$K\pi$ Scattering study for KLF

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Introduction

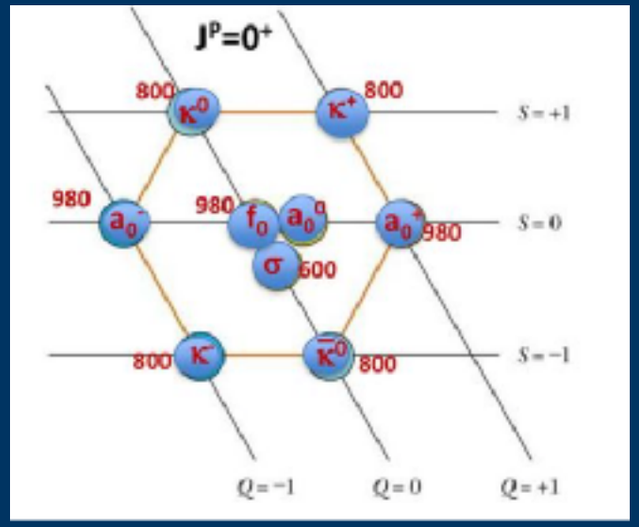
K-long facility provides opportunity to study kaon-pion interaction using neutral kaon beam scattered with nucleon and producing $K\pi$ with $\mathbf{K_L N \rightarrow \{K\pi\}X,\ X = N, \Delta}$

Study of Kaon-pion interaction has multiple implication including Strange meson spectroscopy, in the test of chiral perturbation theory, and physics beyond SM model.

1. Strange meson spectroscopy:

K_0^* (800), K_0^* (1430), K_1^* (892), K_1^* (1410), K_2^* (1430), K_3^* (1780) .... : enable direct investigation of scalar and vector meson

κ/ K_0^* (800) light scalar meson. "needs confirmation" @PDG (since 2018).



Light scalar meson nonets

2. Test of ChPT:

Technique to study QCD in the non-perturbative regime;
-> Using effective lagrangian where Goldstone bosons, π, η, K are the fundamental degrees of freedom.

Lack of sufficient data at low energy, $K\pi$ scattering is not quite succesful compare to $\pi\pi$ scattering.

3. Standard Model Test and Physics beyond SM: V_{us} element of CKM directly depends on strangeness changing form factors. These form factors at low energy can be obtained from the study of $K\pi$ scattering using dispersion relation.

Previous Measurement (SLAC)

LASS spectrometer with Charged Kaon beam at 13 GeV

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

$K\pi$ partial wave analysis shows evidence of s, p and d-wave at M(Kpi) = 0.896, 1.434, 1.78

$$L_0 = \frac{\sqrt{-t}}{m_\pi^2 - t} G^L_{K\pi^+}(m_{K\pi}, t),$$

$$L_1^- = \sqrt{\frac{L(L+1)}{2}} G^L_{K\pi^+}(m_{K\pi}, t)\gamma_c(m_{k\pi})\exp(b_c(m_{k\pi})(t - m_\pi^2)),$$

$$L_1^+ = \sqrt{\frac{L(L+1)}{2}} G^L_{K\pi^+}(m_{K\pi}, t)[\gamma_c(m_{k\pi})\exp(b_c(m_{k\pi})(t - m_\pi^2)) - 2i\gamma_a(m_{k\pi})ex$$

$$L_\lambda^\pm = 0, \lambda \geq 2.$$

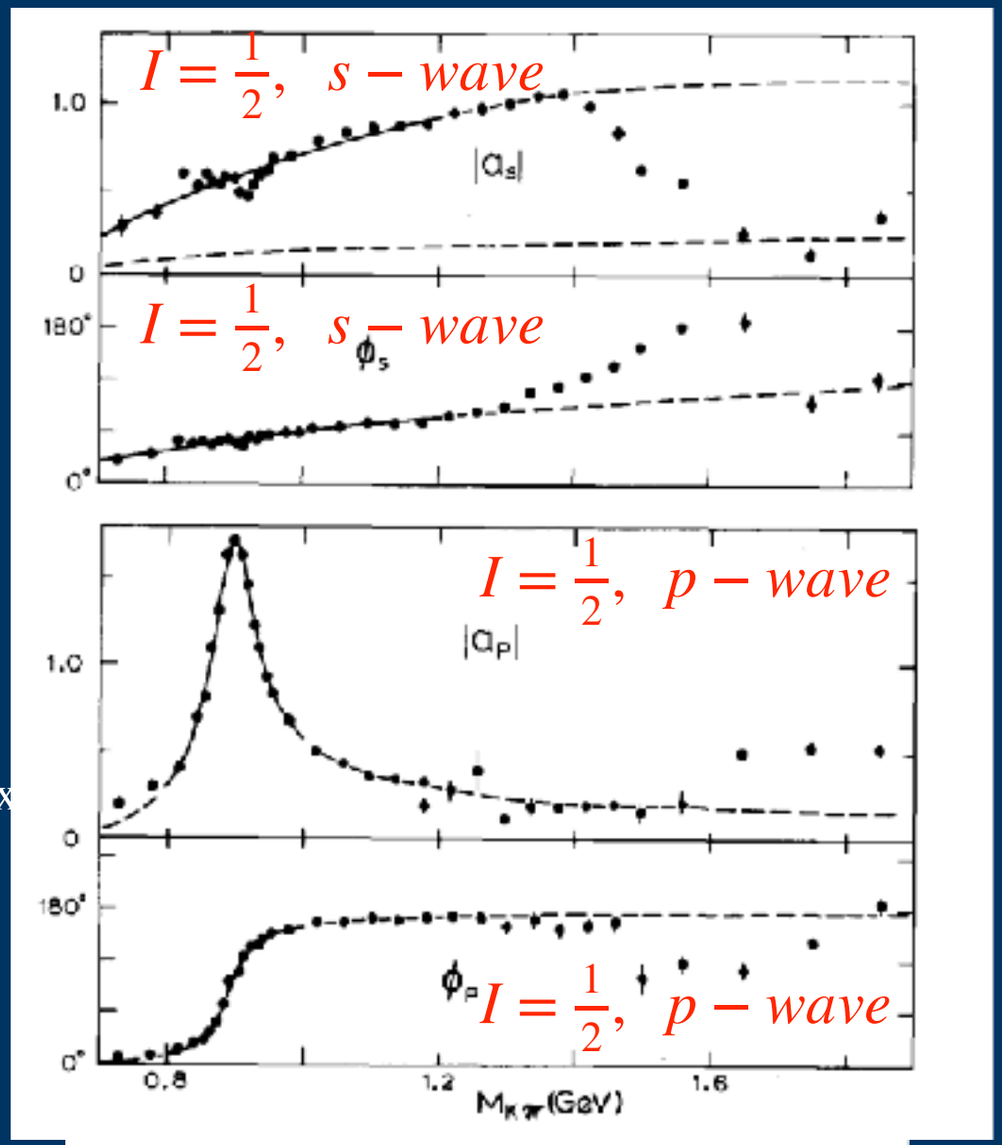
$$G^L_{K\pi^+}(m_{K\pi}, t) = N\frac{m_{K\pi}}{\sqrt{q}} a_L(m_{K\pi})\exp(b_L(m_{k\pi})(t - m_\pi^2))$$

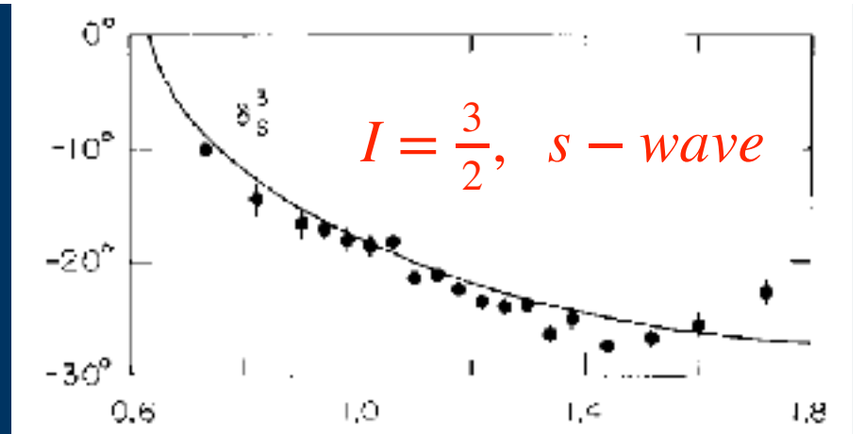
$a_L^I = a_L^{I=1/2} + \frac{1}{2}a_L^{I=3/2}$ Elastic region s-wave 3/2 ($M(K\pi) < 1.3$)

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

- Isospin separated phases and amplitude are used to calculate mass and width of Kappa.
- Need more data.

Phase of s=3/2, s=1/2, and p=1/2 wave





Possible Reactions with K-long beam

$KL\pi+ \to KL\pi+: \frac{a^2}{3} + \frac{2b^2}{3}$

$KL\pi+ \to KS\pi+: \frac{a^2}{3} - \frac{b^2}{3}$

$KL\pi+ \to K+\pi0: -\frac{a^2}{3} + \frac{b^2}{3}$

$KL\pi0 \to KL\pi0: \frac{a^2}{3} + \frac{2b^2}{3}$

$KL\pi0 \to K+\pi-: -\frac{a^2}{3} + \frac{b^2}{3}$

$KL\pi0 \to K-\pi+: -\frac{a^2}{3} + \frac{b^2}{3}$

$KL\pi- \to KL\pi-: \frac{a^2}{3} + \frac{2b^2}{3}$

$KL\pi- \to KS\pi-: -\frac{a^2}{3} + \frac{b^2}{3}$

$KL\pi- \to K-\pi0: -\frac{a^2}{3} + \frac{b^2}{3}$

Provided by A. Rhodas

-> These amplitude has both charge and neutral pion exchange.

