

# ***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<sub>L</sub> Facility Beamline and Hardware*

- *Electron Beam*
- *Compact Photon Source*
- *Be Target*
- *Flux Monitor*
- *K<sub>L</sub> Beam*
- *LH<sub>2</sub>/LD<sub>2</sub> Target*

## Summary

# Hyperon Spectroscopy

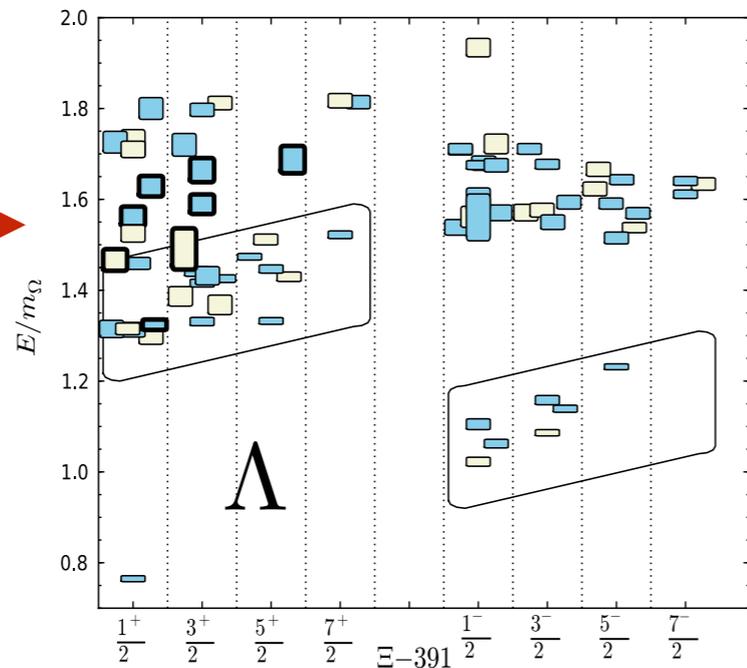
According to *LQCD* there should be many more states including hybrids (thick bordered)

**8-states**

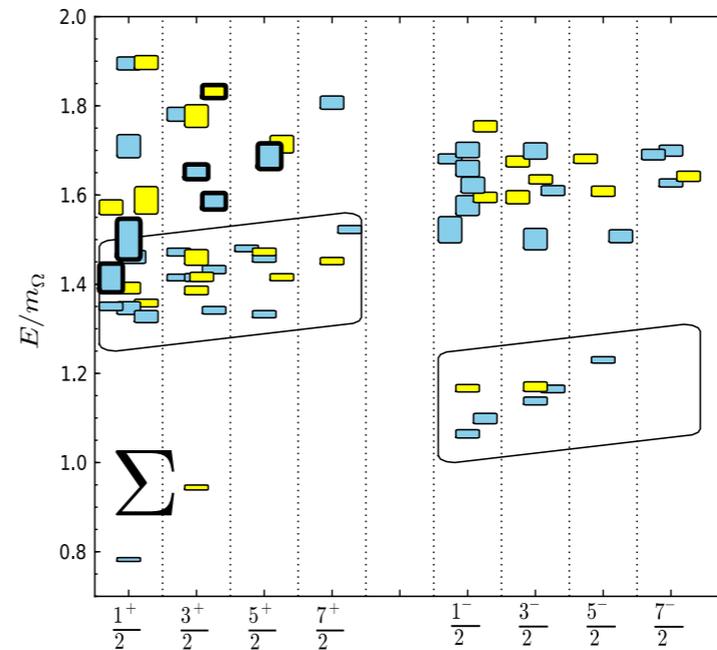
\*\*\*\*

**5-states**

\*\*\*



$\Sigma-391$



**6-states**

\*\*\*\*

**4-states**

\*\*\*

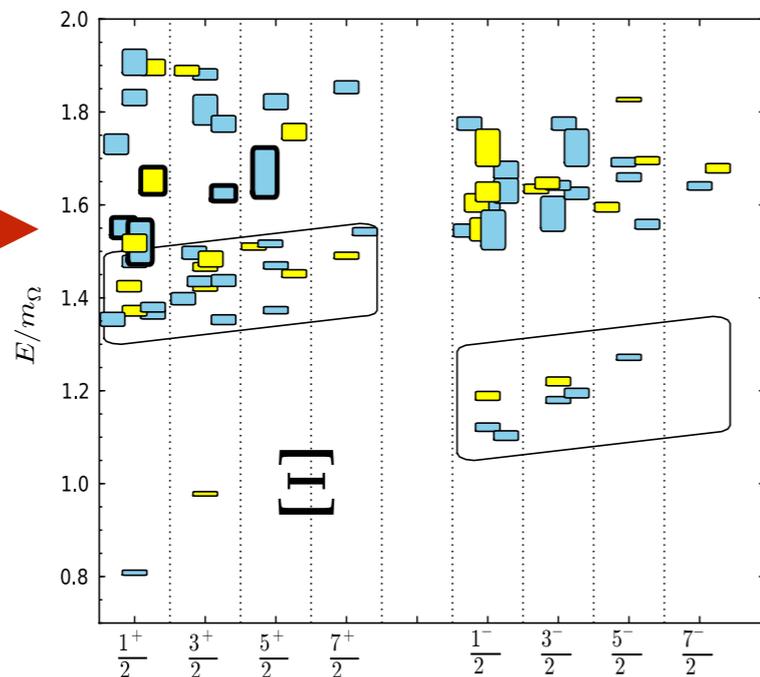


**3-states**

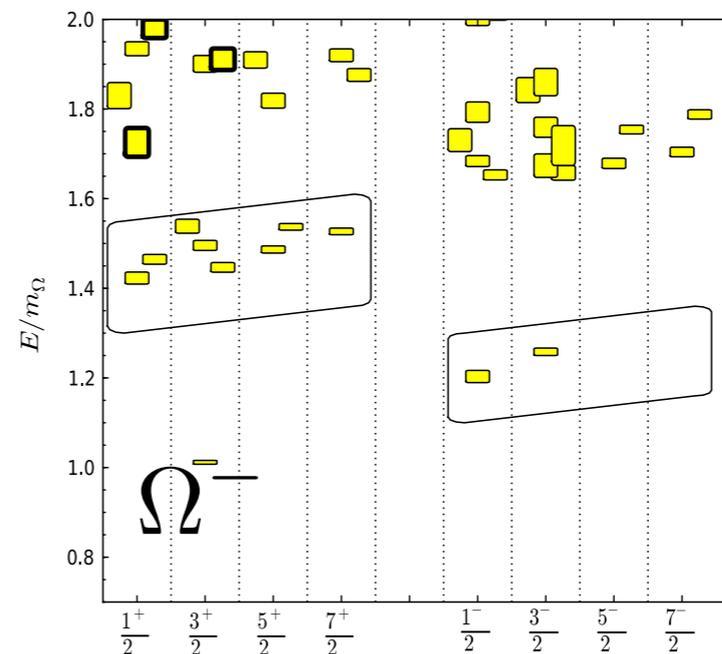
\*\*\*\*

**4-states**

\*\*\*



$\Omega-391$



**1-state**

\*\*\*\*

**1-state**

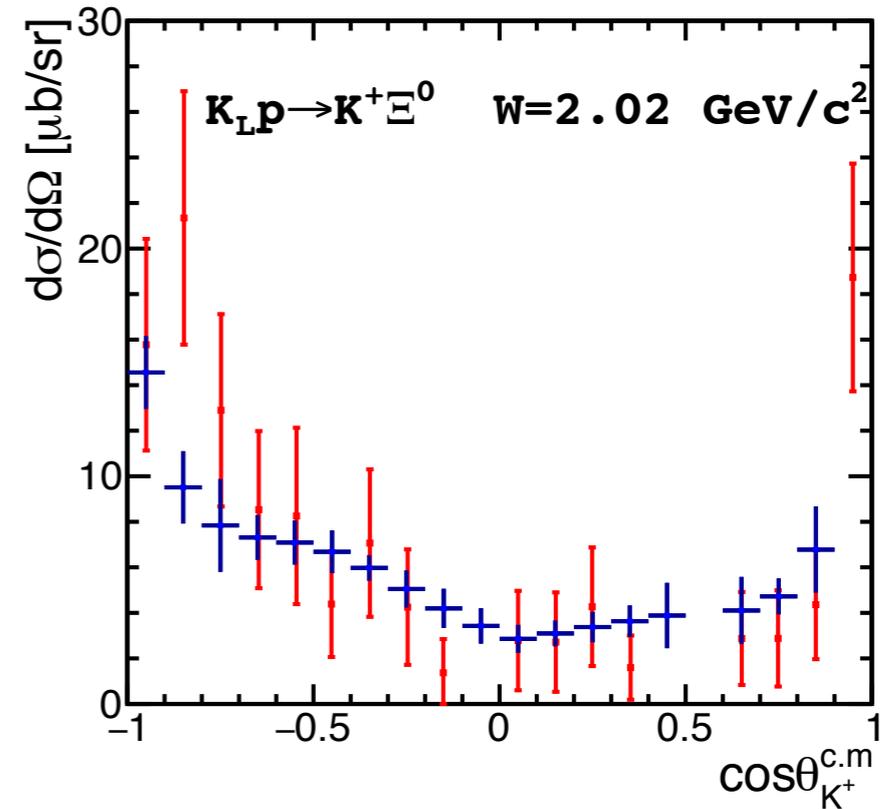
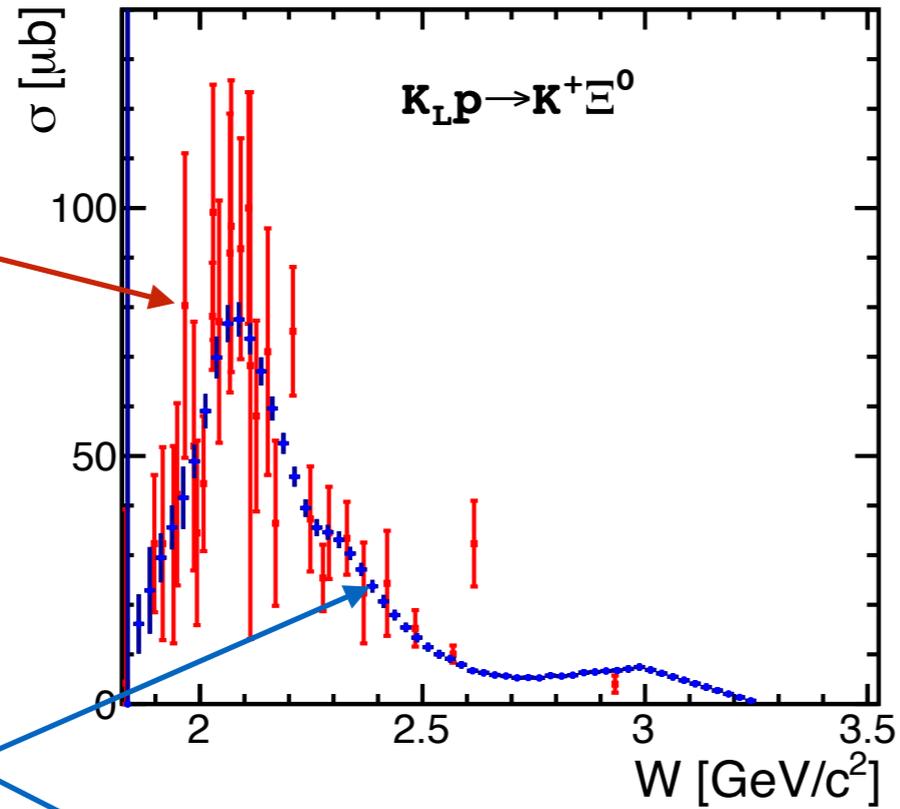
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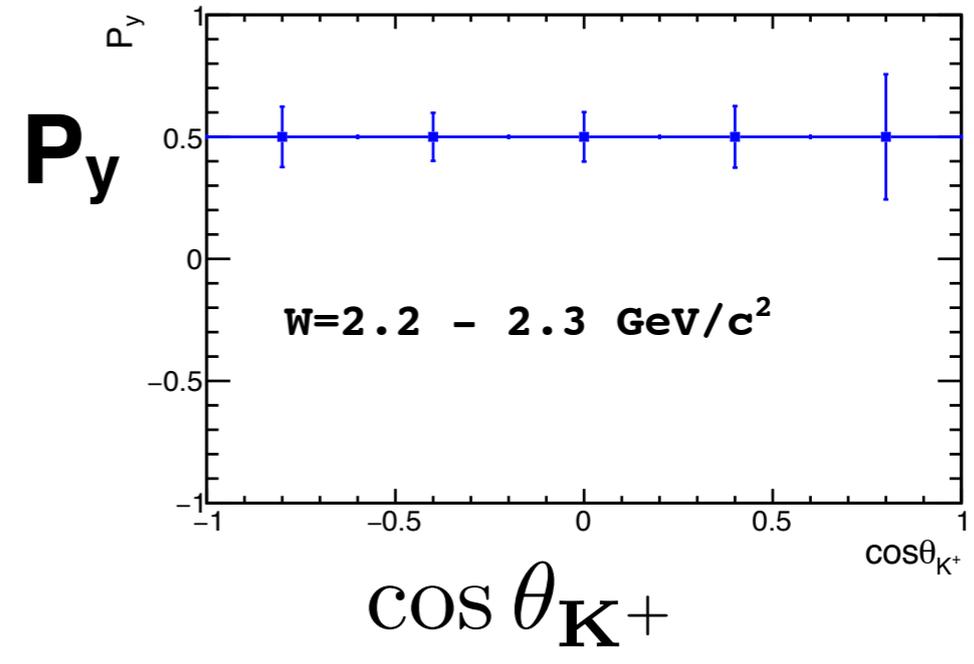
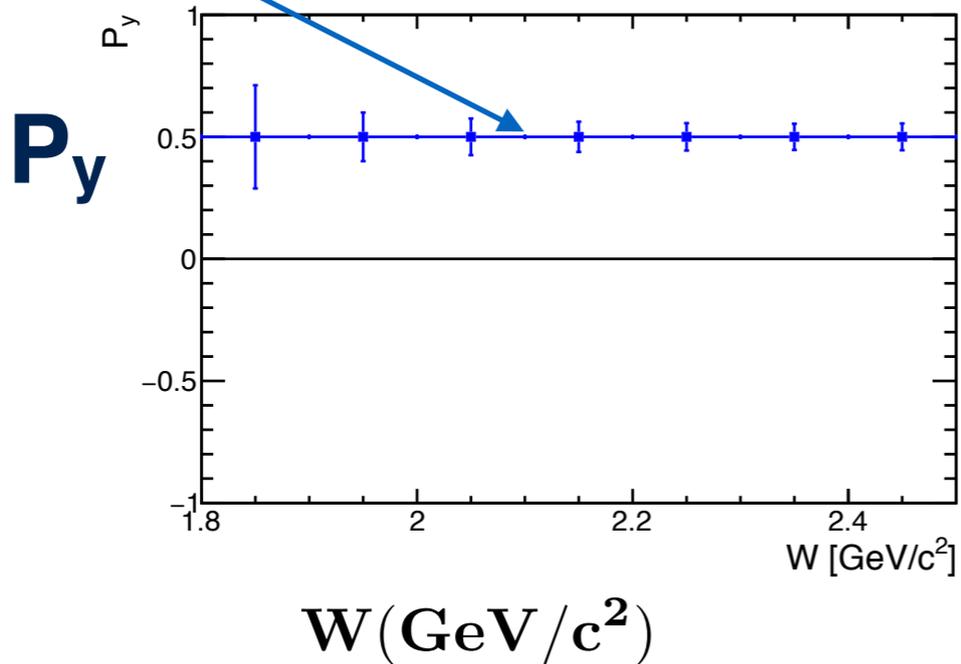
Edwards, Mathur, Richards and Wallace, *Phys. Rev. D* 87, 054506 (2013)

