K-Long Beam Experiment

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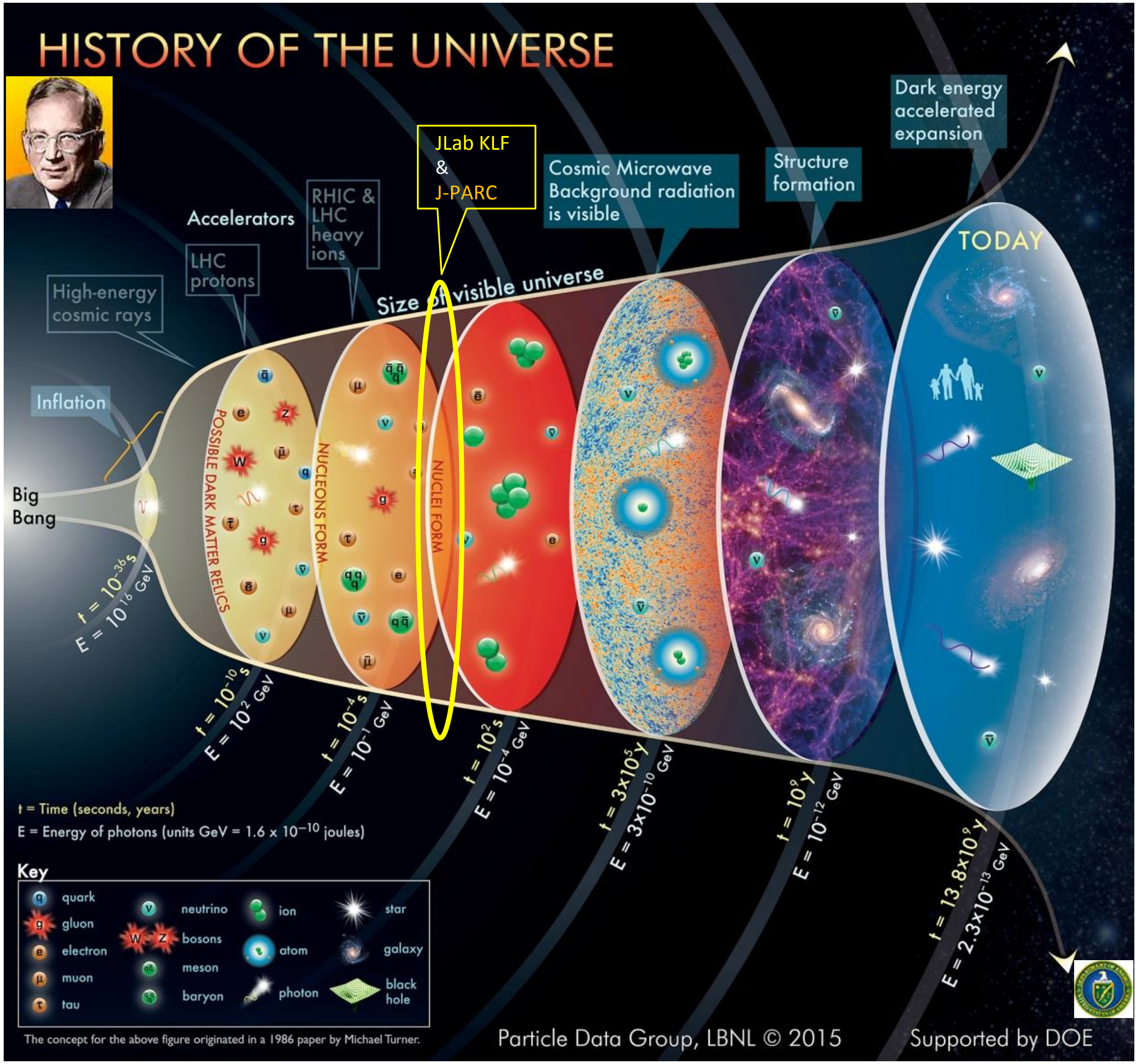
(for GlueX Collaboration)

- Thermodynamics at freeze-out
- Spectroscopy of hyperons
- PWA for strange sector
- K_Lp database
- Opportunity with K_L beam
- Expected K_Lp 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**.

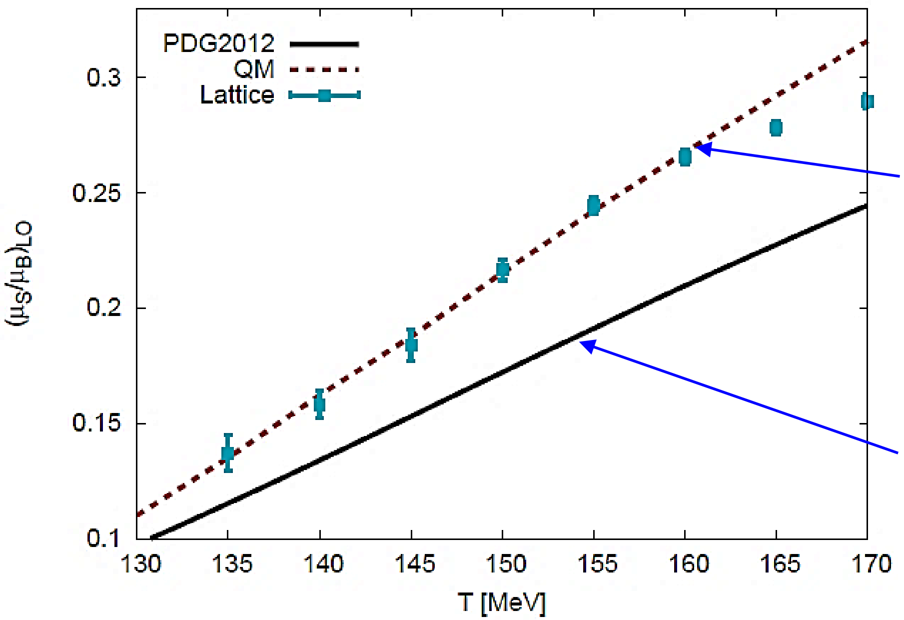
- For that reason, advancing our understanding of formation of **baryons** from quarks & gluons requires new experiments to search for any **missing** hyperon states or resonances.

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

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



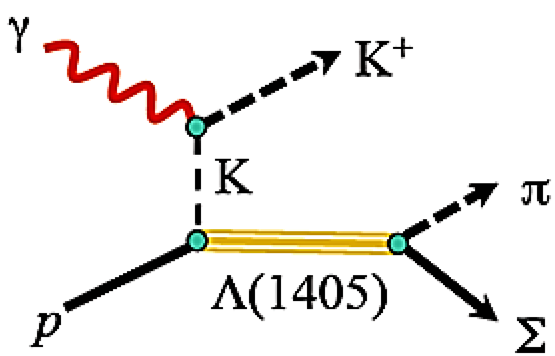
- **+** ``**Missing**” **Hyperons** (**QM** calculations).
- Contribution from **observed Resonances.** PDG particle data group

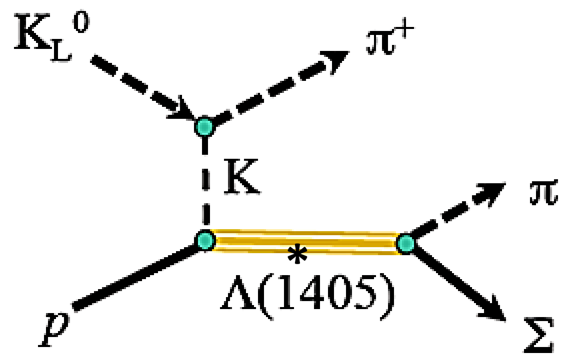
Courtesy of Claudia Ratti, YSTAR2016

Sample of Hunting for Bumps

Outlook at GlueX for $\Lambda(1405)$ Line-Shape Measurement

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





- Measurement may be feasible

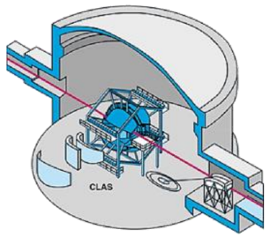
- $K_L^0 p \to \Lambda(1405)\pi^+ \to \Sigma^{+0-}\pi^{-0+}\pi^+$

Courtesy of Reinhard Schumacher, KL2016

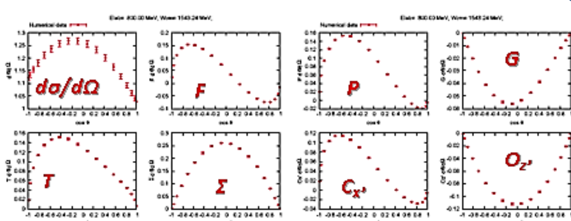
Road Map to Baryon Spectroscopy

Facility

Experiment

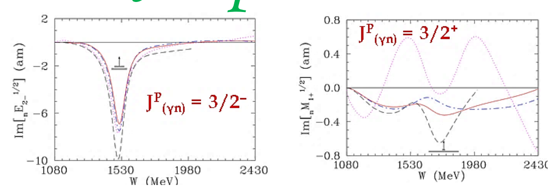


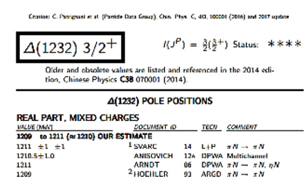
Data

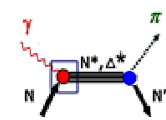


PWA

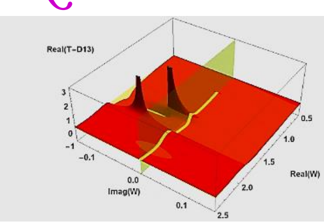
Amplitudes



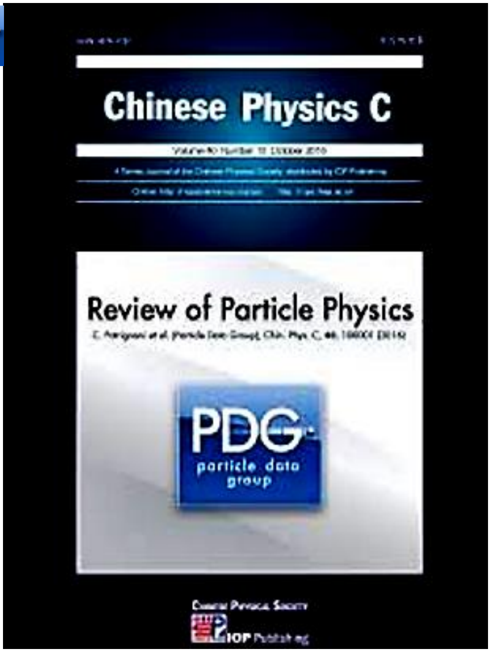




Resonances



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]0)	[illegible]	[illegible]
N([illegible]5)	[illegible]	[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(2700)	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(2150)	1/2	[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)	1/2[illegible]	[illegible]
Λ(1820)	5/2$^+$	[illegible]
Λ(1830)	5/2$^-$	[illegible]
Λ(1890)	3/2$^+$	[illegible]
Λ(2000)		[illegible]
Λ([illegible])	7/2$^+$	[illegible]
Λ(2100)	7/2$^-$	****
Λ(2110)	5/2$^+$	***
Λ(2325)	3/2$^-$	*
Λ(2350)	9/2$^+$	***
Λ(2585)		**

Σ^+	1/2$^+$	****
Σ^0	1/2$^+$	****
Σ^-	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]/2$^+$	*
Σ(1880)	1/2$^+$	**
Σ(191[illegible])	5/2$^+$	****
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)		*

Ξ^0	1/2$^+$	****
Ξ^-	1/2$^+$	****
Ξ(1530)	[illegible]	****
Ξ(162[illegible])		*
Ξ(1690)		***
Ξ(182[illegible])	3/2$^-$	***
Ξ(19[illegible])		***
Ξ(2030)	$\geq \frac{5}{2}^?$	***
Ξ([illegible])		*
Ξ(2250)		**
Ξ(2370)		**
Ξ(2500)		*
Ω^-	3/2$^+$	[illegible]
Ω([illegible]0)$^-$		[illegible]
Ω([illegible]80)$^-$		[illegible]
Ω([illegible]70)$^-$		[illegible]

Λ_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$^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	1/2$^+$	***
Ξ_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$^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	1/2$^+$	***
$\Omega_c(2770)^0$	3/2$^+$	***
Ξ_{cc}^+		*
Λ_b^0	1/2$^+$	***
Σ_b	1/2$^+$	***
Σ_b^*	3/2$^+$	***
Ξ_b^0, Ξ_b^-	1/2$^+$	***
Ω_b^-	1/2$^+$	***

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

- **Pole** position in complex energy plane for **hyperons** has been made only recently, in **2010**.

