Strange Hadron Spectroscopy with the KLong Facility at Jefferson Lab

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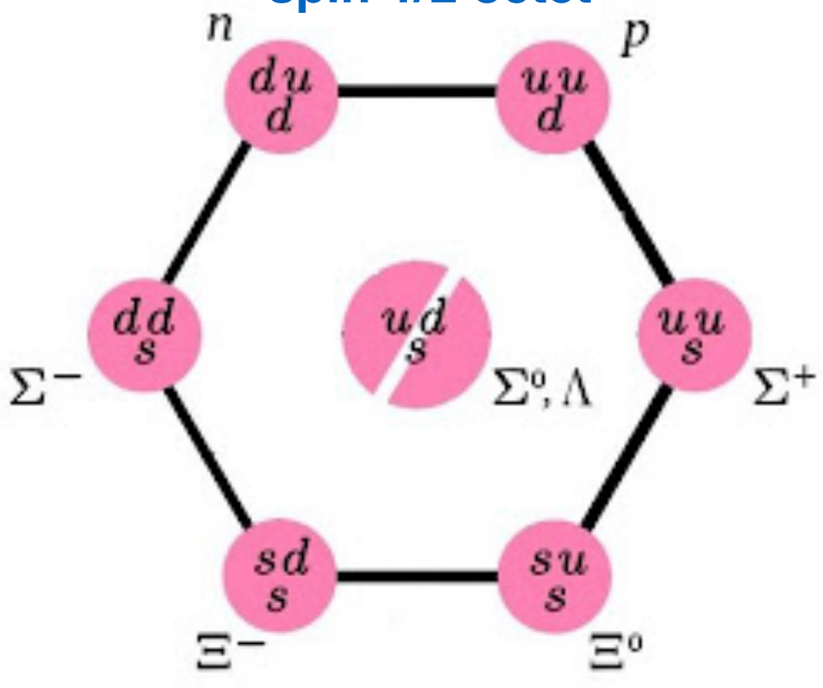
(for the KLF Collaboration)

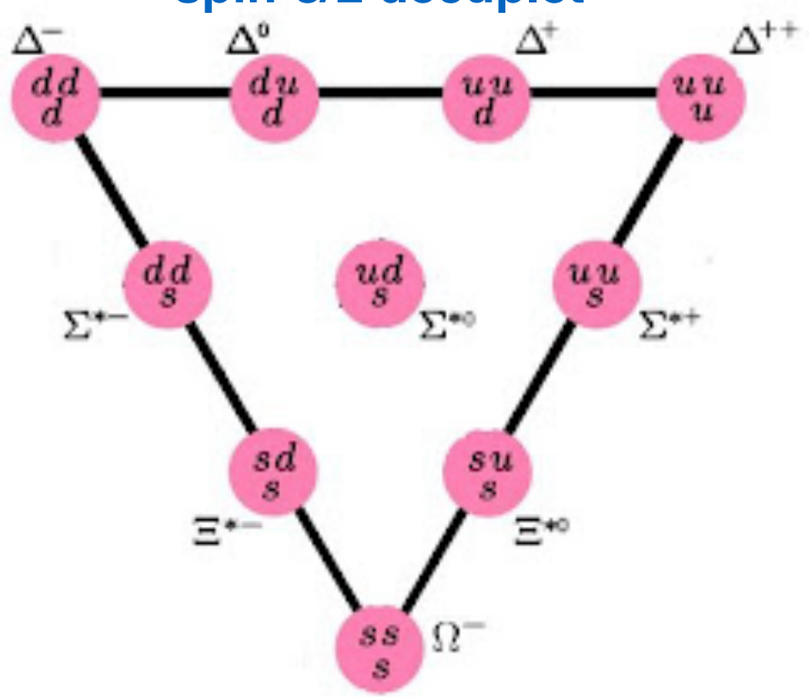
19th International Conference on Hadron Spectroscopy and Structure (HADRON 2021)
July 30, 2021

Strange Quarks and Hadron Spectroscopy

spin-1/2 octet



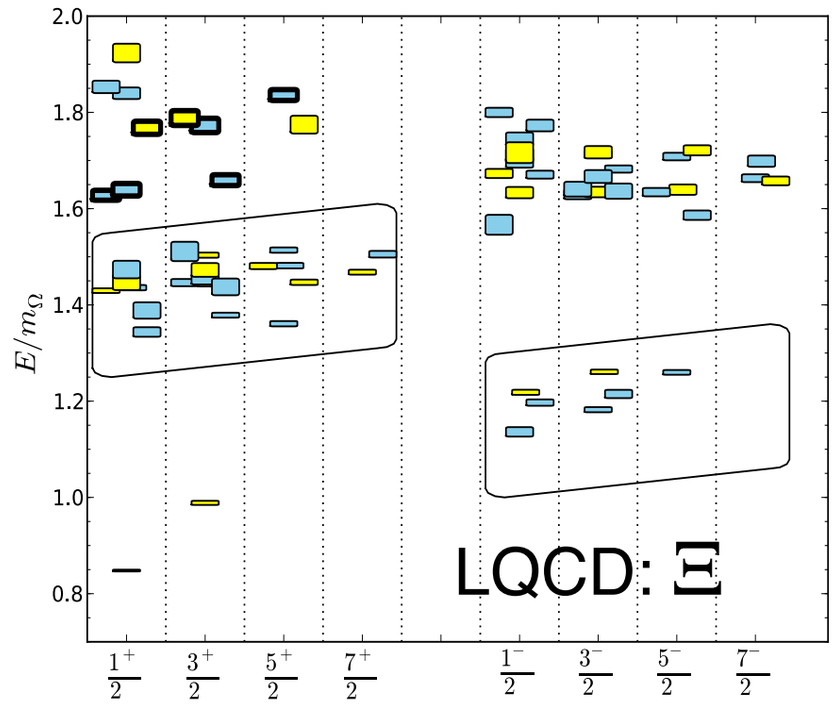
spin-3/2 decuplet



	PDG 2004	PDG 2020	LQCD
N*	15	21	62
Δ	10	12	38
Λ	14	14	71
Σ	10	9	66
Ξ	6	6	73
Ω	2	2	36

- Rich spectrum of uds baryons expected
- Study of properties with # of strange-quarks gives insight into baryon interactions, d.o.f.
- Important input to high-density/temperature hadron physics
- Many more states expected than observed!

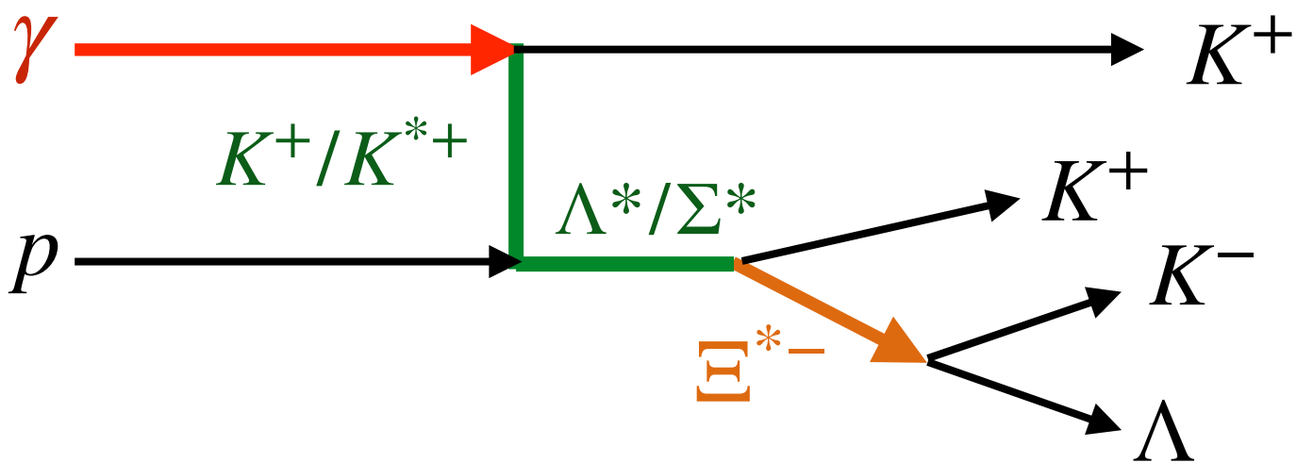
[PDG 3* & 4* states]



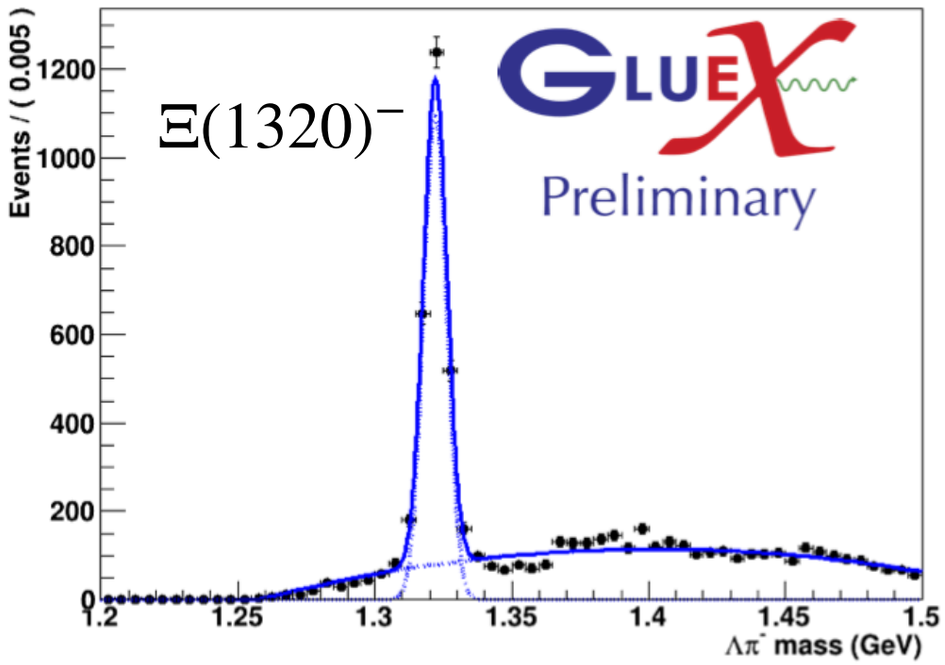
hadspec: PRD 87, 054506 (2013)

How can we produce hyperons?

Photoproduction



$\gamma p \to K^+K^+(\Lambda\pi^-)$



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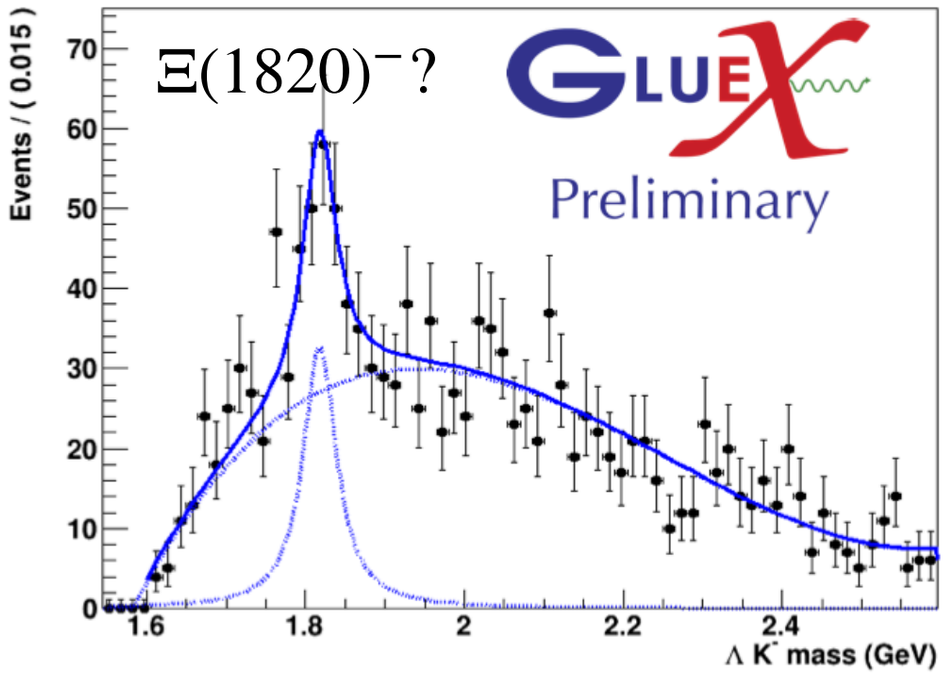

GlueX: MENU2019, AIP Conf.Proc. 2249, 030041 (2020)

How can we produce hyperons?

