap
- Cathode strip chambers (CSC):
  - proportional chambers with cathode planes segmented into strips
  - cover $2.0 < |\eta| < 2.7$
- Trigger chambers:
  - barrel ($|\eta| < 1.05$) – Resistive Plate chambers (RPC)
  - end-cap ($1.05 < |\eta| < 2.4$) – Thin Gap Chambers (TGC)

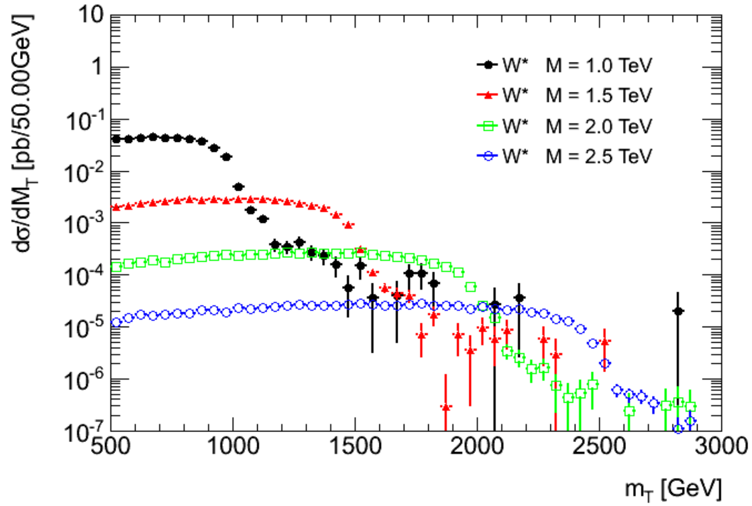
Signal and Background

Signal samples

- Signal samples: W’, W* - generated for different mass points

W’/W* mass [GeV]	W’ σB [pb]	W* σB [pb]
150	1299.7	-
200	494.65	-
300	107.53	-
400	36.47	32.834
500	15.12	13.612
600	7.287	-
750	2.843	2.4309
1000	0.7659	0.61184
1250	0.2451	0.18194
1500	0.08777	0.059298
1750	0.0337	0.020278
2000	0.01326	0.0071366
2250	0.00605	0.0025477
2500	0.00289	0.00091657
2750	0.001559	0.00033089
3000	0.000872	0.00012051
3500	0.000388	-



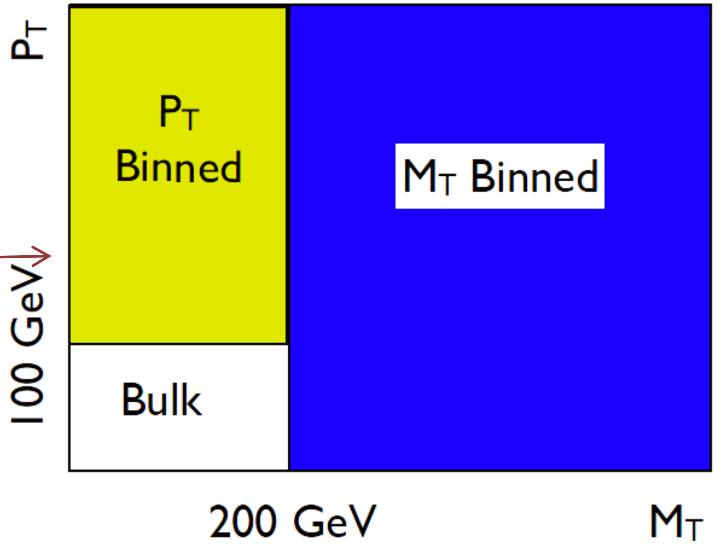


Background

- W→lν - most dominant and irreducible
- Z →ll - when one lepton is not reconstructed
- Dibosons (WW, WZ, ZZ)
- ttbar
- single t
- Wγ
- QCD (estimated from data)

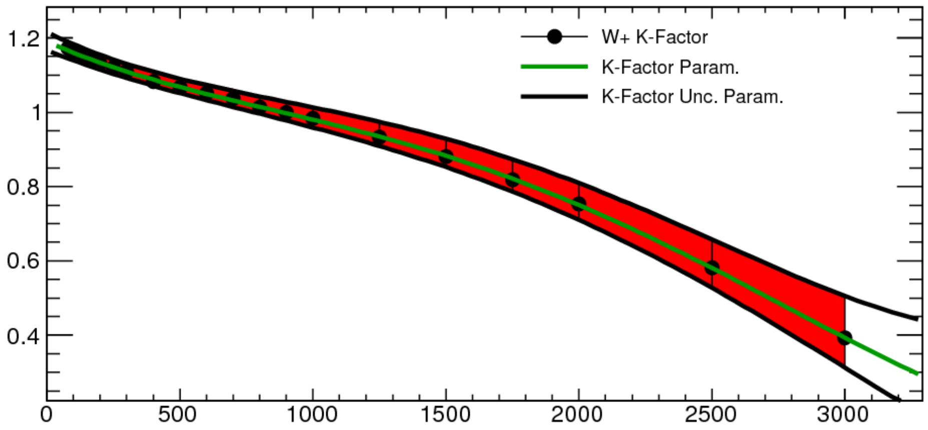
Sample	σB [pb]
W→lν	8938
Z →ll	856
WW	11.49
WZ	3.481
ZZ	0.976
ttbar	80.2
single t	14.6 - 0.47
Wγ	72.87

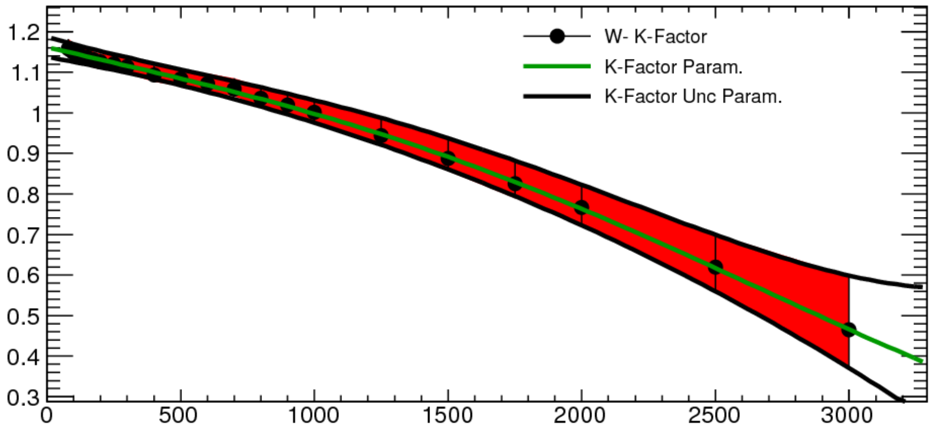
For W background along with bulk samples also mass and p_T binned samples are used to cover statistic in high m_T and hight p_T respectively. Relevant truth mass and truth p_T filters are applied.



k-Factors

- Mass dependent k-Factors for NNLO were obtained
- k-Factors include EW corrections
- Polynomial fit was applied
- Uncertainties were evaluated
- Should be applied separately for W^+ and W^-
- Applied as event weight





Event selection

- Good Runs (luminosity blocks): all significant parts detector were working properly ~4.7 fb^{-1}

- Primary vertex: at least 3 tracks, $|z|<200$ mm

- Jet Cleaning: to avoid events with spurious MET, events are rejected if they have a bad jet with $E_T > 20$ GeV

Electron channel selection

- Trigger: EF_g80_loose (EF_e20_medium)
- Author electron 1 or 3
- $|\eta^{cluster}|<2.47$ (excluding crack: $1.37< |\eta^{cluster}|<1.52$)
- $E_T > 85$ GeV (25 GeV)
- Medium electron
- Blayer if expected
- Object Quality (OQ)
- LAr noise suppression (reject if LAr Error >1)
- $|d_0^{PV}|<1$ mm & $|z_0^{PV}|<5$ mm
- Trigger match ($\Delta R < 0.15$)

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

- Exactly 1 electron
- Calo Isolation: Etcone40(corrected) < 9 GeV
- MET > 85 GeV (25 GeV)
- MET/ET > 0.6 cut was dropped. It was used in previous analysis to suppress QCD. Now it is not needed due to high E_T and MET thresholds