-> Amplitudes are isospin combination of I=1/2 and I=3/2, a and b.

-> Isospin separation require analysis of at least two reactions with different polarity.

Two reactions are selected with charge pion exchange

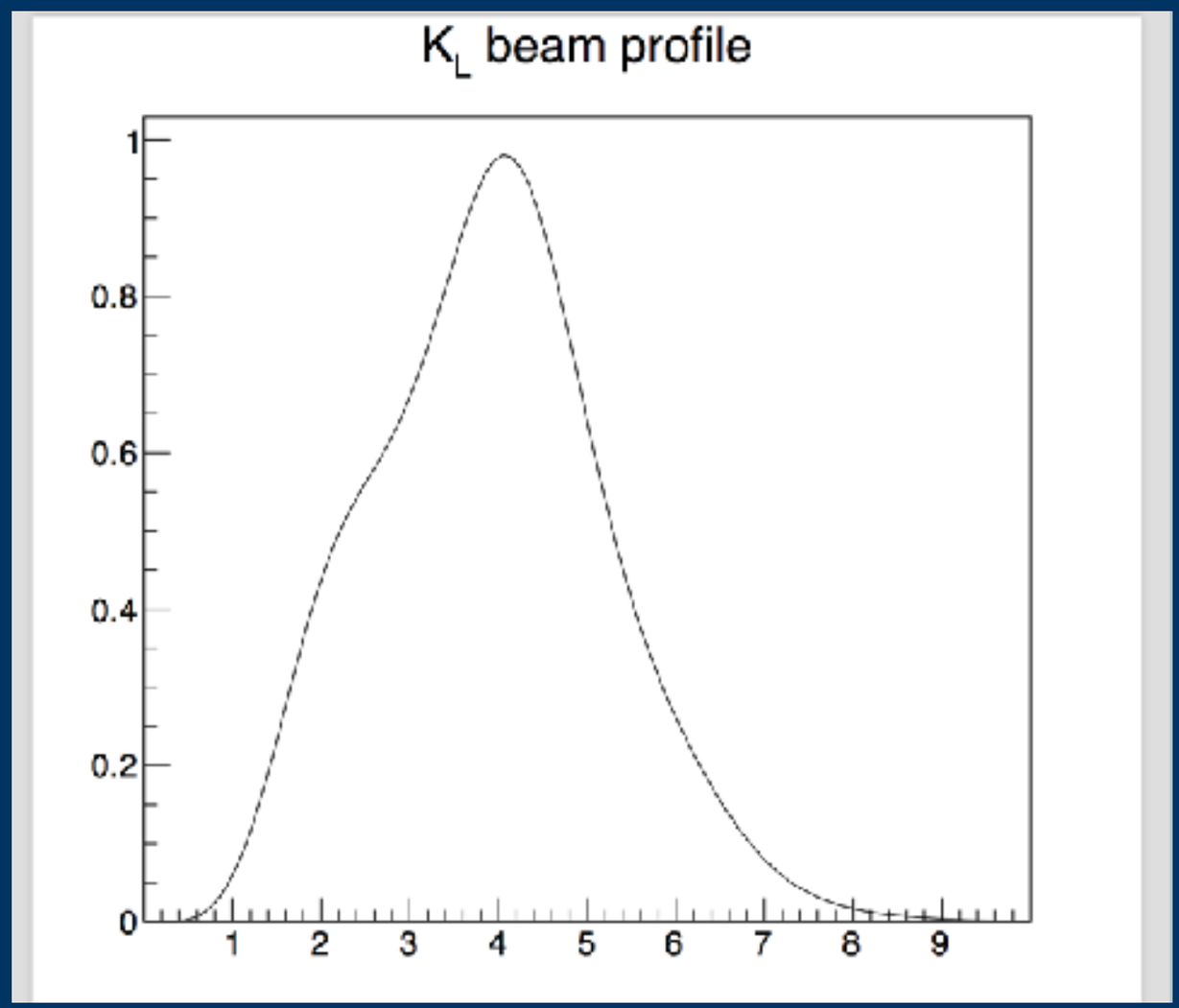
$$K_L p \to K_L \pi^- \Delta^{++}(p\pi^+)$$

