Strange Hadron Spectroscopy with Secondary K_L Beam in Hall-D

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Old Dominion University
Norfolk, VA

AANL, Yerevan, October 28, 2021

Dedicated to the Memory of Professor Maxim Polyakov
Who Unexpectedly Passed Away in August 2021

Outline

-Introduction

-K_L Facility Beamline and Hardware

- Electron Beam
- Compact Photon Source
- Be Target
- Flux Monitor
- K_L Beam
- LH_2/LD_2 Target

-Expected Physics results

- Hyperon Spectroscopy
- Strange Meson Spectroscopy
- Early Universe

Summary

48th PROGRAM ADVISORY COMMITTEE (PAC 48)

August 10-14, 2020

September 25, 2020

U.S. DEPARTMENT OF ENERGY

JSA

Prepared for the U.S. Department of Energy
under Contract DE-AC05-06OR23177

Recommendations

PAC 48 SUMMARY OF RECOMMENDATIONS								
Number	**Contact Person**	**Title**	**Hall**	**Days Req'd**	**Days Awarded**	**Scientific Rating**	**PAC Decision**	**Topic**
C12-18-005	M. Boer	Timelike Compton Scattering Off Transversely Polarized Proton	C	50			**C2**	4
C12-19-001	M. Amarian	Strange Hadron Spectroscopy with Secondary KL Beam in Hall D	D	200	200	A-	**Approved**	1

Title: Strange Hadron Spectroscopy with Secondary KL Beam in Hall D

Spokespersons: M. Amaryan (contact), M. Bashkanov, S. Dobbs, J. Ritman, J. Stevens, I. Strakovsky

Motivation: The spectroscopy of strange baryons and mesons, including their fundamental strong interactions, are the focus of this proposal. New and unique data can be obtained with an intense K_L beam aimed at a hydrogen/deuterium target, using the GlueX apparatus to detect final state particles.

Measurement and Feasibility: The proponents have answered all questions outlined in the PAC47 report. Substantial progress has been made on the issues of simulations: details on backgrounds and background reactions have been demonstrated, a demonstration of partial wave analysis for hyperon production was given. The proponents have demonstrated the measuring technique of missing mass reconstruction, allowing them to extend the measuring range both regarding small, four-momentum transfers and isospin decomposition. No show stoppers have been pointed out by the TAC.

Issues: The PAC strongly recommends that the collaboration intensify their cooperation on two issues. (1) Coordinated leadership must be established together with the host laboratory to address the various technical issues connected with the R&D efforts and construction of the K_L beam. (2) Continuous cooperation with JPAC and associated members is recommended for the development of tools to master the challenges connected with the clean extraction of $K\pi$ scattering, the identification of the exchange processes at small momentum transfers, and the amplitude analysis for Δ final states.

Summary: The future K_L facility will add a new physics reach to JLab, and the PAC is looking forward to see the idea being materialized, in conjunction with the plans for Hall D as spelled out in the 2019 White Paper. The collaboration should now devote all its energy to turn this challenging project into an experimental facility and in parallel prepare for a successful data analysis.

This happens because of strong support and dedicated efforts of the KLF Collaboration

comprised of 160 physicists from 68 Universities across 19 countries worldwide

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

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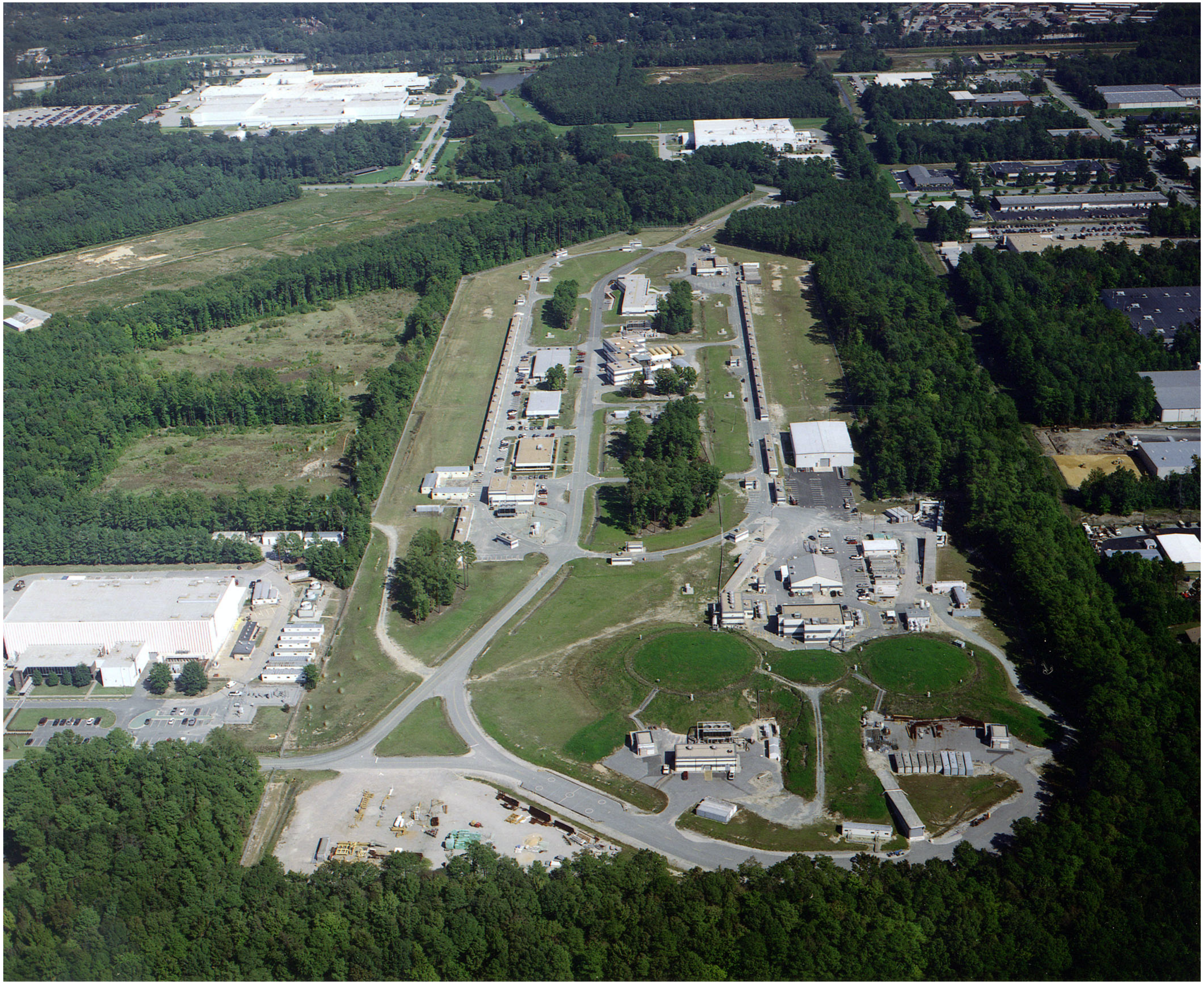
There Were Many Questions

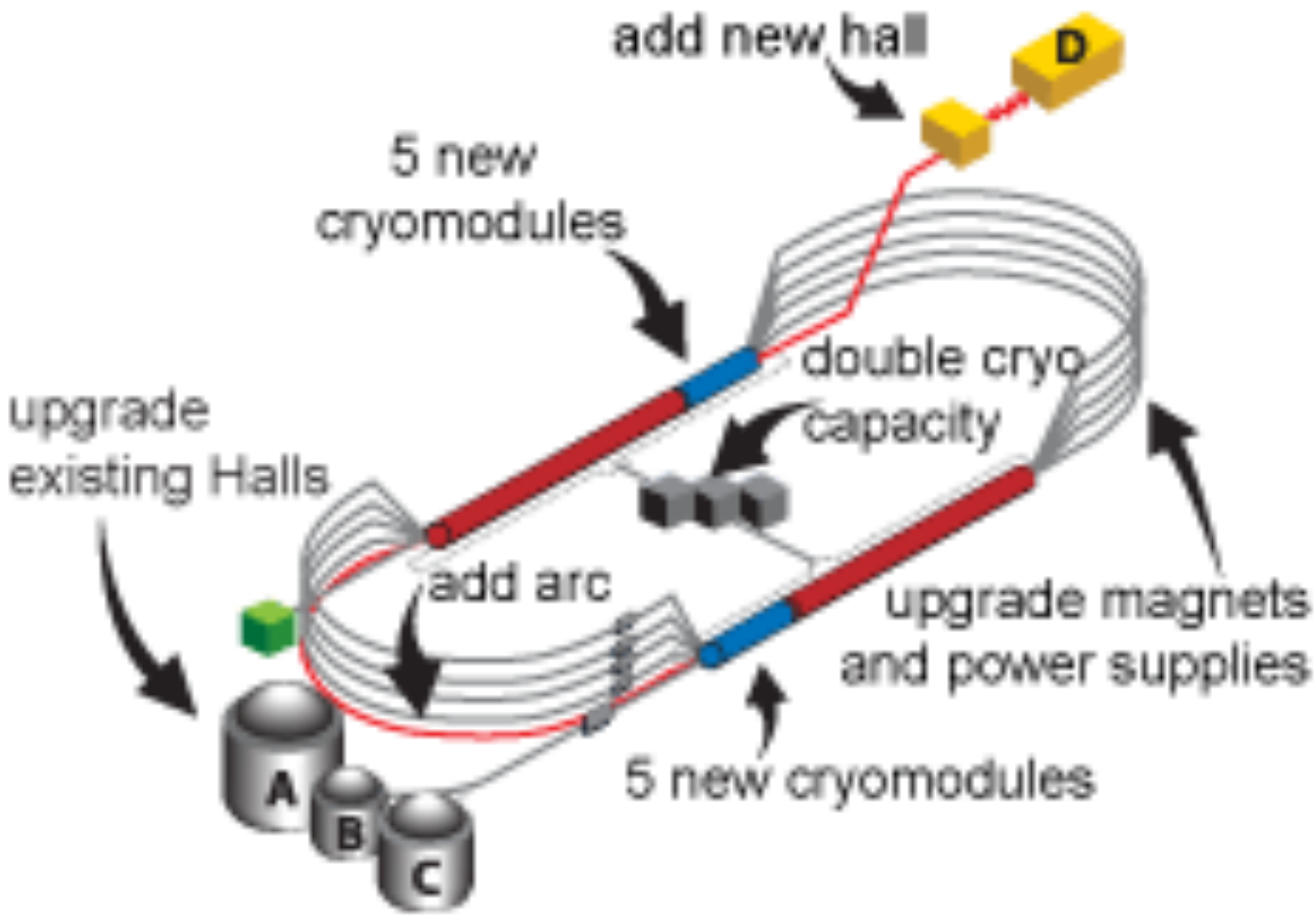
- Why to use kaon beam? What is the advantage compared to electrons or photons?
- What is so special about K-long compared to charged kaon beam?
- What is the advantage of producing secondary kaon beam with EM probe, compared to a proton beam?
- How much CEBAF accelerator could make a breakthrough compared to previous results at SLAC?
- Why to do this experiment, what are we going to learn?
- How will it affect our knowledge on hyperon spectroscopy?
- What are we going to learn about strange meson spectroscopy ?
- Many more questions - some constructive and some less so - answers to which shaped the approved proposal.

Thomas Jefferson National Accelerator Facility Newport News, Virginia, Aerial View.

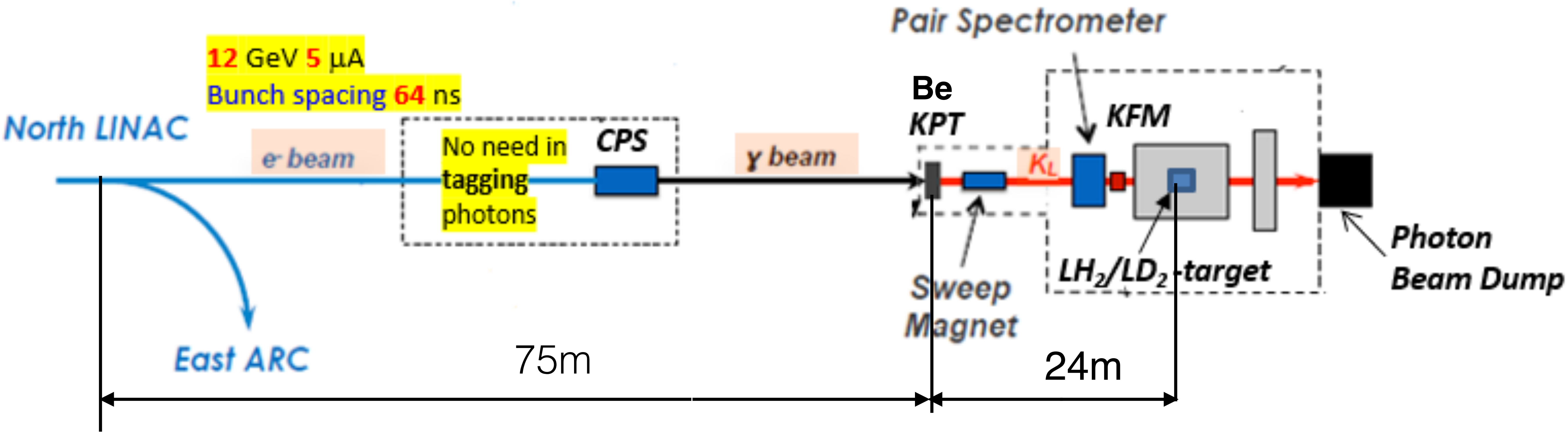


Continuous Electron Beam Acccelerator Facility (CEBAF)

