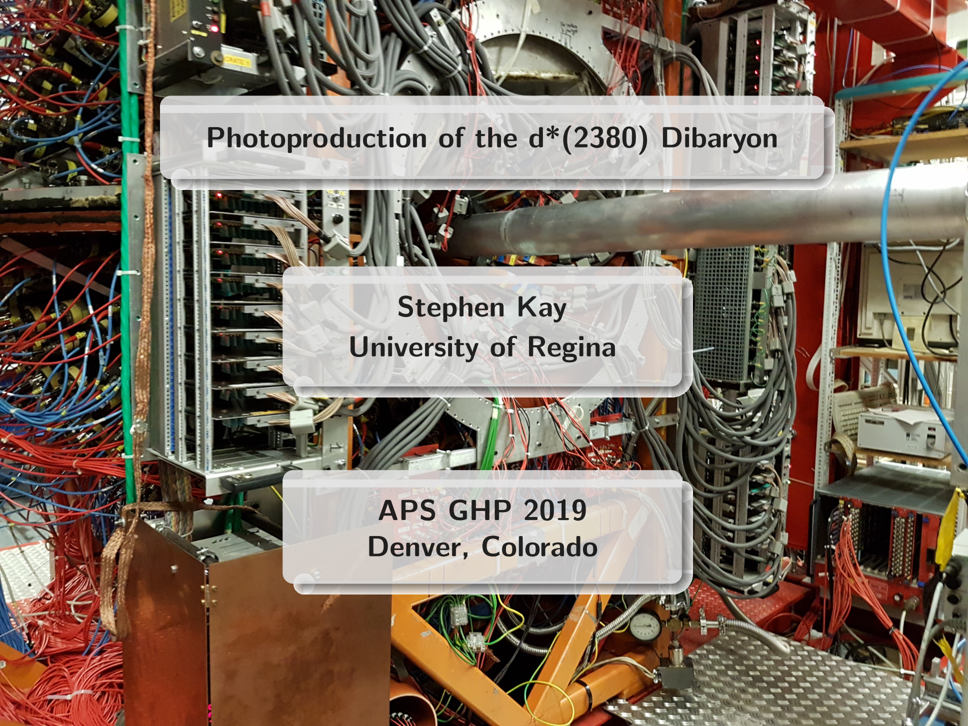


Photoproduction of the d*(2380) Dibaryon

Stephen Kay

University of Regina

APS GHP 2019

Denver, Colorado

Overview

- Motivation
- Experimental Setup
- Σ Results
- $C_{x'}$ Preliminary Results

Motivation - Recent Observations

- LHCb has recently observed tetraquark and pentaquark candidate states

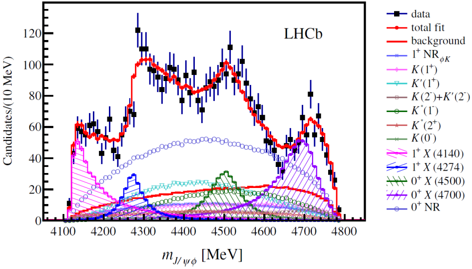
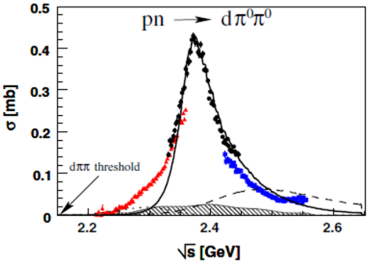


Figure: [1] - LHCb measurements of the decay $B^+ \to J/\psi\phi K^+$ indicating four tetraquark candidates

- A *uuuddd* hexaquark candidate, the d*(2380), has also been observed by another collaboration

[1] - R.Aaij. et. al. PRL, 118:022003, 2017

Motivation - d*(2380) Dibaryon



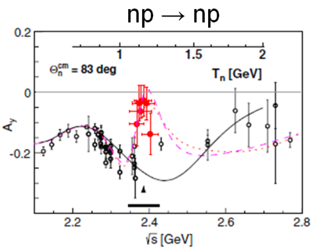
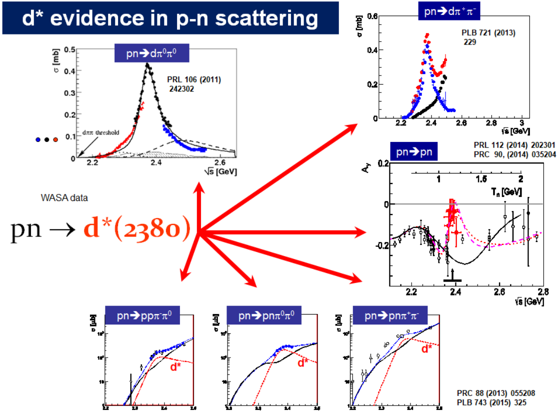


Figure: [1,2] - Results from WASA-at-COSY showing structure at $\sqrt{s} = 2380$ MeV

