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# $K_L$-Beam Facility at Jefferson Lab

Hovanes Egiyan

Jefferson Lab

(for KLF Collaboration)

# Overview

- Introduction
- Physics Motivation
- Hall D at Jefferson Lab
- KLF facility
  - Compact Photon Source (CPS)
  - Kaon Production Target (KPT)
  - Kaon Flux Monitor (KFM)
- Status of the project
- Conclusions and Outlook

# KLF Experiment

- Use CEBAF electron beam to create a tertiary $K_L$ beam *to study strange hadron spectroscopy*.
- Use existing GlueX experimental setup in Hall D that has been used to study meson spectroscopy in photoproduction.
  - Very good detector system for studying exclusive final states.
- Create intense $K_L$ flux (~$10^4$ kaons/s) on cryo-target.
- Experimental proposal approved by JLAB Program Advisory Committee in 2020.
  - 100 days on $LH_2$ target
  - 100 days on $LD_2$ target.
- Estimated cost to JLAB of ~$2.3M .
- Formal KLF collaboration is currently being formed to construct the equipment and to conduct the experiments.
  - New collaborators are welcome.

Proposal for JLab PAC48

## Strange Hadron Spectroscopy with Secondary $K_L$ Beam in Hall D


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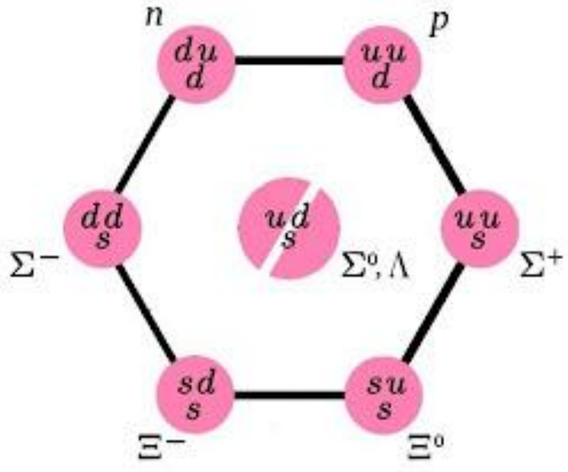
# Collaboration Map

# Strange Baryons

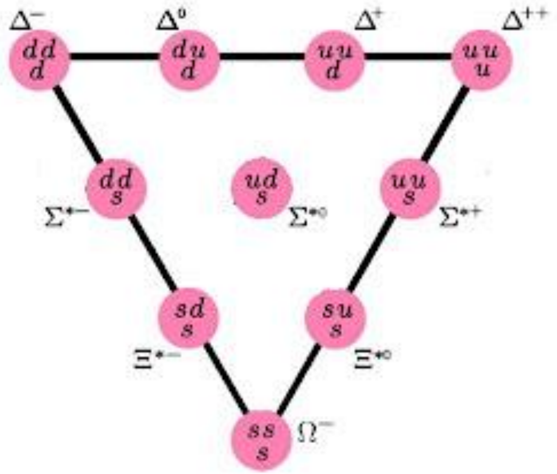
- CQM and LQCD expect more hyperon states than experimentally observed.
  - Mismatch in the number of states is significantly worse for hyperons than for N* sector.
- Study of the properties of the states with strange quarks gives insight into the underlying dynamics and into the relevant degrees of freedom.
- Important input to high-density/temperature hadron physics

| | 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 |

[PDG 3* & 4* states]




S=1/2

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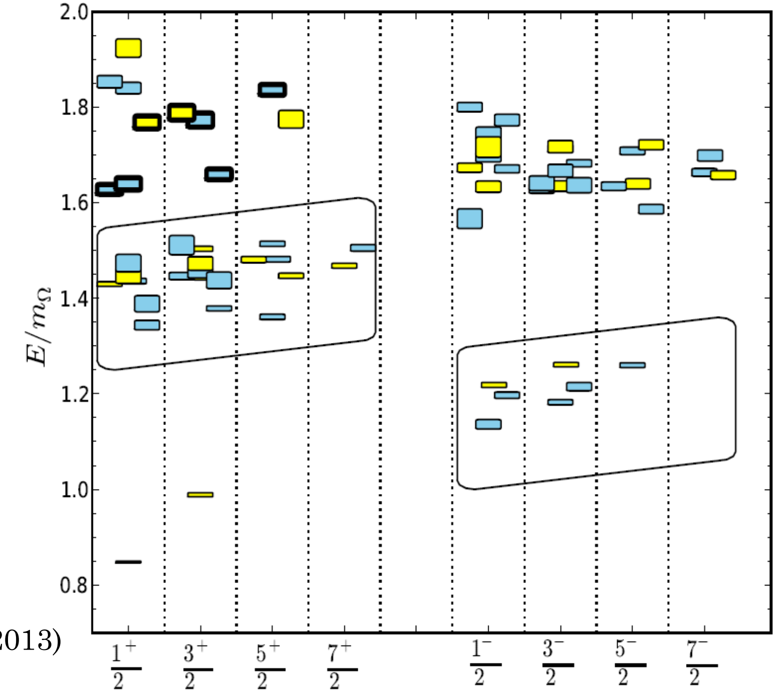


Ξ-s in LQCD

Phys. Rev. D 87, 054506 (2013)

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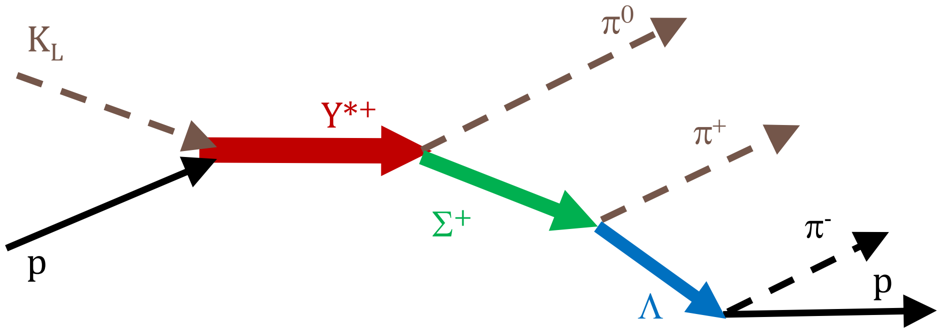
# πΣ and πΛ Channels

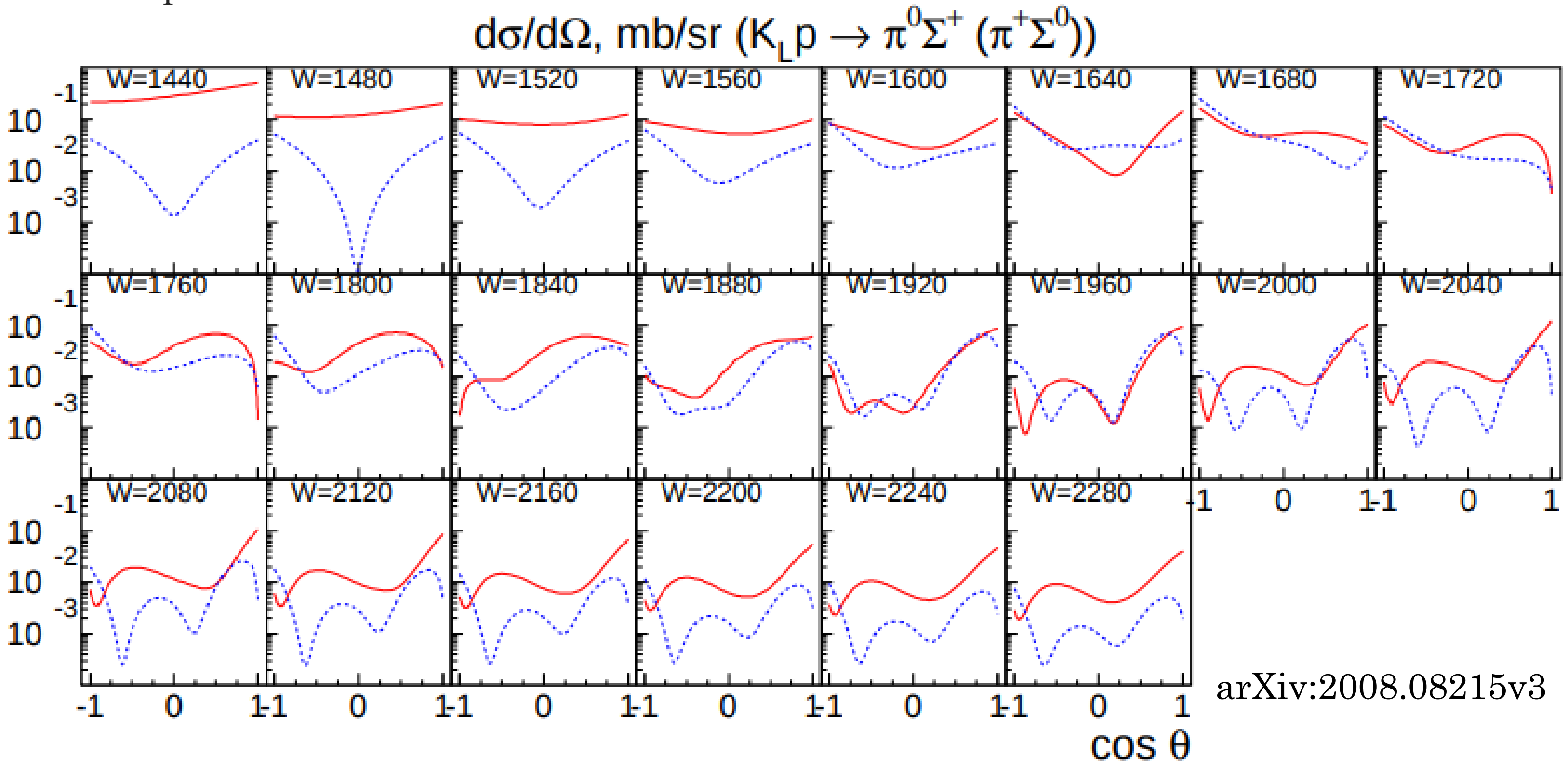



- Using πΣ and πΛ channels, we can access excited Σ* and Λ* state.
- Reactions using ($K_L$& p) in the initial state has different isospin contributions in the amplitudes from when using ($K_L$ & n) or ($K^-$ & p) in the initial state.
- Perform global PWA analysis to settle the spectrum of excited state hyperons.
  - We can measure cross sections and induced polarizations

