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

Aims of Jefferson Lab Thomas Jefferson National Accelerator Facility K LONG FACILITY *Project*

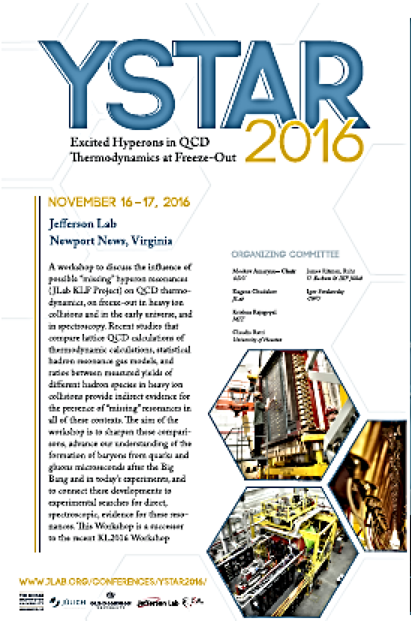
- K LONG FACILITY project has firmly to establish secondary K_L beam line at Jefferson Lab Thomas Jefferson National Accelerator Facility,
  with *flux* of *three order of magnitude higher* than SLAC had,
  for scattering experiments on both *proton* & *neutron* (*first* time !) targets in order.

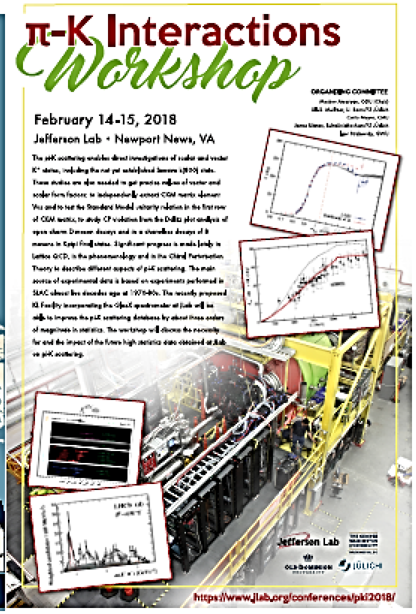
- To determine differential cross sections & self-polarization of strange *hyperons*
  with GlueX detector to enable precise *PWA* in order to determine all *resonances*
  up to *2500* MeV in spectra of Λ^*, Σ^*, Ξ^*, & Ω^*.

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

- K LONG FACILITY 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*.

Four International Workshops Supported KLF Program





KL2016
[60 people from 10 countries, 30 talks] *https://www.jlab.org/conferences/kl2016/*
OC: M. Amaryan, 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. Amaryan, E. Chudakov, K. Rajagopal, C. Ratti, J. Ritman, & I. Strakovsky

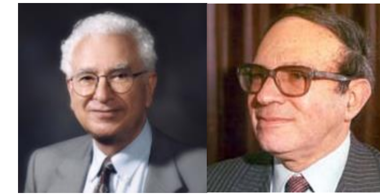
HIPS2017
[43 people from 4 countries, 19 talks] *https://www.jlab.org/conferences/HIPS2017/*
OC: T. Horn, C. Keppel, C. Munoz-Camacho, & I. Strakovsky

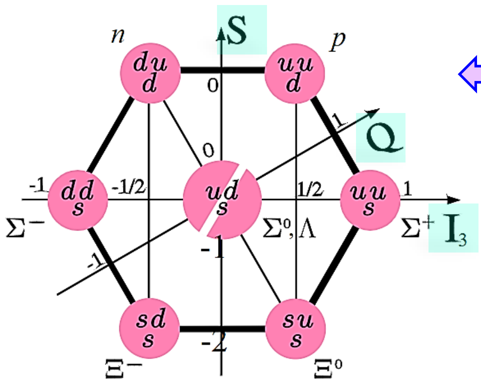
PKI2018
[48 people from 9 countries, 27 talks] *http://www.jlab.org/conferences/pki2018/*
OC: M. Amaryan, U.-G. Meissner, C. Meyer, J. Ritman, & I. Strakovsky

In total: 222 participants & 103 talks

Hyperon Spectroscopy

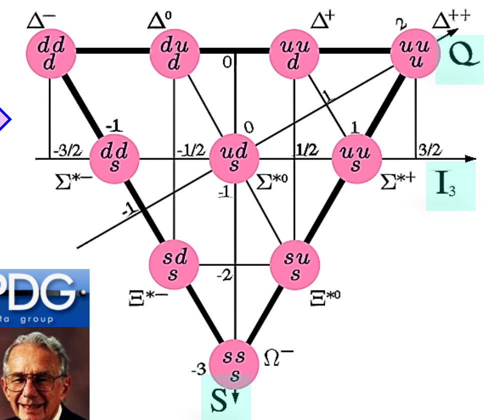
Baryon Multiplets of Eight-fold Way





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

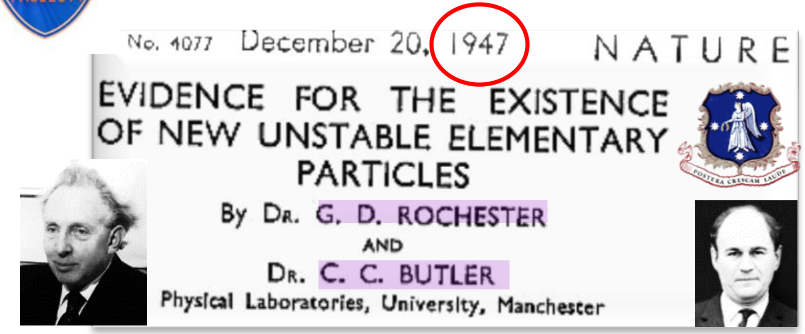
Spin 3/2 baryon decuplet: Δ^*, Σ^*, Ξ^*, Ω^*



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.

A bit of History for Hyperons

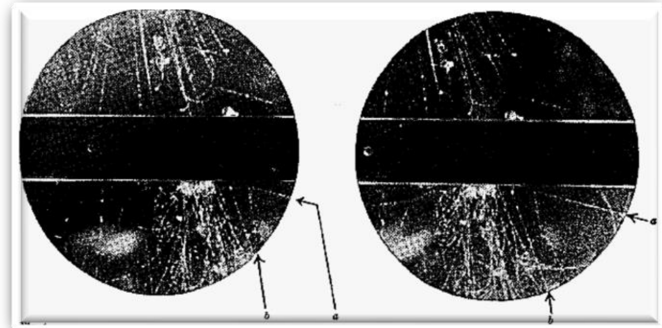

No. 4077 December 20, 1947 NATURE

EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

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

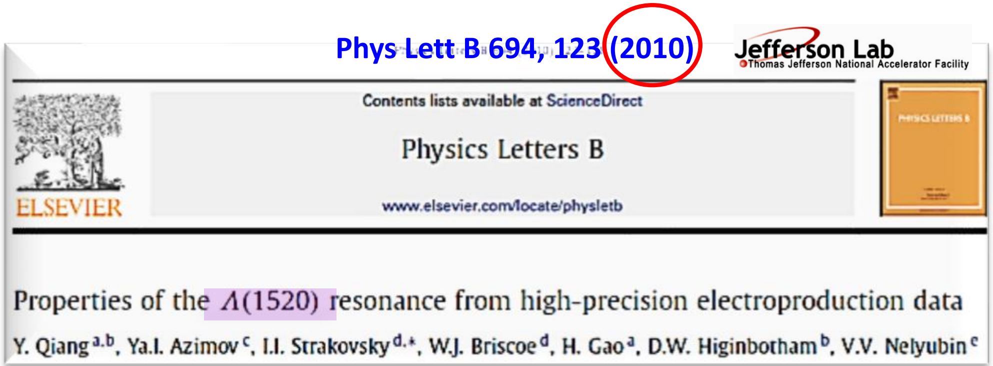
Physical Laboratories, University, Manchester

- *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

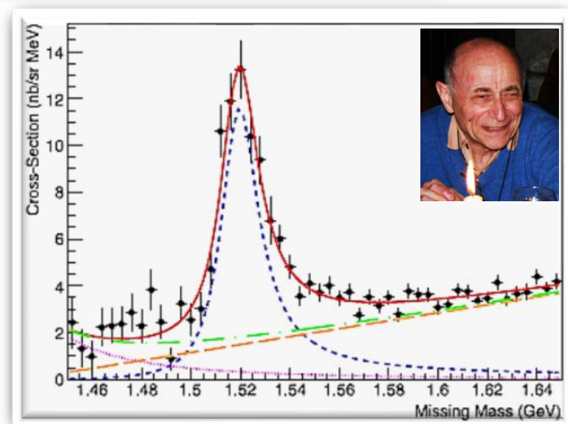
Physics Letters B

ELSEVIER

www.elsevier.com/locate/physletb

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

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



What Can Be Learned with K_L Beam ?

Target →	Proton	Neutron	[*first* measurements]
Elastic & Charge-Exchange	$K_L p \to K_S p$ $K_L p \to K^+ n$	$K_L n \to K_S n$ $K_L n \to K^- p$	
Two-body with ***S*** = –1	$K_L p \to \pi^+ \Lambda$ $K_L p \to \pi^+ \Sigma^0$	$K_L n \to \pi^0 \Lambda$ $K_L n \to \pi^0 \Sigma^0$	
Two-body with ***S*** = –2	$K_L p \to K^+ \Sigma^0$ $K_L p \to K^+ \Sigma^{0*}$	$K_L n \to K^0 \Sigma^0$ $K_L n \to K^0 \Sigma^{0*}$	
Three-body with ***S*** = –2	$K_L p \to \pi^+ K^+ \Sigma^-$ $K_L p \to \pi^+ K^+ \Sigma^{-*}$	$K_L n \to \pi^+ K^- \Sigma^0$ $K_L n \to \pi^+ K^- \Sigma^{0*}$	
Three-body with ***S*** = –3	$K_L p \to K^+ K^+ \Omega^-$ $K_L p \to K^+ K^+ \Omega^{-*}$	$K_L n \to K^+ K^0 \Omega^-$ $K_L n \to K^+ K^0 \Omega^{-*}$	

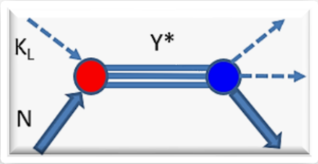
- To search for ``*missing*” hyperons, we need measurements of production reactions:

Σ^*: $K_L^0 p \to \pi \Sigma^* \to \pi\pi\Lambda$

Λ^*: $K_L^0 p \to \pi \Lambda^* \to \pi\pi\Sigma$

Ξ^*: $K_L^0 p \to K\Xi^*, \pi K \Xi^*$

Ω^*: $K_L^0 p \to K^+ K^+ \Omega^*$



$K_L p \to \pi^+ \Sigma^0$ & $\pi^0 \Sigma^+$

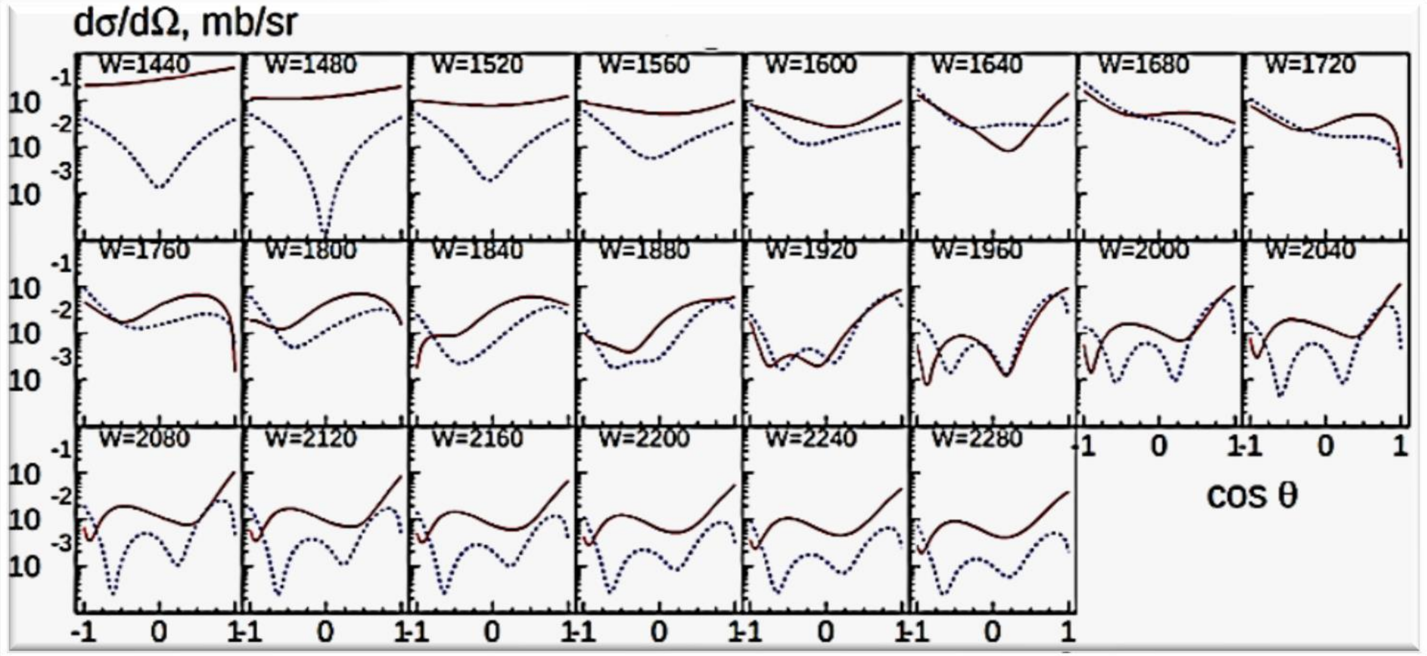
- *Isospin Amplitudes:*

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

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

$$|A(\bar{K}^0 p)|^2 = |A_1|^2.$$

- Two different solutions.

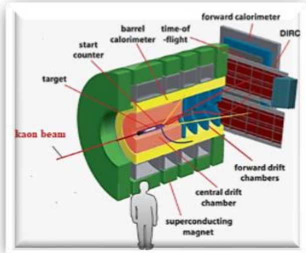


Road Map to Hyperon Spectroscopy

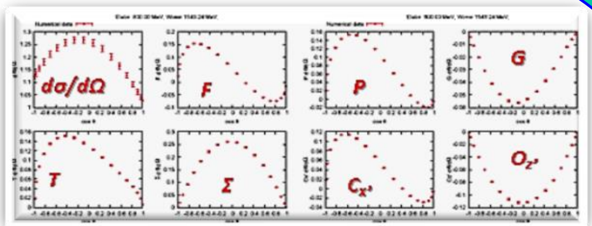
- That is not hunting for bumps.

Facility

Experiment

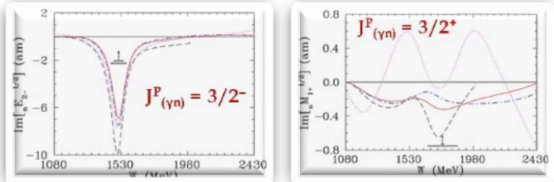


Data

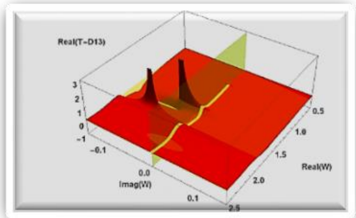


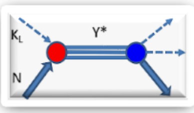
PWA

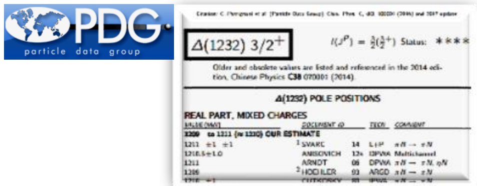
Amplitudes



Resonances





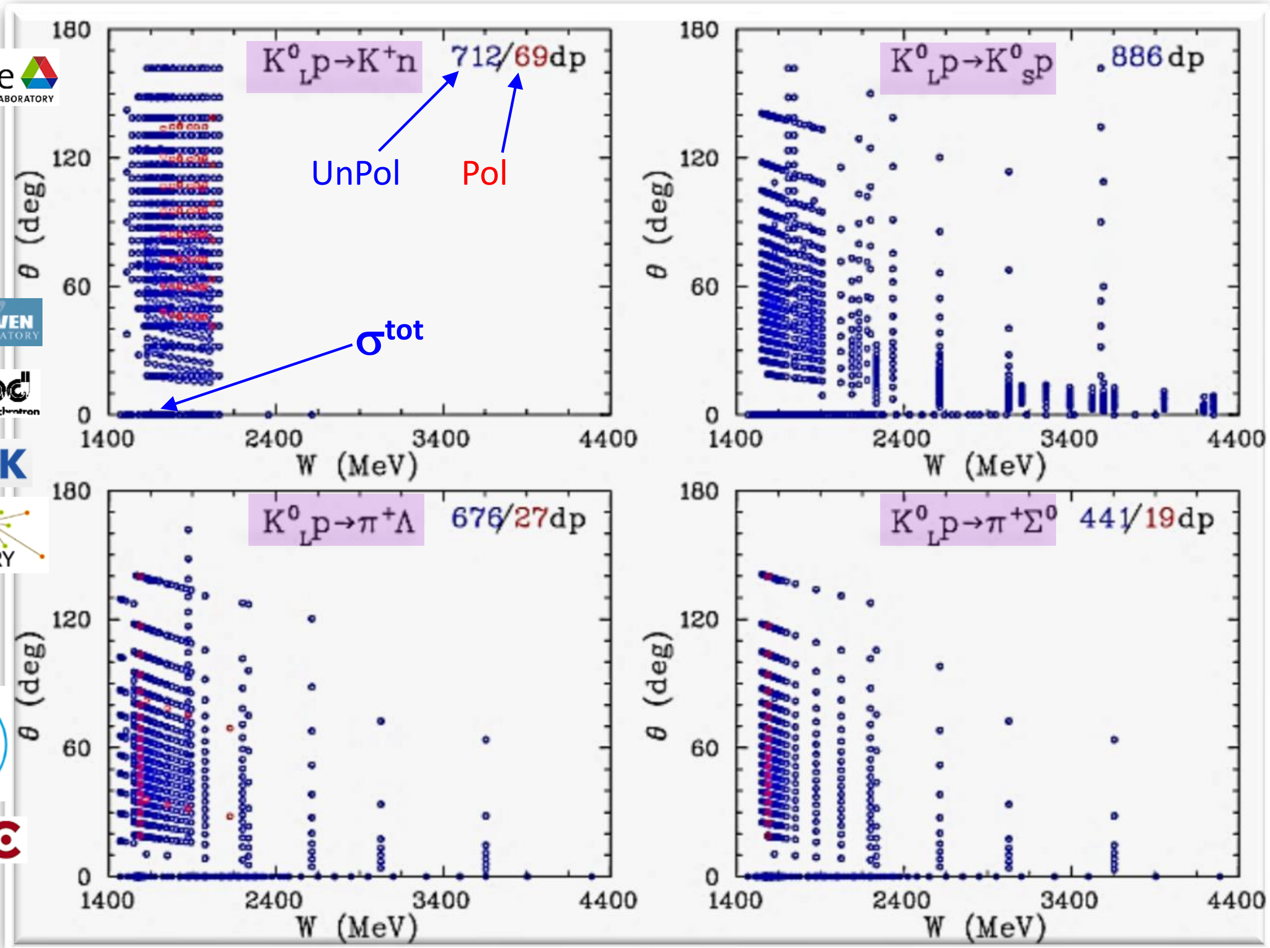


World K–long Data – Ground for Hyperon Phenomenology

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** 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 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.

