University of Glasgow

π^- Electroproduction from the Neutron at CLAS

Gavin Murdoch
PhD Student
Supervisor: Dr. Daria Sokhan

Outline

Introduction:

- Analysis motivation
- JLab
- CLAS
- EG1-DVCS experiment
- Analysis goal

Analysis:

- PID
- Asymmetries

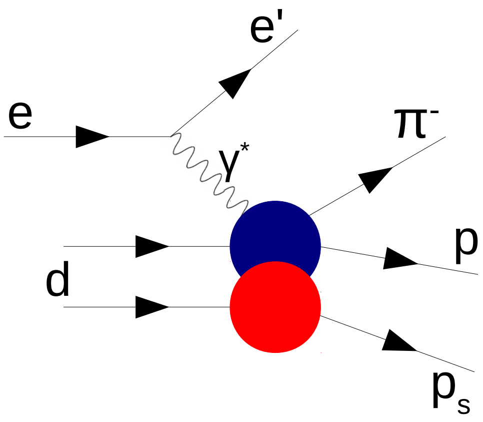
sPlot Technique:

- Overview
- In use
- Kinematics of data sample

Results:

- Beam asymmetry extraction

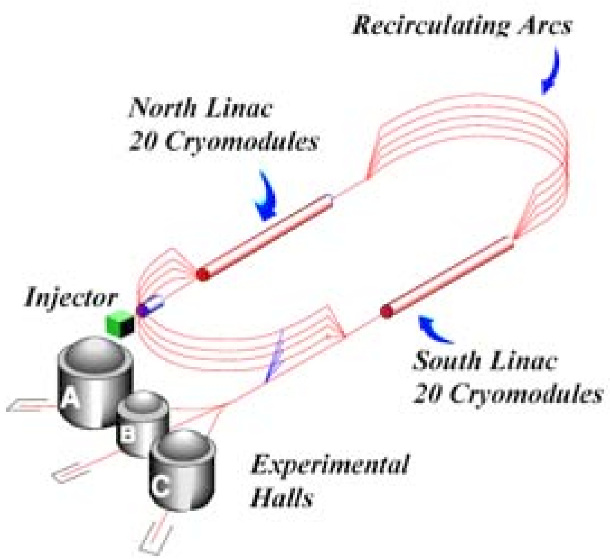
Introduction: Analysis Motivation

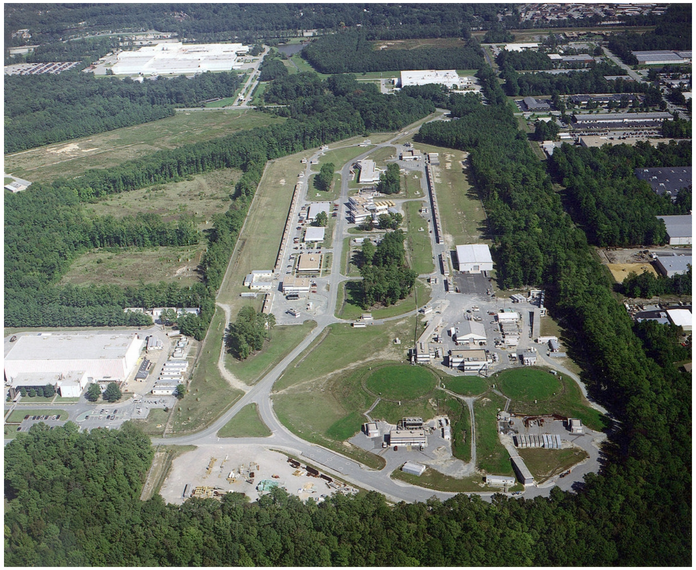


- π^- electroproduction from quasi-free neutron in $^{14}ND_3$
  - Actually looking at
    $e\ d \rightarrow e'\ \pi^-\ p\ (p_s)$
- Motivation:
  - Electroproduction with high Q^2
  - Polarised beam **and** target
  - Published data on neutron is limited
  - Process sensitive to contributions from individual nucleon resonance states
  - Provide constraints to Partial Wave Analyses for resonance parameters

Introduction: JLab

- Thomas Jefferson National Accelerator Facility, Virginia, USA
- Pre-12 GeV upgrade (just completed)
- Precision scattering experiments in 3 experimental halls
- Highly polarised electron beam (up to ~85%)
- Superconducting RF linacs – maximum E_{beam} of 6 GeV



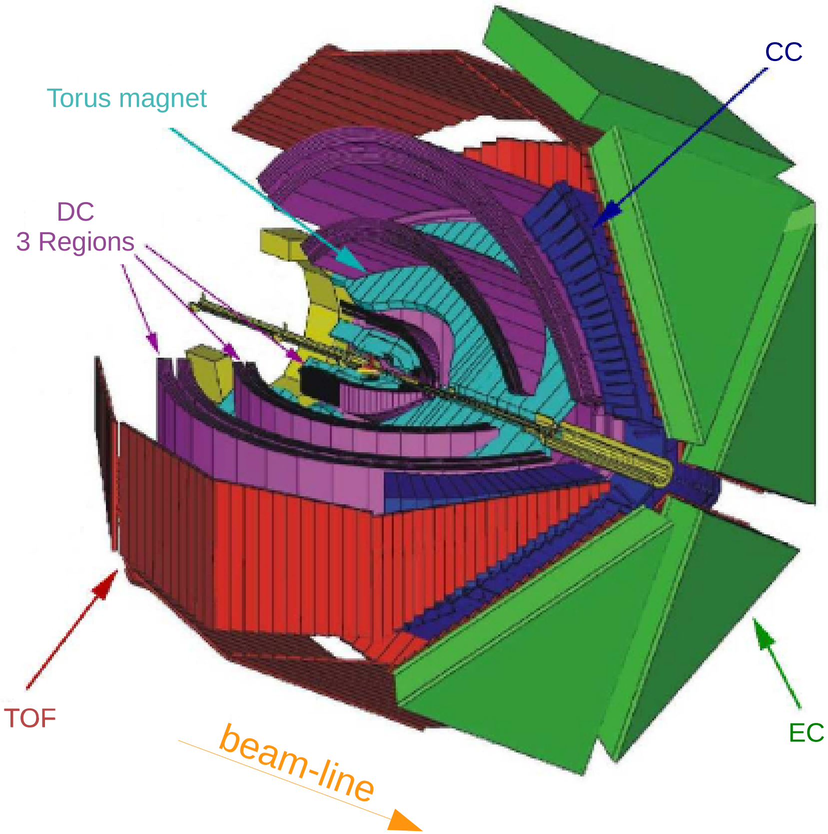


Introduction: CLAS

- CEBAF Large Acceptance Spectrometer (CLAS) surrounding the target
- Near 4π solid angle coverage
- Toroidal magnet system **(torus magnet)**

- 6 independent sectors with detector subsystems:
  - Drift Chambers **(DC)**
    →measure momentum and charge of particles
  - Cherenkov Counters **(CC)**
    →distinguish electrons from other particles
  - Time-of-Flight Scintillators **(TOF)**
    →measure time, therefore determine speed
  - Electromagnetic Calorimeters **(EC)**
    →identify electrons and detect neutrals

