K-Long Beam Experiment at Jefferson Lab

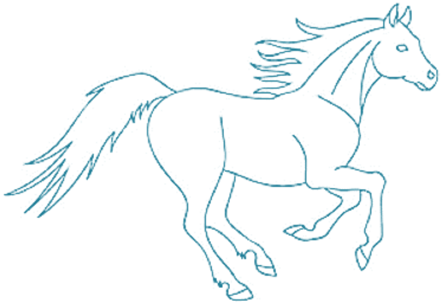
Igor Strakovsky*
The George Washington University
(for KLF Collaboration)

Unfortunately, On-line

arXiv:2008.08215 [nucl-ex]

* Supported by DE-SC0016583

Outline



- *Aims of KLF Project.*
- *KLF Experiment.*
- *Hyperon Spectroscopy.*
- *Strange Meson Spectroscopy.*
- *Impact to Study Early Universe.*
- *KLF Potential.*
- *A Bit of History.*
- *Summary.*

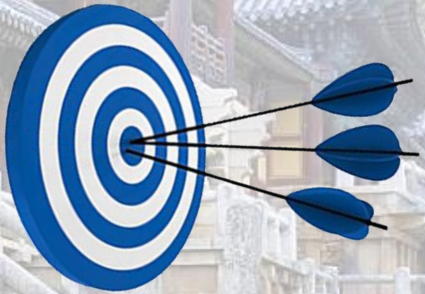
https://wiki.jlab.org/klproject/index.php/Main_Page

E12-12-19-001

Worldwide Interest in K-LONG FACILITY *Physics*

110 experimentalists &
42 theorists
from **68** labs
across **19** countries
worldwide

Aims of KLF Project



Highlights

- project has firmly to setup secondary K_L beam line @ Jefferson Lab,
  with *flux* of *three order of magnitude higher* than SLAC had,
  for scattering experiments on both *proton* & *neutron* (*first* time !) targets.

- *CEBAF* will remain ***prime facility*** for fixed target electron scattering @ luminosity ***frontier***.

- We will determine differential cross sections & self-polarization of *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^*.

- 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*.

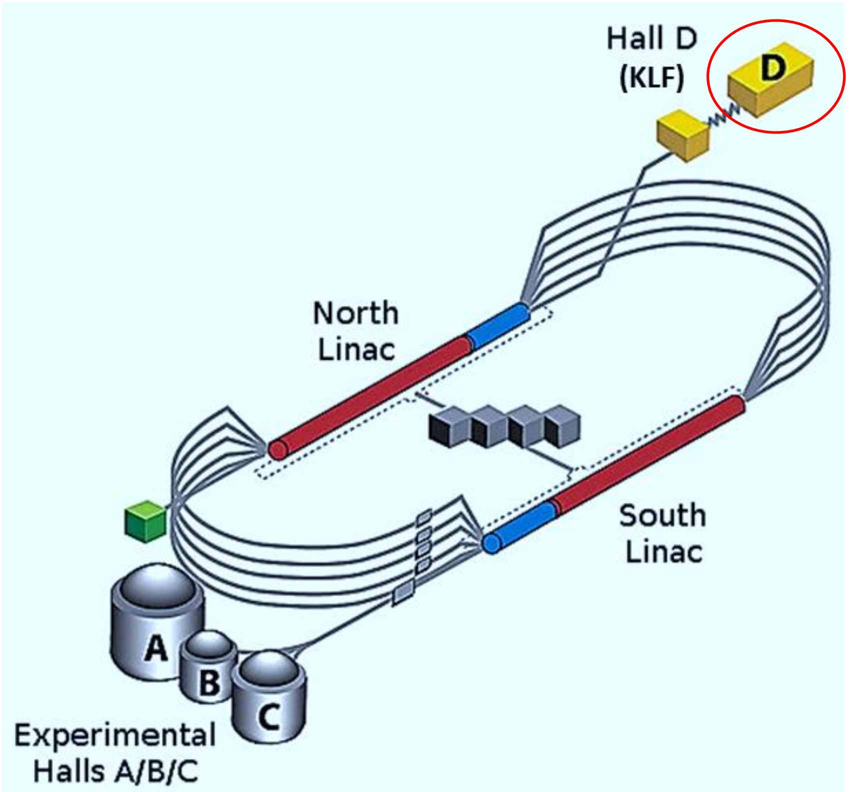
- We intend to do *strange meson spectroscopy* by studies of π-K interaction
  to locate *pole* positions in I = *1/2* & *3/2* channels.

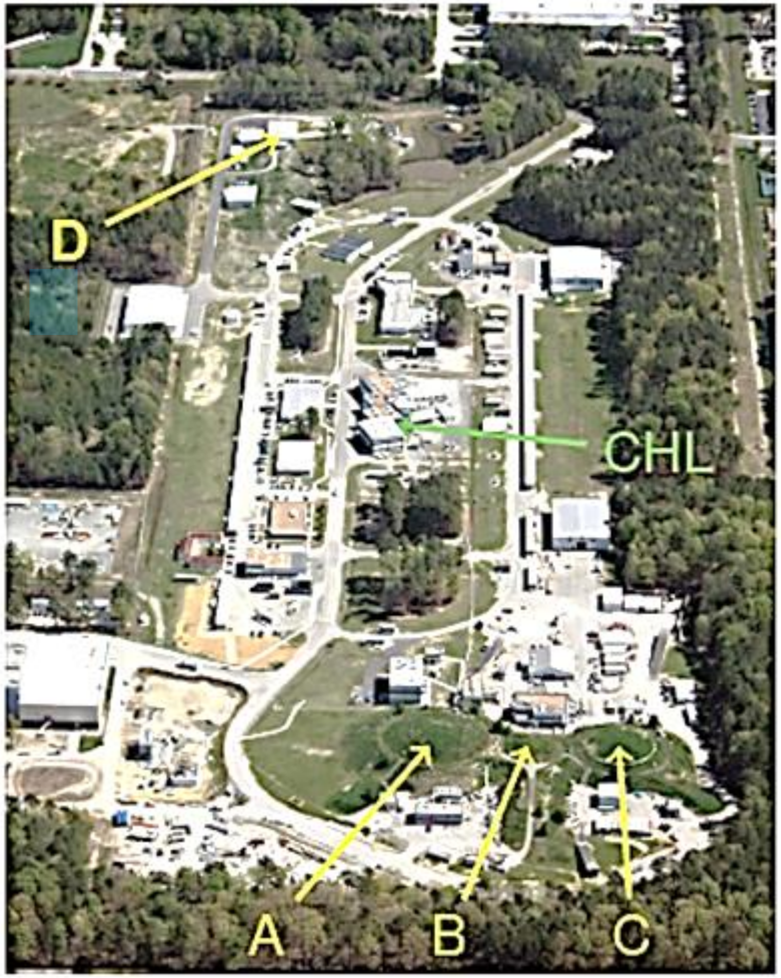
Questions to

- Why to use *kaon beam*? What is advantage compared to *electrons* or *photons*?
- What is so special about *K-long* compared to *charged kaon* beam?
- What is advantage of producing secondary kaon beam with *EM* probe, compared to *proton* beam?
- How much ***CEBAF*** accelerator could make breakthrough compared to previous results @ SLAC ?
- Why to do this *KLF* experiment, what are we going to learn?
- How will it affect our knowledge on *hyperon spectroscopy*?
- What are we going to learn about strange *meson spectroscopy*?
- Is this *KLF* experiment about "stamp collection" or what?
- There are many more *questions* - some constructive & some less so - answers to which shaped approved proposal.

Courtesy of Moskov Amaryan, JLUO2021

KLF Experiment





- 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 $\Longrightarrow$ KL-beam

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.
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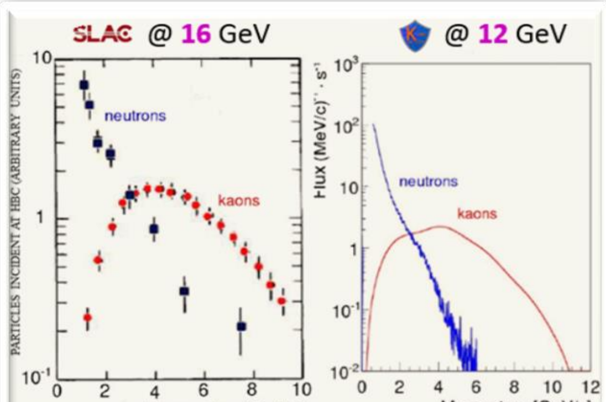
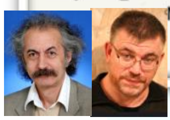
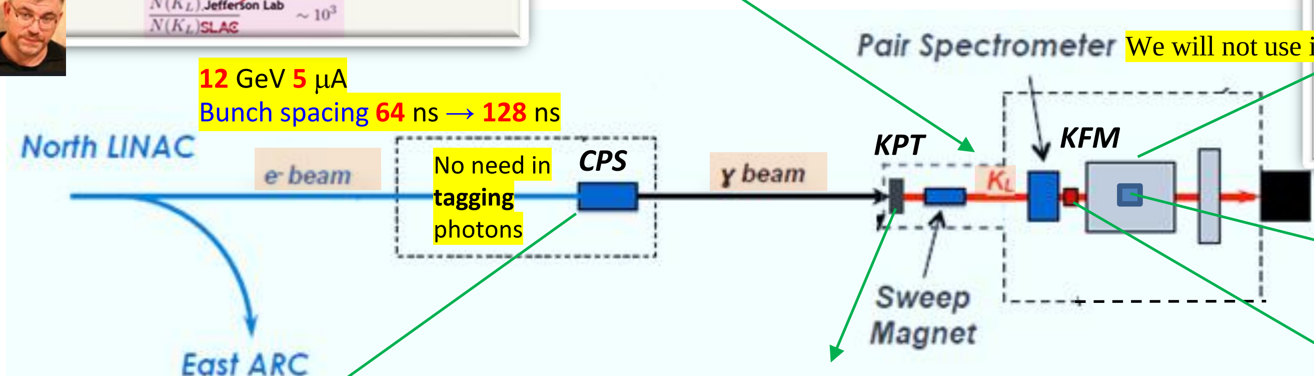
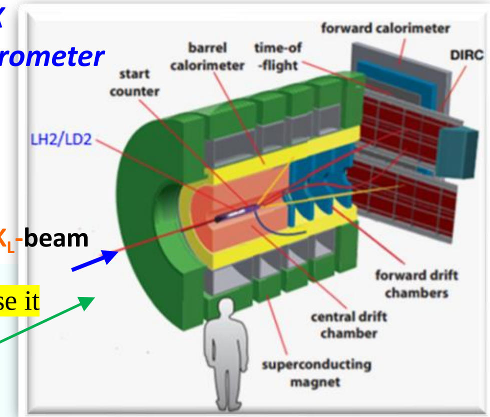


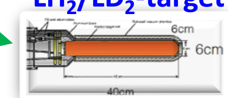




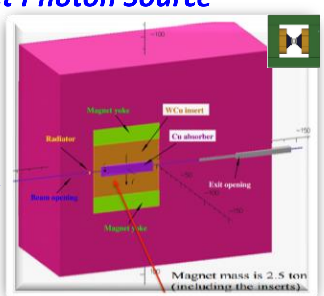
GlueX Spectrometer



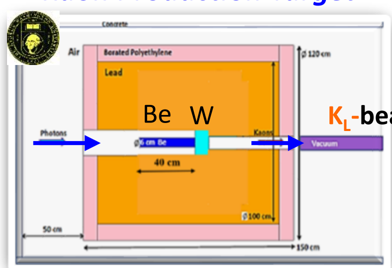
LH_2/LD_2-target



Compact Photon Source

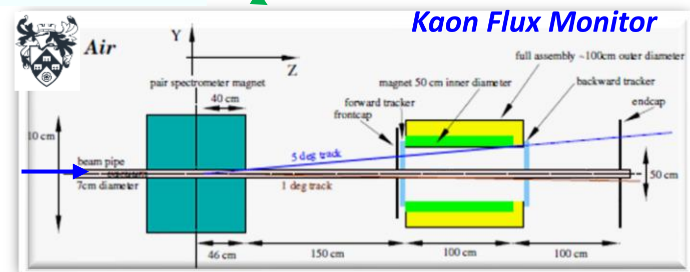


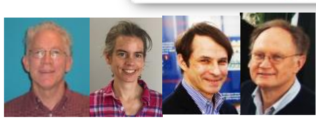
Kaon Production Target



IS *et al.* [arXiv:2002.04442 [physics.ins-det]]

Kaon Flux Monitor





D. Day *et al.* Nucl Instrum Meth A **957**, 163429 (2020)

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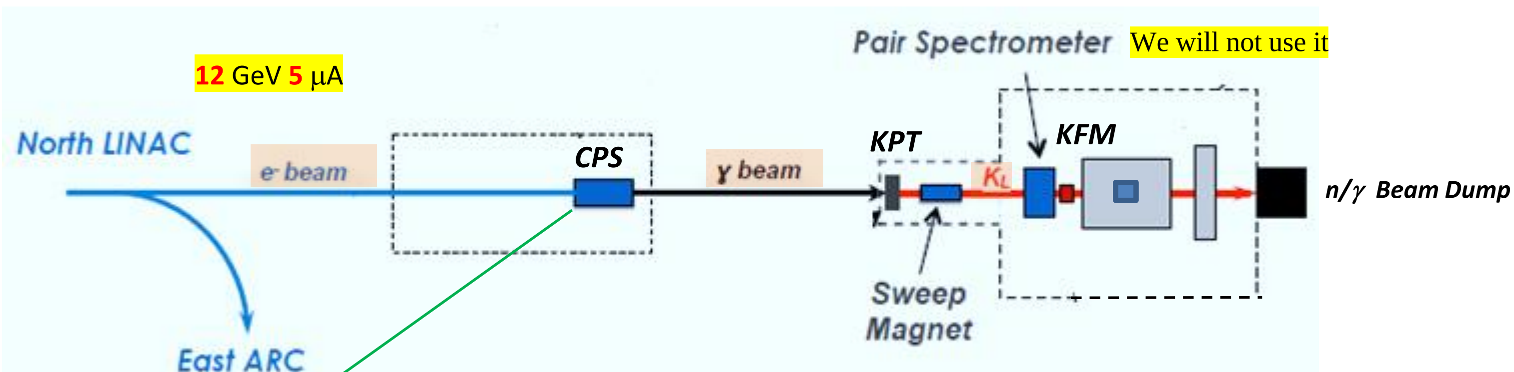
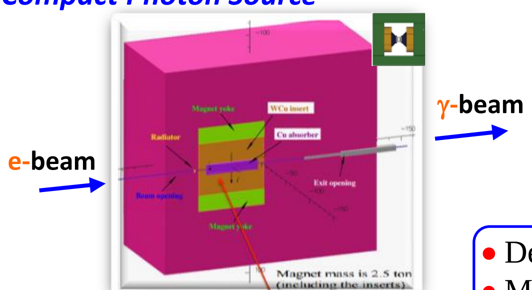
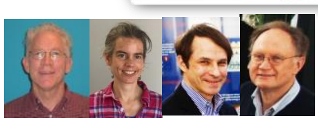


Compact Photon Source



- Details of *CPS* are designed by Collaboration.
- Meets Jefferson Lab *RadCon* Radiation Requirements.



