Study of Hyperon Nucleon Interactions with CLAS

Daniel Watts

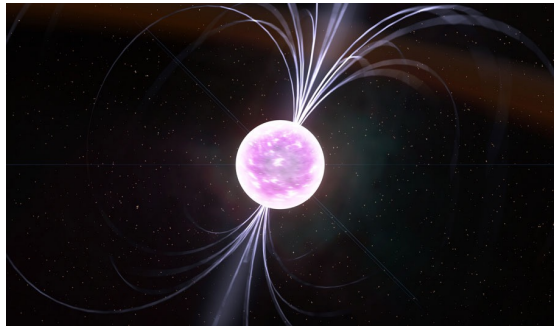
(CLAS collaboration)

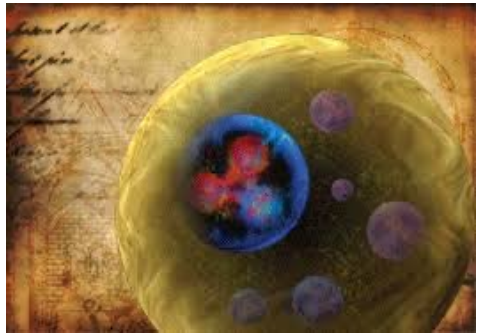
Outline

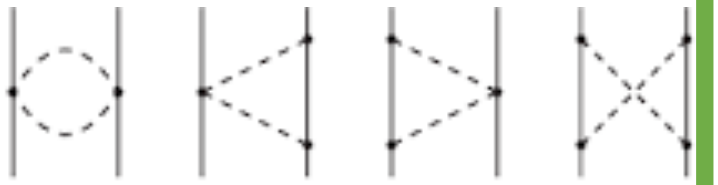
- Motivation
- Thomas Jefferson Laboratory
  - The CEBAF Large Acceptance Spectrometer (CLAS)
- Recent results – published and in progress
  - The published results on Λp scattering
  - Current status of Σp , Λd scattering analyses
  - Polarisation observables in FSI – a new window on YN interactions?
  - KLF@JLAB – a next generation tagged hyperon beam facility
- Summary and Outlook

Why study the Hyperon Nucleon Interaction?

- An improved understanding Y-N interaction potentials would impact a range of fields:
  - Better constraints on composition of neutron stars
  - Better understanding of hypernuclear structure and hyperon matter
  - A more unified picture of the SU(3) baryon-baryon interaction - challenging theories of the strong interaction





