

KLF for Hadron Spectroscopy

Igor Strakovsky

The George Washington University

(for KLF Collaboration)



- Aims of *KLF* Project.
- *Hyperon* Spectroscopy.
- *Strange Meson* Spectroscopy.
- A Bit of *History*.
- *KLF* Beamline & Hardware.
- *KLF* Time Requested.
- Summary.
- Impact to Study Early *Universe*.

arXiv:2008.08215 [nucl-ex]






* Supported by  DE-SC0016583



Aims of KLF Project





-  project has firmly to establish secondary K_L beam line at  , with *flux* of *three order of magnitude higher* than **SLAC** 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 *2500* MeV in spectra of Λ^* , Σ^* , Ξ^* , & Ω^* .
- In addition, we intend to do *strange meson spectroscopy* by studies of π - K interaction to locate the *pole* positions in $l = 1/2$ & $3/2$ channels.
-  has link to *ion-ion high energy* facilities as  &  & will allow understand formation of our world in *several microseconds* after *Big Bang*.





Four International Workshops Supported KLF Program

PHYSICS WITH NEUTRAL KADIN BEAM AT JLAB
KL2016

FEBRUARY 1-3, 2016
JEFFERSON LAB
NEWPORT NEWS, VIRGINIA

SCOPE

The Workshop is following CLIC12-15-001 "Physics Opportunities with Secondary K⁺ beam at JLab" and is devoted to the physics of hyperons produced by the beam using an spectrometer and polarized targets with CLIC2 set up in Hall D. The workshop will focus on the hyperon spectroscopy. Such studies could contribute to the existing research program on hadron spectroscopy at Jefferson Lab.

The Workshop will also aim at fostering the international collaboration in particular between the US and EU research institutions and scientists.

The Workshop would help to address the comments made by the PAC43, and to prepare the I&D proposal for the next PAC43.

ORGANIZING COMMITTEE

Moshe Amarian, CDL, chair
Eugene Chudakov, JLab
Curtis Meyer, CDL
Michael Pennington, JLab
Sergei Rittman, Rutherford-Bevis & MP, JLab
Igor Strakovsky, OJL

www.jlab.org/conferences/kl2016

YSTAR 2016

Excited Hyperons in QCD Thermodynamics at Freeze-Out

NOVEMBER 16 - 17, 2016

Jefferson Lab
Newport News, Virginia

A workshop to discuss the influence of possible "resonance" hyperon resonances (JLab KLF Project) on QCD thermodynamics, on freeze-out in heavy ion collisions and in the early universe, and in spectroscopy. Recent studies that compare lattice QCD calculations of thermodynamic quantities, statistical hadron resonance gas models, and ratios between resonant yields of different hadron species in heavy ion collisions provide indirect evidence for the presence of "missing" resonances in all of these contexts. The aim of the workshop is to sharpen these comparisons, advance our understanding of the formation of baryon free quarks and gluons meson states after the Big Bang and in today's experiments, and to connect these developments to experimental searches for direct spectroscopic evidence for these resonances. This Workshop is a successor to the recent KL2016 Workshop.

ORGANIZING COMMITTEE

Moshe Amarian - Chair	Igor Strakovsky, OJL
Eugene Chudakov - JLab	Igor Strakovsky, OJL
Krishan Rajagopal - MIT	Curtis Meyer, University of Chicago



www.jlab.org/conferences/ystar2016/

HIPS 2017
New Opportunities with High-Intensity Photon Sources

February 6-7, 2017
Catholic University of America
Washington, DC U.S.A.

This workshop aims at producing an optimized photon source concept with potential increase of scientific output at Jefferson Lab, and at reflecting the science for hadron physics experiments benefiting from such a high-intensity photon source. The workshop is dedicated to bringing together the community directly using such sources for photo-production experiments, or for conversion into X, gamma. The modification of hadron production capability and high intensity photon sources may provide greatly enhanced scientific benefits to direct hadron spectroscopy. The wide-angle and filter-free Compton scattering. Potential prospects of such a high-intensity source with modern potential impact will also be discussed. The availability of X, gamma would open new avenues for hadron spectroscopy, for example for the investigation of "missing" hyperon resonances, with potential impact on QCD thermodynamics and on freeze-out both in heavy ion collisions and the early universe.

Organizing Committee:
Eugene Chudakov - JLab
Curtis Meyer - CDL
Igor Strakovsky - OJL

π -K Interactions Workshop

February 14-15, 2018
Jefferson Lab - Newport News, VA

The π -K scattering studies about investigations of scalar and vector K* states, including the use of virtual kaons (K⁰) states. From studies on the world to get precise values of π -K scattering and vector form factors to independent π -K vector form factors. You will hear the Standard Model, lattice QCD in the framework of QCD lattice, to study CP violation from the Dalitz plot analysis of π -K decays. From resonance theory and in particular focus of π mesons in Regge trajectories. Significant progress is made both in lattice QCD, in the phenomenology and in the Chiral Perturbation Theory to describe different aspects of π -K scattering. The main source of experimental data is based on experiments performed in SLAC. There has been studies up to 1970s. The workshop proposed by Jefferson Lab involving the π -K scattering studies at JLab will be able to improve the π -K scattering database by about three orders of magnitude in statistics. The workshop will discuss the necessity for and the impact of the new high statistics data obtained at JLab on π -K scattering.

Organizing Committee:
Eugene Chudakov - JLab
Curtis Meyer - CDL
Igor Strakovsky - OJL

KL2016

[60 people from 10 countries, 30 talks] <https://www.jlab.org/conferences/kl2016/>
OC: M. Amarian, E. Chudakov, C. Meyer, M. Pennington, J. Ritman, & I. Strakovsky

YSTAR2016

[71 people from 11 countries, 27 talks] <https://www.jlab.org/conferences/ystar2016/>
OC: M. Amarian, E. Chudakov, K. Rajagopal, C. Ratti, J. Ritman, & I. Strakovsky

HIPS2017

[43 people from 4 countries, 19 talks] <https://www.jlab.org/conferences/hips2017/>
OC: T. Horn, C. Keppel, C. Munoz-Camacho, & I. Strakovsky

PKI2018

[48 people from 9 countries, 27 talks] <http://www.jlab.org/conferences/pki2018/>
OC: M. Amarian, U.-G. Meissner, C. Meyer, J. Ritman, & I. Strakovsky

In total: 222 participants & 103 talks

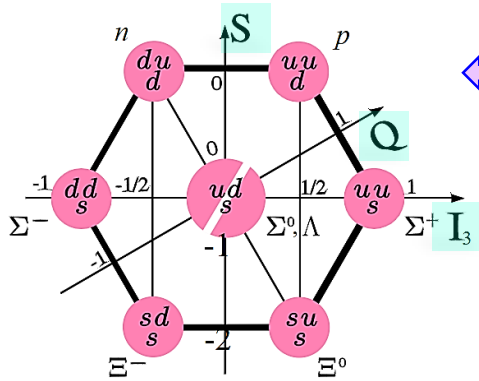


Hyperon Spectroscopy



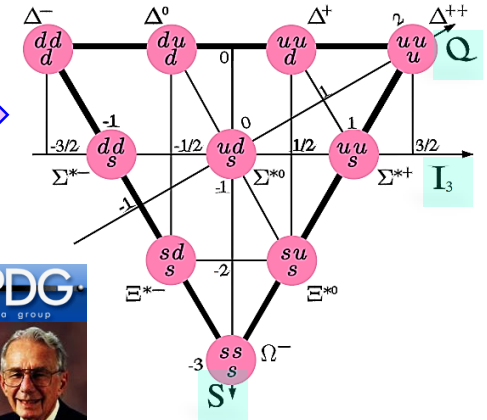


Baryon Multiplets of Eight-fold Way



← Spin 1/2 baryon octet: N^* , Λ^* , Σ^* , Ξ^*

Spin 3/2 baryon decuplet: Δ^* , Σ^* , Ξ^* , Ω^* →

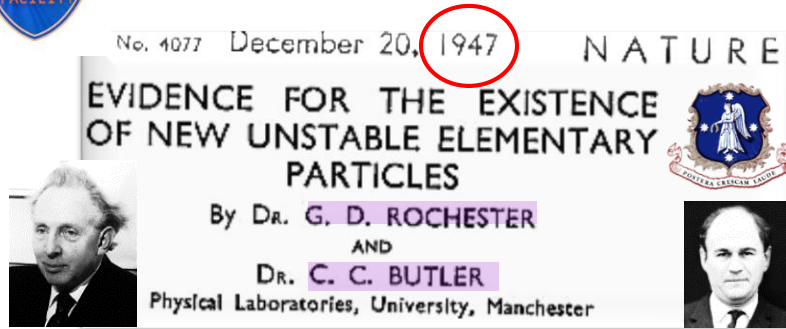


Resonance	QM & LQCD	Observed
N^*	64	16
Δ^*	22	10
Λ^*	17	14
Σ^*	43	10
Ξ^*	42	6
Ω^*	24	2

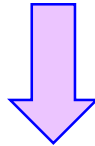
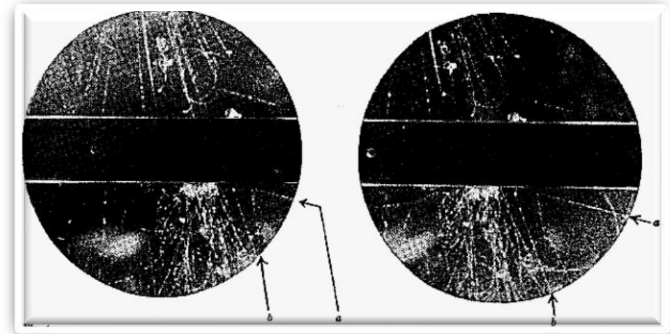


- Seriousness of “*missing-states*” problem is obvious from these numbers.
- One needs to *complete* $SU(3)_F$ multiplets.





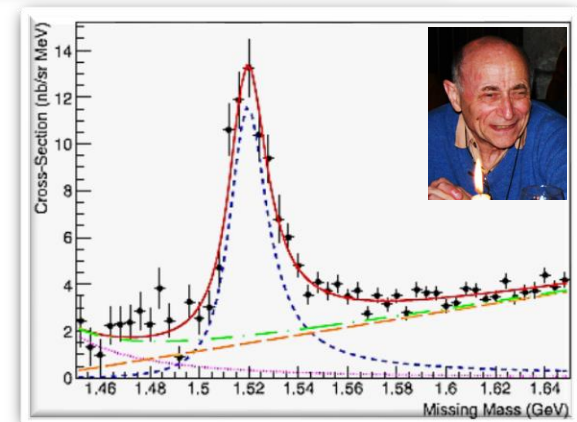
- First hyperon, $\Lambda(1116)1/2^+$, was discovered during study of cosmic-ray interactions.
- It led to discovery of *strange quark*.



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

Phys Lett B 694, 123 (2010) Jefferson Lab
 Contents lists available at ScienceDirect
 Physics Letters B
 www.elsevier.com/locate/physletb

Properties of the $\Lambda(1520)$ 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



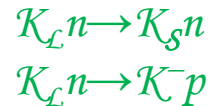
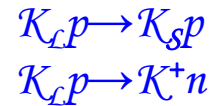
What Can Be Learned with K_L Beam?

