Backward Meson Electroproduction from the Hall C KaonLT Experiment

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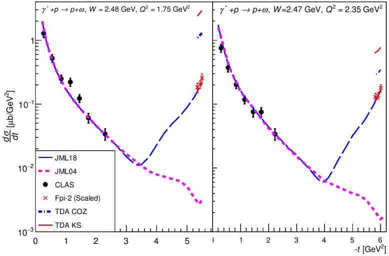
University of Regina

22/09/20

Outline

- Hall C 6 GeV u-Channel results
- Hall C 12 GeV u-Channel prospects
- Hall C LT separation experiments
- First look at protons from the KaonLT experiment
- Future outlook

- Backward angle meson electroproduction is a useful experimental tool to study TDAs
- Analysis of Hall C 6 Gev era data observed backward angle ω electroproduction
- For further info, see talk by G. Huber on 21/09/20



W.B. Li, et al., Phys. Rev. Lett. 123 (2019) 182501., arXiv: 1910.00464

Hall C u-Channel prospects in the 12 GeV era

- Can we see the backward angle peak seen in ω electroproduction in other channels?
  - Over a broad kinematic range too?
- Measure the u-dependence of LT separated cross sections
  - Relevance of Regge-rescattering and TDA mechanisms in JLab 12 GeV kinematics
- Where possible, measure σ_T/σ_L ratio over a wide Q^2 range for $W > 2$ GeV
  - Where does σ_T dominate over σ_L as predicted by the TDA formalism?
- Determine Q^2 dependence of σ_T at fixed x_B
  - Where does $\sigma_T \propto 1/Q^8$ as predicted by the TDA formalism
- What data do we have available to investigate these issues?
  - Kaon and Pion LT separation experiments

The Hall C 12 GeV LT Separation Experiments

- Two Hall C 12 GeV experiments focus on determining LT separated cross sections
- E12-09-011 (Spokespeople: T. Horn, G Huber, P. Markowitz)
  - LT separated kaon cross section
  - Will attempt to extract F_K
  - All settings acquired in 2018-2019
- E12-19-006 (Spokespeople: D. Gaskell, T. Horn, G. Huber)
  - LT separated pion cross section
  - F_π to high Q^2 ($8.5\ GeV^2$)
  - Pion reaction mechanism studies
  - Some settings acquired in 2019
- Wide range of kinematics acquired for LT separation
- As with the 6 GeV data, can also analyse the same data to look for protons
  - Access to backward angle meson electroproduction

LT Separations in Hall C

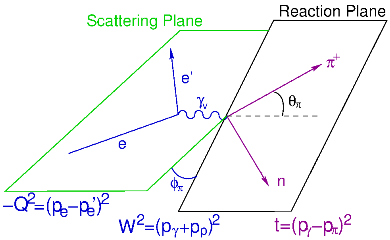
- The physical cross section for the electroproduction process is given by -

$$2\pi\frac{d^2\sigma}{dtd\phi} = \epsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi,$$

$$\epsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

- $\epsilon \rightarrow$ Virtual photon polarisation

- Take measurements at differing values of ϵ
- Lorentz invariant quantities constant at each point
  - Q^2, W, t, u



Physics Settings - Acquired

- All physics settings for the kaon (E12-09-011) and 3 PAC days worth of settings for the pion (E12-19-006) already acquired through various beamtime periods in 2018/2019

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	$-u_{min}$	ϵ
10.6 & 8.2	5.5	3.02	0.1098	0.53/0.18
10.6 & 8.2	4.4	2.74	0.1248	0.72/0.48
10.6 & 8.2	3.0	3.14	0.0058	0.67/0.39
10.6 & 6.2	3.0	2.32	0.1727	0.88/0.57
10.6 & 6.2	2.115	2.95	0.0001	0.79/0.25
4.9 & 3.8	0.5	2.40	-0.0157	0.70/0.45
4.6, 3.7 & 2.8	0.375	2.20	-0.0072	0.781/0.629/0.286
4.6, 3.7 & 2.8	0.425	2.20	-0.0046	0.774/0.617/0.264
3.7	1.45	2.02	0.1525	0.617
4.6	2.12	2.05	0.2293	0.559