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

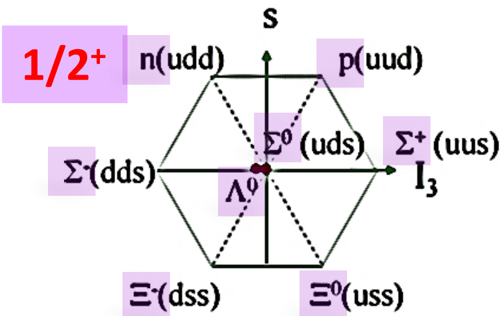
- **PDG16** has **109 Baryon Resonances** (**58** of them are **4*** & **3***).

- In case of **SU(6) X O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** & **four 56**).

Jefferson Lab
Thomas Jefferson National Accelerator Facility

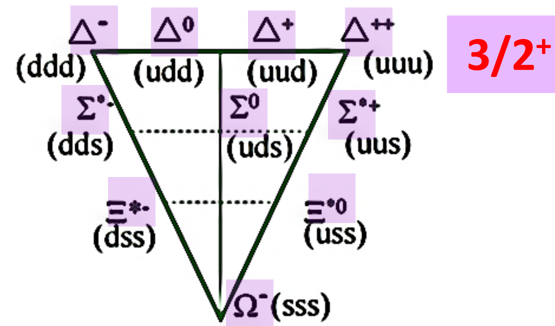
Baryon Resonances

- **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:



Octet: **N***, **Λ***, **Σ***, **Ξ***

Decuplet: **Δ***, **Σ***, **Ξ***, & **Ω***



- 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***.

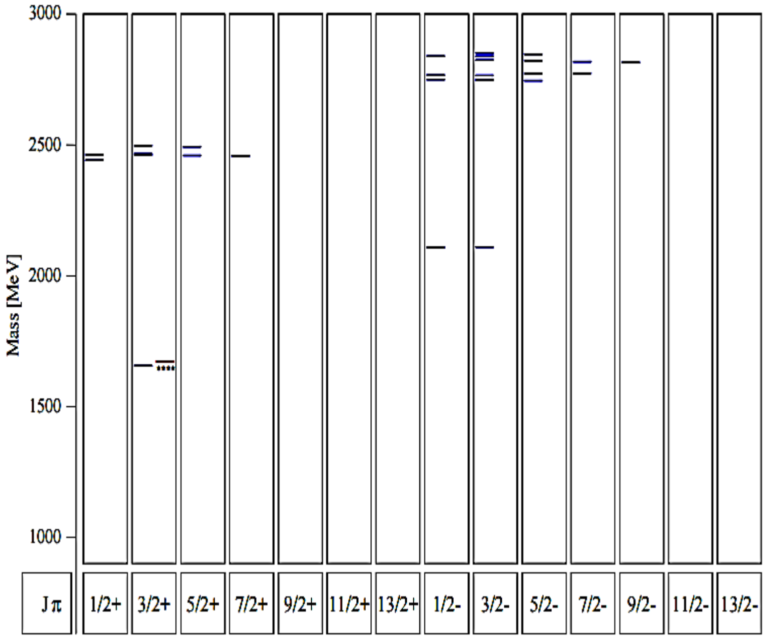
B.M.K. Nefkens, πN Newsletter, **14**, 150 (1997)

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)

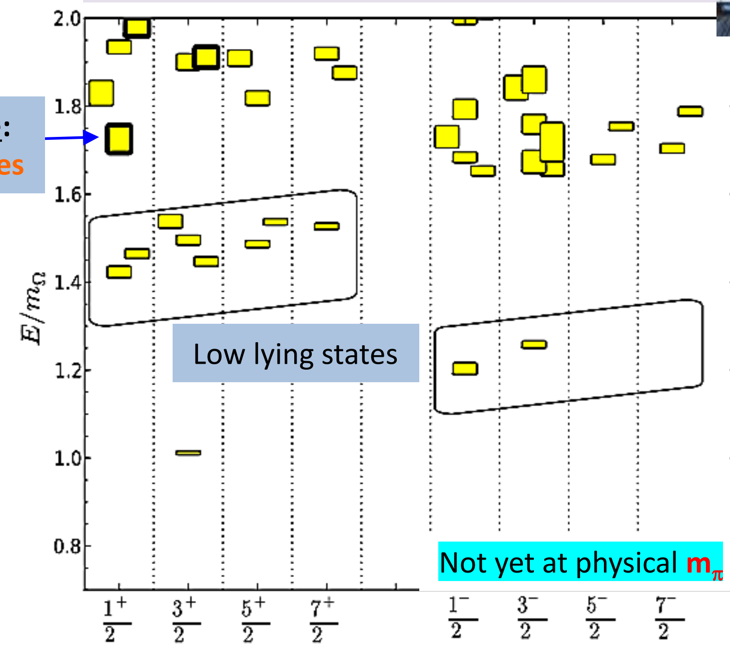
- Ω baryon spectrum in **QM**.



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

- Ω baryon spectrum in **LQCD**.

Thick frame: Hybrid states



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

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

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

Why We Have to Measure Double-Strange Cascades in JLab

- **Heavy quark symmetry** (**Isgur–Wise symmetry**) suggests that multiplet splittings in **strange**, **charm**, & **bottom** **hyperons** should scale as approximately inverses of corresponding **quark masses**: $\mathbf{1/m_s : 1/m_c : 1/m_b}$

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

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

- 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 Λ-splittings. It would work **even better** for Ξ, Ξ_c, Ξ_b splittings, & should be **very good** for Ω, Ω_c, Ω_b splittings.

PDG particle data group

Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	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

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_Lp** scattering are given by

$$\frac{d\sigma}{d\Omega} = \bar{\lambda}^2(|f|^2 + |g|^2)$$

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

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

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

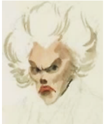
Partial-Wave Expansion

- 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**.

Isospin Amplitudes

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

$$\boxed{\begin{aligned} K_L^0 &= \frac{1}{\sqrt{2}}\left(K^0 - \overline{K^0}\right) \\[2ex] K_S^0 &= \frac{1}{\sqrt{2}}\left(K^0 + \overline{K^0}\right) \end{aligned}}$$

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

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

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

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

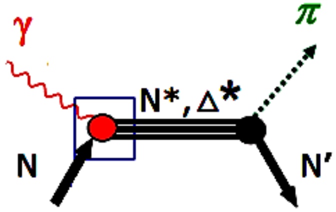


Photo-Decay Amplitudes in BW & Pole Forms

• Pole is main signature of resonance !

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

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 $10^{-3}(\mathrm{GeV})^{-1/2}$. 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_π	$A_{1/2}$	$A_{3/2}$
$\Delta(1232)\,3/2^+$	(1233, 119)	60	-141 ± 3	-258 ± 5	(1211, 99)	52 [$-47°$]	-136 ± 5 [$-18°$]	-255 ± 5 [$-6°$]
$N(1440)\,1/2^+$	(1485, 284)	112	-60 ± 2		(1359, 162)	38 [$-98°$]	-66 ± 5 [$-38°$]	
$N(1520)\,3/2^-$	(1515, 104)	33	-19 ± 2	$+153\pm3$	(1515, 113)	38 [$-5°$]	-24 ± 3 [$-7°$]	$+157\pm6$ [$+10°$]
$N(1535)\,1/2^-$	(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)

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

$$
\begin{aligned}
T(K^0_L p \to K^0_S p) &= \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) \\
&- \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) \\
T(K^0_L p \to K^0_L p) &= \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) \\
&+ \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) \\
T(K^0_L p \to K^+ n) &= \frac{1}{\sqrt{2}}\left(\frac{1}{2}T^1(KN \to KN) - \frac{1}{2}T^0(KN \to KN)\right) \\
&- \frac{1}{2}T^1(\overline{K}N \to \overline{K}N)
\end{aligned}
$$

- New GlueX data with J-PARC hadronic program via K^- induced measurements (complimentary program) will greatly constrain **PWA**s & reduce model-dependent uncertainties in extraction of strange resonance properties.

$$
\begin{aligned}
T(K^- p \to K^- p) &= \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) + \frac{1}{2}T^0(\overline{K}N \to \overline{K}N) \\
T(K^- p \to \overline{K^0} n) &= \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) - \frac{1}{2}T^0(\overline{K}N \to \overline{K}N) \\
T(K^+ p \to K^+ p) &= T^1(KN \to KN) \\
T(K^+ n \to K^+ n) &= \frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)
\end{aligned}
$$

How to Search for "Missing" Hyperons

- **New data** for inelastic **K_Lp** scattering would significantly improve our knowledge of **Σ^***, **Λ^***, & **Ξ^*** 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:

$$\Sigma^*: \quad K_L^0 p \to \pi\Sigma^* \to \pi\pi\Lambda$$
$$\Lambda^*: \quad K_L^0 p \to \pi\Lambda^* \to \pi\pi\Sigma$$
$$\Xi^*: \quad K_L^0 p \to K\Xi^*, \pi K\Xi^*$$

$\Longrightarrow$ Double Strange Cascades

$$\Omega^*: \quad K_L^0 p \to K^+K^+\Omega^*$$

- 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**.

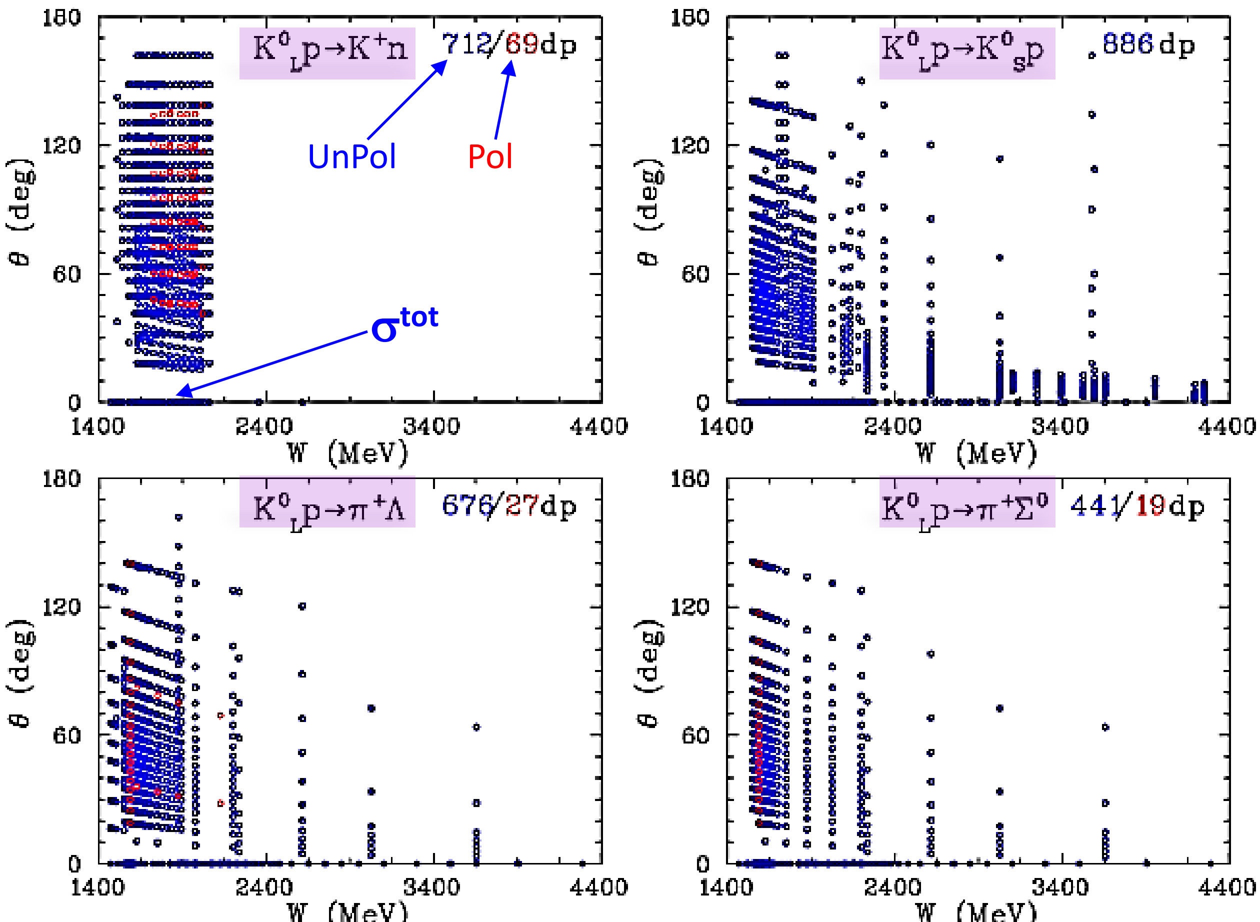
— Data Analysis Center —
Institute for Nuclear Studies
THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