Target \rightarrow *Proton*

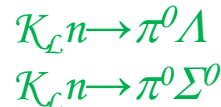
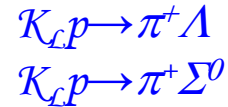
Neutron

[first measurements]

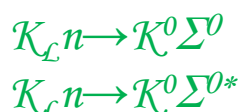
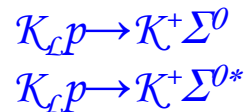
Elastic & Charge-Exchange



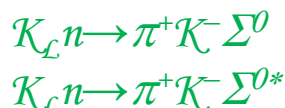
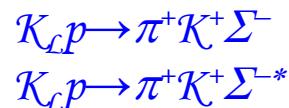
Two-body with $S = -1$



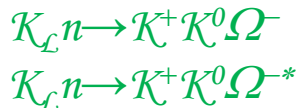
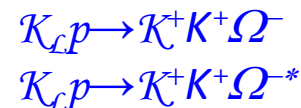
Two-body with $S = -2$



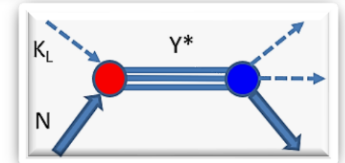
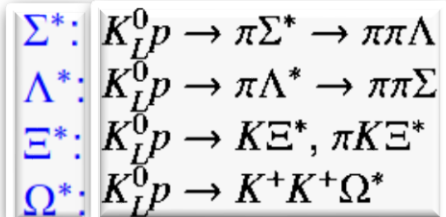
Three-body with $S = -2$



Three-body with $S = -3$



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





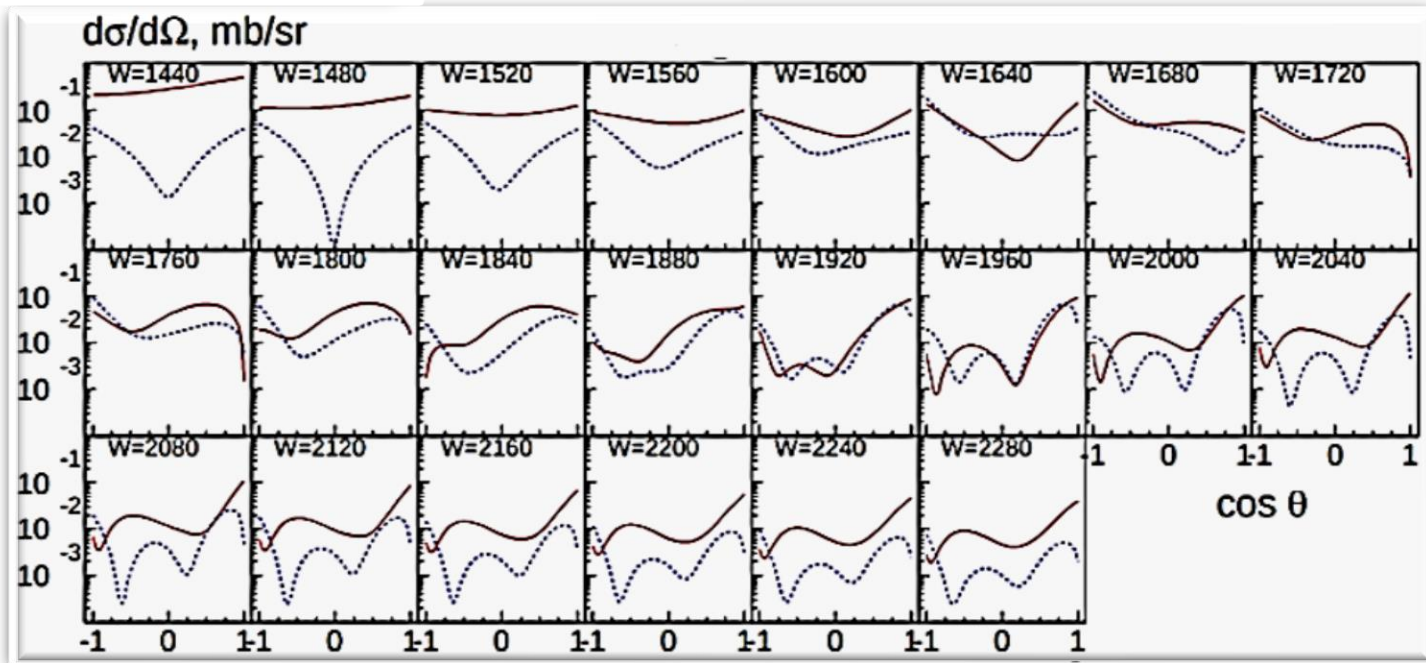
• **Isospin Amplitudes:**

$$|A(K^{-}p)|^2 = \frac{1}{2}(|A_1|^2 + |A_0|^2 + 2\text{Re}(A_1A_0^*))$$

$$|A(K^0n)|^2 = \frac{1}{2}(|A_1|^2 + |A_0|^2 - 2\text{Re}(A_1A_0^*))$$

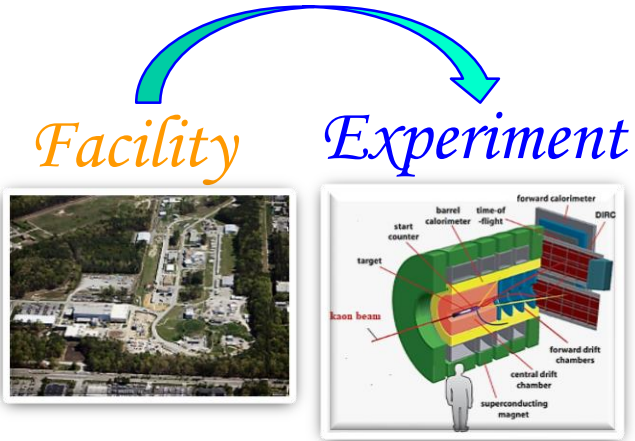
$$|A(K^0p)|^2 = |A_1|^2.$$

• **Two different solutions.**

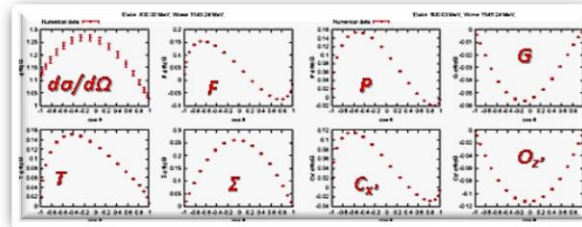


Road Map to Hyperon Spectroscopy

• That is not hunting for bumps.

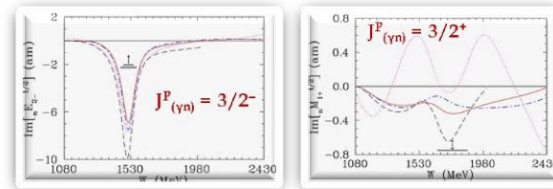


Data

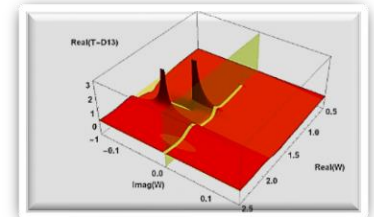


PWA

Amplitudes



Resonances



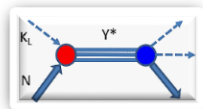
Gruber, C. *Journal of Particle Data Group*, *Chin. Phys. C*, 40 (2016) and 2017 update.

$\Delta(1232) \ 3/2^+$ $J^P = \frac{3}{2}^+$ Status: ***

Older and obsolete values are listed and referenced in the 2014 edition, *Chinese Physics C* 38 (2015) (2014).

$\Delta(1232)$ POLE POSITIONS

REMARKS	REFERENCE	TYPE	COMMENT
REAL PART, MIXED CHARGES			
1211 ±1 ±1	SWARC 14	SIP	σP → πN
1212 ±1 0	ANDEWICH 126	DPAM	Multichannel
1213	ARNOT 06	DPAM	σP → πN, σN
1216	FIEDELIC 03	ANSD	σP → πN
1218 ±1	FRANZOSINI 02	DPAM	σP → πN





World K -long Data – Ground for Hyperon Phenomenology

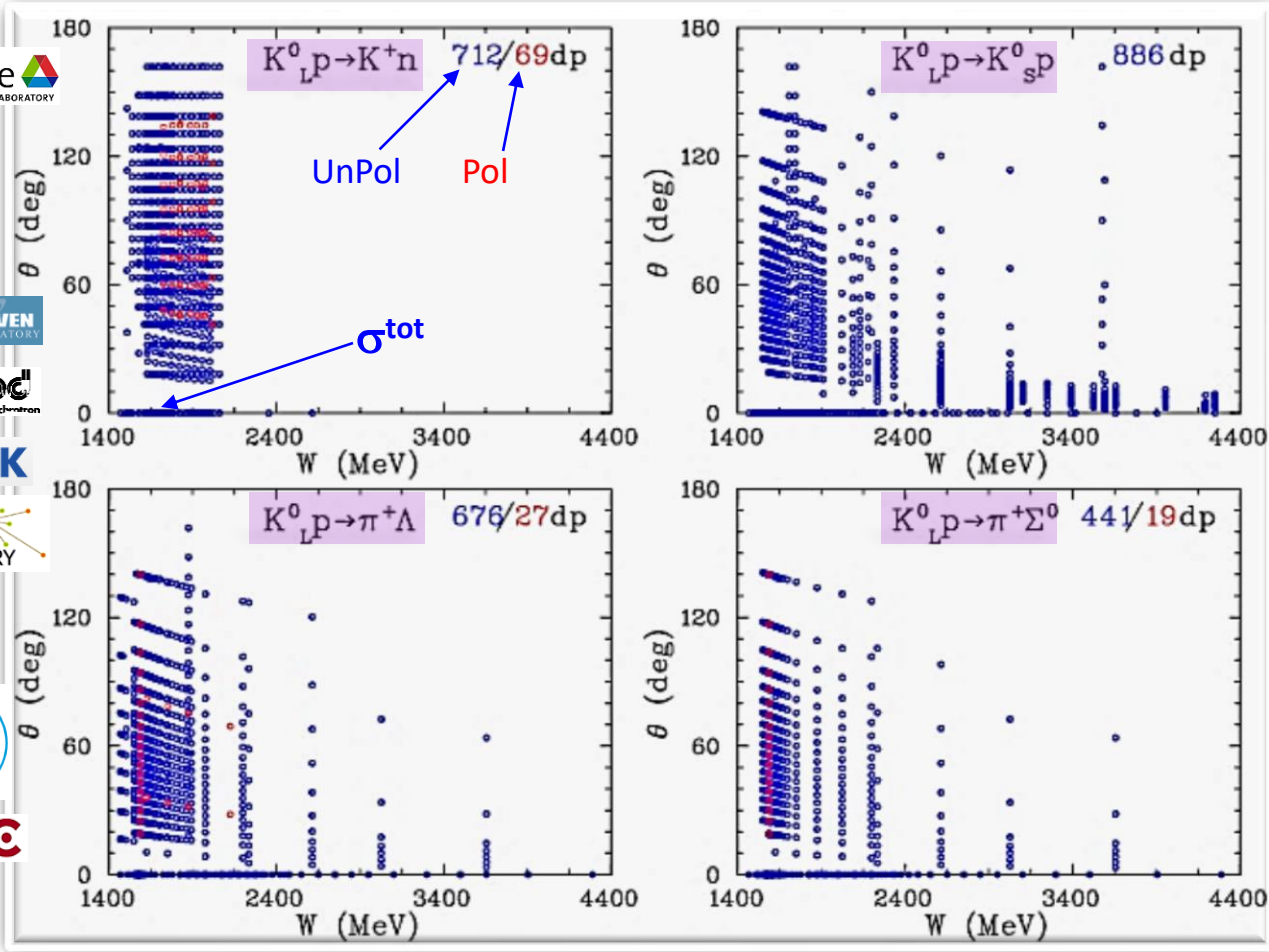
$W = 1.45 - 5.05$ GeV

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



- Limited number of K_L induced measurements (1961 – 1982)
 $2426 d\sigma/d\Omega$, $348 \sigma^{\text{tot}}$, & $115 P$ 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 phenomenological 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.





