# *Physics Perspectives for Future K-Long Facility at JLab*

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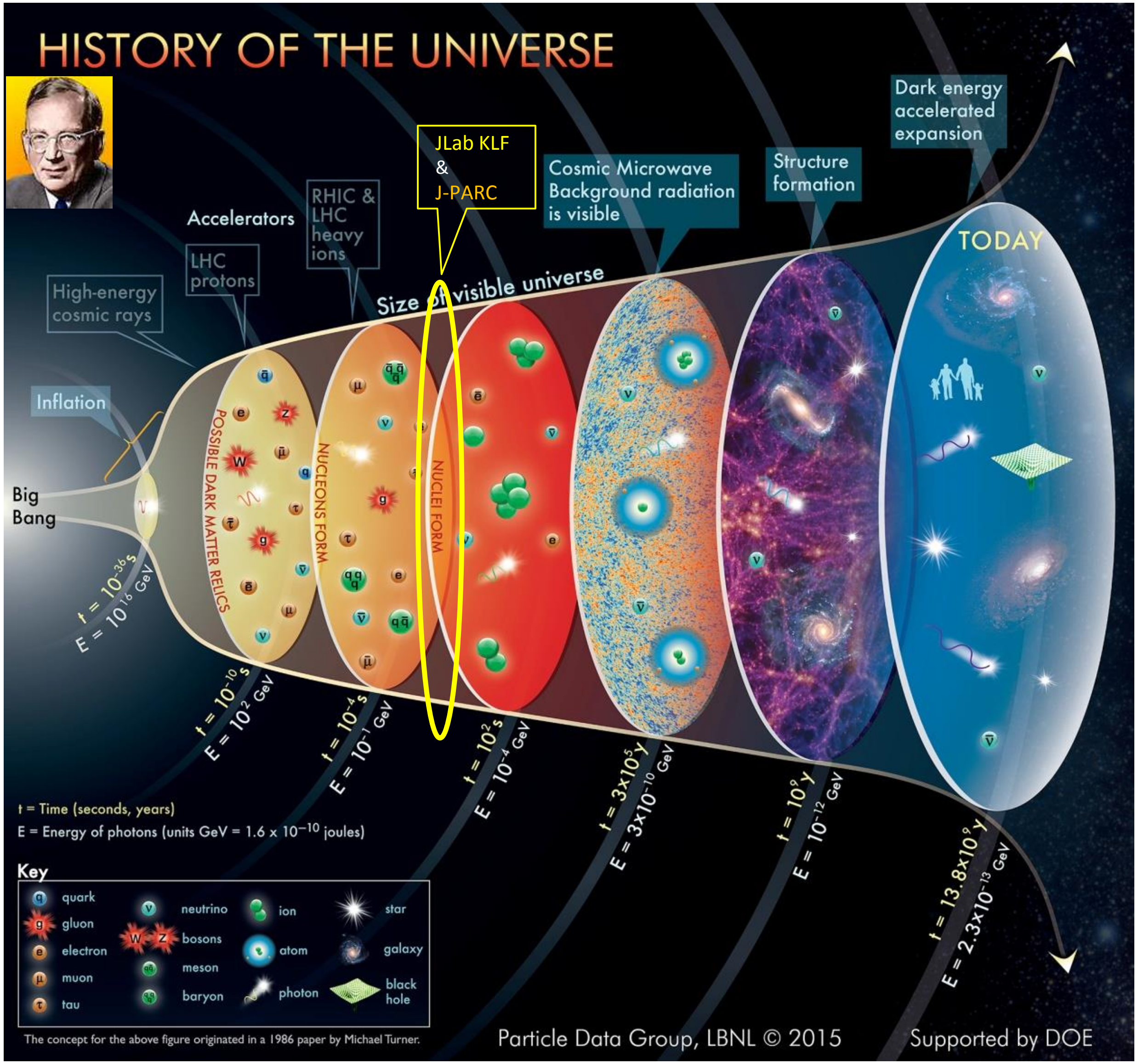
*(for GlueX Collaboration)*

- Thermodynamics at freeze-out
- Spectroscopy of hyperons
- PWA for strange sector
- $K_L p$ database
- Opportunity with $K_L$ beam
- Expected $K_L p$ data
- Summary

[*] Supported by DE-SC0016583

# History of the Universe




- The omission of any ``**missing hyperon states**" in **Standard Model** will negatively impact our understanding of QCD **freeze-out** in heavy-ion & hadron collisions, hadron spectroscopy, & thermodynamics of **early Universe**.

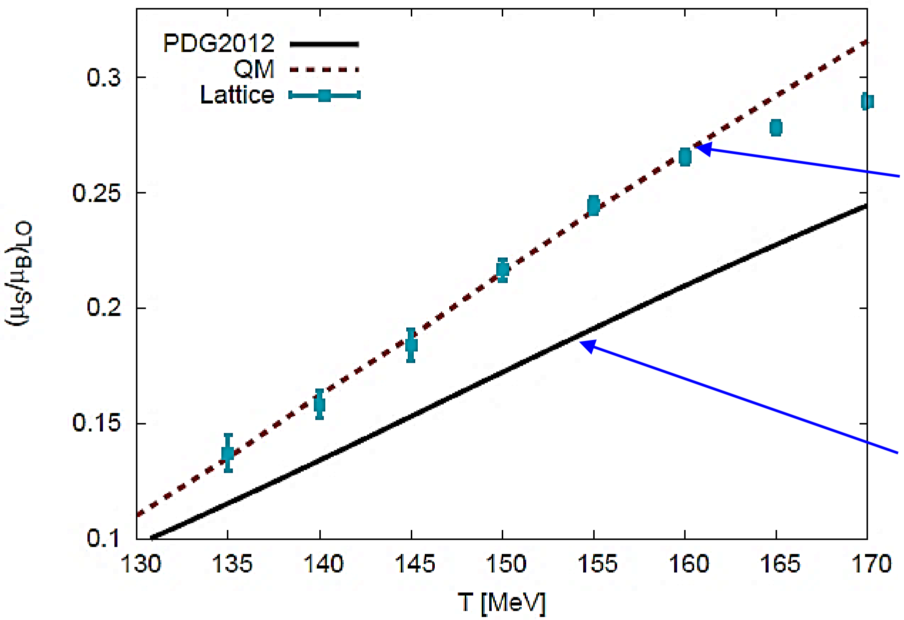
- For that reason, advancing our understanding of formation of **baryons** from quarks & gluons requires new experiments to search for any **missing** hyperon states or resonances.

# *Thermodynamics at Freeze-Out*

- Recent studies that compare **LQCD** calculations of thermodynamic, statistical **Hadron Resonance Gas** models, & ratios between measured yields of different hadron species in heavy ion collisions provide indirect evidence for presence of ``missing” resonances in all of these contexts.

**Chemical Potential**

$$\left(\frac{\mu_S}{\mu_B}\right)_{LO} = -\frac{\chi_{11}^{BS}}{\chi_2^S} - \frac{\chi_{11}^{QS}}{\chi_2^S}\frac{\mu_Q}{\mu_B}$$



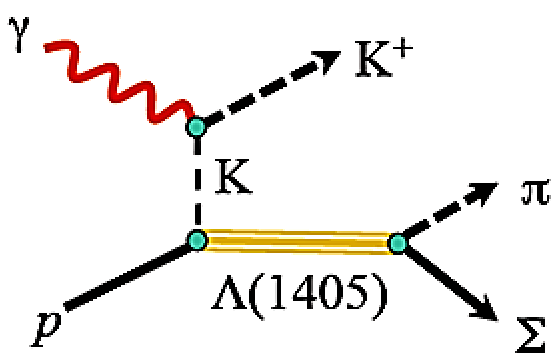

- **+ ``Missing” Hyperons (QM calculations).**
- Contribution from **observed Resonances.**

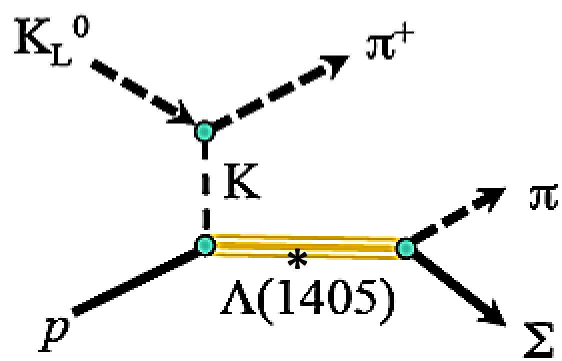
Courtesy of Claudia Ratti, YSTAR2016

# Sample of Hunting for Bumps

## Outlook at GlueX for Λ(1405) Line-Shape Measurement

- That is doable while **PWA** technology is much more promising.

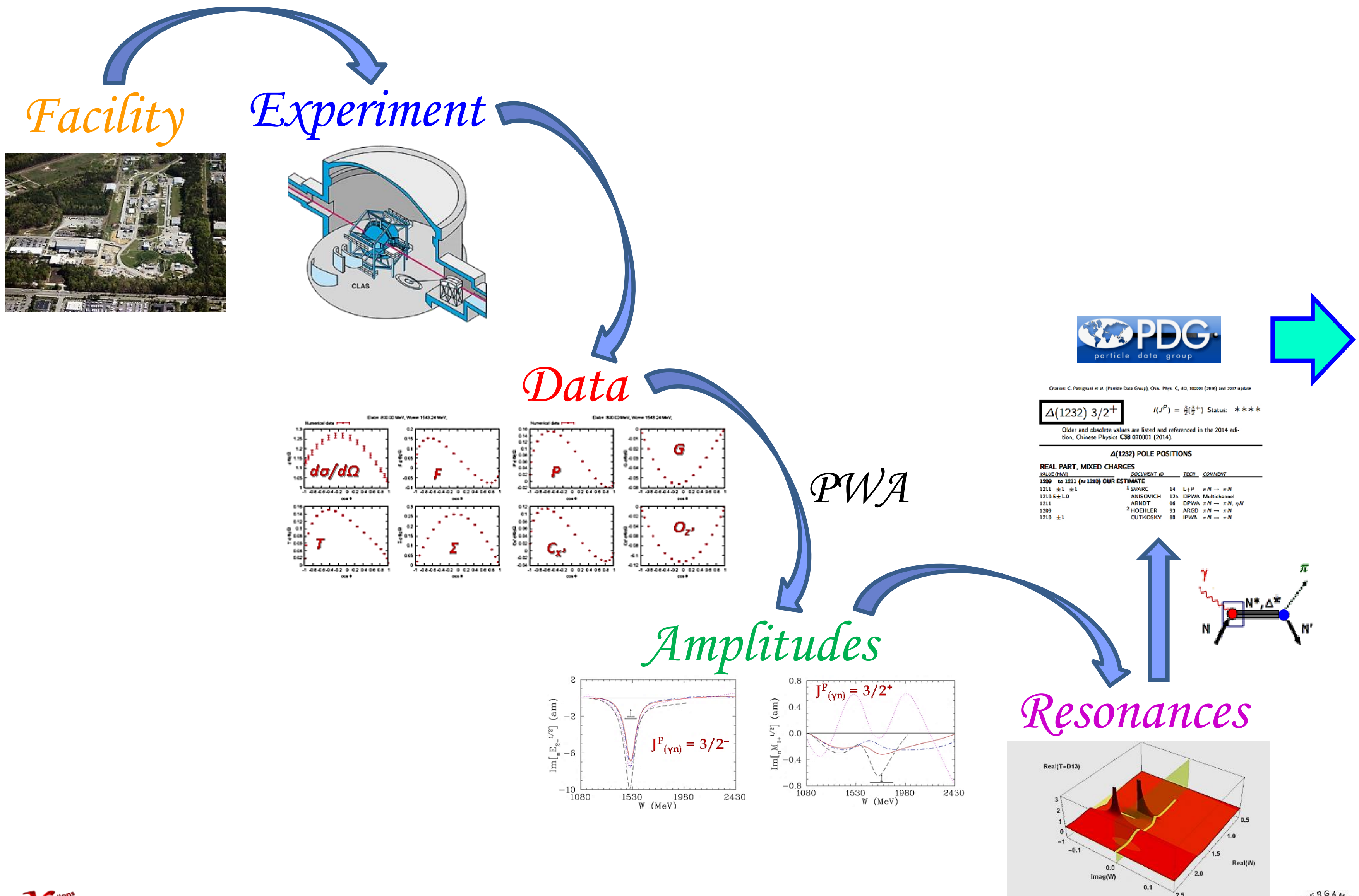



- Measurement may be feasible
- $K_L^0 p \to \Lambda(1405)\pi^+ \to \Sigma^{+0-}\pi^{-0+}\pi^+$

Courtesy of Reinhard Schumacher, KL2016

# Road Map to Baryon Spectroscopy



# *Baryon Sector at PDG16*

## *GW Contribution*

C. Patrignani *et al,* Chin Phys C **40**, 090001 (2016)

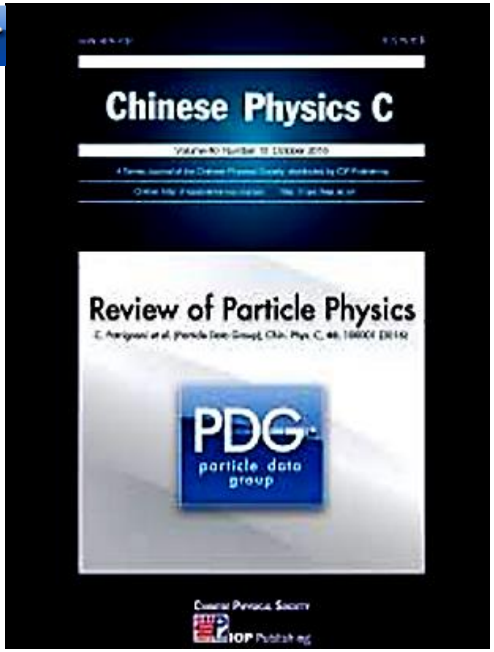
| | | |
|---|---|---|
| p | 1/2+ | **** |
| n | 1/2+ | **** |
| N(1440) | 1/2+ | **** |
| N(1520) | 3/2− | **** |
| N(1535) | 1/2− | **** |
| N(1650) | 1/2− | **** |
| N(1675) | 5/2− | **** |
| N(1680) | 5/2+ | **** |
| N(1685) | | * |
| N(1700) | 3/2− | *** |
| N(1710) | 1/2+ | *** |
| N(172[illegible]) | 3/2+ | [illegible] |
| N(19[illegible]) | 5/2+ | [illegible] |
| N(1[illegible]) | 3/2− | [illegible] |
| N(1[illegible]) | [illegible]/2+ | ** |
| N([illegible]5) | [illegible] | ** |
| N([illegible]00) | [illegible] | *** |
| N([illegible]90) | 7/[illegible] | ** |
| N(2000) | 5/2+ | ** |
| N(2040) | 3/2+ | * |
| N(2060) | 5/2− | ** |
| N(2100) | 1/2+ | * |
| N(2120) | 3/2− | ** |
| N(2190) | 7/2− | **** |
| N(2220) | 9/2+ | **** |
| N(2250) | 9/2− | **** |
| N(2600) | 11/2− | *** |
| N(2[illegible]00) | 13/2+ | ** |