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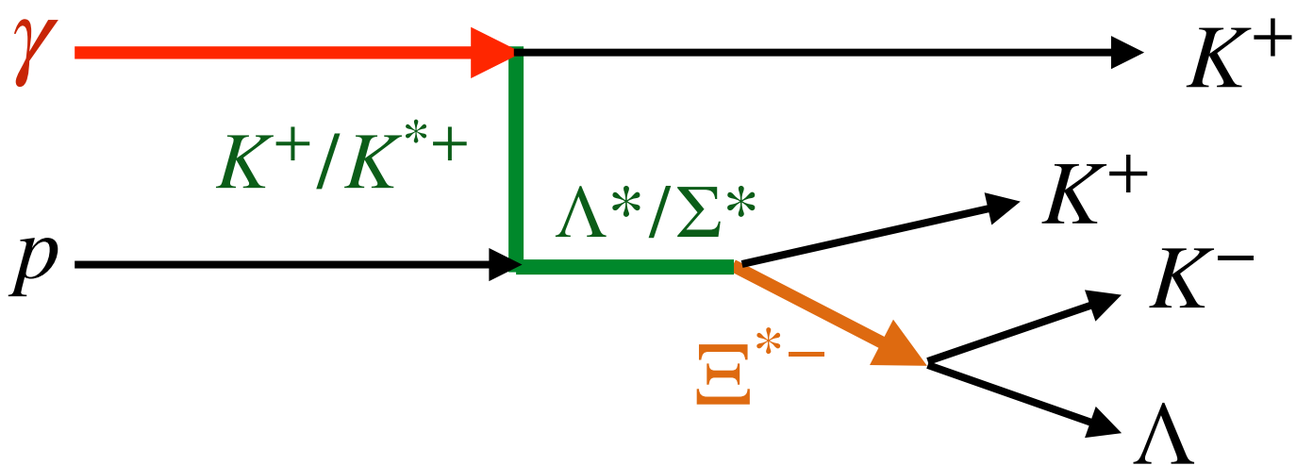
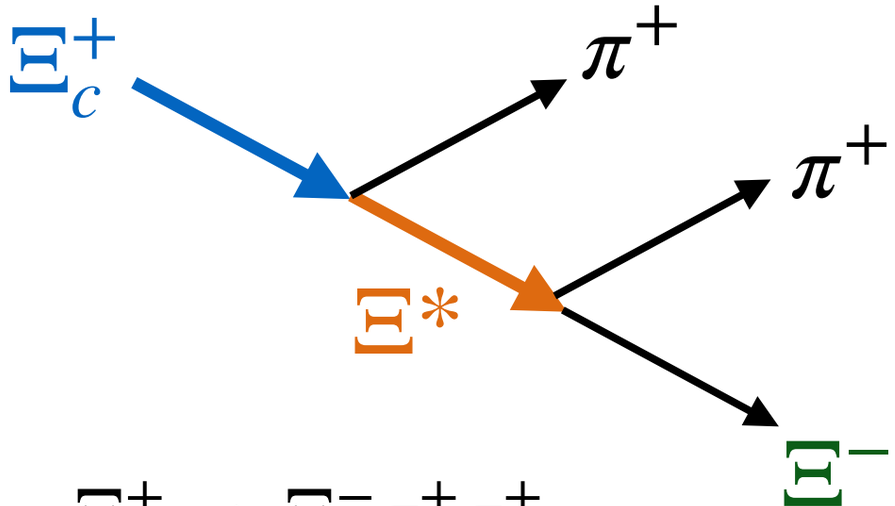
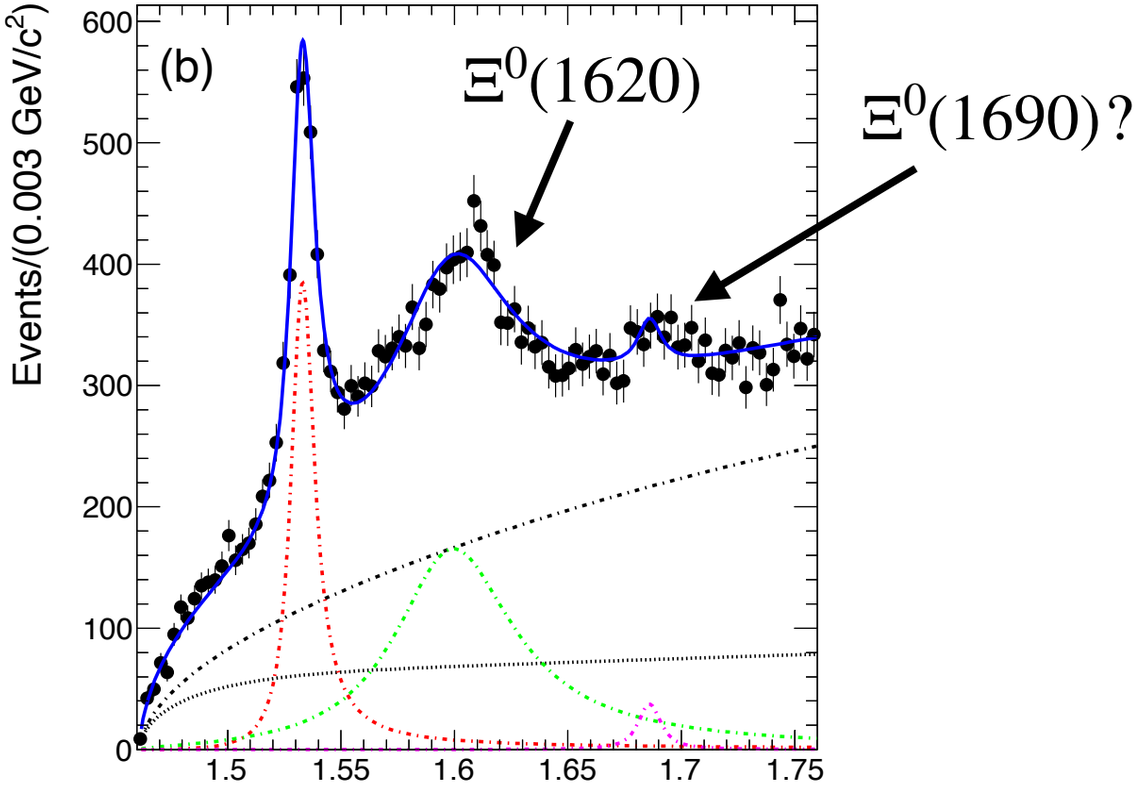


Decay





Belle: PRL 122, 072501 (2019)

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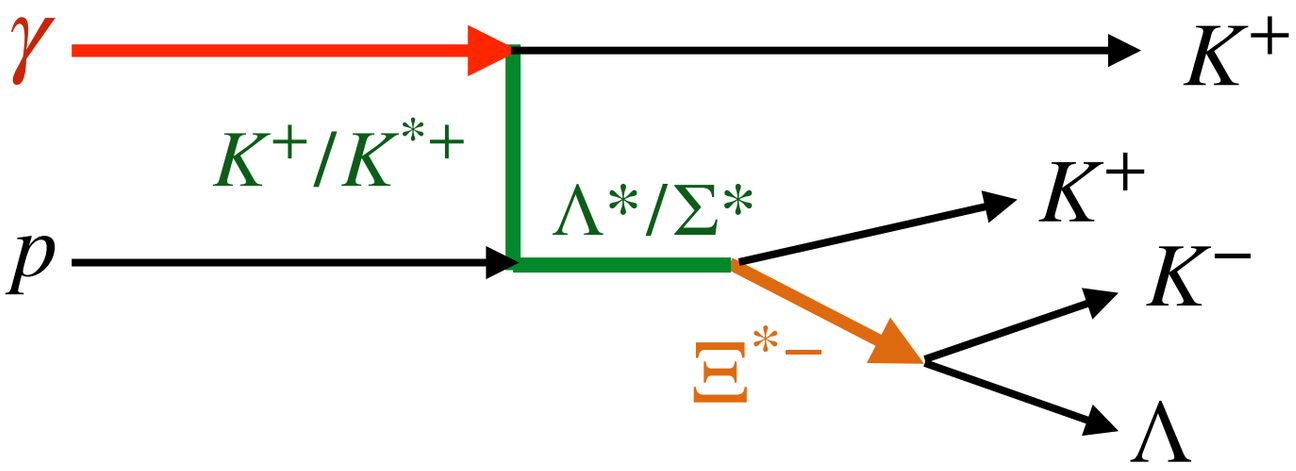
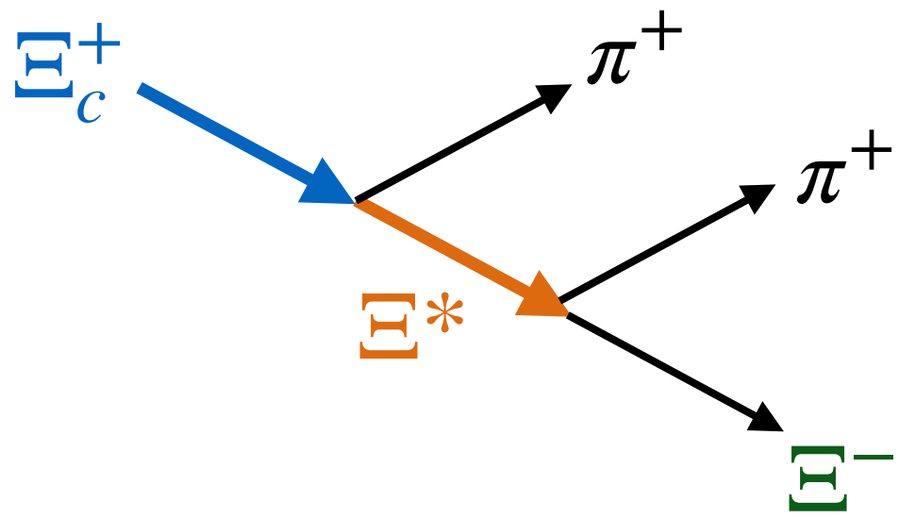
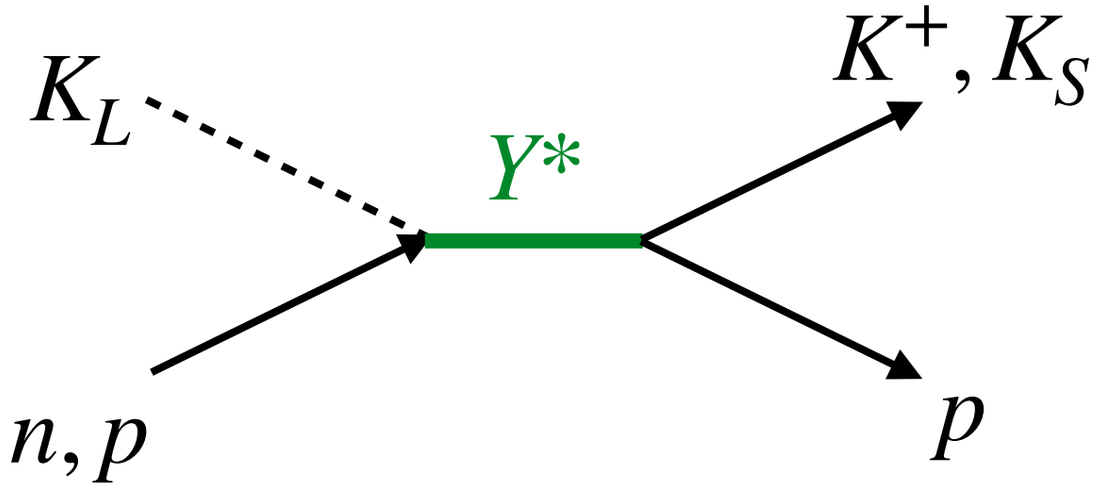


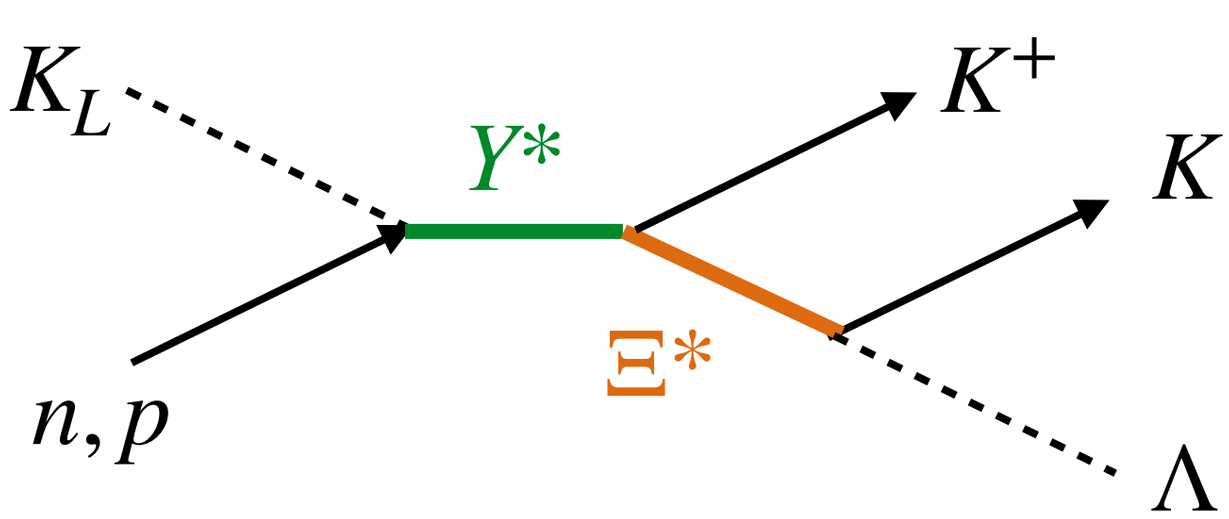
Decay



Direct production



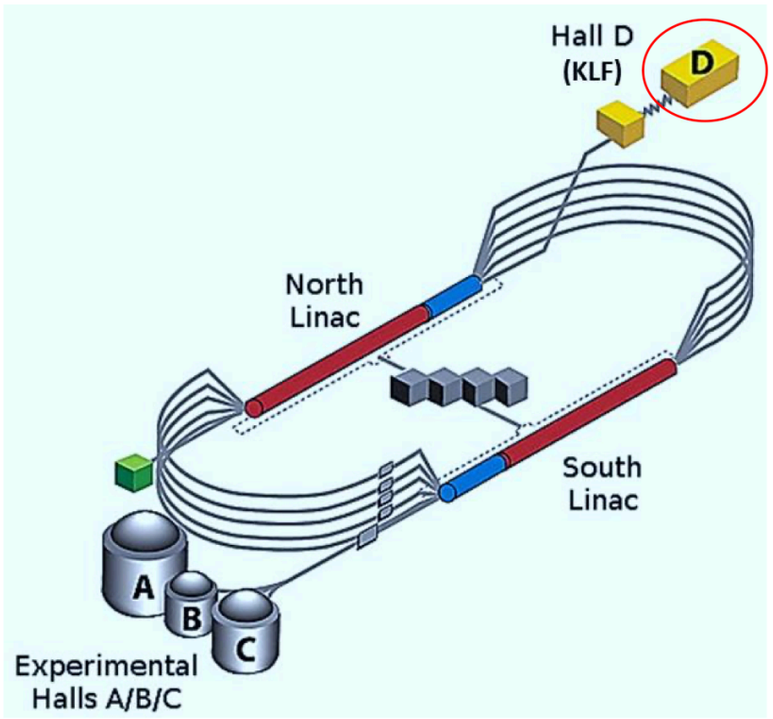
Associated production

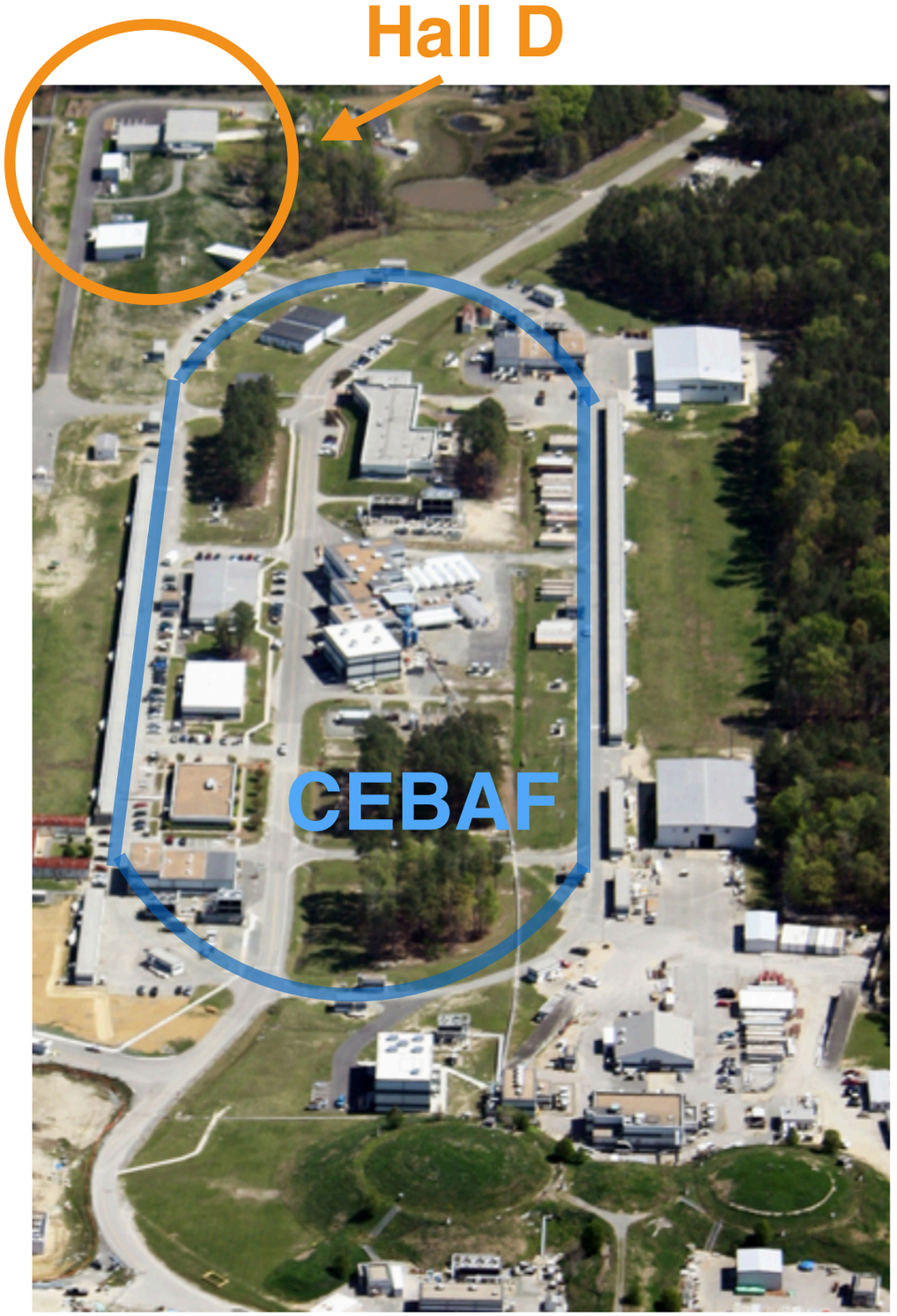


- Kaon beams allow for high-statistics production of strange quark hadrons
- K_L beam provides unique data for spectroscopy

