Overview of KLF Proposal and PAC47 Report

Moskov Amaryan

Old Dominion University
Norfolk, VA

KLF Collaboration Meeting, October 2, 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

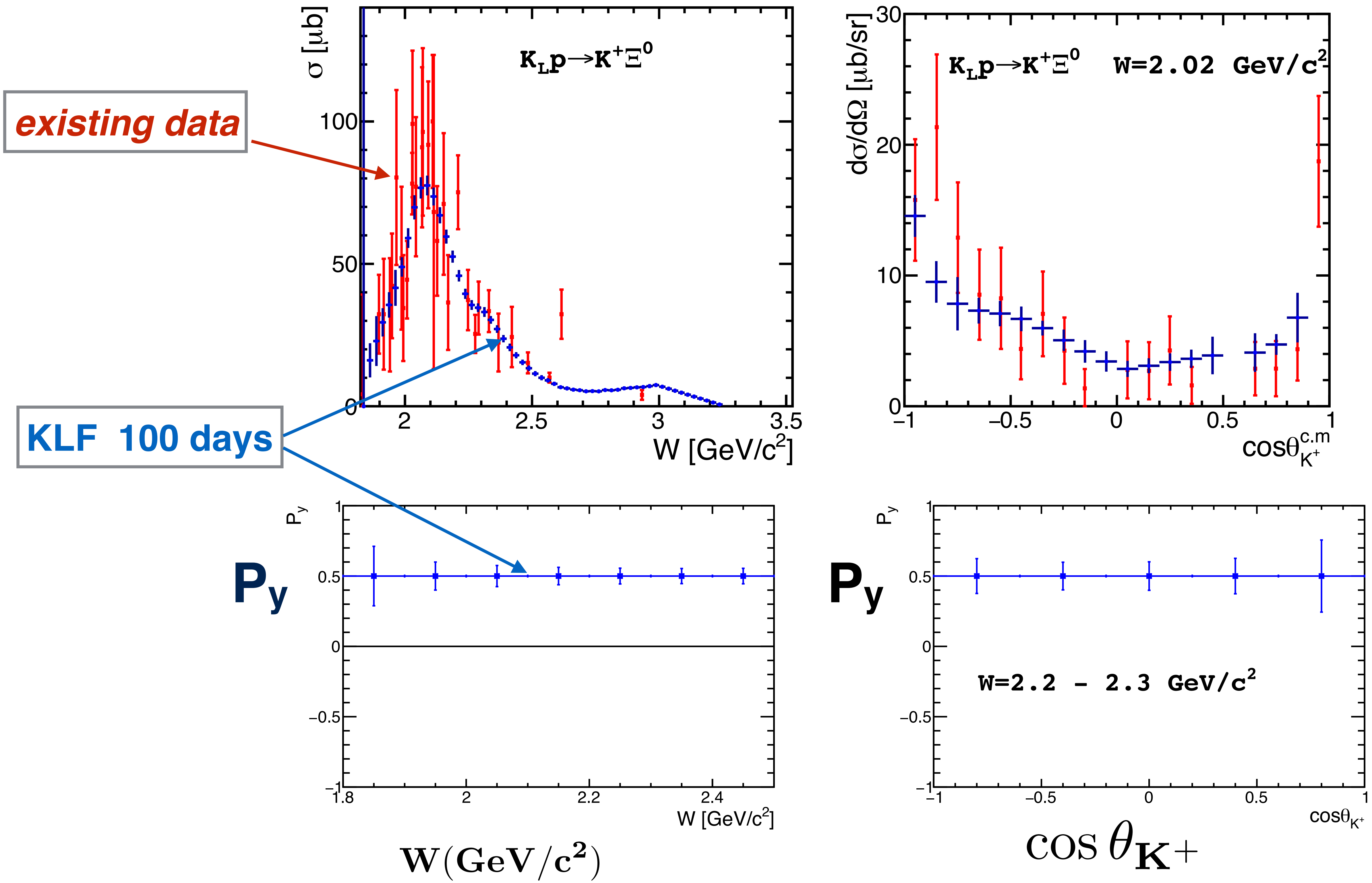
- *Hyperon Spectroscopy*
- *Strange Meson Spectroscopy*
- *Thermodynamics of Early Universe*

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



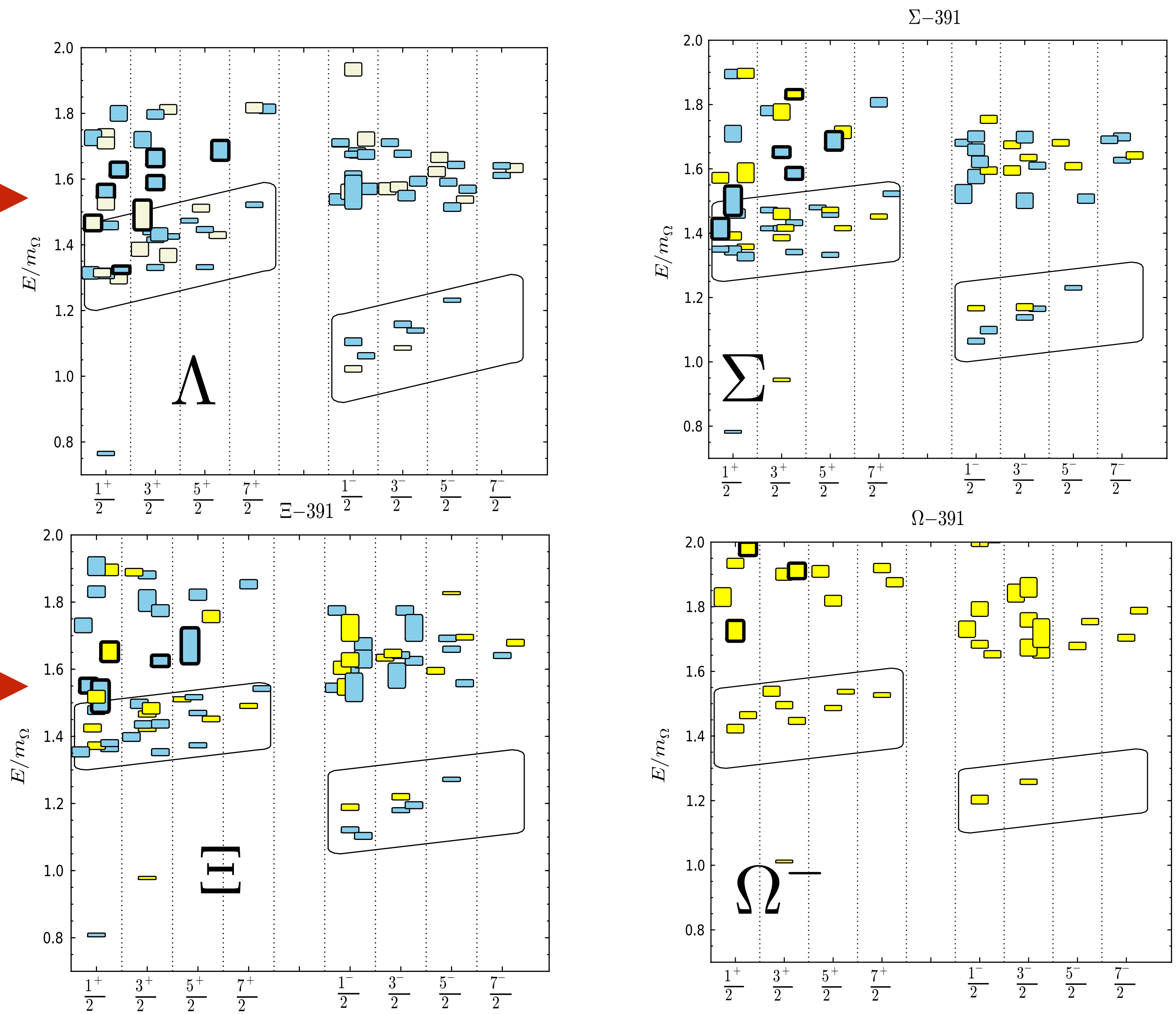
Hyperon Spectroscopy

*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

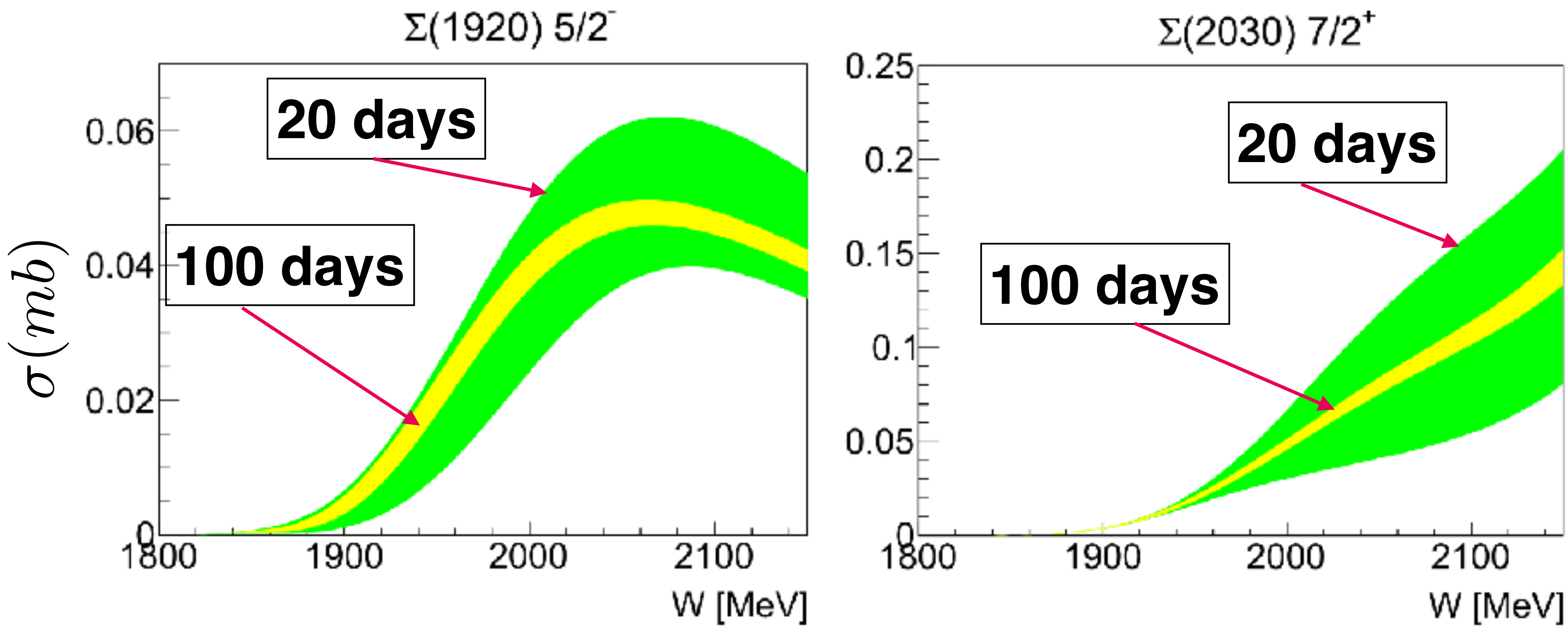
For Scattering experiments on both proton & neutron targets one needs to determine:

- **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

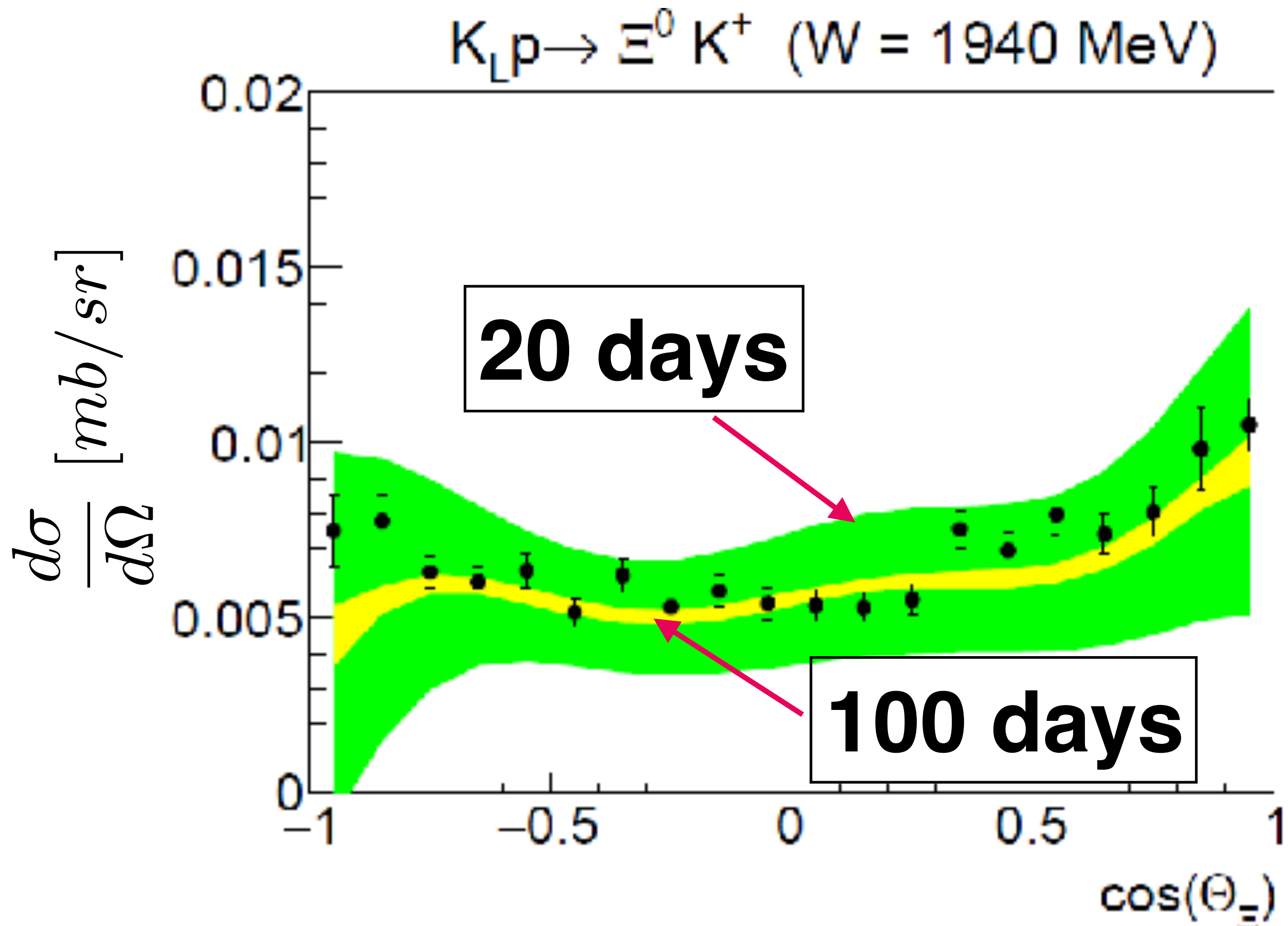
Total Cross Section $K_L p \to K^+ \Xi^0$



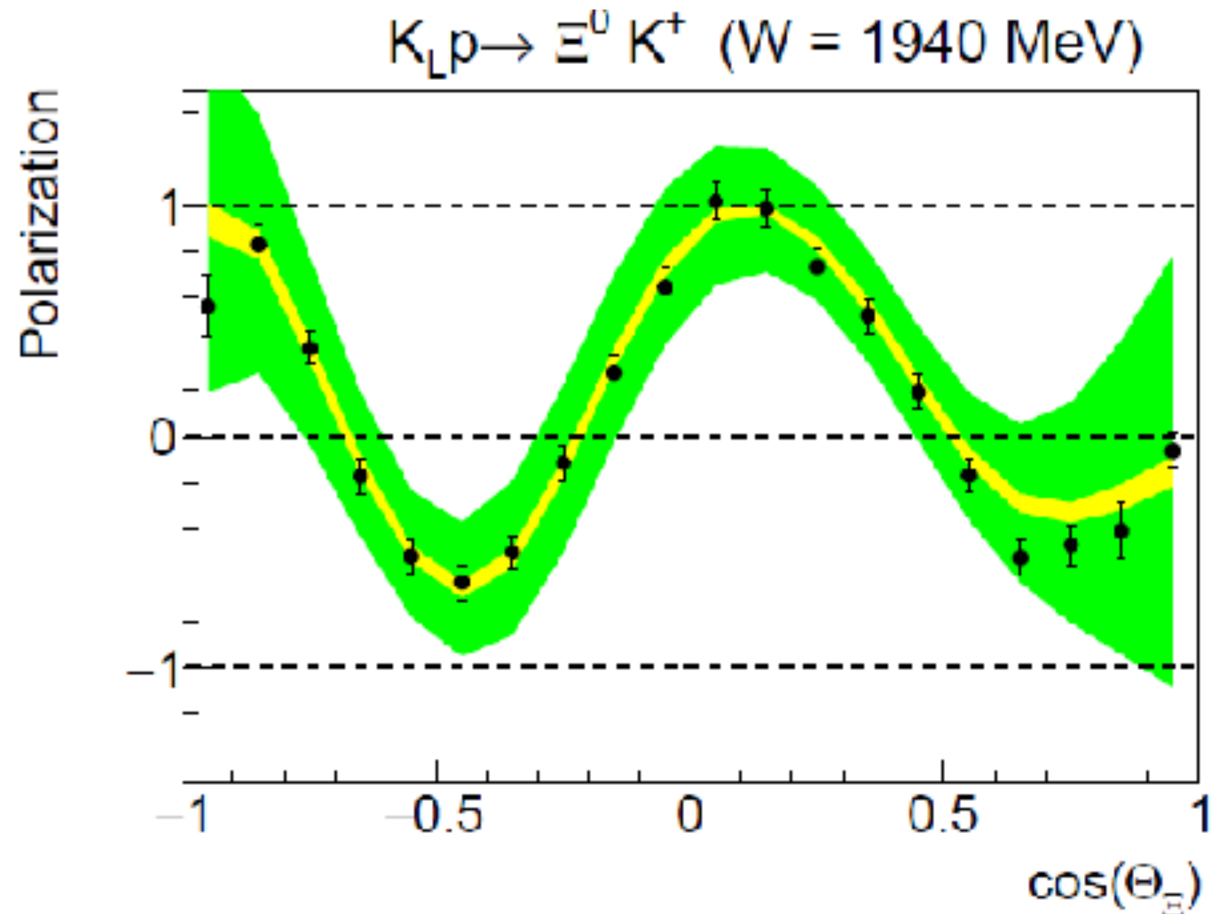
Obviously: at least 100 days needed to get precise solution

