Recent N* results from photoproduction experiments at CLAS

Daria Sokhan

IPN Orsay, France

On behalf of the CLAS collaboration and Jefferson Laboratory

Contents:

- Nucleon excitation spectrum
- Meson photoproduction
- Polarisation observables
- Jefferson Lab, CLAS and photon beams
- Selected results from:
  - ✓ Unpolarised target experiments – g8, 13
  - ✓ Polarised target experiments – FroST, HDice

Nucleon excitation spectrum

- Little known - predictions primarily from the Lattice and phenomenological models (*eg*: constituent quark-models, di-quark model…)

- Many more resonances predicted by some models than observed

Missing resonances

- Not present in nature or just not yet observed?

- Insufficient experimental observables measured to resolve ambiguities.

N^*	Status	$SU(6) \otimes O(3)$	Parity	Δ^*	Status	$SU(6) \otimes O(3)$
$P_{11}(938)$	****	$(56, 0^-)$	+	$P_{33}(1232)$	****	$(56, 0^+)$
$S_{11}(1535)$	****	$(70, 1^-)$				
$S_{11}(1650)$	****	$(70, 1^-)$		$S_{31}(1620)$	****	$(70, 1^-)$
$D_{13}(1520)$	****	$(70, 1^-)$	-	$D_{33}(1700)$	****	$(70, 1^-)$
$D_{13}(1700)$	***	$(70, 1^-)$				
$D_{15}(1675)$	****	$(70, 1^-)$				
$P_{11}(1520)$	****	$(56, 0^-)$		$P_{31}(1875)$	****	$(56, 2^+)$
$P_{11}(1710)$	***	$(70, 0^-)$	+	$P_{31}(1835)$		$(70, 0^+)$
$P_{11}(1880)$		$(70, 2^+)$				
$P_{11}(1975)$		$(20, 1^-)$				
$P_{13}(1720)$	****	$(56, 2^+)$		$P_{33}(1600)$	***	$(56, 0^+)$
$P_{13}(1870)$	*	$(70, 0^-)$		$P_{33}(1920)$	***	$(56, 2^+)$
$P_{13}(1910)$		$(70, 2^-)$	+	$P_{33}(1985)$		$(70, 2^+)$
$P_{13}(1950)$		$(70, 2^-)$				
$P_{13}(2030)$		$(20, 1^-)$				
$F_{15}(1680)$	****	$(56, 2^-)$		$F_{35}(1905)$	****	$(56, 2^+)$
$F_{15}(2000)$	**	$(70, 2^-)$	+	$F_{35}(2000)$	**	$(70, 2^+)$
$F_{15}(1995)$		$(70, 2^-)$				
$F_{17}(1990)$	**	$(70, 2^-)$	+	$F_{37}(1950)$	****	$(56, 2^+)$

Meson Photoproduction

❖ Real **photons** – well understood EM interaction, giving access to EM properties of resonances.

❖ Meson photoproduction – for pseudo-scalar mesons:

- 4 invariant complex reaction amplitudes
- **16** single and double **polarisation observables**

❖ Partial Wave Analysis (**PWA**) fits used to extract resonance parameters (eg: angular momentum, parity).

❖ Require measurements of **cross-section** and **7** additional, carefully chosen polarisation observables to remove ambiguities.

W.-T. Chiang and F. Tabakin, Phys. Rev. C **55**, 2054 (1997).

❖ *Different polarisation observables are extracted through different combinations of **polarised beams** and **targets** and measurements of **recoil polarisation.***

Polarisation Observables

Usual symbol	Helicity representation	Transversity representation	Experiment required [a]	Type
$d\sigma/dt$	$\lvert N\rvert^2+\lvert S_1\rvert^2+\lvert S_2\rvert^2+\lvert D\rvert^2$	$\lvert b_1\rvert^2+\lvert b_2\rvert^2+\lvert b_3\rvert^2+\lvert b_4\rvert^2$	$\{-;-;-\}$	S
$\Sigma\, d\sigma/dt$	$2\mathrm{Re}(S_1^* S_2 - ND^*)$	$\lvert b_1\rvert^2+\lvert b_2\rvert^2-\lvert b_3\rvert^2-\lvert b_4\rvert^2$	$\{L(\frac{1}{2}\pi,0);-;-\}$ $\{-;y;y\}$	S
$T\, d\sigma/dt$	$2\mathrm{Im}(S_1N^* - S_2D^*)$	$\lvert b_1\rvert^2-\lvert b_2\rvert^2-\lvert b_3\rvert^2+\lvert b_4\rvert^2$	$\{-;y;-\}$ $\{L(\frac{1}{2}\pi,0);0;y\}$	S
$P\, d\sigma/dt$	$2\mathrm{Im}(S_2N^* - S_1D^*)$	$\lvert b_1\rvert^2-\lvert b_2\rvert^2+\lvert b_3\rvert^2-\lvert b_4\rvert^2$	$\{-;-;y\}$ $\{L(\frac{1}{2}\pi,0);y;-\}$	S
$G\, d\sigma/dt$	$-2\mathrm{Im}(S_1S_2^* + ND^*)$	$2\mathrm{Im}(b_1b_3^* + b_2b_4^*)$	$\{L(\pm\frac{1}{4}\pi);z;-\}$	BT
$H\, d\sigma/dt$	$-2\mathrm{Im}(S_1D^* + S_2N^*)$	$-2\mathrm{Re}(b_1b_3^* - b_2b_4^*)$	$\{L(\pm\frac{1}{4}\pi);x;-\}$	BT
$E\, d\sigma/dt$	$\lvert S_2\rvert^2-\lvert S_1\rvert^2-\lvert D\rvert^2+\lvert N\rvert^2$	$-2\mathrm{Re}(b_1b_3^* + b_2b_4^*)$	$\{c;z;-\}$	BT
$F\, d\sigma/dt$	$2\mathrm{Re}(S_2D^* + S_1N^*)$	$2\mathrm{Im}(b_1b_3^* - b_2b_4^*)$	$\{c;x;-\}$	BT
$O_x\, d\sigma/dt$	$-2\mathrm{Im}(S_2D^* + S_1N^*)$	$-2\mathrm{Re}(b_1b_4^* - b_2b_3^*)$	$\{L(\pm\frac{1}{4}\pi);-;x'\}$	BR
$O_z\, d\sigma/dt$	$-2\mathrm{Im}(S_2S_1^* + ND^*)$	$-2\mathrm{Im}(b_1b_4^* + b_2b_3^*)$	$\{L(\pm\frac{1}{4}\pi);-;z'\}$	BR
$C_x\, d\sigma/dt$	$-2\mathrm{Re}(S_2N^* + S_1D^*)$	$2\mathrm{Im}(b_1b_4^* - b_2b_3^*)$	$\{c;-;x'\}$	BR
$C_z\, d\sigma/dt$	$\lvert S_2\rvert^2-\lvert S_1\rvert^2-\lvert N\rvert^2+\lvert D\rvert^2$	$-2\mathrm{Re}(b_1b_4^* + b_2b_3^*)$	$\{c;-;z'\}$	BR
$T_x\, d\sigma/dt$	$2\mathrm{Re}(S_1S_2^* + ND^*)$	$2\mathrm{Re}(b_1b_2^* - b_3b_4^*)$	$\{-;x;x'\}$	TR
$T_z\, d\sigma/dt$	$2\mathrm{Re}(S_1N^* - S_2D^*)$	$2\mathrm{Im}(b_1b_2^* - b_3b_4^*)$	$\{-;x;z'\}$	TR
$L_x\, d\sigma/dt$	$2\mathrm{Re}(S_2N^* - S_1D^*)$	$2\mathrm{Im}(b_1b_2^* + b_3b_4^*)$	$\{-;z;x'\}$	TR
$L_z\, d\sigma/dt$	$\lvert S_1\rvert^2+\lvert S_2\rvert^2-\lvert N\rvert^2-\lvert D\rvert^2$	$2\mathrm{Re}(b_1b_2^* + b_3b_4^*)$	$\{-;z;z'\}$	TR

❖ *Complete measurement requires cross-section, Σ, T, P and four double-polarisation observables!*

a) Notation: $\{P_\gamma;P_T;P_R\}$

- P_γ Beam polarisation
- $L(\theta)$ Linear polarisation at angle θ to scattering plane
- C Circular polarisation
- P_T Direction of target polarisation
- P_R Component of recoil polarisation measurement