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

Event Generation

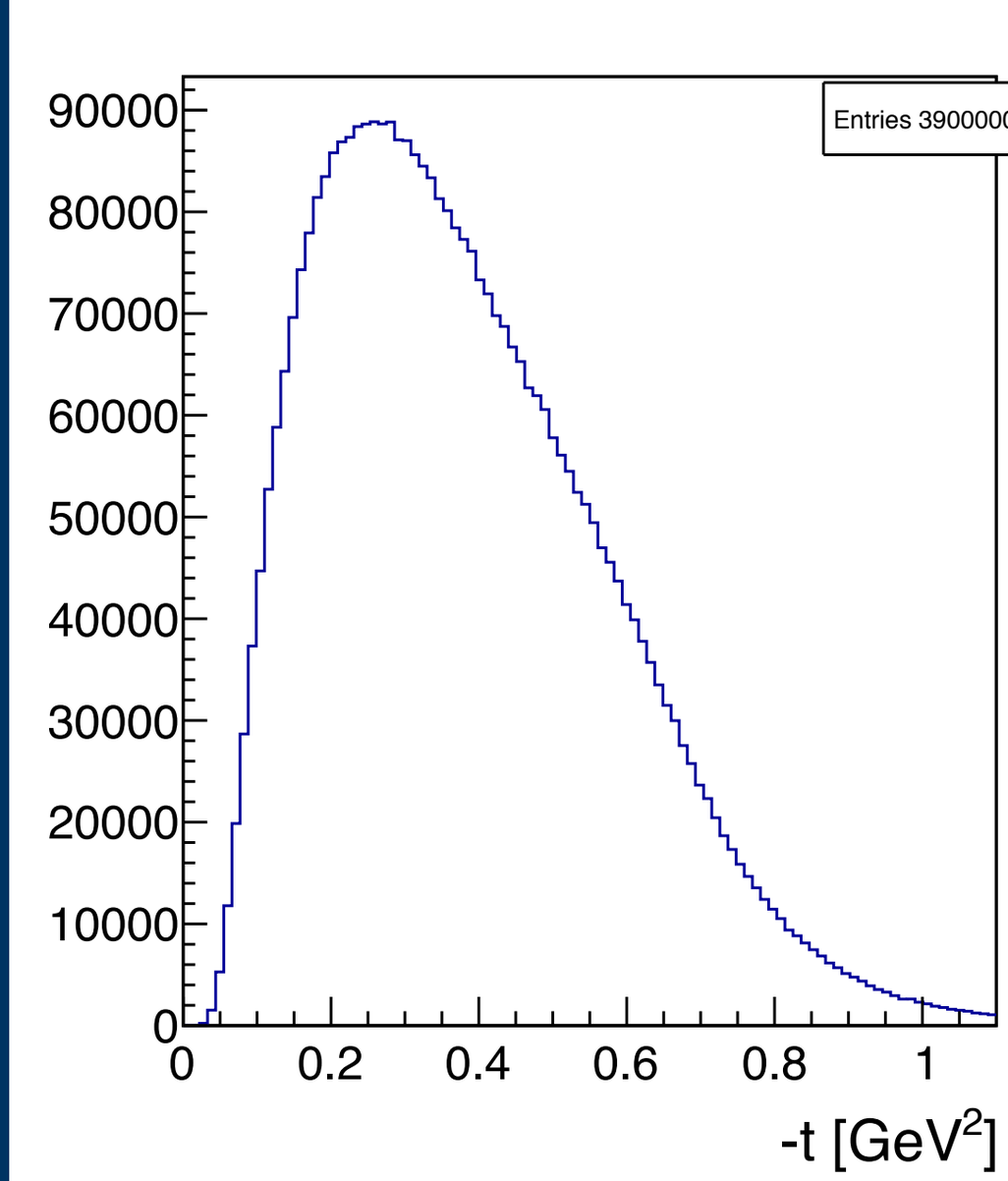
K_L beam generated

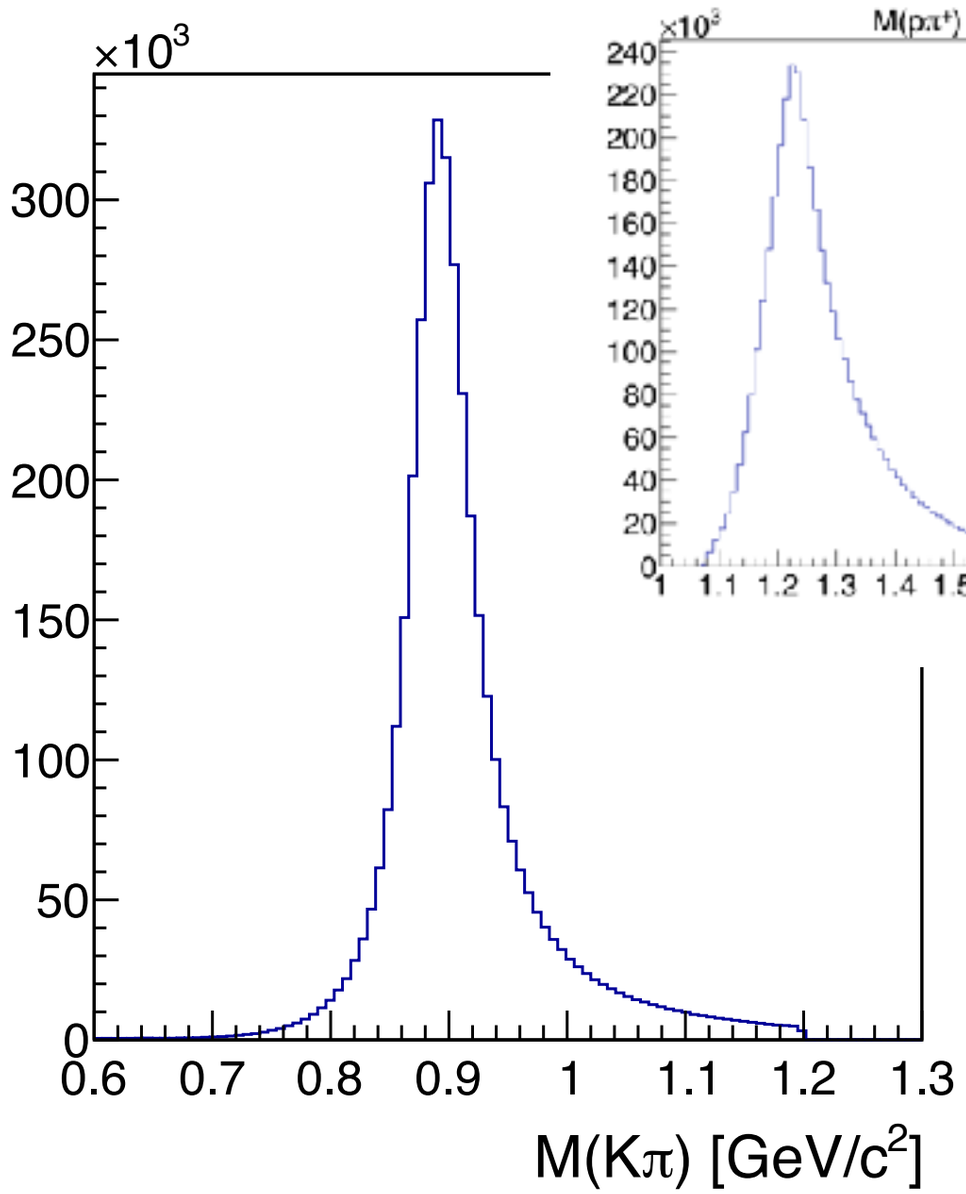
- assuming the K_L beam originates from Be target at 24 m upstream of glueX target.
- using momentum distribution provided by I. Larin.



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

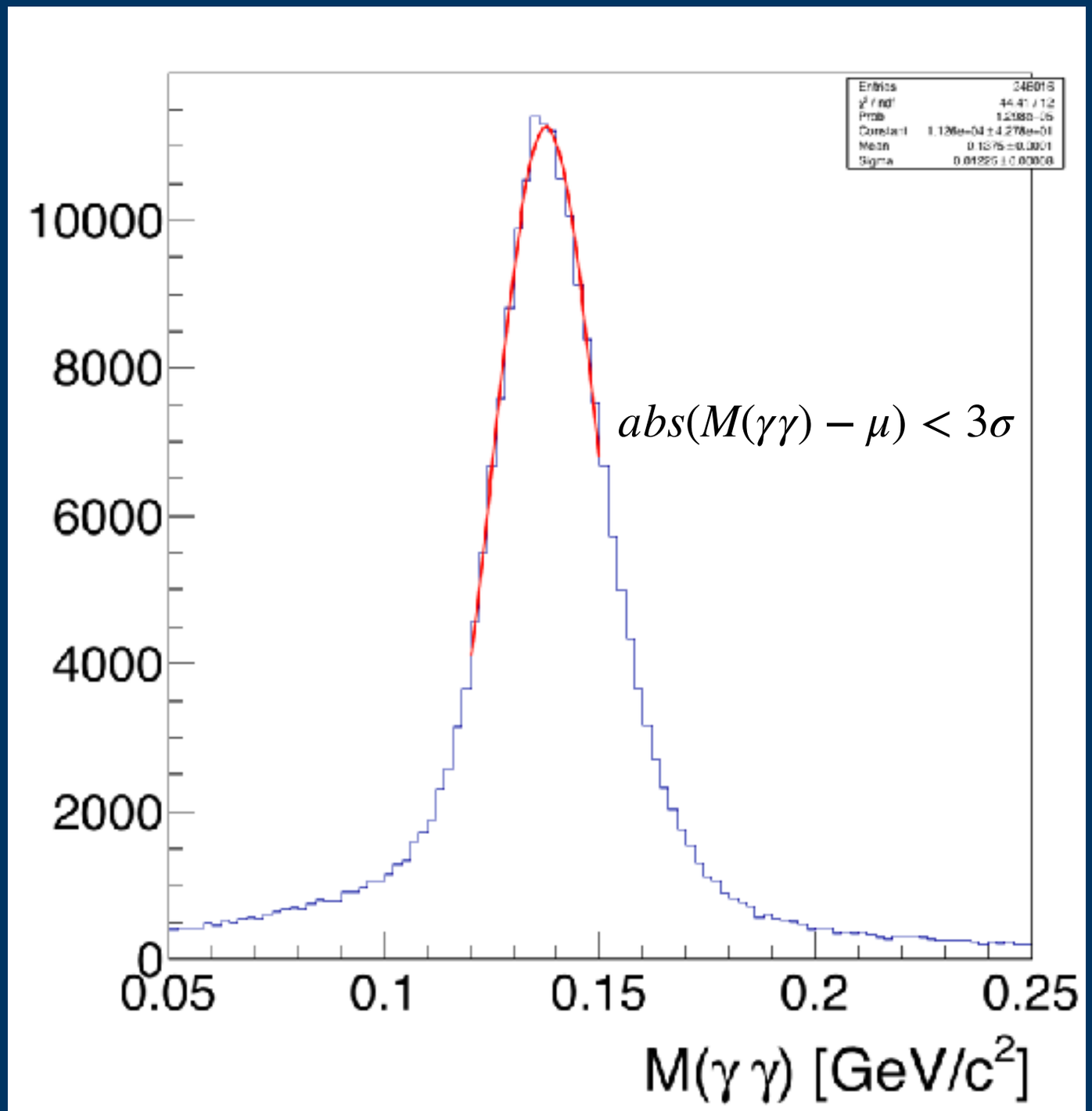
Generate K^{*-} decay to $K^-\pi^0$ with recoil Δ^{++}





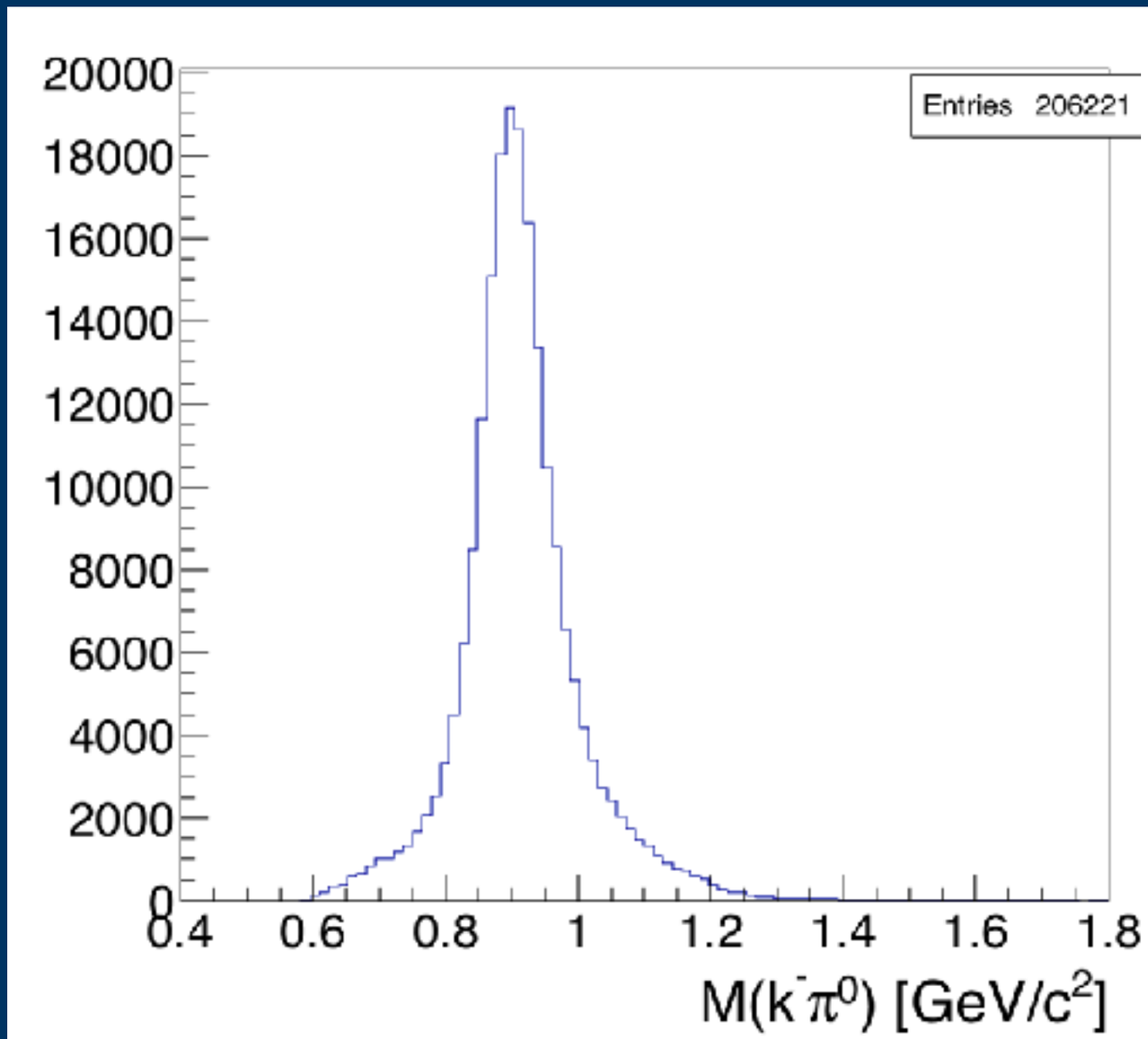
Reconstruction $\mathbf{K_L p \to K^- \pi^0 \Delta^{++}(p\pi^+)}$