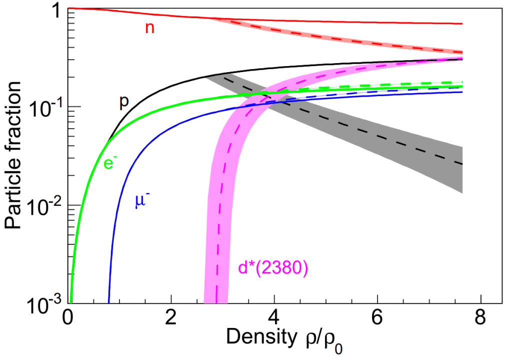
- d* has $J^{\pi} = 3^{+}$, $m = 2380$ MeV and $\Gamma = 70$ MeV

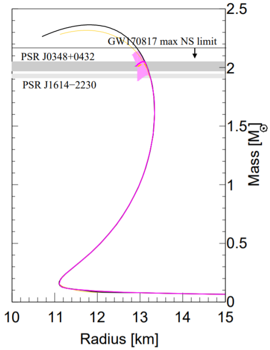
- d* predominantly (90%) decays via $d* \rightarrow \Delta\Delta$

[1] - PRL 106, 242302 (2011), [2] - PRL 112, 202301 (2014)

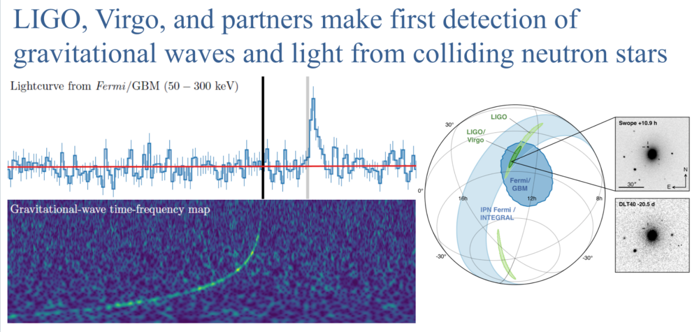

d* evidence in p-n scattering
pn→dπ0π0
PRL 106 (2011) 242302
√s [GeV]
WASA data
pn → d*(2380)
pn→dπ+π-
PLB 721 (2013) 229
pn→pn
PRL 112 (2014) 202301
PRC 90, (2014) 035204
pn→ppπ-π0
pn→pnπ0π0
pn→pnπ+π-
d*
PRC 88 (2013) 055208
PLB 743 (2015) 325

Motivation - New Degree of Freedom in Neutron Stars?





I. Vidaña, M. Bashkanov, D.P. Watts, A. Pastore, PLB 781, pp112-116, 2018



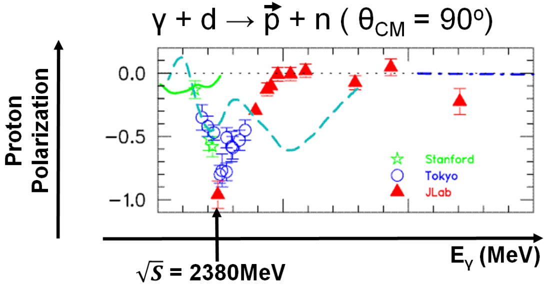
- Need to know more about size and internal structure of d*(2380)

$\rightarrow$ Need photoproduction measurements

Motivation - d*(2380) Photoproduction

- One potential photoproduction channel is $\gamma + d \rightarrow d^* \rightarrow p + n$

- Anomalous proton polarisation in d* region?



R. Gilman and F. Gross nucl-th/0111015 (2001) , H. Ikeda et al., PRL 42, May 1979, 1321 , T. Kamae, T. Fujita, PRL 38, Feb 1977, 471

Motivation - d*(2380) Dibaryon

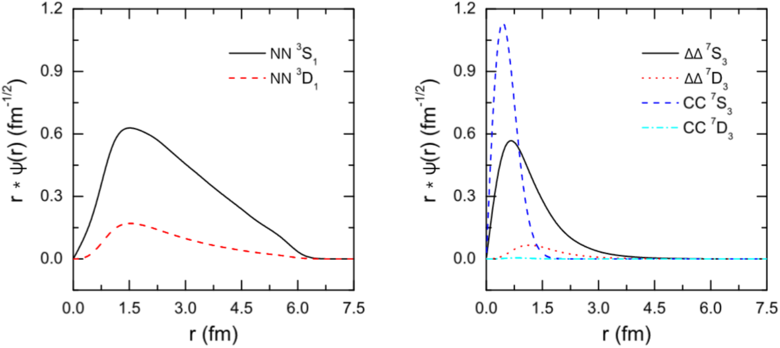


Figure: [1] - Model predictions of the "size" of the d* (right) compared to deuteron (left)

[1] - Chin. Phys. C 39, 7, 071001 (2015)

Motivation - Polarisation Observables

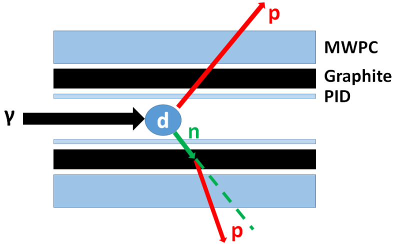
- Can gain information about the state by measuring polarisation observables in the reaction

