Proposal for JLab PAC45

Strange Hadron Spectroscopy with a Secondary KL Beam at GlueX

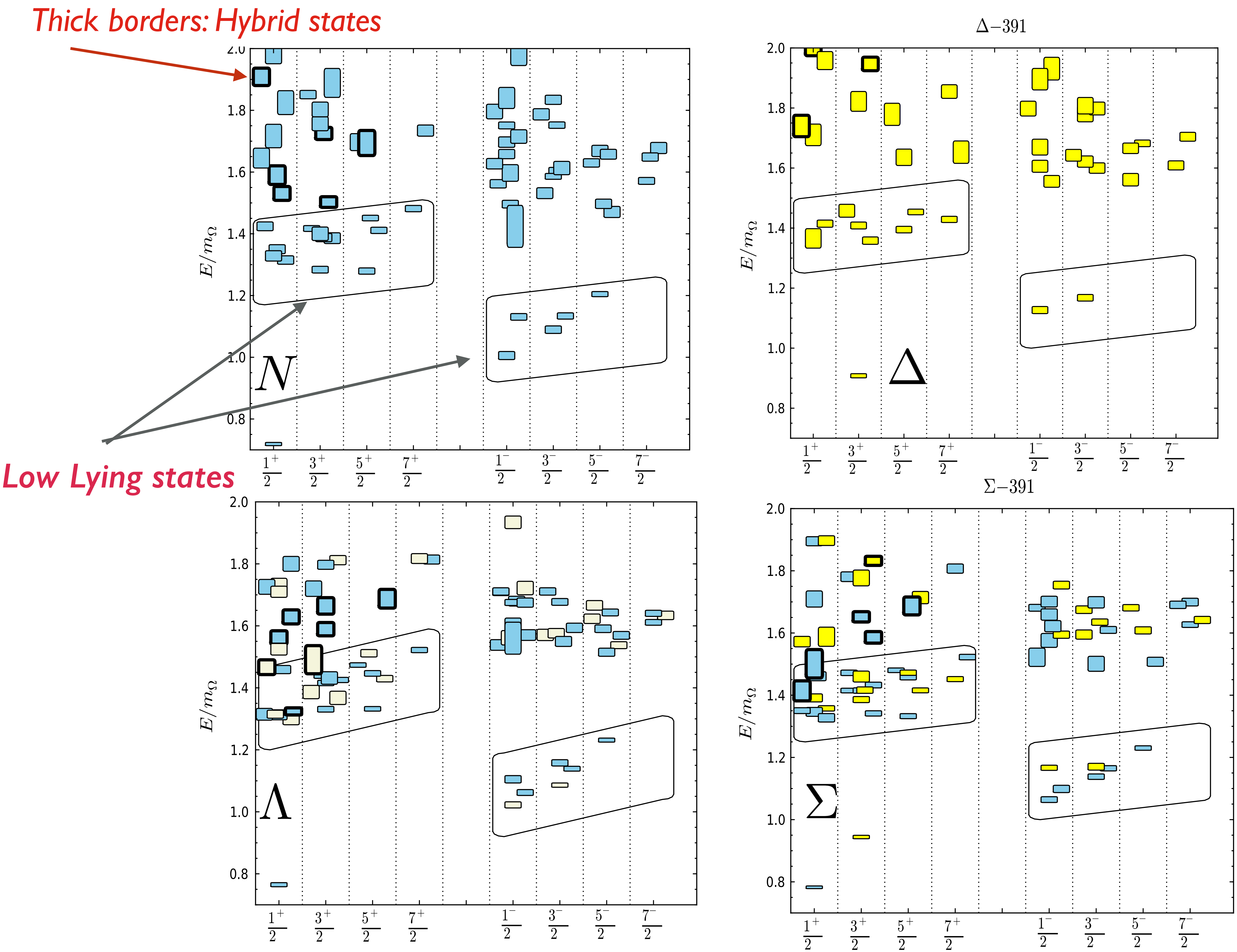
Moskov Amaryan

The GlueX Collaboration Meeting, May 17, 2017

Outline

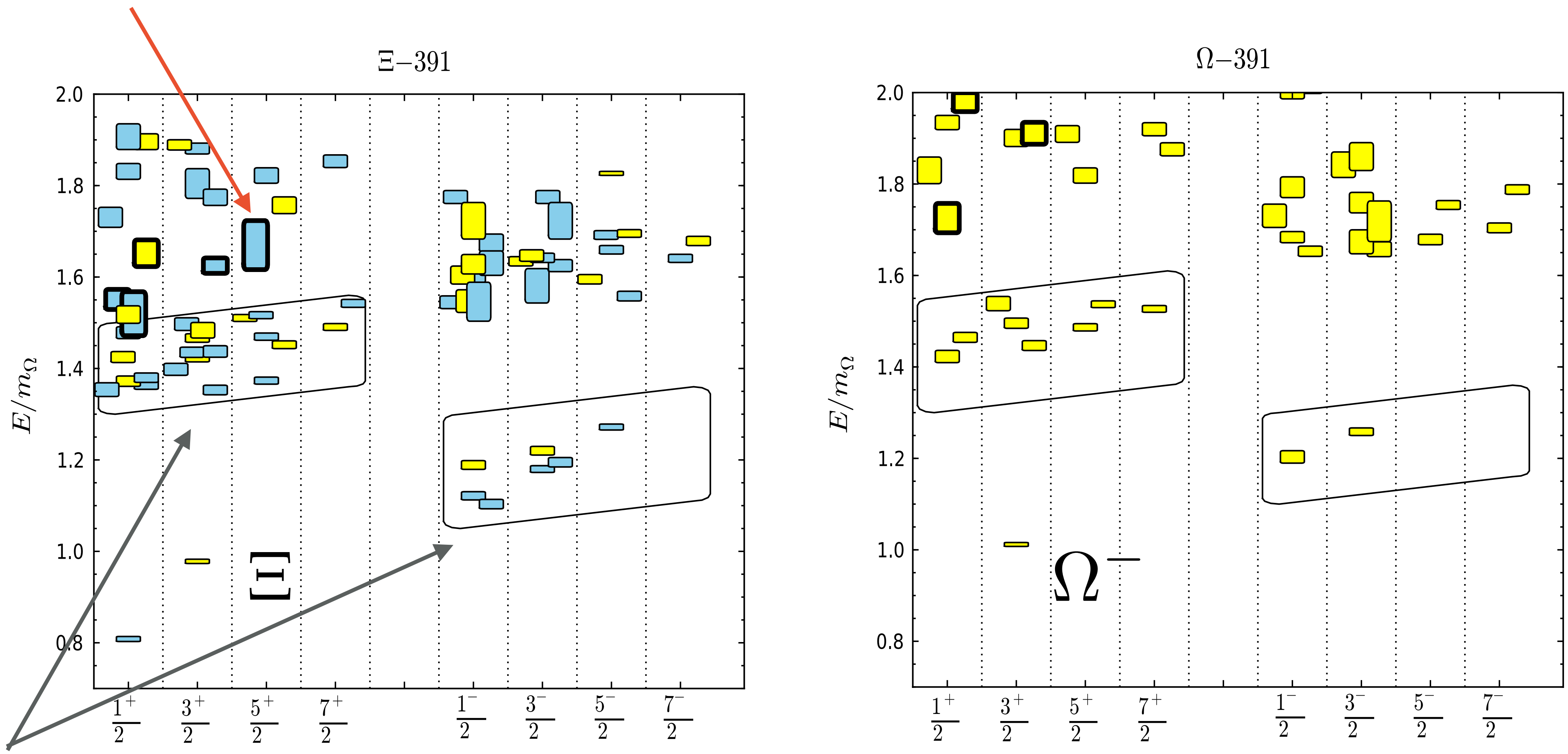
- Physics Motivation
- Hyperon Spectroscopy
- Meson Spectroscopy
- Previous measurements
- The KL Facility at JLab
- Prposed measurements
- Summary

Lattice QCD calculations



Lattice QCD calculations

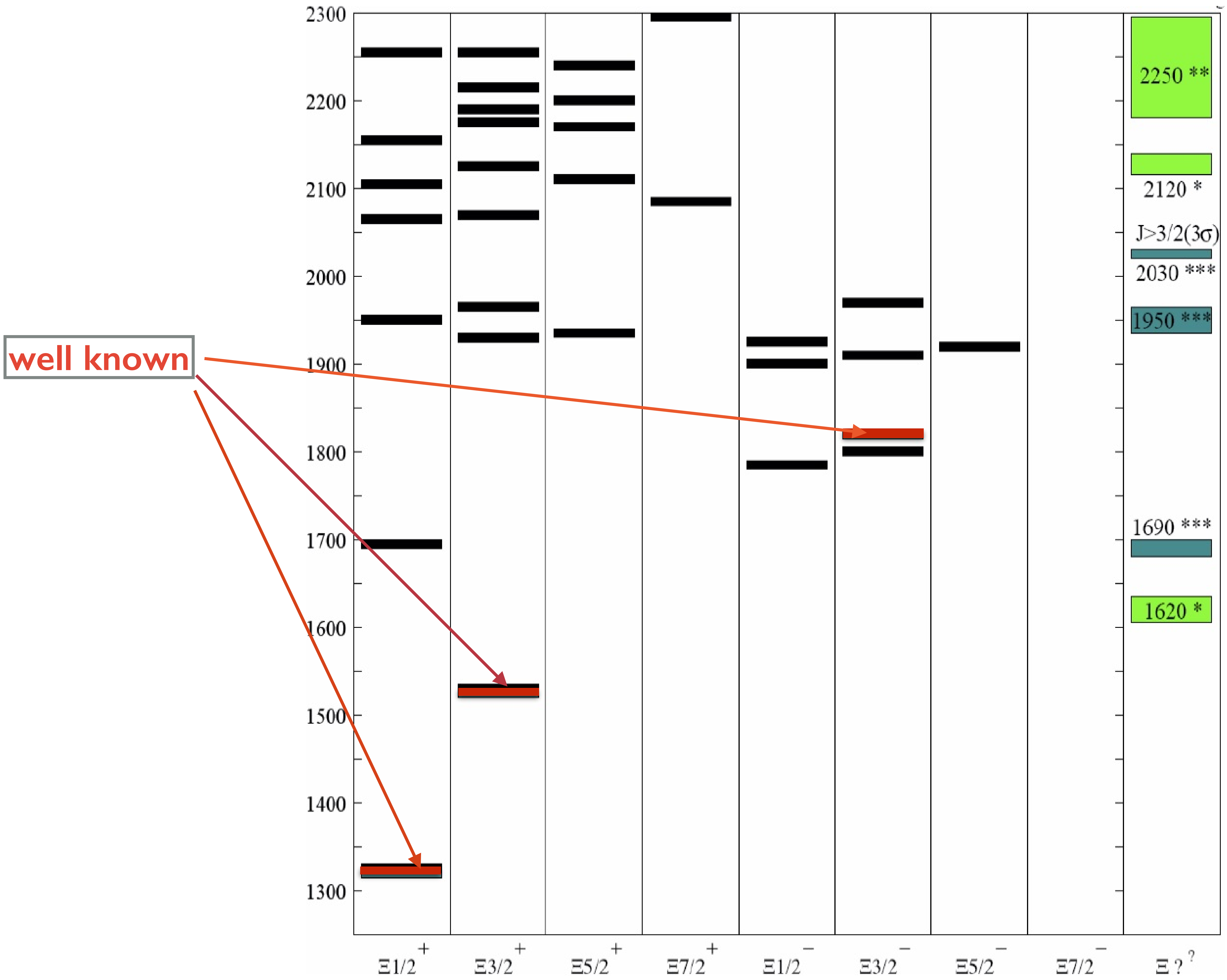
Thick borders: Hybrid states



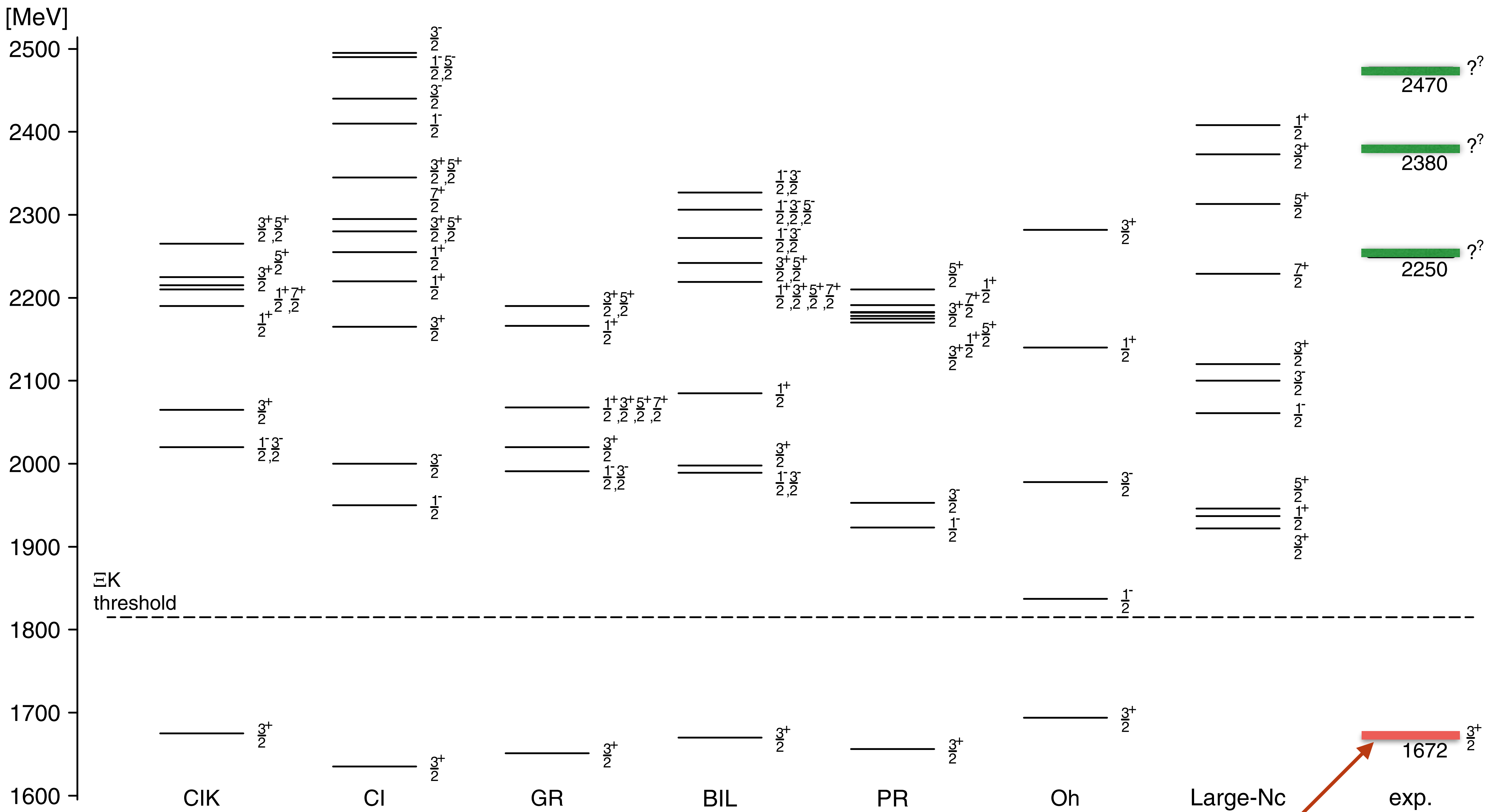
Low Lying states

Edwards, Mathur, Richards and Wallace
Phys. Rev. D 87, 054506 (2013)

Status of Ξ^*


2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
2250 **
2120 *
J>3/2(3σ)
2030 ***
1950 ***
1690 ***
1620 *
Ξ1/2 +
Ξ3/2 +
Ξ5/2 +
Ξ7/2 +
Ξ1/2 −
Ξ3/2 −
Ξ5/2 −
Ξ7/2 −
Ξ ? ?
well known

Status of Ω^{-*}



only one well known state?