Muon channel selection

- Trigger:
  - EF_mu22 || EF_mu22_MG || EF_mu40_MSonly_barrel (before period J)
  - EF_mu22_medium || EF_mu22_MG_medium || EF_mu40_MSonly_barrel_medium (after period J)
- STACO combined
- p_T>25 GeV
- MCP ID hits requirements
- $|d_0^{PV}|<0.2$ mm & $|z_0^{PV}|<1$ mm
- Exactly one muon
- MS hits:
  - N^{MDT} hits > 2 for all three barrel stations
  - $N_\varphi^{RPC/TGC}$ hits> 1 for at least two stations
  - No misaligned chambers (BEE, EE, BIS78)
  - No Barrel-Endcap overlap
  - No CSC hits ($|\eta| < 2.0$)
- Trigger match ($\Delta R<0.10$)
- Isolation: $\Sigma p_T^{\Delta R<0.3}/p_T^{\mu} < 0.05$
- MET > 25 GeV
- $|S(q/p)| = |\delta(q/p)/\sigma(\delta(q/p))| < 5.0$

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

QCD background estimate

Data-driven QCD estimate

- Event which has one jet which fakes lepton or real lepton from a heavy flavor quark decay and other jet is mismeasured faking MET

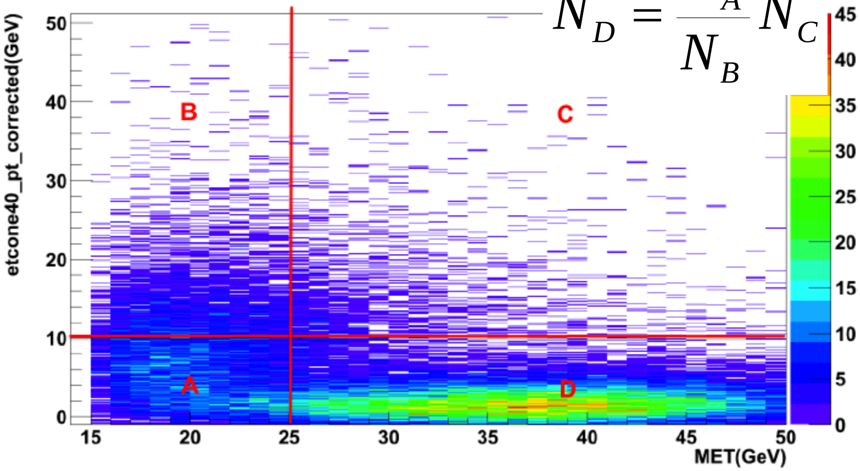
- Methods to estimate QCD in the electron channel:
  - ABCD
  - Calorimeter isolation template
  - Inverted electron identification
  - Matrix method

- Methods to estimate QCD in the muon channel:
  - Matrix method
  - Inverted isolation

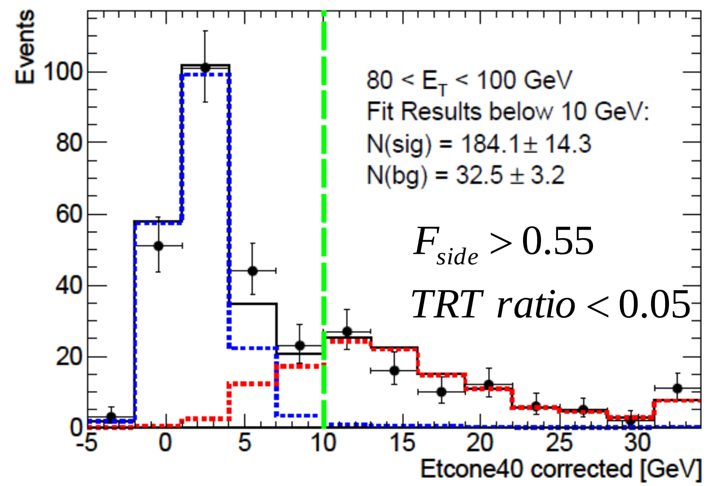
QCD estimate (electron channel)

ABCD method

$$N_D = \frac{N_A}{N_B} N_C$$

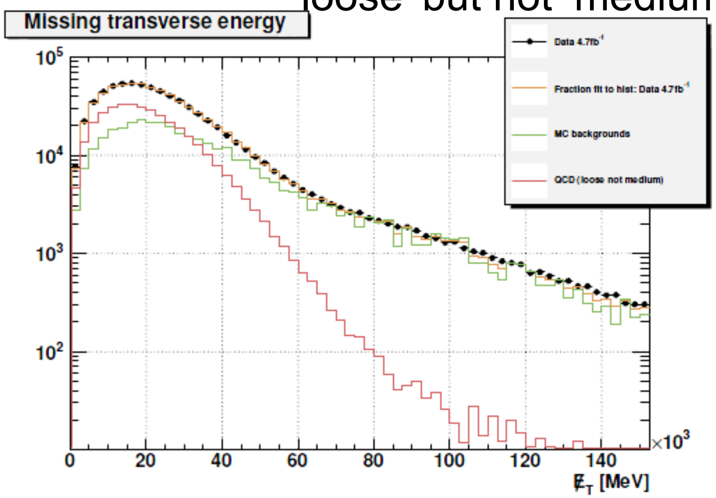


Calorimeter isolation template



Inverted electron identification

'loose' but not 'medium'



Matrix method

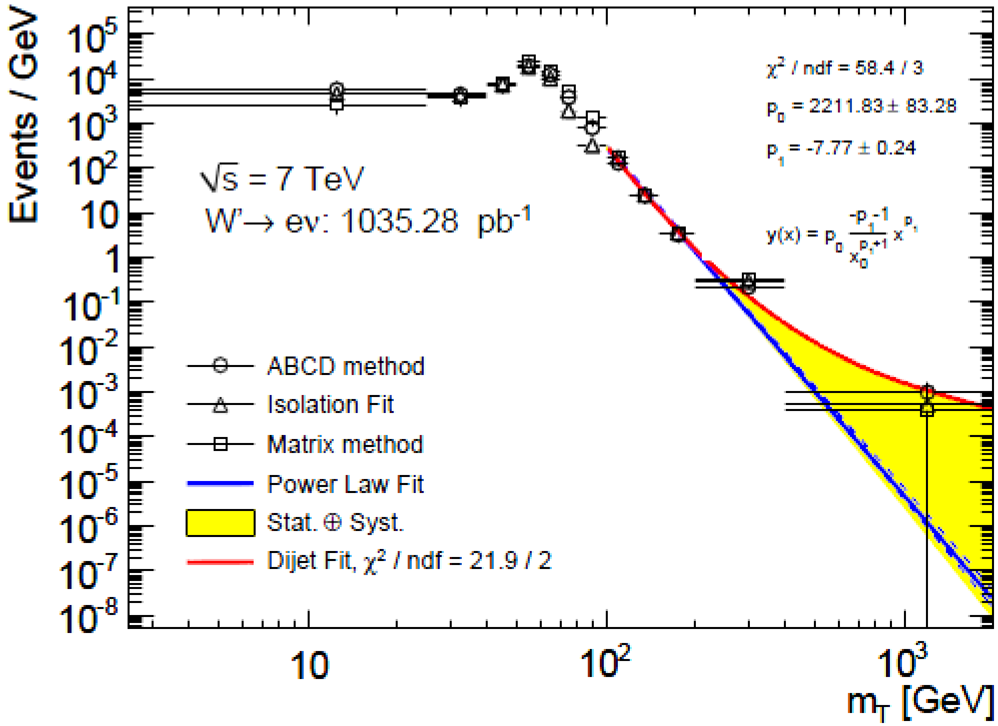
'tight' – W' electron selection

'loose' – B-layer cut was removed

$$\varepsilon_{\text{real}} = \frac{N^{\text{real}}_{\text{tight}}}{N^{\text{real}}_{\text{loose}}} \quad \text{and} \quad \varepsilon_{\text{fake}} = \frac{N^{\text{fake}}_{\text{tight}}}{N^{\text{fake}}_{\text{loose}}}$$

$$N^{\text{fake}}_{\text{tight}} = \frac{\varepsilon_{\text{fake}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} \left(\varepsilon_{\text{real}} N_{\text{loose}} - N_{\text{tight}} \right)$$

