Measurements of J/ψ Polarization Observables with RG-A and RG-C datasets

Kayleigh Gates, Pierre Chatagnon, Bryan McKinnon, Kathleen Ramage, Richard Tyson



UNIVERSITY of York





University of Glasgow



Motivation

$$\langle N' \mid T^{\mu,\nu}_{q,g} \mid N \rangle = \bar{u}(N')\left(A_{g,q}(t)\gamma^{\{\mu}P^{\nu\}} + B_{g,q}(t)\frac{iP^{\{\mu}\sigma^{\nu\}}\rho\Delta_{\rho}}{2M} + C_{g,q}(t)\frac{\Delta^{\mu}\Delta^{\nu} - g^{\mu\nu}\Delta^{2}}{M} + \bar{C}_{g,q}(t)Mg^{\mu\nu} \right) u(N)$$

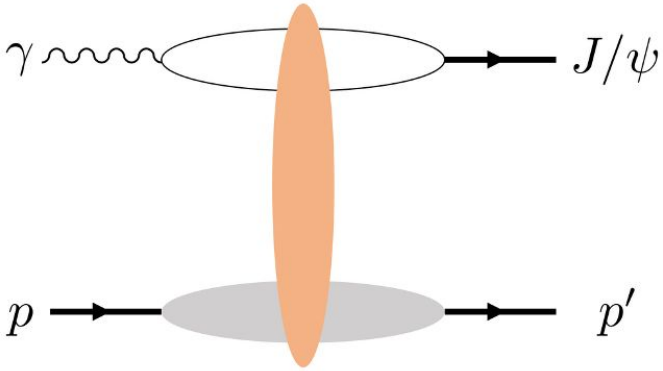
- Matrix elements of the proton's **Energy-Momentum Tensor (EMT)** can be parameterised in terms of **Gravitational Form Factors (GFFs)**
- The gluonic GFFs provide information on the momentum (A(t)) and total angular momentum (A(t), B(t)) distributions and, pressure and shear (C(t)) forces in the proton.
- GFFs accessible through measurements of the differential cross-section of J/ψ with respect to *t* in the near threshold region.

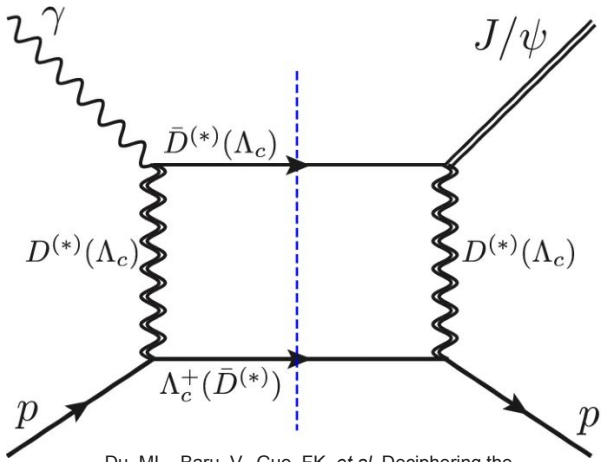
Motivation

The J/ψ near-threshold production mechanism is still a point of contention

No factorization has been proven for this process, preventing a proper interpretation in terms of gluonic content

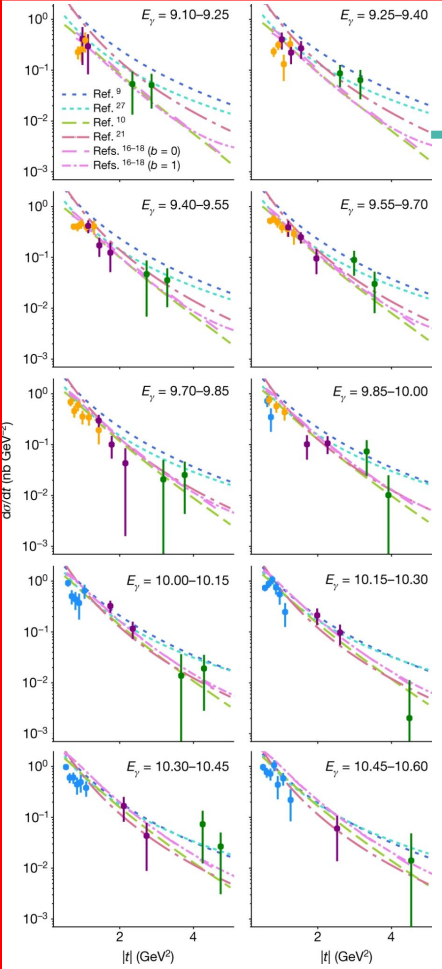
- A **two-gluon exchange** would give access to the **gluonic mechanical properties** of the target
- The 2015 and 2019 LHCb **Pentaquarks** have not been observed in photoproduction experiments
- Suggested **intermediate open-charm states**, pomeron exchange, meson exchange…





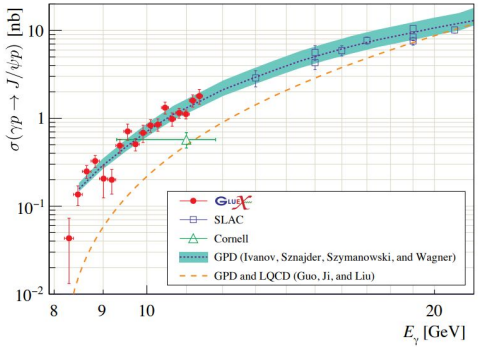
Du, ML., Baru, V., Guo, FK. *et al.* Deciphering the mechanism of near-threshold photoproduction. *Eur. Phys. J. C* 80, 1053 (2020). https://doi.org/10.1140/epjc/s10052-020-08620-5

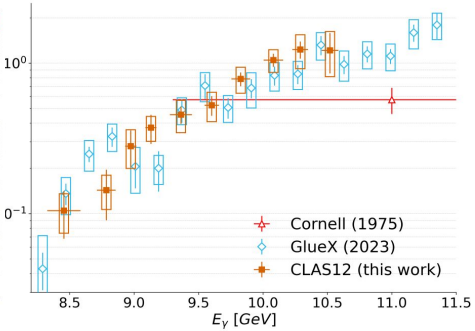
Previous Measurements



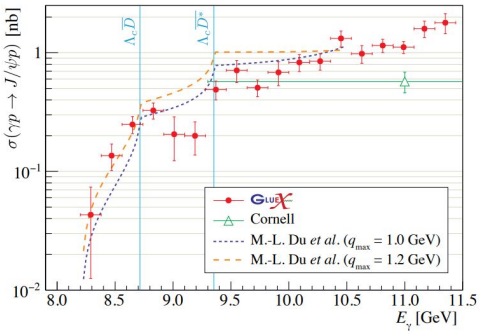
Duran, B., et al. "Determining the gluonic gravitational form factors of the proton." *Nature* 615.7954 (2023): 813-816.

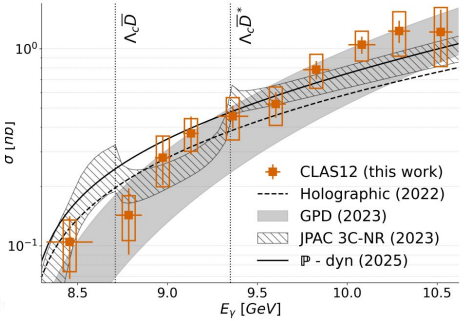
J/ψ photoproduction on free proton: Hall C, GlueX & CLAS12





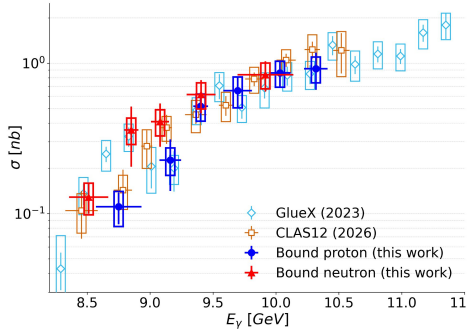
S. Adhikari et al., Phys. Rev. C 108, 025201 (2023), arXiv:2304.03845 [nucl-ex].

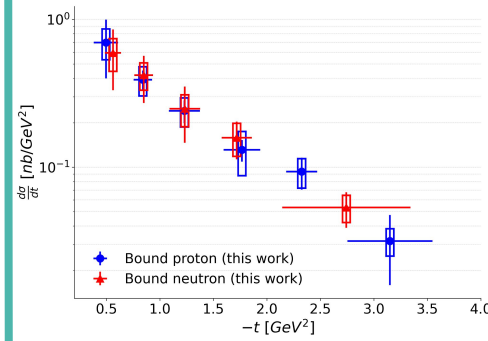




P. Chatagnon et al. (CLAS Collaboration), (2026), arXiv:2602.22128 [hep-ex].

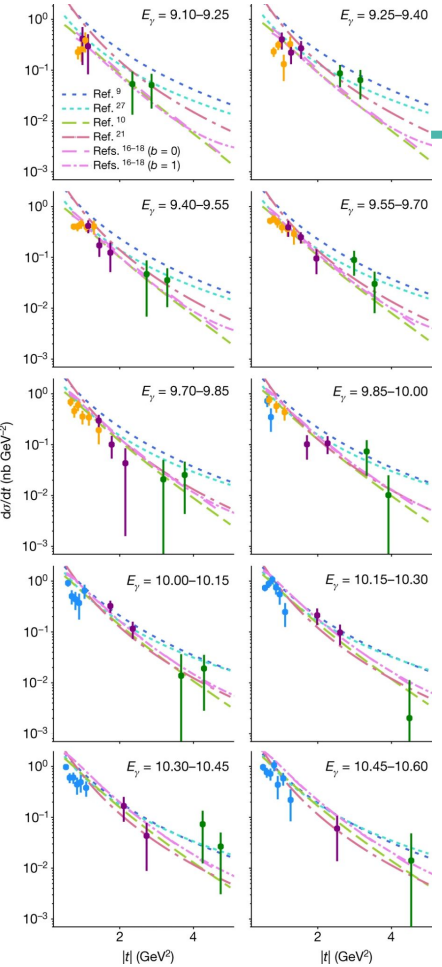
J/ψ photoproduction on bound p/n: CLAS12





