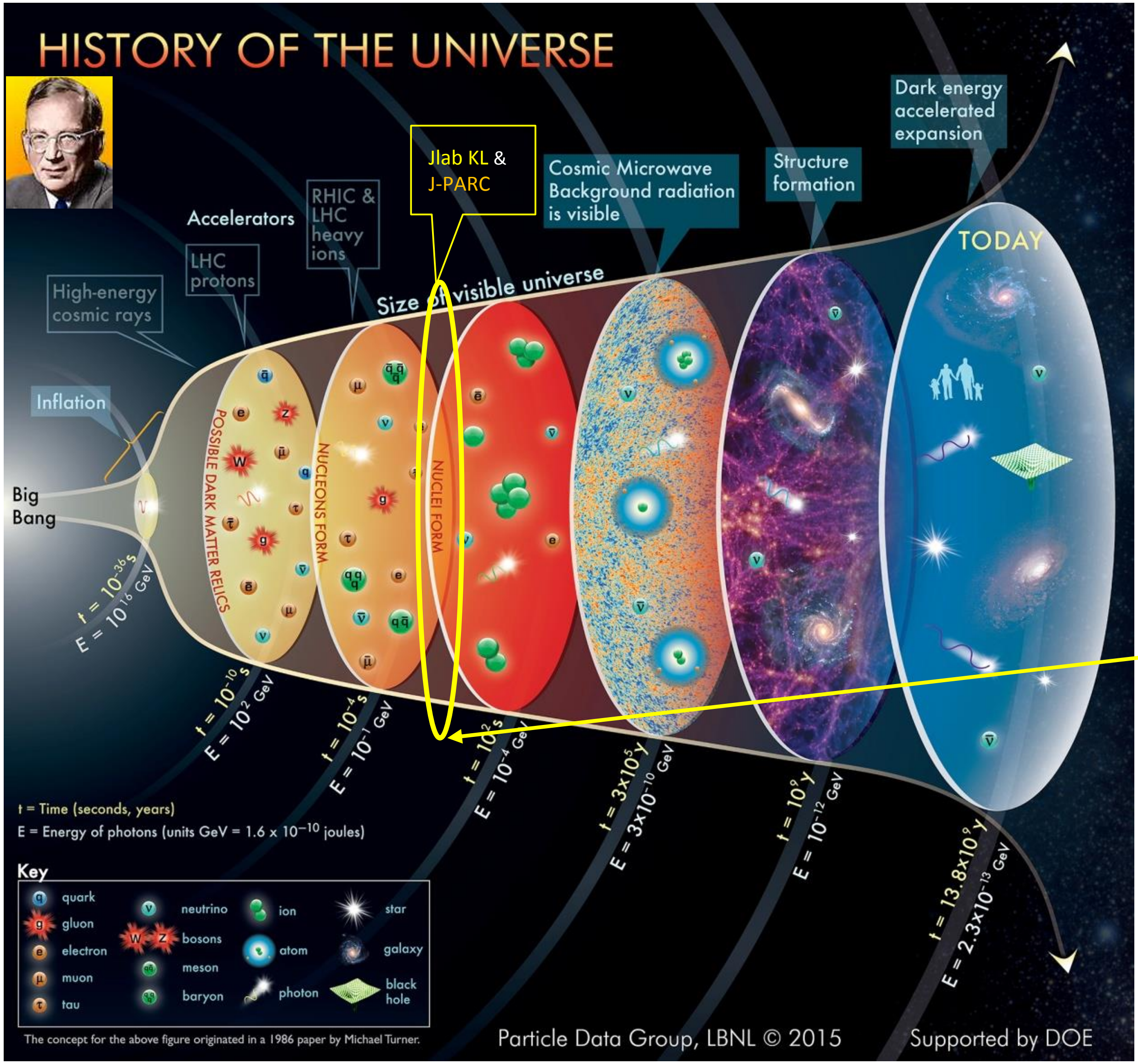
Physics Perspectives for Future K-Long Facility

Igor Strakovsky[*]
The George Washington University
(for GlueX Collaboration)

- Thermodynamics at freeze-out.
- Spectroscopy of hyperons.
- PWA for strange sector.
- $K_L p$ data.
- Opportunity with K_L beam.
- Neutron background.
- Expected $K_L p$ data.
- Mutual projects.
- JLab Workshops.
- Summary.

[*] Supported by DE-SC0016583

History of the Universe



- There is Influence of possible "**missing**" hyperons on QCD thermodynamics, on **freeze-out** in heavy ion & hadon collisions & in **early Universe**, & in spectroscopy.

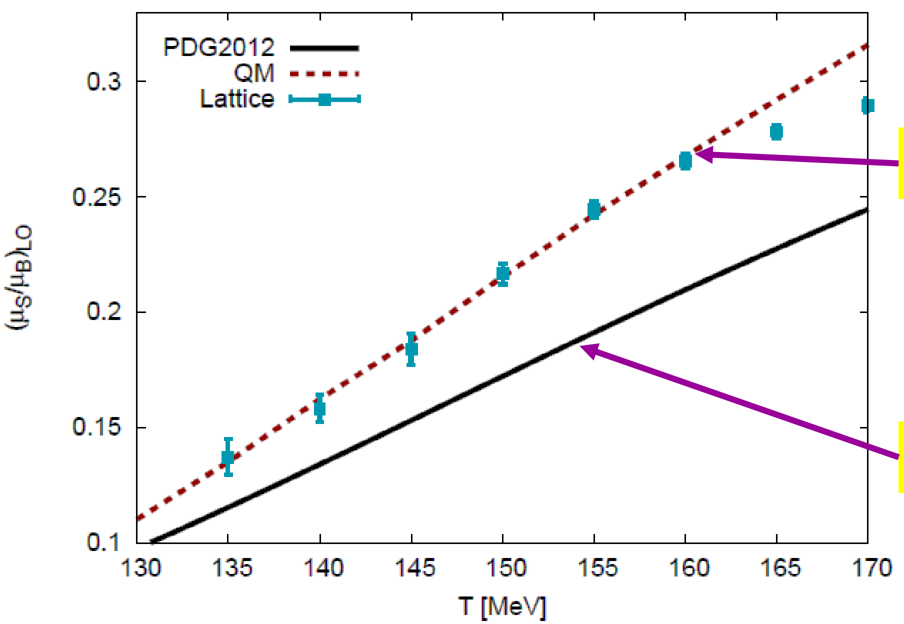
- Advance our understanding of **formation** of **baryons** from **quarks** & **gluons** **microseconds** after **Big Bang** & in today's experiments, & connection these developments to experimental searches for direct, spectroscopic, evidence for these "**missing**" resonances.

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 the presence of "missing" resonances in all of these contexts.

Chemical Potential

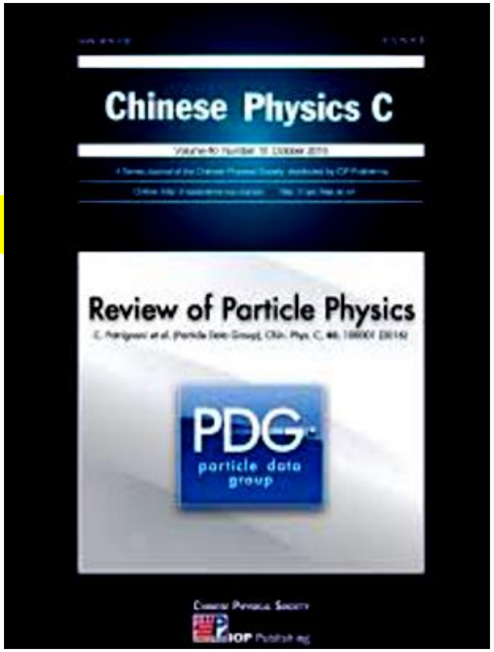
$$\left(\frac{\mu_S}{\mu_B}\right)_{LO} = -\frac{\chi_{11}^{BS}}{\chi_2^S} - \frac{\chi_{11}^{QS}}{\chi_2^S}\frac{\mu_Q}{\mu_B}$$



- **+** "**Missing**" **Hyperons** (**QM** calculations).
- Contribution from **observed** **Resonances**. PDG

Courtesy of Claudia Ratti, YSTAR2016

Baryon Sector at PDG16



GW — Data Analysis Center — Institute for Nuclear Studies, The George Washington University

GW Contribution

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

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(17$[illegible]$)$	$3/2^+$	[illegible]
$N(18$[illegible]$)$	$5/2^+$	[illegible]
$N(1$[illegible]$5)$	[illegible]$/2^-$	***
$N($[illegible]$0)$	[illegible]2^+	**
$N($[illegible]$95)$	[illegible]	**
$N($[illegible]$00)$	3[illegible]	***
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	[illegible]
$\Delta(1930)$	$5/2$[illegible]	[illegible]
$\Delta(1940)$	[illegible]2^-	[illegible]
$\Delta(1950)$	$7/2^+$	[illegible]
$\Delta(2000)$	$5/2^+$	[illegible]
$\Delta(21$[illegible]$)$	$1/2^-$	[illegible]
$\Delta($[illegible]$)$	[illegible]	[illegible]
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	[illegible]
$\Lambda(1690)$	$3/2^-$	[illegible]
$\Lambda(1800)$	$1/2$[illegible]	[illegible]
$\Lambda(1810)$	[illegible]2^+	[illegible]
$\Lambda(1820)$	[illegible]$/2^+$	[illegible]
$\Lambda(1830)$	$5/2^-$	[illegible]
$\Lambda(1890)$	$3/2^+$	[illegible]
$\Lambda(2000)$		*
$\Lambda(2020)$	$7/2^+$	*
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	**
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	[illegible]	****
$\Sigma(1690)$		**
$\Sigma(1750)$	[illegible]2^-	***
$\Sigma(1770)$	[illegible]$^+$	*
$\Sigma(1775)$	[illegible]$/2^-$	****
$\Sigma(1840)$	$3/2^+$	[illegible]
$\Sigma(1$[illegible]$)$	$1/2^+$	**
$\Sigma(1915)$	[illegible]	****
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	[illegible]	[illegible]
$\Xi(162$[illegible]$)$		*
$\Xi(1690)$		***
$\Xi(1820)$	[illegible]	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq$ [illegible]	***
[illegible]		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	[illegible]
$\Omega($[illegible]$0)^-$		[illegible]
$\Omega($[illegible]$80)^-$		[illegible]
$\Omega($[illegible]$70)^-$		

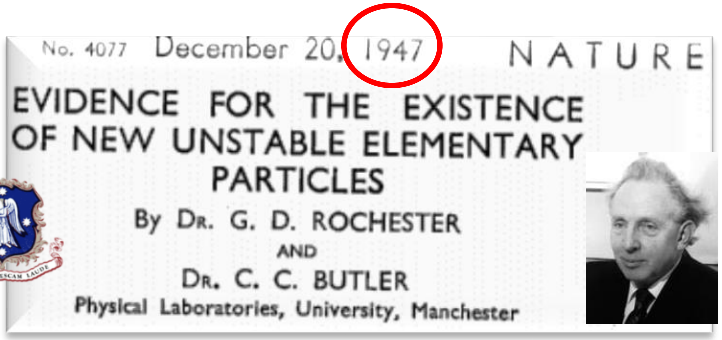
Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	***
$\Xi_c'^+$	$1/2^+$	***
$\Xi_c'^0$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
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^-	$1/2^+$	***

- **Pole** position in complex energy plane for **hyperons** has began to be studied only recently (2010), **first of all** for **Λ(1520)**.

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)**, it would be required **434** baryons, if all revealed multiplets were completed (**three 70** & **four 56**).

A bit of Strange History


No. 4077 December 20, 1947 NATURE

EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

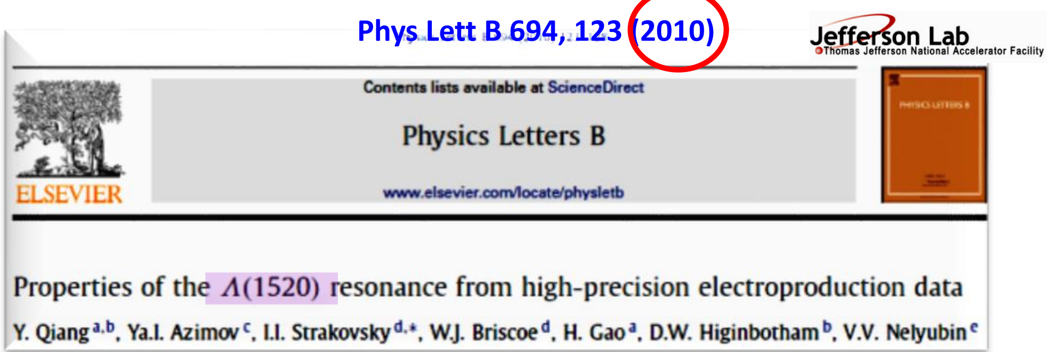
By DR. G. D. ROCHESTER AND DR. C. C. BUTLER

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**.

