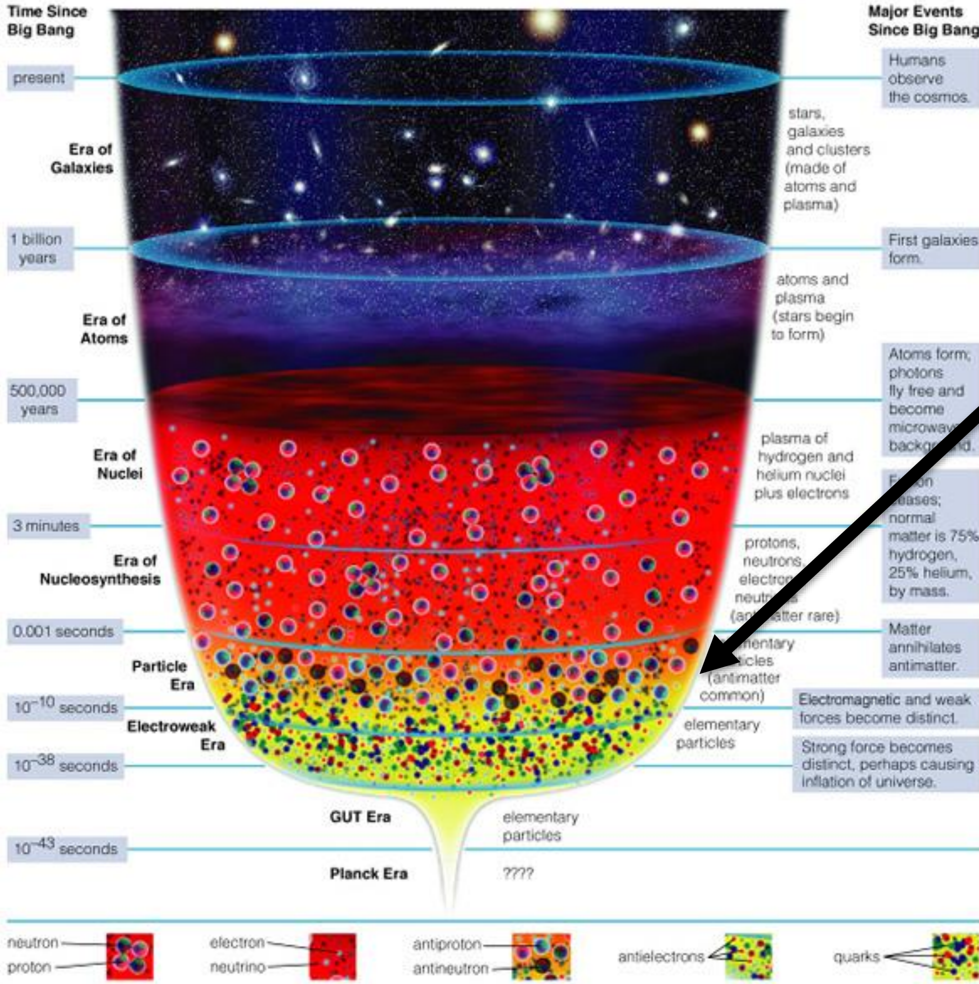
K_L-Facility

Mikhail Bashkanov

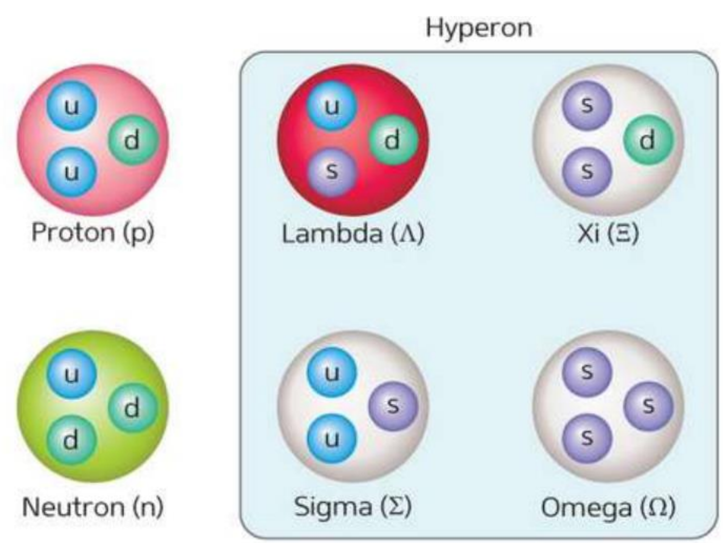
Outlook

- Why kaon beam is crucial?
- Why strangeness?
- K_L Facility in a Nutshell
- Strange baryons
- Exotic states
- Rare decays - Standard Model and Beyond