Protons from the KaonLT Data

- Hadron PID is done offline
  - Can also analyse "pion" and "kaon" data to look at protons
- Study backward angle meson production
  - "Knocking a proton out of the proton"

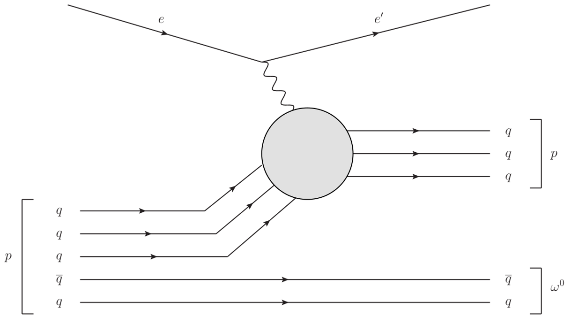
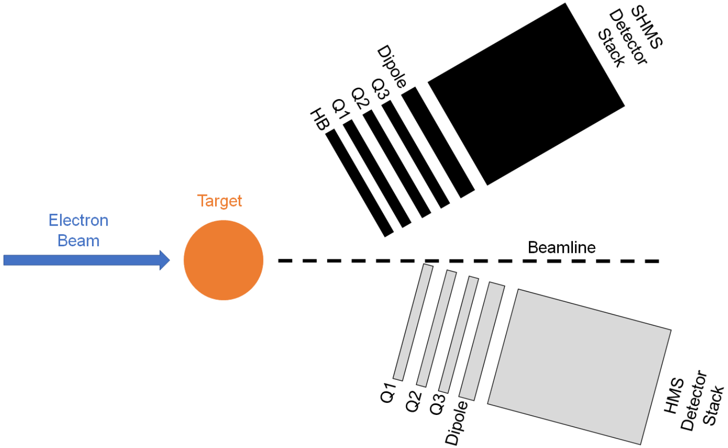