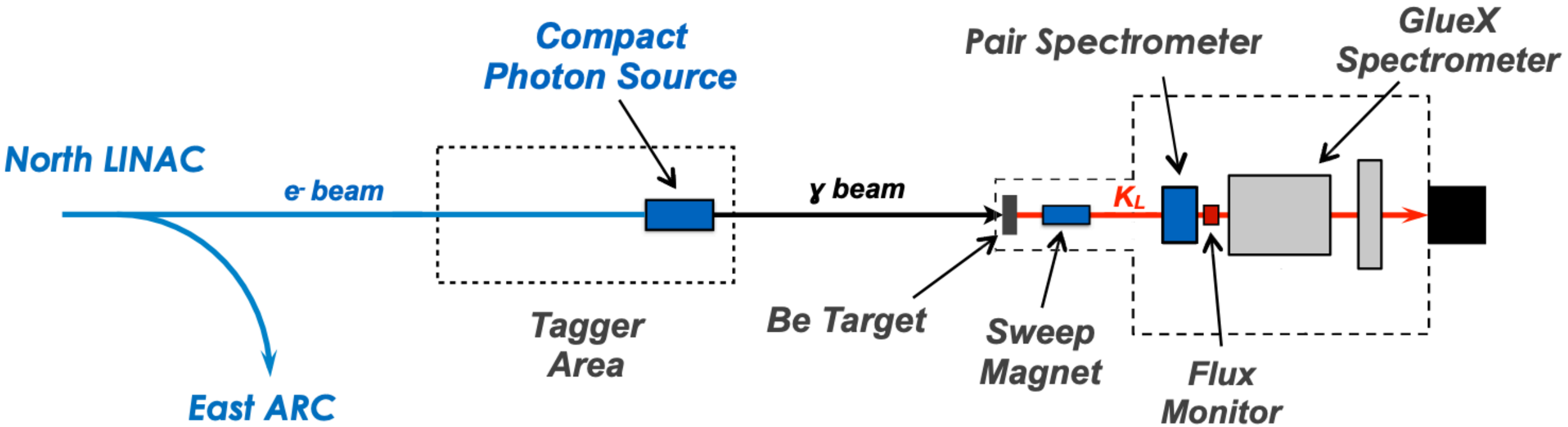
KLF: Hall D @ Jefferson Lab

- The K_L beam Facility is located in Hall D at Jefferson Lab
  - Approved for 200 days of running [proposal: arXiv:2008.08215]
  - Tertiary beam: electrons → photons → K_L
  - Uses GlueX large acceptance solenoidal spectrometer



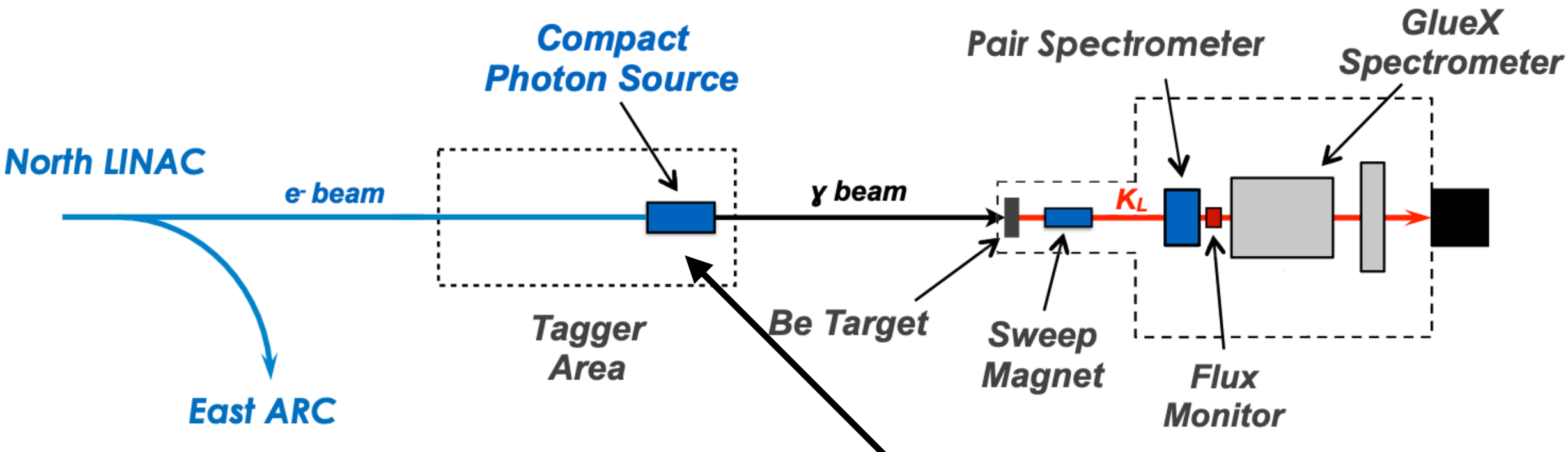


KLF Beamline

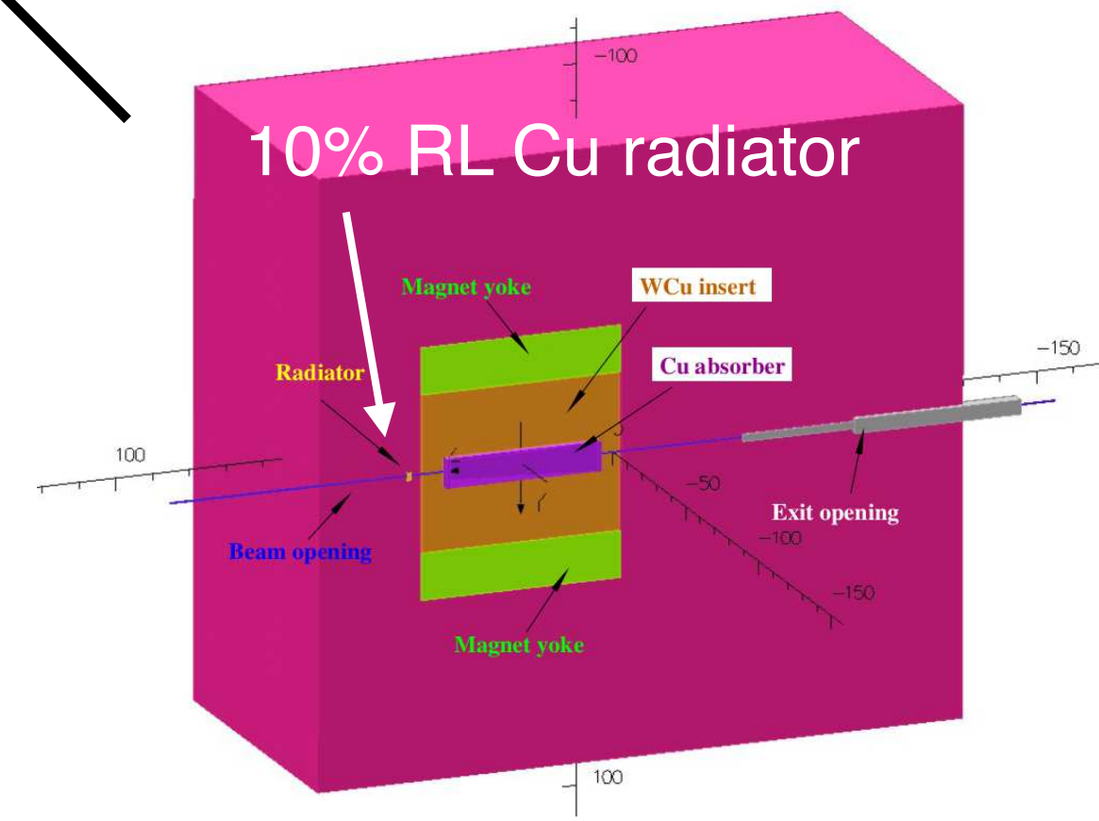


- 12 GeV e^- beam @ 5 μA with
  64 ns bunch spacing from CEBAF

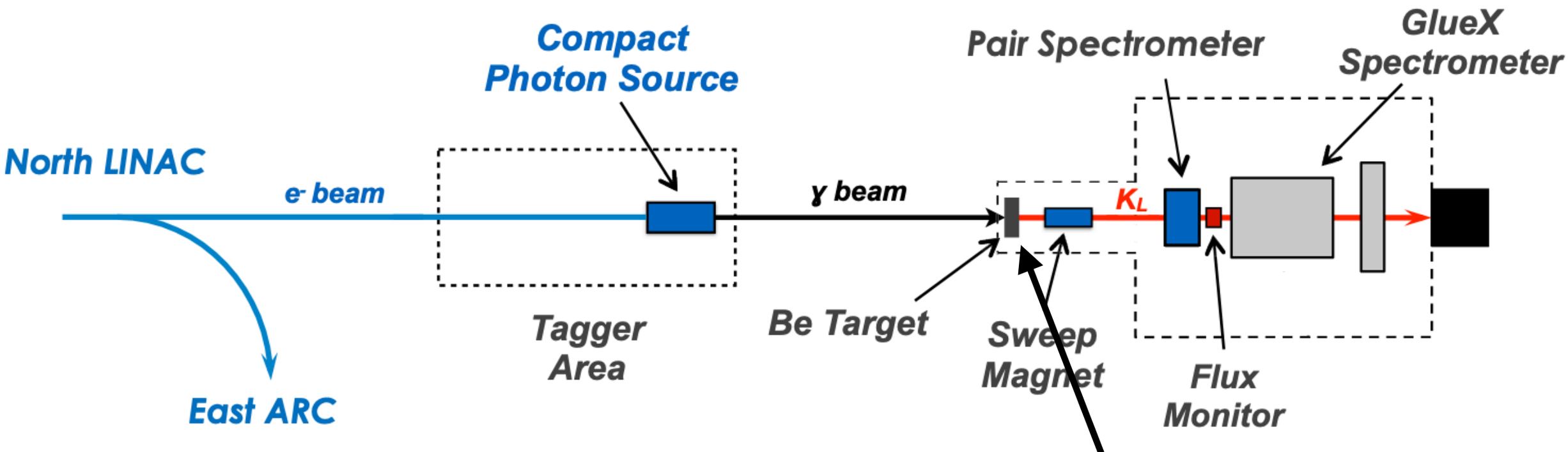
KLF Beamline



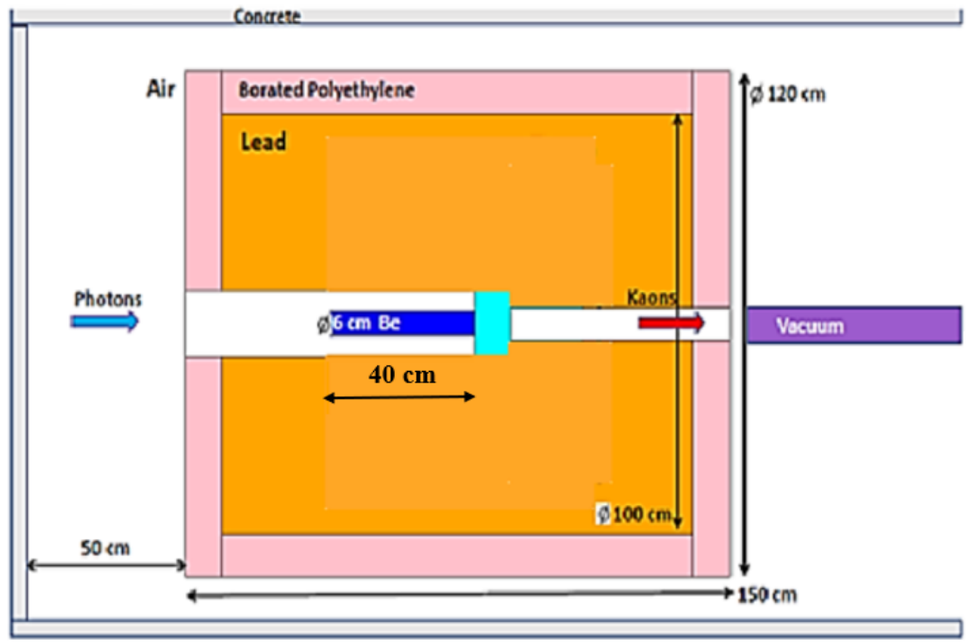
- 12 GeV e⁻ beam @ 5 μA with 64 ns bunch spacing from CEBAF
- Compact Photon Source (CPS) provides intense, untagged ɣ beam