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

Octet: **N***, **Λ***, **Σ***, **Ξ***
Decuplet: **Δ***, **Σ***, **Ξ***, & **Ω***

  - Number of experimentally identified resonances of each baryon family in PDG summary tables is **17 N***, **24 Δ***, **14 Λ***, **12 Σ***, **7 Ξ***, & **2 Ω***.
  - **Constituent Quark** models, for instance, predict existence of no less than **64 N***, **22 Δ*** states with **mass < 3** GeV.

- Seriousness of "**missing-states**" problem is obvious from these numbers.

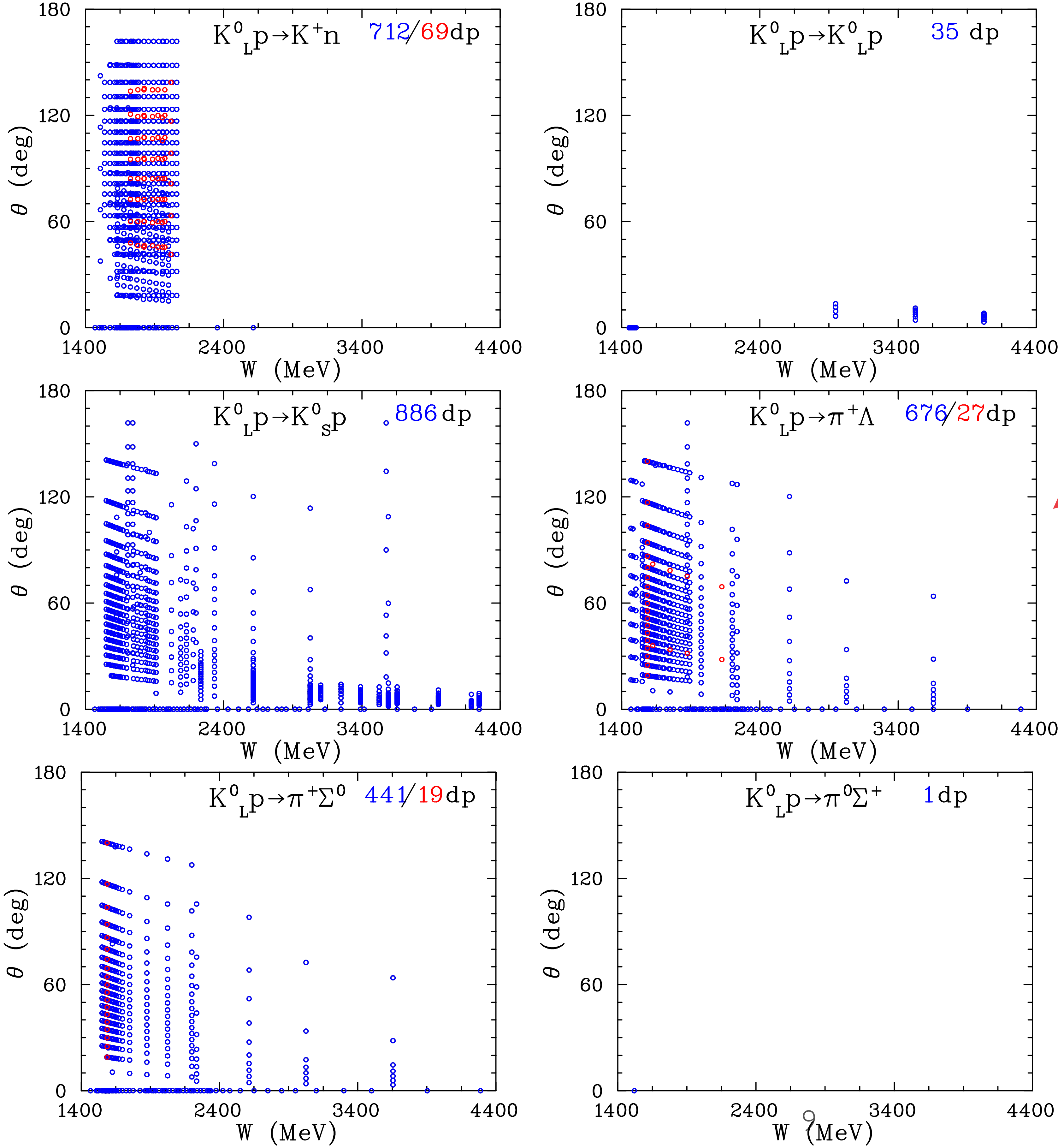
- To complete **$SU(3)_F$** multiplets, one needs no less than **17 Λ***, **41 Σ***, **41 Ξ***, & **24 Ω***.

Strange Mesons

almost half not established

STRANGE ($S = \pm1$, $C = B = 0$)	$I(J^P)$	STRANGE ($S = \pm1$, $C = B = 0$)	$I(J^P)$
• $K^{\pm}$	$1/2(0^-)$	• $K^*(1680)$	$1/2(1^-)$
• K^0	$1/2(0^-)$	• $K_2(1770)$	$1/2(2^-)$
• K^0_S	$1/2(0^-)$	• $K^*_3(1780)$	$1/2(3^-)$
• K^0_L	$1/2(0^-)$	• $K_2(1820)$	$1/2(2^-)$
$K^*_0(800)$	$1/2(0^+)$	$K(1830)$	$1/2(0^-)$
• $K^*(892)$	$1/2(1^-)$	$K^*_0(1950)$	$1/2(0^+)$
• $K_1(1270)$	$1/2(1^+)$	$K^*_2(1980)$	$1/2(2^+)$
• $K_1(1400)$	$1/2(1^+)$	• $K^*_4(2045)$	$1/2(4^+)$
• $K^*(1410)$	$1/2(1^-)$	$K_2(2250)$	$1/2(2^-)$
• $K^*_0(1430)$	$1/2(0^+)$	$K_3(2320)$	$1/2(3^+)$
• $K^*_2(1430)$	$1/2(2^+)$	$K^*_5(2380)$	$1/2(5^-)$
$K(1460)$	$1/2(0^-)$	$K_4(2500)$	$1/2(4^-)$
$K_2(1580)$	$1/2(2^-)$	$K(3100)$	$?^?(?^{??})$
$K(1630)$	$1/2(?^?)$		
$K_1(1650)$	$1/2(1^+)$		