Figure - W.Li. PhD Thesis, University of Regina 2017

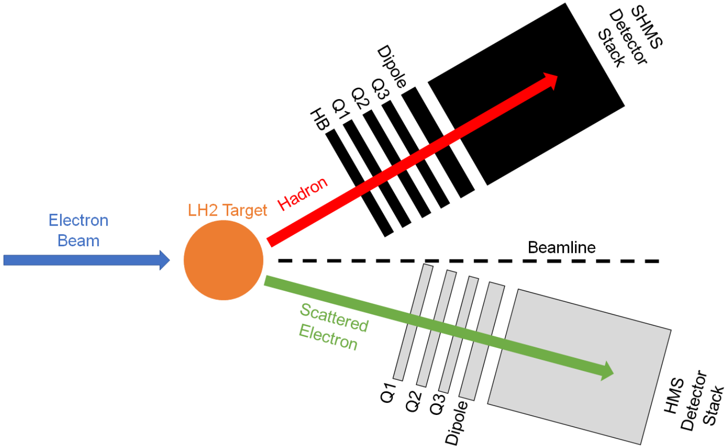
Hall C in the 12 GeV era

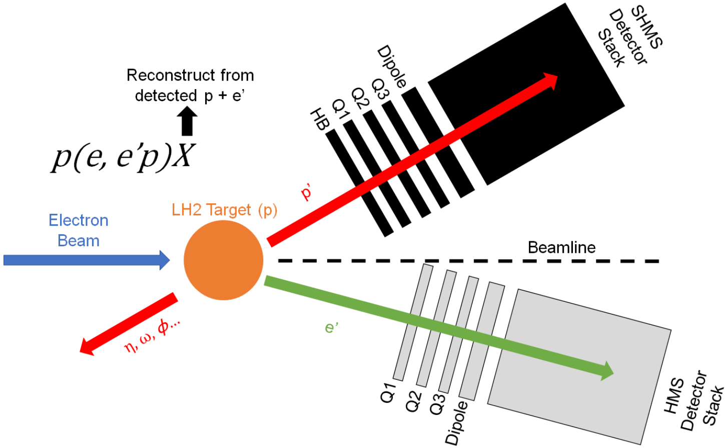
- Hall C is designed to measure precision differential cross sections and form factors
- Two advanced, rotatable, high resolution magnetic spectrometers
    - **HMS** - High Momentum Spectrometer
    - **SHMS** - Super High Momentum Spectrometer
- The SHMS was added as part of the 12 GeV upgrade program
    - The SHMS replaced the SOS
- Capable of operating at high rates across a wide range of configurations in angle and momentum

Hall C in the 12 GeV era



Hall C in the 12 GeV era - KaonLT Experiment




Reconstruct from
detected p + e'
p(e, e'p)X
Electron
Beam
LH2 Target (p)
p'
η, ω, ϕ...
e'
Beamline
HB
Q1
Q2
Q3
Dipole
SHMS
Detector
Stack
Q1
Q2
Q3
Dipole
HMS
Detector
Stack

SHMS Detector Stack

- SHMS detects hadrons
- HMS detects electrons
- Wide angular and momentum range for each
- SHMS Aero and HGC used for PID
  - Aerogel $\rightarrow K/p$ separation
    - Four different n used
  - HGC $\rightarrow K/\pi$ separation

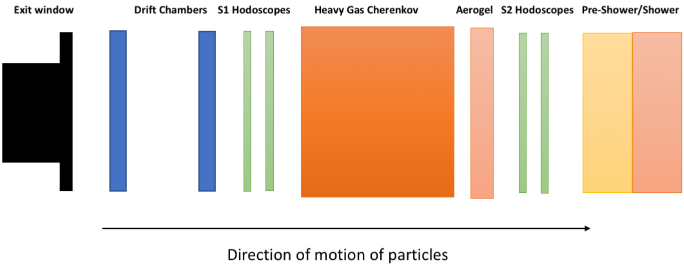


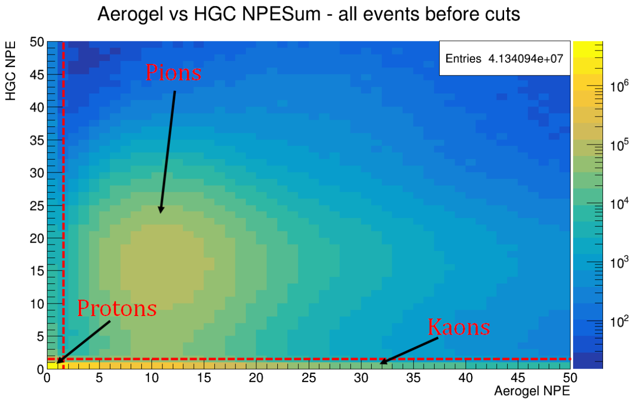
Image Credit - A. Usman University of Regina

KaonLT Data - First Look

- Conducted a very preliminary examination of the KaonLT data
- A lot of analysis still required to determine critical efficiencies and offsets
- As discussed, hadron PID is done offline
- Want an electron signal in the HMS that is **coincident** with a proton signal in the SHMS
- Apply a series of cuts to the data
  - Acceptance cuts
  - Electron PID cuts
  - Proton PID cuts
  - Coincidence time cuts
- Calculate missing mass and determine produced meson
  - $M_{Miss} = \sqrt{(E_e + m_p - E_{e'} - E_{p'})^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_{p'})^2}$

