KLF@JLab

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STRONG2020, Munich, September 13-16, 2022

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

-Physics Motivation

- 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

Proposal for JLab PAC48

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

Shankar Adhikari[43], Moskov Amaryan (Contact Person, Spokesperson)[43], Arshak Asaturyan[1], Alexander Austregesilo[49], Marouen Baalouch[8], Mikhail Bashkanov (Spokesperson)[63], Vitaly Baturin[43], Vladimir Berdnikov[11,35], Olga Cortes Becerra[19], Timothy Black[60], Werner Boeglin[13], William Briscoe[19], William Brooks[54], Volker Burkert[49], Eugene Chudakov[49], Geraint Clash[63], Philip Cole[32], Volker Crede[14], Donal Day[61], Pavel Degtyarenko[49], Alexandre Deur[49], Sean Dobbs (Spokesperson)[14], Gail Dodge[43], Anatoly Dolgolenko[26], Simon Eidelman[6,41], Hovanes Egiyan (JLab Contact Person)[49], Denis Epifanov[6,41], Paul Eugenio[14], Stuart Fegan[63], Alessandra Filippi[25], Sergey Furletov[49], Liping Gan[60], Franco Garibaldi[24], Ashot Gasparian[39], Gagik Gavalian[49], Derek Glazier[18], Colin Gleason[22], Vladimir Goryachev[26], Lei Guo[14], David Hamilton[11], Avetik Hayrapetyan[17], Garth Huber[53], Andrew Hurley[56], Charles Hyde[43], Isabella Illari[19], David Ireland[18], Igal Jaegle[49], Kyungseon Joo[57], Vanik Kakoyan[1], Grzegorz Kalicy[11], Mahmoud Kamel[13], Christopher Keith[49], Chan Wook Kim[19], Eberhard Klemp[5], Geoffrey Krafft[49], Sebastian Kuhn[43], Sergey Kuleshov[2], Alexander Laptev[33], Ilya Larin[26,59], David Lawrence[49], Daniel Lersch[14], Wenliang Li[56], Kevin Luckas[28], Valery Lyubovitskij[50,51,52,54], David Mack[49], Michael McCaughan[49], Mark Manley[30], Hrachya Marukyan[1], Vladimir Matveev[26], Mihai Mocanu[63], Viktor Mokeev[49], Curtis Meyer[9], Bryan McKinnon[18], Frank Nerling[15,16], Matthew Nicol[63], Gabriel Niculescu[27], Alexander Ostrovidov[14], Zisis Papandreou[53], KiJun Park[49], Eugene Pasyuk[49], Peter Pauli[18], Lubomir Pentchev[49], William Phelps[10], John Price[7], Jörg Reinhold[13], James Ritman (Spokesperson)[28,68], Dimitri Romanov[26], Carlos Salgado[40], Todd Satogata[49], Susan Schadmand[28], Amy Schertz[56], Axel Schmidt[19], Daniel Sober[11], Alexander Somov[49], Sergei Somov[35], Justin Stevens (Spokesperson)[56], Igor Strakovsky (Spokesperson)[19], Victor Tarasov[26], Simon Taylor[49], Annika Thiel[5], Guido Maria Urciuoli[24], Holly Szumila-Vance[19], Daniel Watts[63], Lawrence Weinstein[43], Timothy Whitlatch[49], Nilanga Wickramaarachchi[43], Bogdan Wojtsekhowski[49], Nicholas Zachariou[63], Jonathan Zarling[53], Jixie Zhang[61]

Theoretical Support:

Alexey Anisovich[5,44], Alexei Bazavov[38], Rene Bellwied[21], Veronique Bernard[42], Gilberto Colangelo[3], Aleš Cieplý[46], Michael Döring[19], Ali Eskanderian[19], Jose Goity[20,49], Helmut Haberzettl[19], Mirza Hadžimehmedović[55], Robert Jaffe[36], Boris Kopeliovich[54], Heinrich Leutwyler[3], Maxim Mai[19], Terry Mart[65], Maxim Matveev[44], Ulf-G. Meißner[5,29], Colin Morningstar[9], Bachir Moussallam[42], Kanzo Nakayama[58], Wolfgang Ochs[37], Youngseok Oh[31], Rifat Omerovic[55], Hedim Osmanović[55], Eulogio Oset[62], Antimo Palano[64], Jose Peláez[34], Alessandro Pilloni[66,67], Maxim Polyakov[48], David Richards[49], Arkaitz Rodas[49,56], Dan-Olof Riska[12], Jacobo Ruiz de Elvira[3], Hui-Young Ryu[45], Elena Santopinto[23], Andrey Sarantsev[5,44], Jugoslav Stahov[55], Alfred Švarc[47], Adam Szczepaniak[22,49], Ronald Workman[19], Bing-Song Zou[4]

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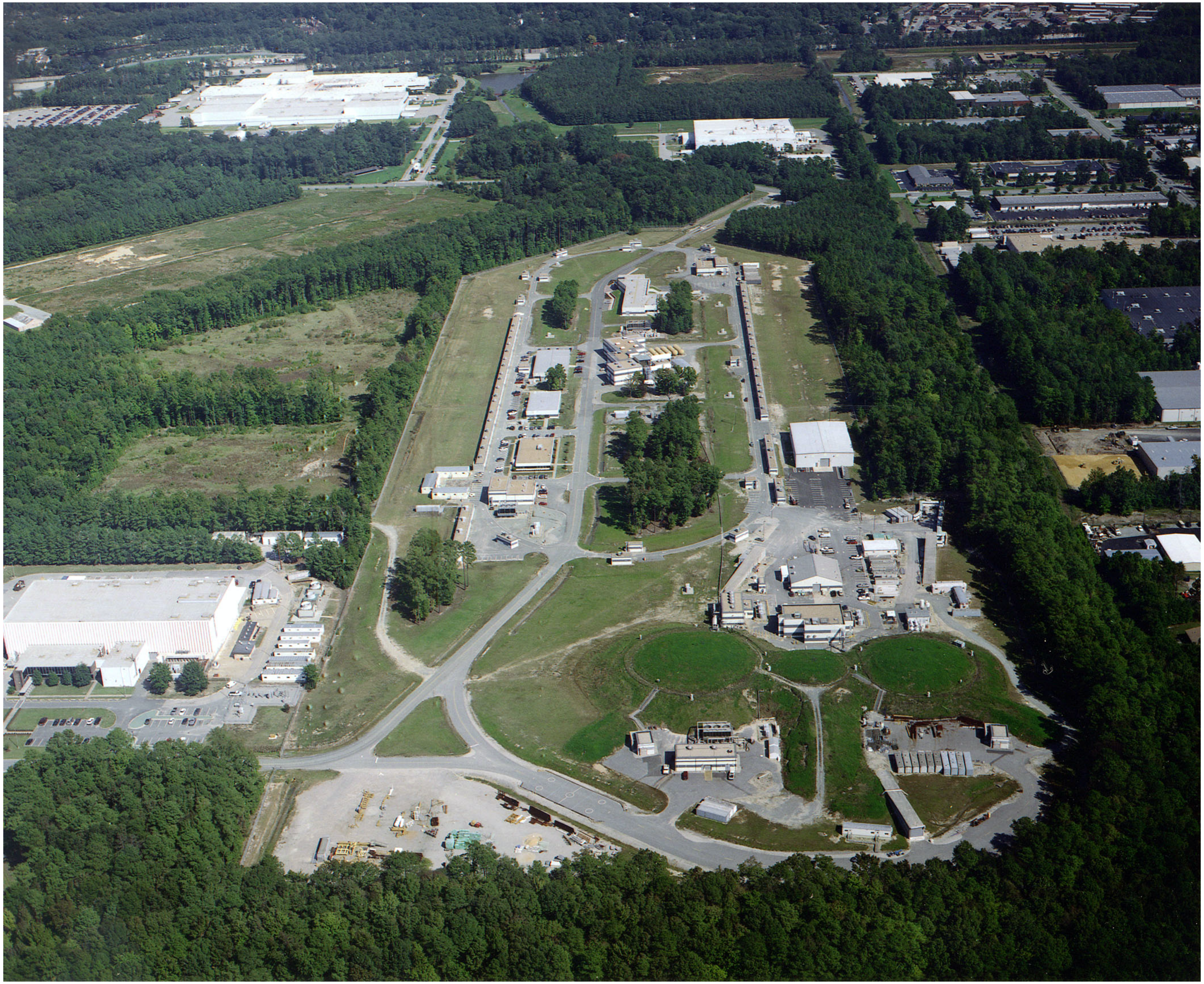
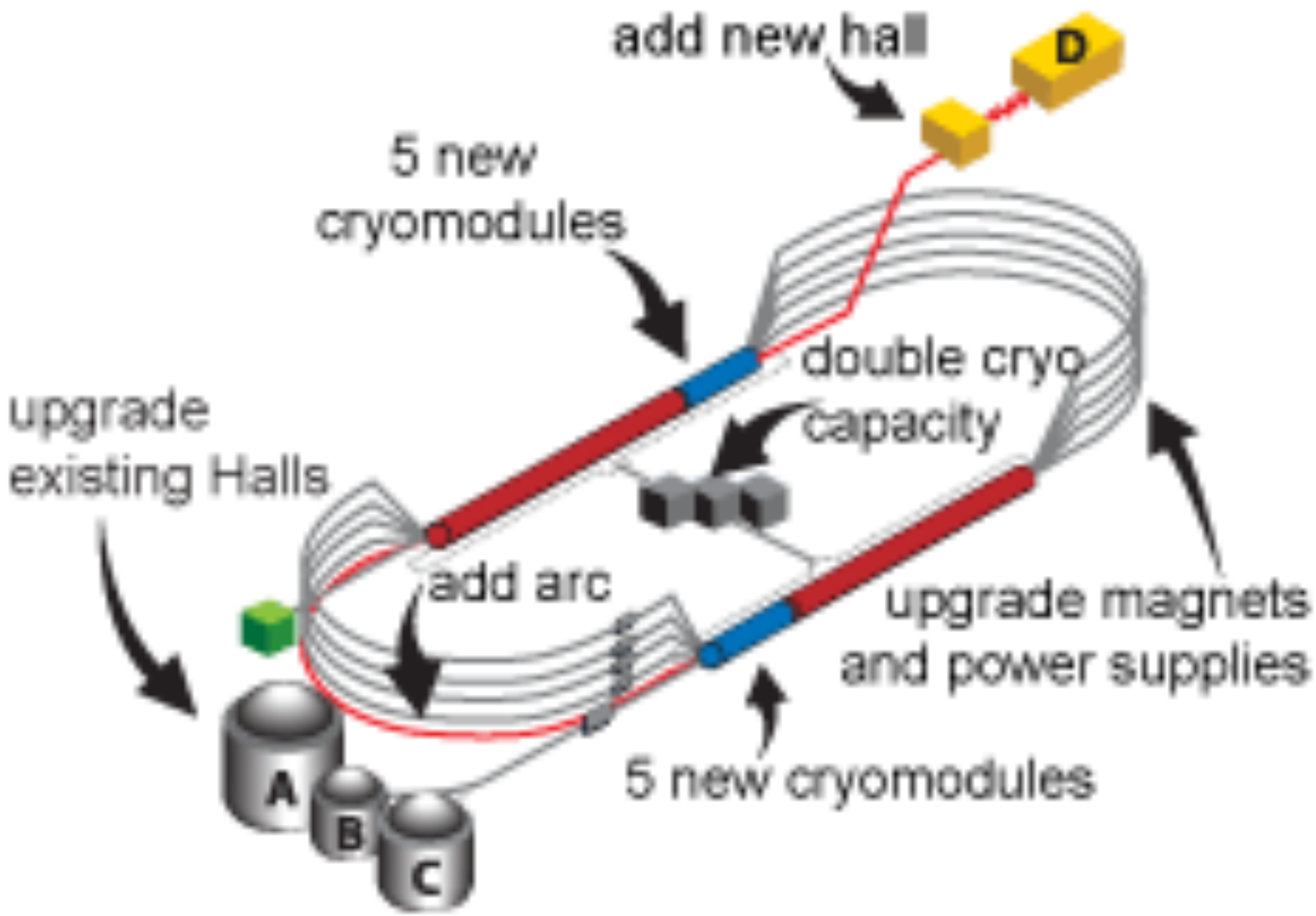
Thomas Jefferson National Accelerator Facility
Newport News, Virginia, Aerial View.

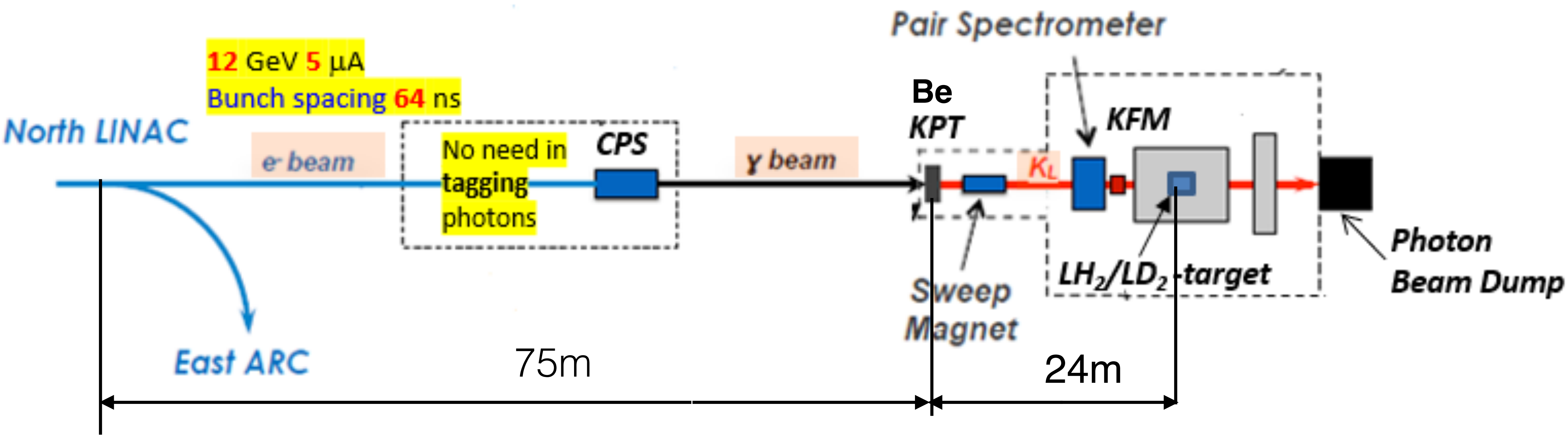


Continuous Electron Beam Acccelerator Facility (CEBAF)