12 GeV Electron Beam



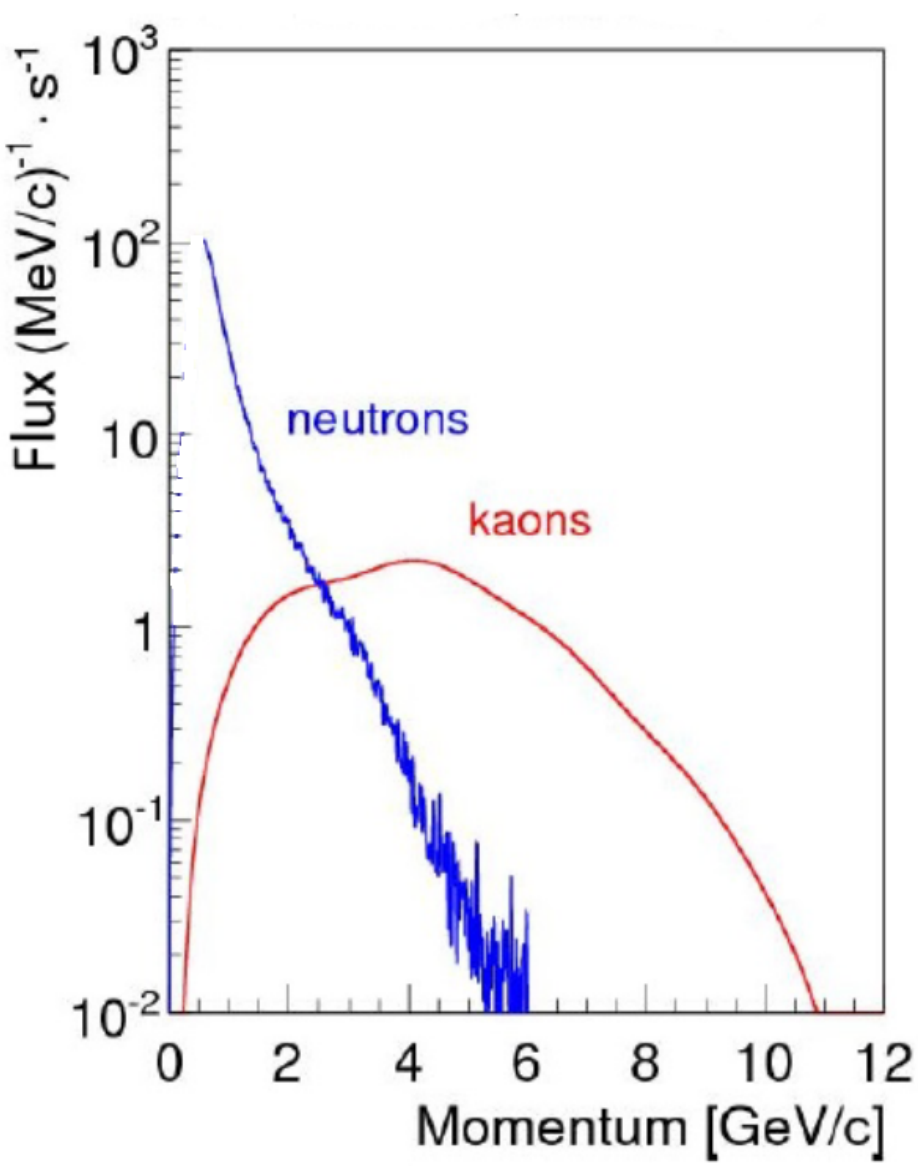
Hall-D beamline and GlueX Setup



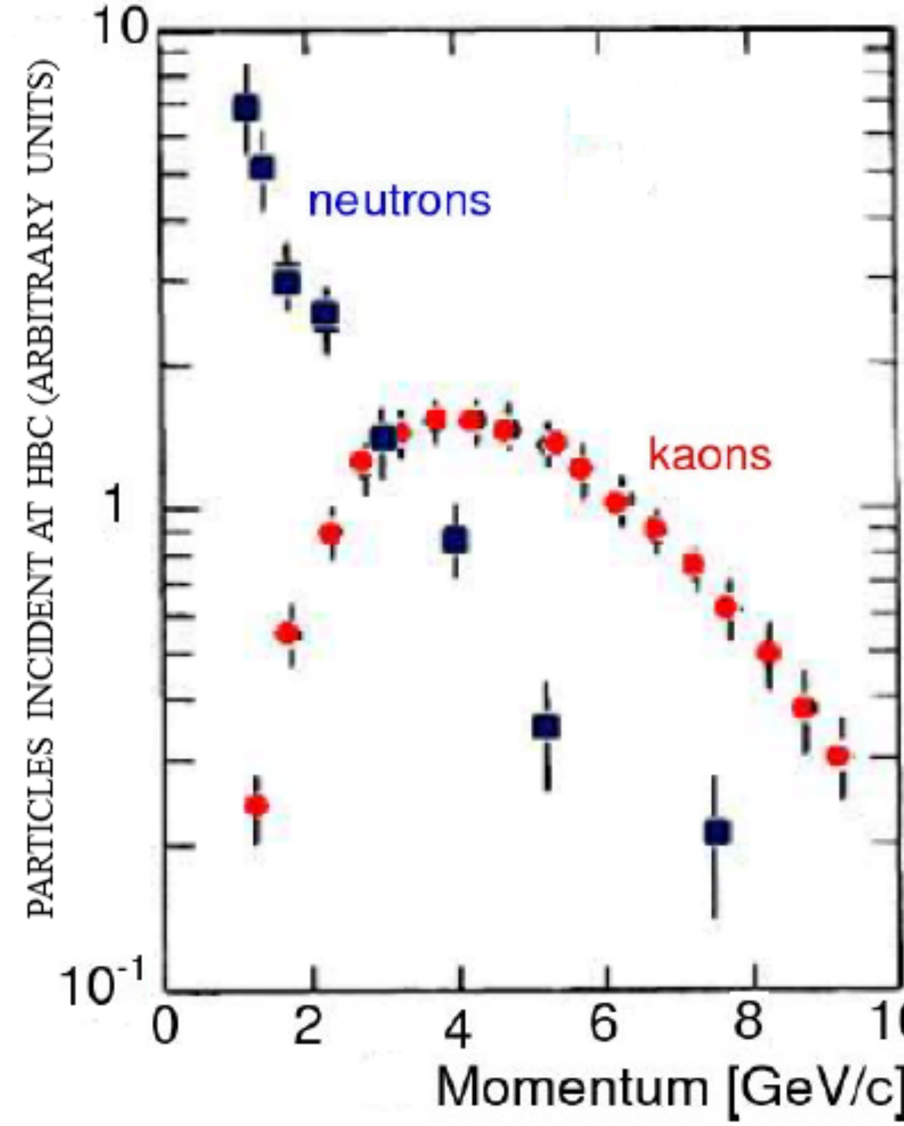
https://arxiv.org/pdf/2008.08215.pdf

K_L Beam Flux

JLab 12 GeV



SLAC 16 GeV



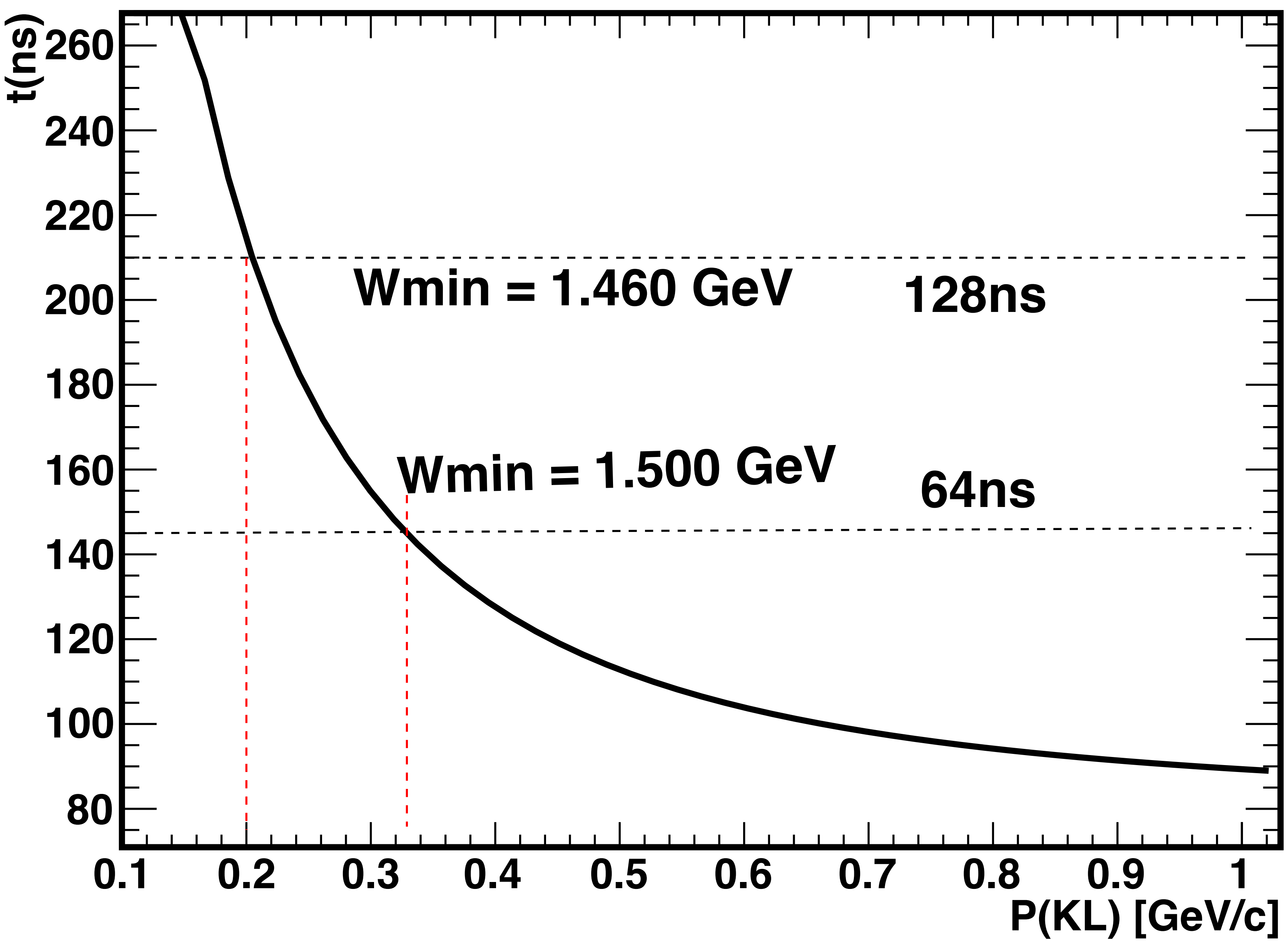
$$N(K_L)/sec \sim 10^4 \rightarrow \frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

Electron Beam Parameters

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

Bunch spacing $\quad 64\ ns$

(Now *128 ns confirmed feasible*



5.7 K_L Momentum Determination and Beam Resolution

The mean lifetime of the K_L is 51.16 nsec ($c\tau = 15.3$ m) whereas the mean lifetime of the K^- is 12.38 nsec ($c\tau = 3.7$ m) [1]. For this reason, it is much easier to perform measurements of K_Lp scattering at low beam energies compared with K^-p scattering.

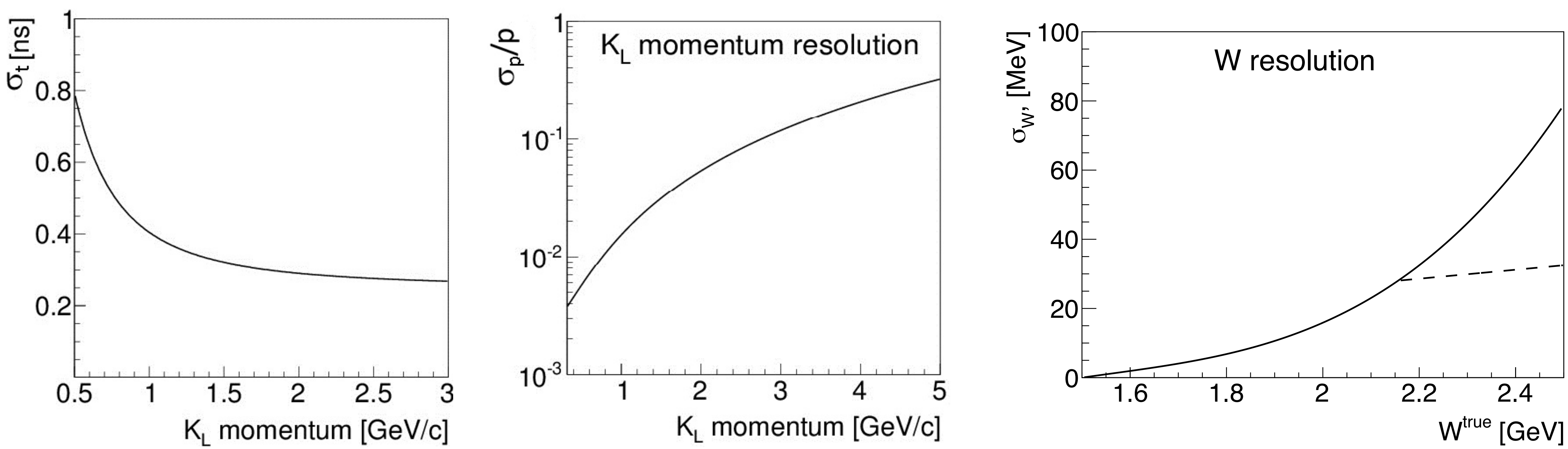


Figure 30: Left: Time resolution (σ_t) for K_L beam as a function of K_L-momentum. Middle: Momentum resolution (σ_p/p) as a function of momentum (note, log scale). Right: Energy resolution (σ_W) as a function of energy. The dashed line shows approximate W resolution from reconstruction of the final-state particles.

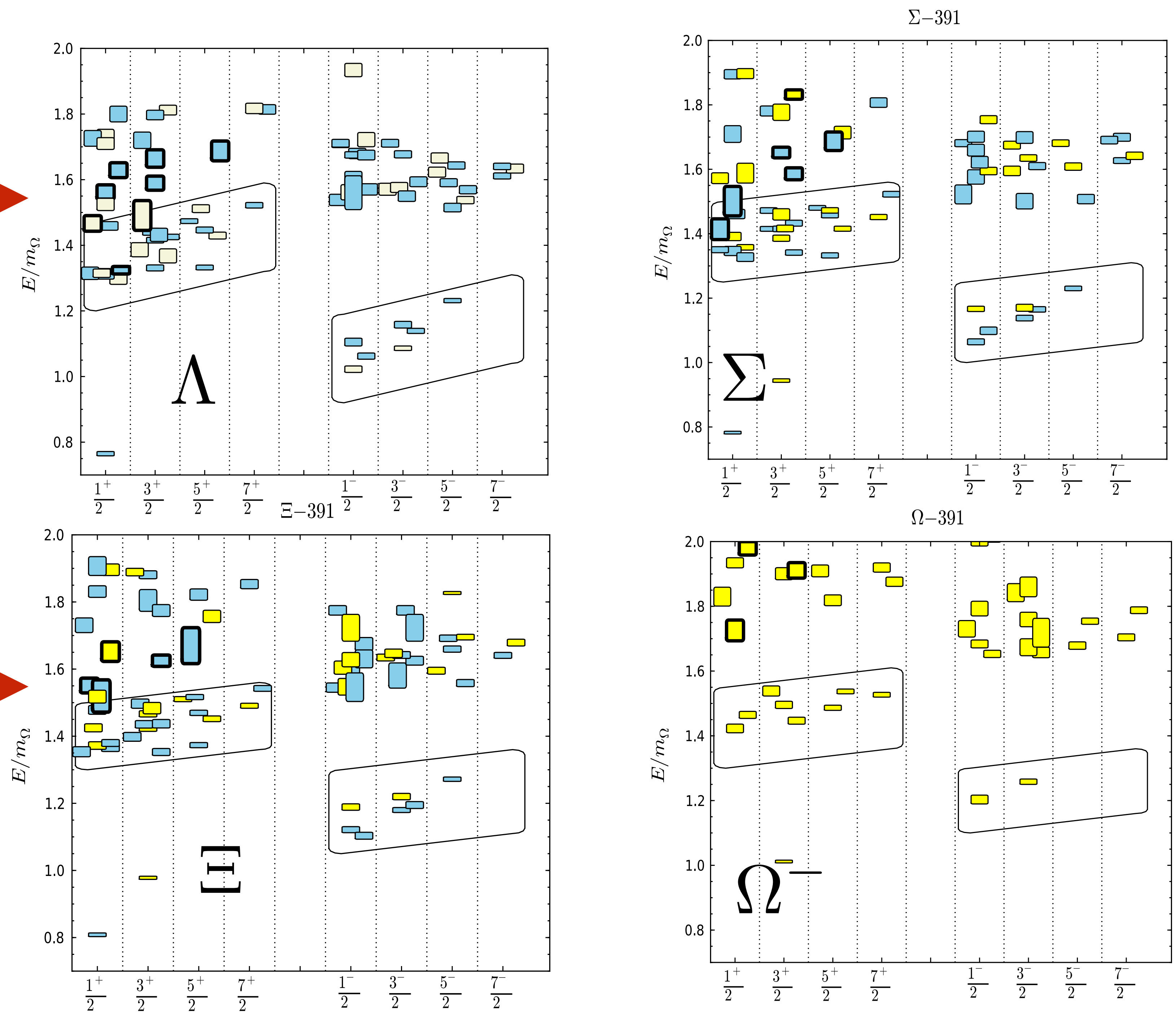
Hyperon Spectroscopy

According to ***LQCD*** *there should be*

many more states including hybrids (thick bordered)