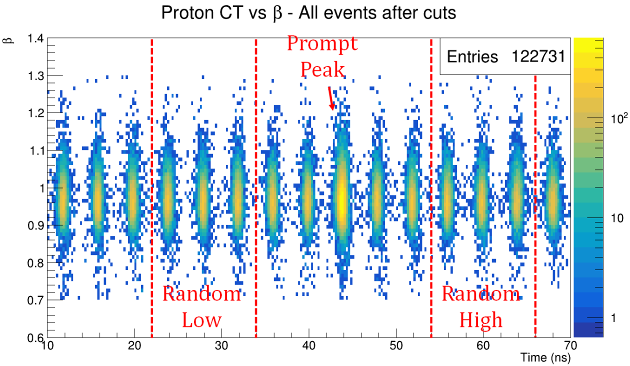
Proton PID - Cherenkov Cuts

- Expect protons to not leave a signal in either Cherenkov detector
- Cut on < 0.5 NPE in each Cherenkov



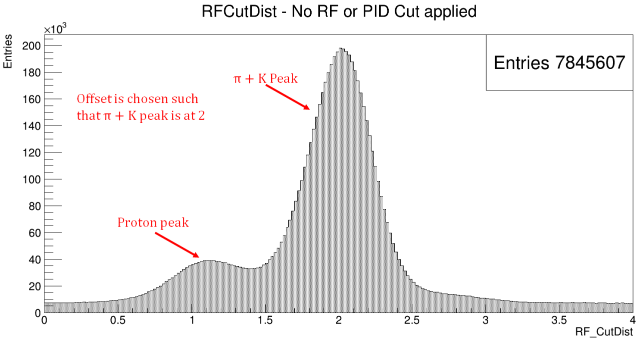
Proton PID - Cointime

- Select prompt peak in time spectrum
- Select a low and high random window to estimate background from random coincidences
- $t_{coin} = t_{HMS} - t_{SHMS}$



Proton PID - RF Time

- For some runs, can utilise RF timing signal from accelerator to identify proton events
- Take difference between RF signal and hodoscope start time
- Distinct peak for events that pass other proton PID cuts



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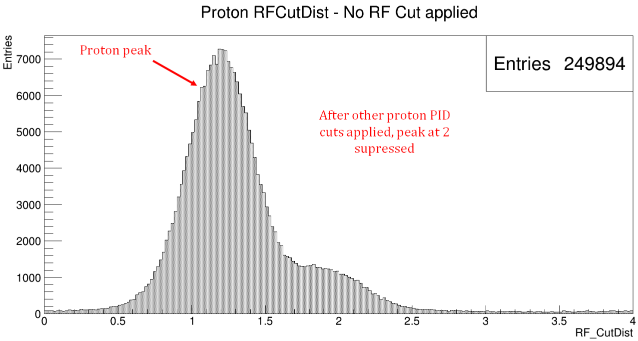
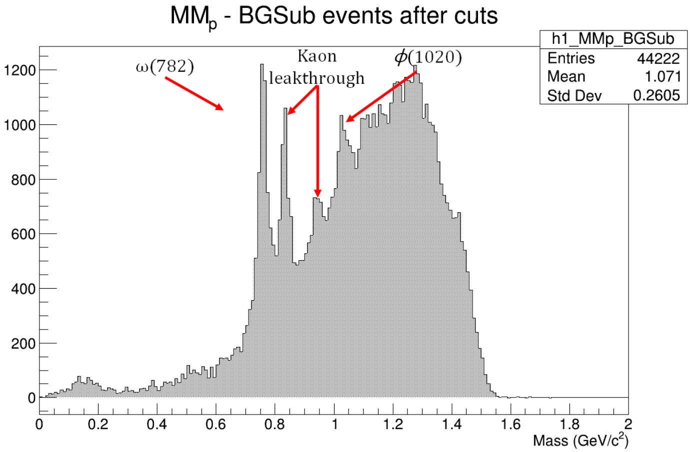


