

Strange Hadron Spectroscopy with a Secondary K_L Beam in Hall-D

Moskov Amaryan

*Old Dominion University
Norfolk, VA*

(for the  *Collaboration)*

PAC48, JLab, August 11, 2020

Outline

Proposal Update

- *Hyperon Spectroscopy*
- *Strange Meson Spectroscopy*

K_L Facility Beamline and Hardware

- *Electron Beam*
- *Compact Photon Source*
- *Be Target*
- *Flux Monitor*
- *K_L Beam*
- *LH₂/LD₂ Target*

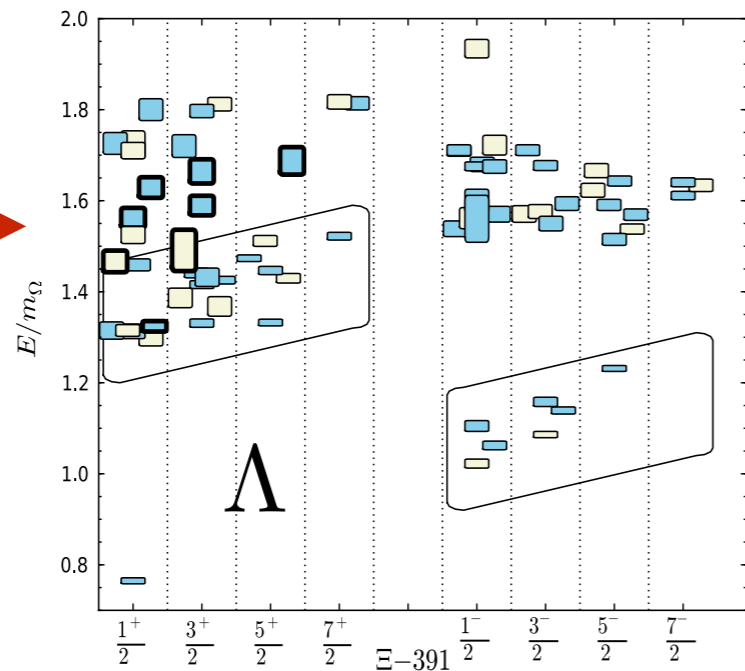
Summary

Hyperon Spectroscopy

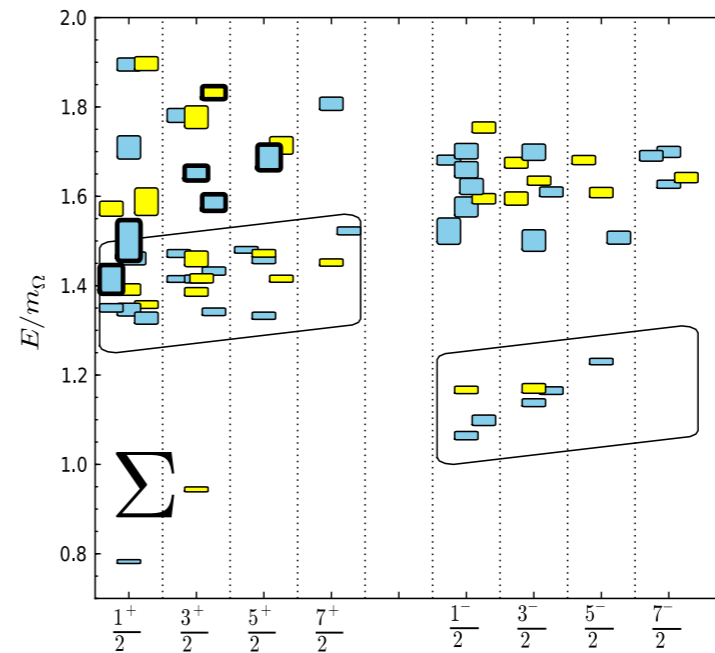
According to *LQCD* there should be many more states including hybrids (thick bordered)

8-states

5-states



$\Sigma-391$



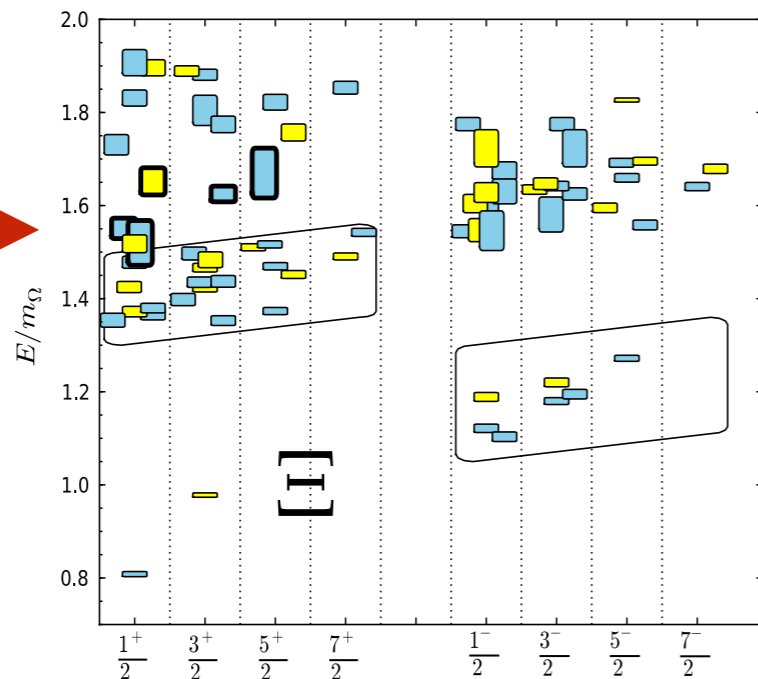
6-states

4-states

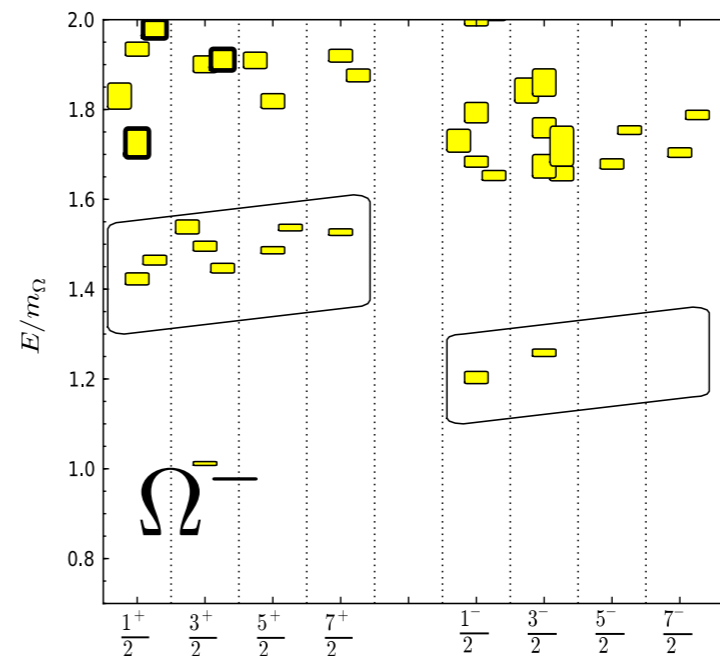


3-states

4-states



$\Omega-391$



1-state

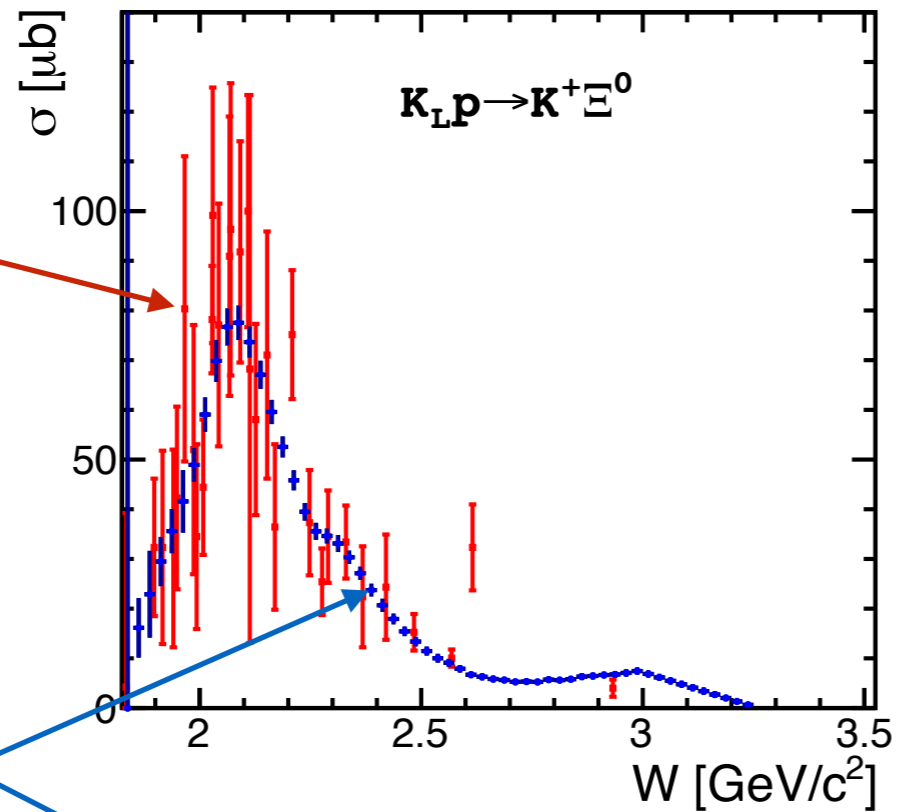
1-state



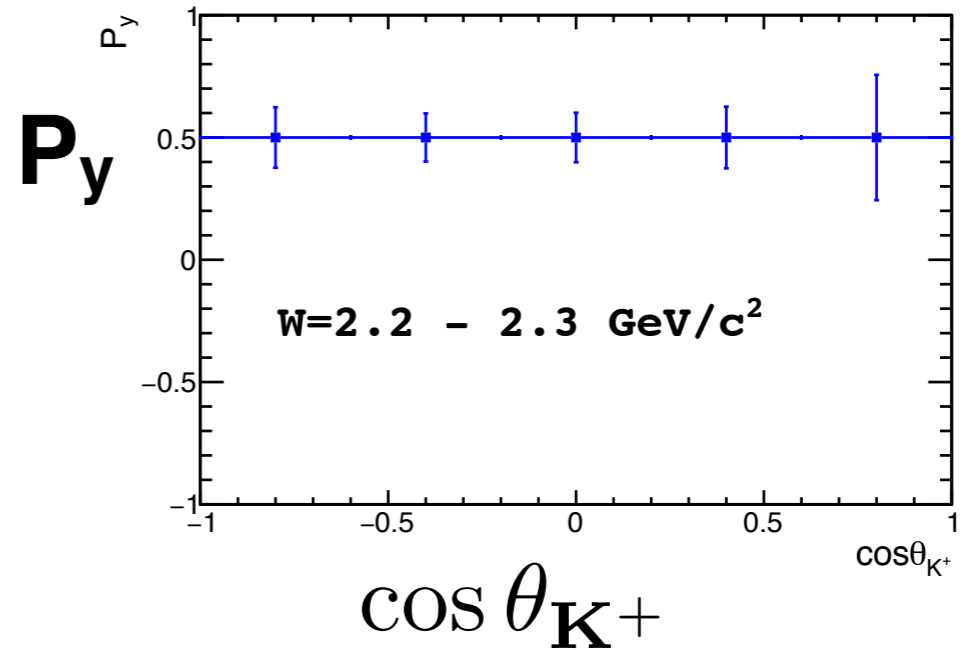
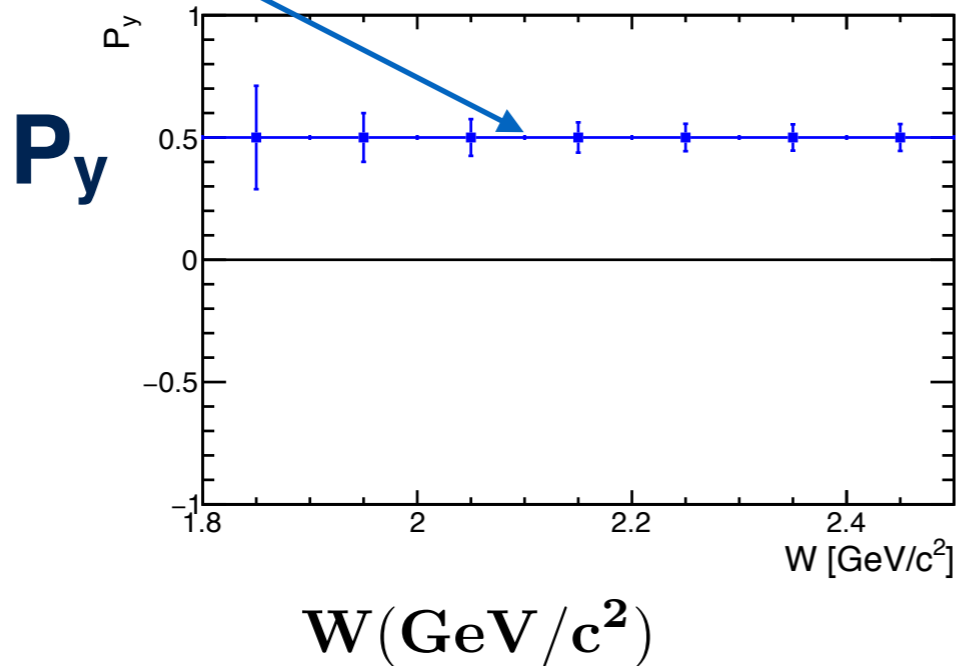
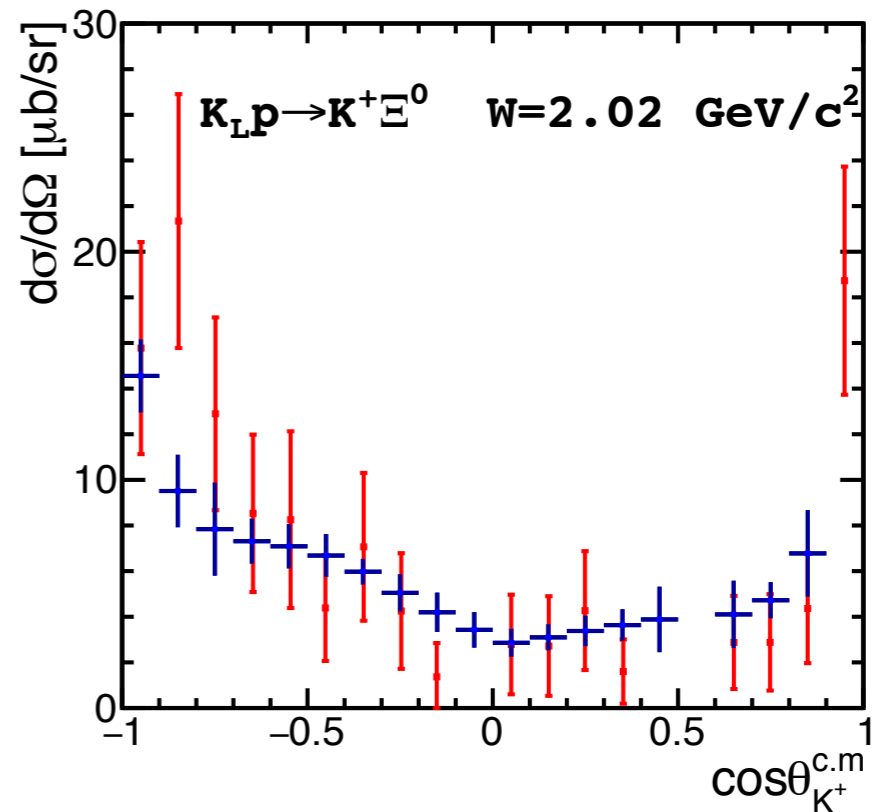
Edwards, Mathur, Richards and Wallace, *Phys. Rev. D* 87, 054506 (2013)

Measurements on Proton Target

existing data



KLF 100 days



Search for Hyperon Resonances with PWA

In Scattering experiments on both proton & neutron targets one needs to measure:

- differential cross sections**
- polarization of strange hyperons**
- perform Partial Wave Analysis**
- look for poles in complex energy plane**
- identify excited hyperons with masses up to 2400 MeV In a formation and production reactions**

