Search for Θ^+ in $K_L p \longrightarrow K^+ n$ Reaction with JLab KLF

Igor Strakovsky

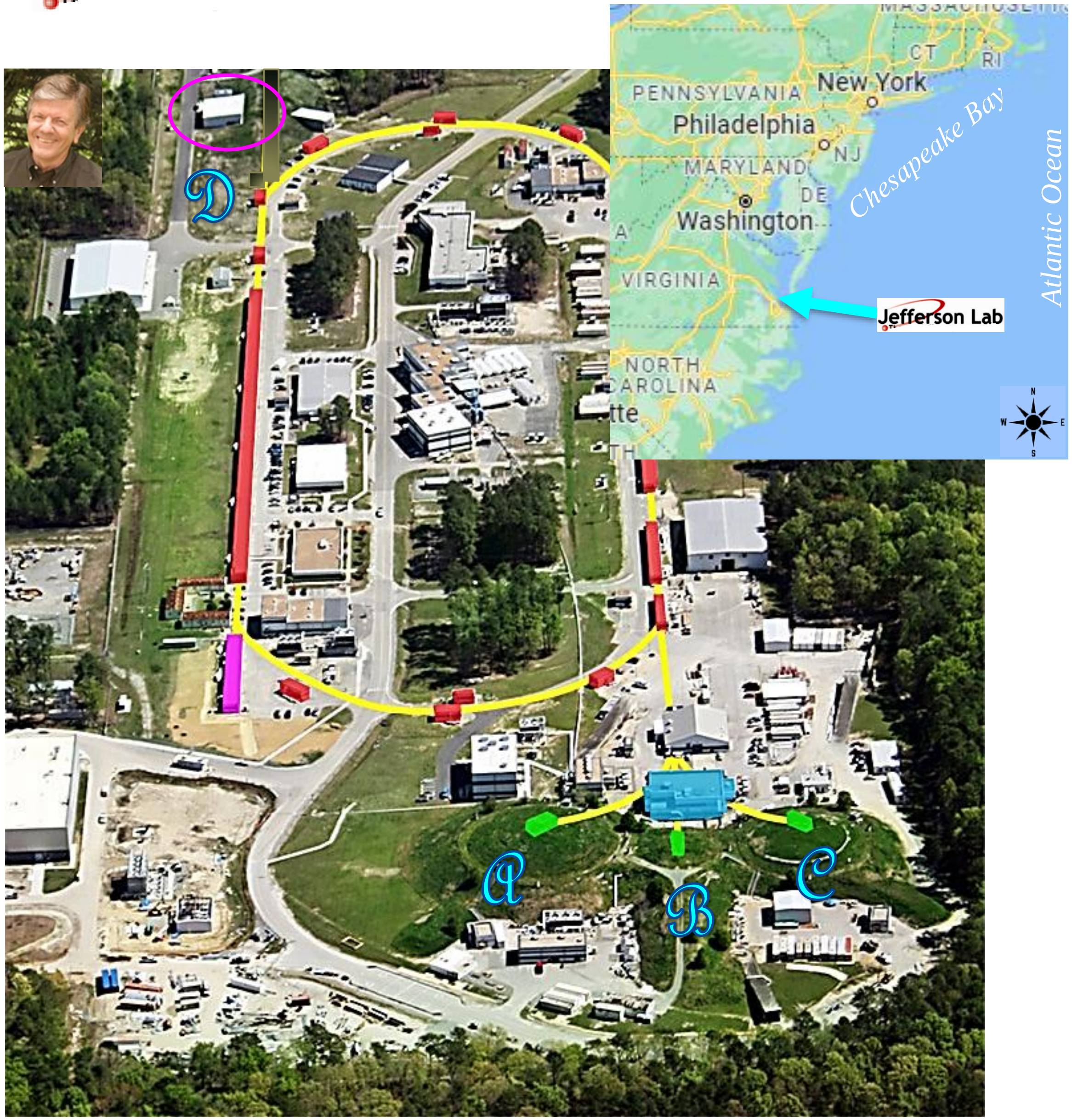
The George Washington University

- *KLF @ Jefferson Lab.*
- *Hyperon spectroscopy.*
- *Exotic:*
  - *N(1680).*
  - *Θ^+(1540).*
- *Were we are going.*
- *Summary.*
- *A bit of history.*

Supported by DE–SC0016583

KLF at Jefferson Laboratory

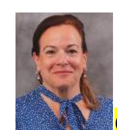
Jefferson Lab *Continuous Electron Beam Accelerator Facility in 2024*



1995 — 2012…
Energy 0.4 — 6.0 GeV
- 200 μA, *Polarization* 85%
- Simultaneous delivery **3** Halls – A, B, C

- 500+ PhDs completed
- On average 22 US Ph.Ds per year, roughly 25–30% of US Ph.Ds in nuclear physics
- 1530 users in FY16, ~1/3 international from 37 countries

…2016 — …
Energy 0.4 — 12.0 GeV
- 150 μA, *Polarization* 85%
- Simultaneous delivery 4 Halls
- FY18: First try simultaneous delivery to **4** Halls — A, B, C, D



Courtesy of Thia Keppel, 2017

E12-19-001

8

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

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D



Experimental Support:

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Theoretical Support:

Extensive Theoretical Support

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Jefferson Lab *PAC48 Report*, ***2020***

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.

e-Print: 2008.08215 [nucl-ex]

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

E12-12-19-001

This Happens because of Strong Support & Dedicated Efforts of Collaboration

126 experimentalists &
42 theorists
from **74** labs
across **20** countries
worldwide

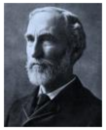
- project has firmly to setup secondary K_L beamline @ Jefferson Lab, with *flux* of *three order of magnitude higher* than SLAC had, for scattering experiments on both *proton* & *neutron* (*first* time !) targets.

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

- 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**. To complete ***SU(3)***$_F$ *multiplets*, one needs no less than 48 *Λ**, 38 *Σ**, 61 *Ξ**, & 31 *Ω** .

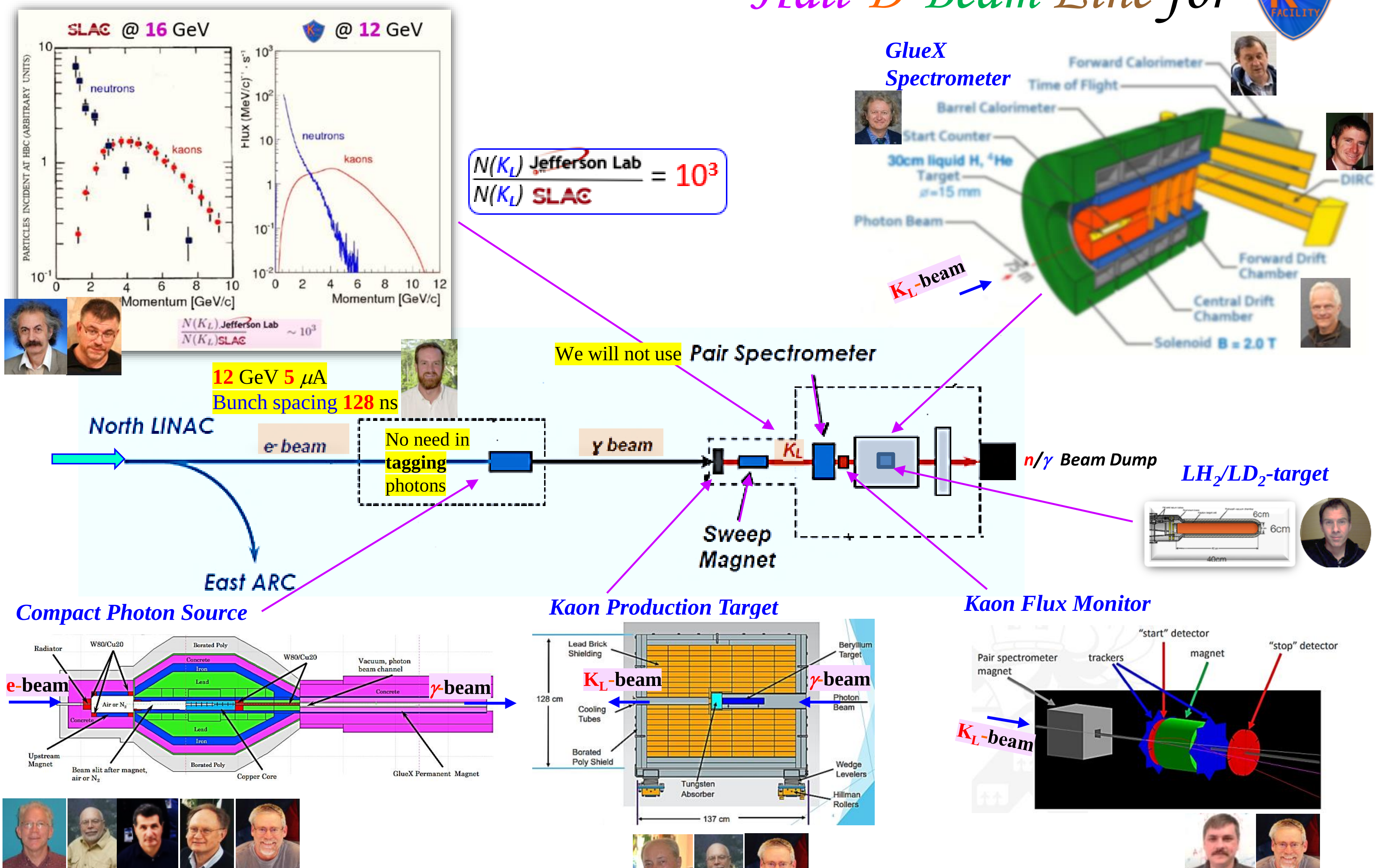
- We intend to do *strange meson spectroscopy* by studies of *π-K* interaction to locate *pole* positions in I = 1/2 & 3/2 channels.

- has link to *ion-ion high energy* facilities such as CERN & & will allow understand formation of our world in *several microseconds* after *Big Bang*. *Hyperons* are playing *leadin**g*** role to reproduce *Chemical Potential*.



Josiah Willard Gibbs

Hall D Beam Line for K_{LONG} FACILITY



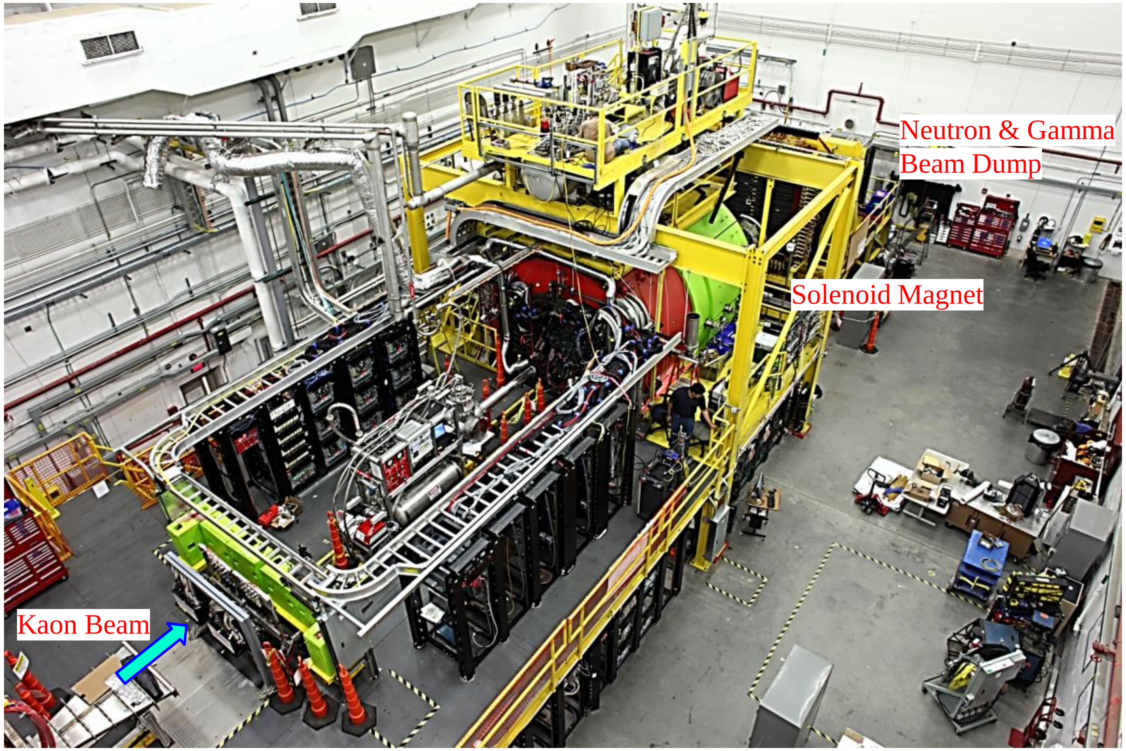
D. Day *et al*. Nucl Instrum Meth A **957**, 163429 (**2020**)

Hall D for K LONG FACILITY

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

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

Experimental Hall [***GlueX Spectrometer***, ***KFM***, ***SC***, ***Cryo Target***]

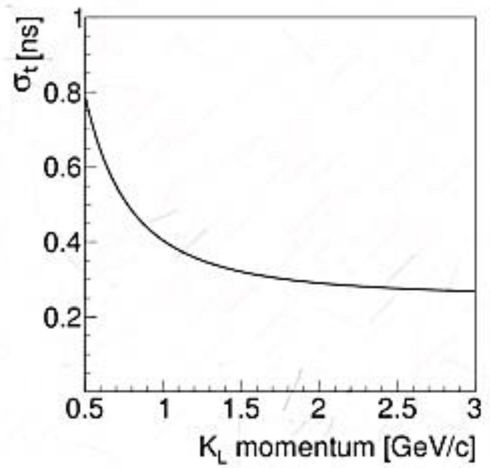


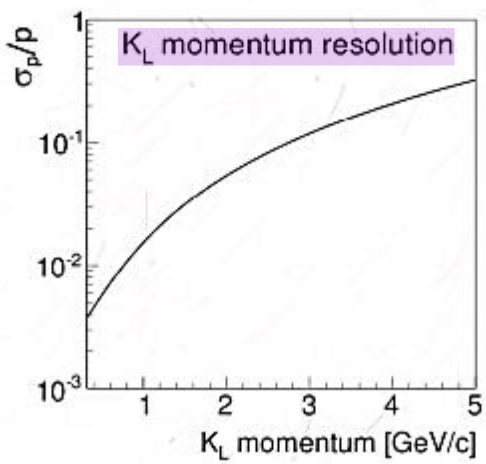
Tagger Hall [***CPS***]

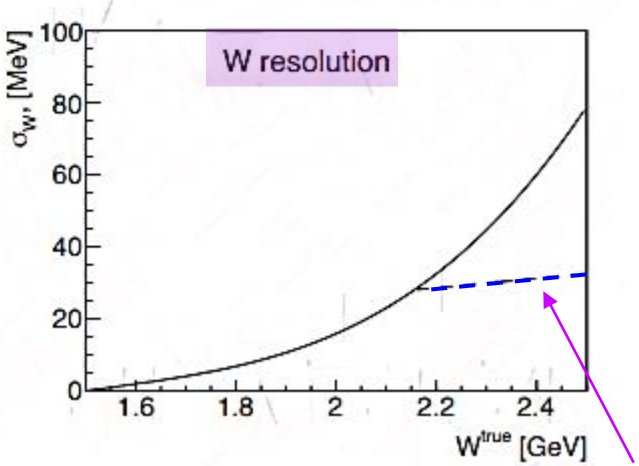
Collimator Cave [***KPT***]

