$K^+\Sigma^0$ Photoproduction at Backward Angle at GlueX Experiment

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Backward-Angle (u-channel) Physics Workshop 09/23/2020

Introduction

K^+ – psuedoscalar meson with quark content $u\bar{s}$

Σ^0 – hyperon with quark content uds

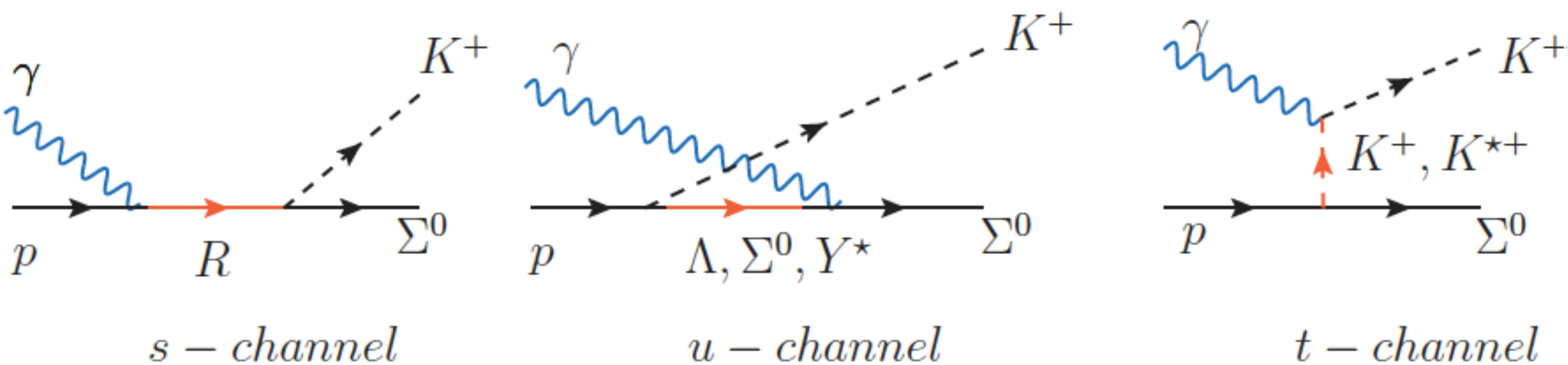
$\gamma p \rightarrow K^+\Sigma^0$

- Mandelstam variables are defined as

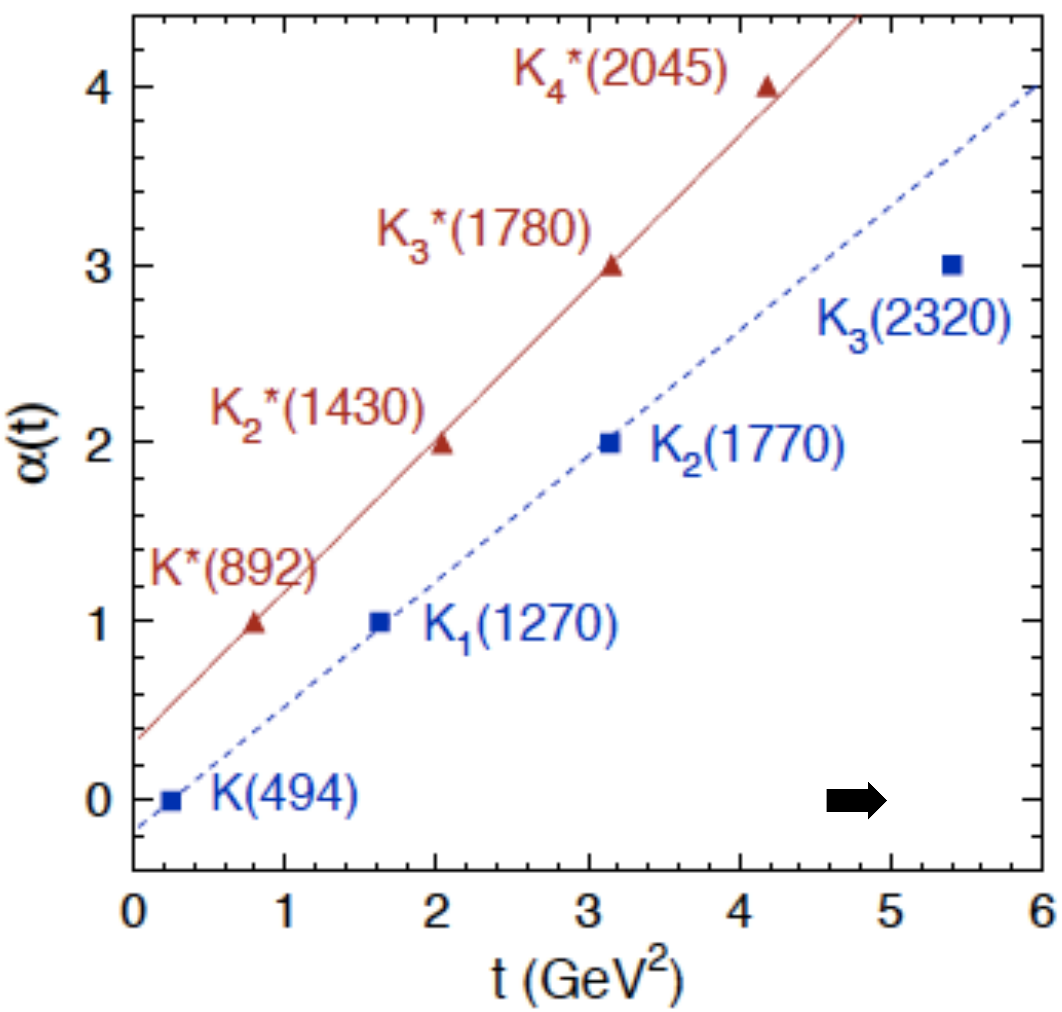
$$s = (p_\gamma + p_p)^2$$

$$t = (p_\gamma - p_{K^+})^2$$

$$u = (p_p - p_{K^+})^2$$



Regge Model



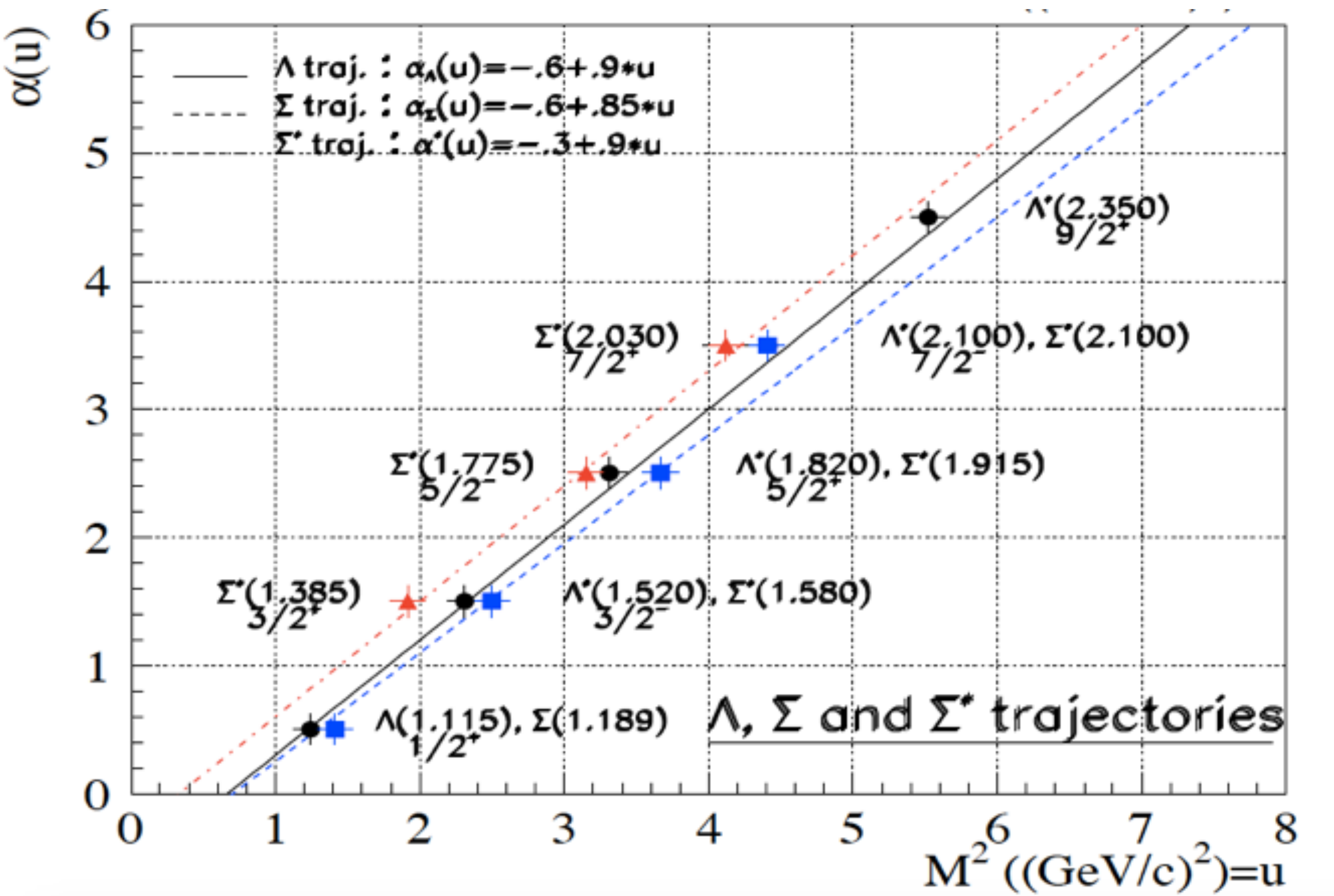
***t*-channel**

$$\alpha_X(t) = \alpha_{X,0} + \alpha'_X(t - m_X^2)$$

Phys. Rev. C **75**, 045204 (2007)

- Scattering amplitude ➡ exchange of Regge trajectories at high energies
- Regge trajectory ➡ resonances with identical internal quantum numbers but different total angular momenta J
- Have relation $J_i = \alpha(m_i^2)$ for different masses

Regge Model



u-channel

M. Guidal, PhD thesis, DAPNIA/SPhN-96-03T, CE Saclay (1996)

Physics Motivation

for $\gamma p \to K^+\Sigma^0$

helicity amplitudes

$$f_1 = f_{1+,0+}$$
$$f_2 = f_{1+,0-}$$
$$f_3 = f_{1-,0+}$$
$$f_4 = f_{1-,0-}$$

Nucl. Phys. B53, 197 (1973)

$$f_1^{\pm} = \frac{1}{2}(f_1 \pm f_4)$$
$$f_2^{\pm} = \frac{1}{2}(f_2 \mp f_3)$$

