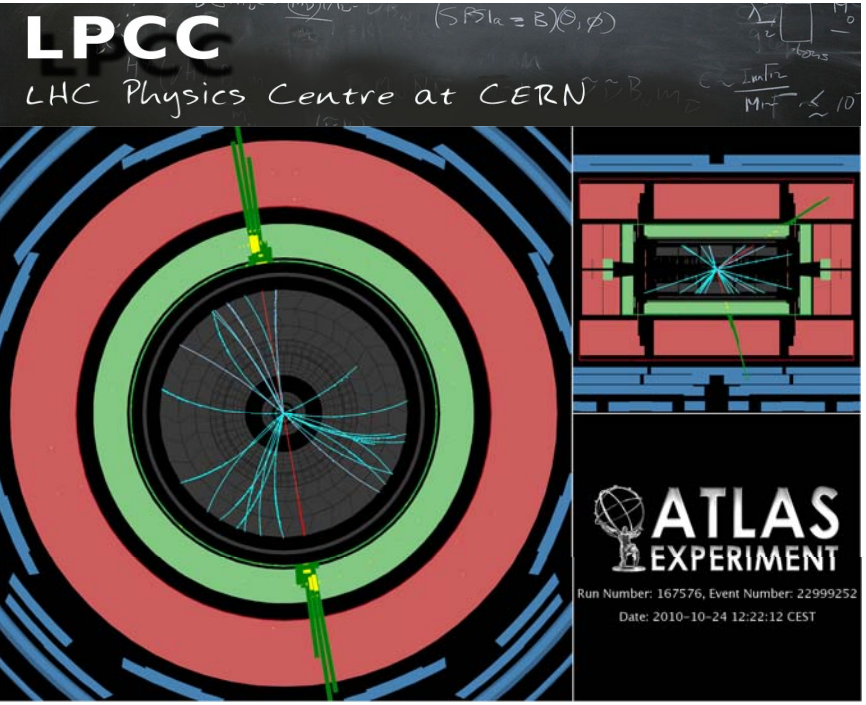
Resonances in leptonic channels and $\ell\ell qq$ contact interactions in ATLAS



- Lepton reconstruction and identification
- $\ell\ell$ and $\ell\nu$ data
- Models
- Limits

Fabienne Ledroit

on behalf of the **ATLAS** collaboration

LPCC on BSM, 11-13 April 2011, CERN

Search strategy

- Search for neutral ($\ell\ell$) and charged ($\ell\nu$) resonances (ℓ=e,μ)

- Analyse full 2010 data set
  - $\ell\ell$: reprocessed data: ~40/pb
  - $\ell\nu$: non-reprocessed data: ~36/pb

- Main observable:
  - $\ell\ell$: invariant mass $m_{\ell\ell}$
  - $\ell\nu$: transverse mass m_T

$$m_{ll} = \sqrt{E_{ll}^2 - \|\mathbf{p}_{ll}\|^2}$$

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

- Main challenge: reconstruct and identify ***very*** high p_T leptons

Electron reco and ID

Reconstruction

- sliding window clustering algorithm
- $|\eta| < 2.4$ (eν) or 2.47 (ee) (exclude 1.37-1.52)
- correct energy or exclude clusters close to dead readout

Energy resolution:
$\sigma(E)/E$ = 1.1% (barrel)
1.8% (endcaps)

Identification

- $p_T > 25$ GeV
- «medium» identification
- Pixel hit in first layer

- $z_0 < 5$ mm, $d_0 < 1$ mm (eν)
- *isolation criterion*:
$\Sigma E_T(\Delta R < 0.4) < 10$ GeV (eν)

Muon reconstruction

Muons

- «combined» reconstruction: ID track + MS track
- $|\eta| <$ 1.05 ($\mu\nu$) or 2.4 ($\mu\mu$)
- $p_T >$ 25 GeV
- ID: at least 1 pixel hit and 6 SCT hits + TRT
- **MS: at least 2 hits in each of 3 layers, >0 ϕ hit, use only well aligned chambers**
- $z_0 <$ 1 ($\mu\mu$) or 5 ($\mu\nu$) mm, $d_0 <$ 0.2 ($\mu\mu$) or 1 ($\mu\nu$) mm
- *isolation criterion*: $\Sigma p_T(\Delta R < 0.3)/p_T(\mu) < 0.05$

Average momentum resolution: 20% at 1 TeV

Event selection

$\ell\ell$

- Single lepton trigger(s)
- Primary vertex with >2 tracks
- **At least 2 leptons**
- Opposite charges (muons)

Efficiency for 1 TeV Z'_{SSM}:

60% (ee), 40% ($\mu\mu$)

$\ell\nu$

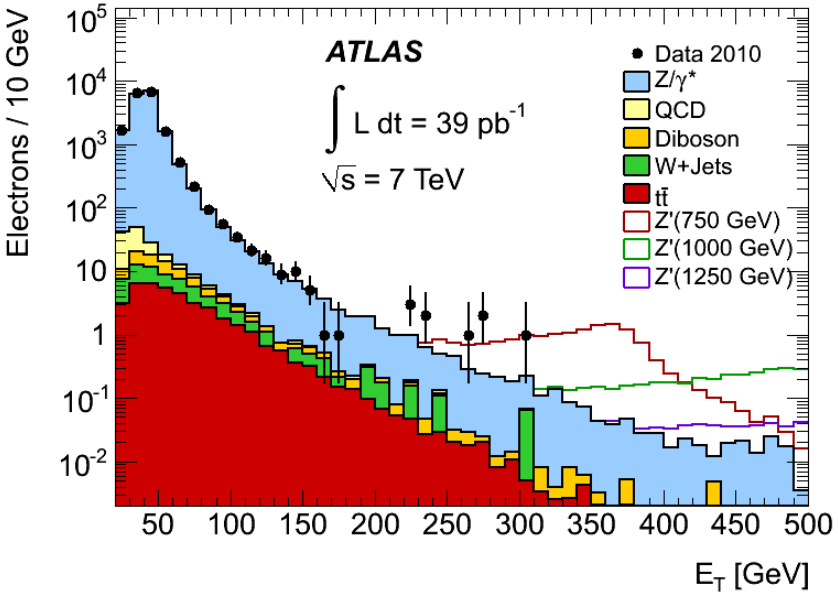
- Single lepton trigger(s)
- Primary vertex with >2 tracks
- **Exactly one lepton**
- **E_T^{miss} > 25 GeV**
- $E_T^{miss} > 0.6\ E_T$ (electron)

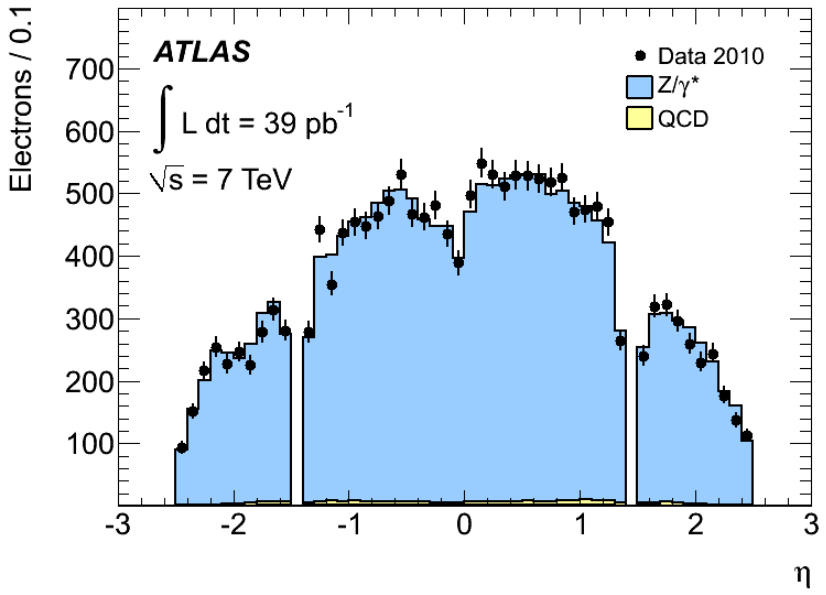
Efficiency for 1.5 TeV W'_{SSM}:

53% ($e\nu$), 38% ($\mu\nu$)

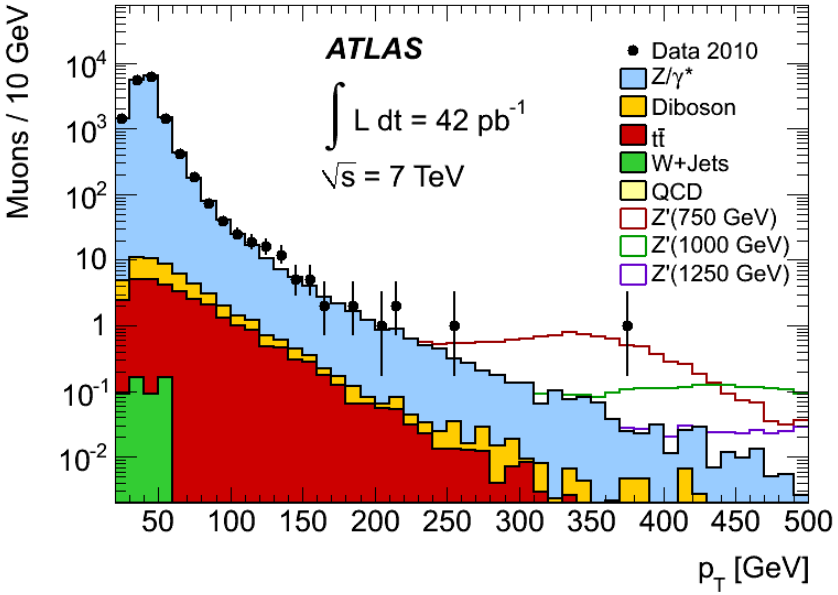
Lepton kinematics ($\ell\ell$)

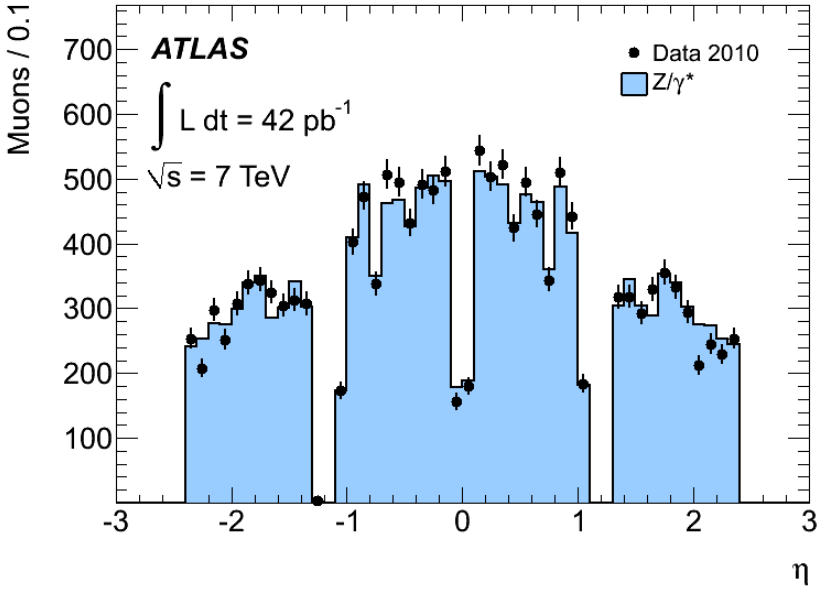
ee





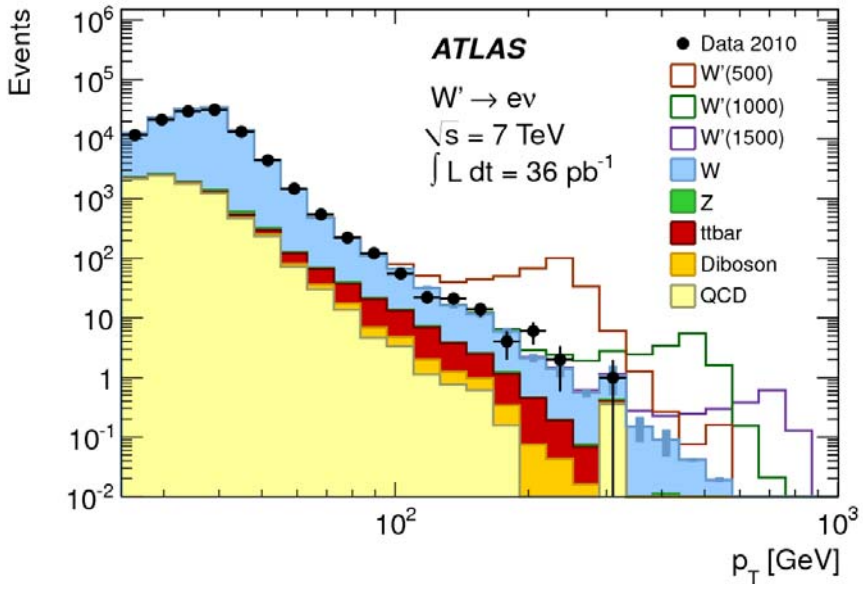
μμ

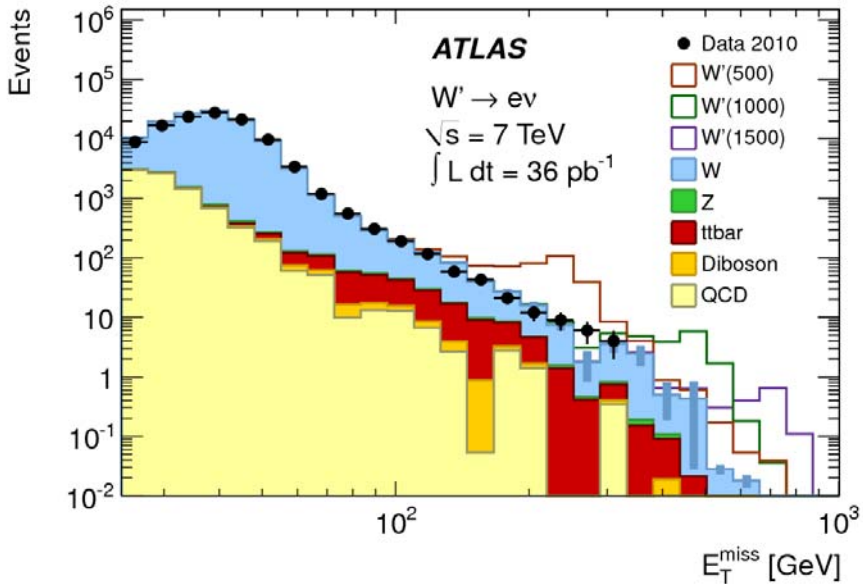




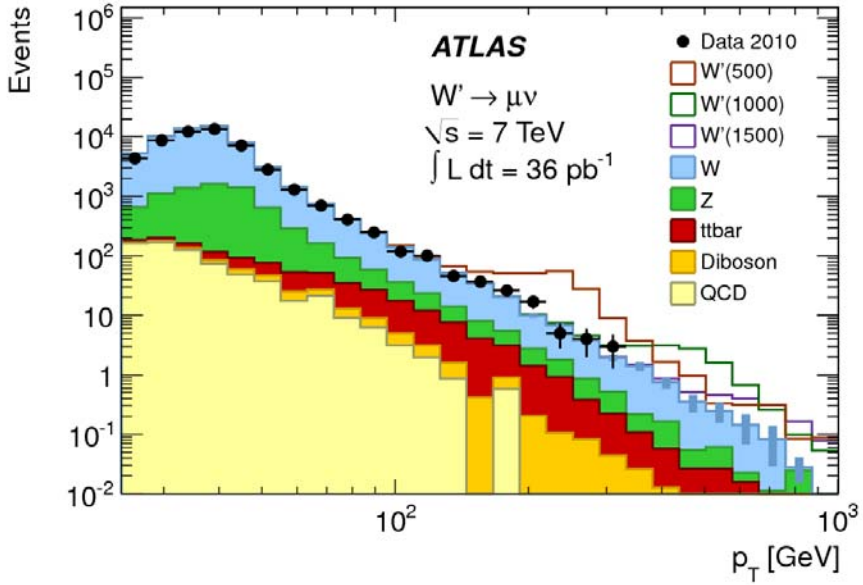
Lepton kinematics ($\ell\nu$)