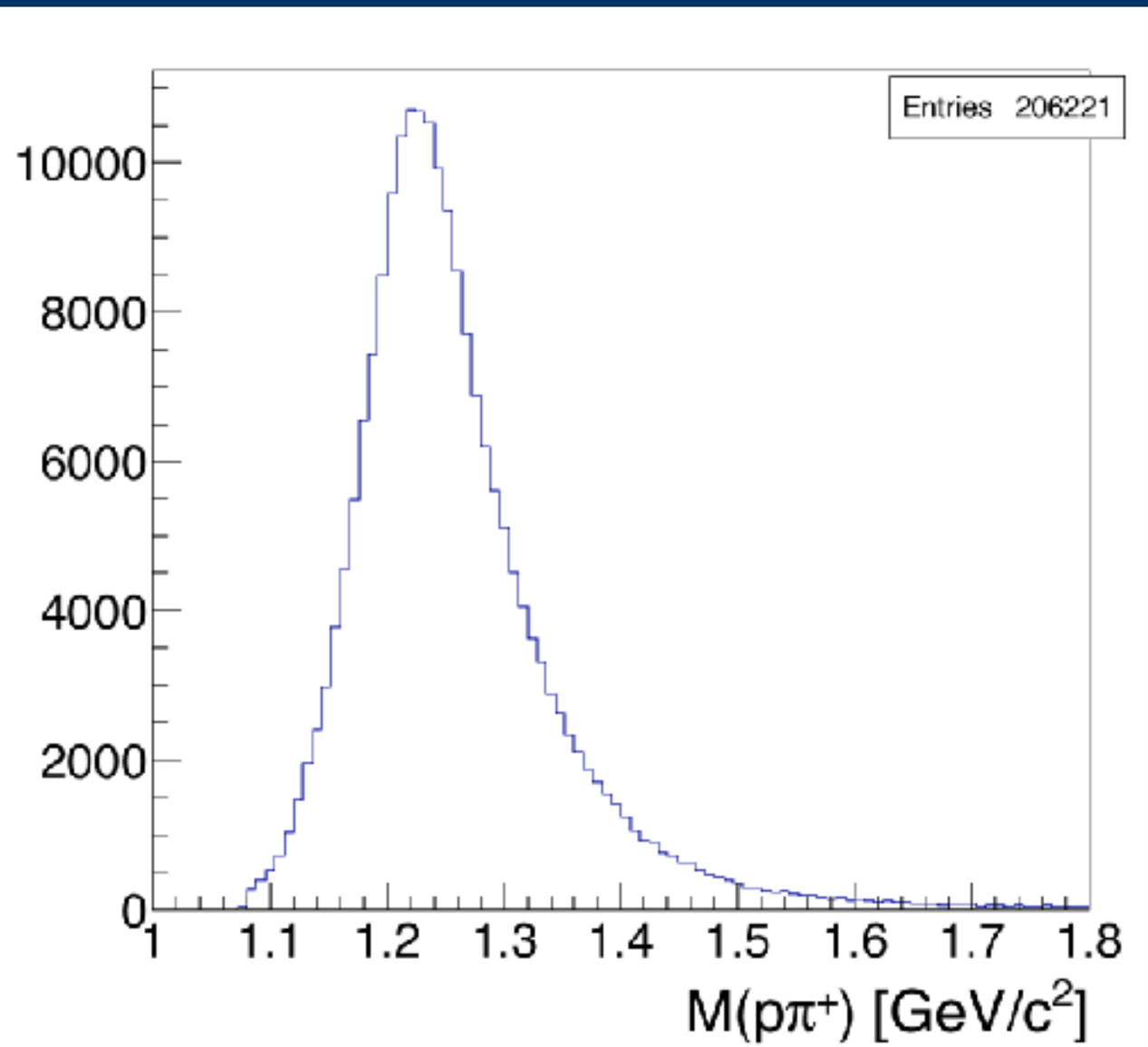
Invariant mass of reconstructed π^0



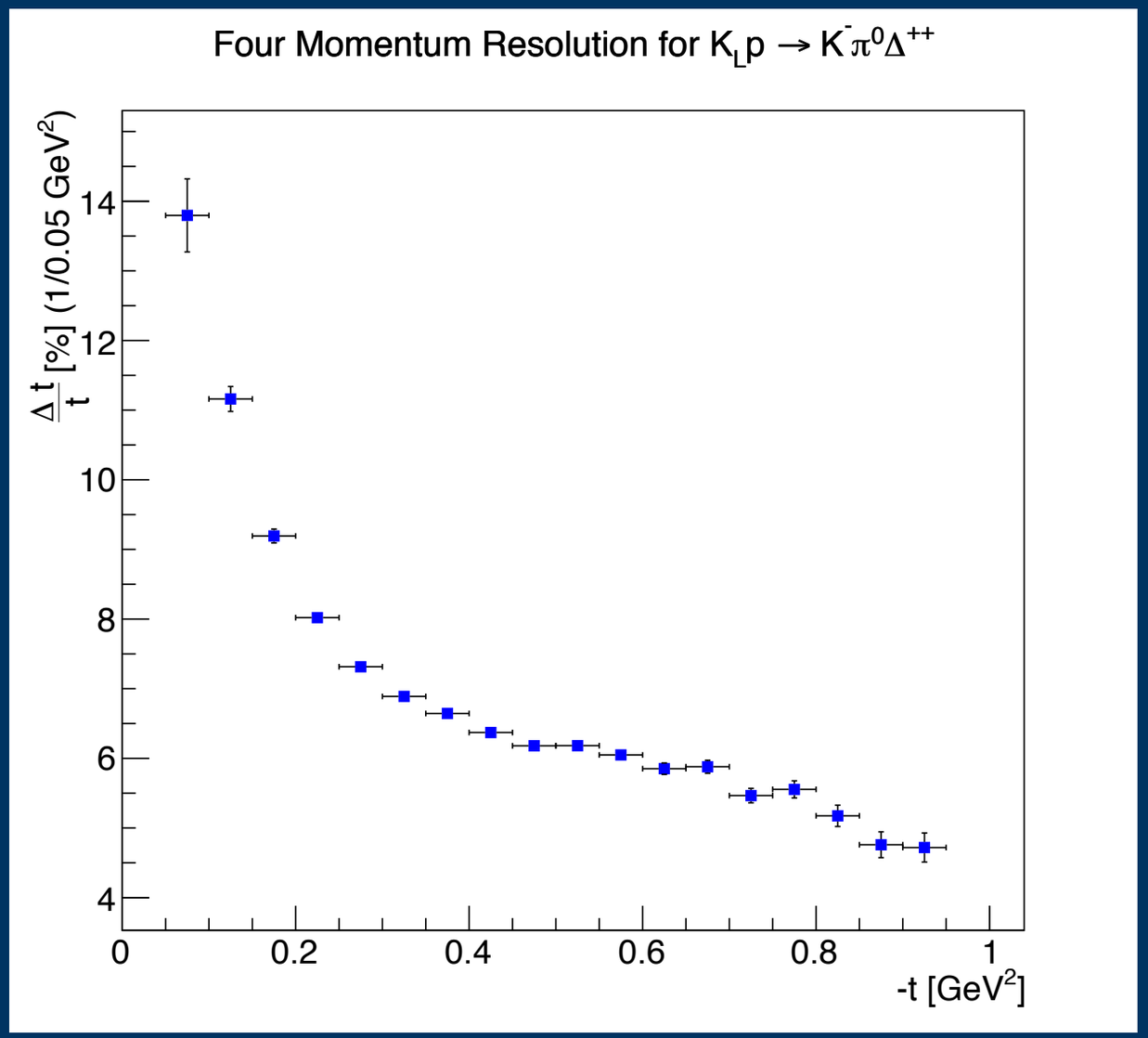
Reconstruction $K_L p \to K^- \pi^0 \Delta^{++}(p\pi^+)$

