Investigating 3q and 6q systems with electromagnetic beams

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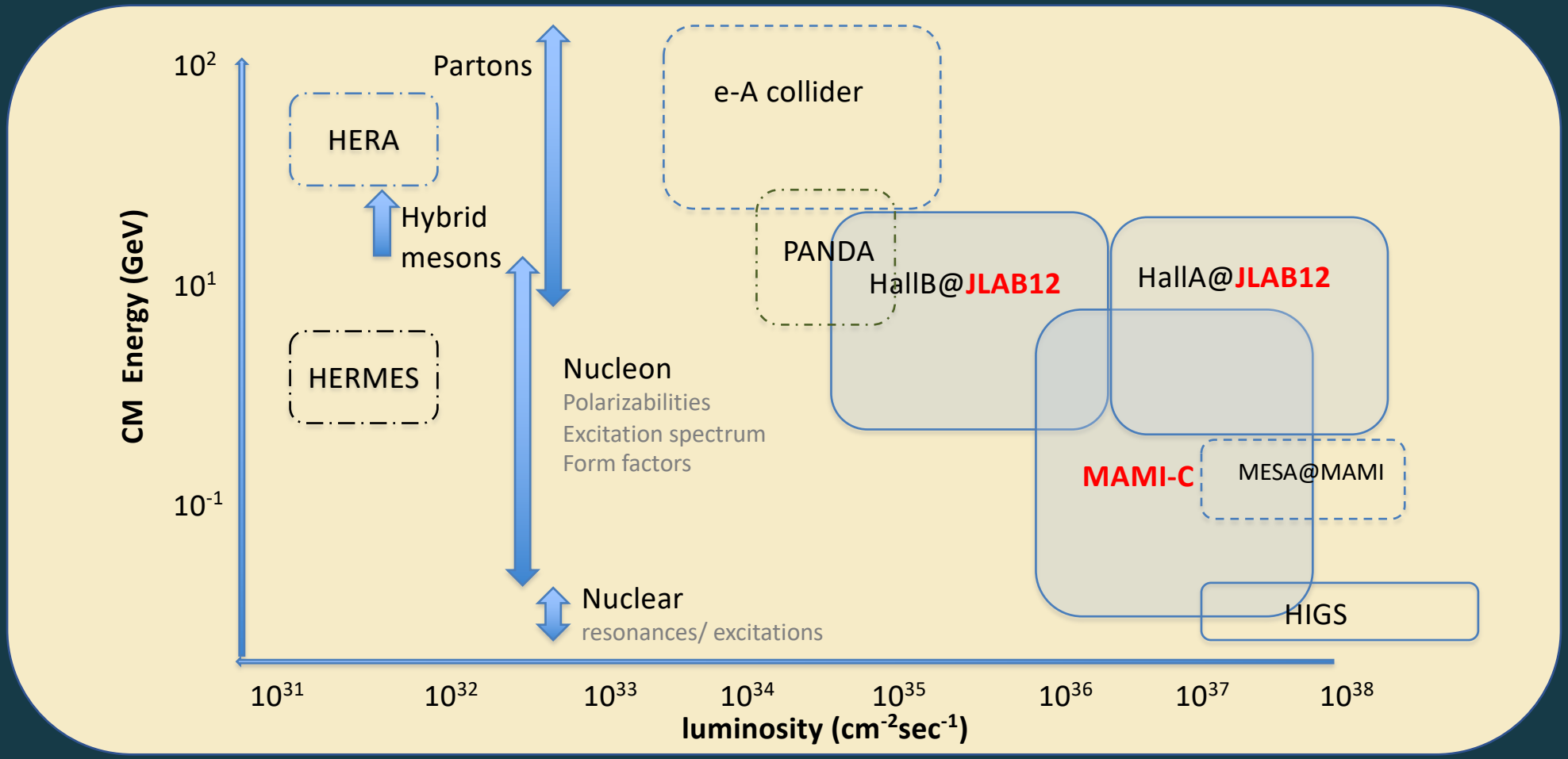
Overview

- The MAMI and JLAB facilities
- Recent results for constraining the N*
- The d*(2380) potential hexaquark
- Summary

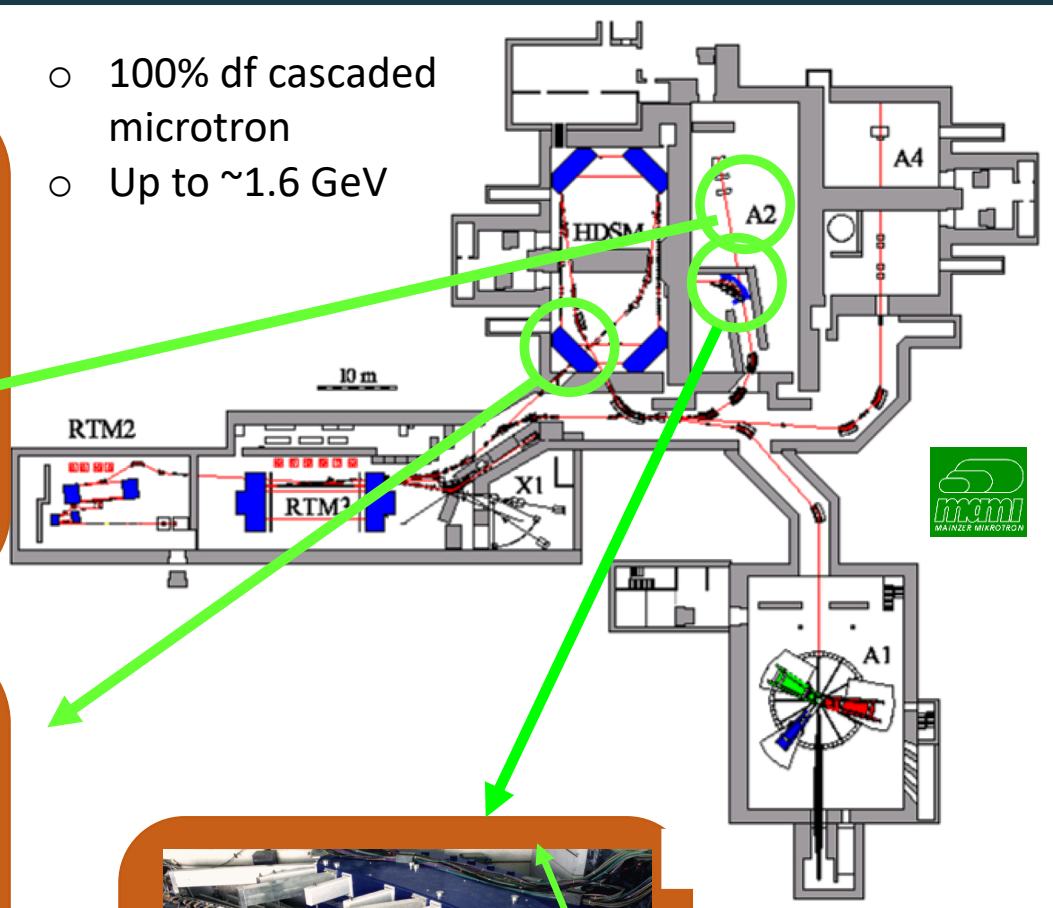
Overview of EM beam facilities



Plus others …

The MAMI-C facility

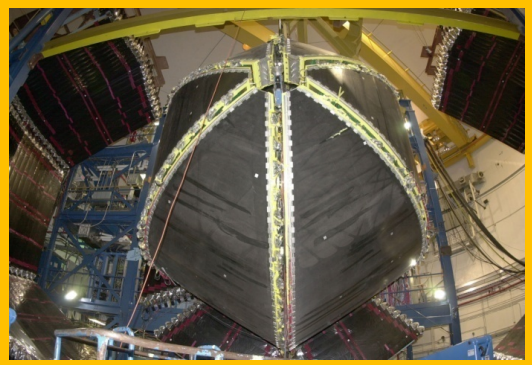
- 100% df cascaded microtron
- Up to ~1.6 GeV



Jefferson Lab

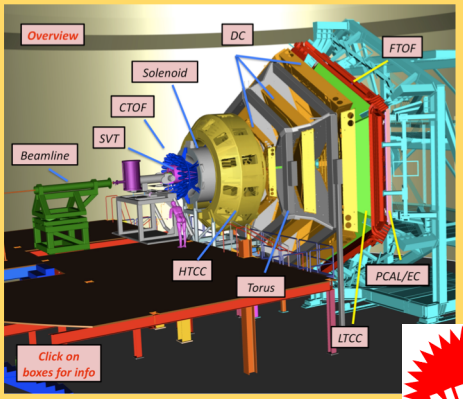
- 1.4km racetrack microtron
- Up to 12 GeV beam energy
- Recent addition of new hall (D)

clas
CEBAF Large Acceptance Spectrometer



- Multi layer, large acceptance (tracking, calorimetry, ToF)
- Near complete coverage in azimuthal angle, ~8-140° in polar

CLAS12



NEW!

- Designed for operation with upgraded 12 GeV beam
- Running since 2018 !
- Electron scattering and quasi-real γ beam

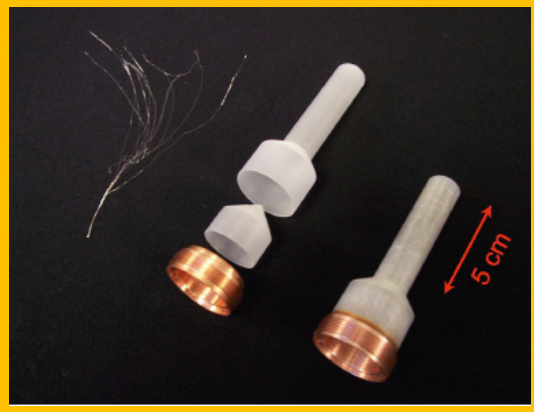
Targets at JLAB and MAMI

Frozen nucleon spin (DNP) targets

- Polarise via DNP: 70 GHz μwave @~2.5 T -> e^- polarization to p/d

- Holding coil ≈ 0.5T.
  Relaxation times ≈ 2000 hours

HDice target



- Polarise impurities (para H2,D2) ~ (10^{-4}) concentration
- Transfer to (ortho) HD (long relax time)

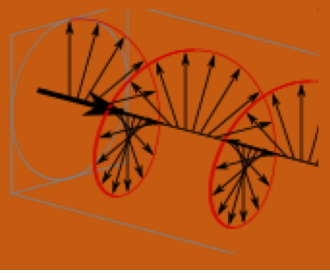
HDice

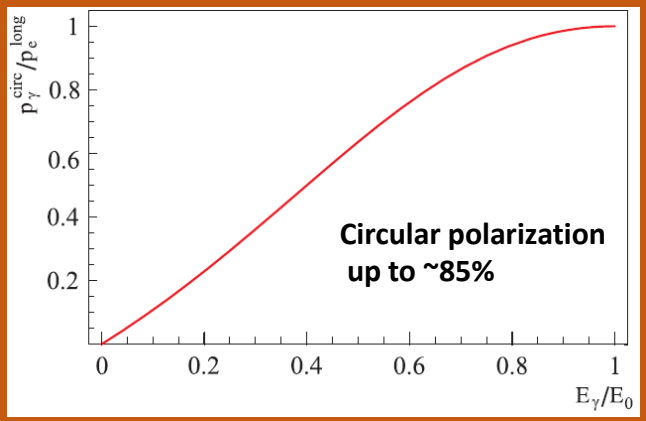
clas
CEBAF Large Acceptance Spectrometer

Polarised photon beams at JLAB and MAMI

Circular polarisation

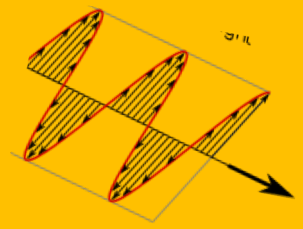
- Bremsstrahlung of longitudinally polarized e^- on amorphous radiator