PWA Formalism

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

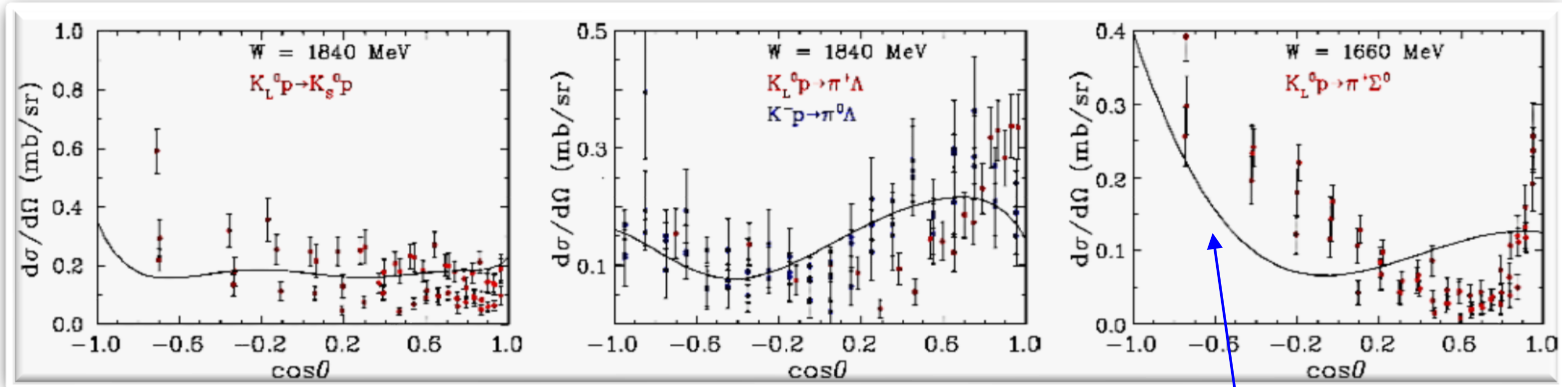
$$\frac{d\sigma}{d\Omega} = \bar{\lambda}^2\left(|f|^2 + |g|^2\right)$$

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

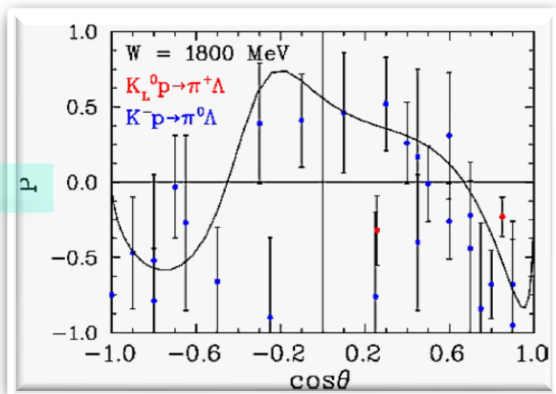
$\bar{\lambda} = \hbar/k$ & k is momentum of incoming kaon in CM.

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

Samples of PWA Results for Current DB



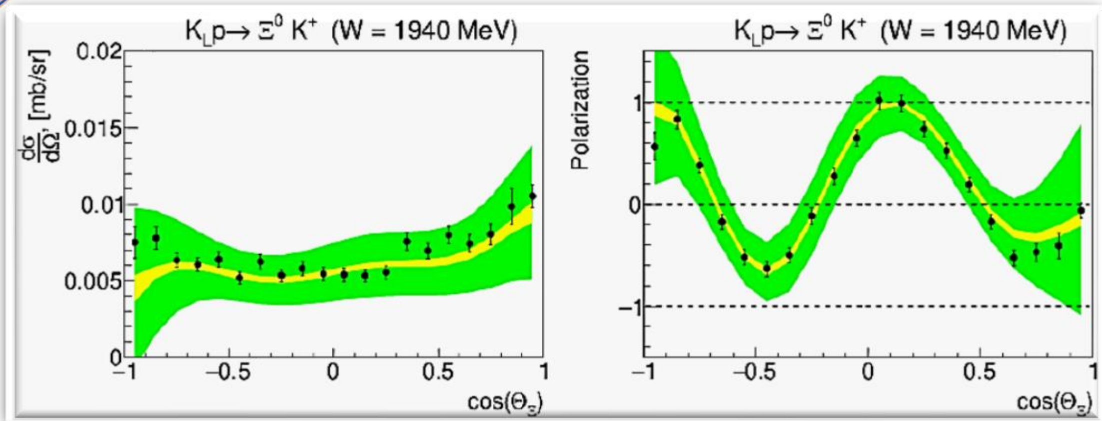
- *PWA* (&) predictions at lower & higher energies have poorer agreement for *S ≠ 0* data than for *S = 0* data.

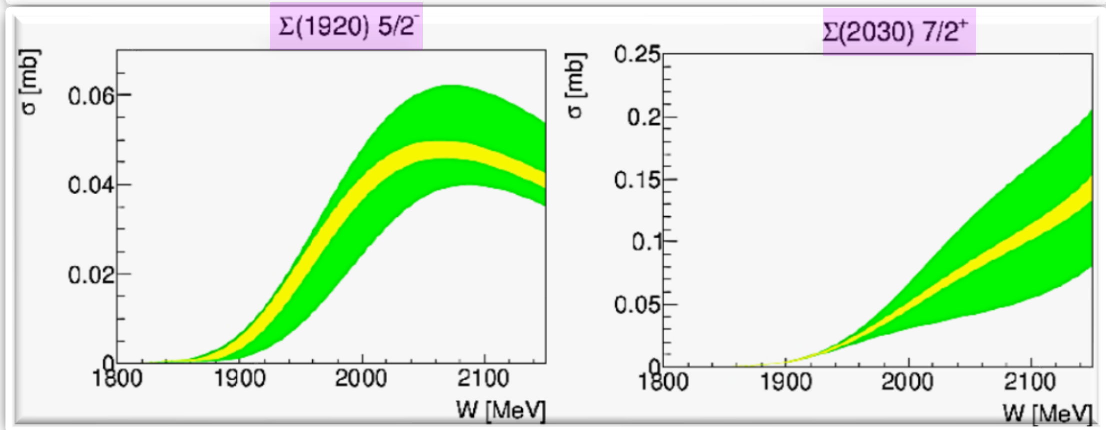


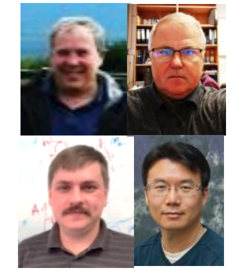
- Polarized measurements are *tolerable* for any *PWA* solutions.

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

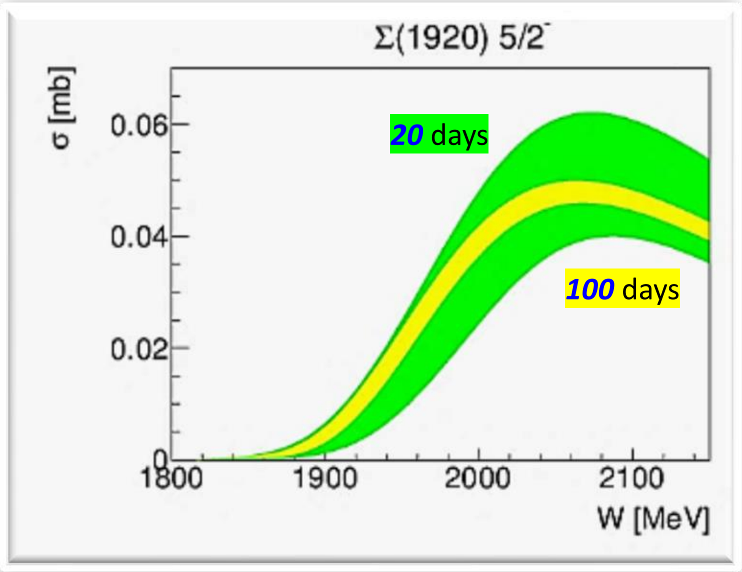
20 days

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

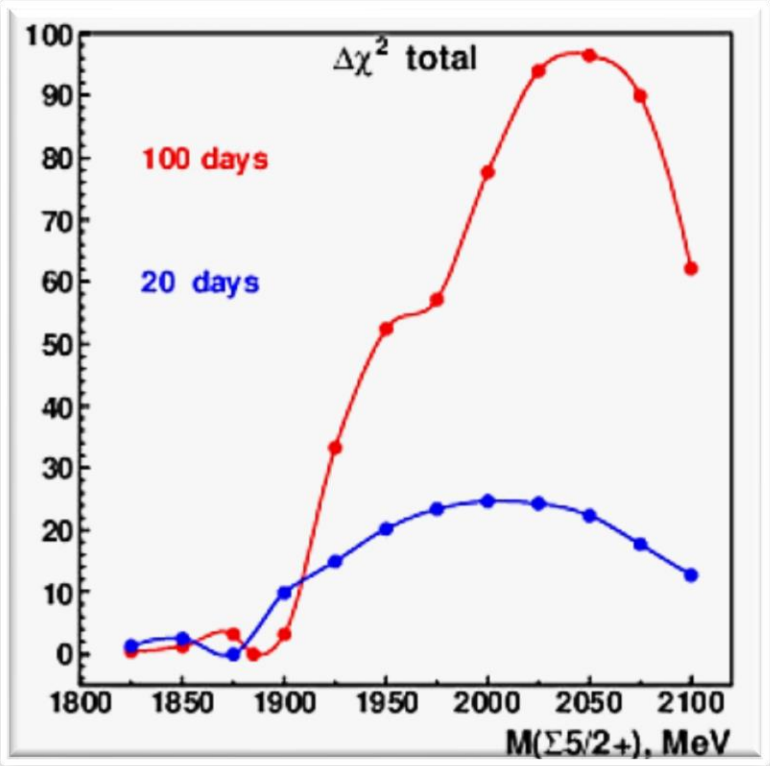
Resonance	20 days: M, Γ	100 days: M, Γ	PDG: M, Γ	hadspec M
$\Sigma(1920)5/2^-$	1977±21±25 327±25±25	1923±10±10 321±10±10	?	2027 2487 2659 2781
$\Sigma(2030)7/2^+$	1981±30±30 350±80	1930±20±30 400±40	2030±10 180±30	2686 2709 2793 2806

Systematics

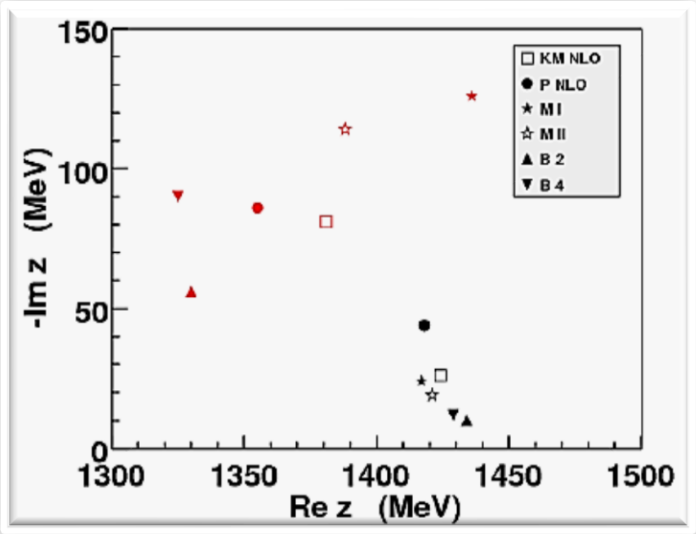
- At least ***100*** days needed to get precise solution.