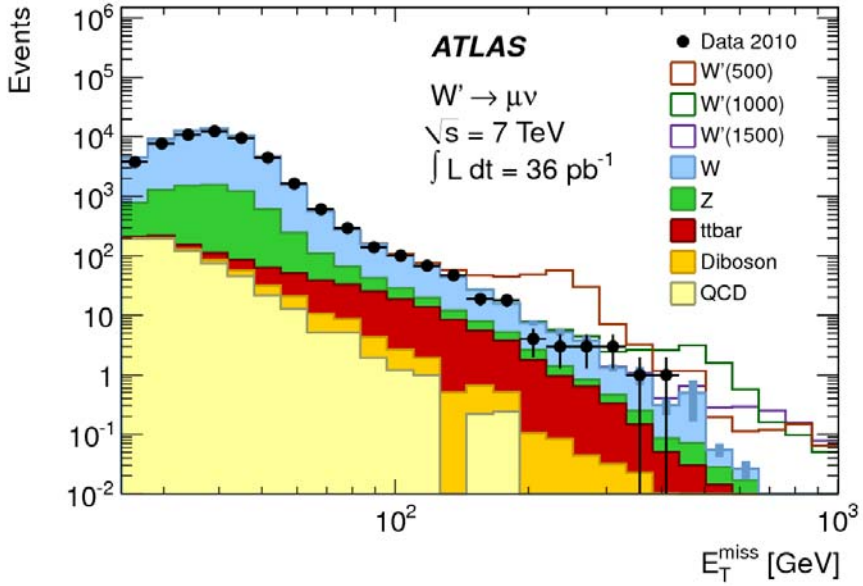
$e\nu$





$\mu\nu$

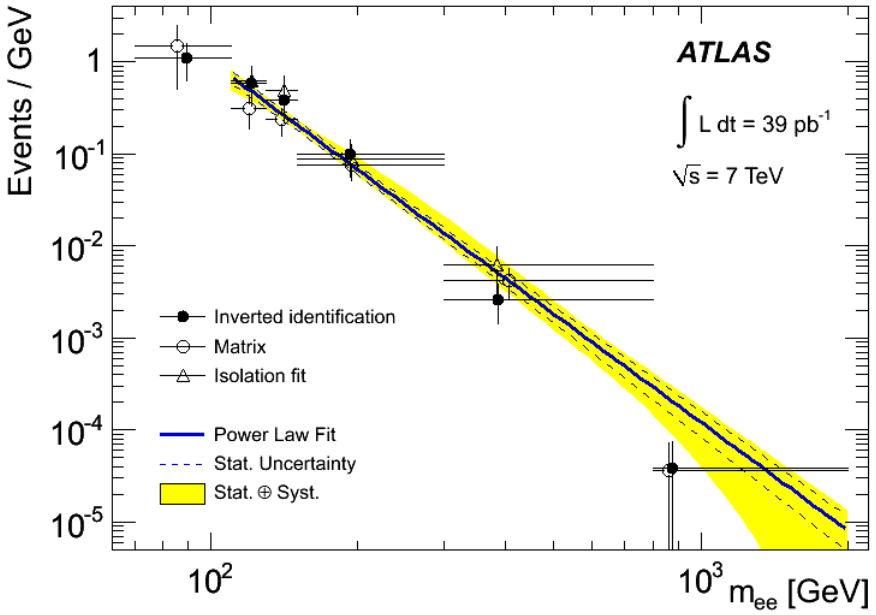




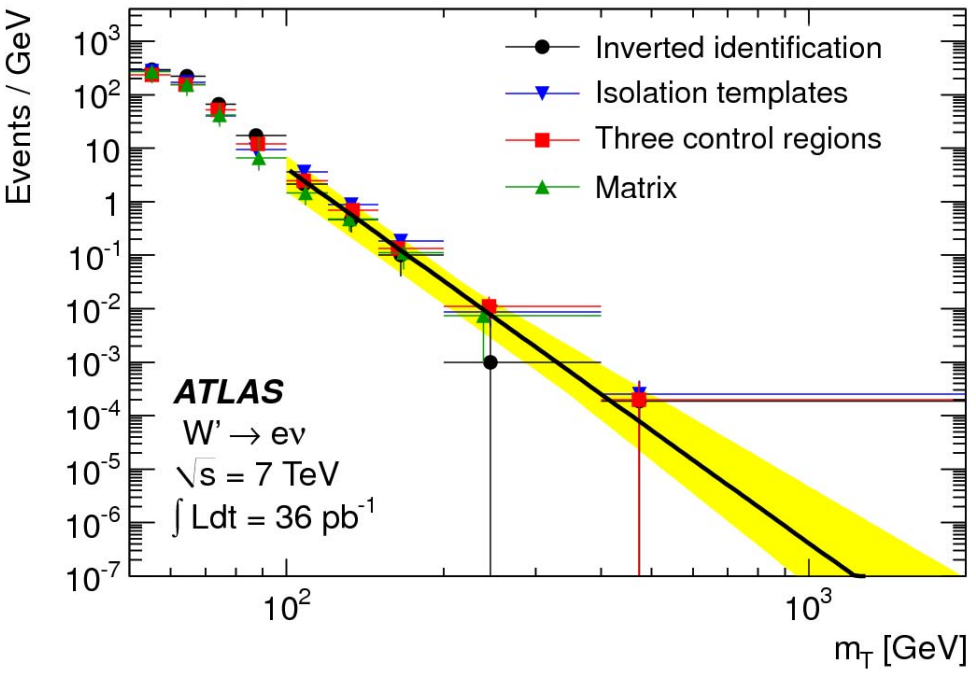
QCD evaluation

Data driven, 3-4 methods combined and extrapolated to signal region (*power law* fit above Z region):

ee:



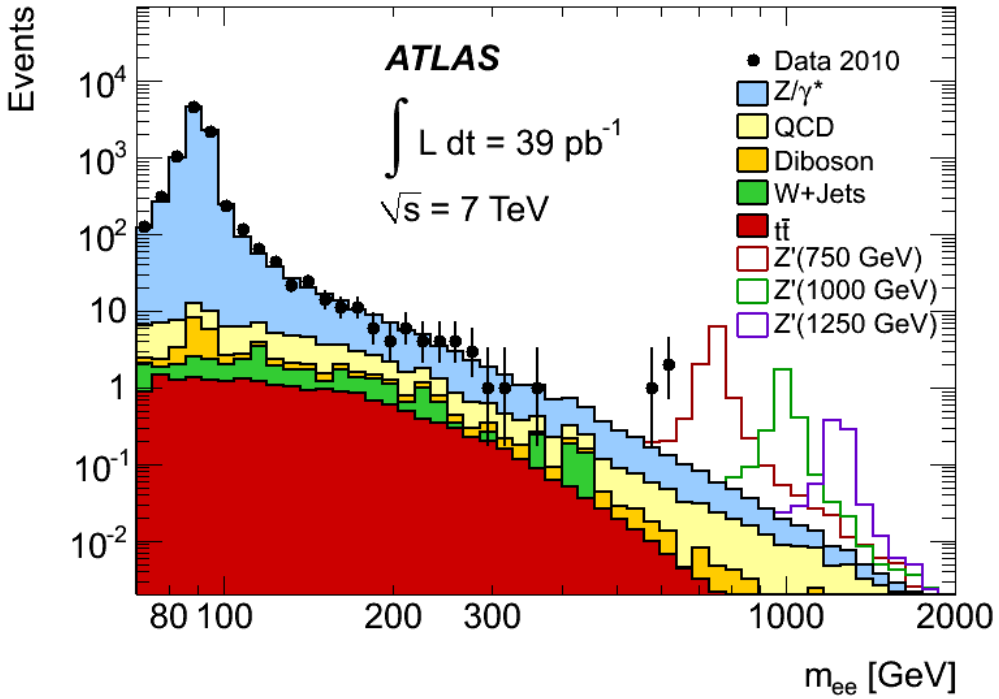
eν:

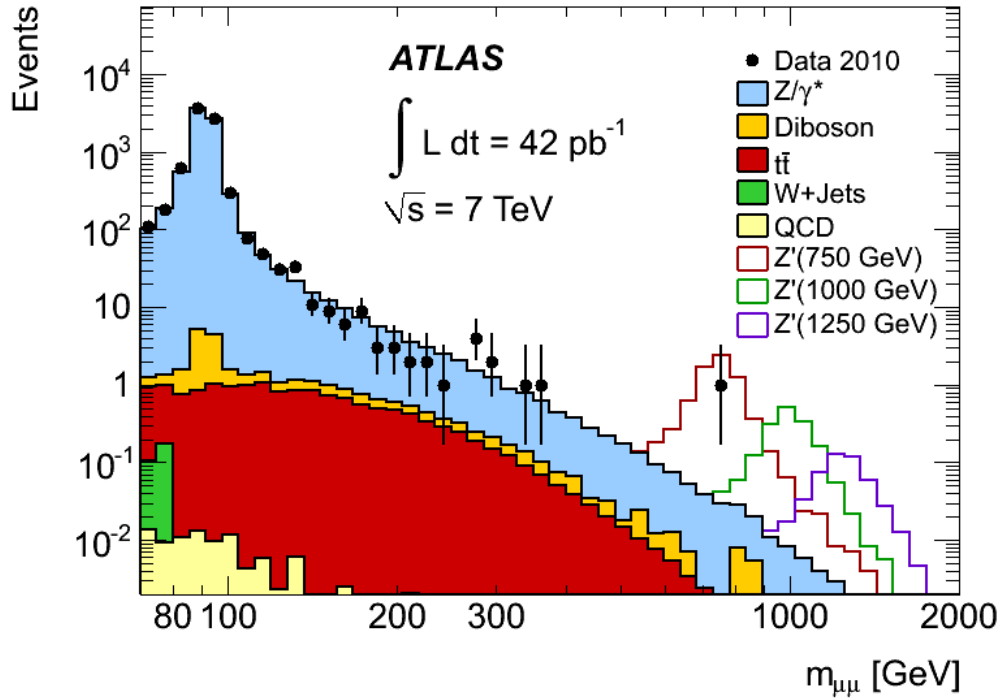


μμ: negligible

μν: MC + 1 similar data driven method

$\ell\ell$ invariant mass

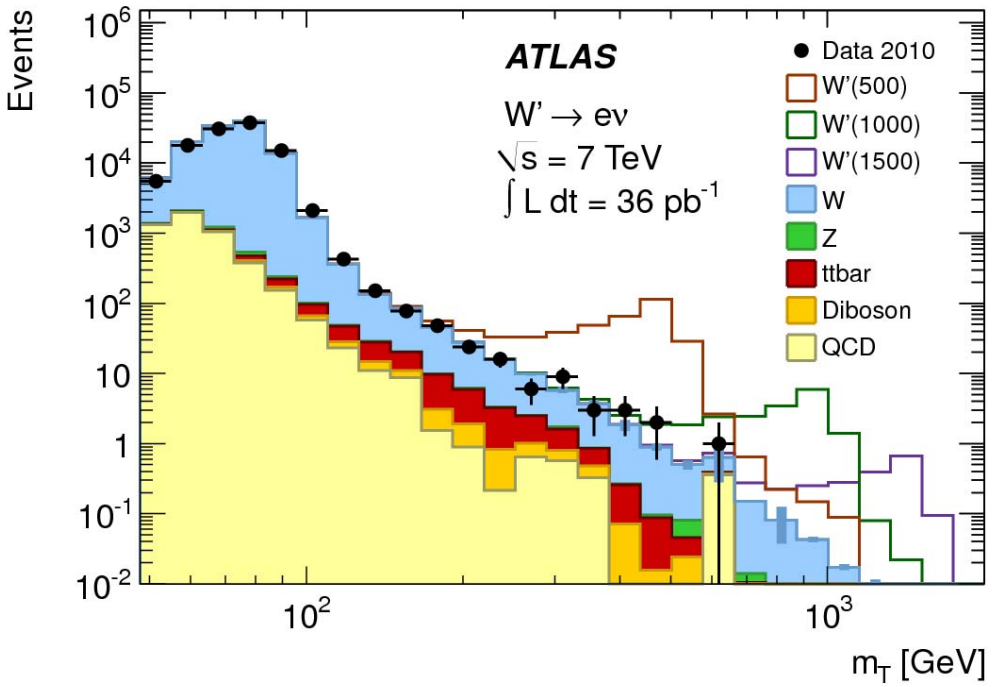


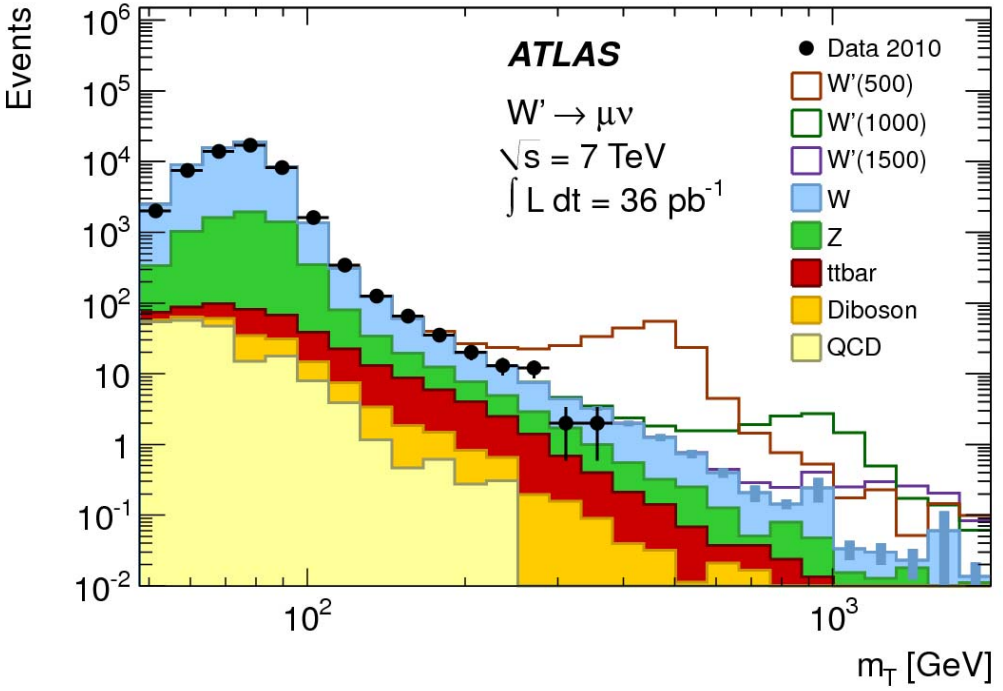


Data well described by Standard Model

No excess at large $m_{\ell\ell}$

lν transverse mass





Data well described by Standard Model

No excess at large m_T

New gauge bosons

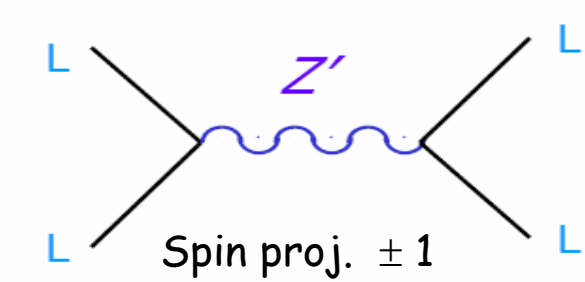
« Standard »

Minimal gauge coupling

- SSM benchmark Z', W'
- E_6 motivated Z'

Narrow width: few% of M

Leptonic BR: 3-8%



« Excited »

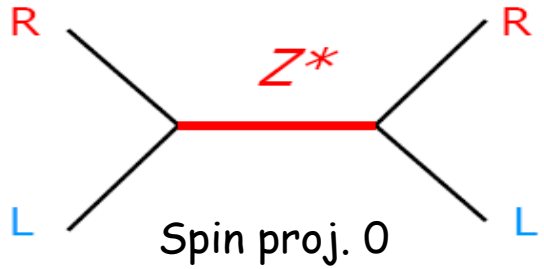
Magnetic gauge coupling

- Effective model Z*, W*

$$\begin{pmatrix} H^+ \\ H^0 \end{pmatrix} \leftrightarrow \begin{pmatrix} W_\mu^{*+} \\ Z_\mu^* \end{pmatrix}$$

Narrow width: 3.4% of M

Leptonic BR: 8%



M. V. Chizhov, V. A. Bednyakov, and J. A. Budagov, *Proposal for Chiral-Boson Search at LHC via Their Unique New Signature*, Physics of Atomic Nuclei **71** (2008) 2096–2100.

