



$K\pi$ Scattering study for KLF

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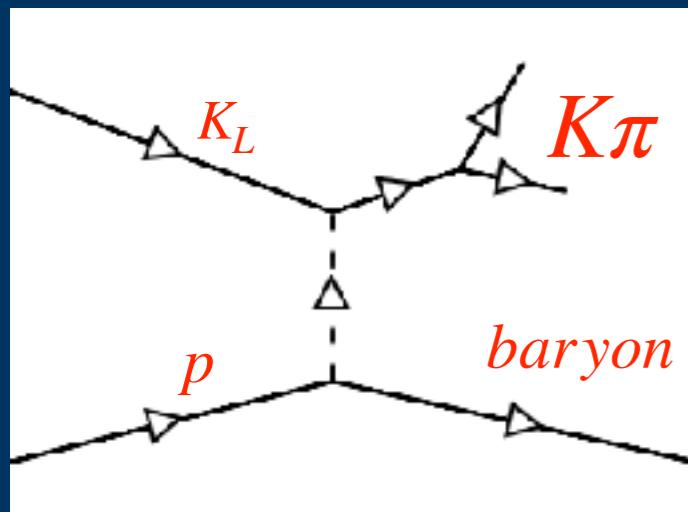
Introduction

Study of $K\pi$ scattering enables direct investigations of scalar and vector K^* states.

$K_0^*(800)$, $K_0^*(1430)$, $K_1^*(892)$, $K_1^*(1410)$, $K_2^*(1430)$, $K_3^*(1780)$...

$\kappa/ K_0^*(800)$ light scalar meson. “needs confirmation” @PDG (since 2018).

Amplitude analysis of $K\pi$ system reveals the status...



S- wave: $K^*(800)/\kappa, K_0^*(1430), \dots$

P- wave: $K^*(892), K^*(1680), \dots$

D- wave: $K_2^*(1430), \dots$

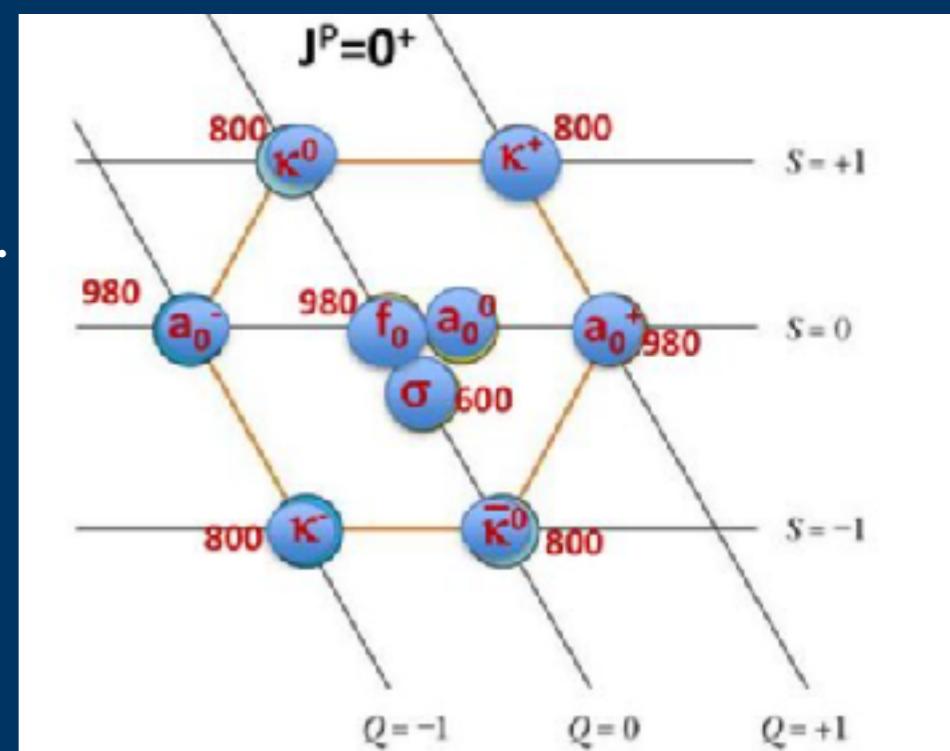
– Unlike vector and tensor, identification of scalar mesons are difficult to disentangle due to larger width.

... $K_0^*(800)$ should be studied at low momentum transfer region (close pion pole).

K-long Facility

- Study of $K\pi$ scattering at KLF will support the existence of $\kappa(800)$ and significantly improve on the uncertainties of determination of its mass and width

Light scalar meson nonets



Scalar meson nonets;
all four kappa states possible at KLF.

Previous Calculation M_k/Γ_k

PDG 2018

	$M_k(\text{MeV})$	$\Gamma_k(\text{MeV})$	
S. Descotes-Genon and B. Moussallam	658 ± 13	557 ± 24	Roy-Steiner dispersive method
Zhou, Zheng	694 ± 53	606 ± 89	"
Jamin et al.	708	610	
Aitala et al.	$721 \pm 19 \pm 43$	$584 \pm 43 \pm 87$	$D \rightarrow K\pi\pi$ study
Pelaez	750 ± 18	452 ± 22	
Bugg	760	684 ± 120	$D \rightarrow K\pi\pi$ and $J/\psi \rightarrow K^*(890)K\pi$
Ablikim et al.	841 ± 23	618 ± 52	
Ishida et al.	877	668^{+235}_{-110}	

$K^*(800)/\text{Kappa}$ mass and width from recent calculation

- Most of these results are calculated using experimental data of $K\pi$ scattering from SLAC.
- Approach such as Roy-Steiner dispersive, it requires partial waves of possible cross channel along with phase-shift.
- No data around threshold; it were compensated by imposing the unitarity constraints.

SLAC Experiment and Amp. Analysis

LASS spectrometer with Charged Kaon beam at 13 GeV

$$K^\pm p \rightarrow K^\pm \pi^+ n, \quad I = 1/2 \text{ and } I=3/2$$

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

$$I_{prod}(m_{k\pi}, t', \Omega) = \frac{1}{\sqrt{4\pi}} \sum_{L,M \geq 0} t_L^M(m_{k\pi}, t') (2 - \delta_{M_0}) Re[Y_{LM}(\Omega)]$$

Developed model for PWA to extract $K\pi$ elastic scattering amplitude (a_L) related to $-t$; which is independent to the particle recoiling against $K\pi$ system.

$$L_0 = \frac{\sqrt{-t}}{m_\pi^2 - t} G_{K\pi^+}^L(m_{K\pi}, t), \quad \text{The production amplitude is then parametrized as,}$$

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

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

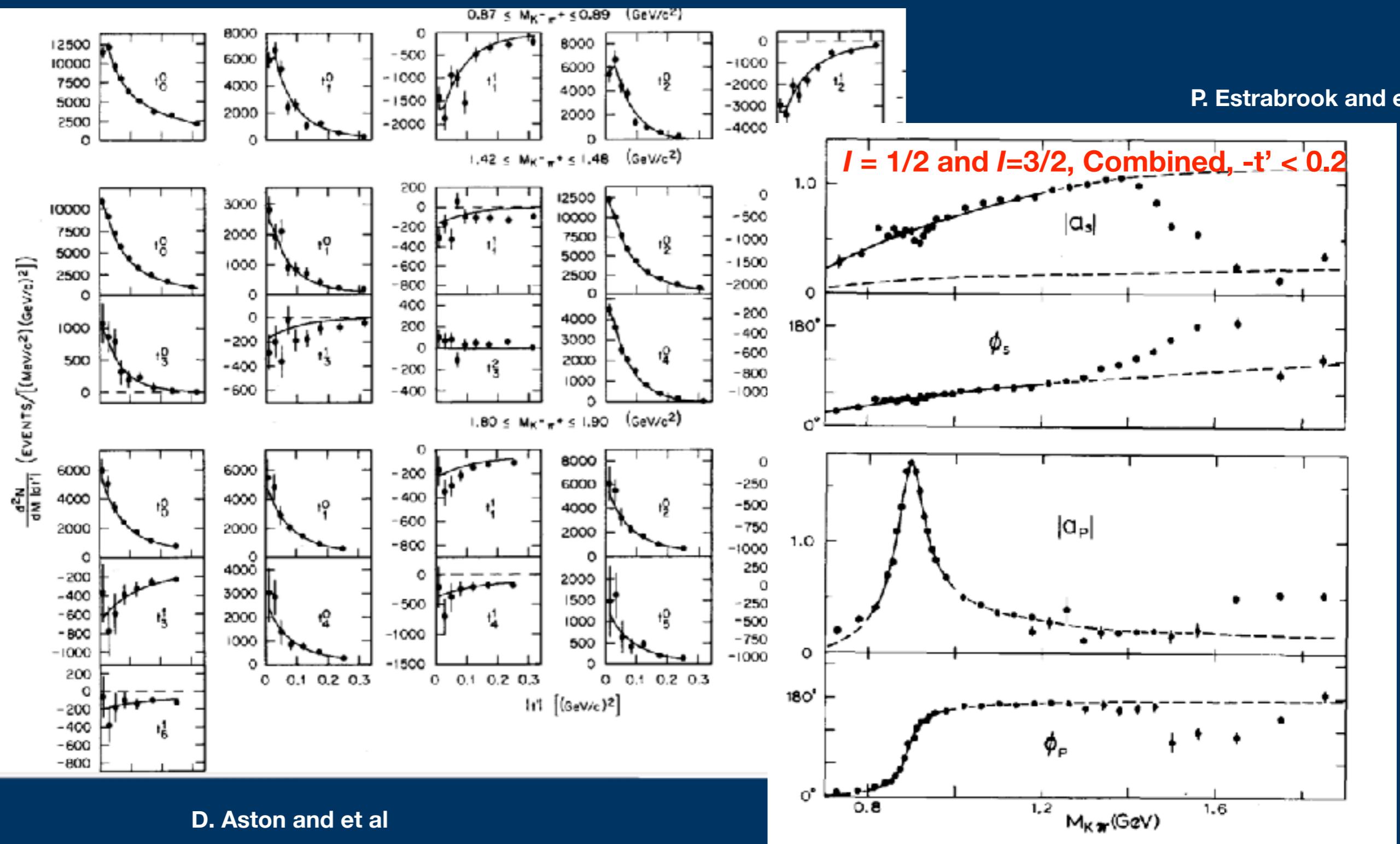
$$L_\lambda^\pm = 0, \lambda \geq 2.$$

$$G_{K\pi^+}^L(m_{K\pi}, t) = N \frac{m_{K\pi}}{\sqrt{q}} a_L(m_{K\pi}) \exp(b_L(m_{k\pi})(t - m_\pi^2)), a_L^l = \sqrt{(2L+1)} \epsilon^I \sin \delta_L^I e^{\delta_L^I}$$

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

SLAC experiment (...cont)