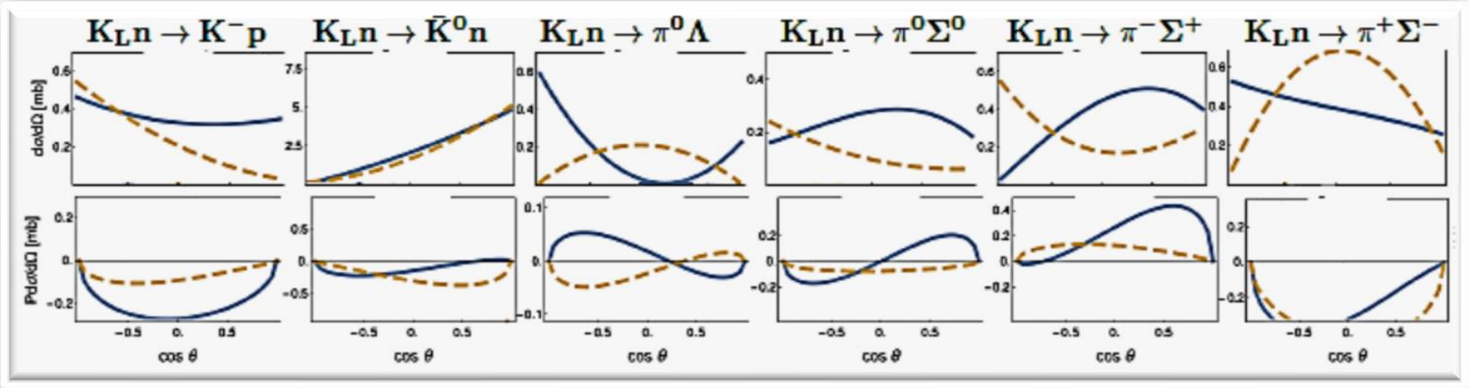
- χ^2 changes if *resonance* is out.



Theory for "Neutron" Target Measurements

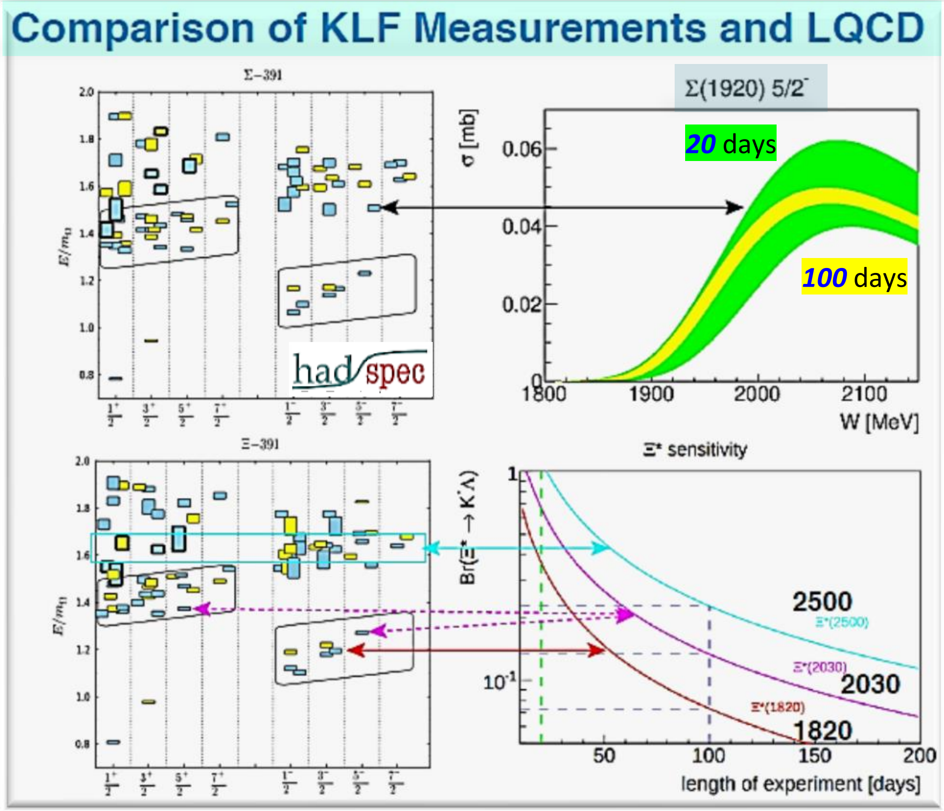


- There are 6 different models.
- *Pole* positions of *Λ(1405)* in chiral unitary approaches.
- Each symbol represents position of 1st (black) & 2nd (red) pole in each model.



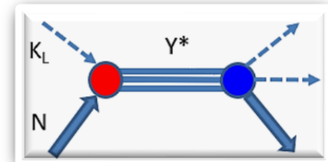
- P_{KL} = 300 MeV/c

Summary of Hyperon Spectroscopy



- We showed that KLF 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 Thomas Jefferson National Accelerator Facility ?*
  Because nowhere else in existing facilities this can be done.

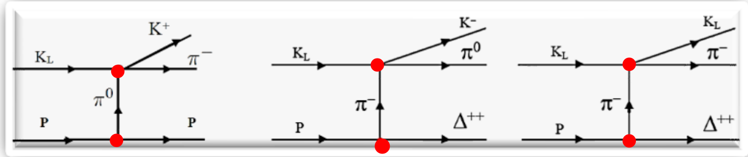
- *Why should we care that there are dozens of missing states ?*

…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.

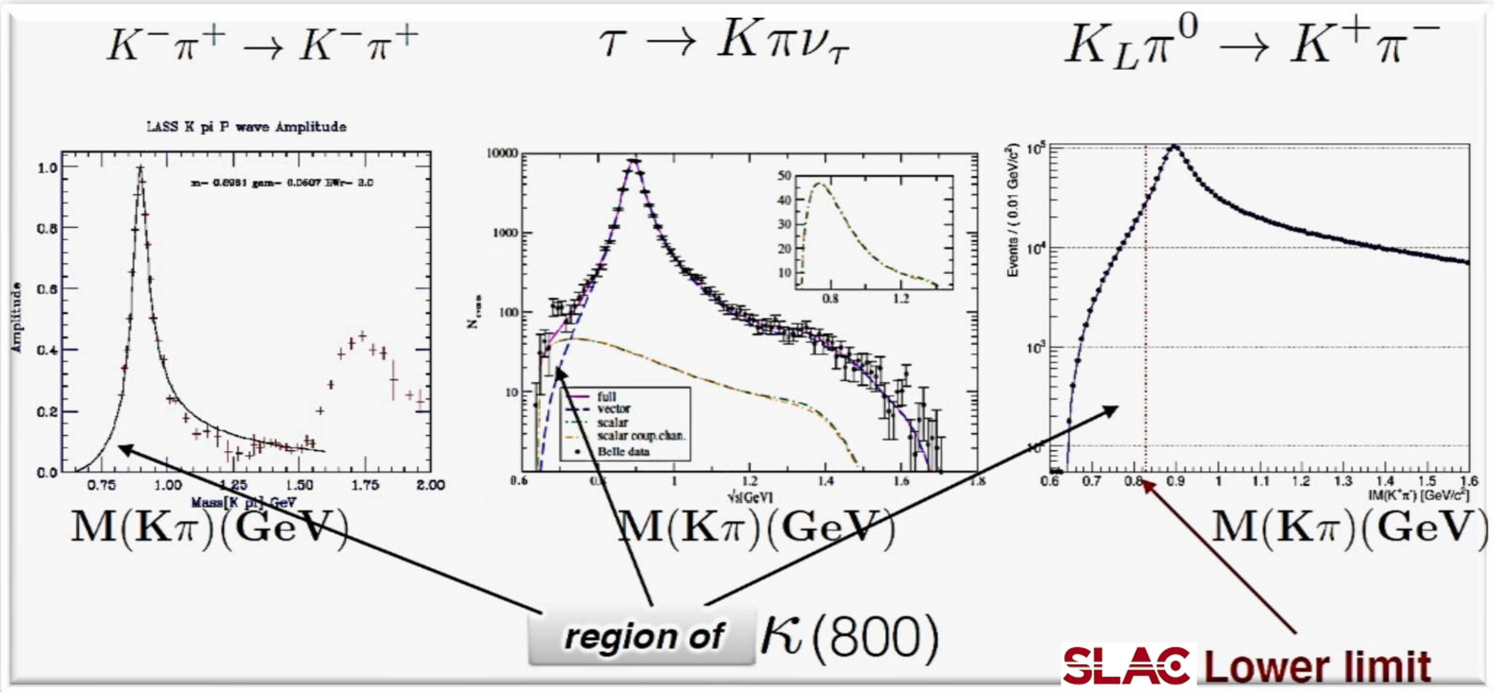
2015 Long Range Plan for Nuclear Science

