UNIVERSITY *of York*

K_L-Facility

strange hadron spectroscopy with a secondary K_{Long} beam

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arXiv:2008.08215v3
KLF proposal 2020

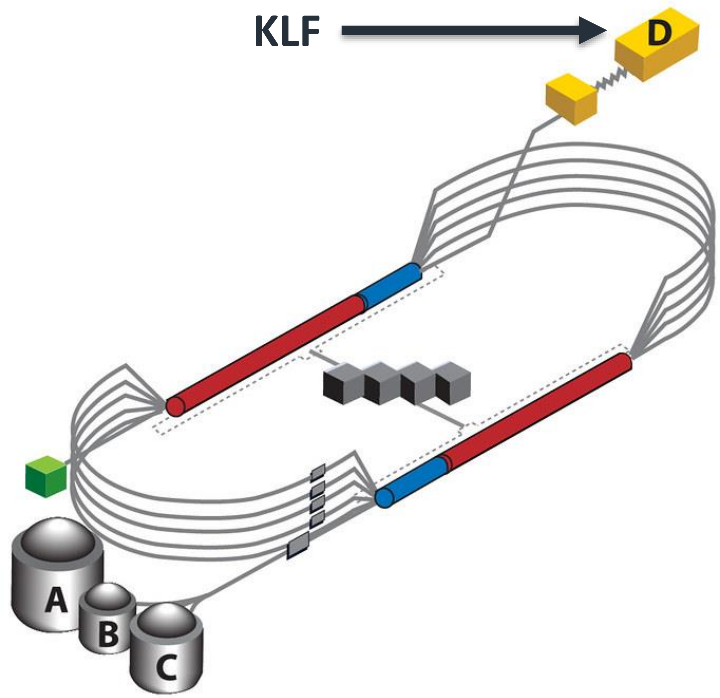
Outlook

UNIVERSITY of York

- K_L FACILITY IN A NUTSHELL
- WHY KAON BEAM?
- WHY STRANGENESS?
- BARYON SECTOR
  - Missing resonances
  - Exotic states (cusps, dynamically generated resonances, hadronic molecules)
- MESON SECTOR
- STANDARD MODEL AND BEYOND

KLF, step 1 (CEBAF)

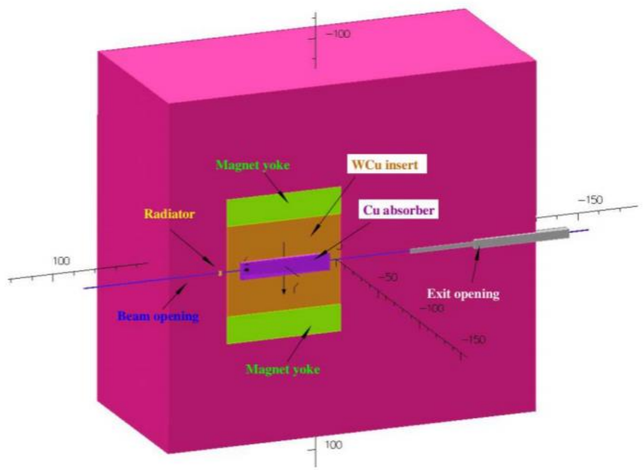
JLAB



Electron Beam:

- 12 GeV
- $5\mu A$
- 64 ns (128 ns) bunch spacing

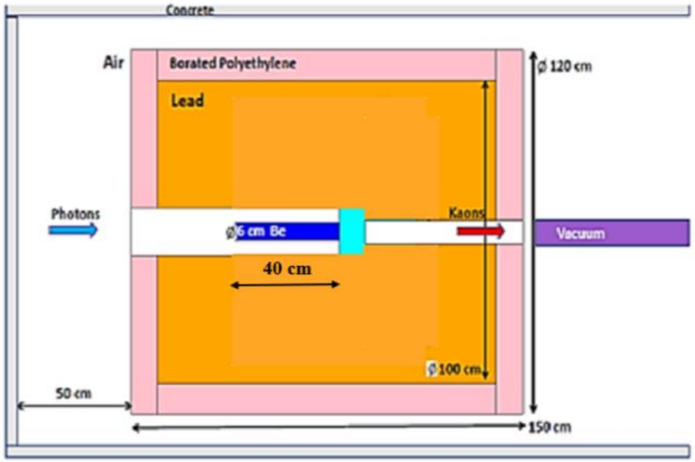
KLF, step 2 (Compact Photon source)



CPS:

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

KLF, step 3 (K_L production target)

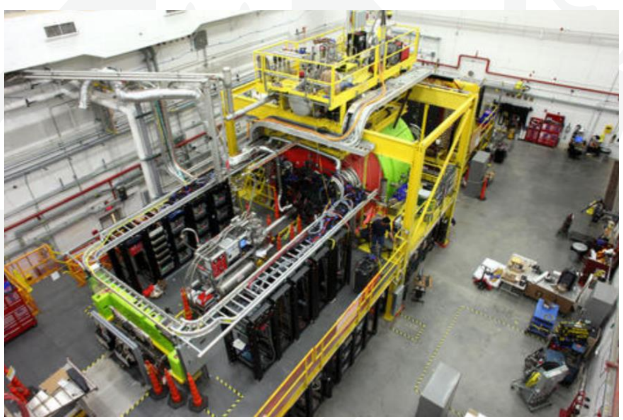


K_L production target:

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

KLF, step 4 (GlueX)