Bonn-Gatchina PWA

Diff. Cross Section



Polarization



Again: at least 100 days to get precise solution

Some Numerical Results

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

$$\begin{cases} 100d\ M = \underline{1.923 \pm 0}.010 \pm 0.010\ GeV \\ \qquad \Gamma = 0.321 \pm 0.01 \pm 0.010\ GeV \\ 20d\ M = \underline{1.977 \pm 0}.021 \pm 0.025\ GeV \end{cases}$$

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

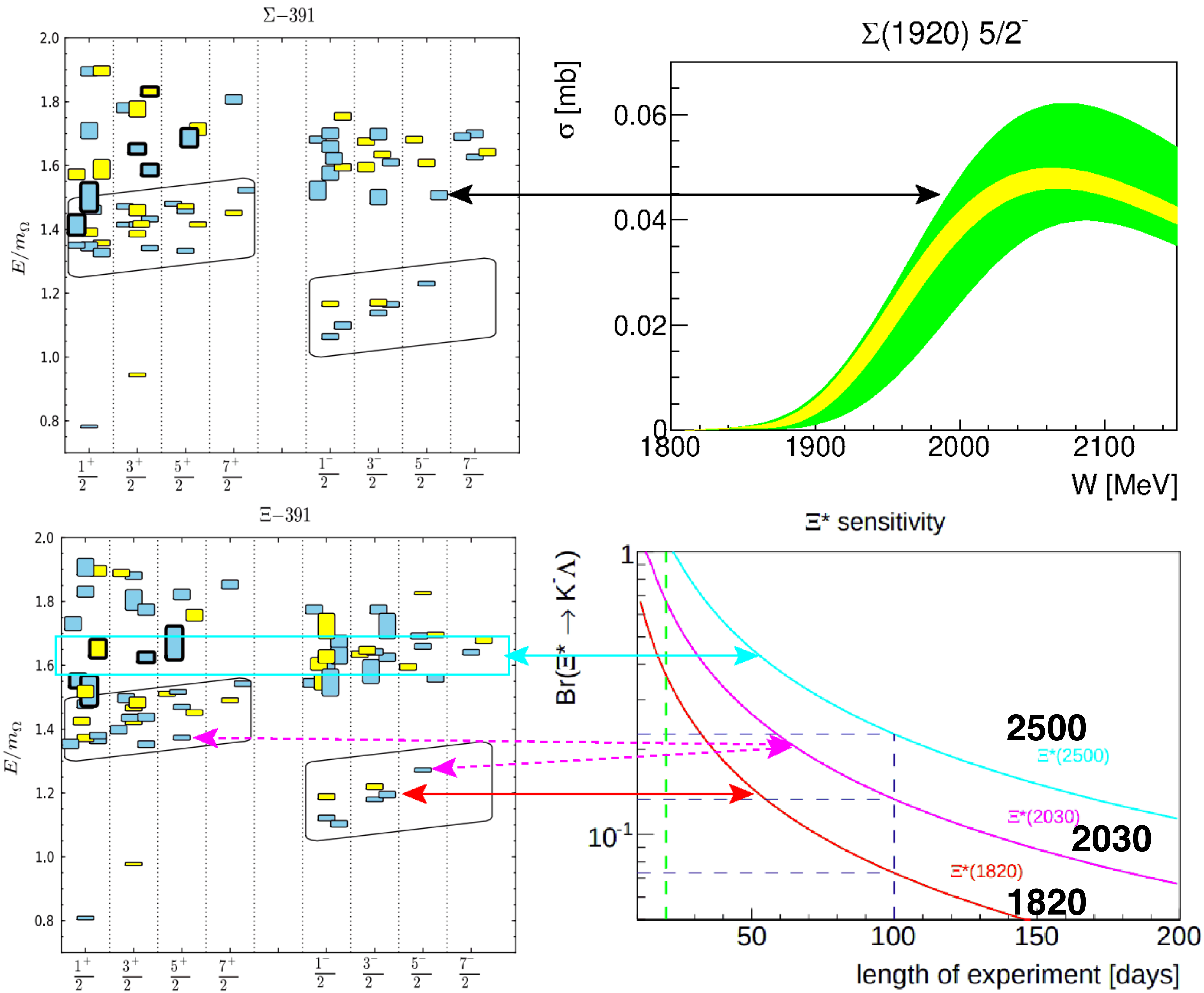
$$PDG2018\ M = 1.775 \pm 0.005$$

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

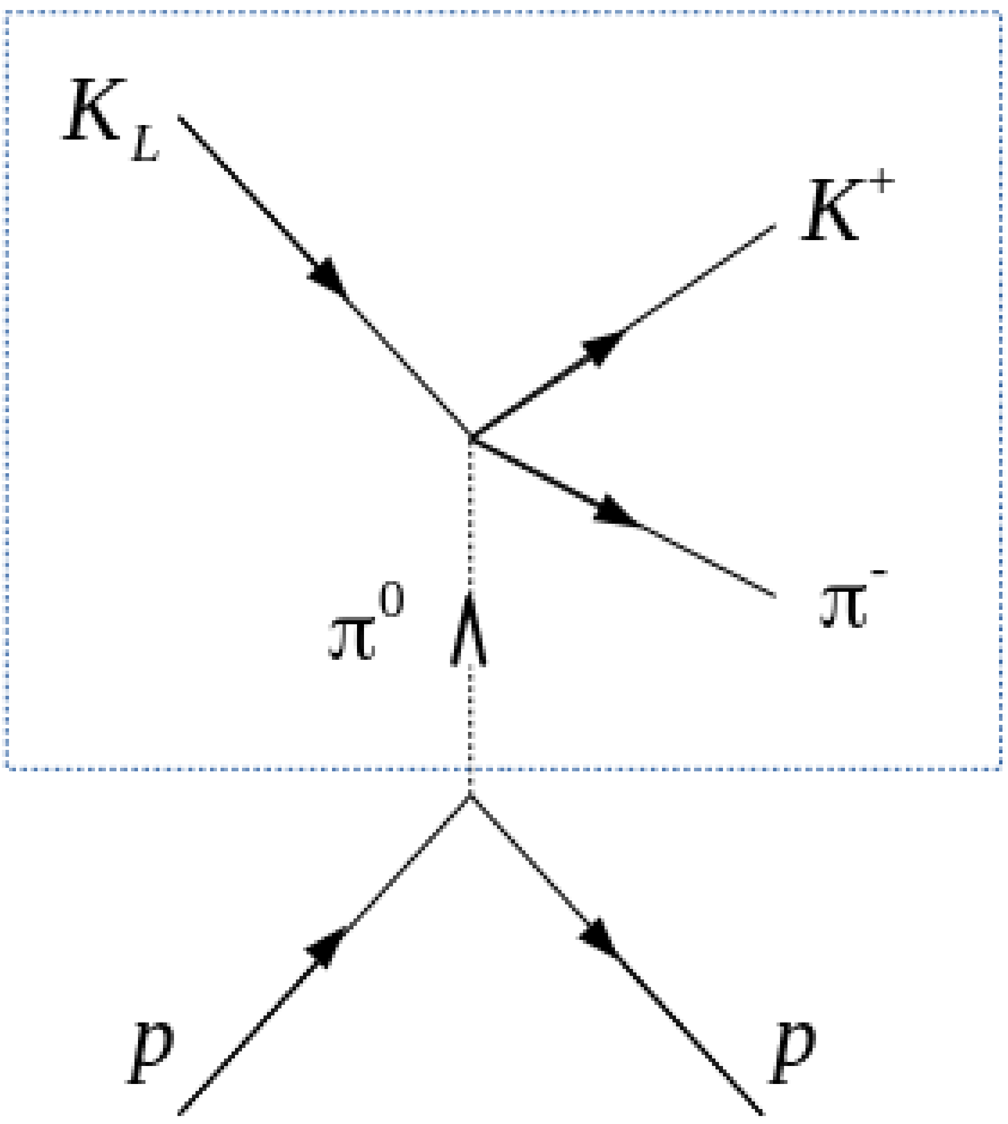
Why should we care that there are dozens of missing states?