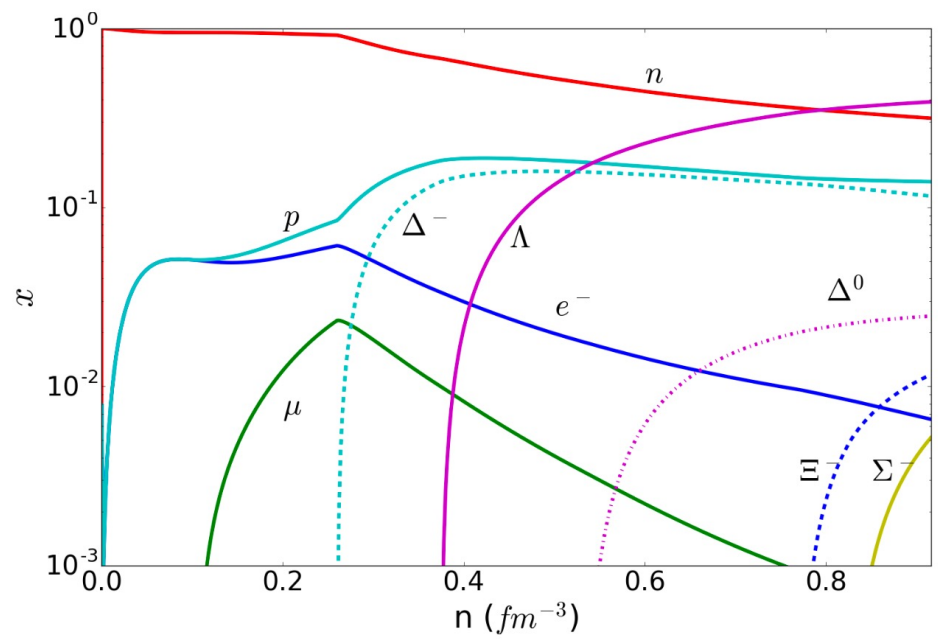


Neutron stars

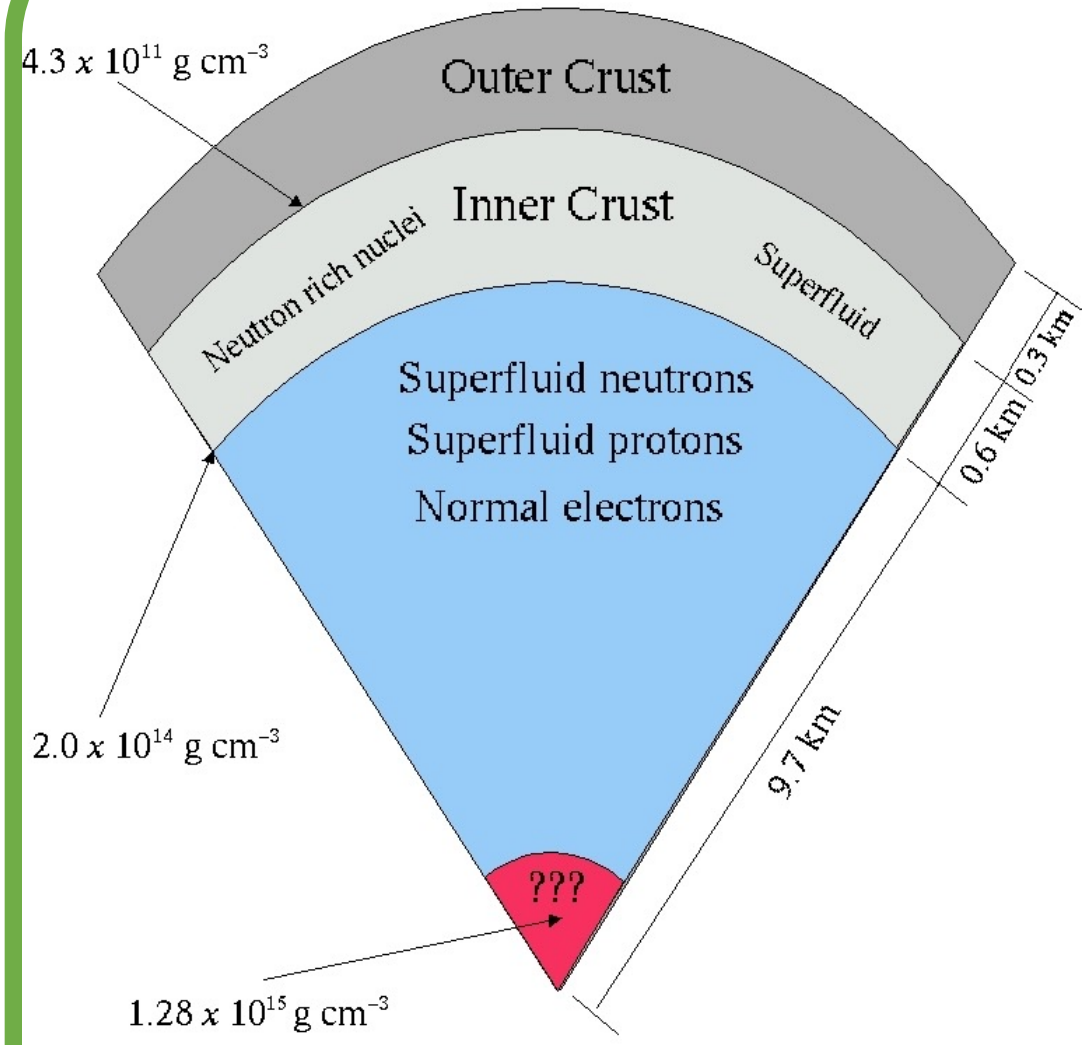
- Compact supernova remnants

  Radius ~10km
  Surface velocity up to ~1/4c

- Composition debated
- Terrestrial constraints -> hadron/nuclear

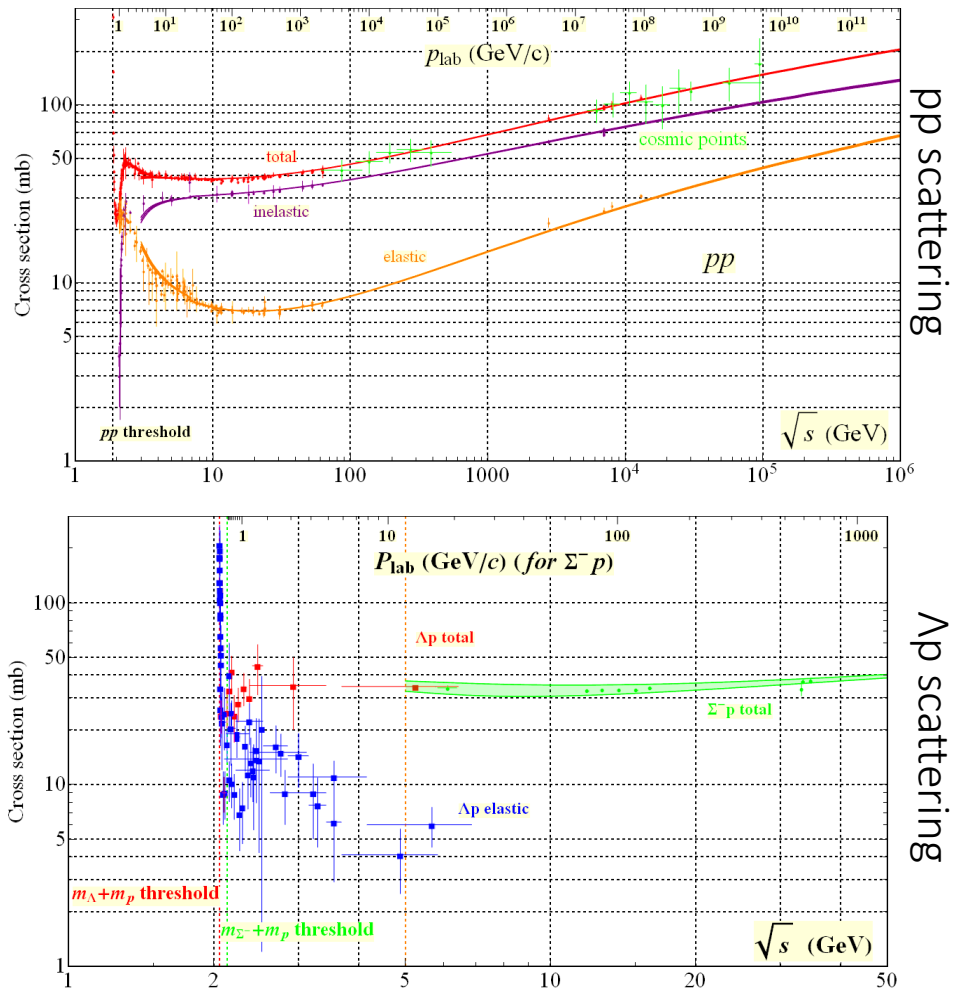


Ribes *et al* 2019 *ApJ* 883 168



Neutron Star Pizza

The paucity of Λ-p data



Plots from PDG 2018

Total of <1300 observed Λp → Λ p

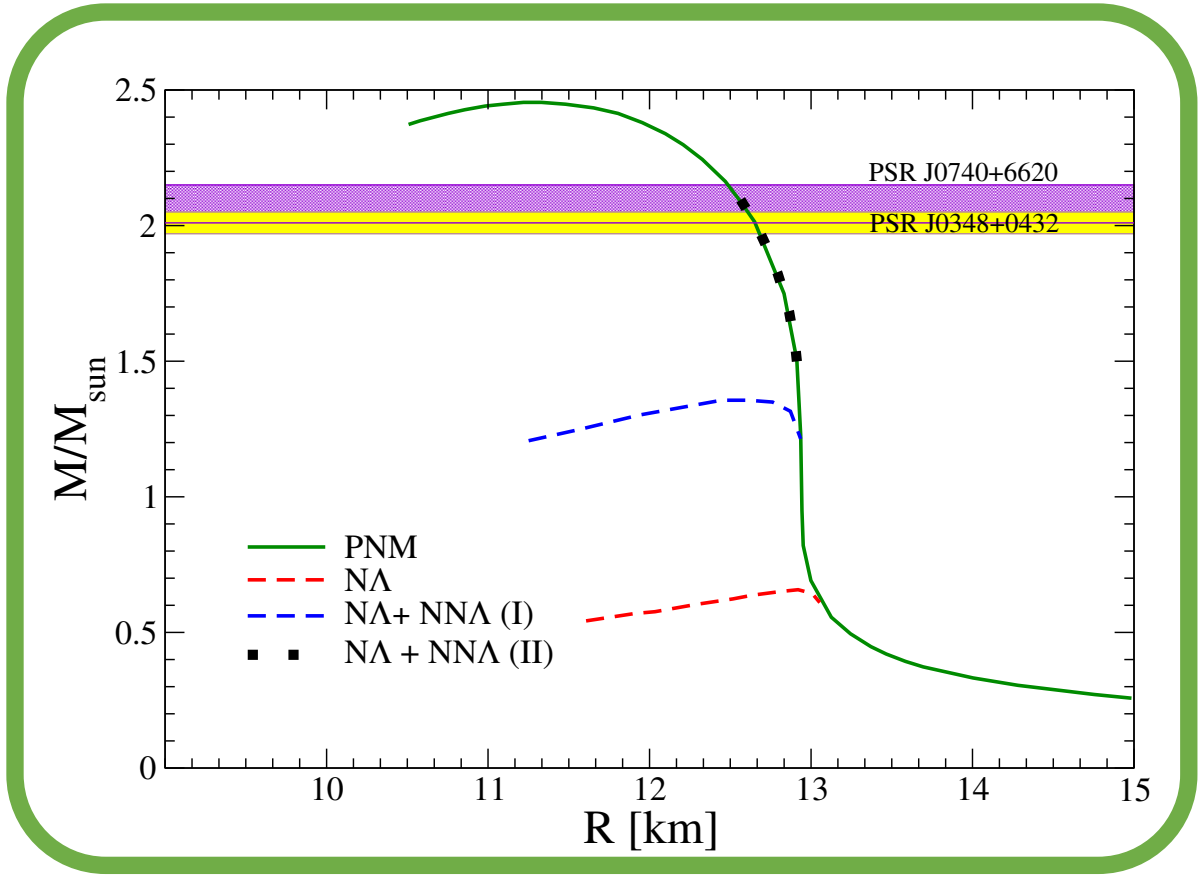
Λ source	Detector	p_Λ	$N_{\Lambda p\to\Lambda p}$
$\pi^- p \to \Lambda K^0$	LH_2 BC	0.5–1.0	4
$\pi^- p \to \Lambda K^0$	LH_2 BC	0.4–1.0	14
$K^- N \to \Lambda\pi$	Propane BC	0.3–1.5	26
$K^- N \to \Lambda\pi$	Freon BC	0.5–1.2	86
$K^- A \to \Lambda X$	Heavy Liquid BC	0.15–0.4	11
$K^- p \to \Lambda X$	LH_2 BC	0.12–0.4	75
$nA \to \Lambda X$	Propane BC	0.9–4.7	12
$K^- p \to \Lambda X$	LH_2 BC	1.0–5.0	68
$K^- p \to \Lambda X$	LH_2 BC	0.1–0.3	378
$K^- p \to \Lambda X$	LH_2 BC	0.1–0.3	224
K^-Pt $\to \Lambda X$	LH_2 BC	0.3–1.5	175
pPt $\to \Lambda X$	LH_2 BC	1.0–17.0	109
pCu $\to \Lambda X$	LH_2 BC	0.5–24.0	71

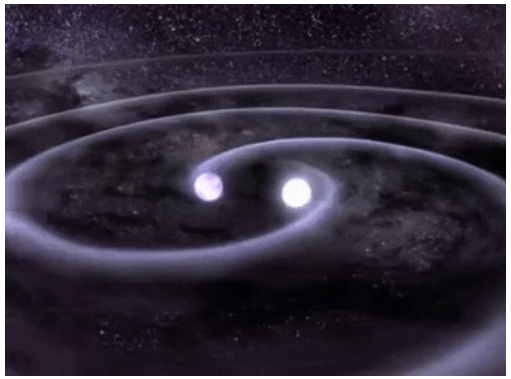
$$a(^1S_0) = -0.7 - -2.6 \text{ fm}$$
$$a(^3S_1) = -1.7 - -2.15 \text{ fm}$$

Free-space scattering data complementary to Λ-Hypernuclear studies where medium mod/many-body effects convoluted with basic Λ–N

The hyperon puzzle

- Hyperons are predicted to appear in the core of NS at $\rho \sim 2 - 3\ \rho_0$
- Hyperons soften the EoS → Reduction on maximum NS mass
- Observation of NS with $M_G > 2M_s$ is incompatible with such soft EoS
  → Hyperon Puzzle
- Better experimental constraint on the Y-N (and in-medium behaviour) is crucial ..





Some Proposed solutions of the hyperon puzzle

- Hyperon Puzzle: Possible solutions

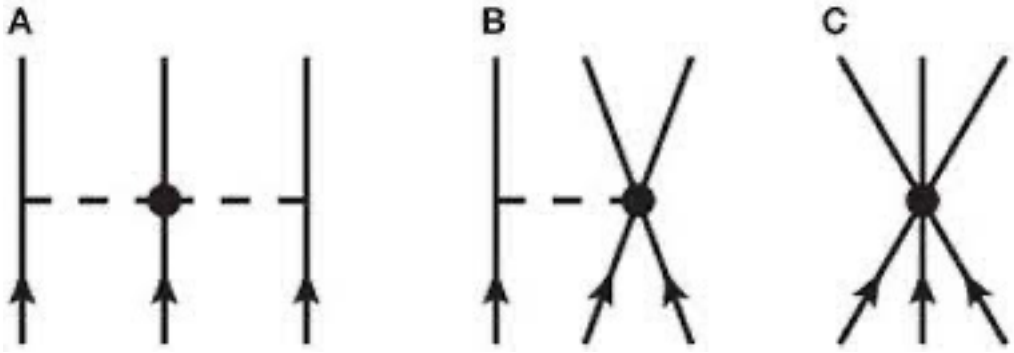
  YY and YN forces

  YNN and YYN three body forces

- Experimental data are crucial to place constraints

- Y-N interaction in free space -> bedrock for exploring higher order effects in medium

- Motivates our current study study using secondary hyperon beams (seeded by gamma beams)

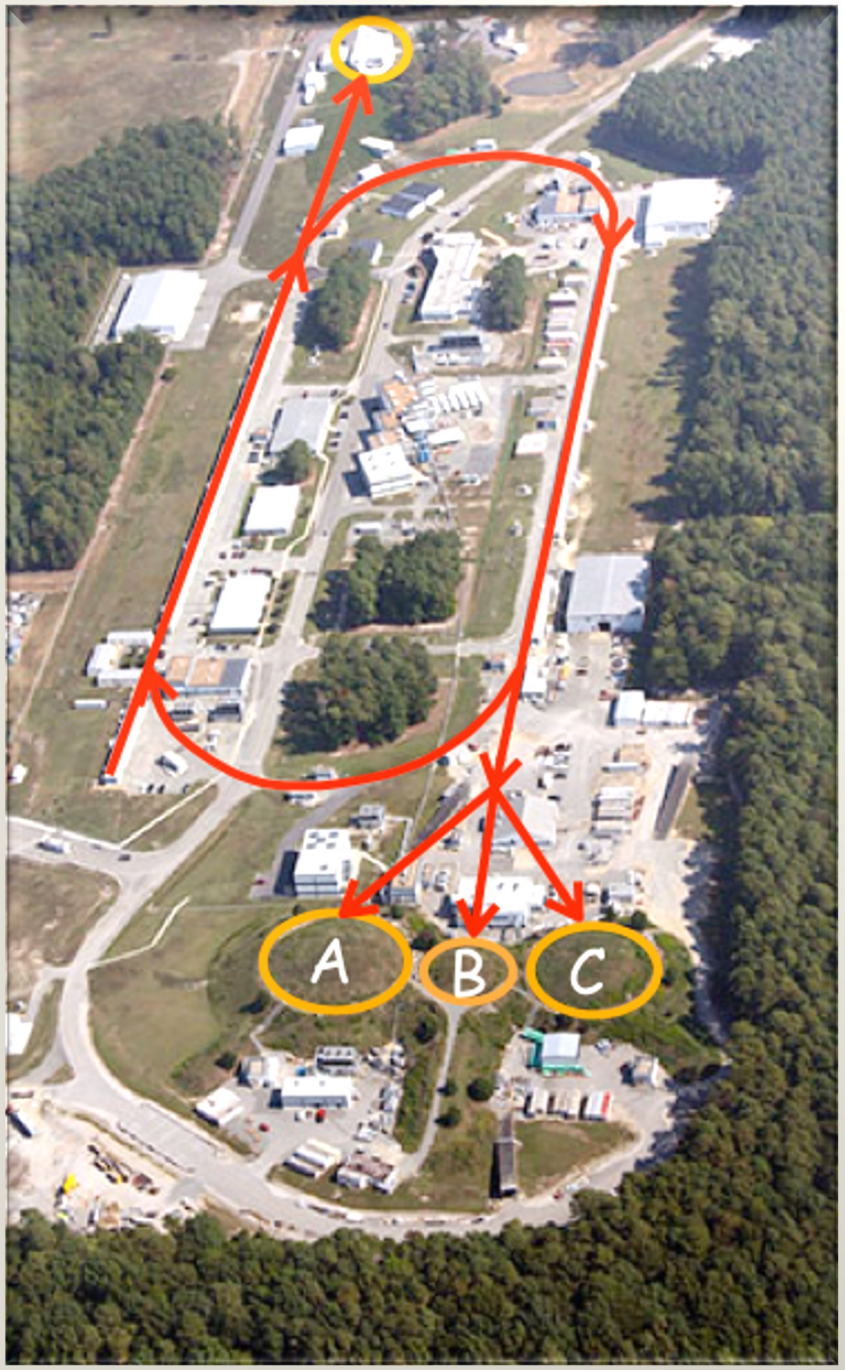


D. Lonardoni, Phys. Rev. Lett. 114, 092301 (2015)
J. Haidenbauer et al., Eur. Phys. J. A 53, 121 (2017)
I. Vidana, Proc. R. Soc. A 474, 20180145 (2018)

