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

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(for the K LONG FACILITY *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
- LH_2/LD_2 Target

Summary

Hyperon Spectroscopy

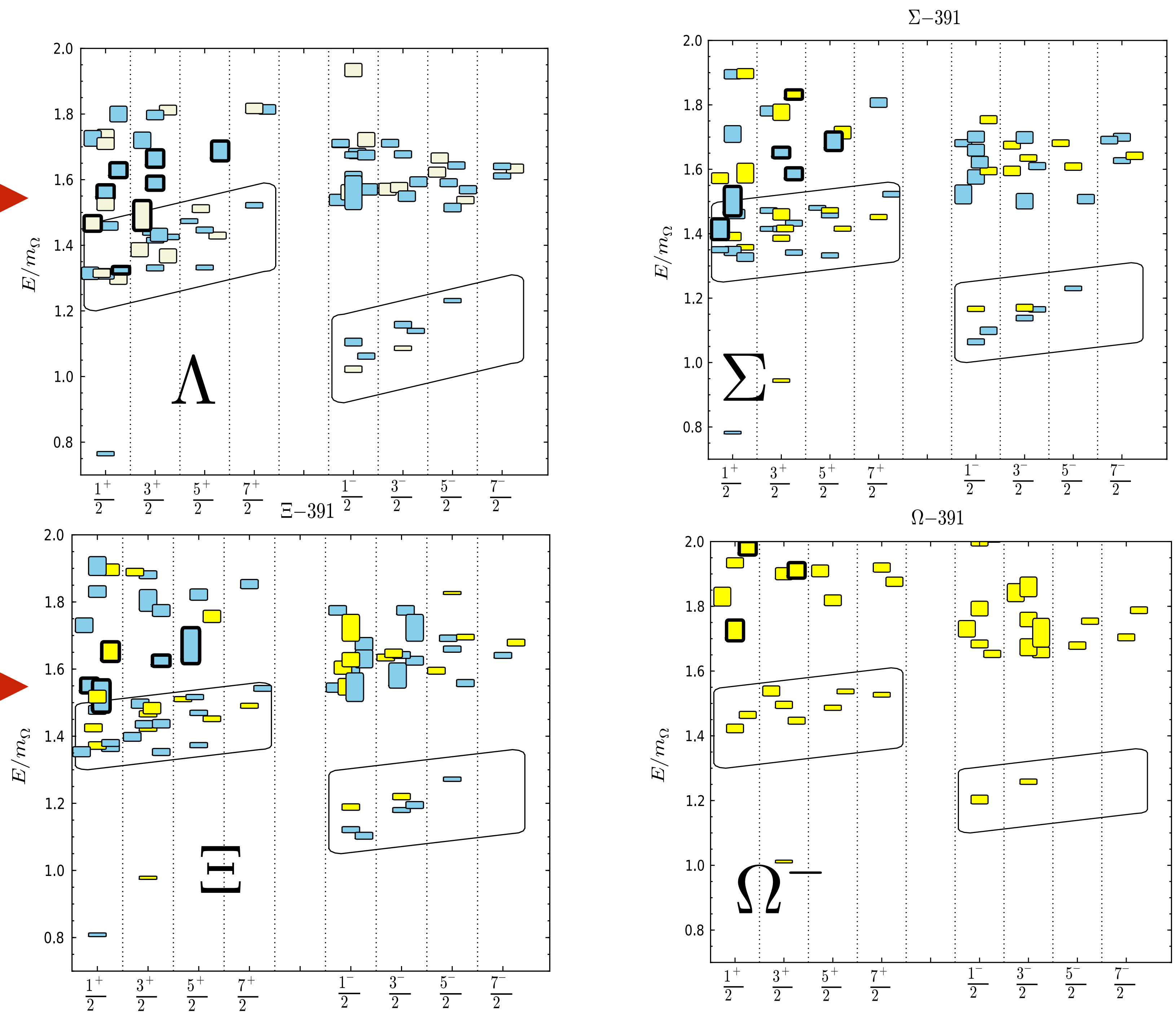
*According to **LQCD** there should be many more states including hybrids (thick bordered)*

8-states
****

5-states
***

3-states
****

4-states
***



6-states
****

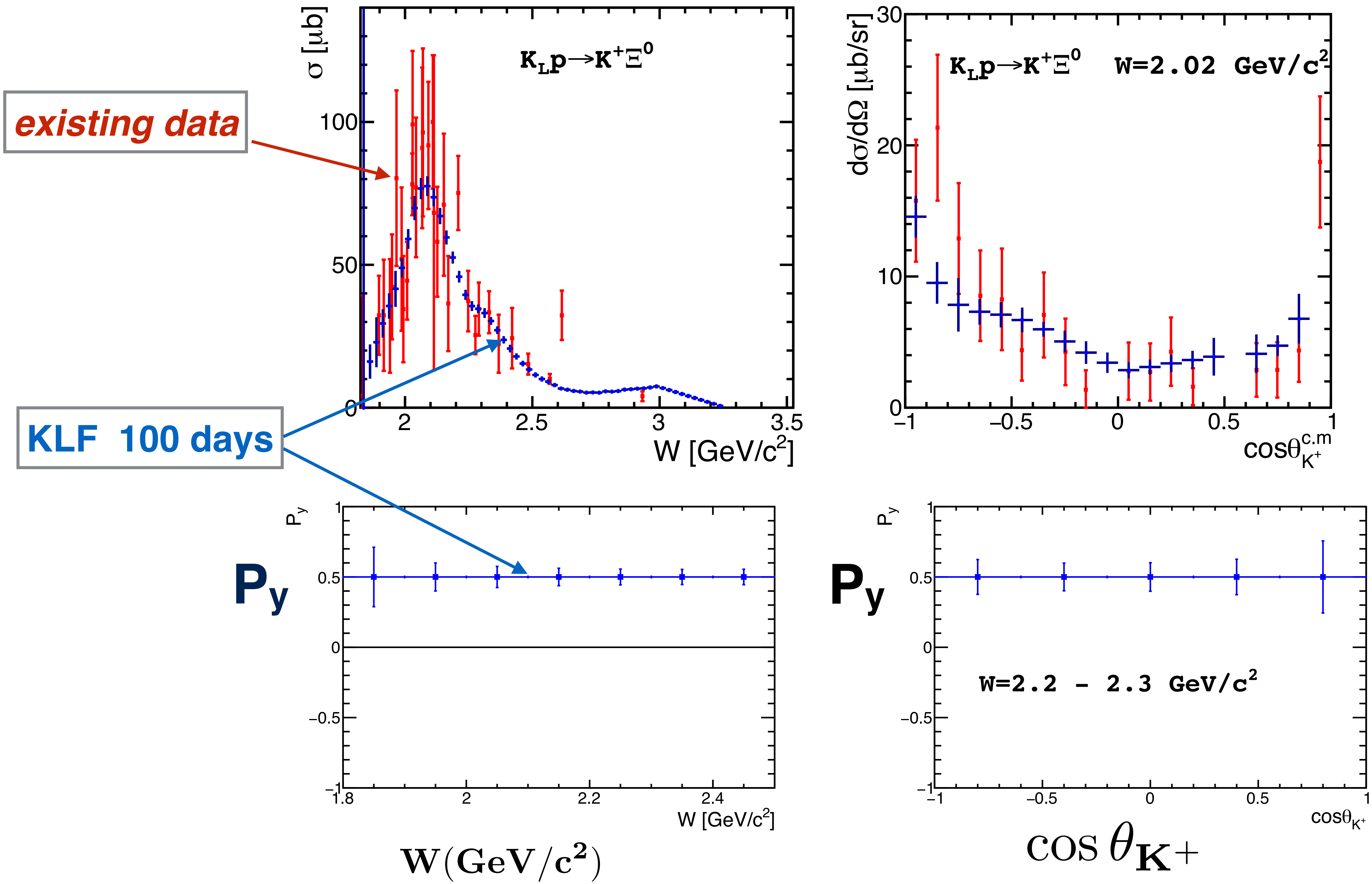
4-states
***

1-state
****

1-state
***

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

Measurements on Proton Target



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**

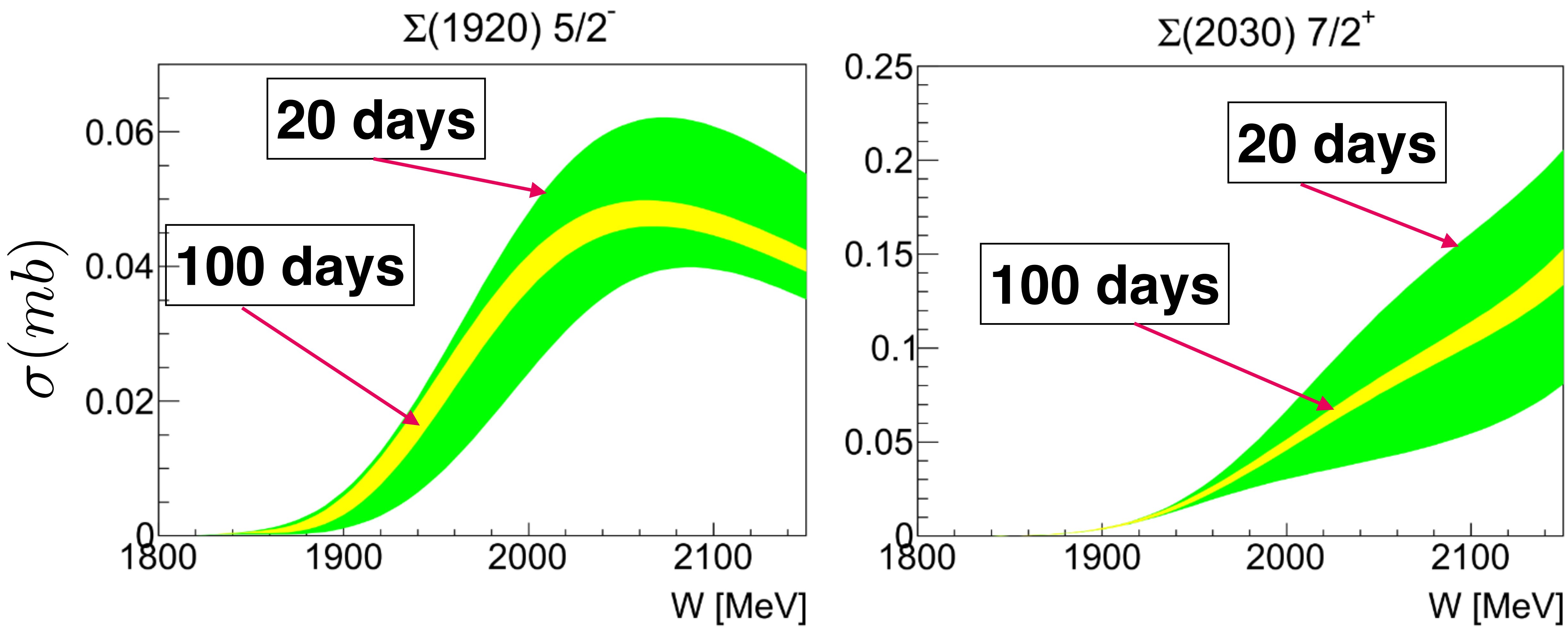
$$\Lambda^*, \Sigma^*, \Xi^* \;\&\; \Omega^*$$

