Prediction of Drell-Yan Angular Coefficients in the ATLAS Detector

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UNIVERSITY

ATLAS
EXPERIMENT

Large Hadron Collider

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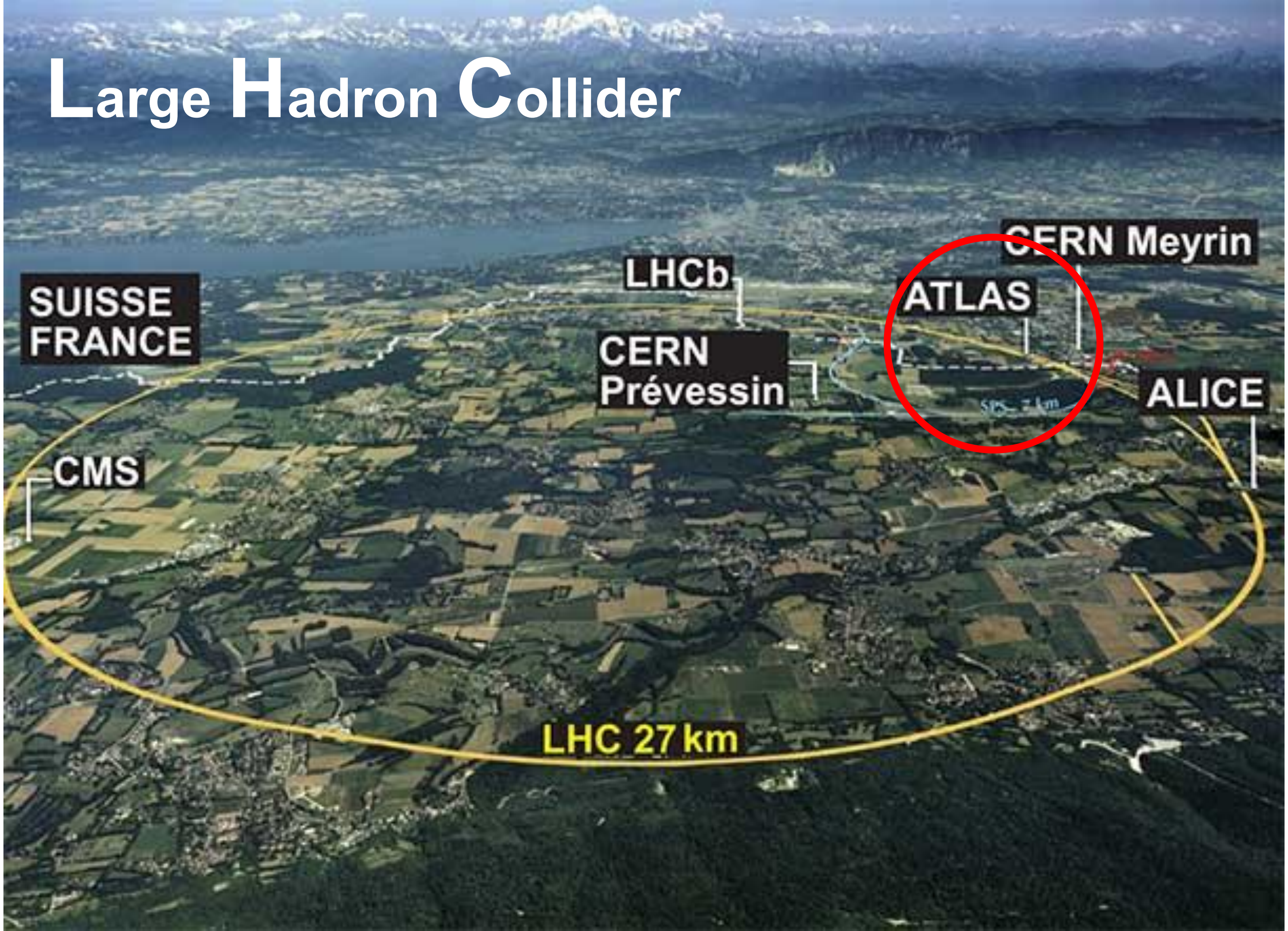
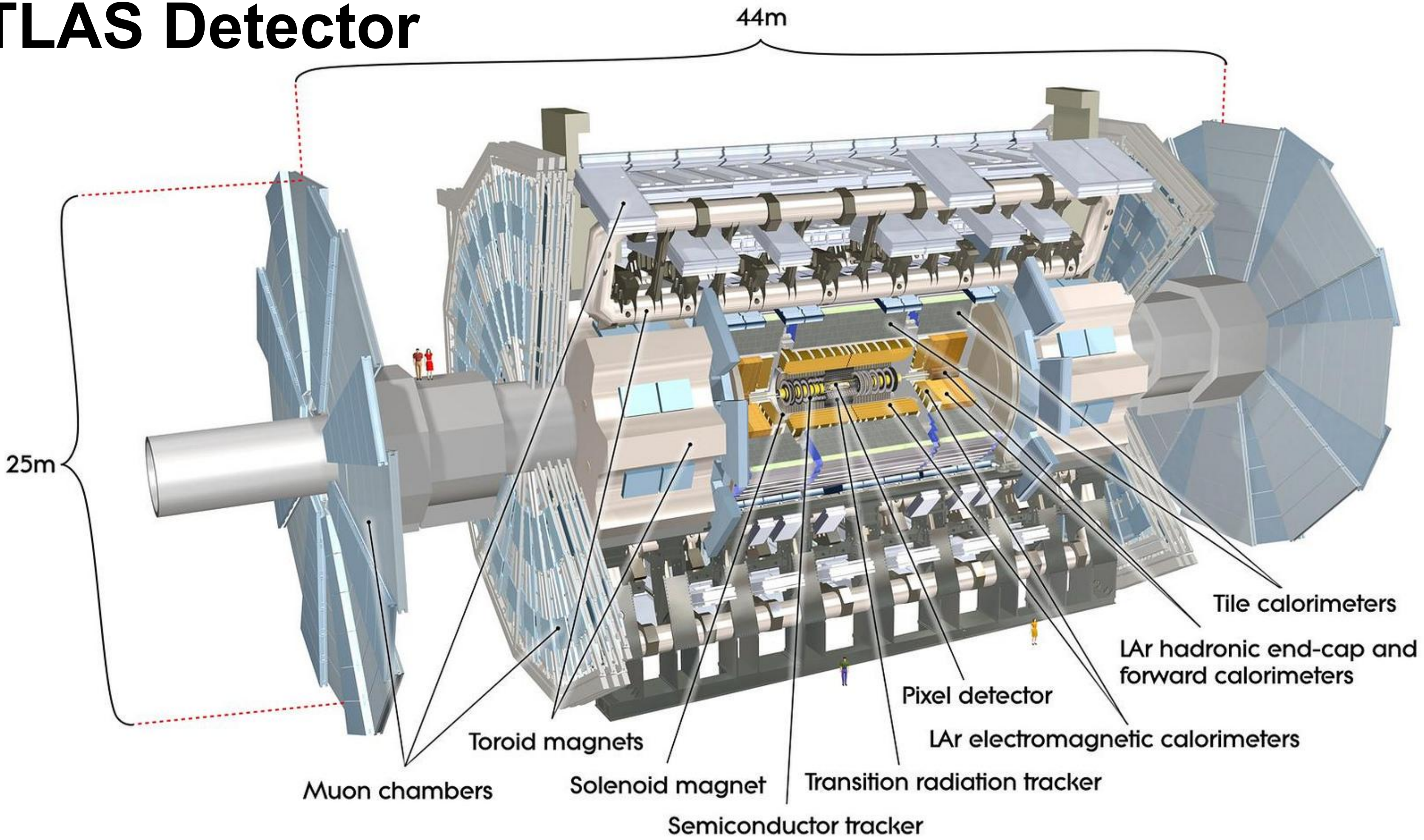