CLAS6@JLAB

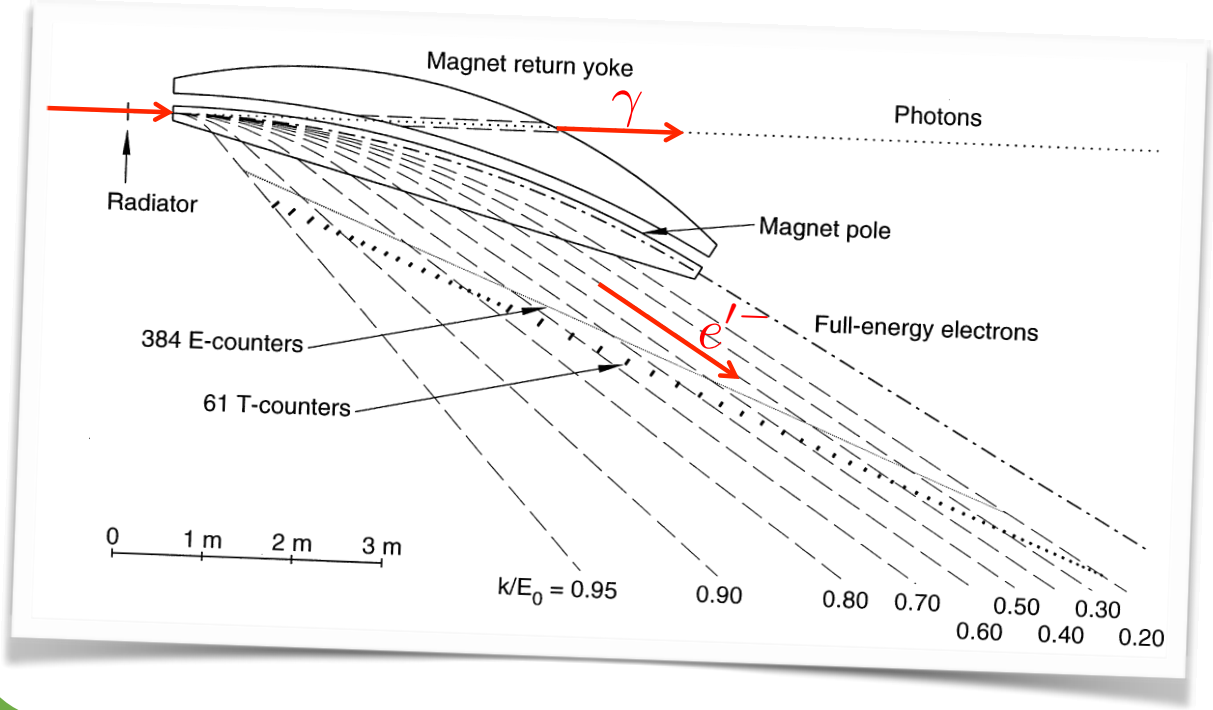
6-GeV era : 1995-2012

- C.W. electron beam
- Polarized Source: P_e ~ 86%
- Beam energies up to E_0 = 6 GeV
- Beam Current up to 200 μA



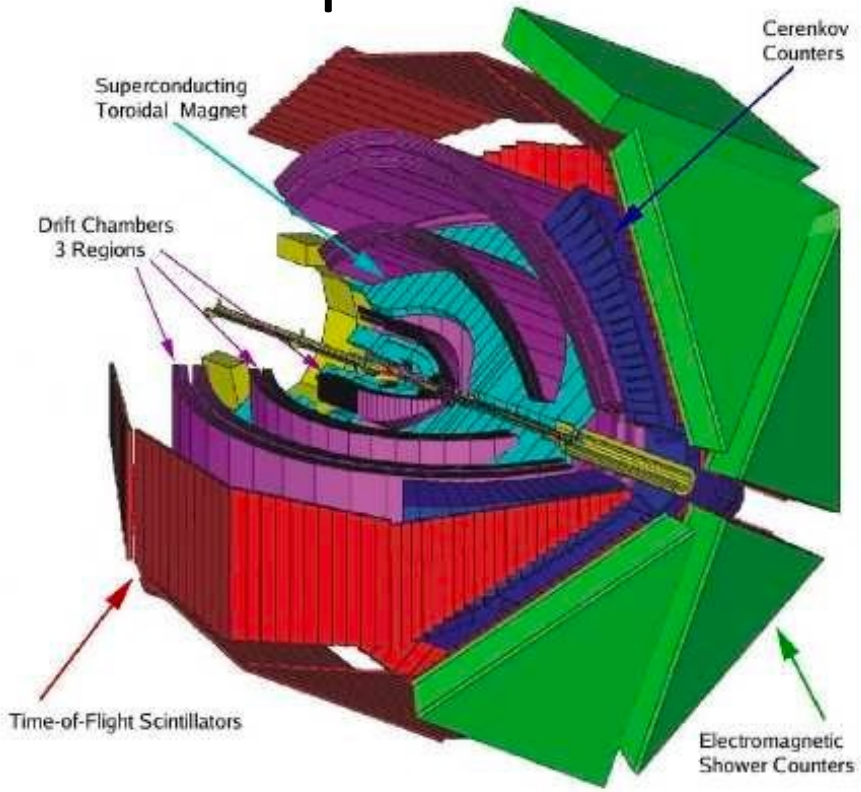
Hall-B at Jefferson Lab

Photon tagger



- Hyperon analysis uses “g12” data set
- Photon energies 1.2 - 5.4 GeV
- Cryogenic liquid H/D targets - 40cm long 4cm diameter

CLAS6 spectrometer



$8^\circ < \theta < 140^\circ$ $\quad \sigma_\theta \sim 1$ mrad

$\phi \sim 1.7\pi$ $\quad \sigma_\phi \sim 4$ mrad

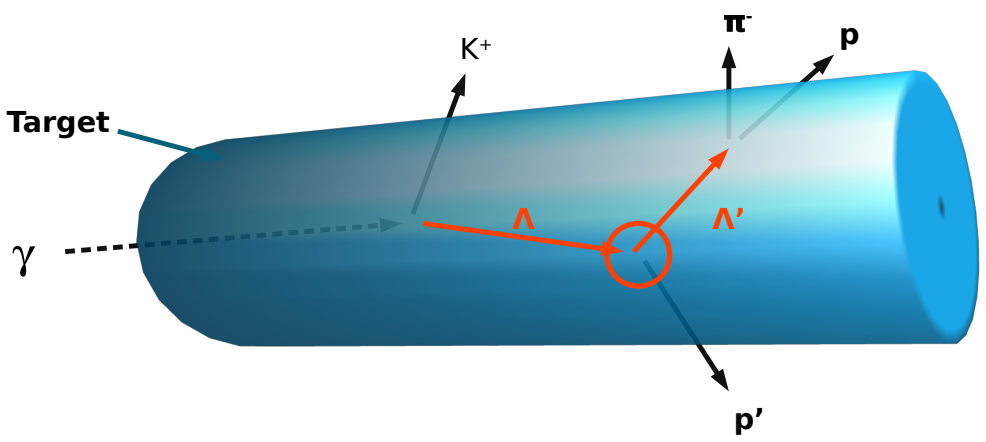
$\sigma_p/p \sim 1\%$

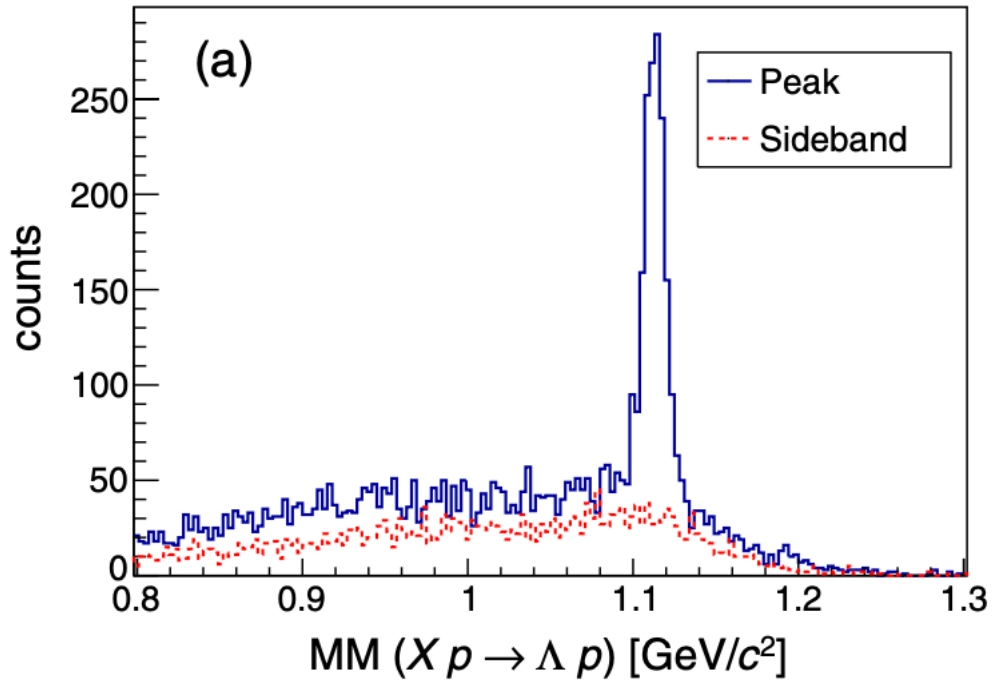
Λp Elastic Scattering

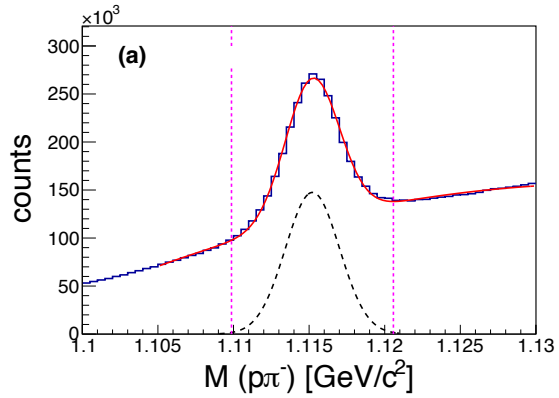
https://doi.org/10.1103/PhysRevLett.127.272303