| | | |
|---|---|---|
| Δ(1232) | 3/2+ | **** |
| Δ(1600) | 3/2+ | *** |
| Δ(1620) | 1/2− | **** |
| Δ(1700) | 3/2− | **** |
| Δ(1750) | 1/2+ | * |
| Δ(1900) | 1/2− | ** |
| Δ(1905) | 5/2+ | **** |
| Δ(1910) | 1/2+ | **** |
| Δ(1920) | 3/[illegible] | *** |
| Δ(1930) | [illegible]/2− | *** |
| Δ(1940) | 3/2− | [illegible] |
| Δ(1950) | 7/2+ | **** |
| Δ(20[illegible]0) | 5/2+ | [illegible] |
| Δ([illegible]) | [illegible] | [illegible] |
| Δ(2200) | 7/2− | * |
| Δ(2300) | 9/2+ | ** |
| Δ(2350) | 5/2− | * |
| Δ(2390) | 7/2+ | * |
| Δ(2400) | 9/2− | ** |
| Δ(2420) | 11/2+ | **** |
| Δ(2750) | 13/2− | ** |
| Δ(2950) | 15/2+ | ** |
| Λ | 1/2+ | **** |
| Λ(1405) | 1/2− | **** |
| Λ(1520) | 3/2− | **** |
| Λ(1600) | 1/2+ | *** |
| Λ(1670) | 1/2− | **** |
| Λ(1690) | 3/2− | **** |
| Λ(1800) | 1/2− | [illegible] |
| Λ(1810) | 1/[illegible] | [illegible] |
| Λ(1820) | 5/[illegible]+ | [illegible] |
| Λ(1830) | [illegible]/2− | [illegible] |
| Λ(1890) | 3/2+ | [illegible] |
| Λ(200[illegible]) | [illegible] | [illegible] |
| Λ([illegible]) | 7/2+ | [illegible] |
| Λ(2100) | 7/2− | **** |
| Λ(2110) | 5/2+ | *** |
| Λ(2325) | 3/2− | * |
| Λ(2350) | 9/2+ | *** |
| Λ(2585) | | ** |

| | | |
|---|---|---|
| $\Sigma^+$ | 1/2+ | **** |
| $\Sigma^0$ | 1/2+ | **** |
| $\Sigma^-$ | 1/2+ | **** |
| Σ(1385) | 3/2+ | **** |
| Σ(1480) | | * |
| Σ(1560) | | ** |
| Σ(1580) | 3/2− | * |
| Σ(1620) | 1/2− | ** |
| Σ(1660) | 1/2+ | *** |
| Σ(1670) | 3/2− | **** |
| Σ(1690) | | ** |
| Σ(1750) | [illegible] | [illegible] |
| Σ(1770) | [illegible]2+ | * |
| Σ(1775) | [illegible]− | **** |
| Σ(1840) | [illegible]+ | * |
| Σ(1880) | 1/2+ | ** |
| Σ(191[illegible]) | 5/2+ | [illegible] |
| Σ([illegible]) | [illegible] | *** |
| Σ(2000) | 1/2− | * |
| Σ(2030) | 7/2+ | **** |
| Σ(2070) | 5/2+ | * |
| Σ(2080) | 3/2+ | ** |
| Σ(2100) | 7/2− | * |
| Σ(2250) | | *** |
| Σ(2455) | | ** |
| Σ(2620) | | ** |
| Σ(3000) | | * |
| Σ(3170) | | * |

| | | |
|---|---|---|
| $\Xi^0$ | 1/2+ | **** |
| $\Xi^-$ | 1/2+ | **** |
| Ξ(153[illegible]) | [illegible] | [illegible] |
| Ξ(162[illegible]) | | * |
| Ξ(1690) | | *** |
| Ξ(182[illegible]) | [illegible]/2− | *** |
| Ξ(195[illegible]) | | *** |
| Ξ(2030) | $\geq \frac{5}{2}$? | *** |
| [illegible] | | * |
| Ξ(2250) | | ** |
| Ξ(2370) | | ** |
| Ξ(2500) | | * |
| $\Omega^-$ | 3/2+ | [illegible] |
| Ω([illegible]0)− | | [illegible] |
| Ω([illegible]80)− | | [illegible] |
| Ω([illegible]70)− | | [illegible] |

| | | |
|---|---|---|
| $\Lambda_c^+$ | 1/2+ | **** |
| $\Lambda_c(2595)^+$ | 1/2− | *** |
| $\Lambda_c(2625)^+$ | 3/2− | *** |
| $\Lambda_c(2765)^+$ | | * |
| $\Lambda_c(2880)^+$ | 5/2+ | *** |
| $\Lambda_c(2940)^+$ | | *** |
| $\Sigma_c(2455)$ | 1/2+ | **** |
| $\Sigma_c(2520)$ | 3/2+ | *** |
| $\Sigma_c(2800)$ | | *** |
| $\Xi_c^+$ | 1/2+ | *** |
| $\Xi_c^0$ | 1/2+ | *** |
| $\Xi_c^{\prime +}$ | 1/2+ | *** |
| $\Xi_c^{\prime 0}$ | 1/2+ | *** |
| $\Xi_c(2645)$ | 3/2+ | *** |
| $\Xi_c(2790)$ | 1/2− | *** |
| $\Xi_c(2815)$ | 3/2− | *** |
| $\Xi_c(2930)$ | | * |
| $\Xi_c(2980)$ | | *** |
| $\Xi_c(3055)$ | | ** |
| $\Xi_c(3080)$ | | *** |
| $\Xi_c(3123)$ | | * |
| $\Omega_c^0$ | 1/2+ | *** |
| $\Omega_c(2770)^0$ | 3/2+ | *** |
| $\Xi_{cc}^+$ | | * |
| $\Lambda_b^0$ | 1/2+ | *** |
| $\Sigma_b$ | 1/2+ | *** |
| $\Sigma_b^*$ | 3/2+ | *** |
| $\Xi_b^0, \Xi_b^-$ | 1/2+ | *** |
| $\Omega_b^-$ | 1/2+ | *** |




- First hyperon was discovered in **1947**.

- **Pole** position in complex energy plane for **hyperons** has been made only recently, **first of all** for **Λ(1520)3/2⁻**.

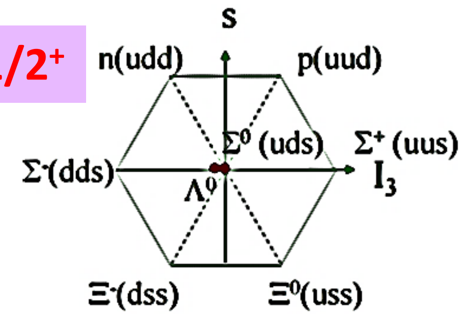
Y. Qung *et al,* Phys Lett B **694**, 123 (2010)

- **PDG16** has **109 Baryon Resonances** (**58** of them are **4*** & **3***).
- In case of **SU(6) X O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

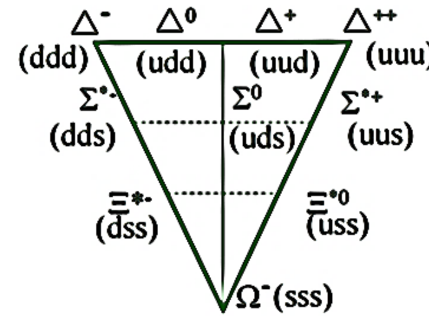
# Baryon Resonances

- **Three light quarks** can be arranged in **6** baryonic **families**, **N***, **Δ***, **Λ***, **Σ***, **Ξ***, & **Ω***.
- **Number of members** in **family** that can exist **is not arbitrary**.
- If **SU(3)$_F$** symmetry of **QCD** is controlling, then:

**1/2$^+$**




**Octet:** **N***, **Λ***, **Σ***, **Ξ***
**Decuplet:** **Δ***, **Σ***, **Ξ***, & **Ω***




**3/2$^+$**

- Number of experimentally identified resonances of each baryon **family** in PDG **Summary Tables** is **16 N***, **10 Δ***, **14 Λ***, **10 Σ***, **6 Ξ***, & **2 Ω***.
- **Constituent Quark** models, for instance, predict existence of no less than **64 N***, **22 Δ*** states with **mass < 3** GeV.

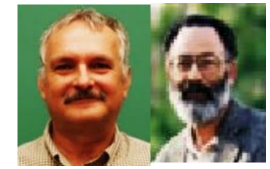
- Seriousness of "**missing-states**" problem is obvious from these numbers.

- To complete **SU(3)$_F$** multiplets, one needs no less than **17 Λ***, **43 Σ***, **42 Ξ***, & **24 Ω***.

B.M.K. Nefkens, πN Newsletter, **14**, 150 (1997)

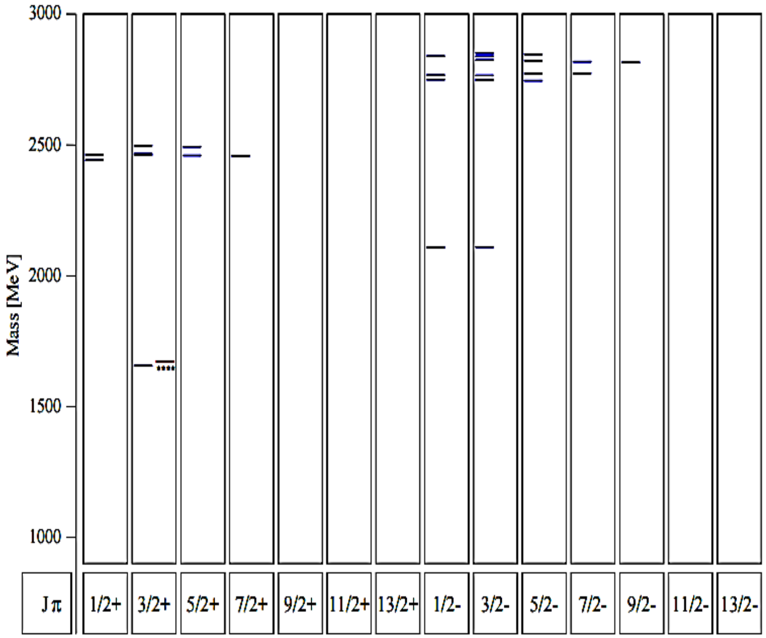
# *Very Strange Resonances & Problem of "Missing" States*

- Experimental **knowledge** of hadron spectrum is **incomplete**: more excited states are expected to exist.



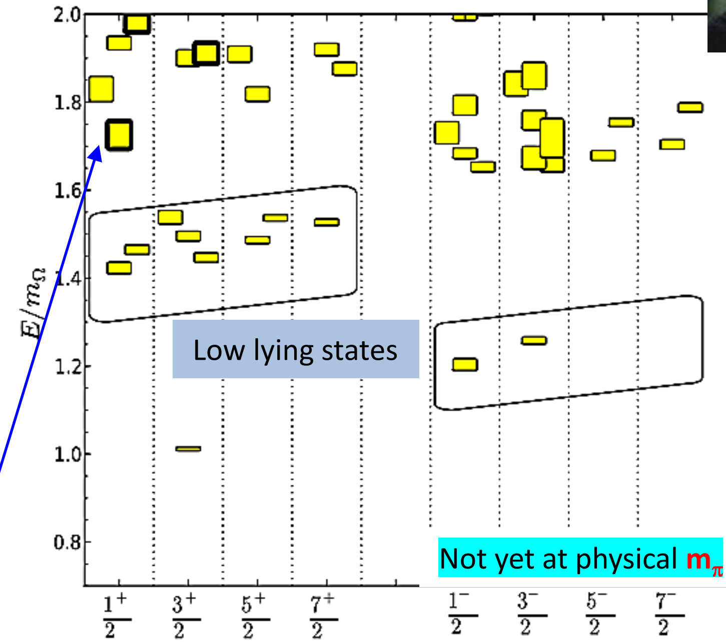
R. Koniuk & N. Isgur, Phys Rev Lett **44**, 845 (1980)

- Ω baryon spectrum in **QM**.




U. Lőring *et al* Eur Phys J A **10**, 447 (2001)

- Ω baryon spectrum in **LQCD**.




R.G. Edwards *et al* Phys Rev D **87**, 054506 (2013)

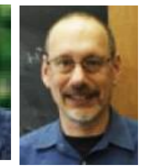
Thick frame: Hybrid states

# What Can Be Learned with $K^0_L$ Beam ?

| | |
|---|---|
| Elastic and charge-exchange | $K^0_L p \to K^0_S p$<br>$K^0_L p \to K^+ n$ |
| Two-body with S=-1 | $K^0_L p \to \pi^+ \Lambda$<br>$K^0_L p \to \pi^+ \Sigma^0$ |
| Two-body with S=-2 | $K^0_L p \to K^+ \Xi^0$<br>$K^0_L p \to K^+ \Xi^{0*}$ |
| Three-body with S=-2 | $K^0_L p \to \pi^+ K^+ \Xi^-$<br>$K^0_L p \to \pi^+ K^+ \Xi^{-*}$ |
| Three-body with S=-3 | $K^0_L p \to K^+ K^+ \Omega^-$<br>$K^0_L p \to K^+ K^+ \Omega^{-*}$ |

# *Why We Have to Measure Double-Strange Cascades in JLab*

- **Heavy quark symmetry** (**Isgur–Wise symmetry**) suggests that multiplet splittings in **strange**, **charm**, & **bottom** **cascades** should scale as approximately inverses of corresponding quark masses, ie,

$$1/m_s : 1/m_c : 1/m_b$$

- If they don't, that scaling failure implies that structures of corresponding states are **anomalous**, & very **different** from one another.

N. Isgur & M.B. Wise, Phys Rev Lett **66** 1130 (1991)

- So far only **hyperon** resonance multiplet, where this scaling can be ``tested" & seen is lowest **negative parity** multiplet:

$$\Lambda(1405)1/2^-–\Lambda(1520)3/2^-, \quad \Lambda_c(2595)1/2^-–\Lambda_c(2625)3/2^-, \quad \Lambda_b(5912)1/2^-–\Lambda_b(5920)3/2^-$$

- It works **approximately** (30%) well for those $\Lambda$-splittings.
  It would work **even better** for $\Xi$, $\Xi_c$, $\Xi_b$ splittings,
  & should be **very good** for $\Omega$, $\Omega_c$, $\Omega_b$ splittings.

Courtesy of Dan-Olof Riska, 2017

- Jefferson Lab (Thomas Jefferson National Accelerator Facility) can do **double cascade** spectrum.
  As LHCb is doing **double charm cascade** spectrum.

$$\Xi_c(2790)1/2^-–\Xi_c(2815)3/2^-$$

R. Aaij *et al*, Phys Rev Lett **119**, 112001 (2017)

# PWA Formalism

- **Differential cross section** & **polarization** for **$K_L p$** scattering are given by

$$\frac{d\sigma}{d\Omega} = \lambda\!\!\!^{-2}\left(|f|^2 + |g|^2\right)$$

$$P\frac{d\sigma}{d\Omega} = 2\lambda\!\!\!^{-2}\,\mathrm{Im}(fg^*)$$

$\lambda\!\!\!^{-} = \hbar/k$ & **k** is momentum of incoming kaon in CM.

**f**(**W**,**θ**) & **g**(**W**,**θ**) are **nonspin–flip** & **spin–flip** amplitudes at **W** & **θ**.

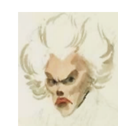
# *Partial-Wave Expansion*

- In terms of partial waves, **f(W,θ)** & **g(W,θ)** can be expanded as

$$f(W,\theta) = \sum_{l=0}^{\infty}[(l+1)T_{l+} + lT_{l-}]P_l(\cos\theta)$$

$$g(W,\theta) = \sum_{l=1}^{\infty}[T_{l+} - T_{l-}]P_l^{1}(\cos\theta)$$

**l** is initial orbital angular momentum.
**$P_l$(cosθ)** is **Legendre** polynomial.
**$P_l'$(cosθ)** is associated **Legendre** function.



Total angular momentum for **$T_{l+}$** is **J**=**l**+**1/2**, while that for **$T_{l-}$** is **J**=**l**–**1/2**.