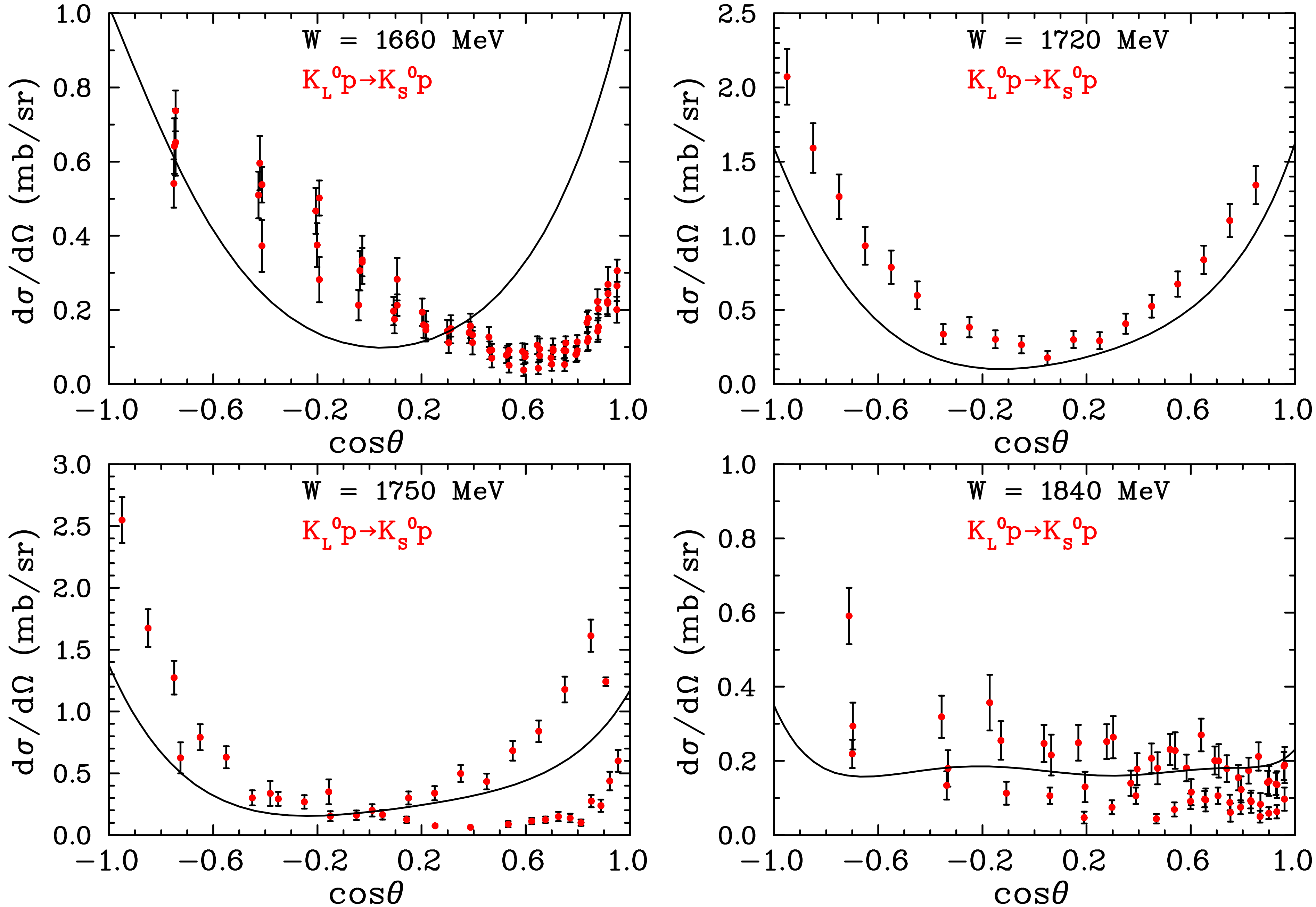
Previous Measurements



Very poor data

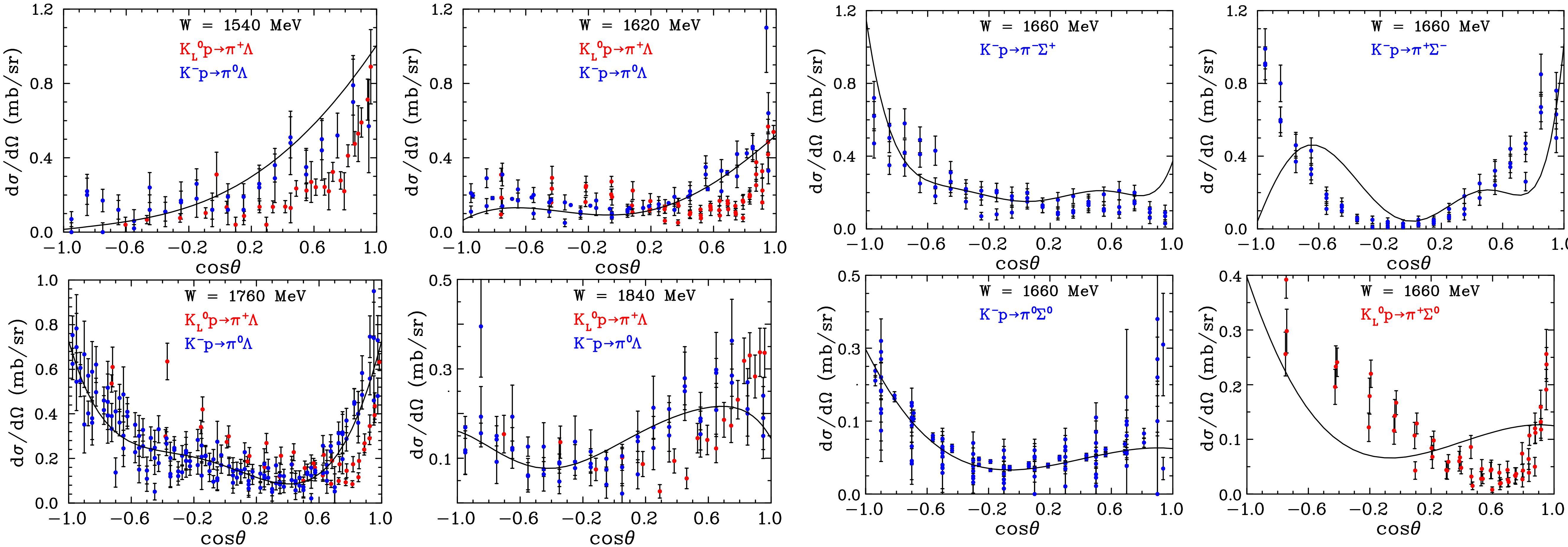
no data on Neutron target at all

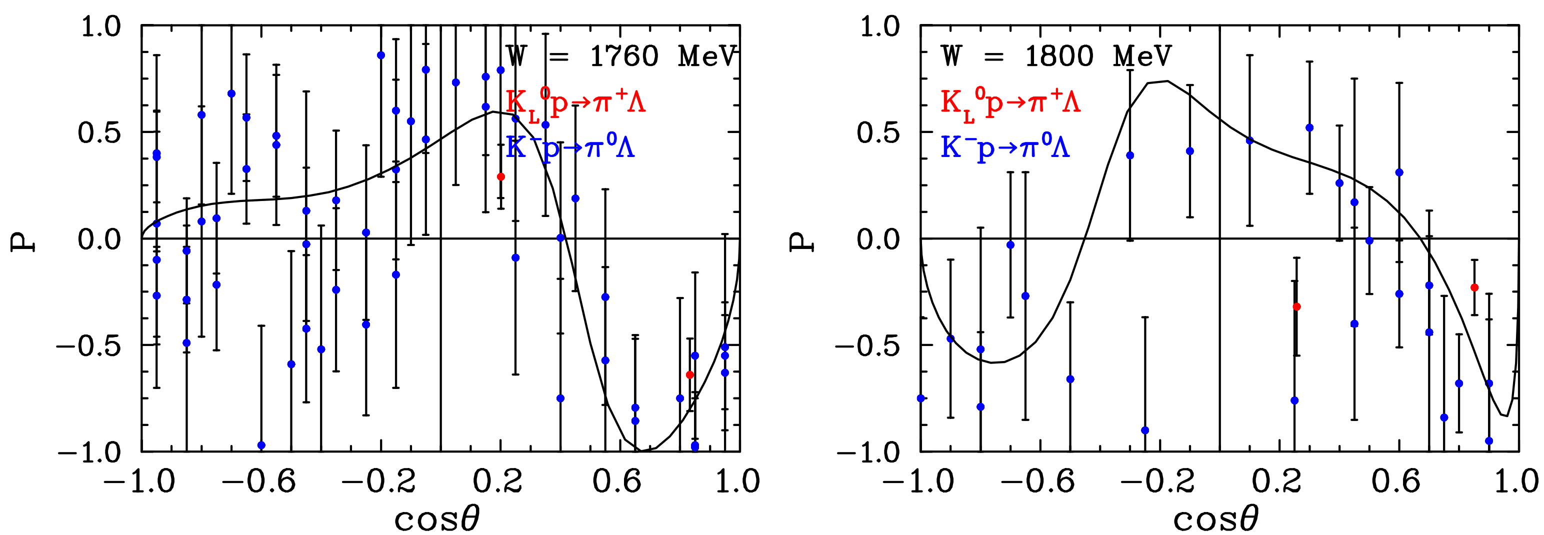
Previous Measurements



Previous Measurements

Cross sections



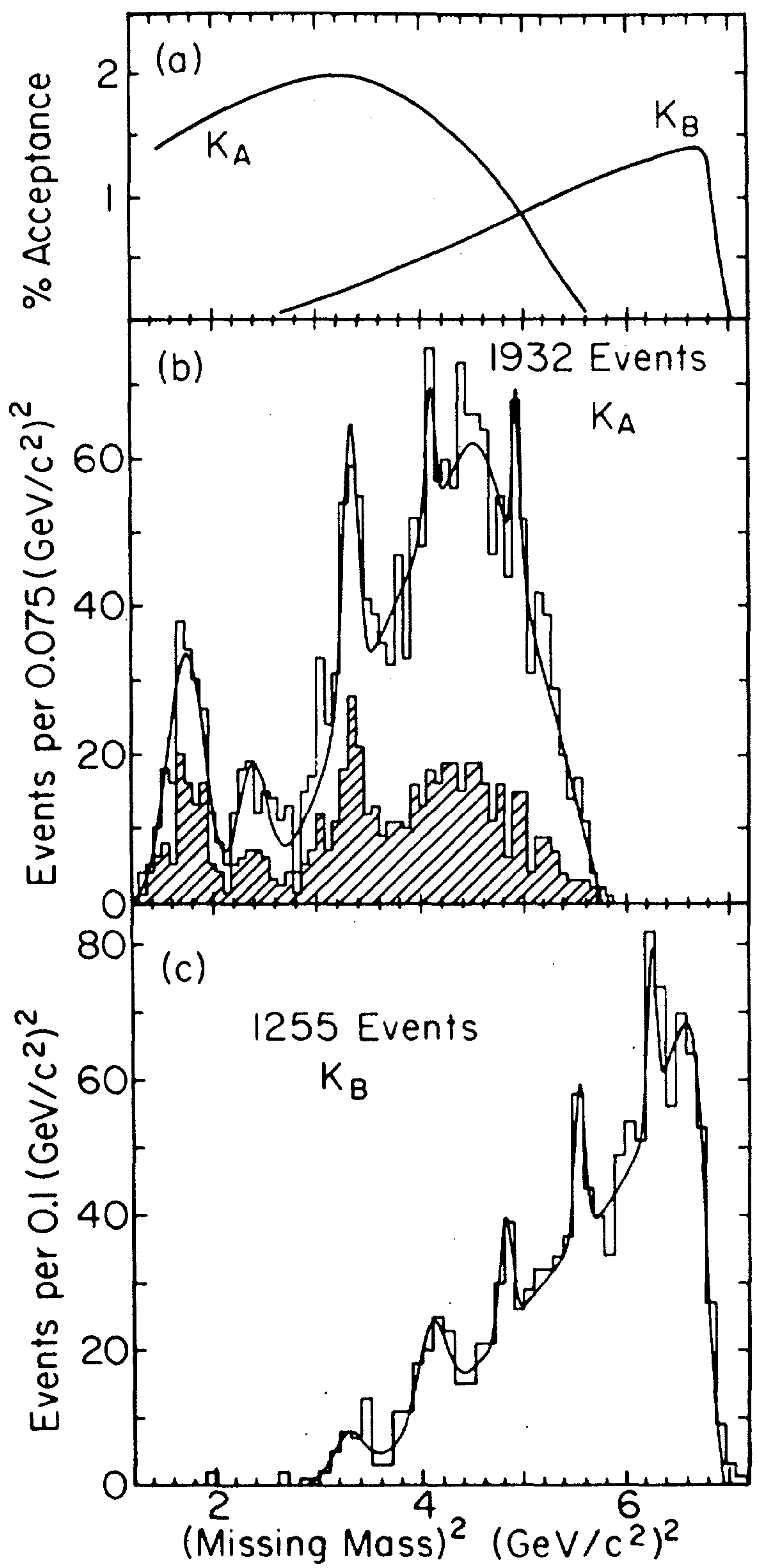


Polarization

all very poor !

Status of Ξ^*

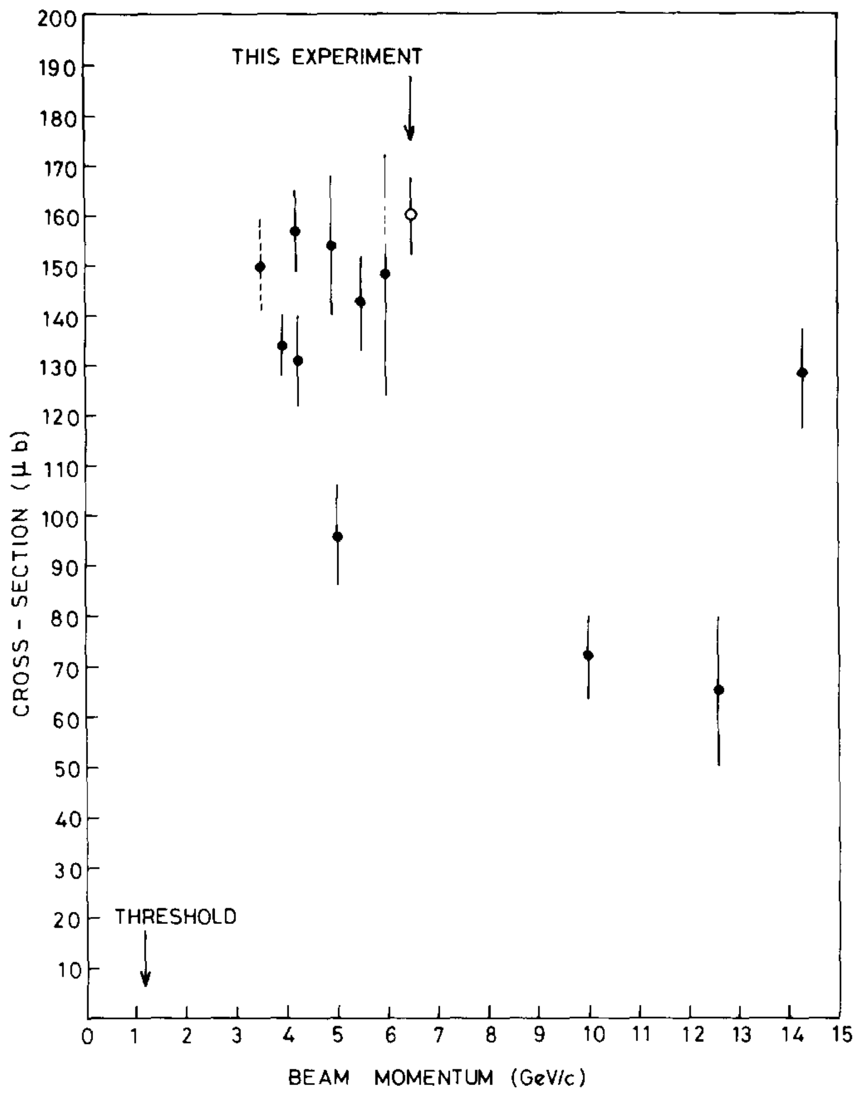
Very poorly measured at AGS (BNL) 32 years ago



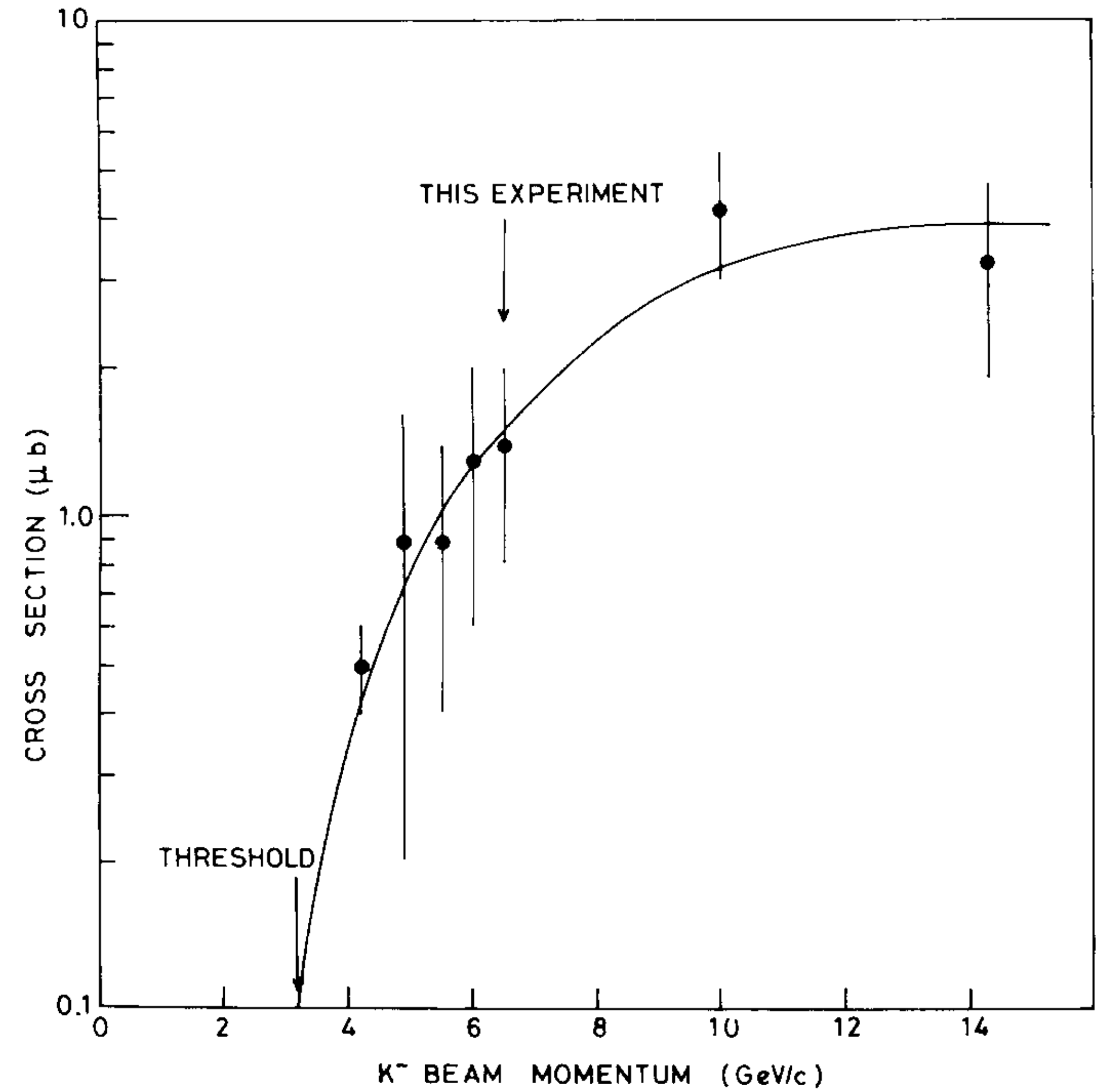
. C.M. Jenkins et al., Phys. Rev. Lett. 51, 951 (1983)