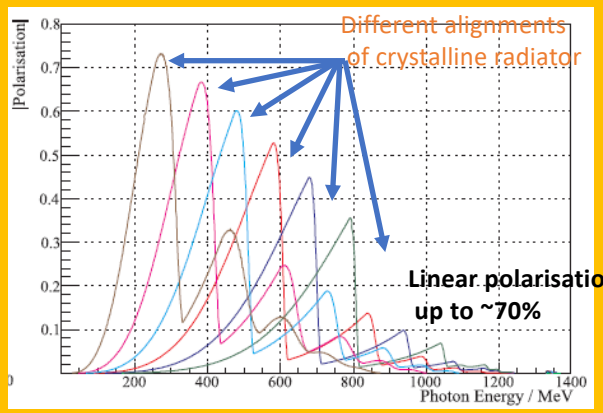




Linear polarisation

- Bremsstrahlung of electron beam on crystalline (diamond) radiator





(Some of the) new results for the N* programme

Obervables in pseudoscalar meson photoproduction

Observable	Polarisation of γ	Polarisation of target	Polarisation of recoil	Amplitudes
1. $\{d\sigma/d\Omega\}/\mathcal{N}$				$=\|b_1\|^2+\|b_2\|^2+\|b_3\|^2+\|b_4\|^2$
Single polarization				
2. P			↑	$=\|b_1\|^2-\|b_2\|^2+\|b_3\|^2-\|b_4\|^2$
3. Σ	→			$=\|b_1\|^2+\|b_2\|^2-\|b_3\|^2-\|b_4\|^2$
4. T		→		$=\|b_1\|^2-\|b_2\|^2-\|b_3\|^2+\|b_4\|^2$
Double polarizaton				
Beam-target				
5. E	●	●		$=2\,\mathrm{Re}(b_1 b_3^* + b_2 b_4^*)$
6. F	●	→		$=2\,\mathrm{Im}(b_1 b_3^* - b_2 b_4^*)$
7. G	→	●		$=2\,\mathrm{Im}(b_1 b_3^* + b_2 b_4^*)$
8. H	→	→		$=-2\,\mathrm{Re}(b_1 b_3^* + b_2 b_4^*)$
Beam-recoil				
9. C_x	●		→	$=-2\,\mathrm{Im}(b_1 b_4^* - b_2 b_3^*)$
10. C_y	●		●	$=2\,\mathrm{Re}(b_1 b_4^* + b_2 b_3^*)$
11. O_x	→		→	$=2\,\mathrm{Re}(b_1 b_4^* - b_2 b_3^*)$
12. O_z	→		●	$=2\,\mathrm{Im}(b_1 b_4^* + b_2 b_3^*)$
Target-recoil				
13. T_x		→	→	$=2\,\mathrm{Re}(b_1 b_2^* - b_3 b_4^*)$
14. T_z		→	●	$=2\,\mathrm{Im}(b_1 b_2^* - b_3 b_4^*)$
15. L_x		●	→	$=-2\,\mathrm{Im}(b_1 b_2^* + b_3 b_4^*)$
16. L_z		●	●	$=2\,\mathrm{Re}(b_1 b_2^* + b_3 b_4^*)$

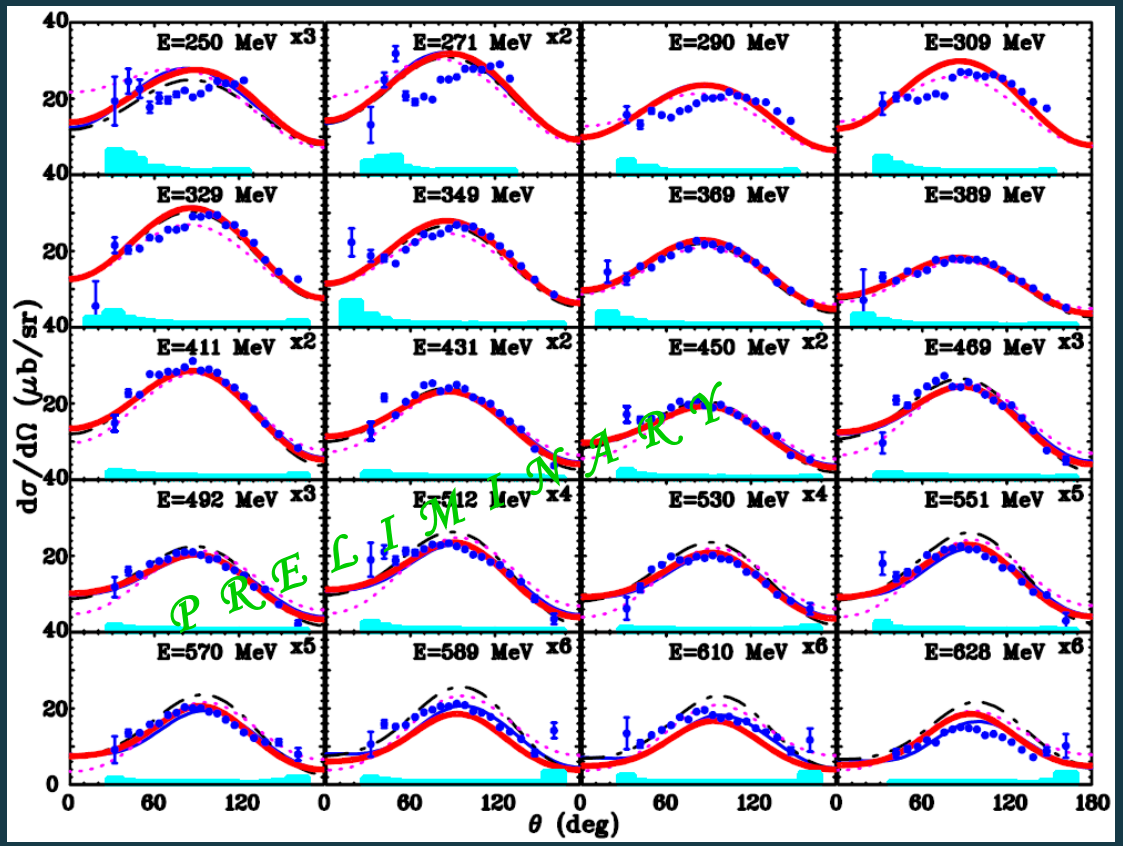
π^0 meson photoproduction off the neutron

Differential cross sections for $\gamma n \rightarrow \pi^0 n$.

New **dσ/dΩ**s by **A2** contribution are **200%** increase on previous world π^0**n** data.

Data up to **E** = **1500** MeV under analysis

Selected photon decay amplitudes **N*→γn** at resonance **poles** determined for **first** time

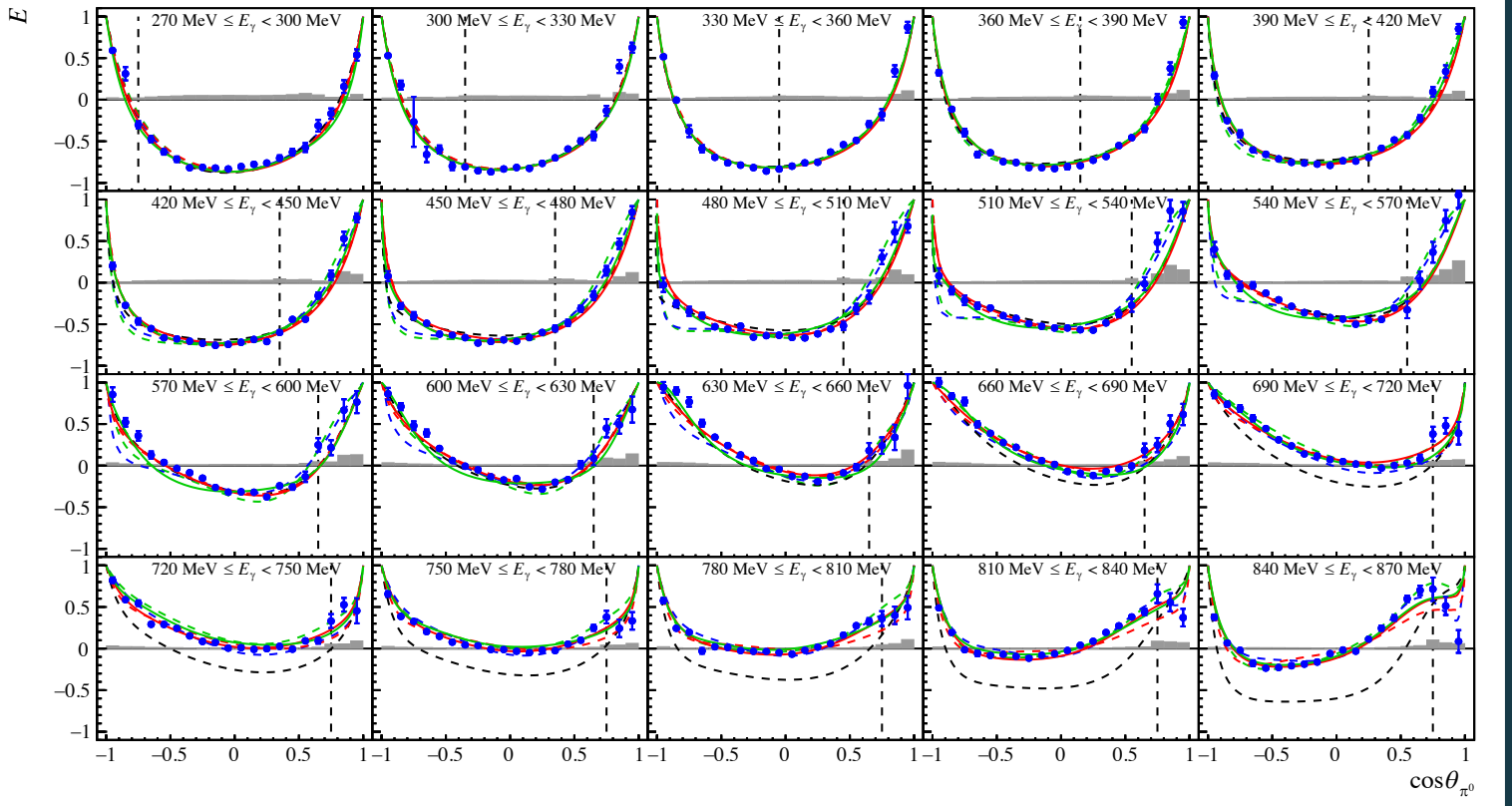


FSI included

Resonance	Coupling	SAID MA19	SAID MA27	BnGa	KSU
$N(1440)1/2^+$	$A_{1/2}(n)$	80±10, 9±2°	65±5, 5±3°	47±12†	13±12†
$N(1520)3/2^-$	$A_{3/2}(n)$	-130±8, 20±6°		-113±12†	-123±6†
$N(1520)1/2^-$	$A_{1/2}(n)$	-45±4, 1±2°		-49±8†	-72±3†
$N(1535)1/2^-$	$A_{1/2}(n)$	-70±10, 2±5°	-55±5, 5±2°	-88±4, 5±4°	-55±6†
$N(1650)1/2^-$	$A_{1/2}(n)$	13±4, -50±15°	14±2, -30±10°	16±4, -28±10°	1±6†

arxiv: 1908.02730

“E” in π^0 photoproduction from proton



$$E = \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} + \sigma^{3/2}} = \frac{N_B^{1/2} - N_B^{3/2}}{N_B^{1/2} + N_B^{3/2}} \cdot \frac{1}{d} \cdot \frac{1}{P_{circ} P_z}$$

- A2 data (this work)
- BnGa-2011-02
- JüBo-2015-FitB
- SAID-CM12
- BnGa-2017
- JüBo-2017
- MAID2007

Analysis by F Afzal (Bonn)