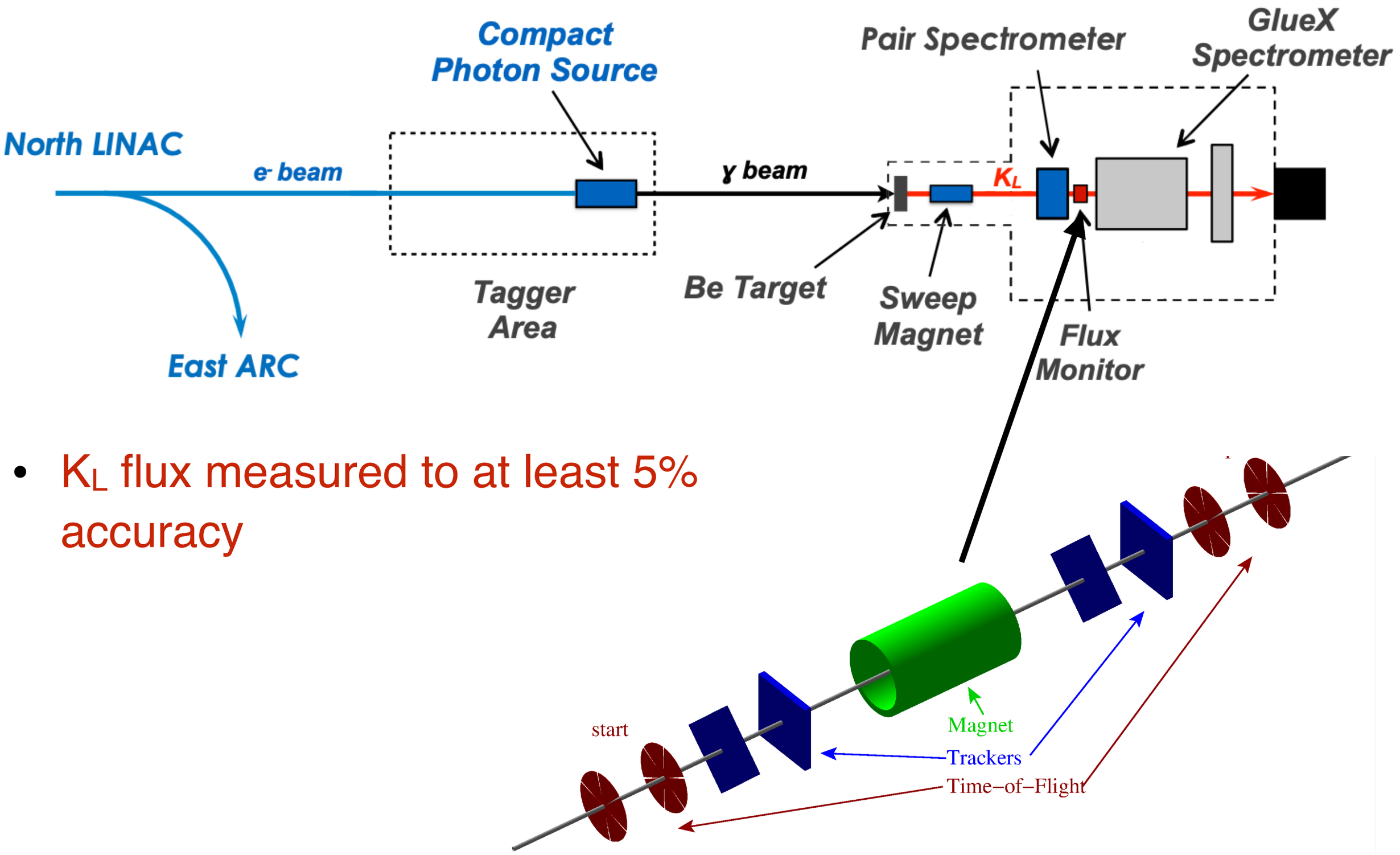
KLF Beamline



- 12 GeV e⁻ beam @ 5 μA with 64 ns bunch spacing from CEBAF
- Compact Photon Source (CPS) provides intense, untagged γ beam
- Beryllium K_L production target yields ~10^4 K_L / second

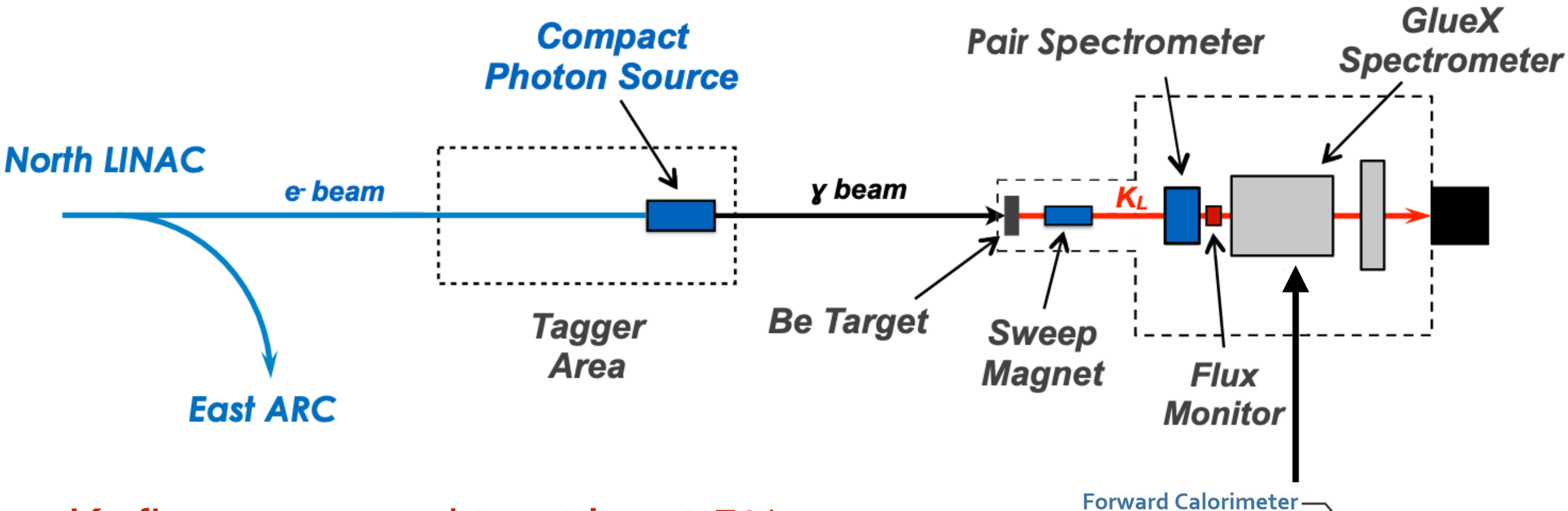


KLF Beamline

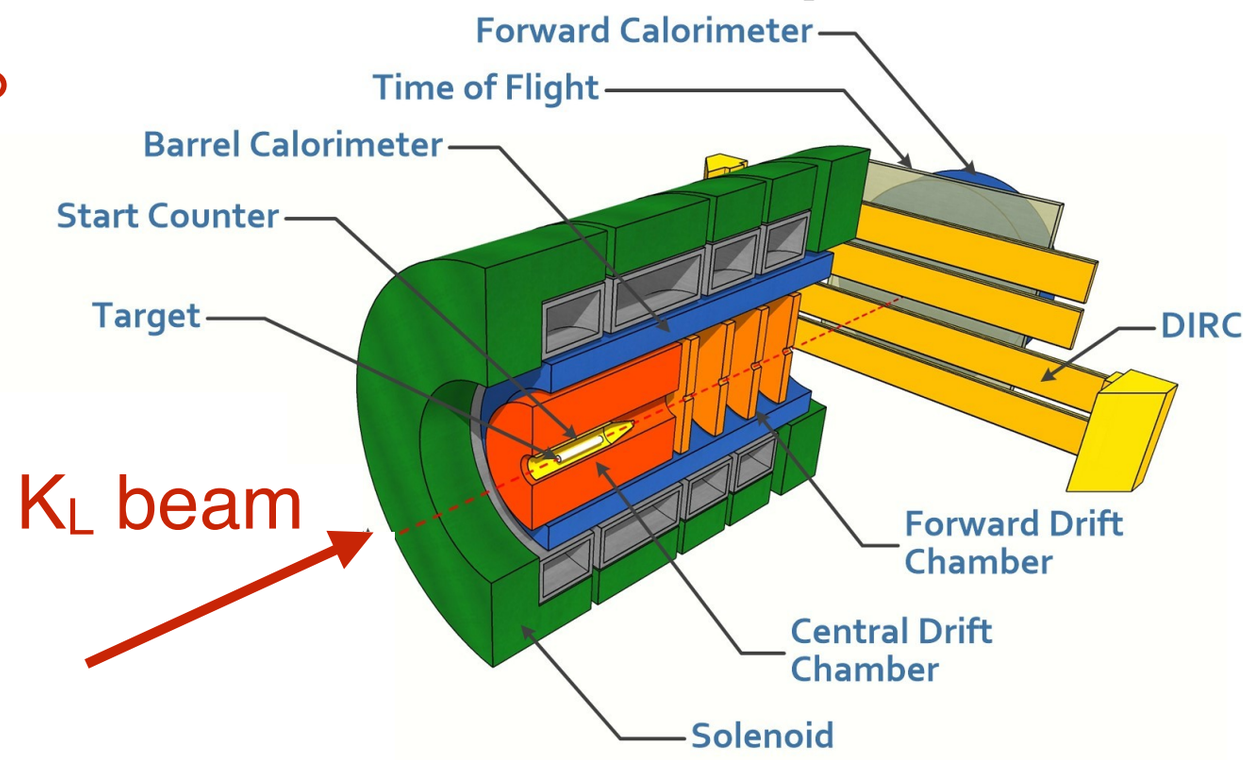


- K_L flux measured to at least 5% accuracy

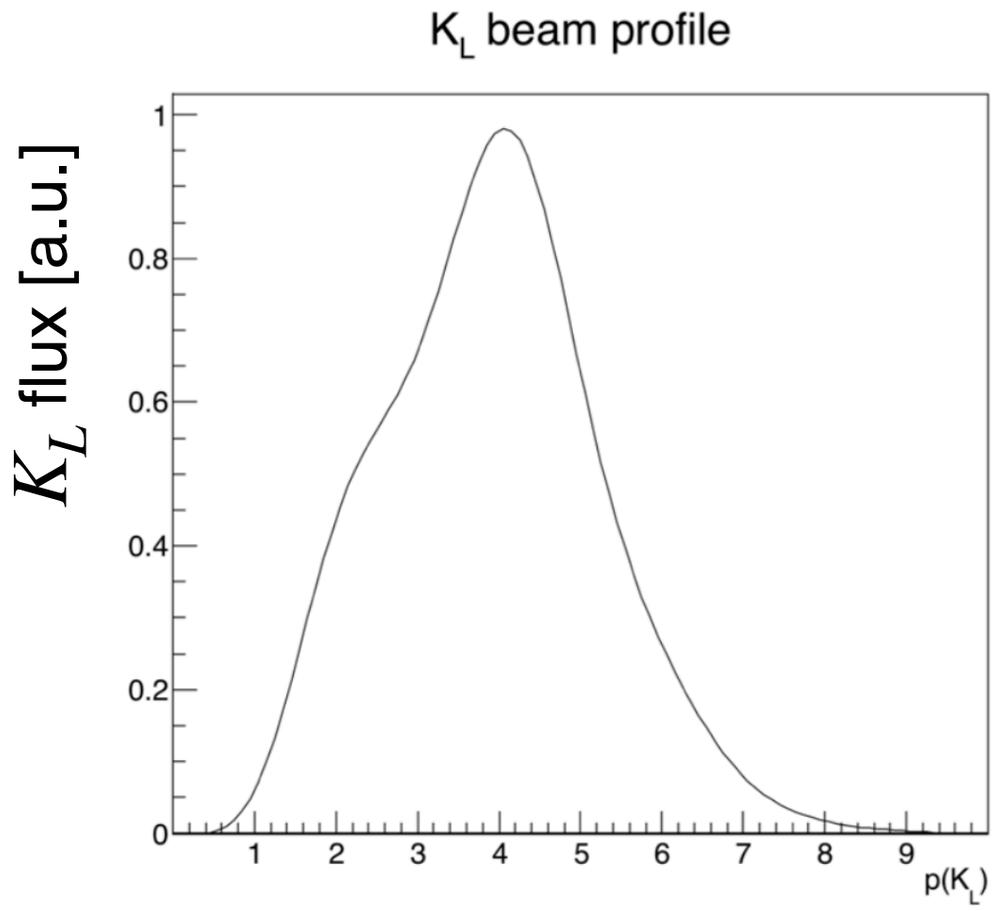
KLF Beamline

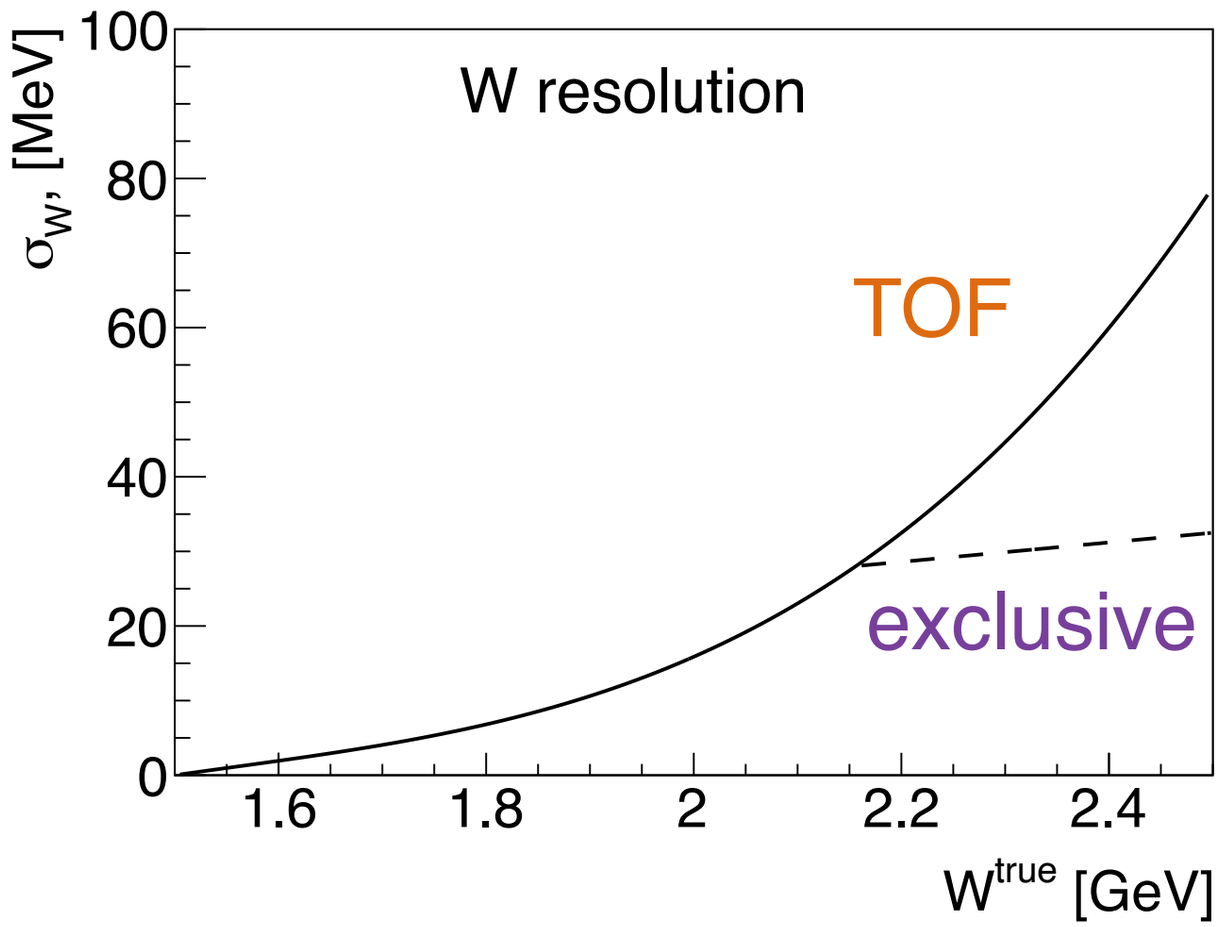


- K_L flux measured to at least 5% accuracy
- GlueX spectrometer provides near hermetic coverage for charged and neutral particles
- New wider LH_2 and LD_2 targets



