Strange Hadron Spectroscopy with Secondary KL Beam in Hall-D

Moskov Amaryan

Old Dominion University
Norfolk, VA

(on behalf of  *Collaboration)*

PAC47, JLab, July 30, 2019

K-long Facility Collaboration

is formed through open opt-in procedure

From GlueX White Paper on Future Hall-D Physics:

There are many unresolved issues in hadron physics and the vast opportunities and advances that only become possible with KL facility. This KL facility would revolutionize our understanding of bound systems containing strange quarks, providing the long sought, high quality experimental data to reach deeper into strange quark sector. This will enable the tremendous recent progress in spectroscopy in both theory and experiment with electromagnetic beams to continue into a new frontier.

Date: June 14, 2019

Proposal for JLab PAC47

Strange Hadron Spectroscopy with Secondary K_L Beam in Hall D

Experimental Support:

S. Adhikari[35], M. J. Amaryan (Contact Person, Spokesperson)[35], A. Austregesilo[39], M. Baalouch[42], M. Bashkanov (Spokesperson)[57], V. Baturin[35], V. V. Berdnikov[52,32], T. Black[55], W. Boeglin[30], W. J. Briscoe[53], V. D. Burkert[33], E. Chudakov[33], P. L. Cole[3], O. Cortes-Becerra[53], V. Crede[45], D. Day[12], P. Degtyarenko[33], S. Dobbs (Spokesperson)[45], G. Dodge[35], A. G. Dolgolenko[31], H. Egiyan[33], P. Eugenio[45], S. Fegan[51], A. Filippi[49], S. Furletov[33], L. Gan[55], A. Gasparyan[20], G. Gavalian[33], D. I. Glazier[19], V. S. Goryachev[31], L. Guo[30], A. Hayrapetyan[18], G. M. Huber[50], A. Hurley[54], C. E. Hyde[35], I. Illari[51], D. G. Ireland[19], K. Joo[44], V. Kakoyan[56], G. Kalicy[52], M. Kamel[30], C. D. Keith[33], C. W. Kim[51], G. Krafft[33], S. Kuhn[35], S. Kuleshov[43], A. B. Laptev[28], I. Larin[1], D. Lawrence[33], D. I. Lersch[45], W. Li[54], V. E. Lyubovitskij[49,46,47,51], D. Mack[33], D. M. Manley[27], H. Marukyan[56], V. Matveev[31], M. McCaughan[33], B. McKinnon[19], C. A. Meyer[39], F. Nerling[16,14], G. Niculescu[22], A. Ostrovidov[45], Z. Papandreou[40], K. Park[33], E. Pasyuk[33], L. Pentchev[33], W. Phelps[53], J. W. Price[11], J. Reinhold[30], J. Ritman (Spokesperson)[7,25], D. Romanov[32], C. Salgado[34], T. Satogata[33], A. M. Schertz[54], S. Schadmand[25], D. I. Sober[52], A. Somov[33], S. Somov[32], J. R. Stevens (Spokesperson)[54], I. I. Strakovsky (Spokesperson)[53], V. Tarasov[31], S. Taylor[33], A. Thiel[19], D. Watts[57], L. Weinstein[35], D. Werthmüller[57], T. Whitlatch[33], N. Wickramaarachchi[35], B. Wojtsekhowski[33], N. Zachariou[57], J. Zhang[12]

Theoretical Support:

A. V. Anisovich[8,15], A. Bazavov[13], R. Bellwied[24], V. Bernard[38], G. Colangelo[4], A. Cieply[41], M. Döring[53], S. Eidelman[36,37], A. Eskandarian[53], J. Goity[33,21], H. Haberzettl[53], M. Hadžimehmedović[50], R. L. Jaffe[10], B. Z. Kopeliovich[51], H. Leutwyler[4], M. Mai[53], V. Mathieu[29], M. Matveev[15], U.-G. Meißner[8,26], V. Mokeev[33], C. Morningstar[39], B. Moussallam[38], K. Nakayama[2], V. Nikonov[8,15], Y. Oh[59], R. Omerović[50], H. Osmanović[50], J. R. Pelaez[29], A. Pilloni[33], D. Richards[33], D.-O. Riska[23], A. Rodas[29], J. Ruiz de Elvira[4], H-Y. Ryu[9], E. Santopinto[17], A. V. Sarantsev[8,15], J. Stahov[50], A. Švarc[58], A. Szczepaniak[6,33], R. L. Workman[50], B. Zou[5],

[1] University of Massachusetts, Amherst, MA 01003, USA
[2] University of Georgia (UGA), Athens, GA 30602, USA
[3] Lamar University, Beaumont, TX 77710, USA
[4] University of Bern, CH-3012 Bern, Switzerland

Outline

Current Status

- *Hyperon Spectroscopy*
- *Strange Meson Spectroscopy*
- *Thermodynamics of Early Universe*

Future Prospects with K_L Facility at JLab

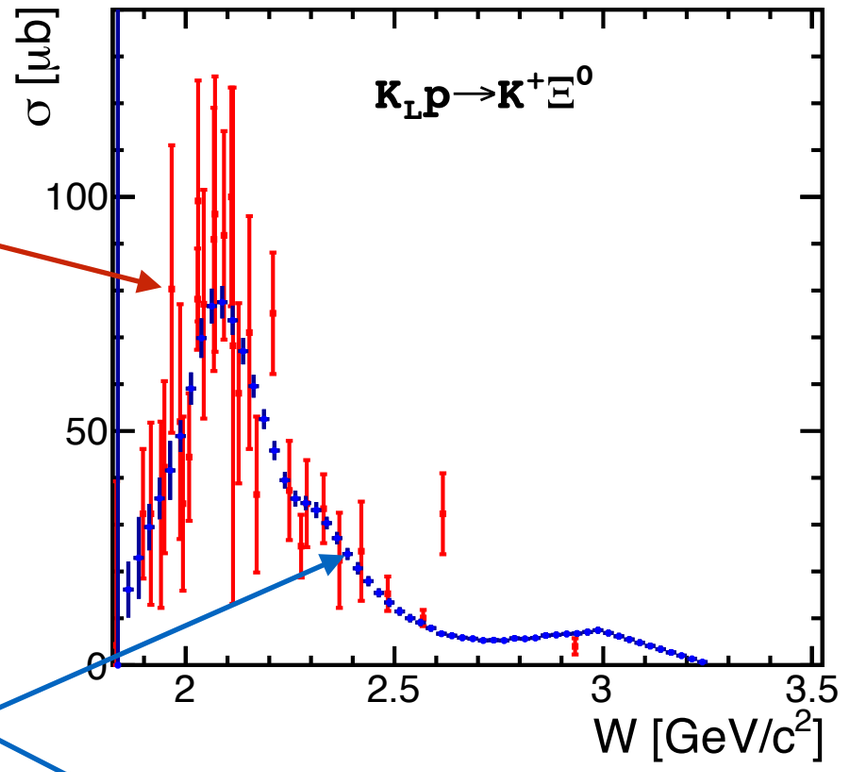
- *Electron Beam*
- *Compact Photon Source*
- *Be Target*
- *Flux Monitor*
- *K_L Beam*
- *LH_2/LD_2 Target*

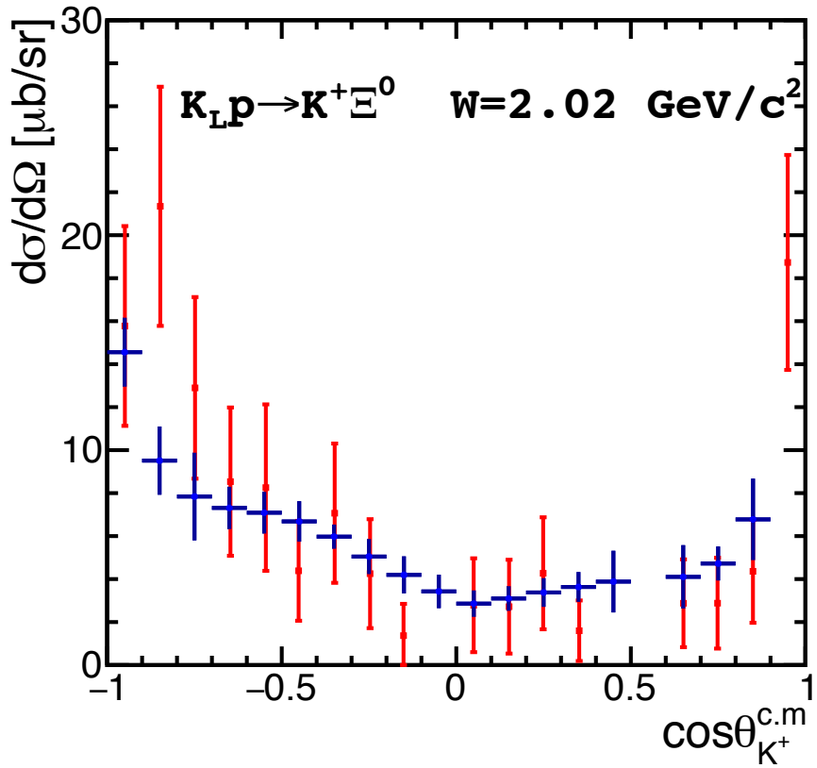
Summary

Measurements on Proton Target

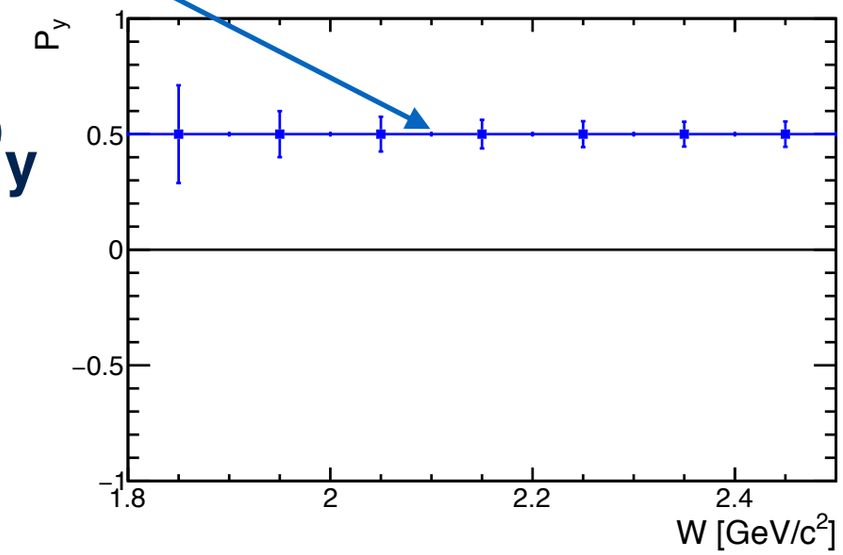
existing data

KLF 100 days



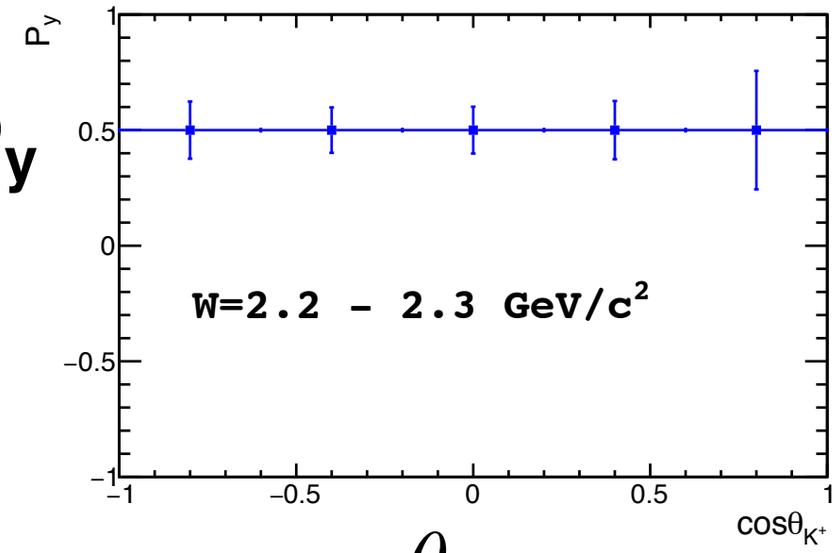


P_y



$\mathbf{W(GeV/c^2)}$

P_y



$\mathrm{COS}\ \theta_{\mathbf{K}+}$

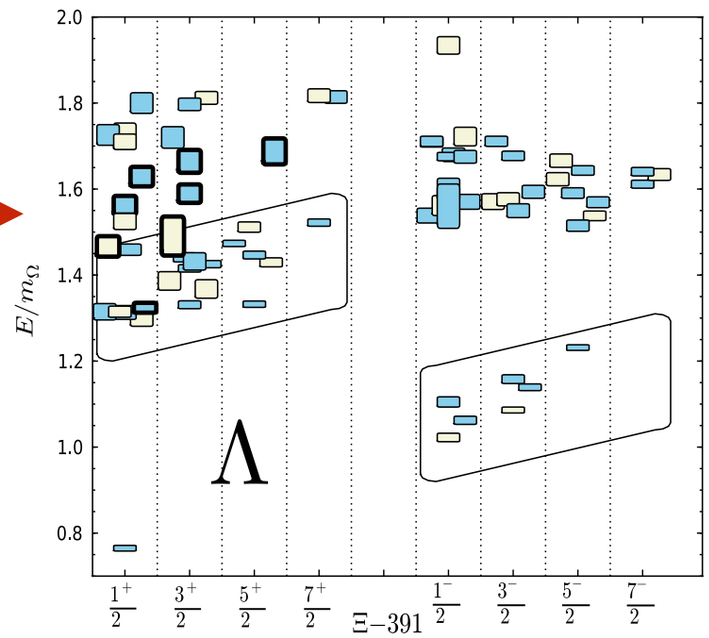
Hyperon Spectroscopy

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

many more states including hybrids (thick bordered)

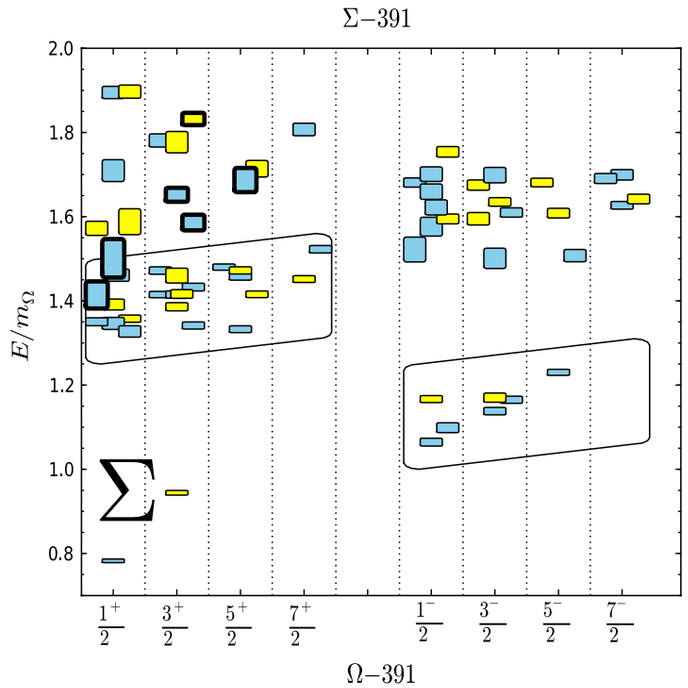
8-states
****

5-states
***



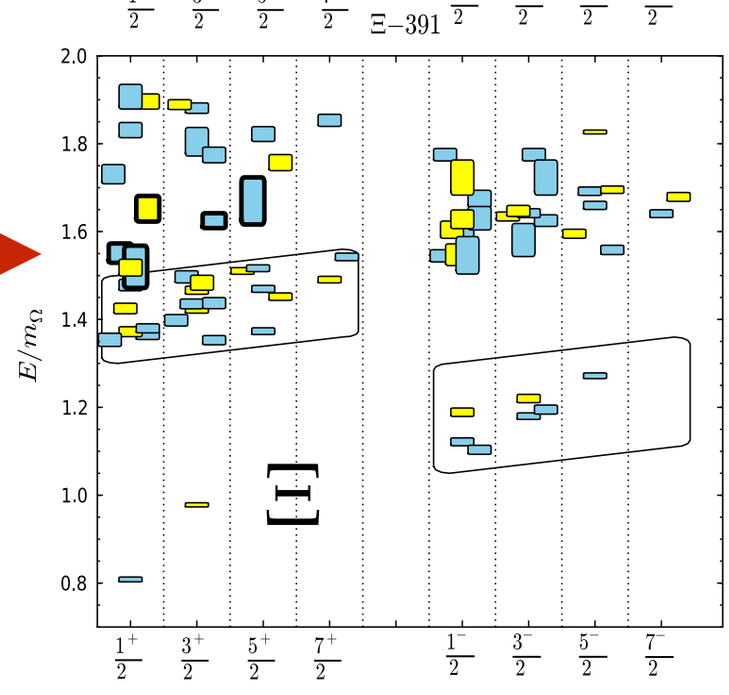
6-states
****

4-states
***



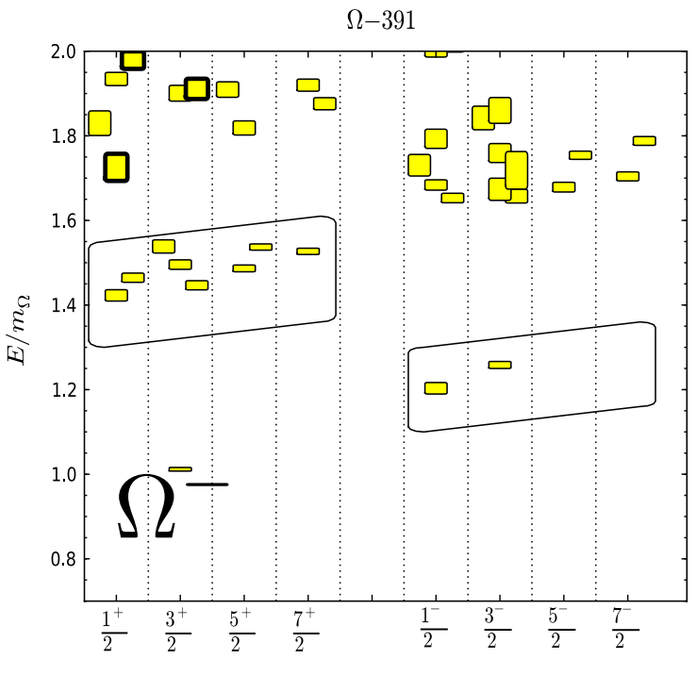
3-states
****

4-states
***



1-state
****

1-state
***



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

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 coupled-channel PWA

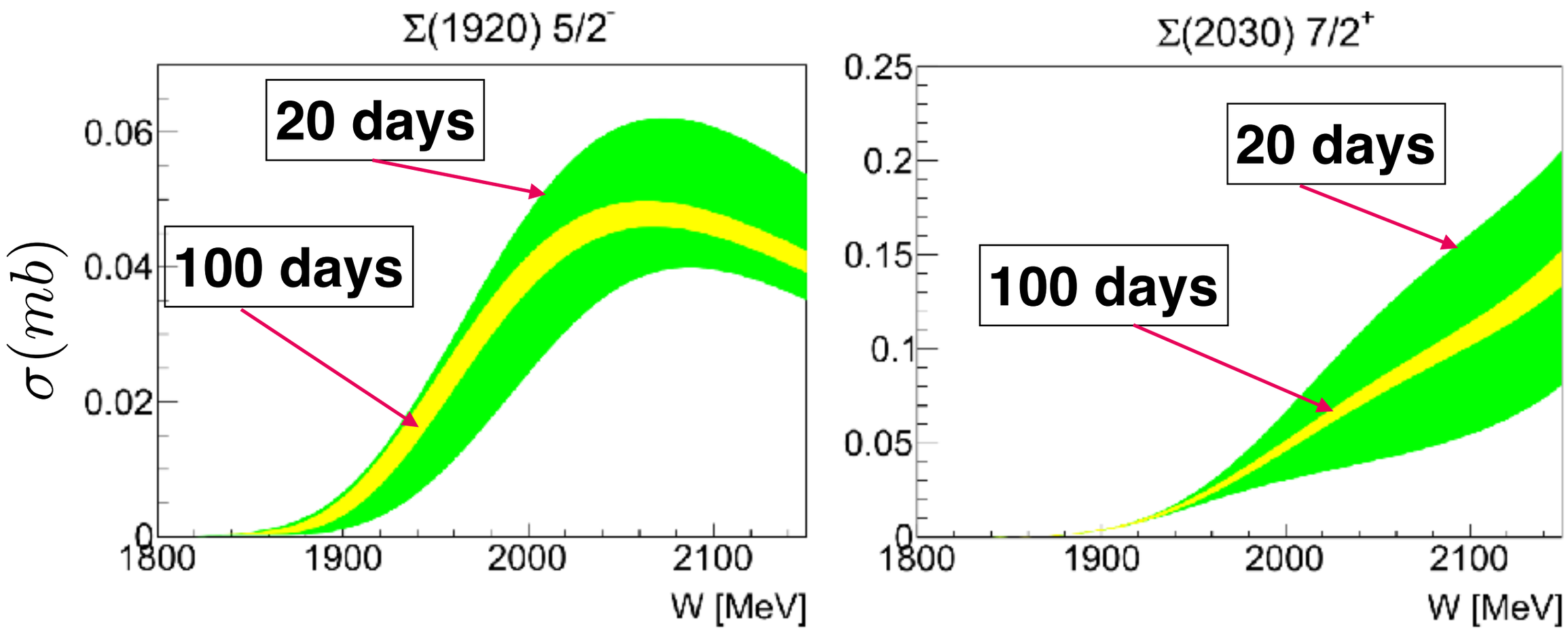
-look for poles in complex energy plane
(contrary to naïve bump hunting)