QCD estimate (electron channel)



Power law fit:

$$y = p_0 \cdot x^{p_1}$$

Dijet fit:

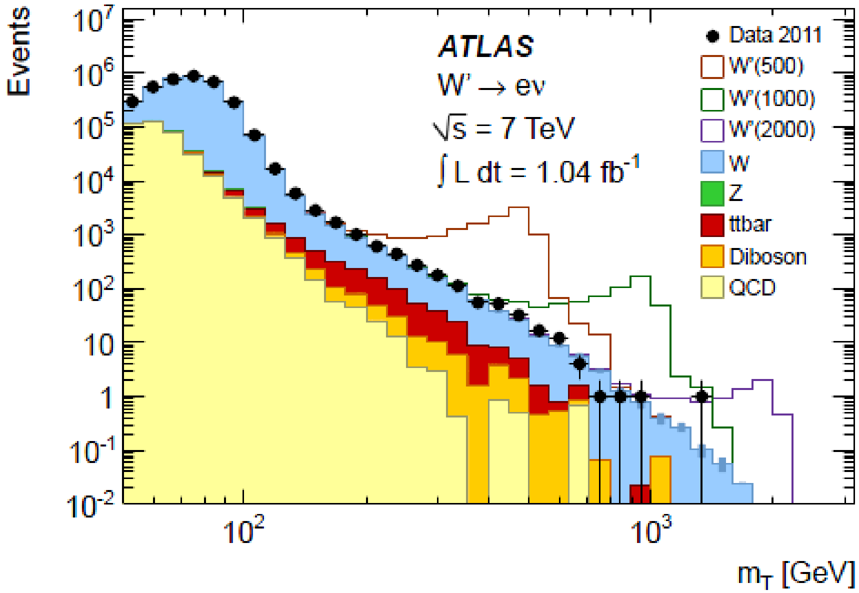
$$y = p_1 \cdot (1 - x)^{p_2} \cdot x^{p_3 + p_4 \ln x}$$

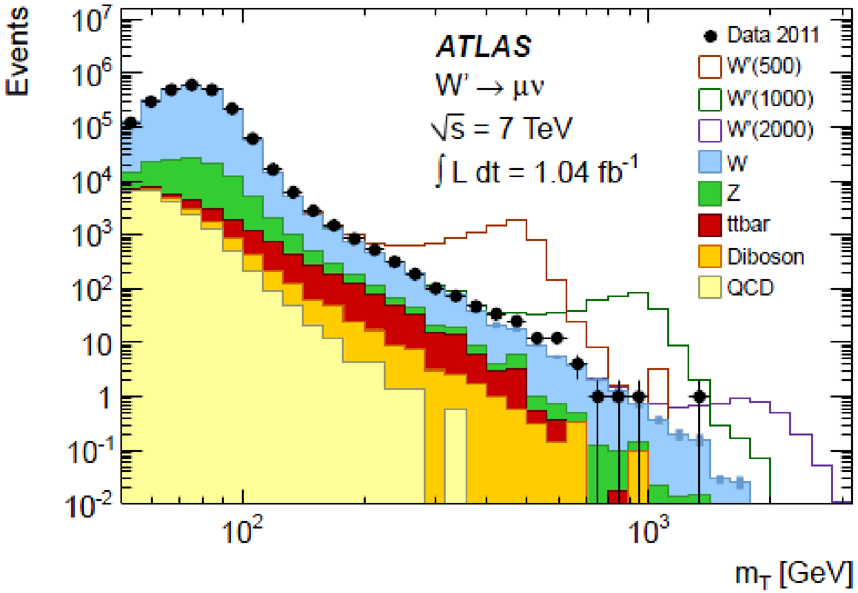
Results with 2011 data

2011 published results (I)

- Conf note was written in summer 2011 (for PLCH, Perugia, 6-11 June) with 205 pb^{-1}

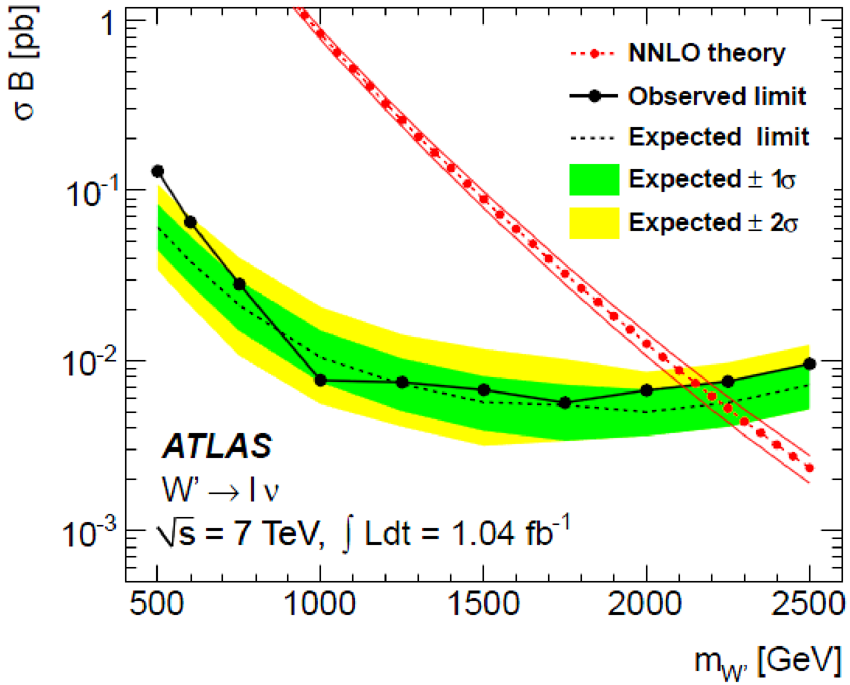
- Paper was shown in EPS (Grenoble, 21-27 June) and was published in PLB with 1 fb^{-1} integrated luminosity *[Phys.Lett. B705 (2011) 28-46]*