Moment produced; scattering amplitude and phase-shift for SLAC



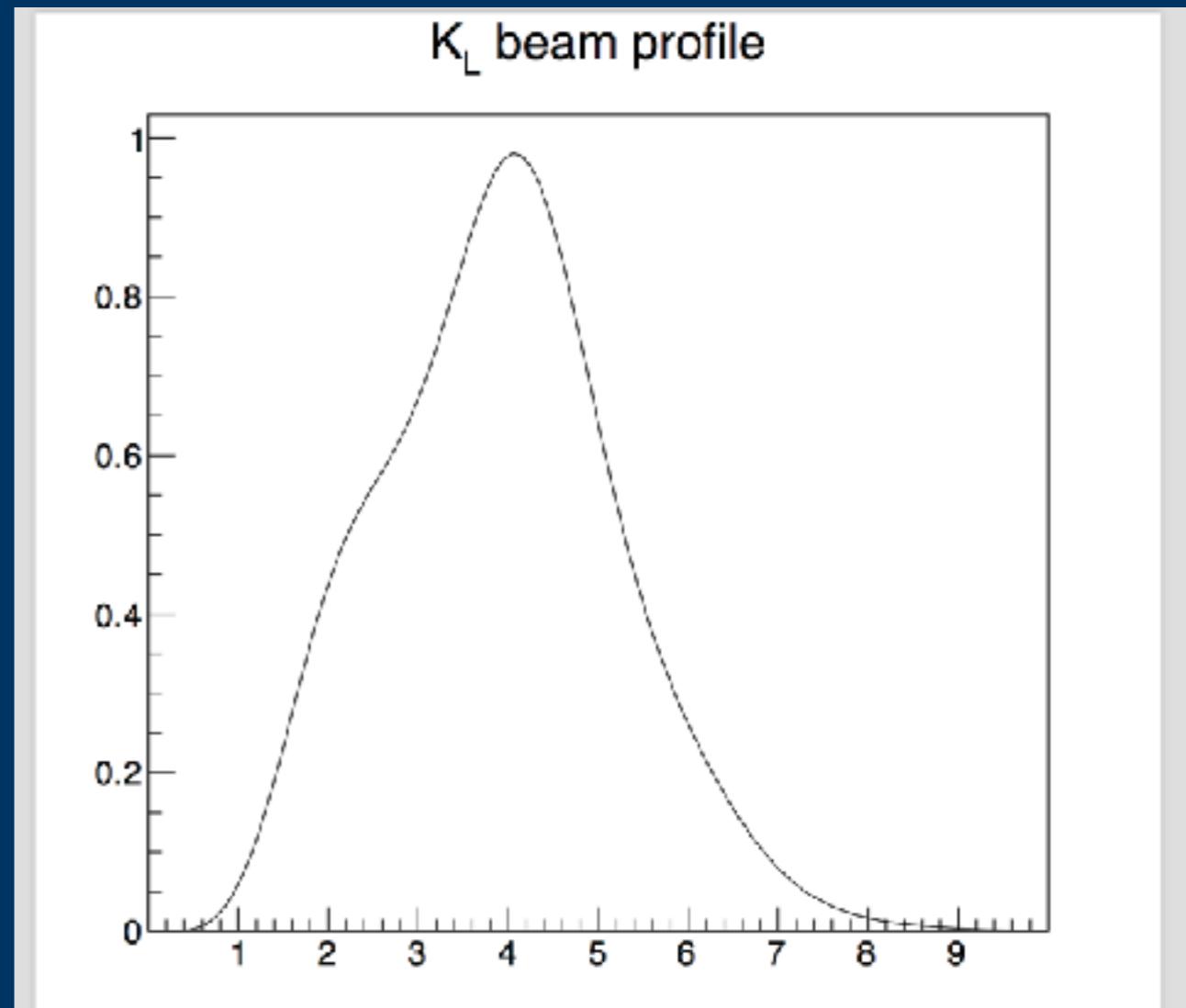
Event Generation

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.

$K\pi$ production: $K_L p \rightarrow K^+ \pi^- p$

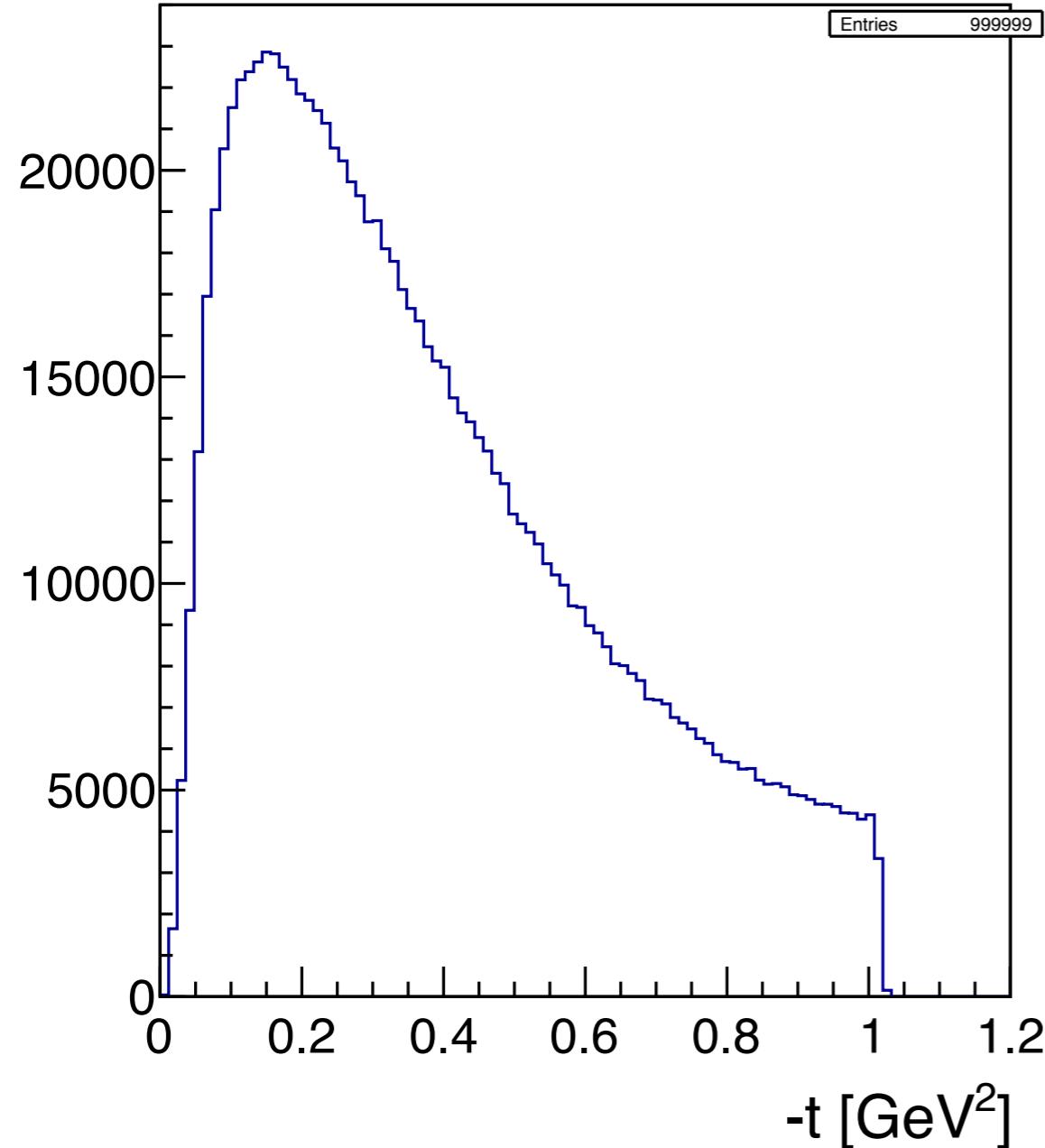
- Generated based on Regge model described in *Nucl.Phys.B10(1969) 151-168.*
- More details can be found in the KLF proposal.



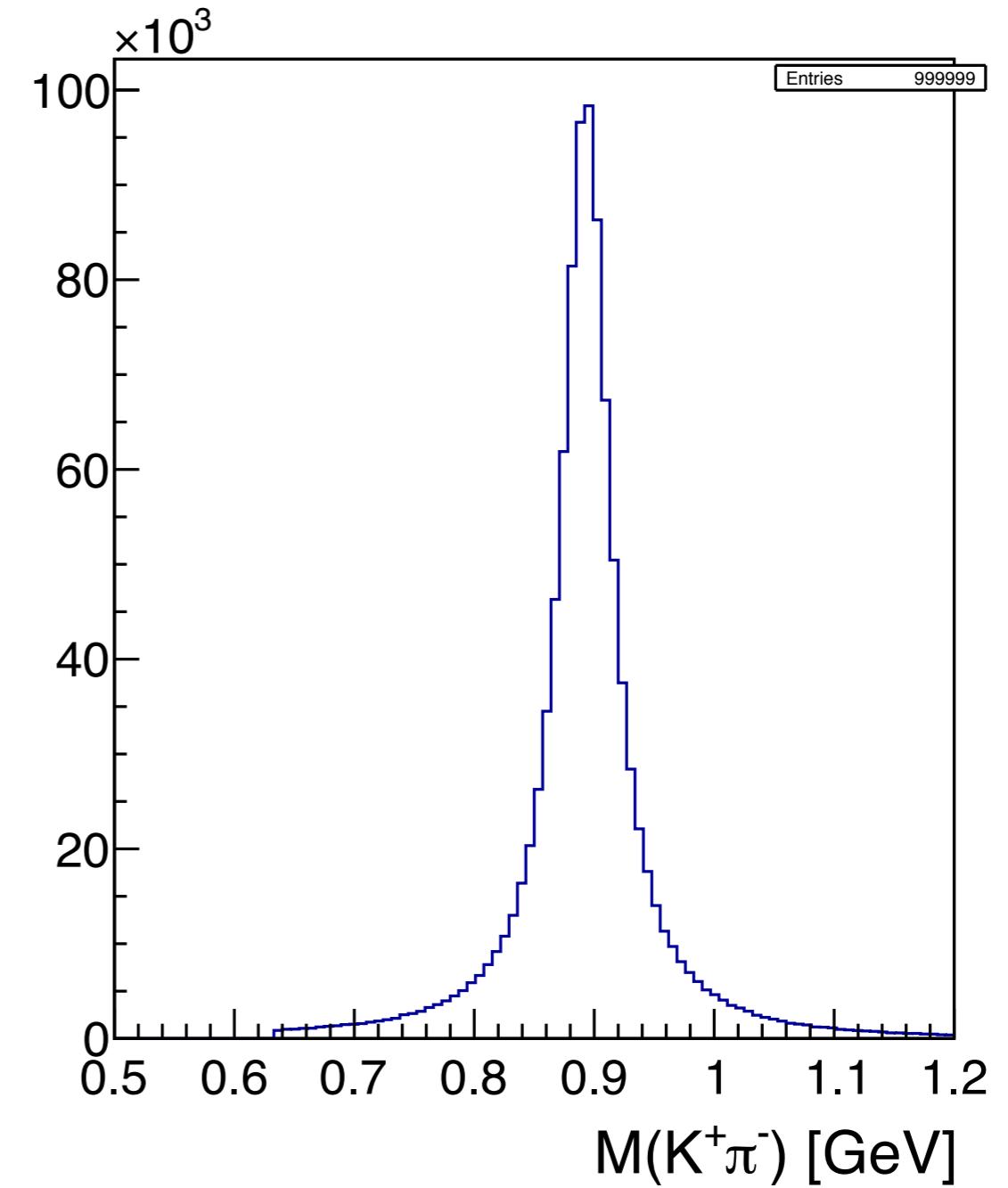
Generation $K_L p \rightarrow K^*(892)p$

Generated Monte Carlo using Regge Model for $K_L p \rightarrow K^*(892)p \rightarrow K^+ \pi^- p$