8-states
****
5-states
***

6-states
****
4-states
***

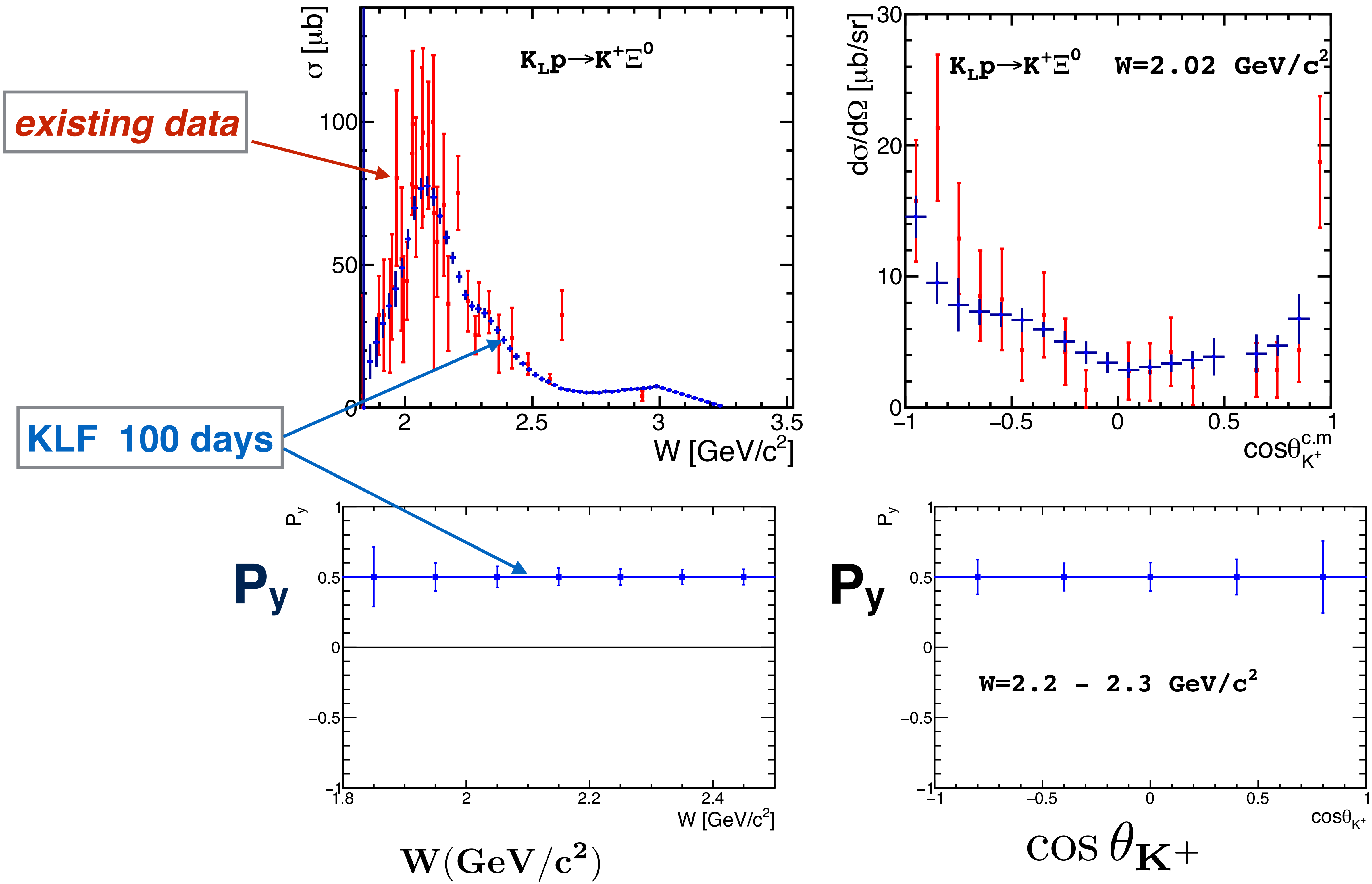


3-states
****
4-states
***

1-state
****
1-state
***

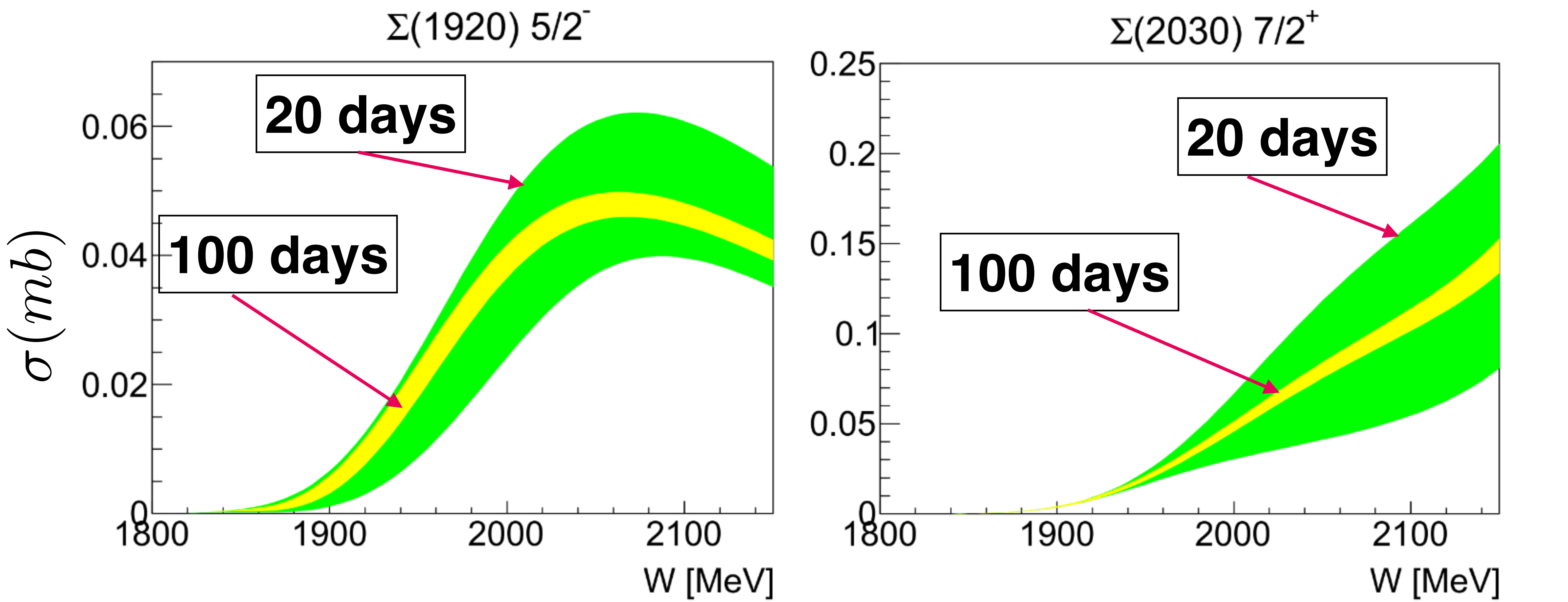
Edwards, Mathur, Richards and Wallace, Phys. Rev. D 87, 054506 (2013)

Measurements on Proton Target



Bonn-Gatchina PWA

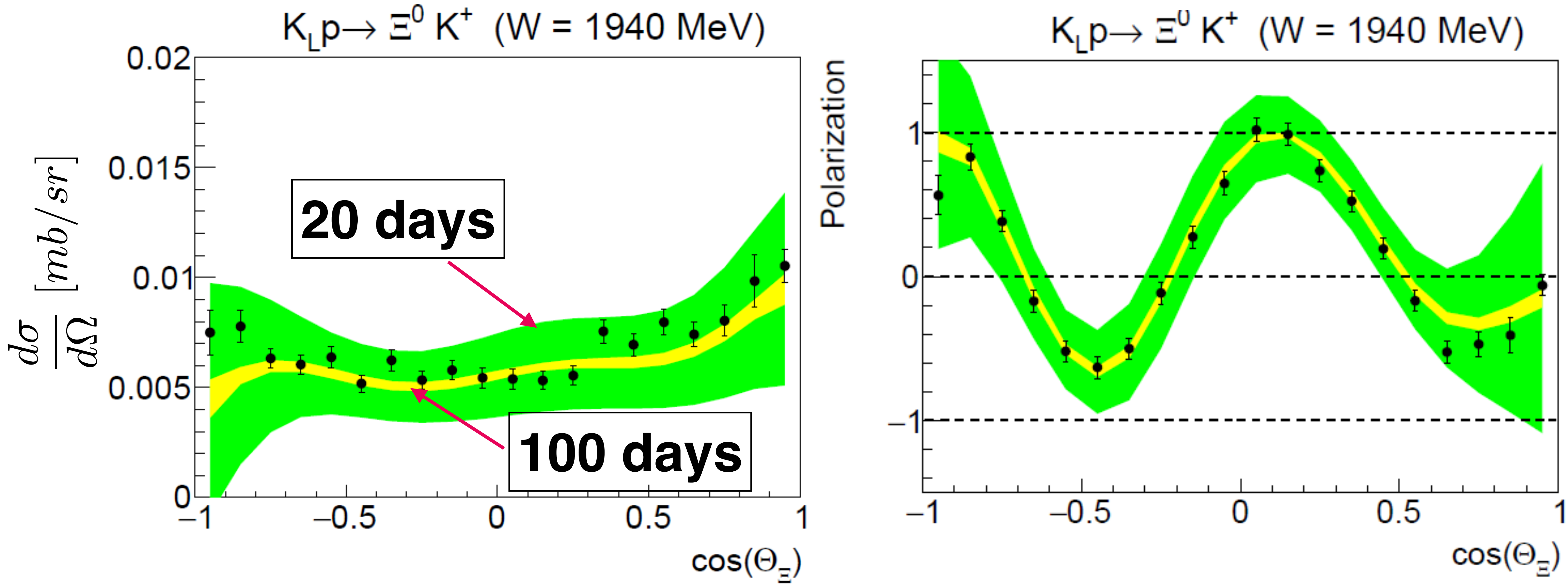
Total Cross Section $K_L p \to K^+ \Xi^0$



Need 100 days of running to get precise solution

Bonn-Gatchina PWA

Diff. Cross Section **Polarization**



Need 100 days of running to get precise solution

Search for Hyperon Resonances with PWA

For Scattering experiments on both
proton & neutron targets one needs to determine:

-differential cross sections

-self 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

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

we use KN scattering data with statistics
generated according to expected K-long Facility (KLF)
data for 100 days to show PWA sensitivity
to obtain results close to the best fit

Strange Meson Spectroscopy

Possible channels with proton and deuterium target and corresponding CG coefficient.

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

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

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

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

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

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

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

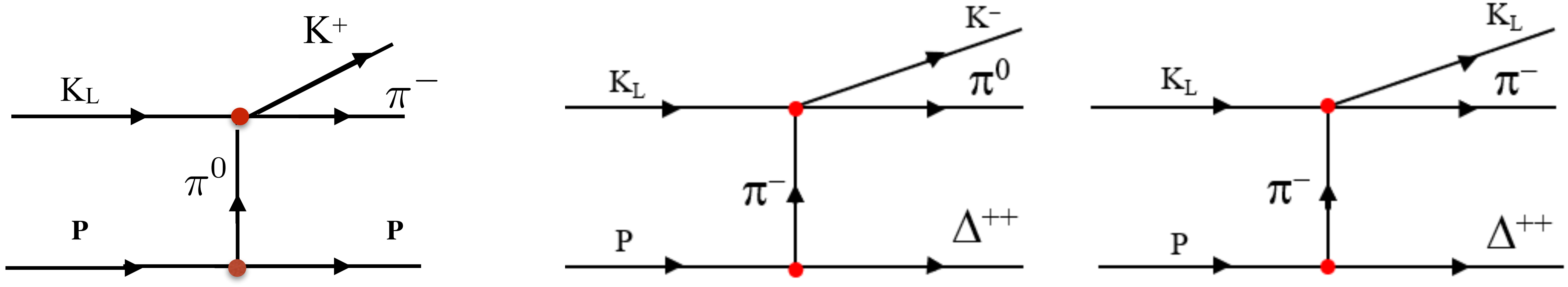
$$K_L n \to K_L\pi^0 n = \langle K_L\pi^0 | K_L\pi^0\rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

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

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

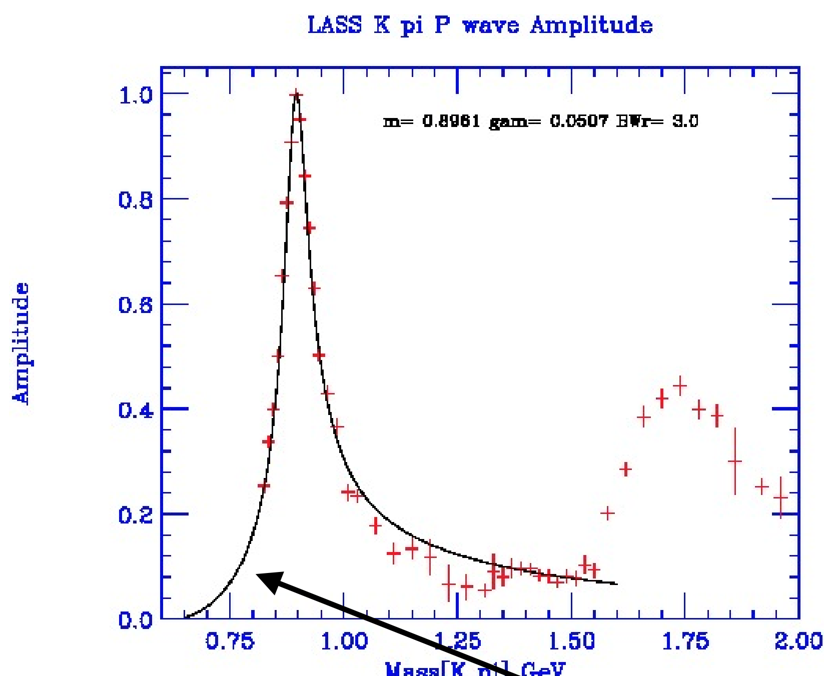
Strange Meson Spectroscopy

$K\pi$ Scattering

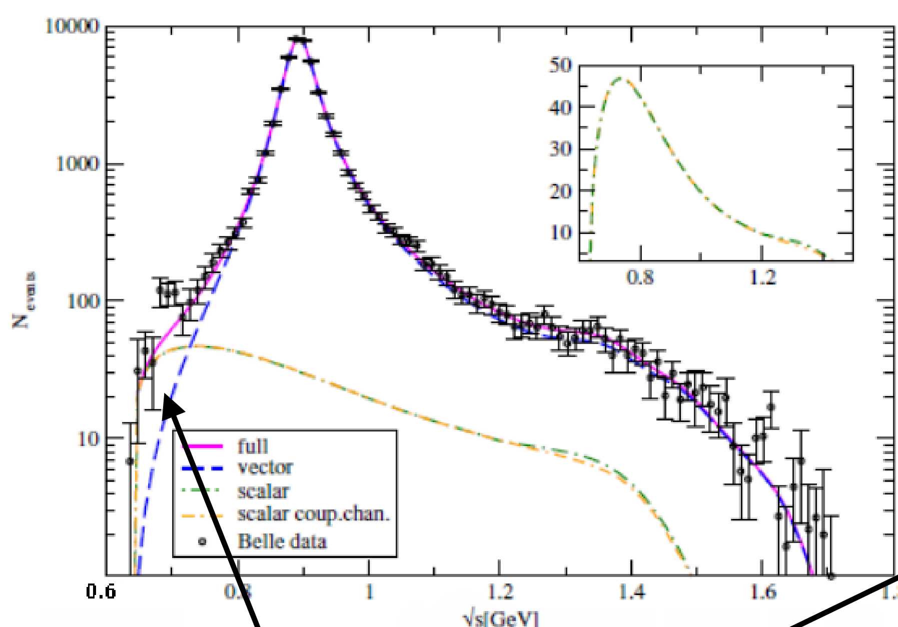


Proposed Measurements

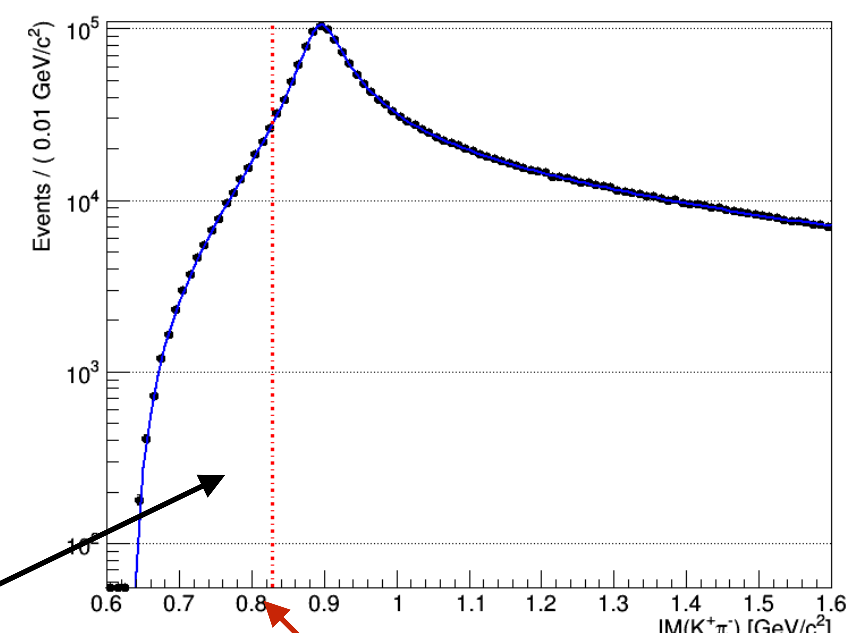
SLAC	Belle	KLF
$K^-\pi^+ \rightarrow K^-\pi^+$	$\tau \rightarrow K\pi\nu_\tau$	$K_L\pi^0 \rightarrow K^+\pi^-$