Strange Meson Spectroscopy

Proposed Measurements

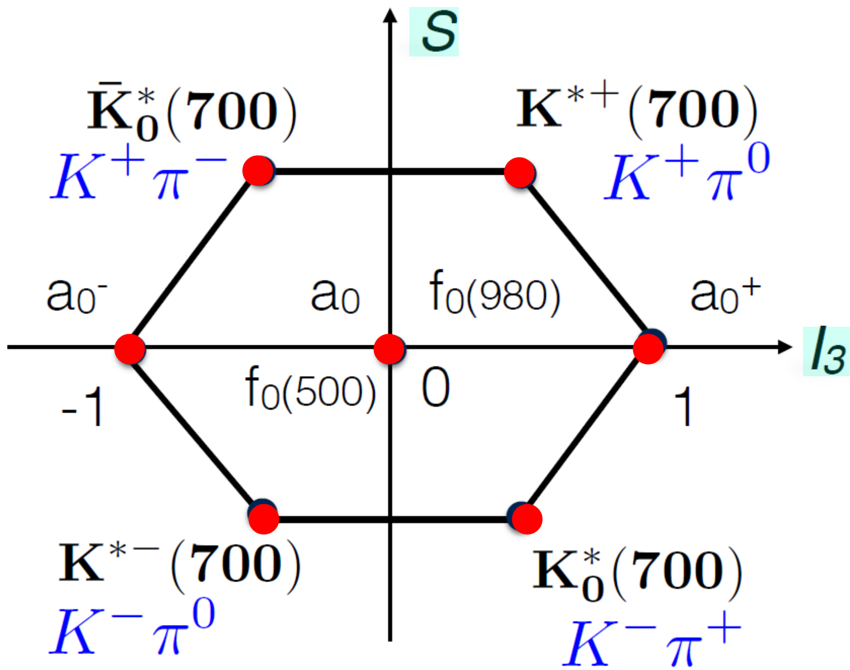


SLAC BELLE



Scalar Meson Nonet

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

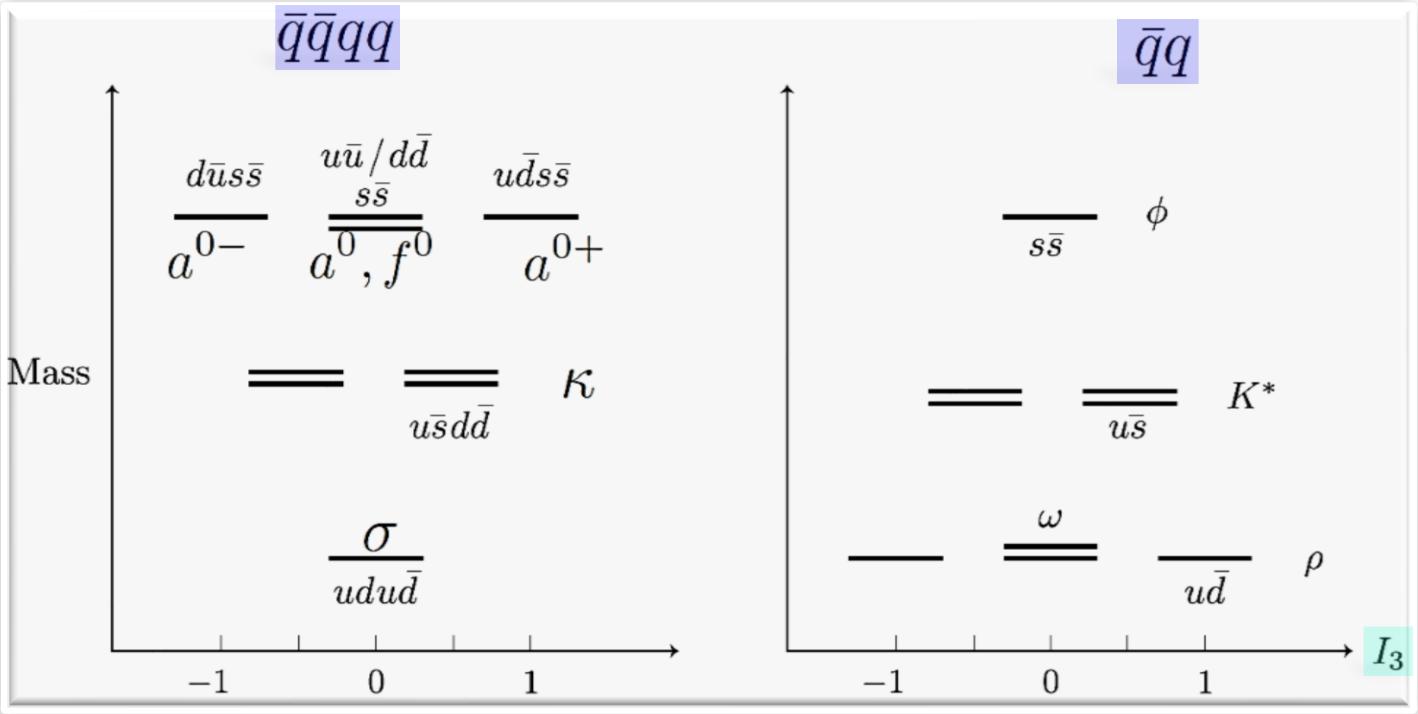


- *Four* states called *κ*.
- PDG: still *need* further confirmation.
- K LONG FACILITY allows determination of all *four* states.

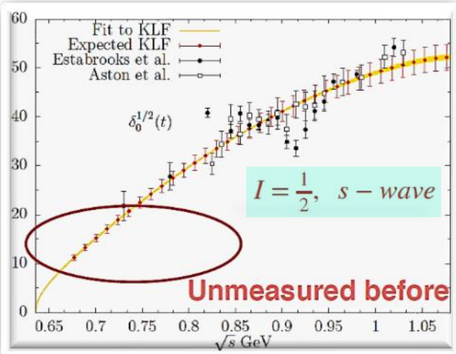
Phenomenology of q^2-bar-q^2

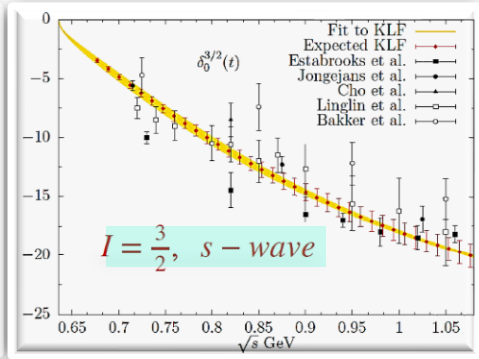
R.J. Jaffe, Phys Rev D **15**, 267 (1977)
arXiv: 0001123 [hep-ph]

Inverted mass hierarchy tetraquarks *Ordinary meson states*

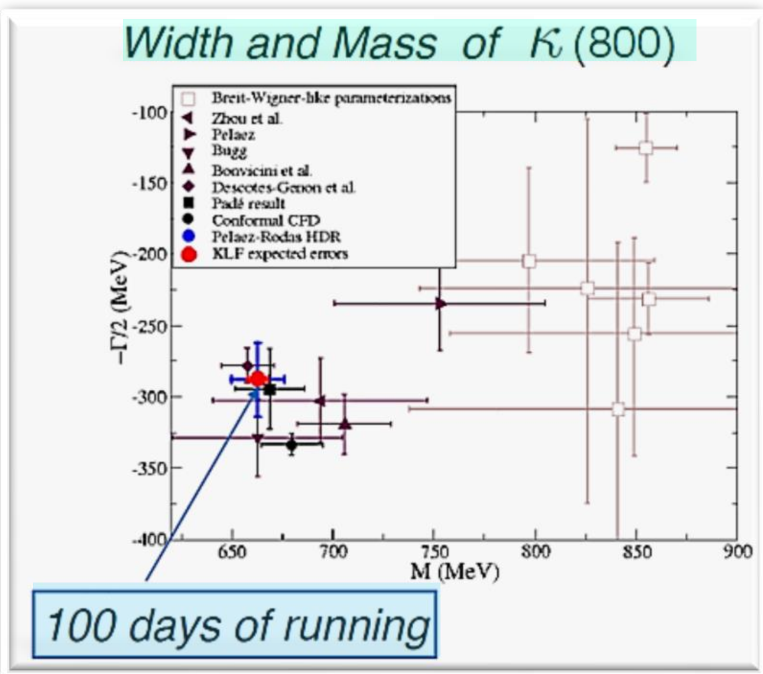


Summary of $K\pi$ Spectroscopy





-  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

A bit of History

PHYSICAL REVIEW VOLUME 138, NUMBER 5B 7 JUNE 1965

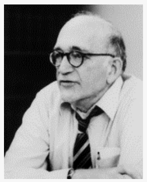
First paper on subject

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.

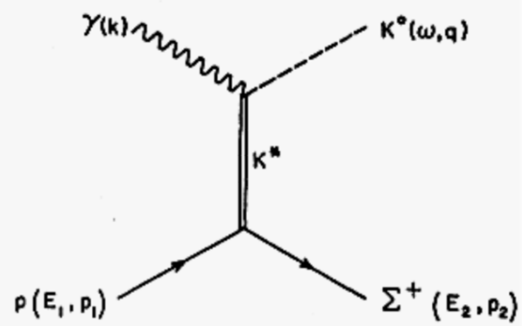


Fig. 1. K^* exchange in photoproduction.

[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

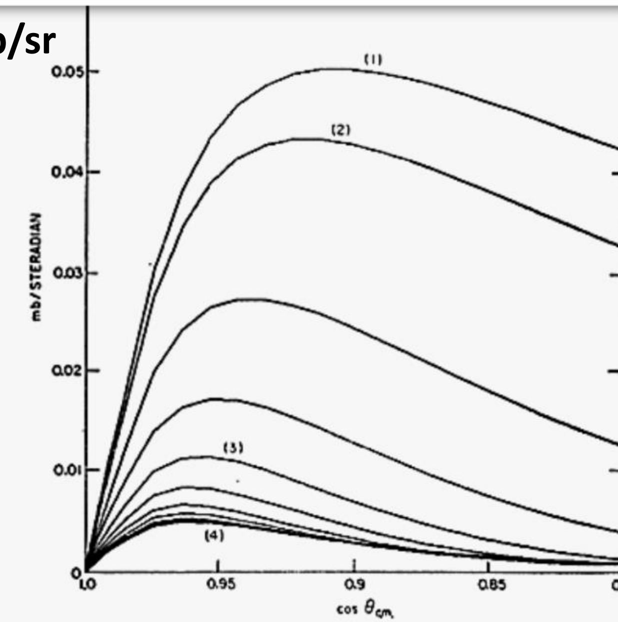


Fig. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and (4) are respectively obtained after the $j=\frac{1}{2},\frac{3}{2},\frac{5}{2},\frac{7}{2}$, and all partial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

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.

is joint project of MIT & Harvard

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)

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)

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.

Sci-Tech DARESBURY

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

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Study photoproduction as means of making clean K0 beams & their decays & later, interactions.

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

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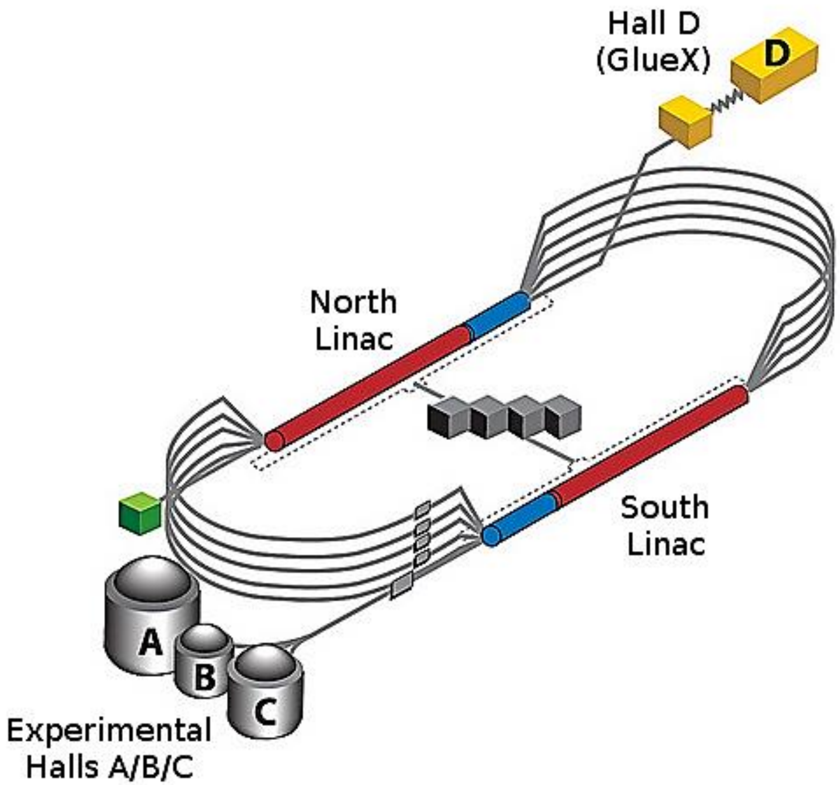
(Received 13 March 1969)