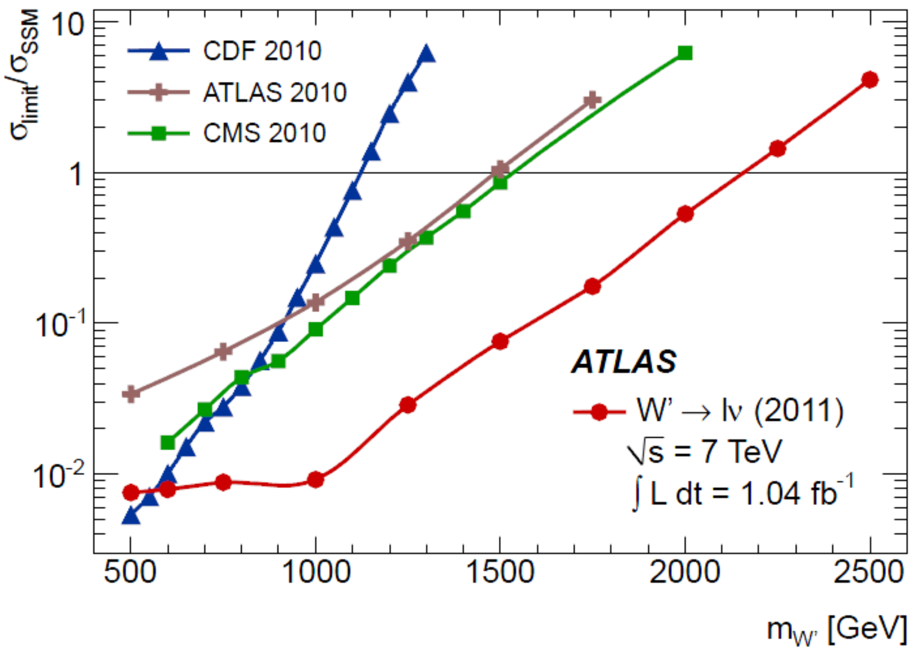




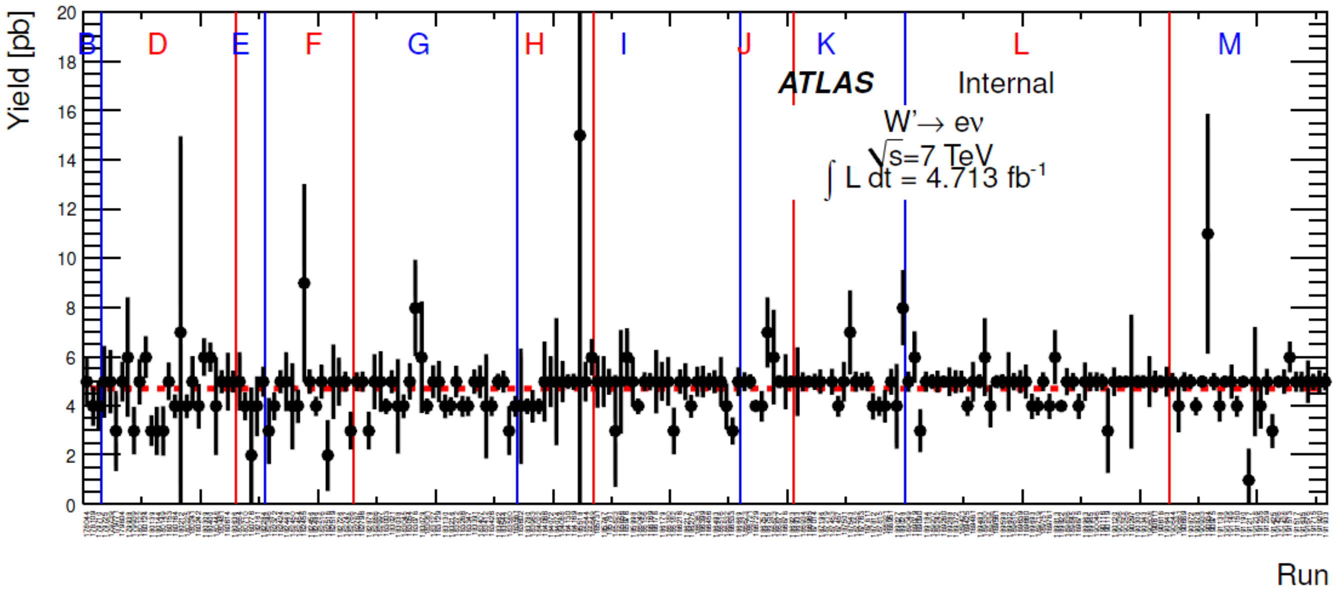
2011 published results (II)

