

Measuring W Boson Drell-Yan Angular Coefficients with the ATLAS Detector

Alexander Bachiu

Supervisor: Dr. Manuella Vinciter

Carleton University

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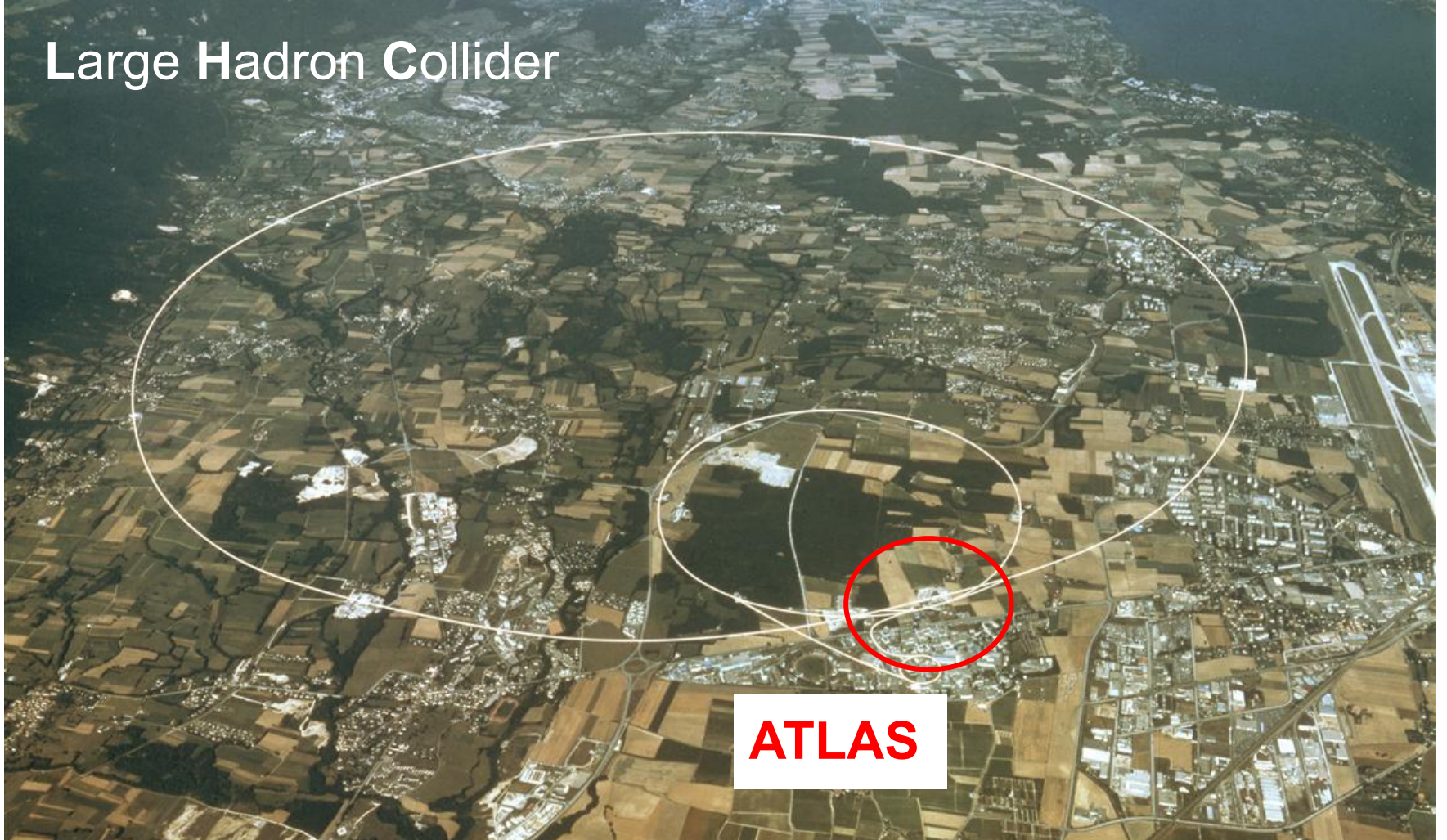
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Large Hadron Collider

