Measurement of the W Boson Drell-Yan Angular Coefficients with the ATLAS Detector

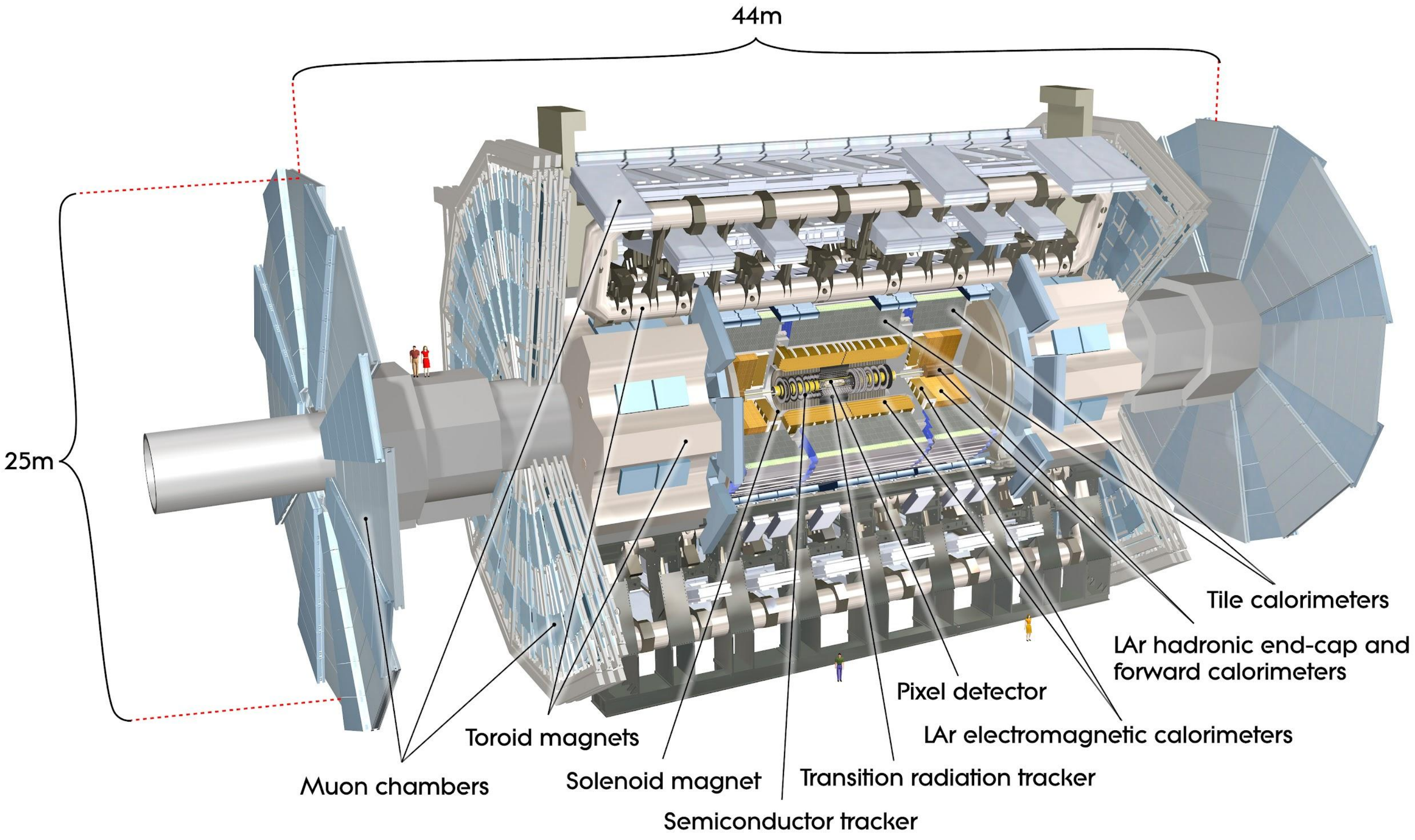
Alexander Bachiu
Carleton University
CAP 2022 - Student Presentation Competition
June 6, 2022