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



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



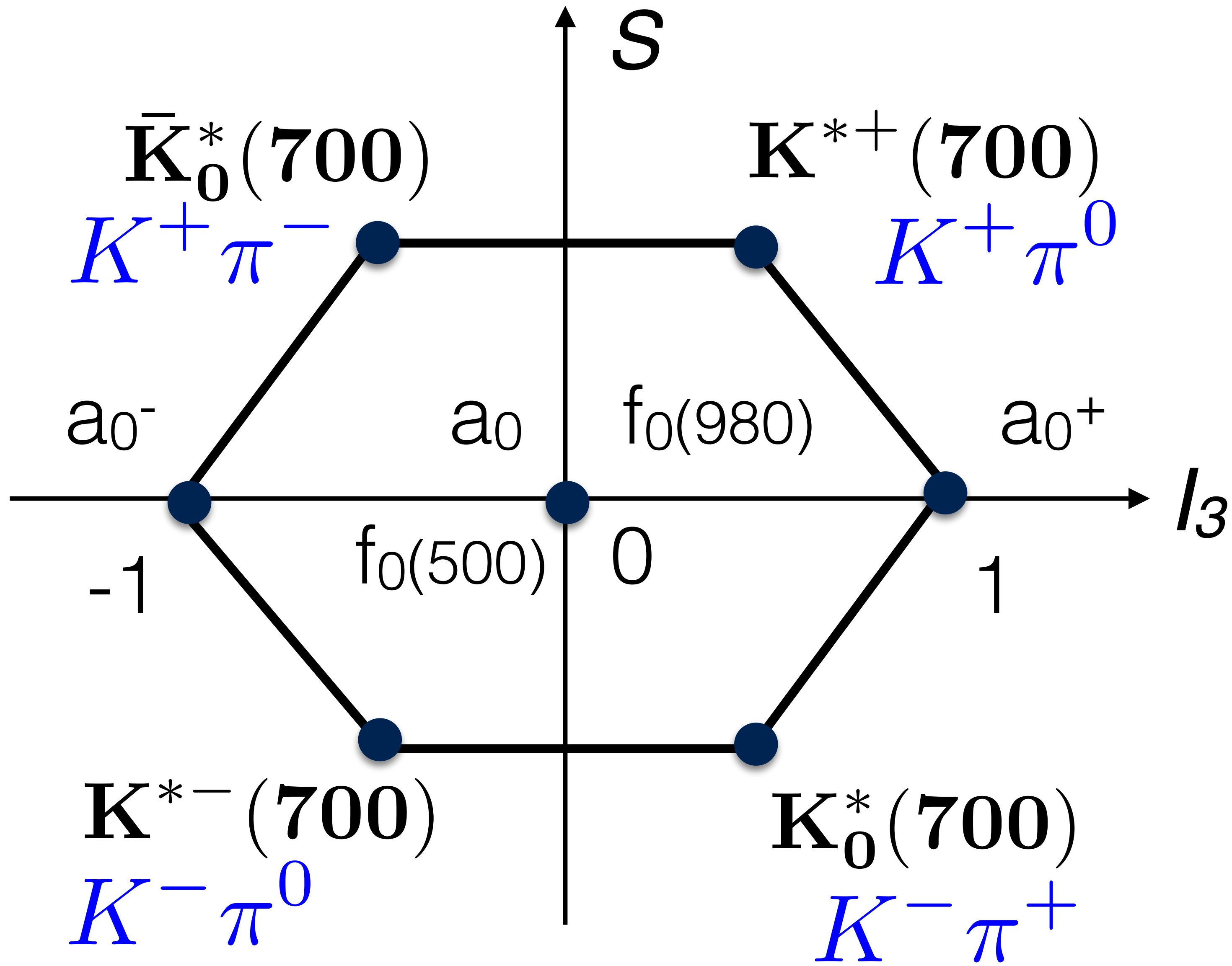
$\mathbf{M(K\pi)(GeV)}$

region of $\kappa(800)$

SLAC Lower limit

Scalar Meson Nonet

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



Four states called κ

still need further confirmation(PDG)

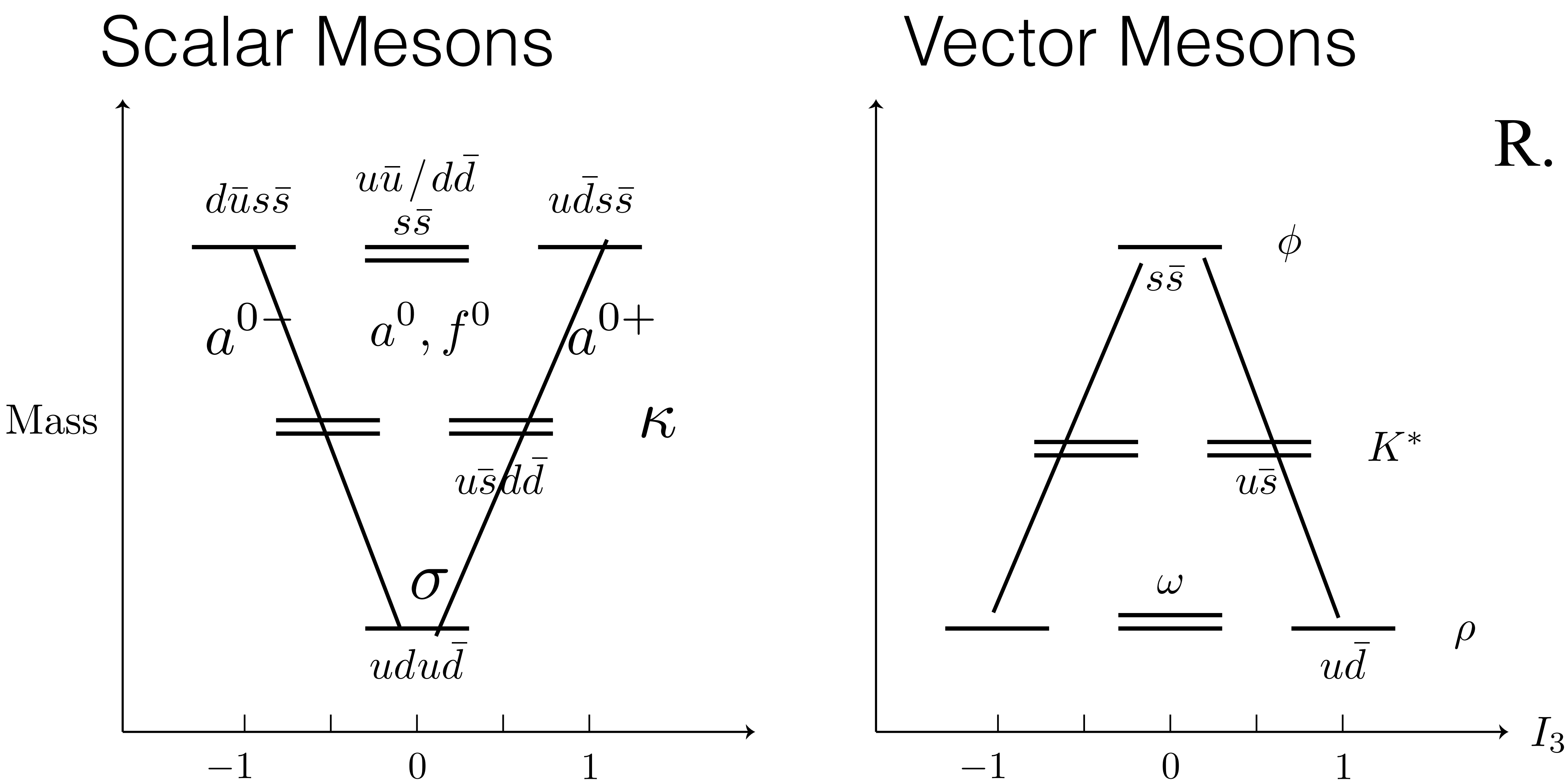
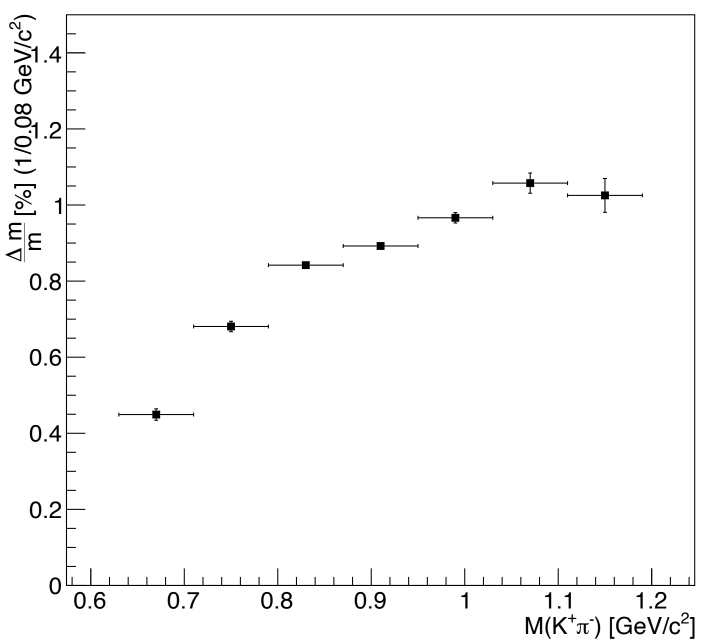


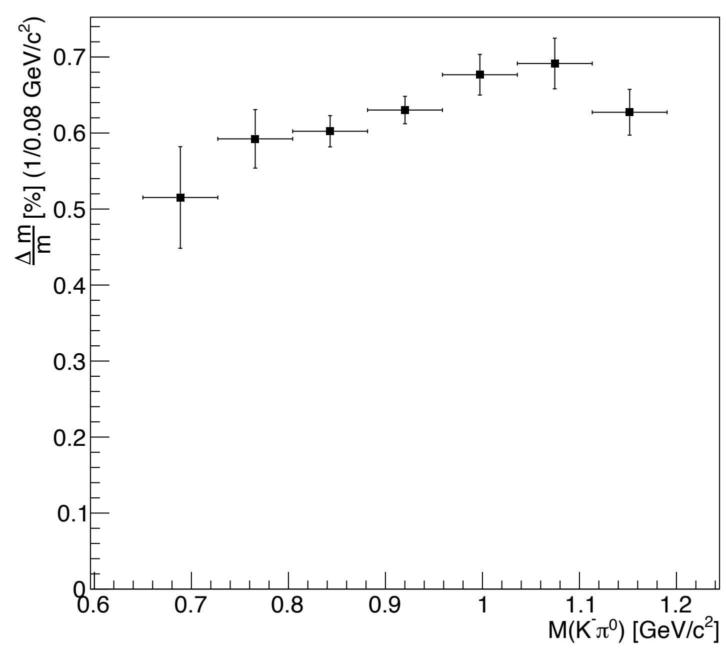
Figure 6. A cartoon representation of the masses of a $\bar{q}\bar{q}qq$ nonet compared with a $\bar{q}q$ nonet.

Very different mass hierarchy
Possibly suggesting 4q tetraquark structure of scalar mesons

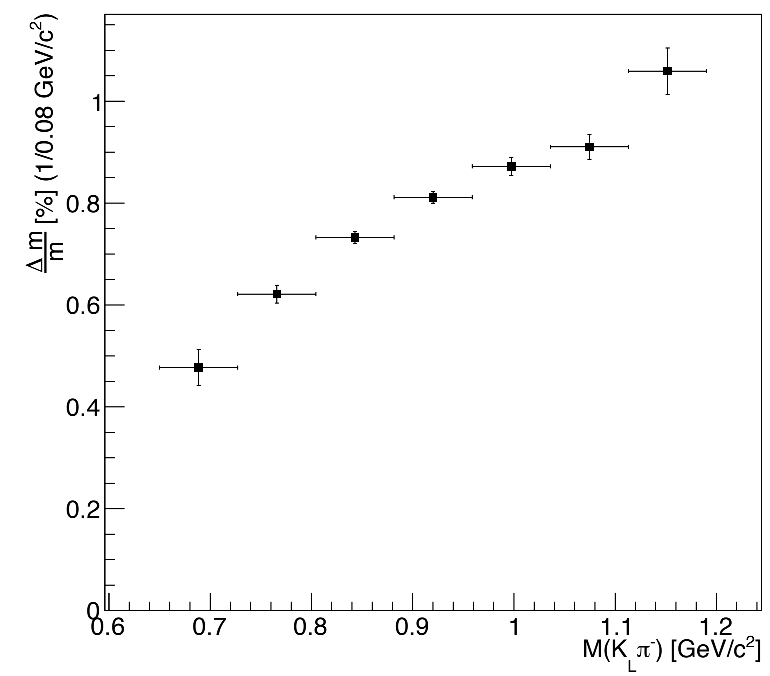
Invariant mass resolution $\Delta m/m$ (%)



$K^+\pi^-$



$K^-\pi^0$



$K_L\pi^-$

Below 1% in all cases

Projected Measurements

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

SLAC Data

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

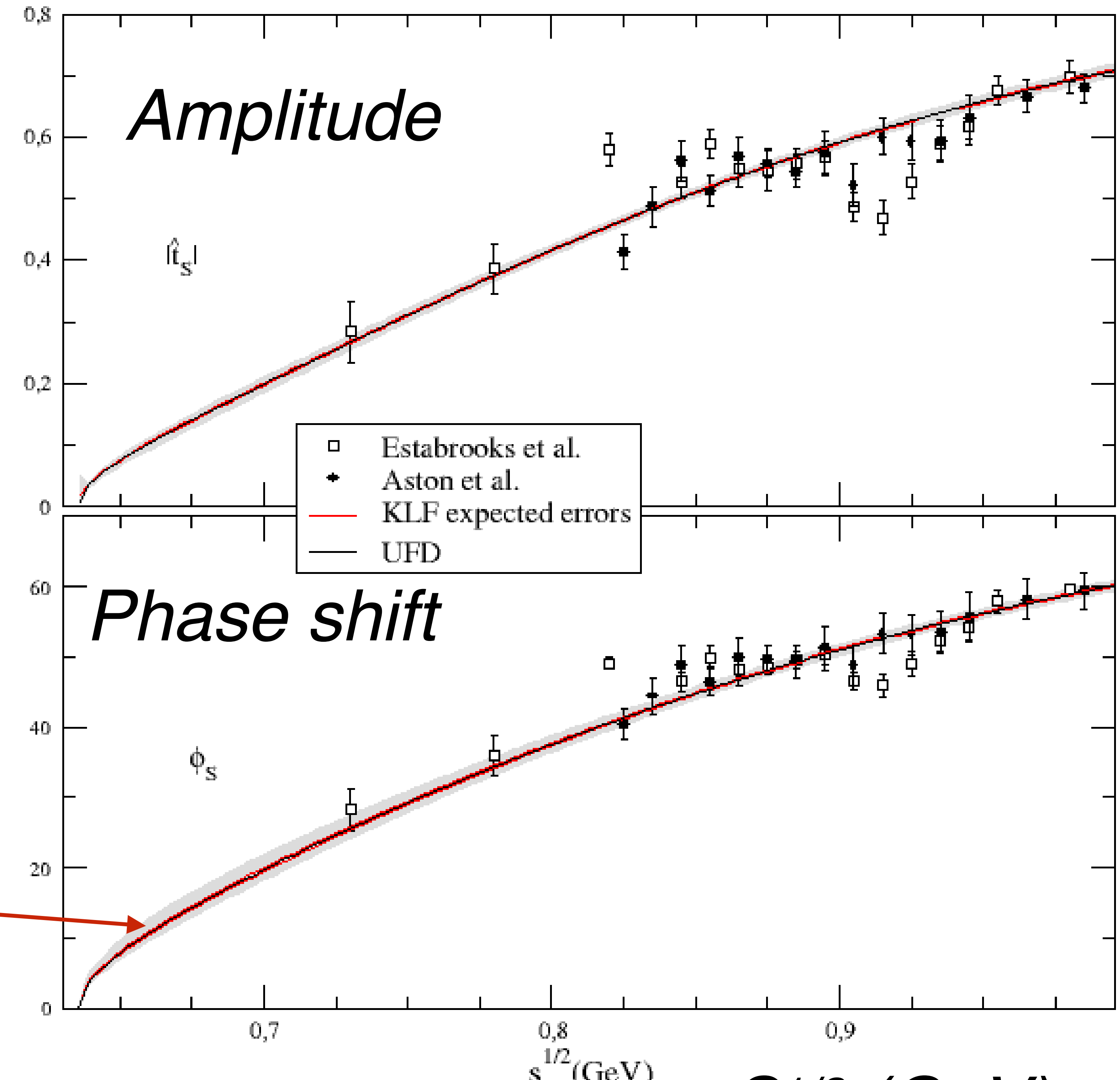
$$K^{\pm}p \to K^{\pm}\pi^{-}\Delta^{++}$$

Estabrooks(1978)

