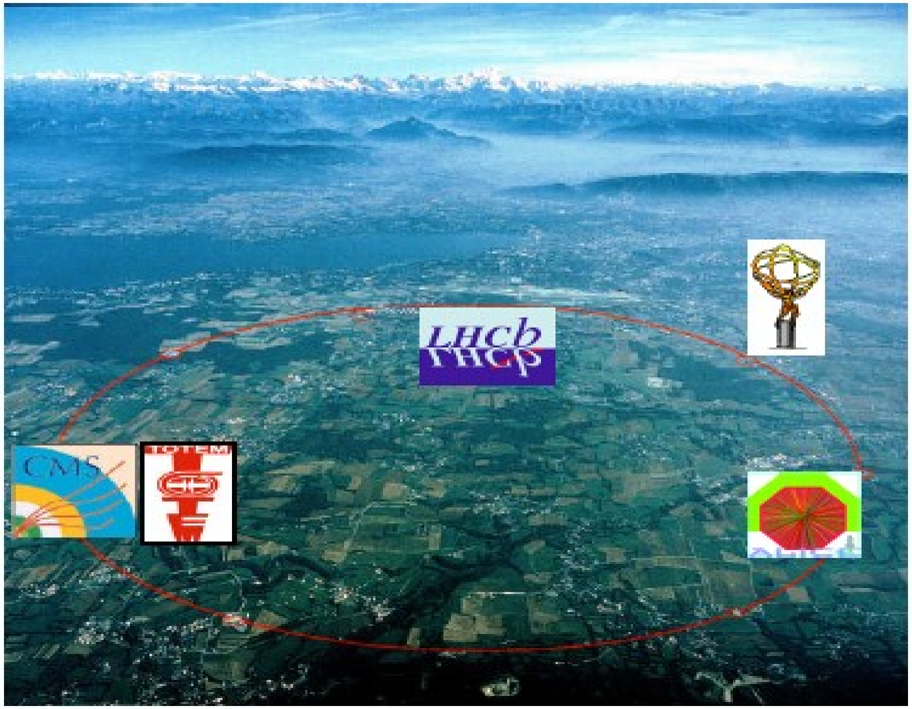
Physics with first fb^{-1}

at Large Hadron Collider

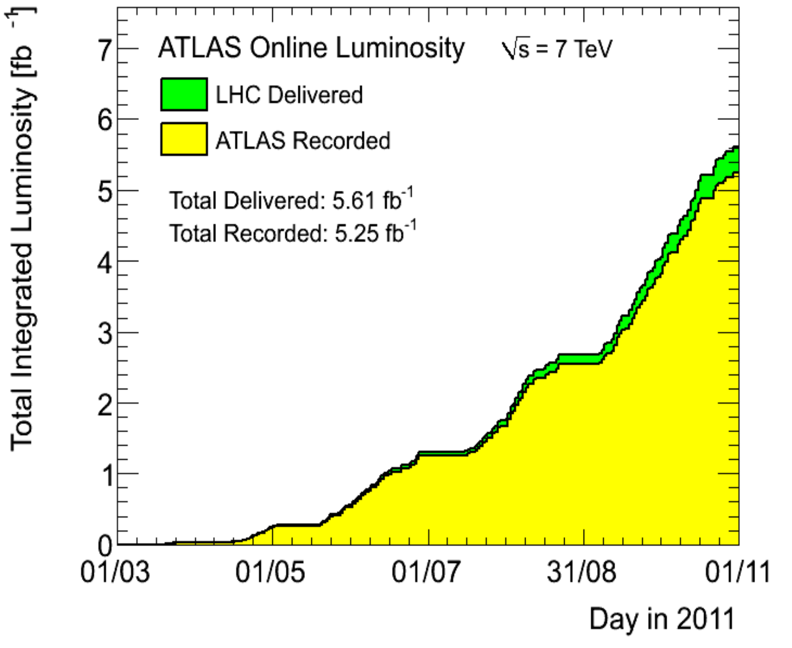
Today:

- **W,Z inclusive cross-section**
- **Asymmetry**
- **W+jets, Z + jets**



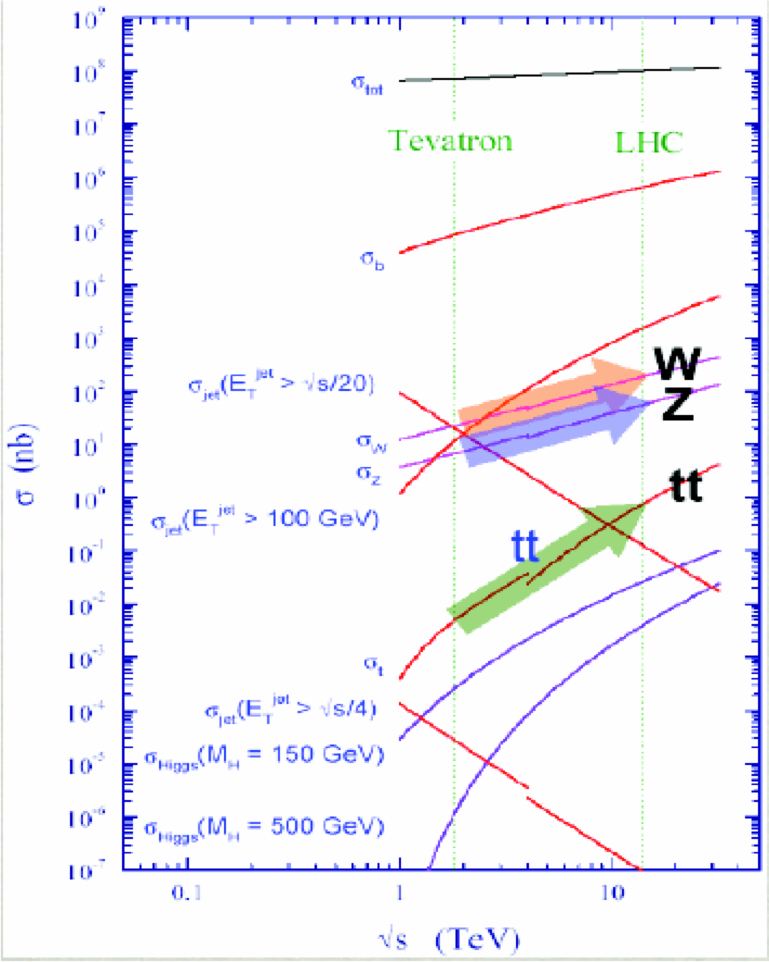
News from last week(s)

- **5.25 fb^{-1} pp collisions recorded by ATLAS**
- **PbPb run of 2011 started**



Bosons at LHC

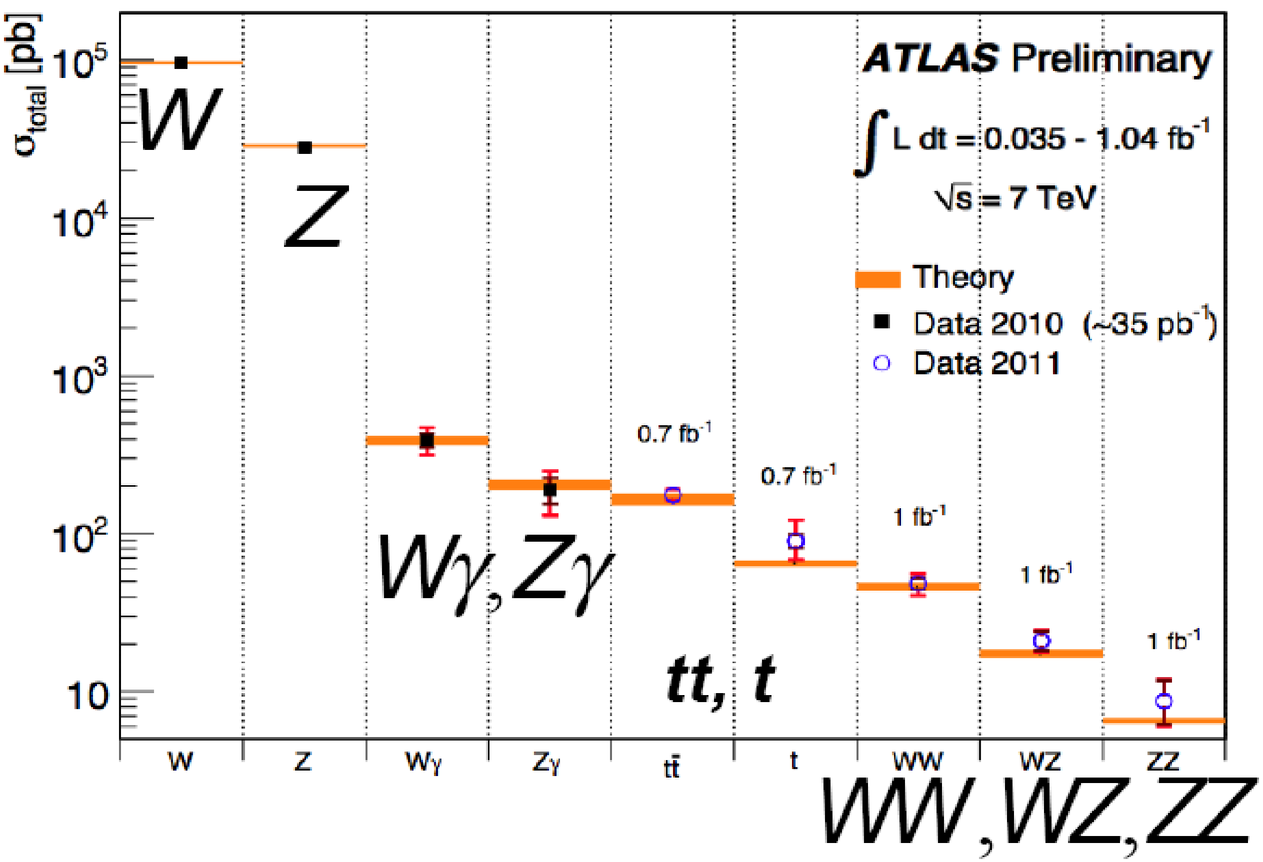
- Well measured by previous experiments
  - Inclusive cross sections, $R(W^+/W^-)$, R(W/Z)
  - Differential distributions, associated jet multiplicity, A_{FB}, etc.
- Yet still educational at the LHC
  - Cross sections at $\sqrt{(s)}$=7TeV
  - New pdf constraints possible
- "Standard candles" for high-p_T analyses
  - Calibration, alignment
  - Independent luminosity measurements



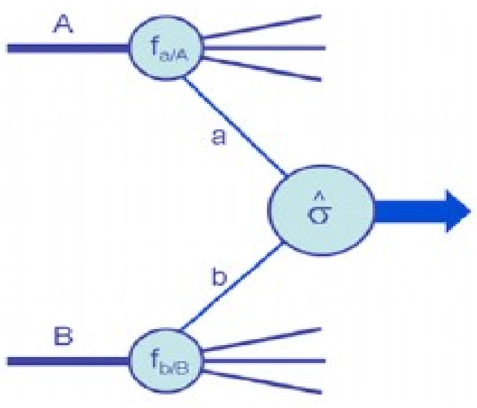
Just departure point for high-p_T Beyond Standard Model analyses

The Standard Model

- SM measurements are the foundations of all searches (33 papers on measurements to date)



Drell-Yan cross-section



- Keywords:
  - factorisation μ_F and renormalisation μ_R scales
  - universal parton distribution functions
  - LO, NLO, NNLO matrix elements and DGLAP kernels

$$\sigma_{AB} = \int \mathrm{d}x_a \mathrm{d}x_b\ f_{a/A}(x_a, Q^2) f_{b/B}(x_b, Q^2)\ \hat{\sigma}_{ab\to X}$$

also depends on μ_R and μ_F, so as to cancel scale dependence in PDF's and α_s, to this order

$$\sigma_{AB} = \int \mathrm{d}x_a \mathrm{d}x_b\ f_{a/A}(x_a, \mu_F^2)\ f_{b/B}(x_b, \mu_F^2)\ \times\ [\hat{\sigma}_0 + \alpha_S(\mu_R^2)\,\hat{\sigma}_1 + \cdots]_{ab\to X}.$$

- All orders cross section has no dependence on μ_F and μ_R; a residual dependence remains (to order α_s^{n+1}) for a finite order (α_s^n) calculations.

DGLAP equations

- Parton distributions used in hard scattering calculations are solutions of DGLAP equations

$$\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{\mathrm{d}z}{z}\Big\{P_{q_i q_j}(z,\alpha_S)q_j(\frac{x}{z},\mu^2) + P_{q_i g}(z,\alpha_S)\; g(\frac{x}{z},\mu^2)\Big\},$$

$$\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{\mathrm{d}z}{z}\Big\{P_{g q_j}(z,\alpha_S)q_j(\frac{x}{z},\mu^2) + P_{gg}(z,\alpha_S)g(\frac{x}{z},\mu^2)\Big\},$$

- Splitting functions have perturbative expansions

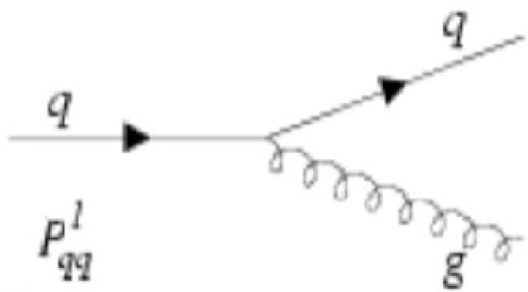
$$P_{ab}(x,\alpha_S) = P_{ab}^{(0)}(x) + \frac{\alpha_S}{2\pi}P_{ab}^{(1)}(x) + \cdots$$

Thus, a full NLO calculation will contain both $\hat{\sigma}_1$ (previous slide) and $P_{ab}^{(1)}$

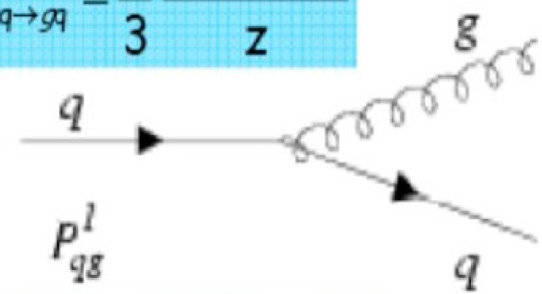
Altarelli-Parisi splitting functions

Altarelli-Parisi splitting functions:

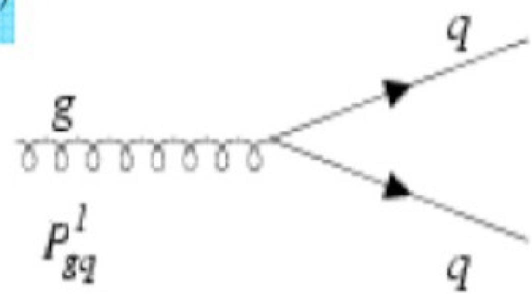
$$P_{q\to qg} = \frac{4}{3}\left(\frac{1+z^2}{1-z}\right)$$



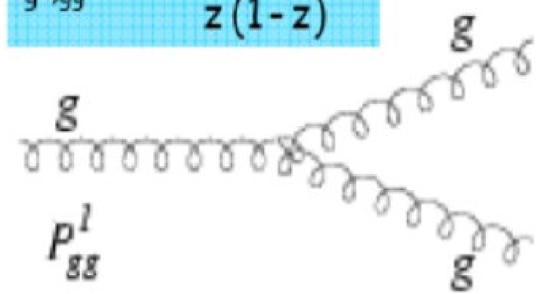
$$P_{q\to gq} = \frac{4}{3}\frac{1+(1-z)^2}{z}$$



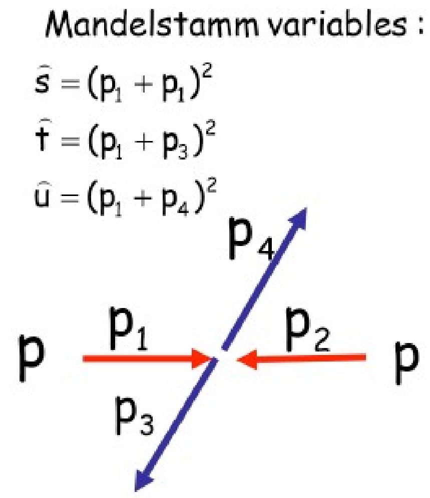
$$P_{g\to q\bar{q}} = \frac{n_f^2}{2}\left(z^2+(1-z)^2\right)$$



$$P_{g\to gg} = 3\frac{(1-z(1-z))^2}{z(1-z)}$$



W/Z production



- Cross sections for on-shell W and Z production (in narrow width limit) given by

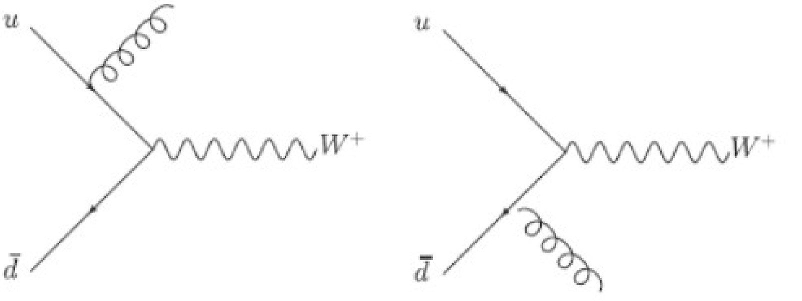
$$\hat{\sigma}^{q\bar{q}'\to W} = \frac{\pi}{3}\sqrt{2}G_F M_W^2 |V_{qq'}|^2 \delta(\hat{s} - M_W^2),$$

$$\hat{\sigma}^{q\bar{q}\to Z} = \frac{\pi}{3}\sqrt{2}G_F M_Z^2 (v_q^2 + a_q^2)\delta(\hat{s} - M_Z^2),$$

- Where $V_{qq'}$ is appropriate CKM matrix element and v_q and a_q are the vector and axial couplings of the Z to quarks
- At LO there is no α_s dependence; EW vertex only
- NLO contribution to the cross section is proportional to α_s; NNLO to α_s^2; ...