Observable	Helicity Amplitude Combination
P_y	$2\Im\sum_{i=1}^{3}[F^*_{i+}F_{(i+3)-} + F_{i-}F^*_{(i+3)+}]$
T	$2\Im\sum_{i=1}^{2}\sum_{j=0}^{1}[F^*_{(i+3j)+}F^*_{(i+3j+1)+} + F_{(i+3j)-}F^*_{(i+3j+1)-}]$
Σ	$2\Re\sum_{i=1}^{3}(-)^{i}[-F_{i+}F^*_{(4-i)-} + F_{(3+i)+}F^*_{(7-i)-}]$
T_1	$2\Im\sum_{i=1}^{3}(-)^{i}[-F_{i+}F^*_{(7-i)+} + F_{i-}F^*_{(7-i)-}]$
$\mathrm{C}_{x'}$	$2\Re\sum_{i=1}^{3}[F^*_{i+}F_{(i+3)-} + F_{i-}F^*_{(i+3)+}]$
$\mathrm{C}_{z'}$	$\sum_{i=1}^{6}\{\lvert F_{i+}\rvert^2 - \lvert F_{i-}\rvert^2\}$
$\mathrm{O}_{x'}$	$2\Im\sum_{i=1}^{3}(-)^{i+1}[F_{i+}F^*_{(7-i)+} + F_{i-}F^*_{(7-i)-}]$
$\mathrm{O}_{z'}$	$2\Im\sum_{i=1}^{3}(-)^{i+1}[F_{i+}F^*_{(4-i)-} + F_{(3+i)+}F^*_{(7-i)-}]$

- F terms relate to helicity amplitudes

Motivation - New Polarimeter

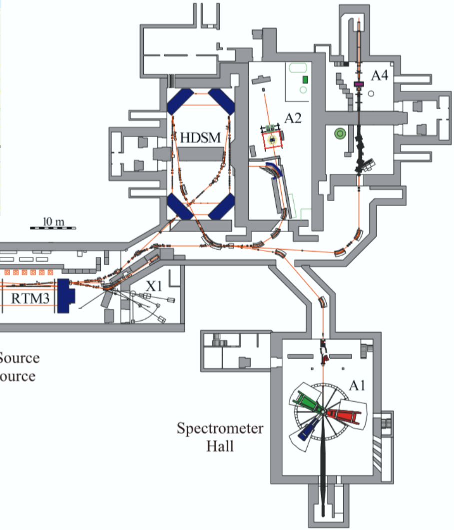
- $\vec{n}$ previously unmeasured
- Polarimeter can measure $\vec{n}$ and $\vec{p}$ simultaneously
- Measure neutron via charge exchange interactions in polarimeter



- Establish if d*(2380) dibaryon has Electromagnetic Coupling
  $\rightarrow$ Tests of size and internal structure

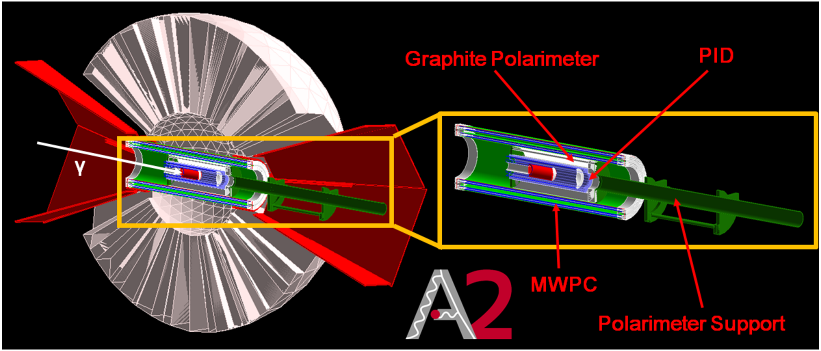
MAMI Layout

Hamburg
Berlin
Germany
Cologne
Prague
Munich
Austria

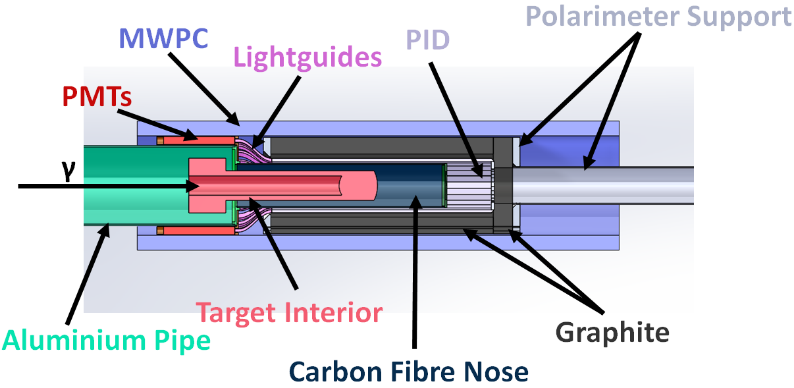


10 m
RTM2
RTM3
RTM1
Injector
Linac
Therm. Source
+ Pol. Source
HDSM
A2
A4
X1
A1
Spectrometer
Hall