ATLAS Detector



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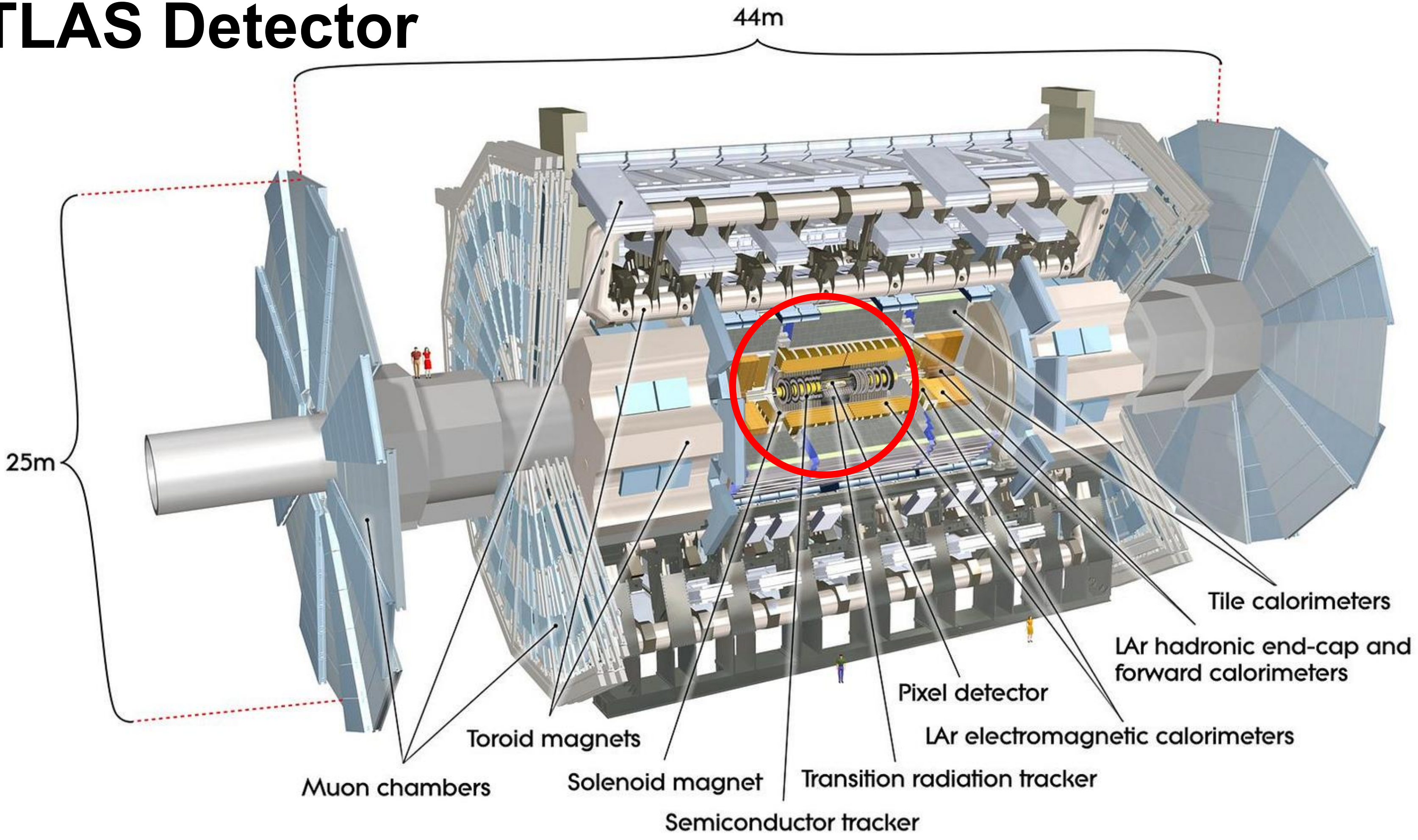
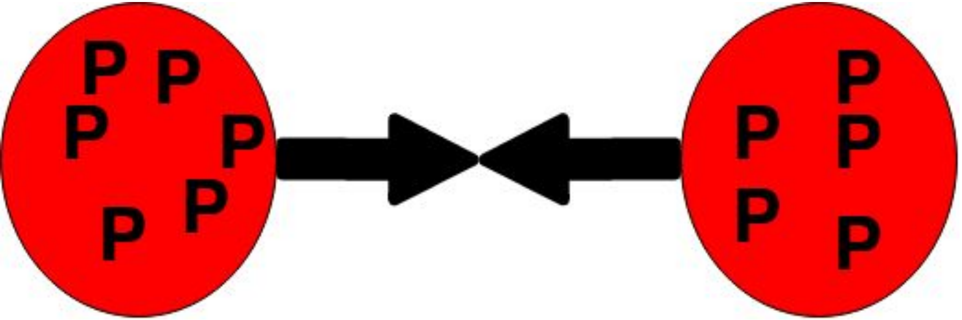