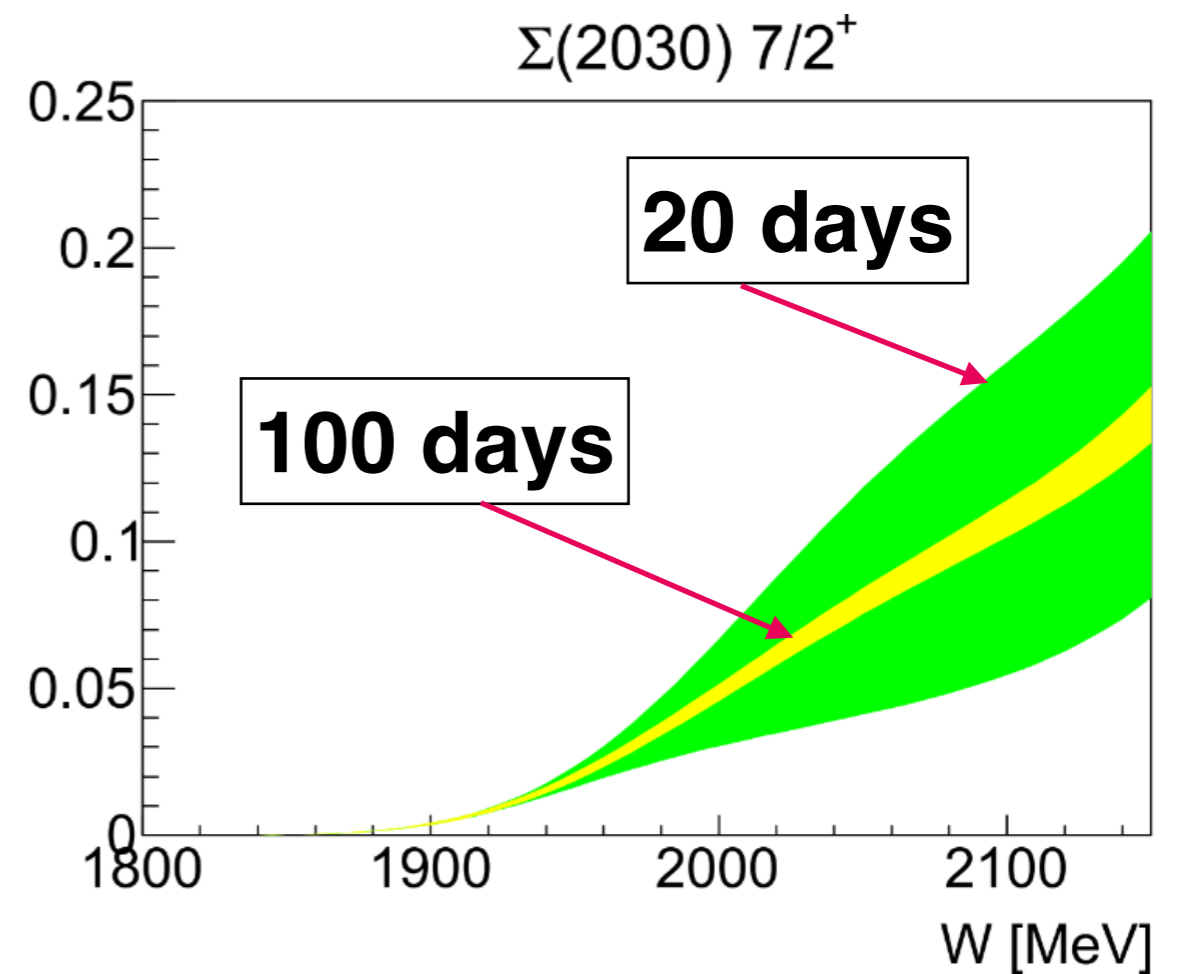
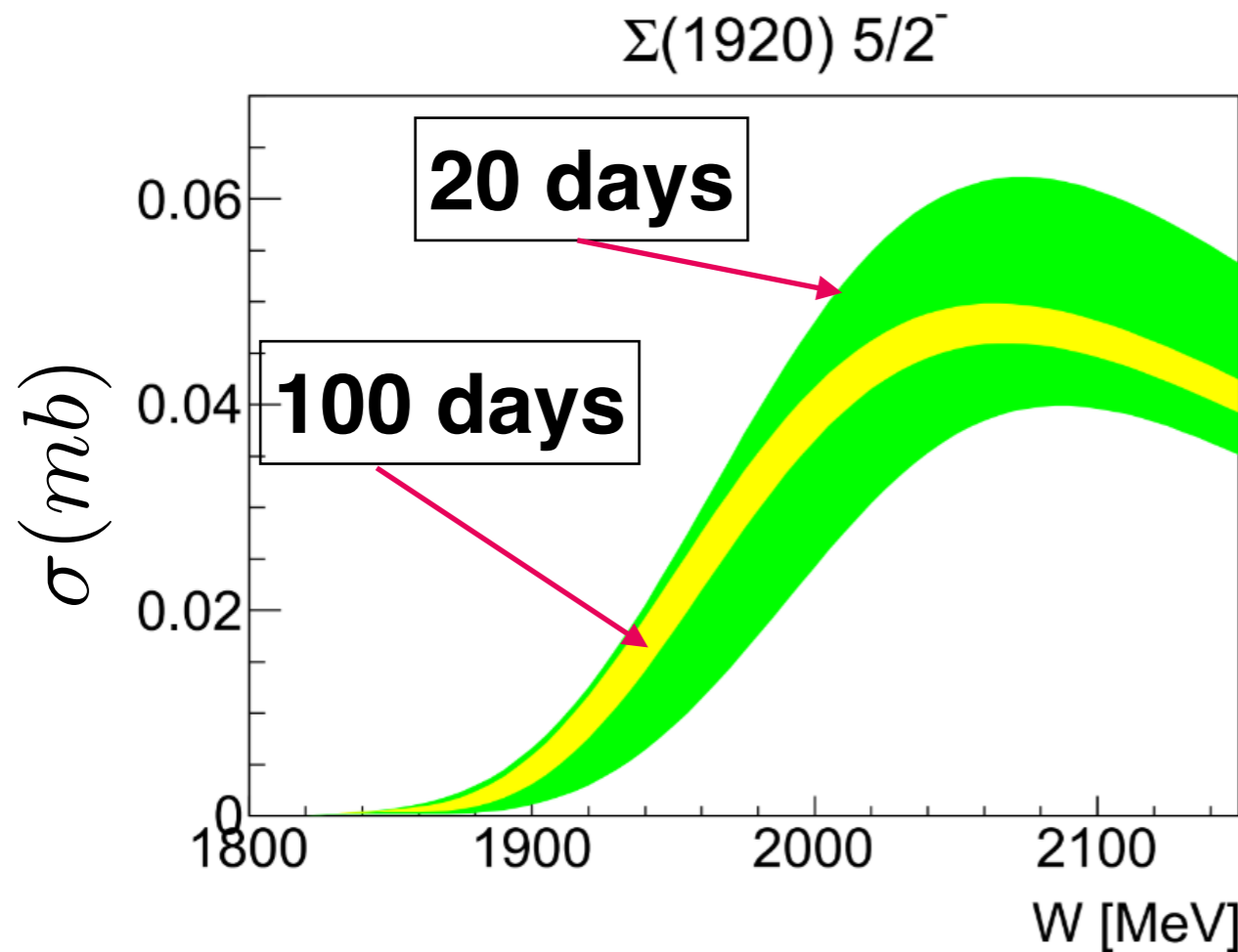
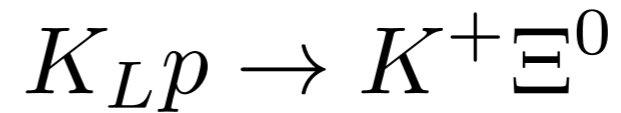
$$\underline{\Lambda^*, \Sigma^*, \Xi^* \text{ \& \ } \Omega^*}$$

-Measurements on a neutron target for the first time

Below we simulate KN scattering data with statistics for 20 and 100 days to demonstrate PWA sensitivity to obtain results close to the simulated one

Bonn-Gatchina PWA

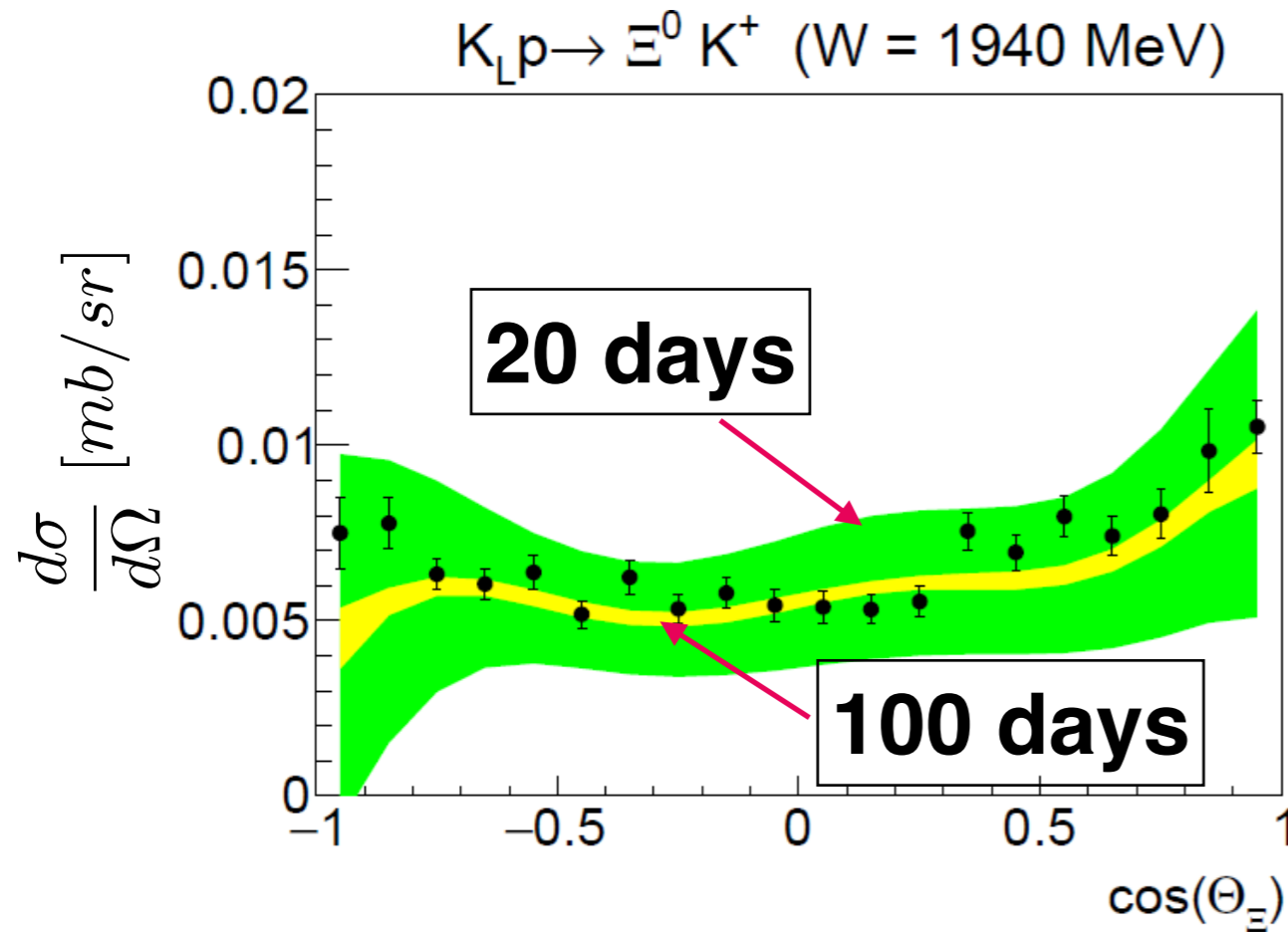
Total Cross Section



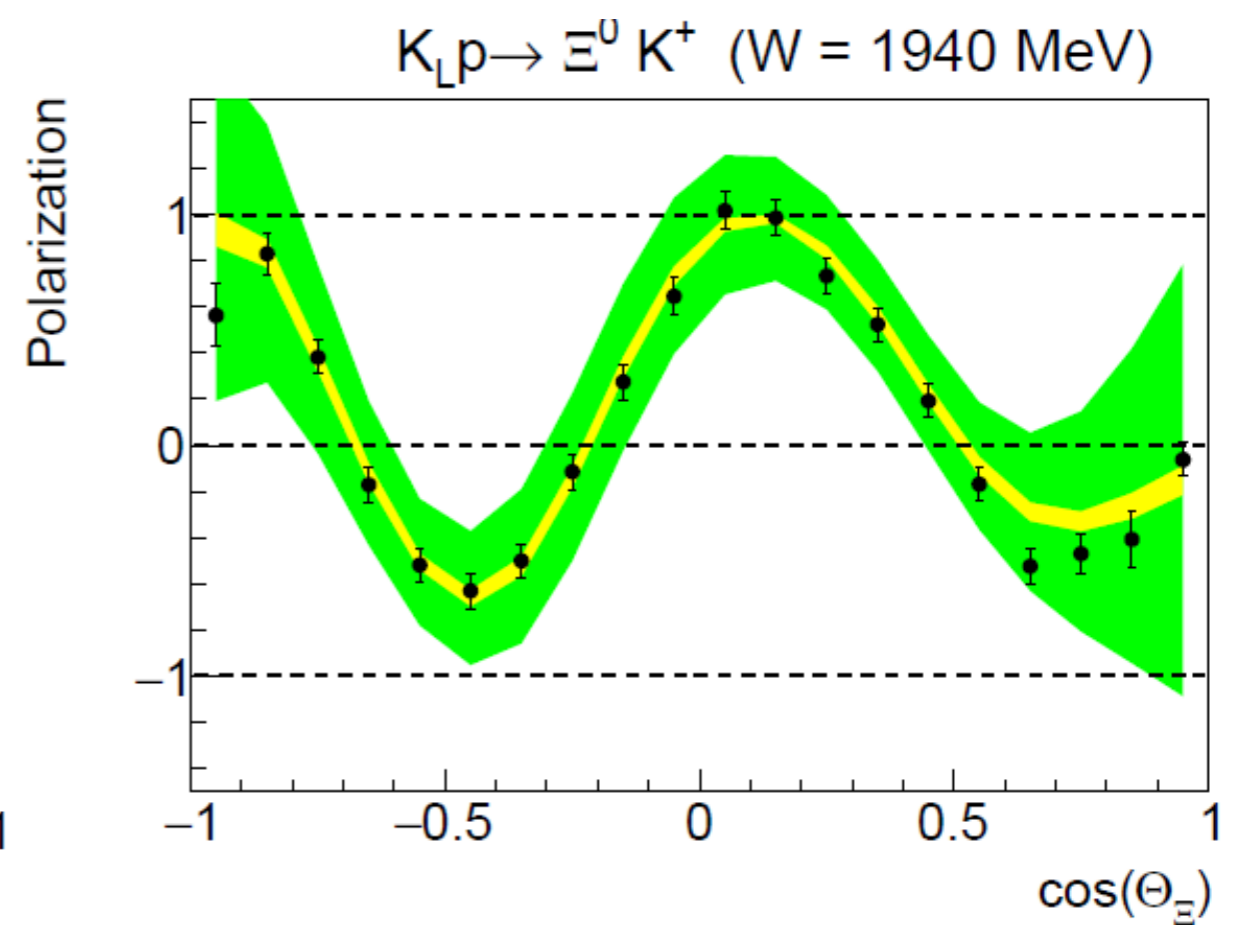
**Need 100 days of running to get precise solution
(see numerical results below)**

Bonn-Gatchina PWA

Diff. Cross Section




Polarization



Need 100 days of running to get precise solution
(see numerical results below)

Numerical Results

Simulated $\Sigma(1920) 5/2^-$


$$\left\{ \begin{array}{l} 100d \quad M = \underline{1.923} \pm 0.010 \pm 0.010 \text{ GeV} \\ \quad \quad \Gamma = 0.321 \pm 0.01 \pm 0.010 \text{ GeV} \\ 20d \quad M = \underline{1.977} \pm 0.021 \pm 0.025 \text{ GeV} \\ \quad \quad \Gamma = 0.327 \pm 0.025 \pm 0.025 \text{ GeV} \end{array} \right.$$