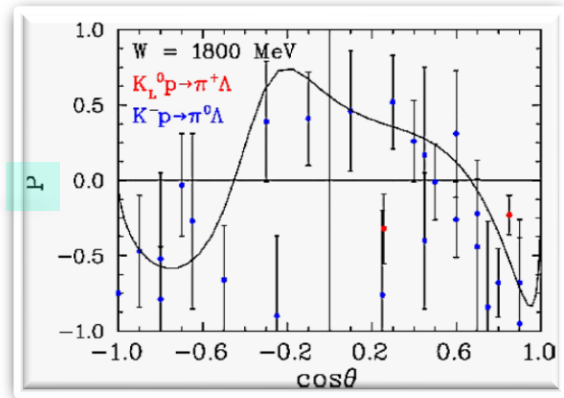
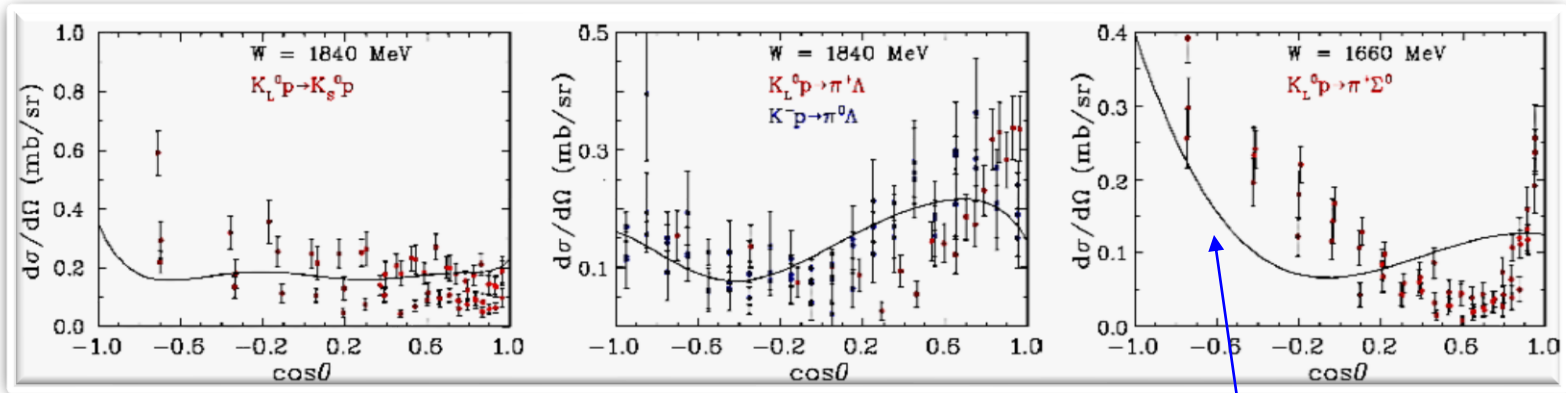
- *Differential cross section* & *polarization* for $K_L p$ scattering are given by



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

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

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

$f(W, \theta)$ & $g(W, \theta)$ are *non-spin-flip* & *spin-flip* amplitudes at W & θ .



• PWA ( & ) predictions at lower & higher energies have poorer agreement for $S \neq 0$ data than for $S = 0$ data.

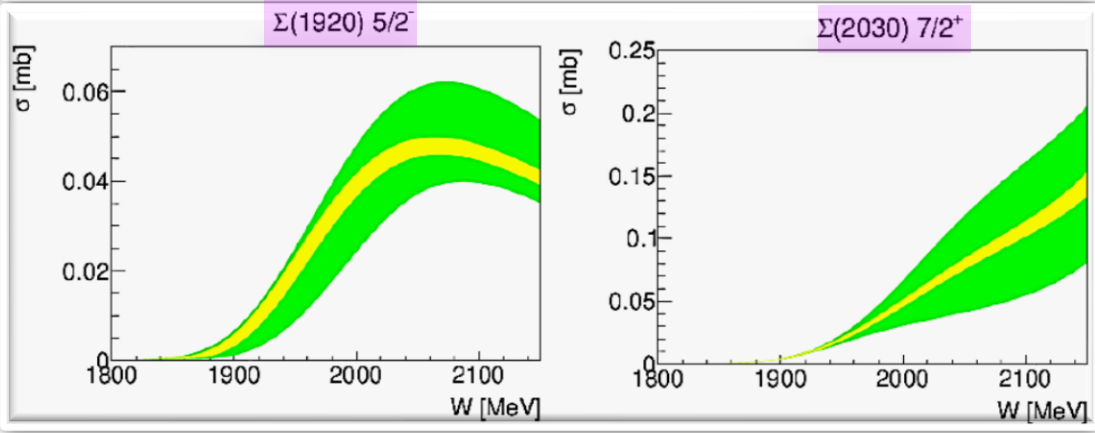
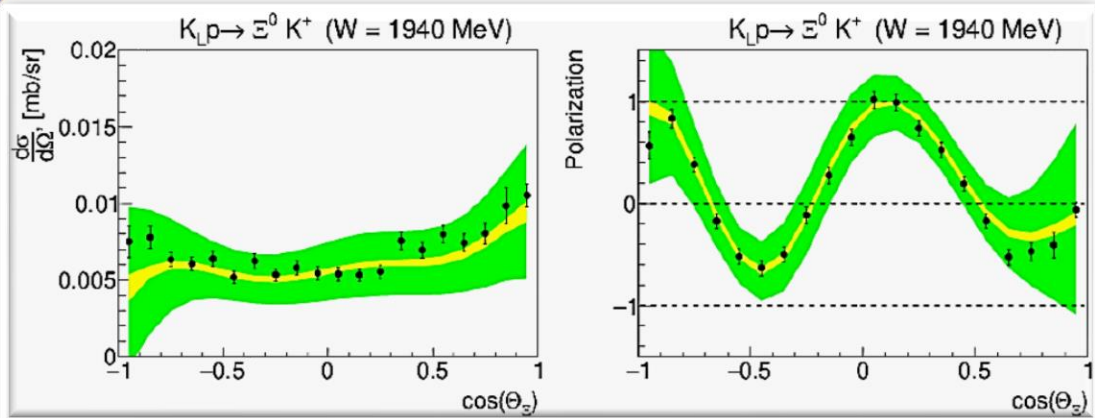
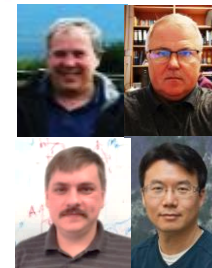
• Polarized measurements are *tolerable* for any PWA solutions.



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



Impact Proposed Data on PWA







• At least **100** days needed to get precise solution. .

100 days

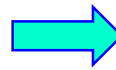
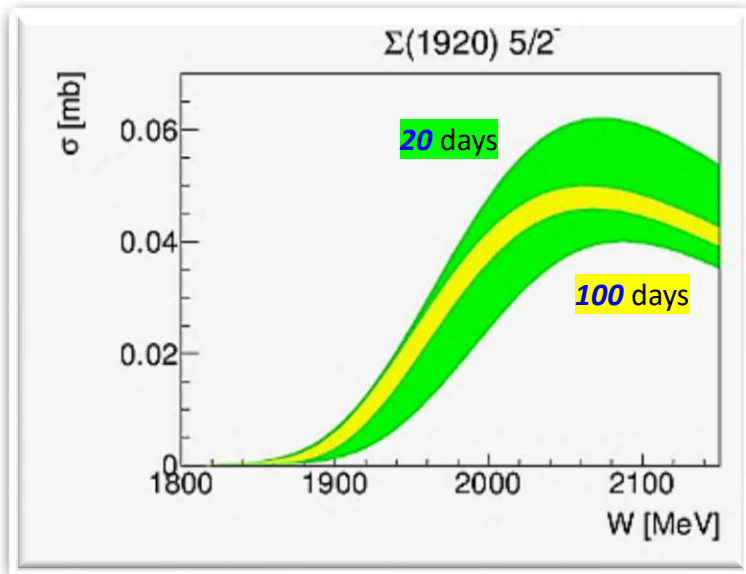
20 days

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

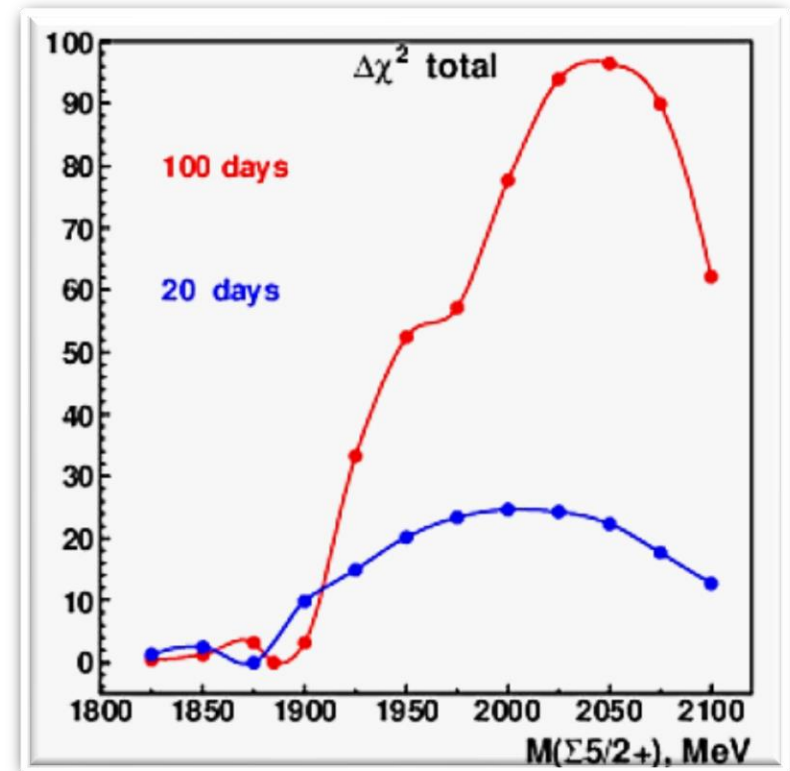
Resonance	 20 days: M, Γ	 100 days: M, Γ	 M, Γ	
Σ(1920)5/2 ⁻	1977±21±25 327±25±25	1923±10±10 321±10±10	?	2027 2487 2659 2781
Σ(2030)7/2 ⁺	1981±30±30 350±80	1930±20±30 400±40	2030±10 180±30	2686 2709 2793 2806

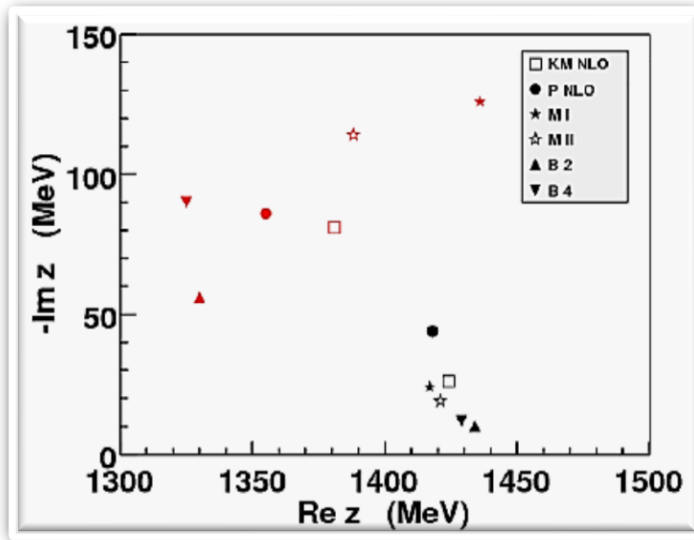


- At least **100** days needed to get precise solution.