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

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

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




arXiv:2008.08215v3

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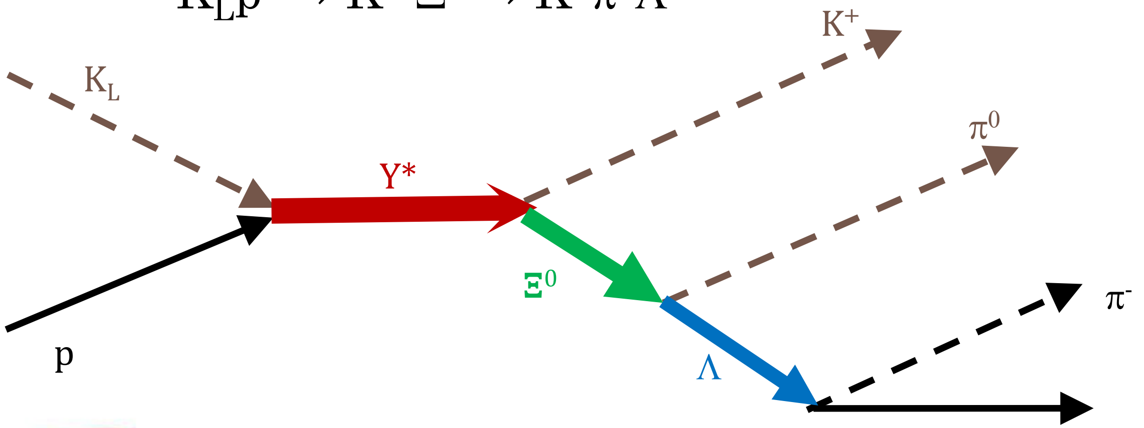
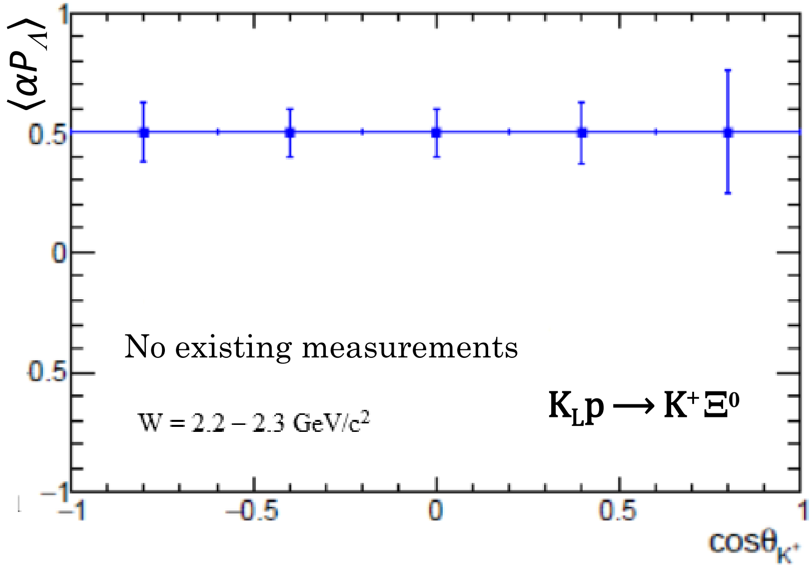
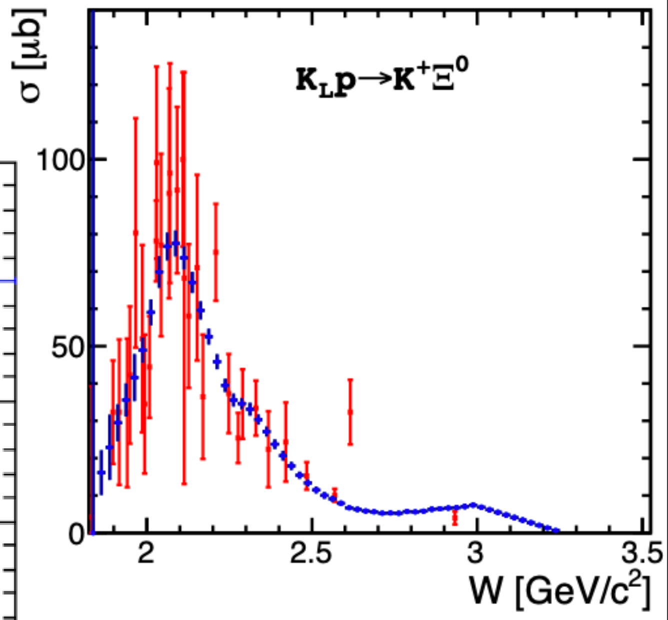
# K Ξ Channel

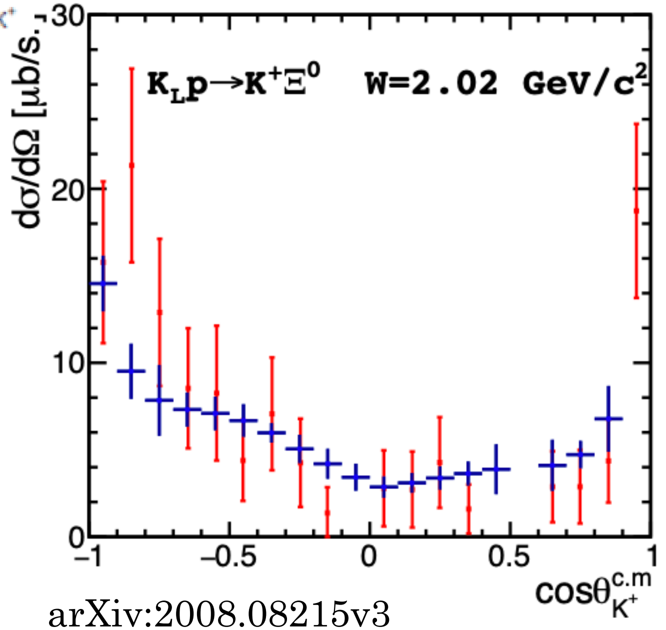
- Can access hyperon states that do not directly couple to πΛ or πΣ channels.
- Measure differential cross section and induced polarization using measured angular distribution of decay products.
  - Constrains underlying dynamics.
- To identify resonance contributions, we must perform a coupled-channeled PWA to extract spin-parity and pole positions of excited hyperons.
- Similarly impressive expectations are for the neutron target.

$K_L p \longrightarrow K^+ \Xi^0 \longrightarrow K^+ \pi^0 \Lambda$



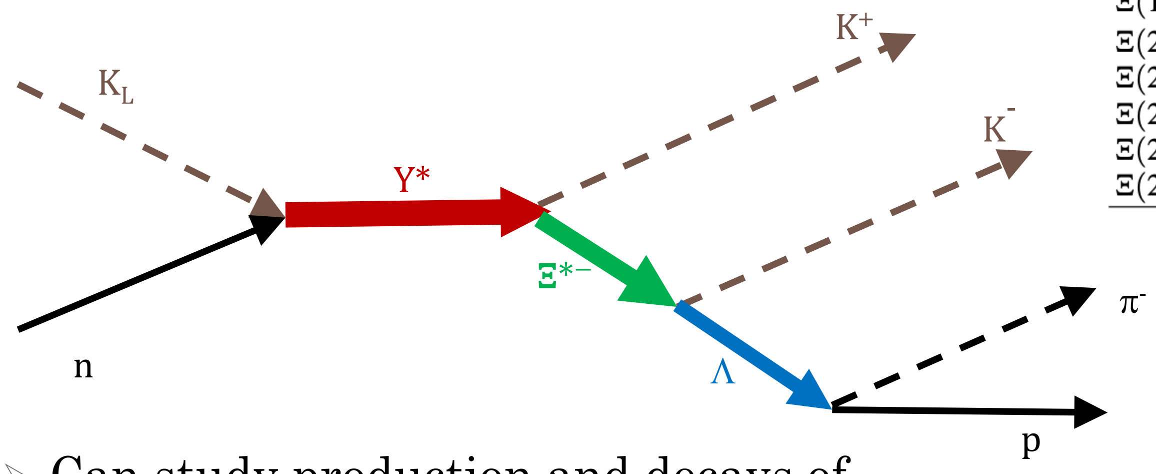




arXiv:2008.08215v3

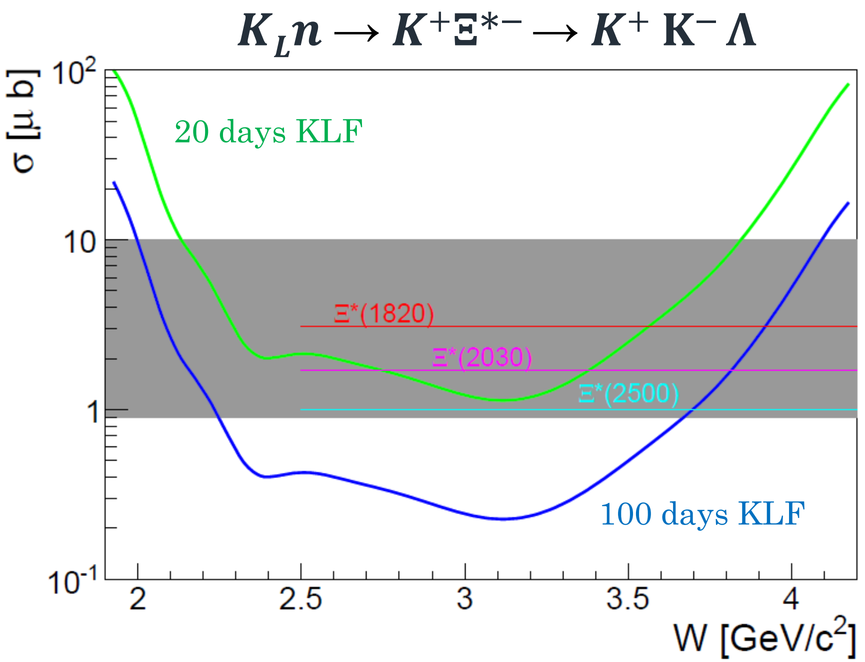
# Excited Cascades Ξ*

$K_L n \longrightarrow Y^* \longrightarrow K^+ \, \Xi^{*-} \longrightarrow K^+ \, K^- \, \Lambda$

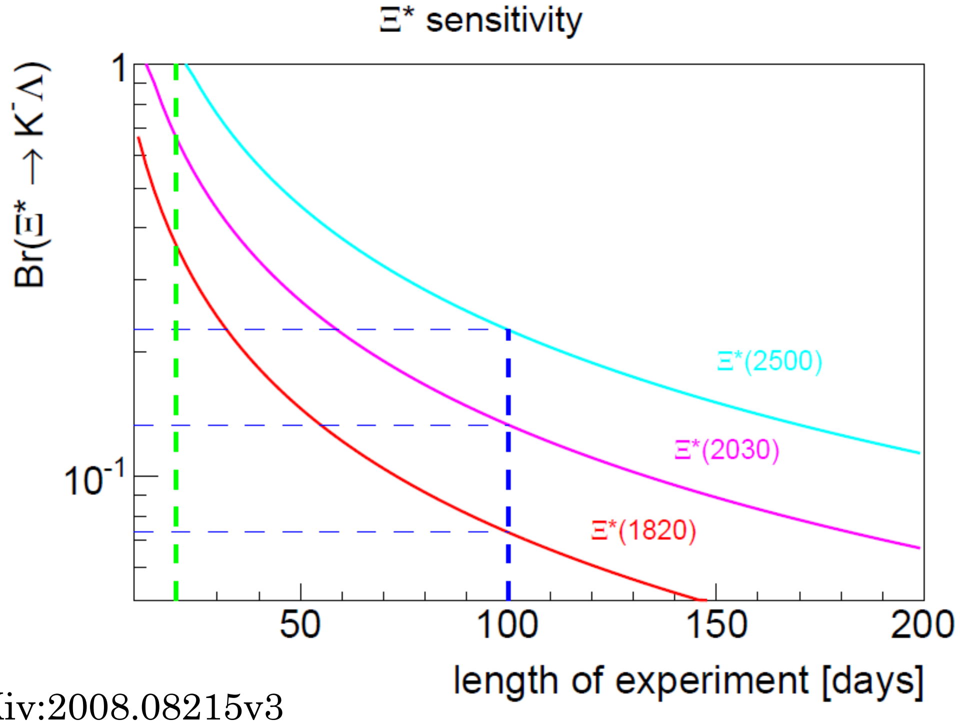



- Can study production and decays of excited cascades.
  - Most of our knowledge of cascade spectrum comes from beam experiments in the 60s–80s.
  - Quantum numbers for some of the excited cascades are not determined.
- We can measure branching ratios for **$K^- \Lambda$** decays of **Ξ*** down to ~4% .

