Carnegie Mellon University

Backward Baryon—Anti-baryon Photoproduction at GlueX

Backward-Angle (u-channel) Physics Workshop

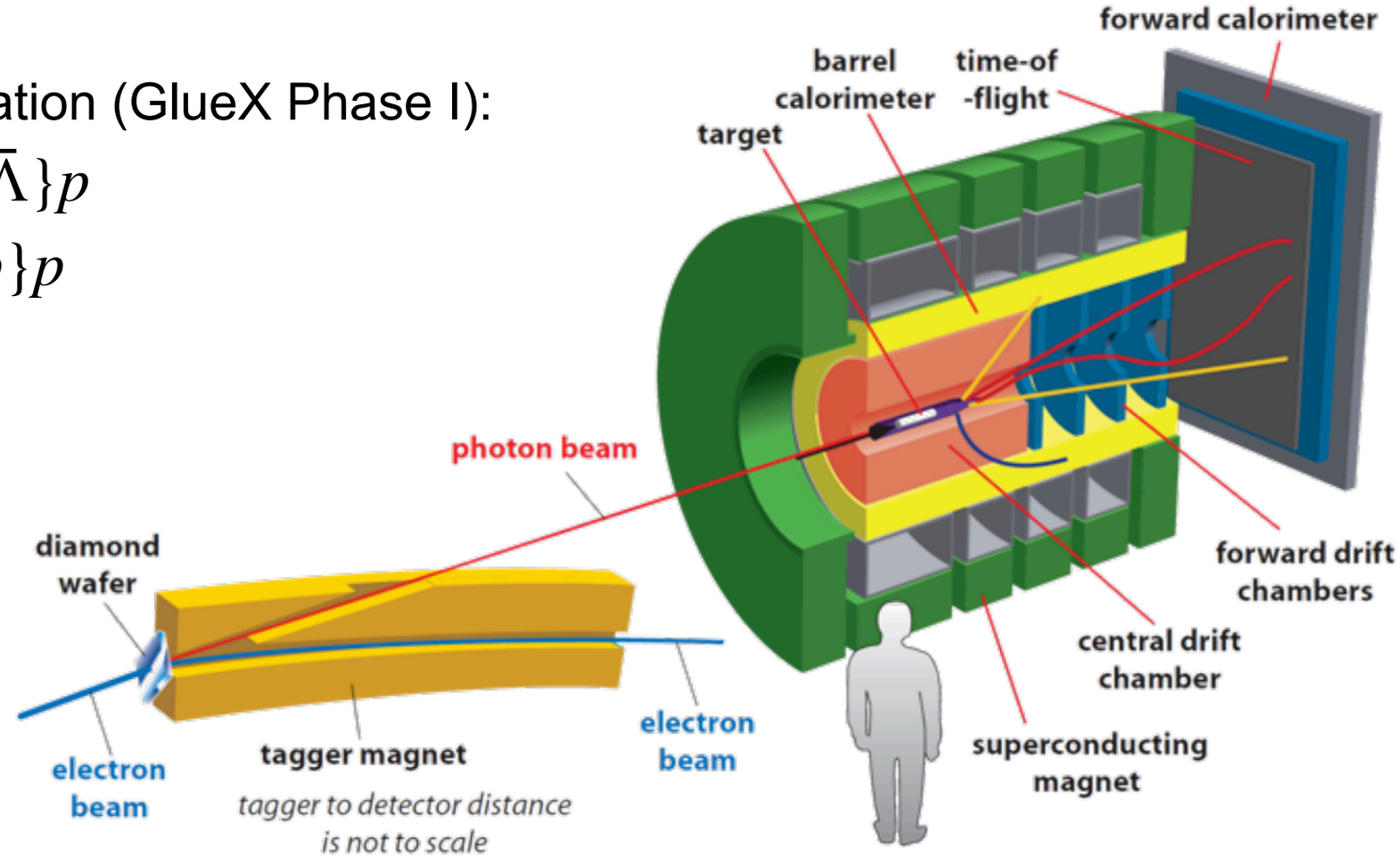
Hao Li

- **Overview**
  - **GlueX Experiment** $\gamma p \to \Lambda\bar{\Lambda}p,\ p\bar{p}p$
- **Data Analysis**
  - **Detection of the Final States**
  - **Angular Distribution Phenomenology**
  - **Comparison of Regge models to approximate angular distributions**
  - **Multi-parameter optimization**

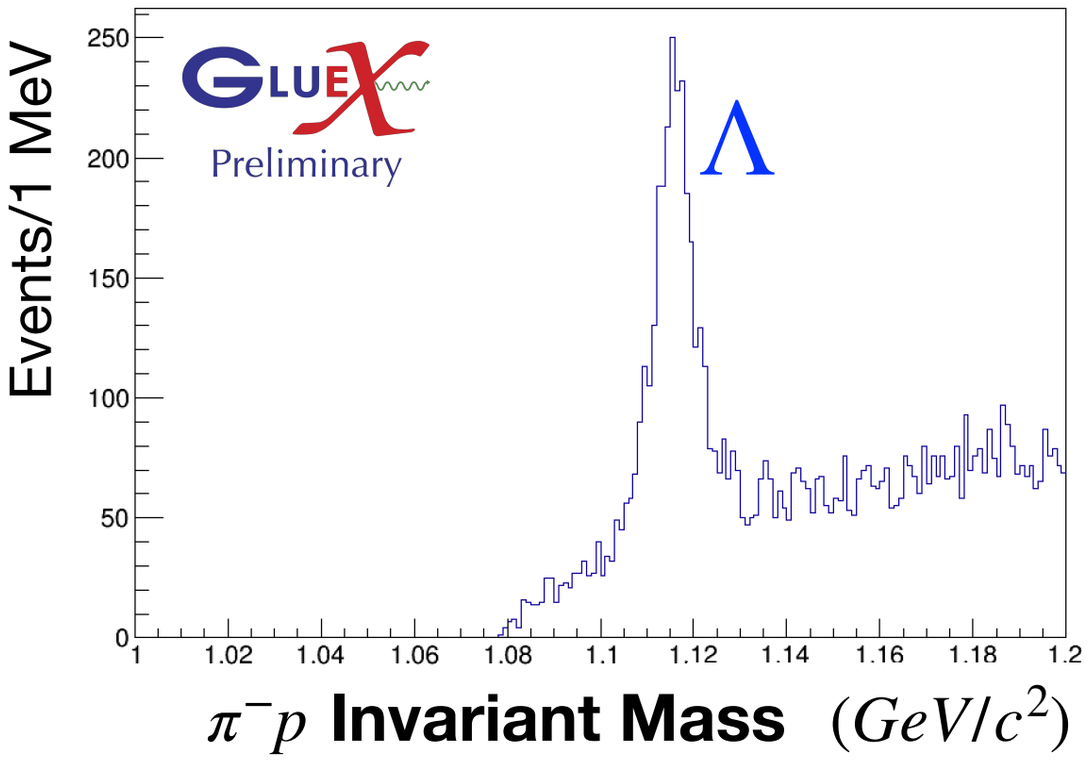
GlueX Experiment at Jefferson Lab

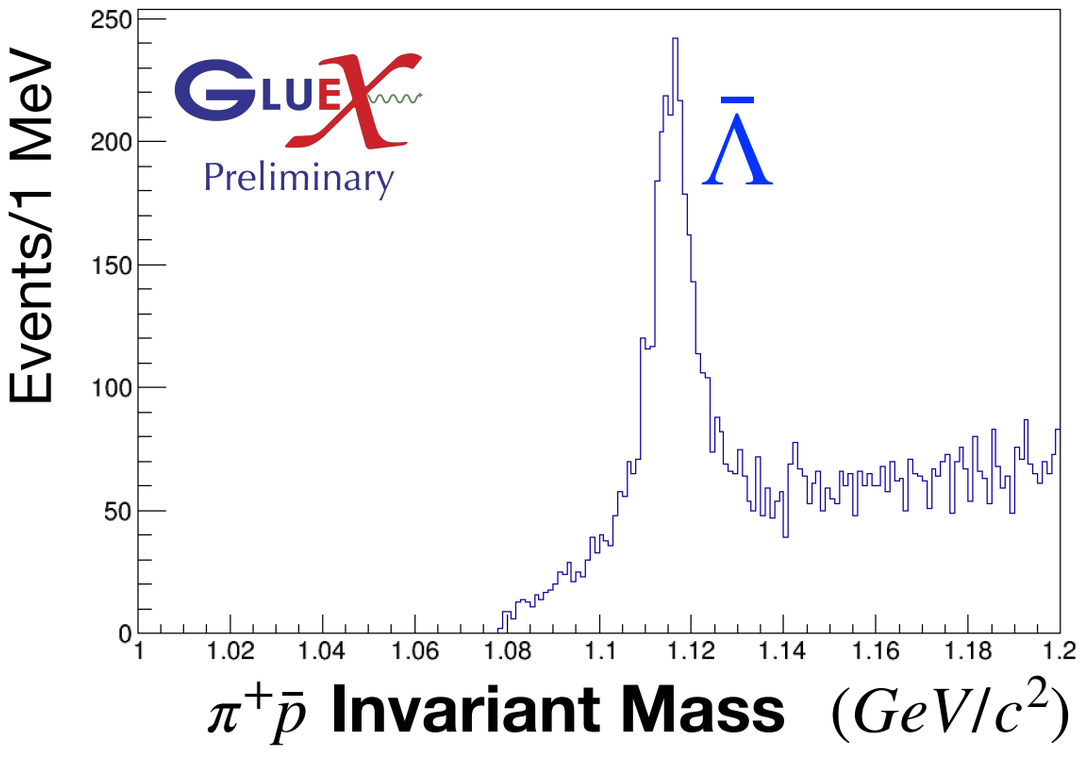
- 4 ~ 11.6 GeV photon Beam
  - Linearly polarized at coherent peak near 9 GeV
  - Four polarization orientations: 0°, 90°, 45°, 135°
  - Produce $\{B\bar{B}\}$ off the proton in the liquid hydrogen target

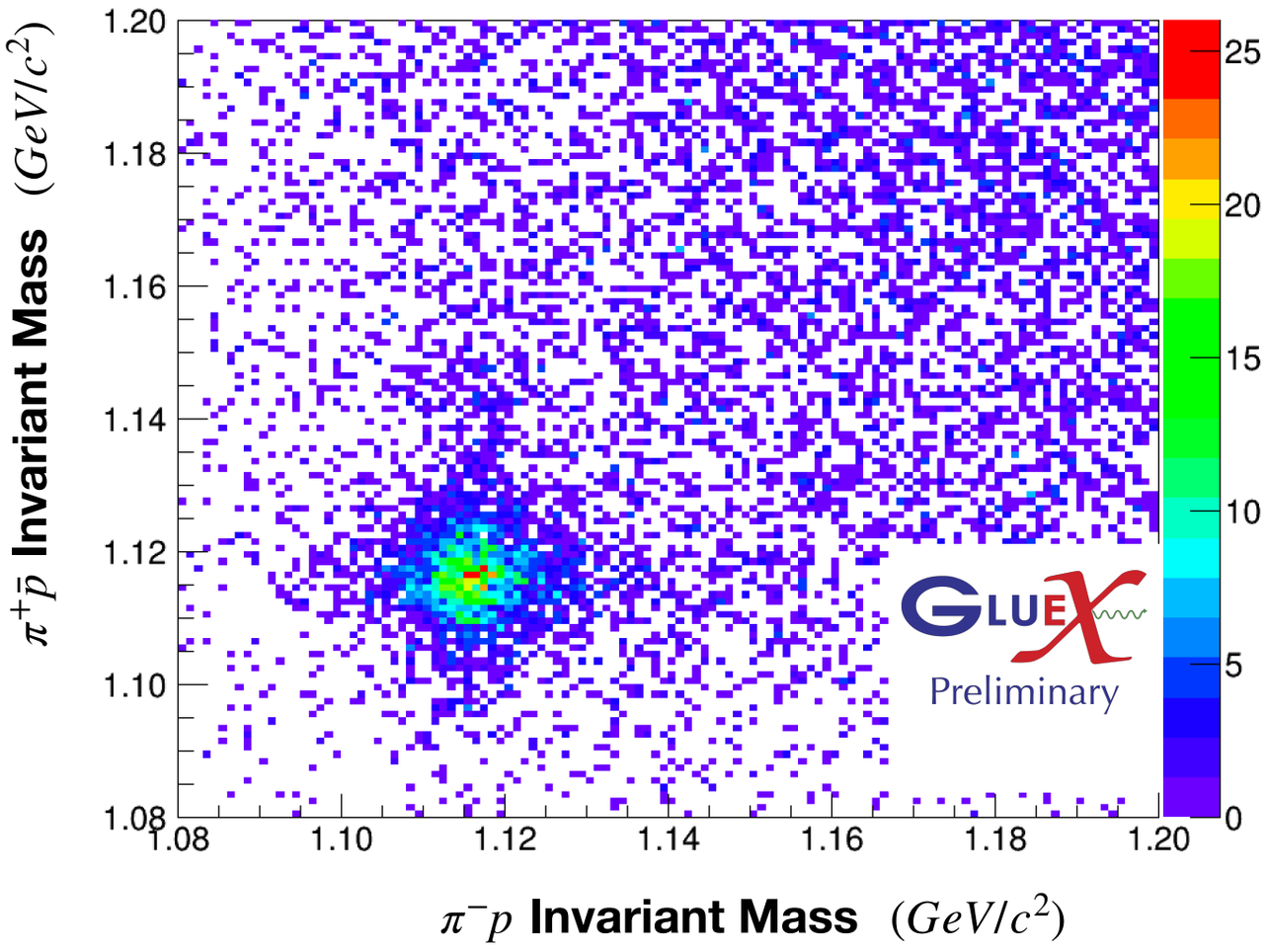
- Total statistics estimation (GlueX Phase I):
  - ~ 0.4 million $\{\Lambda\bar{\Lambda}\}p$
  - ~ 12 million $\{p\bar{p}\}p$