- Ignoring small **CP**-violating terms (**~$10^{-3}$**), we can write

$$K_L^0 = \frac{1}{\sqrt{2}}(K^0 - \overline{K^0})$$

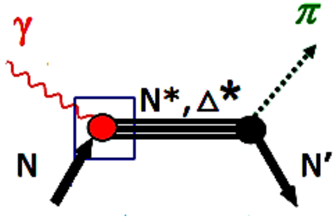
$$K_S^0 = \frac{1}{\sqrt{2}}(K^0 + \overline{K^0})$$

We have both **I = 0** & **I = 1**amplitudes for **KN** & **$\overline{\text{KN}}$** scattering.

Amplitudes **$T_{l+-}$** can be expanded in isospin amplitudes as

$$T_{l\pm} = C_0 T_{l\pm}^0 + C_1 T_{l\pm}^1$$

**$T^I_{l+-}$** are partial-wave amplitudes
with isospin **I** & total angular momentum **J = l+–1/2**
**$C^I$** are appropriate **Clebsch–Gordon** coefficients.




# *Photo-Decay Amplitudes in BW & Pole Forms*

**• Pole is main signature of resonance.**

$$A_h^{BW} = C\sqrt{\frac{q_r}{k_r}\frac{\pi(2J+1)M_r\Gamma_r^2}{m_N\Gamma_{\pi,r}}}\,\tilde{A}_\alpha^h \qquad A_h^{\text{pole}} = C\sqrt{\frac{q_p}{k_p}\frac{2\pi(2J+1)W_p}{m_N\text{Res}_{\pi N}}}\,\text{Res}\,A_\alpha^h$$

**Evaluated at Res Energy**

**Evaluated at Pole**

TABLE I. Breit-Wigner and pole values for selected nucleon resonances. Masses, widths, and residues are given in units of MeV, the helicity 1/2 and 3/2 photo-decay amplitudes in units of $10^{-3}(\text{GeV})^{-1/2}$. Errors on the phases are generally 2–5 degrees. For isospin 1/2 resonances the values of the proton target are given.

| Resonance | Breit-Wigner values | | | | Pole values | | | |
|---|---|---|---|---|---|---|---|---|
| | (Mass, width) | $\Gamma_\pi/2$ | $A_{1/2}$ | $A_{3/2}$ | (Re $W_p$, $-2$ Im $W_p$) | $R_\pi$ | $A_{1/2}$ | $A_{3/2}$ |
| $\Delta(1232)\,3/2^+$ | (1233, 119) | 60 | $-141\pm3$ | $-258\pm5$ | (1211, 99) | 52 [−47°] | $-136\pm5$ [−18°] | $-255\pm5$ [−6°] |
| $N(1440)\,1/2^+$ | (1485, 284) | 112 | $-60\pm2$ | | (1359, 162) | 38 [−98°] | $-66\pm5$ [−38°] | |
| $N(1520)\,3/2^-$ | (1515, 104) | 33 | $-19\pm2$ | $+153\pm3$ | (1515, 113) | 38 [−5°] | $-24\pm3$ [−7°] | $+157\pm6$ [+10°] |
| $N(1535)\,1/2^-$ | (1547, 188) | 34 | $+92\pm5$ | | (1502, 95) | 16 [−16°] | $+77\pm5$ [+4°] | |
| $N(1650)\,1/2^-$ | (1635, 115) | 58 | $+35\pm5$ | | (1648, 80) | 14 [−69°] | $+35\pm3$ [−16°] | |

R.L. Workman *et al*, Phys Rev C **87**, 068201 (2013)

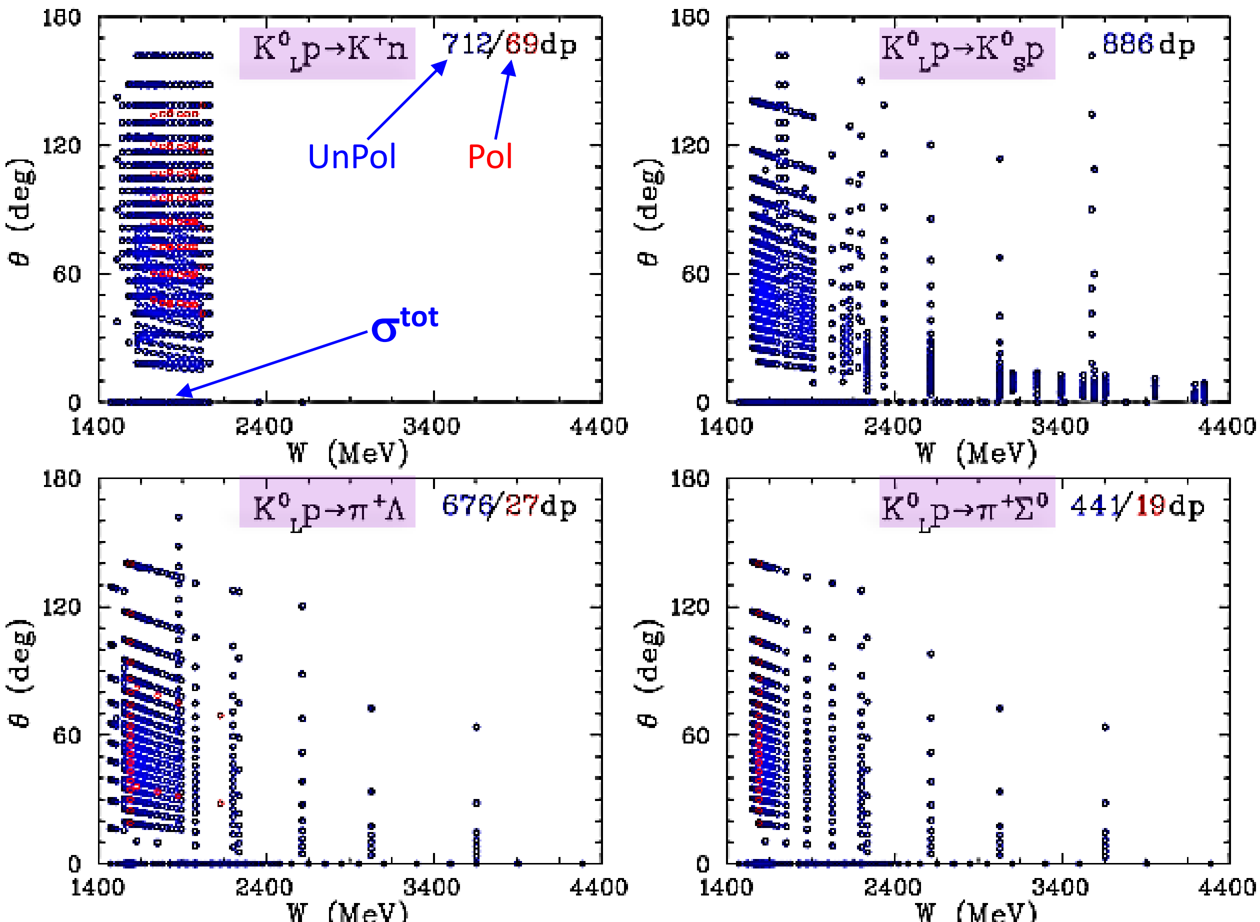
A. Svarc *et al*, Phys Rev C **89**, 065208 (2014)

# World K–long Data – Ground for Hyperon Phenomenology

W = 1.45 – 5.05 GeV

SAID: http://gwdac.phys.gwu.edu/

- Limited number of $K_L$ induced measurements (1961 – 1982) 2426 dσ/dΩ, 348 $\sigma^{tot}$, & 115 P observables do not allow today to feel comfortable with Hyperon Spectroscopy results.




- Limited number of $K_L$ observables in hyperon spectroscopy at present poorly constrain theoretical analyses.
- Overall systematics of previous experiments varies between 15% & 35%. Energy binning is much broader than hyperon widths.
- There were no measurements using polarized target. It means that there are no double polarized observables which are critical for complete experiment program.
- We are not aware of any data on neutron target.

# $KN$ & $\overline{K}N$ Final States

$$T(K^-p \to K^-p) = \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) + \frac{1}{2}T^0(\overline{K}N \to \overline{K}N)$$

$$T(K^-p \to \overline{K^0}n) = \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) - \frac{1}{2}T^0(\overline{K}N \to \overline{K}N)$$

$$T(K^+p \to K^+p) = T^1(KN \to KN)$$

$$T(K^+n \to K^+n) = \frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)$$

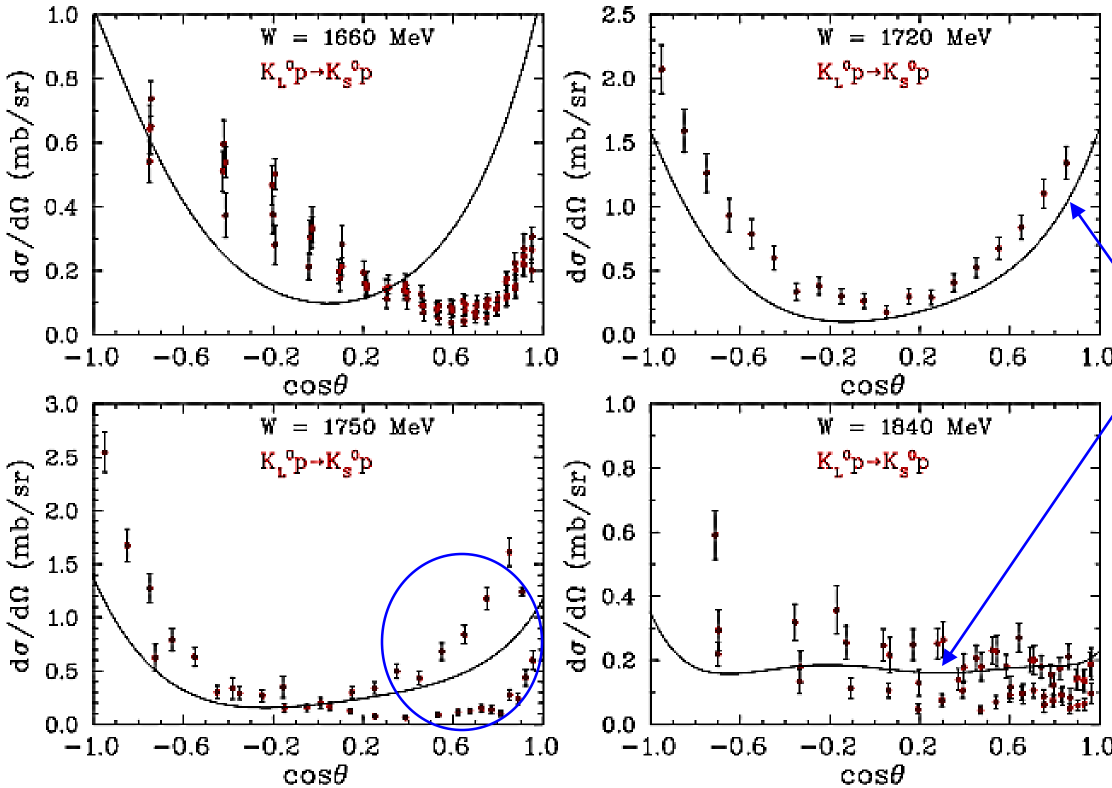
$$T(K_L^0p \to K_S^0p) = \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) - \frac{1}{2}T^1(\overline{K}N \to \overline{K}N)$$

$$T(K_L^0p \to K_L^0p) = \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) + \frac{1}{2}T^1(\overline{K}N \to \overline{K}N)$$

$$T(K_L^0p \to K^+n) = \frac{1}{\sqrt{2}}\left(\frac{1}{2}T^1(KN \to KN) - \frac{1}{2}T^0(KN \to KN)\right) - \frac{1}{2}T^1(\overline{K}N \to \overline{K}N)$$

# *Data for $K_L p \to K_S p$*

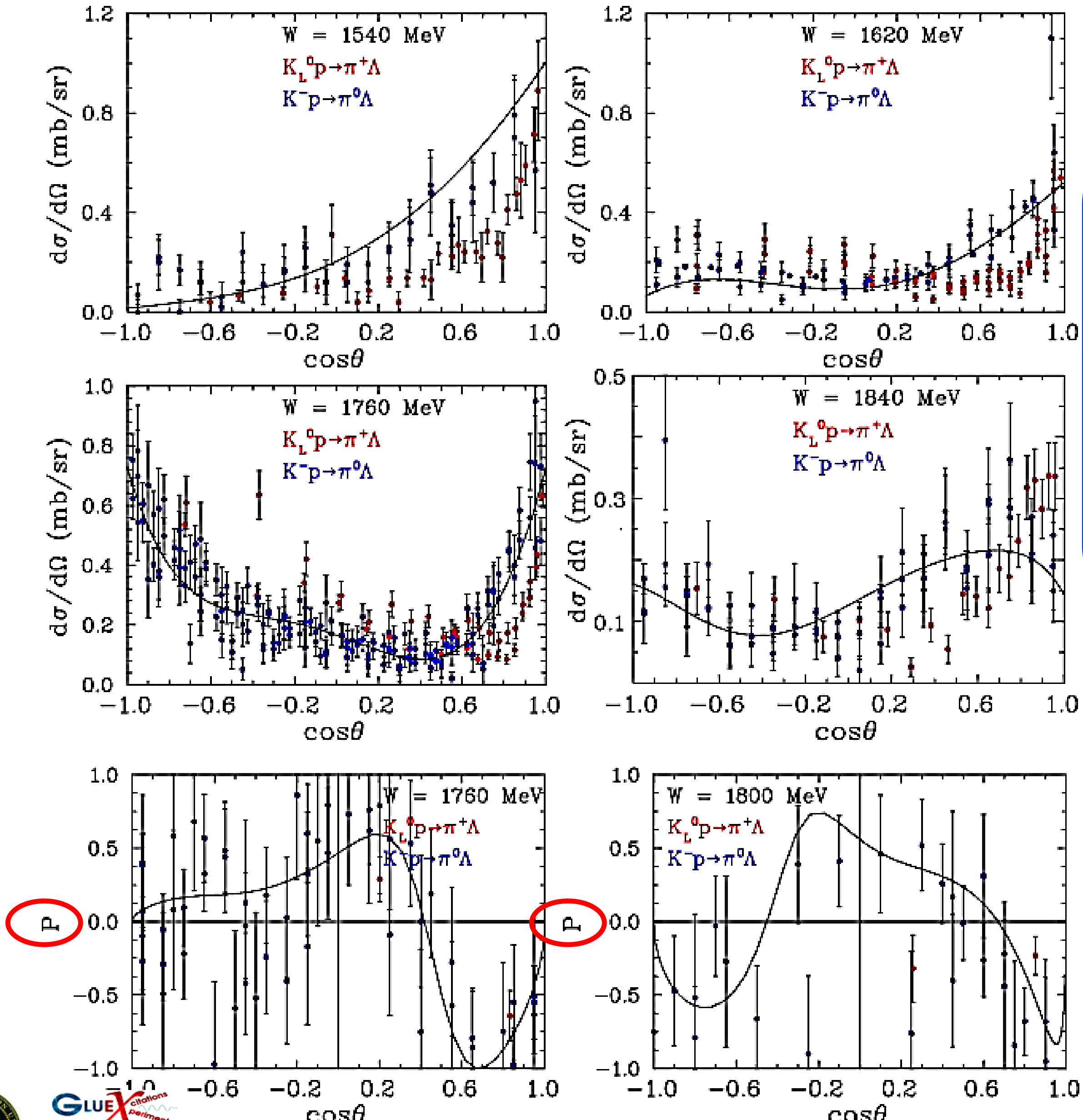
- No **dσ/dΩ** data are available for **$K_L p \to K_L p$** below **W = 3** GeV.