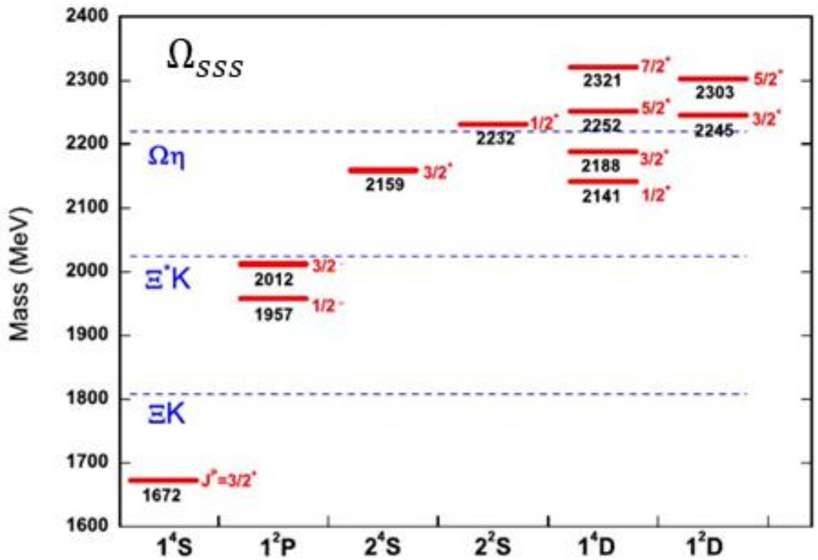
The Early Universe was Strange

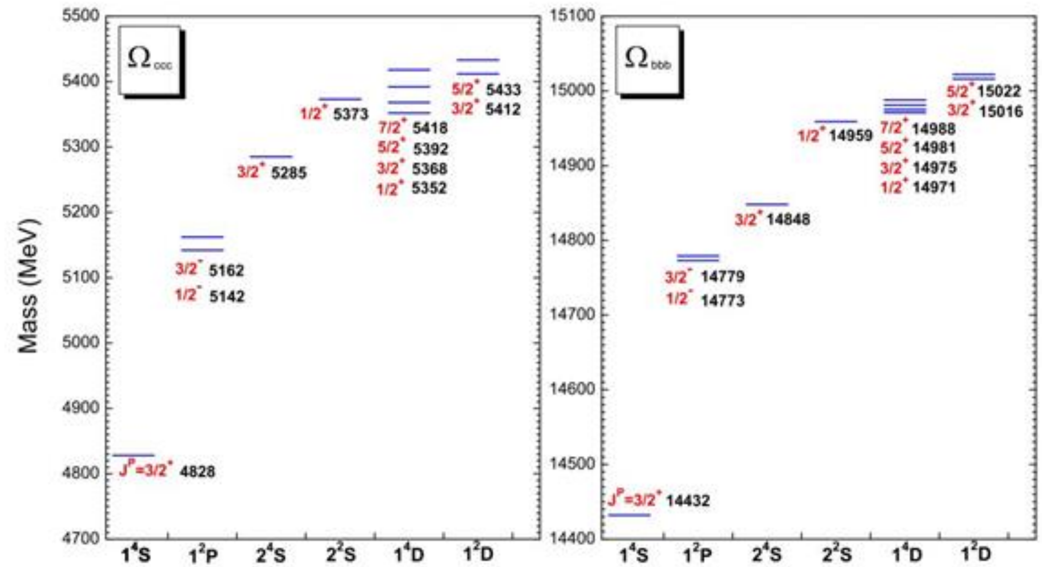


Nearly equal amount of u,d,s quarks

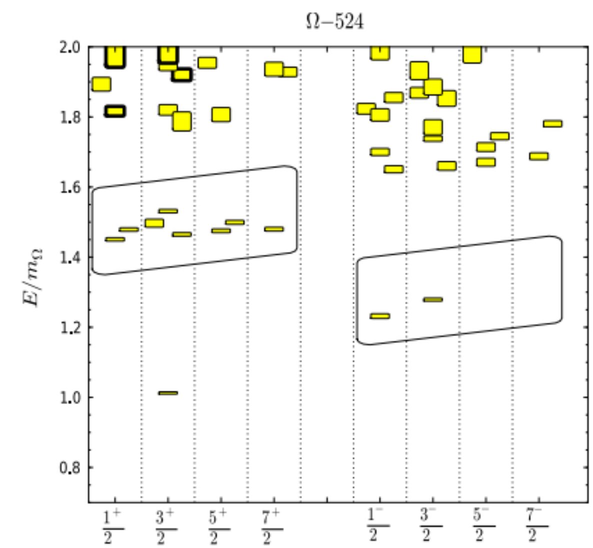


Fingerprints of QCD

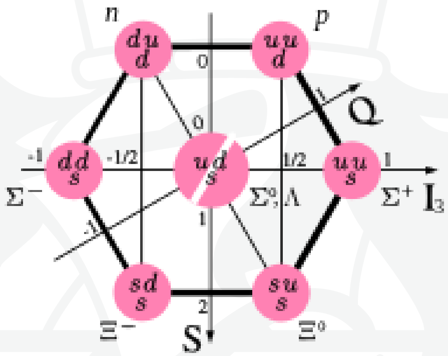




- Lattice QCD predictions are more accurate for "strange" sector compare to "light"
- Production rates are higher than charm/bottom
- The early Universe cooling
- Level splitting is optimal

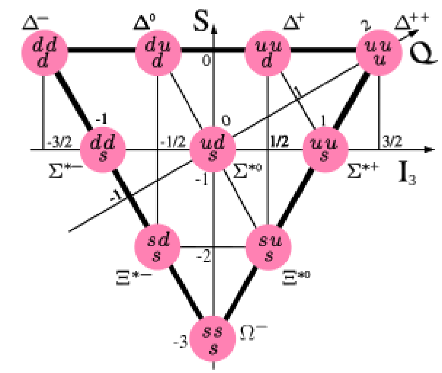


Hyperons



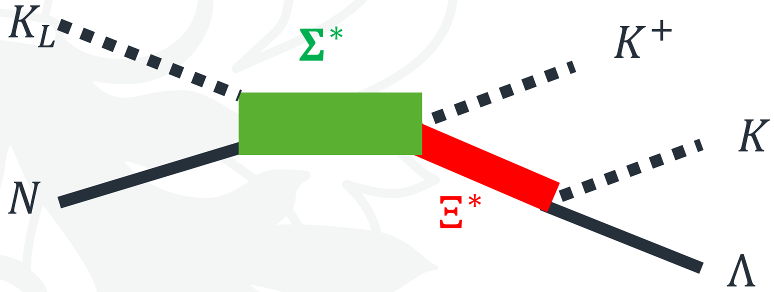
Octet: N^*, $\boldsymbol{\Lambda}^*$, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$

Decuplet: Δ^*, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$, $\boldsymbol{\Omega}^*$

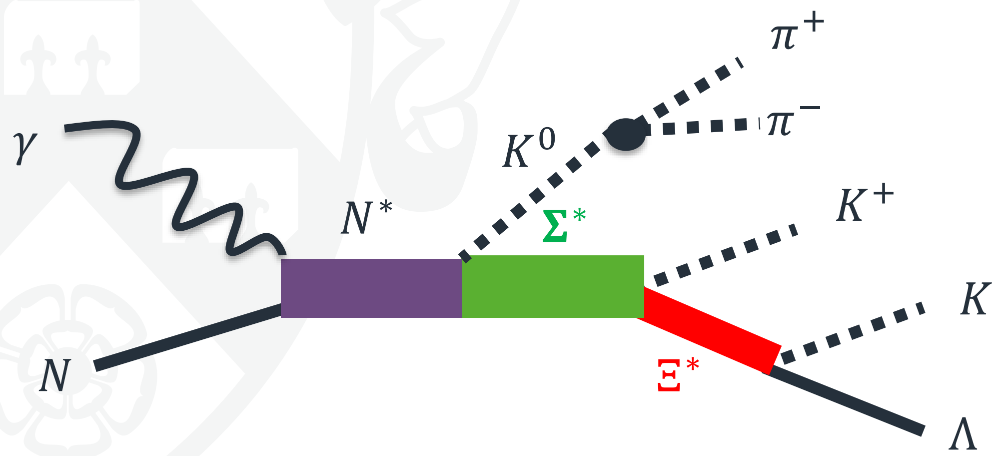


	Predicted LQCD, $M_B < 2.5\ GeV$	"Observed", PDG
N^*	64	21
Δ^*	22	12
$\boldsymbol{\Lambda}^*$	**17**	**14**
$\boldsymbol{\Sigma}^*$	**43**	**9**
$\boldsymbol{\Xi}^*$	**42**	**6**
$\boldsymbol{\Omega}^*$	**24**	**2**

Strange beams?



Direct Σ^* production

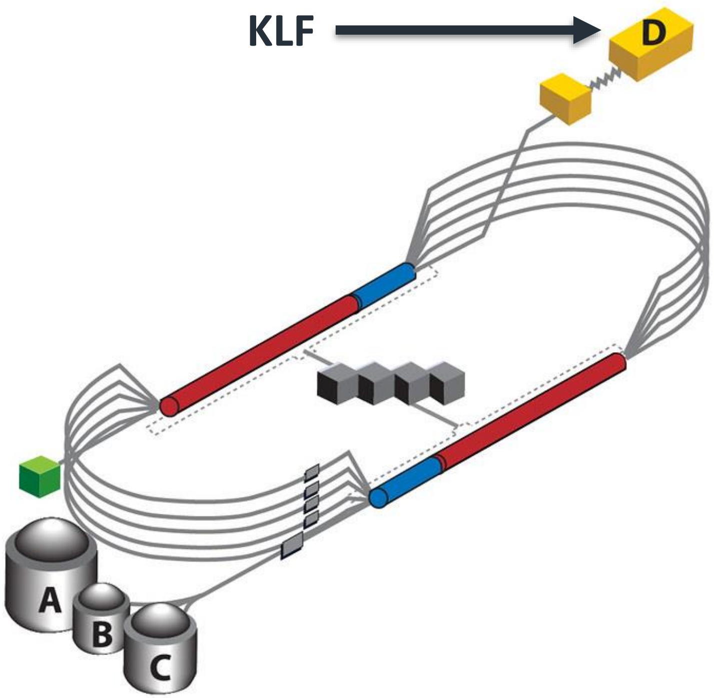


Associated production

K_L beams - How?