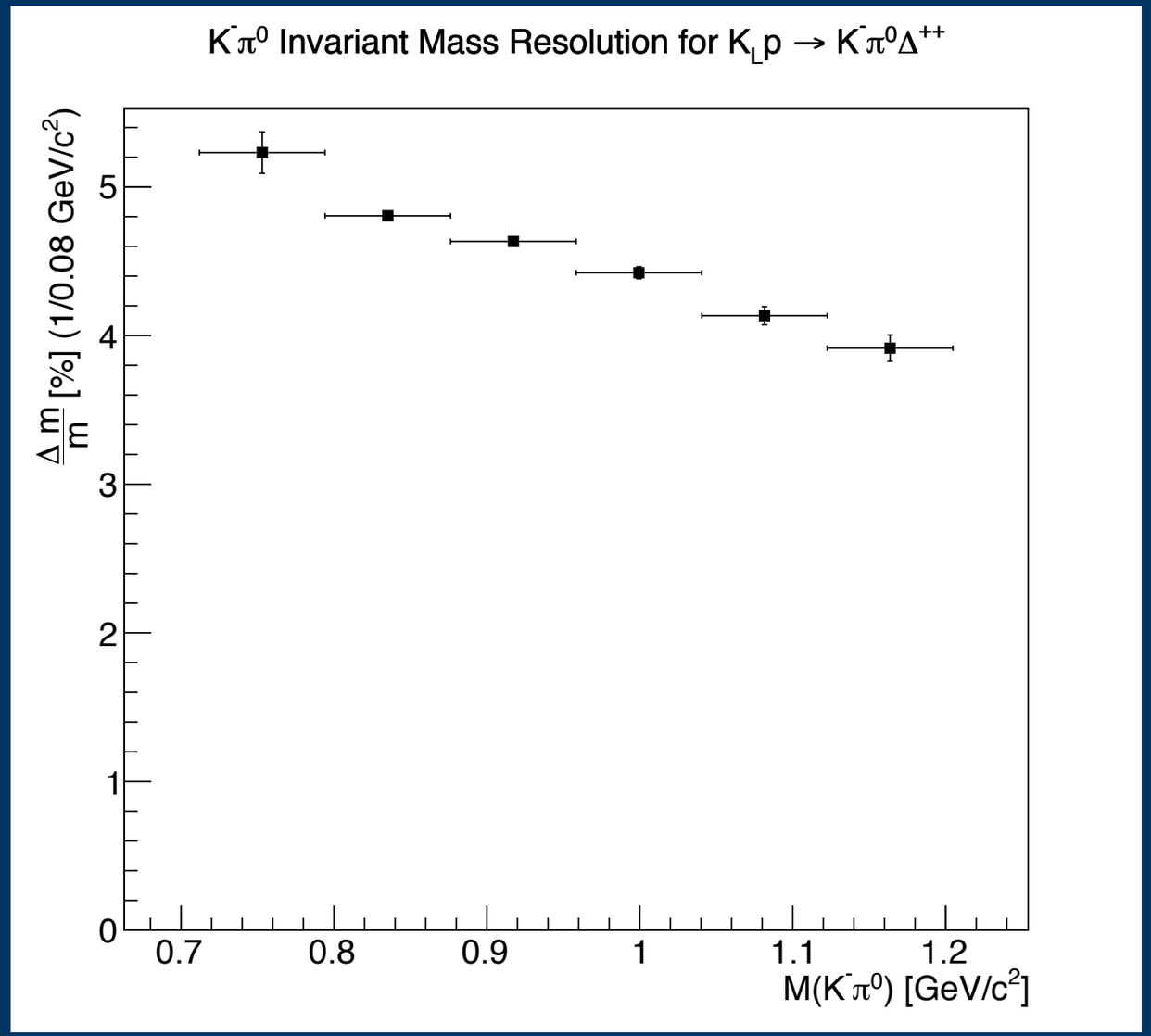
Left: Invariant mass of Kpi. Right: Invariant mass of proton, pi+ after 3 sigma cut on pi0 peak