- **PWA** (**KSU**&**GW**) predictions at lower & higher energies have poorer agreement for **S ≠ 0** data than for **S = 0** data.

H. Zhang *et al* Phys Rev C **88**, 035204 (2013)
H. Zhang *et al* Phys Rev C **88**, 035205 (2013)

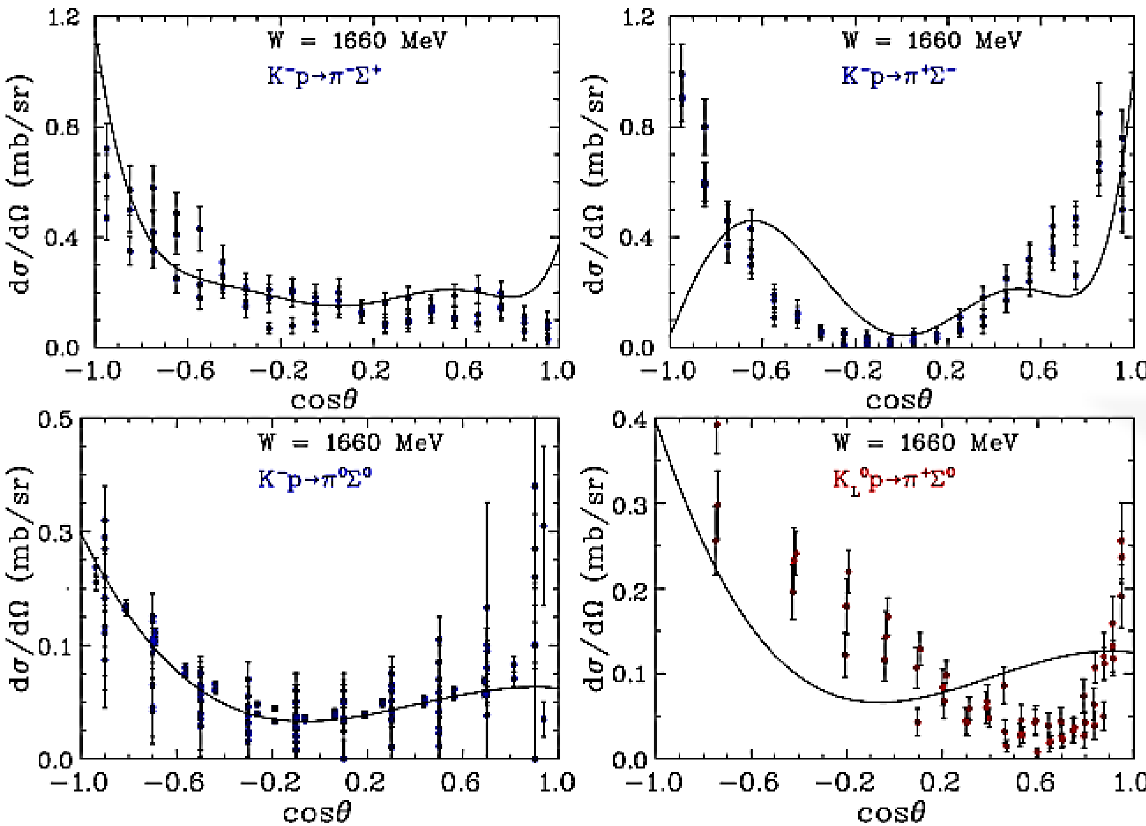
# *Data for* $K_L p \rightarrow \pi^+ \Lambda$ & $K^- p \rightarrow \pi^0 \Lambda$




- $K^- p \rightarrow \pi^0 \Lambda$ & $K_L p \rightarrow \pi^+ \Lambda$ amplitudes imply that their observables measured at same energy should be identical except for small differences due to isospin-violating mass differences in hadrons.

- Polarized measurements are **tolerable** for **any PWA** solutions.

# *Data for* $K_L p \rightarrow \pi^+\Sigma^0$ & $K^- p \rightarrow \pi\Sigma$




- Reactions $K_Lp\rightarrow\pi^+\Sigma^0$ & $K_Lp\rightarrow\pi^0\Sigma^+$ are Isospin selective (only **I = 1** amplitudes are involved) & $K^-p\rightarrow\pi^0\Sigma^0$ isospin selective for **I = 0** whereas reactions $K^-p\rightarrow\pi^-\Sigma^+$ & $K^-p\rightarrow\pi^+\Sigma^-$ involve both **I = 0** & **I = 1** amplitudes.

- New measurements with **$K_L$-beam** would lead to better understanding of **Σ*** states & help constrain **amplitudes** for $K^-p\rightarrow\pi\Sigma$ reactions.

- Quality of **$K_Lp$** data is comparable to that for **$K^-p$** data. It would be advantageous to combine **$K_Lp$** data in new coupled-channel **PWA** with available **$K^-p$** measurements.

- PDG lists only **two** results on **BR** to **KΣ**
  **Λ(2100)7/2⁻** (BR < **3%**)
  **Σ(2030)7/2⁺** (BR < **2%**).

# How to Search for "Missing" Hyperons

- **New data** for inelastic **$K_Lp$** scattering would significantly improve our knowledge of $\Sigma^*$, $\Lambda^*$, & $\Xi^*$ resonances.

- Very few **polarization** data are available for any **$K_Lp$** reactions but are needed to help **remove ambiguities** in **PWA**s.

- To search for ``missing" hyperons, we need measurements of production reactions:

$$
\begin{aligned}
\Sigma^*: &\quad K_L^0 p \to \pi\Sigma^* \to \pi\pi\Lambda \\
\Lambda^*: &\quad K_L^0 p \to \pi\Lambda^* \to \pi\pi\Sigma \\
\Xi^*: &\quad K_L^0 p \to K\Xi^*,\ \pi K\Xi^* \\
\Omega^*: &\quad K_L^0 p \to K^+K^+\Omega^*
\end{aligned}
$$

⟹ Double Strange Cascades

- If such measurements can be performed with good **energy** & **angular** coverage with good **statistics**.

- Then it is very likely that measurements with **$K_L$** beam would find several ``**missing**" **hyperons**.

# *A bit of History*

PHYSICAL REVIEW VOLUME 138, NUMBER 5B 7 JUNE 1965

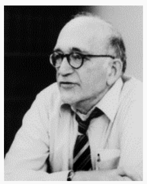
First paper on subject

CP-violation (1964)
Hot topic!

## Photoproduction of Neutral *K* Mesons*

S. D. DRELL AND M. JACOB†
*Stanford Linear Accelerator Center, Stanford University, Stanford, California*

(Received 6 January 1965)



Photoproduction of a neutral $K$-meson beam at high energies from hydrogen is computed in terms of a $K^*$ vector-meson exchange mechanism corrected for final-state interactions. The results are very encouraging for the intensity of high-energy $K_2$ beams at high-energy electron accelerators. A typical magnitude is 20 μb/sr for a lower limit of the $K^0$ photoproduction differential cross section, at a laboratory peak angle of 2°, for 15-BeV incident photons.

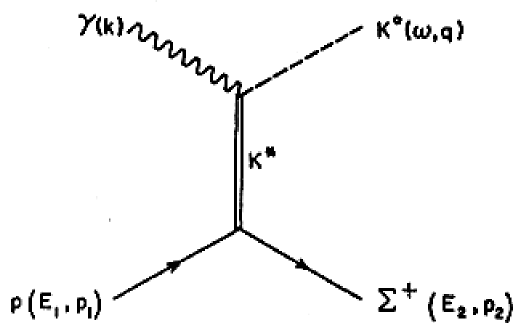



FIG. 1. $K^*$ exchange in photoproduction.

[Not dominant]

Our motivation in carrying out this calculation is to emphasize the strong suggestion that an intense "healthy" $K_2$ beam will emerge from high-energy electron accelerators (SLAC in particular) and will be available for detailed experimental studies.

50 μb/sr

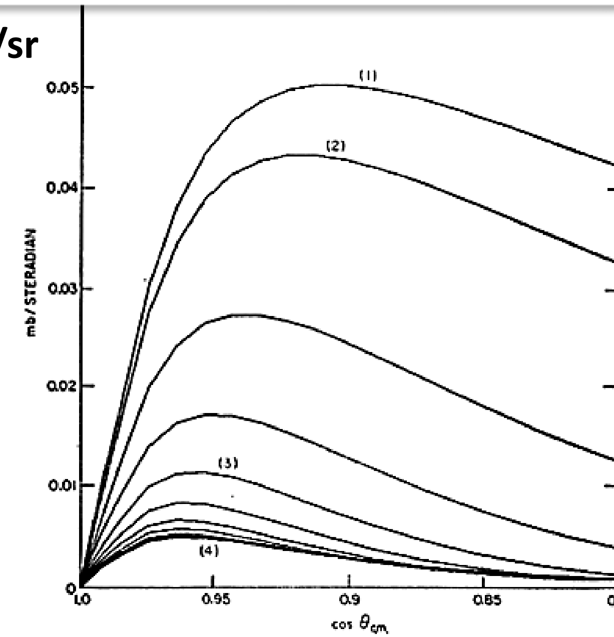



FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partial have been corrected for absorption in final state. The resu shown as directly obtained from and drawn by the comput

Courtesy of Mike Albrow, KL2016

# *A bit of History*

The possibility that useful $K_L$ beam could be made at electron synchrotron by photoproduction was being considered, & 1965 prediction for SLAC by Drell & Jacob was optimistic.

8.B.5
8.B.6

Nuclear Physics B2? (1970) 509-524. North-Holland Publishing Company

PHOTOPRODUCTION OF $K^0$ MESONS FROM PROTONS AND FROM COMPLEX NUCLEI

M. G. ALBROW ‡, D. ASTON, D. P. BARBER, L. BIRD ‡‡,
R. J. ELLISON, C. HALLIWELL, A. E. HARCKHAM ‡‡‡,
F. K. LOEBINGER, P. G. MURPHY, J. WALTERS ‡‡ and A. J. WYNROE
*Schuster Laboratories, The University of Manchester, Manchester M13 9PL*
R. F. TEMPLEMAN
*Daresbury Nuclear Physics Laboratory, Daresbury, Near Warrington, Lancs.*

Received 16 July 1970

Sci-Tech DARESBURY

*"We were at Manchester Univ. close to Daresbury **5** GeV e-synchrotron."*

CP-violation

VOLUME 22, NUMBER 18 PHYSICAL REVIEW LETTERS 5 MAY 1969

PRODUCTION OF $K_2^0$ MESONS AND NEUTRONS BY 10- AND 16-GeV ELECTRONS ON BERYLLIUM*

A. D. Brody, W. B. Johnson, D. W. G. S. Leith, G. Loew, J. S. Loos, G. Luste, R. Miller,
K. Moriyasu, B. C. Shen, W. M. Smart, and R. Yamartino
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

(Received 13 March 1969)

SLAC NATIONAL ACCELERATOR LABORATORY

Systematics of particle anti-particle processes through intrinsic property of K-longs.

Proposal for JLab PAC46

PR12–17–001

## Strange Hadron Spectroscopy with a Secondary $K_L$ Beam at GlueX

S. Adhikari[12], H. Al Ghoul[13], A. Ali[17], M. J. Amaryan[40,*,†], E. G. Anassontzis[2],
A. V. Anisovich[20,14], A. Austregesilo[22], M. Baalouch[40], F. Barbosa[22], A. Barnes[9],
M. Bashkanov[10,†], T. D. Beattie[44], R. Bellwied[21], V. V. Berdnikov[37], T. Black[41], W. Boeglin[12],
W. J. Briscoe[15], T. Britton[22], W. K. Brooks[46], B. E. Cannon[13], E. Chudakov[22], P. L. Cole[23],
V. Crede[13], M. M. Dalton[22], A. Deur[22], P. Degtyarenko[22], S. Dobbs[42], G. Dodge[40],
A. G. Dolgolenko[29], M. Döring[15,22], M. Dugger[1], R. Dzhygadlo[17], R. Edwards[22], H. Egiyan[22],
S. Eidelman[4,31], A. Ernst[13], A. Eskandarian[15], P. Eugenio[13], C. Fanelli[25], S. Fegan[26],
A. M. Foda[44], J. Frye[24], S. Furletov[22], L. Gan[41], A. Gasparian[39], G. Gavalian[22],
V. Gauzshtein[47,48], N. Gevorgyan[50], D. I. Glazier[16], K. Goetzen[17], J. Goity[22,21],
V. S. Goryachev[29], L. Guo[12], H. Haberzettl[15], M. Hadžimehmedović[49], H. Hakobyan[46],
A. Hamdi[17], S. Han[53], J. Hardin[25], A. Hayrapetyan[19], T. Horn[7], G. M. Huber[44], C. E. Hyde[40],
D. G. Ireland[16], M. M. Ito[22], B. C. Jackson[18], N. S. Jarvis[6], R. T. Jones[9], V. Kakoyan[50],
G. Kalicy[7], M. Kamel[12], C. D. Keith[22], C. W. Kim[15], F. J. Klein[15], C. Kourkoumeli[2],
S. Kuleshov[46], I. Kuznetsov[47,48], A. B. Laptev[30], I. Larin[29], D. Lawrence[22], M. Levillain[39],
W. I. Levine[6], K. Livingston[16], G. J. Lolos[44], V. E. Lyubovitskij[47,48,23,46], D. Mack[22], M. Mai[15],
D. M. Manley[27], U.-G. Meißner[20,54], H. Marukyan[50], V. Mathieu[24], P. T. Mattione[22],
M. Matveev[14], V. Matveev[29], M. McCaughan[22], M. McCracken[6], W. McGinley[6], J. McIntyre[9],
C. A. Meyer[6], R. Miskimen[24], R. E. Mitchell[24], F. Mokaya[9], V. Mokeev[22], K. Nakayama[18],
F. Nerling[17], Y. Oh[28], H. Osmanović[49], A. I. Ostrovidov[13], R. Omerović[49], Z. Papandreou[44],
K. Park[22], E. Pasyuk[22], M. Patsyuk[25], P. Pauli[16], R. Pedroni[39], M. R. Pennington[16], L. Pentchev[22],
K. J. Peters[17], W. Phelps[15], E. Pooser[22], B. Pratt[9], J. W. Price[5], N. Qin[53], J. Reinhold[12],
D. Richards[22], D.-O. Riska[11], B. G. Ritchie[1], J. Ritman[3,26,†], L. Robison[42], D. Romanov[37],
H-Y. Ryu[43], C. Salgado[38], E. Santopinto[25], A. V. Sarantsev[20,14], R. A. Schumacher[6],
C. Schwarz[17], J. Schwiening[17], A. Semenov[44], I. Semenov[44], K. K. Seth[42], M. R. Shepherd[24],
E. S. Smith[22], D. I. Sober[7], D. Sokhan[16], A. Somov[22], S. Somov[37], O. Soto[46], N. Sparks[1],
J. Stahov[49], M. J. Staib[6], J. R. Stevens[51,†], I. I. Strakovsky[15,†], A. Subedi[34], A. Švarc[45],
A. Szczepaniak[24,22], V. Tarasov[29], S. Taylor[22], A. Teymurazyan[44], A. Tomaradze[42], A. Tsaris[13],
G. Vasileiadis[2], D. Watts[10], D. Werthmüller[16], N. Wickramaarachchi[40], T. Whitlatch[22],
M. Williams[25], B. Wojtsekhowski[22], R. L. Workman[15], T. Xiao[42], Y. Yang[25], N. Zachariou[10],
J. Zarling[24], Z. Zhang[53], B. Zou[8], J. Zhang[52], X. Zhou[53], B. Zihlmann[22]

- **177** people from **54** institutes are co-authors.

