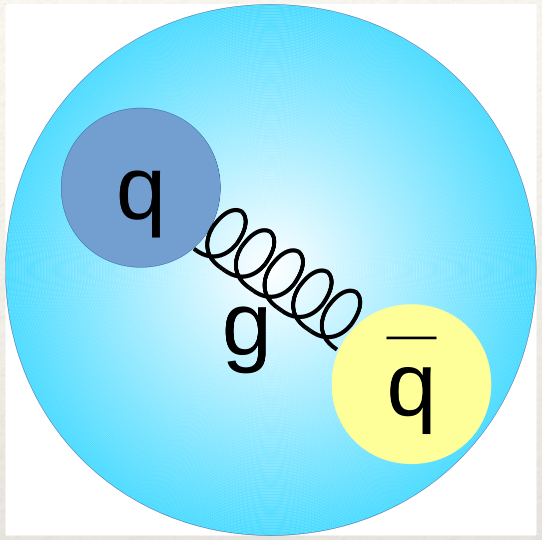
Peter Pauli for the GlueX collaboration

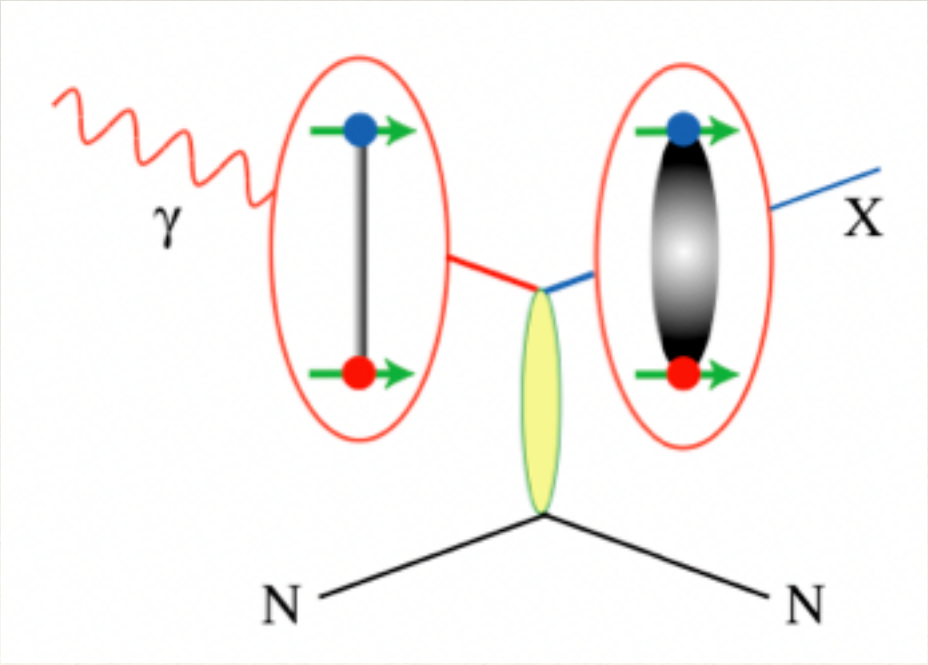
Measurement of spin-density matrix elements in $\Lambda(1520)$ photoproduction at GlueX

STRANU: Hot topics in STRAngeness NUclear and atomic physics 24.5.2021

Motivation

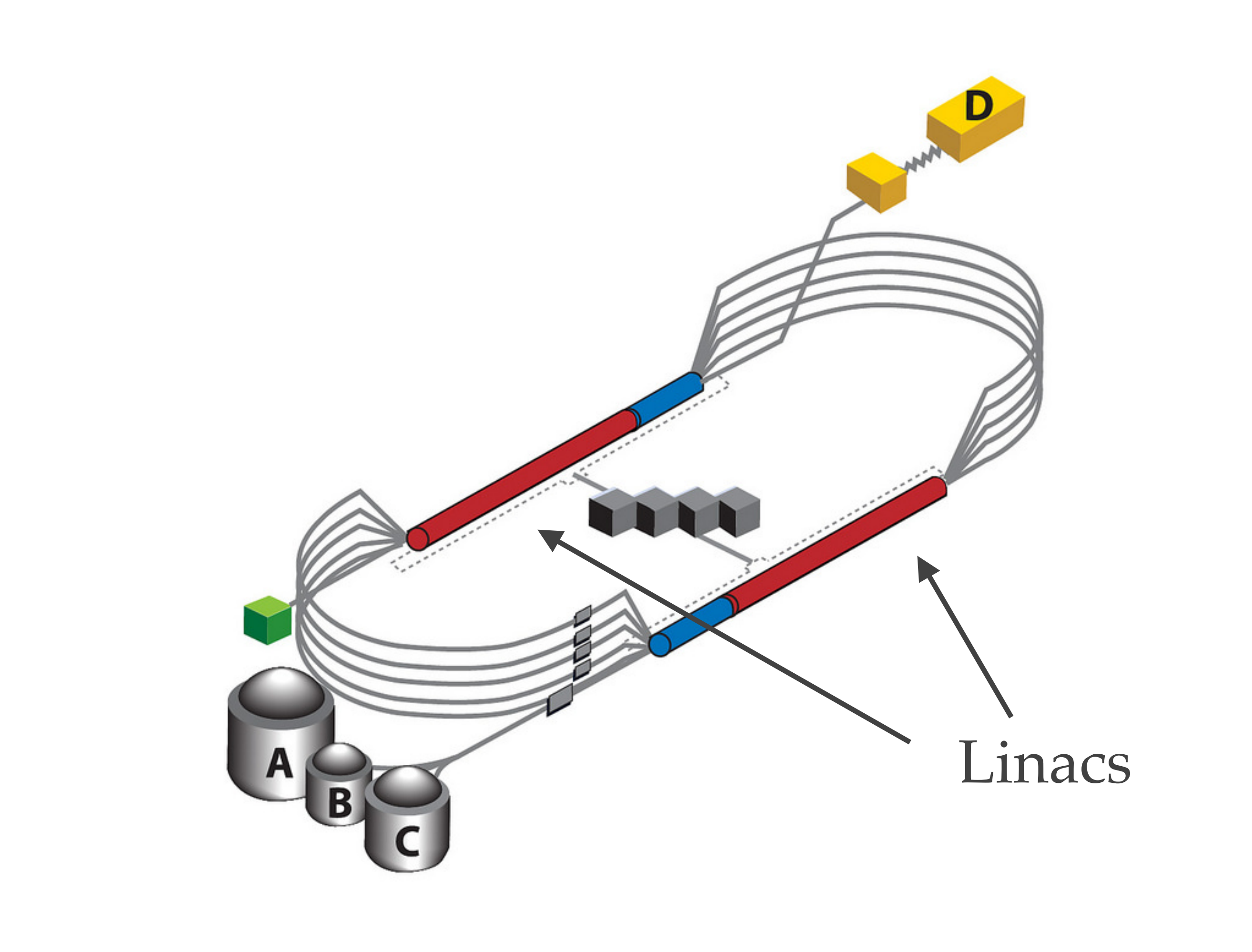


- main objective for GlueX:
  Search and study of hybrid mesons
- need to measure a variety of charged and neutral final states
- requires very good understanding of all involved physics processes
- first step: understand production mechanism