… 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

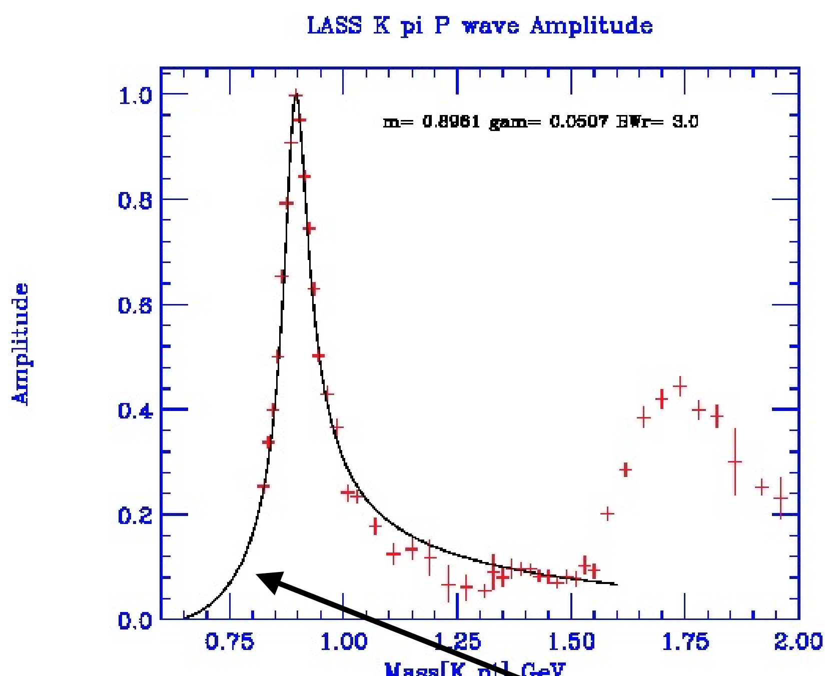
Strange Meson Spectroscopy

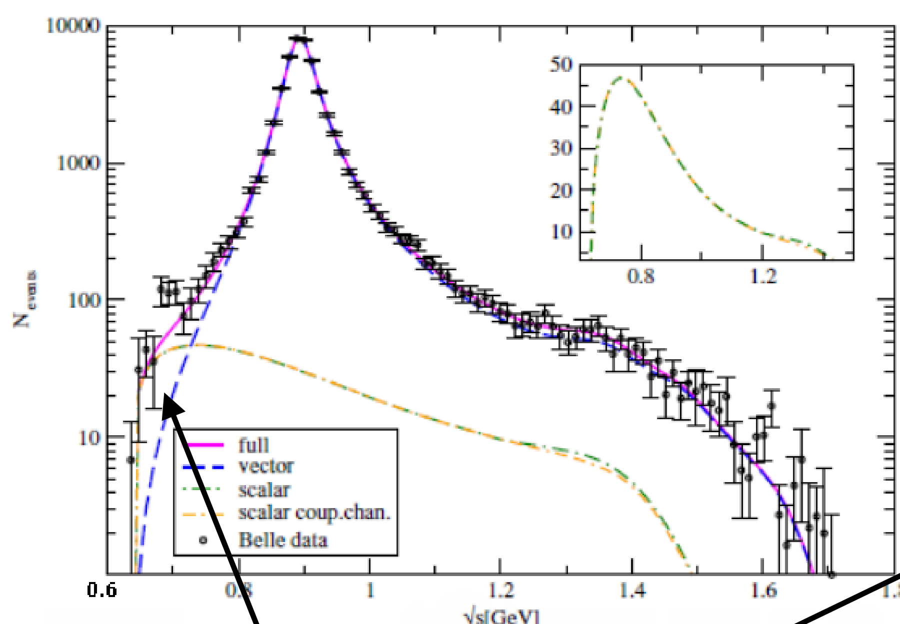
$K\pi$ **Scattering**

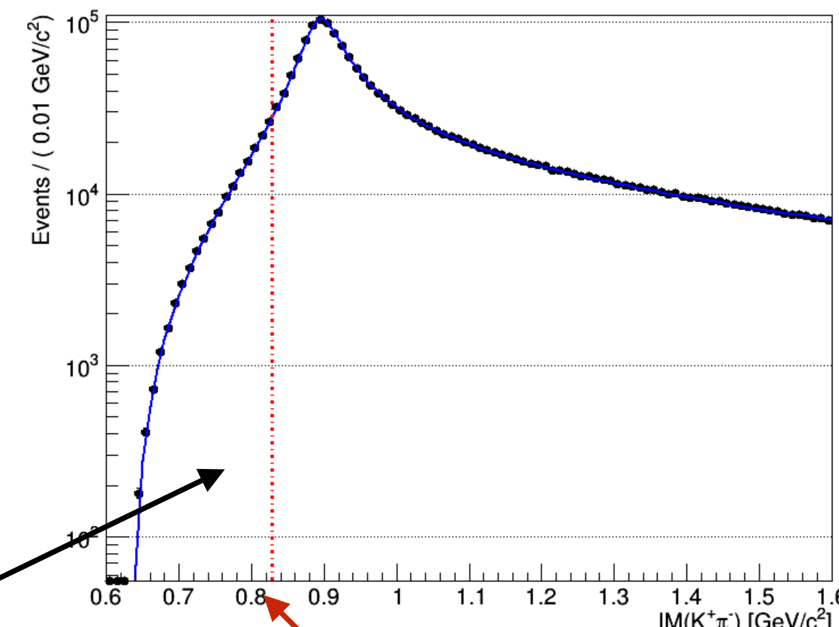


Proposed Measurements

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



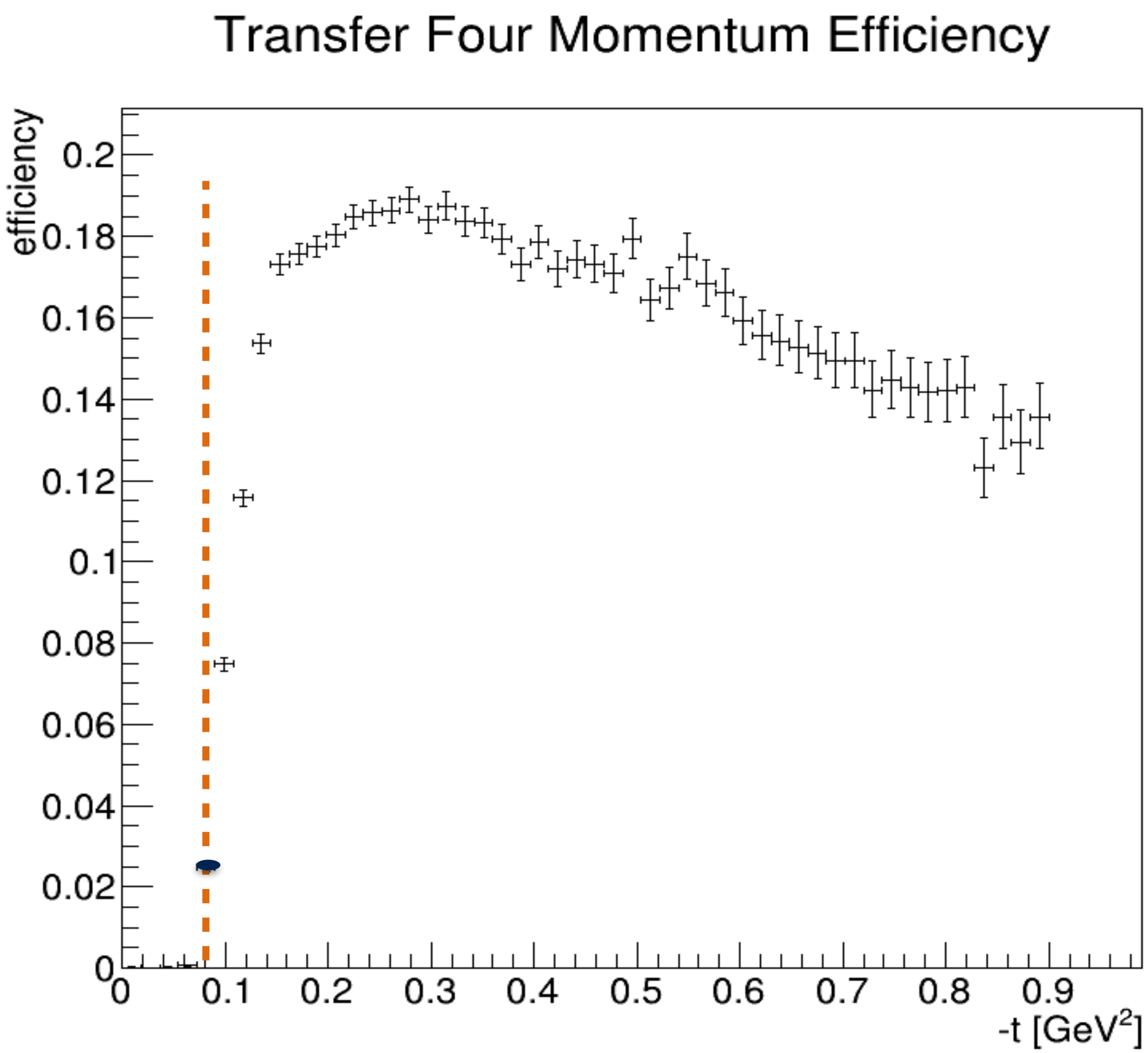


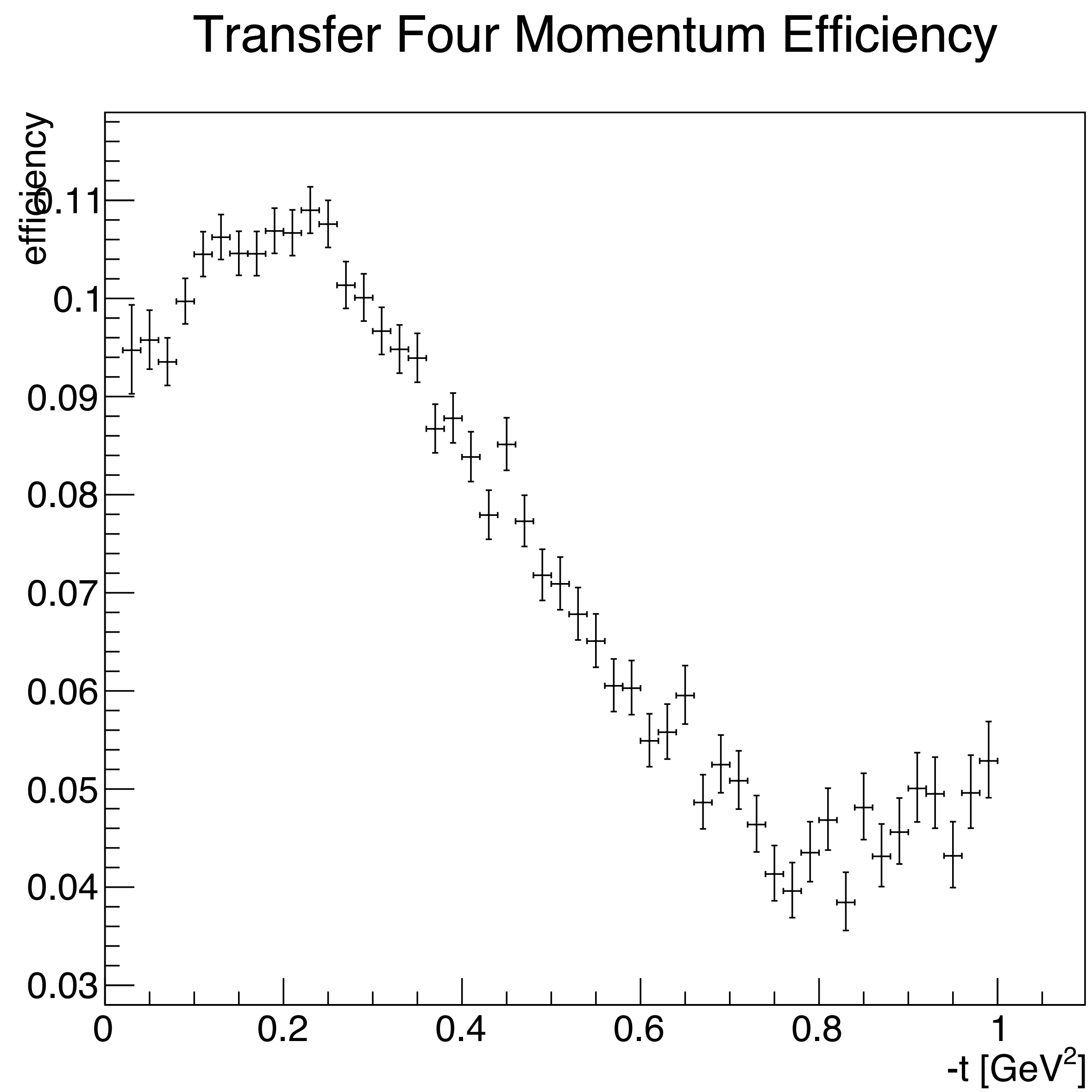


$\mathbf{M(K\pi)(GeV)}$ $\mathbf{M(K\pi)(GeV)}$ $\mathbf{M(K\pi)(GeV)}$

region of $\kappa(800)$

SLAC Lower limit

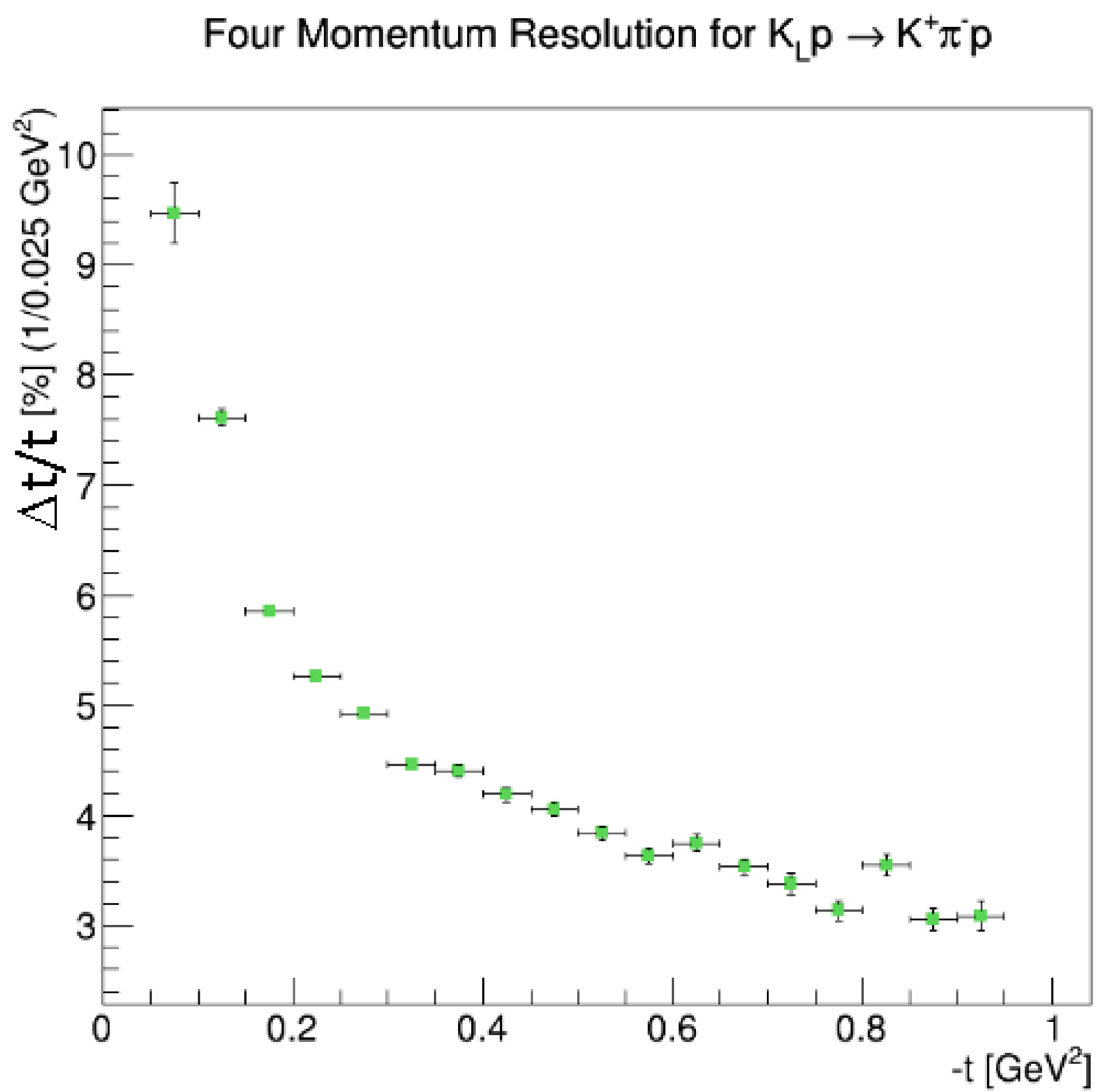


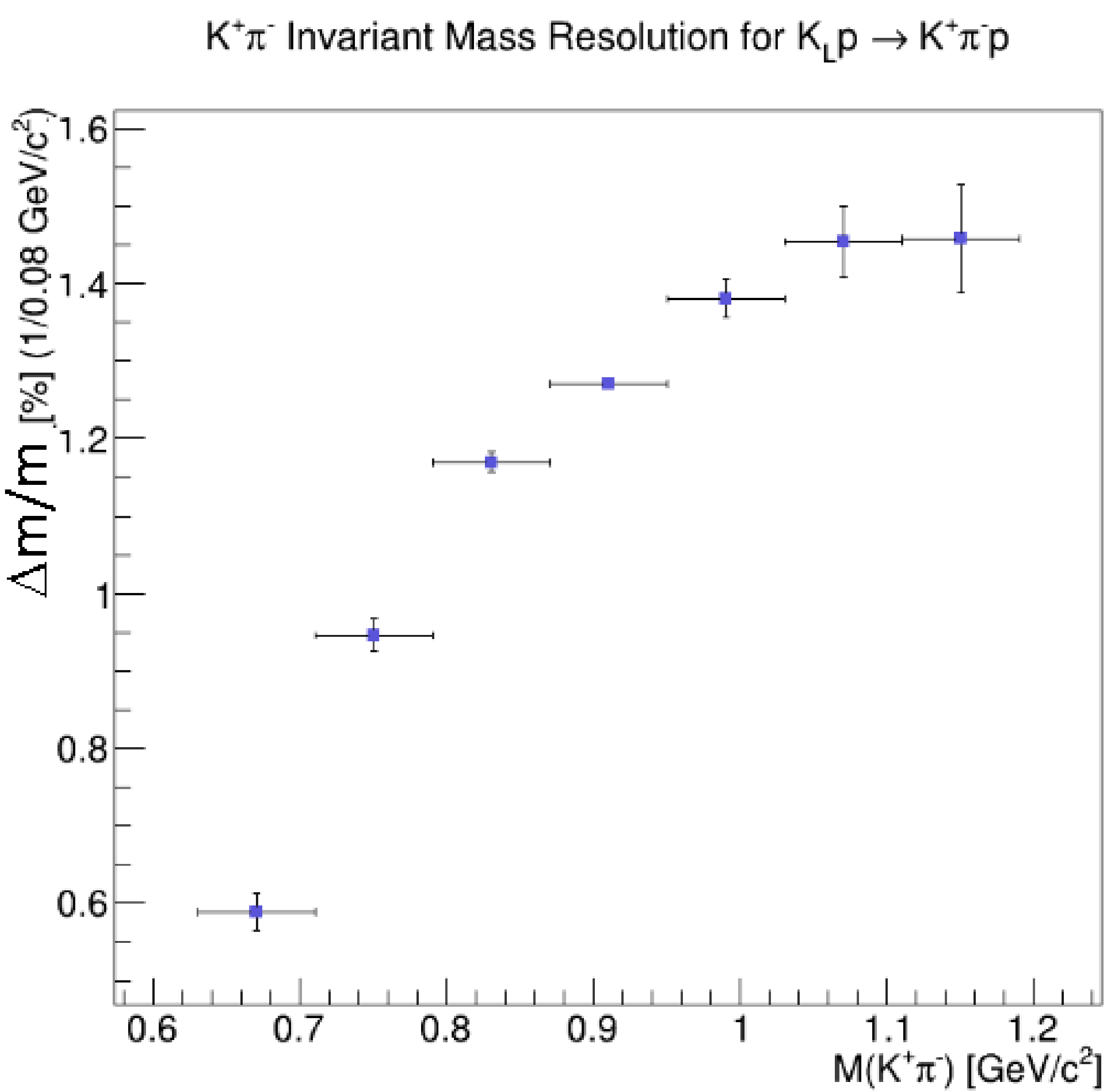


t-down to 0.08 GeV^2 is measurable with proton being detected

t-down to pion pole proton missing

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