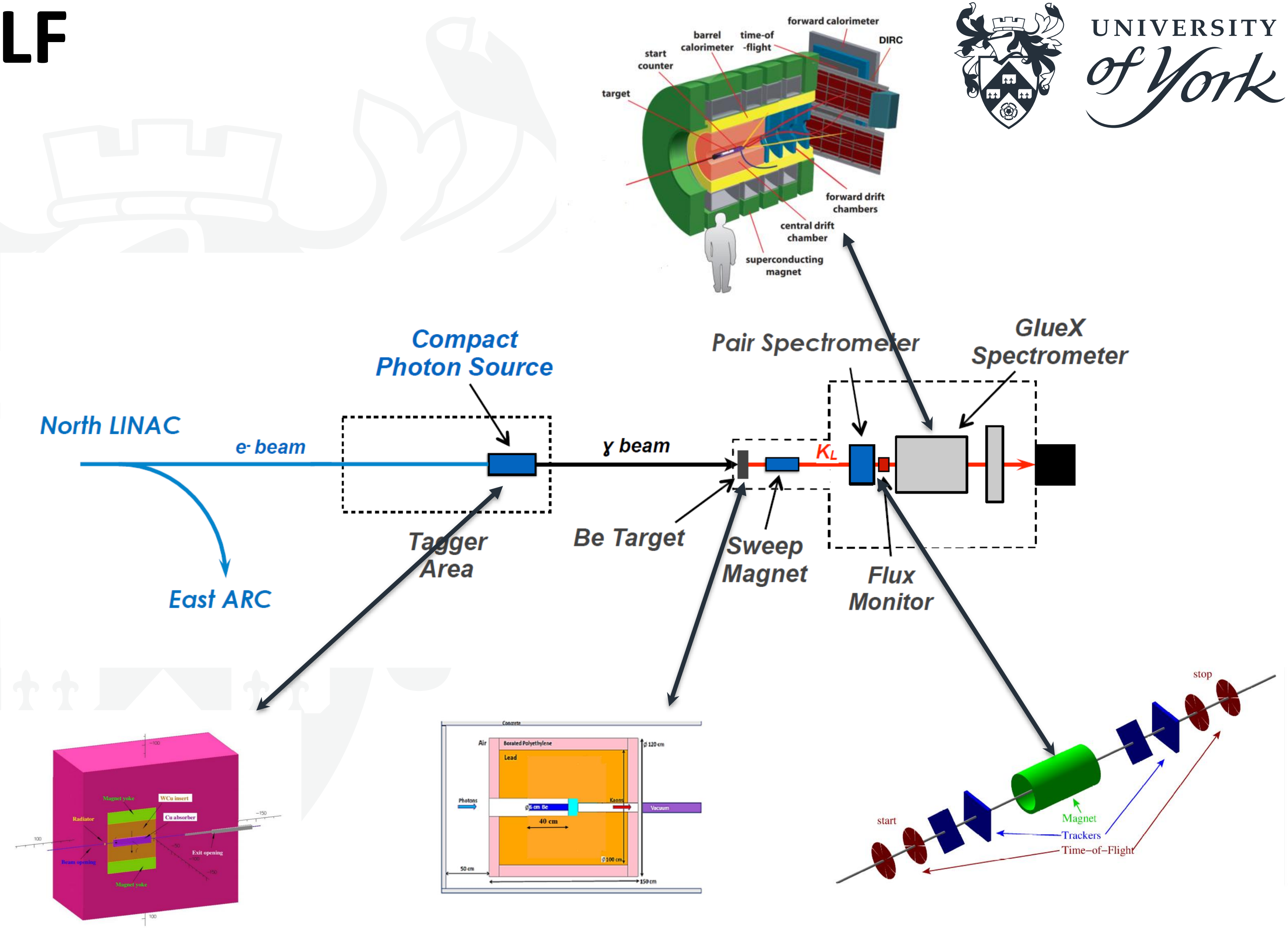
24m time-of -flight



GlueX:

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

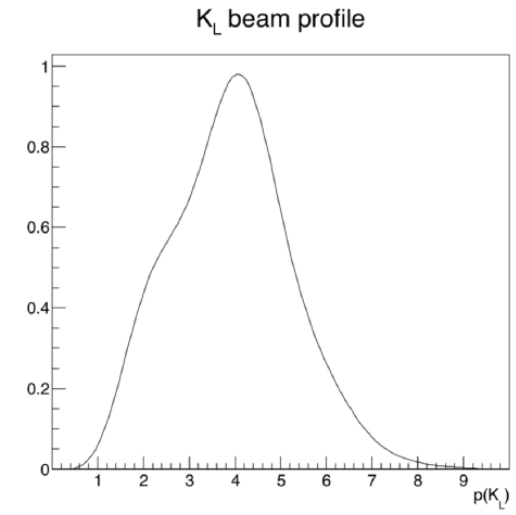
KLF

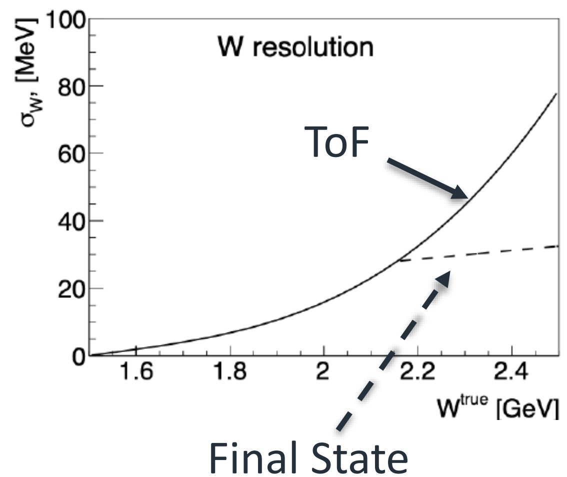


forward calorimeter
barrel calorimeter
time-of -flight
DIRC
start counter
target
forward drift chambers
central drift chamber
superconducting magnet
Compact Photon Source
North LINAC
e- beam
East ARC
γ beam
Pair Spectrometer
GlueX Spectrometer
K_L
Tagger Area
Be Target
Sweep Magnet
Flux Monitor
Magnet yoke
WCu insert
Cu absorber
Radiator
Beam opening
Exit opening
Concrete
Air
Borated Polyethylene
Lead
Photons
Kaons
Vacuum
40 cm
50 cm
150 cm
start
stop
Magnet
Trackers
Time–of–Flight

KLF properties

- Intense K_L beam $\sim 10^4$kaons/s on a cryotarget
  - 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





Why Strange beams?

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^-	$3/2^+$	****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

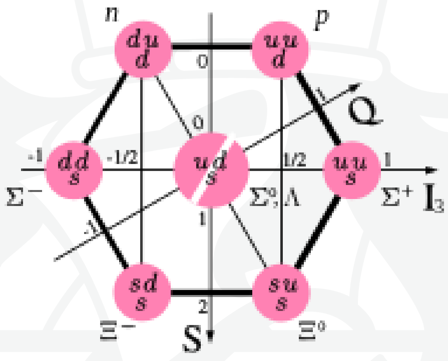
Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	***
$\Xi_c^{\prime +}$	$1/2^+$	***
$\Xi_c^{\prime 0}$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
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

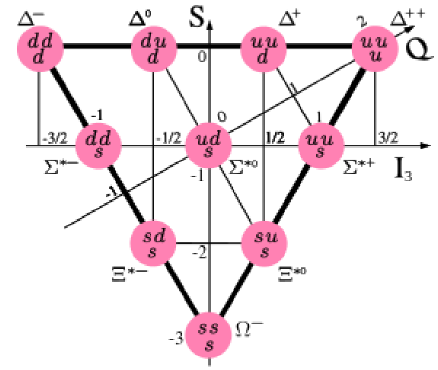
*$\Sigma(2250)$ was downgraded

Hyperons



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

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



	LQCD* ($M < 2M_\Omega$)	"Observed", PDG
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 (2013) 5, 054506

