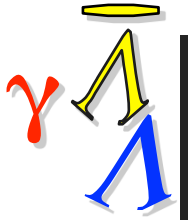
The Reaction $\vec{\gamma}\, p \to \{\bar{\Lambda}\Lambda\}\, p$ Revealed with GlueX



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Hao Li, Samuel Dai

Carnegie Mellon University / GlueX Collaboration

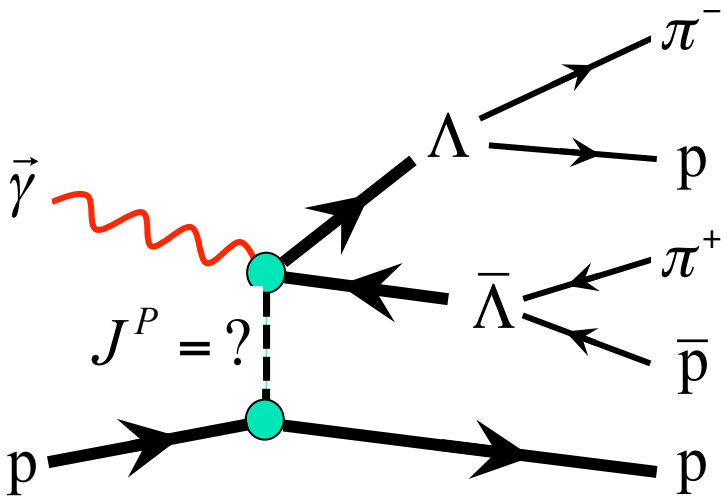
HYP2018 Conference, Portsmouth, VA

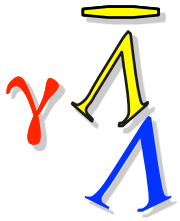
June 26, 2018

Jefferson Lab

Overview

- Exploring baryon-$\overline{\text{baryon}}$ photoproduction
- GlueX in Hall D at JLab
  - Experimental setup & analysis steps
  - Detecting: $\vec{\gamma}\, p \to \{\bar{\Lambda}\Lambda\} p$ (also $\vec{\gamma}\, p \to \{\bar{p}p\} p$)
- Phenomenology for the hyperon channel
  - All spectra shown today are very preliminary



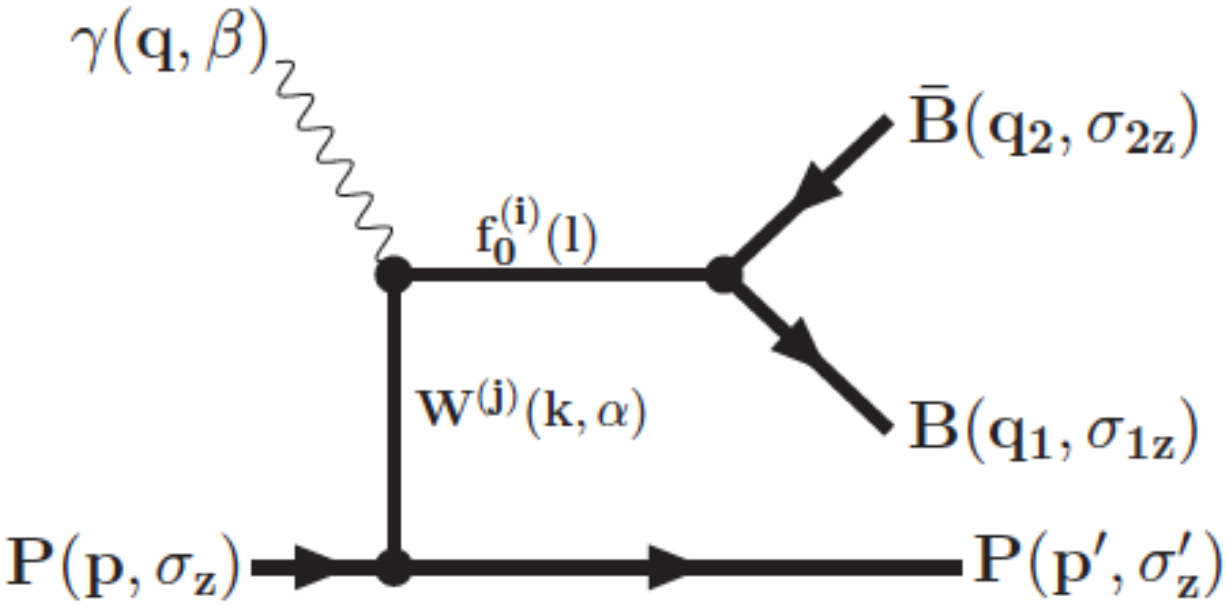


Itemized Goals re $\vec{\gamma}\, p \to \{\bar{\Lambda}\Lambda\} p$

- Study the reaction mechanism:
  - Cross section measurements
  - Compare to $\bar{p}p$
  - Beam spin asymmetry: Σ
- Look for continuum resonances in $p\bar{\Lambda}$ and $\Lambda\bar{\Lambda}$ "baryonium states"
- Spin correlations in $\Lambda\bar{\Lambda}$ creation
  - Singlet fraction
- A CPT test (in principle)

Theory Status – one publication

- Valery Lyubovitskij *et al.** and Priv. Comm.
  - Use: effective hadronic Lagrangian with
    - vector/axial mesons $W_V = \rho^0, \omega$ and $W_A = b_1, h_1,$ + Reggeons
    - scalar mesons $f_0(1370), f_0(1500), f_0(1720)$
  - Beam asymmetry and cross sections for:



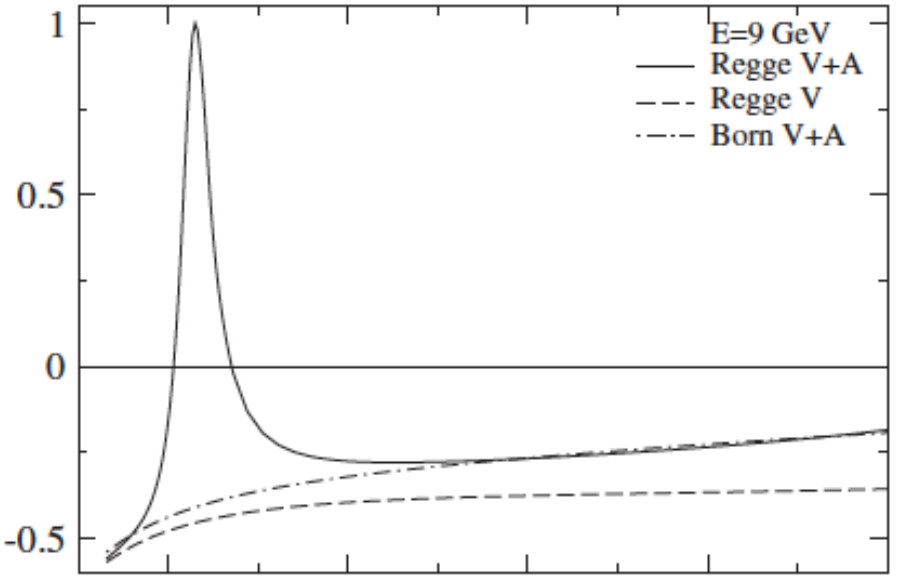
$$\vec{\gamma}\, p \to \{p\bar{p}\}\, p$$

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

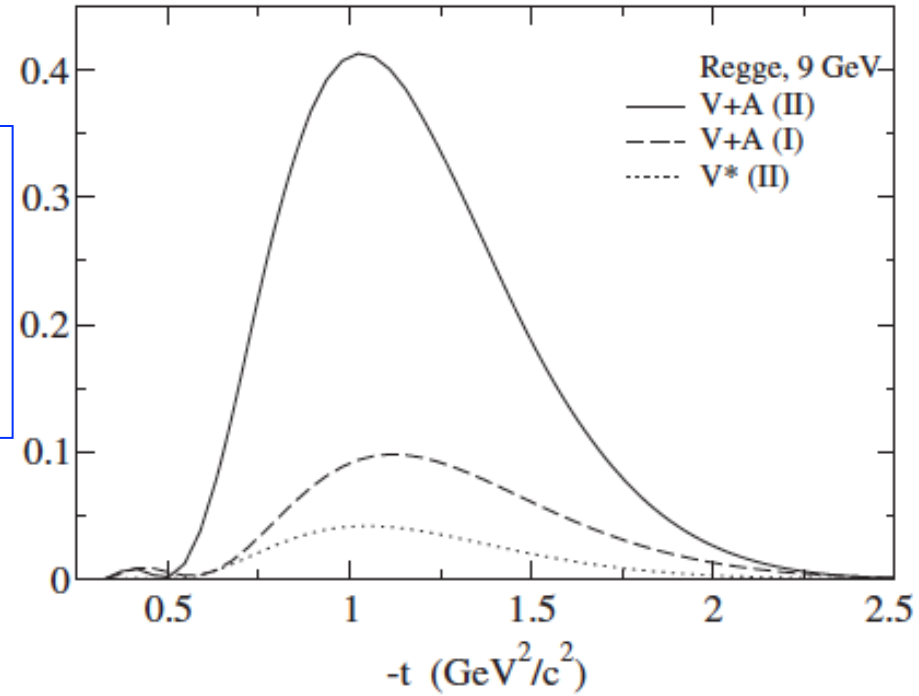
* T. Gutsche, S. Kuleshov, V. Lyubovitskij, I. Obukhovsky, Phys. Rev. D **96**, 054024 (2017)