K_L Momentum Determination & Resolution

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







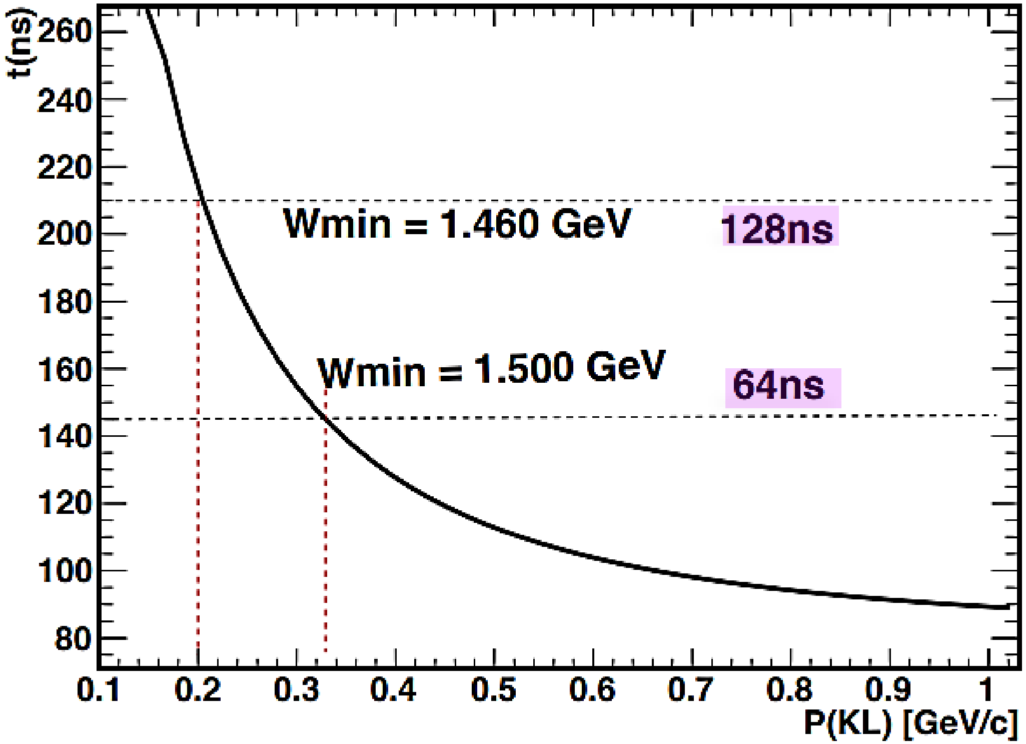
Reconstruction of final-state particles

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

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

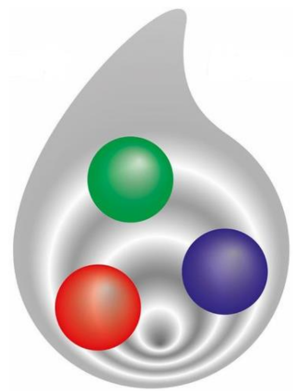
Electron Beam Parameters

- E_e = 12 GeV I = 5 μA
- Bunch spacing 64 ns *vs* 128 ns



- 128 ns confirmed feasible

Hyperon Spectroscopy

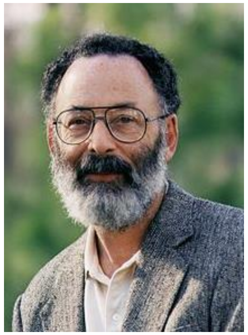


It is clear that we still need much more information about the existence and parameters of many baryon states, especially in the N=2 mass region, before this question of non-minimal SU(6) x O(3) super-multiplet can be settled.

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.

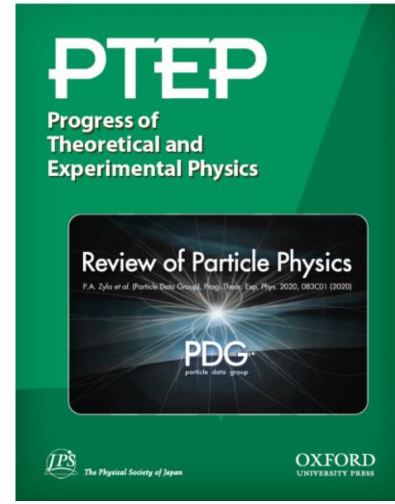
Gerhard Höhler, 1987



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 @ PDG2022



GW Contribution

R.L. Workman *et al*, Prog Theor Exp Phys **2022**, 083C01 (2022)

p	1/2+	****
n	1/2+	****
N(1440)	1/2+	****
N(1520)	3/2−	****
N(1535)	1/2−	****
N(1650)	1/2−	****
N(1675)	5/2−	****
N(1680)	5/2+	****
N(1685)		*
N(1700)	3/2−	***
N(1710)	1/2+	***
N(17[illegible]	3/2+	[illegible]**
N(18[illegible]	5/2+	[illegible]
N(1[illegible])	3/2−	[illegible]**
N(1[illegible]0)	[illegible]/2+	**
N([illegible]5)	[illegible]2−	**
N([illegible]00)	[illegible]	***
N([illegible]90)	7[illegible]	**
N(2000)	5/2+	**
N(2040)	3/2+	*
N(2060)	5/2−	**
N(2100)	1/2+	*
N(2120)	3/2−	**
N(2190)	7/2−	****
N(2220)	9/2+	****
N(2250)	9/2−	****
N(2600)	11/2−	***
N(2700)	13/2+	**

Δ(1232)	3/2+	****
Δ(1600)	3/2+	***
Δ(1620)	1/2−	****
Δ(1700)	3/2−	****
Δ(1750)	1/2+	*
Δ(1900)	1/2−	**
Δ(1905)	5/2+	****
Δ(1910)	1/2+	[illegible]***
Δ(1920)	3/[illegible]	[illegible]**
Δ(1930)	[illegible]/2−	[illegible]**
Δ(1940)	3/2−	[illegible]
Δ(1950)	7/2+	[illegible]**
Δ(20[illegible]0)	5/2+	[illegible]
Δ([illegible])	1/2	[illegible]
Δ(2200)	7/2−	*
Δ(2300)	9/2+	**
Δ(2350)	5/2−	*
Δ(2390)	7/2+	*
Δ(2400)	9/2−	**
Δ(2420)	11/2+	****
Δ(2750)	13/2−	**
Δ(2950)	15/2+	**

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

Σ+	1/2+	****
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]/2+	*
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]/2−	***
Ξ(19[illegible])		***
Ξ(2030)	≥ 5/2?	[illegible]***
[illegible]		*
Ξ(2250)		**
Ξ(2370)		**
Ξ(2500)		*
Ω−	3/2+	[illegible]**
Ω(2[illegible])−		[illegible]***
Ω([illegible]0)−		[illegible]**
Ω([illegible]0)−		[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+	***
$\Xi_c'^+$	1/2+	***
$\Xi_c'^0$	1/2+	***
$\Xi_c(2645)$	3/2+	***
$\Xi_c(2790)$	1/2−	***
$\Xi_c(2815)$	3/2−	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	1/2+	***
$\Omega_c(2770)^0$	3/2+	***
Ξ_{cc}^+		*
Λ_b^0	1/2+	***
Σ_b	1/2+	***
Σ_b^*	3/2+	***
Ξ_b^0, Ξ_b^-	1/2+	***
Ω_b^-	1/2+	***

- PDG 2022 has 133 Baryon Resonances (69 of them are 4* & 3*).
- In case of SU(6) x O(3), 434 states would be present if all revealed multiplets were fleshed out (*three* 70 & *four* 56).
- LQCD results are similar.

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

- First *hyperon* was discovered in **1950**.

V.D. Hopper & S. Biswas, Phys Rev **80**, 1099 (1950)

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

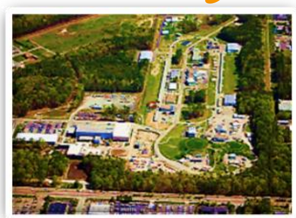
Jefferson Lab

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

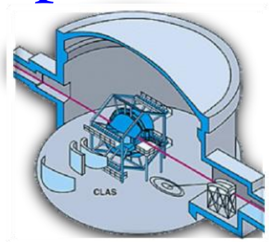
Road Map to Baryon Spectroscopy

- That is not hunting for bumps

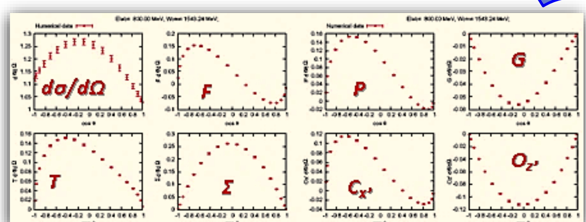
Facility



Experiment

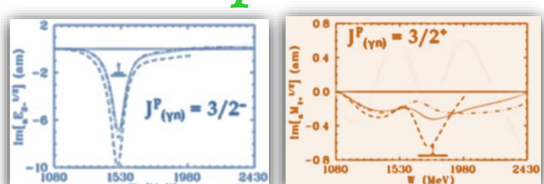


Data



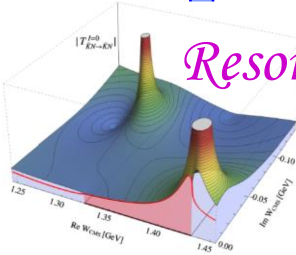
PWA

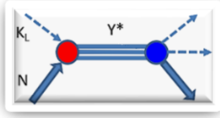
Amplitudes

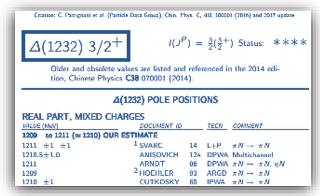


PWA

Resonances







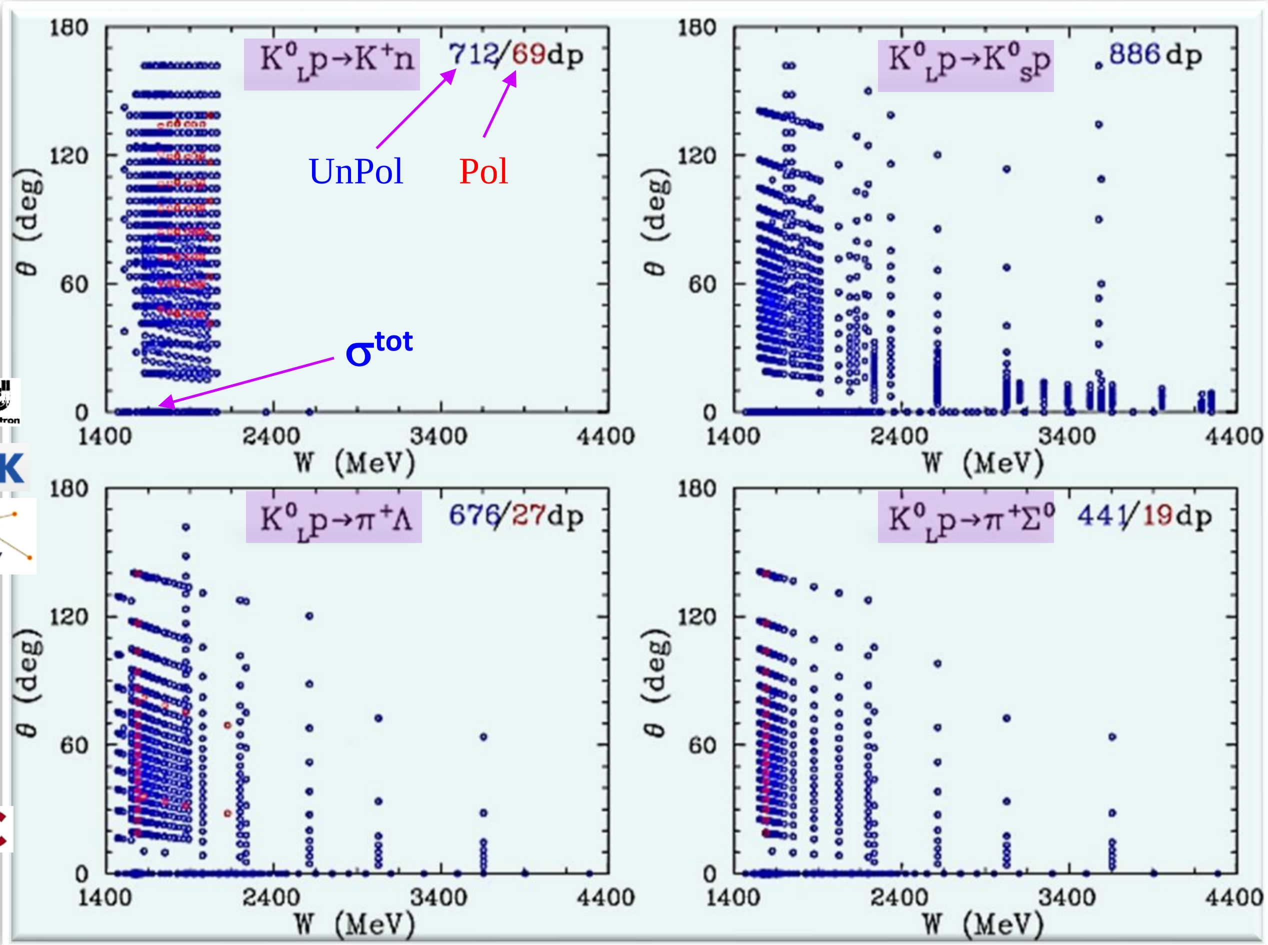
QCD

LQCD

World K–long Data – Ground for Hyperon Phenomenology

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.

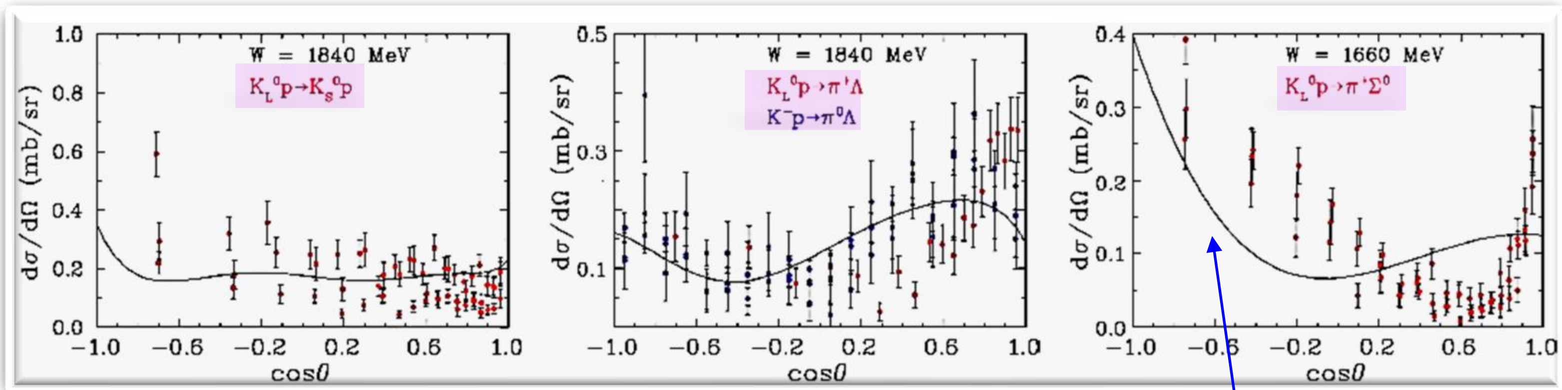


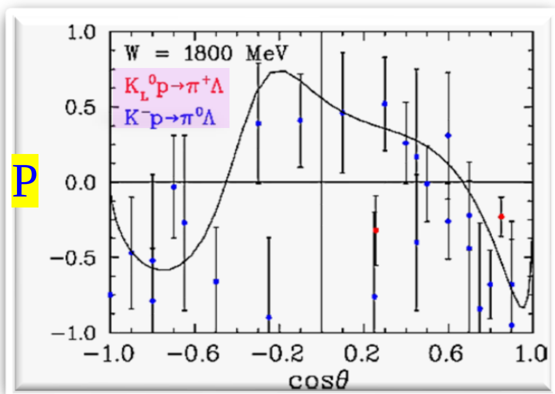
W = 1.45 – 5.05 GeV

- Limited number of K_L observables in *hyperon spectroscopy* @ 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.