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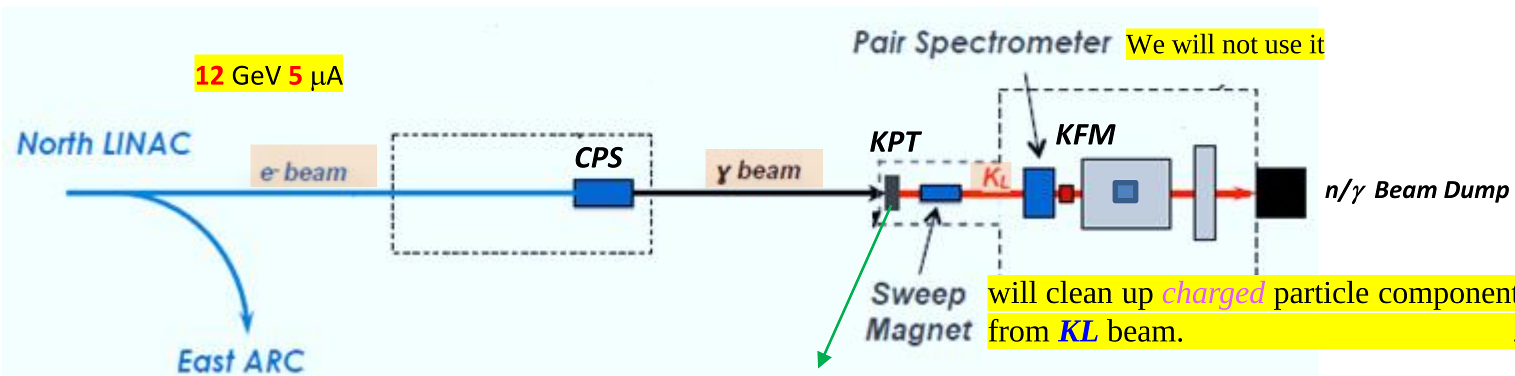

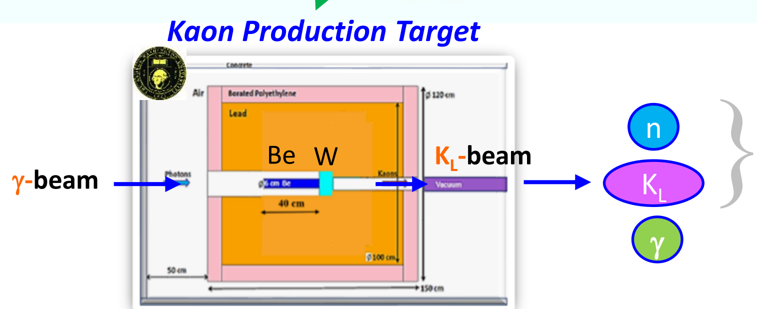

Ratio **n/KL**
- With ***proton*** beam **10^3 – 10^4**.
- With *photon* beam less than **10**.

- Meets Jefferson Lab *RadCon* Radiation Requirements.
- Conceptual Design Endorsed by Hall-D *Engineering Staff*.

IS *et al*. [arXiv:2002.04442 [physics.ins-det]]

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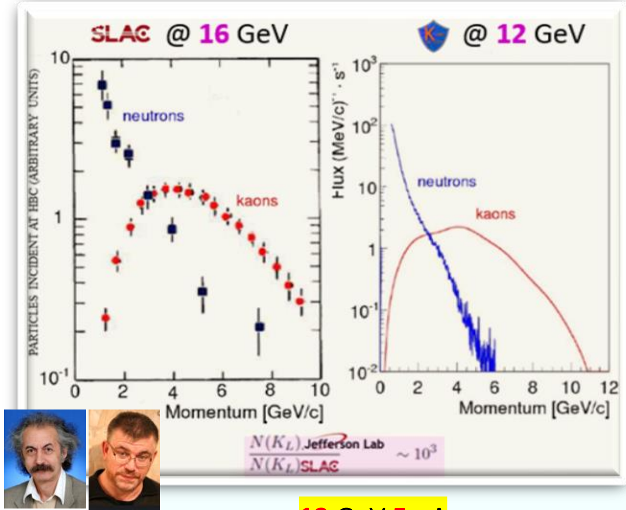
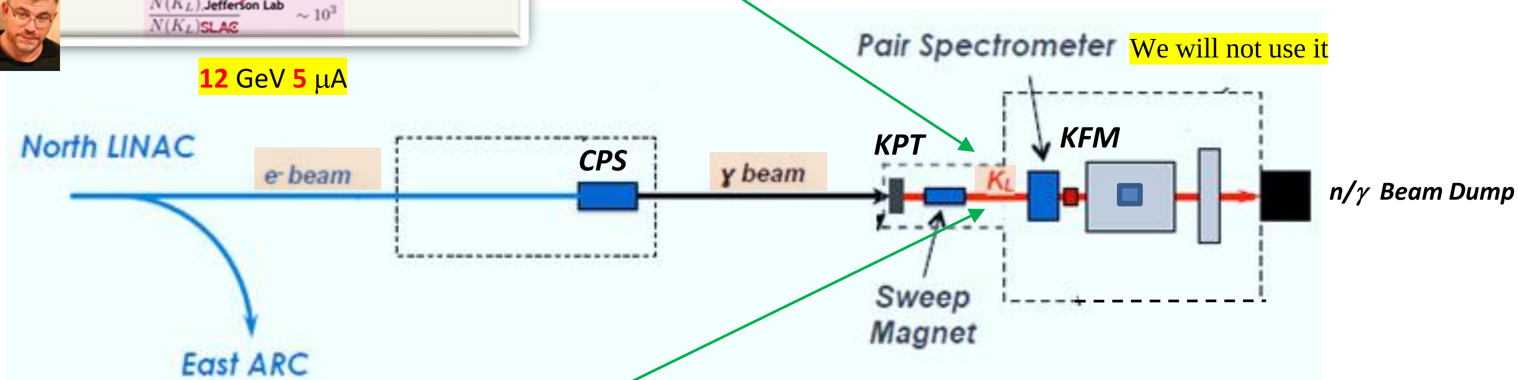
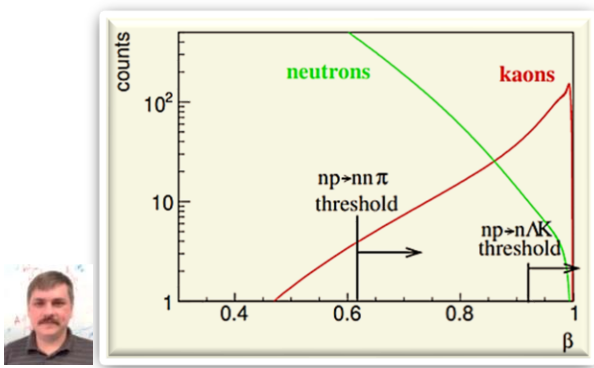
$$\frac{N(K_L)\ \text{Jefferson Lab}}{N(K_L)\ \text{SLAC}} = 10^3$$



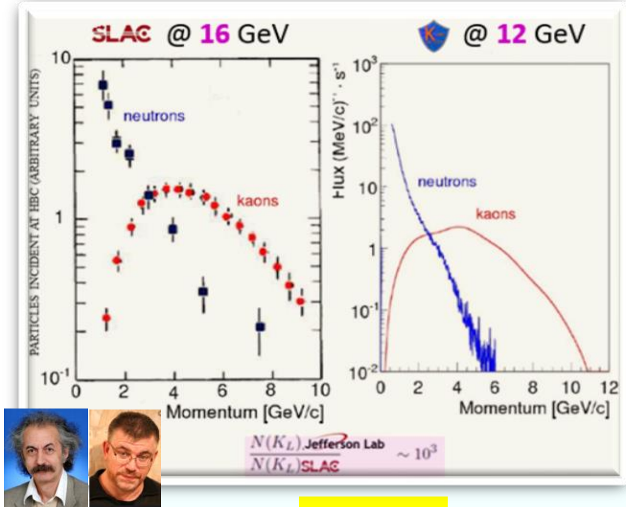
12 GeV 5 μA





- E_n > 1.6 GeV (strangeness threshold) ~1% of *neutron flux*.
- 0.3 < E_n < 1.6 GeV (above pion threshold) ~5% of *neutron flux*.
- E_n < 0.3 GeV ~ 94% of *neutron flux* – do not contribute.
- v_n << v_{KL}.

Hall D Beam Line for KLF



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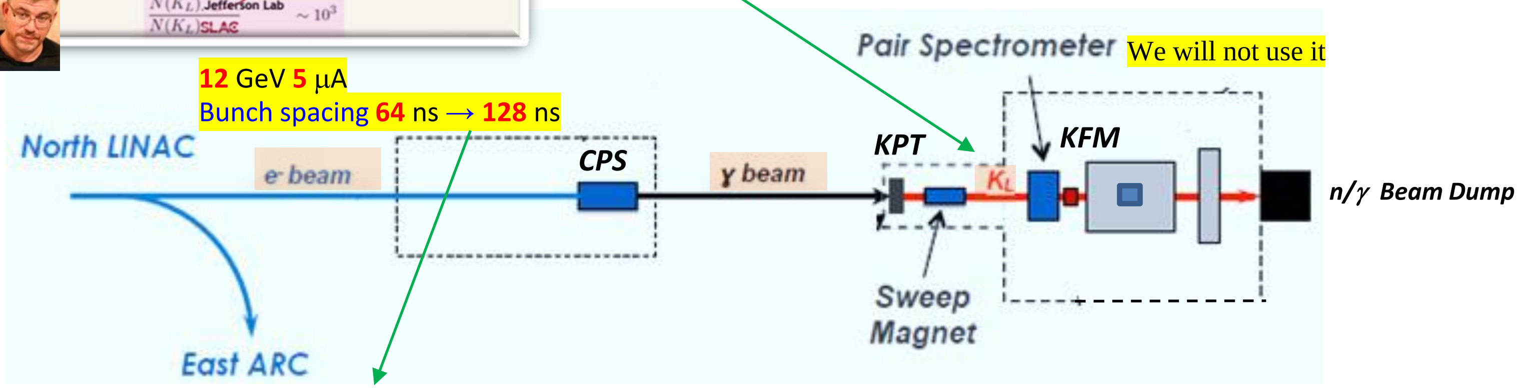
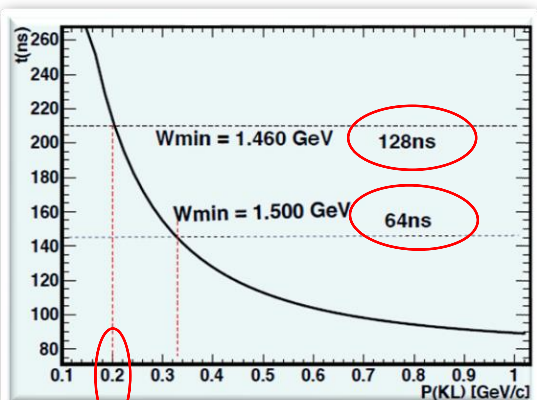
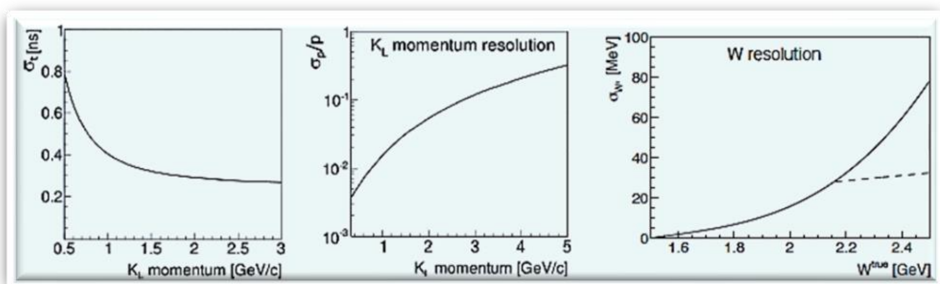
- K_Ls (1×10^4 K_L/sec) are hitting *LH_2/LD_2* target within *GlueX* setting.

- Mean lifetime of *KL* is 51.16 ns (**cτ** = **15.3** m) whereas.
- Mean lifetime of *K^-* is 12.38 ns (**cτ** = **3.7** m).
- For this reason, it is much easier to perform measurements of ***KLp*** scattering @ *low beam momenta* compared with ***Kp*** scattering.





- *Momentum* of KL beam will be measured using TOF time between accelerator bunch (*RF* signal from CEBAF) and reaction in *LH_2*/LD_2 target as detected by *GlueX* spectrometer.



Hall D Beam Line for KLF

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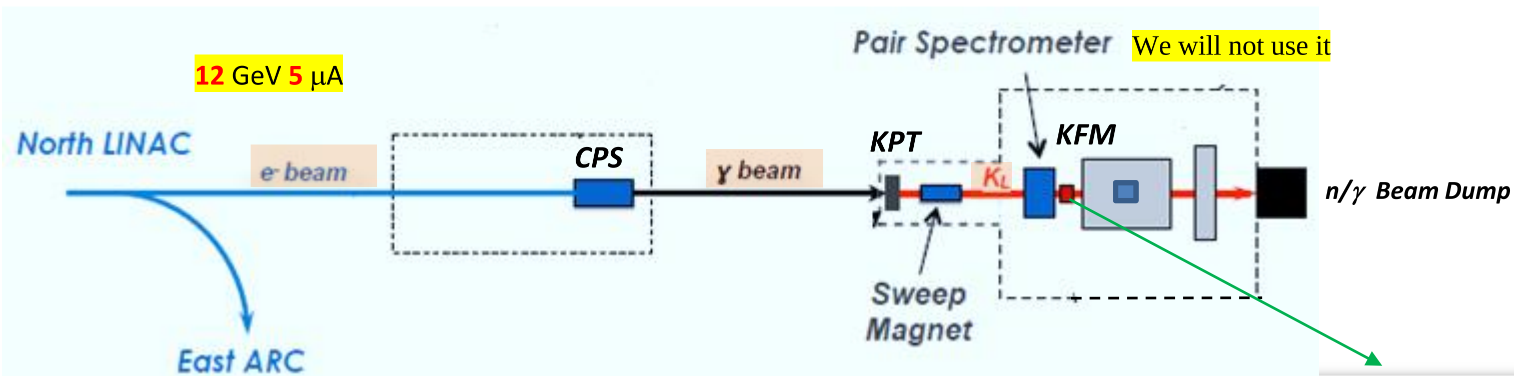
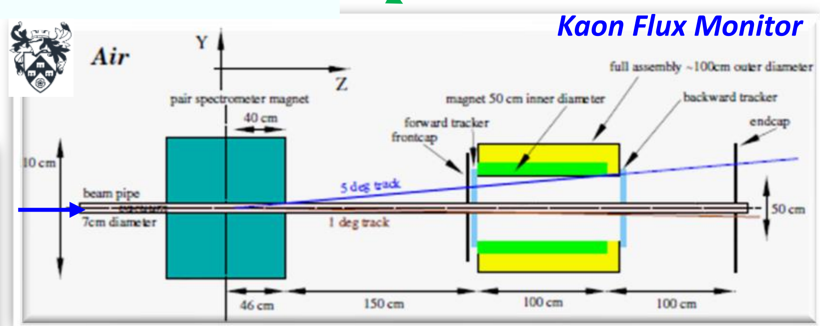
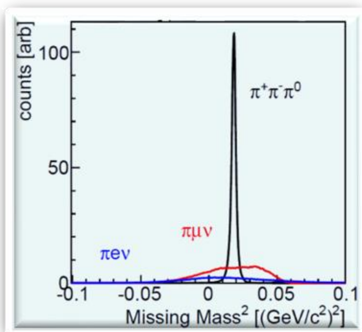




- Flux measurements:
  - Monitor designed by group.
  - Roughly 21% of ***kaon decay*** in flight.
  - Any decay with ***charged particles*** can be used.
  - Stat. err. <1%.
  - Syst. err. ~5%.