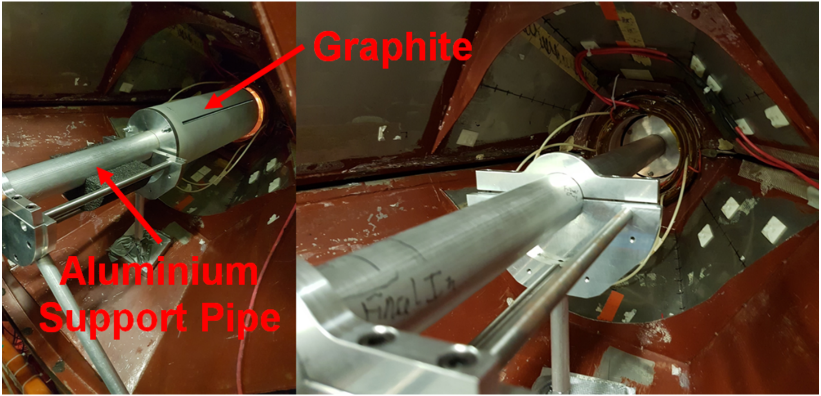
A2 Hall Setup



Overview of Polarimeter Setup



Overview of Polarimeter Setup



August 2016 Experimental Run

- Installed new polarimeter at A2 hall in MAMI

- Real, polarised (circularly and linearly available) photon beam in A2 hall

- $\sim$ 640 hour run in August 2016

- Σ, $C_{x'}$, $C_{z'}$, P_y^p, P_y^n, $O_{x'}$, $O_{z'}$ measurable

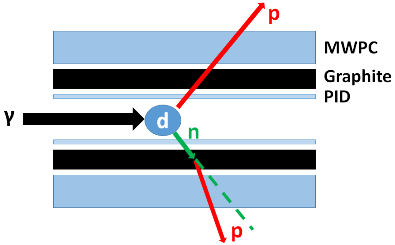
- To measure Σ, need to look at angular distribution for events *without* scattering

- To measure $C_{x'}$ need to examine angular distribution of scattered neutrons

Event Selection - Particle Assignment

- Particle assignment is based upon detector hit combinations

	Proton	Charge Exchange Proton	Neutron
PID	✓	✗	✗
MWPC	✓	✓	✗
CB	✓	✓	✓



Event Selection

- Energy loss correction applied to the proton track

- Reconstruct the "neutron" track from proton track information via - $\underline{n}_{rec} = (\underline{d} + \underline{\gamma}) - \underline{p}$

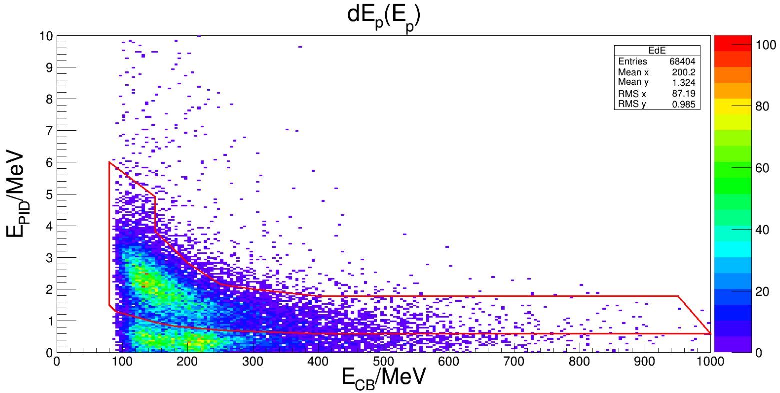
- Cuts:

  - Proton vertex
  - Missing mass of reconstructed track -

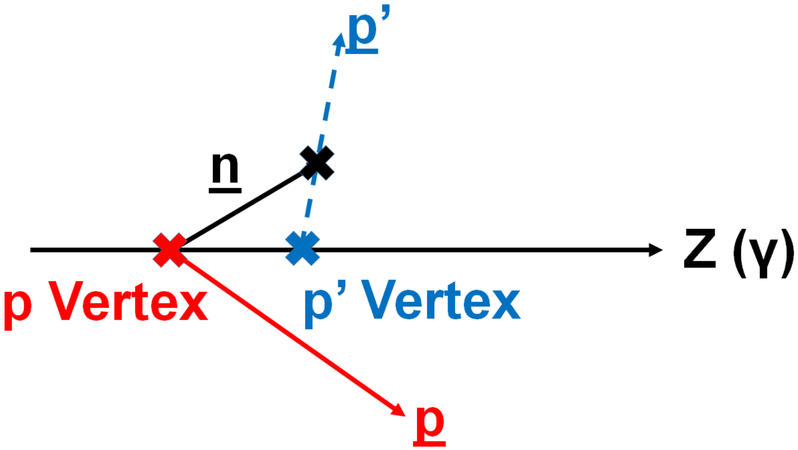
$$M_n = \sqrt{E_n^2 - p_n^2}$$

  - dE_{PID} vs E_{CB} cut on proton track (banana cut)
  - **D**istance **O**f Closest **A**pproach cut (DOCA)