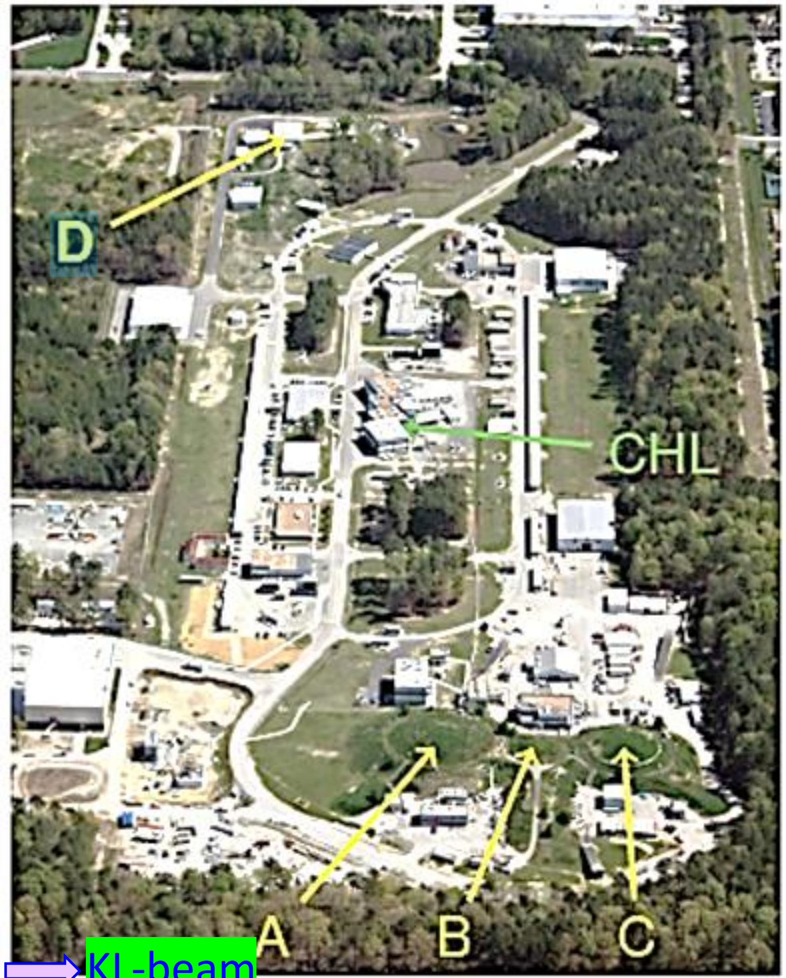
SLAC

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

KLF Beamline & Hardware

Jefferson Lab *in 2020*

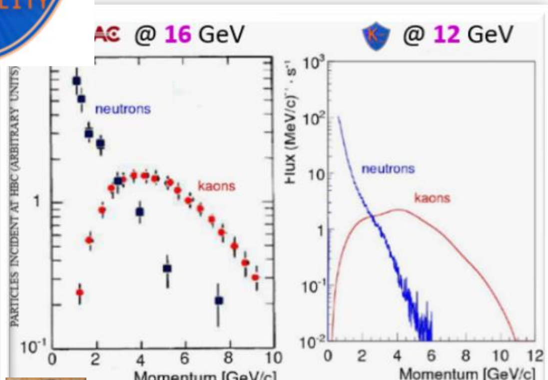




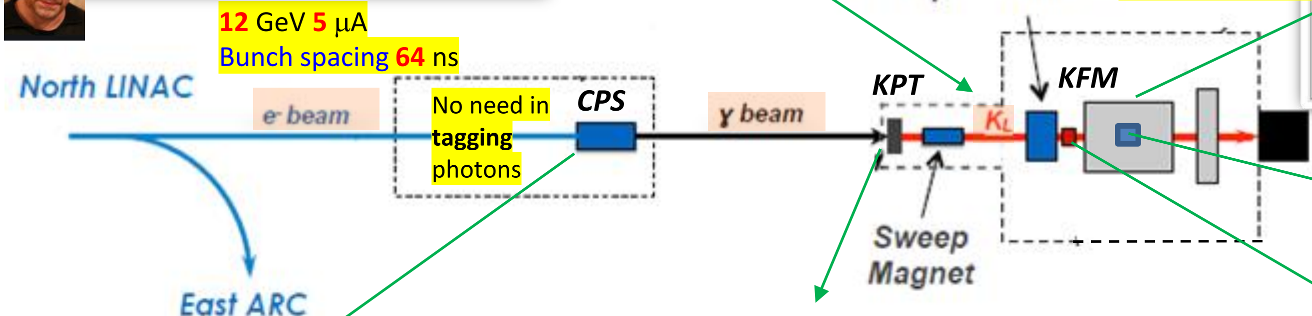
- Accelerator: 2.2 GeV/pass
- Halls A,B,C: e^- 1-5 passes $\leq$11 GeV
- Hall D: e^- 5.5 passes 12 GeV $\Rightarrow$ γ-beam ⇨ KL-beam
- Runs 2017-2018: 5.5 passes 11.7 GeV

Hall D Beam Line for KLF

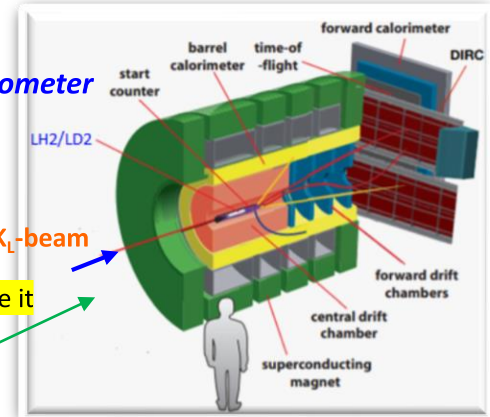
- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ/sec @ E > 1.5 GeV) are hitting Be-target located in collimator alcove.
- K_Ls (1×10^{4} K_L/sec) are hitting LH_2/LD_2 target within GlueX setting.



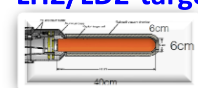
12 GeV 5 μA
Bunch spacing 64 ns

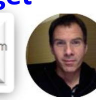


GlueX Spectrometer

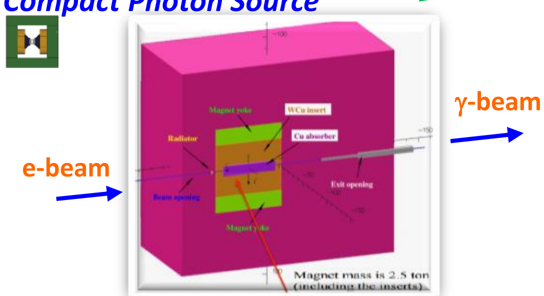


LH2/LD2-target

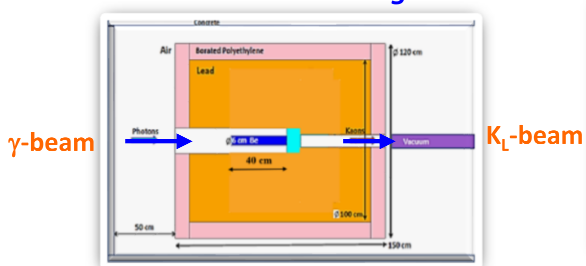




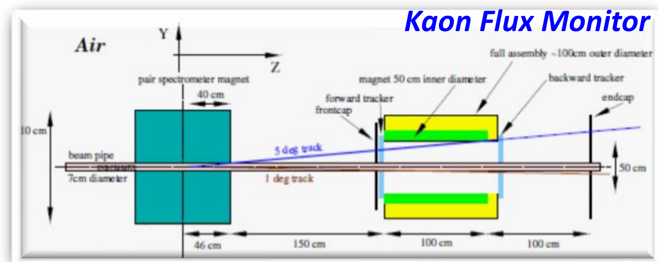
Compact Photon Source



Kaon Production Target

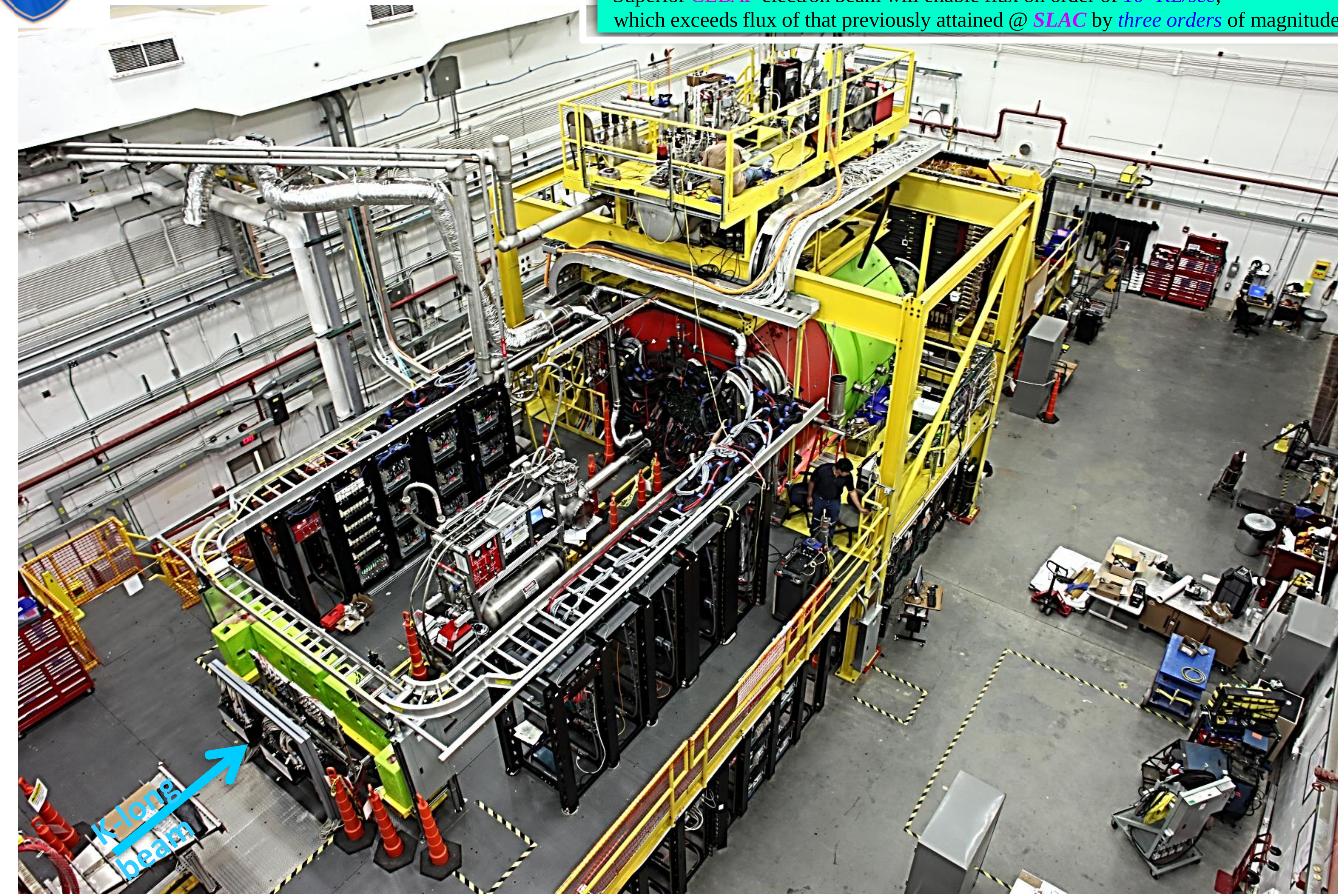


Kaon Flux Monitor



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.