12 GeV Electron Beam



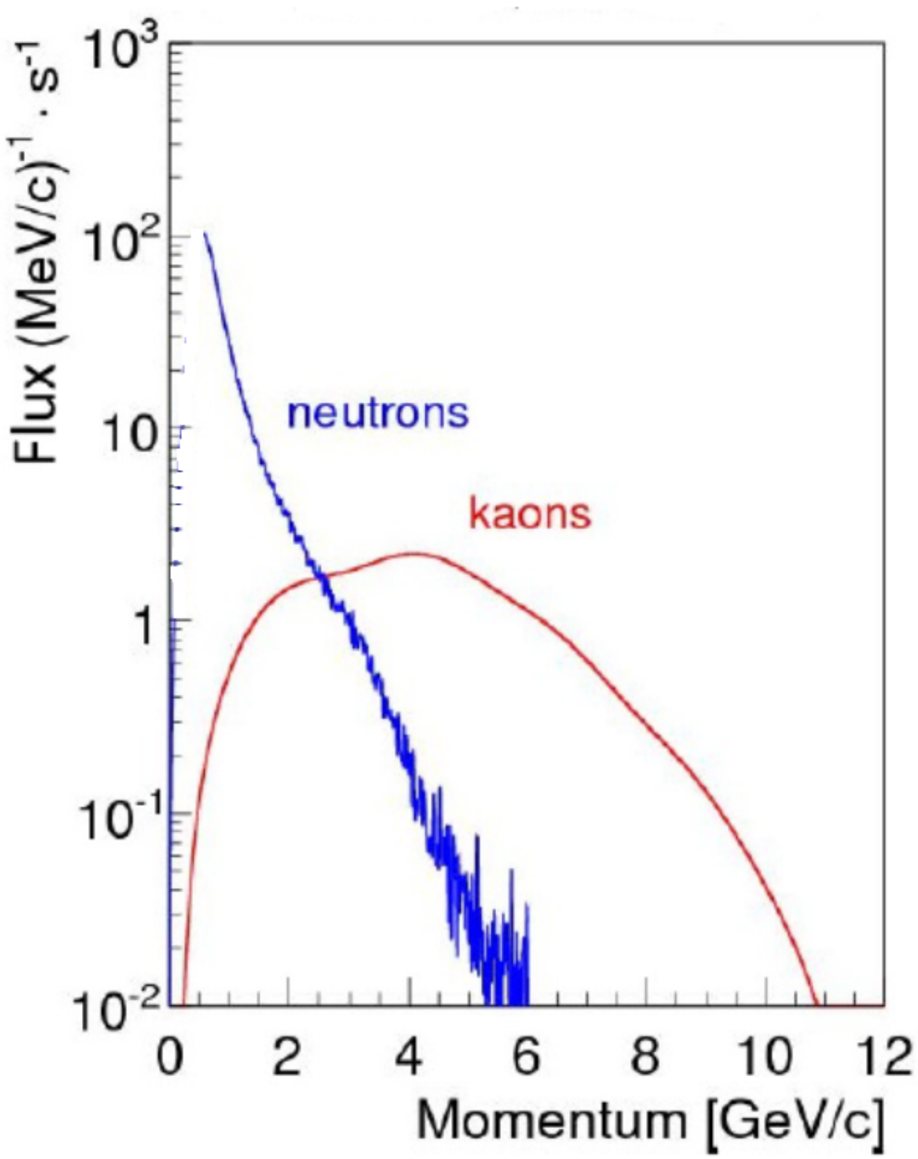
Hall-D beamline and GlueX Setup



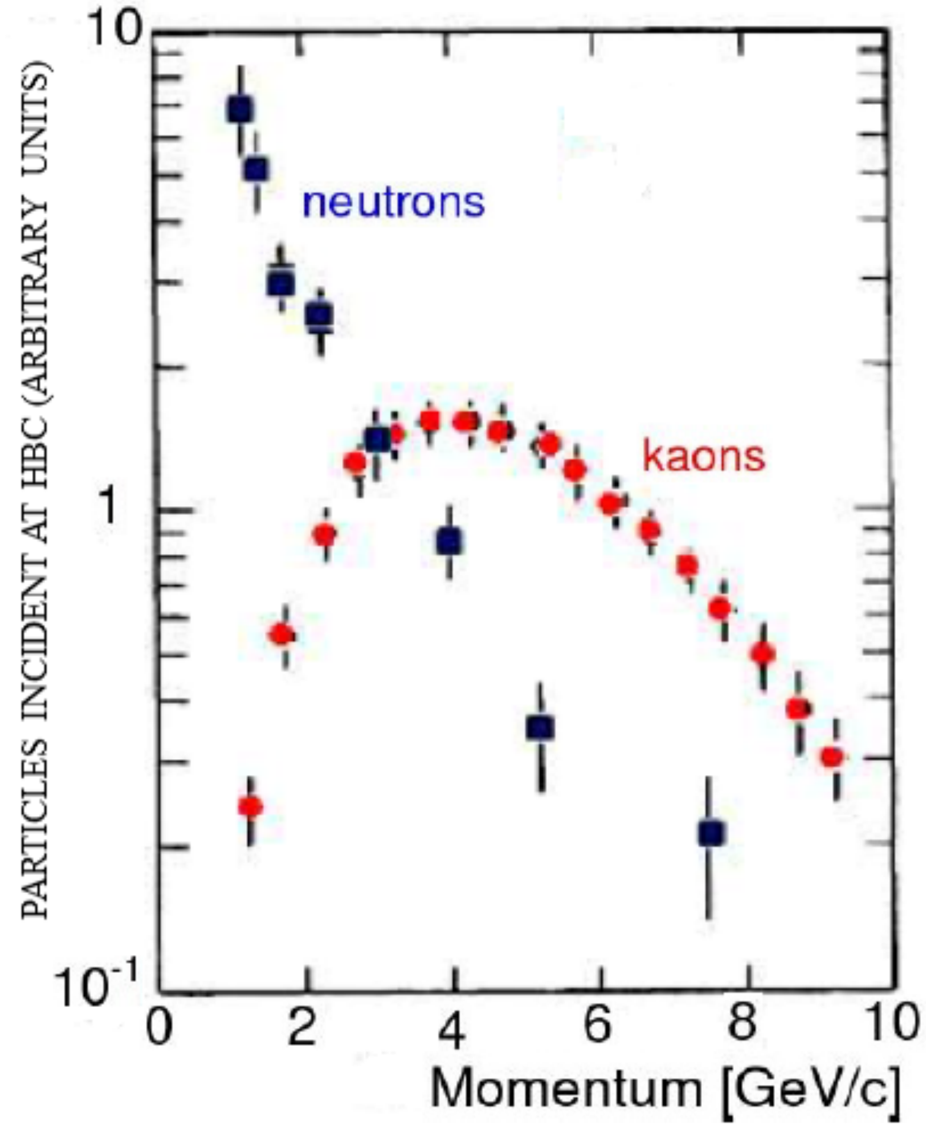
https://arxiv.org/pdf/2008.08215.pdf

K_L Beam Flux

JLab 12 GeV



SLAC 16 GeV



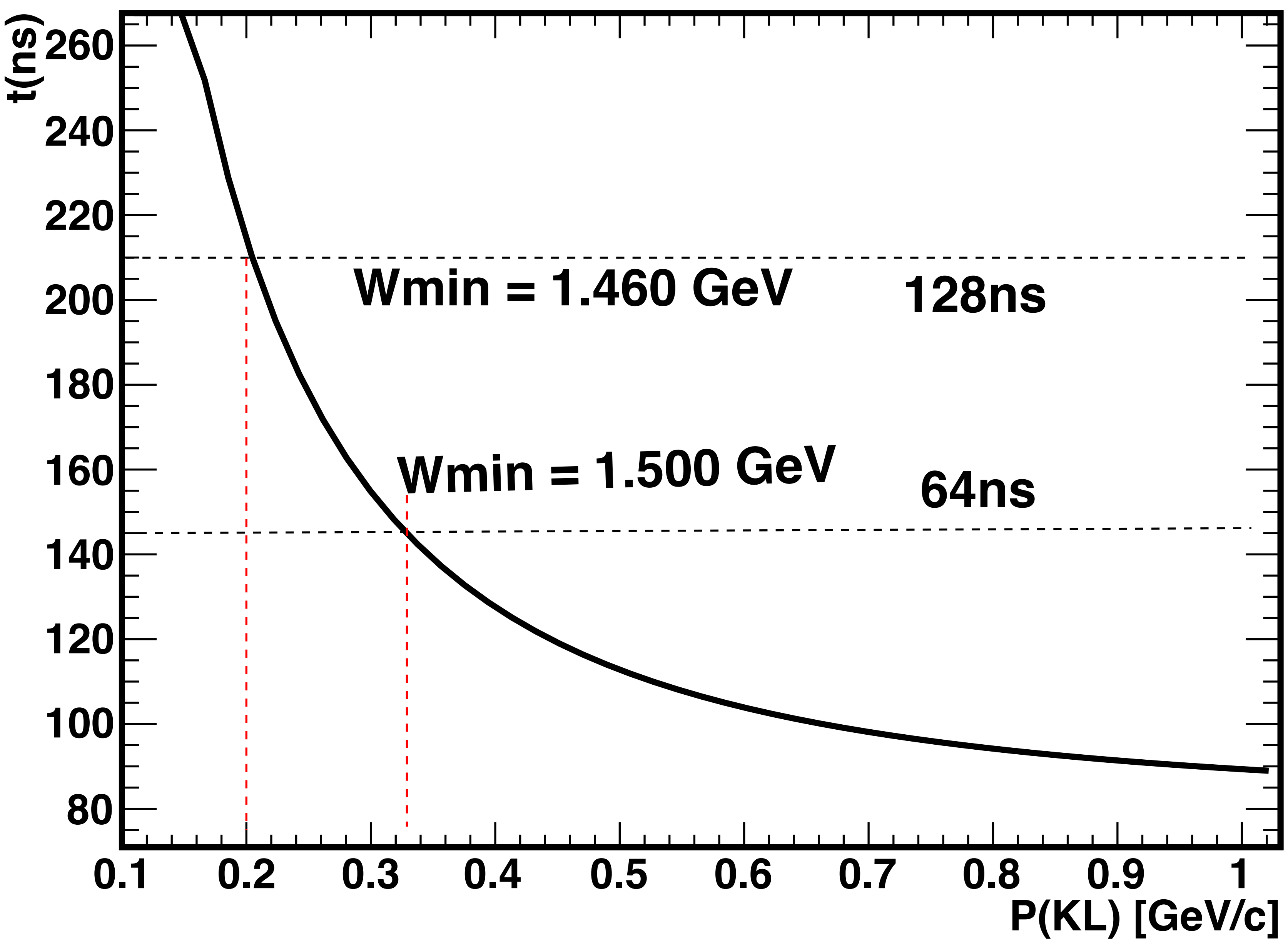
$$N(K_L)/sec \sim 10^4 \rightarrow \frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

Electron Beam Parameters

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

Bunch spacing $\quad 64\ ns$

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.

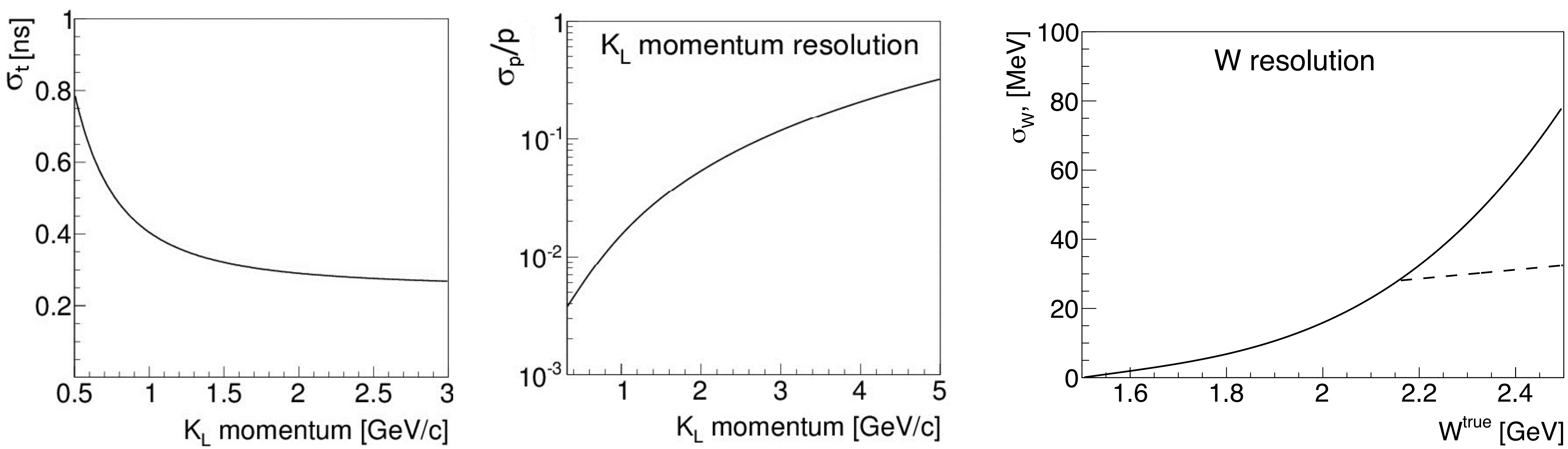


Figure 30: Left: Time resolution (σ_t) for K_L beam as a function of K_L-momentum. Middle: Momentum resolution (σ_p/p) as a function of momentum (note, log scale). Right: Energy resolution (σ_W) as a function of energy. The dashed line shows approximate W resolution from reconstruction of the final-state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

We can do it, but why?

- 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 beams?
- What is the advantage of producing secondary kaon beam with EM probe, compared to the 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.

Hyperon Spectroscopy

LQCD in addition to already known states

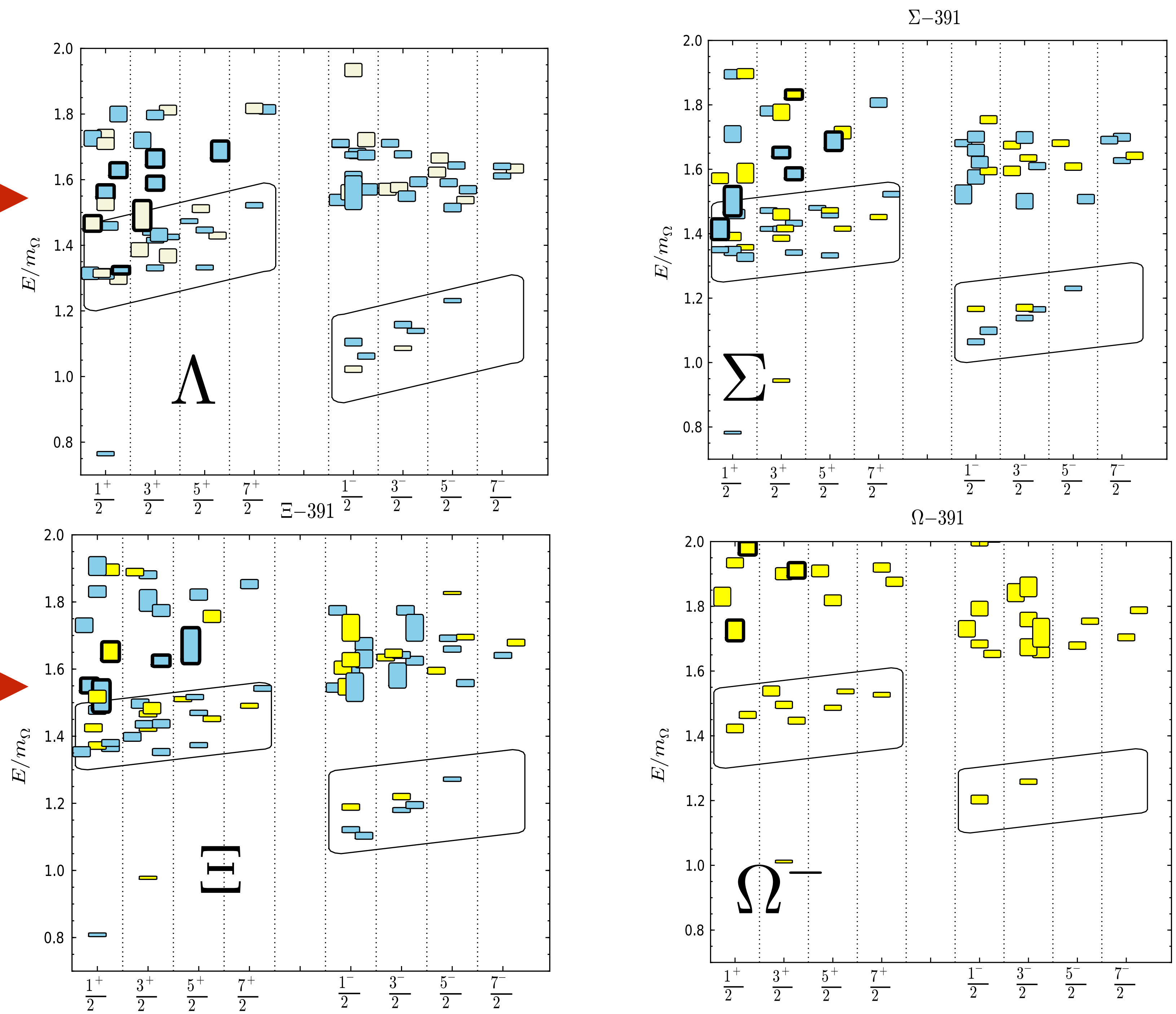
predicts many more including hybrids (thick bordered)