Samples of PWA Results for Current DB

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





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

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

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 $S = -3$	$K_L p \to K^+ K^+ \Omega^-$ $K_L p \to K^+ K^+ \Omega^{-*}$	$K_L n \to K^+ K^0 \Omega^-$ $K_L n \to K^+ K^0 \Omega^{-*}$

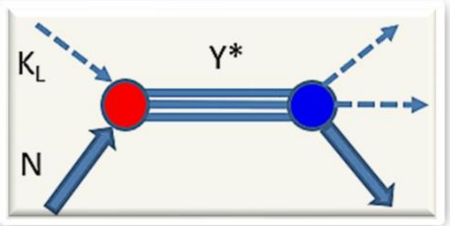
- To search for ``*missing*'' hyperons, we need measurements of production reactions:

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

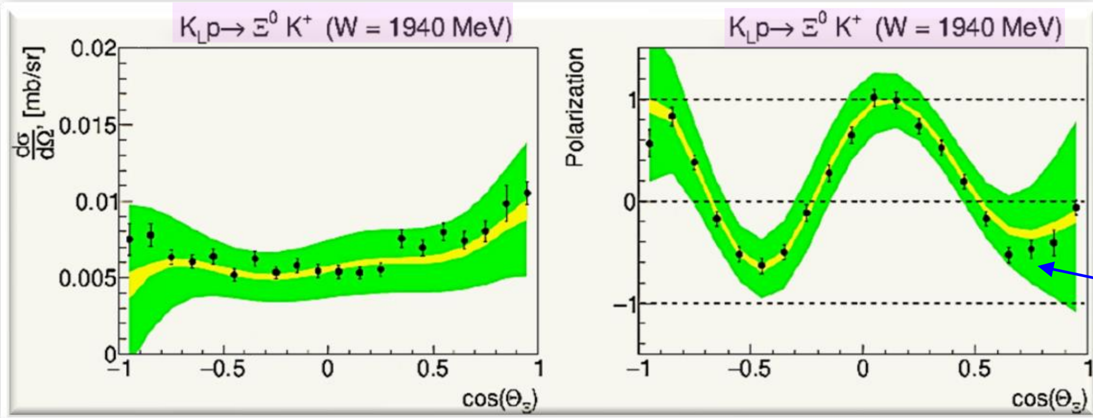
Λ^*: $K_L^0 p \to \pi \Lambda^* \to \pi\pi\Sigma$

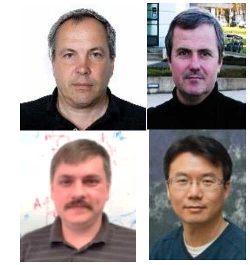
Ξ^*: $K_L^0 p \to K \Xi^*, \pi K \Xi^*$

Ω^*: $K_L^0 p \to K^+ K^+ \Omega^*$



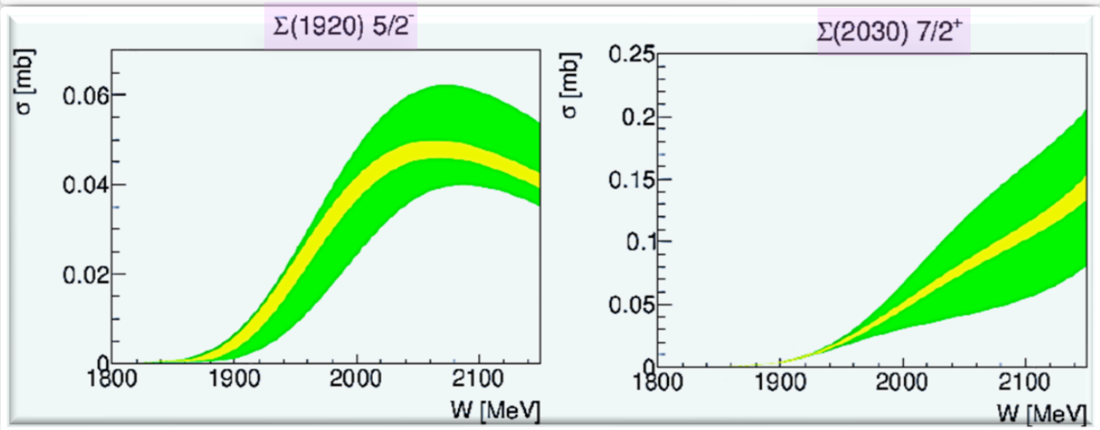
Impact Proposed Data using PWA





- *Quasi-data* using ***GlueX*** detector properties.

GEANT4



100 days

20 days

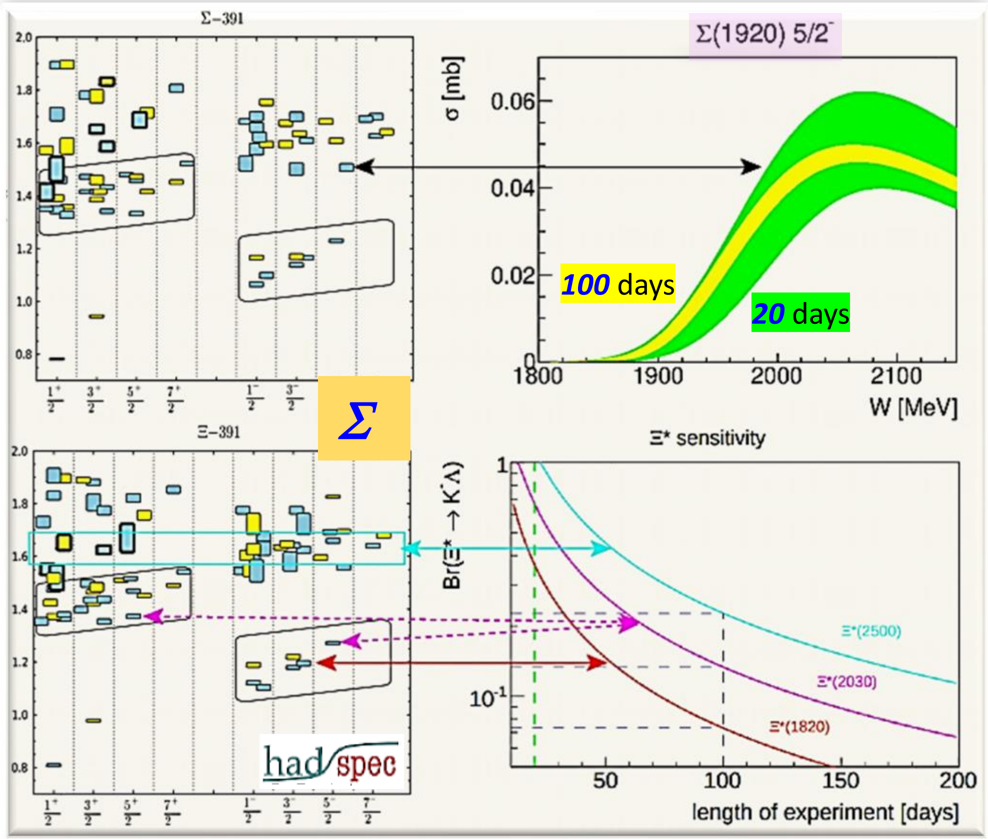
- At least **100** days needed to get *precise* solution.

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

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

Summary of Hyperon Spectroscopy

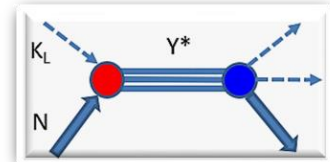
Money Plot



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

- 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 K_L momenta*** @ 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

Narrow Pentaquarks from $\Lambda_b \to J/\psi p K^-$

- QCD gives rise to *hadron spectrum*.

Volume 8, number 3 — PHYSICS LETTERS — 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS

M. GELL-MANN

CI=4087

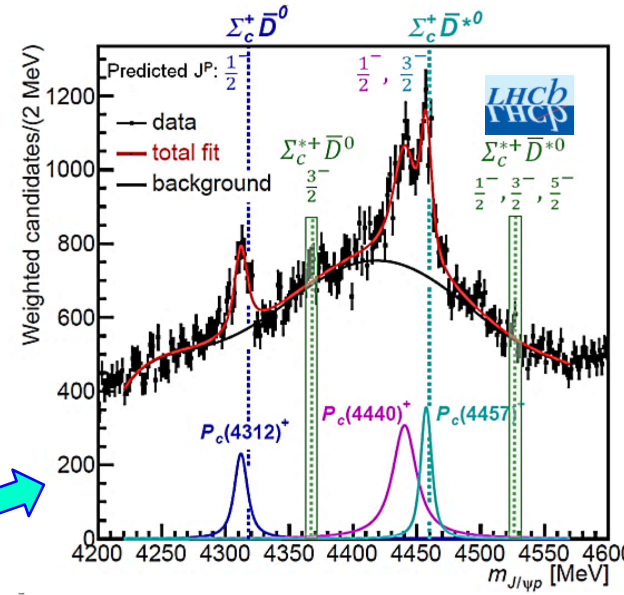
If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" ... Baryons can now be constructed from quarks by using the combinations (q q q), (q q q q $\bar{q}$), etc., while mesons are made out of (q $\bar{q}$), (q q $\bar{q}$ $\bar{q}$), etc.

- Many $\bar{q}q$ & *qqq* states have been *observed*.

PDG 220 & 100.

- $\bar{q}q\bar{q}q$, *qqq* $\bar{q}q$… *are not forbidden* or we *do not know* it yet.

- LHCb claims *evidence* for ***four*** *hidden-charm* $qqq\bar{q}q$ *states* near *open-charm* decay thresholds for $\Sigma_c^+\bar{D}^0$ & $\Sigma_c^+\bar{D}^{*0}$ in $\Lambda_b \to J/\psi\, p\, K^-$ decays.

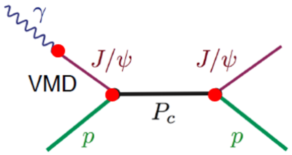


R. Aaij *et al*, Phys Rev Lett **122**, 222001 (**2019**)

CI=666

State	M (MeV)	$\Gamma[Pc \to J/\psi + p]$ (MeV)	Significance
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$	7.3 σ
$P_c(4337)^+$	4337^{+7+2}_{-4-2}	29^{+26+13}_{-12-14}	3.1 – 3.7 σ
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.1}$	5.4 σ
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$	5.4 σ

- Bump *hunting*:
  - no *quantum numbers*
  - no *pole positions*

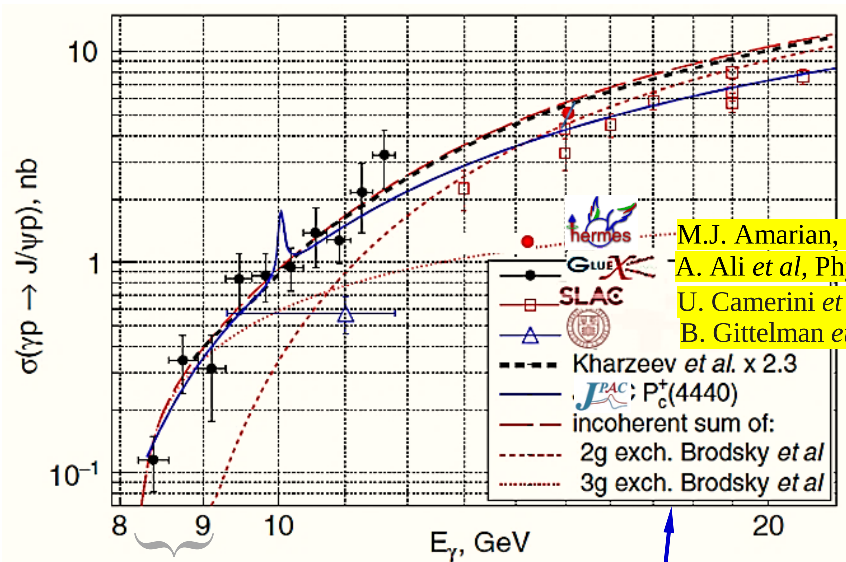


How Bump Hunting works in 2019 GlueX *data ?*

A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)

CI=175

2016–2017 data: **469**±22 $\gamma p \to J/\psi p \to e^+e^- p$ & **68** pb^{-1}



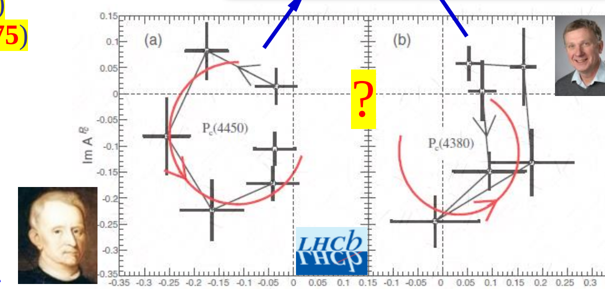
M.J. Amarian, Few-Body Syst Suppl. **11**, 359 (**1999**)
A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)
U. Camerini *et al*, Phys Rev Lett **35**, 483 (**1975**)
B. Gittelman *et al*, Phys Rev Lett **35**, 1616 (**1975**)

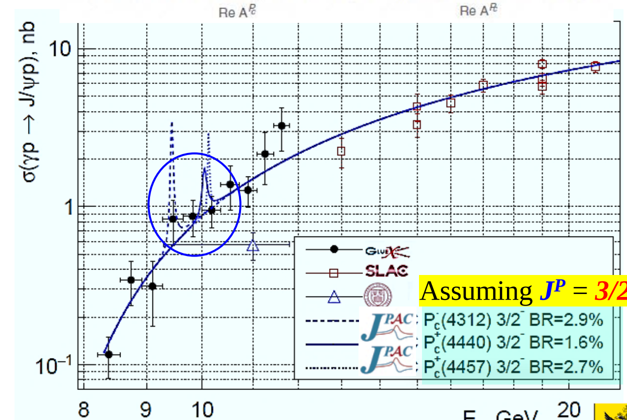
D. Kharzeev, H. Satz, A. Syamtomov, & G. Zinovjev, Nucl Phys A **661**, 568 (**1999**)
JPAC A.N. Hiller Blin *et al*, Phys Rev D **94**, 034002 (**2016**)
S. Brodsky, E. Chudakov, P. Hoyer, & J.M. Laget, Phys Lett B **498**, 23 (**2001**)

- @ *threshold*, ***3g*** works better than *2g*

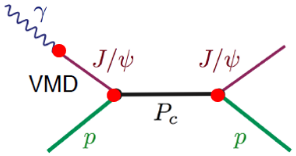
- GlueX sees *no evidence* for LHCb P_cs
  Upper limits @ 90% CL

State	Upper Limit
$P_c(4312)$	**4.6** %
$P_c(4440)$	**2.3** %
$P_c(4457)$	**3.8** %