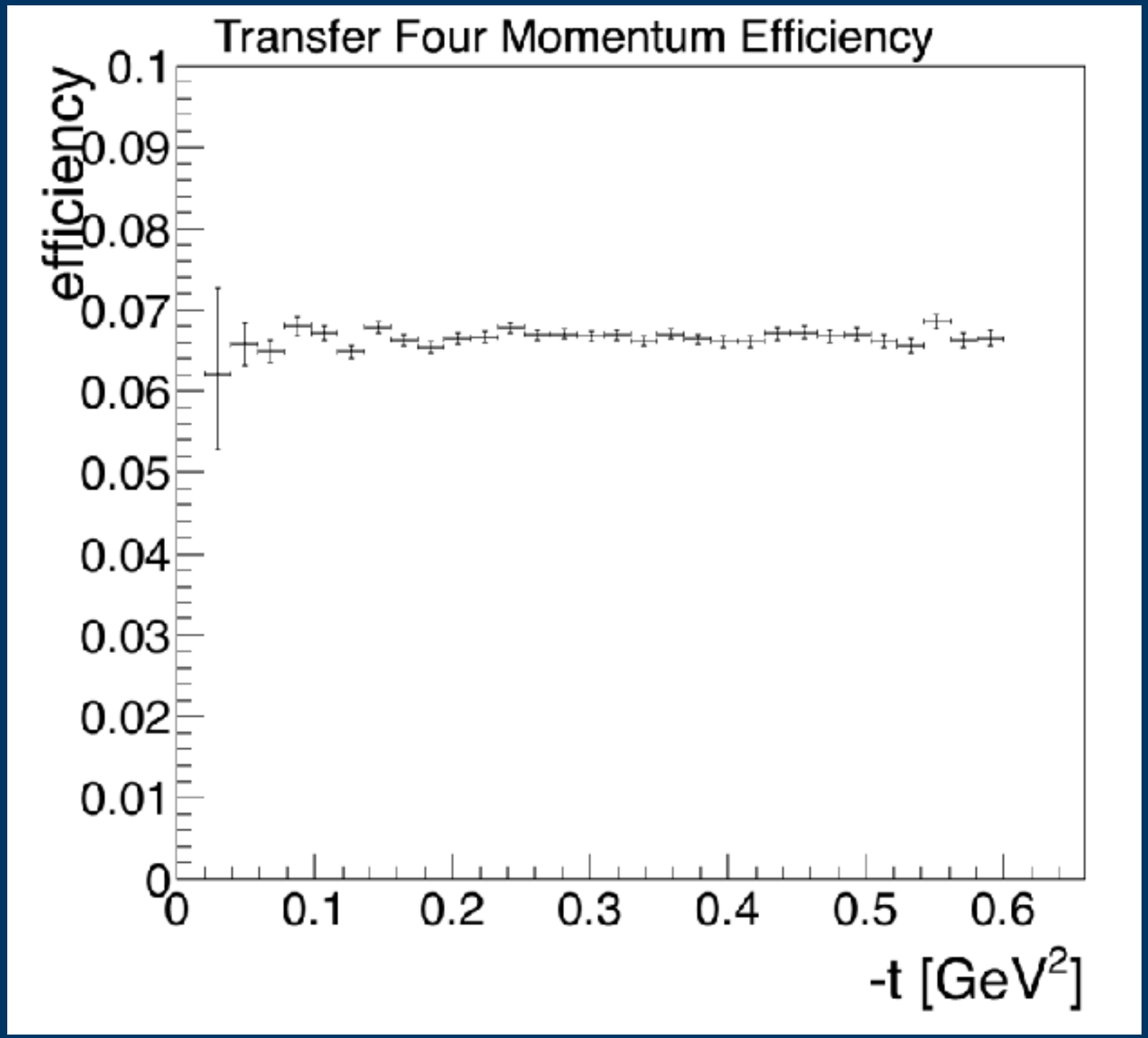


Resolution on -t and K^{*-} mass

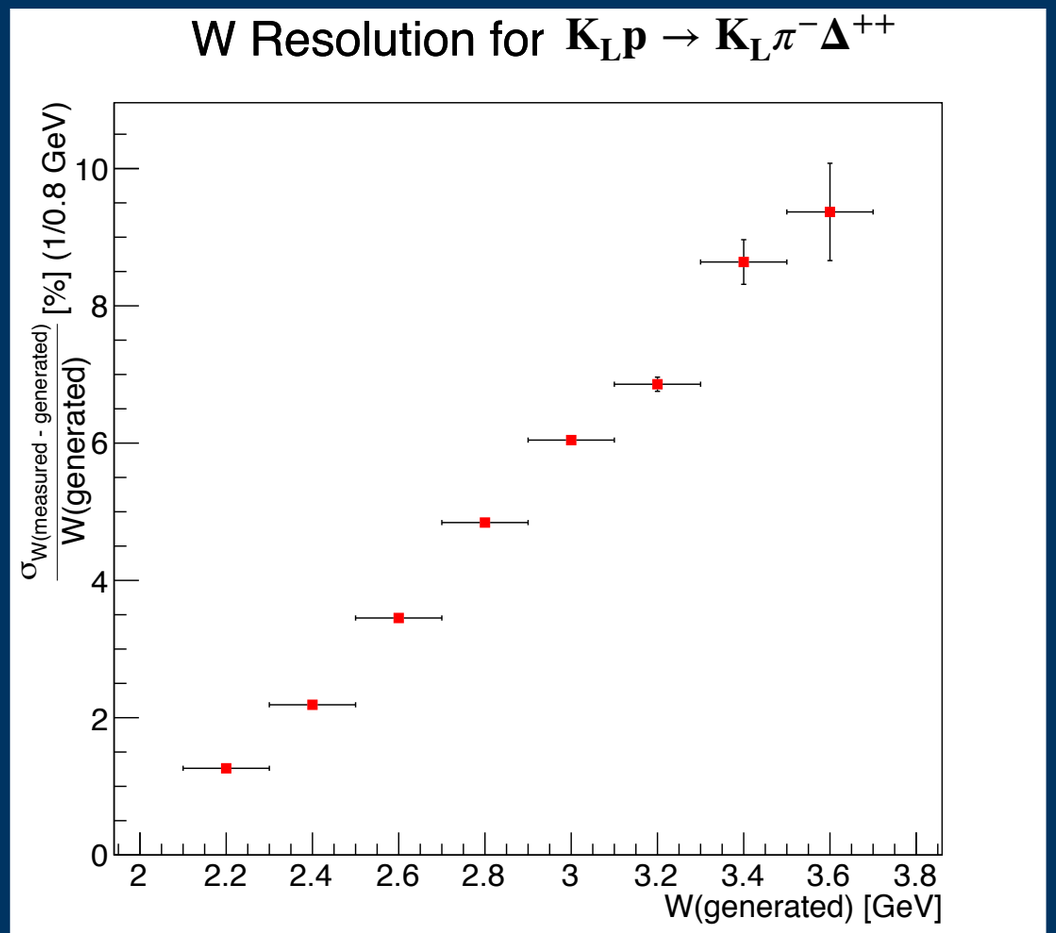


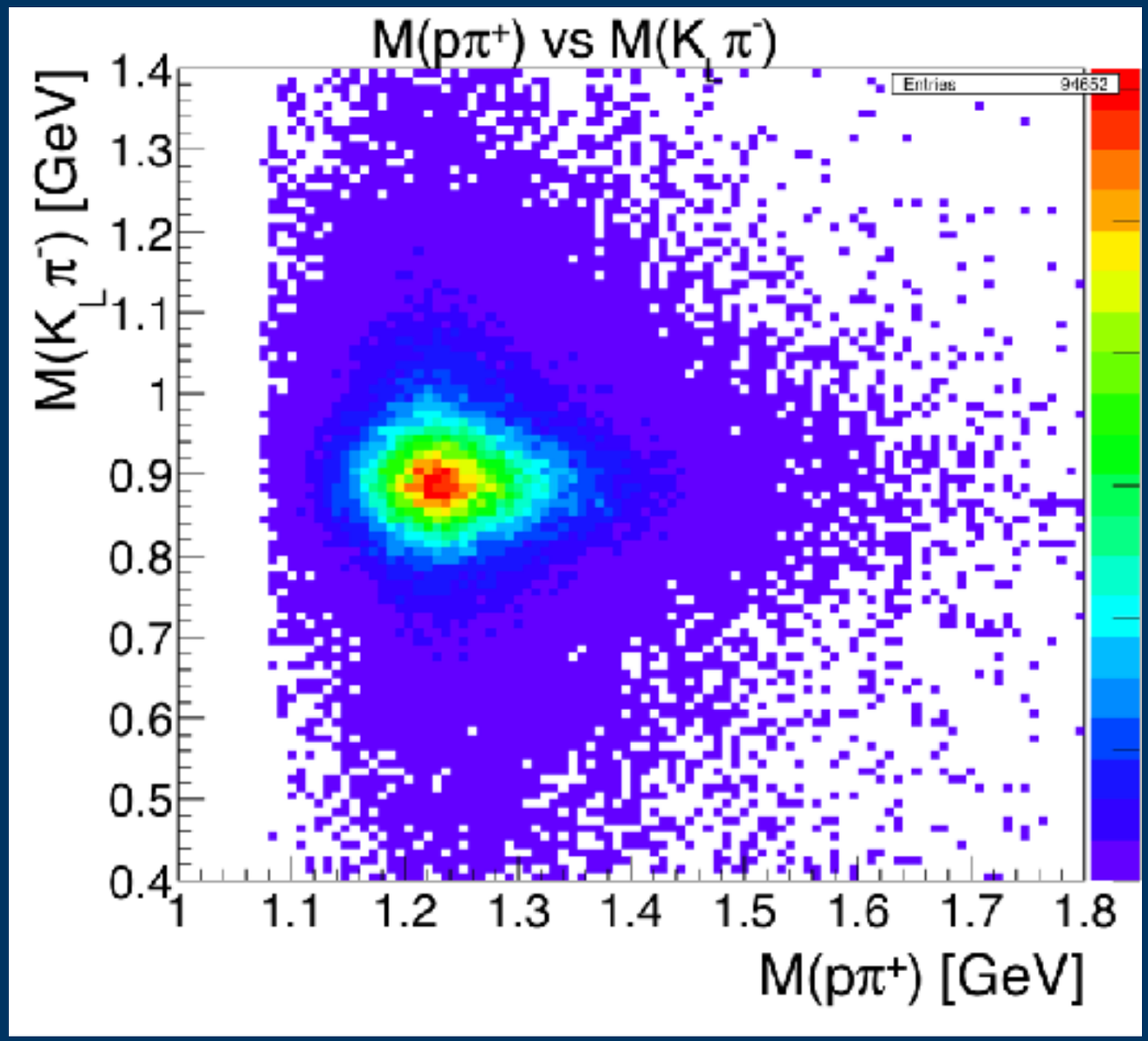


Reconstruction efficiency



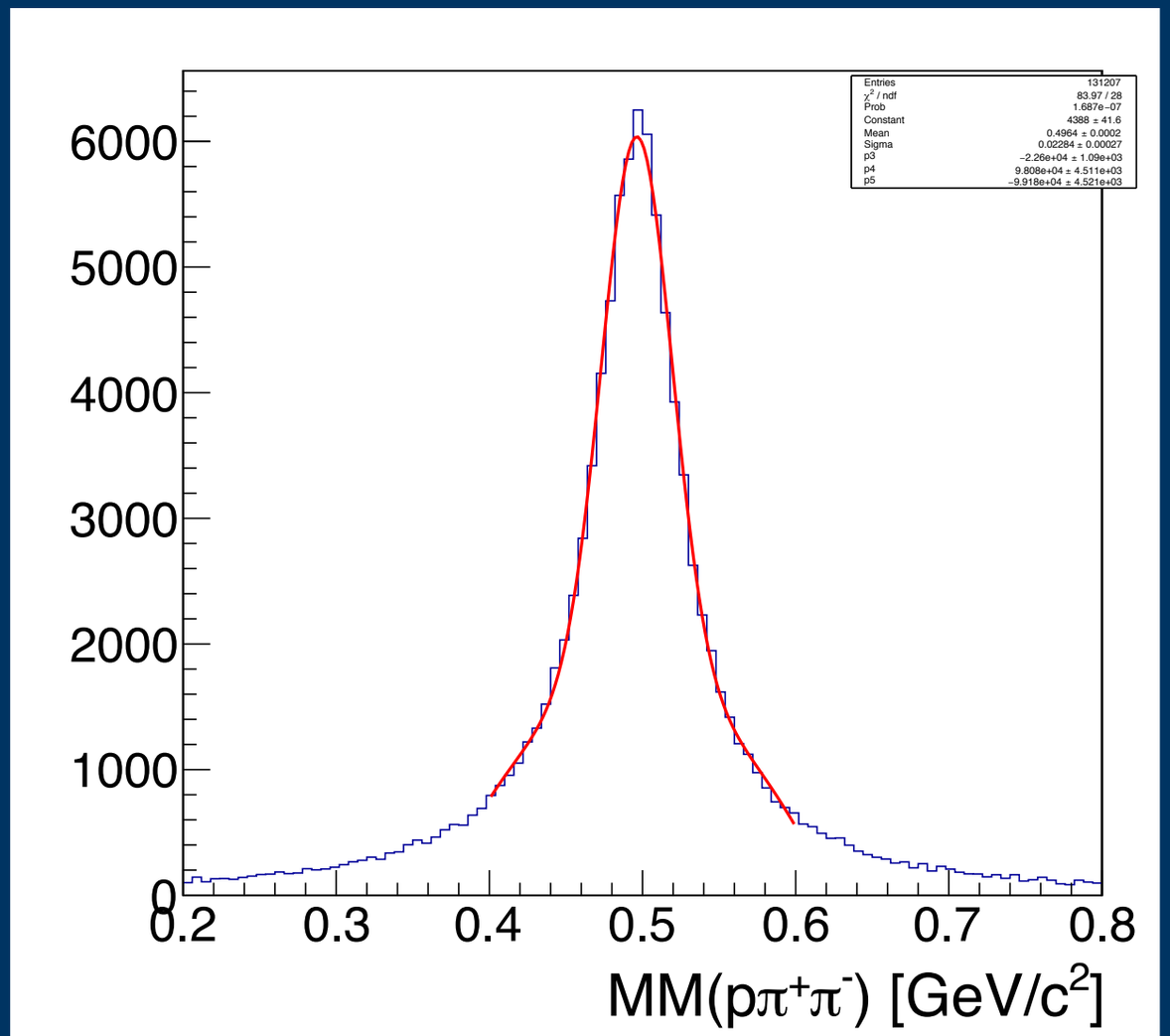
Analysis of $\mathbf{K_L p \rightarrow K_L \pi^- \Delta^{++}(p\pi^+)}$

