Peter Hurck

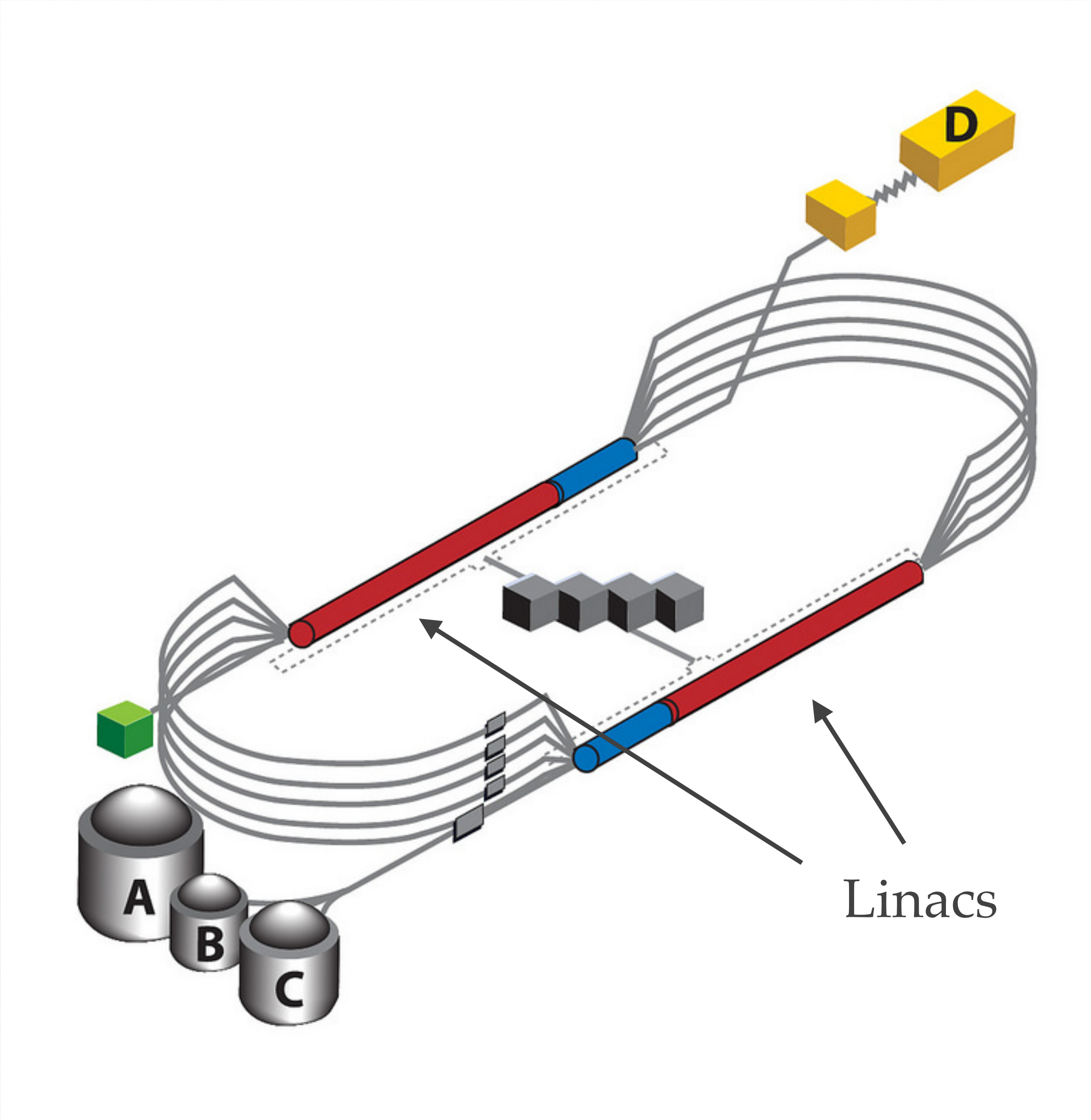
Hyperon spectroscopy at JLab

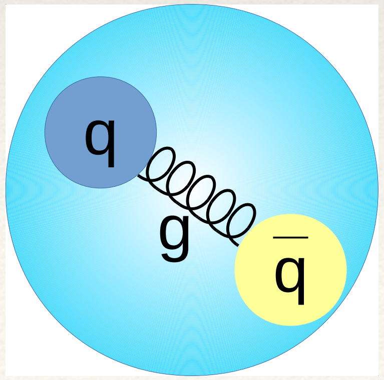
Physics opportunities with proton beams at SIS100

CEBAF at Jefferson Lab

CEBAF at Jefferson Lab

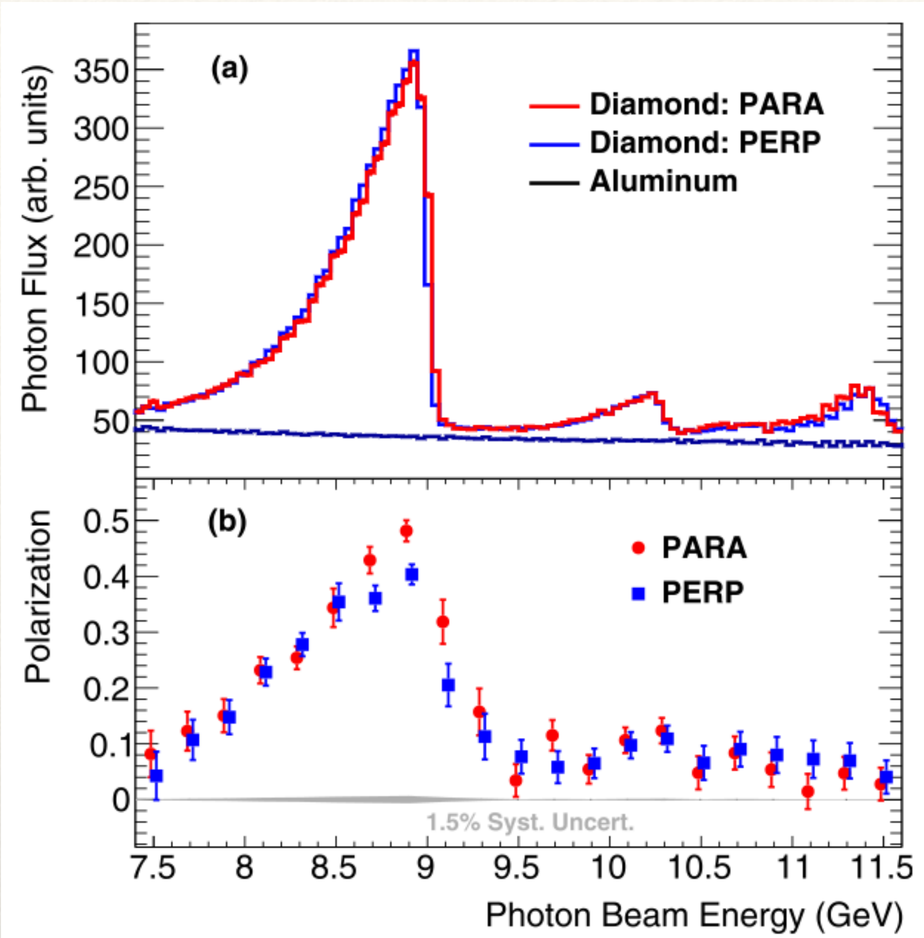
- up to 12 GeV electron beam
- high luminosities for Hall A/C (high resolution spectrometer)
- CLAS12 in Hall B
  - Large acceptance spectrometer
- GlueX in Hall D
  - Focus on exotic hybrid mesons BUT:
    Large data set available to study wide range of reactions





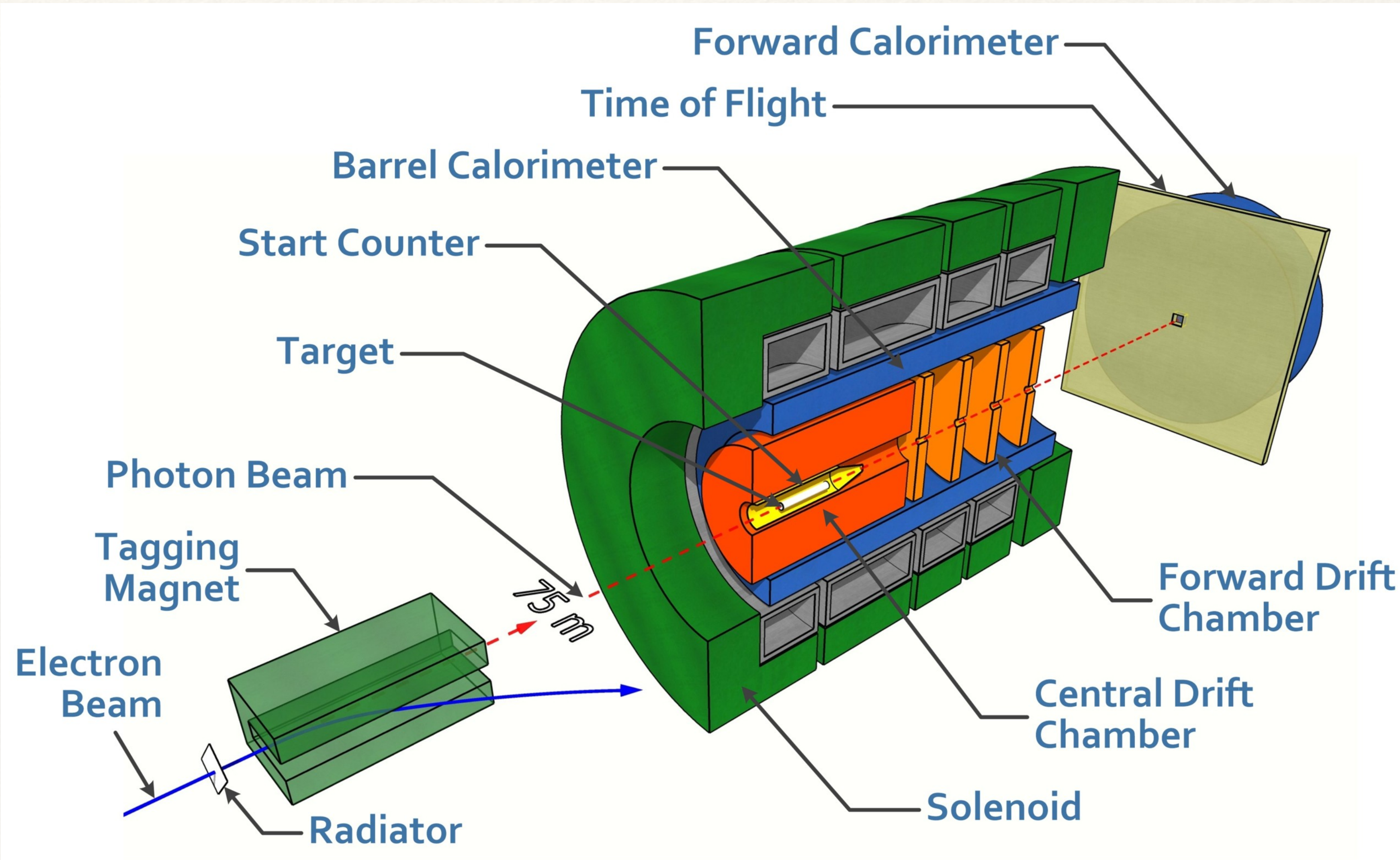
GlueX in Hall D

Nucl. Instrum. & Meth. A**987**, 164807 (2021)



GlueX, Nucl. Instrum. Meth. A 987 (2021) 164807

- produce linearly polarized photon beam via coherent bremsstrahlung on thin diamond

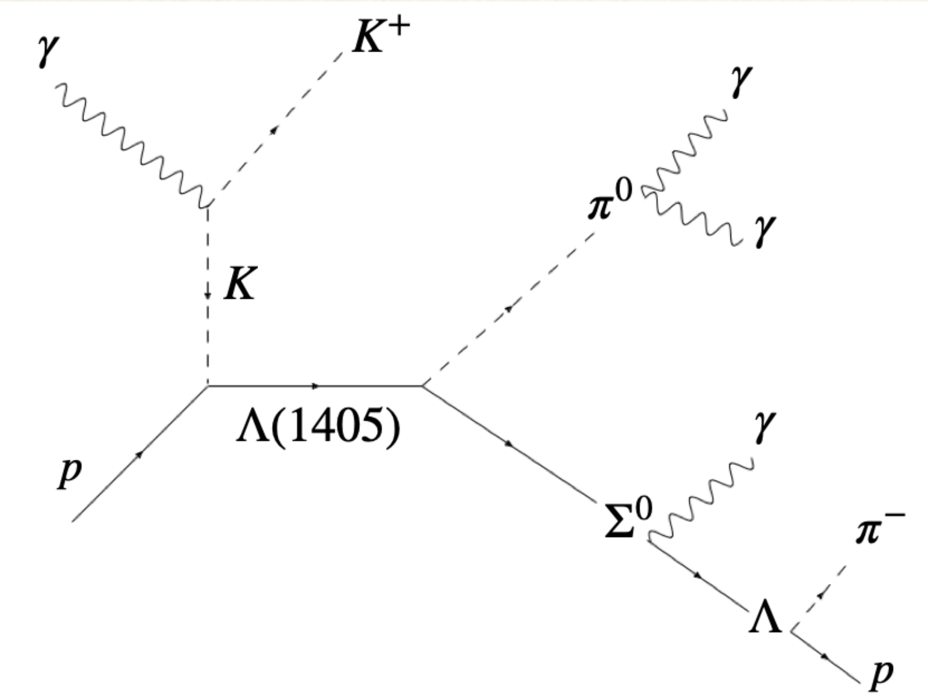


- tag electrons to determine photon energy

- Acceptance: $\theta_{lab} \approx 1^\circ - 120^\circ$
- Charged particles: $\sigma_p/p \approx 1\% - 3\%$ ($8\% - 9\%$ very-forward high-momentum tracks)
- Photons: $\sigma_E/E = 6\%/\sqrt{E} \oplus 2\%$