-identify all $\Lambda^*, \Sigma^*, \Xi^*$ & Ω^* up to 2400 MeV

we use KN scattering data with statistics
generated according to expected K-long Facility (KLF)
data for 20 and 100 days to show PWA sensitivity
to obtain results close to the best fit

Bonn-Gatchina PWA

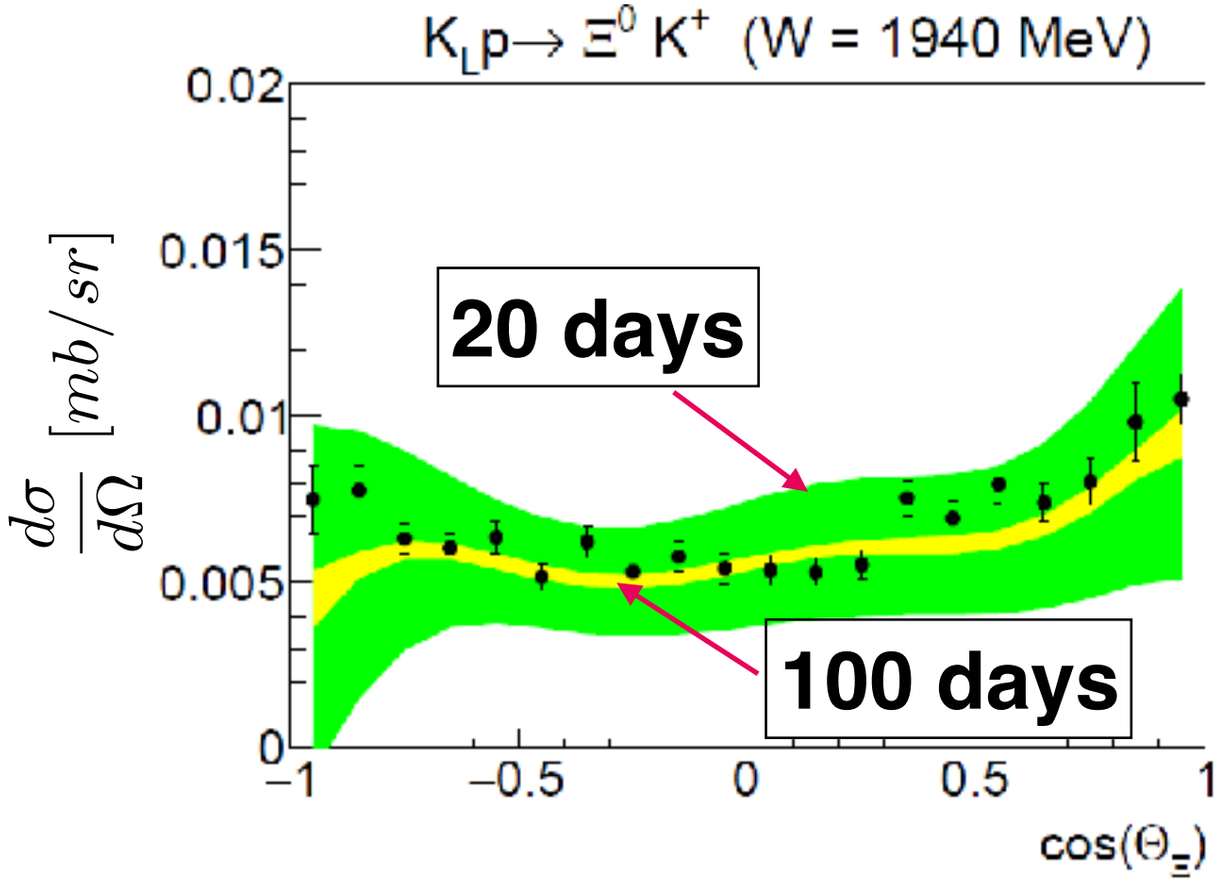
Total Cross Section $K_L p \to K^+ \Xi^0$



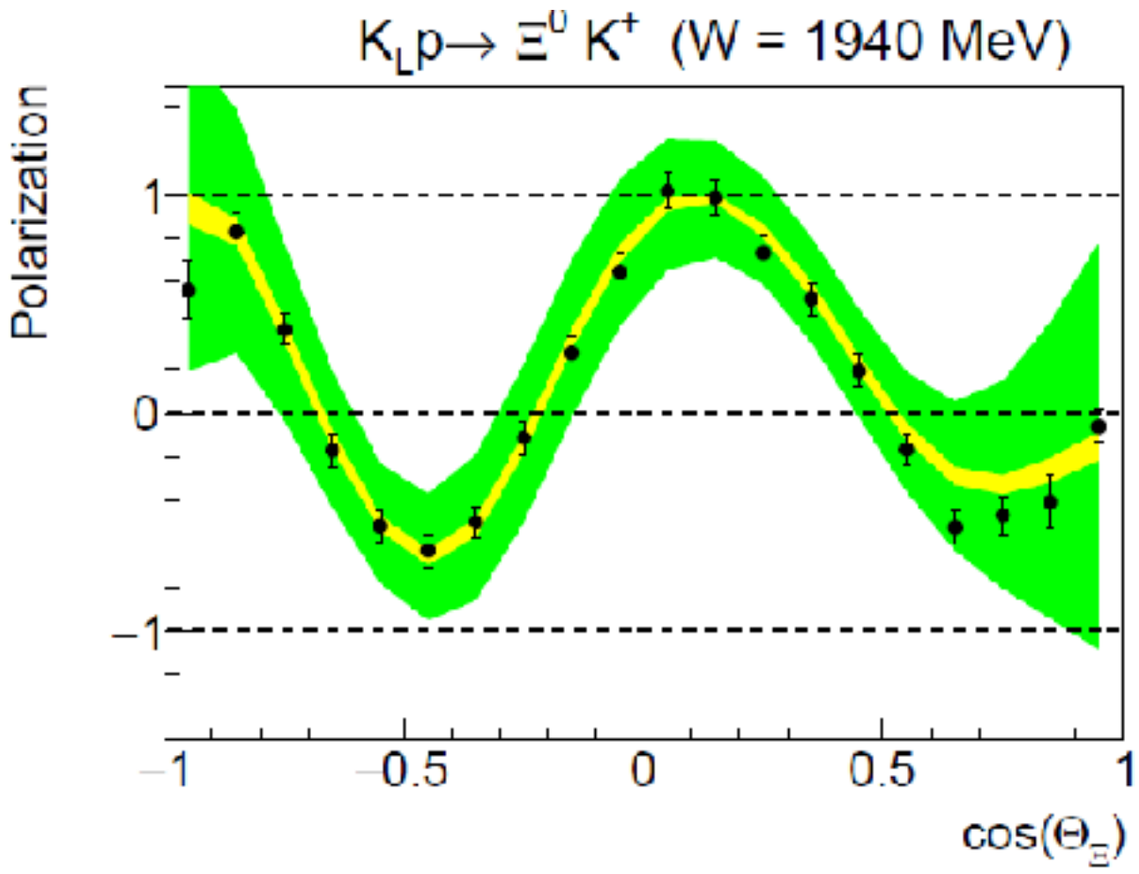
Obviously: at least 100 days needed to get precise solution

Bonn-Gatchina PWA

Diff. Cross Section



Polarization



Again: at least 100 days to get precise solution

Some Numerical Results

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

$$\begin{cases} 100d\ M = 1.923 \pm 0.010 \pm 0.010\ GeV \\ \Gamma = 0.321 \pm 0.01 \pm 0.010\ GeV \end{cases}$$

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

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

$$PDG2018\ M = 1.775 \pm 0.005$$

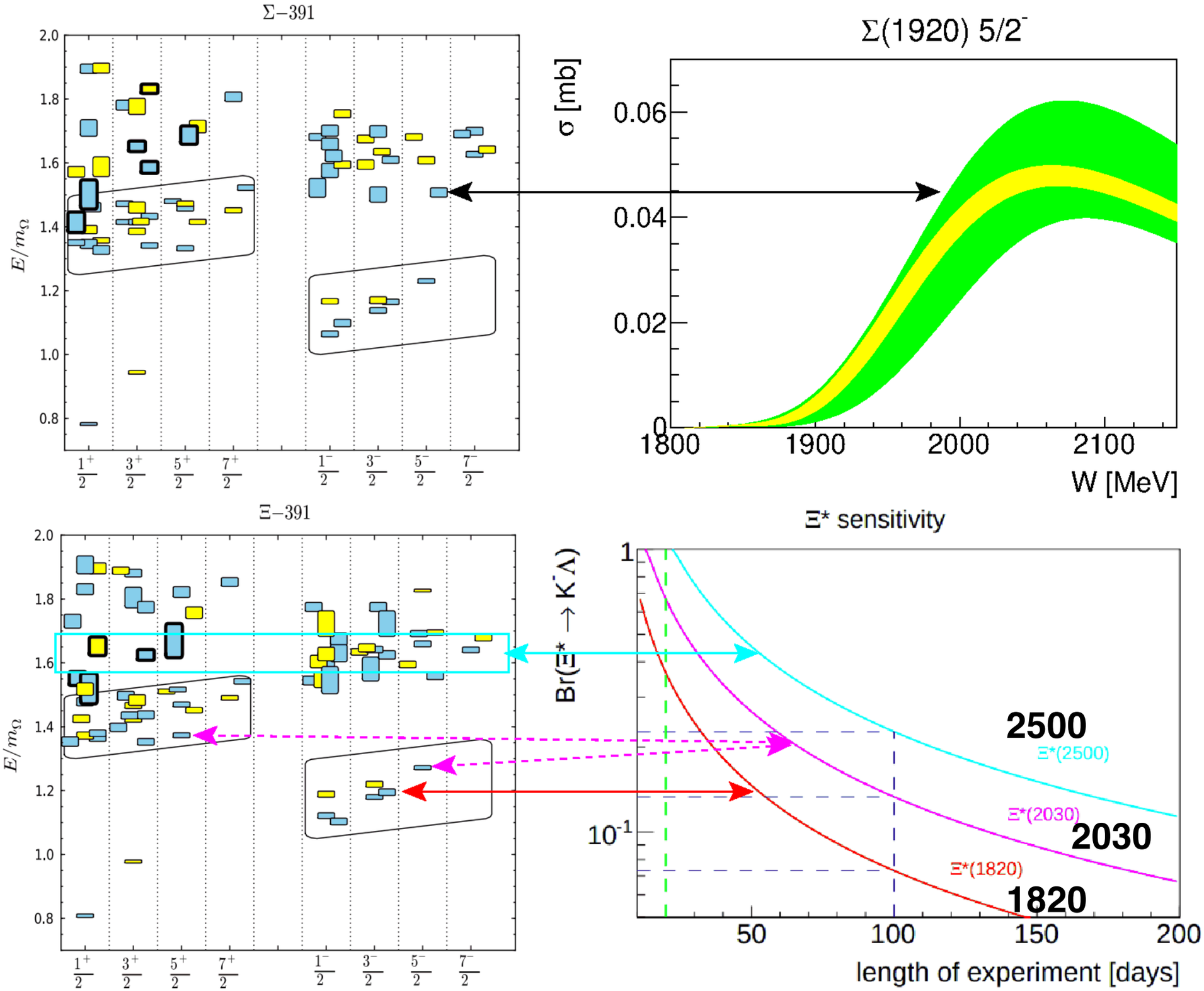
LQCD M=

2.027 GeV
2.487 GeV
2.659 GeV
2.781 GeV

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

LQCD Results are still in progress

Comparison of KLF Measurements and LQCD



Summary of Hyperon Spectroscopy

We showed that KLF sensitivity with 100 days of running will allow to discover many states with a good precision

Why should it be done with KL beam?

This is the only realizable way to observe s-channel resonances having all momenta of KL at once

Why should it be done at JLab?

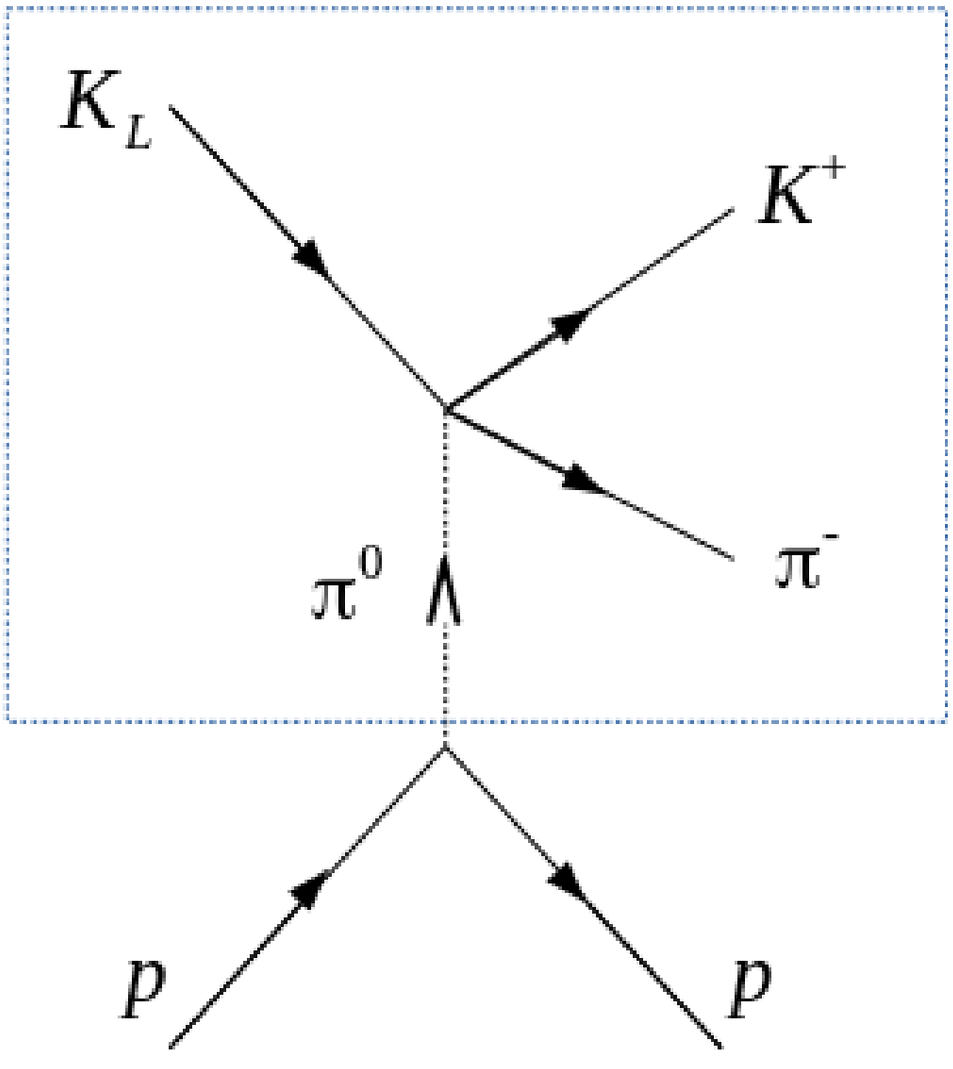
Because nowhere else in existing facilities this can be done

Why should we care that there are dozens of missing states?