Z Boson Production at LHC

We have bunches of protons colliding every 25ns



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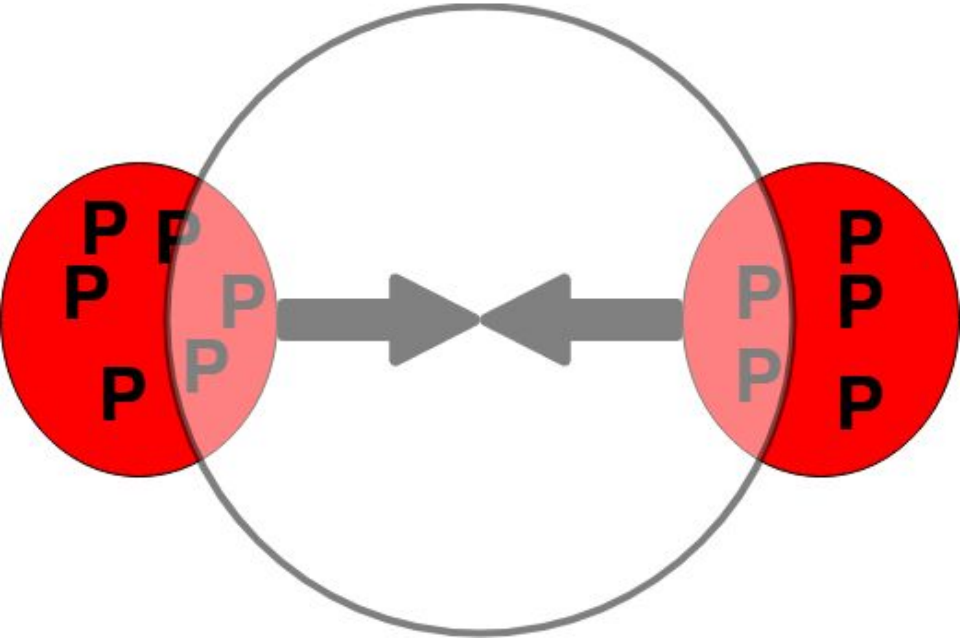

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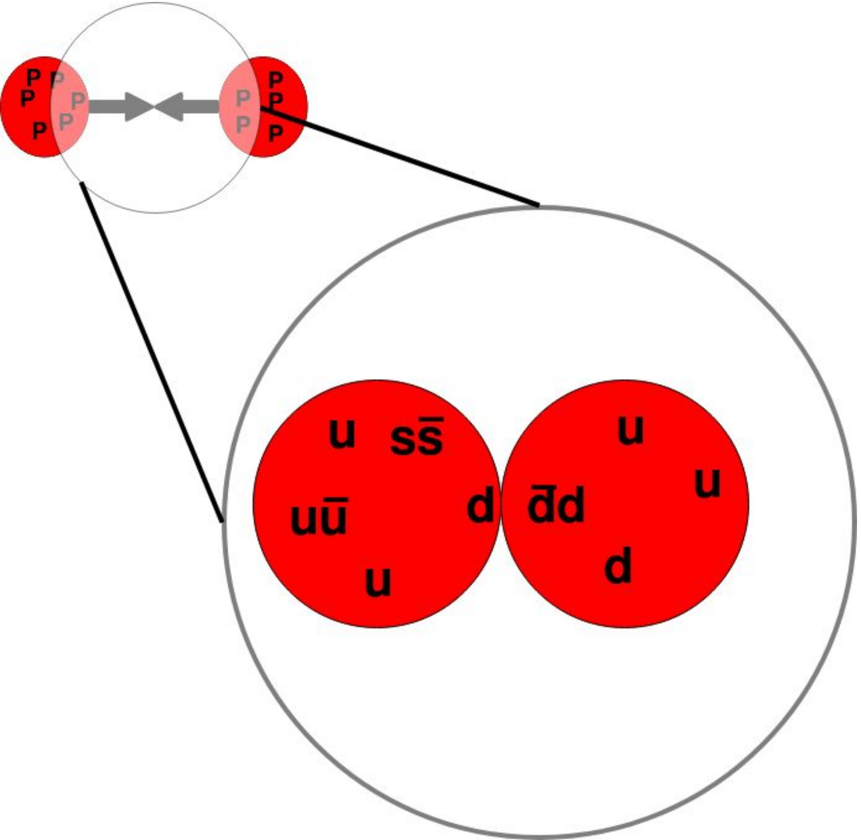

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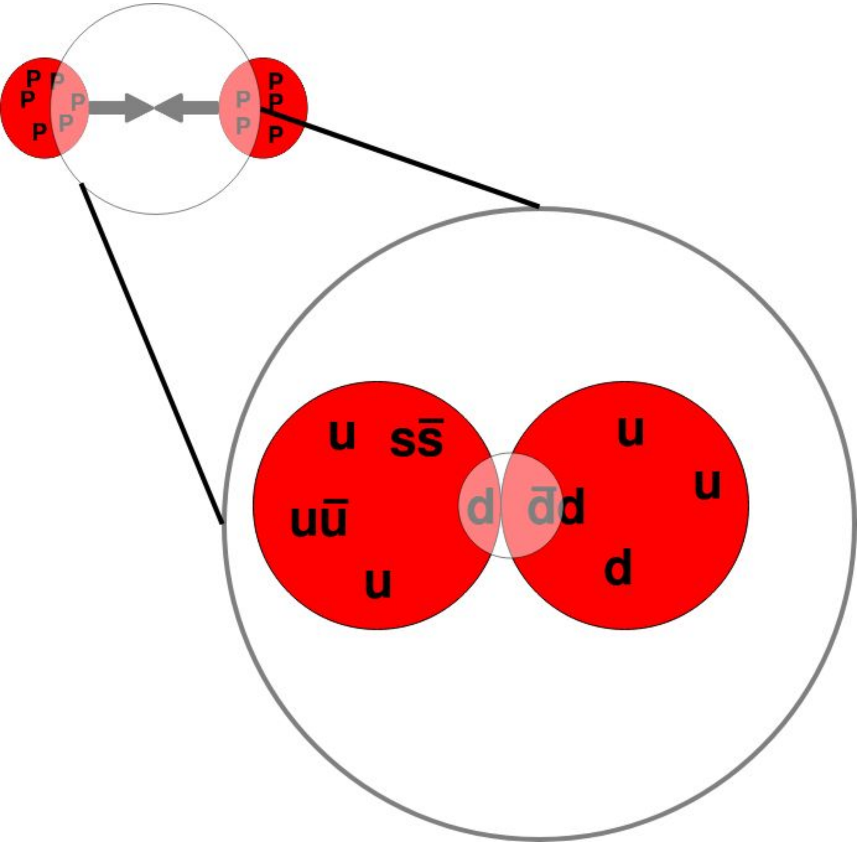