Since 2019: DIRC

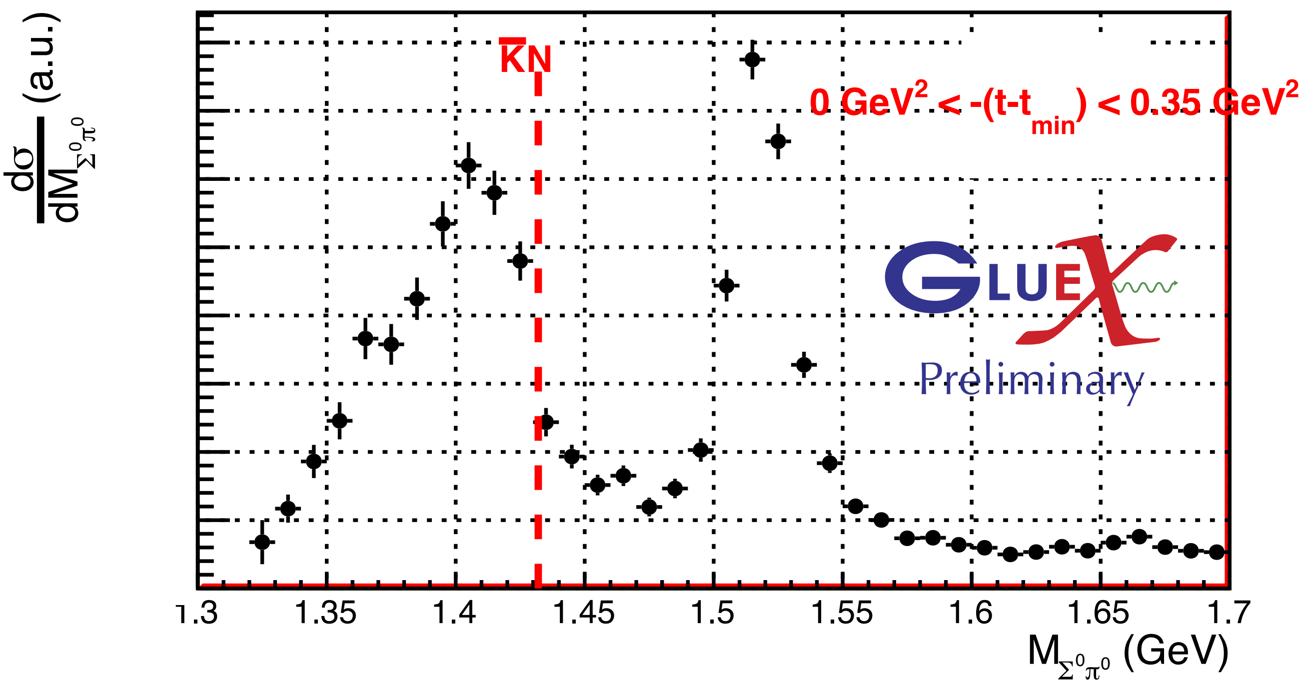
$\Lambda(1405)$ line shape measurement

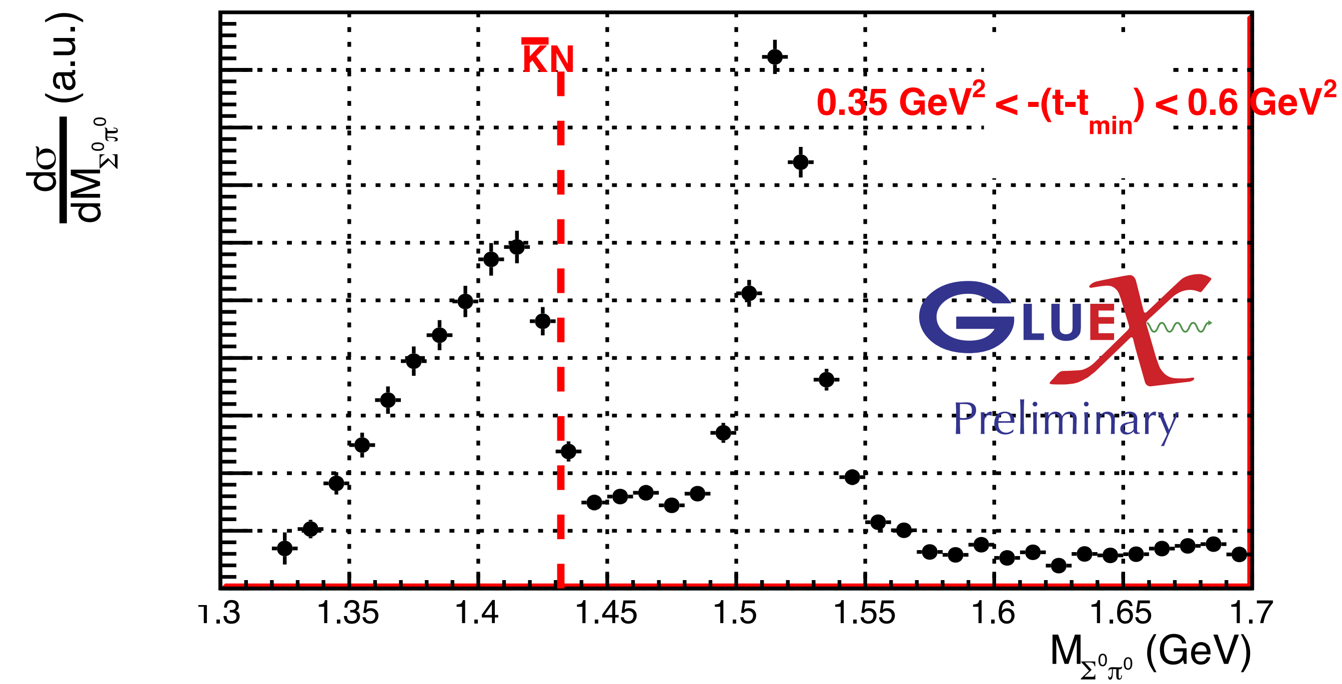


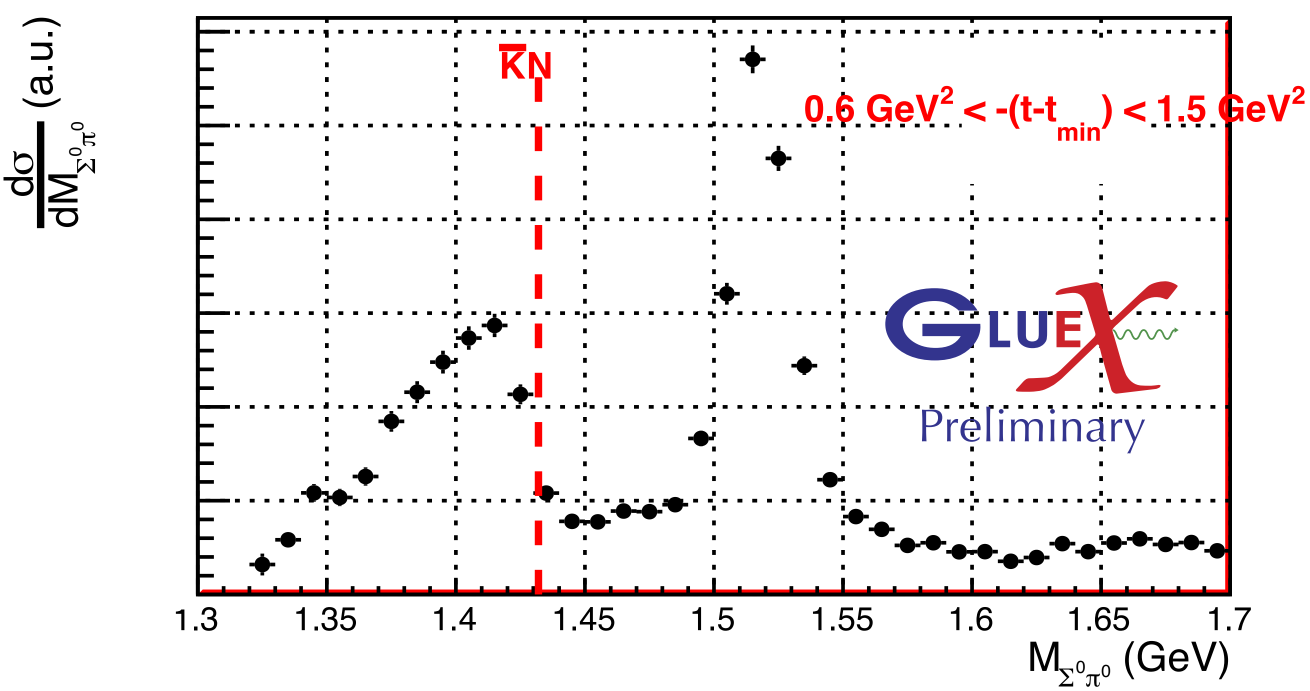
$\Lambda(1405) \to \Sigma^0\pi^0$ ($I = 0$) is free from $\Sigma(1385)$ background

- Excited Λ with $J^P = \frac{1}{2}^-$
- $\Lambda(1405) \to \Sigma\pi$
- Previous measurements (e.g. COSY-Jülich or CLAS) show very clear non-Breit-Wigner line shape
- Interpretation under active investigation
- Many theory models find two-pole structure:
  not just one state
- Recent PDG addition: ** $\Lambda(1380)$

Λ(1405) line shape measurement





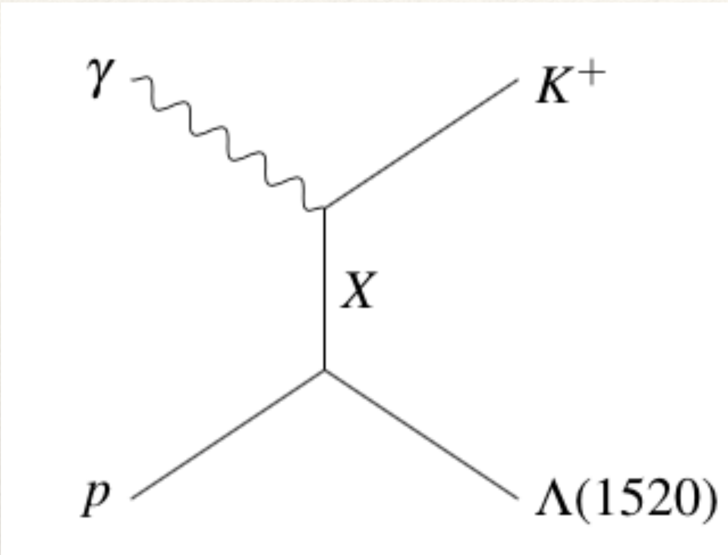


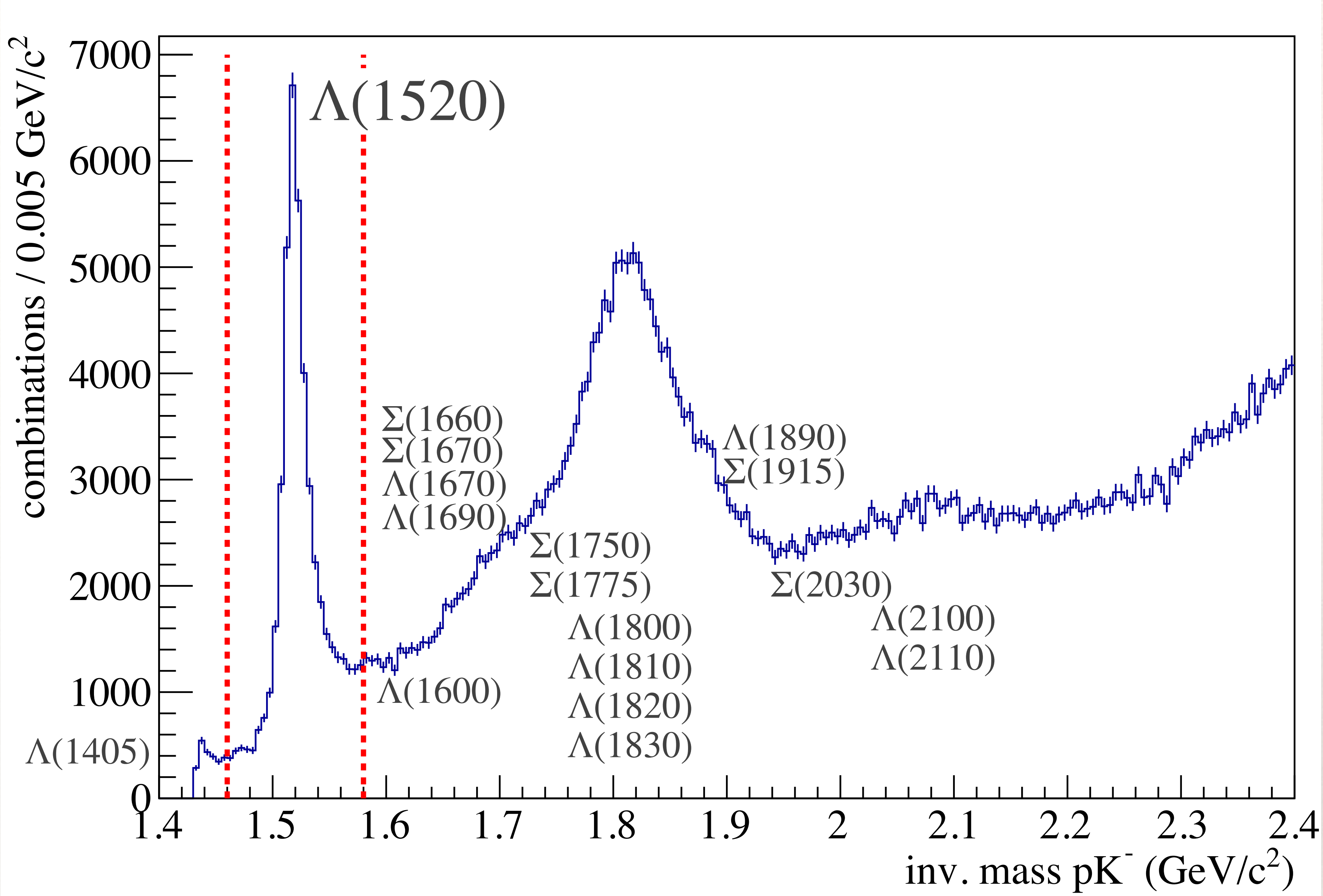
- Λ(1405) t-dependent line shape?
- Could support two-pole structure

Excited hyperons

PH (Phys. Rev. C **105**, 035201)

$\gamma p \to K^+ Y^* \to K^+ K^- p$

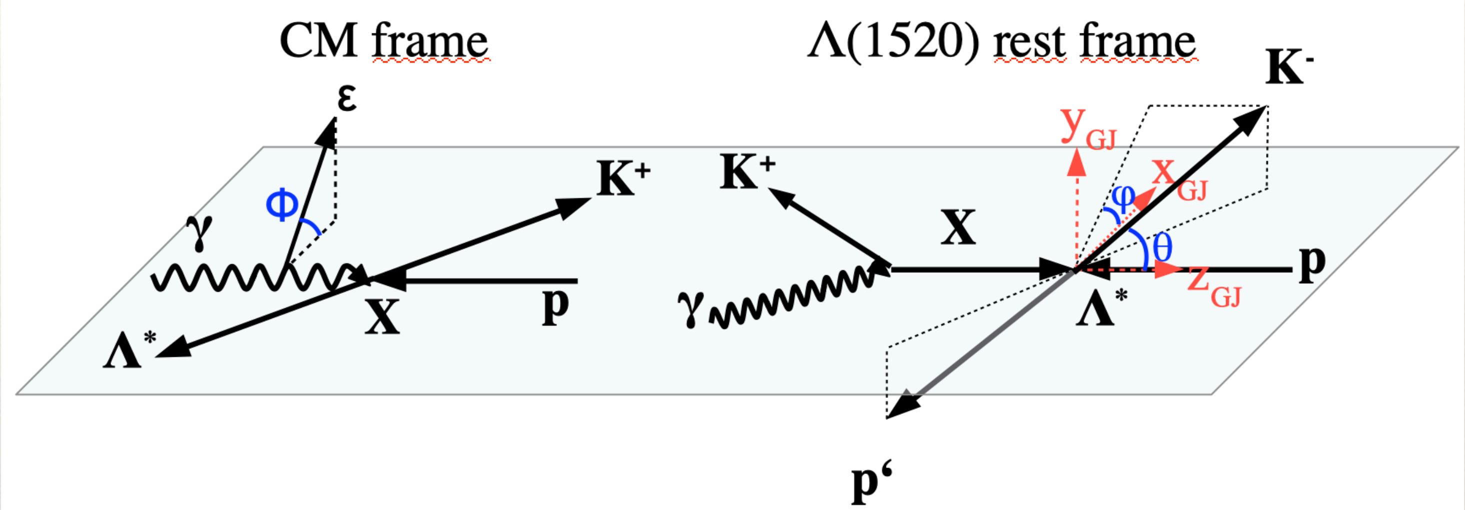




- Many excited Λ^* and Σ^* expected in spectrum
- Most prominent: $\Lambda(1520)$ hyperon with $J^P = 3/2^-$

Λ(1520) Spin-Density Matrix Elements

- parameterise angular distribution of Λ(1520) decay in Gottfried-Jackson frame
- 3 variables: two angles of K^- and photon polarisation
- 9 fit parameters: three unpolarised, six polarised
- gives access to production mechanism