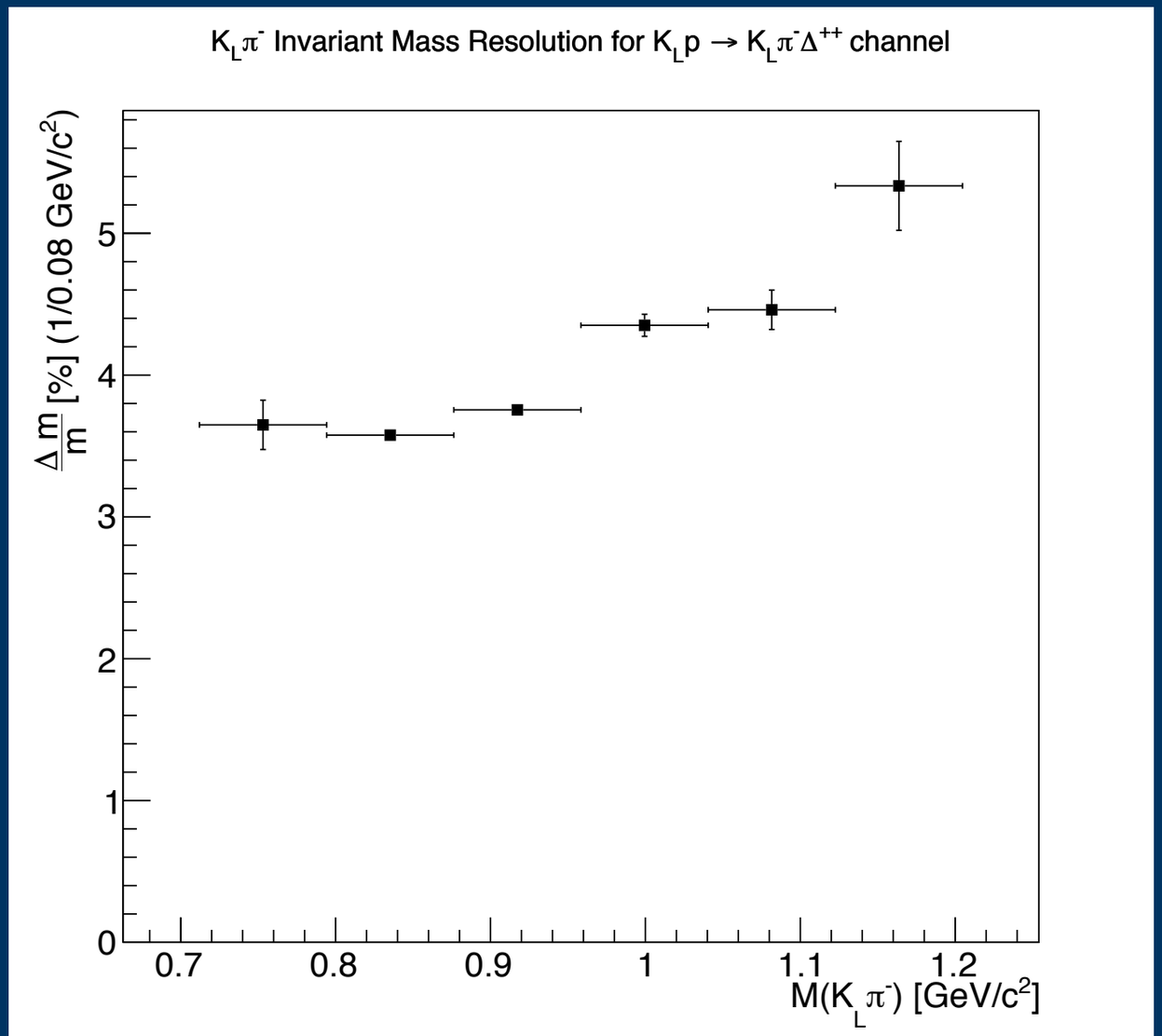




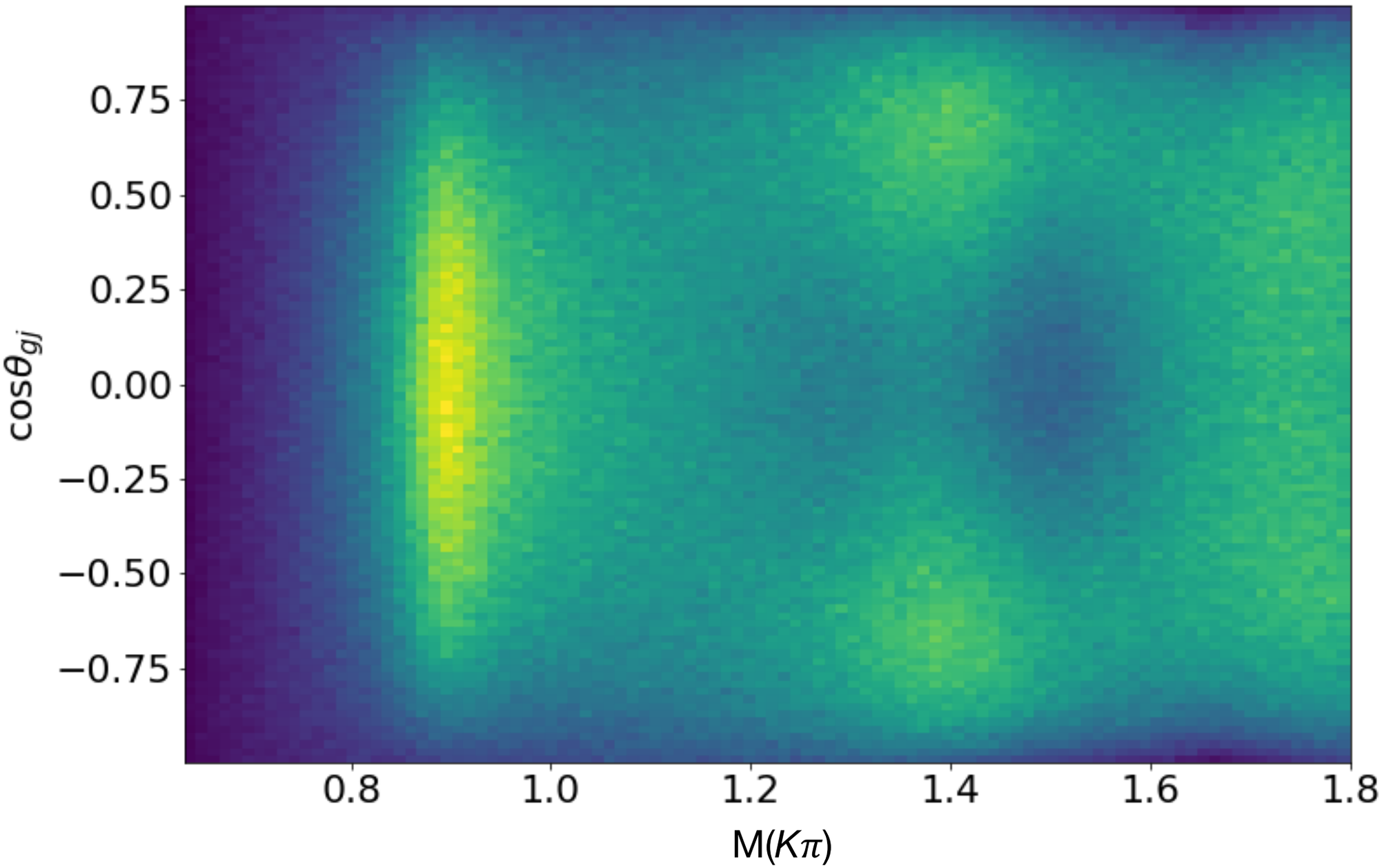
W resolution; K-long reconstructed using time-of-flight