Theory Predictions

Σ



$\frac{d\sigma}{dt}$



$$\vec{\gamma}\, p \rightarrow \{\Lambda\bar{\Lambda}\}\, p$$

$$E_\gamma = 9\ \mathrm{GeV}$$

Large beam asymmetry predicted

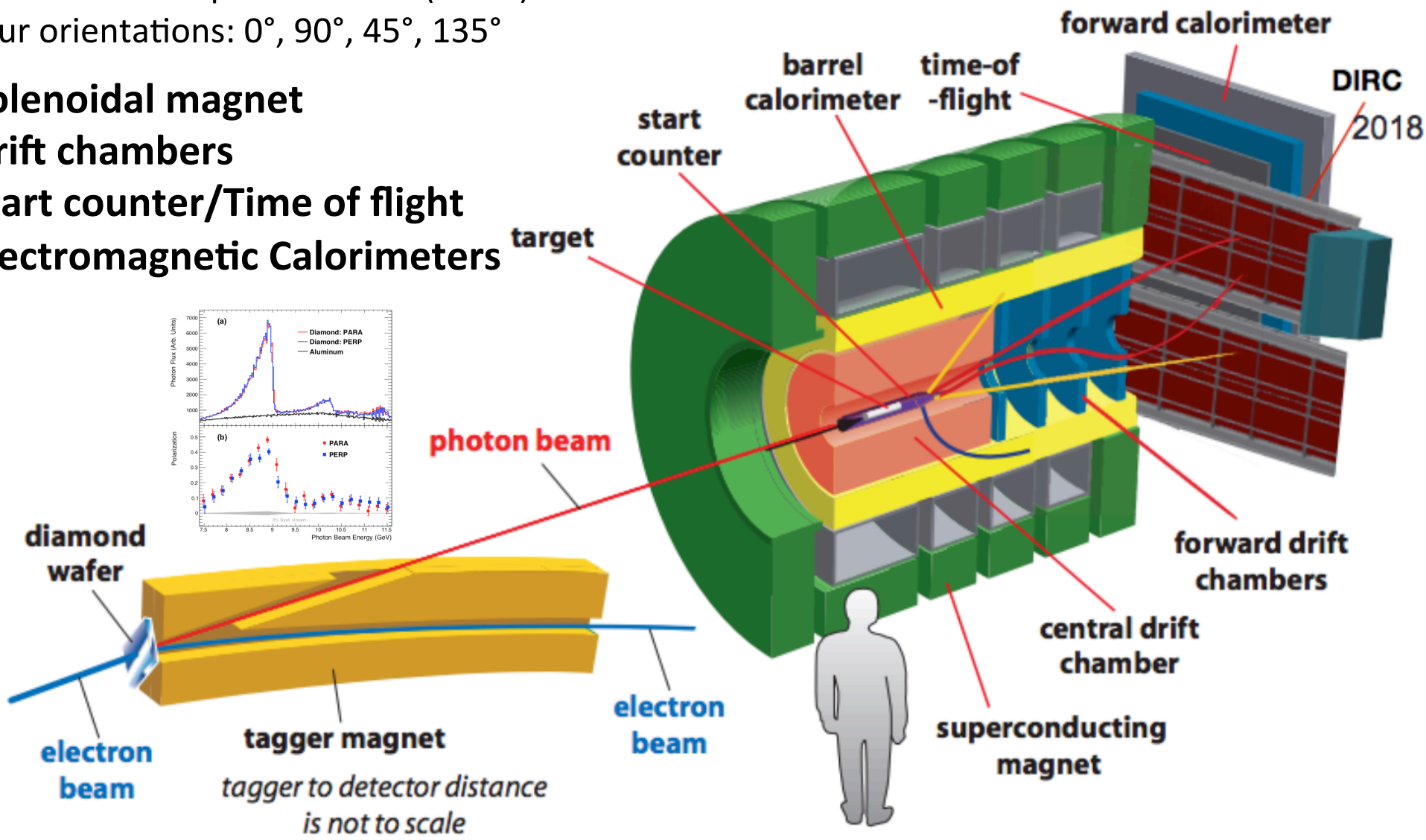
- Cross section predicted to be 1/10 as large as for $p\bar{p}$ case