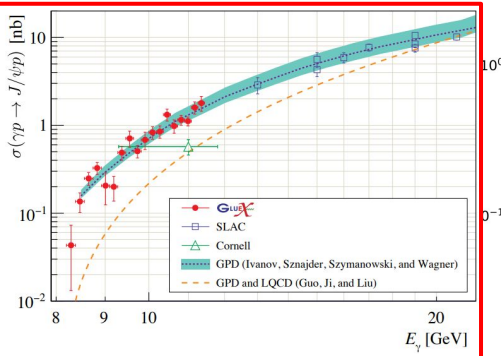
R.Tyson (2026), talk earlier this week

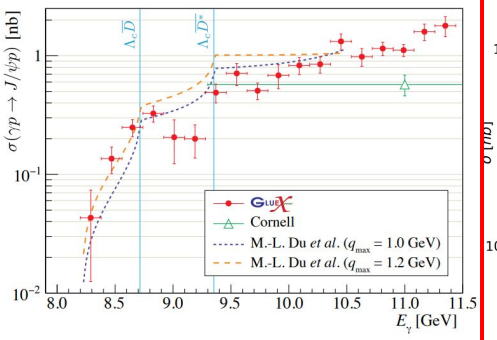
Previous Measurements



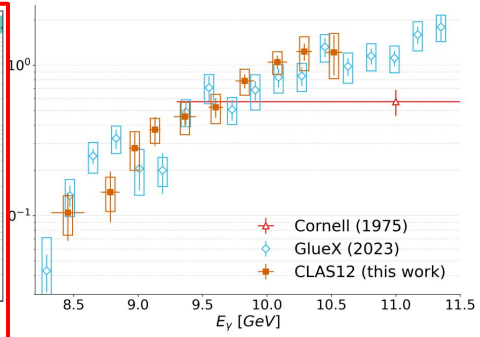
Duran, B., et al. "Determining the gluonic gravitational form factors of the proton." *Nature* 615.7954 (2023): 813-816.

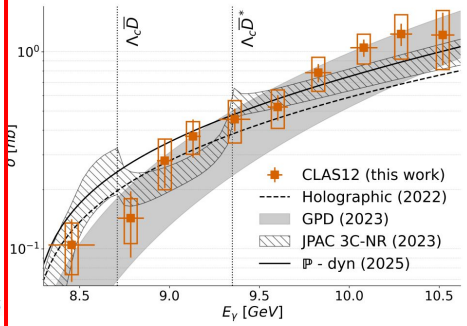
J/ψ photoproduction on free proton: Hall C, GlueX & CLAS12





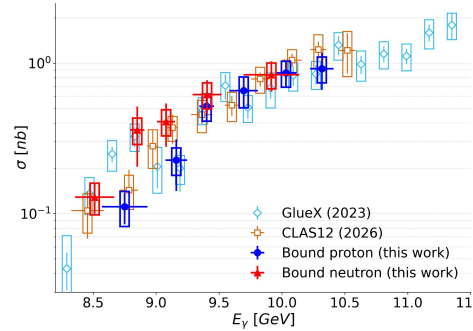
S. Adhikari et al., Phys. Rev. C 108, 025201 (2023), arXiv:2304.03845 [nucl-ex].

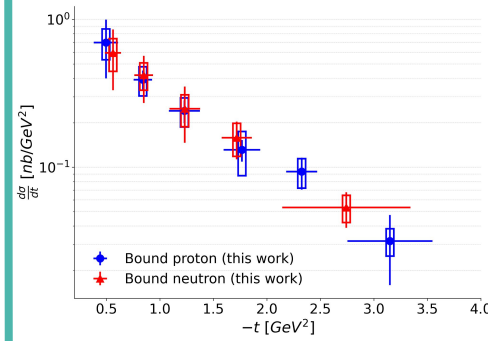




P. Chatagnon et al. (CLAS Collaboration), (2026), arXiv:2602.22128 [hep-ex].

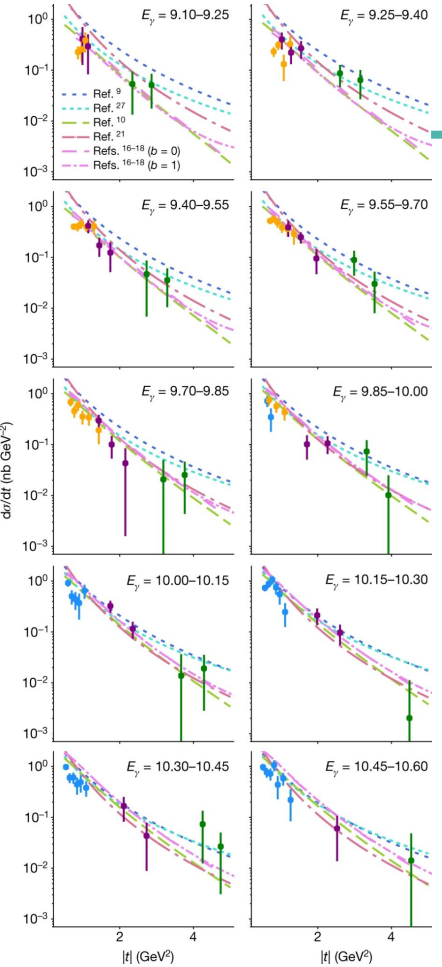
J/ψ photoproduction on bound p/n: CLAS12





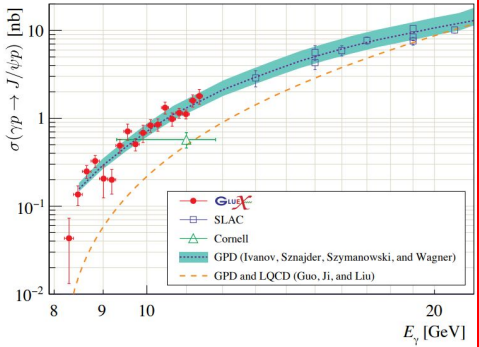
R.Tyson (2026), talk earlier this week

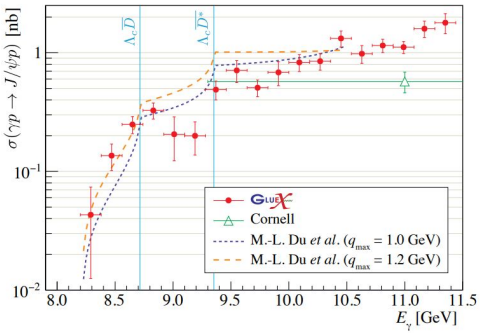
Previous Measurements



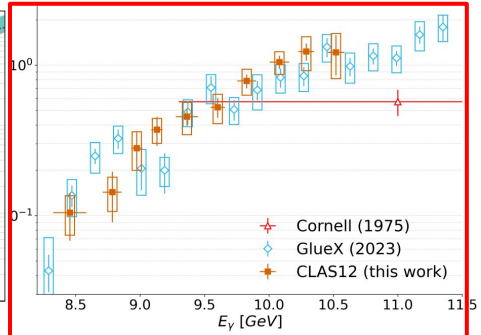
Duran, B., et al. "Determining the gluonic gravitational form factors of the proton." *Nature* 615.7954 (2023): 813-816.

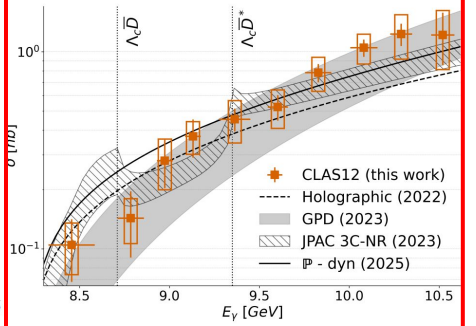
J/ψ photoproduction on free proton: Hall C, GlueX & CLAS12





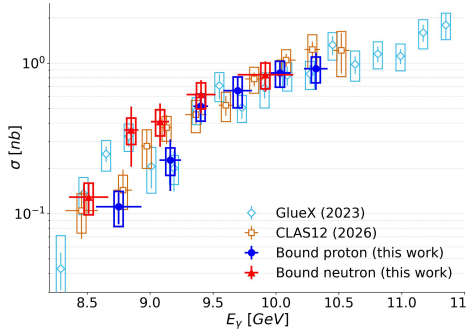
S. Adhikari et al., Phys. Rev. C 108, 025201 (2023), arXiv:2304.03845 [nucl-ex].

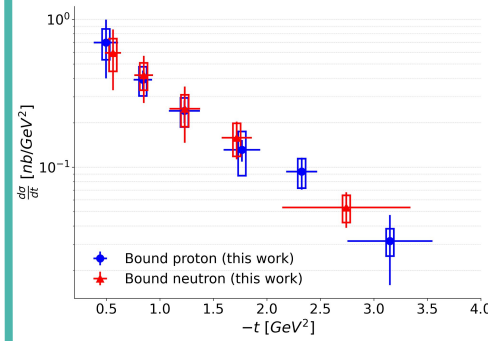




P. Chatagnon et al. (CLAS Collaboration), (2026), arXiv:2602.22128 [hep-ex].

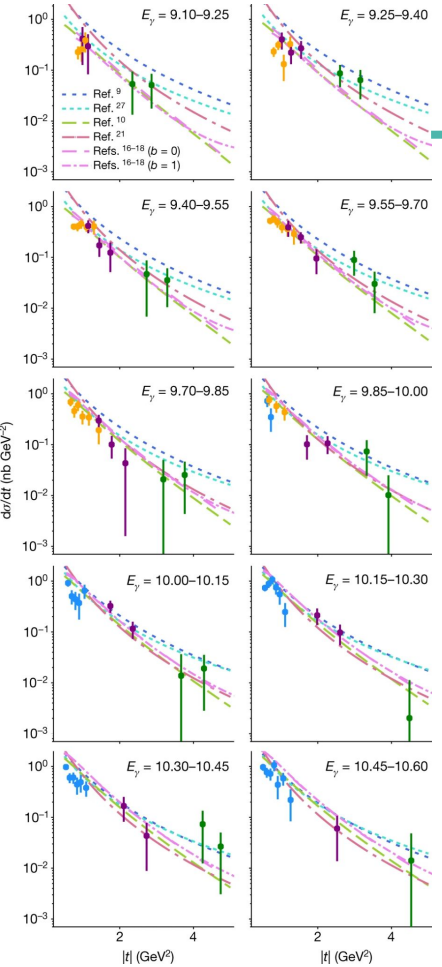
J/ψ photoproduction on bound p/n: CLAS12