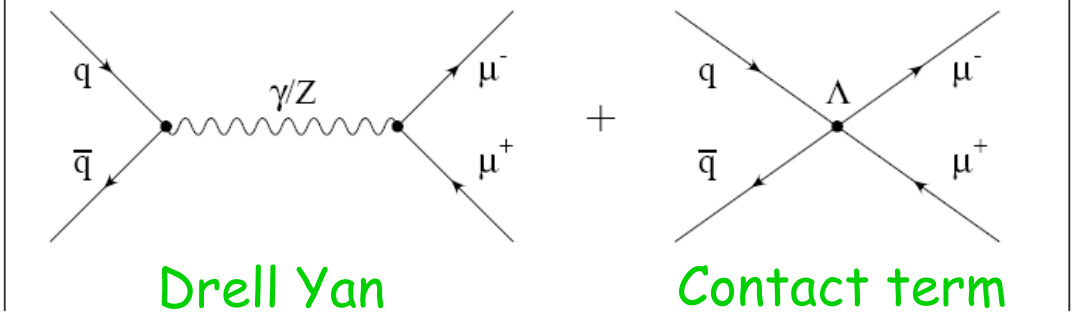
M. Chizhov and G. Dvali, *Origin and Phenomenology of Weak-Doublet Spin-1 Bosons*, arXiv:hep-ph/0908.0924 [hep-ph].

Contact Interactions

Most general Lagrangian = several parameters

$\Rightarrow$ choose a "benchmark" model: Left-Left Isoscalar Model (LLIM)

2→2 scattering cross section:



$$\left|\right|^2$$

$$\frac{d\sigma}{dm_{\mu\mu}} = \frac{d\sigma_{DY}}{dm_{\mu\mu}} - \eta\frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$

F_I = interference term

F_C = pure CI term

Λ = energy scale

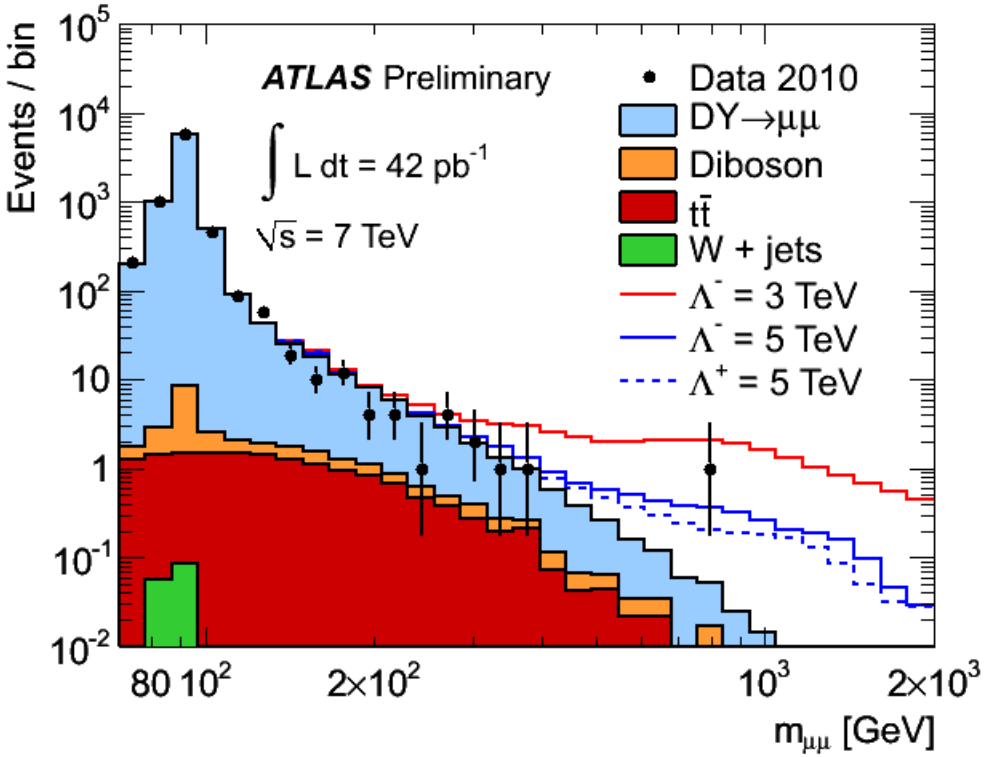
(compositeness: bound constituents)

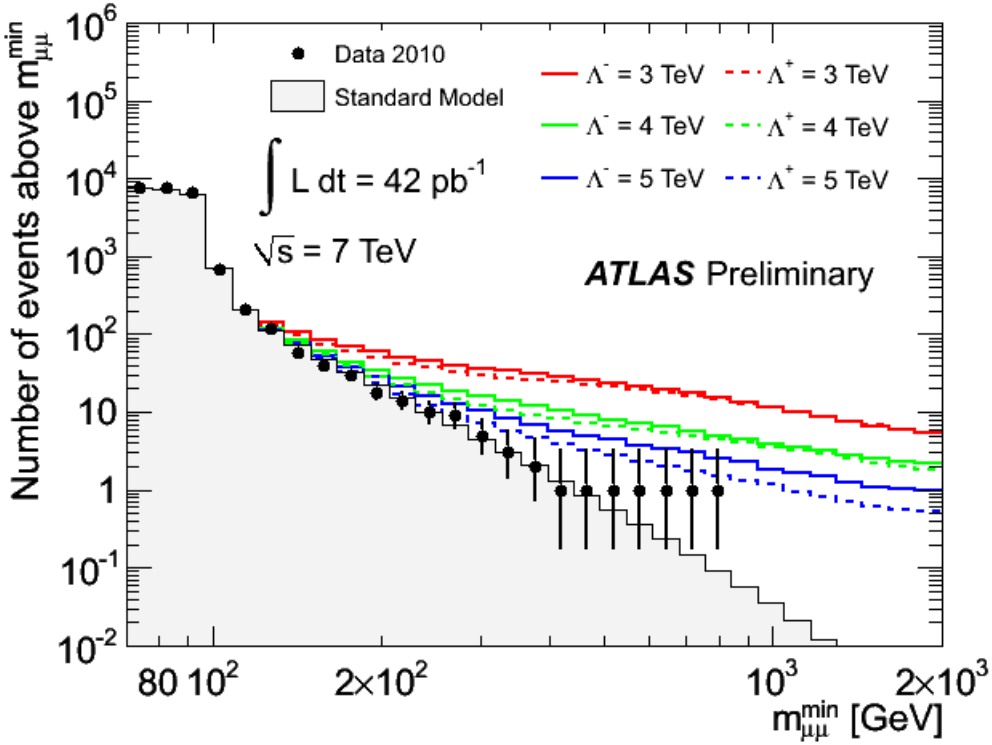
η = -1 *constructive* interference

η = +1 *destructive* interference

μμ invariant mass

New!





Limits extraction

Theory parameter = M (new boson) or $1/\Lambda^2$

$\ell\ell$

- Normalize background to **data** in 70-110 GeV window
- Fit the **shape** of $m_{\ell\ell}$ distrib. above 110 (150) GeV
- Only mass dependent uncertainties (*shape*)*
- Use **Bayesian** statistics

$\ell\nu$

- Normalize background with σ**B** and data sample **luminosity**
- **Count** events above m_T thresholds ($M_{W',W^*}/2$)
- Normalization uncertainties dominate (*level*)
- Use **CL_s** statistics

* Except Z/γ^* cross section for Z'/Z^*

Systematics

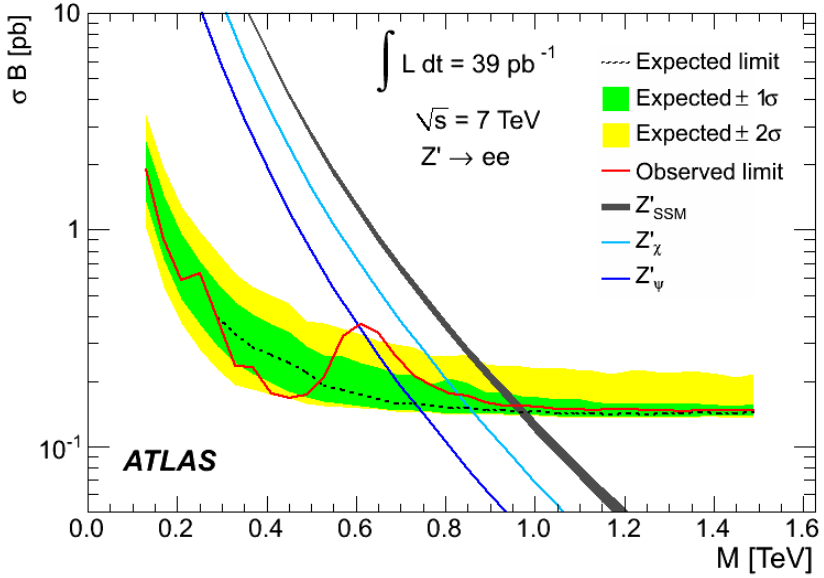
Z', 1 TeV

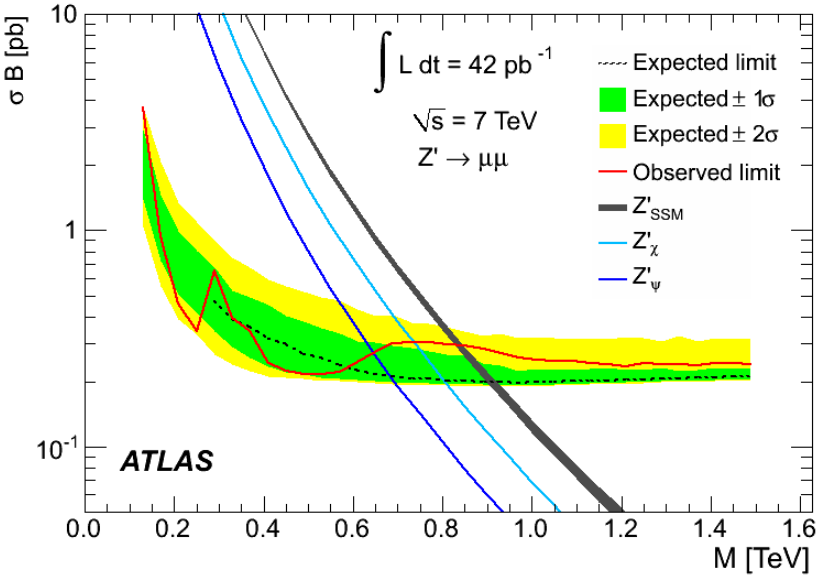
Source	dielectrons		dimuons	
	Z' signal	background	Z' signal	background
Normalization	5%	5%	5%	5%
PDFs	6%	6%	6%	6%
QCD K-factor	3%	3%	3%	3%
Weak K-factor	NA	4.5%	NA	4.5%
Efficiency	-	-	3%	3%
Resolution	-	-	3%	3%
Total	9.4%	9.5%	9.4%	10.4%

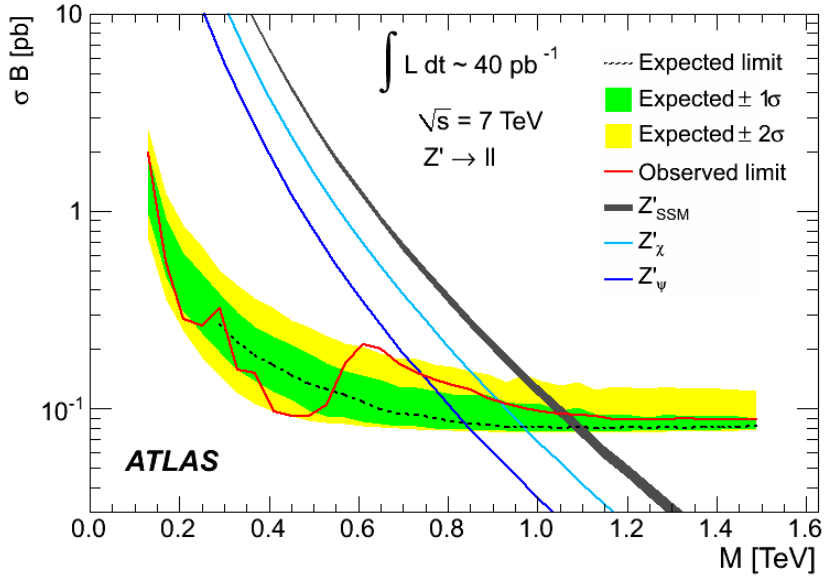
W', 1.5 TeV

Source	ε_{sig}		N_{bg}	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Missing E_{T} scale	0.1%	0.1%	1.1%	**3.4%**
Trigger efficiency	**1.0%**	**0.7%**	1.0%	0.7%
Reco. and id. efficiency	**3.6%**	**1.6%**	**3.6%**	1.3%
Isolation leakage	**2.7%**		**3.4%**	
Energy/momentum resolution	0.1%	0.4%	2.4%	**3.1%**
Energy/momentum scale	**0.8%**	0.1%	**6.6%**	0.1%
Correlated misalignment		0.6%		**3.3%**
QCD background			2.2%	**7.7%**
Monte Carlo statistics	**1.7%**	**1.6%**	2.2%	**16.6%**
Cross section (shape/level)	**0.7%**	**0.7%**	**8.5%**	**7.7%**
Isolation	**1.5%**	**1.5%**	1.0%	1.0%
Other	0.2%	0.4%	0.4%	0.9%
All	5.3%	3.0%	12.6%	20.7%