T. Gutsche, S. Kuleshov, V. Lyubovitskij, I. Obukhovsky, Phys. Rev. D **96**, 054024 (2017)

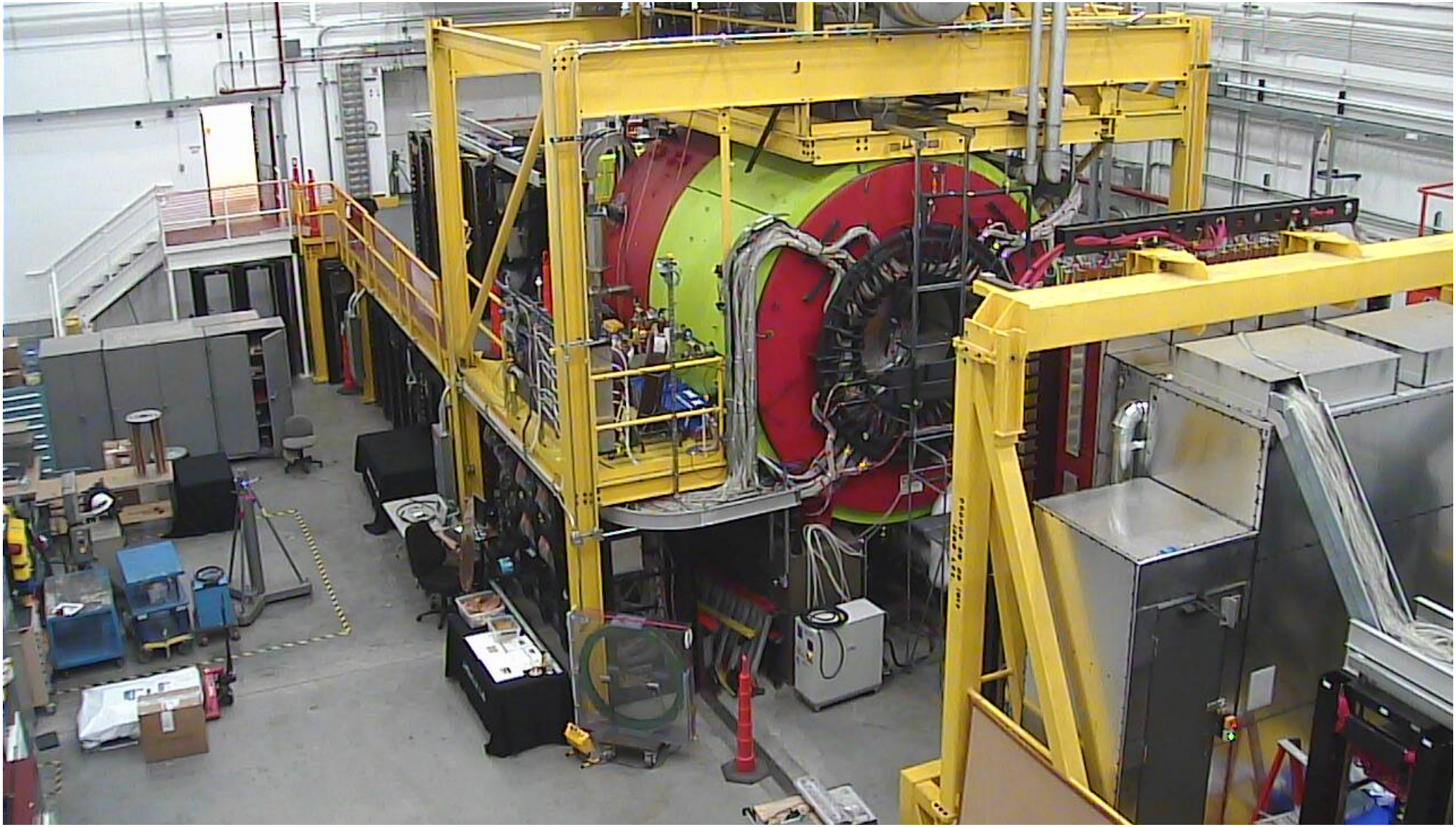
GlueX Detector at JLab

- **~12 GeV e^- beam** converted to:
  - 4 - 11.6 GeV photon beam
  - Linear coherent peak 8-9 GeV (~40%)
  - Four orientations: 0°, 90°, 45°, 135°

- **Solenoidal magnet**
- **Drift chambers**
- **Start counter/Time of flight**
- **Electromagnetic Calorimeters**



GlueX Experiment in Hall D / JLab

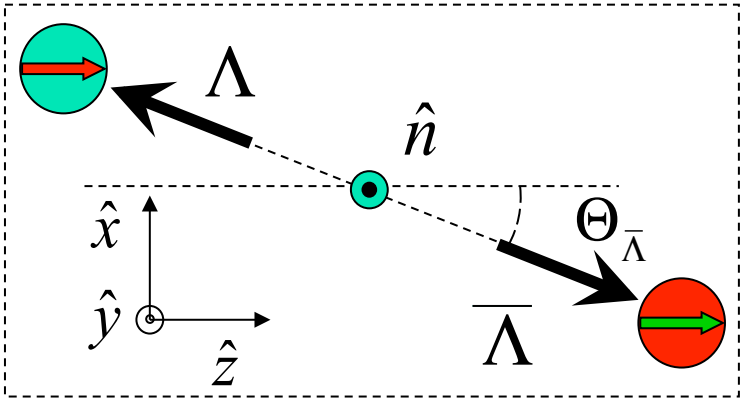


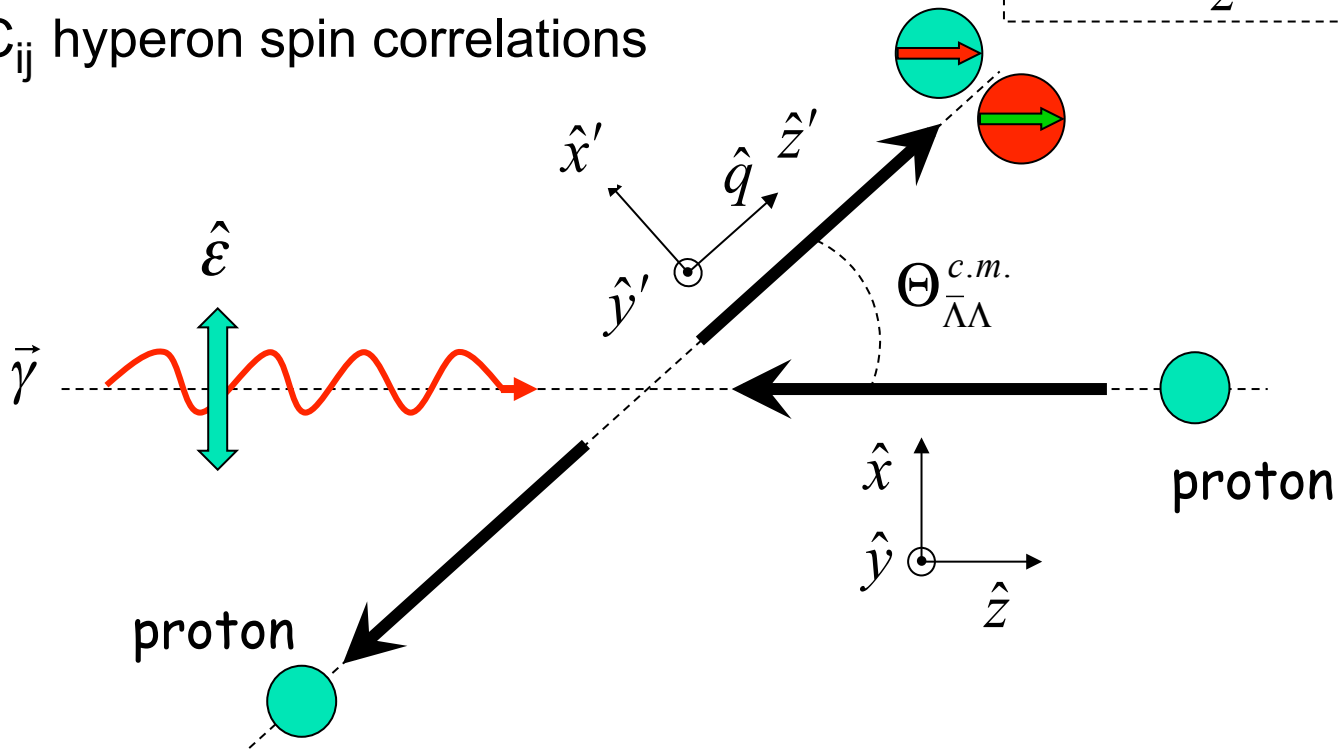
- **Physics-quality data runs in 2016, 2017, 2018, …**
  (this talk)

Overall Kinematics

How is the pair produced?