Reconstructed *KL* mass



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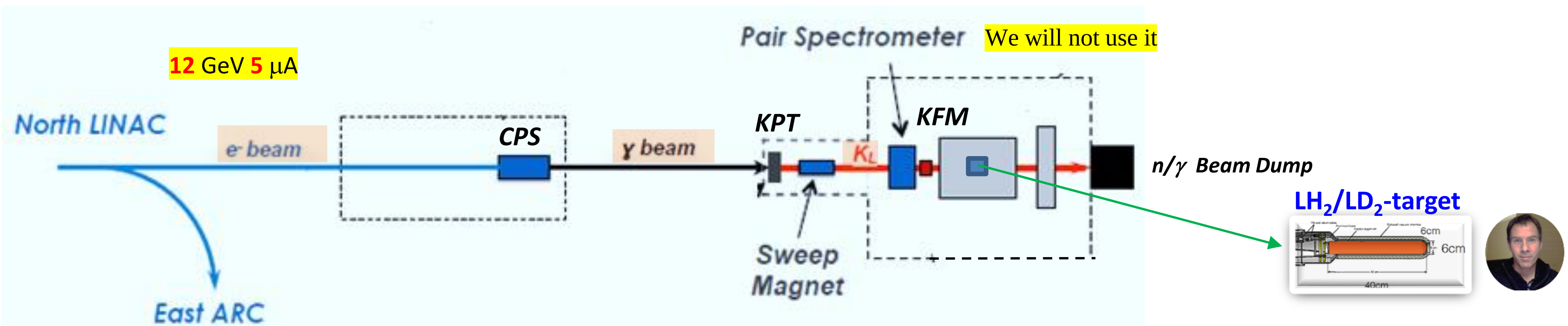

- Longer & ticker LH_2/LD_2 target is needed to enhance production rate.
- Details are designed by Jefferson Lab *Target Group*.

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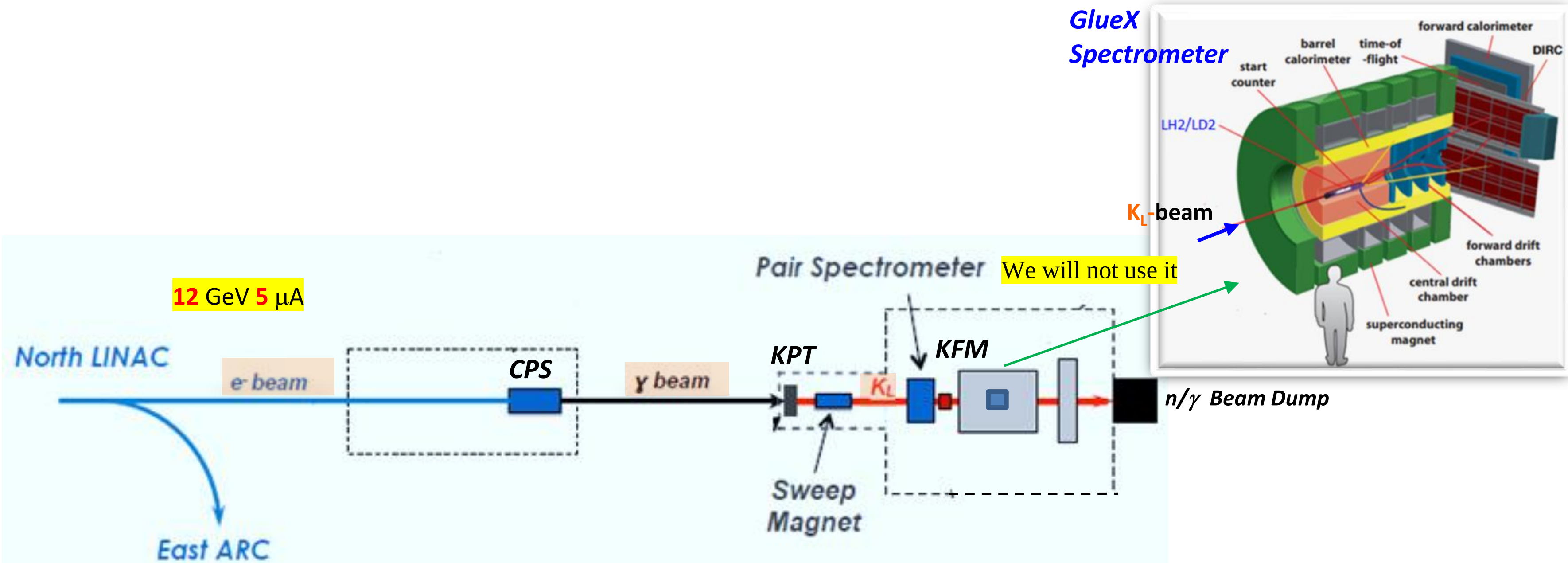
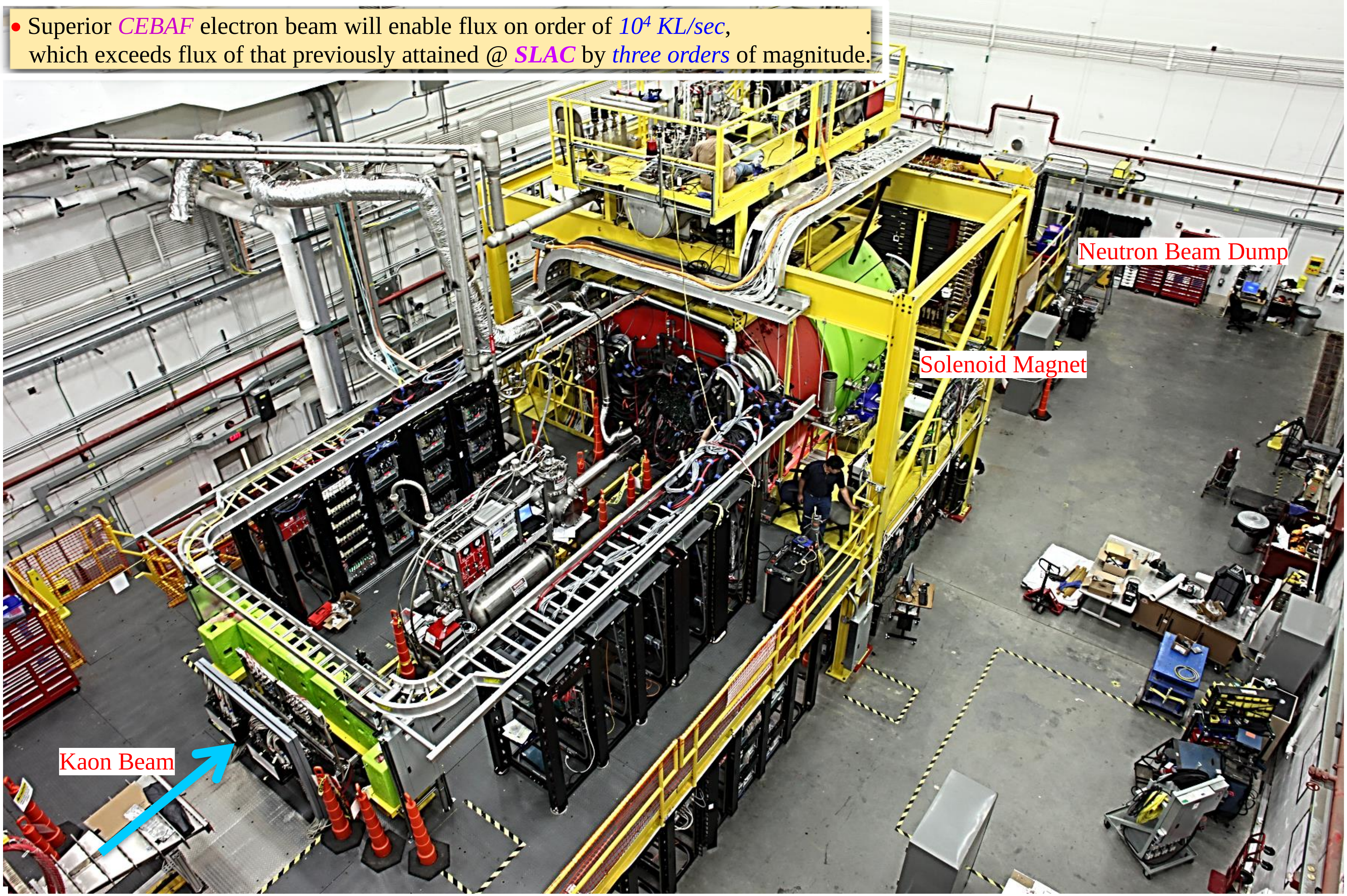


Hall D for KLF

S. Adhikari *et al*, Nucl Inst Meth **987**, 164807 (2021)

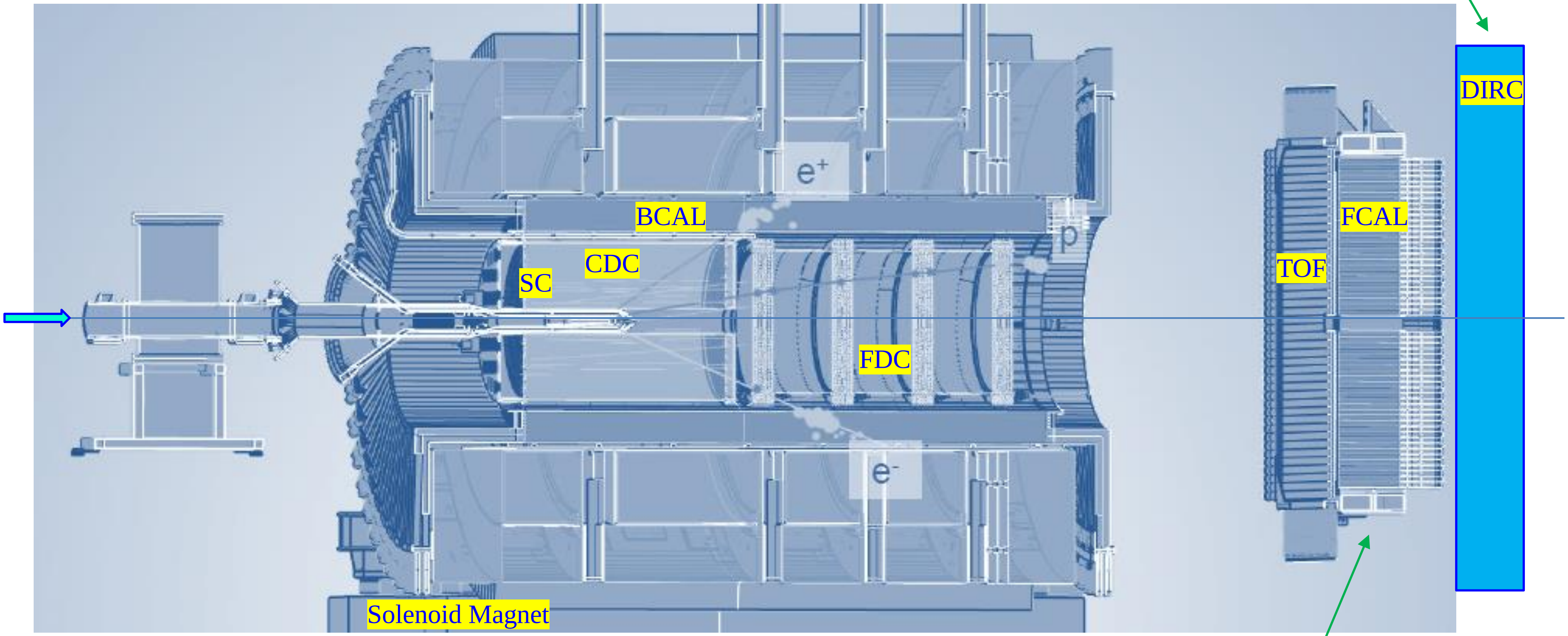
- Superior *CEBAF* electron beam will enable flux on order of *10^4 KL/sec*, which exceeds flux of that previously attained @ ***SLAC*** by *three orders* of magnitude.



GlueX Spectrometer for KLF

S. Adhikari *et al*, Nucl Inst Meth **987**, 164807 (2021)

• DIRC is new.
It came recently



• FCAL II is coming .
with $PbWO_4$ crystals

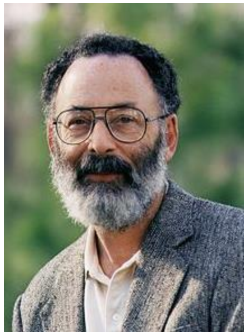
Hyperon Spectroscopy

It is clear that we still need much more information about the existence and parameters of many baryon states, especially in the N=2 mass region, before this question of non-minimal SU(6) x O(3) super-multiplet can be settled.

Dick Dalitz, **1976**

The first problem is the notion of a resonance is not well defined. The ideal case is a narrow resonance far away from the thresholds, superimposed on slowly varying background. It can be described by a Breit-Wigner formula and is characterized by a pole in the analytic continuation of the partial wave amplitude into the low half of energy plane.

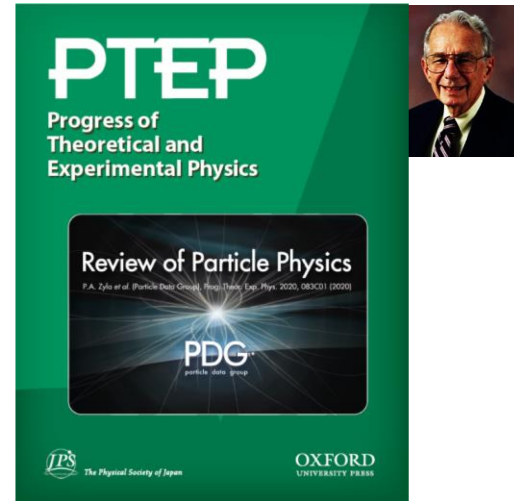
Gerhard Höhler, 1987



*Why N*s are important – The first is that nucleons are the stuff of which our world is made. My second reason is that they are simplest system in which the quintessentially non-Abelian character of QCD is manifest. The third reason is that history has taught us that, while relatively simple, Baryons are sufficiently complex to reveal physics hidden from us in the mesons.*

Nathan Isgur, **2000**

Baryon Sector @ PDG2021



GW Contribution P.A. Zyla *et al*, Prog Theor Exp Phys **2020**, 083C01 (2020)

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(18[illegible])	3/2−	**
N(1[illegible])	[illegible]	**
N([illegible])	[illegible]	**
N([illegible])	[illegible]	***
N([illegible])	7/[illegible]	**
N(2000)	5/2+	**
N(2040)	3/2+	*
N(2060)	5/2−	**
N(2100)	1/2+	*
N(2120)	3/2−	**
N(2190)	7/2−	****
N(2220)	9/2+	****
N(2250)	9/2−	****
N(2600)	11/2−	***
N(2700)	13/2+	**

Δ(1232)	3/2+	****
Δ(1600)	3/2+	***
Δ(1620)	1/2−	****
Δ(1700)	3/2−	****
Δ(1750)	1/2+	*
Δ(1900)	1/2−	**
Δ(1905)	5/2+	****
Δ(1910)	1/2+	[illegible]
Δ(1920)	3/[illegible]	[illegible]
Δ(1930)	[illegible]	[illegible]
Δ(1940)	3/2−	[illegible]
Δ(1950)	7/2+	[illegible]
Δ(20[illegible])	5/2+	[illegible]
Δ([illegible])	[illegible]	[illegible]
Δ(2200)	7/2−	*
Δ(2300)	9/2+	**
Δ(2350)	5/2−	*
Δ(2390)	7/2+	*
Δ(2400)	9/2−	**
Δ(2420)	11/2+	****
Δ(2750)	13/2−	**
Δ(2950)	15/2+	**

Λ	1/2+	****
Λ(1405)	1/2−	****
Λ(1520)	3/2−	****
Λ(1600)	1/2+	***
Λ(1670)	1/2−	****
Λ(1690)	3/2−	****
Λ(1800)	1/2−	***
Λ(1810)	1/[illegible]	***
Λ(1820)	[illegible]	[illegible]
Λ(1830)	5/2−	[illegible]
Λ(1890)	3/2+	[illegible]
Λ(200[illegible])		
Λ([illegible])	7/2+	
Λ(2100)	7/2−	****
Λ(2110)	5/2+	***
Λ(2325)	3/2−	*
Λ(2350)	9/2+	***
Λ(2585)		**

Σ+	1/2+	****
Σ0	1/2+	****
Σ−	1/2+	****
Σ(1385)	3/2+	****
Σ(1480)		*
Σ(1560)		**
Σ(1580)	3/2−	*
Σ(1620)	1/2−	**
Σ(1660)	1/2+	***
Σ(1670)	3/2−	****
Σ(1690)		**
Σ(1750)	[illegible]	[illegible]
Σ(1770)	[illegible]	*
Σ(1775)	[illegible]	****
Σ(1840)	[illegible]	*
Σ(1880)	1/2+	**
Σ(191[illegible])	5/2+	[illegible]
Σ([illegible])	[illegible]	***
Σ(2000)	1/2−	*
Σ(2030)	7/2+	****
Σ(2070)	5/2+	*
Σ(2080)	3/2+	**
Σ(2100)	7/2−	*
Σ(2250)		***
Σ(2455)		**
Σ(2620)		**
Σ(3000)		*
Σ(3170)		*

Ξ0	1/2+	****
Ξ−	1/2+	****
Ξ(153[illegible])	[illegible]	[illegible]
Ξ(162[illegible])		*
Ξ(1690)		***
Ξ(182[illegible])	[illegible]	***
Ξ(19[illegible])		***
Ξ(2030)	≥ 5/2?	[illegible]
[illegible]		*
Ξ(2250)		**
Ξ(2370)		**
Ξ(2500)		*
Ω−	3/2+	[illegible]
Ω([illegible])−		[illegible]
Ω([illegible])−		[illegible]
Ω([illegible])−		[illegible]

Λ_c^+	1/2+	****
$\Lambda_c(2595)^+$	1/2−	***
$\Lambda_c(2625)^+$	3/2−	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	5/2+	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	1/2+	****
$\Sigma_c(2520)$	3/2+	***
$\Sigma_c(2800)$		***
Ξ_c^+	1/2+	***
Ξ_c^0	1/2+	***
$\Xi_c^{\prime +}$	1/2+	***
$\Xi_c^{\prime 0}$	1/2+	***
$\Xi_c(2645)$	3/2+	***
$\Xi_c(2790)$	1/2−	***
$\Xi_c(2815)$	3/2−	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	1/2+	***
$\Omega_c(2770)^0$	3/2+	***
Ξ_{cc}^+		*
Λ_b^0	1/2+	***
Σ_b	1/2+	***
Σ_b^*	3/2+	***
Ξ_b^0, Ξ_b^-	1/2+	***
Ω_b^-	1/2+	***

- First *hyperon* was discovered in 1947.