- Inner Calorimeter (IC) inside **(DC)**
  - detect 4-15 degrees photons



Introduction: EG1-DVCS Experiment

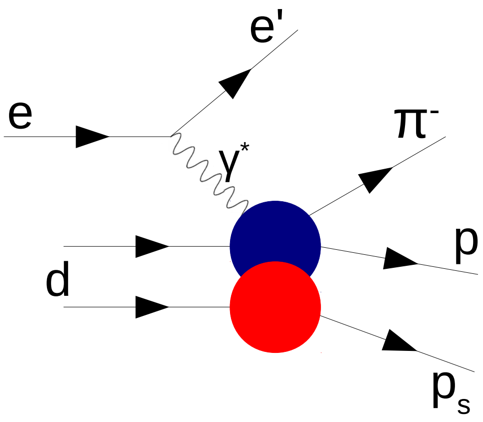
- 2009 experiment with longitudinally **polarised** beam and solid state targets (using Dynamic Nuclear Polarisation):
  - *e* beam ~80% polarisation
  - proton target ~80%, and neutron target ~30%

Expt. Part	Target	Vertex	Beam Energy
B	$^{14}NH_3$	-68 cm	5.97 GeV
C	$^{14}ND_3$	-68 cm	5.76 GeV

- Data taken:
  - 70% on $^{14}NH_3$, 20% on $^{14}ND_3$
  - ~10% on ^{12}C, and 1% empty target

- Target in liquid ^4He bath at low temperature and pressure

Introduction: Analysis Goal



- π^- electroproduction from quasi-free neutron in $^{14}ND_3$
  - Background studies using $^{14}NH_3$ and ^{12}C datasets
  - Actually looking at
    $e\ d \rightarrow e'\ \pi^-\ p\ (p_s)$
- Perform psuedo-exclusive analysis to fully reconstruct reaction:
  - correct for bin migration/dilution effects caused by Fermi momentum
  - Identify events where the proton in the deuteron is a spectator
- Low statistics for data sample:
  - use likelihood method for analysis
  - use background subtraction rather than cuts-based analysis
- Differs from standard approach of exclusivity cuts on kinematically reconstructed values such as missing mass, missing energy, etc.

Analysis: PID

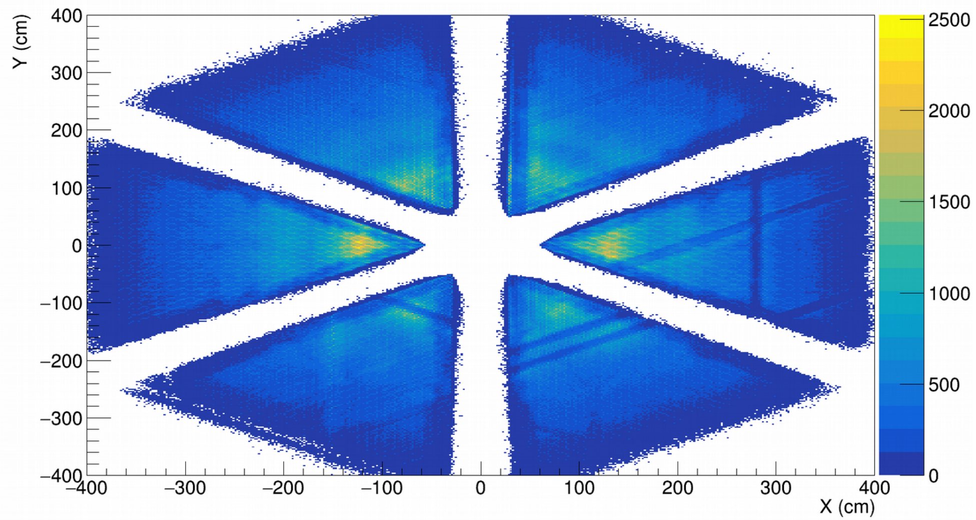
- Exclusive event (without detection of the deuteron's spectator proton)

  $e\ d \rightarrow e'\ \pi^-\ p\ (p_s)$

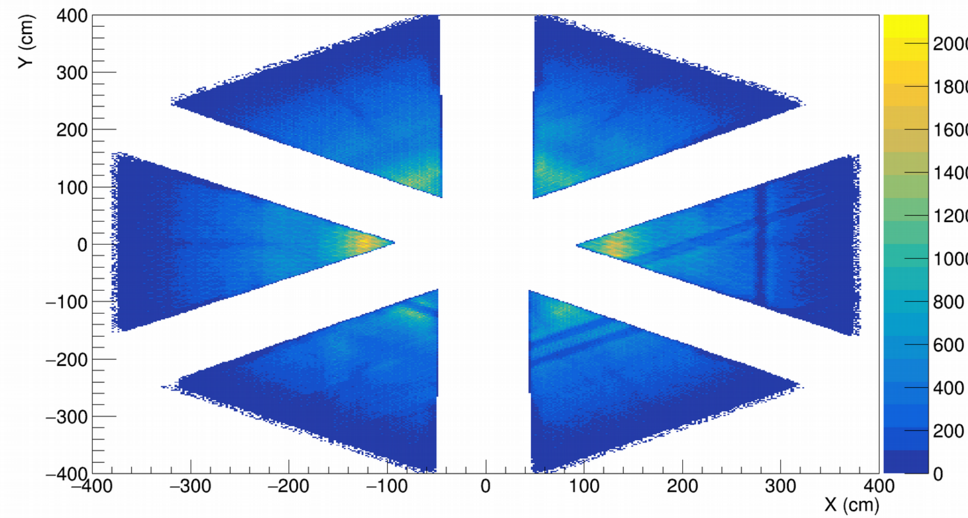
- Particle Identification consists of finding one good electron, π^-, and proton for the event

- Series of cuts are performed, including fiducial cuts:
  - Electromagnetic Calorimeter – require good energy reconstruction for electron
  - Inner Calorimeter (low angle) shadow - avoid energy losses and multiple scattering

Before fiducial cut



After fiducial cut



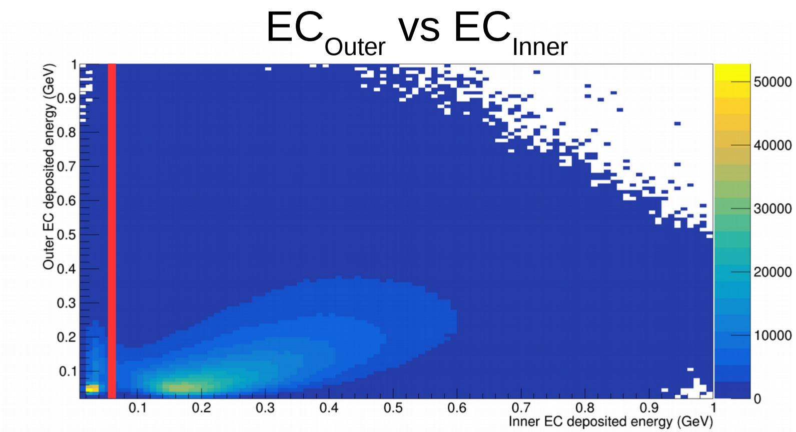
Analysis: PID

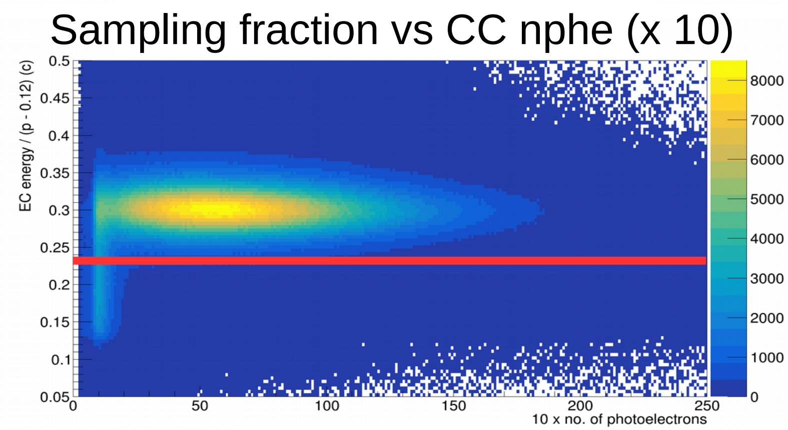
Discriminate electrons from π^- using:

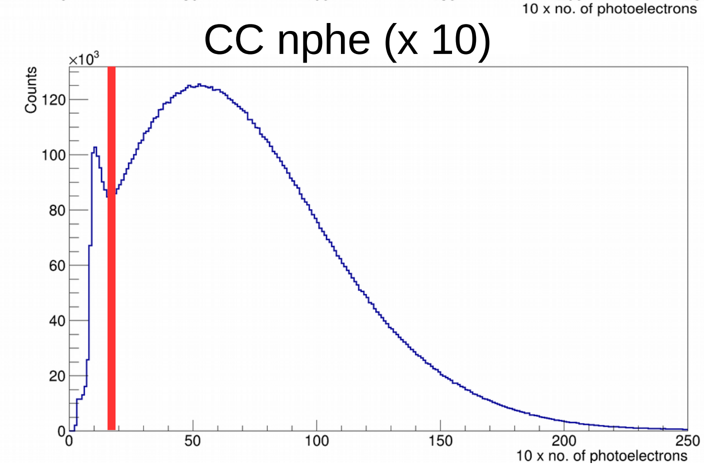
- Minimum energy deposited in inner Electromagnetic Calorimeter
  - EC_{Inner} > 0.060 GeV

- Minimum ratio of energy:momentum (sampling fraction)
  - Sampling fraction > 0.23 c

- Minimum number of photoelectrons (nphe) in Cherenkov Counter
  - Nphe > 1.7



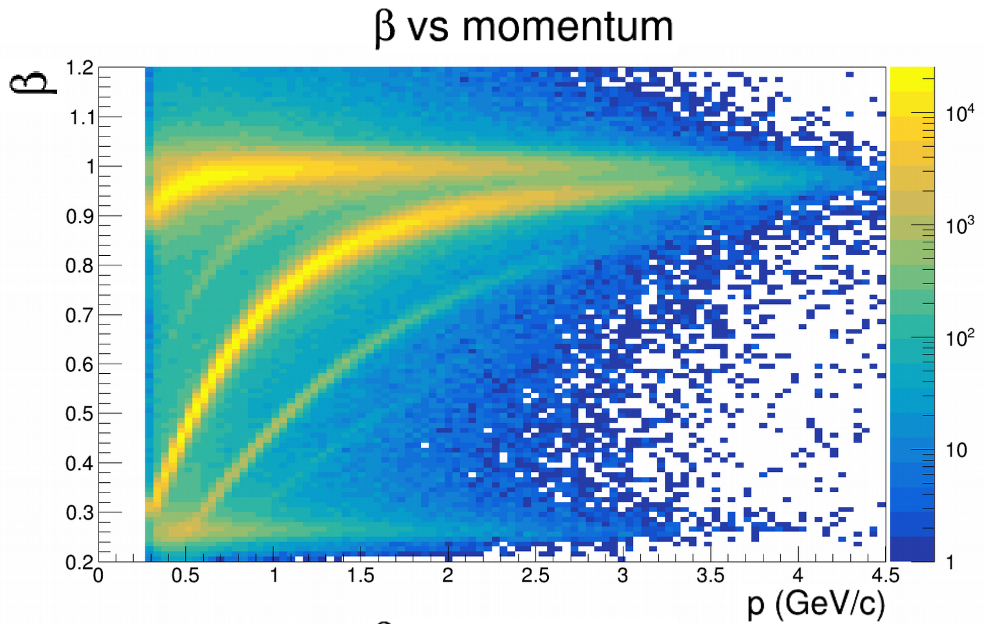


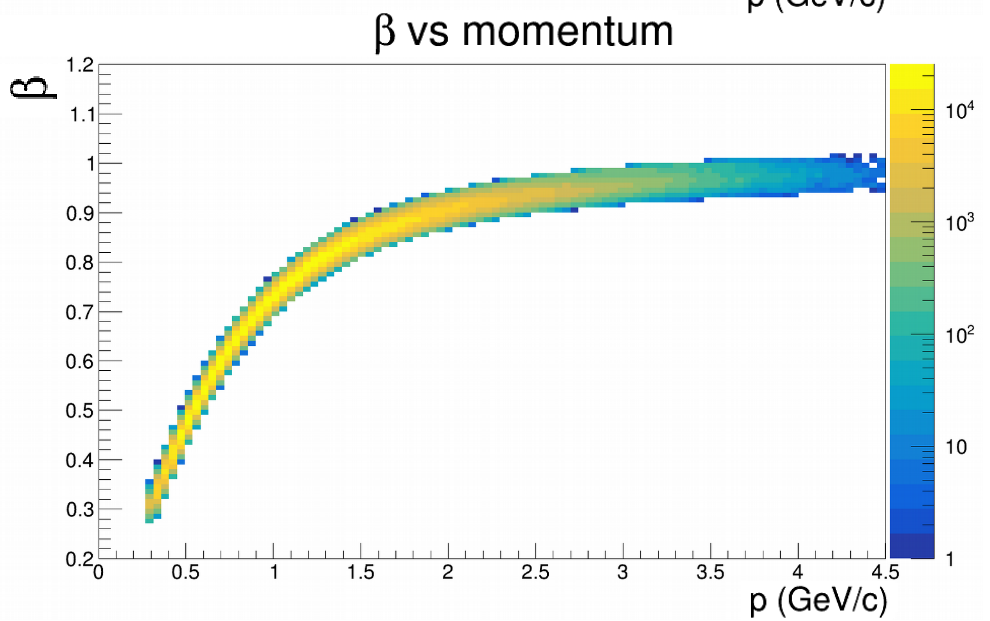


Analysis: PID

PID for protons and π⁻:

- vertex position window (4cm)
- fiducial cut for the shadowing of the Inner Calorimeter
- momentum dependent β cut





p dependent β cut shown in plot is used to discriminate protons from π^+, K^+, deuteron, etc.