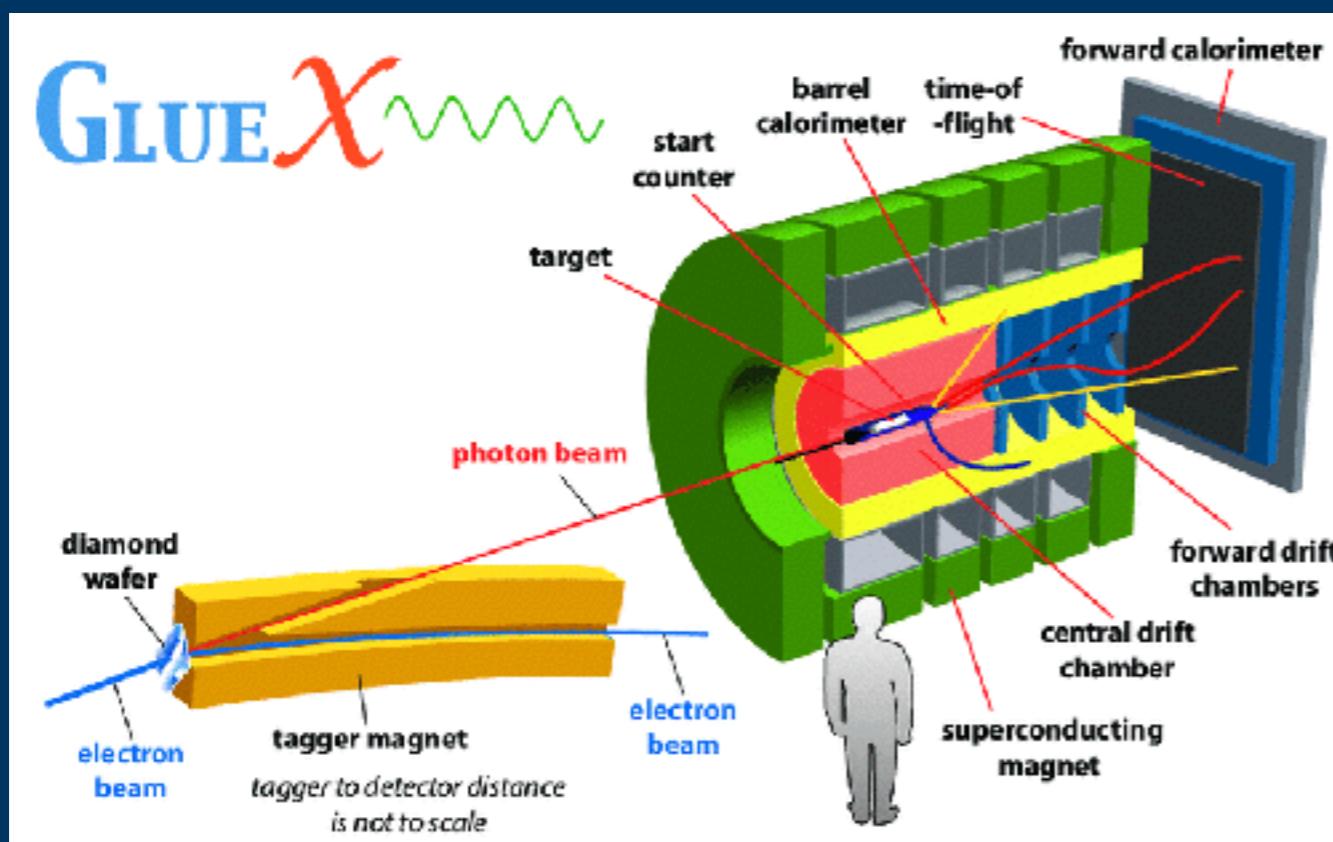
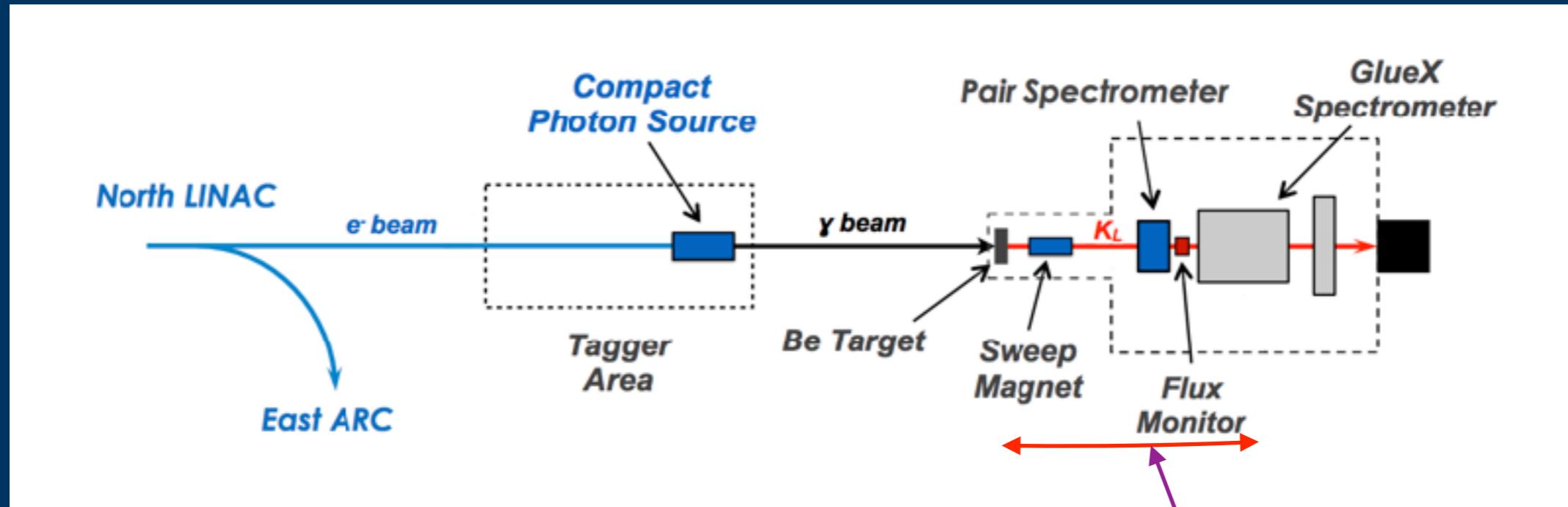
Four Momentum transfer (-t)



$M(K^+ \pi^-)$



K-Long Facility and GlueX Detector



24 m; K_L beam
reconstruction

Reconstruction in GlueX detector

K_L momentum reconstruction:

- from time-of-flight between kaon time at "vertex" and time at Be target.

$$\text{Flight_distance } (L) = 2400 + \text{vertex_z} - 63.8 + \text{Delta}$$

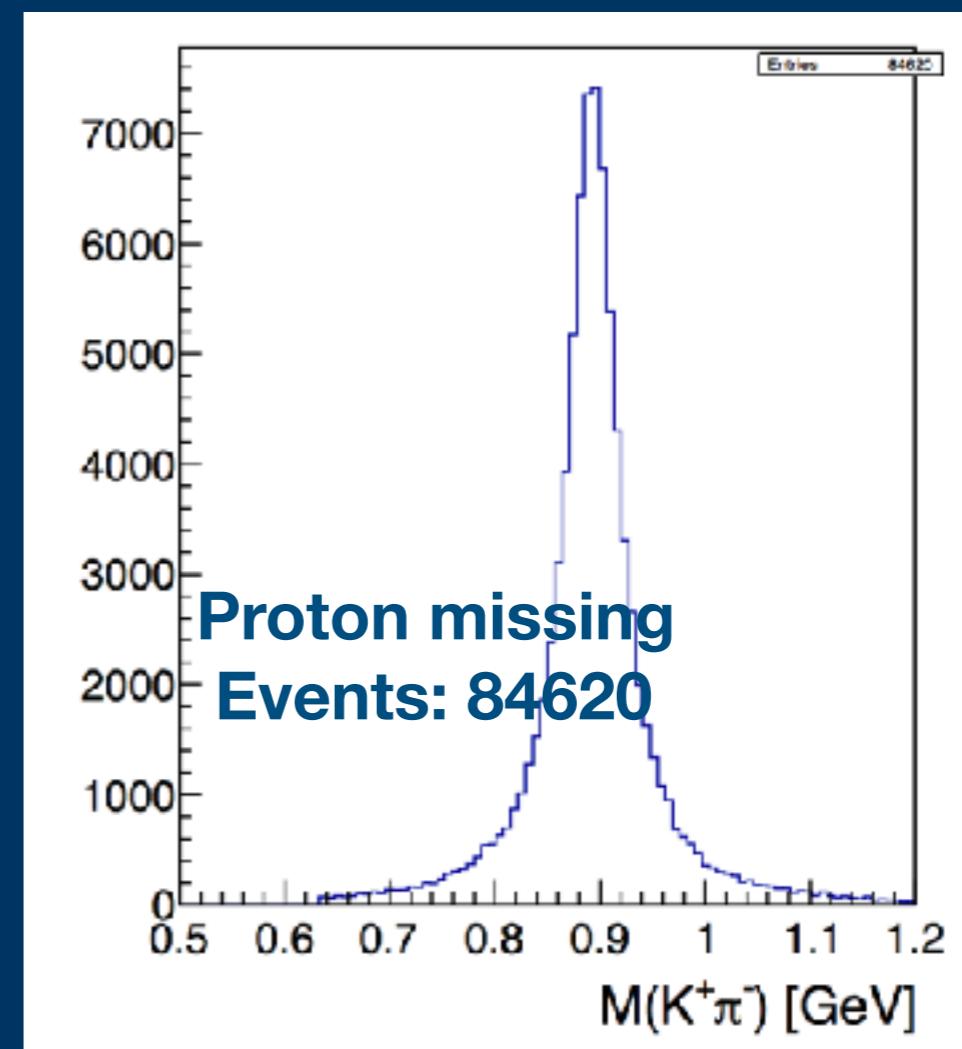
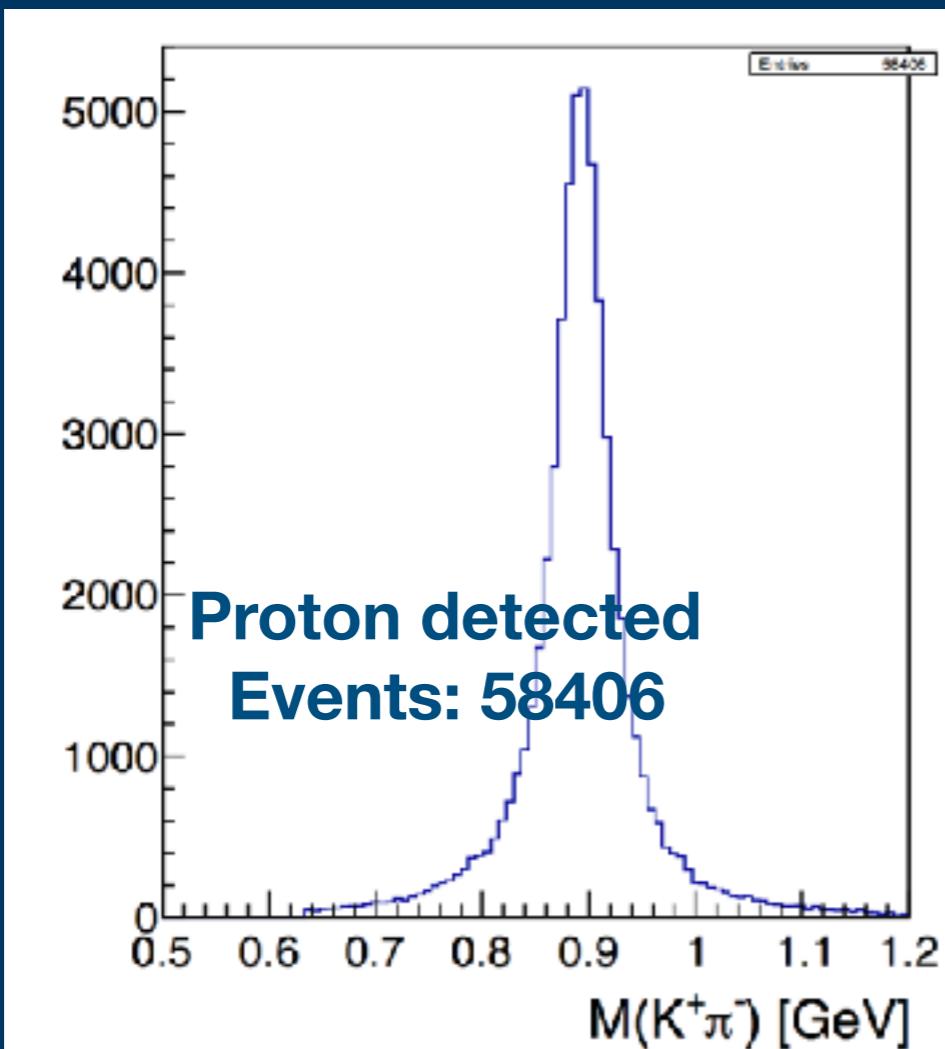
$$\text{flight_time} = \text{Flight_distance}/(c * \text{beta_thrown})$$

$$\text{time_difference} = k_{\text{vertex_time}} - \text{flight_time}; k_{\text{vertex_time}}: \text{TOF time at vertex}$$