Sigma factory

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

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

$K_L p \rightarrow K^+ n$

Non-resonant background

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

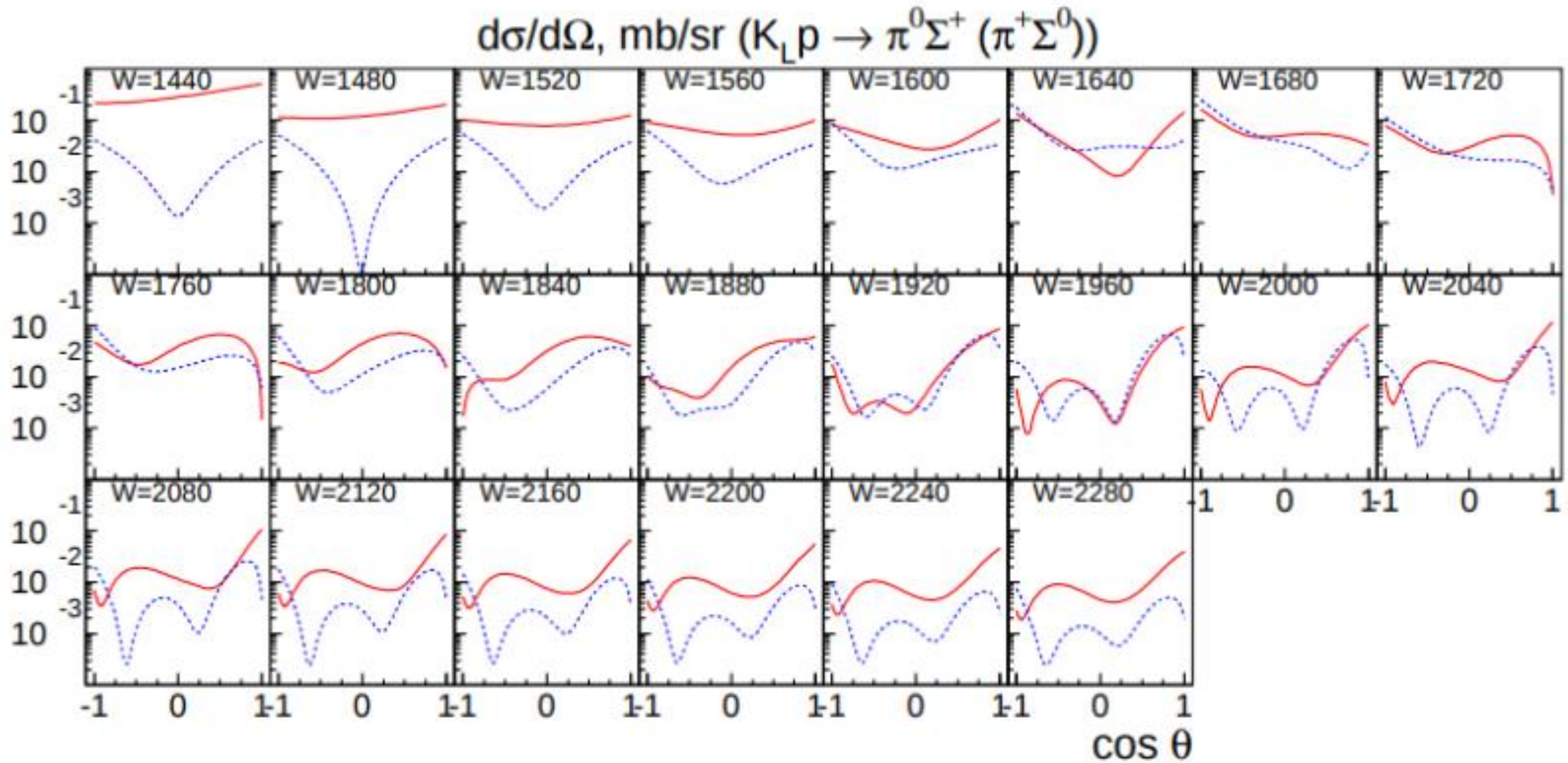
Isospin amplitudes

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

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

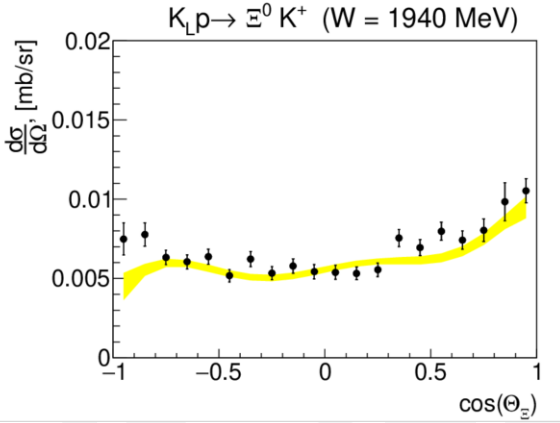
$$|A(K^0 p)|^2 = |A_1|^2.$$

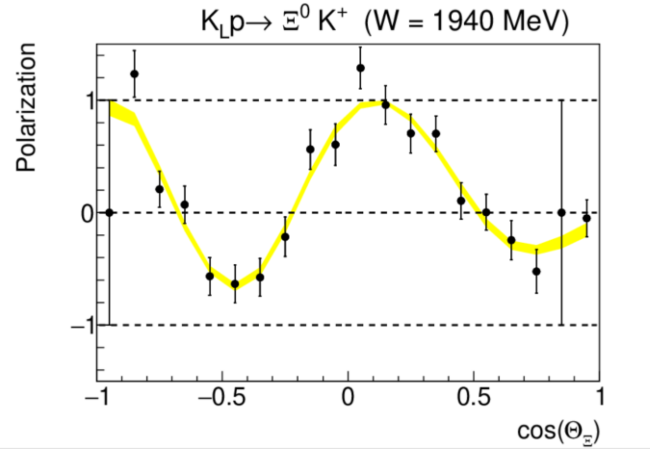
arXiv:2008.08215v3
KLF proposal 2020