# 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**

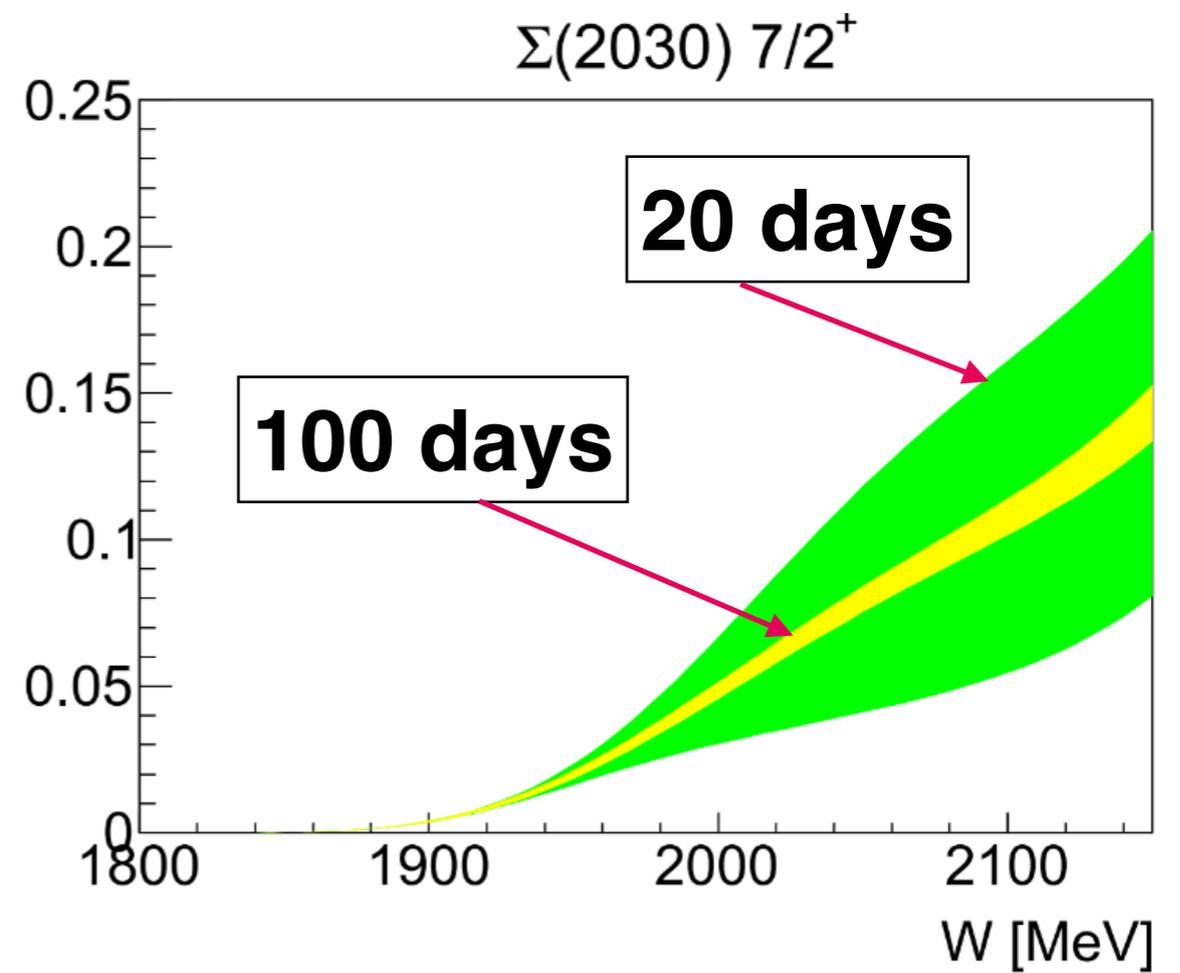
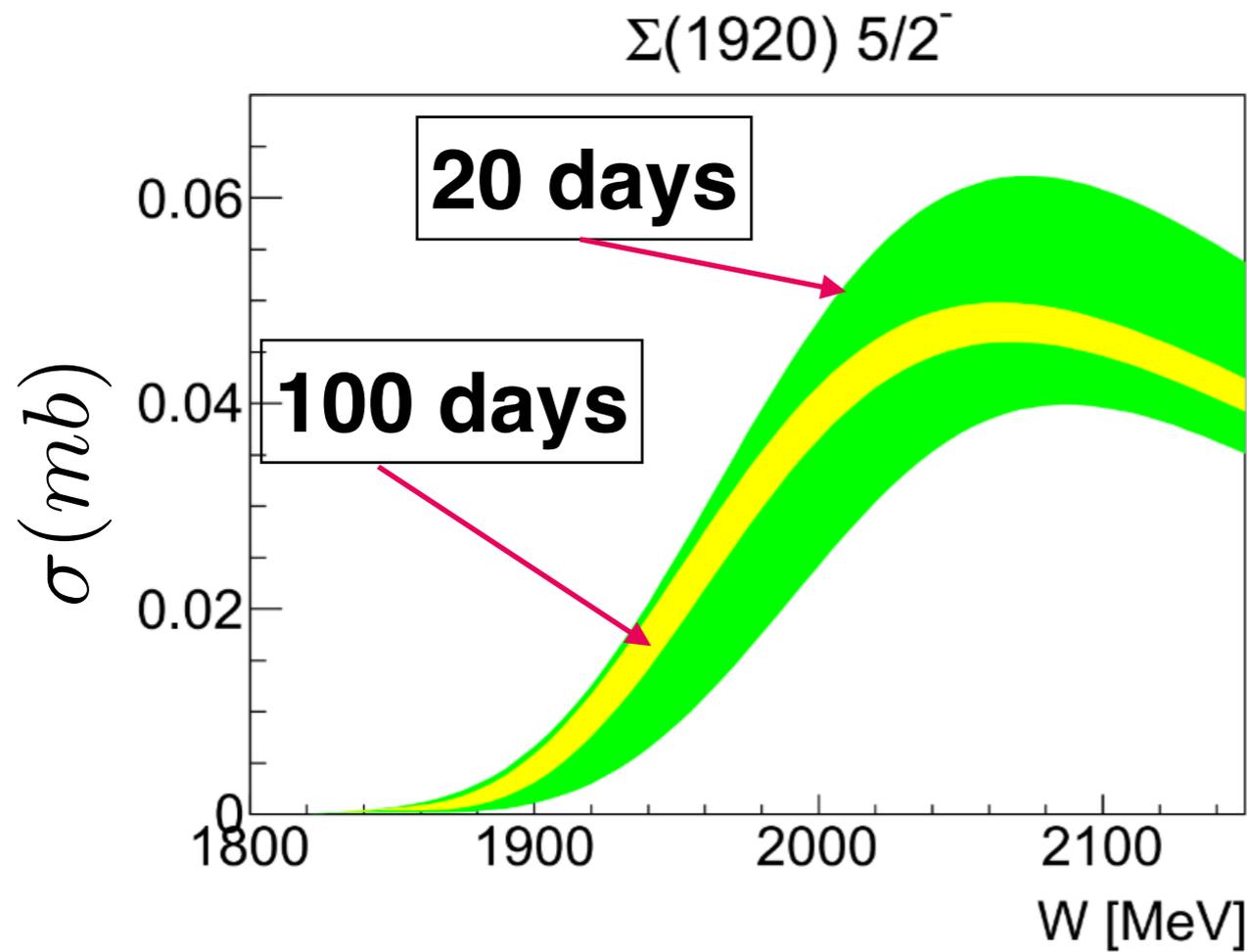
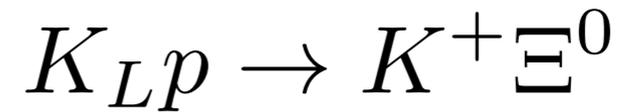
**$\Lambda^*$ ,  $\Sigma^*$ ,  $\Xi^*$  &  $\Omega^*$**

**-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

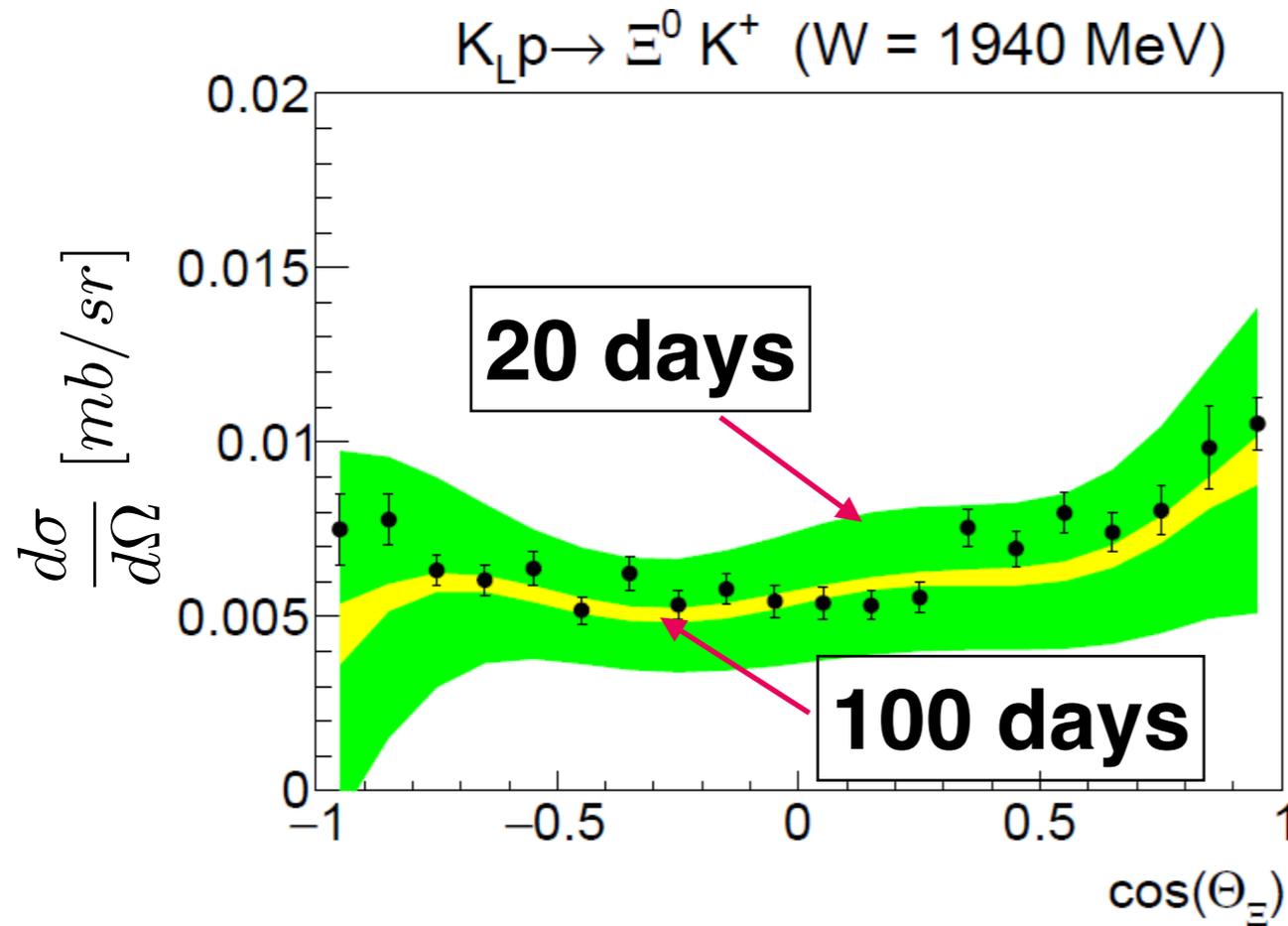
Total Cross Section



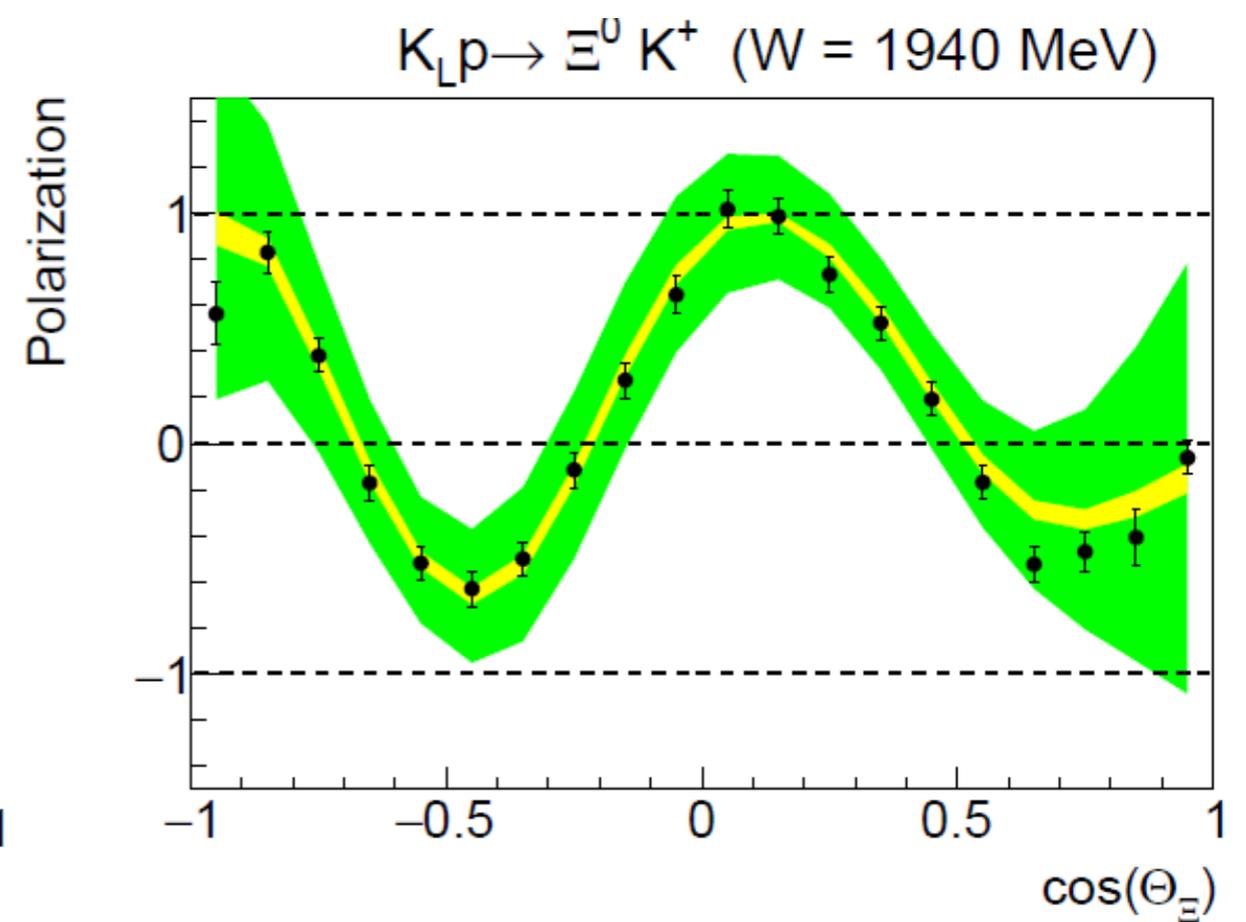
**Need 100 days of running to get precise solution**  
(see numerical results below)