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

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

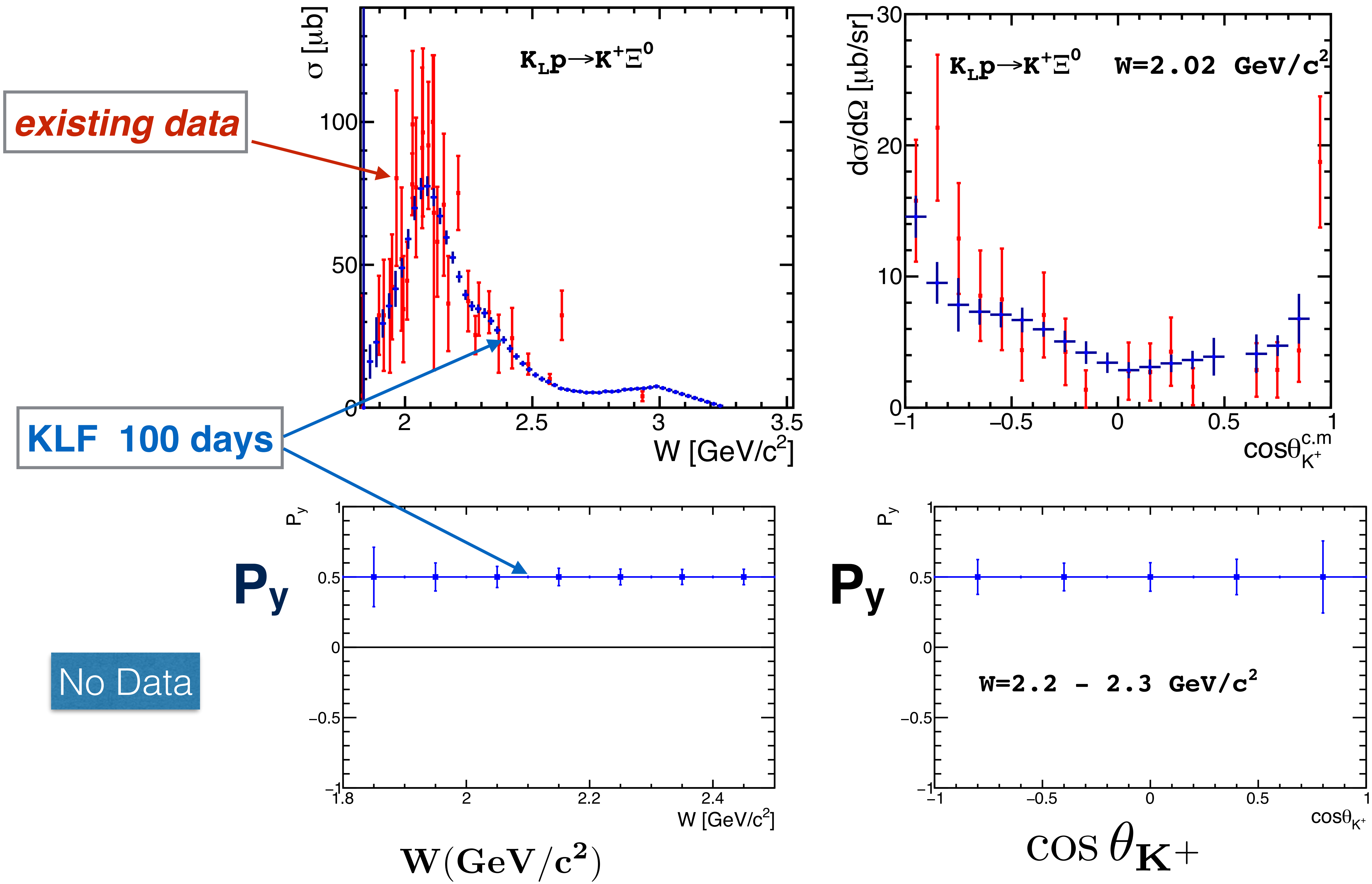
3-states
****
4-states
***

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



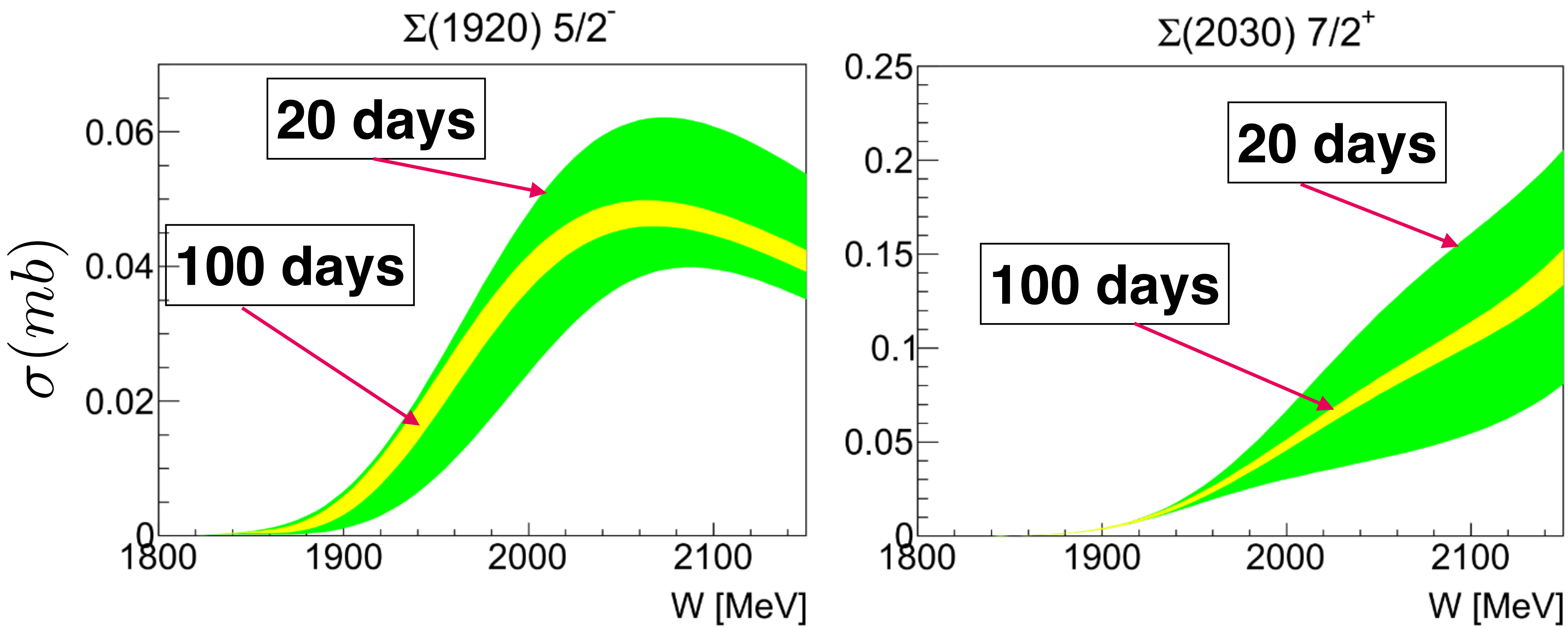
Edwards, Mathur, Richards and Wallace, Phys. Rev. D 87, 054506 (2013)

Measurements on Proton Target



Bonn-Gatchina PWA

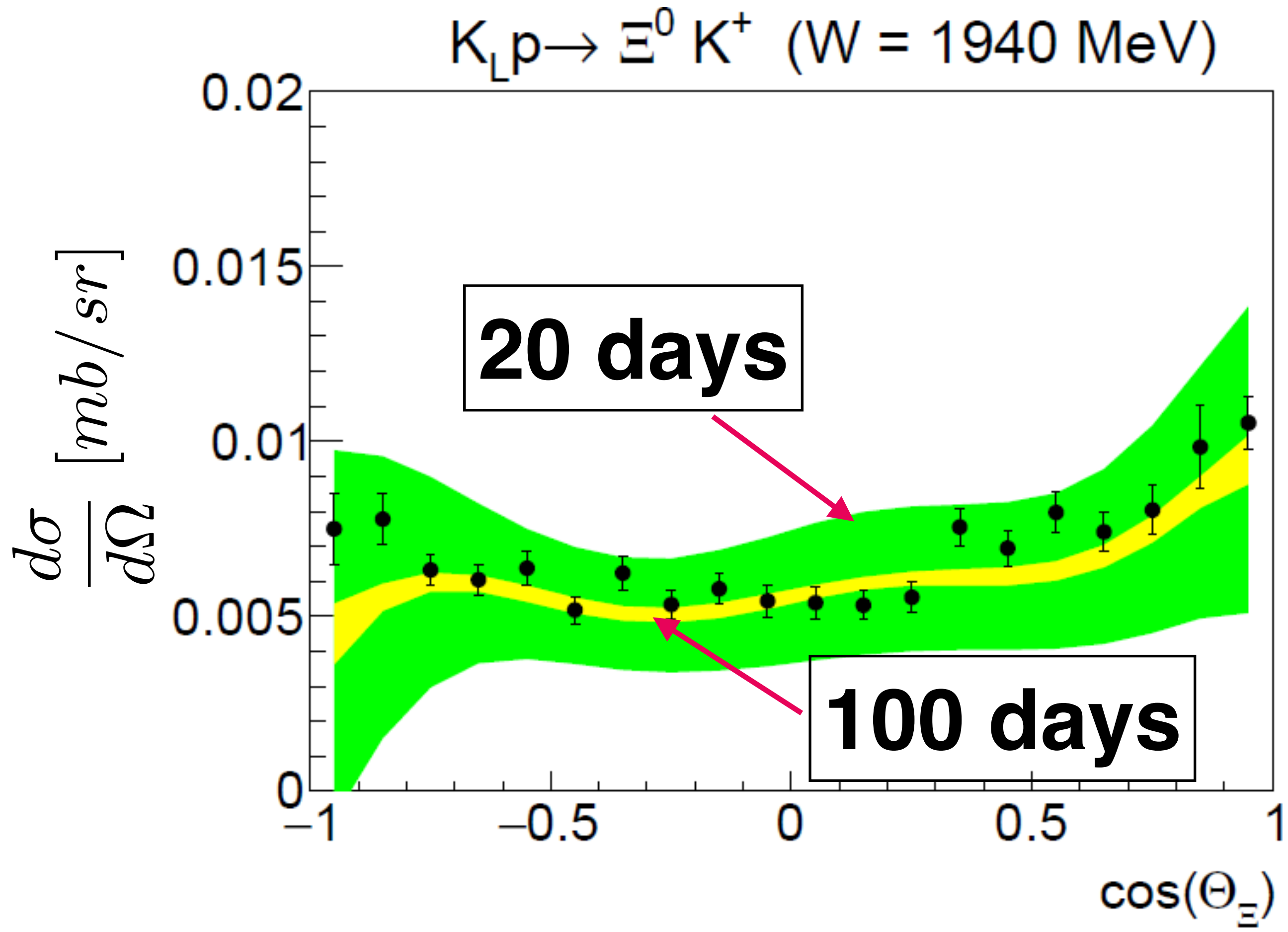
Total Cross Section $K_L p \to K^+ \Xi^0$



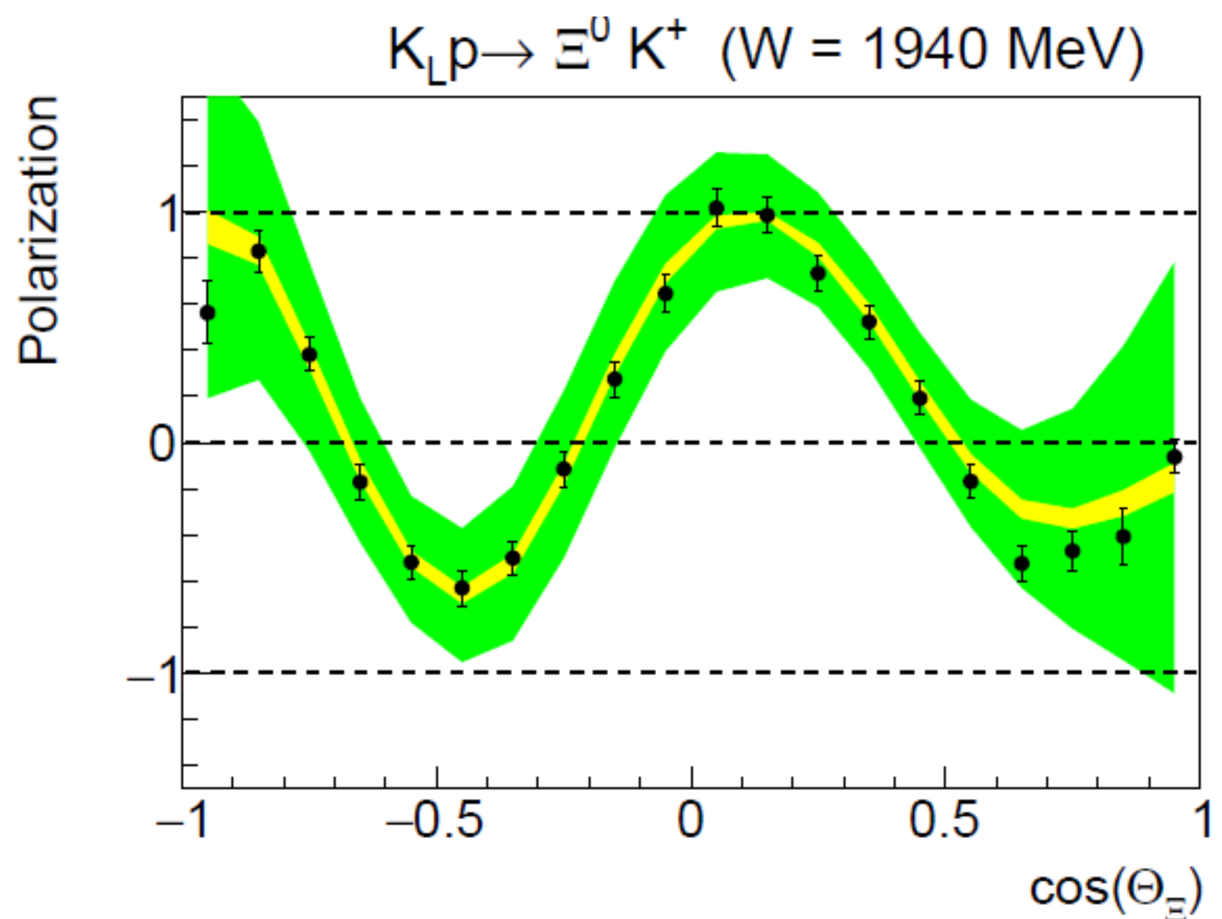
Need 100 days of running to get precise solution

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 2500 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.

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

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

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

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

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

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

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

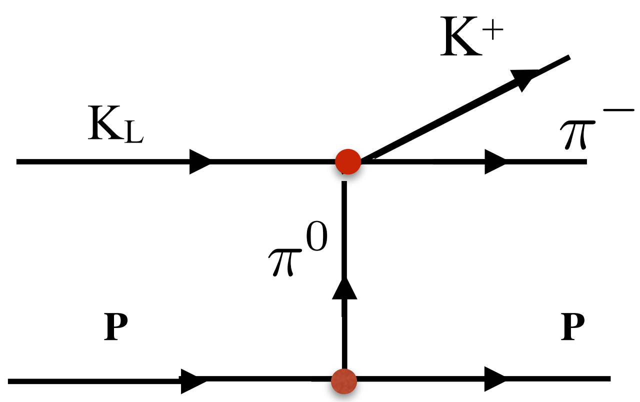
$$K_L n \to K_L \pi^0 n = \langle K_L \pi^0 | K_L \pi^0 \rangle = \frac{1}{3}(T^{\frac{1}{2}} + 2T^{\frac{3}{2}}),$$

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

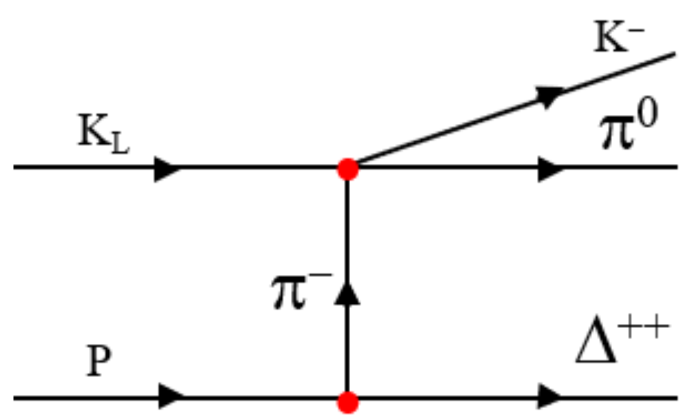
$$K_L n \to K^\pm \pi^0 \Delta^\mp = \langle K_L \pi^\pm | K^\pm \pi^0 \rangle = \pm \frac{1}{3}(T^{\frac{1}{2}} - T^{\frac{3}{2}}),$$