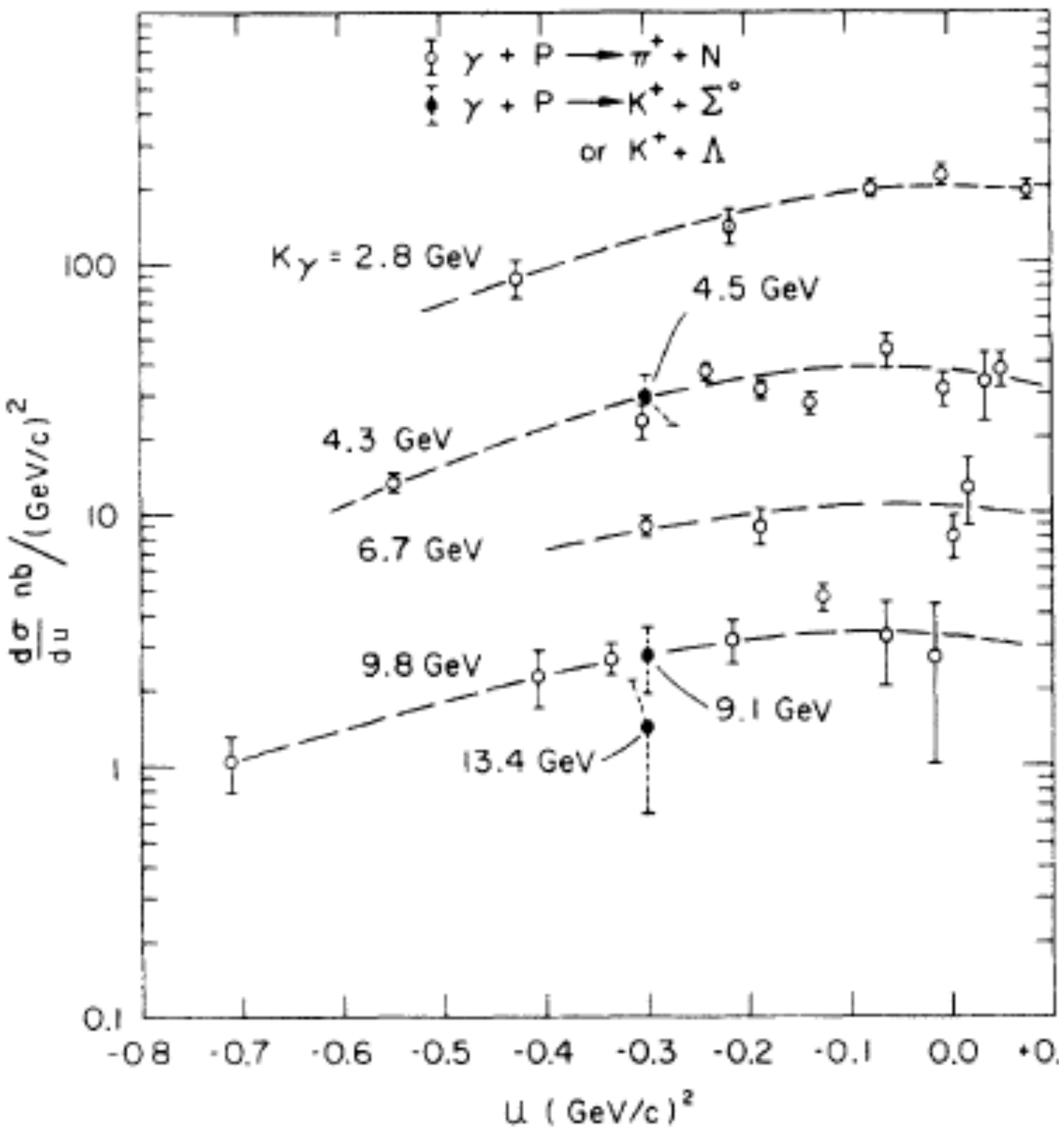
$f_1^+\ ,\ f_2^+$ ➡ natural parity

$f_1^-\ ,\ f_2^-$ ➡ unnatural parity

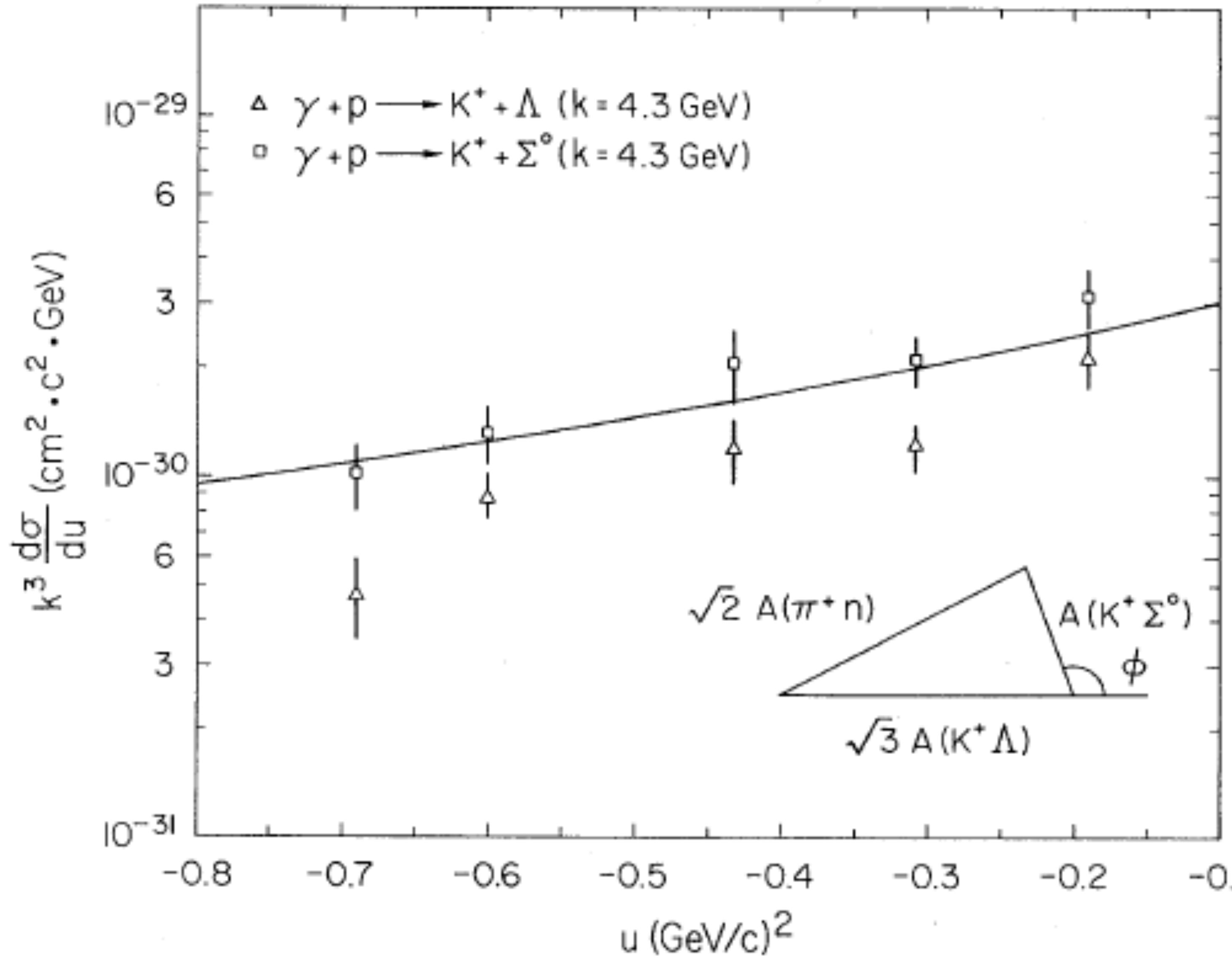
beam asymmetry $$\Sigma = \left[\frac{d\sigma_\perp}{dt} - \frac{d\sigma_\parallel}{dt}\right] \Big/ \left[\frac{d\sigma_\perp}{dt} + \frac{d\sigma_\parallel}{dt}\right]$$
$$= \frac{(|f_1^+|^2 + |f_2^+|^2 - |f_1^-|^2 - |f_2^-|^2)}{(|f_1^+|^2 + |f_2^+|^2 + |f_1^-|^2 + |f_2^-|^2)}$$

- difference between cross sections for photon polarized perpendicular and parallel to reaction plane
- direct measure of type of parity exchange

Previous *u*-channel measurements



Phys. Rev. Lett. **21**, 479 (1968)



Phys. Rev. Lett. **23**, 890 (1969)

$\frac{d\sigma}{du}$ vs. u measurements by SLAC

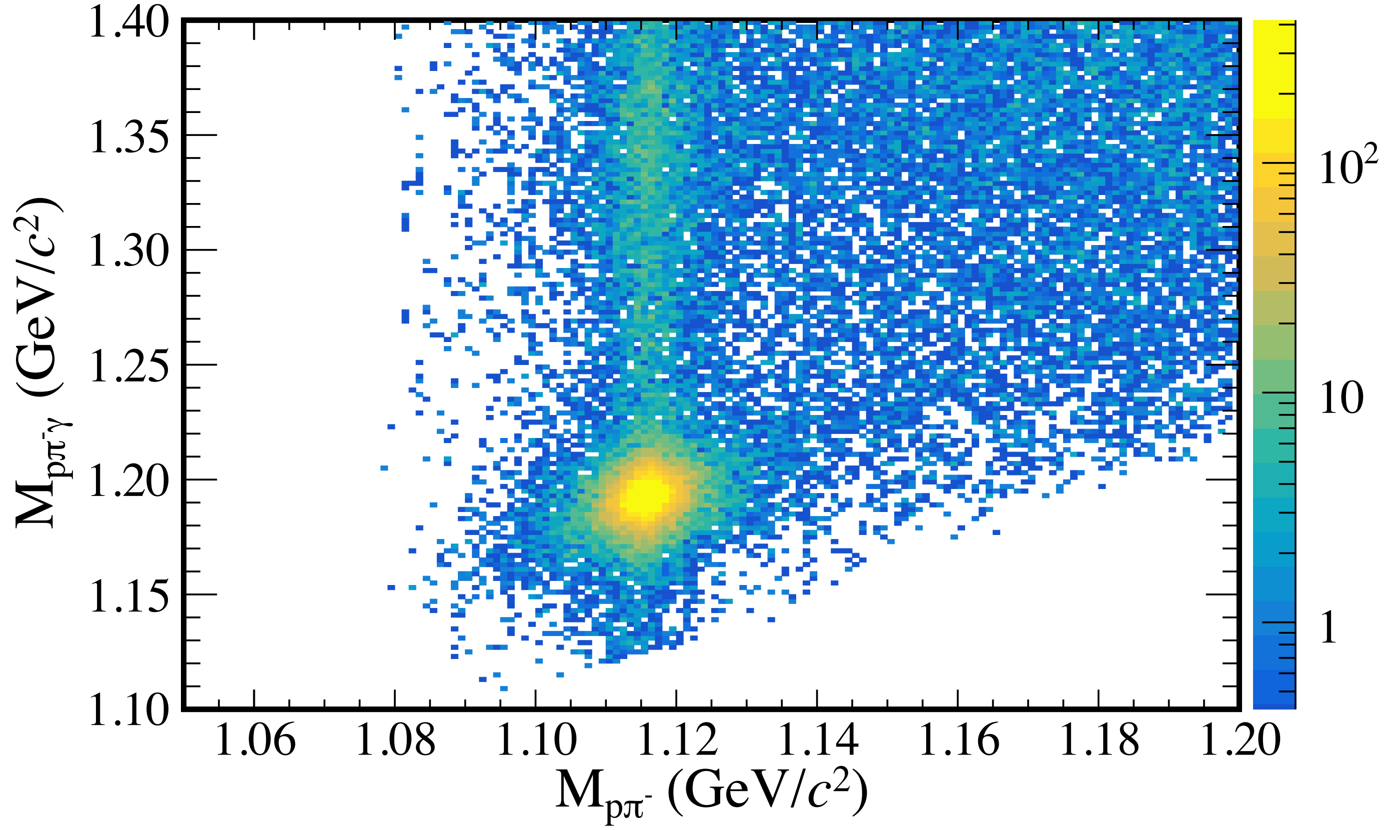
Data Analysis

- Spring 2017 data set - 20% of GlueX phase 1 data
- Luminosity - 20.8 pb^{-1} in 8.2 GeV $< E_\gamma <$ 8.8 GeV

$$\boxed{\begin{array}{l} \gamma p \to K^+\Sigma^0(1193) \\ \Sigma^0 \to \Lambda\gamma \end{array}}$$

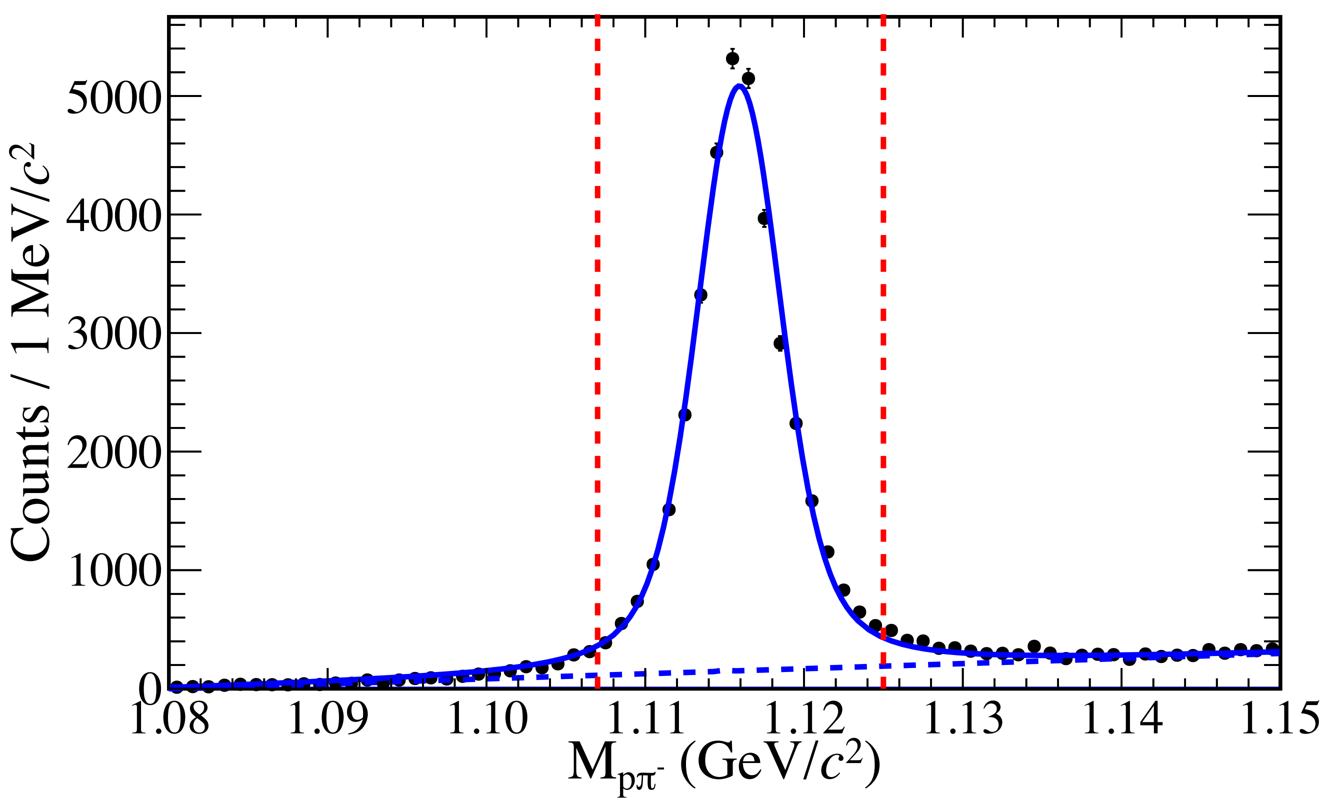
- Select combinations of particles matching the topology of $\gamma p \to K^+\Lambda\gamma \;\; (\Lambda \to \pi^- p)$
  - -0.08 GeV^2 < Missing mass squared of all particles < 0.08 GeV^2
  - Kinematic fit satisfying the conservation of energy and momentum (confidence level $> 10^{-4}$)
  - Kaon is constrained to be in the target region
  - Shower quality > 0.5 to remove extra showers from hadronic split-offs in forward calorimeter

Invariant masses



Phys. Rev. C **101**, 065206 (2020)

$M_{p\pi^-\gamma}$ vs $M_{p\pi^-}$



Signal ➡ Voigtian

Background ➡ 1st order poly.