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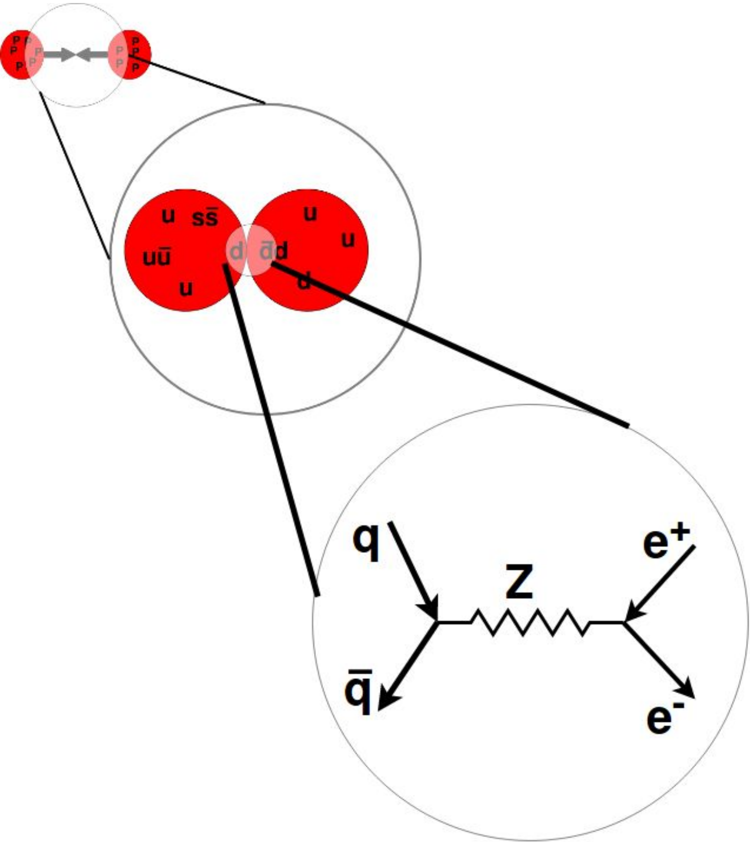

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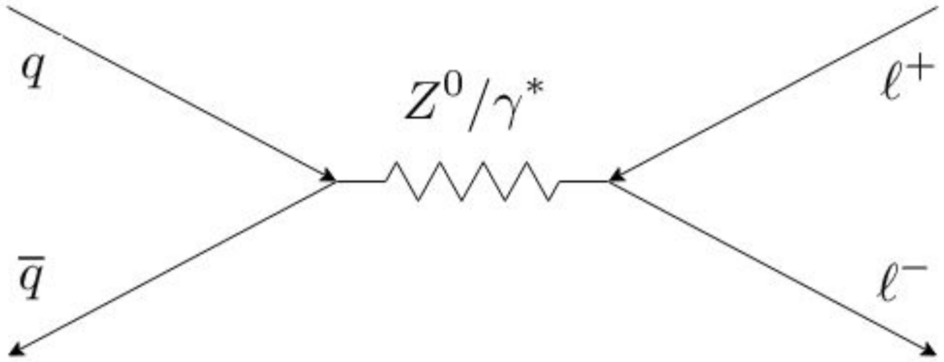
My work focuses on the Drell-Yan process: when a Z boson is produced which has a short lifetime ($3x10^{-25}$ s) and decays into particles like positron-electron pairs

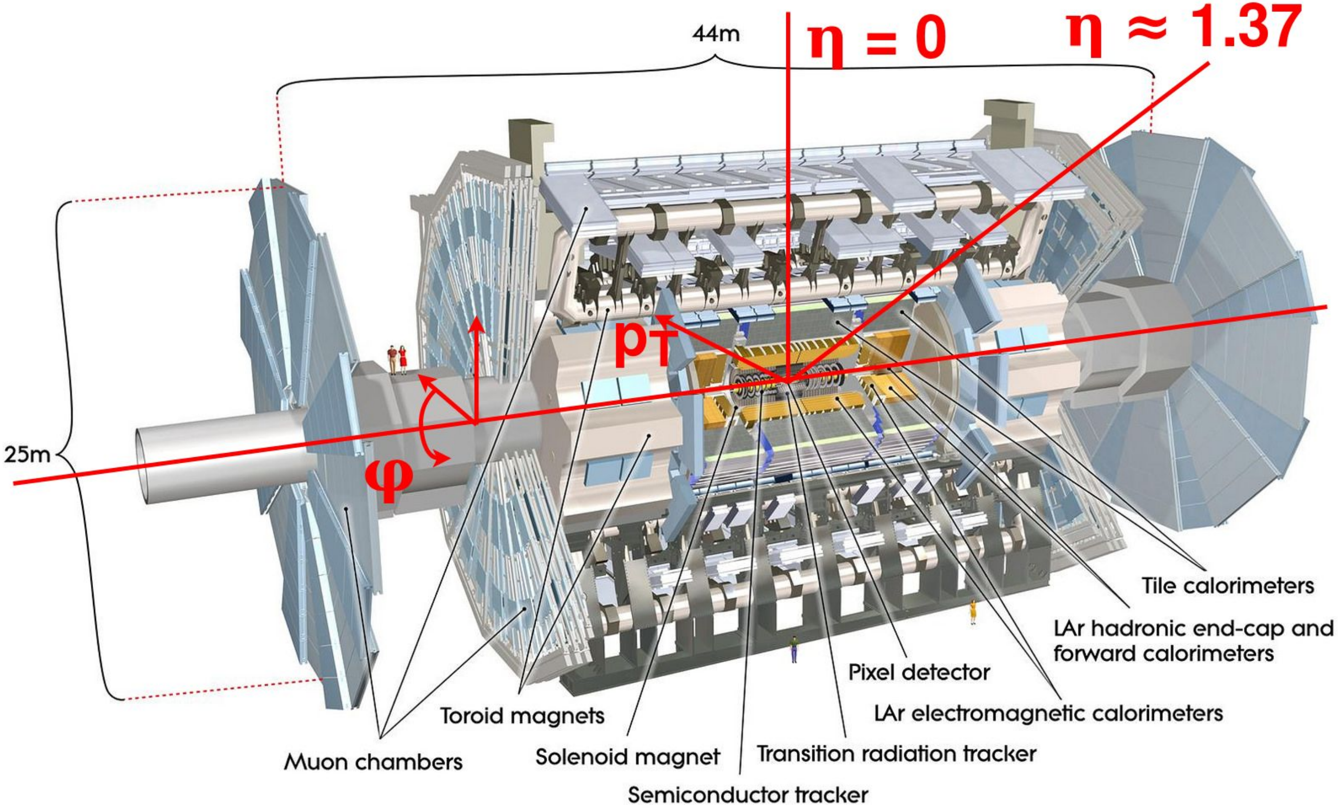
What Can We Learn?