Z' σB 95% CL limits



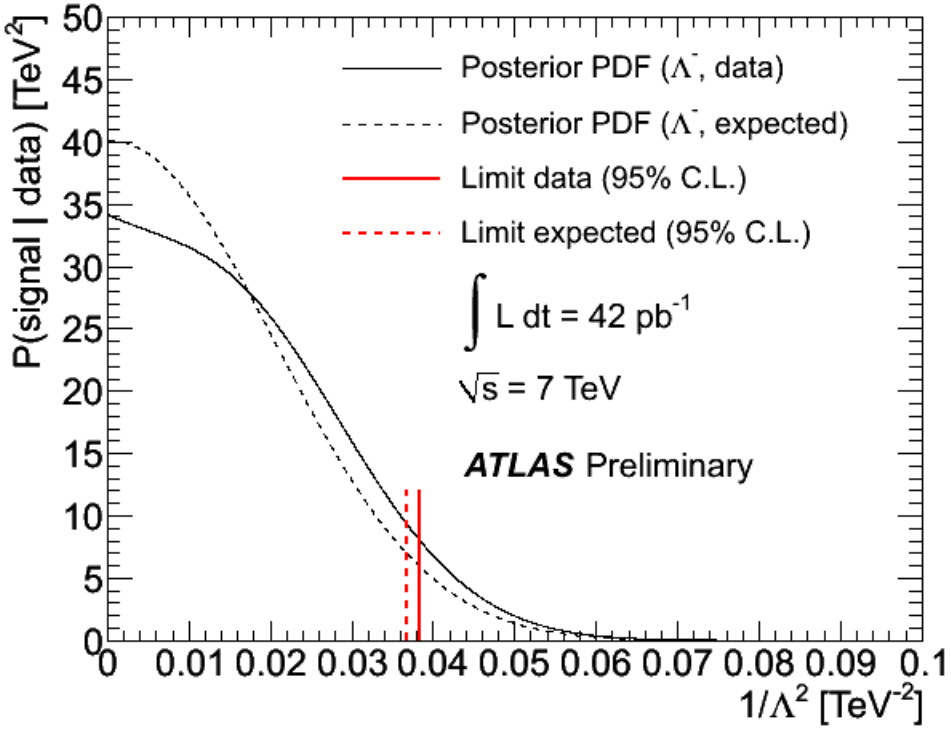




These limits also valid for Z* *above 750 GeV*: similar efficiency

Contact interaction limits

Constructive

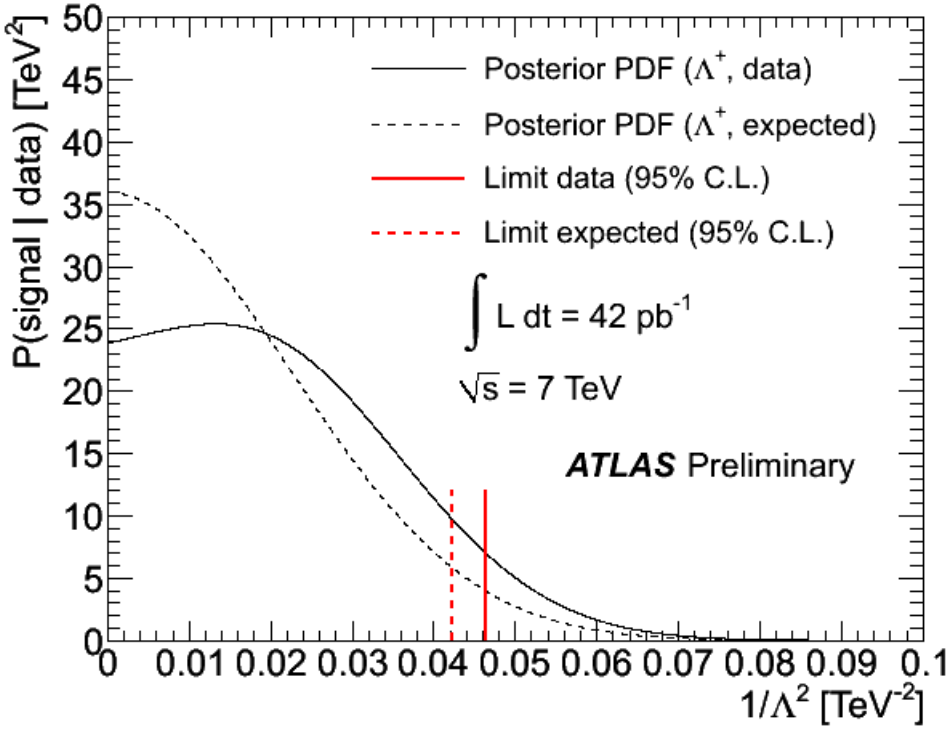


Λ^- data: 4.9 TeV

Λ^- expected: 5.1 TeV

Destructive

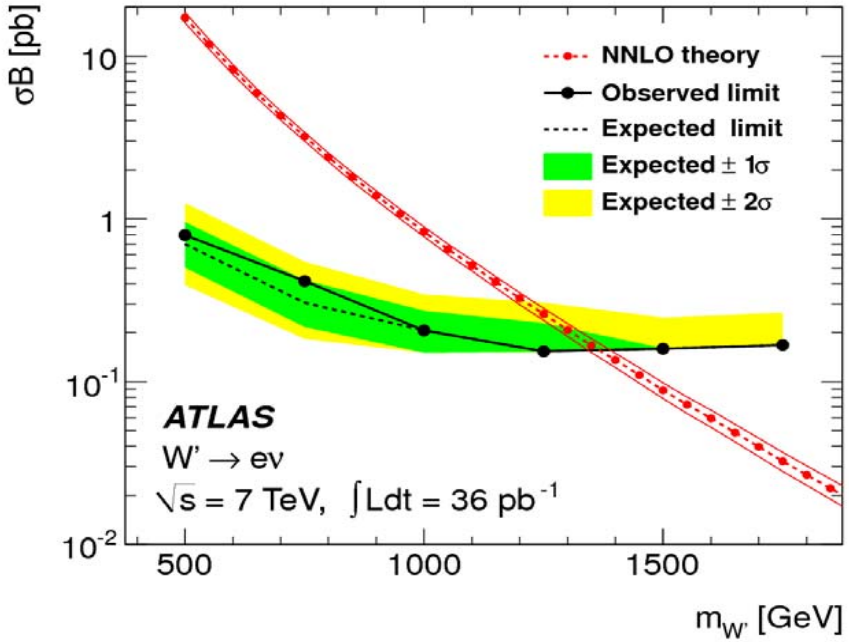
New!

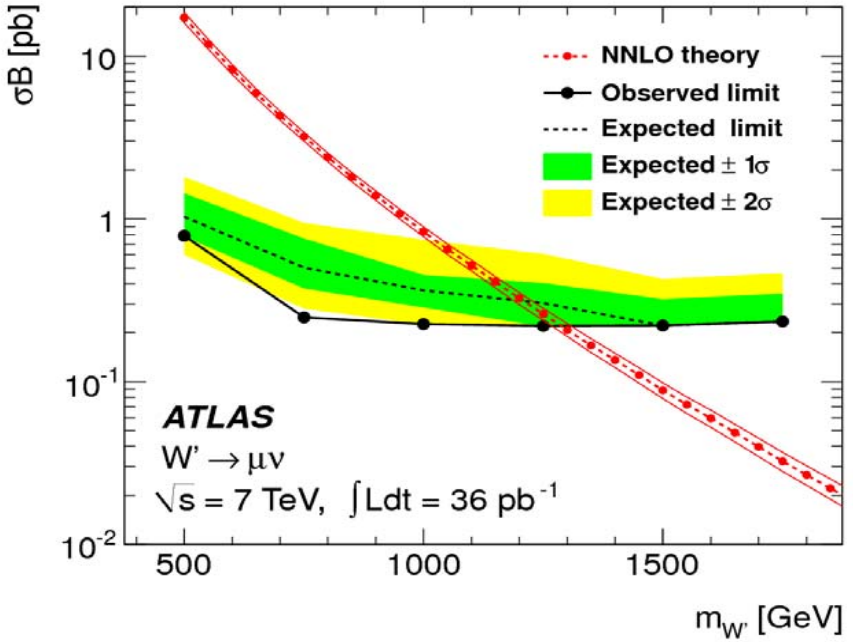


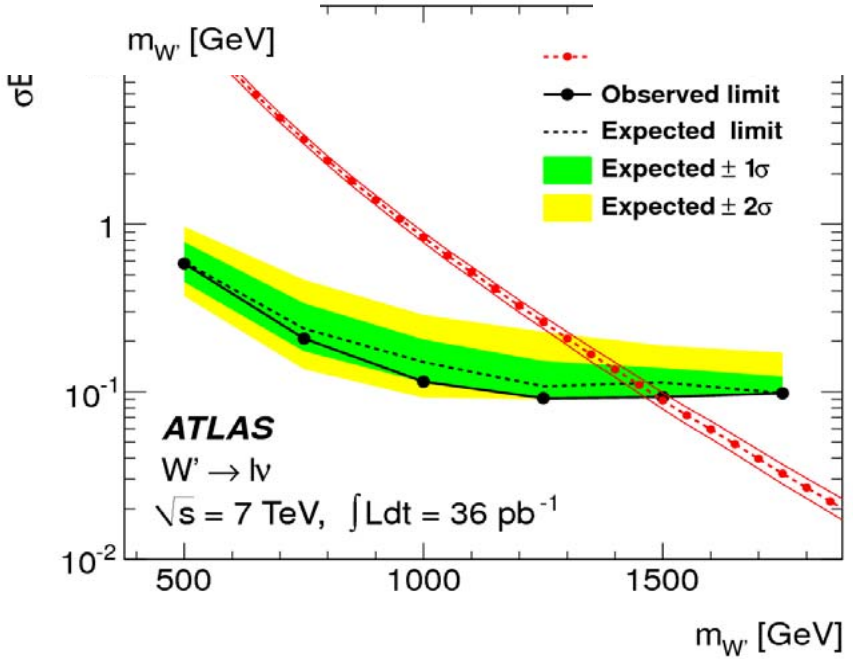
Λ^+ data: 4.5 TeV

Λ^+ expected: 4.8 TeV

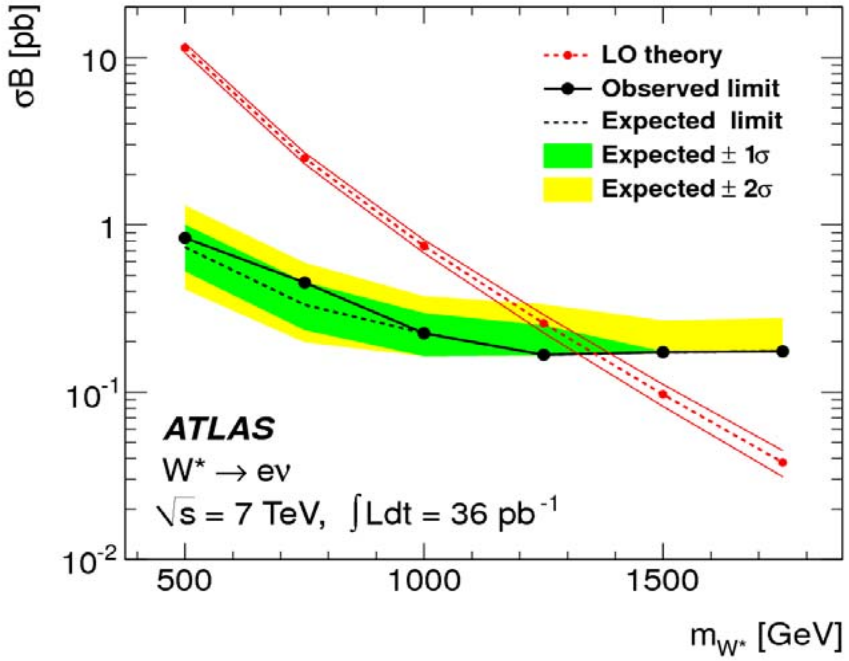
W'_{SSM} σB 95% CL limits

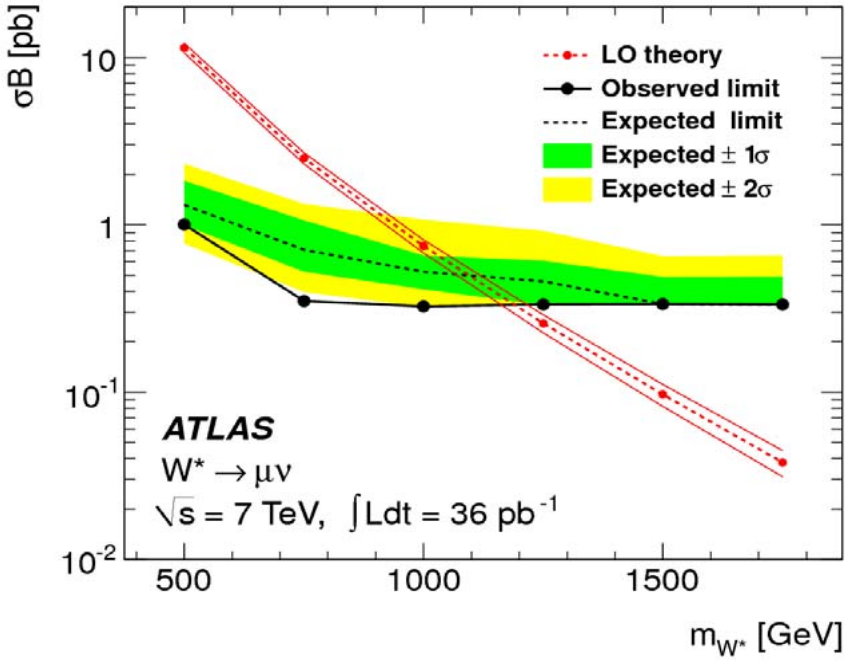


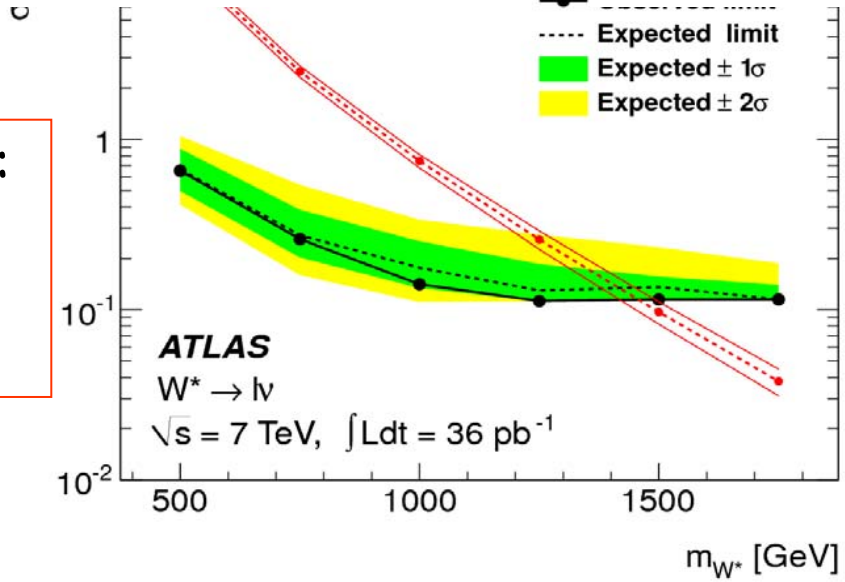




W* σB 95% CL limits







W* efficiency wrt W':

- lower for μν,
- similar for eν

95% CL mass and Λ_{LL} limits

Mass of SSM Z', W' [TeV]

ee: 0.957	eν: 1.37
μμ: 0.834	μν: 1.29
ℓℓ: 1.048	ℓν: 1.49

Mass of Z*, W* [TeV]

ee: 1.058	eν: 1.26
μμ: 0.946	μν: 1.12
ℓℓ: 1.152	ℓν: 1.35

First limits!