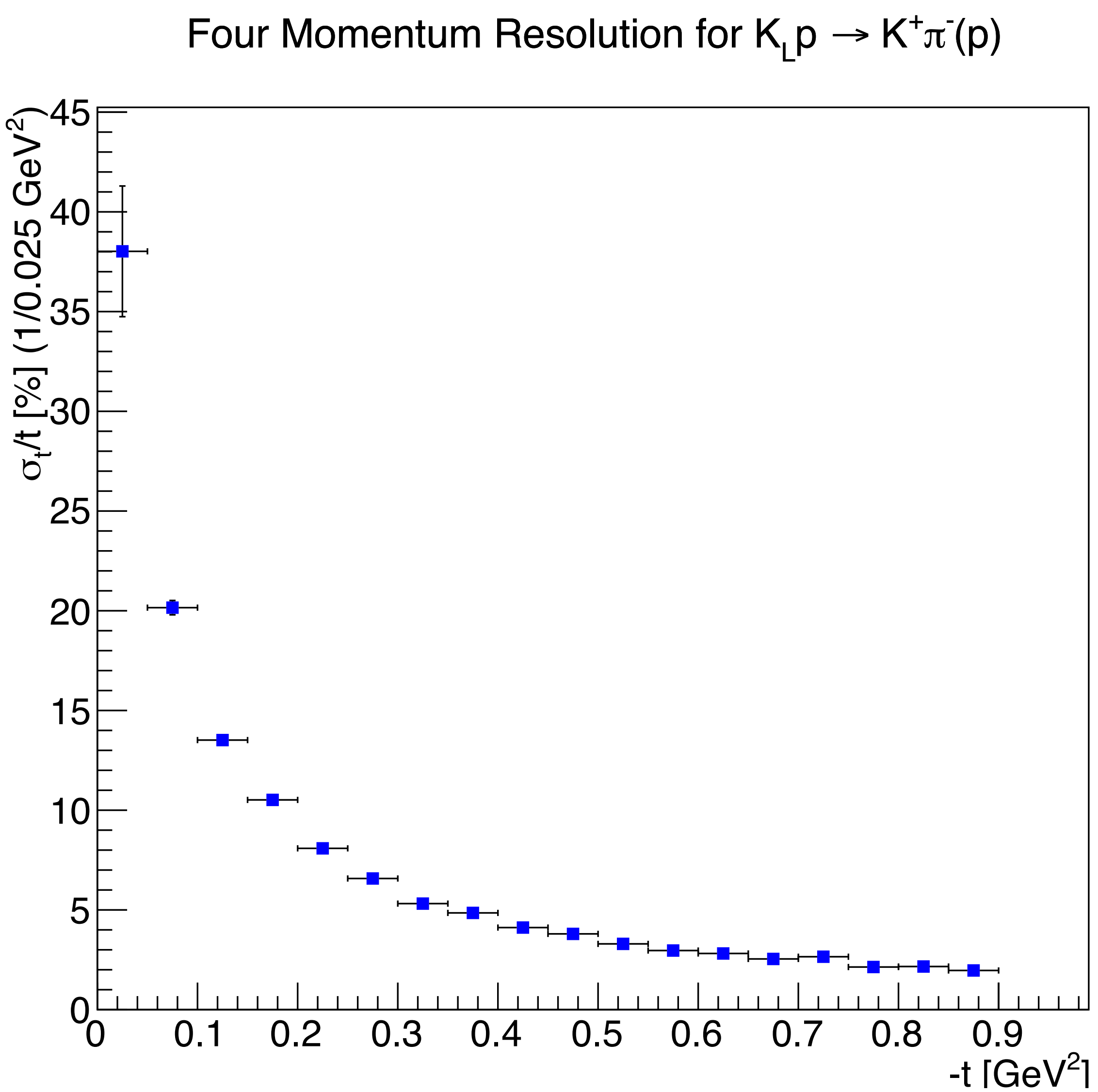


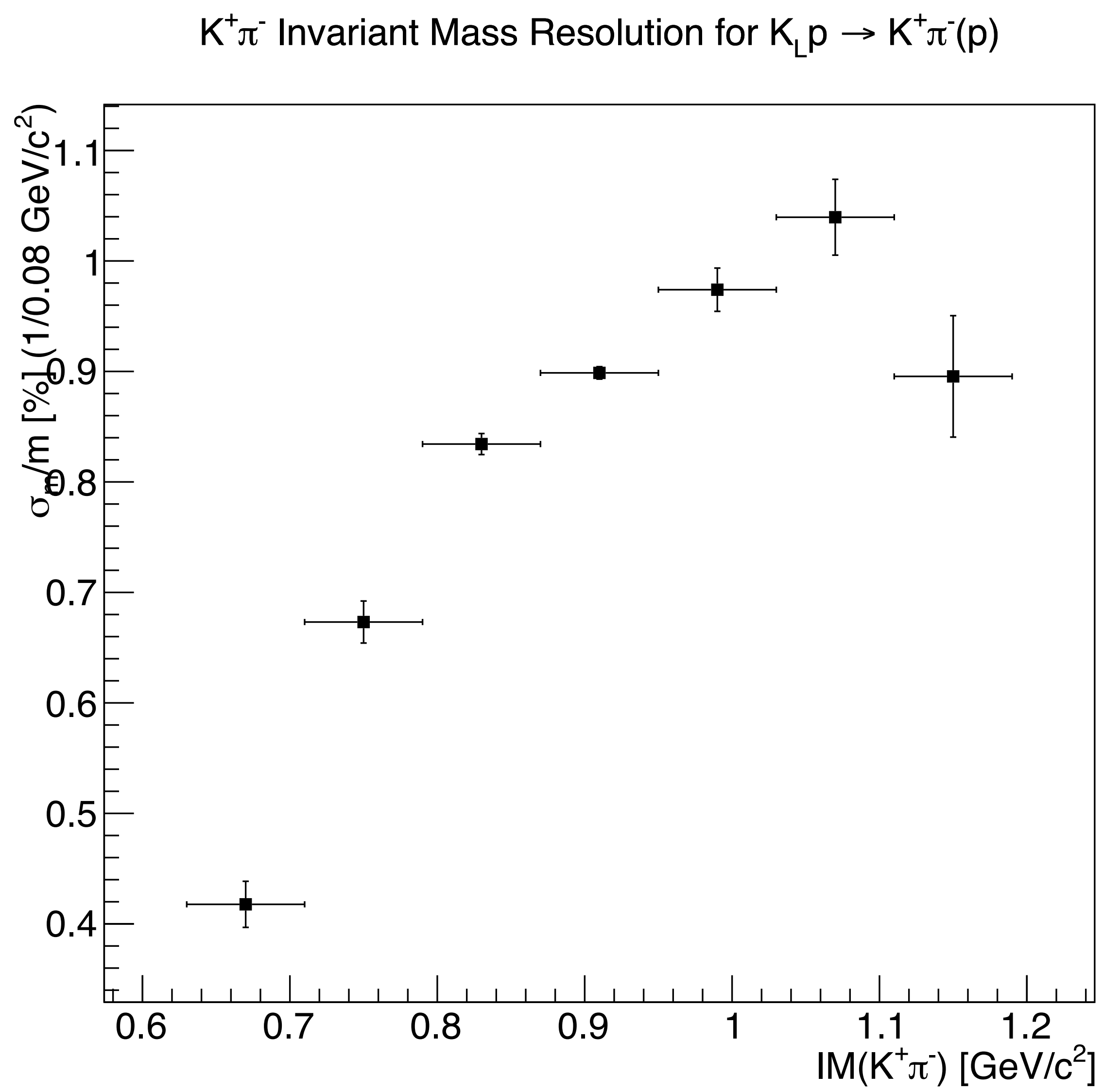


-Good resolution at low-t is needed to be close to pion pole

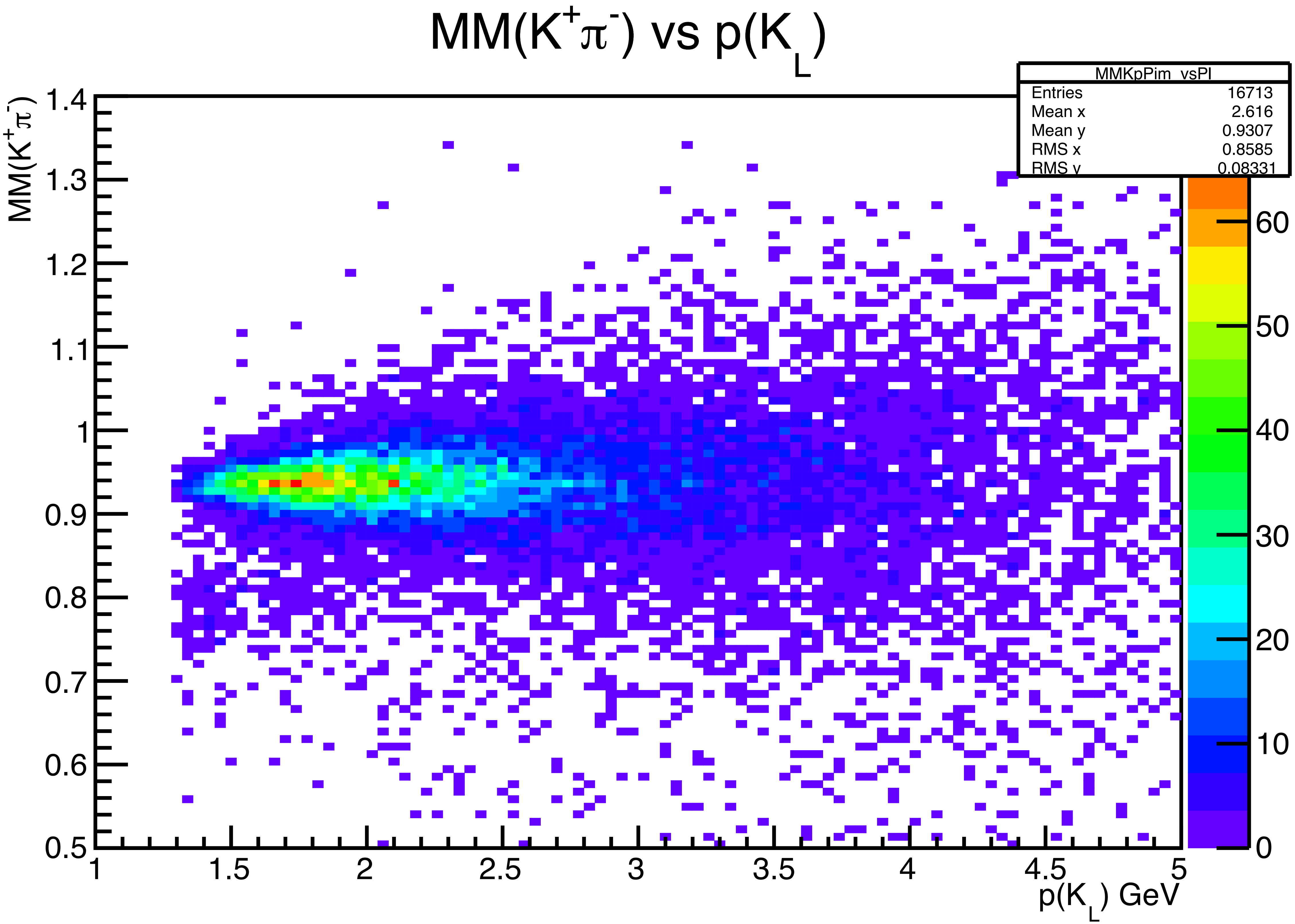
-Binning in ~10 MeV will cover almost entire elastic K-pi scattering range

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

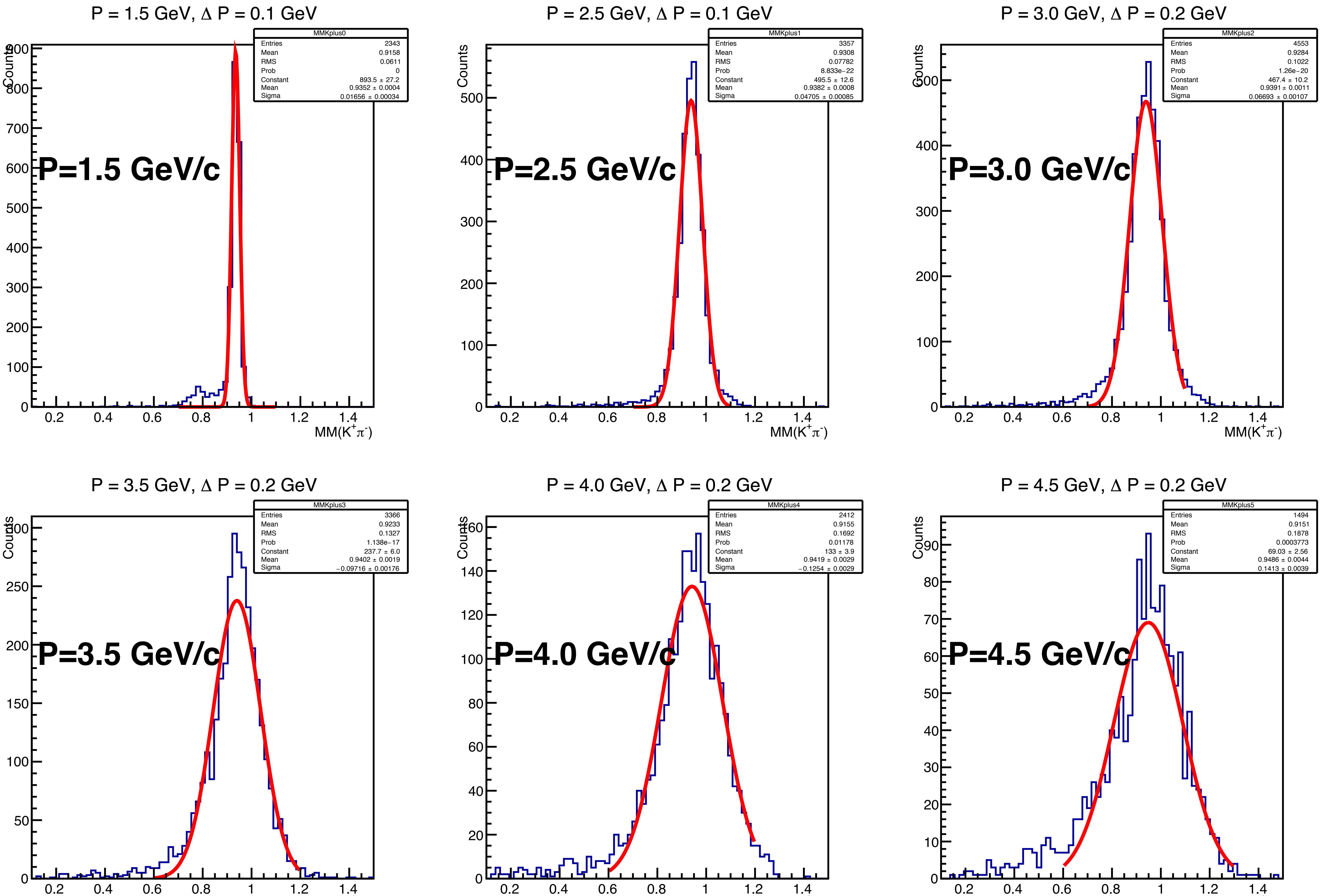




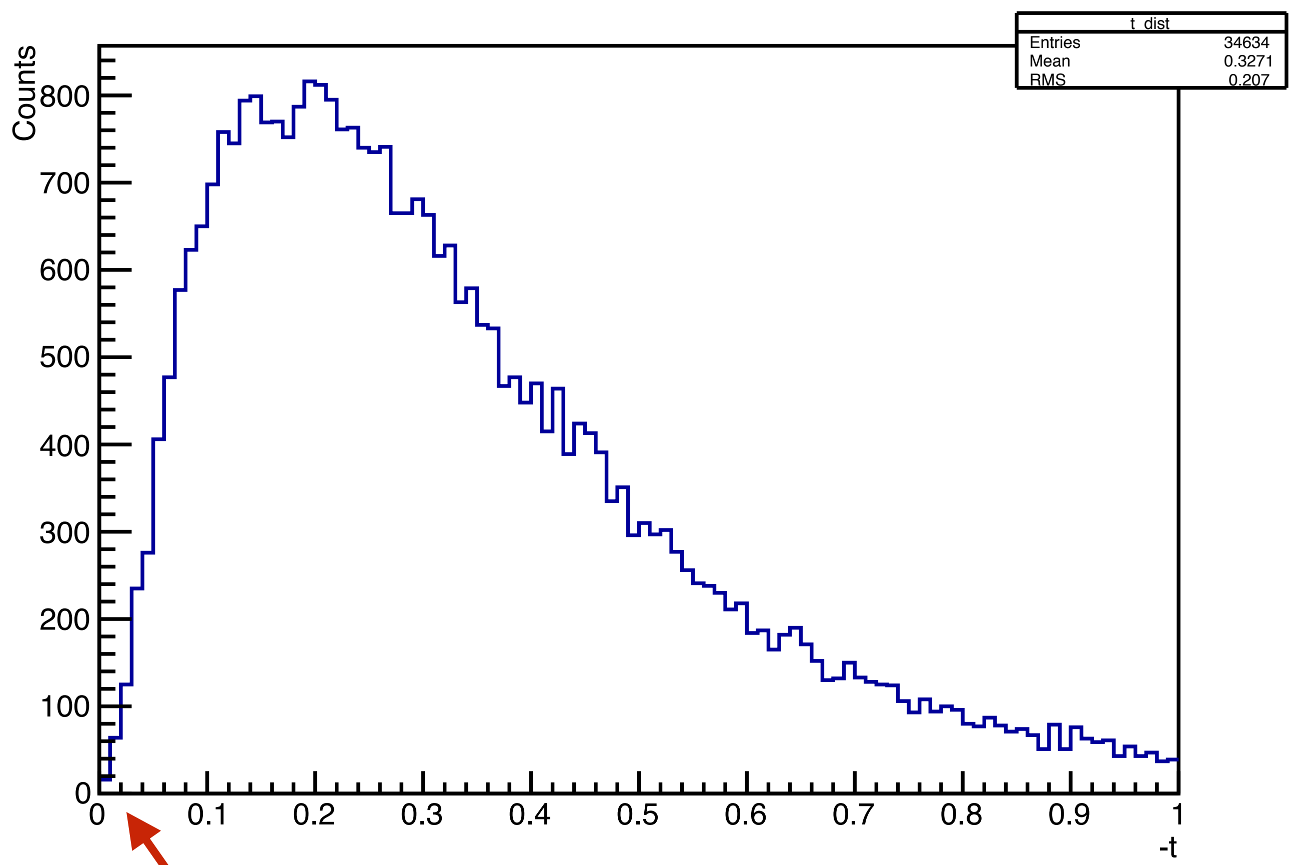
Missing Mass of $K^+\pi^-$ system



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

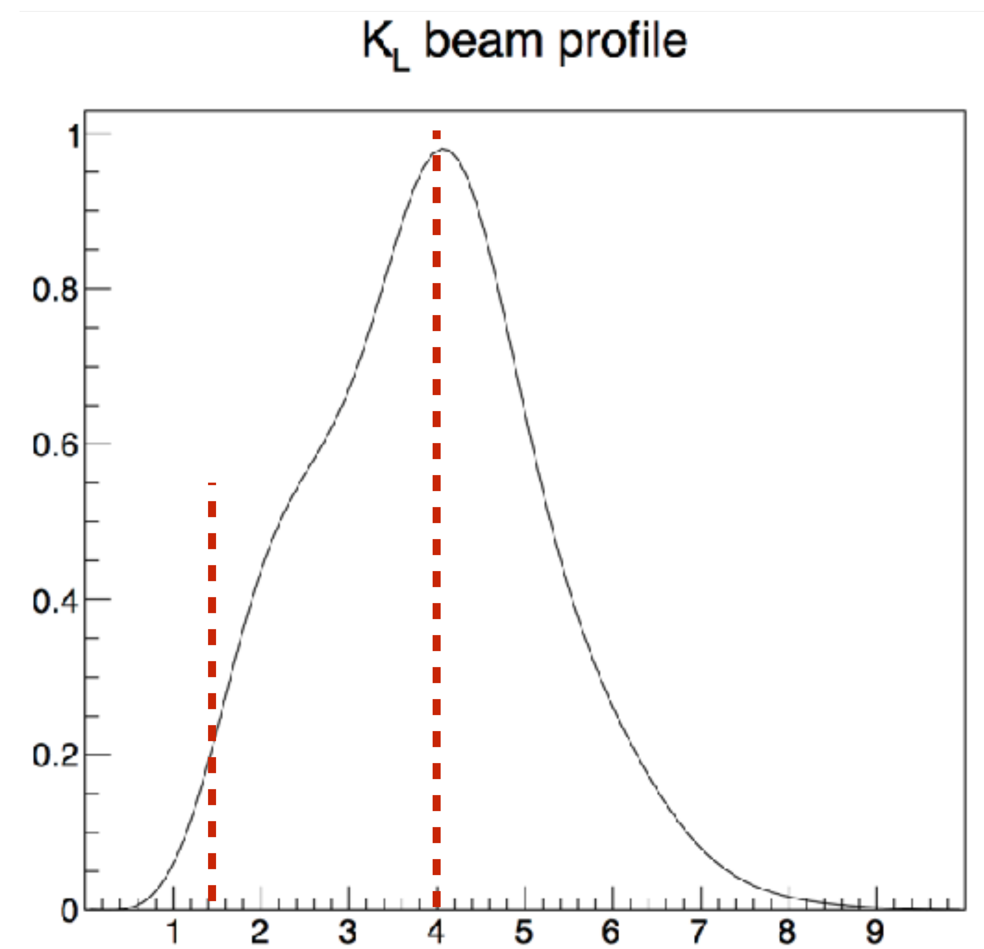


Proton reconstructed via missing mass



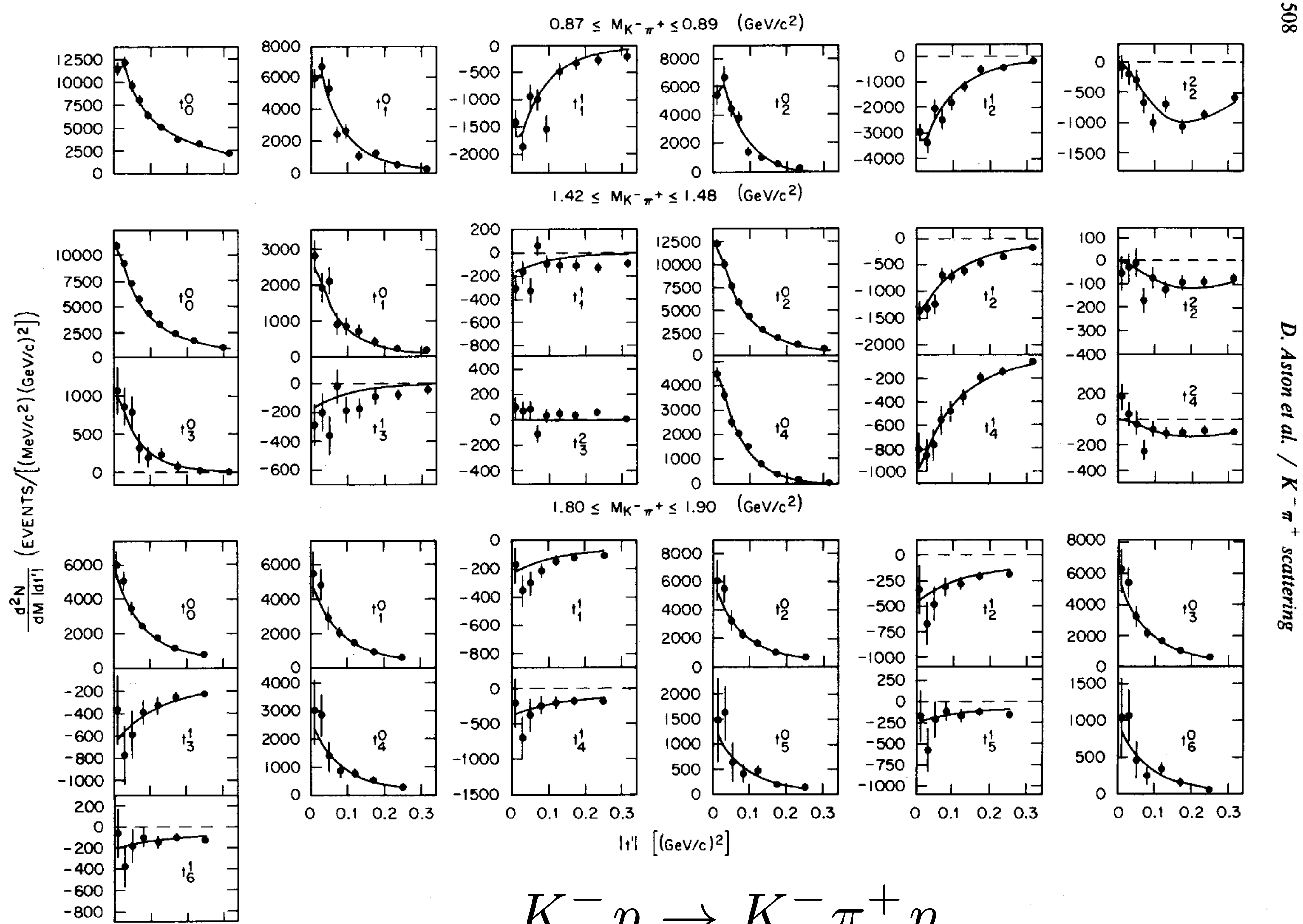
$$-t, (GeV/c)^2$$

Down to pion pole



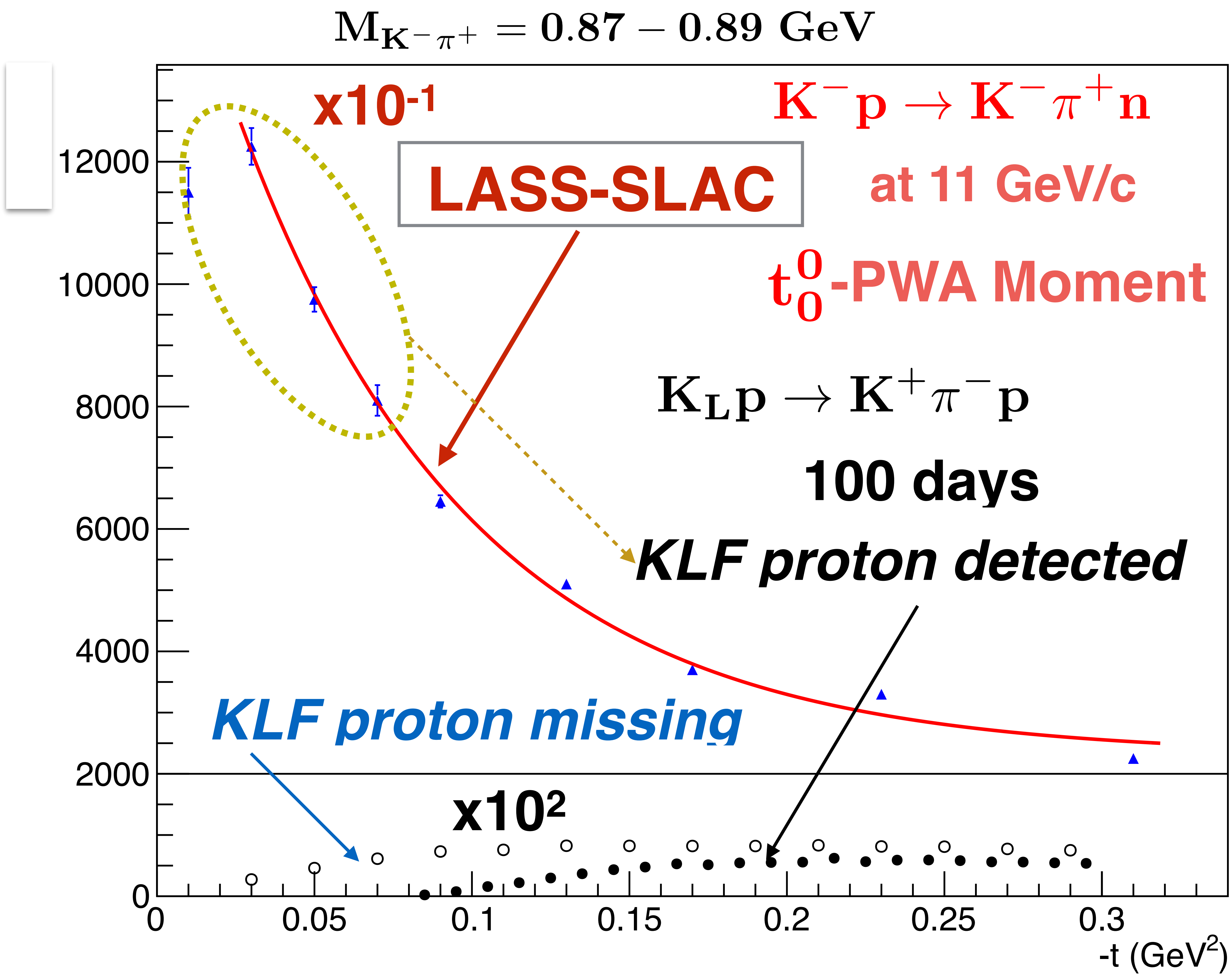
$$P(K_L), GeV/c$$

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.