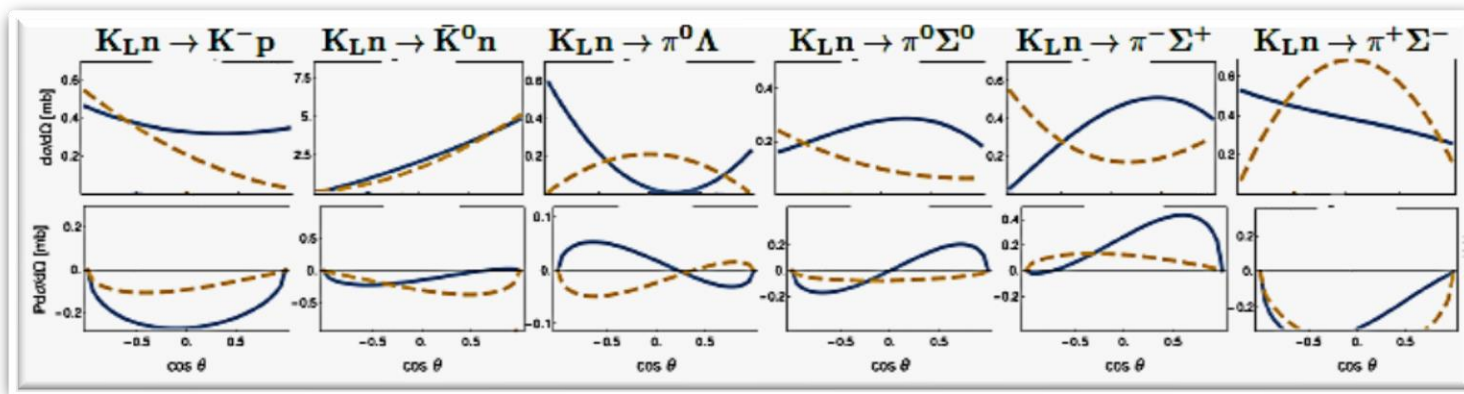


- χ^2 changes if resonance is out.



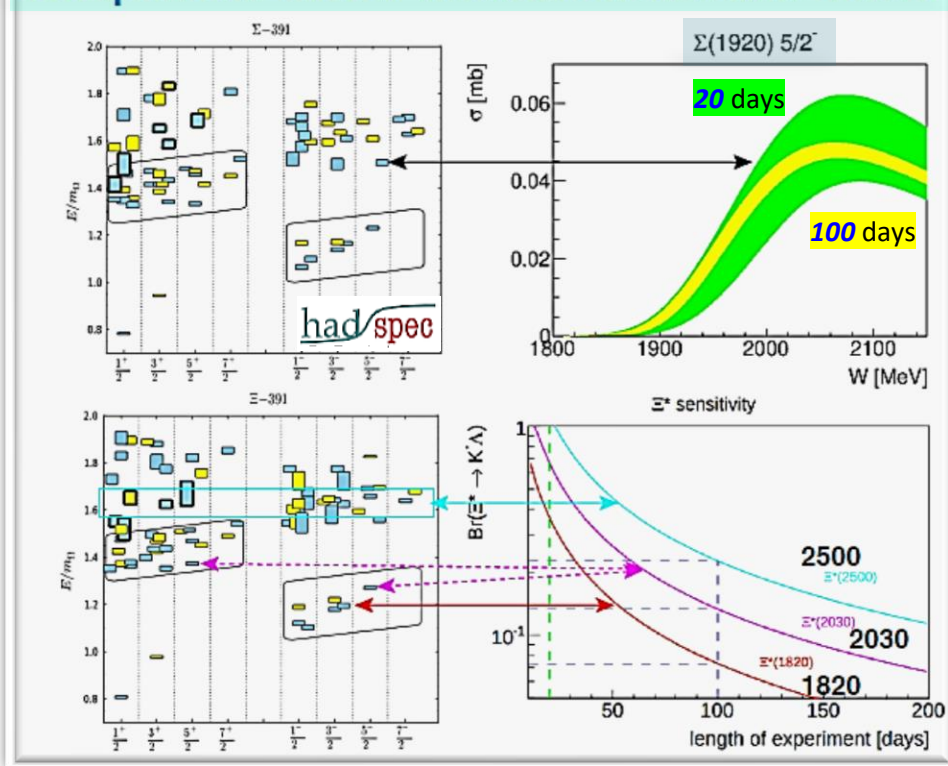


- There are 6 different models.
- Pole positions of $\Lambda(1405)$ in chiral unitary approaches.
- Each symbol represents position of 1st (black) & 2nd (red) pole in each model.



• $P_{KL} = 300$ MeV/c

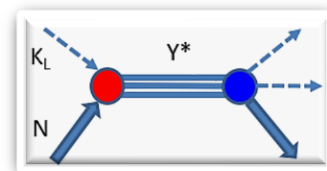
Comparison of KLF Measurements and LQCD



- We showed that  sensitivity with **100 days** of running will allow to discovery many hyperons with good precision.

- *Why should it be done with KL beam ?*

This is only realizable way to observe **s**-channel resonances having all momenta of **KL** at once.



- *Why should it be done at Jefferson Lab* 

Because nowhere else in existing facilities this can be done.

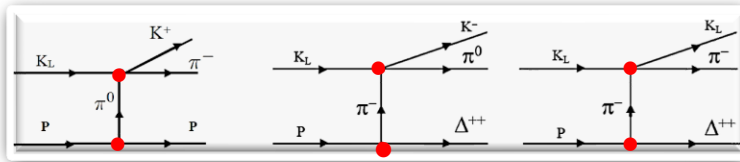
- *Why should we care that there are dozens of missing states ?*

...The new capabilities of the 12-GeV era facilitate a detailed study of baryons containing two and three strange quarks. Knowledge of the spectrum of these states will further enhance our understanding of the manifestation of QCD in the three-quark arena.

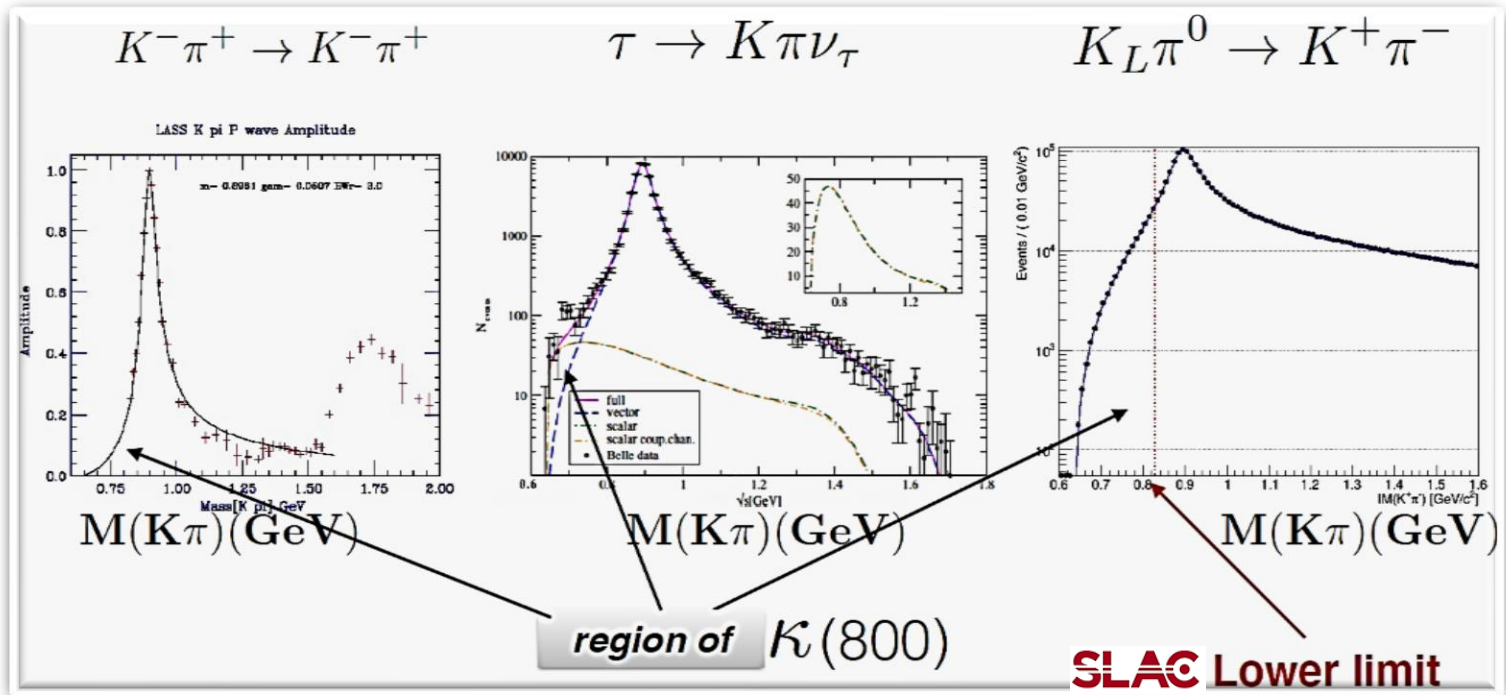
2015 Long Range Plan for Nuclear Science