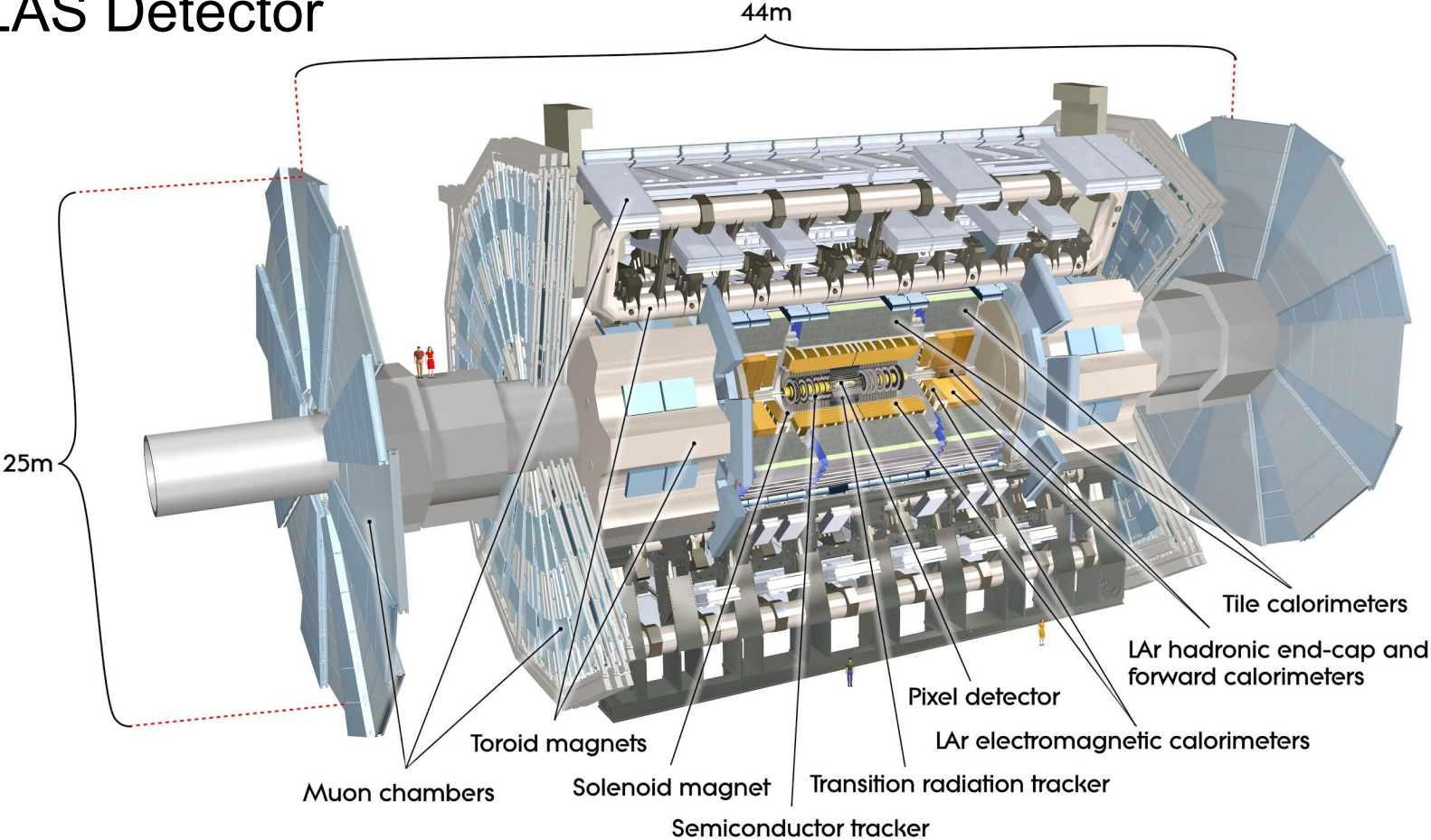


Large Hadron Collider

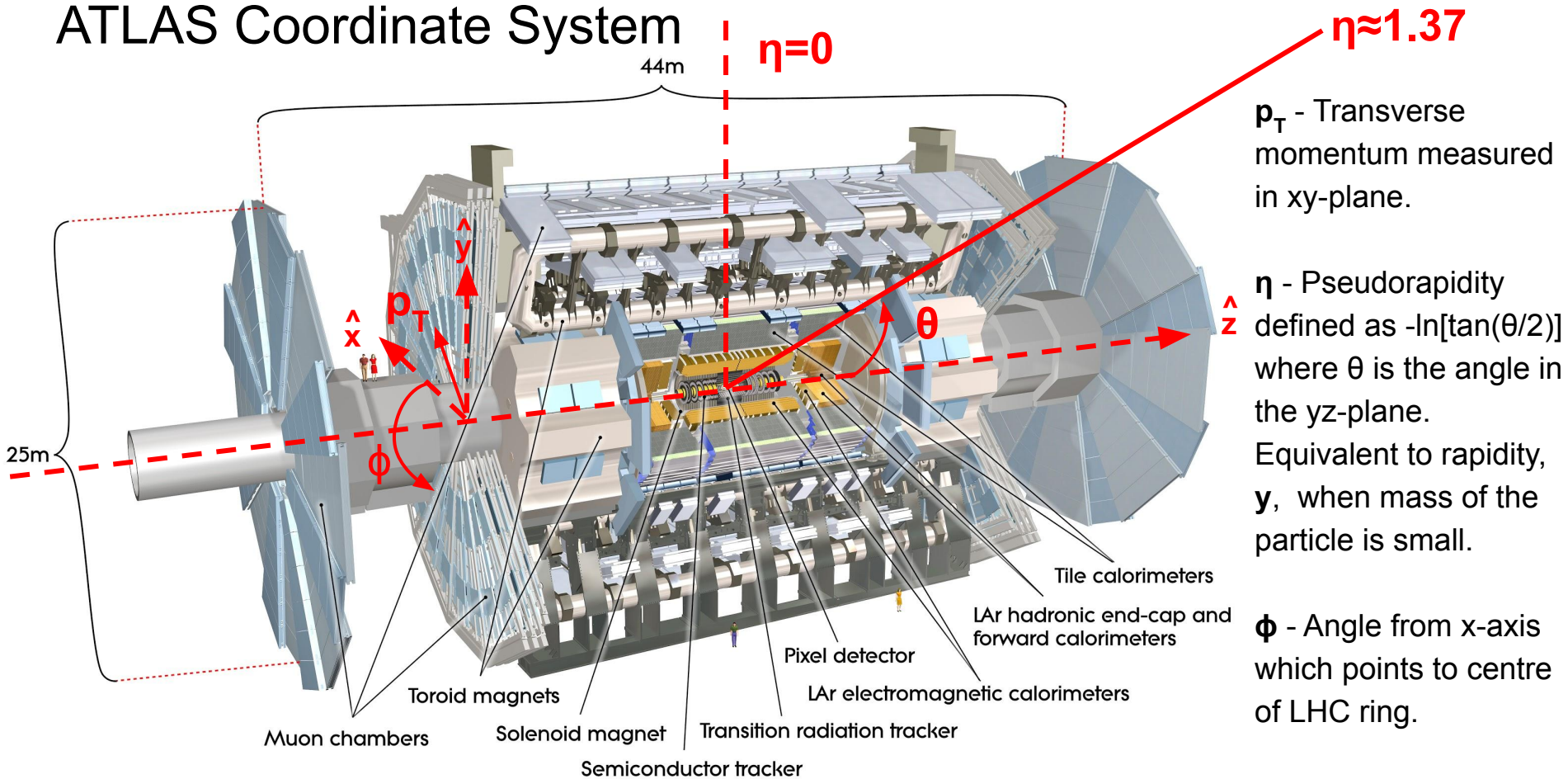


ATLAS

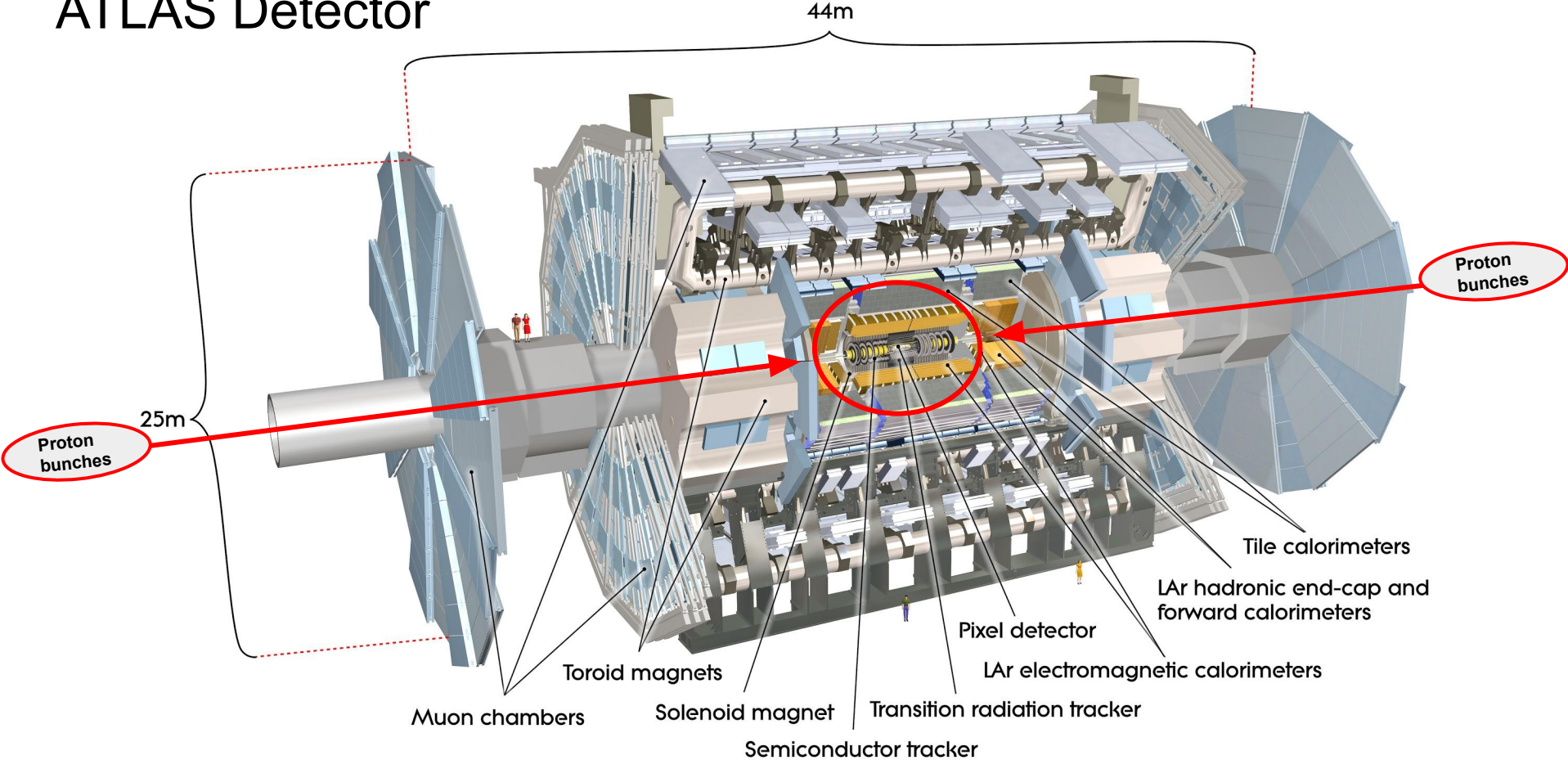