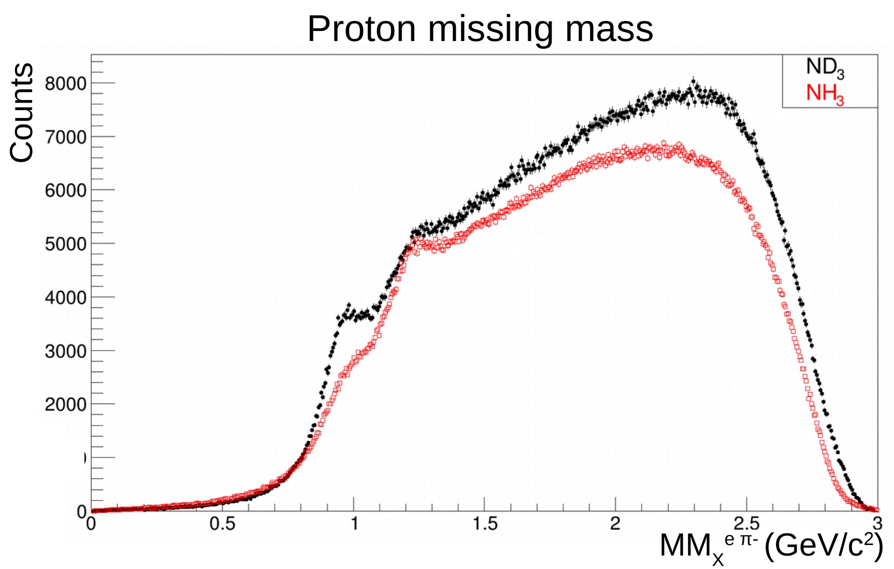
Analysis: PID

Completed PID for fully exclusive e' π- p

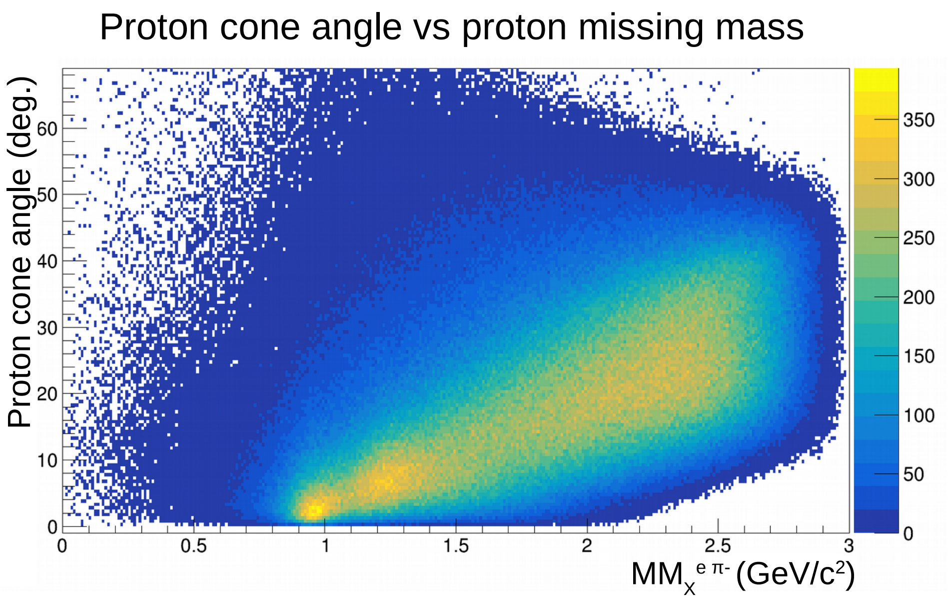
Look at:

e n → e' π- X

assuming stationary free neutron target



Scaling factor for visual purposes



Cone angle: difference in 3 vector angle between measured and reconstructed proton

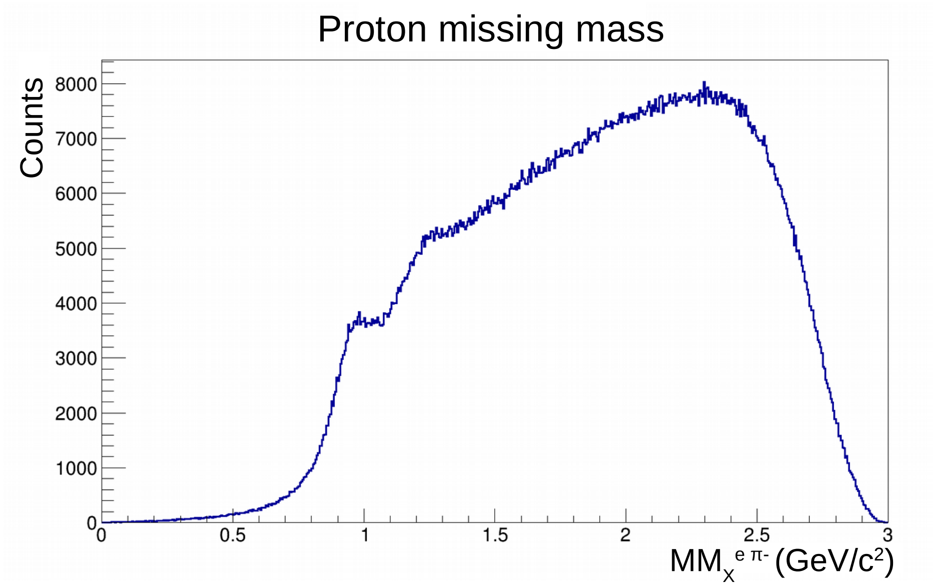
Analysis: PID

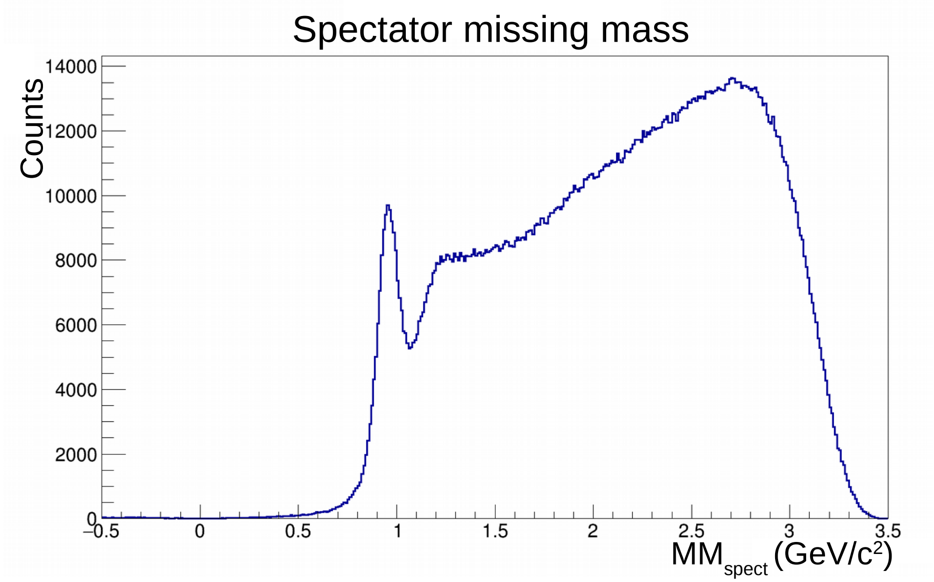
For exclusive measurement of e' π⁻ p, compare proton missing mass (above) with spectator missing mass (below).

proton missing mass: e n → e' π⁻ X

spectator missing mass: e d → e' π⁻ p X

- Again, expect signal peak at mass of proton (~0.94GeV/c²)
- Proton missing mass peak is Fermi smeared
- Spectator missing mass peak just depends on experimental resolution





Analysis: Asymmetries

- Using electron beam → momentum transfer vector is not aligned along beamline
  - Have *x* and *y* polarisation components too

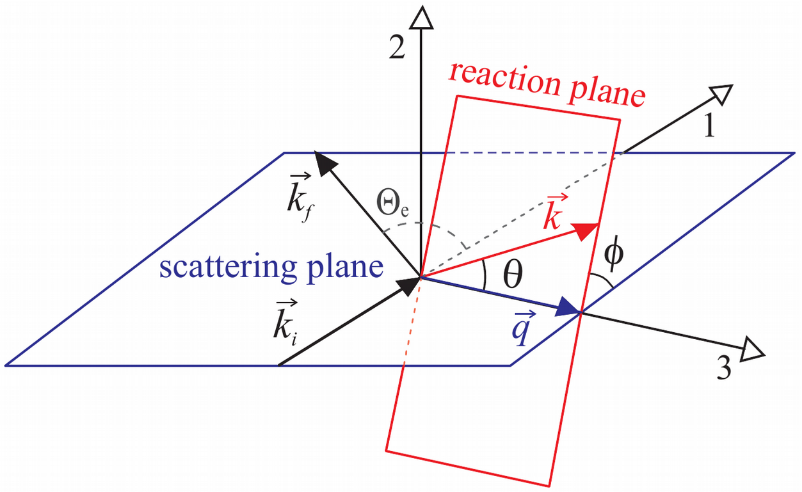
- 3 different polarisation states, defined by:

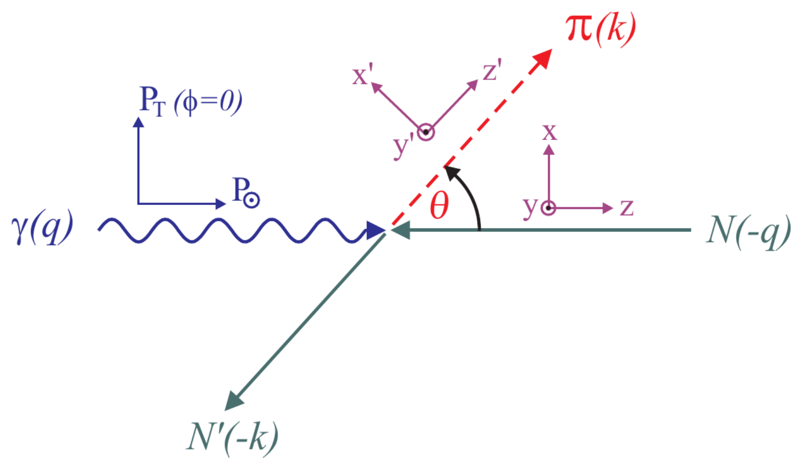
$$\sigma = \sigma_0(1 + P_B A_{LU} + P_T A_{UL} + P_B P_T A_{LL})$$

- where P_B and P_T can be positive or negative
- Asymmetries are sin and cos functions of φ

- Center-of-mass decay angles for final state
  - θ = 0 for forward going π^-
  - φ is opening angle between

$$(\vec{q} \times \vec{k}_i) \text{ and } (\vec{q} \times \vec{k})$$





L. Tiator, et al. [2017].
Amplitude reconstruction from complete electroproduction experiments and truncated partial-wave expansions.
arXiv:1702.08375v1

Analysis: Asymmetries

- Formalism: $\sigma = \sigma_0(1 + P_B A_{LU} + P_T A_{UL} + P_B P_T A_{LL})$
- Spin averaged cross section:

$$\sigma_0 = \sigma_T + \epsilon\sigma_L + \sqrt{2\epsilon(1+\epsilon)}cos(\phi)\sigma_{TL} + \epsilon cos(2\phi)\sigma_{TT}$$

- Beam spin asymmetry is the simplest

$$A_{LU} = \sigma_e/\sigma_0$$

$$\sigma_e = \sqrt{2\epsilon(1-\epsilon)}\sigma_{TL'}sin(\phi)$$

where ε is the virtual photon's polarisation

$$\epsilon = 1/[1 + 2(1 + \nu^2/Q^2)tan^2(\theta_e)]$$

υ is energy of vitual photon

Q^2 is squared virtual photon 4 momentum

θ_e is scattered electron polar angle to beamline

Analysis: Asymmetries

- Target asymmetry: $A_{UL} = \sigma_z/\sigma_0$

where
$$\sigma_z = \sqrt{2\epsilon(1+\epsilon)}[P_x\sigma_{TL_x}sin(\phi)+P_y\sigma_{TL_y}cos(\phi)+P_z\sigma_{TL_z}sin(\phi)] \\ +\epsilon[P_x\sigma_{TT_x}sin(2\phi)+P_y\sigma_{TT_y}cos(2\phi)+P_z\sigma_{TT_z}sin(2\phi)] \\ +P_y(\sigma_{T_y}+\epsilon\sigma_{L_y})$$

- Double asymmetry: $A_{LL} = -\sigma_{ez}/\sigma_0$

where
$$\sigma_{ez} = \sqrt{2\epsilon(1-\epsilon)}[P_x\sigma_{TL'_x}cos(\phi)+P_y\sigma_{TL'_y}sin(\phi)+P_z\sigma_{TL'_z}cos(\phi)] \\ +\sqrt{1-\epsilon^2}[P_x\sigma_{TT'_x}+P_z\sigma_{TT'_z}]$$

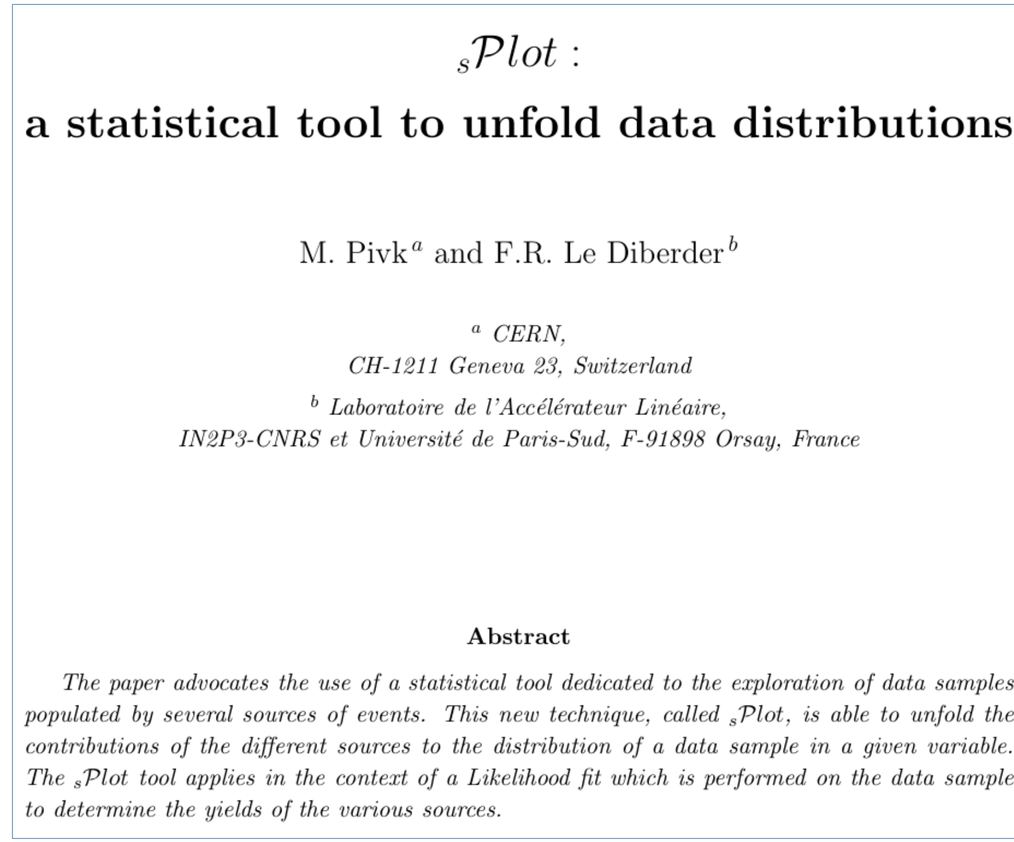
- With direction cosines being:

$P_z = cos(\theta_q)$ $\quad$ $P_y = -sin(\theta_q)sin(\phi)$ $\quad$ $P_x = sin(\theta_q)cos(\phi)$

sPlot Technique: Overview

Likelihood fit – obtain event by event weights for signal

- sPlot is a more elaborate sideband subtraction
- Use spectator missing mass as a discriminating variable
- Calculate sWeights based on this
  - can subtract background not coming from the e d→e' pi- p (p_s) hypothesis



$_s\mathcal{P}lot$:

a statistical tool to unfold data distributions

M. Pivk[a] and F.R. Le Diberder[b]

[a] *CERN, CH-1211 Geneva 23, Switzerland*

[b] *Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université de Paris-Sud, F-91898 Orsay, France*