I. Barker, A. Donnachie, J. Storrow, *Nucl. Phys.* **B 95**, 347 (1975)

Measuring polarisation observables

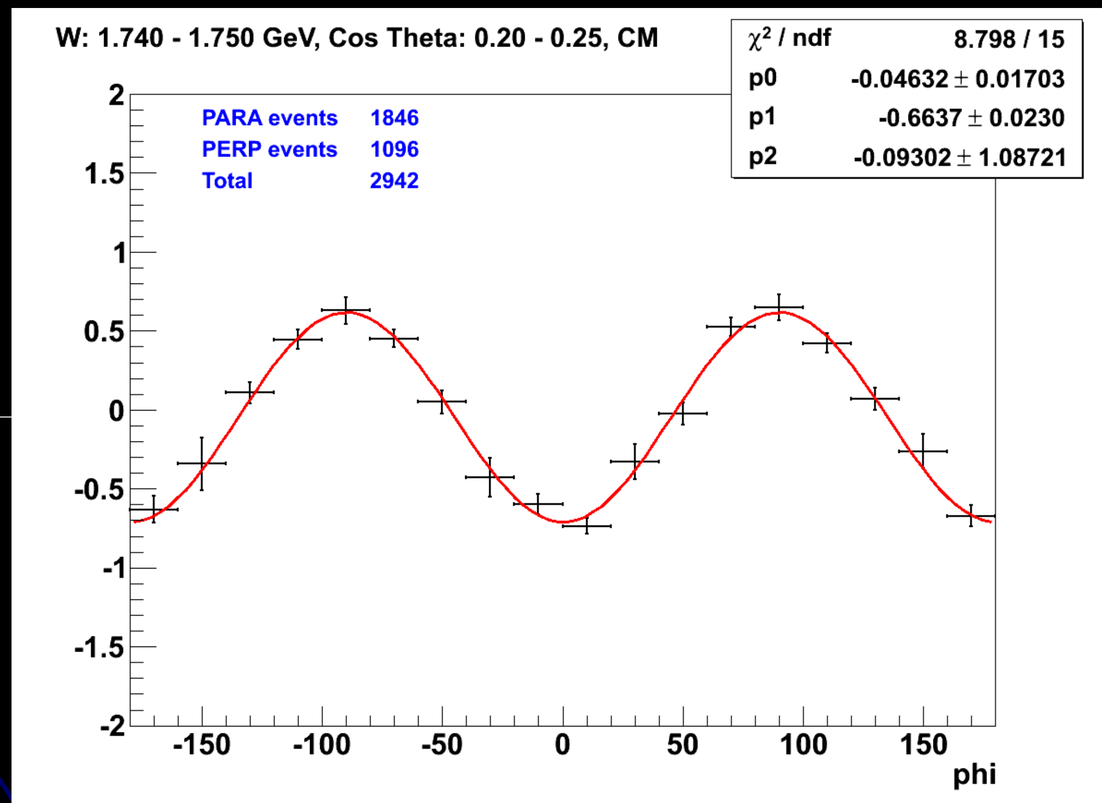
eg: beam asymmetry, Σ

$$\rho_f \frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{unpol}\{1 - P_\gamma^{lin}\Sigma\cos 2\phi$$

$$N_\parallel = N_\theta(1 - P\Sigma\cos 2\varphi)$$

$$N_\perp = N_\theta(1 + P\Sigma\cos 2\varphi)$$

$$\Sigma P\cos 2\varphi = \frac{N_\parallel - N_\perp}{N_\parallel + N_\perp}$$



- Removes detector systematics

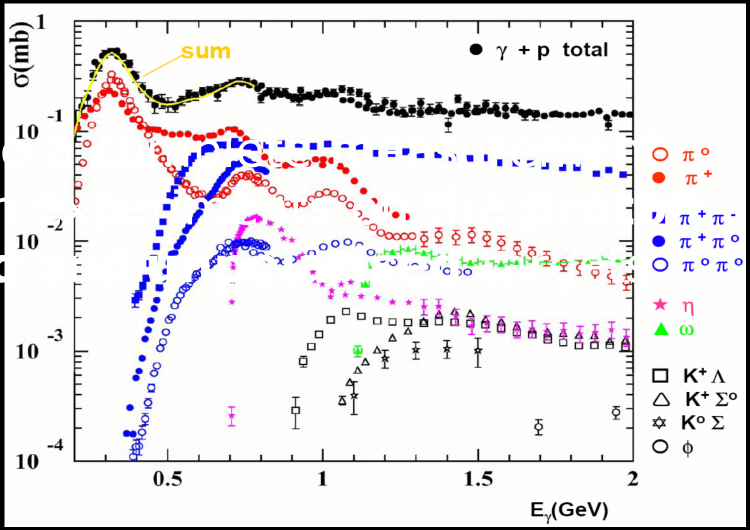
N* programme

❖ EM interaction does not conserve isospin – multipole amplitudes contain **isoscalar** and **isovector** contributions of EM current.

❖ Both **proton** and **neutron** targets are therefore required to study different isospin couplings.

❖ Different meson production channels are sensitive to different resonances.

❖CLAS N* programme is on track t
for a range of meson channels, with
and **neutron**, using both **polarisec**
and photon beams.

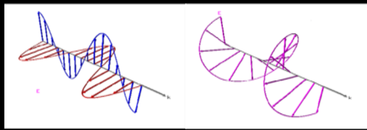


The Jefferson Laboratory

CLAS:

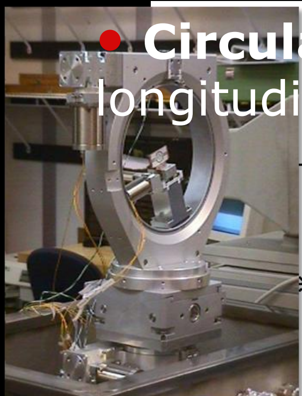
- **Multi-layer** onion of detectors for charged and neutral particles.
- Very **large angular coverage**: **Near full coverage** in azimuthal angle and from **8° to 140°** in scattering angle.

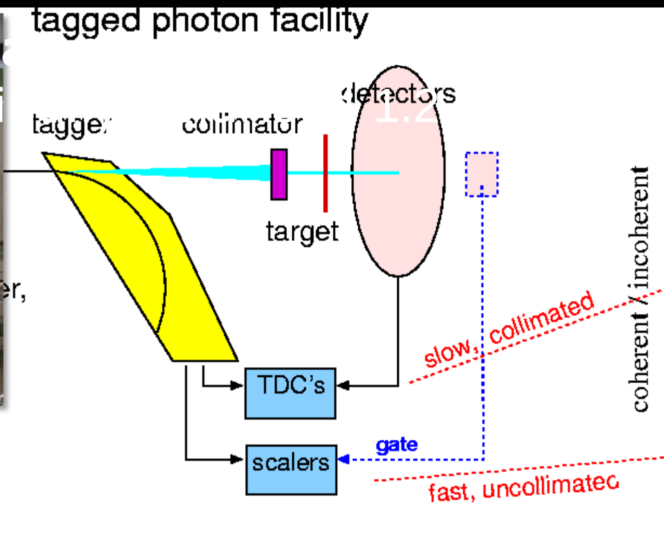
- 1.4 km racetrack electron beam accelerator with two LinAc sections.
- Operating at up to **6 GeV**.

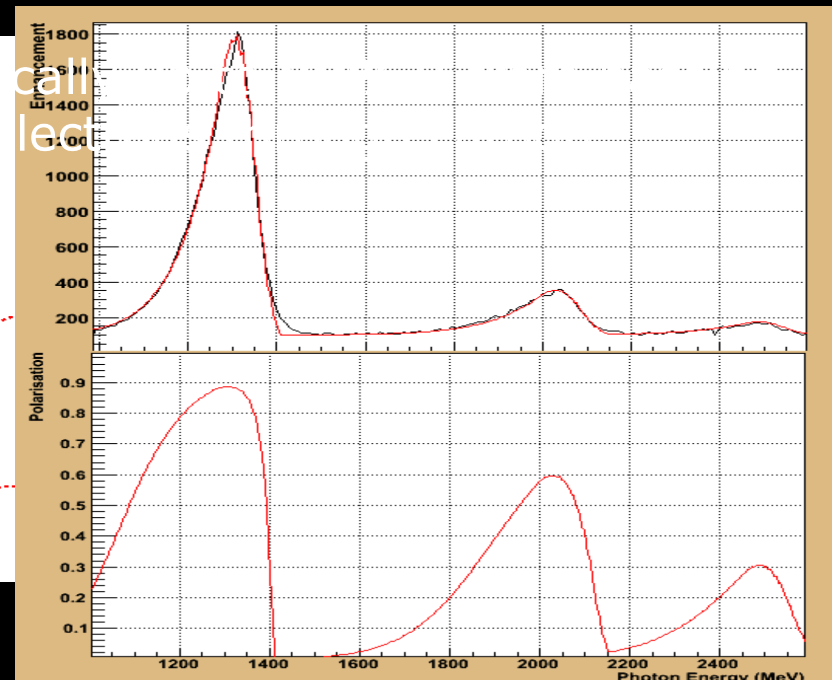


The Photon Beam

- Produced via **bremsstrahlung** of electron beam in a radiator.





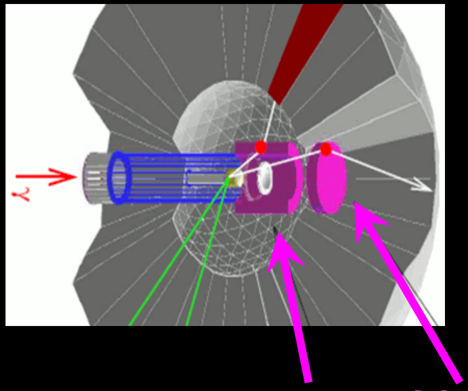


- **Linear** photon polarisation (up to > **90%**): unpolarised electrons through highly ordered crystalline radiator, typically 20 – 50 μm diamond.

- Crystal orientation chosen to produce a "**coherent**" peak of polarised photons at the required energy.