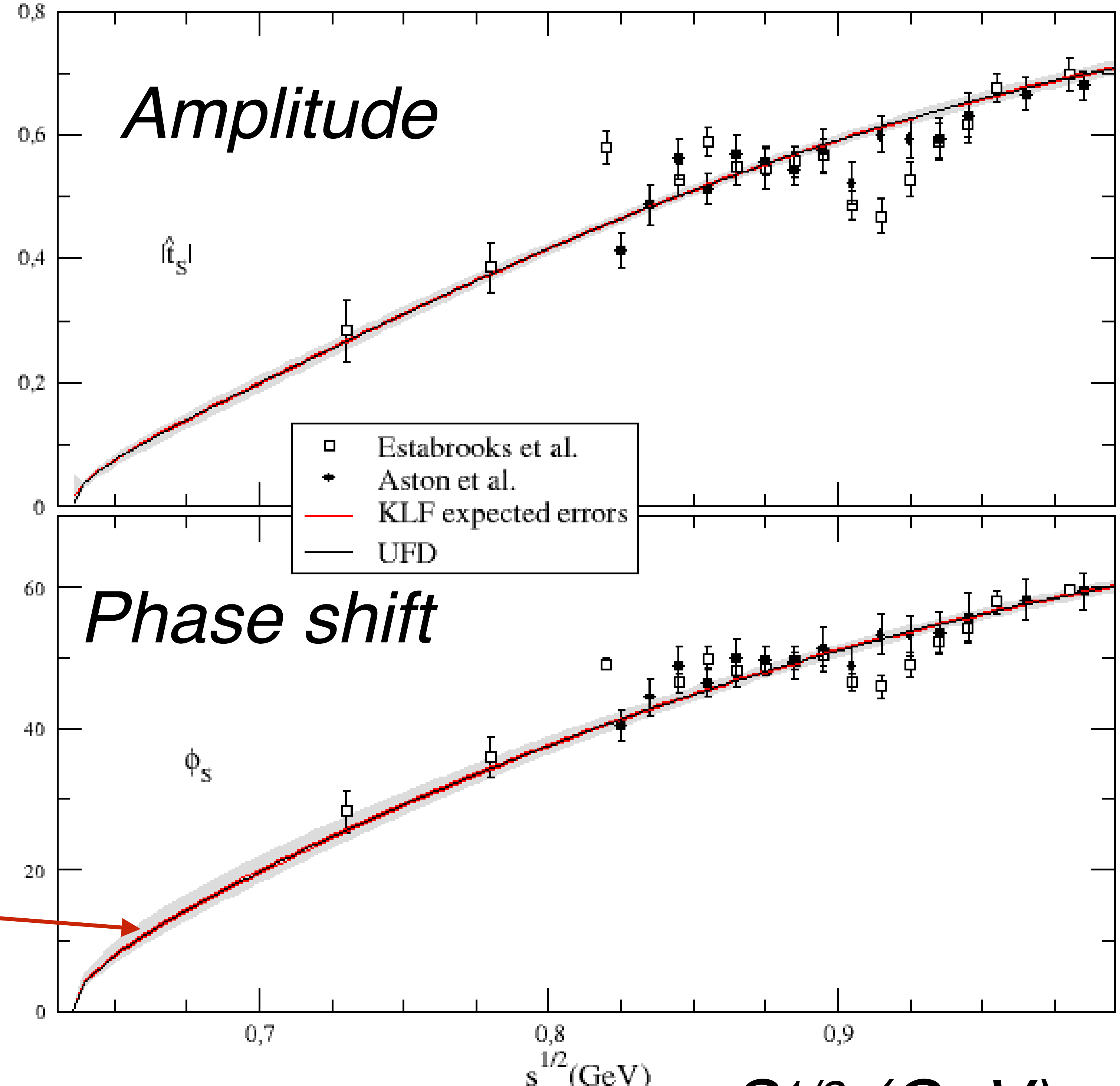


Two orders of magnitude higher statistics with KLF plus down to the threshold of M(K-pi)!

Projected Measurements

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

SLAC Data

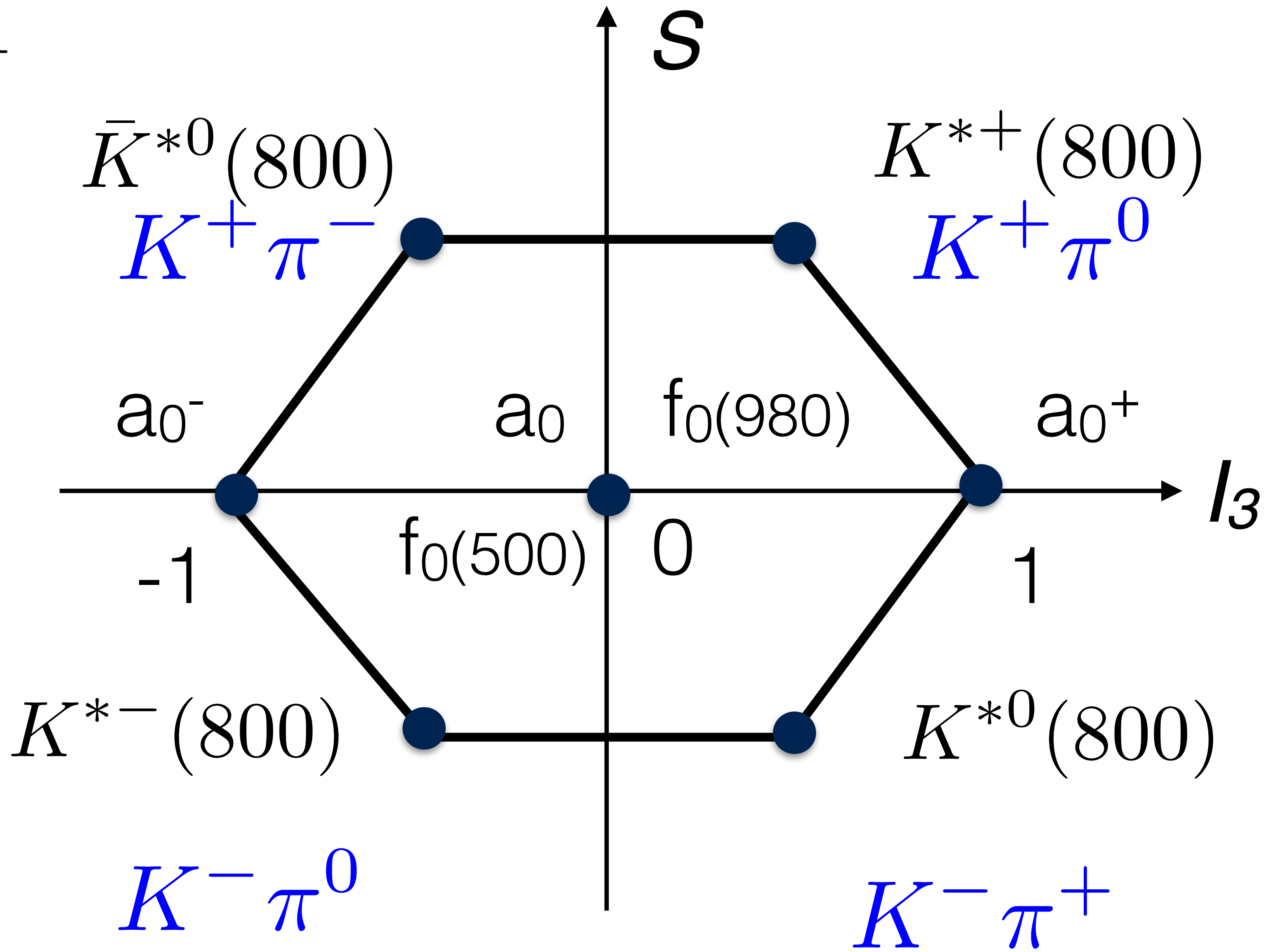


KLF (100 days)

S1/2 (GeV)

Scalar Meson Nonet

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

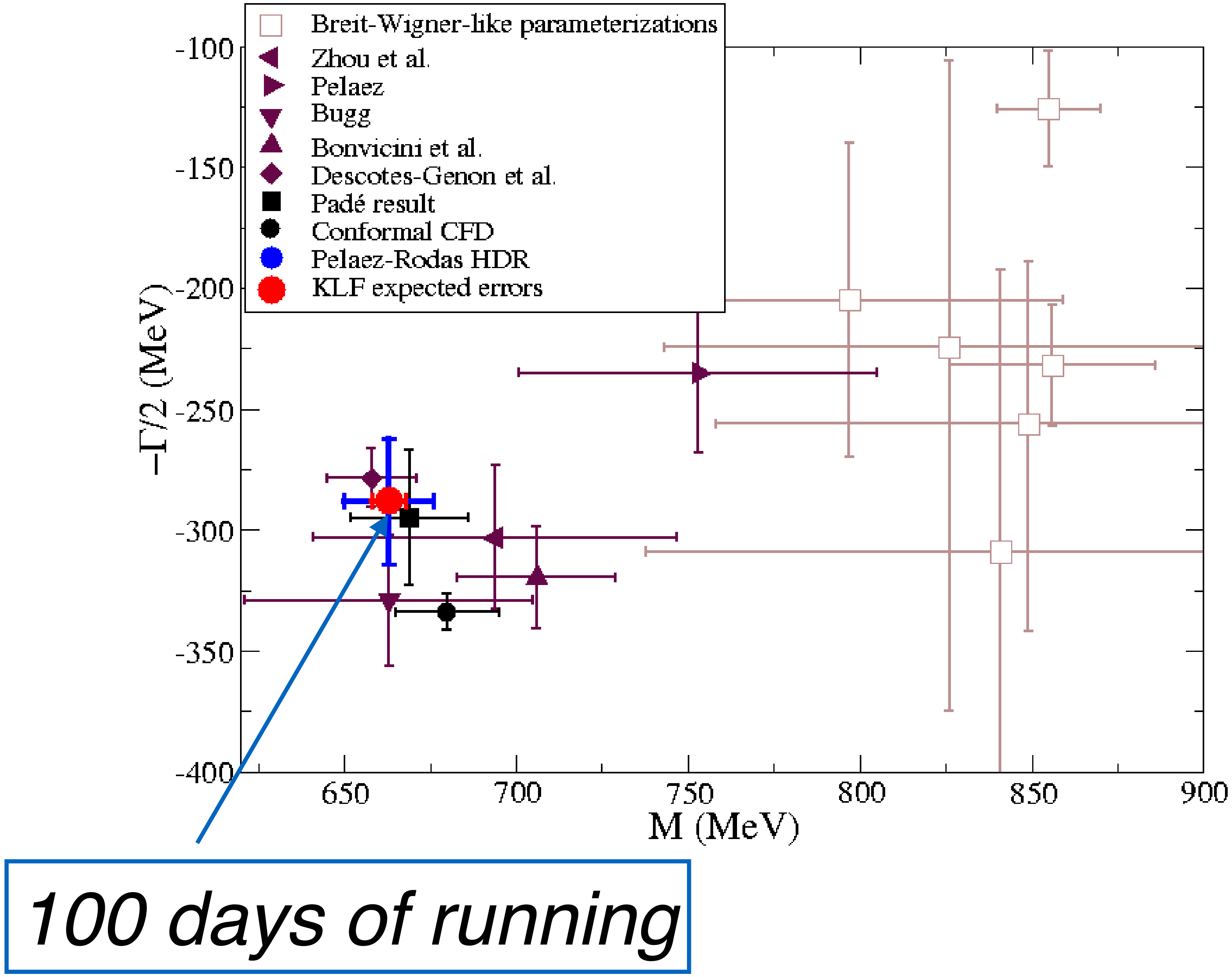


Four states called κ

still need further confirmation(PDG)

We can measure all of them

Width and Mass of κ (800)



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

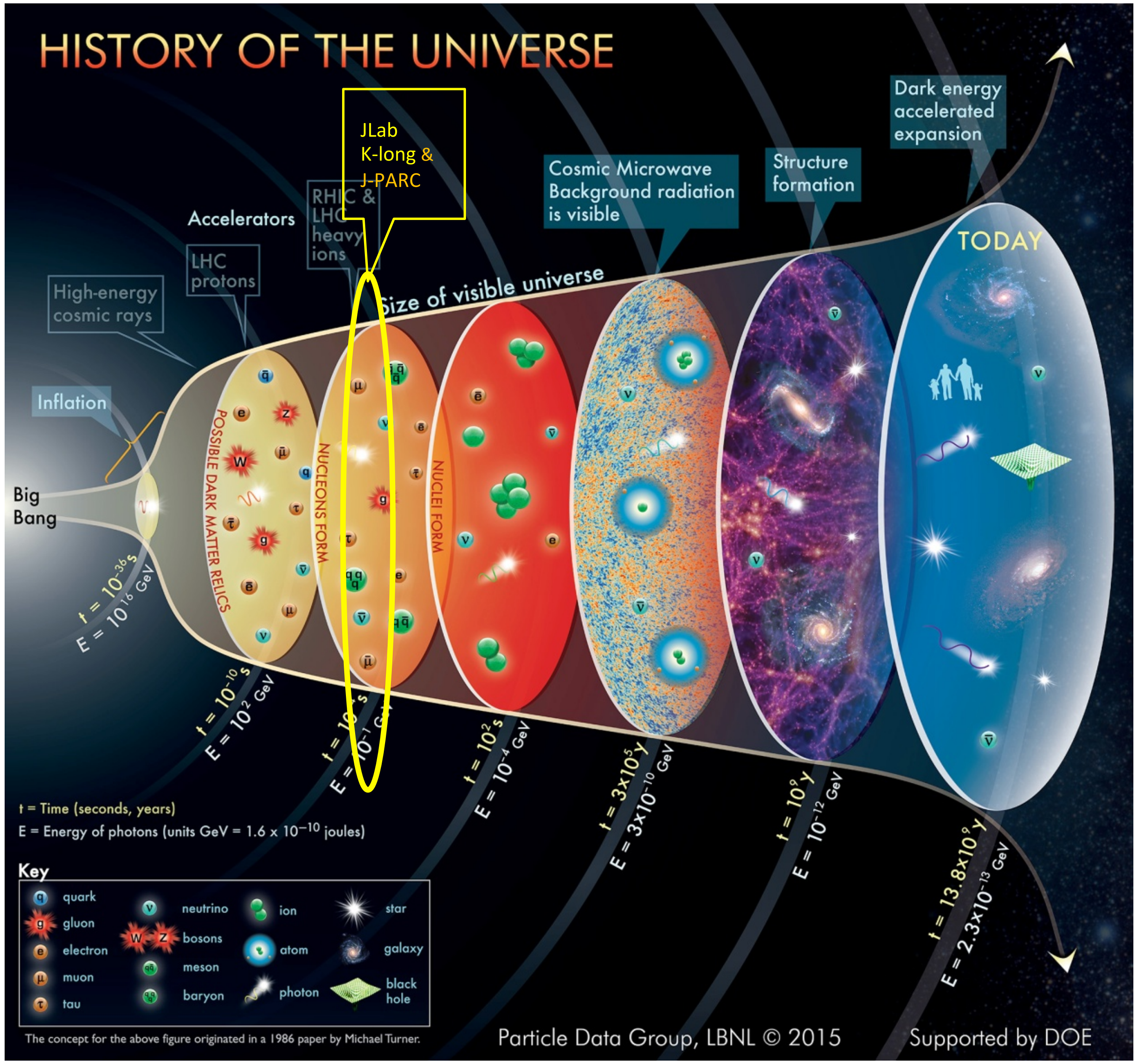
-It will certainly improve still conflictive determination of heavy K*'s parameters