-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

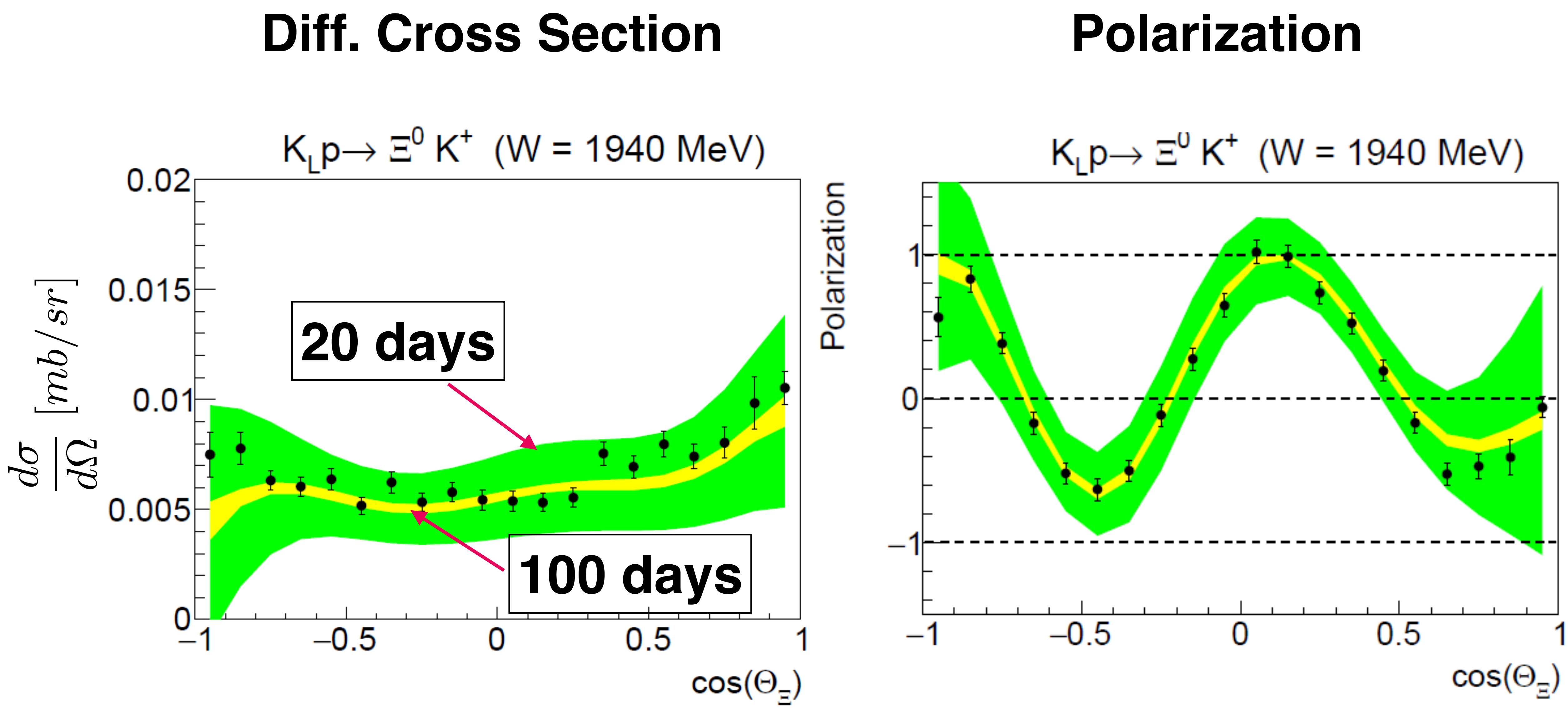
Bonn-Gatchina PWA

Total Cross Section $K_L p \to K^+ \Xi^0$



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

Bonn-Gatchina PWA



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

Numerical Results

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

$$100d\ M = 1.923 \pm 0.010 \pm 0.010\ GeV$$

$$\Gamma = 0.321 \pm 0.01 \pm 0.010\ GeV$$

$$20d\ M = 1.977 \pm 0.021 \pm 0.025\ GeV$$

$$\Gamma = 0.327 \pm 0.025 \pm 0.025\ GeV$$

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

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

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

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

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

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

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

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

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

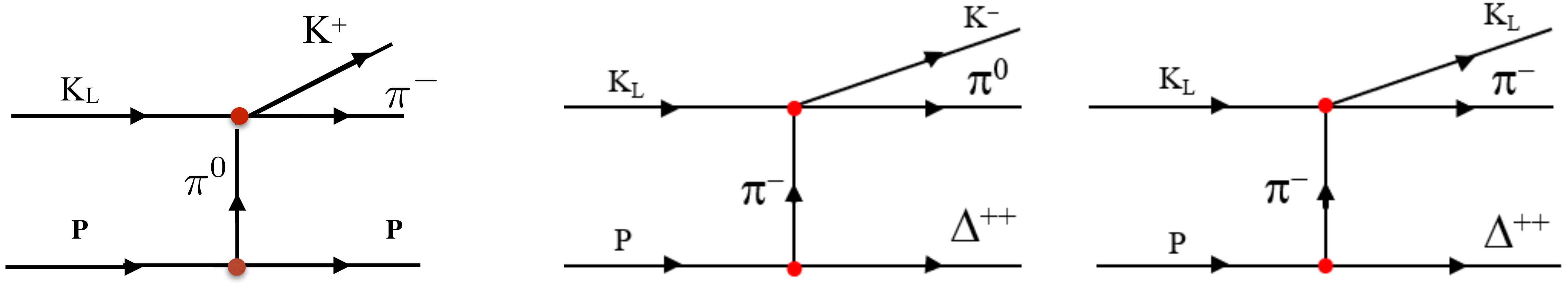
$$K_L n \to K_{(L,S)}\pi^{\pm}\Delta^{\mp} = \langle K_L\pi^{\pm} | K_L\pi^{\pm}\rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

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

Simulated for KLF

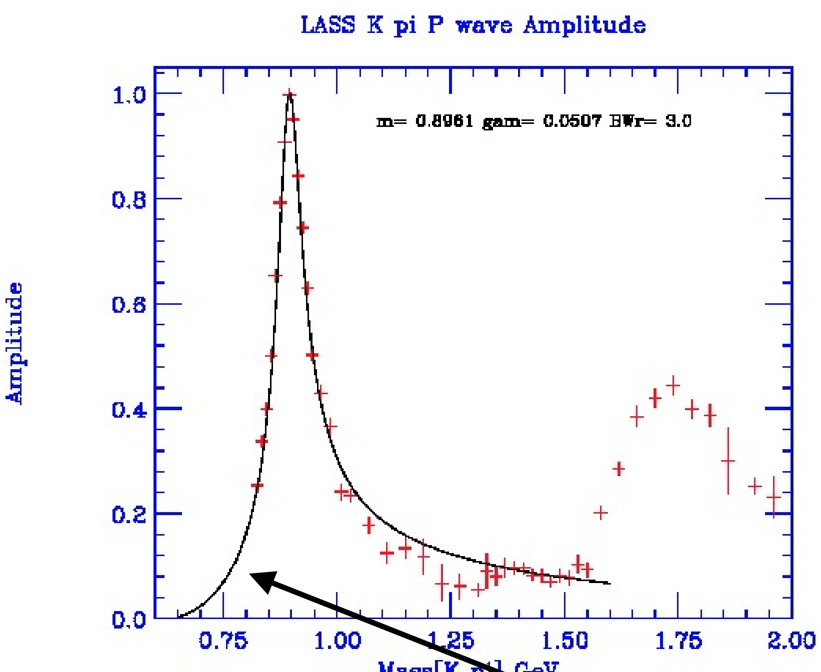
Strange Meson Spectroscopy

Scattering

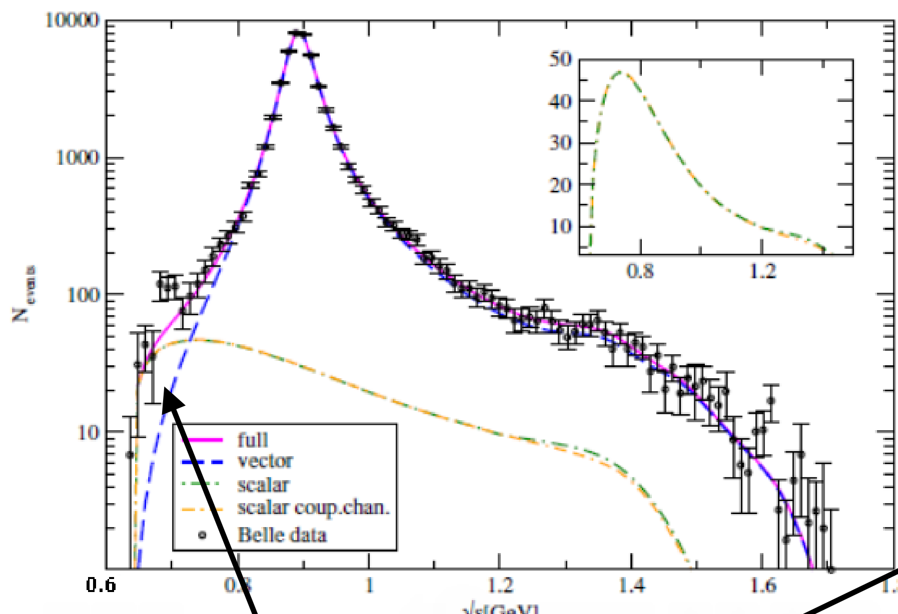


Proposed Measurements

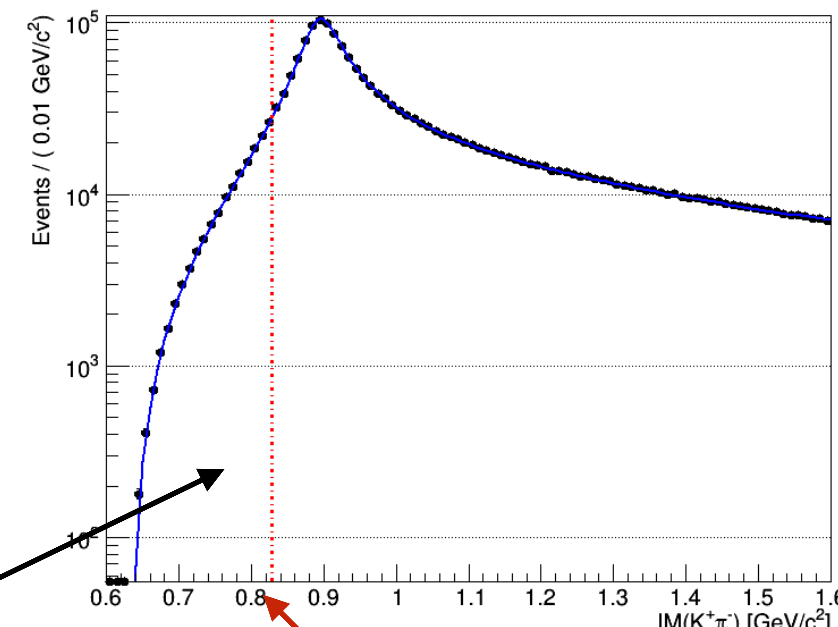
SLAC	Belle	KLF
$K^-\pi^+ \to K^-\pi^+$	$\tau \to K\pi\nu_\tau$	$K_L\pi^0 \to K^+\pi^-$