Assuming $J^P = 3/2^-$

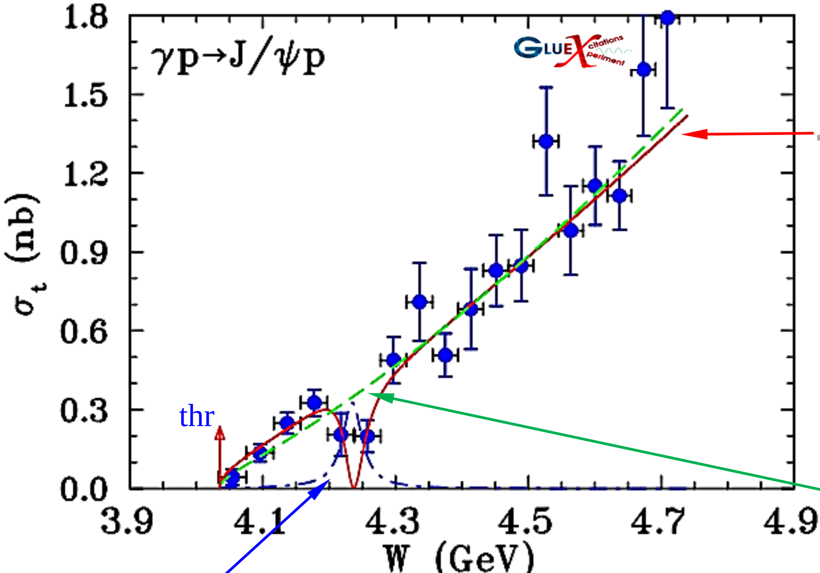


Alternative Solution for GlueX Data

IIS, W.J. Briscoe, E. Chudakov, I. Larin, L. Pentchev, A. Schmidt, R.L. Workman,
Phys Rev C **108**, 015202 (**2023**)

- We suggested to apply *rearrangement interference* for revealing *faint* resonance signals (***amplification*** by *interference* with *strong* background signal).
- Relative *phase* α leads to *constructive* (**bump**) or *destructive* (**dip**) *interference* for particular **PW**.

$$f = b + R \cdot \exp(2i\alpha)$$



Resonance: χ^2/ndf=11.99/12=1.00

M= 4235 ±8 MeV
Γ= 35.4±8.2 MeV
X= 0.023±0.005
α= 40.8±5.7 deg

Resolution ~6 MeV

Seminar: October 2023

Background:
A= 0.00251±0.00046 nb GeV/c
B= 0.00688±0.00083 nb/GeV/c

No Resonance: χ^2/ndf=19.74/16=1.23
A= 0.00183±0.00040 nb GeV/c
B= 0.00766±0.00077 nb/GeV/c

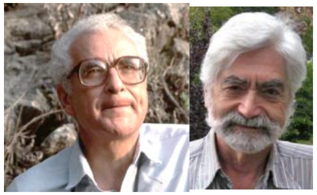
- If "*bump*" is imposed on GlueX data "*by hand*" (consider 7th - 9th energy values up from threshold), qualitative description of data up to **W** = 4.35 GeV is possible, but with higher χ^2, if our fit form is used.

- *Dip position* does not correspond to *real mass* of **P_c(4312)$^+$.**
- It may depend on reaction *mechanism* [including *cusps* (*open charm*)] & background choices.

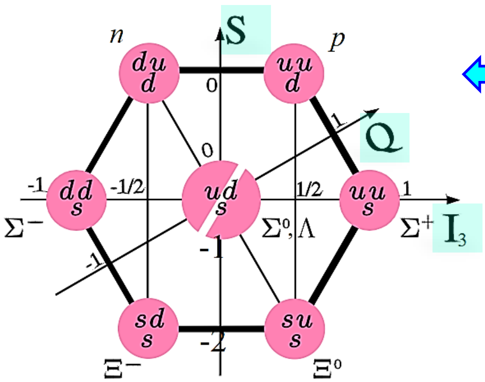
- Obtained mass in our analysis is almost **77** MeV below LHCb determination, but it cannot exclude that this is $P_c(4312)^+$.

Exotic

Baryon Multiplets of Eight-fold Way

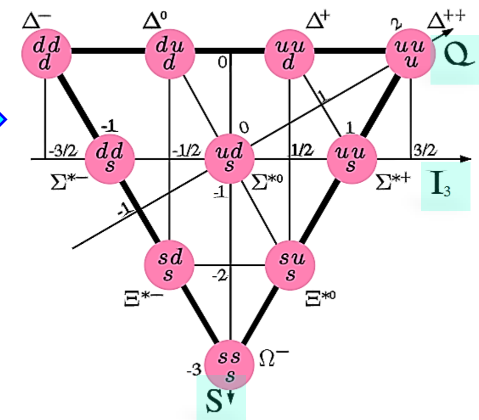


- Three light quarks can be arranged in 6 baryonic families, N*, Δ*, Λ*, Σ*, Ξ*, & Ω*.
- Number of members in family that can exist is not arbitrary.
- If $SU(3)_F$ symmetry of ***QCD*** is controlling, then:



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

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



had spec PDG

Resonance	LQCD	Observed
N^*	62	36
Δ^*	38	29
Λ^*	71	23
Σ^*	66	28
Ξ^*	73	12
Ω^*	36	5

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

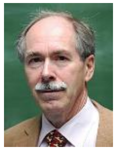
CI=177

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

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

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

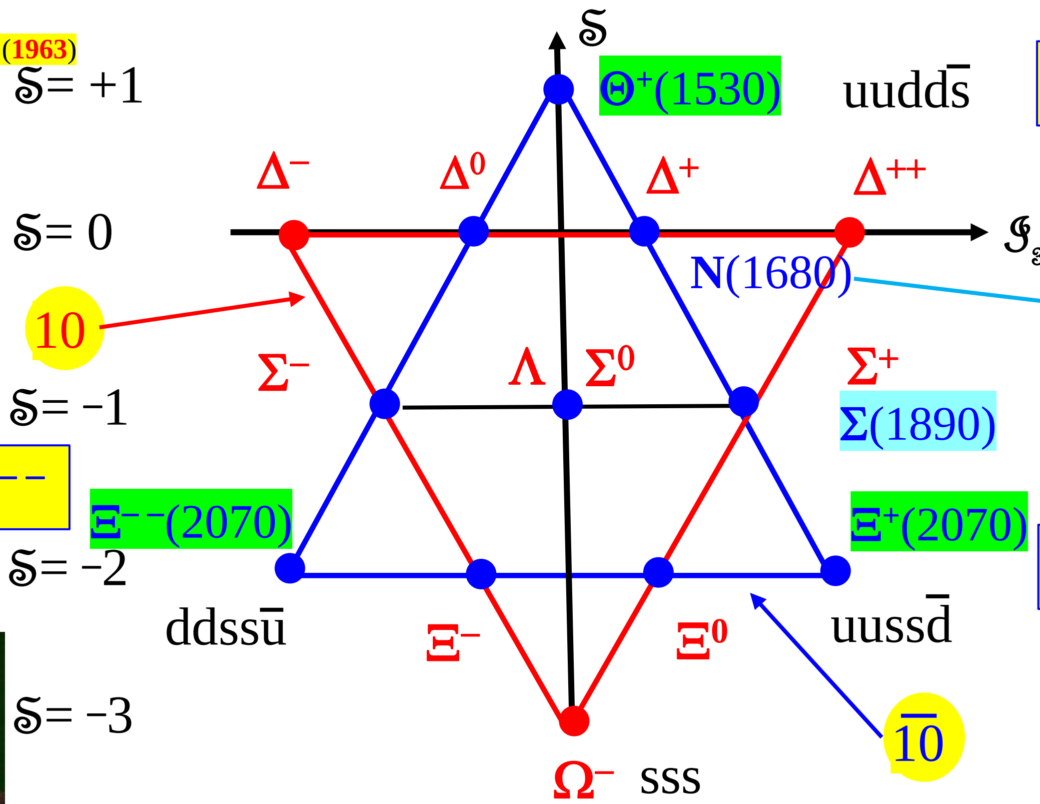
Anyone can ask Big Questions, but it is not easy to ask questions that would suggest new pathways leading to real progress of our understanding. Courtesy of Gerard 't Hooft, 2022



What Else ?

10 & $\overline{10}$ – P wave Multiplets

J.J. de Swart, Rev Mod Phys **35**, 916 (**1963**)



$K_L p \to K^+ n$

$K_L p \to K^+K^+K^+\Xi^{--}$

$K_L p \to K_S \Xi^+$

Not N(1710)

R.A. Arndt *et al.*
Phys Rev C **69**, 035208 (**2004**)

- In addition to ordinary hyperon states made of qqq, experiment may observe exotic Θ^+ pentaquark lying in ***apex*** of $\overline{10}$
- It will also be sensitive to observe exotic Ξ^+ lying in ***right corner*** of $\overline{10}$ in reaction $K_L p \to K_S \Xi^+$
  & to observe another exotic state Ξ^{--} lying in ***left corner of*** $\overline{10}$ in reaction $K_L p \to K^+K^+K^+\Xi^{--}$

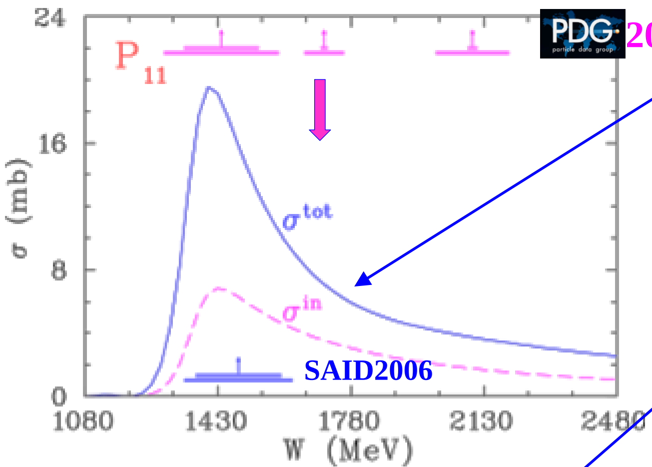
D. Diakonov, V. Petrov, & M.V. Polyakov, Z. Phys. A **359**, 305 (**1997**)

CI=987

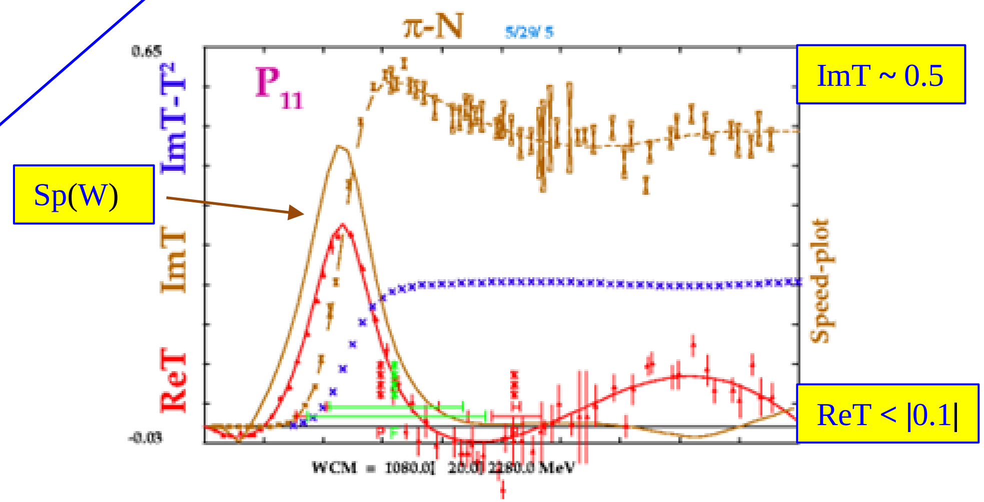
$\mathcal{N}$(1680)

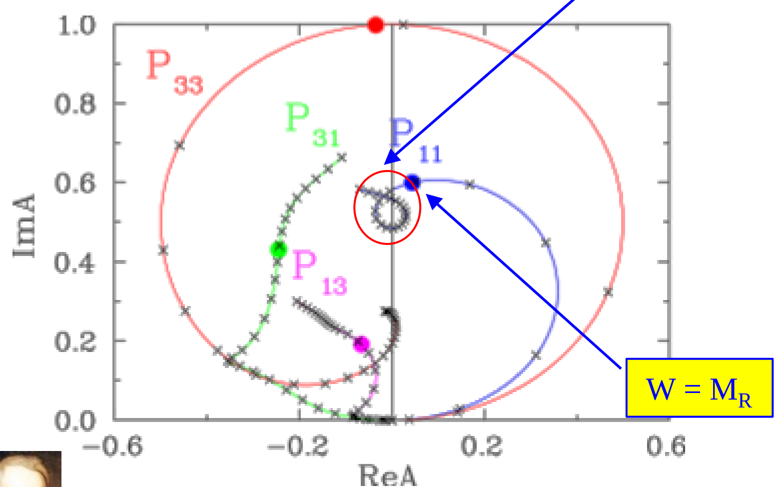
Why PDG N(1710) can't be Member of $\overline{10}$

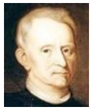
R.A. Arndt *et al*. Phys Rev C **69**, 035208 (**2004**)



- Above **1500** MeV: $\sigma^{tot} \cong 2\sigma^{el} \cong 2\sigma^{in}$ $[\sigma^{tot} = \sigma^{el} + \sigma^{in}]$
- It means nearly pure diffraction: $\eta \to \infty$, $S \cong 0$, $A \cong i/2$, & δ is badly defined.







W = 1080 [50] 2480 MeV

- Sp(W) = |dT/dW| → peak @ W = M(pole)
  @ NonRes → 0

G. Hoehler & A. Schulte, πN Newslett., **7**, 94 (**1992**)

- Above **1500** MeV, Sp(W) is flat

- That allows to conclude that in **πN** elastic, there is no Res in $\mathbf{P_{11}}$ above 1500 MeV, except possible states with small Γ_{el}

2022 vs 1997 for N(1710)

N(1710) 1/2+ $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗∗

N(1710) POLE POSITION (2022)

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1650 to 1750 (≈ 1700) OUR ESTIMATE				
1605 ± 7	ROENCHEN	22	DPWA	Multichannel
1690 ± 15	ANISOVICH	17A	DPWA	Multichannel
1697 ± 23	[1] ANISOVICH	17A	L+P	$\gamma p, \pi^- p \to K\Lambda$
1770 ± 5 ± 2	[2] SVARC	14	L+P	$\pi N \to \pi N$
~~1690 ± 20~~	~~CUTKOSKY~~	~~80~~	~~IPWA~~	~~$\pi N \to \pi N$~~

−2×IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 to 160 (≈ 120) OUR ESTIMATE				
115 ± 5	ROENCHEN	22	DPWA	Multichannel
155 ± 25	ANISOVICH	17A	DPWA	Multichannel
84 ± 34	[1] ANISOVICH	17A	L+P	$\gamma p, \pi^- p \to K\Lambda$
98 ± 8 ± 5	[2] SVARC	14	L+P	$\pi N \to \pi N$
~~80 ± 20~~	~~CUTKOSKY~~	~~80~~	~~IPWA~~	~~$\pi N \to \pi N$~~

N(1710) POLE POSITION (1997)

REAL PART

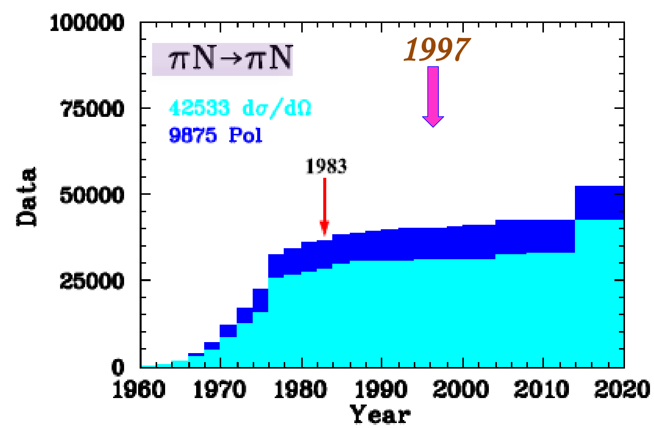
VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1770	ARNDT	95	DPWA	$\pi N \to N\pi$
1690	[5] HOEHLER	93	SPED	$\pi N \to \pi N$
1698	CUTKOSKY	90	IPWA	$\pi N \to \pi N$
1690 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2×IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
378	ARNDT	95	DPWA	$\pi N \to N\pi$
200	[5] HOEHLER	93	SPED	$\pi N \to \pi N$
88	CUTKOSKY	90	IPWA	$\pi N \to \pi N$
80 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

- N(1710) too broad to be *member* of $\overline{10}$…

- Since **1997**, *πN elastic* DB increased by significant amount



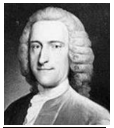
D.G. Ireland, E. Pasyuk, & IIS, Progress Part & Nucl Phys **111**, 103752 (**2020**)

- Originally PWA arose as technology to determine amplitude of reaction via fitting scattering data.