Recoil polarisation

- Currently unable to measure recoil nucleon polarisation, although possibility is a recoil polarimeter similar to that used with the Crystal Ball at MAMI, Mainz (*Dan Watts, Edinburgh*).



- Hyperons are “self-analysing” – polarisation can be determined through the angular distributions of their weak decay products:

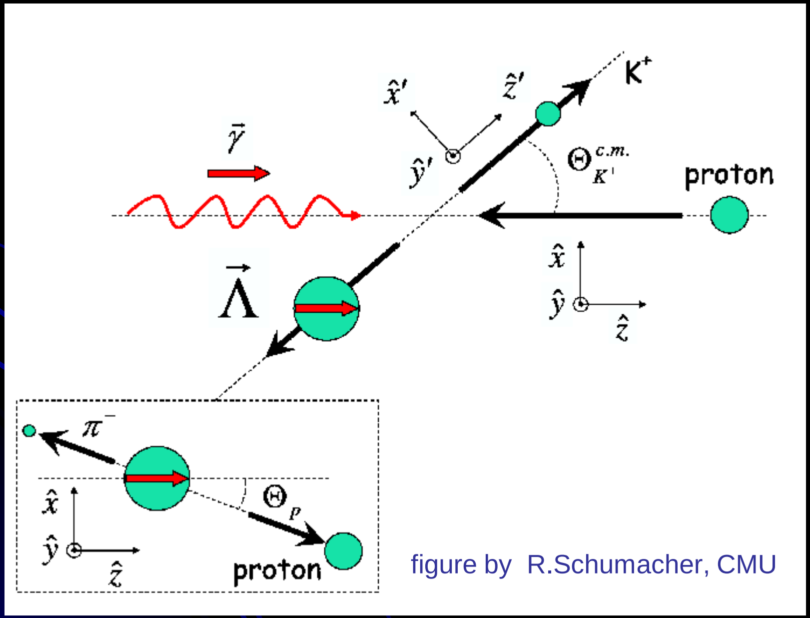


figure by R.Schumacher, CMU

$$\gamma\, p \to K^+ + \Lambda, \qquad \Lambda \longrightarrow p\, \pi^-$$

$$\gamma\, p \to K^+ + \Sigma^0, \qquad \Sigma^0 \to \Lambda + \gamma, \qquad \Lambda \longrightarrow p\, \pi^-$$

Unpolarised target experiments

Two recent experiments:

G8: **Linearly** polarised photons in range 0.9 – 2.1 GeV on LH_2 target. Measurements on the **proton** of:

- ✓ beam asymmetry from
  - $\gamma p \rightarrow \pi^+ n$, $\pi^0 p$ **(see M. Dugger's talk)**
  - $\gamma p \rightarrow \eta p$
  - $\gamma p \rightarrow \eta' p$
- ✓ beam-recoil double polarisation observables from
  - $\gamma p \rightarrow KY$ ($K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^+$)

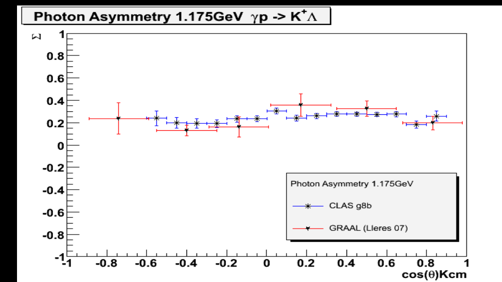
Complements earlier G1 experiment with circularly polarised photons

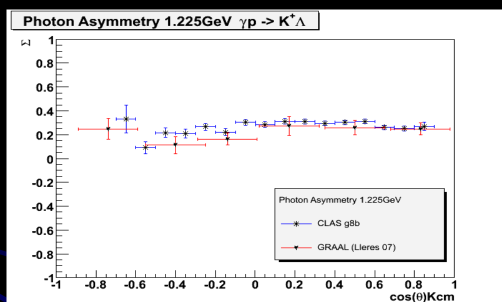
G13: Linearly (1.1 – 2.3 GeV) and circularly (0.4 – 2.5 GeV) polarised photons on LD_2 target. Complementary measurements on the **neutron**.

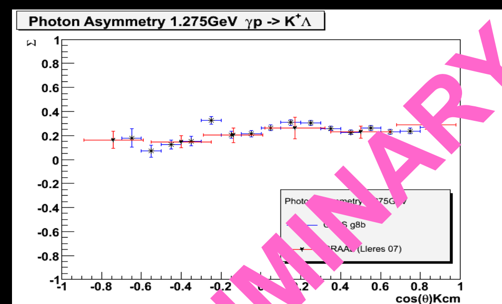
G8b preliminary photon asymmetry results - **$K^+\Lambda$**

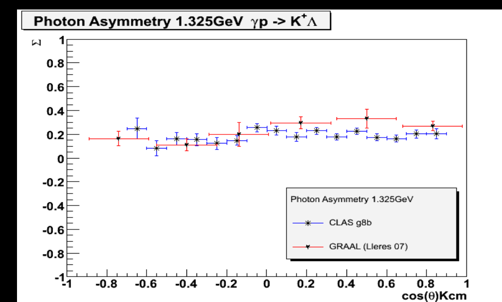
(Craig Paterson, Glasgow)

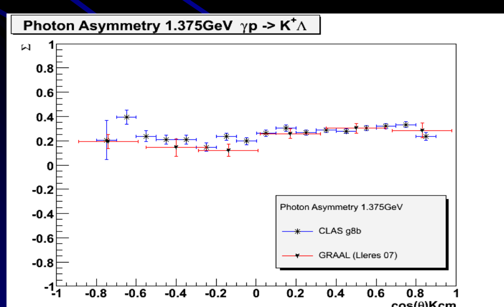
- Compared with previous results from GRAAL (red)
  - 7 energy bins 50 MeV wide
  - Range 1175 – 1475 MeV
  - Good agreement with previous results

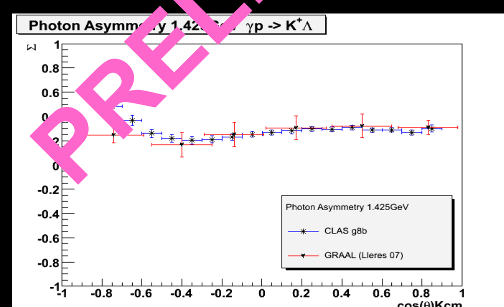


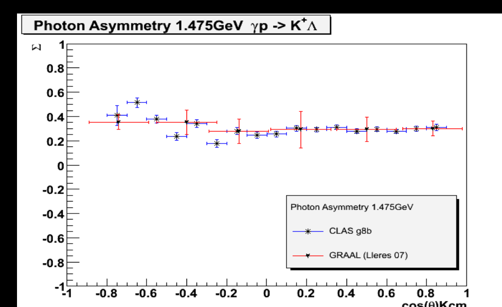










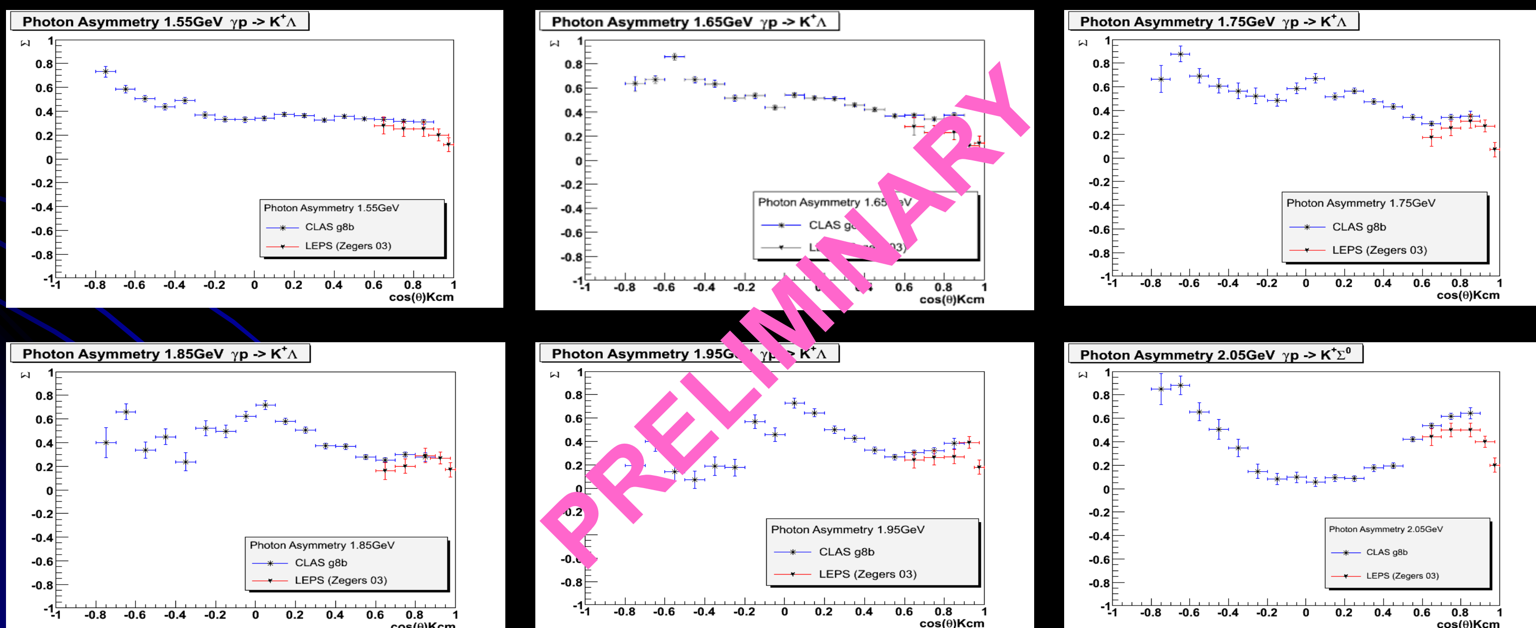


G8b preliminary photon asymmetry results - **$K^+\Lambda$**
(Craig Paterson, Glasgow)