For $3/2^- \rightarrow 1/2^+ + 0^-$:

$$W_0 = \frac{1}{4\pi}\left[3\left(\frac{1}{2} - \rho^0_{11}\right)\sin^2(\theta) + \rho^0_{11}\left(1 + 3\cos^2(\theta)\right) - 2\sqrt{3}\left(\mathrm{Re}(\rho^0_{31})\cos(\varphi)\sin(2\theta) + \mathrm{Re}(\rho^0_{3-1})\cos(2\varphi)\sin^2(\theta)\right)\right]$$

$$W_1 = \frac{1}{4\pi}\left[3\rho^1_{33}\sin^2(\theta) + \rho^1_{11}(1 + 3\cos^2(\theta)) - 2\sqrt{3}\left(\mathrm{Re}(\rho^1_{31})\cos(\varphi)\sin(2\theta) + \mathrm{Re}(\rho^1_{3-1})\cos(2\varphi)\sin^2(\theta)\right)\right]$$

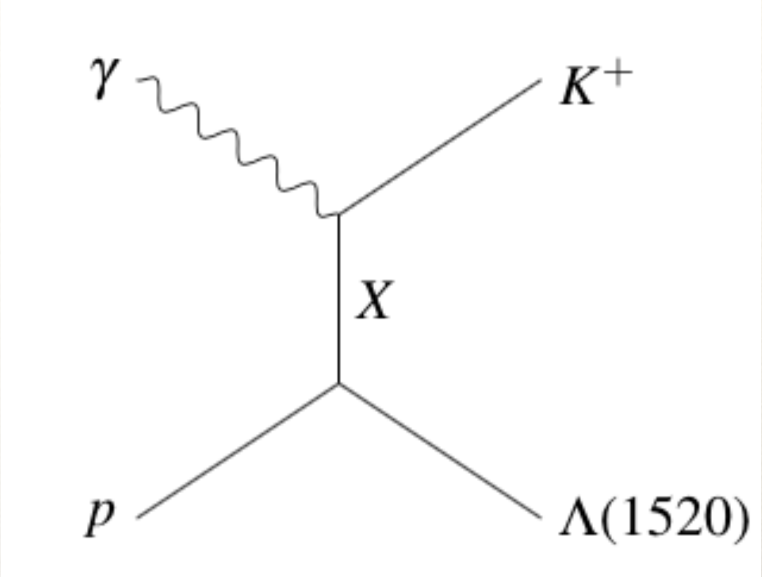
$$W_2 = \frac{1}{4\pi}\left[2\sqrt{3}\left(\mathrm{Im}(\rho^2_{31})\sin(\varphi)\sin(2\theta) + \mathrm{Im}(\rho^2_{3-1})\sin(2\varphi)\sin^2(\theta)\right)\right]$$

$$W = W_0 - P_\gamma\cos(2\Phi)W_1 - P_\gamma\sin(2\Phi)W_2$$

$\Lambda(1520)$ SDME Interpretation

Phys. Rev. C **105**, 035201

- to help with interpretation form combinations of SDMEs which correspond to purely natural (N) and purely unnatural (U) exchange amplitudes



X is exchange particle with spin-parity quantum number J^P and naturality $\eta = P(-1)^J$

Natural: e.g. $K^*(892)$, $K_2^*(1430)$

Unnatural: e.g. $K(492)$, $K_1(1270)$

$$\rho^0_{11} + \rho^1_{11} = \frac{2}{N}(|N_0|^2 + |N_1|^2) \qquad \mathrm{Re}(\rho^0_{31} + \rho^1_{31}) = \frac{2}{N}(N_{-1}N_0^* - N_2N_1^*)$$

$$\rho^0_{11} - \rho^1_{11} = \frac{2}{N}(|U_0|^2 + |U_1|^2) \qquad \mathrm{Re}(\rho^0_{31} - \rho^1_{31}) = \frac{2}{N}(U_{-1}U_0^* - U_2U_1^*)$$

$$\rho^0_{33} + \rho^1_{33} = \frac{2}{N}(|N_{-1}|^2 + |N_2|^2) \qquad \mathrm{Re}(\rho^0_{3-1} + \rho^1_{3-1}) = \frac{2}{N}(N_{-1}N_1^* + N_2N_0^*)$$

$$\rho^0_{33} - \rho^1_{33} = \frac{2}{N}(|U_{-1}|^2 + |U_2|^2) \qquad \mathrm{Re}(\rho^0_{3-1} - \rho^1_{3-1}) = \frac{2}{N}(U_{-1}U_1^* + U_2U_0^*)$$

$$N = 2(|N_{-1}|^2 + |N_0|^2 + |N_1|^2 + |N_2|^2 + |U_{-1}|^2 + |U_0|^2 + |U_1|^2 + |U_2|^2)$$

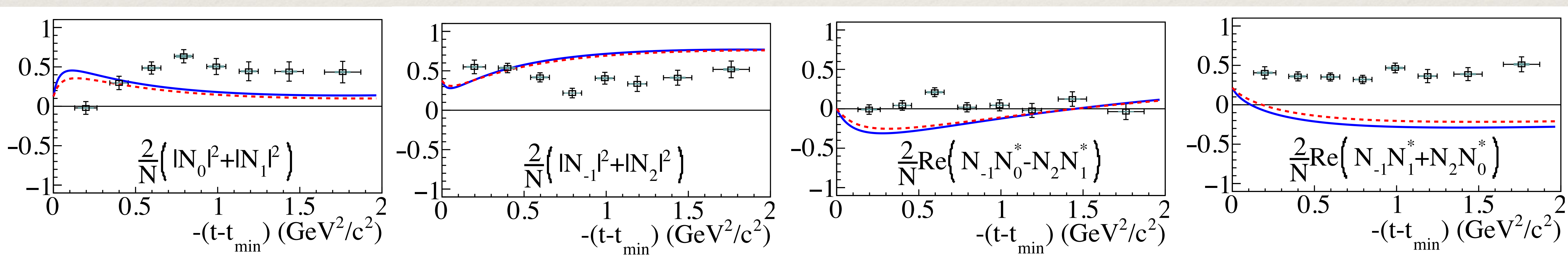
work by V. Mathieu (JPAC)

Λ(1520) SDME Interpretation

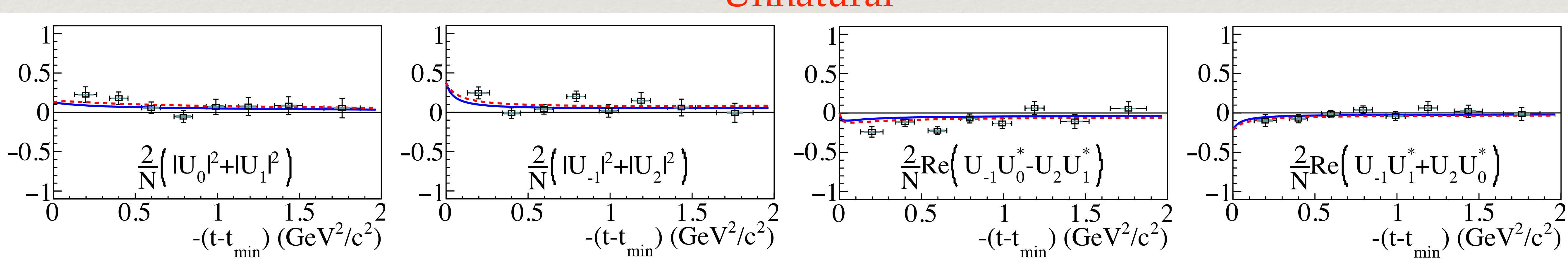
Phys. Rev. C **105**, 035201

- red and blue show model predictions in Reggeized framework (priv. comm. based on [1])
- natural amplitudes dominate
- More work needed to model the reaction accurately

Natural

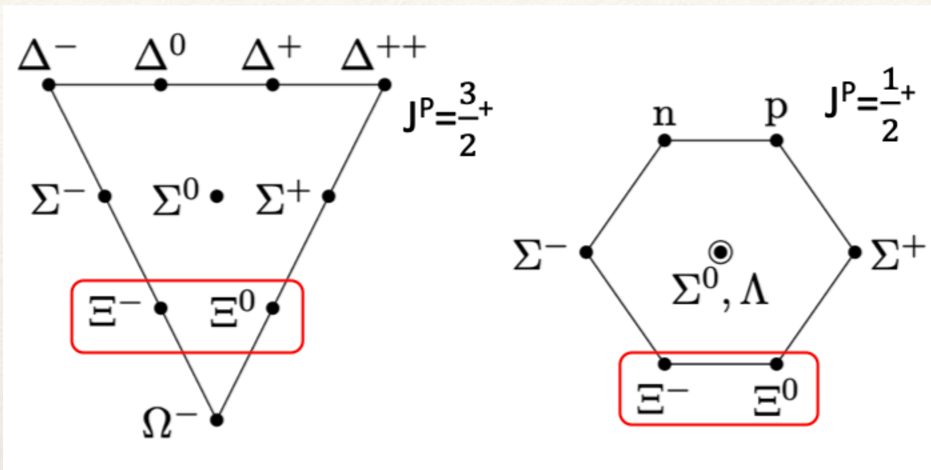


Unnatural



*[1] Byung-Geel Yu and Kook-Jin Kong, Phys. Rev. C **96**, 025208 (2017)*

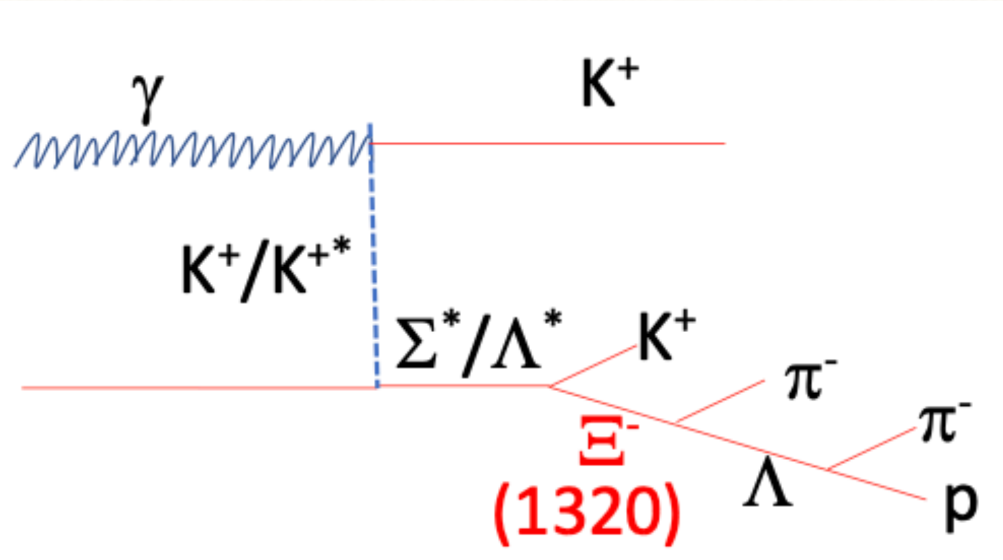
Cascades at GlueX

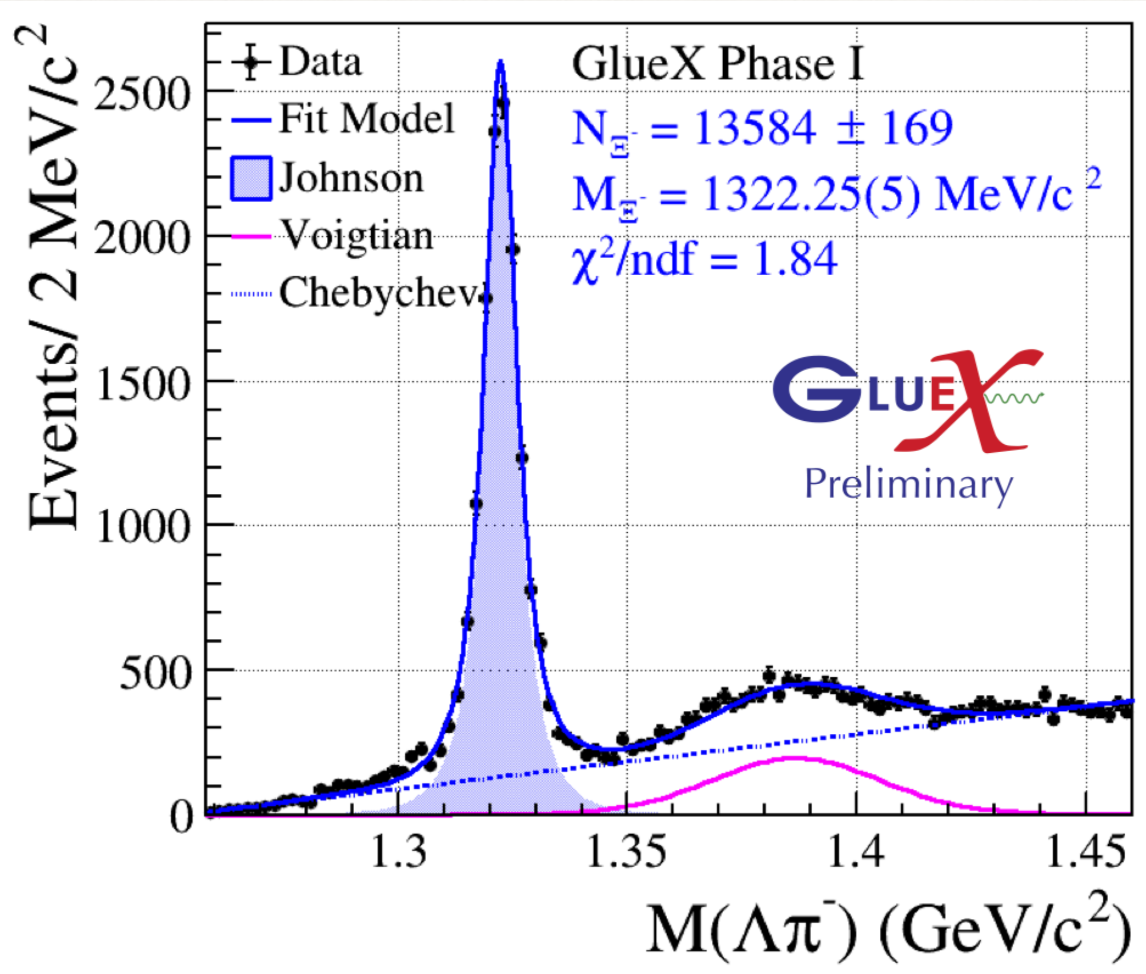


Particle	J^P	Overall Status	– Status as seen in – $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$
$\Xi(1318)$	$1/2^+$	****				
$\Xi(1530)$	$3/2^+$	****	****			
$\Xi(1620)$		*	*			
$\Xi(1690)$		***		***	**	
$\Xi(1820)$	$3/2^-$	***	**	***	**	**
$\Xi(1950)$		***	**	**		*
$\Xi(2030)$		***		**	***	
$\Xi(2120)$		*		*		
$\Xi(2250)$		**				
$\Xi(2370)$		**				
$\Xi(2500)$		*		*	*	

- Only six well known states (>3***)
- Would expect as many Ξs as N^*s and Δs
- Not many photoproduction experiments have been performed so far ($S = -2$)
- GlueX with its good charged and neutral final state particle coverage could help here
- Difficult analyses due to many final state particles