World K–long Data – Ground for Hyperon Phenomenology

W = 1.45 – 5.05 GeV

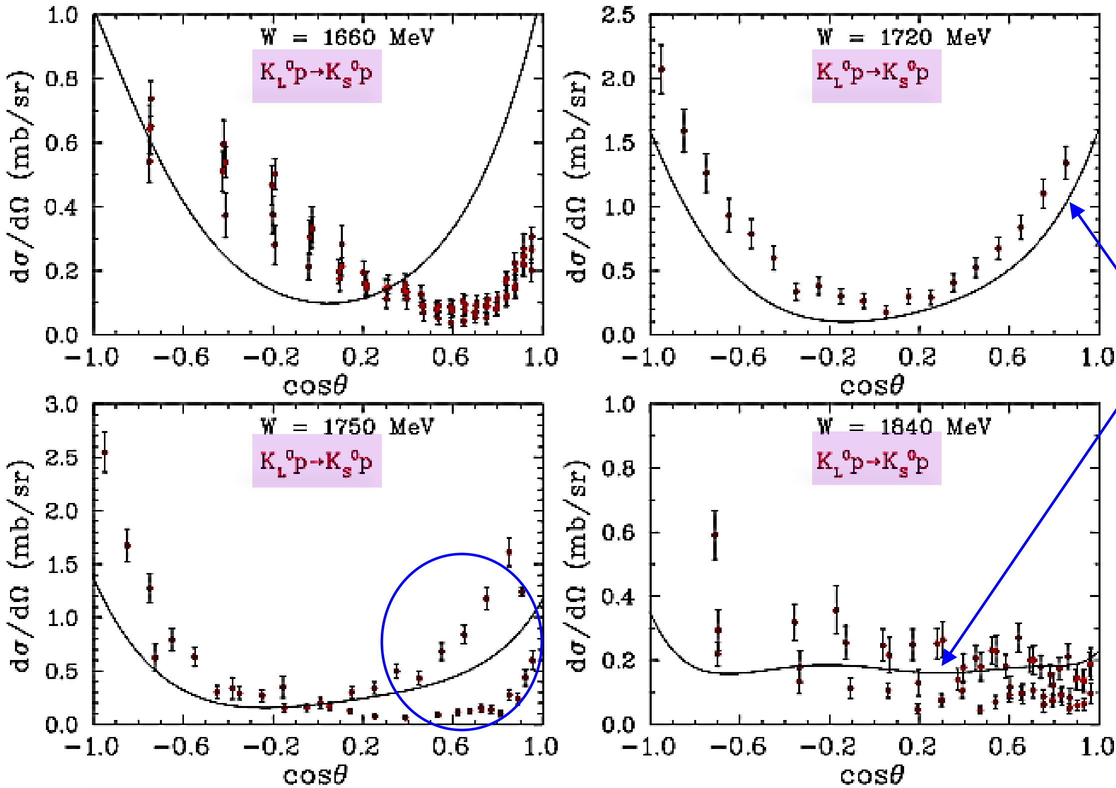
SAID: http://gwdac.phys.gwu.edu/

- Limited number of K_L induced measurements (**1961 – 1982**) **2426 dσ/dΩ**, **348 σ^{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

Data for $K_L p \to K_S p$



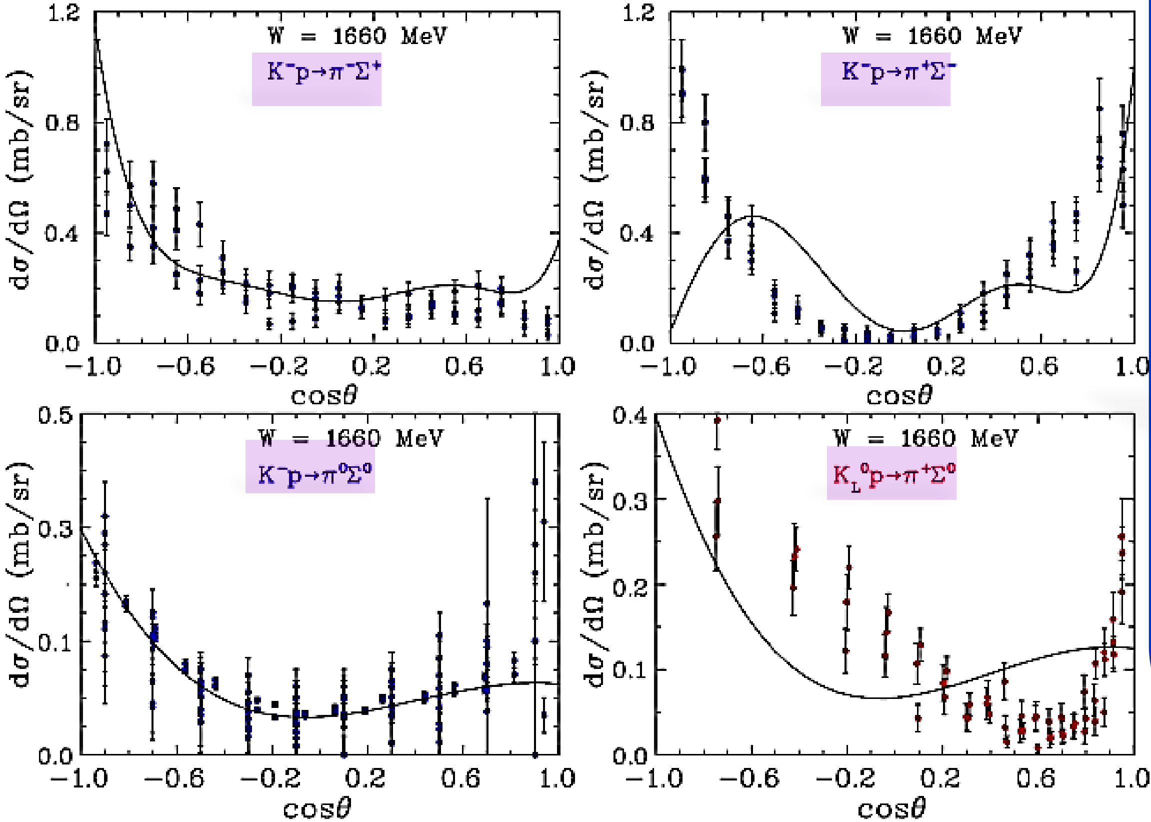
- No **dσ/dΩ** data are available for **$K_L p \to K_L p$** below **W = 3** GeV.

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

R.L. Workman *et al* Phys. At. Nucl. **69**, 90 (2006)
R.L. Workman *et al* Phys. Rev. C **70**, 028201 (2004)

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

Data for $K_L p \to \pi^+\Sigma^0$ & $K^- p \to \pi\Sigma$



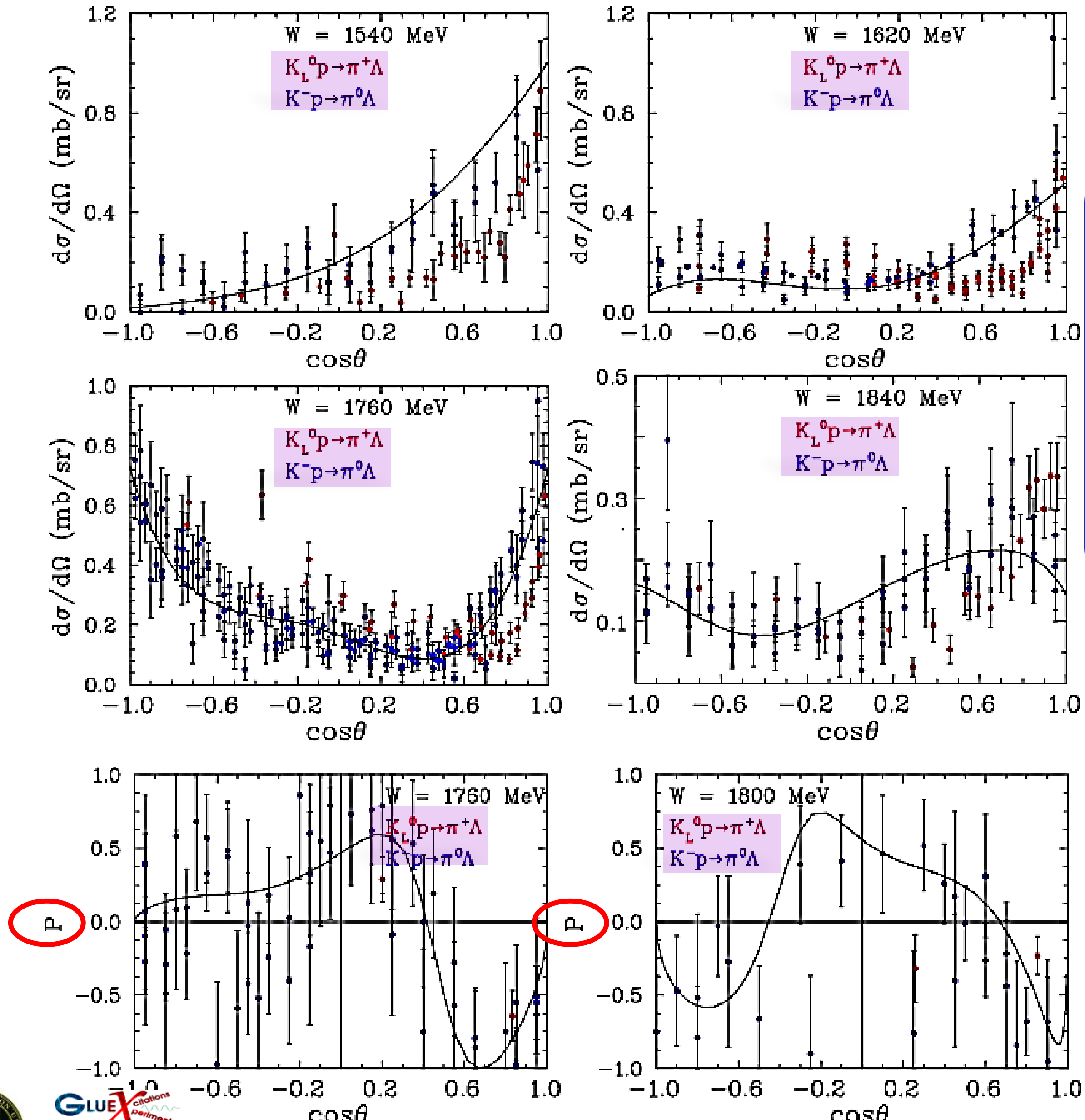
- Reactions $K_L p \to \pi^+\Sigma^0$ & $K_L p \to \pi^0\Sigma^+$ are Isospin selective (only **I = 1** amplitudes are involved) & $K^- p \to \pi^0\Sigma^0$ isospin selective for **I = 0** whereas reactions $K^- p \to \pi^-\Sigma^+$ & $K^- p \to \pi^+\Sigma^-$ involve both **I = 0** & **I = 1** amplitudes.

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

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

- PDG lists only **two** results on **BR** to $K\Sigma$ — **$\Lambda(2100)7/2^-$** (BR < **3%**), **$\Sigma(2030)7/2^+$** (BR < **2%**).

Data for $K_L p \to \pi^+ \Lambda$ & $K^- p \to \pi^0 \Lambda$



- $K^- p \to \pi^0 \Lambda$ & $K_L p \to \pi^+ \Lambda$ 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.

A bit of History

PHYSICAL REVIEW VOLUME 138, NUMBER 5B 7 JUNE 1965

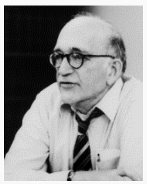
First paper on subject

Photoproduction of Neutral K Mesons*

CP-violation (1964)
Hot topic!

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.

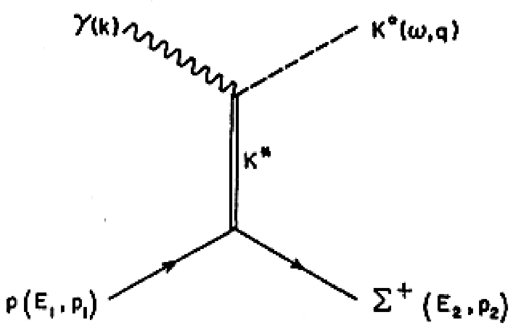


FIG. 1. K^* exchange in photoproduction.