- Compared with previous results from LEPS (red)
  - 6 energy bins 100 MeV wide
  - Range 1550 – 2050 MeV
  - More bins for our data

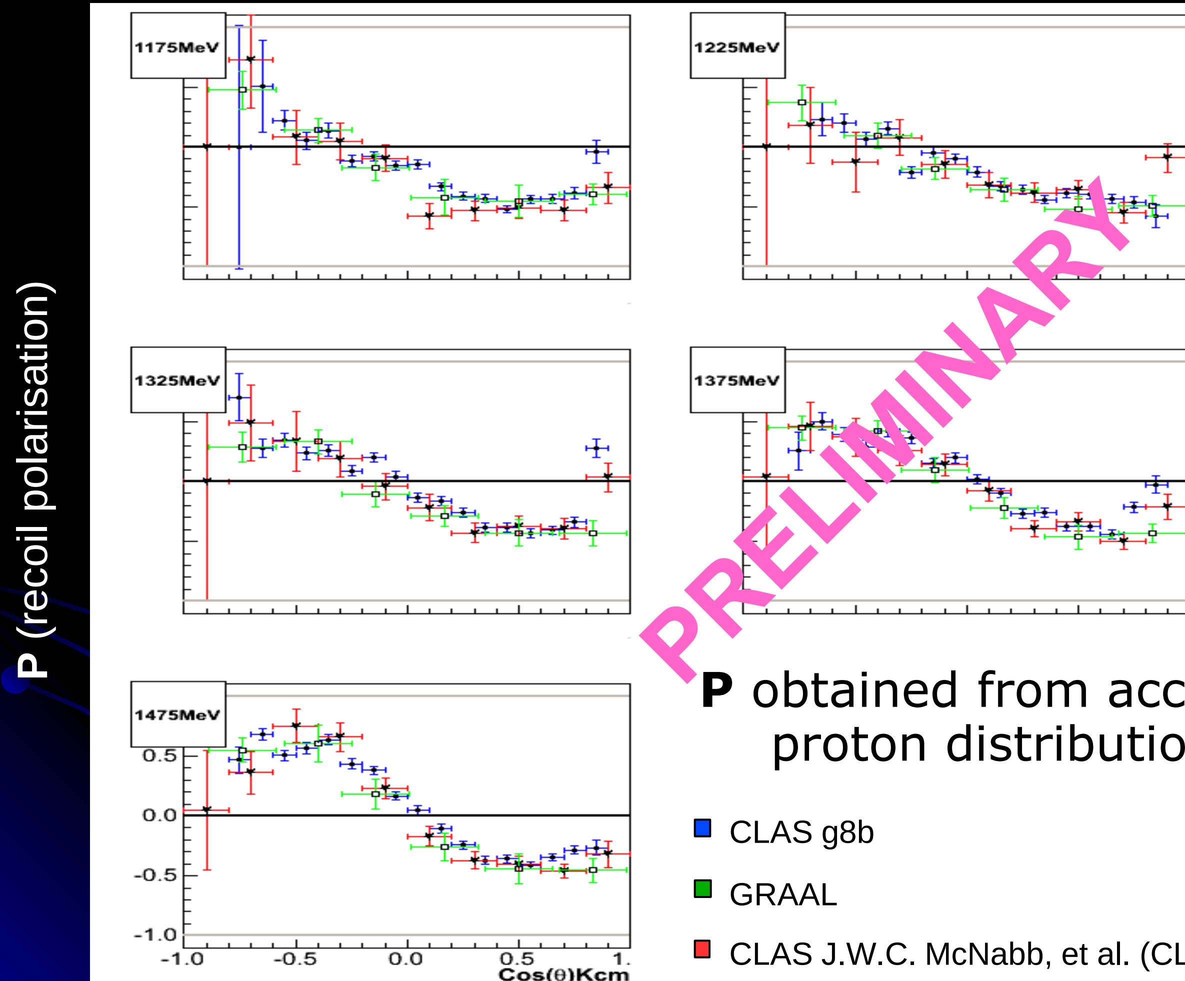
Increase the angular coverage to backward angles

LEPS also recently have some consistent, new points at backward angles.
Hicks et al., PRC 76, 042201(R) (2007).



G8b preliminary recoil polarisation results - $K^+\Lambda$

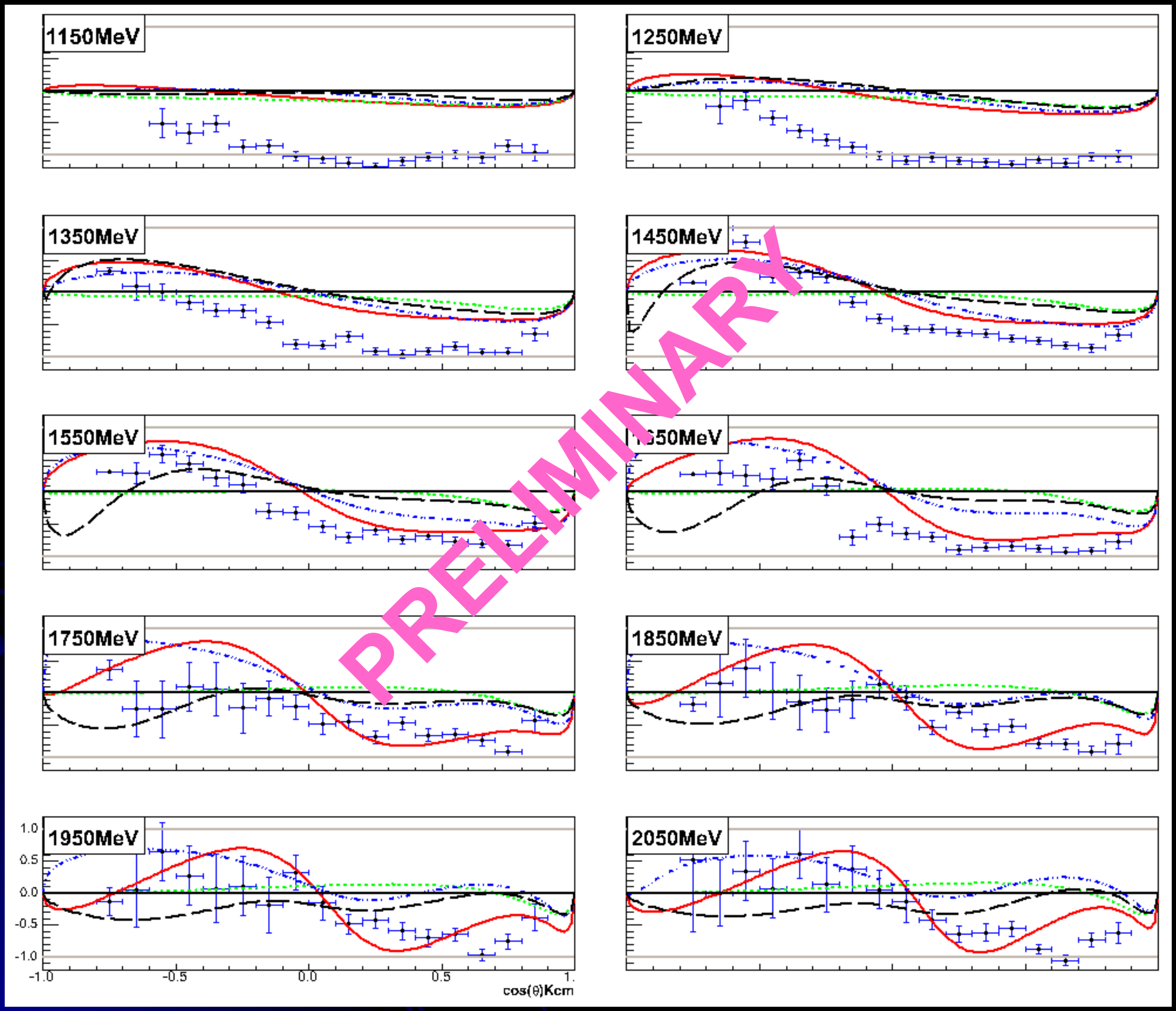
(Craig Paterson, Glasgow)



P obtained from acceptance-corrected proton distribution

- CLAS g8b
- GRAAL
- CLAS J.W.C. McNabb, et al. (CLAS) Phys. Rev. C 69, 042201(R) (2004)