Using leptons we can learn more about the production of Z bosons including further understanding of the structure of the colliding protons.

We can also measure the Weak Mixing Angle, $\sin^2\theta_W$, which is a free parameter in the Standard Model

ATLAS Coordinate System

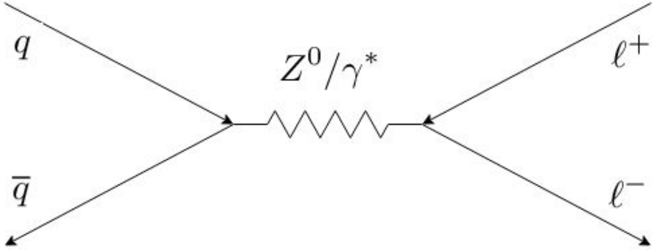


p_T - Transverse Momentum measured in xy-plane

η - Pseudorapidity defined as -ln[tan(θ/2)] where θ is from positive z-axis. Equivalent to rapidity ,**y**, when mass of the particle is small

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

Drell-Yan Angular Coefficients



The differential cross-section tells us the probability of the process happening given certain conditions

Because we have two spin ½ particles going to a spin 1 particle decaying to two spin ½ particles we have helicity dependent cross-sections.

The ratios of these helicity dependent cross-sections over the unpolarized cross-section are denoted by A_i, known as the Drell-Yan Angular Coefficients

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

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

Moments Method

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

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

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

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

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

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

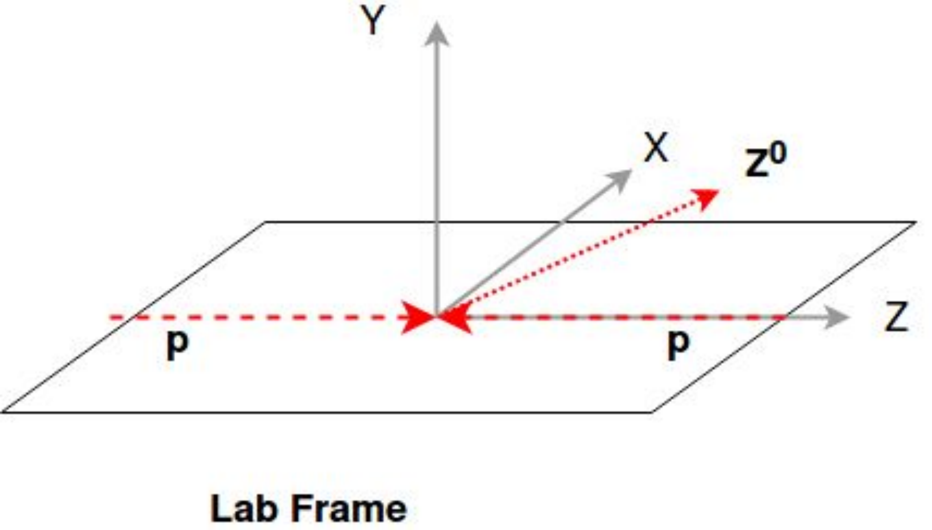
Recall that mean is the first moment of a distribution and variance is the second central moment. Similarly we can take the moment of our differential cross-section

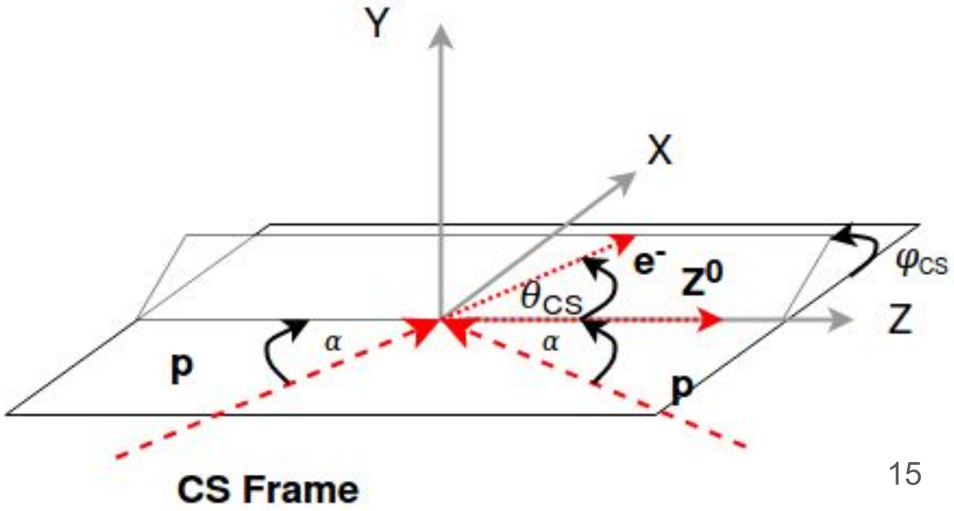
Taking the moments exploits the orthogonality of the P_i's (related to Y^{ℓ}_{m}) which allows us to solve for each A_i