Strange Meson Spectroscopy

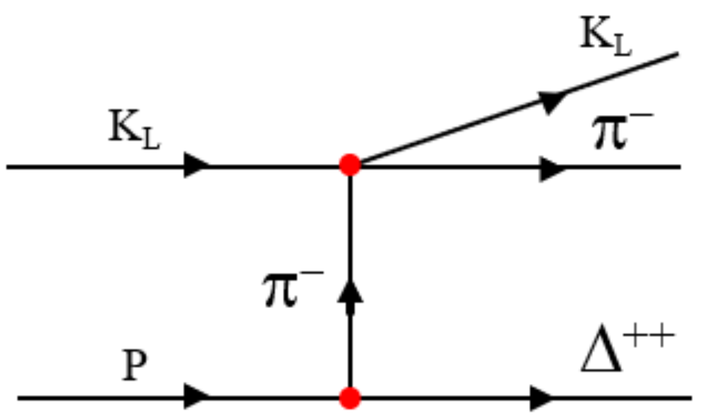
$K\pi$ Scattering



$$\frac{1}{3}(T^{1/2} - T^{3/2})$$



$$\frac{1}{3}(T^{1/2} - T^{3/2})$$

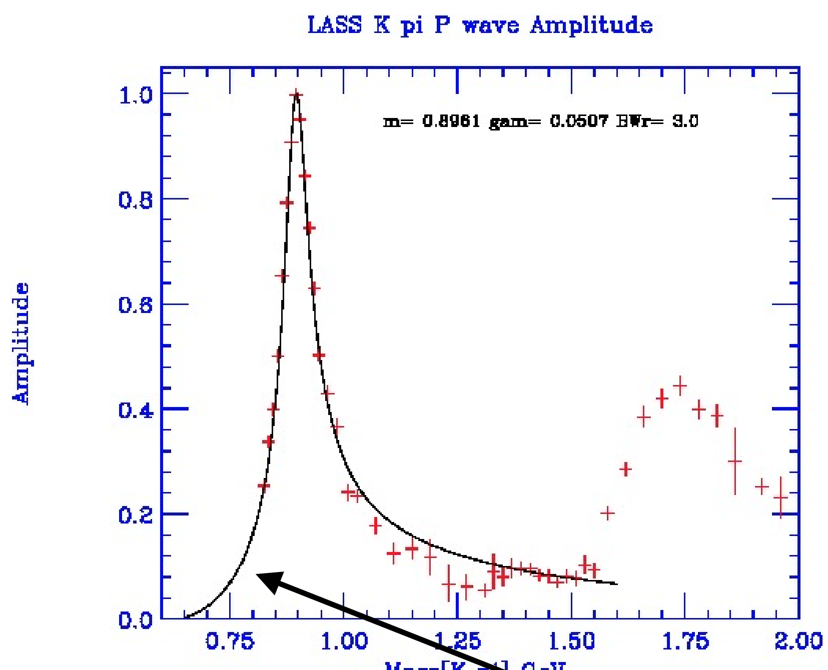


$$\frac{1}{3}(T^{1/2} + T^{3/2})$$

Proposed Measurements

SLAC

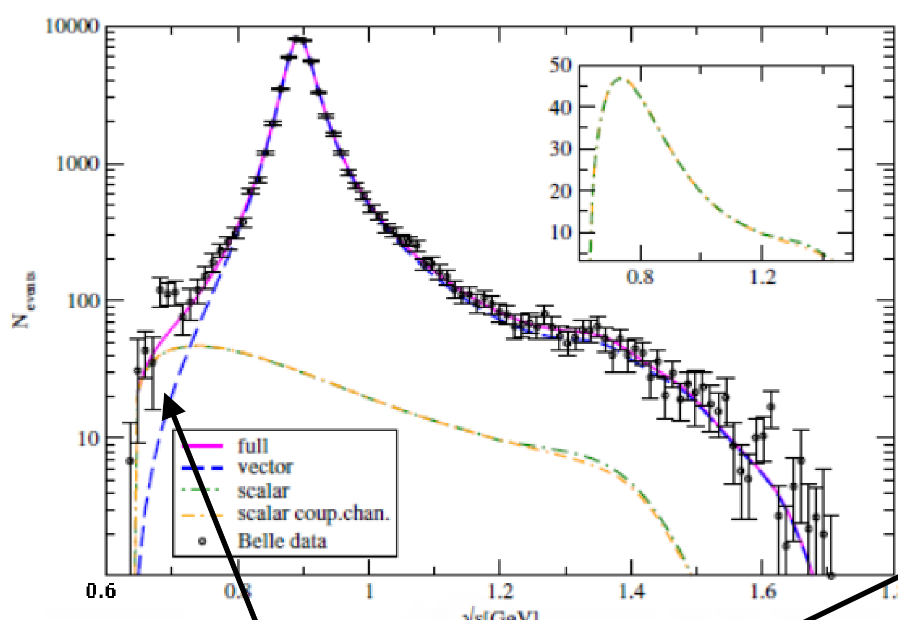
$$K^-\pi^+ \to K^-\pi^+$$



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

Belle

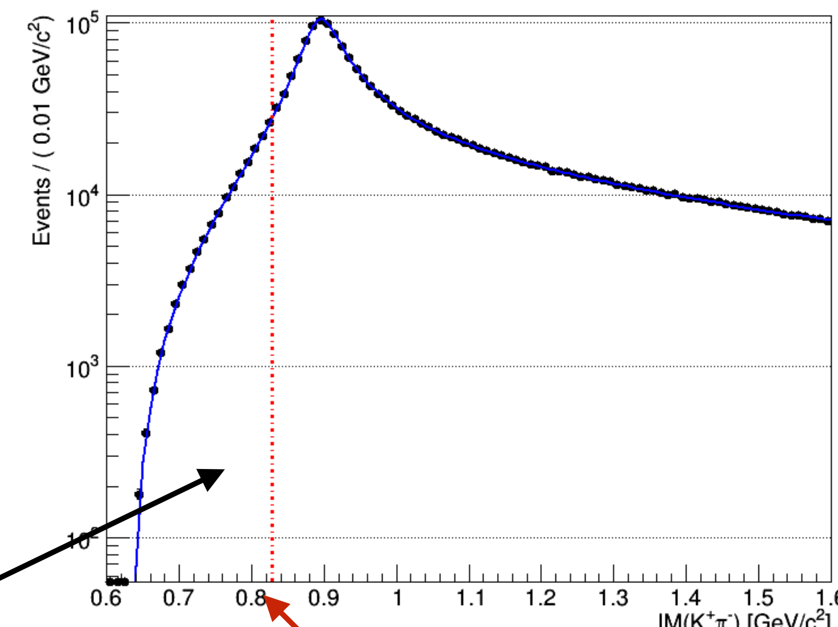
$$\tau \to K\pi\nu_\tau$$



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

KLF

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



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

region of $\kappa(800)$

SLAC Lower limit

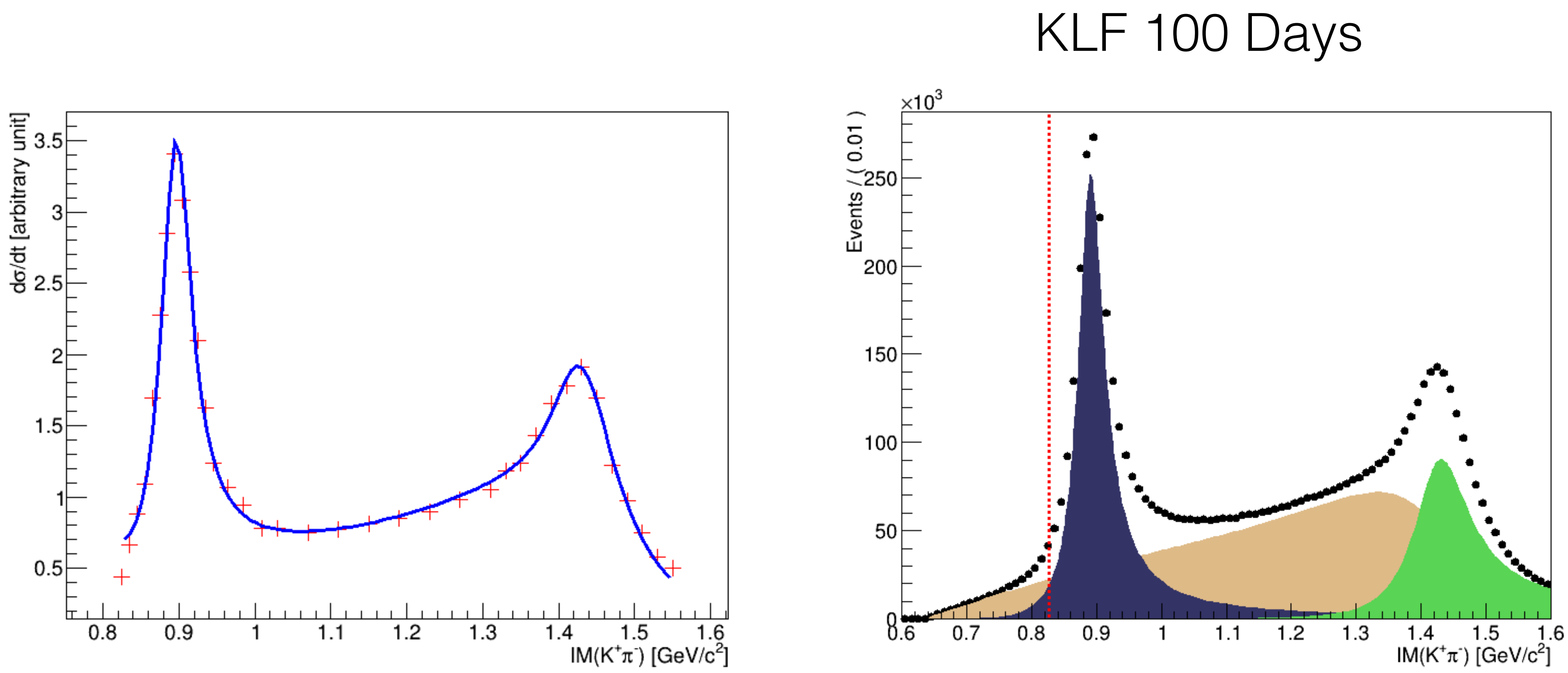
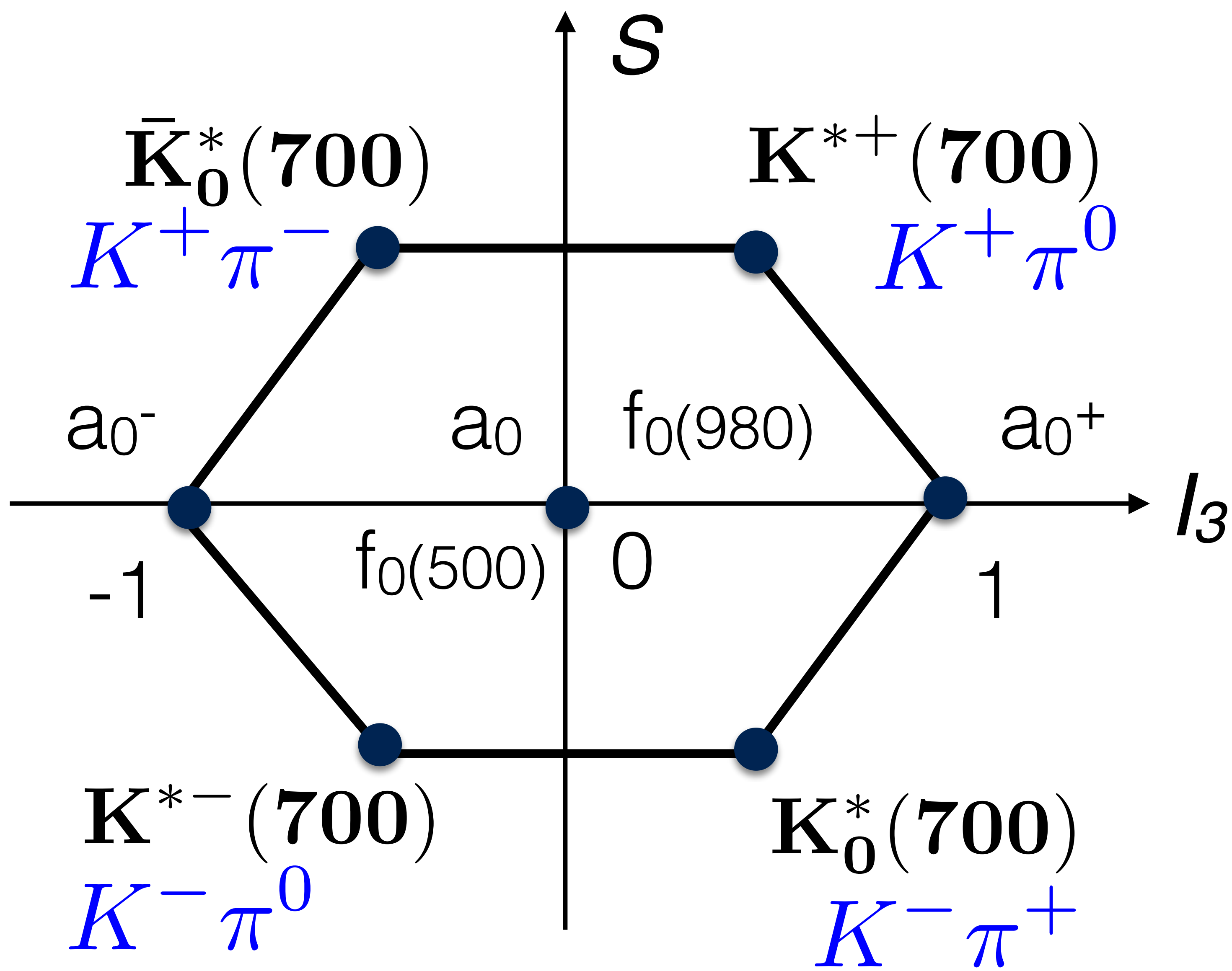


Figure 11: Left: Cross section of $K^- p \to K^+ \pi^- n$ as a function of the invariant mass from LASS results [27]. The blue line is the fit to the cross section using composite model containing two RBWs, spin-1 and spin-2, and S-wave LASS parameterization. Right: Expected distribution of the $K^+\pi^-$ invariant mass below 1.6 GeV from KLF after 100 days of running. The dark blue function represents the $K^+\pi^-$ P-wave, light brown the S-wave and green the D-wave. The dashed line represents the threshold of $K\pi$ invariant mass in LASS results [27].

Scalar Meson Nonet

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



Four states called κ

still need further confirmation(PDG)

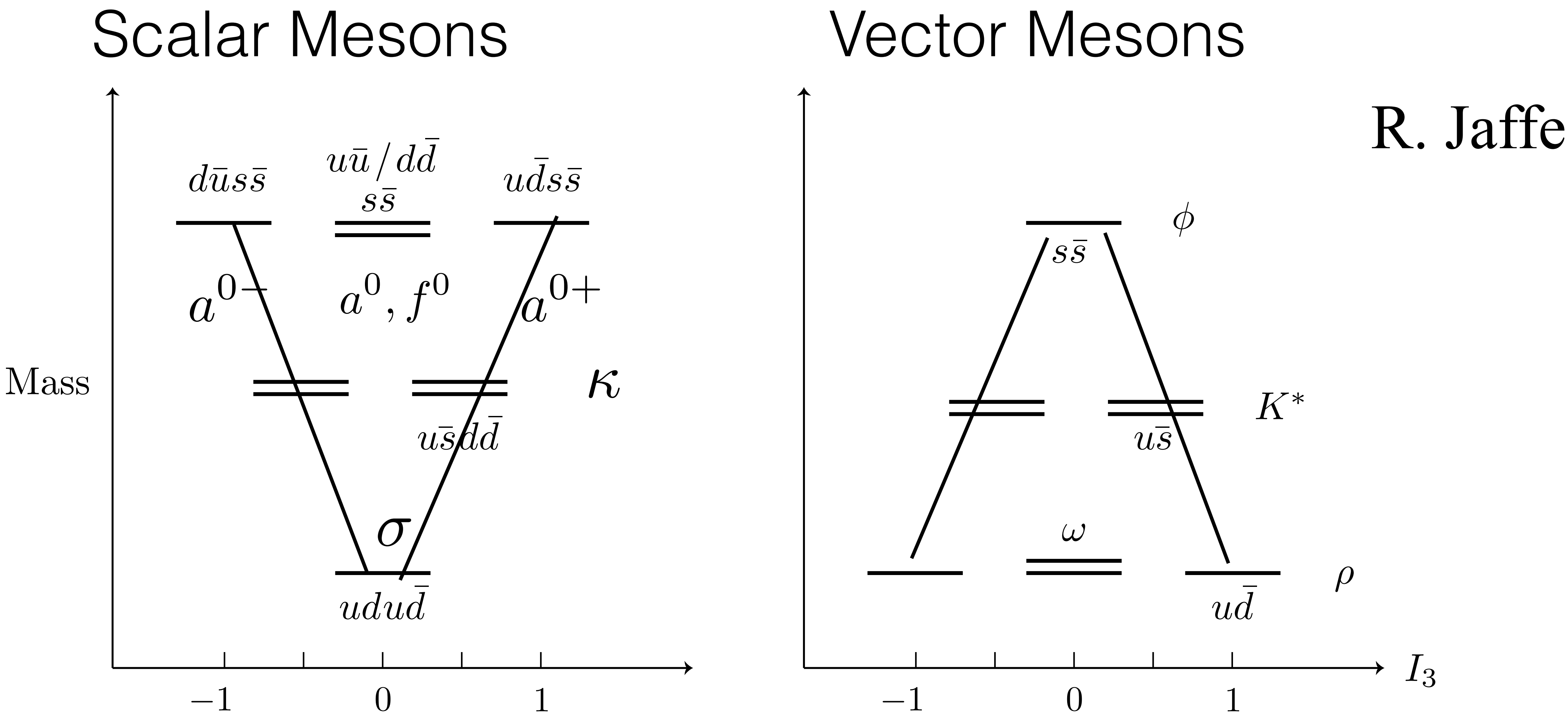
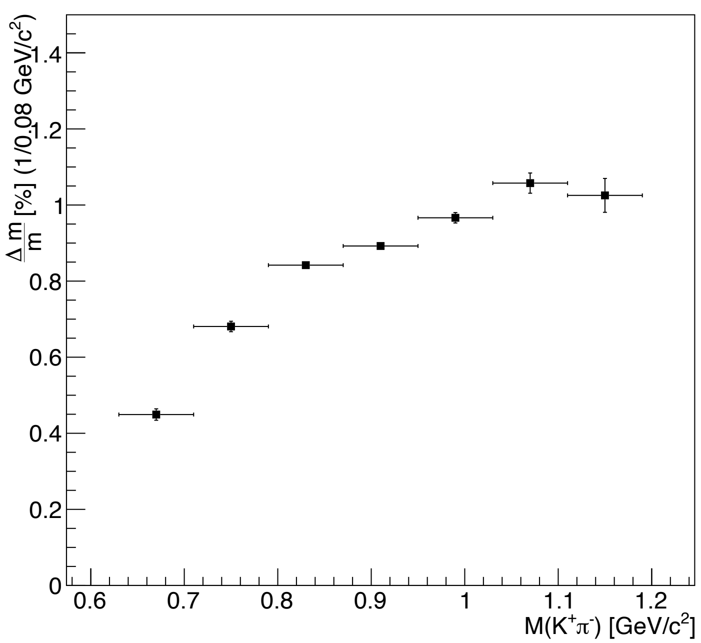


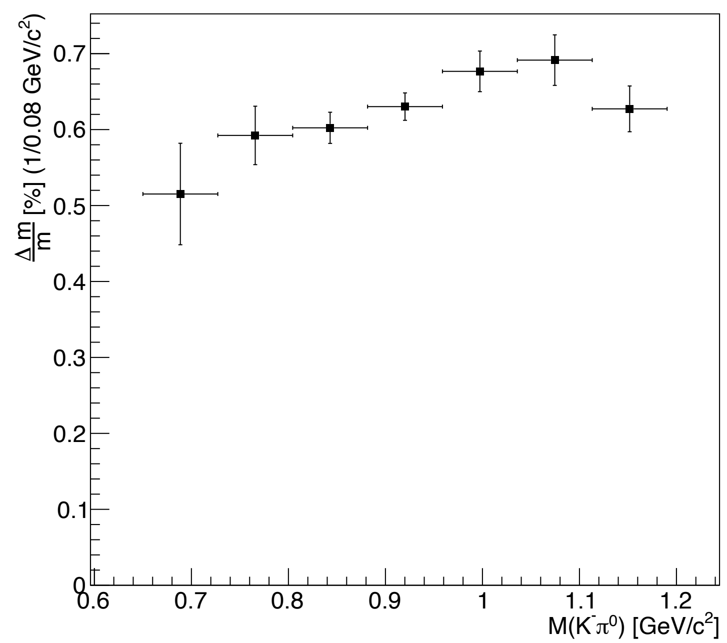
Figure 6. A cartoon representation of the masses of a $\bar{q}\bar{q}qq$ nonet compared with a $\bar{q}q$ nonet.