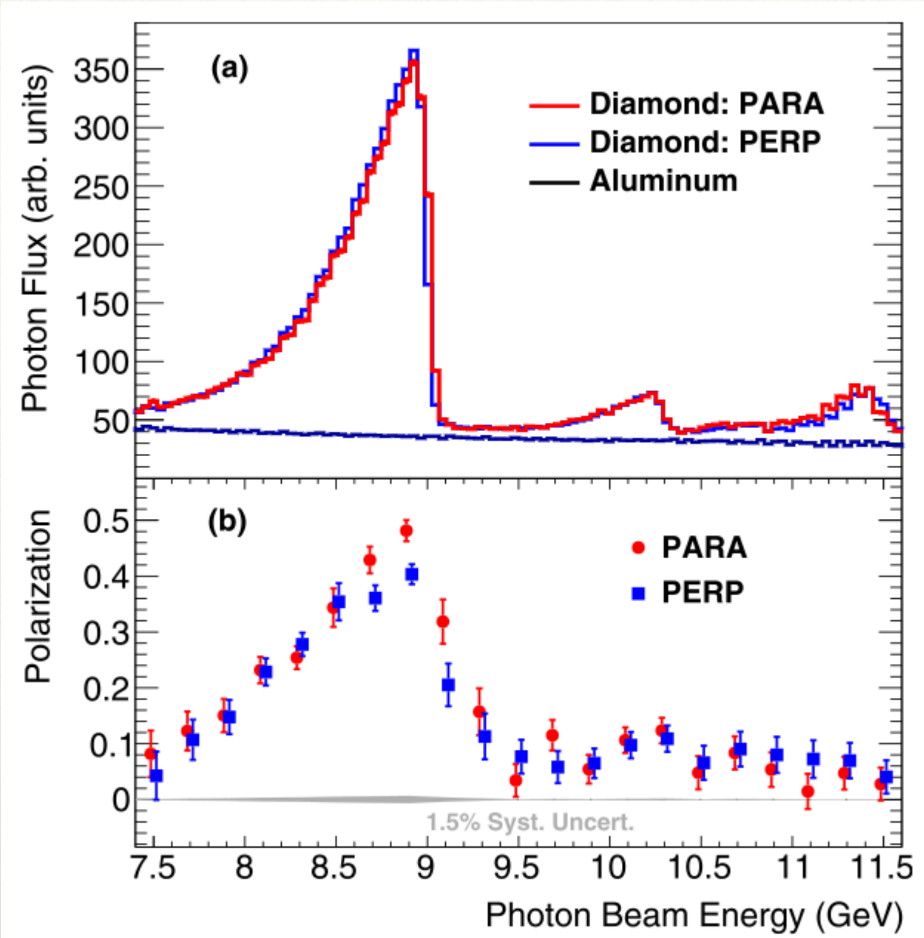


CEBAF at Jefferson Lab

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



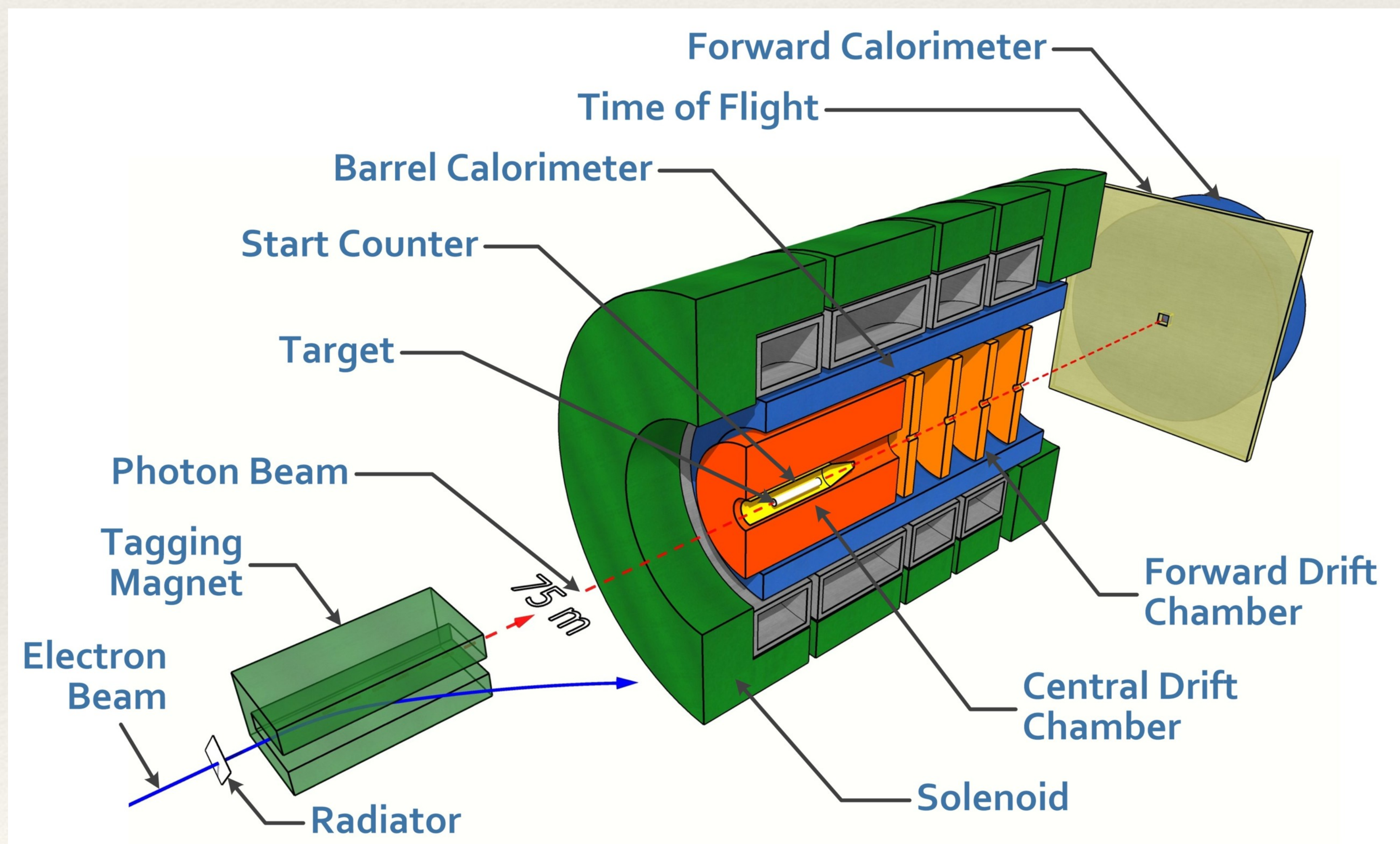
GlueX experiment



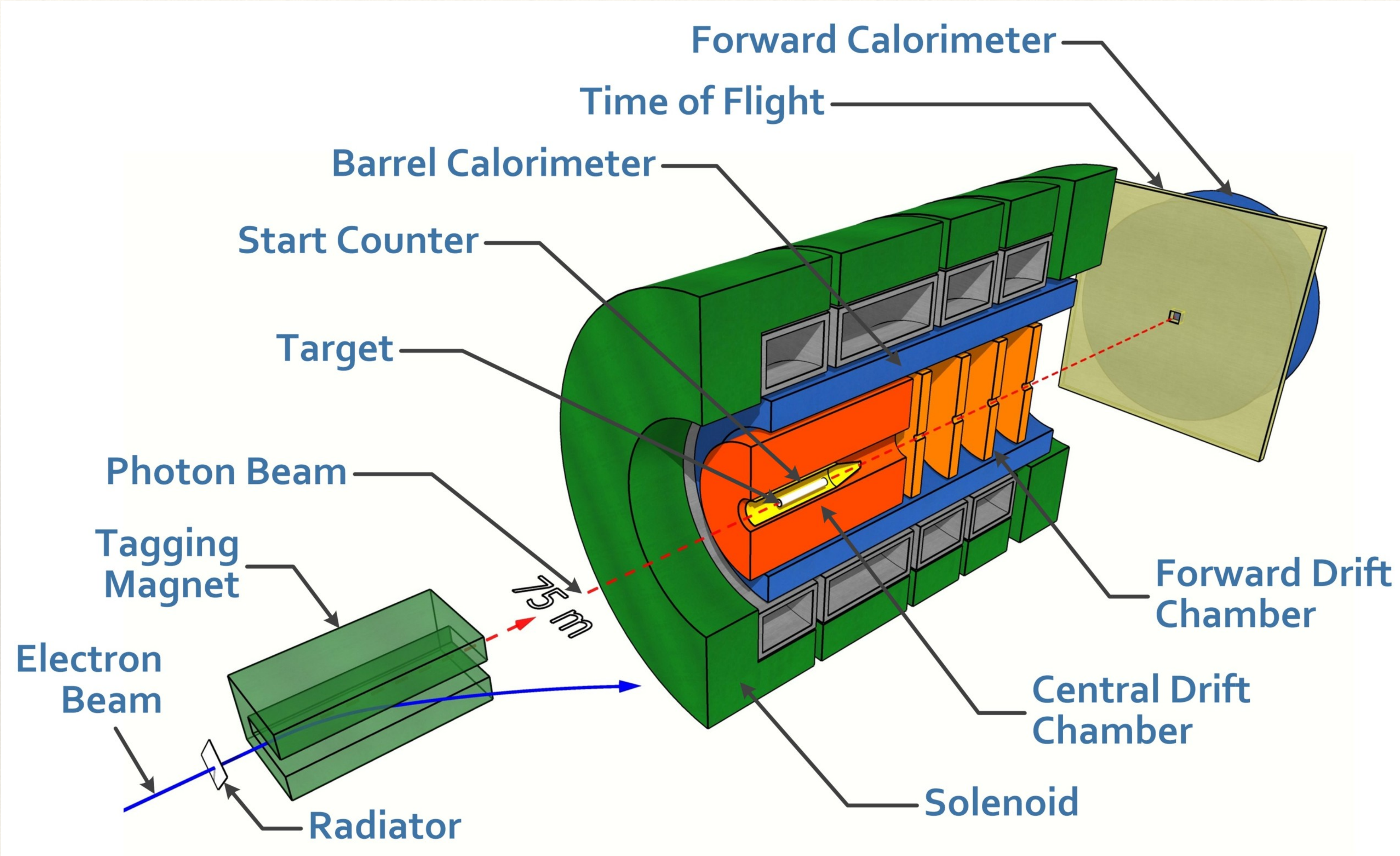
https://doi.org/10.1016/j.nima.2020.164807