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

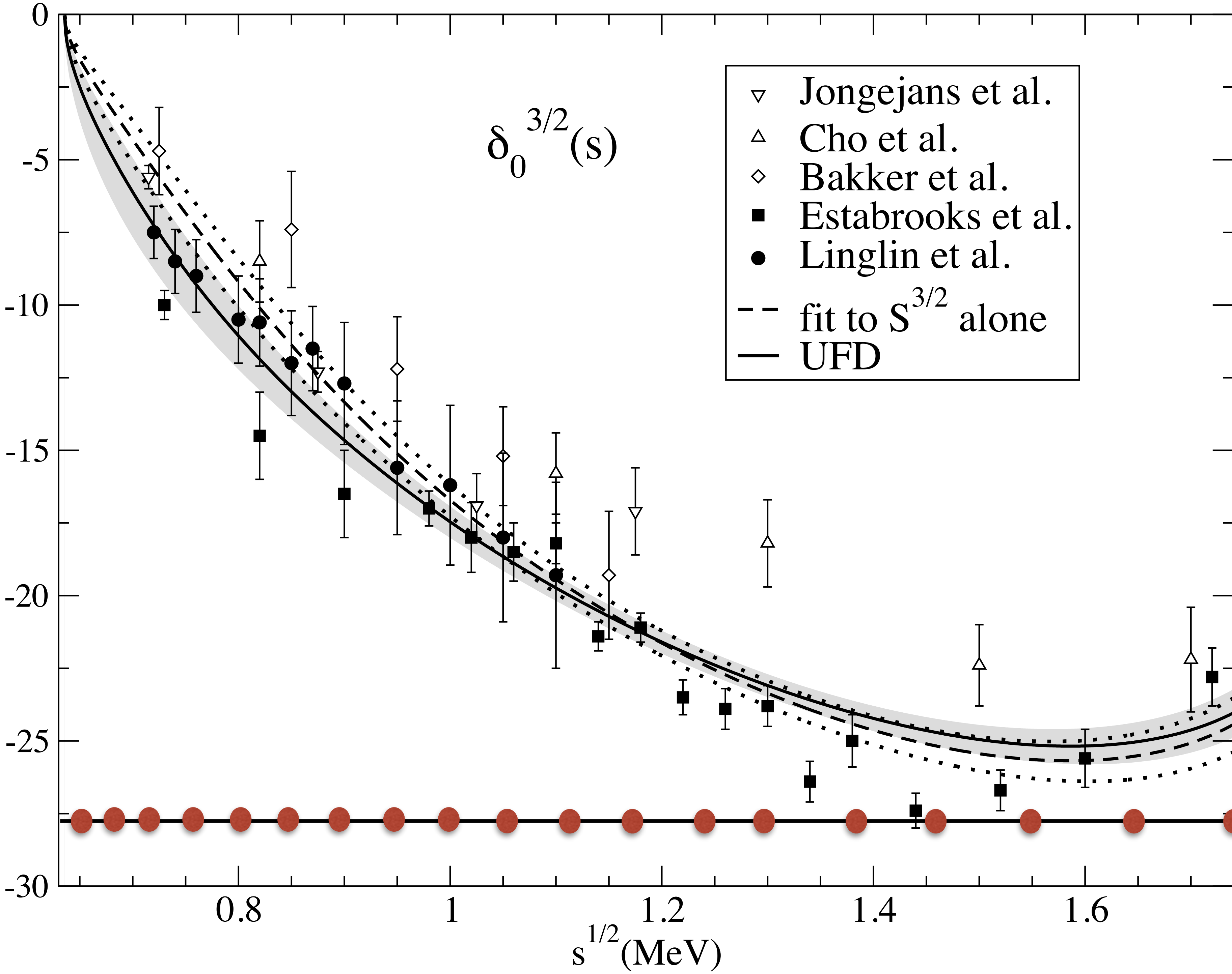
Aston(1988)

KLF (100 days)



$S^{1/2}$ (GeV)

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)

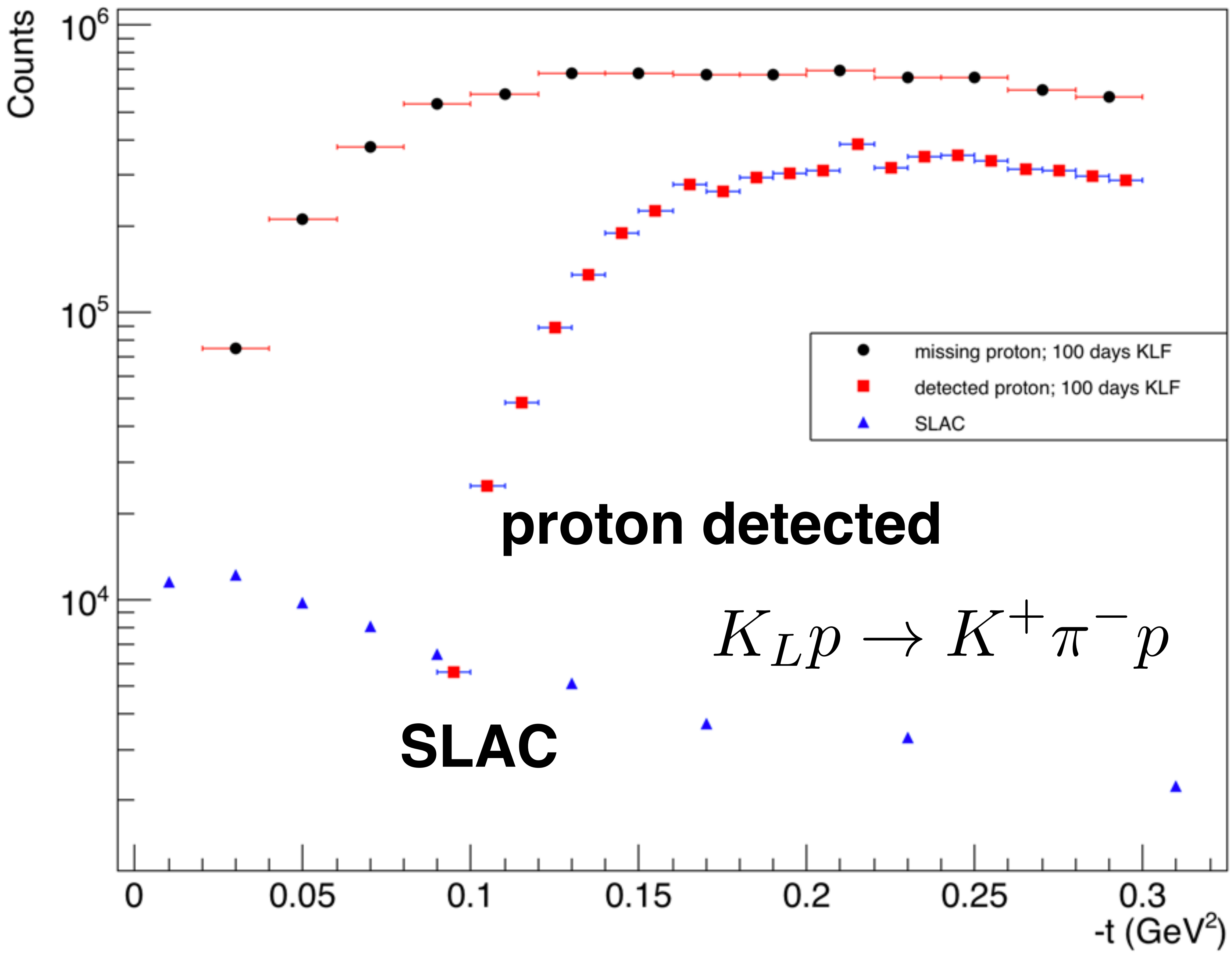
$$K^{\pm}p \rightarrow K^{\pm}\pi^{+}n$$

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

KLF 100 days

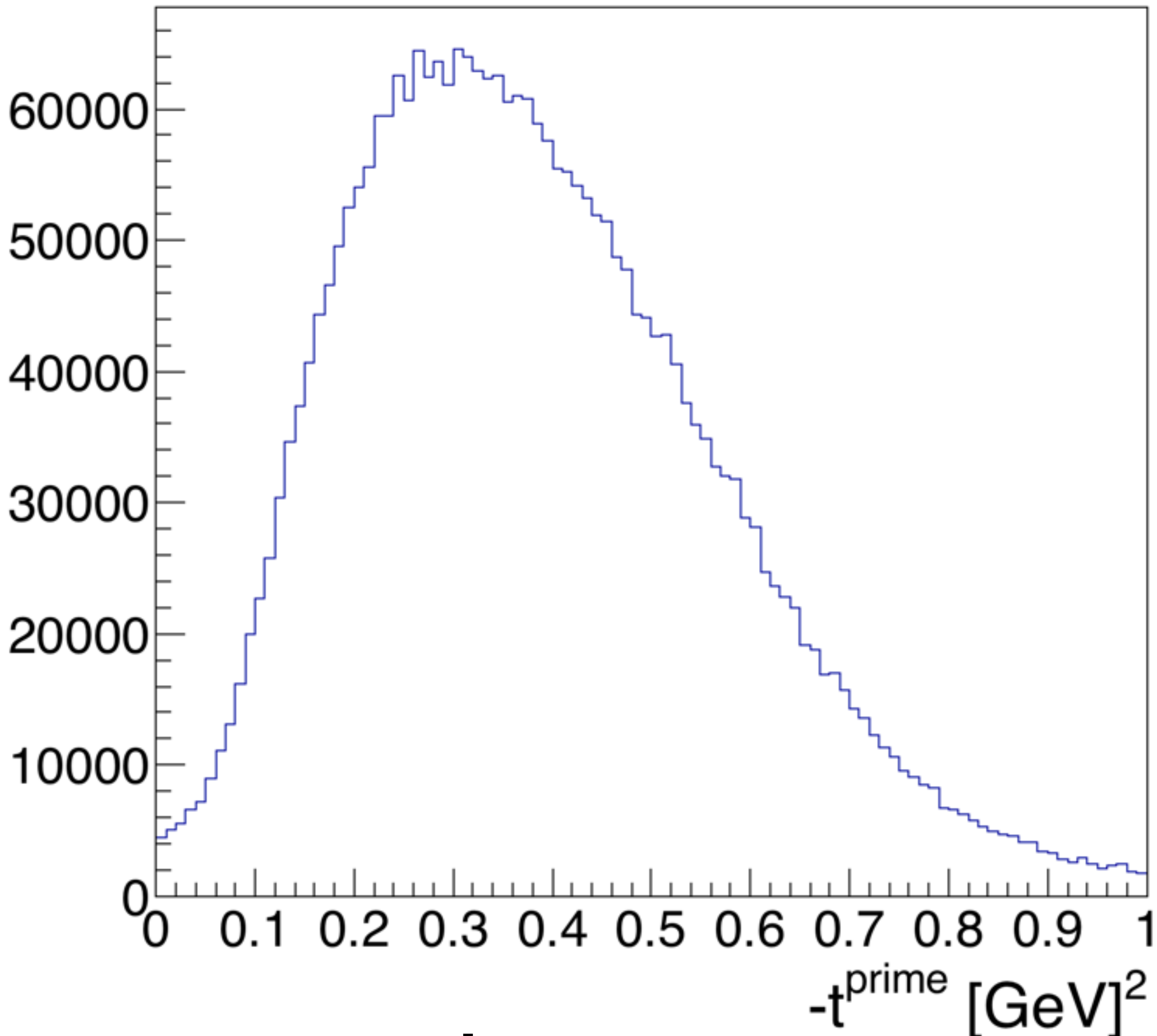
From Pelaez and Rodas paper: PRD93(2016)

100 days KLF



Counts
10^6
10^5
10^4
0
0.05
0.1
0.15
0.2
0.25
0.3
-t (GeV^2)
missing proton; 100 days KLF
detected proton; 100 days KLF
SLAC
proton detected
$K_L p \rightarrow K^+ \pi^- p$
SLAC

$$K_L p \to K^{(-,0)} \pi^{(0,-)} \Delta^{++}$$



t'=t-t$_{min}$

Phase-shift

For L=0, 1

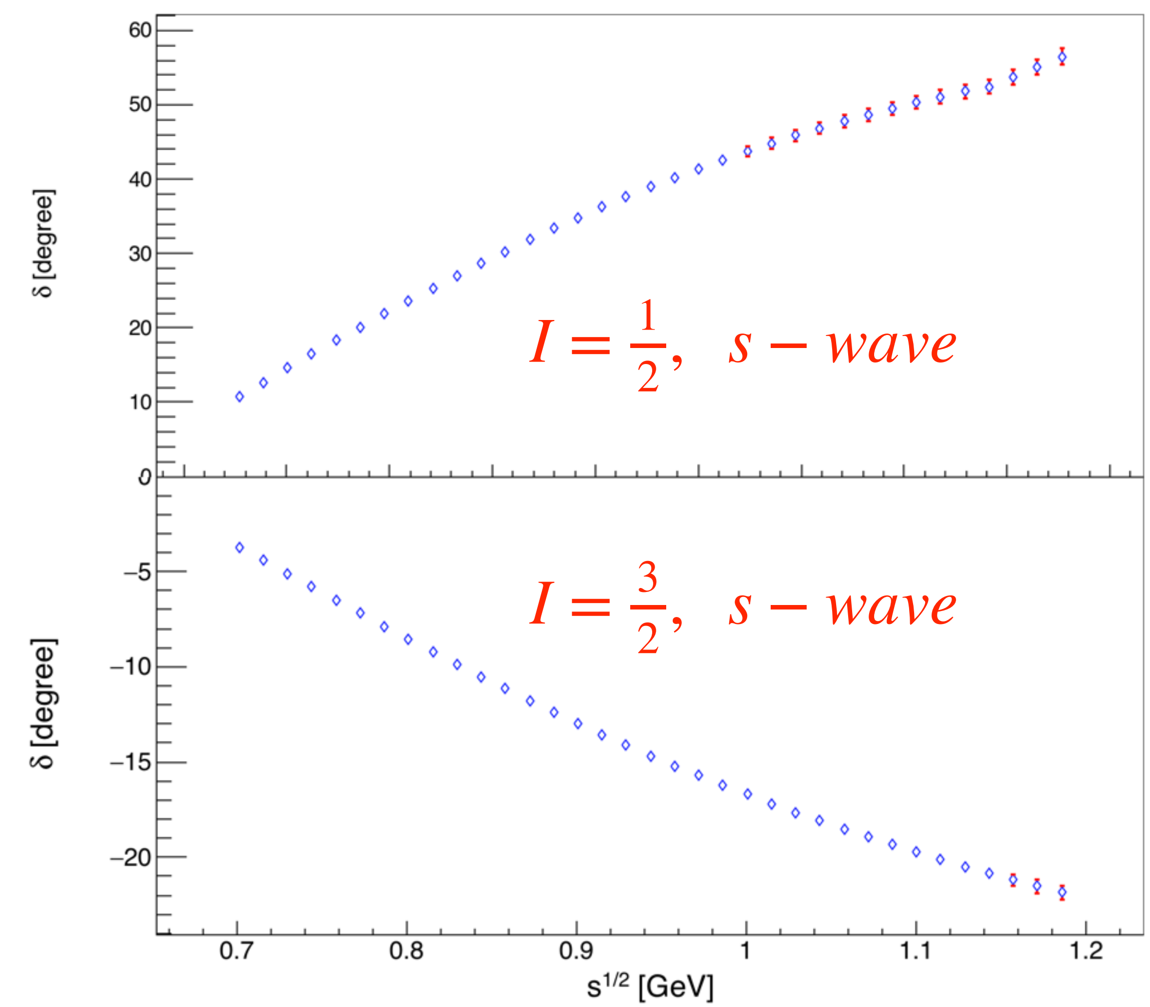
$$A^I(cos\theta_{GJ}, \phi_{GJ}) = \frac{\sqrt{4\pi}}{q_i}\sum_{l,m} a_l^I(2l+1)Y_l^m(cos\theta_{GJ}, \phi_{GJ})$$