... The new capabilities of the 12-GeV era facilitate a detailed study of baryons containing two and three strange quarks. Knowledge of the spectrum of these states will further enhance our understanding of the manifestation of QCD in the three-quark arena.
2015 Long Range Plan for Nuclear Science

Strange Meson Spectroscopy

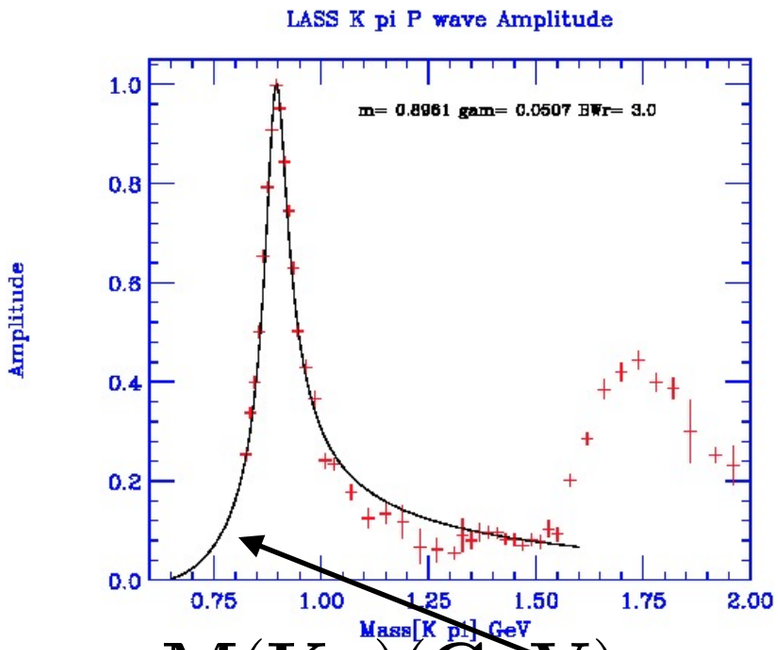
$K\pi$ Scattering



Proposed Measurements

SLAC

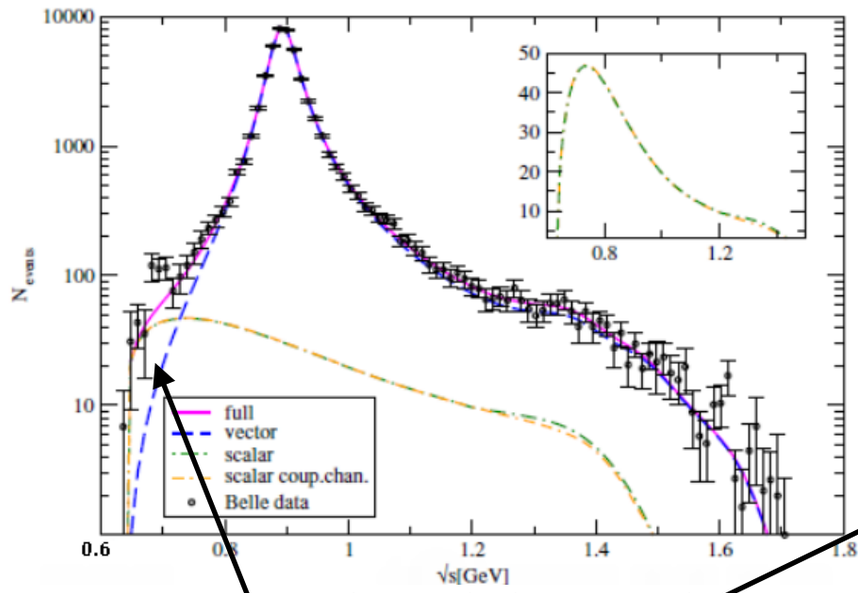
$$K^-\pi^+ \to K^-\pi^+$$



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

Belle

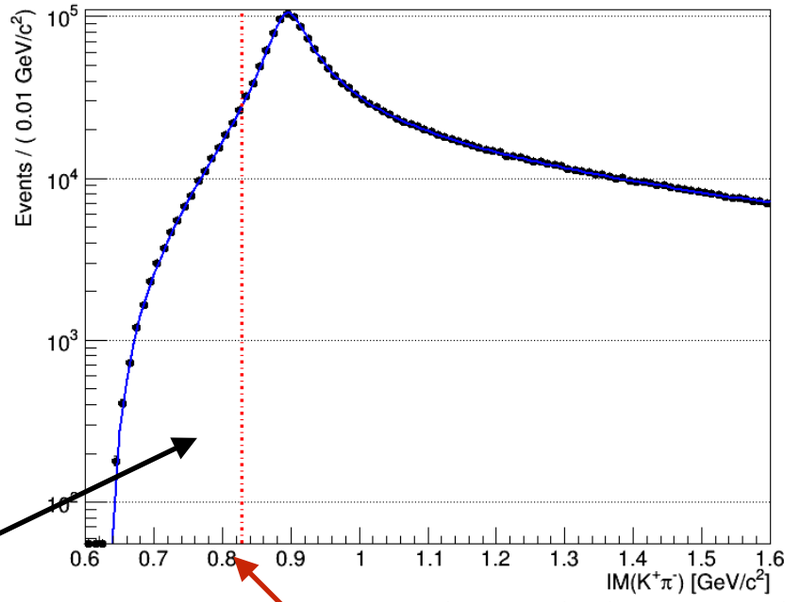
$$\tau \to K\pi\nu_\tau$$



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