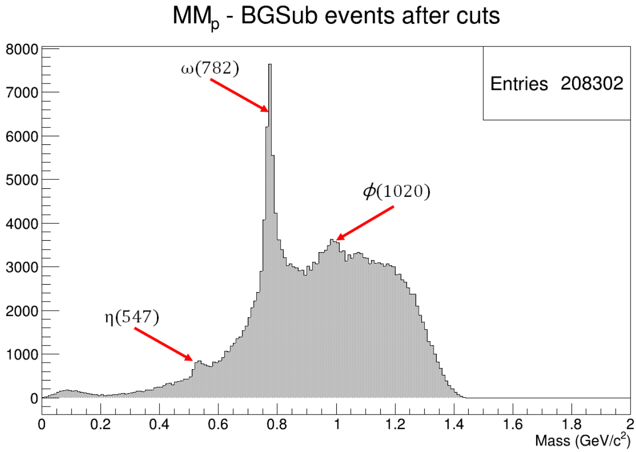
Missing Mass Spectra- Kaon Leakthrough

- $Q^2 = 2.115, W = 2.95, \epsilon = 0.79$, central setting



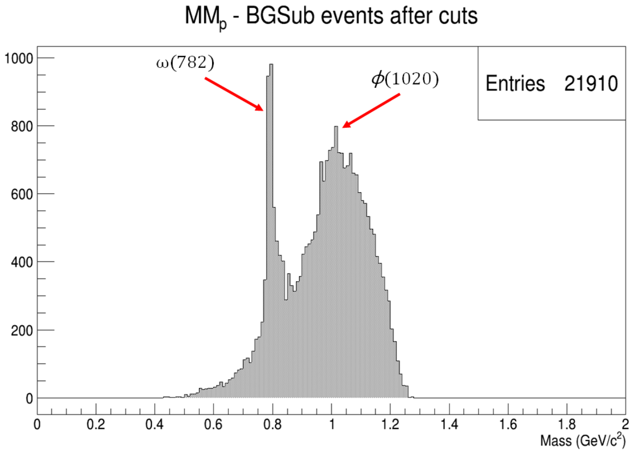
Missing Mass Spectra - ϵ Dependence

- $Q^2 = 3.0, W = 2.32, \epsilon = 0.88$, central setting



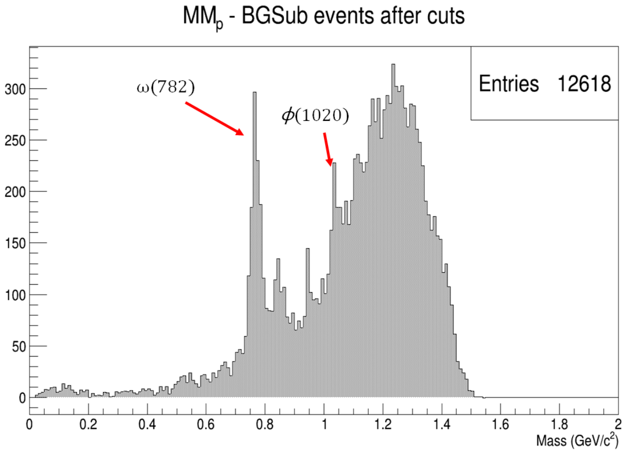
Missing Mass Spectra - ϵ Dependence

- $Q^2 = 3.0, W = 2.32, \epsilon = 0.57$, central setting



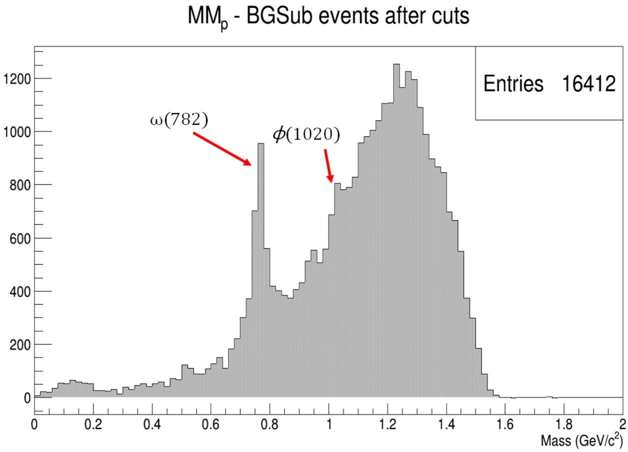
Missing Mass Spectra - ϕ Dependence

- $Q^2 = 3.0, W = 3.14, \epsilon = 0.67$, left setting



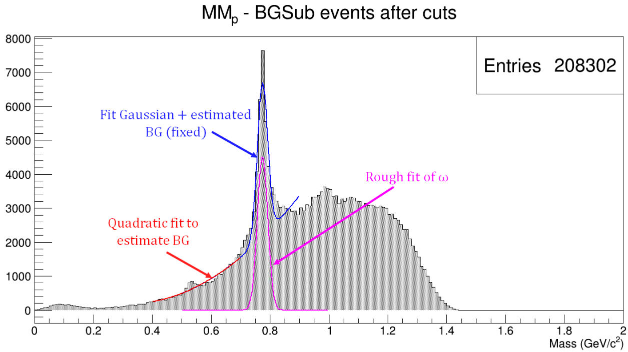
Missing Mass Spectra - ϕ Dependence

- $Q^2 = 3.0, W = 3.14, \epsilon = 0.67$, right setting



ω to ϕ Ratios

- $Q^2 = 3.0, W = 2.32, \epsilon = 0.88$, central setting
- Apply some very rough fits to the data to estimate ω/ϕ peak ratios



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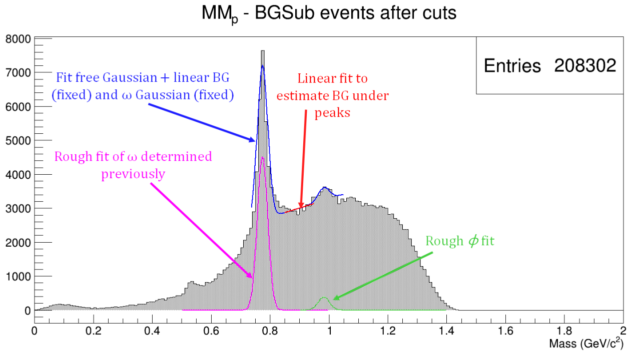

ω to ϕ Ratios