Detection of the Weak Decays: $\gamma p \to \Lambda\ \bar{\Lambda}\ p,\ \Lambda \to \pi^- p$, $\bar{\Lambda} \to \pi^+ \bar{p}$







- **Kinematic fit with Λ, $\bar{\Lambda}$ masses not constrained.**

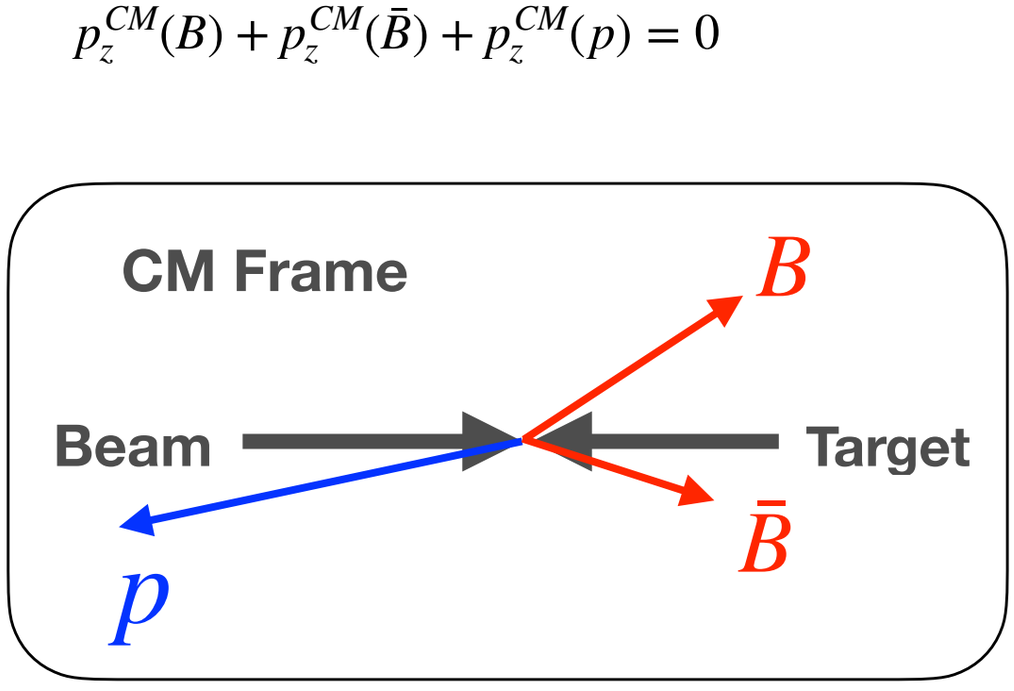
van Hove Diagram for 3-body $\{B\bar{B}\}p$ Final States (CM Frame)

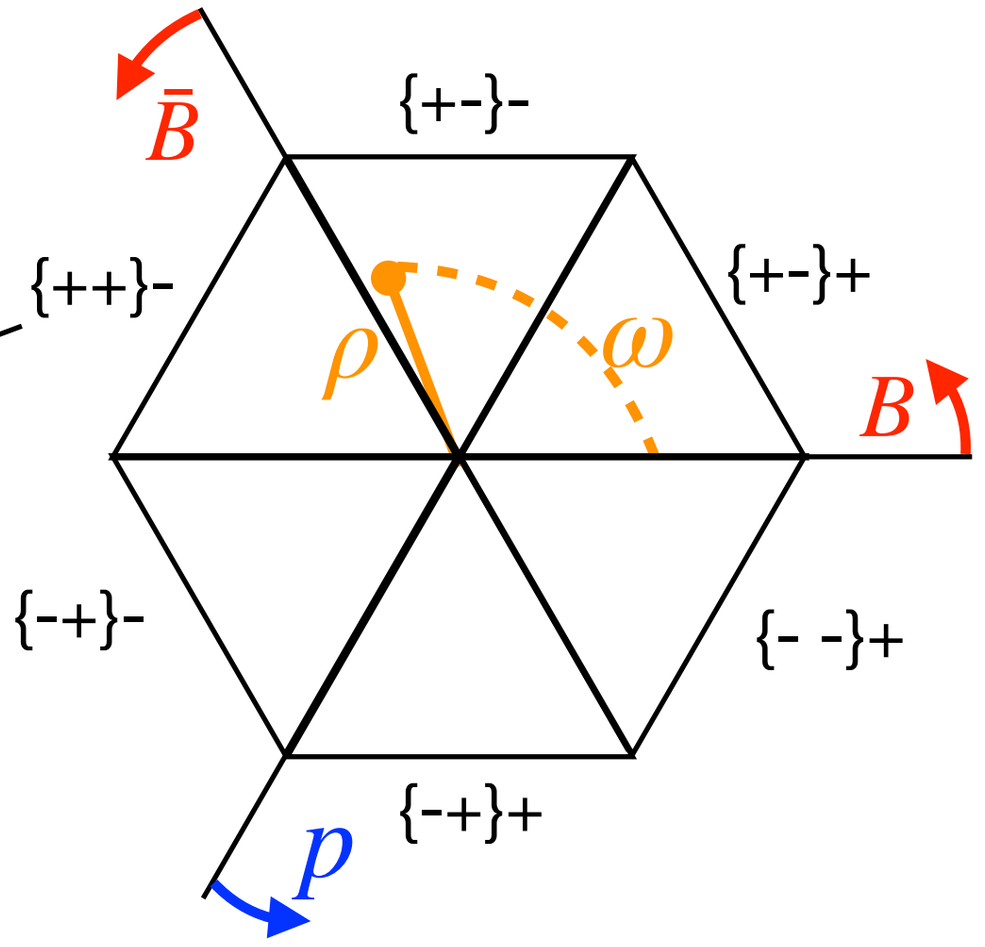
Longitudinal momentums in **CM Frame**
represented with ω and ρ in van Hove diagram:

$$\begin{cases} p_z^{CM}(B) = \rho \sin(\omega) \\ p_z^{CM}(\bar{B}) = \rho \sin(\omega - \frac{2}{3}\pi) \\ p_z^{CM}(p) = \rho \sin(\omega - \frac{4}{3}\pi) \end{cases}$$

$$p_z^{CM}(B) + p_z^{CM}(\bar{B}) + p_z^{CM}(p) = 0$$

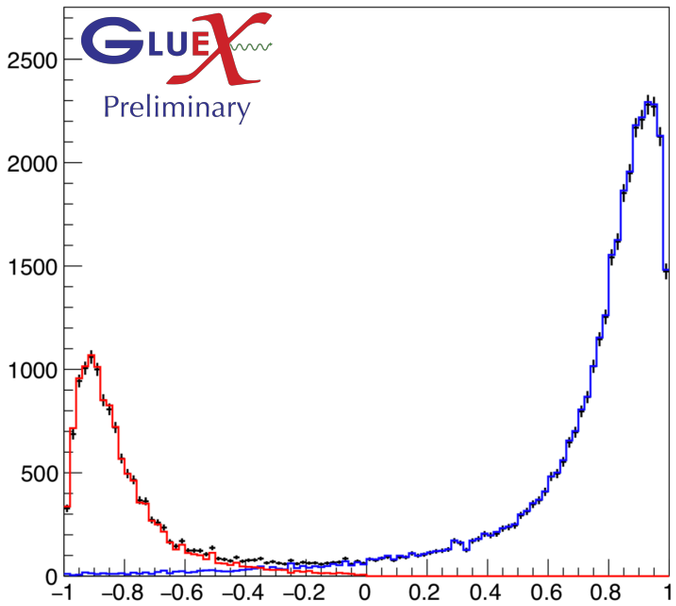
$$\begin{cases} \omega = \arctan\left(\dfrac{-\sqrt{3}p_z^{CM}(B)}{p_z^{CM}(B) + 2p_z^{CM}(\bar{B})}\right) + \pi \\ \rho = \sqrt{\dfrac{3}{2}}\sqrt{[p_z^{CM}(B)]^2 + [p_z^{CM}(\bar{B})]^2 + [p_z^{CM}(p)]^2} \end{cases}$$



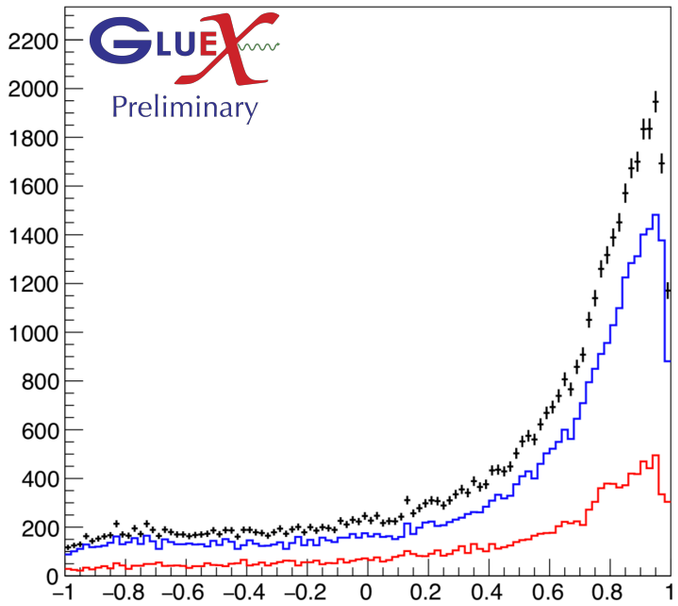


- Visualize the angular distribution of 3-body system in CM
- Easy to identify production modes between t-channel and u-channel

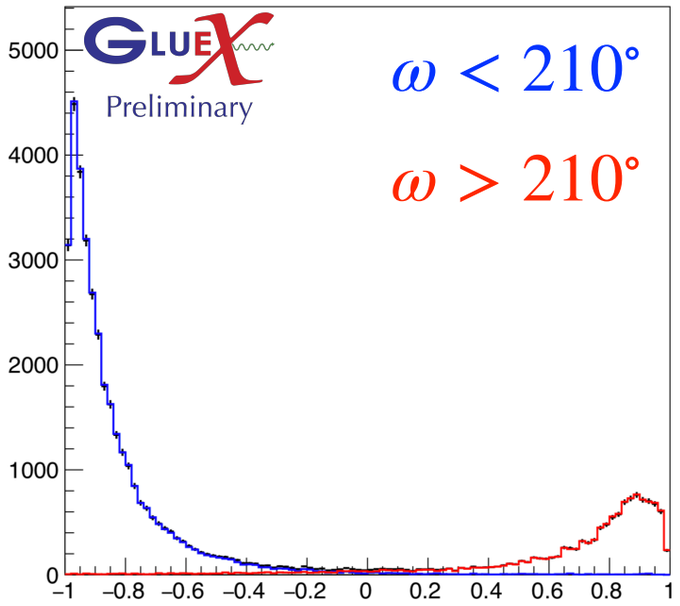
Angular Distributions of $\Lambda\bar{\Lambda}p$