Cross Sections

$$K^- p \to \Xi^- X$$



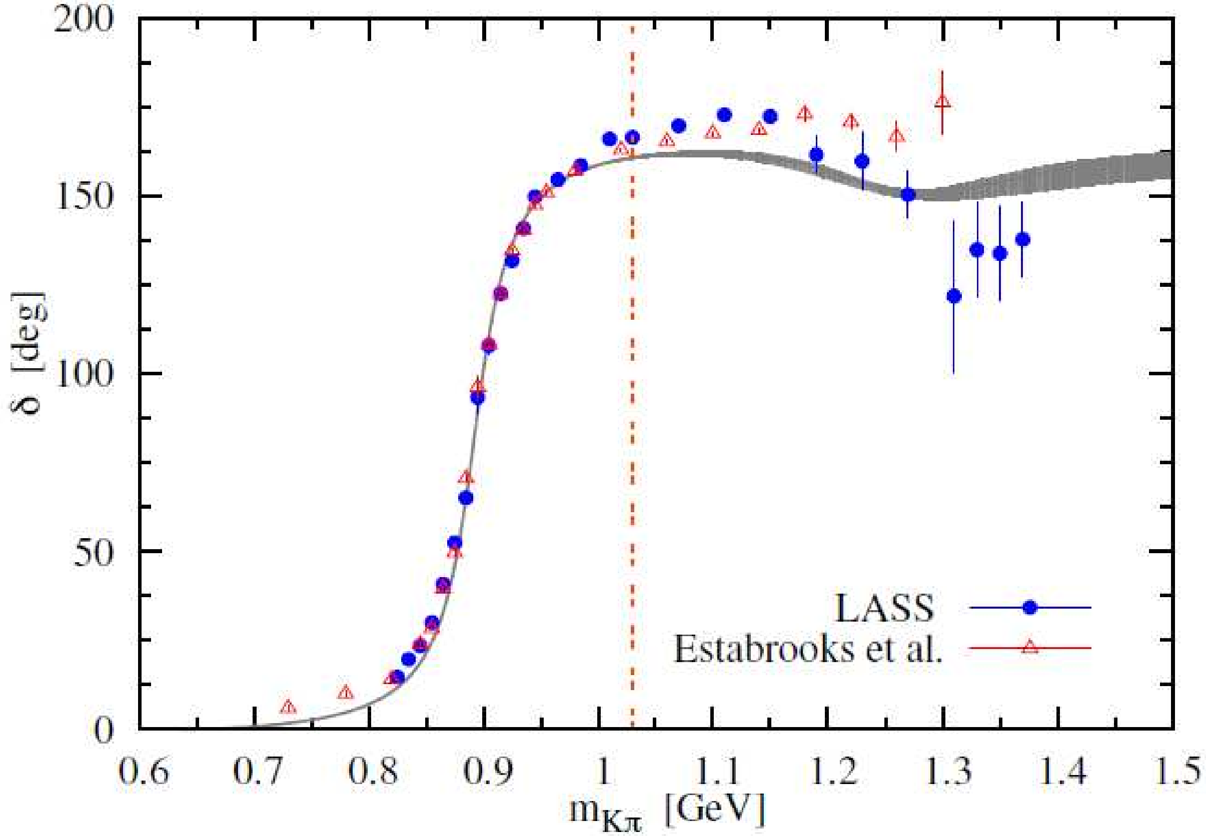
$$K^- p \to \Omega^- X$$

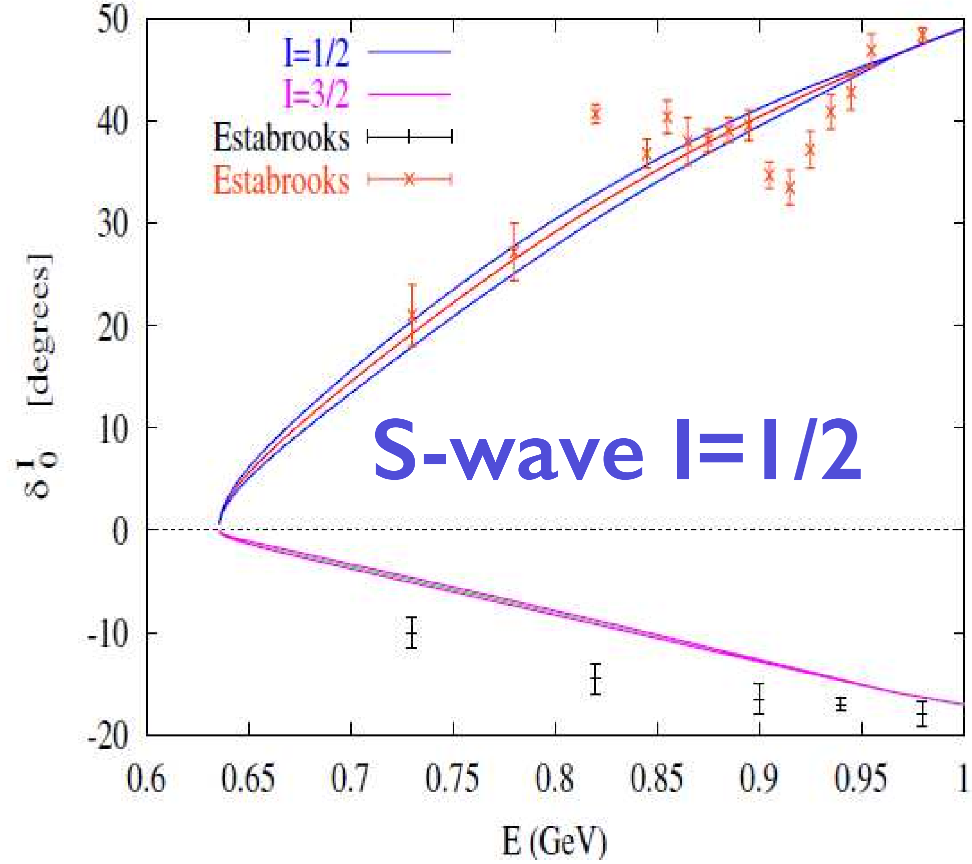


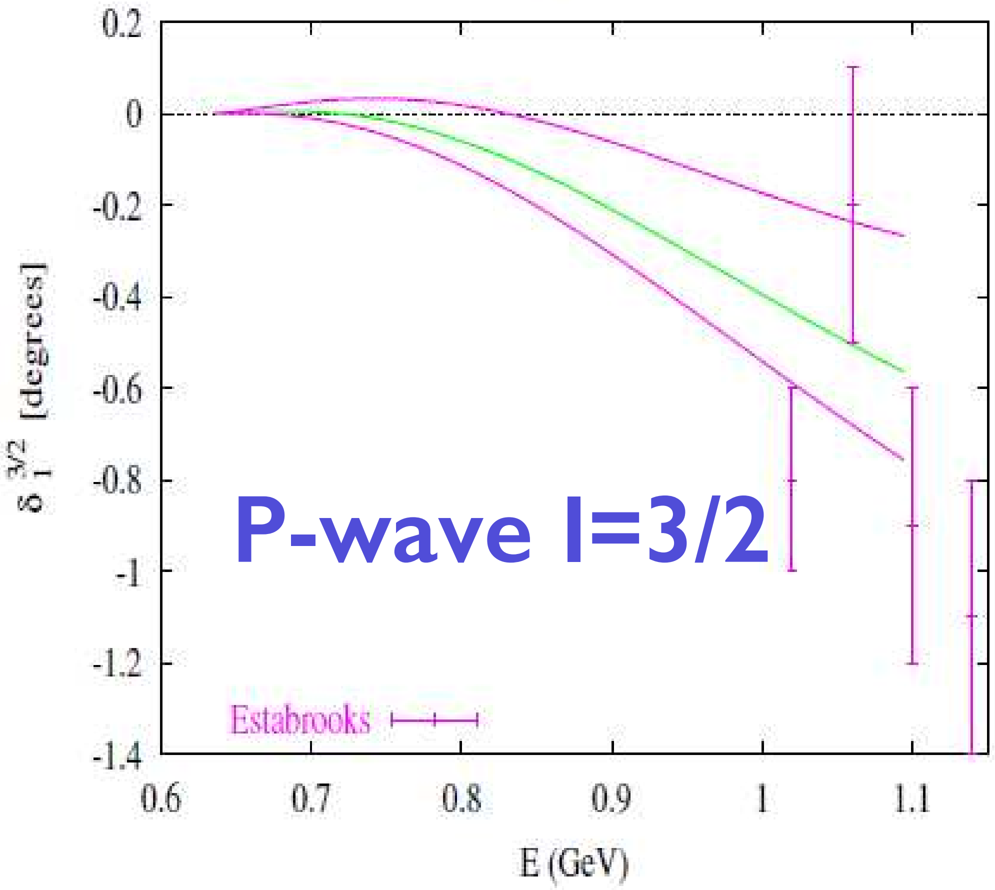
J.K. Hassal et al., NPB 189 (1981)

K-pi Scattering

P-wave I=1/2



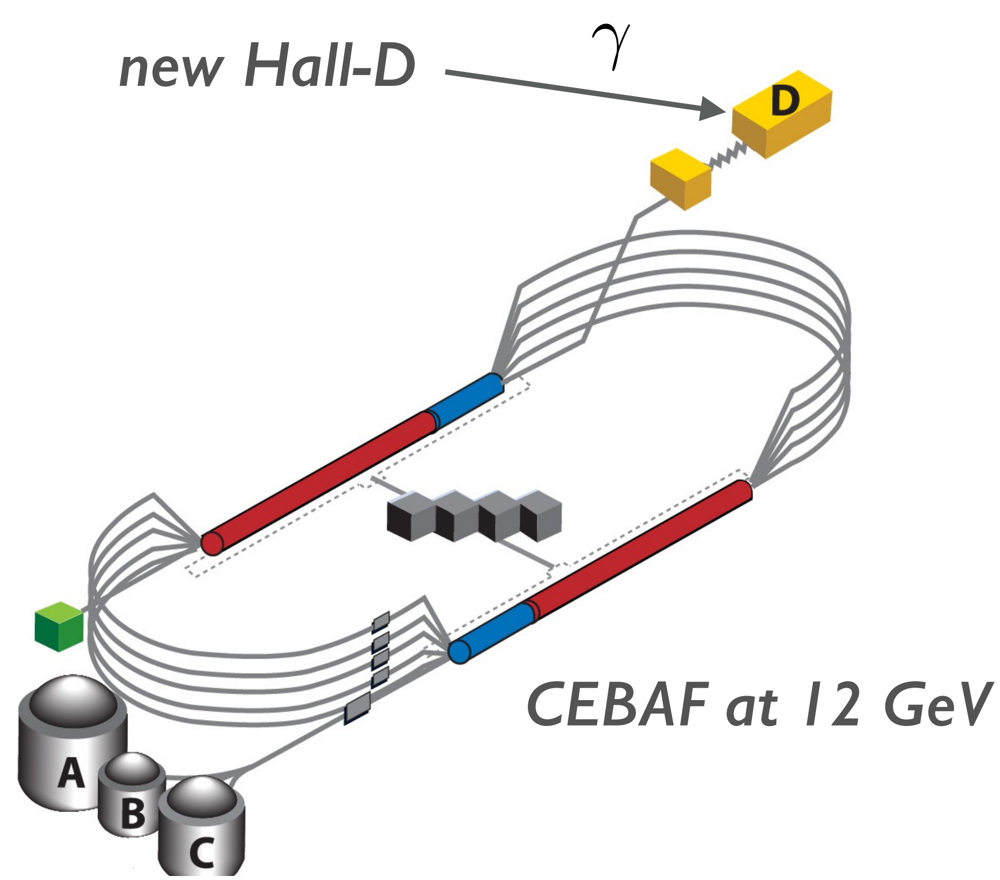




How to make a kaon beam?

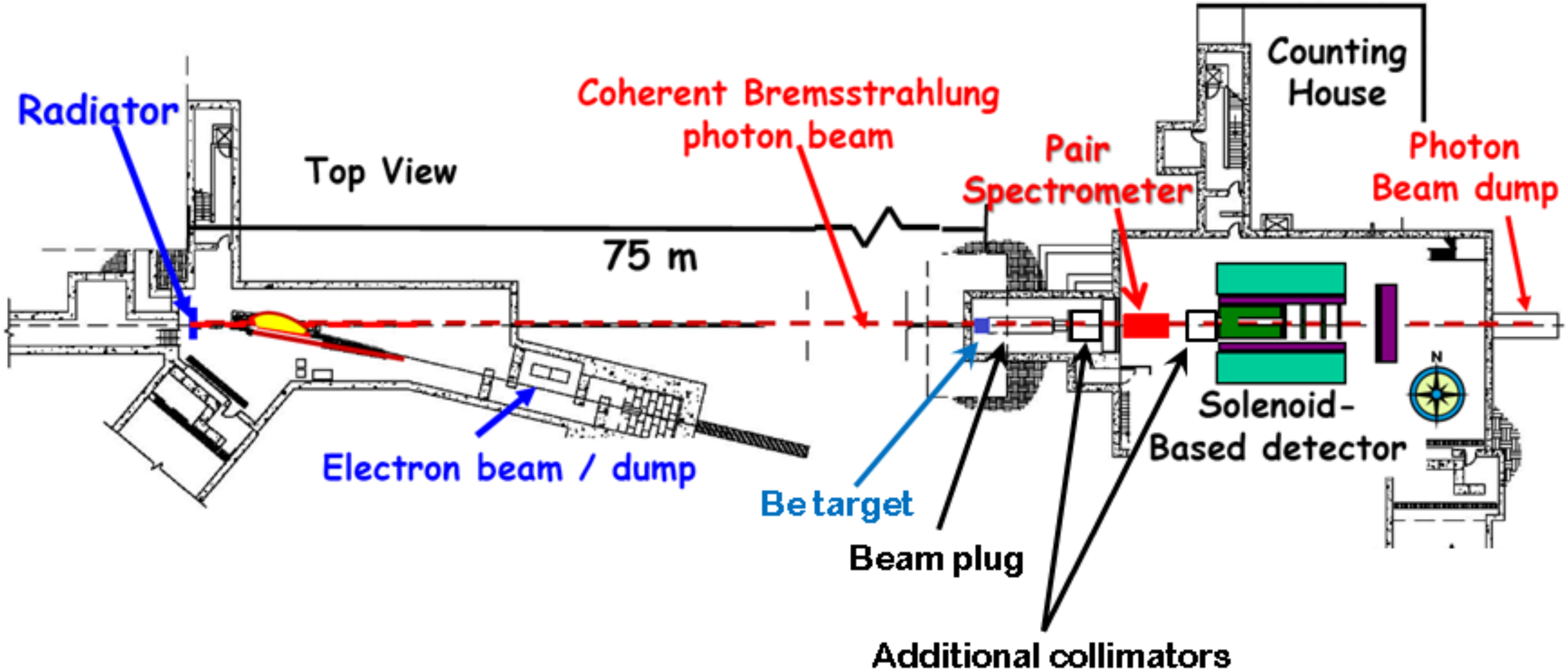
Thomas Jefferson National Accelerator Facility