Final State particle reconstruction $K_L p \rightarrow K^* p \rightarrow K^+ \pi^- p$

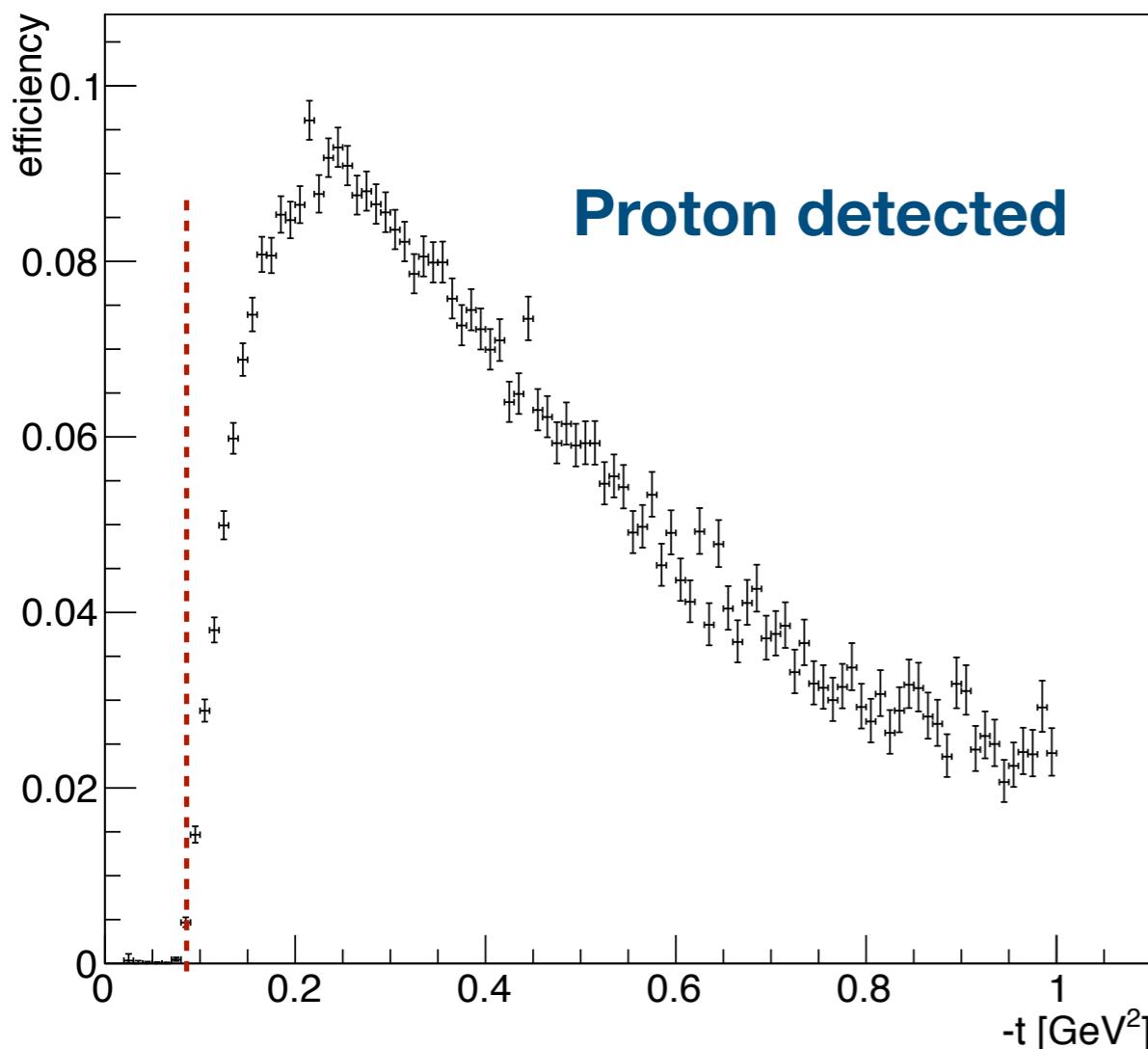
- K^+, π^- and proton
- K^+, π^- and (proton)