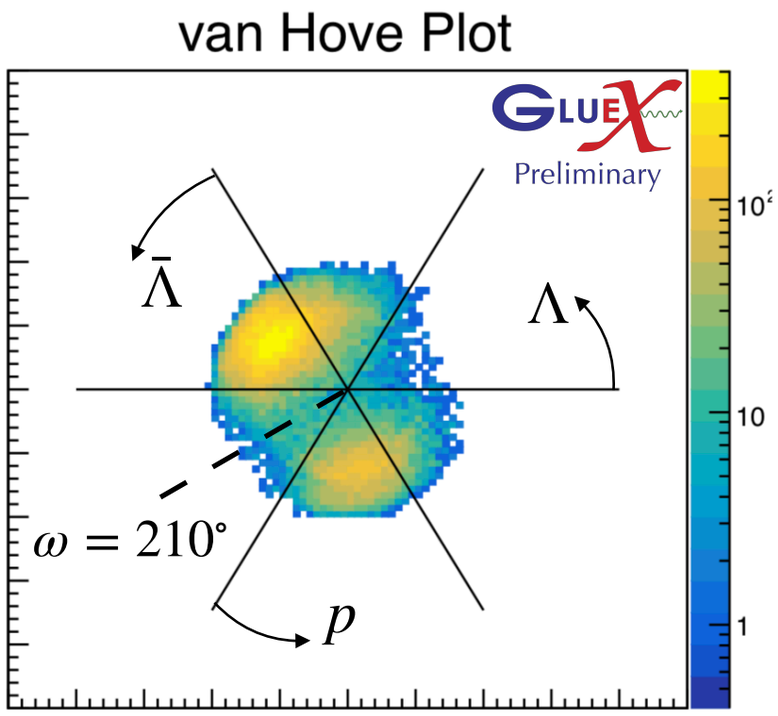
$\cos\Theta^{CM}(\Lambda)$

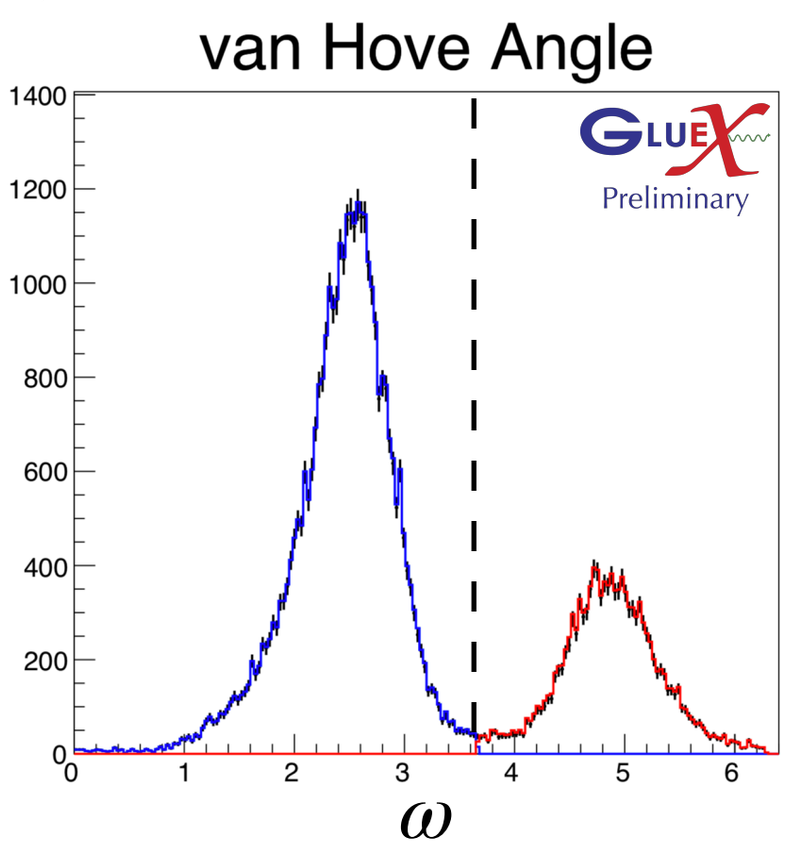


$\cos\Theta^{CM}(\bar{\Lambda})$

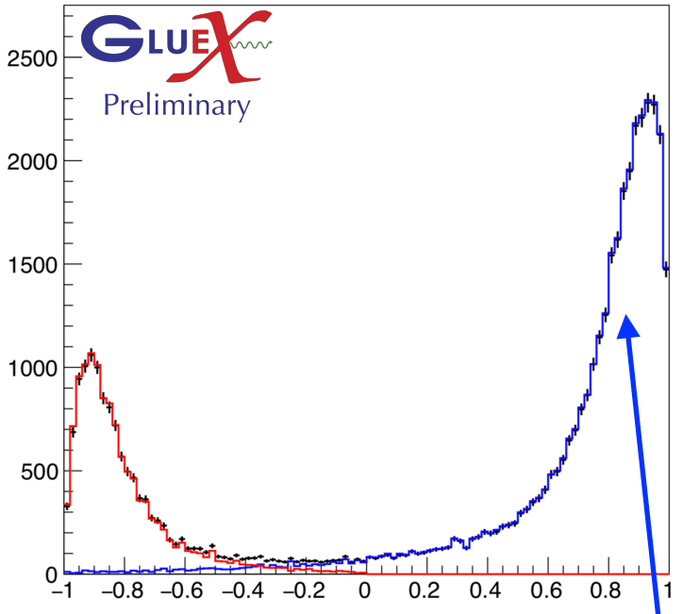


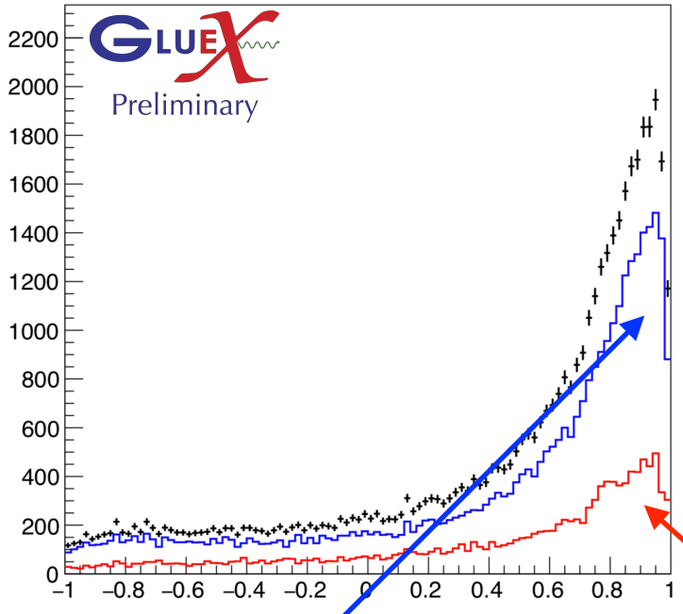
$\cos\Theta^{CM}(p)$

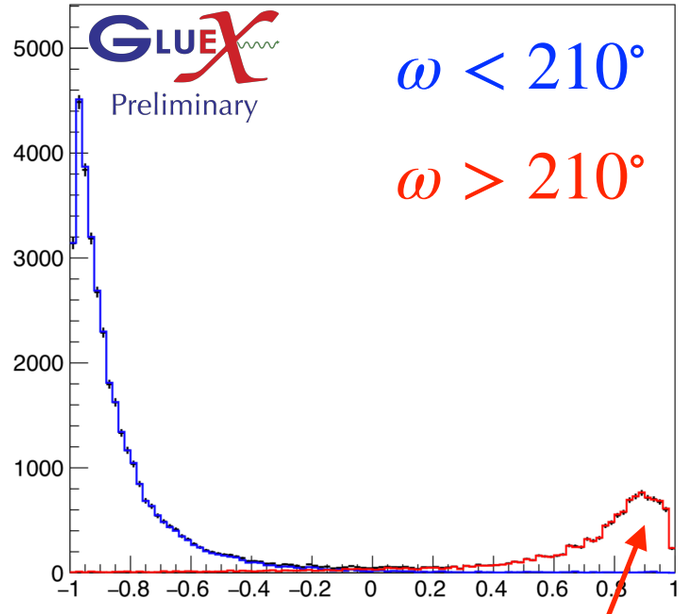


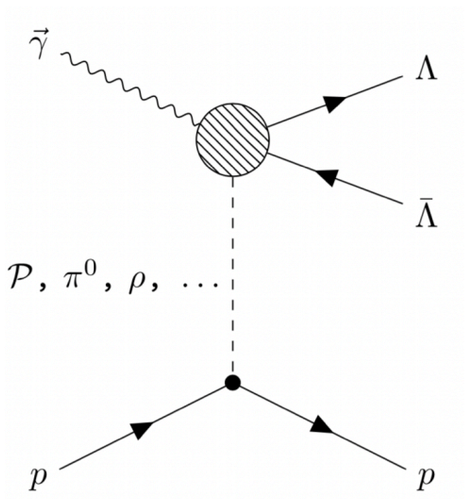


Angular Distributions of $\Lambda\bar{\Lambda}p$

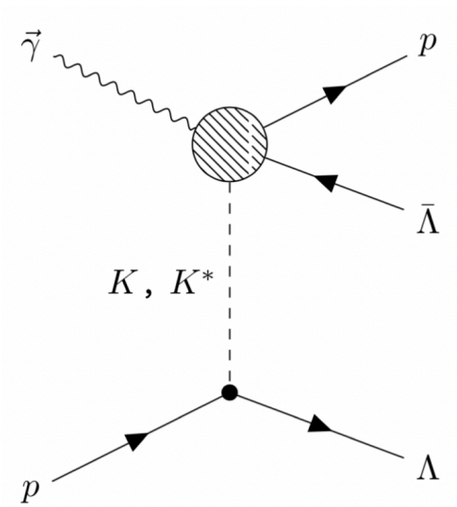






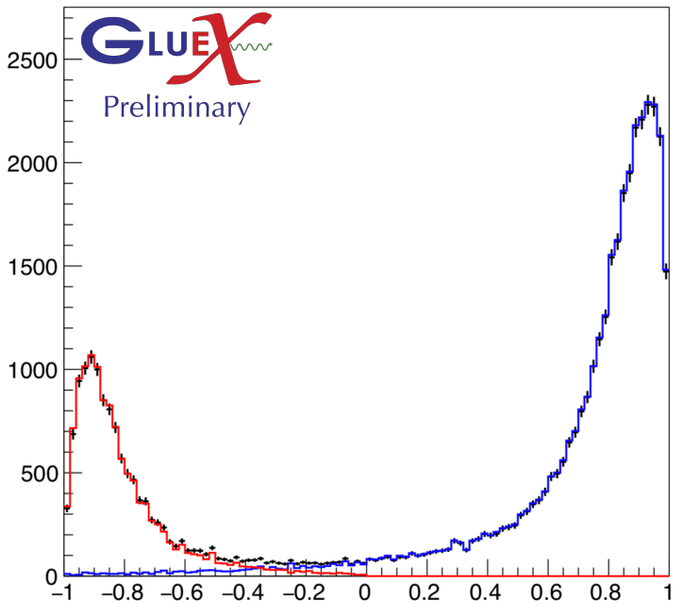


non-strange t-channel exchange

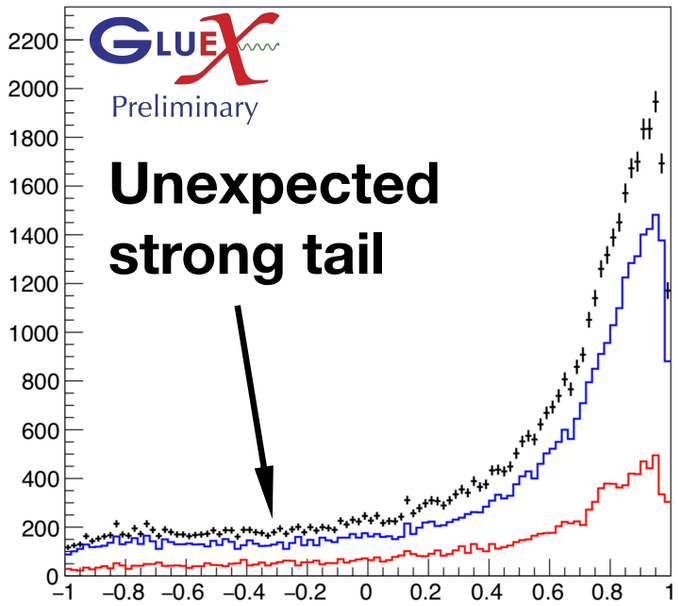


strange t-channel exchange

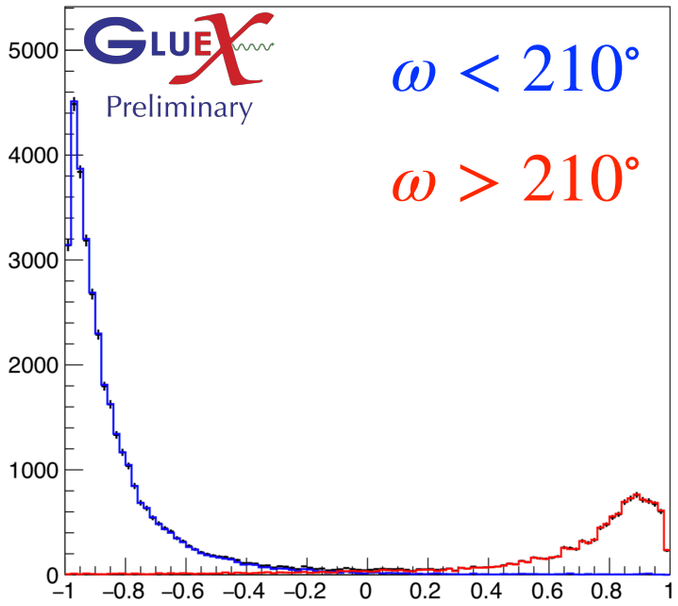
Angular Distributions of $\Lambda\bar{\Lambda}p$