  ⇒ That is *non-trivial mathematical problem* – looking for solution of ill-posed problem following to Hadamard & Tikhonov.
  [number of equations less than number of unknown quantities]

  ⇒ There are two main technologies to look for solution:
  (i) *least-squares minimization* of functions which are linear in unknown parameters, χ^2 &
  (ii) *likelihood measures goodness* of fit of statistical model.
  [*Minimizing* χ^2 is equivalent to *maximizing* (log) likelihood just case not small statistics]

  
  Roger Cotes

  
  Sir Ronald Aylmer Fisher

  ⇒ Model *independent* treatment or data *driven* treatment.

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

- Standard PWA
  ⇒ Reveals only *wide Resonances*, but not too wide (Γ_R < **500** MeV) & possessing not too small BR (BR > **4**%).
  ⇒ Tends (by construction) to miss *narrow Resonances* with Γ_R < **20** MeV.

Narrow Resonances in PWA

R.A. Arndt, Y.I. Azimov, M.V. Polyakov, IIS, & R.L. Workman, Phys Rev. C **69**, 035208 (**2004**)

CI=150

- Because PWA (by construction) tends to *miss narrow* Res with $\Gamma < 20$ MeV
- We assume existence of Res & *refit* over whole DB

- Insertion of *narrow* Res in PWA for

Elastic case: $e^{2i\delta} \Rightarrow e^{2i\delta_R} e^{2i\delta_B}$

$$e^{2i\delta_R} = (M_R - W + i\,\Gamma_R/2) / (M_R - W - i\,\Gamma_R/2)$$

Inelastic case: $\eta\, e^{2i\delta} \Rightarrow \langle a|S|a\rangle = r_a A(W)\, e^{2i\delta_R} + (1 - r_a)\, B(W)$

$$r_a = BR(R \to a) \qquad |A(M_R)| = 1 \qquad \Sigma r_a = 1$$

$\eta \le 1 \Rightarrow$ $\quad r_a\, |A(W)| + (1 - r_a)\, |B(W)| \le 1$

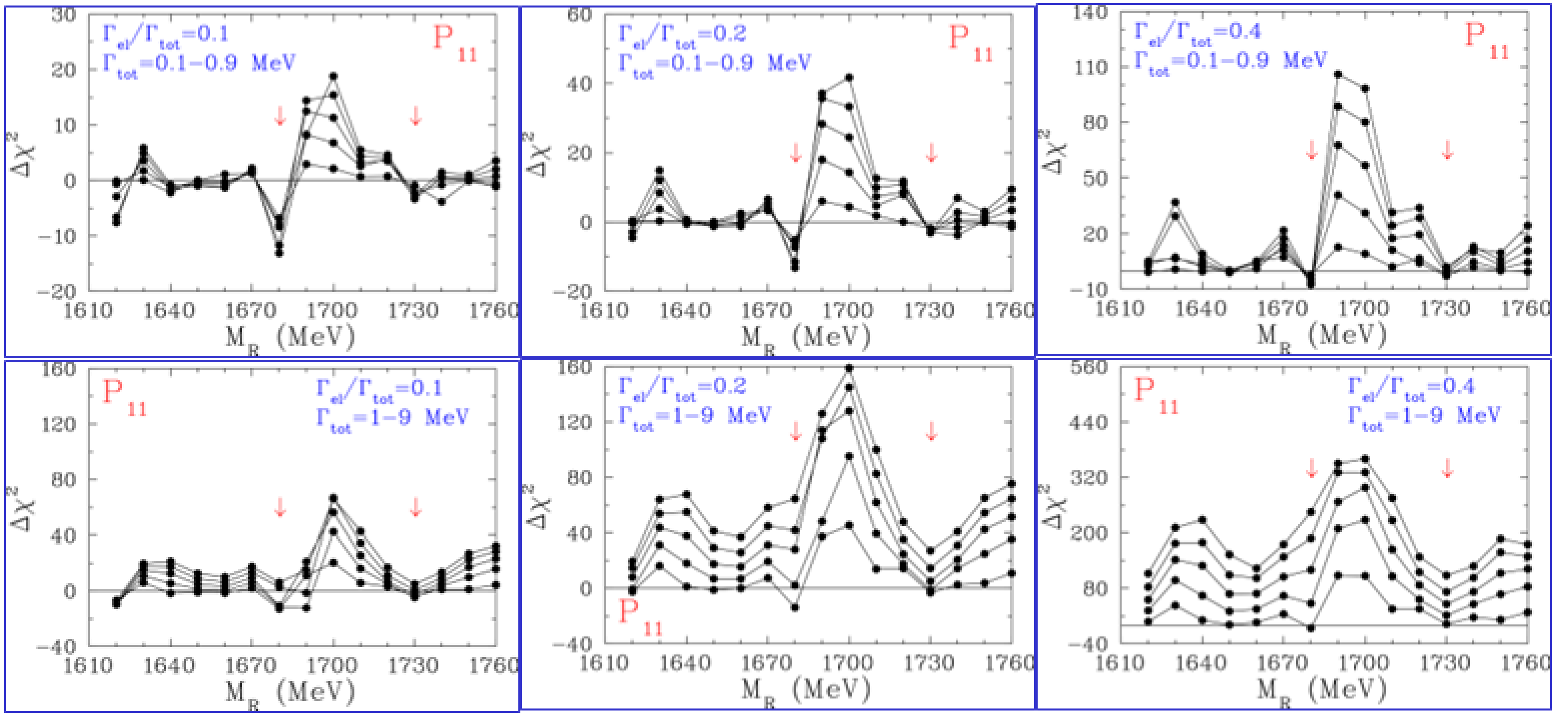
- Refitting
  - *Worse description*
    - $\Rightarrow$ Res with corresponding M_R & Γ_R is not supported
  - *Better description*
    - $\Rightarrow$ Res may exist
    - $\Rightarrow$ Effect can be due to various corrections (*eg, thresholds*)
    - $\Rightarrow$ Both possibilities can contribute

  Some additional checks are necessary
- True Res should provide effect only in particular PW
- While Non-Res source may show similar effects in various PWs

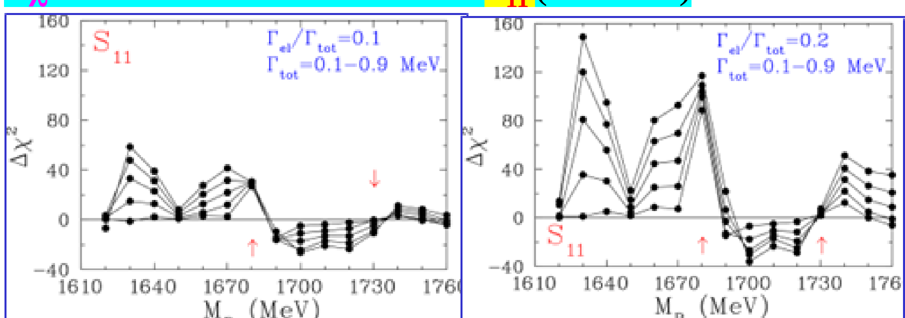
Modified πN PWA

R.A. Arndt, Y.I. Azimov, M.V. Polyakov, IIS, & R.L. Workman, Phys Rev. C 69, 035208 (2004)

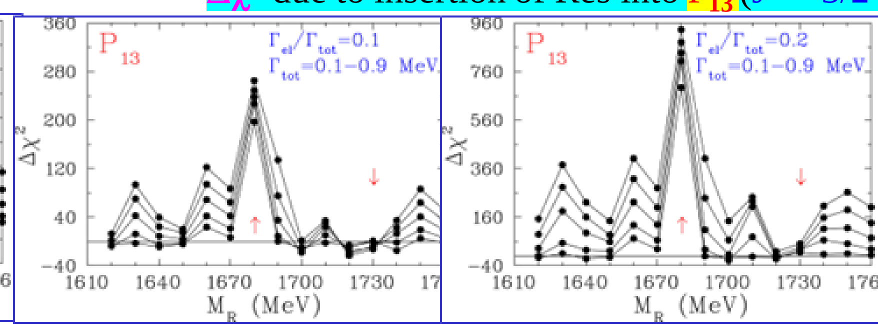
$\Delta\chi^2$ due to insertion of Res into P_{11} ($J^P = 1/2^+$)



$\Delta\chi^2$ due to insertion of Res into S_{11} ($J^P = 1/2^-$)

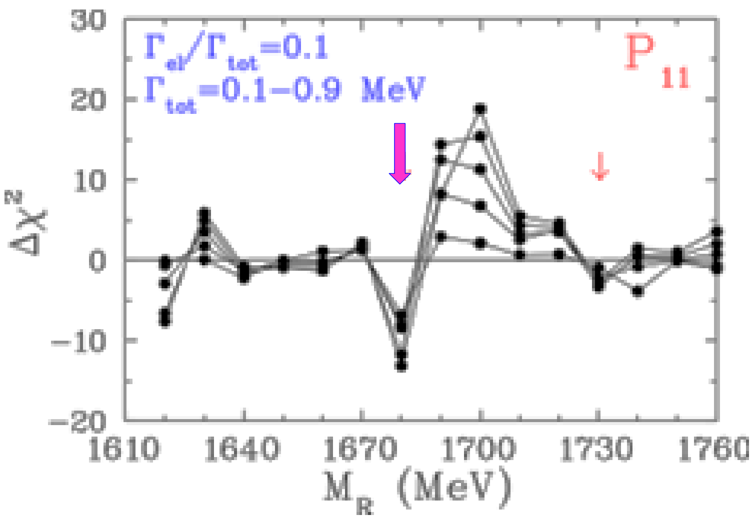


$\Delta\chi^2$ due to insertion of Res into P_{13} ($J^P = 3/2^+$)



Modified πN PWA for N(1680)

R.A. Arndt, Y.I. Azimov, M.V. Polyakov, IIS, & R.L. Workman, Phys Rev. C **69**, 035208 (**2004**)



- SAID group were considering πN partial wave P_{11}, as this amplitude, which is associated with resonances having $J^P = 1/2^+$.
- Character of χ^2 changes, $\Delta\chi^2$, after inserting narrow resonance with range of *masses*, *widths*, & *BRs* is illustrated.
- Negative values of $\Delta\chi^2$ emerge most readily near M_R = 1680 MeV & 1730 MeV.
- We see that $\Delta\chi^2$ becomes negative only for $\Gamma_{el} = (\Gamma_{el} / \Gamma_{tot})\ \Gamma_{tot}$ within bounds.
- Available data cannot reliably discriminate Γ_{el} below these bounds.

- Res contributes ~ $\Gamma_{el} / (M_R - W)$, @ $|M_R - W| >> \Gamma_R$
- Two candidates: M_R = 1680 MeV   1730 MeV
  $\Gamma_{\pi N}$ < 0.5 MeV   < 0.3 MeV
- Procedure is less sensitive to Γ_{tot}

Θ^+ Flavor Partner, $N^*(J^P = 1/2^+)$

R.A. Arndt, Y.I. Azimov, M.V. Polyakov, IIS, & R.L. Workman, Phys Rev. C 69, 035208 (**2004**)

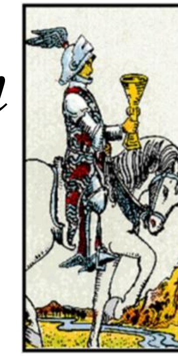
- Theoretical analysis is rather uncertain but nevertheless may be used for orientation

- If $\Gamma_\Theta \leq$ **0.5** MeV, then expected structure for decays of **Θ**-partner **N*** looks as follows:

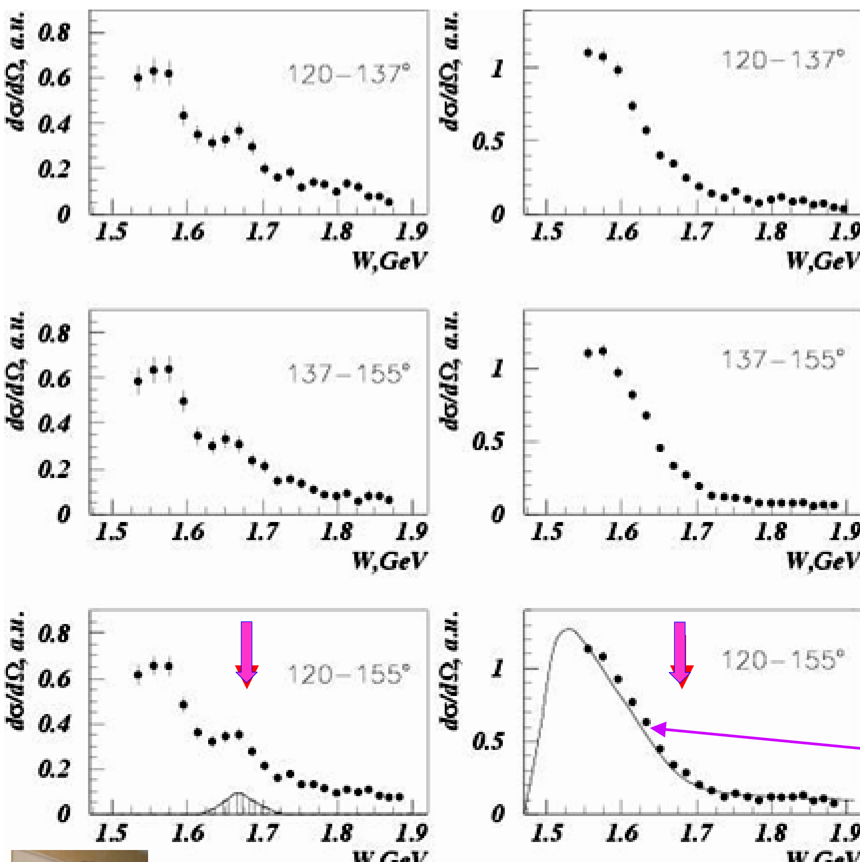
  ⇒ $\Gamma(N^* \to \pi\Delta)$ ~ 6 MeV [forbidden for $\overline{10}$, open due to $\overline{10}$-**8** mixing]
  ⇒ $\Gamma(N^* \to \eta N)$ ~ **0.5** – **2** MeV
  ⇒ $\Gamma(N^* \to K\Lambda)$ ~ **0.5** – **1.5** MeV
  ⇒ $\Gamma(N^* \to \pi N)$ ~ **0.3** – **0.5** MeV [non-trivial cancellation due to mixing is required]
  ⇒ $\Gamma(N^* \to \pi\pi N)$ [out of $\pi\Delta$] **?**
  ⇒ $\Gamma(N^* \to K\Sigma)$ is small **?**

  ⇒ $\Gamma(N^* \to \text{all})$ ~ **10** MeV [$\Gamma_{\pi N} / \Gamma_{tot} \leq$ **10 %**]
  Ratio of modes πN and ηN is sensitive to mixing

η Photoproduction from

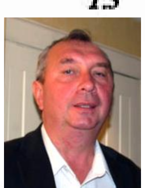


$\gamma n \rightarrow \eta n$ $\gamma p \rightarrow \eta p$



V. Kuznetsov *et al*. [arXiv:hepex/0409032 [hep-ex]]

CI=59



- In the case of ``*neutron*" target, FSI is problematic.