K_L Beam Properties





- Flux of ~10^4 K_L/s with E ≈ 1–9 GeV
  - ~10^3 times previous SLAC K_L beam measurements
- Beam momentum (or c.m.e. W) measured through TOF or exclusive final state reconstruction

Example: Σ* Production

- Focus on 2-body final states
  - Proton target: only Σ*
    - $K_L p \to K_S p$
    - $K_L p \to \pi^+ \Lambda$
    - $K_L p \to K^+ \Xi^0$
    - $K_L p \to \pi^0 \Sigma^+$
    - $K_L p \to \eta \Sigma^+$
    - $K_L p \to \omega \Sigma^+$
  - Neutron target: Λ* and Σ*

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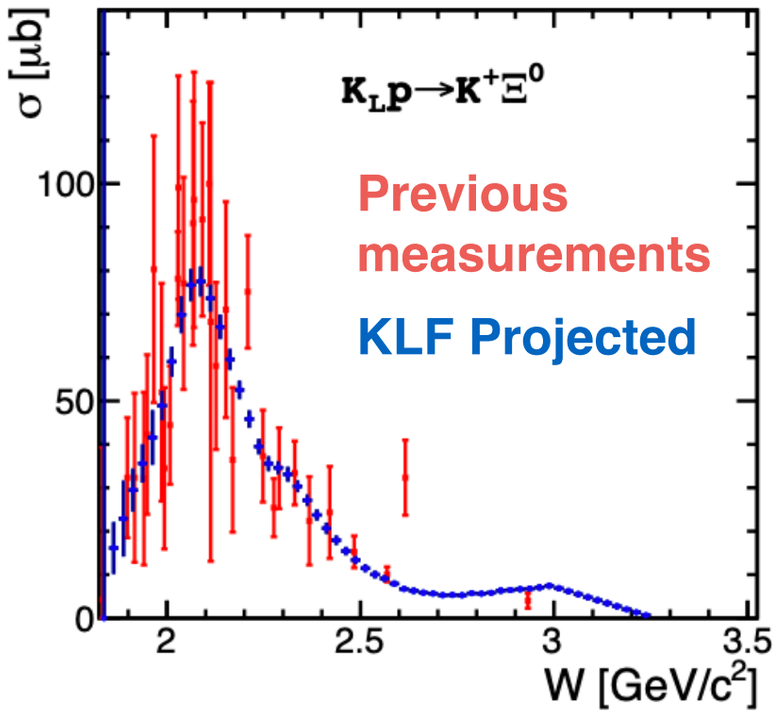
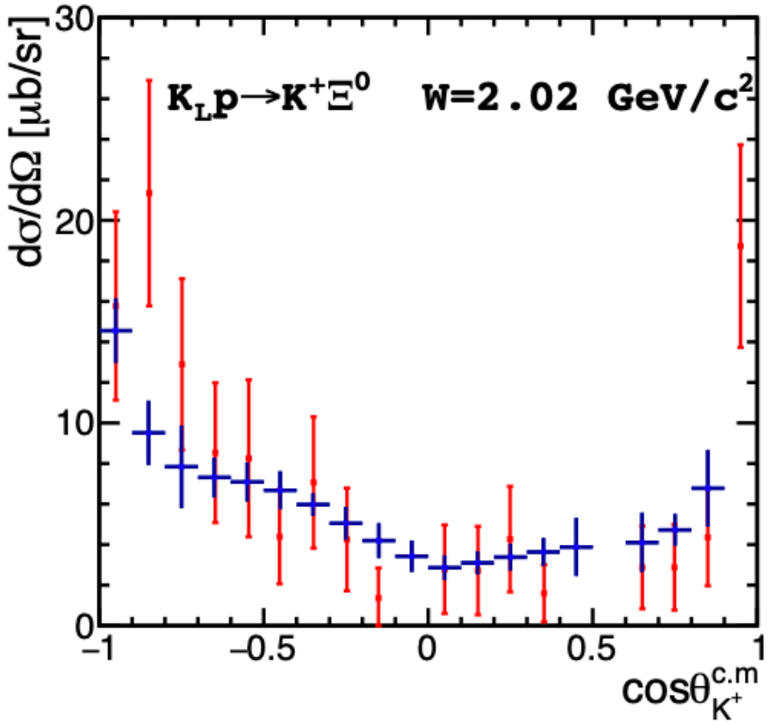
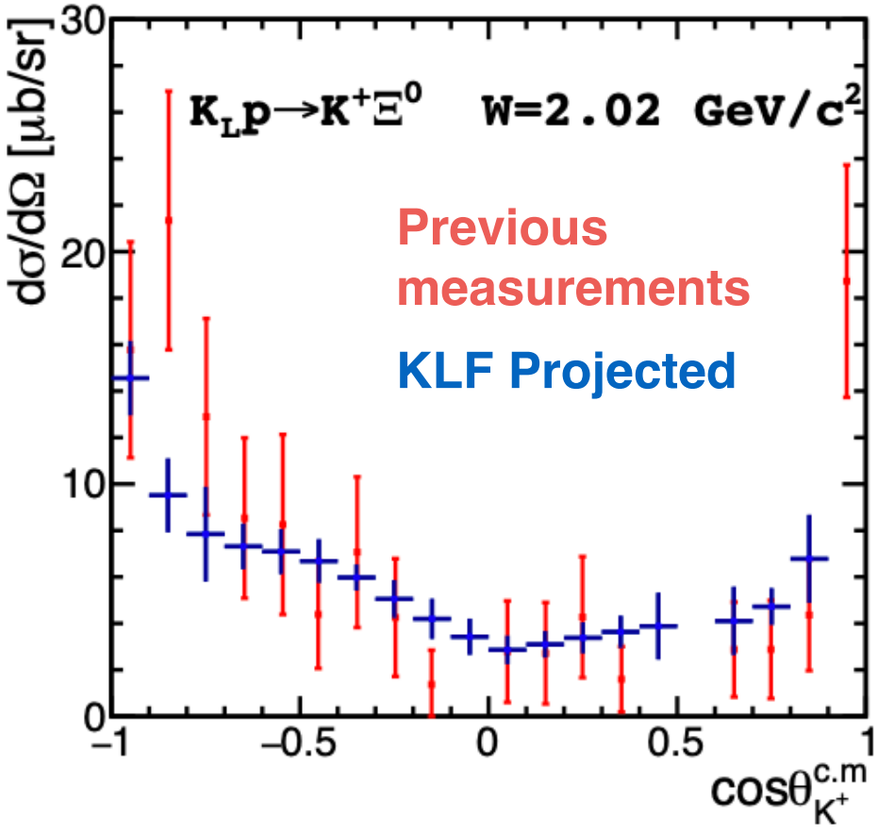
    - $K_L p \to \eta \Sigma^+$
    - $K_L p \to \omega \Sigma^+$
  - Neutron target: Λ* and Σ*
- Exclusive final states reconstructed well in GlueX spectrometer
- KLF will provide precision cross section measurements

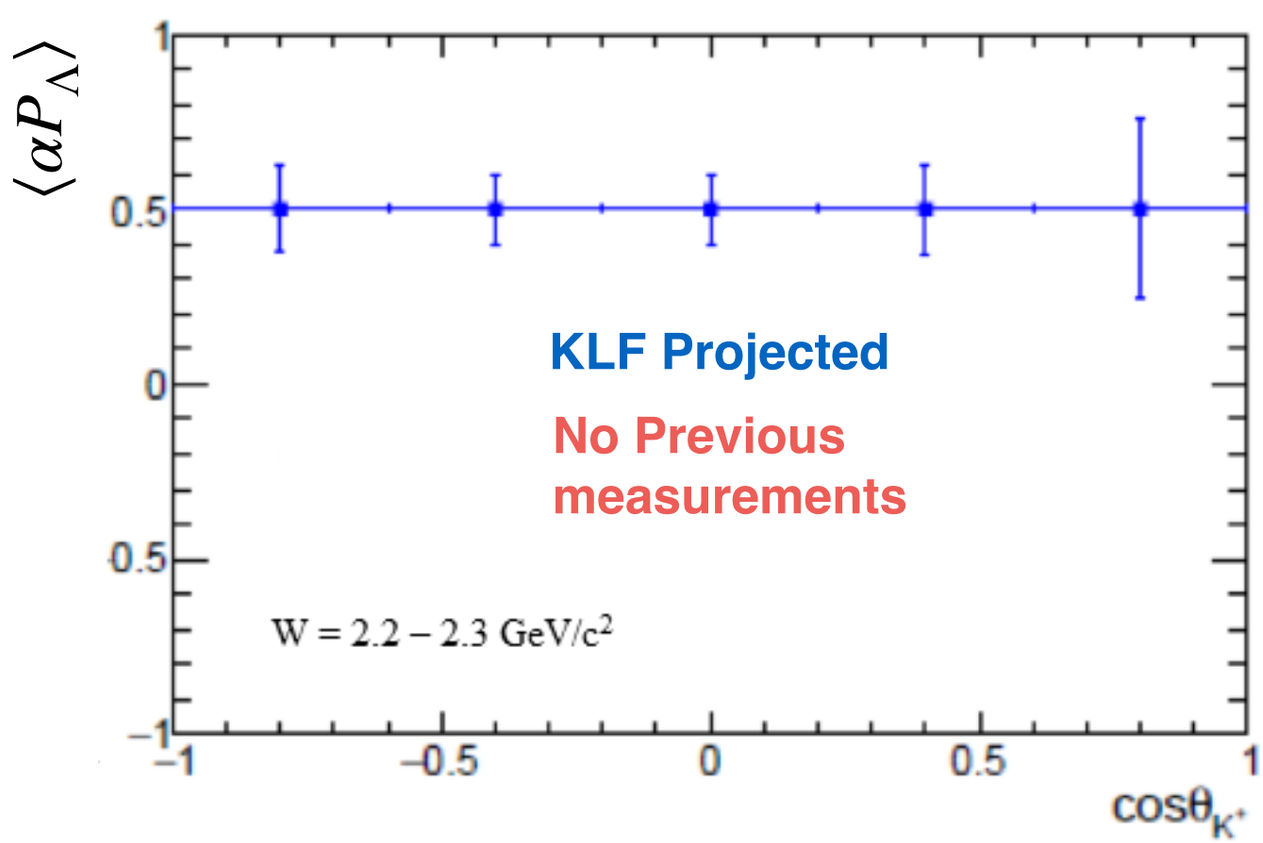




KLF: Partial Wave Analysis

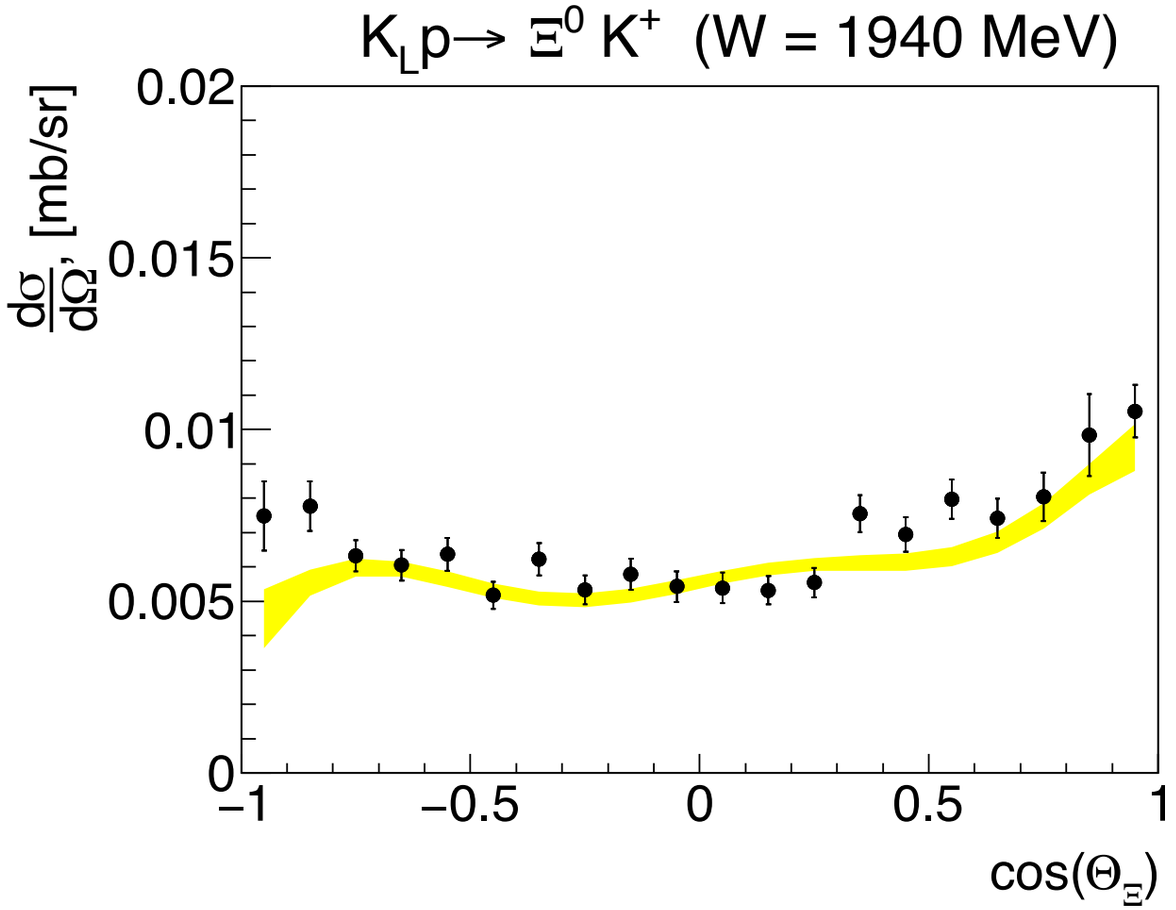
- To identify resonance contributions, we must perform a coupled-channeled PWA to extract spin-parity and pole positions
- Inputs: $d\sigma/d\Omega$, hyperon self-polarization from decay