Allowing access to A_3 and A_4 which we can use to measure $\sin^2\theta_W$

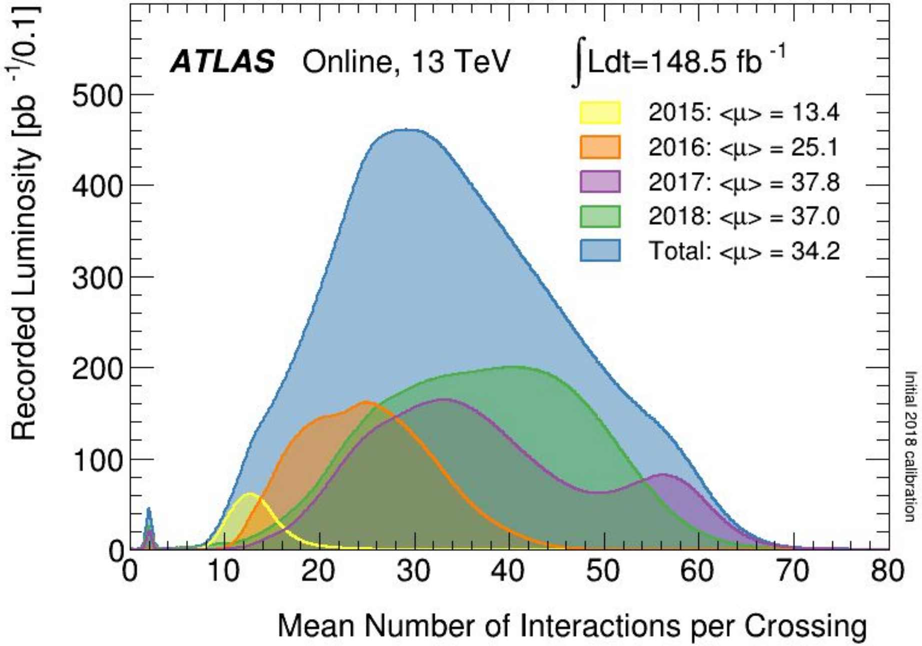
Reference Frame

A_i's are frame dependent, I work in the Collins-Soper frame where the Z axis is in the rest frame of the Z boson in the direction of it's longitudinal polarization, Y axis is normal to pp plane, and X is orthogonal





Special Data Set



With a large number of interactions per bunch crossing there is a lot of pileup

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

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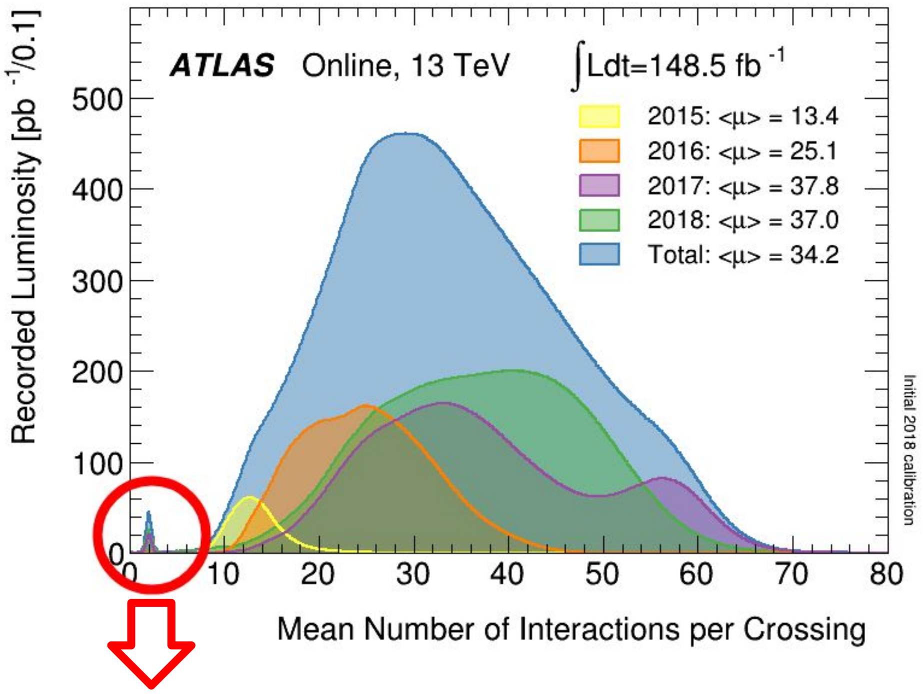


$\int Ldt = 339.8\ pb^{-1}$ **$\sigma_Z \sim 5 \times 10^4 pb$**

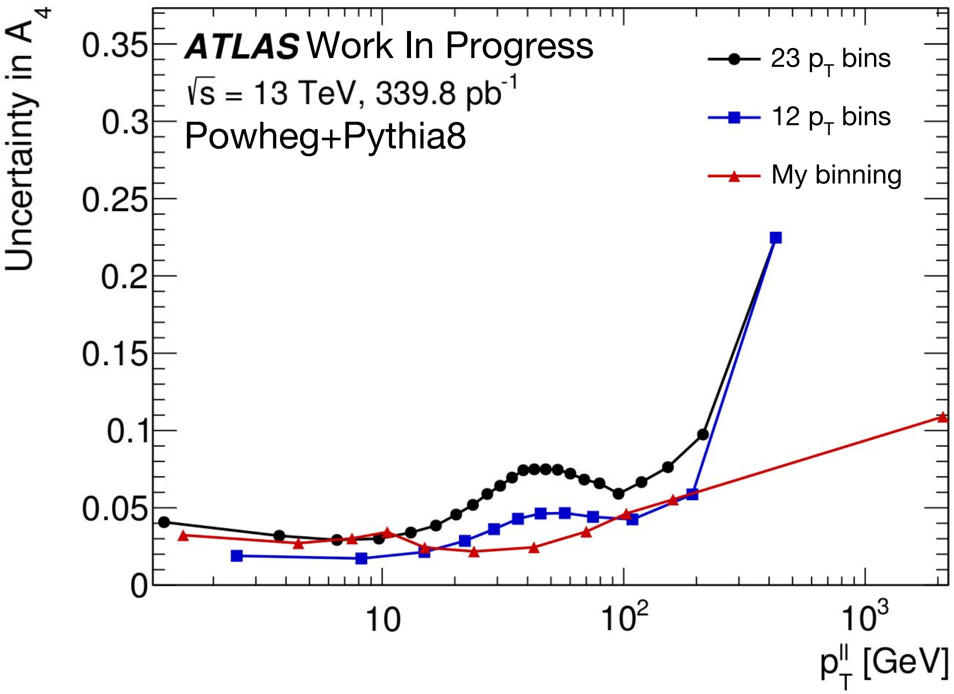
With a large number of interactions per bunch crossing there is a lot of pileup