Well Reconstructed Kpi system in both cases; More stat for proton missing

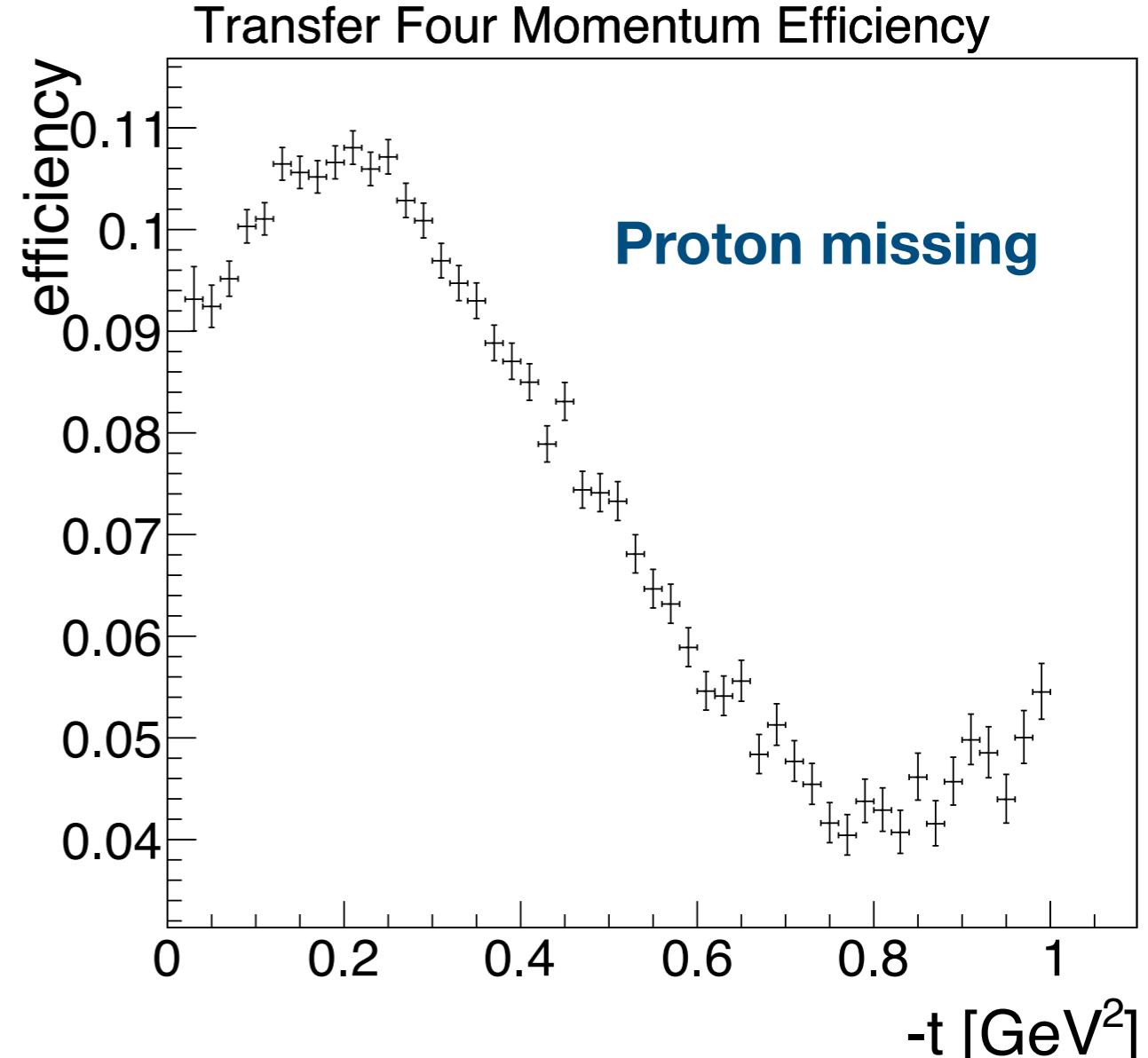


Efficiency

Transfer Four Momentum Efficiency



Transfer Four Momentum Efficiency

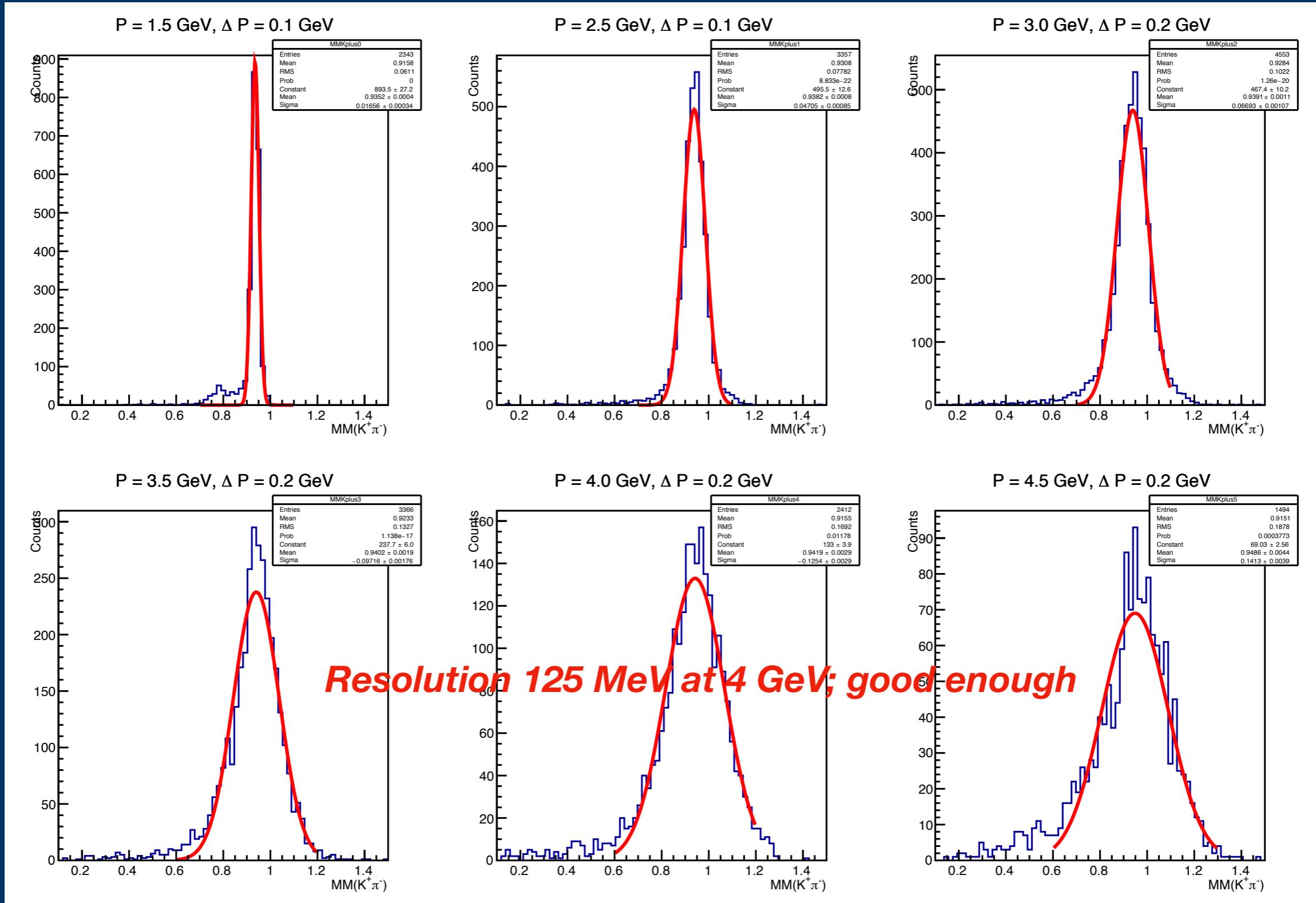


With proton being detected,
 $-t$ stop at 0.08 GeV^2

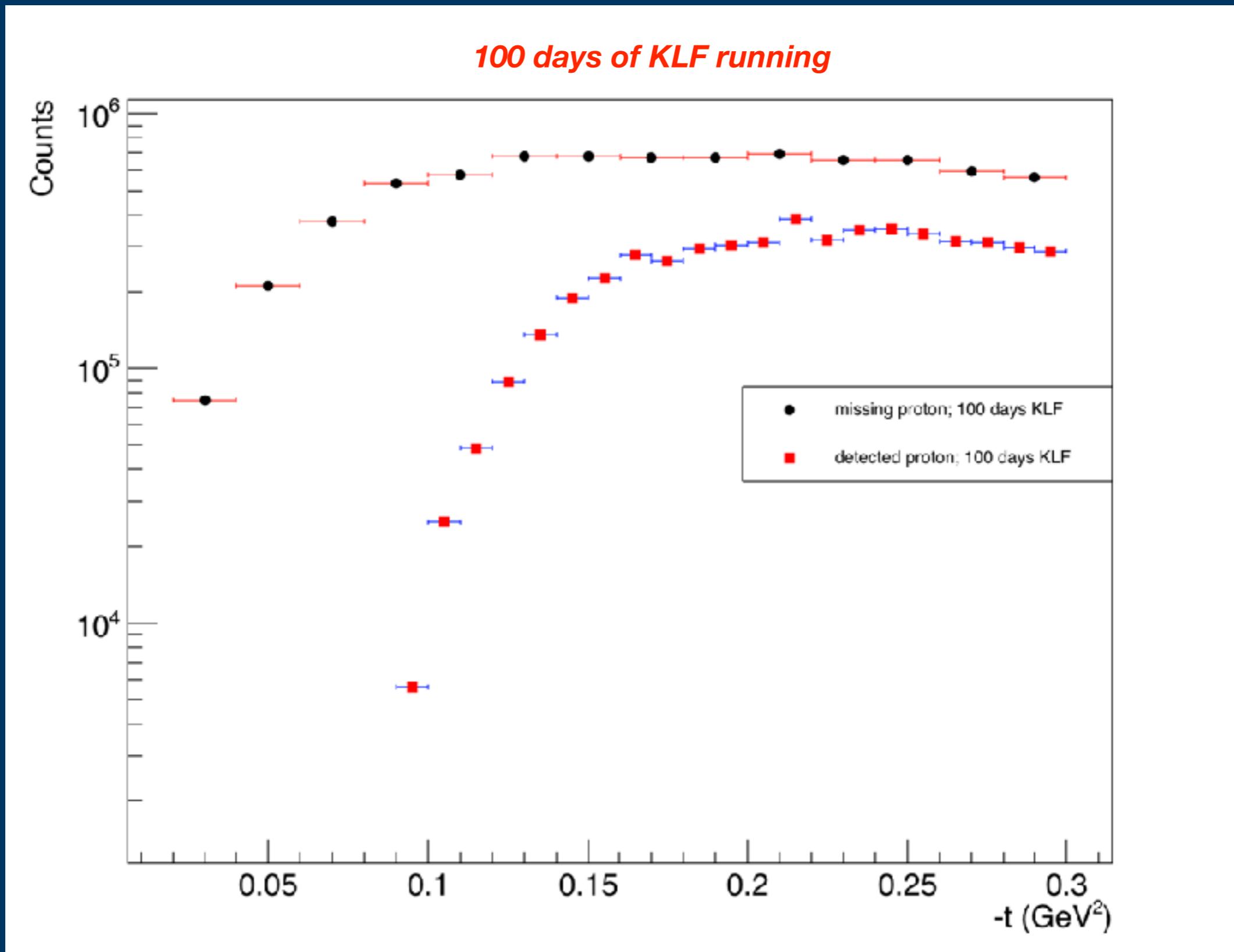
$-t$ reach to pion pole for the
missing proton

Missing mass of $K^+\pi^-$

Missing mass at different beam momentum



Expected Statistics for two topology



Partial Wave Analysis of $K\pi$ system

$$K_L p \rightarrow K^\pm \pi^\mp p$$

$$K_L p \rightarrow K_L \pi^- \Delta^{++}$$

On shell pion, the elastic $K\pi$ amplitude reduces to

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

$$a_l^I = (c_{1/2} a^{\frac{1}{2}} + c_{3/2} a^{\frac{3}{2}})$$

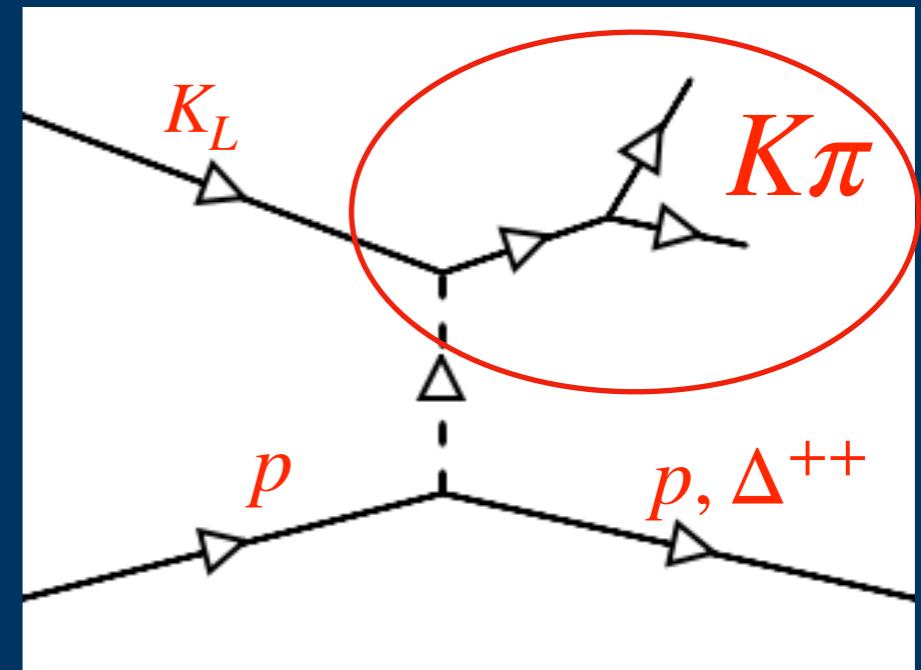
C 's are isospin CG coefficient.

General expression of intensity distribution include both production and decay amplitude

$$I(\theta_{GJ}, \phi_{GJ}) = \sum_{\alpha} V_{\alpha} A_{\alpha}(\theta_{GJ}, \phi_{GJ}) \rho V_{\alpha}^* A_{\alpha}^*(\theta_{GJ}, \phi_{GJ})$$

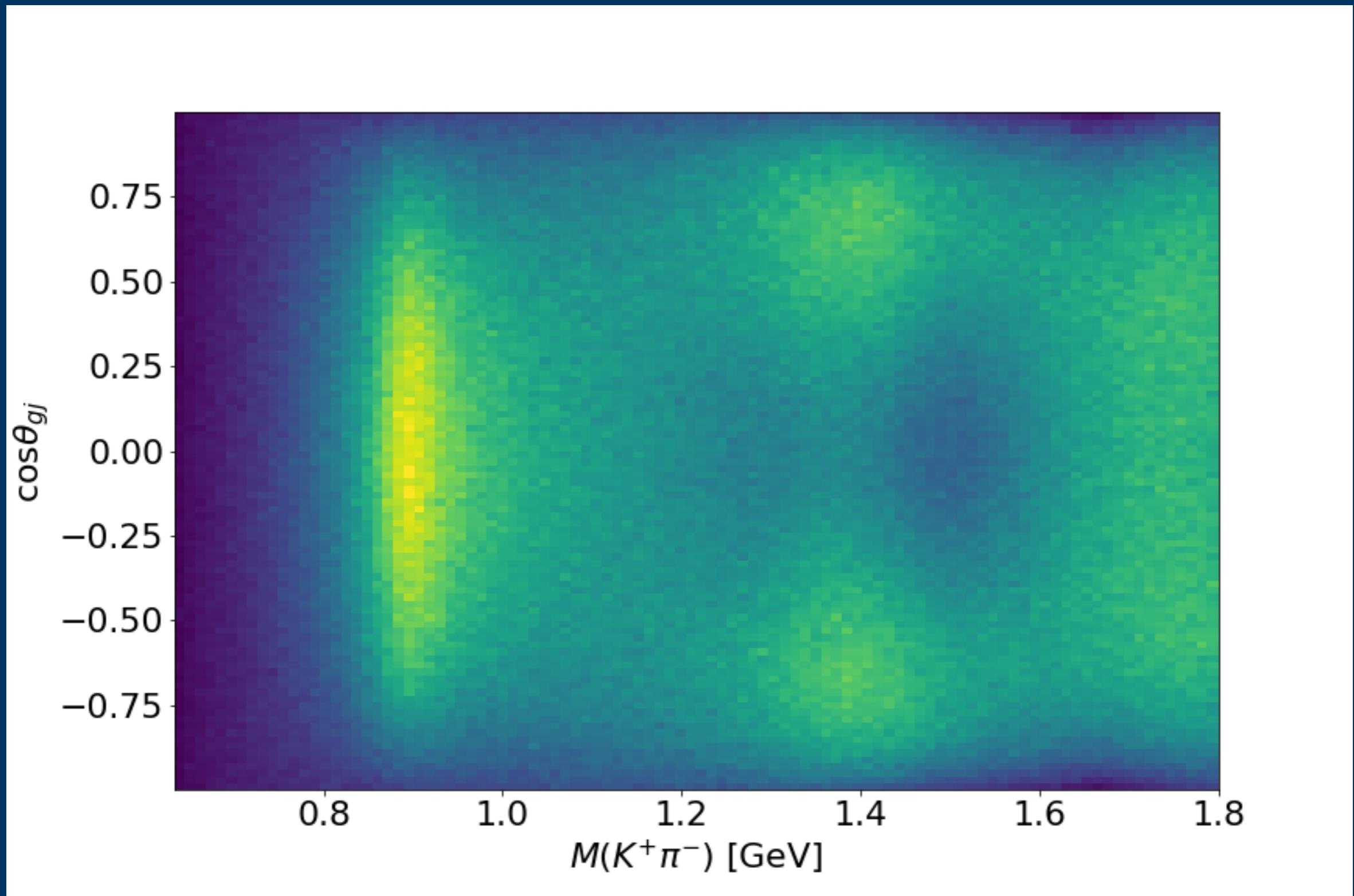
α are all possible quantum numbers.

Applied likelihood fit to estimate production amplitude for each wave set.