[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

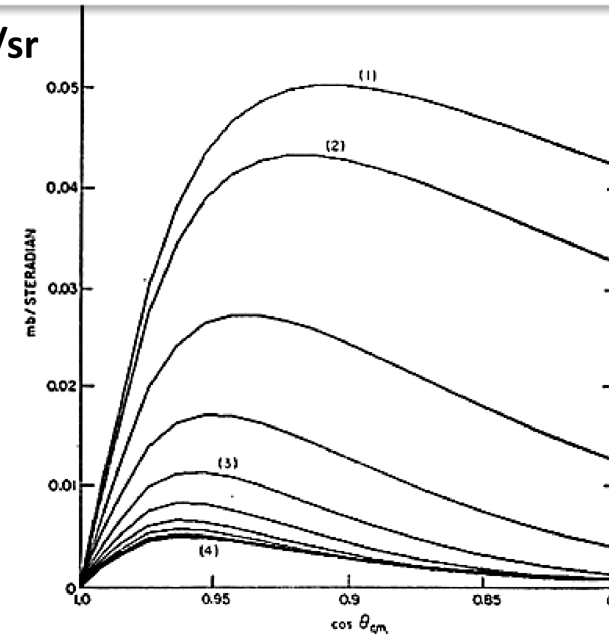


FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partia have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

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 B23 (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

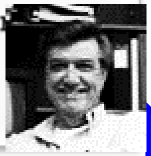
*"We were at Manchester Univ. close to Daresbury **5** GeV e-synchrotron."*

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.

JLab PR12-17-001

Proposal for JLab PAC46

PR12–17–001

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Strange Hadron Spectroscopy with a Secondary K_L Beam at GlueX

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[32], M. Baalouch[40], F. Barbosa[22], A. Barnes[9],
M. Bashkanov[16,†], T. D. Beattie[44], R. Bellwied[22], 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[12], G. Dodge[40],
A. G. Dolgolenko[20], 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[30], G. Gavalian[22],
V. Gauzshtein[47,48], N. Gevorgyan[50], D. I. Glazier[16], K. Goetzen[17], J. Goity[22,21],
V. S. Goryachev[20], 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[20], D. Lawrence[22], M. Levillain[30],
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[20], 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[30], M. R. Pennington[16], L. Pentchev[22],
K. J. Peters[17], W. Phelps[12], E. Pooser[22], B. Pratt[9], J. W. Price[5], N. Qin[23], 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[20], 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[22], X. Zhou[53], B. Zihlmann[22]

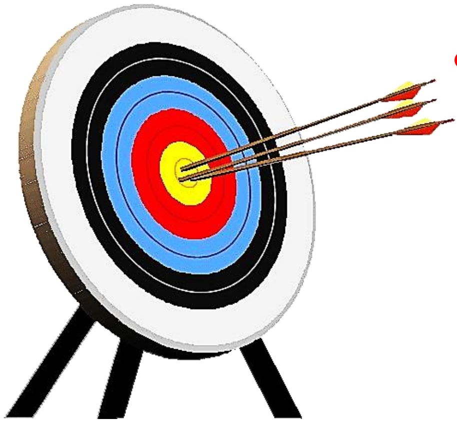


- **177** people from **54** institutes are co-authors.

Hyperon & Strange Meson Spectroscopy

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

Aims of Jlab KLF Project

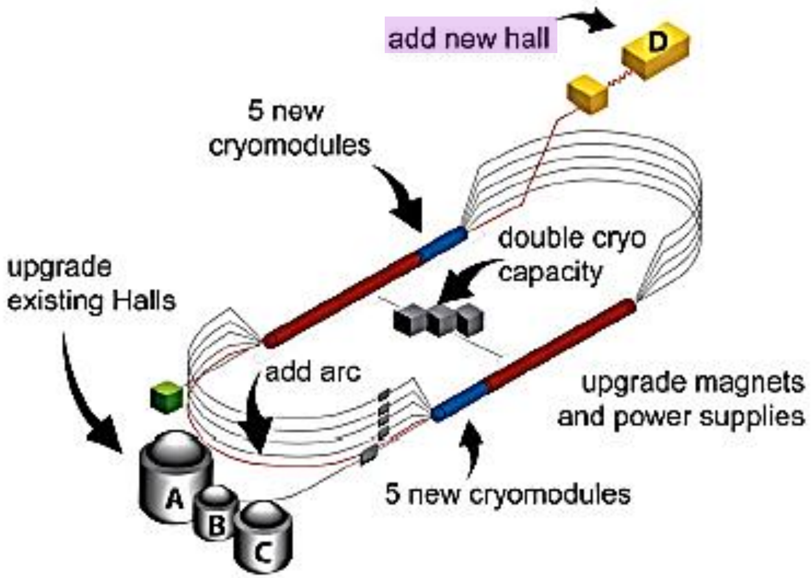


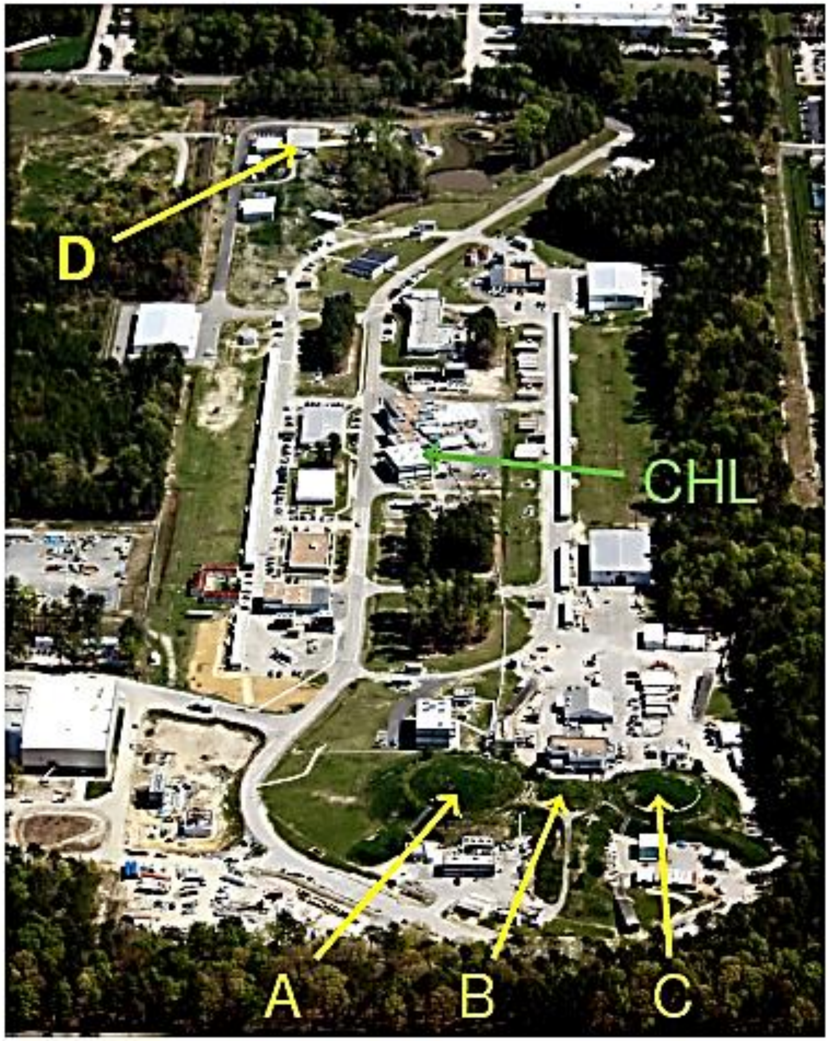
- **KLF** project has to **establish** secondary K_L beam line at Jefferson Lab Thomas Jefferson National Accelerator Facility with **flux** of ***three order of magnitude*** higher than SLAC NATIONAL ACCELERATOR LABORATORY had, for scattering experiments on both **proton** & **neutron** (first time **!**) 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 **3** GeV in spectra of Λ^*, Σ^*, Ξ^*, & Ω^*.

- In addition, we intend to do **strange meson spectroscopy** by studies of **π-K** interaction to locate **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





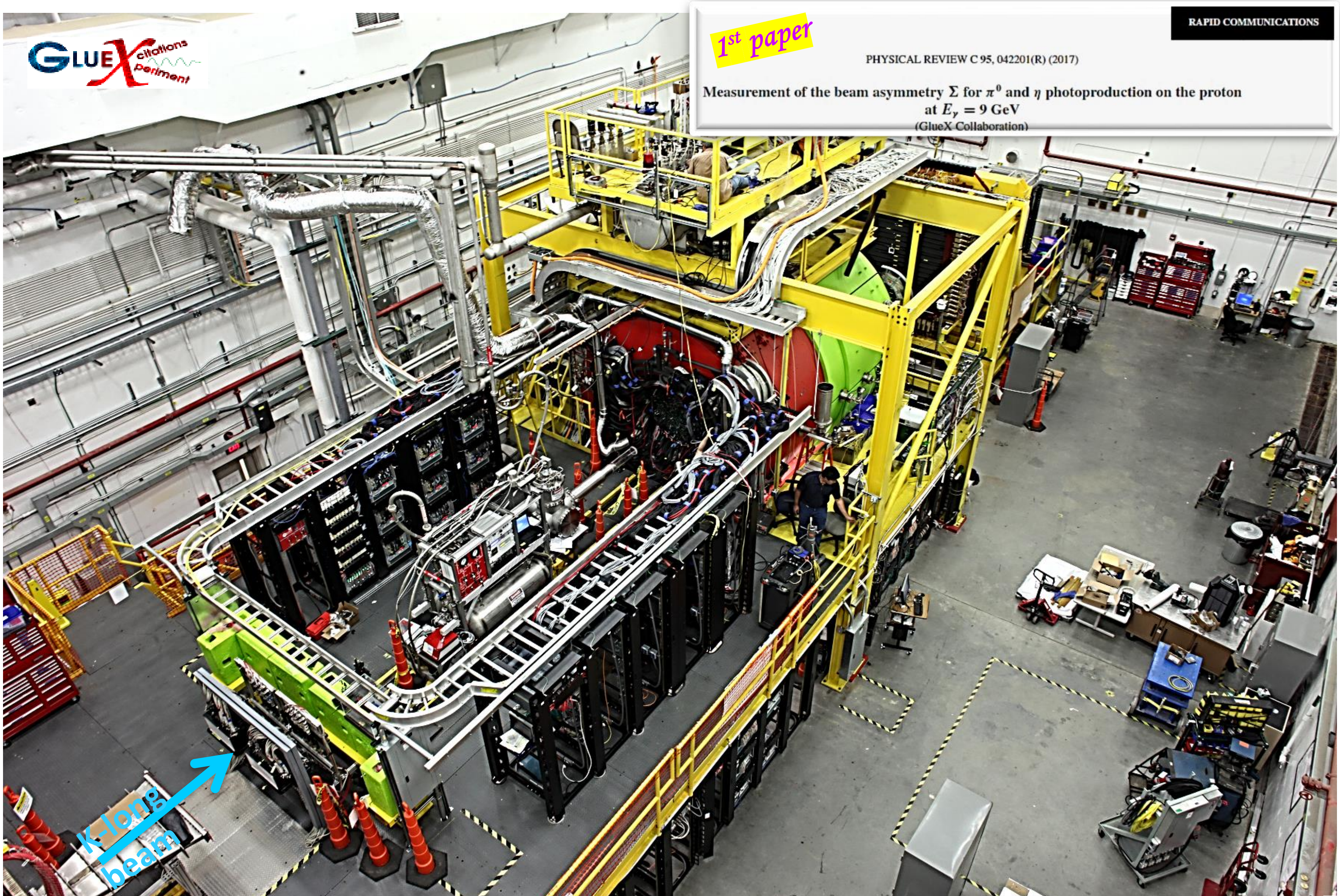
Upgrade Goals

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

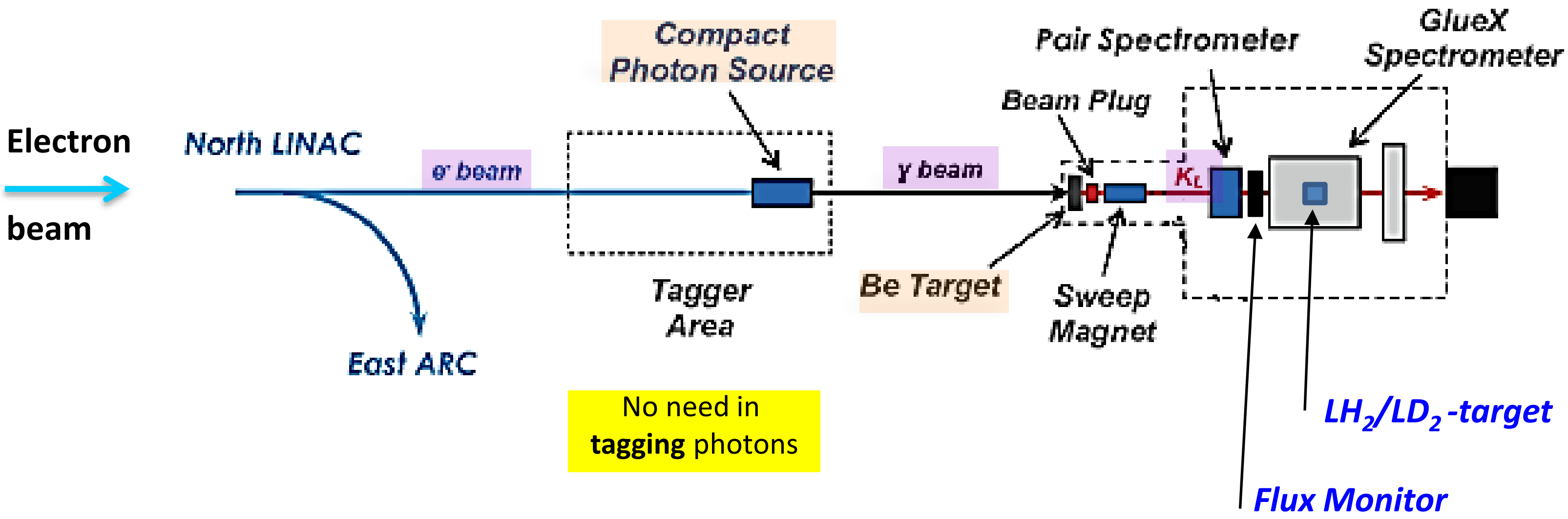
Upgrade Status

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

Hall D/GlueX


1st paper
RAPID COMMUNICATIONS
PHYSICAL REVIEW C 95, 042201(R) (2017)
Measurement of the beam asymmetry Σ for π^0 and η photoproduction on the proton at $E_\gamma = 9$ GeV
(GlueX Collaboration)
K-long beam