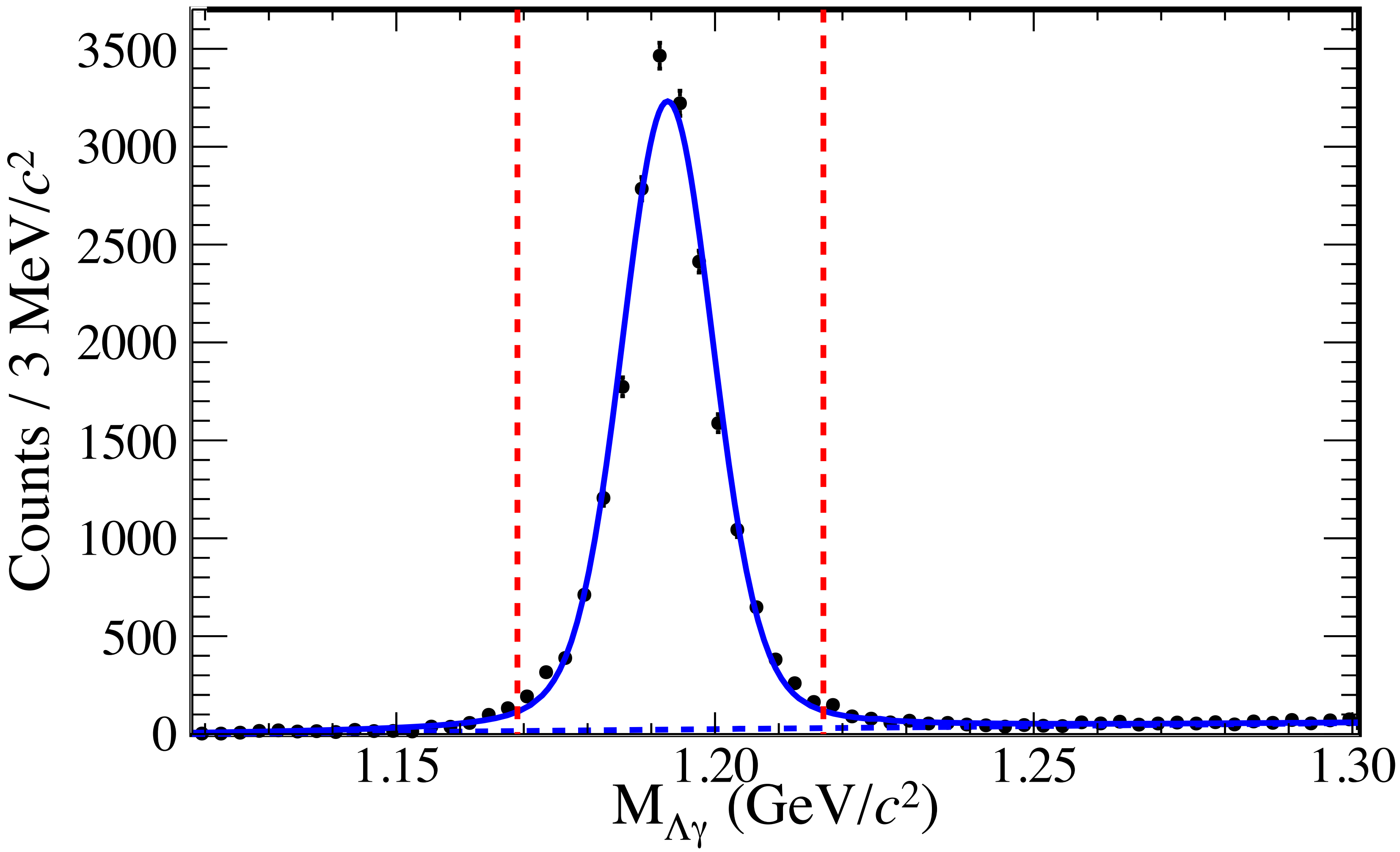
$\Lambda(1116)$

$\text{mean} = 1116\,\text{MeV}$

$\sigma = 3\,\text{MeV}$

Invariant mass of $\Lambda\gamma$

- Events within $1.107\,\mathrm{GeV}/c^2 < M_{\pi^- p} < 1.125\,\mathrm{GeV}/c^2$



Signal ➡ Voigtian

Background ➡ 1st order poly.

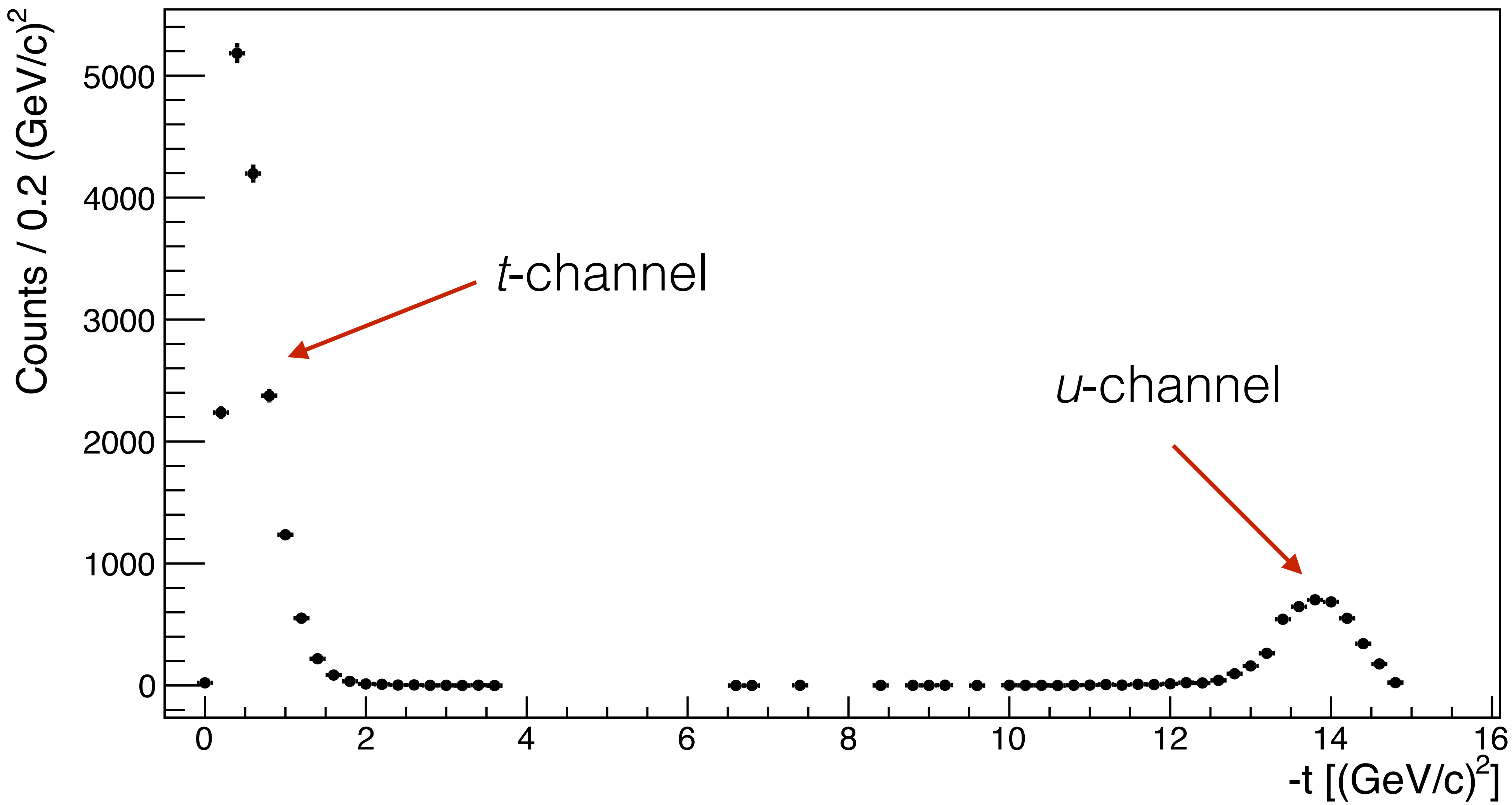
$\mathrm{mean} = 1193\,\mathrm{MeV}$

$\sigma = 8\,\mathrm{MeV}$

- Background under Σ^0 peak $\sim 2\%$

-*t* distribution

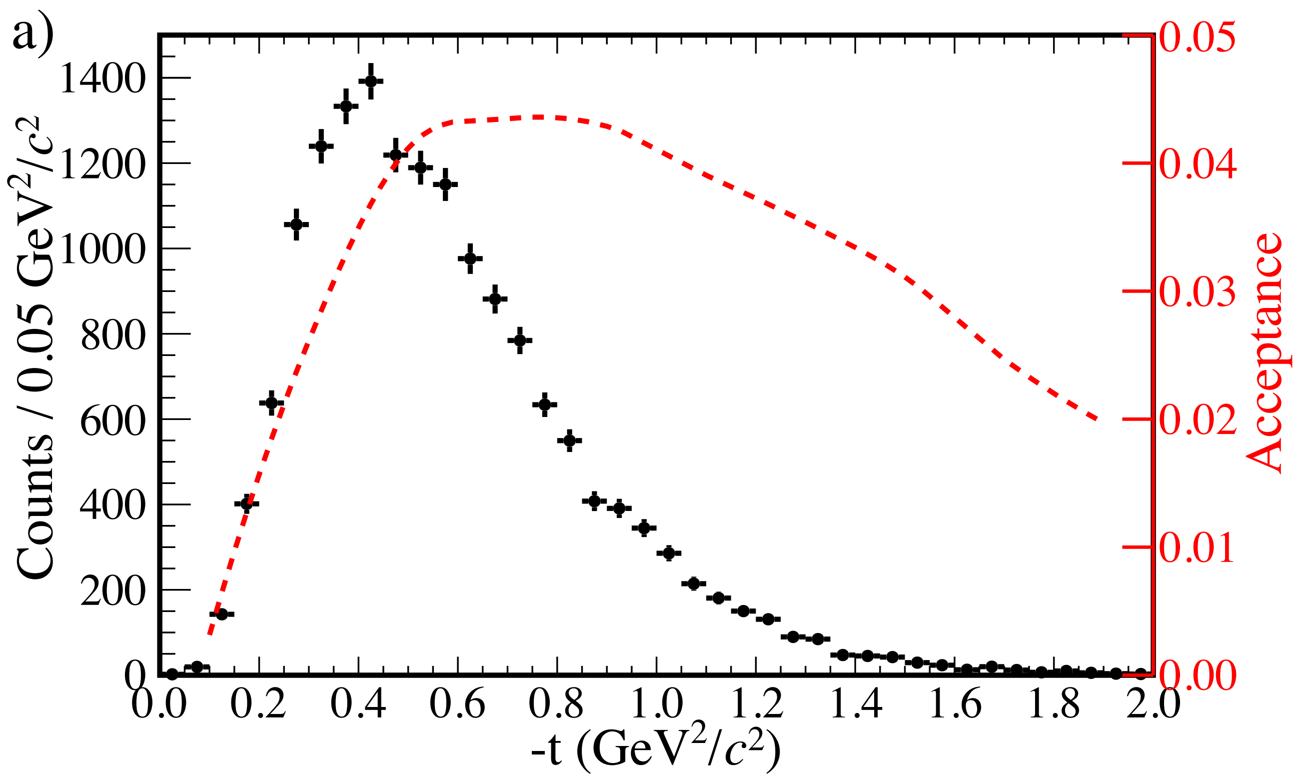
- Events within $1.169\,\mathrm{GeV}/c^2 < M_{\Lambda\gamma} < 1.217\,\mathrm{GeV}/c^2$