- **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

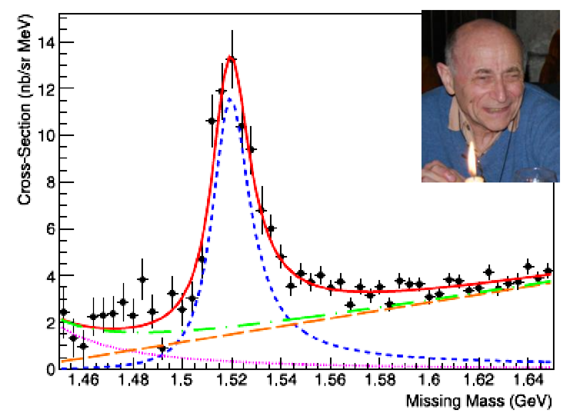
Physics Letters B

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]

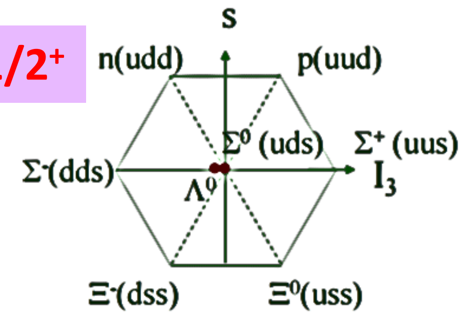


- Clearly, complete understanding of **three-quark bound** states requires to learn about baryon resonances in ``**strange sector**" as well.

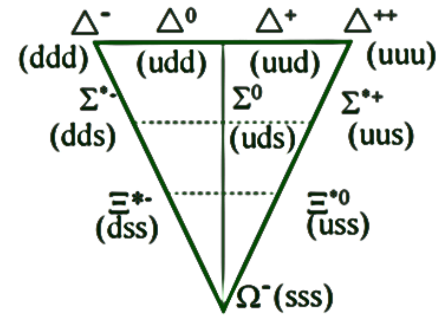
Baryon Resonances

- **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.

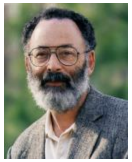
- Seriousness of "**missing-states**" problem is obvious from these numbers.

- 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)

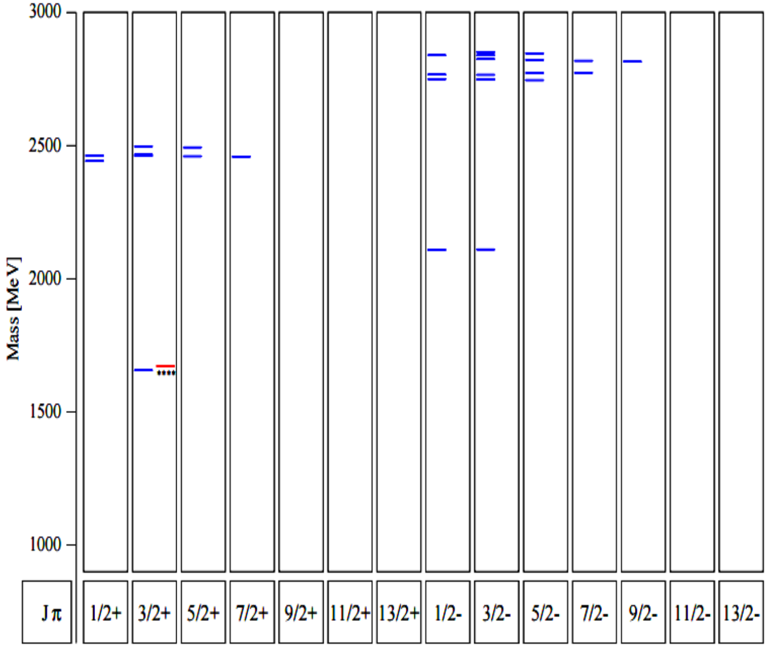
Very Strange Resonances & Problem of "Missing" States

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



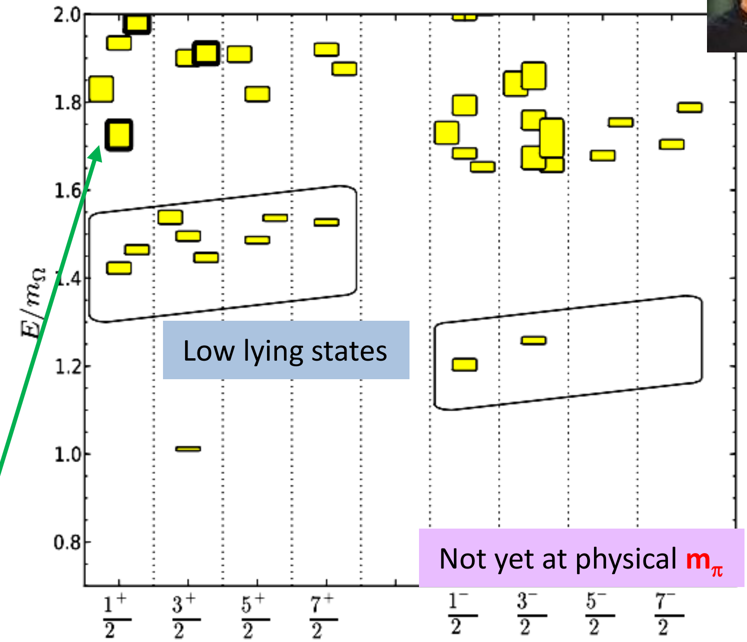
R. Koniuk and N. Isgur, Phys Rev Lett **44**, 845 (1980)

- Ω baryon spectrum in **QM**.



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

- Ω baryon spectrum in **LQCD**.



Low lying states

Not yet at physical m_π

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

Thick frame: Hybrid states

PWA for Baryons

- **Originally** **PWA** arose as technology to determine amplitude of reaction via **fitting** scattering data.
  That is **non-trivial mathematical problem** – looking for solution of **ill-posed** problem following to **Hadamard** and **Tikhonov**.


- **Resonances** appeared as **by-product**
  [bound states objects with definite quantum numbers, mass, lifetime, & so on].

Most of our current knowledge about bound states of **three light quarks** has come mainly from **$\pi N \rightarrow \pi N$ PWAs**:

Karlsruhe-Helsinki,

Carnegie-Mellon-Berkeley,

& **GW**.


Main source of **EM** couplings is **GW** & **BnGa** analyses.

- **Differential cross section** & **polarization** for K_Lp scattering are given by

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

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

$\lambda\!\!\!^{-} = \hbar/k$ & **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.
$P_l(\cos\theta)$ is Legendre polynomial.
$P_l'(\cos\theta)$ 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

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

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

We have both **I = 0** & **I = 1** amplitudes for **KN** and **$\overline{K}$N** 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 isopin **I** and total angular momentum **J = l+–1/2**
C^I are appropriate **Clebsch-Gordon** coefficients.

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

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

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

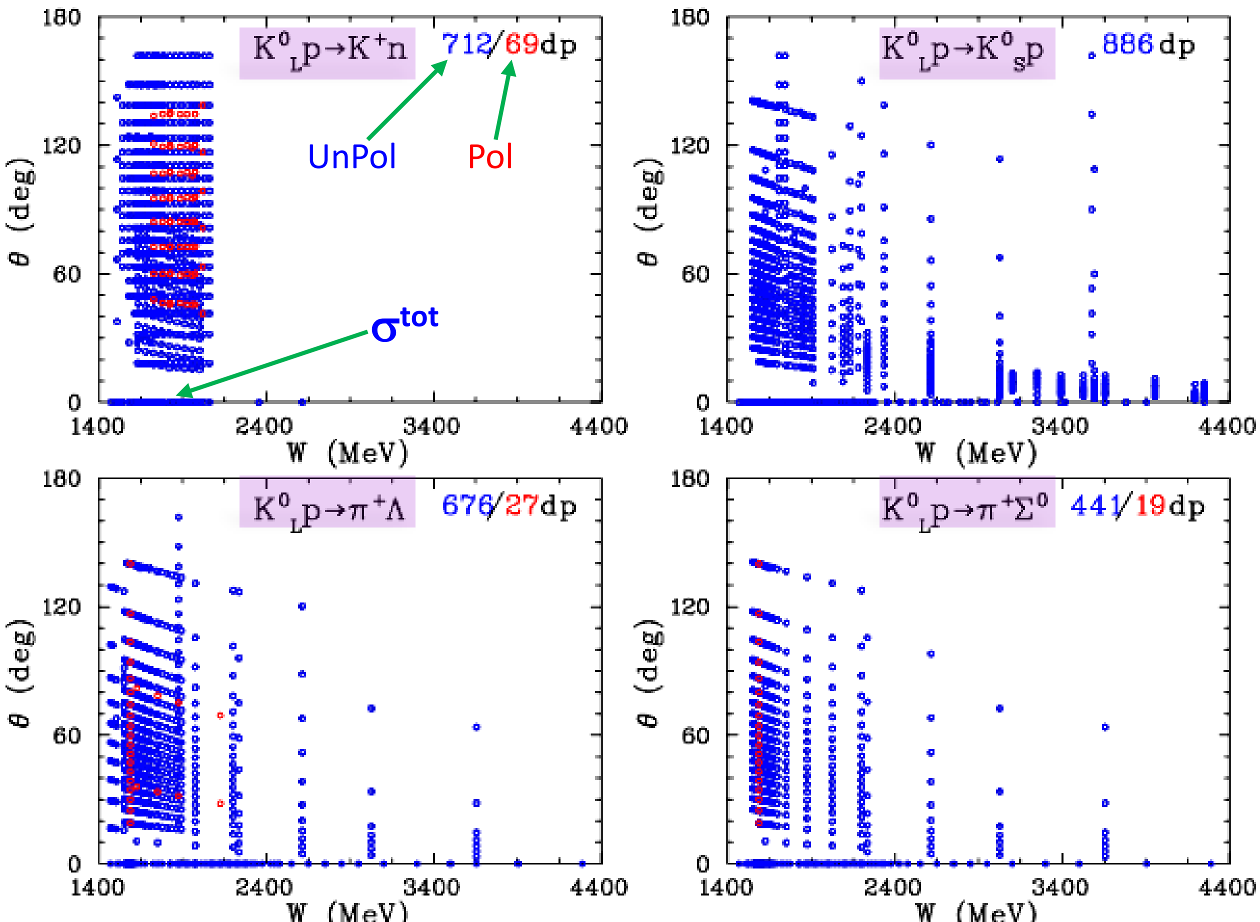
World K–long Data – Ground for Hyperon Phenomenology

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

W = 1.45 – 5.05 GeV

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

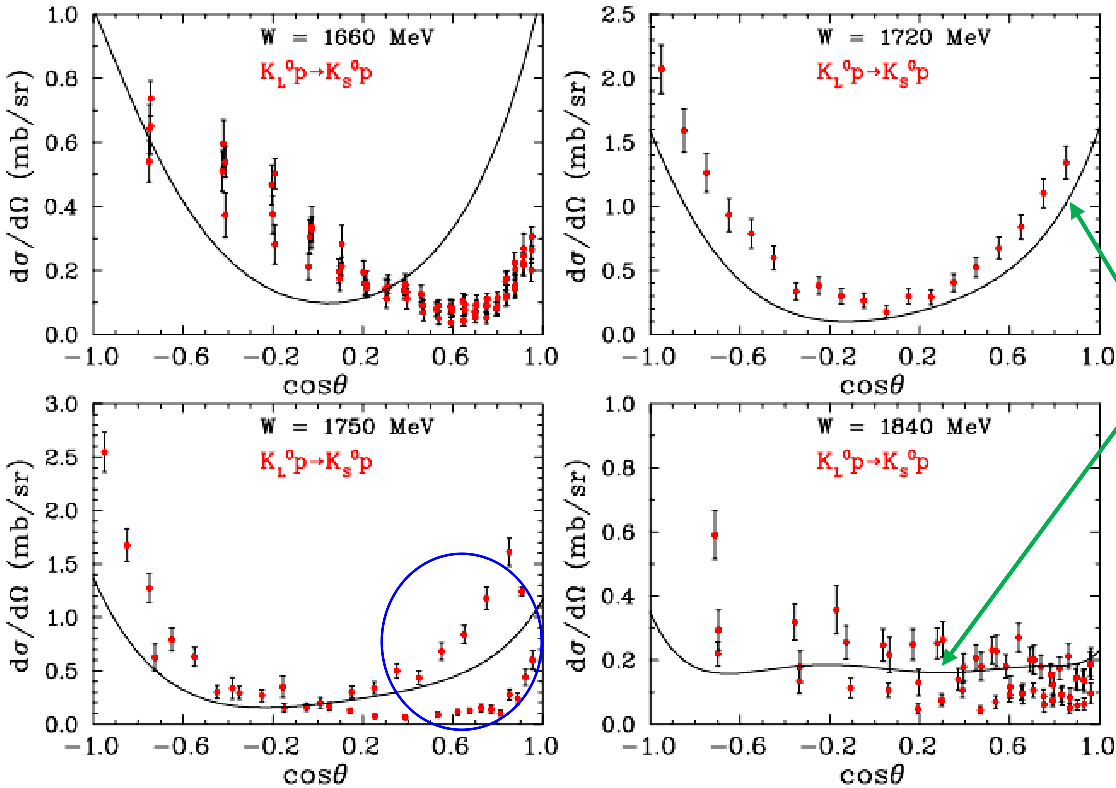
- Limited number of K_L induced measurements (**1961 – 1982**) **2426 dσ/dΩ, 348 σ^{tot}, & 115 P** observables do not allow today to **feel comfortable** with **Hyperon Spectroscopy** results.