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

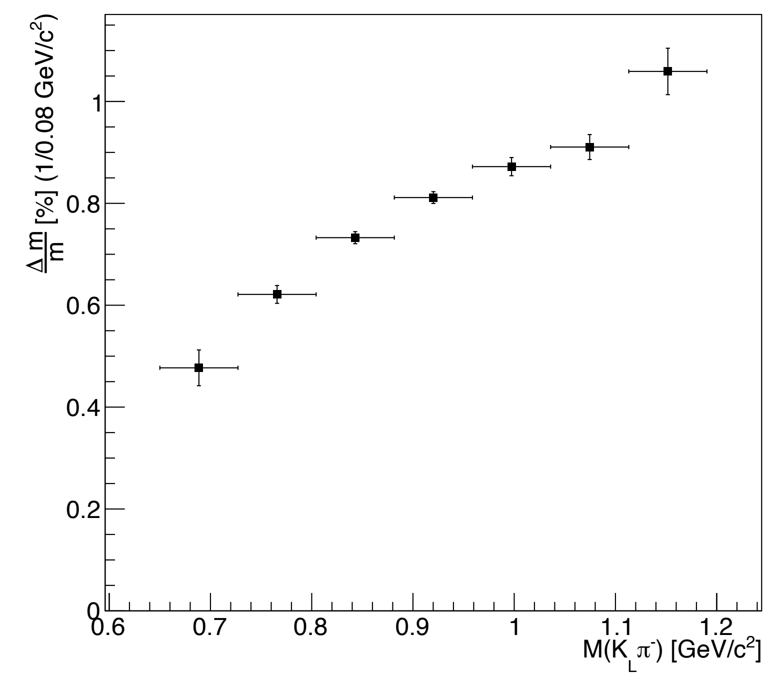
Invariant mass resolution $\Delta m/m\ (\%)$



$K^+\pi^-$



$K^-\pi^0$



$K_L\pi^-$

Below 1% in all cases

Projected Measurements

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

SLAC Data

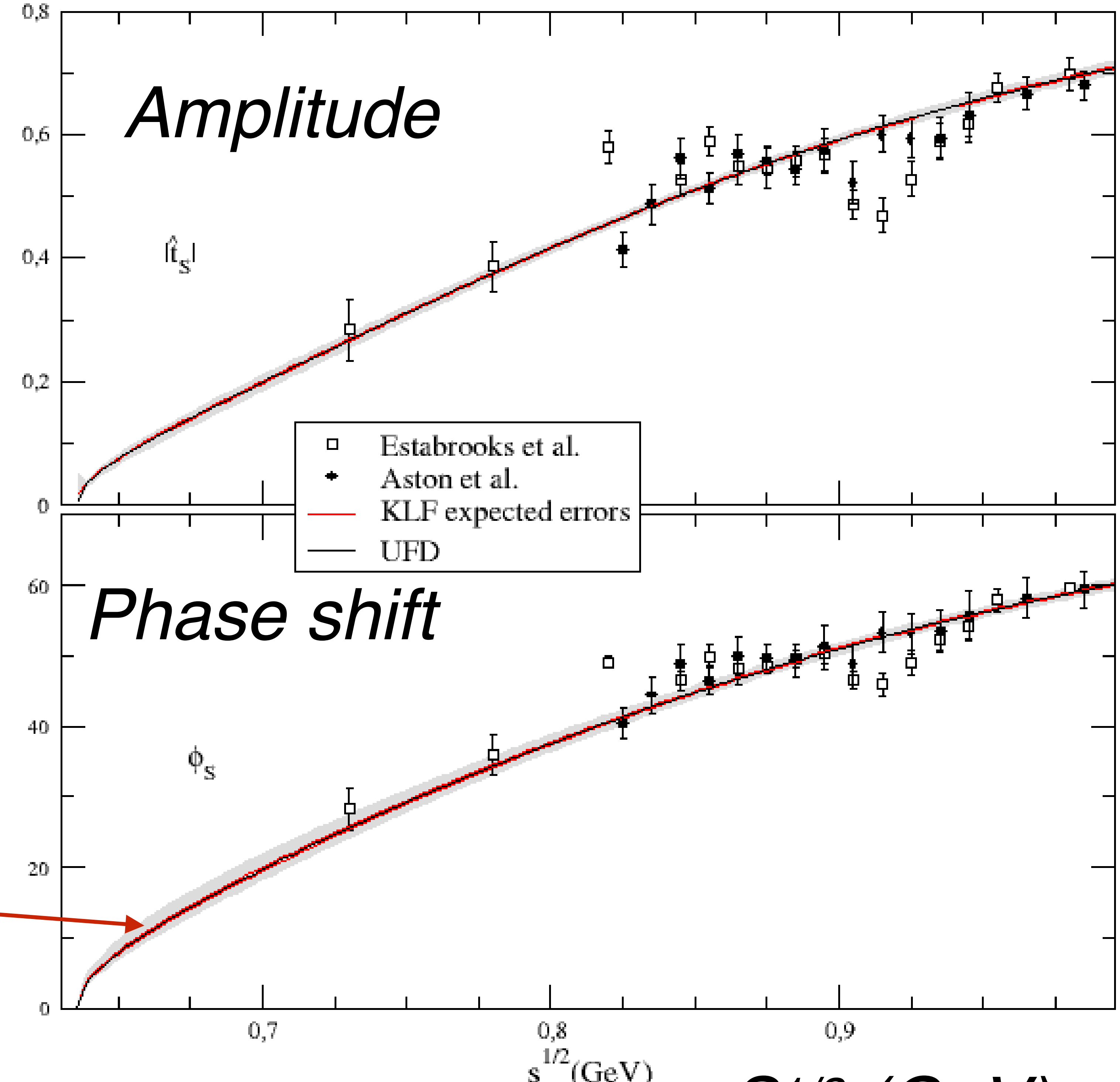
$$K^{\pm}p \to K^{\pm}\pi^{+}n$$
$$K^{\pm}p \to K^{\pm}\pi^{-}\Delta^{++}$$

Estabrooks(1978)

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

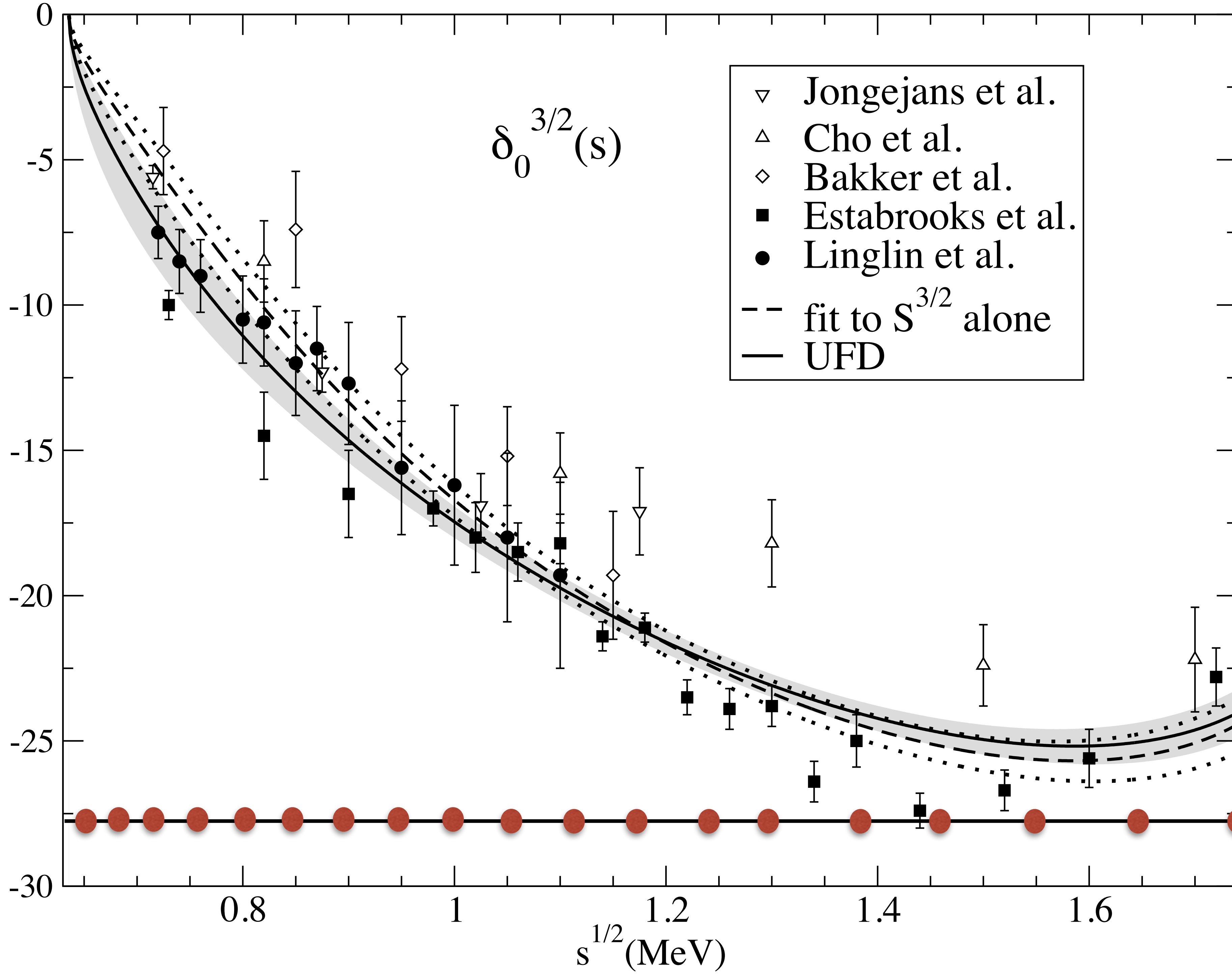
Aston(1988)

KLF (100 days)



S1/2 (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)

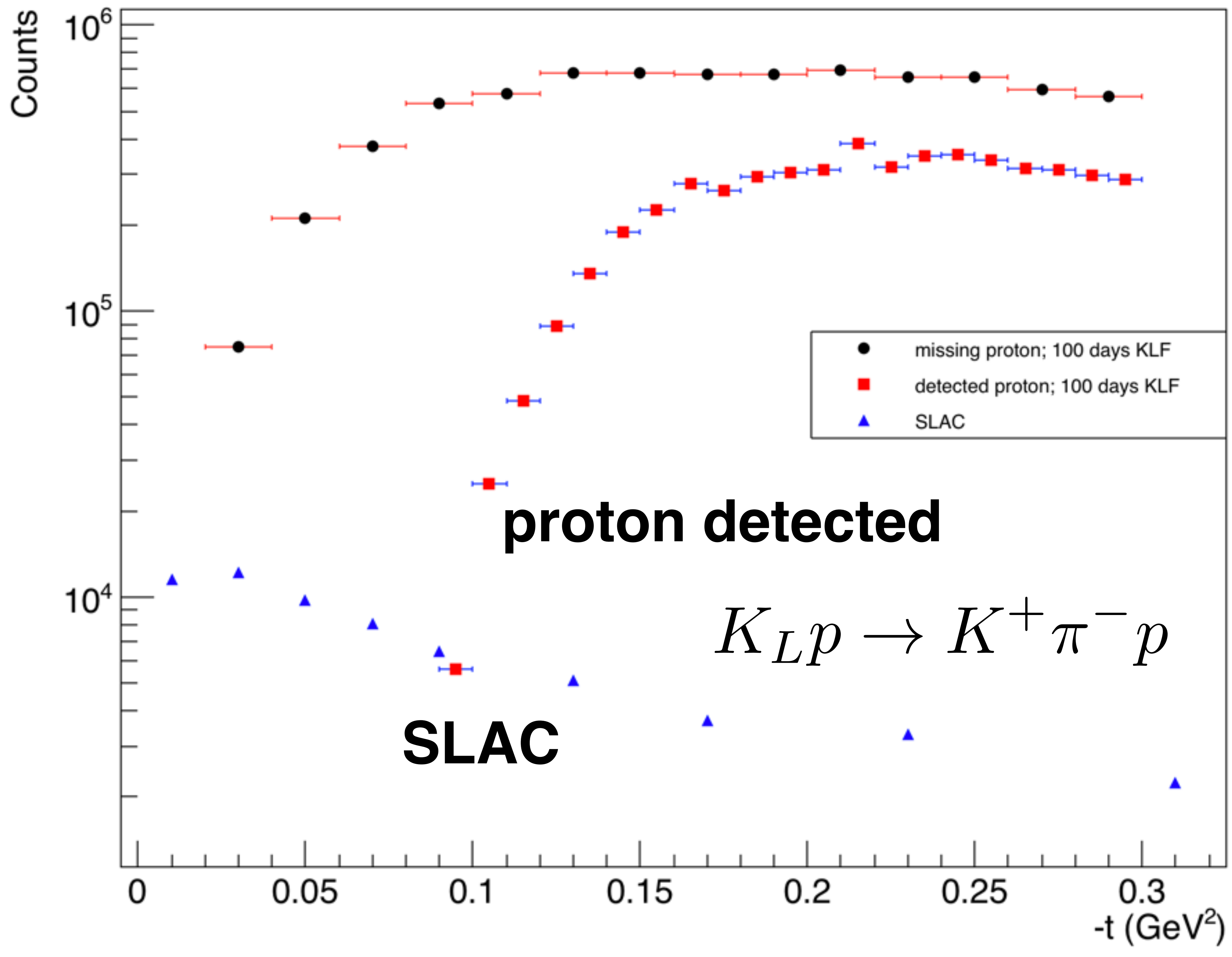
$K^{\pm}p \to K^{\pm}\pi^{+}n$

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

KLF 100 days

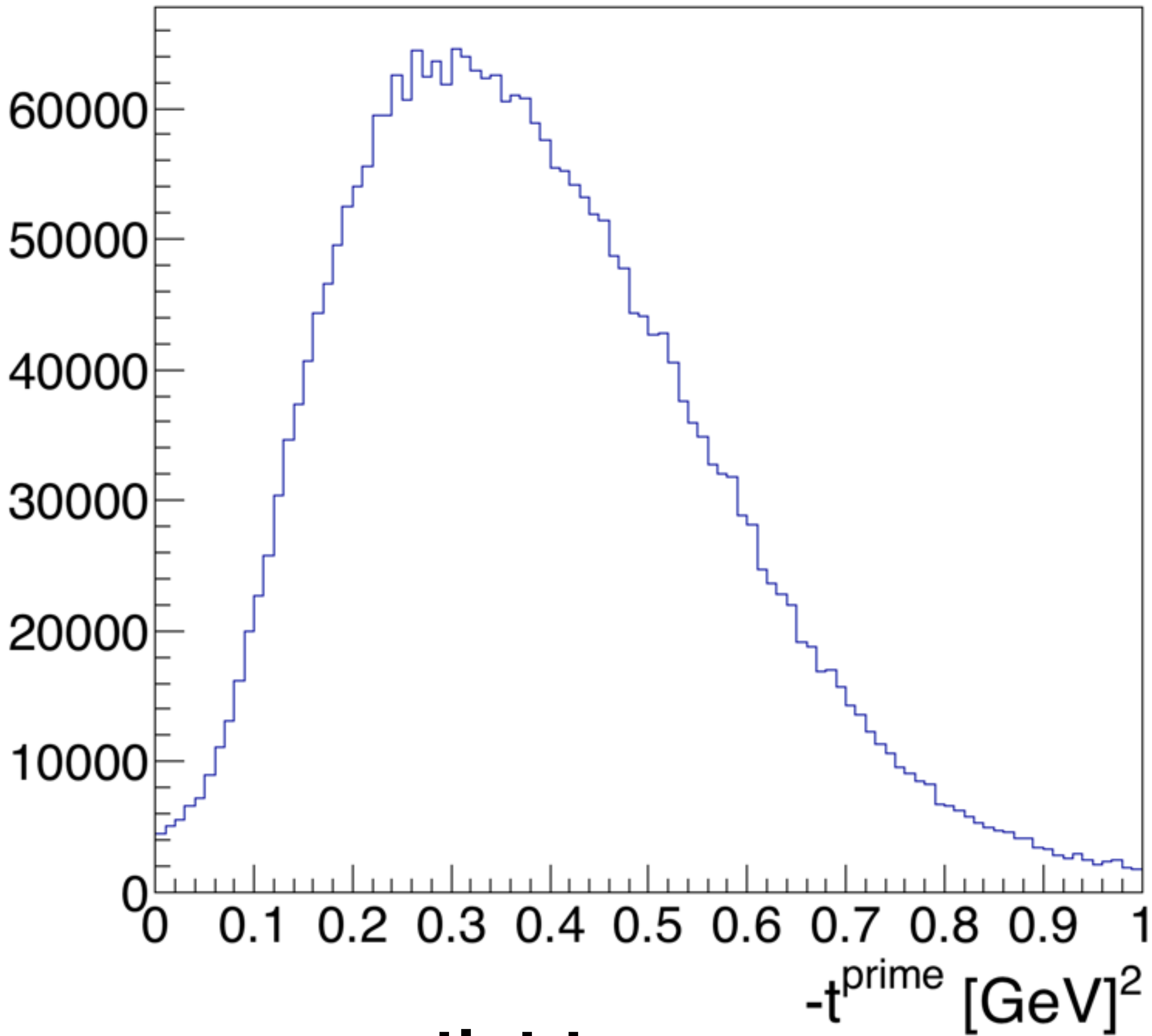
From Pelaez and Rodas paper: PRD93(2016)

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

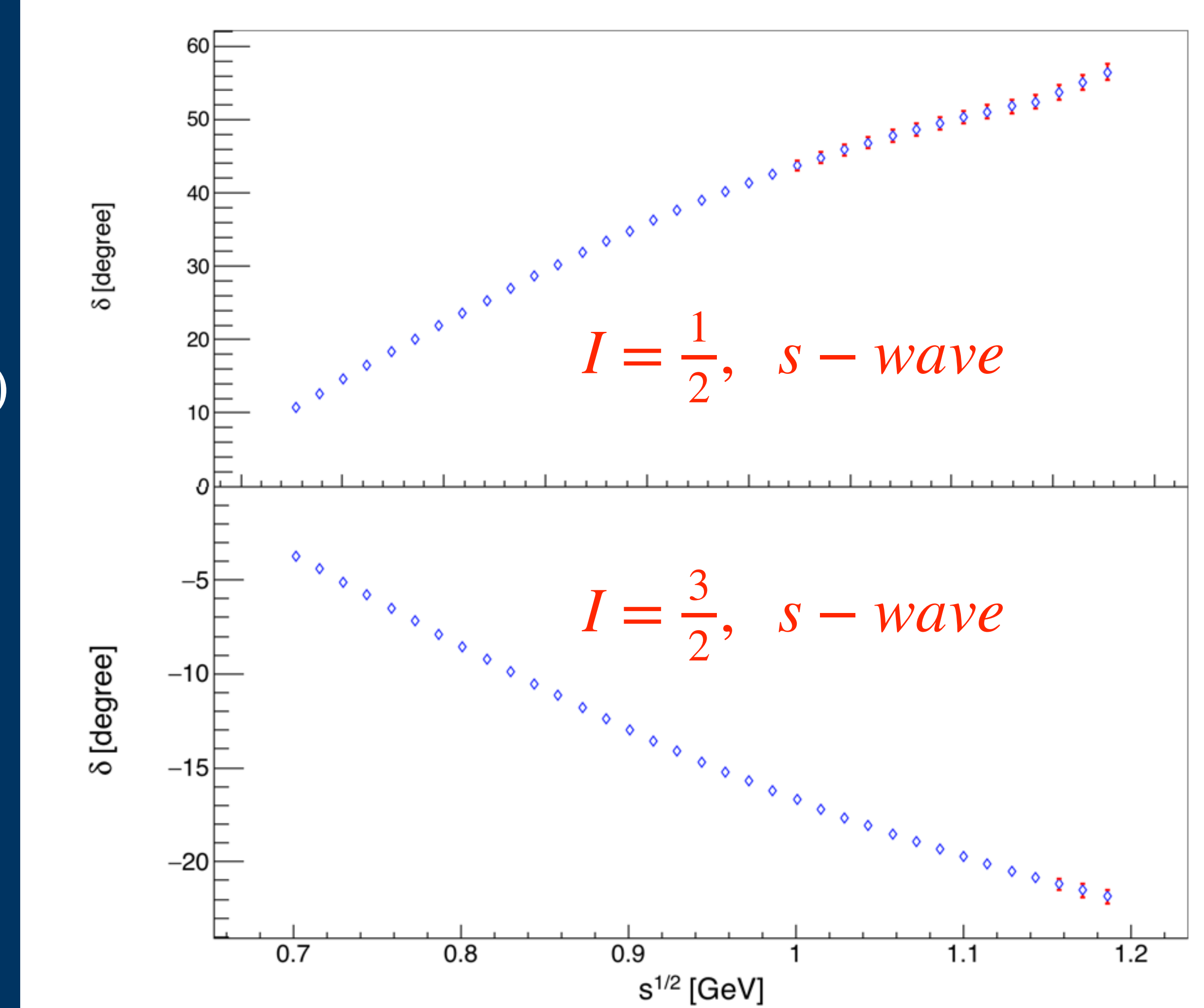
$$A^I(cos\theta_{GJ}, \phi_{GJ}) = \frac{\sqrt{4\pi}}{q_i}\sum_{l,m} a_l^I(2l+1)Y_l^m(cos\theta_{GJ}, \phi_{GJ})$$