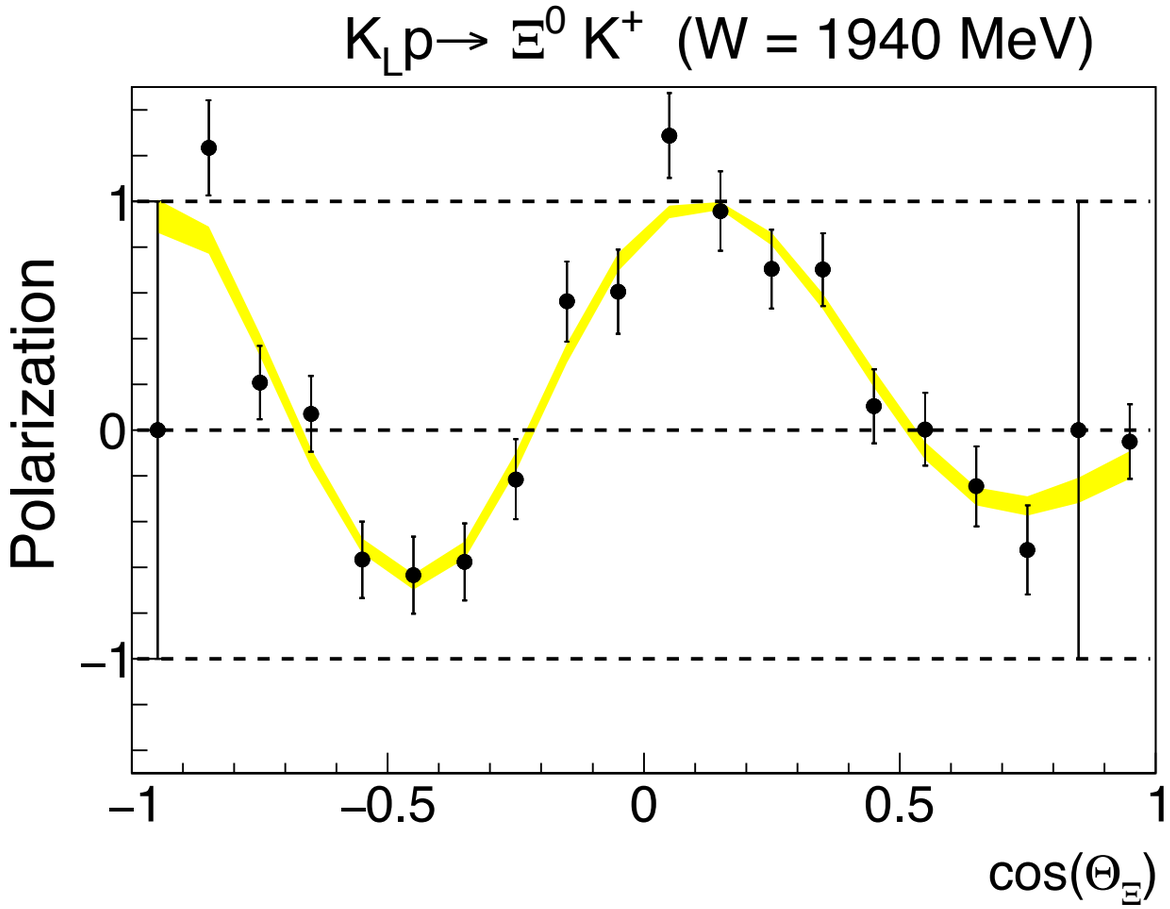




KLF: Σ* Expectations

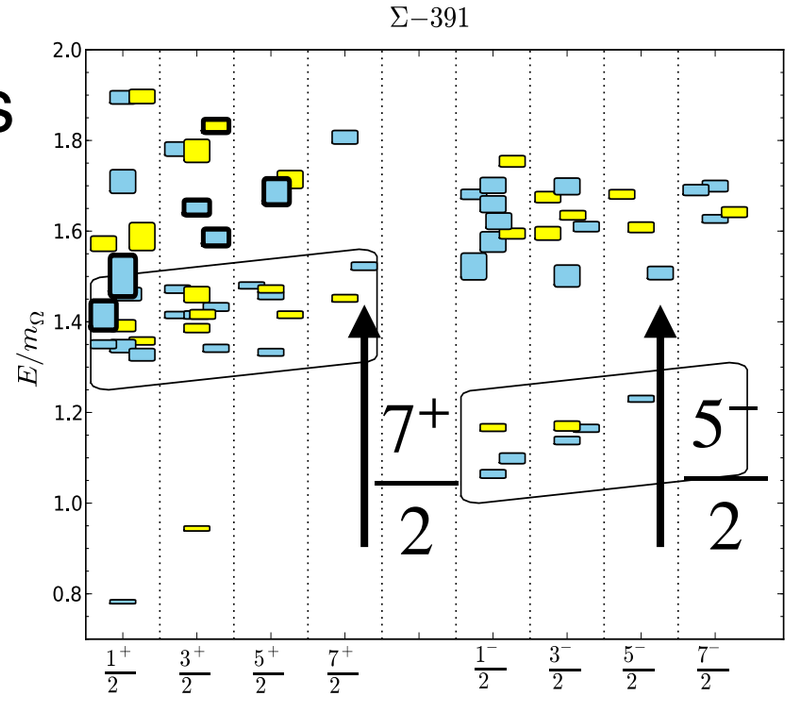
- Psuedodata for $K_L p \to K^+ \Xi^0$ with 2 Σ* states
  - $\Sigma^*(5^-/2): \; M = 1.94 \text{ GeV}, \Gamma = 0.35 \text{ GeV}$
  - $\Sigma^*(7^+/2): \; M = 1.94 \text{ GeV}, \Gamma = 0.4 \text{ GeV}$
- Projected uncertainties for $d\sigma/d\Omega$ and P [100 days on proton target]

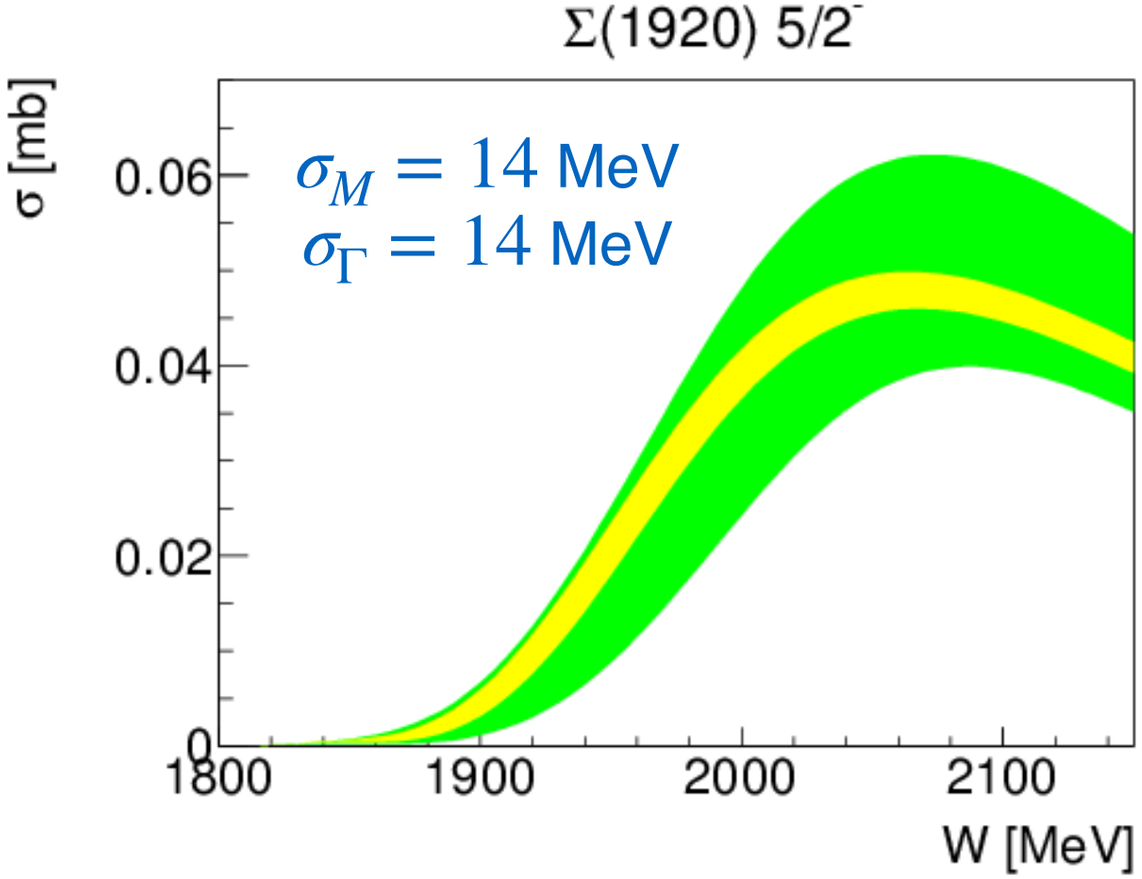


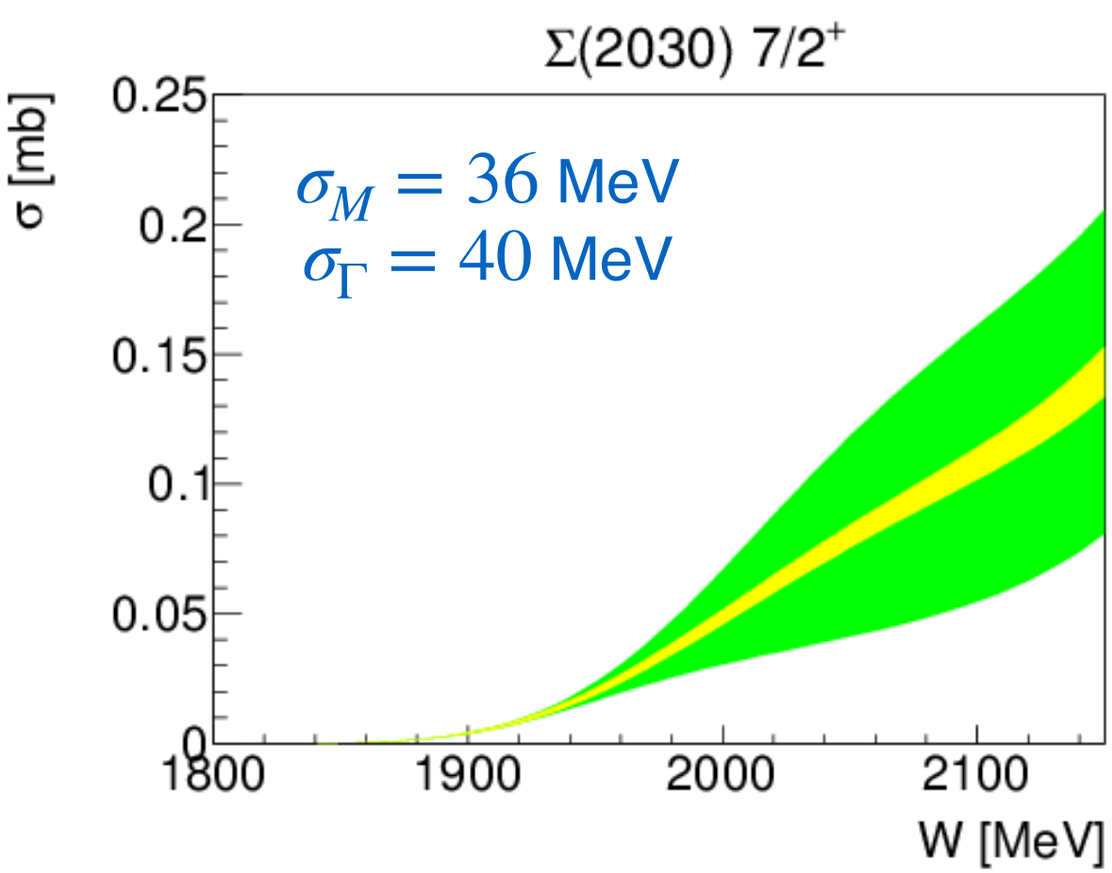


KLF: Σ* Expectations

- Psuedodata for $K_L p \to K^+ \Xi^0$ with 2 Σ* states
- Projected impact on resonance parameters
- Can provide precision determination of resonance pole parameters







Isospin Amplitudes in πΛ / πΣ

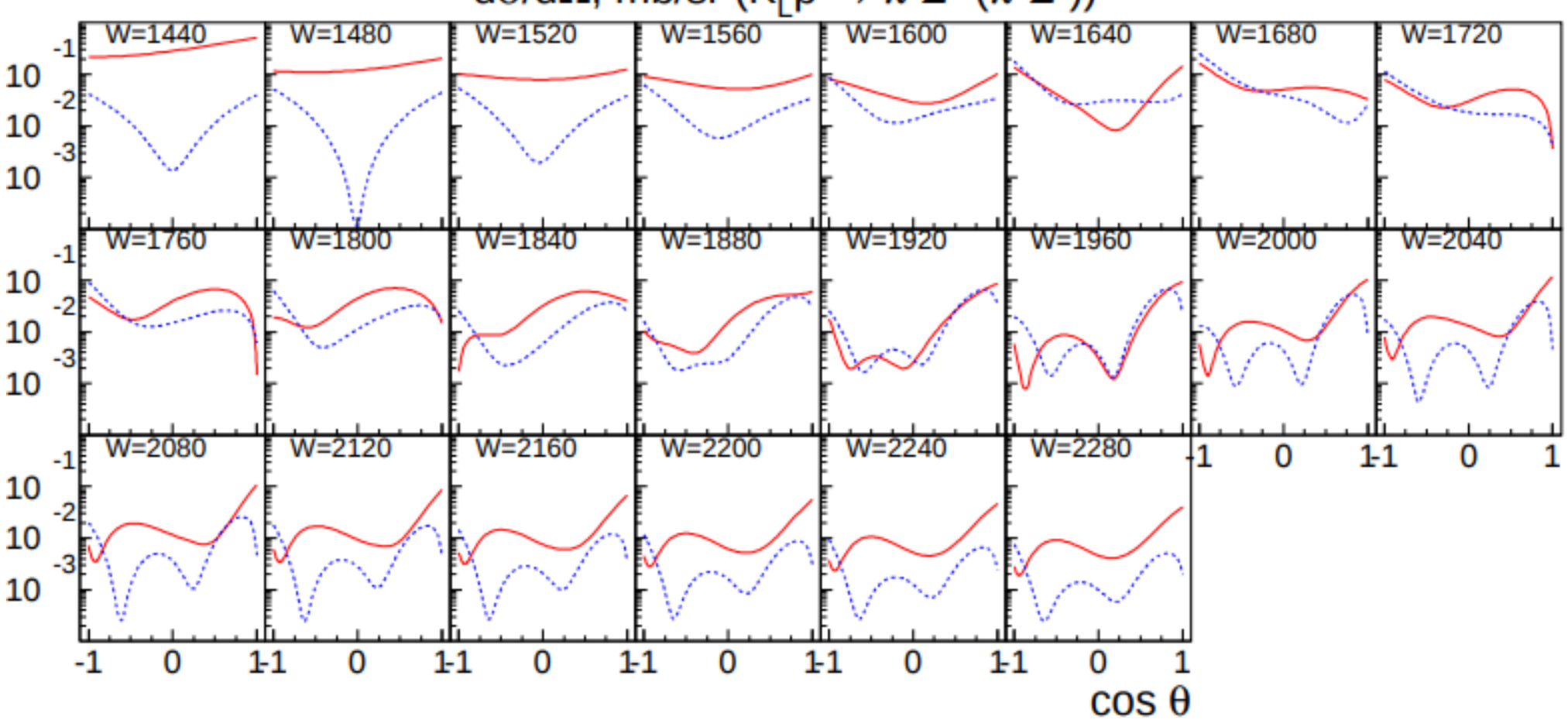
- K_L production of πΛ / πΣ has different isospin amplitudes than with K^-
  - Complementary measurement provides key data!
- Example BnGn prediction **with** and **without** 3 new Σ* states