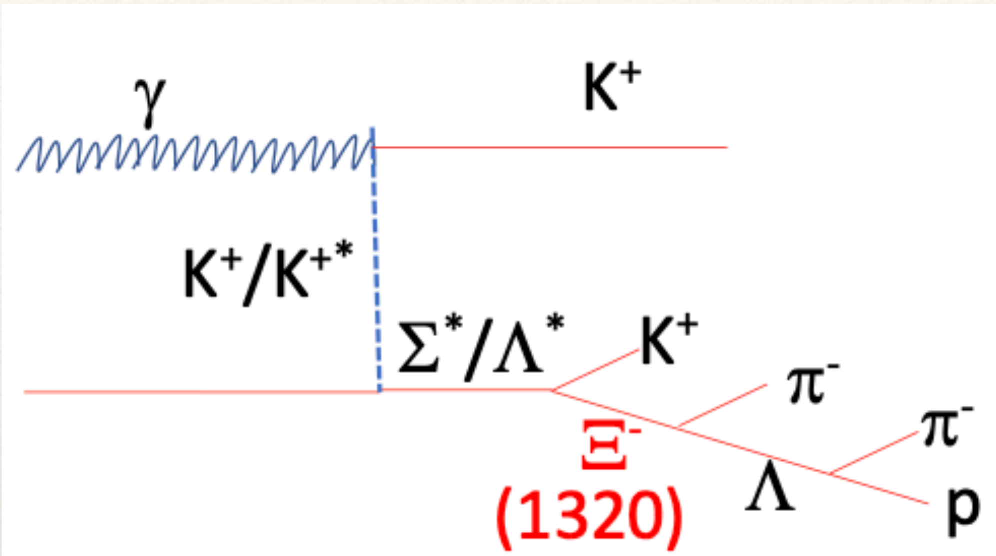
Cascades at GlueX

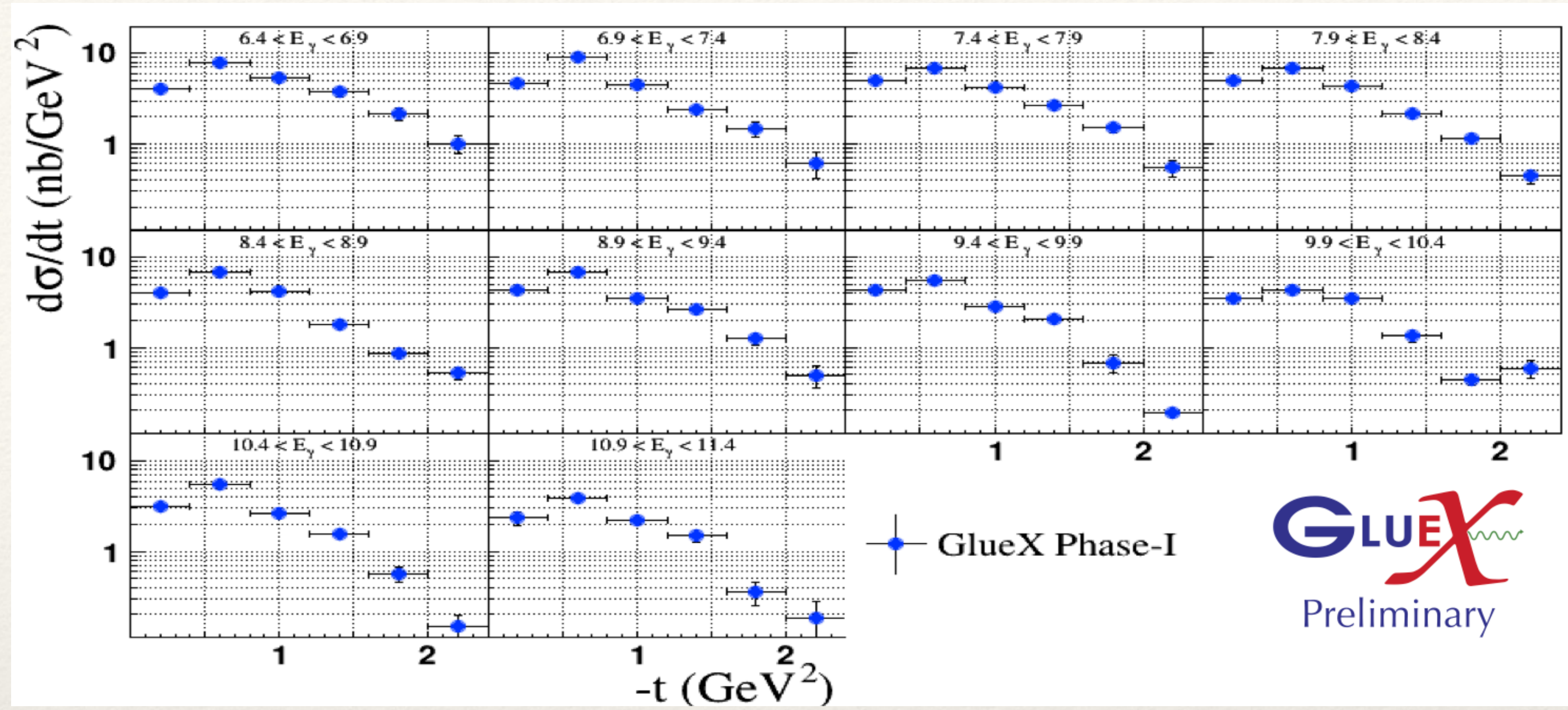


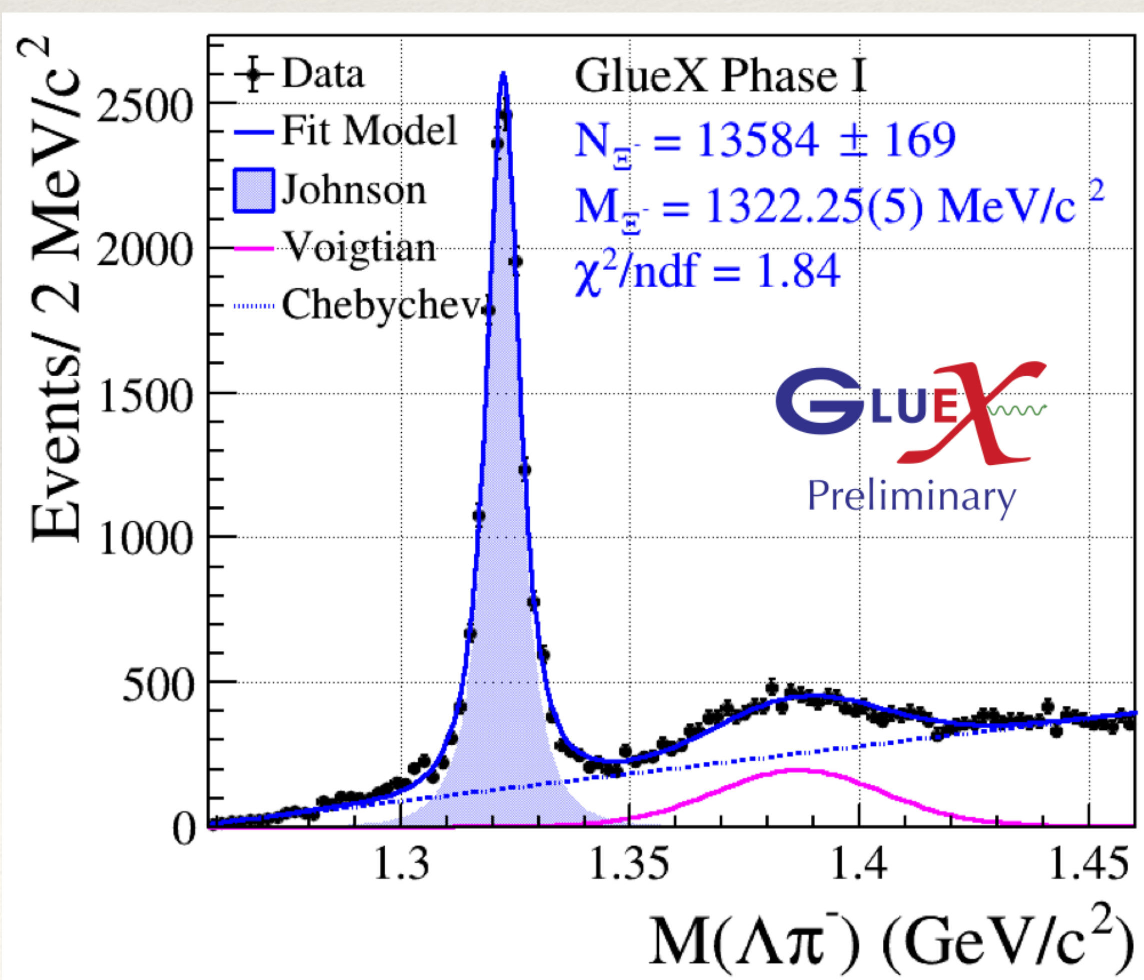


Cascades at GlueX

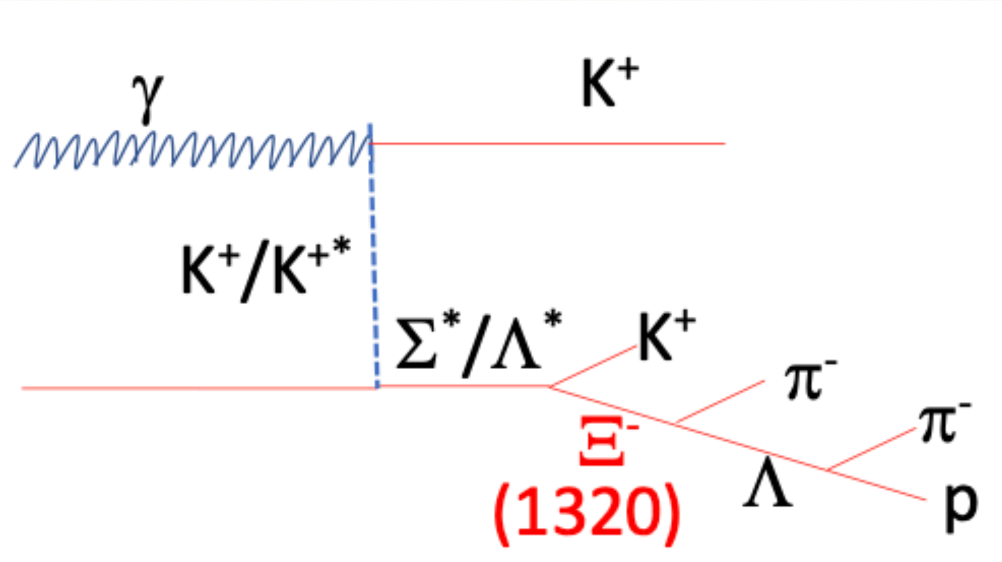
J. Hernandez (Baryon 2022)