KLF, step 1 (CEBAF)

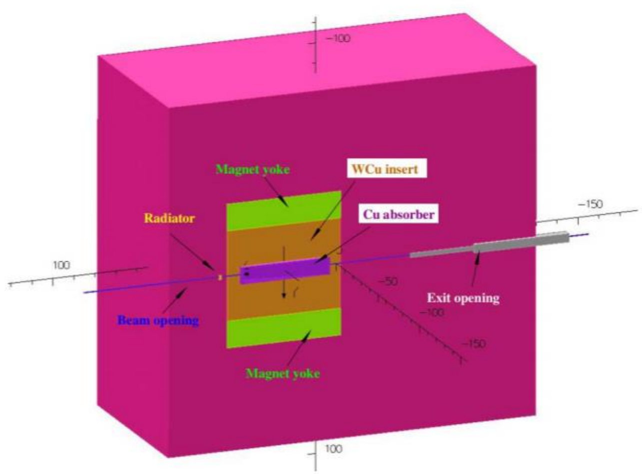
JLAB



Electron Beam:

- 12 GeV
- $5\mu A$
- 64 ns bunch spacing

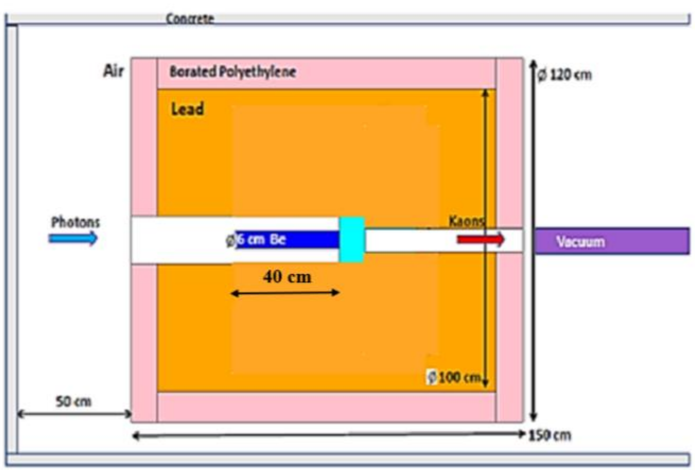
KLF, step 2 (Compact Photon source)



CPS:

- 10% RL copper radiator
- 60kW heat
- ~100t shielding
- Brightest manmade source of photons of these energies

KLF, step 3 (K_L production target)

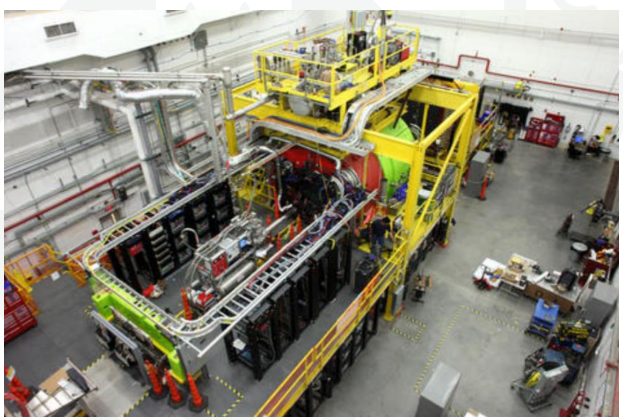


K_L production target:

- 40 cm Be
- 6kW heat
- ~12t shielding
- $10^4 - 10^5$ Kaons per second

KLF, step 4 (GlueX)

24m time-of -flight



GlueX:

- 4pi coverage
- Both neutral and charged particles
- Nice PID
- K_L energy reconstruction from ToF

KLF highlights

Proposal for JLab PAC48

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

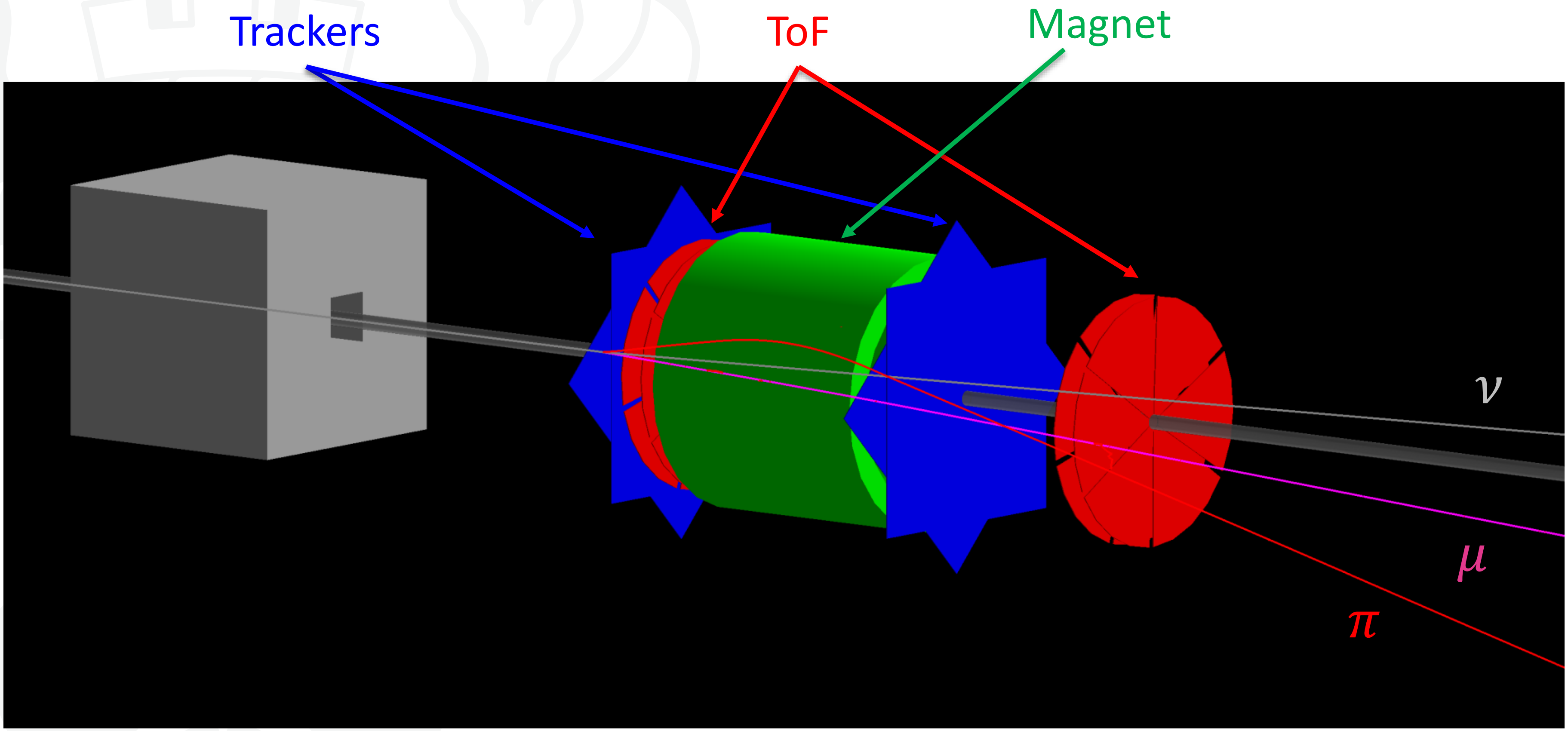
Shankar Adhikari[43], Moskov Amaryan (Contact Person, Spokesperson)[43], Arshak Asaturyan[1], Alexander Austregesilo[49], Marouen Baalouch[8], Mikhail Bashkanov (Spokesperson)[63], Vitaly Baturin[43], Vladimir Berdnikov[11,35], Olga Cortes Becerra[19], Timothy Black[60], Werner Boeglin[13], William Briscoe[19], William Brooks[54], Volker Burkert[49], Eugene Chudakov[49], Geraint Clash[63], Philip Cole[32], Volker Crede[14], Donal Day[61], Pavel Degtyarenko[49], Alexandre Deur[49], Sean Dobbs (Spokesperson)[14], Gail Dodge[43], 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[24], 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[43], 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[49], Sebastian Kuhn[43], Sergey Kuleshov[2], Alexander Laptev[33], Ilya Larin[26,59], 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[40], 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[24], Holly Szumila-Vance[19], Daniel Watts[63], Lawrence Weinstein[43], Timothy Whitlatch[49], Nilanga Wickramaarachchi[43], Bogdan Wojtsekhowski[49], Nicholas Zachariou[63], Jonathan Zarling[53], Jixie Zhang[61]