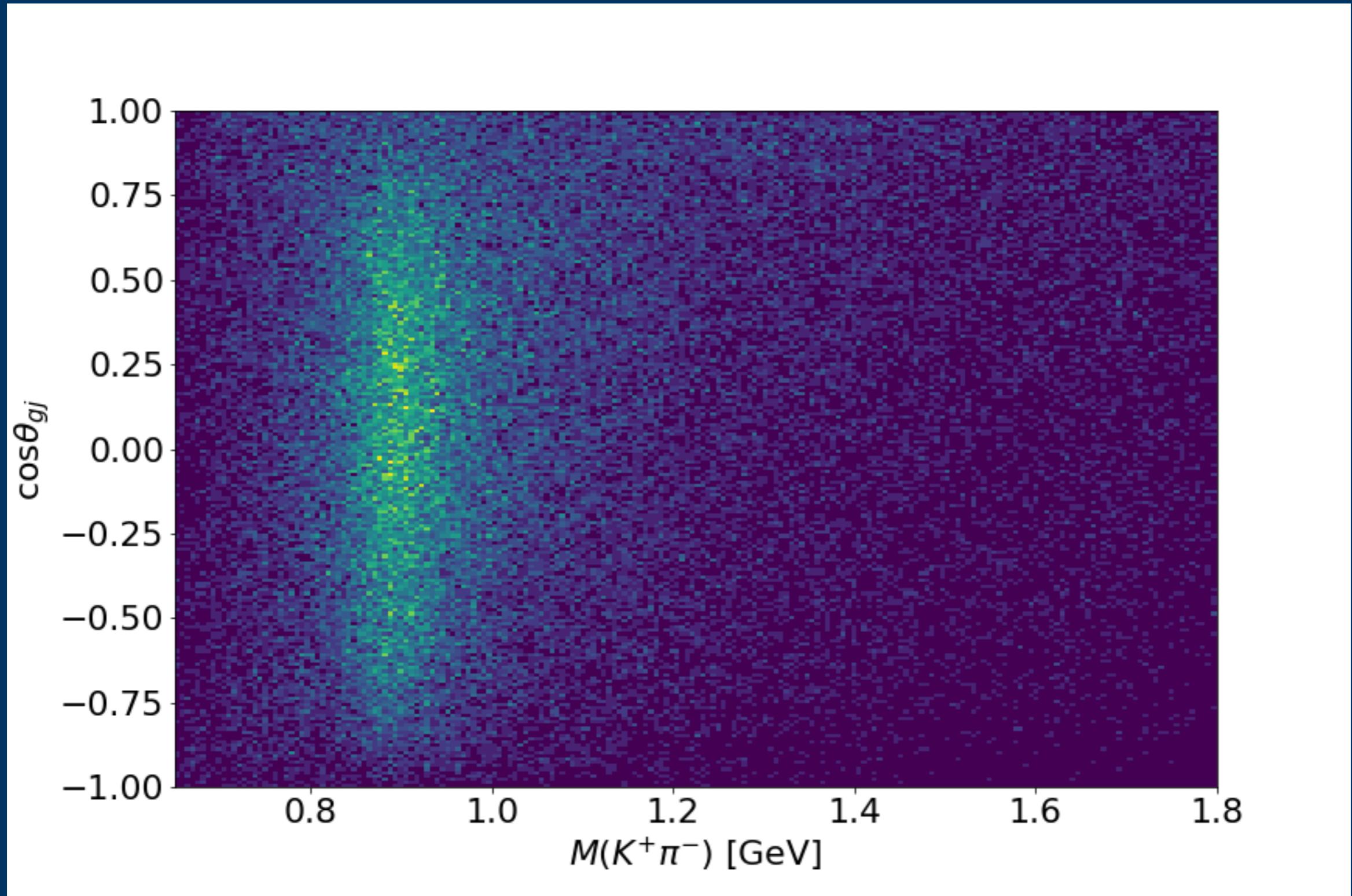


GJ-angle: Generated

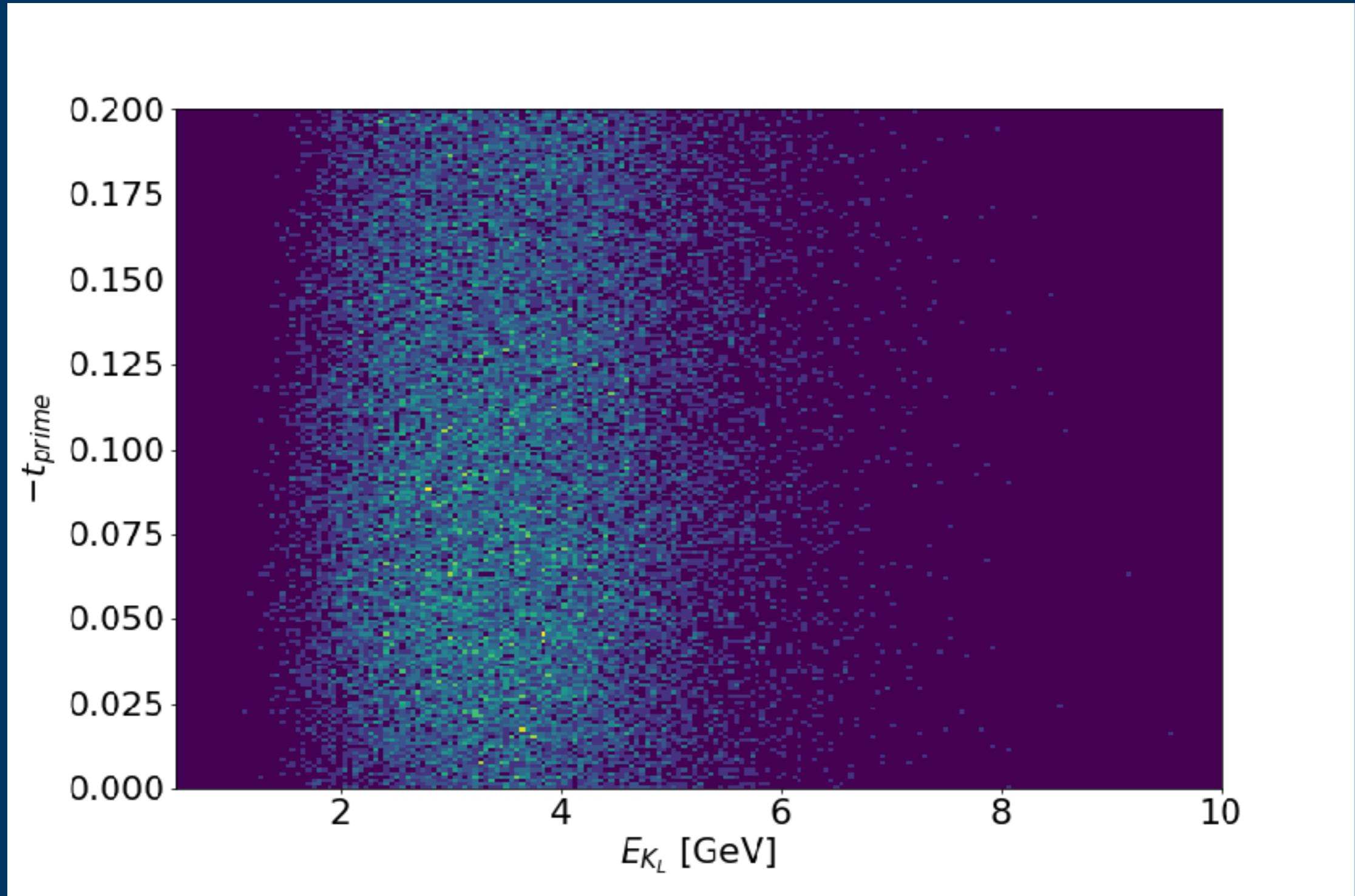
S,P and D wave sets are given for generation



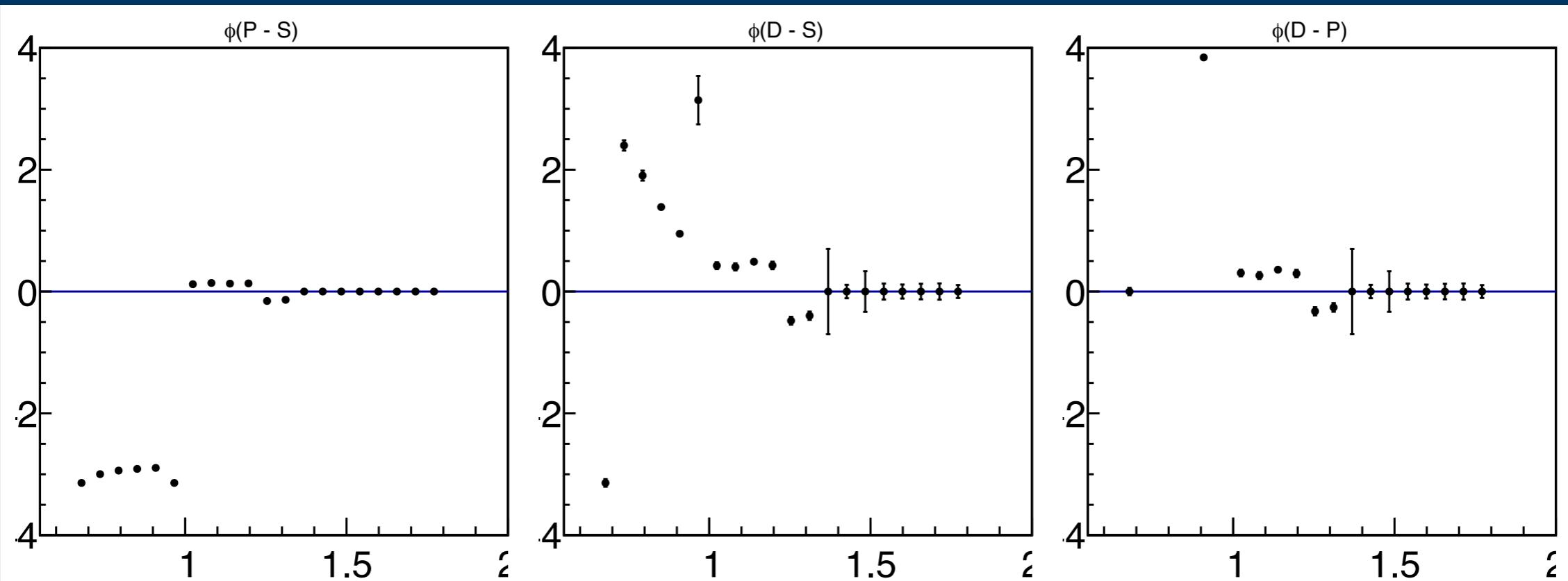
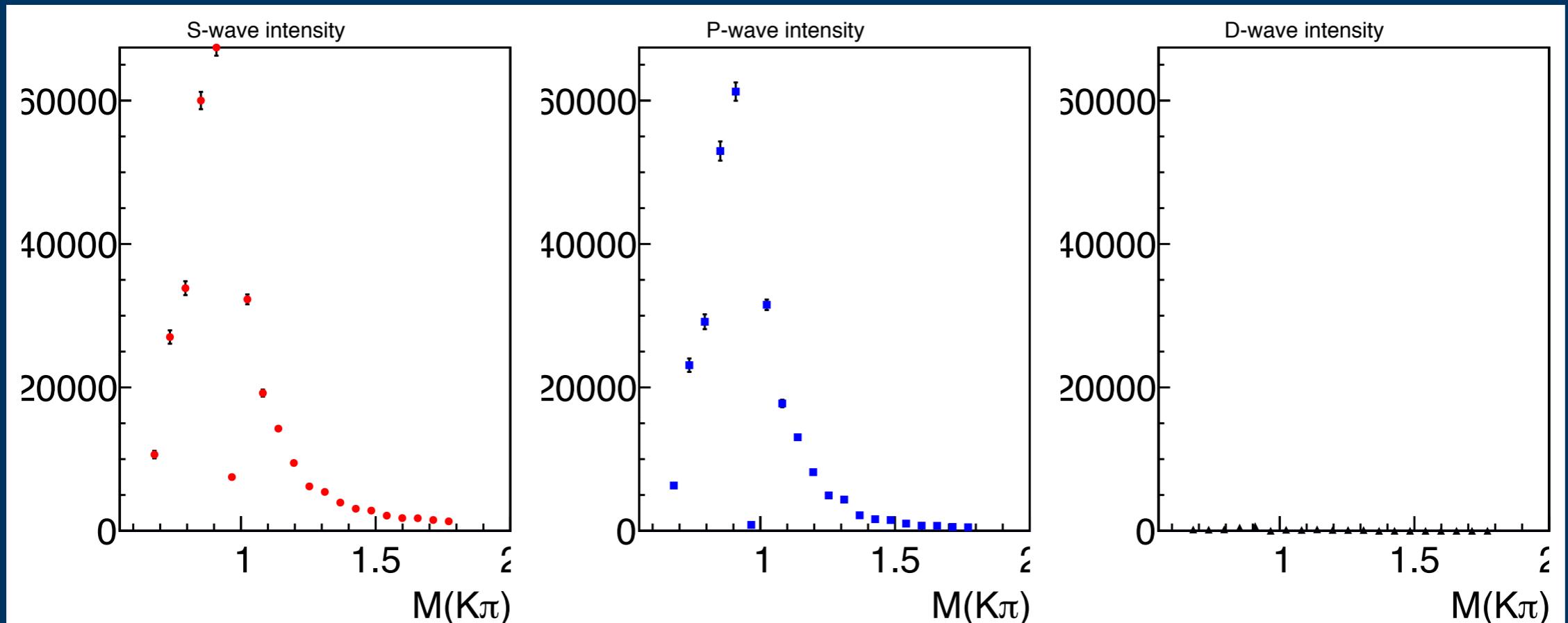
GJ-angle: Reconstructed