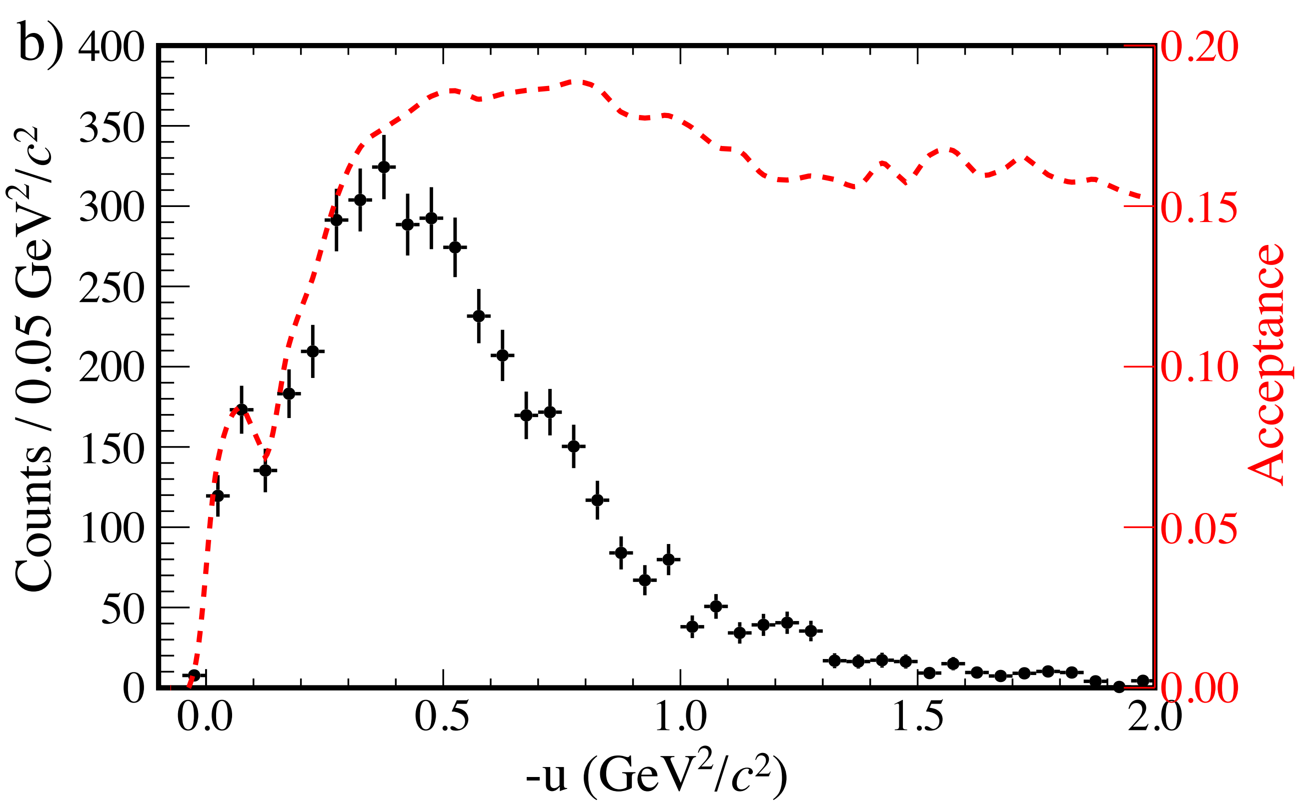


$$t = (p_{\mathrm{beam}} - p_{K^+})^2$$

- Observe both t- and u-channel contributions

Acceptance



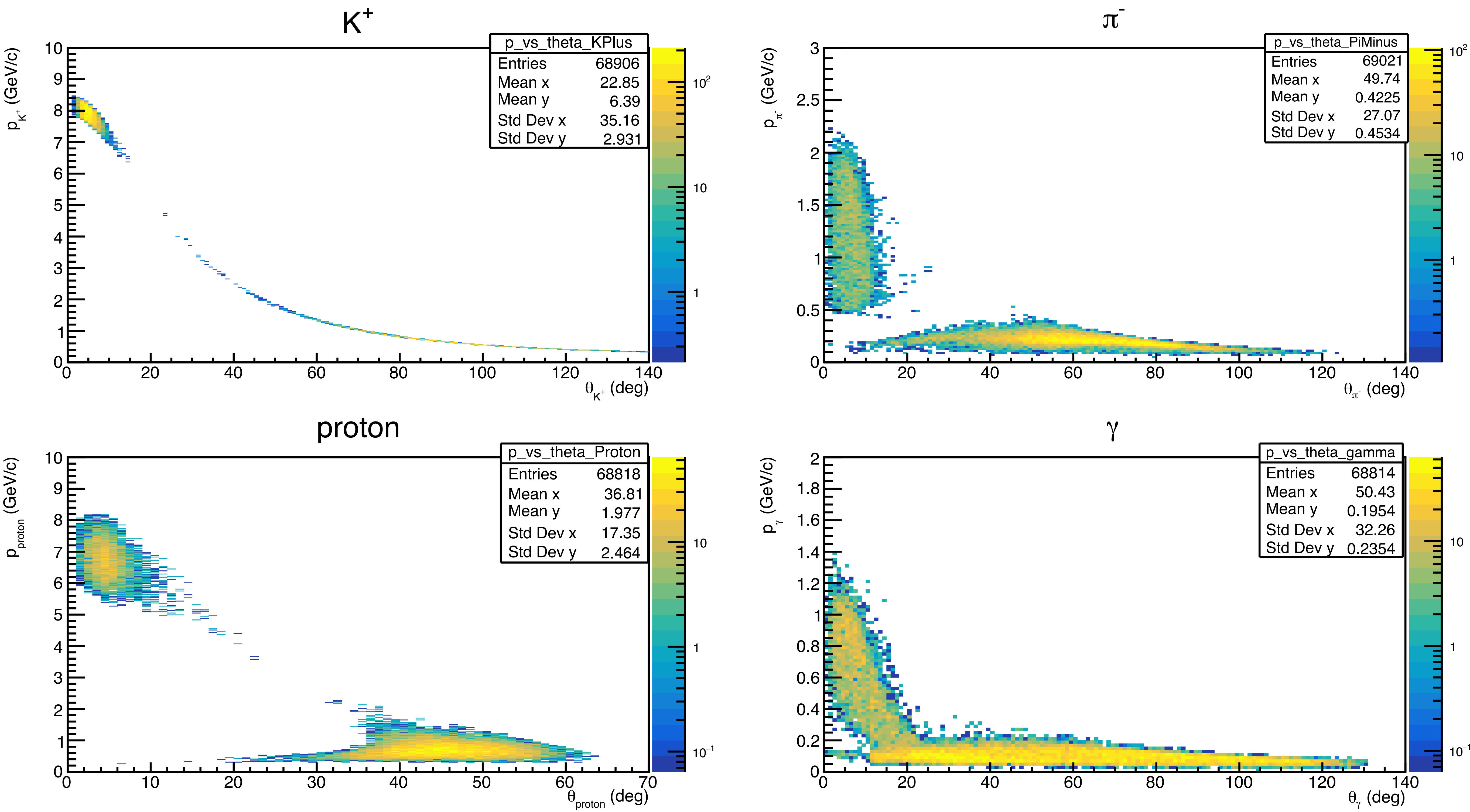


t-channel yield $\sim 4 \times$ u-channel yield

$$u = (p_{\text{target}} - p_{K^+})^2$$

Higher acceptance for u-channel

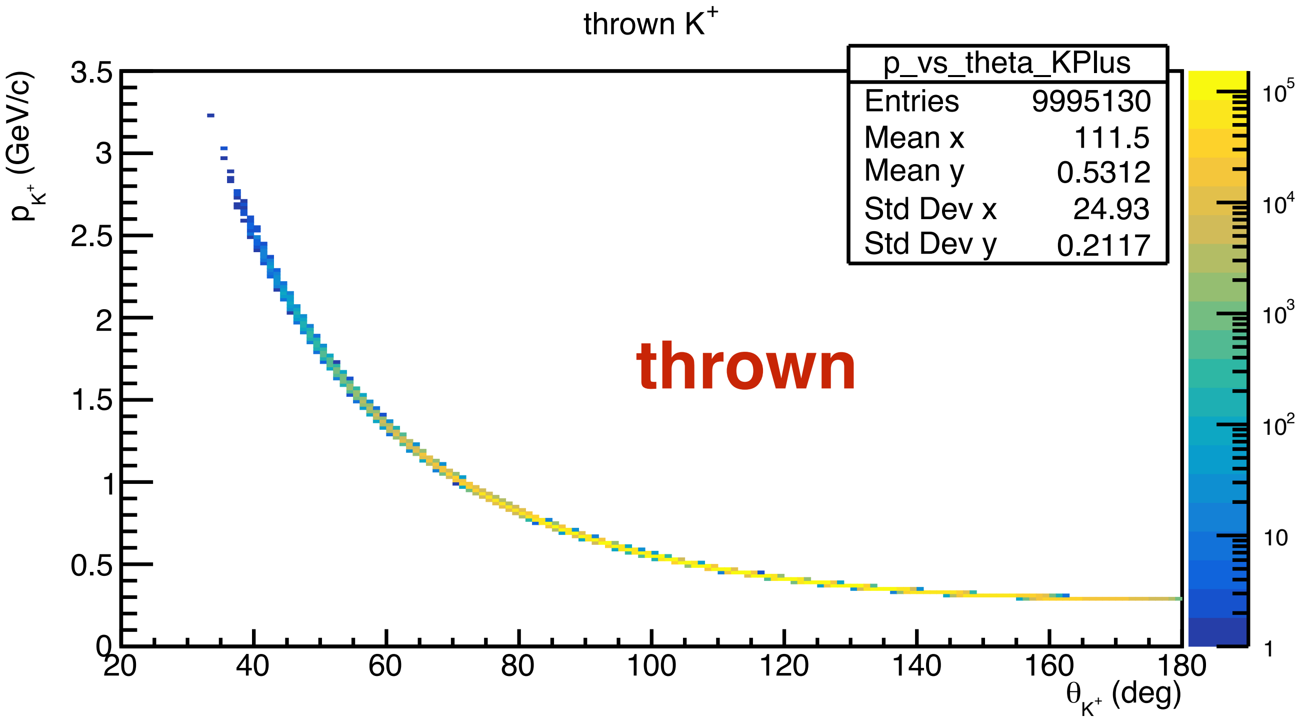
Kinematics (p vs theta) : data

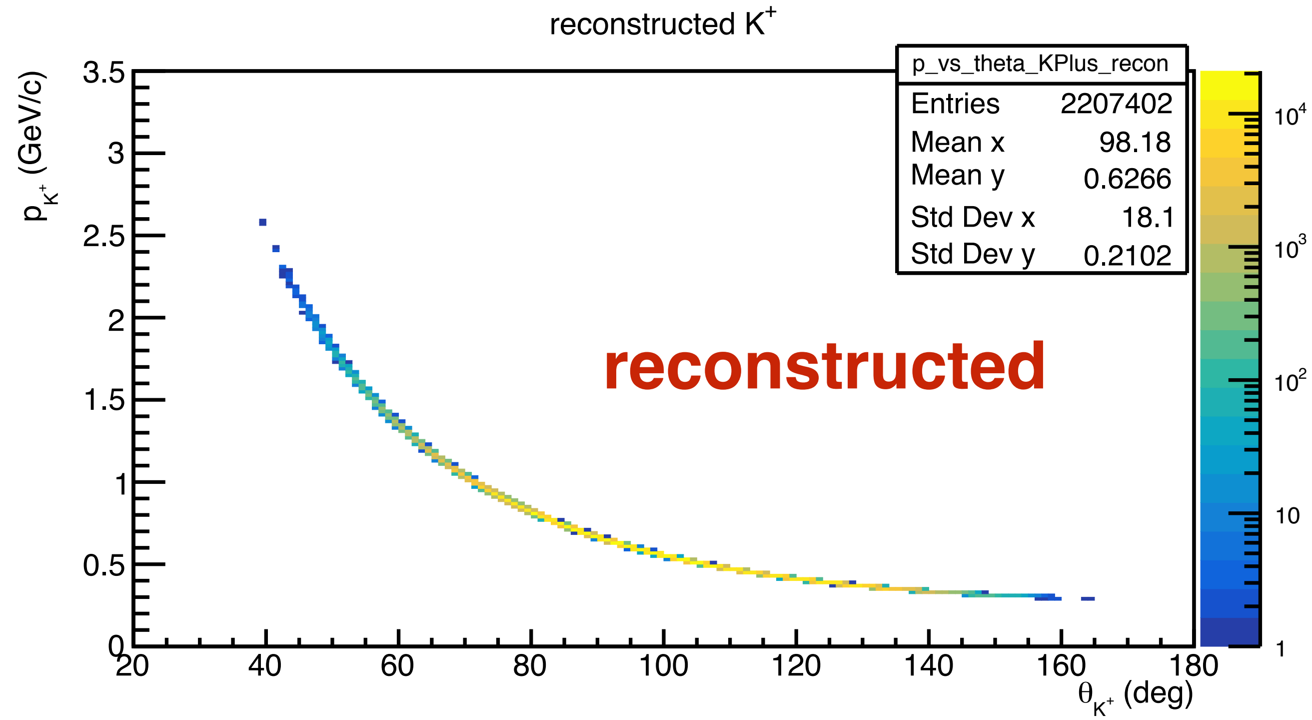


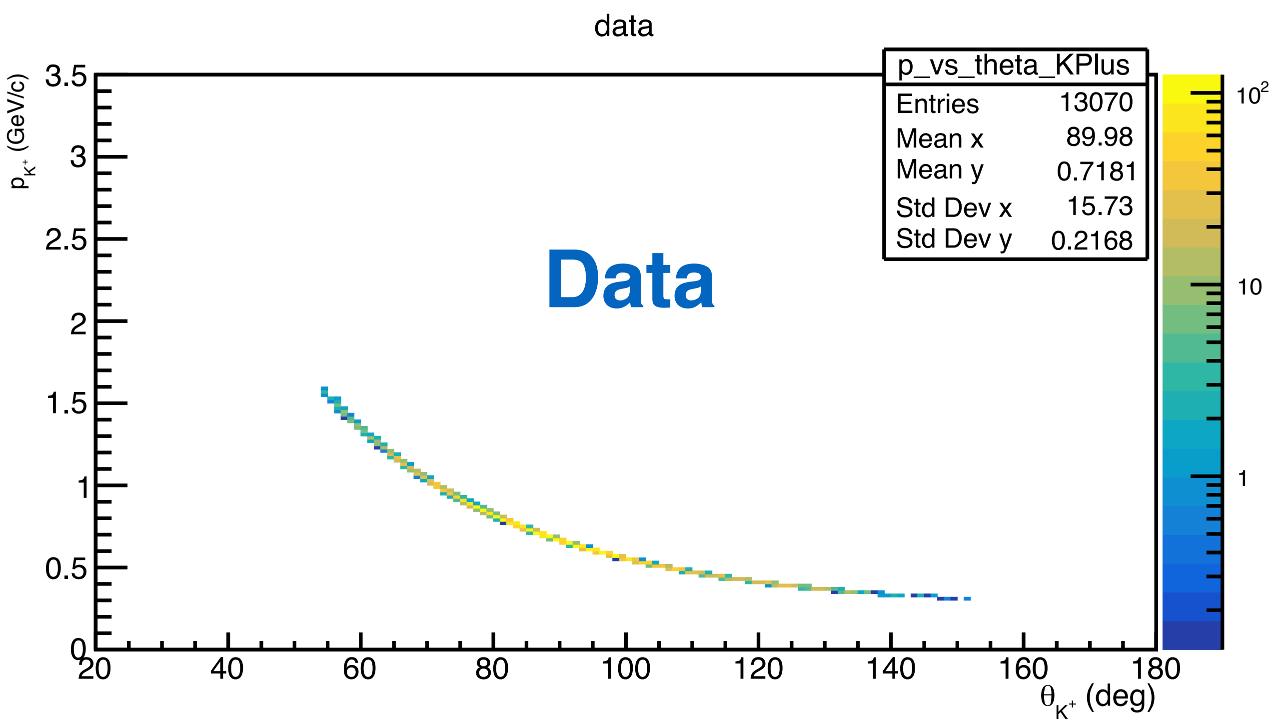
- Events with no cut on $-t$

Kinematics for *u*-channel

MC





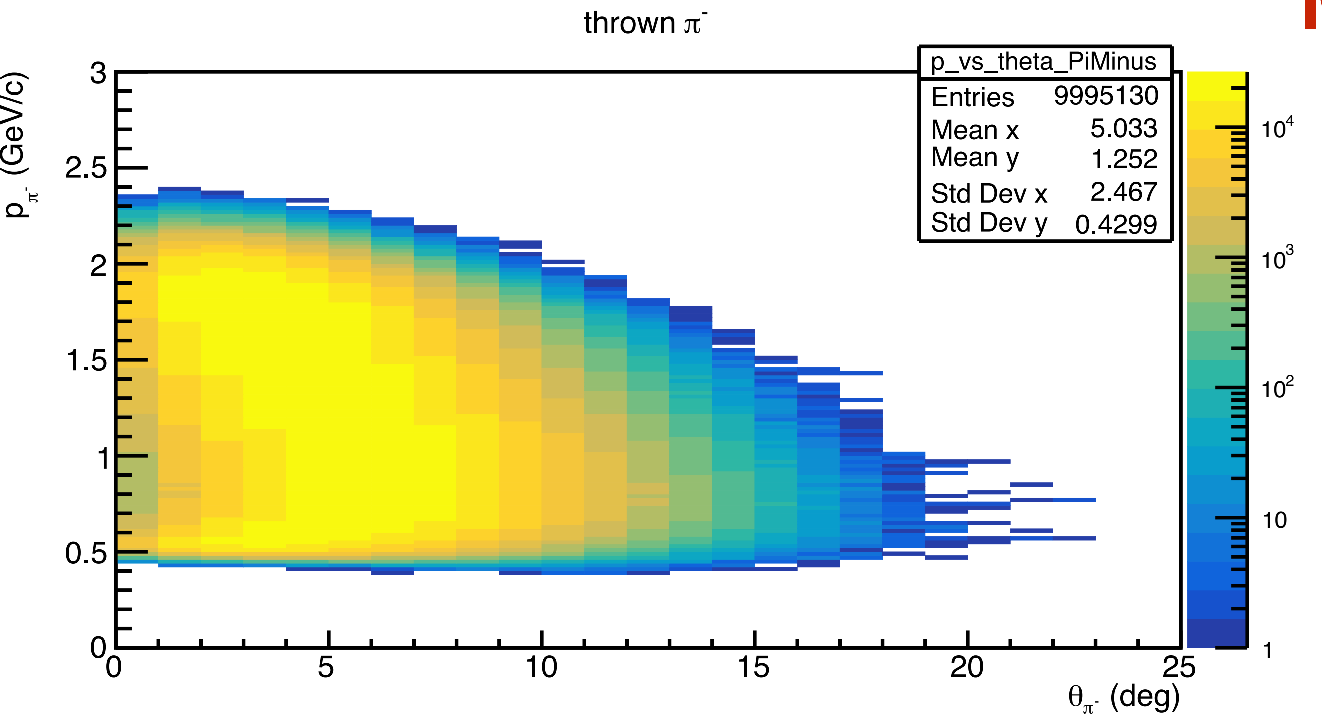