ATLAS Detector



ATLAS Coordinate System

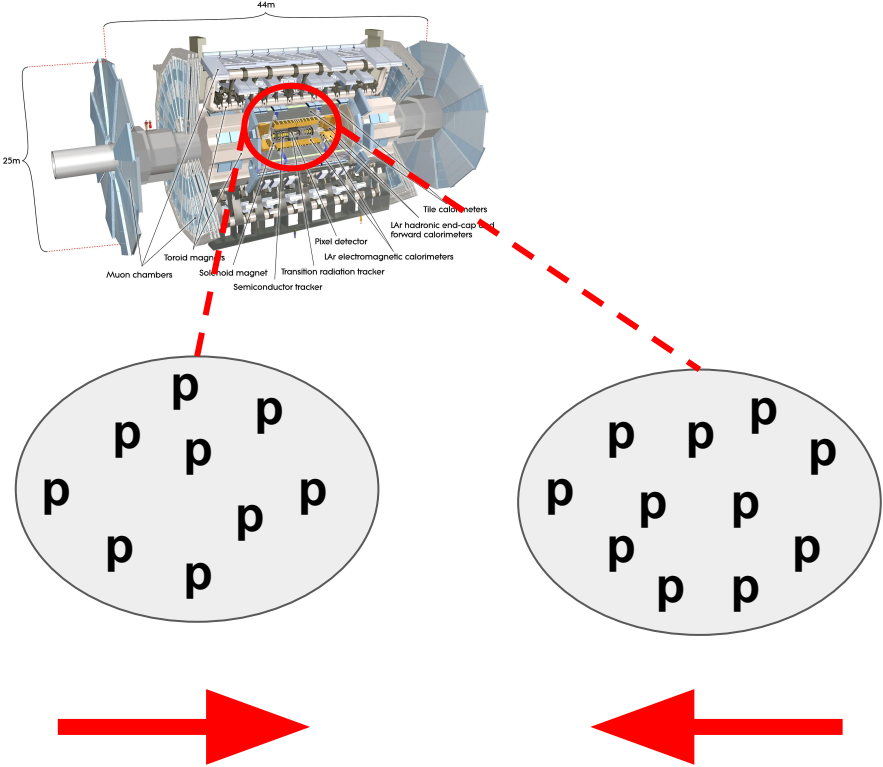


ATLAS Detector

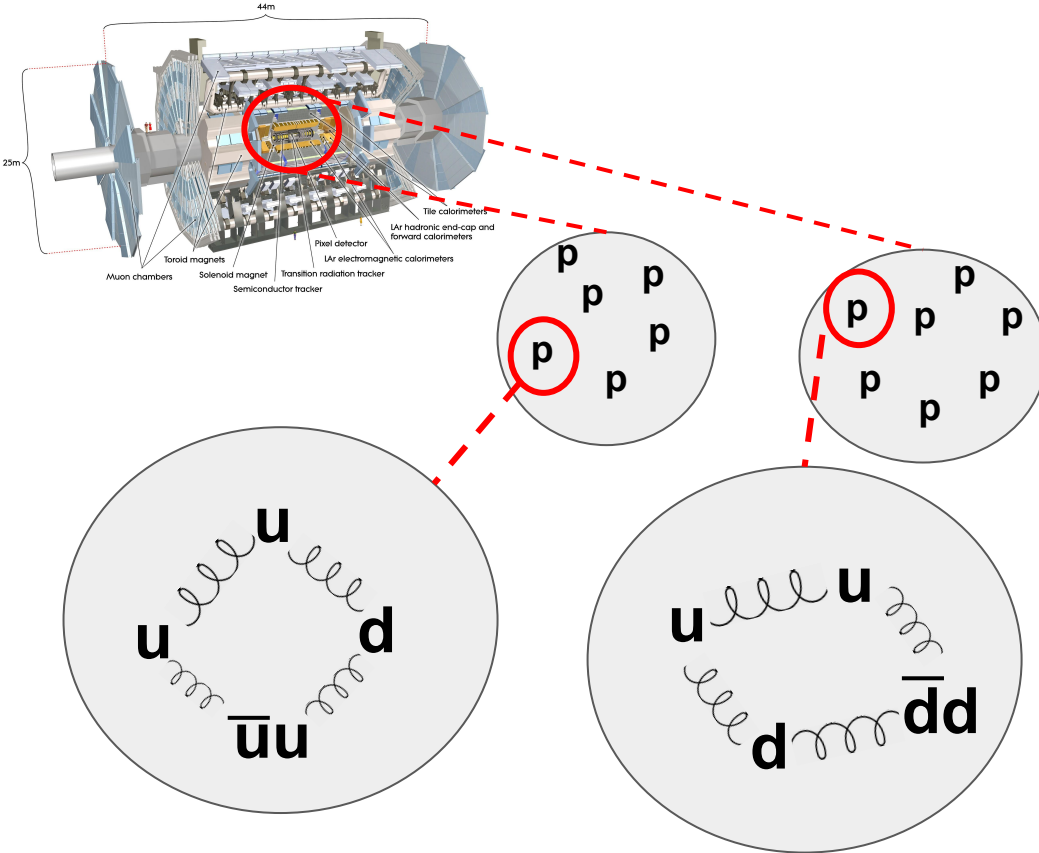


W Boson Production