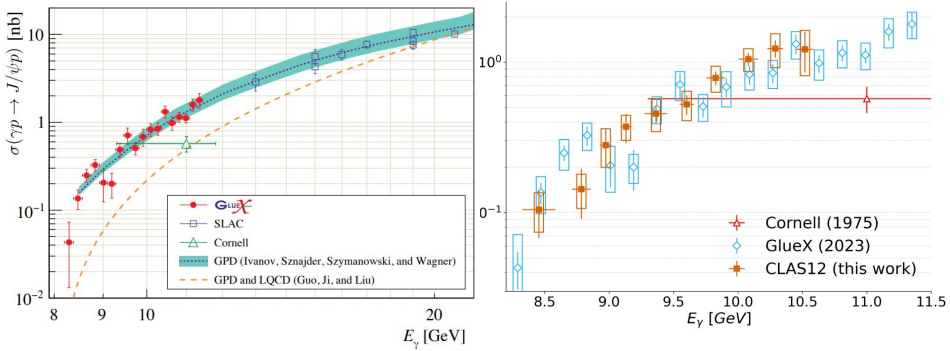
R.Tyson (2026), talk earlier this week

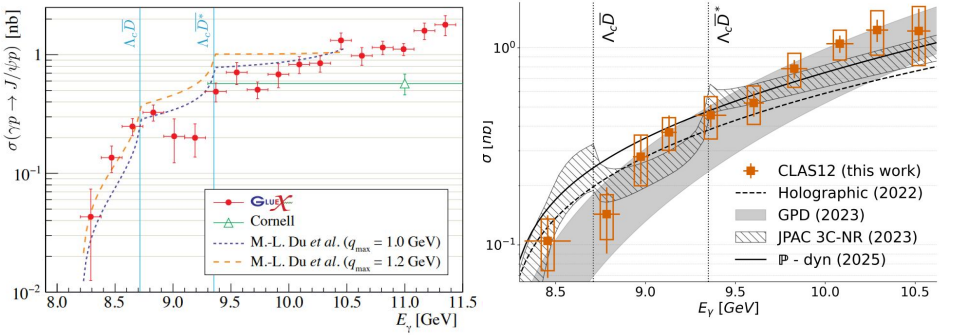
Previous Measurements



Duran, B., et al. "Determining the gluonic gravitational form factors of the proton." *Nature* 615.7954 (2023): 813-816.

J/ψ photoproduction on free proton: Hall C, GlueX & CLAS12

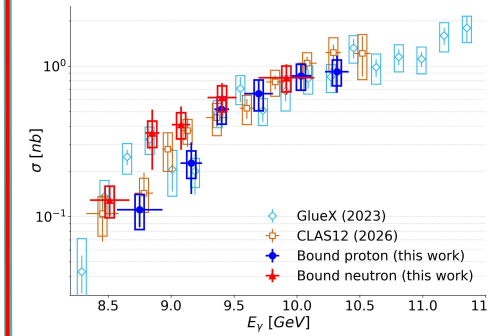


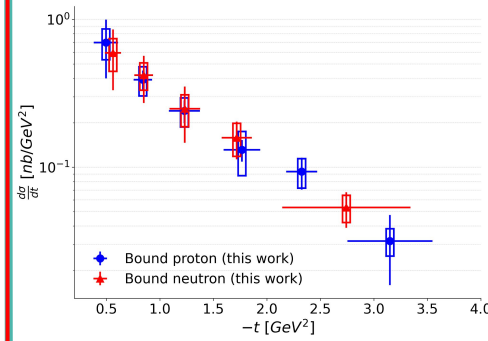


S. Adhikari et al., Phys. Rev. C 108, 025201 (2023), arXiv:2304.03845 [nucl-ex].

P. Chatagnon et al. (CLAS Collaboration), (2026), arXiv:2602.22128 [hep-ex].

J/ψ photoproduction on bound p/n: CLAS12





R.Tyson (2026), talk earlier this week

Polarisation Observables

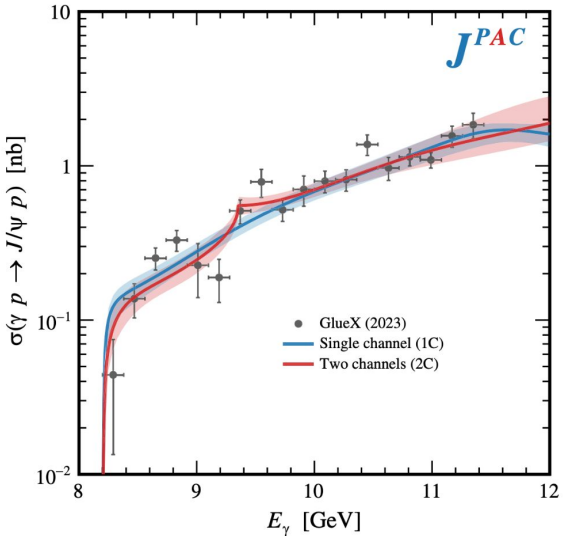
Existing cross section measurements do not have the statistical precision to distinguish production mechanisms.

Polarisation observables would help **disentangle production mechanisms**:

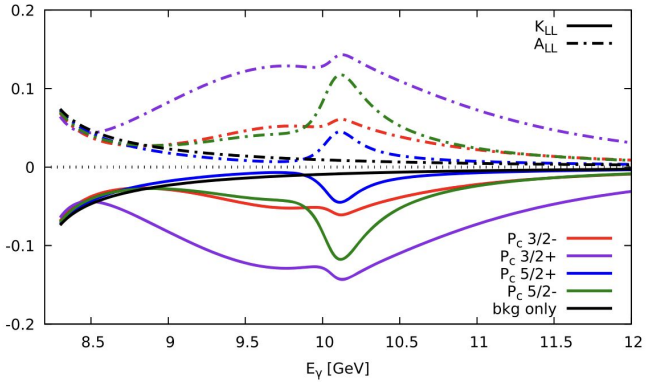
- BSA and unpolarised SDMEs in RG-A
- TSA, DSA in RG-C

JPAC Collaborators are currently **producing model predictions for polarisation asymmetries**, for various production mechanisms

- Expect 2-Gluon exchange to be flat



Winney, Daniel, et al. "Dynamics in near-threshold J/ψ photoproduction." *Physical Review D* 108.5 (2023): 054018.



Winney, Daniel, et al. "Double polarization observables in pentaquark photoproduction." *Physical Review D* 100.3 (2019): 034019.

Datasets

RG-A

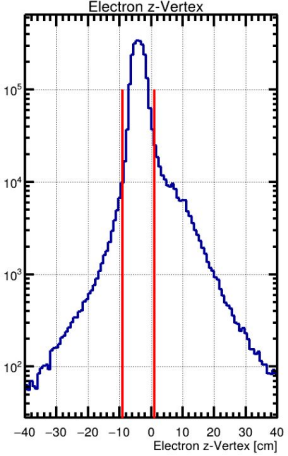
- **Liquid hydrogen target**
- Three run periods - Spring 2018, Fall 2018 and Spring 2019
  - 536 runs in Spring18 (388 inbending)
  - 353 runs in Fall18 (169 inbending)
  - 121 runs in Spring19 (all inbending)

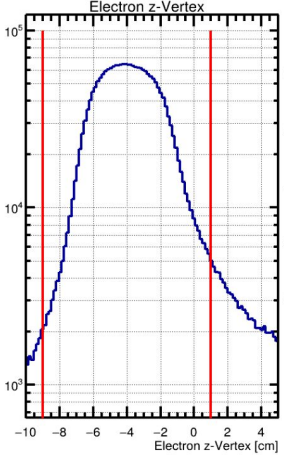
RG-C

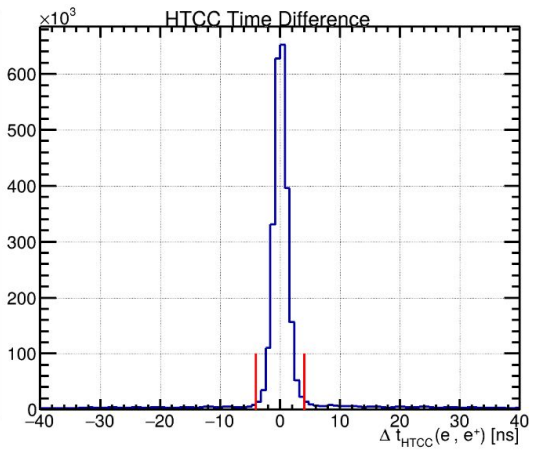
- **Longitudinally polarised target**
- Three run periods - Summer 2022, Fall 2022, Winter/Spring 2023
- Total of 334 good NH3 runs
- Runs taken on Carbon, CH2, Empty and Foils, across all three periods for dilution factor studies.

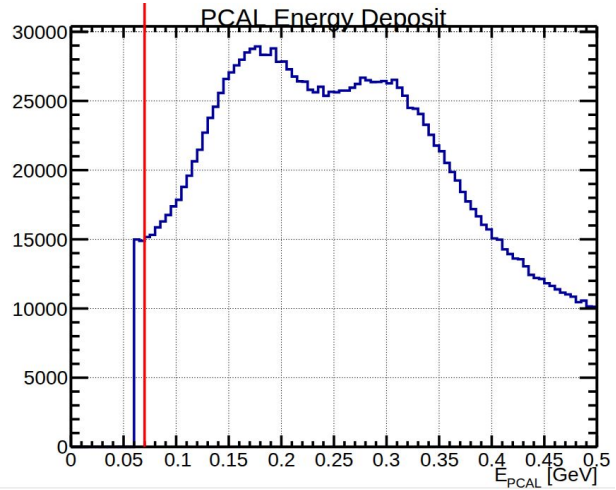
Fiducial cuts

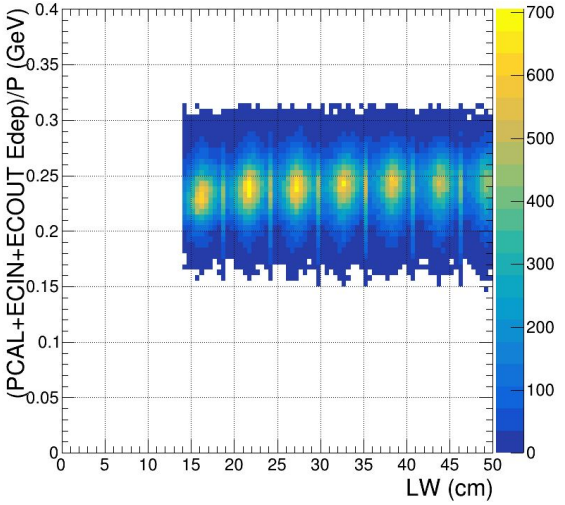
- -9cm < $|Vz_{e^-}|$ < 1cm (Summer)
- -7.5cm < $|Vz_{e^-}|$ < 2.5cm (Fall)
- $\Delta t_{HTCC}(e^+,e^-) < 4ns$
- $min_{EDep}(PCAL) > 0.07$ GeV
- if $p_{e+,e-} < 4.5$ GeV;
  $SF_{ECIN} > 0.15 - SF_{PCAL}$
- PCAL LW edge = 14 cm
- ECAL dead PMT strips cut
- RGA cuts follow those in the RGA Analysis note and procedures