- produce photon beam via coherent bremsstrahlung on thin diamond

- tag electrons to determine photon energy



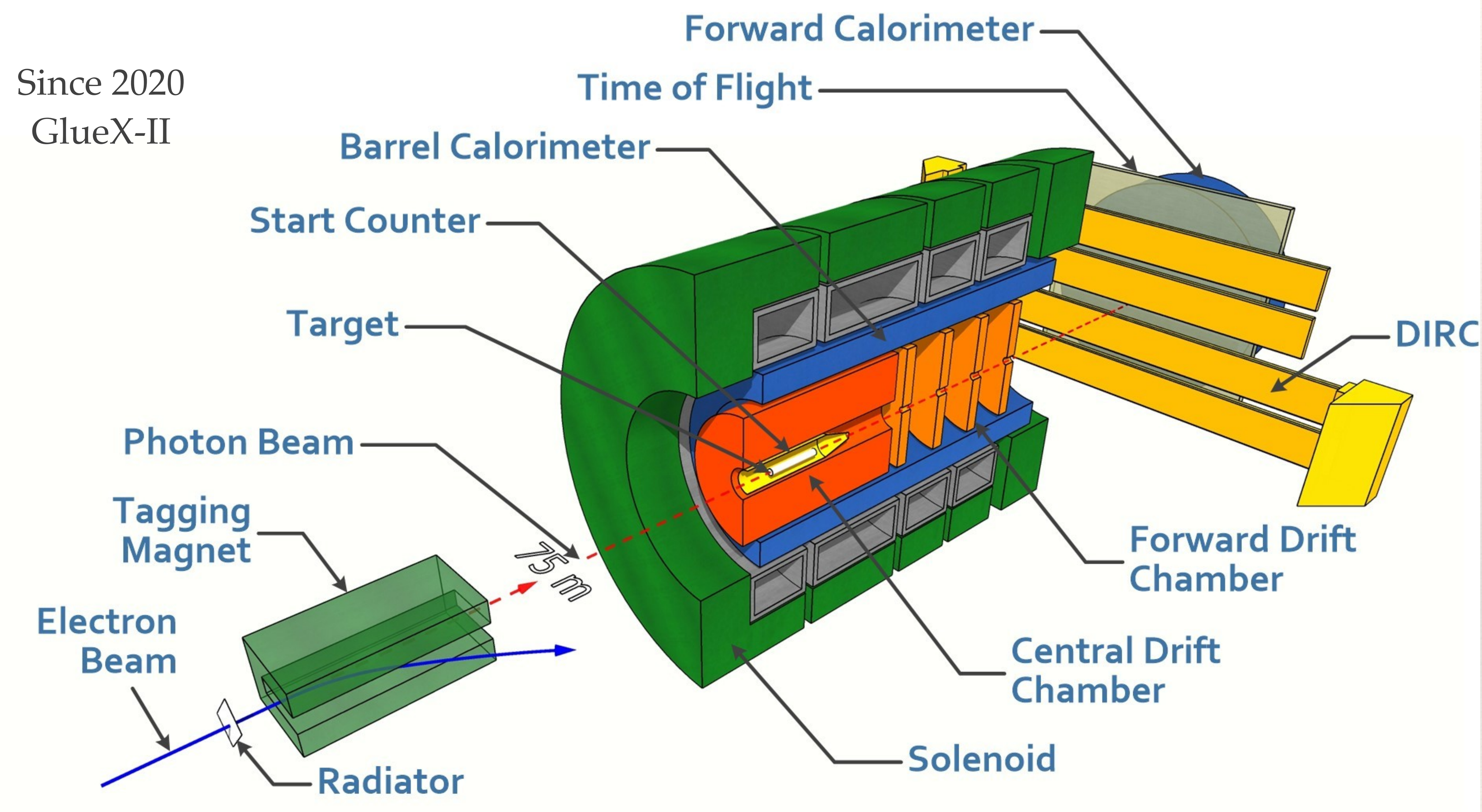
GlueX experiment



- Acceptance: $1^\circ - 120^\circ$
- Charged particles: $\sigma_p/p \approx 1\% - 3\,\%$
- Photons: $\sigma_E/E = 6\,\%/\sqrt{E} \oplus 2\,\%$

GlueX experiment

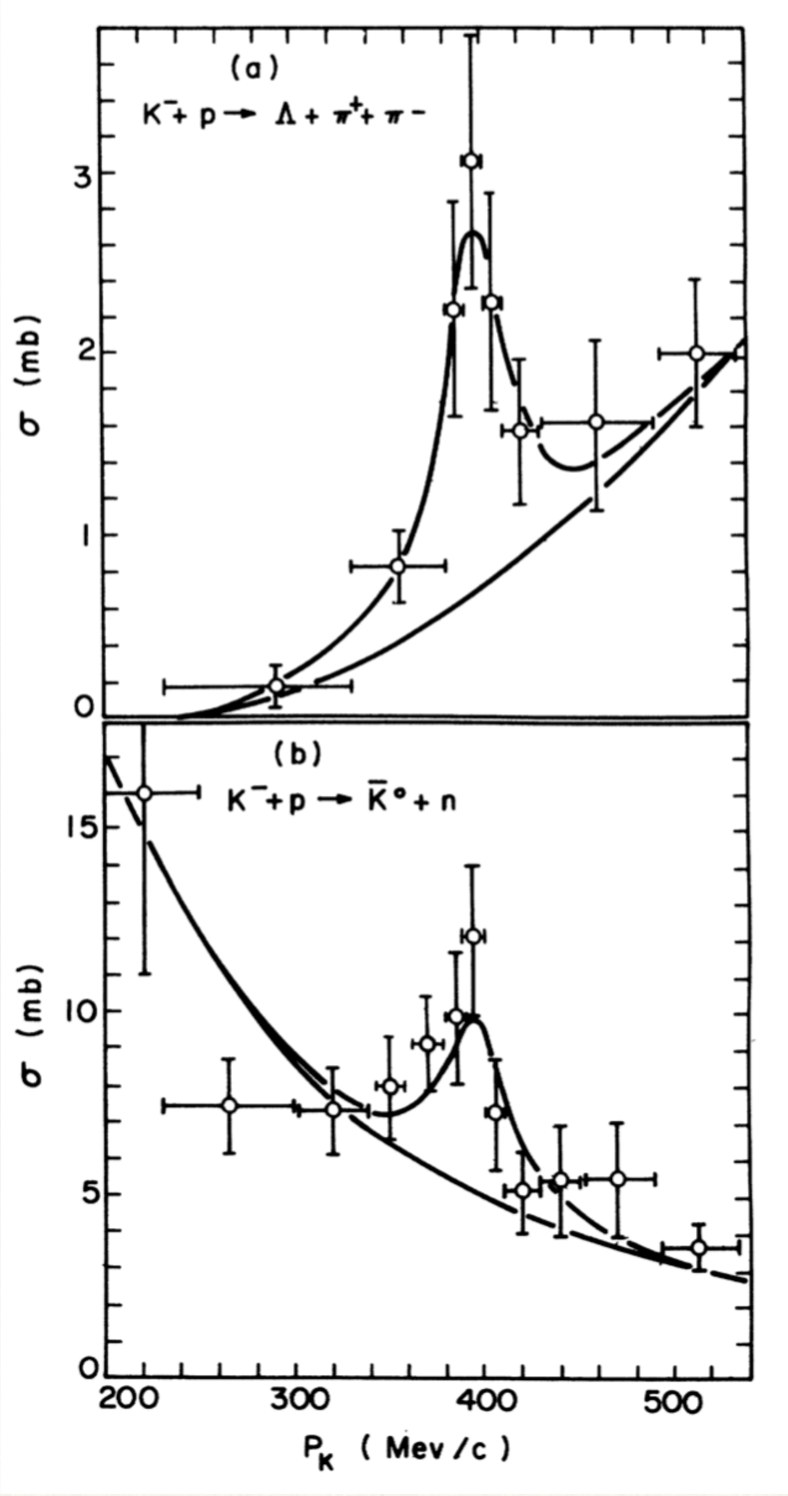
Since 2020
GlueX-II



- Detection of internally reflected Cherenkov light
- Improved π/K separation up to 3-4 GeV $\longrightarrow$ important for strangeness physics