W/Z p_T distributions

- Most of W/Z produced at low p_T but can be produced at non-zero p_T due to the diagrams with emitted gluon



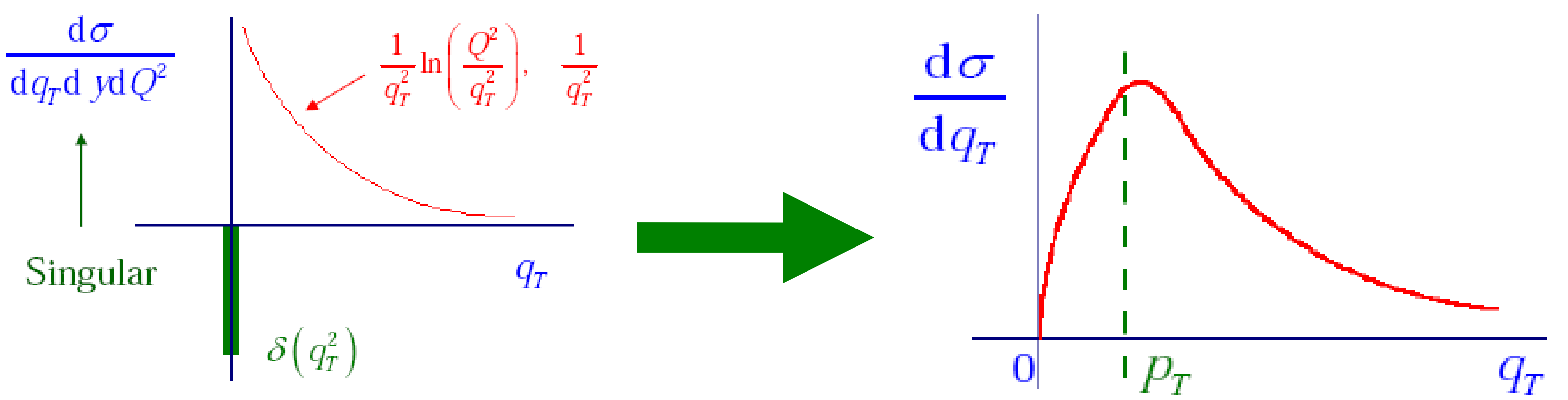
$$\sum |\mathcal{M}^{q\bar{q}' \to Wg}|^2 = \pi \alpha_S \sqrt{2} G_F M_W^2 |V_{qq'}|^2 \, \frac{8}{9} \, \frac{\hat{t}^2 + \hat{u}^2 + 2M_W^2 \hat{s}}{\hat{t}\hat{u}} \, ,$$

$$\sum |\mathcal{M}^{gq \to Wq'}|^2 = \pi \alpha_S \sqrt{2} G_F M_W^2 |V_{qq'}|^2 \, \frac{1}{3} \, \frac{\hat{s}^2 + \hat{u}^2 + 2\hat{t} M_W^2}{-\hat{s}\hat{u}} \, ,$$

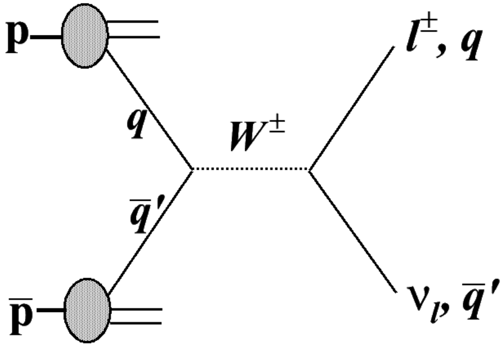
- Sum over colors and spins in initial states and average over same in final states
- Transverse momentum distribution obtained by convoluting these matrix elements with pdf's in usual way

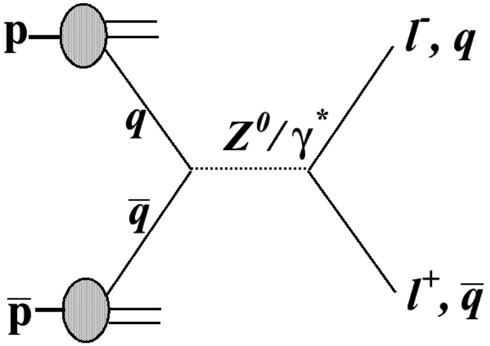
QCD resummation

- Resummation: reorganise calculations in terms of large Logs $L(Q^2/p_T^2)$; regularised at low p_T range;
- Different schemes: CSS which includes also non-perturbative effects; Sudakov form factors; exponentation;



Cross-section at LHC (7TeV)





$$\sigma^{NNLO}_{W^+\to\ell\nu} = 6.15\,\mathrm{nb}$$

$$\sigma^{NNLO}_{W^-\to\ell\nu} = 4.3\,\mathrm{nb}$$

$$\sigma^{NNLO}_{W\to\ell\nu} = 10.45\,\mathrm{nb}$$

$$\sigma^{NNLO}_{Z/\gamma*\to\ell\ell} = 0.989\,\mathrm{nb}$$

$$\sigma(W^+) \neq \sigma(W^-)$$

W^+ production: $u\bar{d} + c\bar{s}$

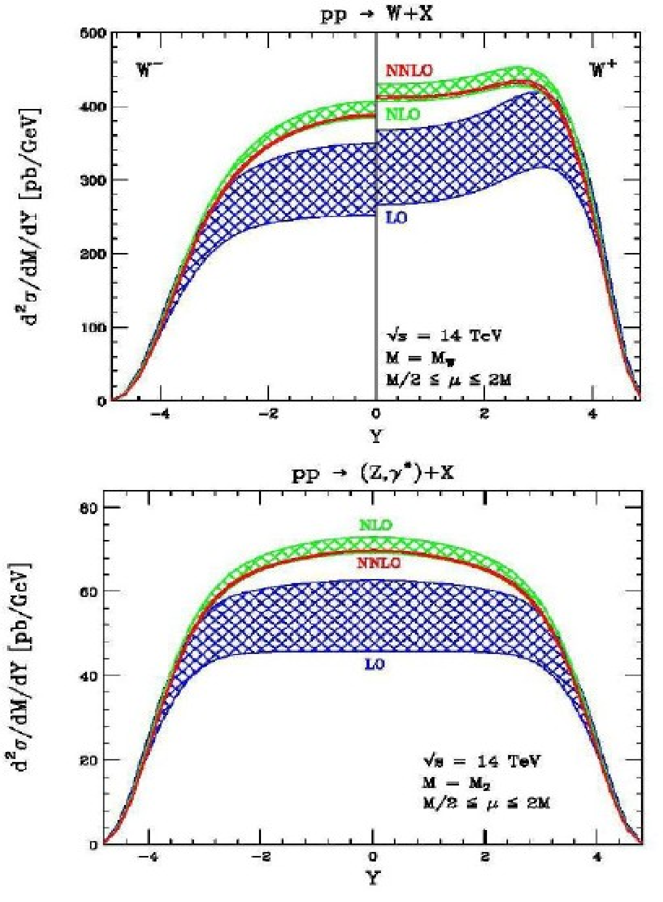
W^- production: $d\bar{u} + s\bar{c}$

Z production: $u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} + b\bar{b}$

- Test QCD (up to NNLO) in production
  - Hard and soft gluon emission
- Sensitive to parton distribution functions
- Extract electroweak parameters
  - $\sin\Theta_W$, m_W, quark-boson couplings

Monte Carlo simulations

- Base-line generators:
  - Pythia, Herwig (LO),
  - MCatNLO (NLO)
  - POWHEG (NLO)
- Used as components of for cross-checks
  - FEWZ: complete NLO, NNLL
  - ResBos: NNLL resumation
  - Horace: full 1-loop electroweak
  - PHOTOS:final state QED (exponentiated)



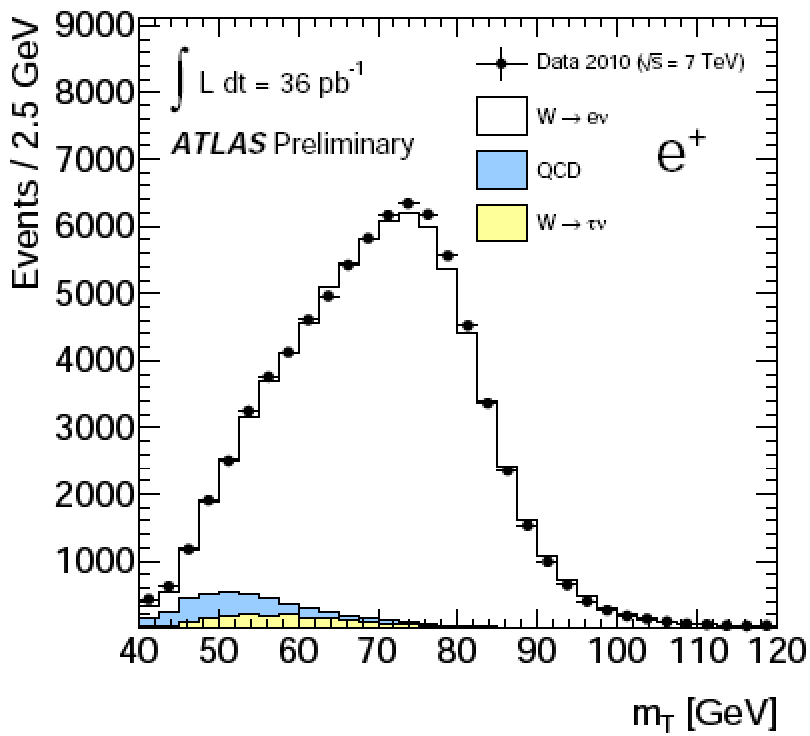
Event selection

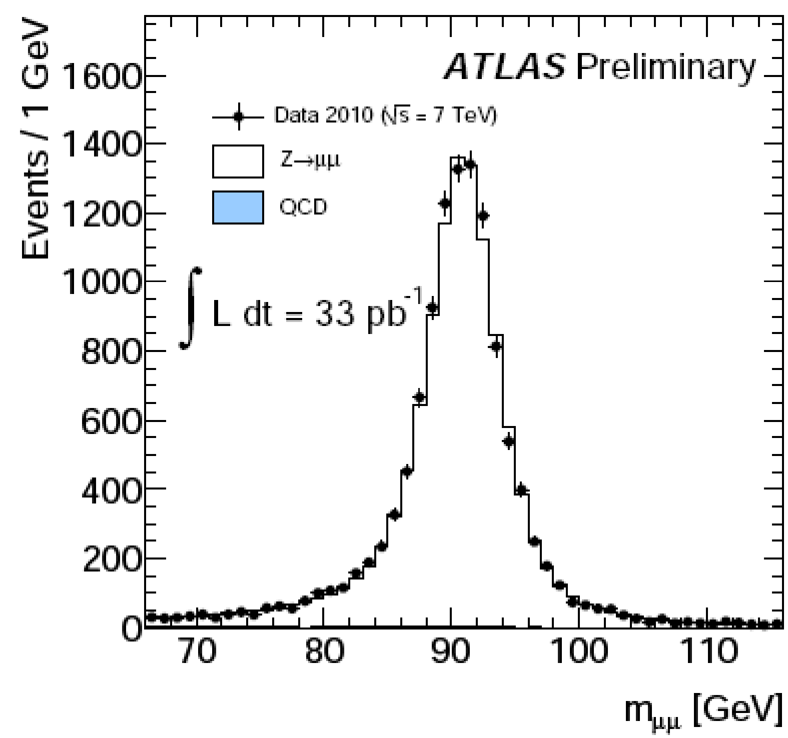
$W \to \ell\nu$

- One e/μ with $p_T > 20$ GeV
- $E_T^{miss} > 25$ GeV
- $m_T(\ell, E_T^{miss}) > 40$ GeV