| State | $J^P$ | Overall Status |
|---|---|---|
| Ξ(1318) | $1/2^{+a}$ | **** |
| Ξ(1530) | $3/2^+$ | **** |
| Ξ(1620) | | * |
| Ξ(1690) | | *** |
| Ξ(1820) | $3/2^-$ | *** |
| Ξ(1950) | | *** |
| Ξ(2030) | $5/2^?$ | *** |
| Ξ(2120) | | * |
| Ξ(2250) | | ** |
| Ξ(2370) | | ** |
| Ξ(2500) | | * |




$\Xi^* \rightarrow \Lambda K$
$\Xi^* \rightarrow \Xi\pi$
$\Xi^* \rightarrow \Xi\eta$
$\Xi^* \rightarrow \Xi\omega$
$\Xi^* \rightarrow \Sigma K$




arXiv:2008.08215v3

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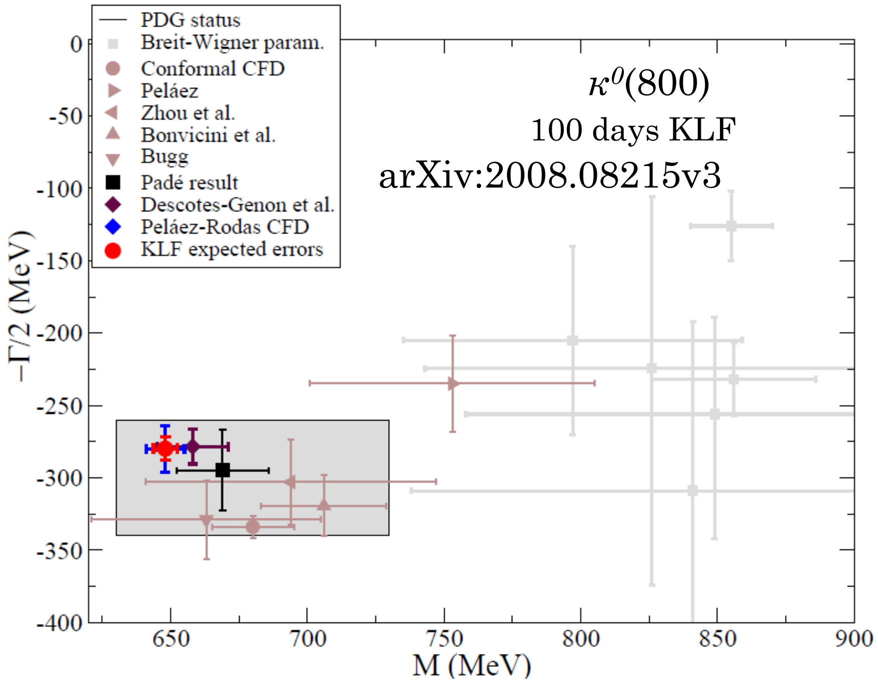
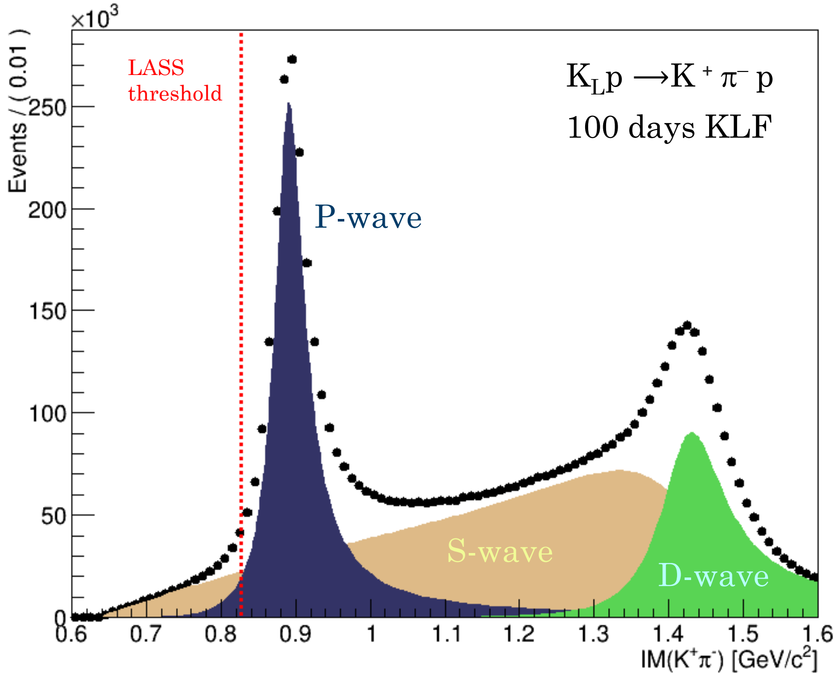
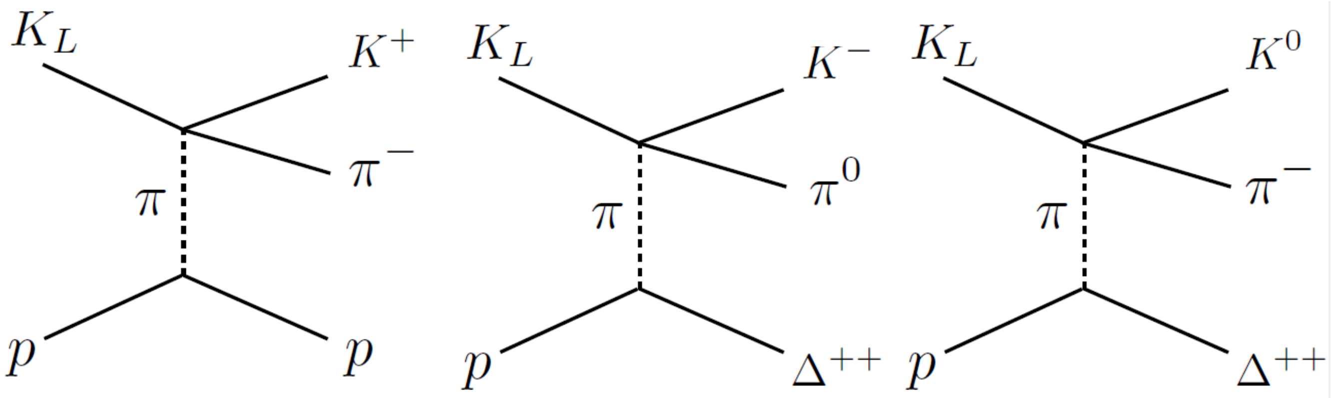
# Kπ Spectroscopy

- The simplest hadronic reaction that involves s-quark
  - crucial for understanding non-pQCD.
- Locate pole positions in I=1/2 & I=3/2 channels
  - Existence of the exotic state $\kappa^0(700)$ (I=1/2, S-wave $0^{++}$) is still unclear.
    - Need data at invariant masses closer to ~650 MeV to reconcile ChPT models, data, and LQCD.
  - Separating isospin contributions will require $K_L$ detection.

$$K_L p \to K_L \pi^0 p,$$
$$K_L p \to K^{\pm}\pi^{\mp} p,$$
$$K_L p \to K_{(L,S)}\pi^+ n,$$
$$K_L p \to K^+\pi^0 n,$$
$$K_L p \to K^-\pi^0 \Delta^{++},$$
$$K_L p \to K_{(L,S)}\pi^- \Delta^{++}$$



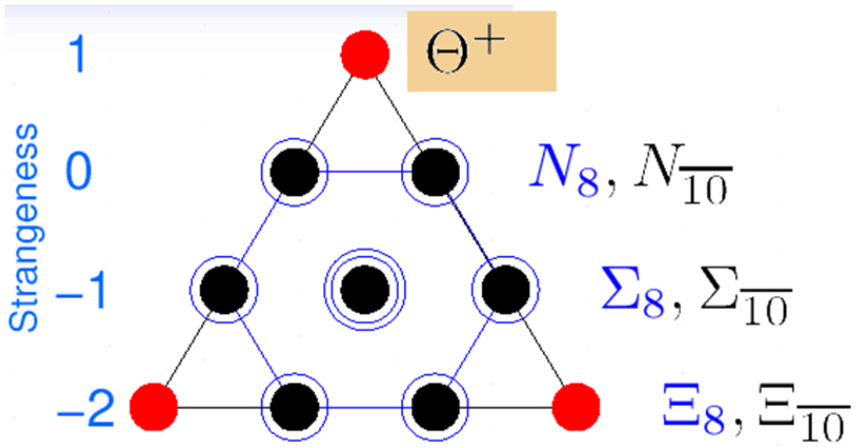



# Other topics

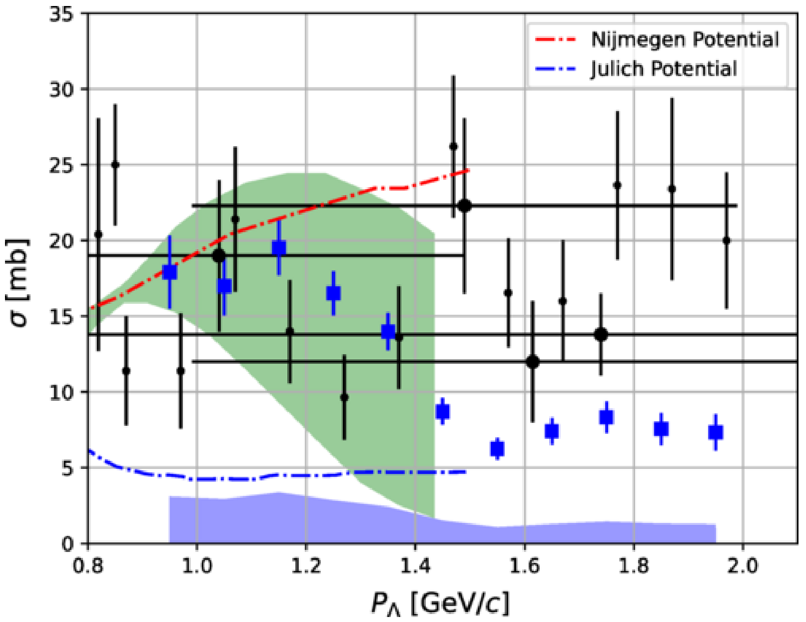
S=1/2

- Study of $\Omega^*$ ($S$=-3) states.
- Neutron induced reactions.
- $K_L p \rightarrow K^+ n$ reaction to study non-resonant background to hyperon production
  - Resonant structure would mean an exotic state.
- Hyperon-nucleon scattering.
  - Important for neutron star equation of state
- "Parasitic" experimental setups to study hypernuclei.