- Effect is absent in case of $\gamma p \rightarrow \eta p$ & agreed with *Chiral Quark Soliton* approach prediction.

M.V. Polyakov & A. Rathke, Eur Phys J A **18**, 691 (**2003**)

CI=117

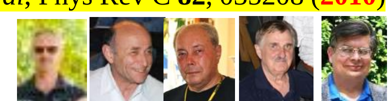
- In exact $SU(3)_F$, transition magnetic moment $\mu(p^* \rightarrow p)$ should vanish, since U-spins are **3/2** for **p***, **1/2** for **p**, & **0** for γ.
- With violation of $SU(3)_F$, this transition moment becomes non-vanishing, but is still much smaller than $\mu(n^* \rightarrow n)$.

Y.I. Azimov, V. Kuznetsov, M.V. Polyakov, & IIS, Phys Rev D **75**, 054014 (**2007**)

CI=10

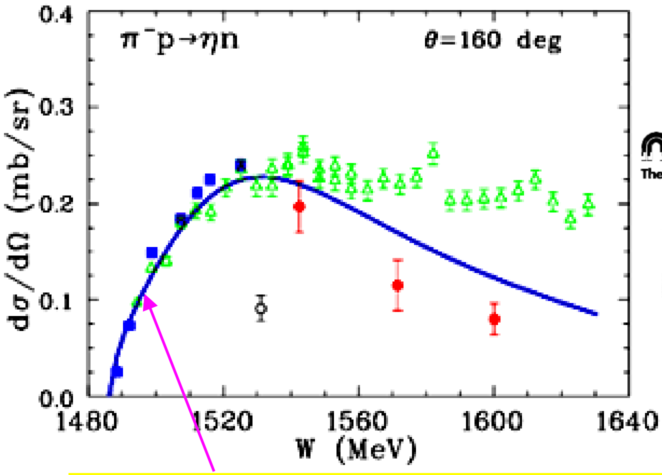
E.F. McNicoll *et al*, Phys Rev C **82**, 035208 (**2010**)

A2



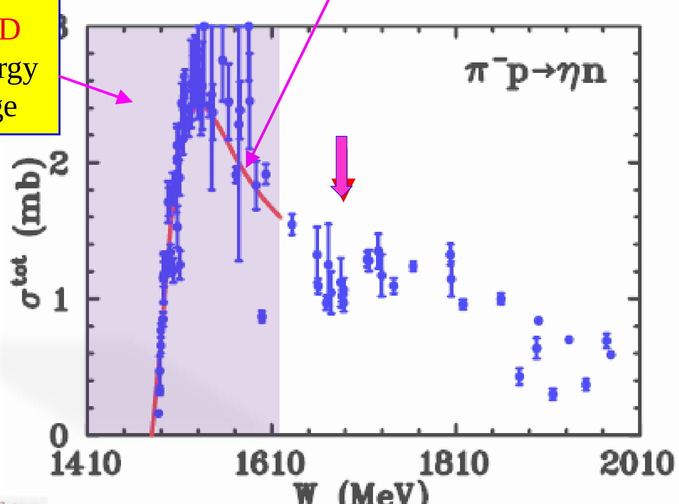
CI=158

$\pi^- p \to \eta n$ *above SAID πN PWA ability*

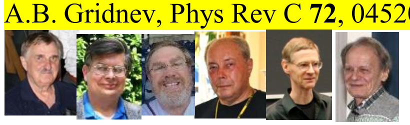


R.L. Workman, R.A. Arndt, W.J. Briscoe, M.W. Paris, & IIS, Phys. Rev. C **86**, 035202 (**2012**). **CI=118**

SAID Energy range



R.A. Arndt, W.J. Briscoe, T.W. Morrison, IIS, R.L. Workman, & A.B. Gridnev, Phys Rev C **72**, 045202 (**2005**) **CI=56**

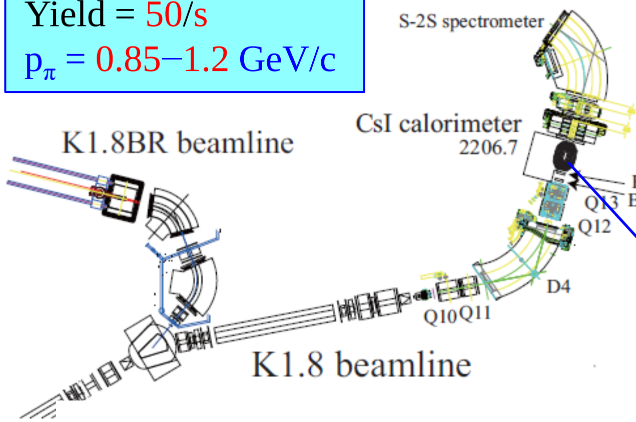


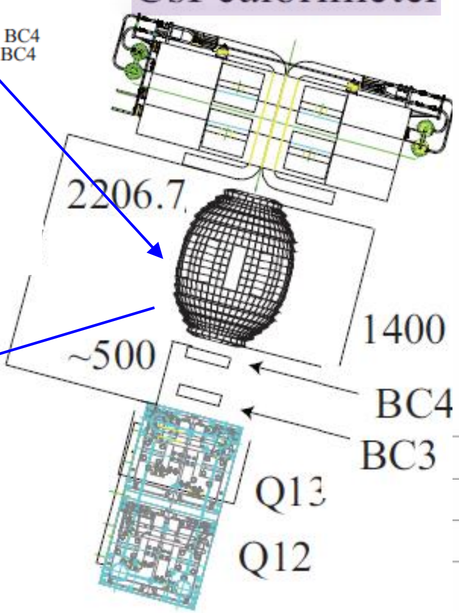
- *SAID* group performed coupled channel analysis of πN system including πp elastic scattering & $\pi^- p \to \pi^0 n$ with $\pi^- p \to \eta n$.
- Attractive factor for reaction $\pi^- p \to \eta n$ is that is playing role of *isospin filtering*.
- Unfortunately, $\pi^- p \to \eta n$ data above 800 MeV (**W** = 1630 MeV) is not reliable for PWA.
- Most of nimrod data does not satisfy requirements:
  - *systematics* is 10% or more,
  - *momentum uncertainties* are up to 100 MeV/c,
  - & so on).
- That is main reason why *SAID* coupled channel analysis had no chance to look for N(1680) using $\pi^- p \to \eta n$ reaction data.

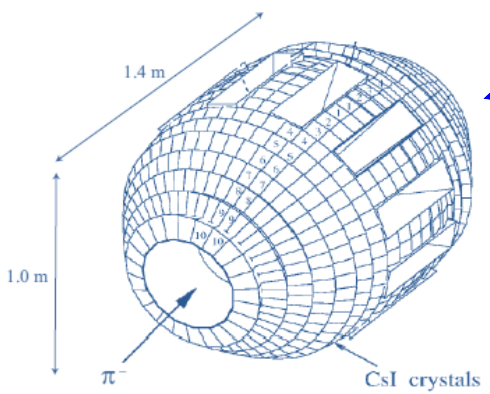
J-PARC for $\pi^- p \to \eta n$

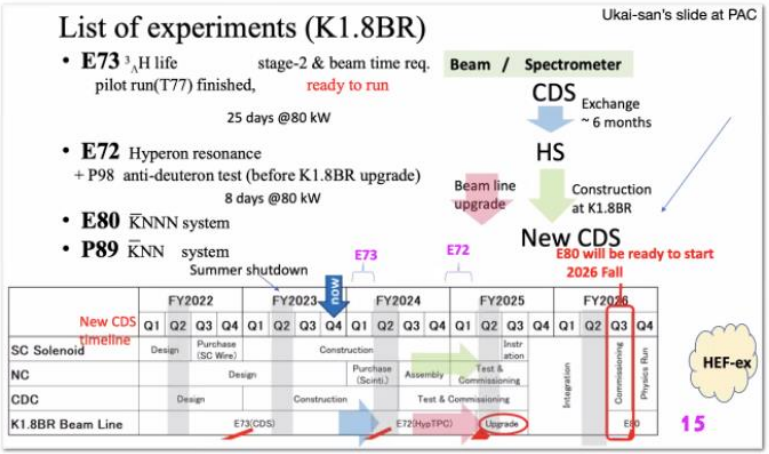
H. Kohri *et al*, J-PARC Proposal **P102** (2023)

K1.8 beamline
Cryo LH_2 target
Cs(Tl) calorimeter
9 days of beam
Yield = 50/s
p_π = 0.85−1.2 GeV/c









	2024	2025	2026	2027	2028	2029
K1.8	E70		E75, E63-R, E45, E90, P102 ??			
K1.8BR	E73	E72	E80 (new CDS)			

Θ+ p

- Expected *decay* properties of N(1680) are essentially model-dependent & *Chiral Quark Soliton* approach with violated $SU(3)_F$ [mixing $N_{10^*} - N_8$] gives:
  - $\Gamma(\eta N)$ ~ 2 MeV
  - $\Gamma(tot)$ ~ 10 MeV

R.A. Arndt, Y.I. Azimov, M.V. Polyakov, IIS, & R.L. Workman, Phys Rev. C **69**, 035208 (**2004**)

- Who can't do that
  - HADES - *Flux* is too low.
  - - *Energy* is low.

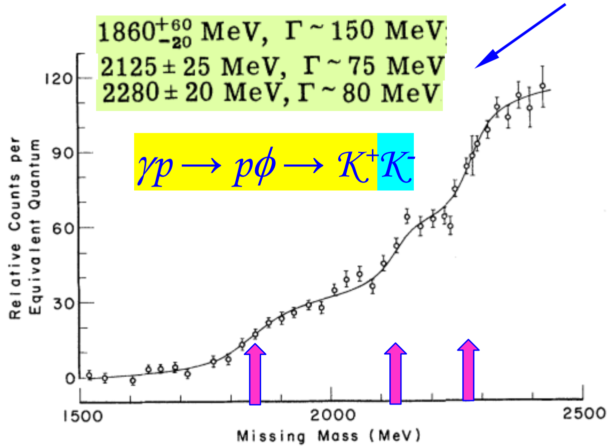
$\Theta^+(1540)$

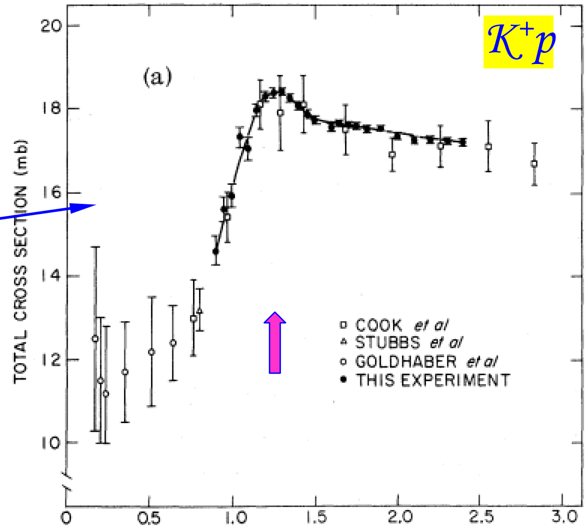
Prehistory of Search for Exotic - I

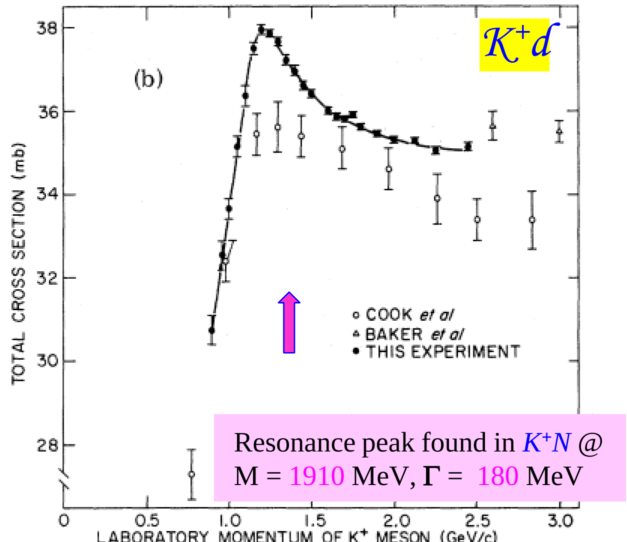
- Problem of observing *multiquark* (*exotic* &/or `*cryptoexotic*') states is as old as *quark* themselves.

- First *experimental* results on search for baryon exotics in *KN* system.

CEA {
R. Cool *et al*, Phys Rev Lett **17**, 102 (**1966**)
R. Abrams *et al*, Phys Rev Lett **19**, 259 (**1967**)
J. Tyson *et al*, Phys Rev Lett **19**, 255 (**1967**)

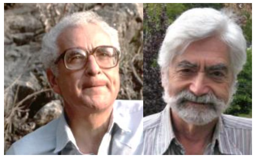






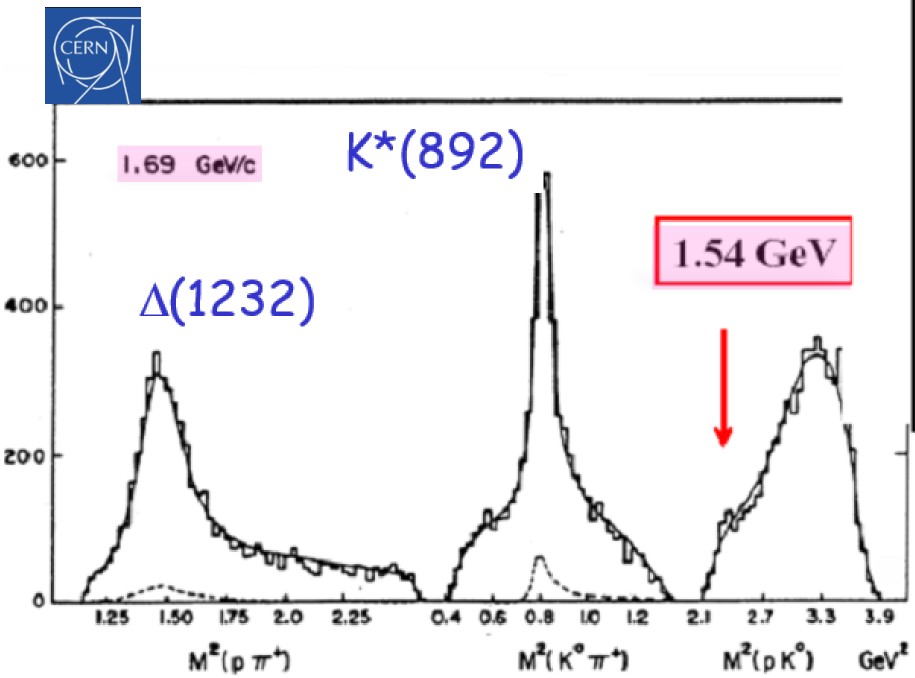
- Were published soon after *invention* of *quarks*.

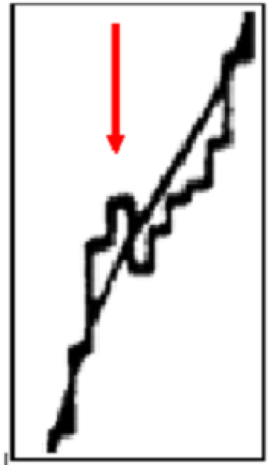
M. Gell-Mann, Phys Lett **8**, 214 (**1964**)
G. Zweig, CERN preprint TH-401, TH-412, **1964**



Prehistory of Search for Exotic - II

Bubble Chamber: $K^+p \to pK^0X$



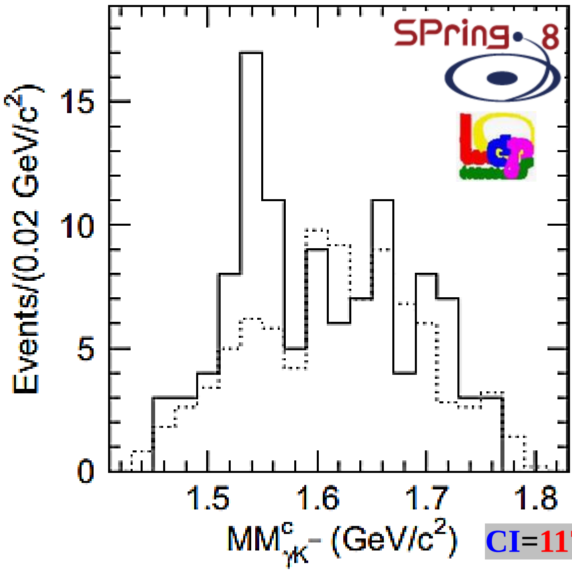


A. Berthon *et al*, Nucl Phys B **63**, 54 (1973)

Unclaimed !