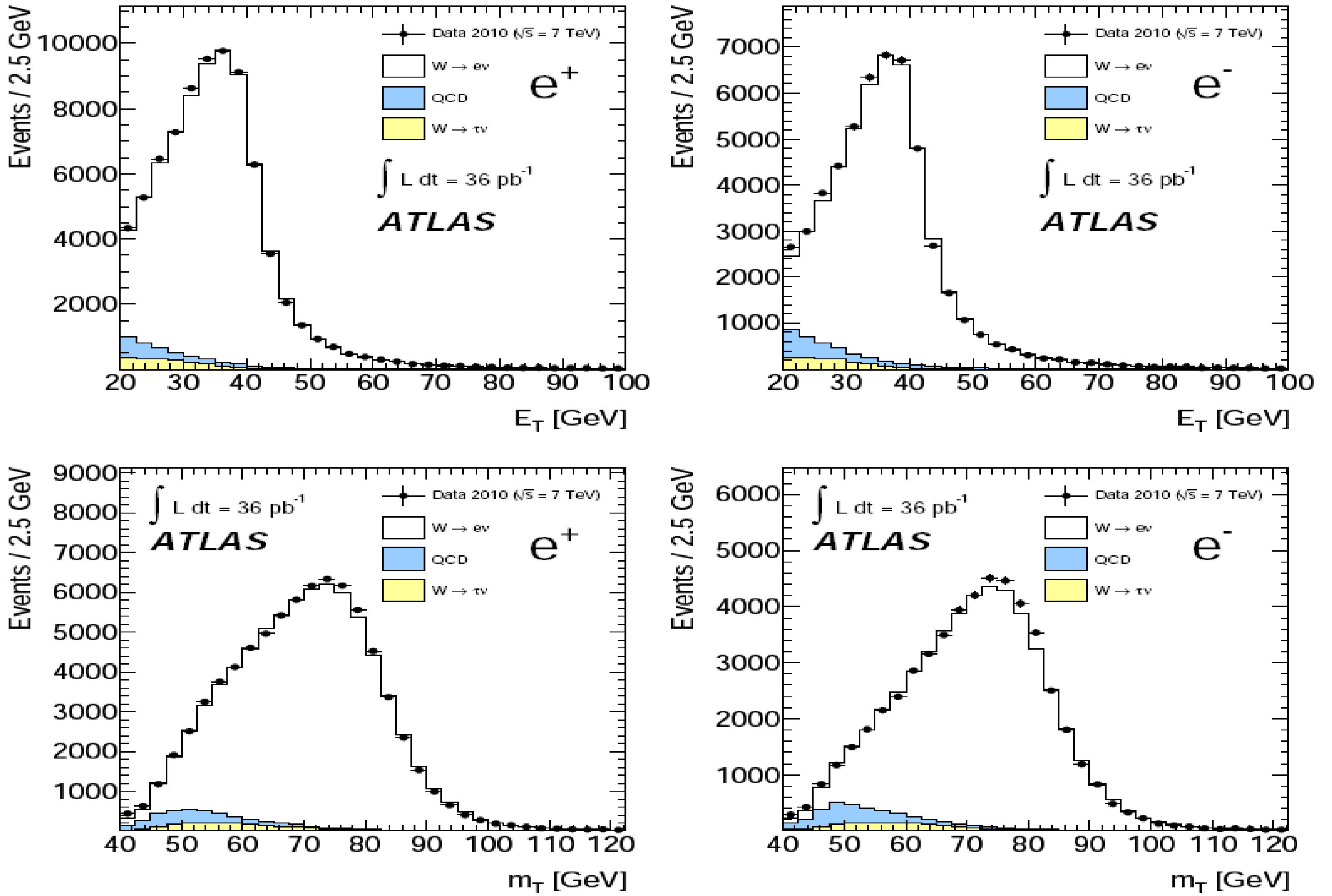
$Z \to \ell\ell$

- Two e/μ with $p_T > 20$ GeV
- $m_{\ell\ell} = 66–116$ GeV

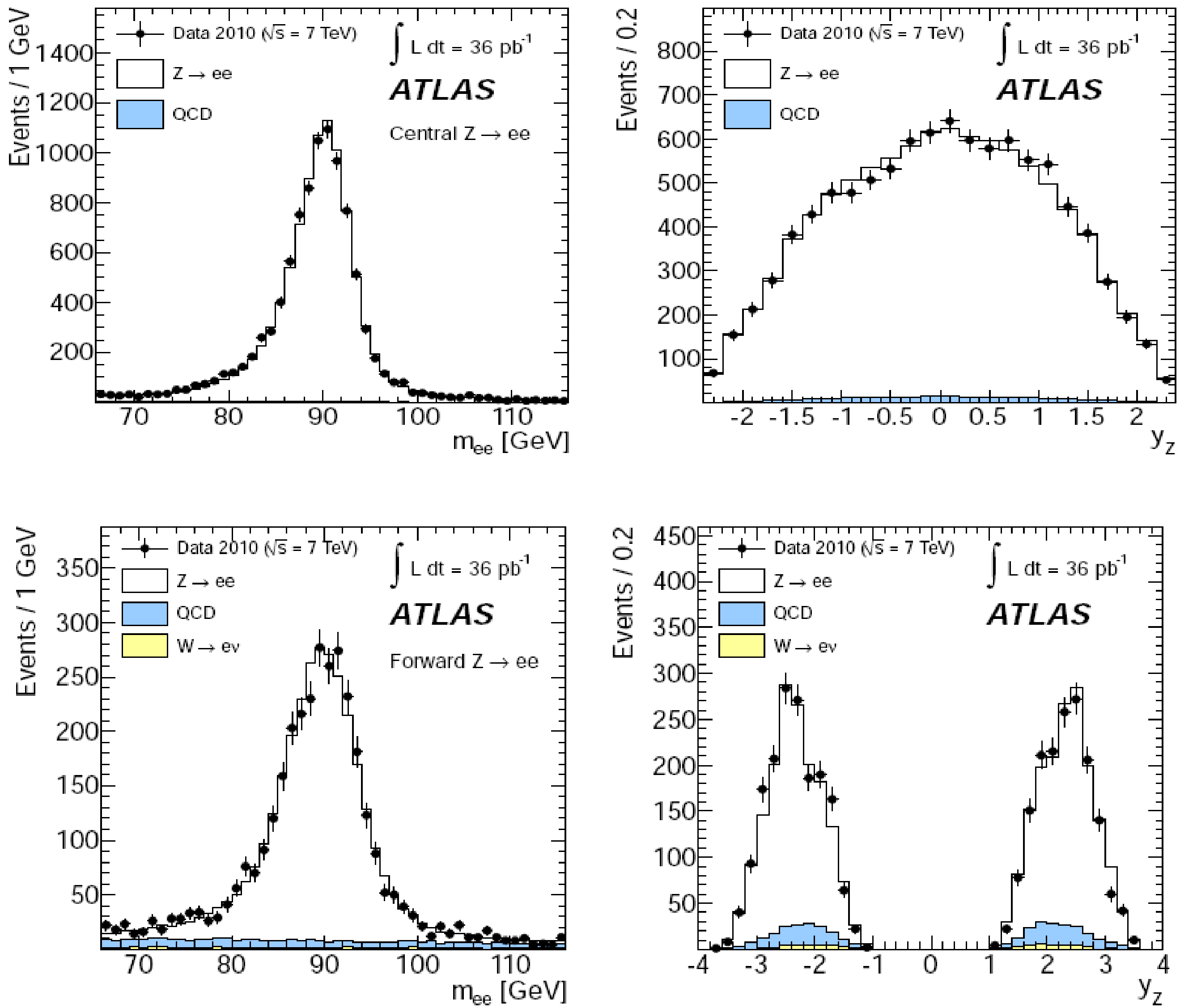




Event selection

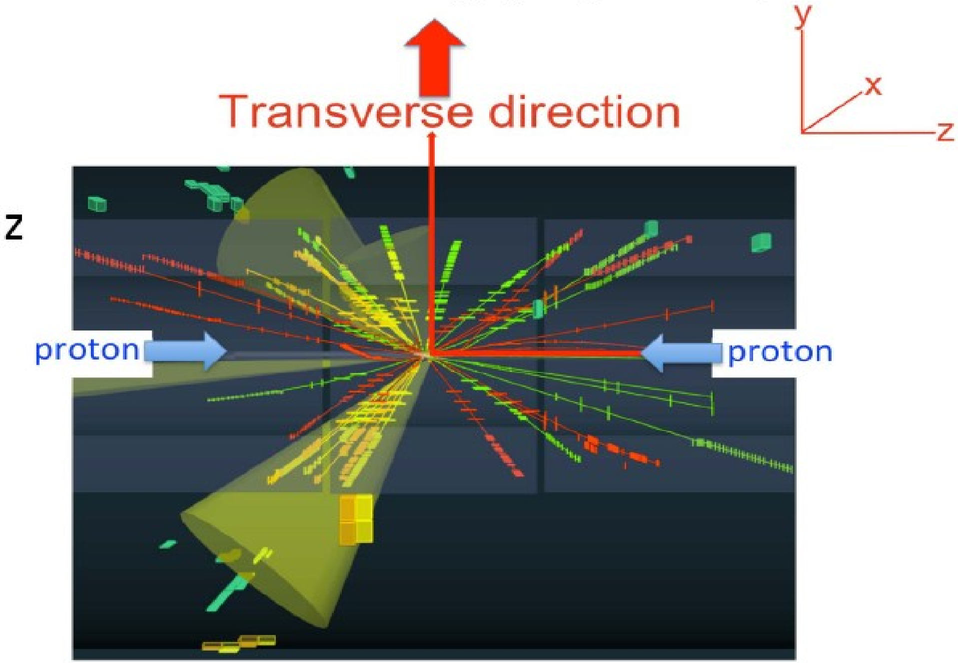


Event selection



Missing transverse energy

- In pp collisions at the LHC, a significant, unmeasured amount of energy escapes in z direction
- Total initial and final momentum is zero in transverse direction
- Imbalance of energy in transverse direction signals presence of weakly or non-interacting particles such as neutrinos



$$E_T^{miss} = \sqrt{(E_x^{miss})^2 + (E_y^{miss})^2}$$

$$E_{x(y)}^{miss} = -\sum_{particles} E_{x(y)}$$

$$\sum E_T = \sum_{particles} E_T$$

2

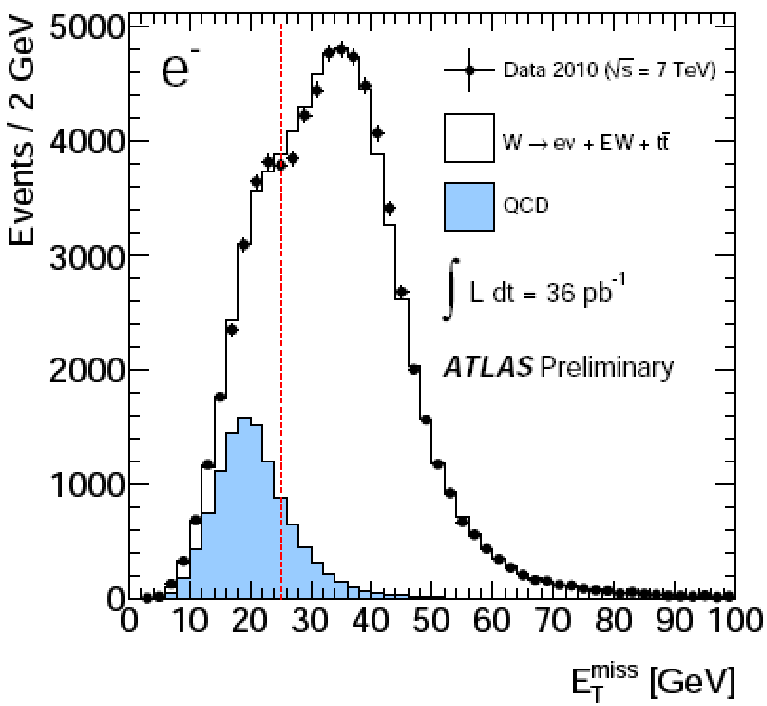
QCD background estimation

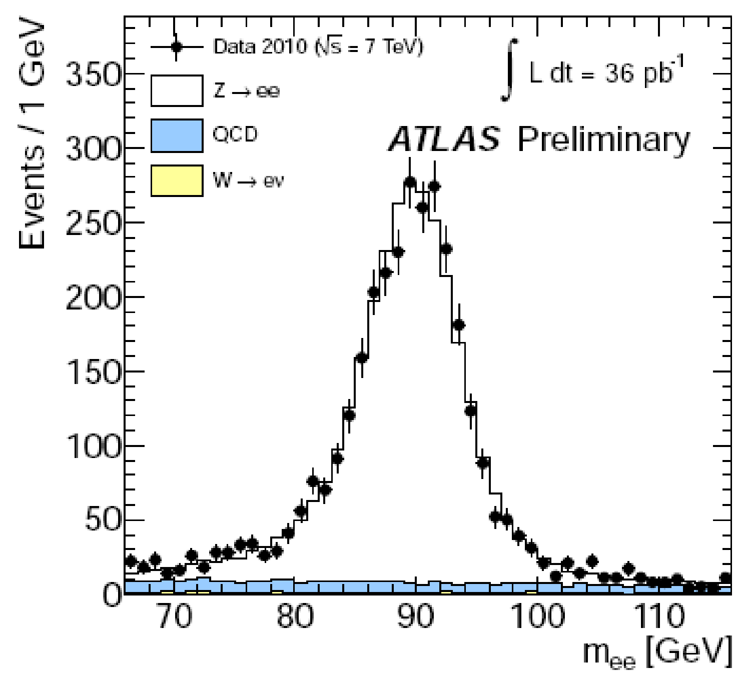
$W \to e\nu$: template fit to E_T^{miss}. Template derived from data with inverted electron ID and isolation.

$Z \to ee$: template fit to $m_{\ell\ell}$ to a sample with looser electron ID, extrapolated to the signal region.

$W \to \mu\nu$: matrix method using track isolation.

$Z \to \mu\mu$: ABCD method with track isolation in $m_{\mu\mu}$ side-band.





Cross-section measurement

$$\sigma = \frac{N_{\text{obs}} - N_{\text{bkg}}}{A \cdot C \cdot \int dt\, \mathcal{L}}$$

N_{obs}: number of observed events in the signal region

N_{bkg}: estimated number of background events

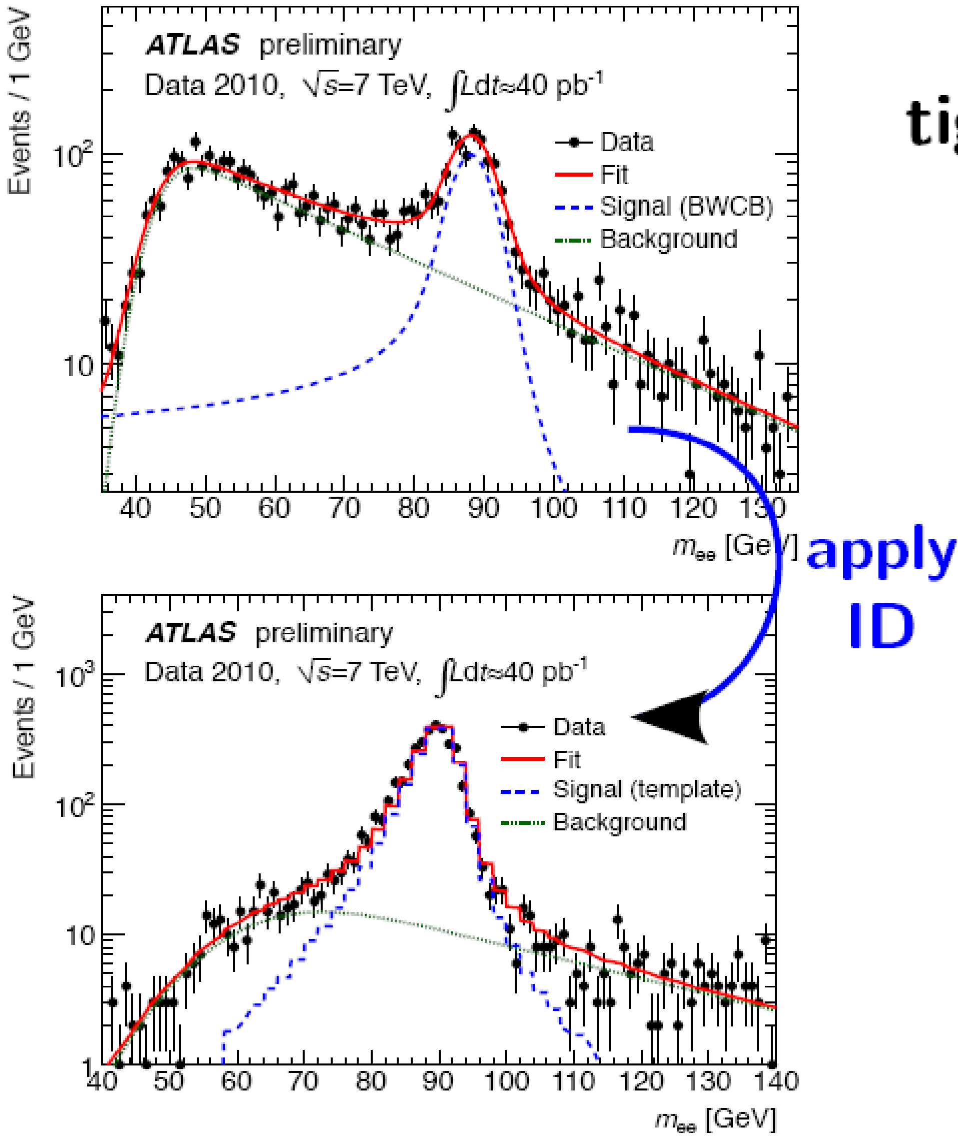
- EW backgrounds are estimated with Monte Carlo, constrained to data with performance scale factors.
- QCD backgrounds are estimated with **data-driven** methods.

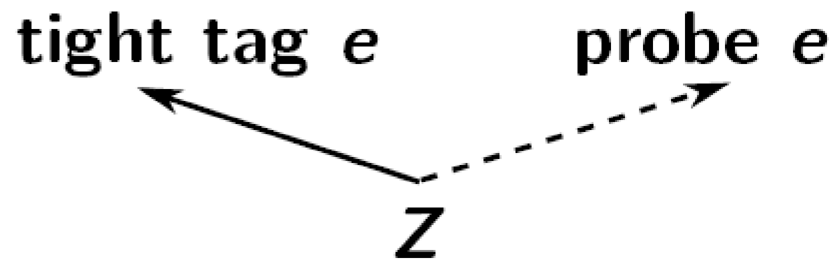
A: kinematic acceptance factor, estimated with generator-level Monte Carlo.

C: summarizes reconstruction efficiency, estimated with reconstructed Monte Carlo, corrected with **scale factors**.