**Hyperon & Strange Meson Spectroscopy**

- We plan to resubmit full **Proposal** for **JLab PAC46** in **2018**.

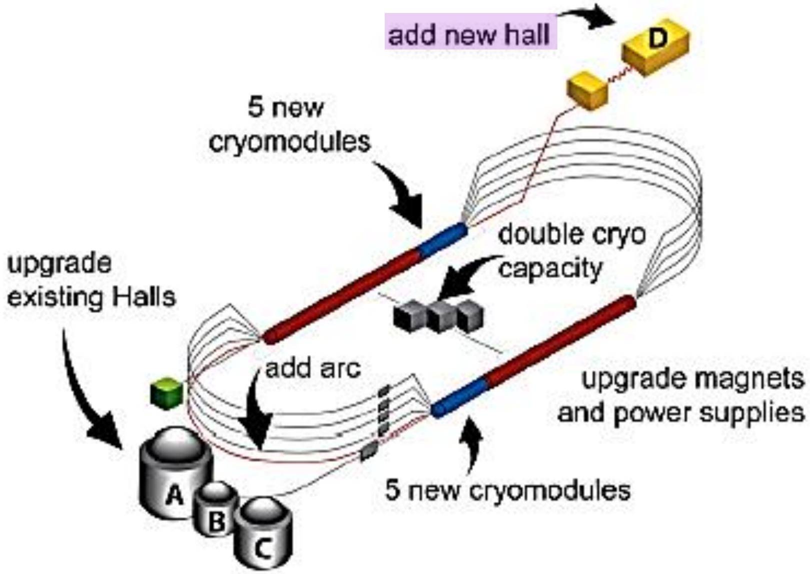
# *Aims of Jlab KLF Project*

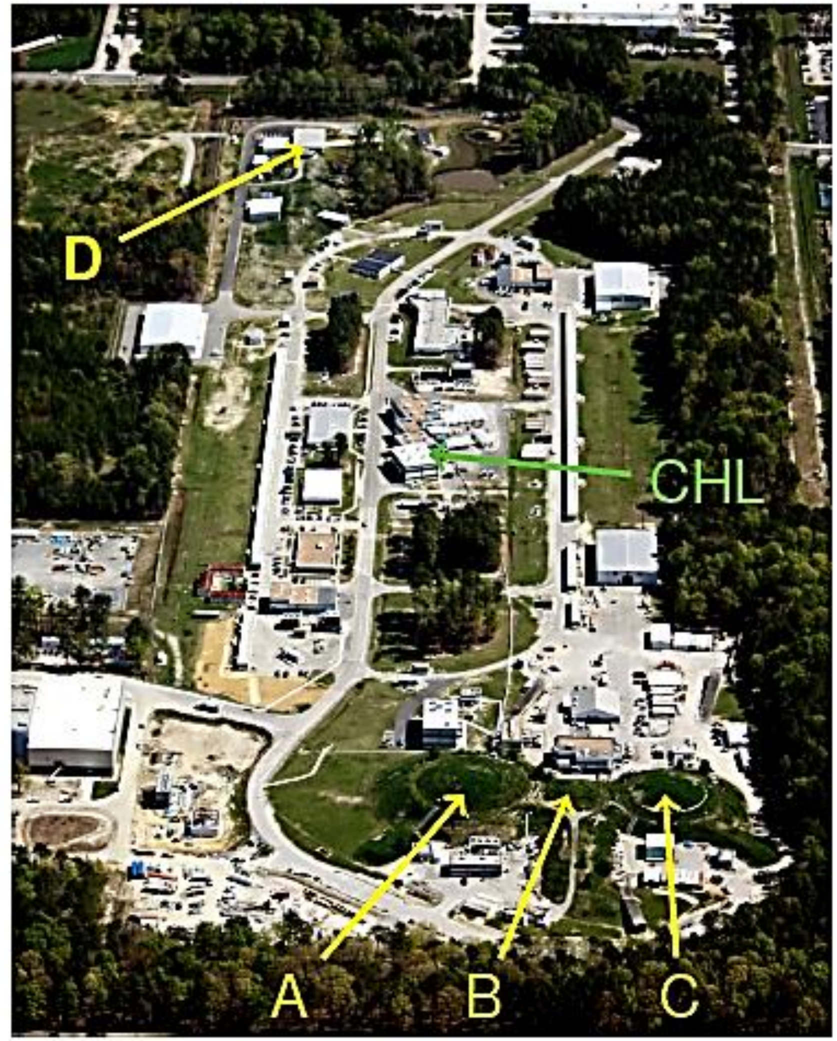
- **KLF** project has to **establish** secondary $K_L$ beam line at Jefferson Lab (Thomas Jefferson National Accelerator Facility), with **flux** of ***three order of magnitude higher*** than SLAC National Accelerator Laboratory had, for scattering experiments on both **proton** & **neutron** (first time !) targets in order to determine **differential cross sections** & **self-polarization** of strange **hyperons** with GlueX detector to enable precise **PWA** in order to determine all **resonances** up to **2400** MeV in spectra of $\Lambda^*$, $\Sigma^*$, $\Xi^*$, & $\Omega^*$.

- In addition, we intend to do **strange meson spectroscopy** by studies of the **$\pi$-K** interaction to locate the **pole** positions in **I** = **1/2** & **3/2** channels.

- **KLF** has link to **ion-ion high energy** facilities as CERN & Brookhaven National Laboratory & will allow understand formation of our world in **several microseconds** after **Big Bang**.

# CEBAF Upgrade to 12 GeV




*Upgrade Goals*

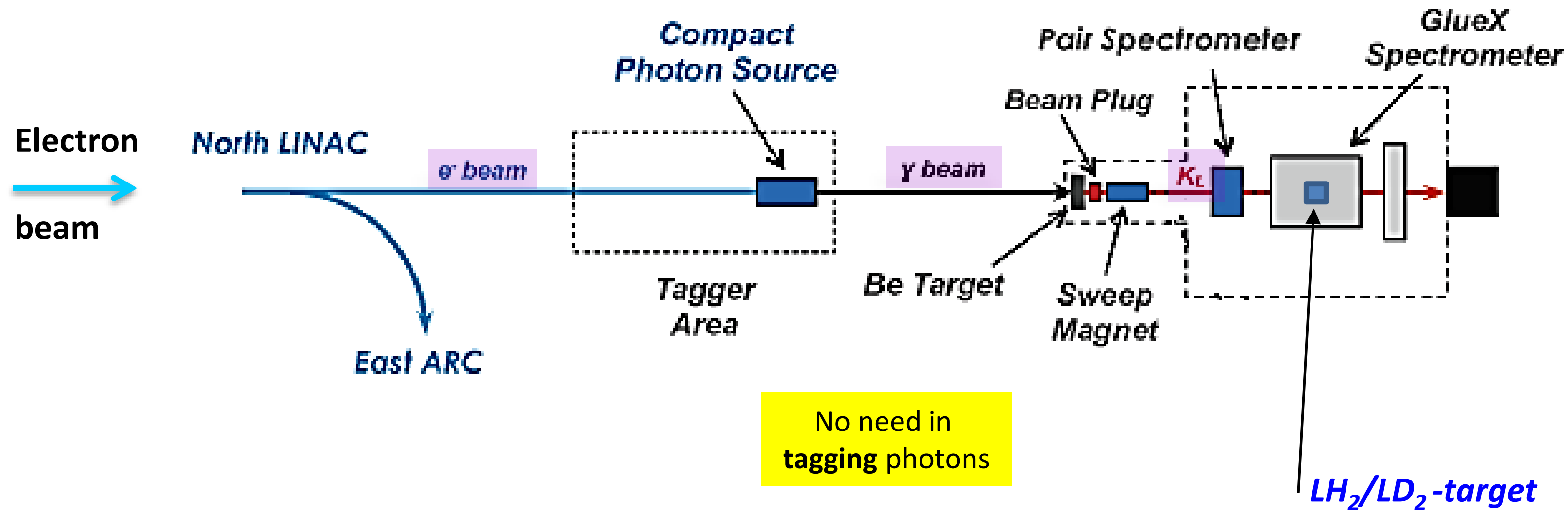
- Accelerator: 6 GeV $\Rightarrow$ 12 GeV
- Halls A,B,C: $e^-$ <11 GeV, $< 100\ \mu$A
- Hall D: $e^-$ 12 GeV $\Rightarrow \gamma$-beam

*Upgrade Status*

- Reached 12 GeV in Dec 2015
- Halls A,D: finished
- Halls B,C: about a year to go

...ov KL2016. Feb 2016 Overview of *Hall D* 3 / 32

# *Hall D Beam Line Set up for K-longs*

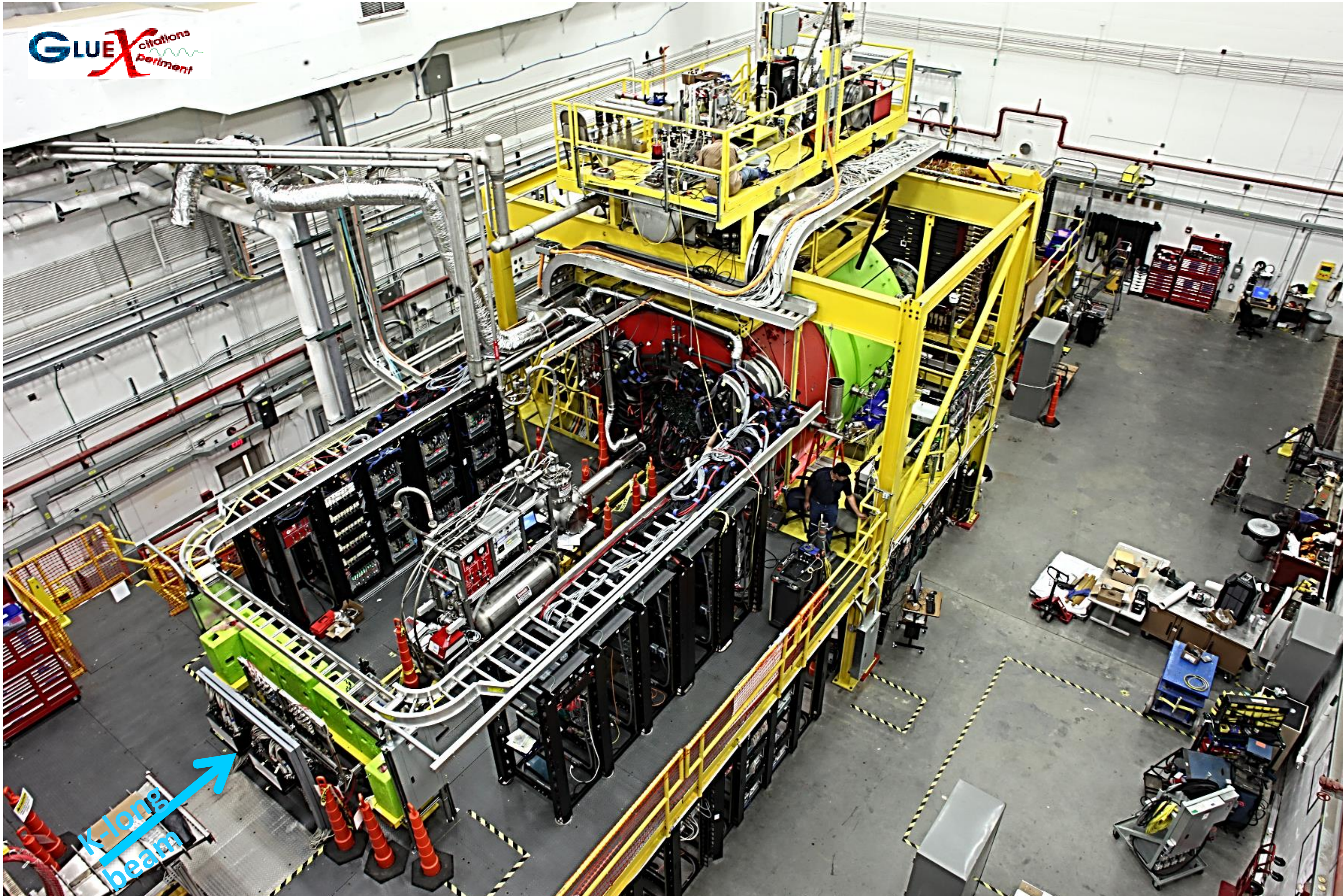



No need in
**tagging** photons

**$I_e$** = **5** μA
**W**-radiator = **0.1** R.L.
**Be**-target = **1.7** R.L.

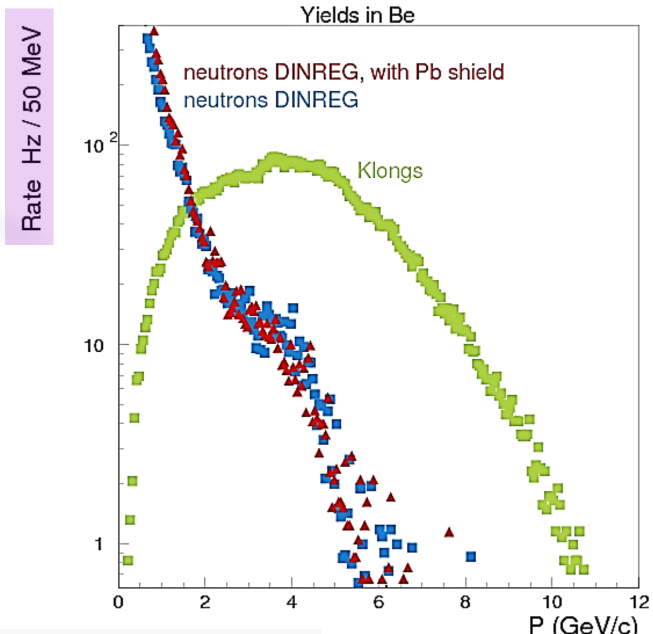
- **Electrons** are hitting **W**-radiator at **CPS**.
- **Photons** are hitting **Be**-target at **cave**.
- **$K_L$s** are hitting the **$LH_2$/$LD_2$** target within **GLueX** setting.

# *Hall D/GlueX*



# *K-long & Neutron Rate on GlueX $LH_2$/$LD_2$-target*

**MC @ 12 GeV**




**Data @ 16 GeV**

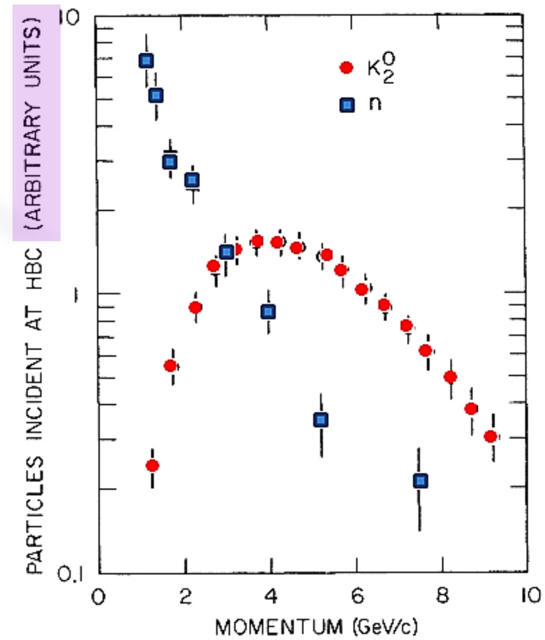
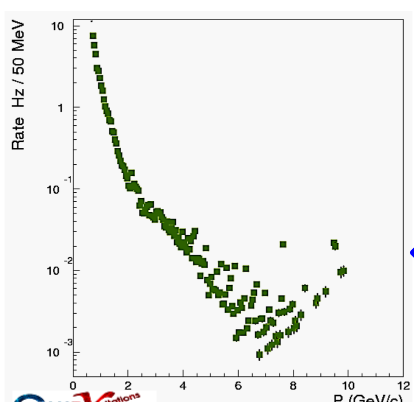


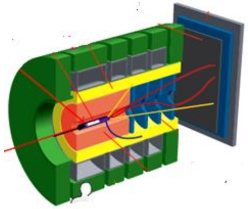

FIG. 2. Comparison of the neutron and $K_2{}^0$ fluxes at the hydrogen bubble chamber for 2° production with 16-GeV electrons. A.D. Brody *et al* Phys Rev Lett **22**, 966 (1969)




Flux ratio $n/K_L$

- Delivered with **64** ns bunch spacing avoids overlap in range of **p** = **0.35** – **10.0** GeV/c.