# Bonn-Gatchina PWA

## Diff. Cross Section



## Polarization



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

# Numerical Results

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


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

**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)”**

# $K\pi$ Scattering on a proton and deuteron targets

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

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

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

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

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

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

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

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

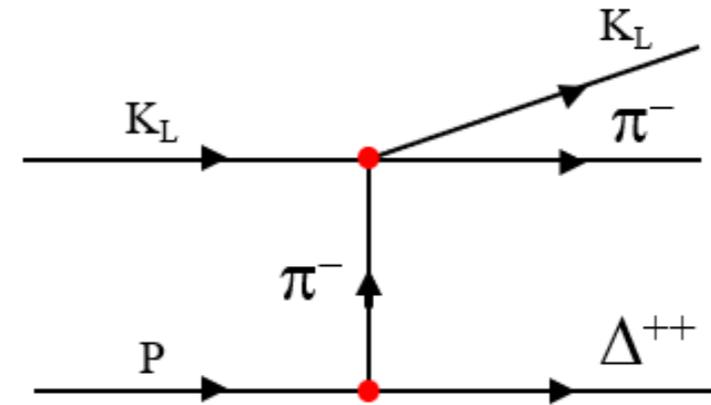
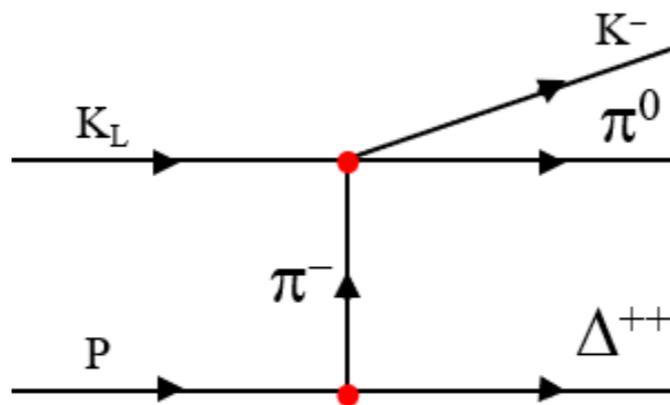
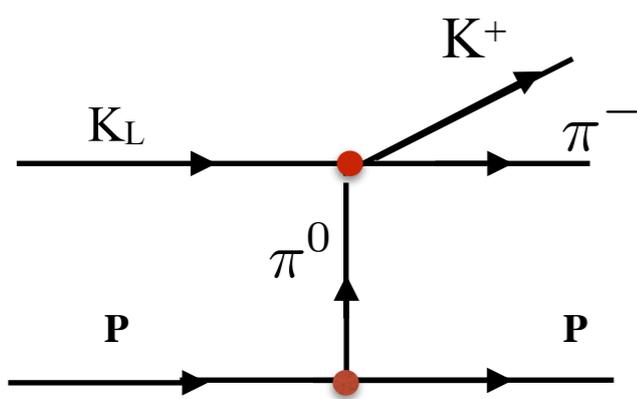
$$K_L n \rightarrow K_{(L,S)} \pi^\pm \Delta^\mp = \langle K_L \pi^\pm | K_L \pi^\pm \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

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

**Simulated  
for KLF**

# Strange Meson Spectroscopy

## Scattering



# Proposed Measurements

SLAC

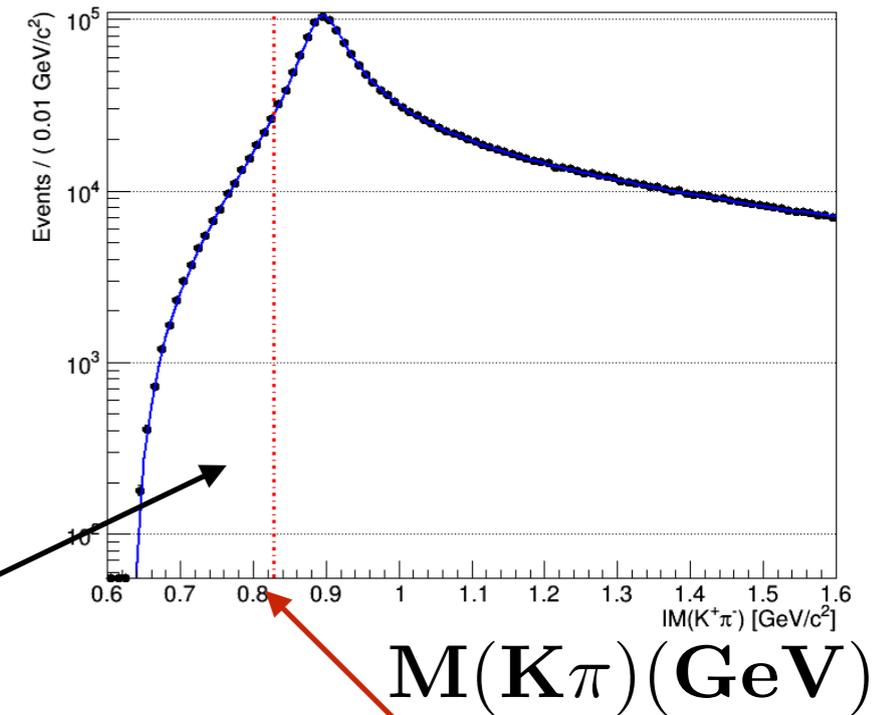
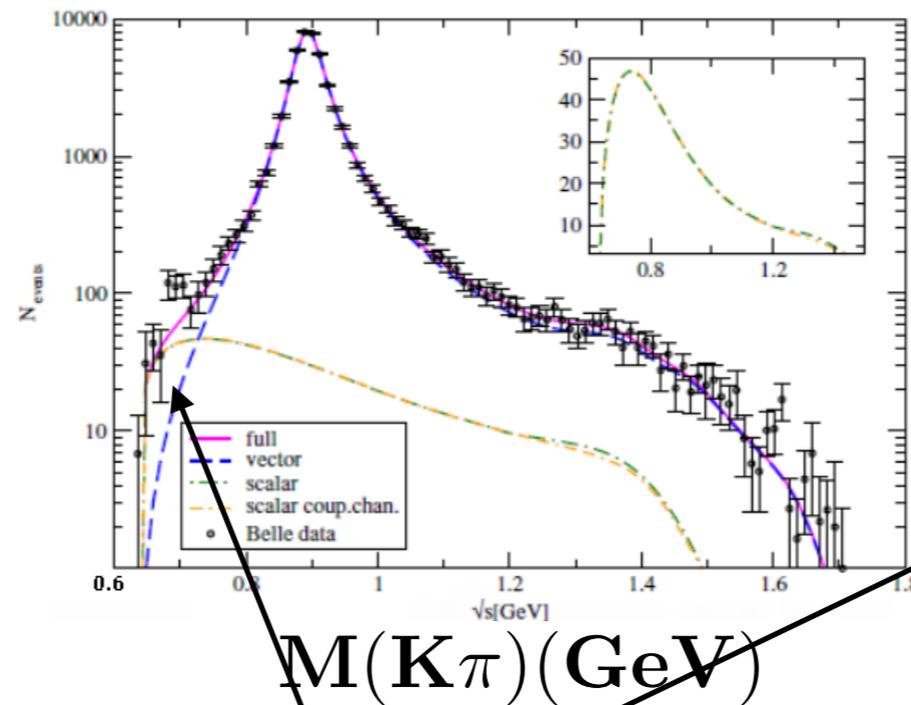
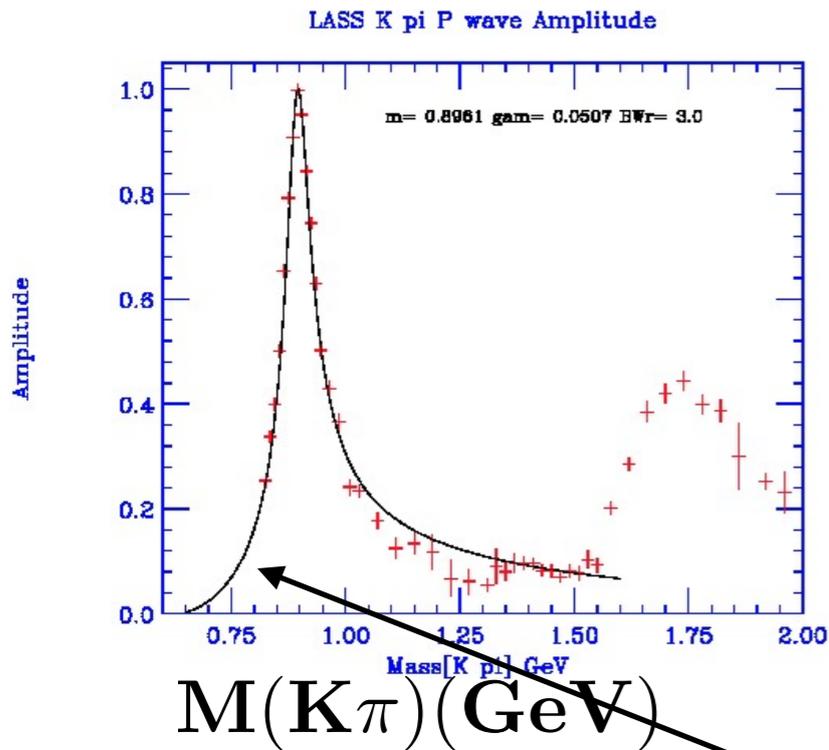
$$K^- \pi^+ \rightarrow K^- \pi^+$$