Carleton University

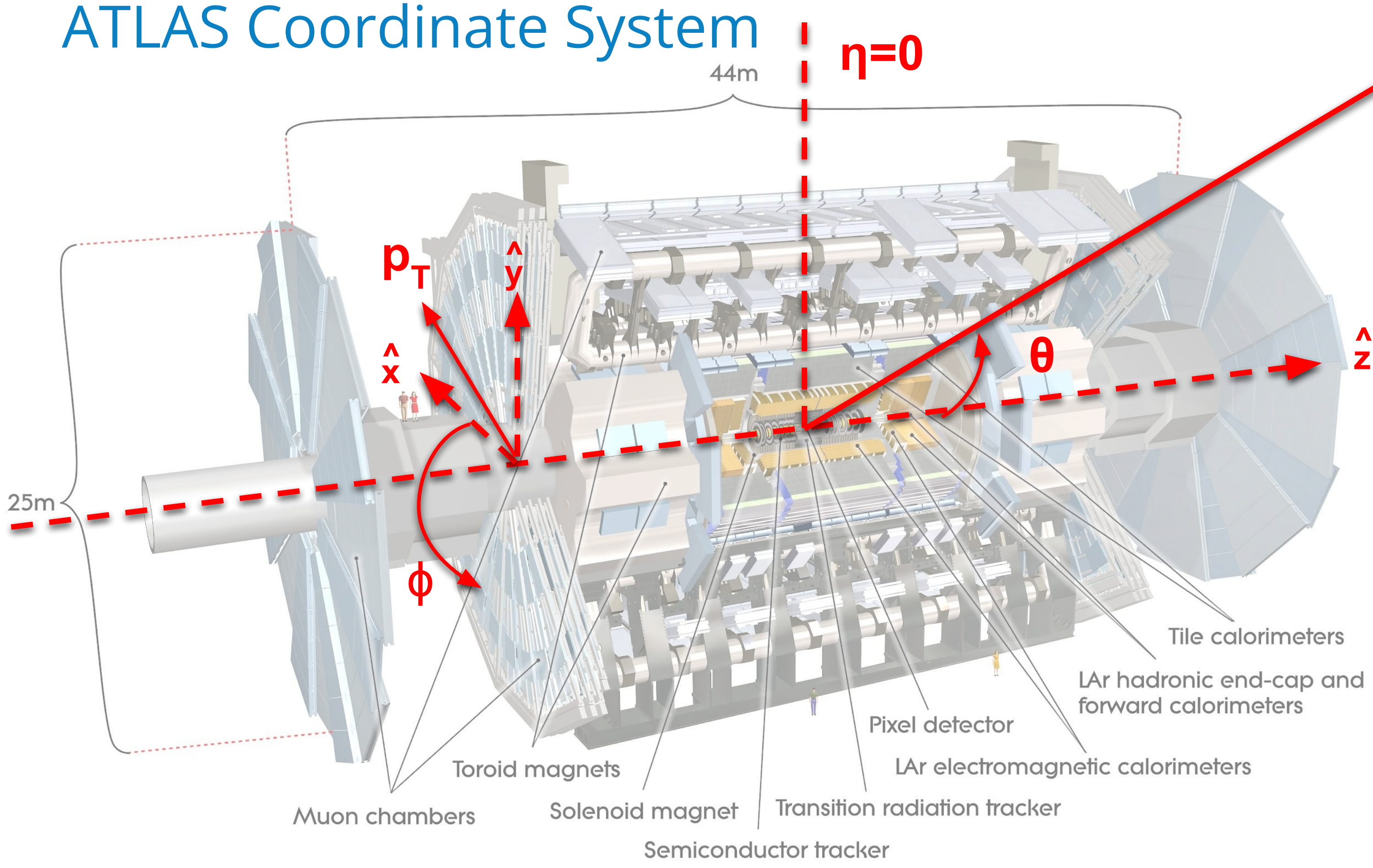
ATLAS EXPERIMENT

Large Hadron Collider

ATLAS Detector



ATLAS Coordinate System

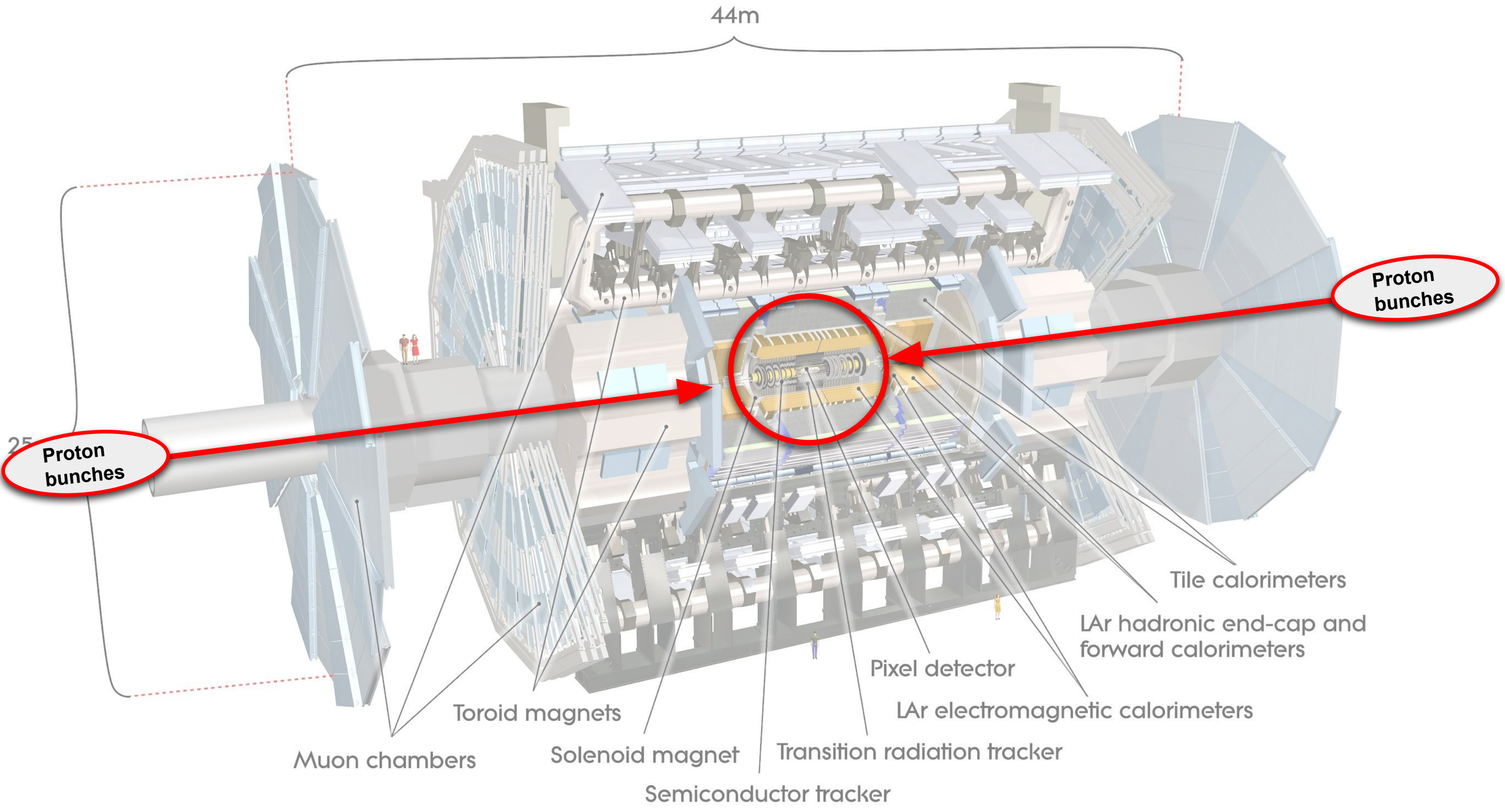


p_T - Transverse momentum measured in xy-plane.