$\cos\Theta^{CM}(\Lambda)$



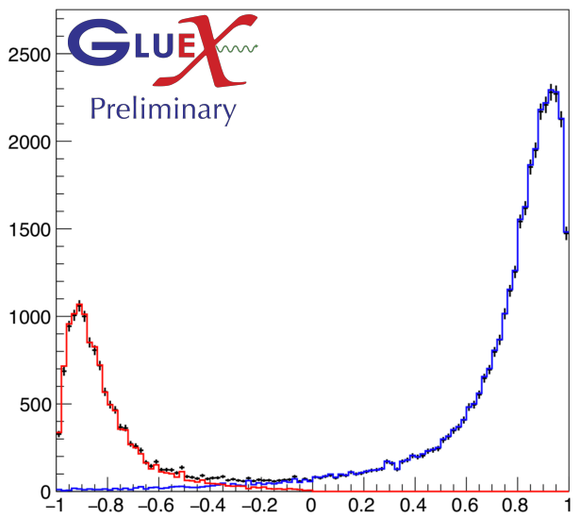
$\cos\Theta^{CM}(\bar{\Lambda})$



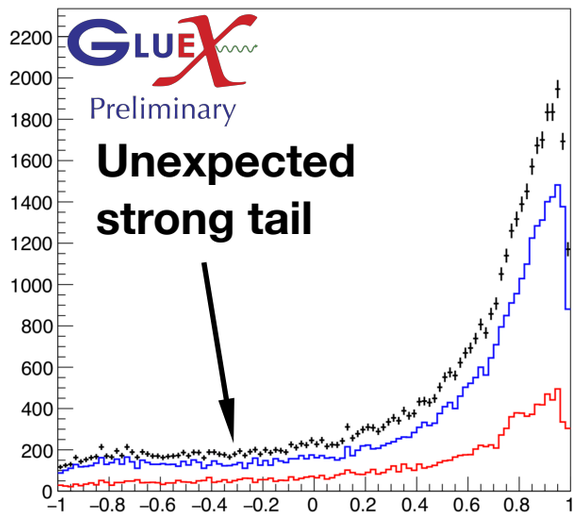
$\cos\Theta^{CM}(p)$

Angular Distributions of $\Lambda\bar{\Lambda}p$ & $p\bar{p}p$

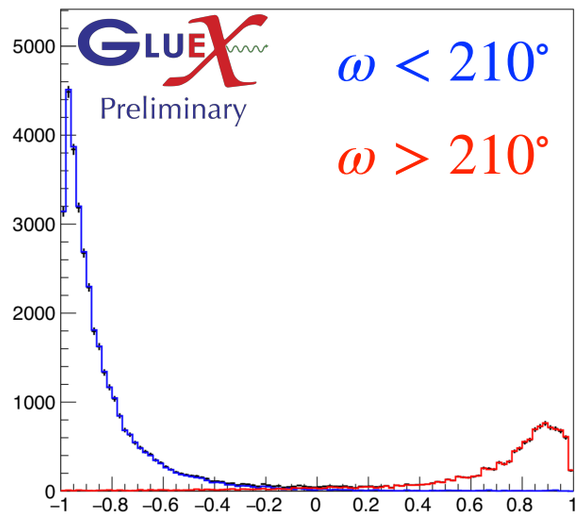
$\gamma p \to \Lambda\bar{\Lambda}p$



$\cos\Theta^{CM}(\Lambda)$

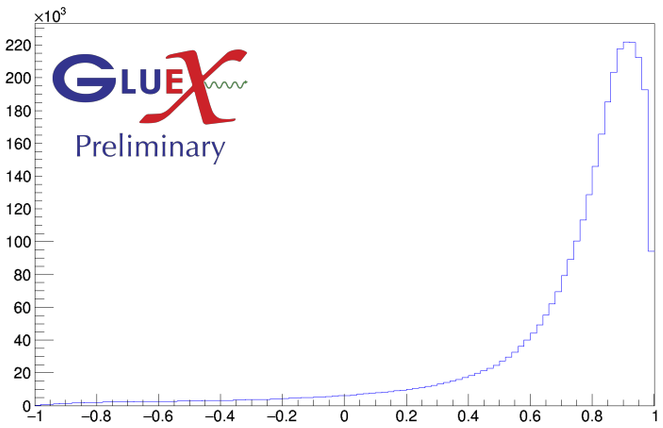


$\cos\Theta^{CM}(\bar{\Lambda})$

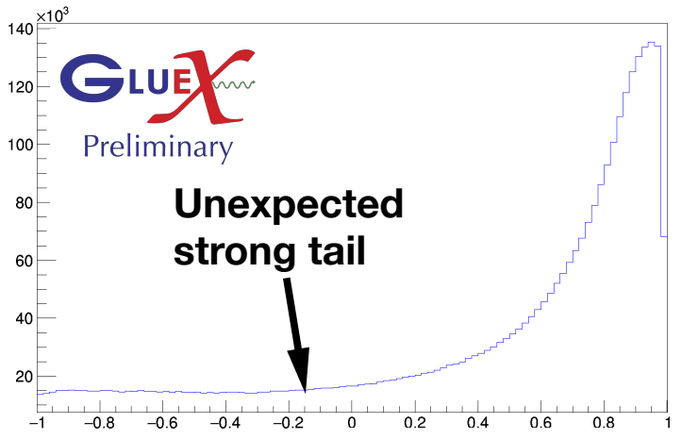


$\cos\Theta^{CM}(p)$

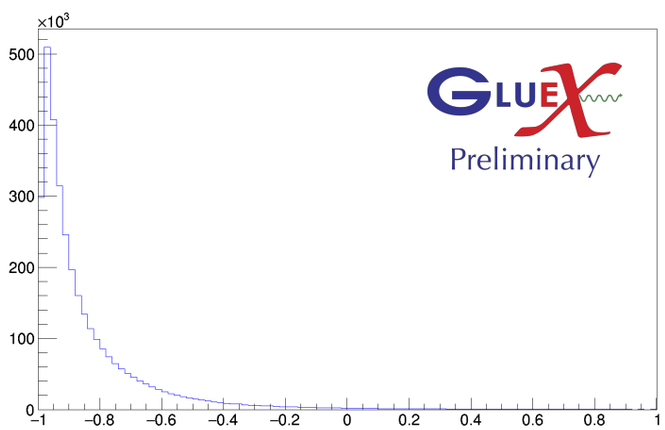
$\gamma p \to p\bar{p}p$



$\cos\Theta^{CM}(p_{fwd})$



$\cos\Theta^{CM}(\bar{p})$



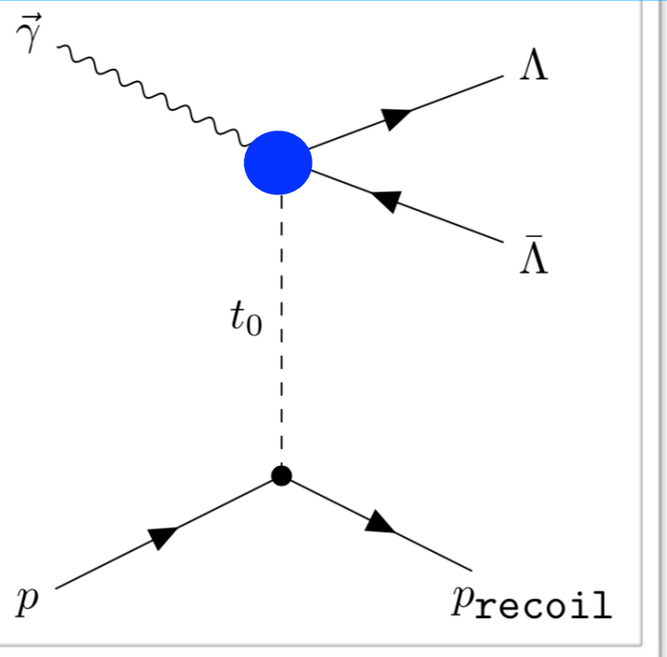
$\cos\Theta^{CM}(p_{bkwd})$

“Bank” of Reaction Mechanisms

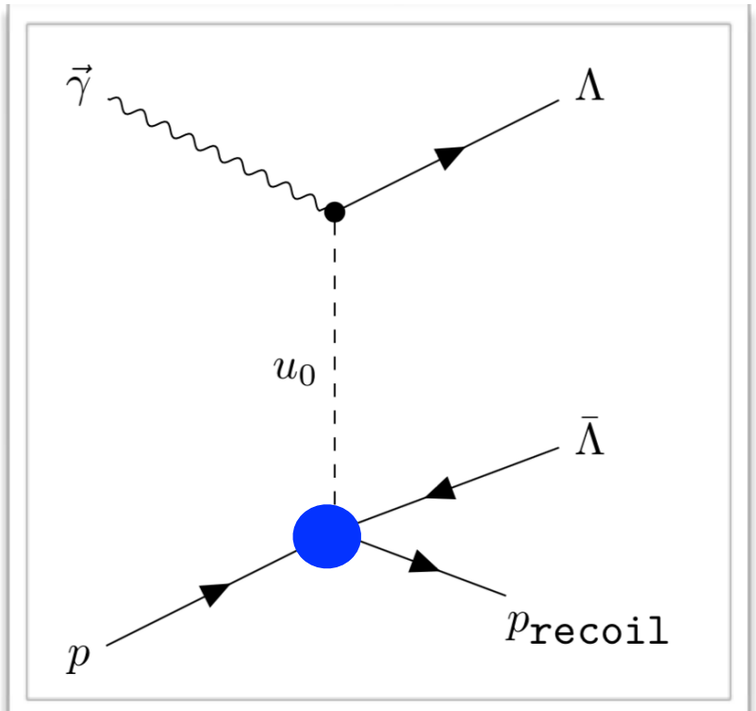
“single Regge” model

t-channel

Dominant Mechanism

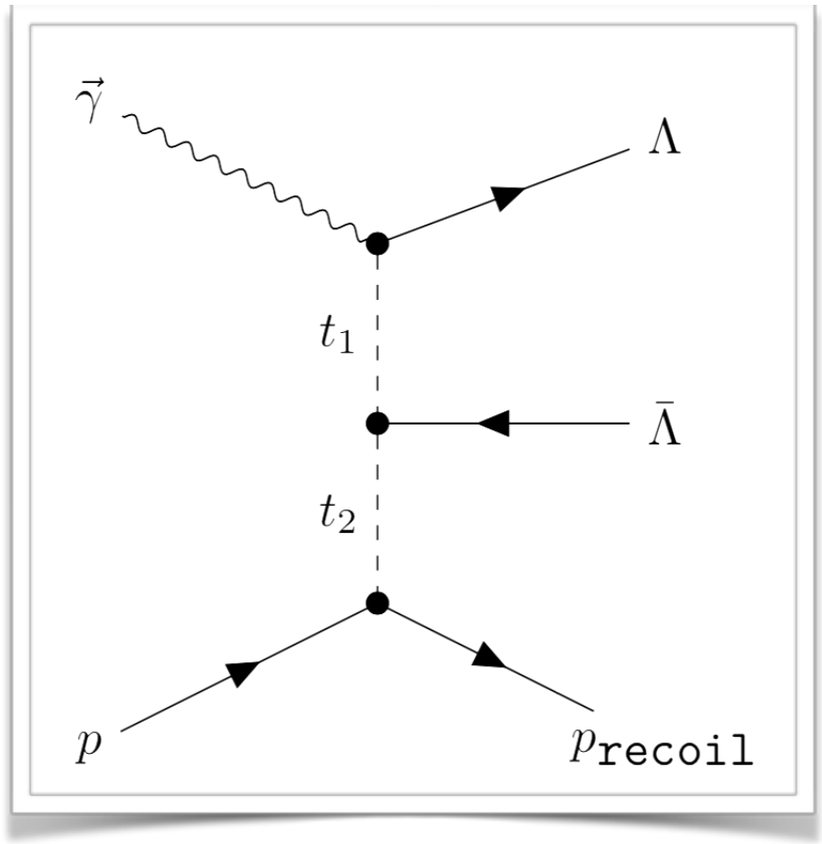


u-channel



$$\frac{d\sigma}{dt_0} \sim \exp(b_0 t_0)$$

“double Regge” model

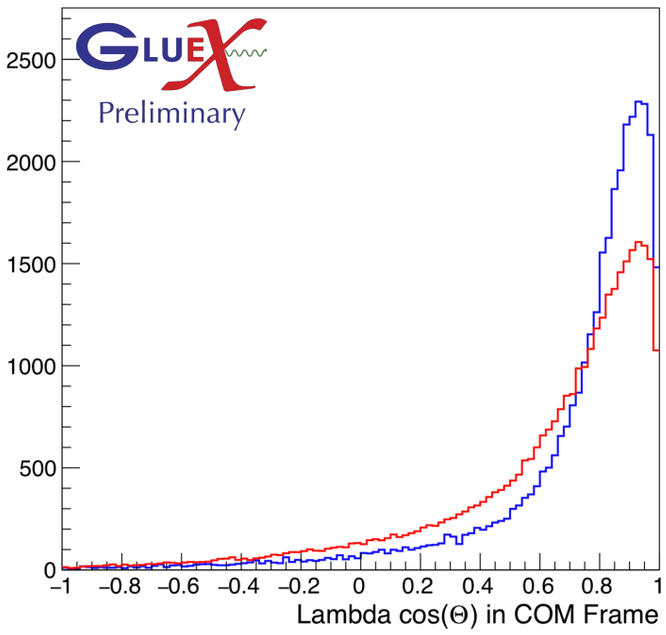


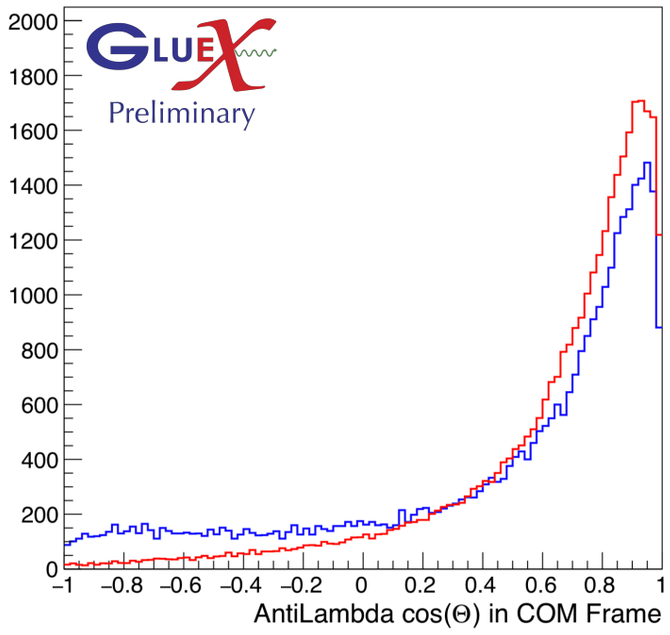
$$\frac{d\sigma}{dt_1 dt_2} \sim \exp(b_1 t_1)\exp(b_2 t_2)$$