Pentaquark Antidecuplet

Phys. Rev. Lett. **127**, 272303

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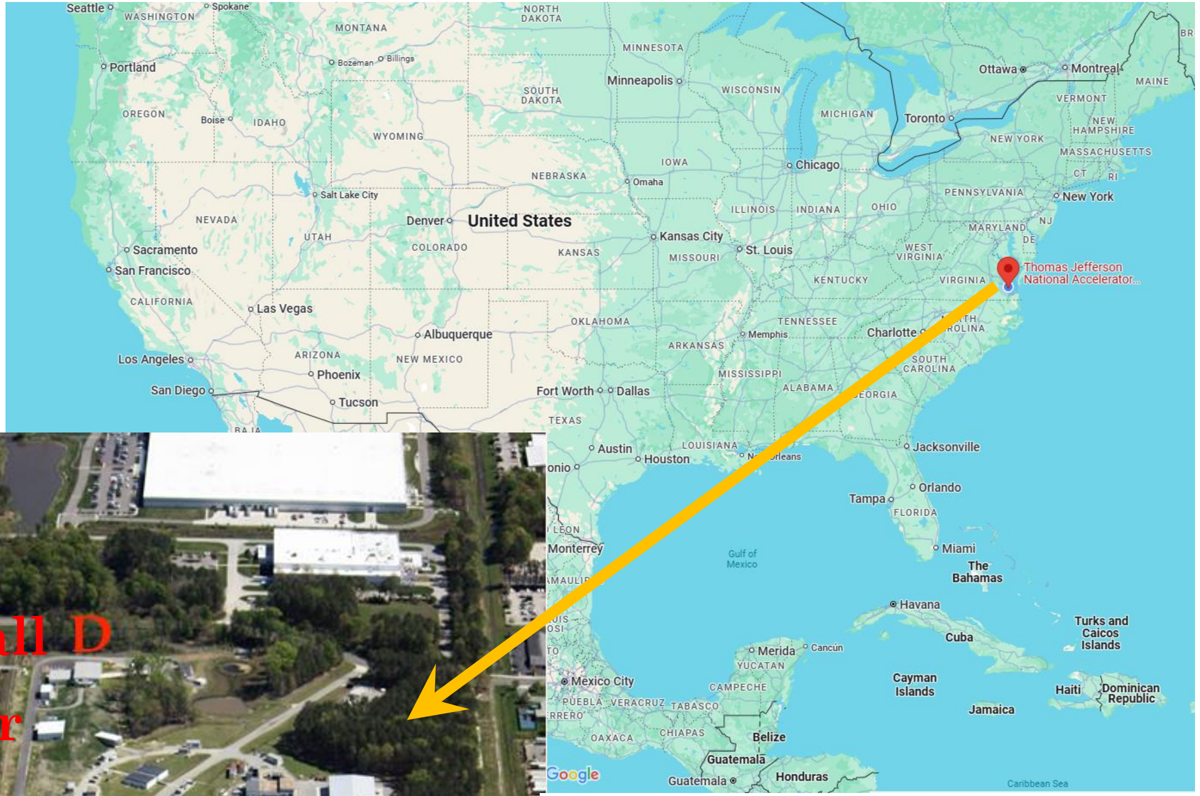
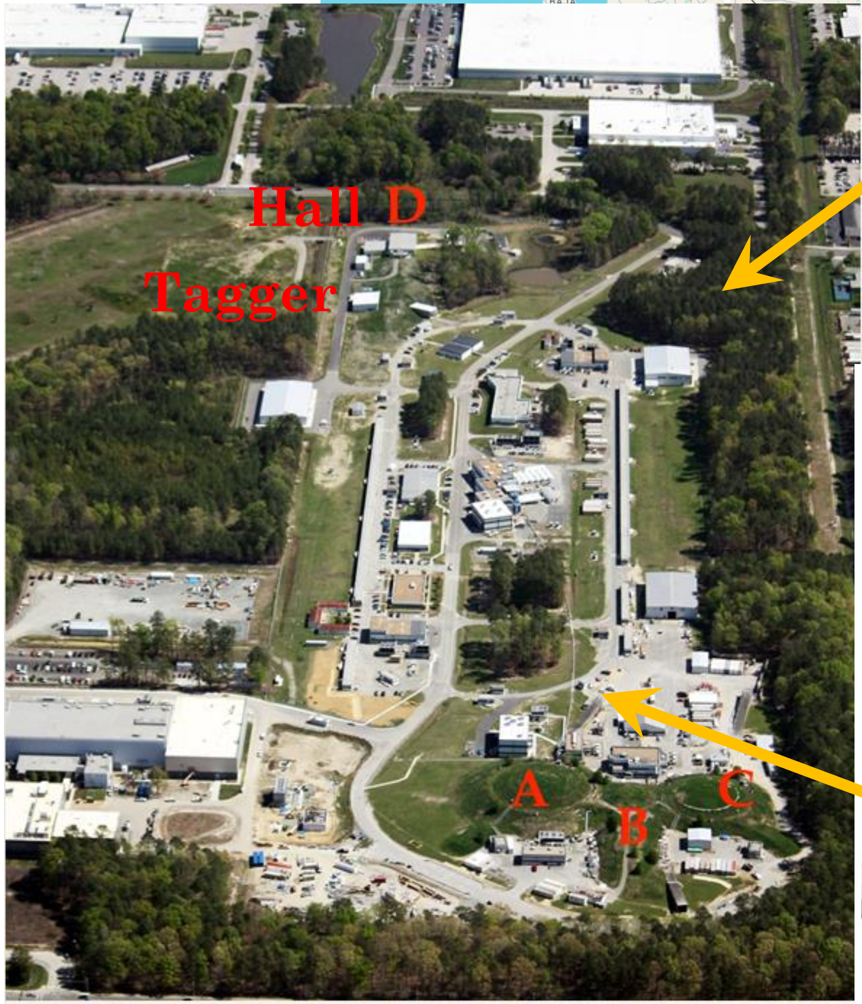
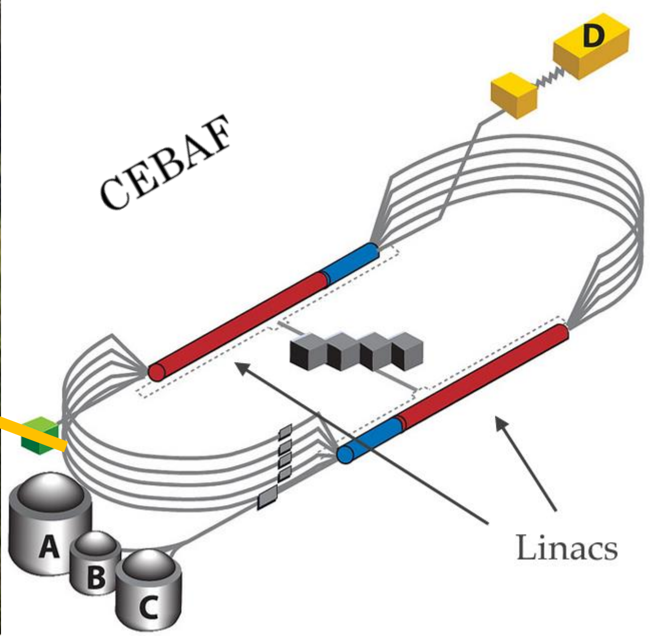
# CEBAF @ JLAB

- Up to 12 GeV polarized continuous electron beam
  - ~1.5 GHz beam time structure
- Four experimental Halls: A, B, C, D
  - Each halls receives an electron beam bunch every ~4ns
- Experimental program concentrates predominantly on hadronic physics.
  - Hall D :
    - Meson spectroscopy
    - $J/\Psi$ near-threshold photoproduction
    - Rare meson decays
    - Pion polarizabilities
    - Color transparency and short-range correlations in nuclei.

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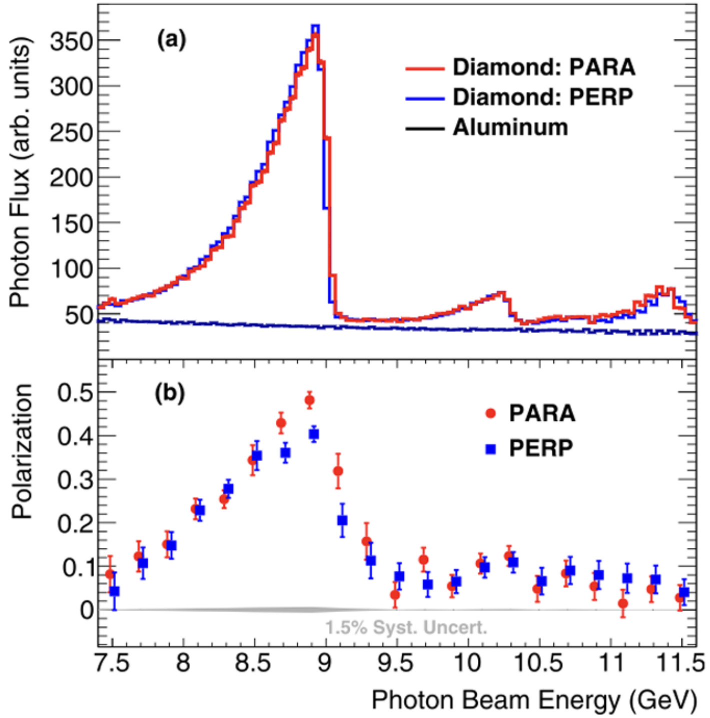
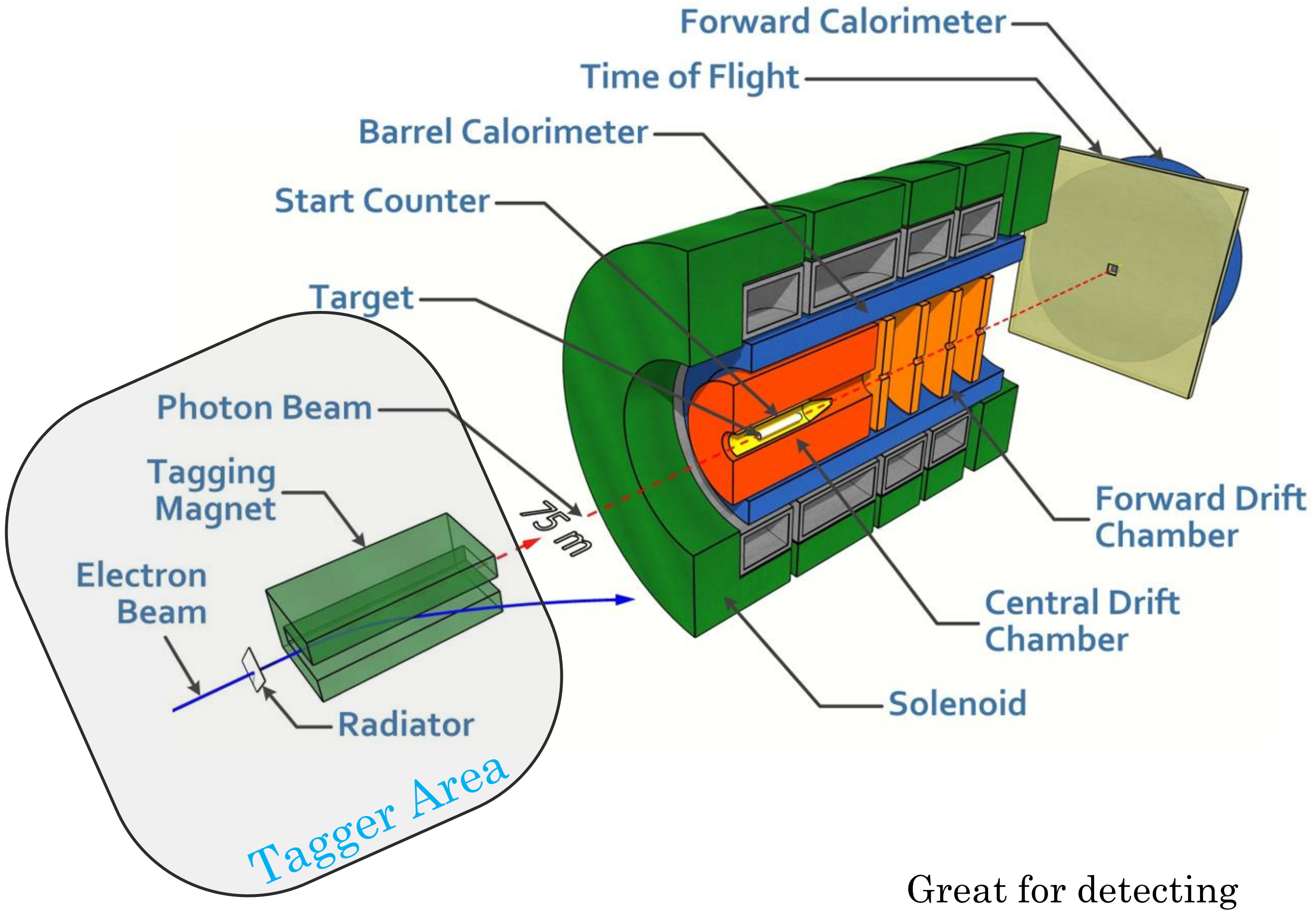
# GlueX in Hall D