Theoretical Support:

Alexey Anisovich[5,44], Alexei Bazavov[38], Rene Bellwied[21], Veronique Bernard[42], 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[44], 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[34], 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[5,44], Jugoslav Stahov[55], Alfred Švarc[47], Adam Szczepaniak[22,49], Ronald Workman[19], Bing-Song Zou[4]

- Largest collaboration at proposal stage
- ~$2 for the beamline modifications & new targets
- 200 days allocated beamtime
- >1Bn kaons/day
- 3 OoM higher Kaon tagged flux

Flux Monitor



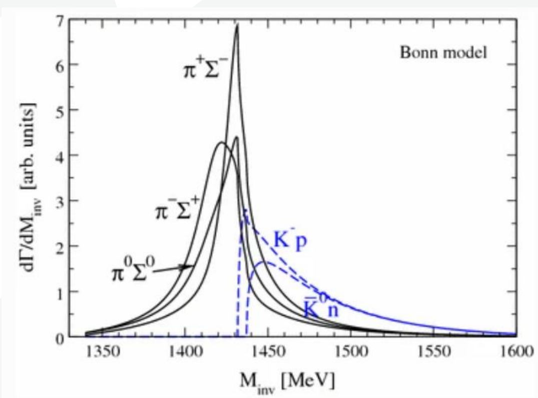
UK contribution

Strangeness – a new window into QCD exotics

Strangeness is a key

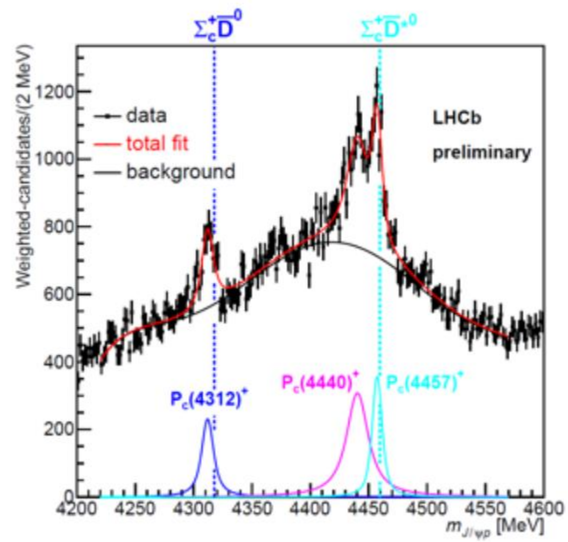
- Many thresholds
  - Cusps
  - Molecules
  - Tetraquarks
  - Pentaquarks
  - Hexaquarks

$\Lambda_b \to J/\psi\Lambda(1405)$



•L. Roca, M. Mai, E. Oset & Ulf-G. Meißner

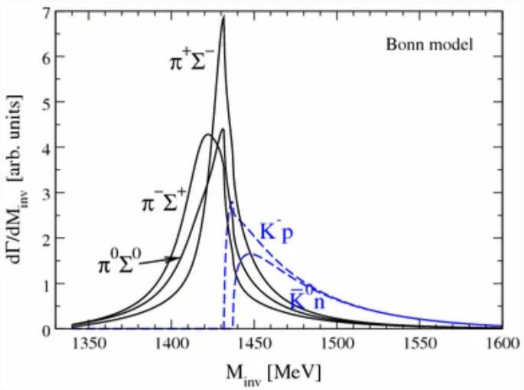
$\Lambda(1405) \leftrightarrow \pi\Sigma/\bar{K}N$-molecule



$\mathrm{P}(4450) \leftrightarrow \bar{\mathrm{D}}^*\Sigma_c$-molecule

Molecules and cusps

$\Lambda_b \to J/\psi\Lambda(1405)$



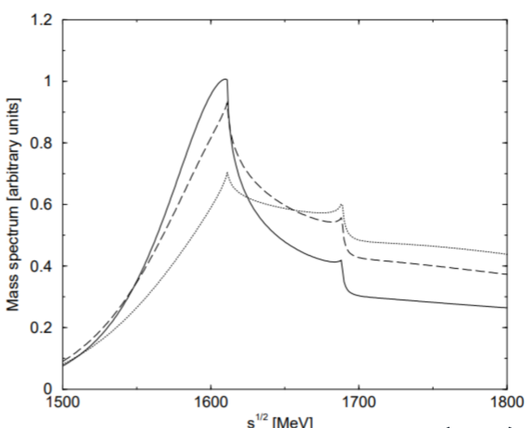
•L. Roca, M. Mai, E. Oset & Ulf-G. Meißner

- Many thresholds
  - Cusps
  - Molecules
  - Dynamic resonances

- $\Lambda(1670)$, $\bar{K}N$ vs $\pi\Sigma$ vs $\eta\Lambda$
- $\Sigma(1620)$

States?
Decay channels?
Resolution?

$\Xi(1620)$



$\Xi\pi, \Lambda\bar{K}, \Sigma\bar{K}, \Xi\eta$

$M(\Xi\pi)$

A. Ramos, E. Oset , C. Bennhold

Strangeness is a key

- Many thresholds
  - Cusps
  - Molecules
  - Dynamic resonances

Light quark sector:

+ high statistics
+ easy to produce
- too broad
- too many interferences

Strange sector:

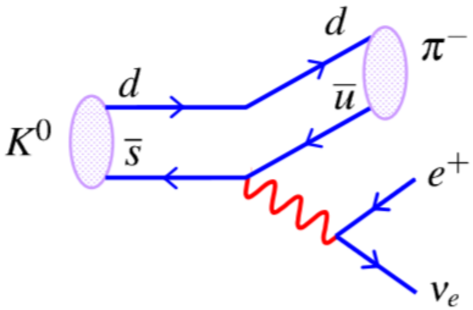
+ high statistics
+ easy to produce with K_L
+ perfect width
+ decent spacing

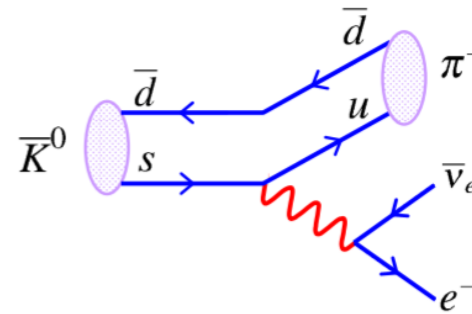
Heavy quark sector:

- low statistics
- hard to produce
- too narrow

Standard Model and Beyond

CP in K_L





$$K^0 \to \pi^- e^+ \nu_e$$
$$\overline{K^0} \to \pi^+ e^- \overline{\nu_e}$$

$$K_L = \frac{1}{\sqrt{2(1+|\epsilon|^2)}}\left((1+\epsilon)K^0 - (1-\epsilon)\overline{K^0}\right)$$

$|\epsilon| \sim 6.6 \cdot 10^{-3} \to$ CP is violated !