Mass of E_6 Z' [TeV]

ℓℓ: 0.738 – 0.900

Λ_{LL}^-, Λ_{LL}^+ - qqμμ C.I. [TeV]

4.9, 4.5

World's best limits!!

Conclusion and outlook

With ~40/pb of data, ATLAS has set limits:

- at the level of Tevatron: Z', or above: W'
- first ones on new models: Z*, W*
- world's best on qqμμ contact interactions

Coming soon: increased luminosity, improved acceptance (calorimeter readout, MS alignment), more models

Stay tuned !

Many thanks to the organizers!

References:
The ATLAS Collaboration, arXiv:1103.3864, submitted to PLB
The ATLAS Collaboration, arXiv:1103.6218 , submitted to PLB

Extra slides

Tevatron limits

Mass of SSM gauge boson [TeV]

CDF ee: 0.963 (2.5/fb)

D0 ee: 1.023 (5.4/fb)

CDF μμ: 1.071 (5.3/fb)

CDF eν: 1.12 (5.3/fb)

D0 eν: 1.00 (1/fb)

Λ_{LL}^-, Λ_{LL}^+ of $qq\ell\ell$ C.I. [TeV]

CDF ee: 5.9, 3.7 (450/pb)

D0 ee: 4.2, 3.3 (120/pb)

CDF μμ: 4.2, 2.9 (110/pb)

E_6 limits

Mass of E_6 Z' [TeV]

Combined ($\ell\ell$) limits:

	ψ	N	η	I	S	χ
Observed	0.738	0.763	0.771	0.842	0.871	0.900
Expected	*0.837*	*0.860*	*0.866*	*0.922*	*0.945*	*0.965*

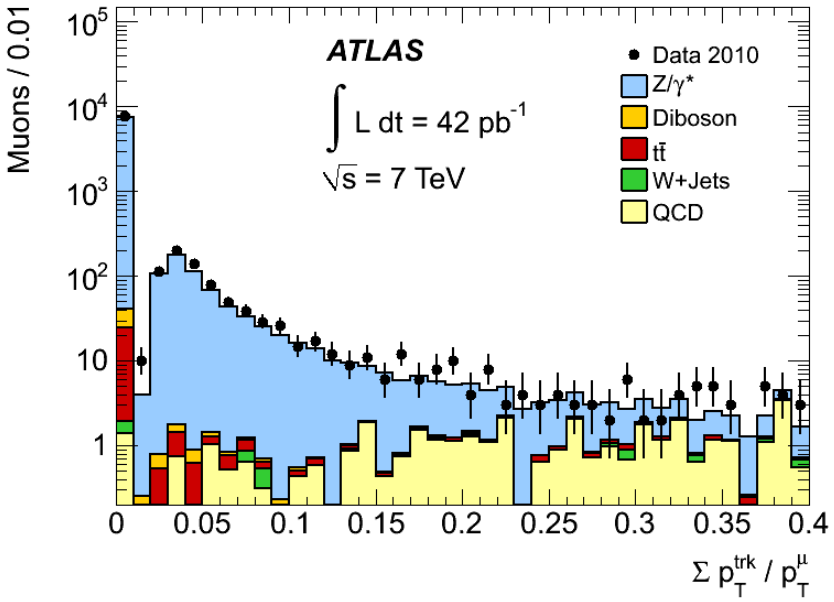
Event counts

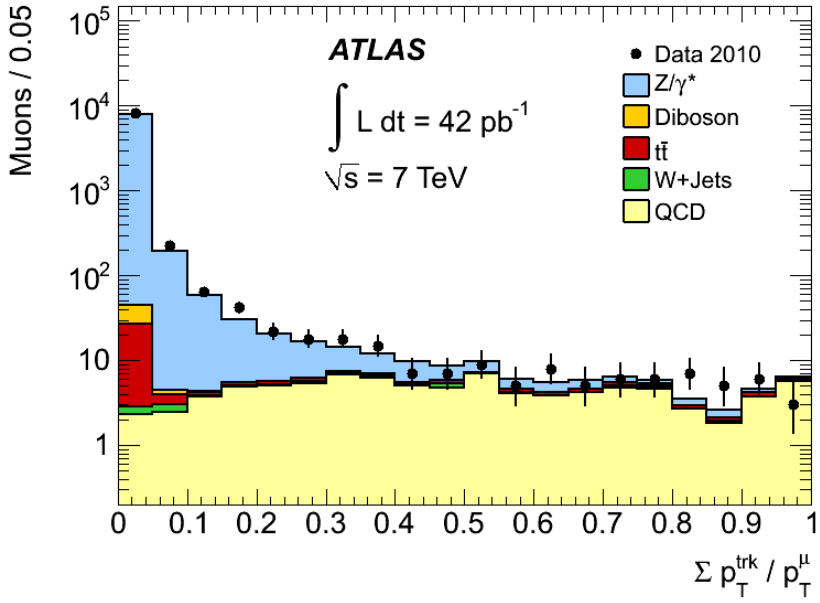
$m_{e^+e^-}$ [GeV]	70-110	110-130	130-150	150-170	170-200
Z/γ^*	8498.5 ± 7.9	104.9 ± 3.3	36.8 ± 1.3	19.4 ± 0.7	14.7 ± 0.6
$t\bar{t}$	8.2 ± 0.8	2.8 ± 0.3	2.1 ± 0.2	1.7 ± 0.2	1.7 ± 0.2
Diboson	12.1 ± 0.9	1.0 ± 0.2	0.7 ± 0.2	0.5 ± 0.2	0.5 ± 0.1
W + jets	6.0 ± 1.8	3.7 ± 1.2	1.2 ± 0.5	1.3 ± 0.5	1.2 ± 0.4
QCD	32.1 ± 7.1	8.4 ± 1.8	5.5 ± 0.8	3.2 ± 0.6	2.8 ± 0.8
Total	8557.0 ± 10.8	120.9 ± 4.0	46.4 ± 1.6	26.2 ± 1.1	20.8 ± 1.1
Data	8557	131	49	20	18
$m_{e^+e^-}$ [GeV]	200-240	240-300	300-400	400-800	800-2000
Z/γ^*	9.5 ± 0.4	6.0 ± 0.3	3.2 ± 0.1	1.6 ± 0.1	0.1 ± 0.0
$t\bar{t}$	1.2 ± 0.1	0.9 ± 0.1	0.5 ± 0.0	0.2 ± 0.0	0.0 ± 0.0
Diboson	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
W + jets	1.1 ± 0.4	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0
QCD	1.9 ± 0.8	1.3 ± 0.7	0.8 ± 0.4	0.5 ± 0.2	0.1 ± 0.1
Total	14.1 ± 1.0	8.8 ± 0.7	4.8 ± 0.5	2.7 ± 0.3	0.2 ± 0.1
Data	13	9	3	3	0

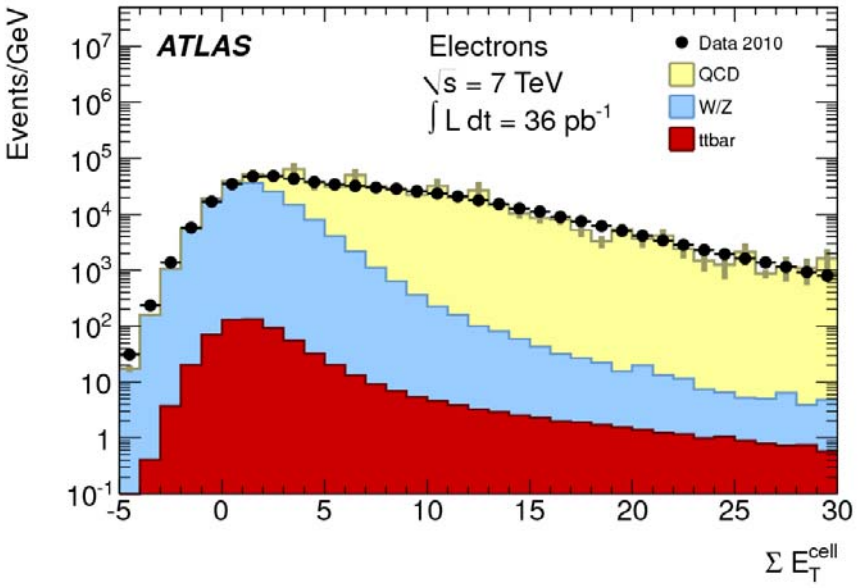
$m_{\mu^+\mu^-}$ [GeV]	70-110	110-130	130-150	150-170	170-200
Z/γ^*	7546.7 ± 7.1	98.4 ± 3.1	33.4 ± 1.1	17.2 ± 0.6	12.8 ± 0.5
$t\bar{t}$	6.0 ± 0.6	2.4 ± 0.3	1.7 ± 0.2	1.2 ± 0.1	1.2 ± 0.1
Diboson	10.0 ± 0.5	0.8 ± 0.1	0.6 ± 0.0	0.5 ± 0.0	0.4 ± 0.0
W + jets	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
QCD	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total	7563.0 ± 7.2	101.6 ± 3.1	35.7 ± 1.2	18.9 ± 0.7	14.4 ± 0.5
Data	7563	101	41	11	11
$m_{\mu^+\mu^-}$ [GeV]	200-240	240-300	300-400	400-800	800-2000
Z/γ^*	7.8 ± 0.3	5.1 ± 0.2	2.5 ± 0.1	1.3 ± 0.1	0.1 ± 0.0
$t\bar{t}$	1.0 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Diboson	0.3 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
W + jets	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
QCD	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total	9.1 ± 0.4	6.0 ± 0.2	3.0 ± 0.1	1.5 ± 0.1	0.1 ± 0.0
Data	7	6	2	1	0

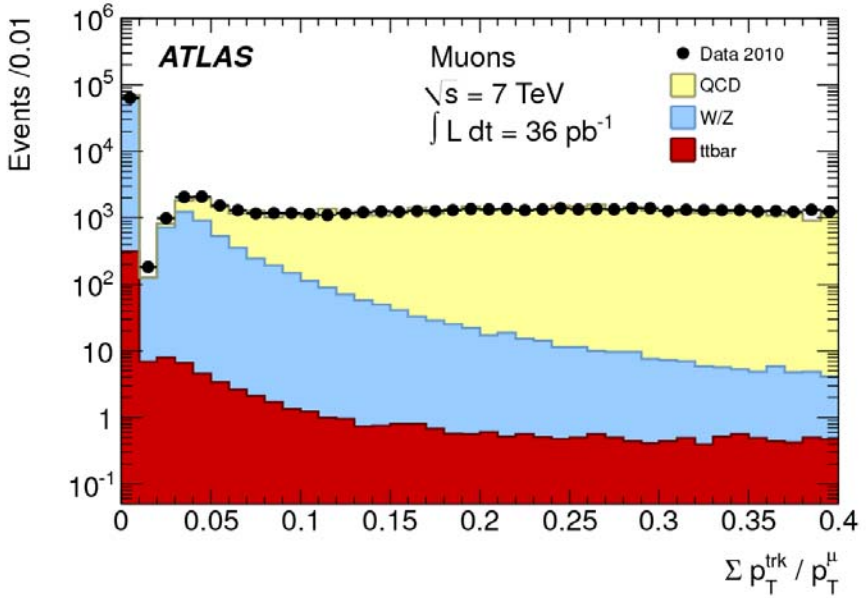
m [GeV]	decay	$\varepsilon_{\mathrm{sig}}$ W'	$\varepsilon_{\mathrm{sig}}$ W^*	N_{sig} W'	N_{sig} W^*	N_{bg}	N_{obs}
500	$e\nu$	0.556 ± 0.024	0.530 ± 0.022	349 ± 30	208 ± 18	21.5 ± 2.0	24
	$\mu\nu$	0.339 ± 0.008	0.265 ± 0.005	212 ± 17	104 ± 8	20.3 ± 1.1	16
750	$e\nu$	0.565 ± 0.025	0.520 ± 0.022	65.8 ± 4.8	39.6 ± 3.5	4.05 ± 0.35	6
	$\mu\nu$	0.362 ± 0.009	0.257 ± 0.005	42.1 ± 2.7	19.6 ± 1.5	5.48 ± 0.44	0
1000	$e\nu$	0.562 ± 0.025	0.516 ± 0.022	17.1 ± 1.4	10.5 ± 1.0	1.11 ± 0.11	1
	$\mu\nu$	0.381 ± 0.010	0.264 ± 0.006	11.6 ± 0.9	5.4 ± 0.5	2.05 ± 0.25	0
1250	$e\nu$	0.552 ± 0.026	0.505 ± 0.023	5.23 ± 0.51	3.22 ± 0.42	0.400 ± 0.054	0
	$\mu\nu$	0.386 ± 0.011	0.255 ± 0.006	3.66 ± 0.33	1.63 ± 0.20	1.01 ± 0.17	0
1500	$e\nu$	0.530 ± 0.028	0.488 ± 0.025	1.71 ± 0.21	1.06 ± 0.17	0.159 ± 0.020	0
	$\mu\nu$	0.383 ± 0.012	0.252 ± 0.006	1.24 ± 0.14	0.54 ± 0.08	0.62 ± 0.13	0
1750	$e\nu$	0.503 ± 0.027	0.482 ± 0.028	0.59 ± 0.09	0.37 ± 0.07	0.069 ± 0.009	0
	$\mu\nu$	0.360 ± 0.012	0.254 ± 0.007	0.43 ± 0.06	0.20 ± 0.04	0.47 ± 0.09	0

Isolation


ATLAS
∫ L dt = 42 pb-1
√s = 7 TeV
Data 2010
Z/γ*
Diboson
tt̄
W+Jets
QCD
Muons / 0.01
Σ pTtrk / pTμ

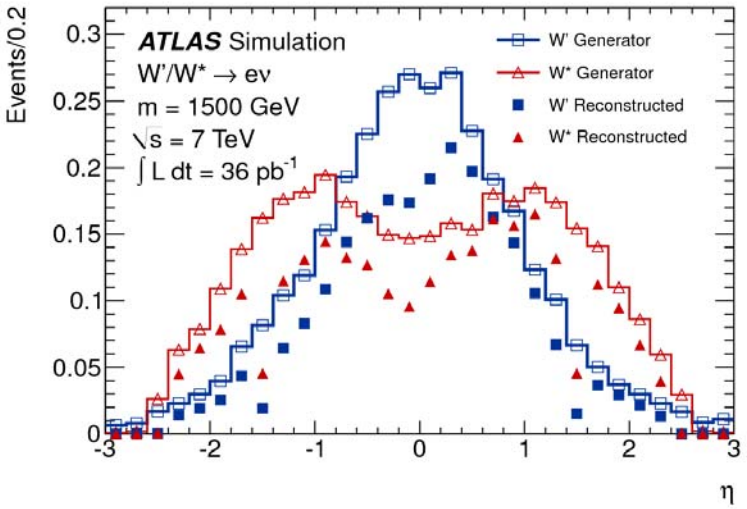

ATLAS
∫ L dt = 42 pb-1
√s = 7 TeV
Data 2010
Z/γ*
Diboson
tt̄
W+Jets
QCD
Muons / 0.05
Σ pTtrk / pTμ