Aerial View

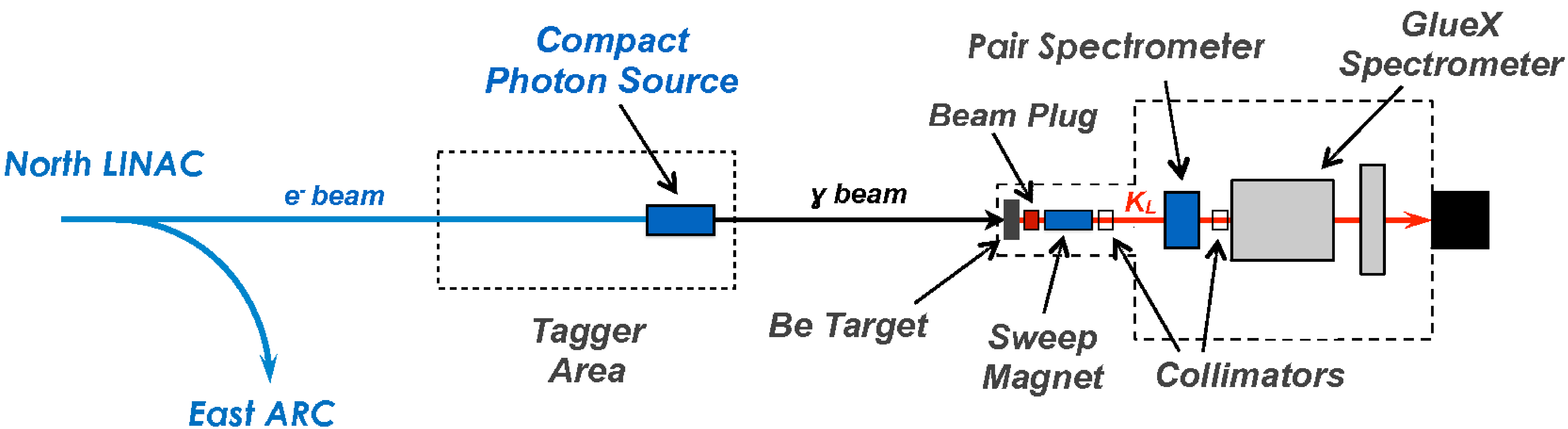


Hall D Beamline

Current setup



KL Beam



- Radiator 0.1 R.L.
- Compact Proton Source
- Be target 40cm
- Distance Be-LH2 16m
- LH2 target 40cm
- LH2 target R=3cm

K^0_L beam (continued)

-Electron beam with $I_e = 5\mu A$

-Delivered with 64 ns bunch spacing avoids overlap in the range of P=0.3-10.0 GeV/c

-Momentum measured with TOF

-K^0_L flux mesured with pair spectrometer

-*Side remark: Physics case with polarized targets is under study and feasible*

Rate of neutrons and K^0_L on GlueX target

- **PRL22.996 (1969) Brody et al.**

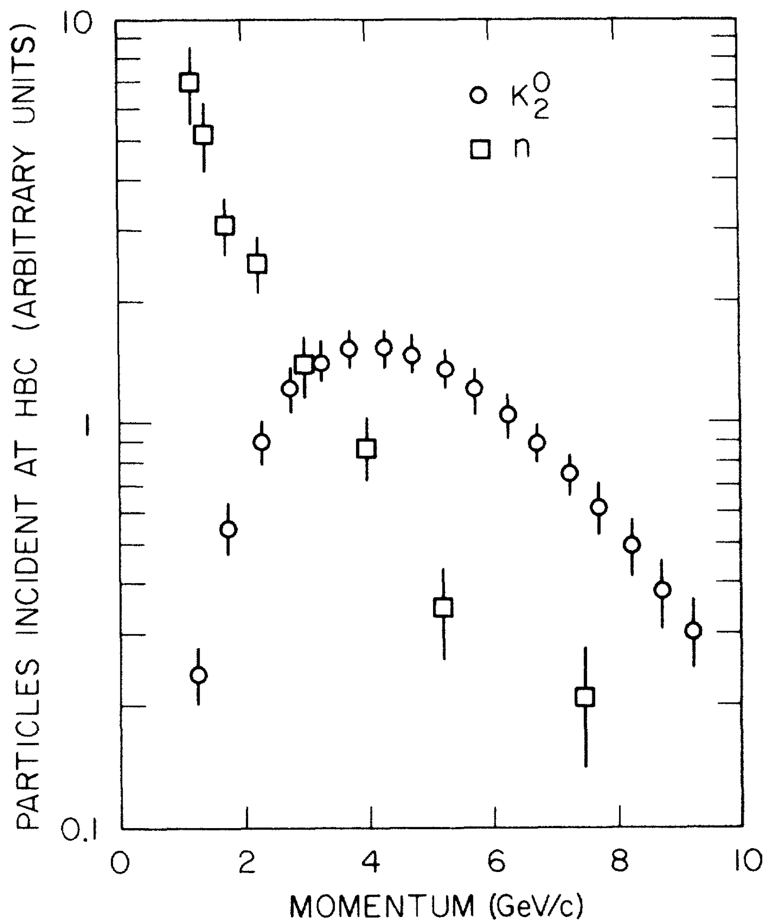
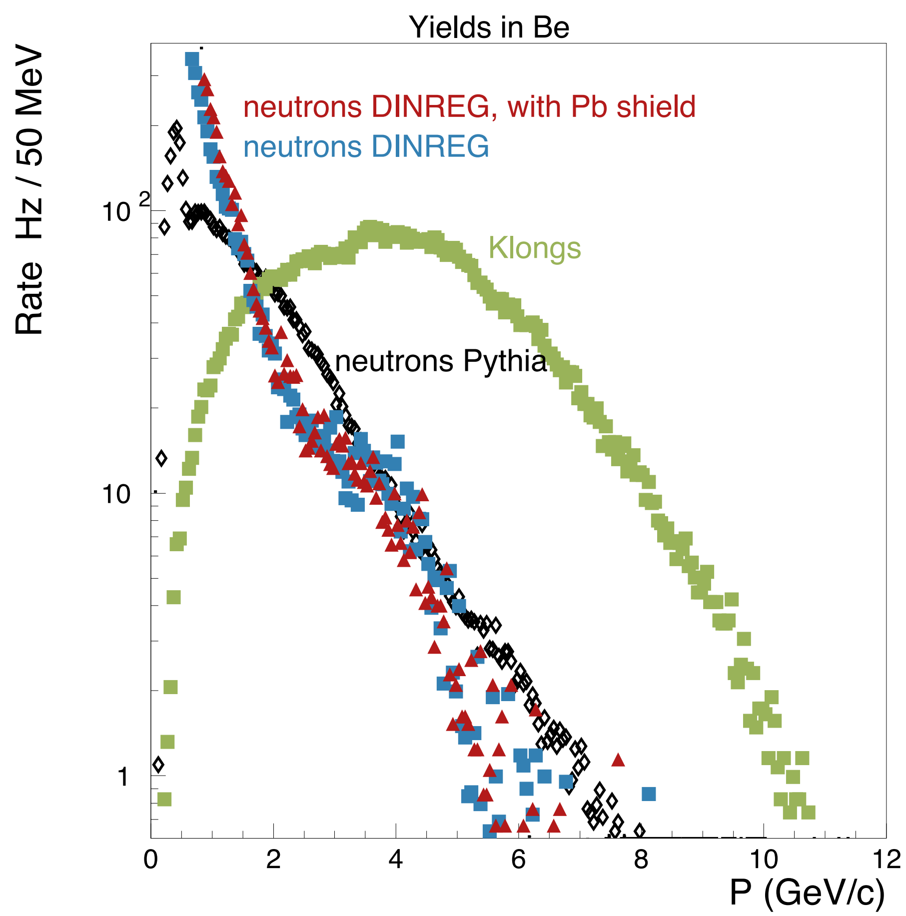


FIG. 2. Comparison of the neutron and K_2^0 fluxes at the hydrogen bubble chamber for 2° production with 16-GeV electrons.

- **JLAB**



- **With a proton beam ratio $n/K_L = 10^3\text{-}10^4$**

proposed facility is $\epsilon = \frac{N_{K_L}(K_LF)\Delta\Omega_{K_LF}}{N_{K_L}(SLAC)\Delta\Omega_{SLAC}} = 2.4 \times 10^3$ *more effective*

one month

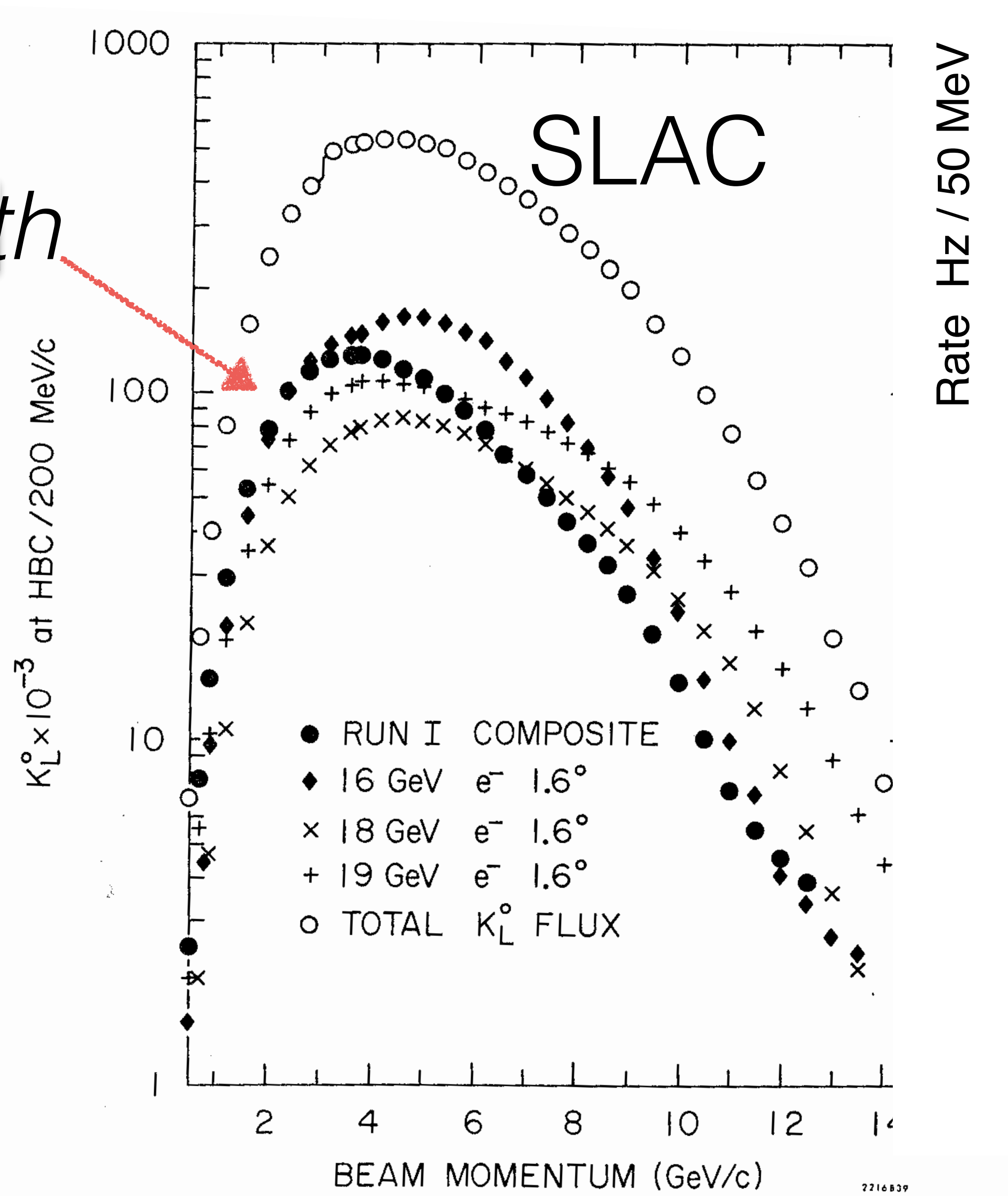
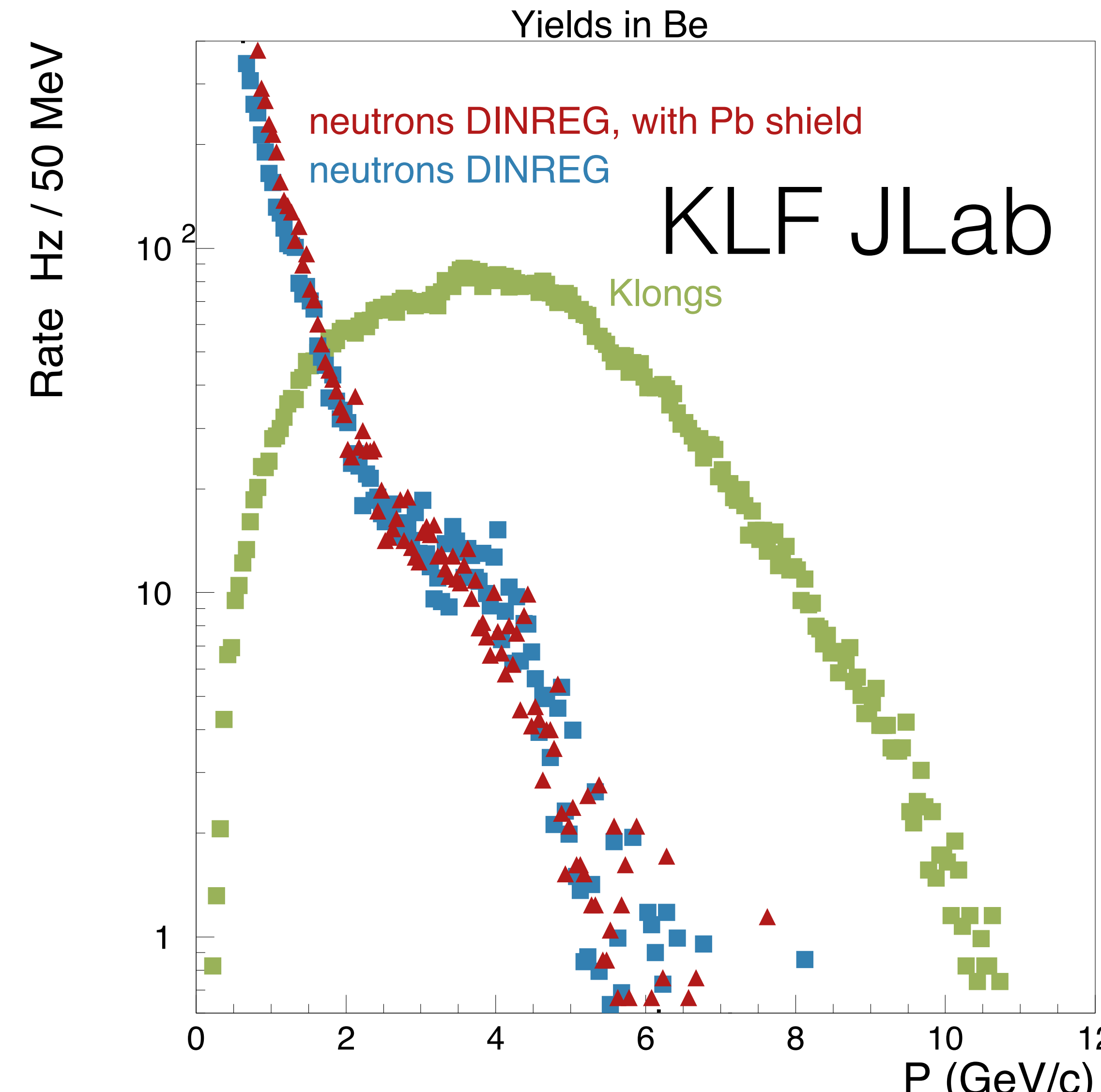


FIG. 9--Beam flux versus incident K_L^0 momentum. Only the Run I (●) flux has been determined absolutely. The fluxes shown for the 16, 18, and 19 GeV e⁻ at 1.6° (♦, X, and +) exposures are derived from the unnormalized intensities of Table 1 times the α coefficients of Table 2. The discontinuity at 3.0 GeV/c in the total K_L^0 flux (○) is due to the use of the triggered film from the 19 GeV e⁻ exposure only for K_L^0 momenta greater than 3.0 GeV/c (see text).