Belle

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

KLF

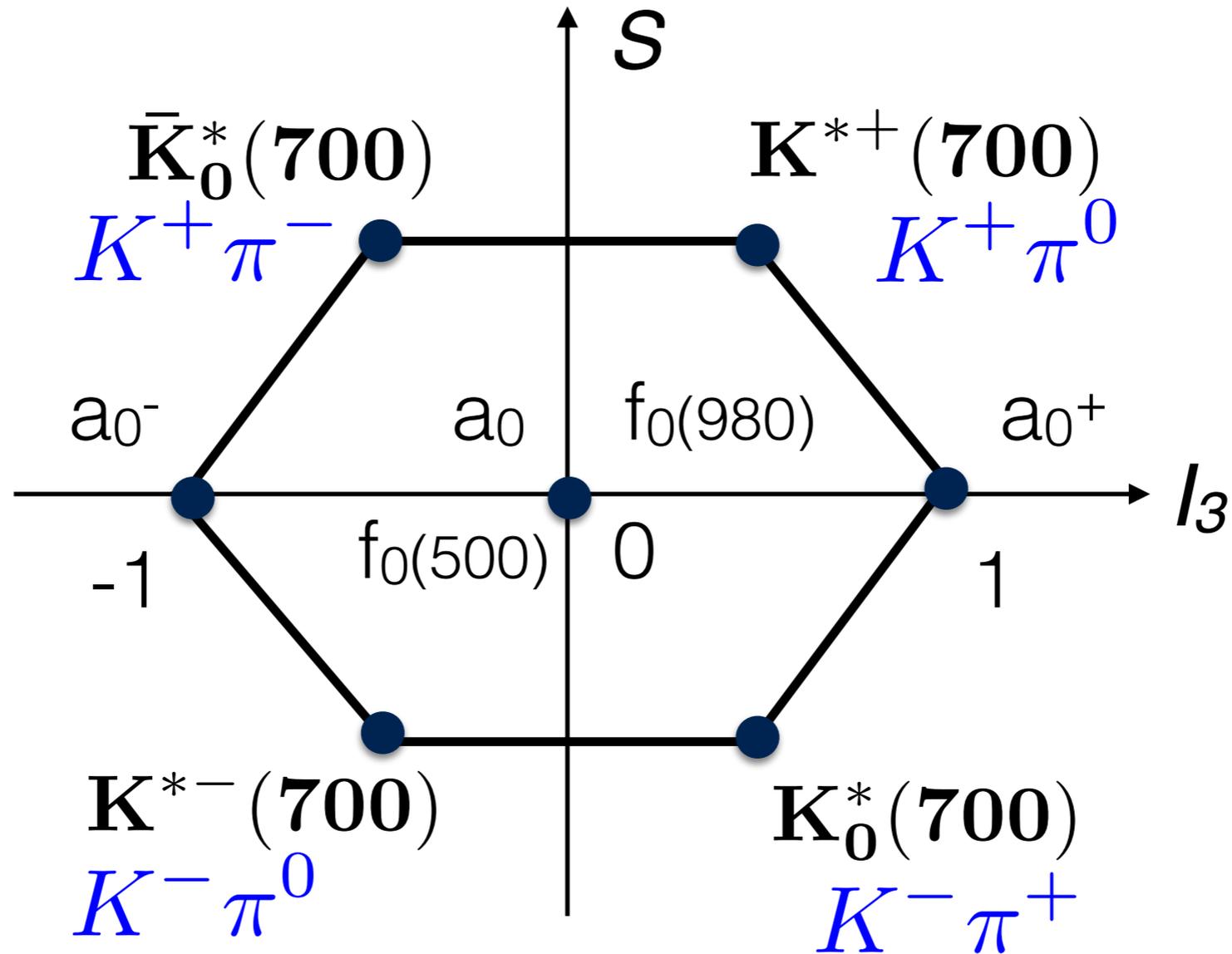
$$K_L \pi^0 \rightarrow K^+ \pi^-$$



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

# Scalar Meson Nonet

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

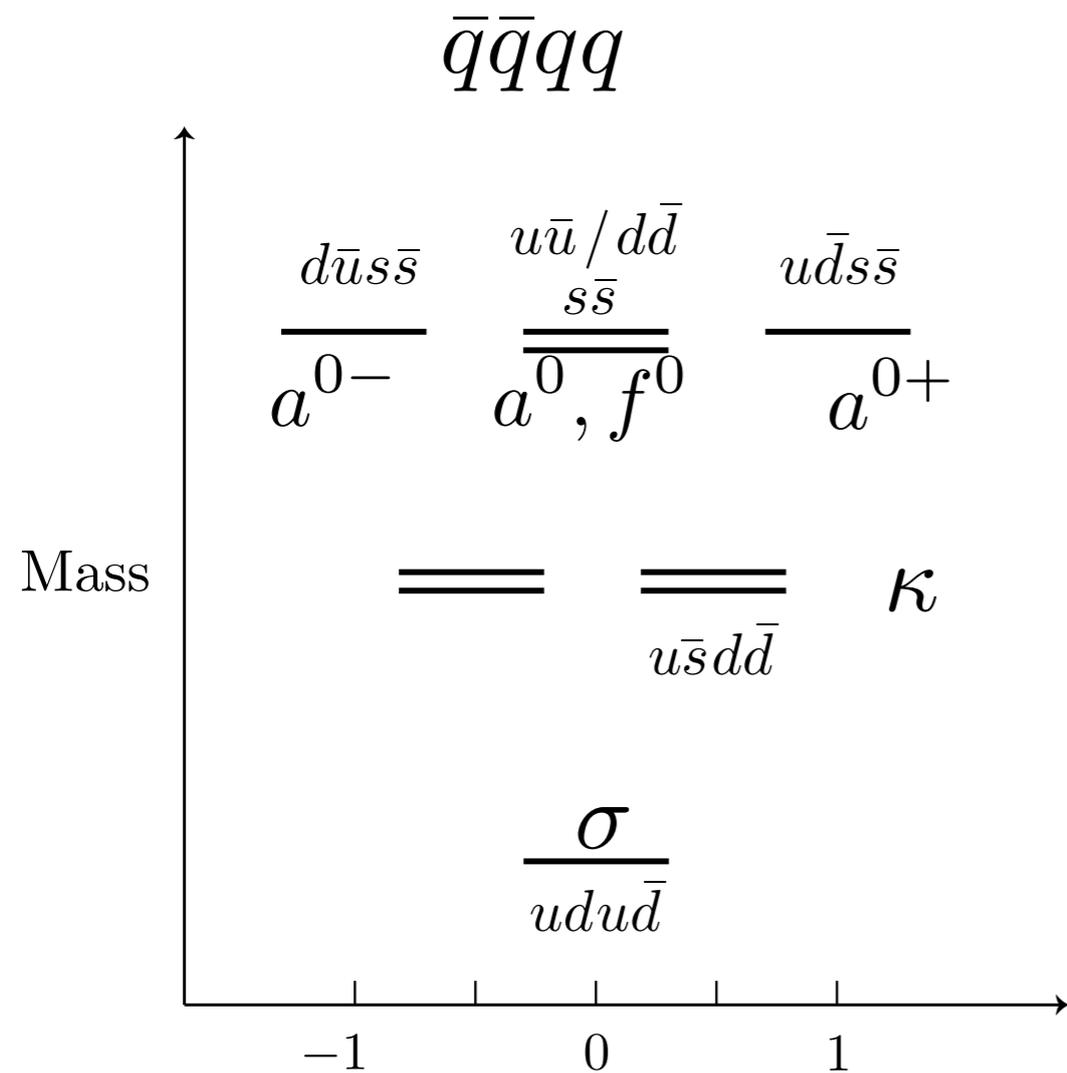


Four states called  $\kappa$

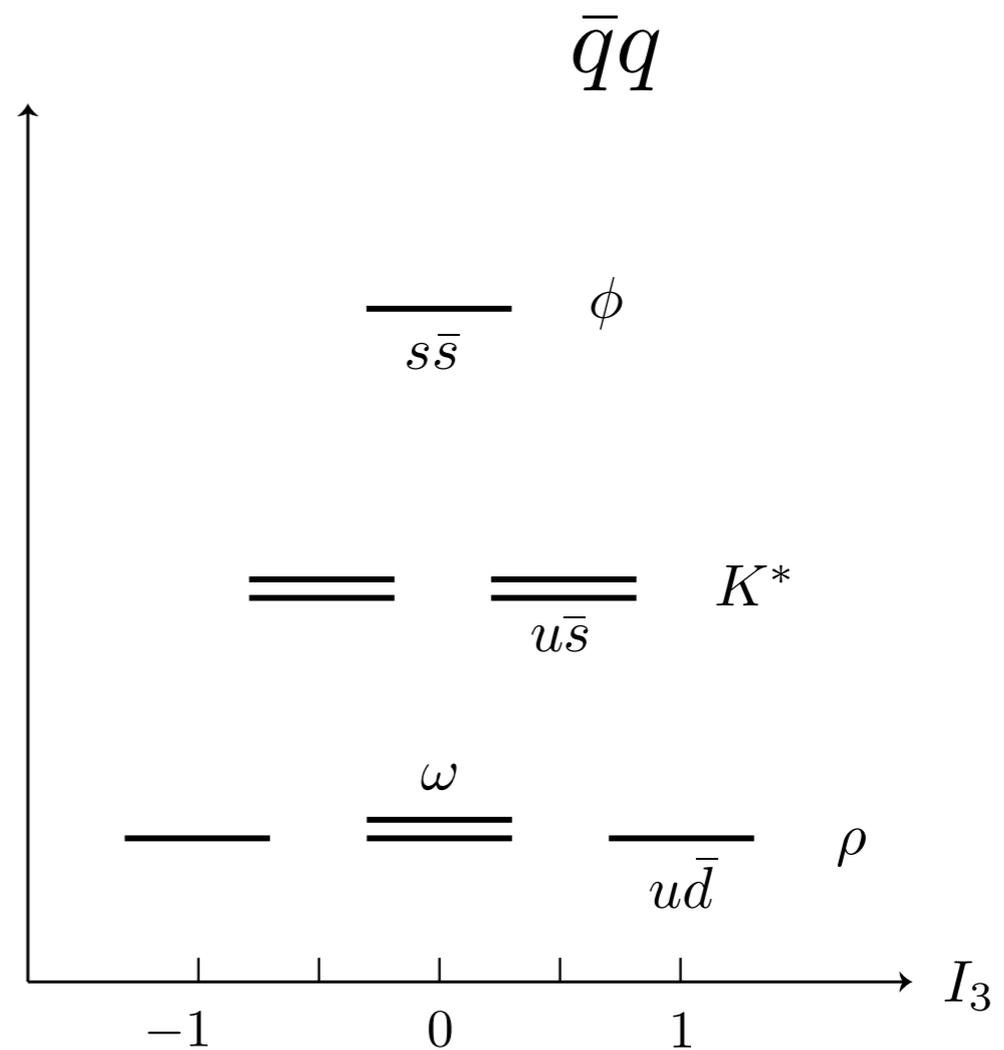
Still need further confirmation (PDG2020)