- Many settings need further work to cleanly isolate ϕ from background
  - Statistics available on some settings also a limiting factor
- Can get a rough estimate of ω to ϕ ratio for some kinematics however
  - Quoting for central setting only

Q^2/GeV^2	W$/GeV$	ω/ϕ high ϵ	ω/ϕ low ϵ
0.5	2.4	2.93	2.69
3.0	2.32	11.9	3.34
3.0	3.14	4.47	1.81

Outlook - Physics Settings To Be Acquired

- Many physics settings still need to be acquired for the pion
- Long and complex experimental run
- Cross section estimations already produced and published for many of these settings by B. Pire, K. Semenov-Tian-Shansky and L. Szymanowski

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	$-u_{min}$	ϵ
11.0/8.8/6.7	1.60	3.00	-0.0157	0.817/0.689/0.408
11.0/8.8/8.0	2.45	3.20	-0.0090	0.709/0.505/0.383
11/9.9/8.8/8.0	3.85	3.07	0.0368	0.666/0.572/0.436/0.301
11.0/9.9/8.0	5.00	2.95	0.1029	0.633/0.530/0.238
11.0/9.9/9.2	6.00	3.19	0.0949	0.452/0.304/0.184
11.0/9.2	8.50	2.79	0.3709	0.430/0.156