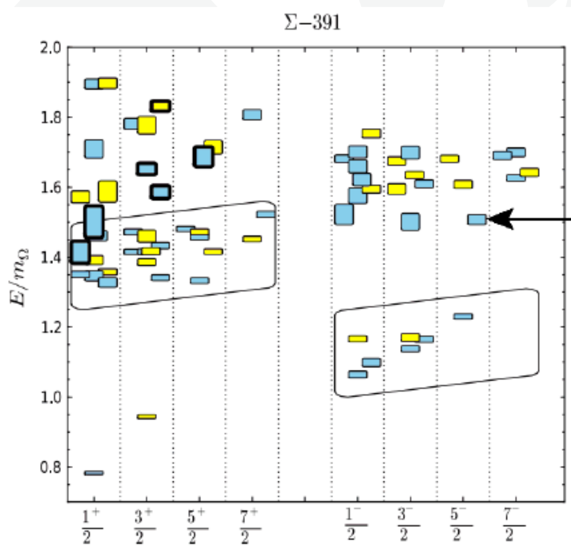


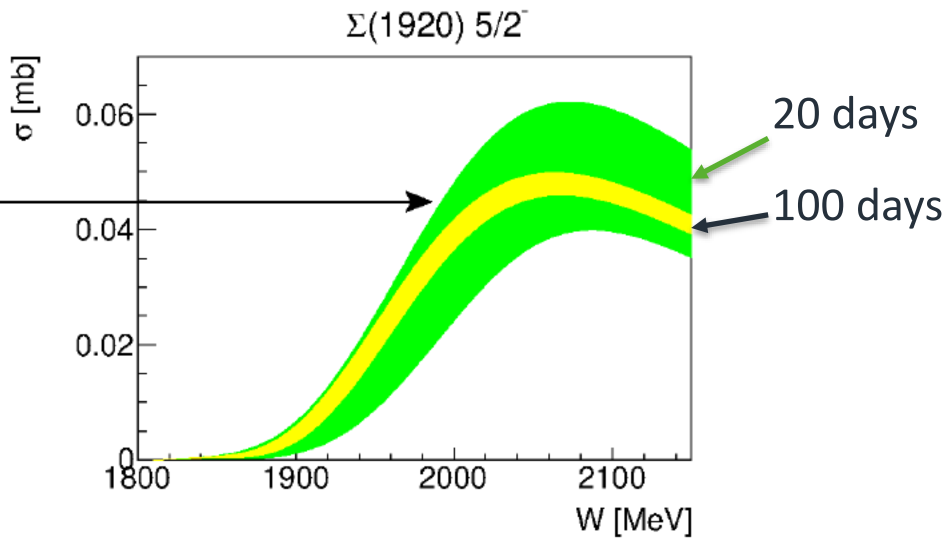
Expected results

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

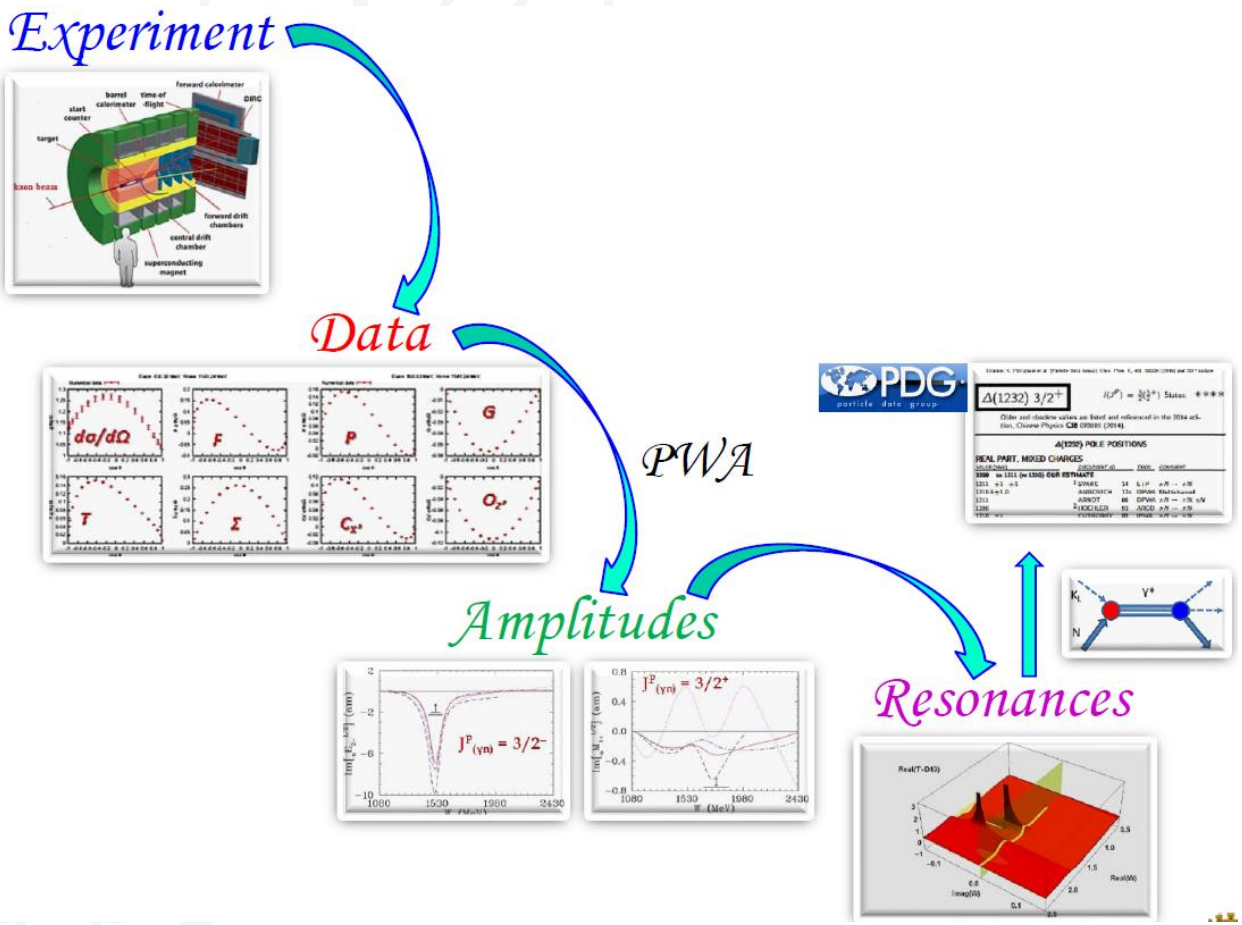






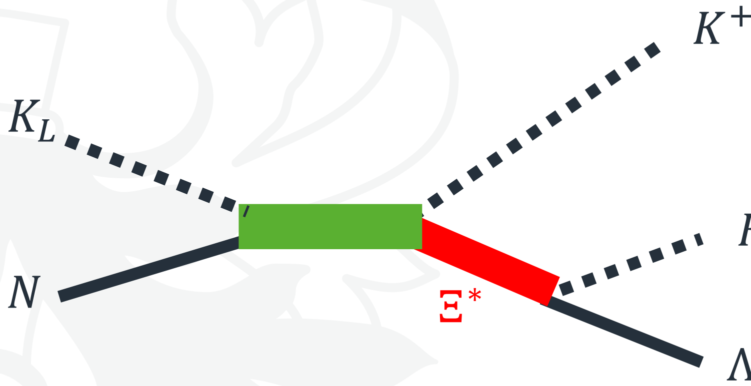


Strategies: bottom → up vs top → down



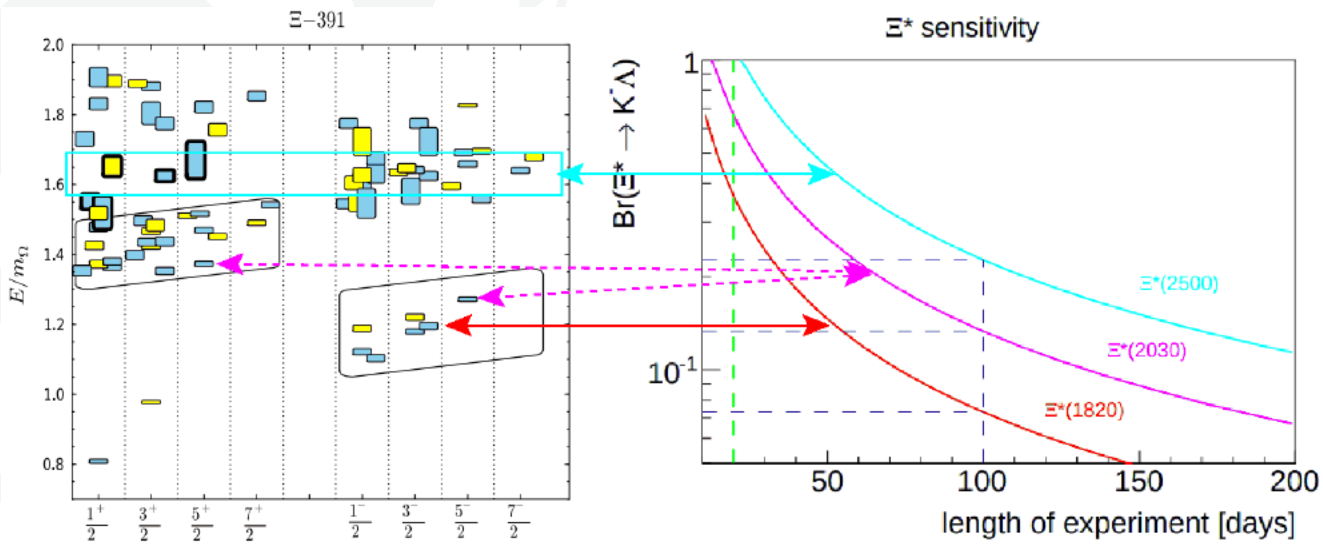
from I. Strakovsky

Excited Ξ^* in associated production



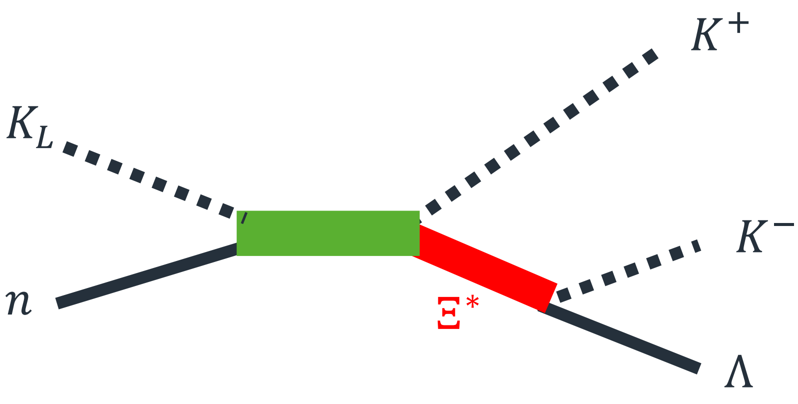
$\Xi^* \to \Lambda K$
$\Xi^* \to \Xi\pi$
$\Xi^* \to \Xi\eta$
$\Xi^* \to \Xi\omega$
$\Xi^* \to \Sigma K$