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

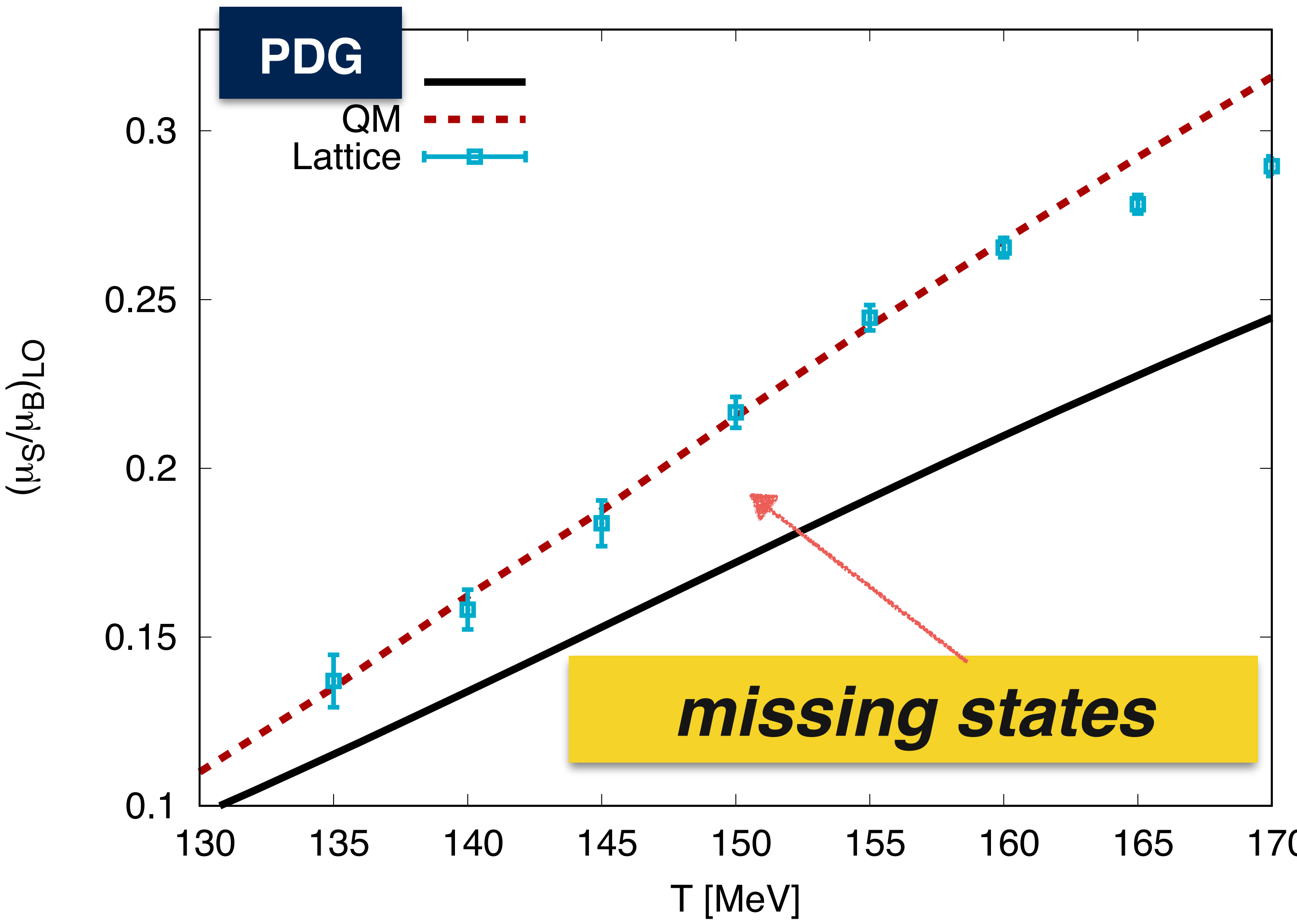
-Finally, and very importantly, it will reduce by more than a factor of two the uncertainty in the mass determination of K*(800) and by factor of five the uncertainty on its width, and therefore on its coupling

-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

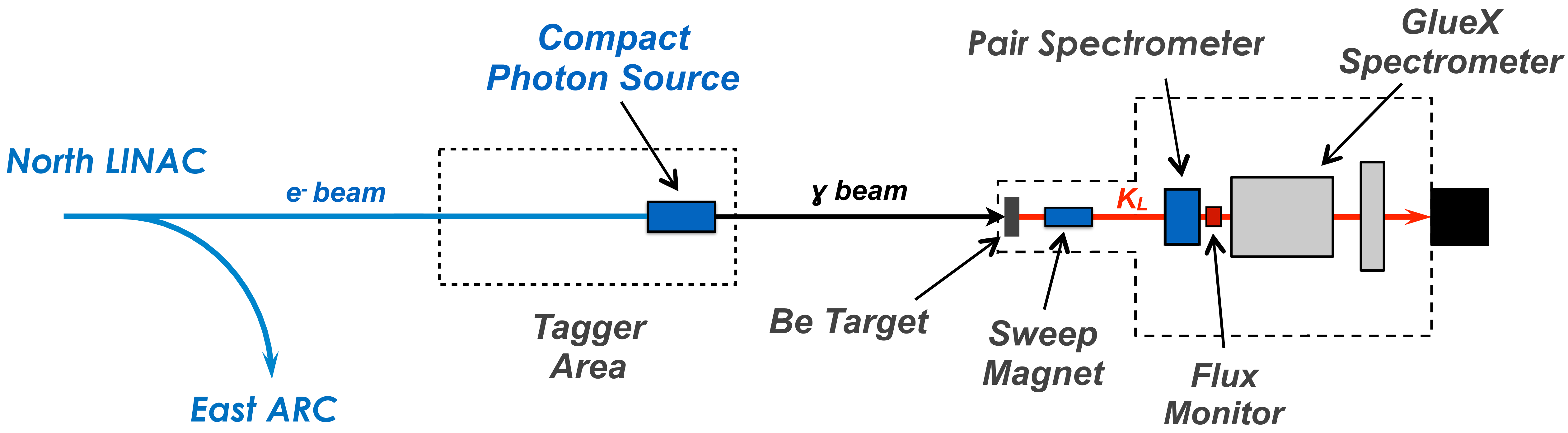


YSTAR2016 Proceedings arXiv: 1701.07346

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

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

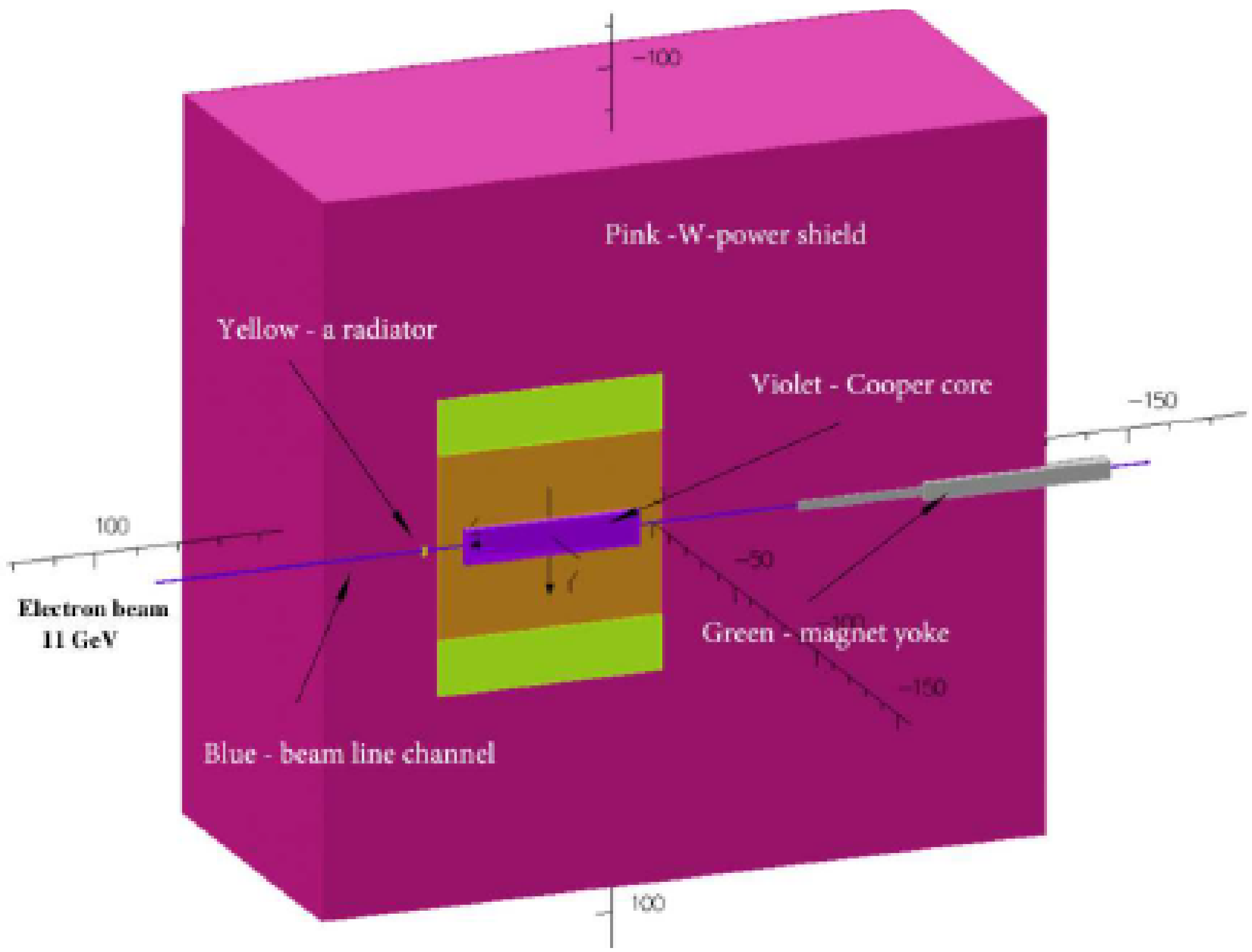
Bunch spacing $\qquad 64\ ns$

No major problems.

Doable !