η - Pseudorapidity defined as $-\ln[\tan(\theta/2)]$ where θ is the angle in the yz-plane. Equivalent to rapidity, **y**, when mass of the particle is small.

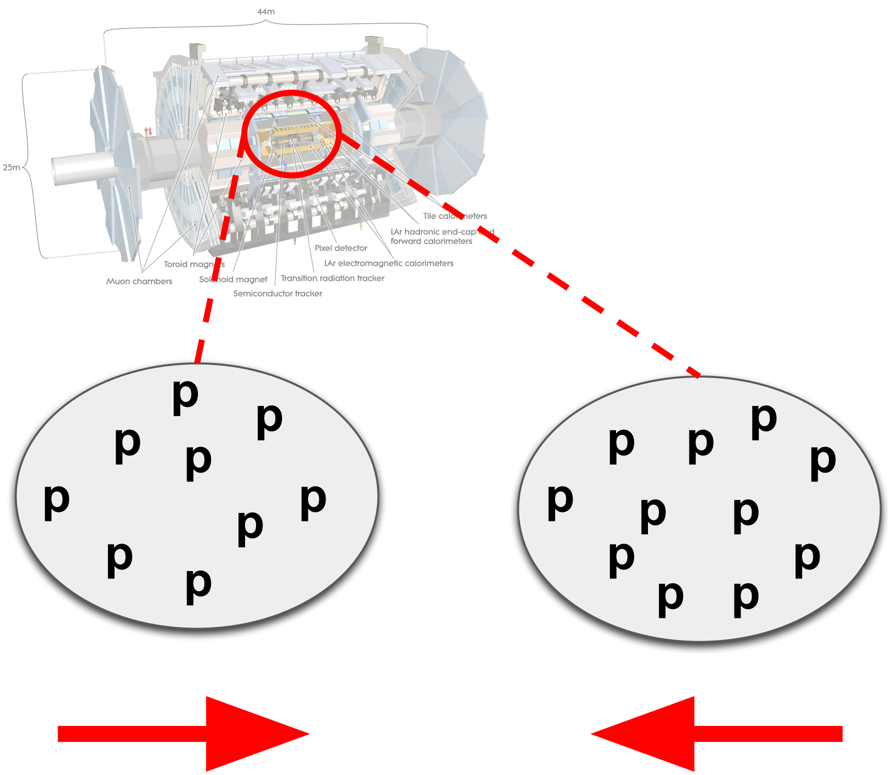
ϕ - Angle from x-axis which points to centre of LHC ring.