$\Lambda(1520)$

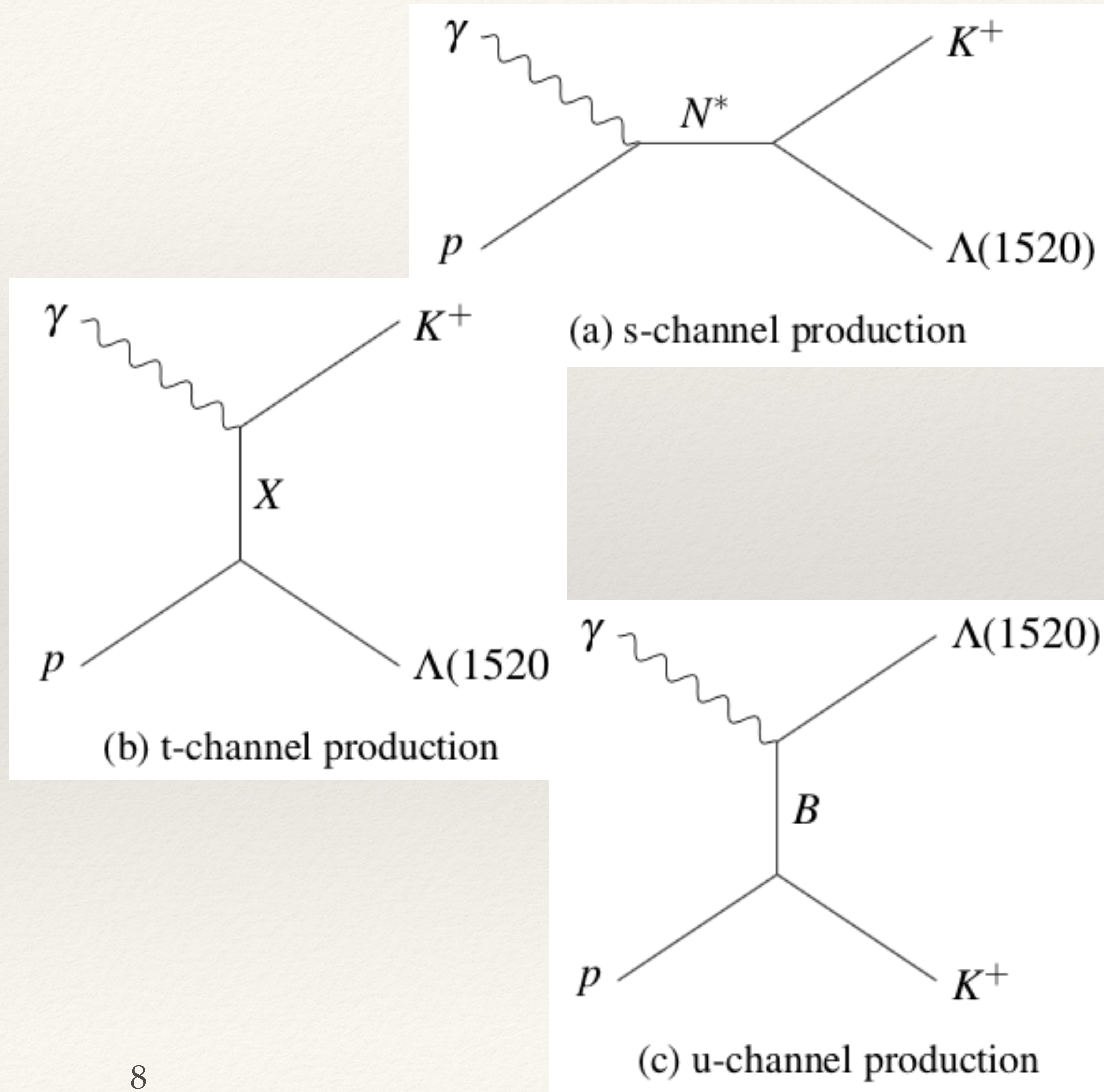
- Quark content *uds* with $J^P = 3/2^-$
- Discovered in 1962 (K^- beam)
- Previous photo production measurements at much lower or higher energies



M. Ferro-Luzzi, R.D. Tripp, M.B. Watson, *Phys.Rev.Lett.* 8 (1962) 28

$\Lambda(1520)$

- One of many initial analyses to understand detector and important physics processes, especially production processes
- Spin-density matrix elements parameterise the angular distribution of the decay and are directly related to the production process