For the same state:

LQCD M=
(broad range of solutions)

2.027 GeV
2.487 GeV
2.659 GeV
2.781 GeV

R.G. Edwards et al.,
“PRD 87,no.5. 054506 (2013)”

Scattering on a proton and deuteron targets

$$K_L p \rightarrow K^\pm \pi^\mp p = \langle K_L \pi^0 | K^\pm \pi^\mp \rangle = \pm \frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

$$K_L p \rightarrow K_L \pi^0 p = \langle K_L \pi^0 | K_L \pi^0 \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

$$K_L p \rightarrow K_{(L,S)} \pi^+ n = \langle K_L \pi^+ | K_L \pi^+ \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

$$K_L p \rightarrow K^+ \pi^0 n = \langle K_L \pi^+ | K^+ \pi^0 \rangle = -\frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

$$K_L p \rightarrow K^- \pi^0 \Delta^{++} = \langle K_L \pi^- | K^- \pi^0 \rangle = \frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

$$K_L n \rightarrow K^\pm \pi^\mp n = \langle K_L \pi^0 | K^\pm \pi^\mp \rangle = \pm \frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

$$K_L p \rightarrow K_{(L,S)} \pi^- \Delta^{++} = \langle K_L \pi^- | K_L \pi^- \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

$$K_L n \rightarrow K_L \pi^0 n = \langle K_L \pi^0 | K_L \pi^0 \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

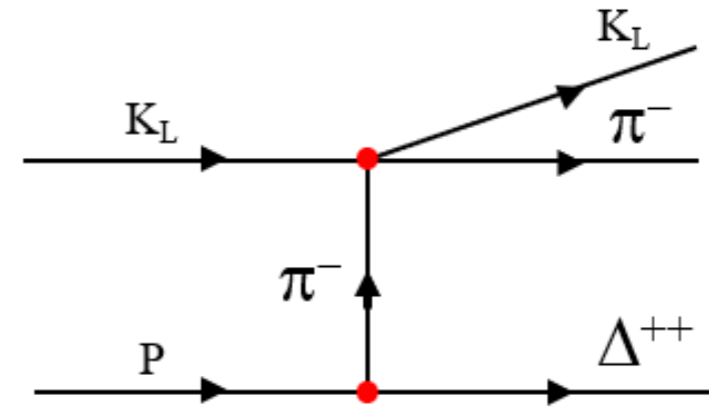
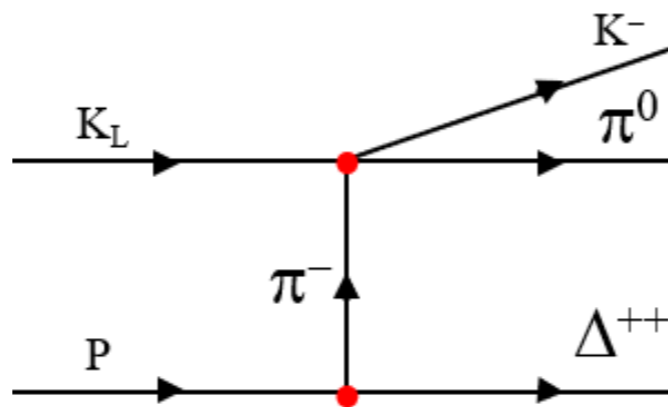
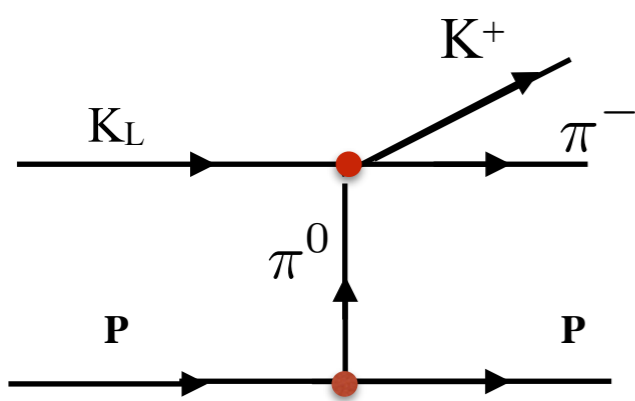
$$K_L n \rightarrow K_{(L,S)} \pi^\pm \Delta^\mp = \langle K_L \pi^\pm | K_L \pi^\pm \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

$$K_L n \rightarrow K^\pm \pi^0 \Delta^\mp = \langle K_L \pi^\pm | K^\pm \pi^0 \rangle = \pm \frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

**Simulated
for KLF**

Strange Meson Spectroscopy

$K\pi$ Scattering



Proposed Measurements

SLAC

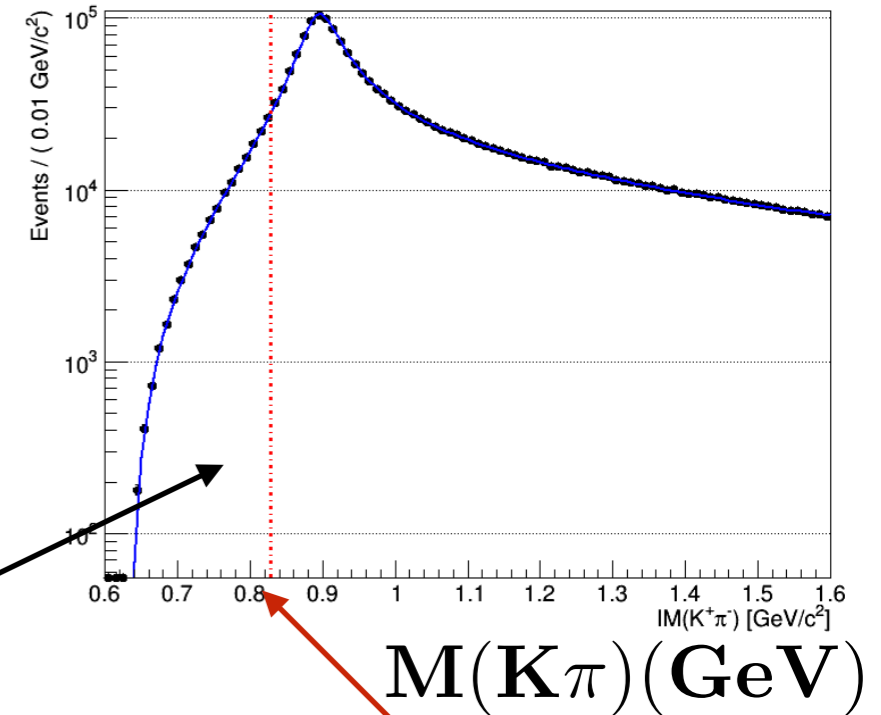
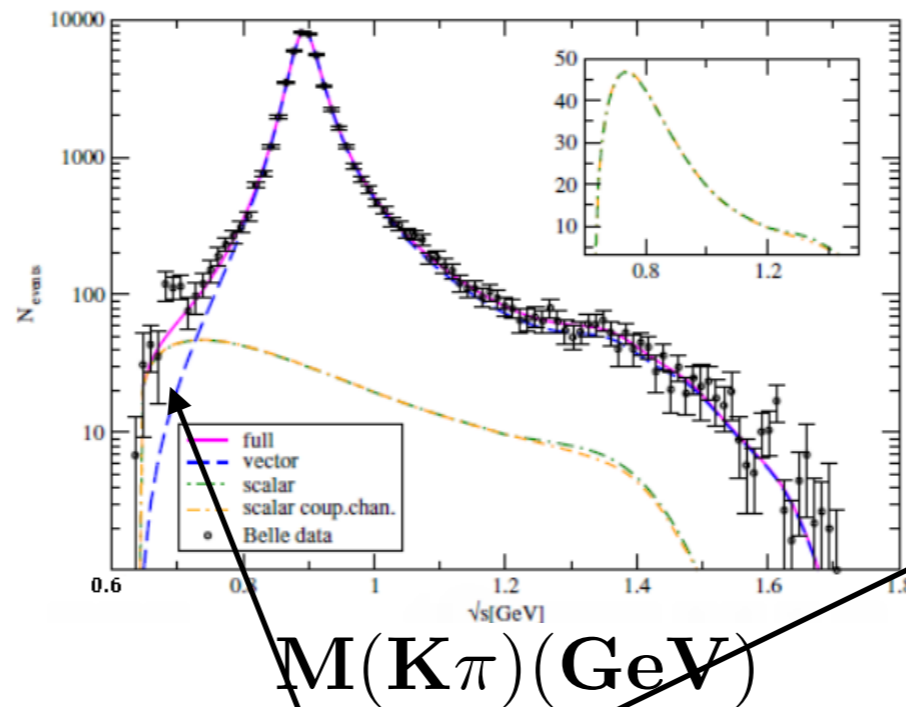
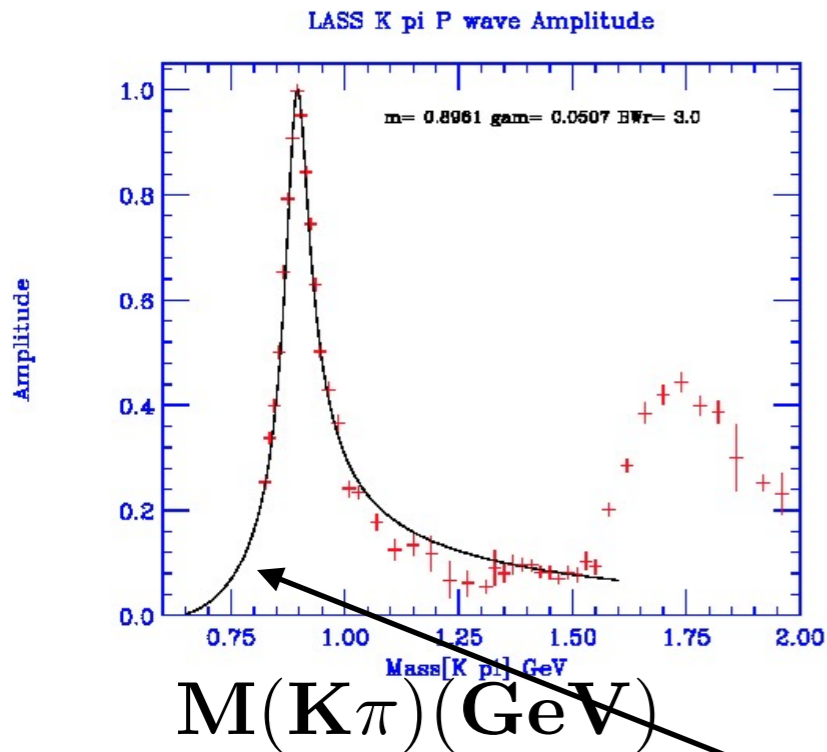
$$K^- \pi^+ \rightarrow K^- \pi^+$$