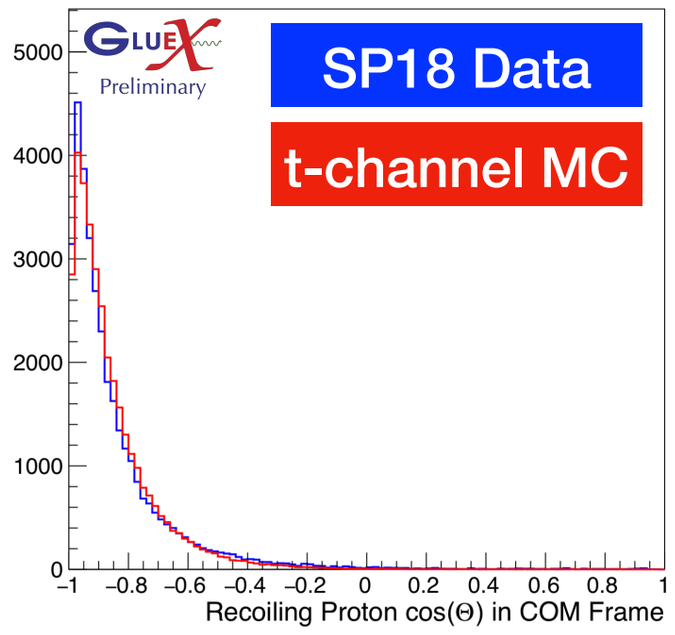
Multiple ways define the mass of the pair:

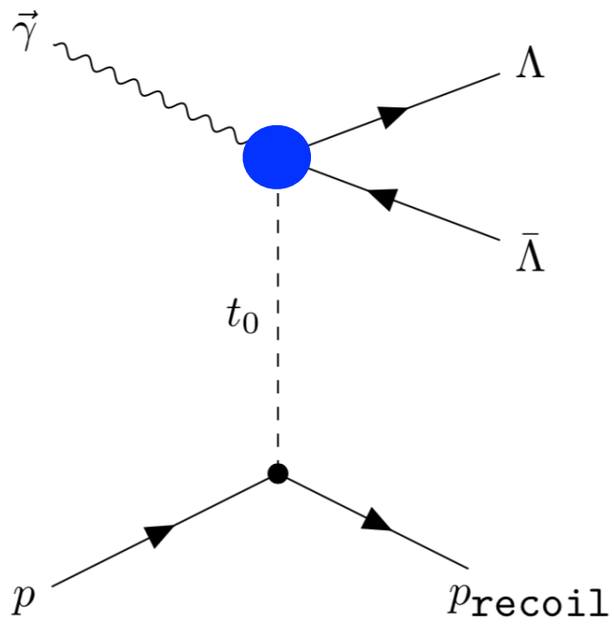
- **IM**$\{\Lambda\bar{\Lambda}\}$ ~ **Breit-Wigner**(m_R, Γ_R)
- **"clustering effect"** $\sim \exp[-(M_{\Lambda\bar{\Lambda}} - 2m_\Lambda)/m_c]$

Data vs MC for Single Regge (t-channel)

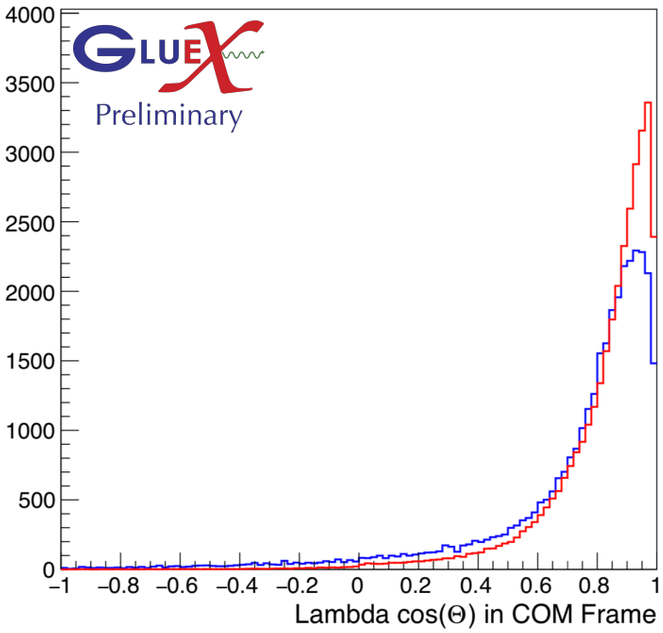


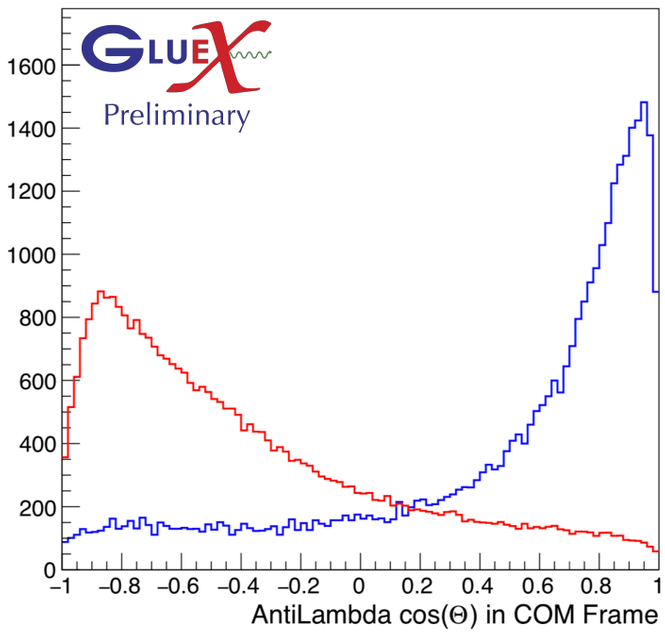


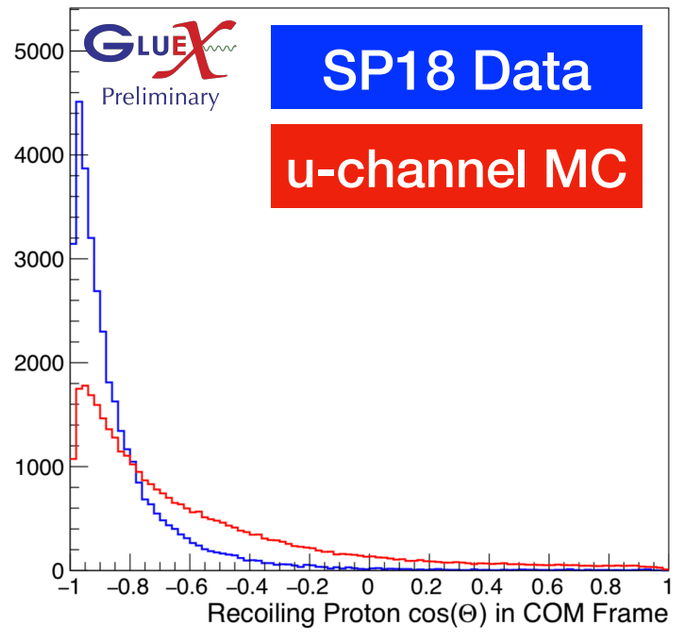


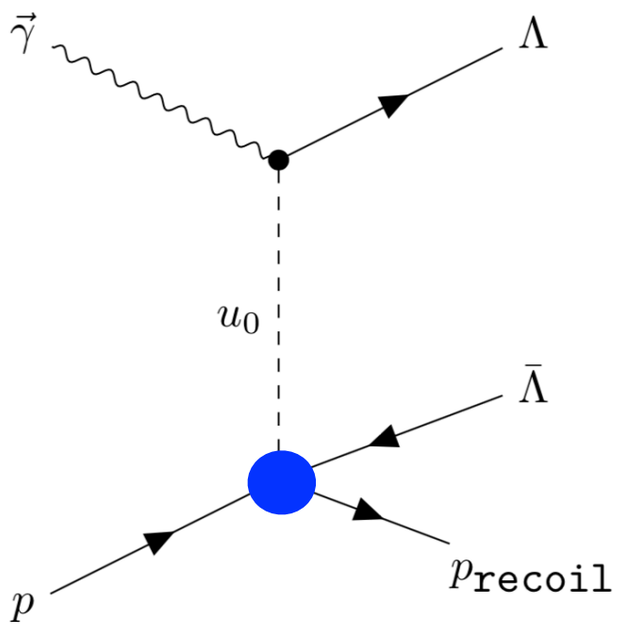


Data vs MC for Single Regge (u-channel)