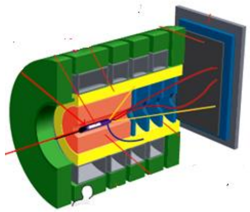
Hall D Beam Line Set up for K-longs



No need in **tagging** photons

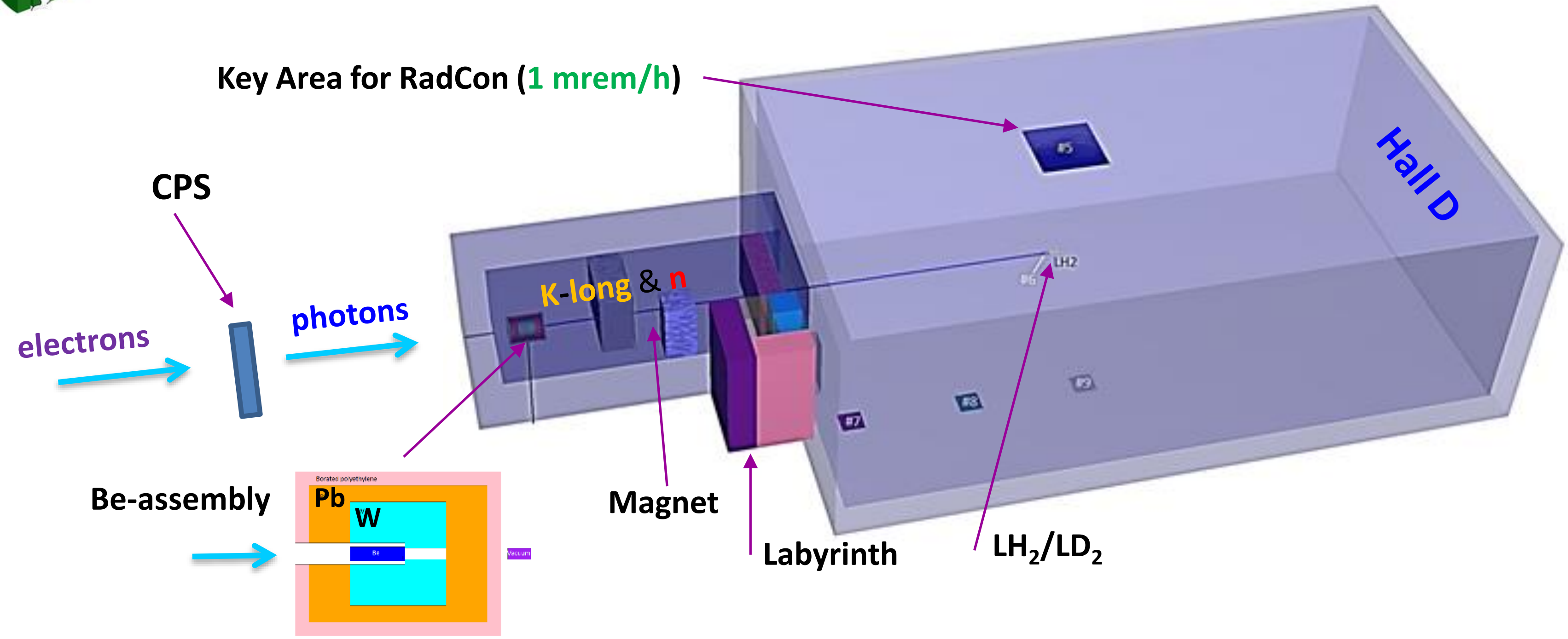
I$_e$ = **5** μA
W-radiator = **0.1** R.L.
Be-target = **1.7** R.L.

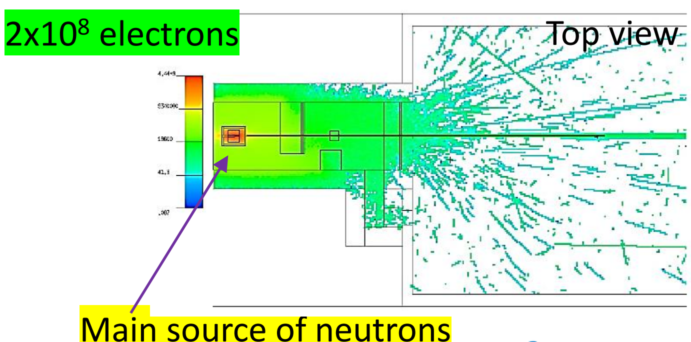
- **Electrons** are hitting **W**-radiator at **CPS**.
- **Photons** are hitting **Be**-target at **cave**.
- **K_Ls** are hitting the **LH_2/LD_2** target within **GLueX** setting.

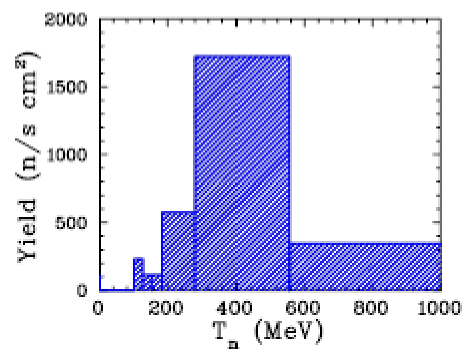


Expected Neutron Background

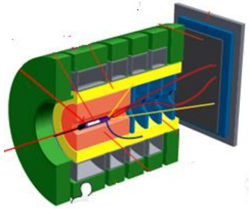
- Most **important** & **unpleasant** **background** for K_L comes from **neutrons**.



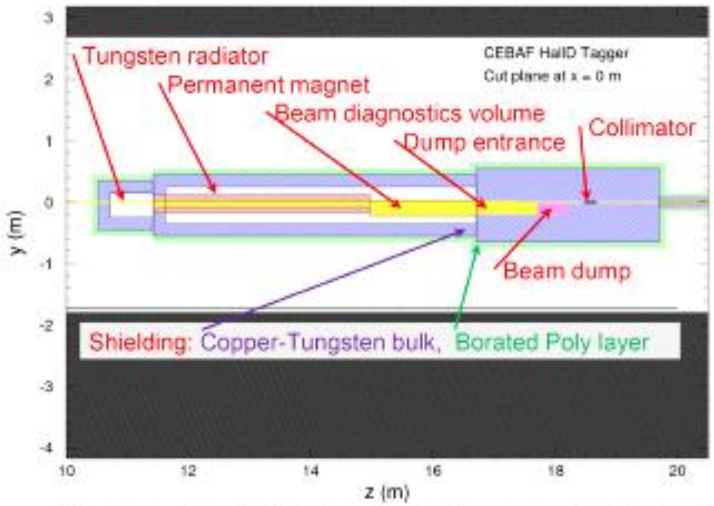


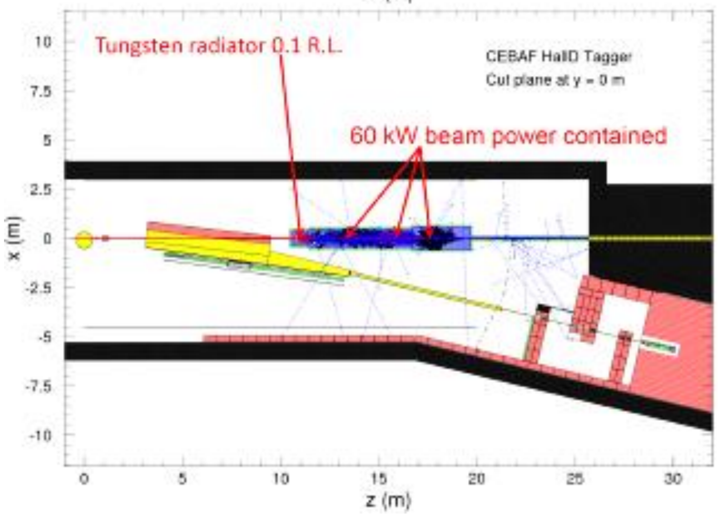


- For **neutron** calculations, we use **MCNP6** transport code.



Compact Photon Source & Be-Target





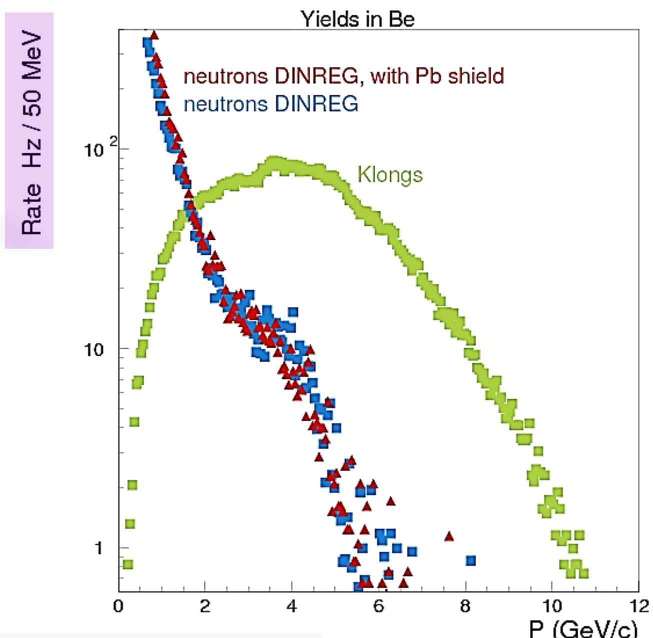
PAC45 Report:

*The **CPS** design is progressing but details on the **KL** target and shielding for the detector need to be fleshed out.*

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

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

MC @ 12 GeV



Data @ 16 GeV

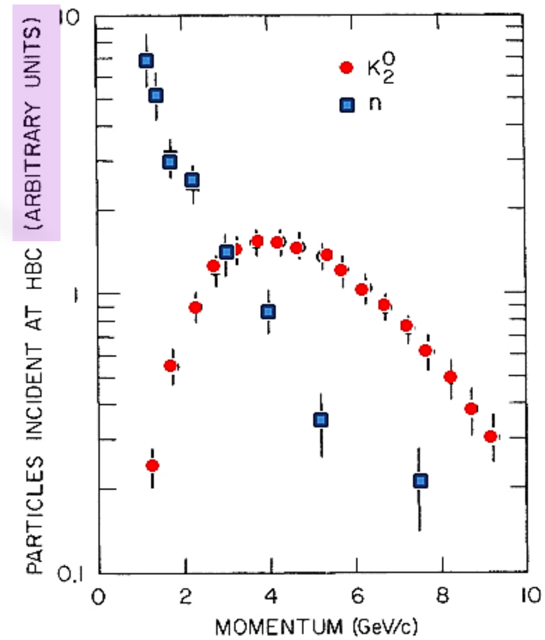
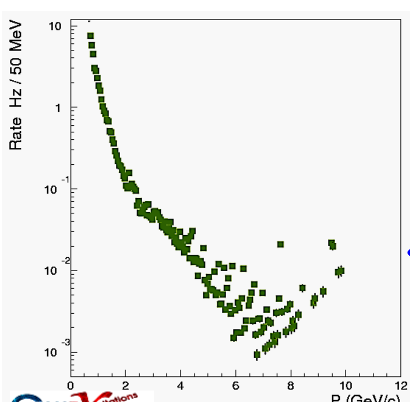


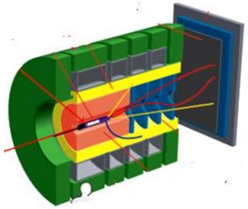
FIG. 2. Comparison of the neutron and K_2^0 fluxes at the hydrogen bubble chamber for 2° production with 16-GeV electrons. A.D. Brody *et al* Phys Rev Lett **22**, 966 (1969)



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.