Belle

$$\tau \rightarrow K \pi \nu_\tau$$

KLF

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

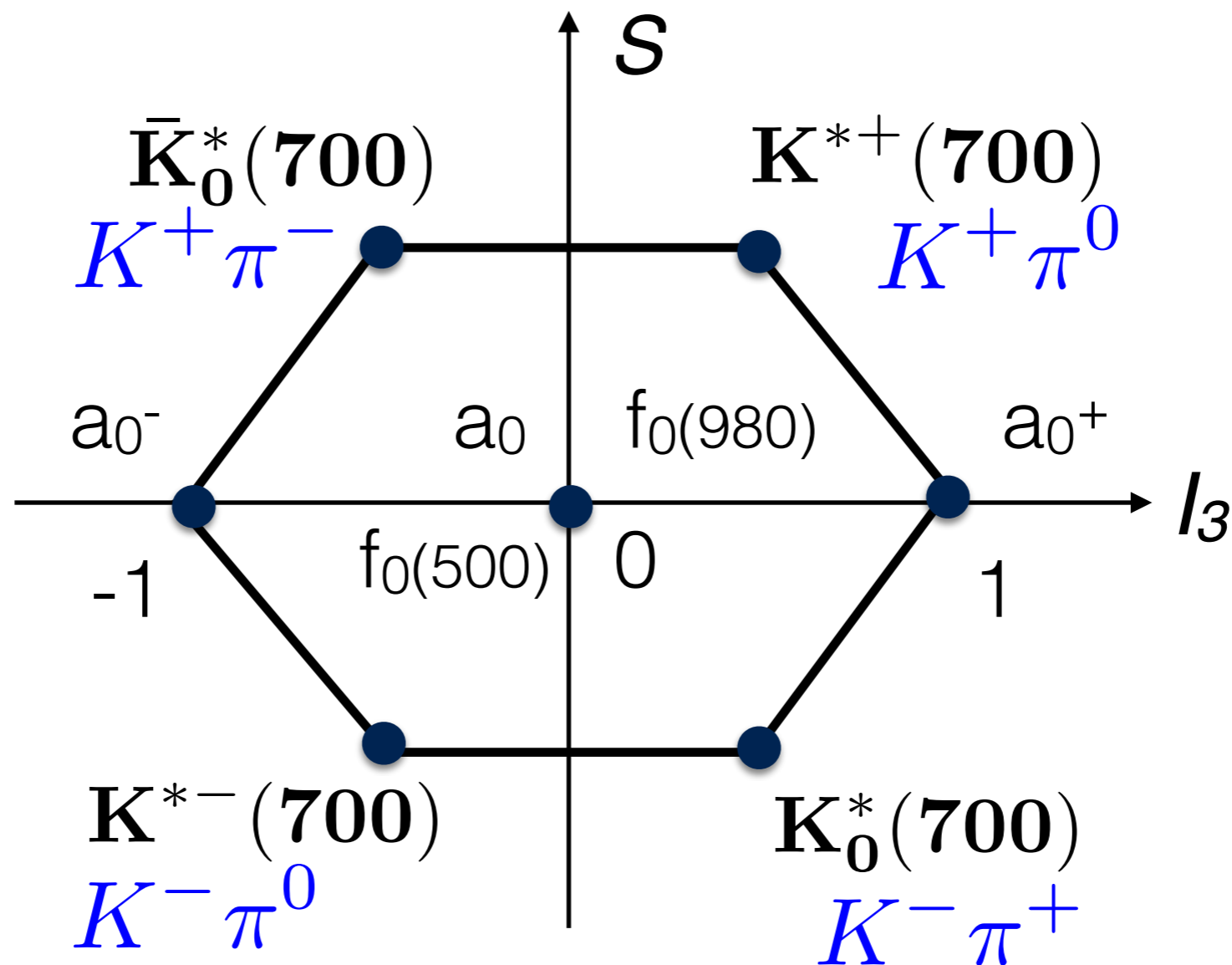


region of $\mathcal{K}(800)$

SLAC Lower limit

Scalar Meson Nonet

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

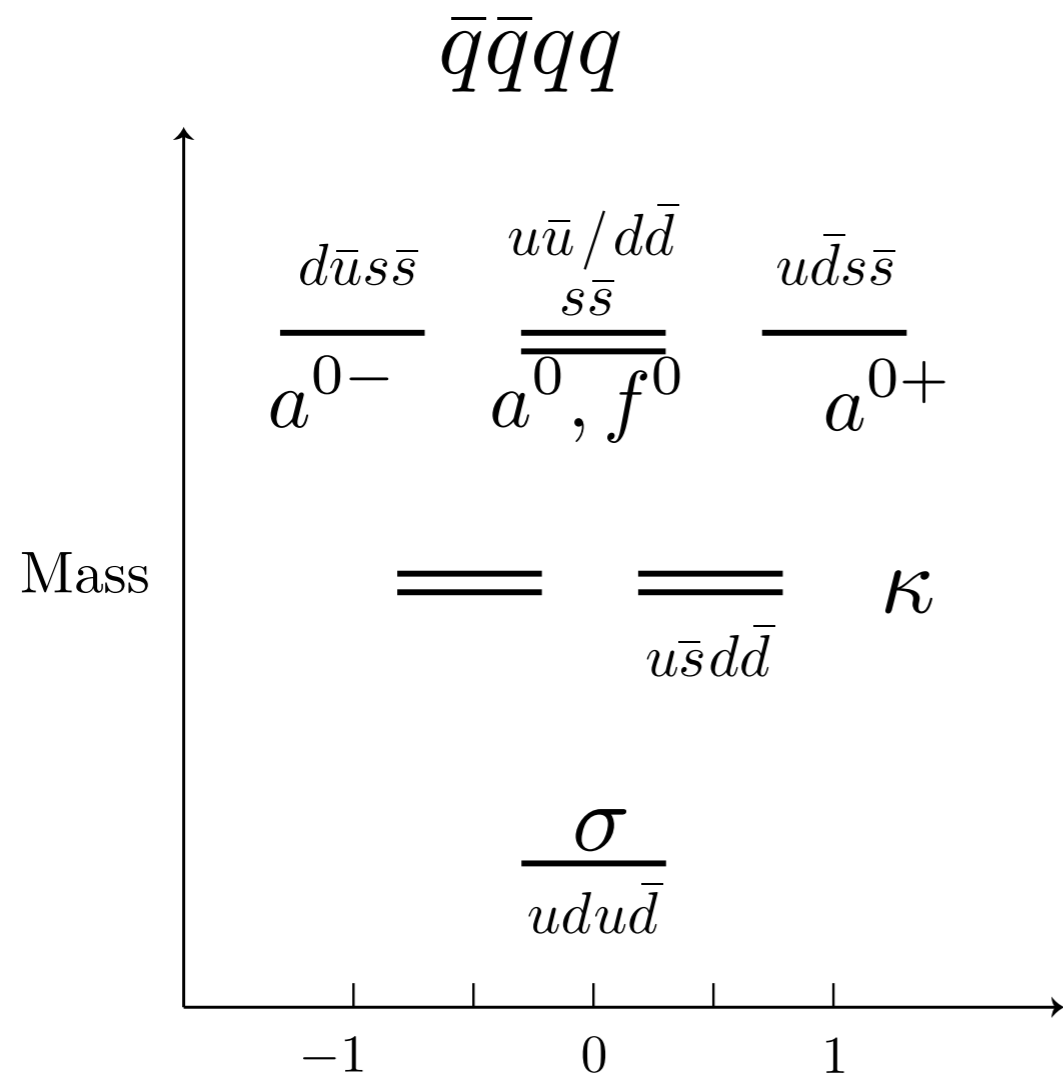


Four states called \mathcal{K}

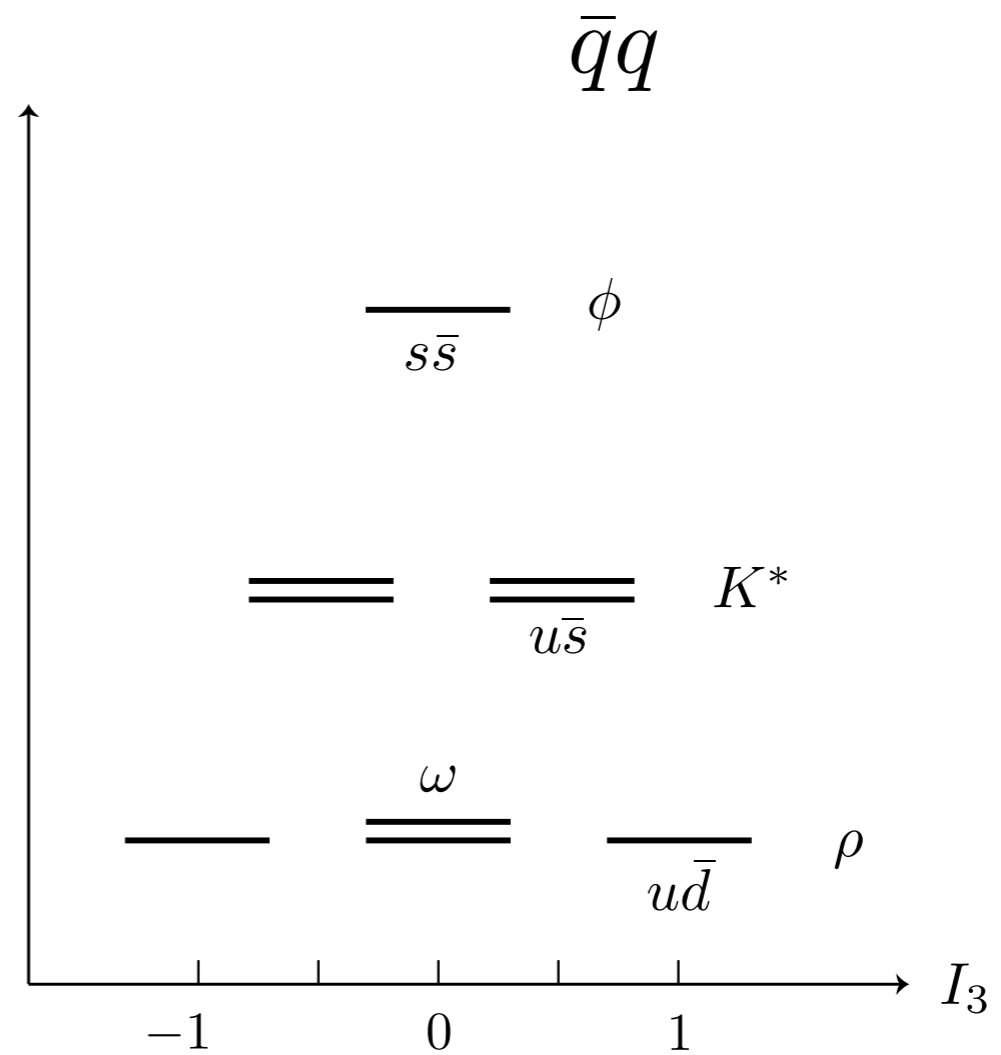
Still need further confirmation (PDG2020)

KLF allows measurement of all four states

Inverted mass hierarchy tetraquarks

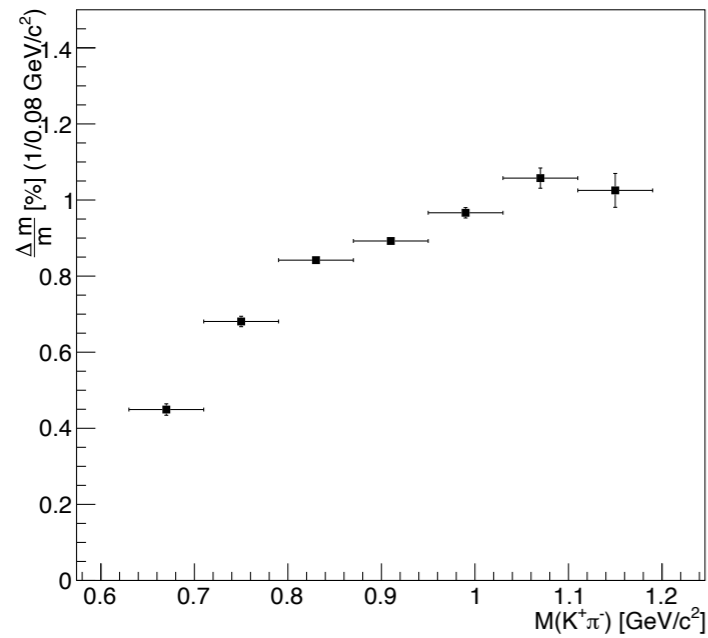


ordinary meson states

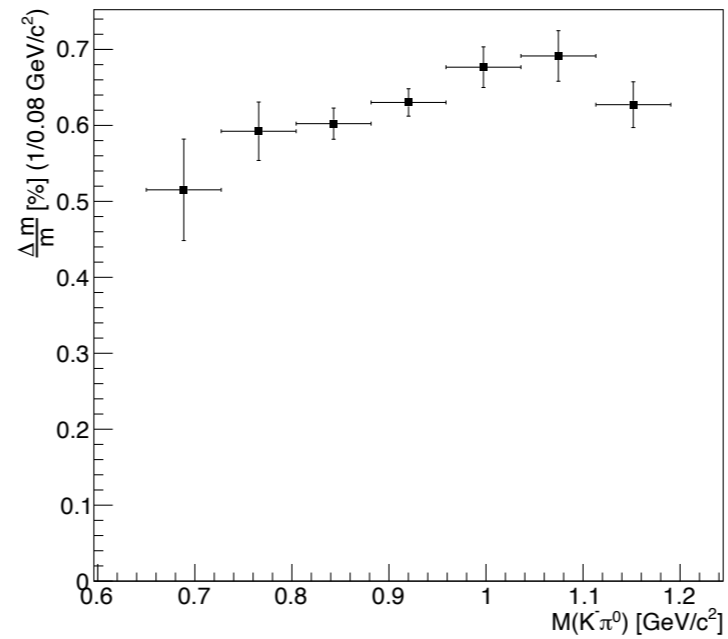


R. Jaffe, PRD 15, 267 (1977).

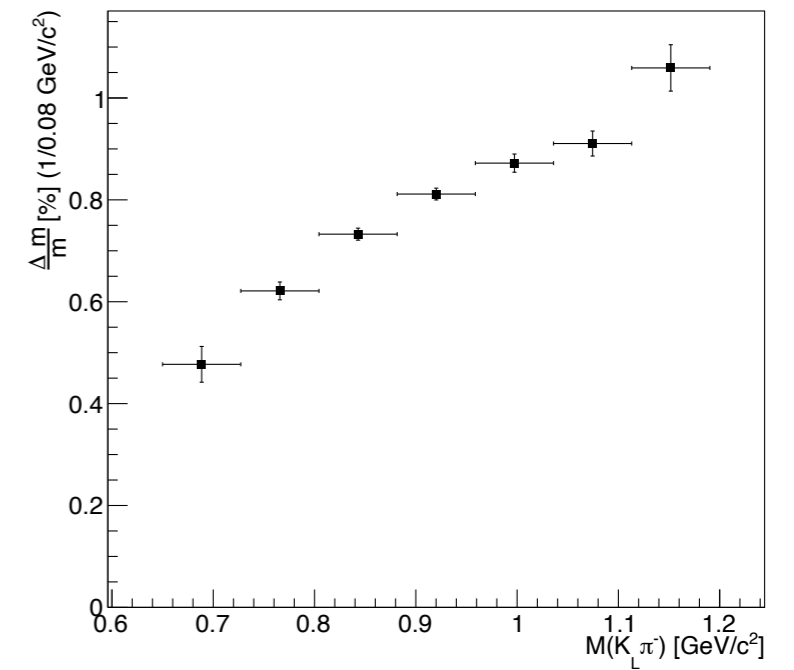
Invariant mass resolution



$$K^+\pi^-$$



$$K^-\pi^0$$



$$K_L\pi^-$$

Below 1% in all three simulated cases

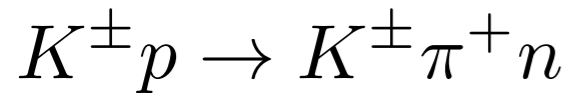
Projected Measurements

$I=3/2+1/2$

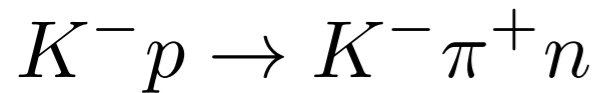
S -wave

Presented at PAC47

SLAC Data

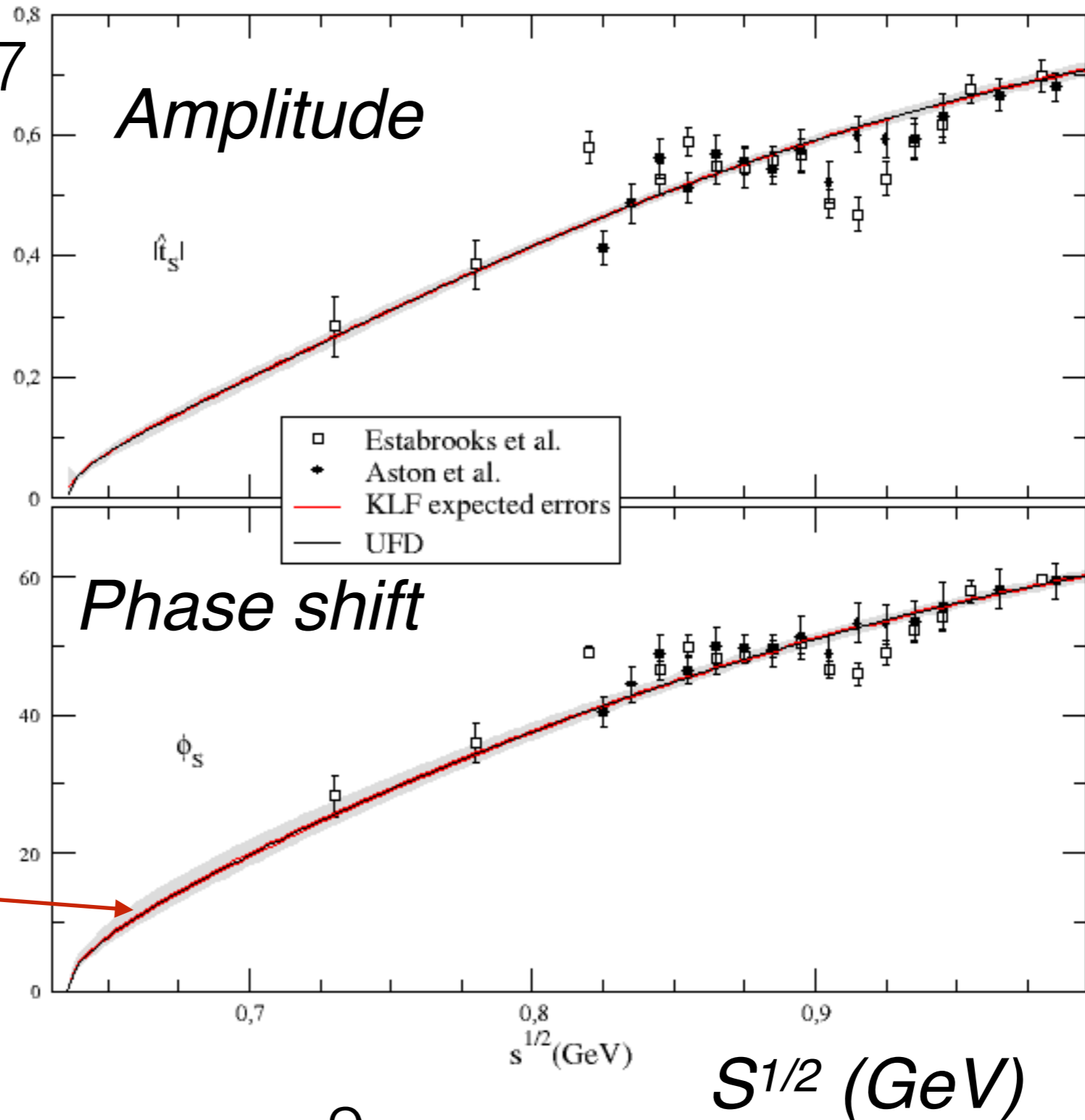


Estabrooks(1978)