KLF

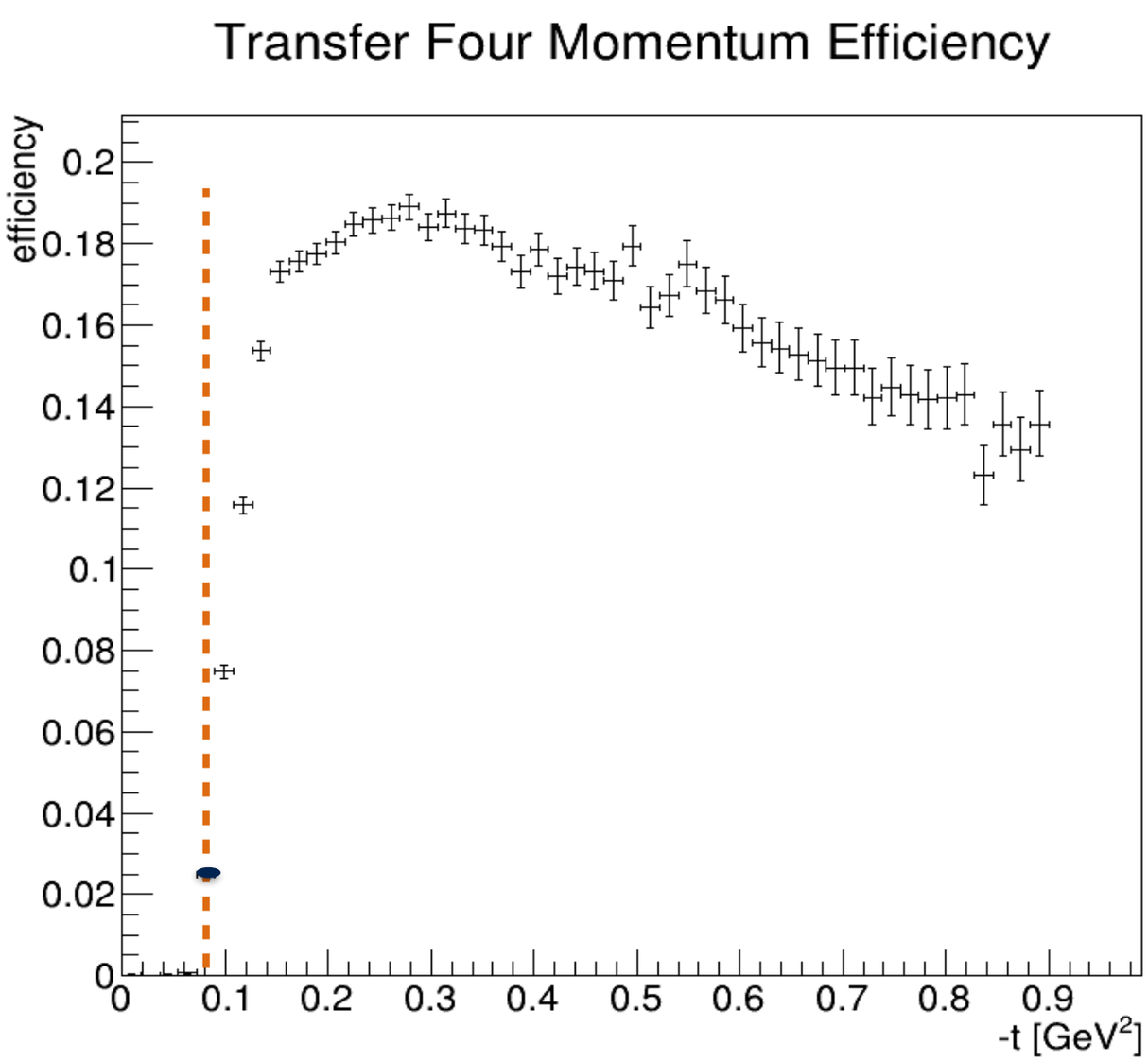
$$K_L\pi^0 \to K^+\pi^-$$

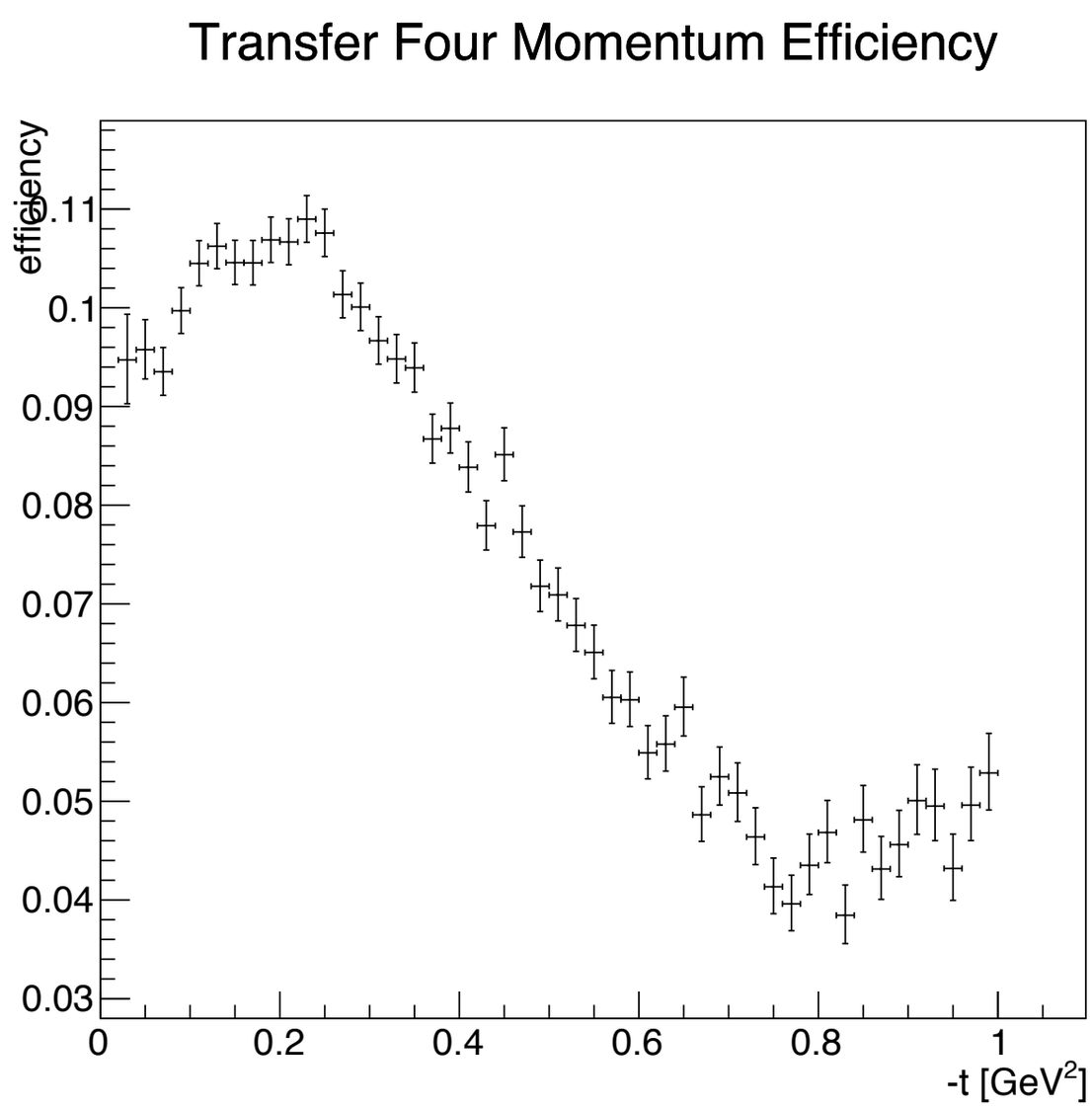


$\mathbf{M(K\pi)(GeV)}$

region of $\kappa(800)$

SLAC Lower limit

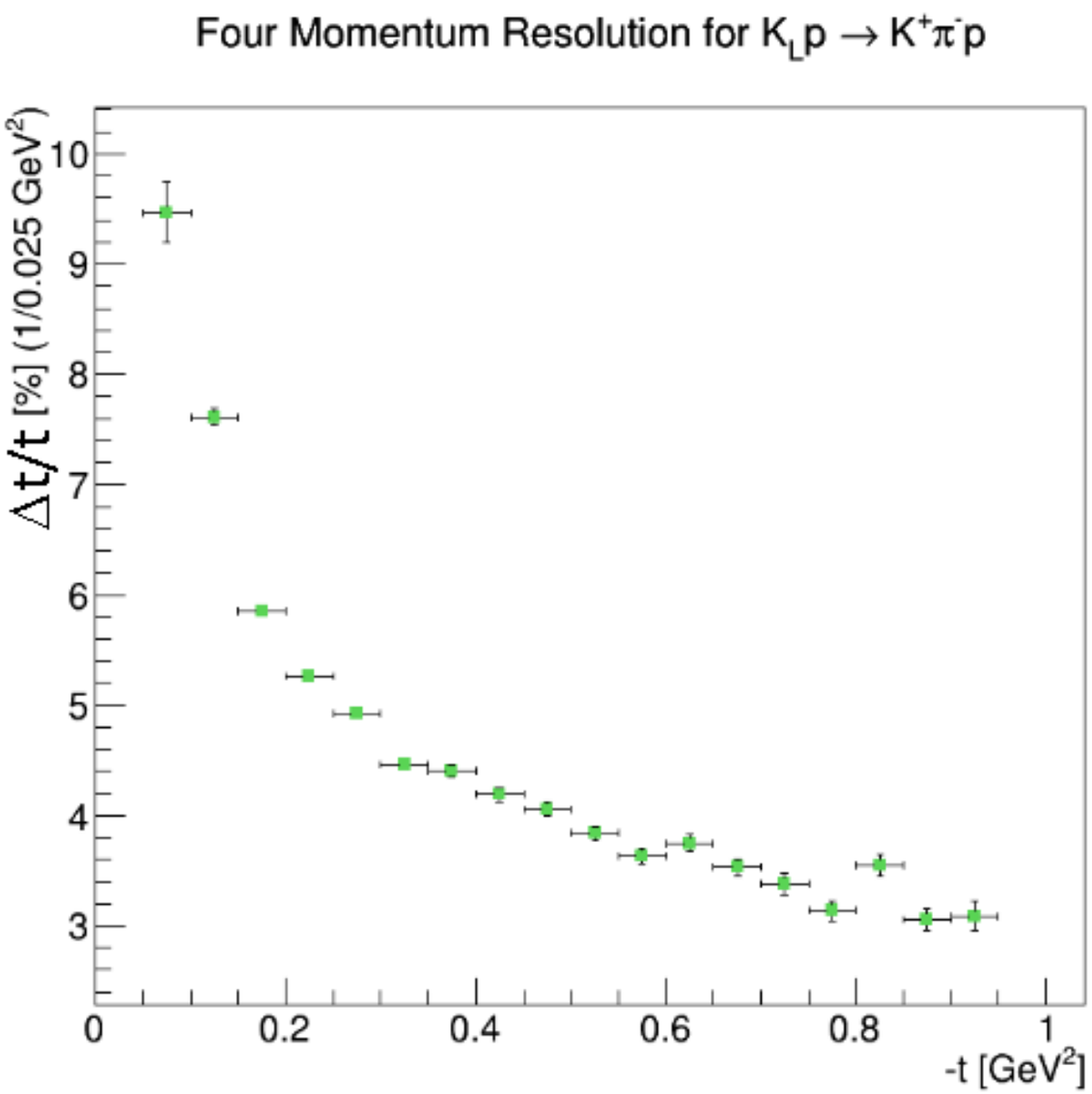


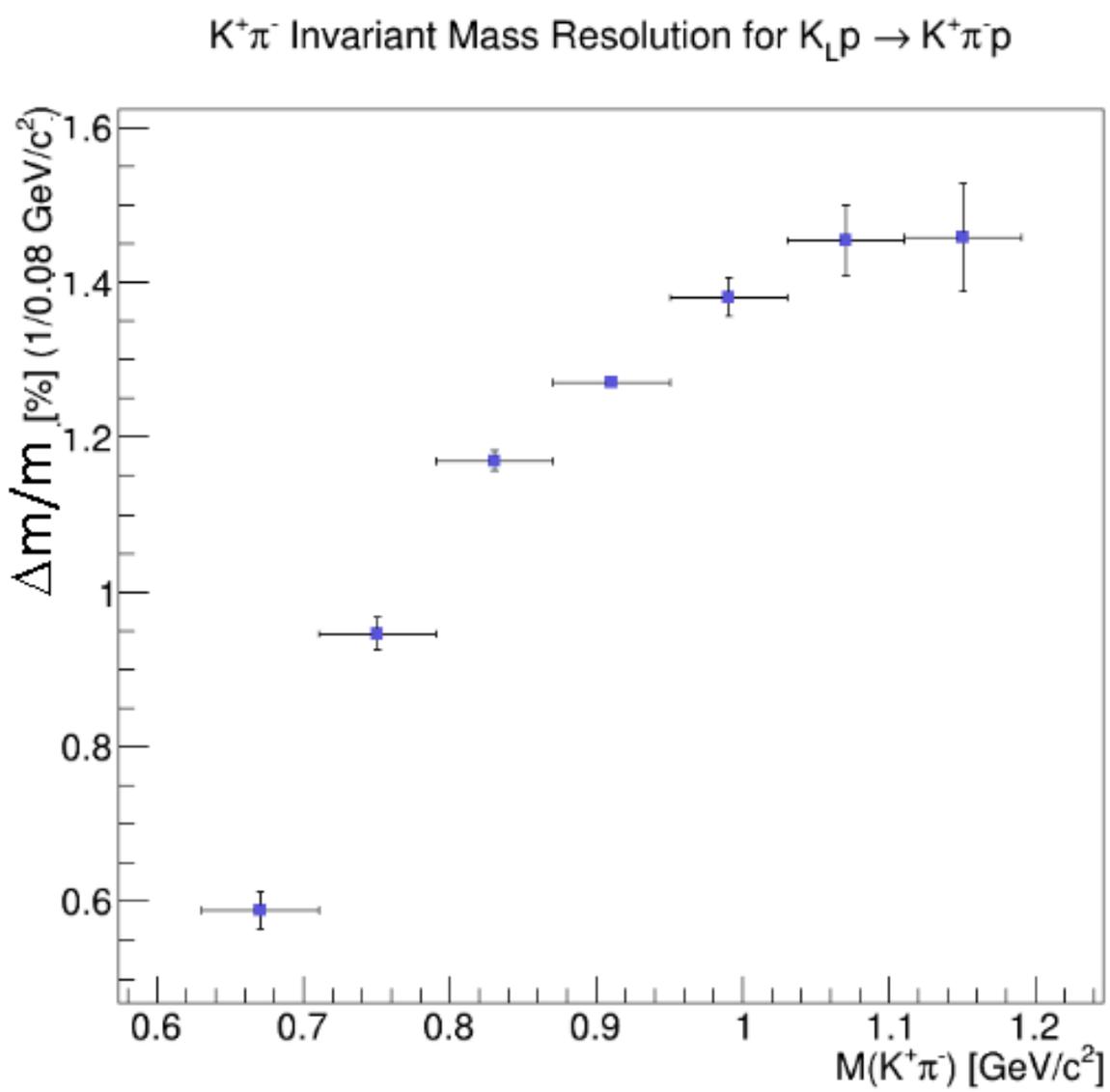


t-down to 0.08 GeV² is measurable with proton being detected

t-down to pion pole proton missing

$K\pi$ ***Scattering*** **(proton detected)**

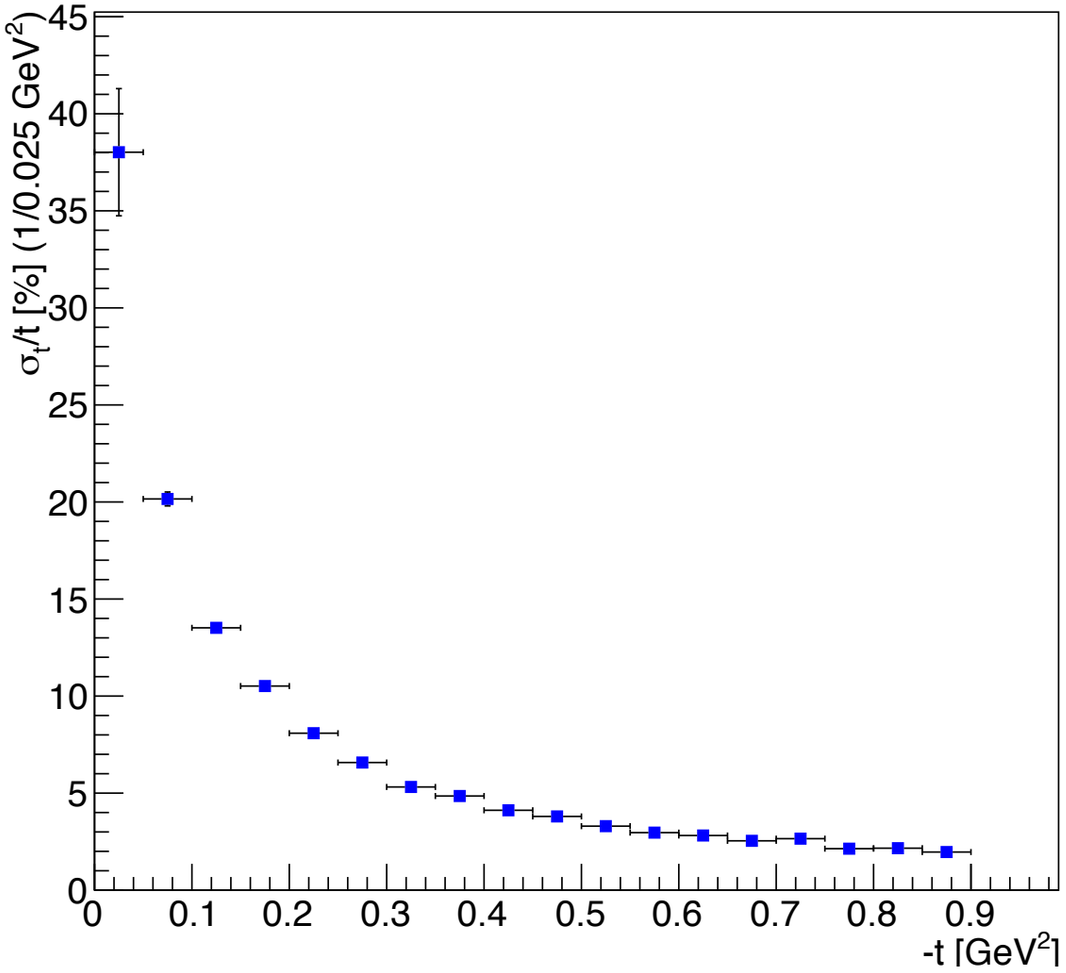


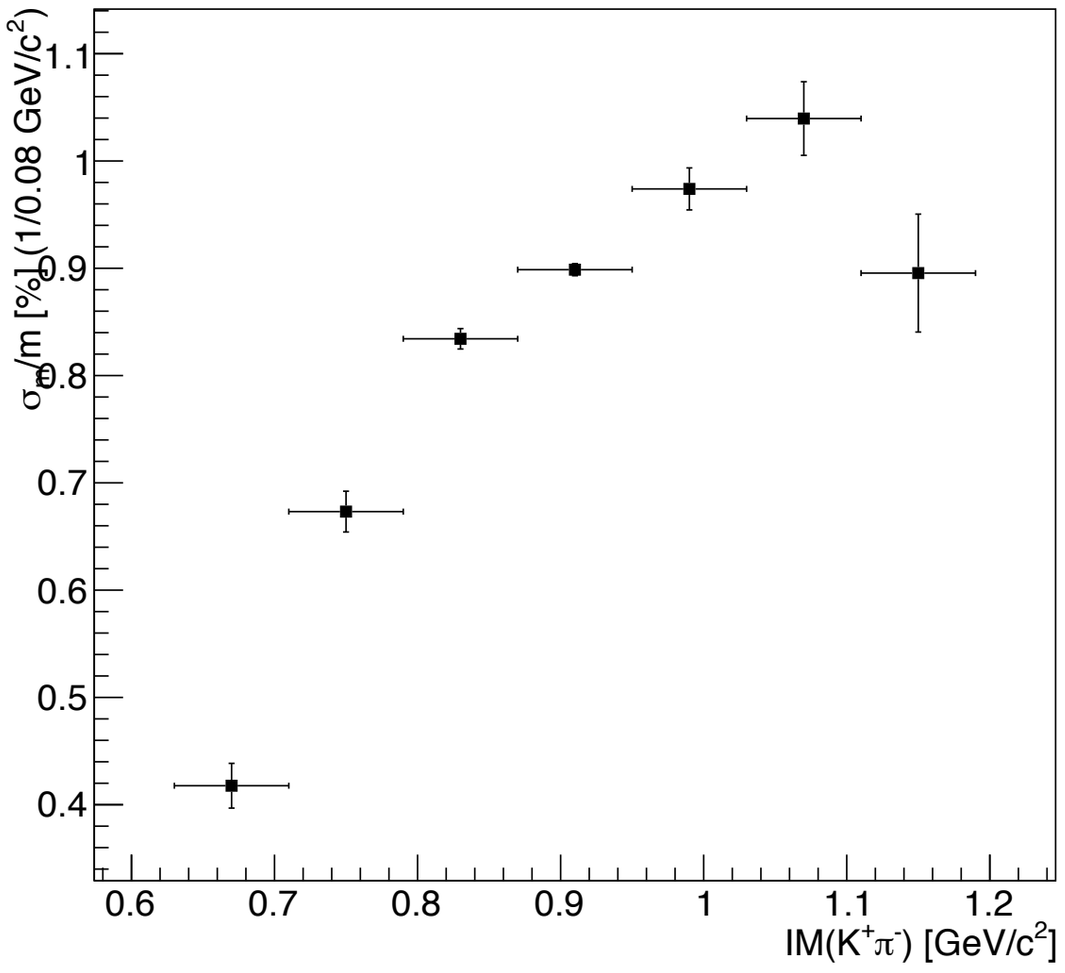


-Good resolution at low-t is needed to be close to pion pole

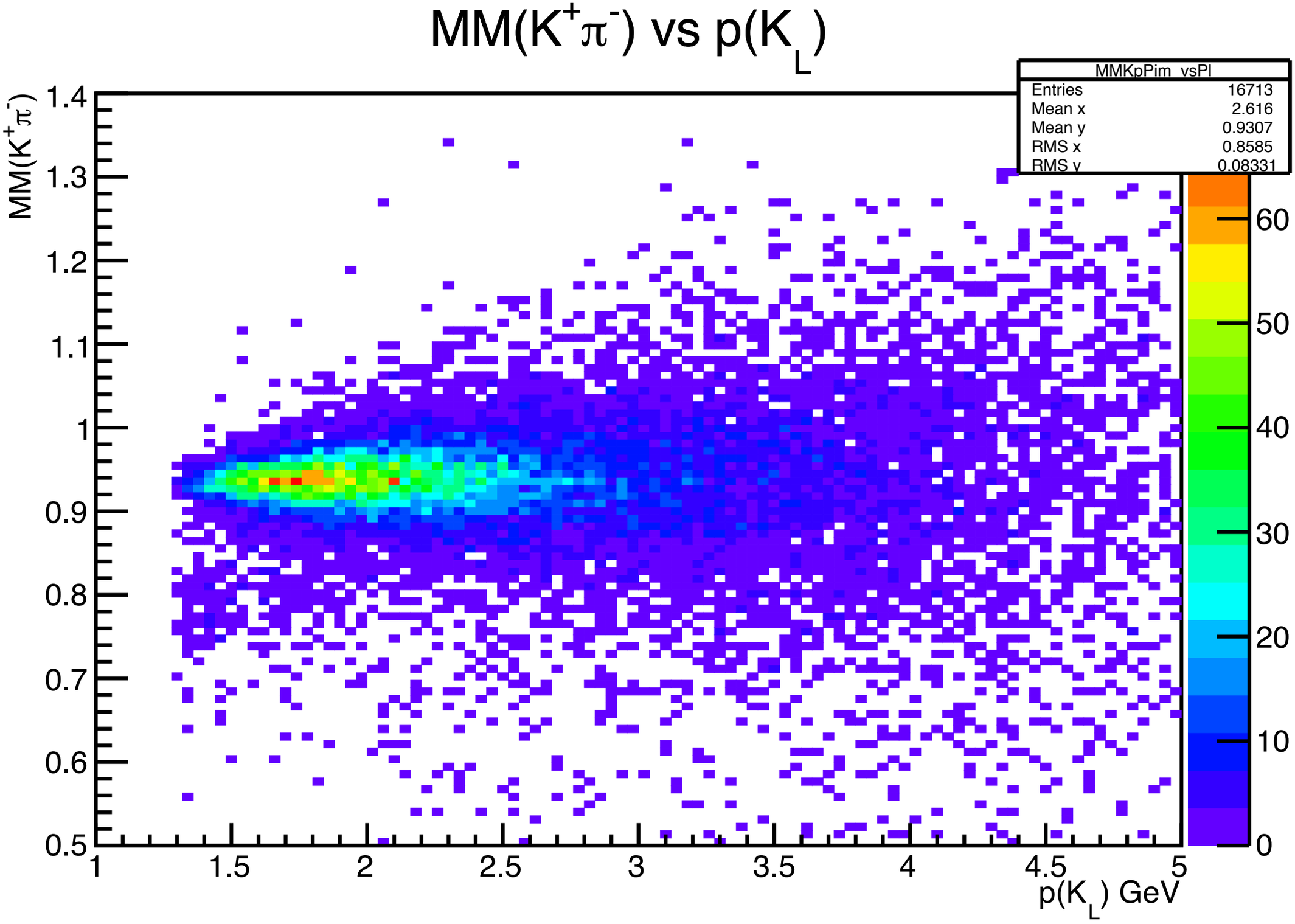
-Binning in ~10 MeV will cover almost entire elastic K-pi scattering range