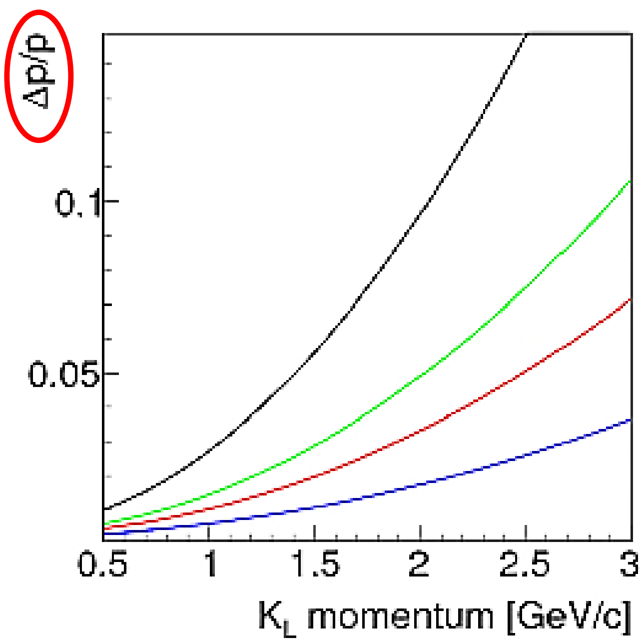
- With **proton** beam, ratio $n/K_L$ = $10^3$–$10^4$.

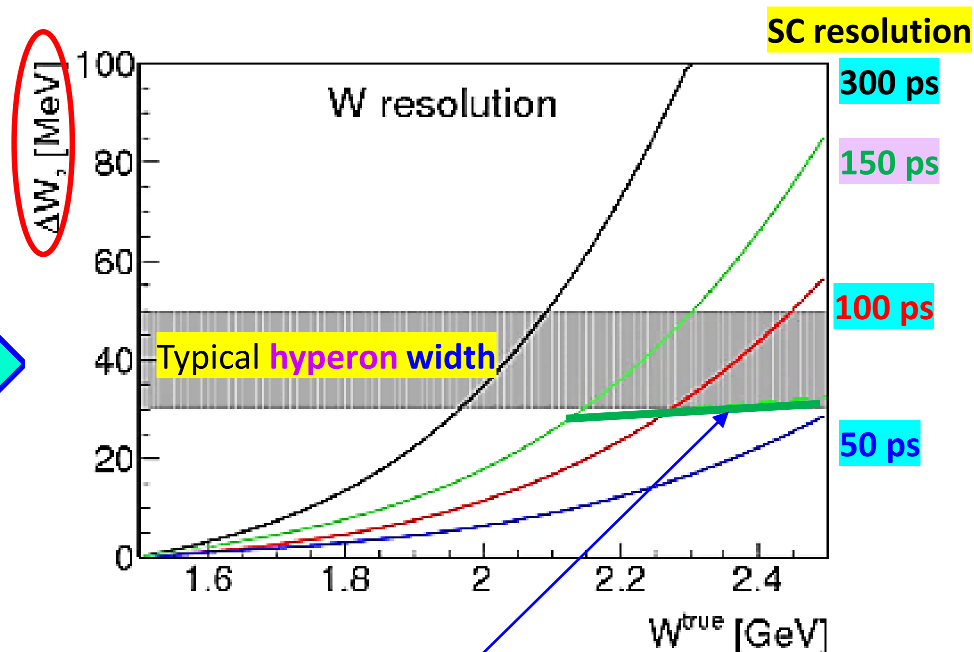


# *Expected Energy-Resolution*

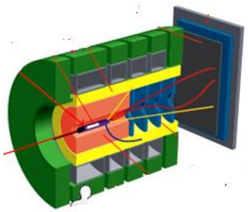
- Mean lifetime of $K^-$ is **12.38** ns ($c\tau$ = **3.7** m) whereas mean lifetime of $K_L$ is **51.16** ns ($c\tau$ = **15.3** m).

  Thus, it is possible to perform measurements of $K_Lp$ scattering at **lower energies** than $K^-p$ scattering due to high beam flux.
- Momentum measured with **TOF** between **SC** (surrounded **$LH_2/LD_2$**) & **RF** from **CEBAF**.



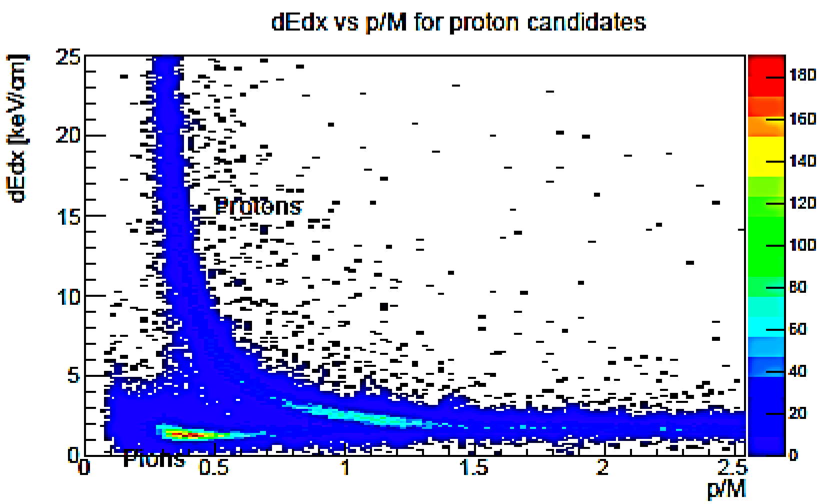




**150 ps & final state reconstruction**

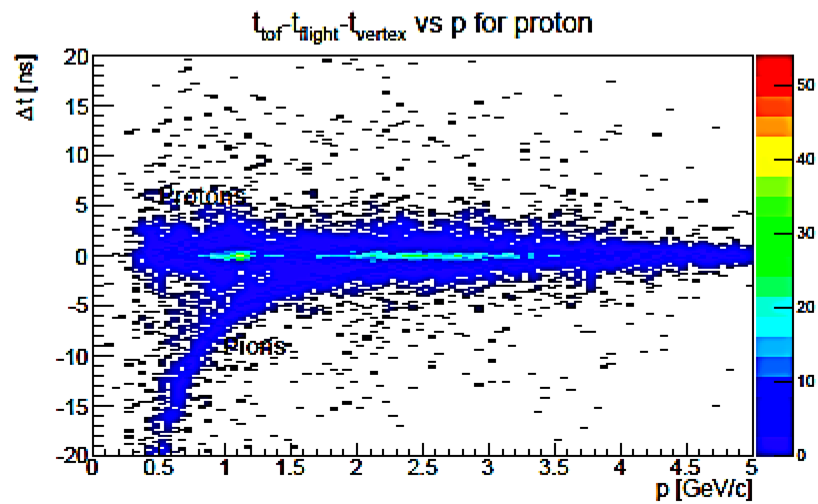


# *Expected Particle Identification*

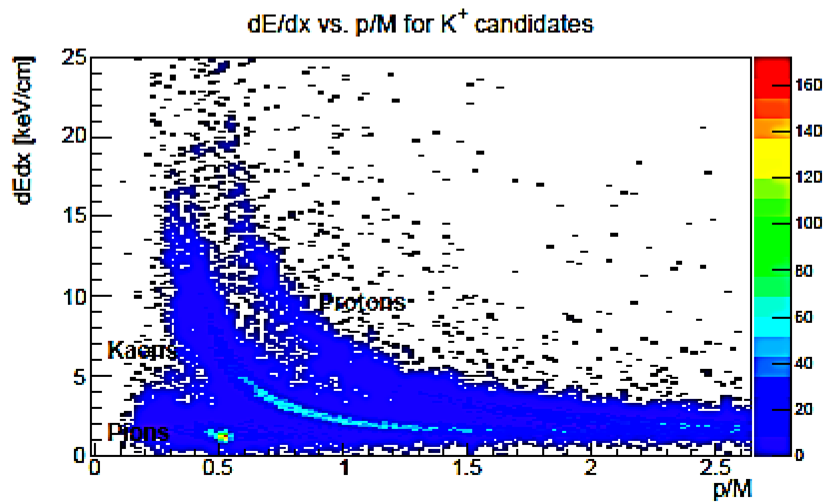
- **dE/dx** for **$pK_S$**.




- Time difference at primary ``vertex" for proton hypothesis for **$pK_S$** using **TOF.**



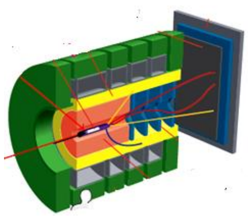

- **dE/dx** for **$K^+\Xi^0$**.



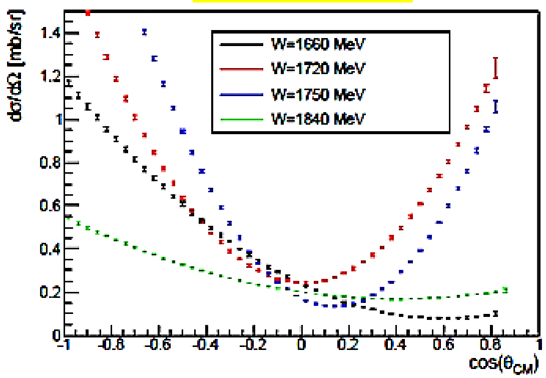
# *Expected Cross Sections vs Bubble Chamber Data*

- **GlueX** measurements will span **cosθ** from **–0.95** to **0.95** in CM above **W** = **1490** MeV.

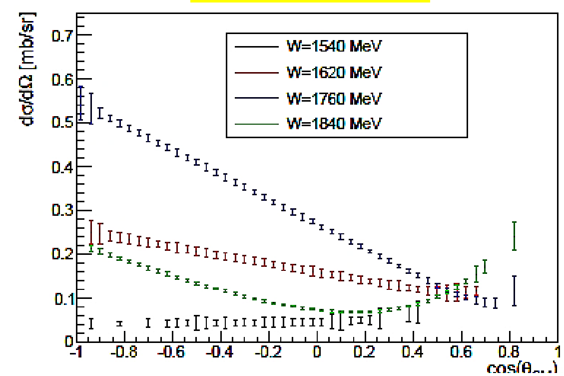
- $K_L$ rate is **$10^4$** $K_L$/s = **2500 x** SLAC NATIONAL ACCELERATOR LABORATORY
- Uncertainties (statistics only) correspond to **100** days of running time for:



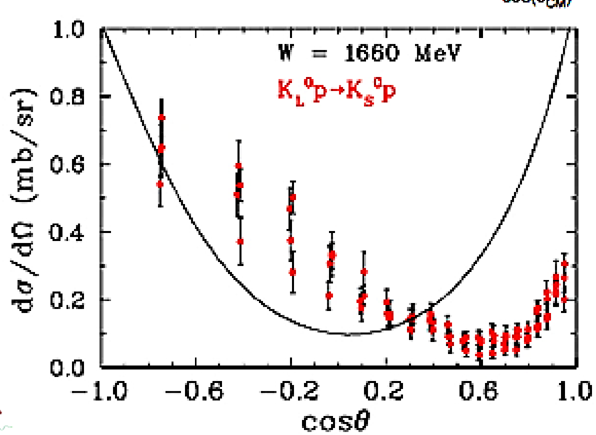
**$K_Lp \rightarrow K_Sp$**

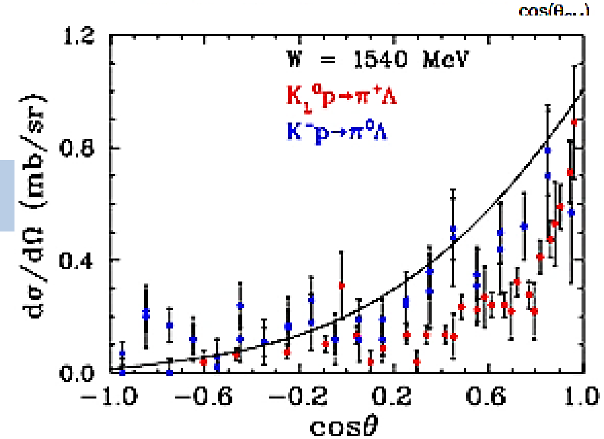



**$K_Lp \rightarrow \pi^+\Lambda$**

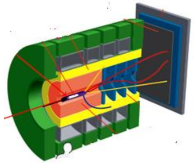



Expected **GlueX Data**



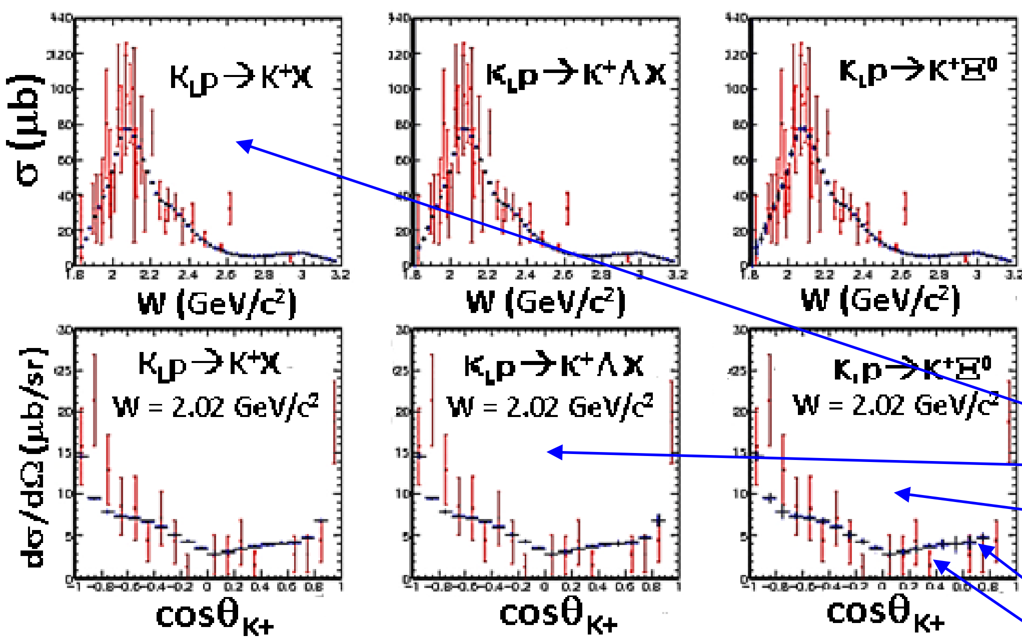




**BC Data**



# $K_Lp \to K^+\Sigma^0$ for Double Strange Hyperons

- Total & diff **Xsec** for different **topologies**



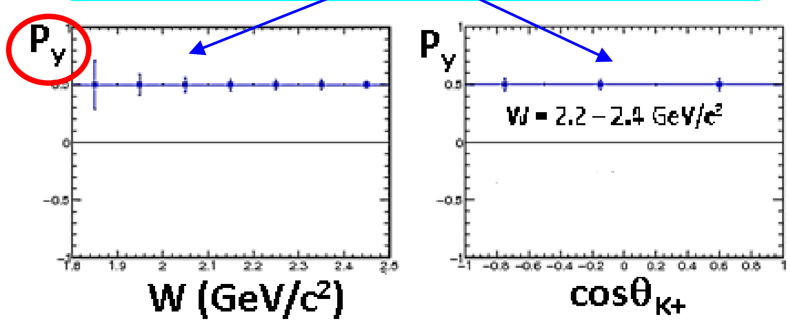

| Particle | $J^P$ | Overall status | $\Xi\pi$ | $\Lambda K$ | $\Sigma K$ | $\Xi(1530)\pi$ | Other channels |
|---|---|---|---|---|---|---|---|
| | | | Status as seen in — | | | | |
| $\Xi(1318)$ | 1/2+ | **** | | | | | Decays weakly |
| $\Xi(1530)$ | 3/2+ | **** | **** | | | | |
| $\Xi(1620)$ | | * | * | | | | |
| $\Xi(1690)$ | | *** | | *** | ** | | |
| $\Xi(1820)$ | 3/2− | *** | ** | *** | ** | ** | |
| $\Xi(1950)$ | | *** | ** | ** | | * | |
| $\Xi(2030)$ | | *** | | ** | *** | | |
| $\Xi(2120)$ | | * | | * | | | |
| $\Xi(2250)$ | | ** | | | | | 3-body decays |
| $\Xi(2370)$ | | ** | | | | | 3-body decays |
| $\Xi(2500)$ | | * | | * | * | | 3-body decays |