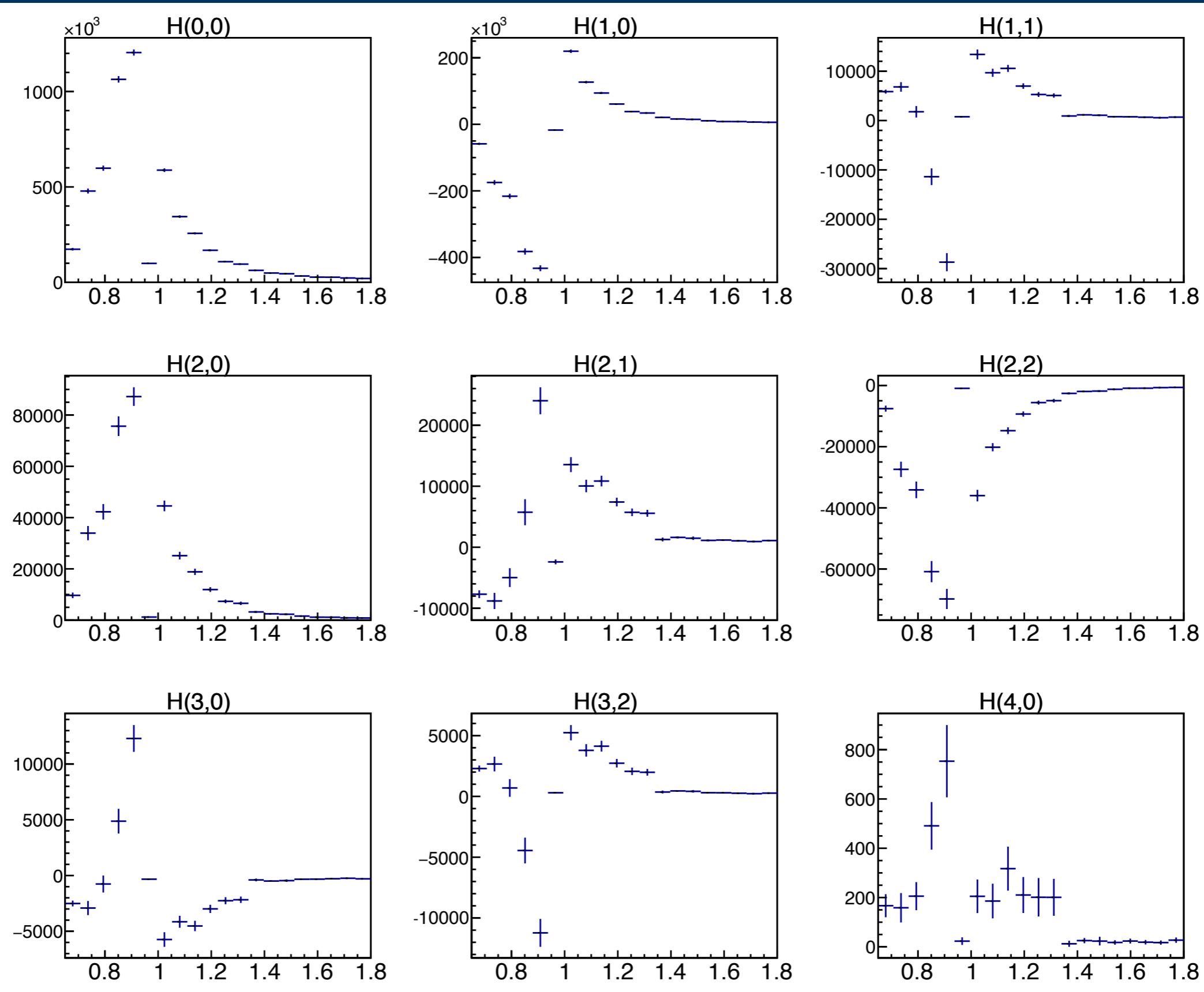
$K\pi$ system: $-t < 0.2$ vs E_{beam}



Intensities and Phase-shift



Moments



Conclusion

$K\pi$ simulation was performed using Geant4.

- Resolution look good enough for $-t$ and $M(K^+\pi^-)$ for both missing and detected proton cases.
- Missing proton help to reach down to pion pole in the small $-t$ region whereas detected proton in the final state, stop $-t$ at 0.08 GeV^2

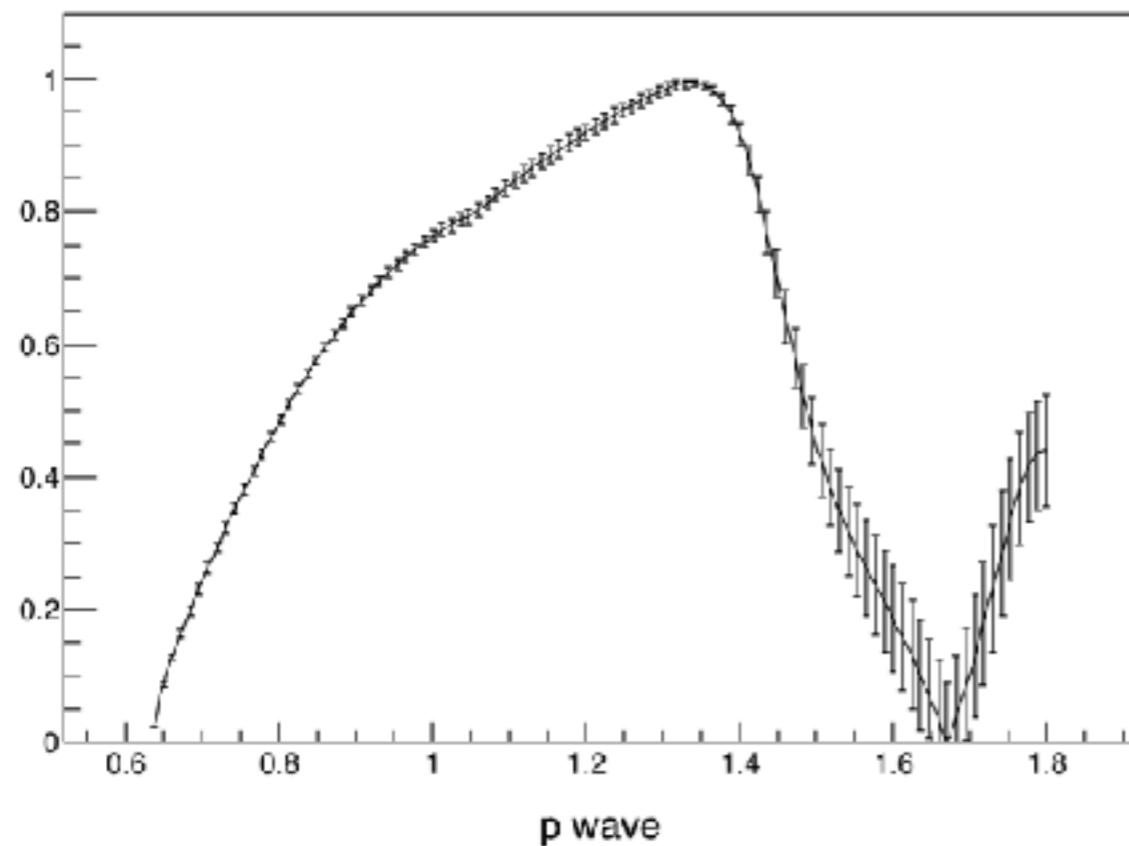
$K\pi$ Partial Wave Analysis

- PWA was done with production amplitude. Should be extracted with the revised version of production elastic $K\pi$ amplitude.
- Might require some theoretical support to parametrize the amplitudes in a right way.