$\Delta\Omega = 20\mu sr$

SLAC-177
R.J. Jamartino

$\Delta\Omega = \pi R^2/16 = \pi \times 3^2 \times 10^{-4}/16^2 = 11\mu sr$

in one month (24x30=720h):

at 3 GeV N(K$_L$)/200 MeV/c=0.15x10^6

in one hour :

at 3 GeV N(K$_L$)/200 MeV/c =70x4x3.6x10^3 ~ 10^6

N(KLF)/N(SLAC) = 720/0.15 = 4800

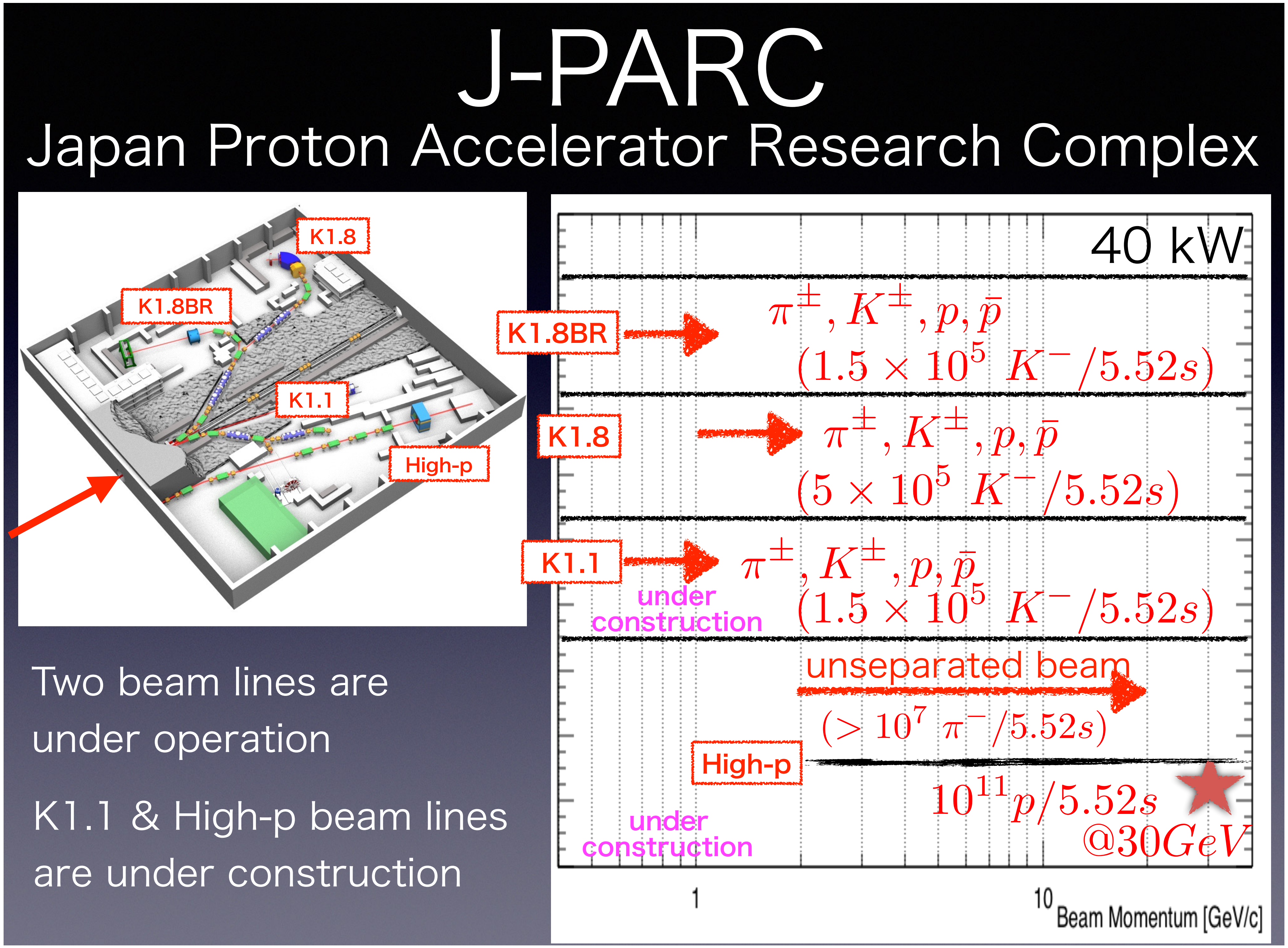
- **ProjectX (Fermi Lab) arXiv:1306.5009**

Table III-2: Comparison of the K_L production yield. The BNL AGS kaon and neutron yields are taken from RSVP reviews in 2004 and 2005. The *Project X* yields are for a thick target, fully simulated with LAQGSM/MARS15 into the KOPIO beam solid angle and momentum acceptance.

	Beam energy	Target (λ_I)	$p(K)$ (MeV/c)	K_L/s into 500 μsr	$K_L : n$ ($E_n > 10$ MeV)
BNL AGS	24 GeV	1.1 Pt	300-1200	60×10^6	$\sim 1 : 1000$
Project X	3 GeV	1.0 C	300-1200	450×10^6	$\sim 1 : 2700$

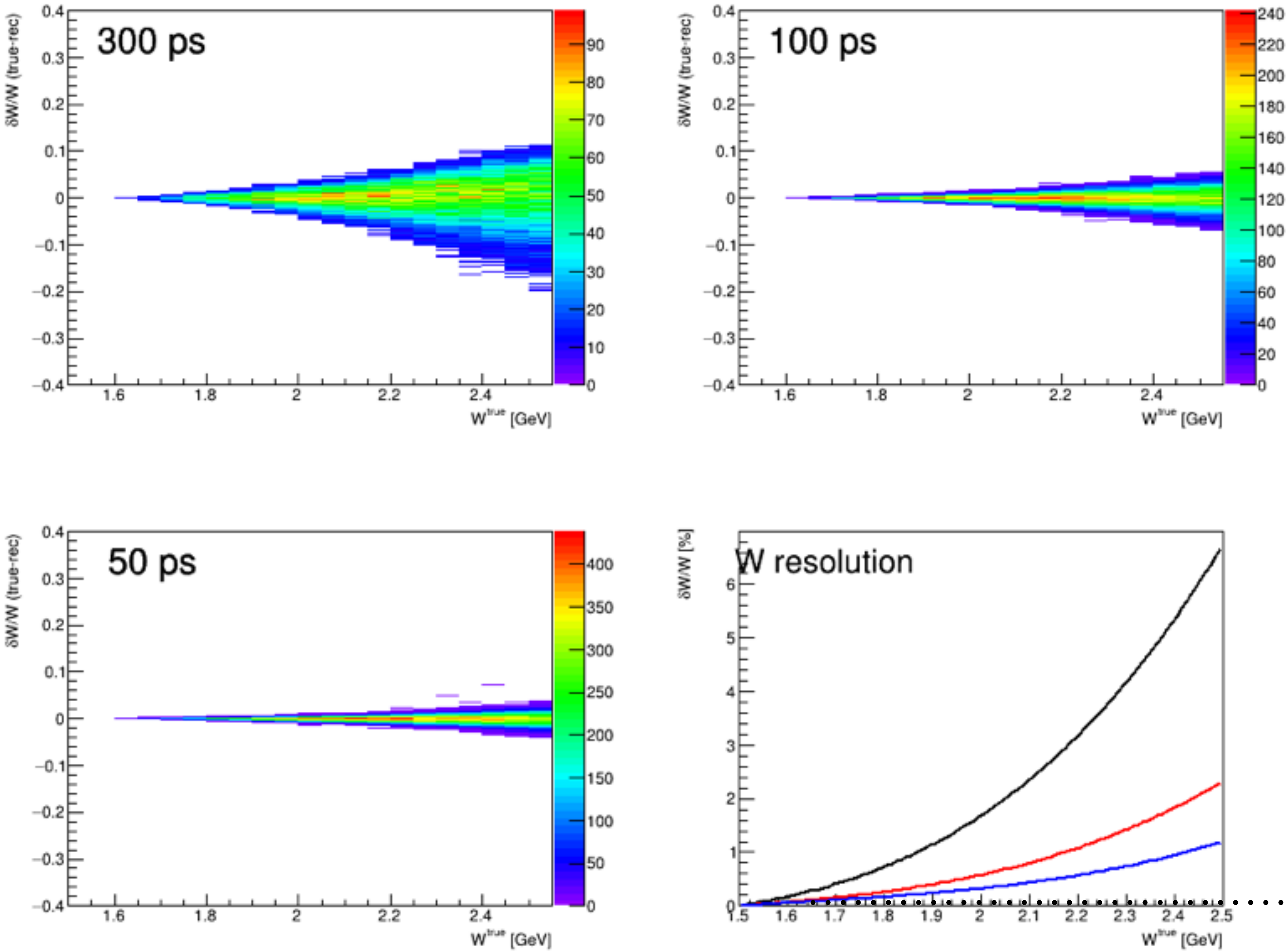
KL beam can be used to study rare decays
However it will be impossible to use it for hyperon spectroscopy
because of momentum range and n/K Ratio

Other Facilities



Talk by Onishi at KL2016

W Resolution



Expected rates

Production	J-PARC*	Jlab (this proposal)
flux/s	$3 \times 10^4 K^-$	$3 \times 10^4 K_L$
$\Xi^* /month$	3×10^5	2×10^5
$\Omega^{-*} /month$	600	4000

* H.~Takahashi, NP A 914, 553 (2013)
M.~Naruki and K.~Shirotori, LOI-2014-JPARC

Proposed Measurements

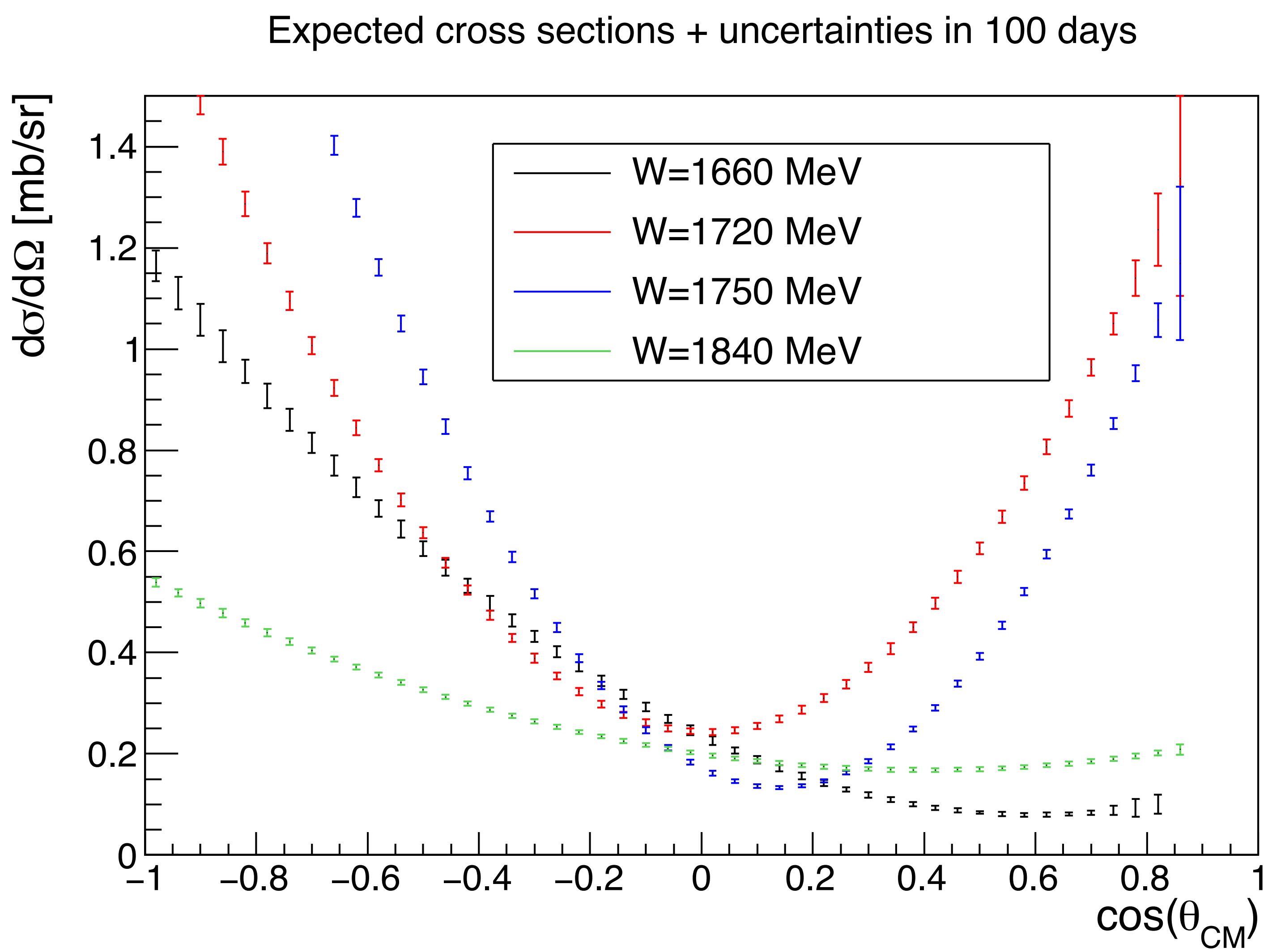


Figure 29: Reconstructed $K_L p \rightarrow K_S p$ differential cross sections for various values of W for 100 days of running.

