



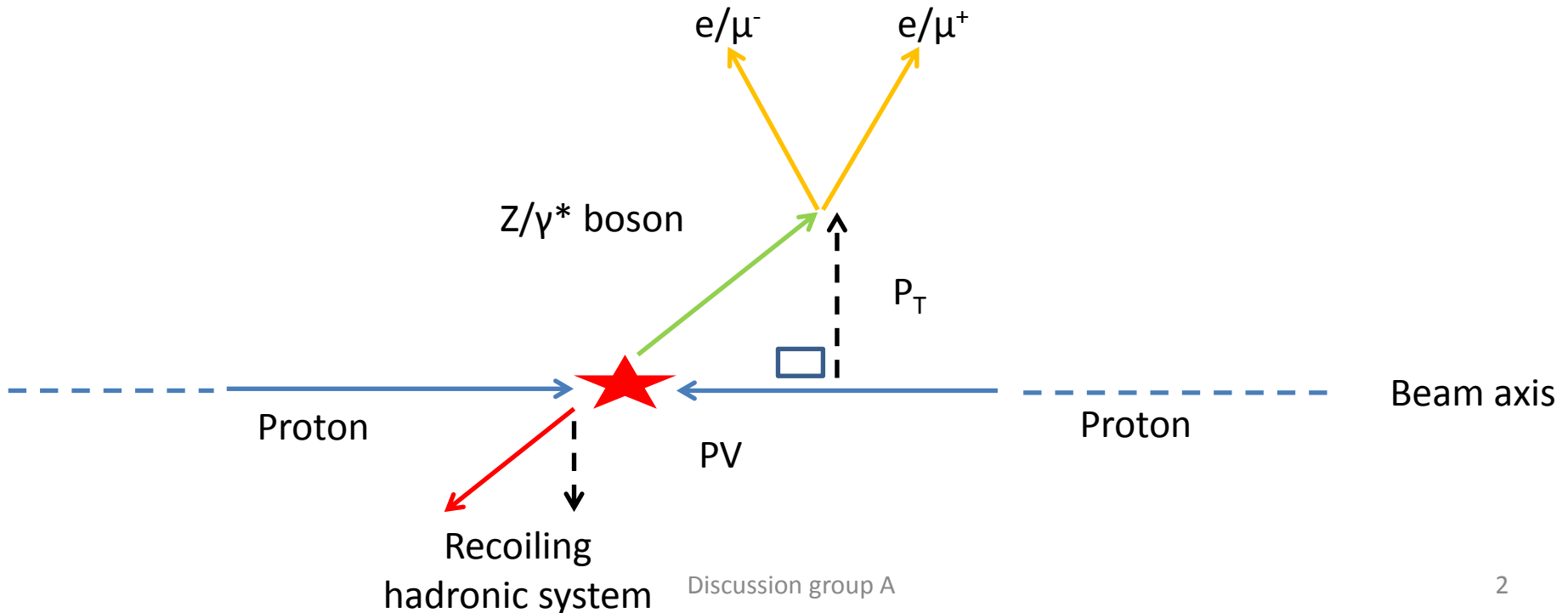
Measurement of the transverse momentum distribution of Z/γ^* bosons in p-p collisions at $\sqrt{s} = 7\text{TeV}$ with the ATLAS detector

Discussion group A
Conference Centre

What are we measuring?



- Due to QCD initial state radiation in p-p collisions Z/γ^* bosons can be produced with a momentum component transverse to the beam axis
- Simple di-lepton signatures can be identified with little background and allow a precise reconstruction of the boson trajectory and P_T :



What are we measuring?



- Measure the normalised transverse momentum distribution – defined as:

$$1/\sigma_{\text{FID}} \times d\sigma_{\text{FID}} / d(P_{\text{T}})$$

- Where σ_{FID} = the measured inclusive cross-section for $pp \rightarrow Z/\gamma^* + X$ multiplied by the branching ratio of $Z/\gamma^* \rightarrow l^+l^-$ (within the detector fiducial acceptance)
- Results will be compared to those of:
 - Theoretical QCD calculations
 - The output of various event generators

Why is it important?