KLF: 1Bn K_L per day

Rare decays

- Firs ever measurement of KL beta decay
- Physics beyond SM
  - Rare final state
  - Precise calculations

K_L beta-decay

$$K_L \rightarrow K^+ e^- \overline{\nu_e}$$
$$K_L \rightarrow K^- e^+ \nu_e$$

$M(K_L) = 497.611\ MeV$
$M(K^{+/-}) = 493.696\ MeV$
$M(e^{+/-}) = 0.511\ MeV$
Available Phase Space **$3.4\ MeV$**

BUT!!!

- In flight decay (boosted)
- Can build dedicated detector
- Br$(K^0 \rightarrow K^{\pm} e^{\mp}\ \nu) \sim 10^{-9}$ (N.N. Shishov, Yad. Phyz. 82, 86, (2019))
- ~50 decays per beamtime

Science landscape with KLF

- Hyperon structure and interactions
- QCD exotics in a strange sector
- Physics beyond SM
  - K_L CP-violating decays
  - K_L rare decays
- K_L -> nuclear physics
  - Hypernuclei
- Clean tagged neutron beam
  - Nuclear reactions
- Intense photon beam
  - Spallation source

Conclusion

- KL beam facility is under construction
- Commencing 2026 – largest collaboration in JLab history
- Exciting possibilities to elucidate strange quark sector
  - Up to 1 new particle per week of beamtime
- Technical design/prototyping/construction

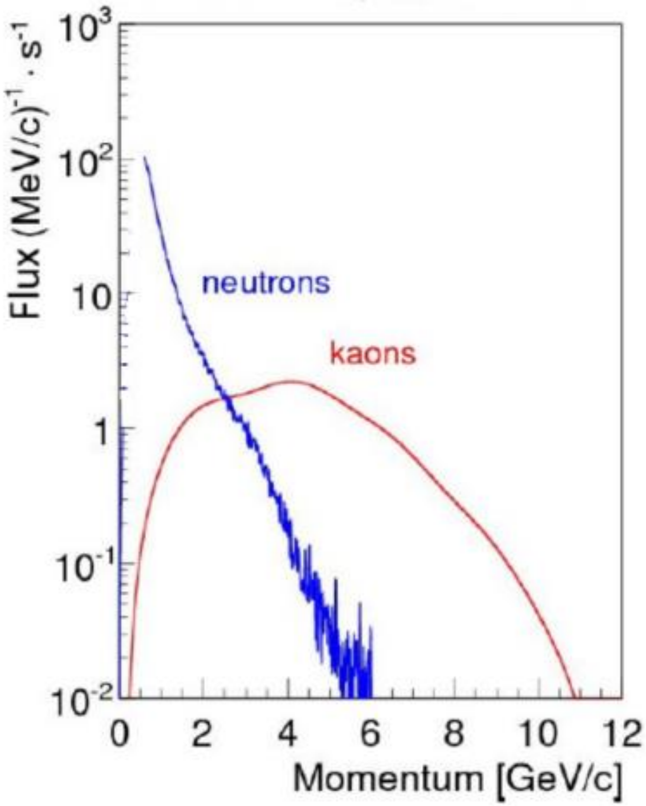
New collaborators welcome!!!

More information at https://wiki.jlab.org/klproject

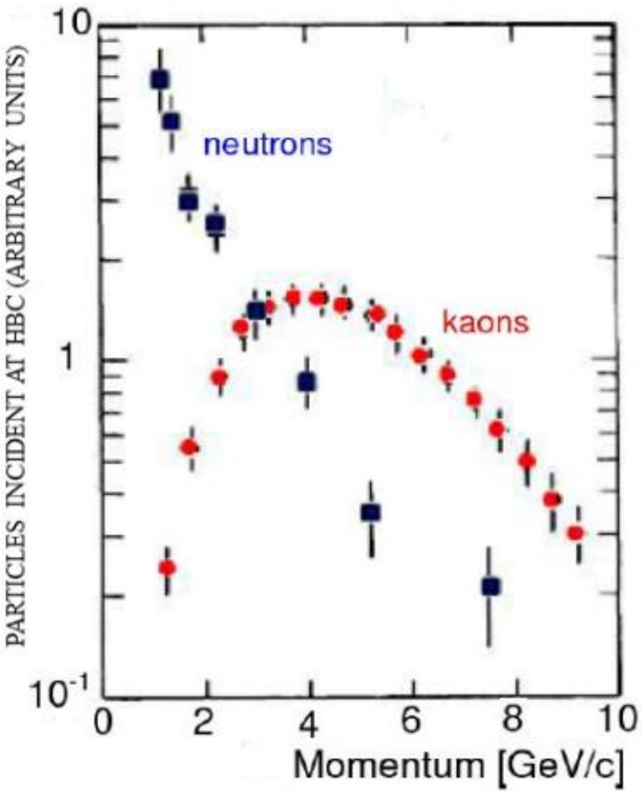
Back up slides

KLF beams

KLF (simulation)



SLAC (measurements)



Sigma factory

$K_L p \rightarrow K_s p$
$K_L p \rightarrow \pi^+ \Lambda$
$K_L p \rightarrow K^+ \Xi^0$
$K_L p \rightarrow \pi^0 \Sigma^+$
$K_L p \rightarrow \eta \Sigma^+$
$K_L p \rightarrow \omega \Sigma^+$
$K_L p \rightarrow \eta' \Sigma^+$