W Boson Production



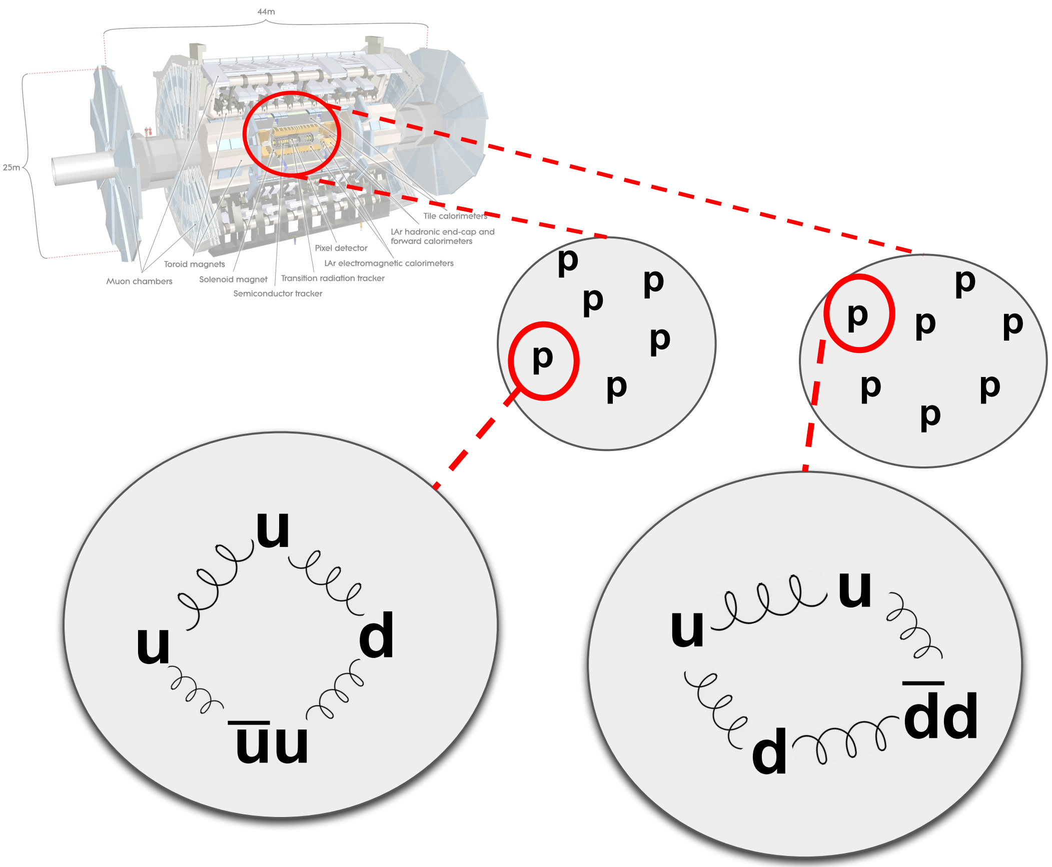
W Boson Production

Bunches of protons are collided every 25 ns.