Bunches of protons are collided every 25 ns.



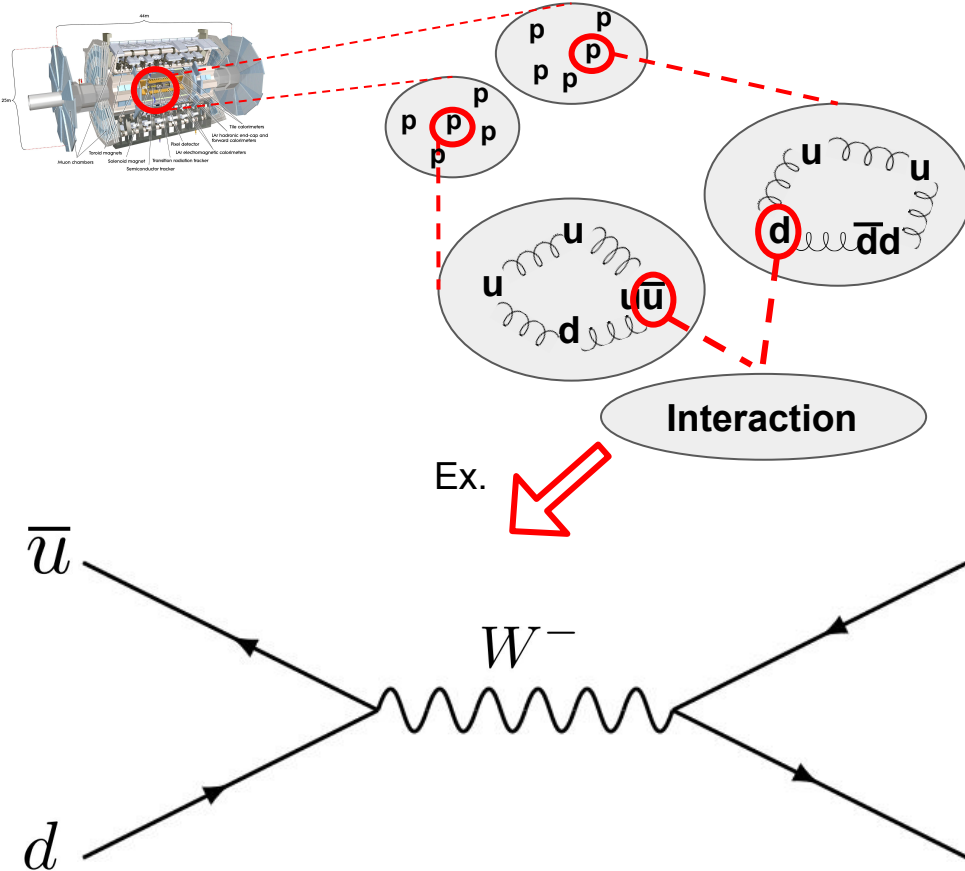
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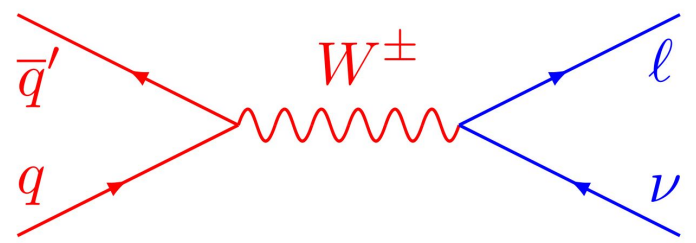
Each proton has 3 valence quarks (uud) but it can have quark-antiquark pairs created and destroyed from gluon interactions.