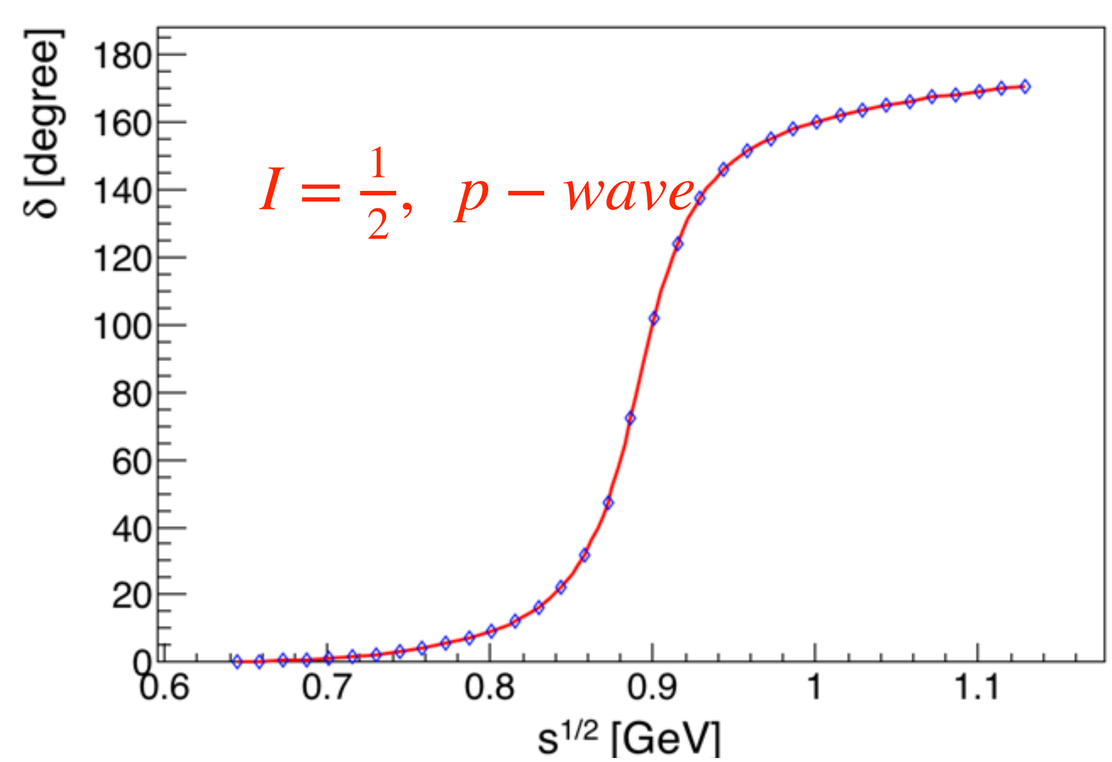
In the elastic region

$$a_L^I = a_L^{I=1/2} + \frac{1}{2}a_L^{I=3/2}$$

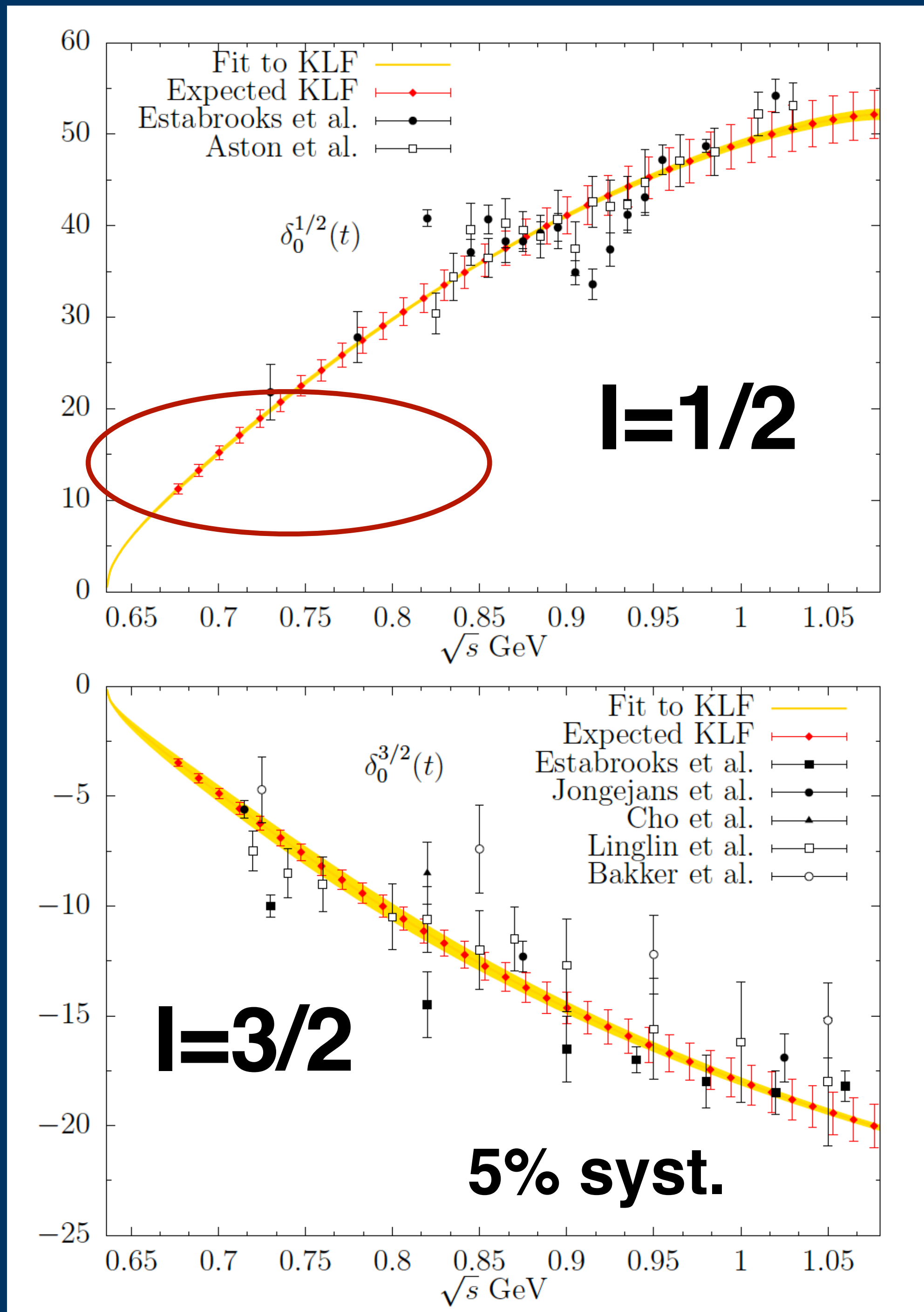
$$a_L^I = \sqrt{(2L+1)}\epsilon^I \sin\delta_L^I e^{\delta_L^I}$$

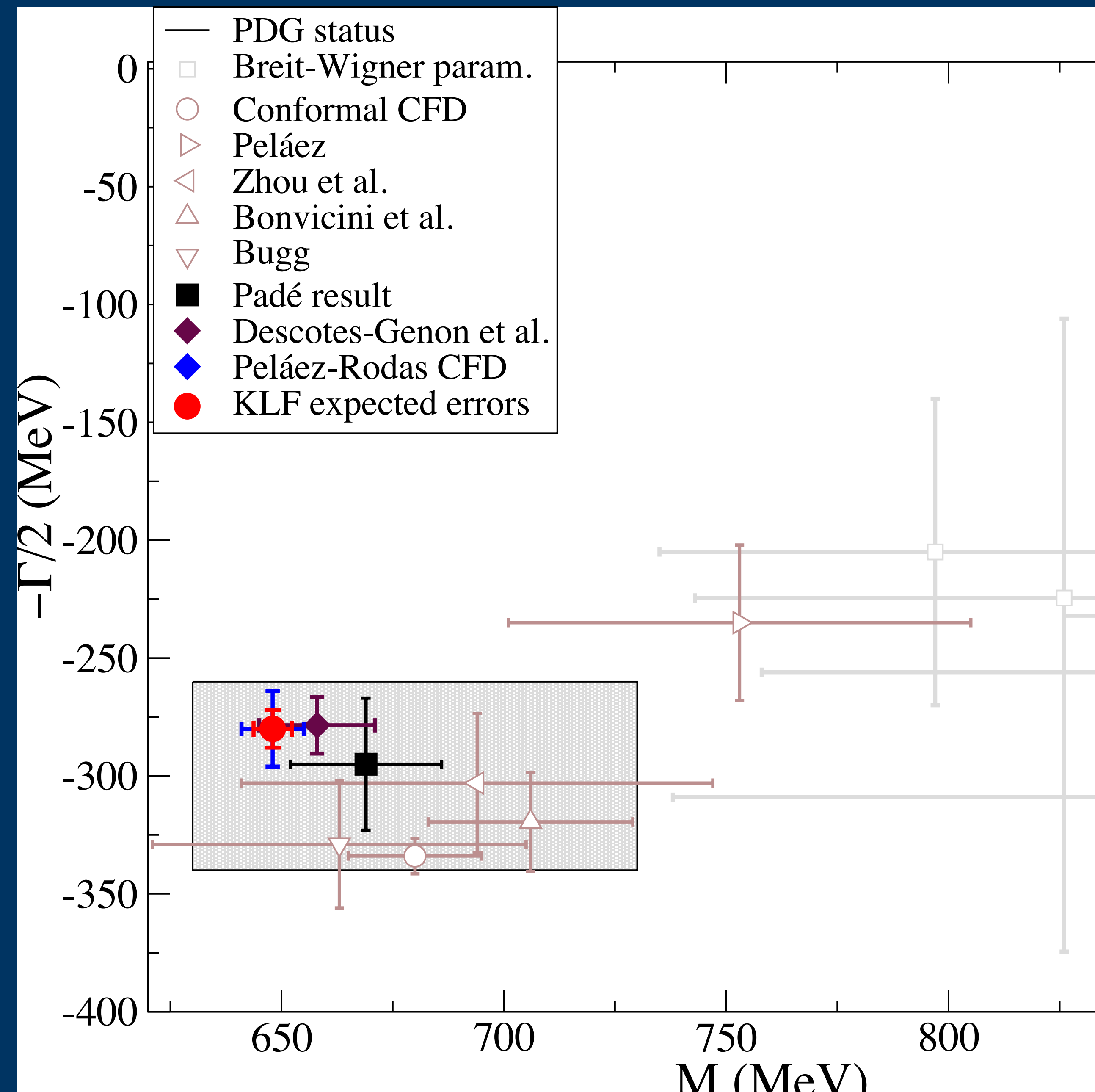
Results include statistical uncertainty only.





Kappa Mass and Width





S wave phase shift, I =1/2 and
I = 3/2 with statistical and systematic
uncertainities.

More data points are added close to threshold from KLF.

Roy-Steiner dispersion approach
J.R. Pelaez and et.al. Phys. Rev. D 93, 074025

$$\sqrt{s_\kappa} \equiv M - i\Gamma/2 = 648 \pm 4 \; - \; i280 \pm 8 \; MeV$$

Summary of $K\pi$ Scattering

-The KLF will have a very significant impact on our knowledge on $K\pi$ scattering amplitudes

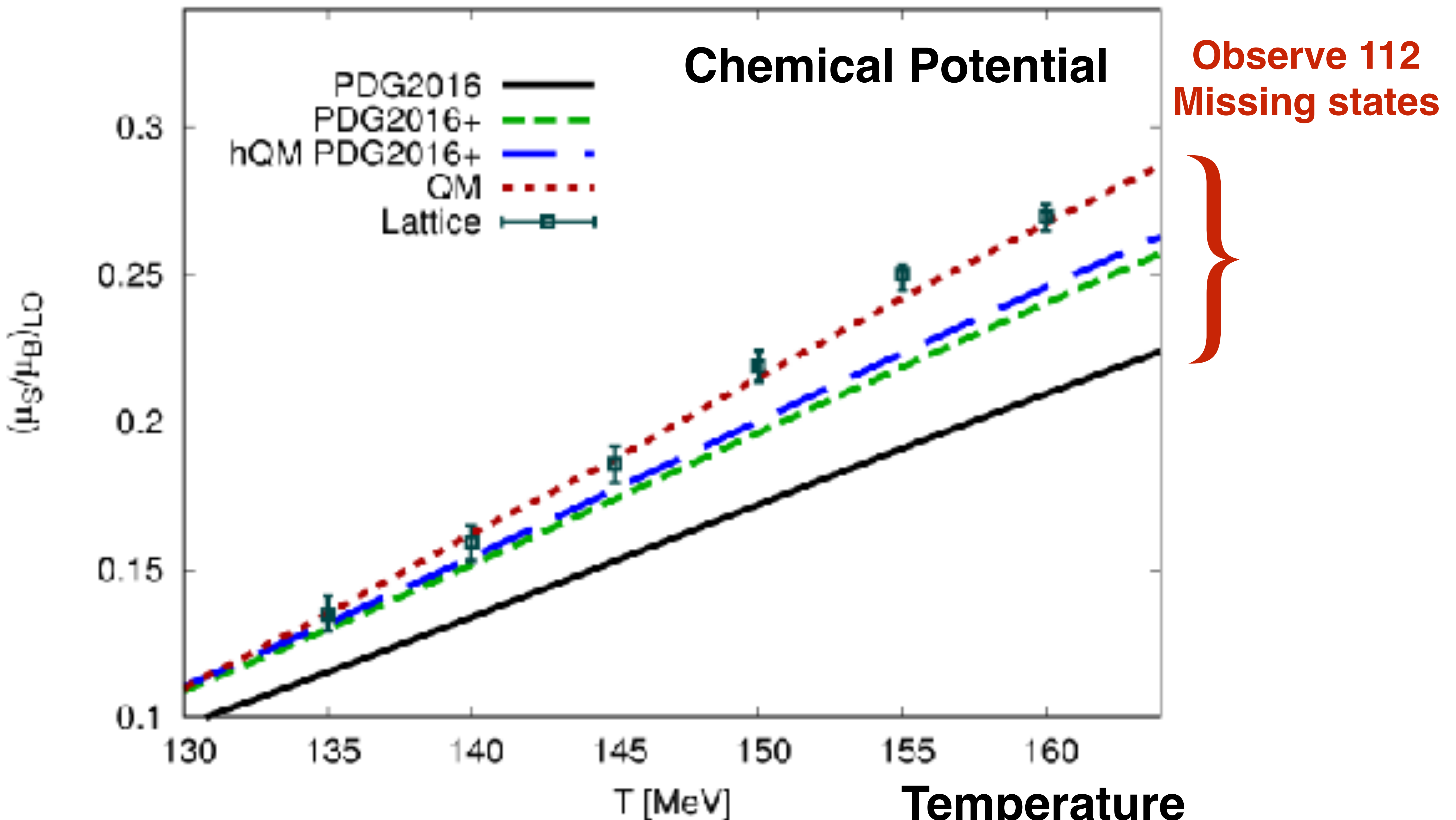
-It will certainly improve still conflictive determination of heavy K*'s parameters

-It will help to settle the tension between phenomenological determinations of scattering lengths from data versus ChPT and LQCD

-Finally, and very importantly, it will reduce by more than a factor of two the uncertainty in the mass determination of K*(700) and by factor of five the uncertainty on its width, and therefore on its coupling

-It will help to clarify debates of its existence, and therefore a long standing problem of existence of the scalar nonet

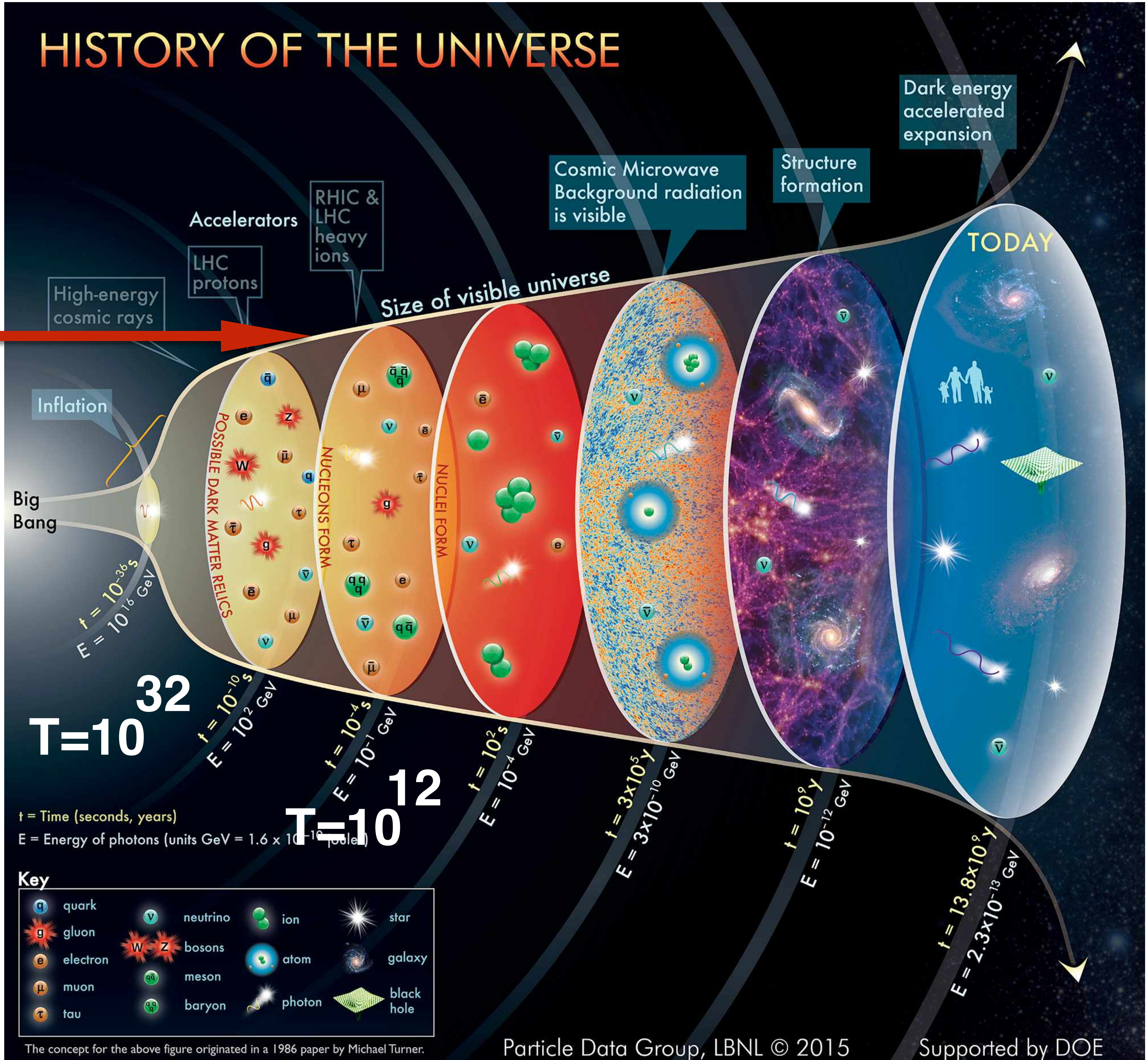
Formation of Visible Matter during the Freeze-Out of the Universe after the Big Bang