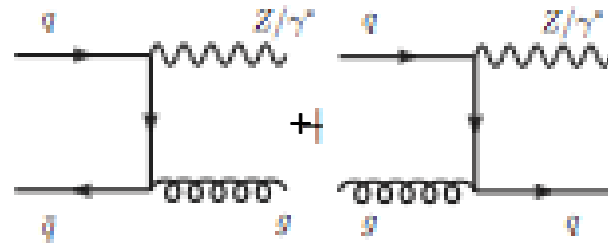


- W mass measurement uses lepton P_T directly:
 - $M_T = (2p_T^l p_T^{\nu}(1 - \cos \theta_{lv}))^{\frac{1}{2}}$
 - Can use Z P_T measurement (uncertainty due to hadronic recoil, measured accurately here)
 - W mass important in own right as input to ρ parameter (handle on new physics and Higgs mass):
 - $\rho \approx \frac{M_Z^2}{M_W^2 \cos^2 \theta_W} = 1.0008 + 0.0017 - 0.0007$
 - ρ is 1 at tree level
- Validation of generators and tunes, input for PDFs
- Measurement currently being improved: larger dataset and better discrimination

QCD predictions

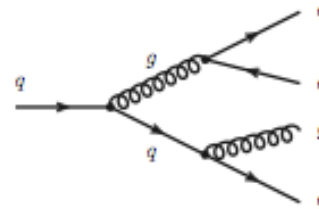
Theory calculation

- Perturbative QCD: $\alpha_s(Q^2 > \Lambda_s^2) < 1$
 - We can calculate differential cross section, but divergent for $p_T \rightarrow 0$: **FEWZ**
- Soft and collinear parton emission:
 - Divergencies not calculable at fixed order, lead to terms $\sim \log^{2N}(Q^2/Q_0^2)$
 - Combination of pQCD with next-to-next-to-leading-log (NNLL) resummation: **RESBOS**
 - similar treatment in parton shower



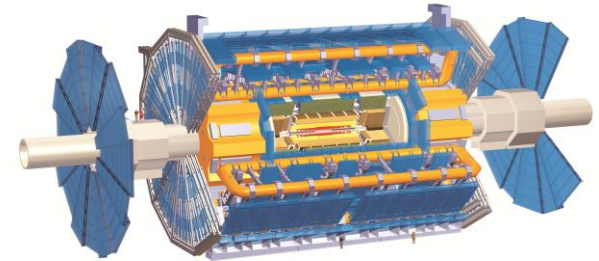
Event generation

- **PYTHIA**, **HERWIG**: pure parton shower, but weight up hard emissions $O(\alpha_s^0) \rightarrow O(\alpha_s^1)$ (with MRST2007LO* PDF)
- **POWHEG**, **MC@NLO**: merge NLO pQCD with parton shower from PYTHIA / HERWIG (with CTEQ6.6 PDF)
- **ALPGEN**, **SHERPA**: pQCD calculations at LO for emissions of ≤ 5 partons, matched with corresponding parton shower evolution (with CTEQ6.6 / CTEQ6L1 PDF)