KLF allows measurement of all four states

## Inverted mass hierarchy tetraquarks

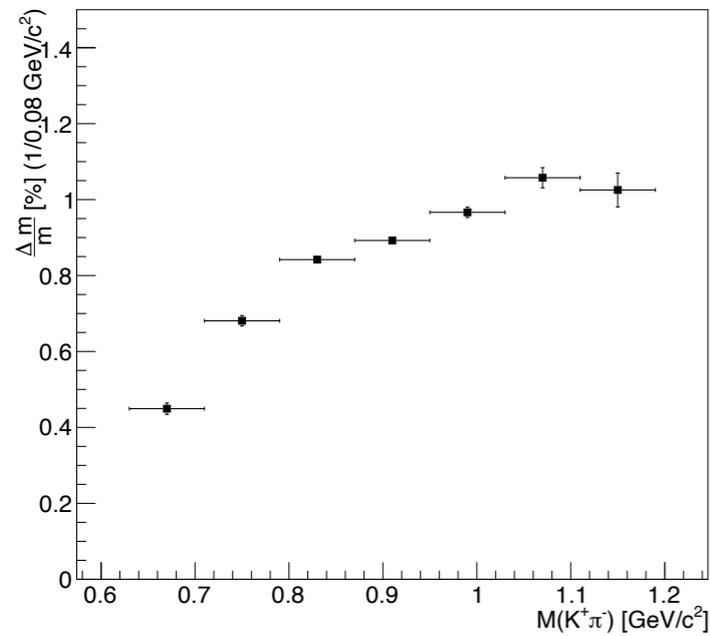


## ordinary meson states

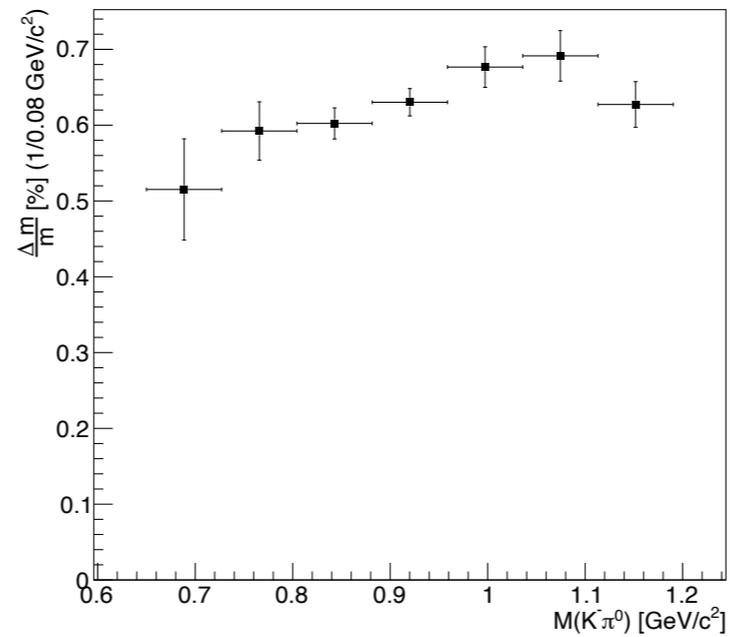


R. Jaffe, PRD 15, 267 (1977).

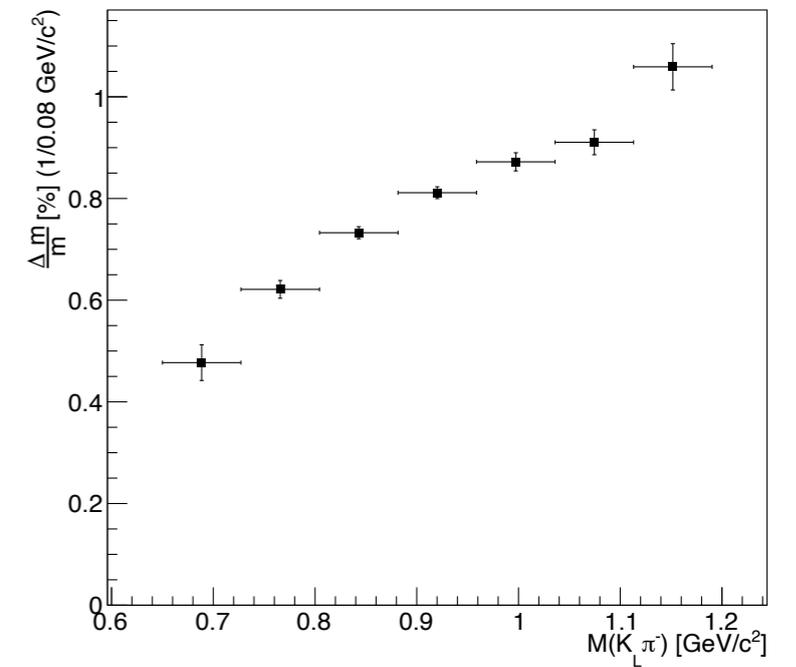
# Invariant mass resolution



$$K^+\pi^-$$



$$K^-\pi^0$$



$$K_L\pi^-$$

**Below 1% in all three simulated cases**

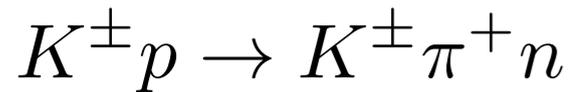
# Projected Measurements

$I=3/2+1/2$

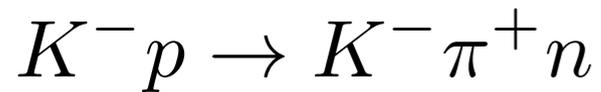
$S$ -wave

Presented at PAC47

## SLAC Data

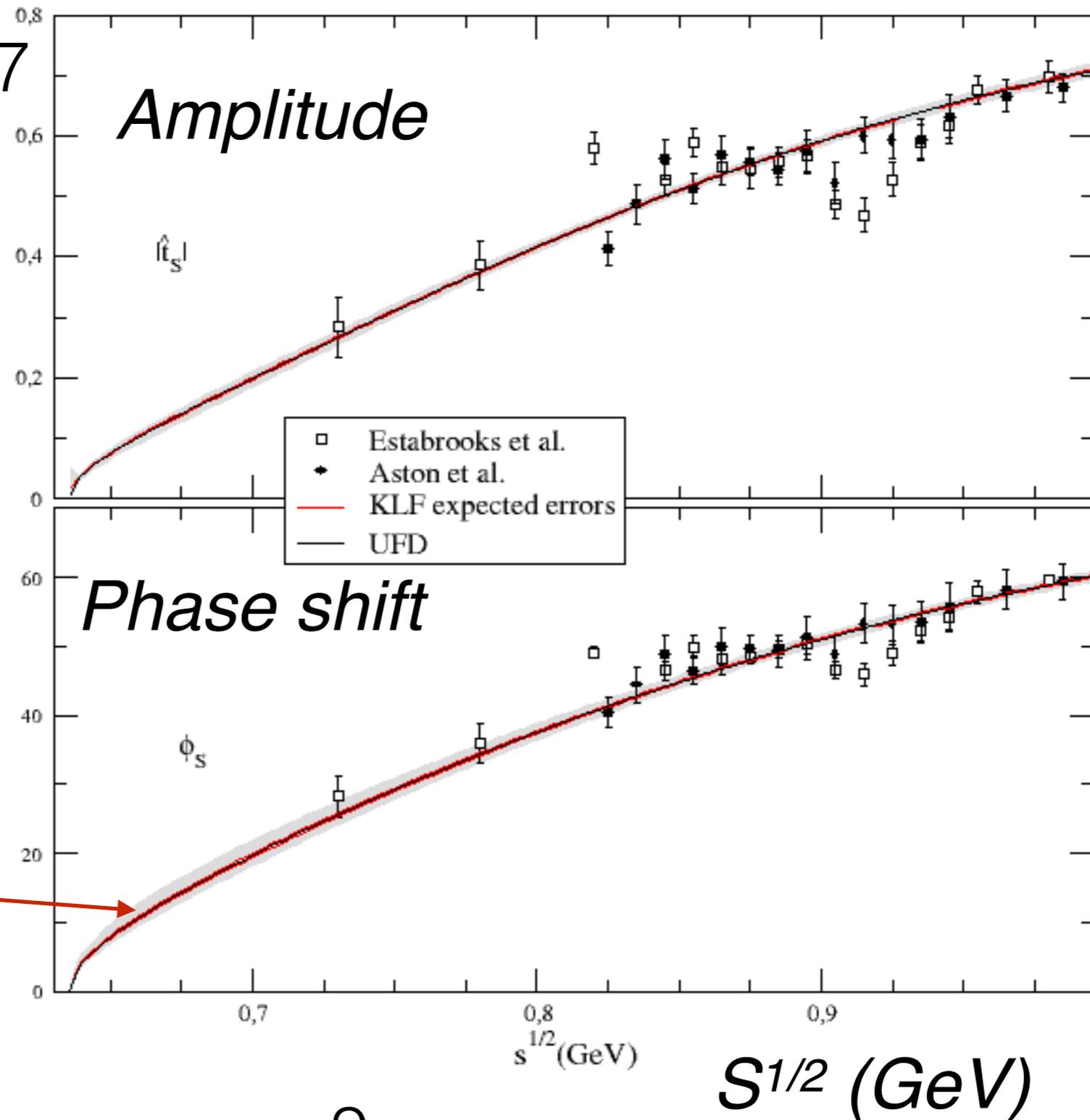