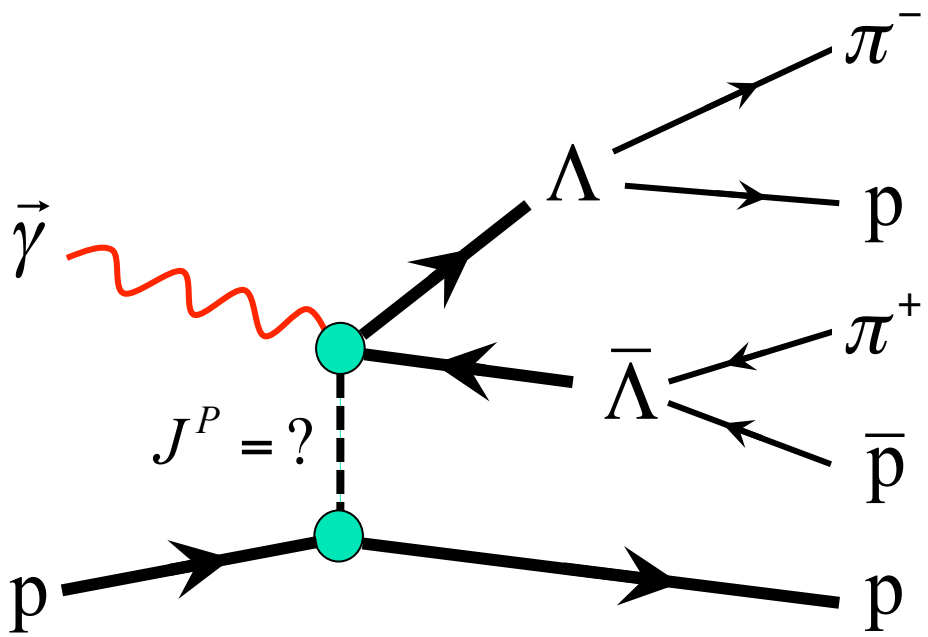
- Orbital angular momentum?
- Spin state: singlet or triplet?
- u-channel vs t-channel?
- Need differential cross sections
- Need spin observables
  - Σ beam spin asymmetry
  - C_{ij} hyperon spin correlations



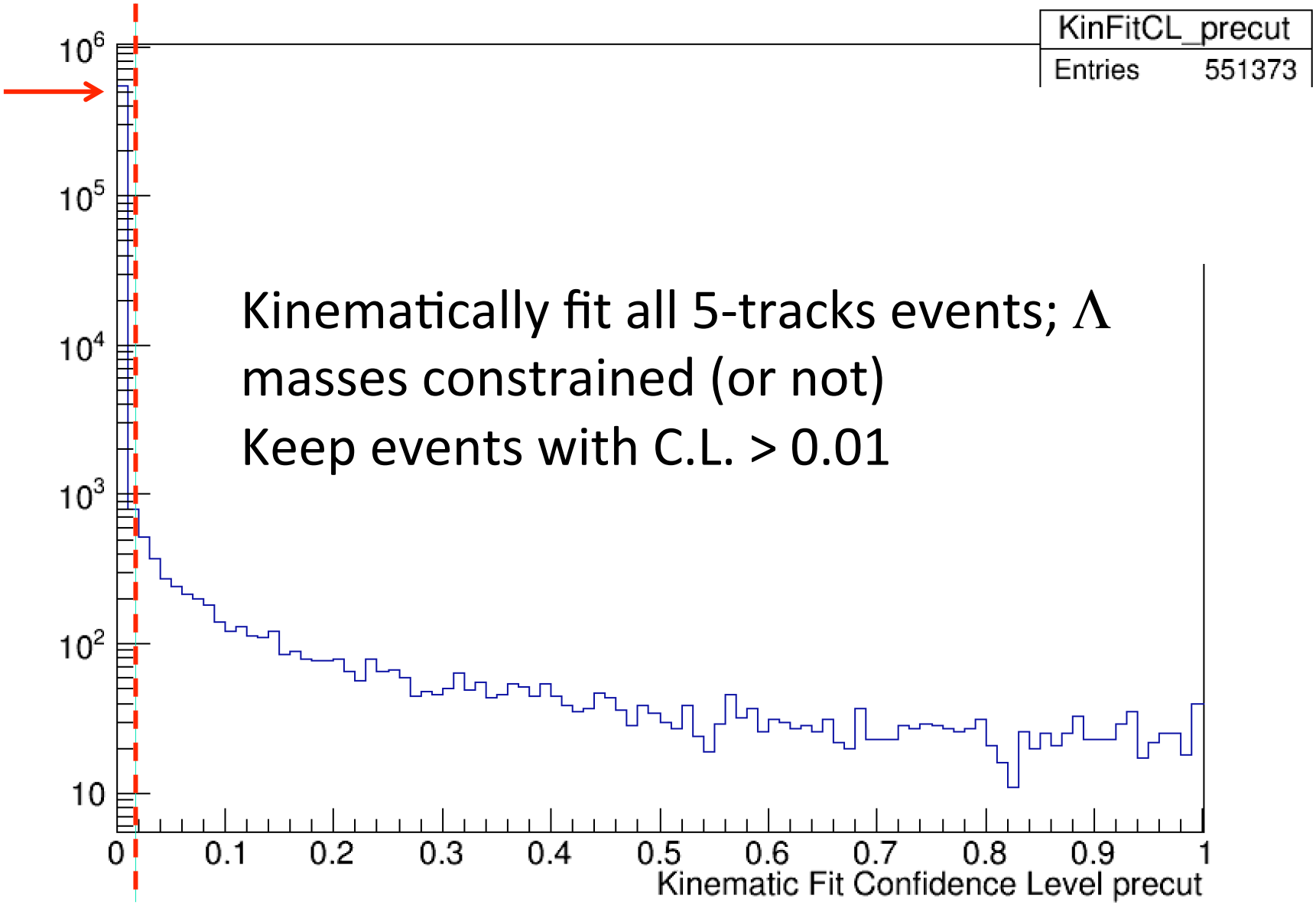


Kinematic Fitting

- Vary measured momenta within the permitted range to enforce *exact* momentum and energy conservation
- Fit to 5 track GlueX events
  - Without constraining Λ masses and fitting to a single vertex
  - With Λ masses constrained and detached vertices