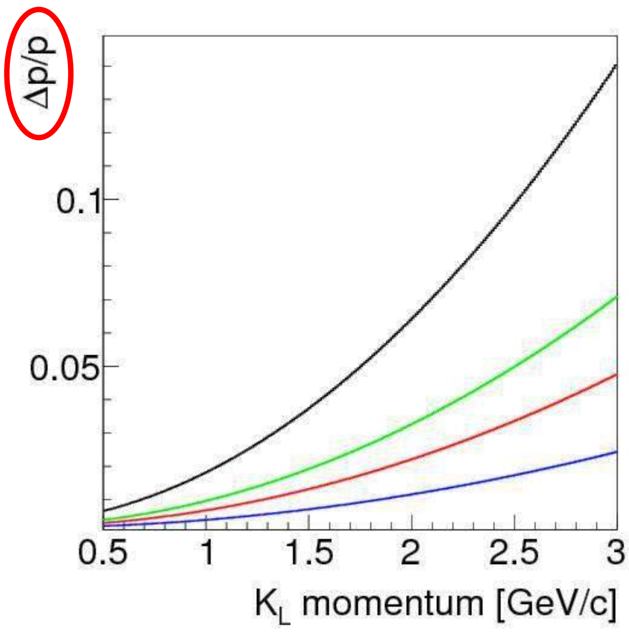


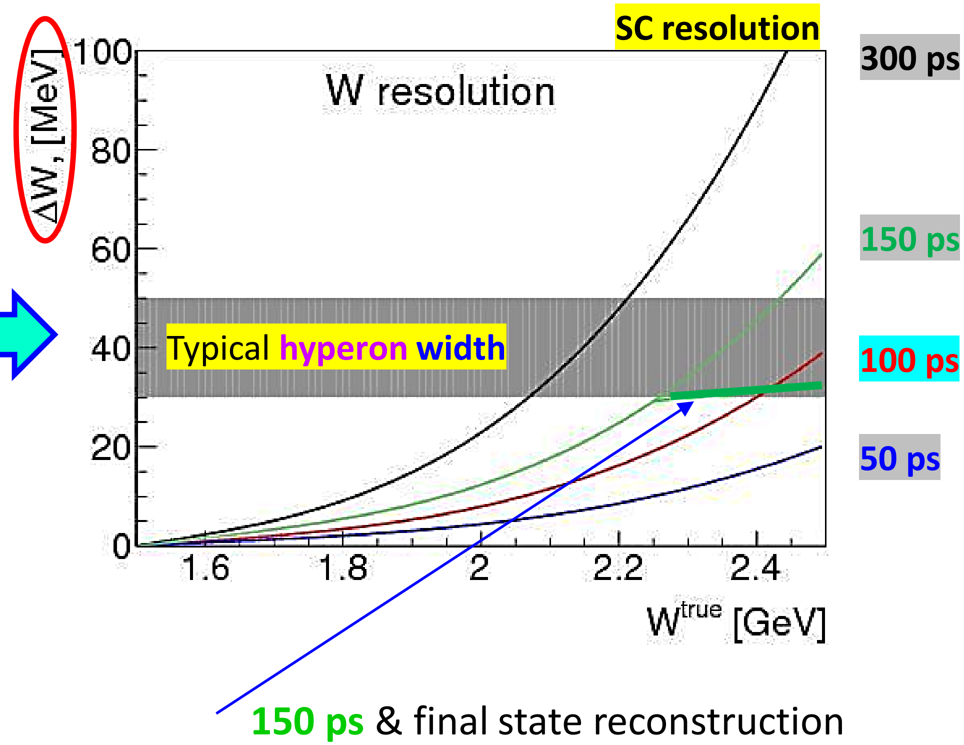
Expected Energy-Resolution

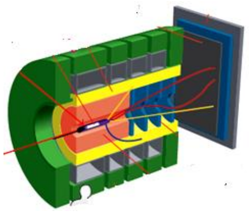
- Mean lifetime of K^- is **12.38** ns ($c\tau$ = **3.7** m) whereas mean lifetime of K_L is **51.16** ns ($c\tau$ = **15.3** m).

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**.





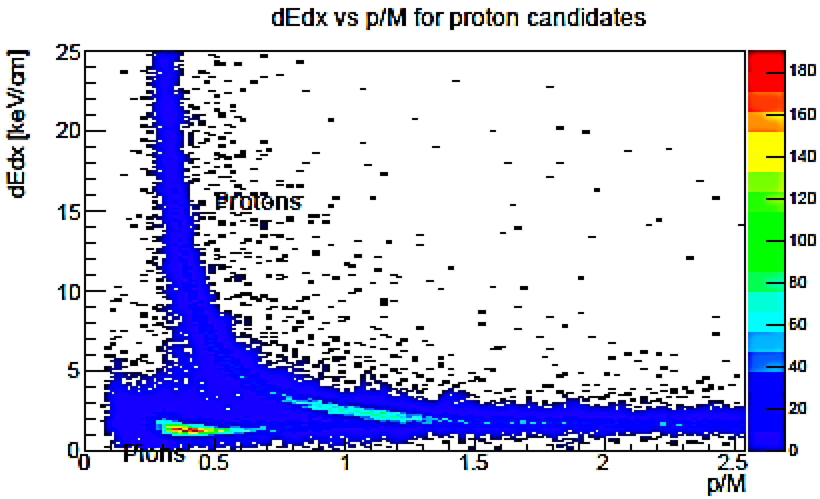


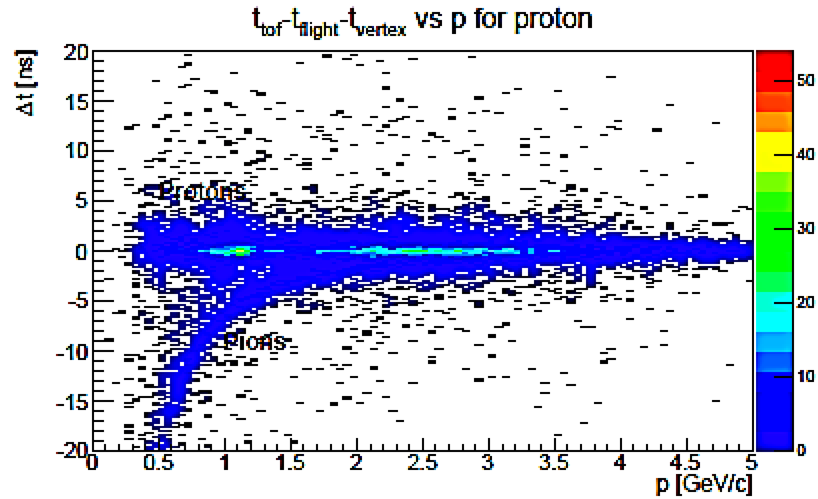
Expected Particle Identification

GEANT4

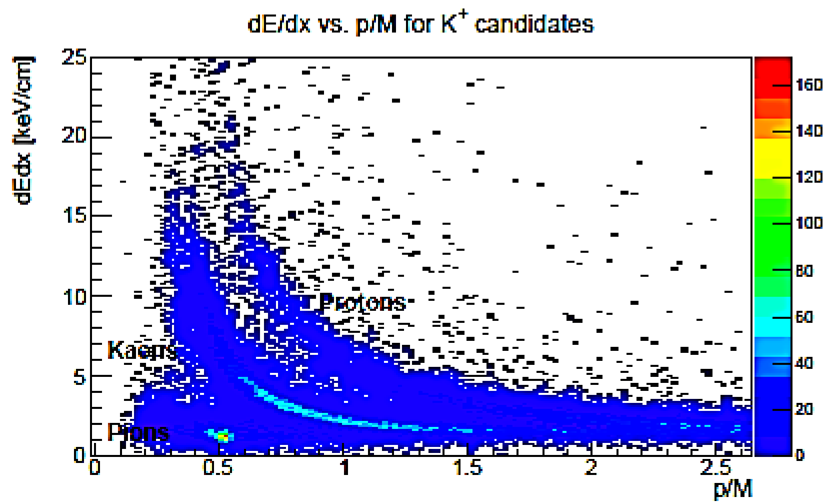
- **dE/dx** for **pK$_S$.**

- 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

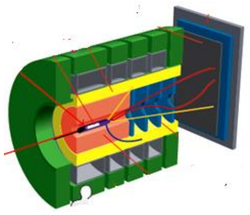
- **GlueX** measurements will span **cosθ** from **–0.95** to **0.95** in CM above **W** = **1490** MeV.

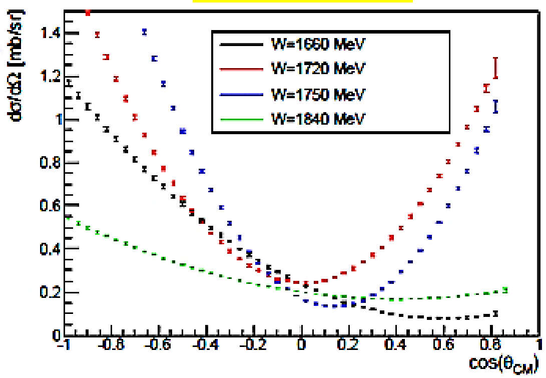
- K_L rate is 10^4 K_L/s = **2500** x SLAC NATIONAL ACCELERATOR LABORATORY
- Uncertainties (statistics only) correspond to **100** days of running time for:

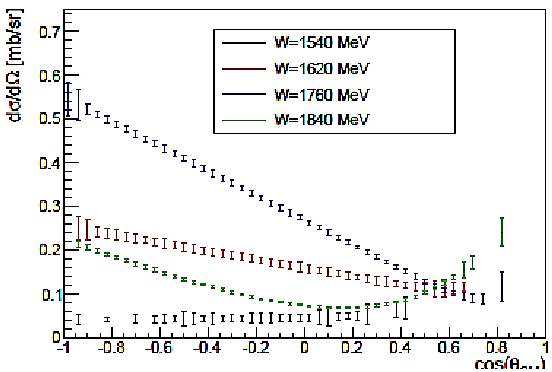
$K_Lp \rightarrow K_Sp$

$K_Lp \rightarrow \pi^+\Lambda$

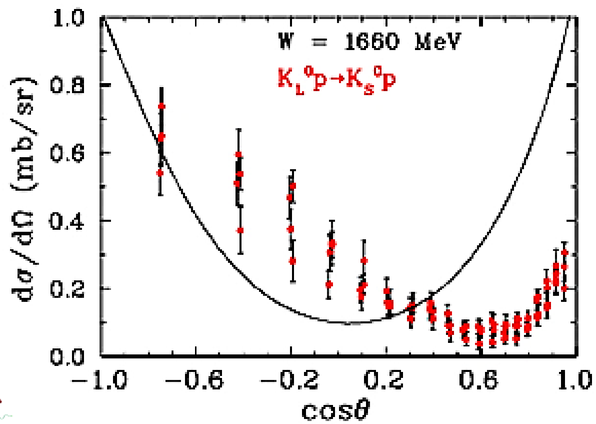
GEANT4

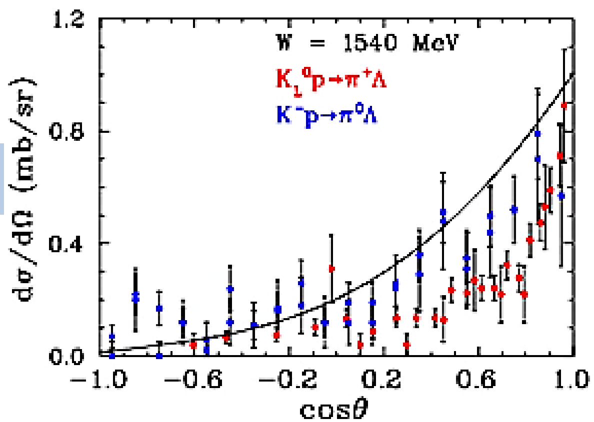






Expected **GlueX Data**

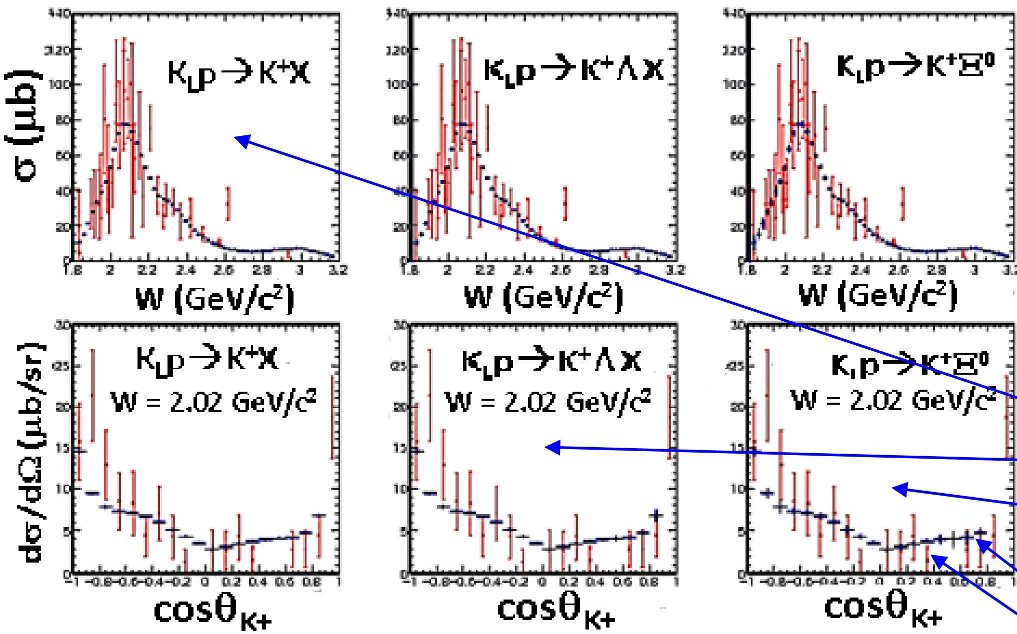




BC Data

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

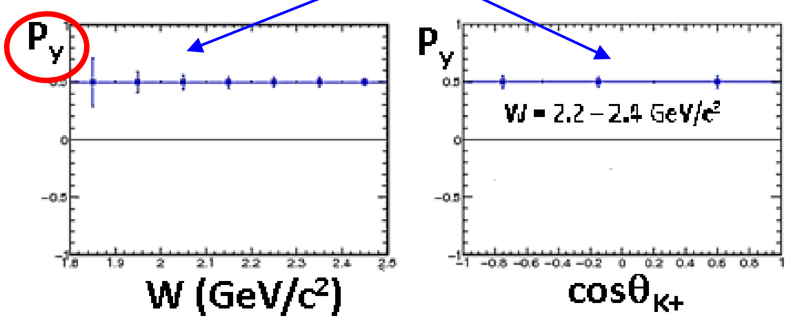
- Total & diff **Xsec** for different **topologies**



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

Expected data
Available data

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

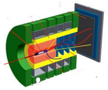


$$K_Lp \to K^+\vec{\Xi}^0 \to K^+\vec{\Lambda}\pi^0 \to K^+p\pi^-\pi^0$$

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

PAC45 Report:

*The beam time request is dominated by the hyperon polarimetry measurements. A **simulated** example of a partial wave analysis, and how it would feed into the proposed spectroscopy measurements, will be needed in a future proposal.*

- JPAC & groups will evaluate impact of new **KLF** measurements to compare available data **w**/**o** GlueXcitations Experiment quasi-data generated using GEANT4 & knowing  detector properties.

Pion-Kaon Interaction

- Detailed study of **Kπ** system is very important to extract so-called **Kπ vector** & **scalar** form factors to be compared with $\tau \to K\pi\nu_\tau$ decay & can be used to constrain $\mathbf{V_{us}}$ 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			**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	$J/\psi \to K_S^0 K_S^0 \pi^+\pi^-$
849 ±77 $^{+18}_{-14}$	1421	2,3	512 ± 80 $^{+92}_{-44}$	1421	[19,20] ABLIKIM 10E	BES2	$J/\psi \to K^\pm K_S^0 \pi^\mp \pi^0$
841 ±30 $^{+81}_{-73}$	25k	4,5	618 ± 90 $^{+96}_{-144}$	25k	[19,21] ABLIKIM 06C	BES2	$J/\psi \to \overline{K}^*(892)^0 K^+\pi^-$
658 ±13		6	557 ± 24		[22] DESCOTES-G..06	RVUE	$\pi K \to \pi K$
797 ±19 ±43	15k	7,8	410 ± 43 ± 87	15k	[23,24] AITALA 02	E791	$D^+ \to K^-\pi^+\pi^+$

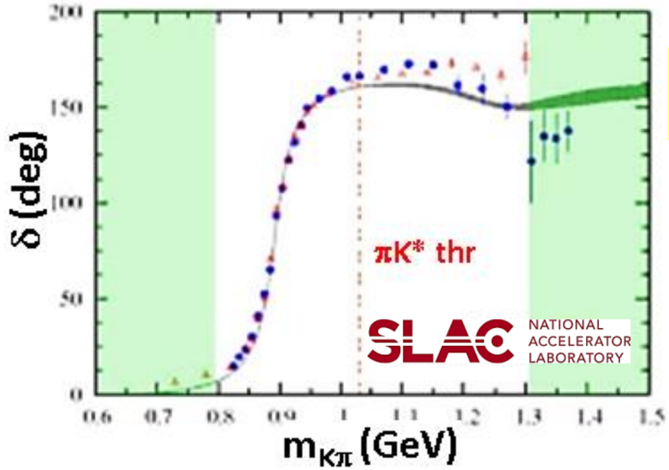
PDG particle data group

$K^*(892)$

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

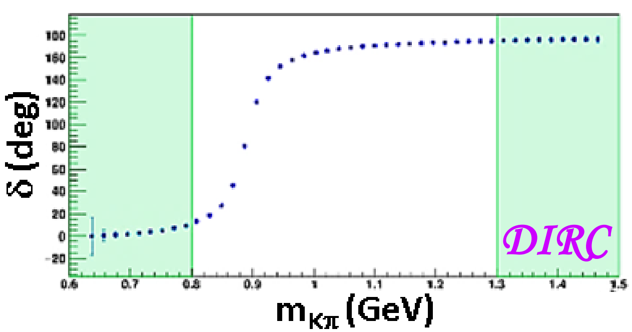
S. Descotes-Genon & B. Moussallam, Eur Phys J C **48**, 553 (2006)

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

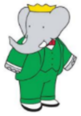


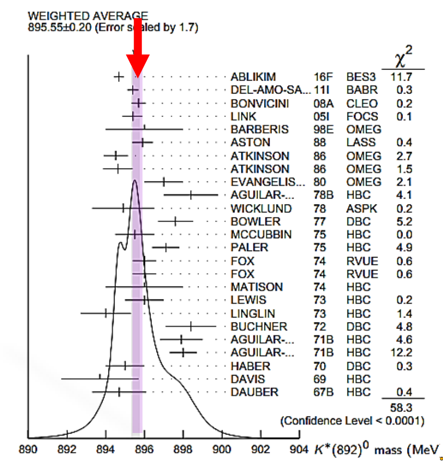
Fit to τ-decay from BELLE:
D.R. Boito, R. Escribano, M. Jamin, JHEP **1009**, 031 (2010)

LASS @ SLAC: D. Aston *et al*. Nucl Phys B **296**, 493 (1988)
SLAC: 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.

- It came from  .



IV

Speakers: Amaryan

Nemenov

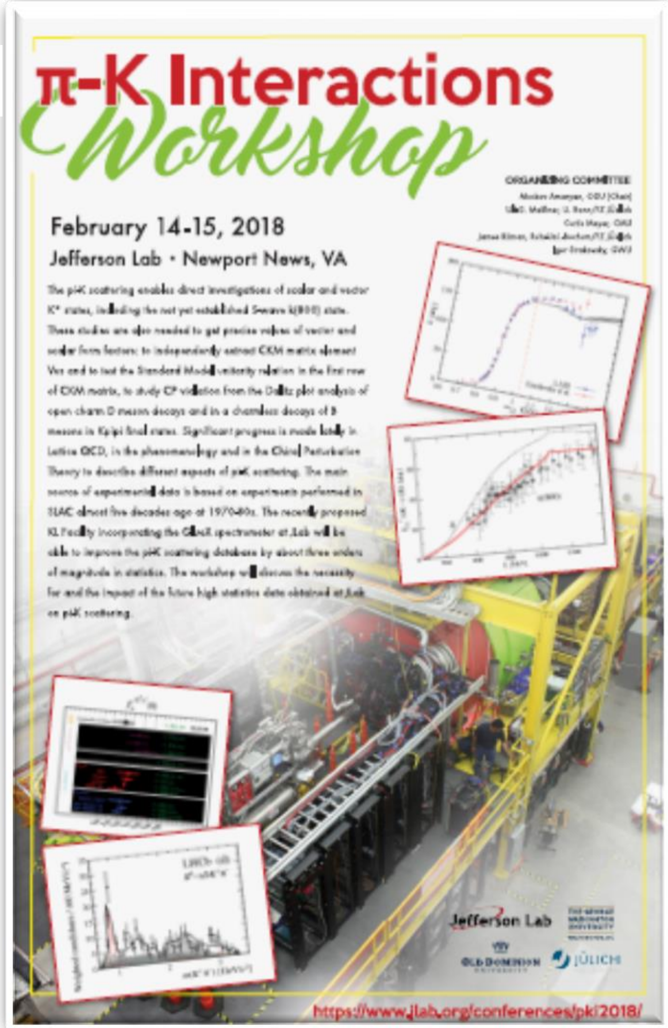
Qiu

Lo

Mai

Pal

38 people
from
10 countries & 27 talks



Morningstar

Coutinho

Beane

Edwards

Pelaez

Guo

Leskovec

Szczepaniak

Palano

Grube

Rusetsky

Pilloni

Mohler

Kubis

Stevens

de Elvira

Baalouch

Filippi

Ivanov

Epifanov

Moussallam

Doering

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 Jefferson Lab Thomas Jefferson National Accelerator Facility
  - To do **measurements** which bring new physics.

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

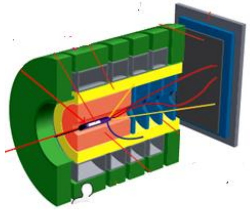
- **JLab K-long Facility** would advance **Hyperon Spectroscopy** & study of **strangeness** in nuclear & hadronic physics.
  It may extract very many missing strange states.
  To complete **$SU(3)_F$** multiplets, one needs no less than **17 Λ^*, 43 Σ^*, 42 Ξ^*, & 24 Ω^*.**

- **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**.

Wer's nicht glaubt, bezahlt einen Taler.

Backup Slides



Time Request

- Expected statistics for differential cross sections of different reactions with **LH_2** & below **W = 3** GeV for **100 days** of beam time.

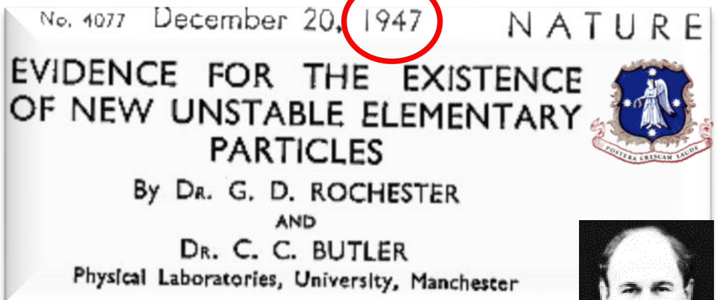
For $d\sigma/d\Omega$

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

$\Longrightarrow$ 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

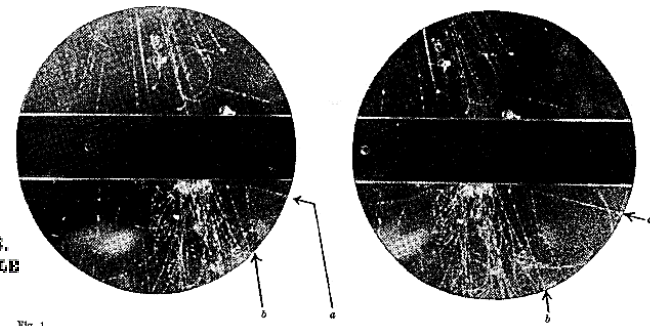

No. 4077 December 20, 1947 NATURE

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**.