These quarks and gluons can interact to produce many different particles such as the W/Z bosons.

The W boson decays quite quickly ($\sim 10^{-25}$ s), one of the ways is into a charged lepton and a neutrino.

Quark-antiquark pairs going to W/Z bosons decaying into leptons is called the Drell-Yan process.

Drell-Yan Angular Coefficients



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

The total probability of the process happening can be described by the cross-section, σ . The probability of this happening given certain conditions (like kinematics) is the differential cross-section.

Because we have 2 spin $\frac{1}{2}$ particles going to a spin 1 particle which decays into 2 spin $\frac{1}{2}$ particles we get 8 helicity dependent cross-sections.

The ratios of these helicity dependent cross-sections over the unpolarized cross-section are denoted by A_i and are known as the **Drell-Yan Angular Coefficients**. These are coupled to polynomials P_i , which are related to Y'_m . (ex. $P_2 = \frac{1}{2} \sin^2\theta \cos 2\varphi$)

Why Do We Want To Measure These Coefficients?

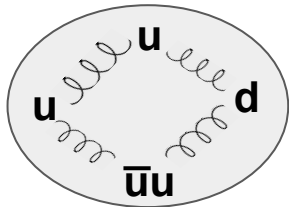
The coefficients have been measured for the Z boson but have never been measured for the W!

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

$$m_W (\text{ATLAS @ 7 TeV}) = 80370 \pm 7 (\text{stat}) \pm 11 (\text{exp. sys}) \pm \mathbf{14 (\text{mod. sys})} \text{ MeV}^{[1]}$$

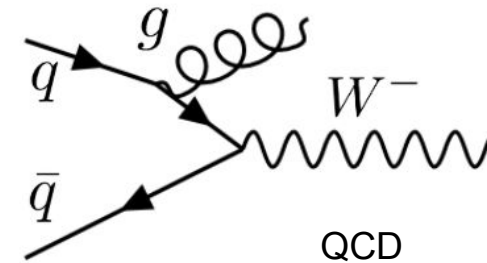
The biggest bottleneck is the physics modelling uncertainties:

Parton Distribution Function



Physics Modelling Uncert. [MeV]

Electroweak	5
QCD (p_T^W)	6
QCD (A_i)	6
PDFs	9



Allows for probing parton distribution functions as W^+ production mainly depends on u and \bar{d} , while W^- depends on d and \bar{u} .

Measuring the charge asymmetry can be used to constrain PDFs.

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

Moments Method

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

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

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

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

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

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

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

We want to be able to measure each A_i individually so we need to separate them, this is done by taking the moment.

Recall the mean is the first moment of a probability distribution and likewise the variance is related to the second moment.

By taking the moment of the polynomials we are able to exploit their orthogonality (recall related to Y'_m) to get each A_i .

But You Can't Measure the Neutrino?

Neutrinos aren't able to be directly measured with the ATLAS detector.

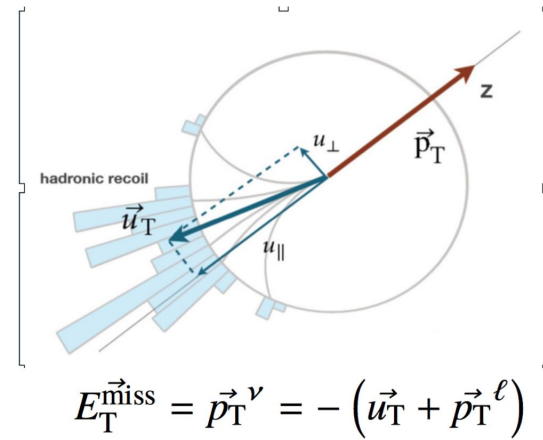
Instead the transverse momentum is approximated with the missing transverse energy.