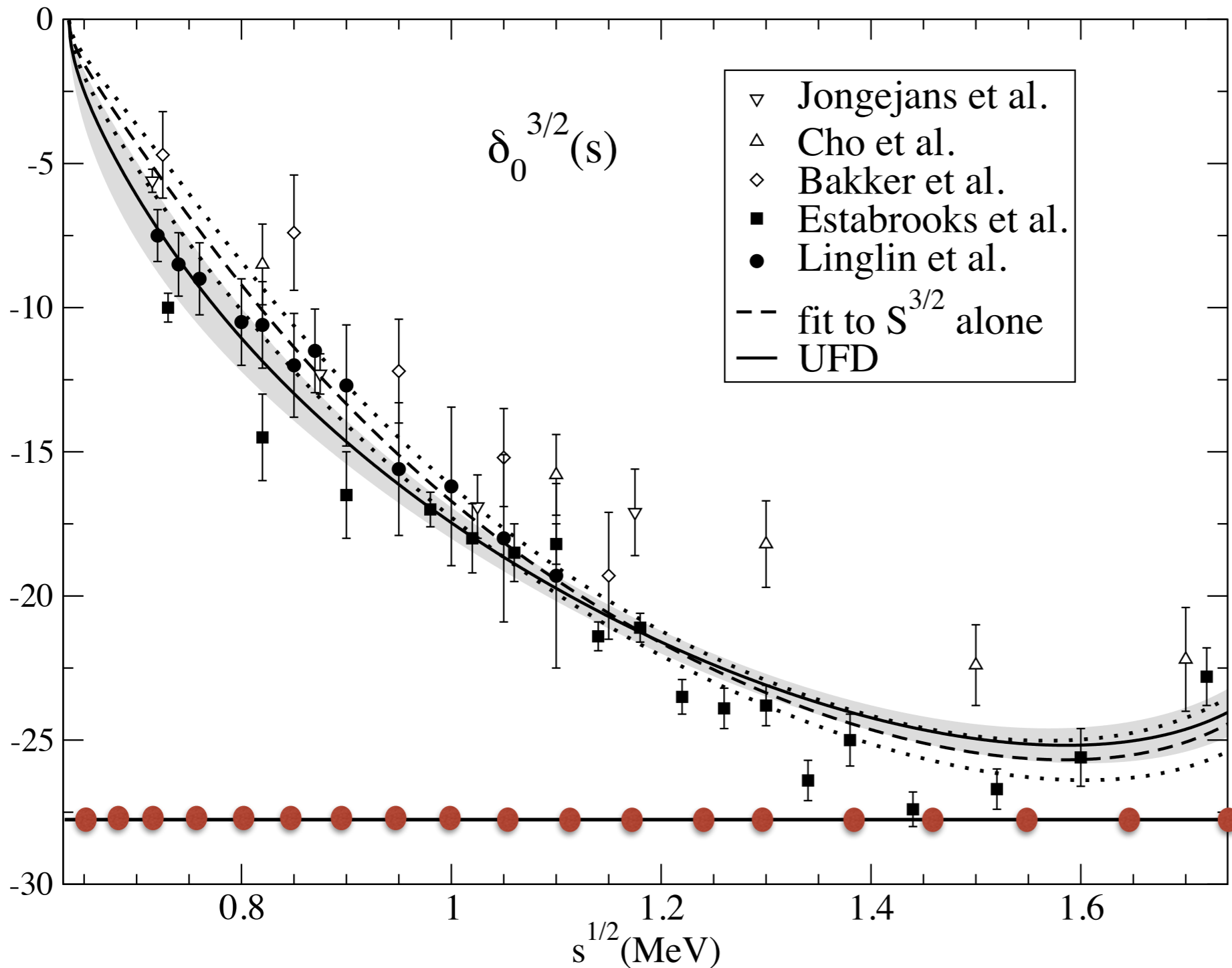


Aston(1988)

**Scaled
KLF data
(100 days)**



$I=3/2$ S -wave



4.25 GeV Saclay
5.5 GeV CERN
3.0 GeV ANL
13.0 GeV SLAC
14.3 GeV CERN

Estabrooks(1978)

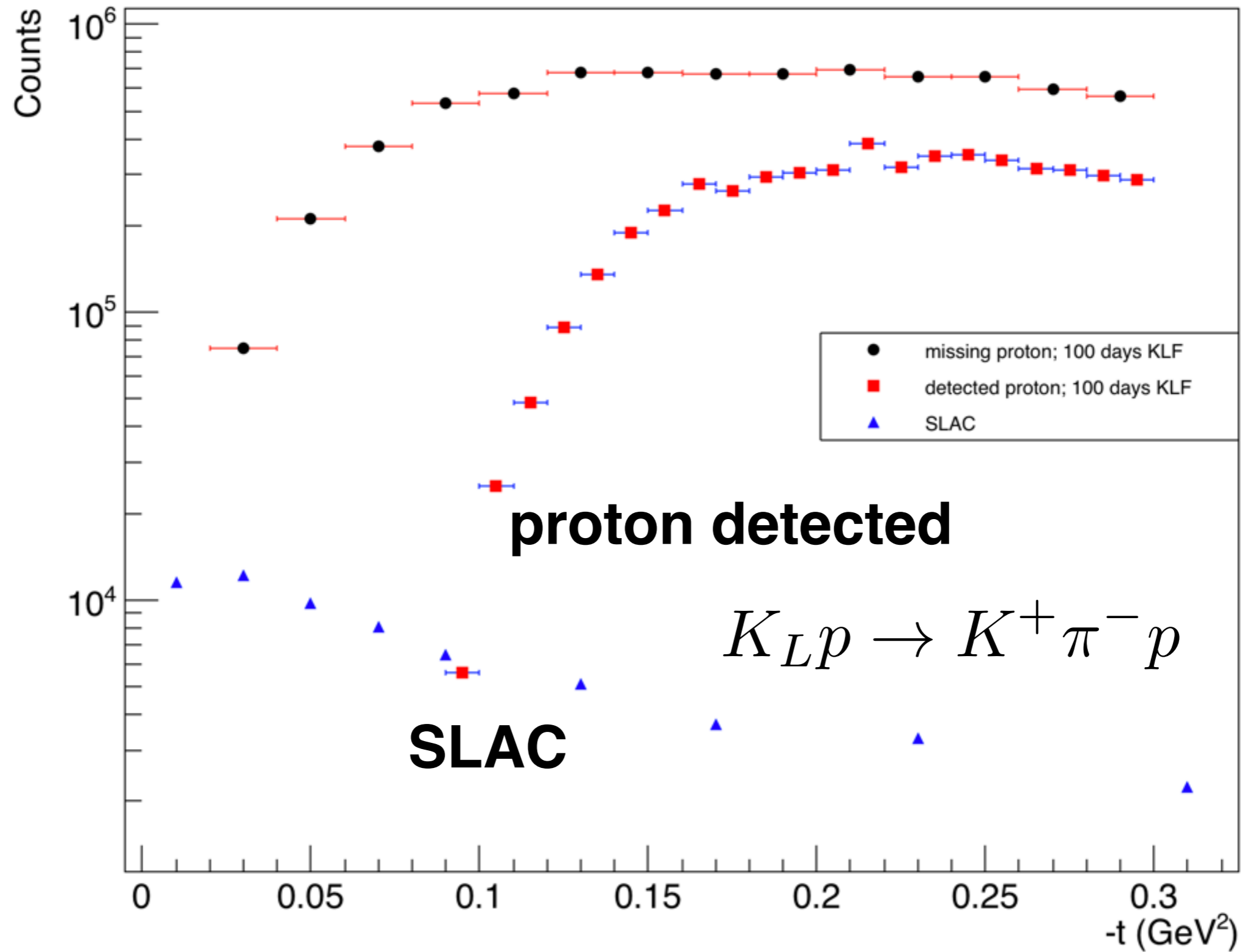
$$K^\pm p \rightarrow K^\pm \pi^+ n$$

$$K^\pm p \rightarrow K^\pm \pi^- \Delta^{++}$$

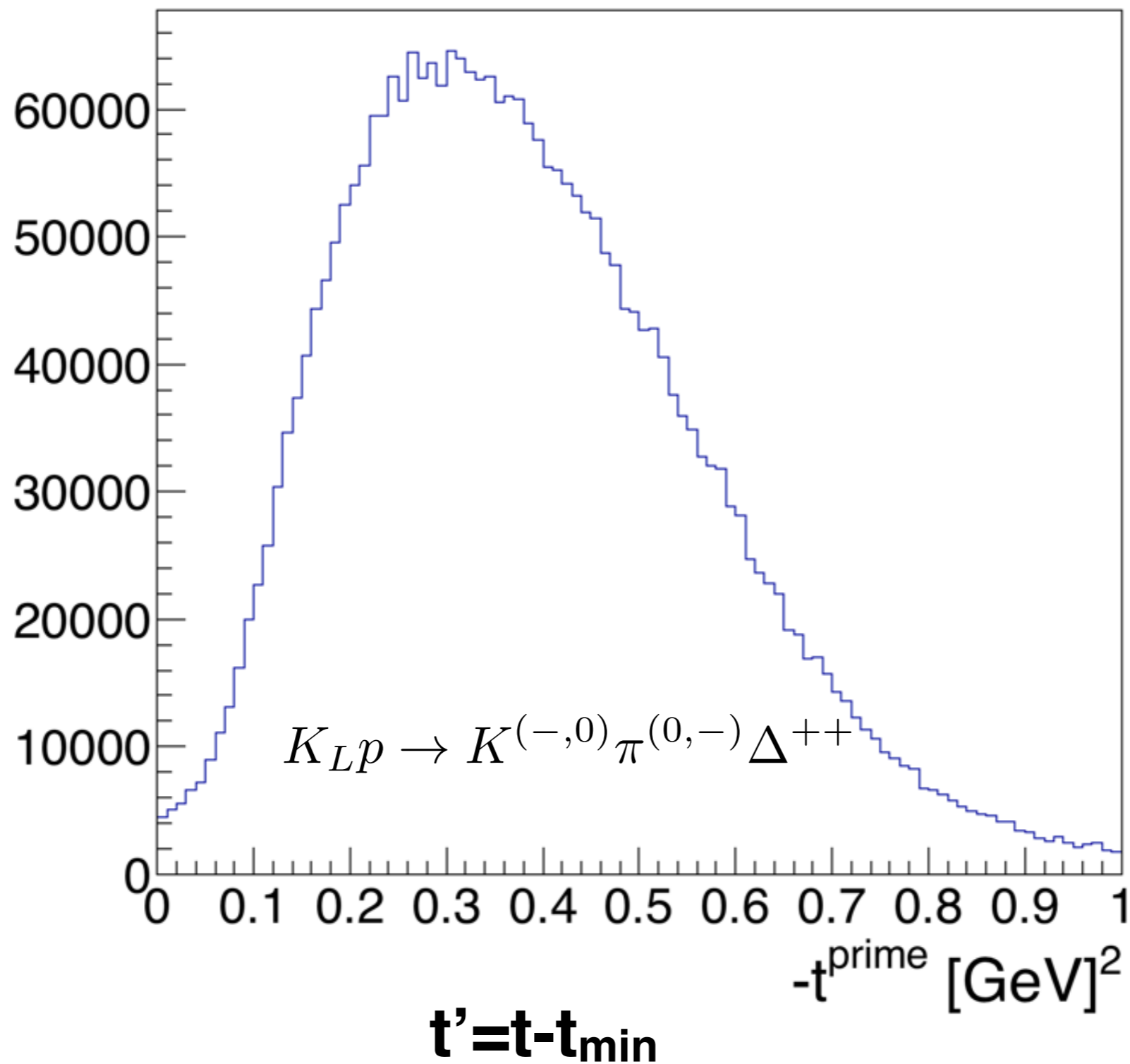
**KLF 100 days
(scaled)**

From Pelaez and Rodas paper: PRD93(2016)

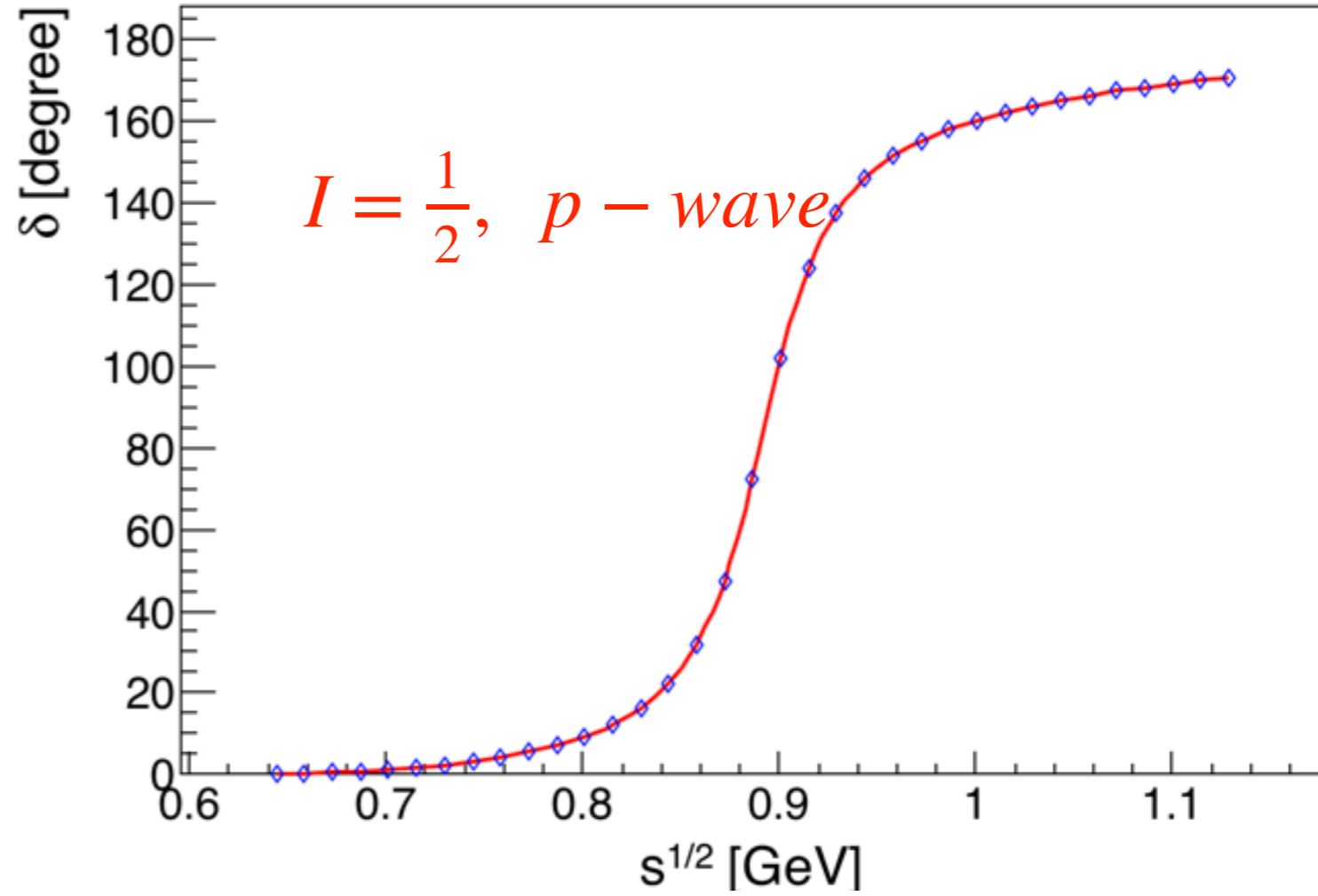
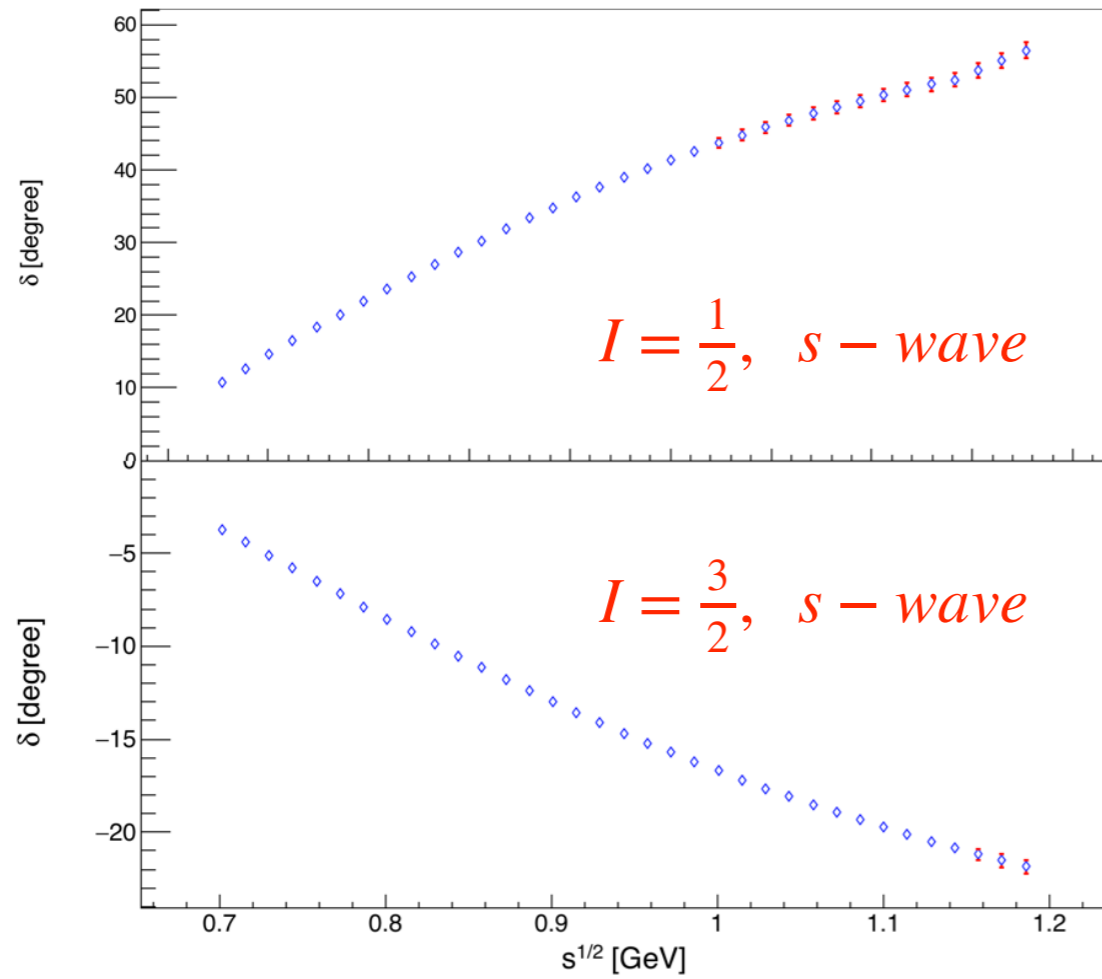
Projected Statistics