~10^{11} protons per bunch

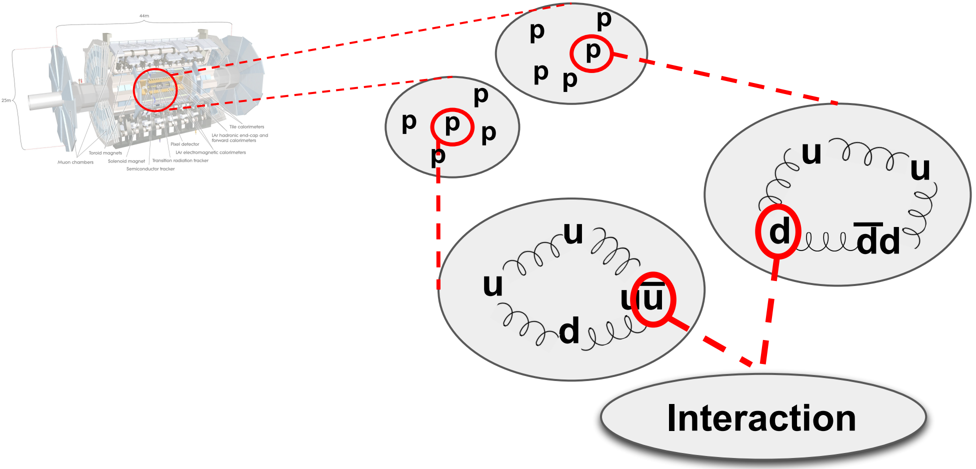
W Boson Production



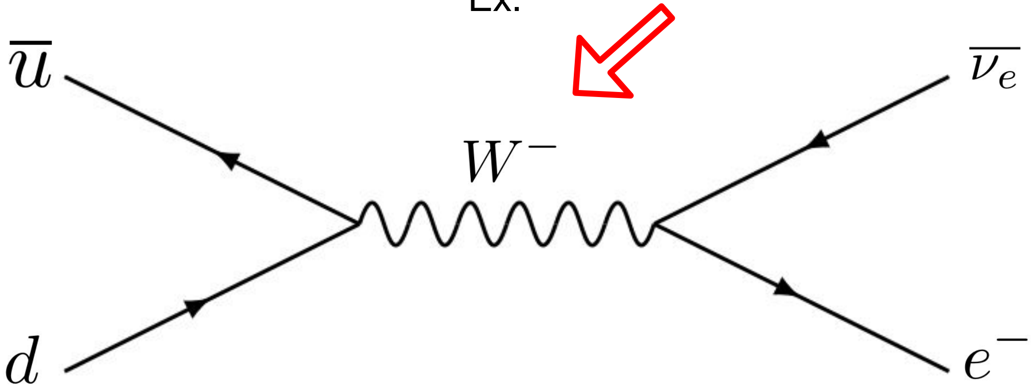
Bunches of protons are collided every 25 ns.

Each proton has 3 valence quarks (uud) but it can have quark-antiquark pairs created and destroyed from gluon interactions.

W Boson Production



Ex.



Bunches of protons are collided every 25 ns.

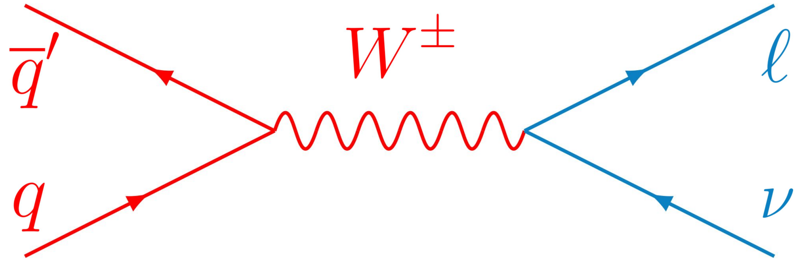
Each proton has 3 valence quarks (uud) but it can have quark-antiquark pairs created and destroyed from gluon interactions.

Quark and gluon interactions produce many different particles like W/Z bosons.

W boson decays quickly (~10^{-25}s), one way is into a charged lepton and a neutrino.

W/Z bosons produced from quark-antiquark pairs and decaying into leptons is called the Drell-Yan process.

Drell-Yan Angular Coefficients



$$\frac{d^5\sigma}{dp_T^W\,dy^W\,dm^W\,d\cos\theta\,d\varphi} = \frac{3}{16\pi}\frac{d^3\sigma^{U+L}}{dp_T^W\,dy^W\,dm^W}\left\{(1+\cos^2\theta)+\sum_{i=0}^{7}A_i(p_T^W, y^W, m^W)\,P_i(\cos\theta,\varphi)\right\}$$

Differential cross-section exact to all orders of QCD!

Fully described by 8 helicity dependent cross-sections.

Ratios of helicity dependent over unpolarized denoted by **A_i**, known as **Drell-Yan Angular Coefficients**.

Coefficients coupled to polynomials **P_i** , which are related to Y^{ℓ}_{m}. (ex. $P_2 = \frac{1}{2}\sin^2\theta\cos 2\varphi$)

Why Do We Want To Measure These Coefficients?