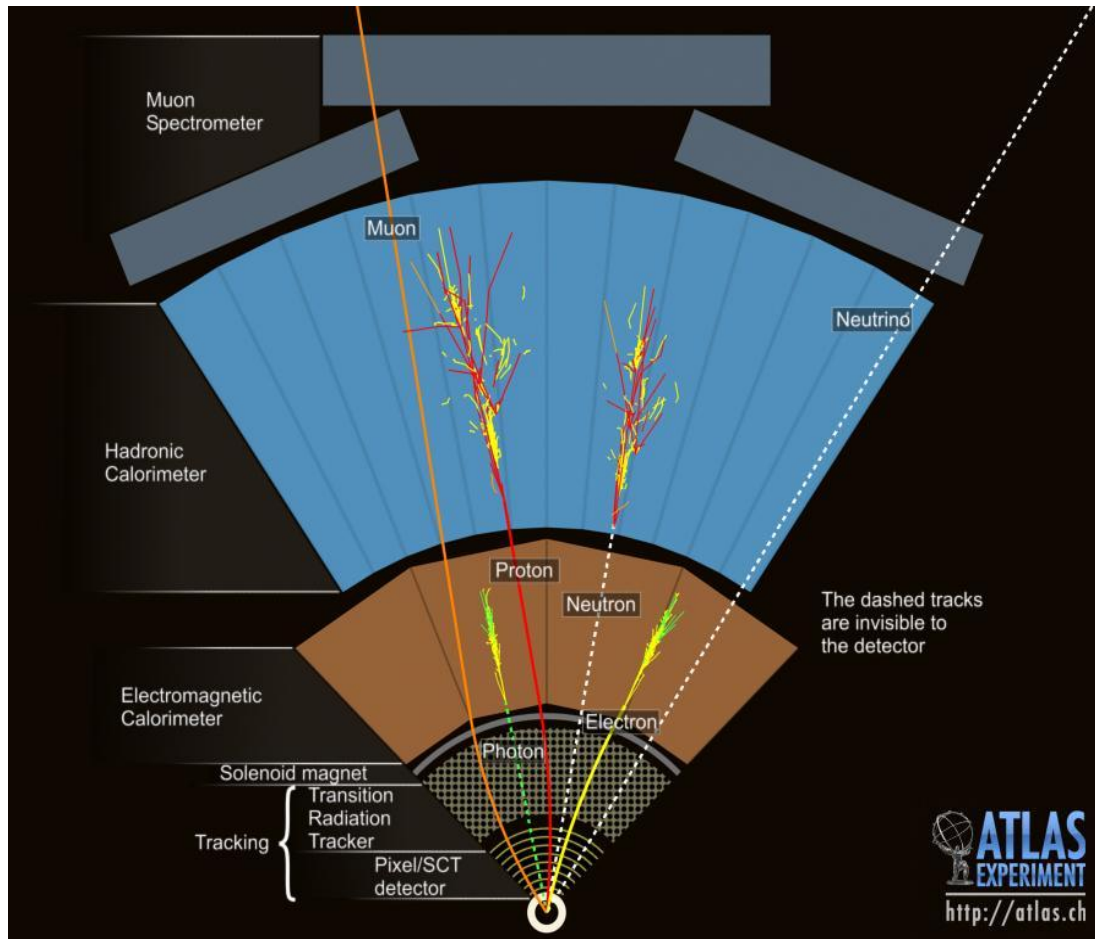
The ATLAS detector

General-purpose experiment at the Large Hadron Collider
collecting proton-proton collisions at $\sqrt{s}=7\text{TeV}$



Reconstruction of leptons relies mainly on:

- Tracking systems
- EM calorimeter
- Muon spectrometer



A 3-level trigger system reduces
the overall event rate

2 triggers used in this analysis:

- single muon with $p_T > 15\text{GeV}$
- single electron with $p_T > 13\text{GeV}$

Similar trigger and offline
selection

• Trigger efficiencies were
estimated in data using $Z/\gamma^* \rightarrow l+l^-$
candidate events - tag-and-probe
method

- > 95% across range
studied

Offline event selection



- Only data flagged as good quality used
- **Common high level cuts:**
 - At least one primary vertex composed from at least 3 tracks
 - Invariant mass di-lepton pair 66-116 GeV ($M_z \sim 91\text{GeV}$)
- **Lepton channel cuts:**

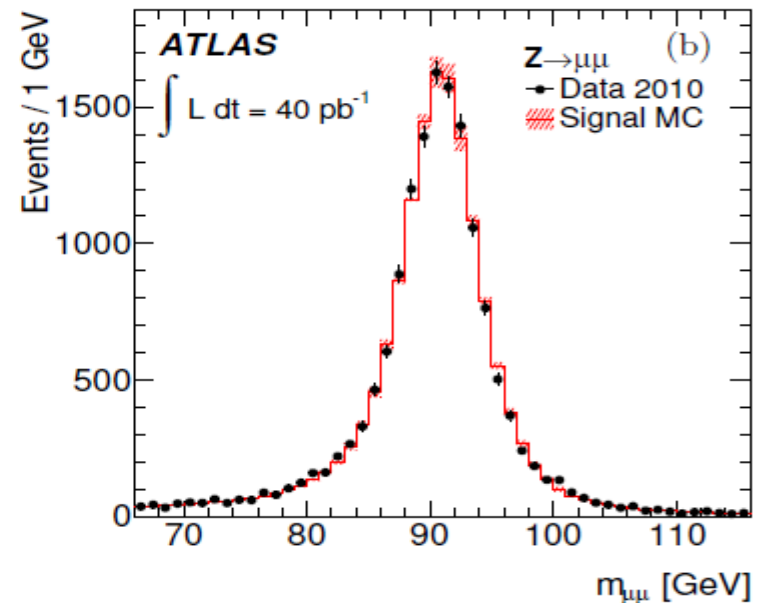
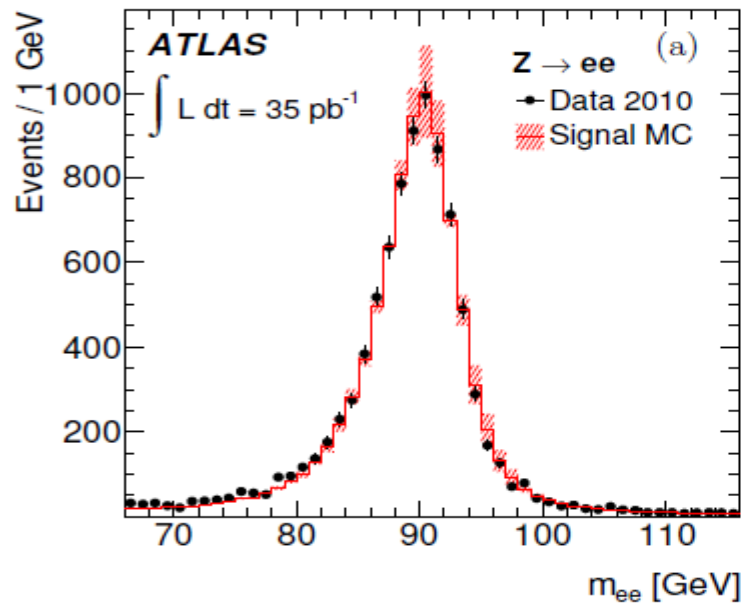
Cut applied	Electron channel	Muon channel
Transverse energy	>20GeV	-
Transverse momentum	-	>20GeV
$ \eta $	<2.4	<2.4