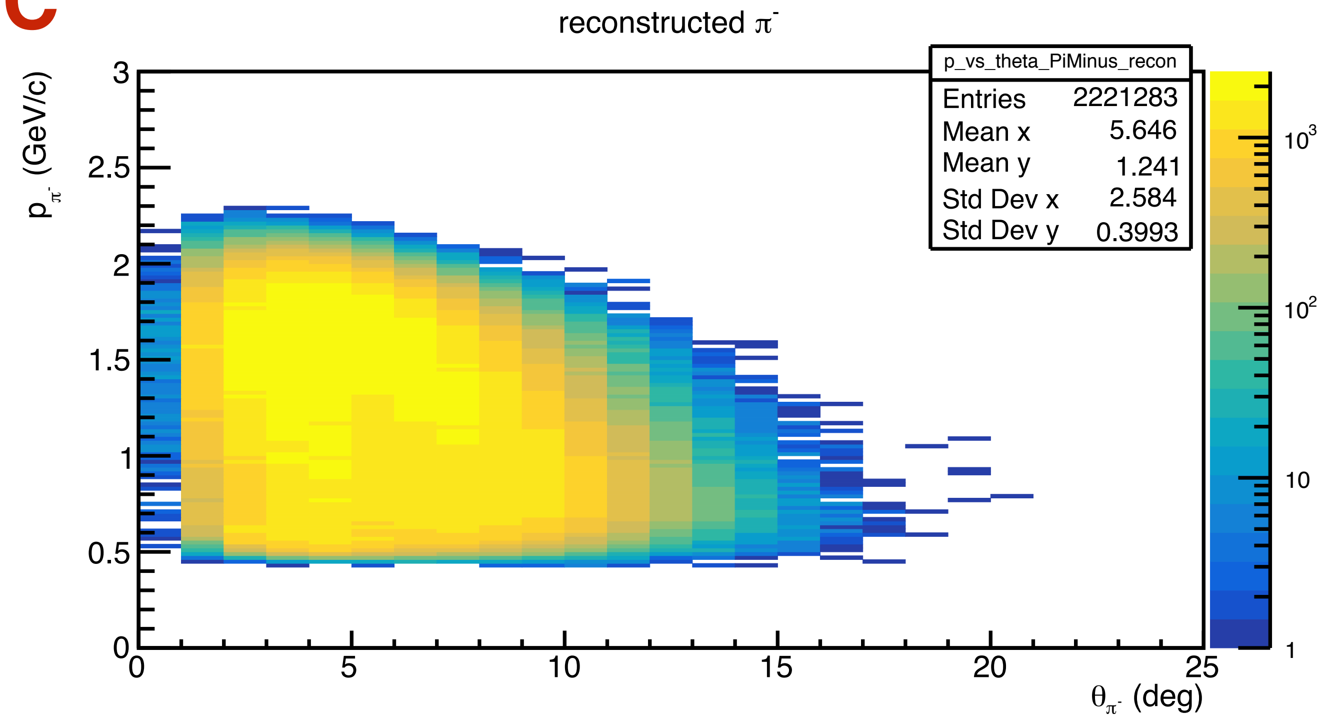
p vs. θ

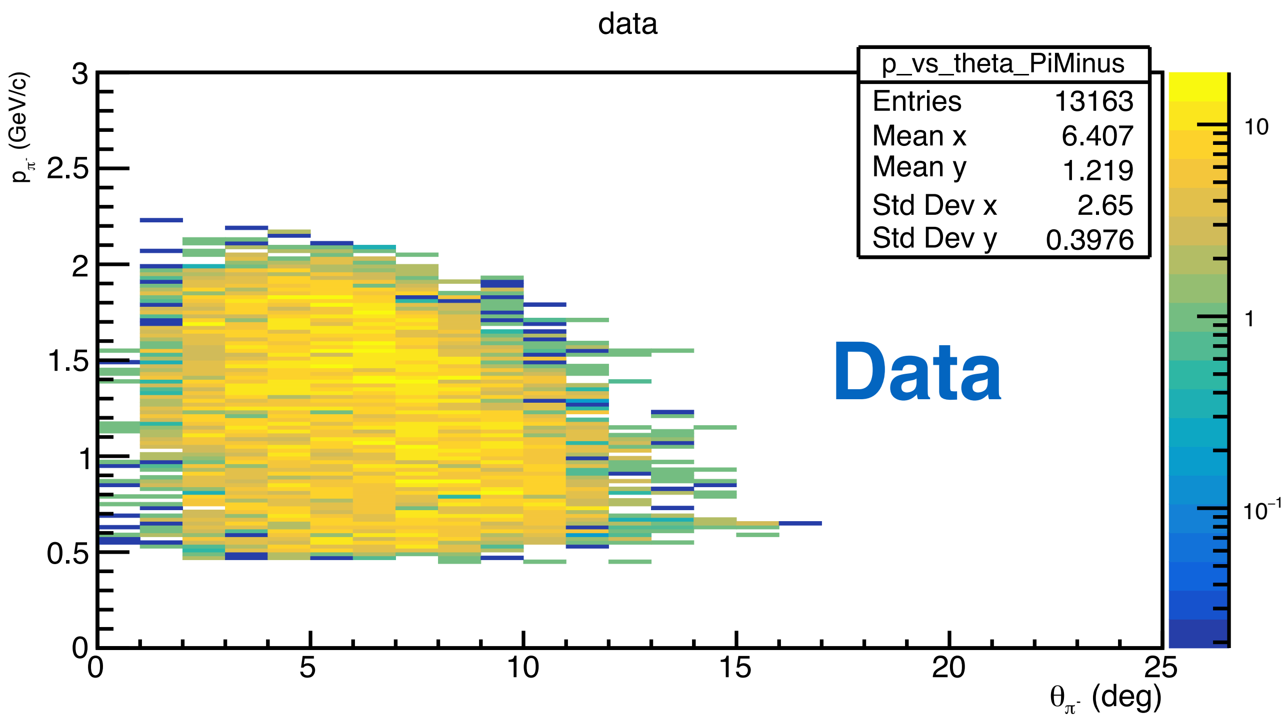
K^+

$-u < 2.0\ \mathrm{GeV}^2$

MC



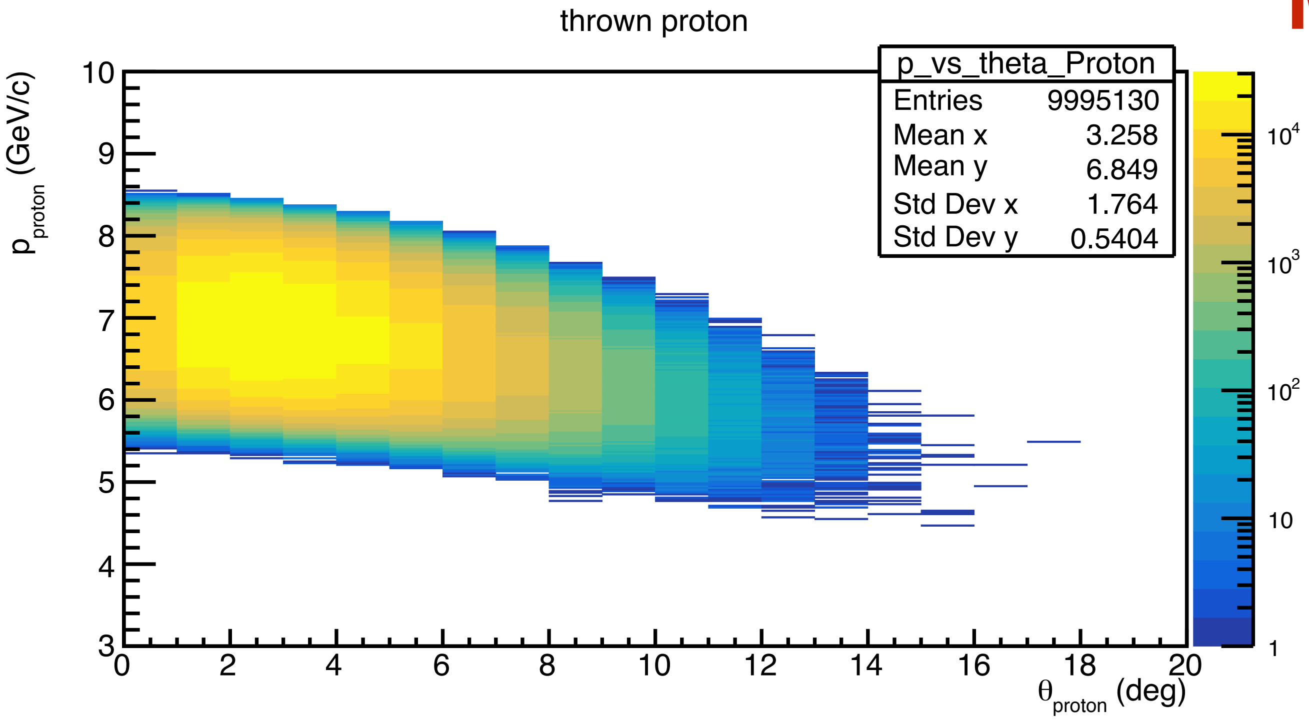


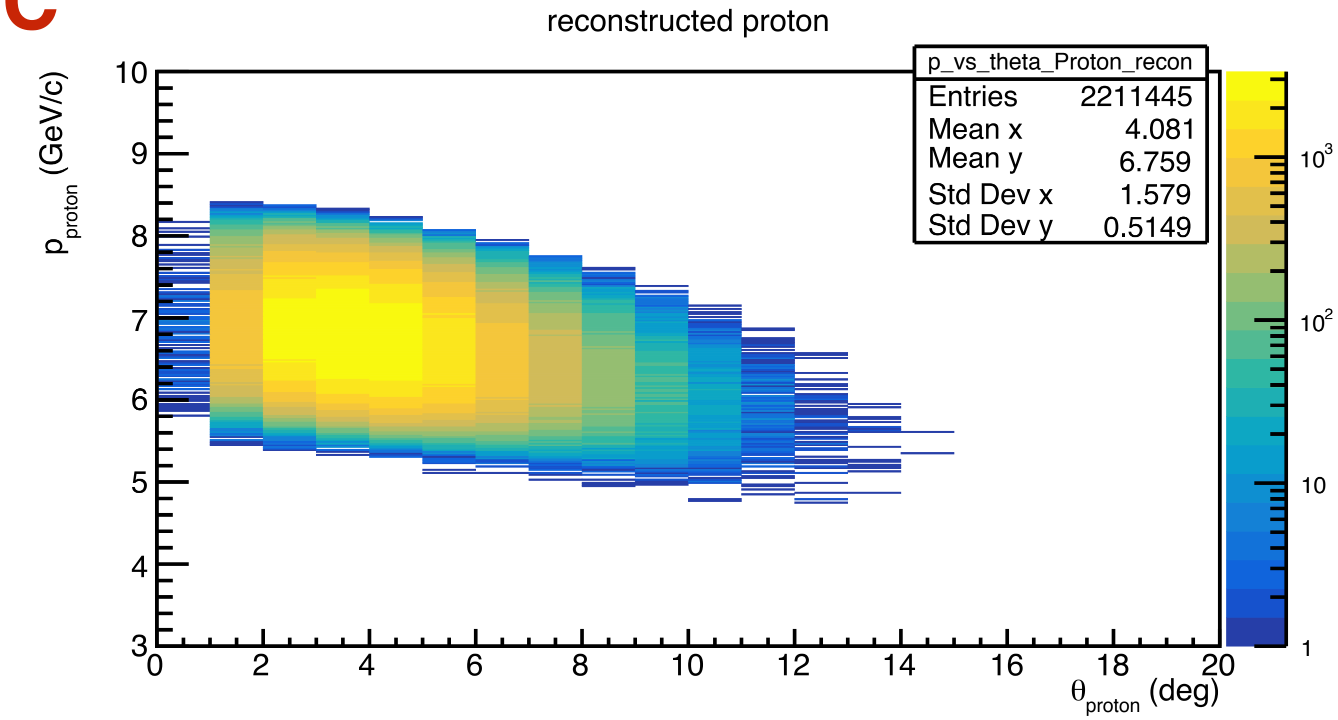


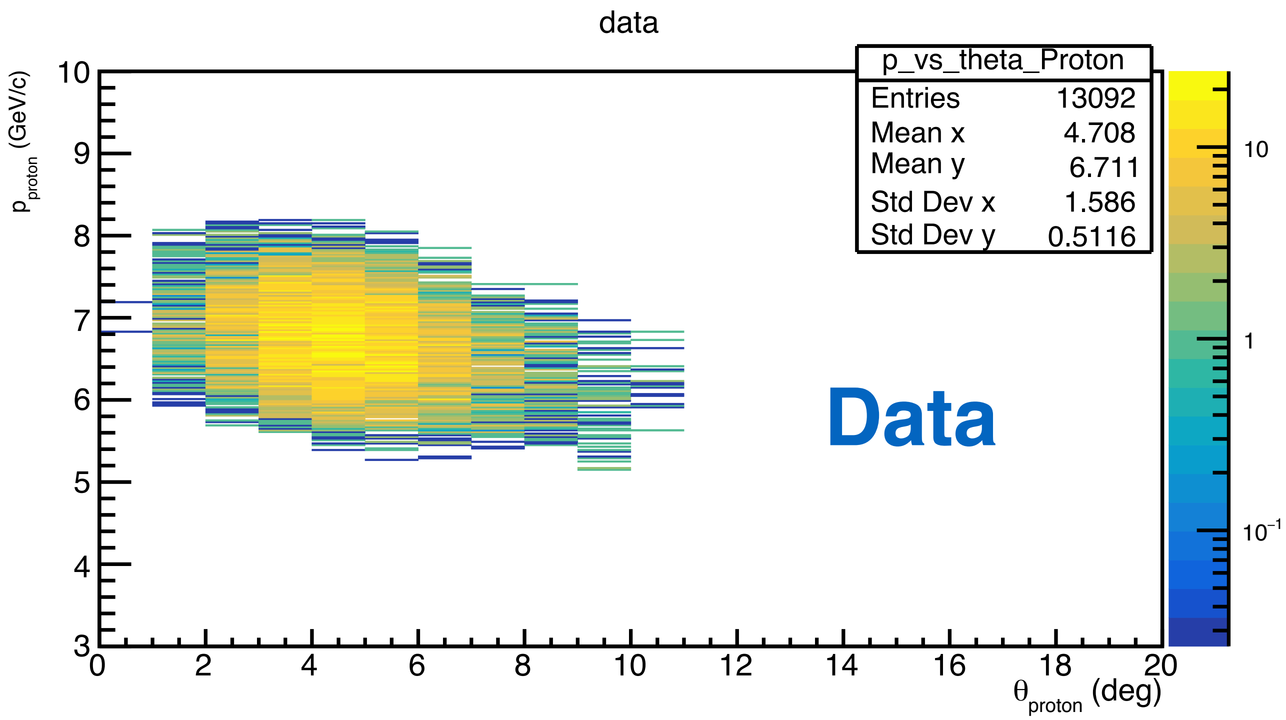
p vs. θ

π^-

MC



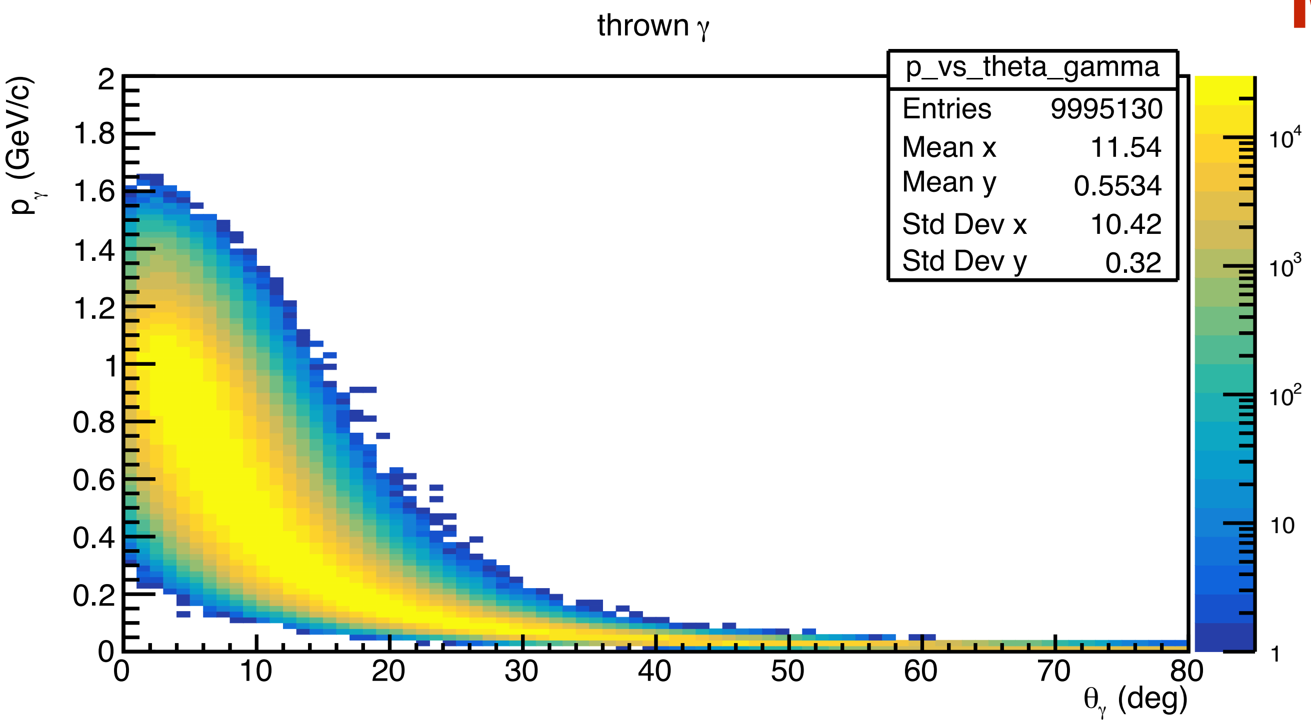


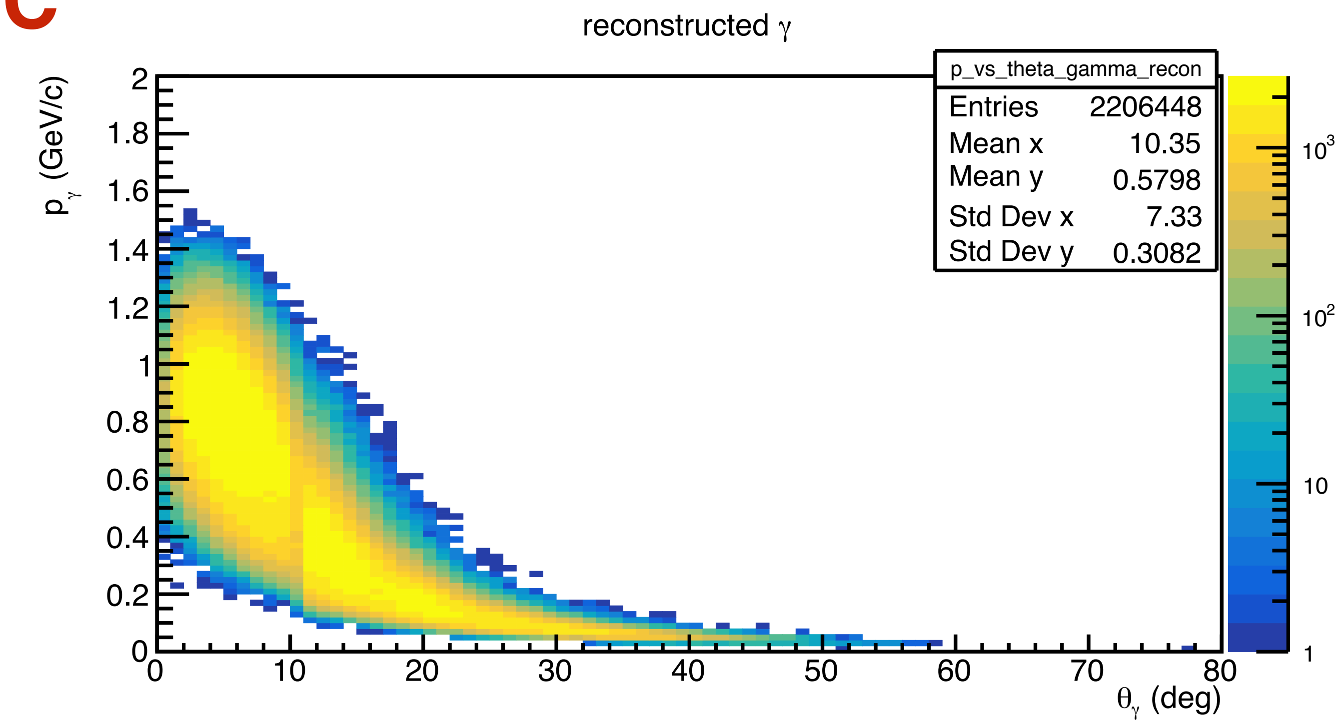


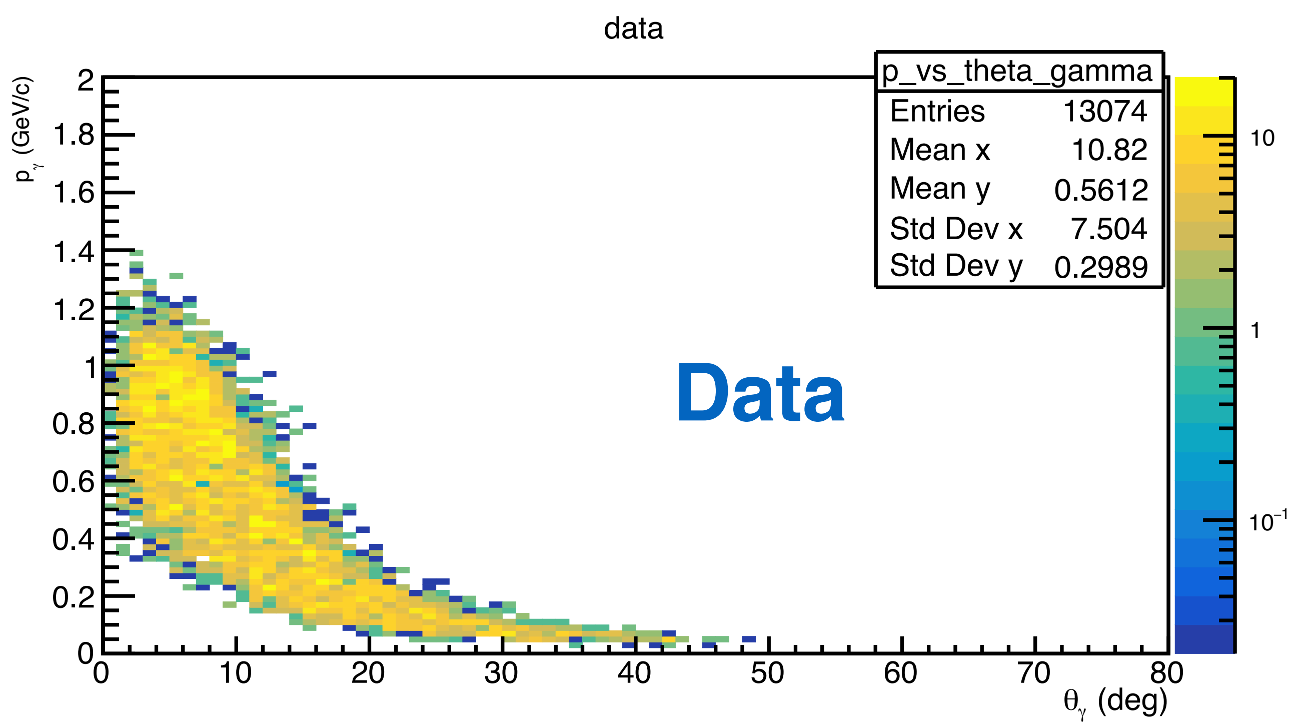
p vs. θ

proton

MC



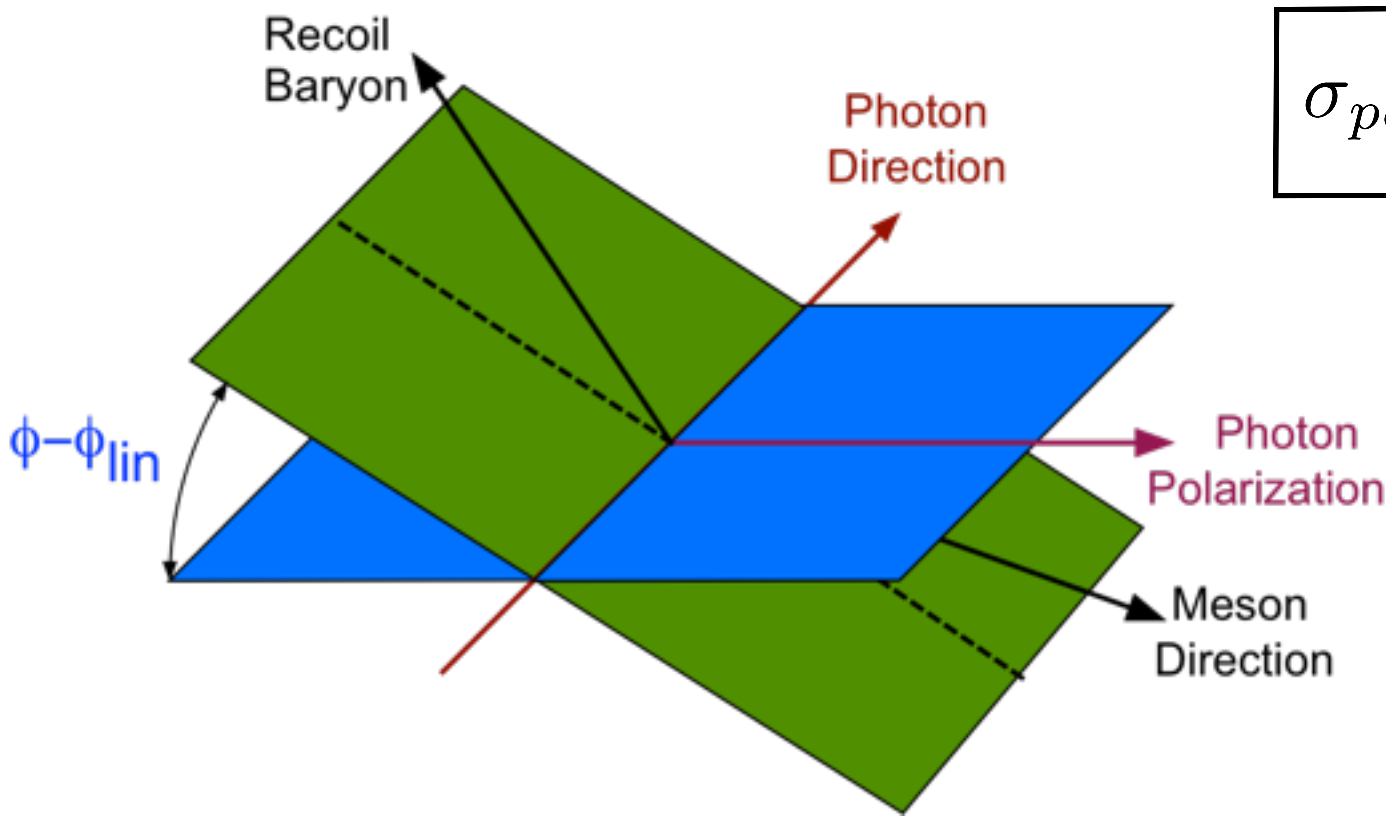




p vs. θ

γ

Beam asymmetry method



$$\boxed{\sigma_{pol} = \sigma_{unpol}[1 - P_\gamma \Sigma \cos(2(\phi - \phi_{lin}))]}$$