$K\pi$ ***Scattering*** **(proton missing)**



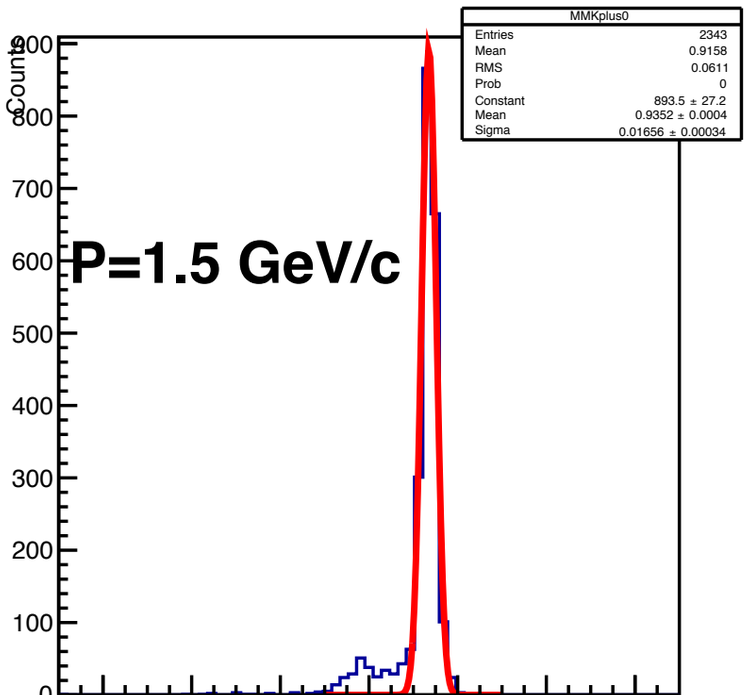


Missing Mass of $K^+\pi^-$ system

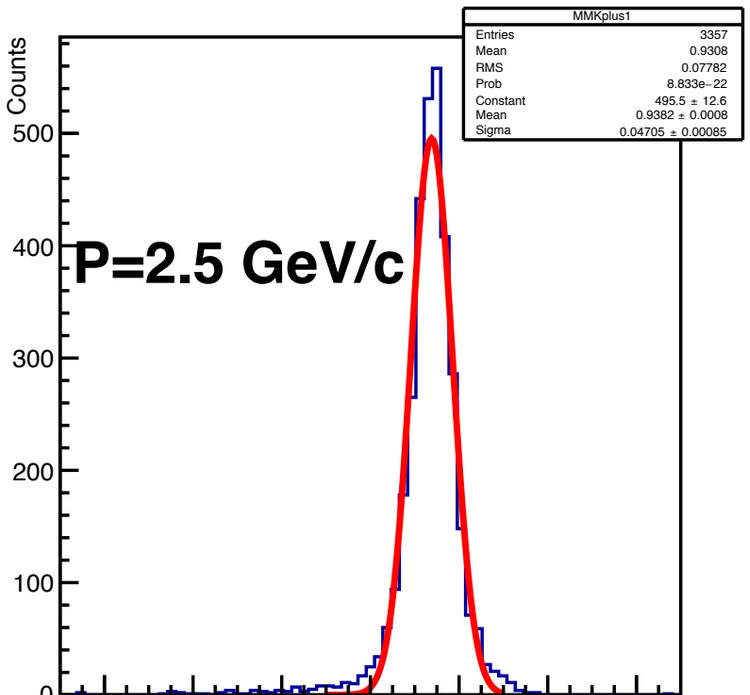


Missing Mass $MM(K^+\pi^-)GeV$

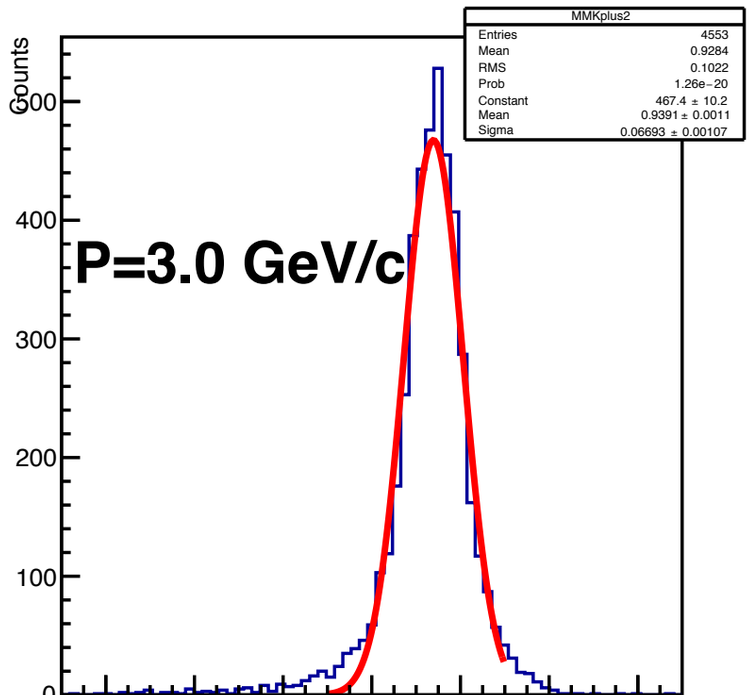
P = 1.5 GeV, Δ P = 0.1 GeV



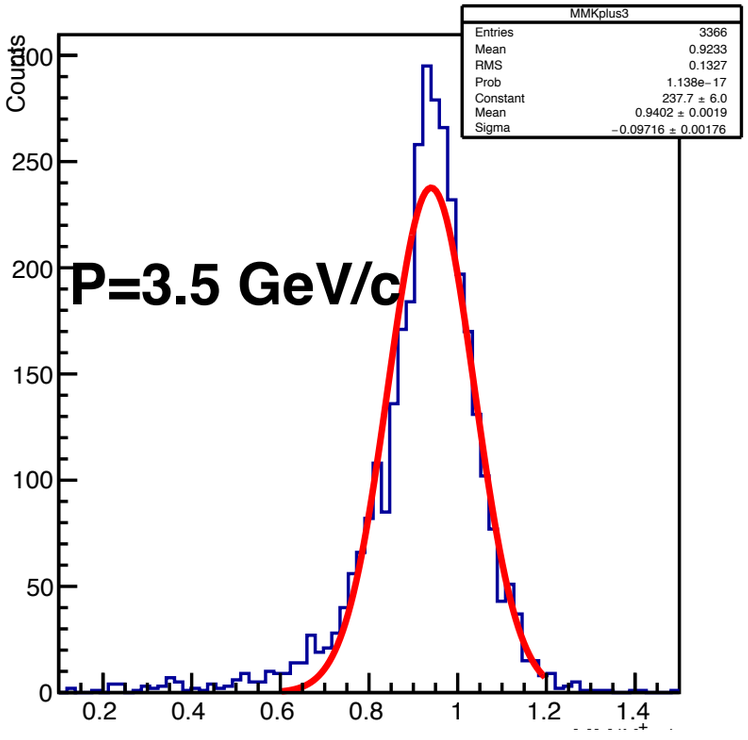
P = 2.5 GeV, Δ P = 0.1 GeV



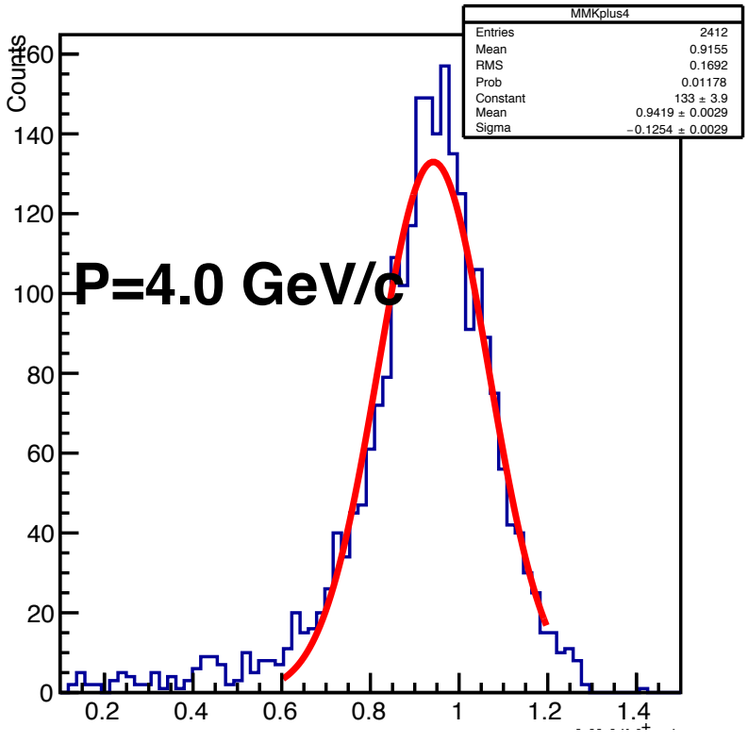
P = 3.0 GeV, Δ P = 0.2 GeV



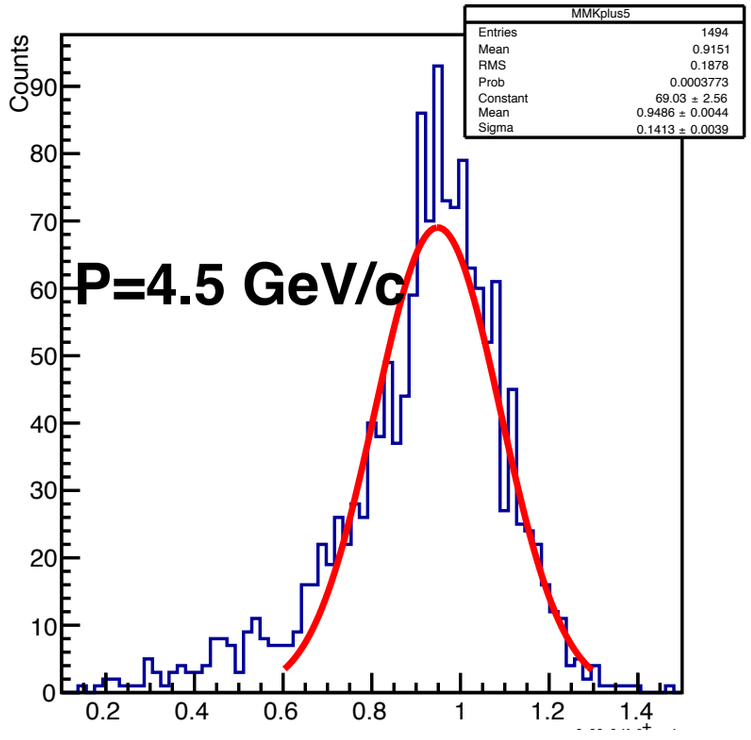
P = 3.5 GeV, Δ P = 0.2 GeV



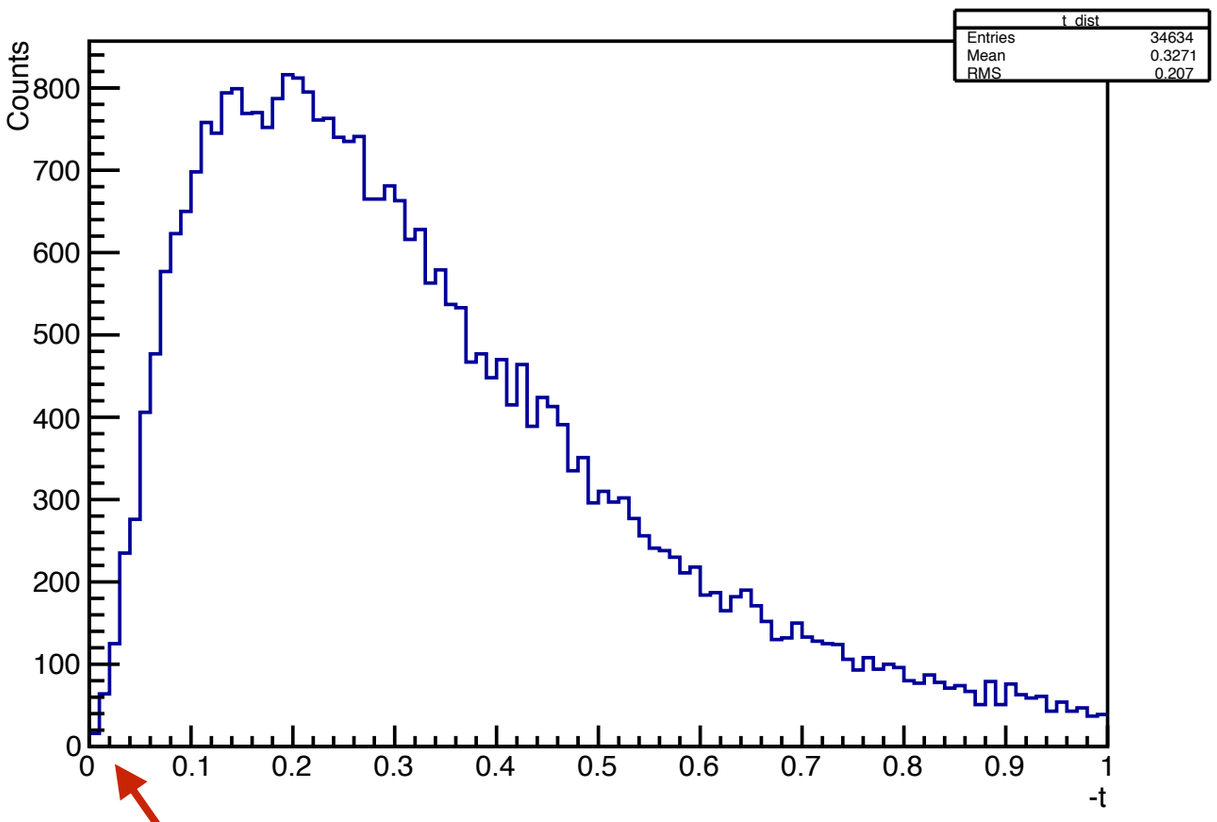
P = 4.0 GeV, Δ P = 0.2 GeV



P = 4.5 GeV, Δ P = 0.2 GeV

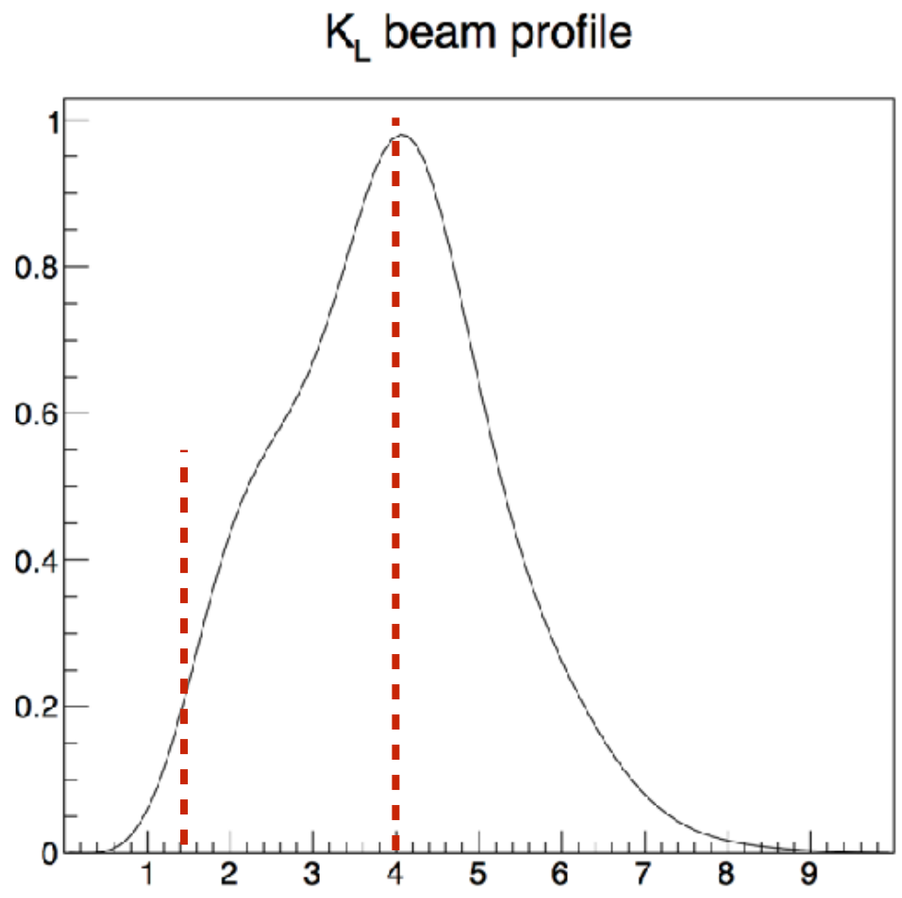


Proton reconstructed via missing mass



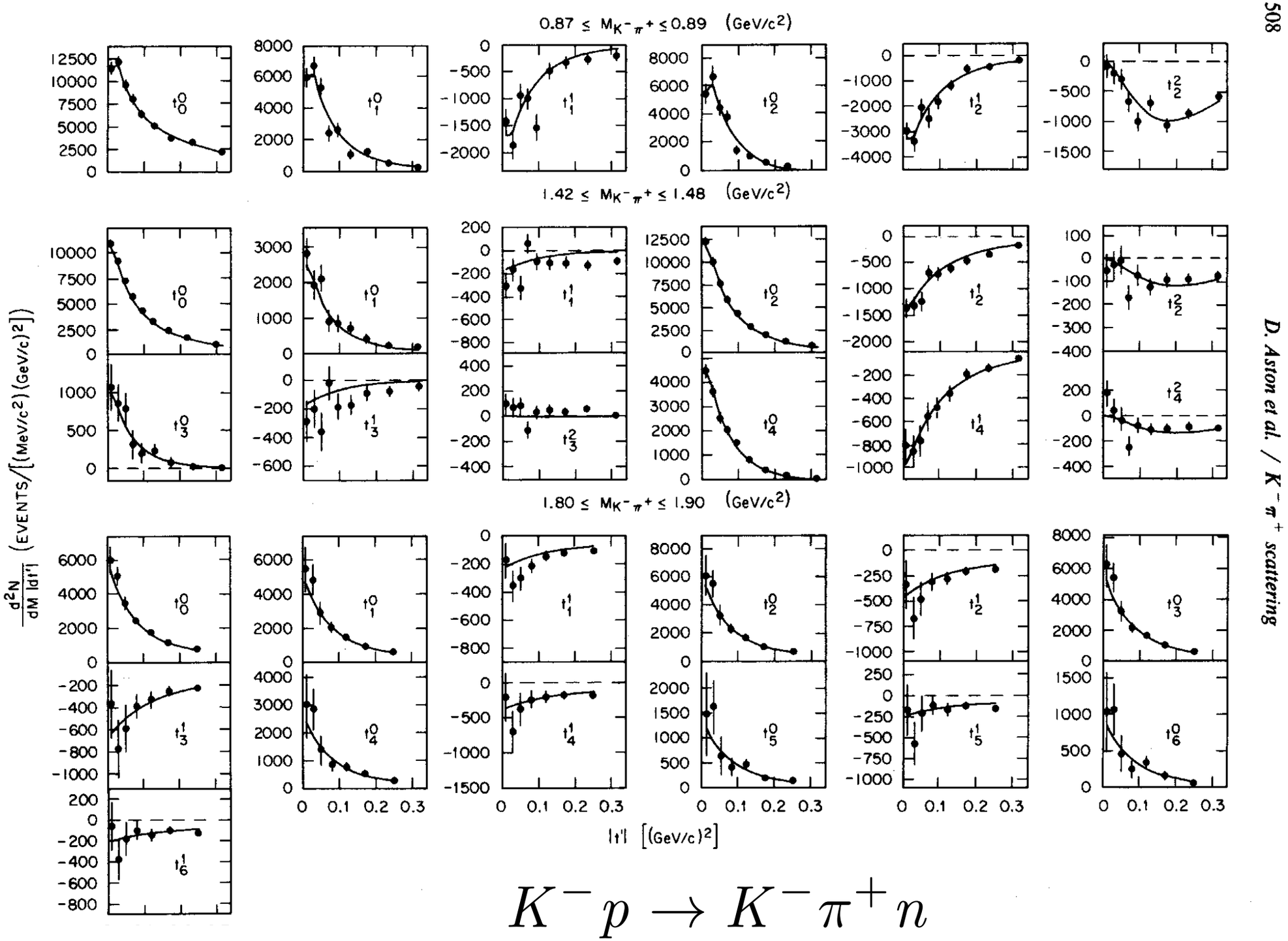
$-t, (GeV/c)^2$

Down to pion pole



$P(K_L), GeV/c$

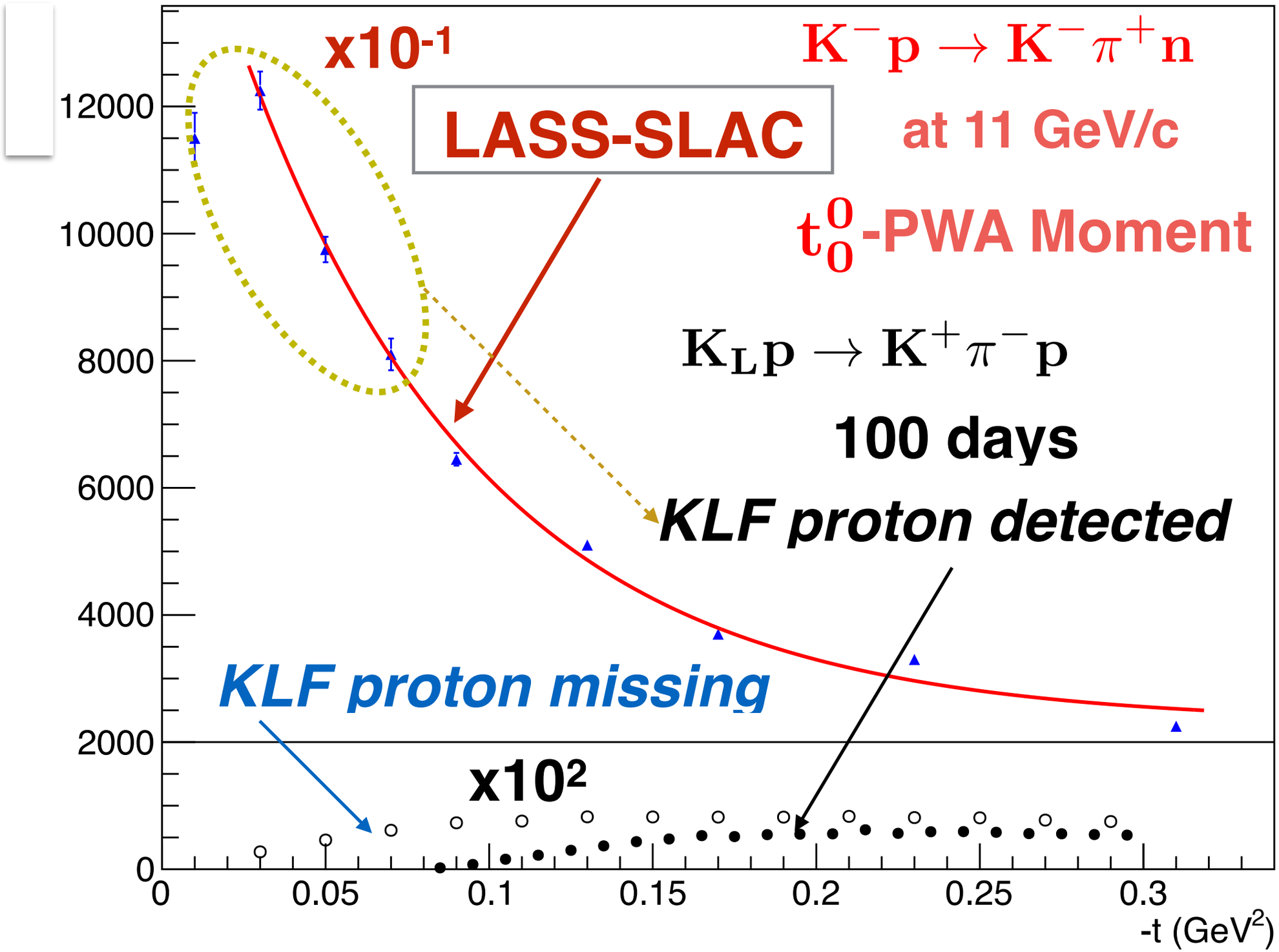
NPB296 Aston et al., LASS at SLAC at 11 GeV



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

Fig. 9. The acceptance corrected unnormalized $K^-\pi^+$ moments as a function of $|t'|$. Three different mass regions are shown; $0.87 \leqslant M_{K\pi} \leqslant 0.89$ GeV/c^2, $1.42 \leqslant M_{K\pi} \leqslant 1.48$ GeV/c^2, and $1.80 \leqslant M_{K\pi} \leqslant 1.90$ GeV/c^2. The curves are the result of a fit to the production model described in the text.

$$M_{K^-\pi^+} = 0.87 - 0.89\ \mathrm{GeV}$$

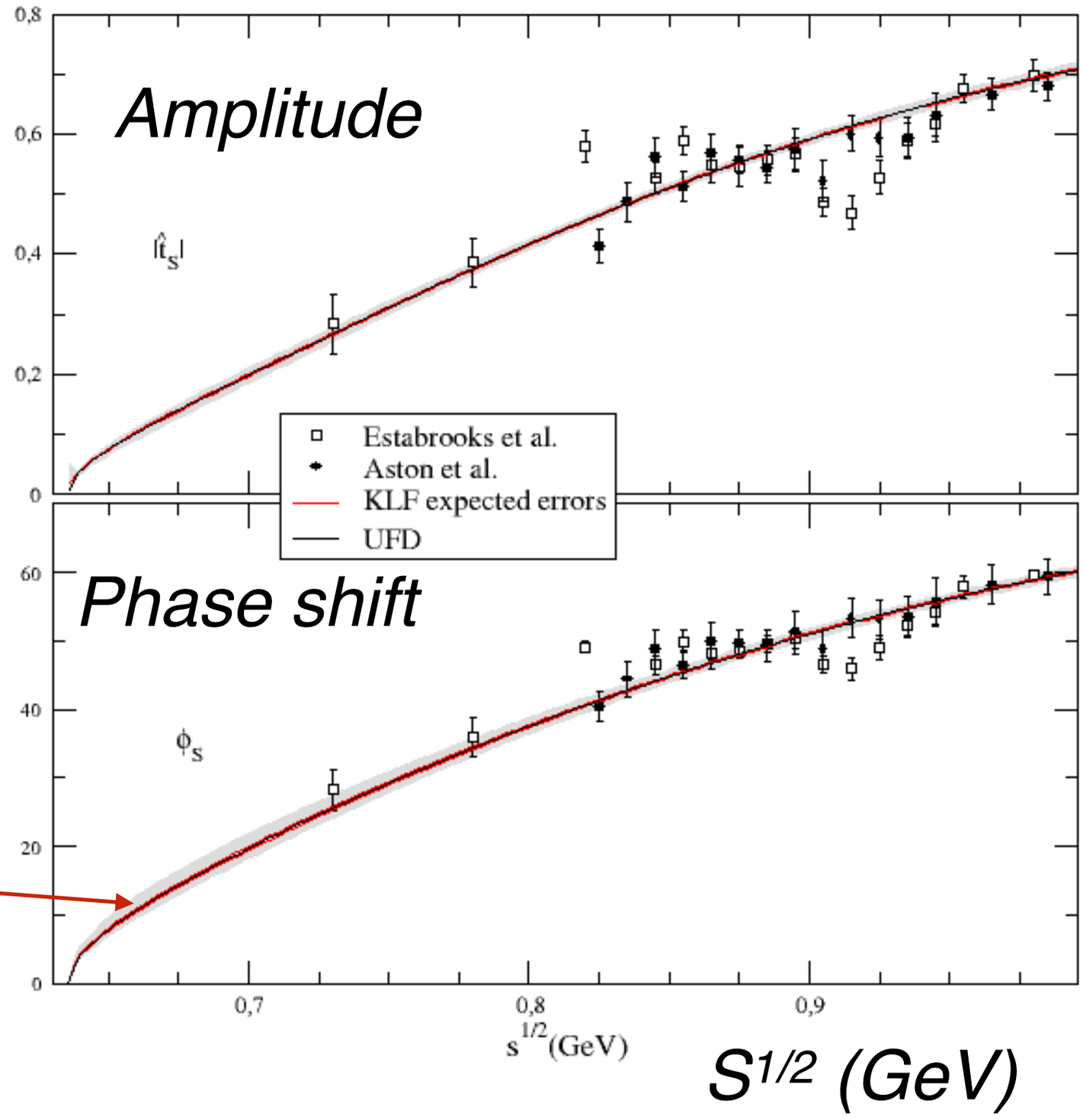


Two orders of magnitude higher statistics with KLF plus down to the threshold of M(K-pi)!