B. Pire, K. Semenov-Tian-Shansky and L. Szymanowski, Phys. Rev. D 91 (2015), 094006

Outlook - Upcoming Beamtime

- Many settings for E12-19-006 scheduled for Jun-Oct 2021

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	$-u_{min}$	ϵ
8.0	2.45	3.20	-0.0090	0.383
8.0	3.85	3.07	0.0368	0.301
9.9	3.85	3.07	0.0368	0.572
8.0	5.00	2.95	0.1029	0.238
9.9	5.00	2.95	0.1029	0.5305
9.2	6.00	3.19	0.0949	0.184
9.9	6.00	3.19	0.0949	0.304
6.0	3.85	2.02	0.5471	0.582
8.0	6.00	2.40	0.4259	0.449
9.2	8.5	2.79	0.3709	0.156

Summary

- Numerous kinematics from Kaon and Pion LT acquired
- Proton events identifiable in the data, clear ω and ϕ peaks visible in the data
  - ω in particular looks very promising
- Many steps to go till a full LT separation of the data is possible
- Early indications that ω to ϕ ratio may change quite significantly between high and low ϵ
  - A lot of work on estimating background needed however
- Lots of data from a wide range of kinematic points to be acquired in the coming few years

Thanks for listening, any questions?

S.J.D. Kay, D. Gaskell, T. Horn, G.M. Huber, P. Markowitz, V. Berdnikov, W.B. Li, V. Kumar , R. Trotta, A. Usman

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Backup Zone

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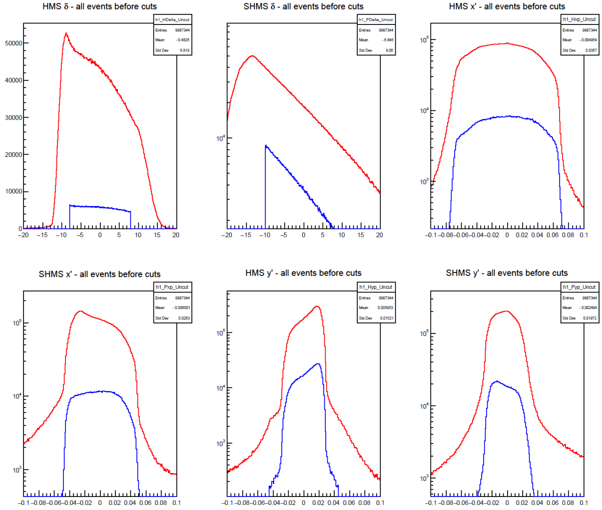
4.6, 3.7 & 2.8	0.38	2.20	0.087	0.781/0.629/0.286

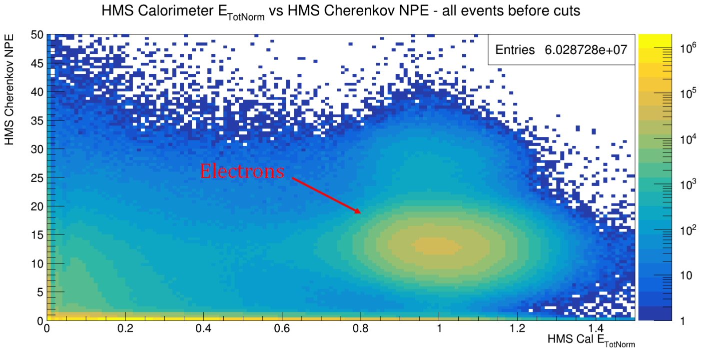
Acceptance Cuts



Electron PID Cuts

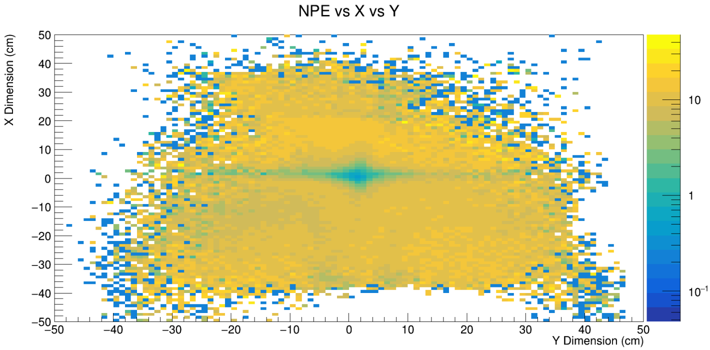
- Want an electron in HMS
- Cut on Cherenkov NPE and normalised energy in the HMS calorimeter