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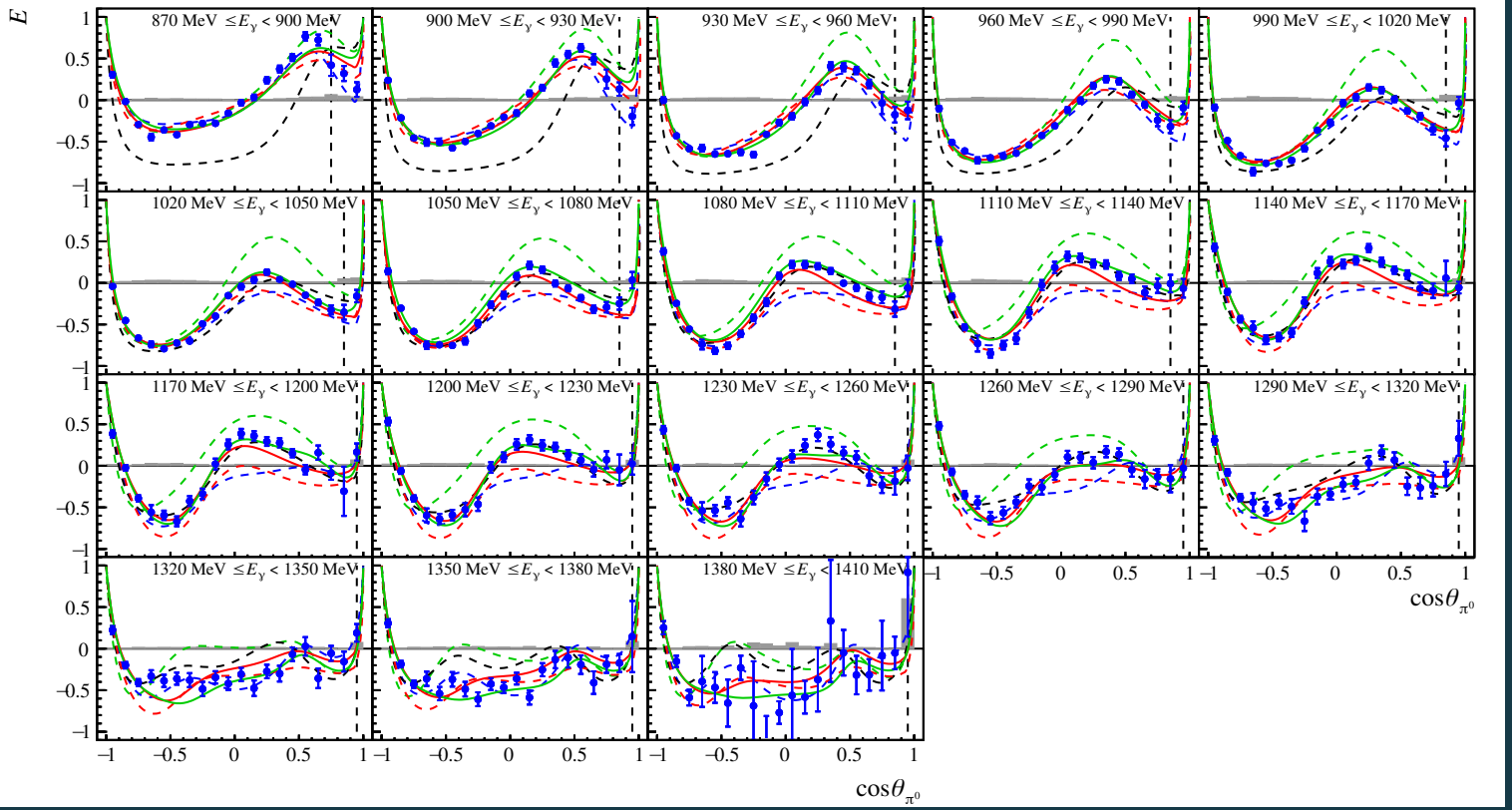

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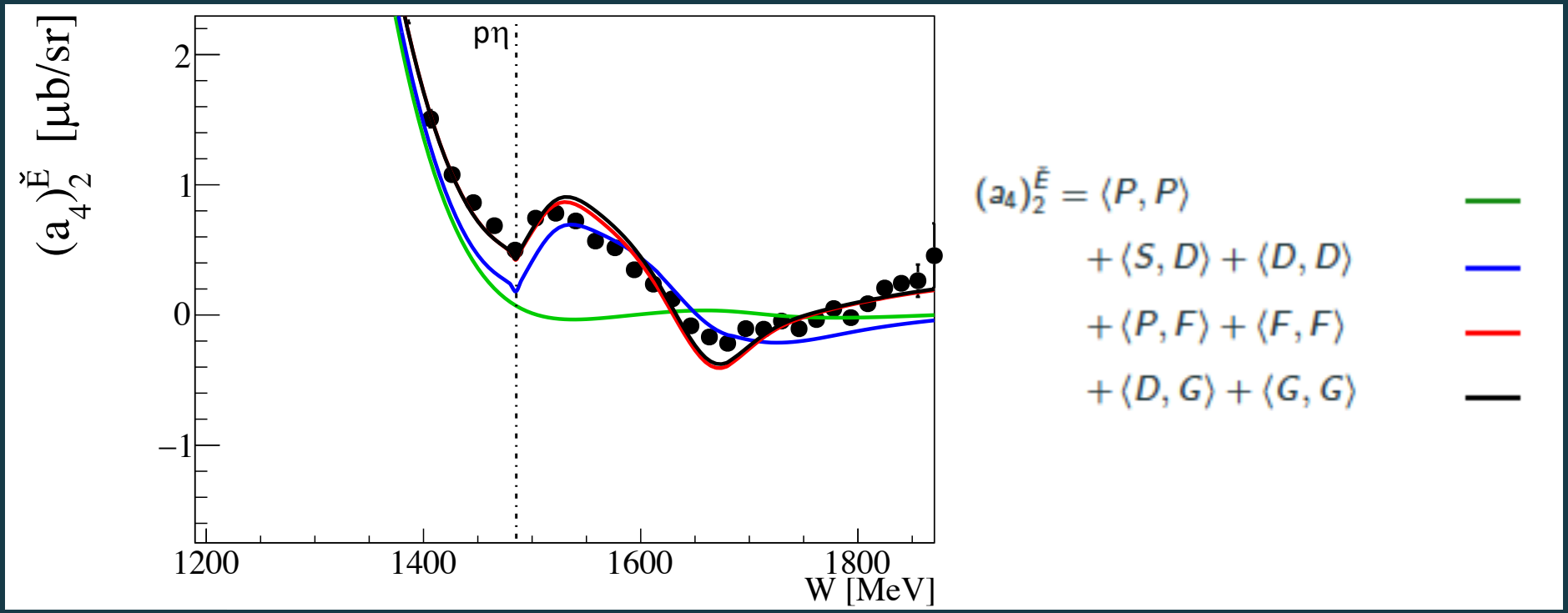
Analysis by F Afzal (Bonn)

“E” in π^0 photoproduction from proton

$$\check{E}(W,\cos\theta) = E(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=0}^{2L_{max}+1}(a_L(W))_k \cdot P_k^0(\cos\theta)$$

See talk of Y. Wunderlich, Tuesday 11am

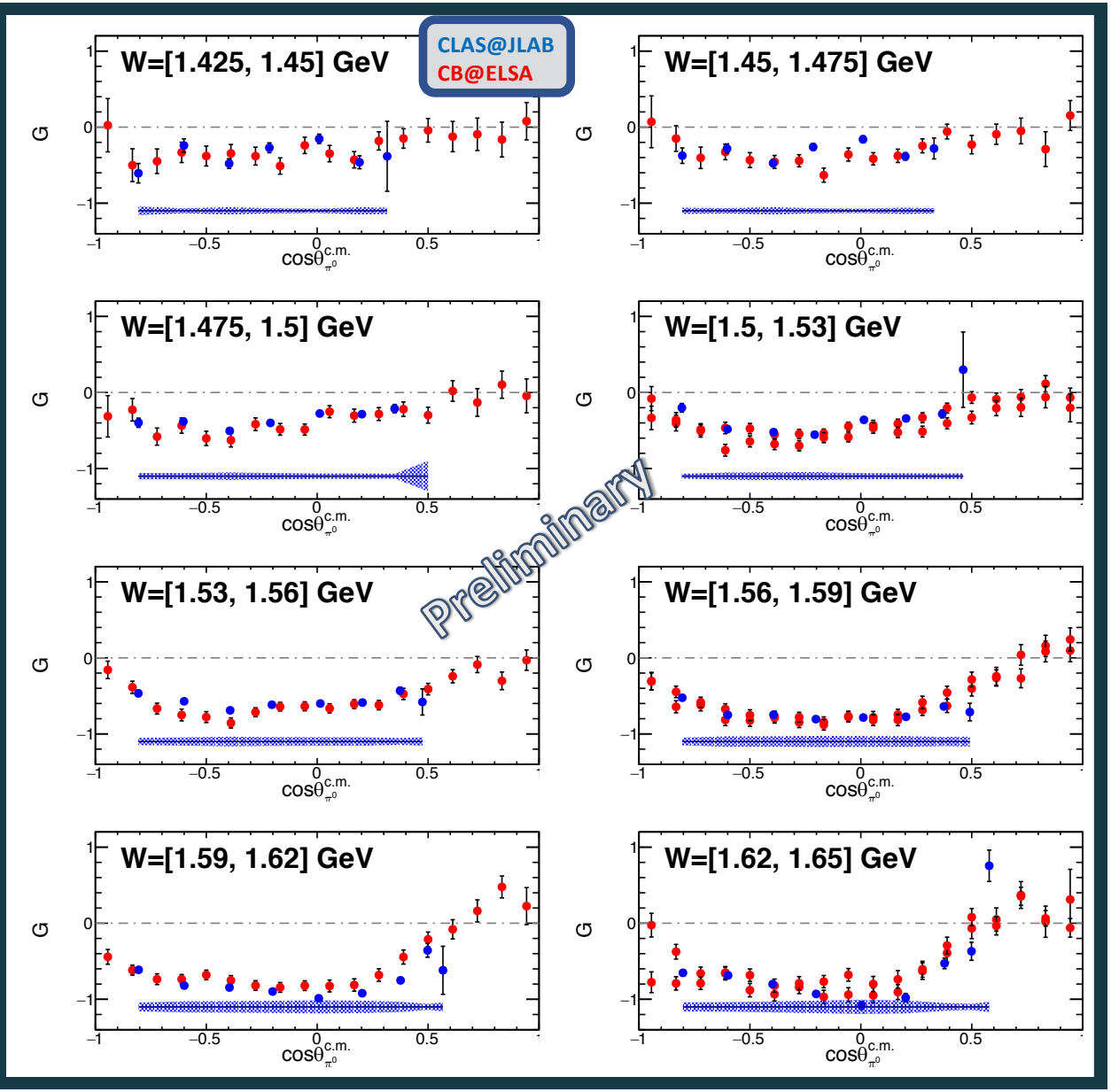


Analysis by F Afzal (Bonn)

G observable in $\gamma(p,\pi^0)p$

- CLAS frozen spin butanol target (FROST)
- Good agreement with CB@ELSA where datasets overlap
- Improvement in kinematic coverage (W) and statistical accuracy
- CLAS data analysed in unbinned maximum likelihood framework

Zachariou, McAndrew, DPW
Under analysis review



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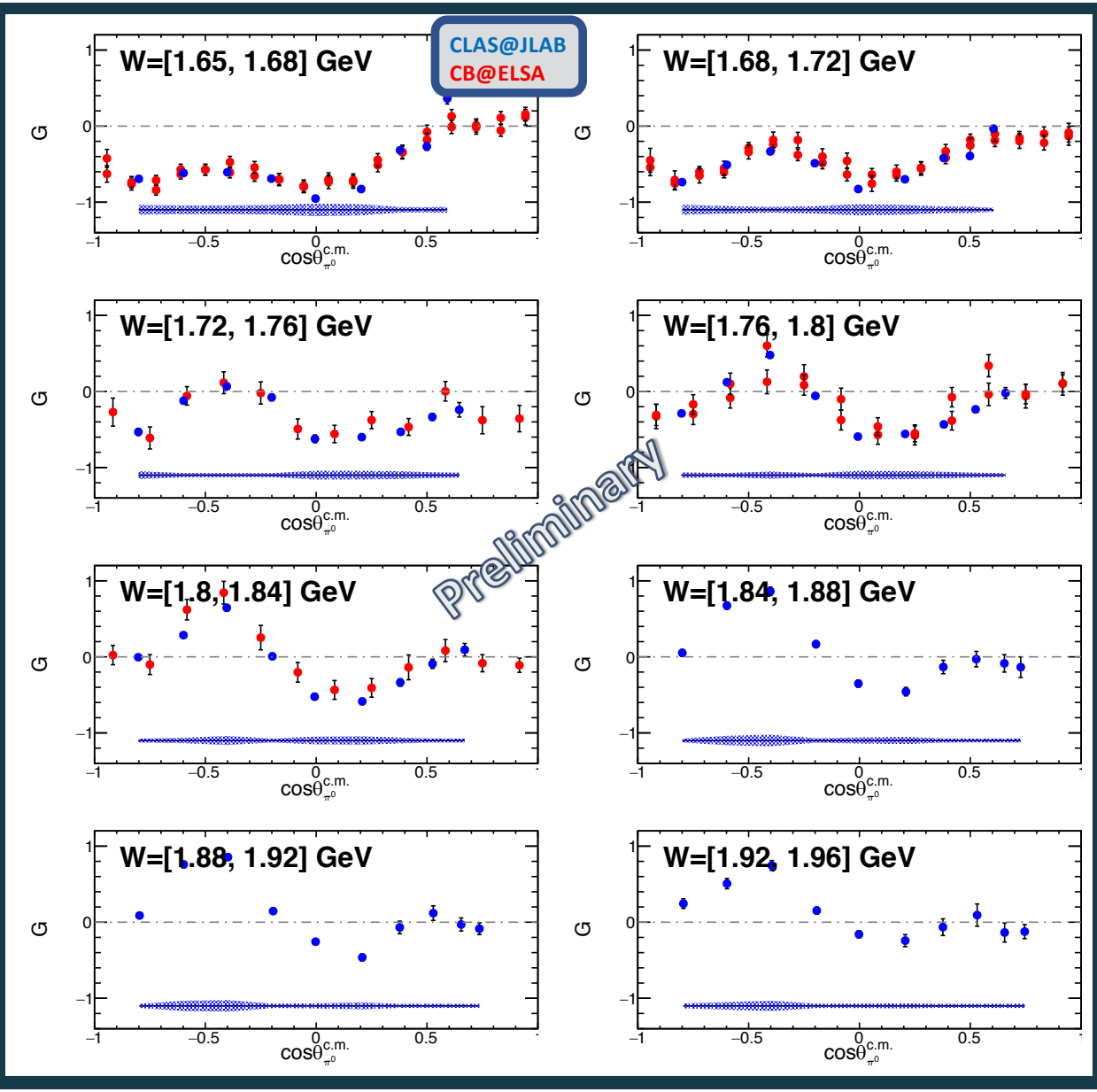