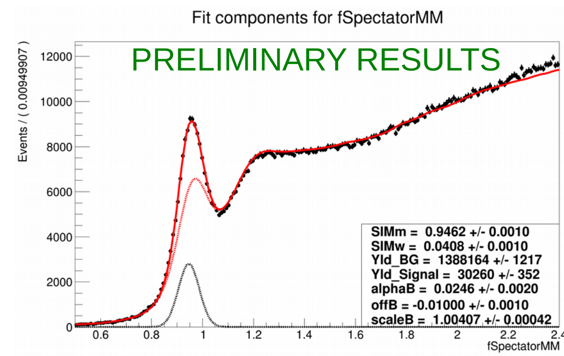
Abstract

The paper advocates the use of a statistical tool dedicated to the exploration of data samples populated by several sources of events. This new technique, called $_s\mathcal{P}lot$, is able to unfold the contributions of the different sources to the distribution of a data sample in a given variable. The $_s\mathcal{P}lot$ tool applies in the context of a Likelihood fit which is performed on the data sample to determine the yields of the various sources.

arXiv:physics/0402083

sPlot Technique: In Use

- Model ND_3 signal with Gaussian, and use NH_3 as background.
- Focus on **missing mass** of the **spectator proton** in the region of 0.81 → 1.08 GeV/c^2.
  - Avoid multi-meson production threshold.

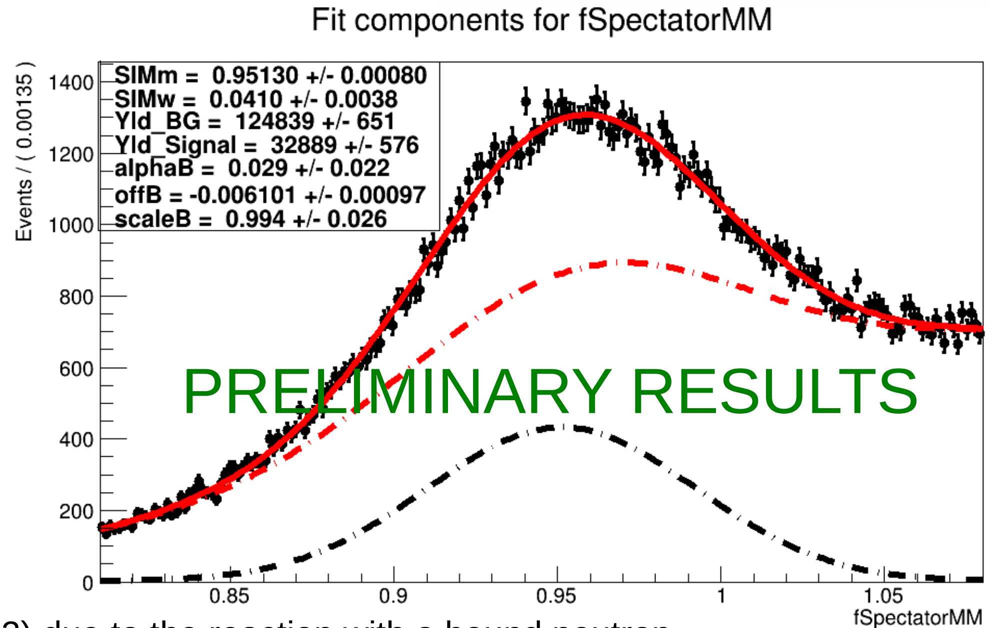


Solid **black** points – ND_3 signal data

Solid **red** line – Total fit Probability Density Function (PDF)

Dashed **red** line – Background PDF based on NH_3 data template

Dashed **black** line – signal PDF - Gaussian



- Integrated over all variables (W, theta, etc.)
- χ^2 for the fit is 1.0697

- Spectator proton missing mass peak is seen in NH3 (and C12) due to the reaction with a bound neutron
  - found to have a larger spectator proton missing momentum

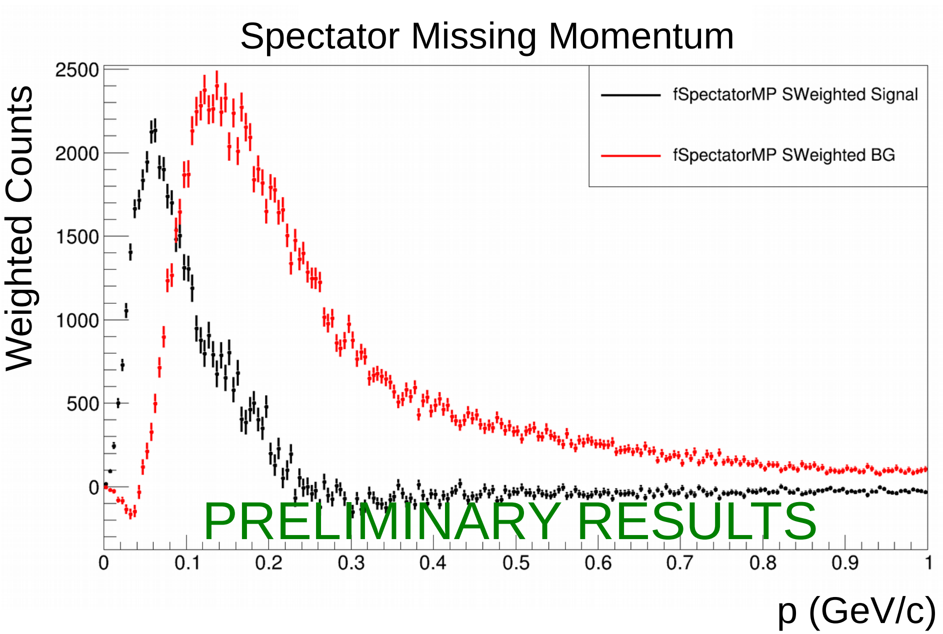
- This method should take care of dilution factor
  - will isolate **polarised** neutrons in deuterium only (avoiding nitrogen)
  - signal most like a **free neutron**

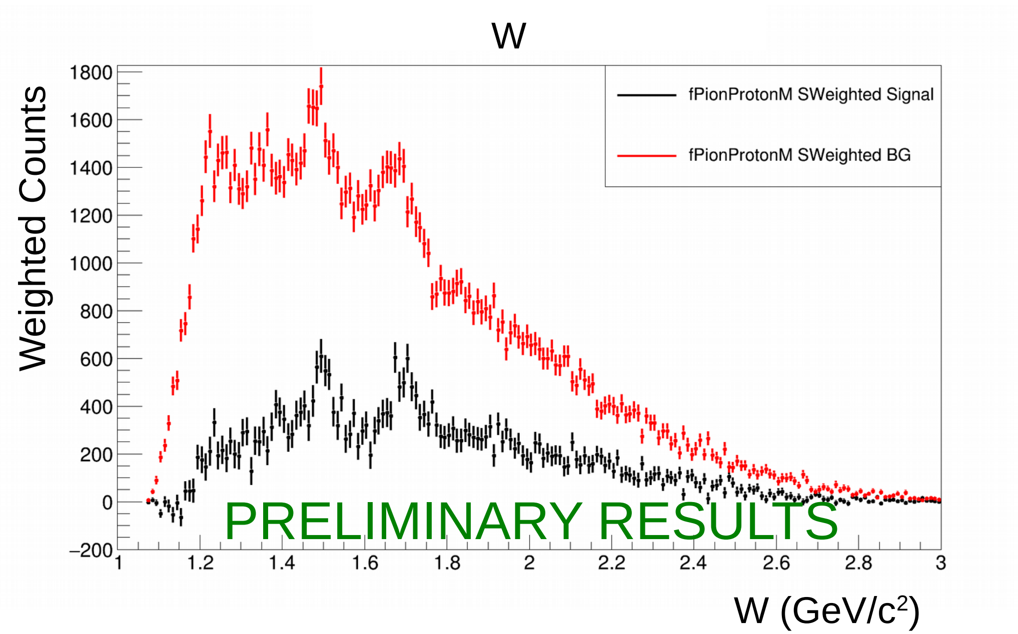
sPlot Technique: Kinematics of data sample