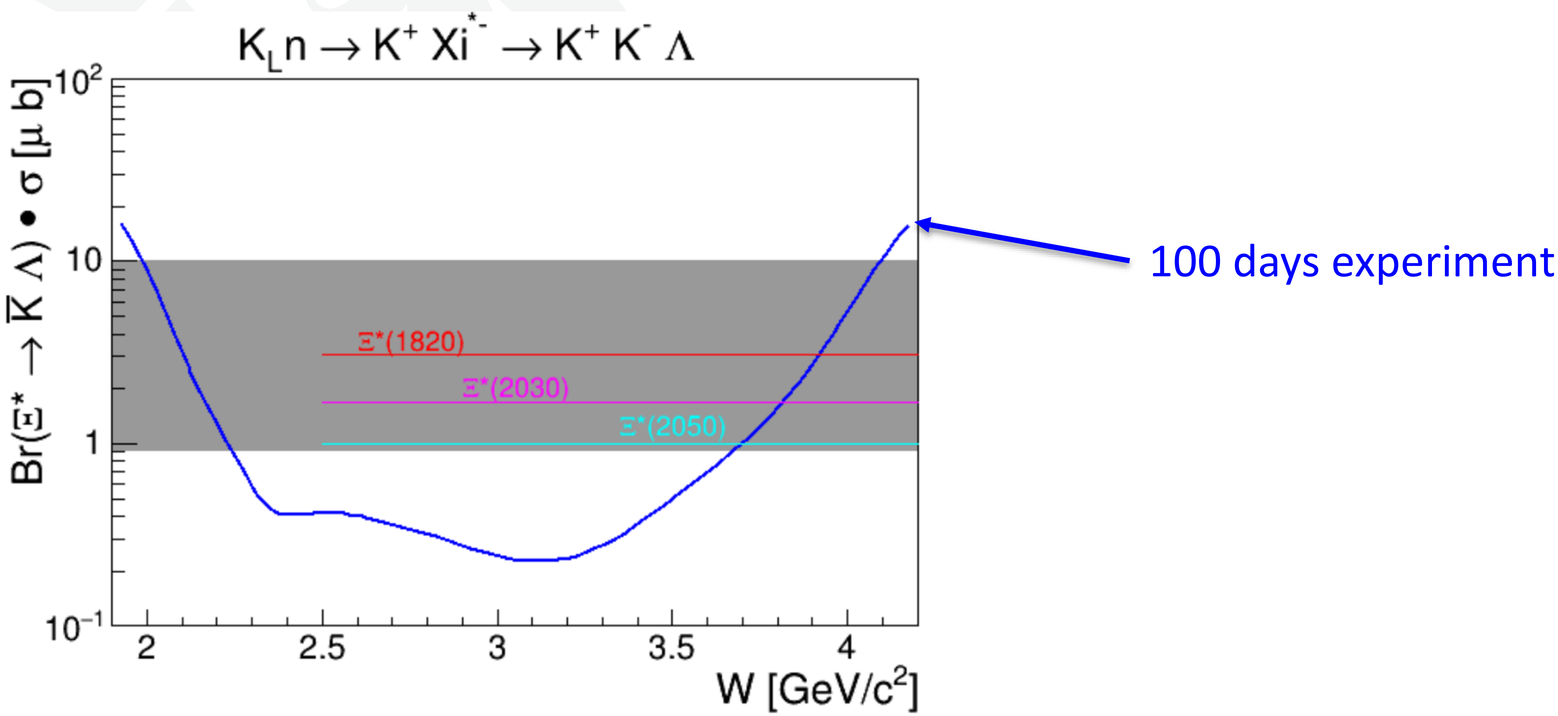
$$K_L n \to K^+\Xi^- \to K^+\Lambda K^-$$



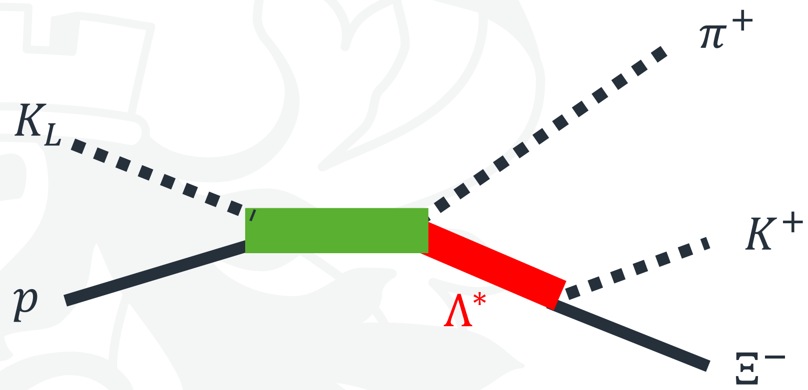
Ξ^* discovery potential

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

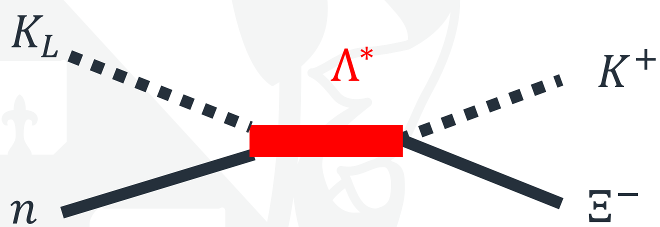




Excited Λ^*



Associated production



Direct formation

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

Why Strangeness?

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

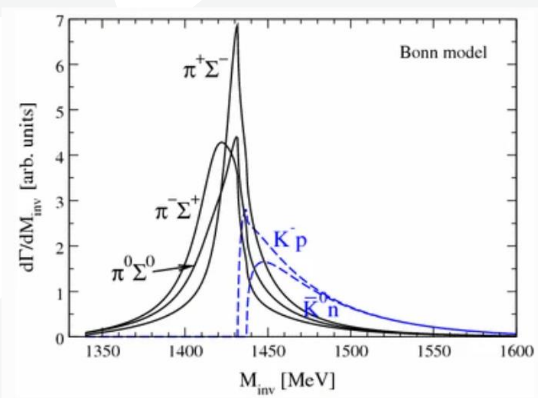
Heavy quark sector:

- low statistics
- hard to produce
- too narrow

Strangeness is a key

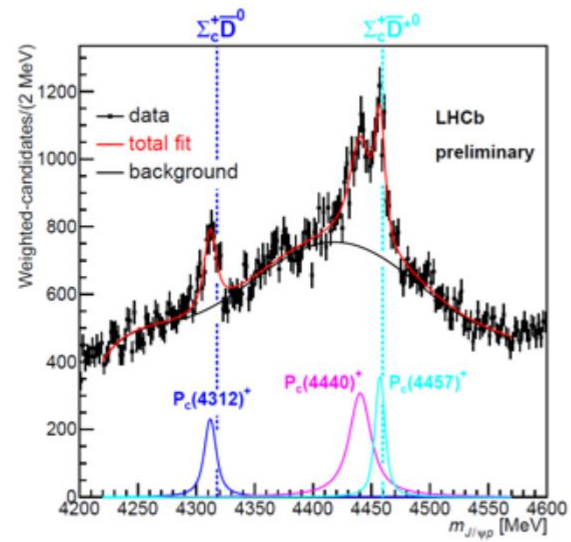
- Many thresholds
  - Cusps
  - Molecules
  - Dynamic resonances

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



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

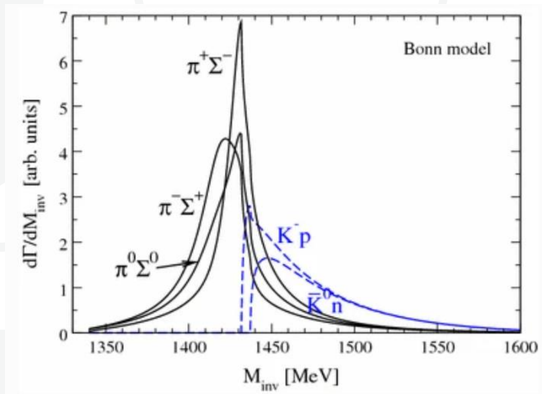
$\Lambda(1405) \leftrightarrow \pi\Sigma/\bar{K}N$-molecule



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

Molecules and cusps

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



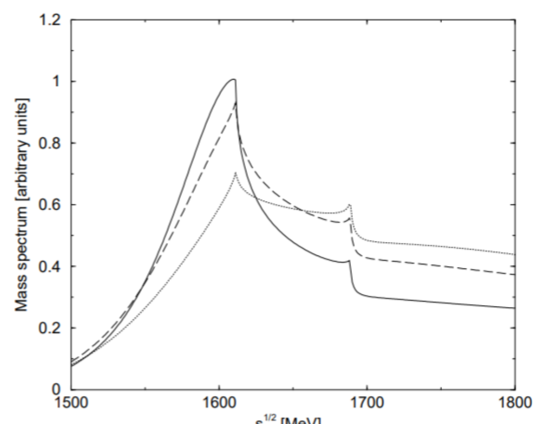
•L. Roca, M. Mai, E. Oset & Ulf-G. Meißner

- Many thresholds
  - Cusps
  - Molecules
  - Dynamic resonances

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

States?
Decay channels?
Resolution?