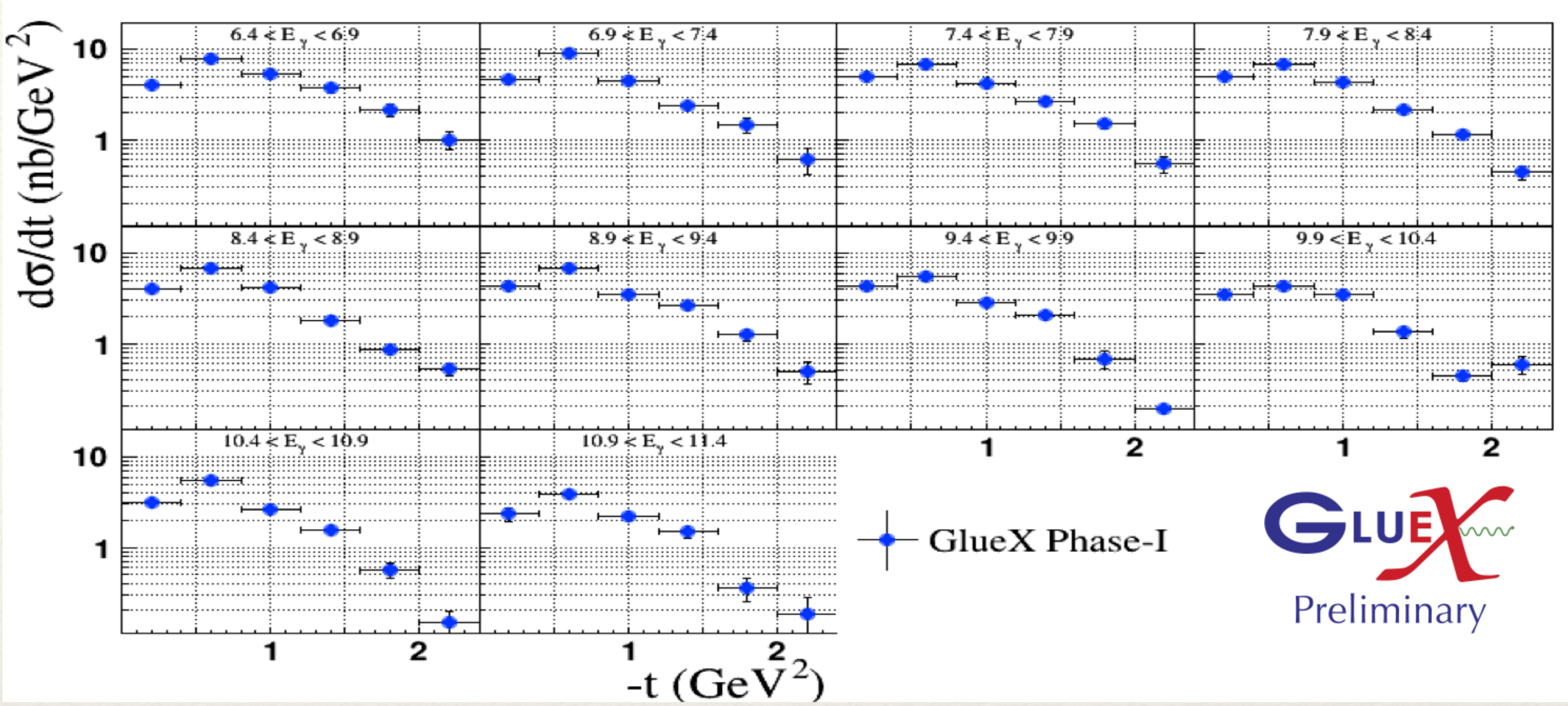


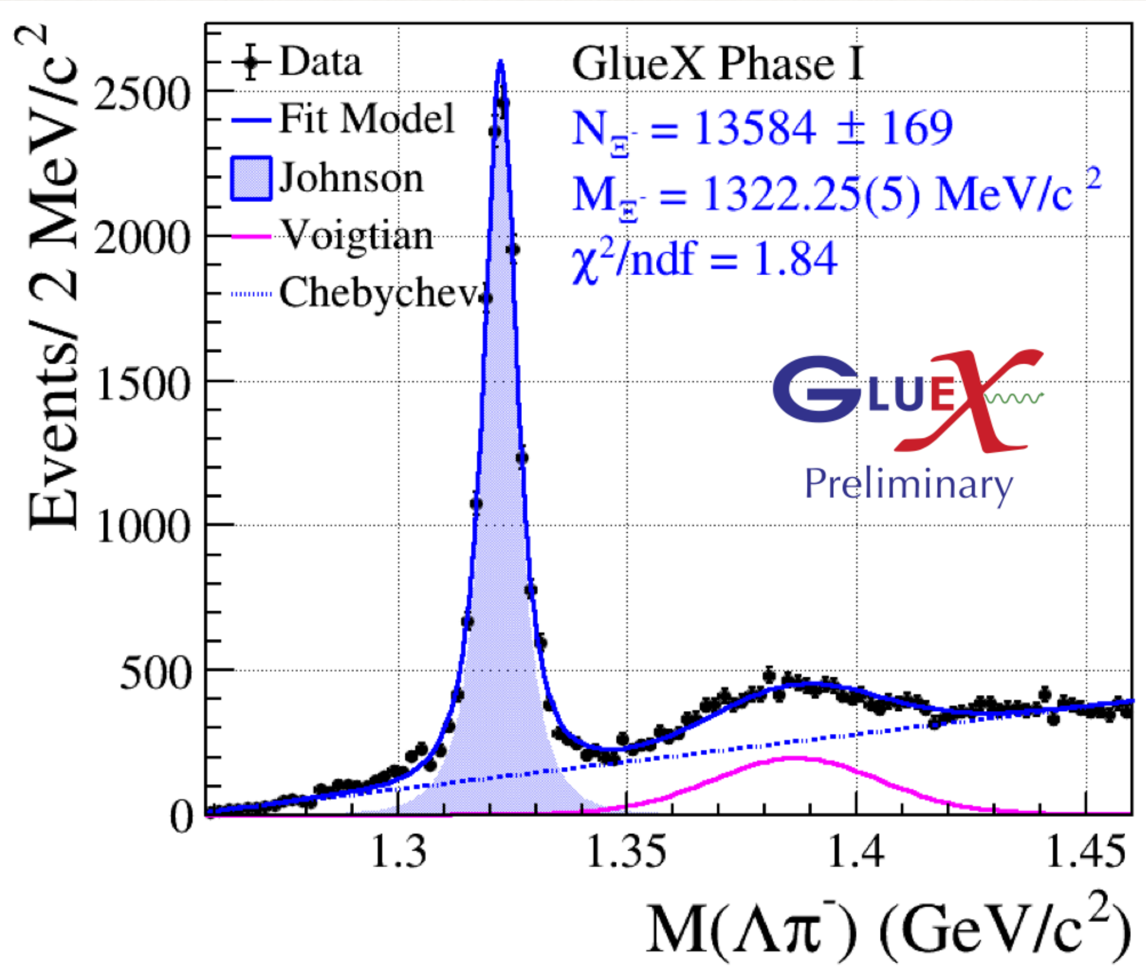


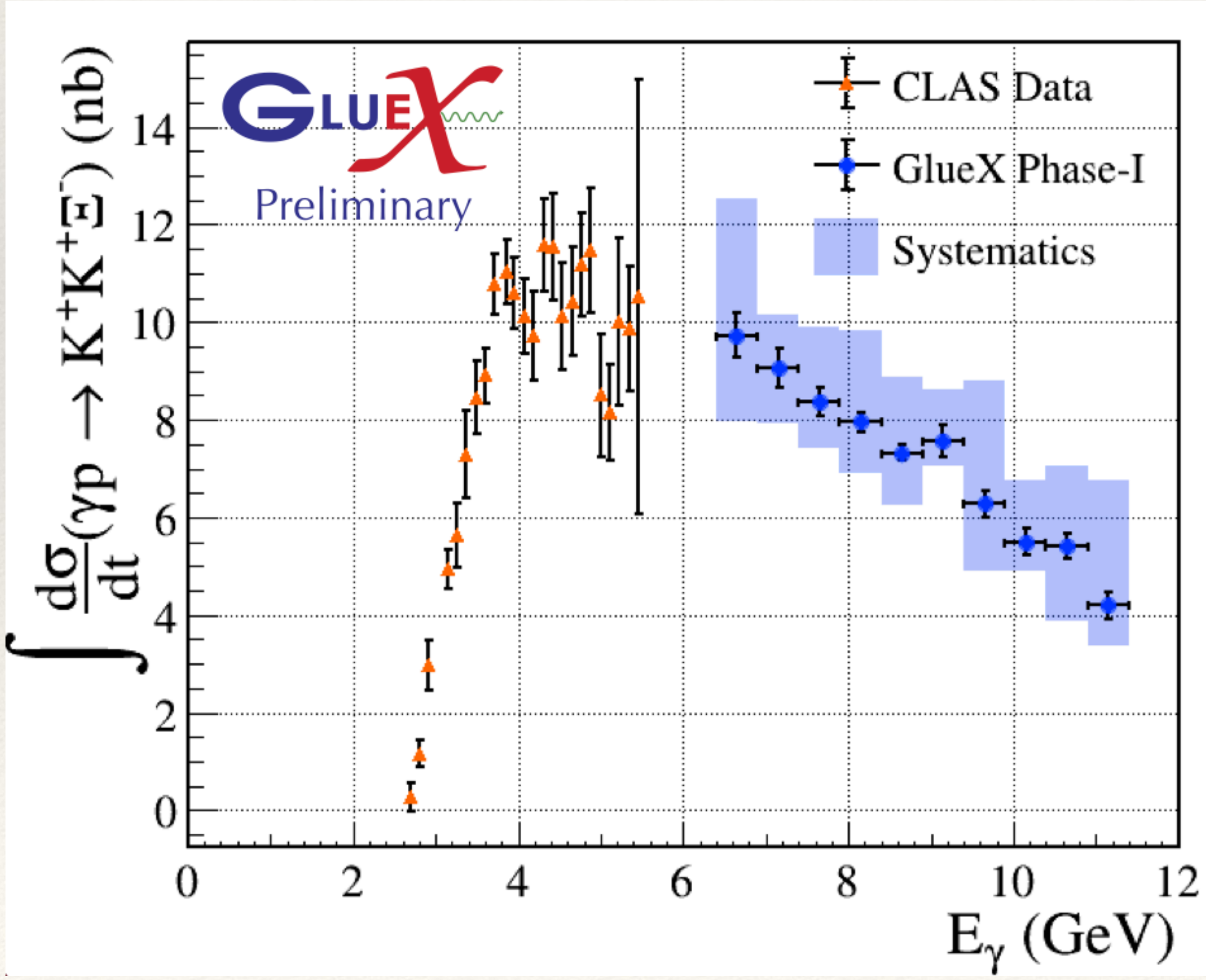


Cascades at GlueX

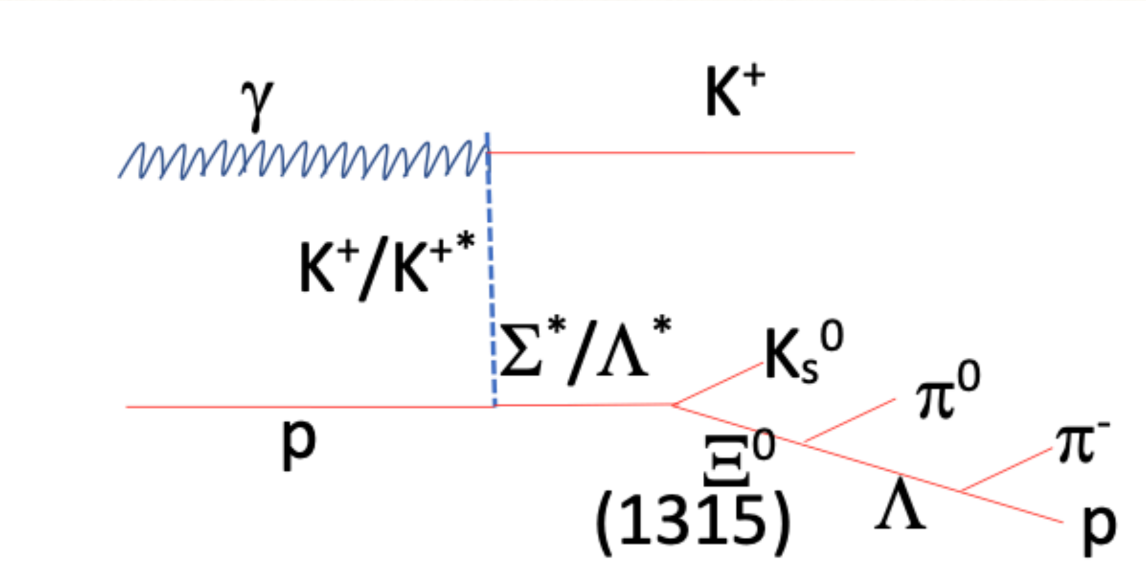




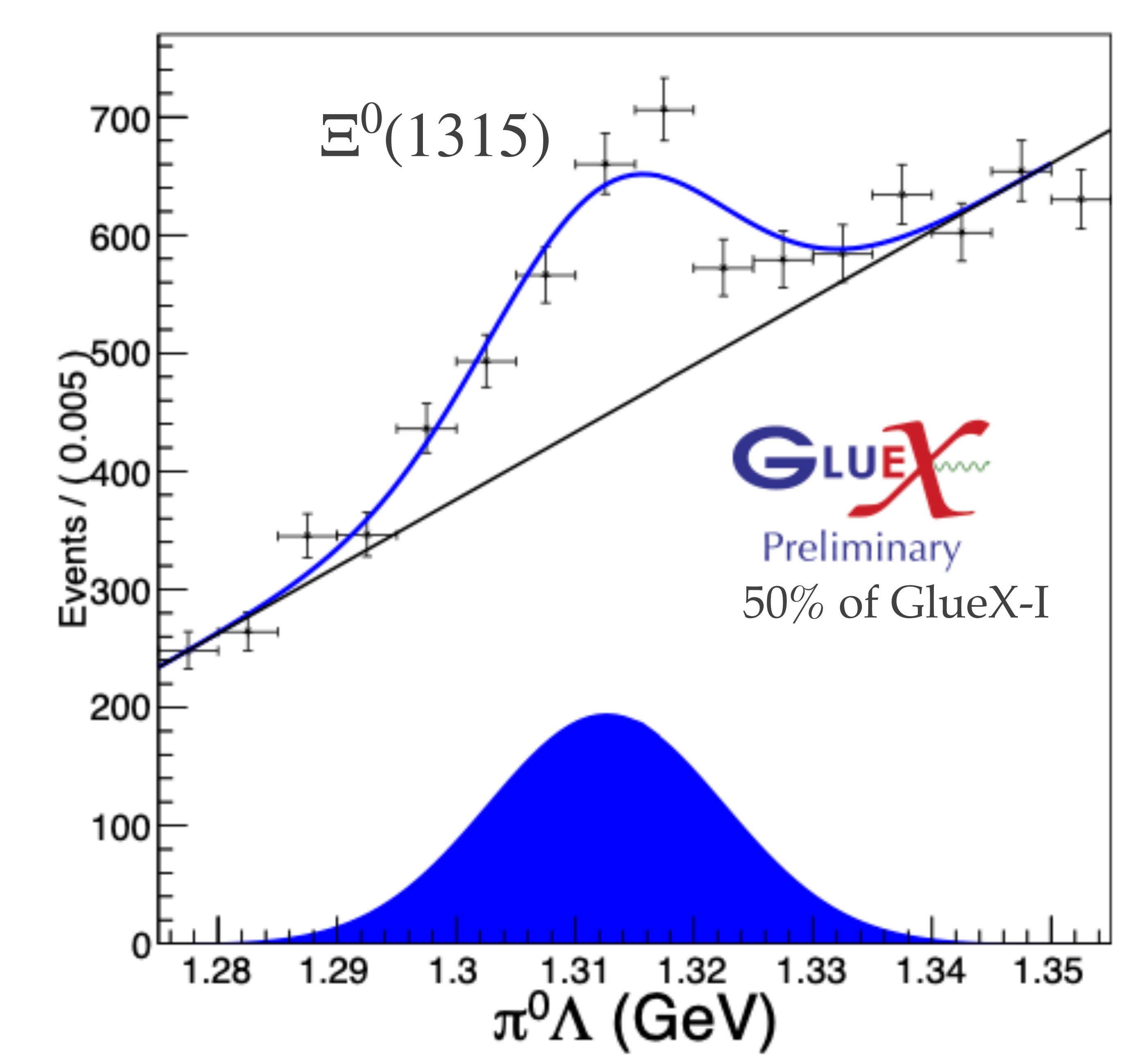




Cascades at GlueX

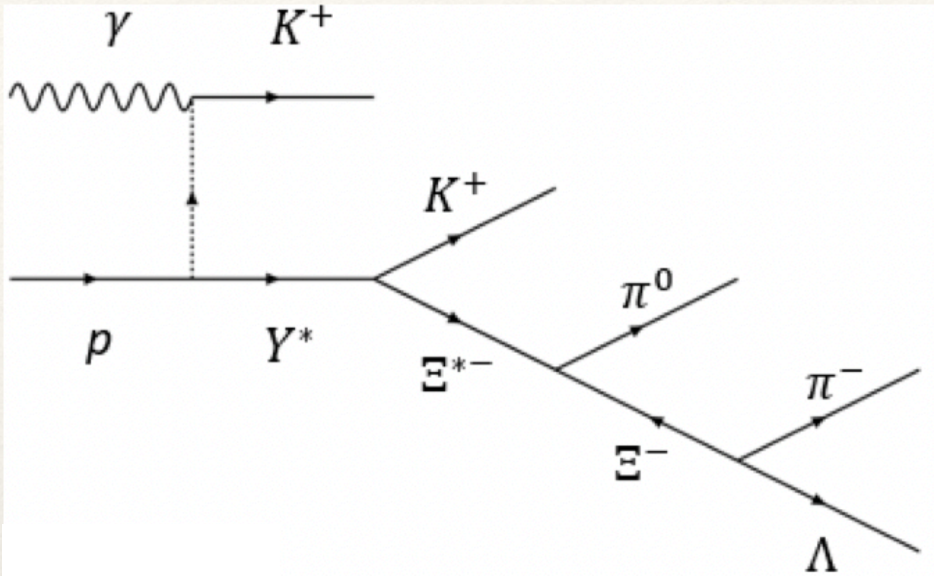


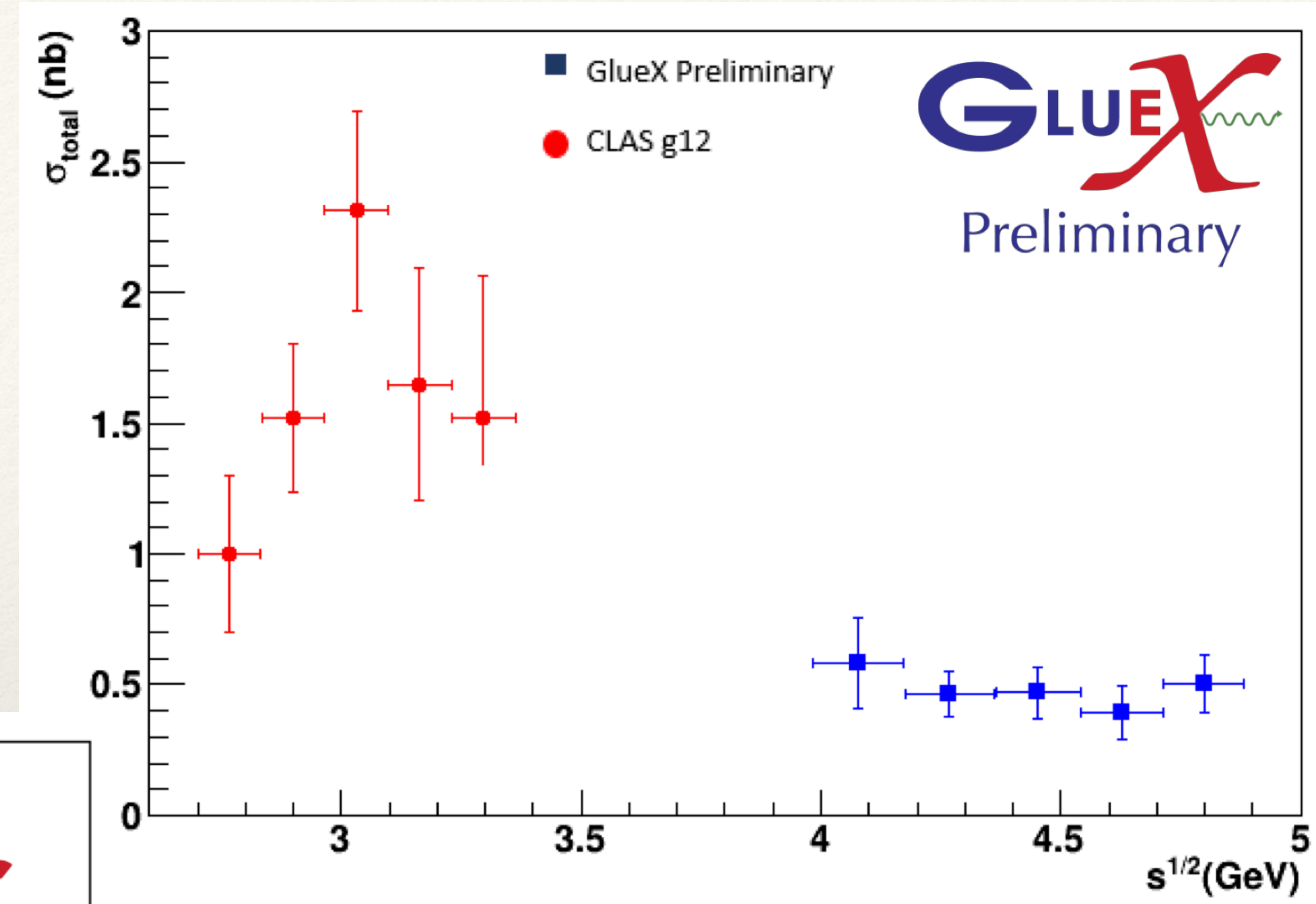
- We see both ground states
- Measure cross-sections for Ξ^-
- Less stats for Ξ^0 but clear signal