- 12 GeV electrons with 4ns beam bunch separation
- Linearly polarized photon beam produced via coherent bremsstrahlung of electrons on a thin ($5x10^{-4}$ X0) diamond radiator.
- Photons are tagged by detecting the electrons in a scintillating detectors (photon tagger).




Great for detecting charged particles and photons in the final states.

- Acceptance: $\theta_{lab} \approx 1^\circ$ - $120^\circ$
- Charged particles: $\sigma_p/p \approx 1\%-3\%$
  - PID using TOF ⊕ dE/dx ⊕ DIRC
- Photons: $\sigma_E/E = 6\% / E \oplus 2\%$

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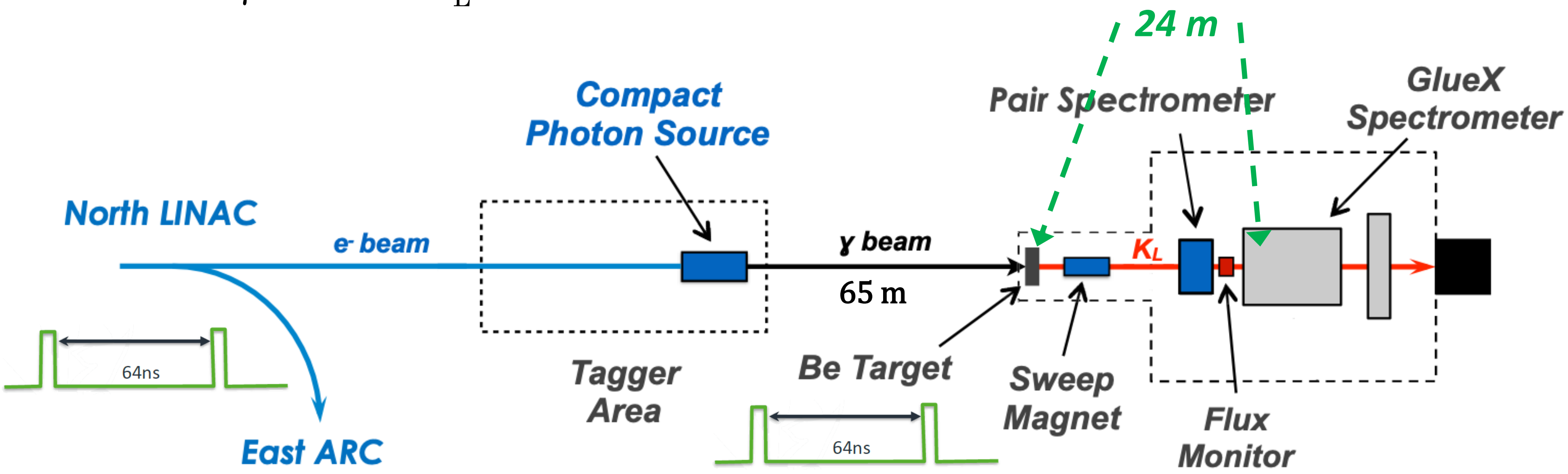
# KLF in Hall D

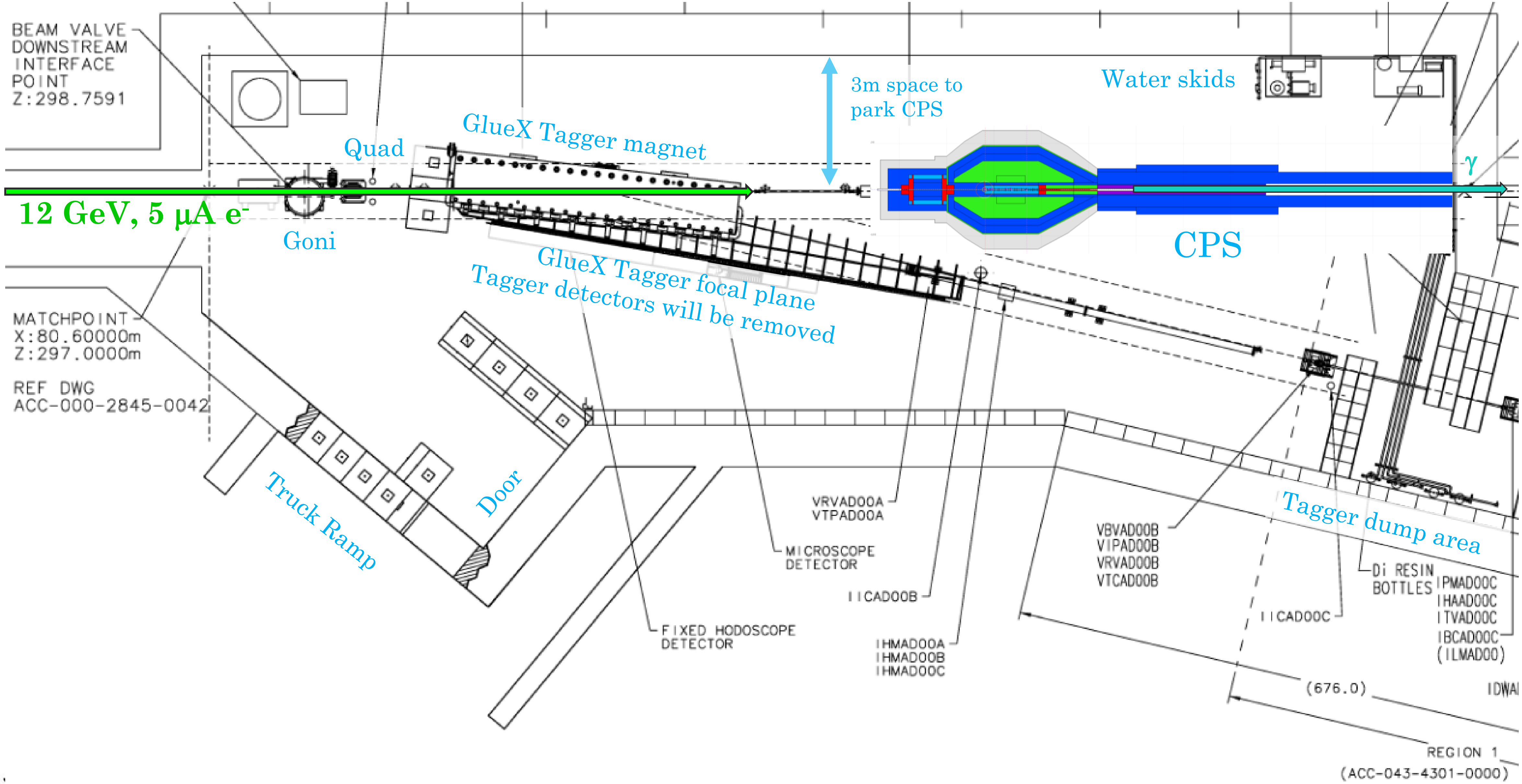
- Use the electron beam delivered to Hall D to produced a high intensity untagged photon beam on ~2% X0 amorphous radiator in the tagger building of Hall D.
- Use a Beryllium target in Hall D collimator cave to produce tertiary beam and absorbed the rest of the beam.
- Use $K_L$ in-flight decays to measure kaon flux in the beamline.
- Tertiary $K_L$ -beam impacts a liquid hydrogen target to produce the final states of interest.
  - LH2 target will need some modifications.
- To determine the momentum of the beam that caused the event in GlueX, KLF will use 64-ns beam structure to allow the low energy kaons to travel the 24m distance between the kaon production point and the hydrogen target.
- Estimated conversion time from γ-beam to $K_L$-beam is ~18 months.

Tertiary beam:

$e^- \longrightarrow \gamma \longrightarrow K_L$

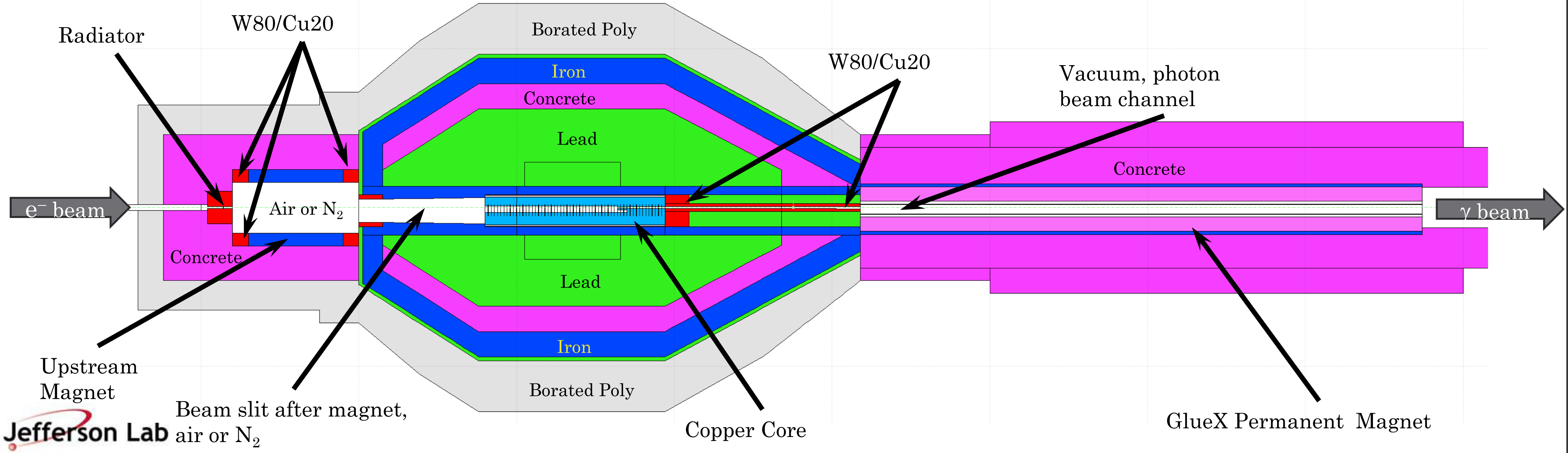


# CPS in Tagger Hall



# Compact Photon Source

- CPS creates intense photon beam for KLF and absorbs the primary electron beam in a cooled copper core.
- Radiator in the upstream section of CPS followed by a horizontally bending magnet.
- Permanent magnet at the exit of CPS to clean up charged particles.
- CPS can be pushed aside for photon beamline restoration.
- CPS shielding is designed to provide radiation environment in the tagger hall with dose rates comparable to nominal GlueX photoproduction experiments.
  - Detail simulations have been done using FLUKA software package to estimate dose rates and power deposition.
- Total estimated weight of CPS is approximately 75 metric tons.
- Estimated cost of the current design is ~$1.2M for CPS.