$\phi_{\rm lin}$

⬇

use 2 orientation sets 0/90 and -45/45

σ_{pol} – cross section for a linearly polarized photon beam

σ_{unpol} – unpolarized cross section

ϕ – angle between plane parallel to the lab floor and K^+ production plane

$\phi_{\rm lin}$ – angle between photon polarization plane and lab floor

P_γ – magnitude of photon beam polarization

Beam asymmetry method

cross sections for two orthogonal polarization orientations

$$\sigma_{\parallel}(\phi) = \sigma_{pol}(\phi, \phi_{lin} = 0) = \sigma_{unpol}(1 - P_{\parallel}\Sigma\cos 2\phi)$$
$$\sigma_{\perp}(\phi) = \sigma_{pol}(\phi, \phi_{lin} = 90) = \sigma_{unpol}(1 + P_{\perp}\Sigma\cos 2\phi)$$

event yields

$$Y_{\parallel}(\phi) \sim N_{\parallel}[\sigma_{unpol}A(\phi)(1 - P_{\parallel}\Sigma\cos 2\phi)]$$
$$Y_{\perp}(\phi) \sim N_{\perp}[\sigma_{unpol}A(\phi)(1 + P_{\perp}\Sigma\cos 2\phi)]$$

$A(\phi)$ ➡ detector acceptance

Yield Asymmetry

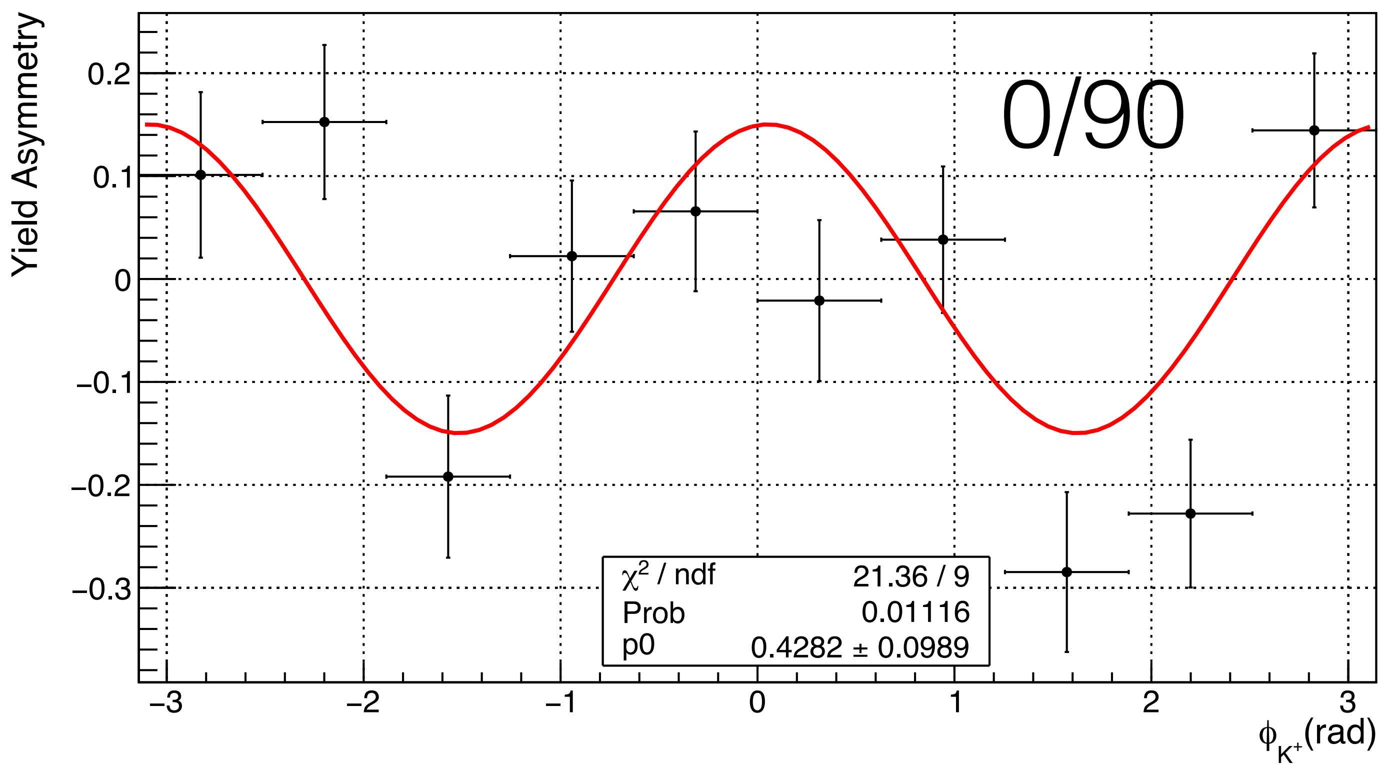
$$\frac{Y(\phi)_{\perp} - F_R Y(\phi)_{\parallel}}{Y(\phi)_{\perp} + F_R Y(\phi)_{\parallel}} = \frac{(P_{\perp} + P_{\parallel})\Sigma\cos 2(\phi - \phi_0)}{2 + (P_{\perp} - P_{\parallel})\Sigma\cos 2(\phi - \phi_0)}$$