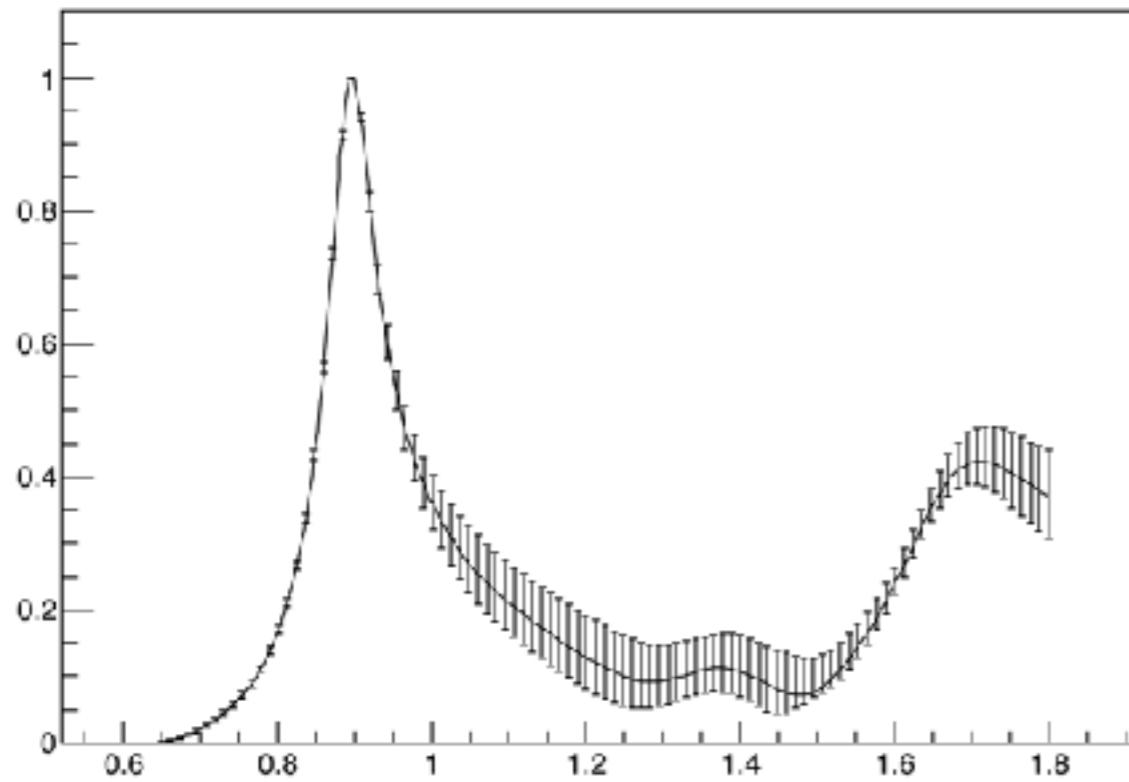
Thank you

Theoretical Amplitudes

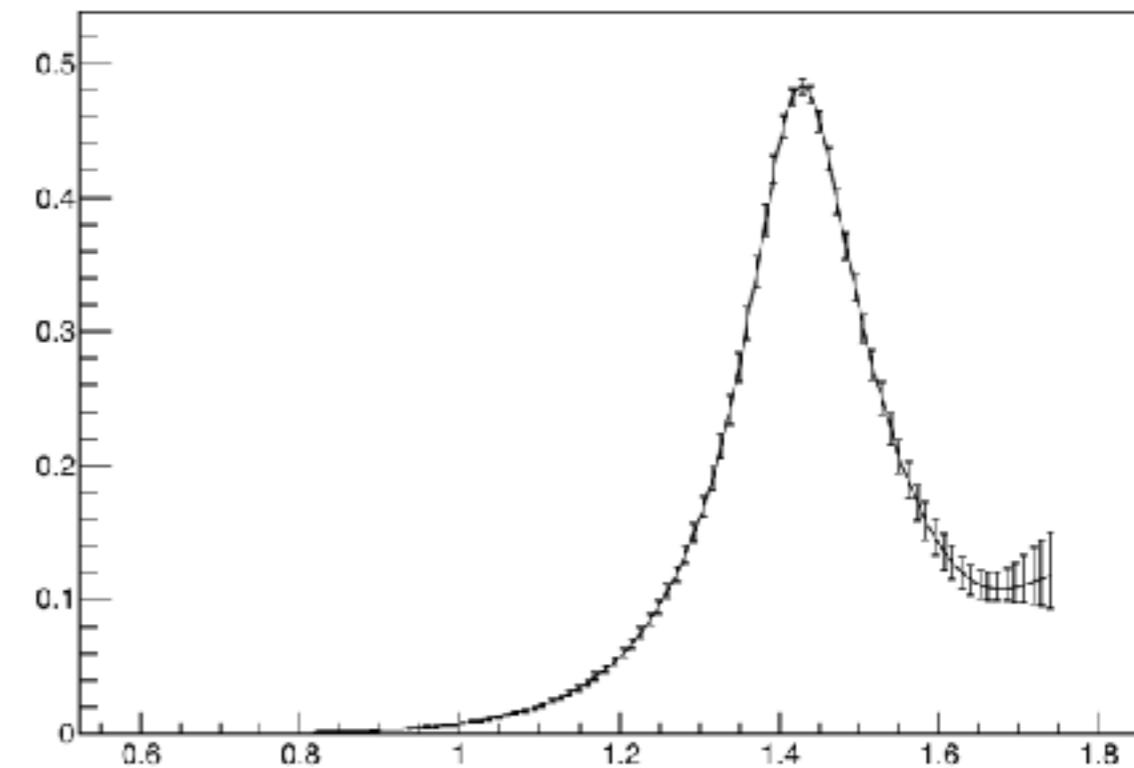
s wave



p wave



d wave



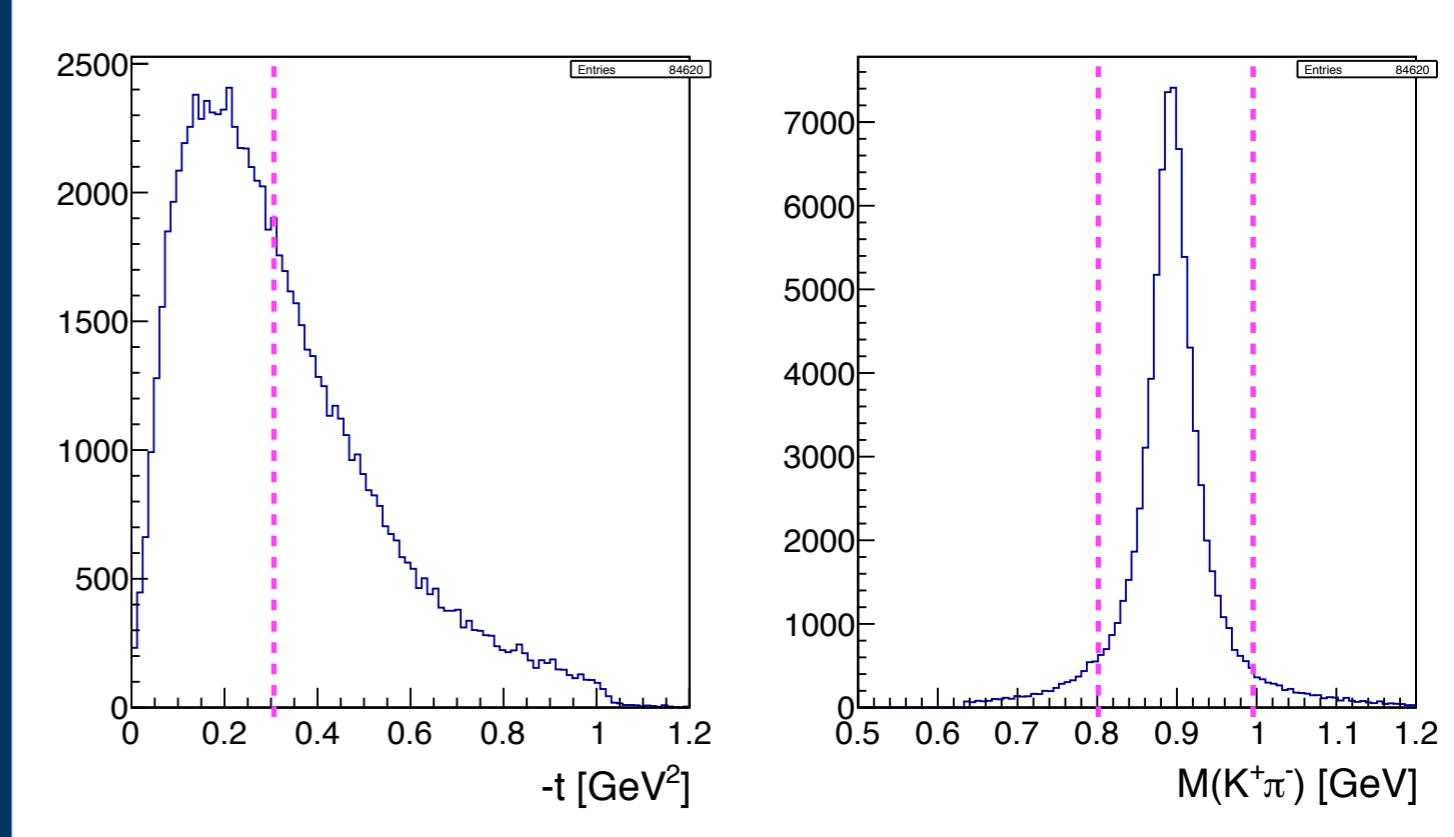
Moment calculation from Amp.

Amptool library: binning on mass and -t

S- wave: $\kappa(800), K_0^*(1430), \dots$

P- wave: $K^*(892), K^*(1680), \dots$

D- wave: $K_2^*(1430), \dots$



Moments: projection of amplitudes

$$H(0,0) = + 1 |S0|^2 + 1 |P0|^2 + 1 |P-|^2 + 1 |D0|^2 + 1 |D-|^2 + 1 |P+|^2 + 1 |D+|^2$$

$$H(1,0) = + 1.1547 Re(P0 * S0) + 1.0328 Re(D0 * P0) + 0.894427 Re(D- * P-) + 0.894427 Re(D+ * P+)$$

$$H(1,1) = + 0.816497 Re(P- * S0) - 0.365148 Re(D0 * P-) + 0.632456 Re(D- * P0)$$

$$H(2,0) = + 0.4 |P0|^2 - 0.2 |P-|^2 + 0.894427 Re(D0 * S0) + 0.285714 |D0|^2 + 0.142857 |D-|^2 - 0.2 |P+|^2 + 0.142857 |D+|^2$$

$$H(2,1) = + 0.489898 Re(P- * P0) + 0.632456 Re(D- * S0) + 0.202031 Re(D- * D0)$$

$$H(2,2) = + 0.244949 |P-|^2 + 0.174964 |D-|^2 - 0.244949 |P+|^2 - 0.174964 |D+|^2$$

S-wave K(800) Kappa

The indications on the presence of Kappa resonance have been reported based on the data of the **E791** and **BES** collaborations.

The results from Roy-Steiner dispersive representation (top row in table) not in agreement with low energy experimental data. This model includes phase shift from LASS experiment of s-wave as well as other waves at high energy.

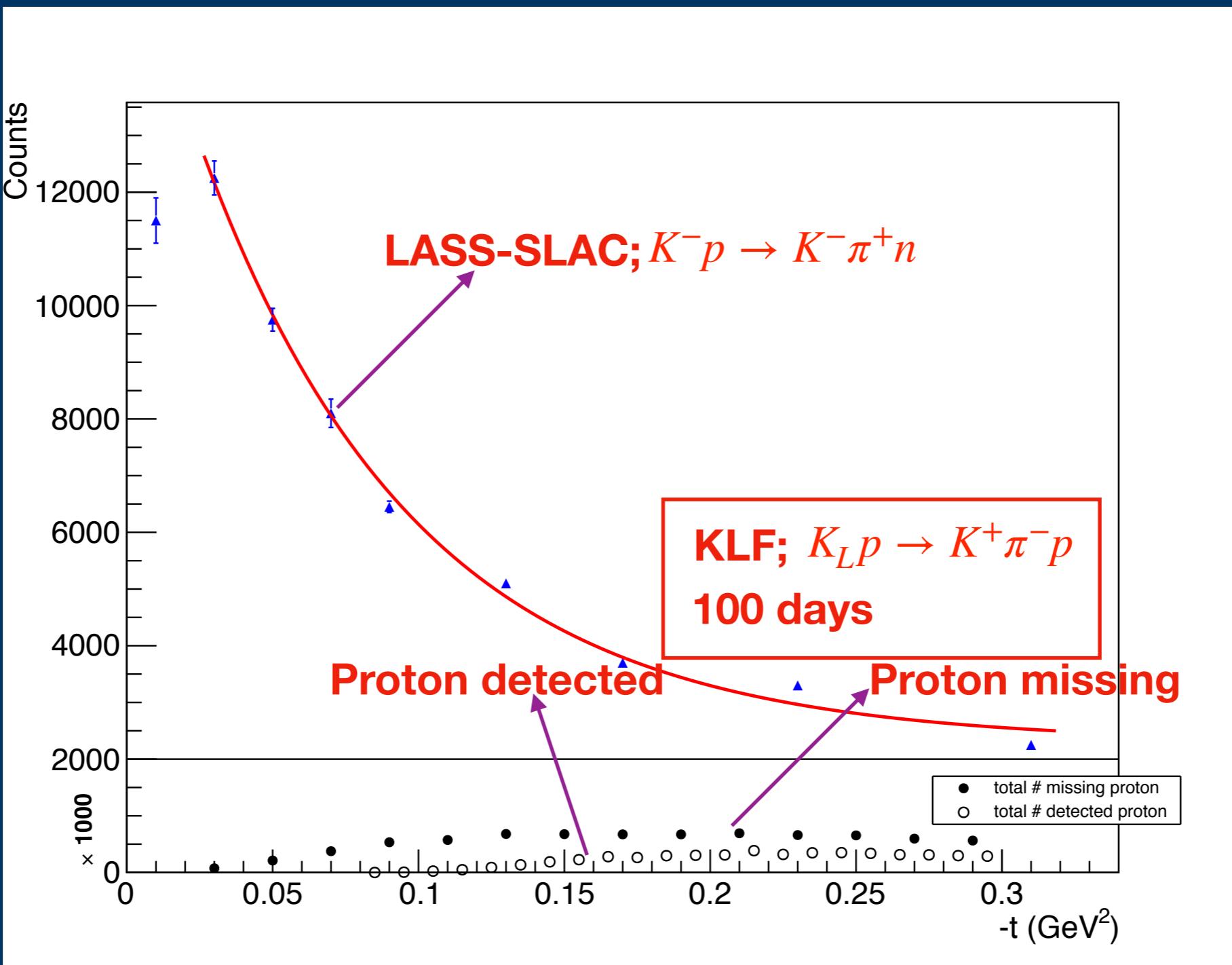
Table: S. Descotes-Genon
and B. Moussallam'06



	M_κ (MeV)	Γ_κ (MeV)
This work	658 ± 13	557 ± 24
Zhou, Zheng [16]	694 ± 53	606 ± 89
Jamin et al. [18]	708	610
Aitala et al. [7]	$721 \pm 19 \pm 43$	$584 \pm 43 \pm 87$
Pelaez [19]	750 ± 18	452 ± 22
Bugg [9]	750^{+30}_{-55}	684 ± 120
Ablikim et al. [20]	$841 \pm 23^{+64}_{-55}$	$618 \pm 52^{+55}_{-87}$
Ishida et al. [14]	877^{+65}_{-30}	668^{+235}_{-110}

The confirmation of pole in the amplitude for elastic πK scattering requires more data at low energy in addition to phase shift from amplitude analysis.

Comparison with SLAC



- Two order of more statistics compared to previous SLAC measurement.