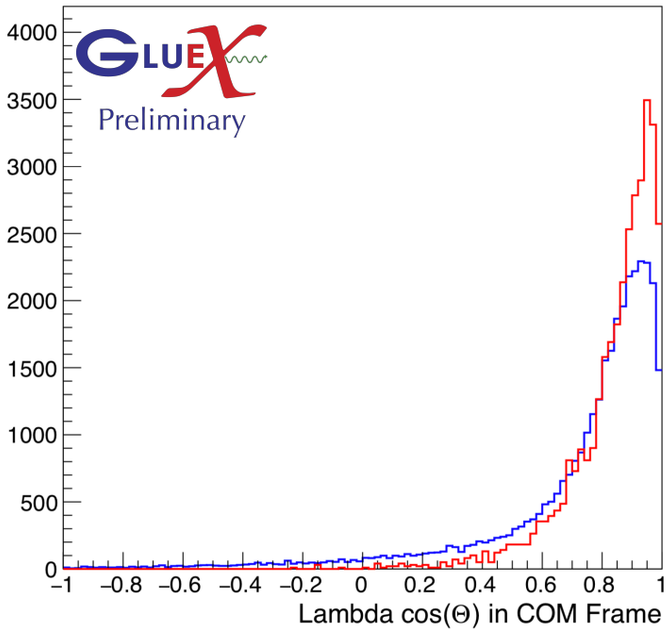


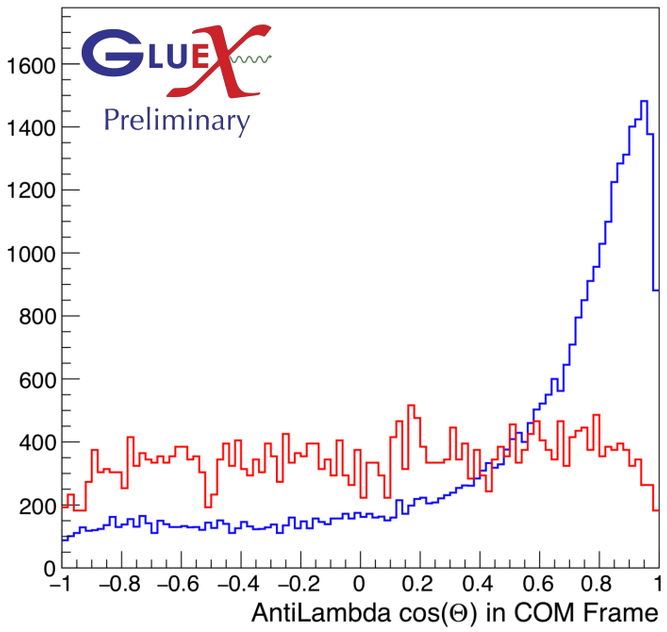


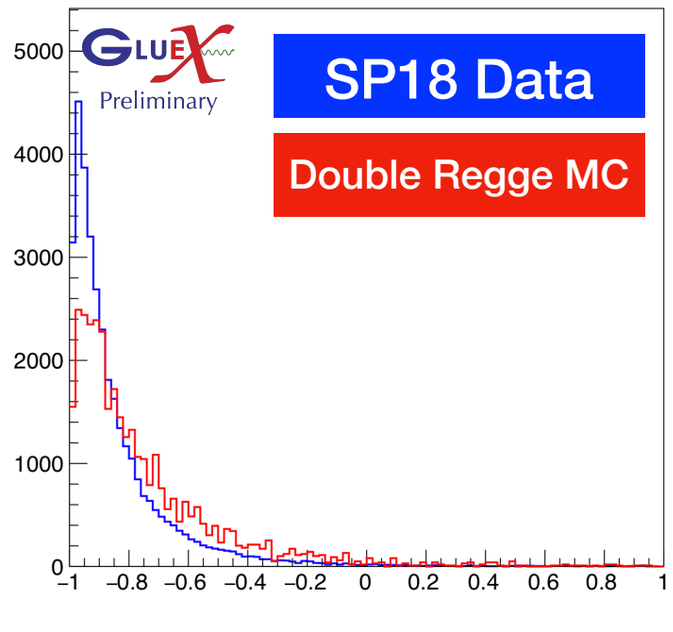


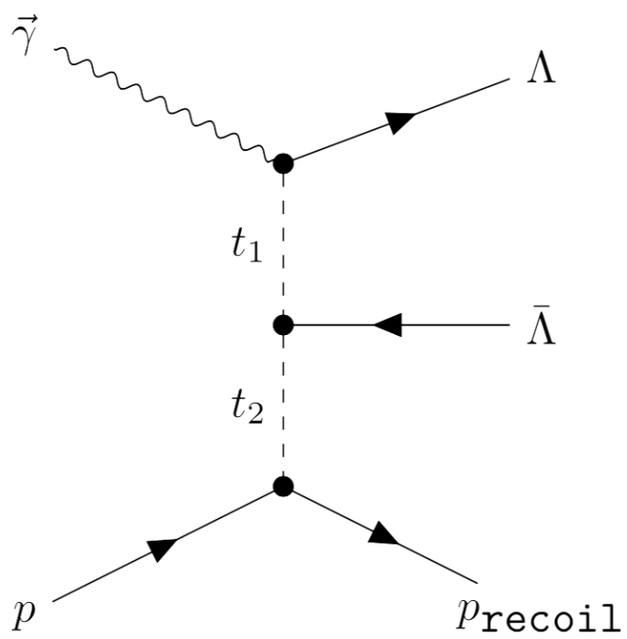


Data vs MC for Double Regge





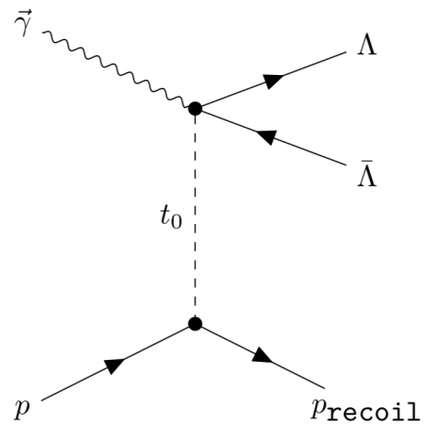


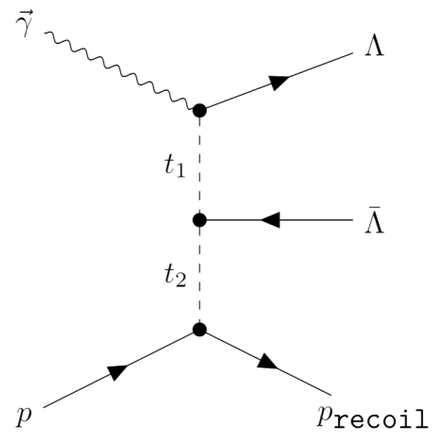


Combining mechanisms

Combined MC =

$$p_0 \left\{ \right\} + (1 - p_0) \left\{ \right\}$$





“Single Regge”

“Double Regge”

$$\frac{d\sigma}{dt_0} \sim \exp(b_0 t_0)$$

$$\frac{d\sigma}{dt_1 dt_2} \sim \exp(b_1 t_1)\exp(b_2 t_2)$$

"clustering effect" $\sim \exp[-(M_{\Lambda\bar{\Lambda}} - 2m_{\Lambda})/m_c]$

Five fit parameters: $p_0,\ b_0,\ m_c,\ b_1,\ b_2$

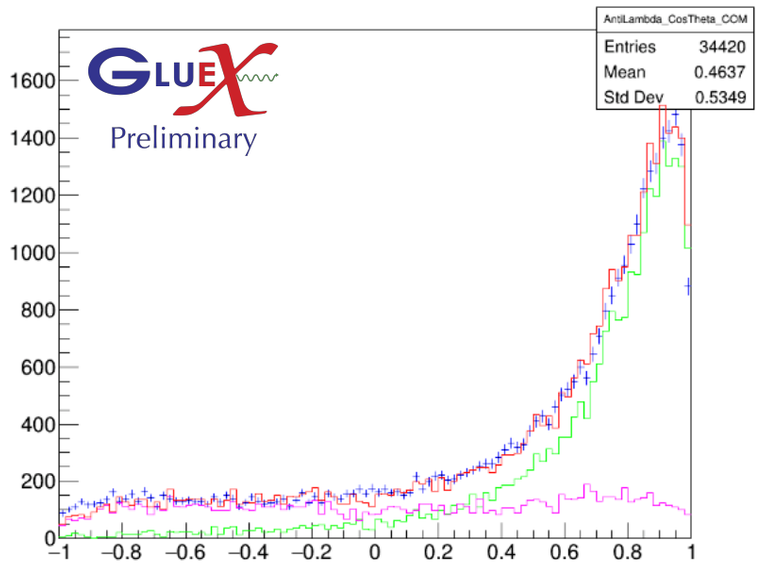
Fit Combined MC to data with TFractionFitter