$\Xi(1620)$

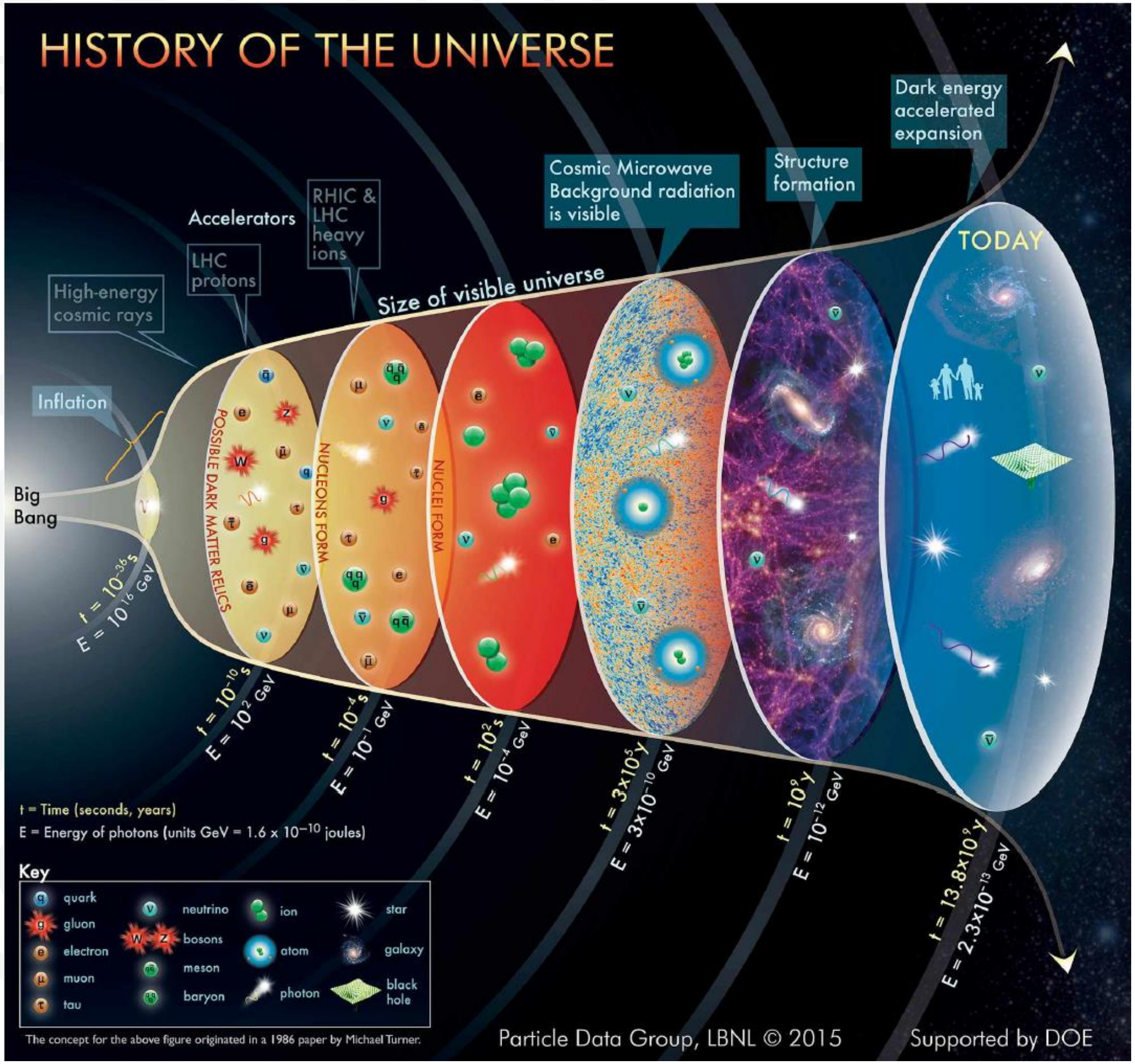


$M(\Xi\pi)$

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

A. Ramos, E. Oset , C. Bennhold

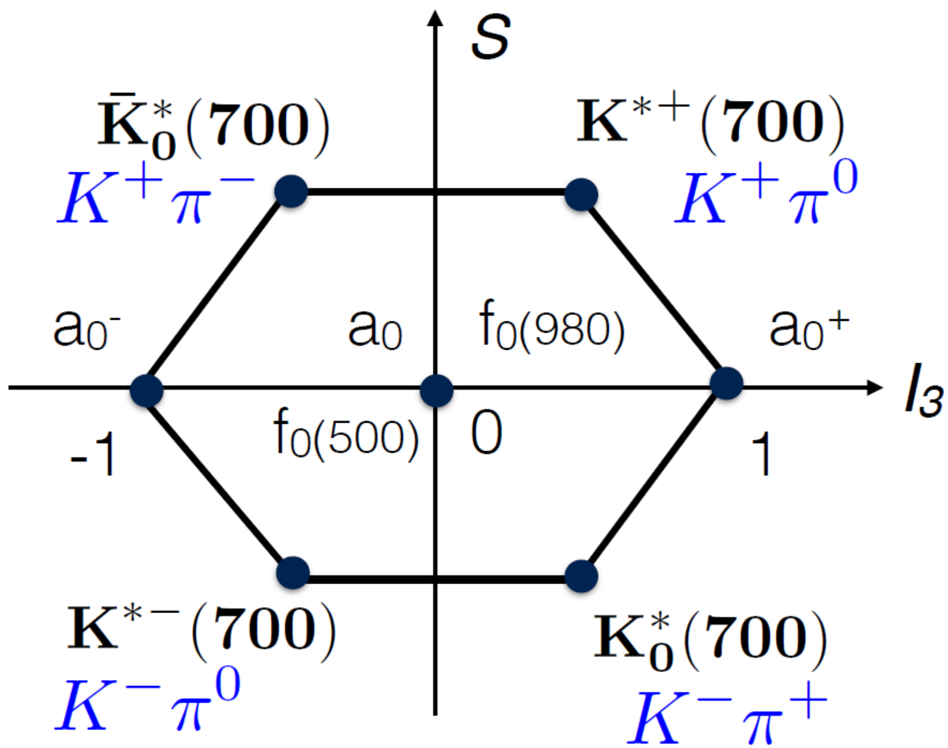
Early Universe



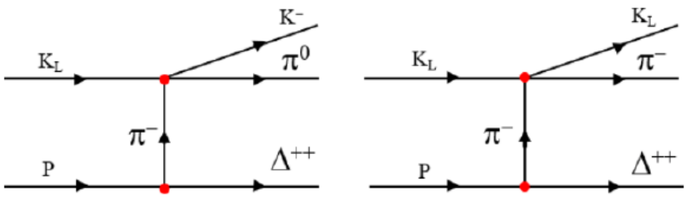
Strange mesons

Kappa mystery

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



Kappa mystery



SLAC

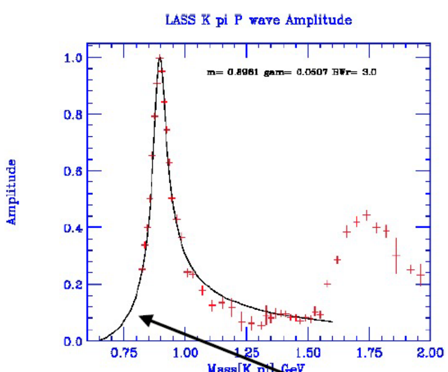
$K^- \pi^+ \to K^- \pi^+$

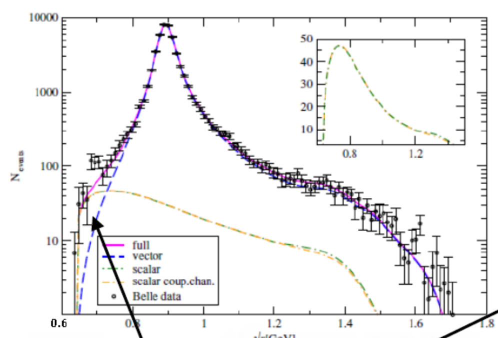
Belle

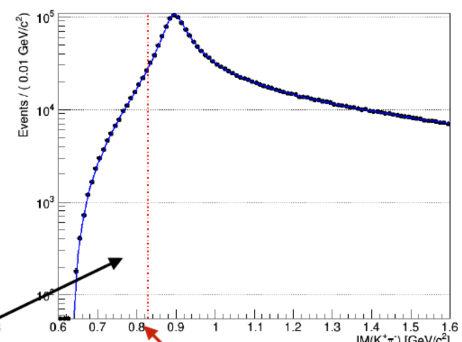
$\tau \to K \pi \nu_\tau$

KLF

$K_L \pi^0 \to K^+ \pi^-$





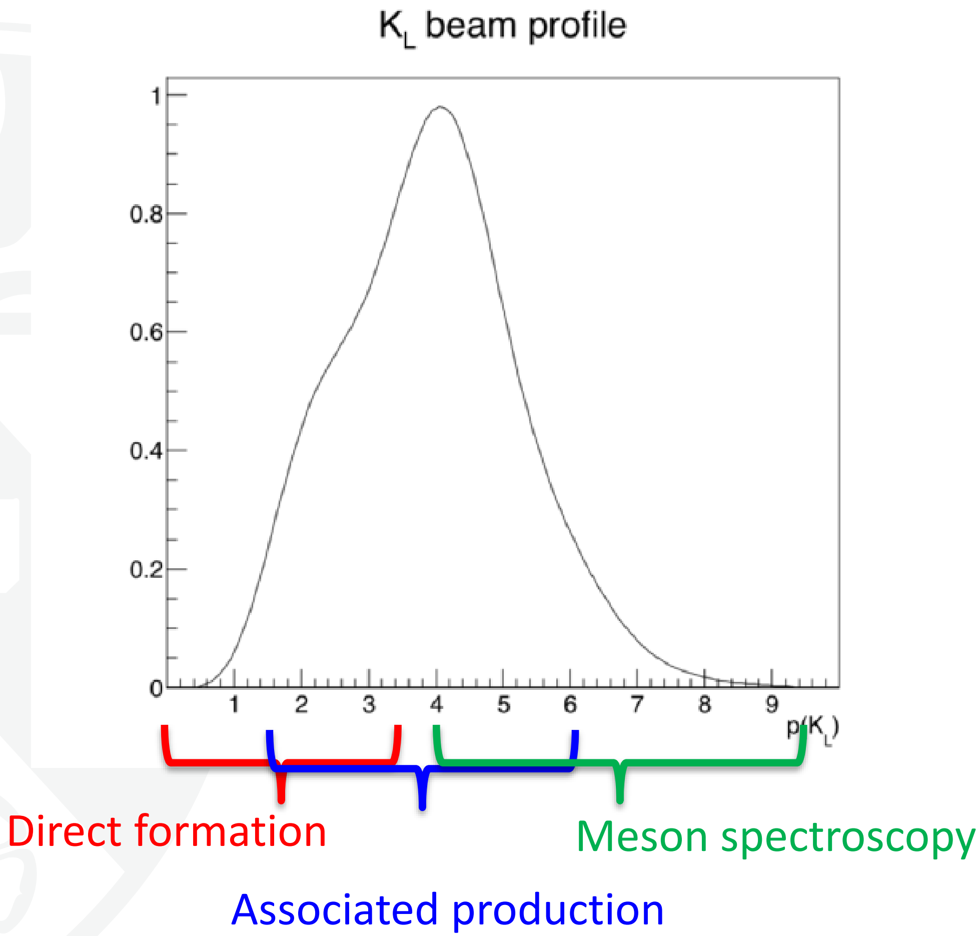


$\mathbf{M(K\pi)(GeV)}$ $\mathbf{M(K\pi)(GeV)}$ $\mathbf{M(K\pi)(GeV)}$