First Experimental Evidences for Θ^+

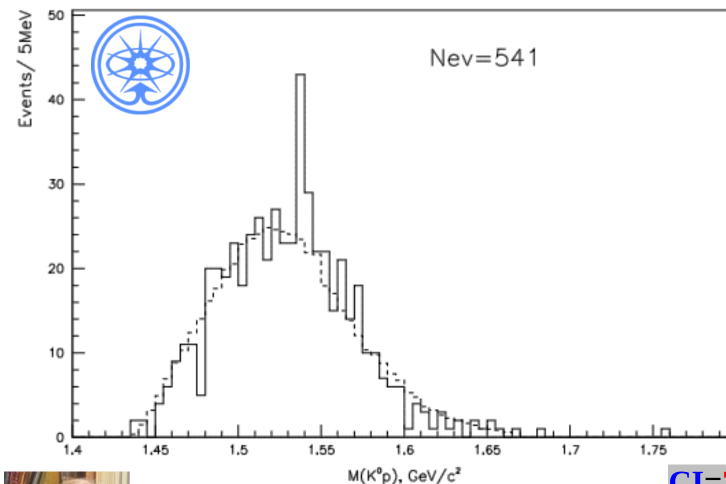
$\gamma n \to K^+K^-n$ reaction on ^{12}C



CI=**1179**

T. Nakano *et al*. Phys Rev Lett **91**, 012002 (**2003**)

$K^+Xe \to K^0pXe'$



CI=**706**

V.V. Barmin *et al*. Phys Atom Nucl **66**, 1715 (**2003**)

$\Gamma(\Theta^+) < 1$ MeV

• Some *theorists* were trying to teach *experimentalists* how to do analysis of data

We use a theoretical model of the $\gamma d \to K^+K^-np$ reaction adapted to the experiment done at LEPS where a peak was observed and associated with the $\Theta^+(1540)$ pentaquark. The study shows that the method used in the experiment to assign momenta to the undetected proton and neutron, together with the chosen cuts, necessarily creates an artificial broad peak in the assumed K^+n invariant mass in the region of the claimed $\Theta^+(1540)$, such that the remaining strength seen for the experimental peak is compatible with a fluctuation of 2σ significance.

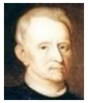
A. Martinez Torres & E. Oset, Phys Rev Lett, **105**, 092001 (**2010**)

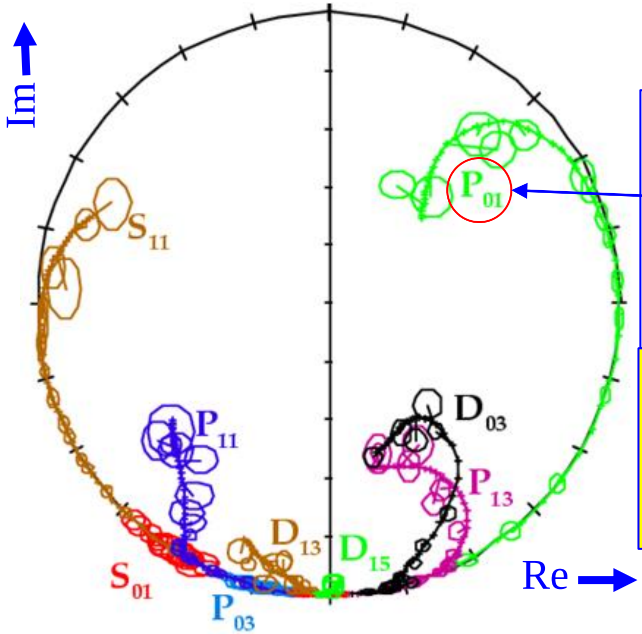
Standard KN PWA

J.S. Hyslop, R.A. Arndt, L.D. Roper, & R.L. Workman, Phys Rev D **46**, 961 (**1992**)

CI=163

T = 0 [20] 1100 MeV

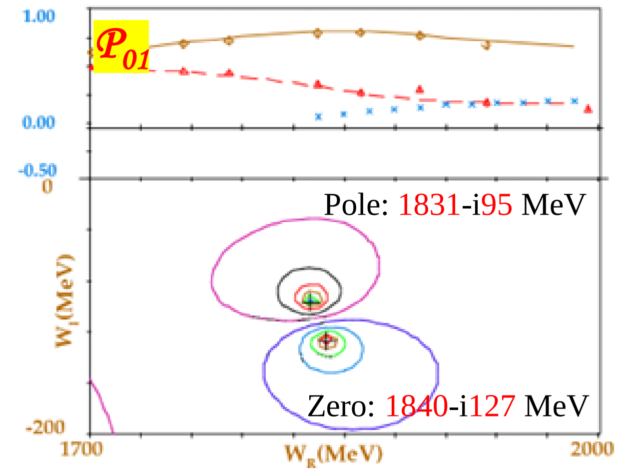


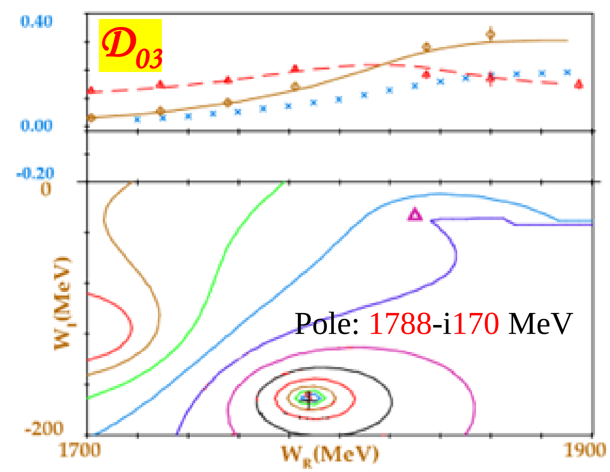


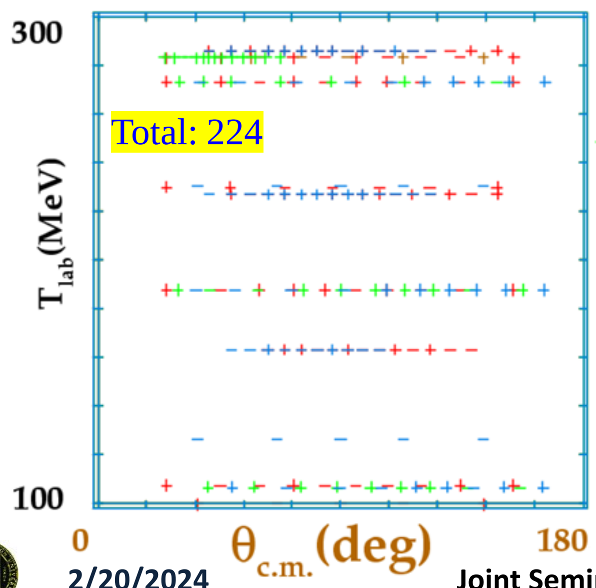
• Pole Positions:

I	Ampl	ReW (MeV)	-ImW (MeV)
0	P_{01}	1831	95
	D_{03}	1788	170
1	P_{13}	1811	118
	D_{15}	2074	253

• All Res in *standard* PWA are too *heavier* & too *broader* than Θ^+.







$K^+n \to K^+n$ – 98
$K^+n \to K^0p$ – 6
$K^+d \to K^0pp$ – 77
$K^+d \to K^+np$ – 43

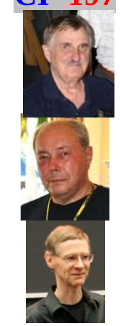
Modified KN PWA for Θ(1540)

R.A. Arndt, IIS, & R.L. Workman, Phys Rev C **68**, 042201(R) (**2003**)

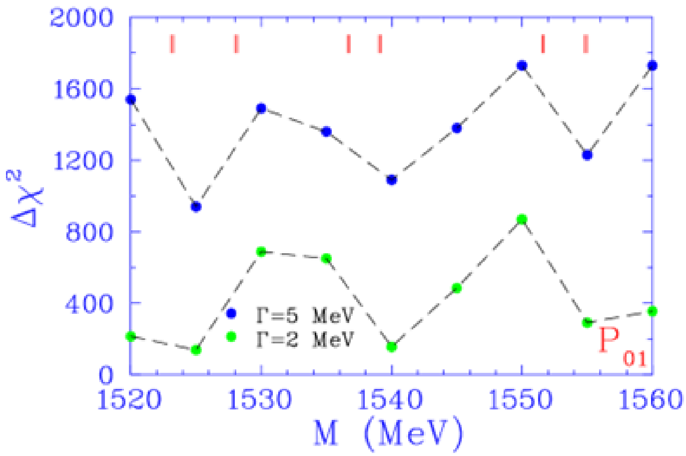
$\Delta\chi^2$ *due to Insertion of Res into Different Waves*

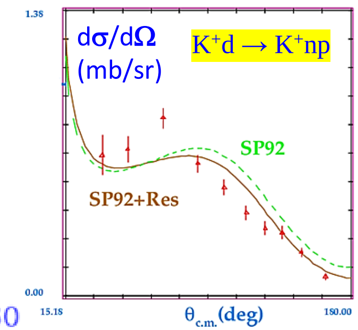
R.A. Arndt, IIS, & R.L. Workman, Phys Rev C **68**, 042201(R) (**2003**)

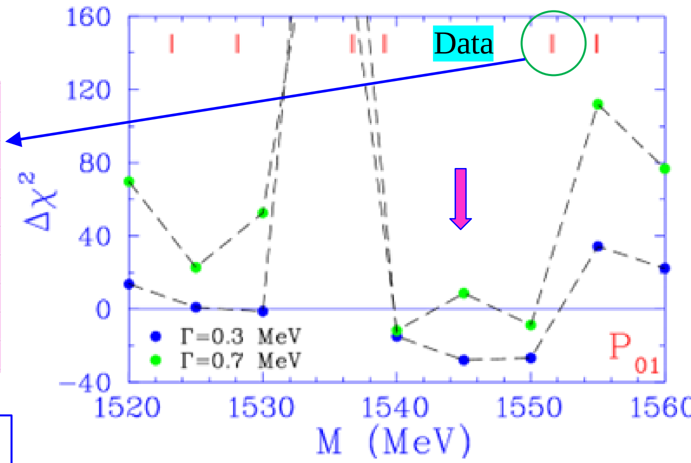
CI=197



P_{01} ($J^P = ½^+$)

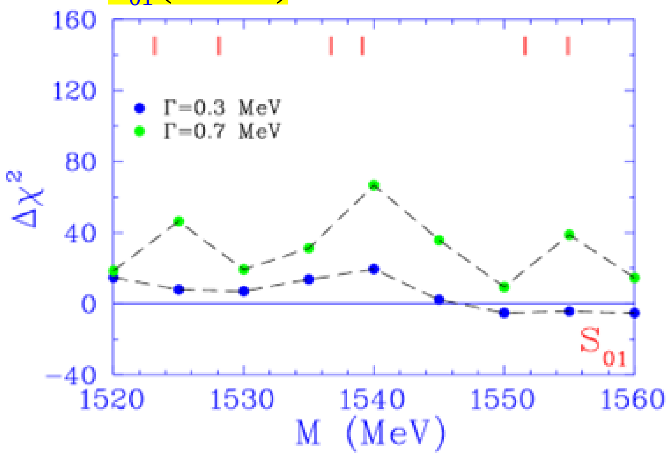




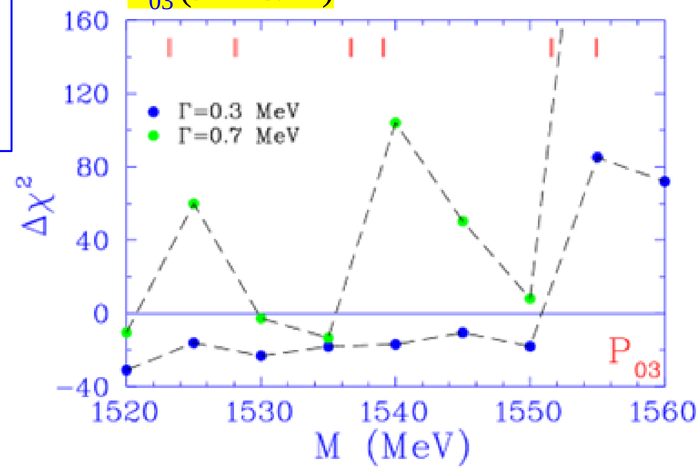


- Res contributes $\sim \Gamma_{el} / (M_R - W)$ @ $|M_R - W| >> \Gamma_R$
- For
  M_R ~ 1545 MeV
  Γ_R < **0.5** MeV

S_{01} ($J^P = ½^-$)



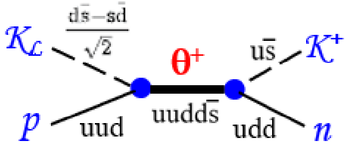
P_{03} ($J^P = 3/2^+$)



For I = 0:
- only one partial wave (P_{01}) admits effect near 1545 MeV: resonance, Γ < **0.5** MeV
- other partial waves (S_{01} & P_{03}) may have the effect only by accompanied by other corrections

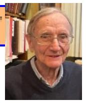
What One Can Expect for $K_L p \to K^+ n$ from K-Long Facility ?