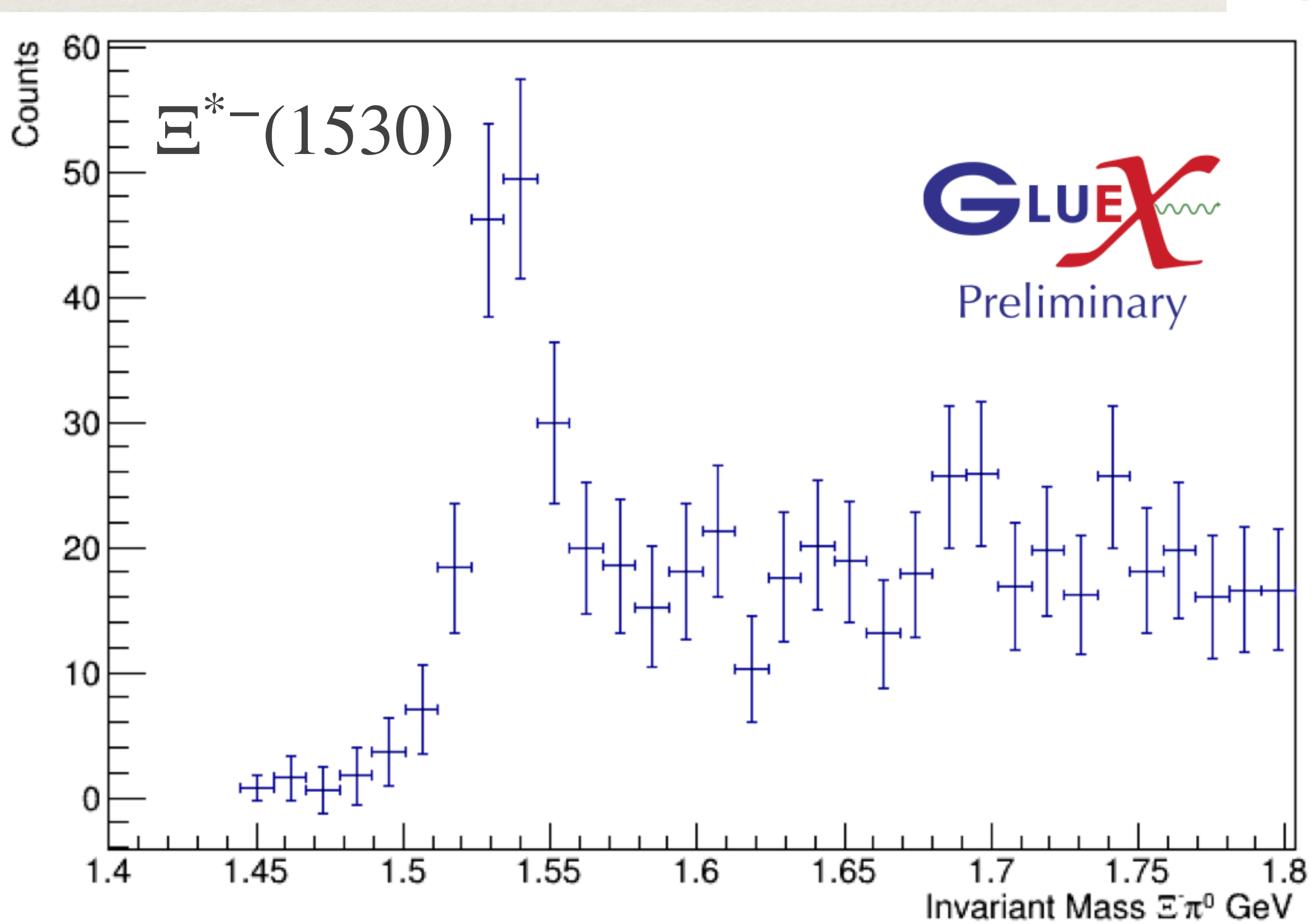


Further Cascades at GlueX

B. Sumner (GHP 2023)

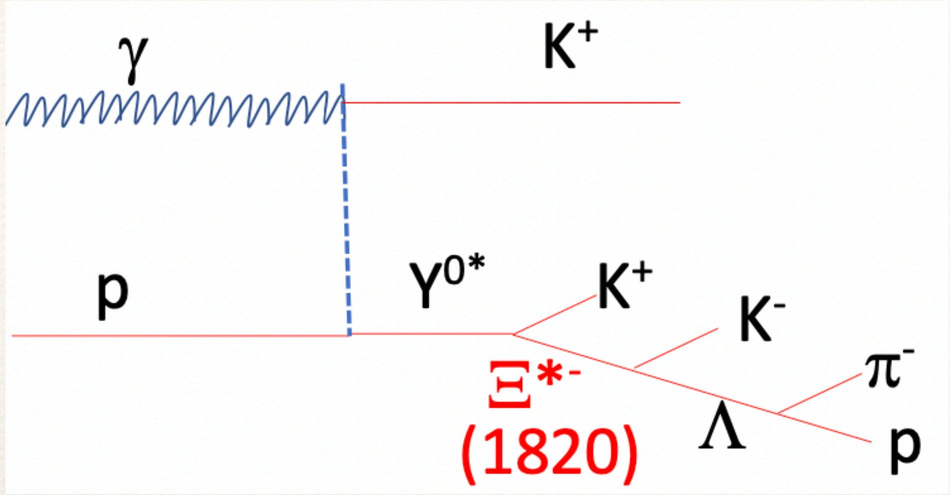


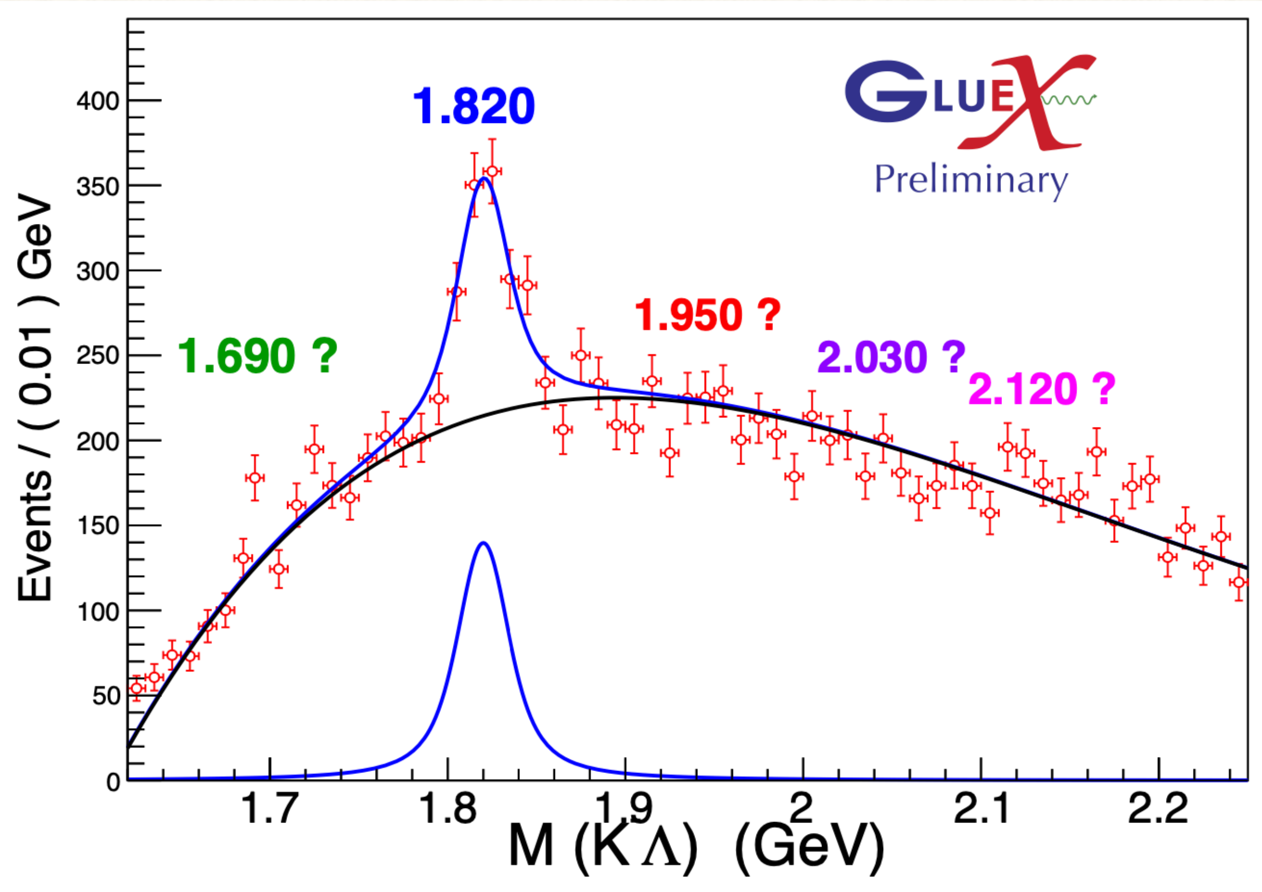


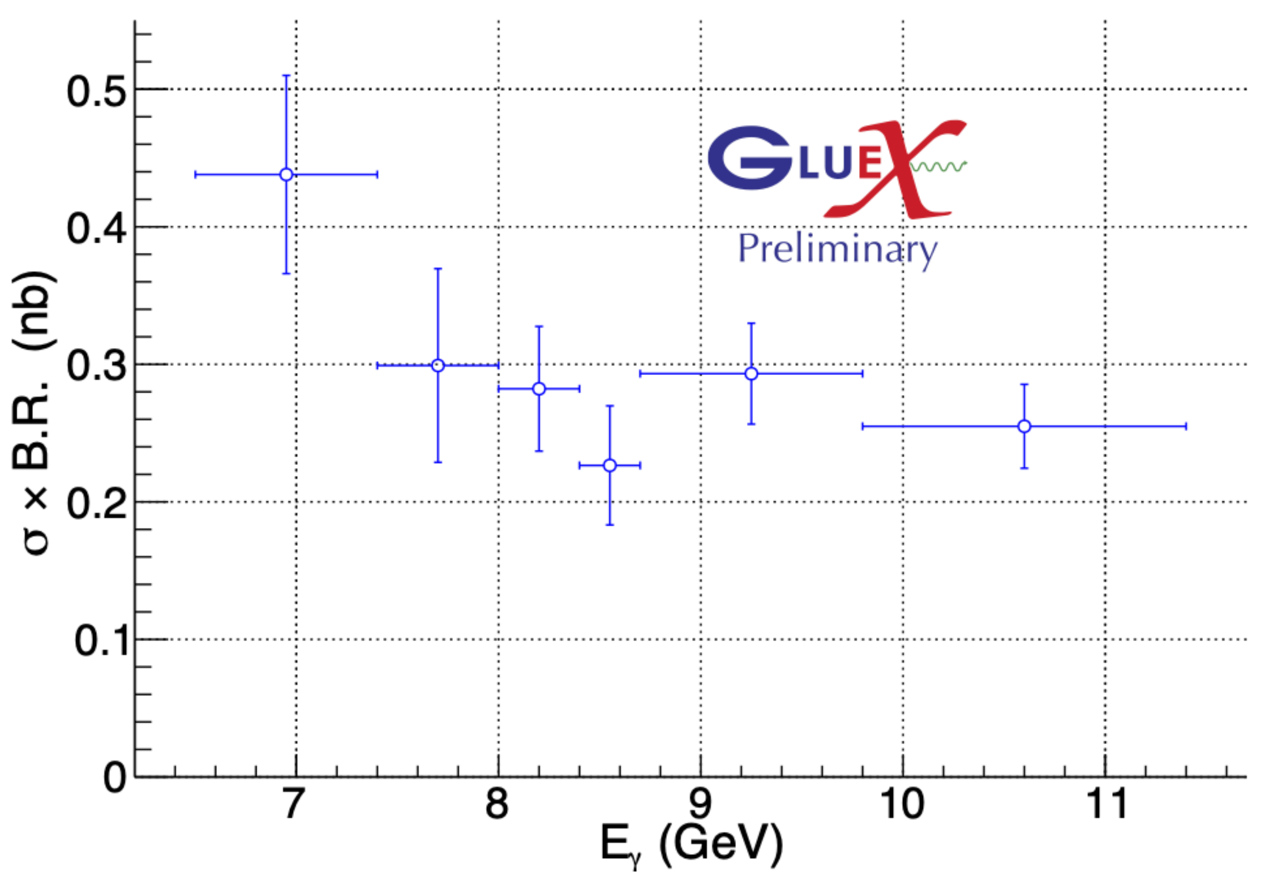


- Measure $\Xi^{*-} \rightarrow \Xi^{-}\pi^{0}$ and determine total Ξ^{*-} cross-section via isospin symmetry