- Most of **data** were obtained from **old** low statistics **measurements** with hydrogen **Bubble Chambers**.
- **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 $K_Lp \rightarrow K_Sp$

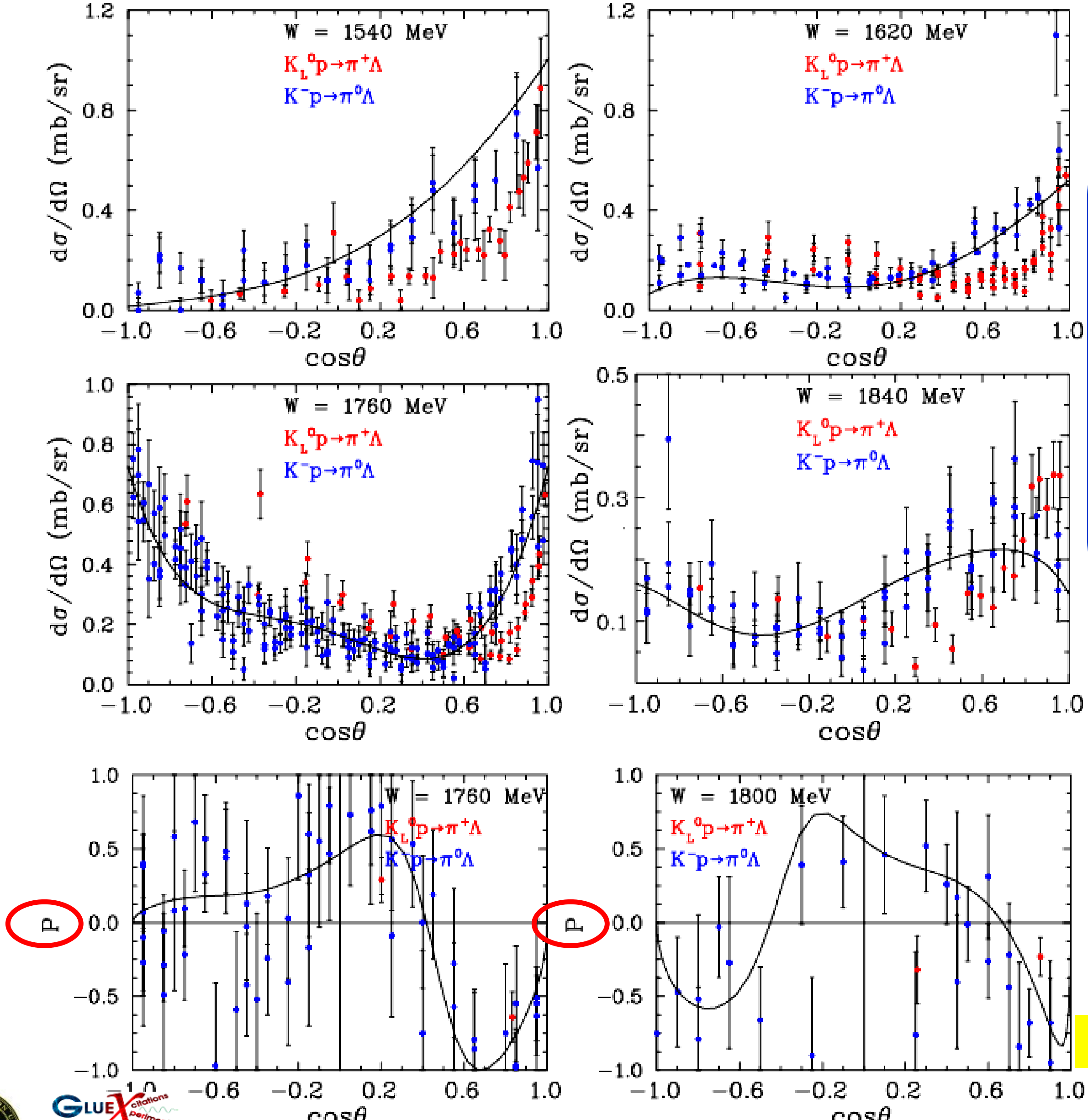
- No **dσ/dΩ** data are available for **$K_Lp \rightarrow K_Lp$** below W = **3** GeV.



- **PWA** (**KSU**&**GW**) predictions at lower & higher energies tend to agree worse with data than in non-strange case.

Courtesy of Mark Manley, KL2016

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

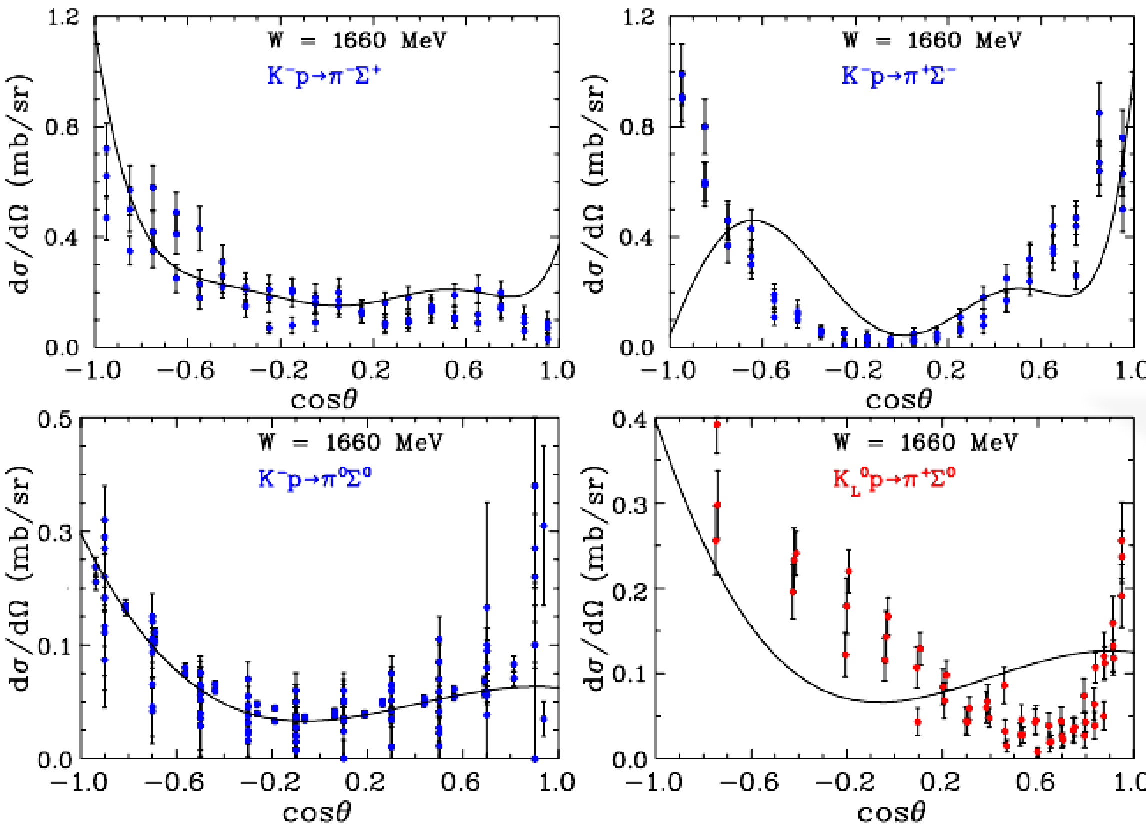


- $K^- p \to \pi^0 \Lambda$ & $K_L p \to \pi^+ \Lambda$ amplitudes imply that their observables measured at same energy should be identical except for small differences due to isospin-violating mass differences in hadrons.

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

Courtesy of Mark Manley, KL2016

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



Courtesy of Mark Manley, KL2016

- 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 a 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%**).

How to Search for "Missing" Hyperons

- **New data** for inelastic **K_Lp** scattering would significantly improve our knowledge of **Σ*** 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:

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

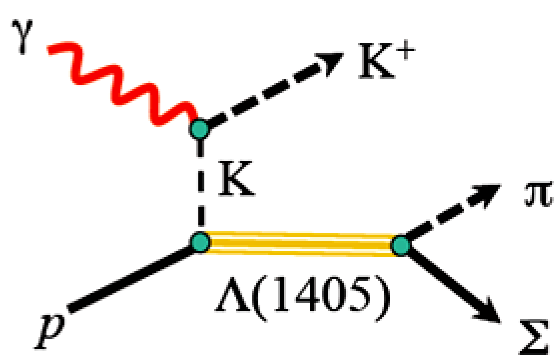
- If such measurements can be performed with good **energy** & **angular** coverage with good **statistics**.

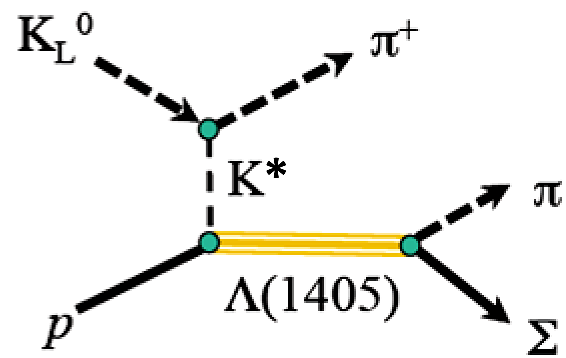
- Then it is very likely that measurements with **K_L beam** would find several "**missing**" **hyperons**.

Courtesy of Mark Manley, YSTAR2016

Sample of Hunting for Bumps

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





- Measurement may be feasible

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

Courtesy of Reinhard Schumacher, KL2016

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.

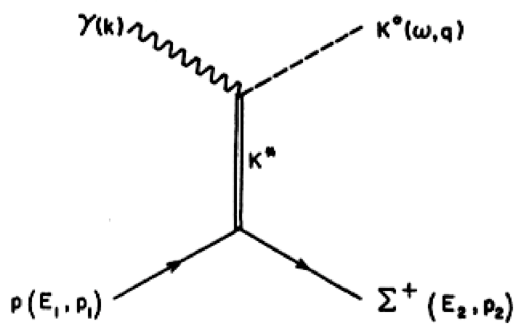


FIG. 1. K^* exchange in photoproduction.

[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

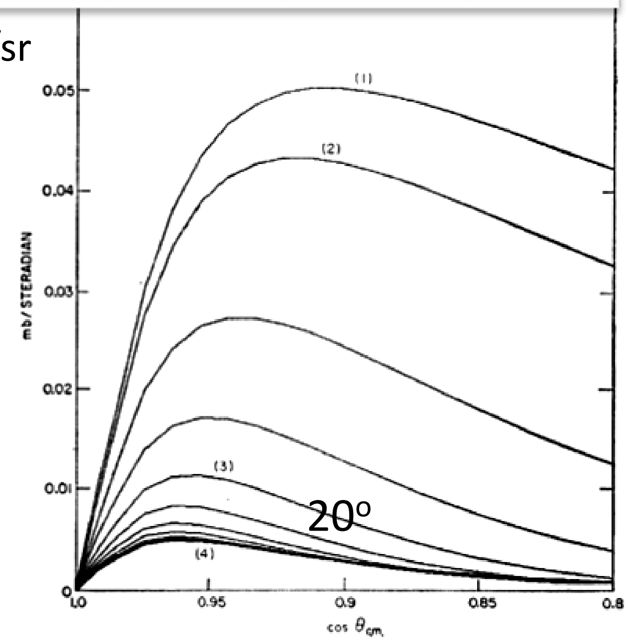


FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and (respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partial have been corrected for absorption in final state. The resul 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 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 LoI12-15-001

A Letter of Intent to Jefferson Lab PAC-43.