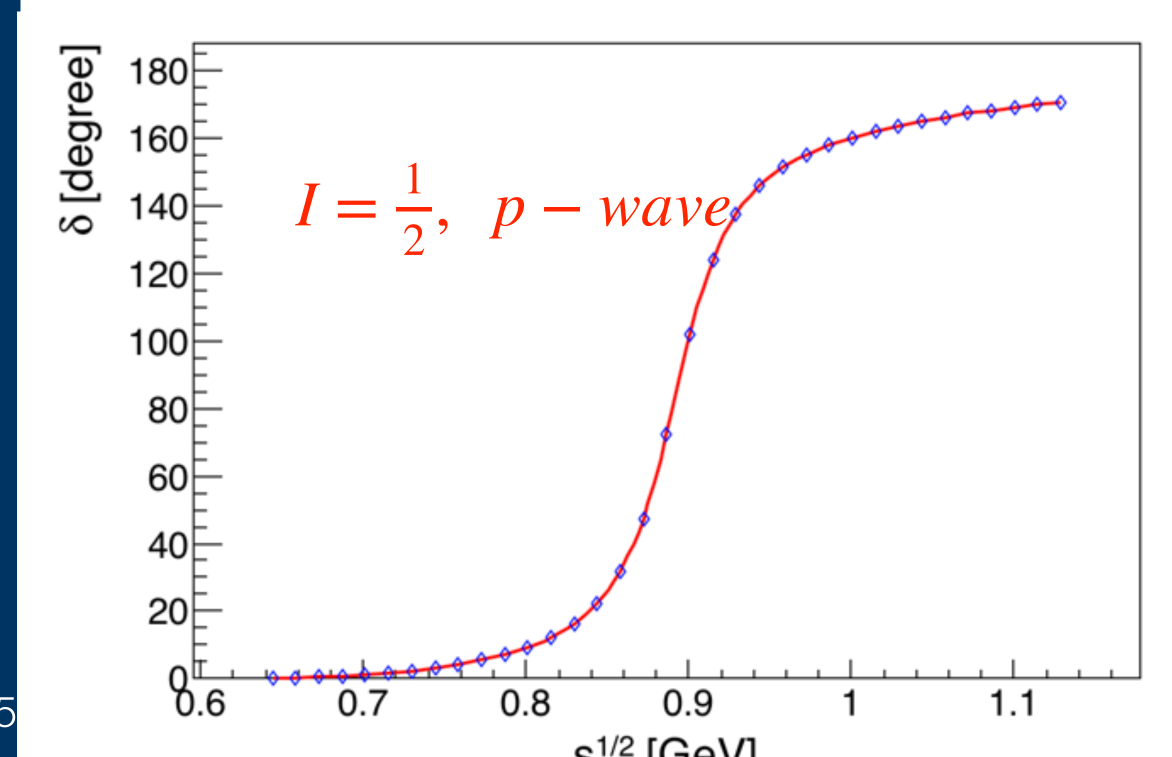
In the elastic region

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

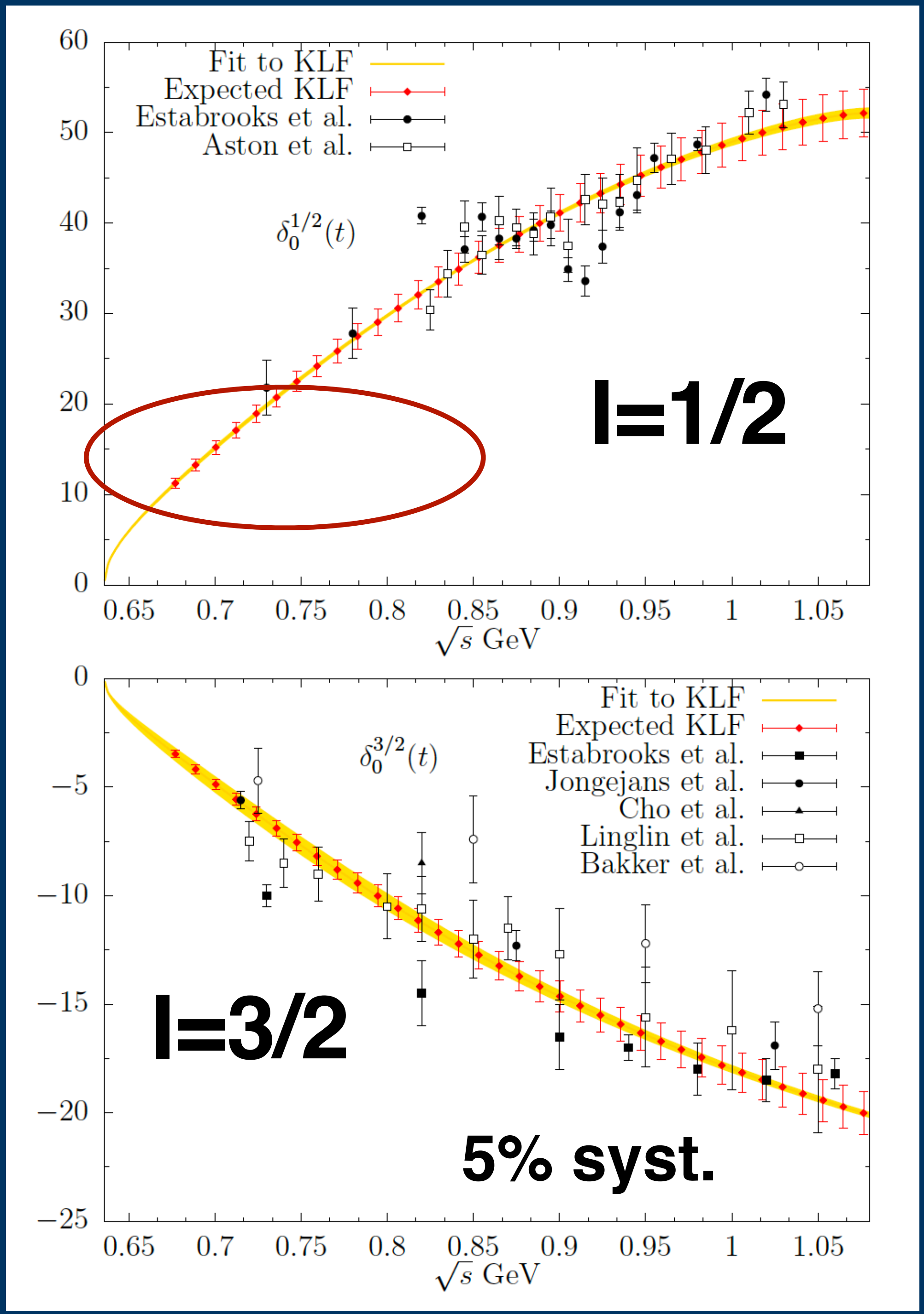
$$a_L^I = \sqrt{(2L+1)}\epsilon^I \sin\delta_L^I e^{\delta_L^I}$$

Results include statistical uncertainty only.

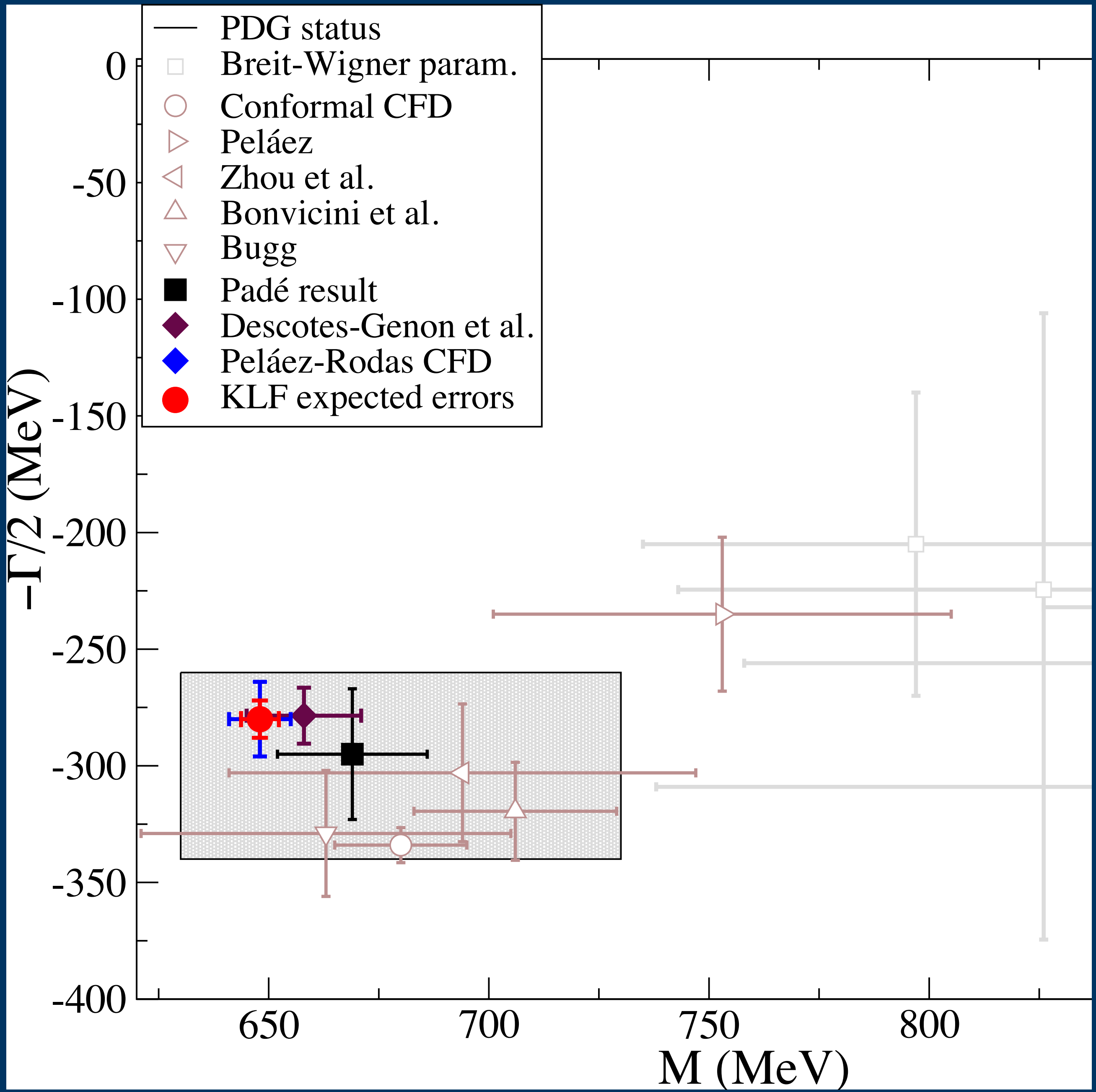




Kappa Mass and Width



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



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

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

More data points are added close to threshold from KLF.

Summary of $K\pi$ Scattering

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

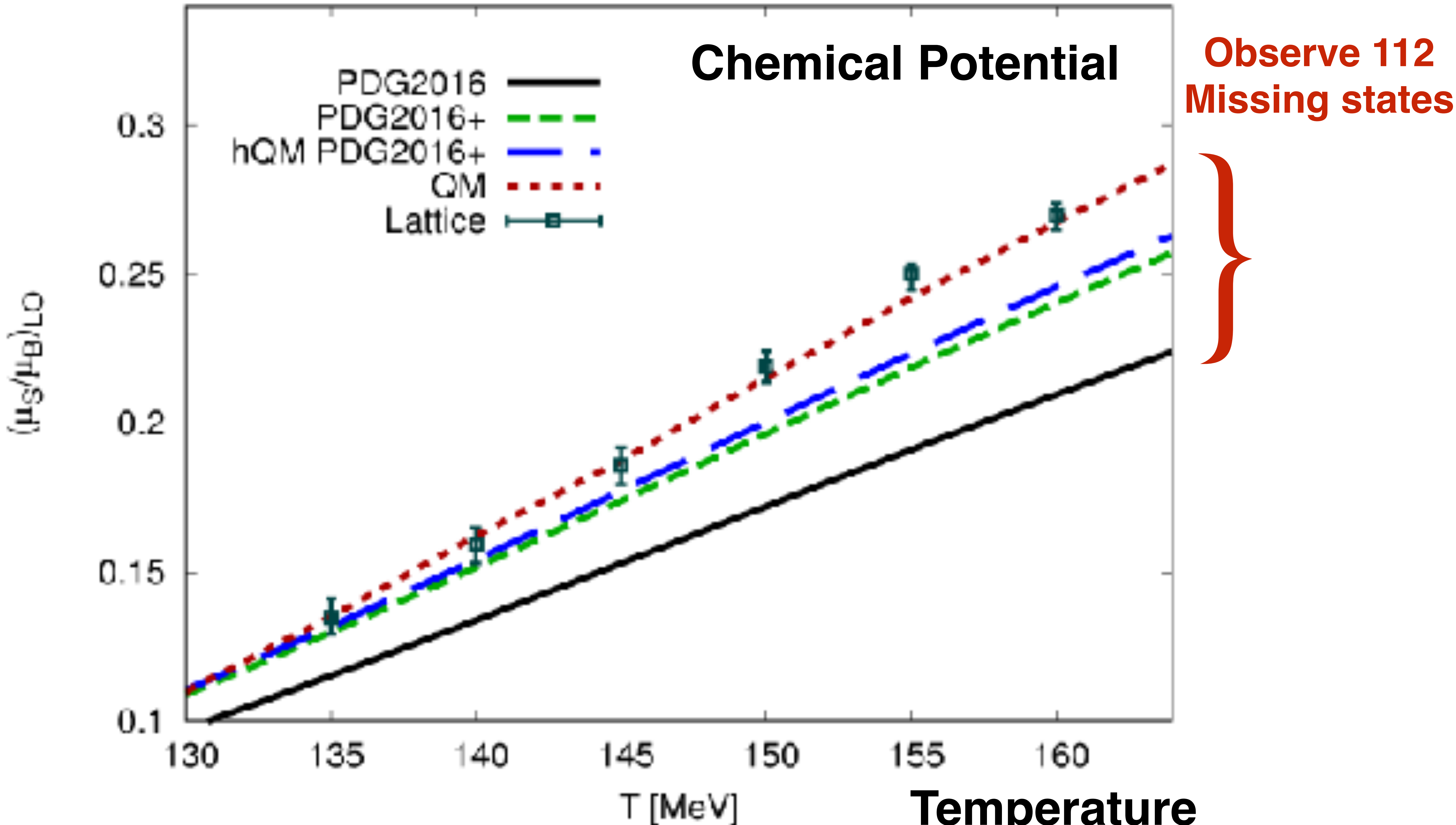
-It will improve on still conflictive determination of heavy K*'s parameters

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

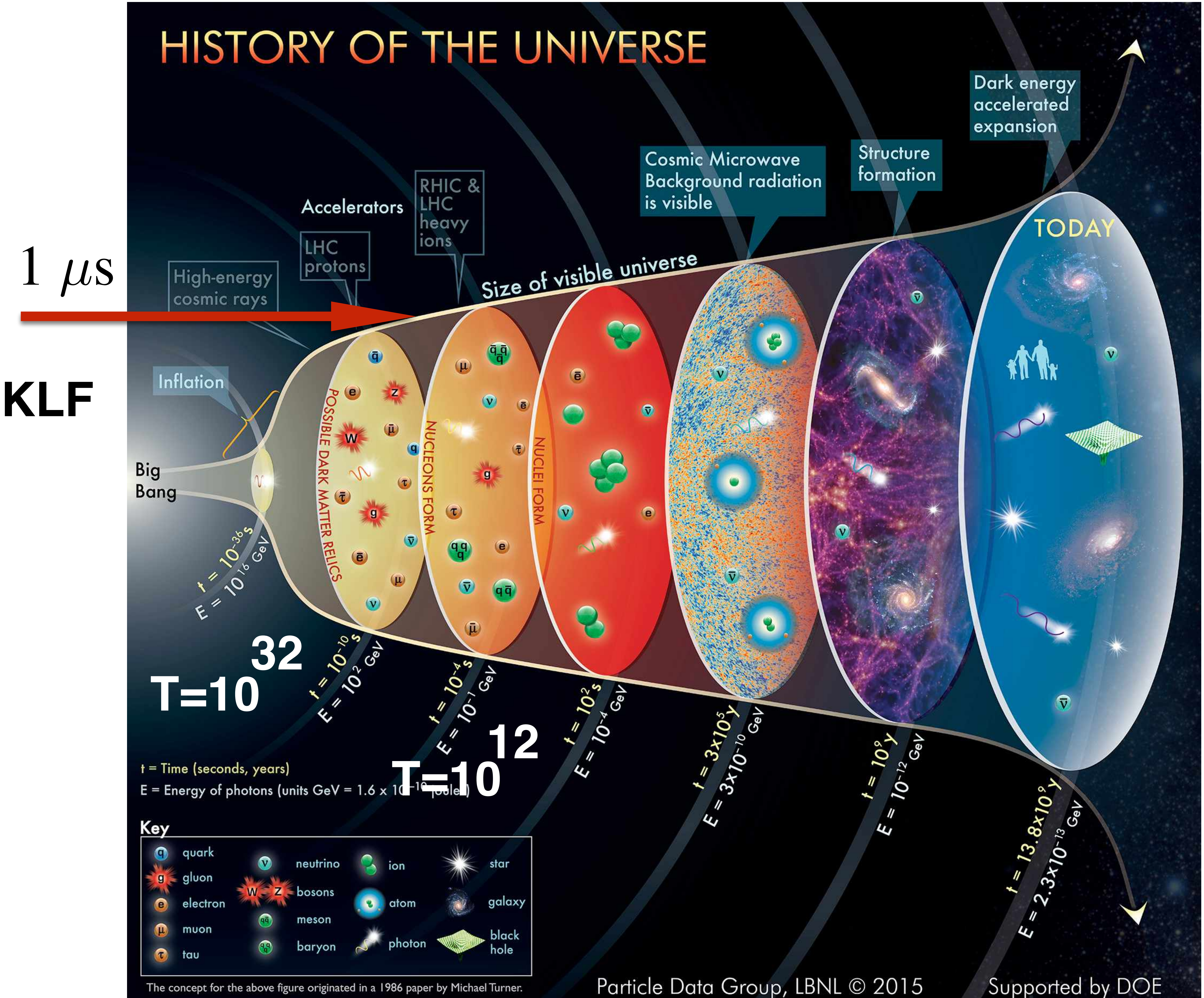
-Finally, and very importantly, it will reduce the uncertainty in the mass determination of K*(700) and by by more than a factor of two and by factor of five the uncertainty on its width