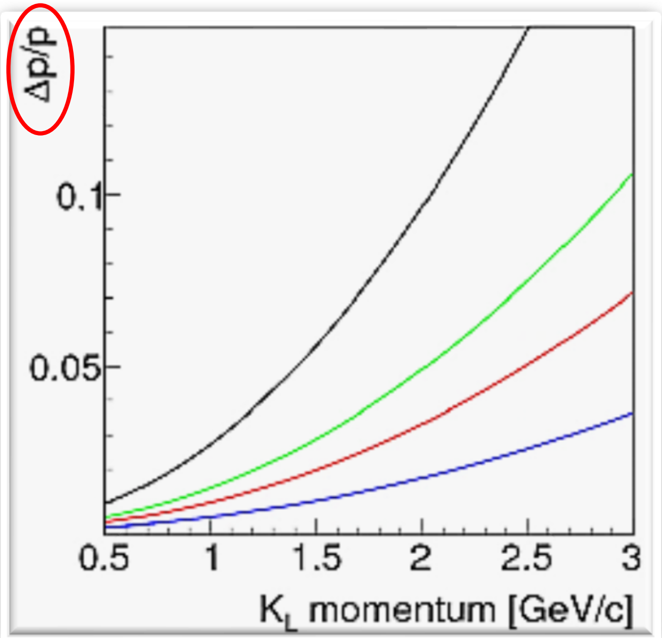


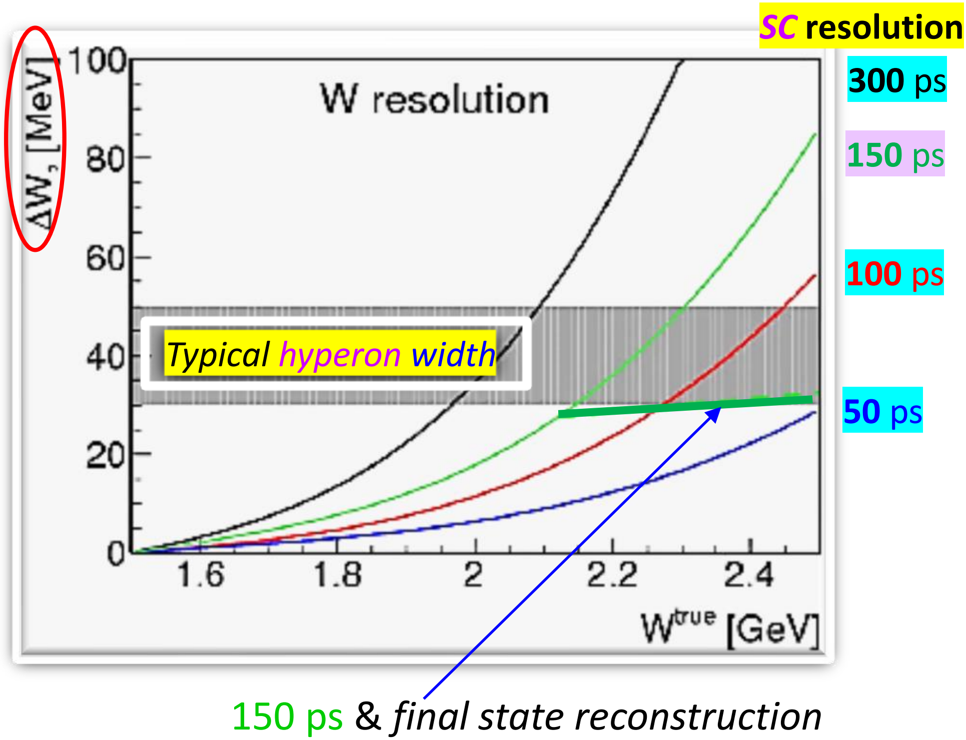
Expected Energy-Resolution

- 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.

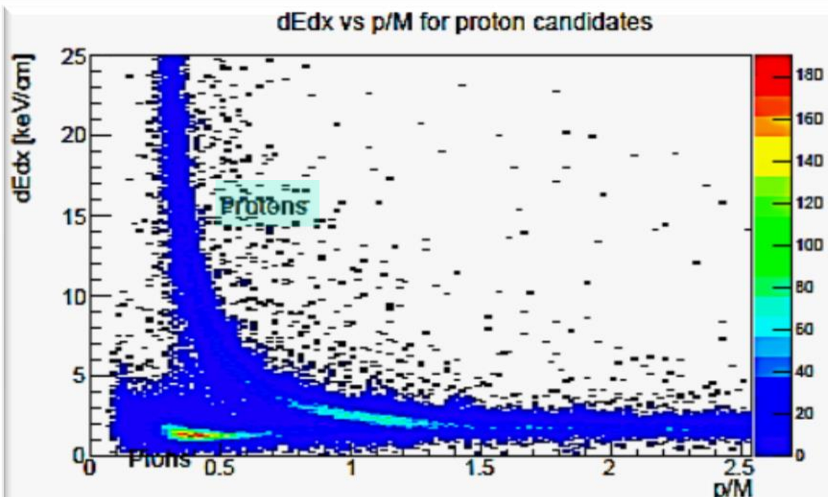
- Momentum measured with *TOF* between *SC* (surrounded LH_2/LD_2) & *RF* from *CEBAF*.

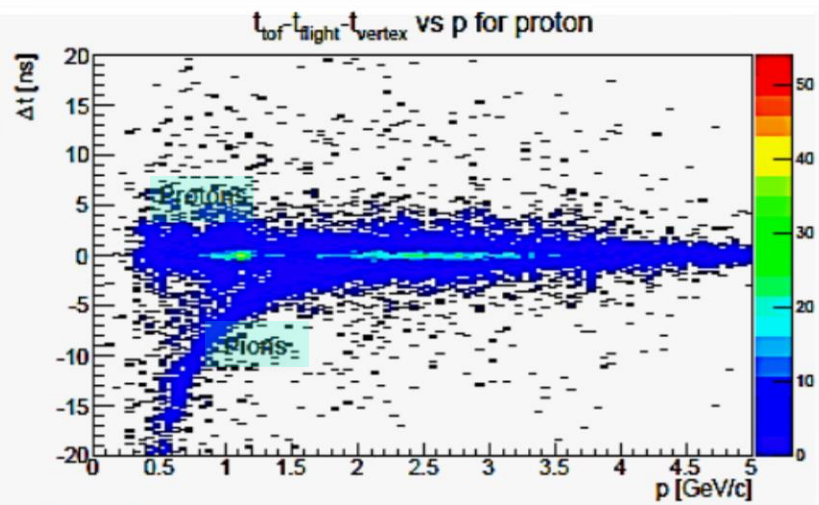




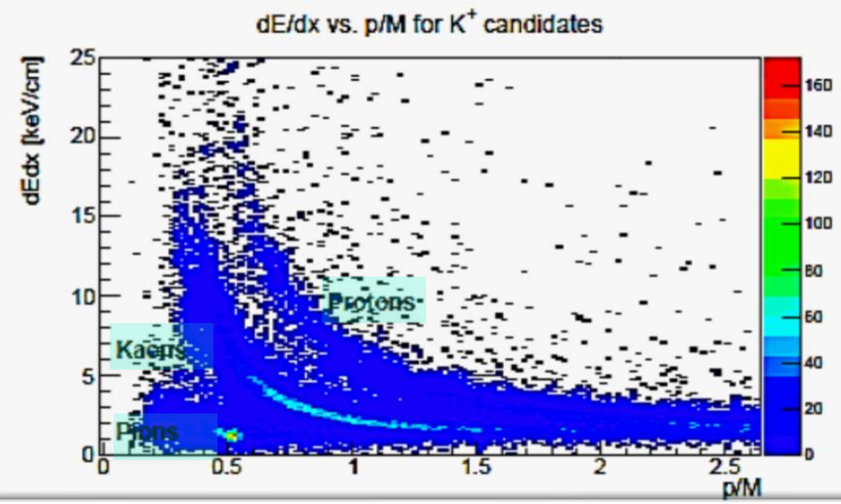
Expected Particle Identification with GlueX

- 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

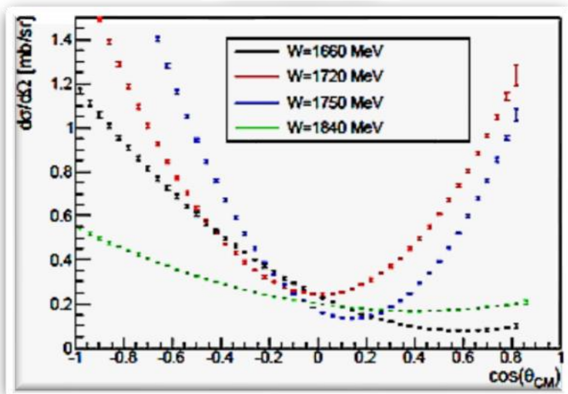
- KLF measurements will span $\cos\theta$ from -0.95 to 0.95 in CM above W = *1490* MeV.