Physics Opportunities with a Secondary K_L^0 Beam at JLab.

Moskov J. Amaryan (spokesperson),[1,*] Yakov I. Azimov,[2] William J. Briscoe,[3] Eugene Chudakov,[4] Pavel Degtyarenko,[4] Gail Dodge,[1] Michael Döring,[3] Helmut Haberzettl,[3] Charles E. Hyde,[1] Benjamin C. Jackson,[5] Christopher D. Keith,[4] Ilya Larin,[1] Dave J. Mack,[4] D. Mark Manley,[6] Kanzo Nakayama,[5] Yongseok Oh,[7] Emilie Passemar,[8] Diane Schott,[3] Alexander Somov,[4] Igor Strakovsky,[3] and Ronald Workman[3]

[1]*Old Dominion University, Norfolk, VA 23529*
[2]*Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia*
[3]*The George Washington University, Washington, DC 20052*
[4]*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606*
[5]*The University of Georgia, Athens, GA 30602*
[6]*Kent State University, Kent, OH 44242*
[7]*Kyungpook National University, Daegu 702-701, Korea*
[8]*Indiana University, Bloomington, IN 47405*

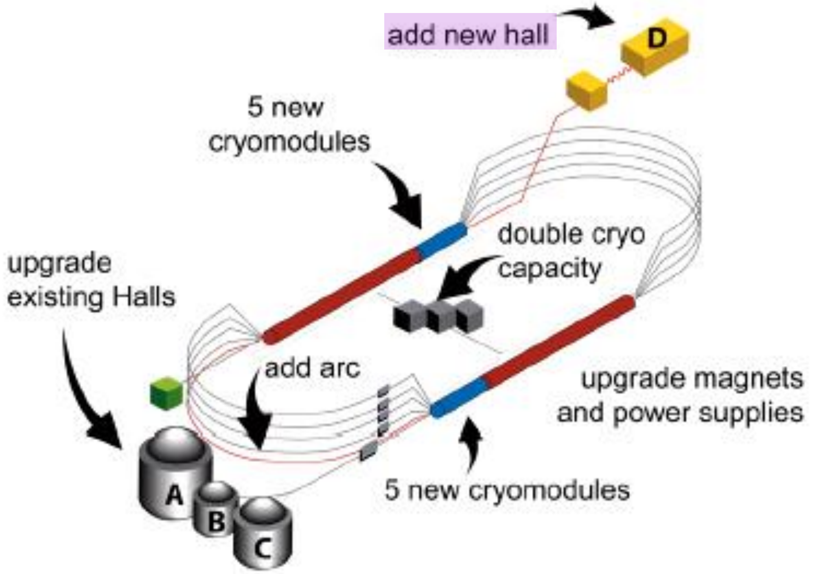
(Dated: May 14, 2015)

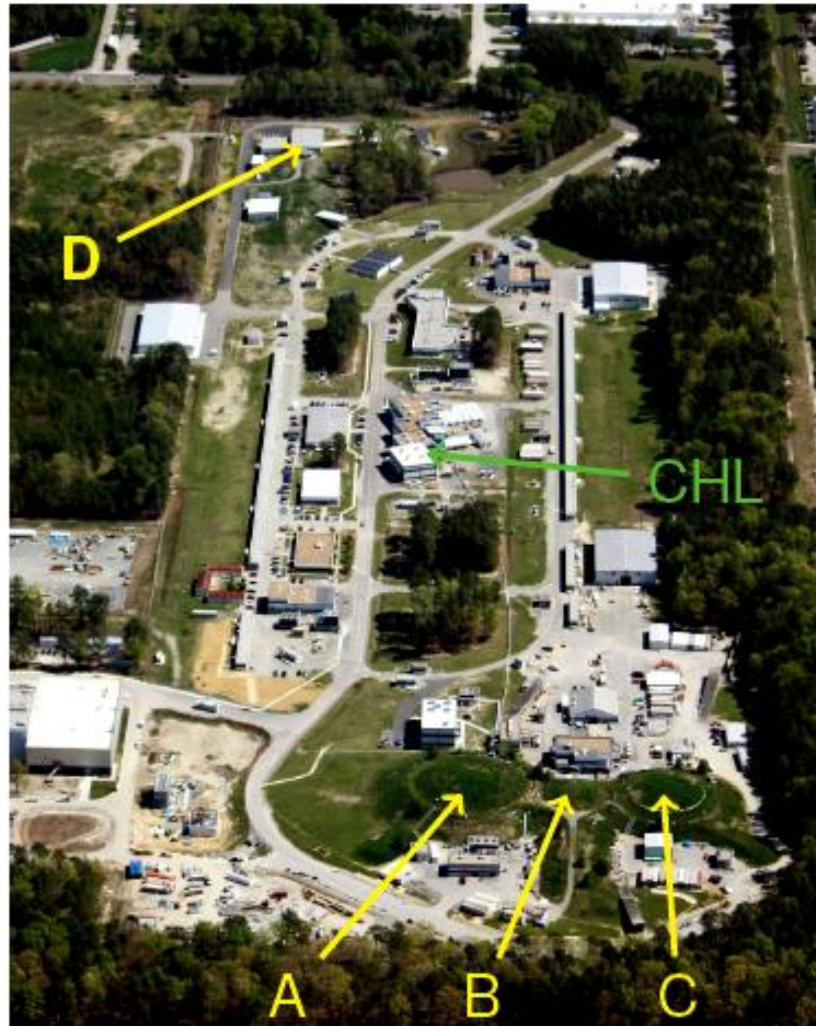
Hyperon Spectroscopy

- We plan to submit a full **Proposal** for **JLab PAC45** in **2017**.

CEBAF Upgrade to 12 GeV

Jefferson Lab
Thomas Jefferson National Accelerator Facility





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

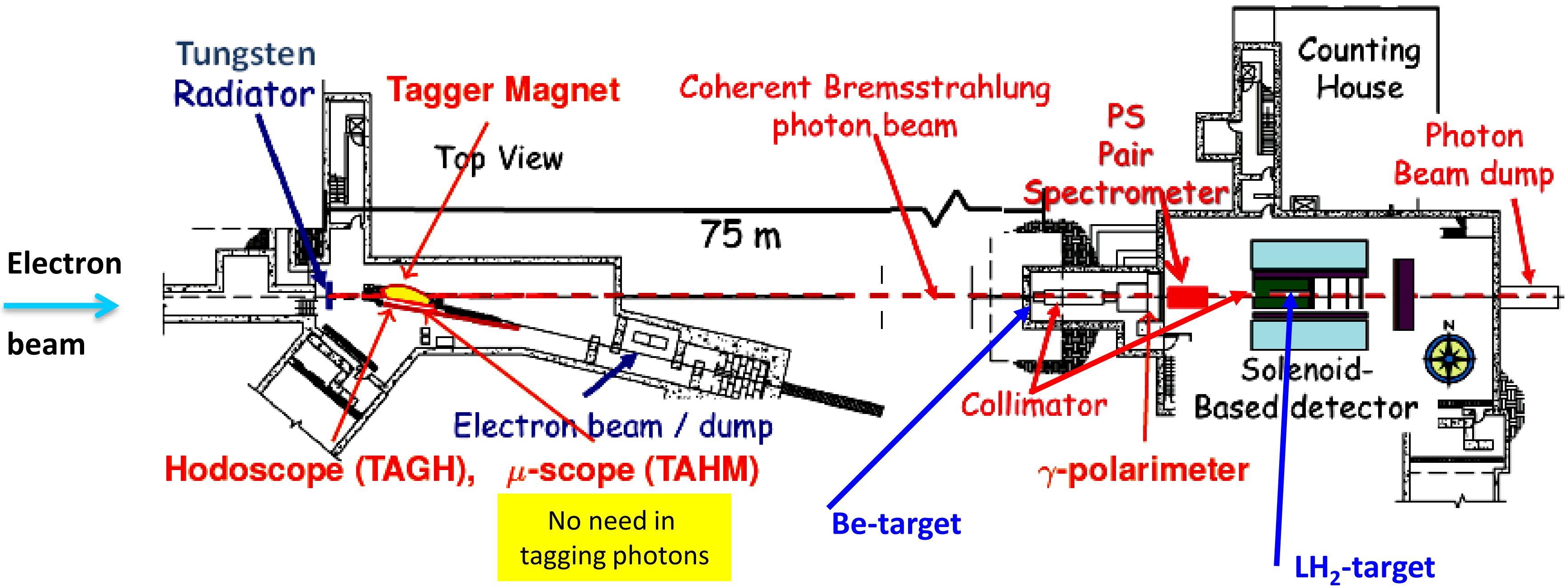
Upgrade Status

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

Courtesy of Eugene Chudakov, KL2016

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

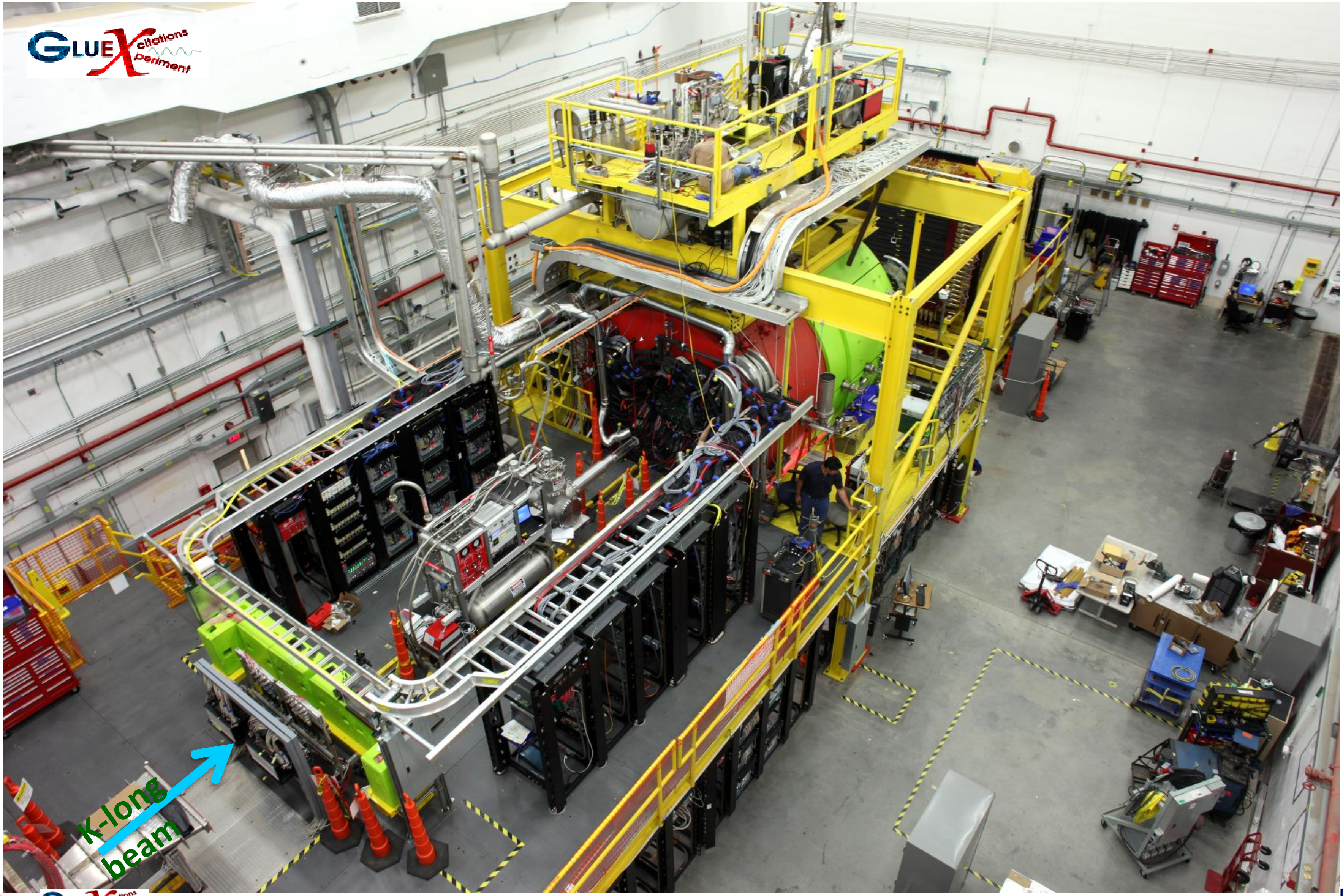
Hall D Beam Line Set up for K-longs



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

- **Electrons** are hitting **W**-radiator.
- **Photons** are hitting **Be**-target.
- **K_Ls** are hitting the **LH_2**-target within **GLueX** setting.