Strange Meson Spectroscopy

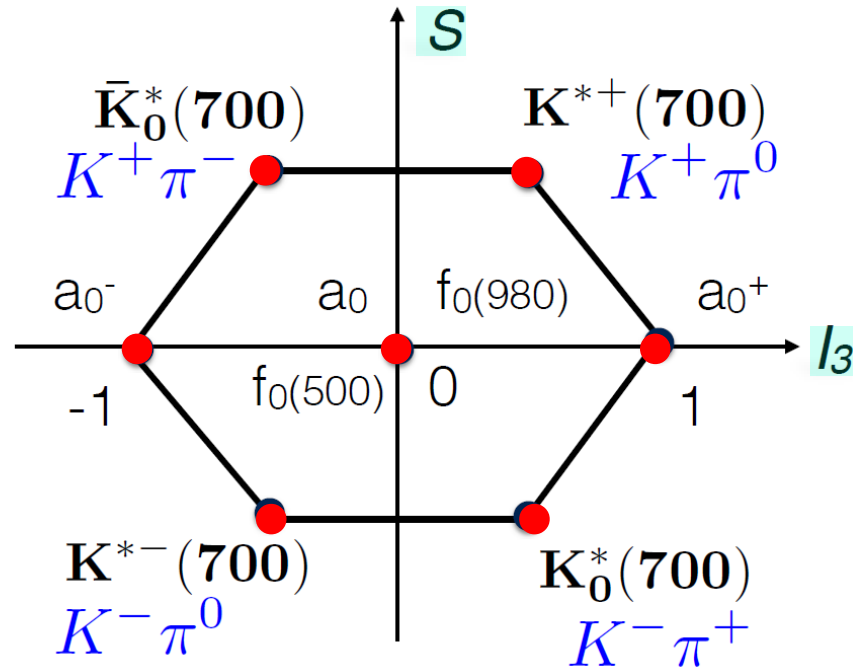




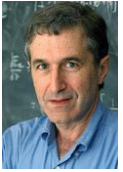
SLAC



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

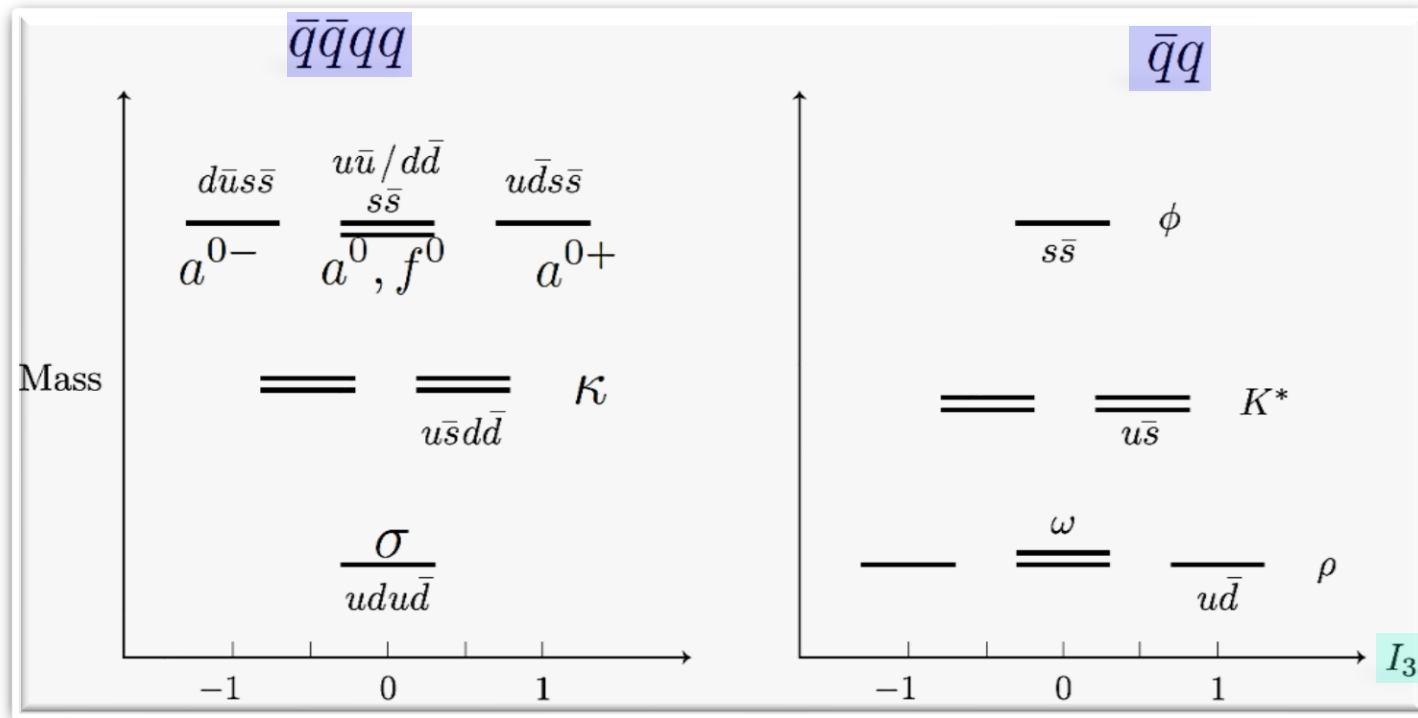


- *Four* states called κ .
- : still *need* further confirmation.
- allows determination of all *four* states.



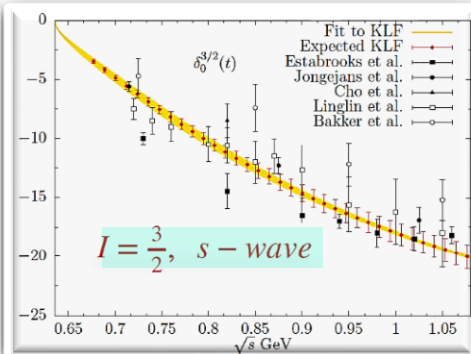
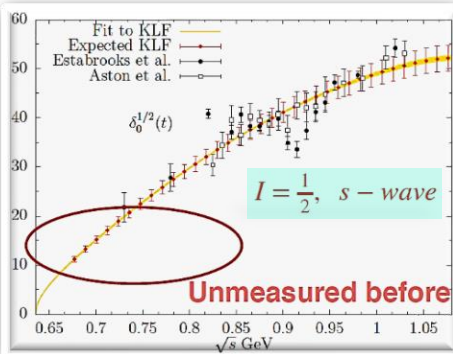
Inverted mass hierarchy tetraquarks

Ordinary meson states

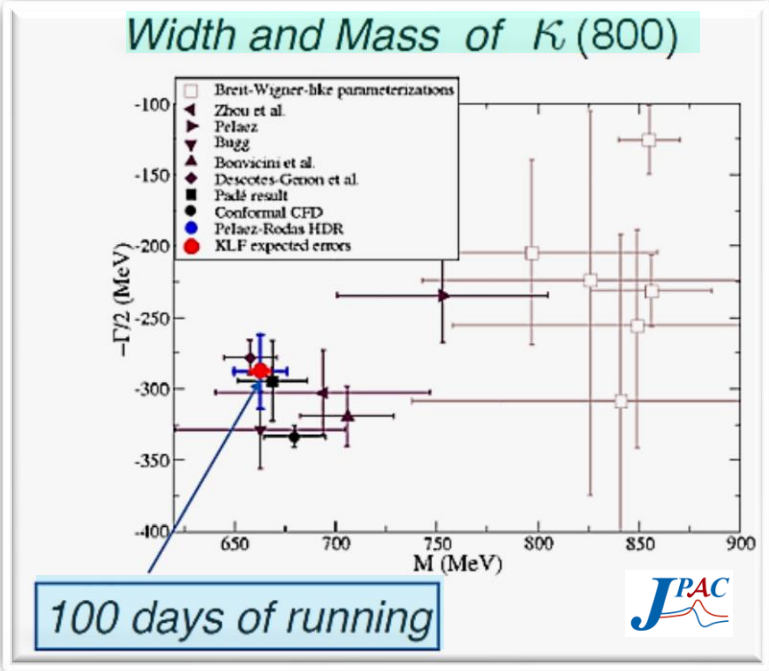




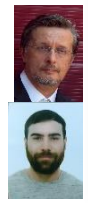
Summary of $K\pi$ Spectroscopy



- will have very significant *impact* on our knowledge on $K\pi$ scattering amplitudes.
- It will certainly improve still conflictive determination of *heavy* K^* 's parameters.
- It will help to settle tension between phenomenological determination of scattering lengths from data vs *ChPT* & *LQCD*.



- For $K^*(800)$, it will reduce:
 - uncertainties* in *mass* by factor of *two* &
 - uncertainty in *width* by factor of *five*.
- It will help to clarify debated of its *existence*, & therefore, long standing problem of existence of *scalar* meson *nonet*.



A Bit of History





PHYSICAL REVIEW

VOLUME 138, NUMBER 5B

7 JUNE 1965

First paper on subject

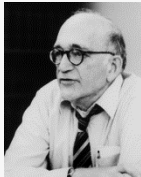
Photoproduction of Neutral K Mesons*

CP-violation (1964)
Hot topic!

S. D. DRELL AND M. JACOB†

Stanford Linear Accelerator Center, Stanford University, Stanford, California

(Received 6 January 1965)

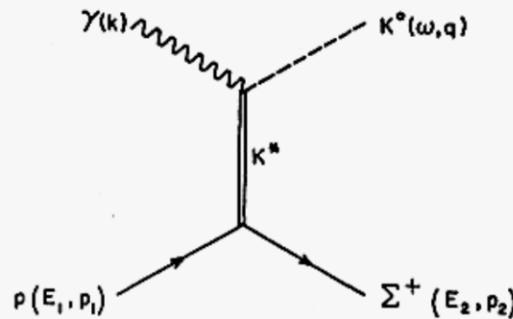


Photoproduction of a neutral K -meson beam at high energies from hydrogen is computed in terms of a K^* vector-meson exchange mechanism corrected for final-state interactions. The results are very encouraging for the intensity of high-energy K_2 beams at high-energy electron accelerators. A typical magnitude is $20 \mu\text{b}/\text{sr}$ 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]



50 $\mu\text{b}/\text{sr}$

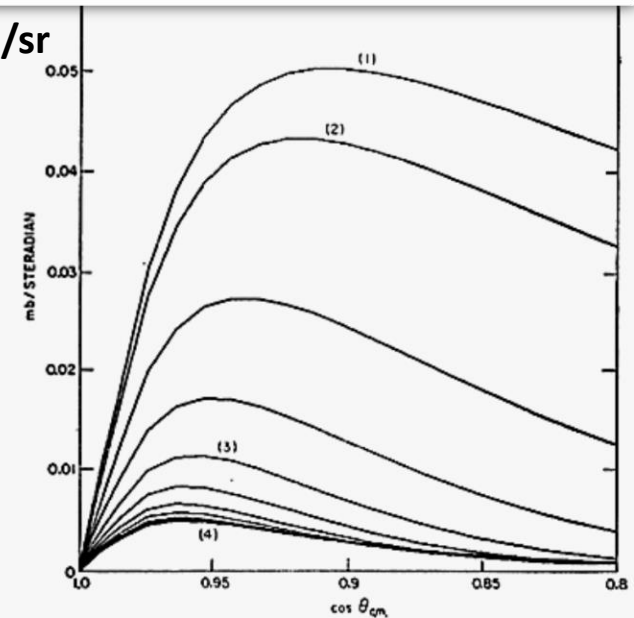


FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and (4) are respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partial waves have been corrected for absorption in final state. The results are shown as directly obtained from and drawn by the computer.

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.

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.