**Estabrooks(1978)**

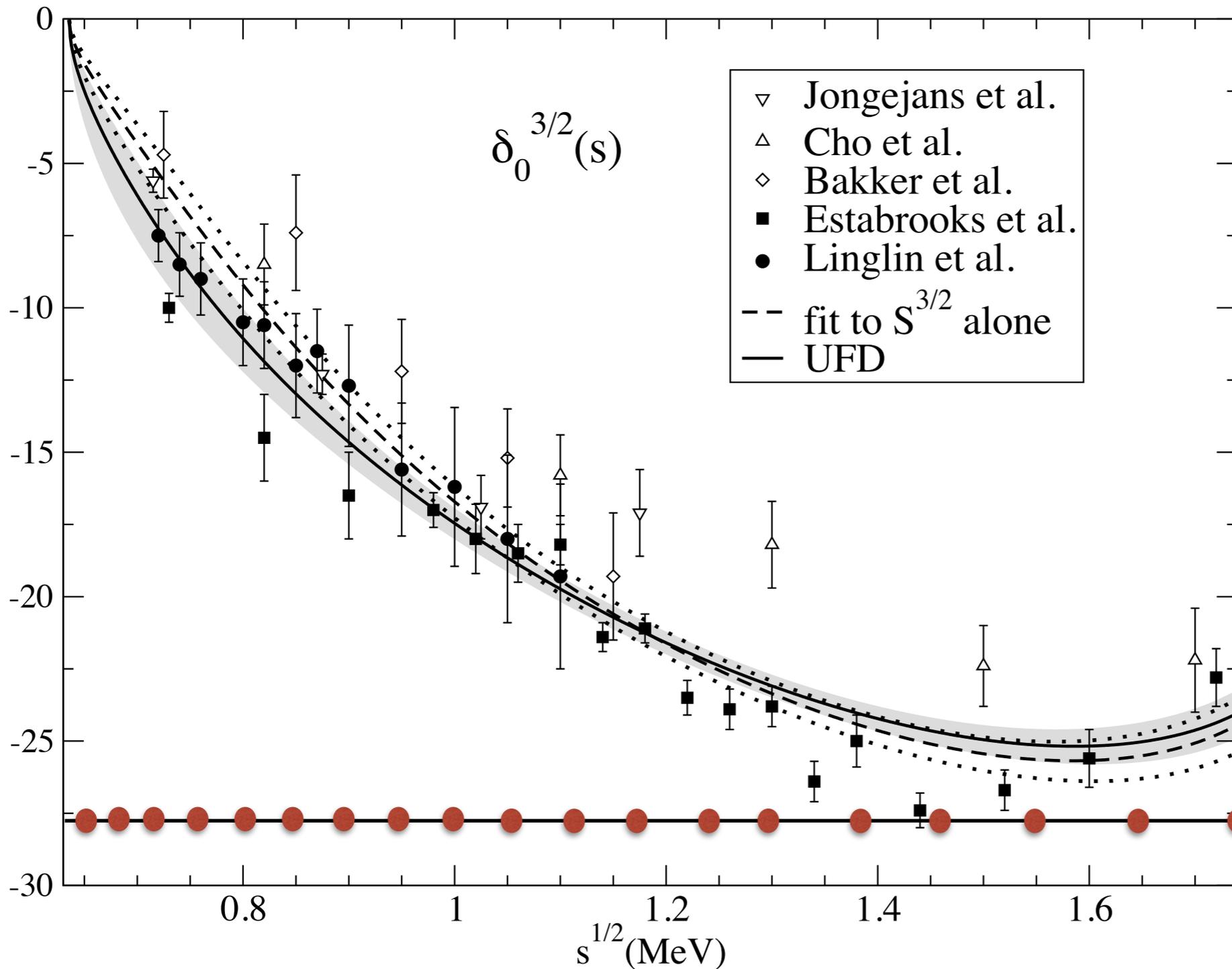


**Aston(1988)**

**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)**

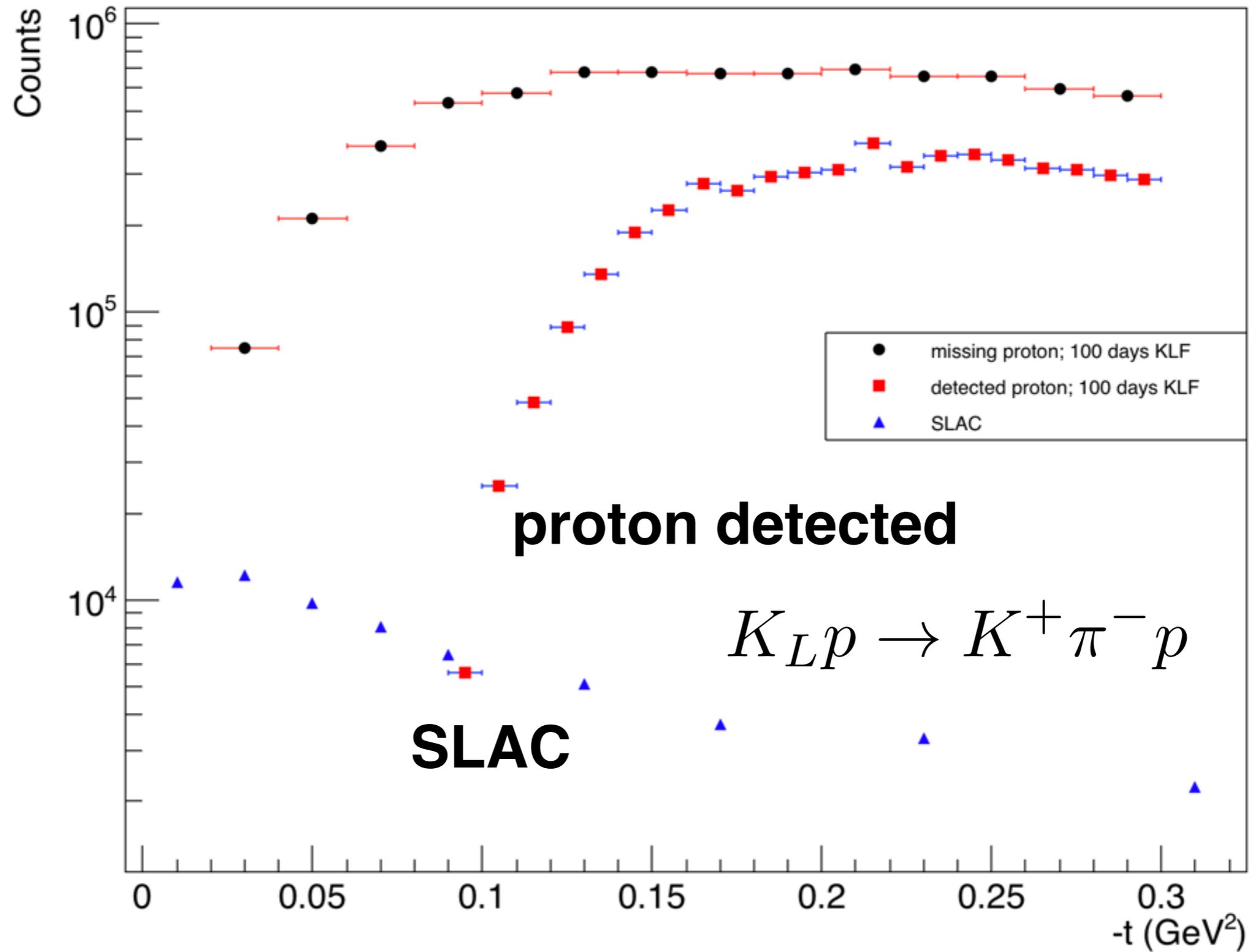
$$K^\pm p \rightarrow K^\pm \pi^+ n$$

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

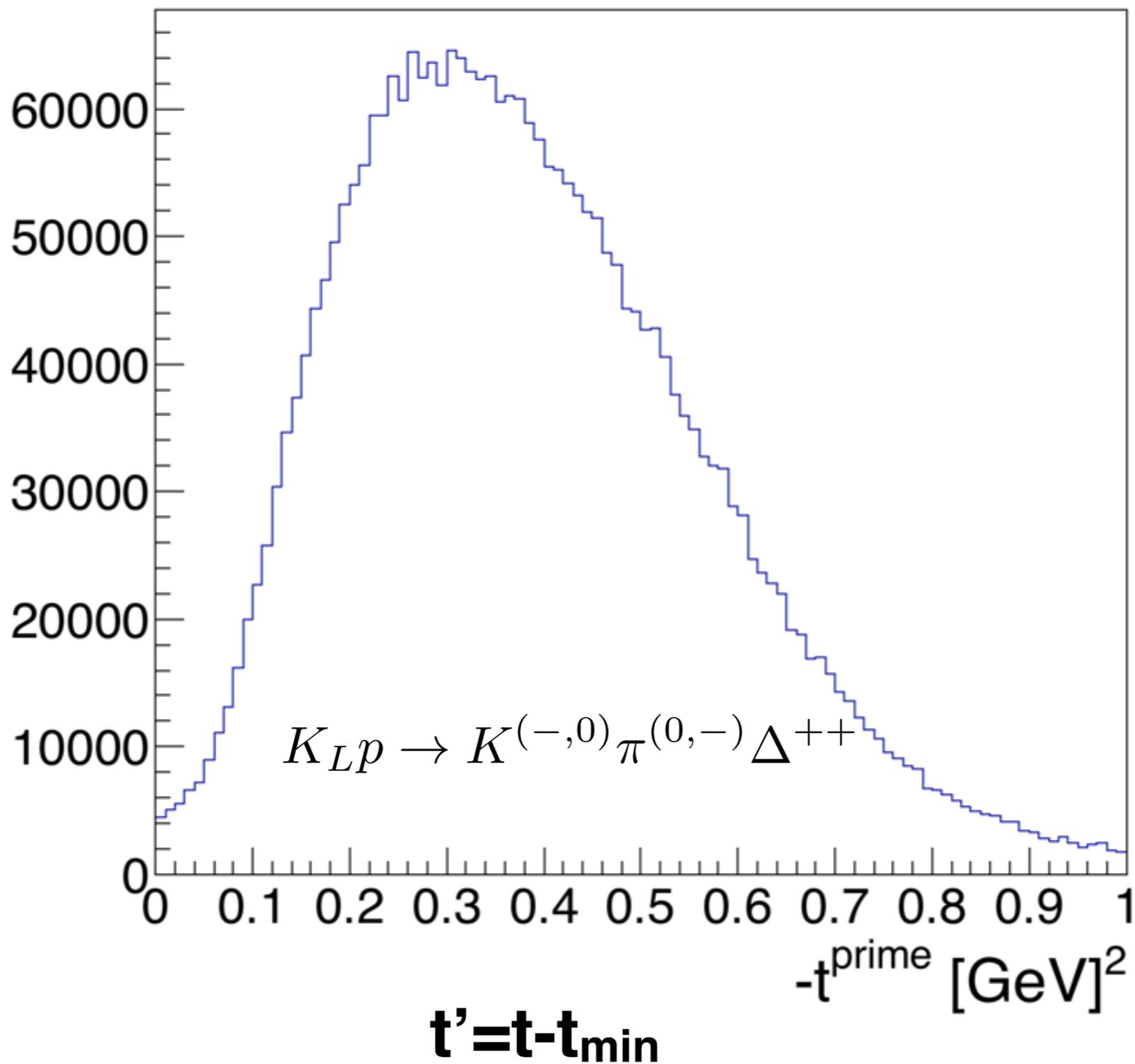
**KLF 100 days  
 (scaled)**

*From Pelaez and Rodas paper: PRD93(2016)*

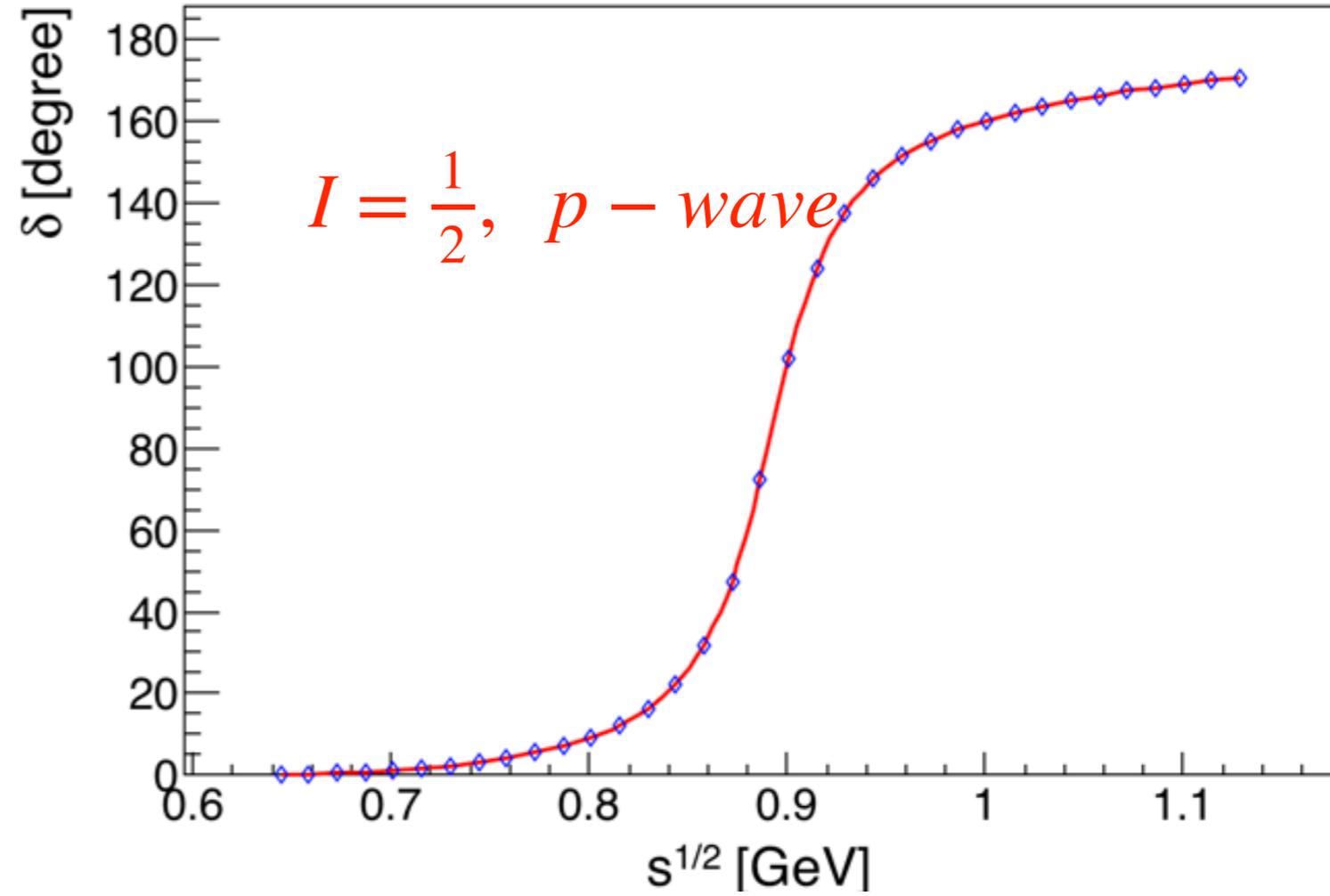
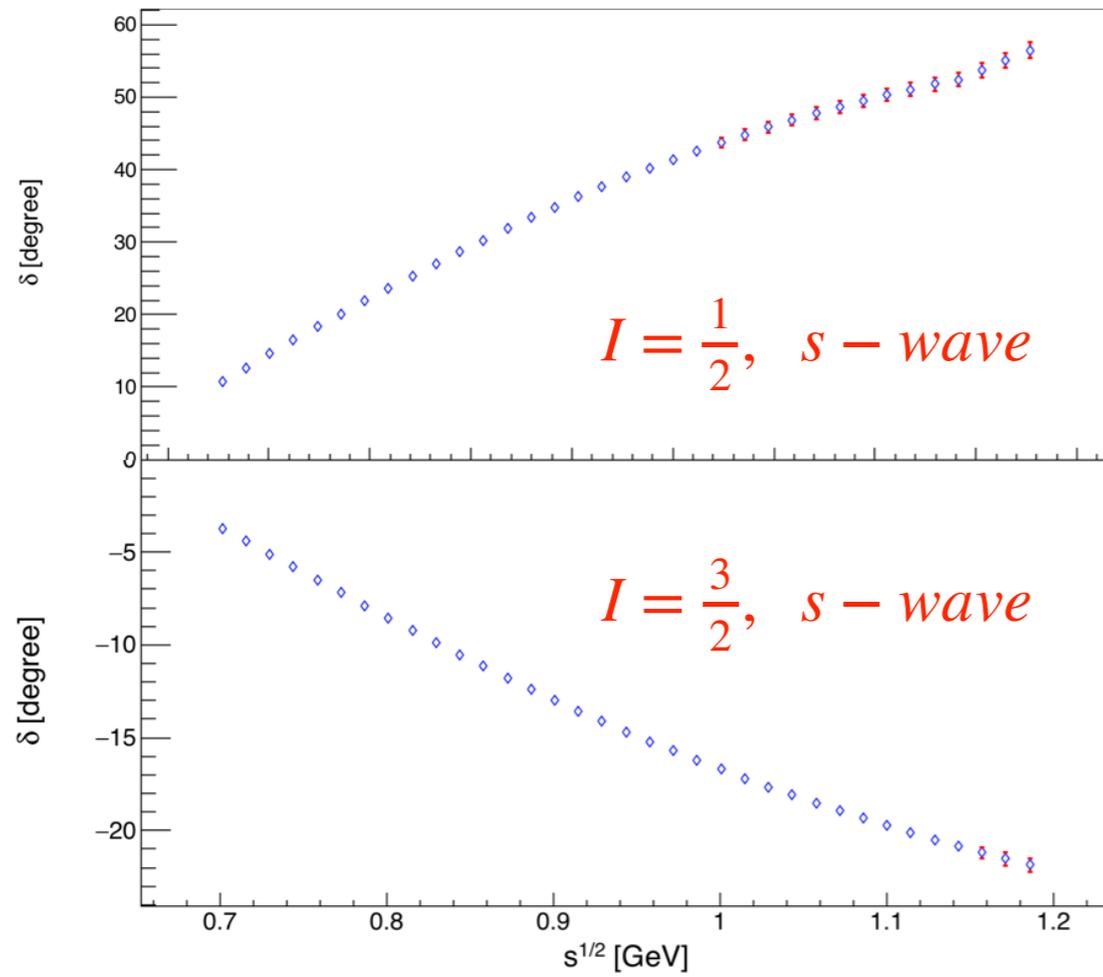
# Projected Statistics



# Distribution of four-momentum

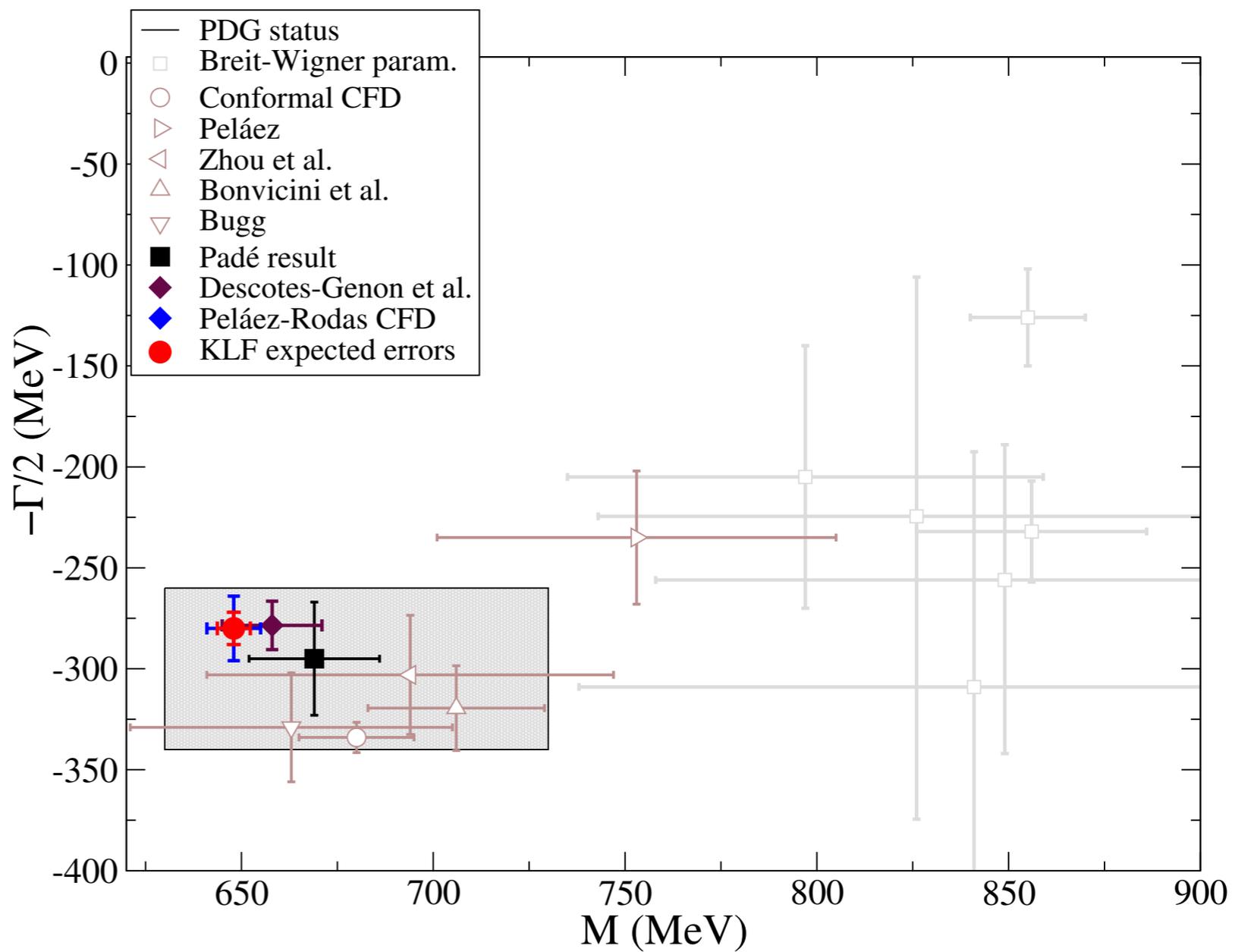
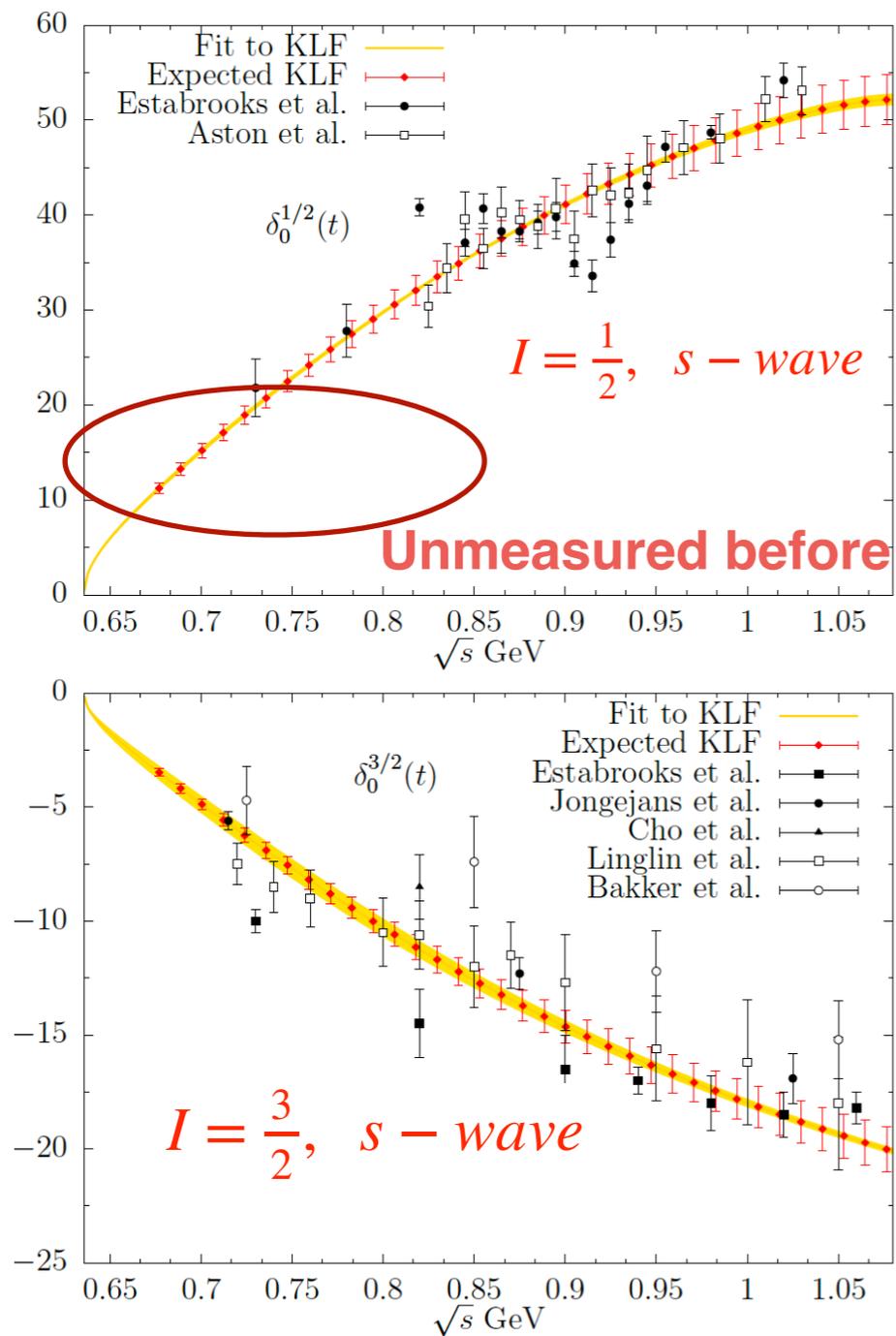