G8b preliminary O_x results - **$K^+\Lambda$**
(Craig Paterson, Glasgow)



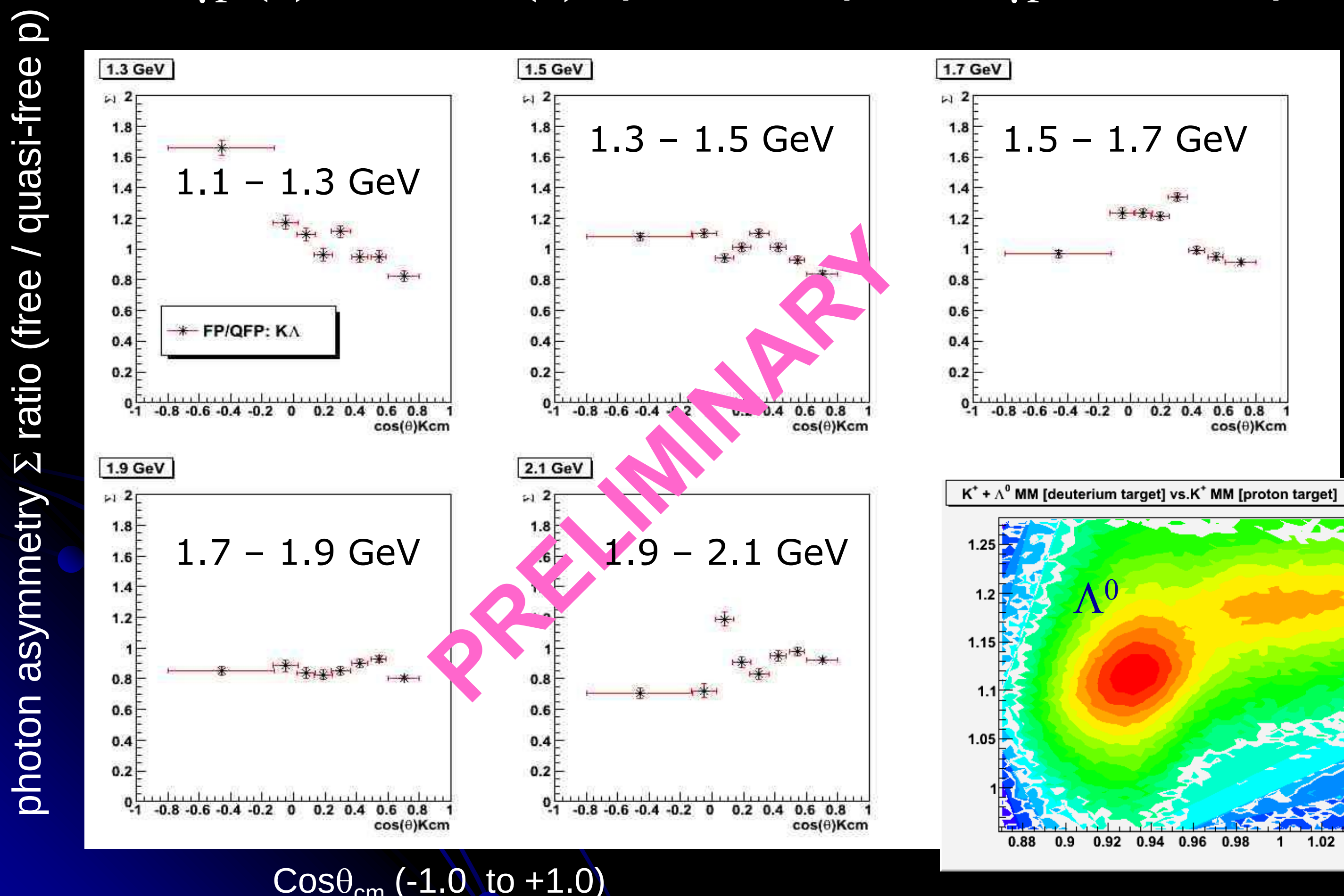
Comparison with Regge-plus-Resonance model from Gent group

- Large Polarizations
- Some evidence for an important role for missing $D_{13}(1900)$ state
- Poor agreement at low energy

G13: How free is the nucleon?

(Russell Johnstone, Glasgow)

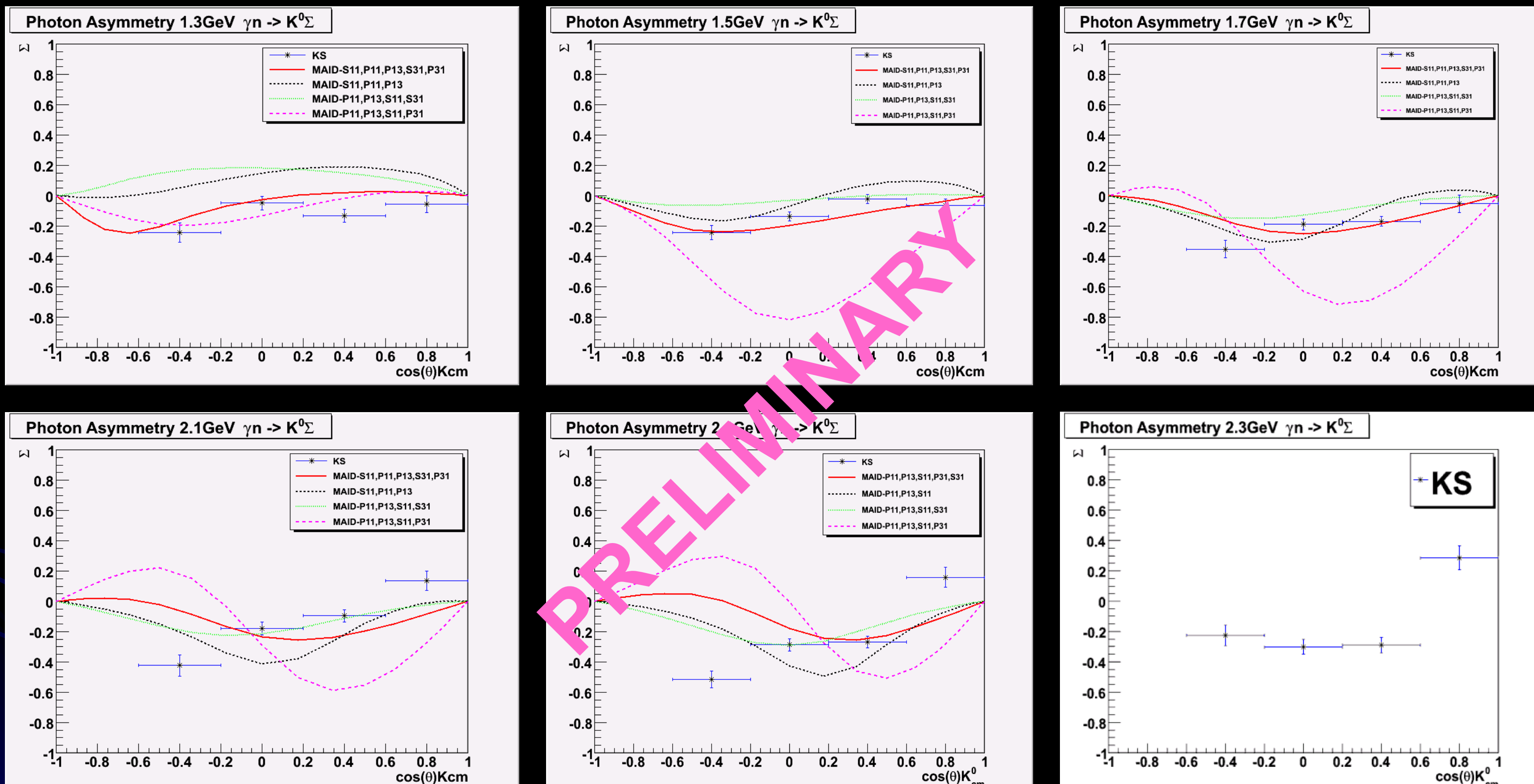
- Compare photon asymmetry of free and bound proton: $\gamma p\ (n) \longrightarrow K^+\Lambda^0\ (n)$ (*G13 data*) with $\gamma p \longrightarrow K^+\Lambda^0$ (*G8 data*)



Indicates that quasi-free neutron is a good approximation to a free neutron

G13 preliminary beam asymmetry results – $K^0\Sigma$

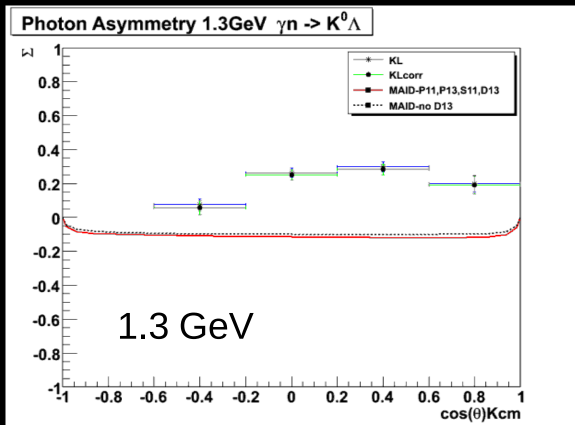
(Neil Hassal, Glasgow)