- Track quality applied for both channels (χ^2 , impact parameter PV)
- Shower shape ID used to confirm electron showers
- Isolated muons reconstructed – rejects jet backgrounds

Selected events



- Invariant mass distribution plots: real data candidates compared to Pythia simulation



- 8923 $Z/\gamma^* \rightarrow e^+e^-$ and 15060 $Z/\gamma^* \rightarrow \mu^+\mu^-$ candidates
- Background contributions negligible (and hence invisible!)

Results: Unfolding P_T^Z

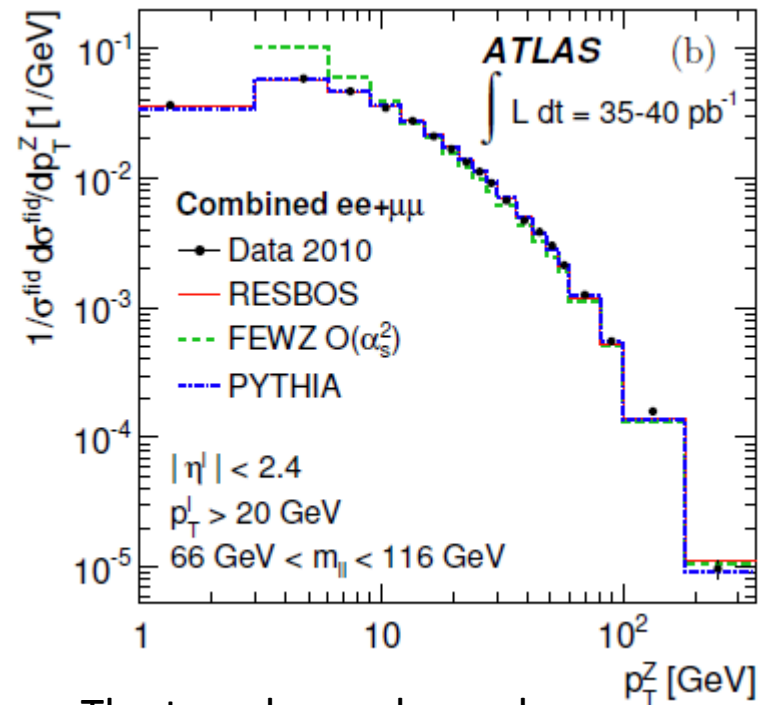


The unfolding procedure corrects the measured distribution to the underlying "true" distribution. It accounts for:

- Lepton selection efficiencies
 - Detector effects
 - QED final state radiation
- **Bin by-bin unfolding:**

$$C_i = \frac{N_{MC,Truth}}{N_{MC,Reco}}$$

$$\frac{\Delta\sigma^i}{\Delta P_T^Z} = \frac{N_{sel}^i - N_{bkg}^i}{L\Delta P_T^Z} \cdot C_i$$



The two decay channels are combined to get the normalized differential cross section shown above.