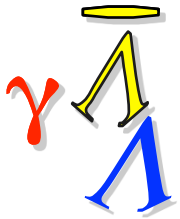


Kinematic Fit Confidence Level



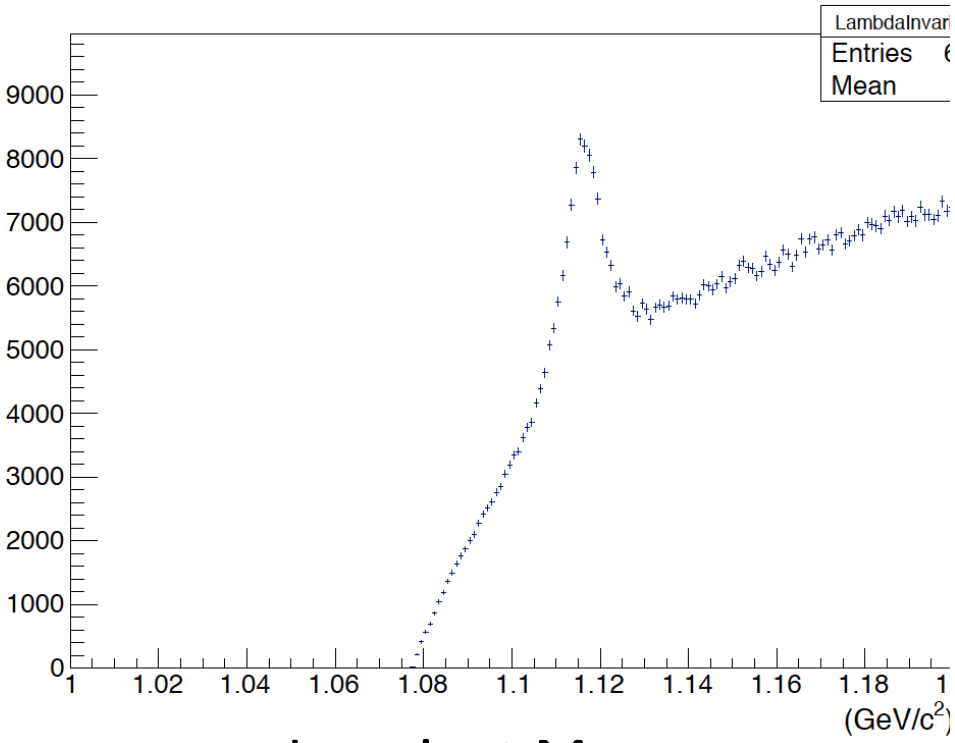
Kinematically fit all 5-tracks events; Λ masses constrained (or not)

Keep events with C.L. > 0.01



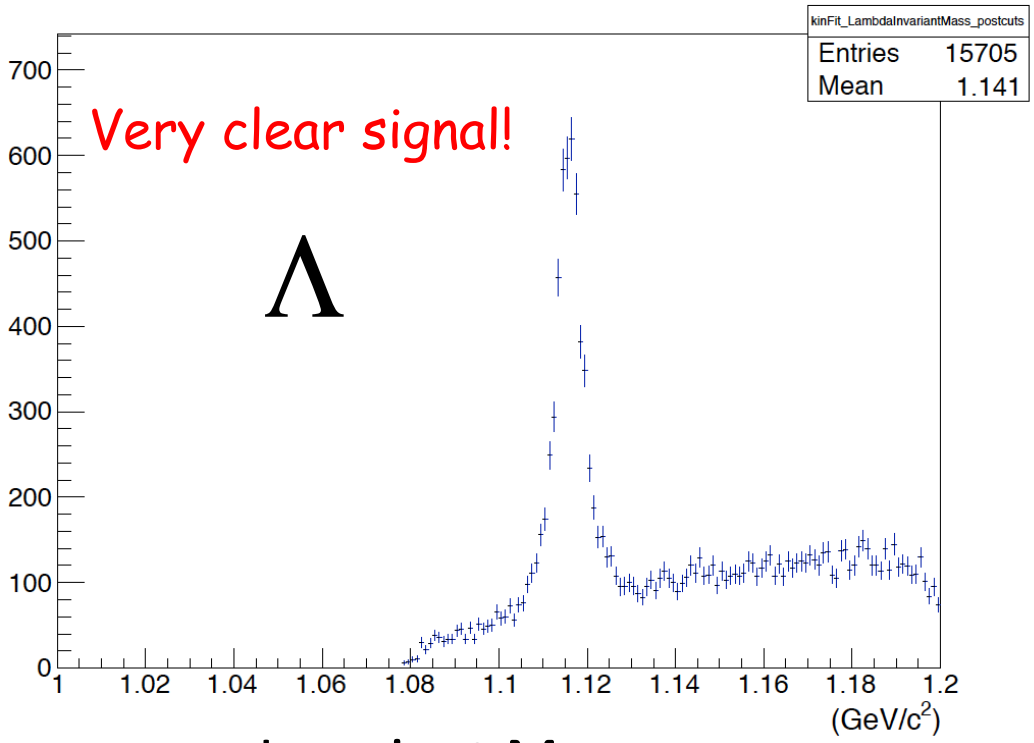
$\pi^- p \leftarrow \Lambda$ Invariant Mass Unconstrained