- No significant excess was observed
- Limit was set to 2.15 TeV

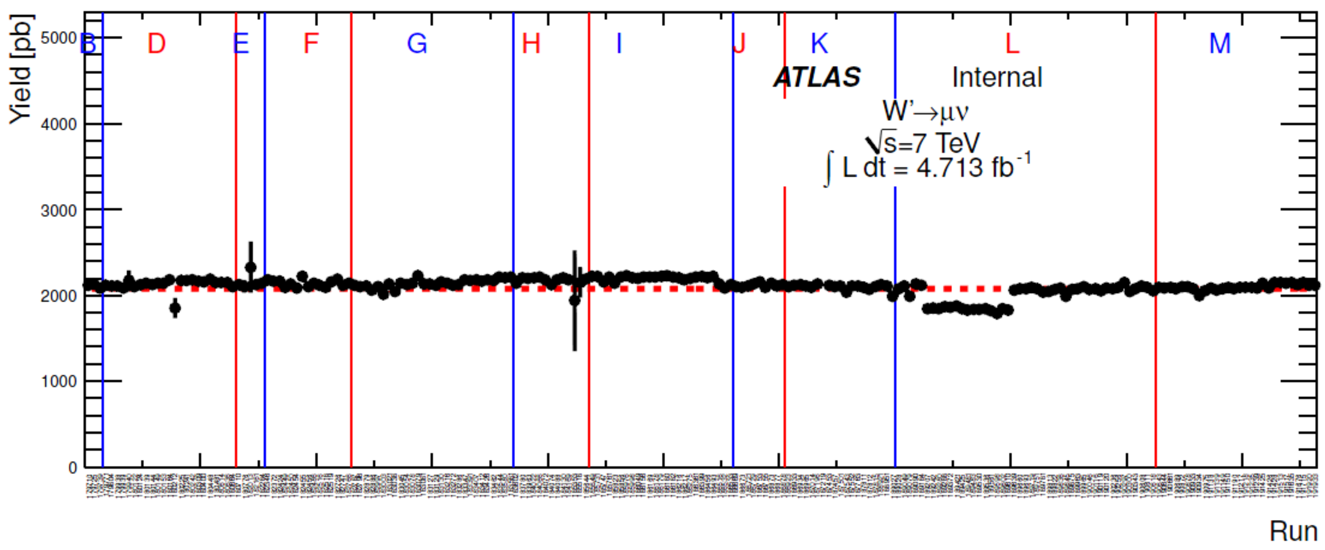




Yield plots

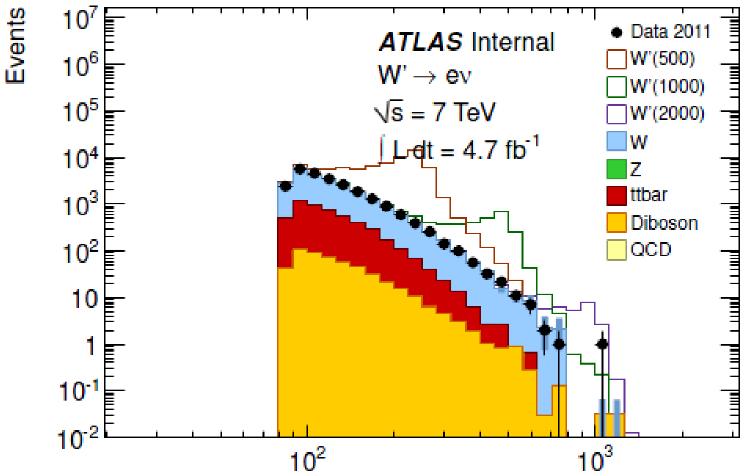


$$Yield = \frac{N_{selected}}{L_{Run}}$$

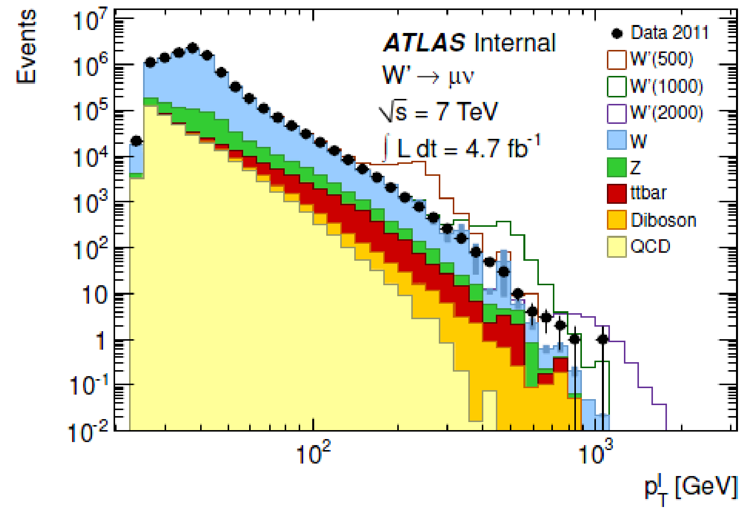


p_T and MET distributions

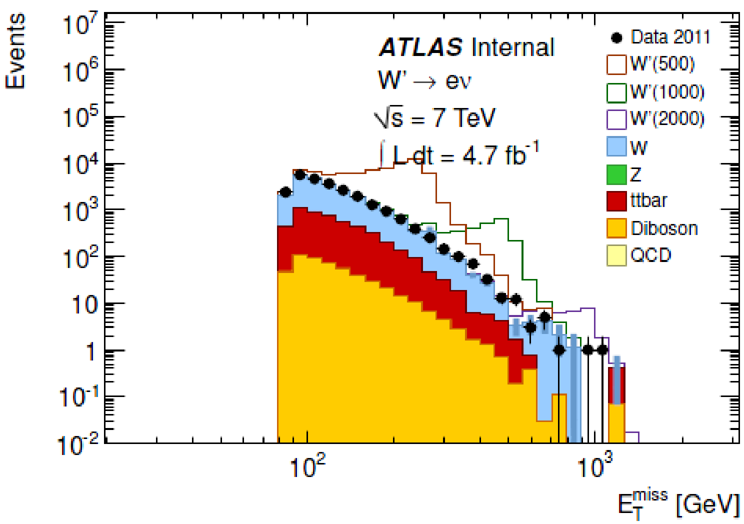
Electron channel

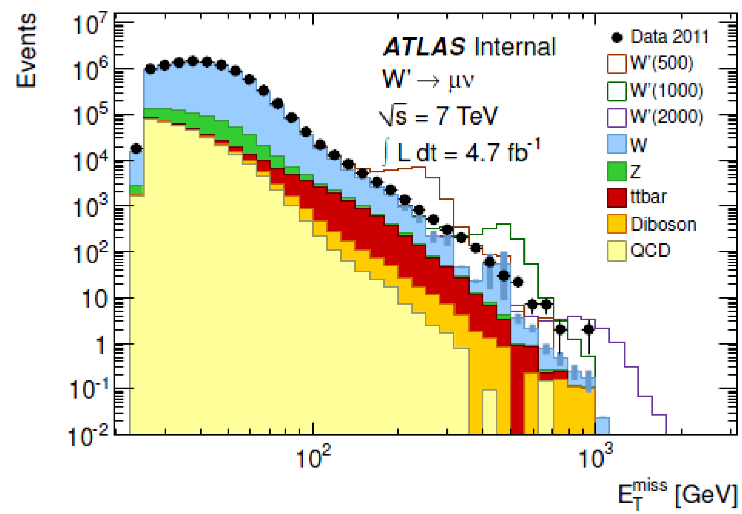


Muon channel



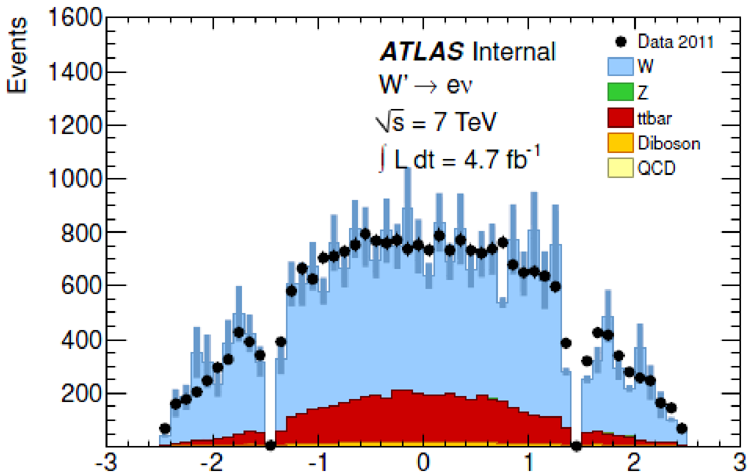
QCD to be added



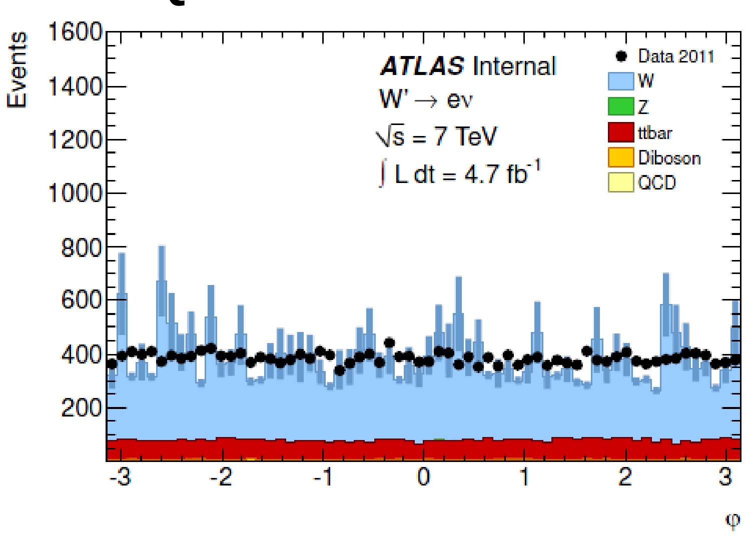


η and φ distributions

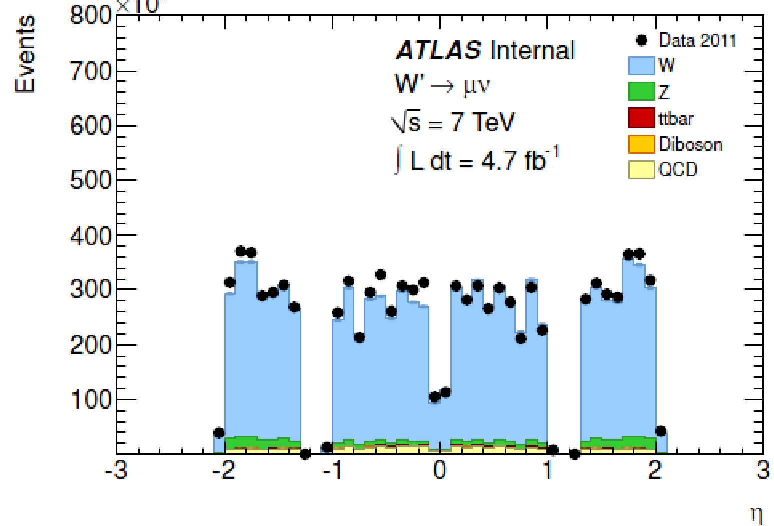