Event Selection - EdE Cut



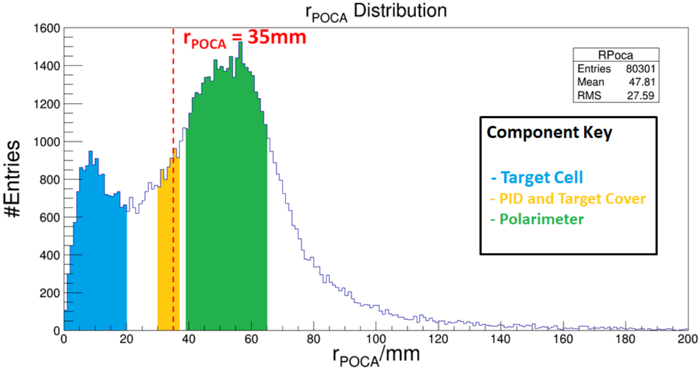
Event Selection - DOCA Method



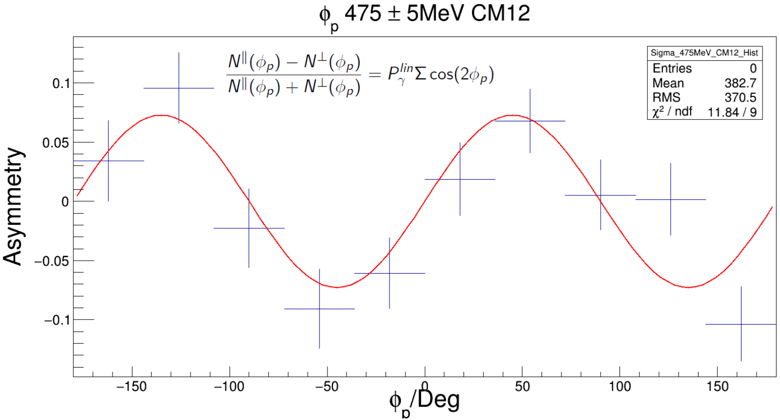
Event Selection - DOCA

- DOCA occurs at the **P**oint **O**f **C**losest **A**pproach (POCA)

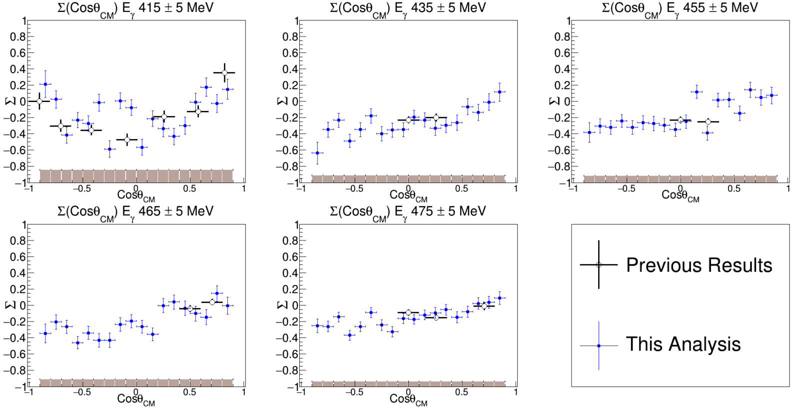
$$r_{POCA} = \sqrt{x_{POCA}^2 + y_{POCA}^2}$$



Σ - Asymmetry Fitting

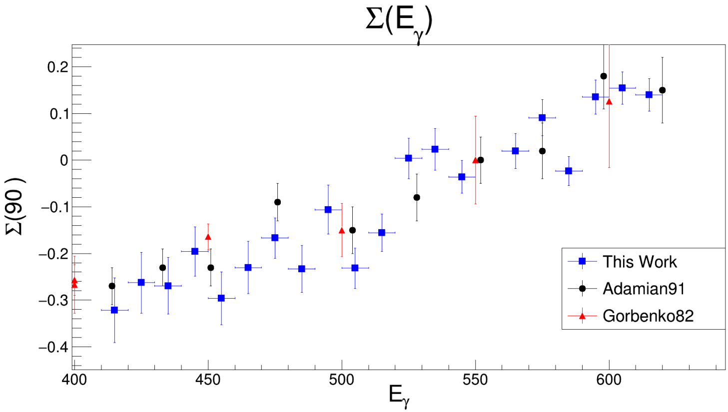


Σ Results



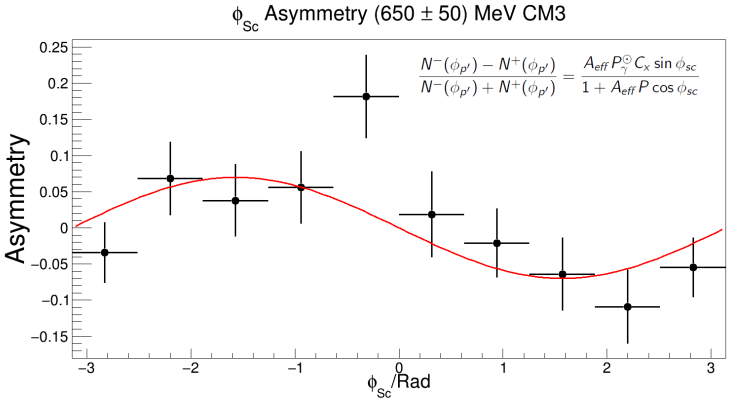
Black Data Points from - J.PhysG, 17, 8, 1189, F. V. Adamian et. al.
Results published in - PLB, 789, 7-12, M. Bashkanov, S.Kay, D.P. Watts, C. Mullen et. al.