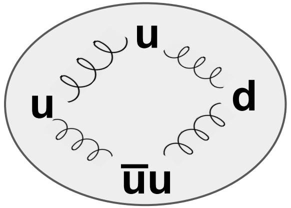
The coefficients have been measured for the Z boson but full suite has never been measured for the W!

They are also an important input to the mass of the W measurement:

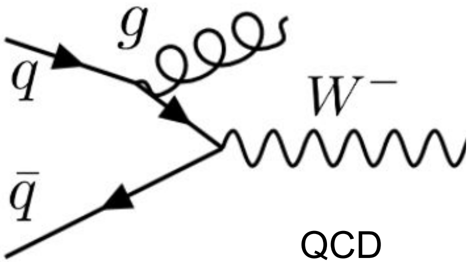
m_W (ATLAS @ 7 TeV) = 80370 ± 7 (stat) ± 11 (exp. sys) ± **14 (mod. sys)** MeV [1]

The biggest bottleneck is the physics modelling uncertainties:

Parton Distribution Function



Physics Modelling Uncert. [MeV]	
Electroweak	5
QCD (p_T^W)	6
QCD (A_i)	6
PDFs	9



QCD

Some coefficients differ for W^+ and W^-, measuring this can help constrain PDFs.

[1] *Eur.Phys.J.C* 78 (2018) 2, 110

Moments Method

$$\frac{d^5\sigma}{dp_T^W dy^W dm^W d\cos\theta d\varphi} = \frac{3}{16\pi}\frac{d^3\sigma^{U+L}}{dp_T^W dy^W dm^W}\left\{(1+\cos^2\theta)+\sum_{i=0}^{7} A_i(p_T^W, y^W, m^W) P_i(\cos\theta,\varphi)\right\}$$

$$\langle P_i(\theta,\varphi)\rangle = \frac{\int d\sigma(p_T, y, \theta, \varphi) P_i(\theta,\varphi) d\cos\theta d\varphi}{\int d\sigma(p_T, y, \theta, \varphi) d\cos\theta d\varphi}$$

$$\langle \frac{1}{2}(1-3\cos^2\theta)\rangle = \frac{3}{20}\left(A_0 - \frac{2}{3}\right)$$

$$\langle \sin 2\theta \cos\varphi\rangle = \frac{1}{5}A_1$$

$$\langle \sin^2\theta \cos 2\varphi\rangle = \frac{1}{10}A_2$$

$$\langle \sin\theta \cos\varphi\rangle = \frac{1}{4}A_3$$

$$\langle \cos\theta\rangle = \frac{1}{4}A_4$$

Want to be able to measure each A_i individually.

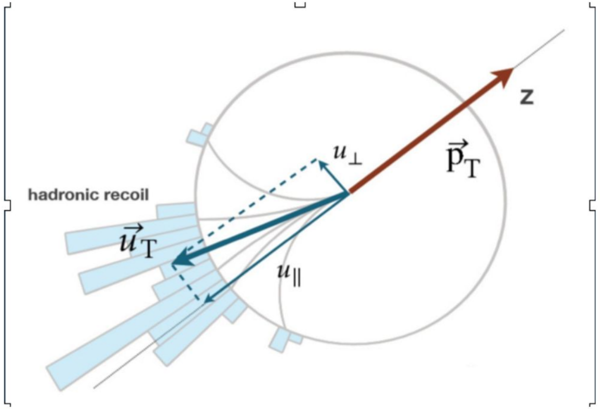
Separated by taking the moment of their polynomial.

Works by exploiting their orthogonality (recall related to Y^{ℓ}_{m}).

Neutrino Reconstruction

Need fully reconstructed neutrino to measure these coefficients.

- p_T approximated by E_T^{Miss} from hadronic recoil
- p_z solved for by imposing a mass constraint $(q_\ell + q_\nu)^\mu (q_\ell + q_\nu)_\mu = m_W^2$ resulting in a quadratic equation



$$E_T^{\vec{miss}} = \vec{p_T}^{\nu} = -\left(\vec{u_T} + \vec{p_T}^{\ell}\right)$$

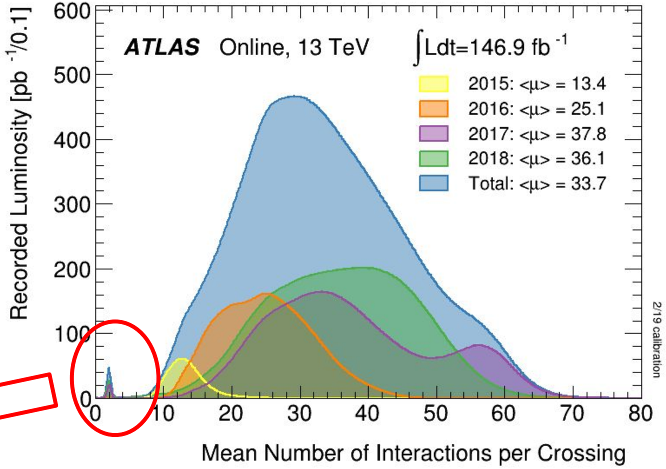
Quadratic equation has two-fold ambiguity but choosing solution at random can statistically resolve correct distributions!