$$|A(K^- p)|^2 = \frac{1}{2}(|A_1|^2 + |A_0|^2 + 2Re(A_1 A_0^*))$$

$$|A(K^0 n)|^2 = \frac{1}{2}(|A_1|^2 + |A_0|^2 - 2Re(A_1 A_0^*))$$

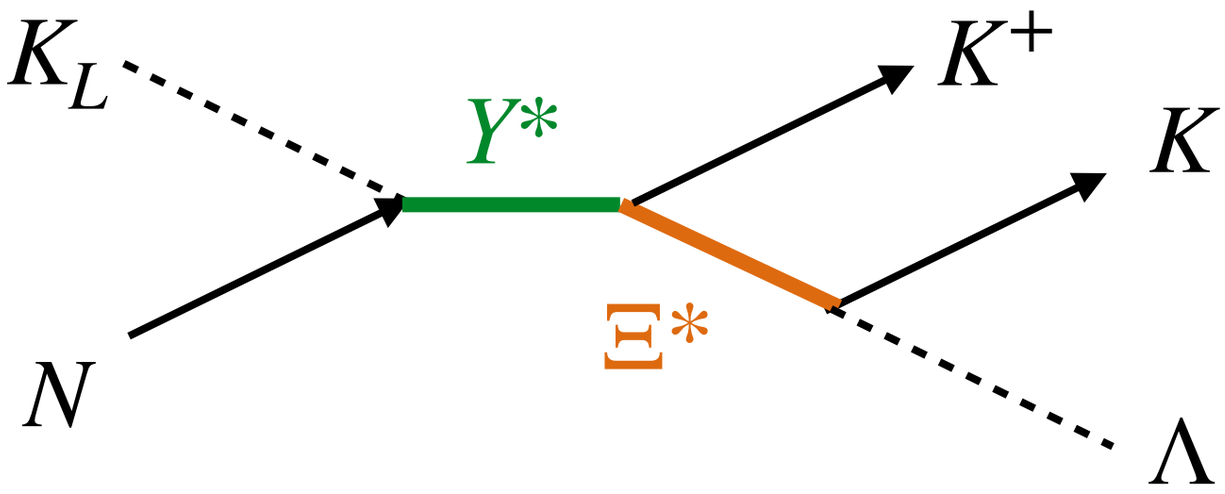
$$|A(K^0 p)|^2 = |A_1|^2$$

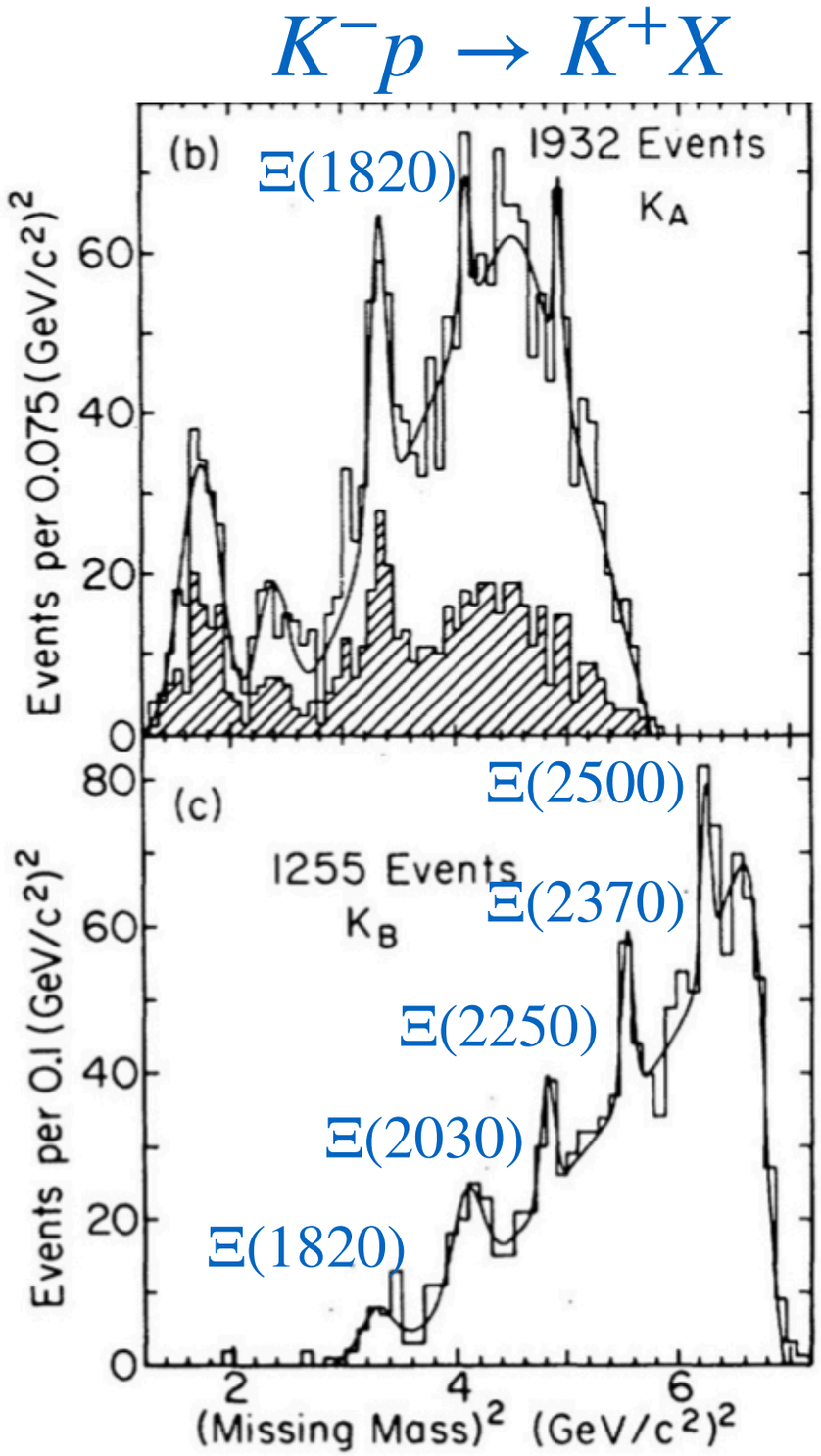
Bonn-Gatchina PWA



Example: Ξ^* Production

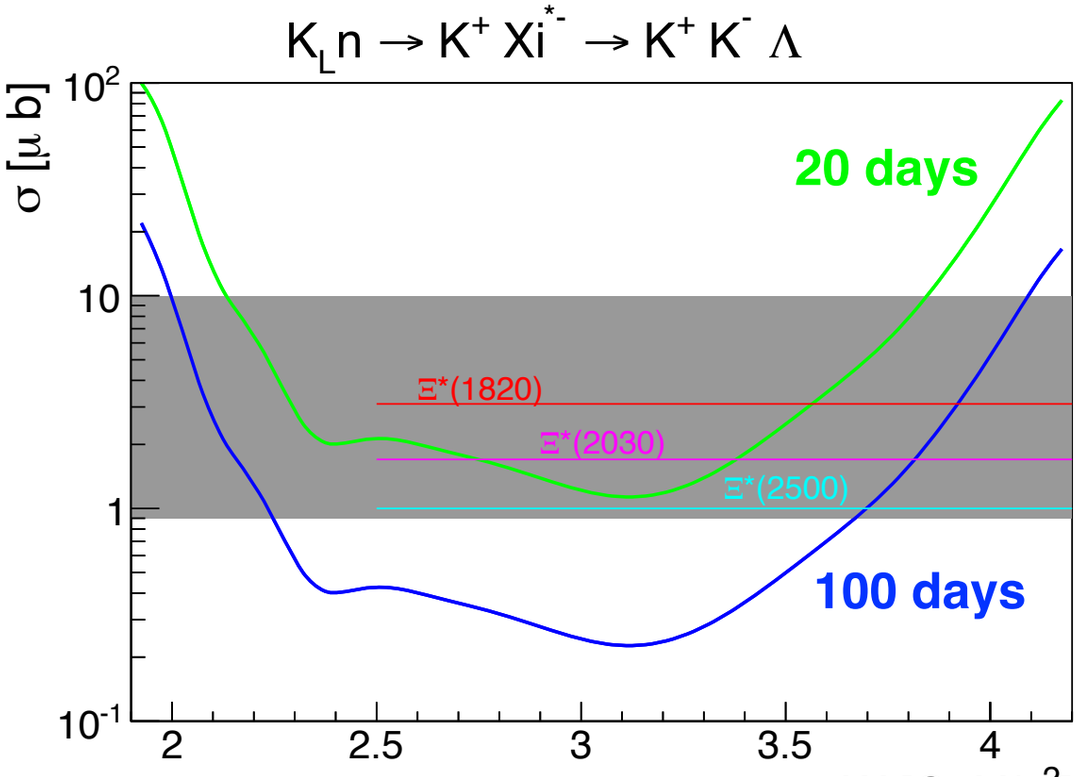
- Most of our knowledge of Ξ spectrum comes from K^- beam experiments in the 60s–80s, with little new until recently
- KLF can search for many decay channels:
  - $\Xi^* \to \Lambda K$
  - $\Xi^* \to \Xi\pi$
  - $\Xi^* \to \Xi\eta$
  - $\Xi^* \to \Xi\omega$
  - $\Xi^* \to \Sigma K$





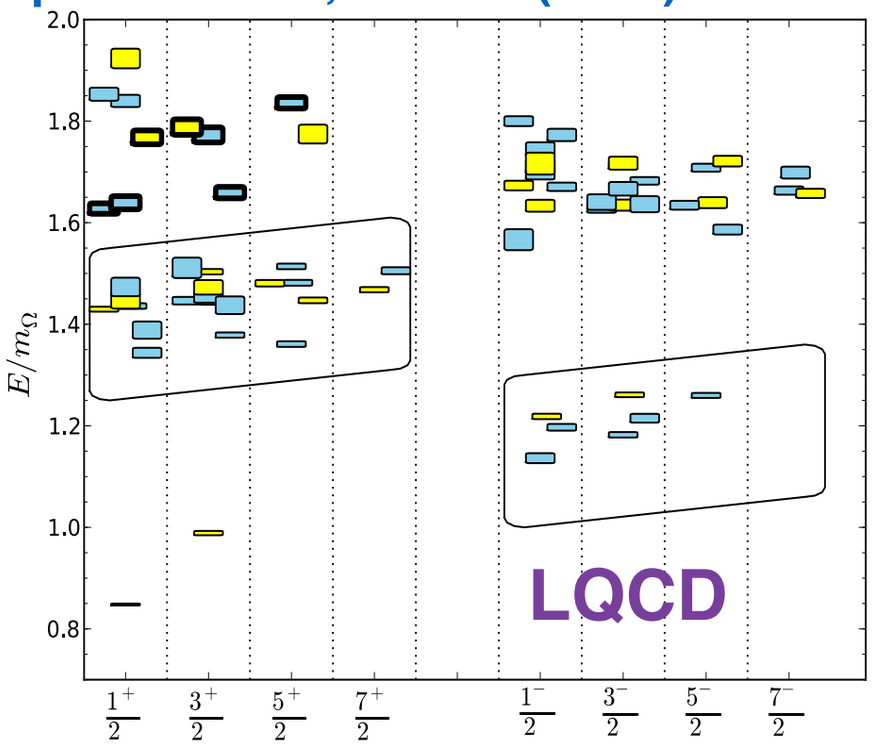
PRL 51, 951 (1983)

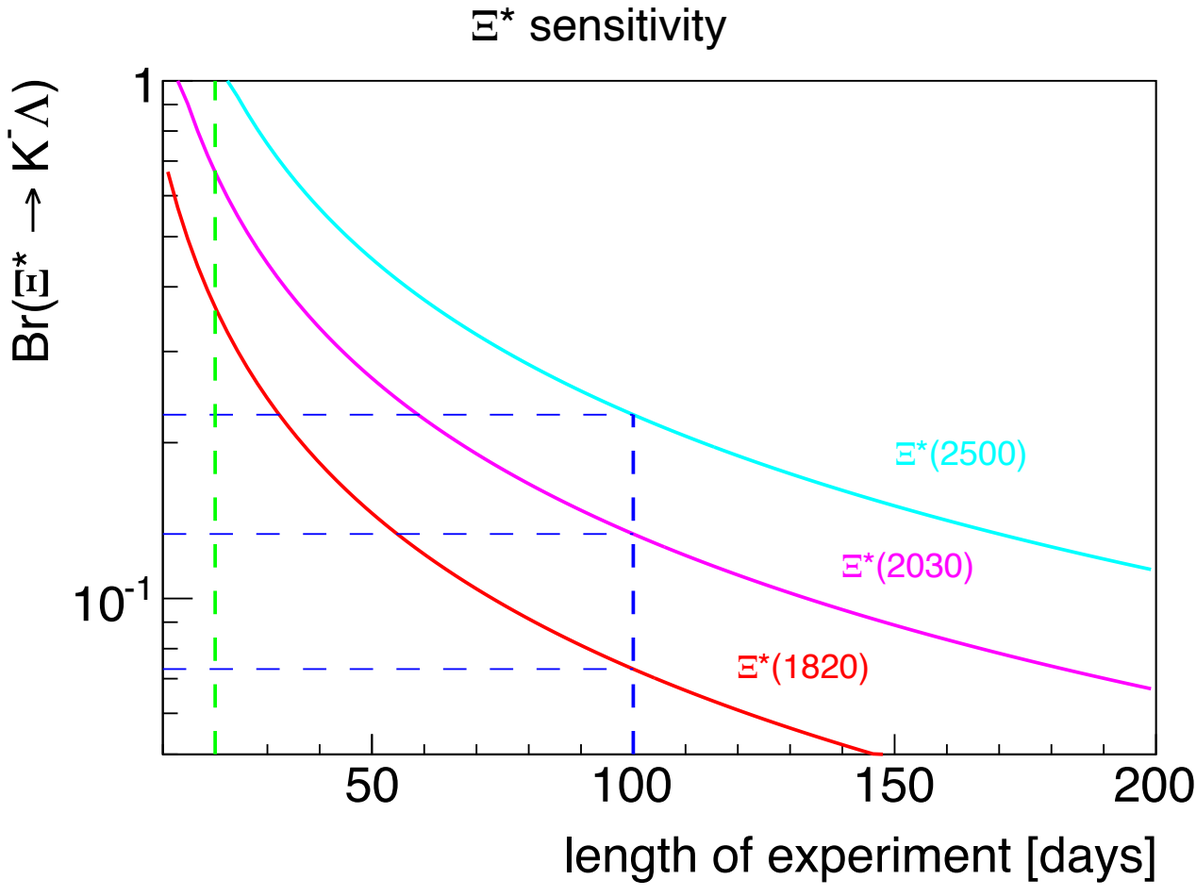
KLF Projections: $K_L n \to K^+ \Xi^{*-}$, $\Xi^{-*} \to \Lambda K^-$



- Expect significant cross sections based on $K^- p$ data
- Significant sensitivity over large mass range

hadspec: PRD 87, 054506 (2013)