Σ Results

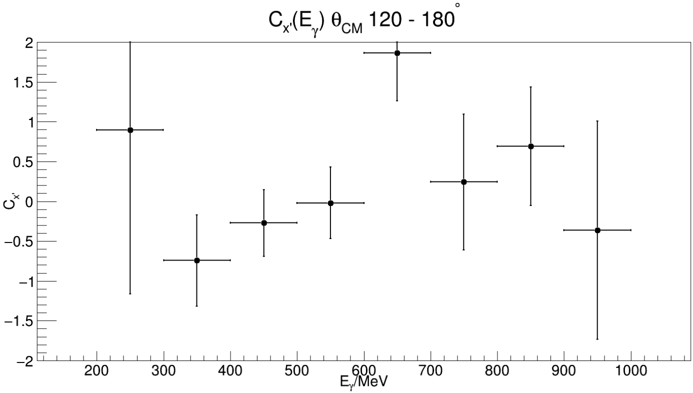


$\Sigma(E_\gamma)$
$\Sigma(90^\circ)$
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
400
450
500
550
600
E_γ
This Work
Adamian91
Gorbenko82

$C_{x'}$ - Asymmetry



$C_{x'}$ - Results



$C_{x'}(E_\gamma)$ θ_{CM} 120 - 180°
2
1.5
1
0.5
$C_{x'}$ 0
−0.5
−1
−1.5
−2
200
300
400
500
600
700
800
900
1000
E_γ/MeV

Outlook and Summary

- Event selection identifies clean sample of scattered events

- Σ results extracted, consistent with existing data and alternative analysis

- Σ results from APLCON analysis published in PLB, PLB 789 pp7-12, https://doi.org/10.1016/j.physletb.2018.12.026

- Initial interpretation of Σ results suggests hints of the influence of the d*(2380)

- Preliminary analysis of $C_{x'}$ carried out

- Refinement of analysis ongoing

Thanks for listening, any questions?

University of Regina

A2

Science & Technology Facilities Council

NSERC CRSNG

CINP ICPN Canadian Institute of Nuclear Physics Institut canadien de physique nucléaire

This research was supported by: The UK Science and Technologies Funding Council (STFC), Studentship 1526286, Grants ST/L00478X/1 and ST/L005824/1 and the Natural Sciences and Engineering Research Council of Canada (NSERC), FRN: SAPIN-2016-00031

In partnership with the A2 collaboration at MAMI

Financial support for this conference presentation was provided by the Canadian Institute of Nuclear Physics

Event Selection - DOCA Method 1/2

- **D**istance **O**f **C**losest **A**pproach (DOCA) method is used to calculate point where scattering event occured

- $\underline{x}_i$ is point of closest approach, $\underline{\hat{u}}_i$ is initial unit vector of track, $\underline{v}_i$ is initial vertex, t_i is scalar constant to be determined

$$\underline{x}_i = \underline{v}_i + t_i \underline{\hat{u}}_i$$

- DOCA occurs at point where distance between two tracks, $\Delta \underline{x}$, is minimised

- For this minimisation the following condition must be true

$$\underline{\hat{u}}_i \cdot \Delta \underline{x} = 0$$

Event Selection - DOCA Method 2/2

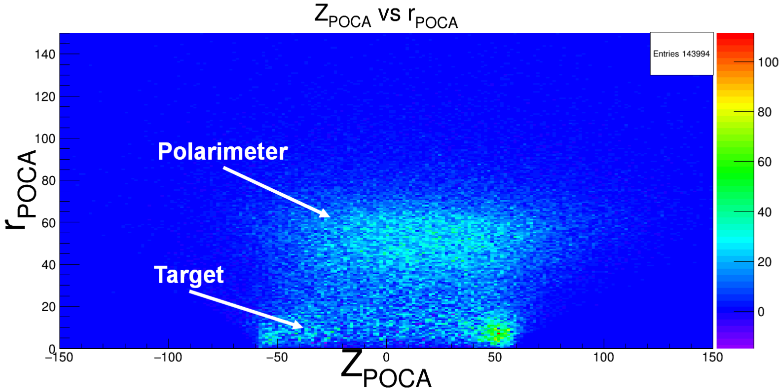
- From this a system of two equations with two unknowns, t_1 and t_2 can be created with solutions

$$t_1 = \frac{\Delta \underline{v} \cdot [\underline{\hat{u}}_1 - \underline{\hat{u}}_2(\underline{\hat{u}}_1 \cdot \underline{\hat{u}}_2)]}{(\underline{\hat{u}}_1 \cdot \underline{\hat{u}}_2)^2 - 1}$$