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



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



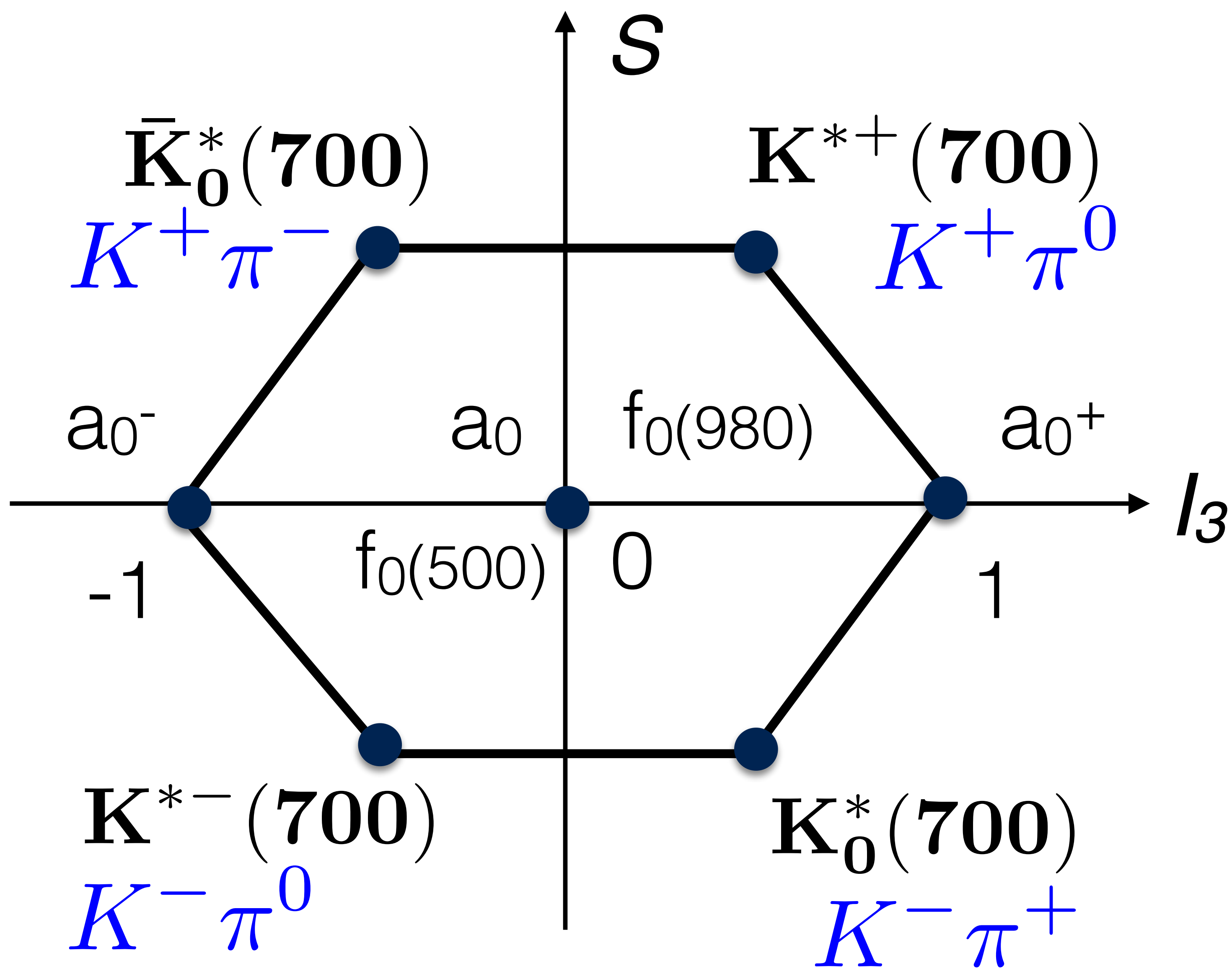
$\mathbf{M(K\pi)(GeV)}$

region of $\kappa(800)$

SLAC Lower limit

Scalar Meson Nonet

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

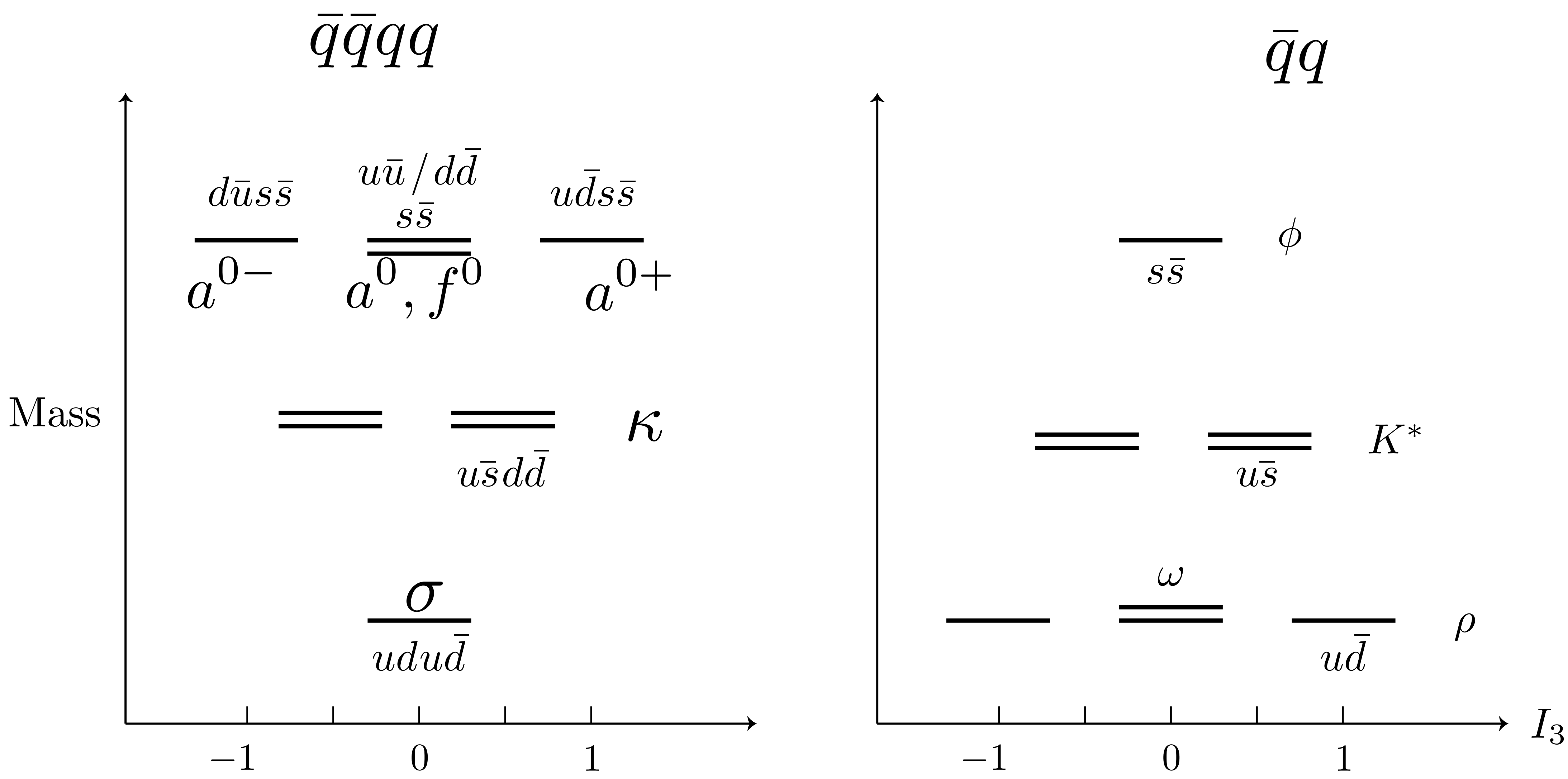


Four states called κ

Still need further confirmation (PDG2020)

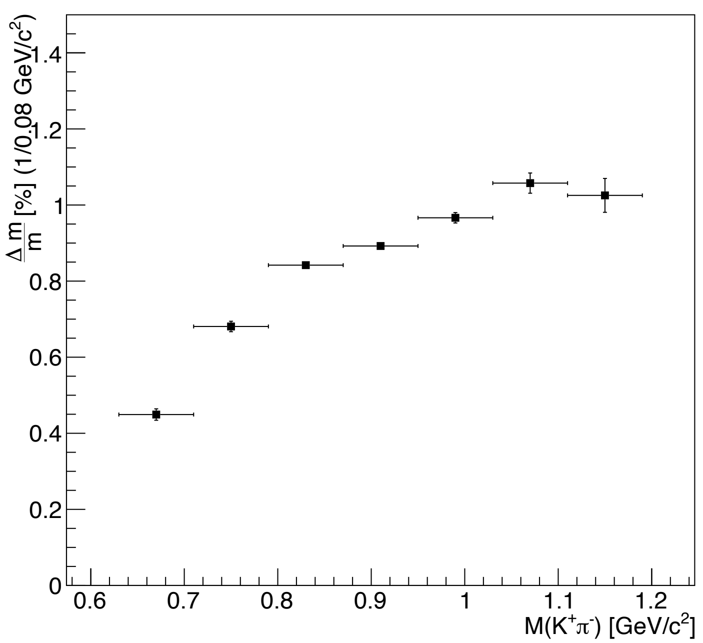
KLF allows measurement of all four states

Inverted mass hierarchy tetraquarks **ordinary meson states**

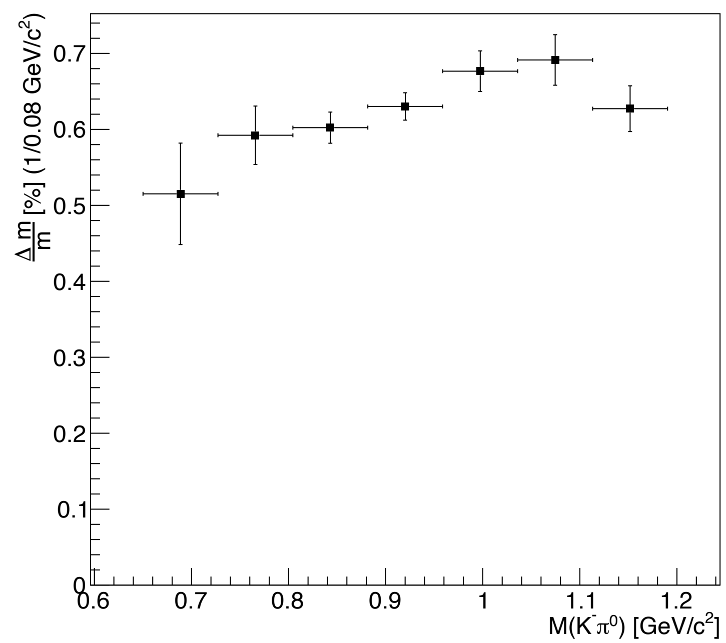


R. Jaffe, PRD 15, 267 (1977).

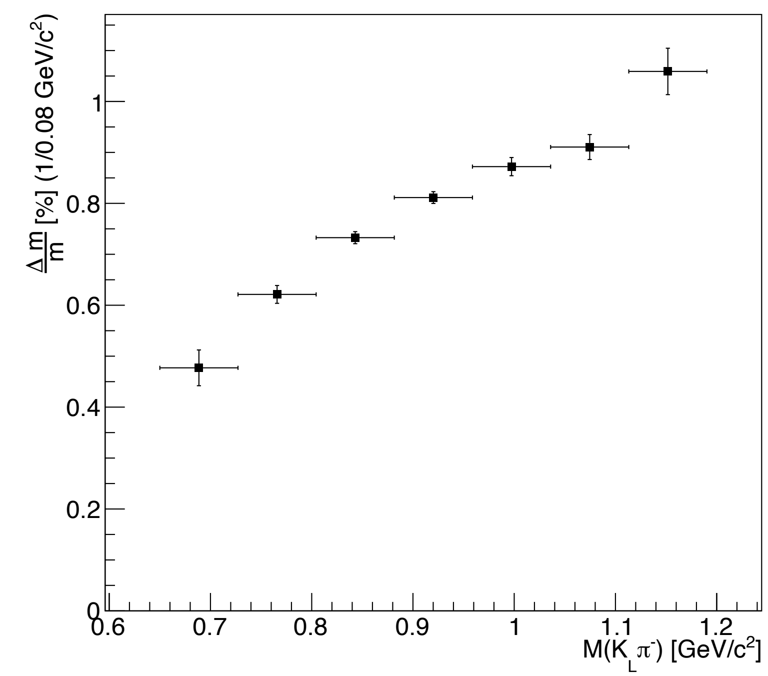
Invariant mass resolution



$K^+\pi^-$



$K^-\pi^0$



$K_L\pi^-$

Below 1% in all three simulated cases

Projected Measurements

I=3/2+1/2 S-wave

Presented at PAC47

SLAC Data

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

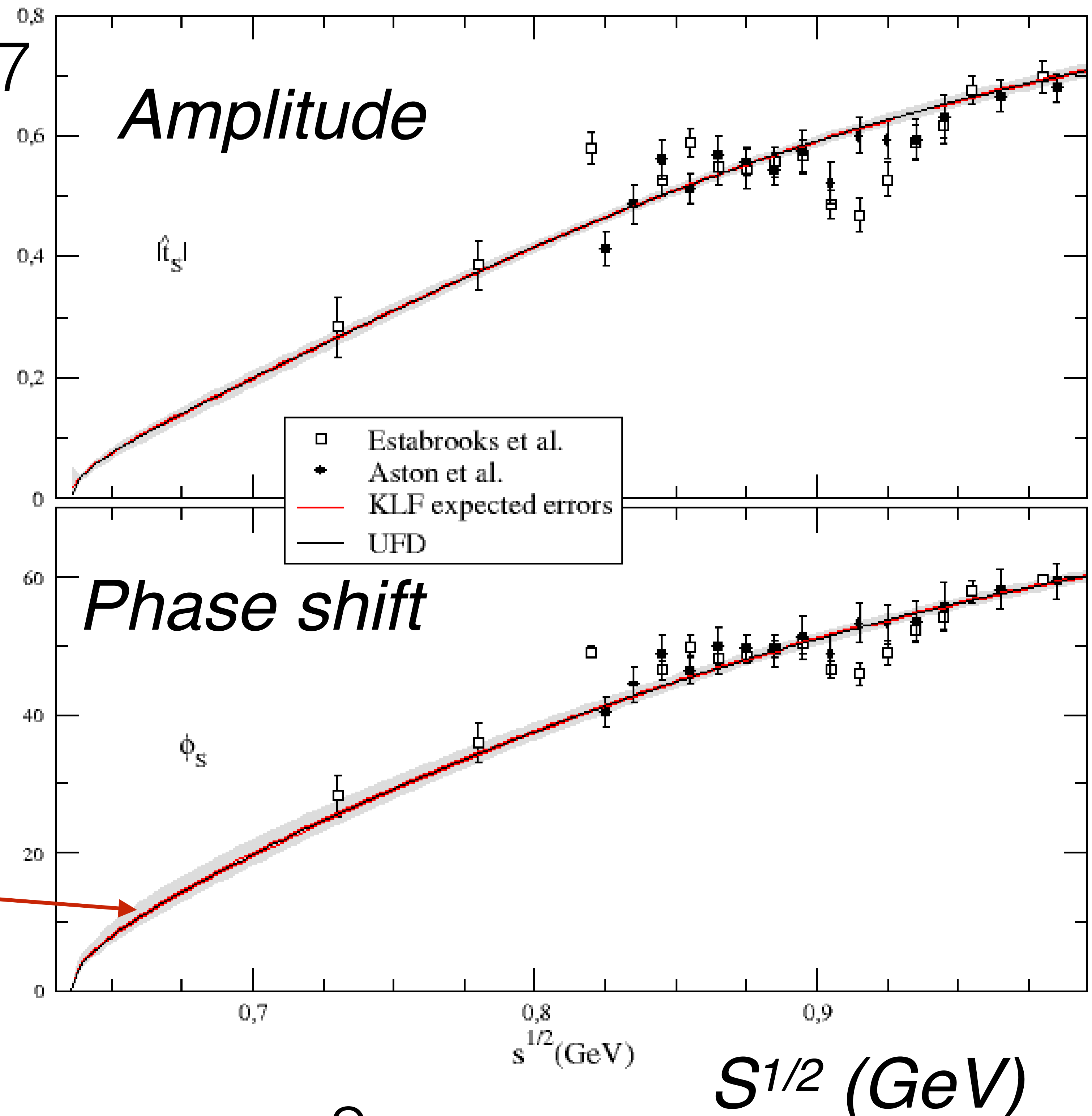
$$K^{\pm}p \rightarrow K^{\pm}\pi^{-}\Delta^{++}$$