Hall D/GlueX



Hall D/GlueX Spectrometer and DAQ

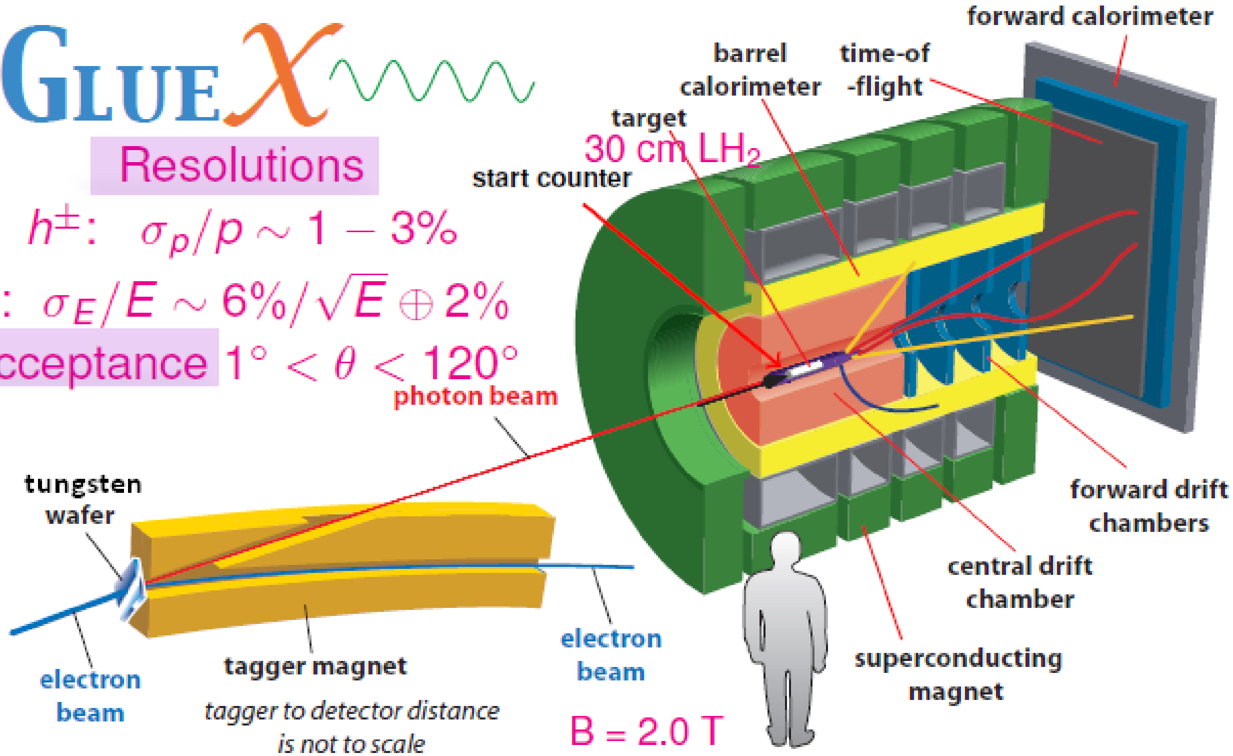
GlueX

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

Courtesy of Eugene Chudakov, YSTAR2016

Expected Rate

Production	J-PARC*	Jlab (this proposal)
flux/s	$3 \times 10^4 K^-$	$10^4 K^0_L$
$\Xi^*/month$	3×10^5	2×10^5
$\Omega^{-*}/month$	600	4000

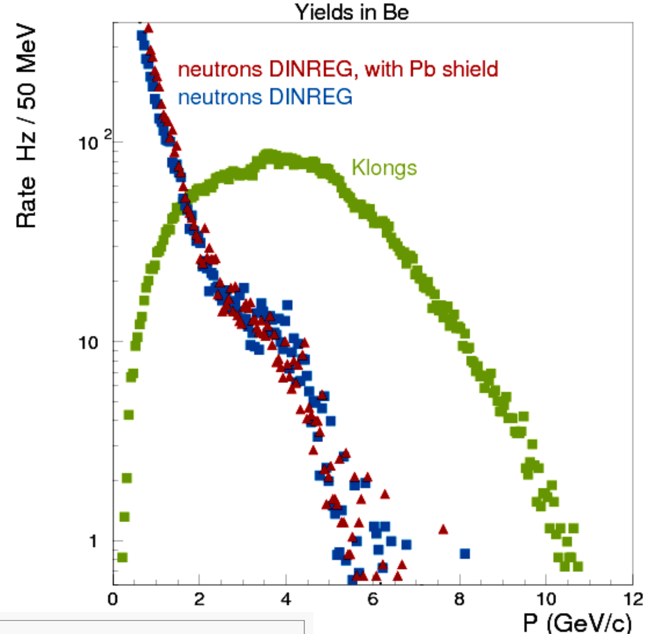
H. Takahashi, Nucl Phys A **914**, 553 (2013)
M. Naruki and K. Shitori, LoI-2014-J-PARC

Courtesy of Moskov Amaryan, GHP2017

K-long & Neutron Rate on GlueX LH_2-target

MC @ **12** GeV

Data @ **16** GeV



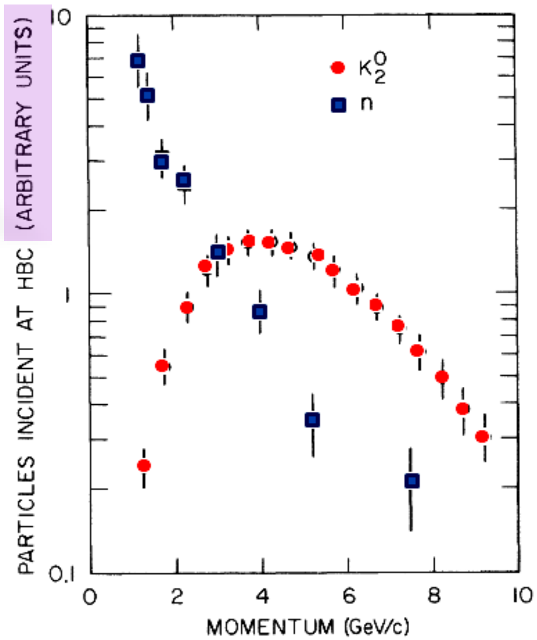
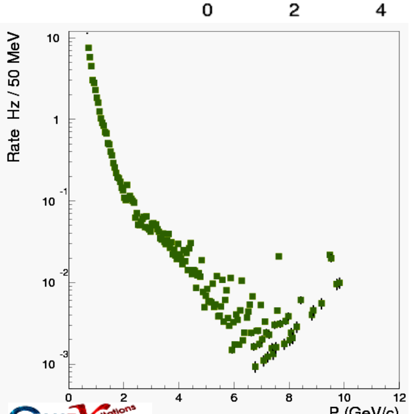


FIG. 2. Comparison of the neutron and $K_2{}^0$ fluxes at the hydrogen bubble chamber for 2° production with 16-GeV electrons.

A.D. Brody *et al* Phys Rev Lett **22**, 966 (1969)



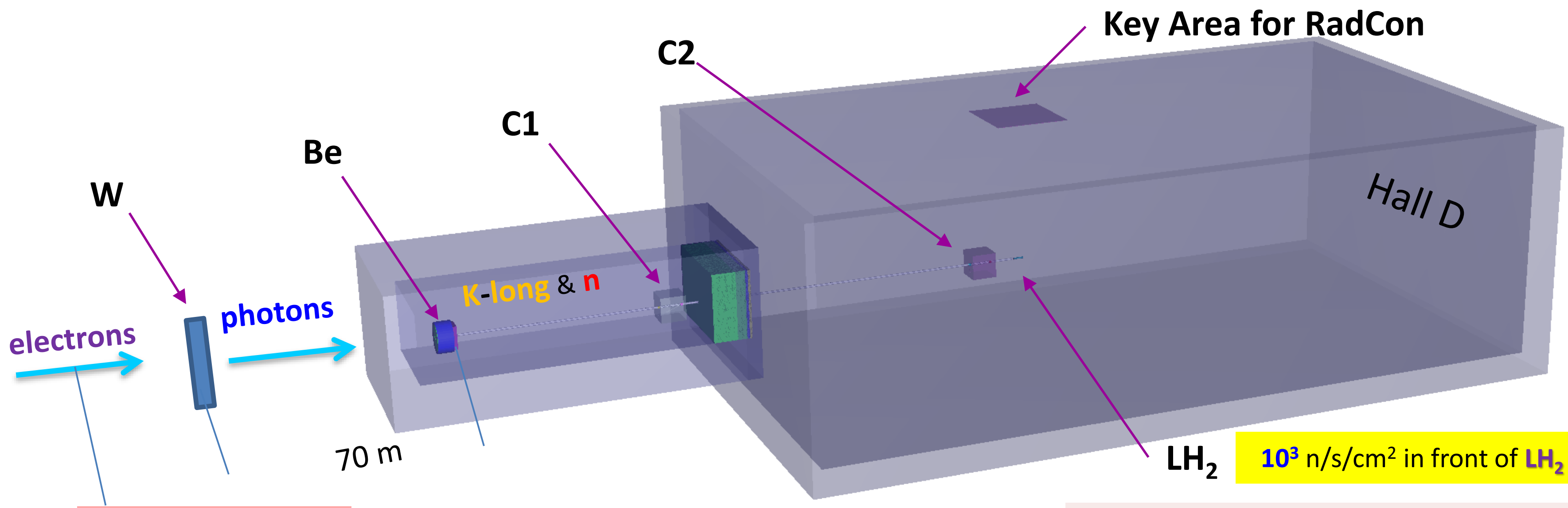
Flux ratio **n/K_L**

- Delivered with **60** 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**.

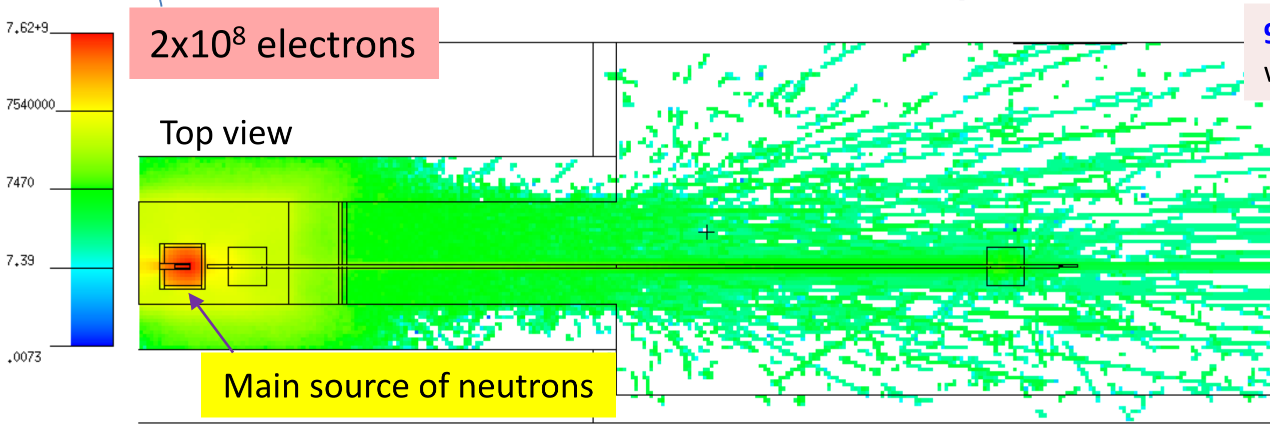
Expected Neutron Background

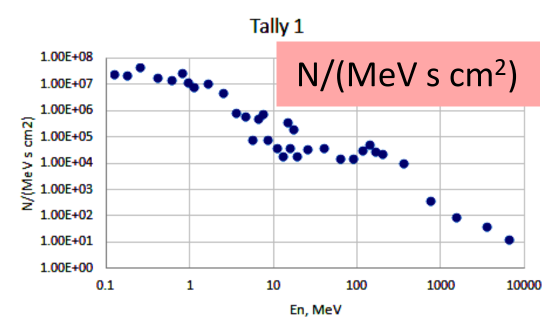
- Most **important** & **unpleasant background** for K_L comes from **neutrons**.