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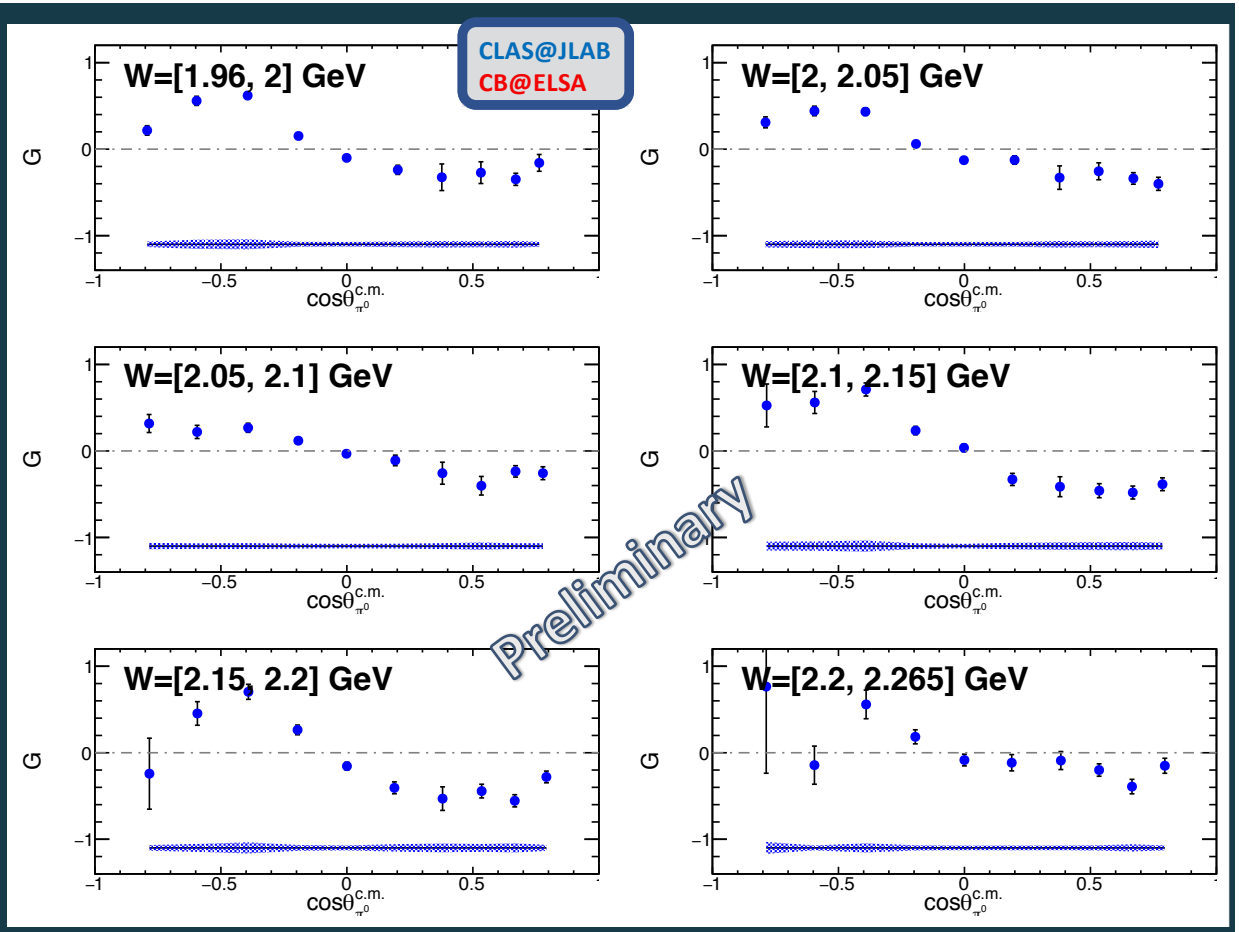

Zachariou, McAndrew, DPW
Under analysis review

CEBAF Large Acceptance Spectrometer

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G observable in $\gamma(p,\pi^+)n$

- First data on G in this channel
- Comparison with published PWA solutions

Eur. Phys. J. A 51, 95 (2015)
Eur. Phys. J. A52, 284 (2016)

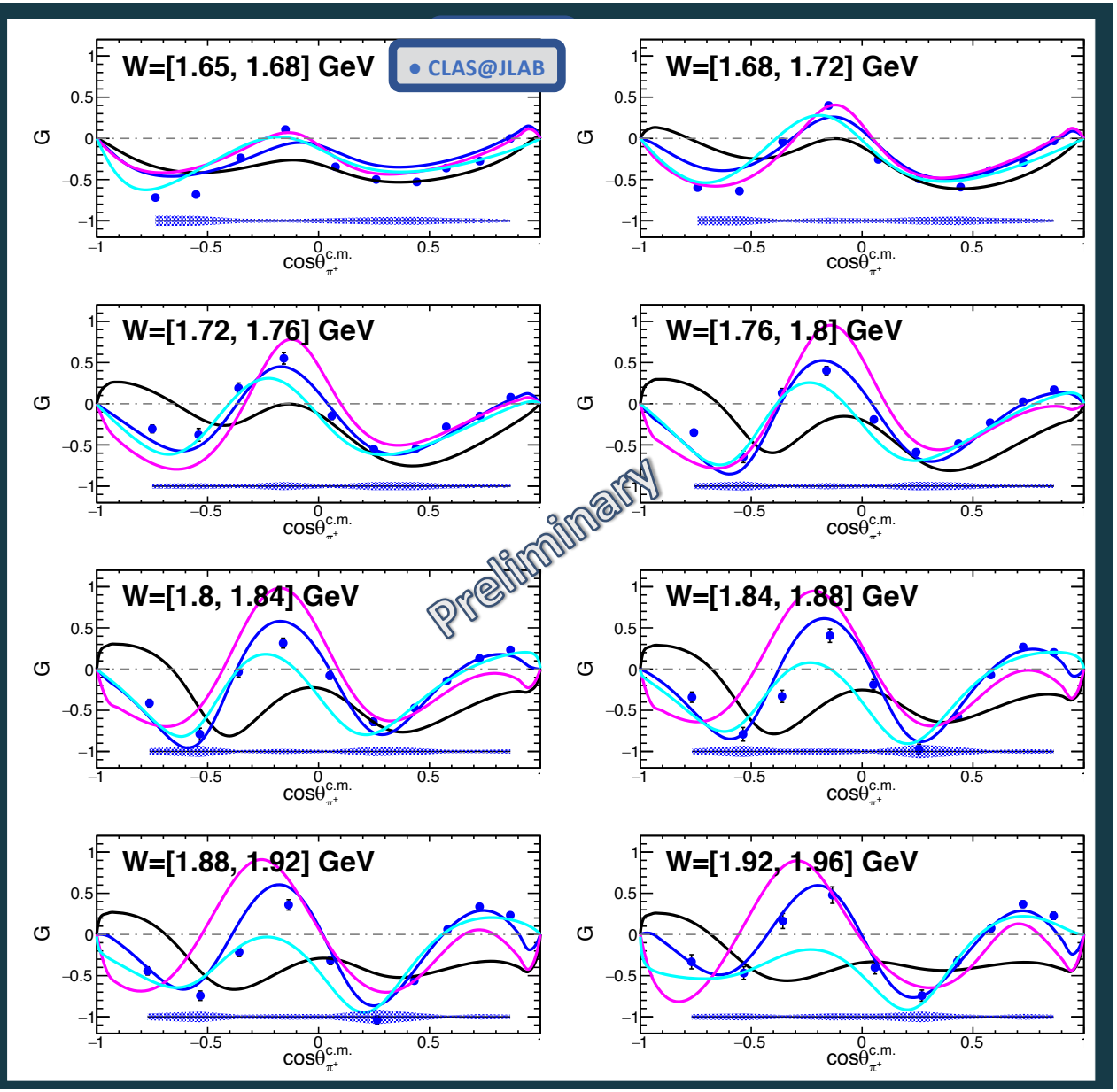
Phys. Rev. C 96, 035204 (2017)

From website

Eur. Phys. J. A 54, 110, 2018

Bonn Gatchina
SAID
MAID
GW-Juelich

Zachariou, McAndrew, DPW
Under analysis review



G observable in $\gamma(p,\pi^+)n$

Eur. Phys. J. A 51, 95 (2015)
Eur. Phys. J. A52, 284 (2016)

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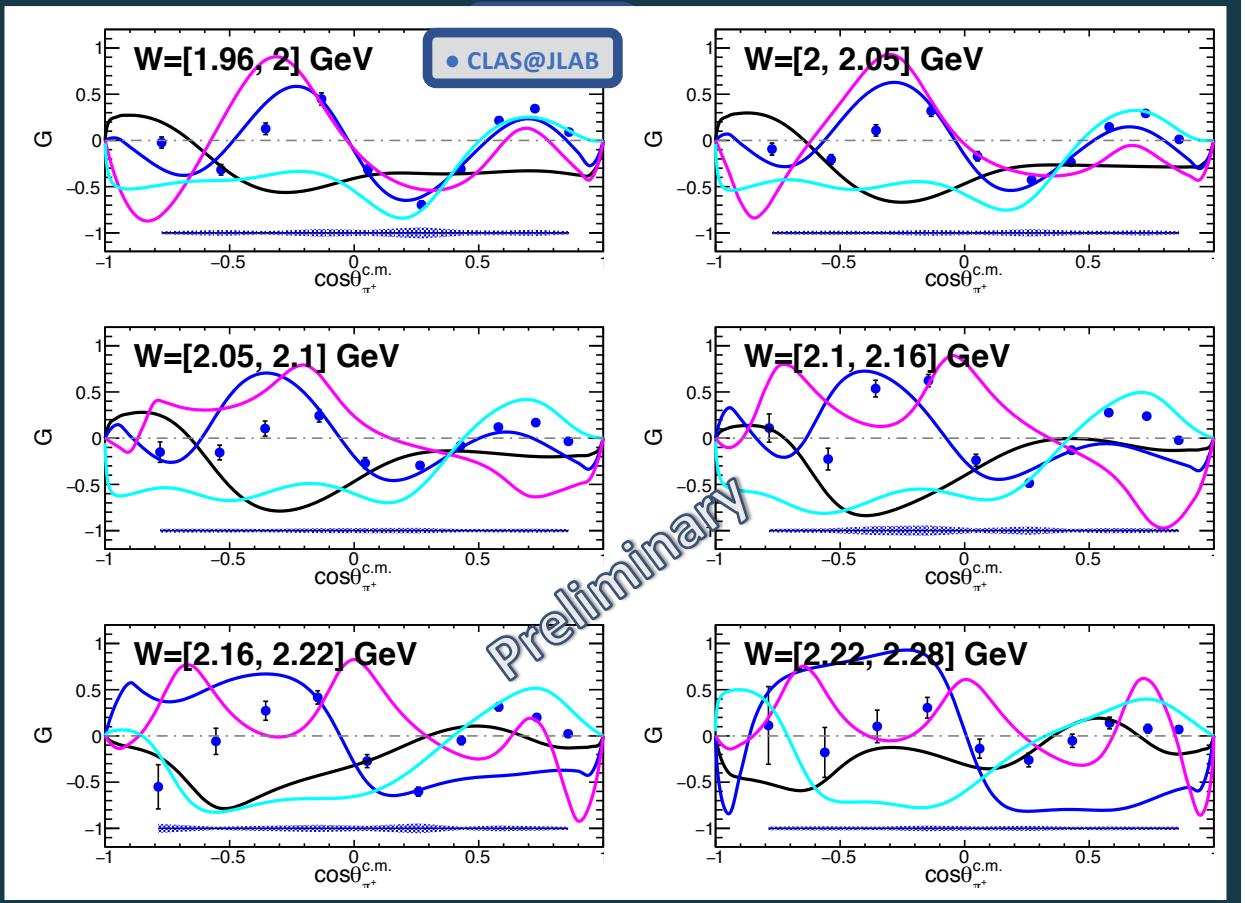