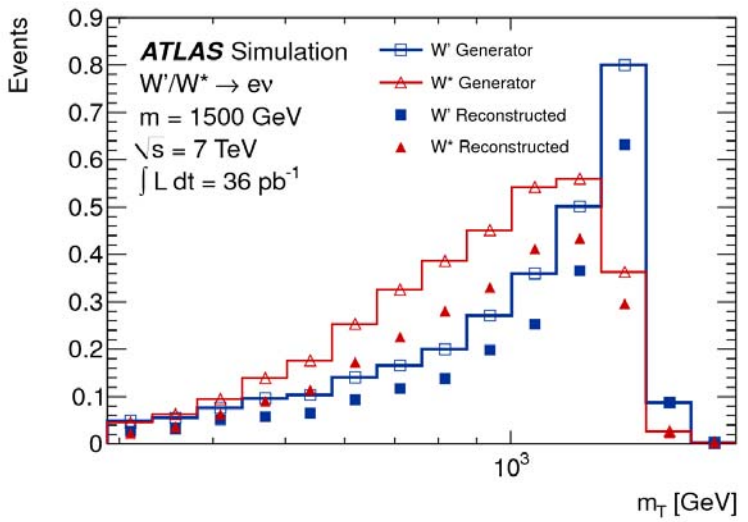

ATLAS
Electrons
√s = 7 TeV
∫ L dt = 36 pb-1
Data 2010
QCD
W/Z
ttbar
Events/GeV
Σ ETcell


ATLAS
Muons
√s = 7 TeV
∫ L dt = 36 pb-1
Data 2010
QCD
W/Z
ttbar
Events /0.01
Σ pTtrk / pTμ

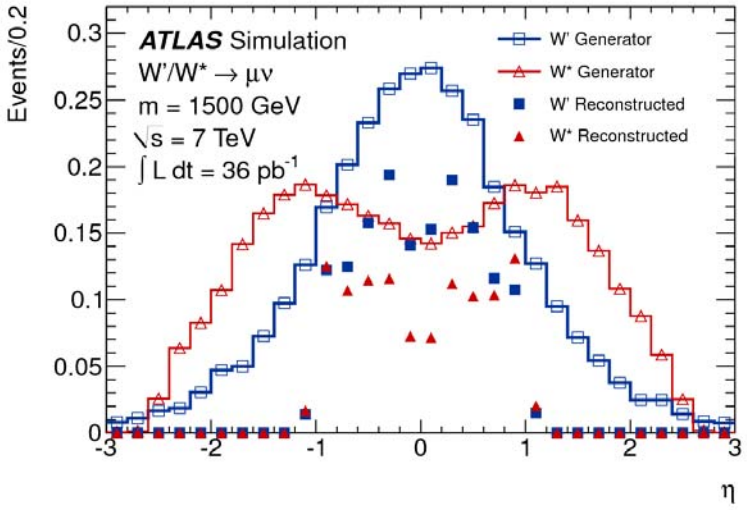
W'/W* comparison

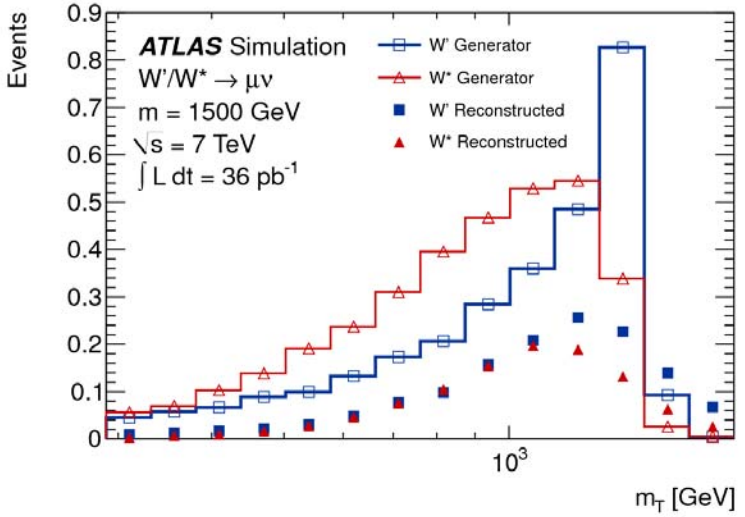
eν



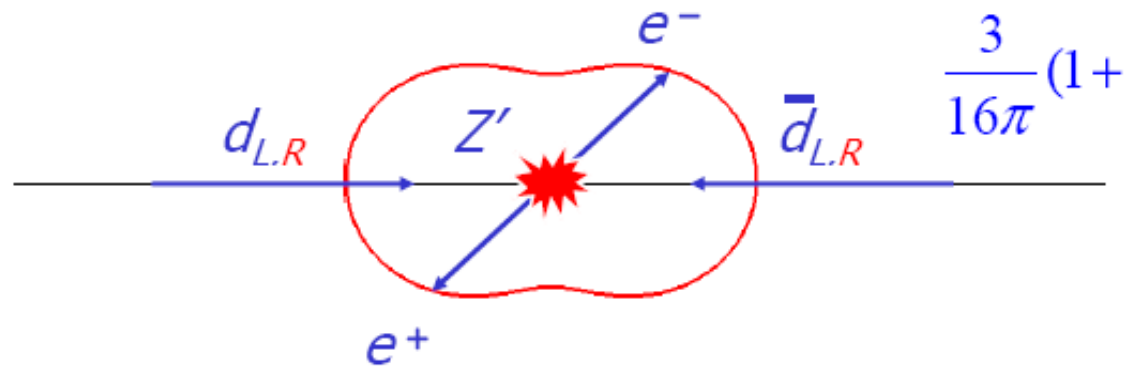


μν

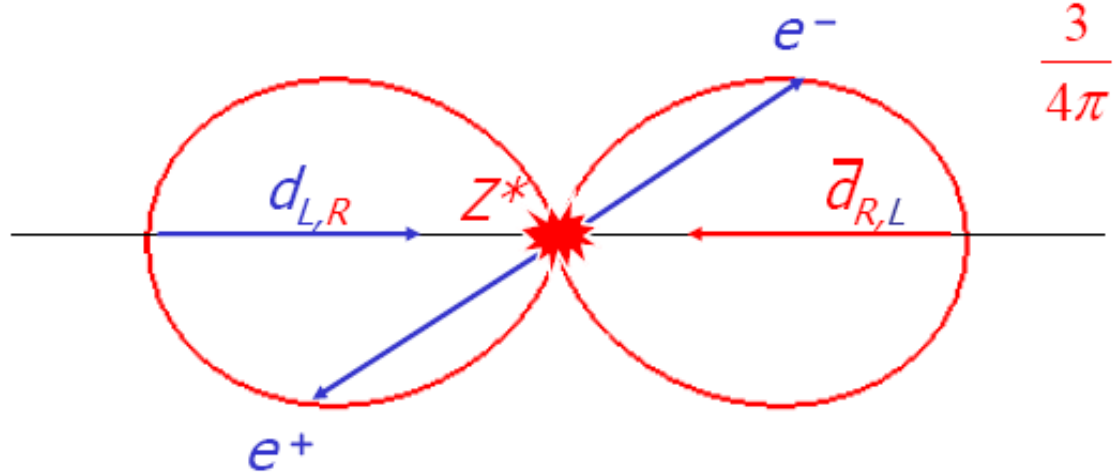




Angular distributions



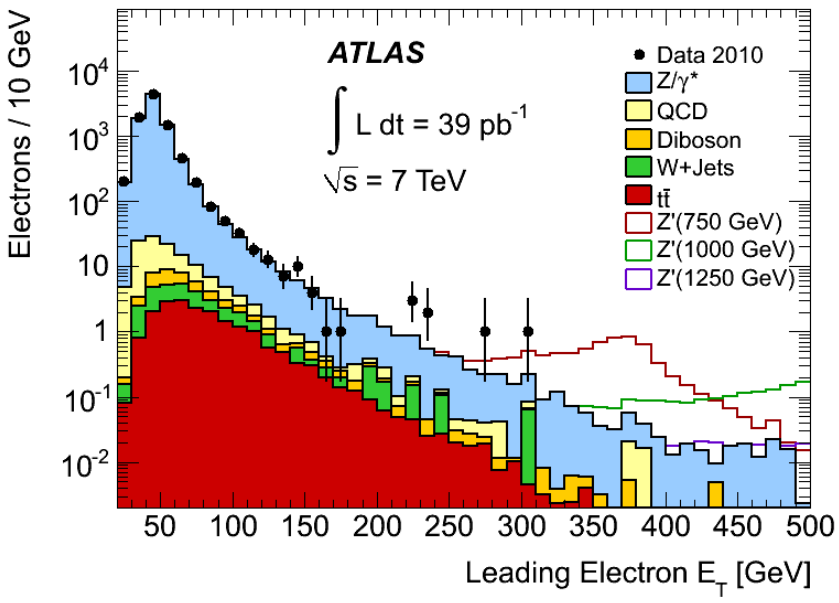
$$\frac{3}{16\pi}(1+\cos^2\vartheta)$$

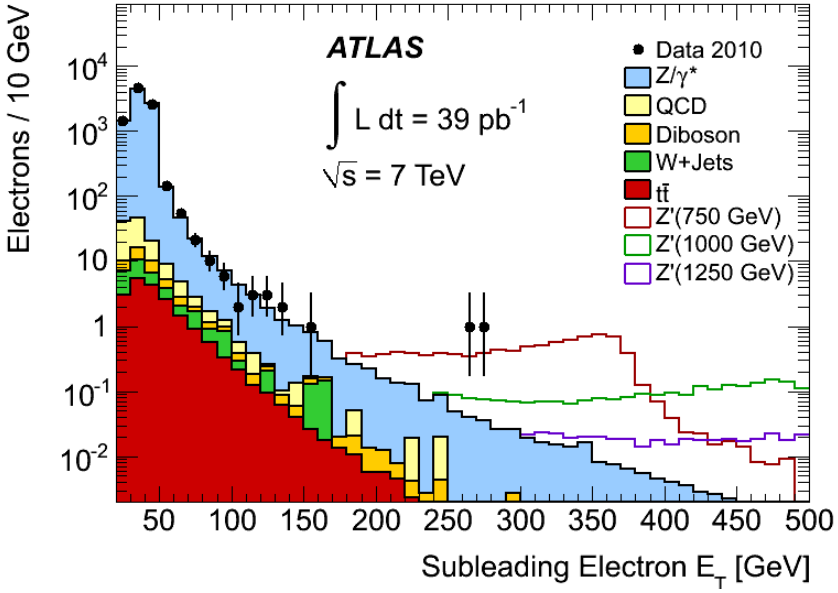


$$\frac{3}{4\pi}\cos^2\vartheta$$

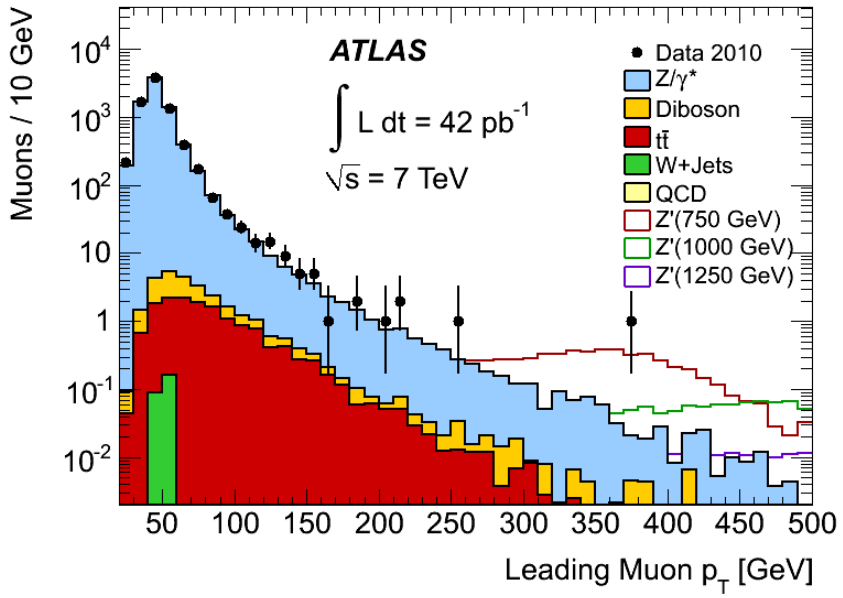
Lepton kinematics ($\ell\ell$)