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

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

The purpose of my research is to see using MC simulation if we can use this data set for a measurement

New Binning



[1] doi: 10.1007/JHEP08(2016)159

Due to low statistics for the data set I was making predictions for I had to develop a **new binning**

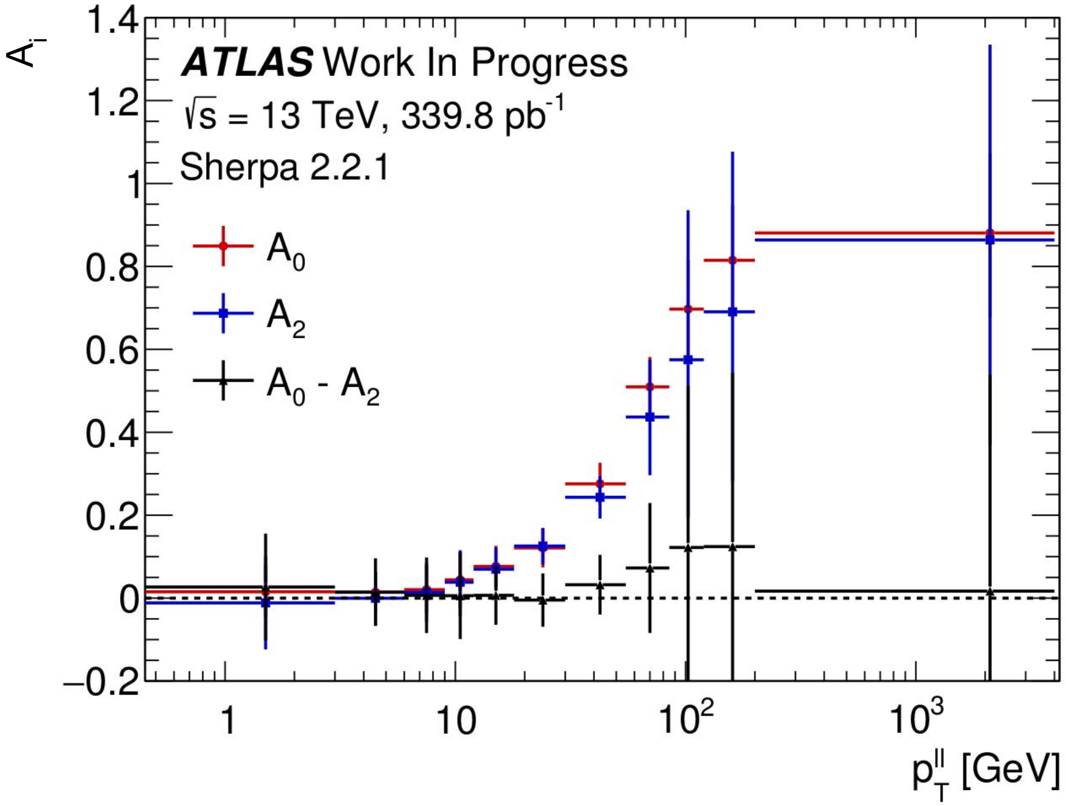
The uncertainty using the **23 bins** previously used from a measurement performed with 8 TeV data[1] from 2012 allows for no sensitivity in the measurement with this special dataset at 13 TeV

Binning optimized around A_3 & A_4 using ATLAS tuned MC Powheg+Pythia8, predictions also done with MC Sherpa 2.2.1

A_0 and A_2

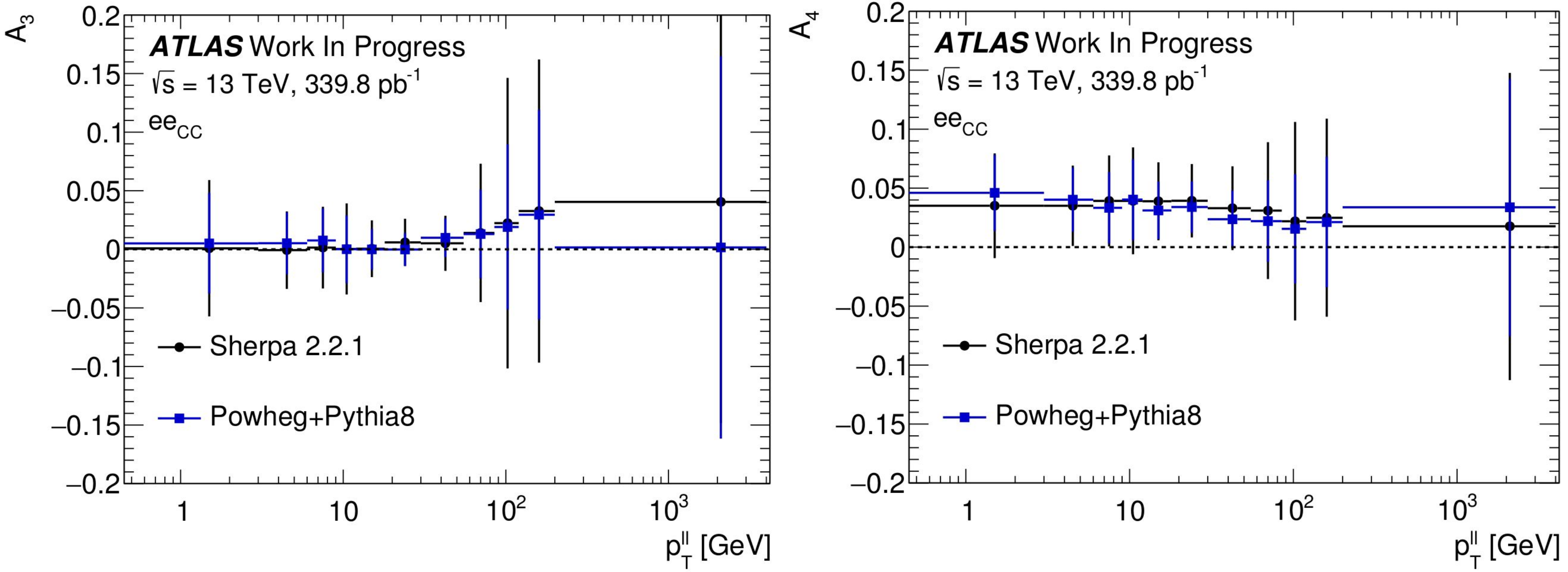
A_0 and A_2 are the same at leading order expansion in QCD theory.