Estabrooks(1978)

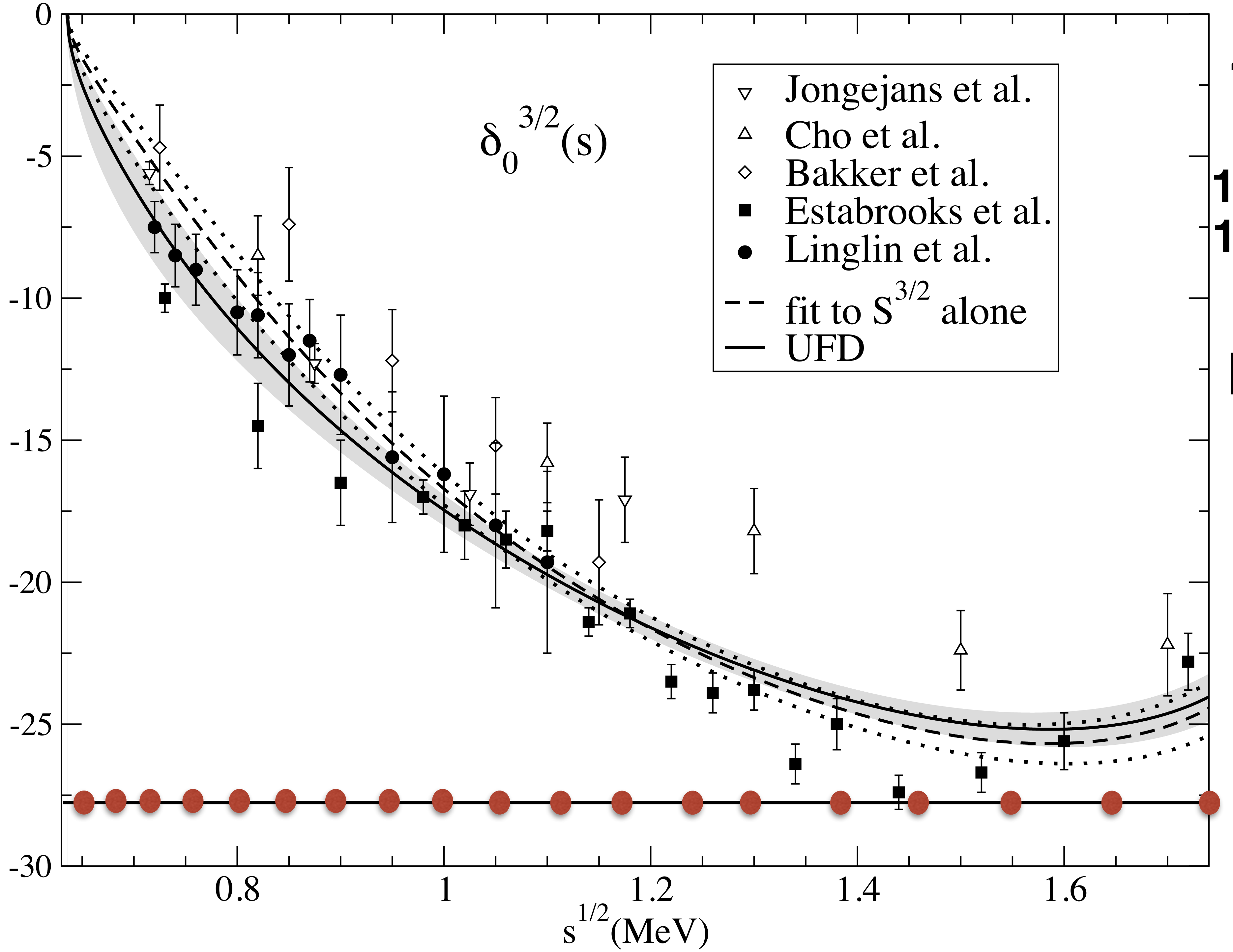
$$K^{-}p \rightarrow K^{-}\pi^{+}n$$

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)

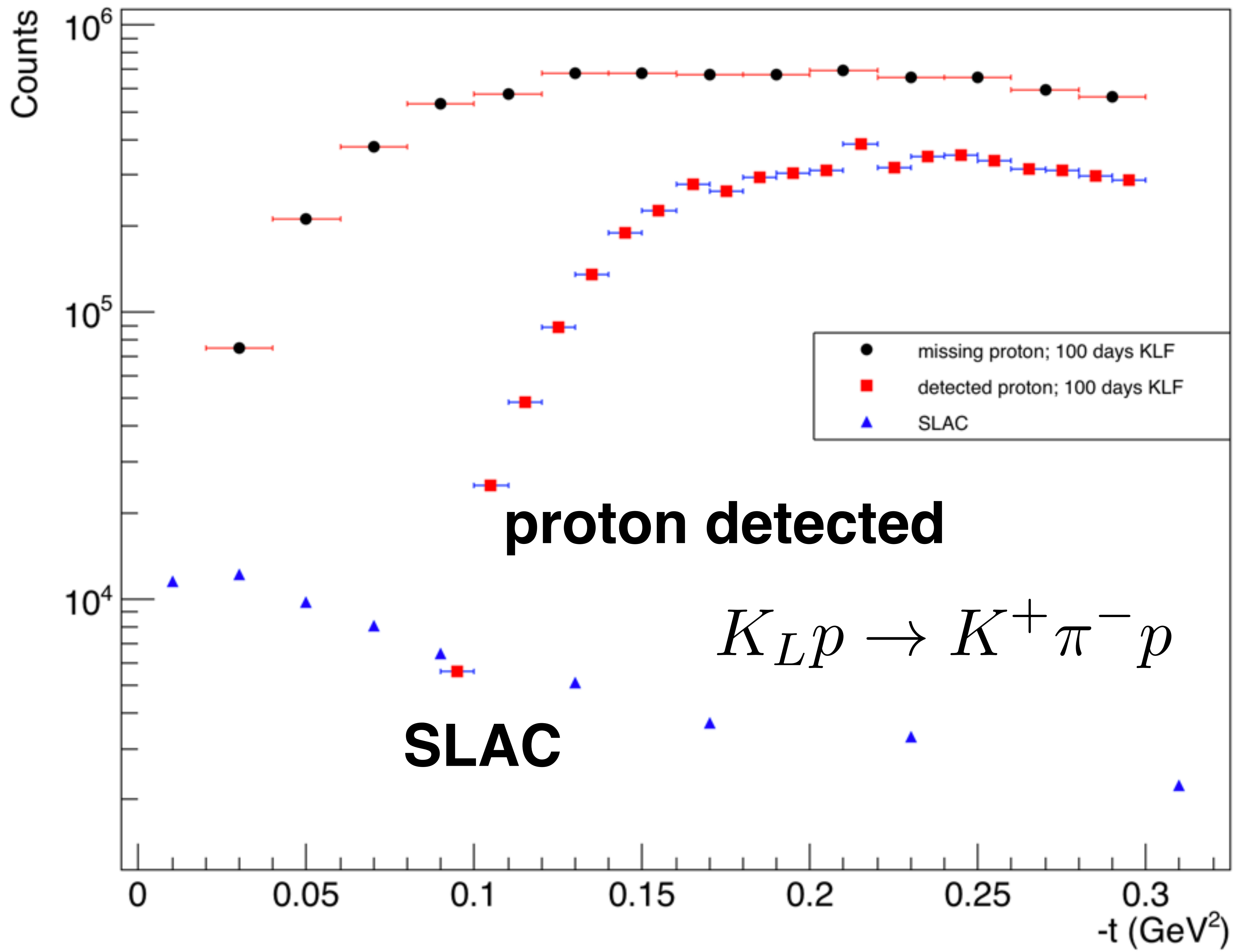
$$K^{\pm}p \to K^{\pm}\pi^{+}n$$

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

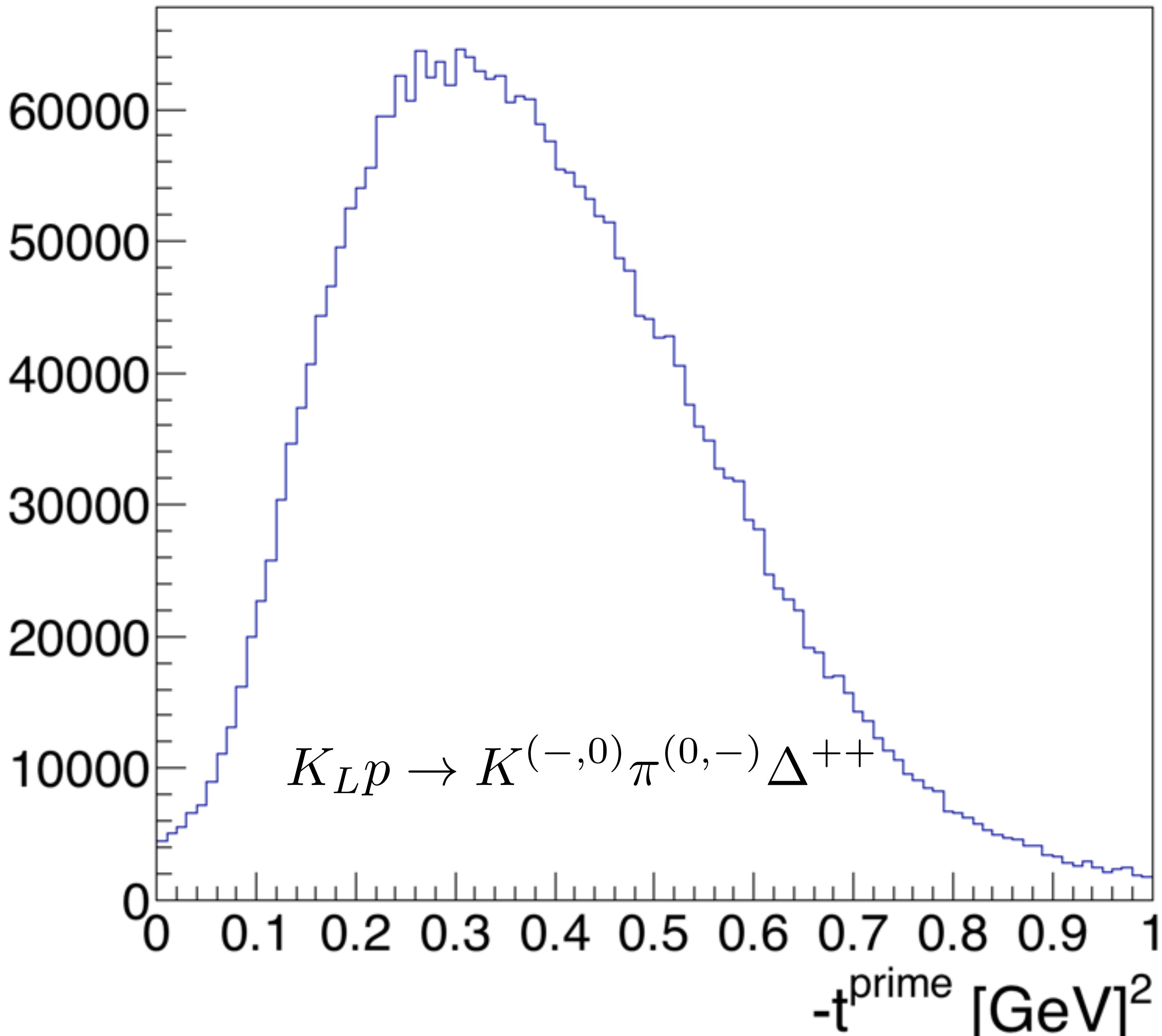
KLF 100 days (scaled)

From Pelaez and Rodas paper: PRD93(2016)