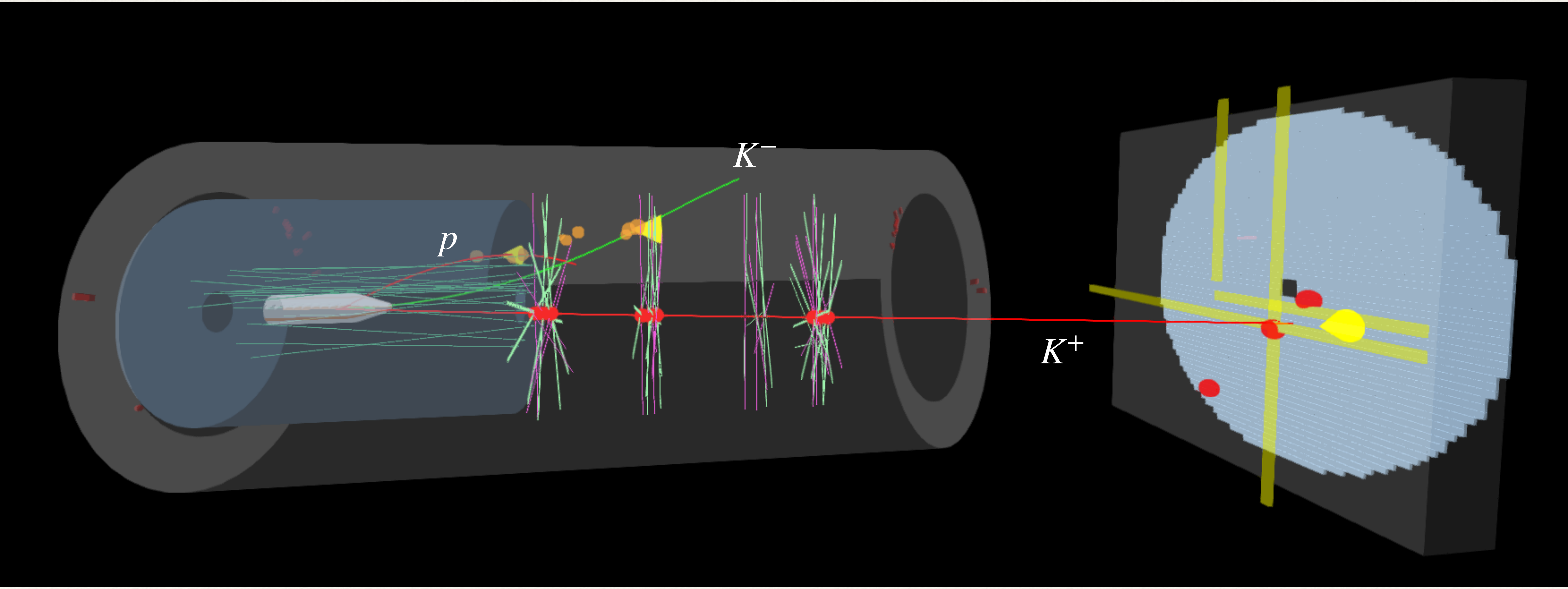
(a) s-channel production

(b) t-channel production

(c) u-channel production

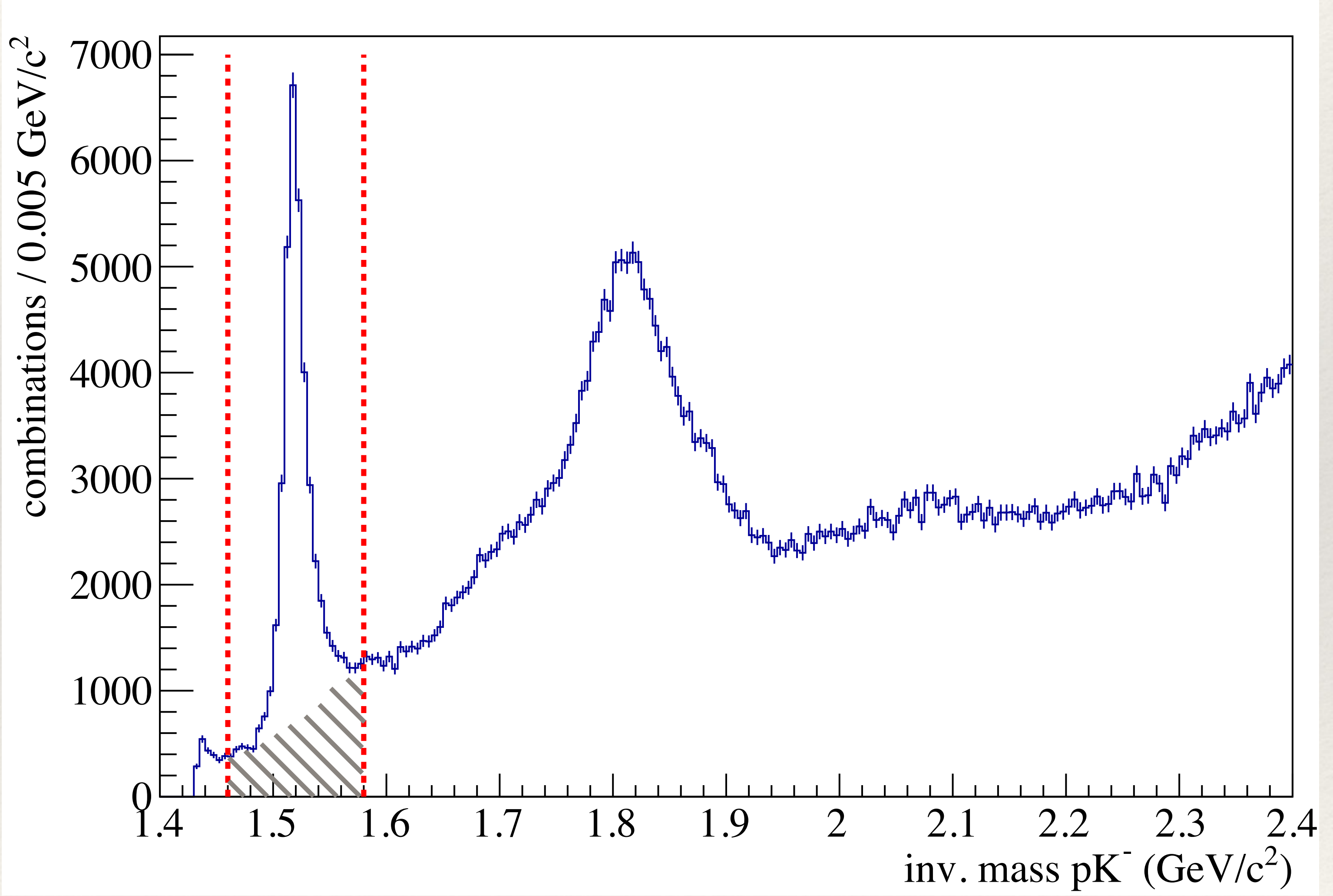
$\Lambda(1520)$

- Study $\vec{\gamma}p \to K^+\Lambda(1520) \to K^+K^-p$



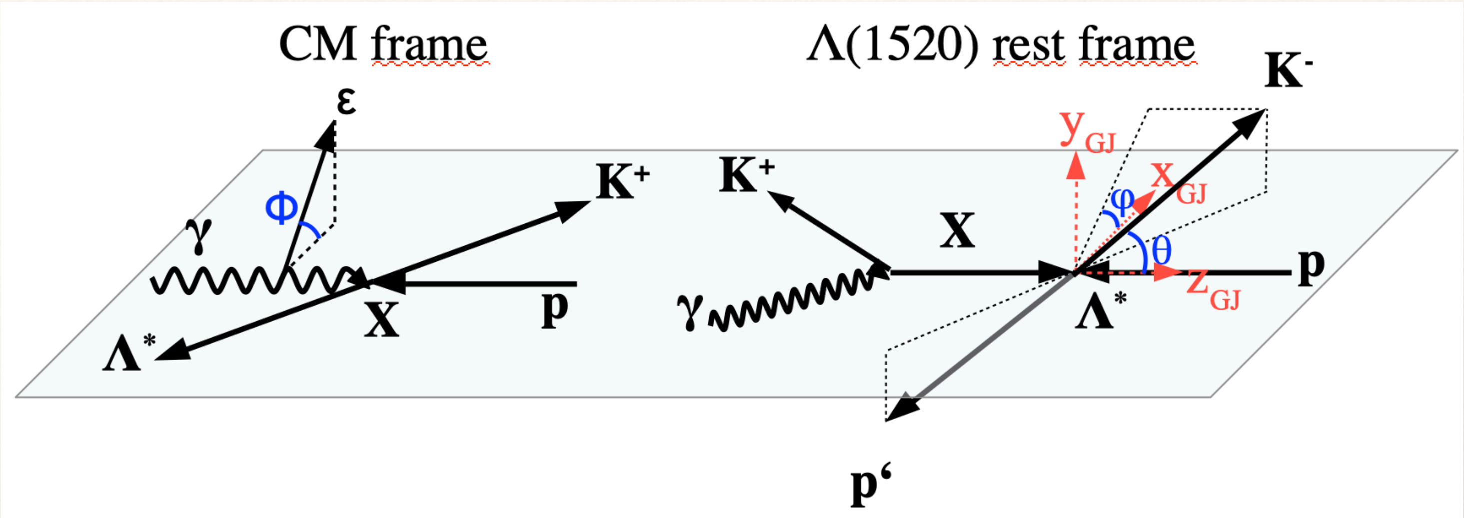
$\vec{\gamma} p \to K^+ \Lambda(1520) \to K^+ K^- p$ selection

- detector timing and dE/dx for PID
- use kinematic fitting to ensure four-momentum conservation
- remove remaining background under $\Lambda(1520)$ with sideband subtraction (sPlot)



Spin-Density Matrix Elements

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



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

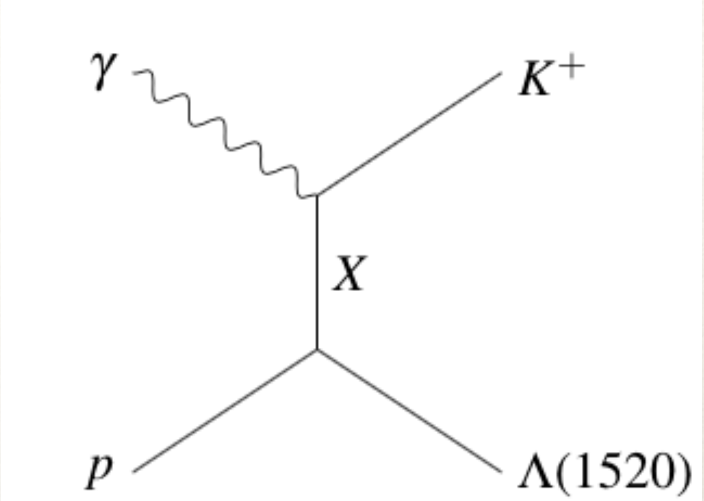
$$W_0 = \frac{1}{4\pi}\left[3\left(\frac{1}{2}-\rho^0_{11}\right)\sin^2(\theta)+\rho^0_{11}\left(1+3\cos^2(\theta)\right)-2\sqrt{3}\left(\mathrm{Re}(\rho^0_{31})\cos(\varphi)\sin(2\theta)+\mathrm{Re}(\rho^0_{3-1})\cos(2\varphi)\sin^2(\theta)\right)\right]$$