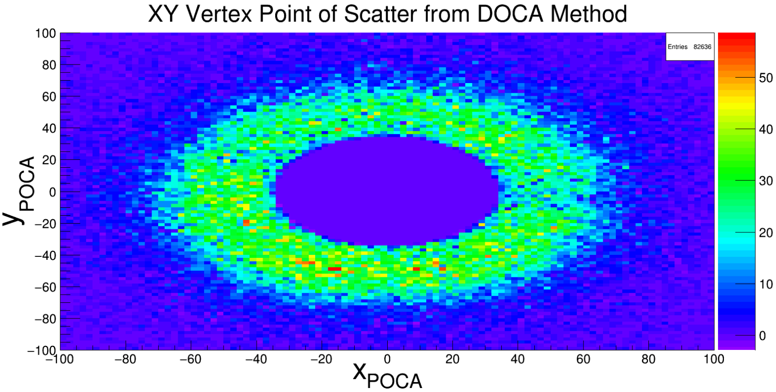
$$t_2 = \frac{\Delta \underline{v} \cdot [\underline{\hat{u}}_1(\underline{\hat{u}}_1 \cdot \underline{\hat{u}}_2) - \underline{\hat{u}}_2]}{(\underline{\hat{u}}_1 \cdot \underline{\hat{u}}_2)^2 - 1}$$

- This allows an interaction point to be defined, this is the **P**oint **O**f **C**losest **A**pproach (POCA)

Event Selection - DOCA



Event Selection - DOCA



Σ Determination

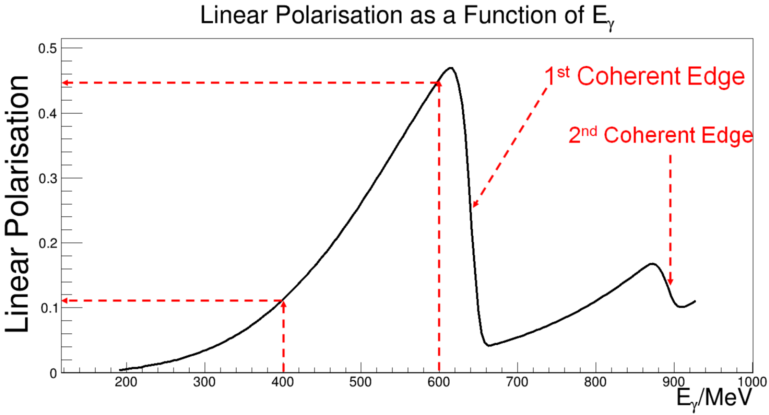
- Can extract Σ by forming the asymmetry

$$\frac{N^{\parallel}(\phi_p) - N^{\perp}(\phi_p)}{N^{\parallel}(\phi_p) + N^{\perp}(\phi_p)} = P_{\gamma}^{lin}\Sigma\cos(2\phi_p)$$

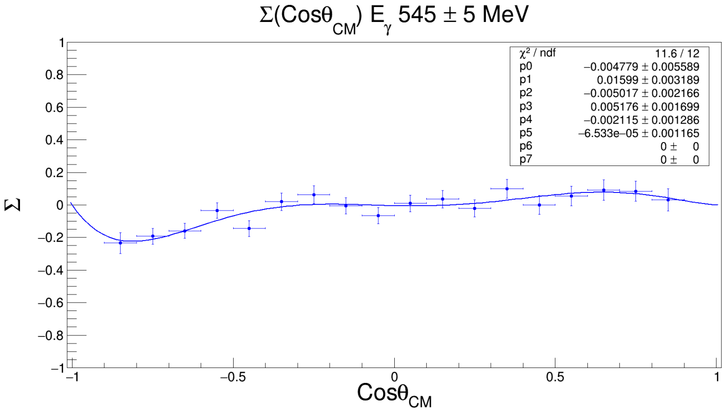
- i.e. $\cos(2\phi_m)$ asymmetry of amplitude $P_{\gamma}^{lin}\Sigma$ between two linear polarisations

- Note that this is **not** a recoil observable, can look at pn events with no scattering