$\int dt\, \mathcal{L}$: integrated luminosity.

Scale factor: tag-and-probe studies



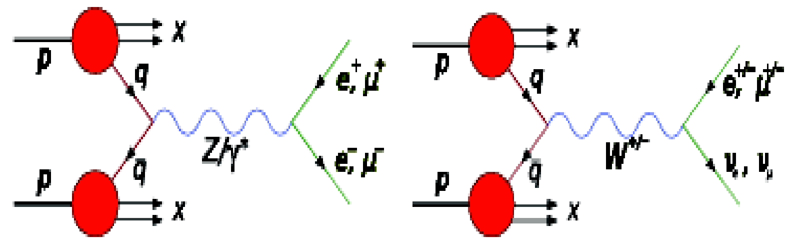


- **"Tag"** events with sufficient purity, leaving an unbiased **"probe"** object.
- Measure probe ID efficiency *in situ*.
- Constrains the performance of our object identification.
- Derive **scale factors** for correcting our simulation.

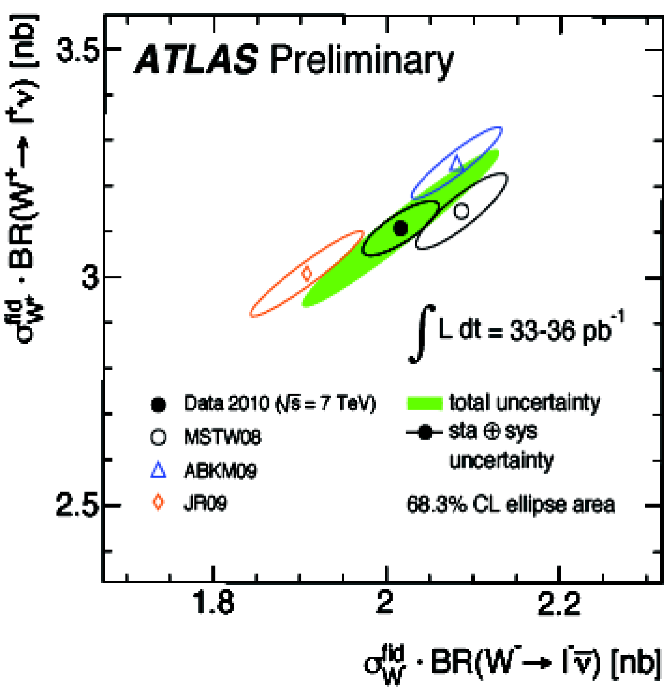
Systematic error

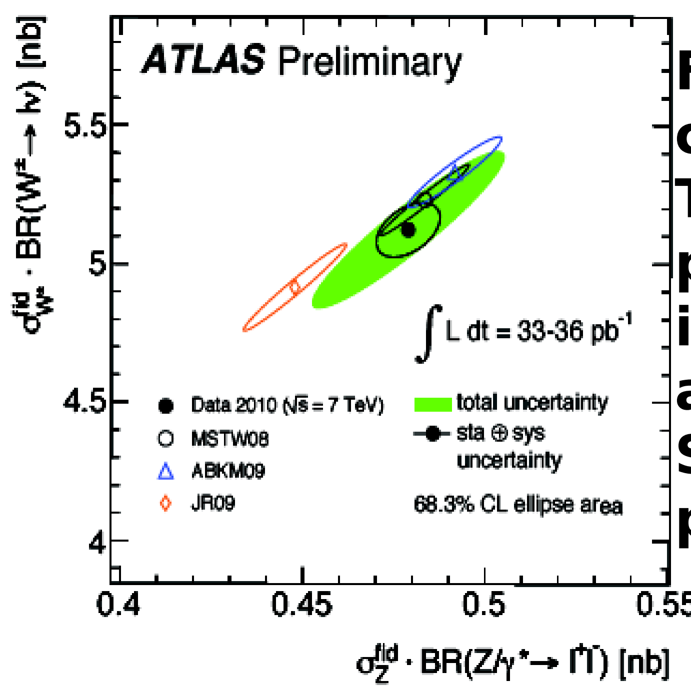
	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W^+}$	$\delta\sigma_{W^-}$	$\delta\sigma_Z$
Trigger	0.4	0.4	0.4	<0.1
Electron reconstruction	0.8	0.8	0.8	1.6
Electron identification	0.9	0.8	1.1	1.8
Electron isolation	0.3	0.3	0.3	—
Electron energy scale and resolution	0.5	0.5	0.5	0.2
Non-operational LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	0.0	0.1	0.1	0.6
QCD background	0.4	0.4	0.4	0.7
Electroweak+$t\bar{t}$ background	0.2	0.2	0.2	<0.1
E_T^{miss} scale and resolution	0.8	0.7	1.0	—
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.6	0.6	0.6	0.3
Total experimental uncertainty	1.8	1.8	2.0	2.7
$A_{W/Z}$ theoretical uncertainty	1.5	1.7	2.0	2.0
Total excluding luminosity	2.3	2.4	2.8	3.3
Luminosity		3.4		

W, Z inclusive measurements



- Inclusive in number of jets, allow to reach high accuracy in QCD predictions.
- Computation available at NNLO on the total cross-section, at NNLO error dominated by PDF's

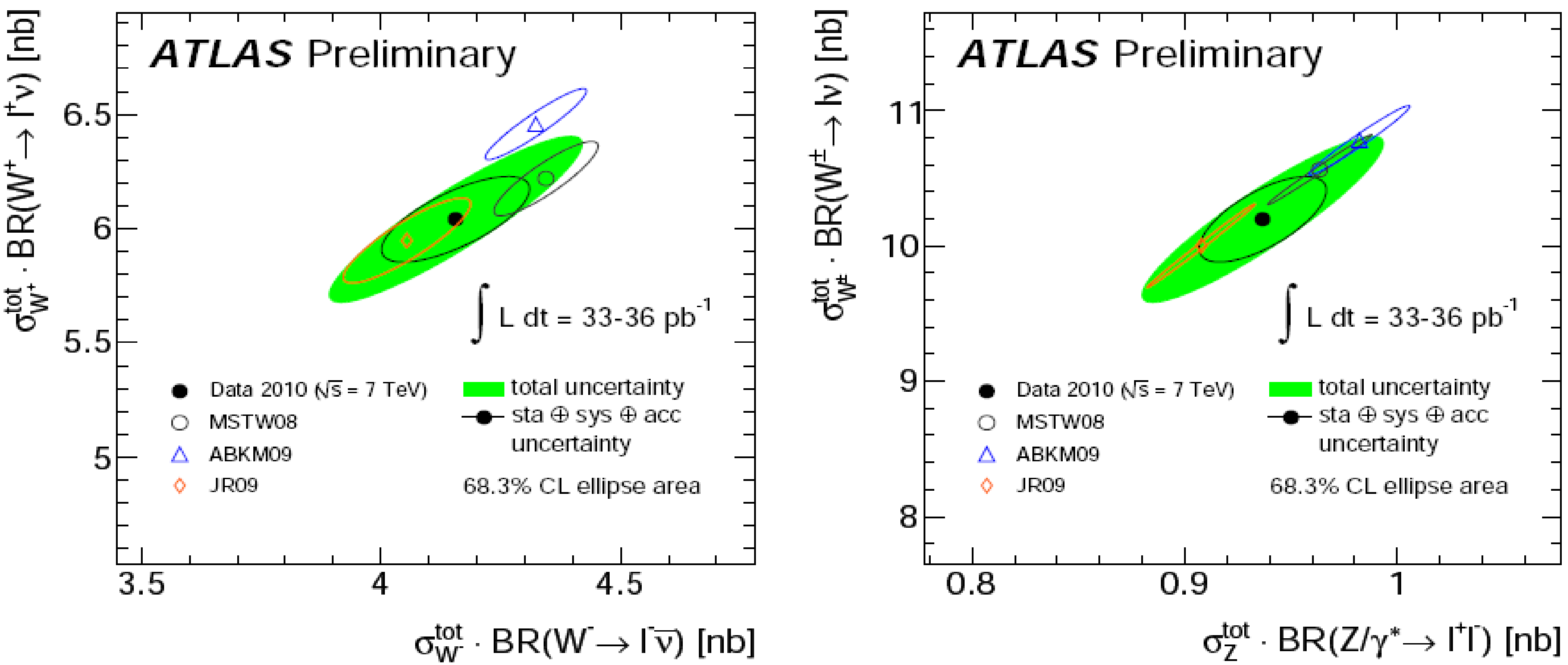




Fiducial cross-section. Theory predictions including acceptance. Sensitive to pdf's set.

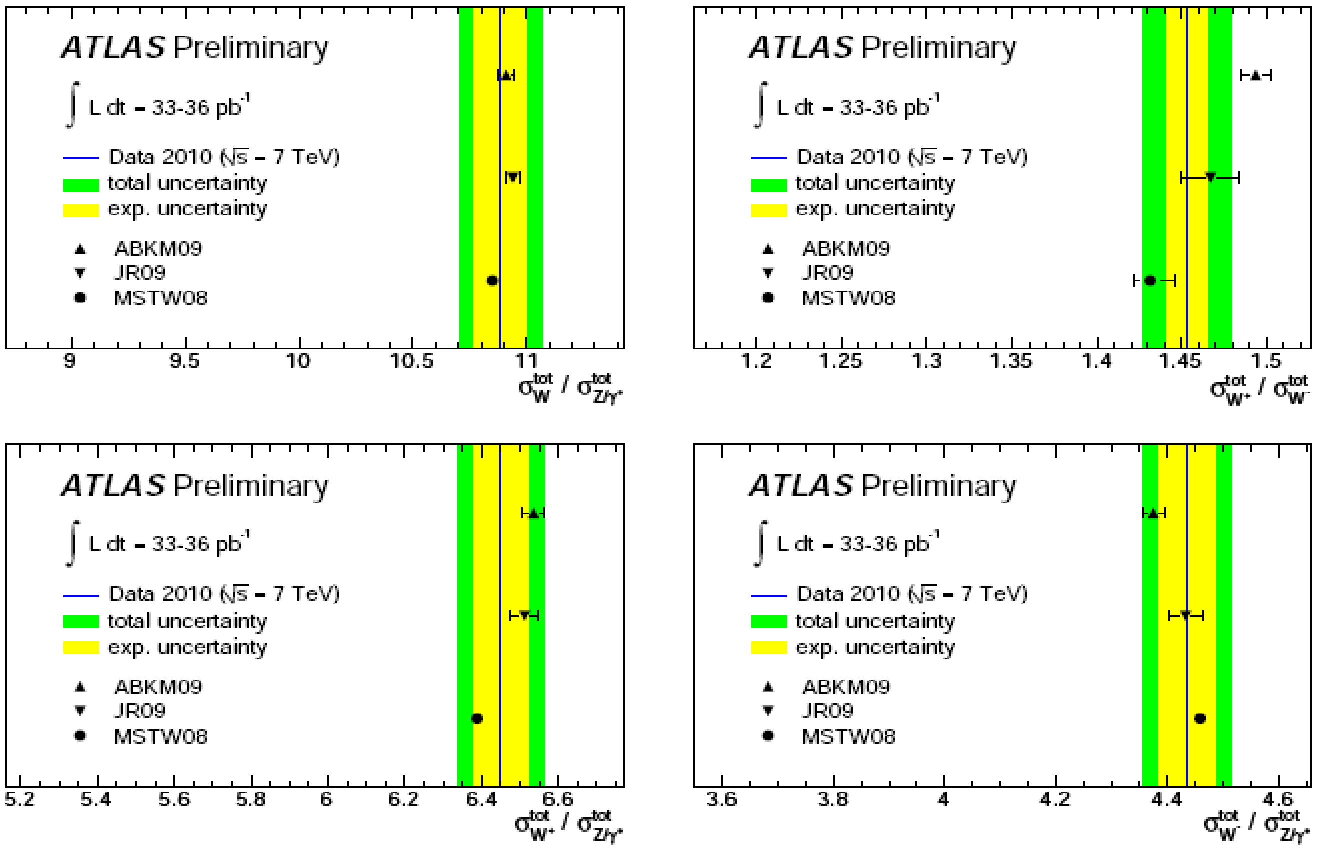
Theory comparison: total cross-section

- Overall remarkable agreement with NNLO PDF predictions
- A few differences between different PDFs (w/ only 68 % CL PDF errors)
- Comparing total cross sections, the acceptance uncertainty accounts for effect of different PDFs on the unmeasured phase space . . .



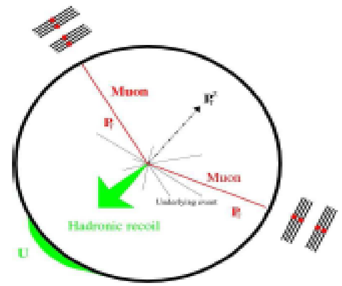
Theory comparison: total cross-section ratios

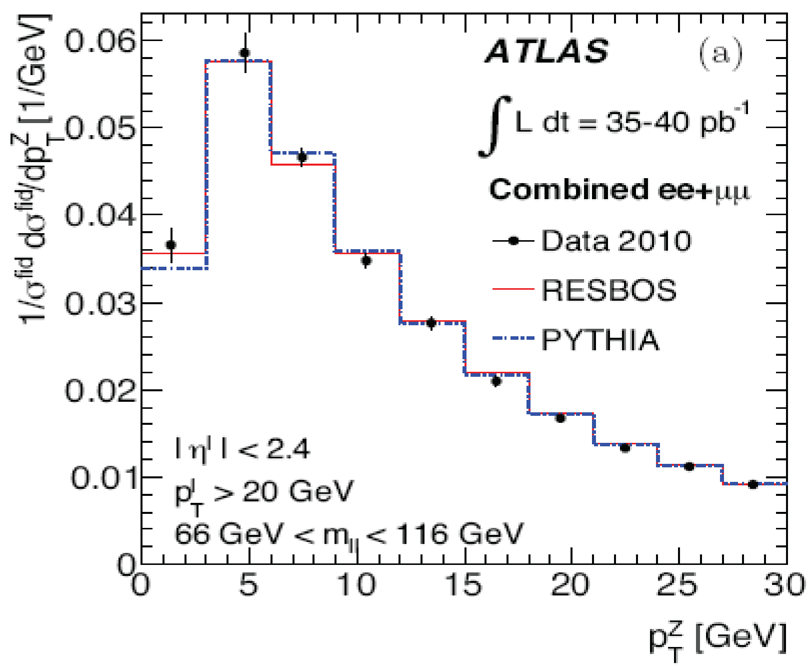
- $W^{\pm}/Z$, W^+/W^- ratios profit from exp. and theor. systematics cancellation
- $W^{\pm}/Z$ ratio measured with total uncert. of $1.5\,\%$, W^+/W^- with $1.7\,\%$



Z boson p_T measurement

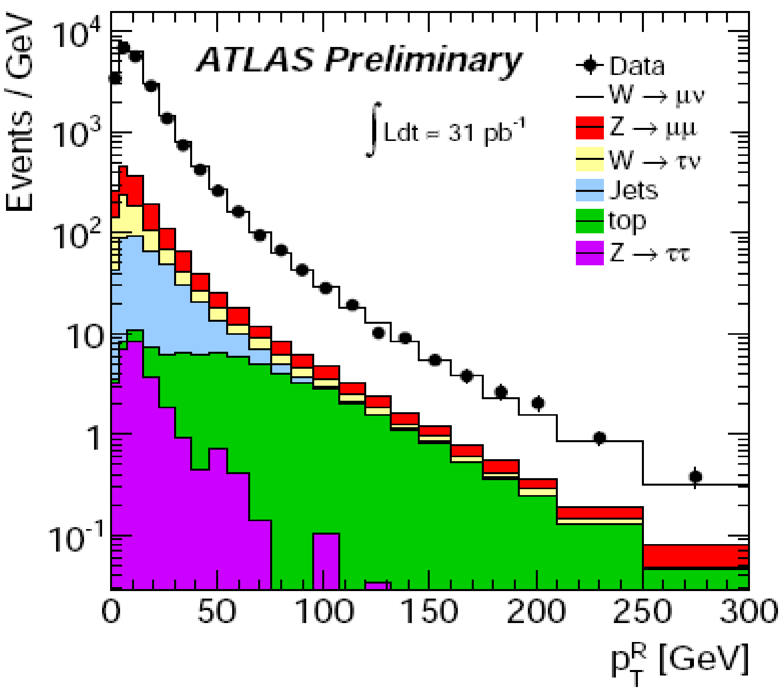
- Important for modeling high-$p_{\rm T}$ lepton kinematics.
- At leading order, $p_{\rm T}^{W/Z} = 0$
- Non-zero $p_{\rm T}^{W/Z}$ is generated through the hadronic recoil of ISR, $p_{\rm T}^{R}$.
- $p_{\rm T}^{Z}$ reconstructed directly from $p_{\rm T}(\mu_1) + p_{\rm T}(\mu_2)$, while $p_{\rm T}^{W}$ reconstructs $p_{\rm T}^{R}$.
- Detector and FSR effects removed with a bin-by-bin unfolding.
- 3-4% precision per bin.