Zachariou, McAndrew, DPW
Under analysis review

CEBAF Large Acceptance Spectrometer

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E observable in $\gamma(n,K^+)\Sigma^-$

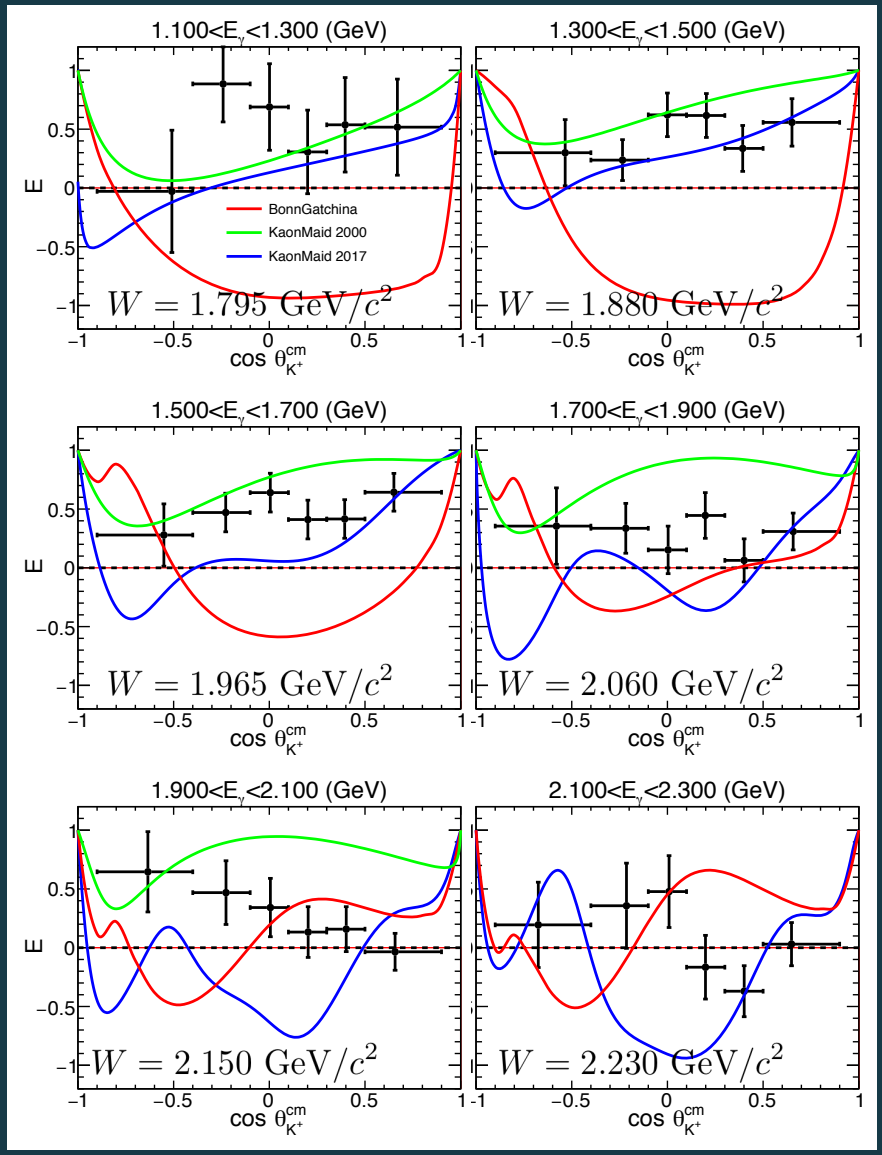
• CLAS@JLAB

- Polarised HD target (g14 run period)
- Poor existing database ($d\sigma/d\Omega$ and Σ with limited kinematic coverage)
- Valuable new data to constrain PWA in strange sector

See also:
PRL 118, 242002 (2017) $\gamma(n,\pi^-)p$

Bonn Gatchina
KAON-MAID (2017)
KAON-MAID (2000)

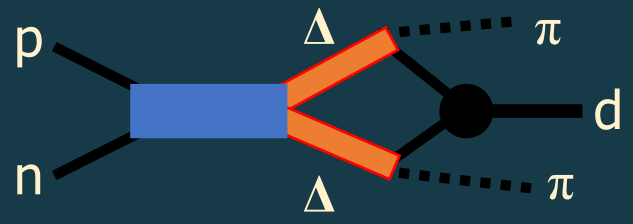
Zachariou, Fleming, DPW
Analysis Review Complete



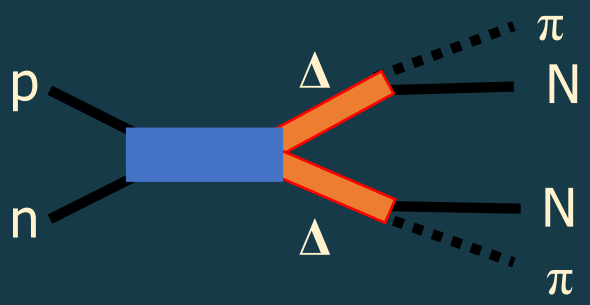
The d*(2380)

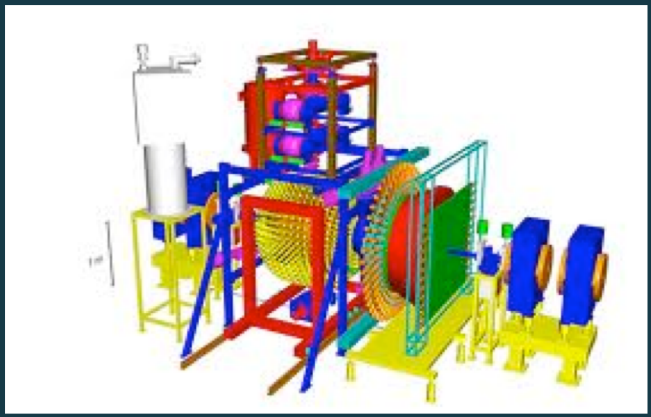
Nucleon scattering with large acceptance

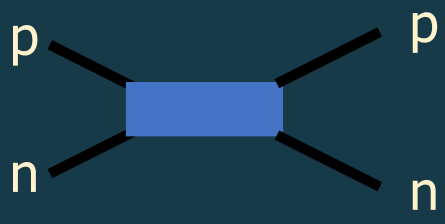
- $pn \rightarrow d^* \rightarrow \Delta\Delta \rightarrow d\pi\pi$