To fully reconstruct the W we still are missing information of the momentum along the z -axis. To solve for this a mass constraint is taken. $(p + q)^\mu (p + q)_\mu = m_W^2$

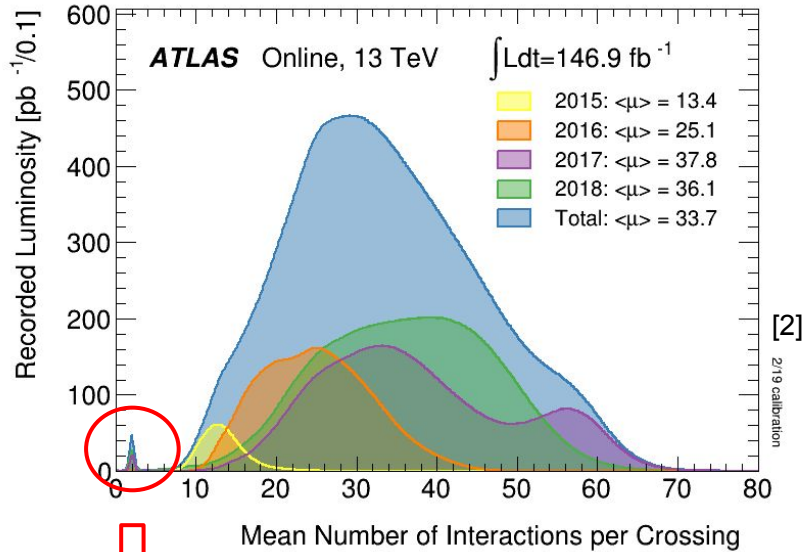
This results in a quadratic equation dependent on the lepton and neutrino kinematics.

However, this results in two equally viable solutions as well as events with no real solution.

When no real solution occurs we are still able use the information in the transverse plane to solve for ϕ to use in the polynomials.



Special Data Sets



Integrated Luminosity = 335.2 pb^{-1}

W production cross-section $\sim 10^4 \text{ pb}$

Pileup occurs in the detector because we have bunch crossings happening every 25 ns where we can have a large number of interactions every bunch crossing.

During 2017 and 2018 special runs of data at 13 TeV were taken with a lower mean interactions per bunch crossing, $\langle \mu \rangle \sim 2$.

This allows for a much lower ambient energy associated to pileup at the sacrifice of lower statistics.

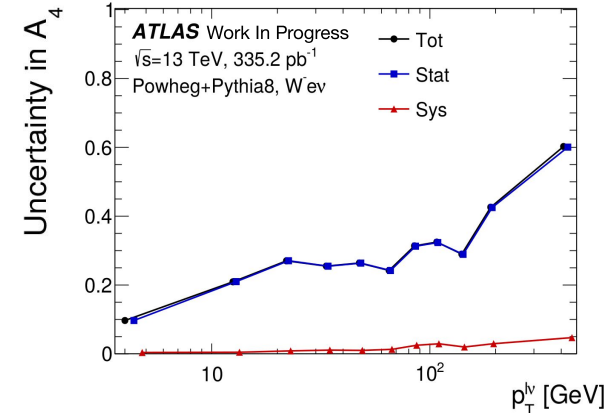
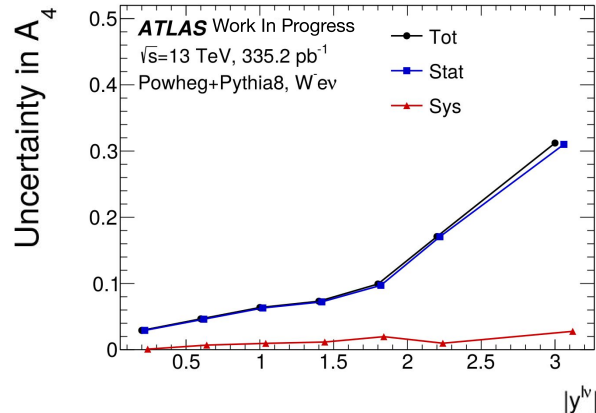
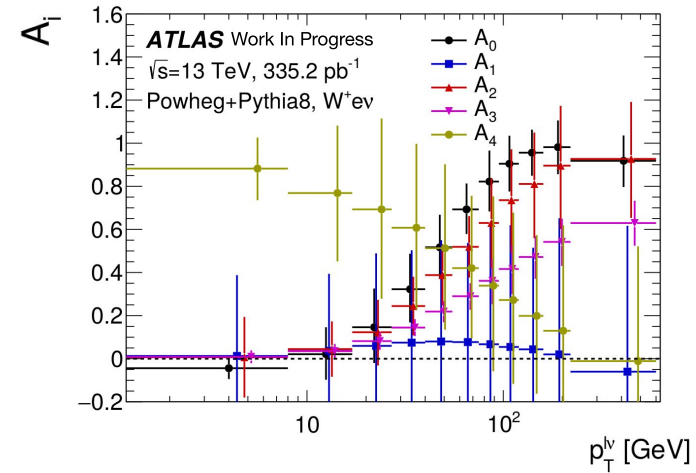
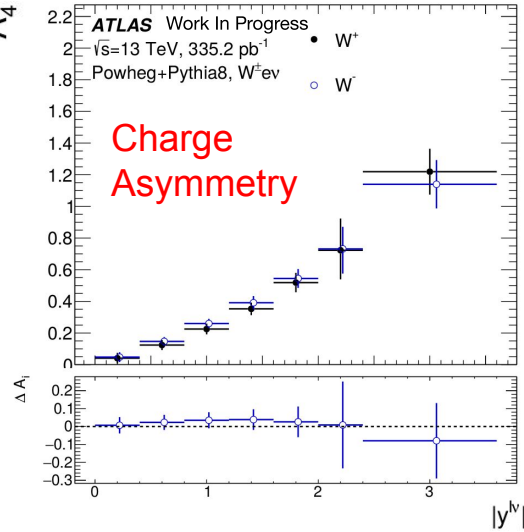
However, this allows for better approximation of the missing transverse energy giving better resolution to the reconstructed kinematics.