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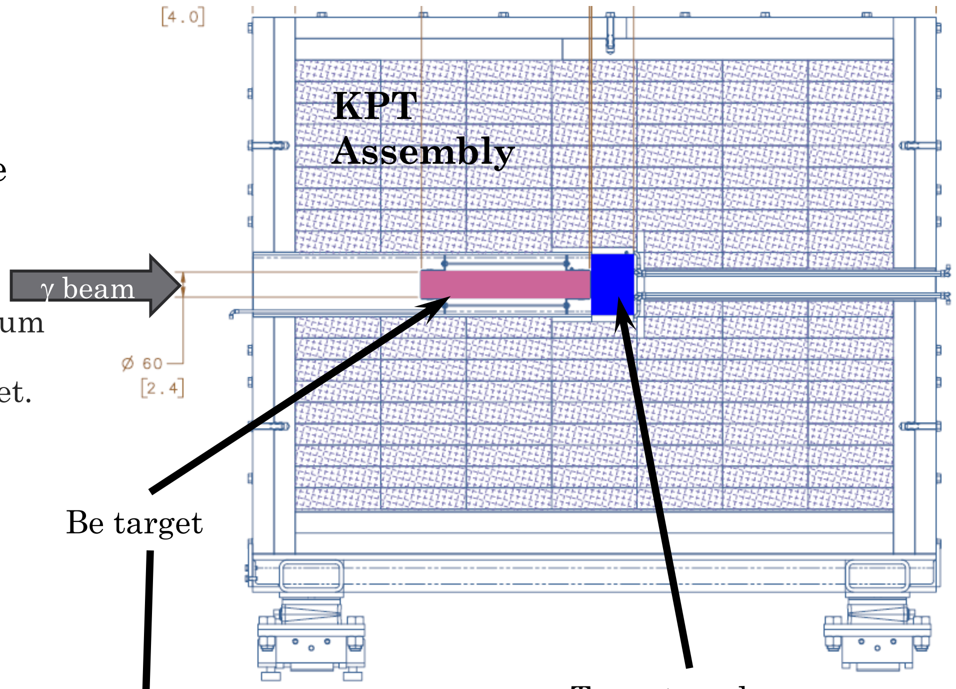
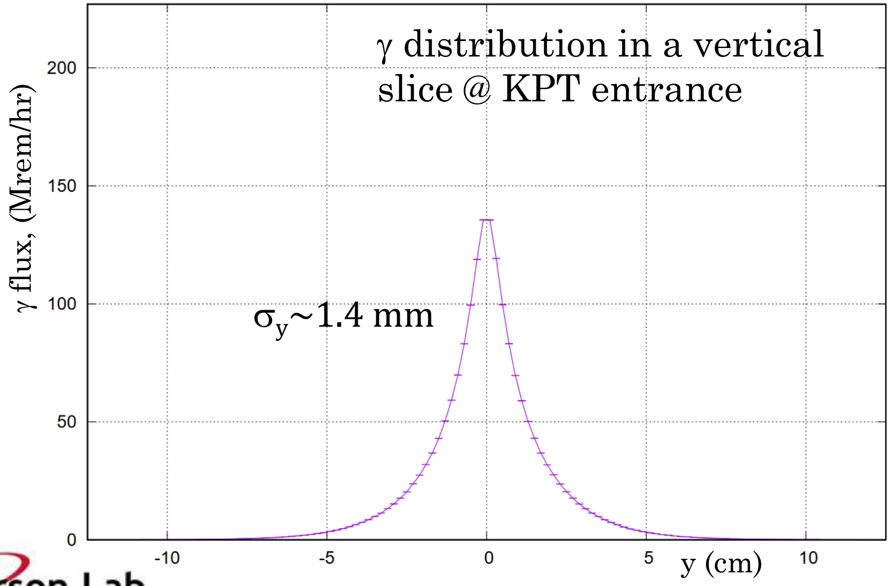
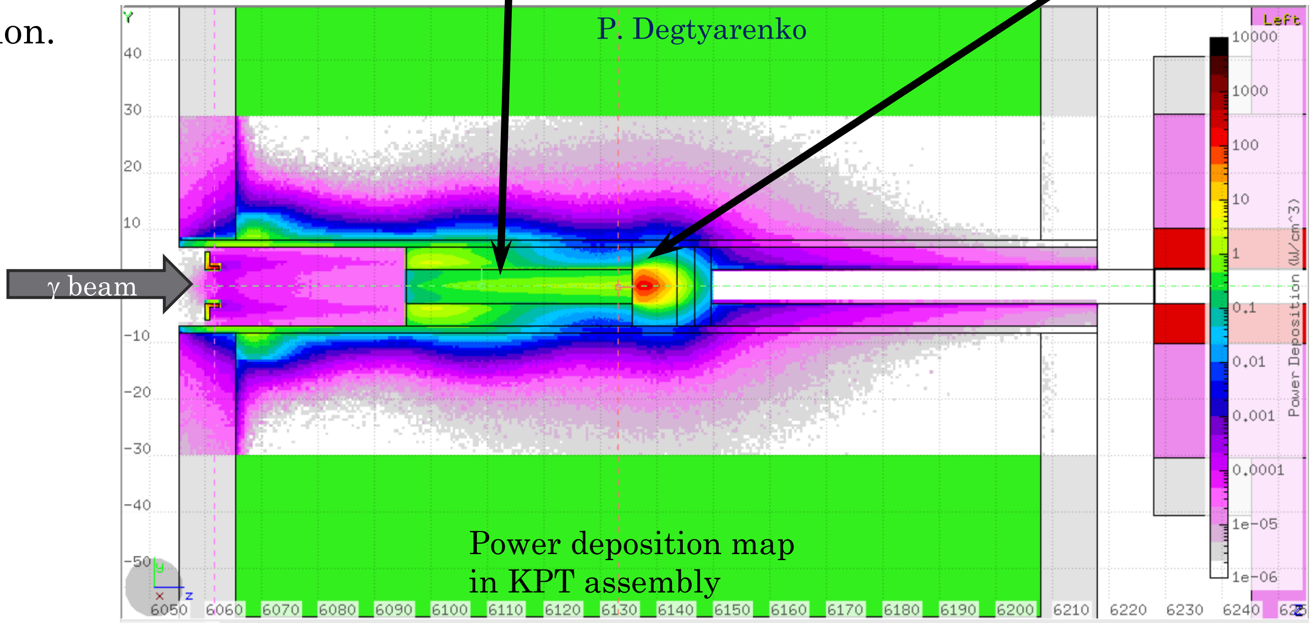
# Kaon Production Target

- Based on our studies, a 40cm long and 6cm wide Beryllium rod would be the optimal choice for producing $K_L$ beam.
- A tungsten plug to stop other particles is expected to be ~14cm.
  - Photons and charged particles are absorbed in a tungsten plug placed after the beryllium target.
  - Significant amount of $K_L$ survive the tungsten plug and the path to the hydrogen target.
- Two magnets after KPT to sweep charged particles out of the beamline.
- Be-target and W-plug are heavily shielded to prevent excessive radiation levels.
- KPT assembly is designed to absorb and dissipate up to 10 KW of power delivered by the photon beam.
- KPT can be pushed aside for photon beamline restoration.



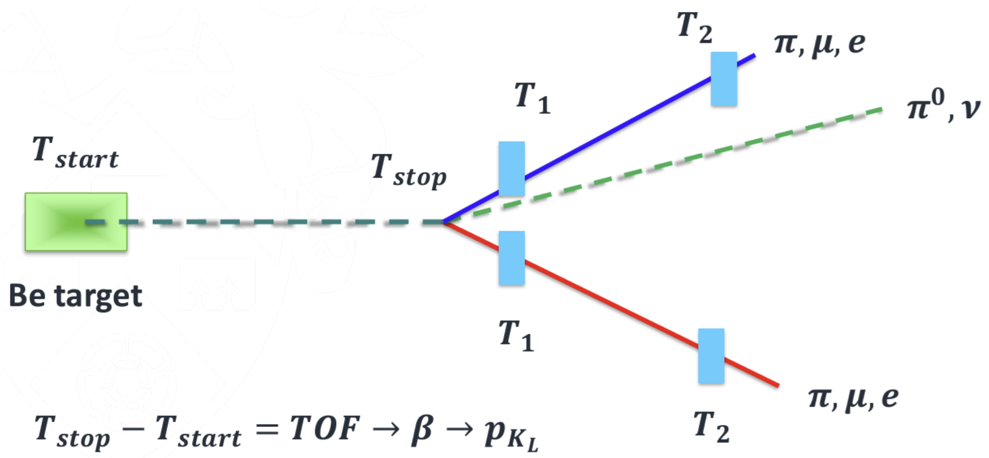
# Kaon Flux Monitor

$K_l \to \pi^{\pm} e^{\mp} \nu_{\mu}$

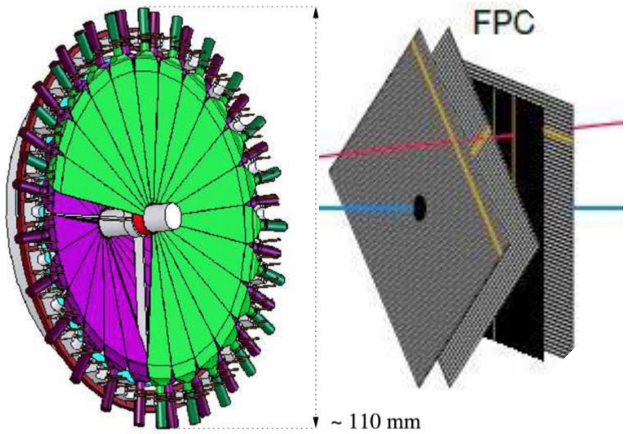
$K_l \to \pi^{\pm} \mu^{\mp} \nu_{\mu}$

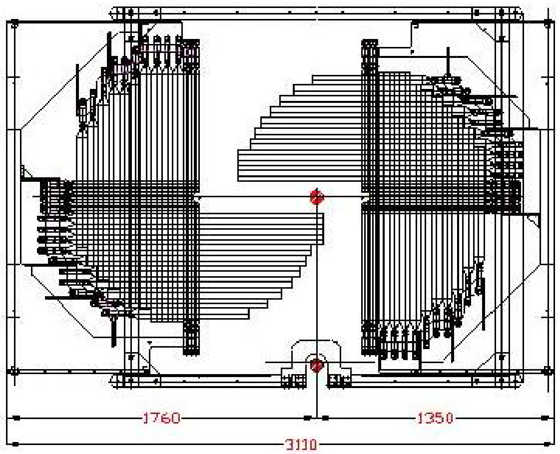
$K_l \to \pi^{+} \pi^{-} \pi^{0}$

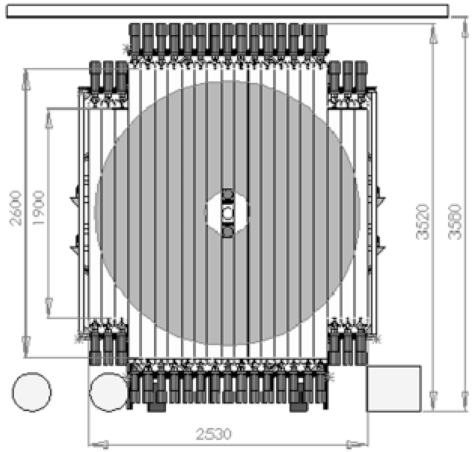
- We can use $K_L$ in-flight decays to measure the KL flux versus momentum and versus transverse position w.r.t beam axis.
  - $K_L$ momentum determined using TOF between KPT and the decay vertex.
- Install Kaon Flux Monitor (KLF) in the location of GlueX Pair Spectrometer.
- We plan to use three separate packages of scintillator detectors, and a tracking system based on straw tubes.
  - All are excess equipment from WASA available free to KLF.