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

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

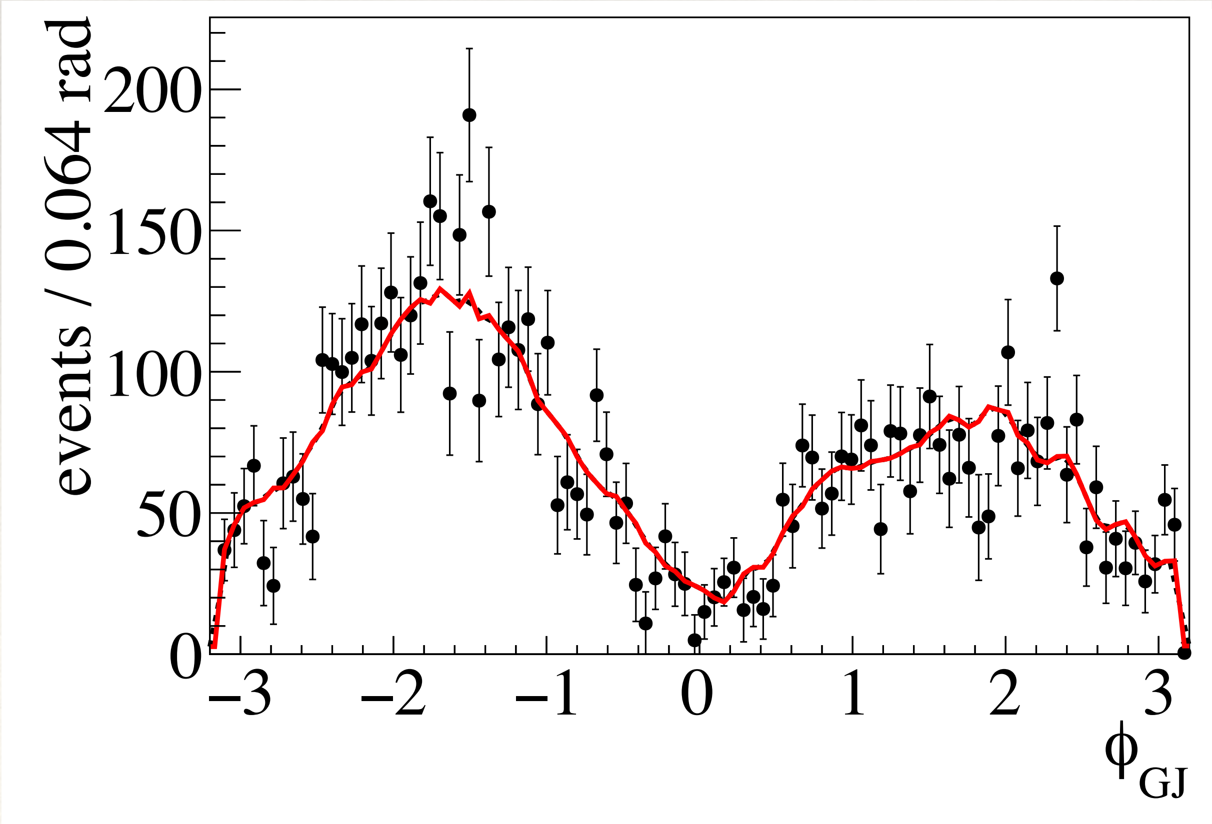
$$W = W_0 - P_\gamma\cos(2\Phi)W_1 - P_\gamma\sin(2\Phi)W_2$$

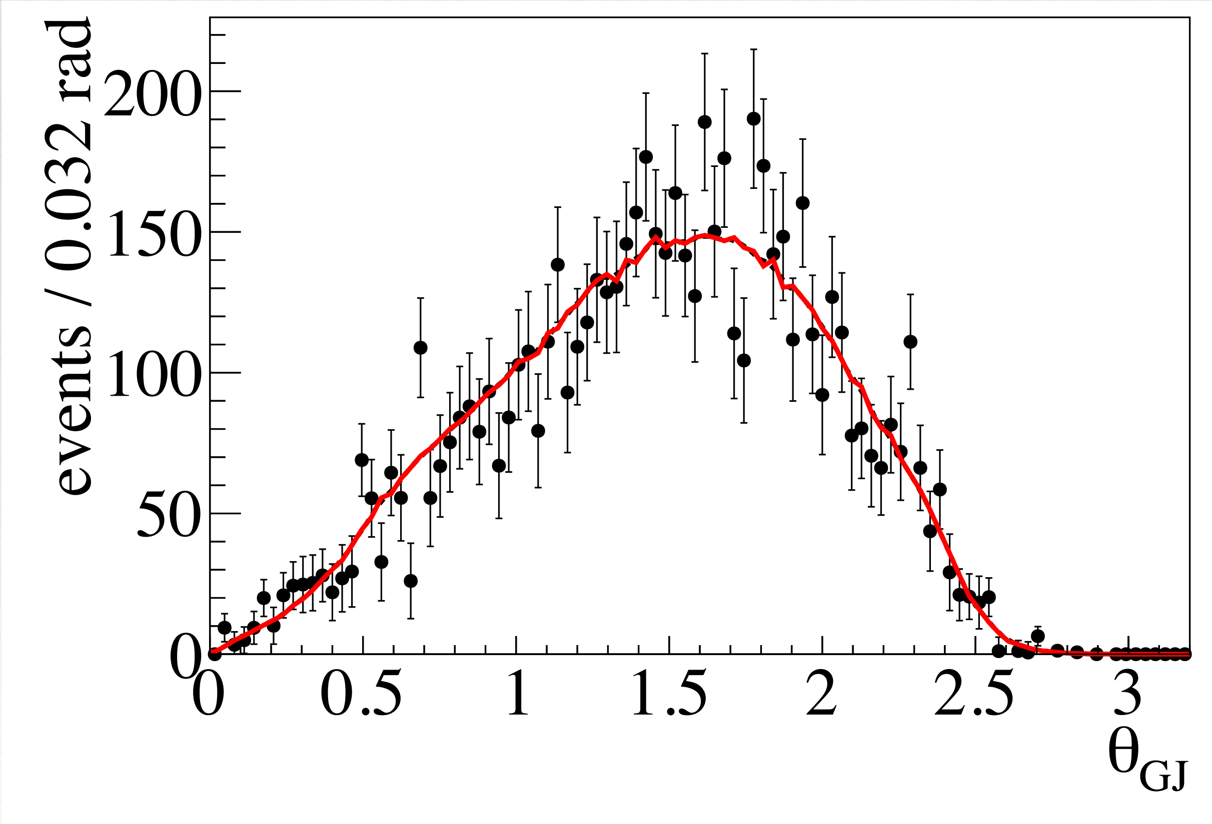
Spin-Density Matrix Elements



- use Markov Chain Monte Carlo for parameter estimation to extract SDMEs
  - sample likelihood distribution, excellent for multidimensional problems
- do this in 8 bins of 4-momentum transfer $t = (p_\gamma - p_{K^+})^2$