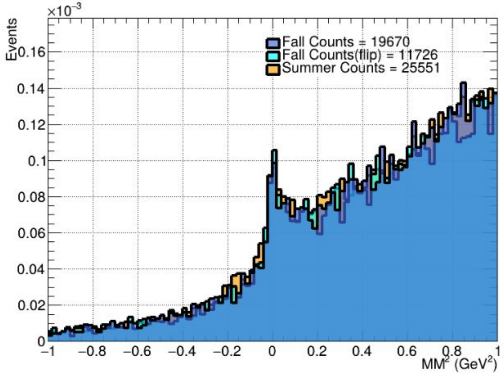


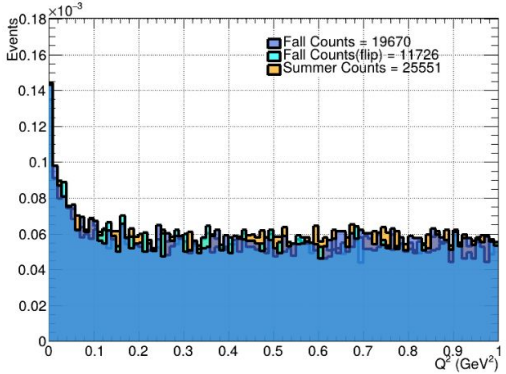


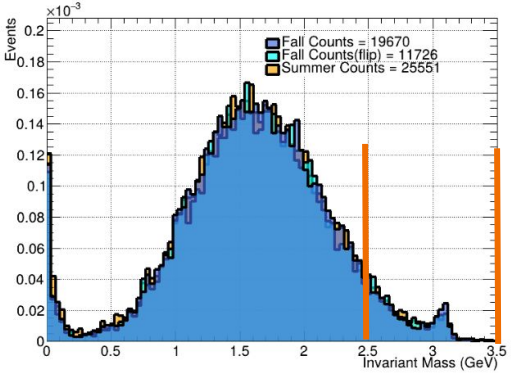




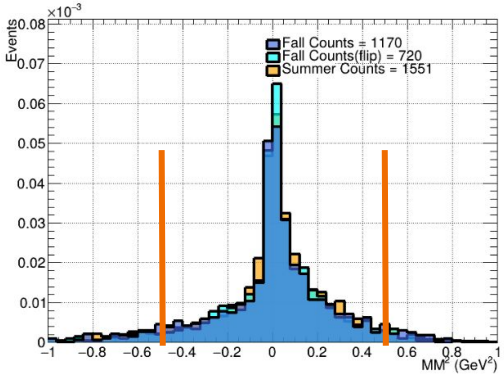
Exclusivity cuts

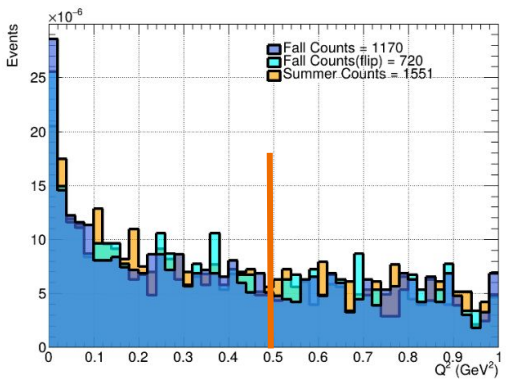


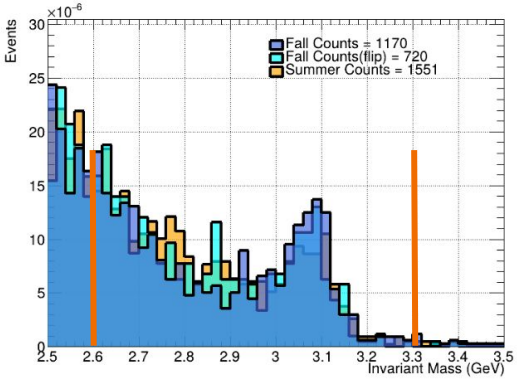




Pre cuts on M_{e+e-} invariant mass







Post cuts on M_{e+e-} invariant mass;