$\Xi^-(1820)$

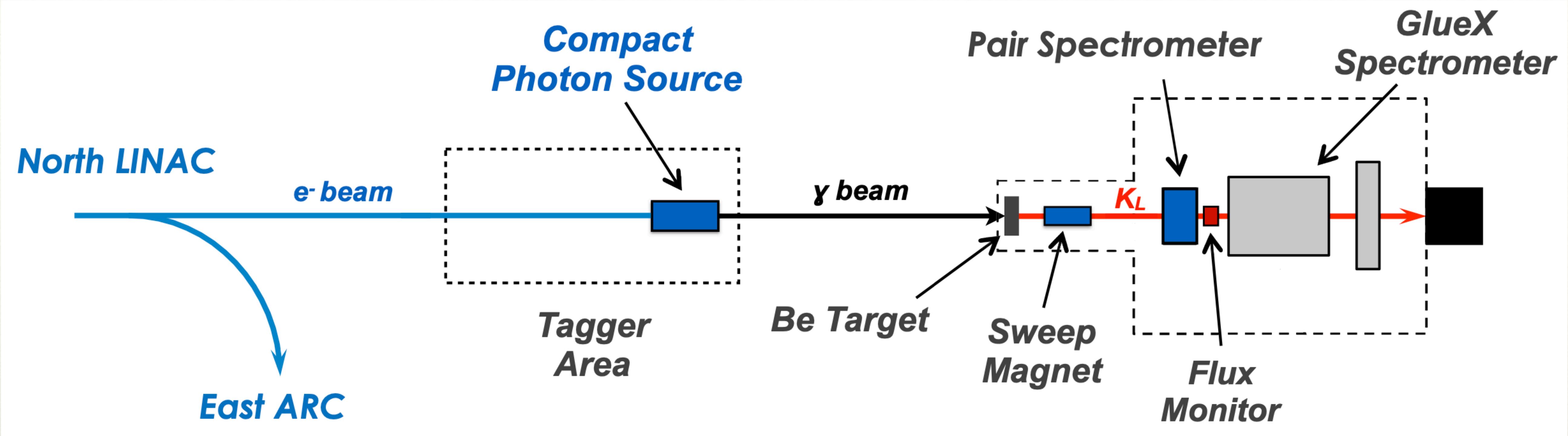




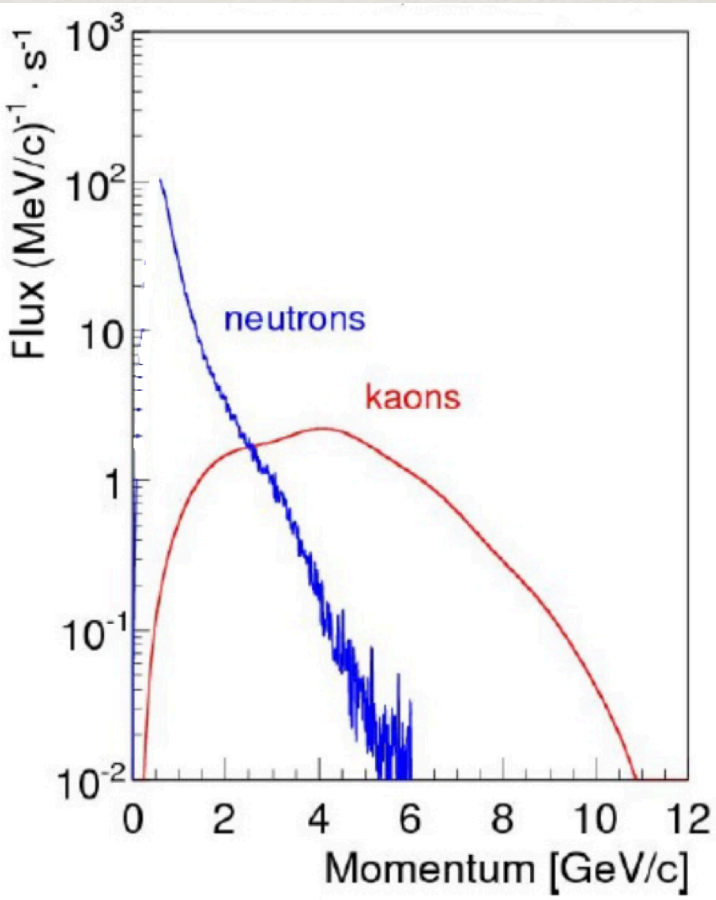


- Excited $\Xi(1820)$ with $J^P = \frac{3}{2}^-$
- *** resonance seen in $K^-\Lambda$ decays
- First measurement of $\Xi(1820)$ in photoproduction
- Only dominating feature in the $K^-\Lambda$ invariant mass

KLong facility in Hall D



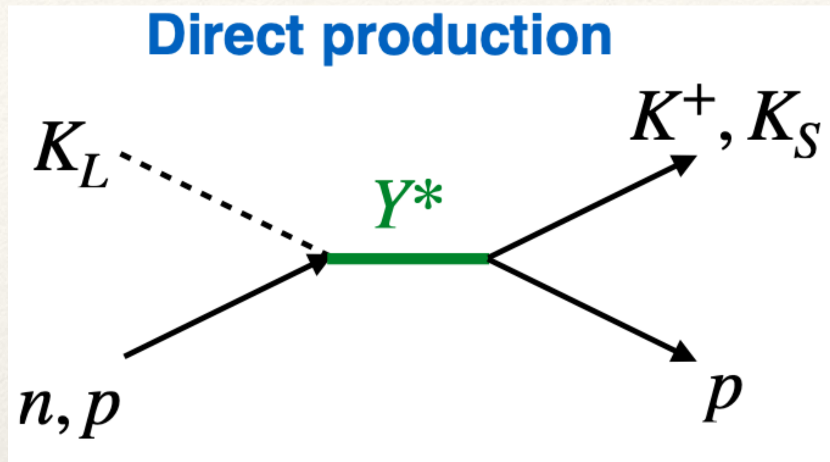
- New kaon beam facility approved to run 200 days in Hall D
  - Study of hyperons and kaon spectroscopy
- Produce $\approx 10^4 K_L\ /s$ (1000 times higher than previous experiments)
- Proton and neutron targets
- Use GlueX spectrometer to identify final state
- Might run 2026-2028

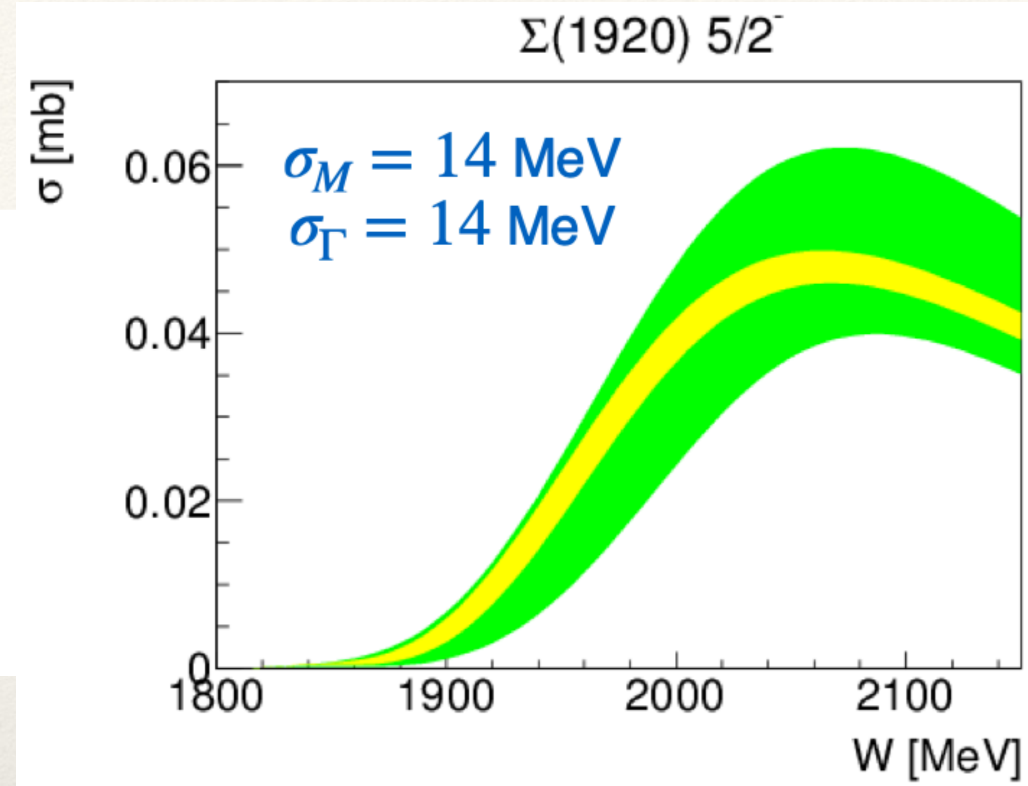


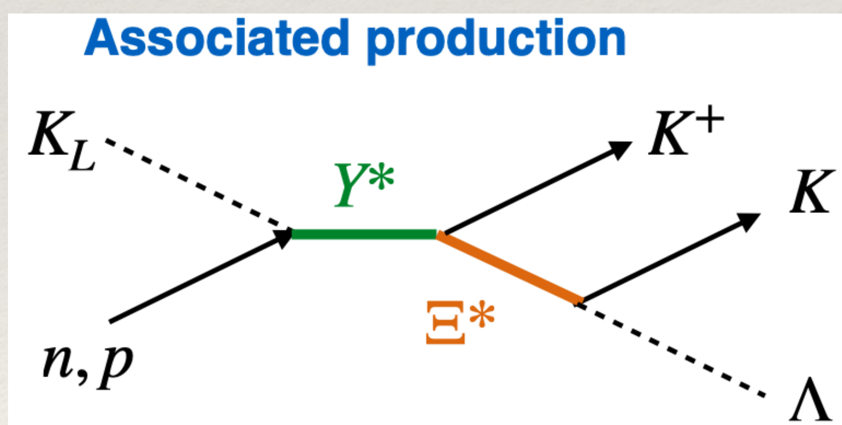
KLong facility in Hall D

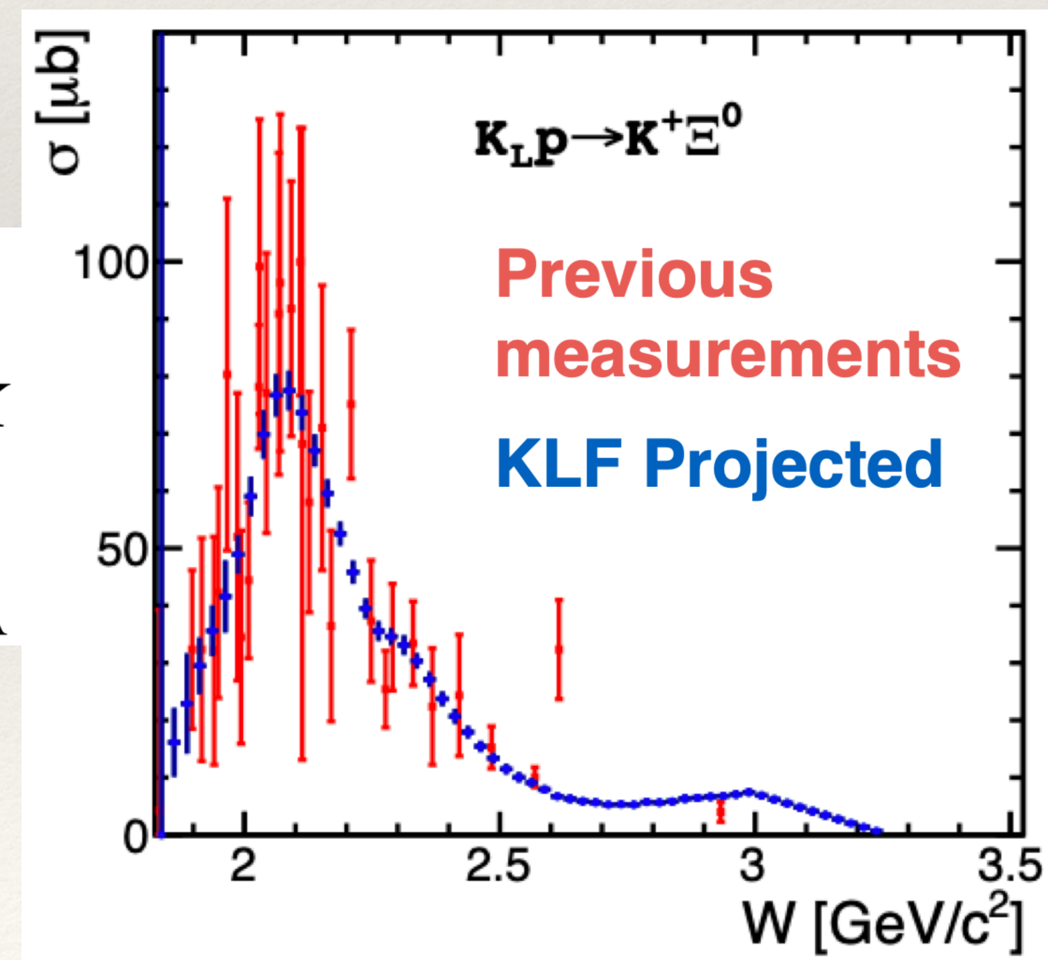
S. Dobbs (HADRON2021)

- Proton target:
  - Only Σ*
- Neutron target:
  - Λ* and Σ*
- Exclusive reconstruction in GlueX spectrometer
- Will provide precision cross-section measurements