$F_R = \frac{N_{\perp}}{N_{\parallel}}$ ➡ photon flux ratio

Σ ➡ beam asymmetry

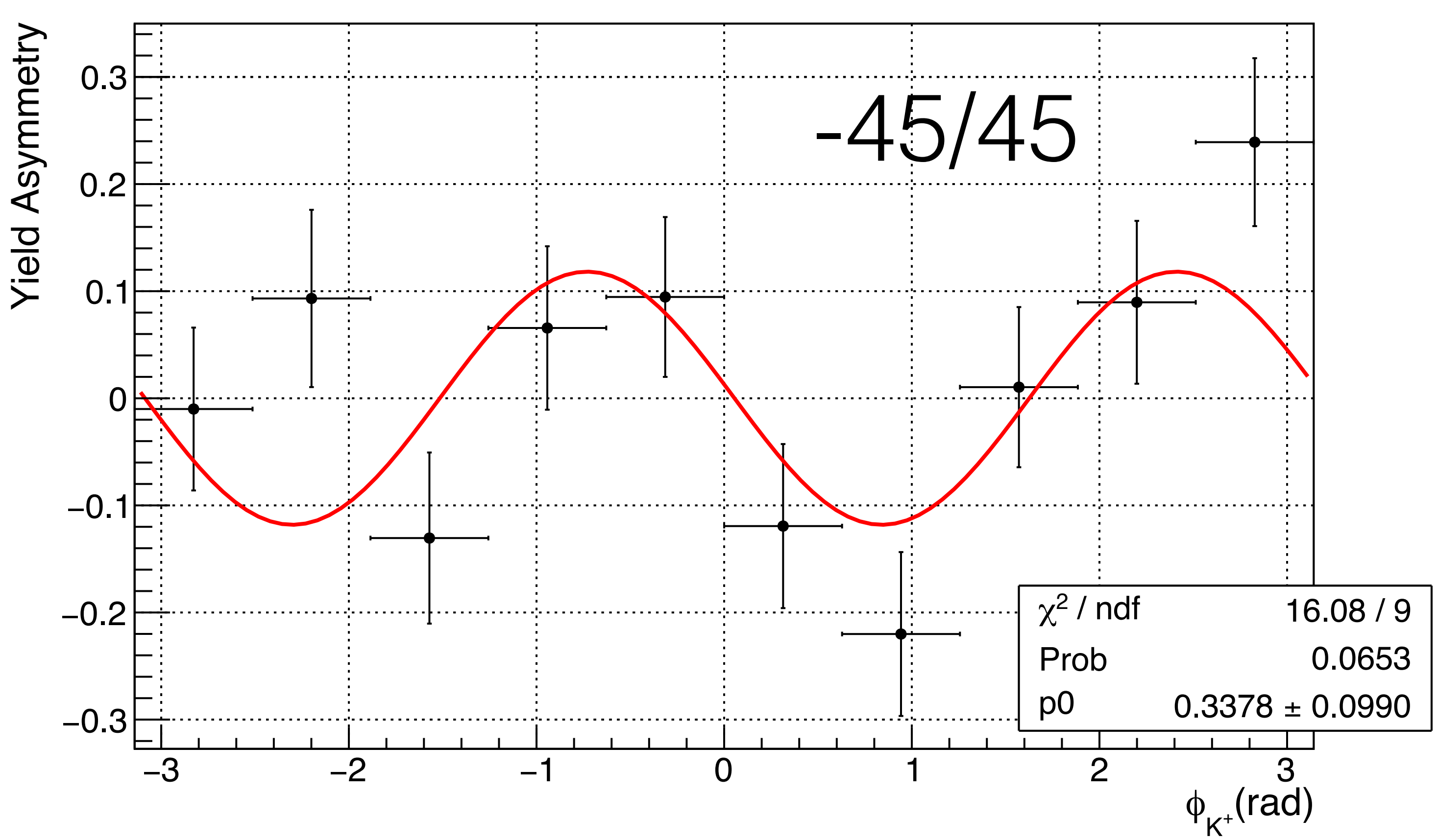
ϕ_0 ➡ phase offset

Yield asymmetry for *u*-channel



$$-u < 2.0\ (\mathrm{GeV}/c)^2$$

$$\Sigma = 0.428 \pm 0.099$$



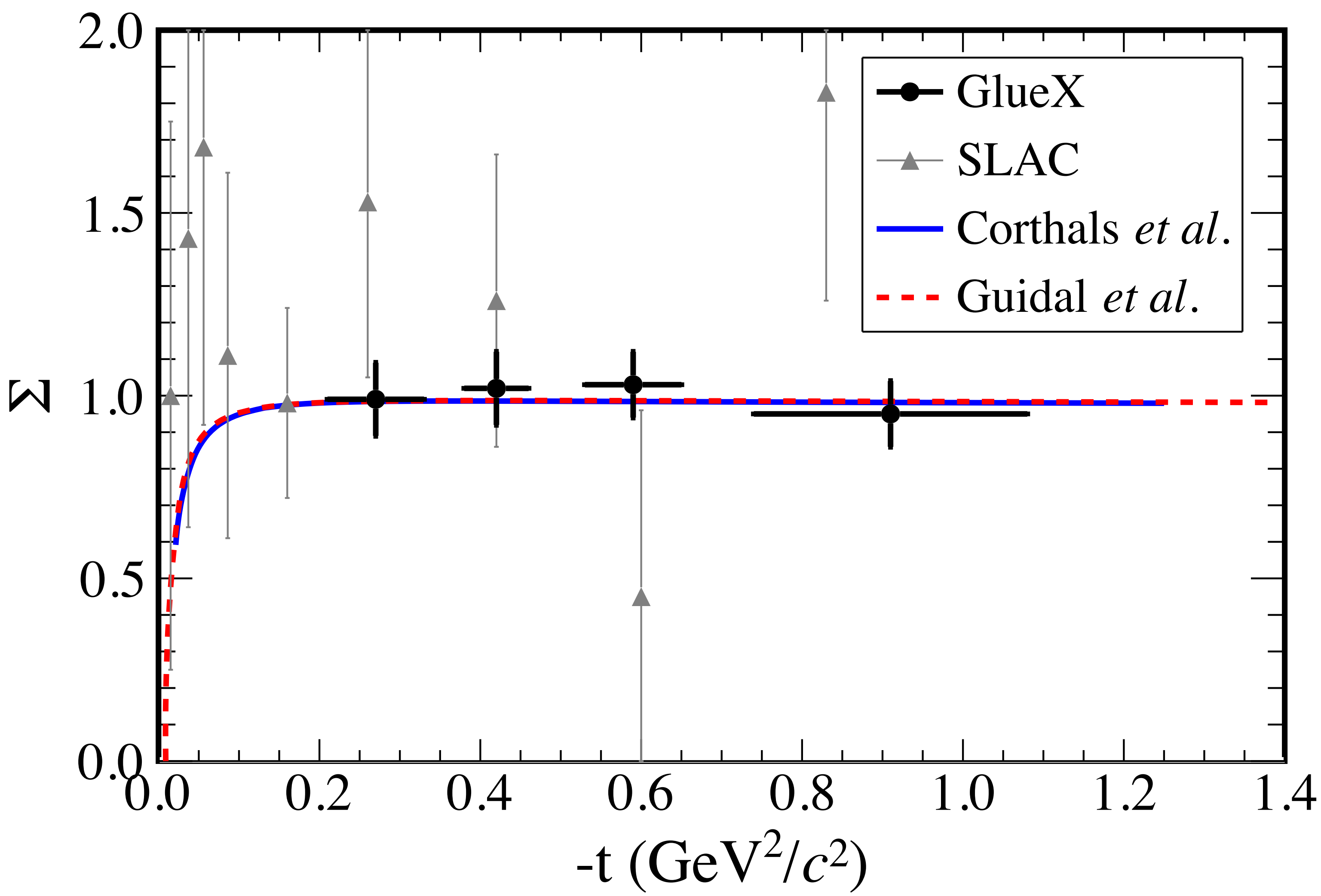
$$\Sigma = 0.338 \pm 0.099$$

Systematics summary for *u*-channel

Study	0/90 Systematic Error	-45/45 Systematic Error
Event selection	0.050	0.040
Phase dependence	0.022	0.021
Flux normalization dependence	0.006	0.002
Background	0.004	0.004
Non-uniform acceptance	0.015	0.015
Total	0.057	0.048

- Main contribution is due to event selection

Beam asymmetry for *t*-channel



SLAC $E_\gamma = 16$ GeV

Phys. Rev. D **20**, 1553 (1979)

Corthals *et* al.

Phys. Rev. C **75**, 045204 (2007)

Guidal *et* al.

Nucl. Phys. A**627**, 645 (1997)

- Average $\Sigma = 1.00 \pm 0.05$ in the $-t = (0.1 - 1.4)$ $(\text{GeV}/c)^2$ range
- $\Sigma \sim 1$ ➡ natural parity exchange with $K^*(892)$ Regge trajectory
- Results consistent with theoretical predictions
- First measurement of Σ for $\gamma p \to K^+\Sigma^0$ beyond baryon resonance region

Beam asymmetry for *u*-channel

$-u$ bin ((GeV/c)^2)	Σ	Stat. uncert.	Syst. uncert.	Total uncert.
$-u < 2.0$	0.410	0.070	0.057	0.090

- u-channel result suggests exchange of both $\Sigma(J = 1/2)$ and $Y^*(J = 3/2)$ trajectories contribute
- There is no prediction for beam asymmetry as a function of u

Summary

- First measurement of Σ in the exclusive reaction $\gamma p \rightarrow K^+\Sigma^0$ beyond baryon resonance region

- Σ as a function of t is consistent with unity and model predictions

- $\Sigma = 0.41 \pm 0.09$ extracted for the u-channel production

- Results will provide important information on strangeness-exchange in photoproduction

Thank You !!

PHYSICAL REVIEW C **101**, 065206 (2020)

Measurement of the photon beam asymmetry in $\vec{\gamma} p \to K^+\Sigma^0$ at $E_\gamma = 8.5$ GeV

S. Adhikari,[22] A. Ali,[10] M. Amaryan,[22,*] A. Austregesilo,[3] F. Barbosa,[14] J. Barlow,[7] E. Barriga,[7] R. Barsotti,[12] T. D. Beattie,[23] V. V. Berdnikov,[17] T. Black,[20] W. Boeglin,[6] W. J. Briscoe,[8] T. Britton,[14] W. K. Brooks,[24] B. E. Cannon,[7] N. Cao,[11] E. Chudakov,[14] S. Cole,[1] O. Cortes,[8] V. Crede,[7] M. M. Dalton,[14] T. Daniels,[20] A. Deur,[14] S. Dobbs,[7] A. Dolgolenko,[13] R. Dotel,[6] M. Dugger,[1] R. Dzhygadlo,[10] H. Egiyan,[14] T. Erbora,[6] A. Ernst,[7] P. Eugenio,[7] C. Fanelli,[16] S. Fegan,[8] A. M. Foda,[23] J. Foote,[12] J. Frye,[12] S. Furletov,[14] L. Gan,[20] A. Gasparian,[19] C. Gleason,[12] K. Goetzen,[10] A. Goncalves,[7] V. S. Goryachev,[13] L. Guo,[6] H. Hakobyan,[24] A. Hamdi,[10] G. M. Huber,[23] A. Hurley,[28] D. G. Ireland,[9] M. M. Ito,[14] N. S. Jarvis,[3] R. T. Jones,[5] V. Kakoyan,[27] G. Kalicy,[4] M. Kamel,[6] C. Kourkoumelis,[2] S. Kuleshov,[24] I. Larin,[15] D. Lawrence,[14] D. I. Lersch,[7] H. Li,[3] W. Li,[28] B. Liu,[11] K. Livingston,[9] G. J. Lolos,[23] V. Lyubovitskij,[25,26] D. Mack,[14] H. Marukyan,[27] V. Matveev,[13] M. McCaughan,[14] M. McCracken,[3] W. McGinley,[3] C. A. Meyer,[3] R. Miskimen,[15] R. E. Mitchell,[12] F. Nerling,[10] L. Ng,[7] H. Ni,[8] A. I. Ostrovidov,[7] Z. Papandreou,[23] M. Patsyuk,[16] C. Paudel,[6] P. Pauli,[9] R. Pedroni,[19] L. Pentchev,[14] K. J. Peters,[10] W. Phelps,[8] E. Pooser,[14] N. Qin,[21] J. Reinhold,[6] B. G. Ritchie,[1] L. Robison,[21] D. Romanov,[17] C. Romero,[24] C. Salgado,[18] A. M. Schertz,[28] R. A. Schumacher,[3] J. Schwiening,[10] K. K. Seth,[21] X. Shen,[11] M. R. Shepherd,[12] E. S. Smith,[14] D. I. Sober,[4] A. Somov,[14] S. Somov,[17] O. Soto,[24] J. R. Stevens,[28] I. I. Strakovsky,[8] K. Suresh,[23] V. V. Tarasov,[13] S. Taylor,[14] A. Teymurazyan,[23] A. Thiel,[9] G. Vasileiadis,[2] T. Whitlatch,[14] N. Wickramaarachchi,[22,†] M. Williams,[16] T. Xiao,[21] Y. Yang,[16] J. Zarling,[23] Z. Zhang,[29] Q. Zhou,[11] X. Zhou,[29] and B. Zihlmann[14]
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