$K_L$ Beam



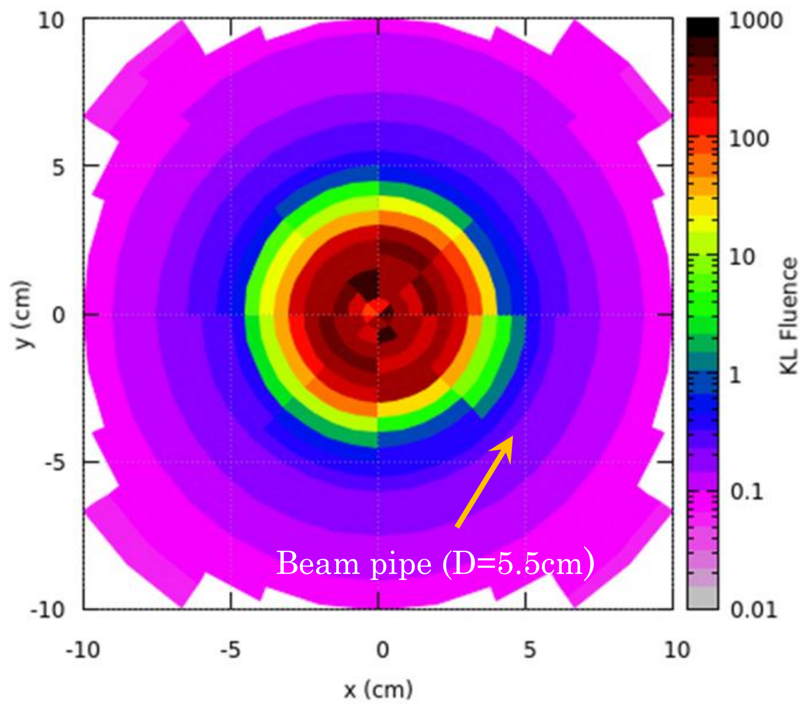




$K_L$ Beam

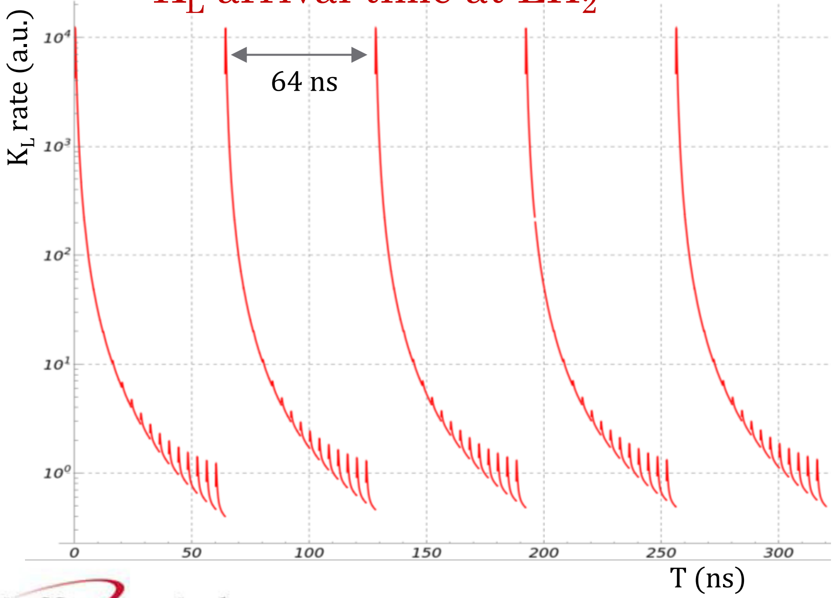
# $K_L$ Beam

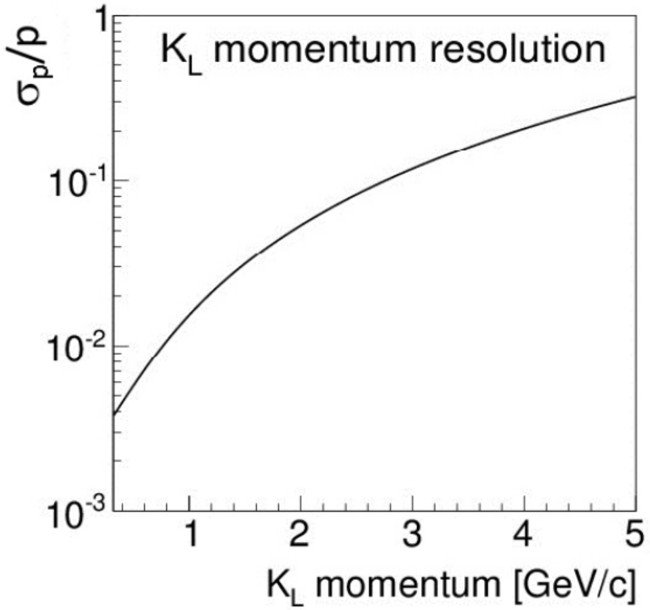
- Kaon beam is mostly constrained to the beam pipe due to the collimation.
- Kaons are created every 64ns – KLF electron beam bunching.
  - Small ~2% bleed-through bunches is expected.
- $K_L$ momentum determined using TOF between KPT and $LH_2$.
  - Above W>2.1 GeV/c², $K_L$ momentum determined using e detected final state.
- We expect neutron background in the beam which should be rejected in the event reconstruction.

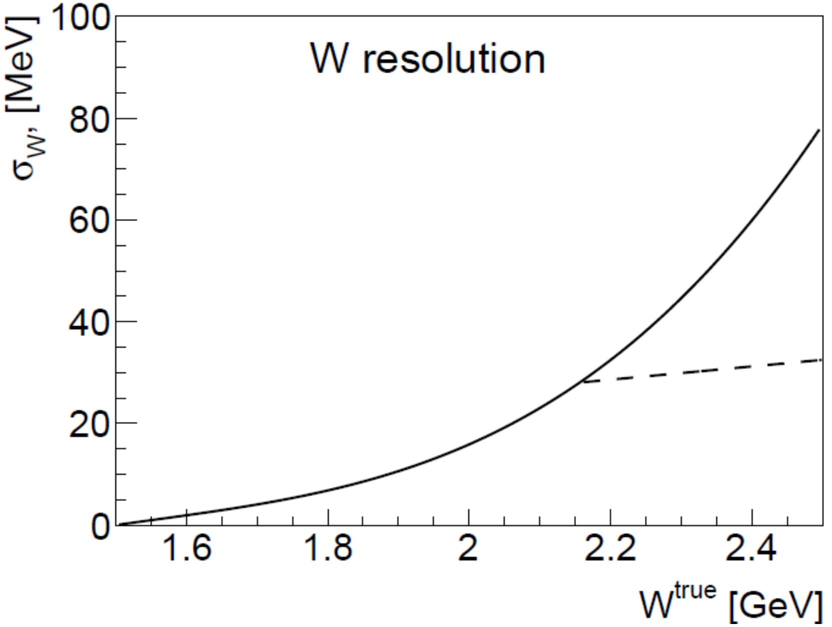
$K_L$ fluence at the $LH_2$ target, P. Degtyarenko