- $pn \rightarrow d^* \rightarrow \Delta\Delta \rightarrow NN\pi\pi$

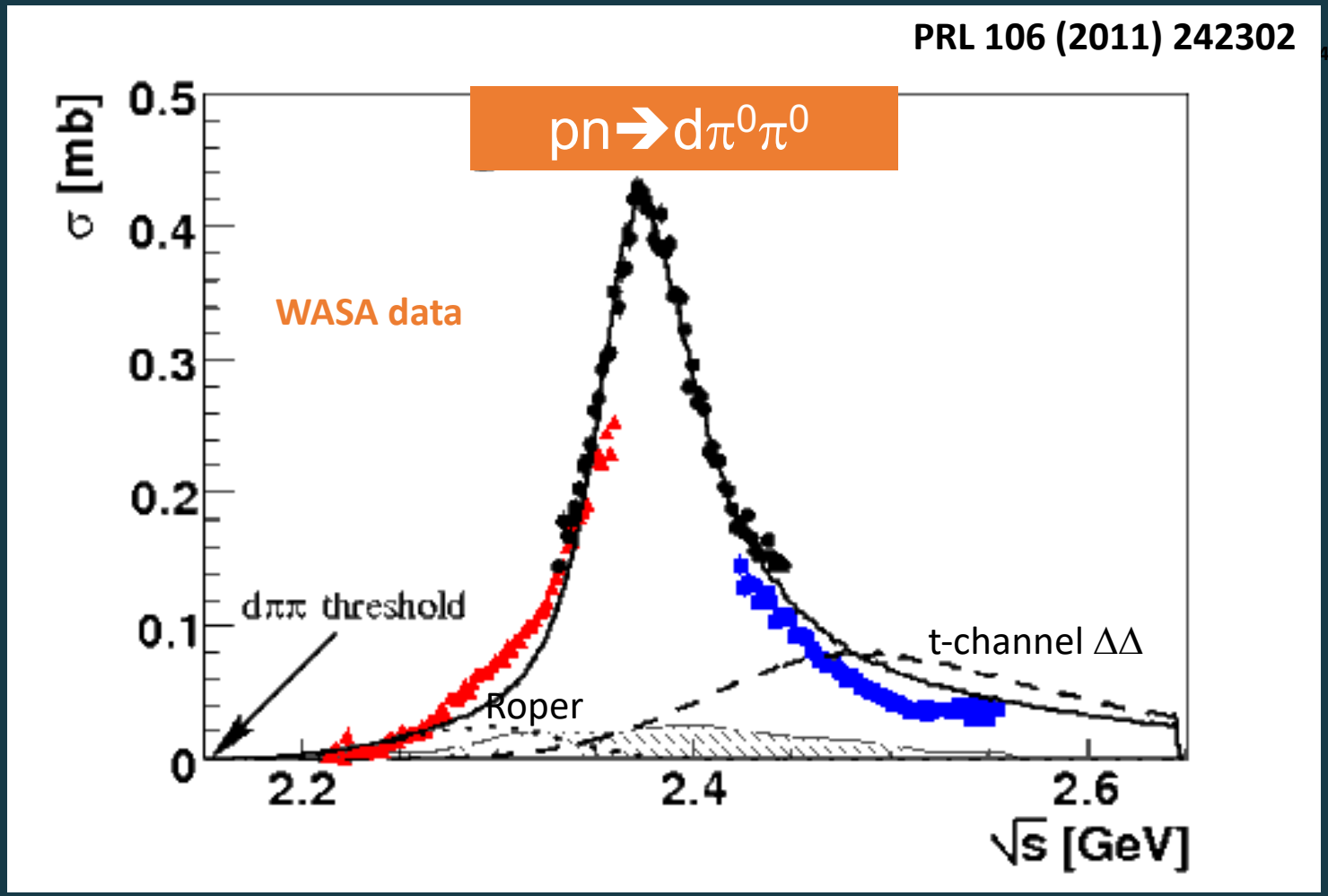


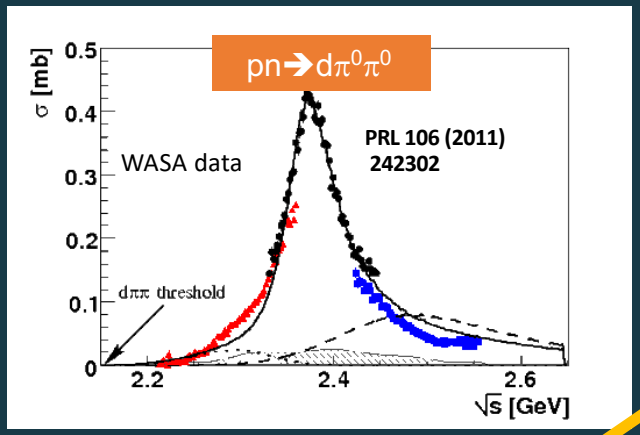


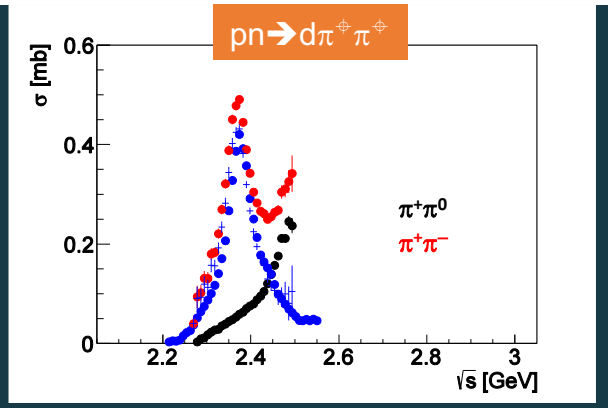


d*(2380) signals

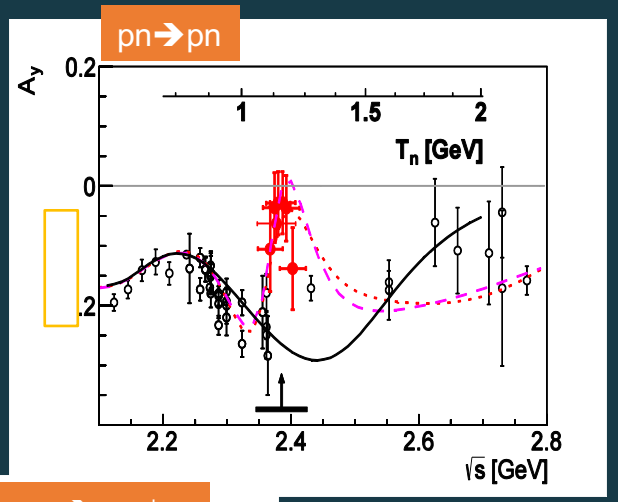
PRL 106 (2011) 242302





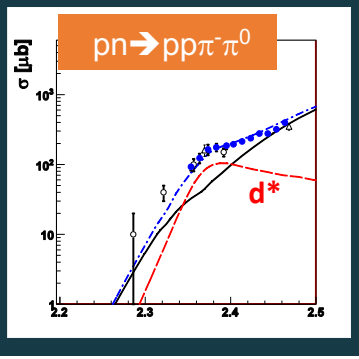


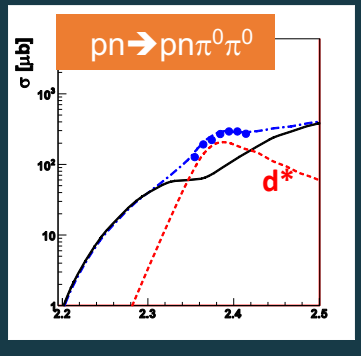
PLB 721 (2013) 229

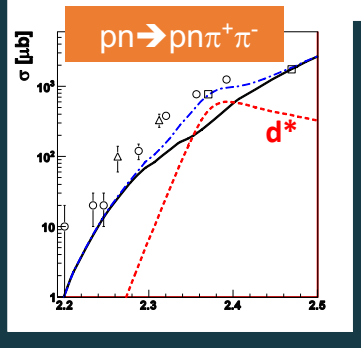


PRL 112 (2014) 202301
PRC 90, (2014) 035204

p + n → **d*(2380)**
I(J^P) = 0(3^+)







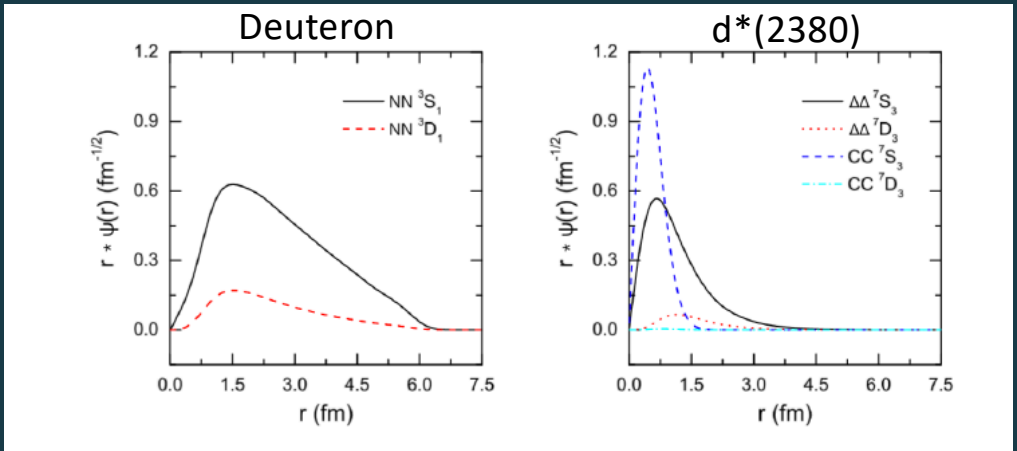
PRC 88 (2013) 055208
PLB 743 (2015) 325

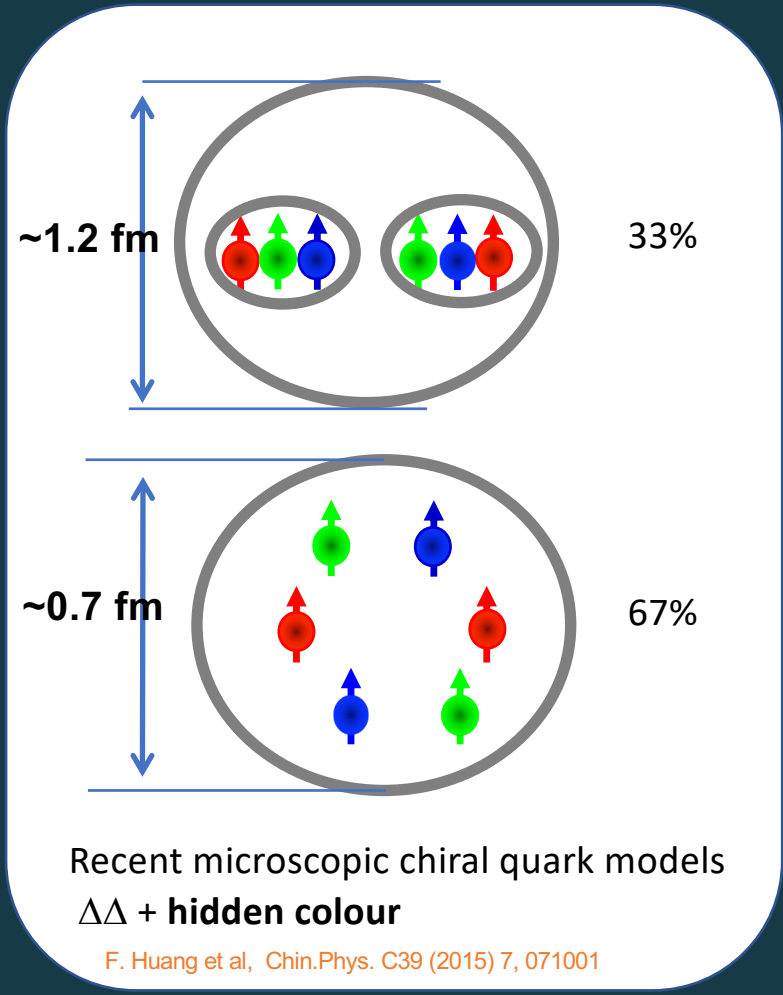
ΔΔ decay ~90%
pn decay ~10%

What is the d*(2380)?

Any quark model with confinement and one gluon exchange *inevitably* predicts a 6-quark object with $(I)J^P=(0)3^+$

T Goldman et. al. Phys. Rev. C 39, 1889 (1989)





Recent microscopic chiral quark models

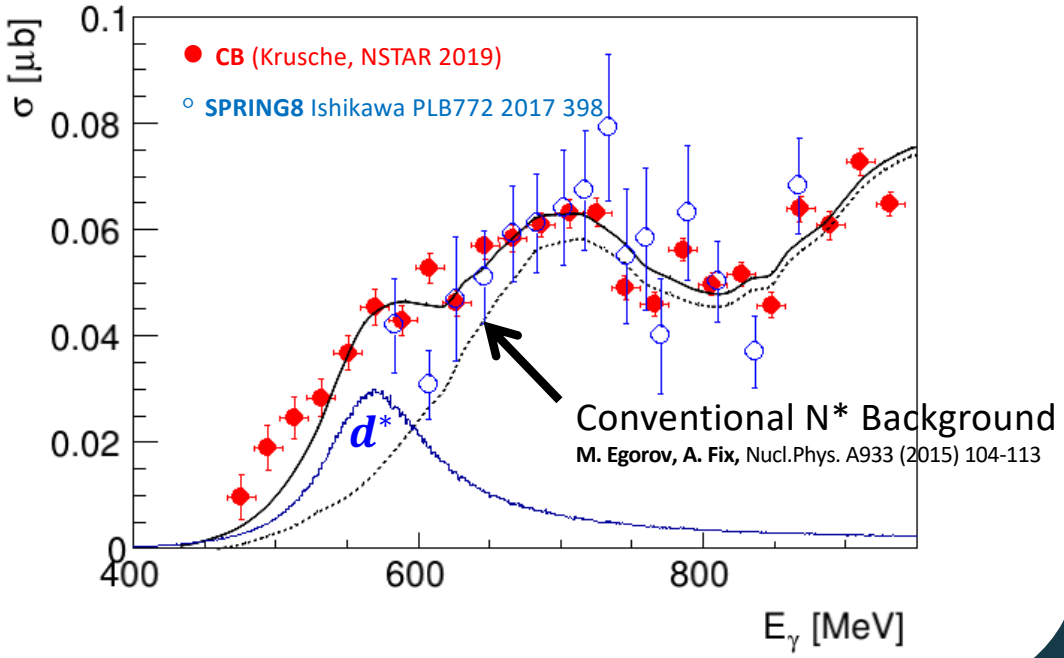
$\Delta\Delta$ + **hidden colour**

F. Huang et al, Chin.Phys. C39 (2015) 7, 071001

Photoproduction of $d\pi^0\pi^0$ final state

Preliminary

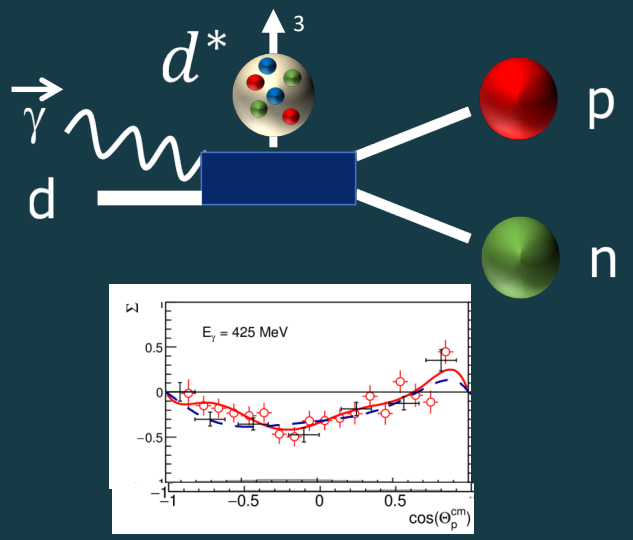
$$\gamma d \rightarrow d\pi^0\pi^0$$



- Photoproduction kinematics challenging
- Deut only at forward angles -> background enhanced, extrapolation over unmeasured phase space, ..
  -> Active deuteron target prototype under construction at UoY
- 3B final state less amenable to PWA

Krusche, Guenther, Under analysis

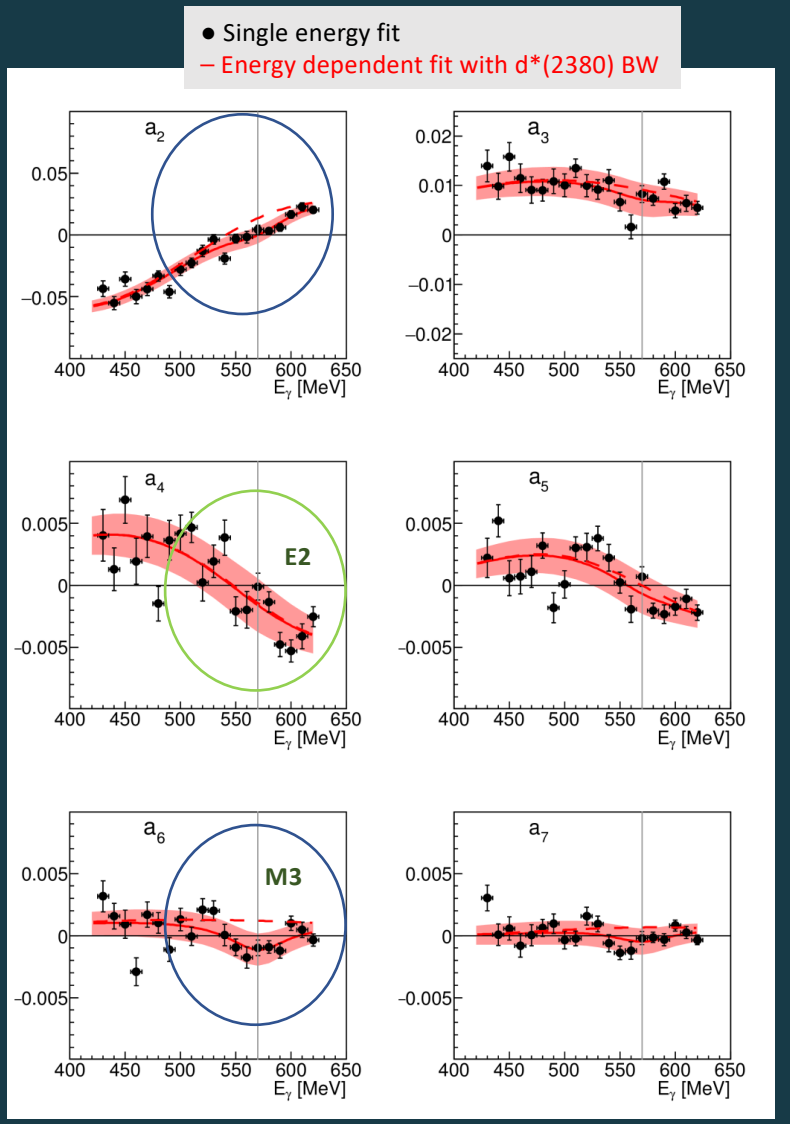
Deuterium photodisintegration (Σ)



$$\Sigma \sim \sum_{l=2} a_l P_l^2(cos\Theta)$$

E2 transition ⇒ small
M3 transition ⇒ dominant

Consistent with $d^*(2380)$ as a compact object !