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

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



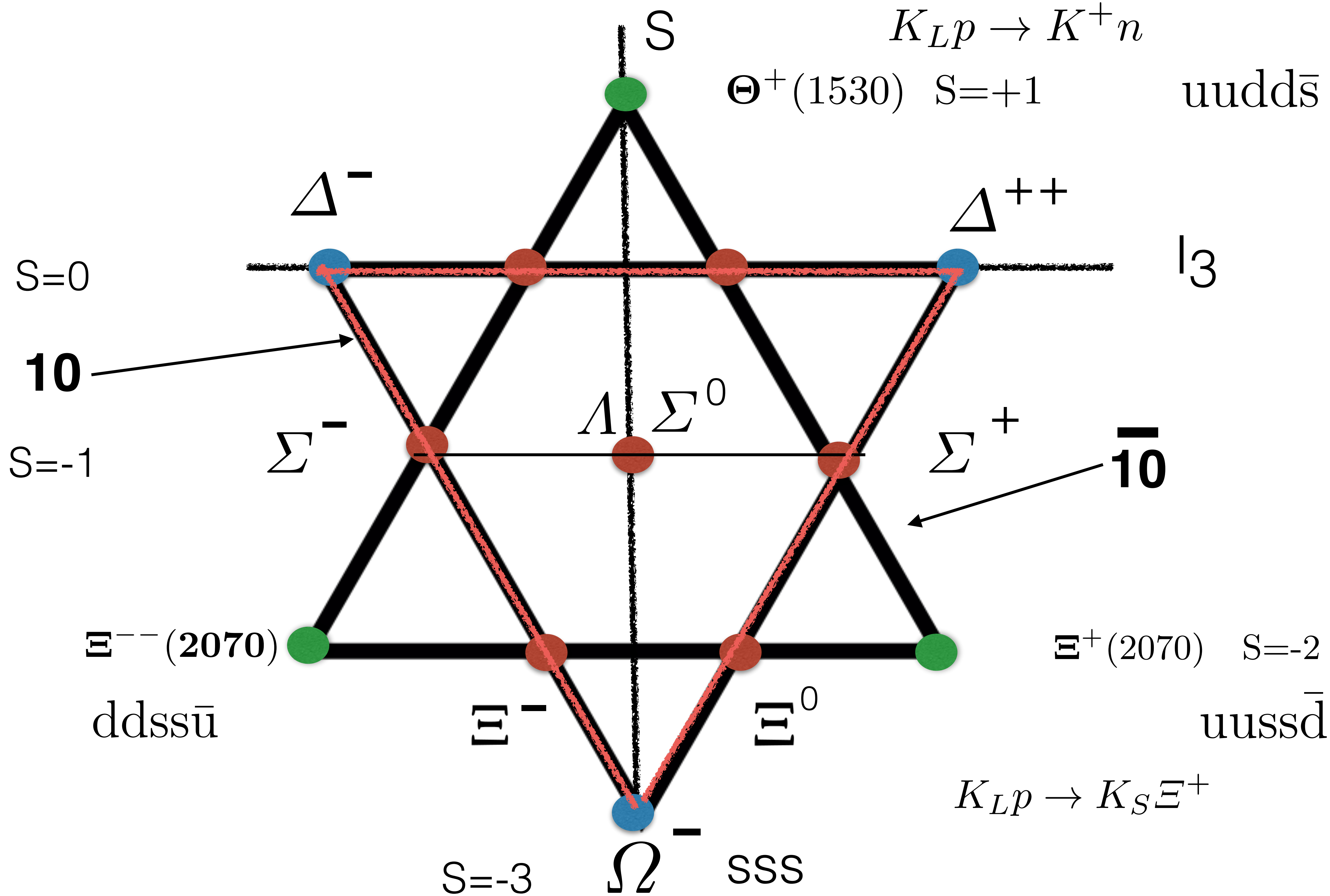
$$dU = T\,dS - p\,dV + \mu\,dN$$



HISTORY OF THE UNIVERSE
1 μs
KLF
T=10^32
T=10^12
Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Size of visible universe
Inflation
Big Bang
TODAY
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^-10 joule)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Particle Data Group, LBNL © 2015
Supported by DOE

What else?

Pentaquarks



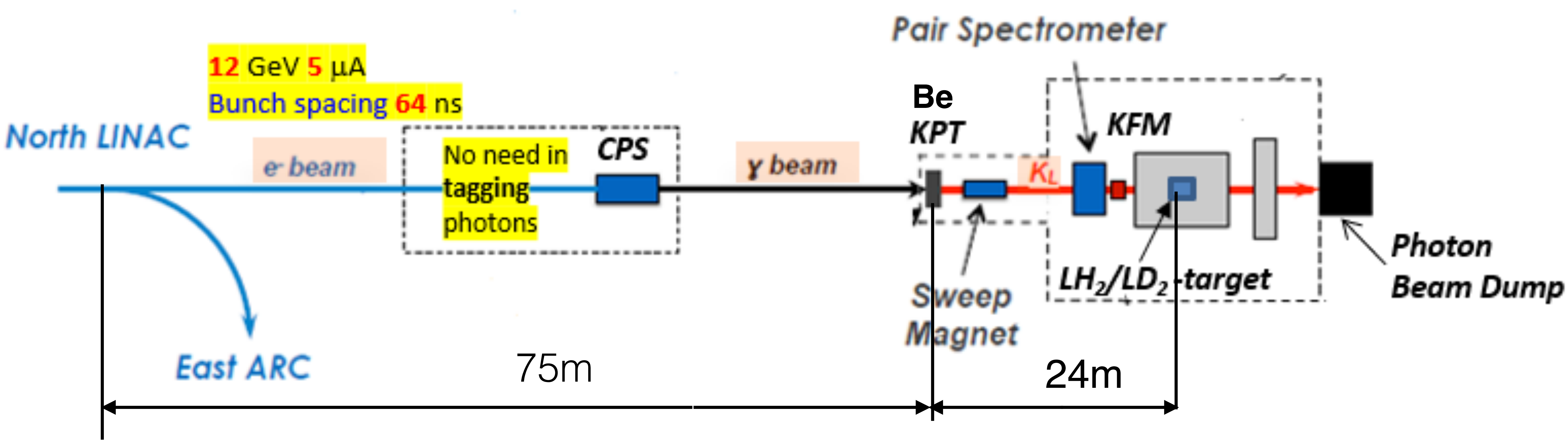
D. Diakonov, V. Petrov and M. V. Polyakov, Z. Phys. A **359**, 305 (1997).

Is everything feasible from hardware point of view?

Next few slides will answer this question.

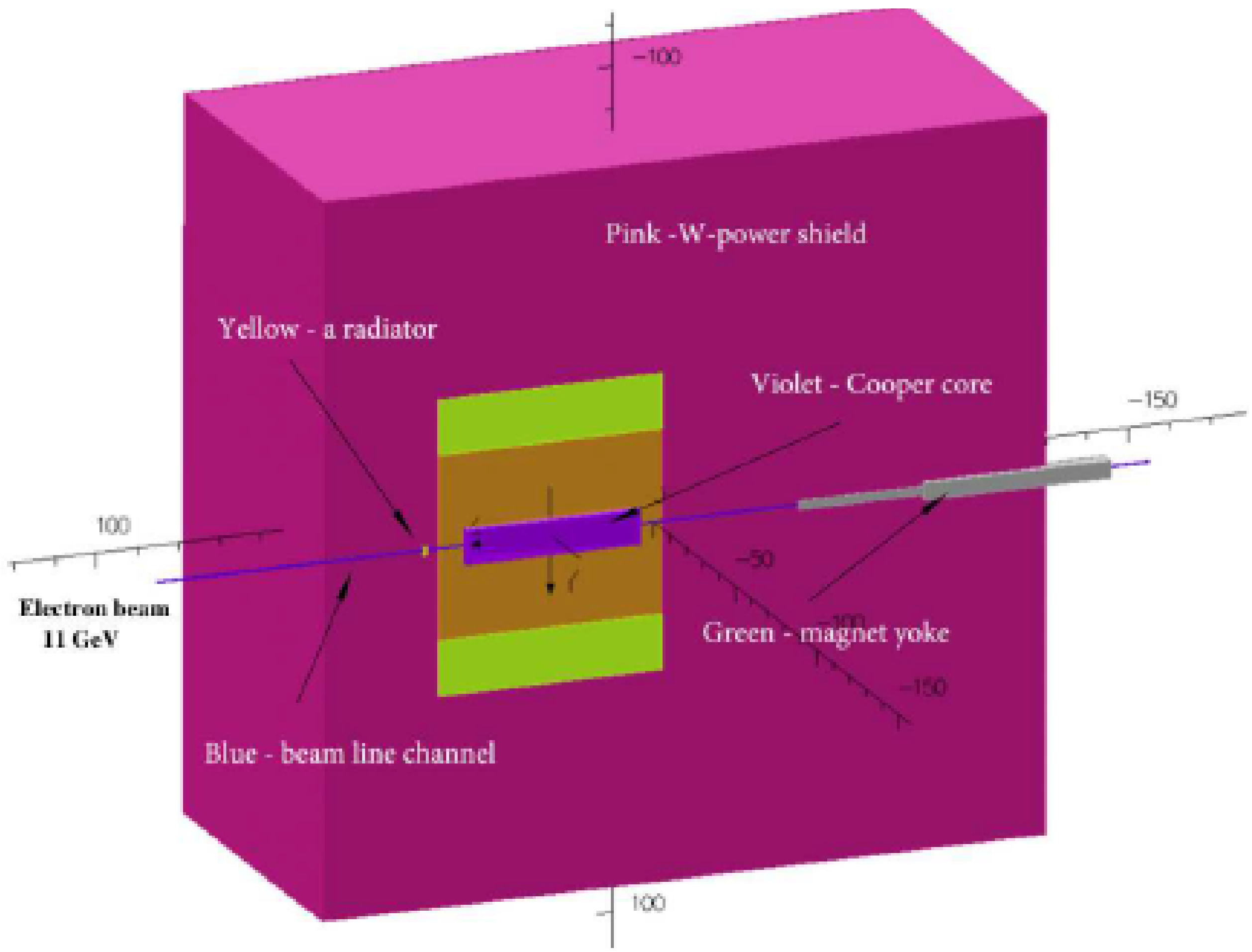
Reminder:

Hall-D beamline and GlueX Setup



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

Compact Photon Source



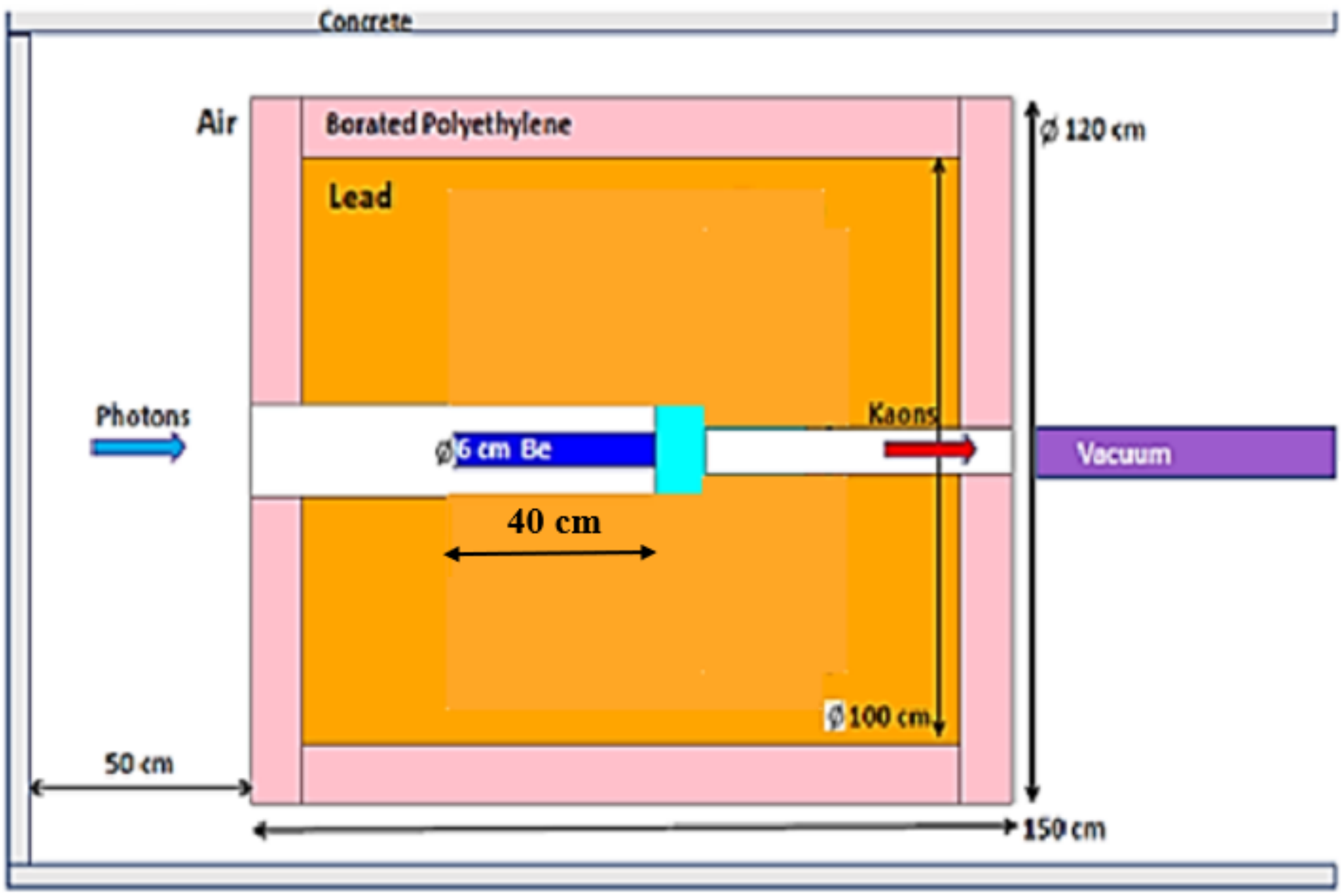
Conceptual design is completed for Halls A&C