[2] <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2>

Predicted Sensitivity A_4

From MC pseudo-data we expect we will be able to have the sensitivity to measure 4 of the coefficients in 1D p_T^W and y^W bins.

We expect to be dominated by statistical uncertainty.



Conclusions

The production and decay of W bosons at the LHC can be separated into 8 helicity dependent cross-sections by exploiting the orthogonality of the polynomials they are coupled to.

Despite not being directly detected, we are able to approximate the neutrino with the missing energy in the ATLAS detector and a mass constraint to fully reconstruct the W boson.

This is with the added benefit of having better recoil resolution with the special data sets.

We expect to be able to measure some of the coefficients in 1D p_T^W and y^W bins which can help reduce the physics modelling uncertainty for measurements like the mass of the W boson.

Work still needed to be done to extract the coefficients with data so stay tuned.

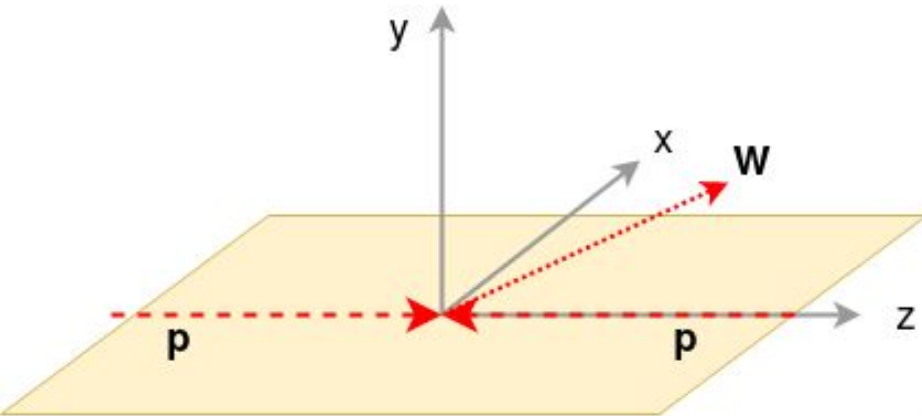
Questions?

Collins-Soper Frame

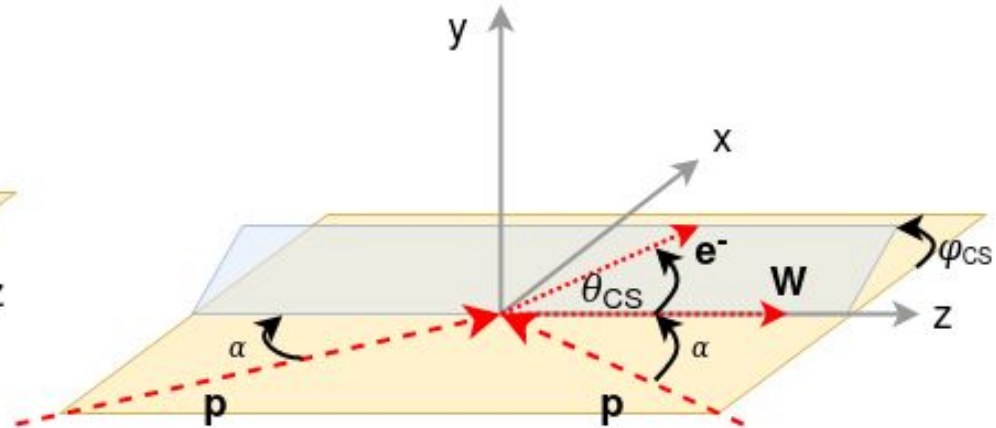
The A_i 's are frame dependent, my research uses the Collins-Soper frame where the z-axis is in the rest frame of the W boson in the direction of its longitudinal polarization, y-axis is normal to the proton-proton plane, and the x-axis is set orthogonal. From this frame we get two angles:

θ_{CS} - the angle between the negatively charged lepton and the z-axis.

φ_{CS} - the angle between the negatively charged lepton and the proton-proton plane.



Lab Frame



CS Frame