Low pileup data sets are used for better hadronic recoil resolution.

Better hadronic recoil resolution is critical for being able to statistically resolve the proper distributions.

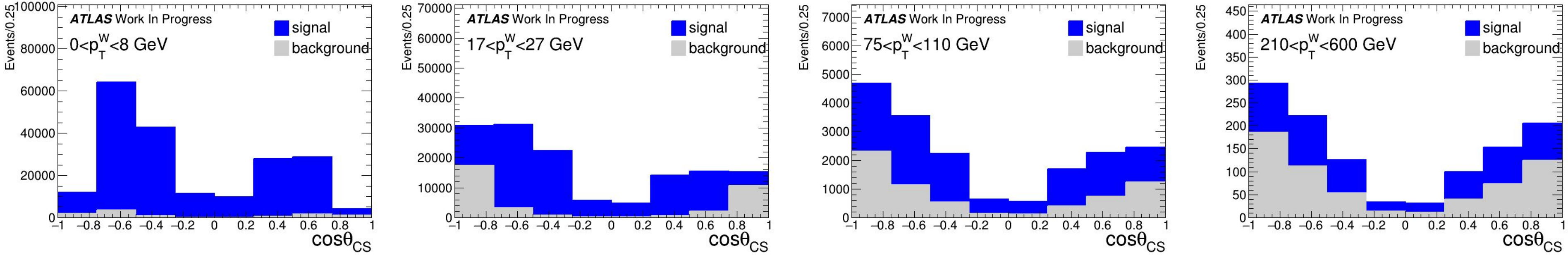
Integrated Luminosity = 335.2pb^{-1}

~ 1M events post-selection per W→eν, W→μν channel

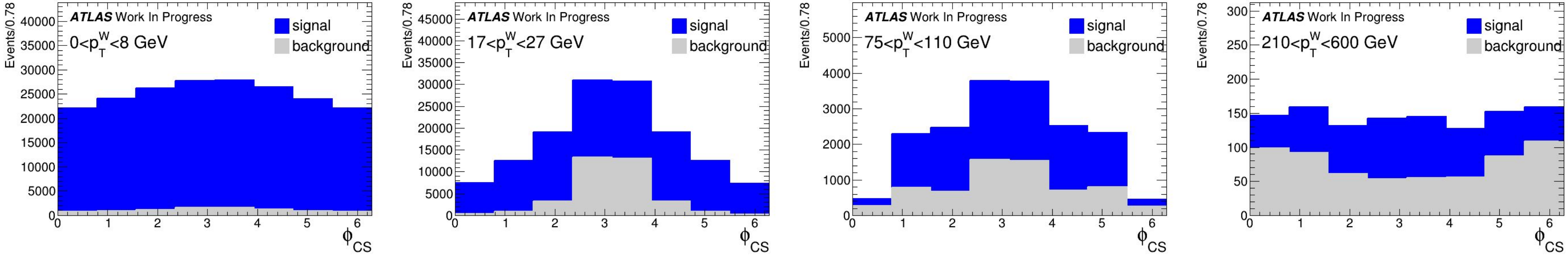


http://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2

Evolution of Angular Distributions*



The angular distributions used to extract the coefficients change with the W boson kinematics such as the ϕ distribution flipping shape from low to high p_T^W.
Backgrounds such as multijet (data derived) and top (Monte Carlo simulated) production alter the shape so understanding it is important.