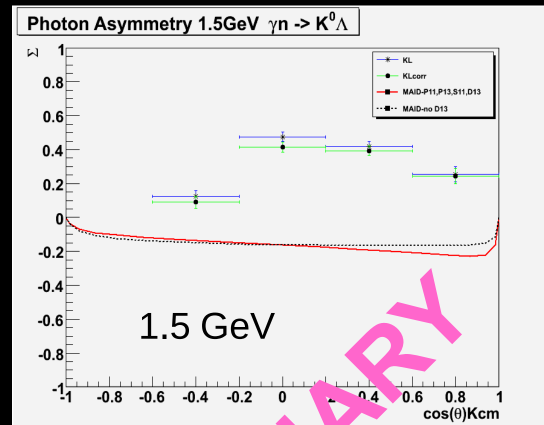


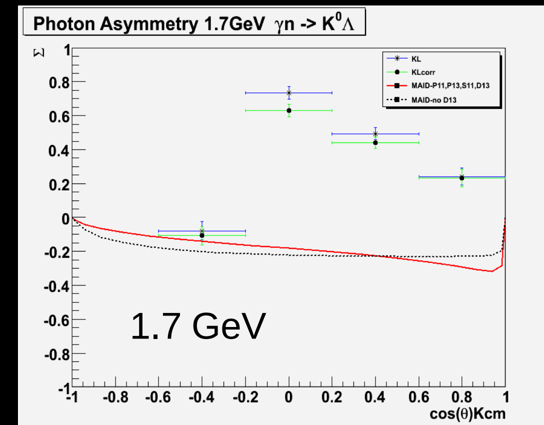
(blue)	KΣ	(red)	MAID - P11, P13, P31, S11, S31	(magenta dotted)	MAID - P11, P13, P31, S11
(green)	MAID – P11, P13, S11, S31	(dark dotted)	MAID – S11, P11, P13		

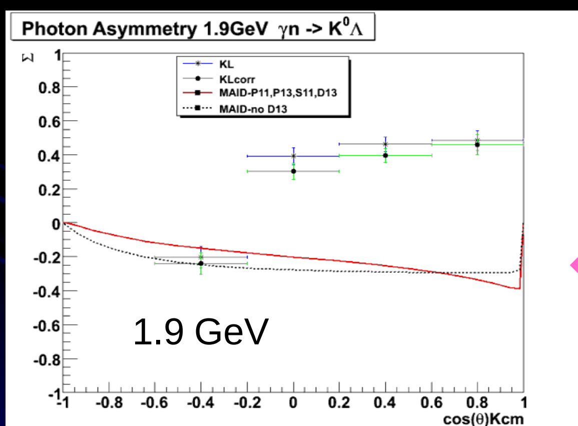
G13 preliminary beam asymmetry results – $K^0\Lambda^0$

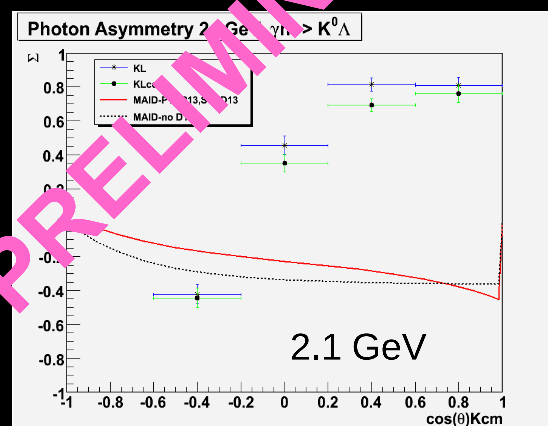
(Neil Hassal, Glasgow)

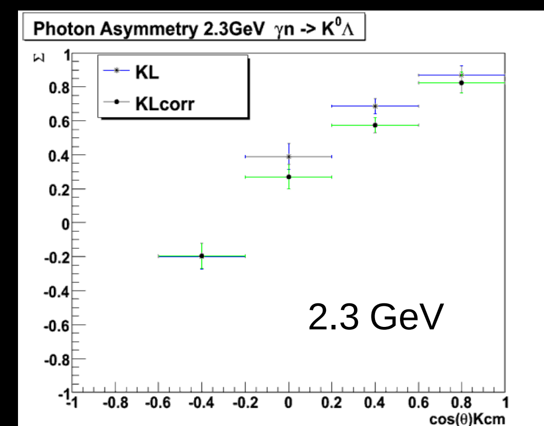












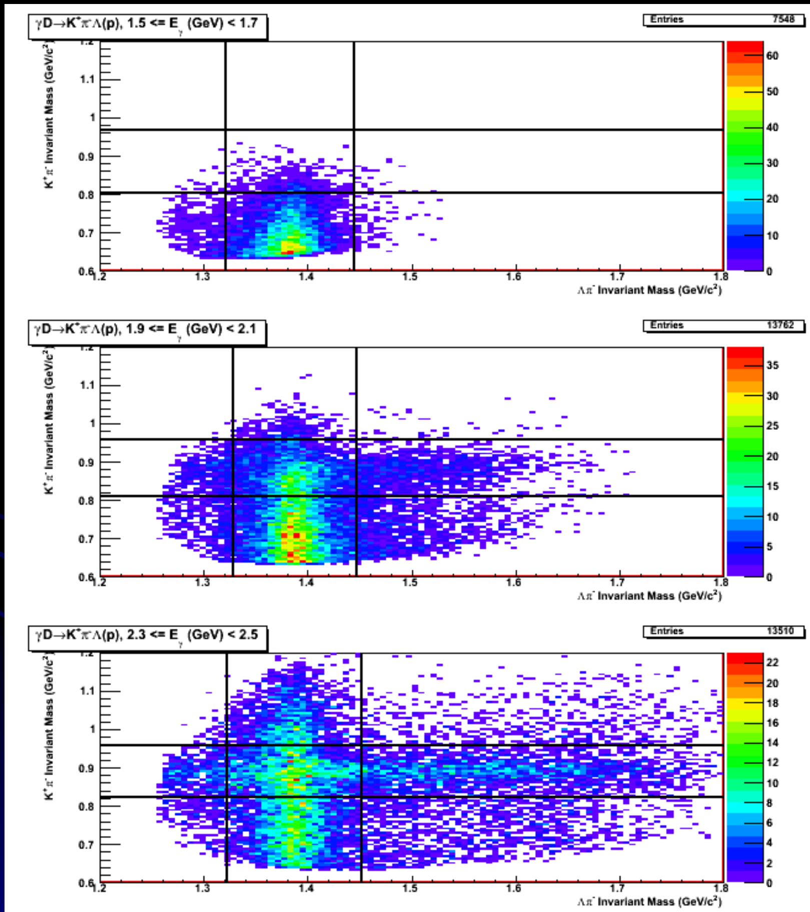
(blue)	$K\Lambda$	(red)	MAID - P11, P13, S11, D13
(dark green)	$K\Lambda$ corrected	(dotted)	MAID - no D13

G13 preliminary K^{*0} and $\Sigma^{-}(1385)$ identification

(Paul Mattione, Rice)

- Cut on overlap between invariant masses of K^{*0} and Σ^{-}

K^{*0}



After cut:

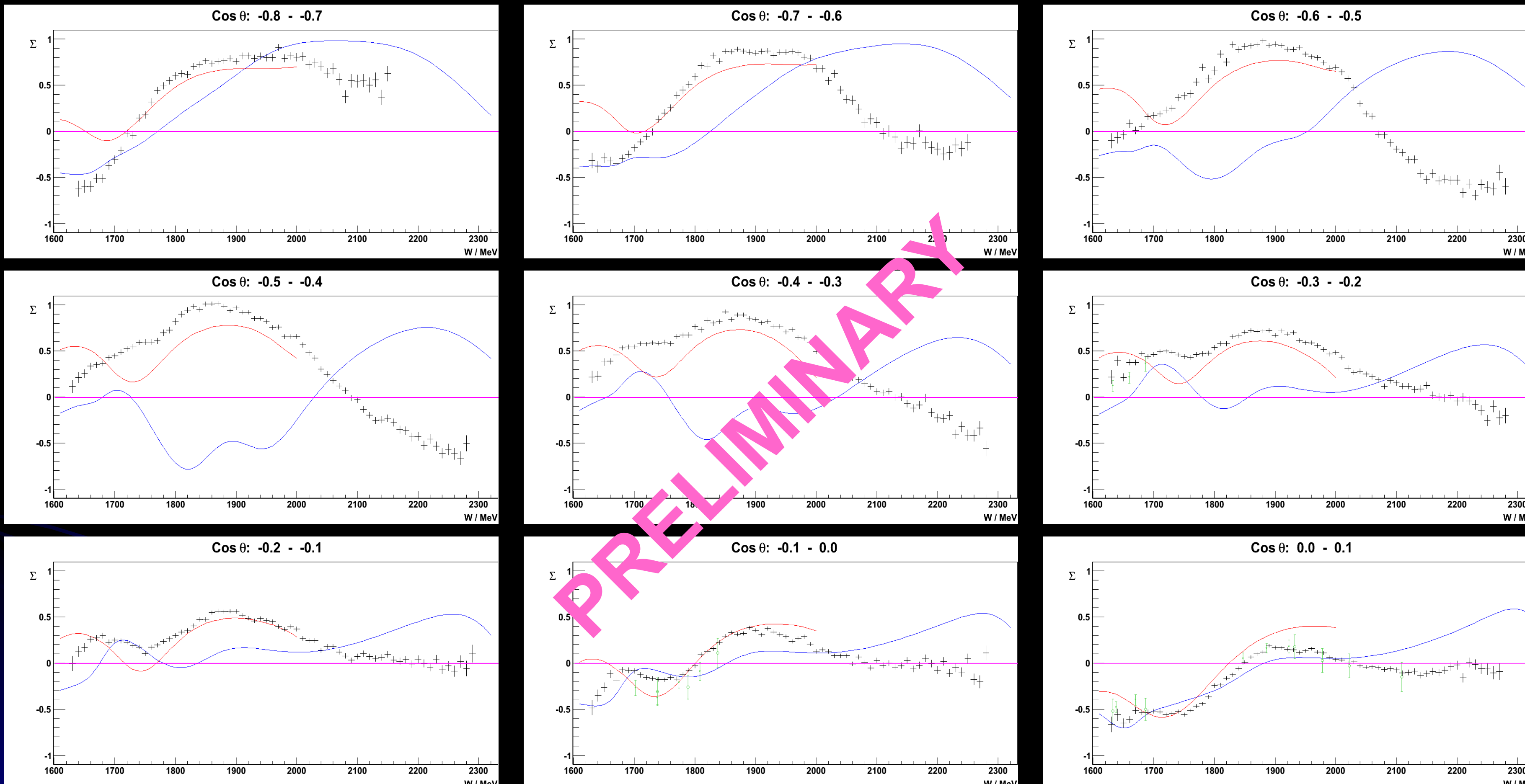
$\gamma\, n \longrightarrow K^{*0}\,\Lambda$ ~5000 events