PHYSICAL REVIEW

VOLUME 156, NUMBER 5

25 APRIL 1967

Photoproduction of Strange Particles*

CAMBRIDGE BUBBLE CHAMBER GROUP†

*Brown University, Providence, Rhode Island, U. S. A.,
 Cambridge Electron Accelerator, Cambridge, Massachusetts, U. S. A.,
 Harvard University, Cambridge, Massachusetts, U. S. A.,
 Massachusetts Institute of Technology, Cambridge, Massachusetts, U. S. A.,
 University of Padova, Padova, Italy,
 and
 The Weizmann Institute of Science, Rehovoth, Israel.*
 (Received 2 November 1966)



is joint project of



&



VOLUME 19, NUMBER 23

PHYSICAL REVIEW LETTERS

4 DECEMBER 1967

OBSERVATION OF PHOTOPRODUCED NEUTRAL K MESONS*

J. F. Schivell,† E. Engels, Jr., and A. Entis
Harvard University, Cambridge, Massachusetts

and

J. M. Paterson
Cambridge Electron Accelerator, Cambridge, Massachusetts

and

L. N. Hand‡
Cornell University, Ithaca, New York

and

A. Sadoff
Ithaca College and Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
(Received 24 August 1967)





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 Nuclear Physics B23 (1970) 509-524. North-Holland Publishing Company
8.B.6

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





Study photoproduction as means of making clean K^0 beams & their decays & later, interactions.

VOLUME 22, NUMBER 18 PHYSICAL REVIEW LETTERS 5 MAY 1969

PRODUCTION OF K_s^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. Mill
K. Moriyasu, B. C. Shen, W. M. Smart, and R. Yamartino
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 13 March 1969)

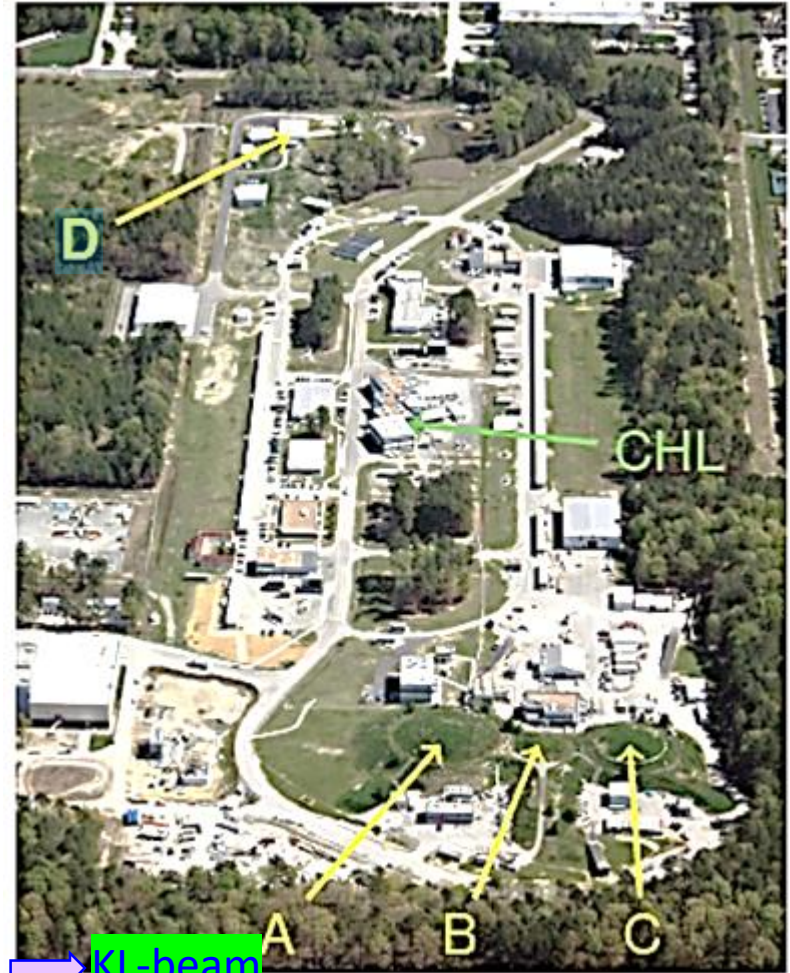
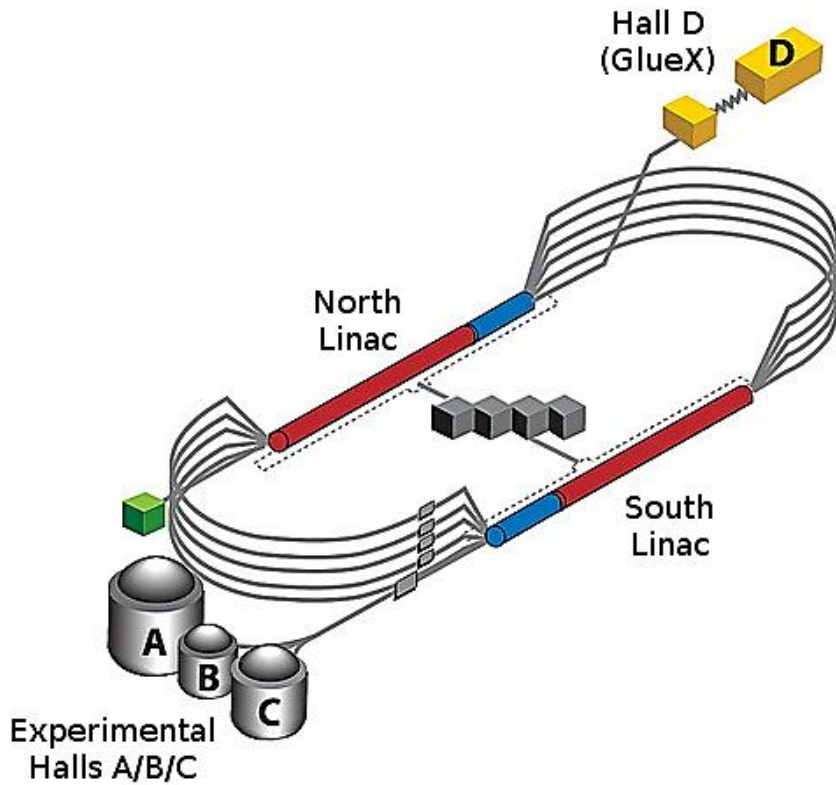


Systematics of particle-anti-particle processes through intrinsic property of K -longs.



KLEF Beamline & Hardware





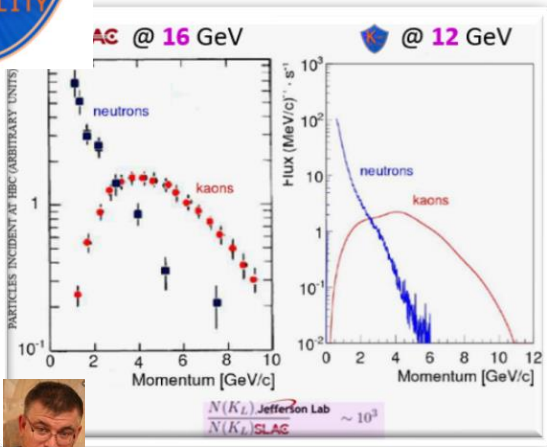
- Accelerator: 2.2 GeV/pass
- Halls A,B,C: e^- 1-5 passes ≤ 11 GeV
- Hall D: e^- 5.5 passes 12 GeV $\Rightarrow \gamma$ -beam \rightarrow KL-beam
- Runs 2017-2018: 5.5 passes 11.7 GeV





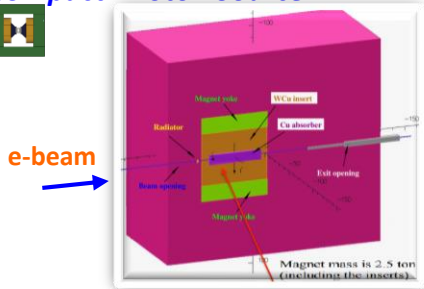
Hall D Beam Line for KLF

- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.
- K_L s (1×10^4 K_L /sec) are hitting LH_2/LD_2 target within GLueX setting.