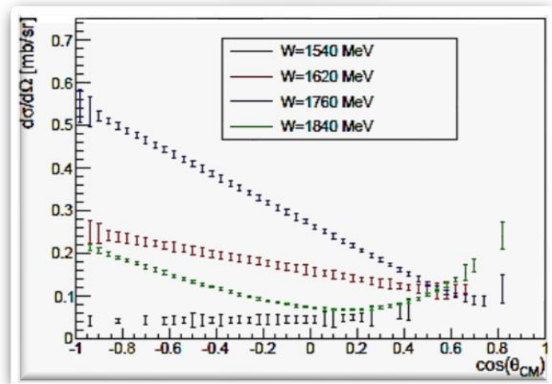
- K_L rate is 10^4 K_L/sec = *2500* x SLAC.
- Uncertainties (statistics only) correspond to *100 days* of running time for:

$K_L p \to K_S p$

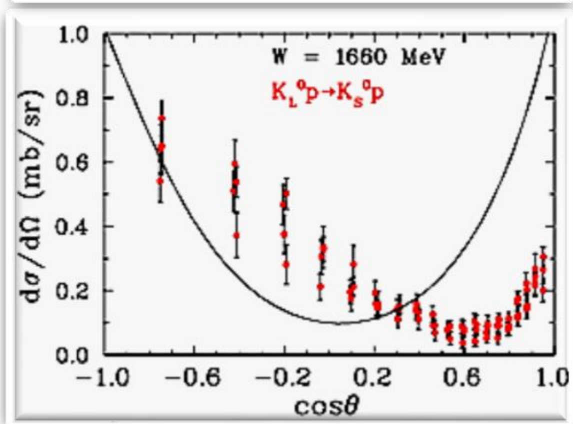
$K_L p \to \pi^+ \Lambda$

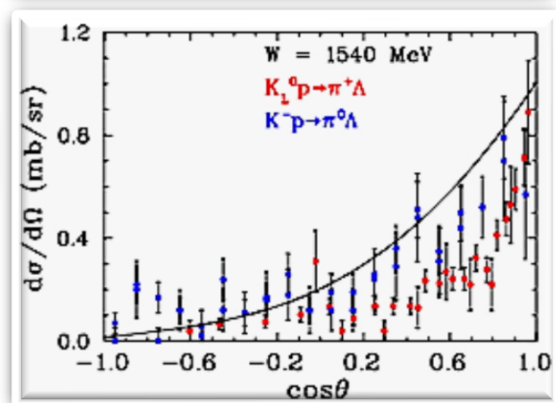
GEANT4





Expected KLF Data





BC Data

KLF Time Requested

Time Request

- 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)
$K_L p \to K_S p$	2.7M
$K_L p \to \pi^+ \Lambda$	7M
$K_L p \to K^+ \Xi^0$	2M
$K_L p \to K^+ n$	60M
$K_L p \to K^- \pi^+ p$	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.

KLF Collaboration Map

- **110** experimentalists &
- **42** theorists are co-authors.

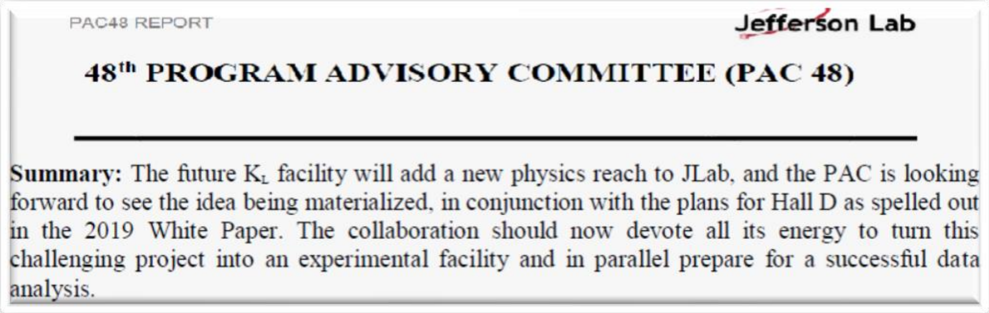
Summary

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

- Jefferson Lab Thomas Jefferson National Accelerator Facility *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.

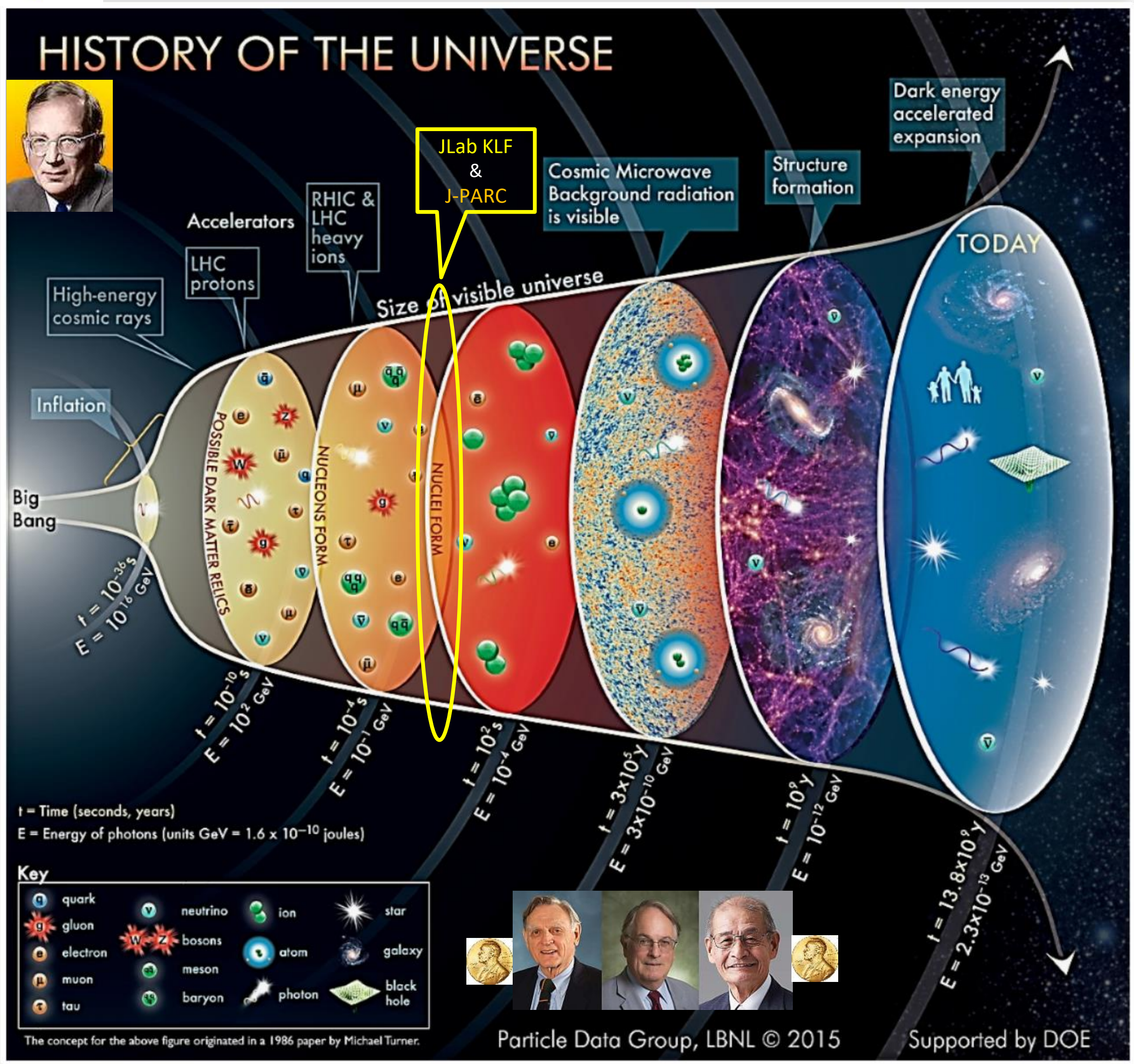

PAC48 REPORT Jefferson Lab

48th PROGRAM ADVISORY COMMITTEE (PAC 48)

Summary: The future K_L facility will add a new physics reach to JLab, and the PAC is looking forward to see the idea being materialized, in conjunction with the plans for Hall D as spelled out in the 2019 White Paper. The collaboration should now devote all its energy to turn this challenging project into an experimental facility and in parallel prepare for a successful data analysis.

Impact to Study Early Universe

History of the Universe



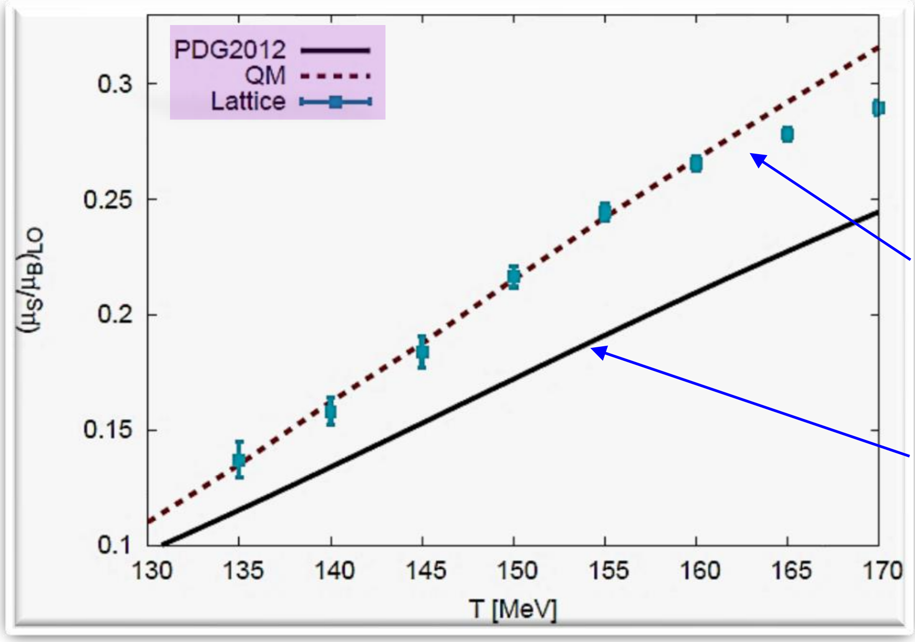
- Omission of any ``*missing hyperon states*" in *Standard Model* will negatively impact our understanding of *QCD freeze-out* in heavy-ion & hadron collisions, *hadron spectroscopy*, & *thermodynamics* of *early Universe*.
- For that reason, advancing our understanding of formation of *baryons* from *quarks* & *gluons* requires new experiments to search for any *missing hyperon* resonances.

Thermodynamics @ *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

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



- *Hyperons*
- Non-strange Baryons
- Mesons
- Nuclei

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

Courtesy of Claudia Ratti, YSTAR2016

Backup Slides

E12-12-19-001

Jefferson Lab
Thomas Jefferson National Accelerator Facility



Proposal for JLab PAC48

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

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

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