region of $\kappa(800)$

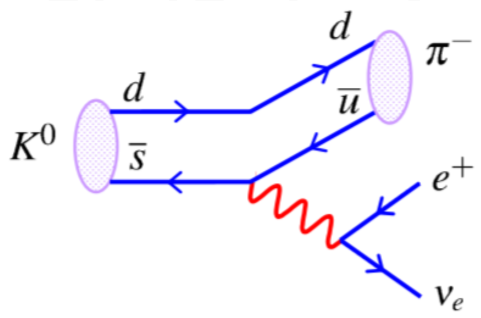
SLAC Lower limit

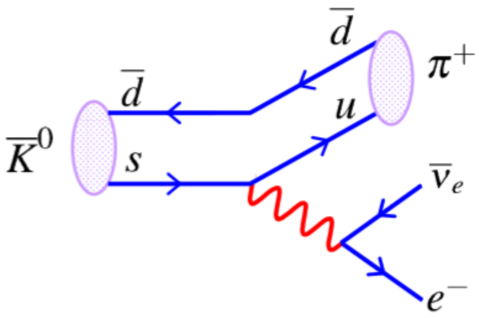
KLF spectroscopy



Standard Model and Beyond

CP in K_L





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

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

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

Rare decays

- Physics beyond SM
  - Rare final state
  - Precise calculations

K_L beta-decay

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

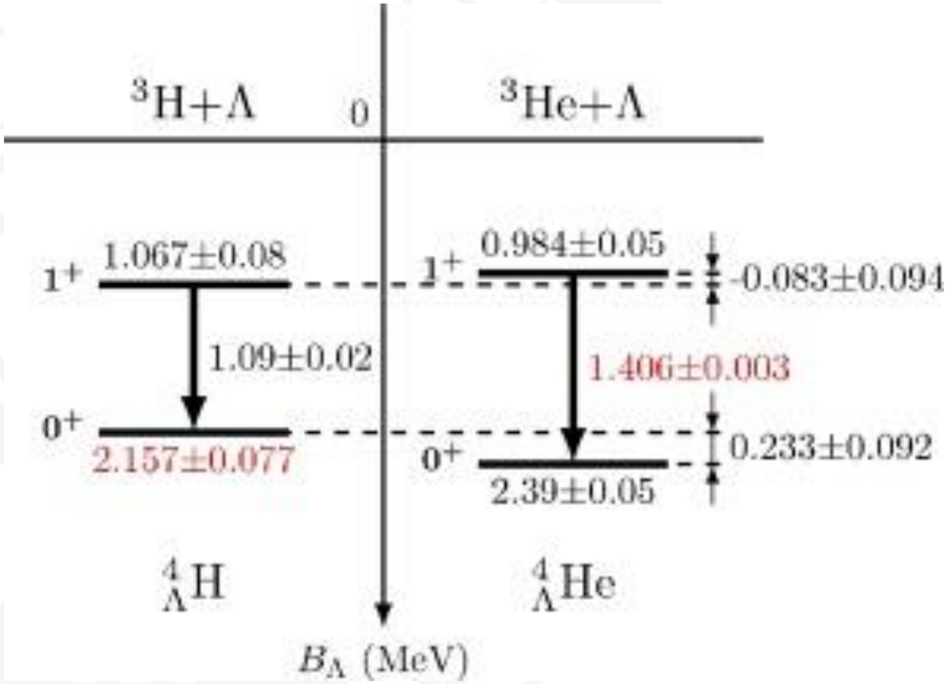
$$M(K_L) = 497.611\ MeV$$
$$M(K^{+/-}) = 493.696\ MeV$$
$$M(e^{+/-}) = 0.511\ MeV$$

Available Phase Space $\mathbf{3.4\ MeV}$

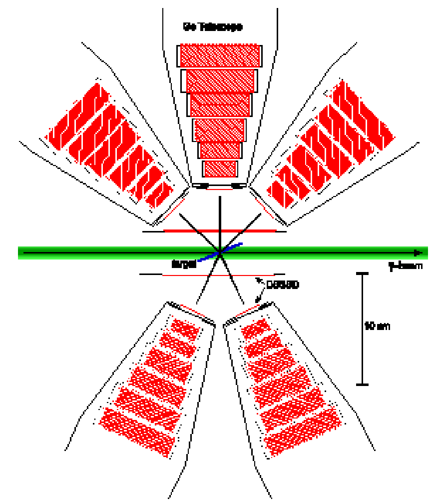
BUT!!!