Projected Measurements

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

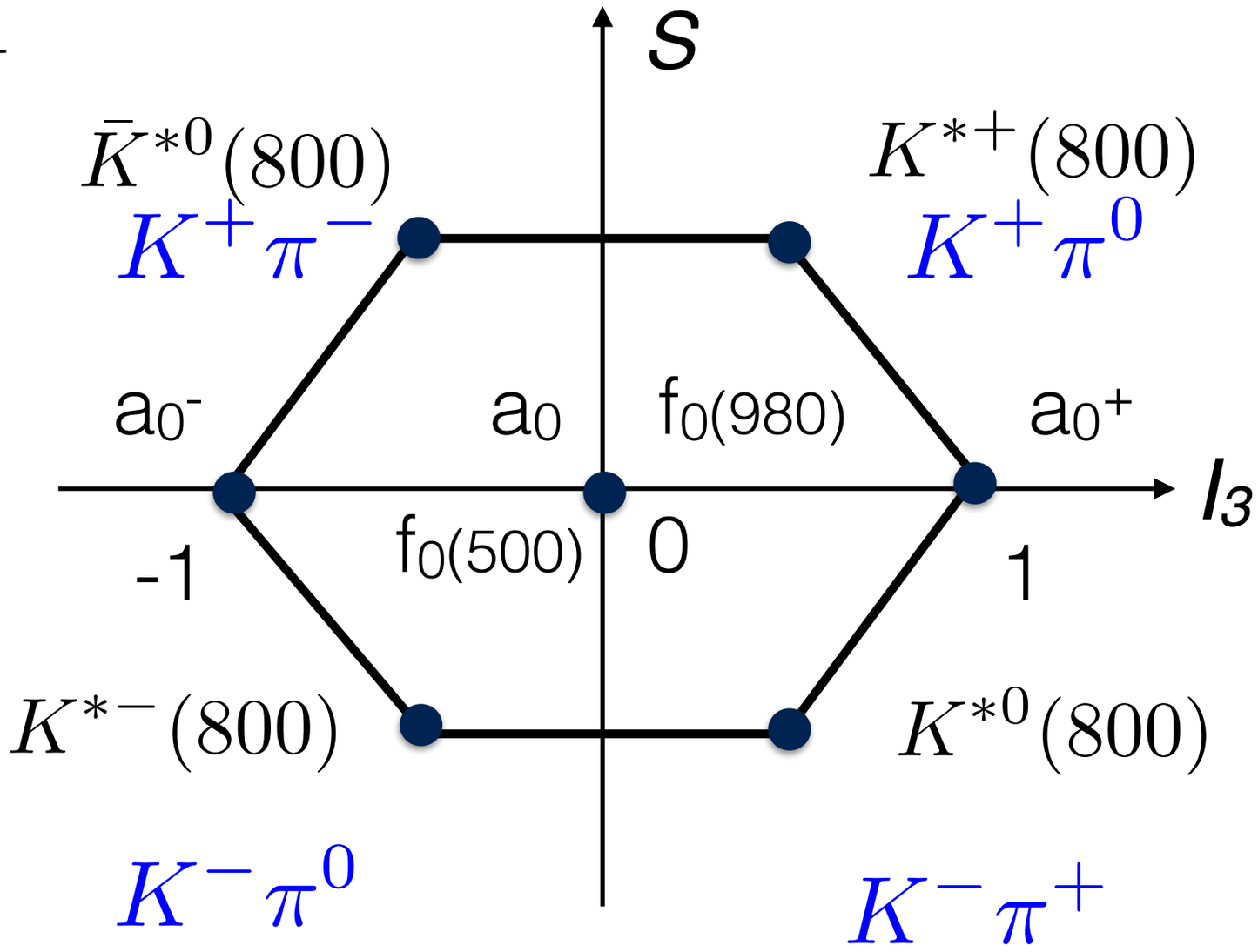
SLAC Data



KLF (100 days)

Scalar Meson Nonet

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

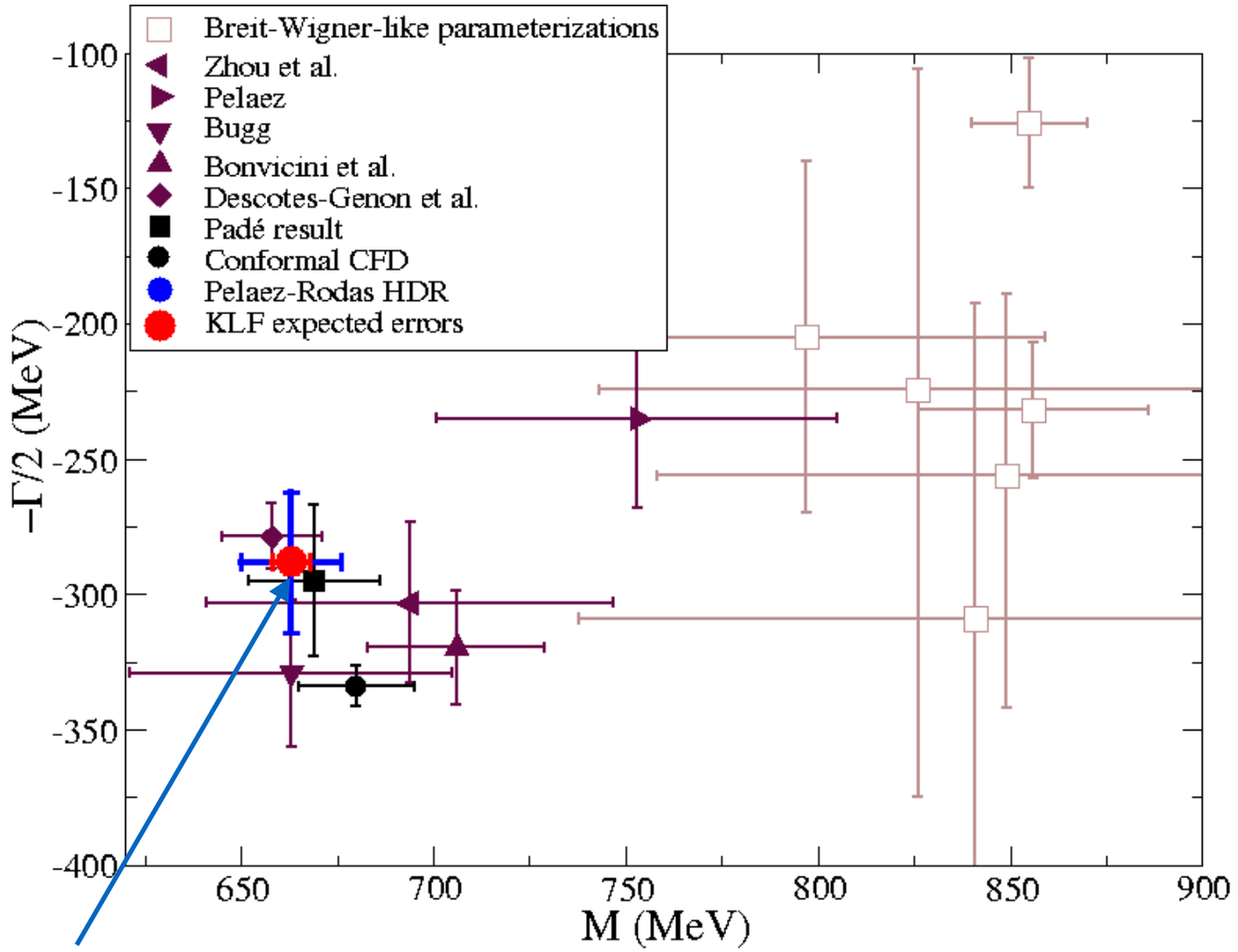


Four states called κ

still need further confirmation(PDG)

We can measure all of them

Width and Mass of κ(800)



100 days of running

Measurement with KLF will reduce:
Uncertainty in the mass by factor of two
Uncertainty in the width by factor of five!

Summary of $K\pi$ Scattering

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

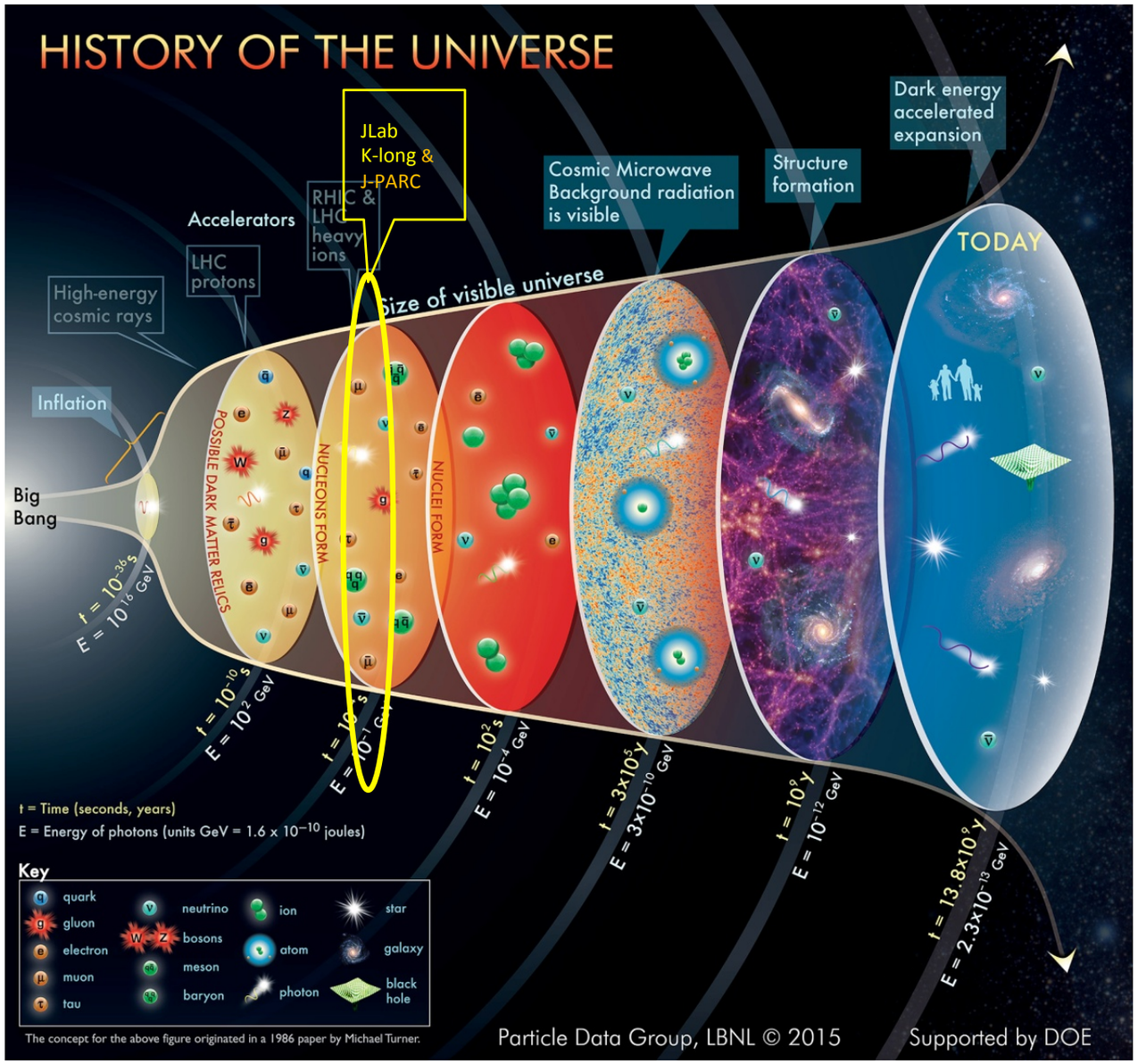
-It will certainly improve still conflictive determination of heavy K*'s parameters

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

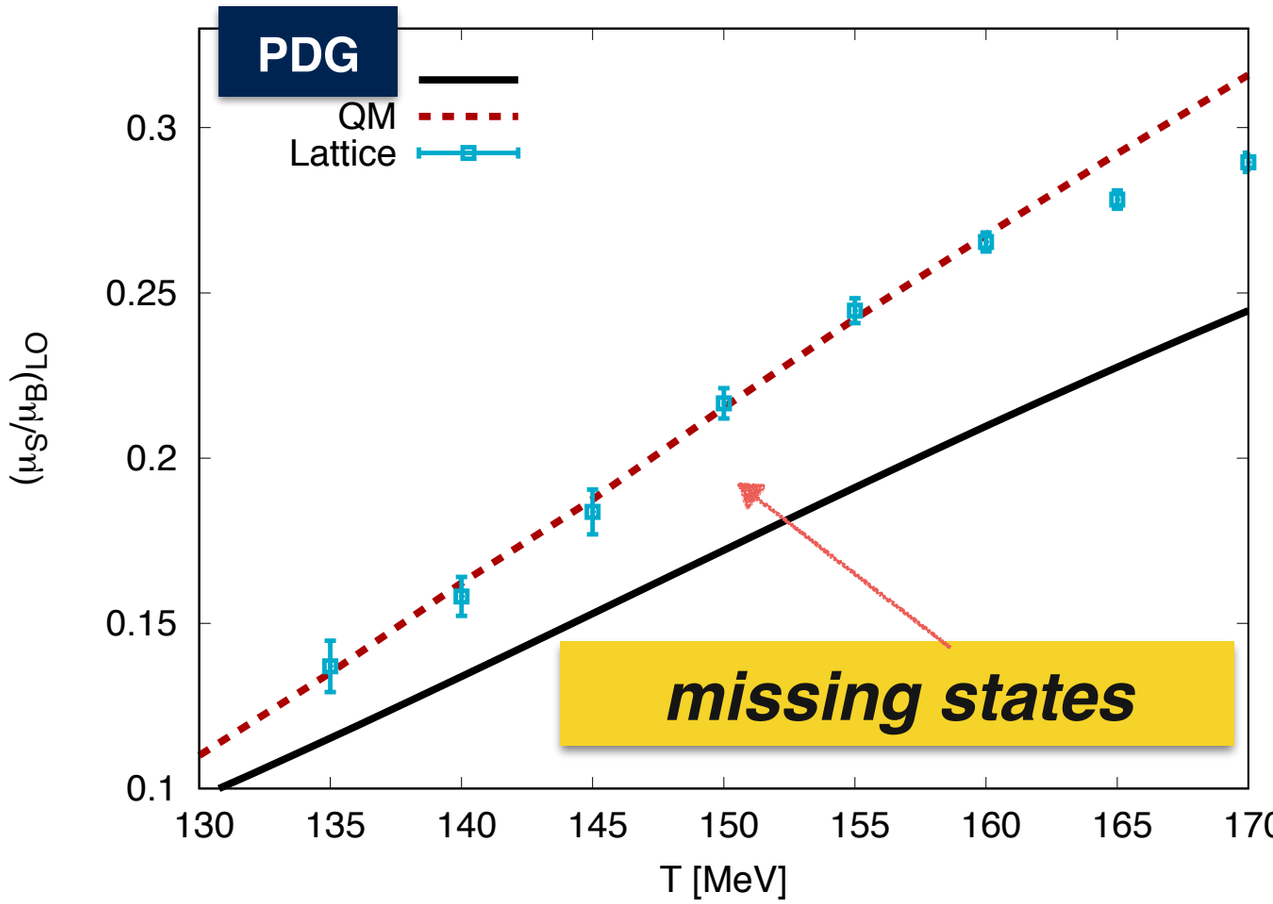
-Finally, and very importantly, it will reduce by more than a factor of two the uncertainty in the mass determination of K*(800) and by factor of five the uncertainty on its width, and therefore on its coupling

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

Evolution of an Early Universe at Freeze-out



Chemical potential

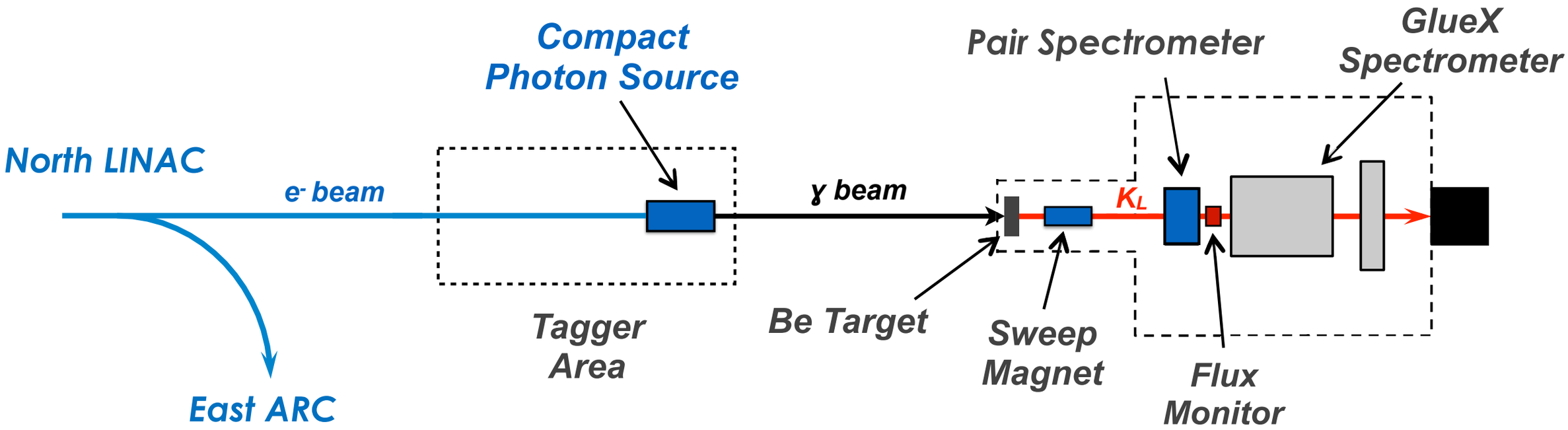


YSTAR2016 Proceedings arXiv: 1701.07346

KL Project will shed a light on thermodynamic properties of EU $1\mu s$ after the Big Bang