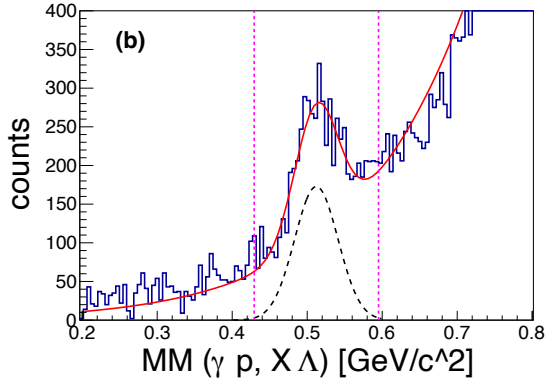
Improved Λ*p* Elastic Scattering Cross Sections between 0.9 and 2.0 GeV/*c* as a Main Ingredient of the Neutron Star Equation of State

J. Rowley,[35] N. Compton,[35] C. Djalali,[35] K. Hicks,[35] J. Price,[2] N. Zachariou,[47] K. P. Adhikari,[36] W. R. Armstrong,[1]

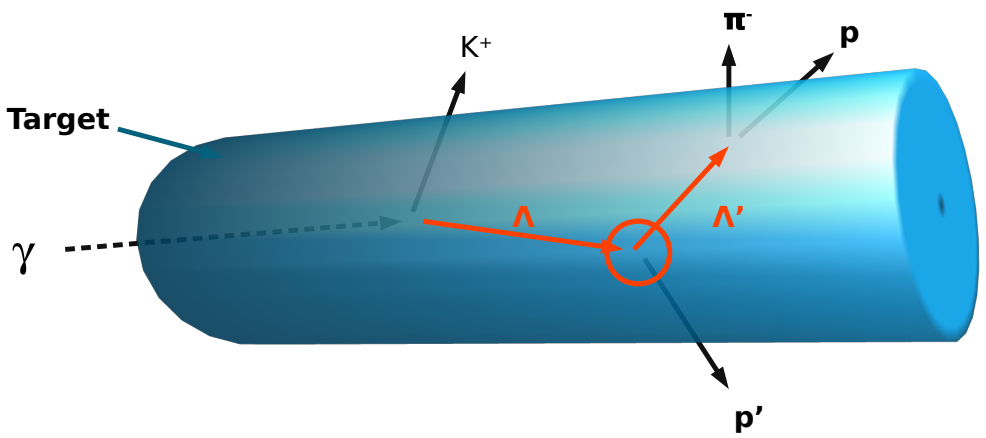






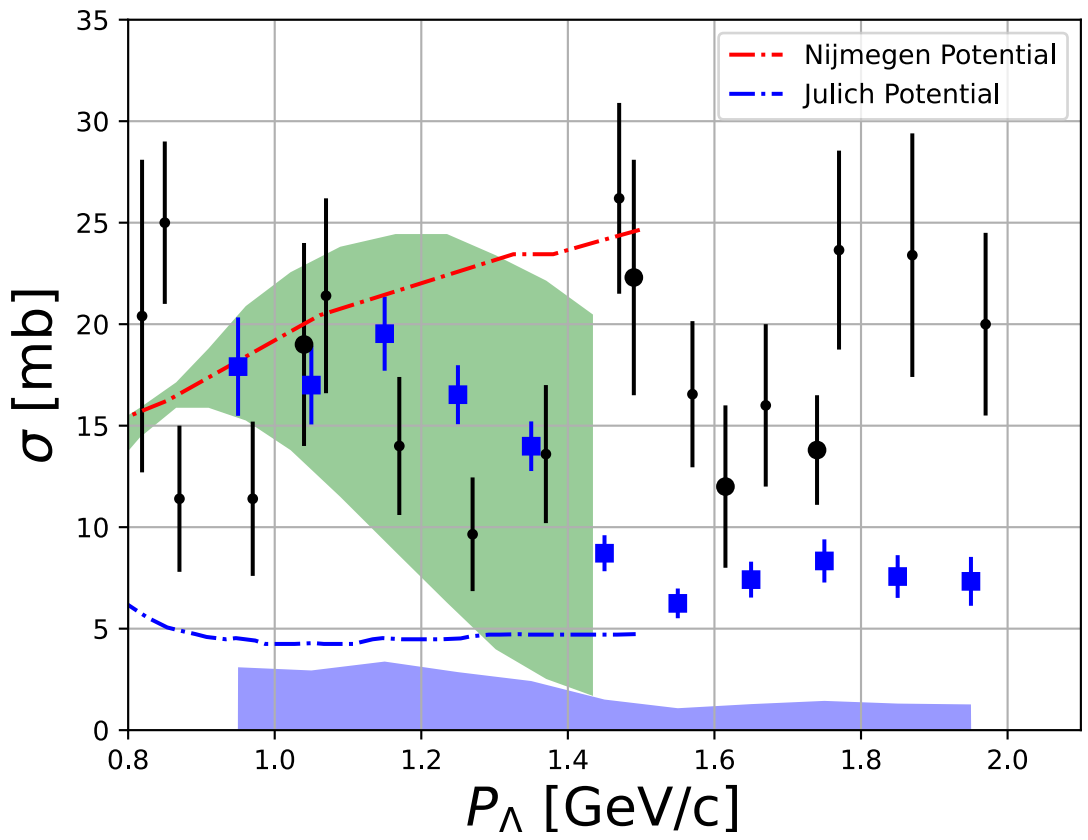


Λp Elastic Scattering



- Cross section determination challenging
- Need careful account of detector acceptance, efficiency

(see paper for details)



NLO chiral EFT(Haidenbauer *Eur. Phys. J. A* **56,** 91 (2020))

Haidenbauer, U.-G. Meißner, Phys. Rev. C 72, 044005 (2005)

Rijken, Stoks, Yamamoto, Phys. Rev. C 59, 21 (1999).

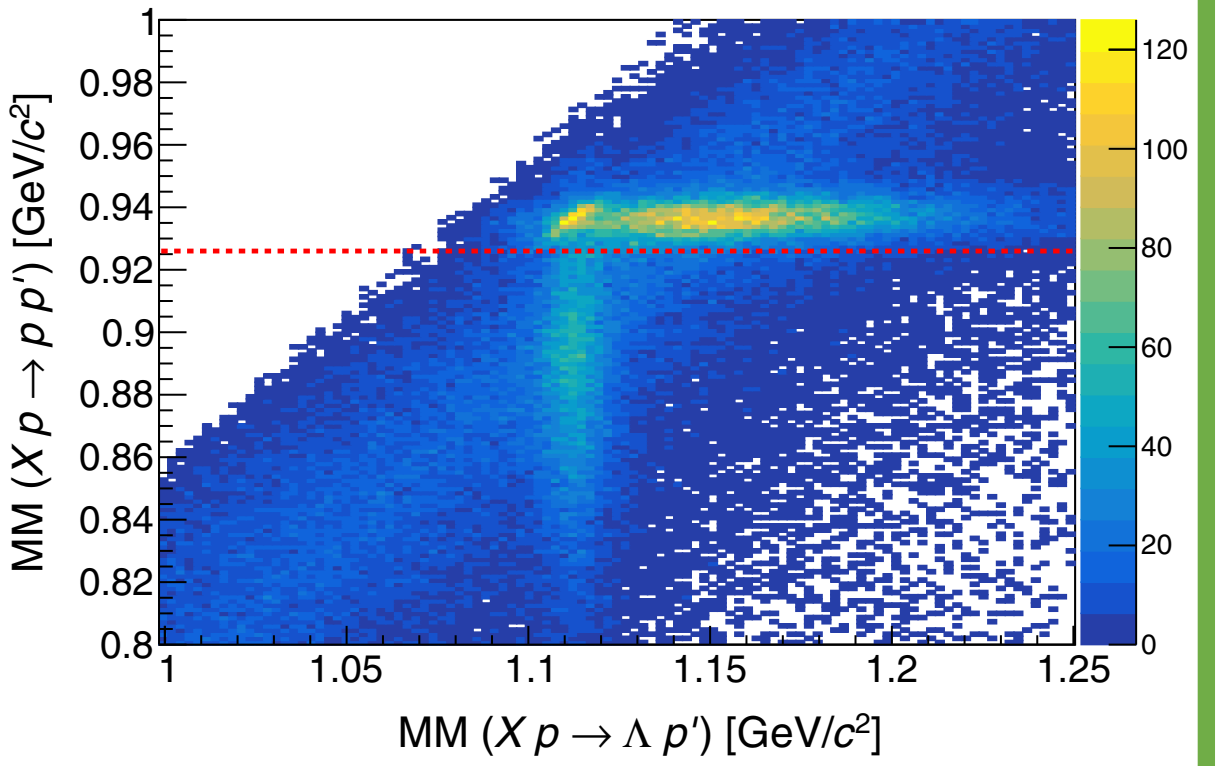
Λp Elastic Scattering - background removal