$$dU = T\,dS - p\,dV + \mu\,dN$$

$1\ \mu s$

KLF

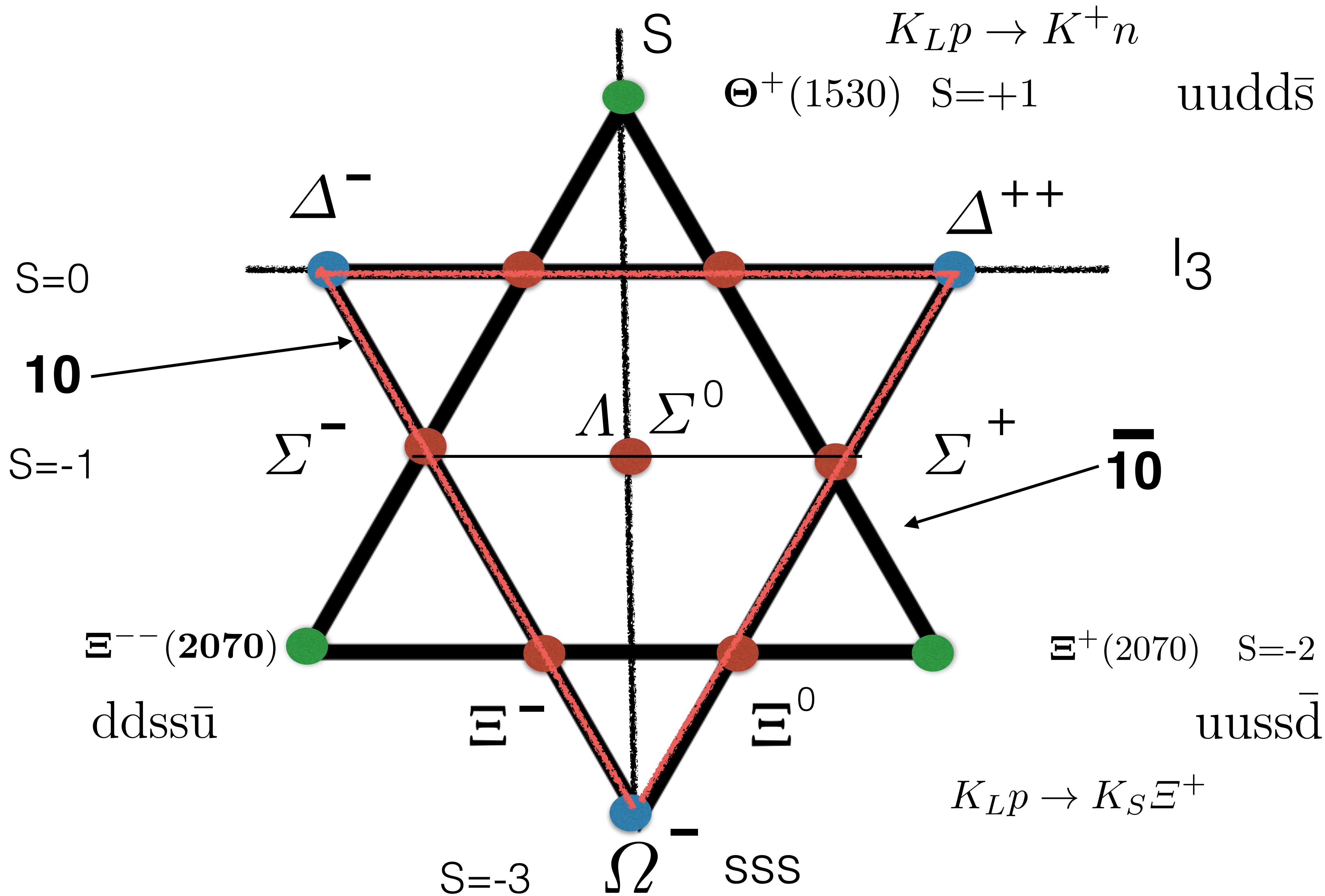


$T=10^{32}$

$T=10^{12}$

What else?

Pentaquarks



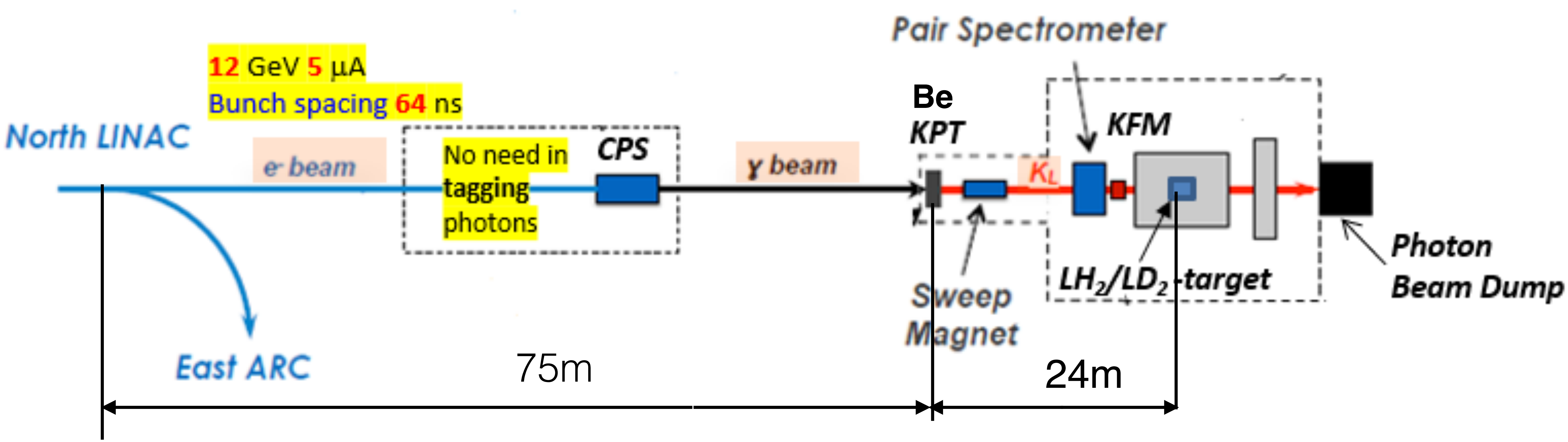
D. Diakonov, V. Petrov and M. V. Polyakov, Z. Phys. A **359**, 305 (1997).

Is everything feasible from hardware point of view?

Next few slides will answer this question.

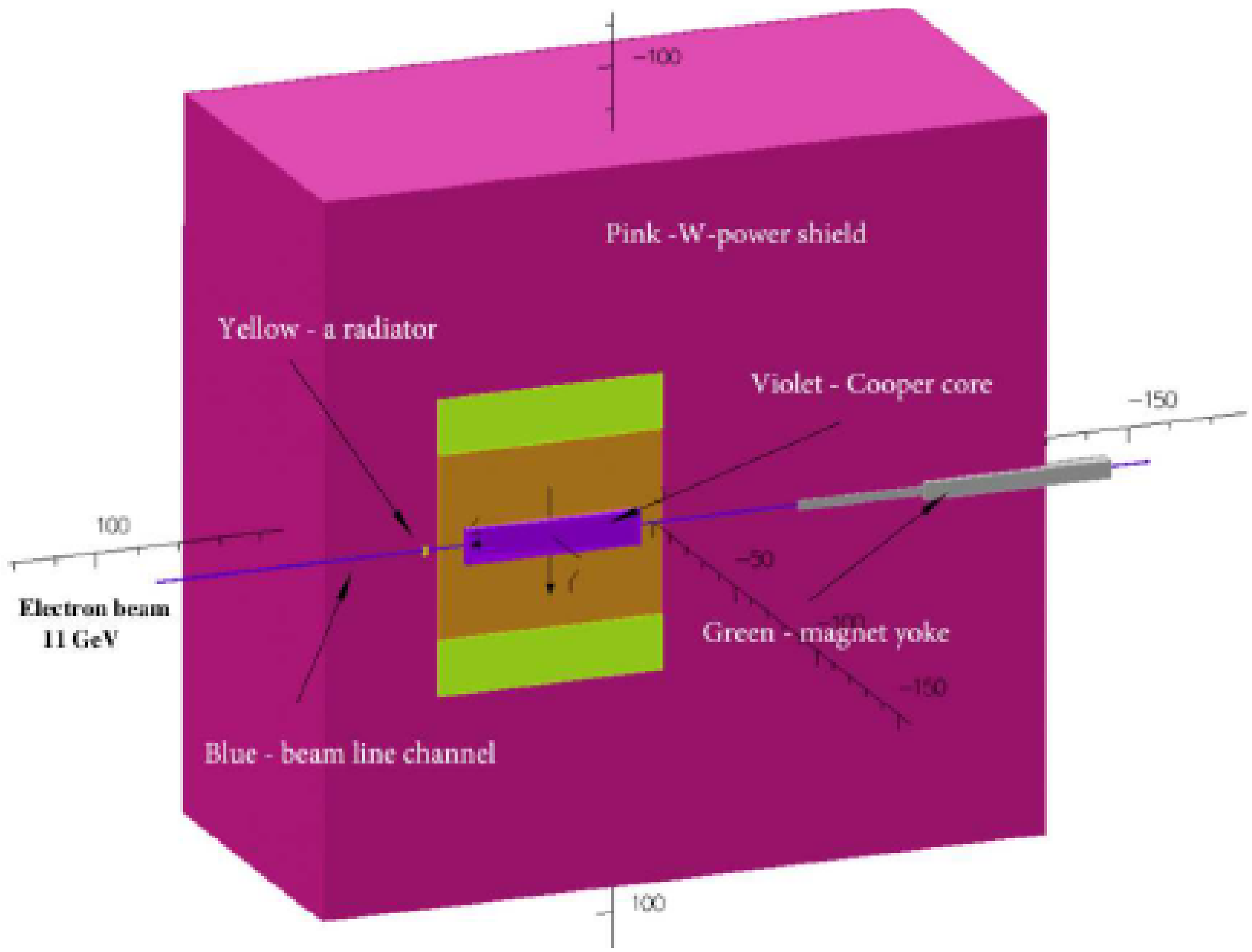
Reminder:

Hall-D beamline and GlueX Setup



https://arxiv.org/pdf/2008.08215.pdf

Compact Photon Source



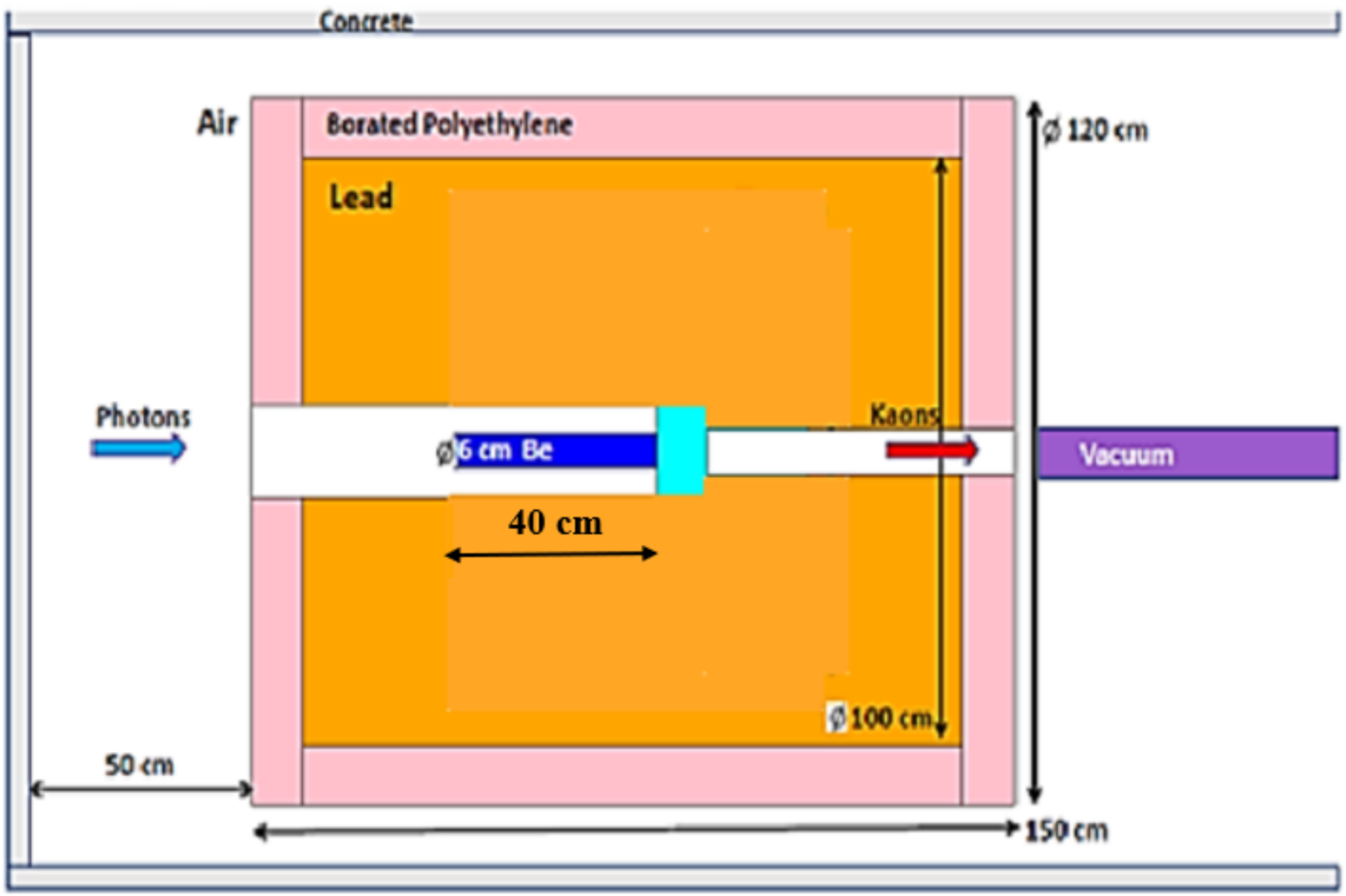
Conceptual design is completed for Halls A&C

The details of the CPS are designed by the CPS Collaboration

Meets RadCon Radiation Requirements

Paper published in NIM, A957(2020)