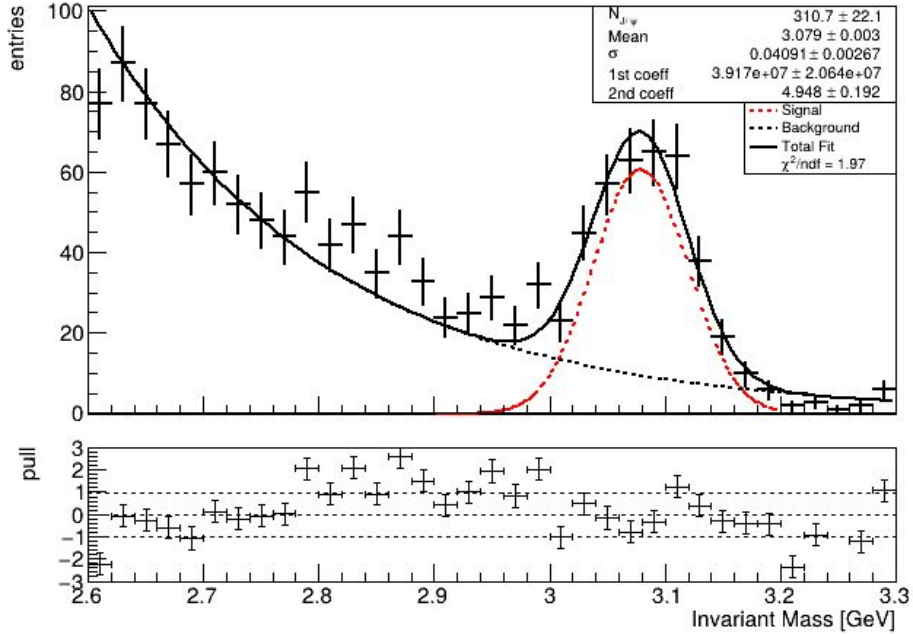
2.5 GeV< M_{e+e-} < 3.5 GeV

$|MM^2|$ < 0.5 GeV^2 and Q^2 < 0.5 GeV^2

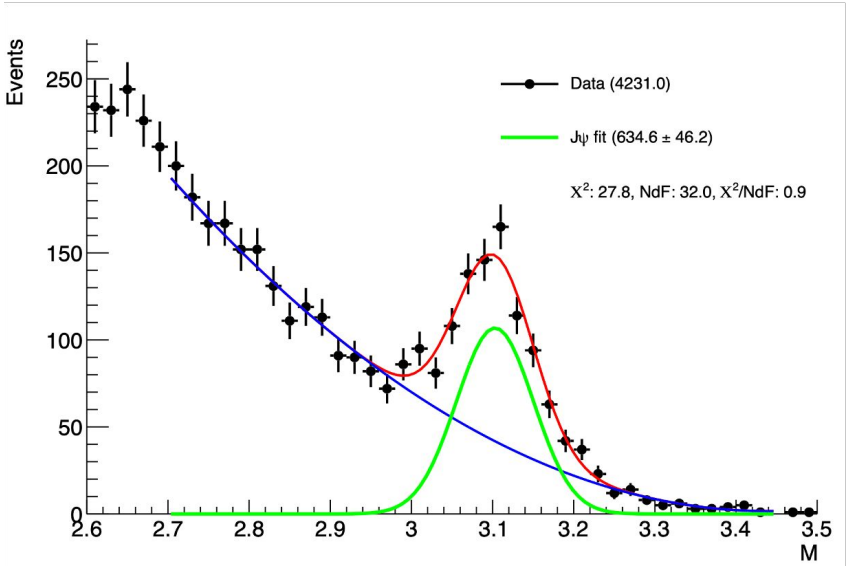
e+,e-, p' all in FD

Final state invariant mass

RGC Summer + Fall



RGA Fall18 (inbending & outbending) + Spring19



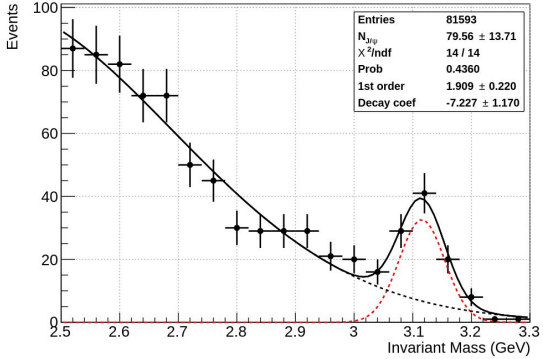
Study by P.Chatagnon

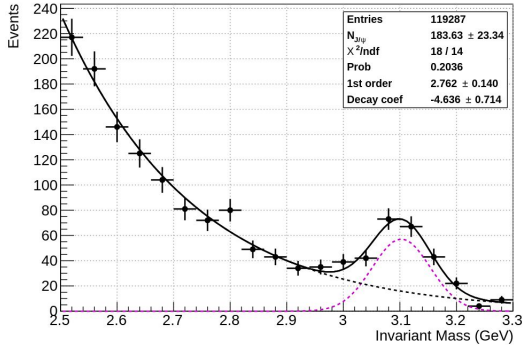
RGA

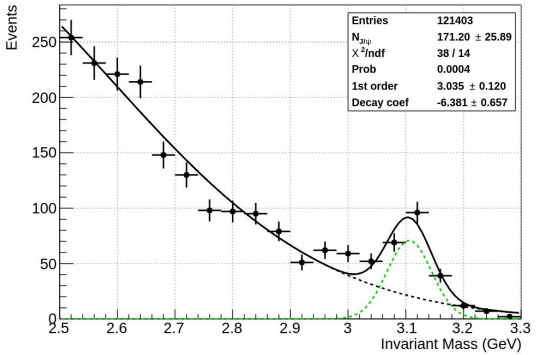
Studies by K.Ramage

Spring 2019 | Fall 2018 | Spring 2018

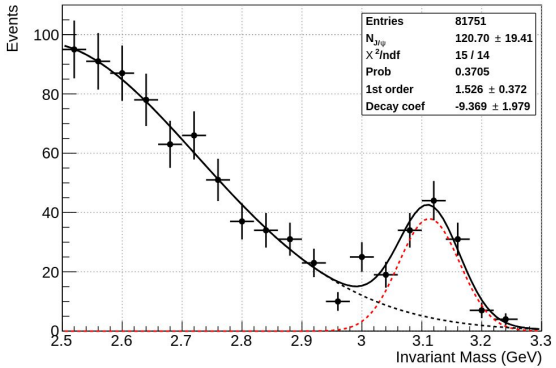
Positive helicity

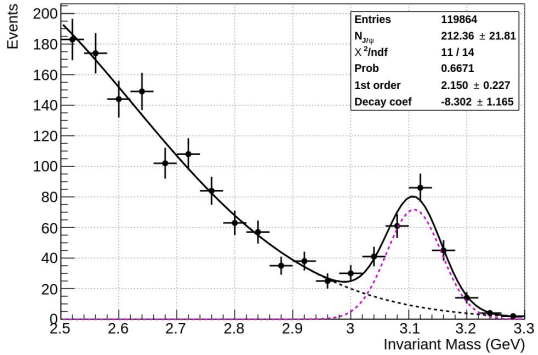


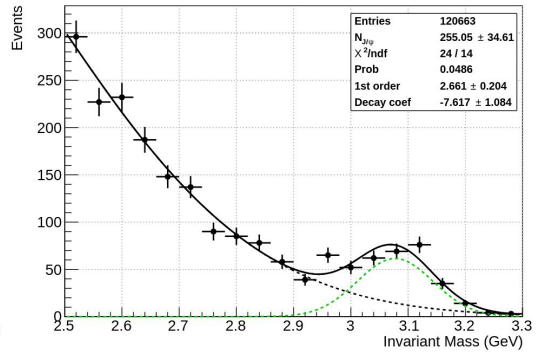




Negative helicity







Asymmetry Equations - Polarised target

BSA; $$A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{Pb \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

TSA; $$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

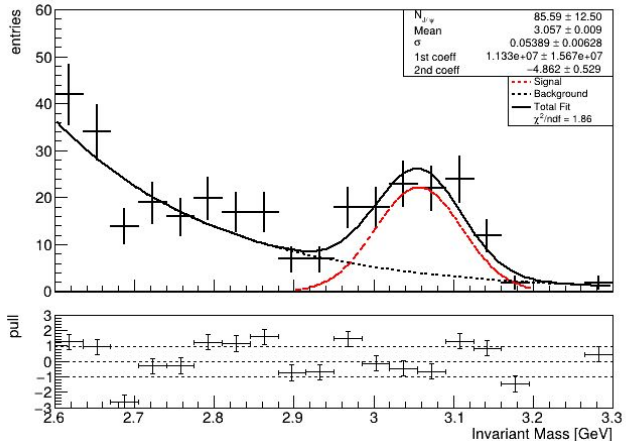
DSA; $$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_B \cdot D_f(P_T^-(N^{++} + N^{-+}) + P_T^+(N^{+-} + N^{--}))}$$