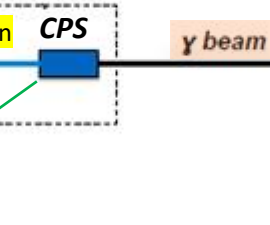
12 GeV 5 μ A
Bunch spacing 64 ns

North LINAC
East ARC
Compact Photon Source

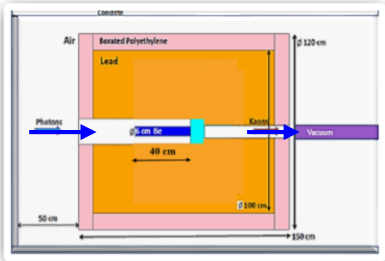


γ -beam

No need in tagging photons



Kaon Production Target

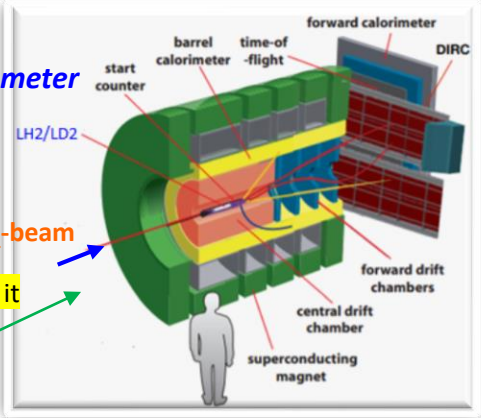


γ -beam

K_L -beam

Pair Spectrometer We will not use it

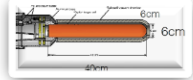
GlueX Spectrometer



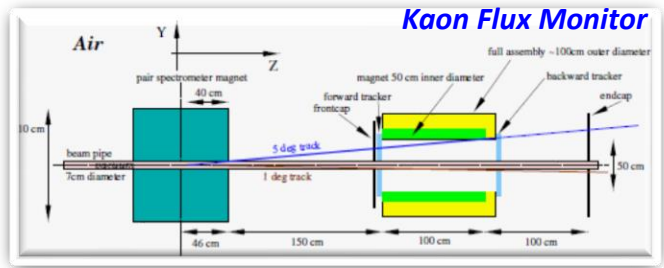
K_L -beam

Photon Beam Dump

LH_2/LD_2 -target



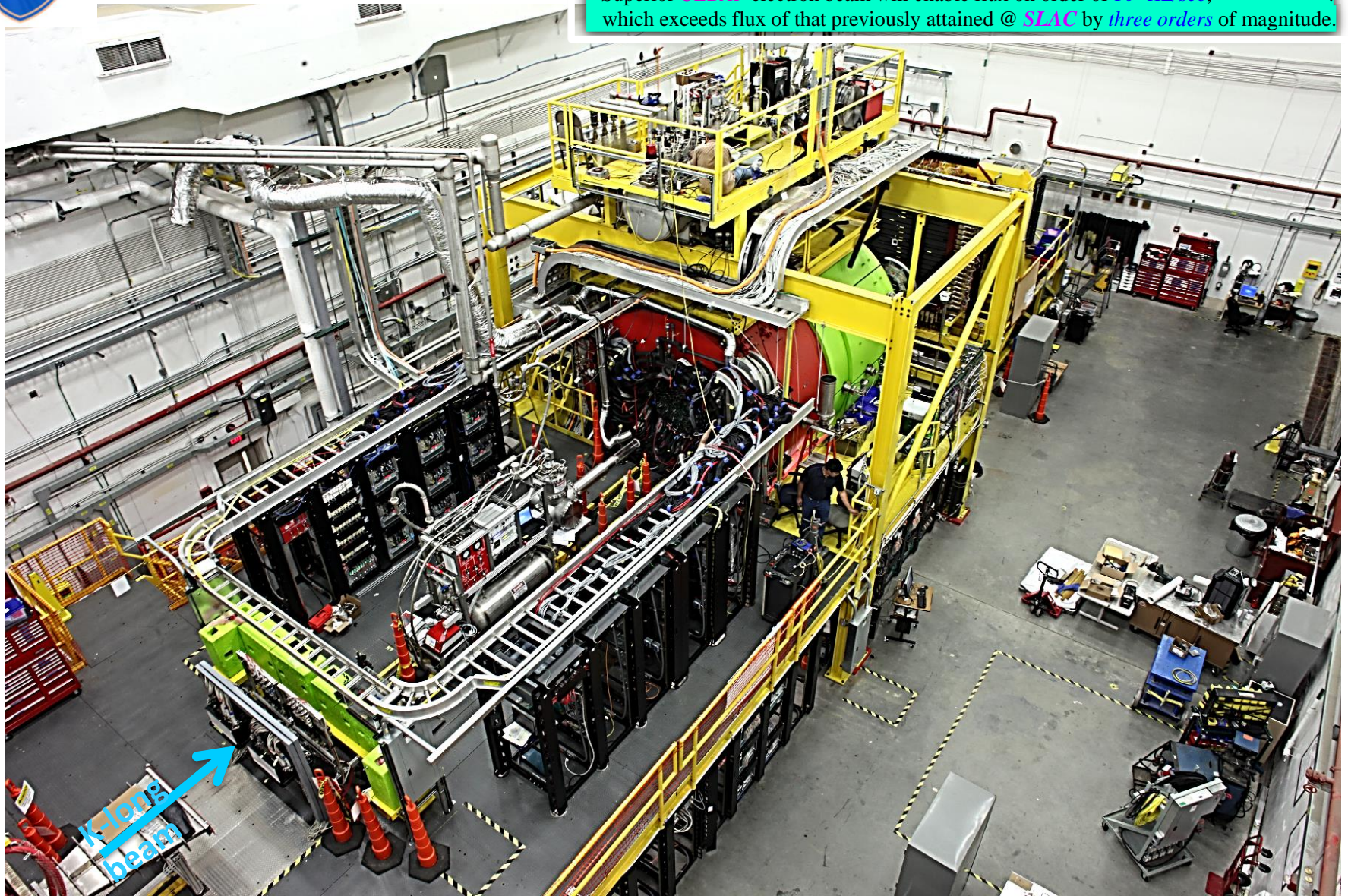
Kaon Flux Monitor





Hall D / KLF

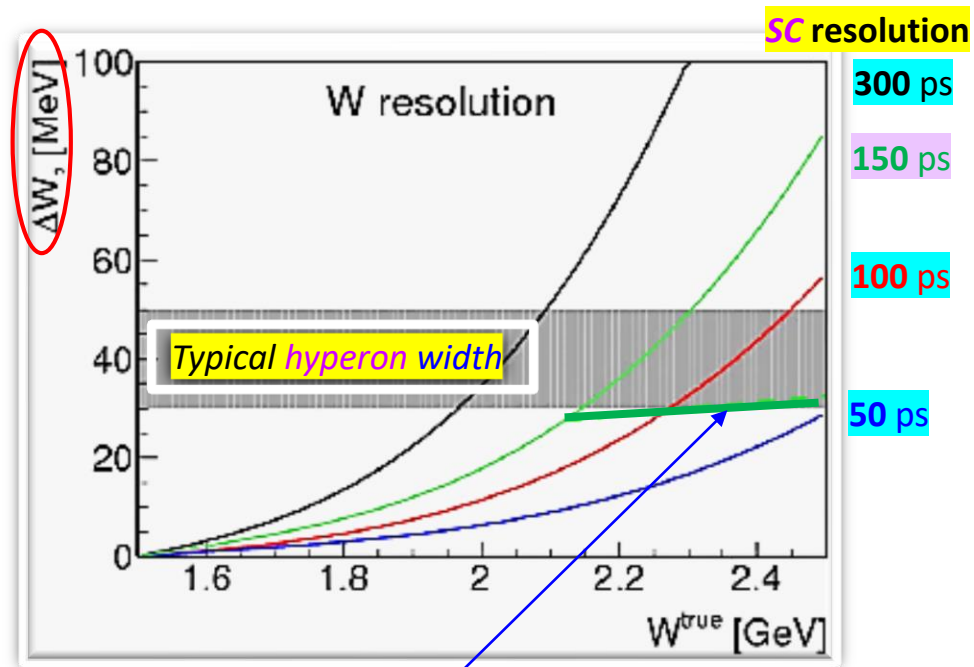
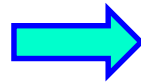
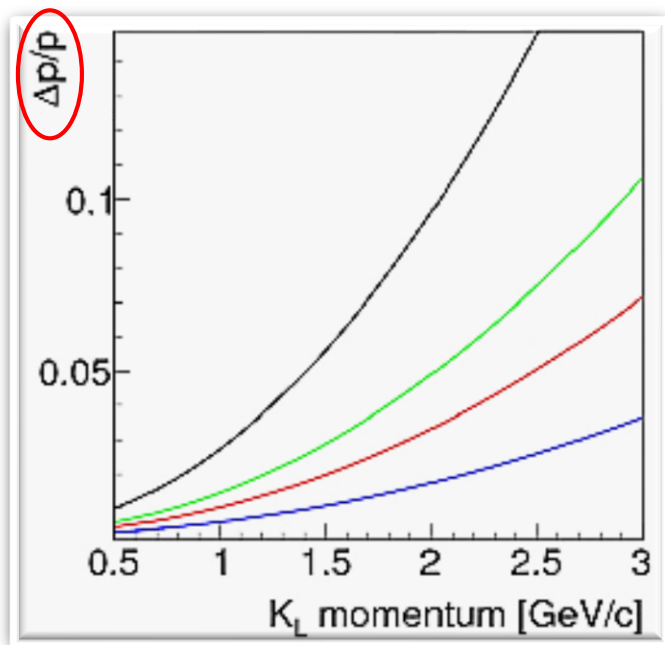
- Superior *CEBAF* electron beam will enable flux on order of 10^4 KL/sec, which exceeds flux of that previously attained @ *SLAC* by *three orders* of magnitude.



- 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 $K_L p$ 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.

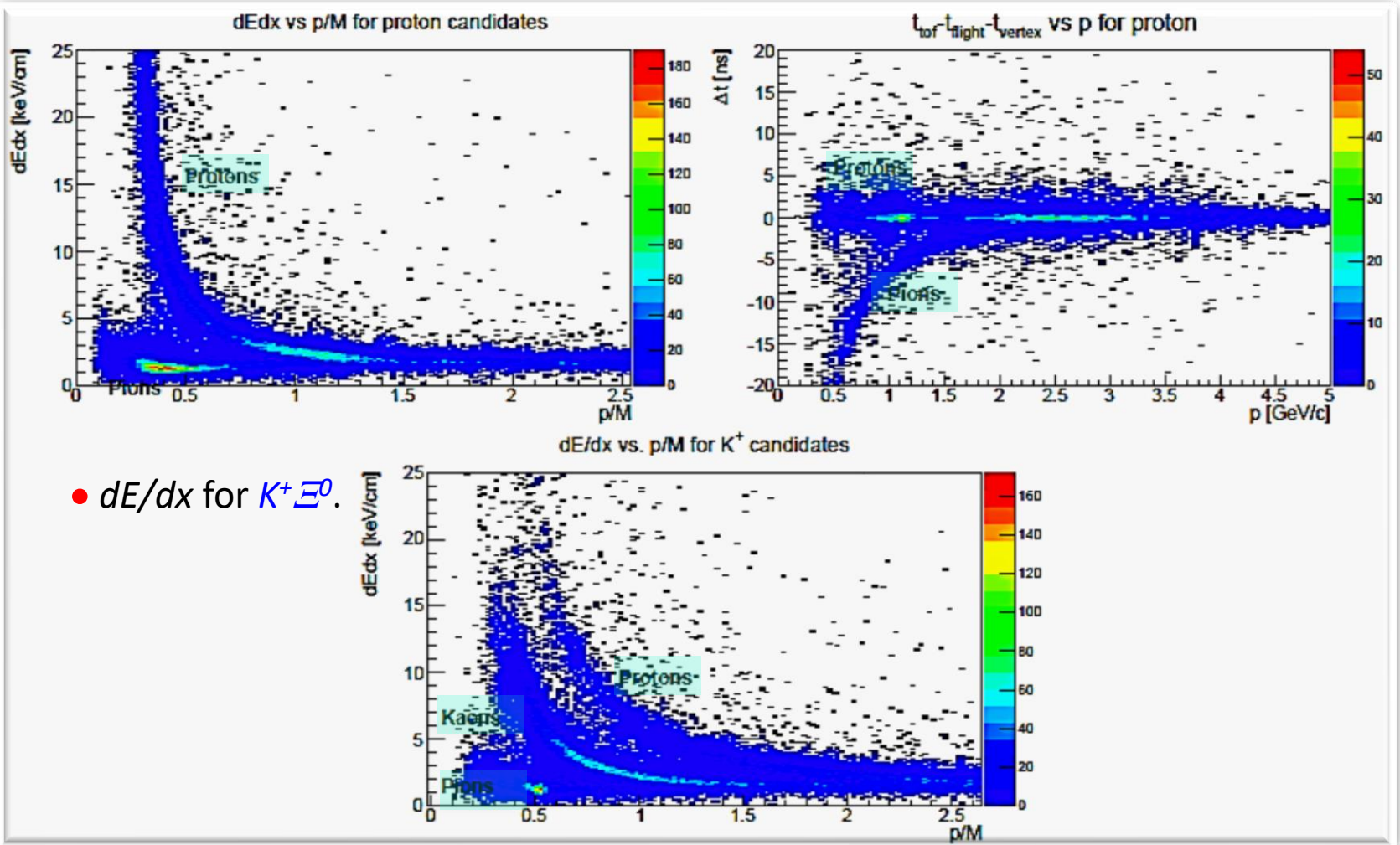


150 ps & final state reconstruction

Expected Particle Identification with *GlueX*

- dE/dx for pK_S .