SP18 Data

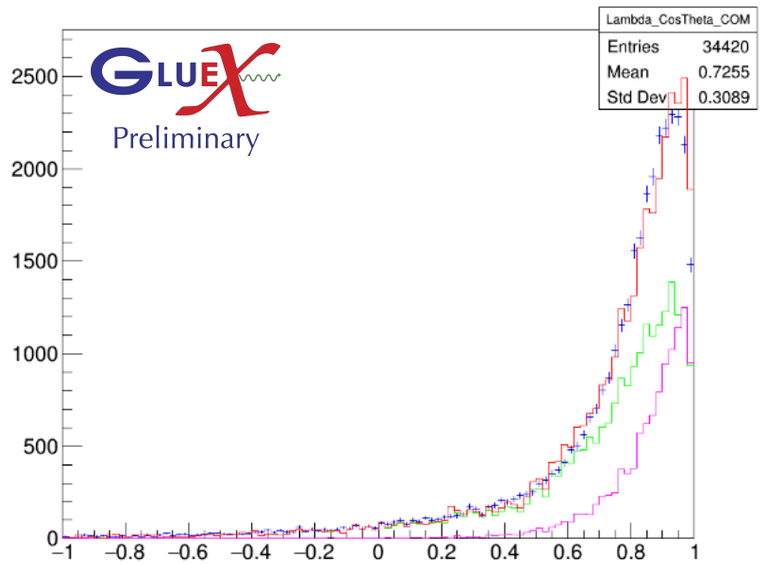
Mixed MC

Single Regge MC

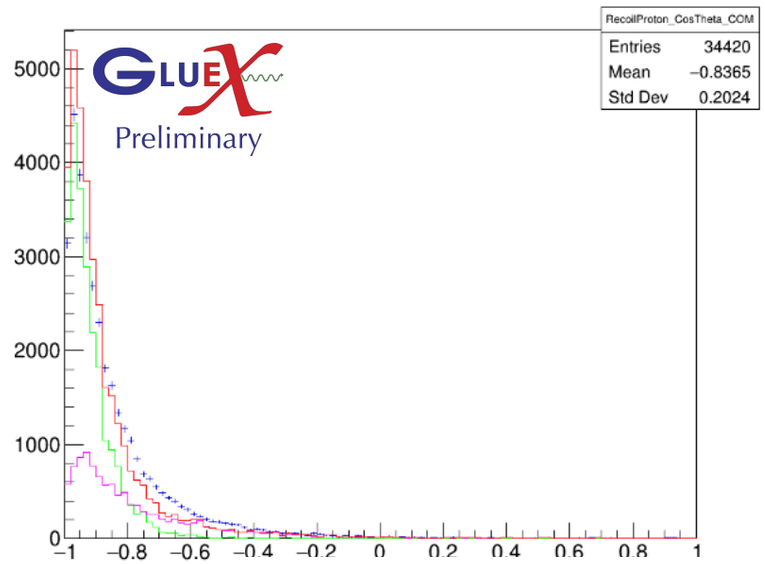
Double Regge MC



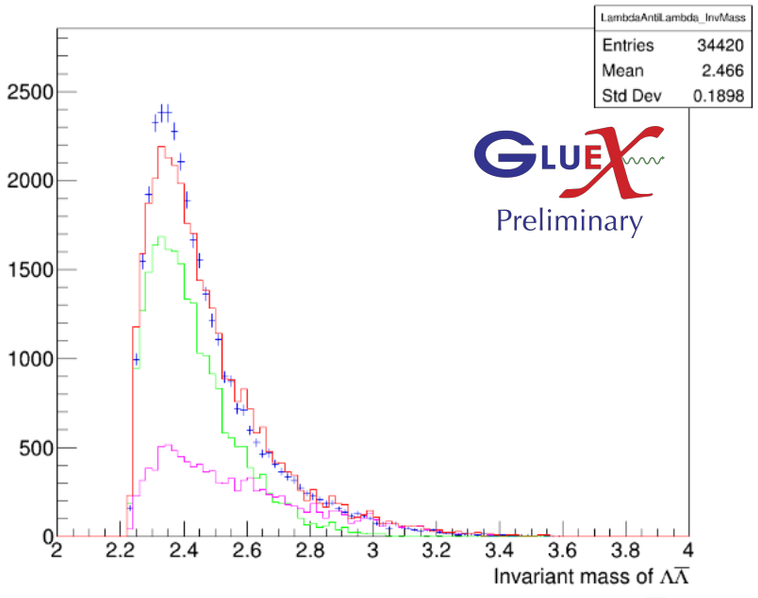
$\cos\Theta^{CM}(\bar{\Lambda})$



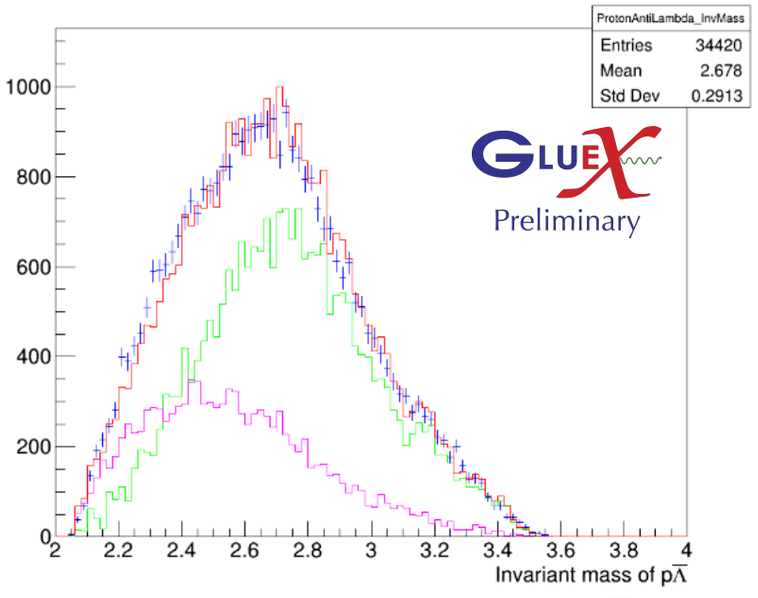
$\cos\Theta^{CM}(\Lambda)$



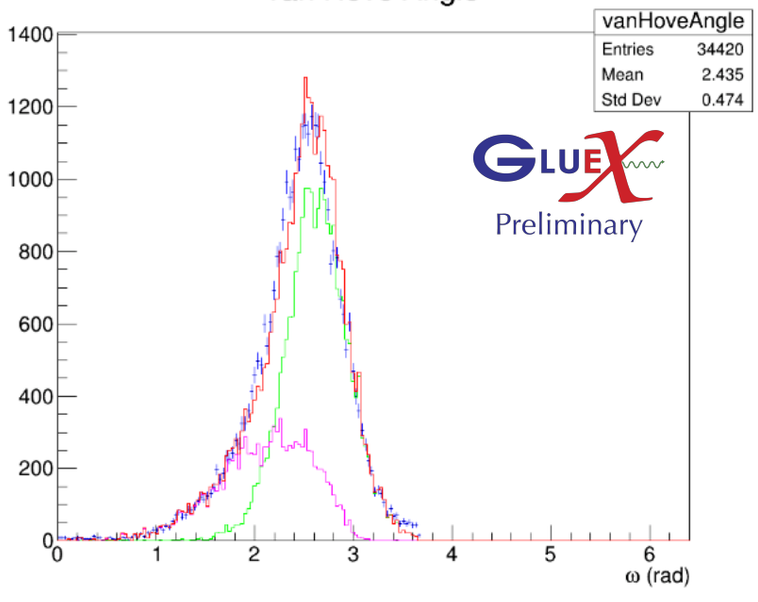
$\cos\Theta^{CM}(p)$



Invariant Mass $\Lambda\bar{\Lambda}$

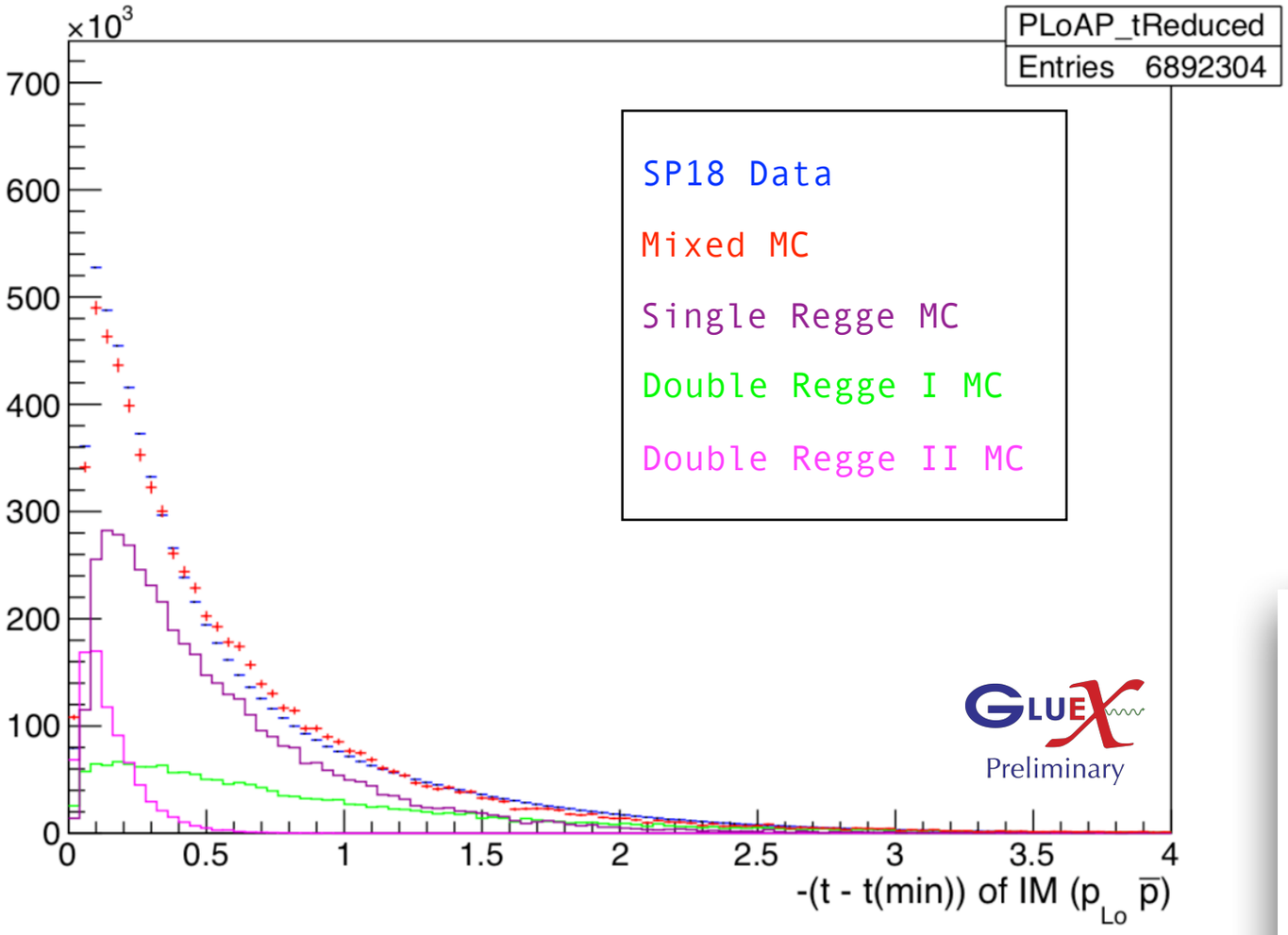


Invariant Mass $p\bar{\Lambda}$

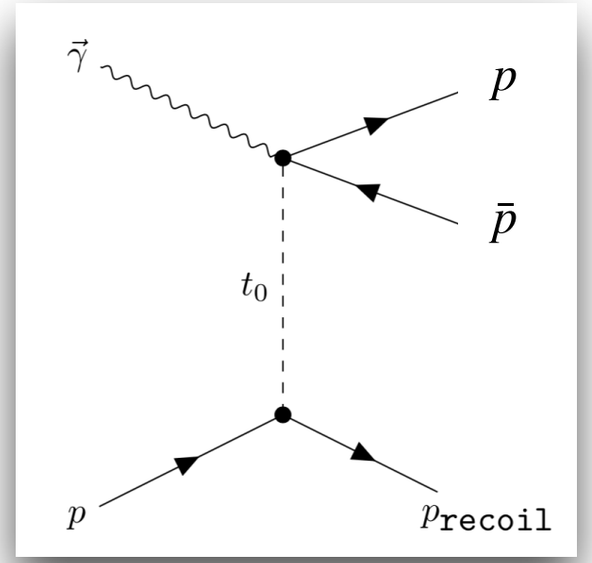


van Hove Angle ω (rad)

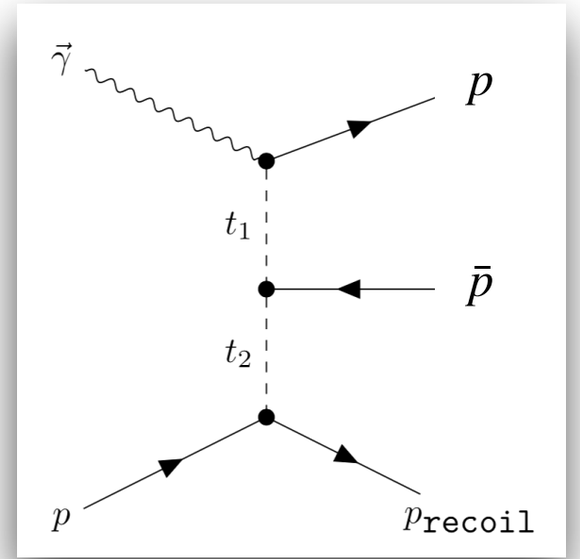
Fit method of the channel $\gamma p \to p\bar{p}p$



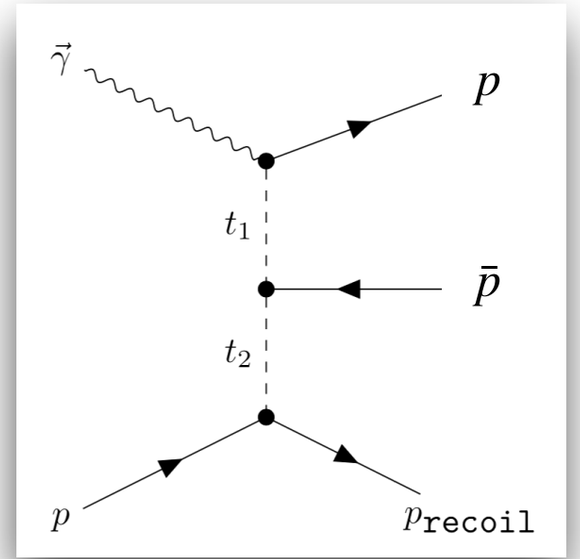
Single Regge



Double Regge I

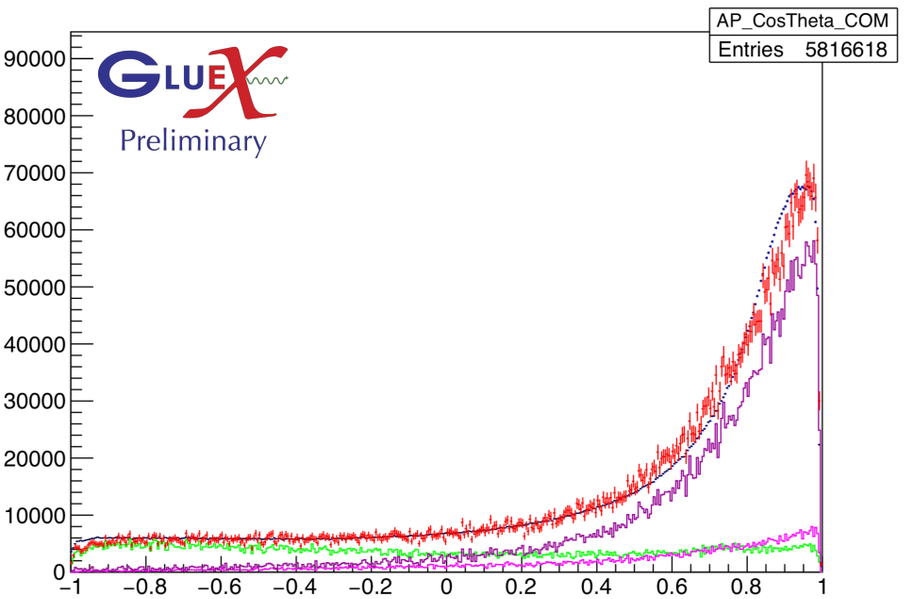


Double Regge II

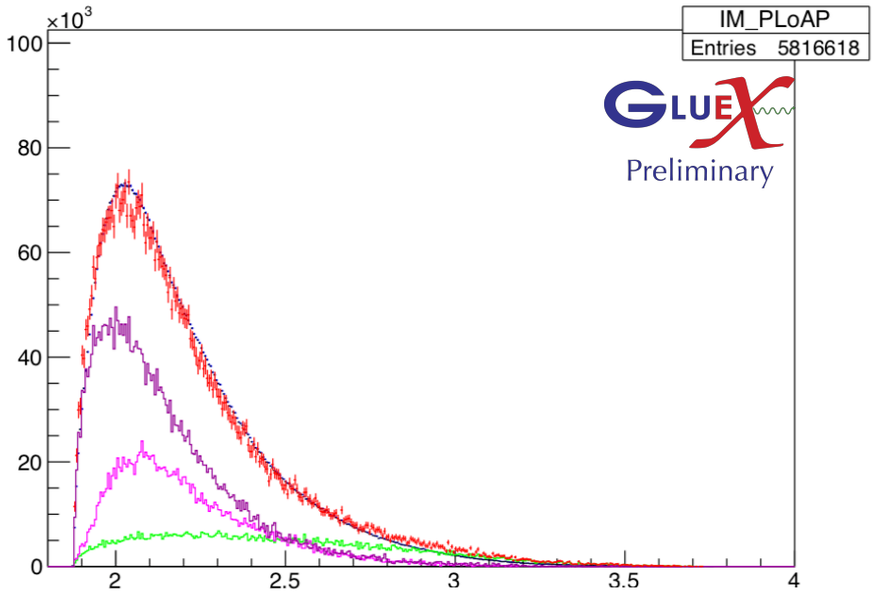


Fit Result of the channel $\gamma p \to p\bar{p}p$

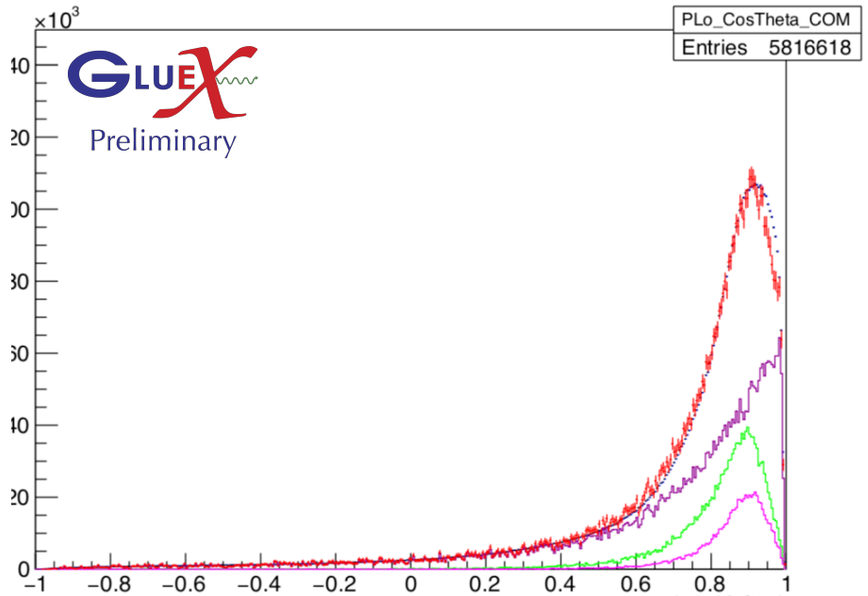
SP18 Data
Mixed MC
Single Regge MC
Double Regge I MC
Double Regge II MC