- Background contribution

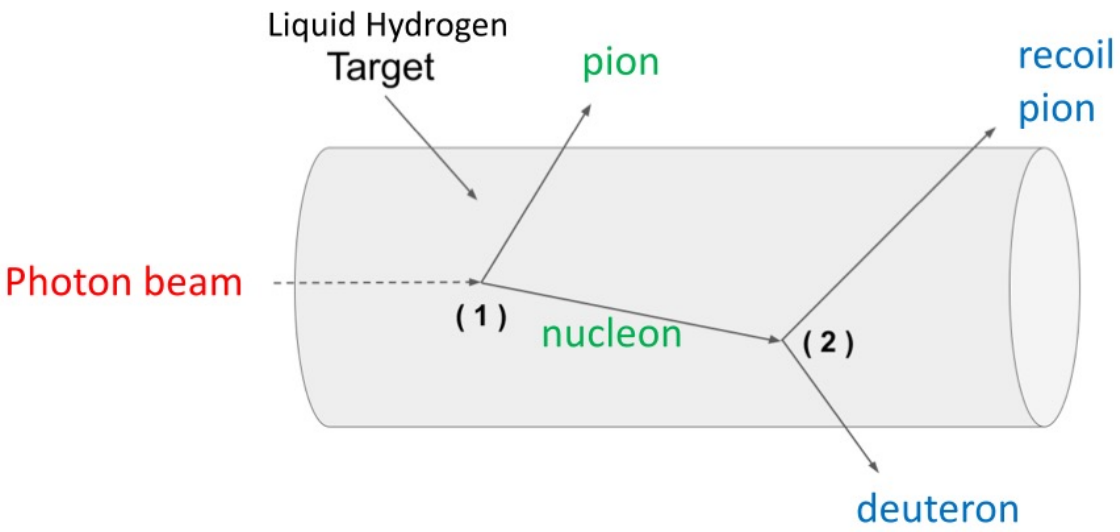
  p(Λ)p → pp

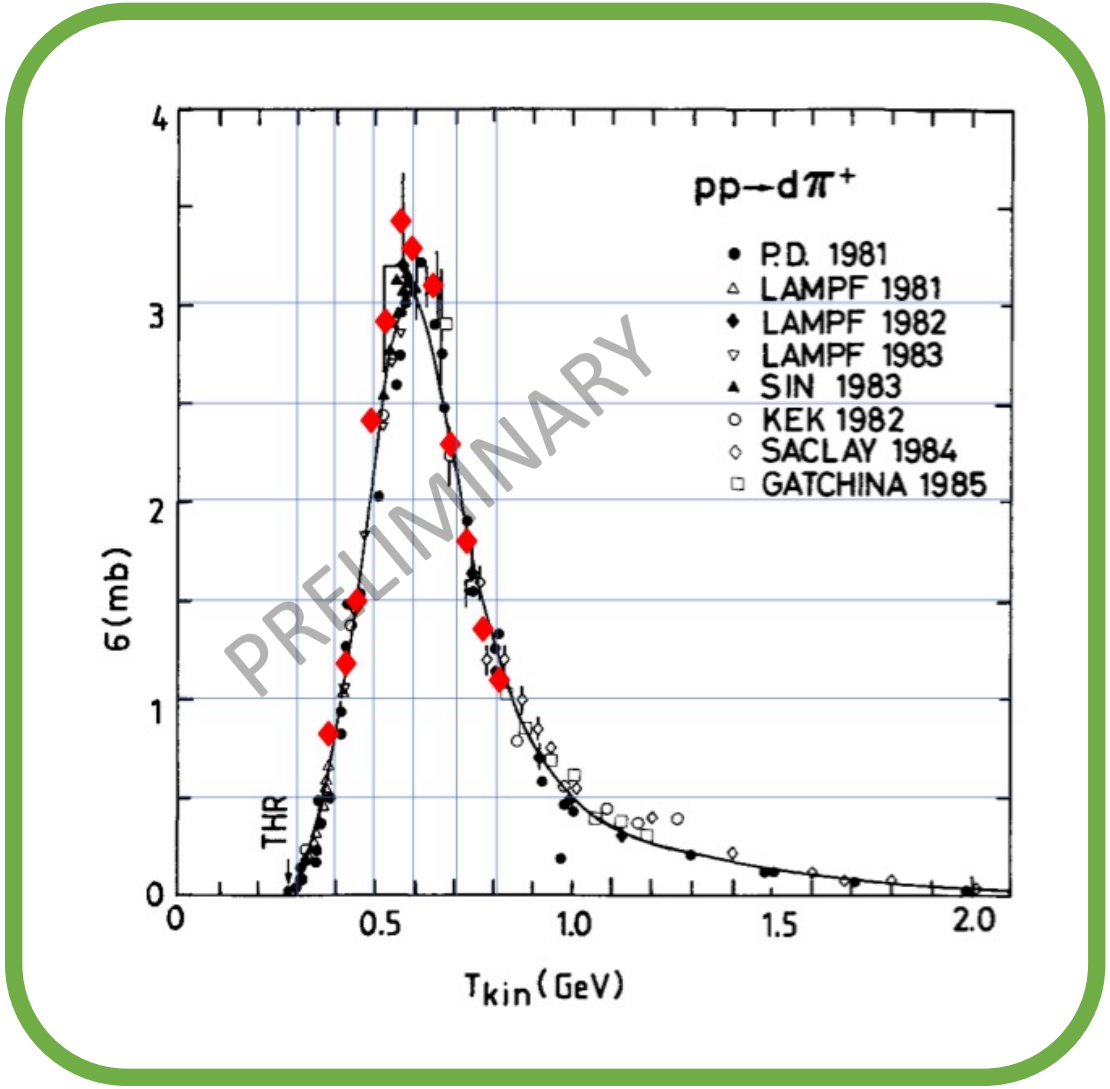
- Can be isolated in CLAS

- Difficult for previous bubble chamber data (systematic at higher momenta?)



Systematic check – pp scattering

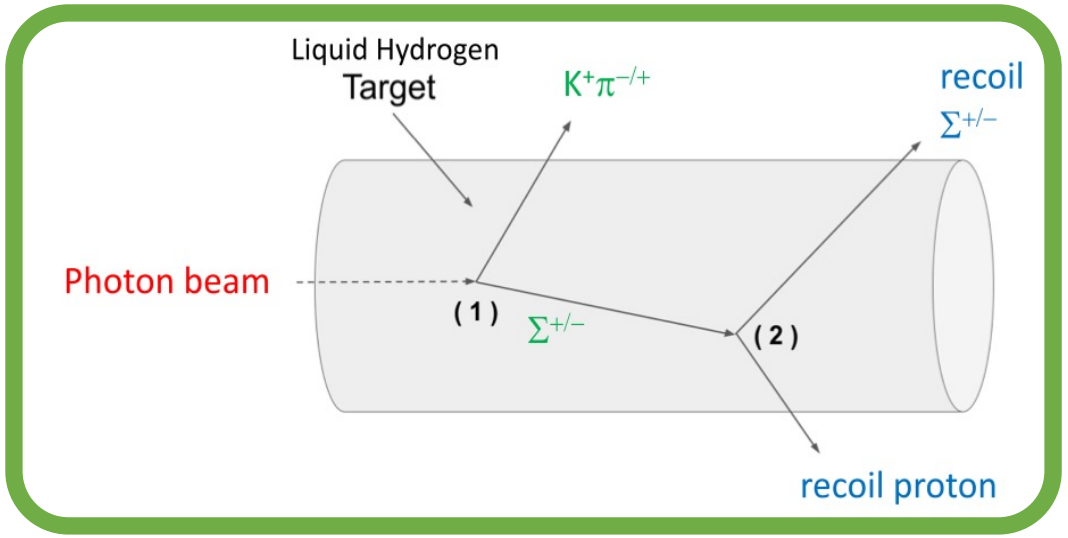


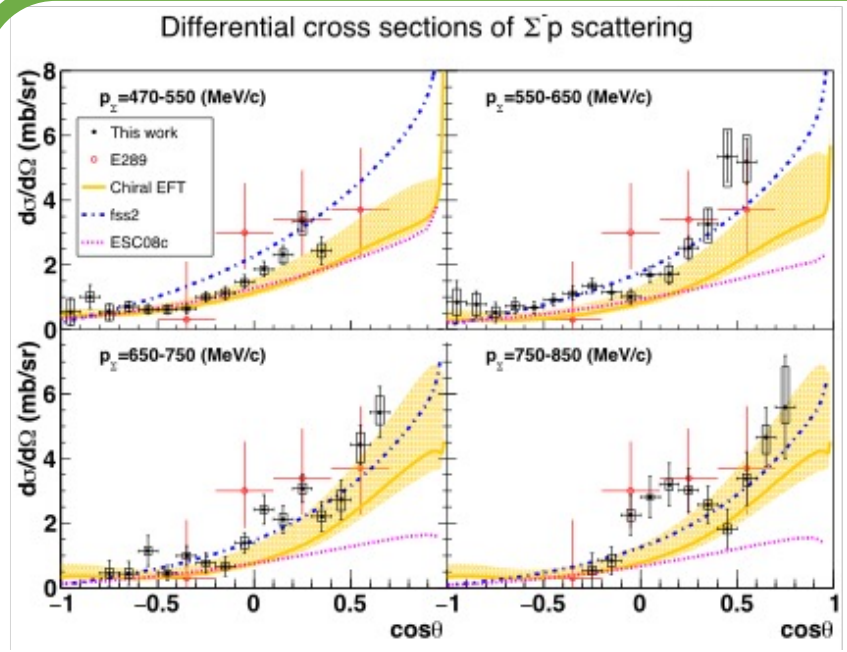


Systematic uncertainties - order 10%

Additional points at higher energies -- TBD

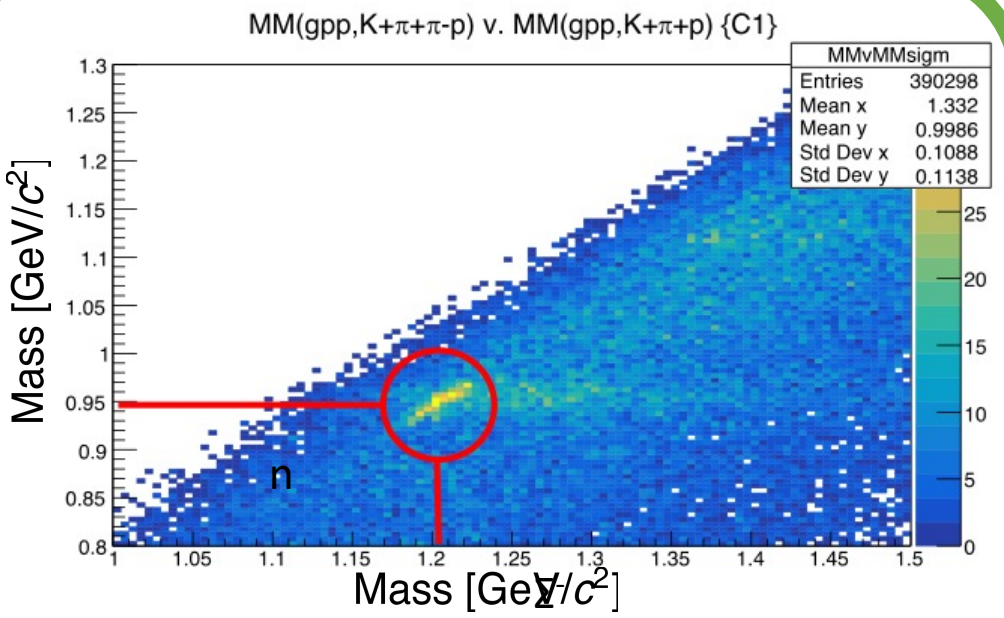
Work in progress - Σp Elastic Scattering