Distribution of four-momentum

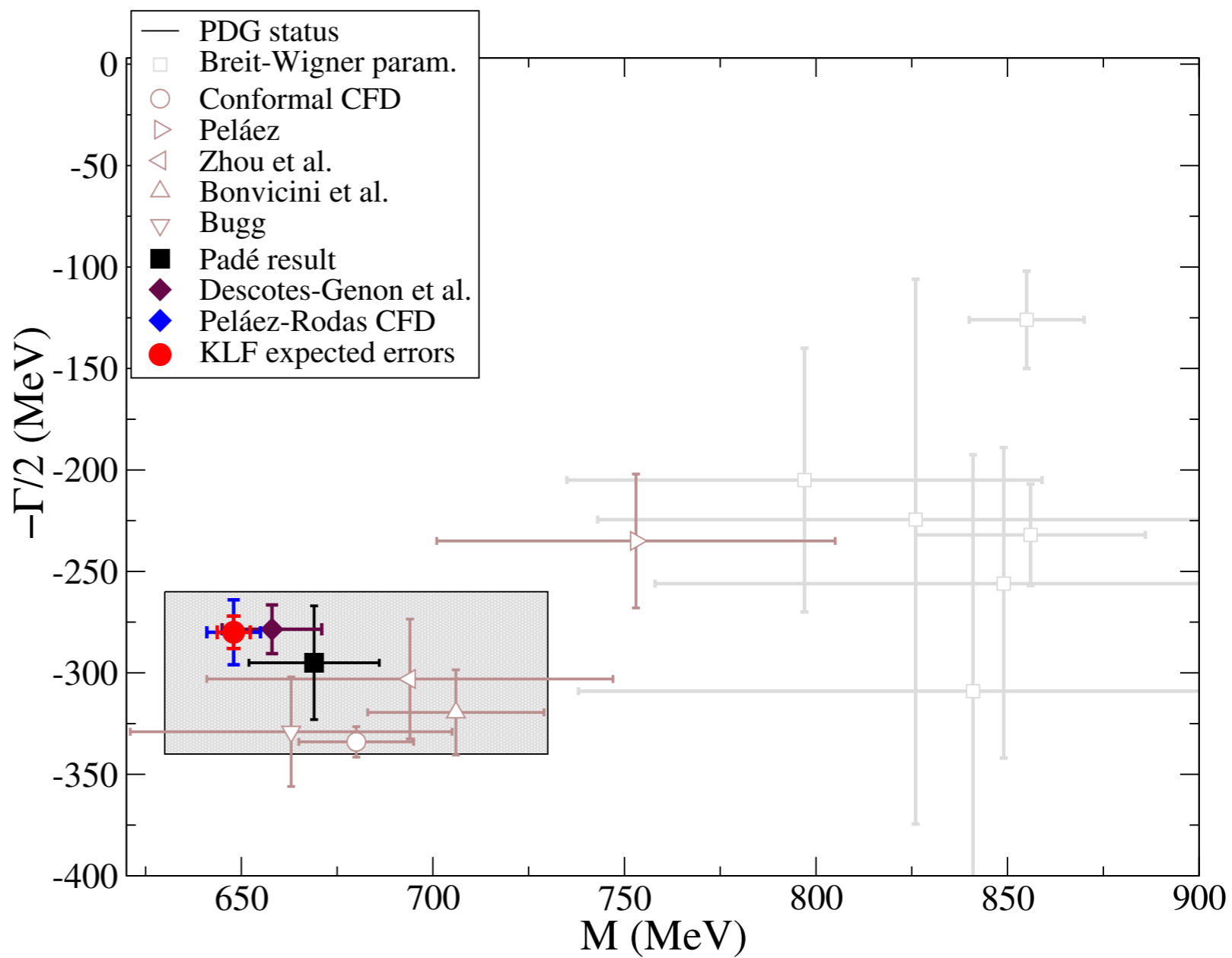
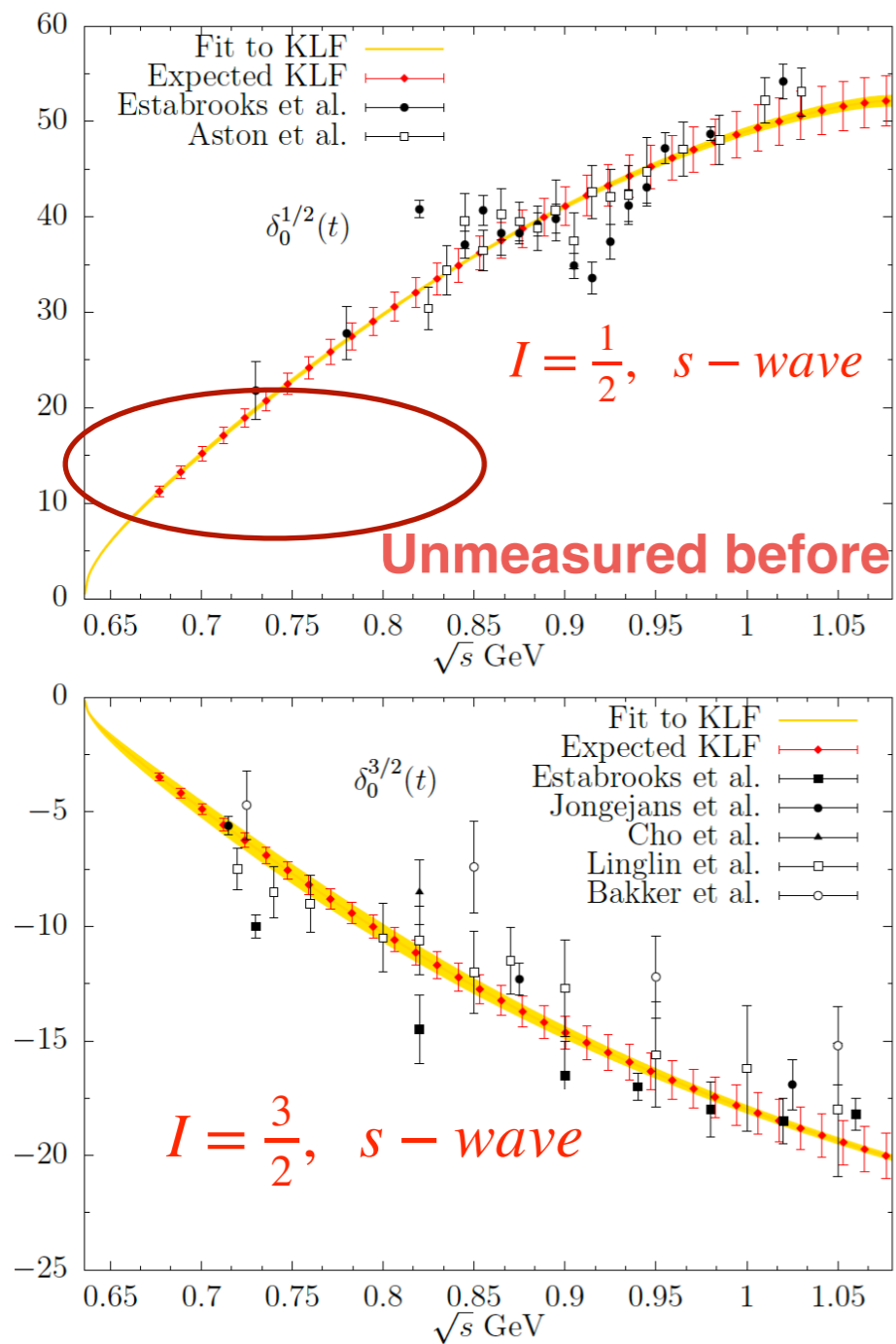


Phase Shift



Phase Shift

Kappa Mass and Width



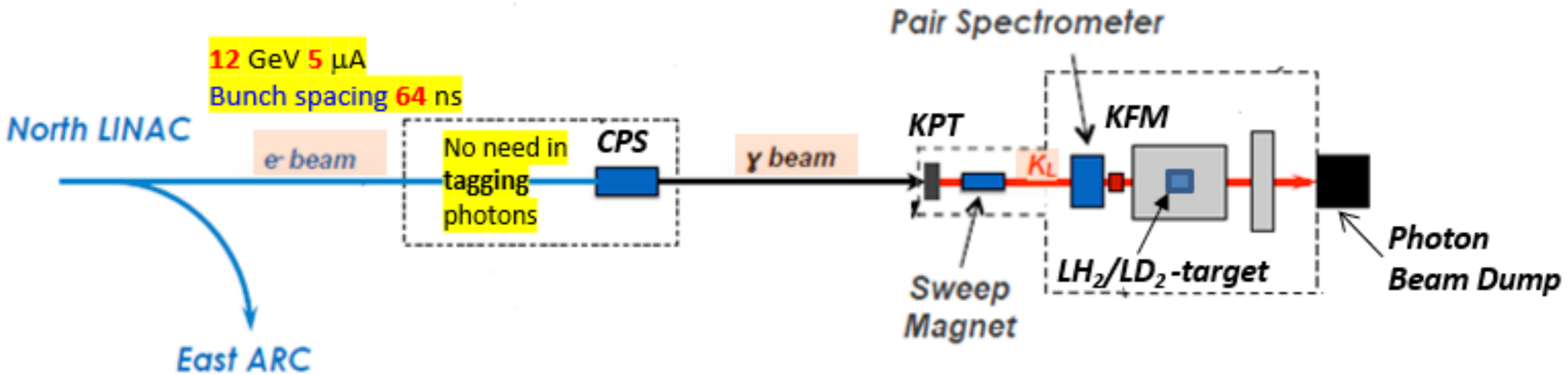
Kappa Investigation

Reference	Pole Position (MeV) $\sqrt{s_\kappa} \equiv M - i\Gamma/2$	Comment
Bonvicini [82]	$706.0 \pm 24.6 - i 319.4 \pm 22.4$	<i>T</i> -matrix pole model from CLEO
Bugg [83]	$663 \pm 42 - i 342 \pm 60$	Model with LO Chiral symmetry
Peláez [84]	$753 \pm 52 - i 235 \pm 33$	Unitarized ChPT up to NLO
Conformal CFD [79]	$680 \pm 15 - i 334 \pm 8$	Conformal parameterization from dispersive fit
Padé [85]	$670 \pm 18 - i 295 \pm 28$	Analytic local extraction from dispersive fit
Zhou <i>et al.</i> [71]	$694 \pm 53 - i 303 \pm 30$	partial-wave dispersion relation. Cutoff on left cut.
Descotes-Genon <i>et al.</i> [11]	$658 \pm 13 - i 279 \pm 12$	Roy-Steiner prediction. No S-wave data used below 1 GeV.
Pelaez-Rodas HDR [23, 80, 81]	$648 \pm 7 - i 280 \pm 16$	Roy-Steiner analysis of scattering data
KLF expected errors	$648 \pm 4 - i 280 \pm 8$	As previous line but with KLF expected errors

Summary of K-pi Scattering

- KLF will have a very significant impact on our knowledge of $K\pi$ scattering amplitudes*
- KLF will help resolve conflicting results for heavy K^* 's parameters*
- KLF will help settle discrepancies in the scattering lengths: determined phenomenologically from data versus ChPT and LQCD*
- KLF it will improve precision of the mass and width of $K^*(700)$ by **factor of two**, and therefore **on its coupling***
- KLF will help to clarify long-standing problem of the existence of the scalar nonet*

Hall D beamline and GlueX Setup



Electron Beam Parameters

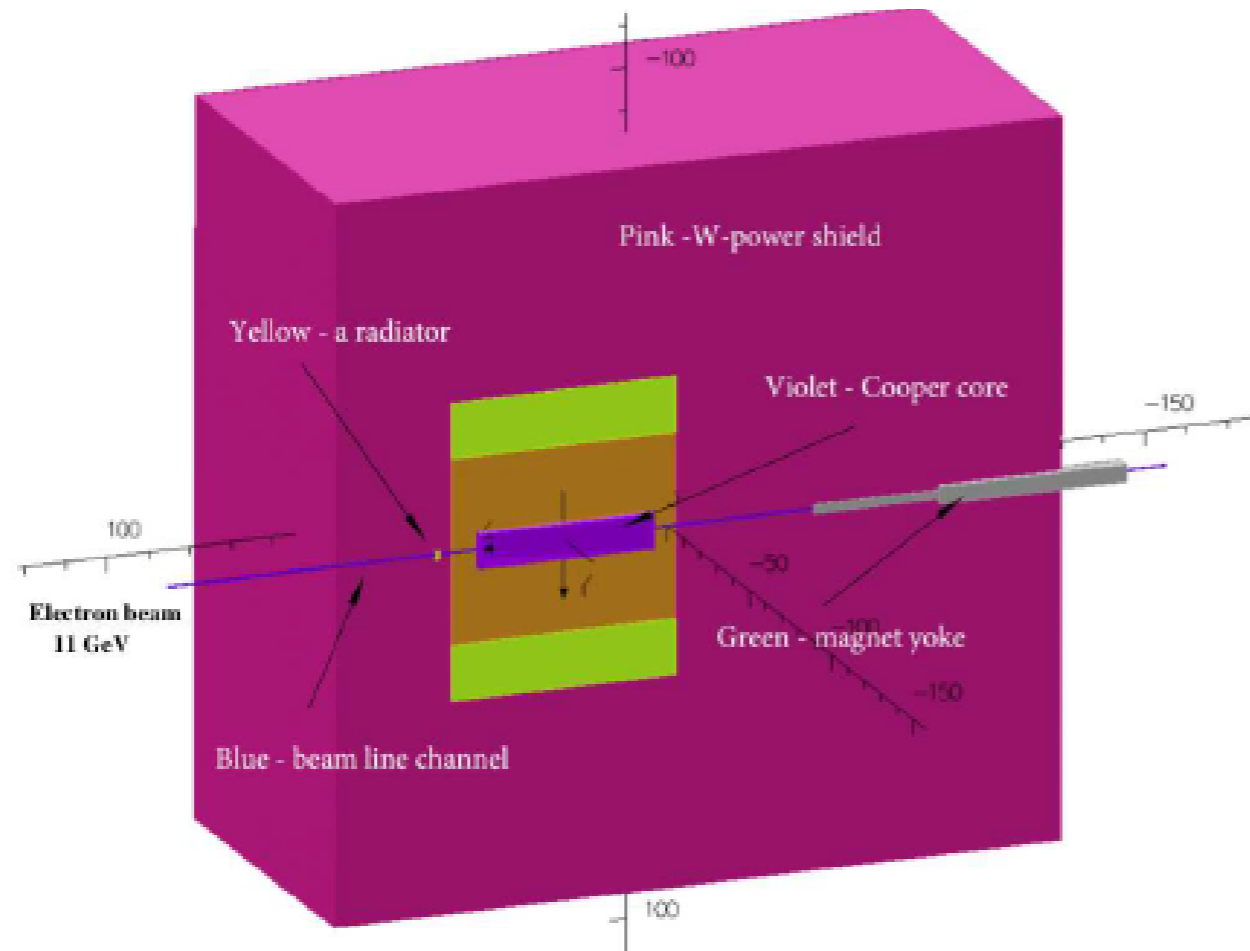
$$E_e = 12 \text{ GeV} \quad I = 5 \mu\text{A}$$
$$\text{Bunch spacing} \quad 64 \text{ ns}$$

No major problems.