- 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

Hypernuclei



Daniel Gazda, Avraham Gal , NPA 954, 161, (2016)



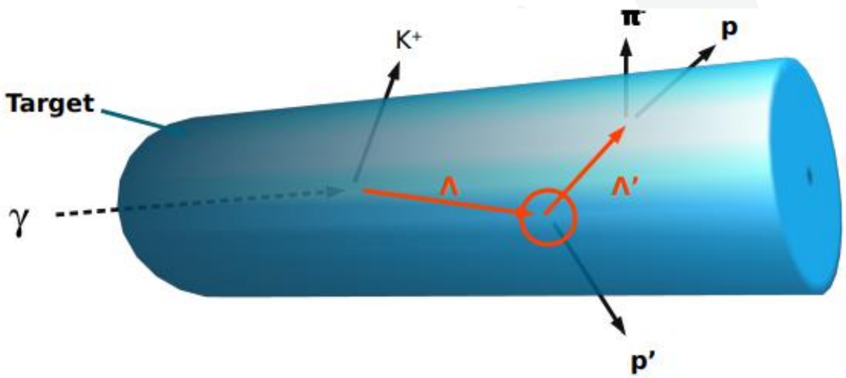
Usual routes: $K^- \boldsymbol{n} \rightarrow \Lambda\pi^-$

$\pi^+ \boldsymbol{n} \rightarrow \Lambda K^+$

KLF route: $K^0 \boldsymbol{p} \rightarrow \Lambda\pi^+$

Double-strangeness KLF route: $K^0 \boldsymbol{p} \rightarrow \Xi K^+$

Hyperon-nucleon Scattering

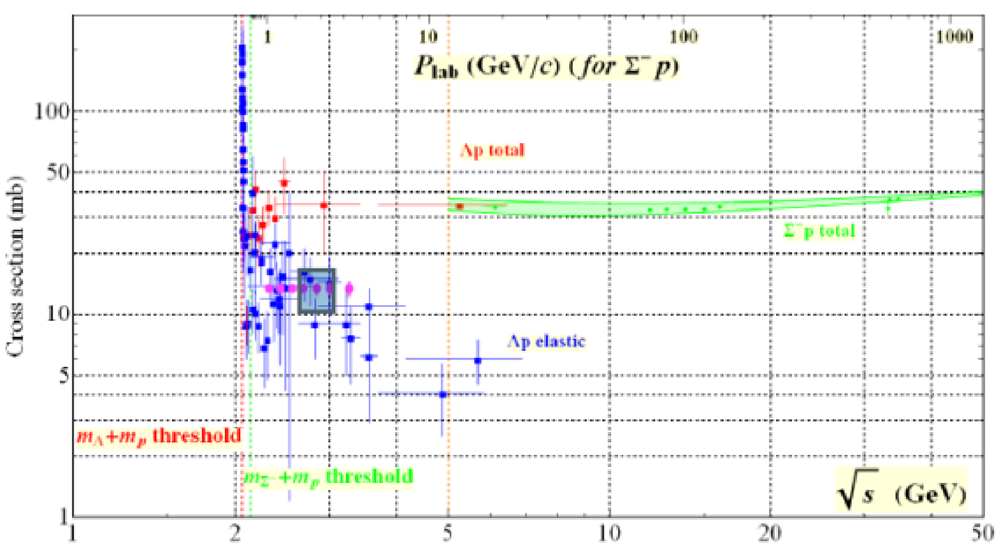


PhysRevLett.127.272303 (2021)

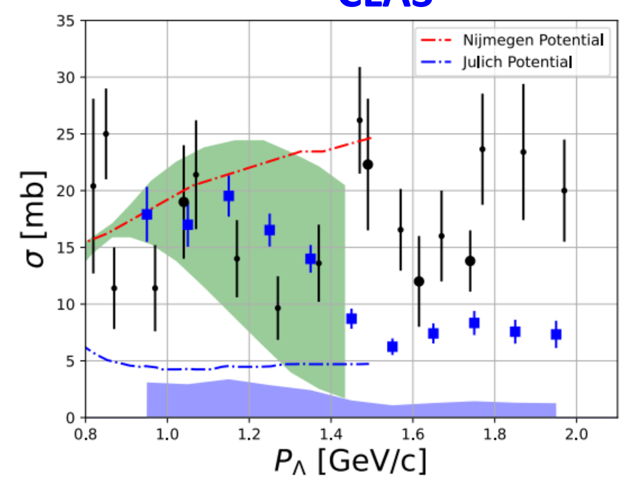
Cross sections
- Λp
- Σ⁻p
- Σ⁺p
- Λd

Polarization observables
- Λn
- Σ⁻p
- Λd
- Λp

KLF



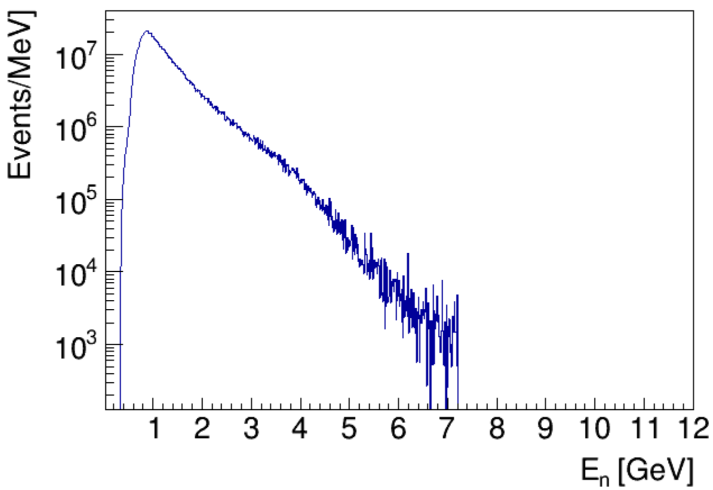
CLAS



J. Haidenbauer and U.-G. Meißner, Phys. Rev. C 72, 044005 (2005)
T. A. Rijken, V. G. J. Stoks, and Y. Yamamoto, Phys. Rev. C 59, 21 (1999).

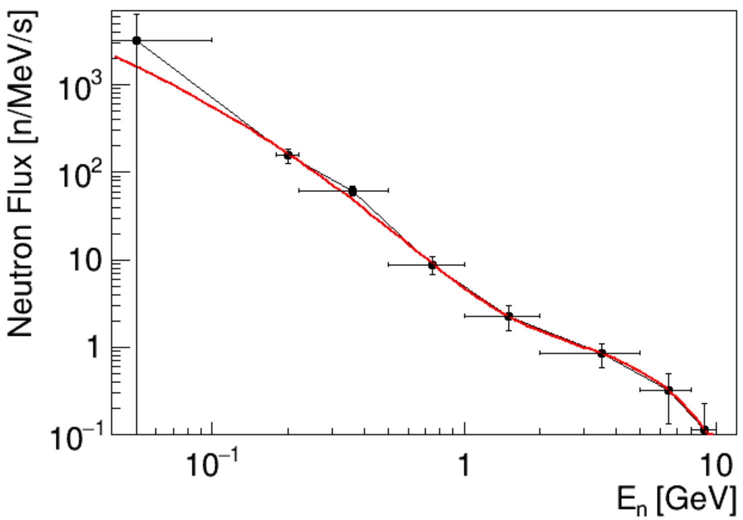
Neutron beam

Neutron induced reactions (hadrons)



np reaction X-sections from SAID

Neutron flux



Low energy Neutron induced reactions-> Nuclear structure

Conclusion

- Proposal for a new KL beam facility has been approved by JLab PAC
- Cross section and Polarisation measurements
  - New $\Lambda^*, \Sigma^*, \Xi^*$ states
  - Up to 1 new particle per week of beamtime
- Technical design/prototyping/construction

New collaborators welcome!!!

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

NSTAR2024
York UK

June 17-21st 2024

York