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

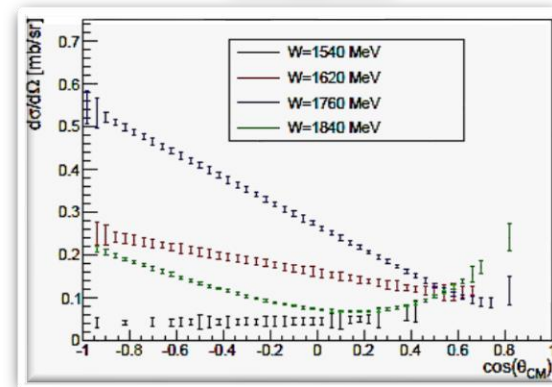
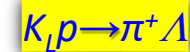
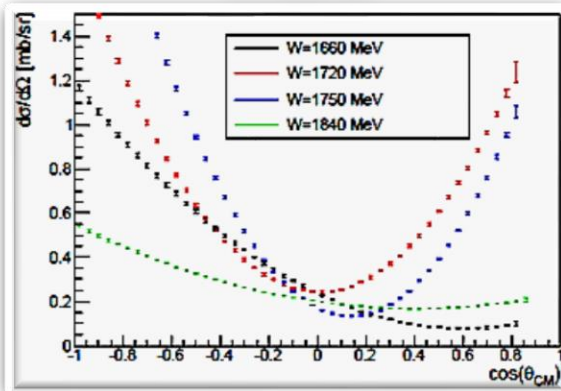


- dE/dx for $K^+ \Xi^0$.

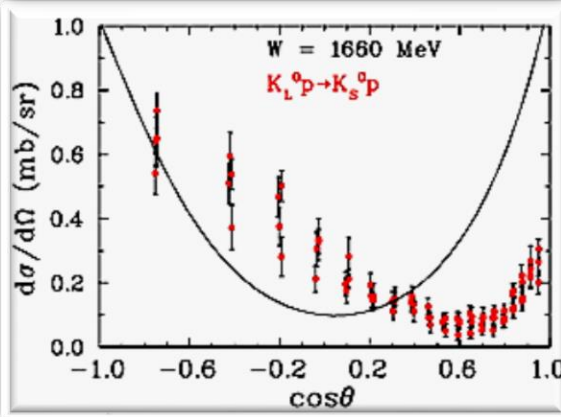
Expected Cross Sections vs Bubble Chamber Data

• measurements will span $\cos\theta$ from -0.95 to 0.95 in CM above $W = 1490$ MeV.

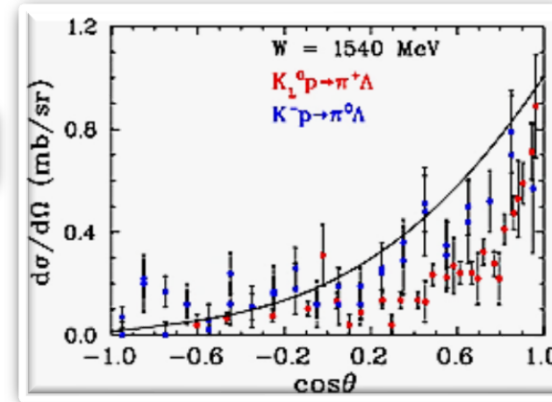
- K_L rate is 10^4 K_L /sec = **2500 x SLAC**.
- Uncertainties (statistics only) correspond to **100 days** of running time for:



Expected
 Data



BC Data



KLF Time Requested



- Expected statistics for differential cross sections of different reactions with LH_2 & below $W = 3.0$ GeV for 100 days of beam time:

For $d\sigma/d\Omega$

Reaction	Statistics (events)
$K_L p \rightarrow K_S p$	2.7M
$K_L p \rightarrow \pi^+ \Lambda$	7M
$K_L p \rightarrow K^+ \Xi^0$	2M
$K_L p \rightarrow K^+ n$	60M
$K_L p \rightarrow K^- \pi^+ p$	7M


For P , statistics is 0.2M

- 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.
- Expected systematics is 10% or less.



- Our goal is

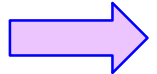
- To *establish KL Facility* @  .
- To do *measurements* which bring new physics.

-  *K-long Facility* would advance *Hyperon Spectroscopy* & study of *strangeness* in nuclear & hadronic physics.

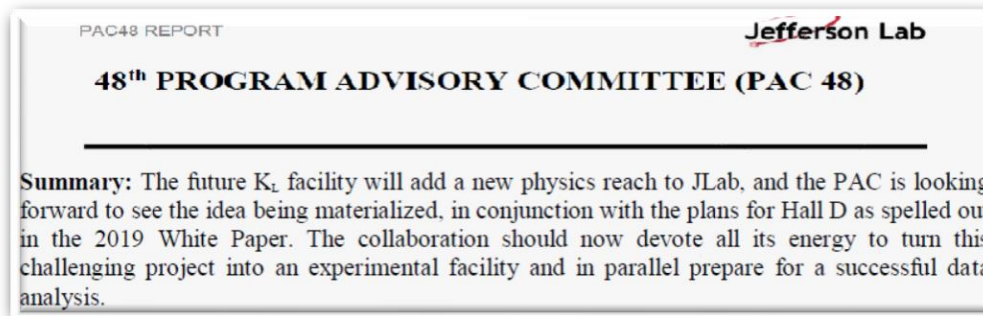
It may extract very many missing strange states.

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*.

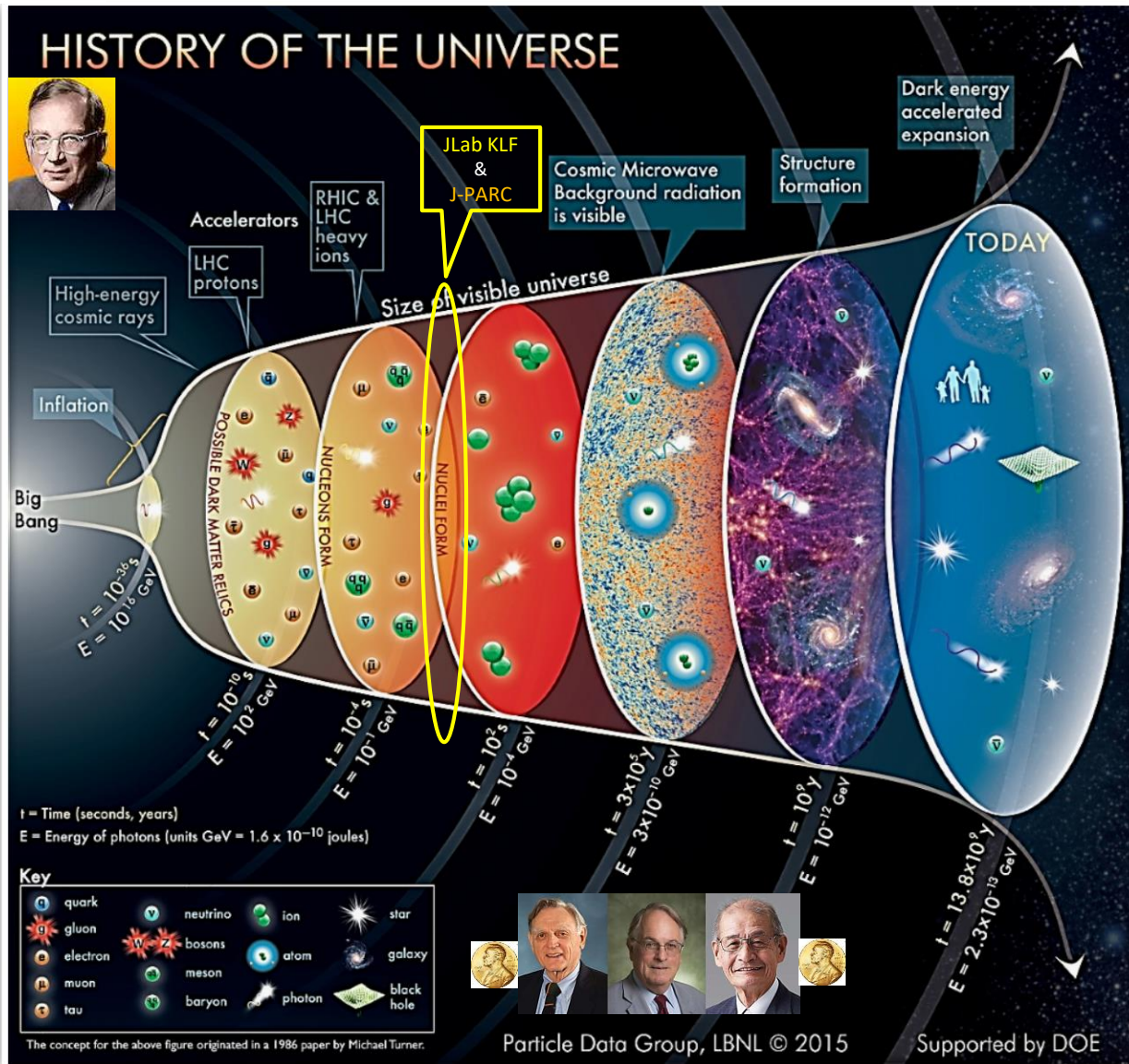


- In *Strange Meson Spectroscopy* PWA will allow to determine excited K^* states including scalar $K^*(700)$ states.



Impact to Study Early Universe





- 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* resonances.

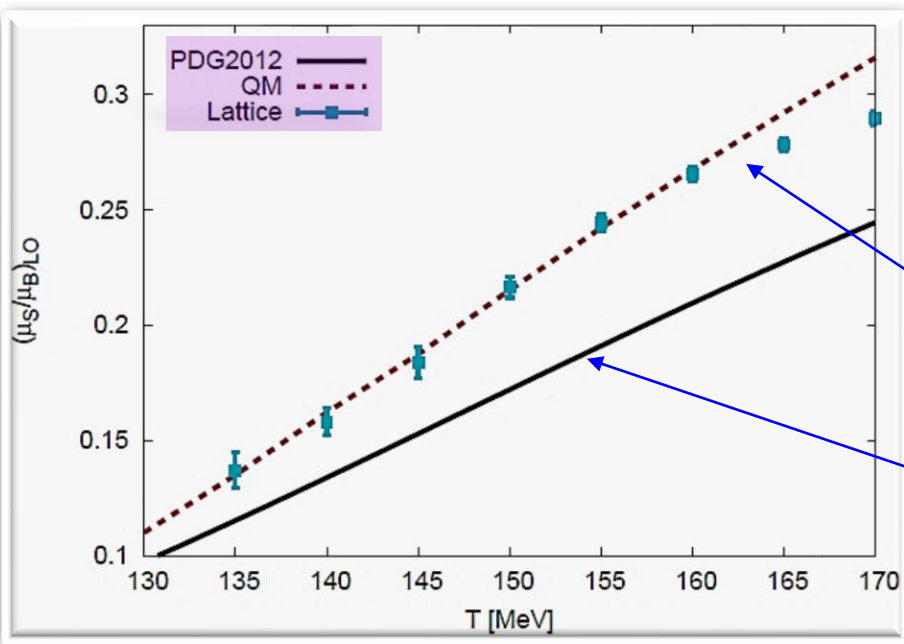
- Recent studies that compare *LQCD* calculations of thermodynamic, statistical *Hadron Resonance Gas* models, & ratios between measured yields of different hadron species in heavy ion collisions provide indirect evidence for presence of "missing" resonances in all of these contexts.



Chemical Potential

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

- Hyperons
- Non-strange Baryons
- Mesons
- Nuclei



- + "Missing" Hyperons (QM/LQCD calculations).

- Contribution from *observed* Resonances.



Courtesy of Claudia Ratti, YSTAR2016



Backup Slides



Proposal for JLab PAC48

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

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arXiv:2008.08215v2 [nucl-ex] 14 Sep 2020