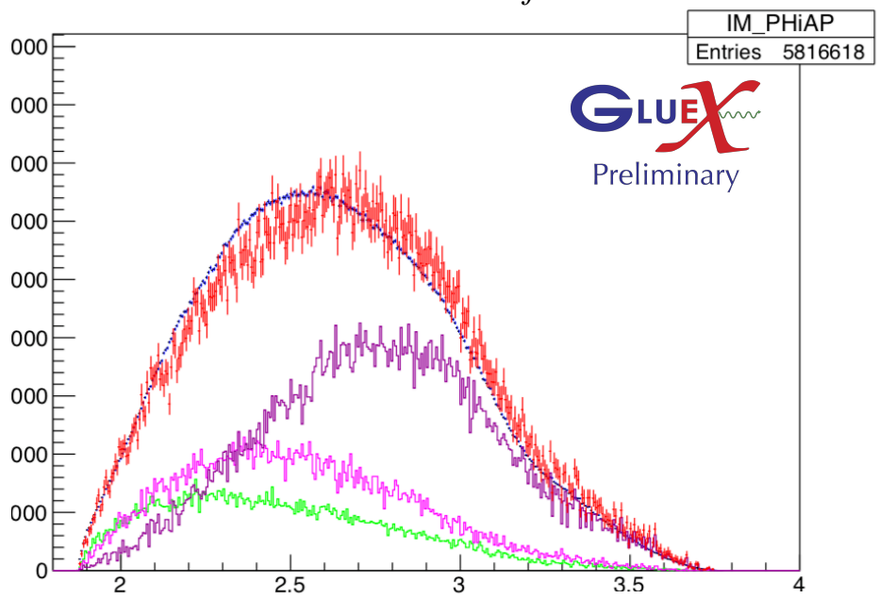
$\cos\Theta^{CM}(\bar{p})$



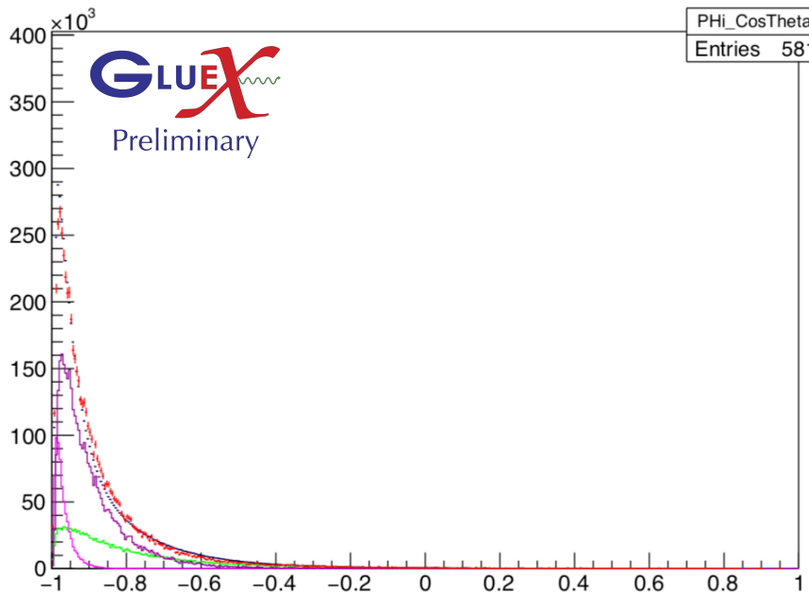
Invariant Mass $p_{fwd}\bar{p}$



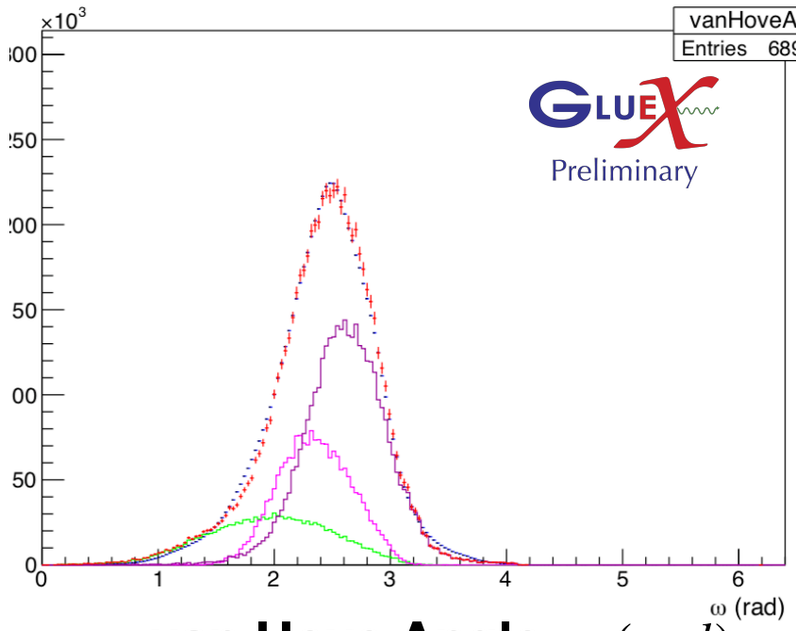
$\cos\Theta^{CM}(p_{fwd})$



Invariant Mass $p_{bkwd}\bar{p}$

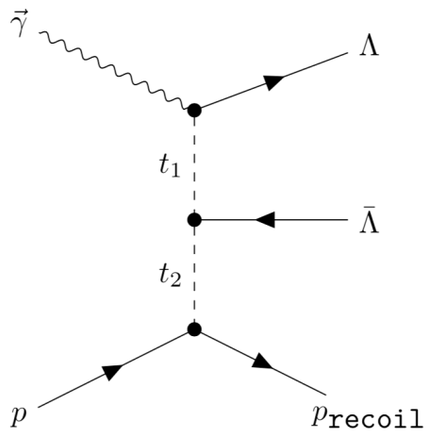


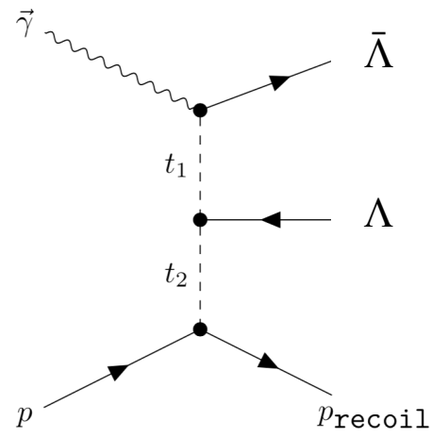
$\cos\Theta^{CM}(p_{bkwd})$

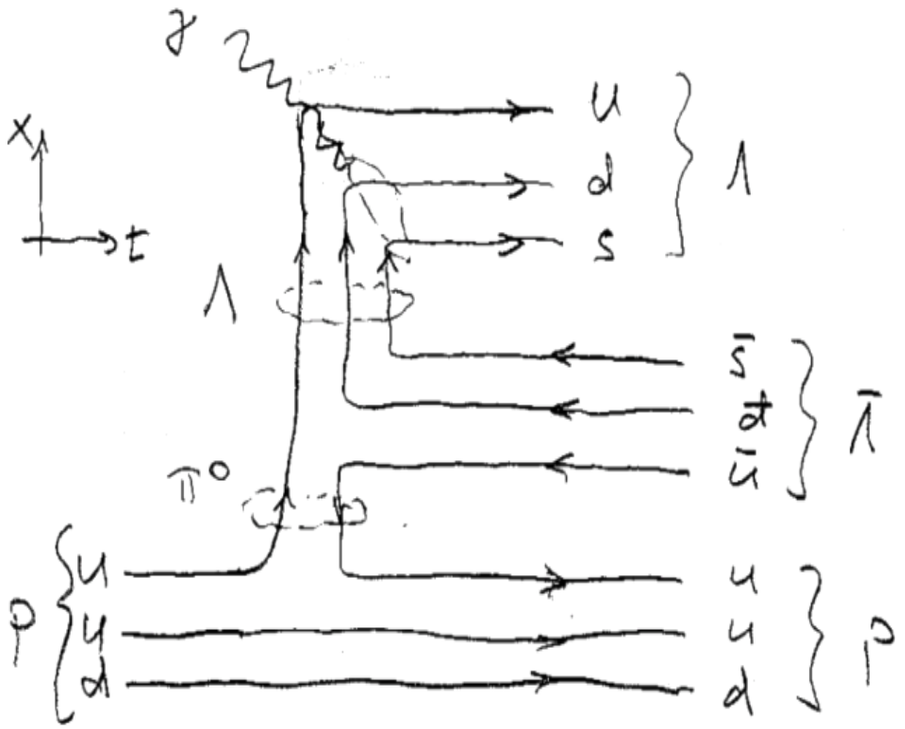


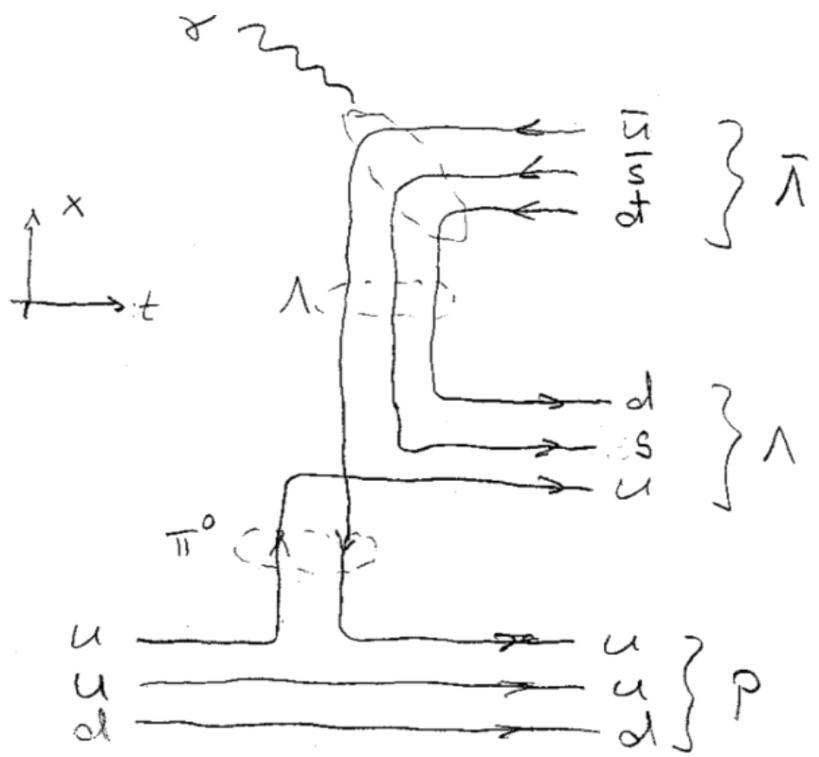
van Hove Angle ω (rad)

Speculation about the asymmetry of double Regge









Conclusion

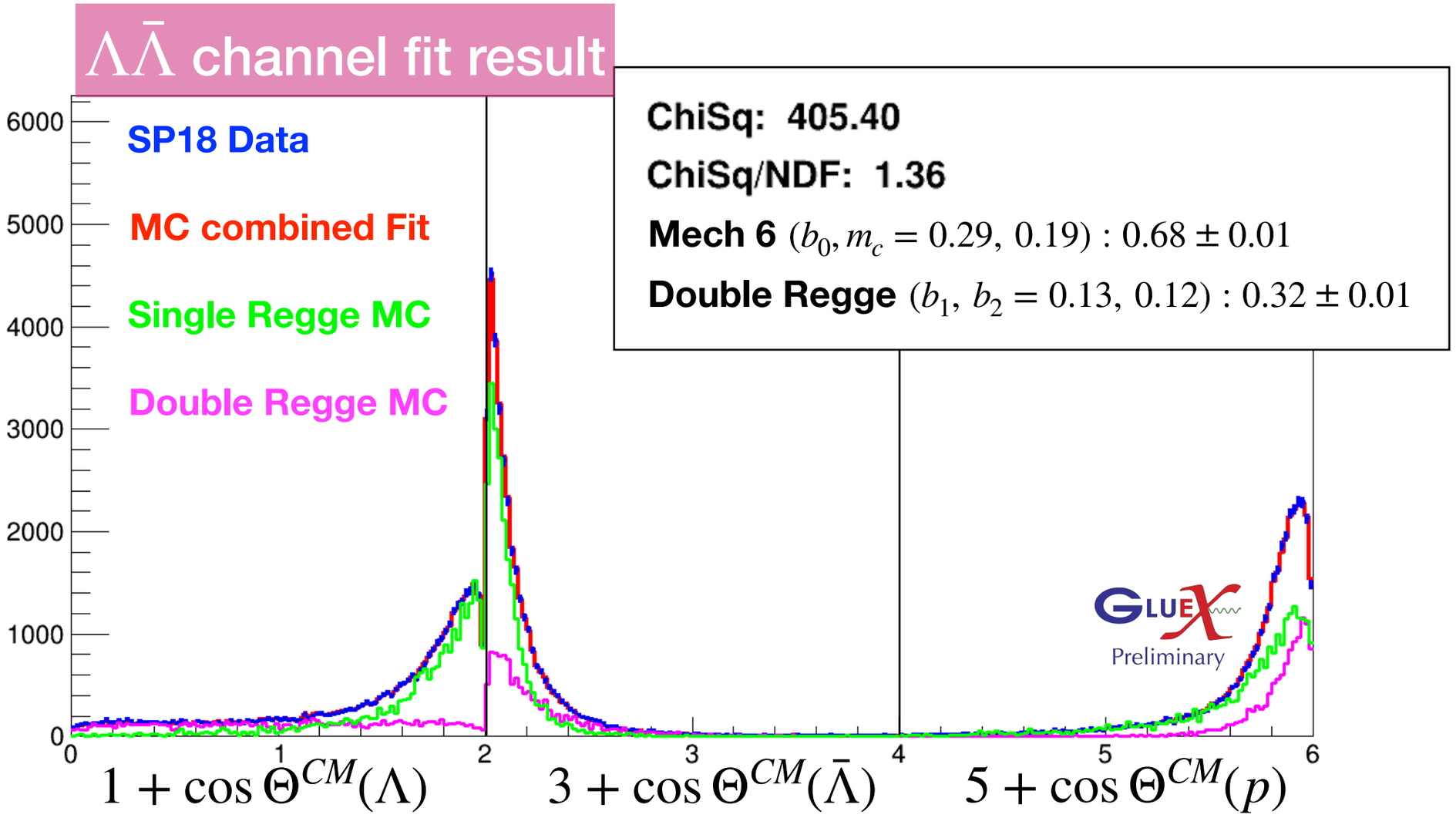
- **Found a simple description with one single Regge and one double Regge mechanism to fit to the $\Lambda\bar{\Lambda}p$ final states data distributions**

- **The $p\bar{p}p$ reaction needs not one, but two double Regge mechanisms**

- **Simple model based on meson/baryon exchange mechanisms fits the data quite well**

Backup slides

Fit Combined MC to data with TFractionFitter



- **A better way to include correlations of variables into the fit is by 2-D histograms**
- **We stick to 1-D since data sizes/MC sample sizes are limited**
- **The list of histograms could be expanded to include more variables such as momentum, invariant mass, and Mandelstam t, for example.**