2 Body Final state
Pure Σ^* channels
Self-polarising observables

$K_L p \rightarrow K^+ n$

Non-resonant background

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

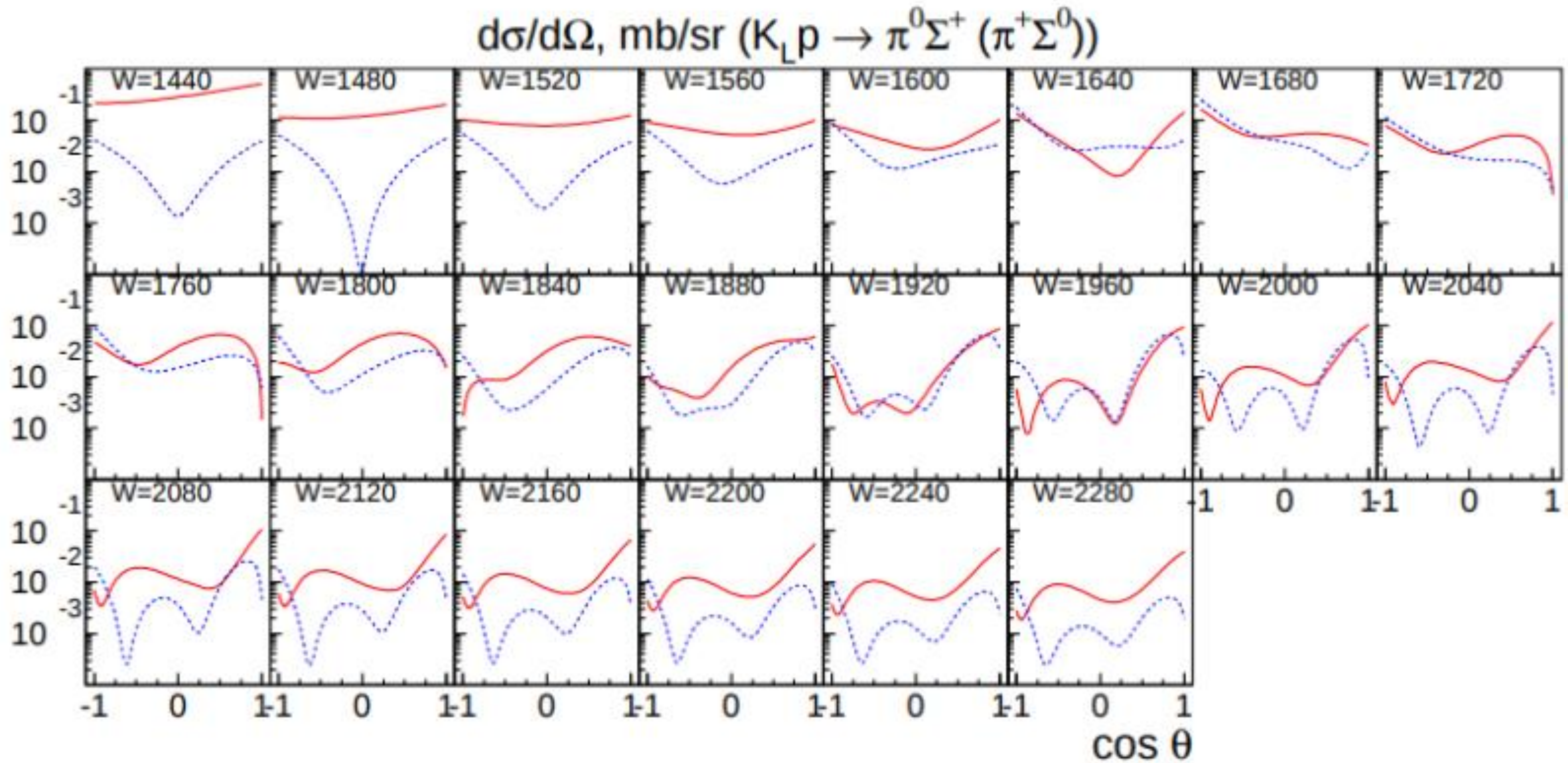
Isospin amplitudes

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

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

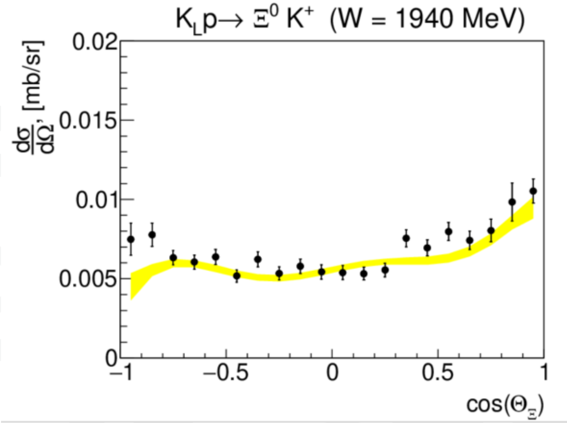
$$|A(K^0p)|^2 = |A_1|^2.$$

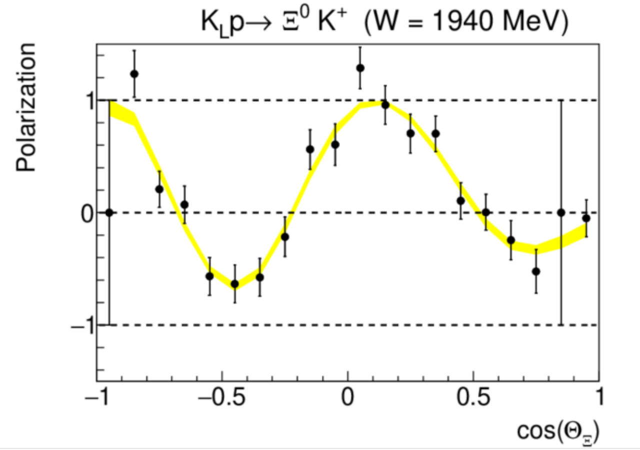
arXiv:2008.08215v3
KLF proposal 2020