At higher order there is a difference between A_0 and A_2 but this dataset may not have the statistical sensitivity to measure this



A_3 and A_4

A_3 and A_4 are the only A_is that can be used to measure the weak mixing angle, $\sin^2\theta_W$

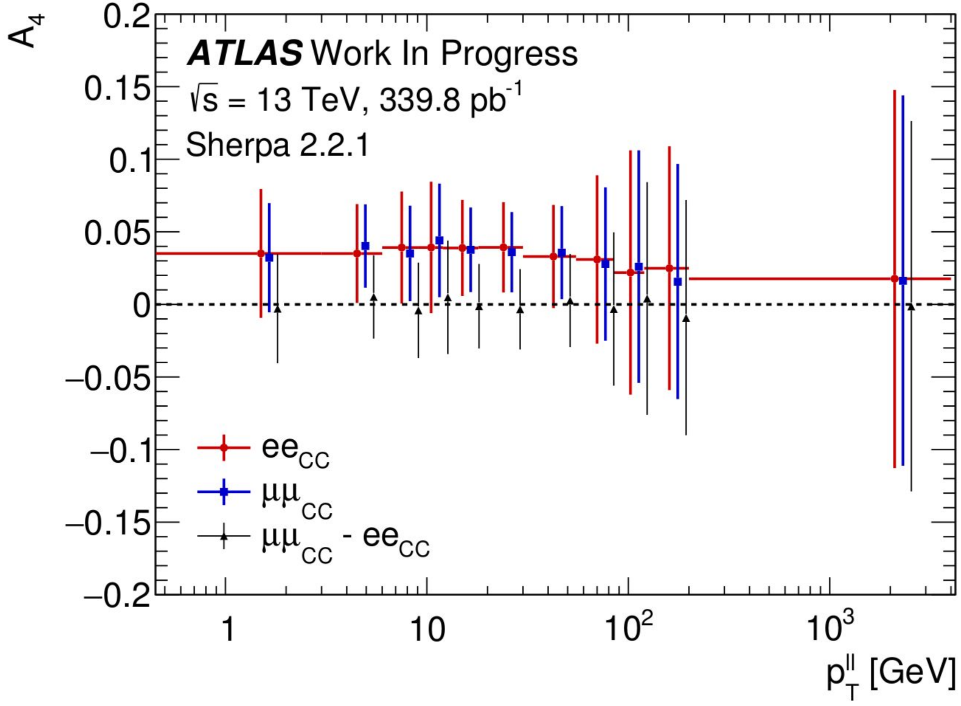


Different Channels

There are two channels I work with, electrons and muons

Where both leptons are identified in the central region of the detector (CC)

The $Z\rightarrow ee$, and $Z\rightarrow\mu\mu$ channels show agreement in the MC so we are able to combine them

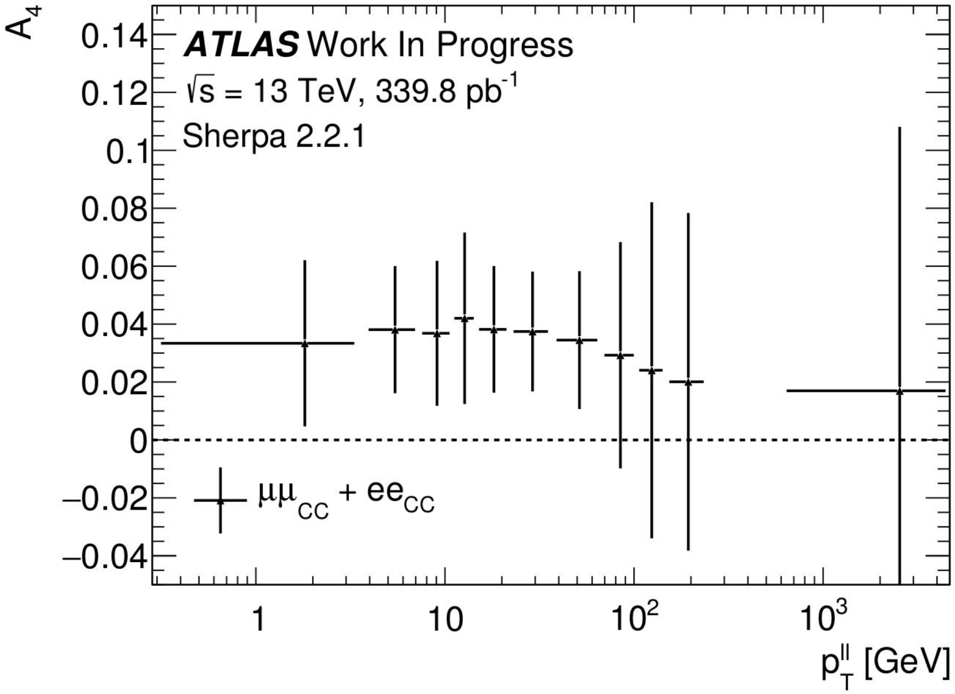


Addition of Channels

Neither the electron nor muon channel have sufficient statistical sensitivity on their own

Using a weighted average we will be able to have the sensitivity to measure A_4

So we should be able to use this small data set to measure the weak mixing angle



Conclusion

From these predictions:

- We won't be able measure either the difference between A_0 and A_2
- Nor will we be able to measure the weak mixing angle from A_3
- If we wish we should be able to have sufficient statistical sensitivity to measure the weak mixing angle from A_4 using this data set by combining the electron and muon channels. Most likely will only use full Run 2 data set.

- Future plans are to extrapolated this methodology to W bosons which have ~10x the events.