G.D. Rochester & C.C. Butler, Nature **160**, 855 (1947)

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

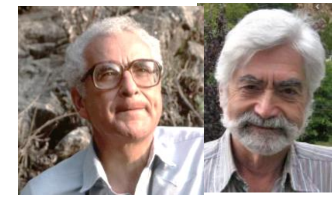
Jefferson Lab

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

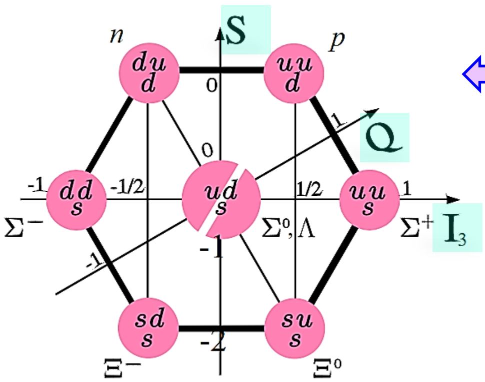
- **PDG2020** has **109 Baryon Resonances** (**58** of them are **4*** & **3***).
- In case of **SU(6) x O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

- LQCD results are similar.

Baryon Multiplets of Eight-fold Way

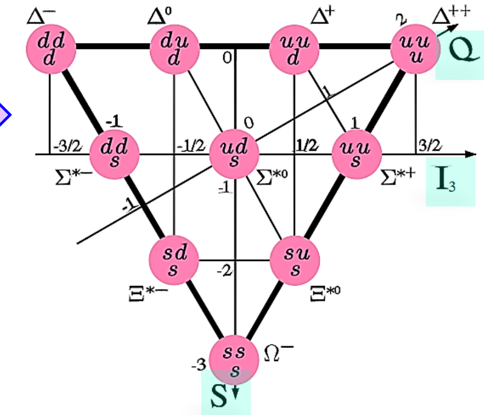


- **Three light quarks** can be arranged in 6 baryonic families, N^*, Δ^*, Λ^*, Σ^*, Ξ^*, & Ω^*.
- Number of members in family that can exist is not arbitrary.
- If $SU(3)_F$ symmetry of *QCD* is controlling, then:



Spin 1/2 baryon octet: N^*, $\boldsymbol{\Lambda}^*$, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$

Spin 3/2 baryon decuplet: Δ^*, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$, $\boldsymbol{\Omega}^*$



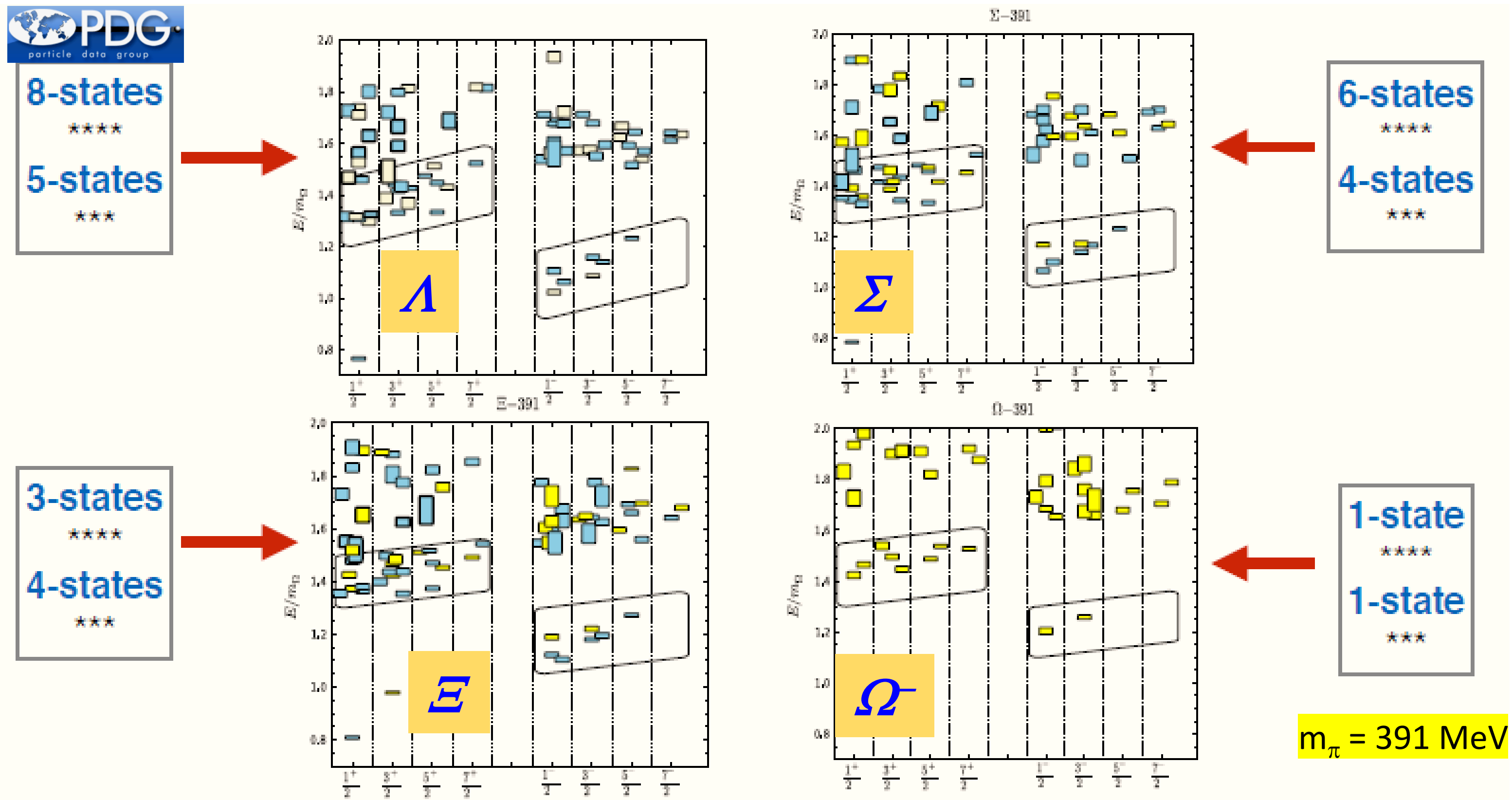
Resonance	LQCD	Observed
N^*	62	21
Δ^*	38	12
Λ^*	71	14
Σ^*	66	9
Ξ^*	73	6
Ω^*	36	2

R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013): $M < 2M_\Omega$

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

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

LQCD for Hyperon Spectroscopy



m_π = 391 MeV

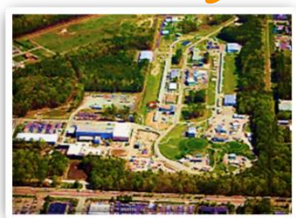
- According to ***LQCD***, there are should be more than 100 states including *hybrids* (thick bordered).

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

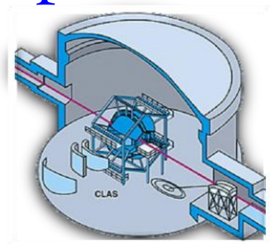
Road Map to Baryon Spectroscopy

- *That is not hunting for bumps*

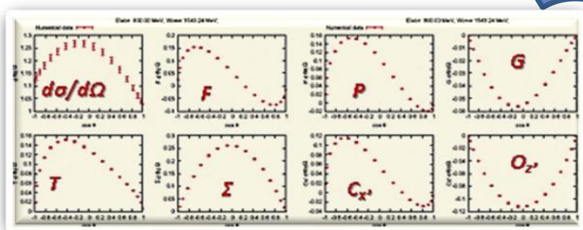
Facility



Experiment

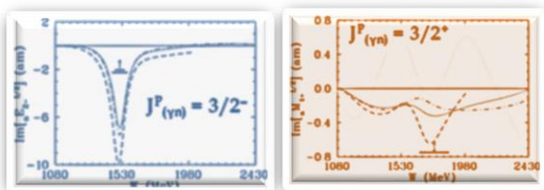


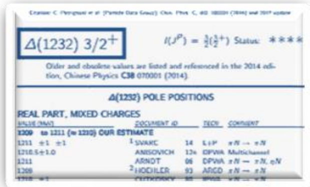
Data



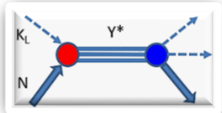
PWA

Amplitudes

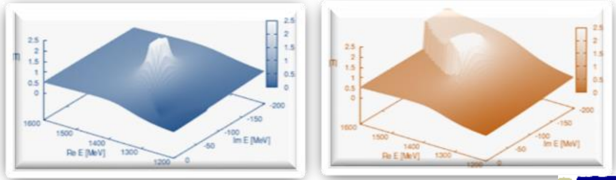



Δ(1232) 3/2+
Δ(1232) POLE POSITIONS
REAL PART, MIXED CHARGES

PWA



Resonances

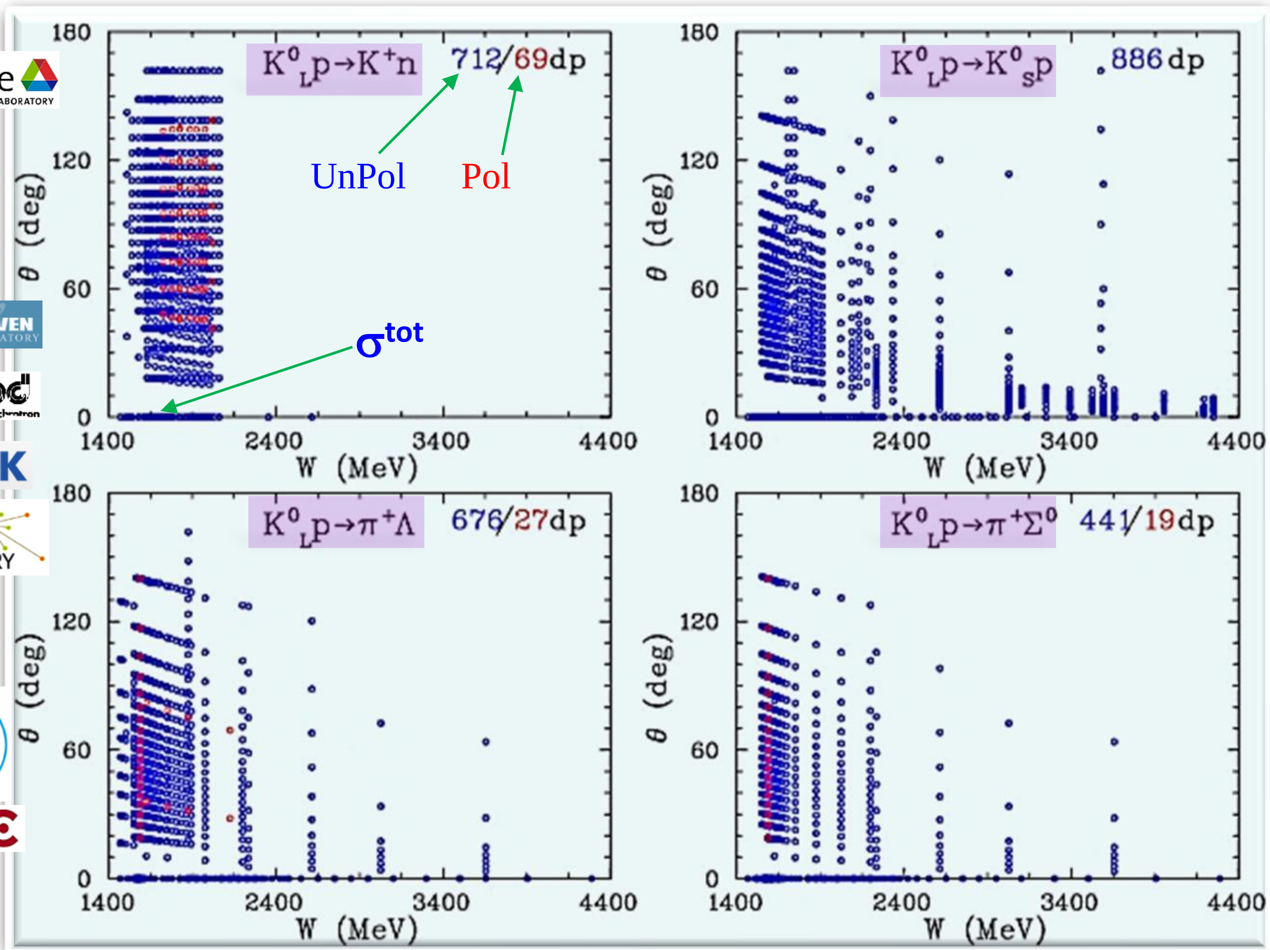


World K–long Data – Ground for Hyperon Phenomenology

W = 1.45 – 5.05 GeV

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

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



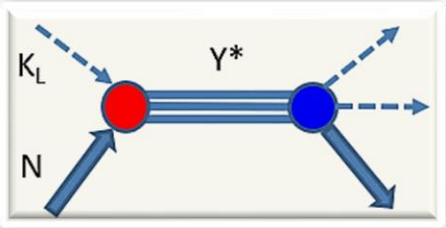
- Limited number of K_L observables in *hyperon spectroscopy* at present poorly constrain phenomenological analyses.
- *Overall systematics* of previous experiments varies between **15**% & **35**%. *Energy binning* is much broader than hyperon widths.
- There were **no** measurements using *polarized 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.