10^3 n/s/cm^2 in front of LH_2

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





Los Alamos NATIONAL LABORATORY EST. 1943

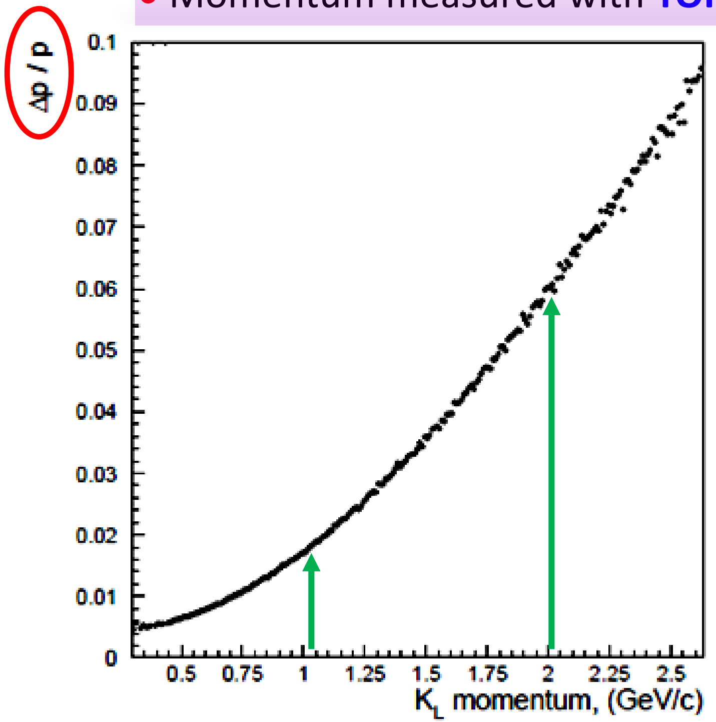
- For **neutron** calculations, we use **MCNP6** transport code.

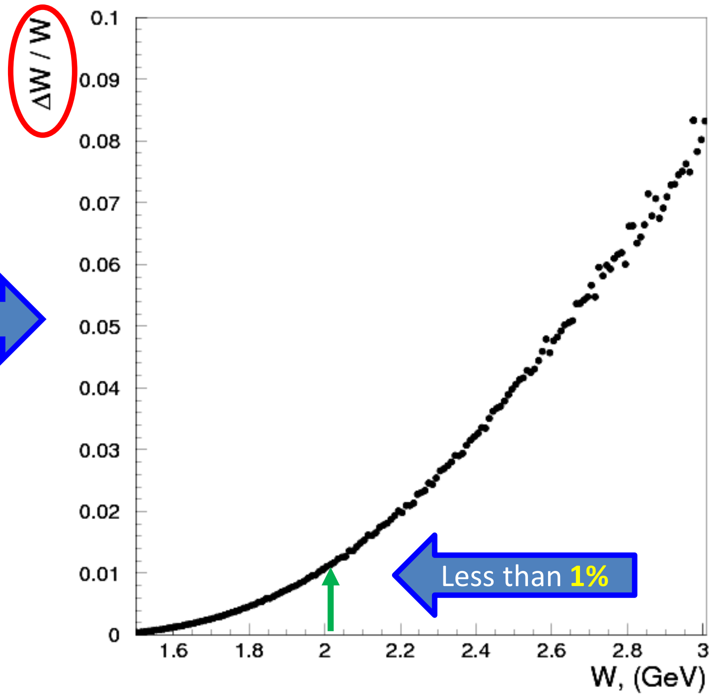
Expected Energy-Resolution

- 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 higher beam flux.

- Momentum measured with **TOF** between **SC** (surrounded LH_2) & **RF** from **CEBAF**.



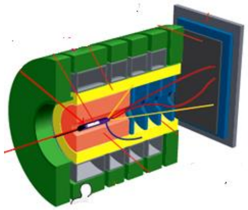


- Momentum resolution $\Delta p/p$ is growing with momentum: for **1** GeV/c is **1.7%**, for **2** GeV/c is **6%**.

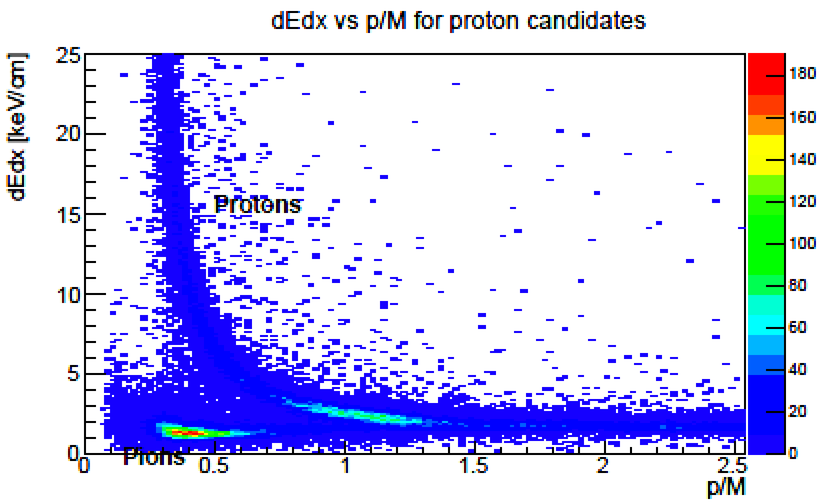
- For **W** < **2** GeV, **ΔW** < **20** MeV which is suitable to study **Hyperons** with Γ = **30** – **50** MeV.

Courtesy of Ilya Larin, KL2016

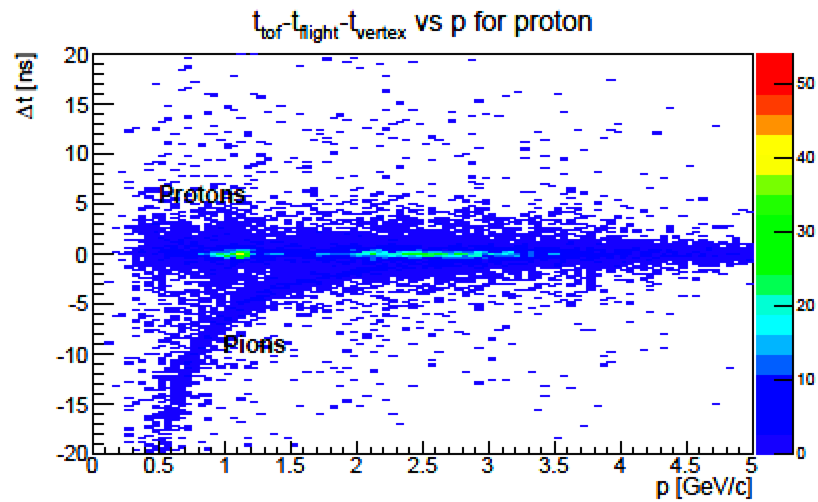
Expected Particle Identification



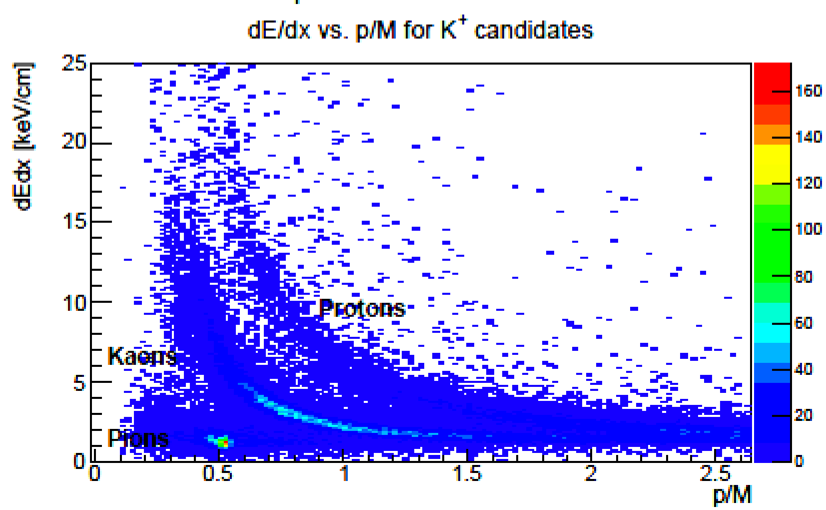
- **dE/dx** for **pK_S**.



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



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



Courtesy of Simon Taylor, KL2016

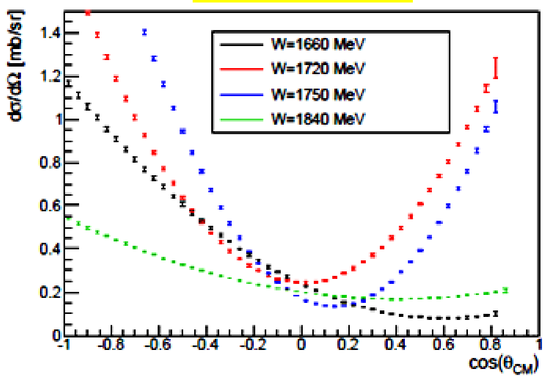
Expected Cross Sections vs Bubble Chamber Data

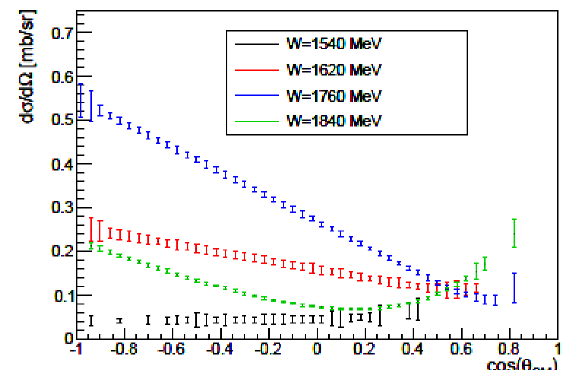
- **GlueX** measurements will span **cosθ** from **–0.95** to **0.95** in c.m. above **W** = **1490** MeV.

Courtesy of
Simon Taylor, KL2016
Mark Manley, KL2016

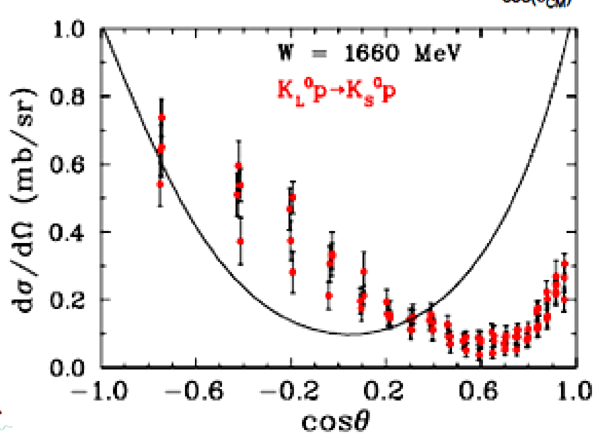
- K_L rate is **10^4** K_L/s.
- Uncertainties (statistics only) correspond to **100** days of running time for:

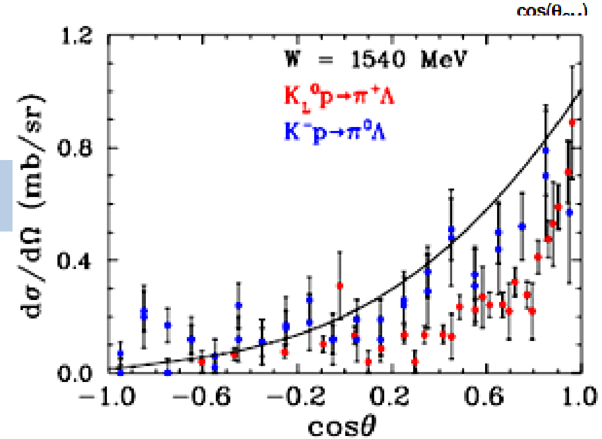
$K_Lp \to K_Sp$ | **$K_Lp \to \pi^+\Lambda$**