Using weights obtained for each event, can reconstruct distributions of variables:

- missing momentum of spectator proton showing peak at 60MeV
- W (invariant mass of detected proton and pion) showing resonance peaks

Signal and **background**

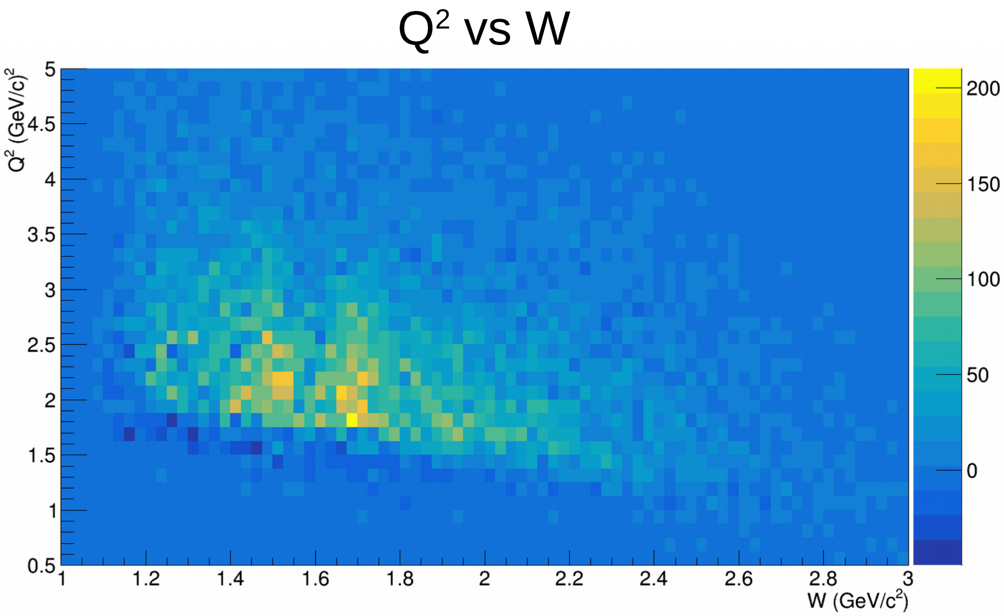


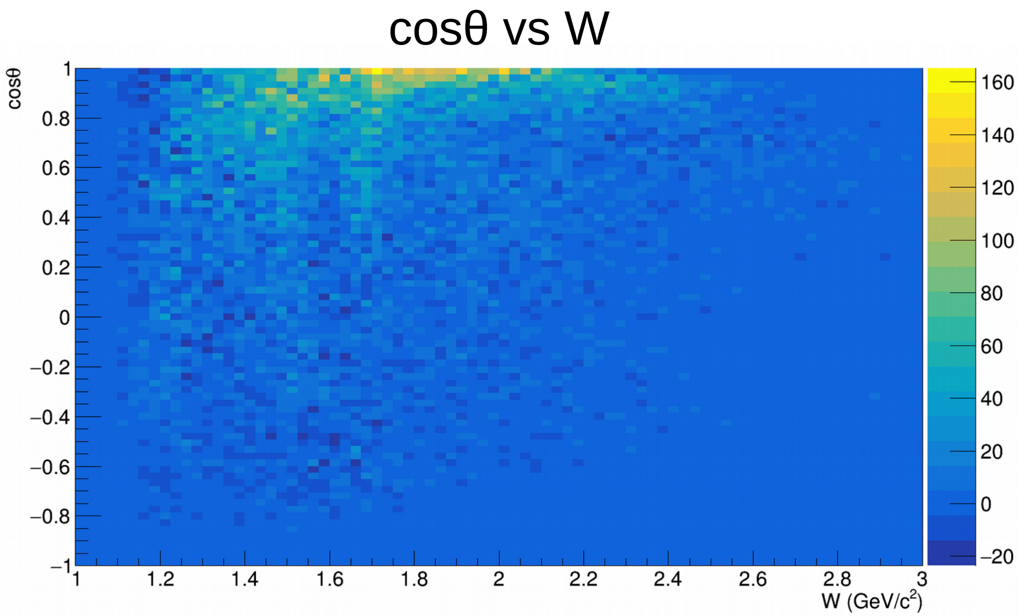


sPlot Technique: Kinematics of data sample

Weights can also show kinematic range of experiment:

- Can see Q^2 for resonances between 1.4→1.6 GeV/c^2 and 1.6→1.8 GeV/c^2
- cosθ shows most π^- are produced in very forward direction

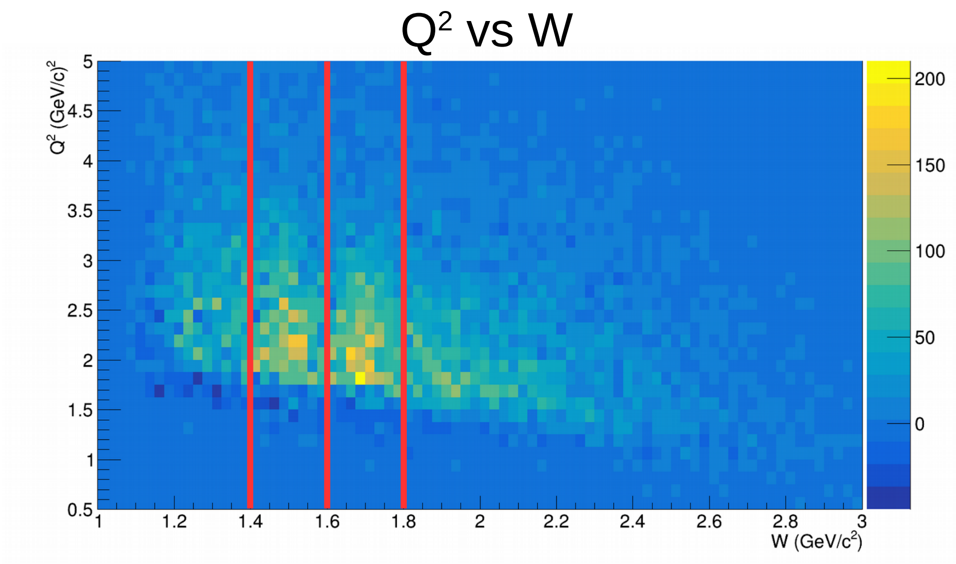




sPlot Technique: Kinematics of data sample

Binning in W:

- Integrating over all other variables (θ, Q^2, etc.)