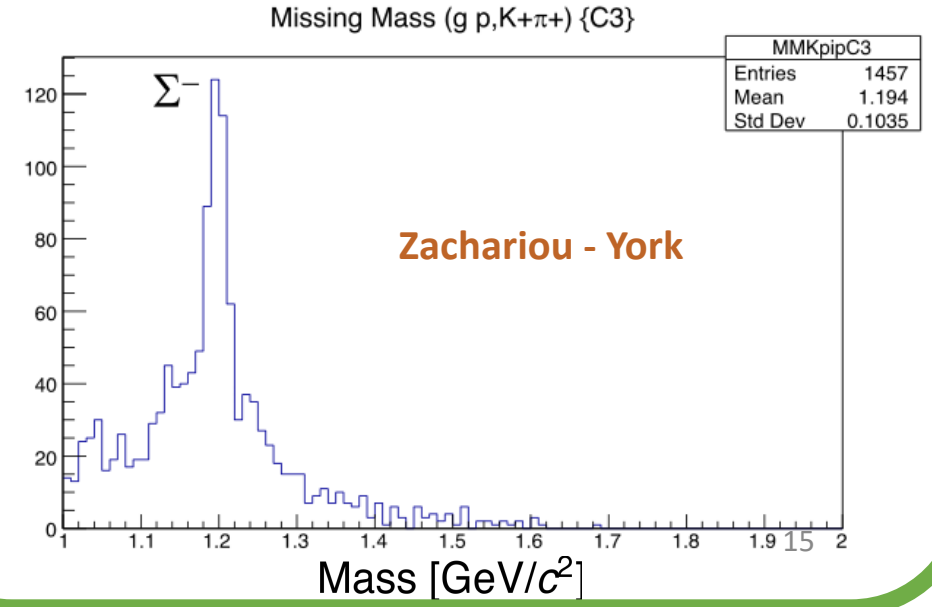




Overlap with recent JPARC, extend momentum range

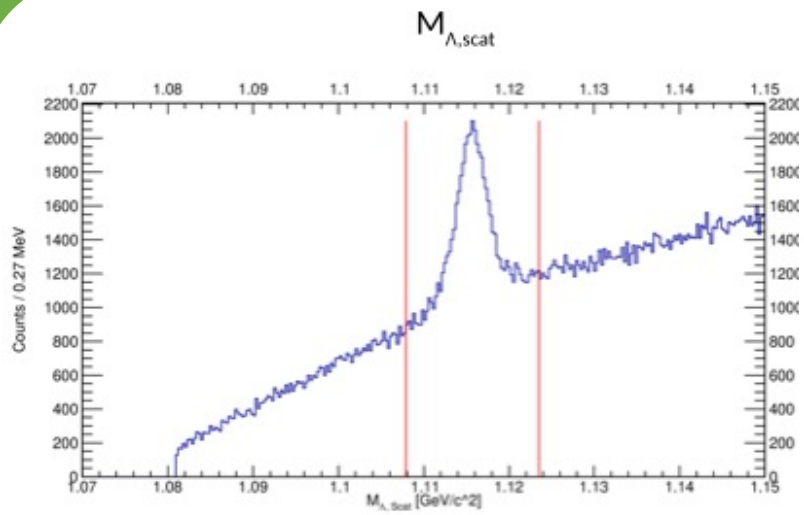
Phys. Rev. C **104**, 045204

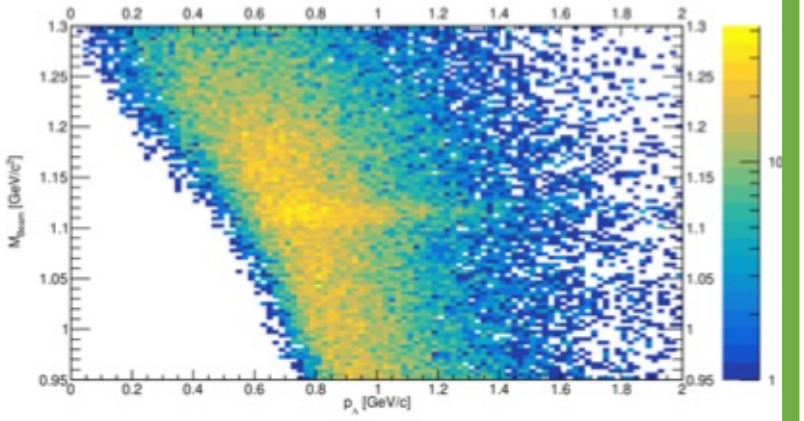


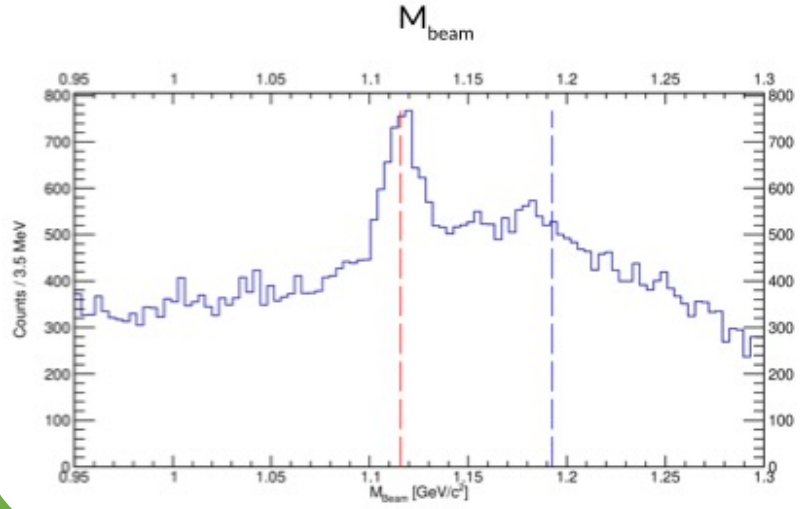


Zachariou - York

Work in progress: Λd elastic scattering

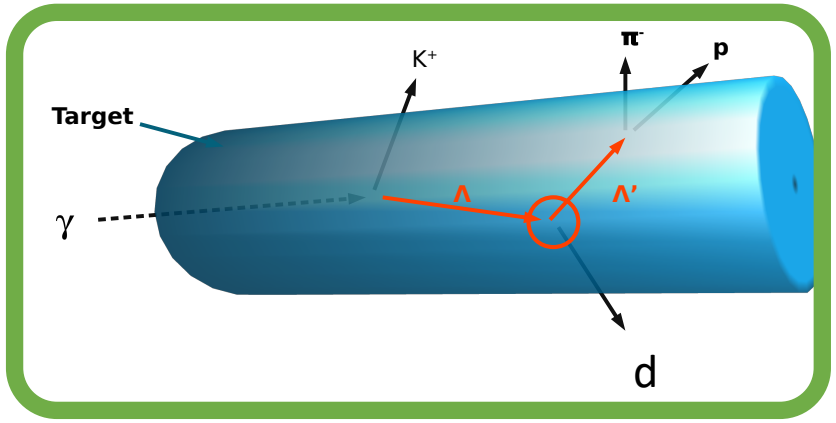






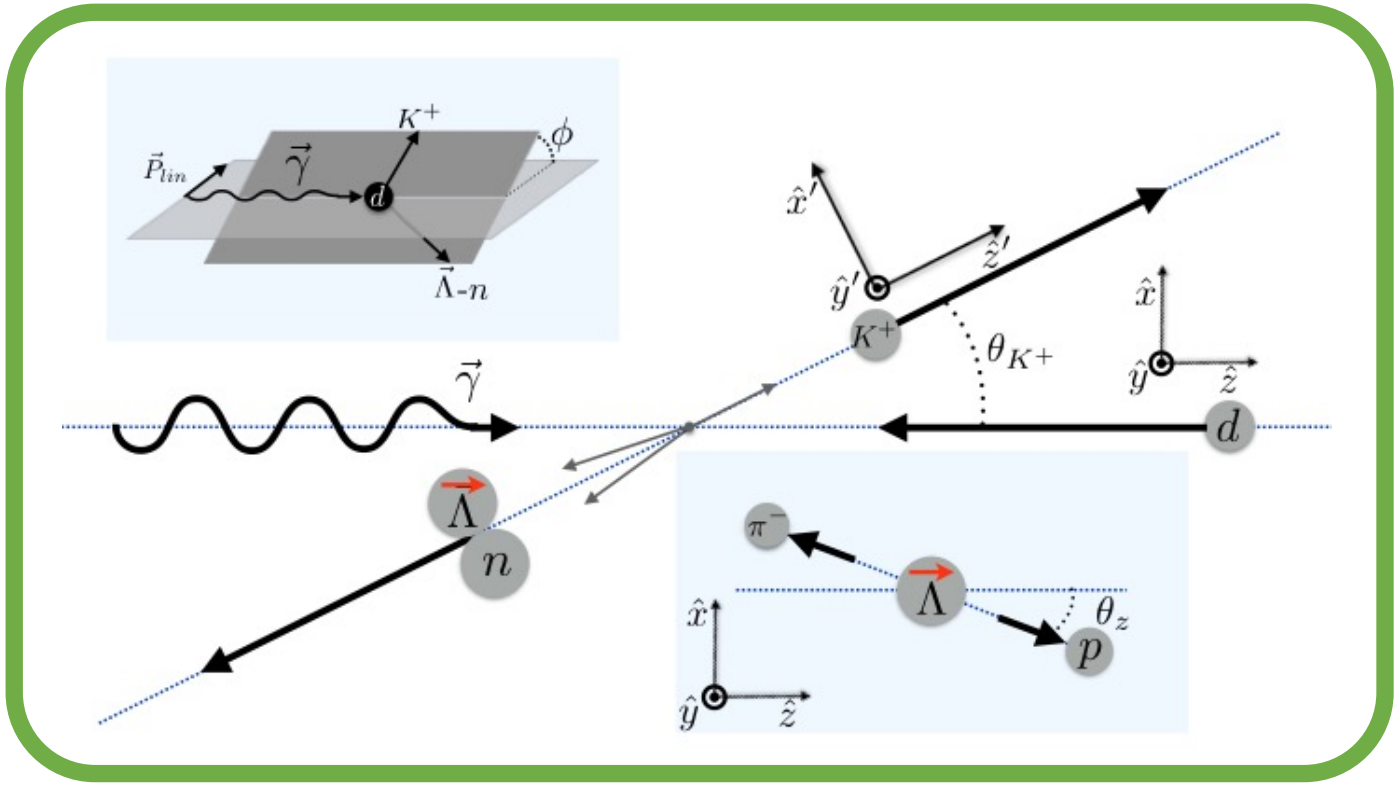
- ~4k events:
  - $p_\Lambda > 0.7$ GeV/c
  - cos(θ): -0.6 - 0.9

Tsumeo, Ilieva, Zachariou - USC/York



Polarisation observables in Hyperon Photoproduction

$$\frac{d\sigma}{d\Omega} = \sigma_0\{1 - P_{lin}\Sigma\cos 2\phi + \alpha\cos\theta_x(-P_{lin}O_x\sin 2\phi - P_{circ}C_x)$$
$$- \alpha\cos\theta_y(-P_y + P_{lin}T\cos 2\phi) - \alpha\cos\theta_z(P_{lin}O_z\sin 2\phi + P_{circ}C_z)\}$$