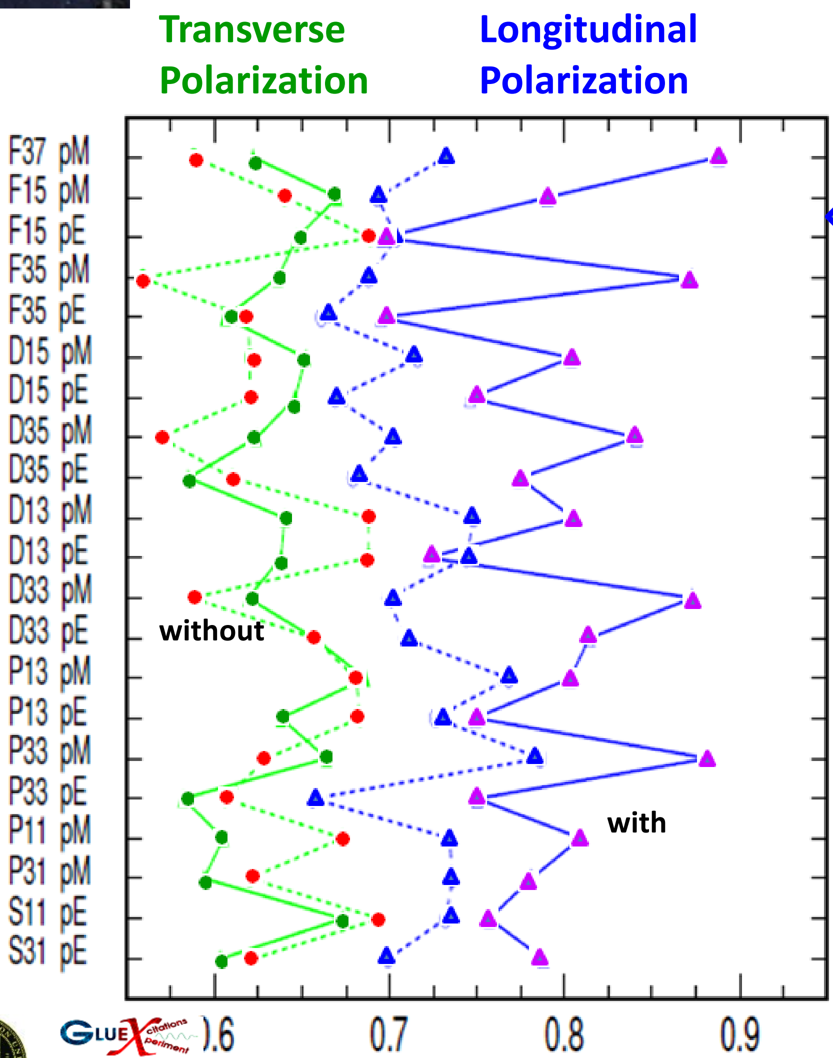
Expected GlueX Data





BC Data

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



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

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

ηp **E**: I. Senderovich *et al* Phys Lett B **755**, 64 (2016)
π^+n **E**: S. Strauch *et al* Phys Lett B **750**, 53 (2015)
More results are coming…

- **KSU&GW** is doing **PWA** including available **K_Lp** & **K^-p** data plus expected **GlueX** data to show potential impact of new **Hall D** measurements.

K_L-Beam in Meson Spectroscopy

VES at Protvino and Crystal Ball at BNL; Other Experiments?

LASS at SLAC: Last experiment to scatter low-momentum (11 GeV/c) Kaons off protons (in the 1970s)

1. K^* Spectroscopy

VES	Hall D	Photoproduction
$K^- p \to (\bar{K}^0 \pi^+ \pi^-)\, n$	$K_L p \to (K_S \pi^+ \pi^-)\, p$	$\gamma p \to K^{*0} \Sigma^+$
$K^- p \to (K^- \pi^+)\, n$	$K_L p \to (K^- \pi^+)\, p$	
$K^- p \to (\bar{K}^0 \pi^-)\, p$	$K_L p \to (K_S \pi^+)\, n$	
$K^- p \to (K^- \eta)\, p$	$K_L p \to (K^+ \eta)\, n$	

2. $s\bar{s}$ Spectroscopy

VES	Hall D	Photoproduction
$K^- p \to (K_S K_S)\, \Lambda$	$K_L p \to (K_S K_S)\, \Sigma^+$	$\gamma p \to (s\bar{s})^* p$
$K^- p \to (K^- K^+)\, \Lambda$	$K_L p \to (K^+ K^-)\, \Sigma^+$	
$K^- p \to (K_S K^\pm \pi^\mp)\, \Lambda$	$K_L p \to (K_S K^\pm \pi^\mp)\, \Sigma^+$	

V. Credé   Strange Meson Spectroscopy

Courtesy of Volker Crede, KL-wiki2017

Fermilab

Project X: Physics Opportunities

Table 1: Comparison of the K_L production yield. The BNL AGS kaon and neutron yields are taken from RSVP reviews in 2004 and 2005. The Project X yields are for a thick target, fully simulated with LAQGSM/MARS15 into the KOPIO beam solid angle and momentum acceptance [68].

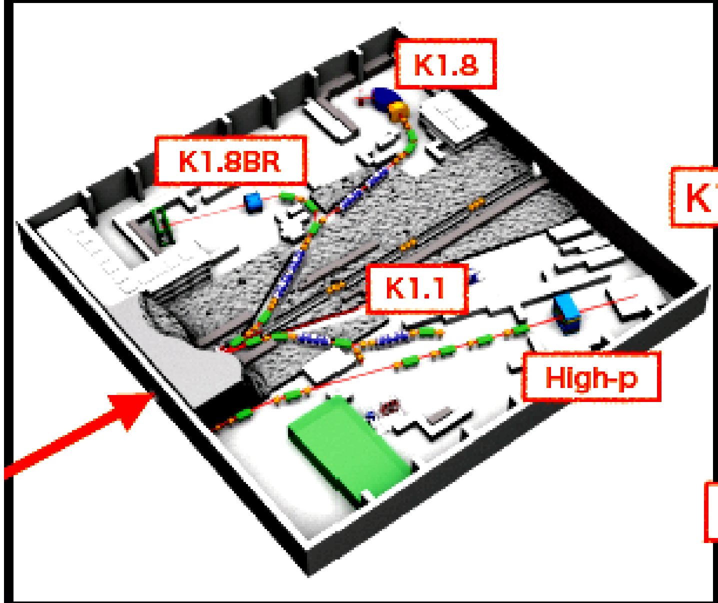
Project	Beam energy (GeV)	Target (λ_I)	$p(K_L)$ (MeV/c)	K_L/s (into 500 μsr)	n/K_L (E_n > 10 MeV)
BNL AGS	24	1.1 Pt	300–1200	60×10^6	~1:1000
Project X	3	1.0 C	300–1200	450×10^6	~1:2700

arXiv:1306.5022, arXiv:1306.5009, arXiv:1306.5024

- **First stage** of **Project X** aims for **neutrinos**.
- Proposed **K_L beam** can be used to study **rare decays** & **CP-violation**.
- It may be impossible to use it for Hyperon Spectroscopy because of **momentum range** & **n/K_L** ratio.