Doable !

Confirmed by accelerator experts (Todd Satogata)

Compact Photon Source



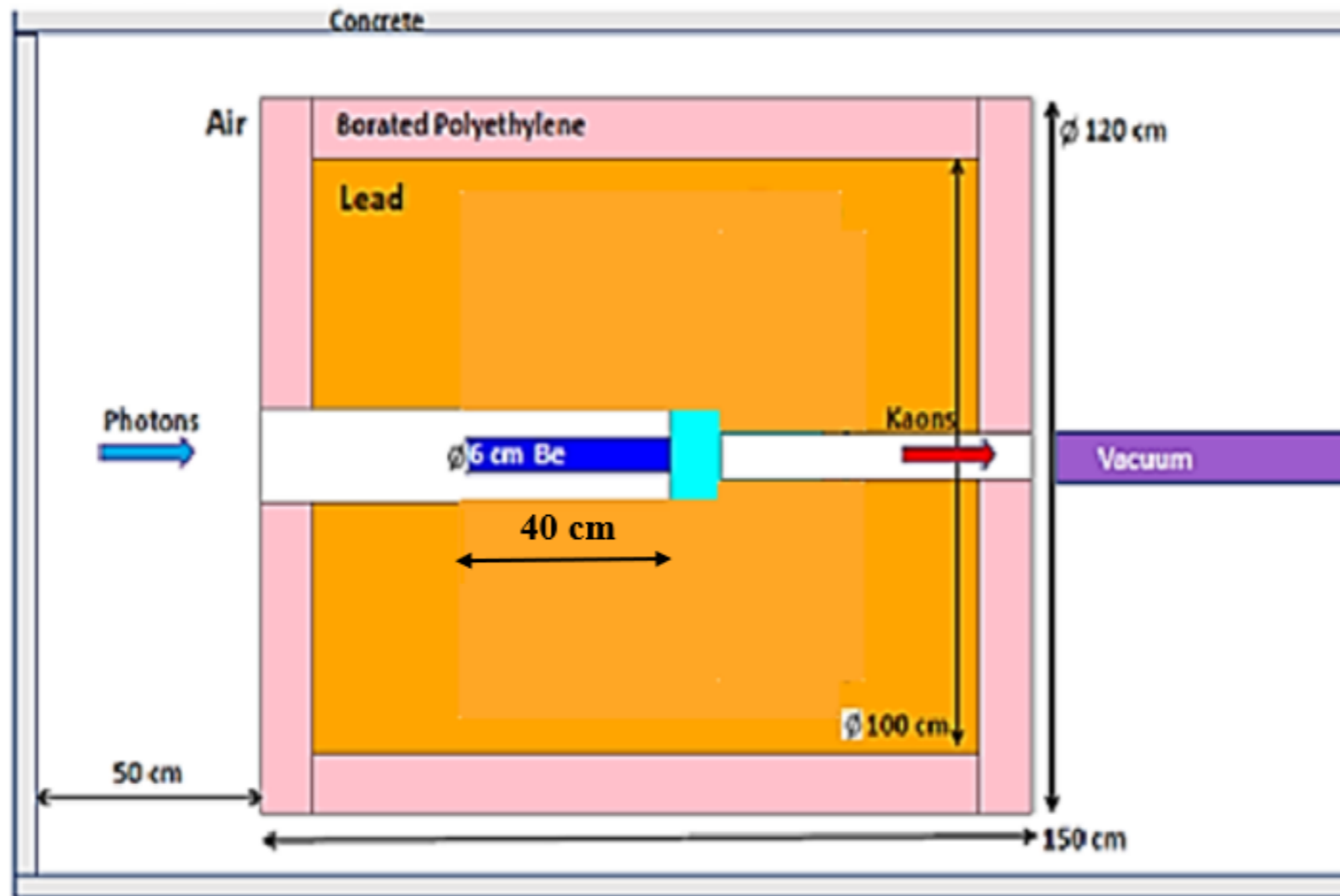
**Conceptual design
completed for Halls A&C**

**Details of the CPS designed
by the CPS Collaboration**

Fulfills RadCon Radiation Requirements

Paper published in NIM, A957(2020)

Be Target Assembly: Conceptual Design

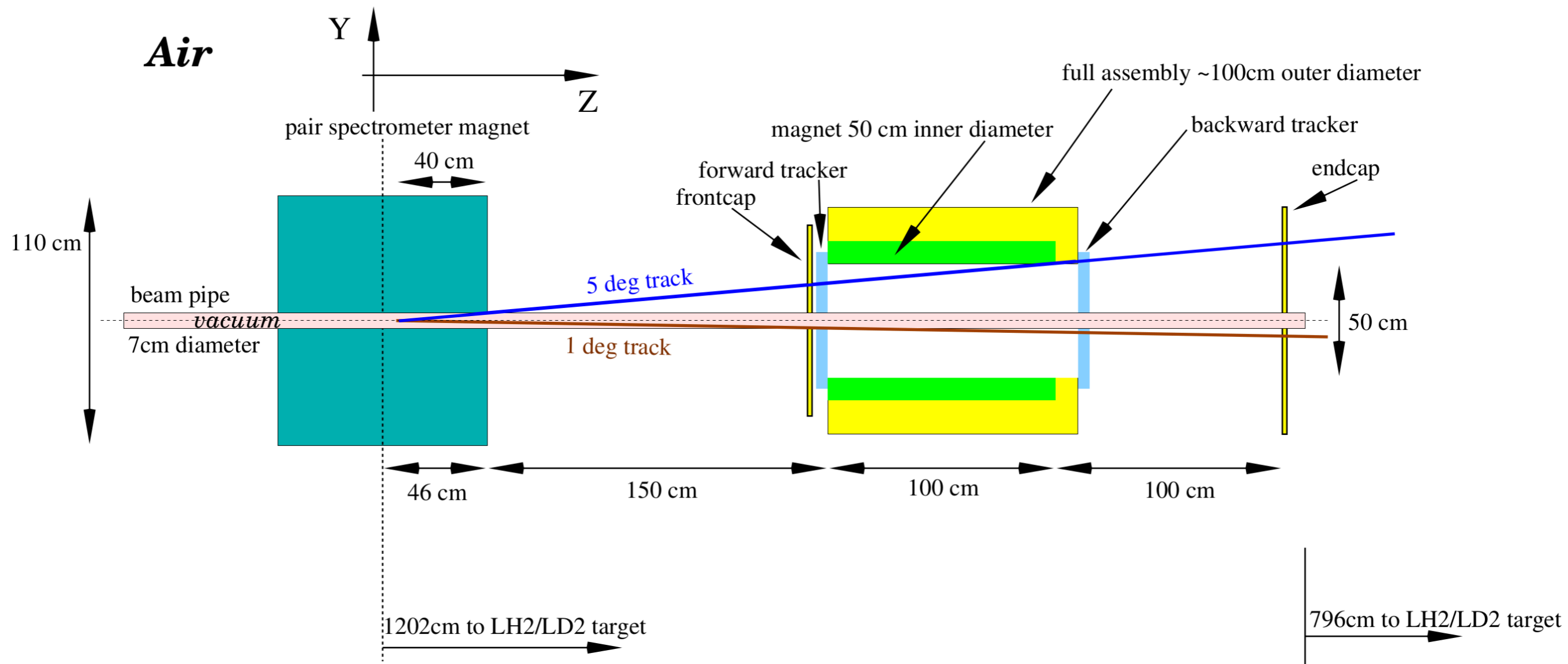


-Meets RadCon Requirements

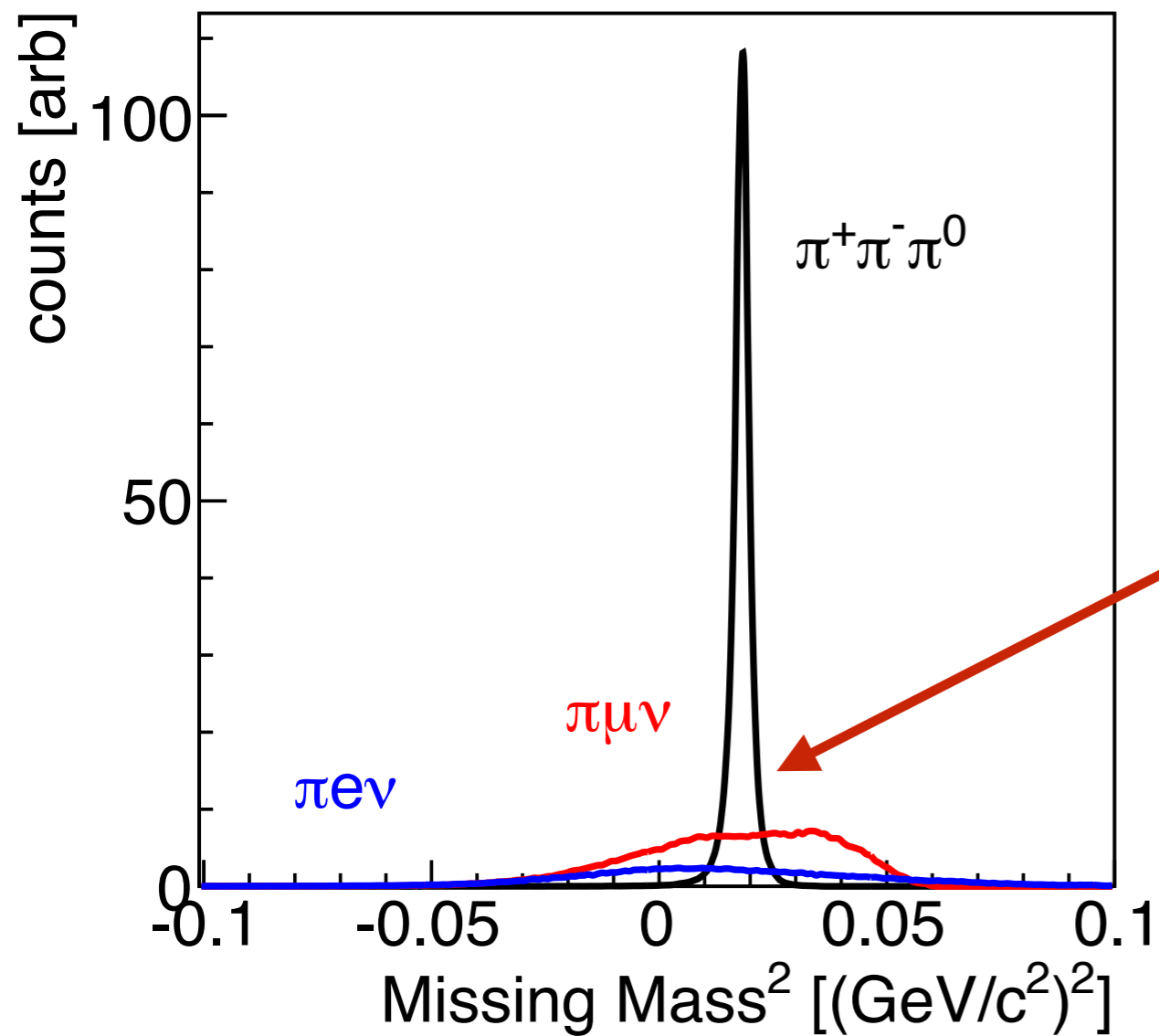
-Conceptual Design Endorsed by Hall-D Engineering Staff

arXiv: 2002.04442

Flux Monitor (FM)