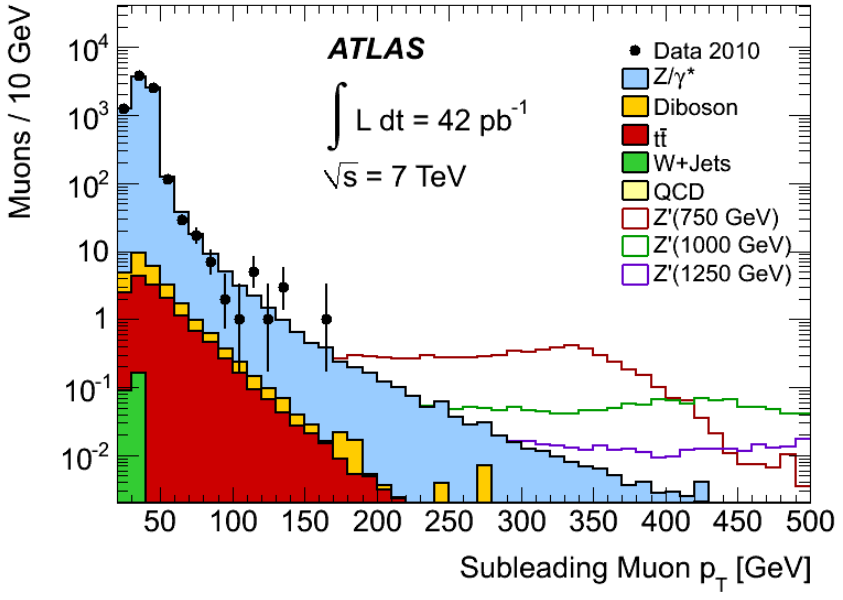
$e\nu$



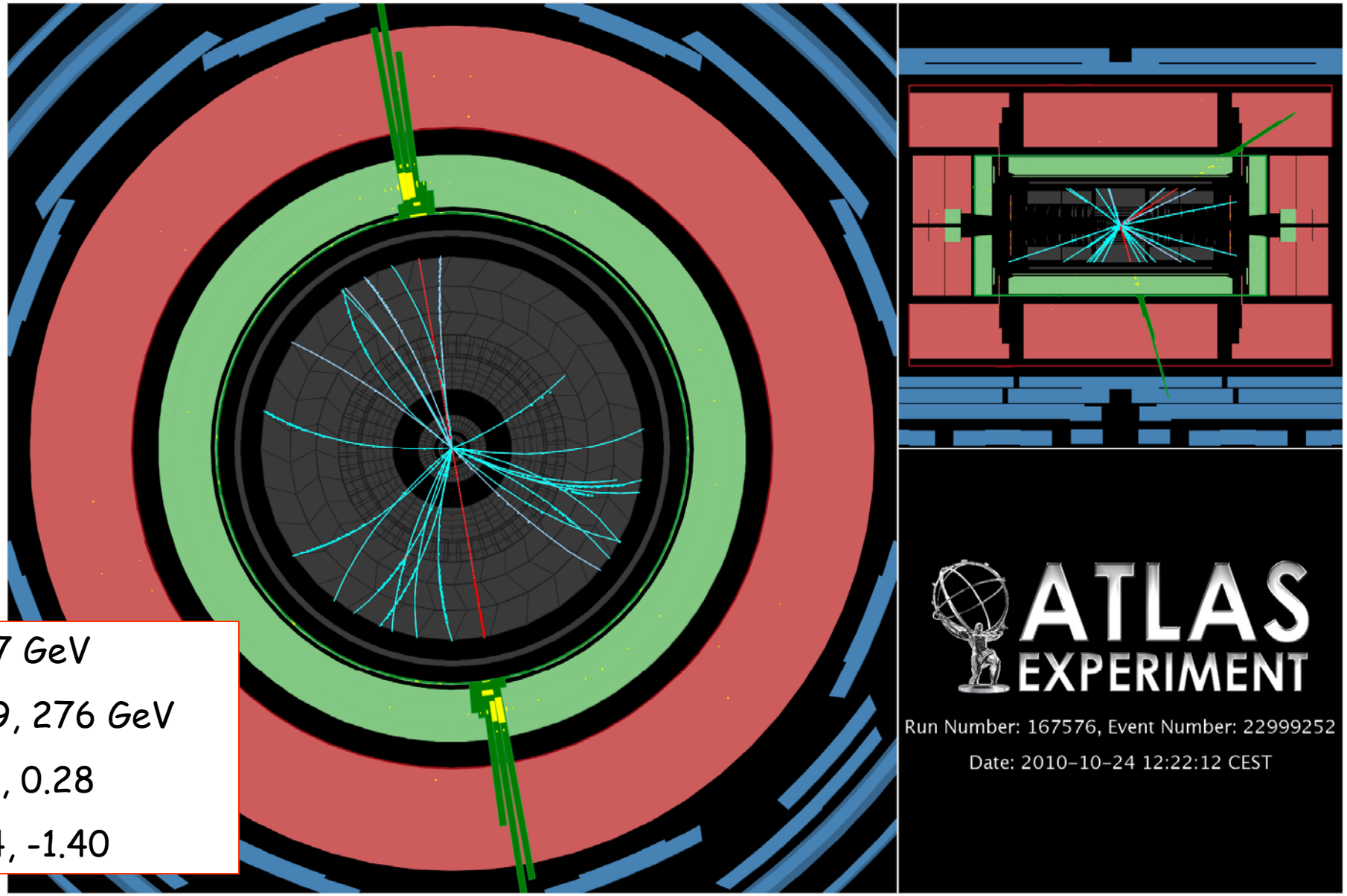


$\mu\nu$





Highest m_{ee} candidate



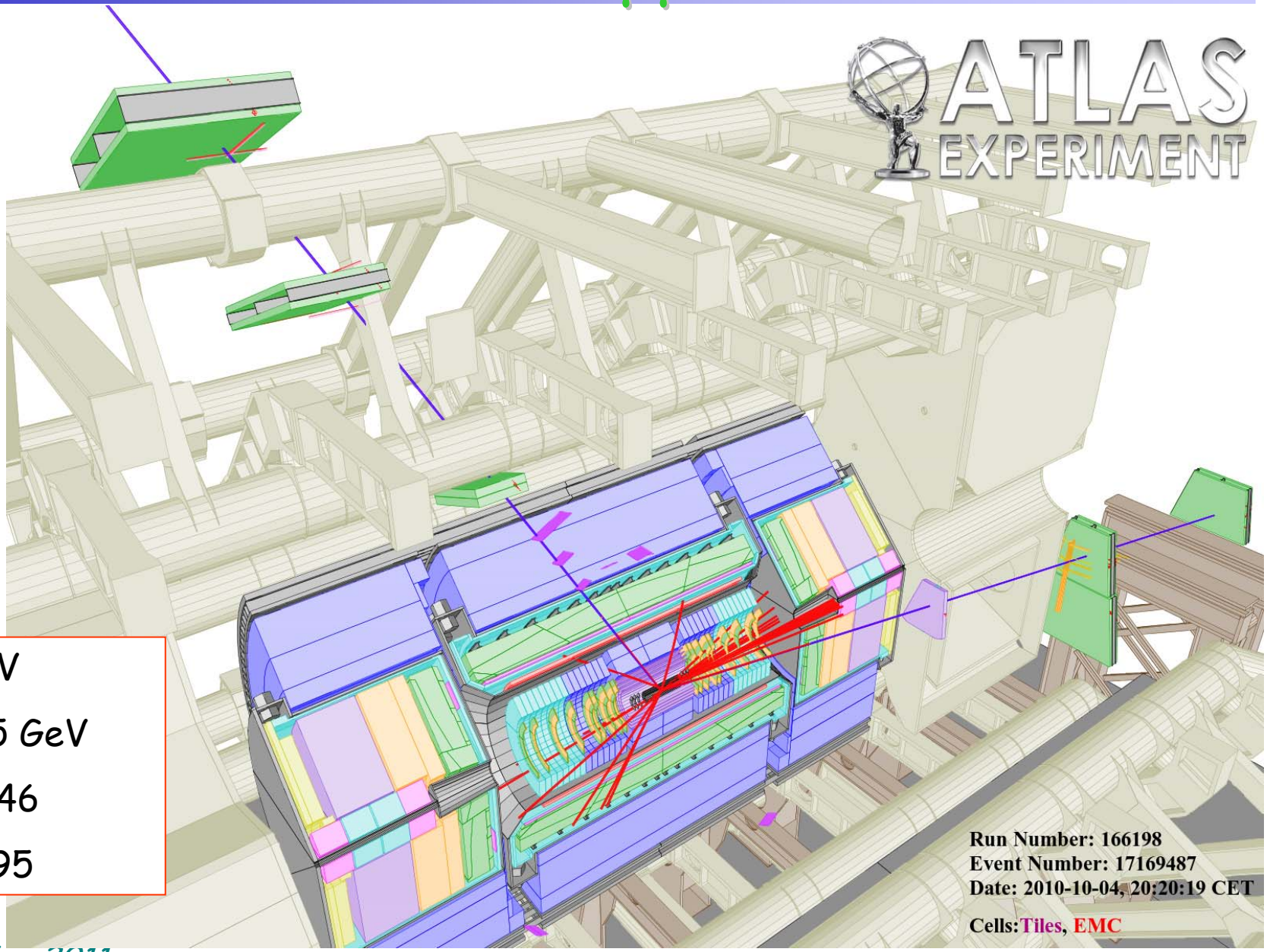
M_{12} = 617 GeV

$p_{T1,2}$=279, 276 GeV

$\eta_{1,2}$=1.22, 0.28

$\Phi_{1,2}$=1.74, -1.40

Highest $m_{\mu\mu}$ candidate



M_{12} = 768 GeV

$p_{T1,2}$=186, 165 GeV

$\eta_{1,2}$=-2.39, 0.46

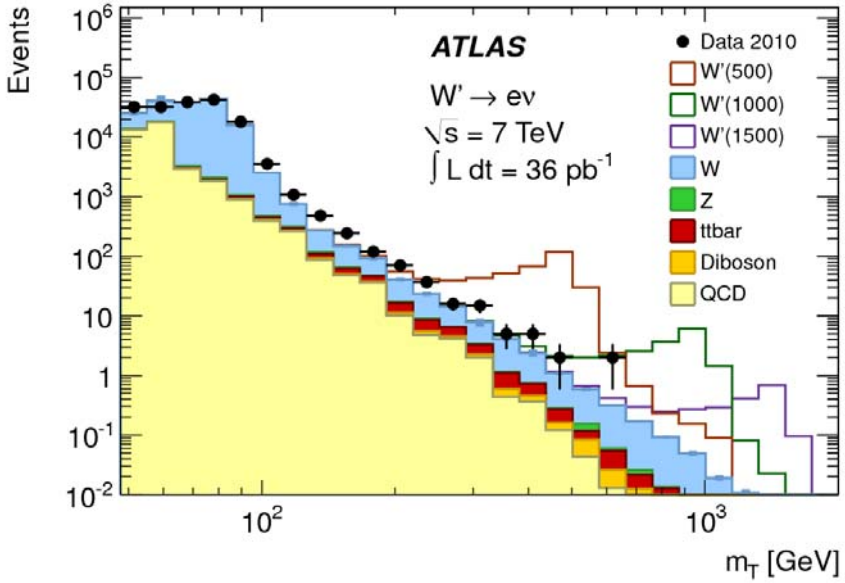
$\Phi_{1,2}$=-1.54, 1.95

Electron identification

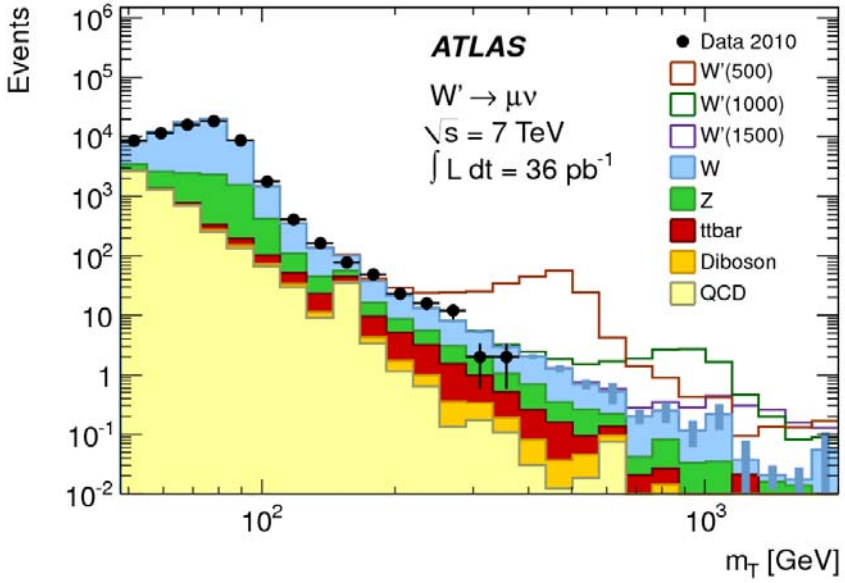
Type	Description	Name
	Loose electron and photon cuts	
Acceptance of the detector	$\|\eta\| < 2.47$ for electrons, $\|\eta\| < 2.37$ for photons ($1.37 < \|\eta\| < 1.52$ excluded)	-
Hadronic leakage	Ratio of E_T in the 1st sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$)	R_{had1}
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| > 0.8$ and $\|\eta\| < 1.37$)	R_{had}
Middle layer of the EM calorimeter	Ratio in η of cell energies in 3×7 versus 7×7 cells.	R_η
	Lateral width of the shower	w_2
	Medium electron cuts (in addition to the loose cuts)	
Strip layer of the EM calorimeter	Total lateral shower width (20 strips)	w_{stot}
	Ratio of the energy difference between the largest and second largest energy deposits over the sum of these energies	E_{ratio}
Track quality	Number of hits in the pixel detector (at least one)	-
	Number of hits in the pixels and SCT (at least seven)	-
	Transverse impact parameter (<5 mm)	d_0
Track matching	$\Delta\eta$ between the cluster and the track in the strip layer of the EM calorimeter	$\Delta\eta_1$
	Tight electron cuts (in addition to the medium electron cuts)	
B-layer	Number of hits in the B-layer (at least one)	
Track matching	$\Delta\phi$ between the cluster and the track in the middle layer of the EM calorimeter	$\Delta\phi_2$
	Ratio of the cluster energy to the track momentum	E/p
TRT	Total number of hits in the TRT (used over the acceptance of the TRT, $\|\eta\| < 2.0$)	-
	Ratio of the number of high-threshold hits to the total number of TRT hits (used over the acceptance of the TRT, $\|\eta\| < 2.0$)	-

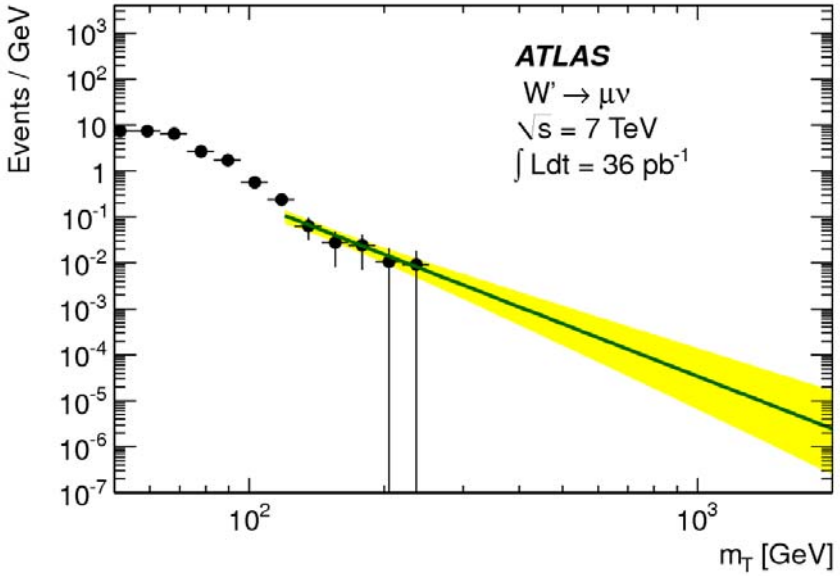
Preselection ($\ell\nu$)