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



G. Hoehler, *Pion-Nucleon Scattering*, Landoldt-Boernstein Vol. **I/9b2**, edited by H. Schopper (Springer, 1983)

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

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

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

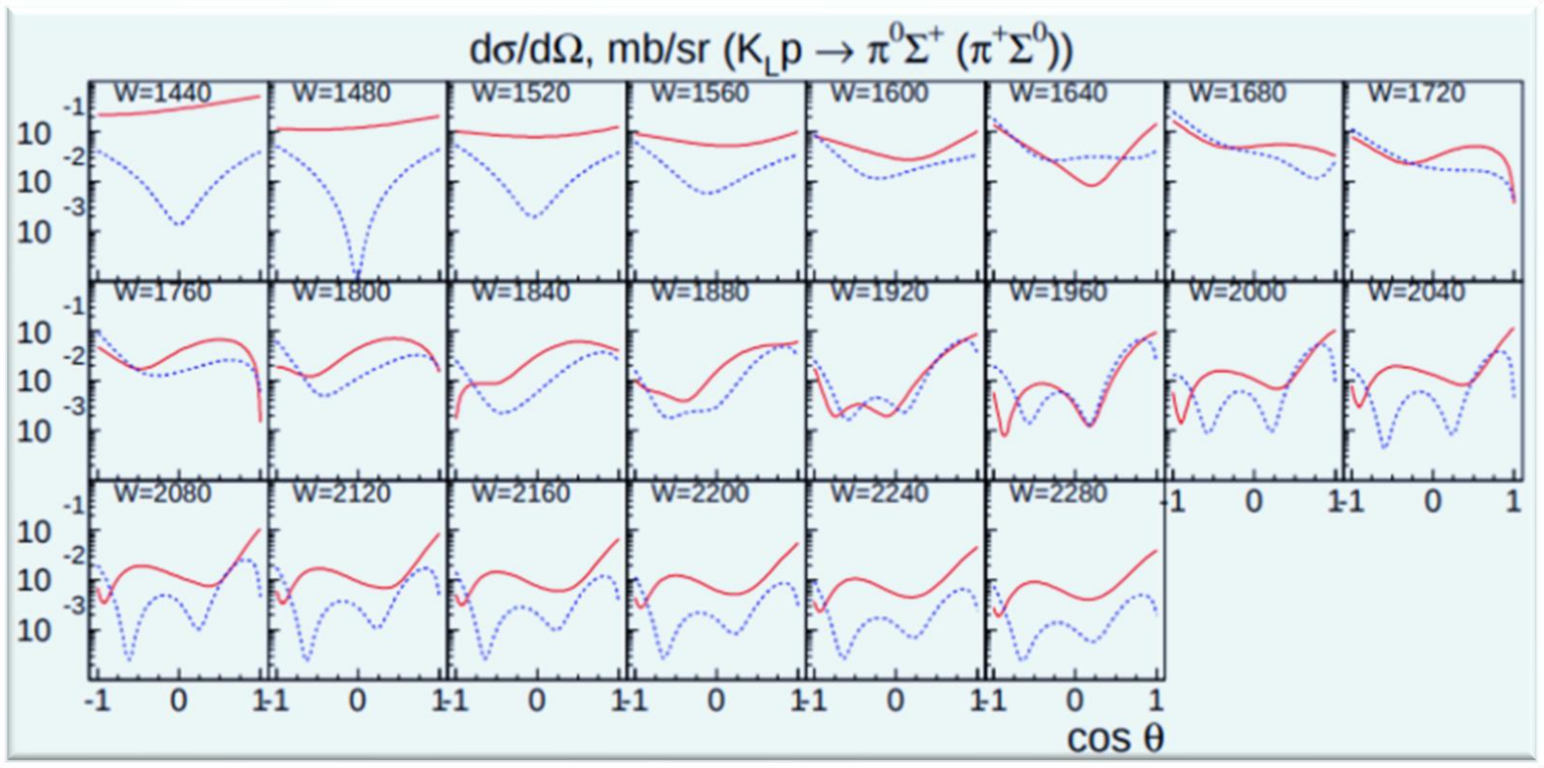
$\lambda\!\!\!^{-} = \hbar/k$ & k is momentum of incoming kaon in CM.

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

New Findings: $\pi\Lambda/\pi\Sigma$

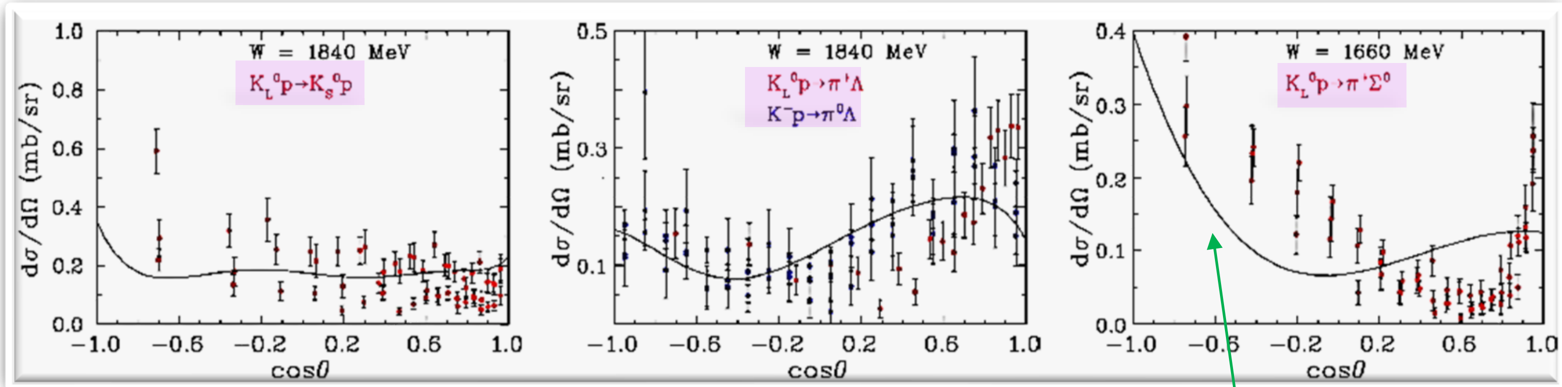
- Isospin Amplitudes

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

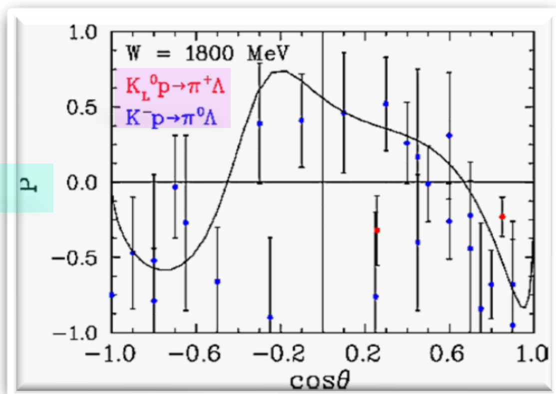


Courtesy of Mikhail Bashkanov & Andrey Sarantsev, 2019

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)

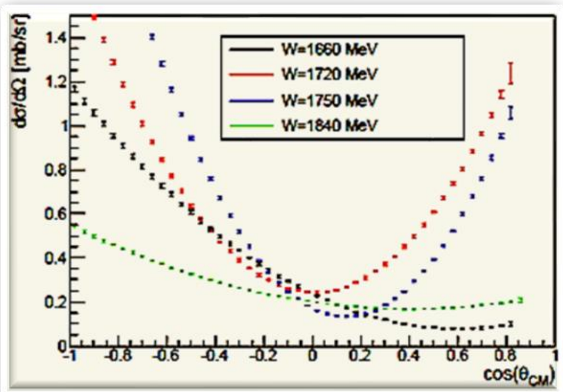
Expected Cross Sections vs Bubble Chamber Data

• KLF measurements will span $\cos\theta$ from -0.95 to 0.85 in CM above W = 1490 MeV.

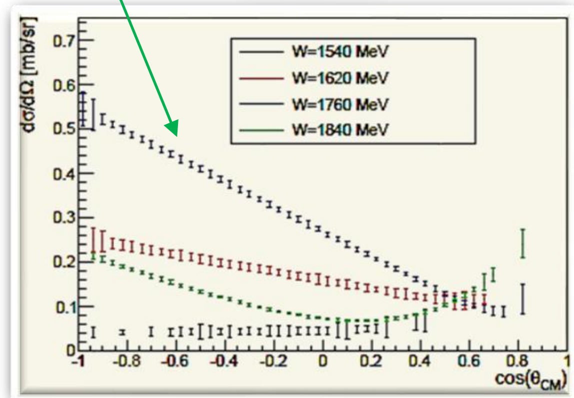
• Uncertainties (statistics only) correspond to *100* days of running time for:

$K_Lp \to K_Sp$

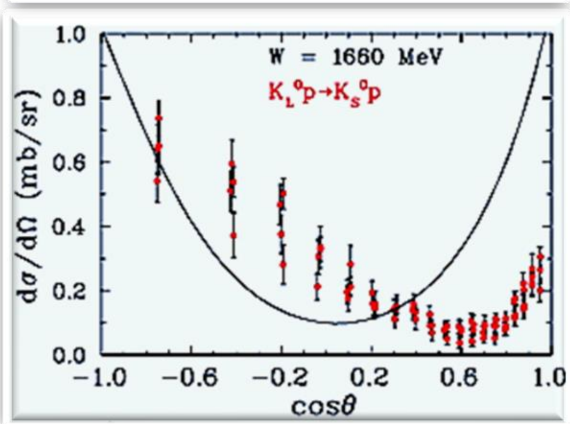
GEANT4



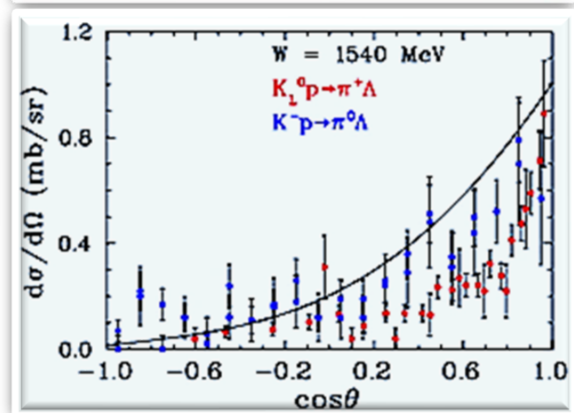
$K_Lp \to \pi^+\Lambda$



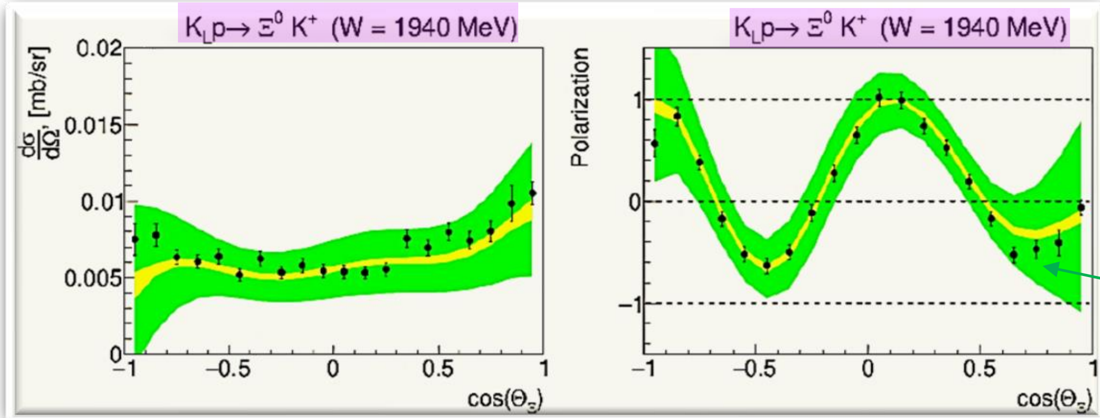
Expected KLF Data

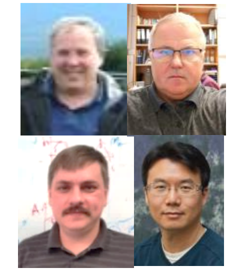


BC Data



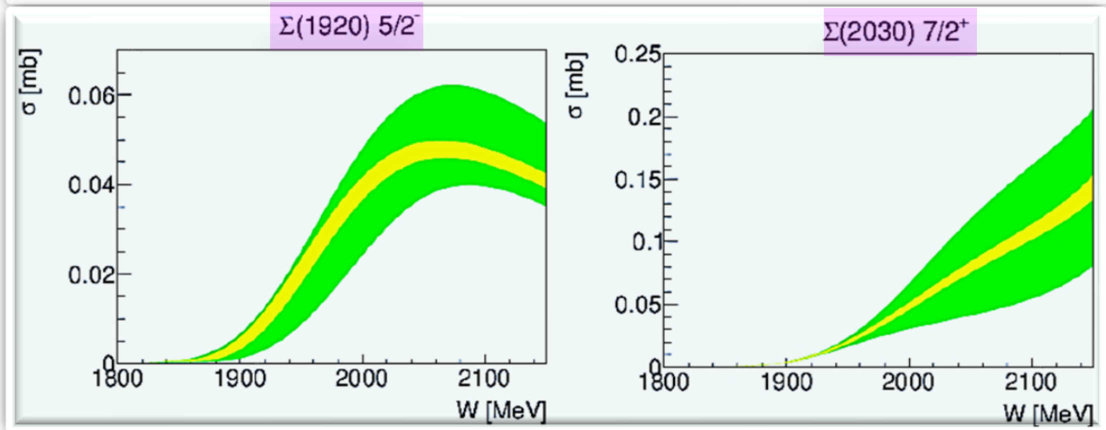
Impact Proposed Data using PWA





Quasi-data using GlueX detector properties

GEANT4



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

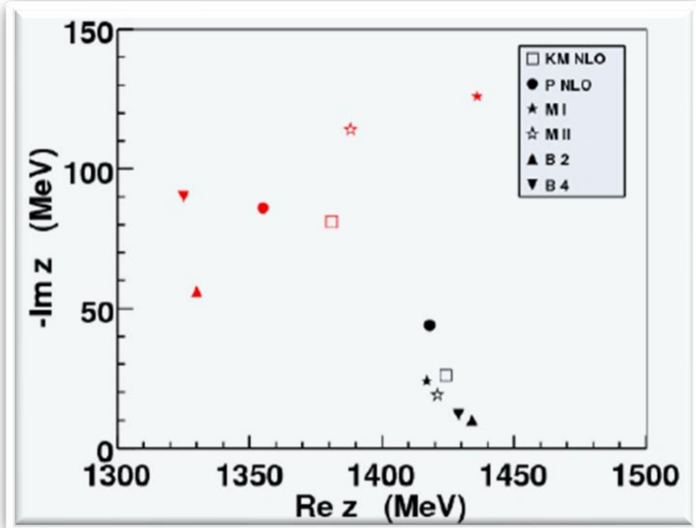
100 days

20 days

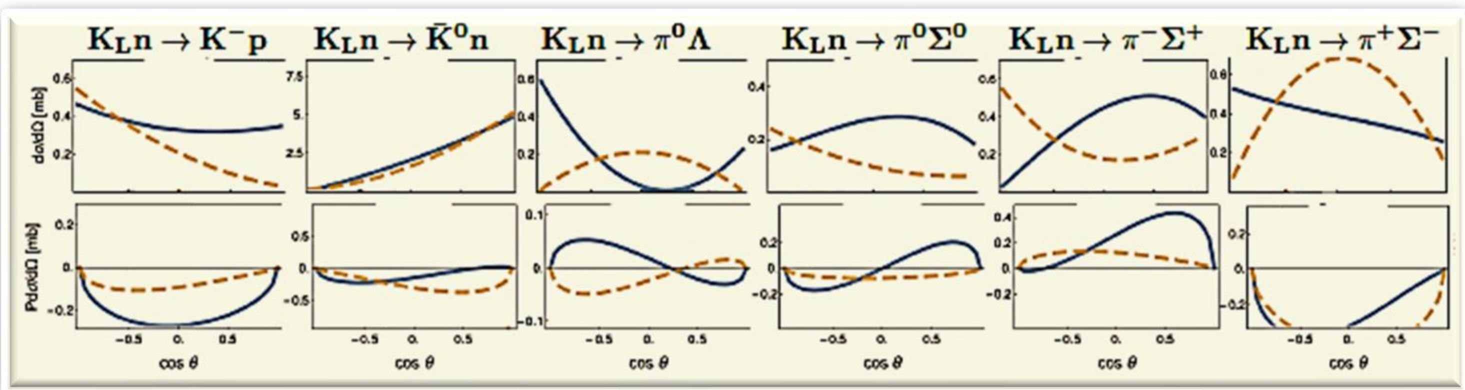
R.G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