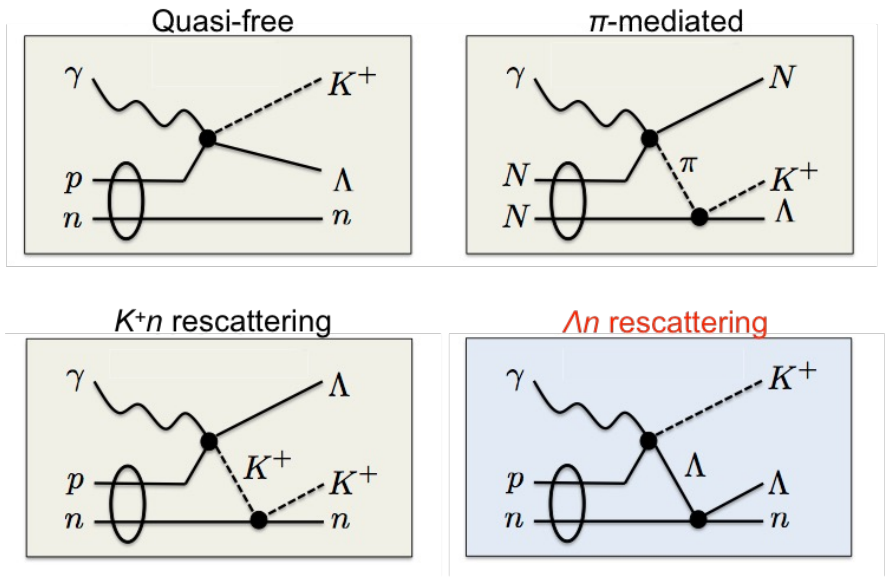


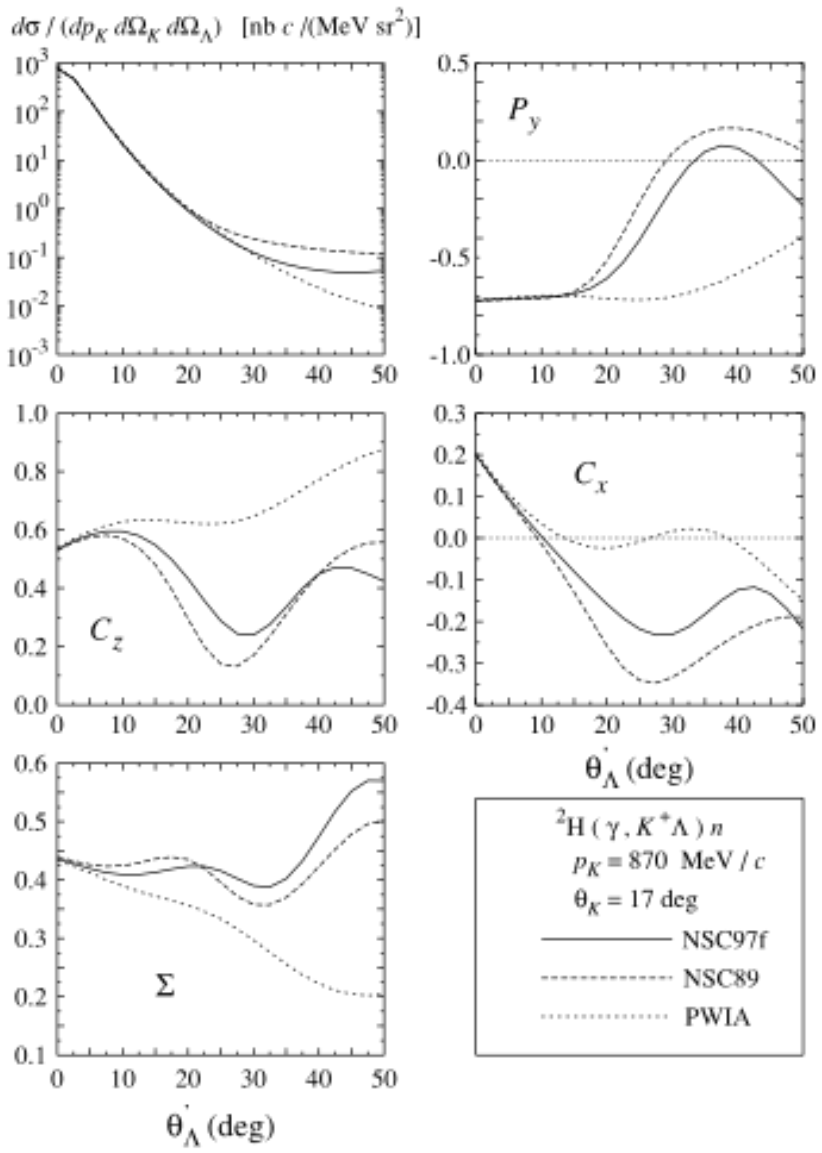
Linearly polarized beam
Circularly polarized beam

Λ Recoil Polarisation
Self-analysing (α=0.75)

Polarisation Observables Λn

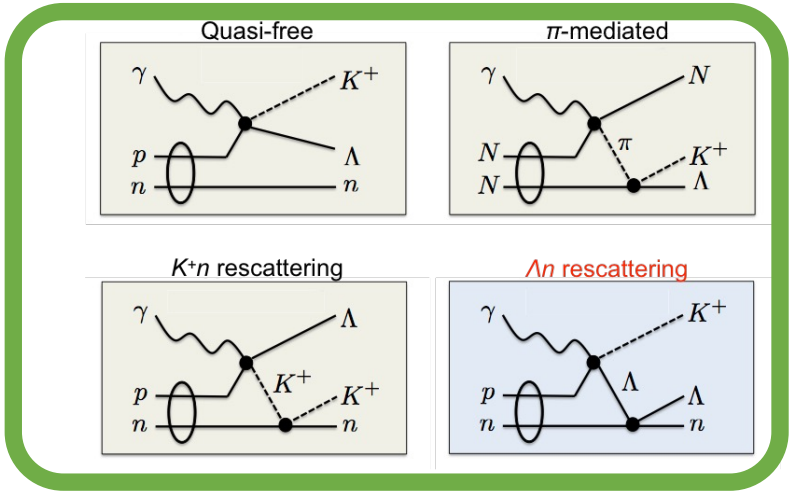
- Rescattering of hyperons in FSI -> powerful info
- *YN* potentials (NSC97F and NSC89) both give correct BE (e.g hypertriton) -> but degeneracy broken in polarisation observables!

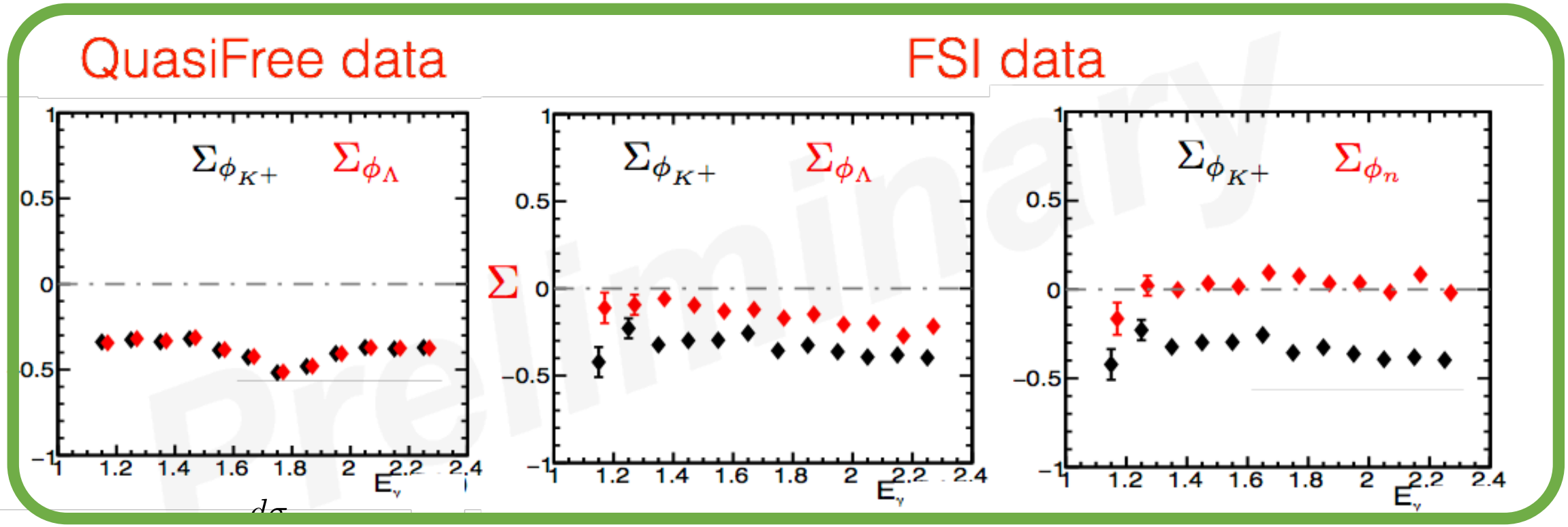




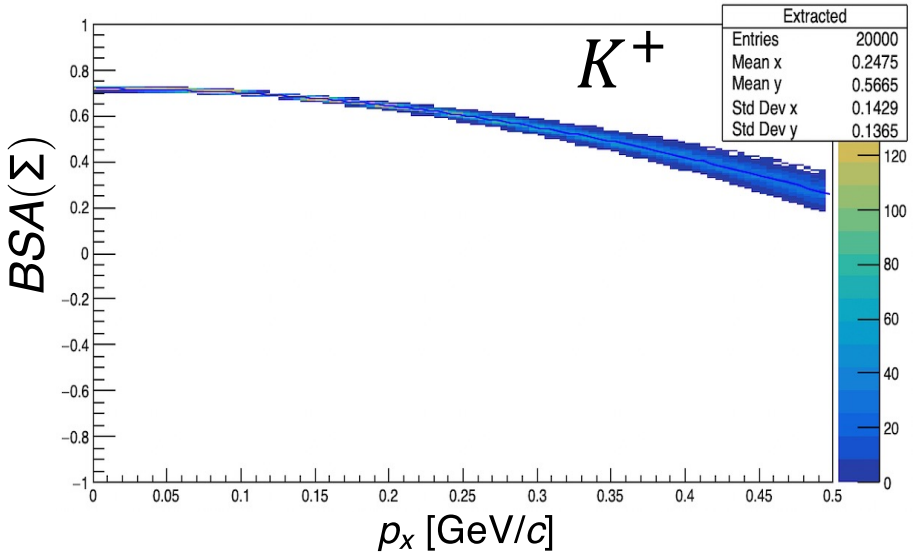
K. Miyagawa et al., Phys. Rev. C 74, 034002 (2006)
Determination of scattering lengths PRC **95**, 034001