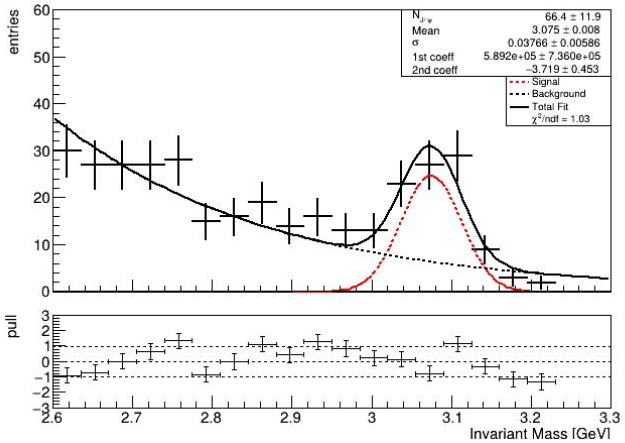
RGC

Summer

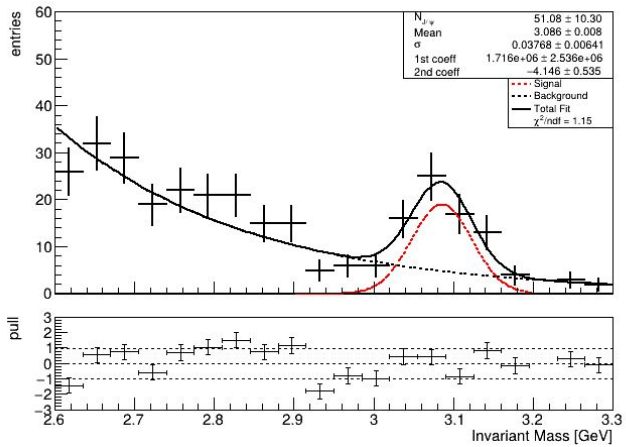
Fall

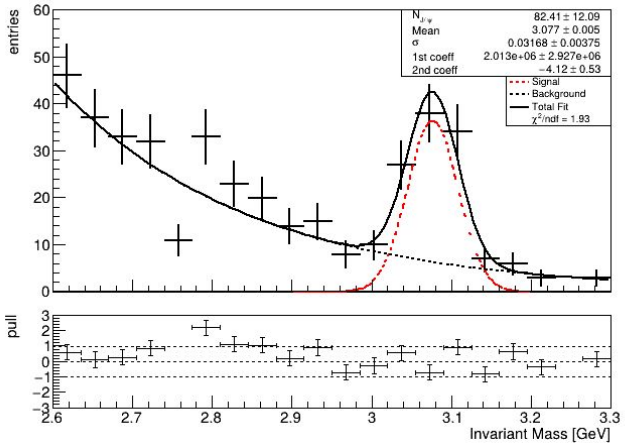
Positive helicity





Negative helicity



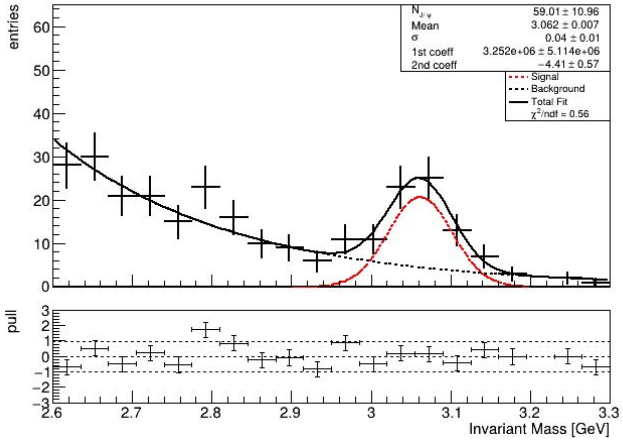


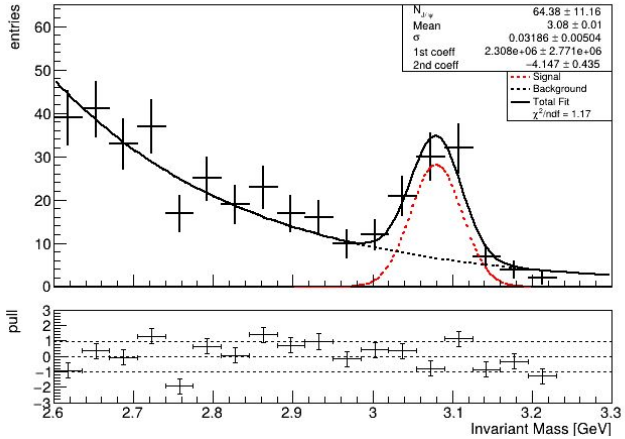
RGC

Summer

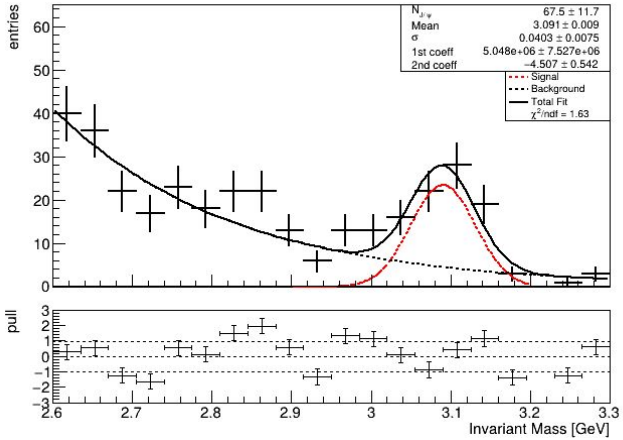
Fall

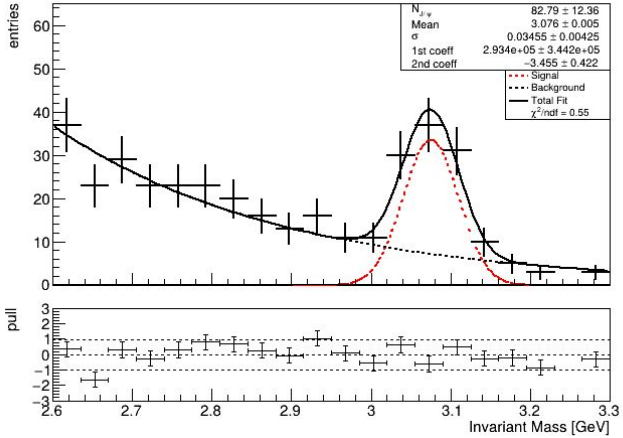
Positive Target pol



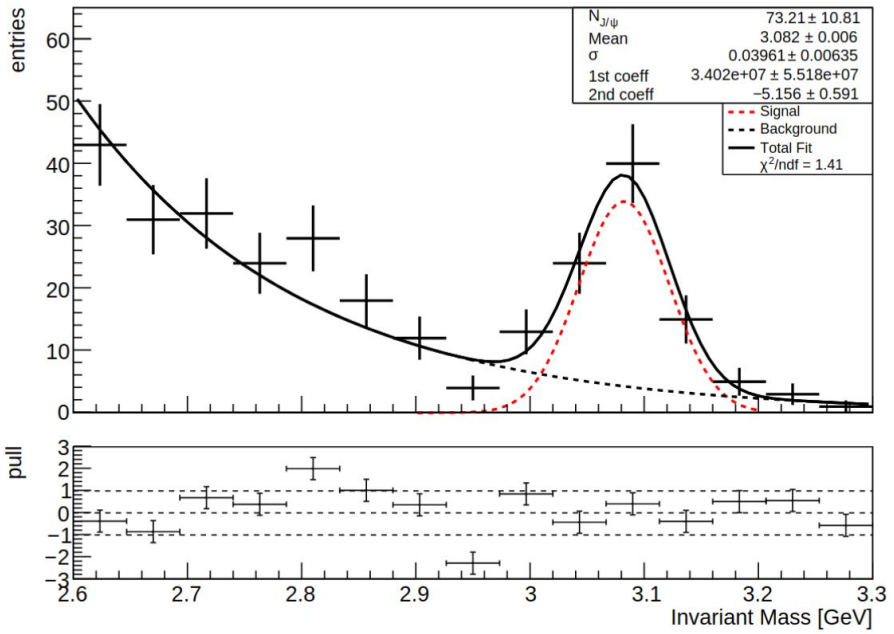


Negative Target pol

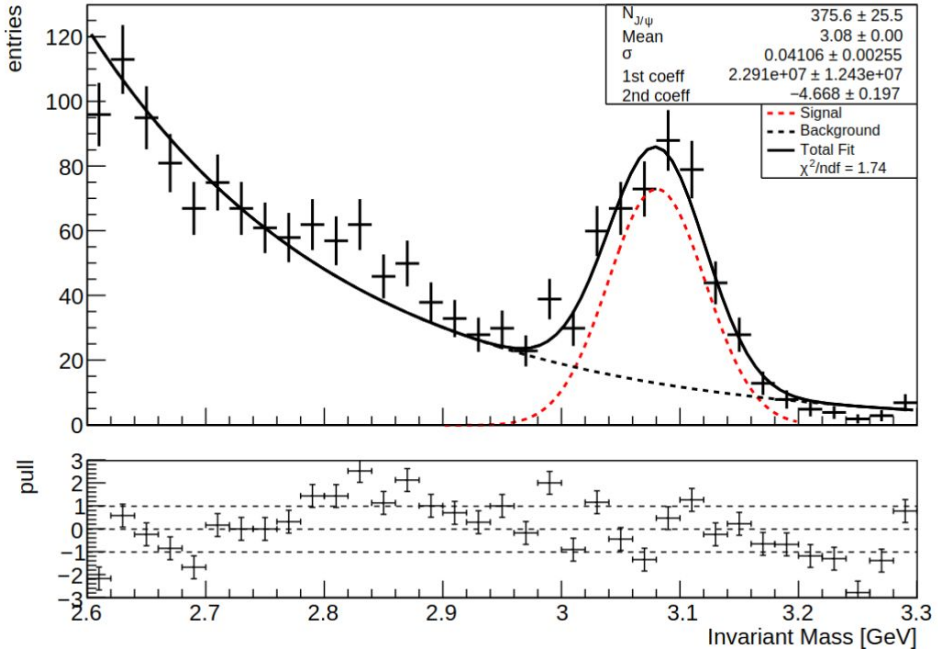




RGC Spring 2023



Summer + Fall + Spring

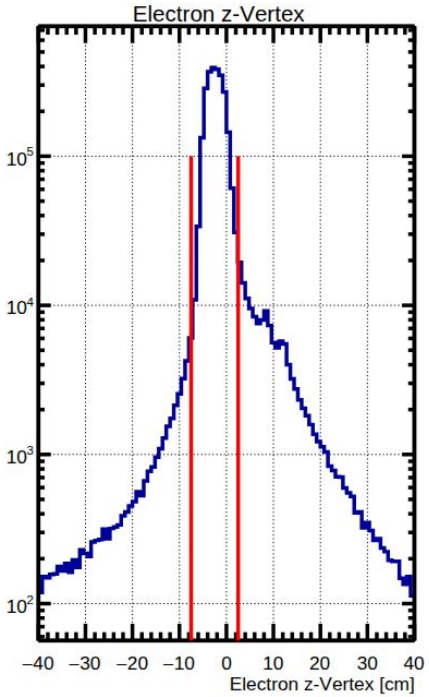


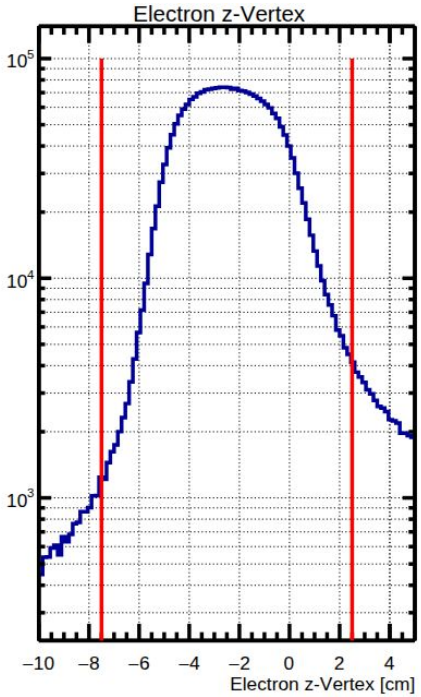
Summary

- **Polarisation observables** would help **disentangle production mechanisms**
- Ability to extract BSA and unpolarised SDMEs using RGA data
- Potential for extraction of both a TSA and DSA in RGC
- Clear peak at J/ψ invariant mass present for both datasets
- Asymmetry extraction in multiple bins looks promising

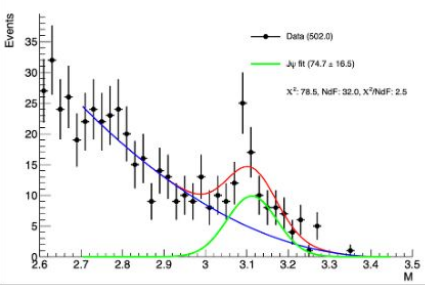
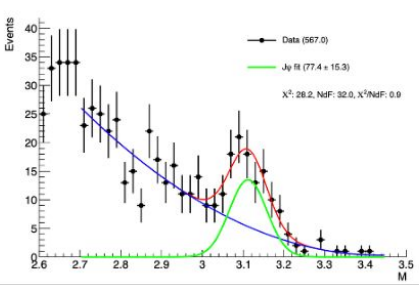
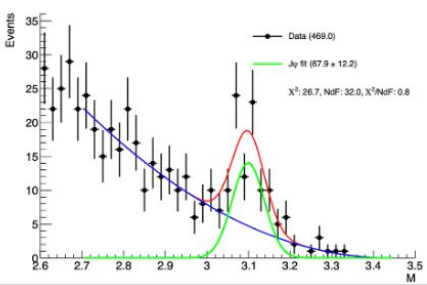
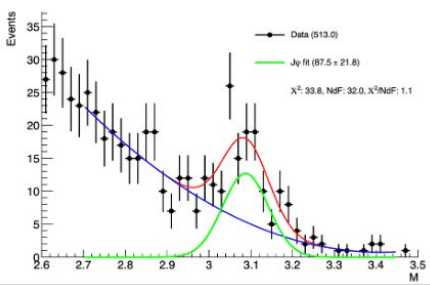
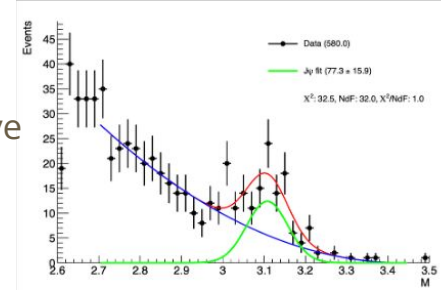
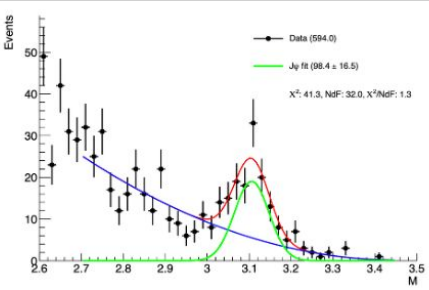
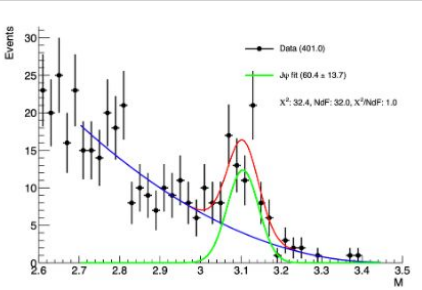
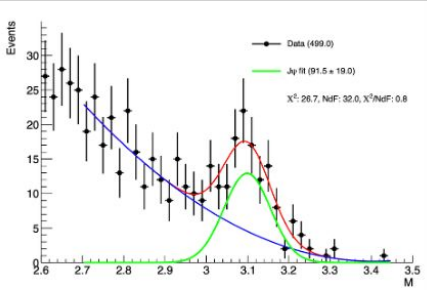
Thank you for your attention!
Questions?