Electron channel

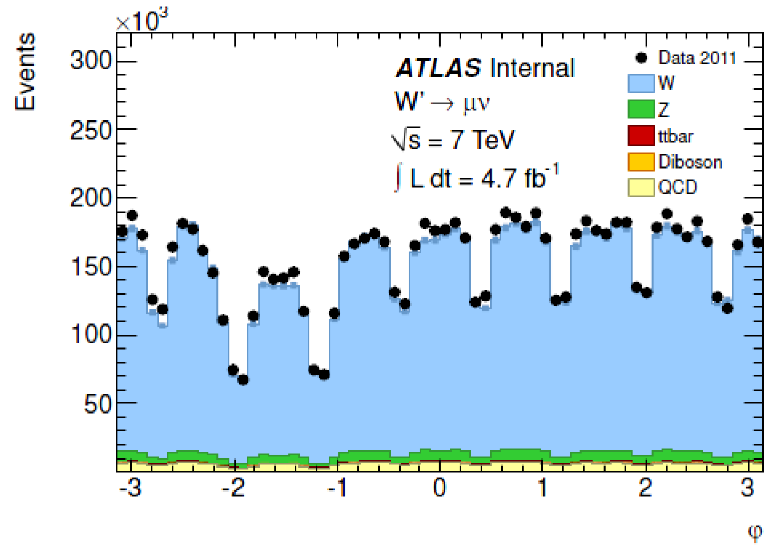


QCD to be added



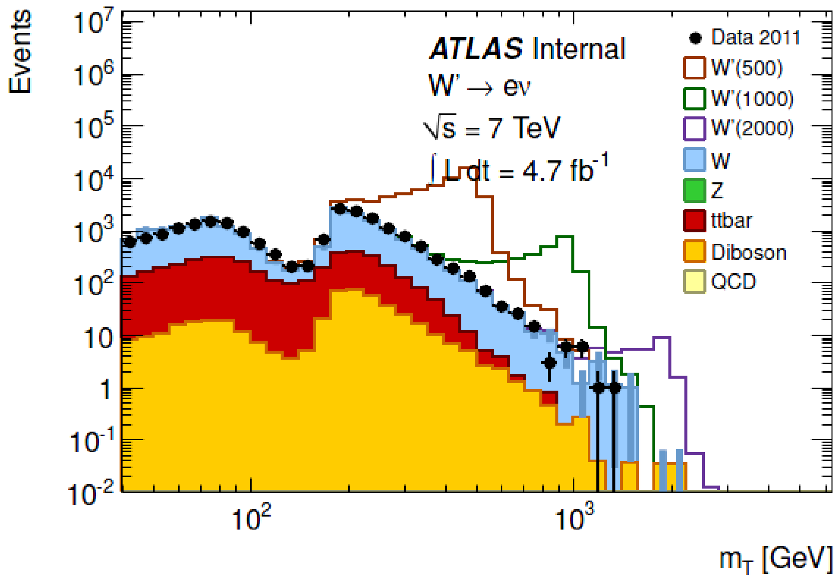
Muon channel



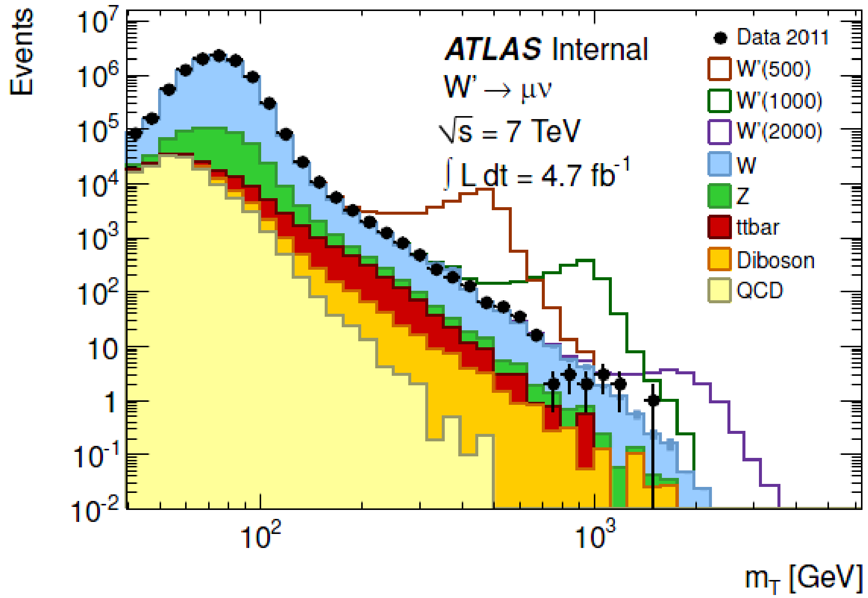


m_T distributions

Electron channel

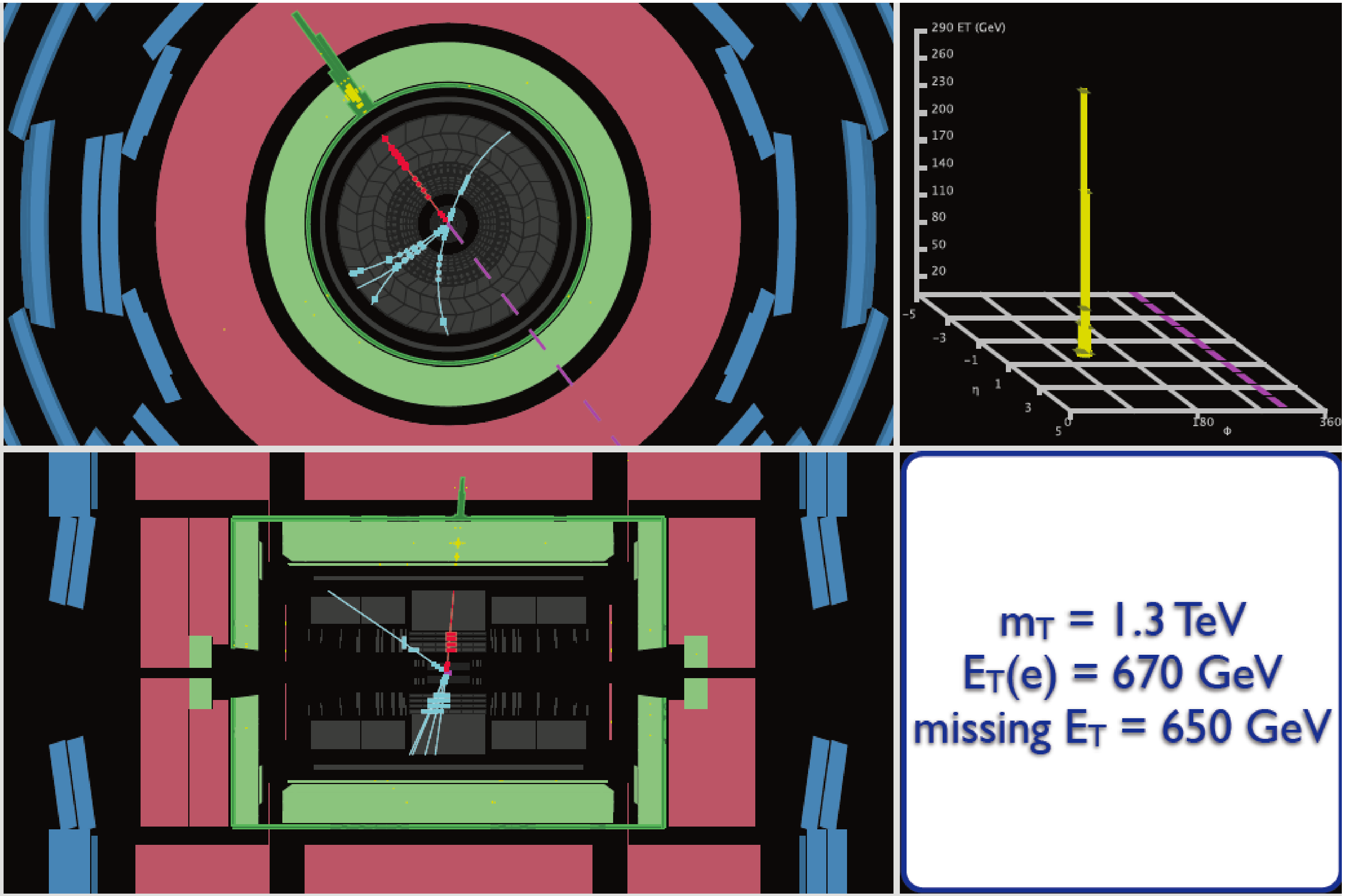


Muon channel



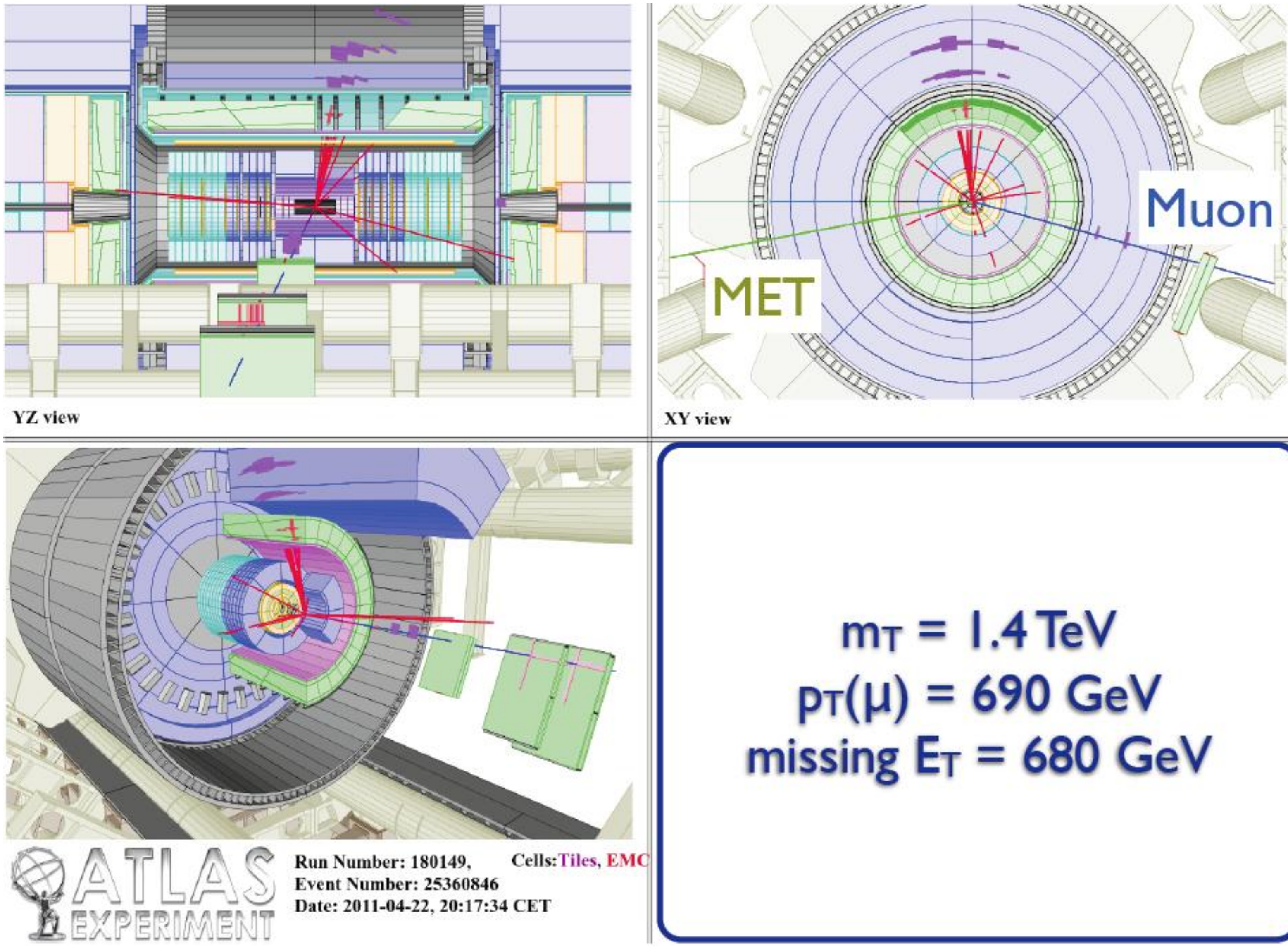
QCD to be added

Highest m_T event (electrons)

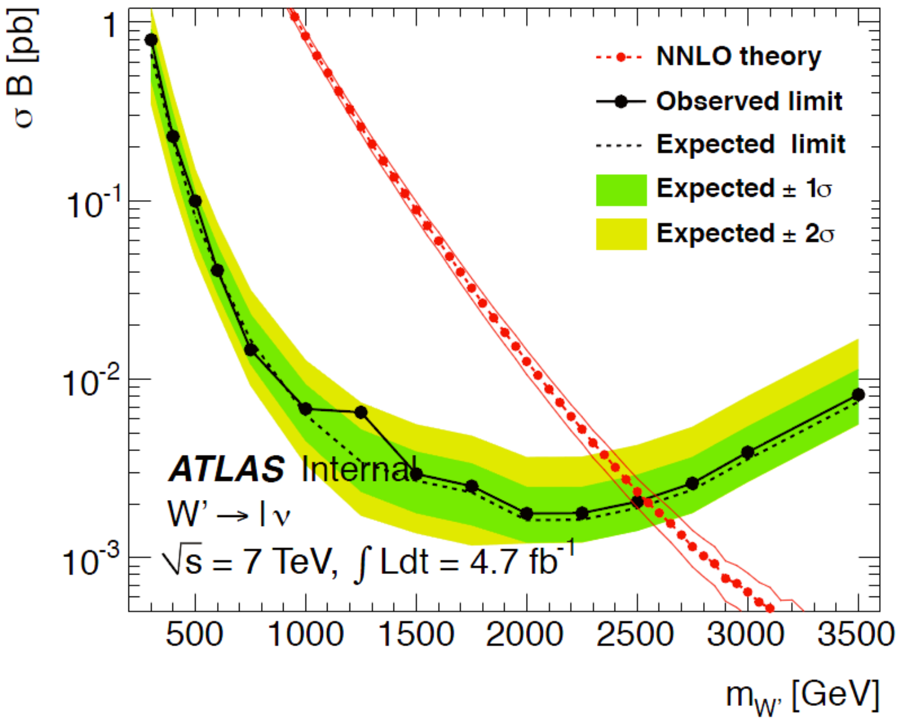


m_T = 1.3 TeV
$E_T(e)$ = 670 GeV
missing E_T = 650 GeV

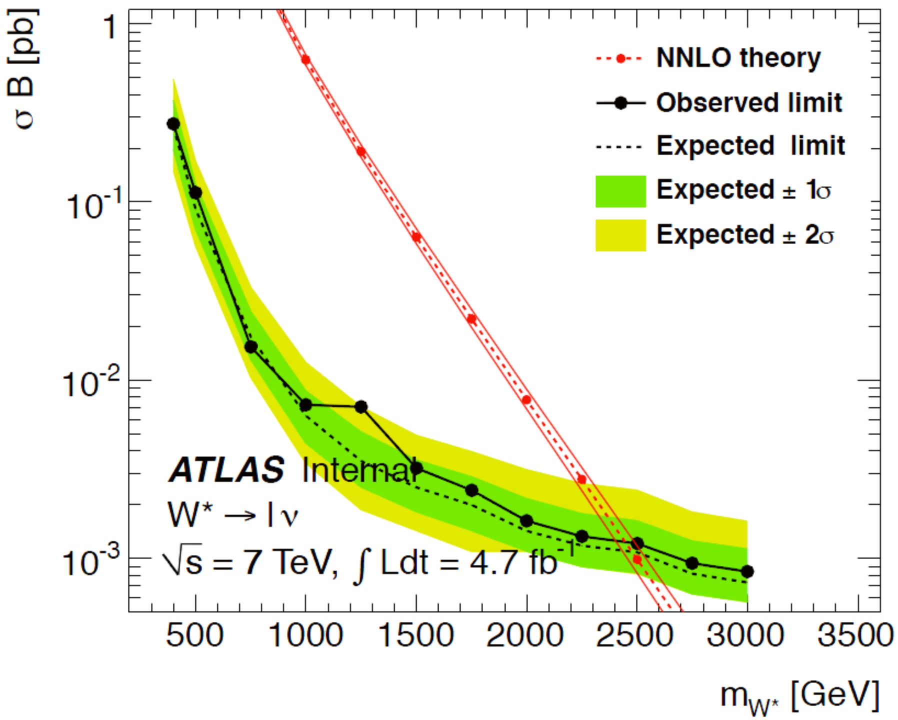
Highest m_T event (muons)



W' and W* Limits