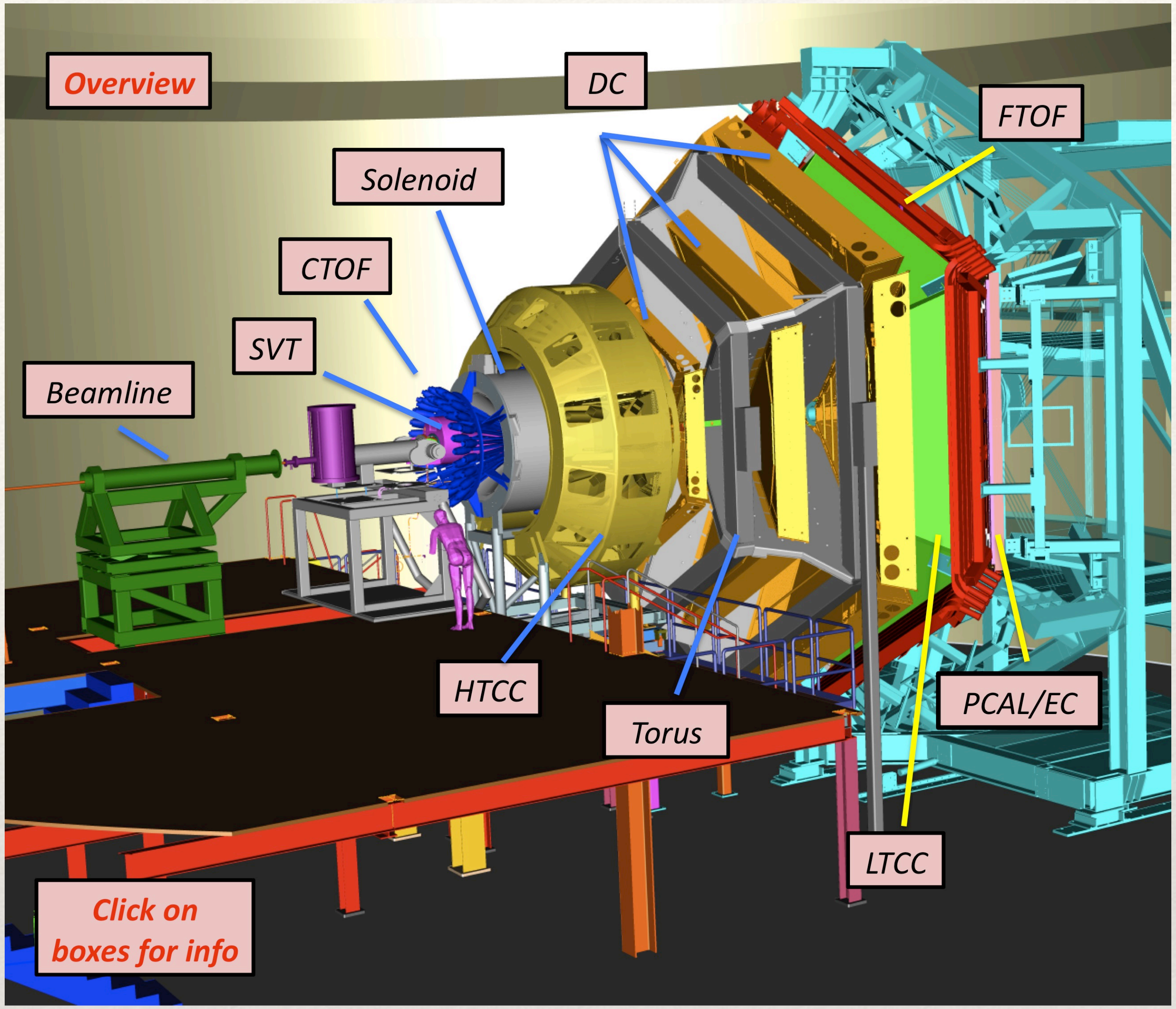






M. Bashkanov, Friday 11am

CLAS(12) in Hall B

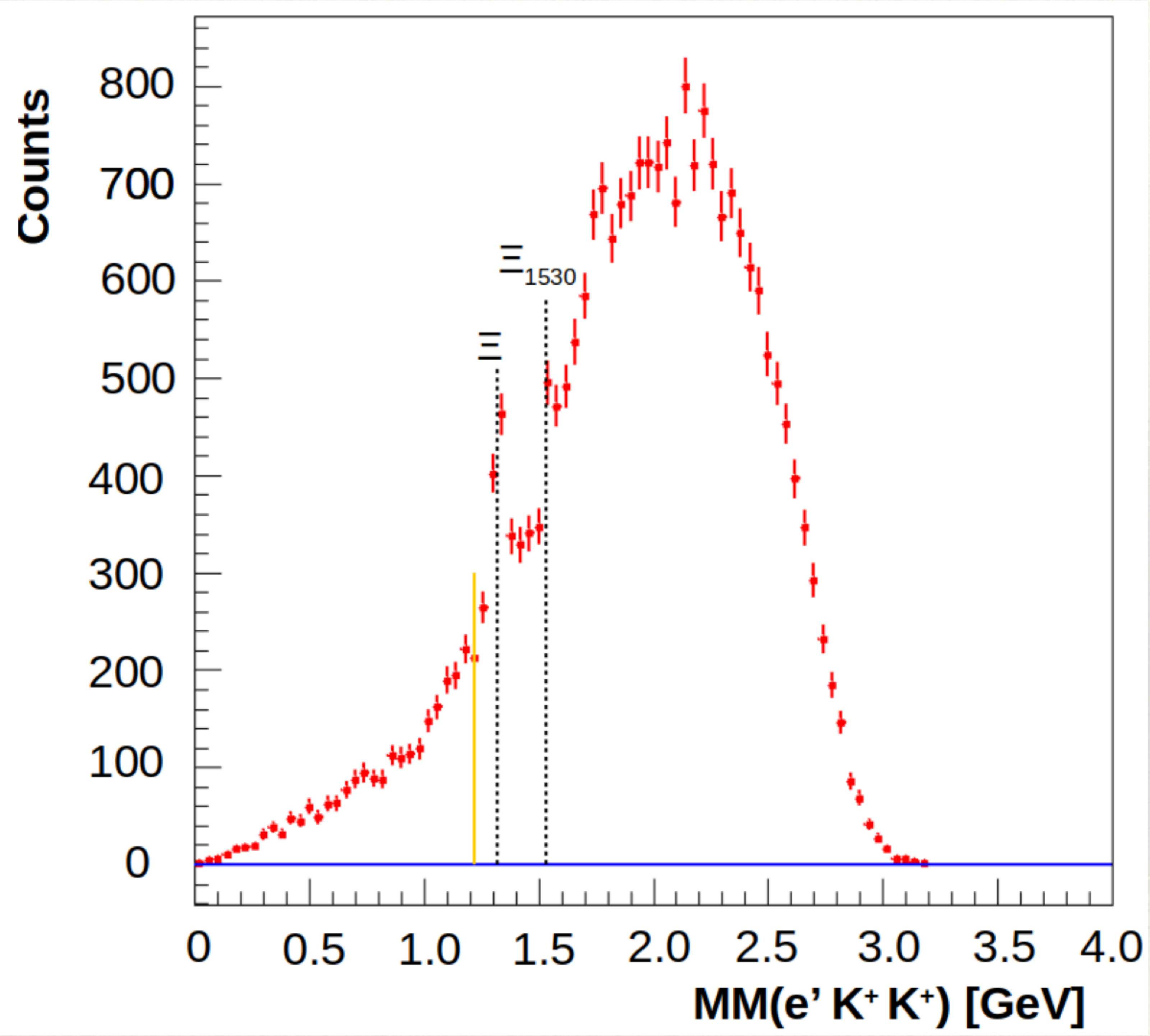


- CEBAF Large Acceptance Spectrometer (1995-2012)
- JLab 12 GeV upgrade completed in 2017 → CLAS12
- Very broad science program
- Many experiments and analyses dedicated to strange baryons
- Providing huge amounts of world data for (double) polarisation experiments
- Searches for cascades
- Search for strange hexaquarks
- Study of hyperon-nucleon interactions

Cascades at CLAS12

Very Strange Group

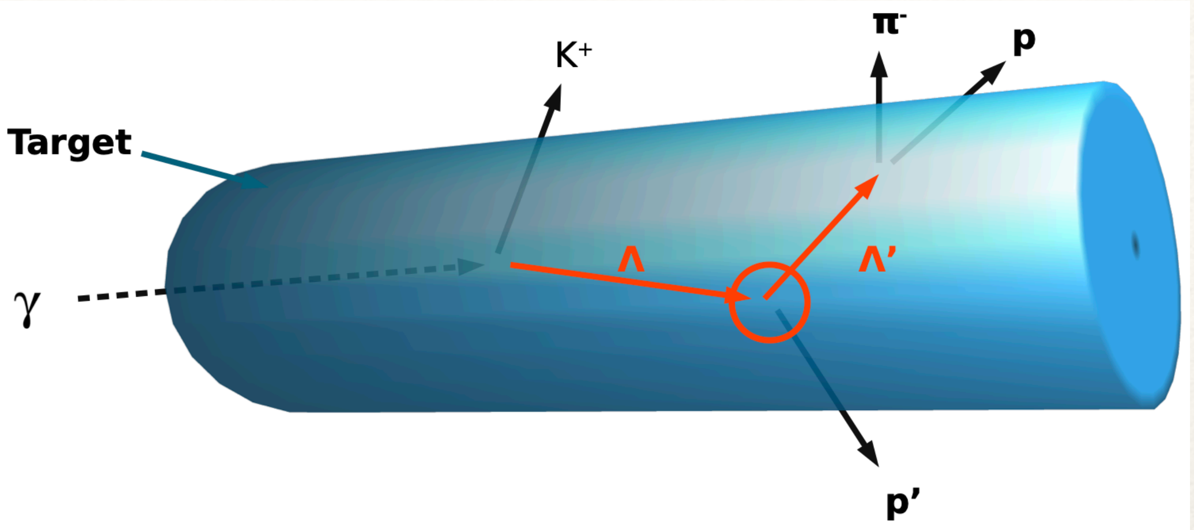
- Studies ongoing to look for $S = -2, -3$ hyperons
- Early results see $\Xi^{(*)}$
- More studies under way

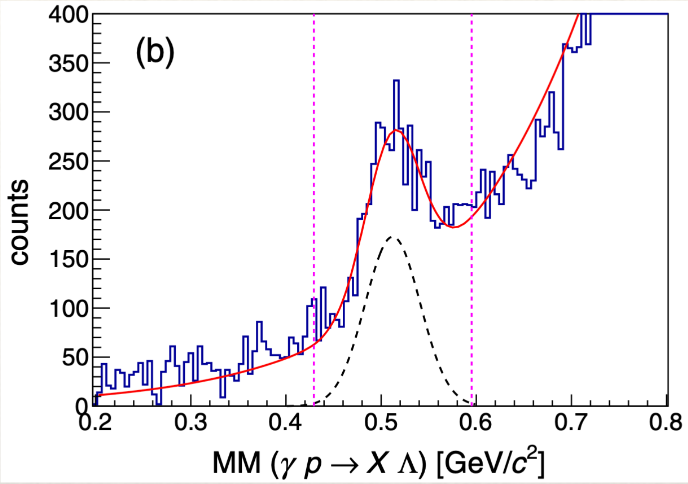


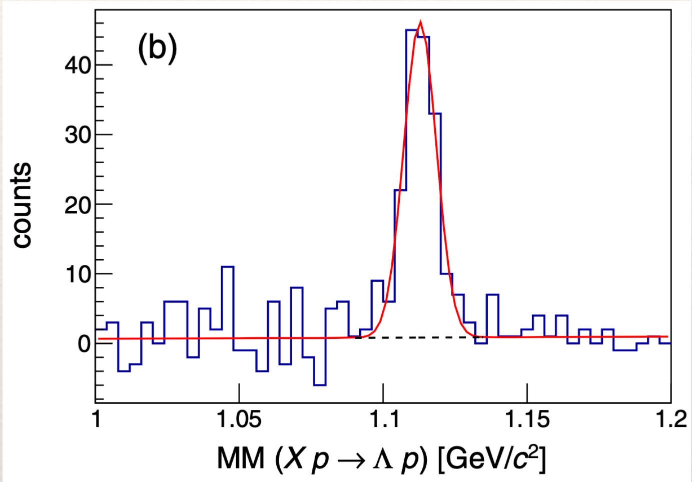
M. Nicol, PhD thesis, 2022

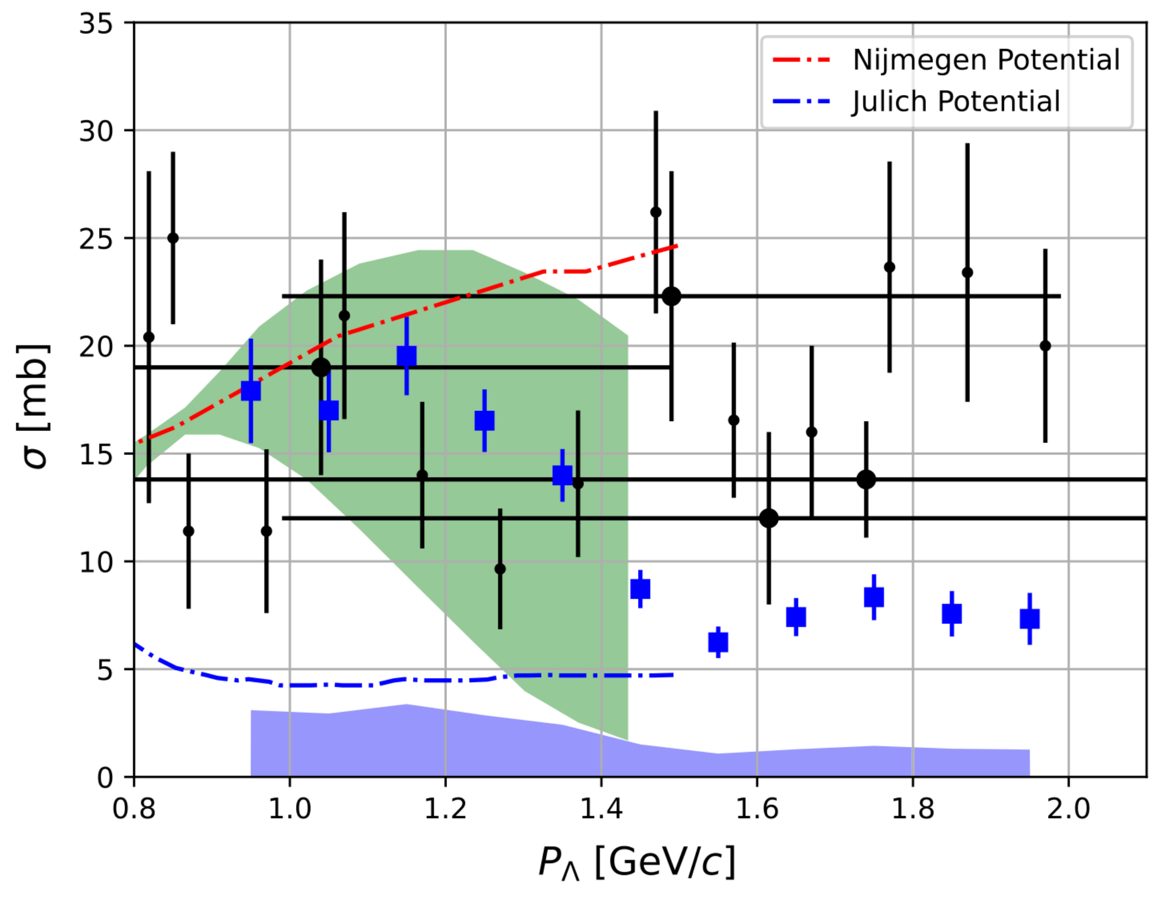
Hyperon scattering

- YN interactions are crucial ingredient in solving the "hyperon puzzle" for neutron stars
- Measure elastic $\Lambda p \rightarrow \Lambda p$ cross-section









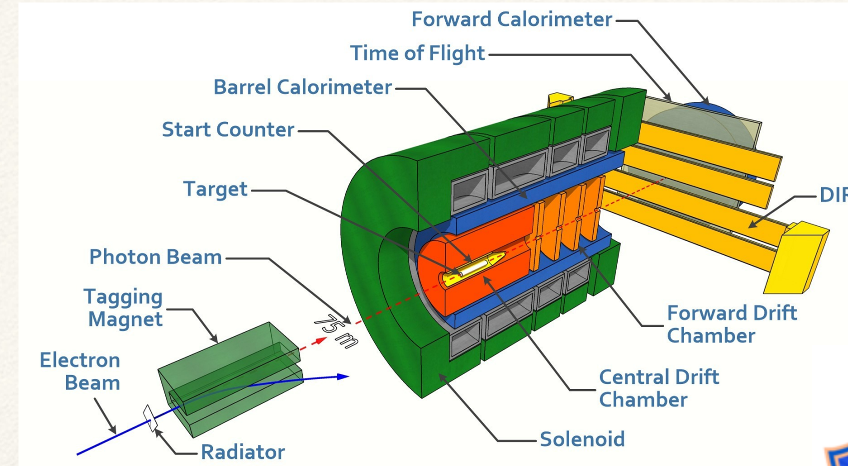
$$\sigma(p_\Lambda) = \frac{Y(p_\Lambda)}{A(p_\Lambda) \times \mathcal{L}(p_\Lambda) \times \Gamma}$$

$$\mathcal{L}(p_\Lambda) = \frac{N_A \times \rho_T \times l}{M} N_\Lambda(p_\Lambda)$$

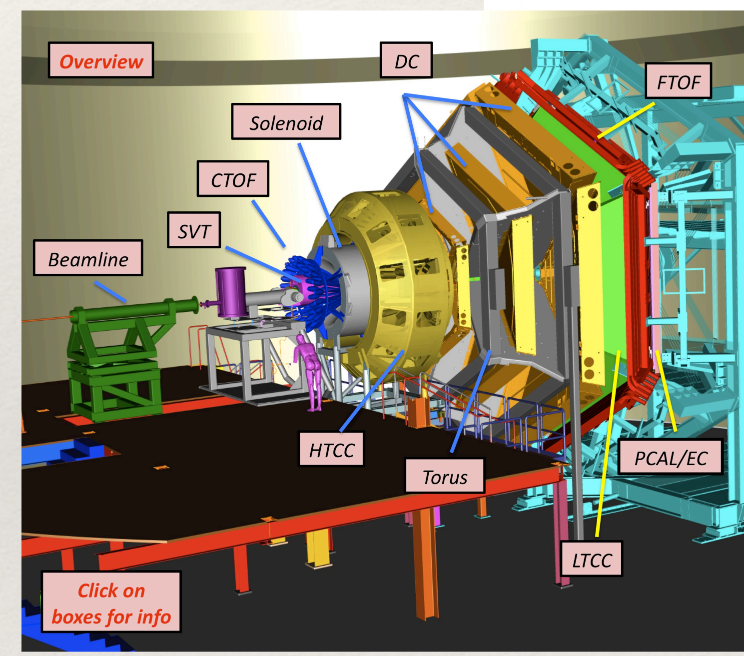
$$\frac{N_\Lambda}{\mathcal{L}_\gamma} = \frac{d\sigma}{d\Omega}(2\pi)[\Delta\cos(\theta)] \qquad P(x) = \exp\left[-\frac{M}{p}\frac{x - x_0}{\tau}\right]$$

Path length determined from simulations, accounting for beam size and kinematic dependence of photoprod. cs., as well as decay length of hyperons

Summary



- JLab delivers exciting strangeness results
- GlueX provides valuable photoproduction data for many different reactions
  - DIRC upgrade will boost analysis power for strange final states
- KLong will be the next big neutral kaon beam facility
- CLAS12 has an ambitious program with many different analyses in the pipeline
- CLAS provides important data such as YN scattering
- Other experimental halls also perform impressive experiments with strange baryons (hypernuclei)



Strange hadron spectroscopy workshop

Glasgow **April 3-5, 2024**

https://indico.cern.ch/e/StrangeHadSpec

SCAN ME

<u>Topics include:</u>

excited kaons

strangeonia

hyperon resonances

the nature of Lambda(1405)