Reconstructed K_L with FM



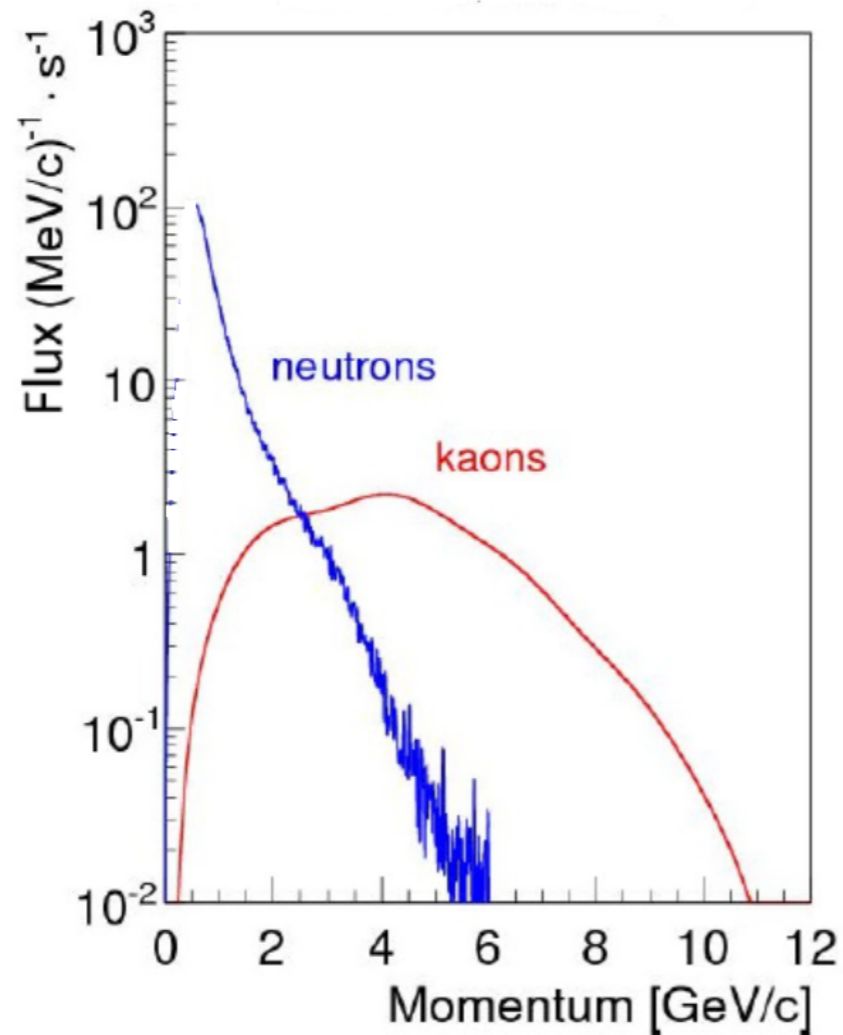
Flux measurement stat. err. <1%

Estimated conservative syst. err. ~5%

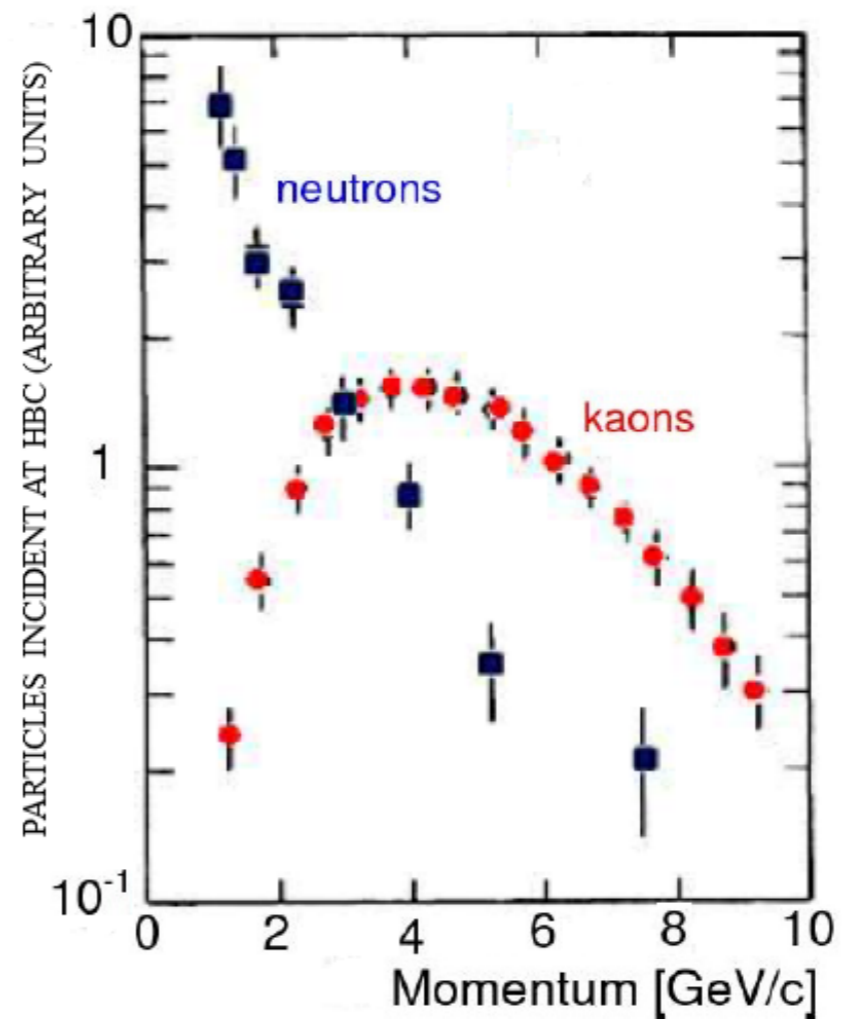
K_L Beam Flux

JLab 12 GeV

SLAC 16 GeV

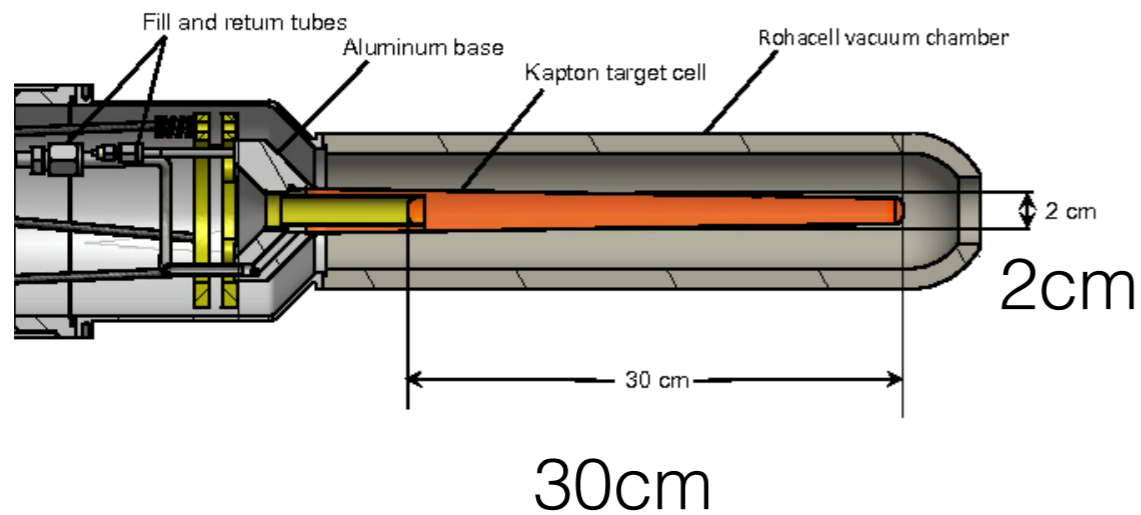


$$N(K_L)/sec \sim 10^4$$

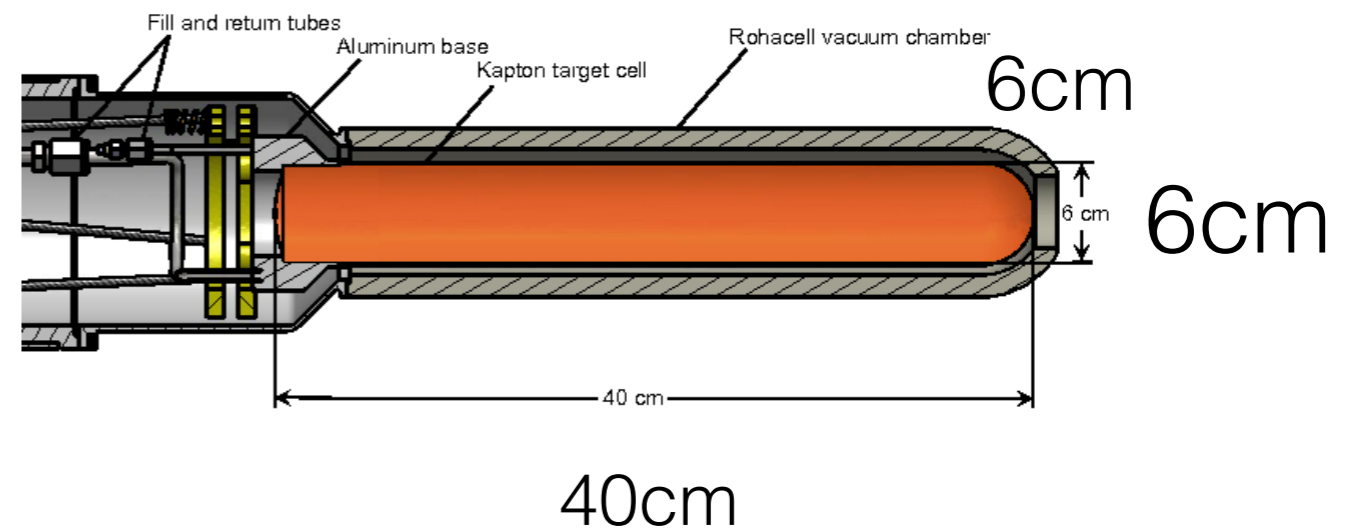


$$\frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

LH2/LD2 Cryogenic target for K_L Beam at Hall D



Current

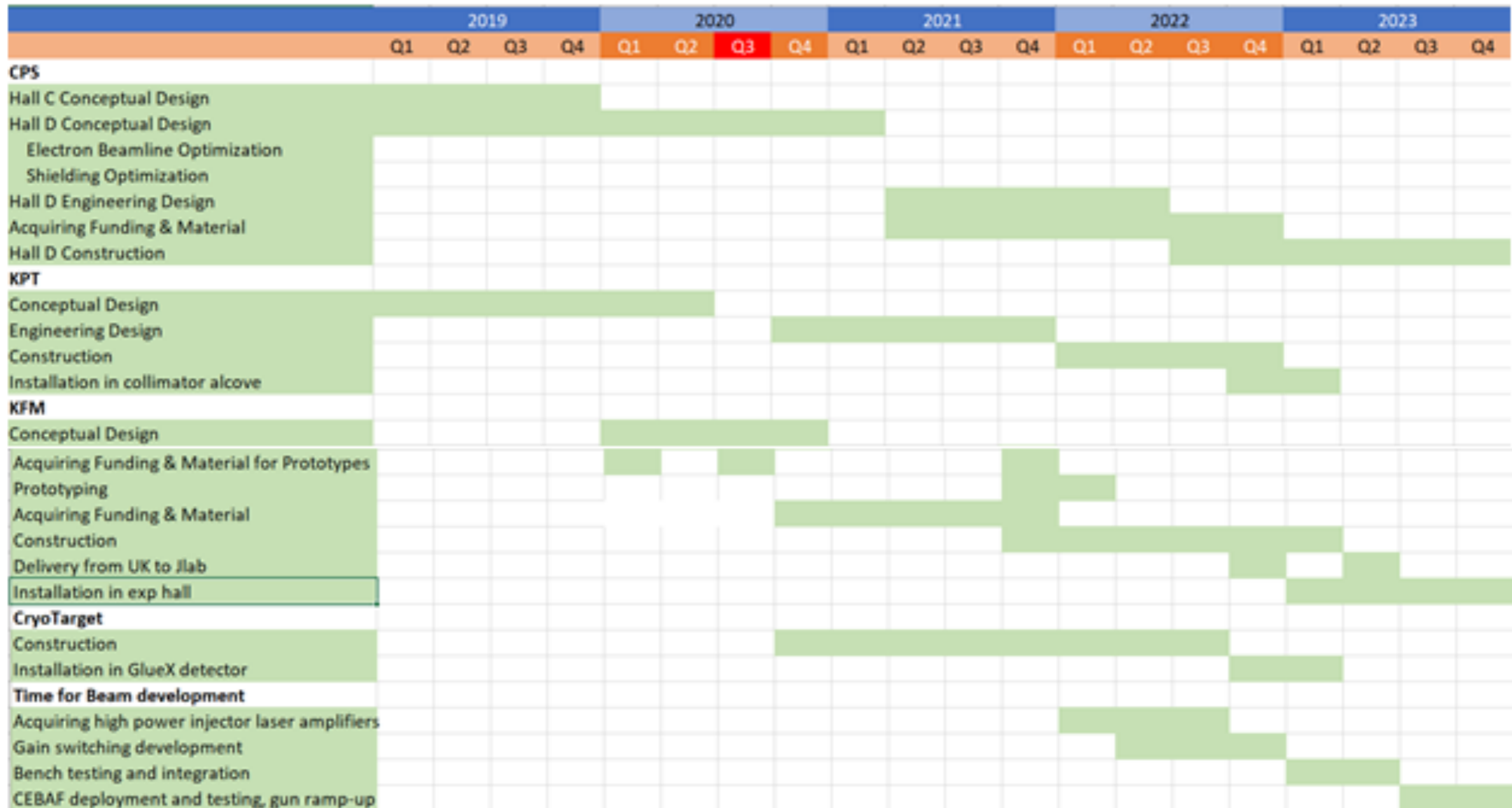


Proposed & Feasible

Longer and thicker target needed to enhance production rate

Conceptual design endorsed by JLAB target group

Timeline of Design, Construction and Installation



The Facility Flexible and can be switched to photon beam in 6 months

PHYSICS WITH NEUTRAL KAON BEAM AT JLAB KL2016

FEBRUARY 1-3, 2016
JEFFERSON LAB
NEWPORT NEWS, VIRGINIA

SCOPE

The Workshop is following Lol12-15-001 "Physics Opportunities with Secondary KL beam at JLab" and will be dedicated to the physics of hyperons produced by the kaon beam on unpolarized and polarized targets with GlueX set up in Hall D. The emphasis will be on the hyperon spectroscopy. Such studies could contribute to the existing scientific program on hadron spectroscopy at Jefferson Lab.

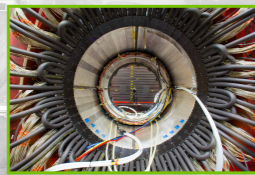
The Workshop will also aim at boosting the international collaboration, in particular between the US and EU research institutions and universities.

The Workshop would help to address the comments made by the PAC43, and to prepare the full proposal for the next PAC44.

ORGANIZING COMMITTEE

Moskov Amaryan, ODU, chair
Eugene Chudakov, JLab
Curtis Meyer, CMU
Michael Pennington, JLab
James Ritman, Ruhr-Uni-Bochum & IKP Jülich
Igor Strakovsky, GWU

WWW.JLAB.ORG/CONFERENCES/KL2016



YSTAR Excited Hyperons in QCD Thermodynamics at Freeze-Out 2016

NOVEMBER 16-17, 2016

Jefferson Lab
Newport News, Virginia

A workshop to discuss the influence of possible "missing" hyperon resonances (JLab KLF Project) on QCD thermodynamics, on freeze-out in heavy ion collisions and in the early universe, and in spectroscopy. Recent studies that compare lattice QCD calculations of thermodynamic calculations, statistical hadron resonance gas models, and ratios between measured yields of different hadron species in heavy ion collisions provide indirect evidence for the presence of "missing" resonances in all of these contexts. The aim of the workshop is to sharpen these comparisons, advance our understanding of the formation of baryons from quarks and gluons microseconds after the Big Bang and in today's experiments, and to connect these developments to experimental searches for direct, spectroscopic, evidence for these resonances. This Workshop is a successor to the recent KL2016 Workshop

ORGANIZING COMMITTEE

Moskov Amaryan - Chair, ODU
Eugene Chudakov, JLab
Krishna Rajagopal, MIT
Claudia Ratti, University of Houston
James Ritman, Ruhr U. Bochum & IKP Jülich
Igor Strakovsky, GWU



WWW.JLAB.ORG/CONFERENCES/YSTAR2016/

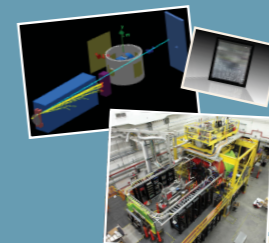


HIPS 2017

New Opportunities with High-Intensity Photon Sources

February 6-7, 2017
Catholic University of America
Washington, DC U.S.A.

This workshop aims at producing an optimized photon source concept with potential increase of scientific output at Jefferson Lab, and at refining the science for hadron physics experiments benefiting from such a high-intensity photon source. The workshop is dedicated to bringing together the communities directly using such sources for photo-production experiments, or for conversion into K_s beams. The combination of high precision calorimetry and high intensity photon sources can provide greatly enhanced scientific benefit to (deep) exclusive processes like wide-angle and time-like Compton scattering. Potential prospects of such a high-intensity source with modern polarized targets will also be discussed. The availability of K_s beams would open new avenues for hadron spectroscopy, for example for the investigations of "missing" hyperon resonances, with potential impact on QCD thermodynamics and on freeze-out both in heavy ion collisions and the early universe.



Organizing Committee:

Tanja Horn - CUA
Cynthia Keppel - JLab
Carlos Munoz-Camacho - IPNO
Igor Strakovsky - GWU



π -K Interactions Workshop

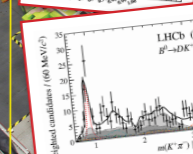
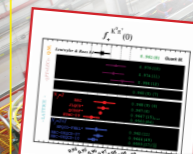
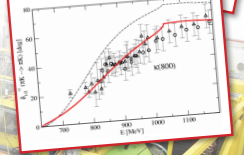
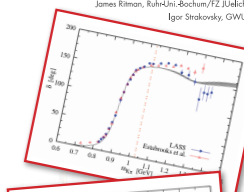
ORGANIZING COMMITTEE

Moskov Amaryan, ODU (Chair)
U.K.G. Meißner, U. Bonn/FZ Jülich
Curtis Meyer, CMU
James Ritman, Ruhr-Uni-Bochum/FZ Jülich
Igor Strakovsky, GWU

February 14-15, 2018

Jefferson Lab • Newport News, VA

The π -K scattering enables direct investigations of scalar and vector K^* states, including the not yet established S-wave $k(800)$ state. These studies are also needed to get precise values of vector and scalar form factors: to independently extract CKM matrix element V_{us} and to test the Standard Model unitarity relation in the first row of CKM matrix, to study CP violation from the Dalitz plot analysis of open charm D meson decays and in a charmless decays of B mesons in Kpipi final states. Significant progress is made lately in Lattice QCD, in the phenomenology and in the Chiral Perturbation Theory to describe different aspects of π -K scattering. The main source of experimental data is based on experiments performed in SLAC almost five decades ago at 1970-80s. The recently proposed KL Facility incorporating the GlueX spectrometer at JLab will be able to improve the π -K scattering database by about three orders of magnitude in statistics. The workshop will discuss the necessity for and the impact of the future high statistics data obtained at JLab on π -K scattering.



<https://www.jlab.org/conferences/pki2018/>



KL2016

[60 people from 10 countries, 30 talks] <https://www.jlab.org/conferences/kl2016/>

OC: M. Amaryan, E. Chudakov, C. Meyer, M. Pennington, J. Ritman, & I. Strakovsky

YSTAR2016

[71 people from 11 countries, 27 talks] <https://www.jlab.org/conferences/YSTAR2016/>

OC: M. Amaryan, E. Chudakov, K. Rajagopal, C. Ratti, J. Ritman, & I. Strakovsky

HIPS2017

[43 people from 4 countries, 19 talks] <https://www.jlab.org/conferences/HIPS2017/>

OC: T. Horn, C. Keppel, C. Munoz-Camacho, & I. Strakovsky

PKI2018

[48 people from 9 countries, 27 talks] <http://www.jlab.org/conferences/pki2018/>

OC: M. Amaryan, U.-G. Meißner, C. Meyer, J. Ritman, & I. Strakovsky

In total: 222 participants & 103 talks



68 Universities from 19 Countries

SUMMARY

- **-Proposed KL Facility has a unique capability to improve existing world database up to three orders of magnitude**
- **-In Hyperon spectroscopy**
PWA will allow to unravel and measure pole positions and widths of dozens of new excited hyperon states
- **-In Strange Meson Spectroscopy**
PWA will allow to measure excited K^* states including scalar $K^*(700)$ states
- **To accomplish physics program**
100 days per LH2 and LD2 is required
- **All components of KL Facility considered are feasible**
-With total cost of the project below \$5M

Thank you !