M. Amaryan, S. Hirama, D. Jido, & IIS, e-Print: 2401.05887 [hep-ex]



$P_{01}(J^P = ½^+)$

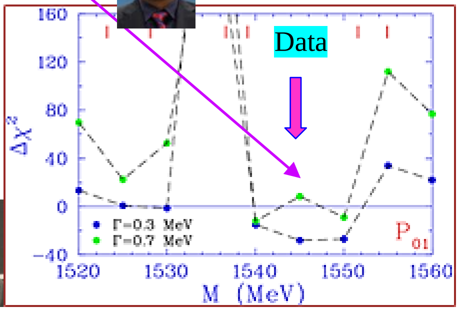
V.V. Barmin *et al* Phys Rev C **89**, 045204 (**2014**): M = **1538**±2 MeV → p_{KL} = **440** MeV/c → k = **0.268** GeV/c & **Γ** = **0.34**±0.10 MeV $K^+Xe \to K^0pXe'$



Ghil-Seok Yang & Hyun-Chul Kim, PTEP **2013**, 013D01 (**2013**) ChSA: **Γ** = **0.5**±0.1 MeV

R.A. Arndt, IIS, & R.L. Workman, Phys Rev C **68**, 042201(R) (**2003**): Modified **KN PWA** gave: **Γ** < **0.5** MeV @ **M** ~ **1545** MeV

Assuming θ^+ width **Γ** = 0.4 MeV

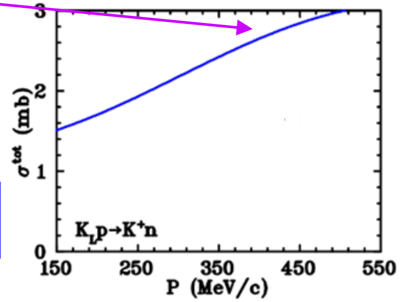


R.N. Cahn & G.H. Trilling, Phys Rev D **69**, 011501(R) (**2004**)

$$\sigma_0 = \frac{2J+1}{(2s_{K_L}+1)(2s_p+1)}\frac{4\pi}{k^2} = 68 \text{ mb}$$

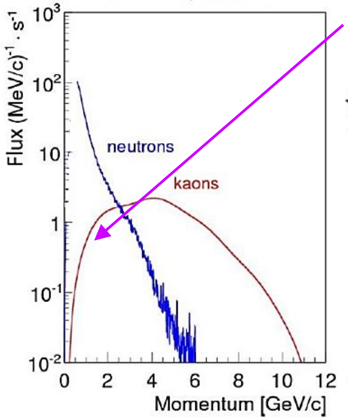
Y. Iizawa, D. Jido, & S. Huebsch, [arXiv:2308.09397 [hep-ph]]: Assuming bkgd Xsec @ 440 MeV/c

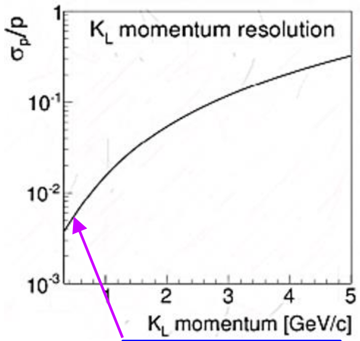
σ_0 = **3** mb



e-Print: 2008.08215 [nucl-ex]

@ 1 MeV/c bin & flux = 0.1 $(\text{MeV/c s})^{-1}$.
It means - we will have **~10^6 K_L/100 days**.

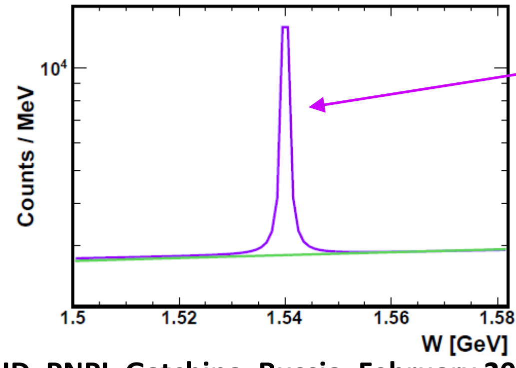




$\sigma_p/p = 6 \times 10^{-3}$

10,000

$$N_{peak} = \frac{\Gamma(\Theta^+)\ \pi\sigma_0\ N_{bkgd}\ B_i B_f}{2\sigma_{bkgd}\ \Delta m_0} = 18,000 \text{ events}$$



18k events in peak in **100** days.
Taking into account
- acceptance &
- efficiency of kaon registration,

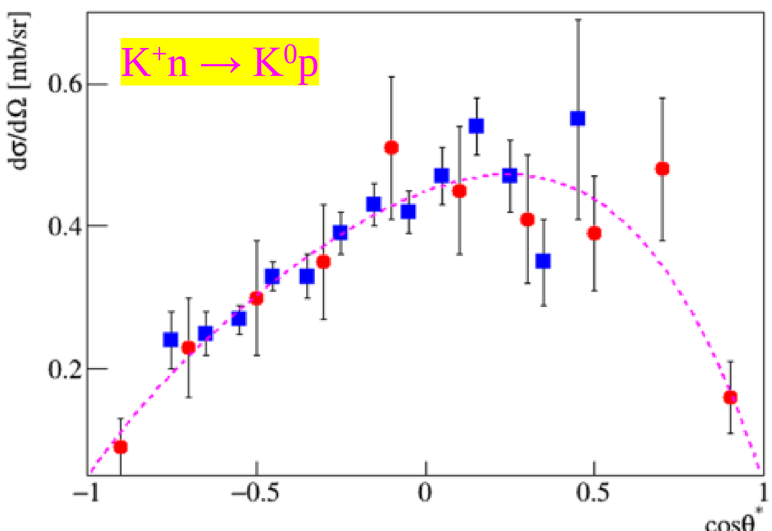
One can expect **100** events per day.

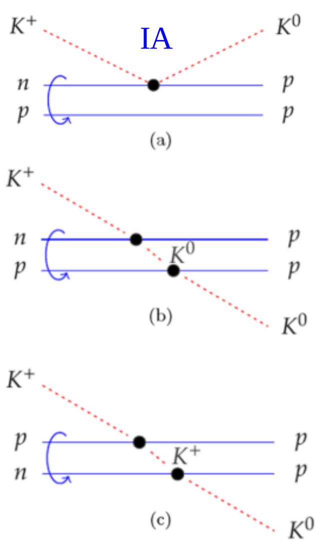
$R = S/B = 4/1$

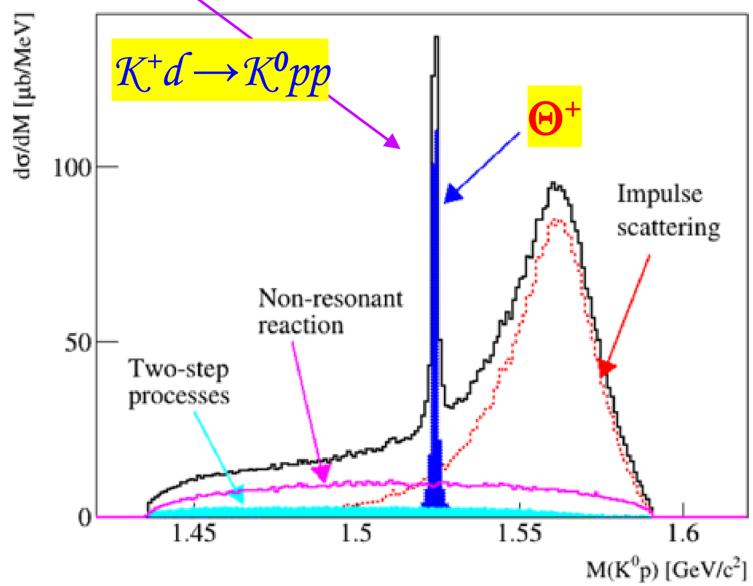
$K^+d \rightarrow K^0pp$ for J-PARC

J.K. Ahn & S.H. Kim, J. Korean Phys. Soc. **82**, 579 (**2023**).

We propose to search for Θ^+ in $K^+d \rightarrow K^0pp$ reaction at p_{K^+}=0.5 GeV/c at J-PARC. A large acceptance Hyperon Spectrometer, which consists mainly of a time projection chamber and a 1-T superconducting magnet, will exclusively measure the decay products of Θ^+, such that $\Theta^+ \rightarrow K^0p$, followed by $K^0 \rightarrow \pi^+\pi^-$, with a mass resolution of 1 MeV at M_Θ. We investigated the feasibility of the proposed experiment using a Monte Carlo simulation. As a result, we expect to collect five orders of magnitude Θ^+ events, assuming a cross section of 300 μb in 15-day beam time at J-PARC.







■ @ 0.434 GeV/c C.J.S. Damerell et al, Nucl Phys B **94**, 374 (**1975**)

● @ 0.470 GeV/c R.G. Glasser et al., Phys. Rev. D **15**, 1200 (**1977**)

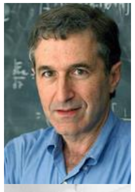
- Expectation is 137,000 Θ^+ events

If Θ^+ does not Survive, `Damned' Questions Revive:

- *Why are there no strongly bound exotic states…, like those of two quarks and two antiquarks or four quarks and one antiquark?*

H. Lipkin, Phys Lett **45B**, 267 (**1973**)

- *…either these states will be found by experimentalists, or our confined, quark-gluon theory of hadrons is as yet lacking in some fundamental, dynamical ingredient which will forbid the existence of these states or elevate them to much higher masses.*



R. Jaffe & K. Johnson, Phys Lett **60B**, 201 (**1976**)

Where We are Going

Beam Time Approved by PAC48

- Expected cornucopia of differential cross sections of different reactions with LH_2 & below W = *2.5* 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

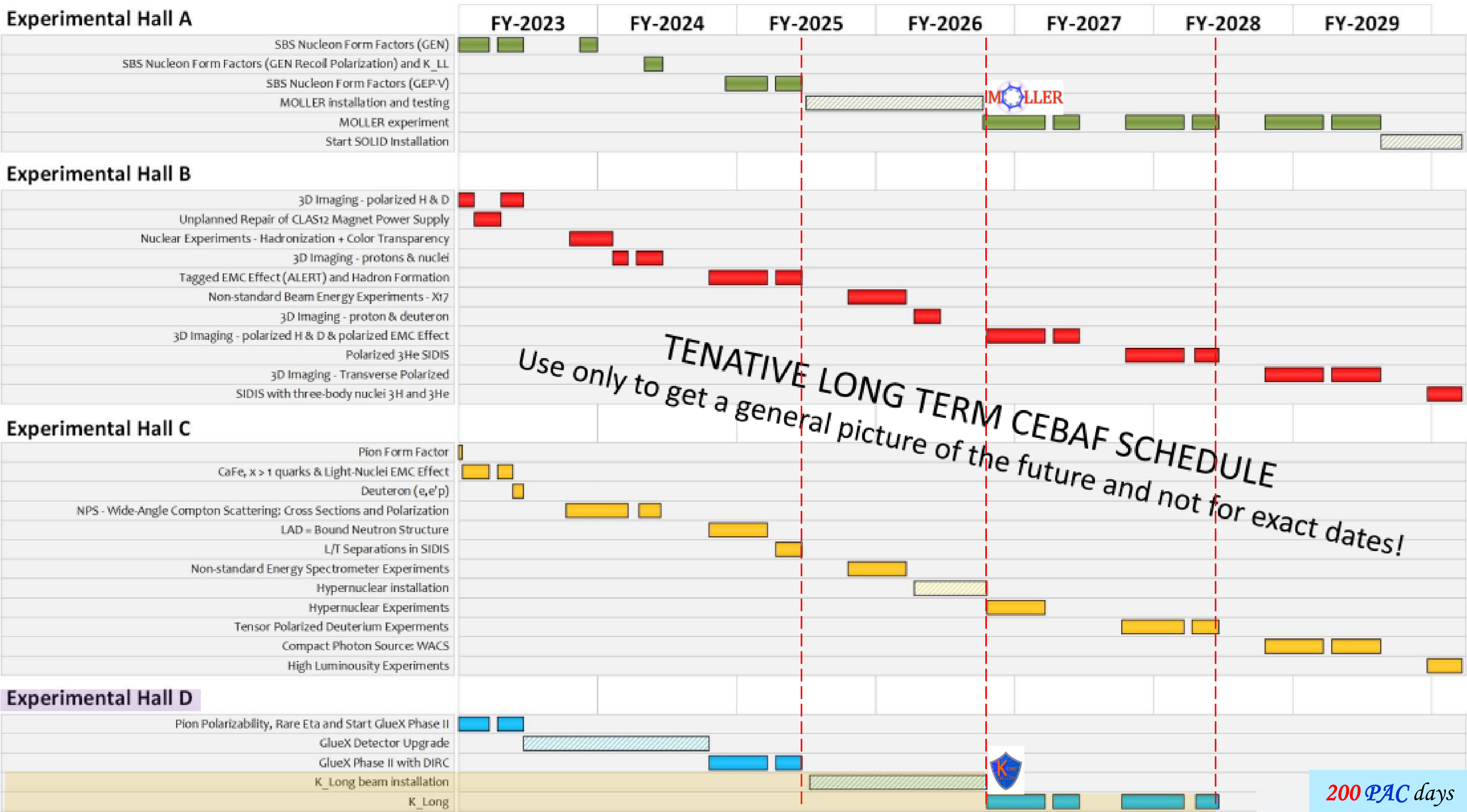
For ***P*****,** statistics is 0.2M

- 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 *cryo* targets.

- Expected systematics for dσ/dΩ is *10*% or less.

Hall D Tentative Schedule

Safety Pauses Shifted Upcoming Schedule Out By Two Months And Is Not Yet Shown On This Figure.



Courtesy of Doug Higinbotham, **Sept 2023**

- Our goal is
  - To setup *KL Facility* @ Jefferson Lab
  - To measure & bring *new physics*.

Experiment was approved in **08/20**.
ERR-I was approved in **08/23**,
ERR-II may come in 06/24.

- Jefferson Lab KLF would advance *Hyperon Spectroscopy* & study of *strangeness* in nuclear & hadronic physics.
  We may have cornucopia of many missing/new strange states.
  To complete ***SU(3)***$_F$ *multiplets*, one needs no less than 48 Λ^*, 38 Σ^*, 61 Ξ^*, & 31 Ω^*.

- Discovering of ``*missing*" *hyperon states* would assist in advance our understanding of formation of *baryons* from *quarks* & *gluons* *microseconds* (!) after *Big Bang*.

Our expectation is to get **1** missed/new *hyperon* per **1** day.

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


BACKUP

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!

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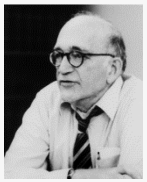
(Received 6 January 1965)



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.

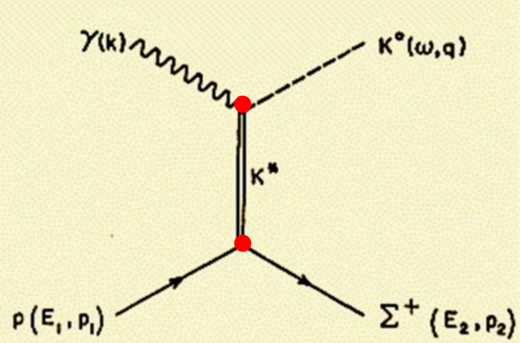


FIG. 1. K^* exchange in photoproduction.

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.

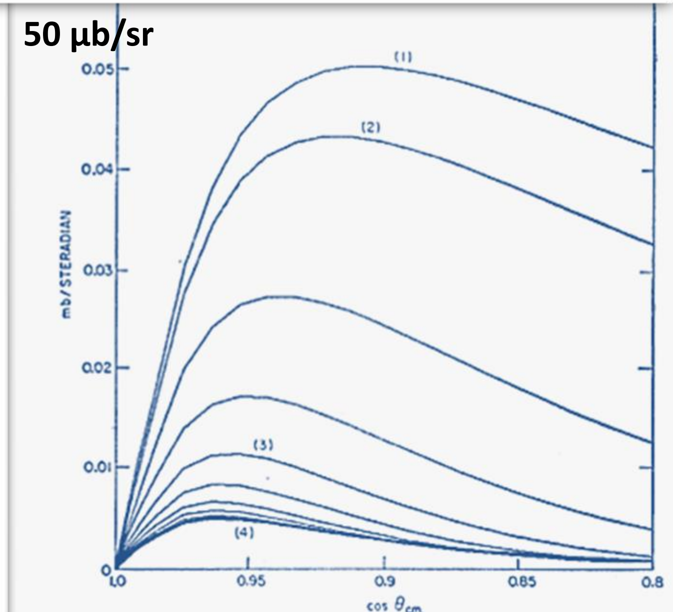


FIG. 3. Center-of-mass differential cross section at 10 BeV. Curve (1) gives the Born approximation. Curve (2) is obtained after subtraction of the $j=\frac{1}{2}$ partial wave. Curves (3) and (4) are respectively obtained after the $j=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$, and all partial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

Courtesy of Mike Albrow, KL2016

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

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 26**th let me know, it would be **strange synchronicity**!*

8.B.5
8.B.6

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PHOTOPRODUCTION OF K^0 MESONS FROM PROTONS AND FROM COMPLEX NUCLEI

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Received 16 July 1970

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*

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
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(Received 13 March 1969)

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

Kinematics for $K_L p \to K^+ n$ & $K_L p \to p K_S$