Electron zVertex - Fall

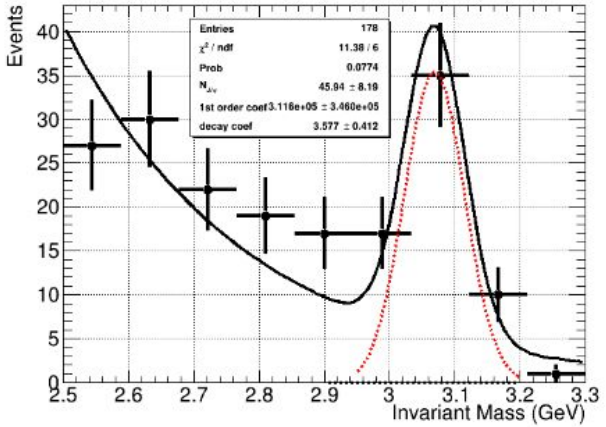




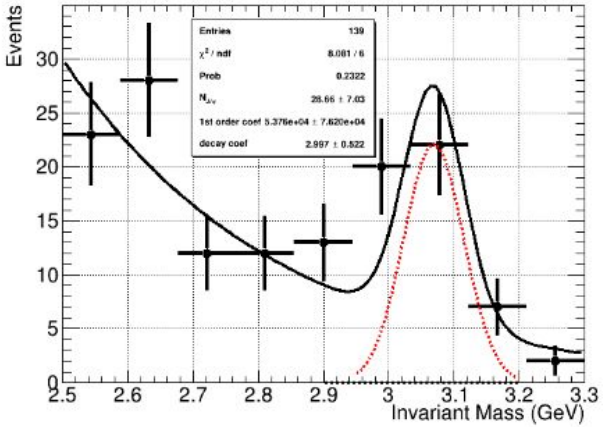
RGA

	-180° to -90°	-90° to 0°	0° to 90°	90° to 180°
Positive helicity				
Negative helicity				