Proposed Measurements

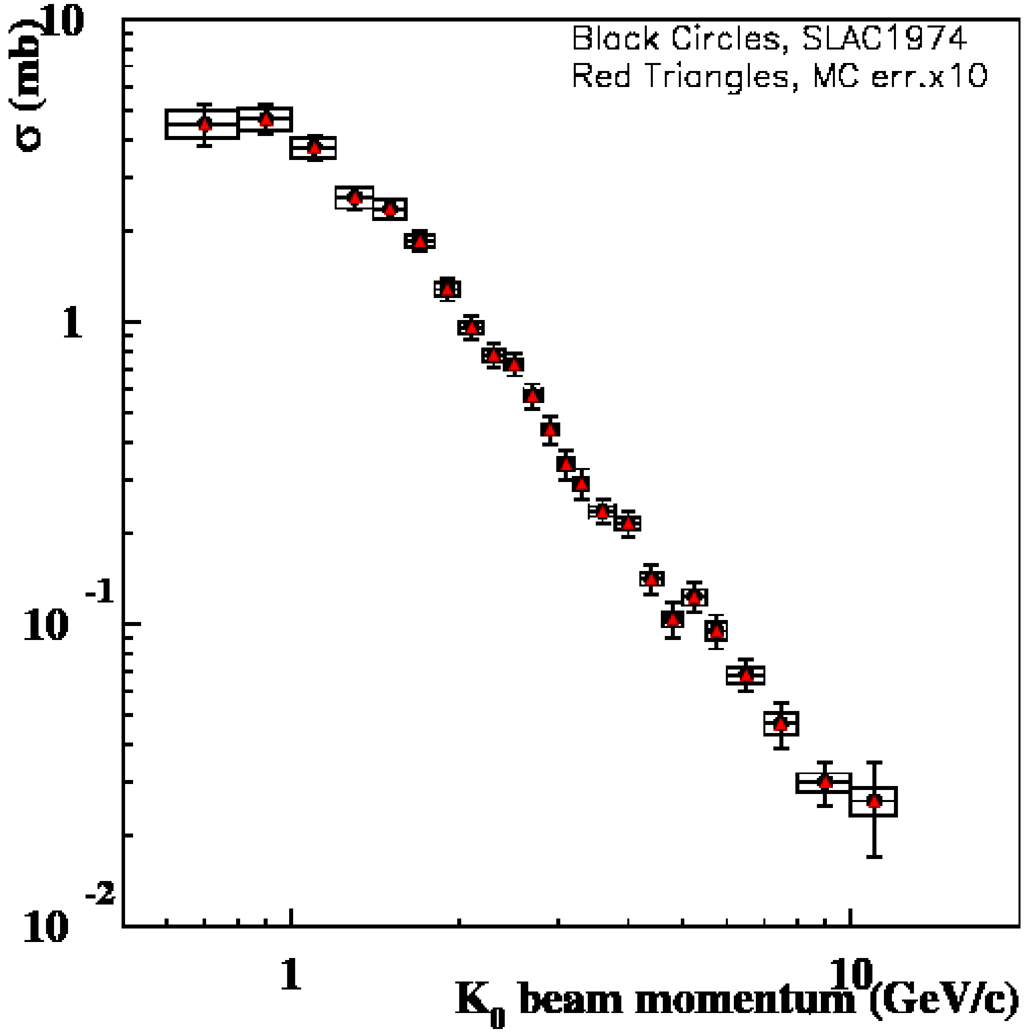


Figure 31: The total cross-section uncertainty estimate (statistical error only) for $K_L p \rightarrow \pi^+ \Lambda$ reaction as a function of K_L beam momentum in comparison with SLAC data [133]. The experimental uncertainties have tick marks at the end of the error bars. The box-shaped error bars in the MC points were increased by a factor of 10.

Proposed Measurements

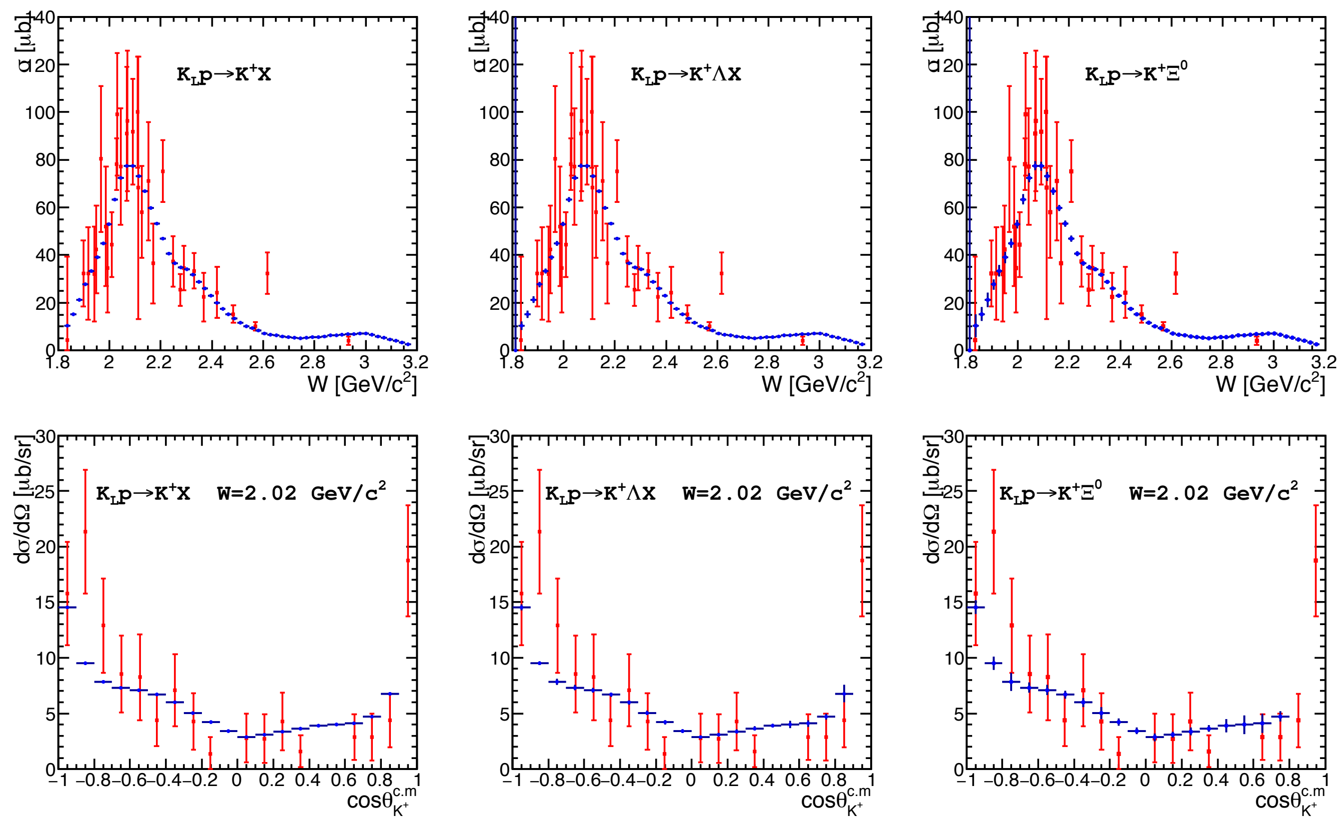


Figure 33: Total and differential cross section statistical uncertainty estimates (blue points) for the three topologies (column 1: only K^+ reconstructed, column 2: $K^+\Lambda$ reconstructed, and column 3: $K^+\Xi^0$ reconstructed) in comparison with data taken from Ref. [134] (red points).

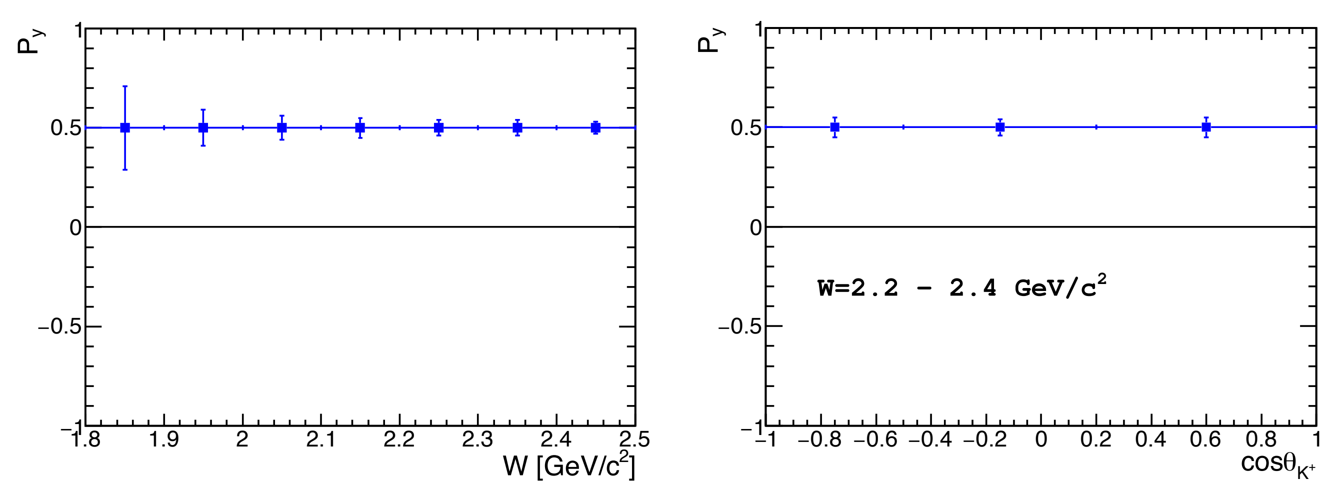


Figure 34: Estimates of the statistical uncertainties of the induced polarization of the cascade as a function of W (one-fold differential) and $\cos\theta_{K^+}$ (two-fold differential).

Proposed Measurements

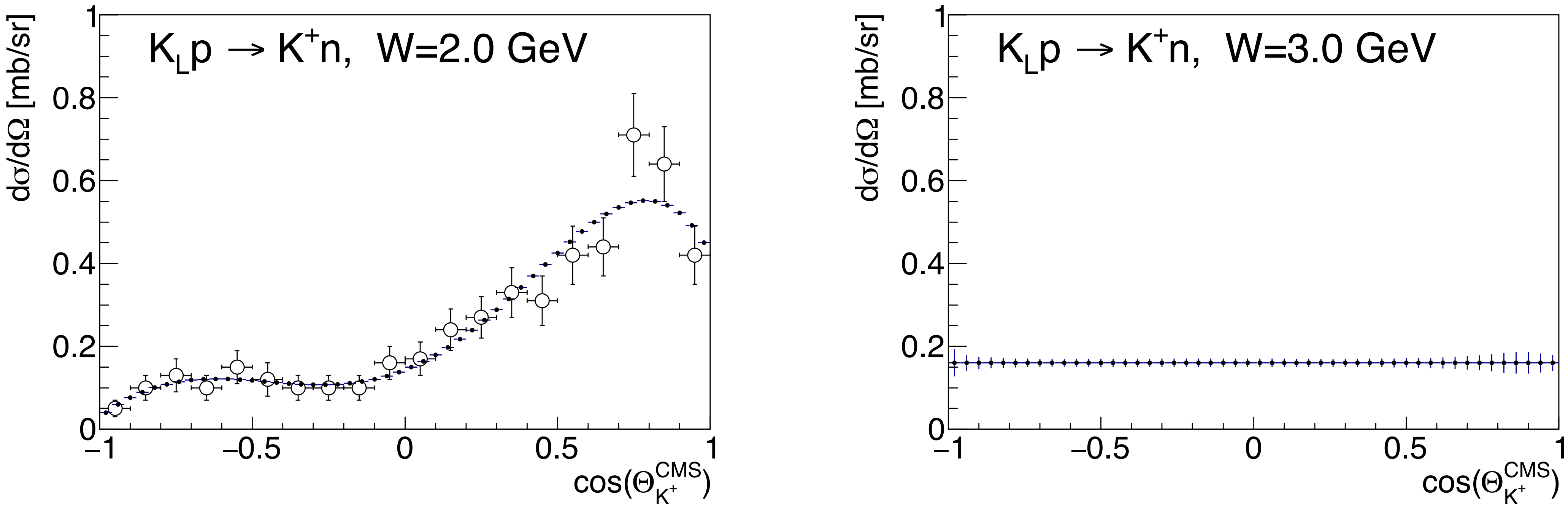


Figure 36: The cross-section uncertainty estimates (statistical only) for $K_L p \rightarrow K^+ n$ reaction for the $W = 2$ GeV (left) in comparison with data from Ref. [136] and $W = 3$ GeV (right) The error bars for the right plot were increased by factor of 10 to make them visible.