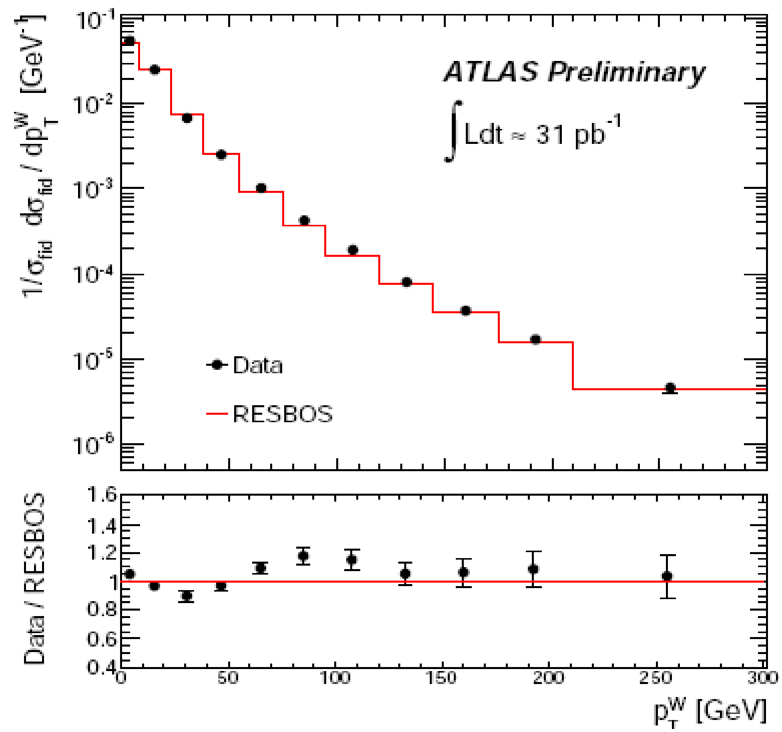




W boson p_T measurement

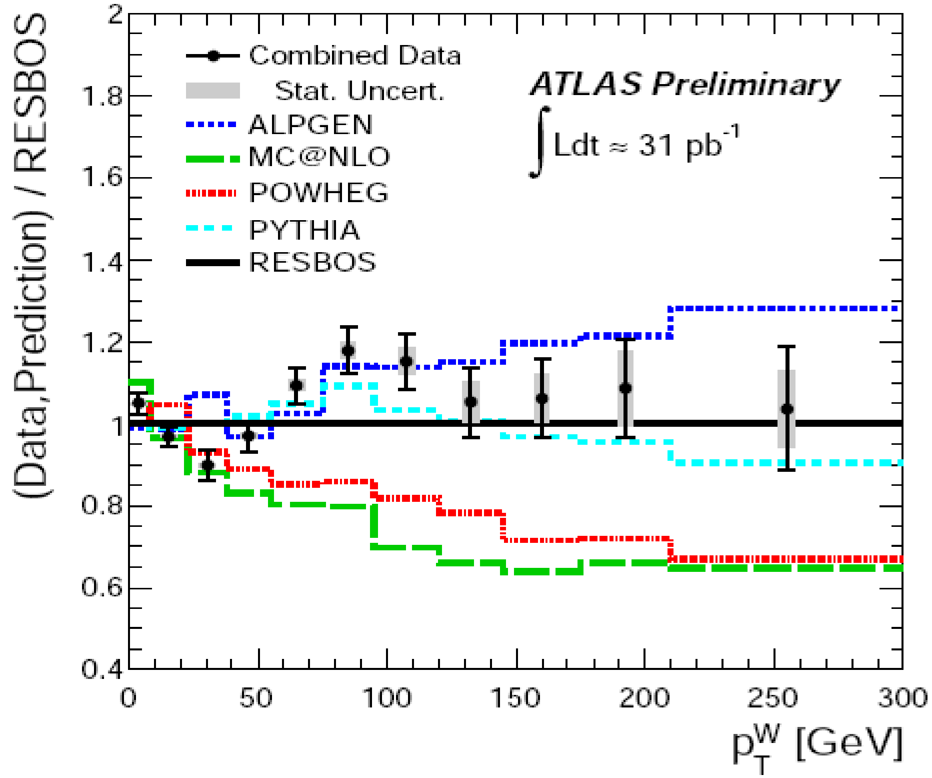
- Necessary for a future precision W mass measurement.
- Detector and FSR effects removed by inverting a response matrix parametrizing the probabilistic mapping of p_{T}^{R} to p_{T}^{W}.





W, Z boson p_T reweighting

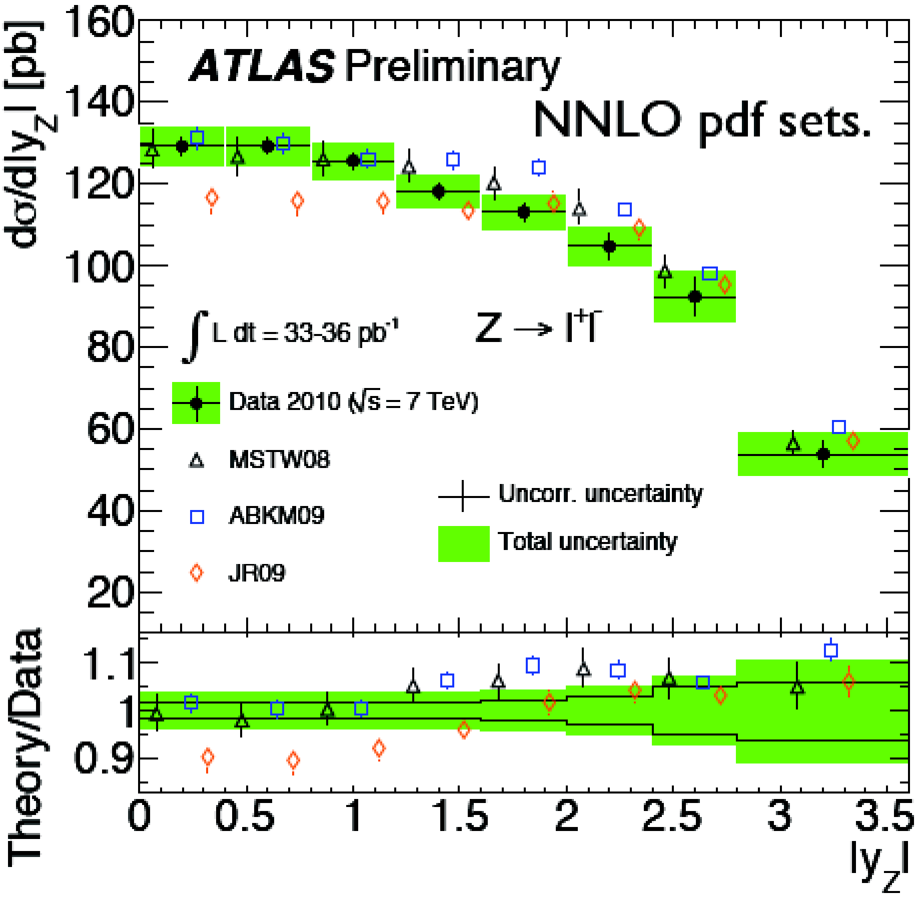
- The modeling of $d\sigma/dp_T^{W/Z}$ can have significant effects on the expected efficiency and acceptance.
- NLO generators MC@NLO and POWHEG have deficits at high $p_T^{W/Z}$.
- NLO effects are important at high $p_T^{W/Z}$ because the W/Z is polarized by higher order QCD.



- $W \to \ell\nu$ and $Z \to \ell\ell$ cross section measurements use MC@NLO reweighted to match $p_T^{W/Z}$ for LO Pythia, which agrees with the data because it has been tuned well to the Tevatron data.

Z differential

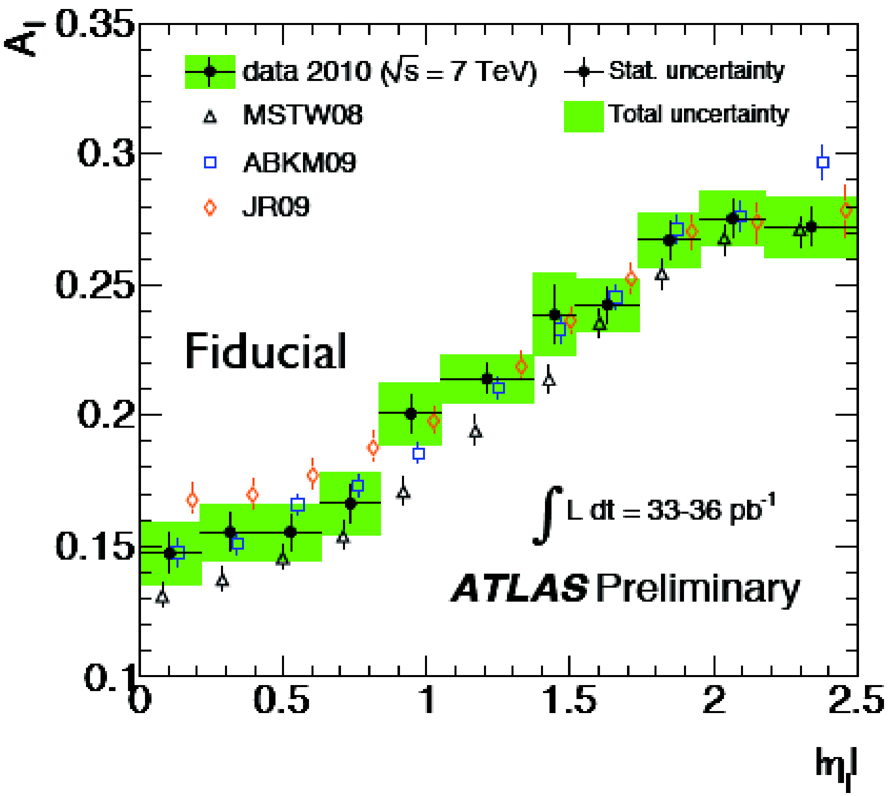
- Inclusive production as a function of the Z pseudorapidity.
- Lepton flavours combined together taking into accoun all correlations.
- Z rapidity reaches |y|<3.5 with special electron reconstruction outside tracking volume (|y|<2.5)

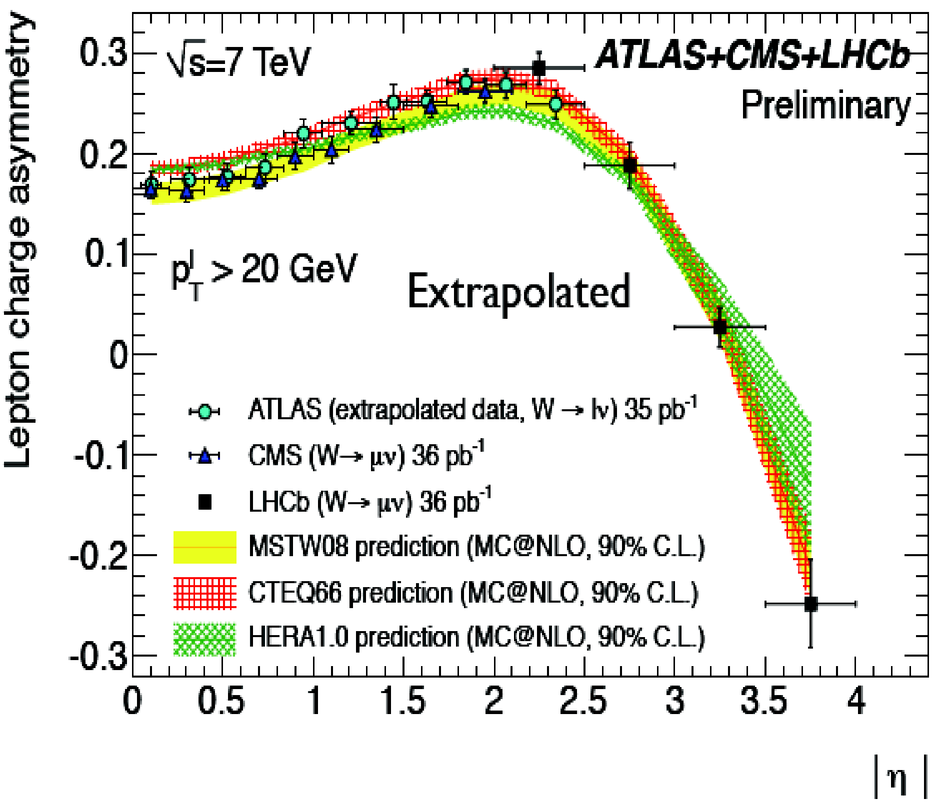


W^{+-} asymmetry

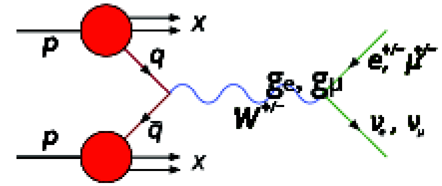
$$A(\eta_l) = \frac{\sigma^{W^+}(\eta_l) - \sigma^{W^-}(\eta_l)}{\sigma^{W^+}(\eta_l) + \sigma^{W^-}(\eta_l)}$$

- Asymmetry induced by the different flavours contributing to W^+ and W^- production and by asymmetry in flavour content of pp interaction





Lepton universality



$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{Br(W \to e\nu)}{Br(W \to \mu\nu)} = 1.006 \pm 0.004\,(\text{sta}) \pm 0.006\,(\text{unc}) \pm 0.023\,(\text{cor}) = 1.006 \pm 0.024$$

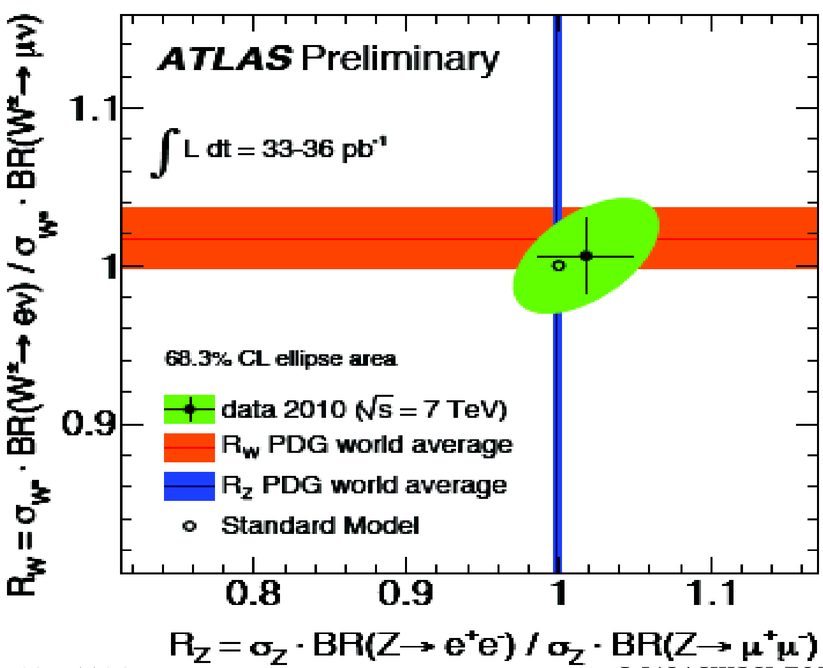
$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{Br(Z \to ee)}{Br(Z \to \mu\mu)} = 1.018 \pm 0.014\,(\text{sta}) \pm 0.016\,(\text{unc}) \pm 0.028\,(\text{cor}) = 1.018 \pm 0.031$$