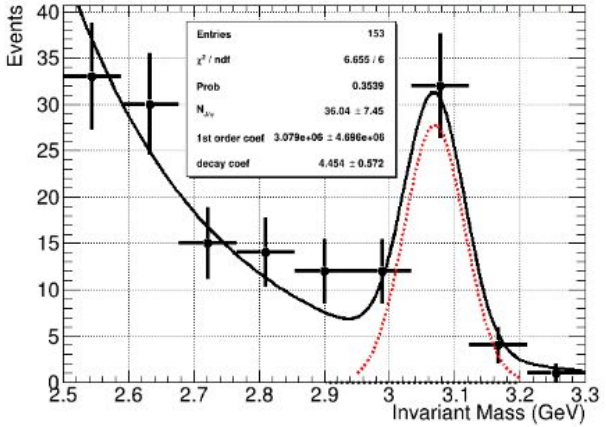
RGC



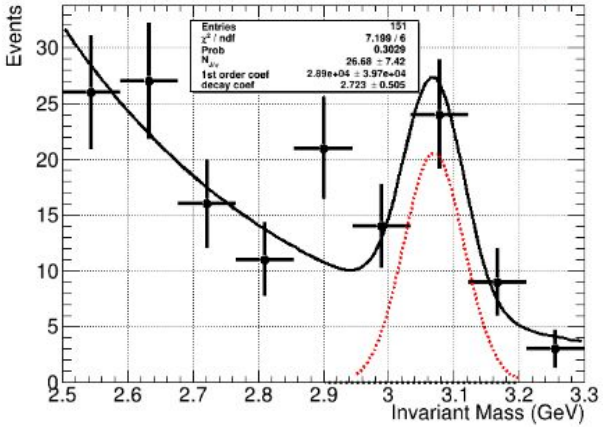
(a) Bin 1 ϕ -180° to -50° $P_b^+ P_T^+$



(b) Bin 1 ϕ -180° to -50° $P_b^+ P_T^-$

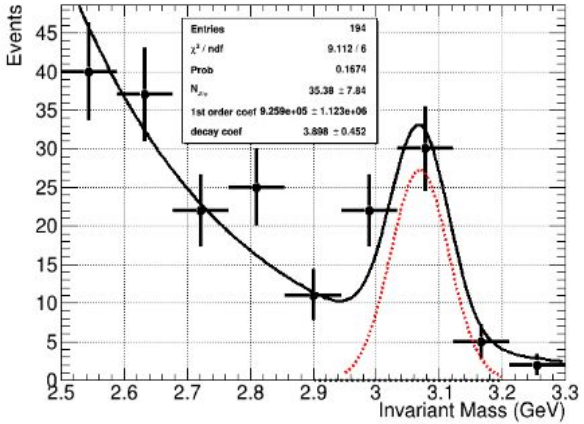


(c) Bin 1 ϕ -180° to -50° $P_b^- P_T^+$

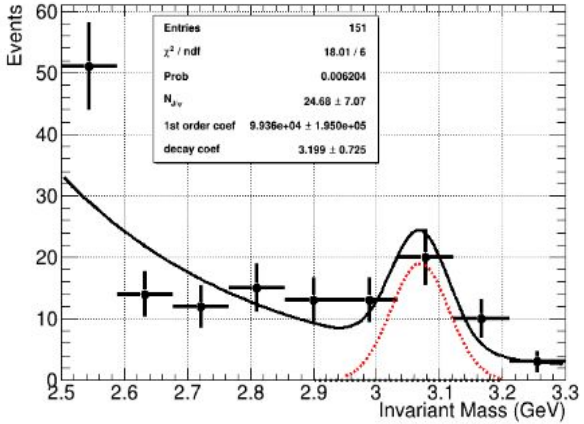


(d) Bin 1 ϕ -180° to -50° $P_b^- P_T^-$

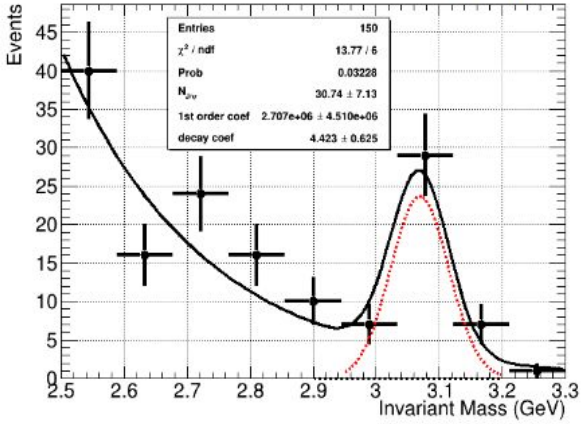
RGC



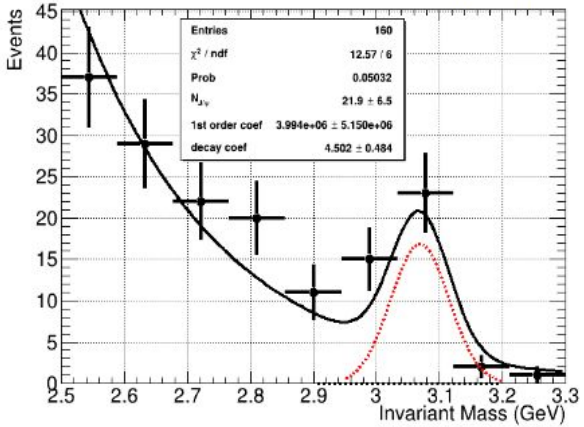
(a) Bin 1 ϕ -50° to 50° $P_b^+ P_T^+$



(b) Bin 1 ϕ -50° to 50° $P_b^+ P_T^-$

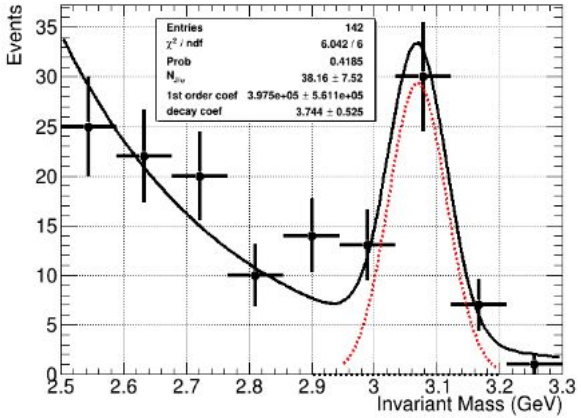


(c) Bin 1 ϕ -50° to 50° $P_b^- P_T^+$

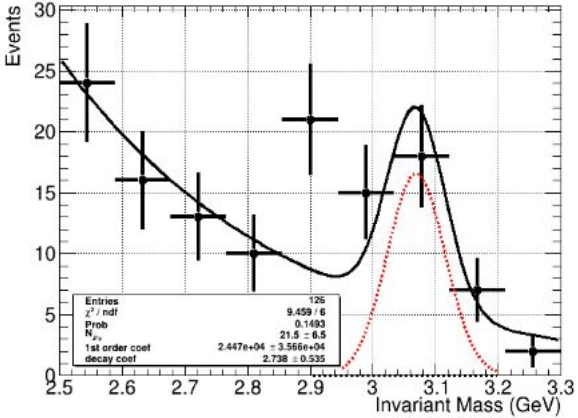


(d) Bin 1 ϕ -50° to 50° $P_b^- P_T^-$

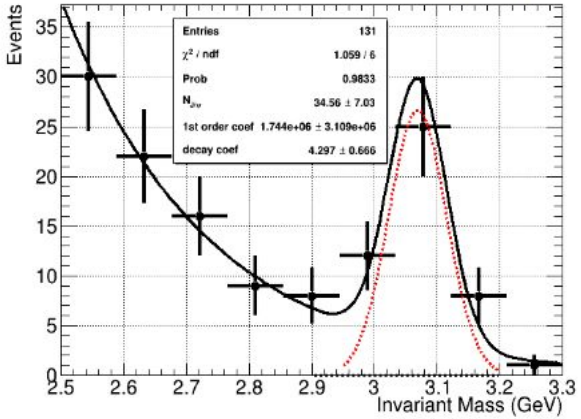
RGC



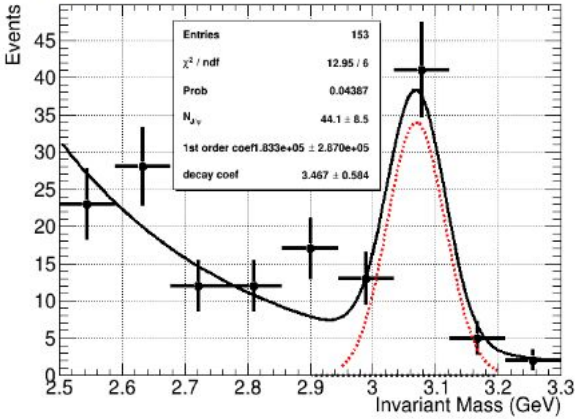
(a) Bin 1 ϕ 50° to 180° $P_b^+ P_T^+$



(b) Bin 1 ϕ 50° to 180° $P_b^+ P_T^-$

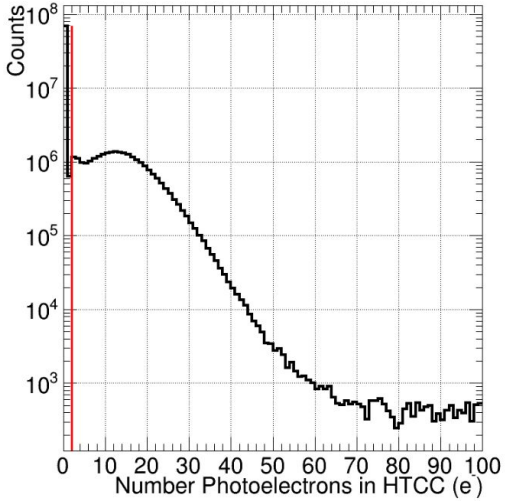


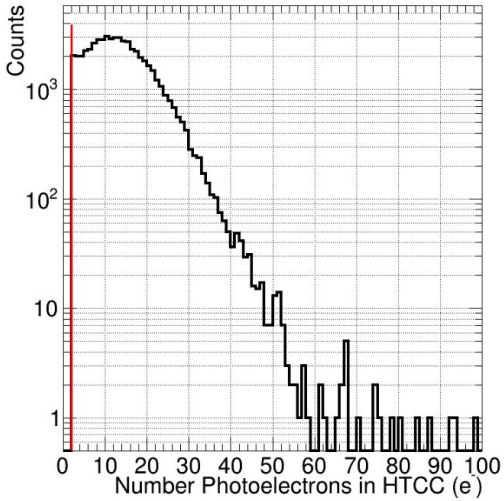
(c) Bin 1 ϕ 50° to 180° $P_b^- P_T^+$

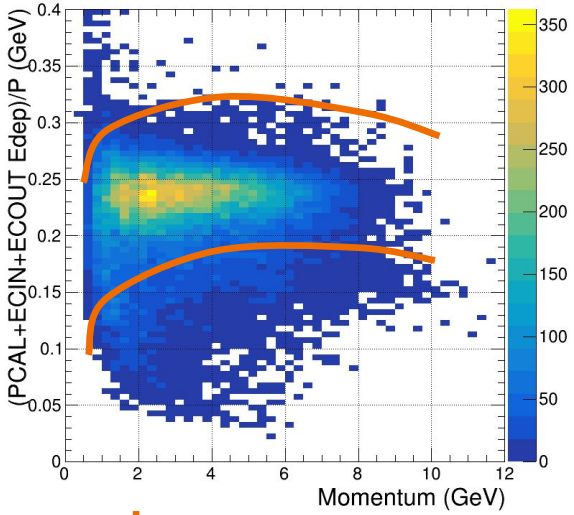


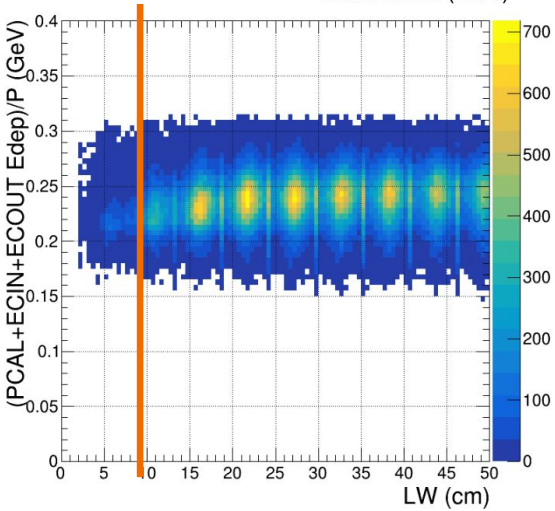
(d) Bin 1 ϕ 50° to 180° $P_b^- P_T^-$

Example of fiducual cuts RGC

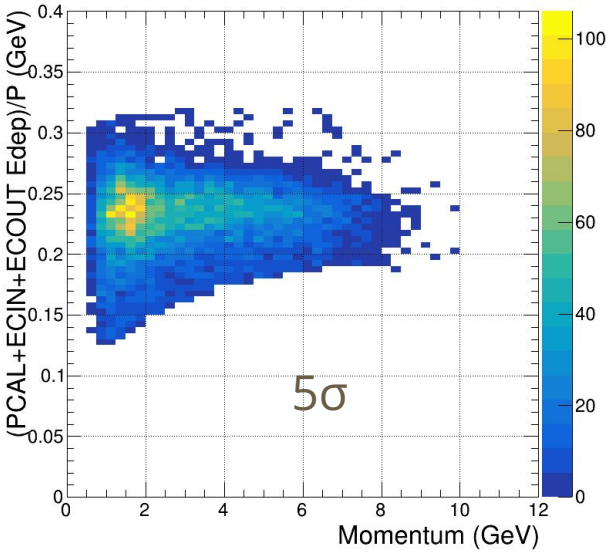


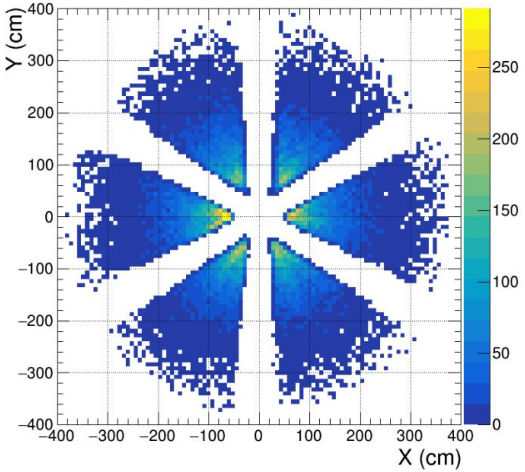


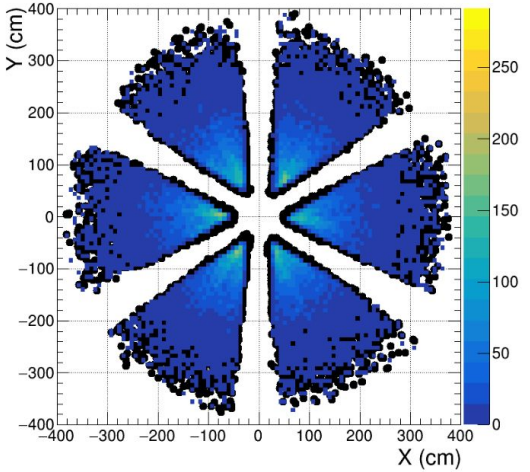


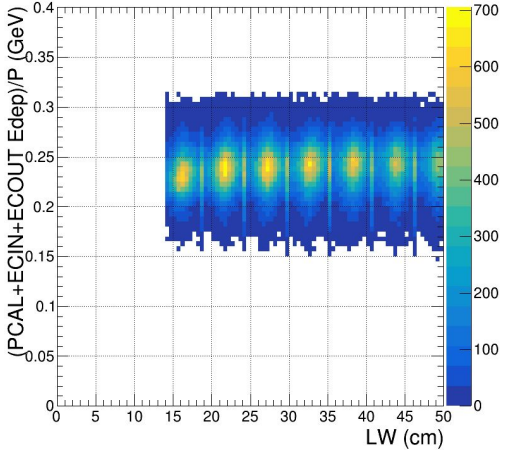


SF, PCAL, after cuts









Dilution Factor updated strategy

334 total ‘good’ NH3 runs across all 10.5GeV runs across all run periods - 69 Carbon, 61 CH2, 9 Foils, 6 Empty.

if statistics allow the following strategy is advised;

- Calculate Packing fraction (PF) once for each **run** epoch (Summer22, Fall22, Winter22/Spring23)
  - PF should be kinematics independent but plotting in different bins is a good cross check
  - This PF is then used for Dilution factor (DF) calculations for the whole run epoch
- Calculate the DF for each kinematic bin, check its dependance on epoch and kinematics

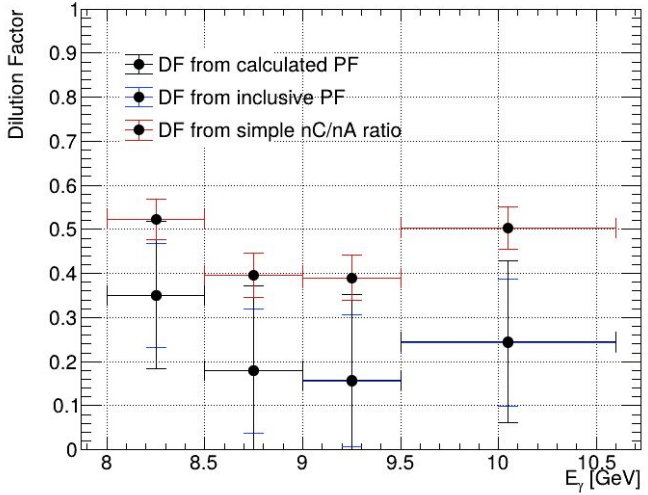
$$DF(PF) = PF\frac{3\rho_A(l_C L\rho_C(n_{CH}-n_{MT})+l_C l_{CH}(\rho_C-\rho_{CH})(n_{MT}-n_F)-l_{CH}L\rho_{CH}(n_C-n_{MT}))}{2l_C l_{CH}n_A\rho_C\rho_{CH}}$$

$$= \frac{3PF\rho_A}{2n_A\rho_C\rho_{CH}}\left(\frac{L}{l_{CH}}\rho_C(n_{CH}-n_{MT})+(\rho_C-\rho_{CH})(n_{MT}-n_F)-\frac{L}{l_C}\rho_{CH}(n_C-n_{MT})\right).$$

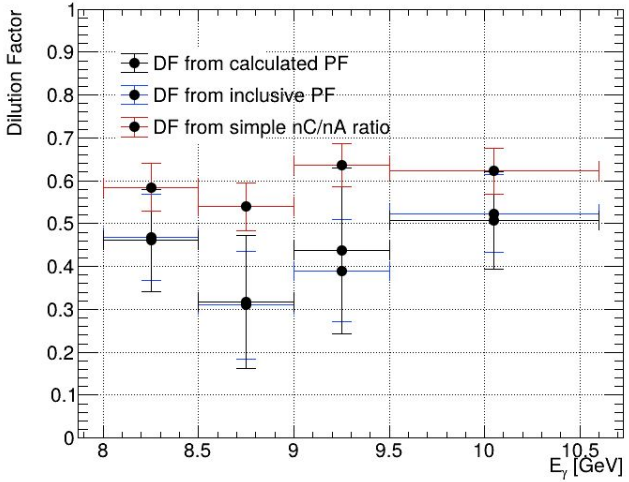
Subscript A, C, CH, MT, F refer to the ammonia, carbon, CH2, empty and empty with no liquid helium (i.e. foils) respectively.

n = number of events in kinematic bin per target.
ϱ = target density
ℓ = target length
L = length of ammonia cell or full target, depending on the calculation used

Summer



Fall pre-flip



Fall post-flip