**Reconstructed**
- $K^+$
- $K^+\Lambda$
- $K^+\Sigma^0$

**Expected** data
**Available** data

D.A. Sharov, V.L. Korotkikh, D.E. Lanskoy, Eur. Phys. J. A **47**, 109 (2011)

- **Recoil Polarization** for **one**-fold differential
  **two**-fold differential




$$K_lp \to K^+\overrightarrow{\Xi^0} \to K^+\overrightarrow{\Lambda}\pi^0 \to K^+p\pi^-\pi^0$$

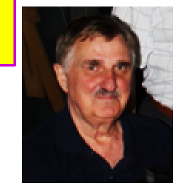
(**measured**, **reconstructed**)

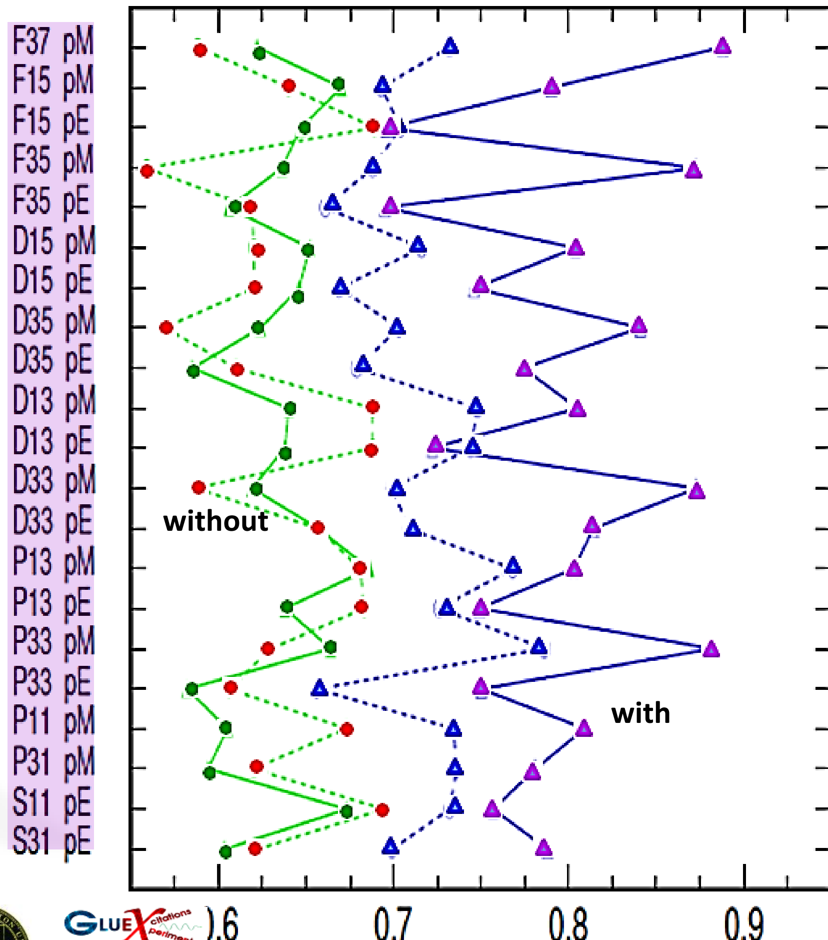
# *Quasi-Data: What to Expect When you're Expecting*

- Prove motivation of **JLab** Proposal ***E-03-105***
  ***Pion PhotoProduction from Polarized Target*** for **FROST** Project.

**Transverse Polarization** [**H**, **P**, **T**, **F**]    **Longitudinal Polarization** [**G**, **E**]

$$R = u(A_{MC}) / u(A_{world})$$






**Average ratio** of **uncertainties** of amplitudes **w/o** expected **FROST** data.

- The data generated by this work will fill # of **gaps** in existing database of single & double meson photoproduction.

- Greatest effect naturally requires measurement of all possible quantities as accomplished by **FROST**.

$\pi^+ n$ **E**: S. Strauch *et al,* Phys Lett B **750**, 53 (2015)
**ηp** **E**: I. Senderovich *et al,* Phys Lett B **755**, 64 (2016)
**ωp** **E**: Z. Akbar *et al*, arXiv:1708.02608 [nucl-ex]
**More results are coming...**

- Detailed study of **Kπ** system is very important to extract so-called **Kπ** vector & scalar form factors to be compared with $\tau \rightarrow K\pi\nu_\tau$ decay & can be used to constrain $V_{us}$ Cabibbo-Kobayashi-Maskawa (**CKM**) matrix element as well as to be used in testing **CP** violation from **Dalitz** plot analysis of open **charm D meson** decays & in **charmless** decays of **B mesons** into **Kππ** final states.

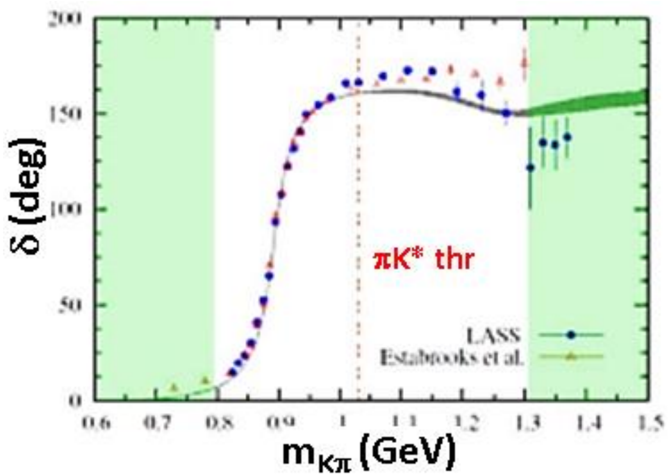
| $K_0^*(800)$ MASS VALUE (MeV) | EVTS | Err | $K_0^*(800)$ WIDTH VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **682 ±29 OUR AVERAGE** | | Err | **547 ± 24 OUR AVERAGE** | | Error includes scale factor of 1.1. | | |
| 826 ±49 $^{+49}_{-34}$ | 1338 | 1 | 449 ±156 $^{+144}_{-81}$ | 1338 | [18] ABLIKIM 11B | BES2 | $J/\psi \rightarrow K_S^0 K_S^0 \pi^+\pi^-$ |
| 849 ±77 $^{+18}_{-14}$ | 1421 | 2,3 | 512 ± 80 $^{+92}_{-44}$ | 1421 | [19,20] ABLIKIM 10E | BES2 | $J/\psi \rightarrow K^\pm K_S^0 \pi^\mp \pi^0$ |
| 841 ±30 $^{+81}_{-73}$ | 25k | 4,5 | 618 ± 90 $^{+96}_{-144}$ | 25k | [19,21] ABLIKIM 06C | BES2 | $J/\psi \rightarrow \overline{K}^*(892)^0 K^+\pi^-$ |
| 658 ±13 | | 6 | 557 ± 24 | | [22] DESCOTES-G..06 | RVUE | $\pi K \rightarrow \pi K$ |
| 797 ±19 ±43 | 15k | 7,8 | 410 ± 43 ± 87 | 15k | [23,24] AITALA 02 | E791 | $D^+ \rightarrow K^-\pi^+\pi^+$ |

# $\kappa(800)$

- Results coming from **Roy-Steiner** & data at higher energy not in agreement with low energy experimental data **need** improvement **!**

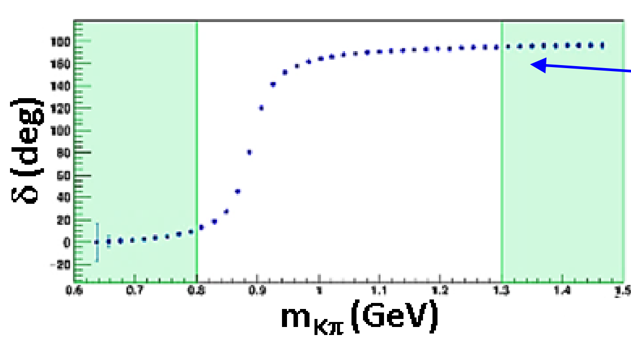
S. Descotes-Genon & B. Moussallam, Eur Phys J C **48**, 553 (2006)

- **I = 1/2 Kπ** scattering **P**-wave phase-shift




**Fit to τ-decay**: D.R. Boito, R. Escribano, M. Jamin, JHEP **1009**, 031 (2010)

**LASS:** D. Aston *et al*. Nucl Phys B **296**, 493 (1988).
**Data:** P. Estabrooks *et al*. Nucl Phys B **133**, 490 (1978).




- **100** days of running period.
  **Statistical errors** are increased by factor of **10** for better visibility.

IV

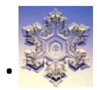
*Pion-Kaon Interaction [PKI2018]*
*Workshop at JLab*
*February 14th through 16th , 2018*

**Organizers**:
Moskov Amaryan
Ulf-G. Meissner
Curtis Meyer
James Ritman
Igor Strakovsky

https://www.jlab.org/conferences/pki2018/

# *Summary*

- **Our goal is**
  - To **establish KL Facility** at **JLab**. Jefferson Lab Thomas Jefferson National Accelerator Facility
  - To do **measurements** which bring new physics.

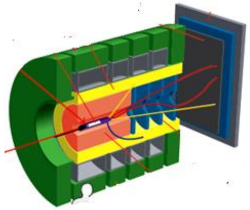
- Here we reviewed what can be learned by studying $K_L p$ & $K_L n$ scattering leading to **two–body** final states (**1st stage**).
  <u>At later stages</u>, we plan to do $K_L N$ on **aka FROST** with hydrogen & deuterium. 

- **JLab K-long Facility** would advance **Hyperon Spectroscopy** & study of **strangeness** in nuclear & hadronic physics.
  **It may extract very many missing strange states.**
  To complete $SU(3)_F$ multiplets, one needs no less than **17 Λ***, **43 Σ***, **42 Ξ***, & **24 Ω***.

- **Discovering** of ``**missing**" **hyperon states** would assist in advance our understanding of **formation** of **baryons** from **quarks** & **gluons** **microseconds** after **Big Bang**.


- **Full Proposal** is coming for **PAC46** in **2018**, **WELCOME** to **JOIN US**.

# *Backup Slides*



# *Time Request*

- Expected statistics for differential cross sections of different reactions with **$LH_2$** & below **W = 3.5** GeV for **100 days** of beam time.

For $d\sigma/d\Omega$

| Reaction | Statistics (events) |
|---|---|
| $K_L p \to K_S p$ | 8M |
| $K_L p \to \pi^+ \Lambda$ | 24M |
| $K_L p \to K^+ \Xi^0$ | 4M |
| $K_L p \to K^+ n$ | 200M |
| $K_L p \to K^- \pi^+ p$ | 2M |

⟹ For **P**, statistics is **0.4M**

- There are no data on ``neutron" targets &, for this reason, it is hard to make realistic estimate of statistics for **$K_L n$** reactions.
  If we assume similar statistics as on proton target, full program will be completed after running **100 days** with **$LH_2$** & **100 days** with **$LD_2$** targets.

# *A bit of Strange History*

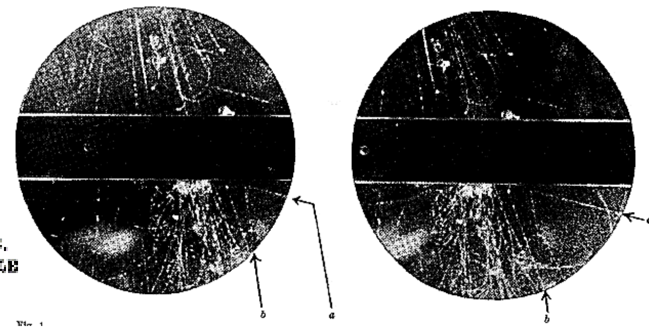
No. 4077 December 20, 1947 NATURE

EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

By Dr. G. D. ROCHESTER AND Dr. C. C. BUTLER

Physical Laboratories, University, Manchester

- **First** hyperon, **Λ(1116)1/2$^+$, was** discovered during study of cosmic-ray interactions.
- It **led** to discovery of **strange quark**.



STEREOSCOPIC PHOTOGRAPHS SHOWING AN UNUSUAL FORK (a b) IN THE GAS. THE DIRECTION OF THE MAGNETIC FIELD IS SUCH THAT A POSITIVE PARTICLE COMING DOWNWARDS IS DEVIATED IN AN ANTICLOCKWISE DIRECTION

- **Pole** position in complex energy plane for **hyperons** has began to be studied only recently, first of all for **Λ(1520)3/2$^-$**.