Bashkanov, DPW, Kay, CB@MAMI; PLB789 (2019) 7-12

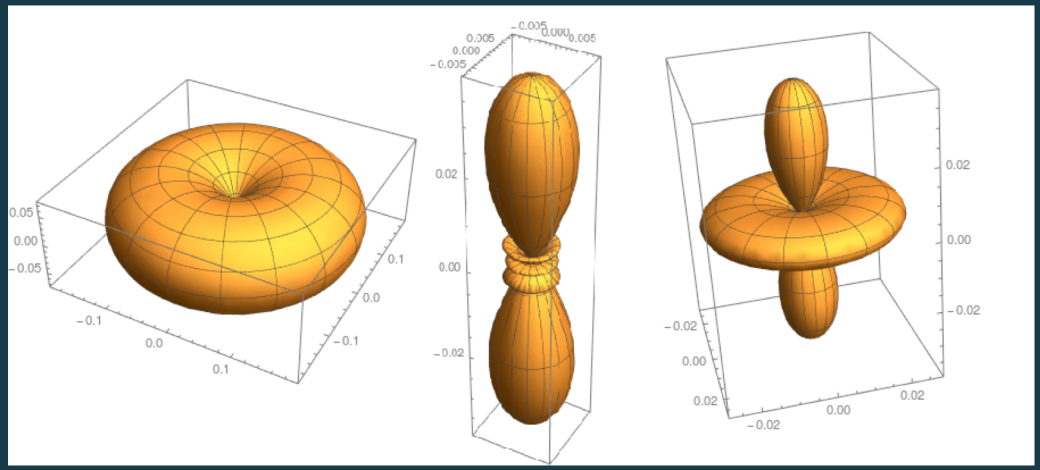
The d*(2380) in a pion cloud model

- Calculations in framework of “pion cloud” model

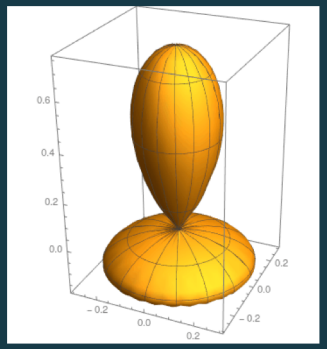
  Cancellation effects for d*(2380)

  -> EQM is small
  -> MOM is large!

- Helps guide future measurements



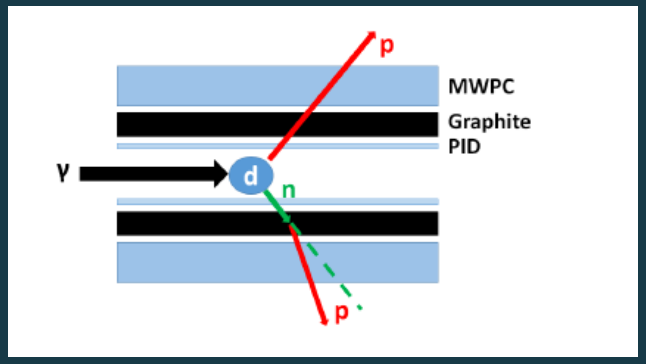
NΔπ NNππ Sum

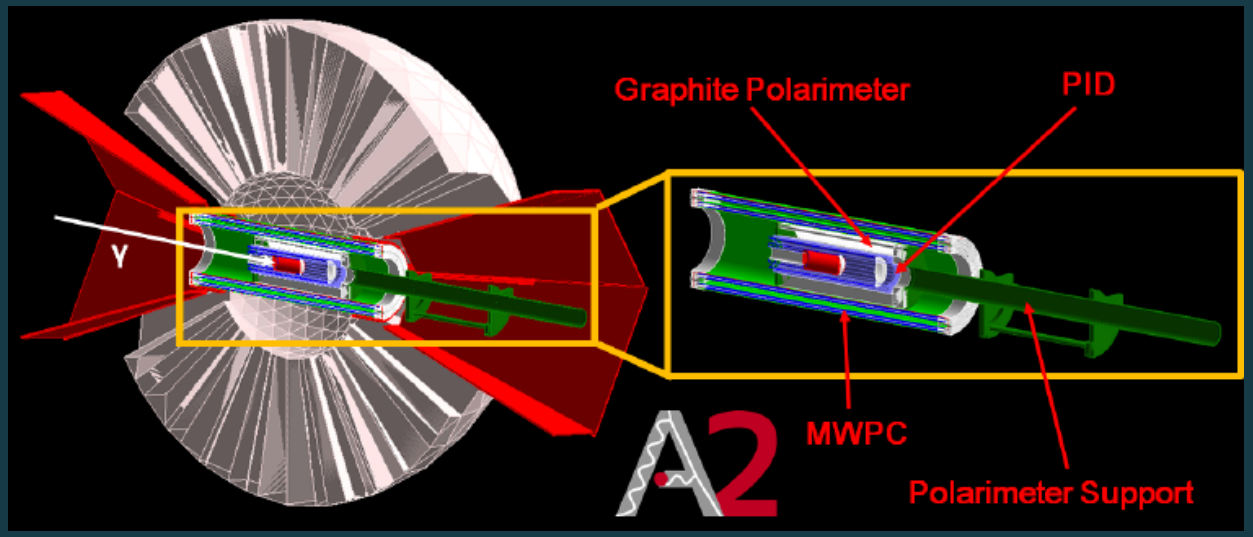


M. Bashkanov, DPW, A. Pastore: PRC 100 (2019) no.1, 012201

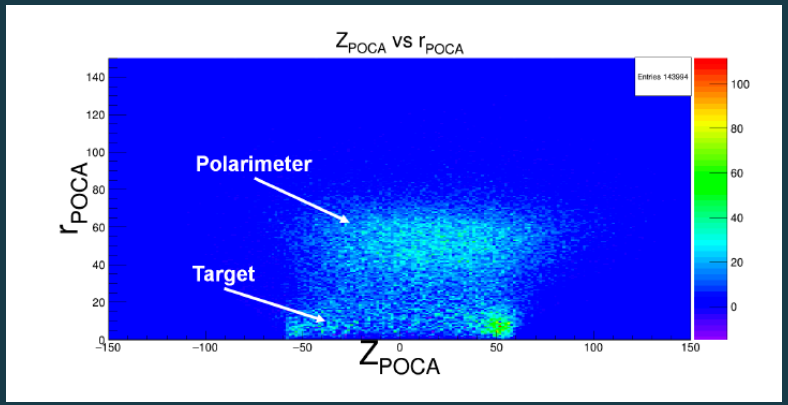
Further observables in deuterium photodisintegration

- Analysing material (graphite) placed between PID and MWPC





- Polarisation extracted from phi modulation of scatter yield (for a determined azimuthal (theta) range)
- Proton and neutron polarization measurements possible

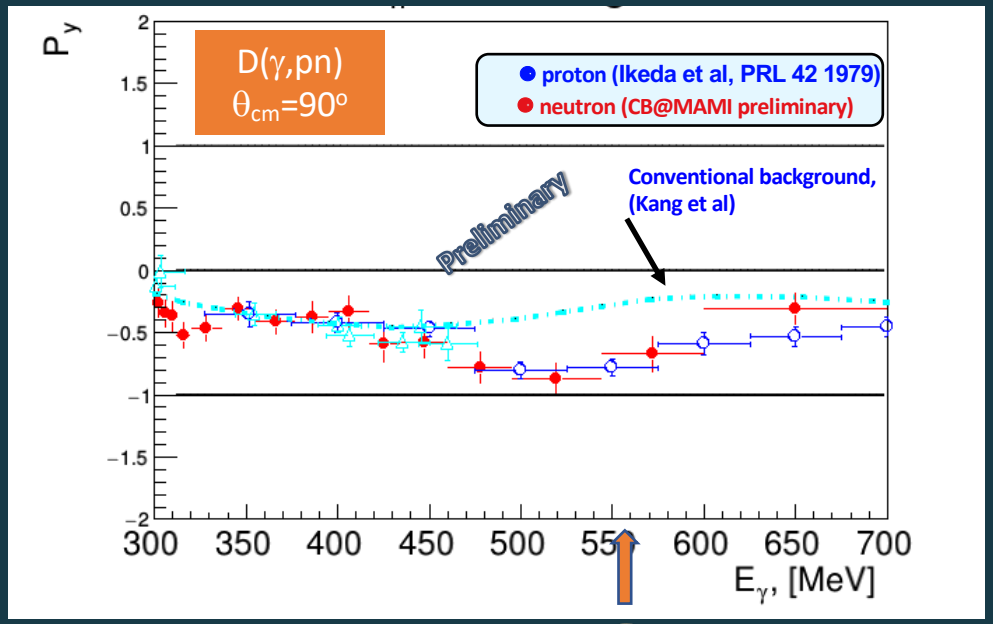


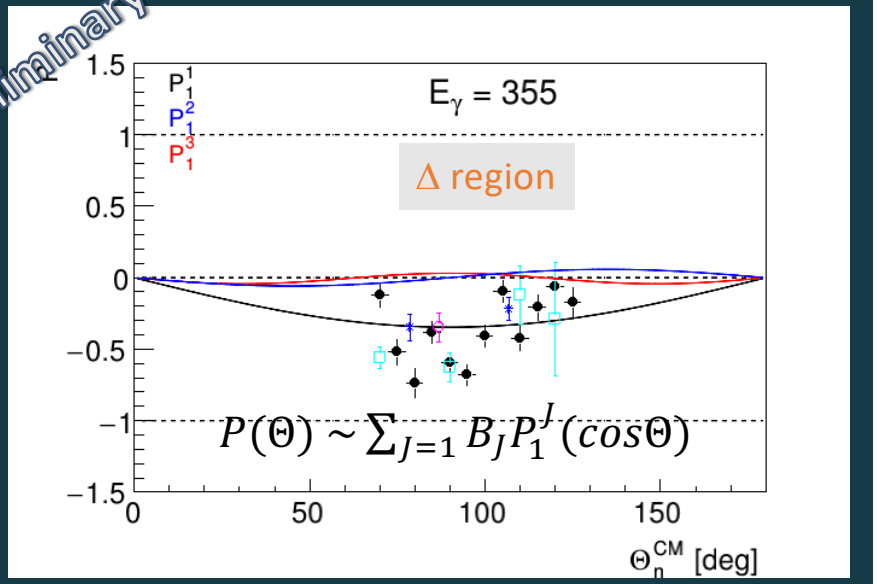
Bashkanov, Glazier, Kay, Mullen, Sikora, DPW