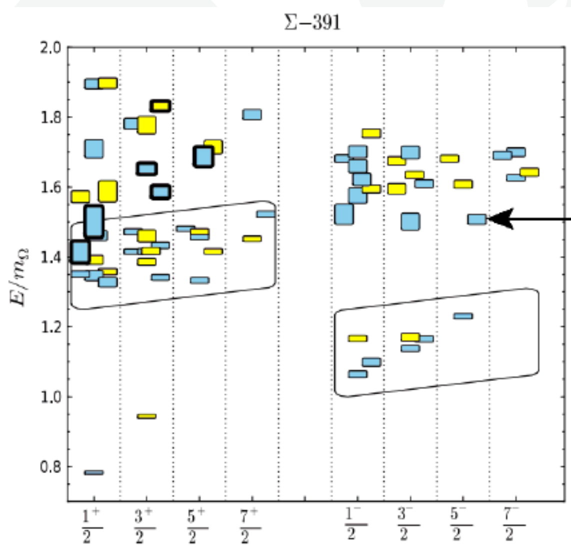


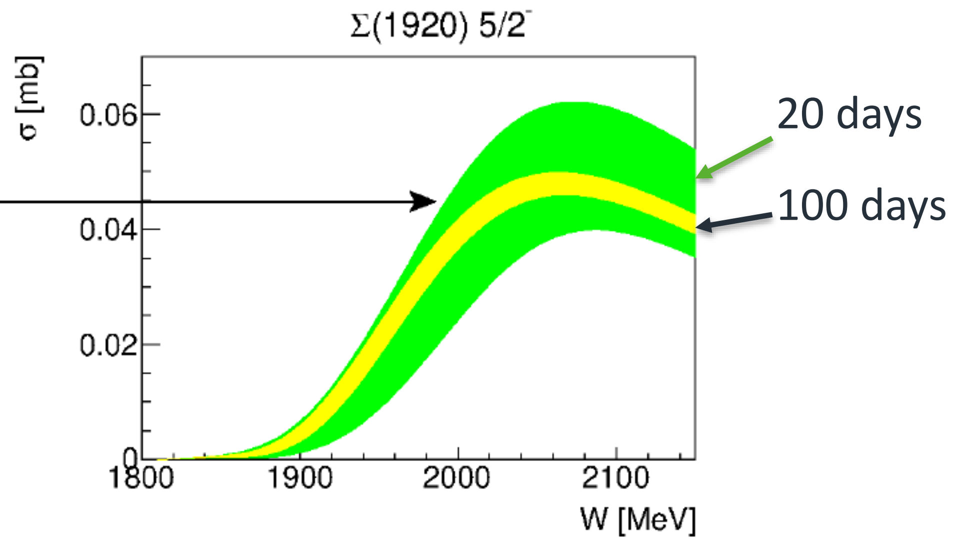
Expected results

$K_L p \rightarrow K^+ \Xi^0$

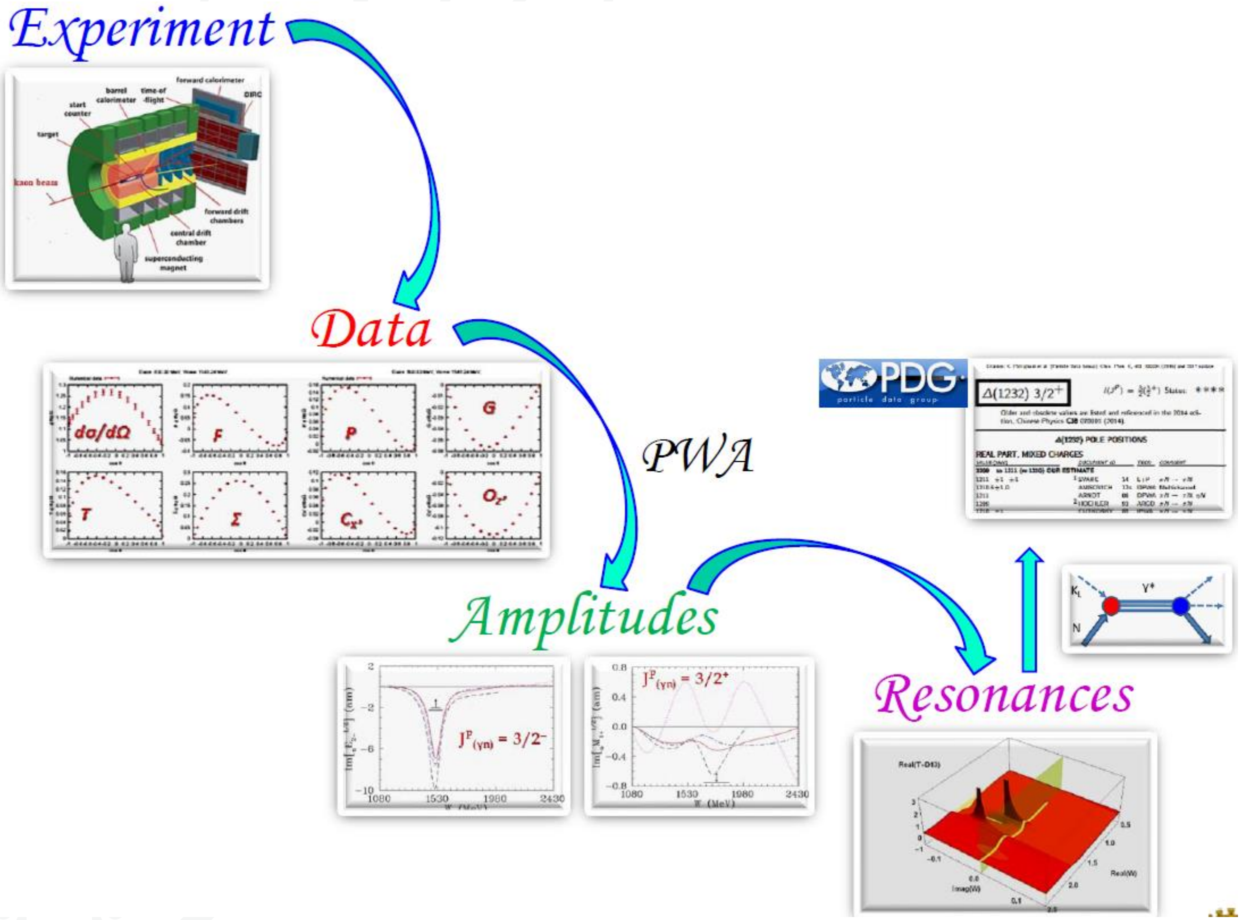






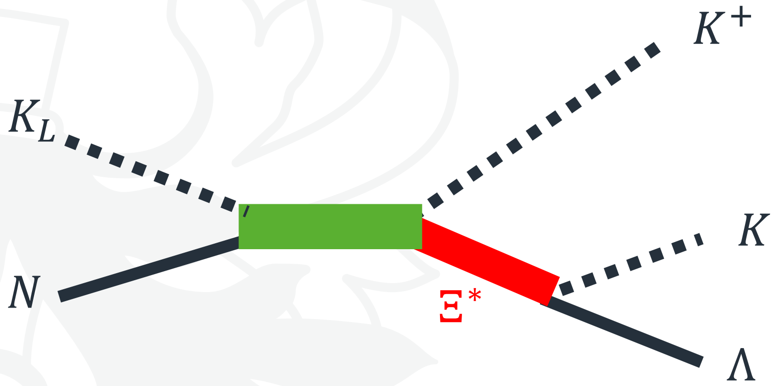


Strategies: bottom → up vs top → down



from I. Strakovsky

Excited Ξ^* in associated production

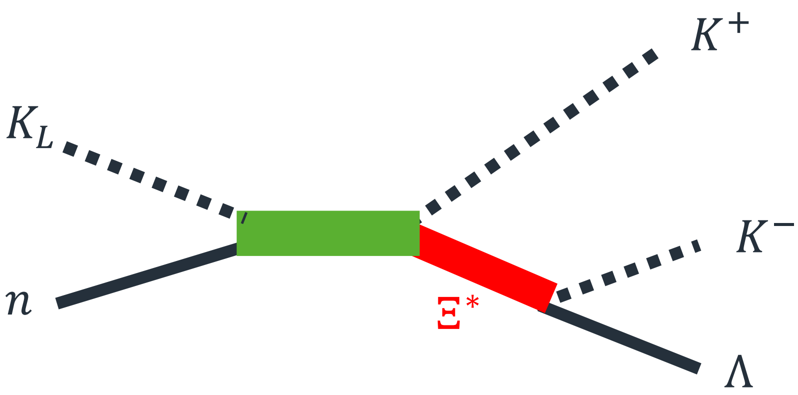


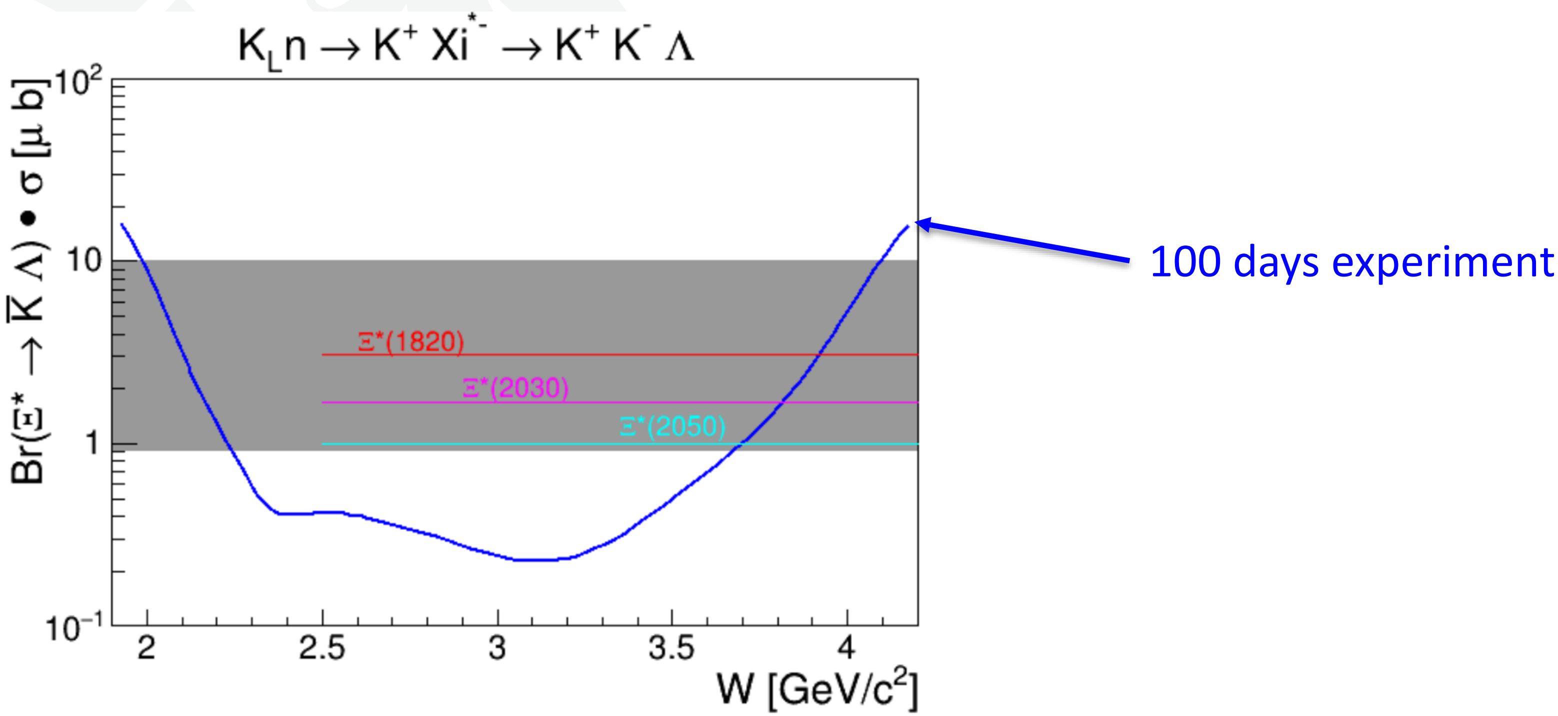
$\Xi^* \to \Lambda K$
$\Xi^* \to \Xi\pi$
$\Xi^* \to \Xi\eta$
$\Xi^* \to \Xi\omega$
$\Xi^* \to \Sigma K$