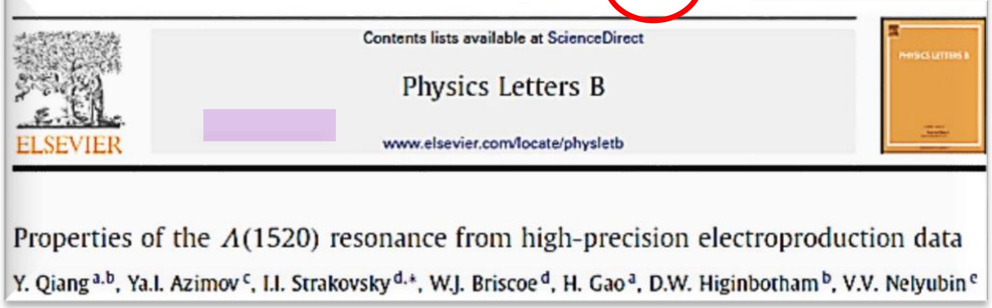
STEREOSCOPIC PHOTOGRAPHS SHOWING AN UNUSUAL FORK (a b) IN THE GAS. THE DIRECTION OF THE MAGNETIC FIELD IS SUCH THAT A POSITIVE PARTICLE COMING DOWNWARDS IS DEVIATED IN AN ANTICLOCKWISE DIRECTION

- **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

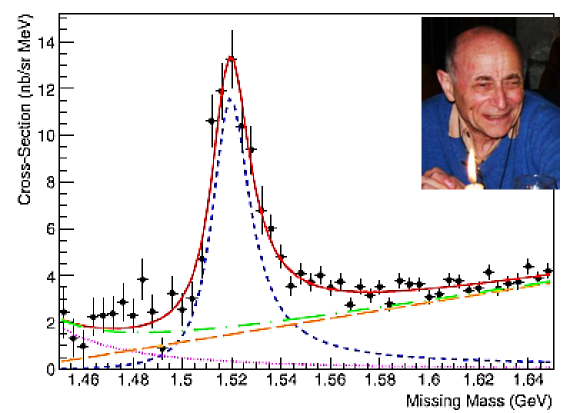
Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

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]

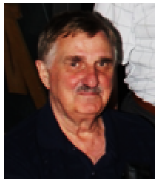


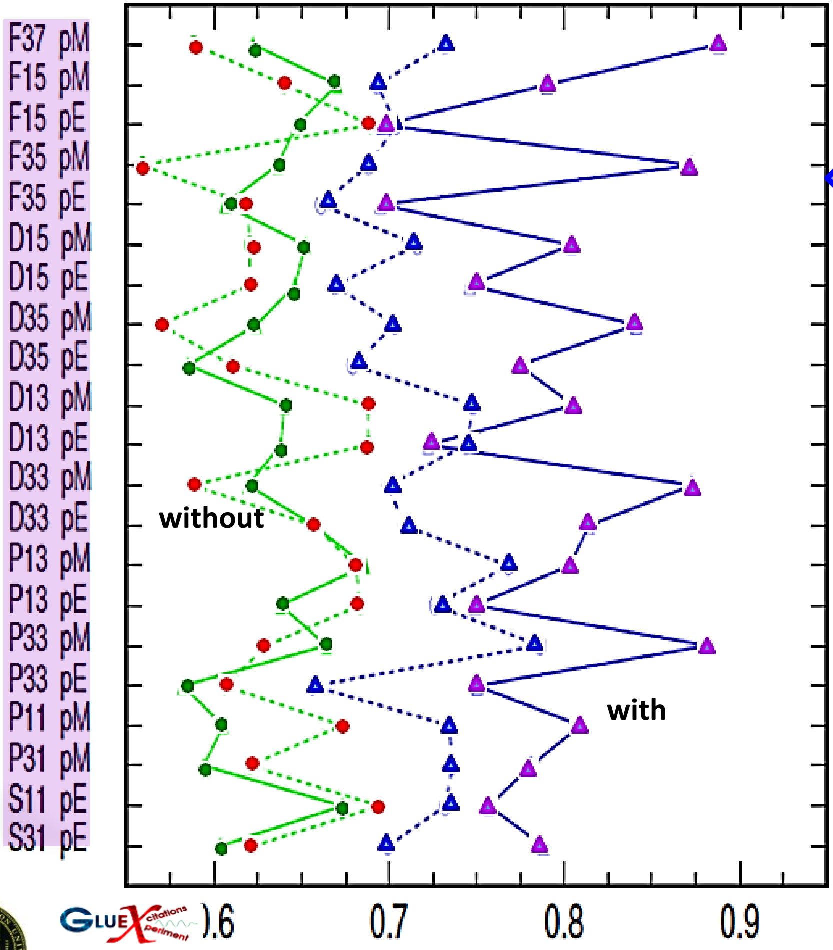
Quasi-Data: What to Expect When you're Expecting

- 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})





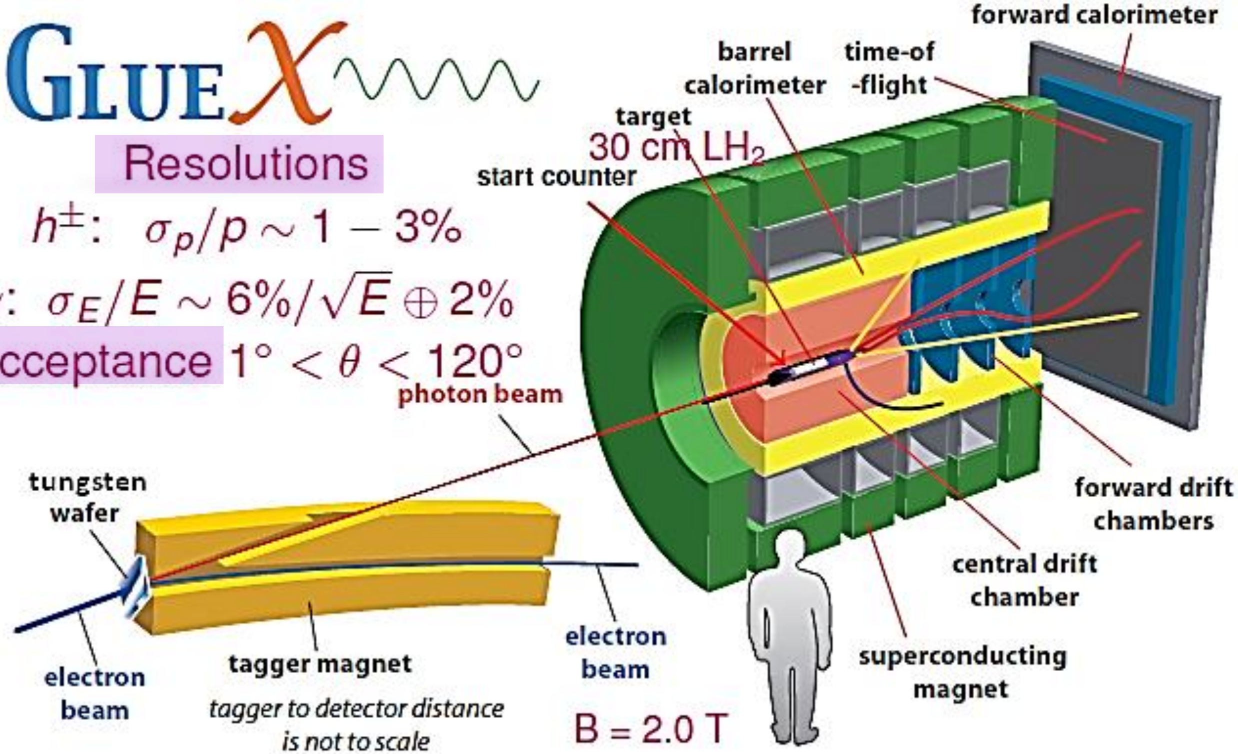
Average ratio of **uncertainties** of amplitudes **w/o** expected **FROST** data.

- 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**.

π^+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...

Hall D/GlueX Spectrometer and DAQ



Resolutions

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

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

Acceptance $1^\circ < \theta < 120^\circ$

Detectors

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

Plans to add

- 2017 L3
- 2018 DIRC

Photoproduction γp 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

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

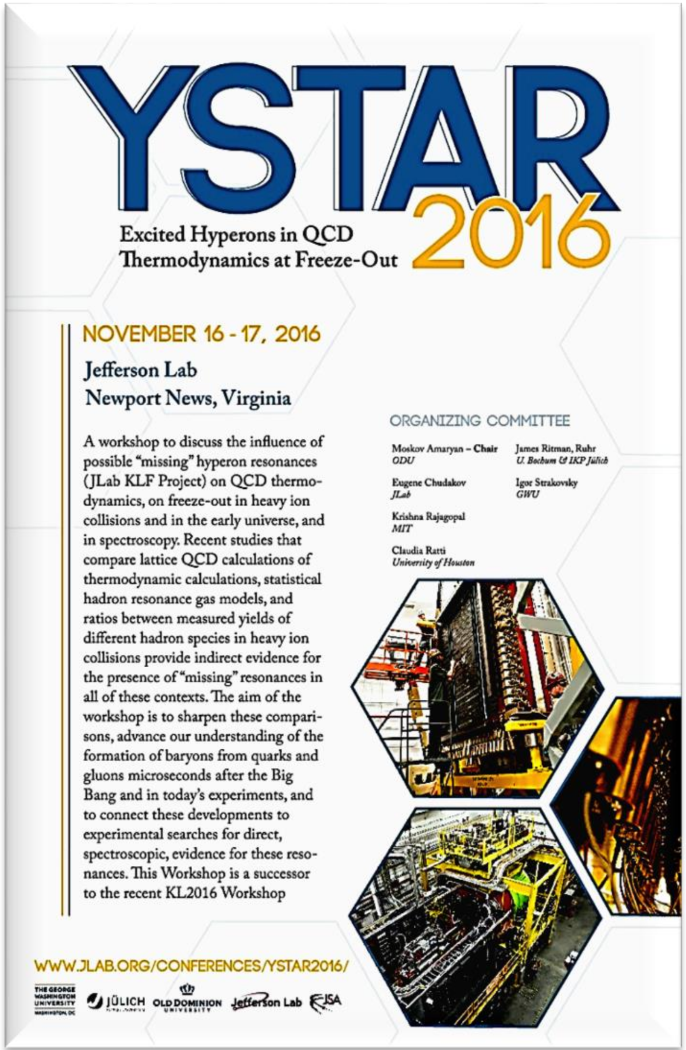
60 people from **9** countries & **30** talks

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

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

II

Speakers: Mai, Chudakov, Garcilazo, Amaryan, Begun, Noronha-Hostler, Myhrer, Ohnishi, Ritman, Capstick, Noumi, Bellwied, Ratti, Tang, Stroth, Guo, Alba, Crede, Manley, Montgomery, Goity, Edwards, Xie, Arriola, Tsuchikawa, Huovinen, Doenigus



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

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

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

III

Speakers: Mai

Goity

Perera

Dominguez

Tadevosyan

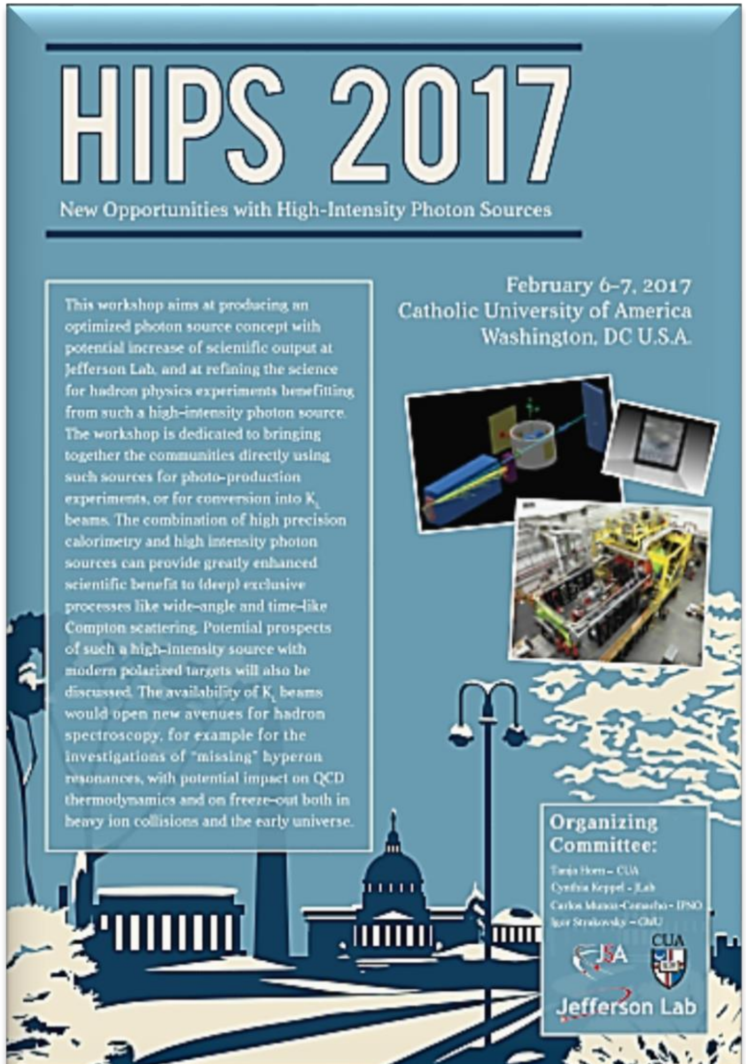
Beminiwhatta

Wojtsekhowski

Degtyarenko

Niculescu

Liuti



Sargsian

Patsyuk

Zhang

Sirca

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

Keppel

Strakovsky

Hamilton

Keller

Kroll

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

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