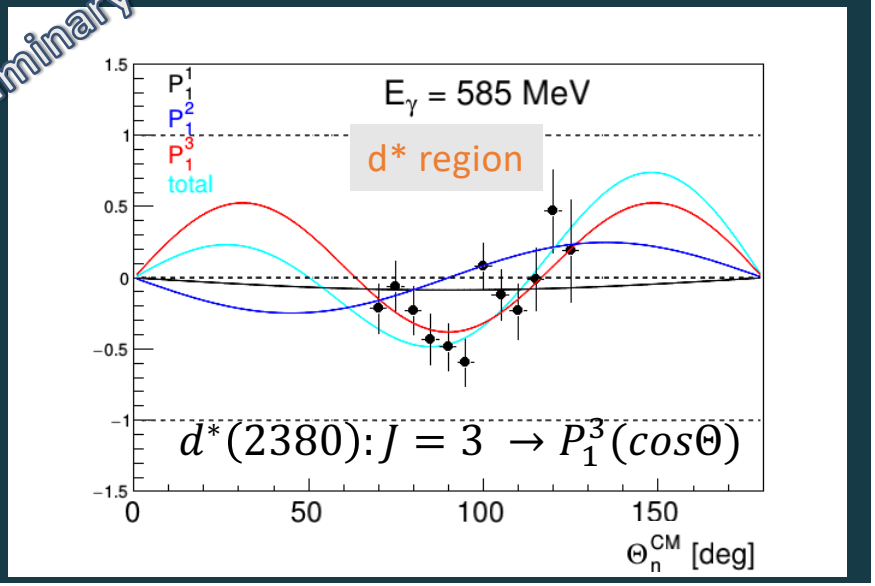
A2 University of York University of Glasgow

Deuterium photodisintegration (P_y)

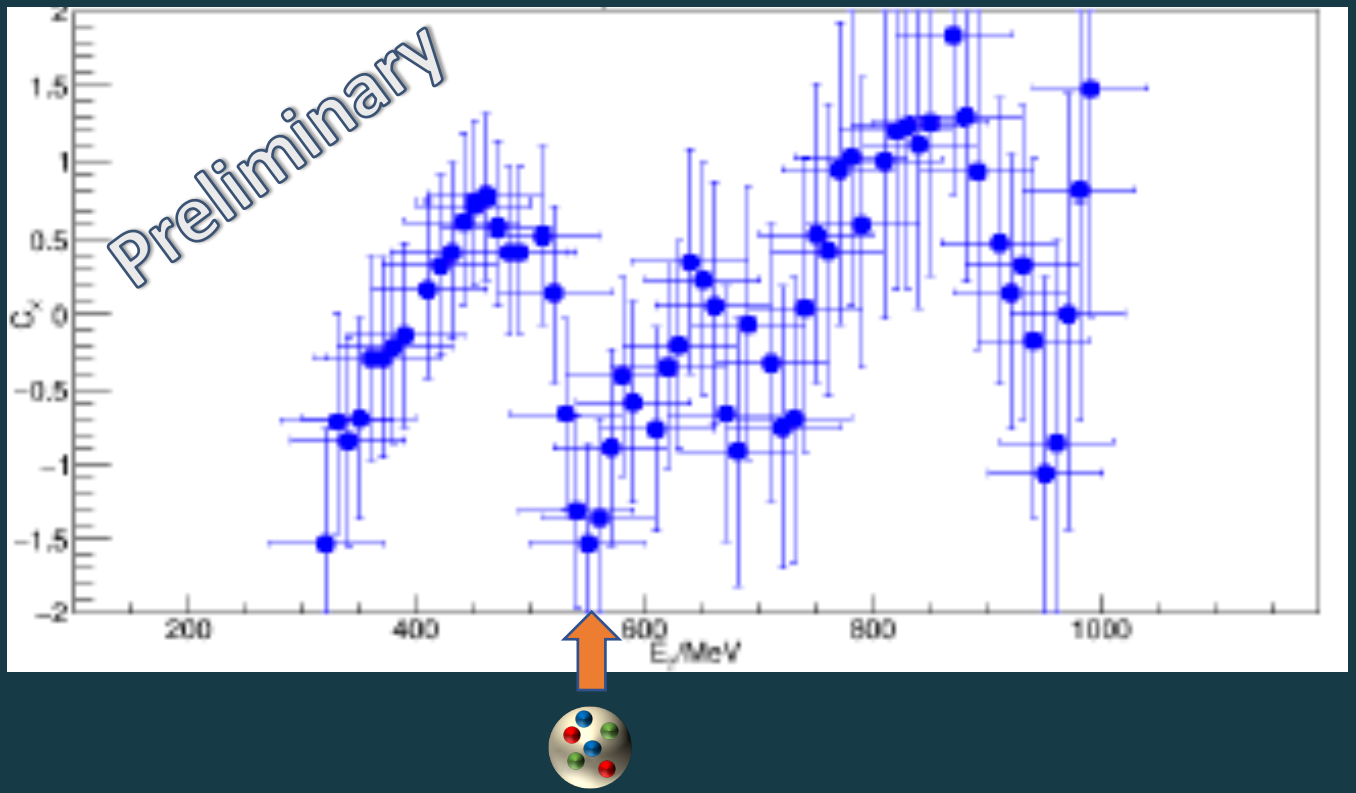
- 1st measurement of final state neutron polarisation
  -> *Both* p and n highly polarised in region of d*!
- Angular dependence – consistent with spin 3!

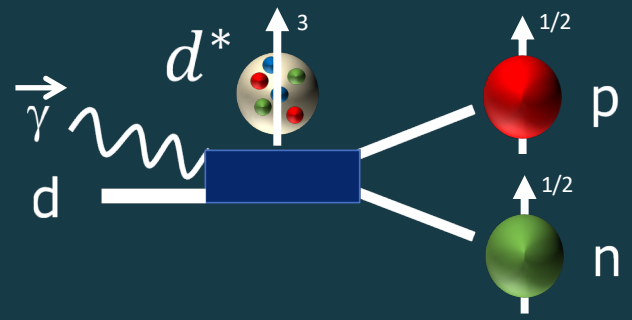






Deuterium photodisintegration (C_x*)

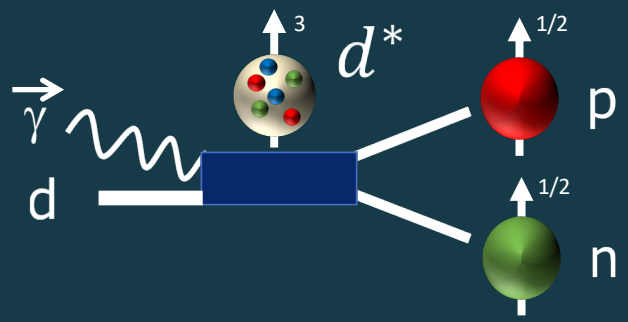




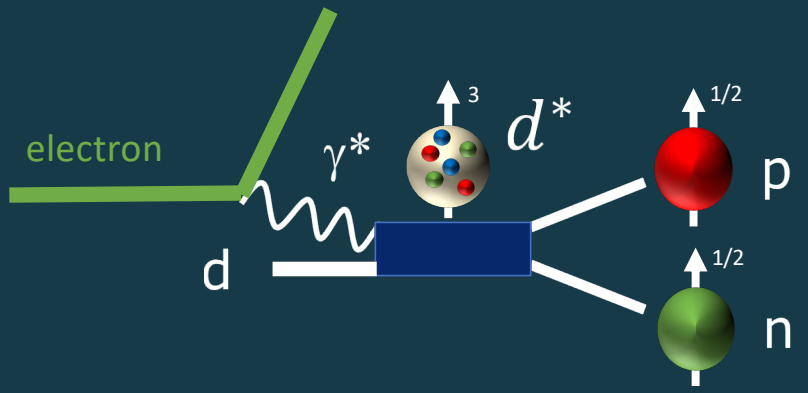
- Indications of strong **polarisation *transfer*** in region of d*
- Caveat: approx. (n,p) analyzing power used in analysis

Bashkanov, DPW, Kay, CB@MAMI; in preparation

The path forward

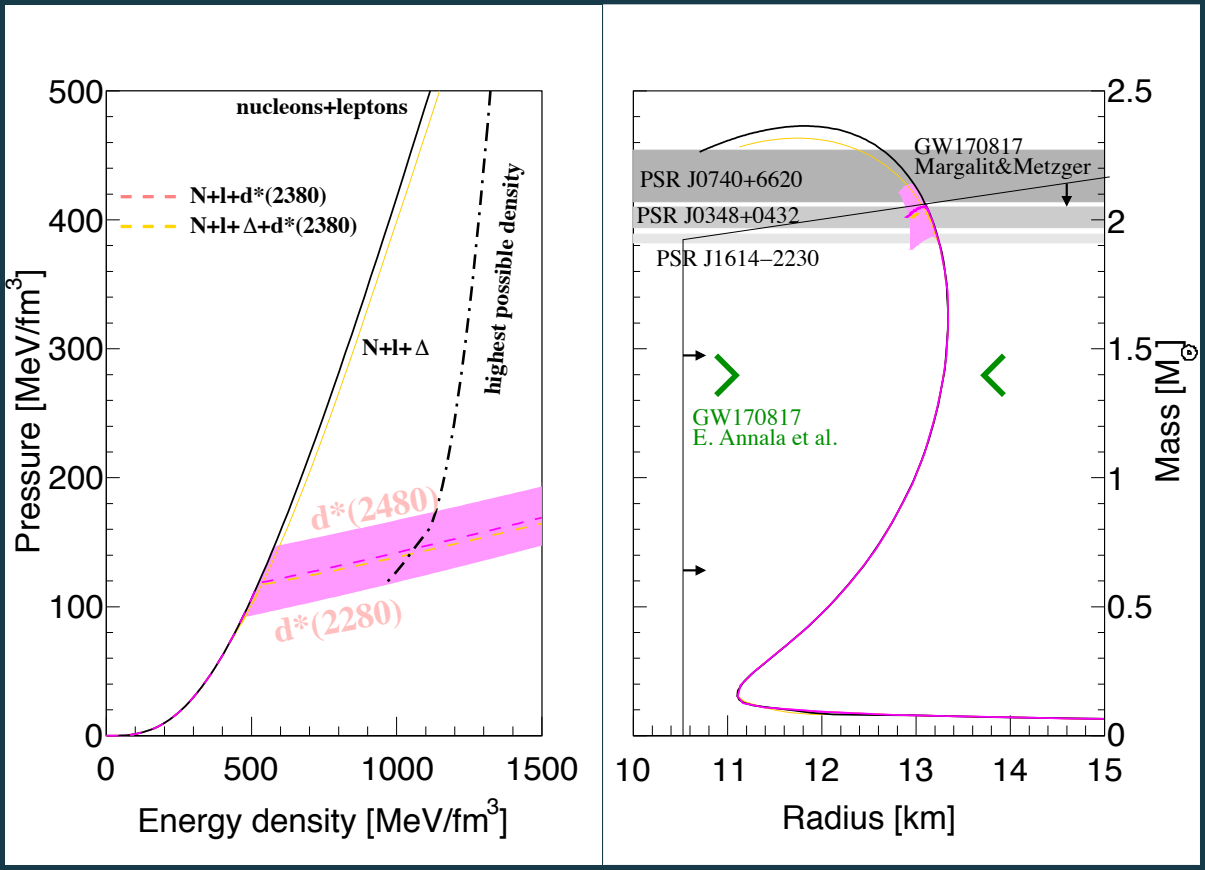


- A dominant M3 EM coupling to d*(2380) is suggested
- Next stage –> Polarised deuteron target
  Active deuteron target

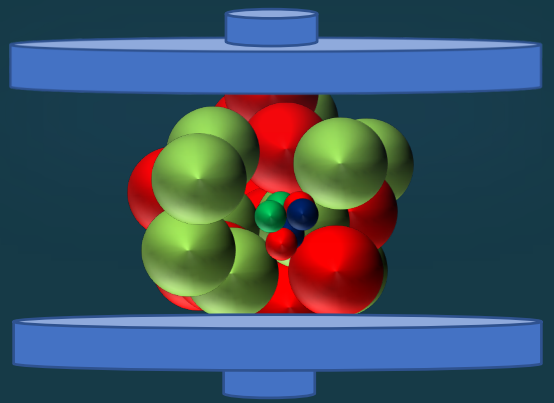


-> Inform future studies to measure the size of the d*(2380)!

The d*(2380) in neutron stars



- d* -> forms copiously above 2.5ρ_0
  ->~20% d* at centre of heavy stars



- Star mass limit - around 2.1M_o

Summary

- Intense polarised γ beams
- Hermetic detector apparatus
- γ, target, recoil polarisation

} Quality datasets to constrain N* and QCD physics

- Signals of EM coupling to d*(2380)?