Be Target Assembly: Conceptual Design

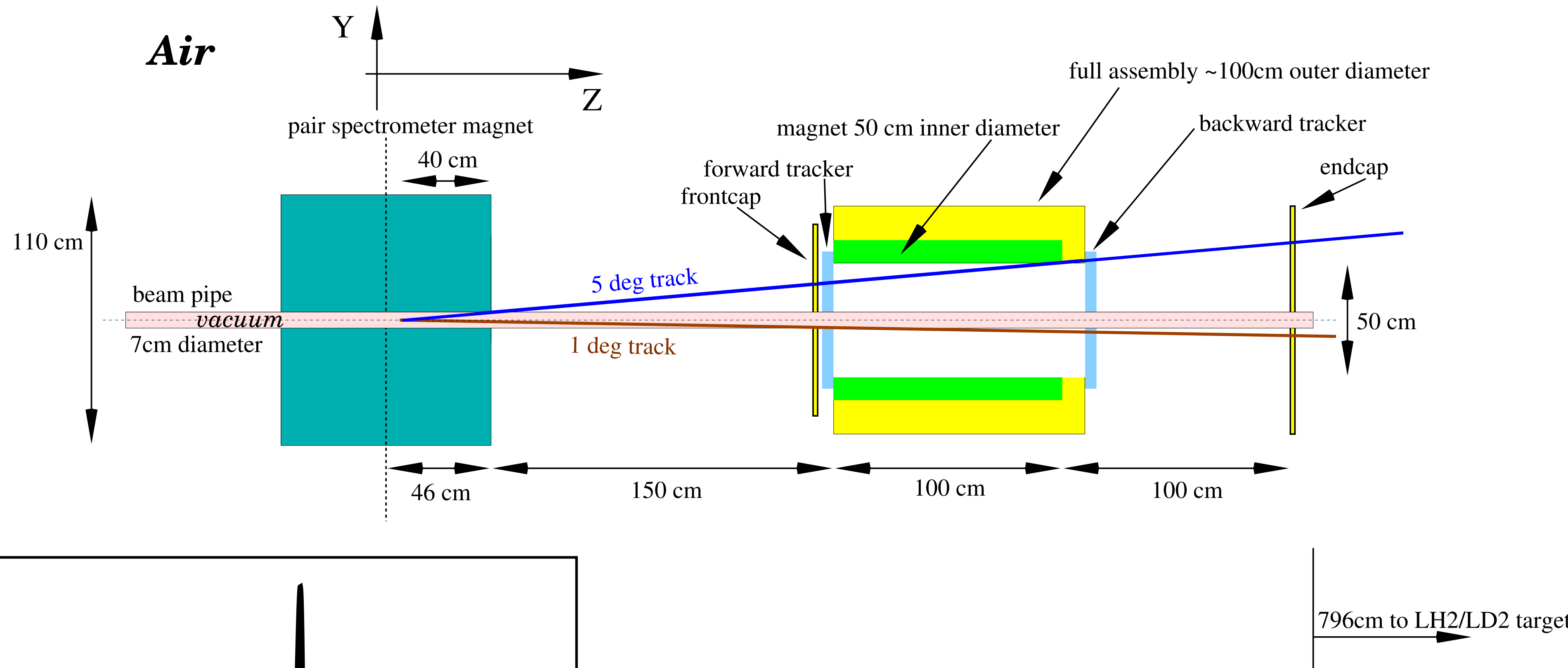


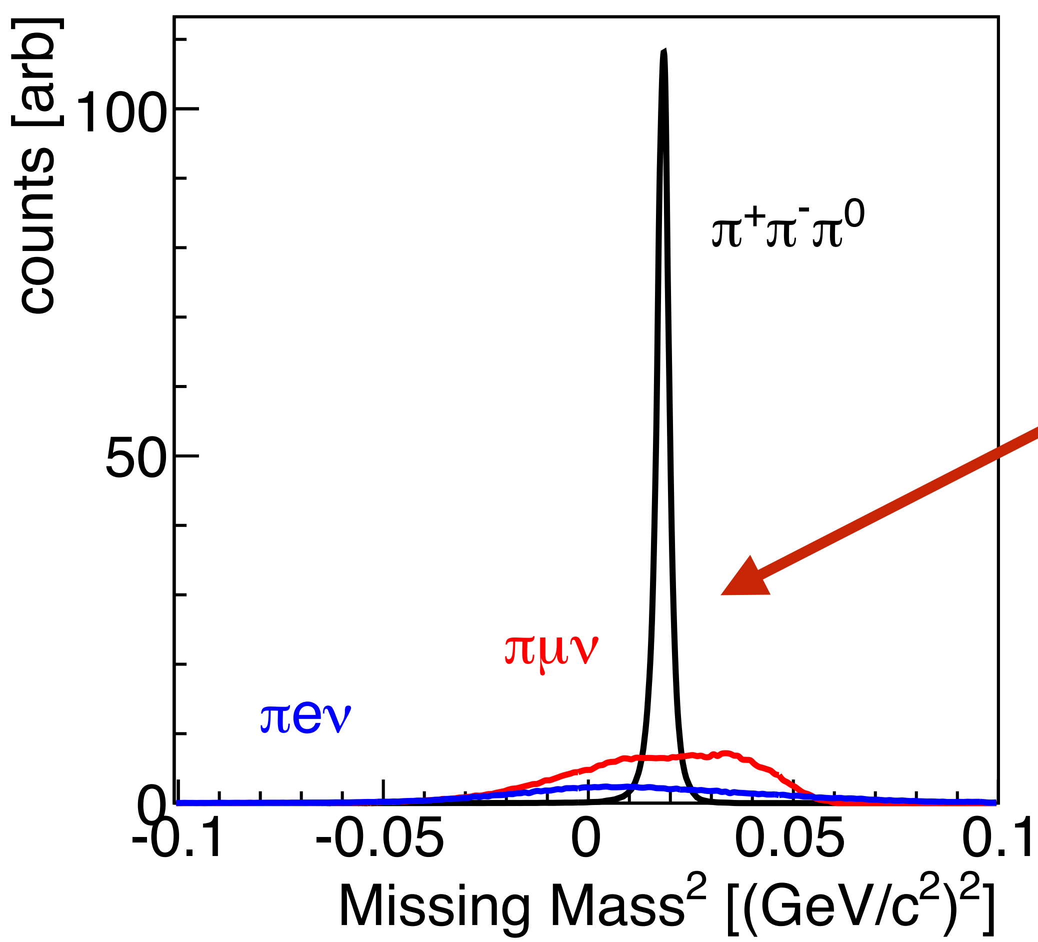
-Meets RadCon Radiation Requirements

-Conceptual Design Endorsed by Hall-D Engineering Staff

arXiv: 2002.04442

Flux Monitor





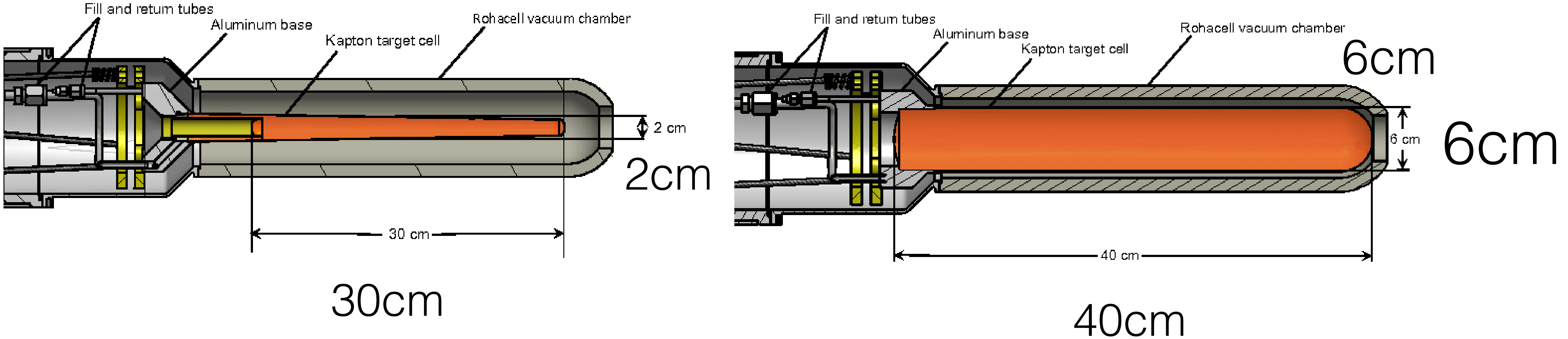
Reconstructed K_L mass

Flux measurement stat. err. <1%

Estimated conservative syst. err. ~5%

LH_2/LD_2 Cryogenic Target for Neutral Kaon Beam at Hall D

The GlueX liquid hydrogen target.



Current

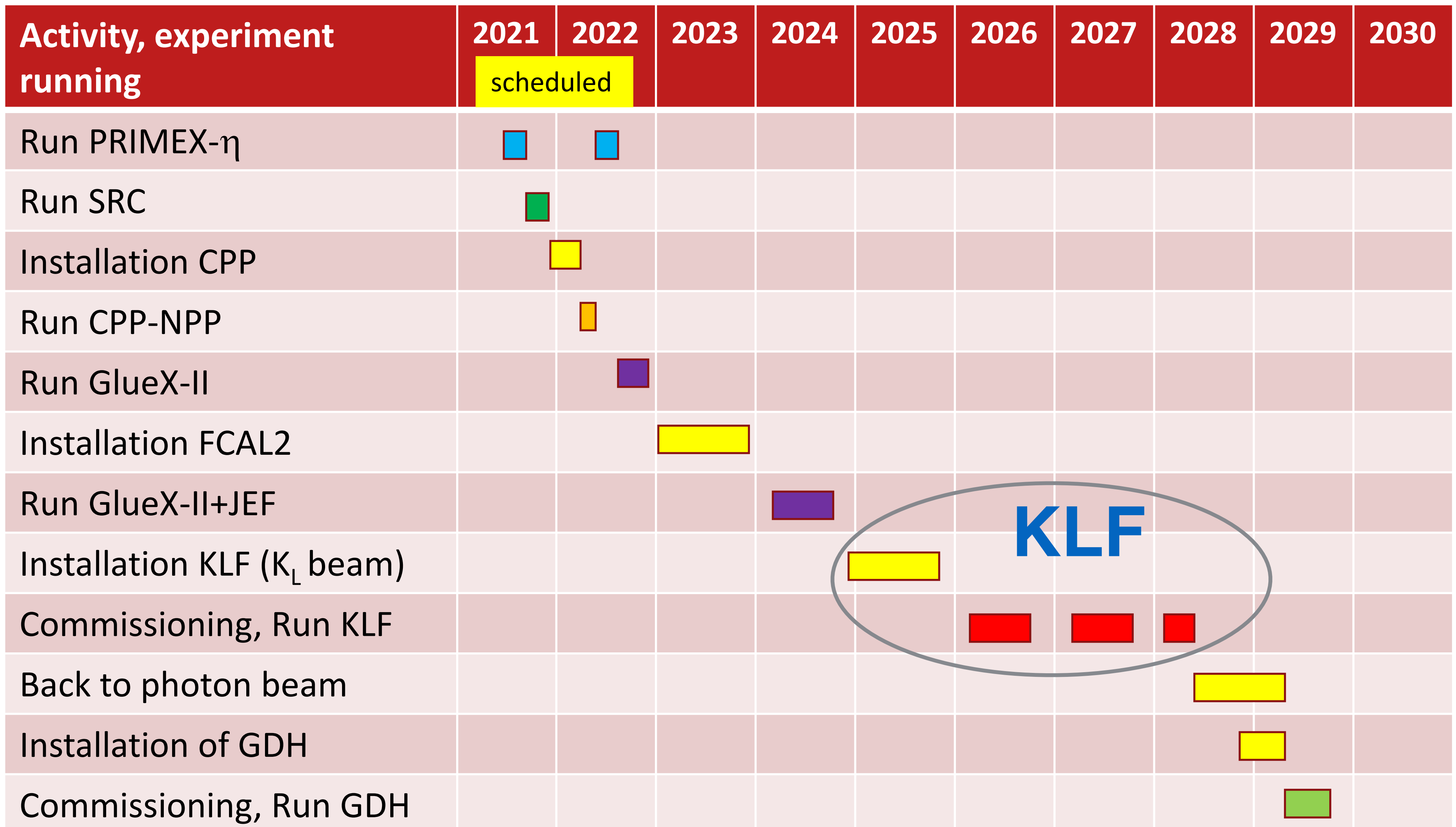
Proposed & Feasible

Longer and ticker target is needed to enhance production rate

Conceptual design has been endorsed by the JLAB target group

Timeline of Design, Construction and Installation

Scheduling Outlook

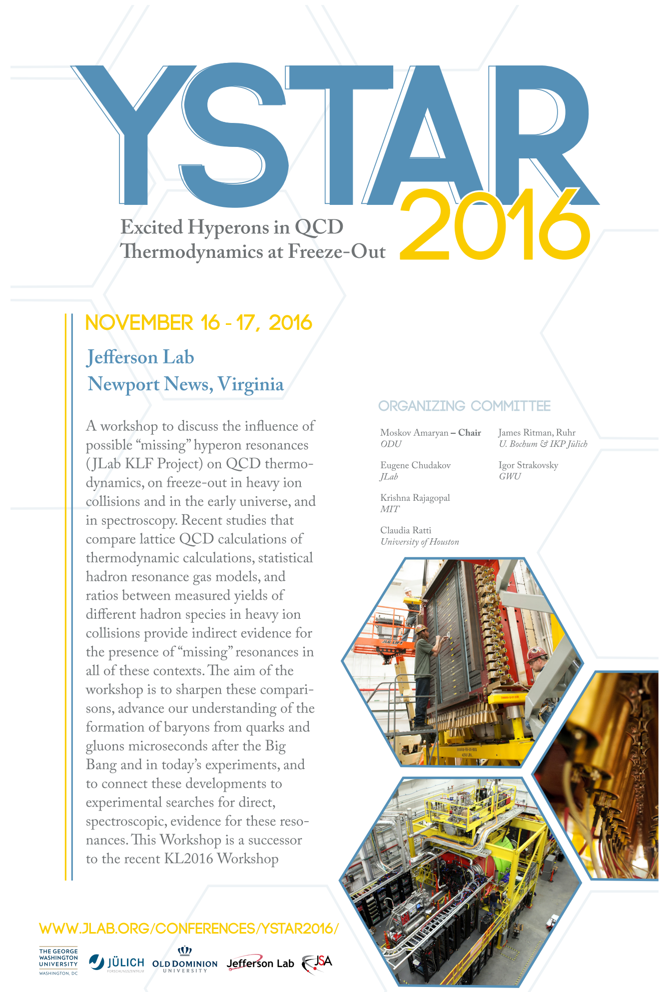


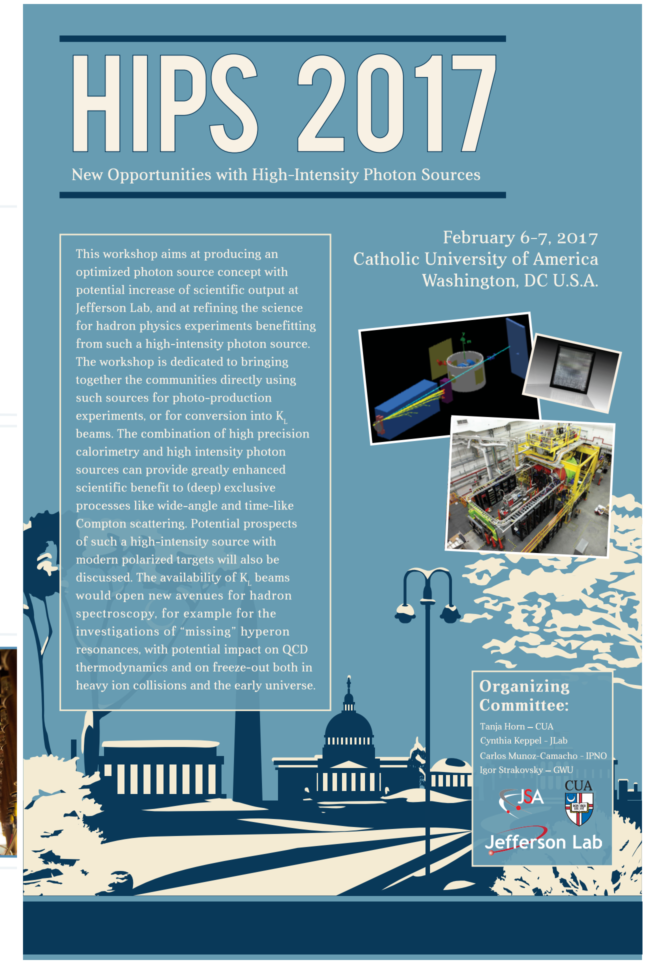
- Assumed 25 weeks/year for Hall D running
- Assumed timely budgeting for KLF and GDH
- Assumed timely construction of JEF,KLF,GDH

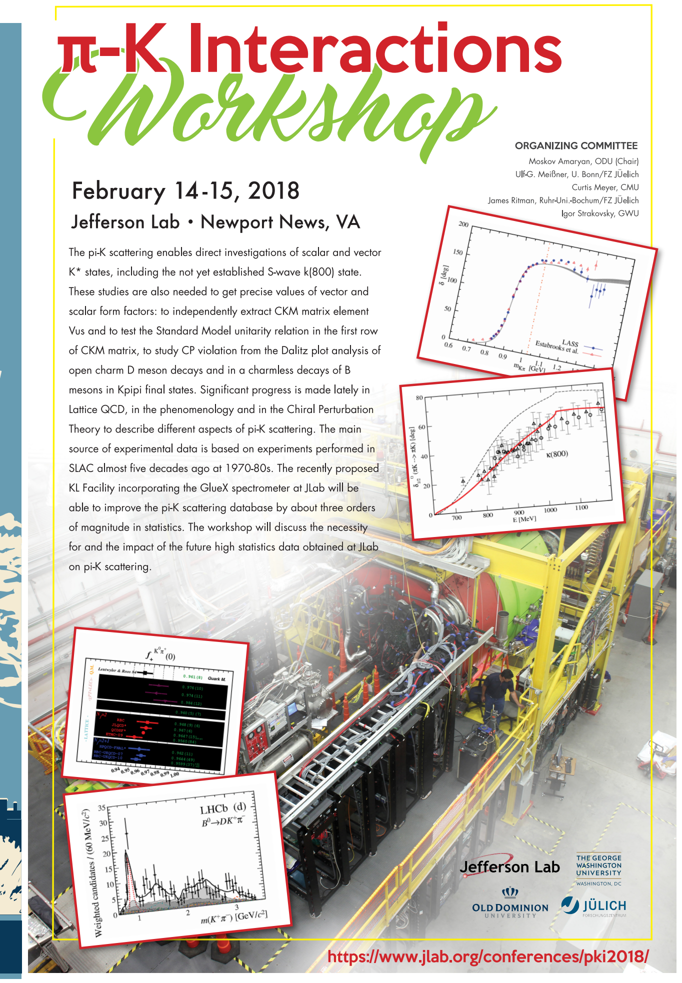
Jefferson Lab

E. Chudakov
GlueX Coll. Meeting, Oct. 2021

The Facility is Flexible and can be switched back to photon beam







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 spectrosocopy
  PWA will allow to unravel and measure pole positions and widths of a few dozens of new excited
- -In Strange Meson Spectroscopy
  PWA will allow to measure excited K* states
- To accomplish physics program 200 days running is approved
- All components of KL Facility considered are feasible

  -With total cost of the project below 5M

At the end we would like to invite everyone to join us.

Thank you !