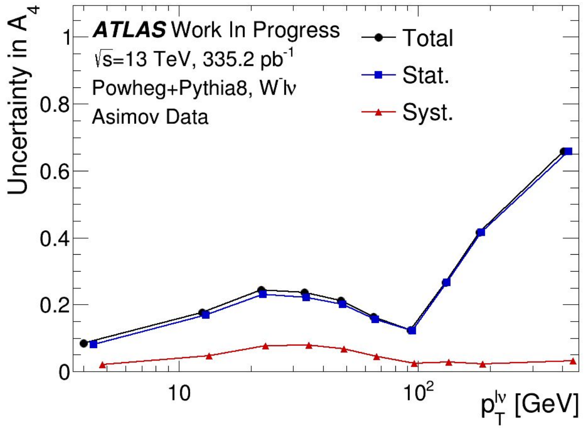


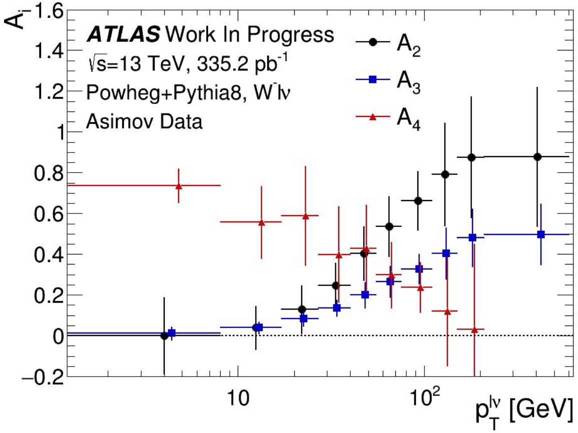
Predictions

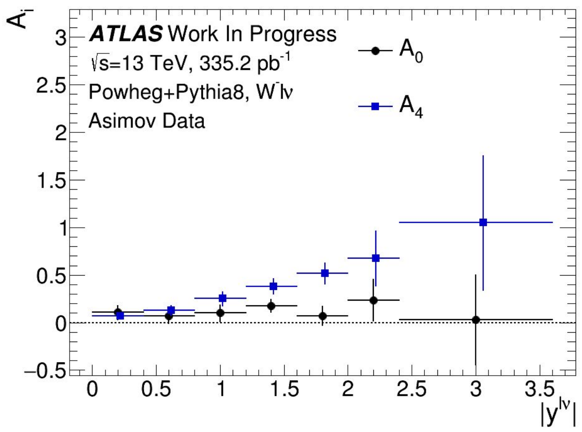
Projected results from simulation to get sensitivity.

We expect to measure 4 coefficients in 10 p_T^W bins from [0, 600] GeV, 2 for the first time.

Separately measure 4 coefficients in 7 y^W bins from [0, 3.6], hasn't been done before.







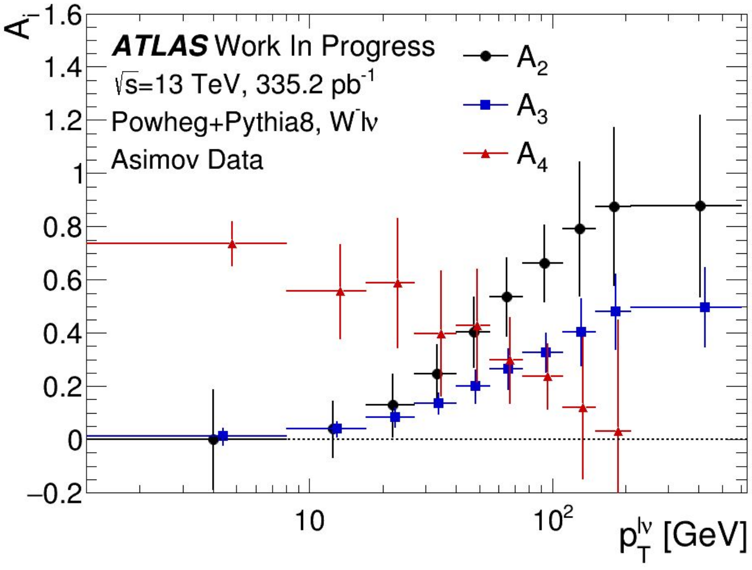
Conclusions

Expect to measure 4 (A_0,A_2,A_3,A_4) coefficients, some for the first time!

Will be statistically limited but will still provide a useful measurement.

Measurement can motivate taking more low pileup data in Run 3!

Important input to make precise ATLAS W mass measurement.



Thank You

Questions?

Collins-Soper Frame

The Ai’s are frame dependent, my research uses the Collins-Soper frame where the z-axis is in the rest frame of the W boson in the direction of its longitudinal polarization, y-axis is normal to the proton-proton plane, and the x-axis is set orthogonal. From this frame we get two angles:

$\boldsymbol{\theta_{cs}}$ - the angle between the negatively charged lepton and the z-axis.

$\boldsymbol{\varphi_{cs}}$ - the angle between the negatively charged lepton and the proton-proton plane.