Converged KINFIT to 5 tracks,
No PID cuts



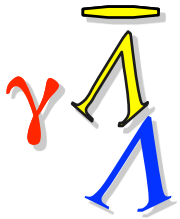
Invariant Mass π^-p

After 1% C.L. cut
and PID cuts



Invariant Mass π^-p

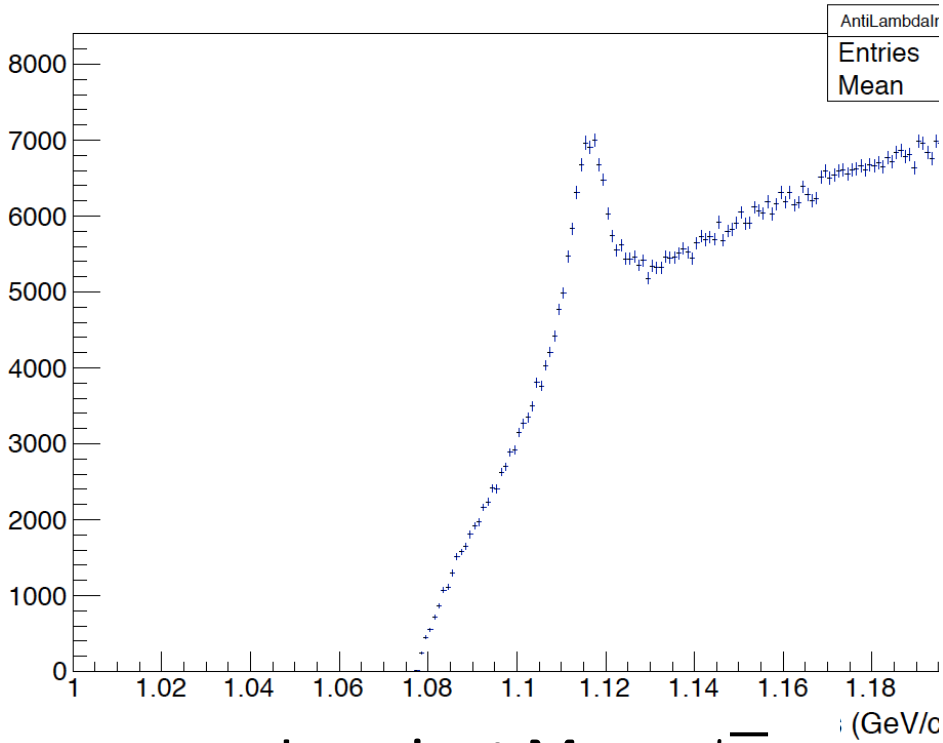
(Plotted here using post-KINFIT variables)



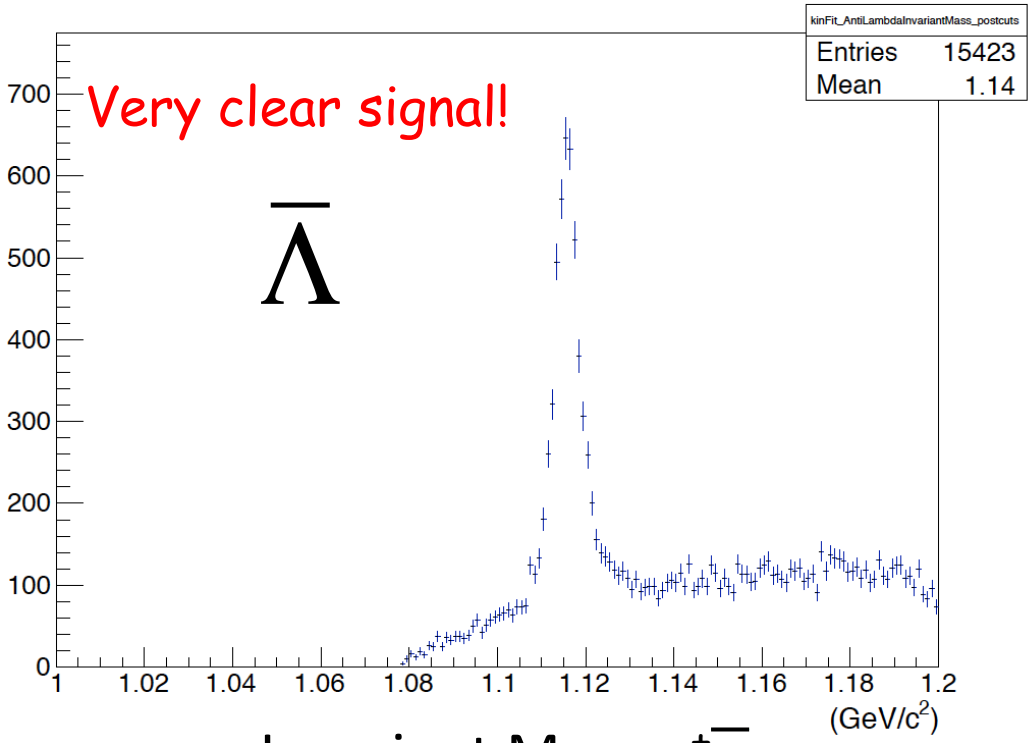
$\pi^+\bar{p} \leftarrow \bar{\Lambda}$ Invariant Mass Unconstrained