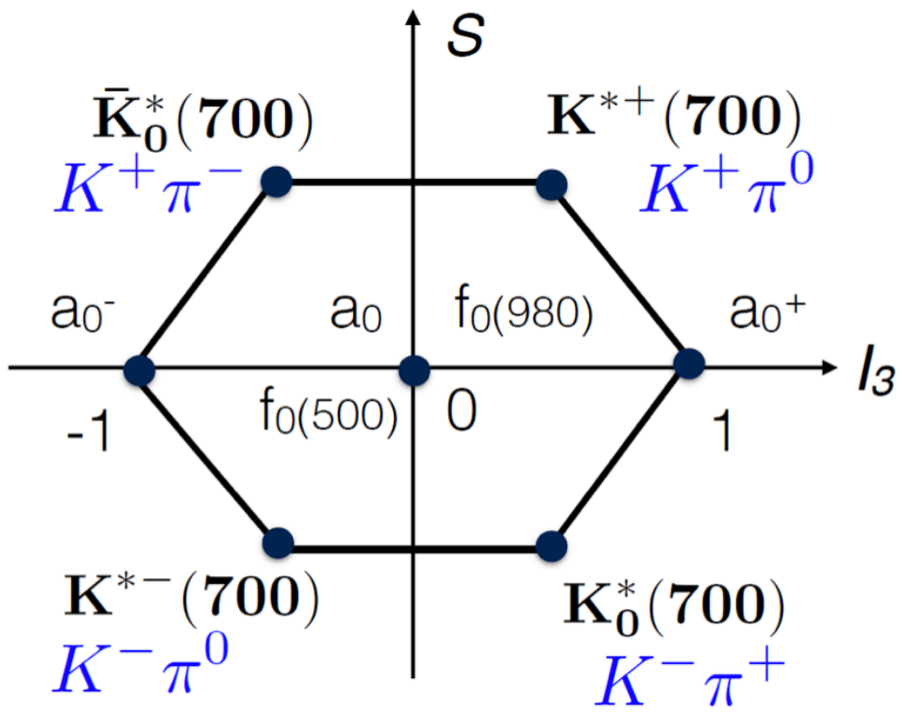




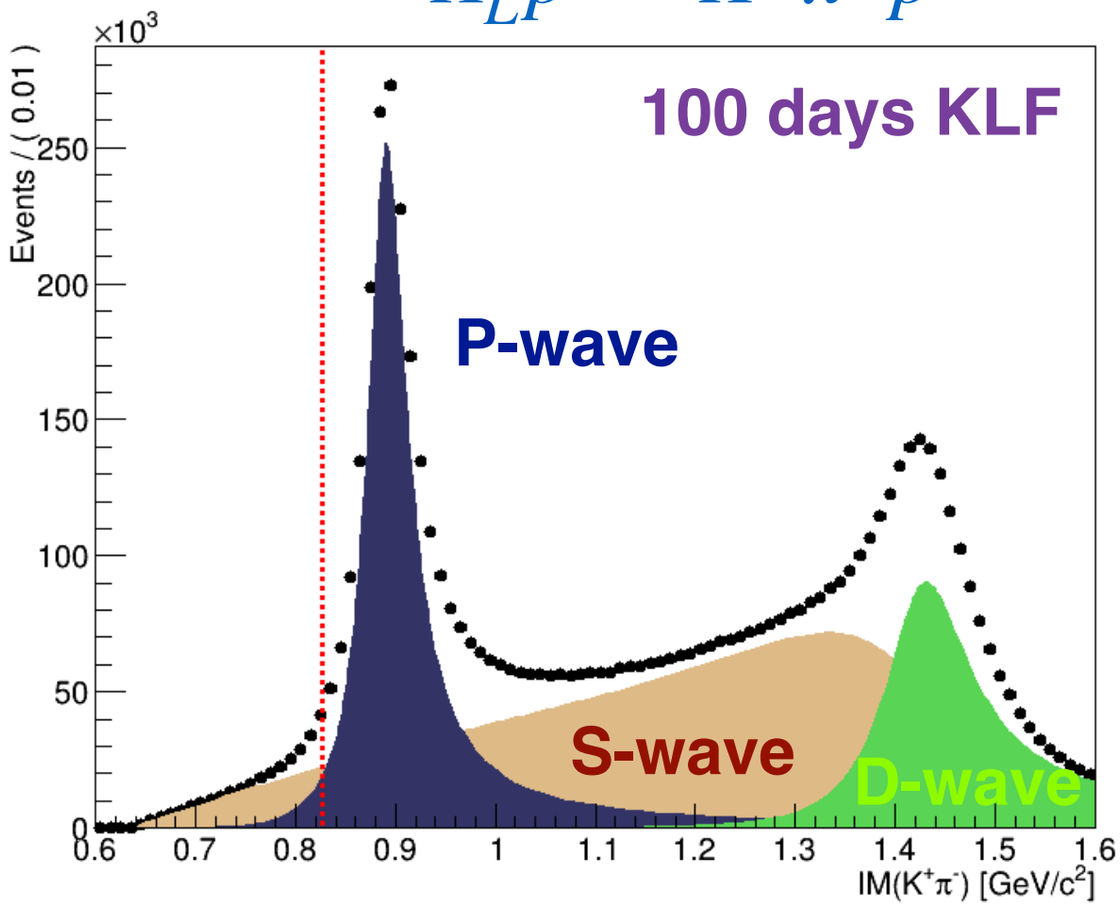
Strange meson spectroscopy

- Again, most knowledge of kaon spectrum comes from older kaon beam experiments
  - More recent insight from e.g. PWA of decays from charm quark hadrons
- High-statistics KLF data gives additional insight
  - Unique access to high mass/spin states
  - Study of scalar $K\pi$ system

$J^{PC} = 0^{++}$

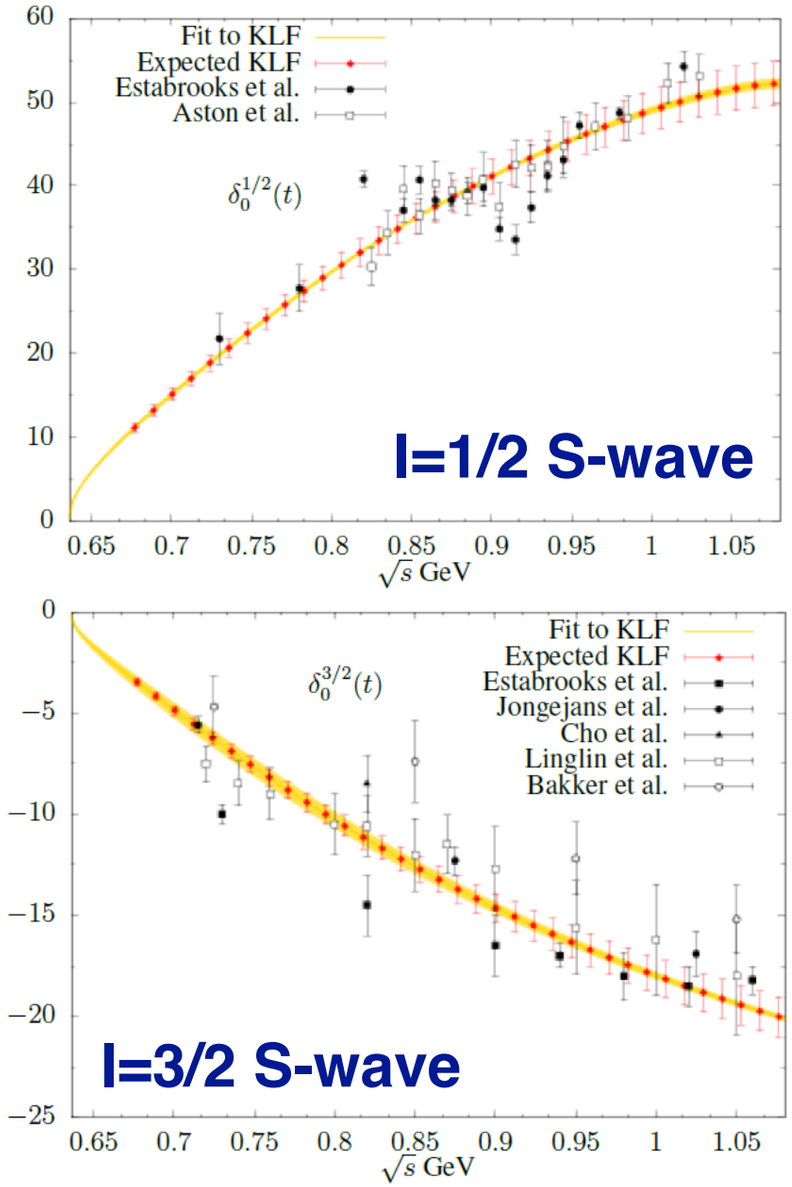


$K_L p \to K^{\pm}\pi^{\mp}p$

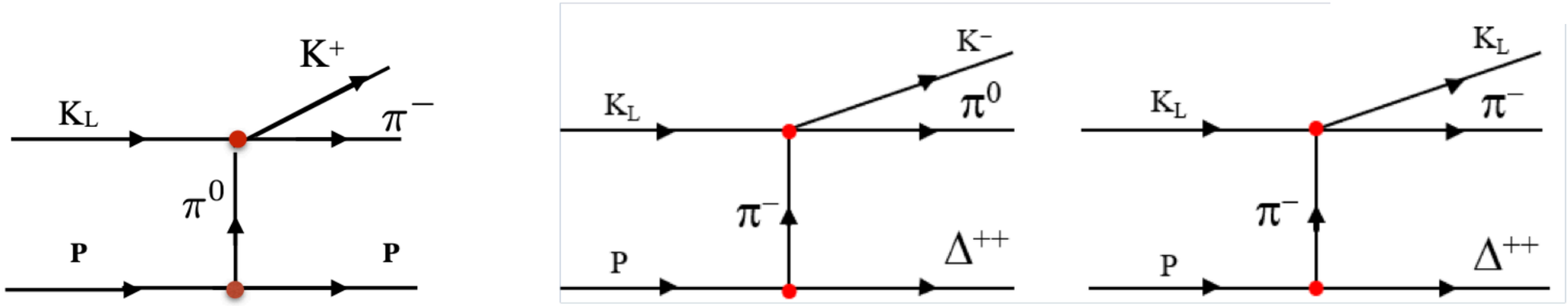


Example: $K\pi$ S-wave

- Study $K\pi$ scattering in several different final states to extract S-wave isospin components
  - Additional input to dispersive analyses of $\kappa/K^*(700)$ properties, especially at low mass/t
  - Challenges: requires K_L detection and detailed reaction models
    - $K_L p \to K_L \pi^0 p$
    - $K_L p \to K^{\pm}\pi^{\mp} p$
    - $K_L p \to K_{(L,S)}\pi^{+} n$
    - $K_L p \to K^{+}\pi^{0} n$
    - $K_L p \to K^{-}\pi^{0}\Delta^{++}$
    - $K_L p \to K_{(L,S)}\pi^{-}\Delta^{++}$

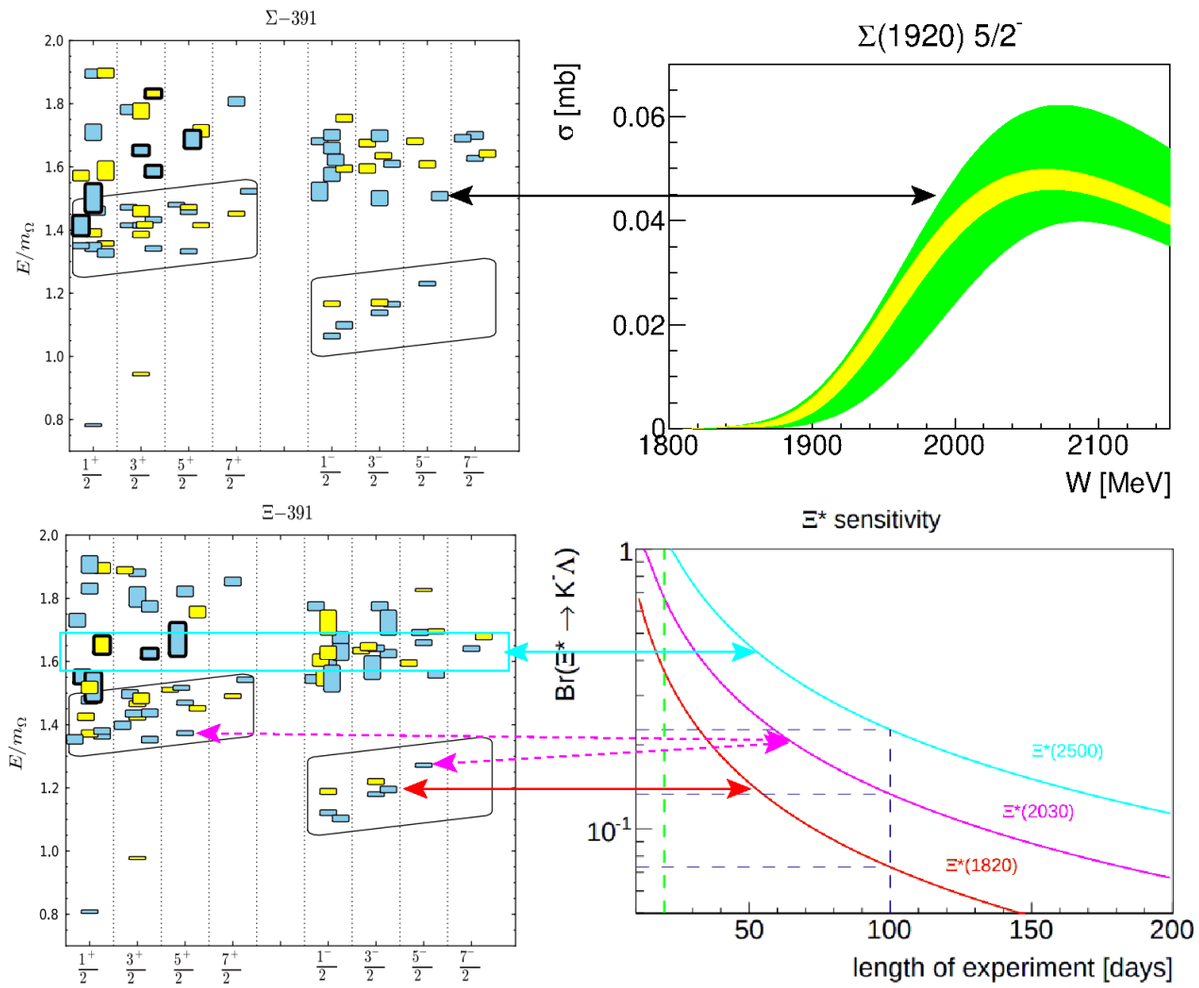


100 days KLF



Summary

- The K_L beam facility in Hall D at JLab has been approved to run for 200 days and will provide a set of unique, high-statistics data
- Cross sections and polarization measurements will allow detailed study of the hyperon spectrum
- Many other possible topics:
  - Neutron-induced reactions
  - Hyperon decays
  - Exotic hadrons
- Technical design of hardware components and simulation studies on-going
- Approved Hall D photon beam program through ~2025



New Collaborators welcome!

More information: https://wiki.jlab.org/klproject