# Phase Shift



# Phase Shift

# Kappa Mass and Width



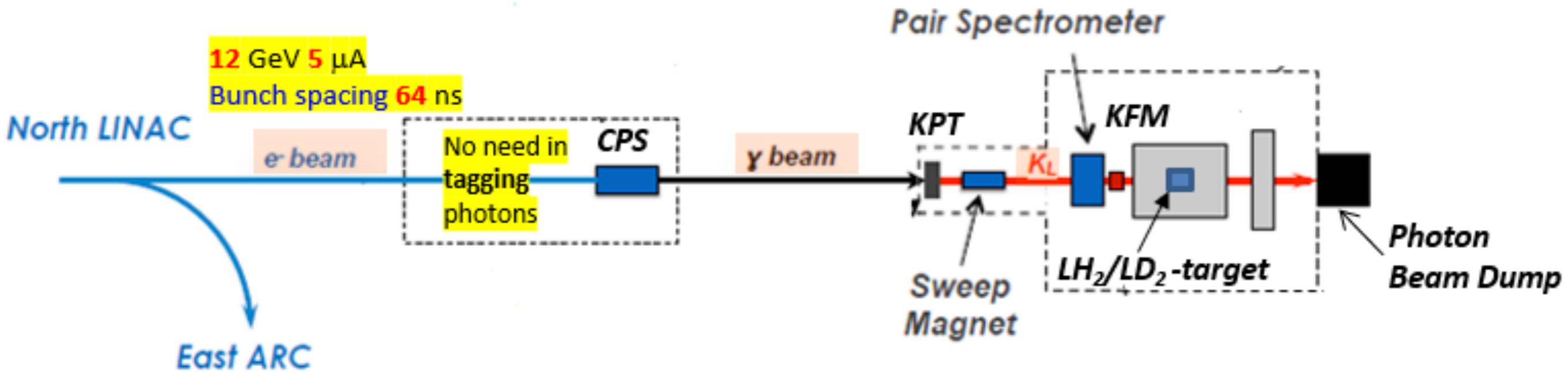
# Kappa Investigation

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
<b>KLF expected errors</b>	<b><math>648 \pm 4 - i 280 \pm 8</math></b>	<b>As previous line but with KLF expected errors</b>

# 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

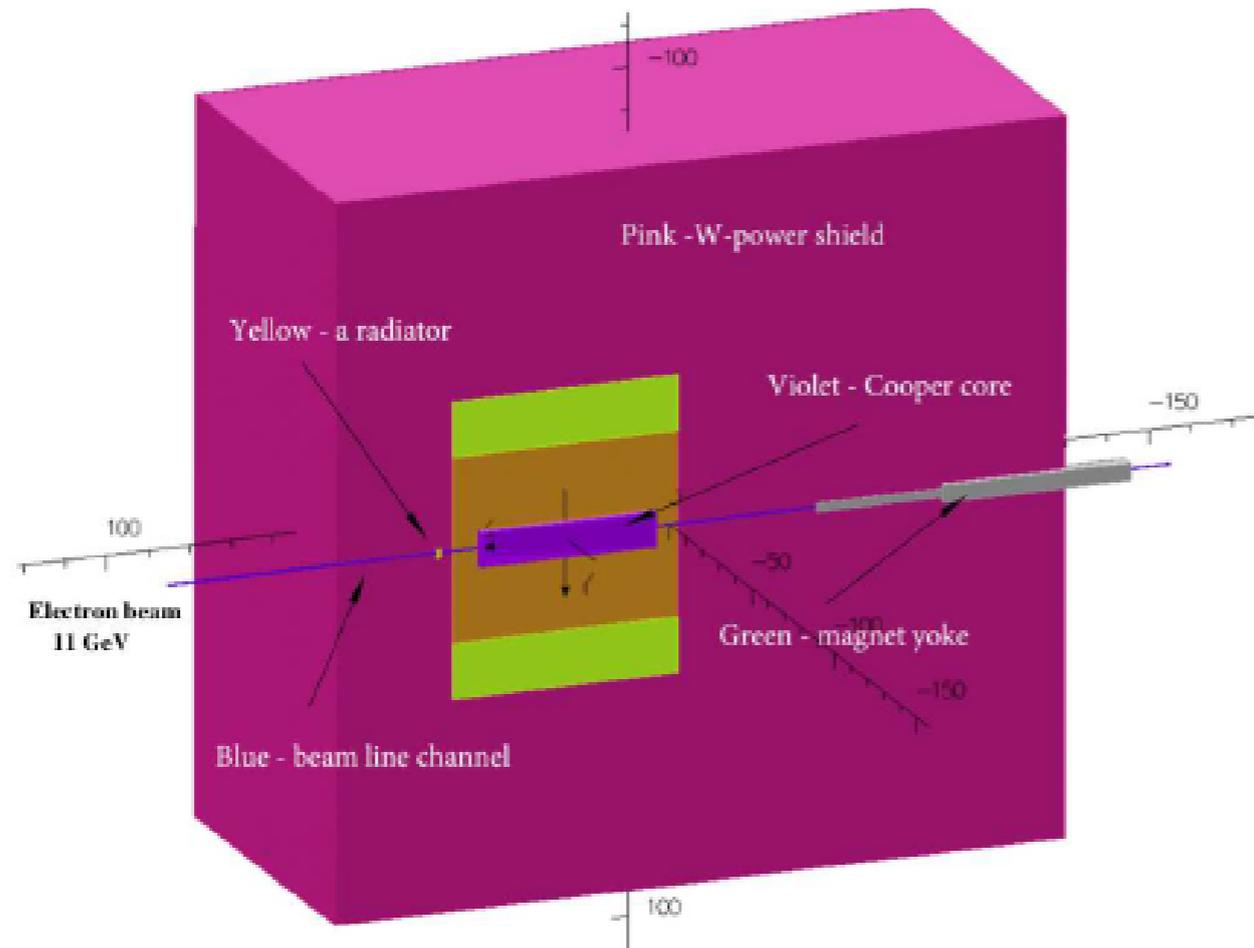
$$E_e = 12 \text{ GeV} \quad I = 5 \mu\text{A}$$
$$\text{Bunch spacing} \quad 64 \text{ ns}$$

*No major problems.*

**Doable !**

**Confirmed by accelerator experts (Todd Satogata)**

# Compact Photon Source



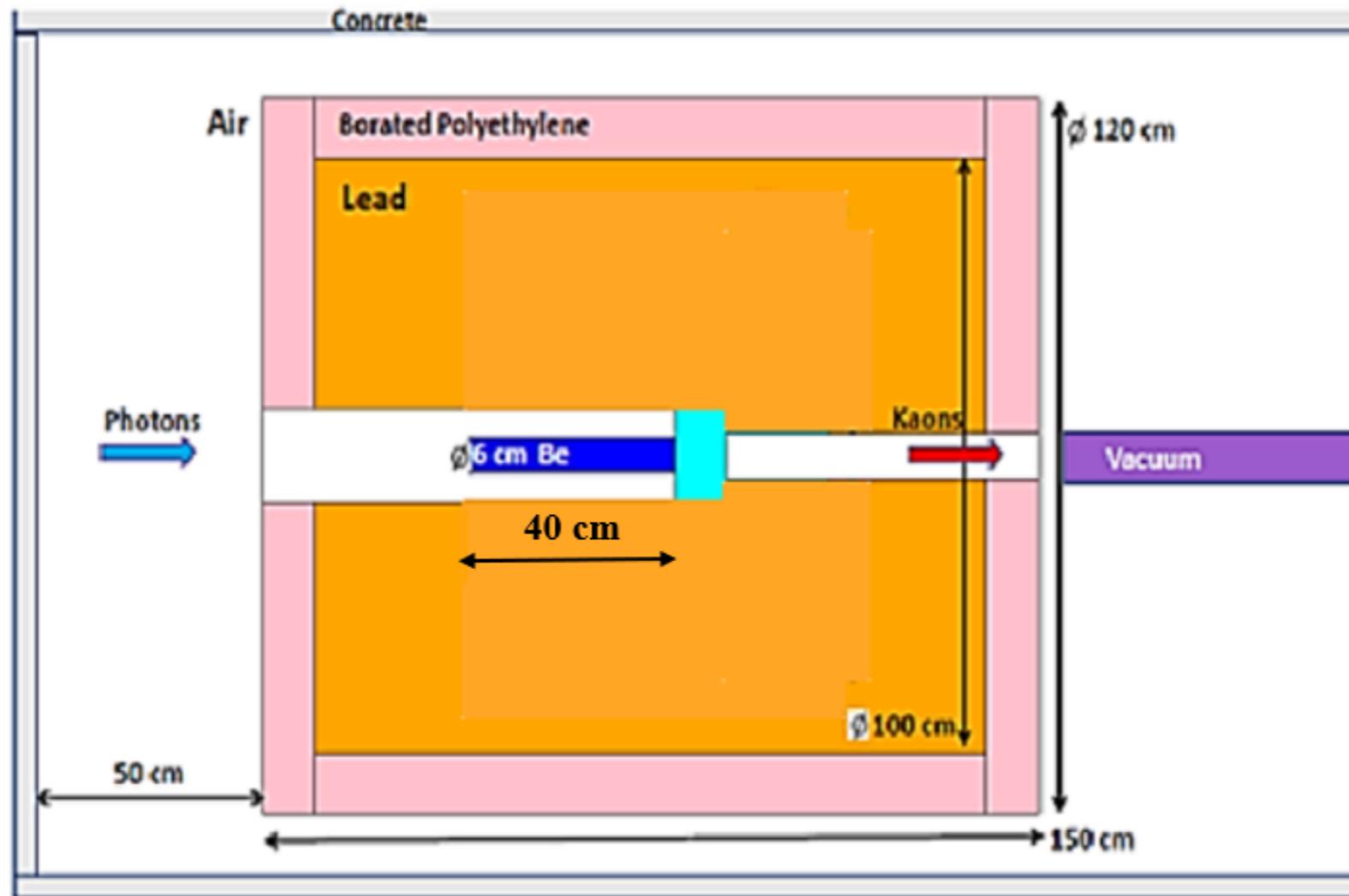
**Conceptual design  
completed for Halls A&C**