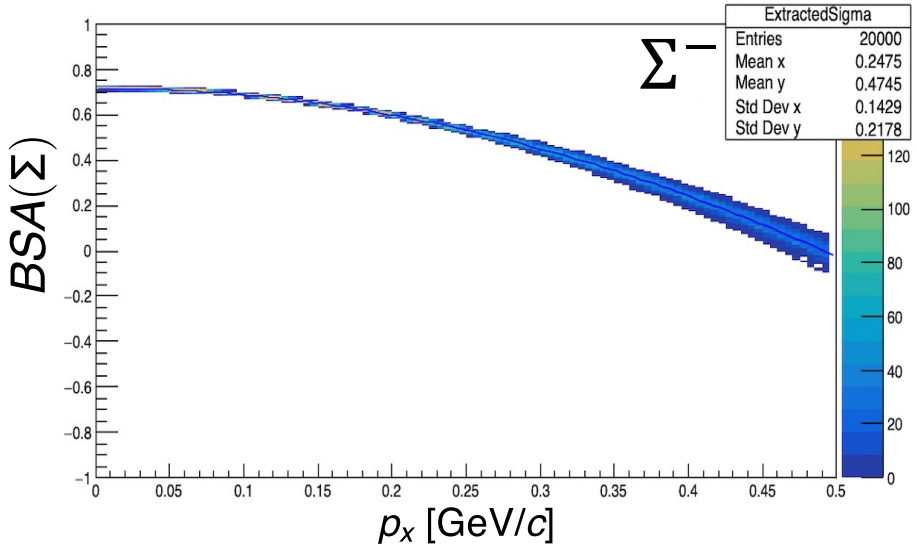
Polarisation Observables Λn

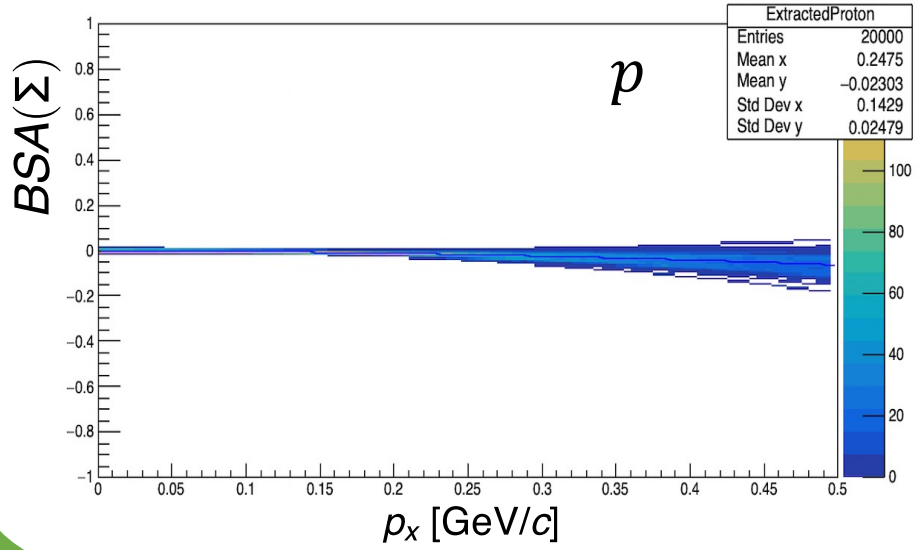




Polarisation Observables Σp







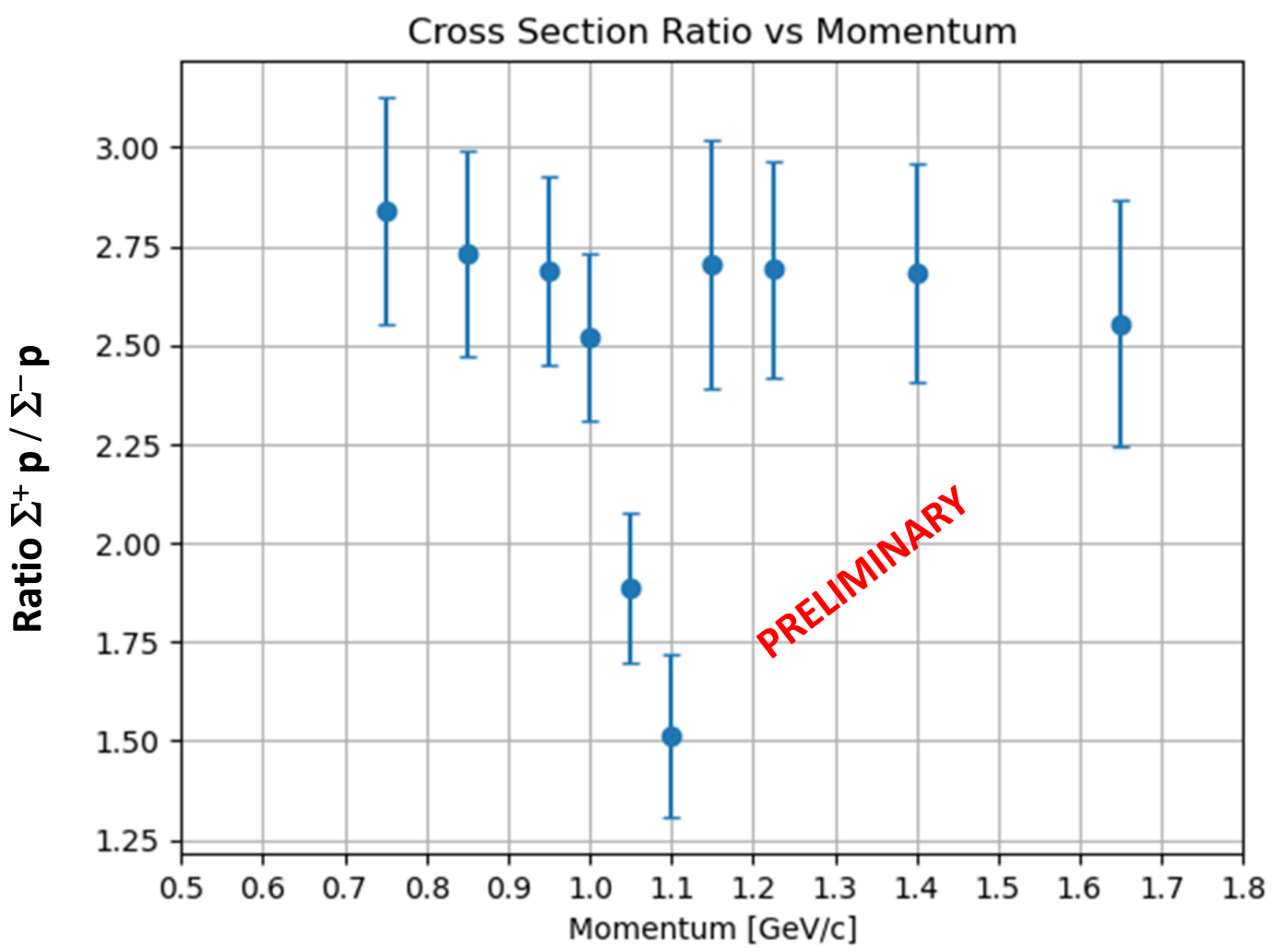
Results extrapolated to zero missing-momentum -> BSA from K, Σ agree ✓

Large dilutions of BSA at higher missing momenta due to FSI

Relative dilutions - constraint on the various FSI contributions (including YN recattering)

ML trained on model predictions - deconvolute

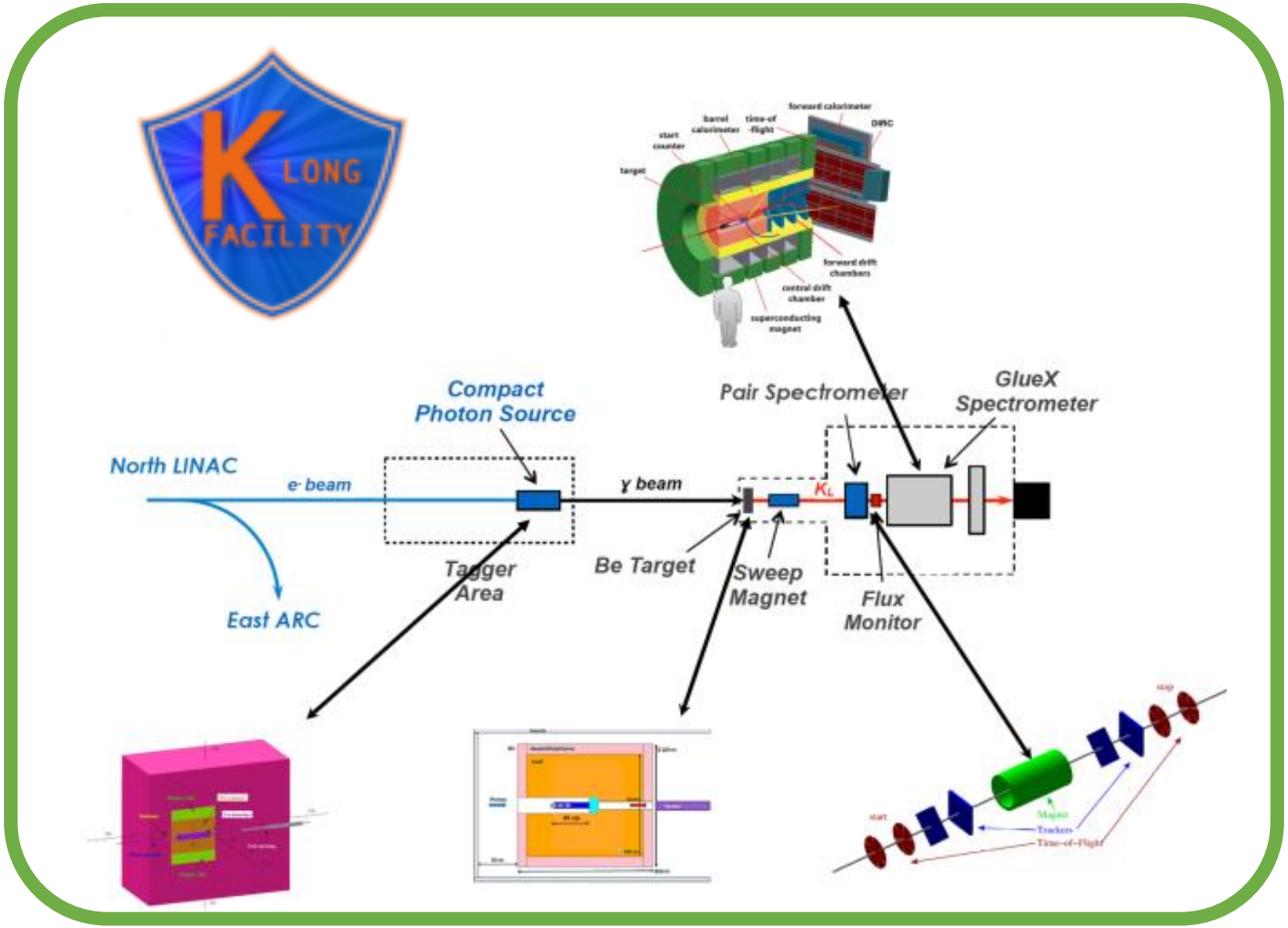
Σp scattering - ratios



- Ratio broadly uniform around 2.5-2.75
- Analysis at early stage

Zachariou, Hadjigvadriel - York

KLF – A next generation hyperon facility



- K-Long facility – Online '26
- Hall D of Jefferson Lab
- CPS >6 OOM in γ–luminosity
- 3 OOM higher hyperon rate
- Larger targets
- Access Ξ-N

Summary and outlook

- Ongoing programmes at JLAB are revealing the YN interaction with a new level of detail
- KLF presents a step change in the quality and intensity of tagged hyperon beams at Jefferson Lab

The team at USC, Ohio, CSU and York leading the works presented here






Thanks for listening !