Proposed Measurements

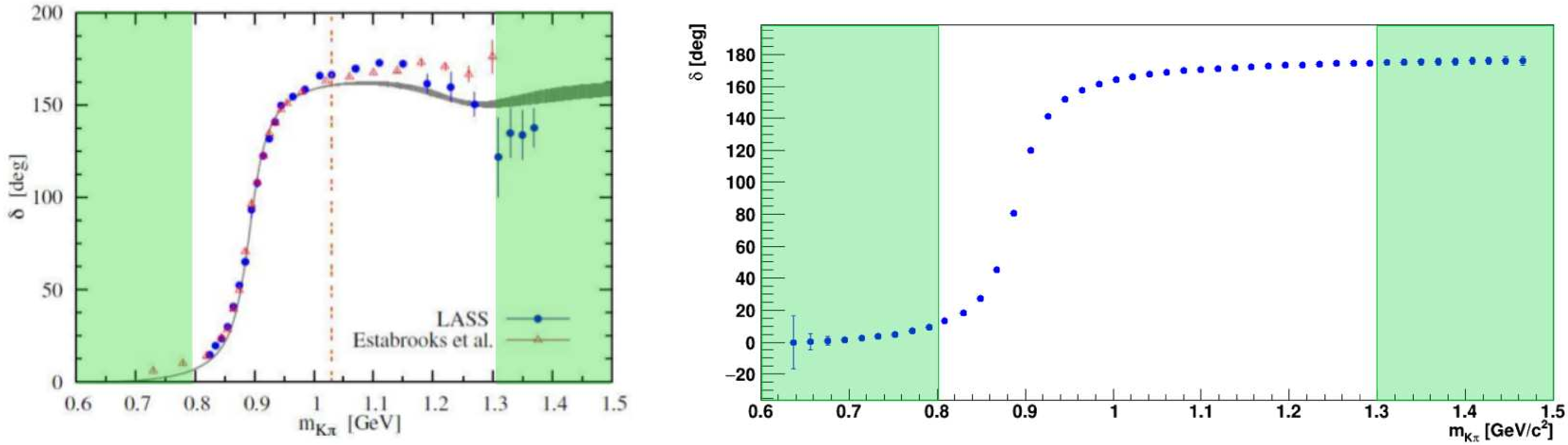


Figure 38: The $I = 1/2$ $K\pi$ scattering P-wave phase-shift function of $m_{K\pi}$. The left panel shows experimental results from LASS [88] and Estabrooks *et al*. [87]. The gray band represents the fit to the τ decay data by Boito *et al*. [103]. On the right panel, we present results of expected measurement for 100 days of running. The statistical errors on the right panel are increased by factor of 10 for a better visibility.

Expected Statistics

Table 1: Expected statistics for differential cross sections of different reactions with LH_2 and below $W = 3.5$ GeV for 100 days of beam time.

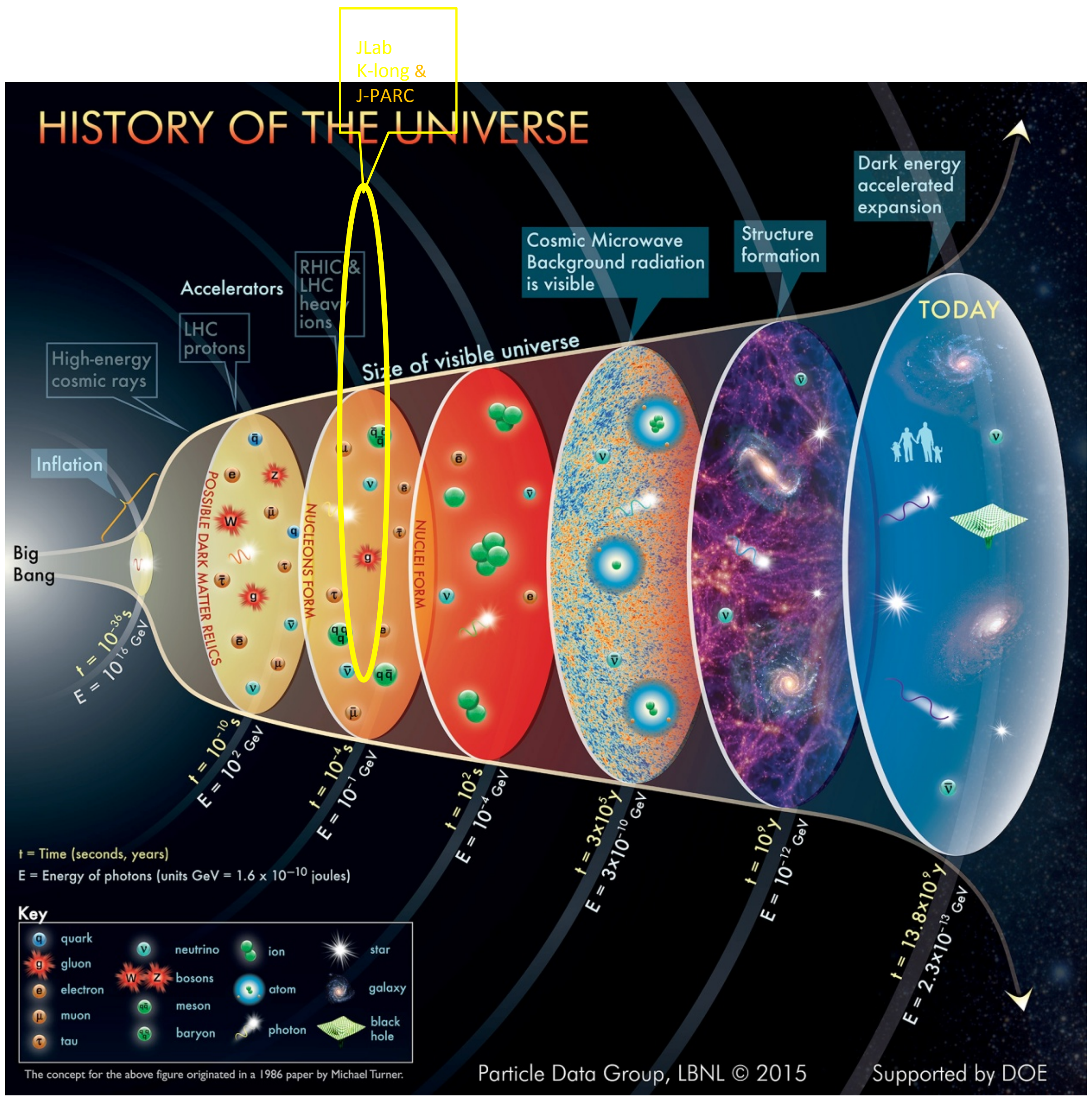
Reaction	Statistics (events)
$K_L p \rightarrow K_S p$	8M
$K_L p \rightarrow \pi^+ \Lambda$	24M
$K_L p \rightarrow K^+ \Xi^0$	4M
$K_L p \rightarrow K^+ n$	200M
$K_L p \rightarrow K^- \pi^+ p$	2M

There are no data on "neutron" targets and, and for this reason, it is hard to make a realistic estimate of the statistics for $K_L n$ reactions. If we assume similar statistics as on a proton target, the full program will be completed after running 100 days with LH_2 and 100 days with LD_2 targets.

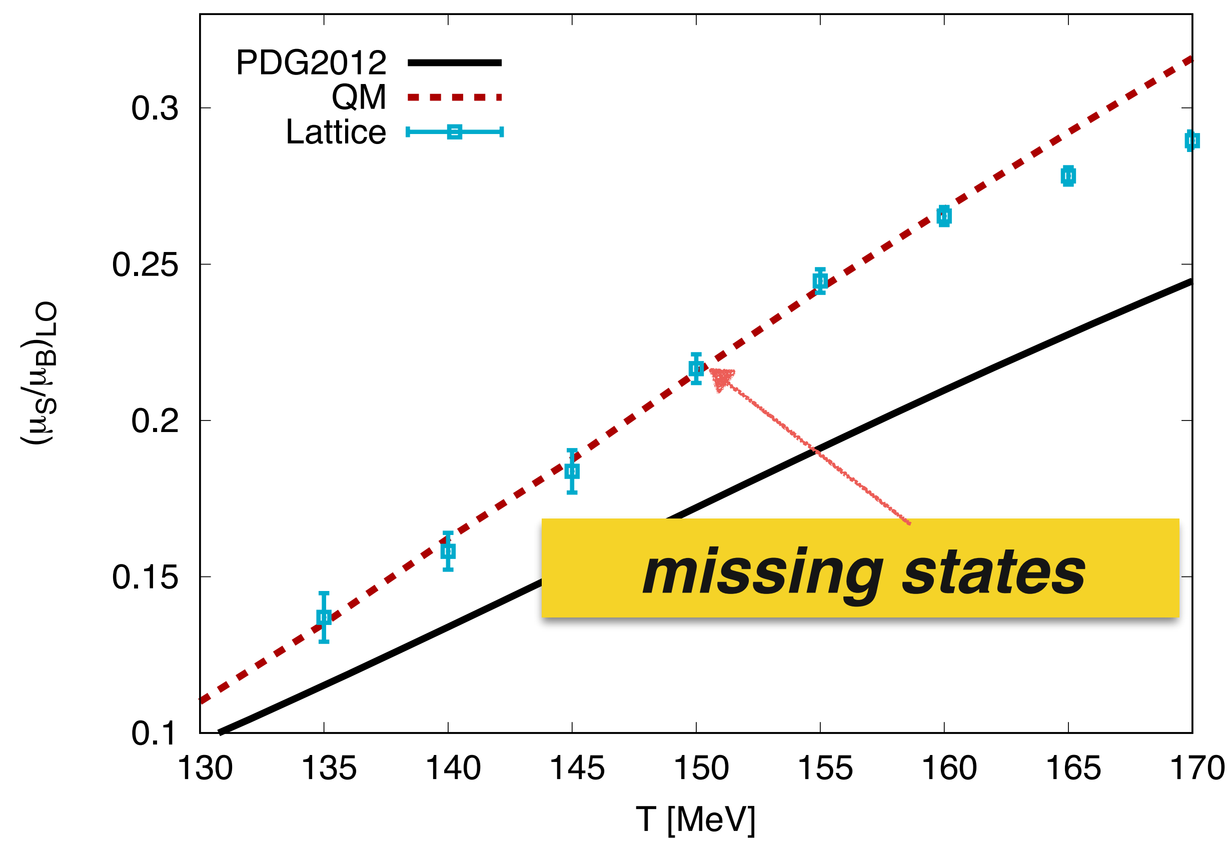
The need for exclusive reconstruction to extract polarization observables further decrease the expected statistics, e.g., from 4M to **400k** events in the $K\Xi$ case. These statistics, however, would allow a precise measurement of the double-differential polarization observables with statistical uncertainties on the order of 5–10%. Secondly, kaon flux has a maximum around $W = 3$ GeV, which decreases rapidly towards high/low W's. Thus, the 100 days of beam time on the LH_2 are essential to maximize the discovery potential of the K_L Facility and cover the densely populated hyperon regime at low-W.

Other Impacts

Evolution of an Early Universe at Freeze-out

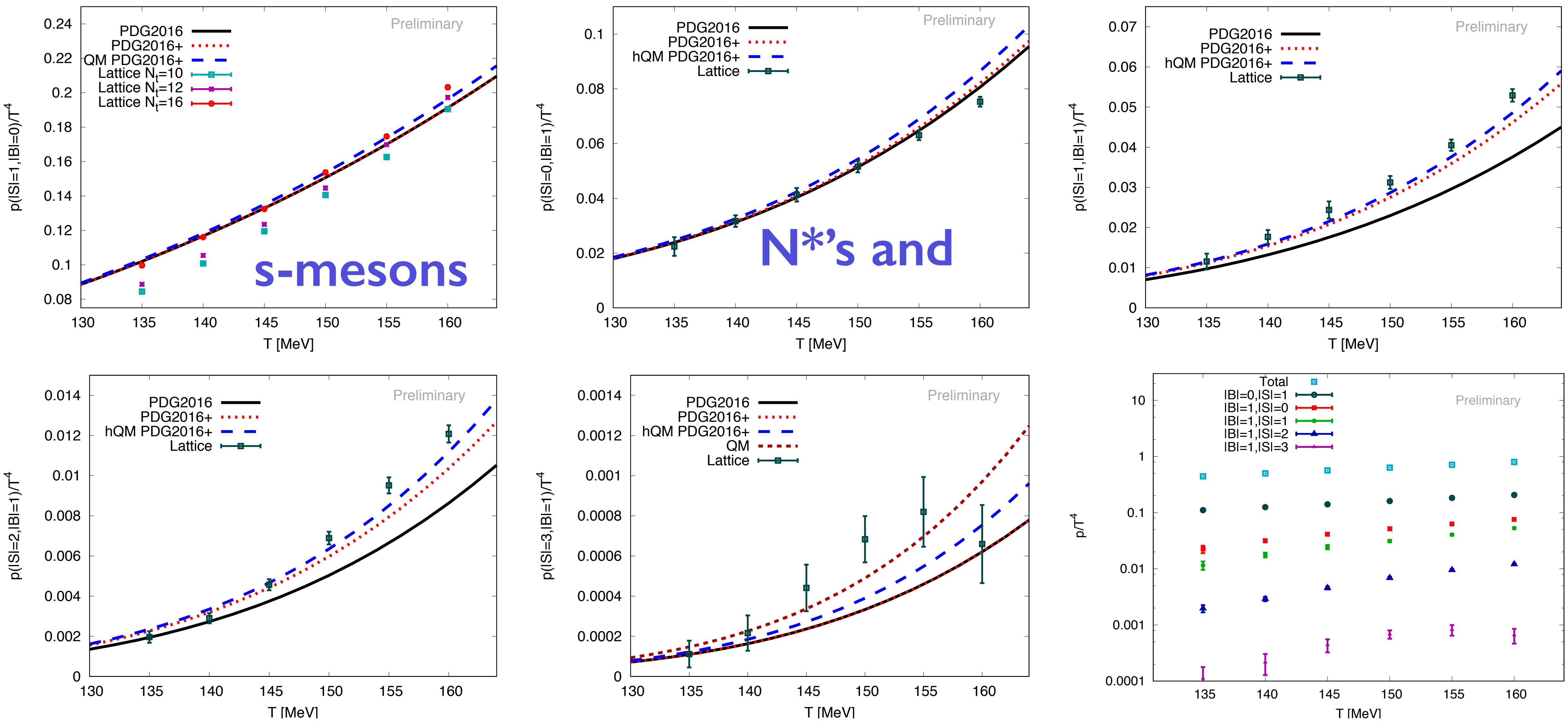


Chemical potential



YSTAR2016 Proceedings arXiv: 1701.07346

Partial pressure P/T⁴



YSTAR2016 Proceedings arXiv:1701.07346

Summary

- KN scattering still remains very poorly studied

- lack of data on excited hyperon states requires significant experimental efforts to be completed

- Experimental data on Kpi system needs to be updated for many different reasons

- Our preliminary studies show that production of few times $10^4 K^0_L$/s at GlueX target in Hall D is feasible

-Proposed setup will have highest intensity K^0_L beam ever used for hadron spectroscopy

-Data obtained at Jlab will be unique and partially complementary to charged kaon data

Thank You!