Observed limit: 2.53 TeV



Observed limit: 2.45 TeV

Summary

- PNPI group plays one of main roles in W’->ev analysis

- Conf note was written in summer 2011 (for PLCH, Perugia, 6-11 June) with 205 pb^{-1}

- Paper was written for EPS (Grenoble, 21-27 June) and was published in PLB with 1 fb^{-1} integrated luminosity *[Phys.Lett. B705 (2011) 28-46]*

- Backup Note should be finished by the end of March

- Goal is for publication with full 2011 data – 4.7 fb^{-1} (PLB)

Backup

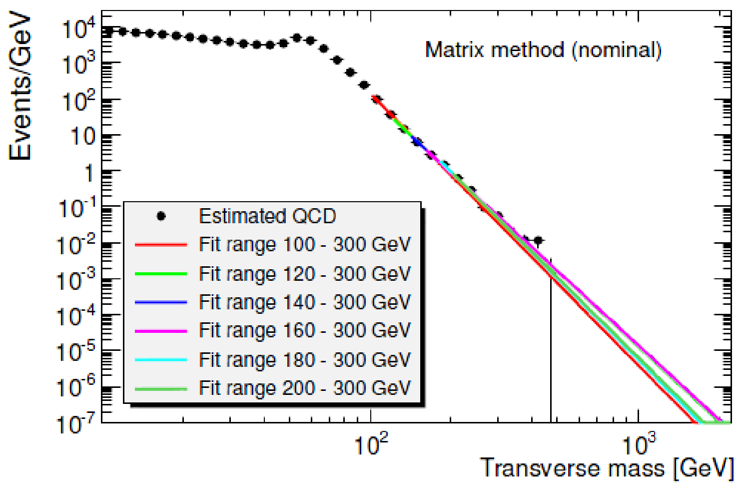
QCD estimate (muon channel)