$\gamma\, n \longrightarrow K^{+}\,\Sigma^{*\,-}$ ~35000 events

Σ^{*-}

G13 preliminary beam asymmetry results – $p\,\pi^-$

(Daria Sokhan)

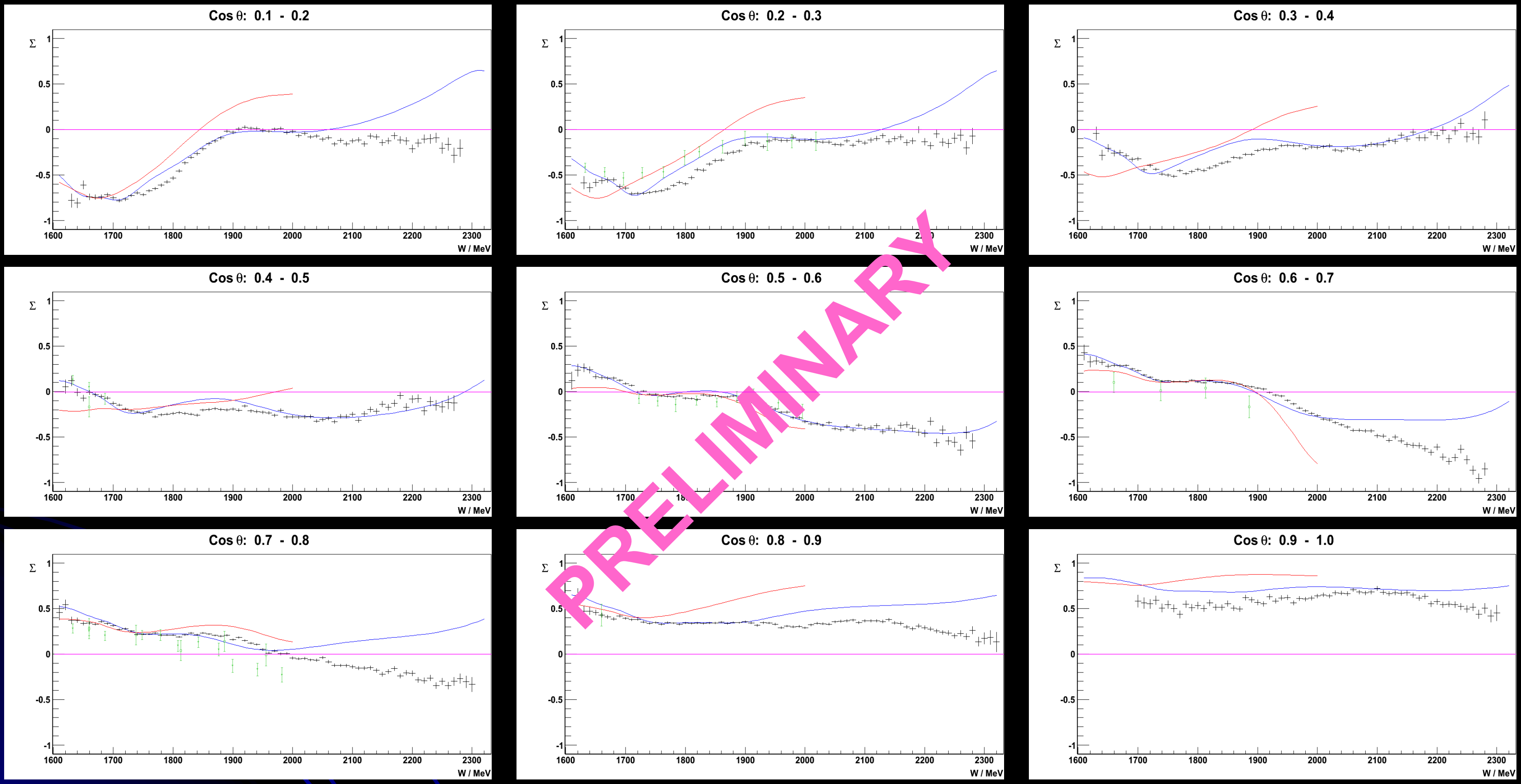


- Previous data (Alspector, PRL **28**, 1403 ('72), Abrahamian,SJNP 32, 69 ('80), Adamyan, JPG **15,** 1797 ('89)).

MAID 07 **SAID 09**

G13 preliminary beam asymmetry results – $p\,\pi^{-}$

(Daria Sokhan)



- Previous data (Alspector, PRL **28**, 1403 ('72), Abrahamian,SJNP 32, 69 ('80), Adamyan, JPG **15,** 1797 ('89)).

MAID 07 **SAID 09**

FroST – target for polarised protons

- **Beam**: circularly and linearly polarised photons at 0.5 – 2.4 GeV.
- **Target**: polarised butanol (C_4H_9OH)
- **Measurements** of single and double polarisation observables from:
  - $\gamma p \rightarrow \pi^0 p$, $\pi^+ n$
  - $\gamma p \rightarrow \pi^+ \pi^- p$
  - $\gamma p \rightarrow \eta p$
  - $\gamma p \rightarrow KY$ ($K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^+$)
- **G9a**: Nov 2007 – Feb 2008

  Longitudinal target polarisation
- **G9b**: Mar – July 2010

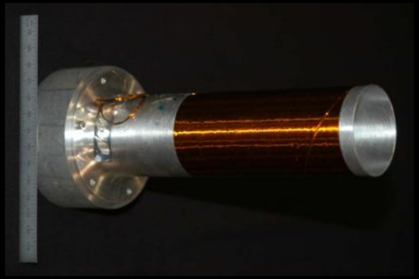
  Transverse target polarisation

Trigger of at least one charged particle in CLAS

FROST

- Butanol target polarised via **Dynamic Nuclear Polarisation** (DNP)

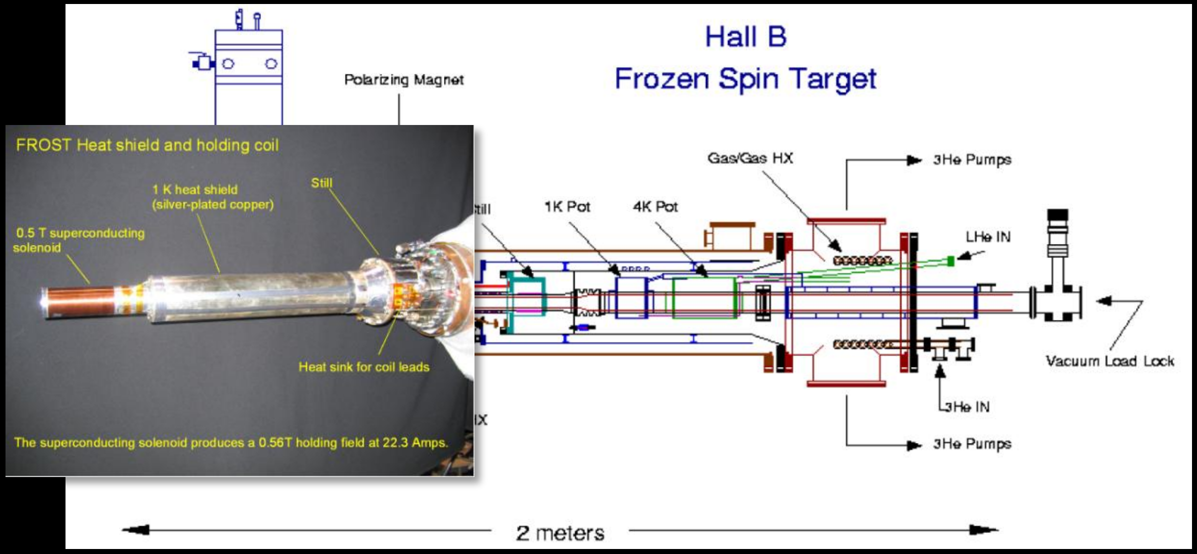
- Polarisation maintained during experiment by 0.5 T superconducting holding coils – providing either a longitudinal or a transverse magnetic field.