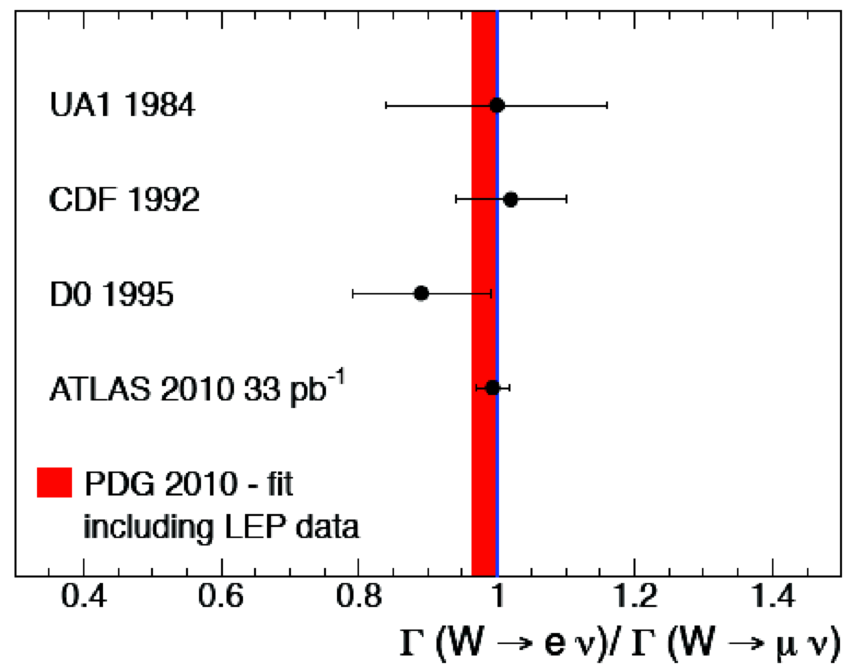
$R_W^{PDG} = 1.017 \pm 0.019$

$R_Z^{PDG} = 0.991 \pm 0.0024$

$R_W = g_e^2/g_\mu^2$ (neglecting loop correction)

$$R_Z = \frac{g_e^2\,(2\sin\theta^e_W - 1) + 4\sin^2\theta^e_W}{g_\mu^2\,(2\sin\theta^\mu_W - 1) + 4\sin^2\theta^\mu_W}$$





Incredible number of V+jets events at 7 TeV

$E_T^{n^{th}\text{ jet}} > 25$ GeV

plus standard cuts on jet (anti-k_T, R=0.4) rapidity, lepton, missing E_T

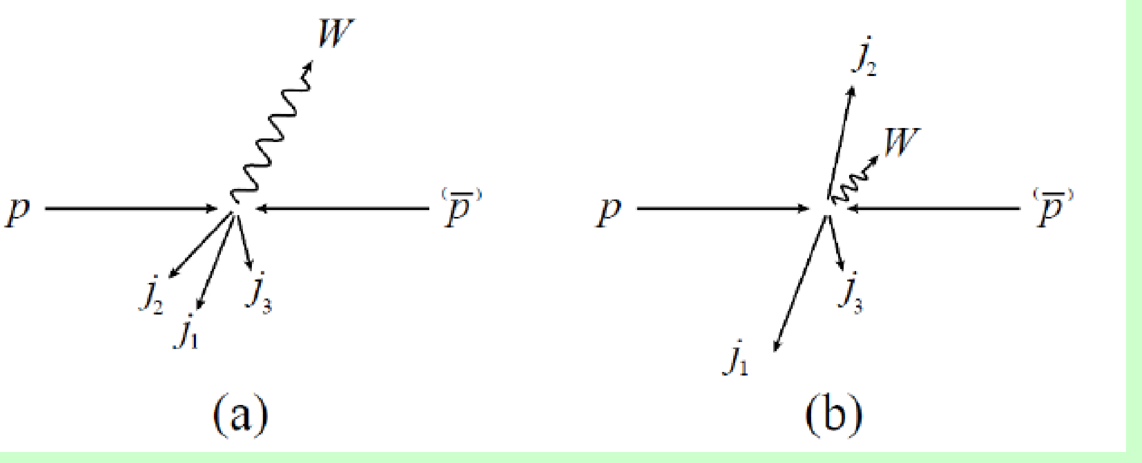
$W^\pm \to e^\pm \nu$ or $\mu^\pm \nu$

$Z^0 \to e^+ e^-$ or $\mu^+ \mu^-$

$\int \mathcal{L}\, dt$ =	2 fb^{-1}
$\sigma(W^\pm j) \approx 800$ pb	1,600,000
$\sigma(W^\pm jj) \approx 200$ pb	400,000
$\sigma(W^\pm jjj) \approx 45$ pb	90,000
$\sigma(Zj) \approx 80$ pb	160,000
$\sigma(Zjj) \approx 20$ pb	40,000
$\sigma(Zjjj) \approx 4.8$ pb	9,600

V+jets dynamics at 7 TeV

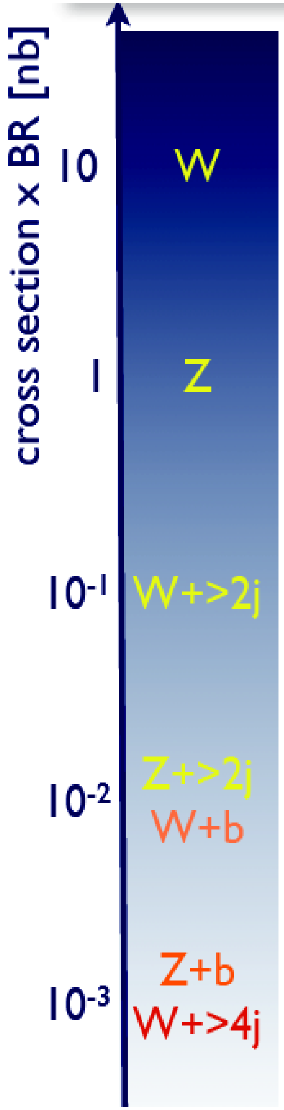
- Can now easily get events with $E_T^{jet} >> M_W$.
- "Soft W" enhancement → tend to be jet dominated: (b) preferred over (a).



- Wide dynamic range at LHC

→ Importance of choosing reasonable scales $\mu_{R,F}$

W/Z + jets physics

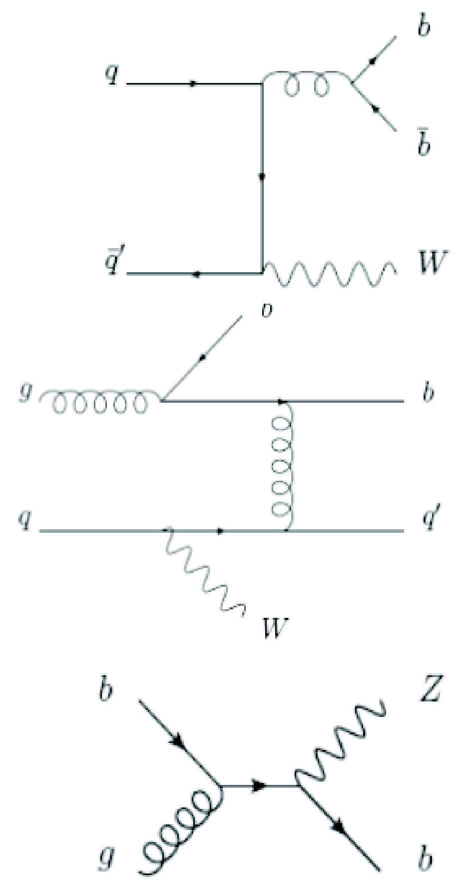


- W/Z+jets physics is a fundamental ingredient for reestablishing the Standard Model (SM) in pp collisions at 7 TeV

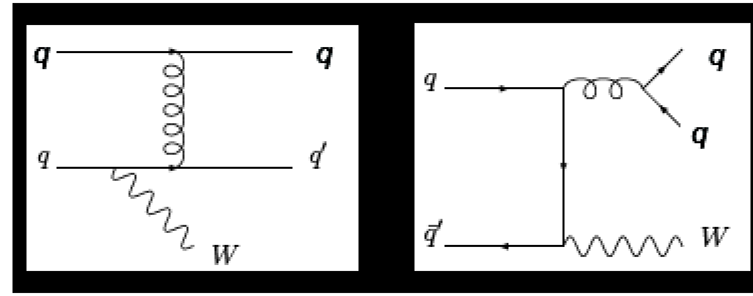
  ✓ larger available energy than at Tevatron:
  => more jets; larger kinematic reach
  => cross sections spanning several orders of magnitude

  ✓ higher relevance of processes initiated by qg and gg scattering
  => different contribution to the cross section compared to Tevatron
  => processes with heavy flavour in the initial state become important

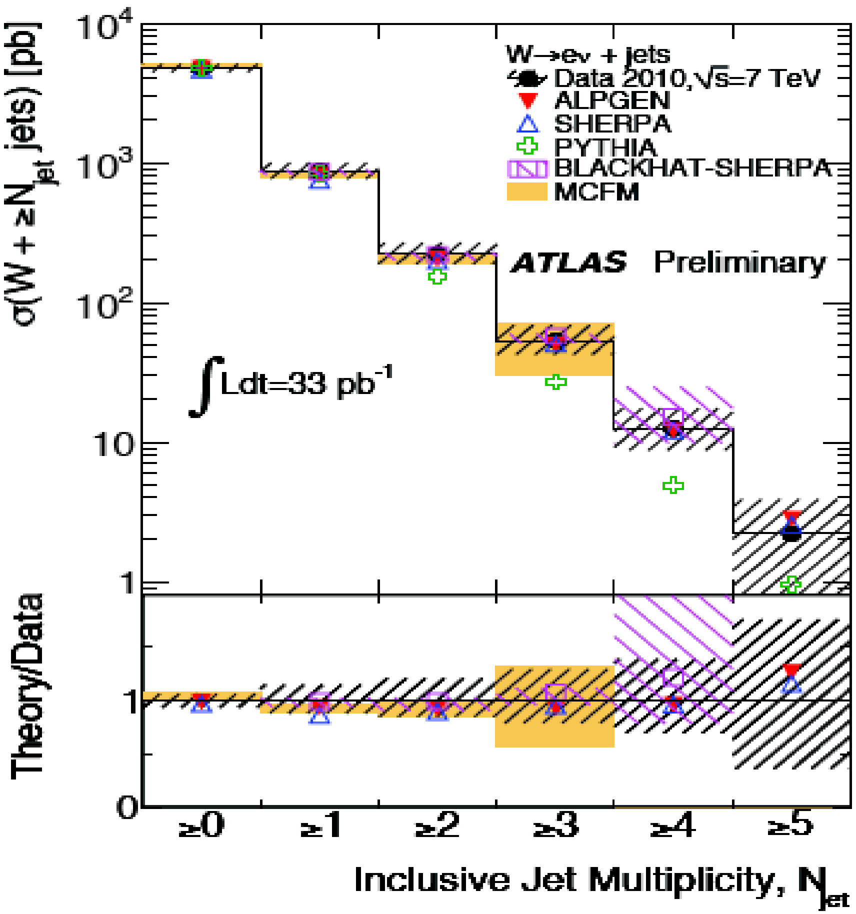
- compelling test for the new NLO pQCD calculations of W/Z+(b)jets (up to 4jet for light- and 2 for b-jets)

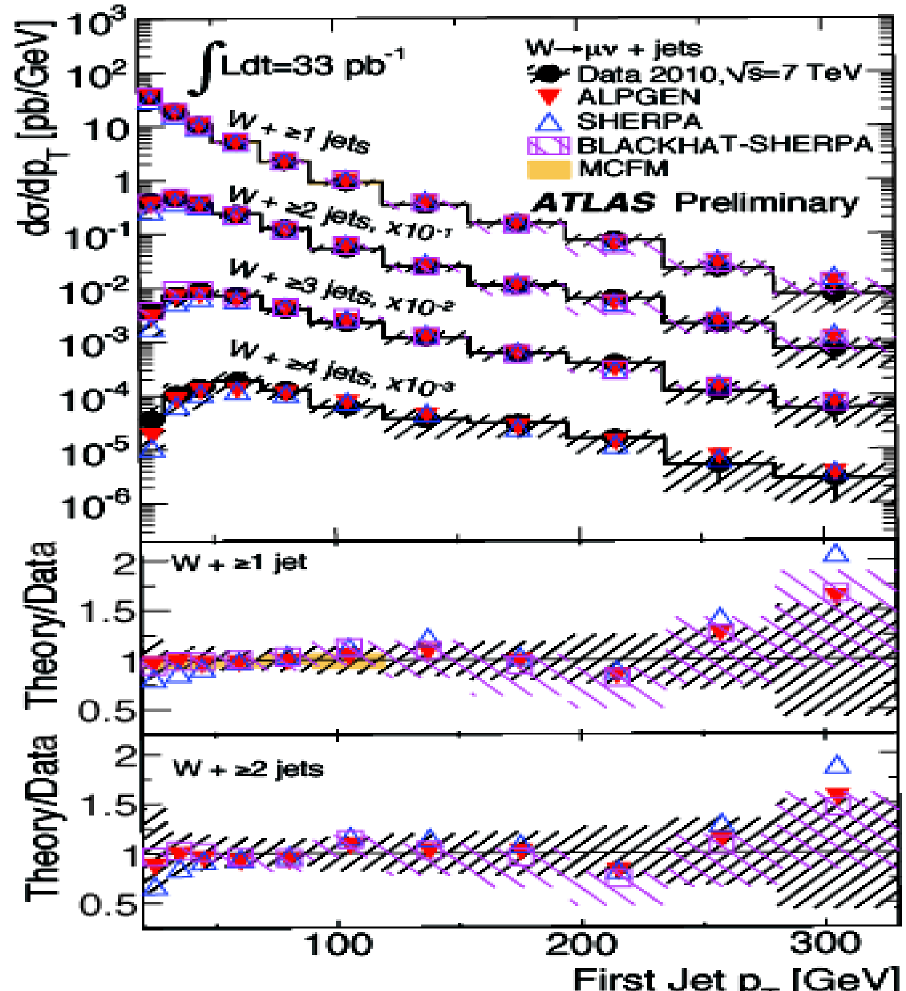


W/Z + jets



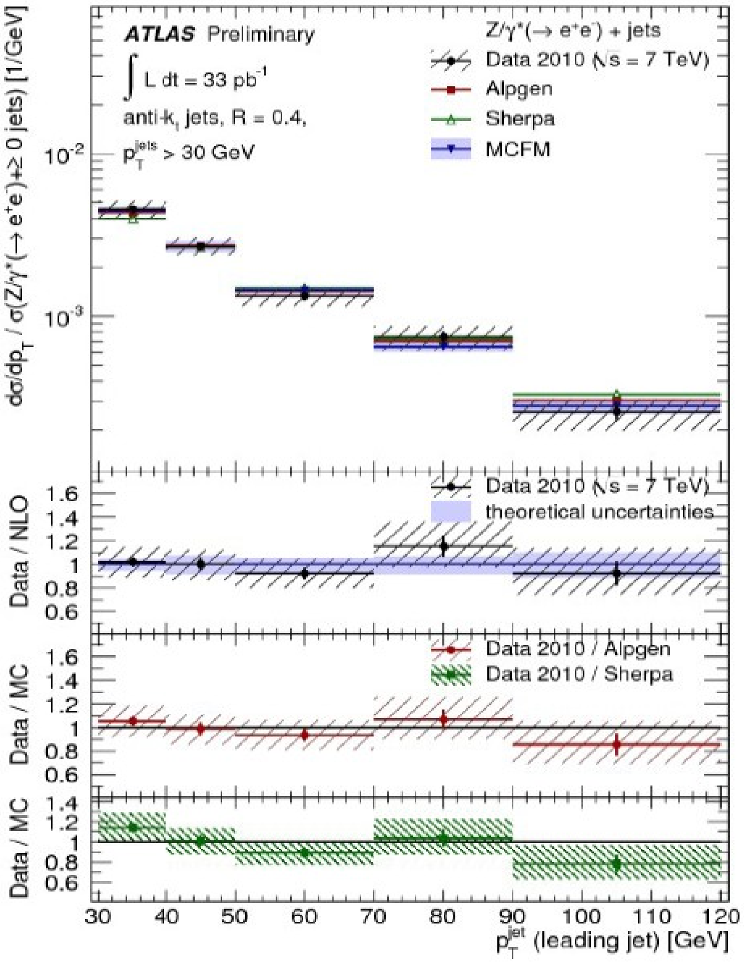
- Measure up to 4-5 jets and up to E_T = 300 GeV