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

Theory for "Neutron" Target Measurements



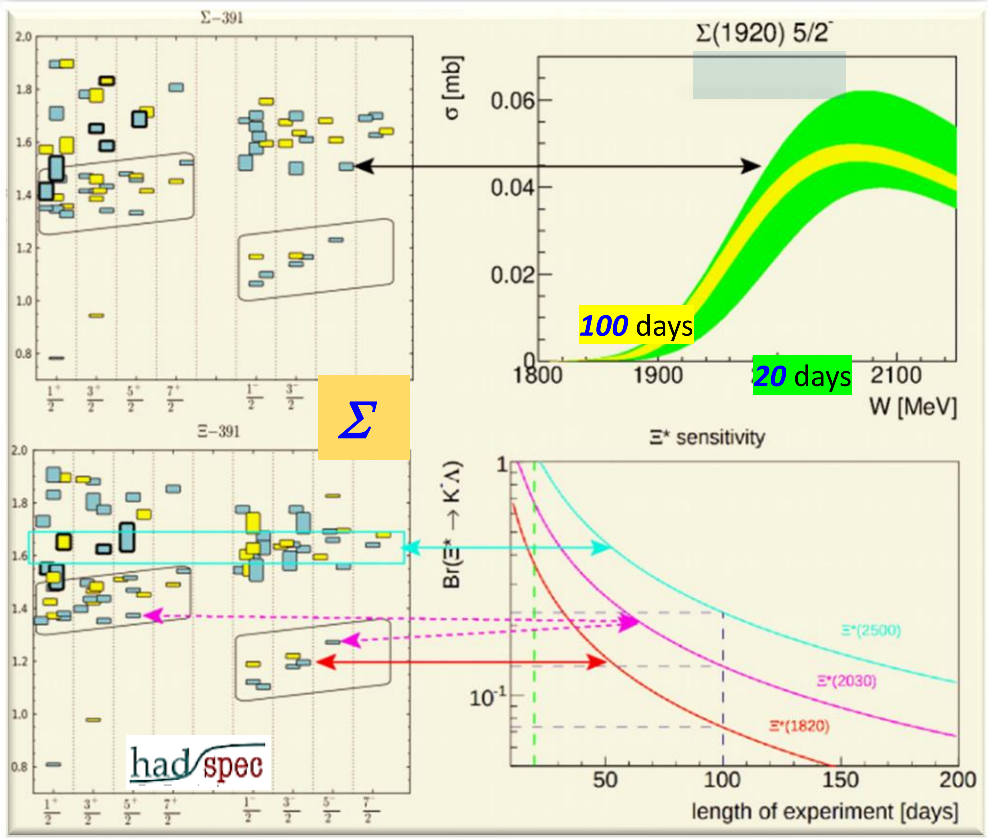
- There are **6** different models.
- *Pole* positions of $\Lambda(1405)$ in chiral unitary approaches.
- Each symbol represents position of 1st (**black**) & 2nd (**red**) pole in each model.



- P_{KL} = 300 MeV/c

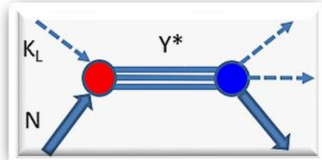
Courtesy of Maxim Mai, 2019

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* @ once (``*tagged*'' *kaons*) .



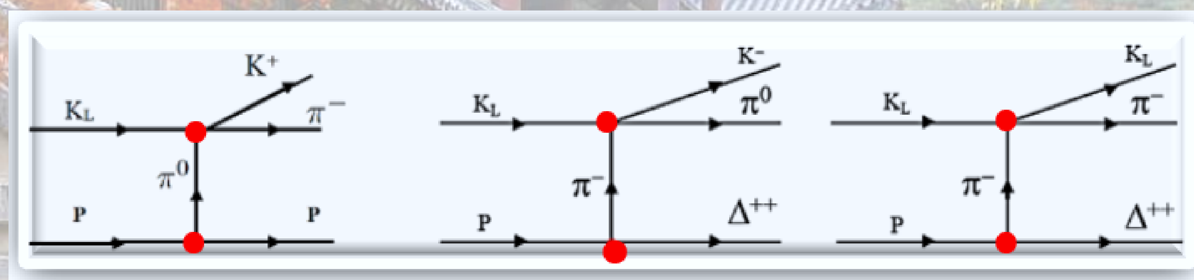
- ***Why should it be done*** @ Jefferson Lab ? Because nowhere else in existing facilities this can be done.

- ***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.

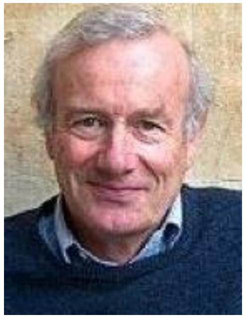
2015 Long Range Plan for Nuclear Science

Strange Meson Spectroscopy



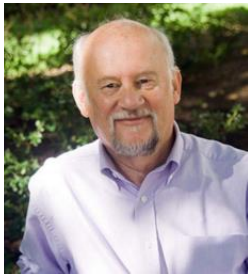
The di-quark or meson-baryon puzzle: Why is the quark-quark interaction just enough weaker than the quark-anti-quark interaction so that di-quarks near the meson mass are not observed, but three-quark systems have masses comparable to those of mesons?

Harry Lipkin, **1973**



For the region below 1 GeV, the debate centers on whether the phenomena are truly resonant or driven by attractive t-channel exchanges, and if the former, whether they are molecules or qq–anti-q-anti-q.

Frank Close, **2007**



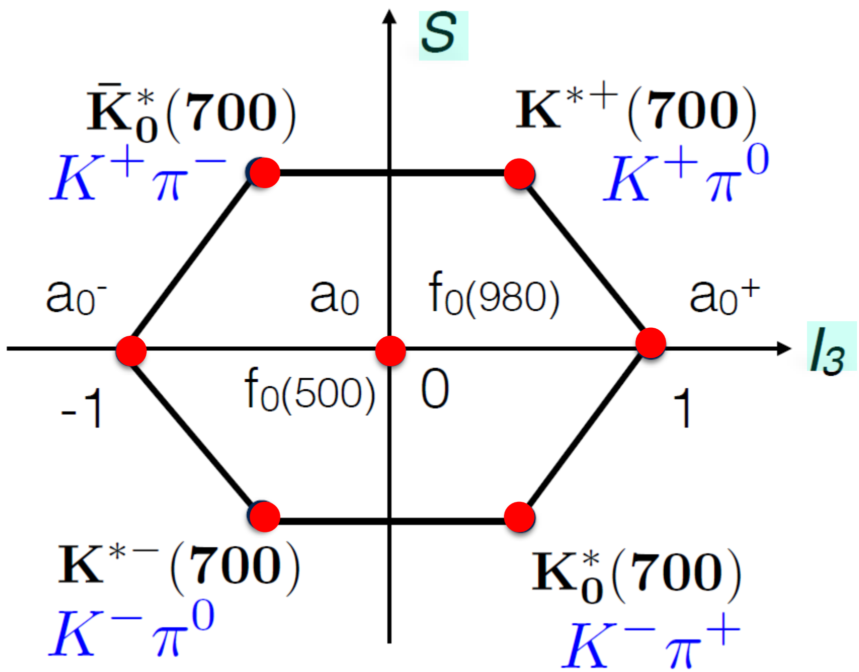
QCD predicts there should be a far richer spectrum, with states made predominantly of glue, we call glueballs, tetra-quark states made of two quarks and two anti-quarks... For almost forty years we have been searching for these additional states. Indeed, we may well have observed some of these, but there is little certainty of what has been found.

Michael Pennington, **2015**

A simple picture for both mesons and baryons is inconsistent with any version of relativistic field theory, where one can not exclude presence of an arbitrary number of virtual quark-anti-quark pairs and/or gluons. Therefore, adequate description of any hadron should use a Fock column, where lines correspond to particular configurations (but with the same ``global'' quantum numbers, like I, J, P, C, and so on).

Yakov Azimov, **2015**

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



- ***Four*** states called *κ(700).*
- PDG particle data group: *still need further confirmation*.
- allows determination of all *four* states.

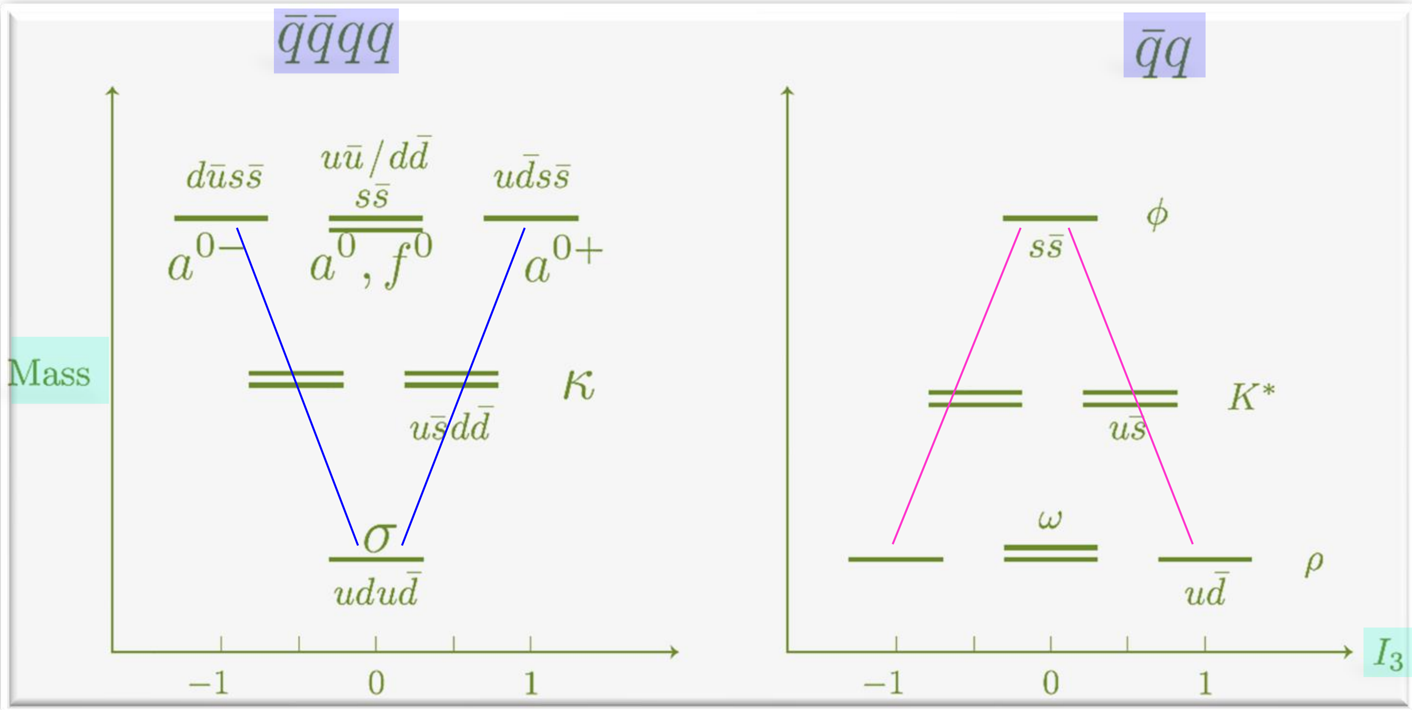
R.J. Jaffe, Phys Rev D **15**, 267 (1977)
arXiv: 0001123 [hep-ph]
arXiv: 0701038 [hep-ph]

Inverted mass hierarchy tetraquarks

Scalar Mesons

Ordinary meson states

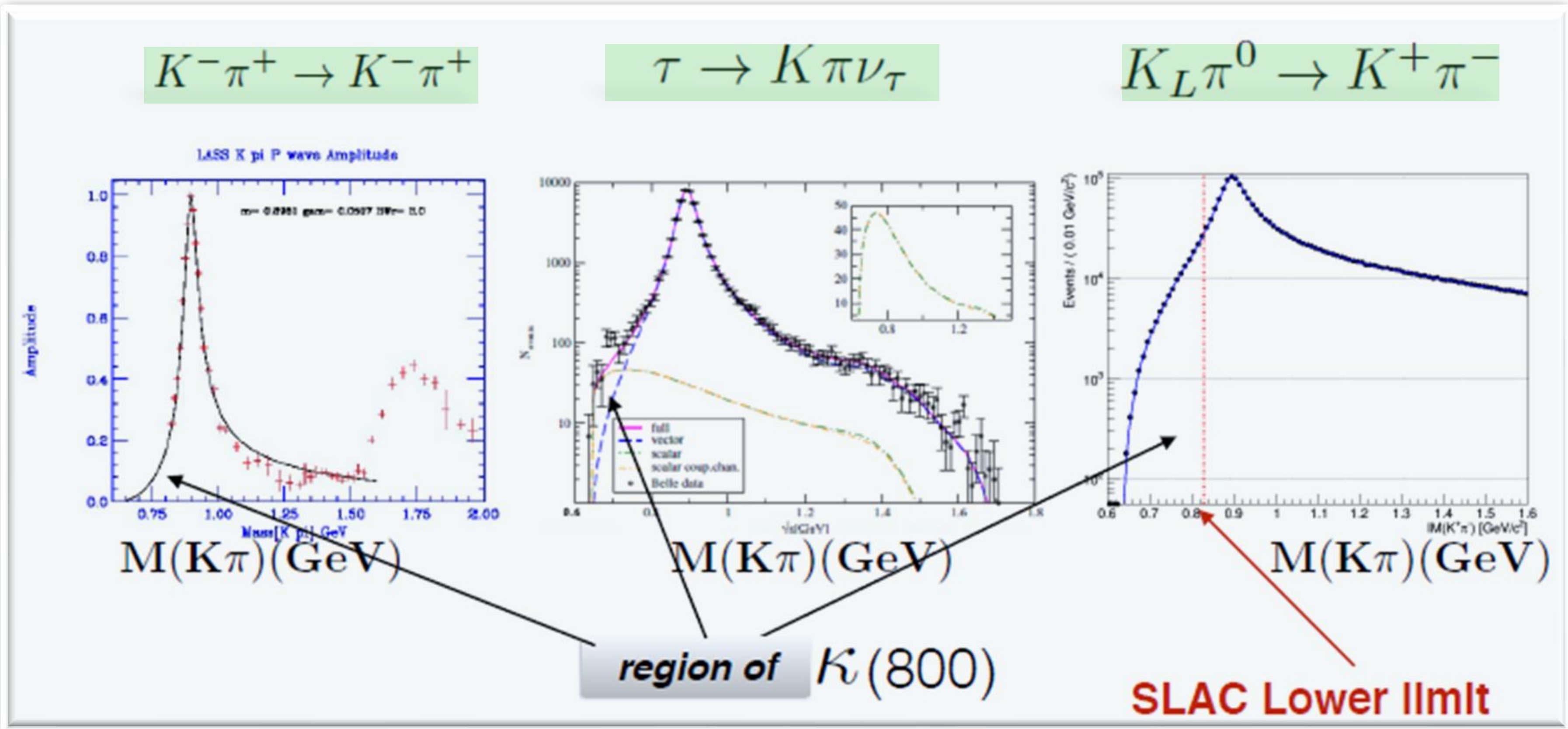
Vector Mesons



- Very different mass *hierarchy*.
- Possibly suggesting *4q tetraquark*.
- Structure of *scalar* mesons.