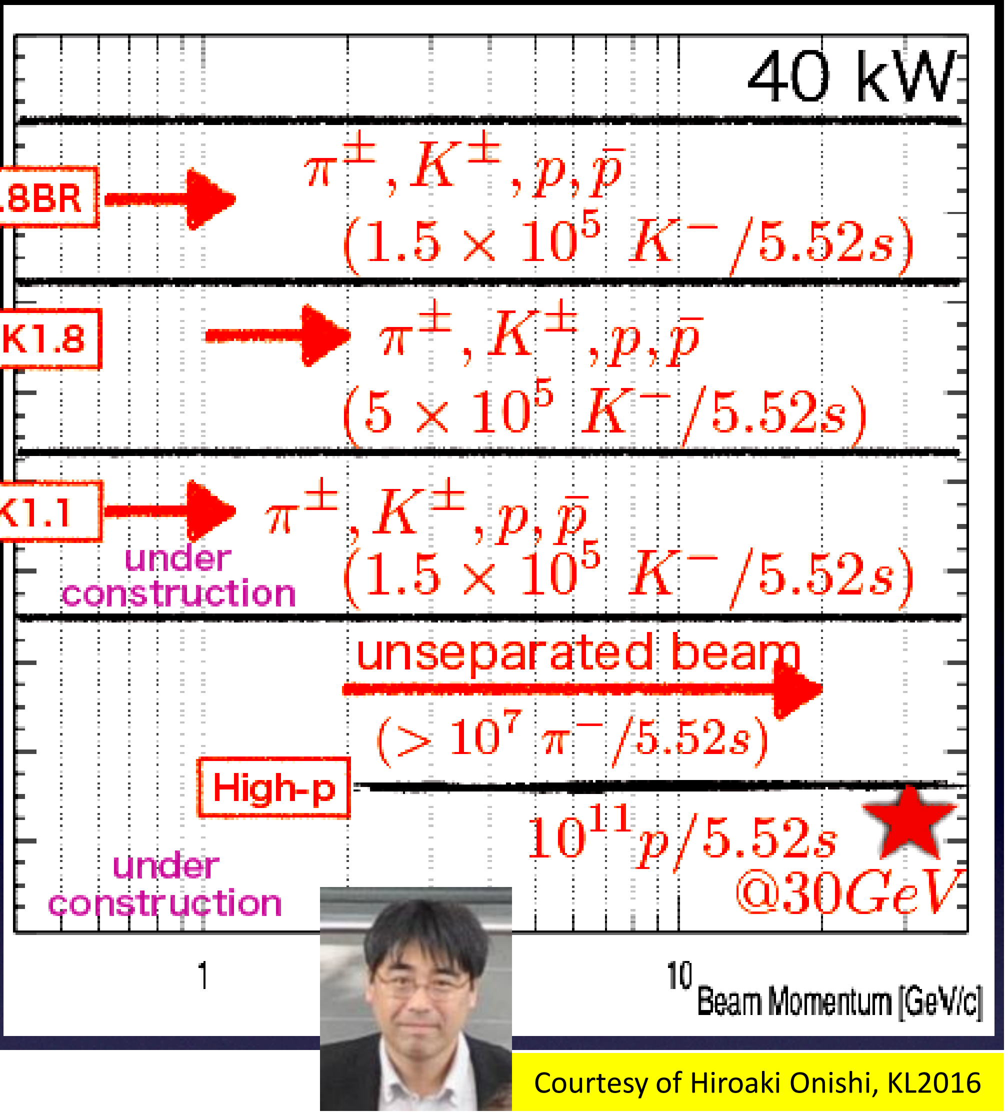
J-PARC

Japan Proton Accelerator Research Complex



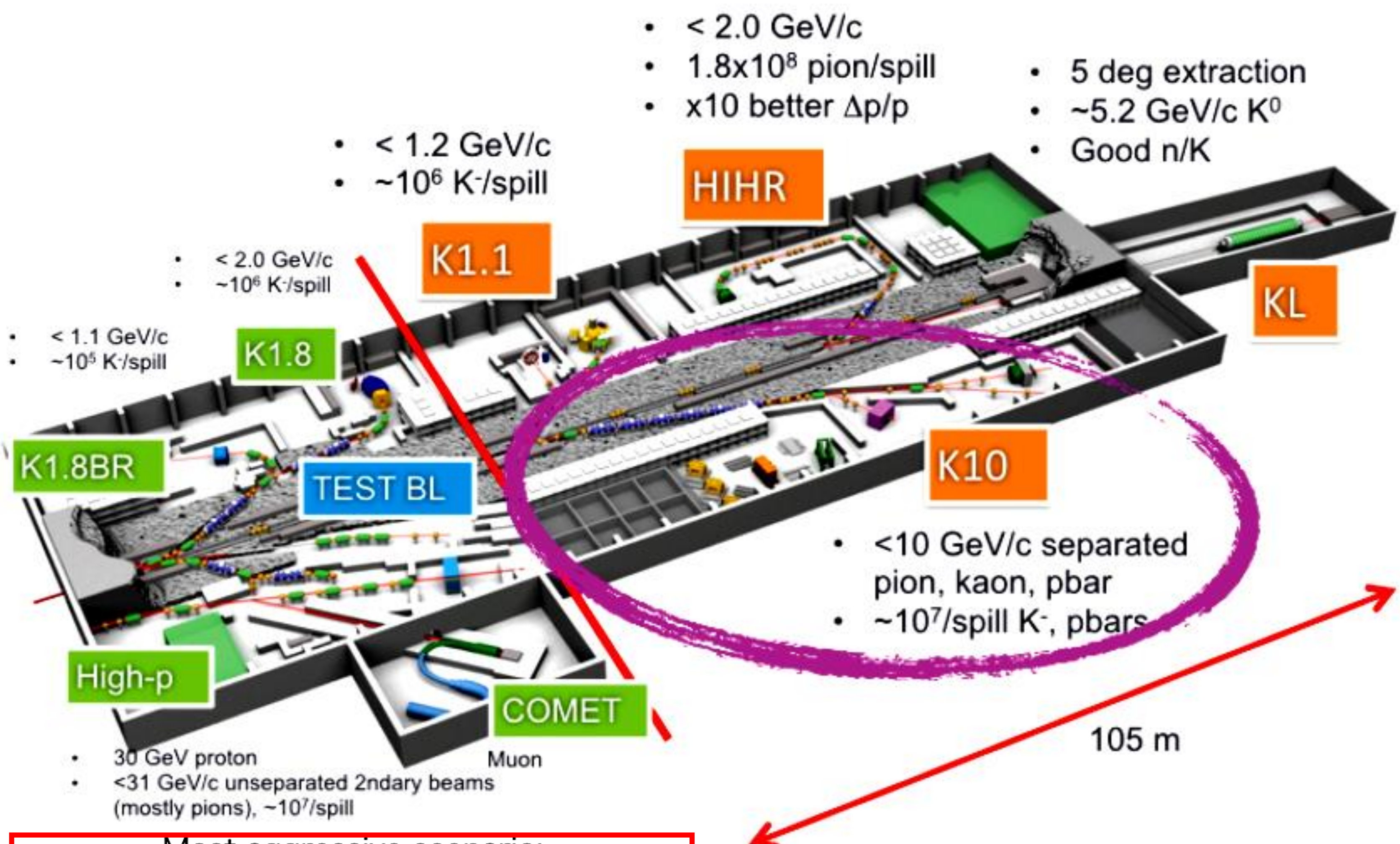
Two beam lines are under operation

K1.1 & High-p beam lines are under construction



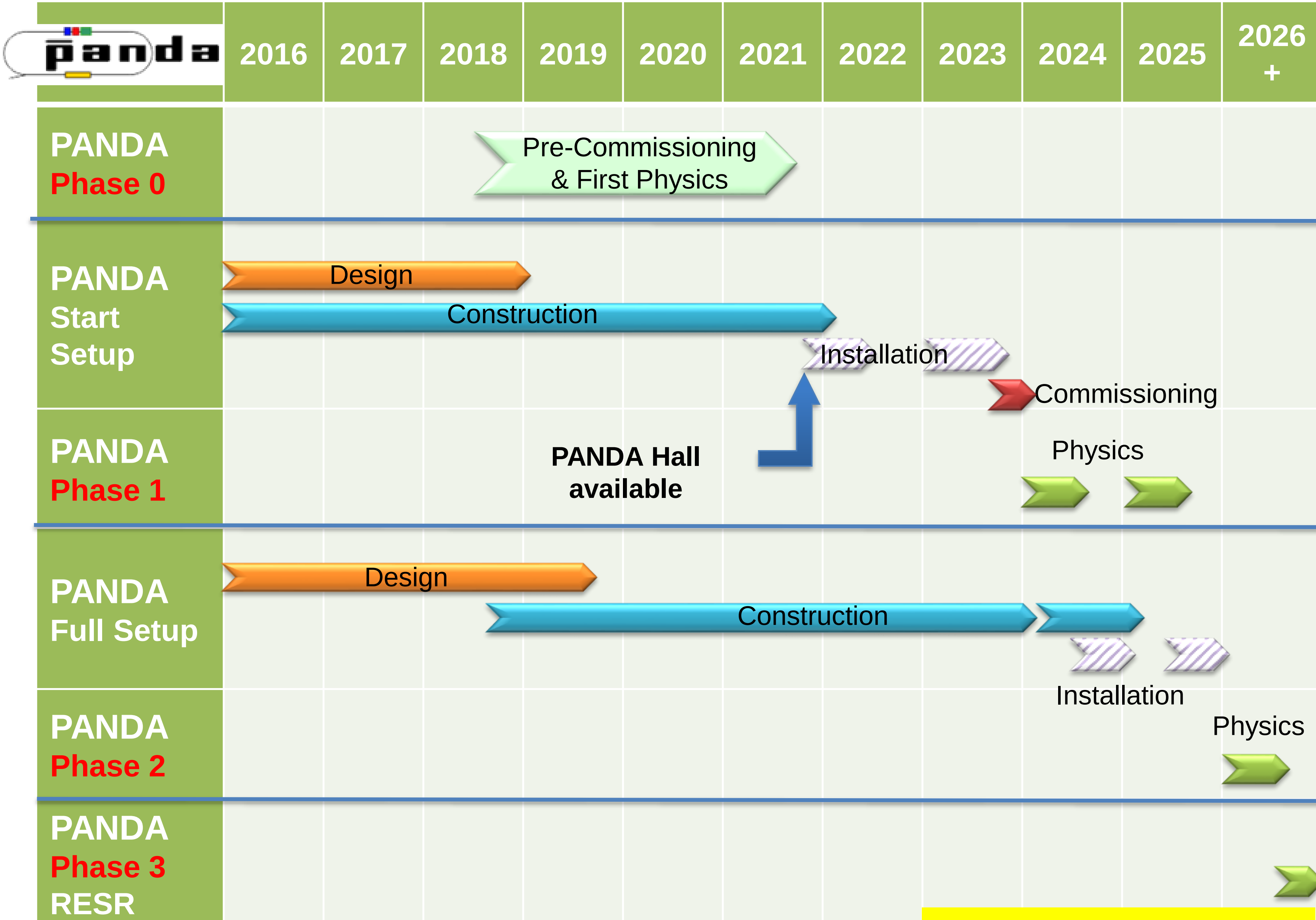
Courtesy of Hiroaki Onishi, KL2016

J-PARC Hadron hall extension



Most aggressive scenario:
we expected to have first beam in 2021/2022

Courtesy of Hiroaki Onishi, YSTAR2016



Courtesy of James Ritman, YSTAR2016

Speakers:

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

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

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

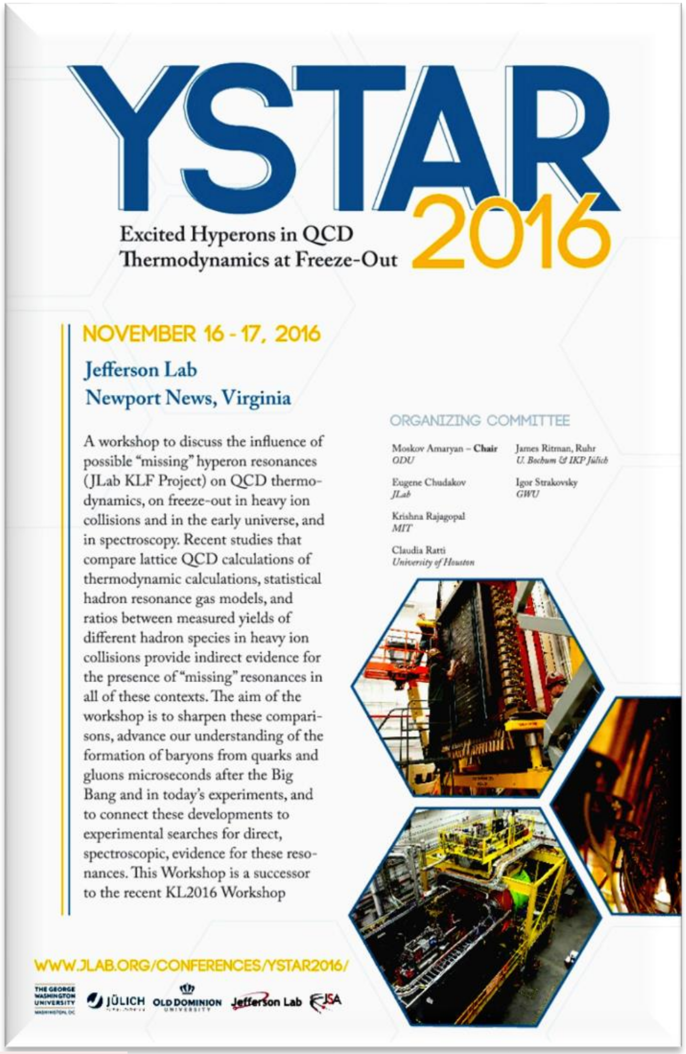
Xie

Arriola

Tsuchikawa

Huovinen

Doenigus



71 people from
11 countries &
27 talks

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

III

Speakers: Mai

Goity

Perera

Dominguez

Tadevosyan

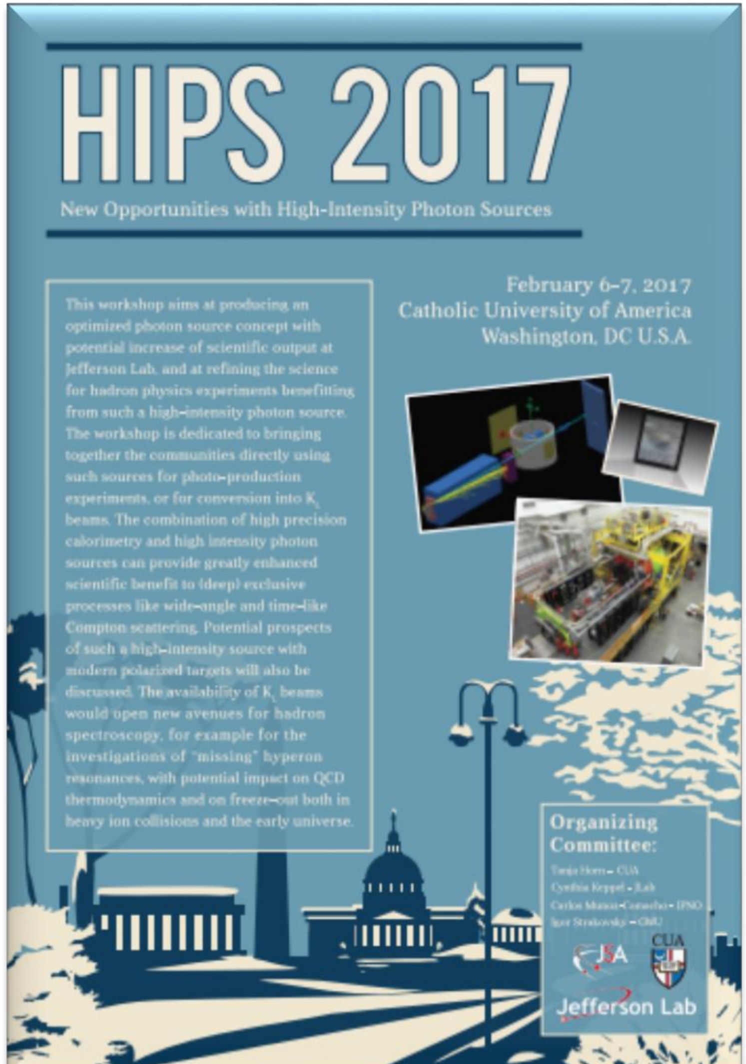
Beminiwhatta

Wojtsekhowski

Degtyarenko

Niculescu

Liuti



Sirca

Keppel

Strakovsky

Kroll

Keller

Hamilton

Sargsian

Patsyuk

Zhang

43 people from
4 countries &
19 talks

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

Summary

- **Our goal is**
  - To **establish KL Facility** at JLab.
  - To do **measurements** which bring new physics.

- Here we reviewed what can be learned by studying K_Lp scattering leading to **two-body** final states (**1^{st} stage**).
  At later stages, we plan to do K_Ln on LD_2 &
  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 **low-lying hypiron states** would assist in advance our understanding of **formation** of **baryons** from **quarks** & **gluons microseconds** after **Big Bang**.

- Full Proposal is coming for **PAC45** in **2017**, **WELCOME** to **JOIN US**.

Thank You






Moskov Amaryan
Yakov Azimov
William Briscoe
Eugene Chudakov
Pavel Degtyarenko
Michael Döring
Alexander Laptev
Ilya Larin
Maxim Mai
Mark Manley
James Ritman
Simon Taylor






igor@gwu.edu