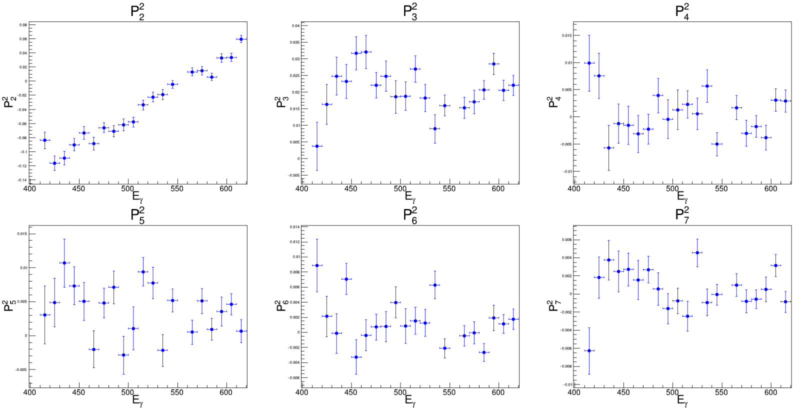
Σ - Linear Polarisation



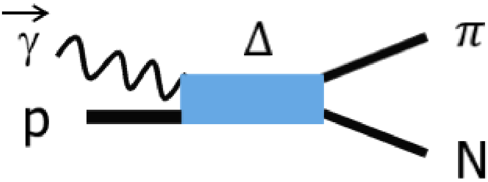
Σ - Interpretation/Analysis



Σ - Interpretation/Analysis



Σ - Quadrupole Deformation



- $\gamma N \rightarrow \Delta$

M1 (1^+) Transition

or

E2 (2^+) Transition

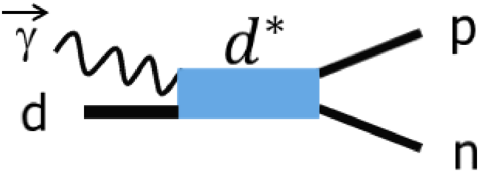
- E2/M1 Ratio given by

$$\frac{E2}{M1} = \frac{1}{2} k M_N \frac{\langle Q_{zz} \rangle_{N\Delta}}{\mu_{n\Delta}} \tag{1}$$

$$\frac{E2}{M1} = 2.5\% \tag{2}$$

Eq1 - T. Watabe et al. hep-ph 9502244 , Result in Eq2 - R. Beck et al. (MAMI-A2) Phys.Rev. C61 (2000) 035204

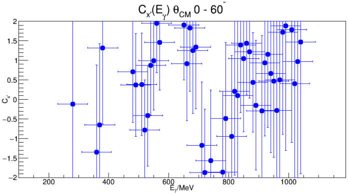
Σ - Quadrupole Deformation

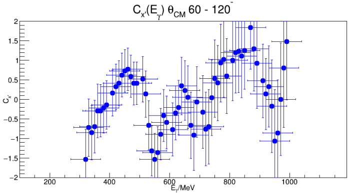


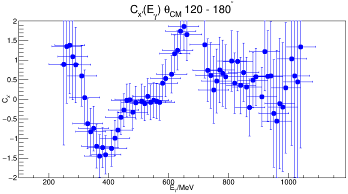
- $\gamma d \rightarrow$ d*

E2 (2^+) Transition
M3 (3^+) Transition
E4 (4^+) Transition

$C_{x'}$ - Energy Variation







$C_{x'}$ Determination

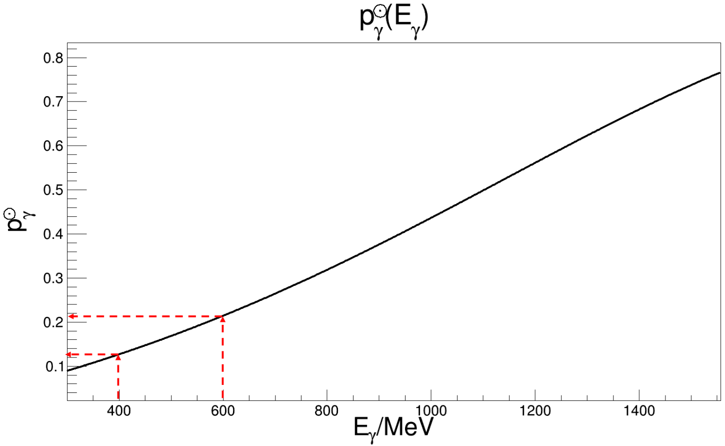
- In a similar manner can determine $C_{x'}$ by forming the asymmetry

$$\frac{N^-(\phi_{p'}) - N^+(\phi_{p'})}{N^-(\phi_{p'}) + N^+(\phi_{p'})} = \frac{A_{eff} P_\gamma^\odot C_{x'} \sin\phi_{sc}}{1 + A_{eff} P \cos\phi_{sc}}$$

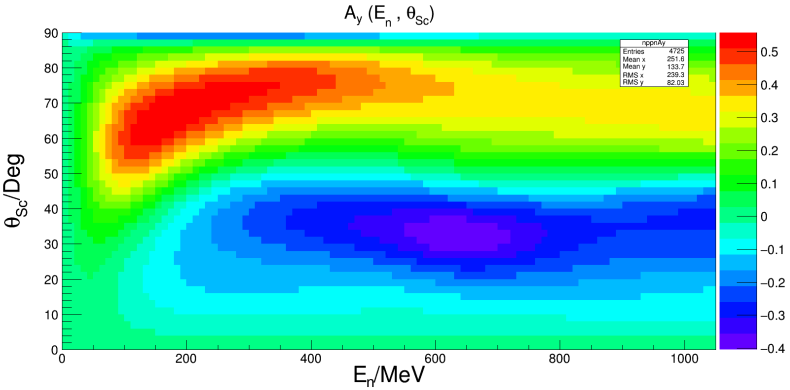
- A_{eff} is the effective analysing power of the charge exchange interaction

- $|A_{eff}| \sim 0.1 - 0.2$

$C_{x'}$ - Circular Polarisation



$C_{x'}$ - Analysing Power



$C_{x'}$ - Scattered Frame

- Asymmetry is also determined for the angle ϕ_{sc}