Projected Statistics

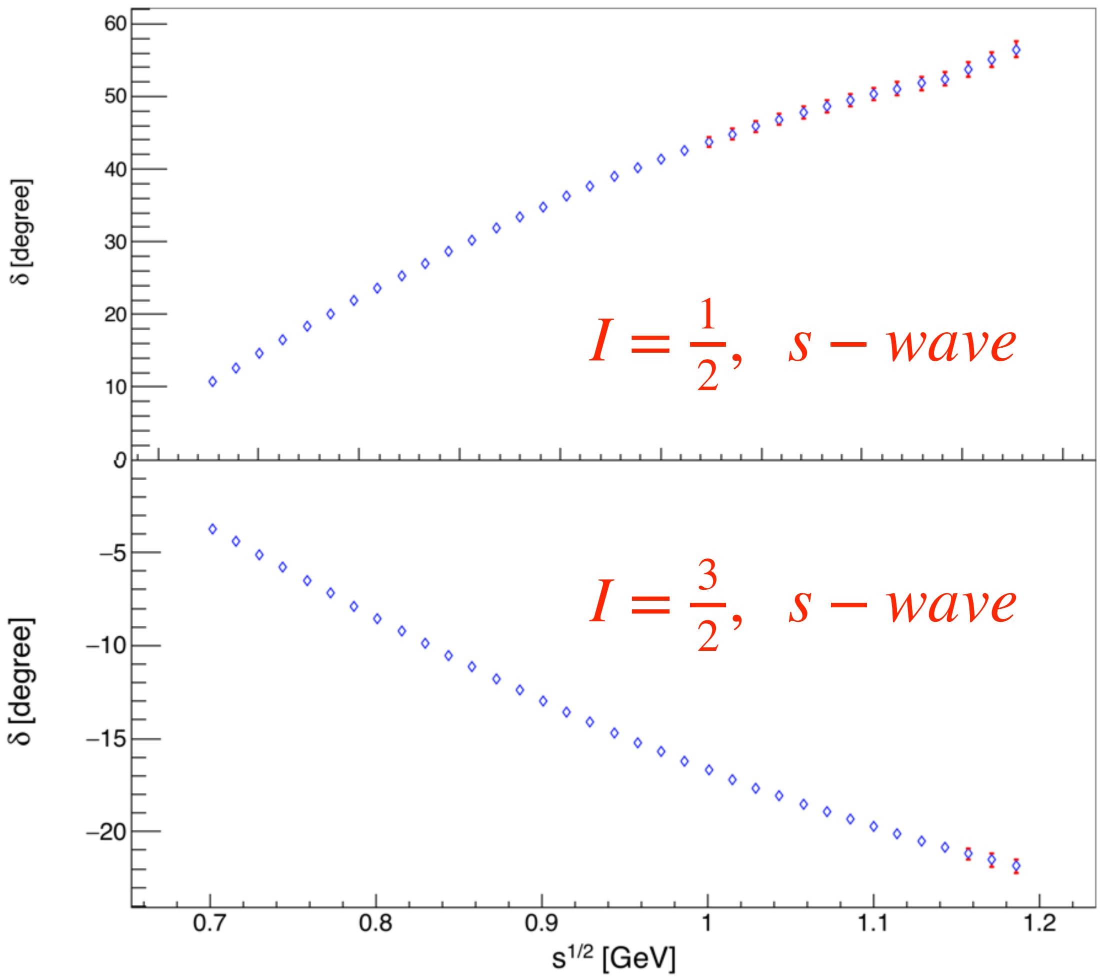


Distribution of four-momentum

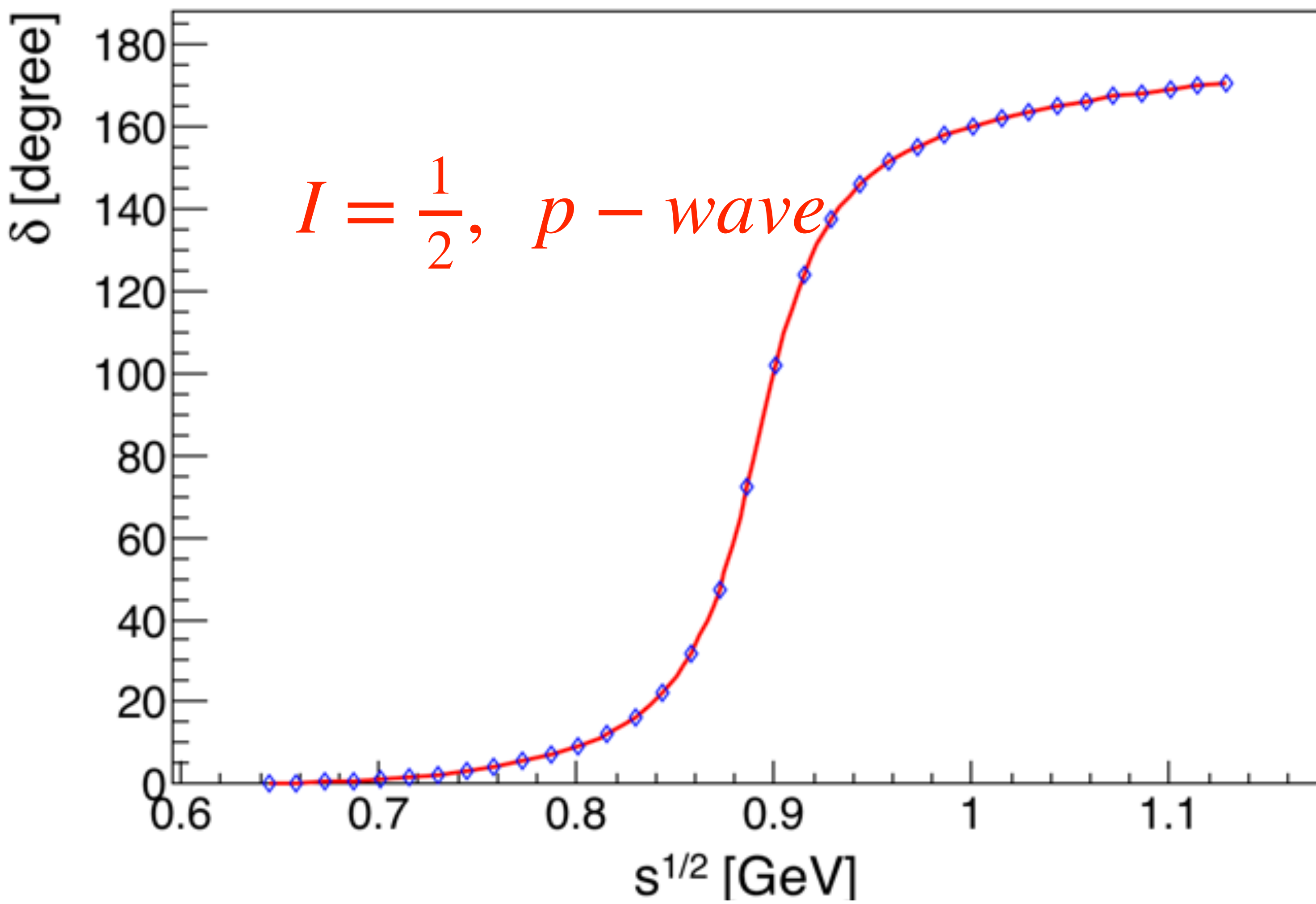


$t' = t - t_{min}$

Phase Shift

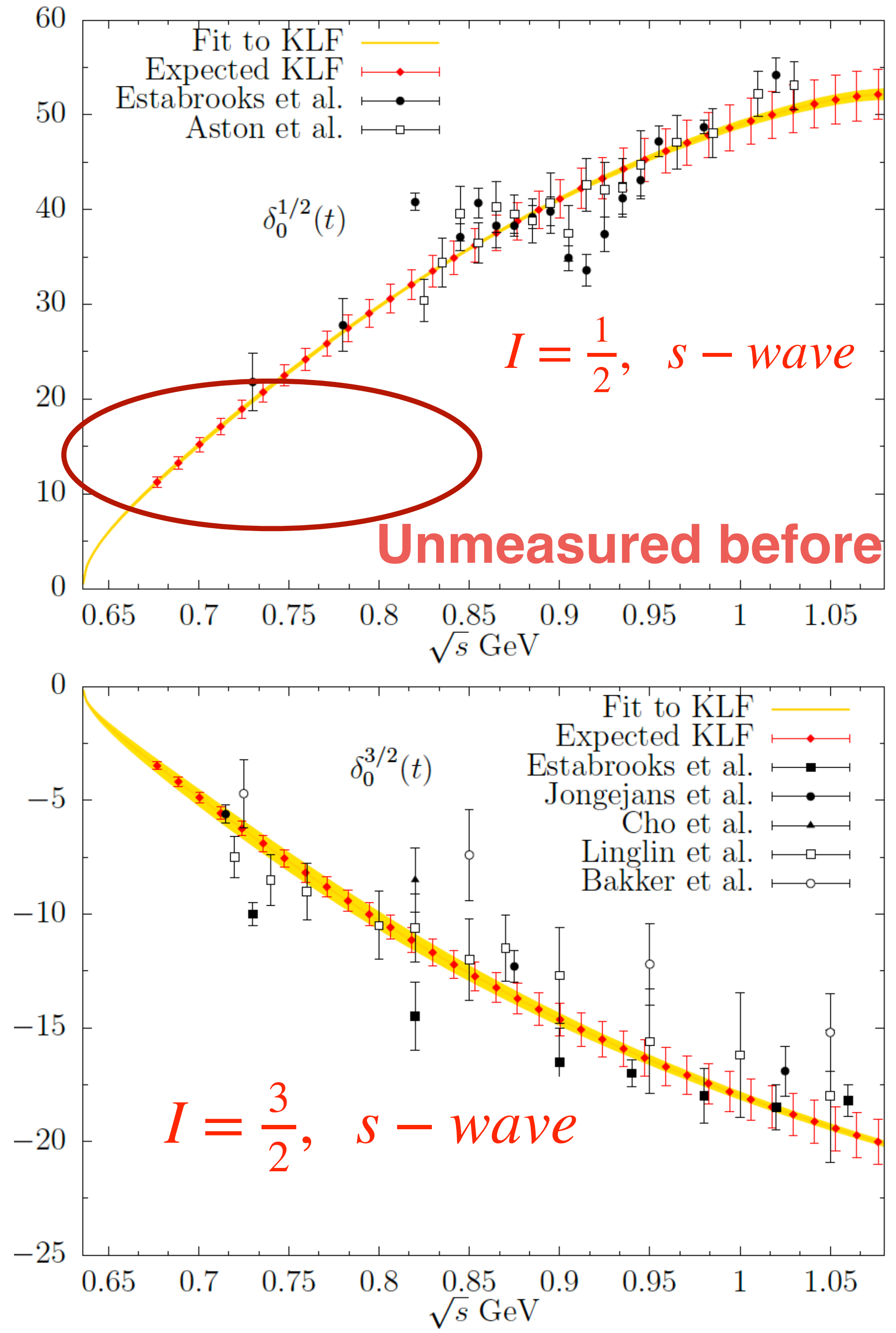


$I = \frac{1}{2}, \quad s - wave$
$I = \frac{3}{2}, \quad s - wave$
δ [degree]
δ [degree]
s^1/2 [GeV]

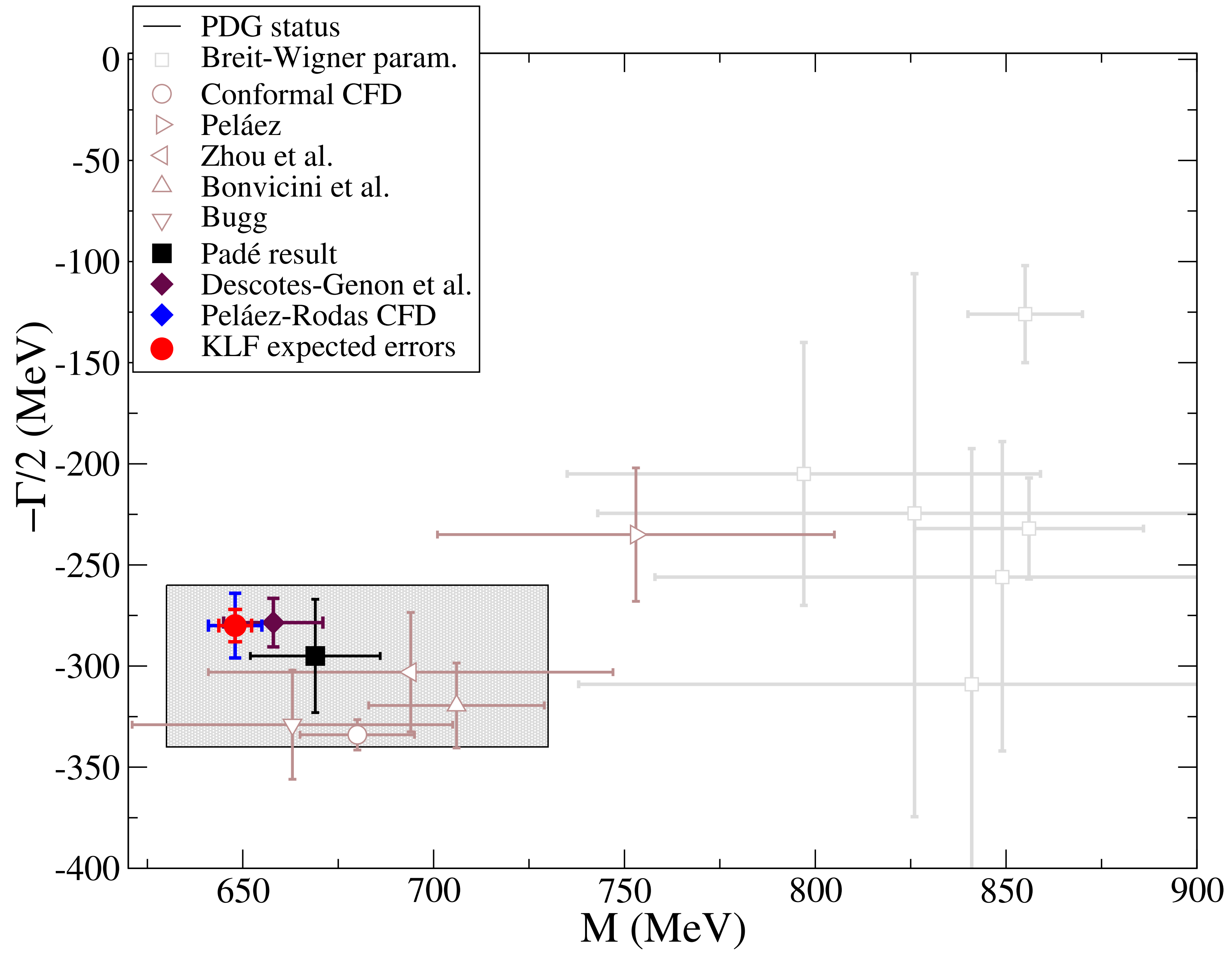


$I = \frac{1}{2}, \quad p - wave$
δ [degree]
s^1/2 [GeV]