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

**Fulfills RadCon Radiation Requirements**

**Paper published in NIM, A957(2020)**

# Be Target Assembly: Conceptual Design



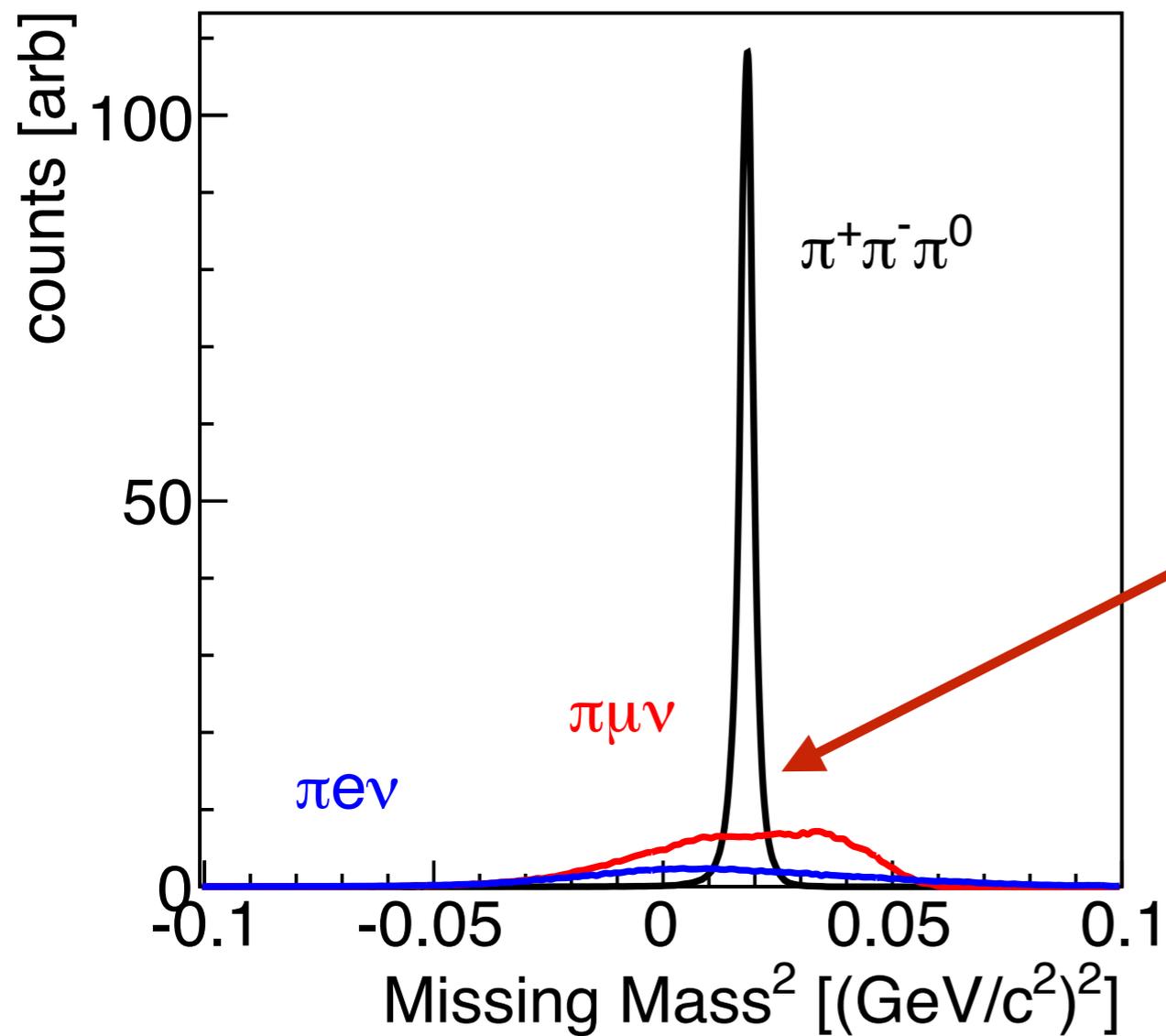
-Meets RadCon Requirements

-Conceptual Design Endorsed by Hall-D Engineering Staff

**arXiv: 2002.04442**



# Reconstructed $K_L$ with FM



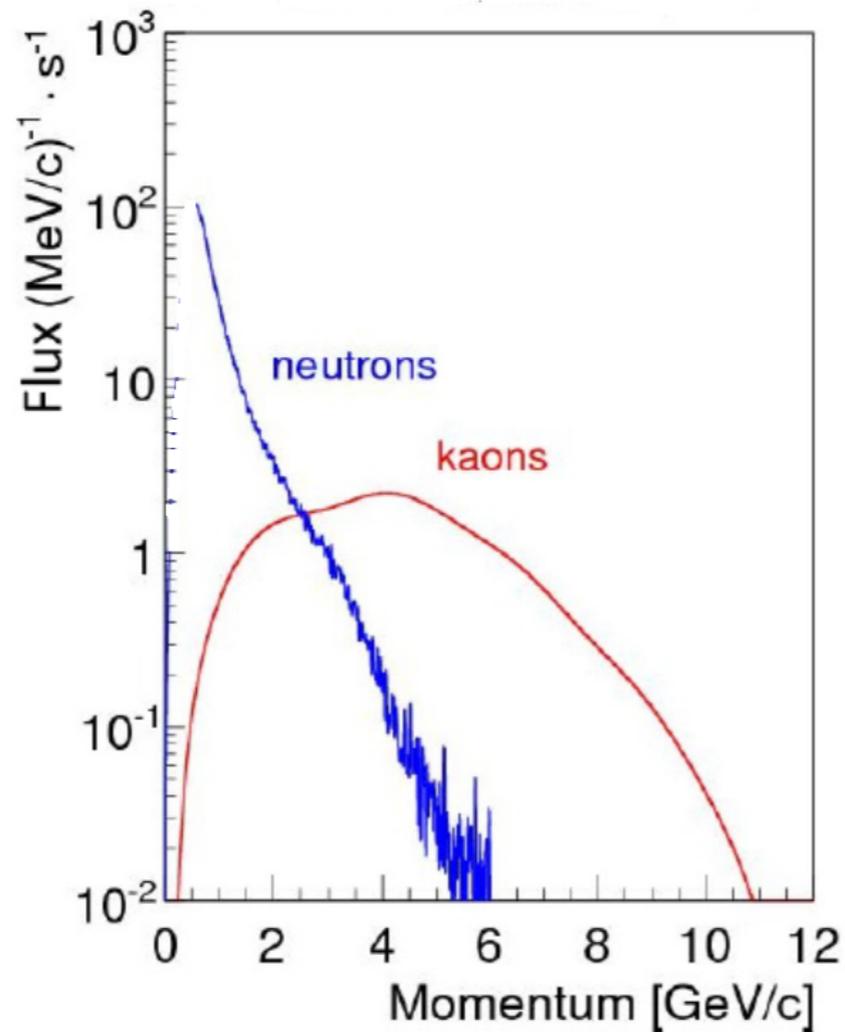
Flux measurement stat. err. <1%

Estimated conservative syst. err. ~5%

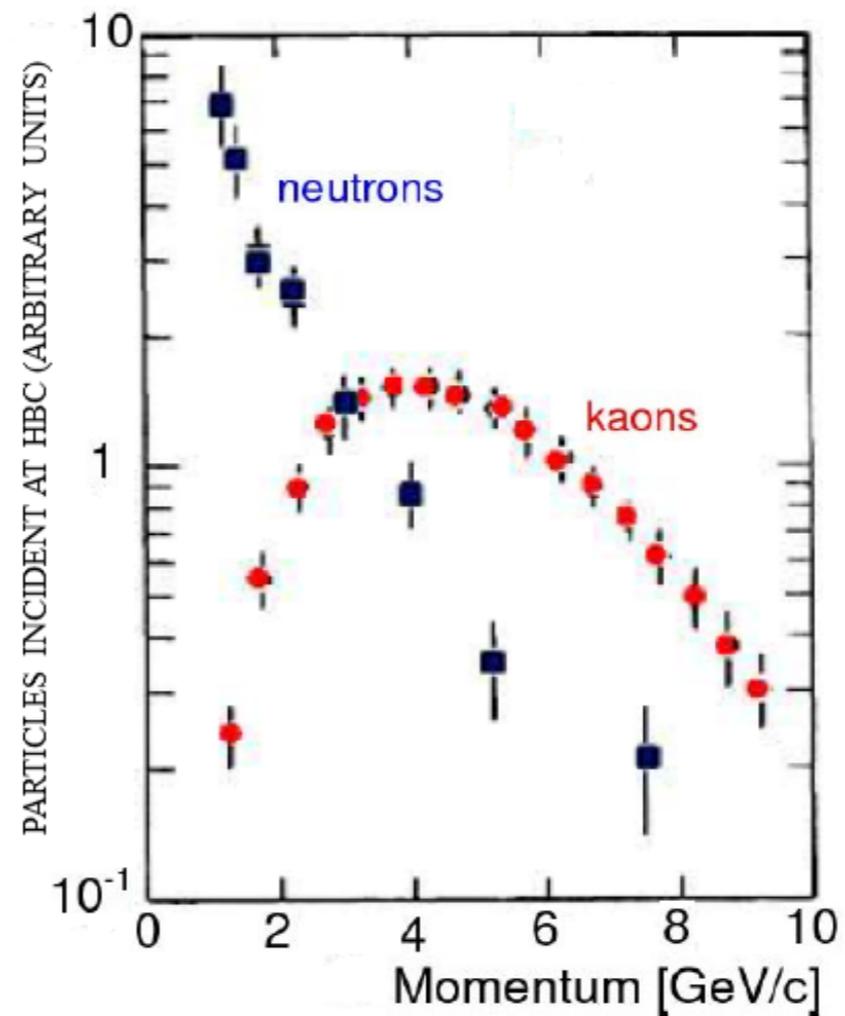
# $K_L$ Beam Flux

JLab 12 GeV

SLAC 16 GeV

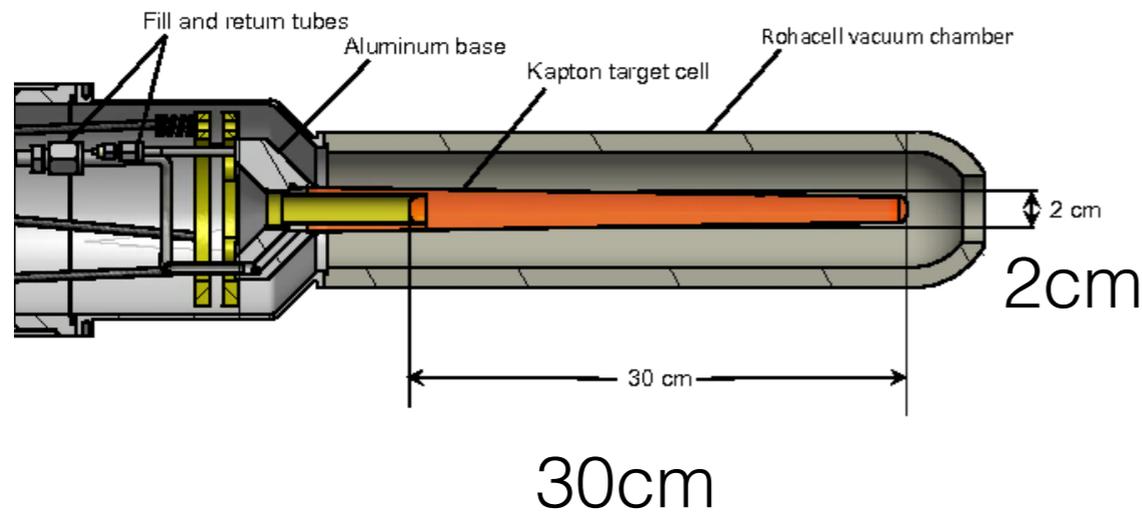


$$N(K_L)/sec \sim 10^4$$

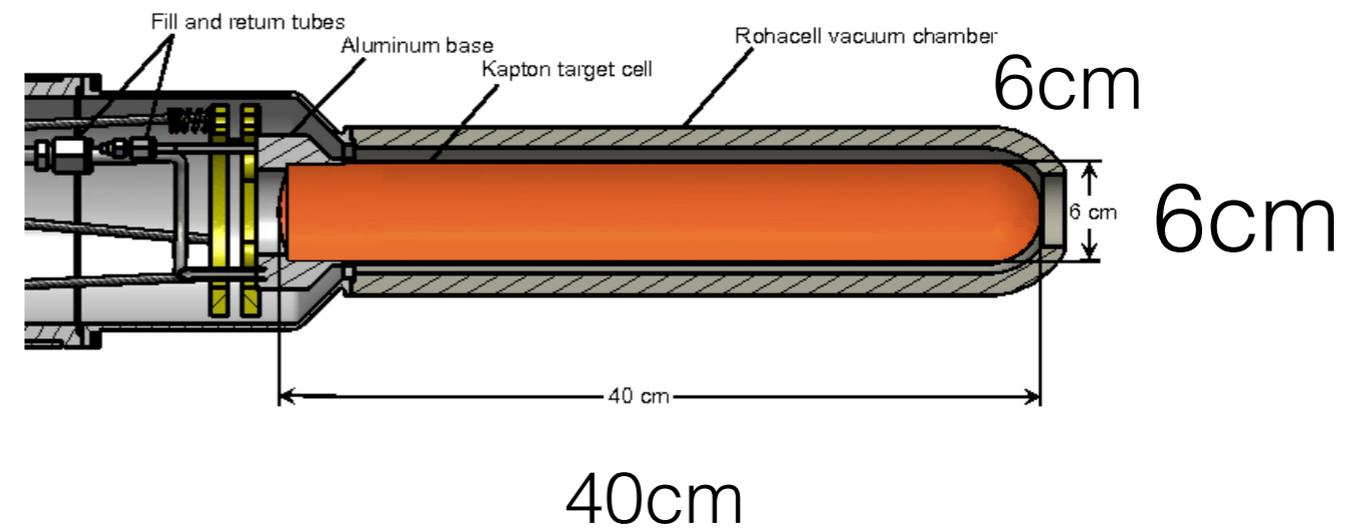


$$\frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

# LH2/LD2 Cryogenic target for K<sub>L</sub> Beam at Hall D



*Current*

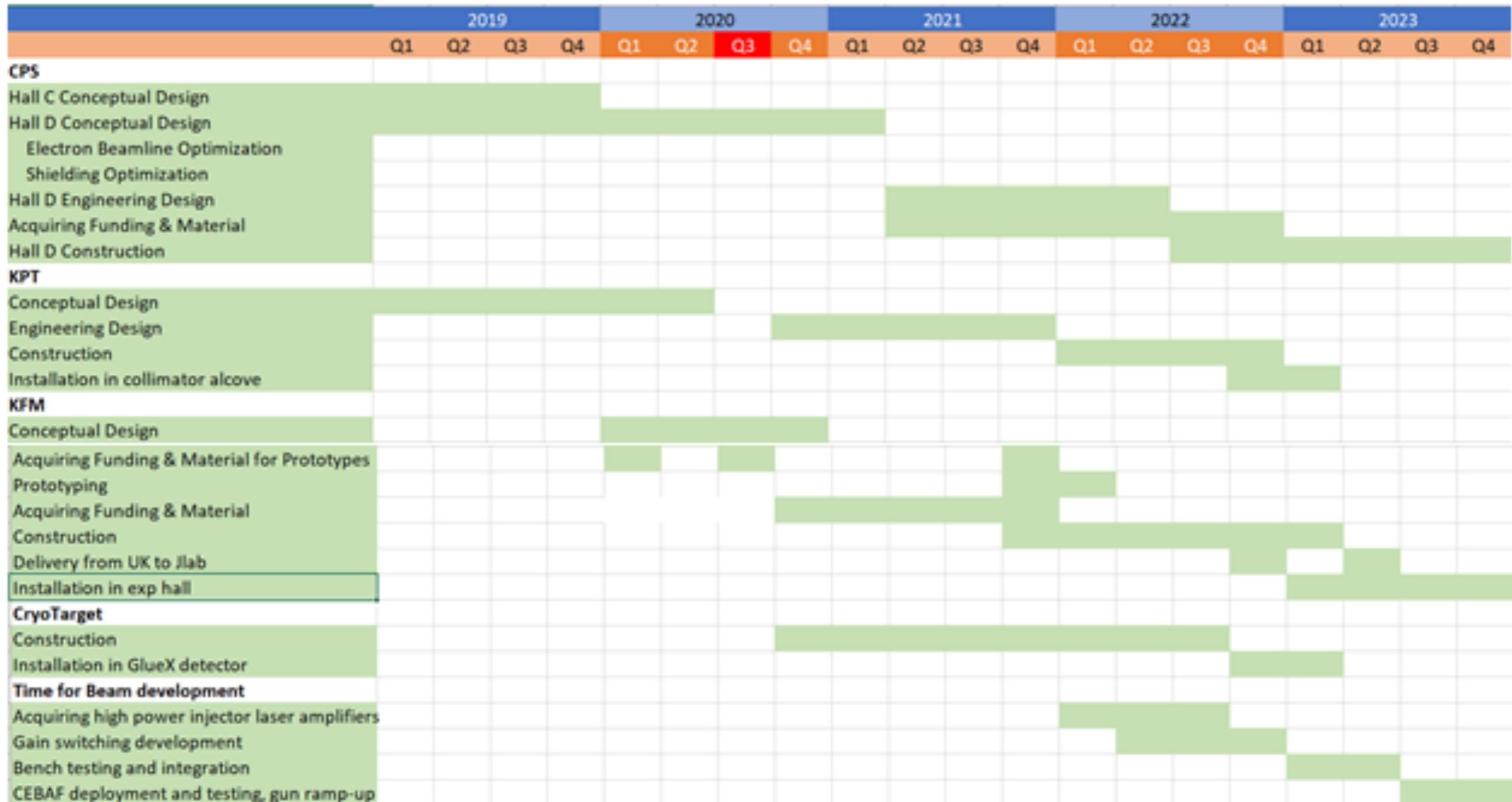


*Proposed & Feasible*

**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 L012-15-001 "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](http://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/](http://WWW.JLAB.ORG/CONFERENCES/YSTAR2016/)

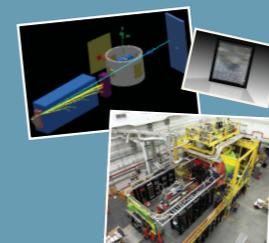


# HIPS 2017

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  $K_L$  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  $K_L$  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



# $\pi$ -K Interactions Workshop

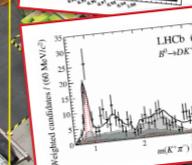
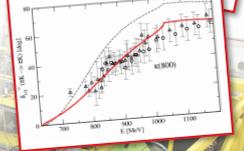
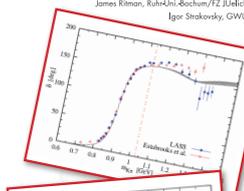
## ORGANIZING COMMITTEE

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  $\pi$ -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  $\pi$ -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  $\pi$ -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  $\pi$ -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



# ***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 !***