W/Z+jets

- cross section measured as a function of several kinematic variables (see end of this talk)
- very good agreement with NLO predictions from MCFM and Blackhat-Sherpa in the total and differential cross sections
- good agreement with matched LO prediction from AlpGen and Sherpa once normalized to the NNLO prediction
- Poor agreement with LO PYTHIA in the high jet multiplicity



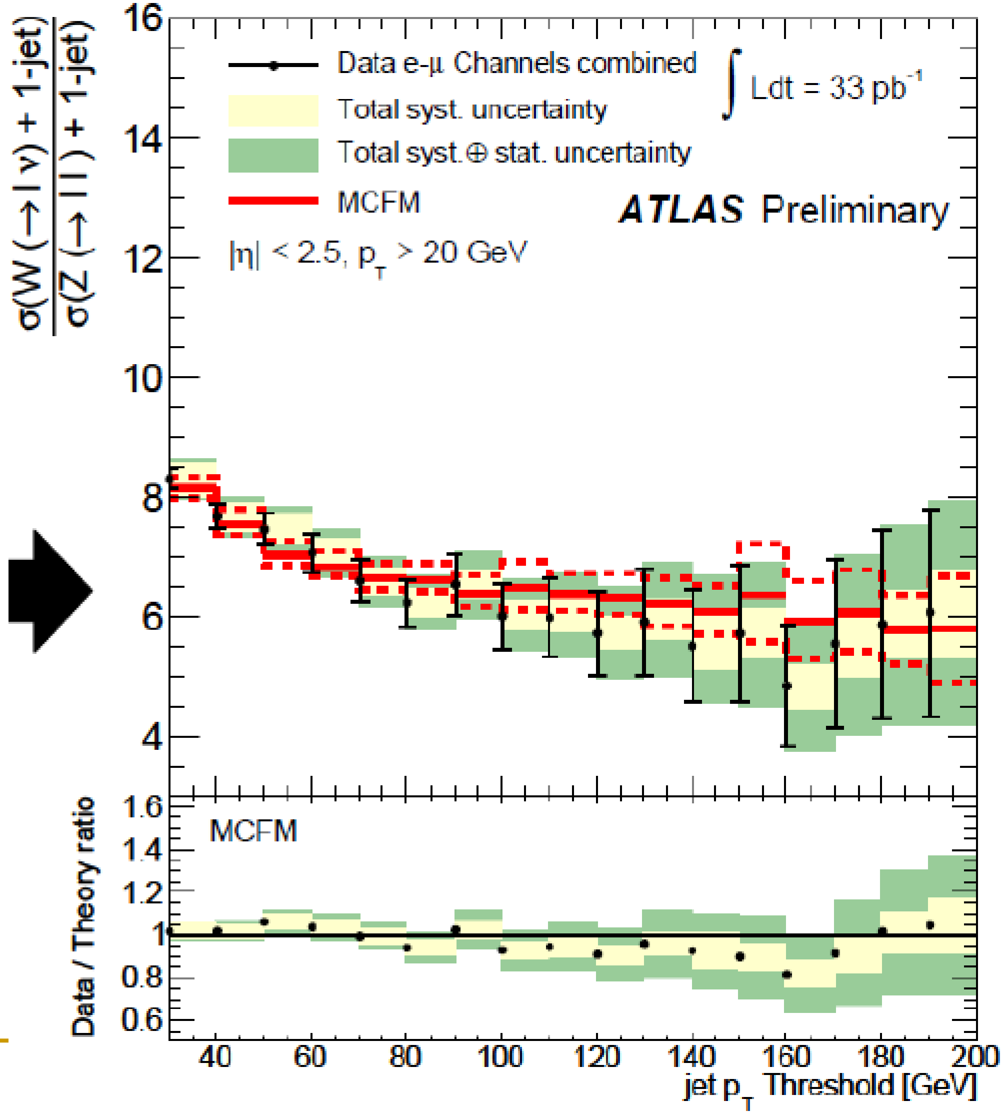
dominant systematics

- JES: 8(26)% for $N_j \geq 1(4)$
- jets from pile-up ≈7%
- lep. reco. ≈ 2%
- QCD bkgd ≈ 2%
- unfolding ≈ 2%

Rjets = ratio W+1jet/Z+1jet

- This is the first time this ratio is measured
  - Sensitive to new physics
  - Very small sensitivity to PDG
    - CTEQ6.6: 0.5%
    - MSTW2008: 0.3%

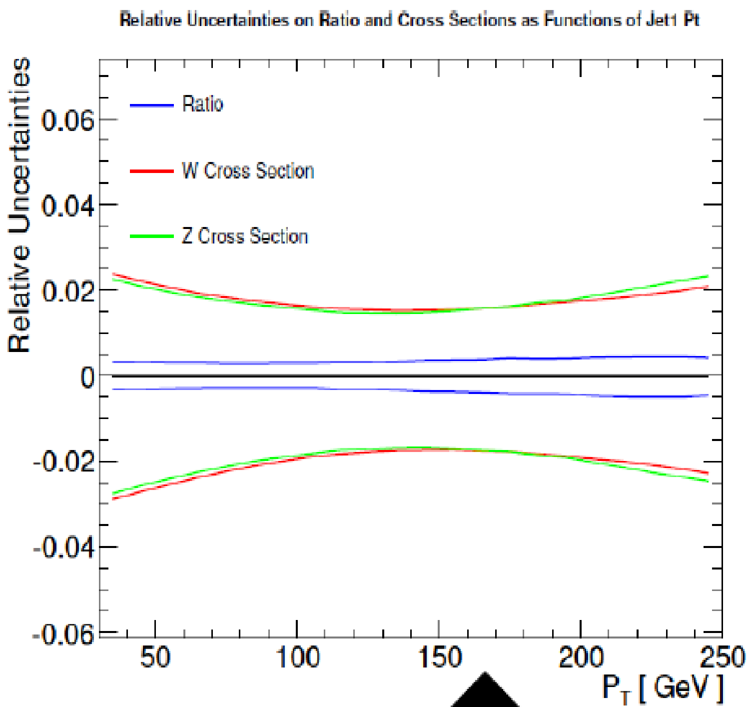
$$R_{\text{jets}}\,(p_T > x) = \frac{\sigma_{W+1\text{-jet}}(p_T > x)}{\sigma_{Z+1\text{-jet}}(p_T > x)}$$



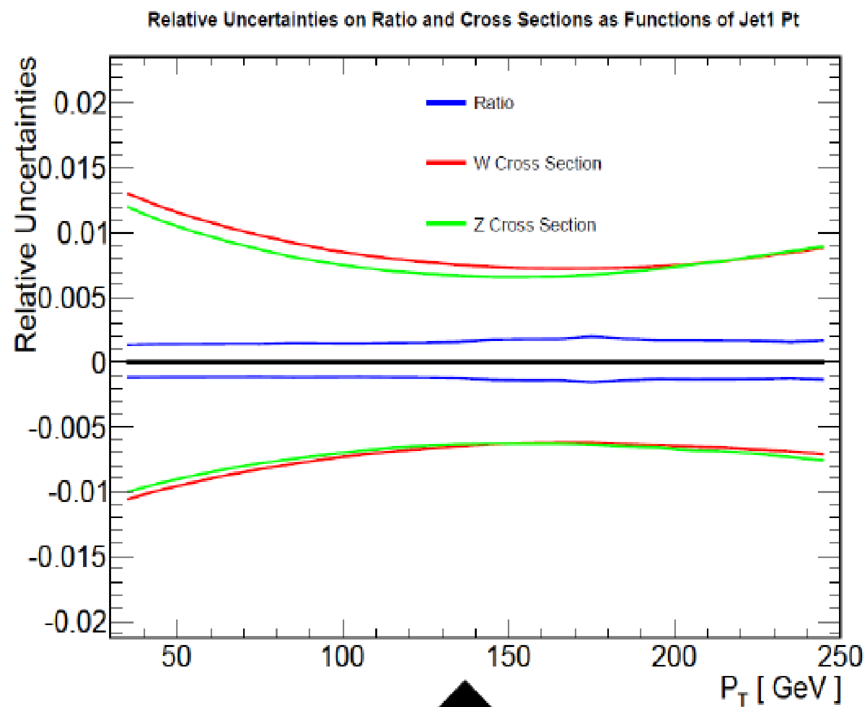
PDF uncertaintity on Rjets

- Very small uncertaintity on PDF's

  CTEQ6.6: 0.5%, MSTW2008: 0.3%



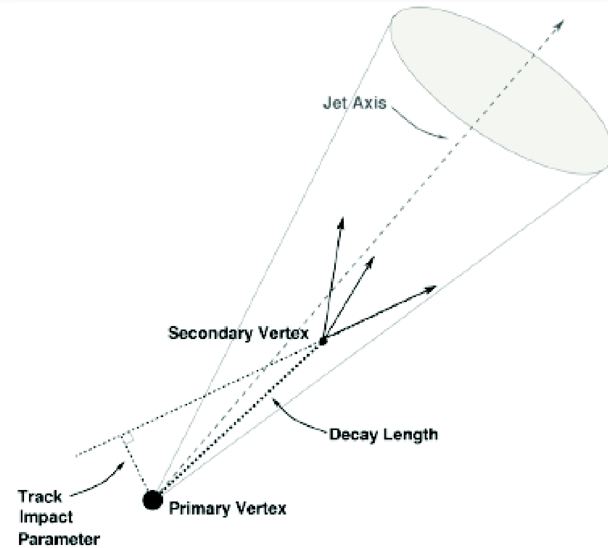
CTEQ6.6

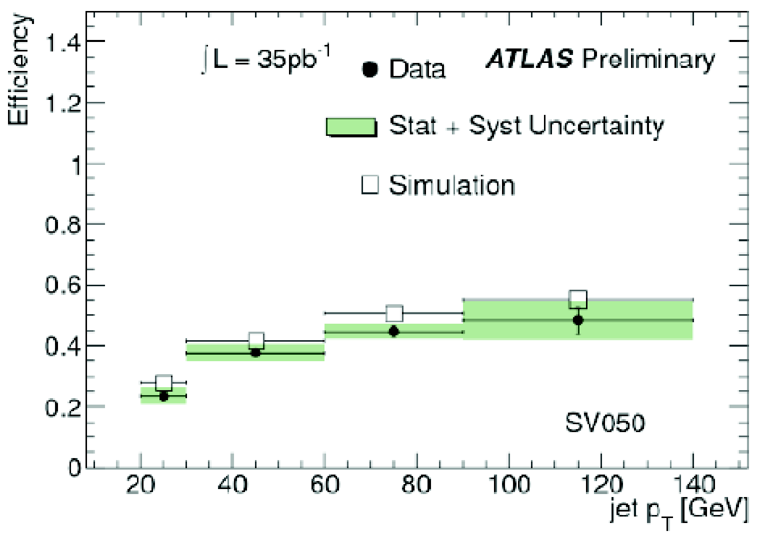


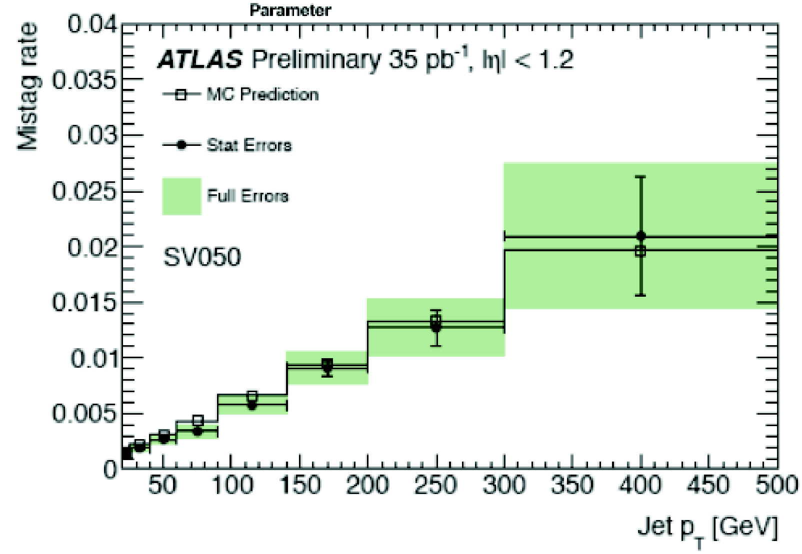
MSTW2008

W/Z + b-jets: b-tagging

- b-jets are selected exploiting the long lifetime (1.5 ps) and the large mass of B-hadrons
- The SV0 b-tagging algorithm is based on requiring a displaced secondary vertex reconstructed within a jet with a decay length significance > 5.85
- The b-tagging efficiency and its systematics is estimated by studying semi-leptonic B decays in QCD muti-jet events, and top events







W/Z+bjets: backgrounds

The b-tag changes the composition of backgrounds with respect to W/Z+jet measurements

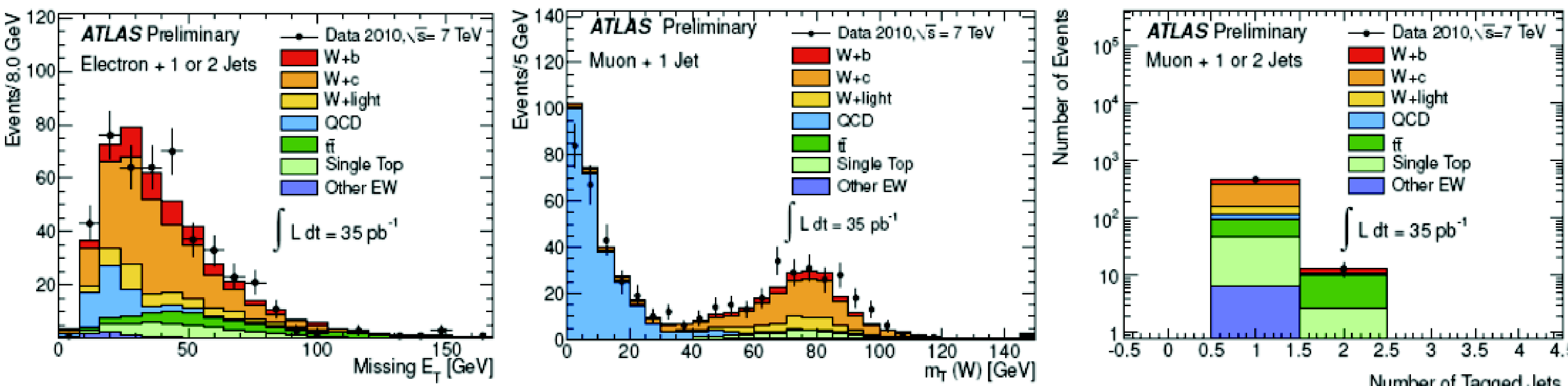
Z+b-jet signal / background > 10
W+b-jet signal / background ≈ 0.5

non-W background

- comes from QCD multi-jet heavy flavour production.
- Tighten lep. ID to keep bkgd <30% with 50% uncertainty

top background

- t-tbar largest background (partially irreducible)
- single-top estimated with MC (partially irreducible)
- top yield measured in the ≥4 jet bin and extrapolated to 1, 2 jet wit MC
  - uncertainty ≈ 30% (JES)
  - b-tag uncertainty reduced to 2%



W/Z+bjets: extraction of b-jets fraction

A maximum likelihood fit to the SV0 mass distribution is used to separate b-jets from c- and light-jets, and extract the flavour fraction on a statistical basis.

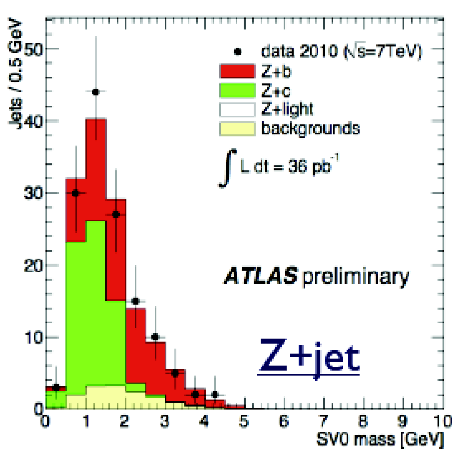
- SV0 mass template are modeled with MC
- template systematics: data vs. MC in multi-jet events enriched in light-, c-, and b-jets.