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±24.6-i 319.4±22.4	T-matrix pole model from CLEO
Bugg [83]	663±42-i 342±60	Model with LO Chiral symmetry
Peláez [84]	753±52-i 235±33	Unitarized ChPT up to NLO
Conformal CFD [79]	680±15-i 334±8	Conformal parameterization from dispersive fit
Padé [85]	670±18-i 295±28	Analytic local extraction from dispersive fit
Zhou *et al.* [71]	694±53-i 303±30	partial-wave dispersion relation. Cutoff on left cut.
Descotes-Genon *et al.* [11]	658±13-i 279±12	Roy-Steiner prediction. No S-wave data used below 1 GeV.
Pelaez-Rodas HDR [23, 80, 81]	648±7-i 280±16	Roy-Steiner analysis of scattering data
KLF expected errors	**648±4-i 280±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

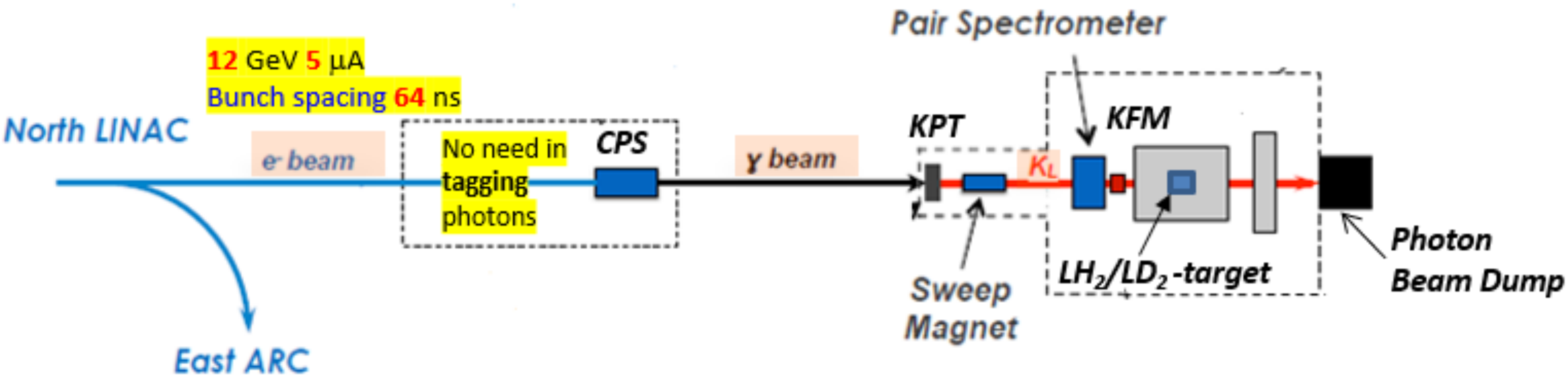
-KLF will help resolve conflicting results for heavy K's parameters*

-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

$E_e = 12\ GeV$ $\qquad I = 5\ \mu A$

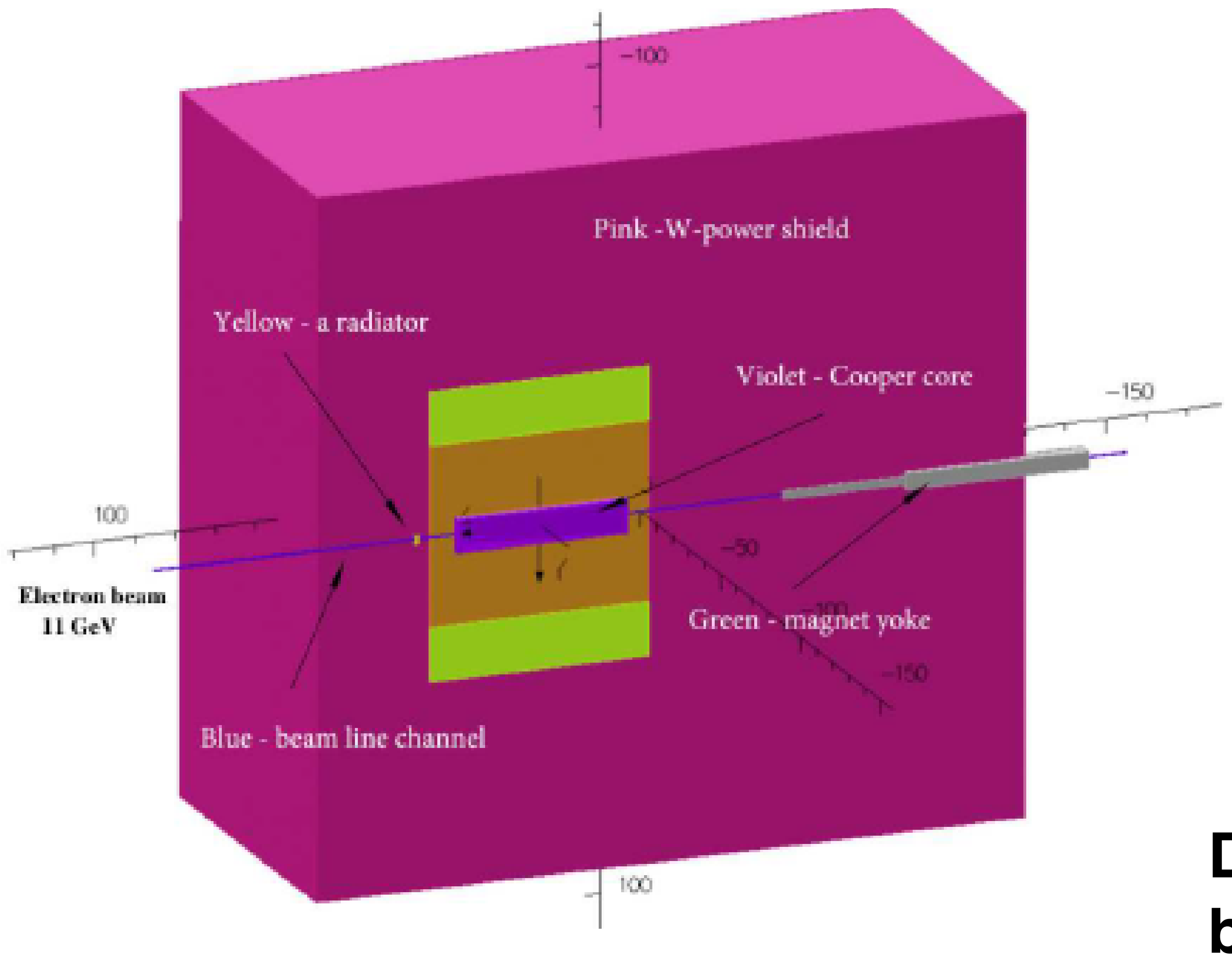
Bunch spacing $\qquad 64\ ns$

No major problems.

Doable !

Confirmed by accelerator experts (Todd Satogata)

Compact Photon Source



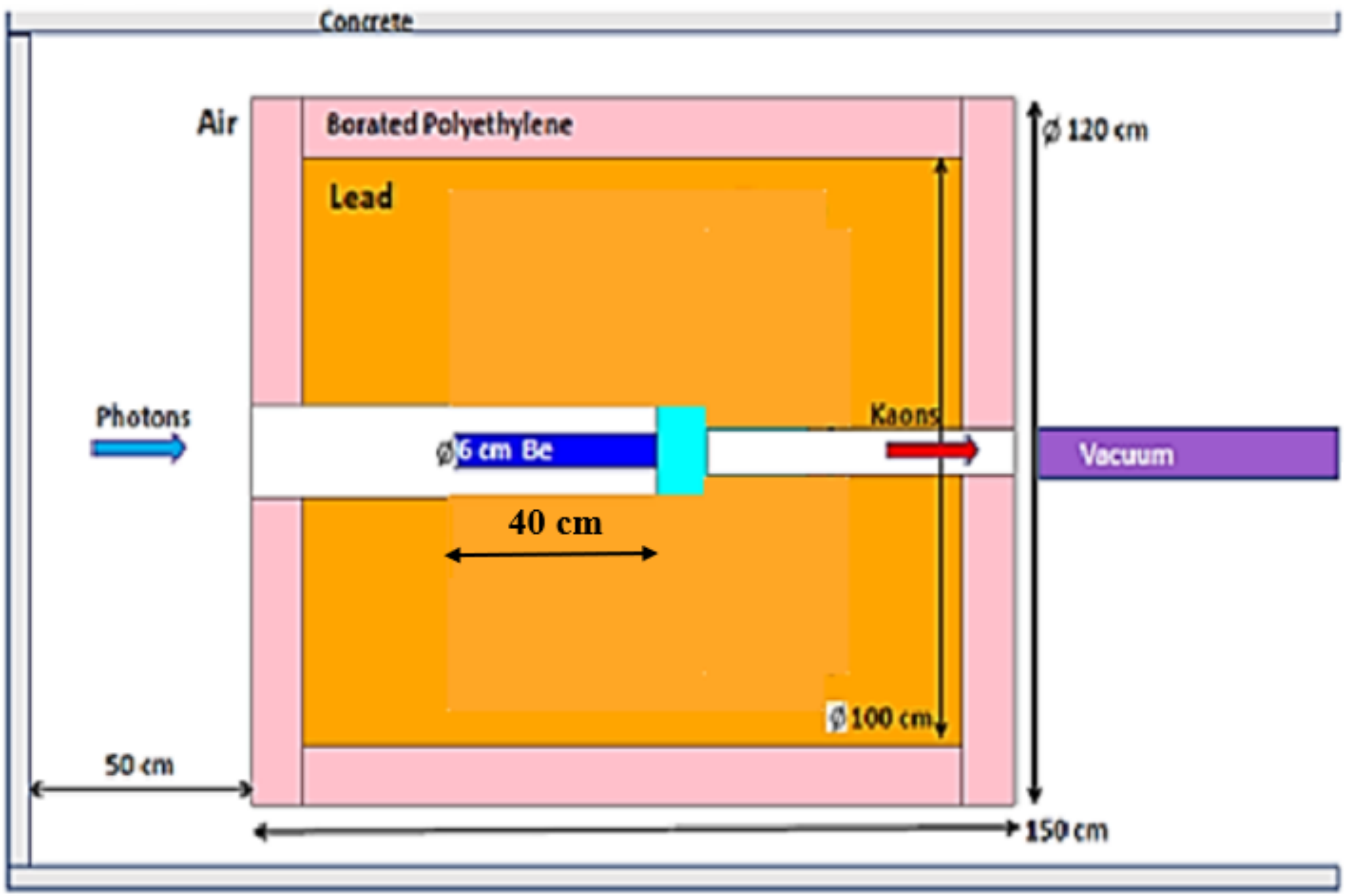
Conceptual design completed for Halls A&C

Details of the CPS designed by the CPS Collaboration

Fulfills RadCon Radiation Requirements

Paper published in NIM, A957(2020)