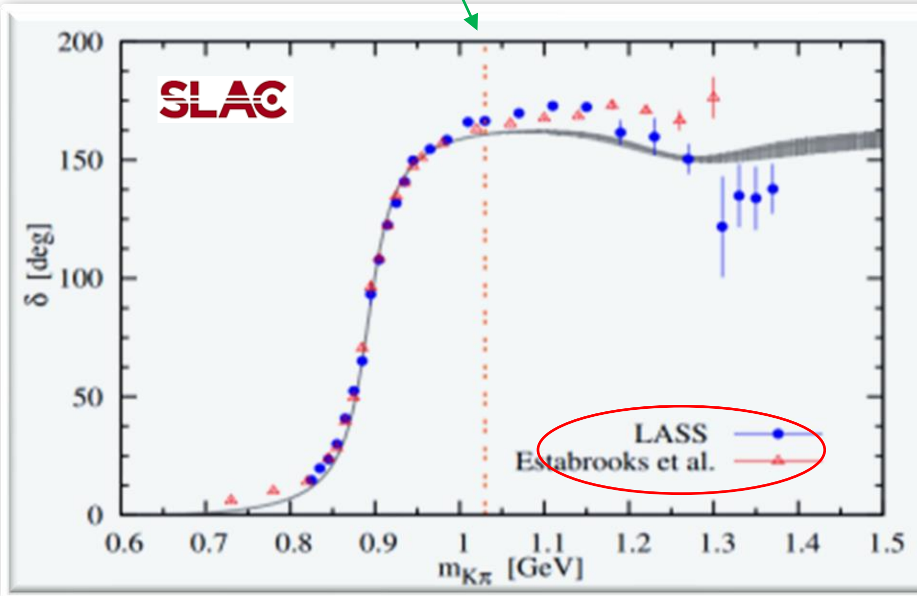
- *Certainly, there is no clear distinction between 4q & ``meson molecule'' categories.*

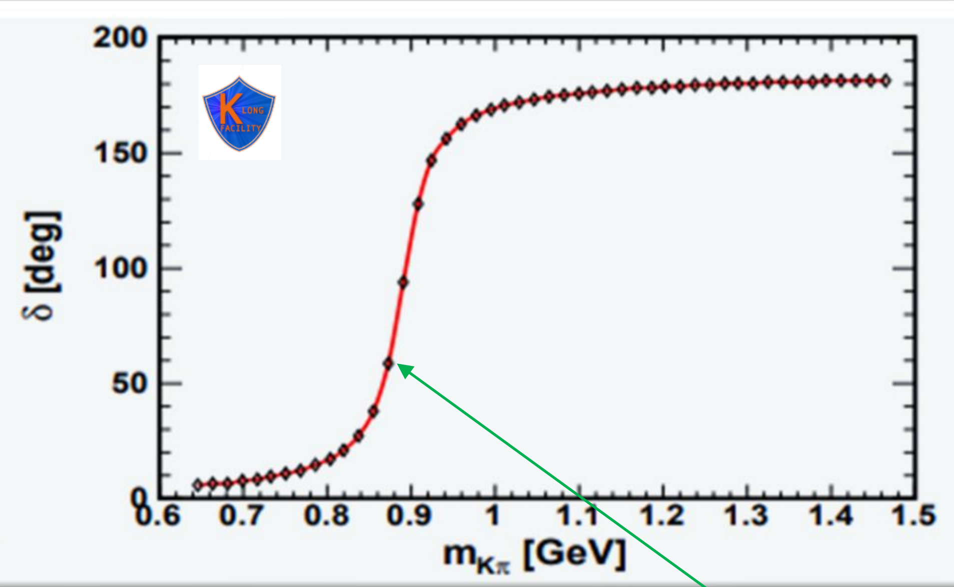
Proposed Measurements for $K\pi$ Scattering



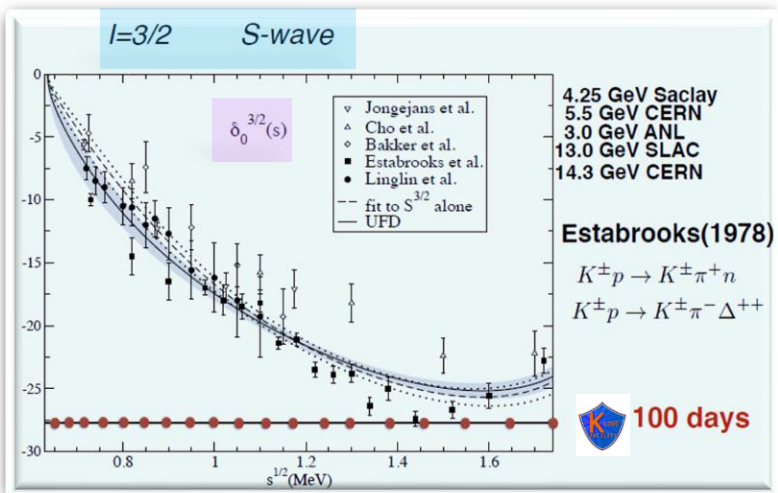
Projected Measurements

Opening first inelastic **K*π** channel

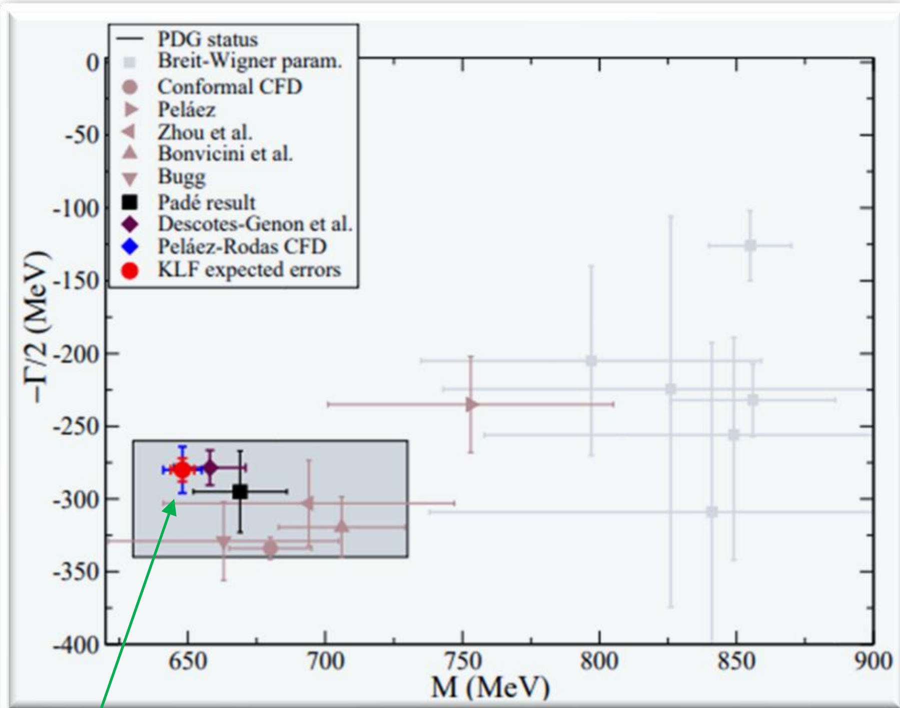




100 days

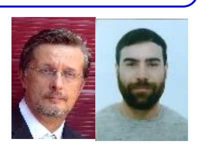


Summary of $K\pi$ Spectroscopy



100 days

- Roy-Steiner dispersion approach
  $M - i\Gamma/2 = (648 \pm 4) - i(280 \pm 8)$ MeV

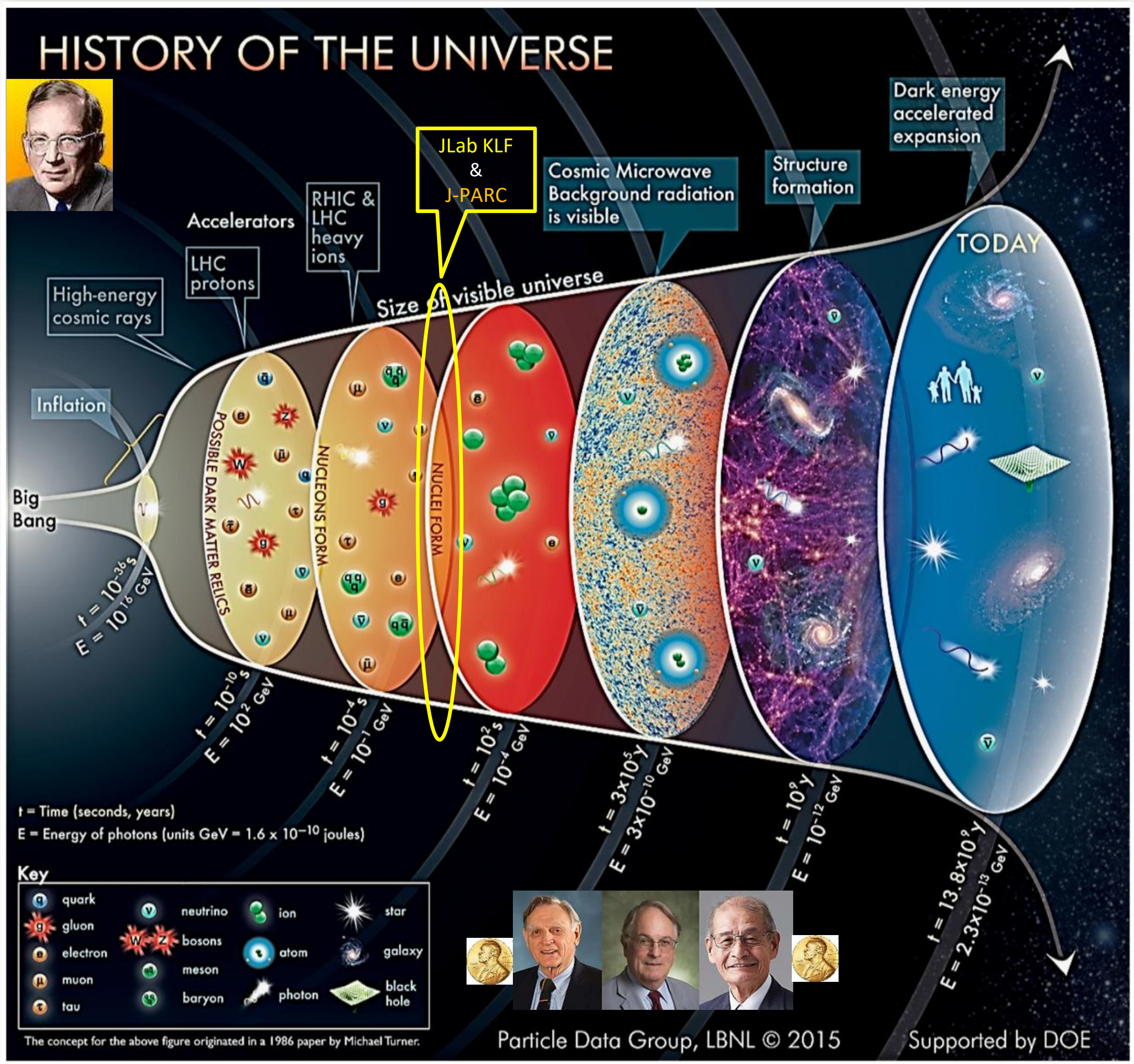


J.R. Pelaez *et al* Phys Rev D **93**, 074025 (2016)

- 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*(700)*, it will reduce:
  - *uncertainties* in *mass* by factor of ***two*** &
  - *uncertainties* 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*.

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*.

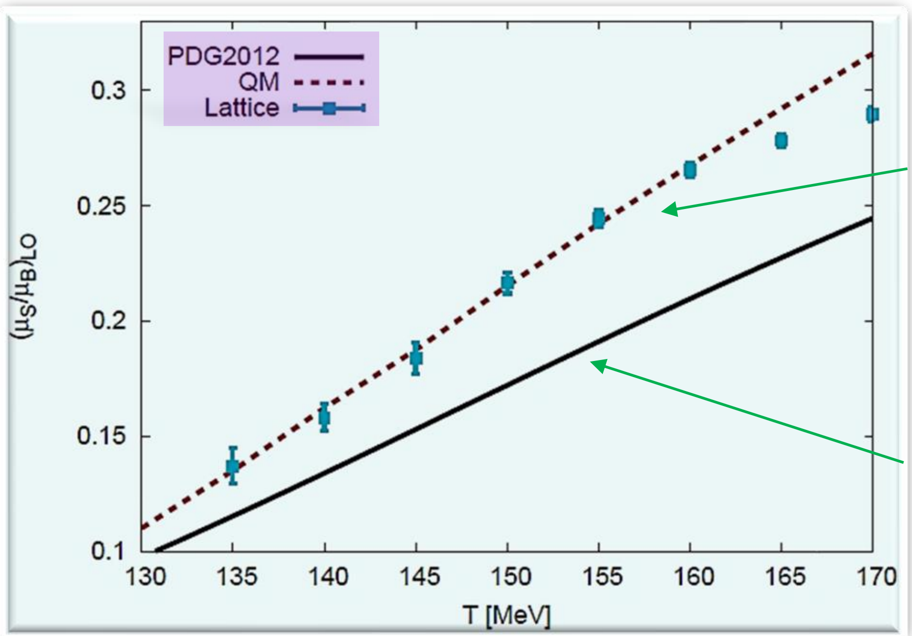
- For that reason, advancing our understanding of formation of *baryons* from ***quarks*** & ***gluons*** requires new experiments to search for any *missing hyperon* resonances.

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

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



- + ``*Missing*" *Resonances* (*QM*/*LQCD* calculations).

Contribution order:
- *Hyperons*
- Non-strange Baryons
- Mesons
- Nuclei

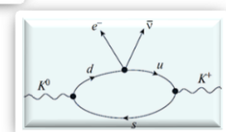
- Contribution from ***observed*** Resonances.

Courtesy of Claudia Ratti, YSTAR2016

KLF Potential

Potential

- For complete experiment, one can use *FROST* hydrogen/deuterium *polarized* target.
- Further potential exists to search for possible *exotic* baryonic states that cannot easily be described by usual three-valence-quark structure.
- Similarly, scattering of kaons from nuclear targets could be favorable method to measure matter form factor (&, therefore, *neutron skin*) of heavy nuclei, with different & potentially smaller systematics than other probes.
- High quality *neutron beam* will allow to study $np \to K^+X$ & $np \to \pi^+X$.
- Short Range Correlation (***SRC***) experiments are doable as well.
- Study *Primakoff* reaction using *KL* probe & nuclear targets is possible via $K^{*0}(892)$ decay into $K^0\gamma$, BR = 0.25 ± 0.20%.
- Physics potential connected with studies of ***CP***-violating decays of *KL* as, e.g, $K_L^0 \to \pi^0\nu\bar{\nu}$ is very appealing.
- High flux KL beam allows first measurement of *KL beta-decay*, $K_L^0 \to K^+e^-\bar{\nu}_e$, BR ~ 4×10^{-9}



A Bit of History

PHYSICAL REVIEW VOLUME 138, NUMBER 5B 7 JUNE 1965

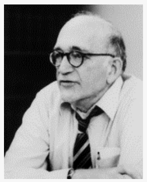
First paper on subject

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.

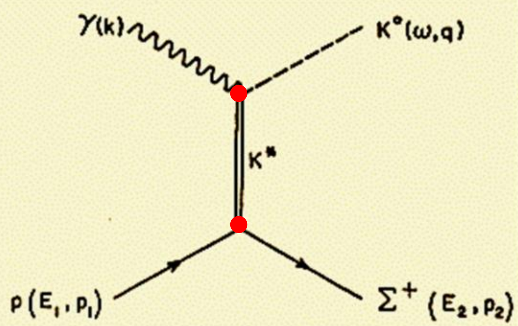


FIG. 1. K^* exchange in photoproduction.

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.