$-t = 0.3 - 0.5\ \mathrm{GeV}^2/c^2$

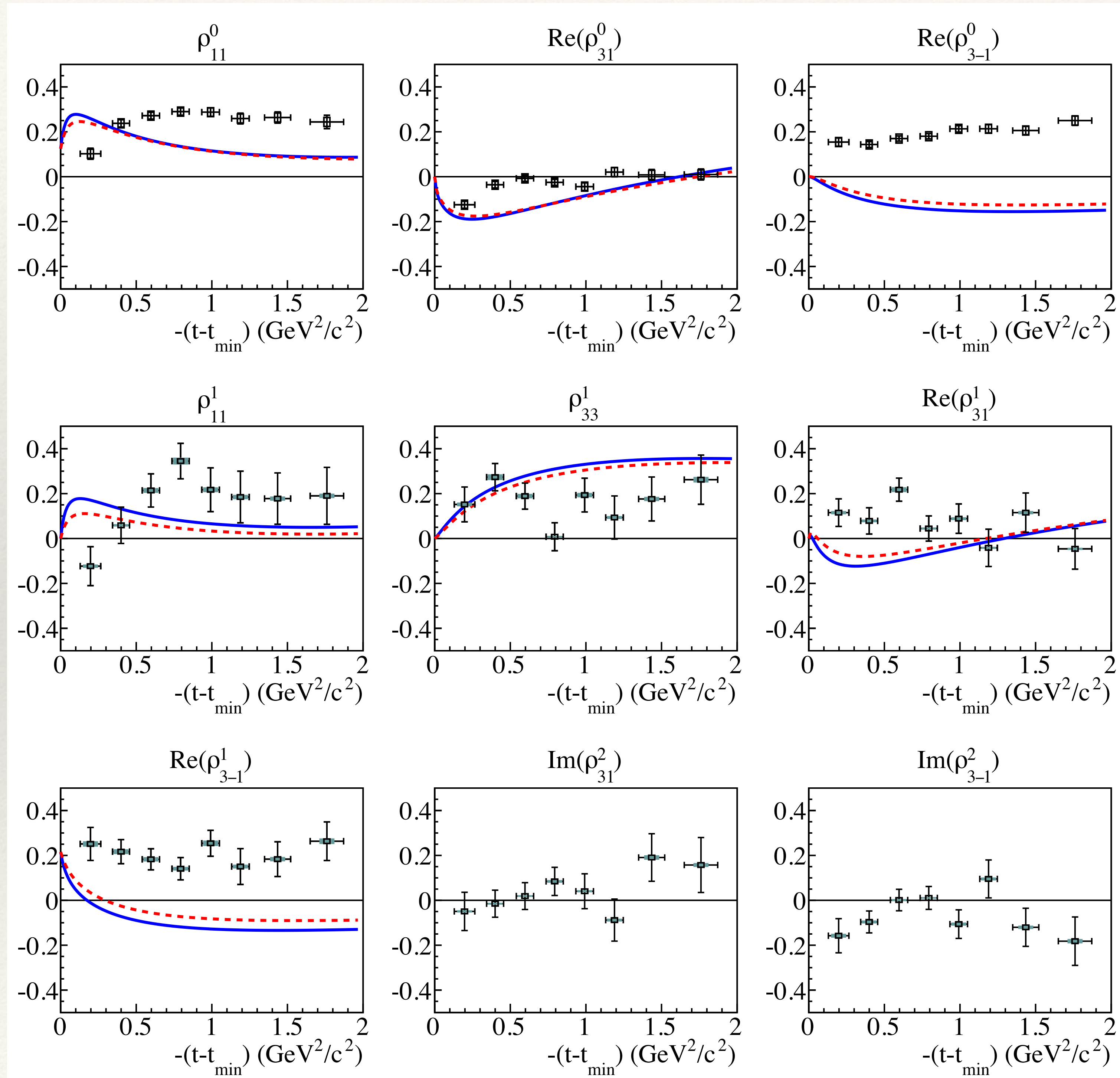




Spin-Density Matrix Elements

GlueX

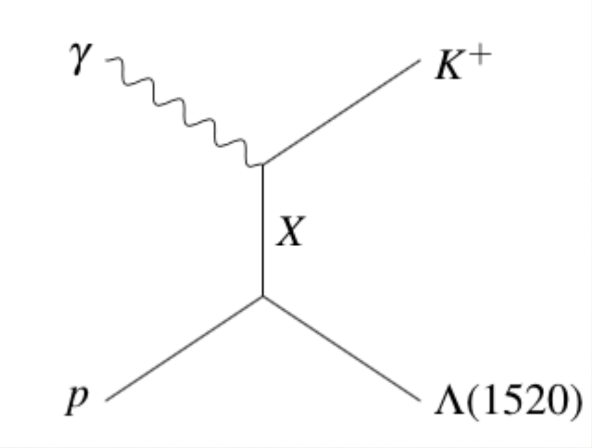
Preliminary



- red and blue show model predictions in Reggeized framework (priv. comm. based on [1])
- these measurements constrain models in the future

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

SDME Interpretation



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. $K(492)$, $K_1(1270)$

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

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

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

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

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

$$\mathrm{Im}\rho_{31}^2 = \frac{2}{N}\mathrm{Im}\left(N_2U_1^* + N_{-1}U_0^* - U_2N_1^* - U_{-1}N_0^*\right)$$

$$\mathrm{Im}\rho_{3-1}^2 = \frac{2}{N}\mathrm{Im}\left(U_2N_0^* + N_{-1}U_0^* - N_2U_0^* - U_{-1}N_1^*\right)$$

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

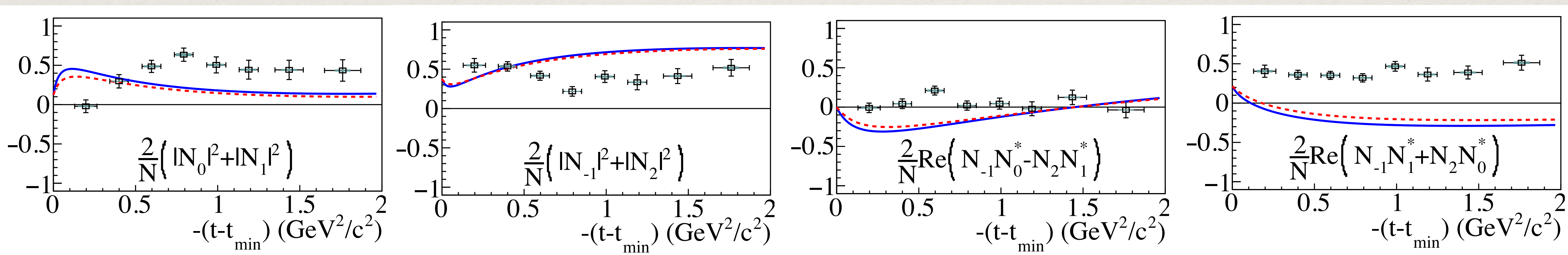
work by V. Mathieu (JPAC)

SDME Interpretation

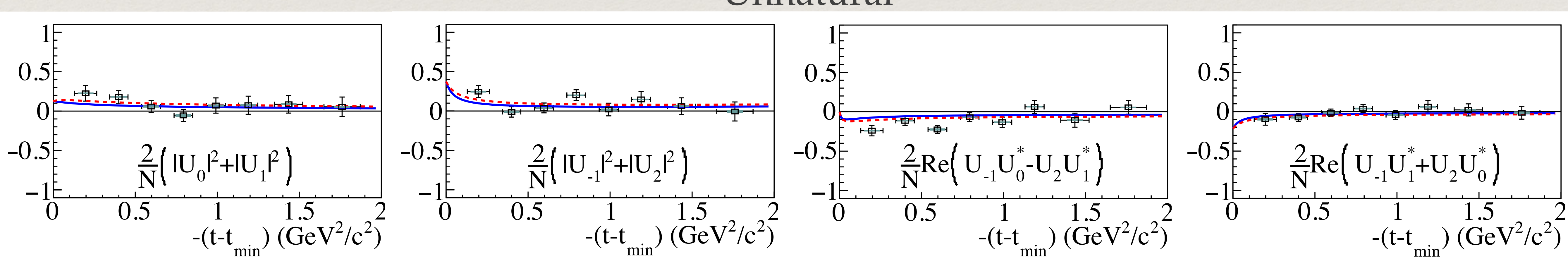
- red and blue show combinations previous model [1]
- natural amplitudes dominate