$$\boldsymbol{K_L n \to K^+ \Xi^- \to K^+ \Lambda K^-}$$

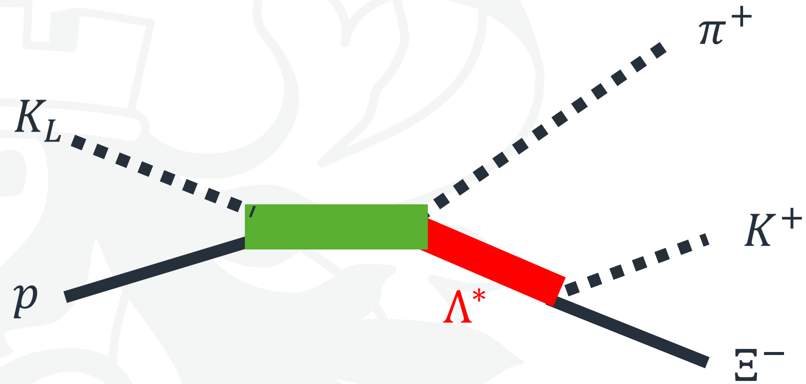
Ξ^* discovery potential

$$K_L n \rightarrow K^+ \Xi^{*-} \rightarrow K^+ \Lambda K^-$$





Excited Λ^*

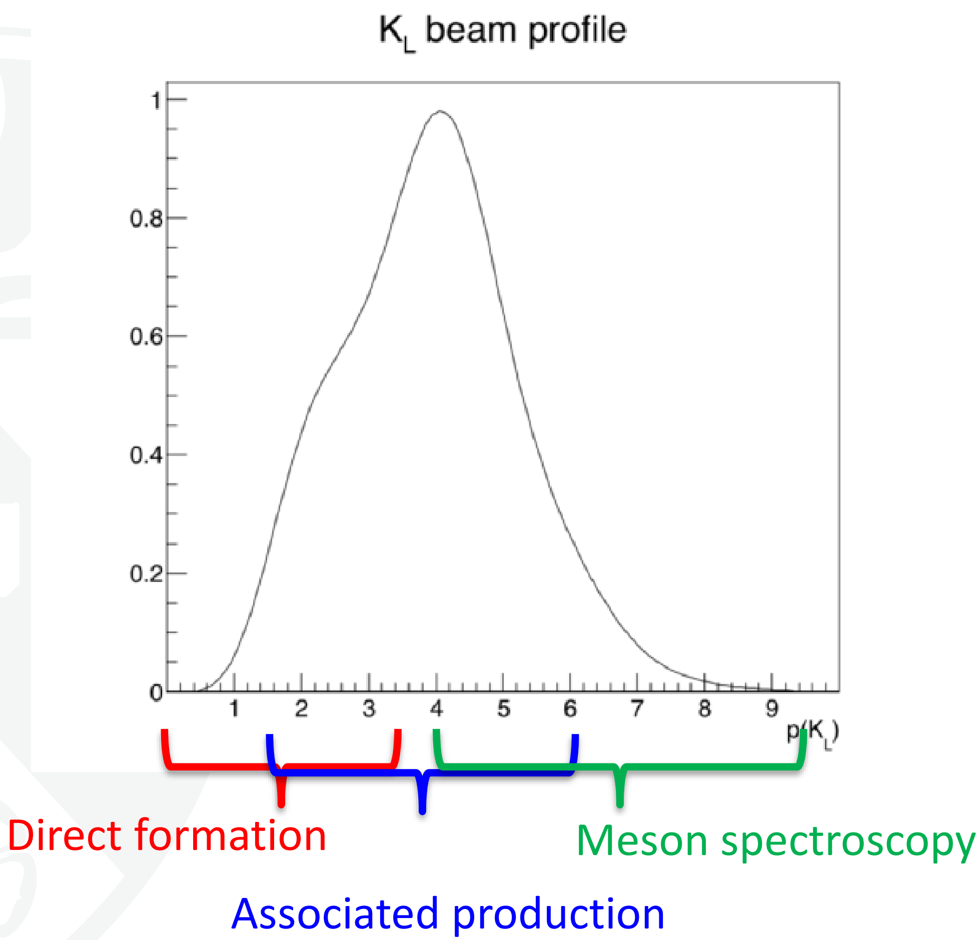


Associated production

Direct formation

- Interference effects
- $\Lambda - \Sigma$ mixing
- Model-independent PWA
- Different background

KLF spectroscopy



Baryon summary table, PDG

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	**
$N(1895)$	$1/2^-$	**
$N(1900)$	$3/2^+$	***
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2300)$	$1/2^+$	**
$N(2570)$	$5/2^-$	**
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*
$\Delta(2200)$	$7/2^-$	*
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$		*
$\Lambda(2020)$	$7/2^+$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1690)$		**
$\Sigma(1730)$	$3/2^+$	*
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1770)$	$1/2^+$	*
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1840)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	*
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq \frac{5}{2}?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

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	$1/2^+$	***
$\Lambda_b(5912)^0$	$1/2^-$	***
$\Lambda_b(5920)^0$	$3/2^-$	***
Σ_b	$1/2^+$	***
Σ_b^*	$3/2^+$	***
Ξ_b^0, Ξ_b^-	$1/2^+$	***
$\Xi_b(5945)^0$	$3/2^+$	***
Ω_b^-	$1/2^+$	***

Number of 3- and 4-star Resonances

Baryon	2004	2020
N^*	15	21
Δ	10	12
Λ	14	14
Σ	10	9*
Ξ	6	6
Ω	2	2

*$\Sigma(2250)$ was downgraded

KLF properties

- Intense K_L beam $\sim 10^4$kaons/s on a target
  - Broad momentum range
    - Controlled by Flux Monitor
  - Excellent W reconstruction
    - Time-of-flight
    - Final state
- Proton and neutron target
  - Approved 100 days LH_2 target
  - Approved 100 days LD_2 target
- Low background level
- Exclusive final states
- Up to 1 new discovered particle per week of beamtime.