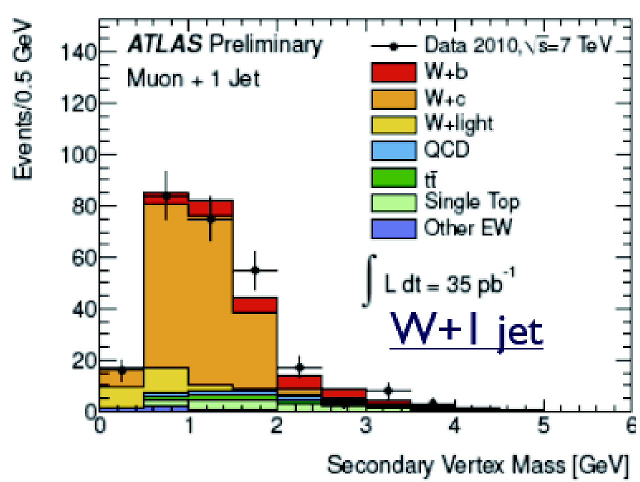
Z+bjet

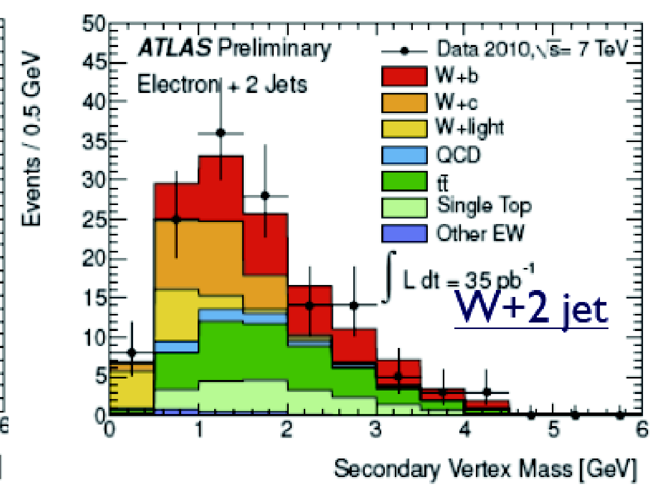
- Fit the combined e and μ samples and each b-tagged jet in the event
- At least 1 b-tagged jet

W+bjet

- 1 b-tagged jet
- about 10% of events have 2 b
- 1 or 2 jet
- fit each jet bin separately for e and μ





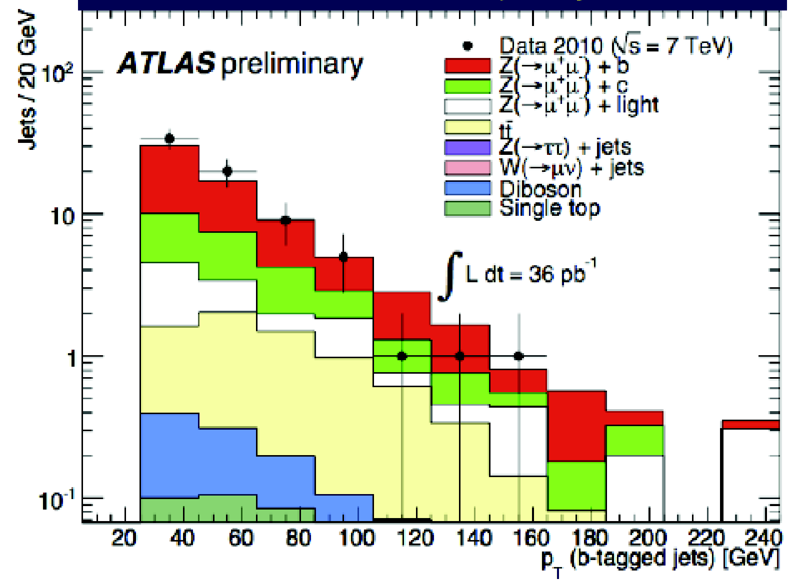


Z+b-jets: results

$$\sigma = \frac{N_b}{C_e \times \mathcal{L}_e + C_\mu \times \mathcal{L}_\mu}$$

- Inclusive b-jet production cross section in association with a Z boson
- Jet fitted yield is corrected for all detector effects with MC LO matched prediction for Zjet (including heavy flavour) from ALPGEN and SHERPA
- uncertainty: ≈ 20% stat. and ≈23% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈10%
  - Z+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈4%
- MCFM in good agreement with data within uncertainty

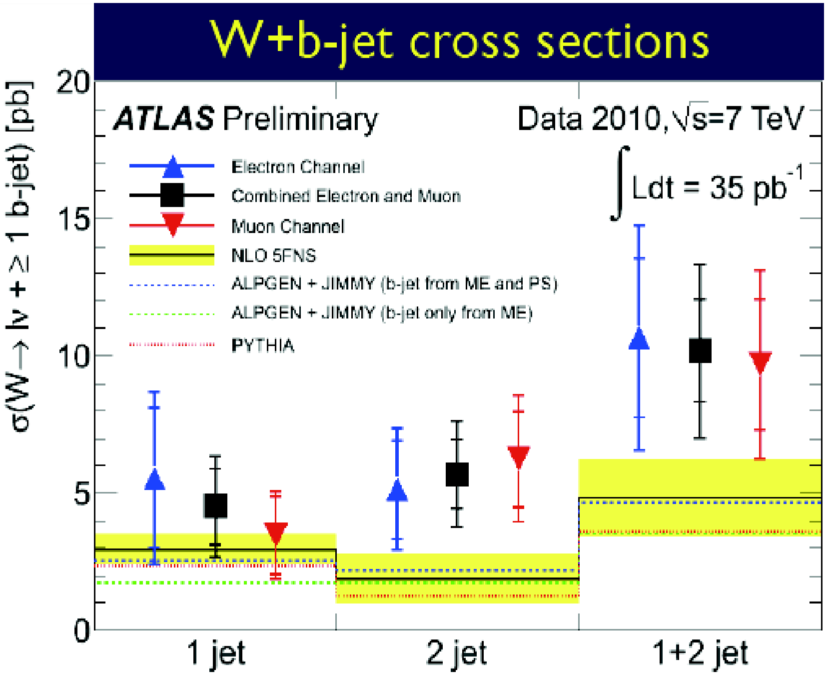
Z+b uncorrected b-jet spectrum



Experiment	$3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb
MCFM	3.40 ± 0.44 pb
ALPGEN	2.23 ± 0.01(stat only)pb
SHERPA	3.33 ± 0.04(stat only) pb

W+b-jets: results

$$\sigma_{W+b-\text{jet}} \times \mathcal{B}(W \to \ell\nu) = \frac{n^{\text{tag}} \cdot f_{W+b-\text{jet}}}{\int Ldt \cdot \mathcal{U}}$$



- W+b-jet cross section (event level)
- First measurement in exclusive jet bins
- event fitted yield is corrected for all detector effects with MC LO matched prediction for Wjet (including heavy flavour) from ALPGEN
- uncertainty: ≈ 20% stat. and ≈25% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈16%
  - top background ≈12%
  - QCD background ≈7%
  - W+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈7%
- NLO prediction obtained in the 5 flavour number scheme [F. Caola *et al.* arXiv:1107.3714]
- NLO agrees within 1.5σ with the measurements

	σ_{vis} [pb]
1 jet	$2.9^{+0.40}_{-0.36}$ (scale) $^{+0.18}_{-0.02}$ (PDF) $^{+0.19}_{-0.10}$ (m_b) $\pm$ 0.20 (non-pert)
2 jet	$1.9^{+0.81}_{-0.37}$ (scale) $^{+0.14}_{-0.02}$ (PDF) $^{+0.06}_{-0.05}$ (m_b) $\pm$ 0.13 (non-pert.)
1+2 jet	$4.8^{+1.20}_{-0.73}$ (scale) $^{+0.32}_{-0.03}$ (PDF) $^{+0.25}_{-0.15}$ (m_b) $\pm$ 0.34 (non-pert.)

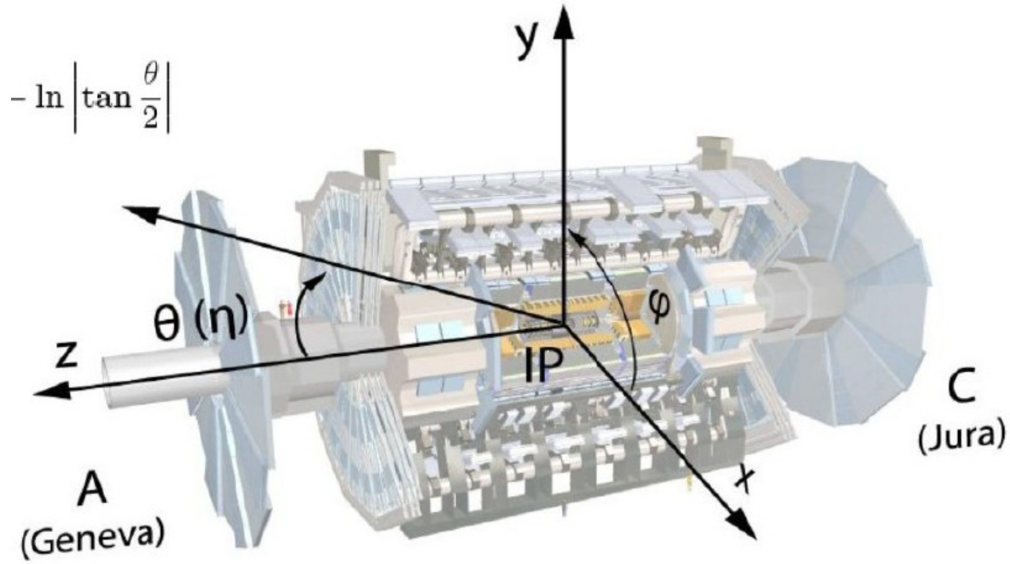
Summary

- The LHC era allowed us to verify QCD in new kinematic regimes, good testing ground for predictions
- Current understanding of detectors allows to do precision measurements in W/Z sector
- Extensive set o measurements also in W/Z+jets differential cross-sections, also with b-tagging
- Overall impressive agreement with MC predictions

Plan

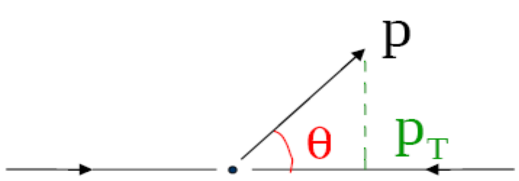
- Amazing how much could have been done with only 36pb^{-1} data accumulated in 2010: numbers of results are still in the pile-line but already theory is being tested quantitatively.... and is holding its own (unfortunately)
  - **23.11** Top physics
  - **30.11** Diboson production and TGS couplings
  - **7.12** B-physics and heavy ions
  - **4.01** Higgs boson... where we are?
  - **18.01** What's new from New Physics searches?

ATLAS Detector



THE ATLAS DETECTOR IS REALLY BIG!

- Length : $\sim$ 46 m
- Radius : $\sim$ 12 m
- Weight : $\sim$ 7000 tons
- $\sim 10^8$ electronic channels
- 3000 km of cables



Transverse momentum

(in the plane perpendicular to the beam)

$$p_T = p \sin\theta$$

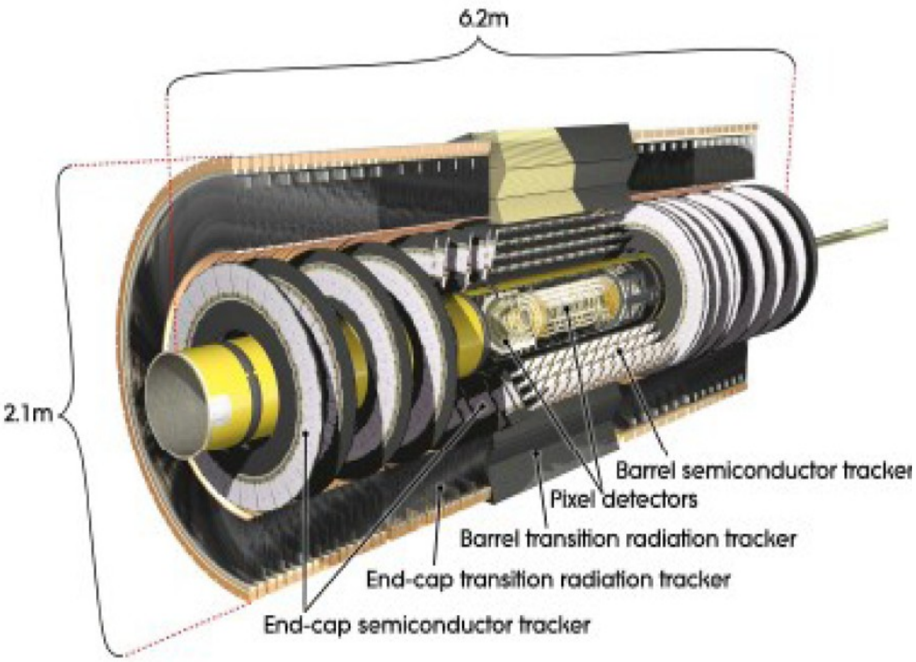
Rapidity: $\eta = -\log\left(\mathrm{tg}\,\frac{\theta}{2}\right)$

$\theta = 90^\circ \rightarrow \eta = 0$

$\theta = 10^\circ \rightarrow \eta \cong 2.4$

$\theta = 170^\circ \rightarrow \eta \cong -2.4$

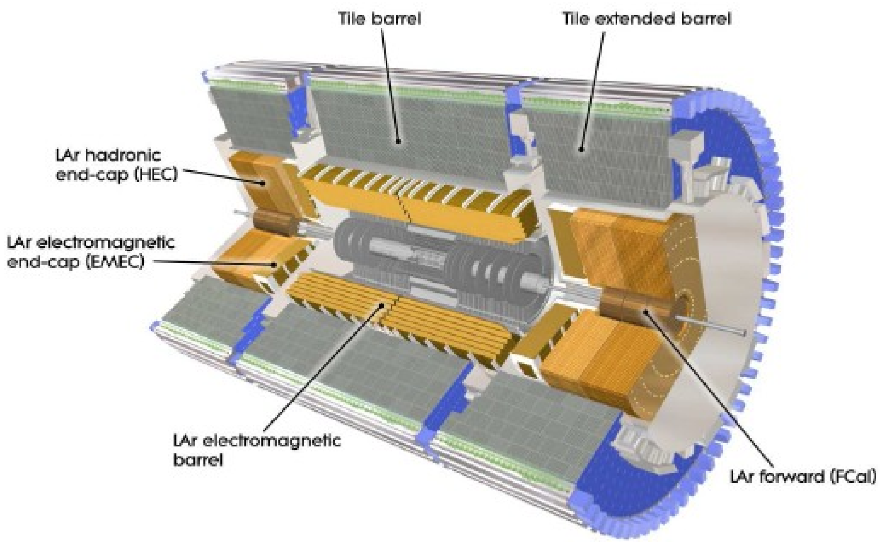
ATLAS Inner Detector



The inner detector $|\eta| < 2.5$ consists of

- Pixel detectors, semi-conductor tracker (SCT), transition radiation tracker
  - $\approx$ 87 million readout channels
  - Immersed in 2T solenoidal magnetic field
- Resolution of $\sigma/p_T = 5 \times 10^{-4} \oplus 0.015$

ATLAS Calorimeters



Electromagnetic and hadronic calorimeters

- Subsystem technology and granularity $\leftrightarrow$ shower characteristics
- Transverse and longitudinal sampling $\approx$ 200000 readout cells up to $|\eta| < 4.9$

Electromagnetic Calorimeters:

- Fine granularity $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ in central region
- Energy resolution $10\%/\sqrt{E}$

Hadronic Calorimeters:

- Granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in central region, less segmented in forward region
- Energy resolution $50\%/\sqrt{E} \oplus 0.03$