Preliminary

Natural



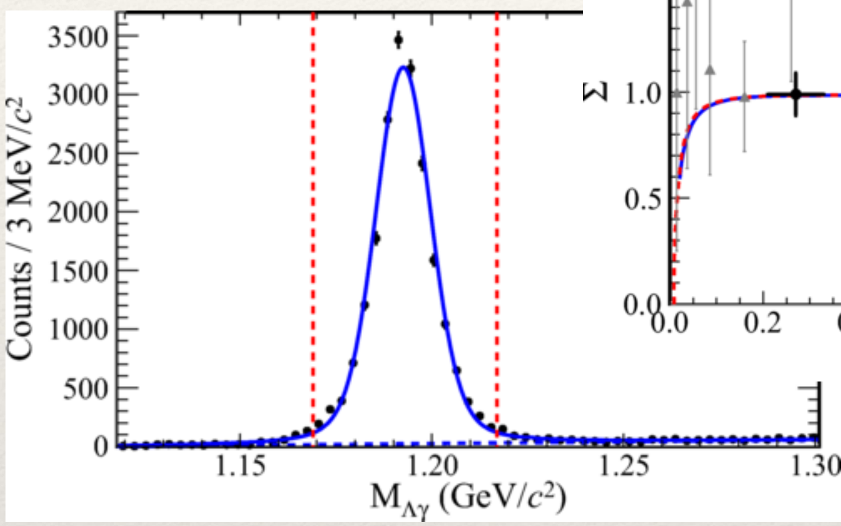
Unnatural

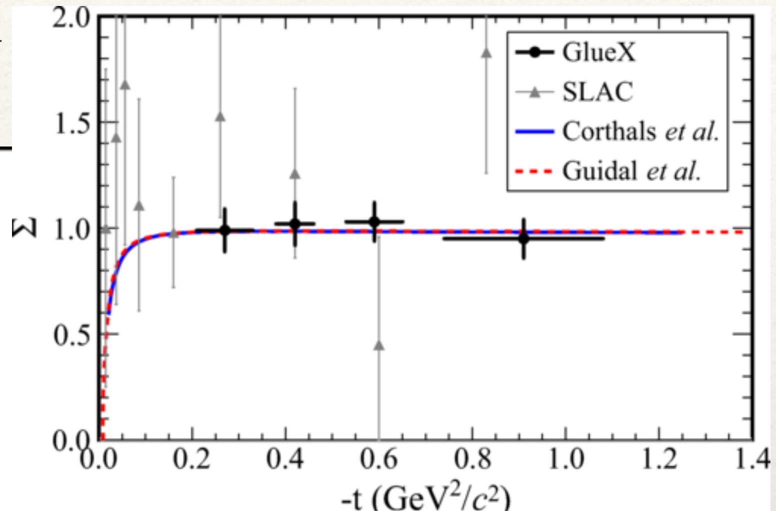


[1] *Byung-Geel Yu and Kook-Jin Kong, Phys. Rev. C* ***96****, 025208 (2017)*

More strangeness related physics in GlueX

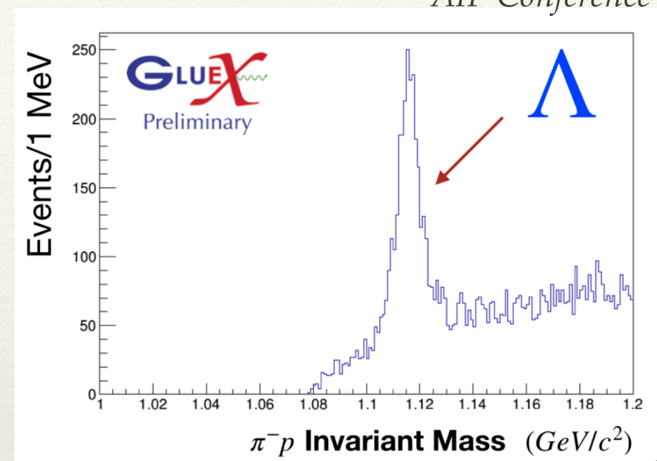
Σ^0 beam asymmetry

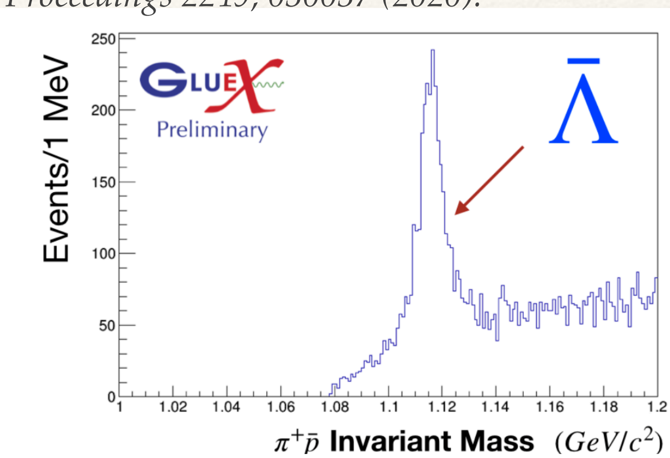


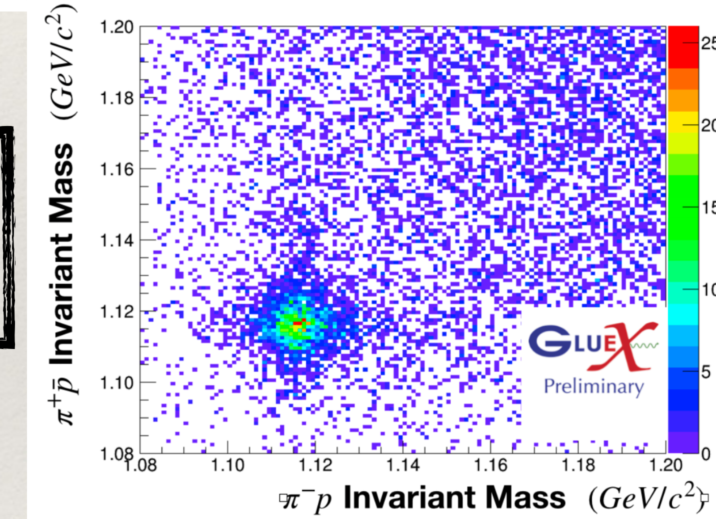


S. Adhikari et al. (GlueX Collaboration)
Phys. Rev. C **101**, 065206 (2020).

Hao Li and Reinhard Schumacher [GlueX Collaboration], AIP Conference Proceedings 2249, 030037 (2020).



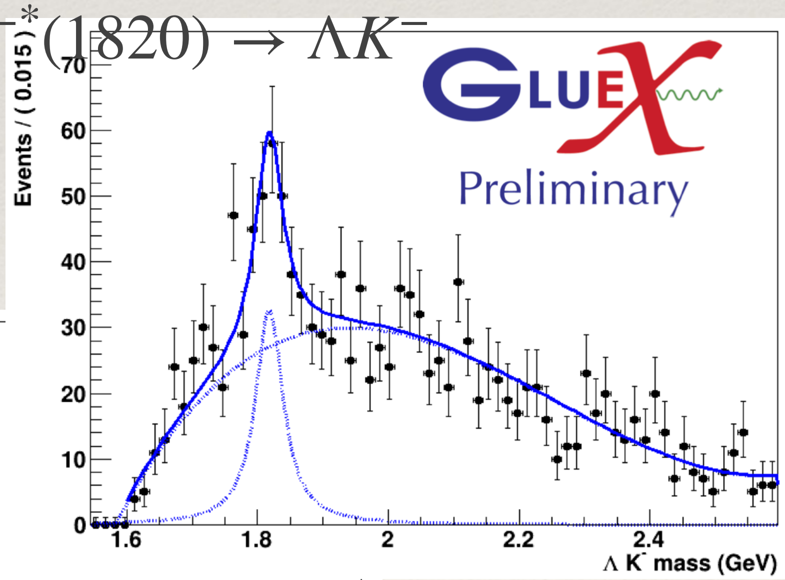


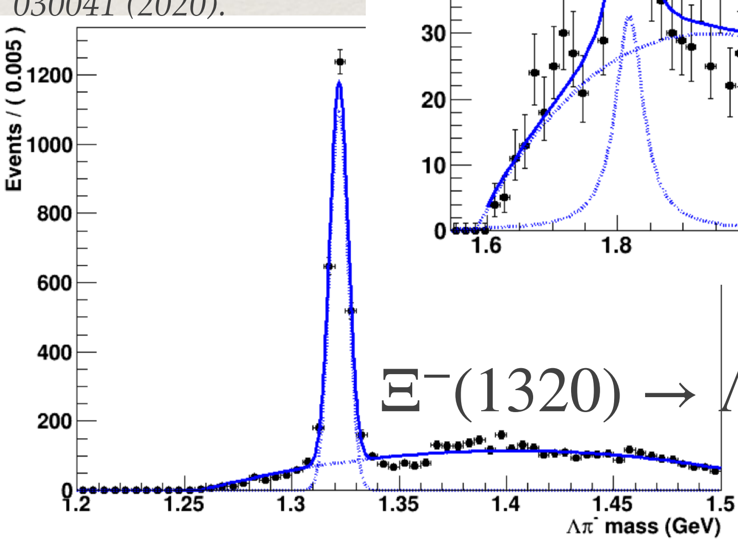


also ongoing $\Lambda(1405)$ analysis

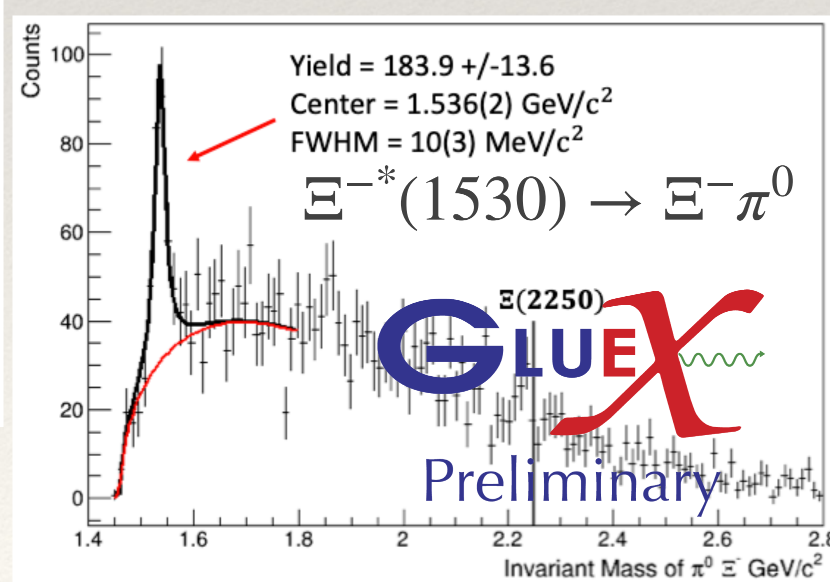
$\Xi^{-*}(1820) \to \Lambda K^-$

Ashley Ernst [GlueX Collaboration], AIP Conference Proceedings 2249, 030041 (2020).





$\Xi^-(1320) \to \Lambda\pi^-$



$\Xi^{-*}(1530) \to \Xi^-\pi^0$

GlueX-II with DIRC started data taking in 2020: much more to come!

Acknowledgments:

gluex.org/thanks

Summary

- First measurement of Λ(1520) SDMEs at GlueX energies and first measurement of polarised Λ(1520) SDMEs in general give new insights into involved production mechanisms
- Paper under collaboration review
- Expect more strangeness related physics from GlueX over the coming months and years