Be Target Assembly: Conceptual Design

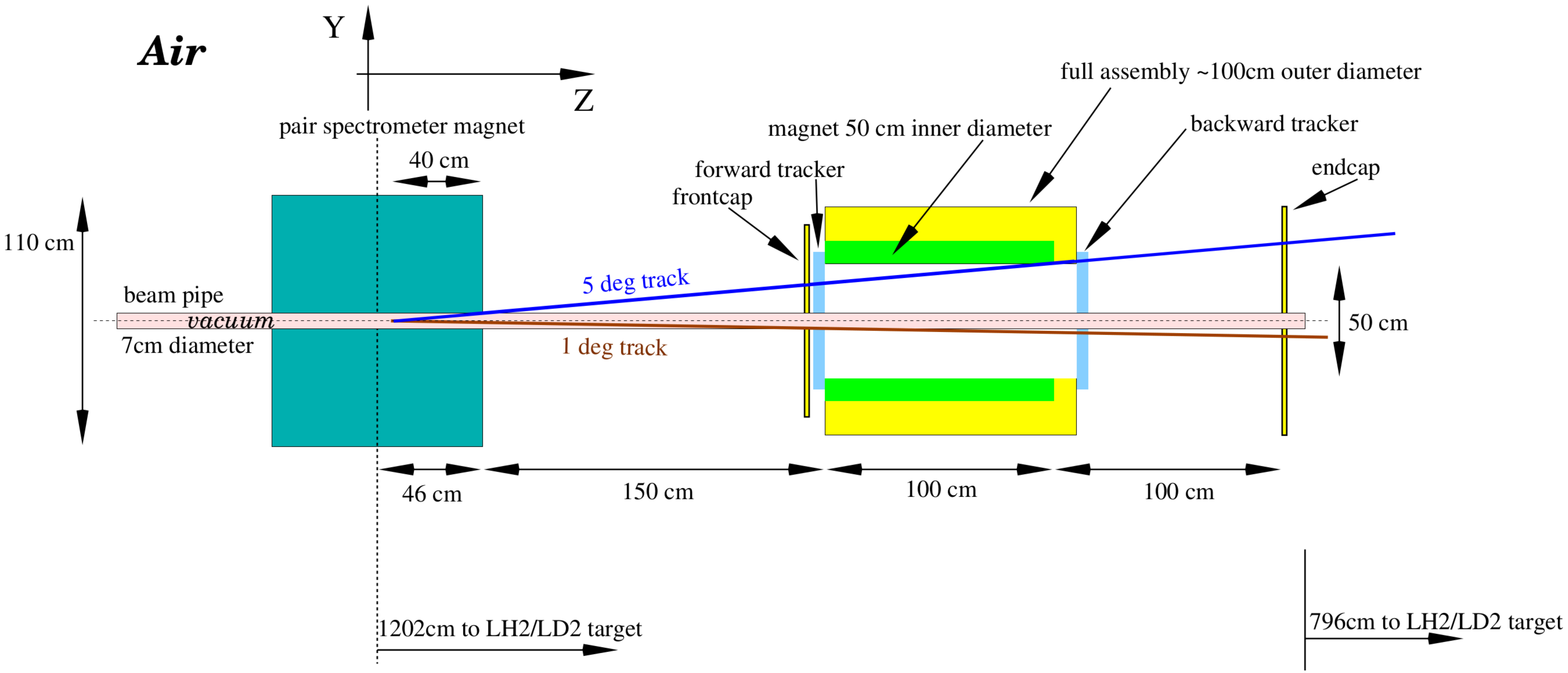


-Meets RadCon Requirements

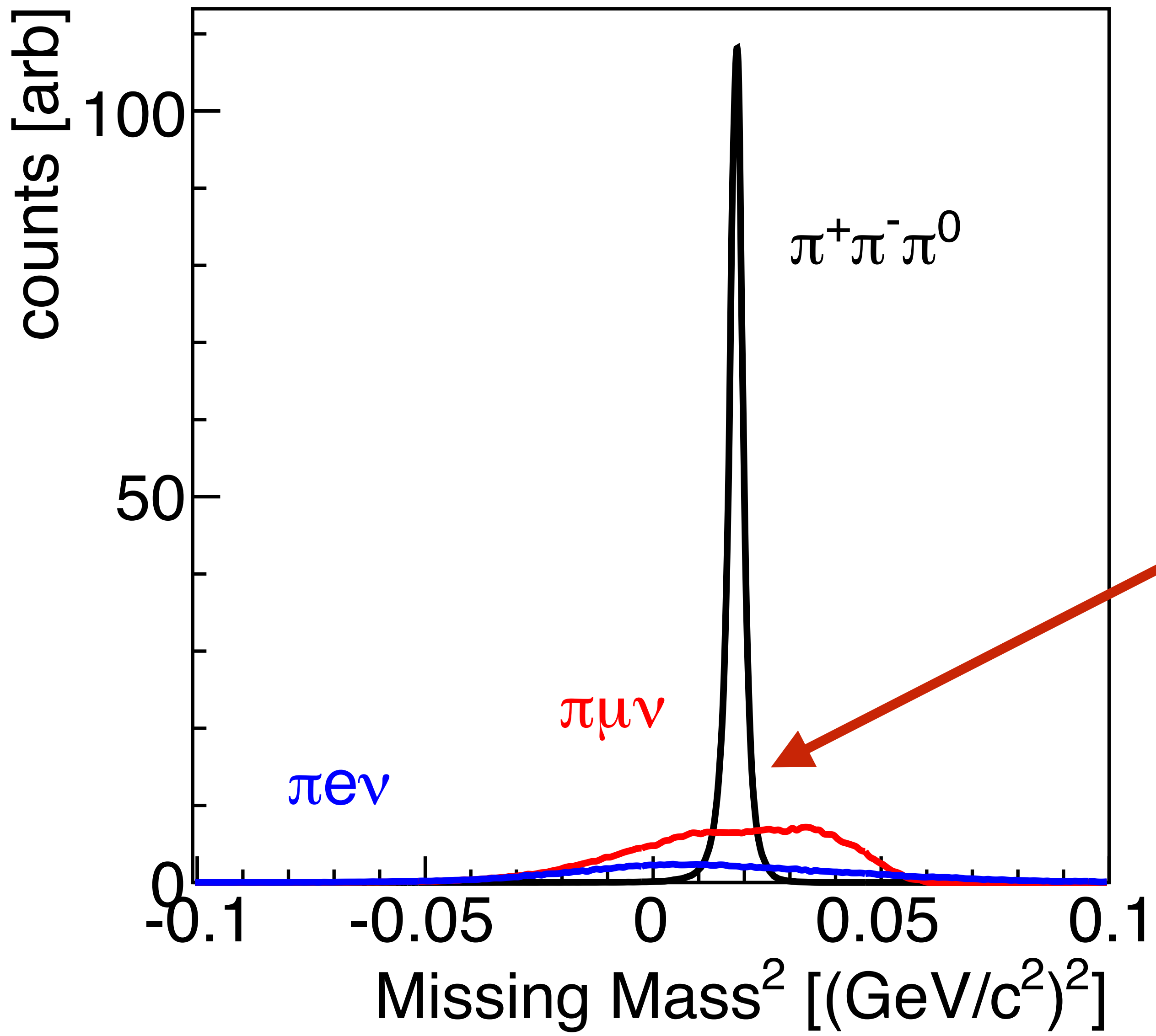
-Conceptual Design Endorsed by Hall-D Engineering Staff

arXiv: 2002.04442

Flux Monitor (FM)