Matrix method

'tight' – W' muon selection
'loose' – Isolation cut was removed

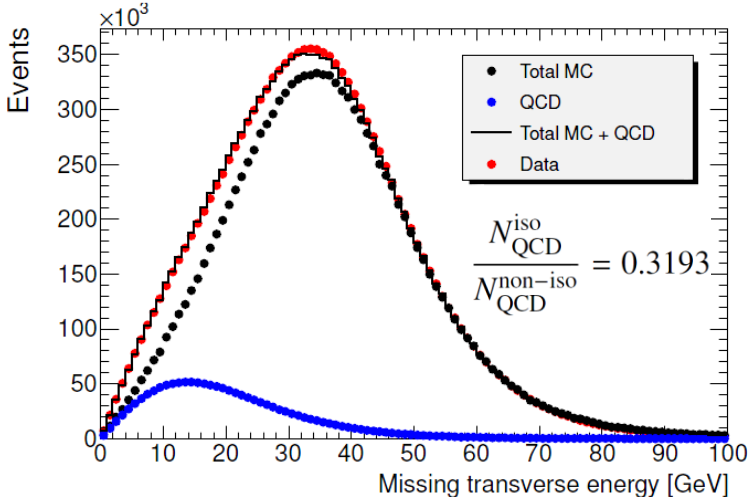
$$\varepsilon_{\text{real}} = \frac{N^{\text{real}}_{\text{tight}}}{N^{\text{real}}_{\text{loose}}} \quad \text{and} \quad \varepsilon_{\text{fake}} = \frac{N^{\text{fake}}_{\text{tight}}}{N^{\text{fake}}_{\text{loose}}}$$

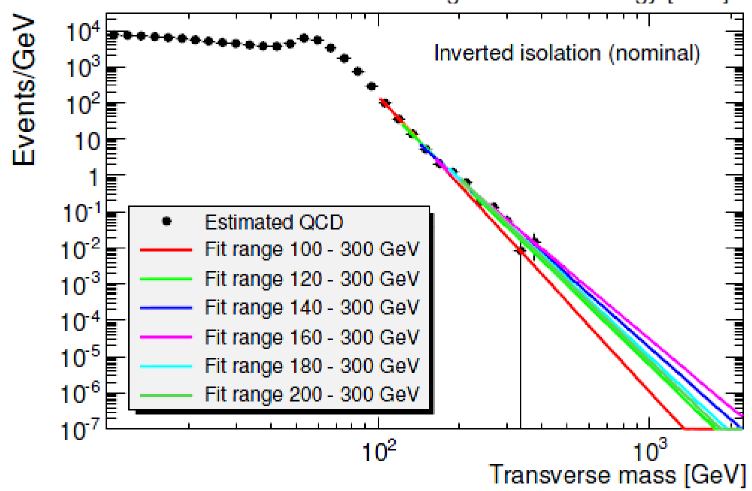
$$N^{\text{fake}}_{\text{tight}} = \frac{\varepsilon_{\text{fake}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} \left(\varepsilon_{\text{real}} N_{\text{loose}} - N_{\text{tight}} \right)$$



Inverted isolation

$0.2 < p_T^{\Delta R<0.3}/p_T^{\mu} < 0.4$





Systematics

- Background MC X-sections and shape uncert. (K-Factors)

- Electrons:

 - Energy scale and resolution (e/gamma recommendations)
 - Medium, Blayer, isolation scale factors (produced by Z' group)
 - Trigger scale factors were evaluated for EF_g80_loose trigger

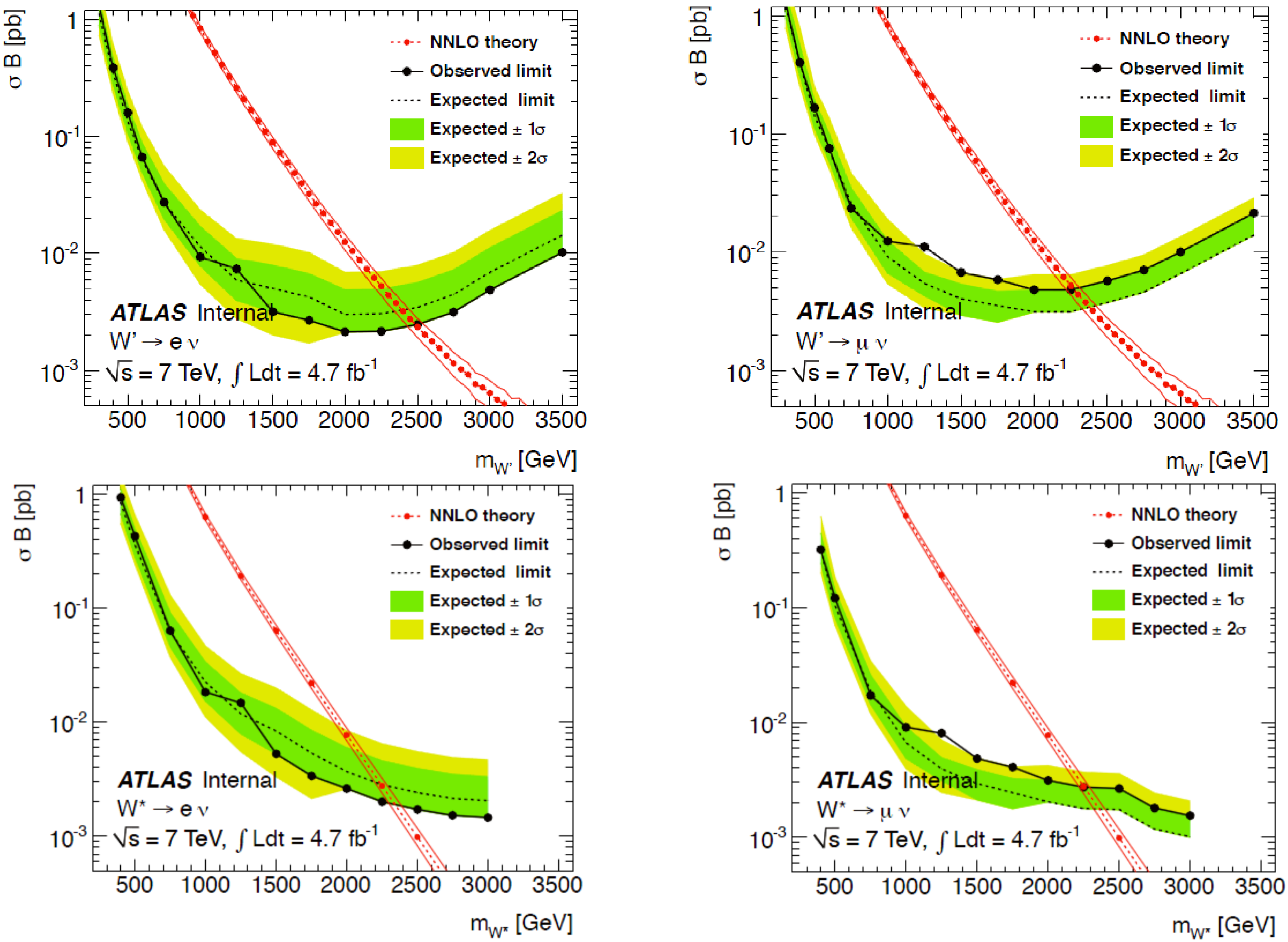
- Muons:

 - Momentum resolution and curvature offset (MCP recommendations)
 - Trigger and Reco efficiency scale factors were produced

- MET:

 - smear by 4.0 GeV or use JET/ETMiss Systematics
 - only one configuration of MET systematics will be chosen
 - MET smearing to be applied to the non-leptonic part of the MET

W’ and W* Limits



Limit setting

- Use Bayes analysis for limit setting

- Using Bayes theorem posterior probability is determined from likelihood. Prior probability chosen to be one:

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

- A discriminant is constructed and p-value is determined as a fraction of trials for which the background only hypothesis will give equal or exceeds the observed value:

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

- 95% CL on *σB* is obtained by finding the value of *σB* for which p-value = 0.05 (i.e. CL_{bayes} = 0.95):

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