Confirmed by accelerator experts

Compact Photon Source

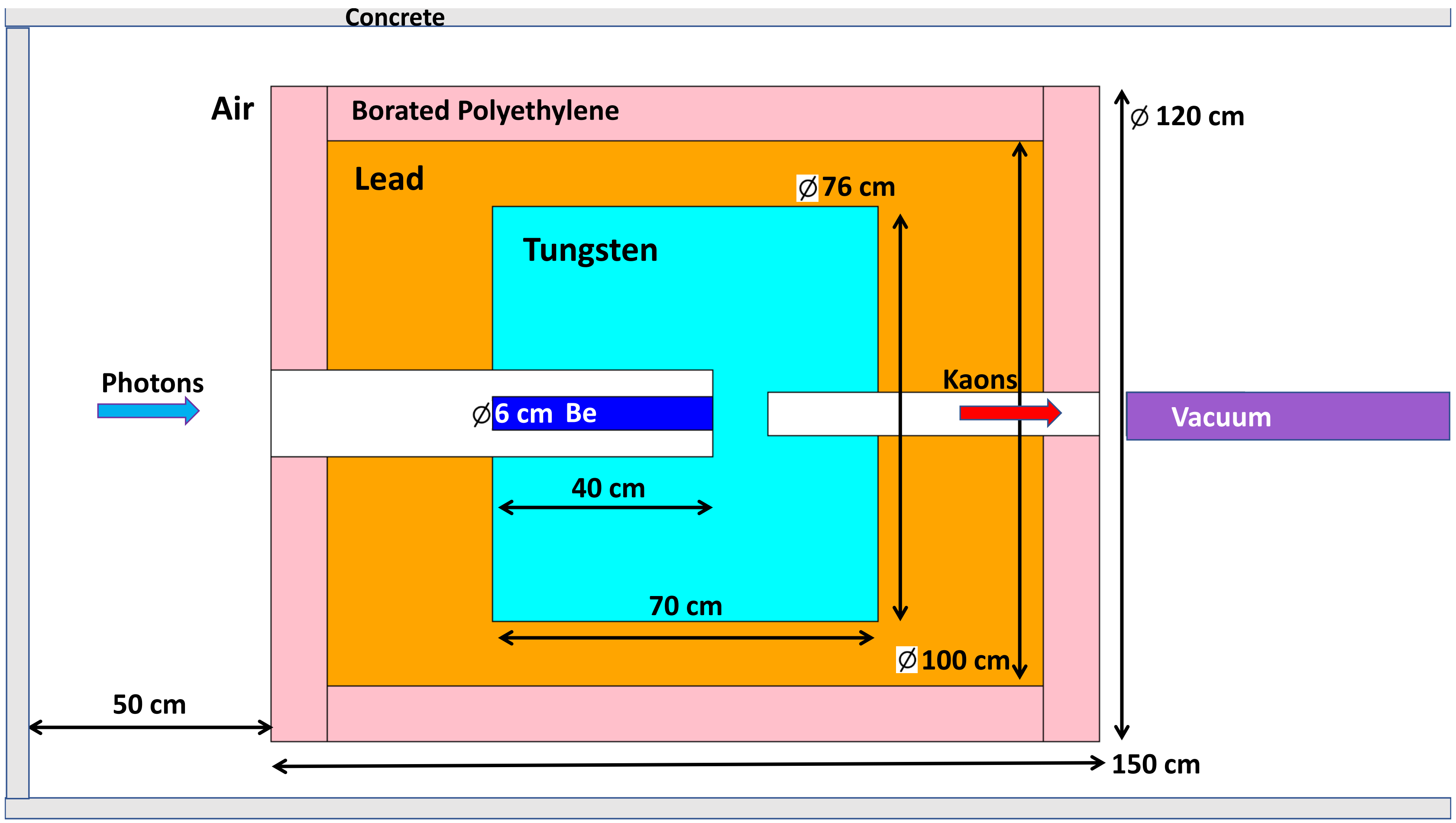


Conceptual design is completed for Halls A&C

The details of the CPS are designed by the CPS Collaboration

Meets RadCon Radiation Requirements

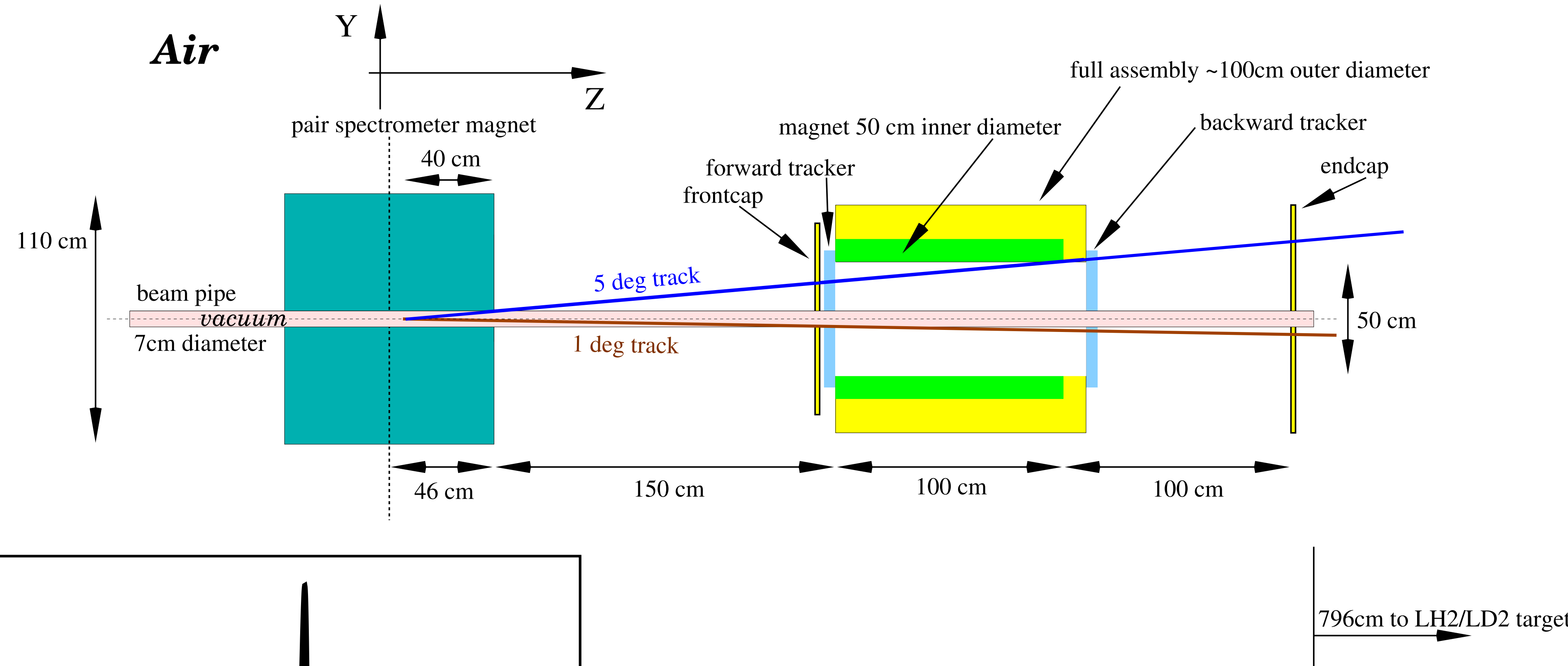
Be Target Assembly: Conceptual Design

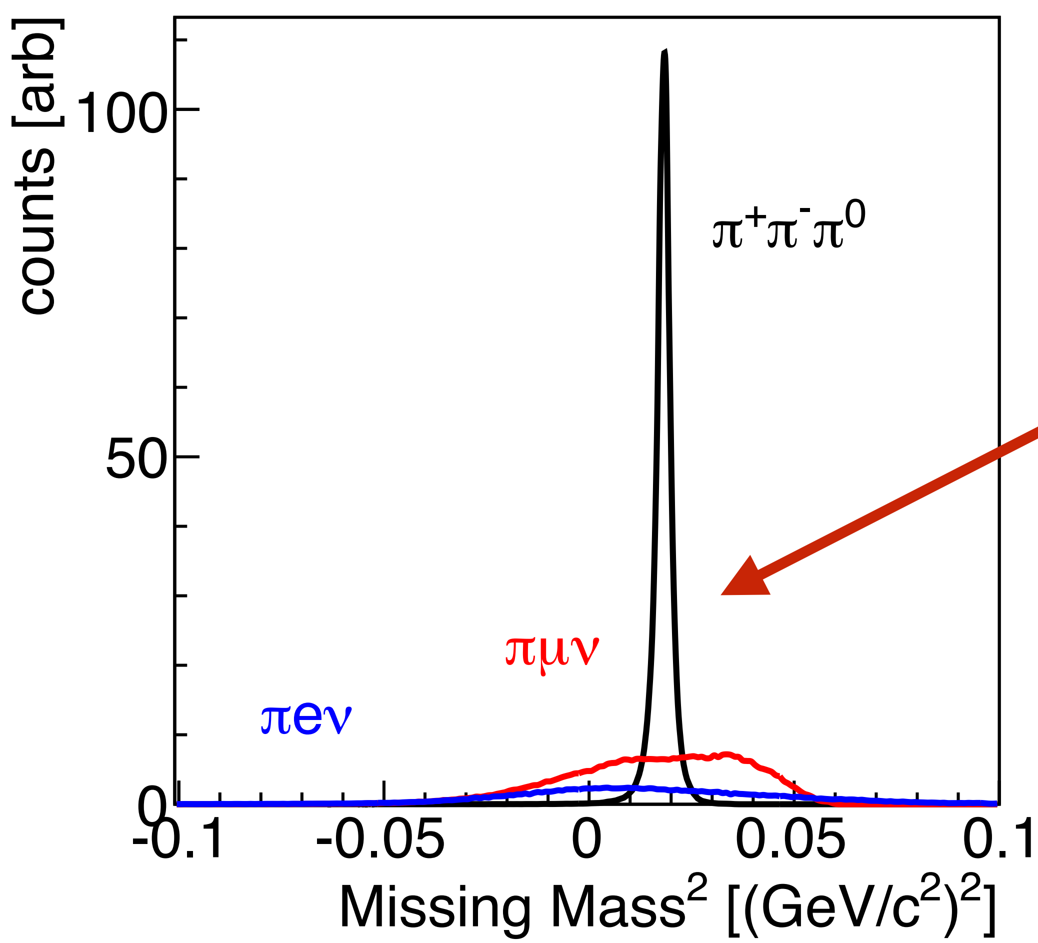


-Meets RadCon Radiation Requirements

-Conceptual Design Endorsed by Hall-D Engineering Staff

Flux Monitor





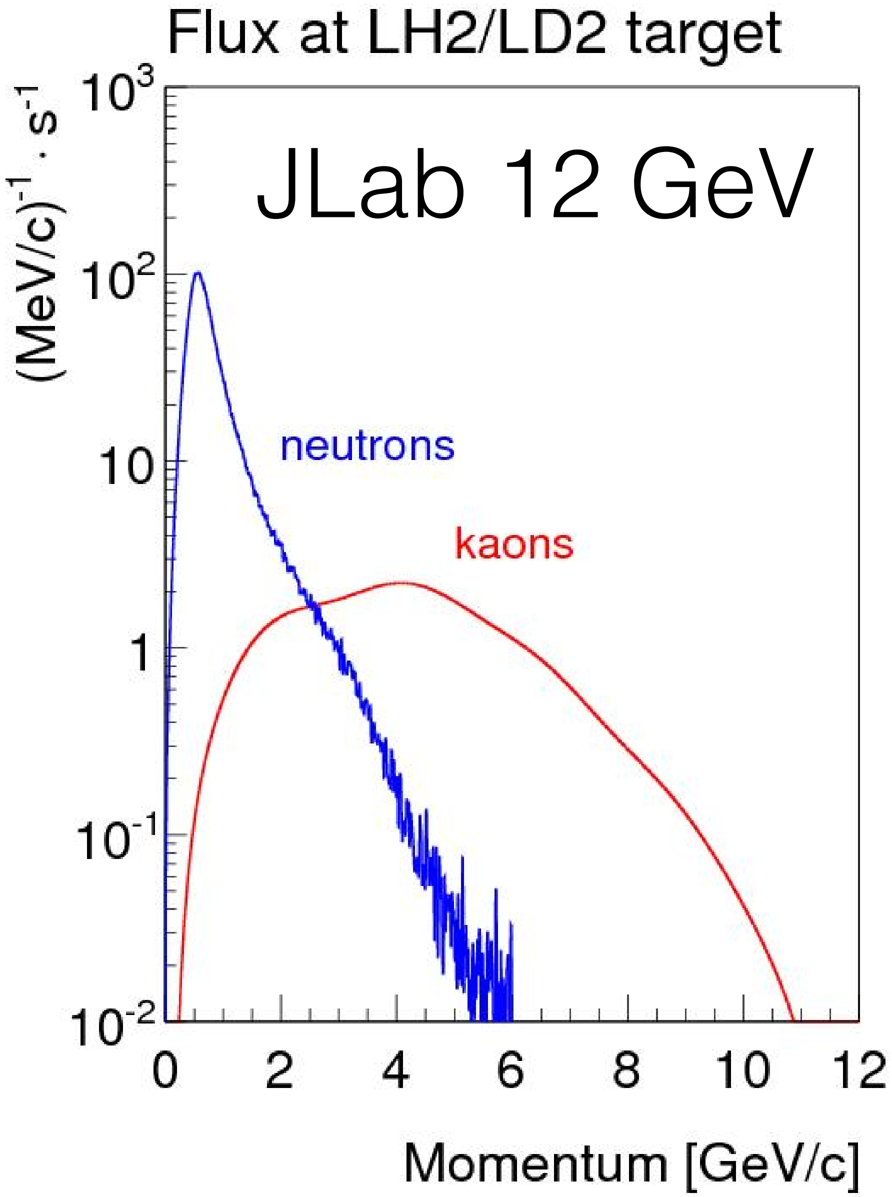
Reconstructed K_L

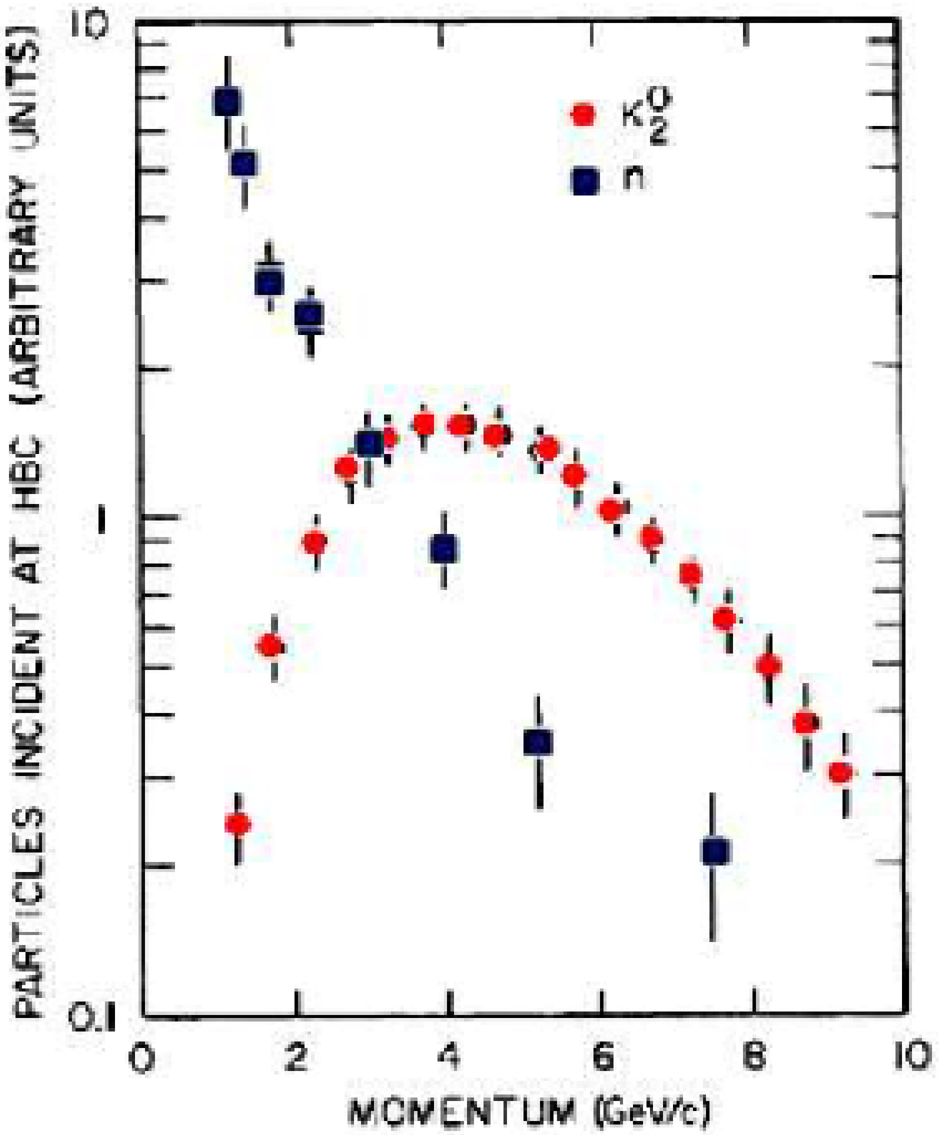
via missing (π^0)

Flux measurement stat. err. <1%

Estimated syst. err. ~5%

K_L Beam Flux



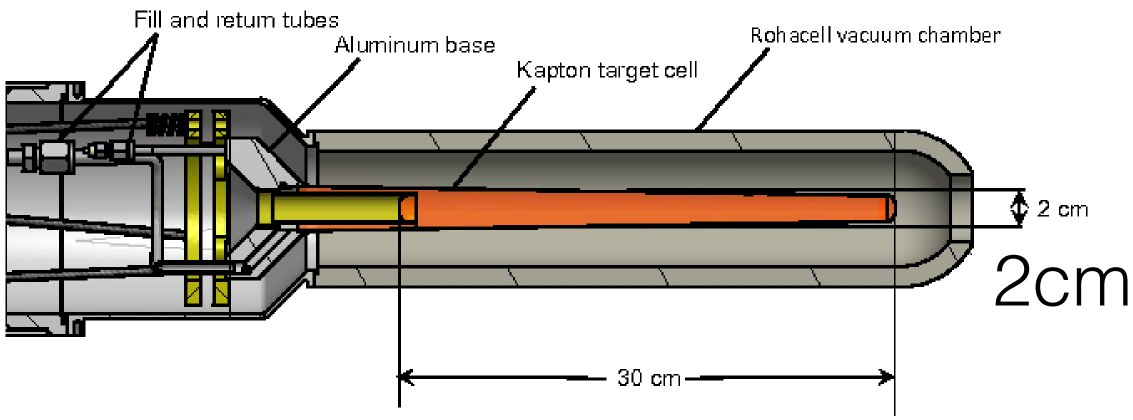


$$N(K_L)/sec \sim 10^4$$

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

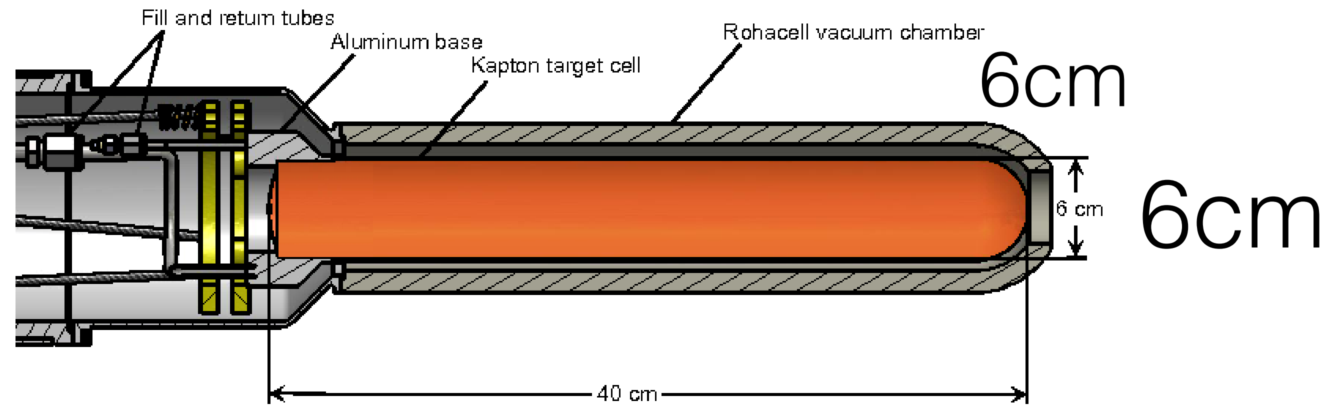
LH_2/LD_2 Cryogenic Target for Neutral Kaon Beam at Hall D

The GlueX liquid hydrogen target.



30cm

Current

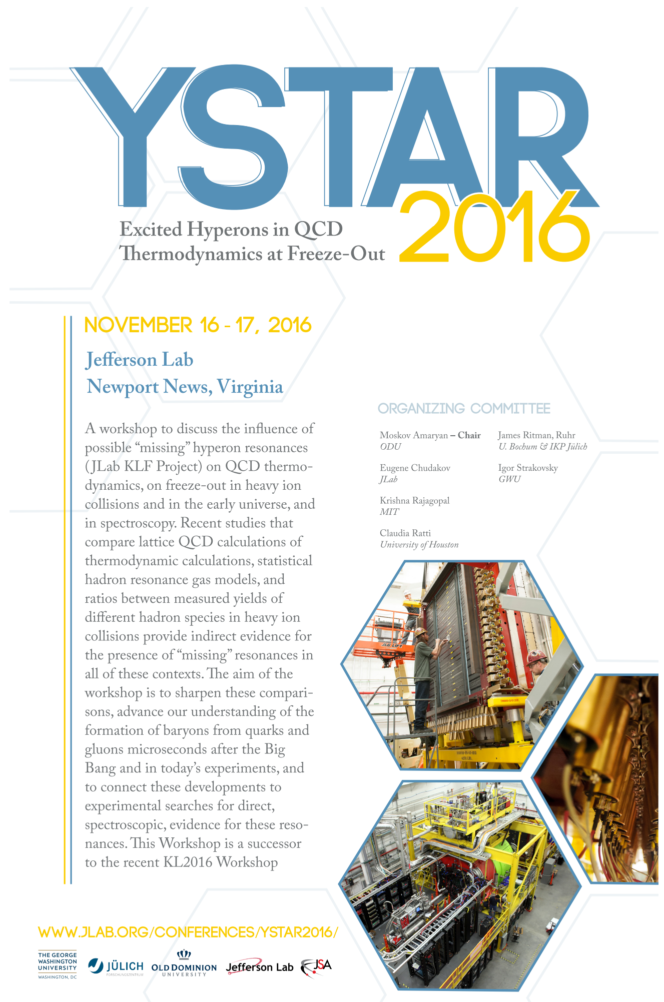


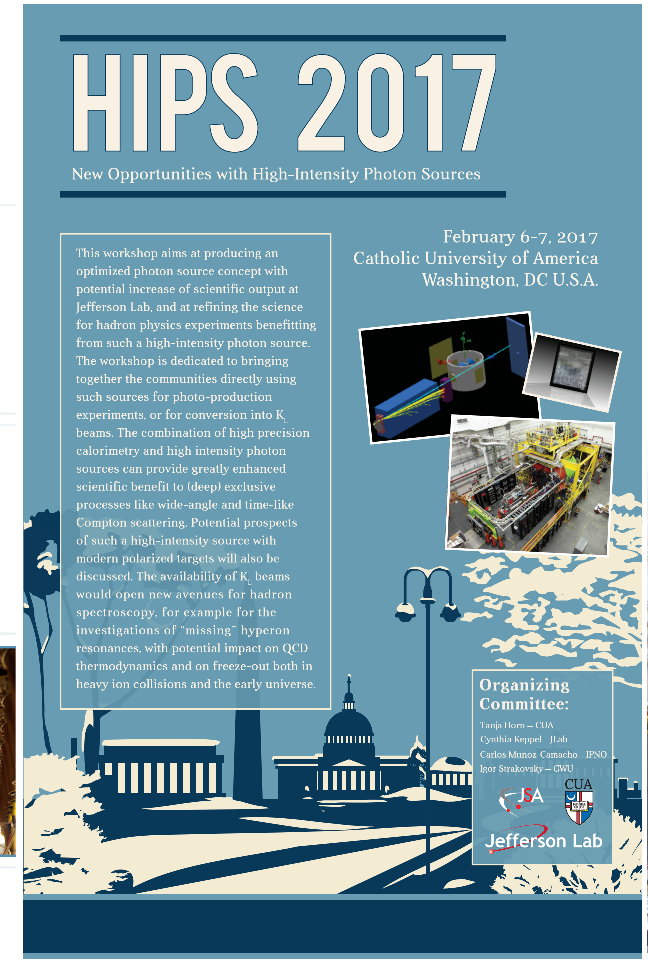
40cm

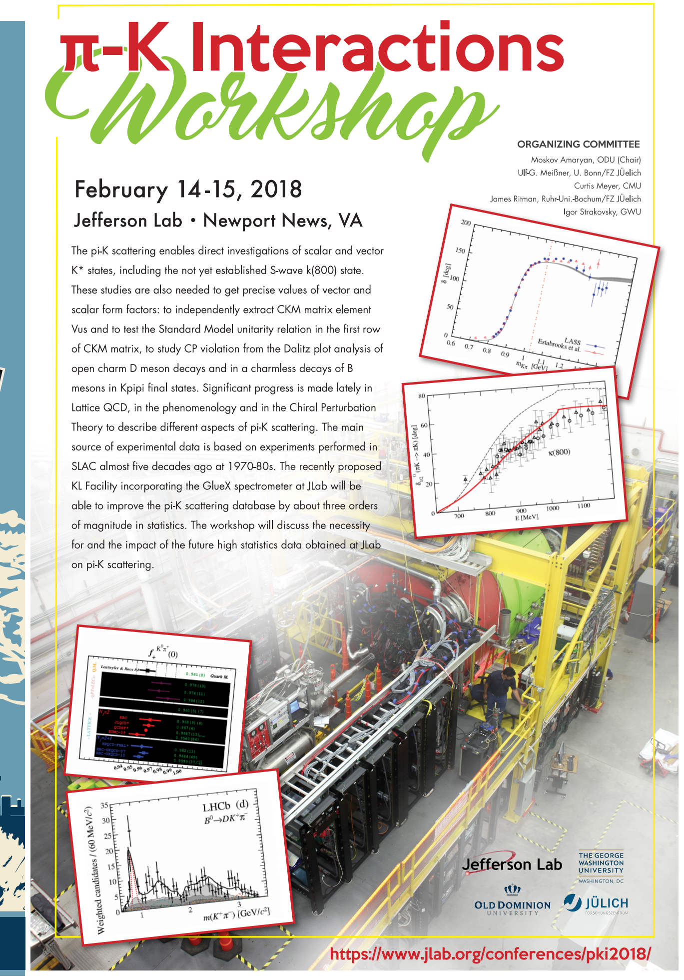
Proposed & Feasible

Longer and ticker target is needed to enhance production rate

Conceptual design has been endorsed by the JLAB target group







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.

PAC47 Final Report

Scientific Rating: N/A
Recommendation: C2

Title: "Strange Hadron Spectroscopy with a Secondary K_L 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, is 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 most significant technical aspect of this proposal is the addition of a Compact Photon Source (CPS) in the beamline leading into Hall D, which will have significant attendant cost and will impose an estimated six months changeover time for alternate running of GlueX. It is also important to be sure that GlueX can handle the background rates from neutrons and other beam-induced contaminants. It seems quite feasible that the GlueX detector can manage to detect the final state particles with enough particle discrimination to meet the spectroscopy needs.

Issues: Several points of discussion concerned the PAC. A) the missing mass technique to replace the direct proton detection at very low values of $|t|$ was only presented in the open session and the details of the underlying simulations should be clarified; B) a realistic simulation including beam backgrounds is to be presented with details to be spelled out and documented thoroughly; C) A realistic project management plan needs to be developed to realize the experiment; D) The analysis and extraction of key physics parameters requires theory guidance, which is now included within the group of proposing authors and makes use of JPAC.