The main part of deficit is due to missing hyperon states

Hall-D beamline and GlueX Setup



Electron Beam Parameters

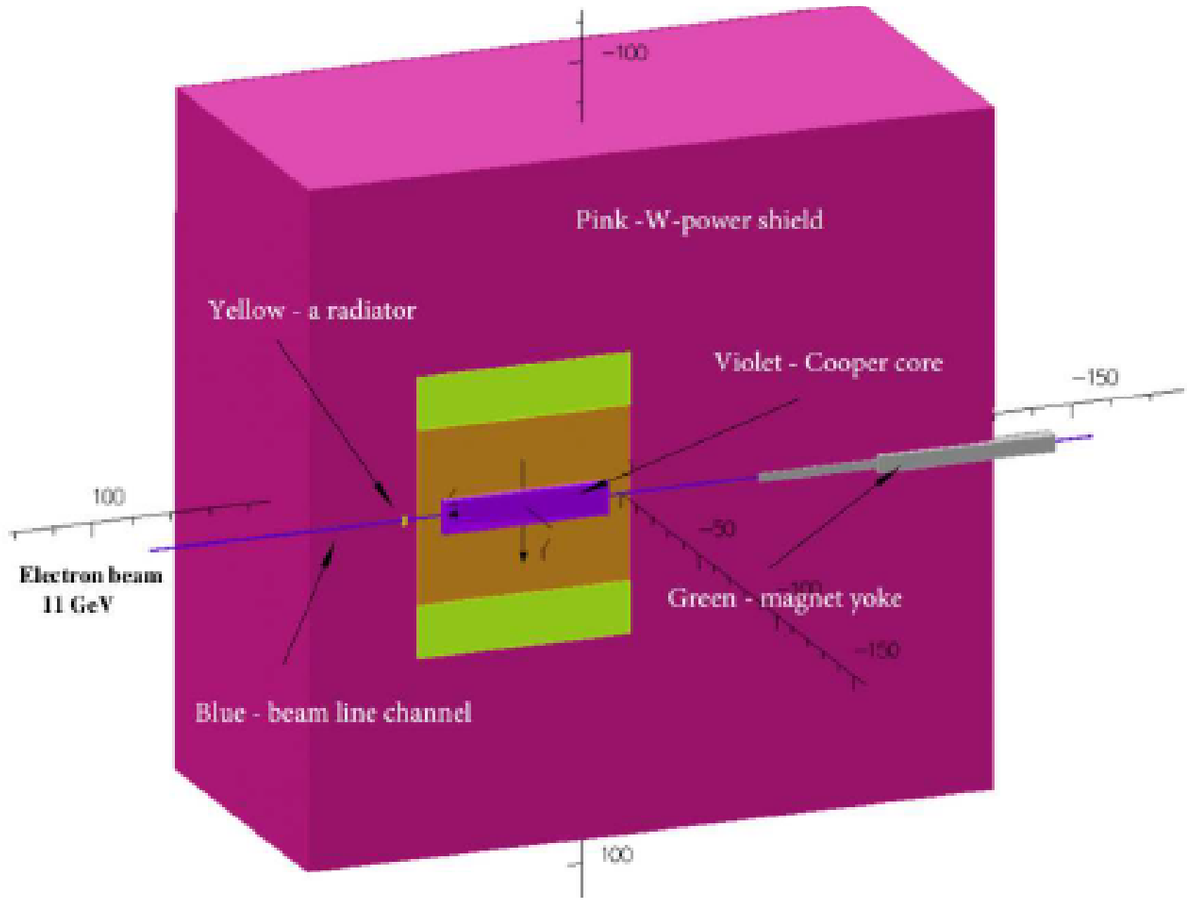
$E_e = 12\ GeV$	$I = 5\ \mu A$
Bunch spacing	$64\ ns$

No major problems.

Doable !

Confirmed by accelerator experts

Compact Photon Source

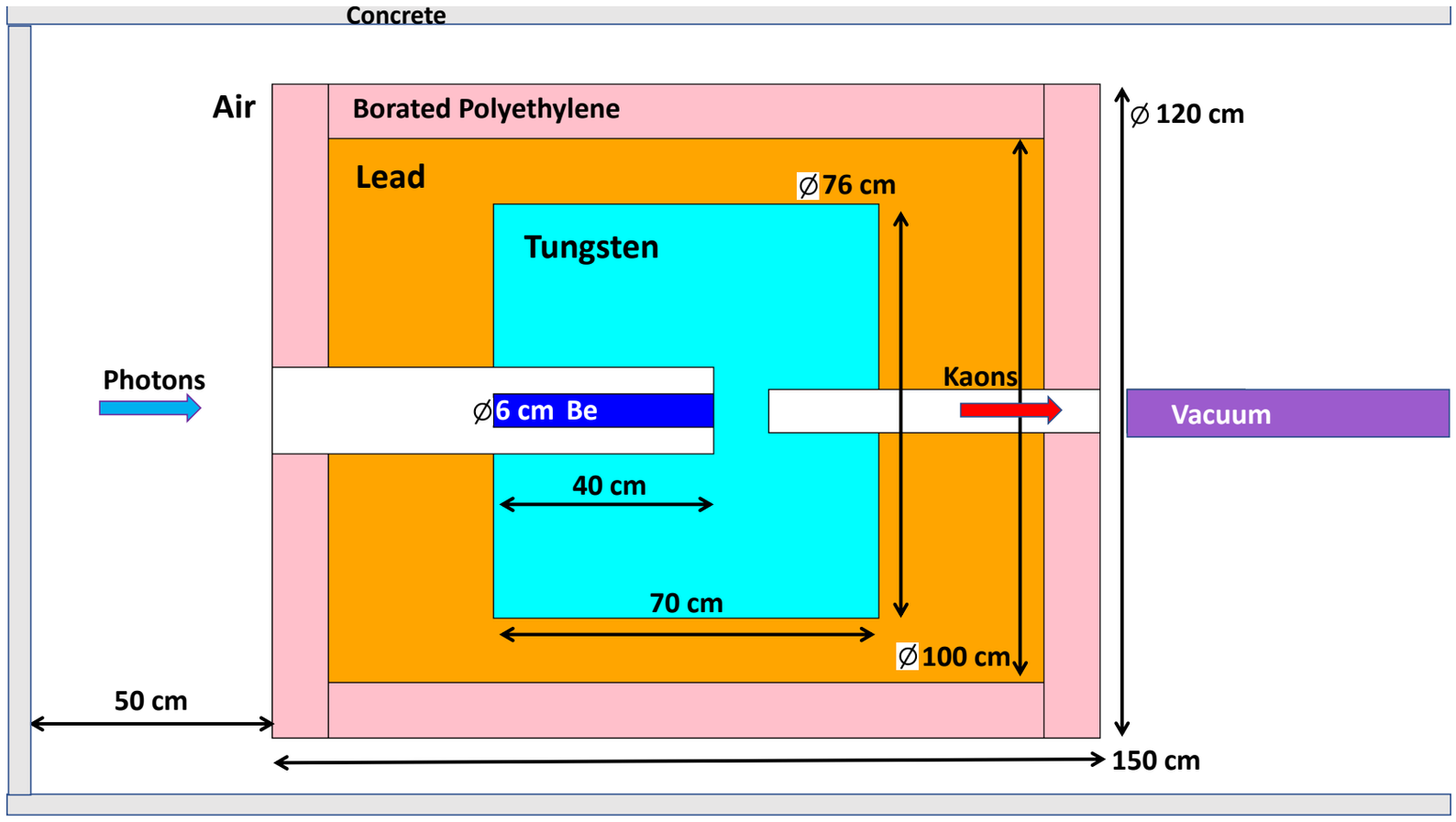


Conceptual design is completed for Halls A&C

The details of the CPS are designed by the CPS Collaboration

Meets RadCon Radiation Requirements

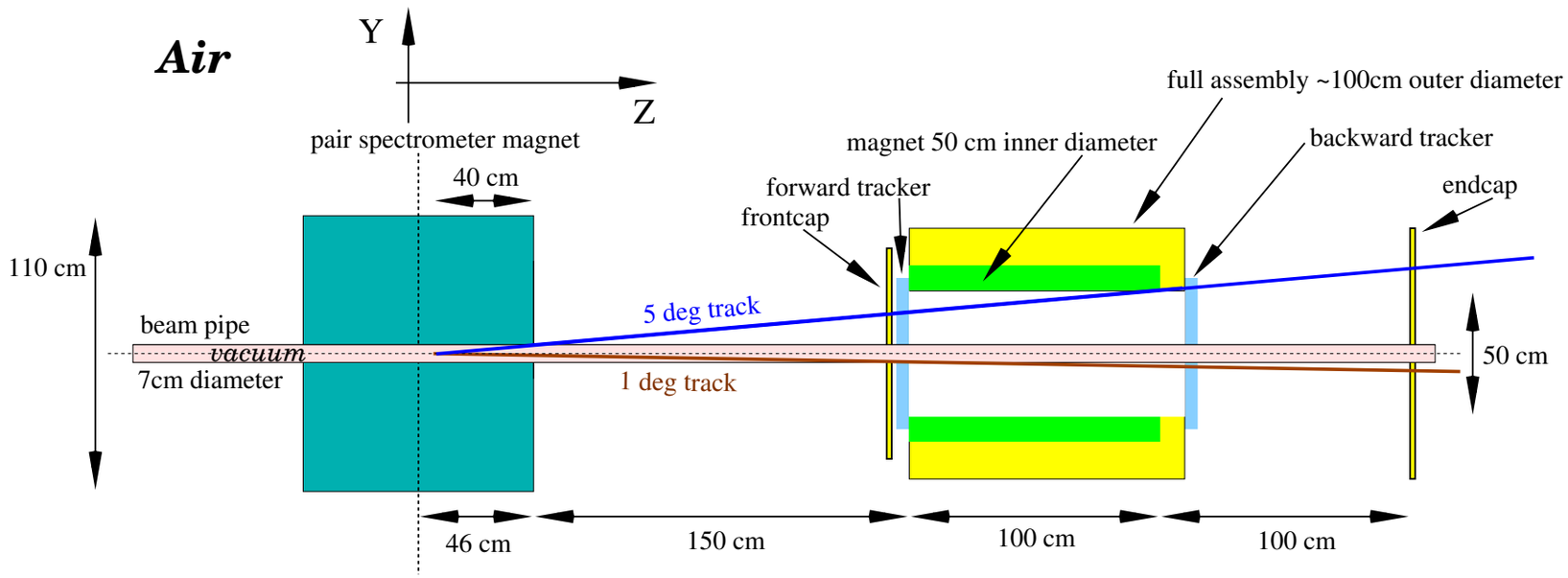
Be Target Assembly: Conceptual Design

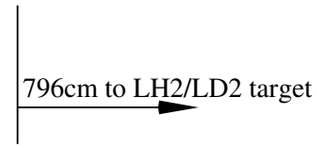


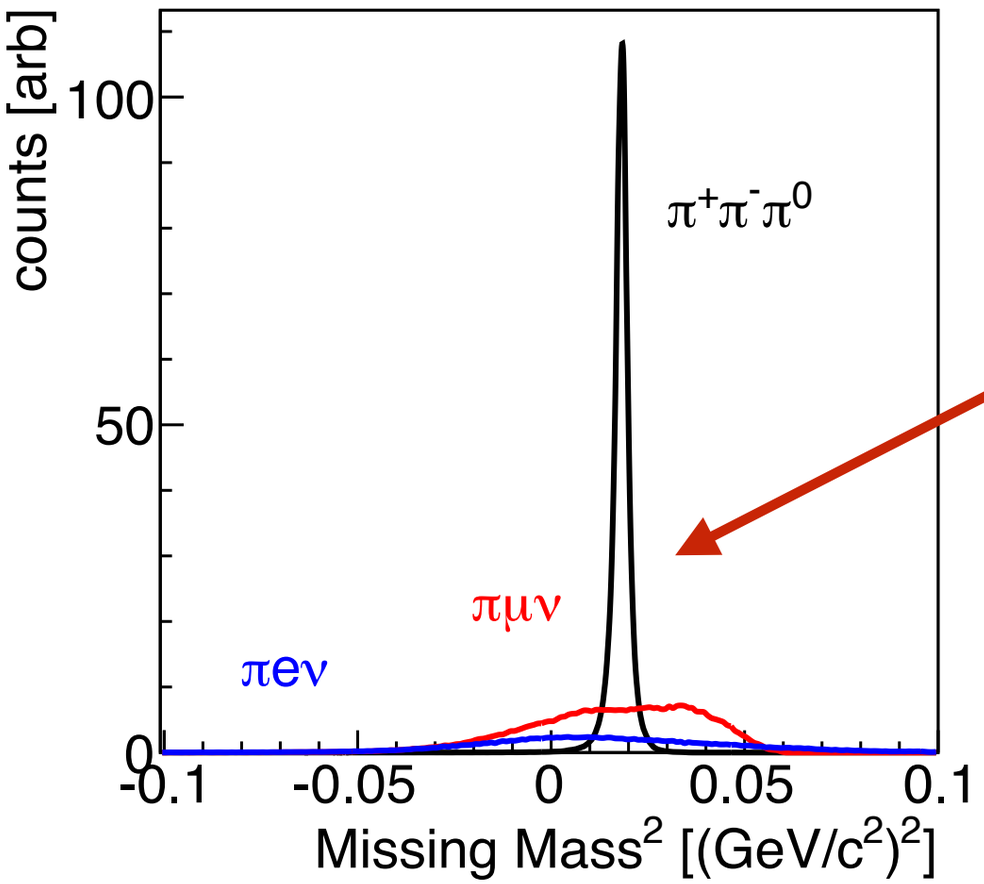
-Meets RadCon Radiation Requirements

-Conceptual Design Endorsed by Hall-D Engineering Staff

Flux Monitor







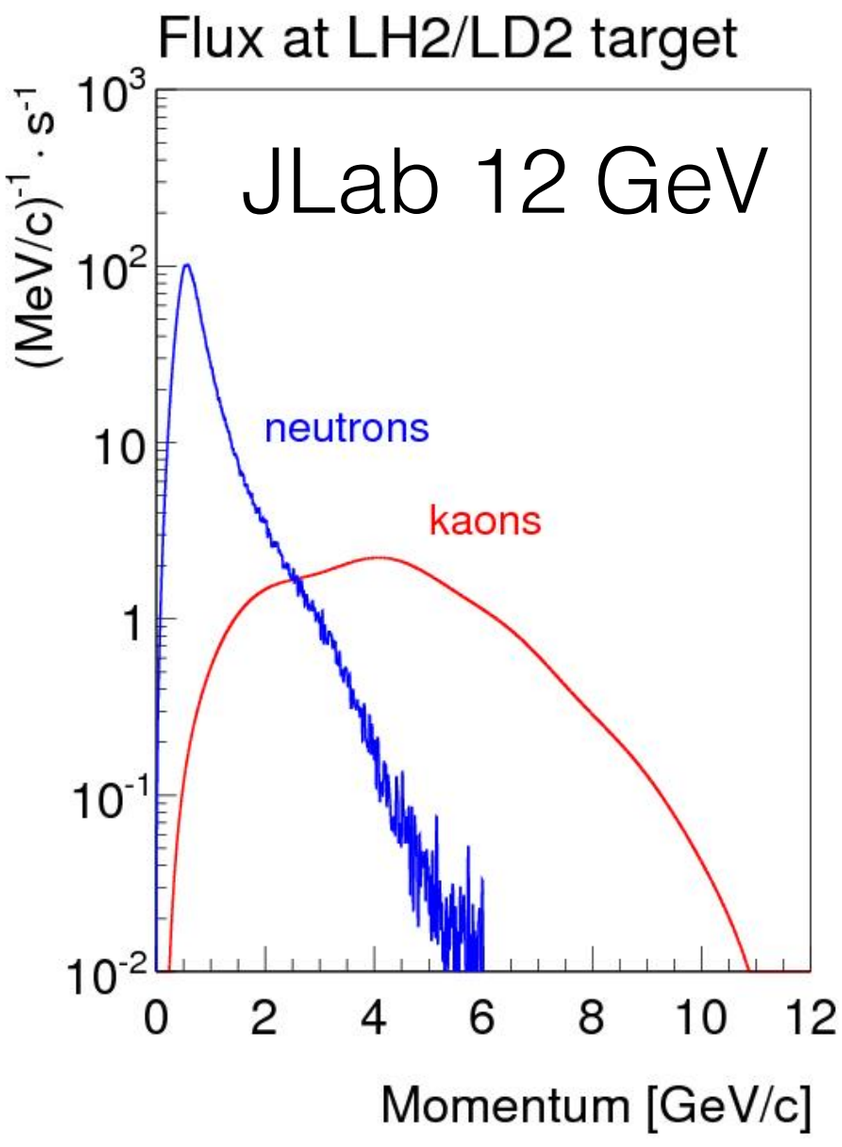
Reconstructed K_L

via missing (π^0)