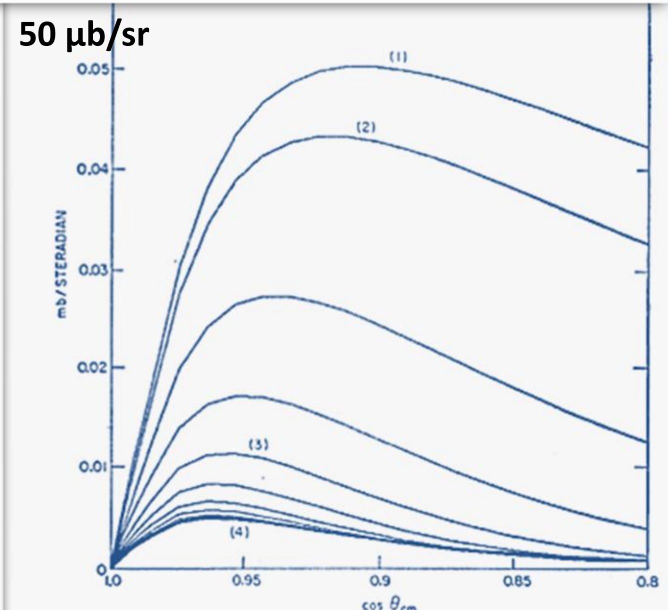


FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and (4) are respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partial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

Courtesy of Mike Albrow, KL2016

A bit of History

The possibility that useful K_L beam could be made @ 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

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 K0 beams & their decays & later, interactions.

From: Mike Albrow **Aug 29, 2020**
To: Igor Strakovsky
Dear Igor, That is excellent news, thank you for letting me know.
In one of those strange coincidences, my professor at Manchester who had the idea for our K0 photoproduction experiments and led the program, Paul Murphy (Manchester Univ.) died on Wednesday Aug 26. He was 89.
I had told him about your plans, he was still interested. He would have been happy to know that 50 years later you are benefitting from his idea.
Best, Mike (I am doing well, thank you)
PS: If your proposal was accepted on Aug 26th let me know, it would be strange synchronicity!

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
SLAC
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.

Summary

- <u>Our goal is</u>
  - To *setup KL Facility* @ Jefferson Lab.
  - To do *measurements* which bring new physics.

- Jefferson Lab would advance *Hyperon Spectroscopy* & study of *strangeness* in nuclear & hadronic physics.
  We may have cornucopia of many missing strange states.
  To complete ***SU(3)***$_F$ *multiplets*, one needs no less than 57 Λ^*, 57 Σ^*, 67 Ξ^*, & 34 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.

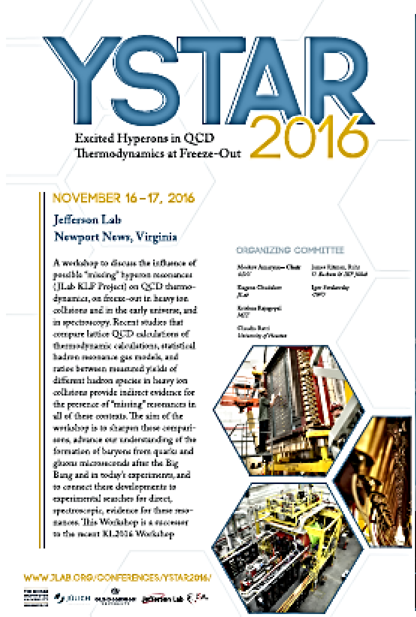
감사합니다

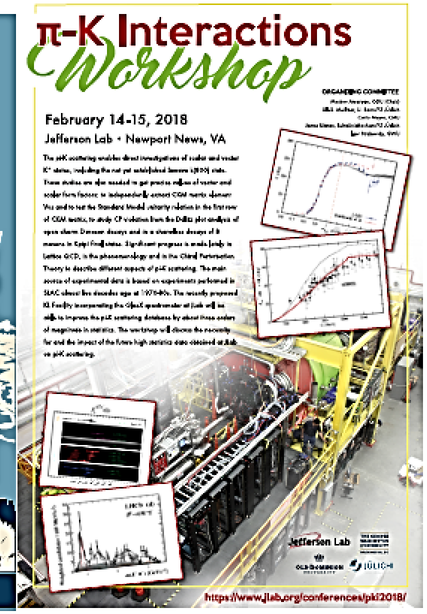
Do you have any questions to speaker?

igor@gwu.edu


BACKUP

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

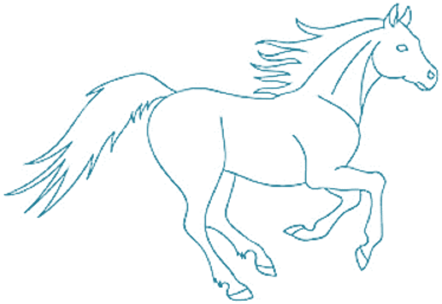
YSTAR2016
[71 people from 11 countries, 27 talks] *https://www.jlab.org/conferences/YSTAR2016/*
OC: M. Amaryan, E. Chudakov, K. Rajagopal, C. Ratti, J. Ritman, & I. Strakovsky

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

Outline



E12-12-19-001

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

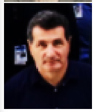
Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

Shankar Adhikari[43], Moskov Amaryan (Contact Person, Spokesperson)[13], Arshak Asaturyan[1], Alexander Austregesilo[49], Marouen Baalouch[8], Mikhail Bashkanov (Spokesperson)[63], Vitaly Baturin[13], Vladimir Berdnikov[11,35], Olga Cortes Becerra[19], Timothy Black[60], Werner Boeglin[13], William Briscoe[19], William Brooks[54], Volker Burkert[49], Eugene Chudakov[49], Geraint Clash[63], Philip Cole[32], Volker Crede[14], Donal Day[61], Pavel Degtyarenko[19], Alexandre Deur[49], Sean Dobbs (Spokesperson)[14], Gail Dodge[13], Anatoly Dolgolenko[26], Simon Eidelman[6,41], Hovanes Egiyan (JLab Contact Person)[49], Denis Epifanov[6,41], Paul Eugenio[14], Stuart Fegan[63], Alessandra Filippi[25], Sergey Furletov[49], Liping Gan[60], Franco Garibaldi[21], Ashot Gasparian[39], Gagik Gavalian[49], Derek Glazier[18], Colin Gleason[22], Vladimir Goryachev[26], Lei Guo[14], David Hamilton[11], Avetik Hayrapetyan[17], Garth Huber[53], Andrew Hurley[56], Charles Hyde[13], Isabella Illari[19], David Ireland[18], Igal Jaegle[49], Kyungseon Joo[57], Vanik Kakoyan[1], Grzegorz Kalicy[11], Mahmoud Kamel[13], Christopher Keith[49], Chan Wook Kim[19], Eberhard Klemp[5], Geoffrey Krafft[19], Sebastian Kuhn[13], Sergey Kuleshov[2], Alexander Laptev[33], Ilya Larin[26,39], David Lawrence[49], Daniel Lersch[14], Wenliang Li[56], Kevin Luckas[28], Valery Lyubovitskij[50,51,52,54], David Mack[49], Michael McCaughan[49], Mark Manley[30], Hrachya Marukyan[1], Vladimir Matveev[26], Mihai Mocanu[63], Viktor Mokeev[49], Curtis Meyer[9], Bryan McKinnon[18], Frank Nerling[15,16], Matthew Nicol[63], Gabriel Niculescu[27], Alexander Ostrovidov[14], Zisis Papandreou[53], KiJun Park[49], Eugene Pasyuk[49], Peter Pauli[18], Lubomir Pentchev[49], William Phelps[10], John Price[7], Jörg Reinhold[13], James Ritman (Spokesperson)[28,68], Dimitri Romanov[26], Carlos Salgado[10], Todd Satogata[49], Susan Schadmand[28], Amy Schertz[56], Axel Schmidt[19], Daniel Sober[11], Alexander Somov[49], Sergei Somov[35], Justin Stevens (Spokesperson)[56], Igor Strakovsky (Spokesperson)[19], Victor Tarasov[26], Simon Taylor[49], Annika Thiel[5], Guido Maria Urciuoli[21], Holly Szumila-Vance[19], Daniel Watts[63], Lawrence Weinstein[13], Timothy Whitlatch[49], Nilanga Wickramaarachchi[13], Bogdan Wojtsekhowski[49], Nicholas Zachariou[63], Jonathan Zarling[53], Jixie Zhang[61]

Theoretical Support:

Alexey Anisovich[5,41], Alexei Bazavov[38], Rene Bellwied[21], Veronique Bernard[12], Gilberto Colangelo[3], Aleš Cieplý[46], Michael Döring[19], Ali Eskanderian[19], Jose Goity[20,49], Helmut Haberzettl[19], Mirza Hadžimehmedović[55], Robert Jaffe[36], Boris Kopeliovich[54], Heinrich Leutwyler[3], Maxim Mai[19], Terry Mart[65], Maxim Matveev[41], Ulf-G. Meißner[5,29], Colin Morningstar[9], Bachir Moussallam[42], Kanzo Nakayama[58], Wolfgang Ochs[37], Youngseok Oh[31], Rifat Omerovic[55], Hedim Osmanović[55], Eulogio Oset[62], Antimo Palano[64], Jose Peláez[31], Alessandro Pilloni[66,67], Maxim Polyakov[48], David Richards[49], Arkaitz Rodas[49,56], Dan-Olof Riska[12], Jacobo Ruiz de Elvira[3], Hui-Young Ryu[45], Elena Santopinto[23], Andrey Sarantsev[5,41], Jugoslav Stahov[55], Alfred Švarc[47], Adam Szczepaniak[22,49], Ronald Workman[19], Bing-Song Zou[1]



https://wiki.jlab.org/klproject/index.php/Main_Page

KLF Time Requested

- Expected cornucopia of 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.

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.

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

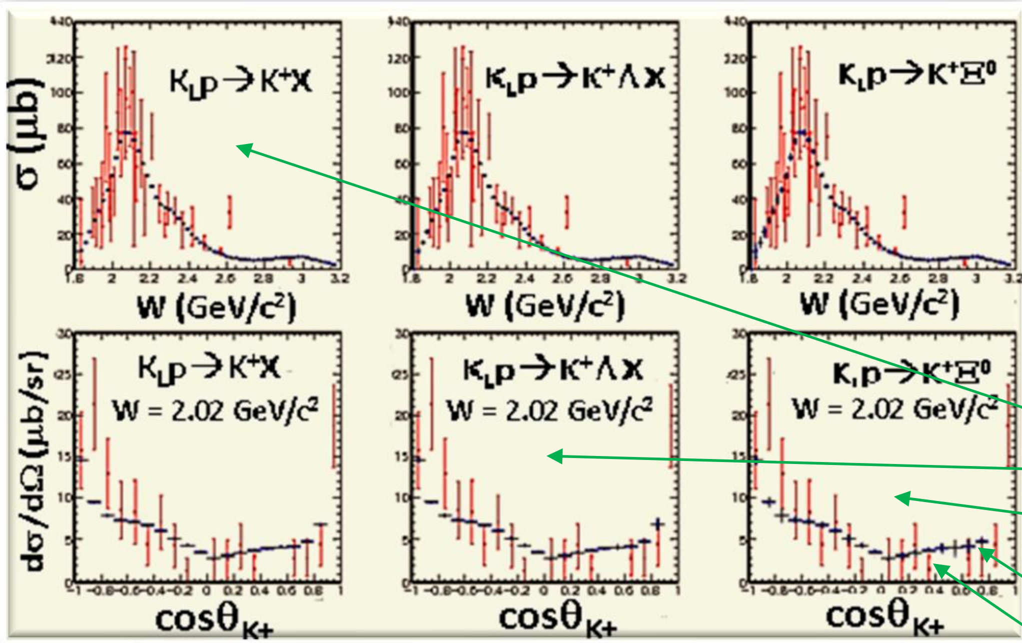
and

A. Sadoff
Ithaca College and Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

(Received 24 August 1967)

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

- Total & diff Xsec for different topologies

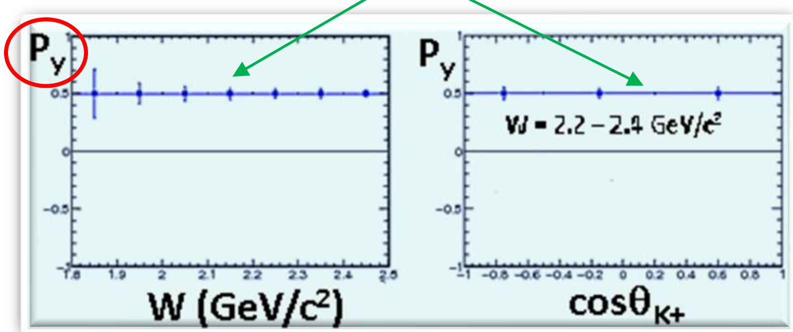


Reconstructed
- K^+
- $K^+\Lambda$
- $K^+\Sigma^0$

KLF data (100 d)
Existing data

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

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

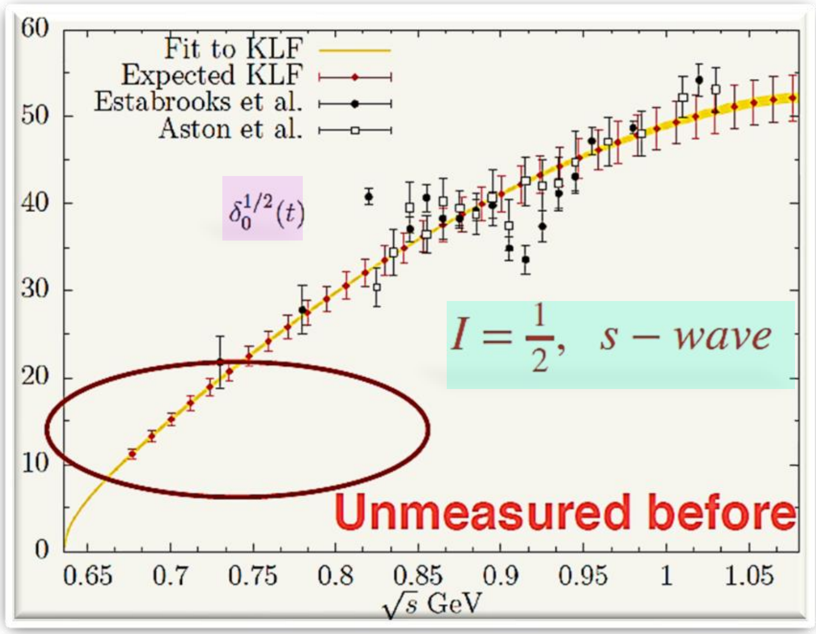


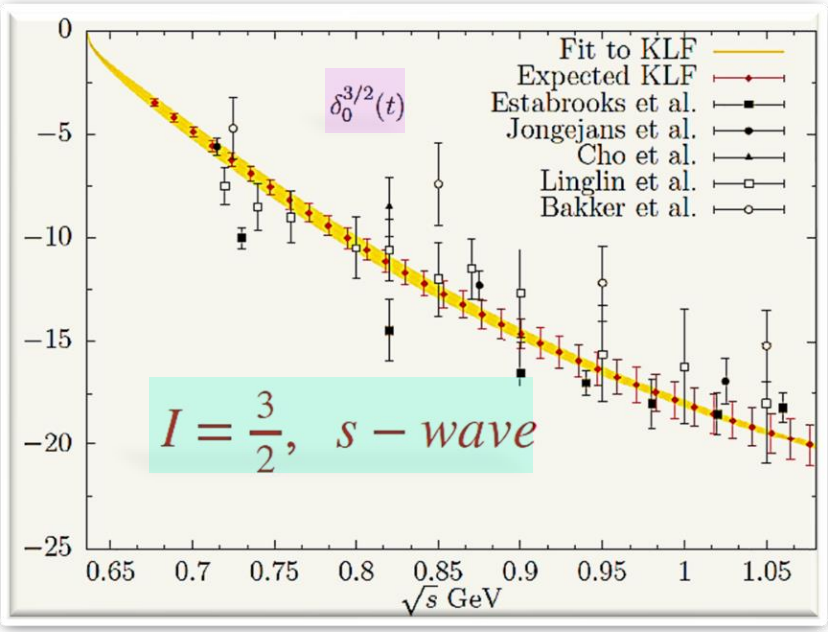
$$K_Lp \to K^+\overrightarrow{\Xi^0} \to K^+\vec{\Lambda}\pi^0 \to K^+p\pi^-\pi^0$$

(measured, reconstructed)

Courtesy of Nick Zachariou, 2019

Kappa Mass & Width





- *S*-wave phase shifts with stat & syst errs.
- More data are added close to threshold from