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

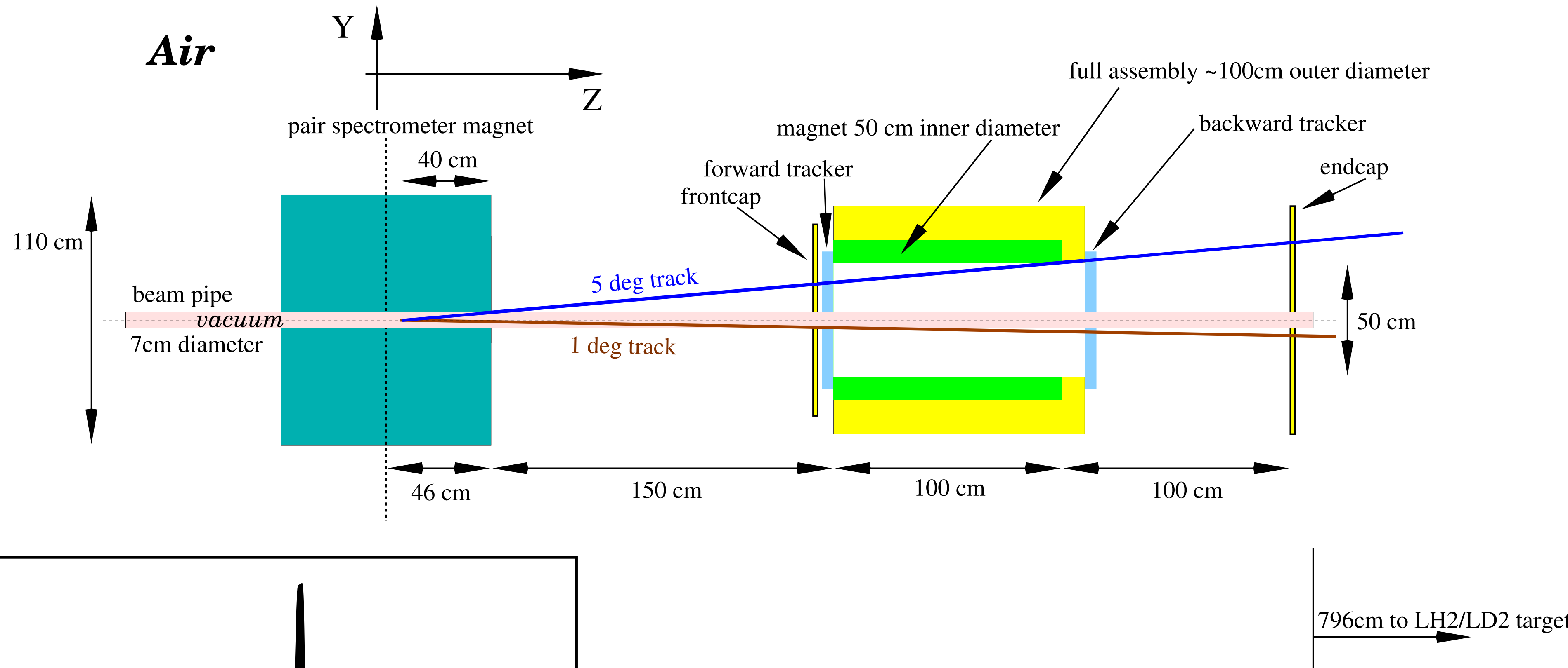


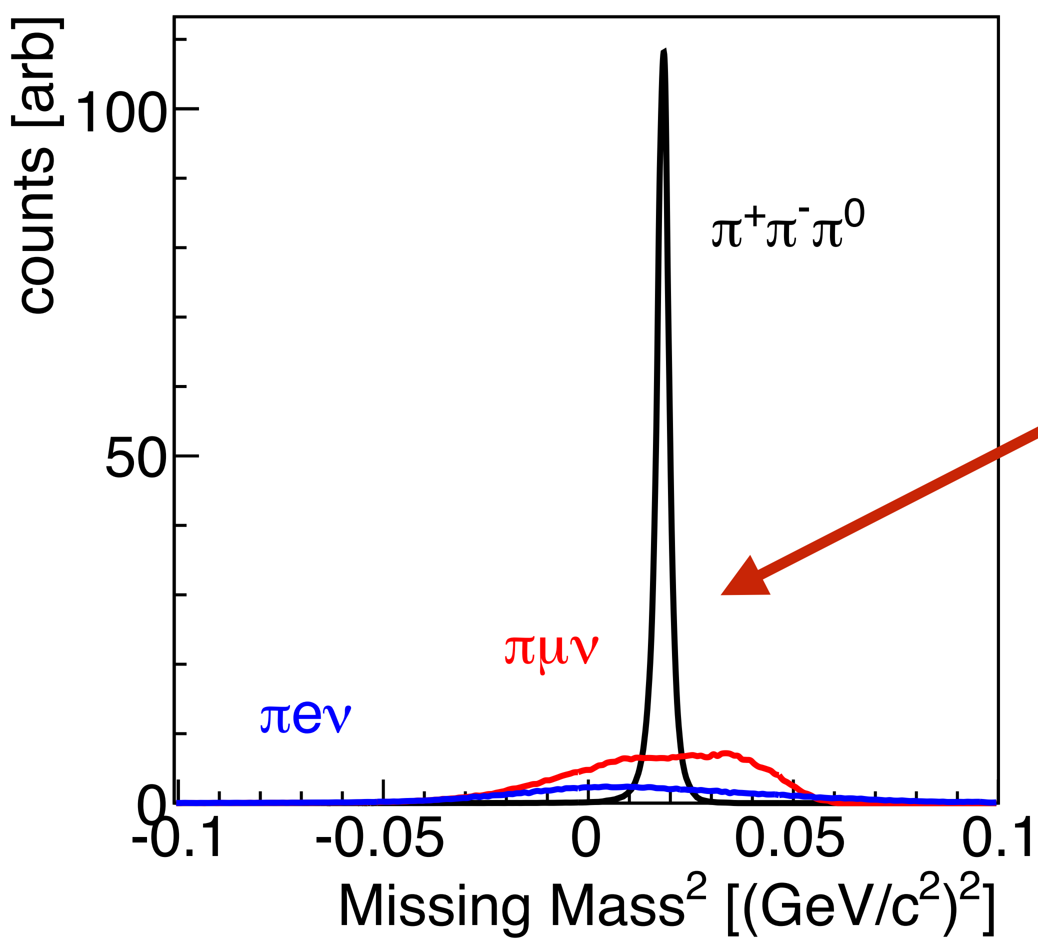
-Meets RadCon Radiation Requirements

-Conceptual Design Endorsed by Hall-D Engineering Staff

arXiv: 2002.04442

Flux Monitor





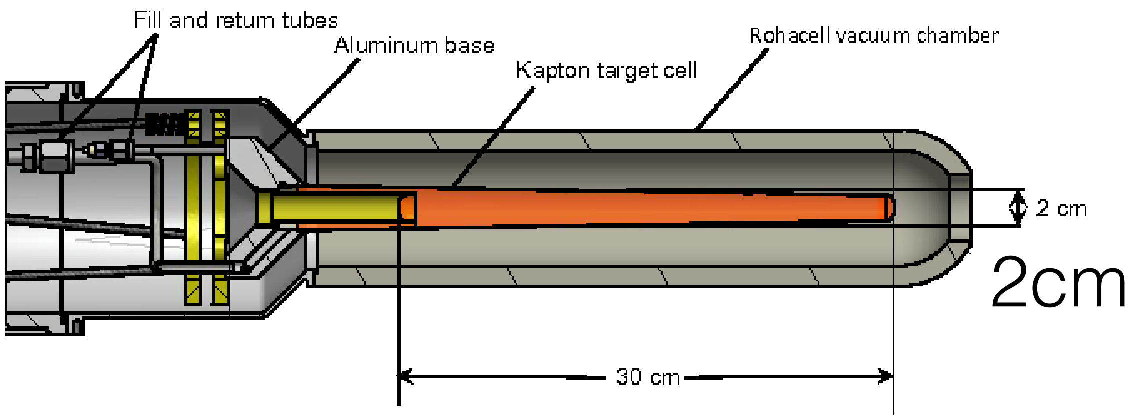
Reconstructed K_L mass

Flux measurement stat. err. <1%

Estimated conservative syst. err. ~5%

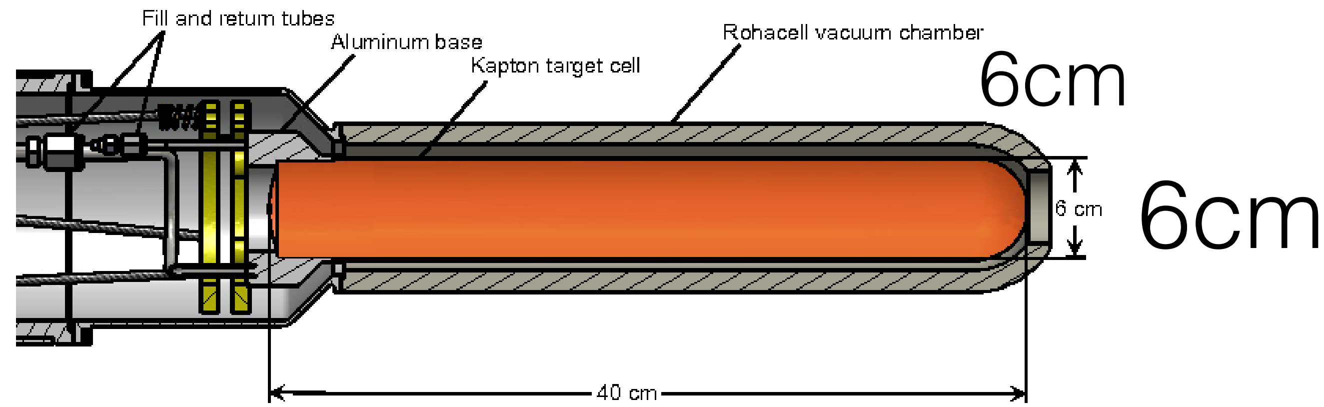
LH_2/LD_2 Cryogenic Target for Neutral Kaon Beam at Hall D

The GlueX liquid hydrogen target.



30cm

Current



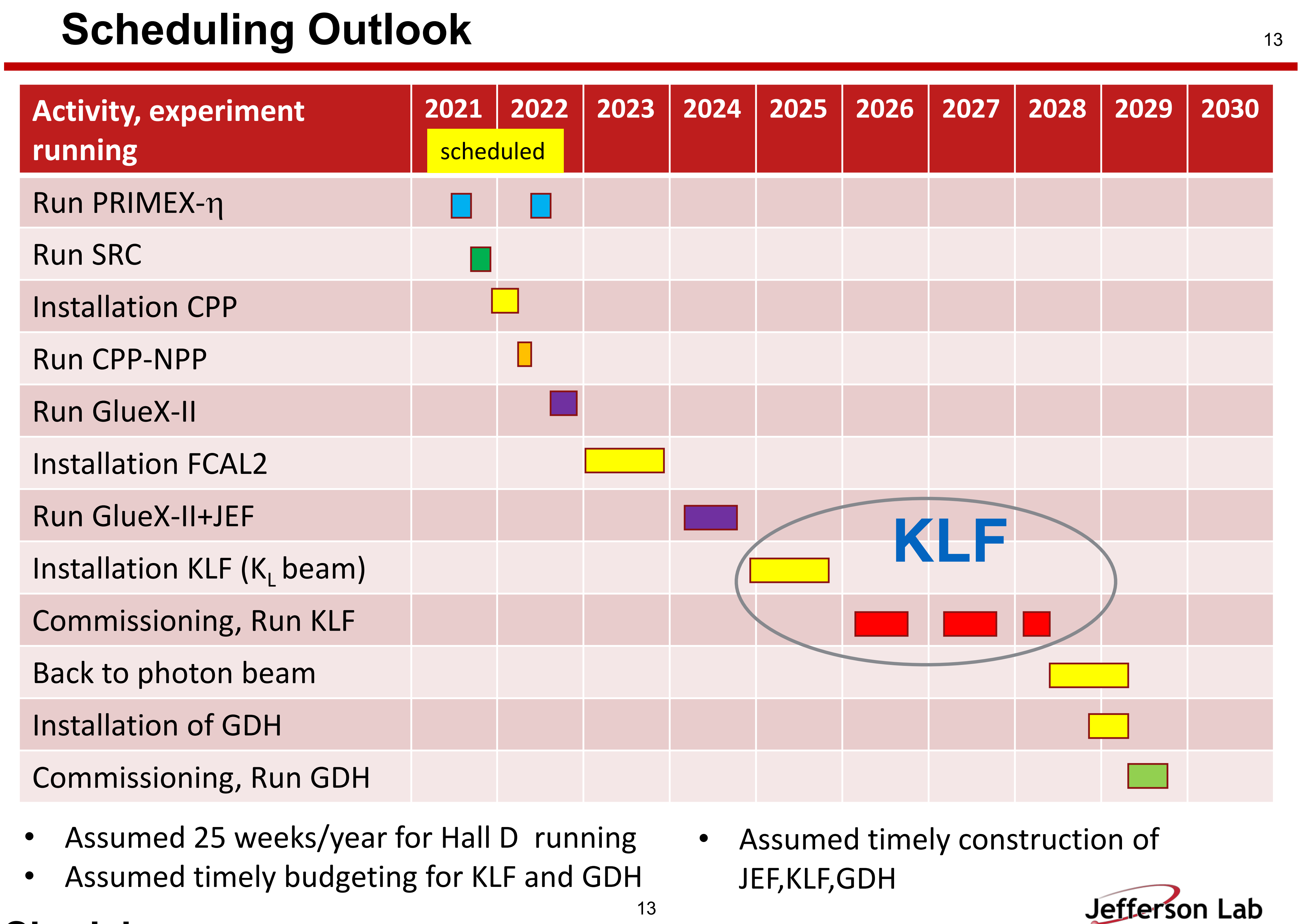
40cm

Proposed & Feasible

Longer and ticker target is needed to enhance production rate

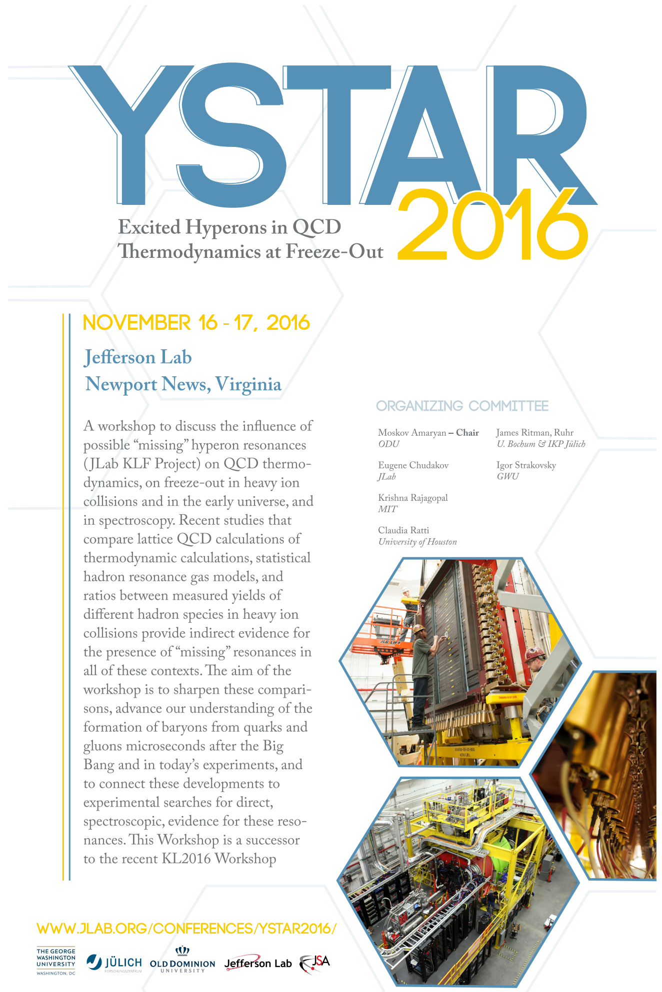
Conceptual design has been endorsed by the JLAB target group

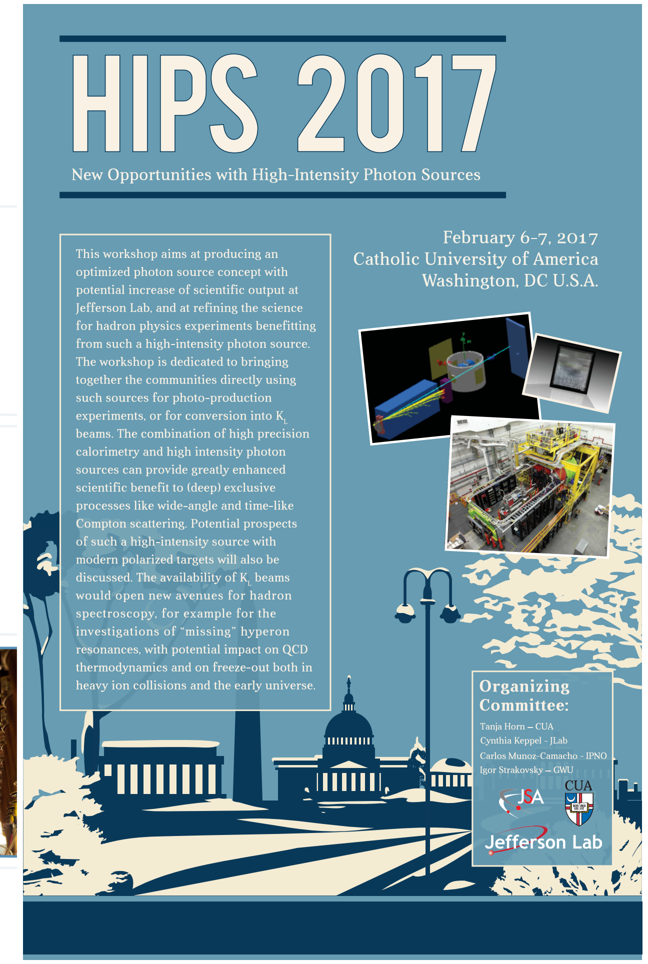
Timeline of Design, Construction and Installation

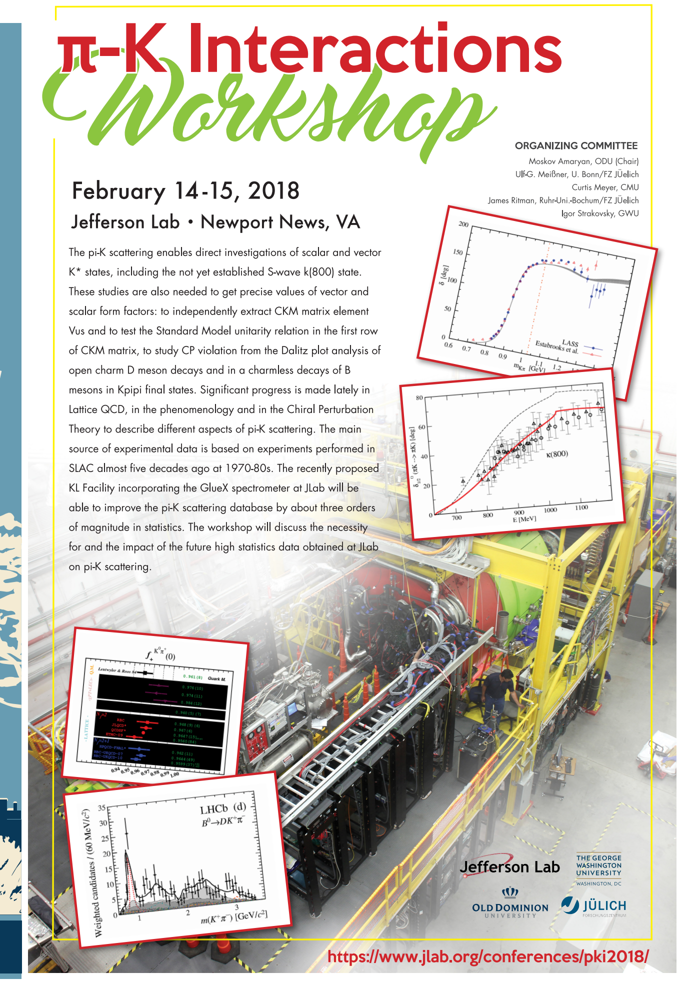


E. Chudakov
GlueX Coll. Meeting, Oct. 2021

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/*](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/*](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/*](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/*](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 2M

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

Thank you !