Analysis of $K_L p \to K_L \pi^- \Delta^{++}(p\pi^+)$

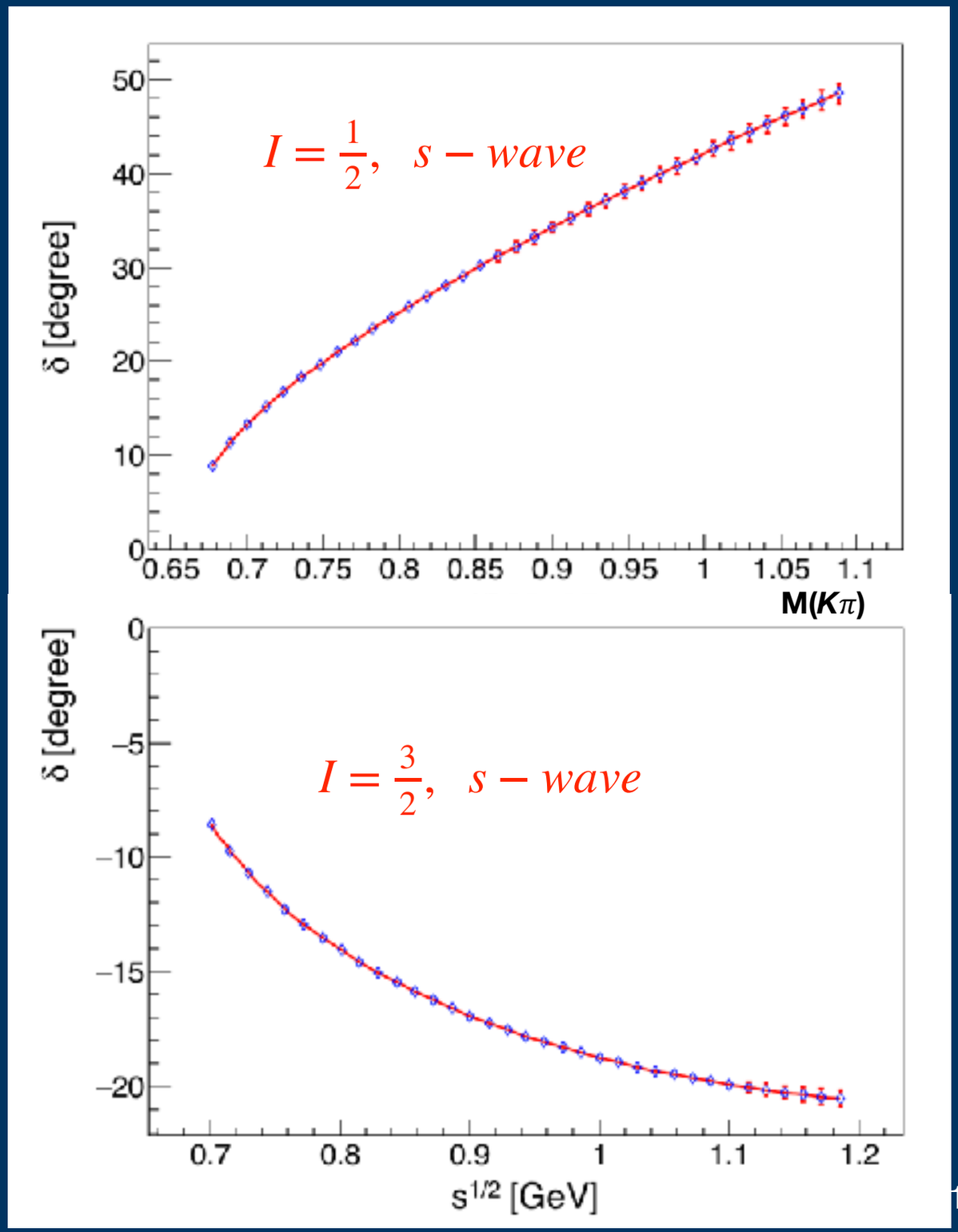


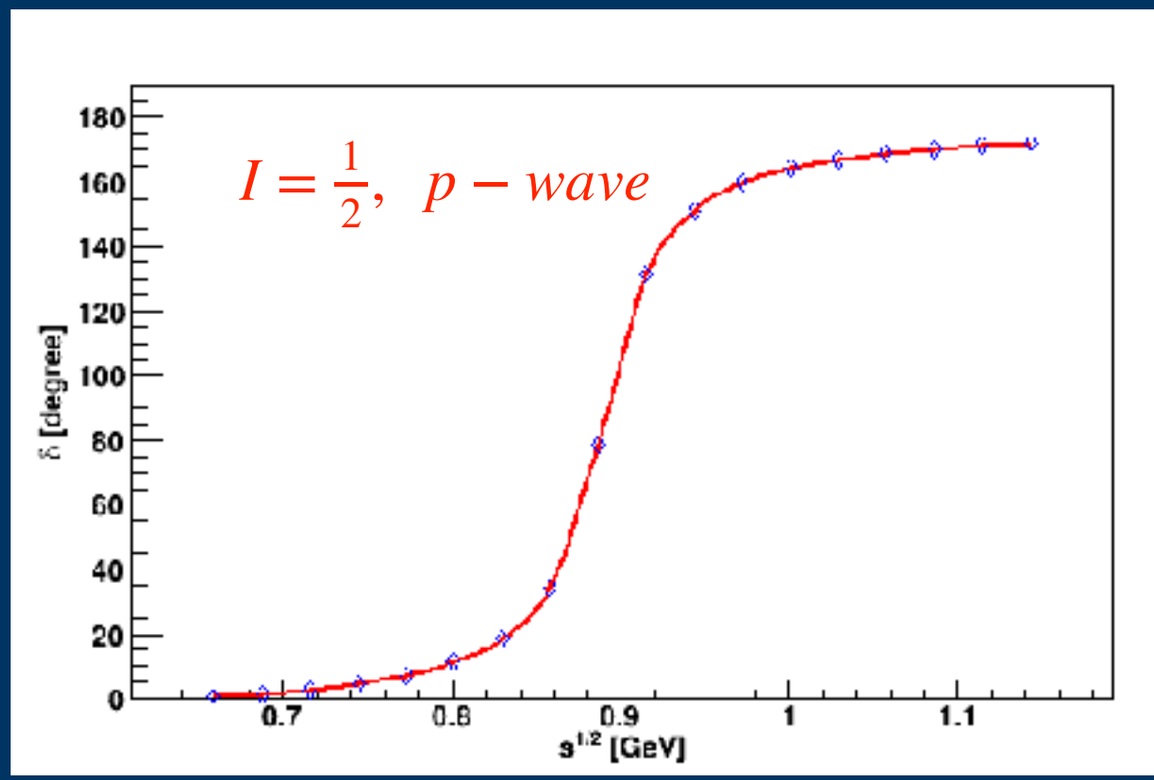


Partial Wave Analysis



Phases for s and p wave

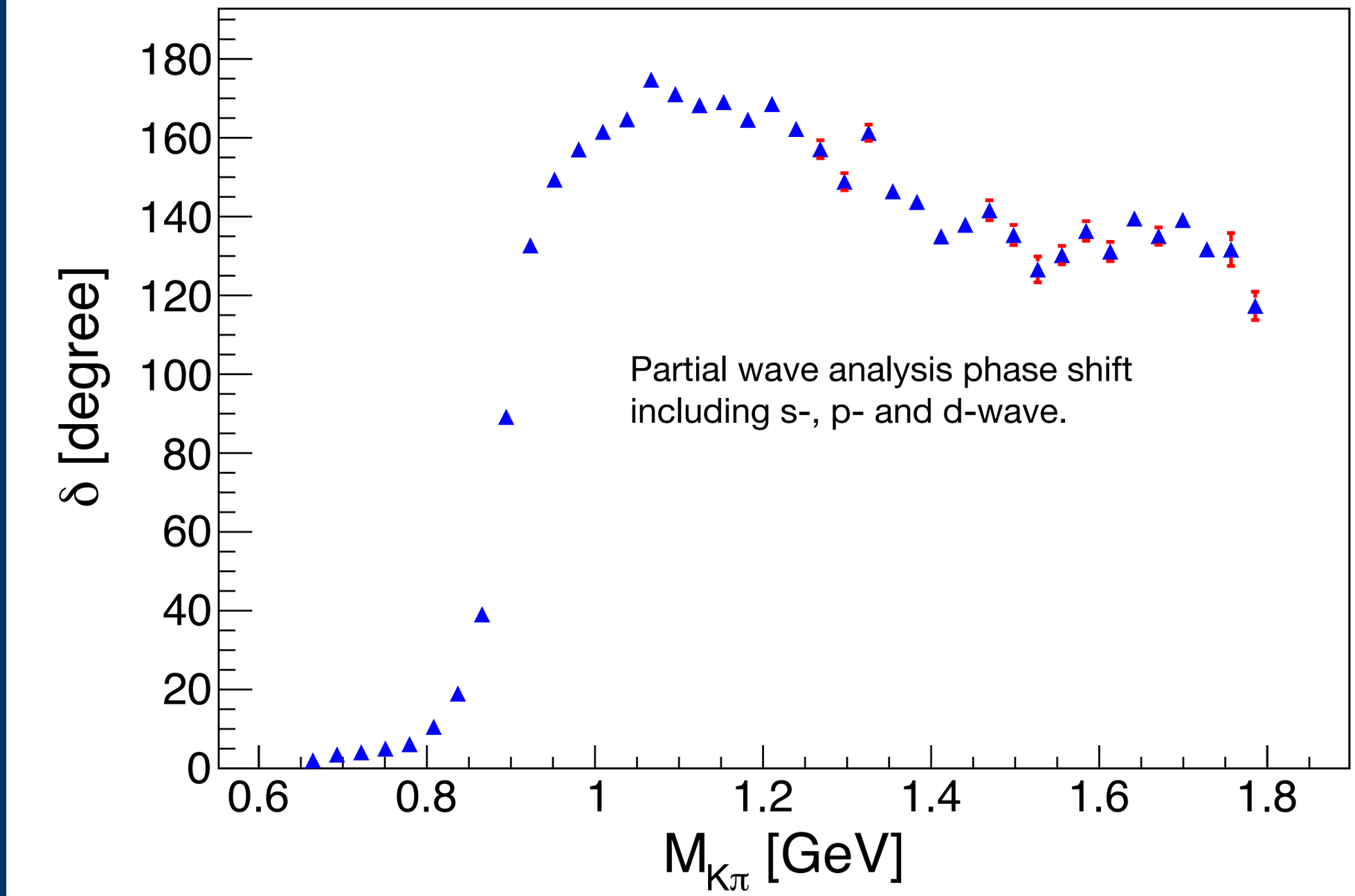




-> Phase vs center of mass for Kpi system.

-> 100 days of KLF running

PhaseShift


δ [degree]
180
160
140
120
100
80
60
40
20
0
0.6
0.8
1
1.2
1.4
1.6
1.8
$M_{K\pi}$ [GeV]
Partial wave analysis phase shift
including s-, p- and d-wave.

Conclusion

$K\pi$ simulation was performed using charged pion exchange channels

- $\mathbf{K_L p \rightarrow K^- \pi^0 \Delta^{++}(p\pi^+)}$ **and** $\mathbf{K_L p \rightarrow K_L \pi^- \Delta^{++}(p\pi^+)}$
- Isospin seperation is duable by the analysis of two different reactions.
- S and P wave phases were calculated.

Possible sources of systematic (discussion welcome)

- background under Delta peak.
- Single wave phase extraction is not completely background free of other waves.
- Complete estimation of systematic is very tricky, SLAC reported 12.5% with their some percentage of conservative estimation.

Thank you

Theoretical Amplitudes