Phys Lett B 694, 123 (2010)

Jefferson Lab Thomas Jefferson National Accelerator Facility

Contents lists available at ScienceDirect

Physics Letters B

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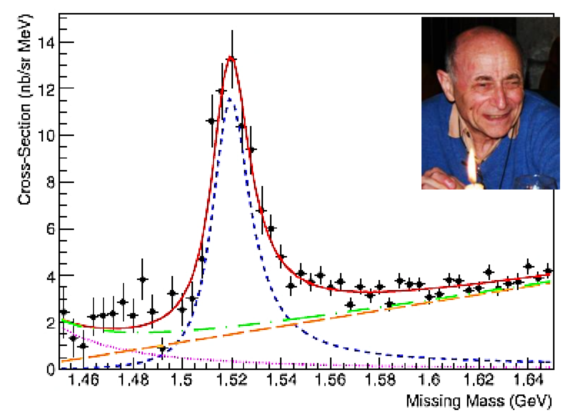
www.elsevier.com/locate/physletb

Properties of the Λ(1520) resonance from high-precision electroproduction data

Y. Qiang[a,b], Ya.I. Azimov[c], I.I. Strakovsky[d,*], W.J. Briscoe[d], H. Gao[a], D.W. Higinbotham[b], V.V. Nelyubin[e]



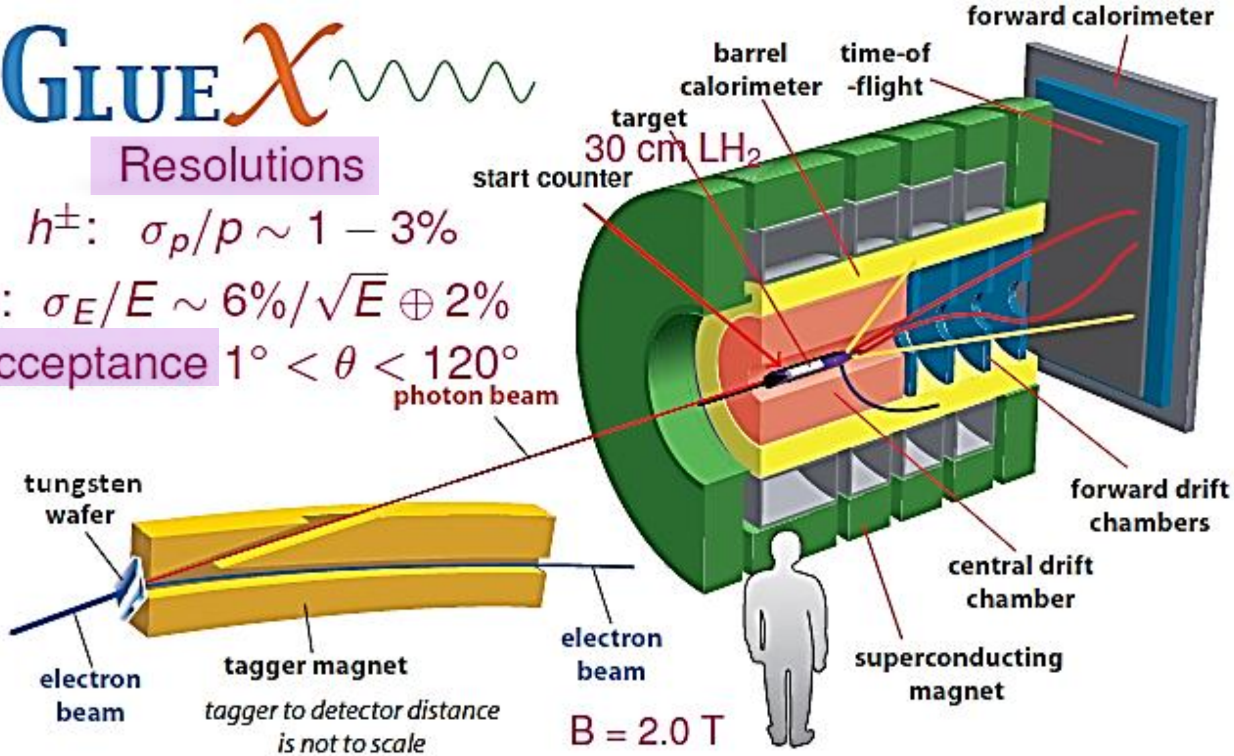
# Hall D/GlueX Spectrometer and DAQ

Resolutions

$h^{\pm}$: $\sigma_p/p \sim 1-3\%$

$\gamma$: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

Acceptance $1° < \theta < 120°$




Detectors

- CDC, FDC
- BCAL, FCAL
- TOF, ST

Plans to add

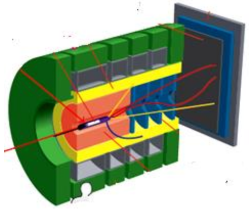
- 2017 L3
- 2018 DIRC

Photoproduction $\gamma p$ 1.5 kHz for a 10 MHz beam; Trigger $\sum E_{CAL} > X$

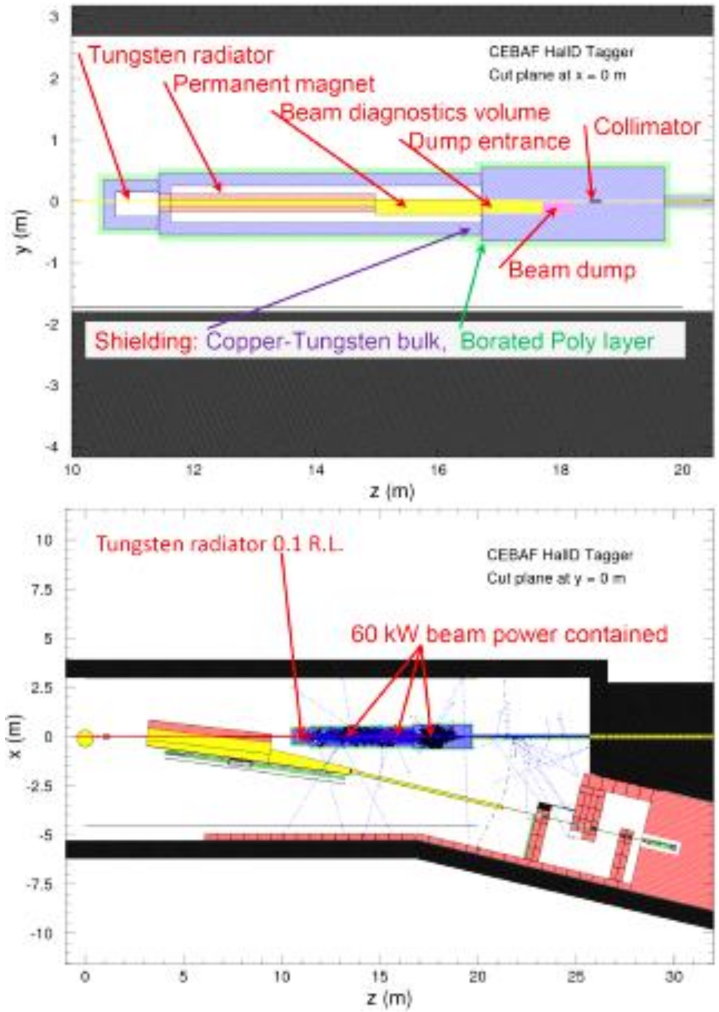
GlueX-I 10 MHz/peak: trigger 20 kHz $\Rightarrow$ DAQ $\Rightarrow$ tape 30 kHz spring 2016

GlueX-II 50 MHz/peak: trigger 100 kHz $\Rightarrow$ DAQ $\Rightarrow$ L3 farm $\sim$ 20 kHz $\Rightarrow$ tape

E.Chudakov YSTAR2016, Nov 2016 Hall D Facility 9 / 24 Jefferson Lab

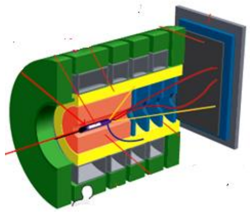


# *Compact Photon Source*

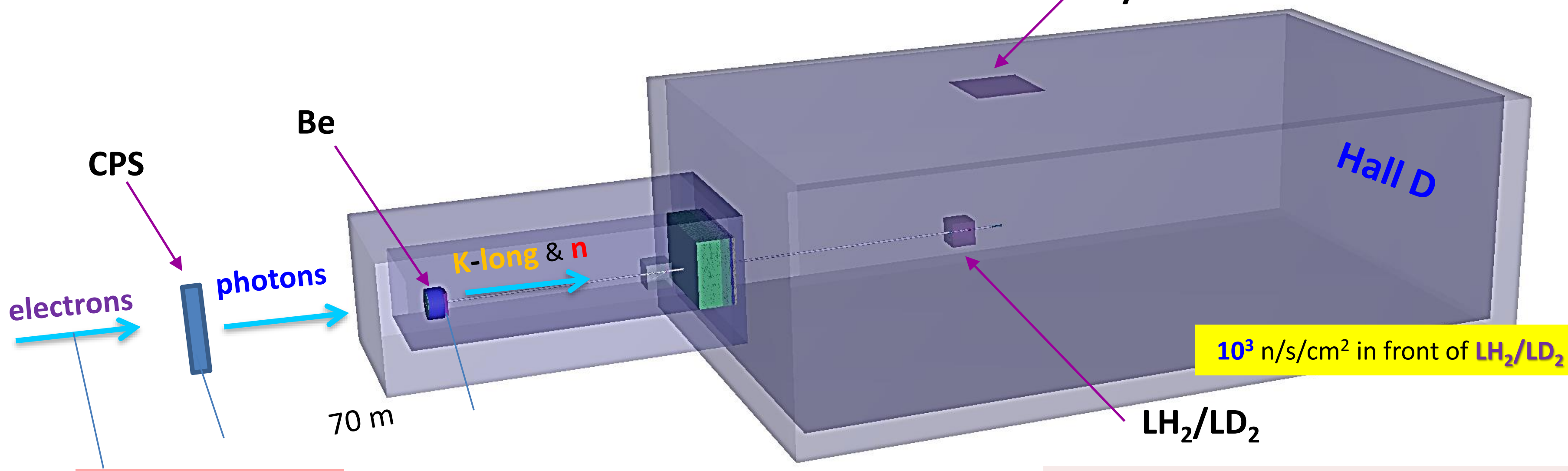


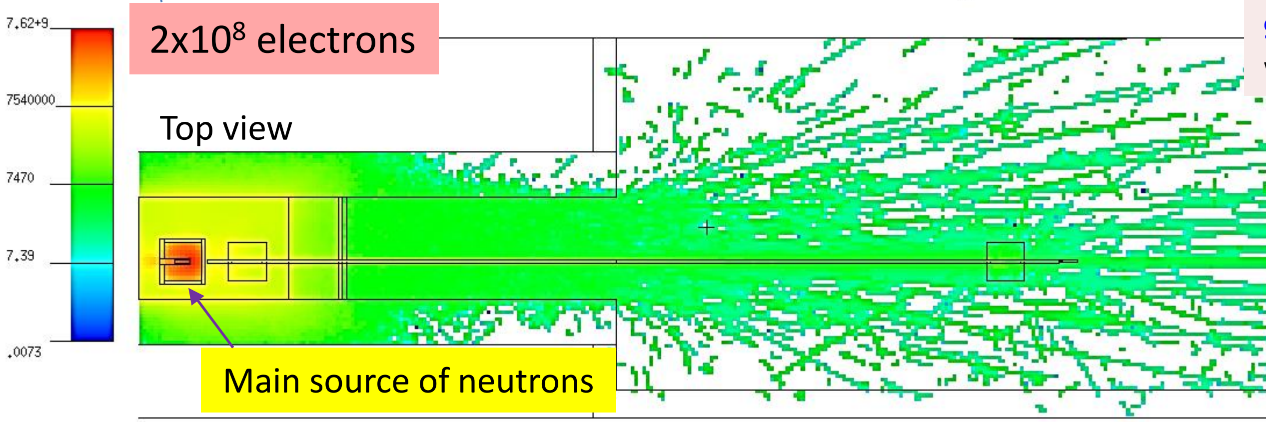

*JLab CPS group is still working to make general design which will work for both Halls D & C.*

# *Expected Neutron Background*

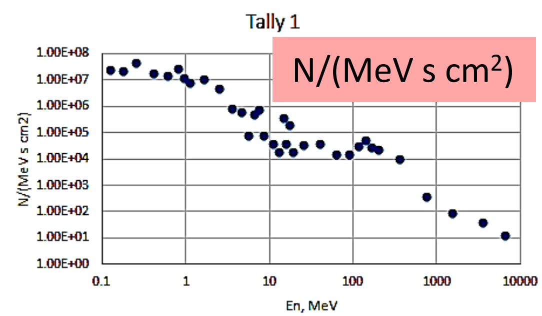


- Most **important** & **unpleasant background** for $K_L$ comes from **neutrons**.




**99%** of neutrons associated with **T** < **90** MeV while **0.6%** of them are for **T** > **125** MeV.




Los Alamos NATIONAL LABORATORY EST.1943

- For **neutron** calculations, we use **MCNP6** transport code.

**Speakers**:

Albrow, Chudakov, Richards, Amaryan, Ramos, Zou, Manley, Schumacher, Filippi, Oset, Myhrer, Montgomery, Kamano, Degtyarenko, Santopinto, Nakayama, Szczepaniak, Ohnishi, Mathieu, Goity, Passemar, Mai, Taylor, Ziegler, Oh, Noumi, Pennington, Keith, Kohl, Larin


**60** people from **9** countries & **30** talks

**Organizers**:
Moskov Amaryan
Eugene Chudakov
Curtis Meyer
Michael Pennington
James Ritman
Igor Strakovsky

https://www.jlab.org/conferences/kl2016/

Speakers: Mai

Chudakov

Garcilazo

Amaryan

Begun

Noronha-Hostler

Myhrer

Ohnishi

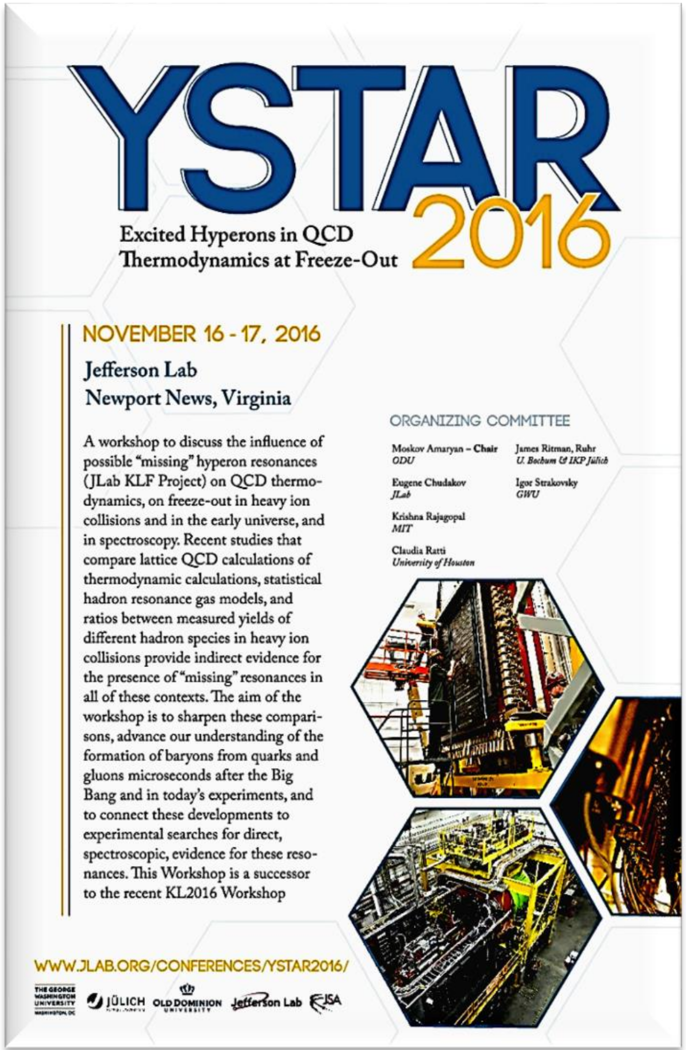
Ritman

Capstick

Doenigus

Huovinen

Tsuchikawa




Arriola

Xie

Edwards

**71** people from **11** countries & **27** talks

Goity

Montgomery

Manley

Crede

Alba

Guo

Stroth

Noumi

Bellwied

Ratti

Tang

**Organizers**:
Moskov Amaryan
Eugene Chudakov
Krishna Rajagopal
Claudia Ratti
James Ritman
Igor Strakovsky

https://www.jlab.org/conferences/YSTAR2016/

**Speakers**: Goity, Perera, Mai, Dominguez, Tadevosyan, Beminiwhatta, Wojtsekhowski, Degtyarenko, Niculescu, Liuti, Sargsian, Patsyuk, Zhang, Kroll, Keller, Hamilton, Strakovsky, Keppel, Sirca


**43** people from **4** countries & **19** talks

**Organizers**:
Tanja Horn
Cynthia Keppel
Carlos Munoz-Camacho
Igor Strakovsky

https://www.jlab.org/conferences/HIPS2017/