- 4 W bins:

  $1.0 \rightarrow 1.4$ GeV/c^2 $1.4 \rightarrow 1.6$ GeV/c^2 $1.6 \rightarrow 1.8$ GeV/c^2 $1.8 \rightarrow 3.0$ GeV/c^2

Mean values:

$\boldsymbol{\theta_q}$ (angle of momentum transfer in lab frame) = **~36 deg** decreasing to **~20 deg**

ε (virtual photon polarisation) = **~0.89** decreasing to **~0.78**

Results: Beam Asymmetry Extraction

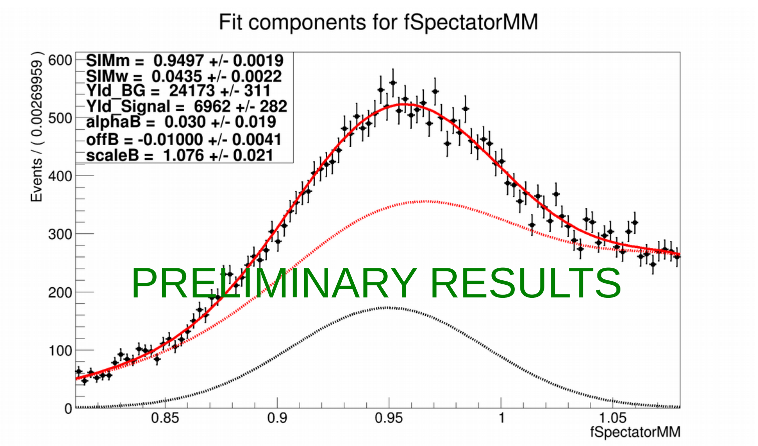
<u>On going analysis effort:</u>

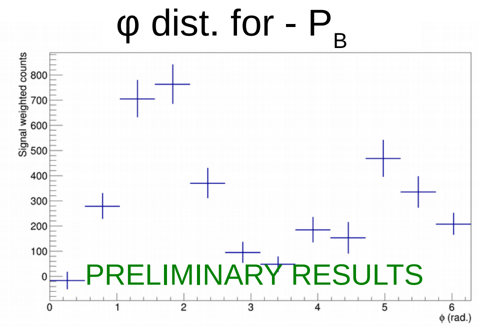
- Looking at W bin of 1.6→1.8 GeV/c^2

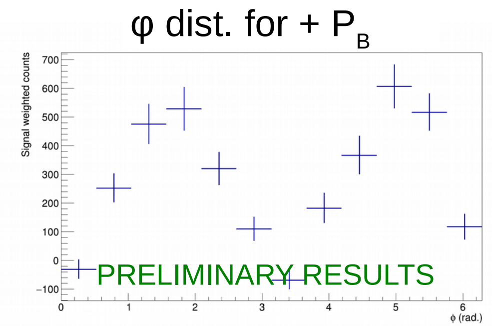
- Asymmetry produced from yields of events with opposite beam polarisation states:

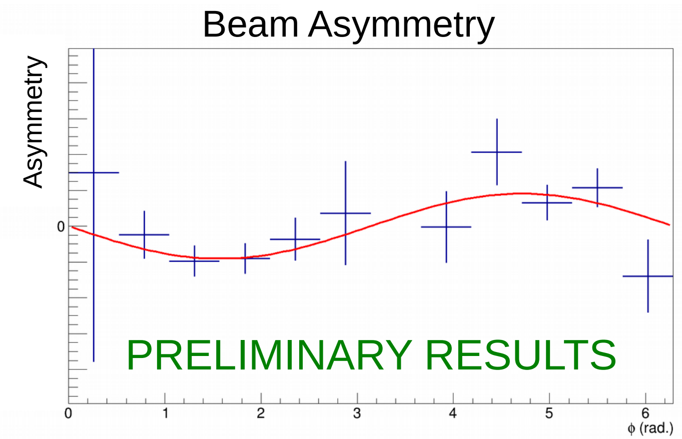
$$A(\phi) = \frac{N^{\rightarrow} - N^{\leftarrow}}{N^{\rightarrow} + N^{\leftarrow}}$$

- Initial fit with P_0*sin(φ)

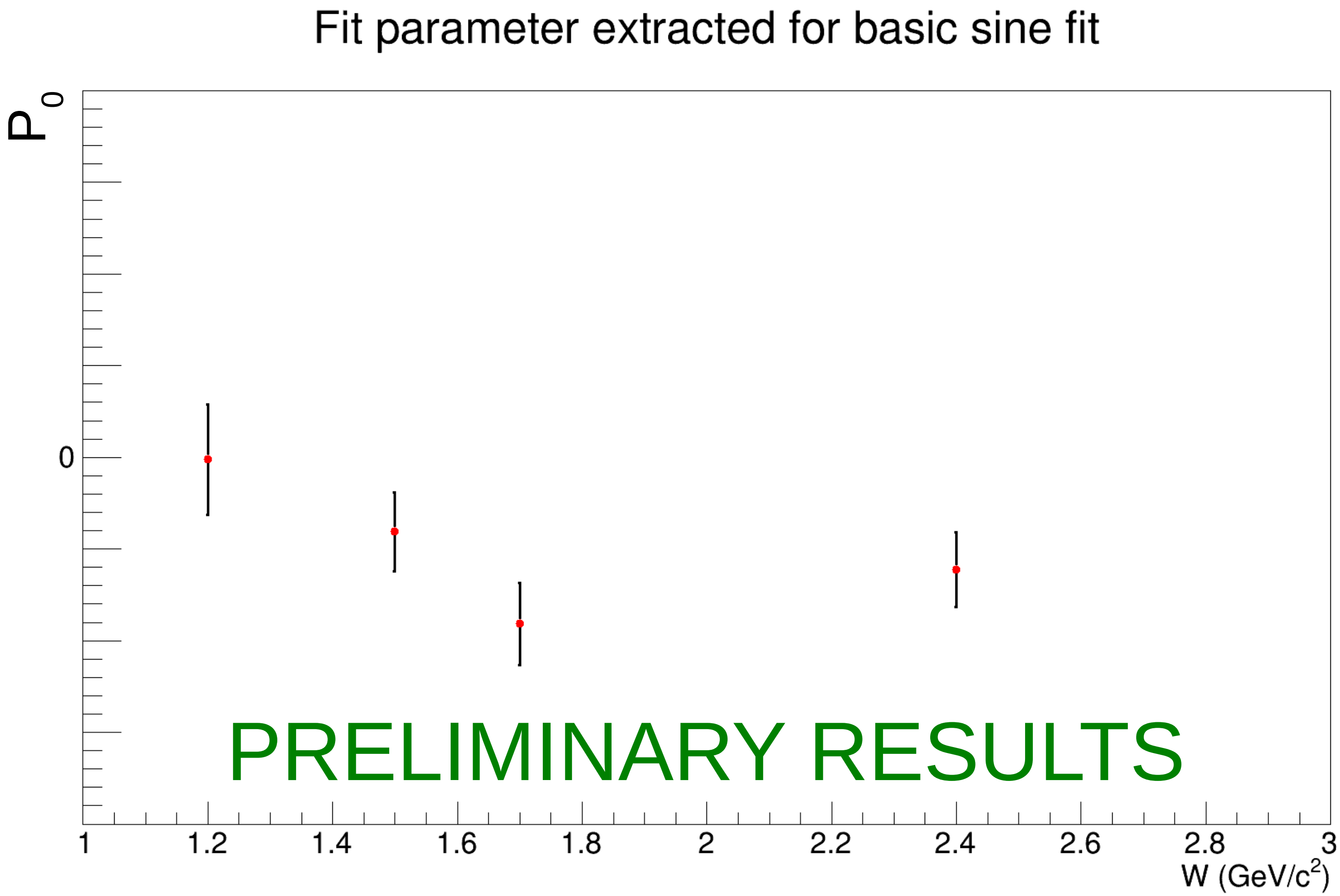








Results: Beam Asymmetry Extraction



Conclusions and Outlook

- Presented ongoing analysis effort using sPlot technique for weighting events in π^- electroproduction from quasi-free neutron

- Have just demonstrated differences of counts as a function of φ in a conventional asymmetry fit

- Low statistics
  - will now use maximum likelihood and compare observable values obtained

- Method will be applied for target and double spin asymmetry