Systematics/backgrounds

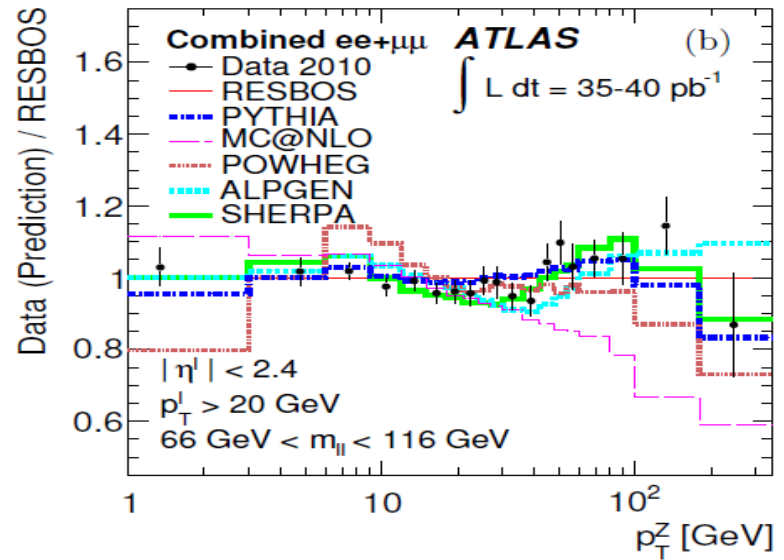
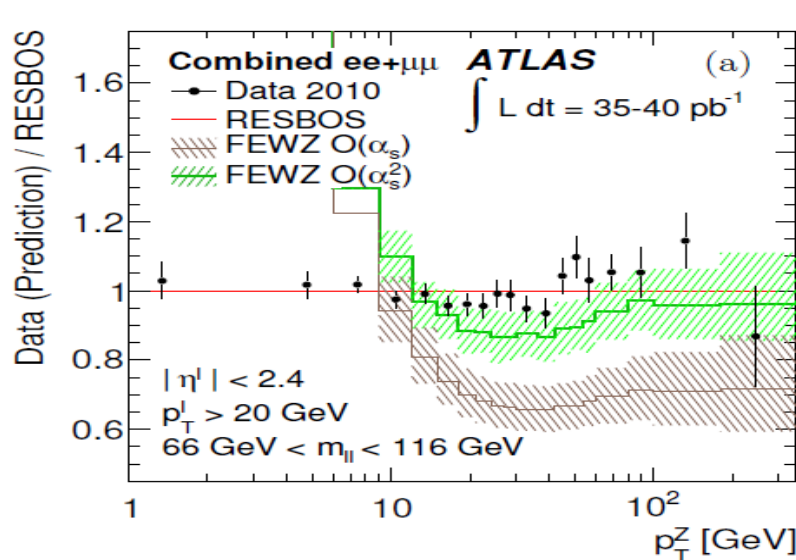


- The unfolding bin-by-bin correction factors are subject to several sources of systematic error
- Systematics evaluated by recalculating bin-by-bin factors using bootstrap method

Systematic contribution	% effect on C_i
Lepton efficiencies	1-5%
Simulation statistics	0-4%
Energy/momentum scales	0-3%

- Smaller effects produced by channel specific backgrounds, event pile-up and QED final state radiation
- N.B. More complex matrix unfolding methods suffer from a lack of statistics but may be suitable for larger data-sets in the future

Results: MC comparisons



- Good description for the entire PT range using RESBOS.
- At $PT > 18 \text{ GeV}$, the central FEWZ $O(\alpha_s)$ prediction underestimates the data by about 10%, which is comparable to the size of the combined experimental and theoretical uncertainty.
- Good agreement with Sherpa, Alpgen, and Pythia
- MC@NLO and POWHEG perform less well.

Conclusions



- Z/γ^* P_T differential distribution measured up to $P_T = 350\text{GeV}$ in p-p collisions at 7 TeV
- The entire spectrum is well described by RESBOS, compatible with FEWZ (within uncertainties)
- There is also excellent agreement with the SHERPA, ALPGEN and Pythia event generators – although other generators perform less well
- Except for at the lowest P_T values, measurement of the spectrum is limited by statistics and NOT systematics – continual improvement to these already impressive results is foreseen in the near future
- Results prove that we have a good handle on the underlying QCD at NLO

Backup: Fit quality



Generator/MC	$\chi^2/ndof$
RESBOS (CTEQ 6.6)	21.7/19
ALPGEN+HERWIG+JIMMY (CTEQ6L1)	31.9/19
SHERPA (CTEQ 6.6)	16.8/19
PYTHIA (MRSTLO*2007)	17.9/19
MC@NLO + PYTHIA	116.9/19
POWHEG	100.4/19