$K_L$ arrival time at $LH_2$

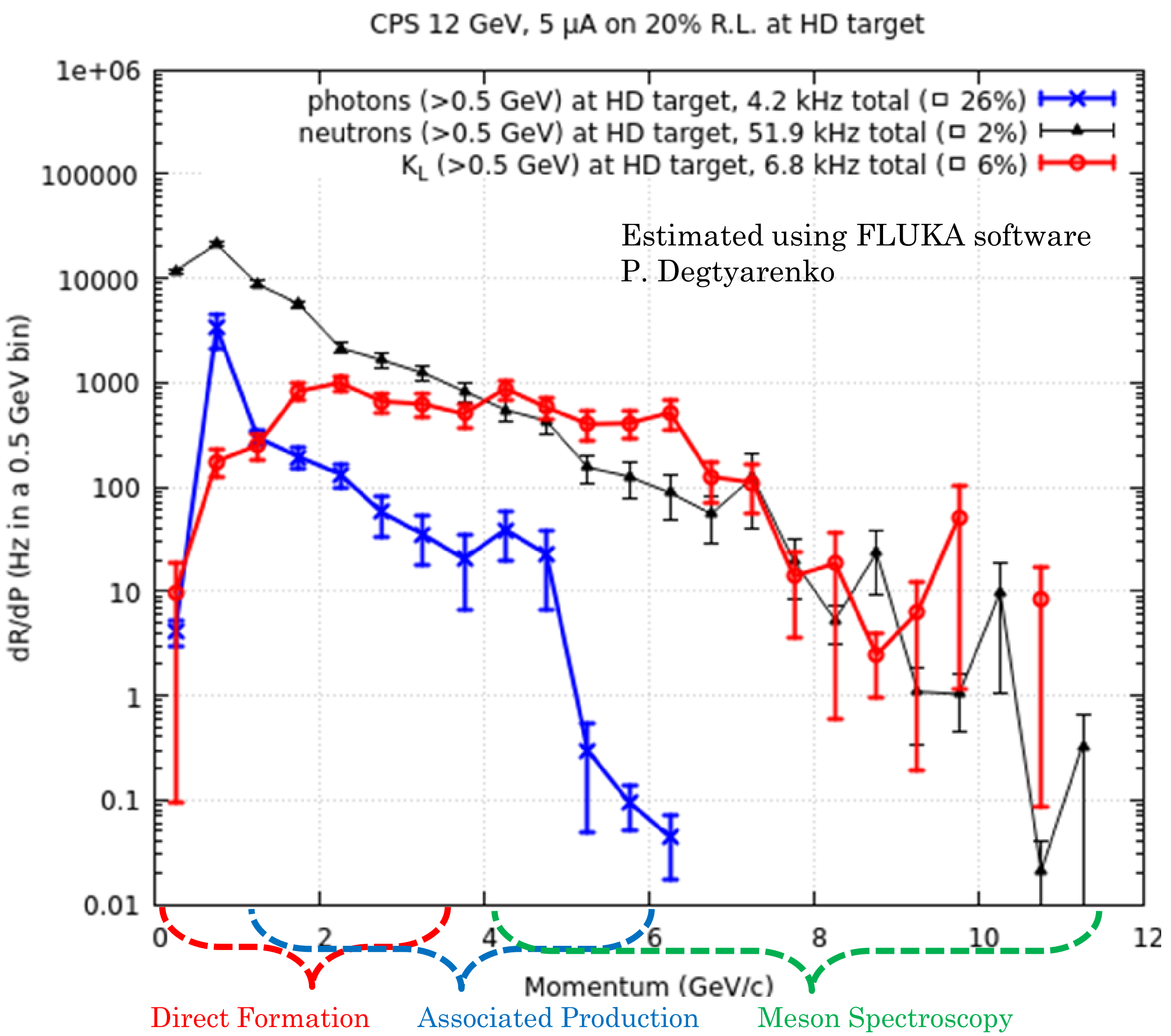


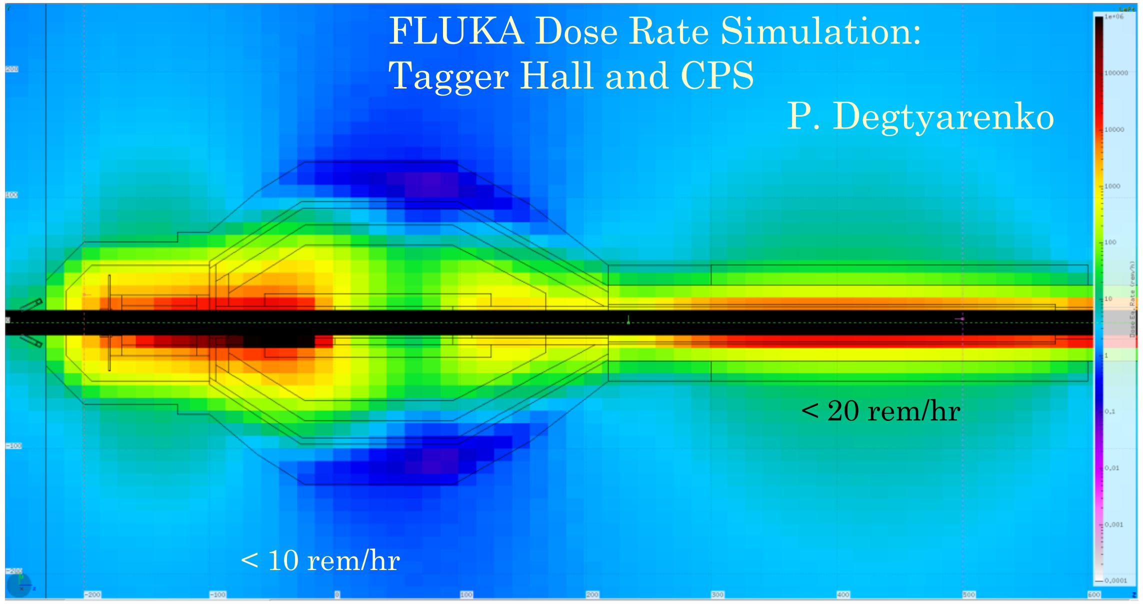
# Beam Particle Spectra

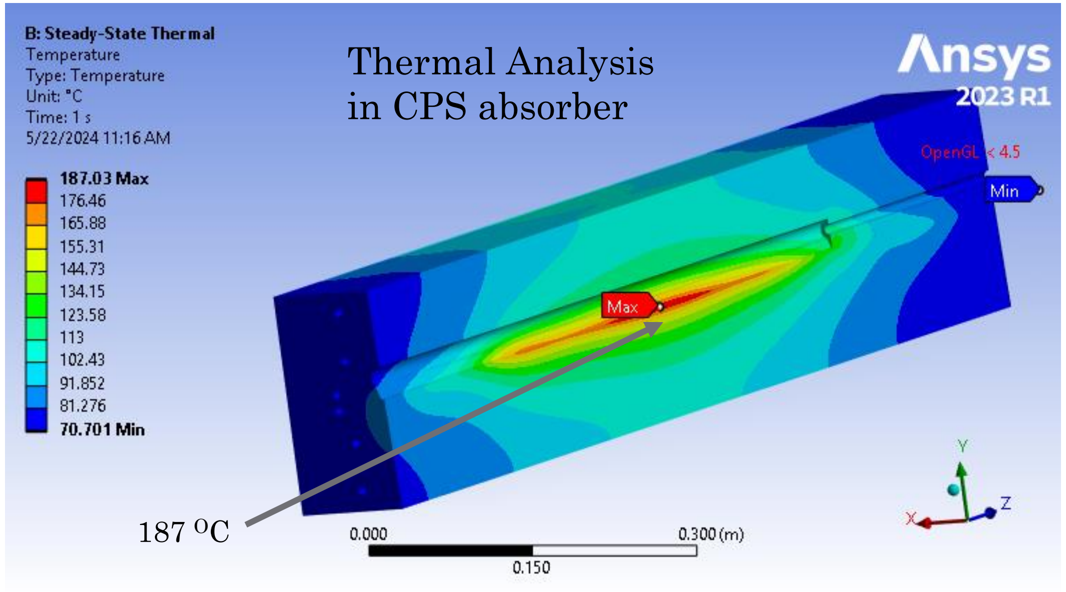
- KLF beam at $LH_2$ target is expected to contain a mix of different kind of particles.
- At low momenta, most of the particles in the beam pipe will be neutrons.
- At high momenta, above 5 GeV/c, we expect mostly $K_L$-s in the beam line.
  - We expect approximately ~10 KHz $K_L$ per second on the $LH_2$ target.
- There is also significant number of muons that originate in the KPT assembly, but they are not constrained to the beam pipe.



# Challenges

- Maintaining radiation environment safe for people and equipment.
  - We perform detailed simulations with FLUKA package to estimate the radiation levels at various beam conditions and adjust our design accordingly.
- Prevent excessive temperatures in CPS that could result in deformation of the photon beam exit channel.
  - Closely monitor beam positions, temperatures in CPS to shut down beam if needed.
- Maintain detector counting rates comparable to those during GlueX-II running.
  - We perform detailed GEANT4 simulations with KLF and GlueX conditions to adjust KLF design parameters.
  - We are considering building a new Start Counter around the target to match the 6cm KLF target diameter.
- Separating out-of-time beam buckets from Hall D laser and bleed-through from other Halls.
  - Simulate various final states with out-of-time beam bunches and physics background channels to evaluate the impact.
  - Initial indication that these should not be a significant problem for $K^+n$ final state.



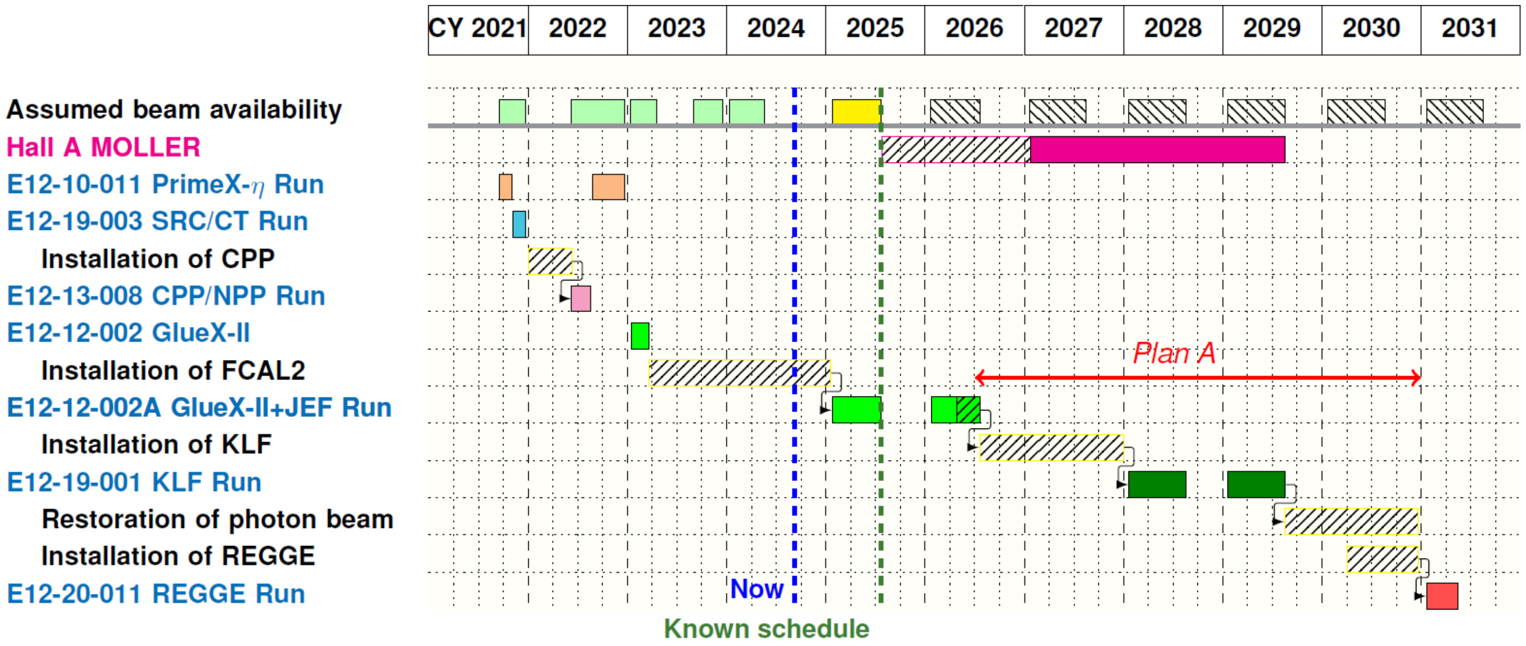

Jefferson Lab

# Status and Timeline

- Conceptual designs of CPS and KPT nearing completion.
  - Some procurements have already started.
- Kaon Flux Monitors detectors physically exist.
  - Need to be shipped from Germany to Jefferson Lab for testing and installations.
- $LH_2$ target requires relatively small modifications
  - Will be constructed by Jefferson Lab target group.
- We are aiming for beginning of KLF installations in the summer of 2026.
  - The experiment would start in the winter of 2028 in this scenario.

- Assumes 25 weeks of CEBAF running in FY25 and 30 weeks afterwards.
- Approved GlueX-III run is not shown

- There are many uncertainties related to the schedule.
  - Funding levels for JLAB
  - Compatibility with MOLLER experiment in Hall A.
  - Available manpower to design and install the new equipment.



# Conclusions and Outlook

- K-Long Facility will be the first hadronic beam experiment at Jefferson Lab.
  - Approved for running for 200 days.
- Data from KLF is expected to make major impact in strangeness physics:
  - identify excited hyperons with masses up to 2.5 GeV/$c^2$ in formation and production reactions,
  - have a significant impact on our knowledge on $K\pi$ scattering amplitudes,
  - improve determination of K*'s parameters, including those for $\kappa^0(700)$.
- Significant progress has been made in the design of KLF equipment.
  - Some technical challenges are being addressed.
- KLF may start running as early as winter of 2028
  - Subject to funding availability and potential scheduling incompatibilities with other experiments.
- New collaborators are welcome !!!
  - This is a good time to join KLF.