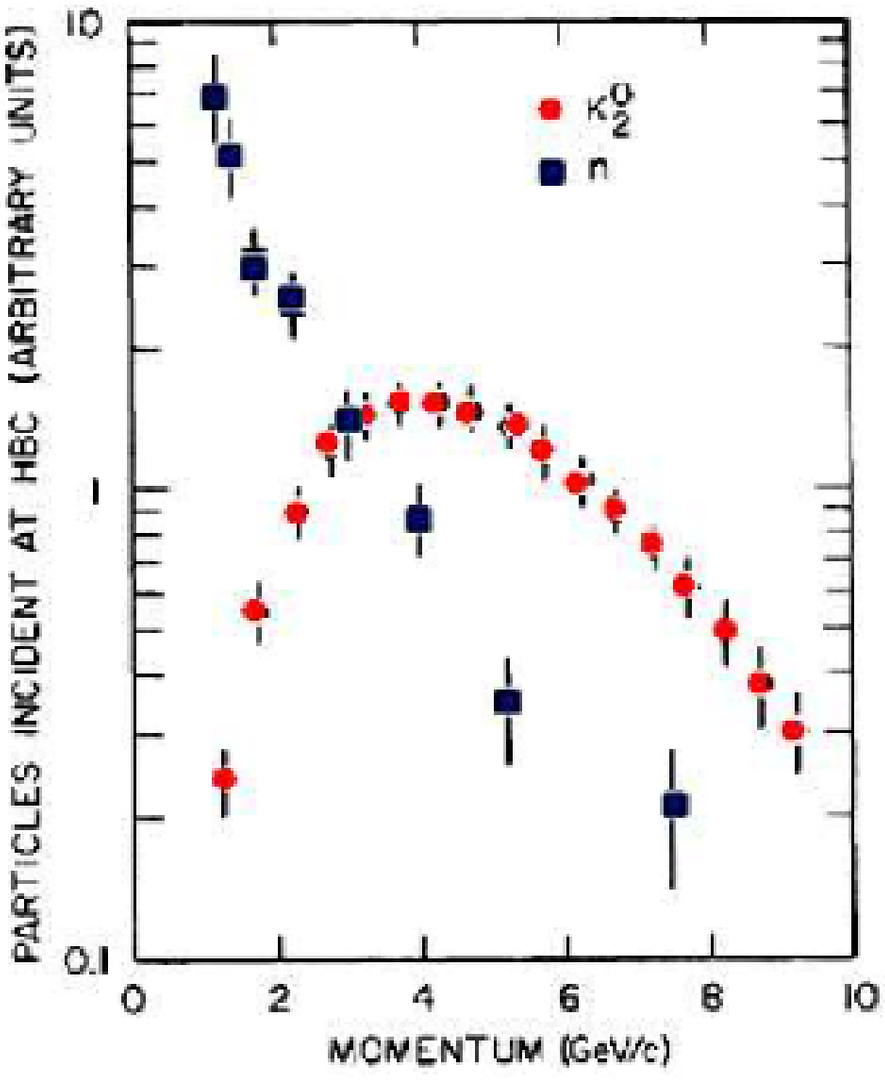
Flux measurement stat. err. <1%

Estimated syst. err. ~5%

K_L Beam Flux



SLAC 16 GeV

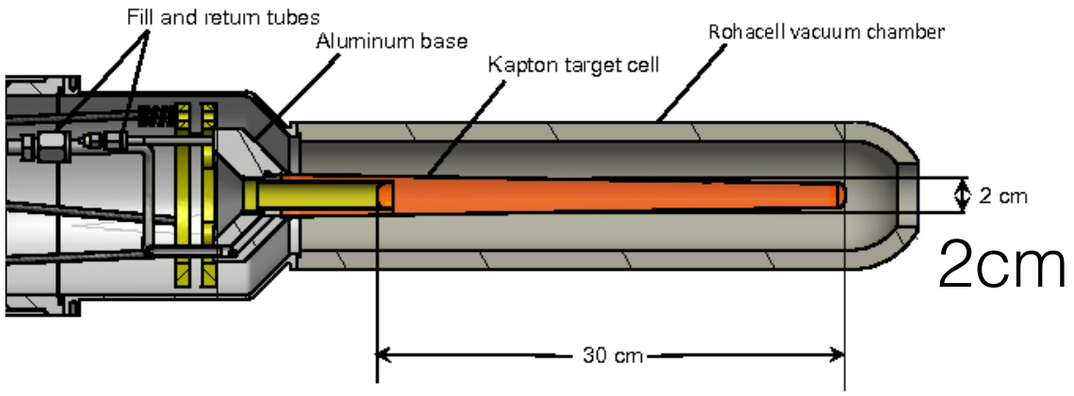


$$N(K_L)/sec \sim 10^4$$

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

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

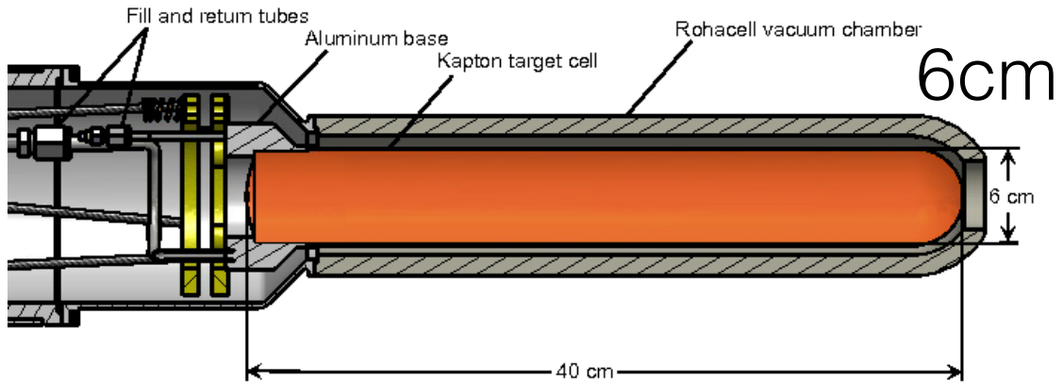
The GlueX liquid hydrogen target.



2cm

30cm

Current



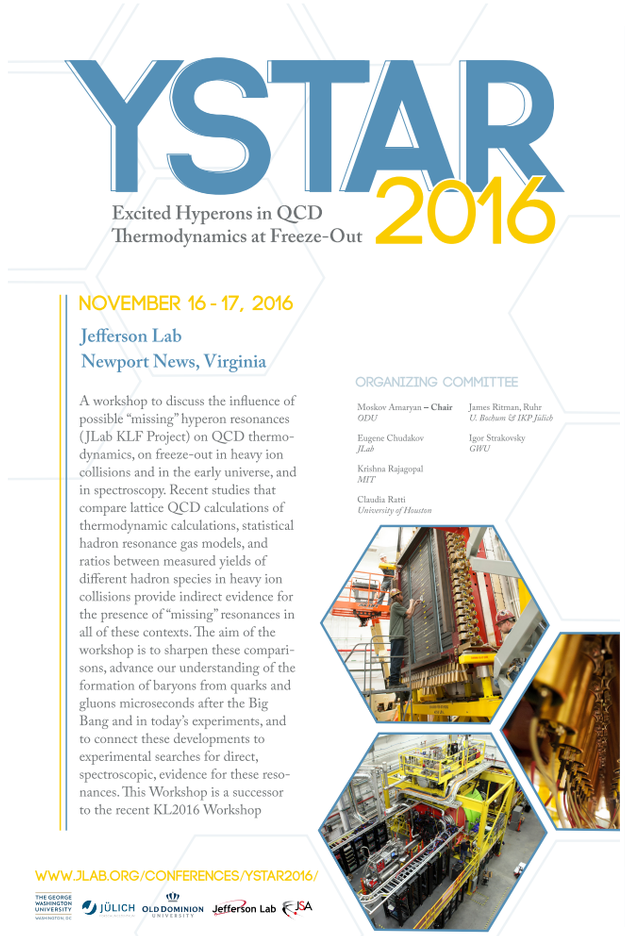
6cm

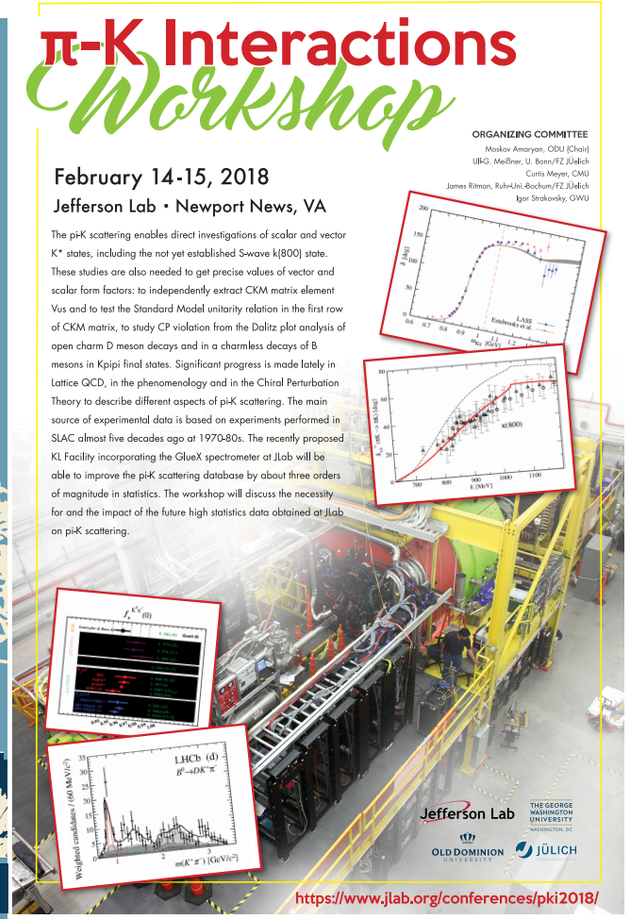
40cm

Proposed & Feasible

Longer and ticker target is needed to enhance production rate

Conceptual design has been endorsed by the JLAB target group





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 spectrsocopy**

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 κ

- **KLF Project will have a strong impact on**

-Thermodynamics of an Early Universe

Summary: ***From TAC Report***

Feasibility: The project appears to be technically feasible. The cost (without local labor) was estimated at about $6M (taking into account the recent CPS estimate), including about $1M for the Flux Monitor, which may become a foreign contribution.

Thank you !

Backup Slides

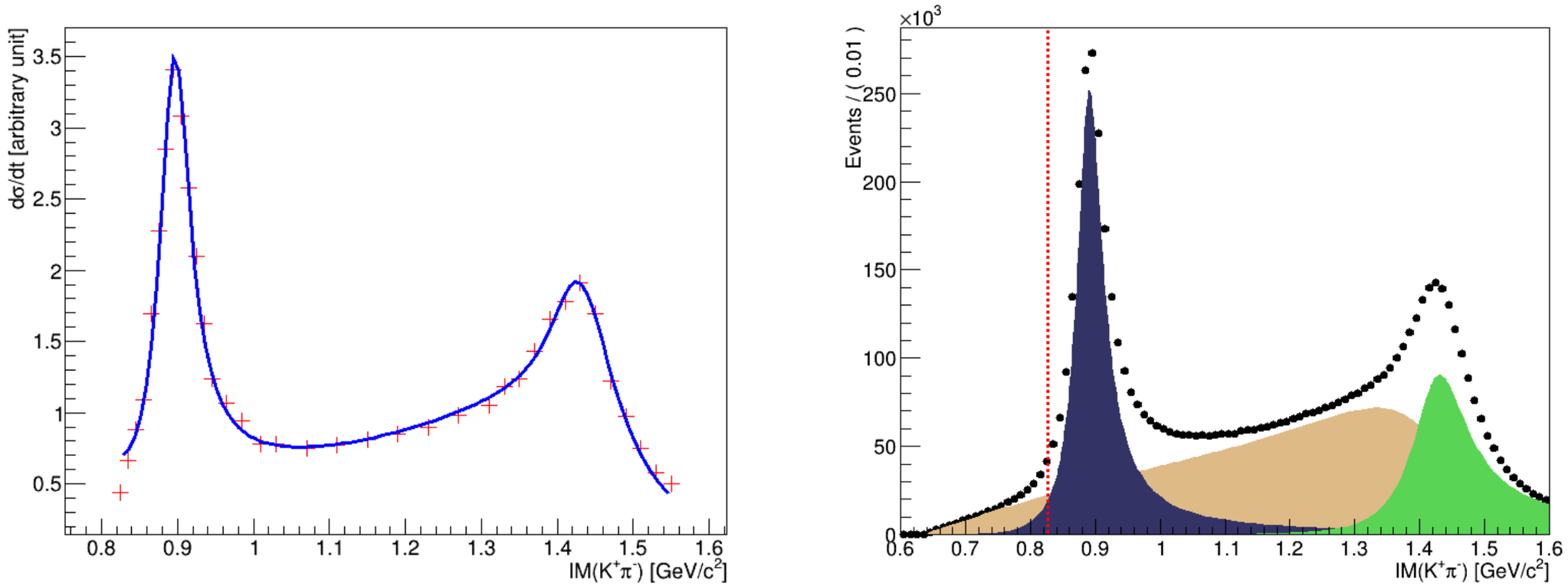
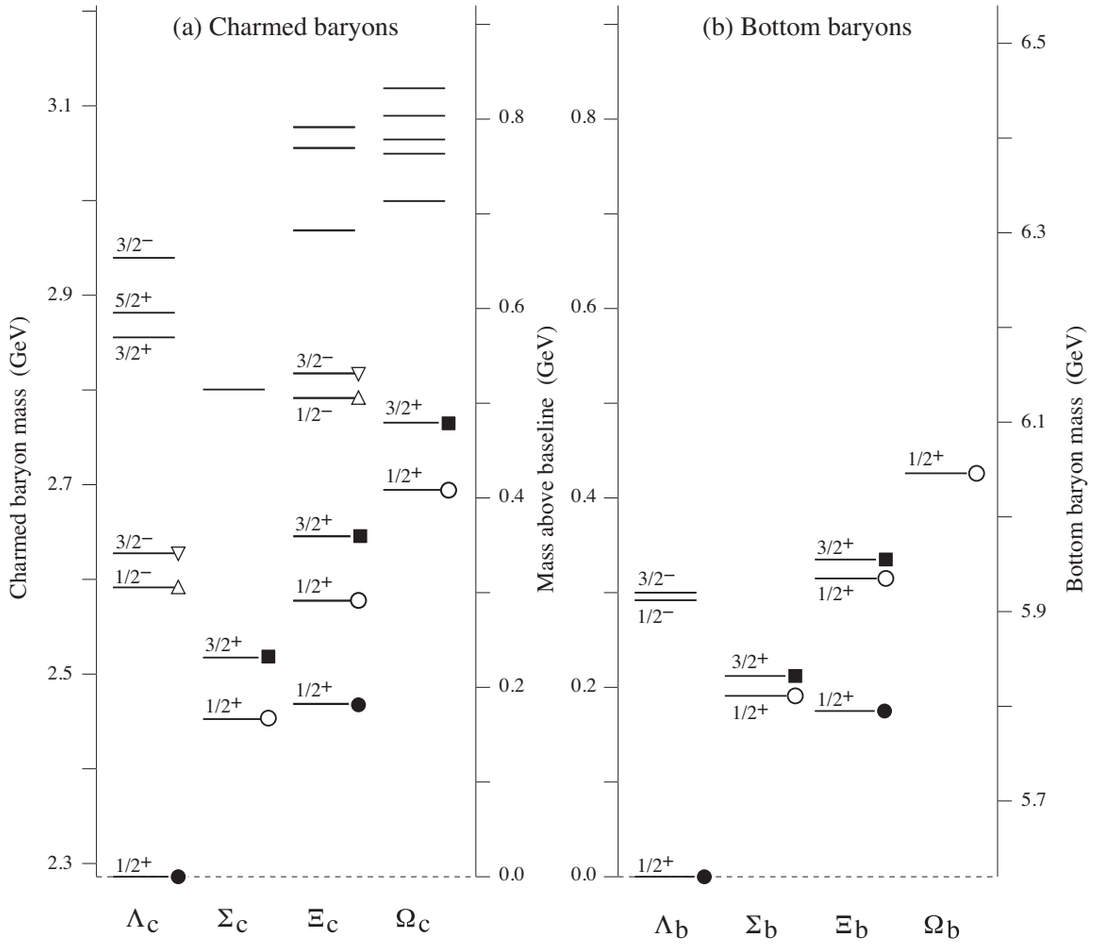
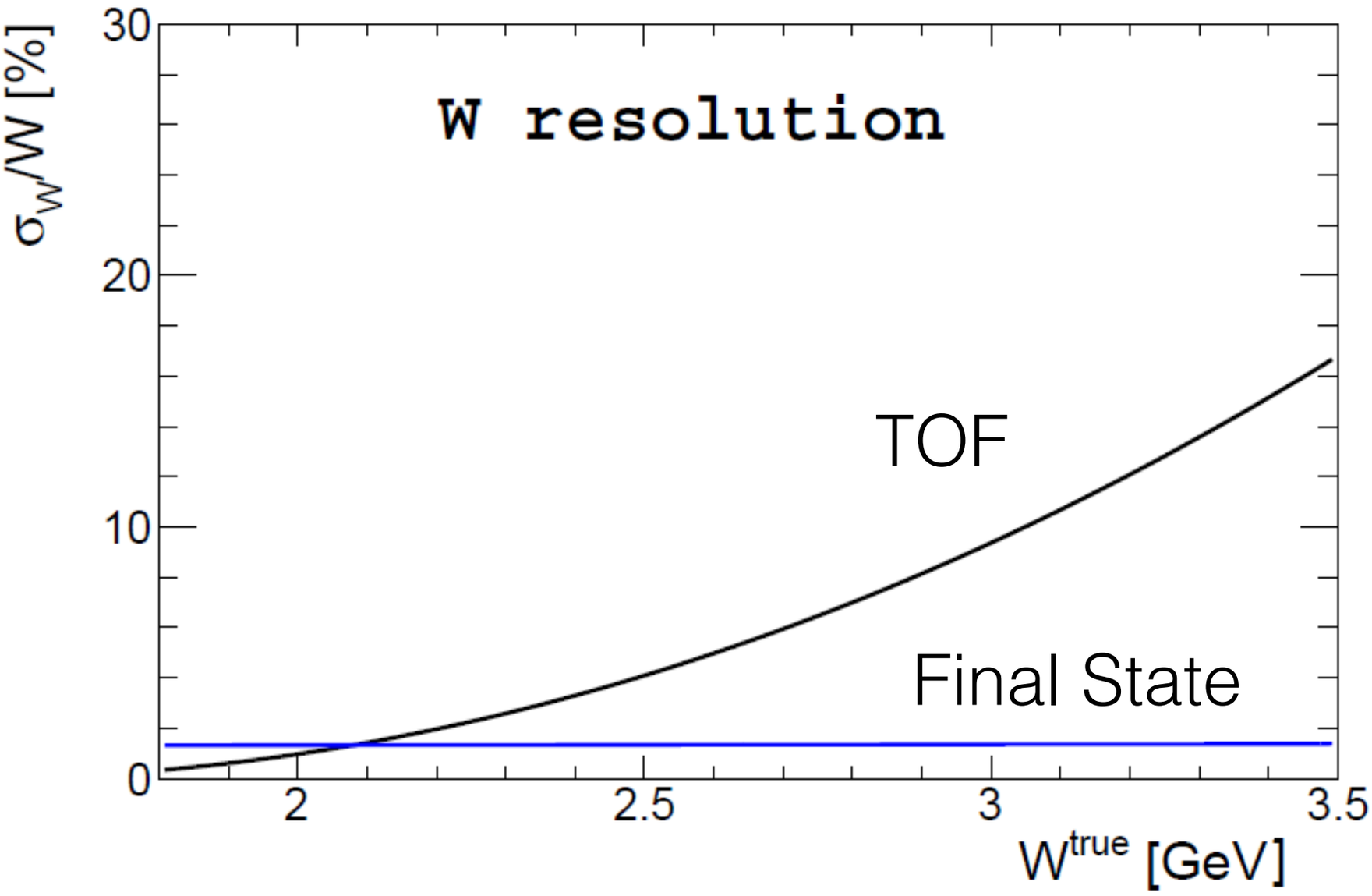


Figure 28: Left panel: Cross section of $K^- p \to K^+ \pi^- n$ as a function of the invariant mass from LASS results [122]. The blue line is the fit to the cross section using composite model containing two RBW, spin-1 and spin-2, and S-wave LASS parameterization. Right panel: Expected distribution of the $K^+\pi^-$ invariant mass below 1.6 GeV from KLF after 100 days of run. 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 [122].


(a) Charmed baryons
(b) Bottom baryons
Charmed baryon mass (GeV)
Bottom baryon mass (GeV)
Mass above baseline (GeV)
3.1
2.9
2.7
2.5
2.3
6.5
6.3
6.1
5.9
5.7
0.8
0.6
0.4
0.2
0.0
3/2−
5/2+
3/2+
1/2−
1/2+
Λc
Σc
Ξc
Ωc
Λb
Σb
Ξb
Ωb


W resolution
σ_W/W [%]
30
20
10
0
2
2.5
3
3.5
W^{true} [GeV]
TOF
Final State