$e\nu$

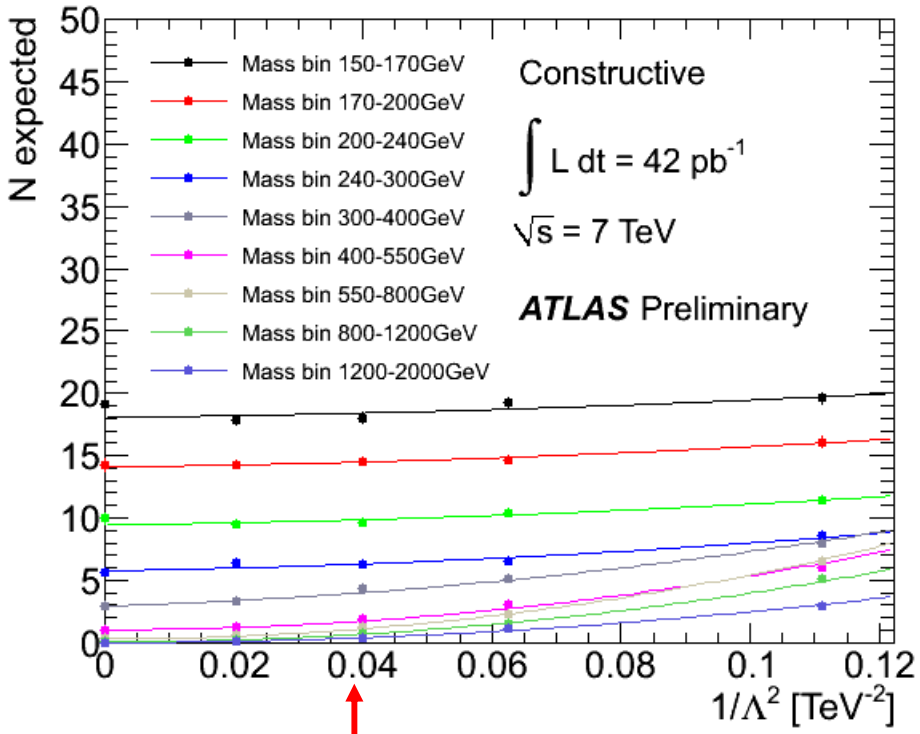


$\mu\nu$

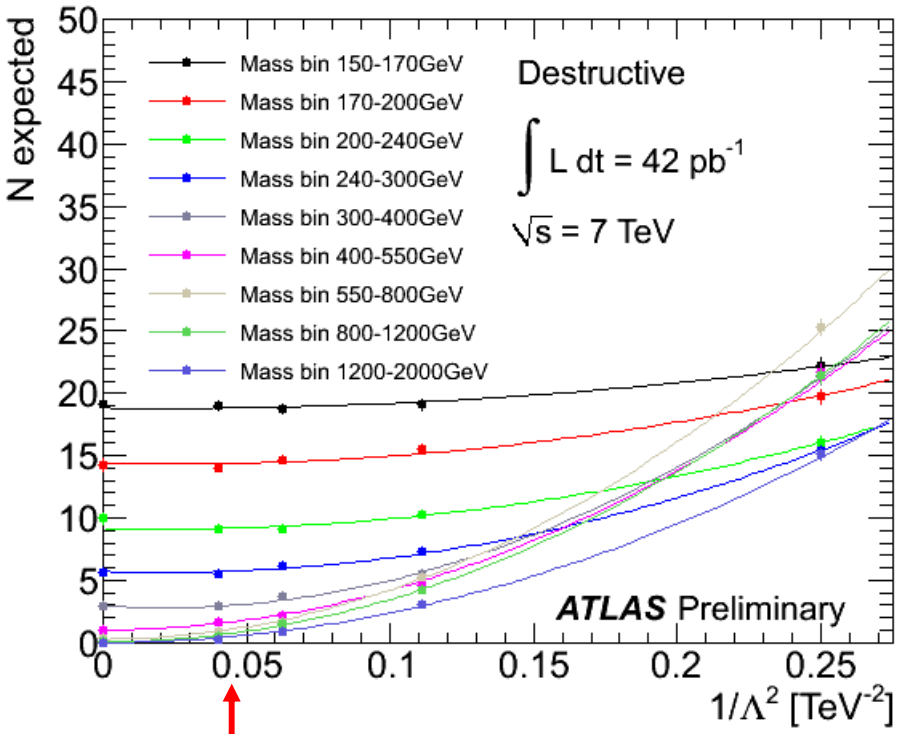




N_{exp} interpolation

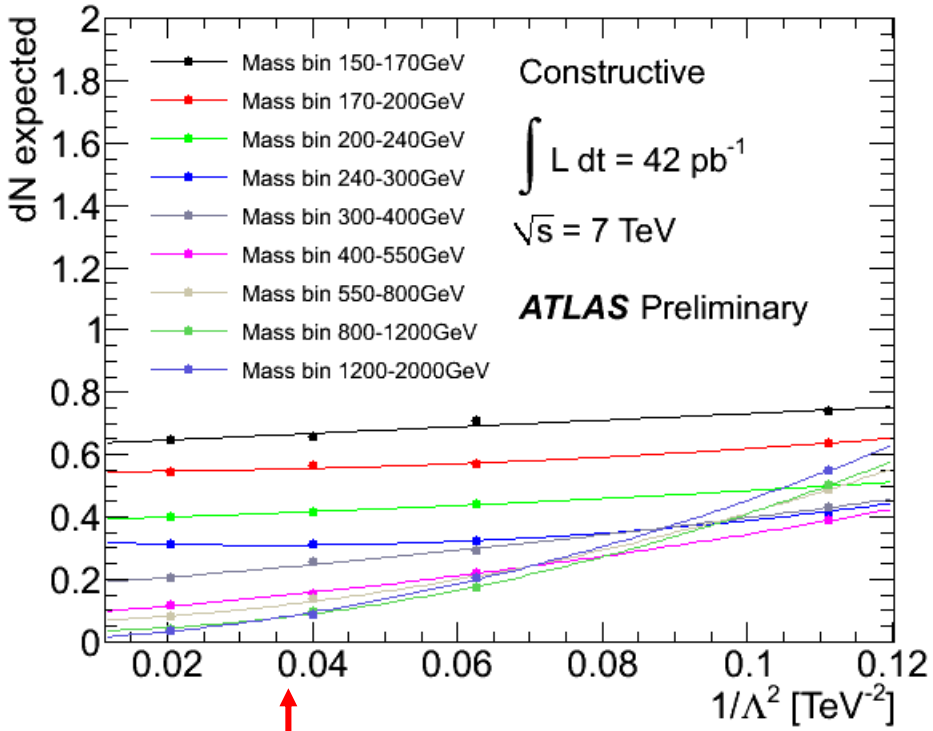


Observed limit

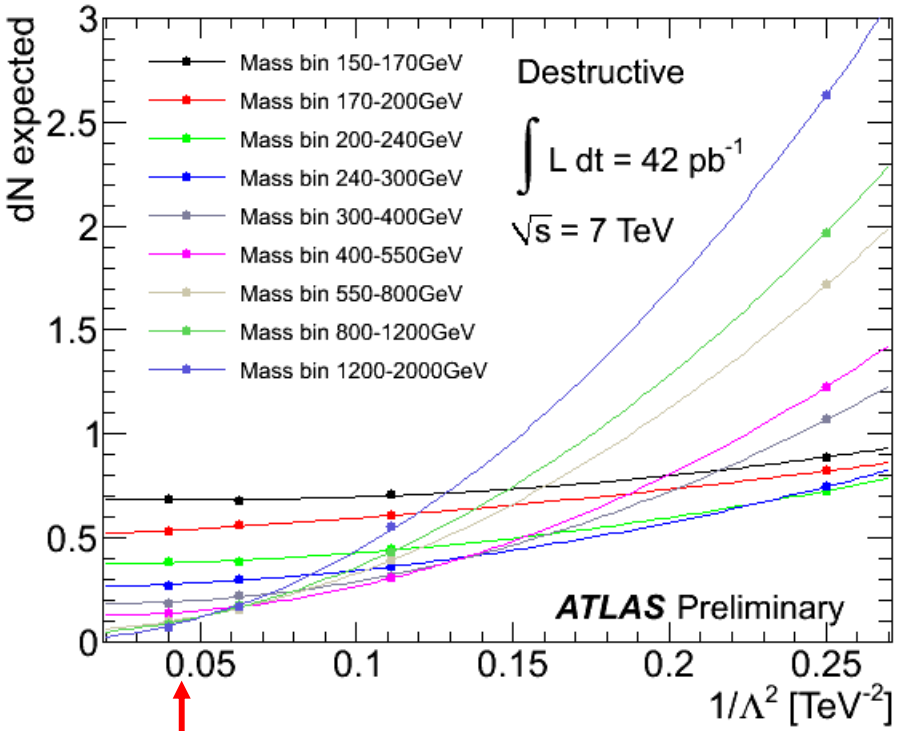


Observed limit

dN_{exp} interpolation

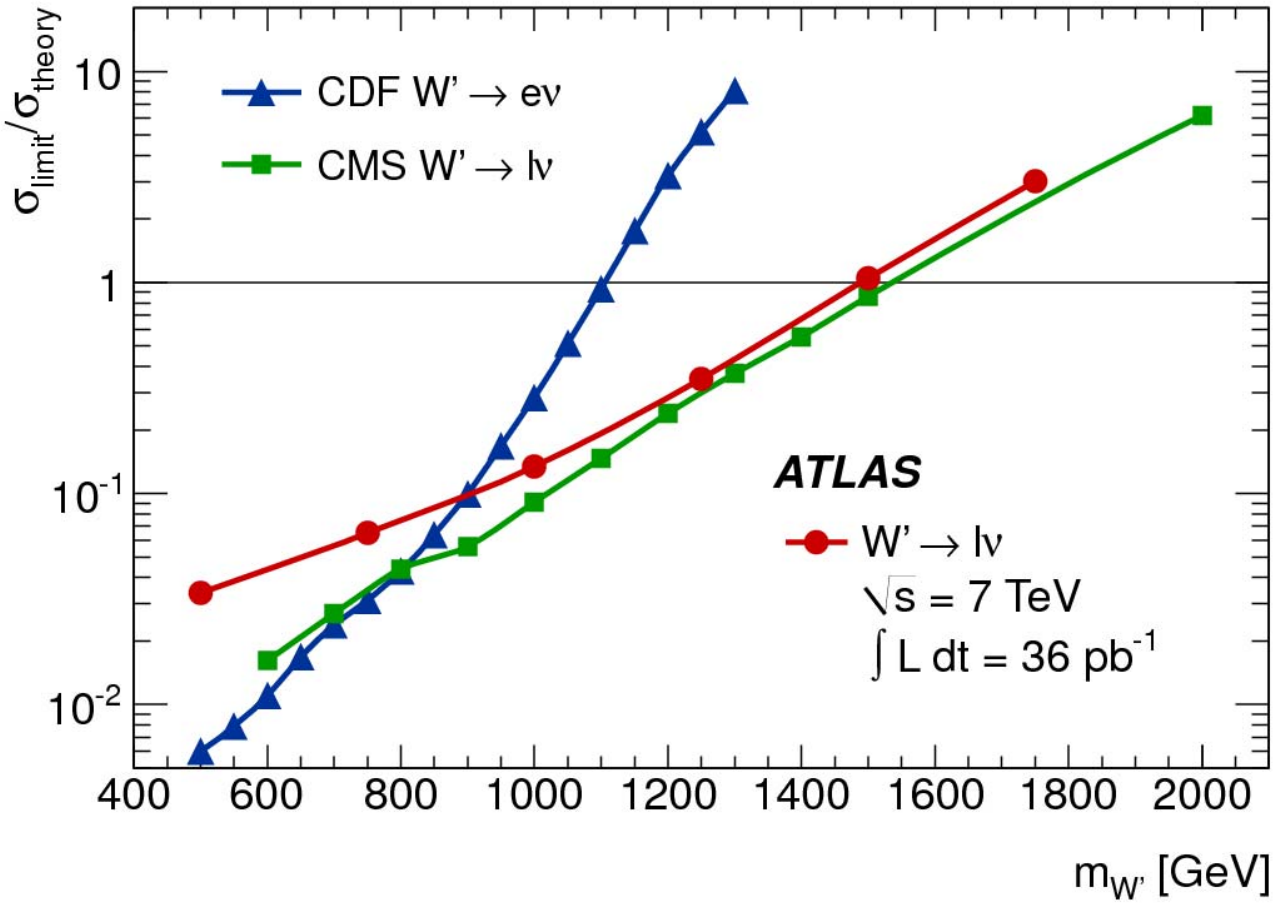


Observed limit



Observed limit

Cross section limit comparison



Backgrounds

$\ell\ell$

- Z/γ^*
- QCD (ee only)
- ttbar
- WW, WZ, ZZ (diboson)
- W+jets (ee only)

$\ell\nu$

- W
- Z ($\mu\nu$ only)
- ttbar
- diboson

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:

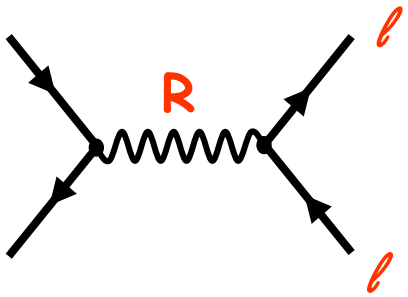
Z, W: NNLO (PHOZPR, FEWZ,MCFMs+HORACE) with MSTW08

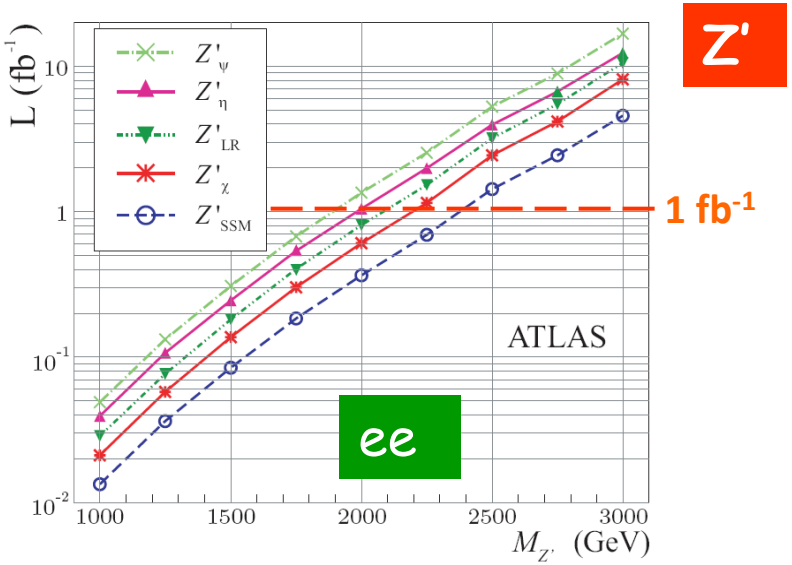
WW, WZ, ZZ: NLO

ttbar: approximate NNLO (HATHOR)

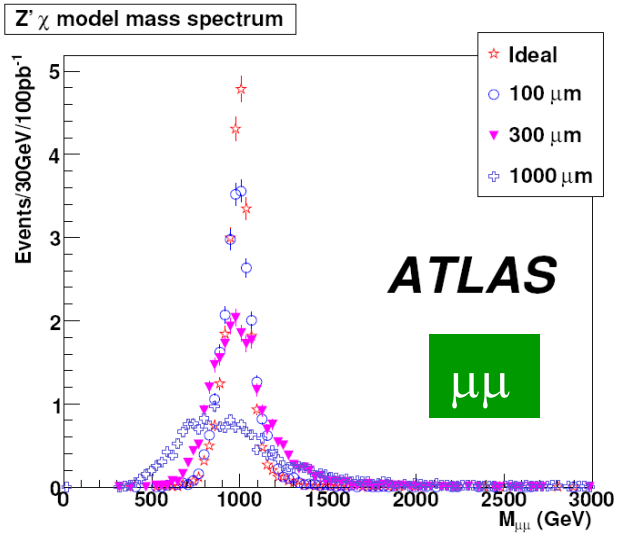
W+jets: NLO, rescaled to inclusive σ at NNLO

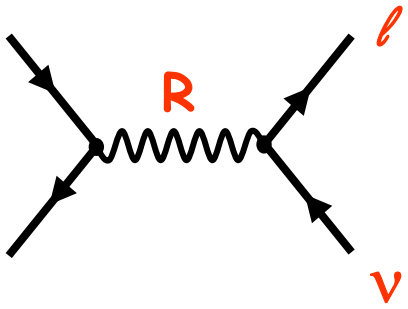
Discovery potential

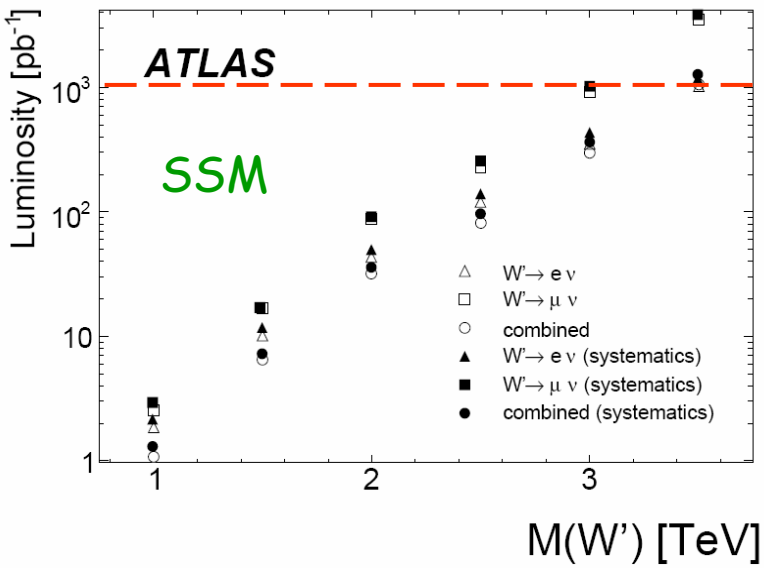




Z'







W'