Racetrack coils for transverse polarization

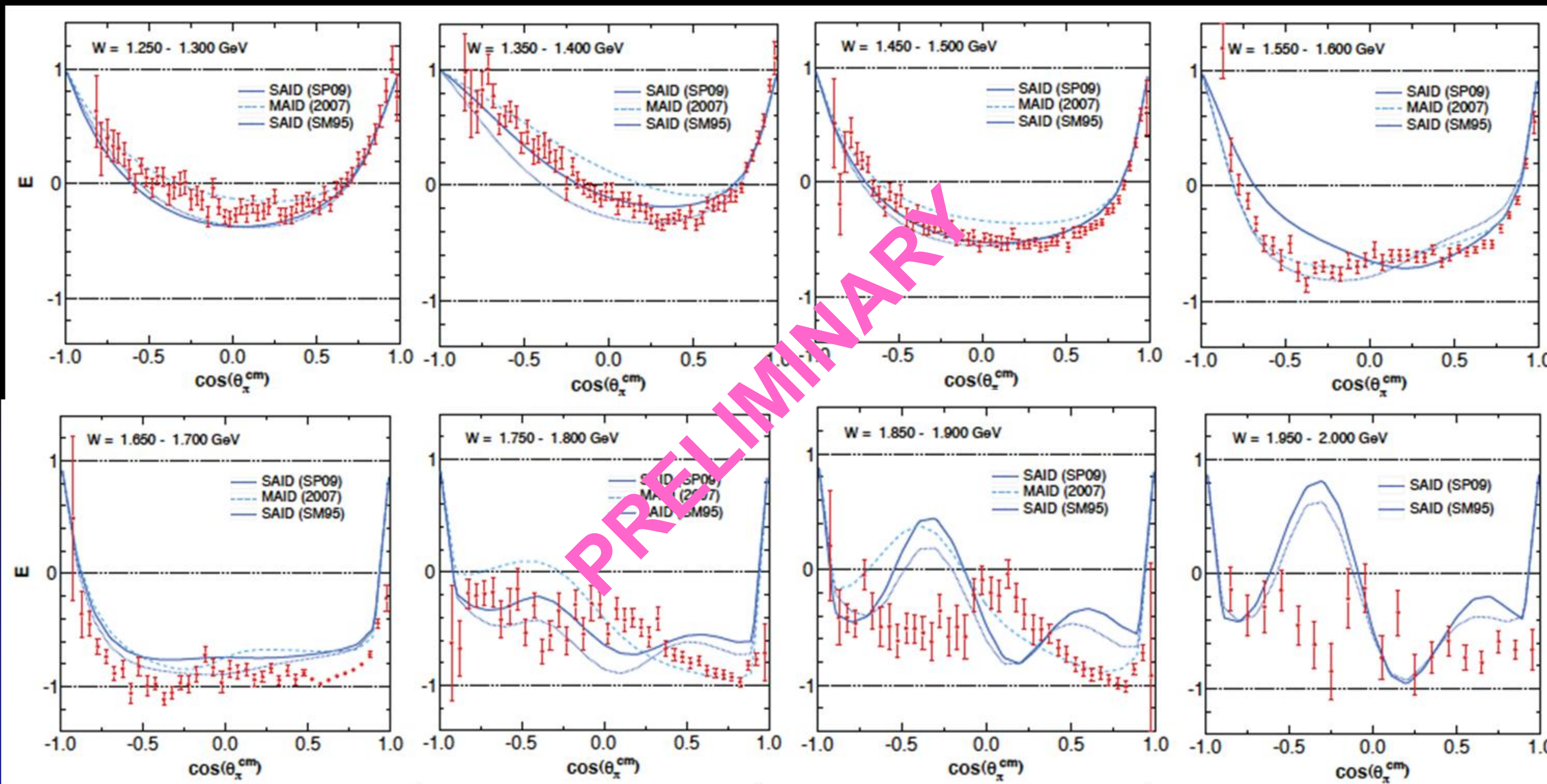
- Custom built dilution refrigerator maintains v. low temperature for long polarisation relaxation time.

- ✓ **T** at operation **< 30 mK**
- ✓ **Polarisation > 90%**
- ✓ Relaxation time up to **4000 hours**



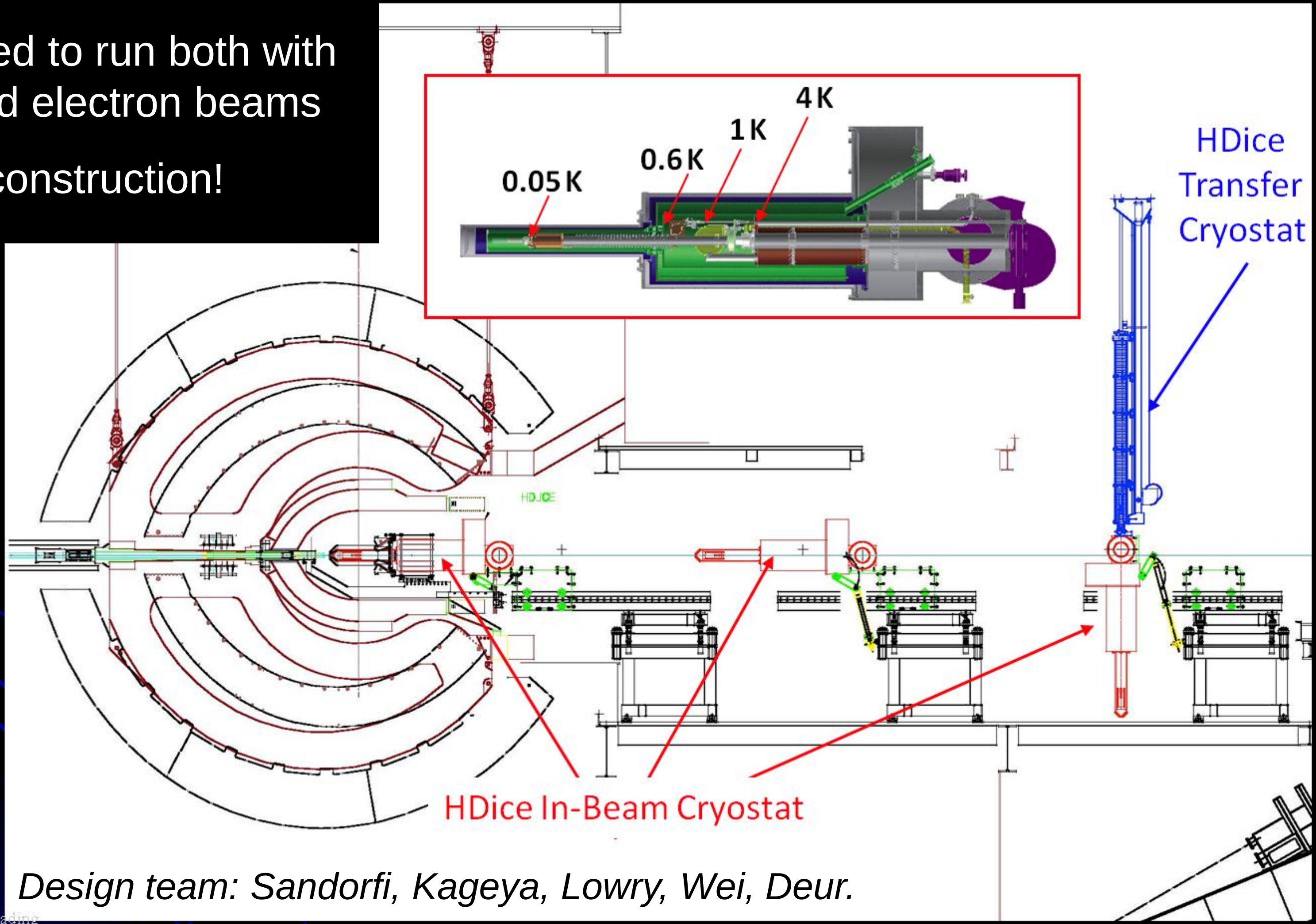
FroST: helicity asymmetry E in $\gamma\, p \rightarrow \pi^{+} n$

(Steffen Strauch, USC)



HDice – polarised neutrons

- Designed to run both with photon and electron beams
- Under construction!



Design team: Sandorfi, Kageya, Lowry, Wei, Deur.

In short…

- Exciting experimental N* programme of meson photoproduction underway at CLAS

- Transversely and longitudinally polarised targets

- Experiments on both proton and neutron

- HDice experiment expected to complete the set of polarisation measurements on a number of channels.

- Approaching a model-independent analysis of meson photoproduction data, which promises much greater insight into the nucleon resonance spectrum.

Watch this space!

Thank you!