$$E_{Norm} = \frac{E_{Cal}}{p}$$



SHMS HGC - NPE Distribution

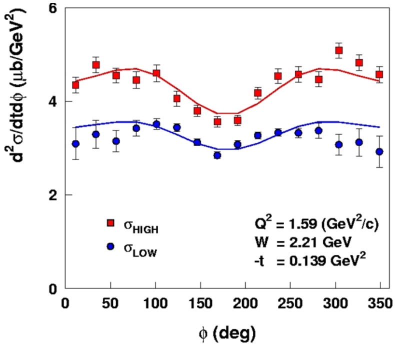
- Region of low efficiency in centre of SHMS HGC
- Need to account for this in further analysis



Measuring $\frac{d\sigma_L}{dt}$ at JLab

- Rosenbluth separation required to isolate σ_L
  - Fix W, Q^2 and $-t$, measure cross section at two beam energies
  - Carry out simultaneous fit at two different ϵ values to determine interference terms

- Careful control of point-to-point systematics crucial, $1/\Delta\epsilon$ error amplification in σ_L
- Spectrometer acceptance, kinematics and efficiencies must all be carefully studied and understood



T. Horn, et al., PRL 97(2006) 192001

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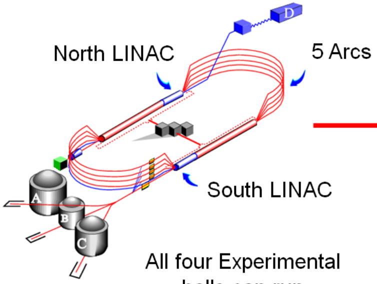
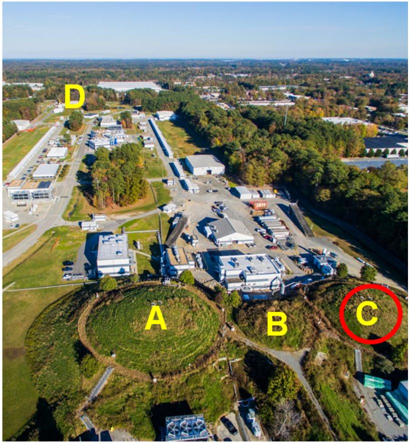
Physics Settings - To Be Acquired Reaction Mechanism Points

- As well as form factor points shown earlier, also have reaction mechanism data points

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	x	ϵ
6.7	1.46	2.02	0.312	0.880
11.0/6.7	2.73	2.63	0.311	0.845/0.513
8.8	2.12	2.05	0.390	0.907
11.0/6.7	3.85	2.62	0.392	0.799/0.360
11.0/6.0	3.85	2.02	0.546	0.898/0.582
11.0/8.0	6.0	2.40	0.551	0.738/0.449
11.0/9.2	8.50	2.79	0.552	0.430/0.156



All four Experimental halls can run simultaneously



RF Timing - Overview

- Take difference between RF time and hodoscope start time
- Need to add an offset to this difference, then take modulo
  - Take mod 4.008 $\rightarrow$ from bunch spacing for the run set shown
  - Offset varies by run and by beam conditions, a value between 0 and 4.008
- Value plotted as time difference is -

$$\mathrm{fmod}(\mathrm{P.hod.fpHitsTime}[0] - \mathrm{T.coin.pRF\_tdcTime} + \textcolor{red}{\mathrm{offset}}, 4.008)$$

- The offset needed can shift quite a bit
  - For example, MCC switching the beam bucket we get causes a shift
- Applying the same offset value and not accounting for this leads to an odd double peaked plot

RF Timing Example

- RF time differences, after common cuts, shown in blue
- Events with pion PID cuts applied shown in red
- Without accounting for the change in beam bucket, clearly see the weird double peaking