This 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 white paper provided to us.

Summary: The collaboration should return to the PAC with a well documented proposal. Simulations addressing backgrounds and the low $|t|$ region are necessary. Also, a well-formed plan is needed to build the beamline and prepare for data taking with GlueX.

Thank you !

Backup Slides

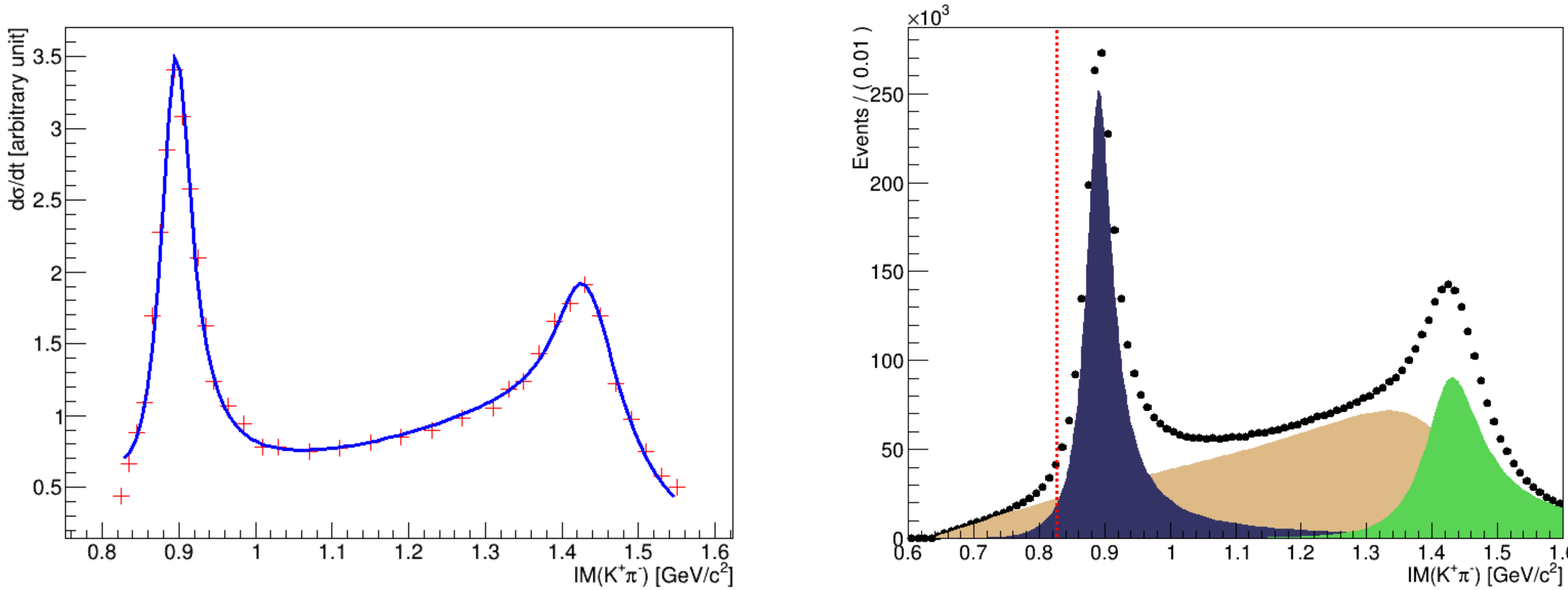
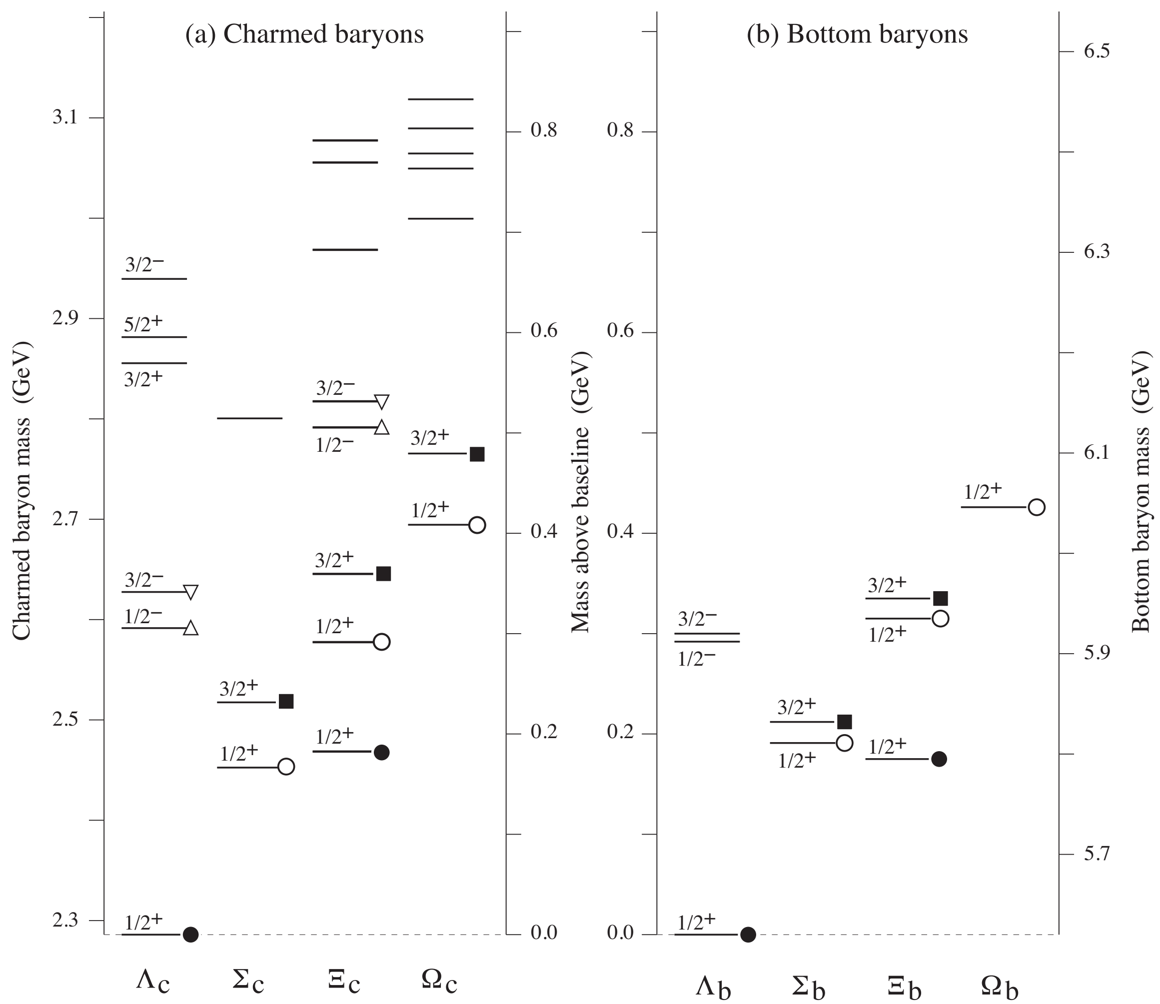
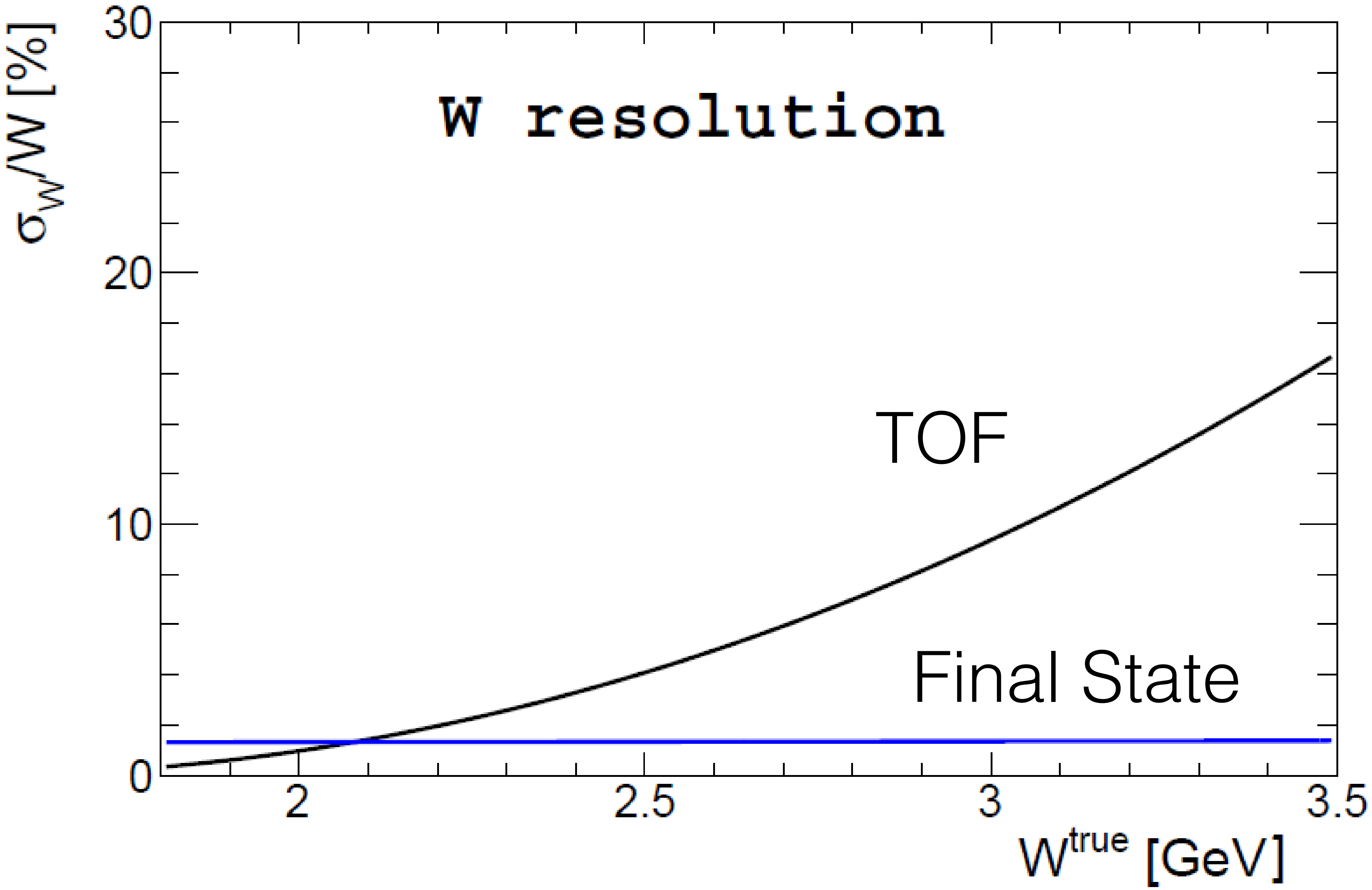


Figure 28: Left panel: Cross section of $K^-p \to K^+\pi^-n$ as a function of the invariant mass from LASS results [122]. The blue line is the fit to the cross section using composite model containing two RBW, spin-1 and spin-2, and S-wave LASS parameterization. Right panel: Expected distribution of 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)
Mass above baseline (GeV)
Bottom baryon mass (GeV)
2.3
2.5
2.7
2.9
3.1
0.0
0.2
0.4
0.6
0.8
5.7
5.9
6.1
6.3
6.5
3/2−
5/2+
3/2+
1/2−
1/2+
Λ_c
Σ_c
Ξ_c
Ω_c
Λ_b
Σ_b
Ξ_b
Ω_b



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

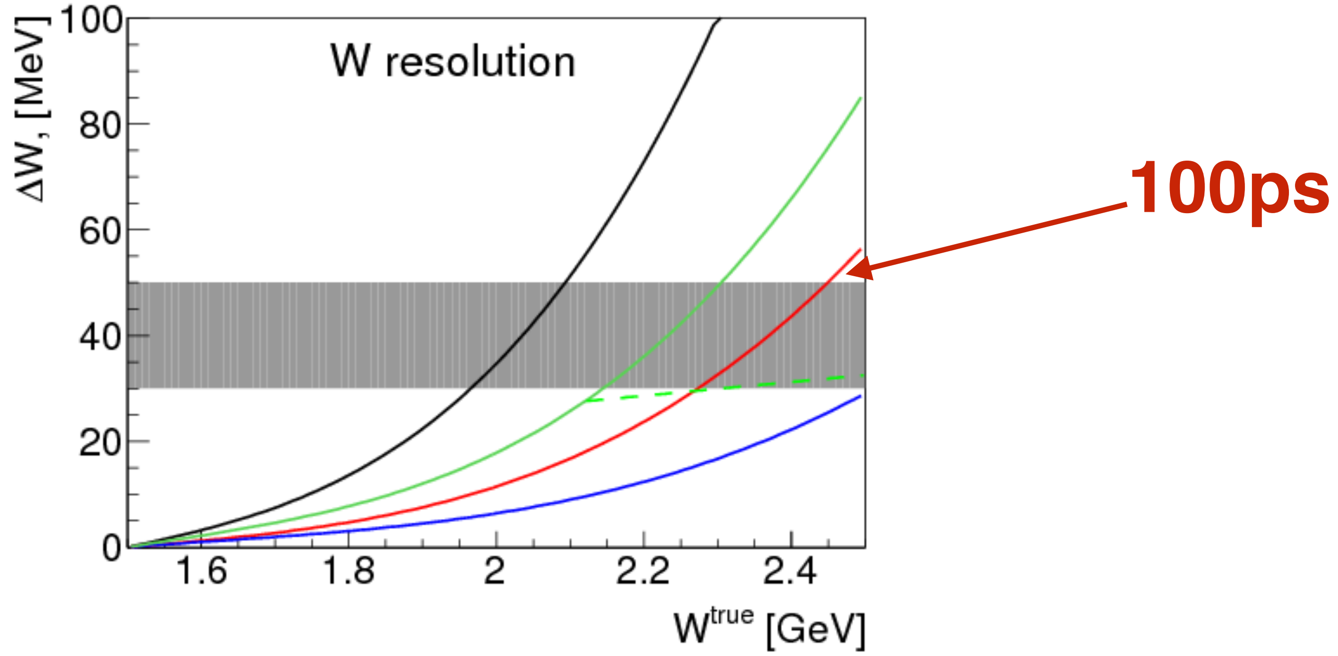
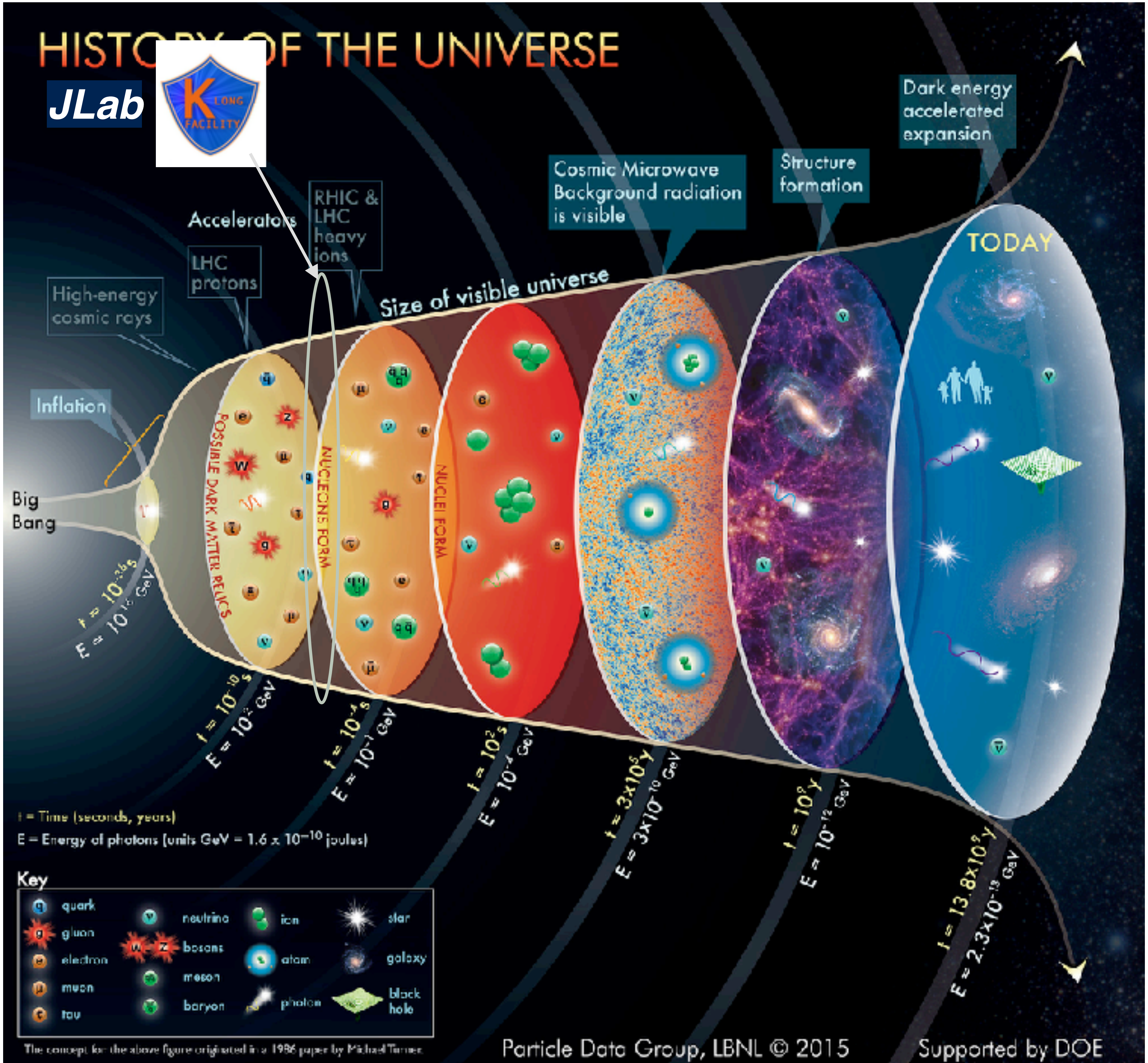


Figure 22: Energy resolution, $\Delta W/W$, as a function of energy, for 300 ps (black), 150 ps (green), 100 ps (red), and 50 ps (blue) time resolution. Green dashed line shows approximate W resolution from reconstruction of final-state particles. Shaded area corresponds to typical hyperon width.


HISTORY OF THE UNIVERSE
JLab
K LONG FACILITY
Dark energy accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Size of visible universe
TODAY
Inflation
Big Bang
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 joules)
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