Reconstructed K_L with FM

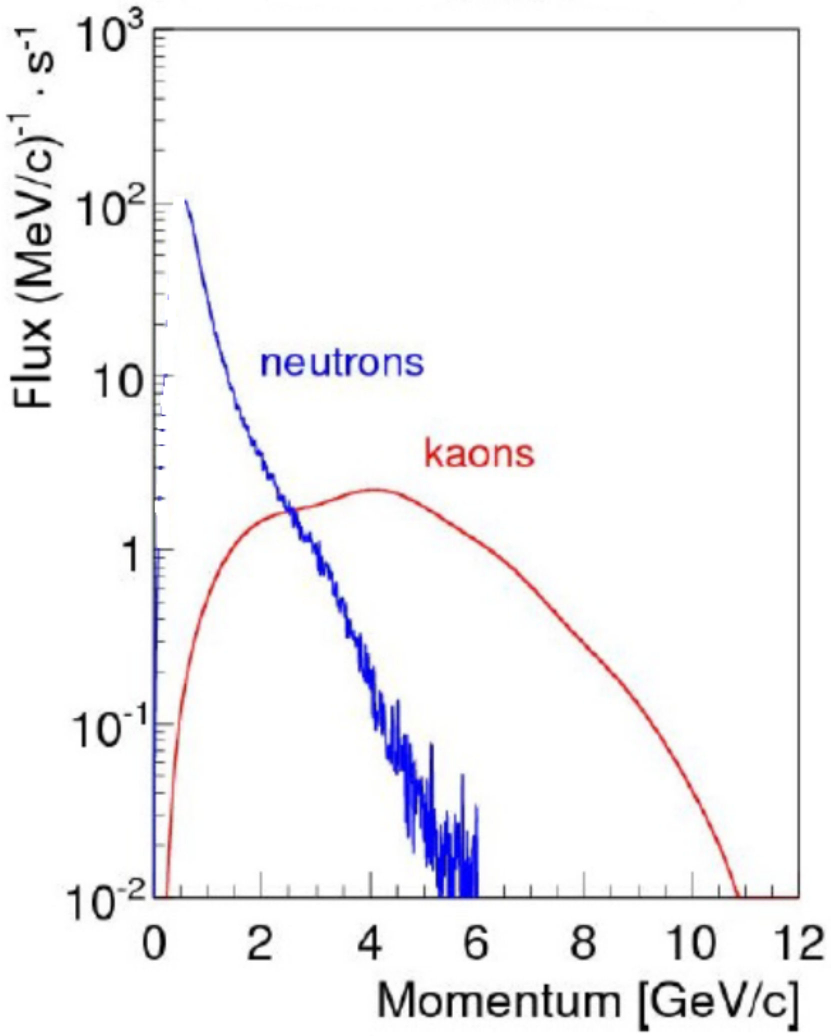


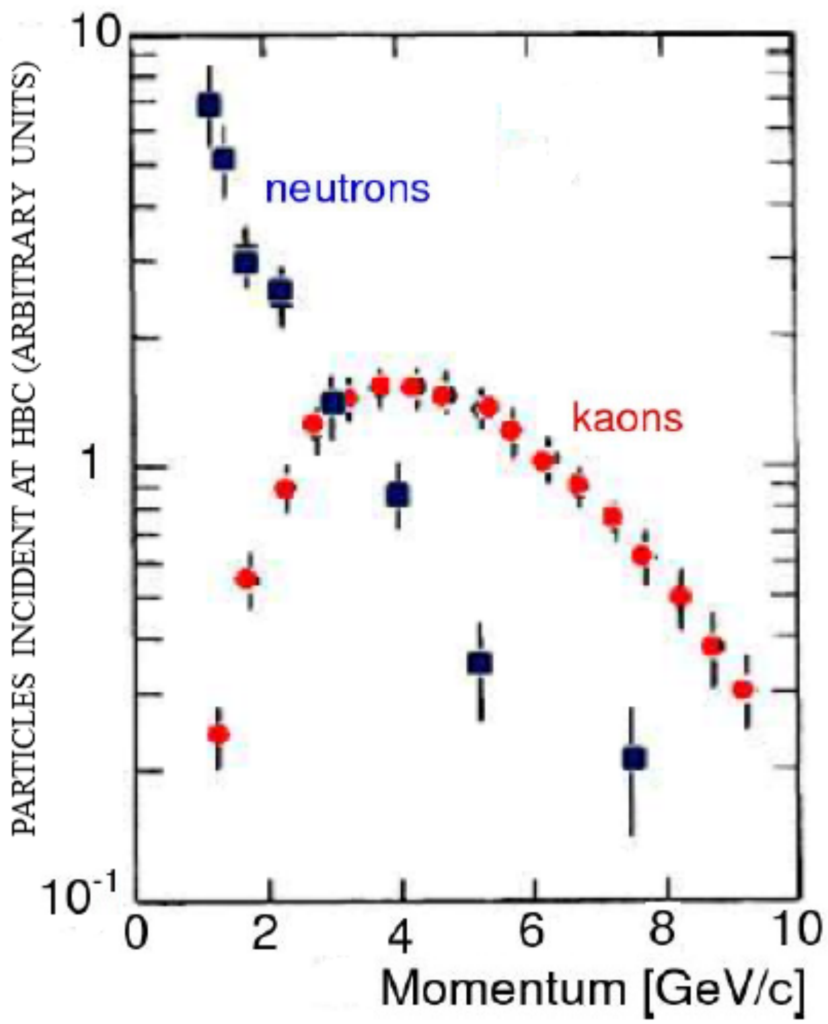
Flux measurement stat. err. <1%

Estimated conservative syst. err. ~5%

K_L Beam Flux

JLab 12 GeV | SLAC 16 GeV

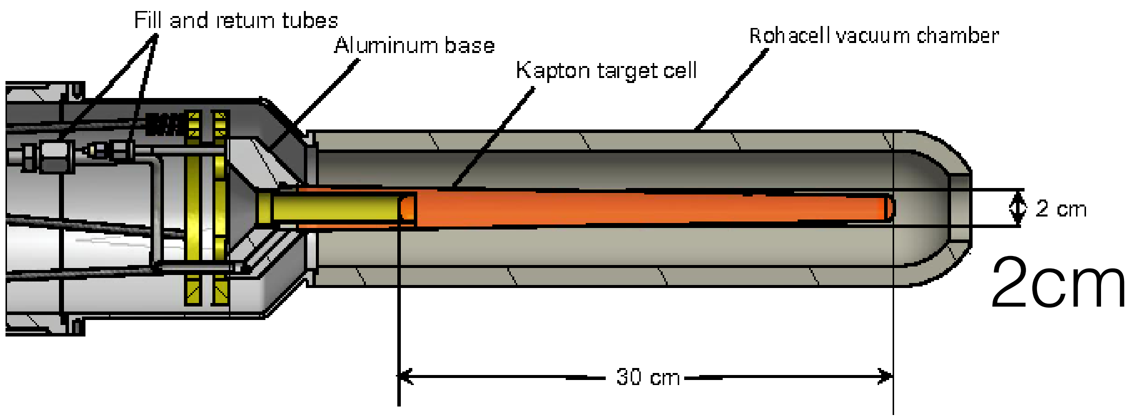




$$N(K_L)/sec \sim 10^4$$

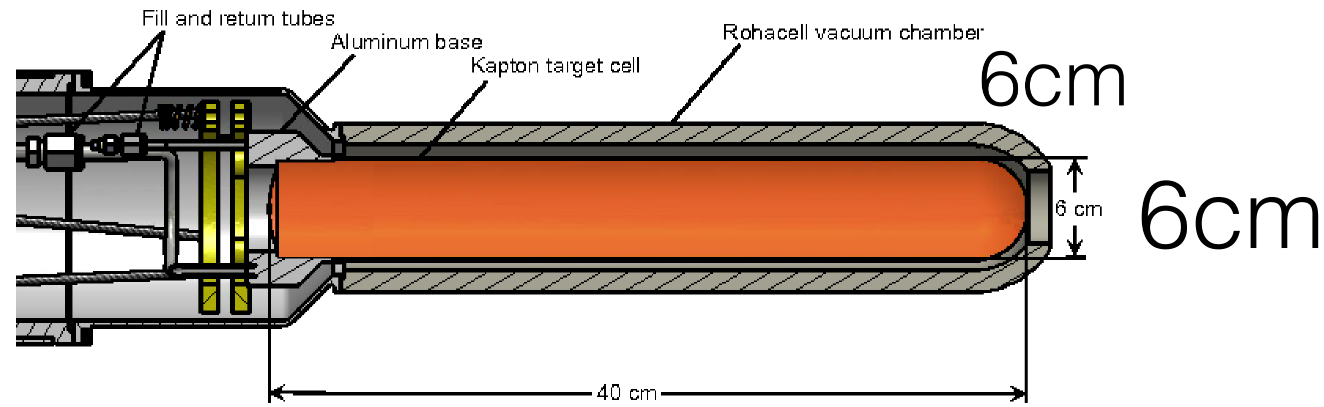
$$\frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

LH2/LD2 Cryogenic target for K_L Beam at Hall D



30cm

Current



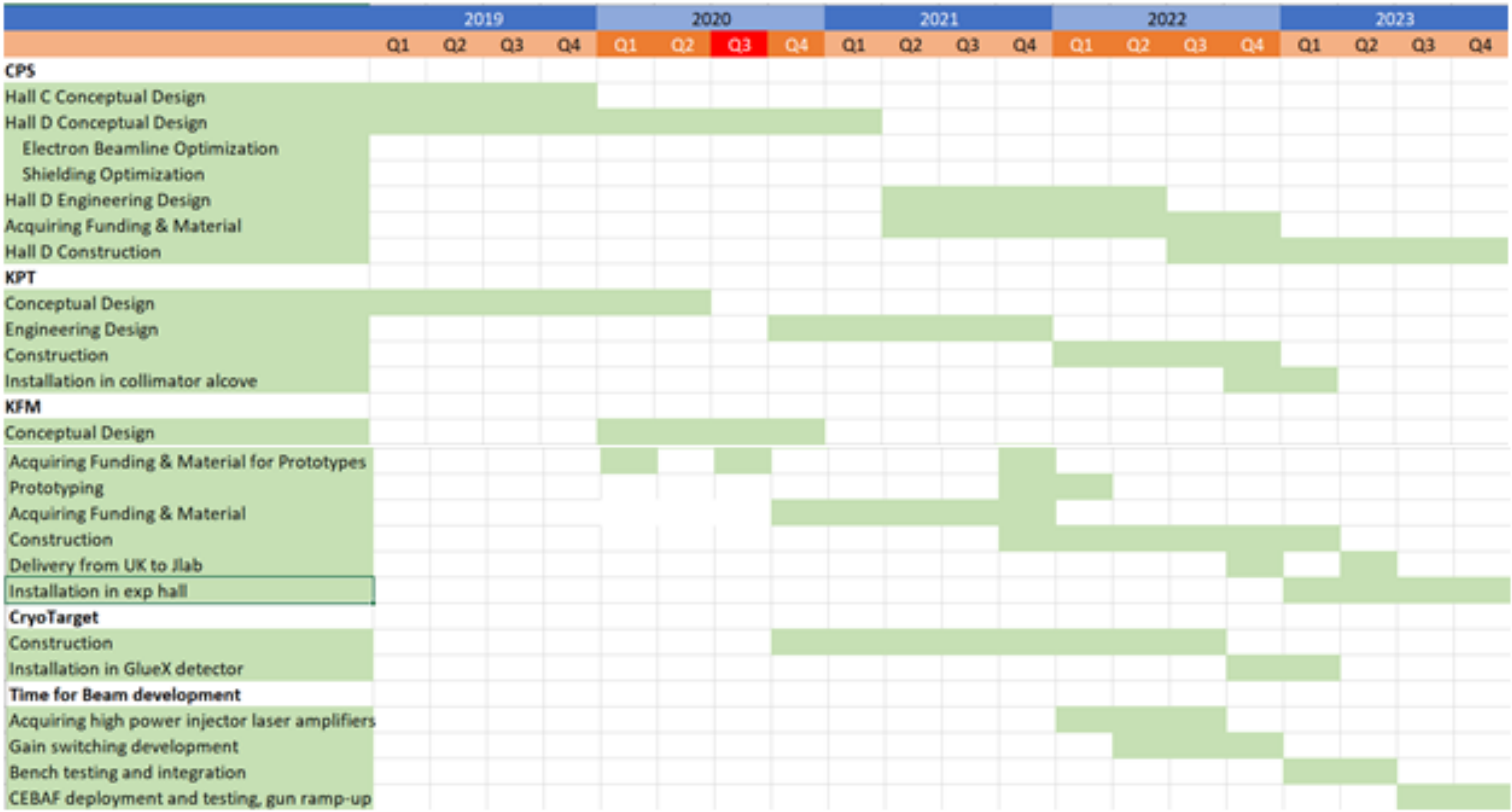
40cm

Proposed & Feasible

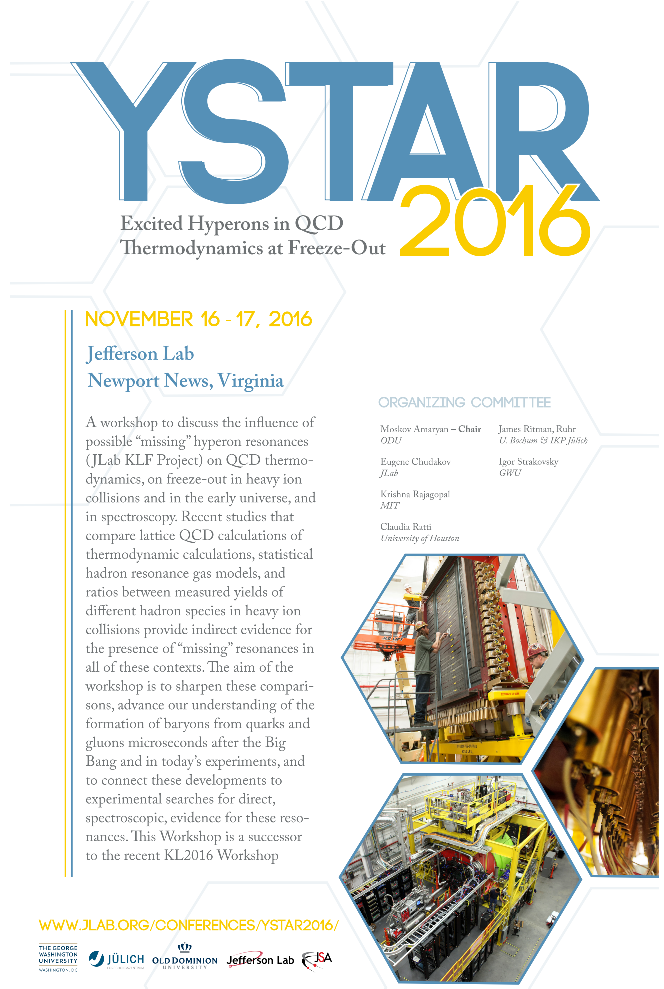
Longer and thicker target needed to enhance production rate

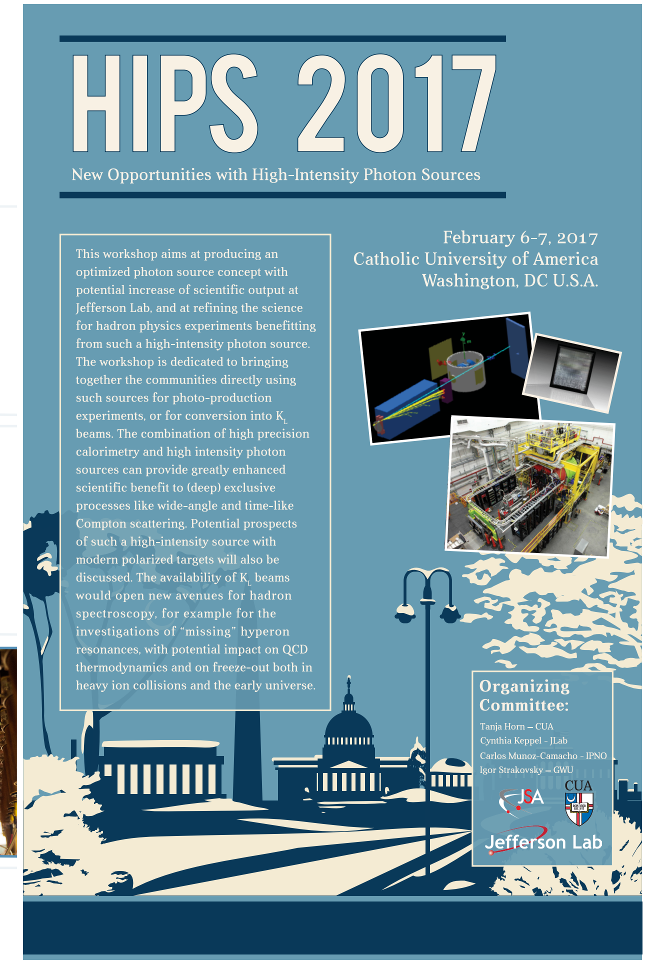
Conceptual design endorsed by JLAB target group

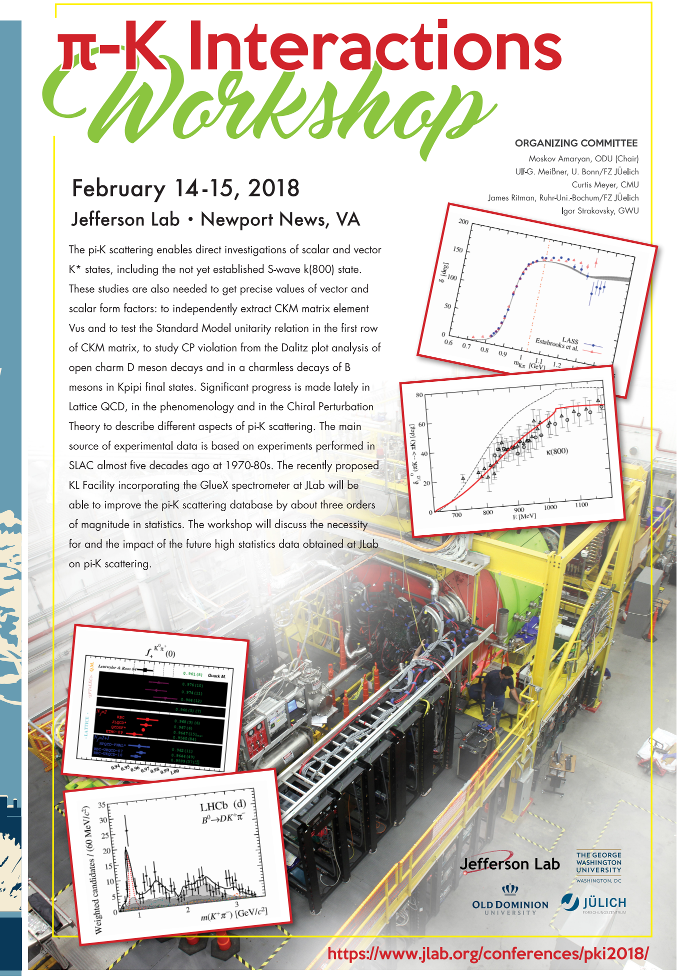
Timeline of Design, Construction and Installation



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







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 spectrosocopy
  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 !