Converged KINFIT to 5 tracks,
No PID cuts

After 1% C.L. cut
and PID cuts



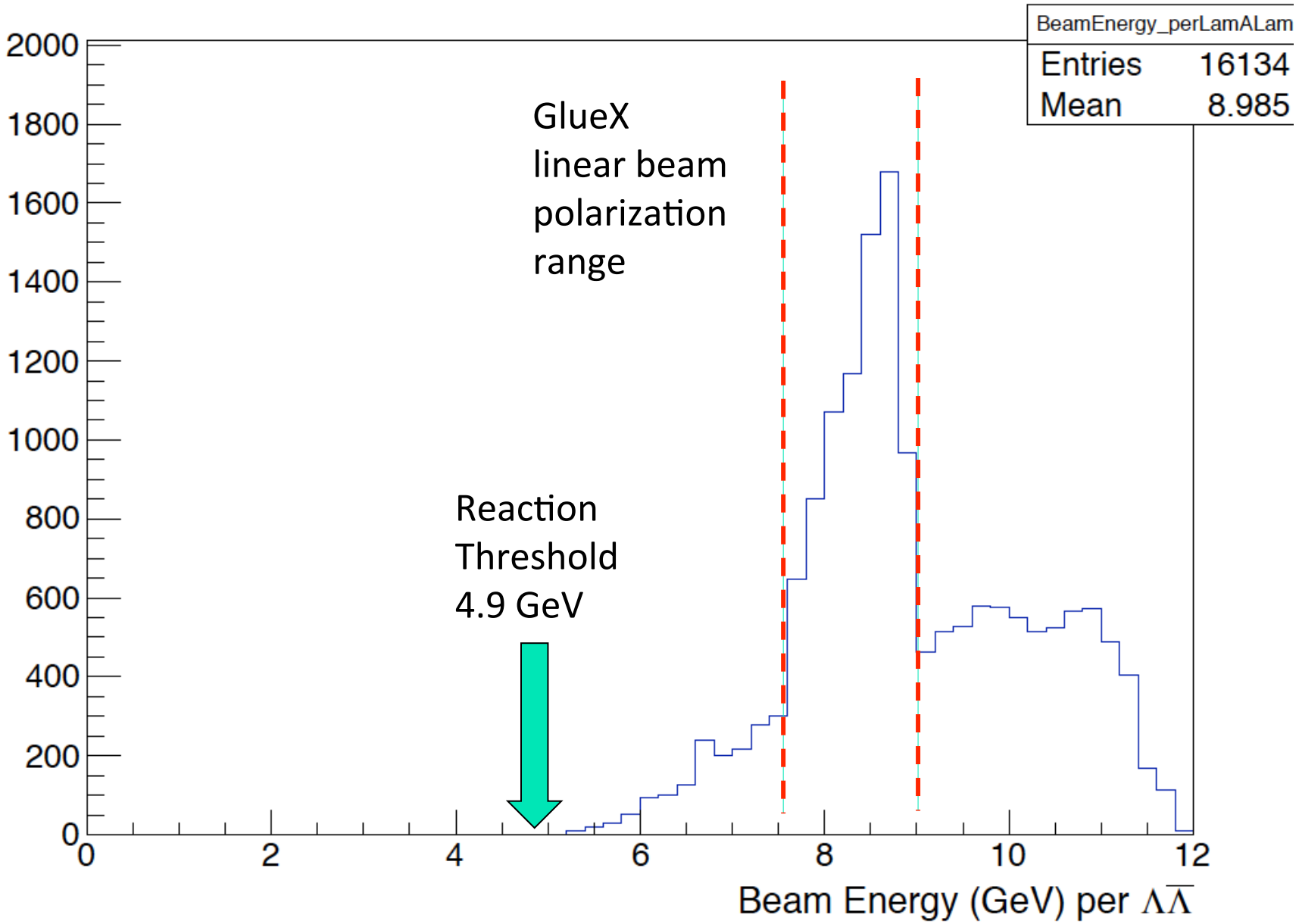
Invariant Mass $\pi^+\bar{p}$



Invariant Mass $\pi^+\bar{p}$

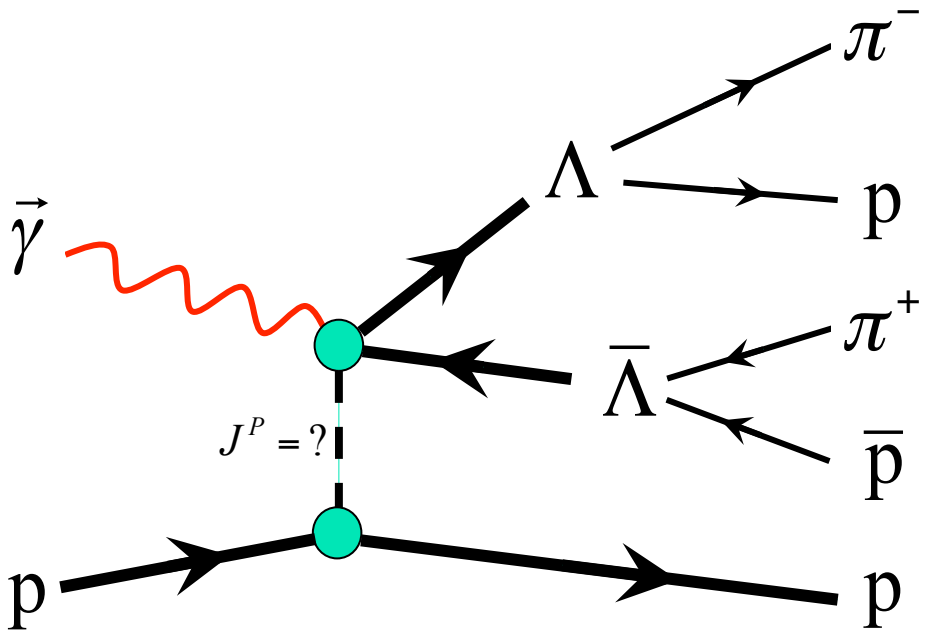
(Plotted here using post-KINFIT variables)

Photon Beam Energy Distribution

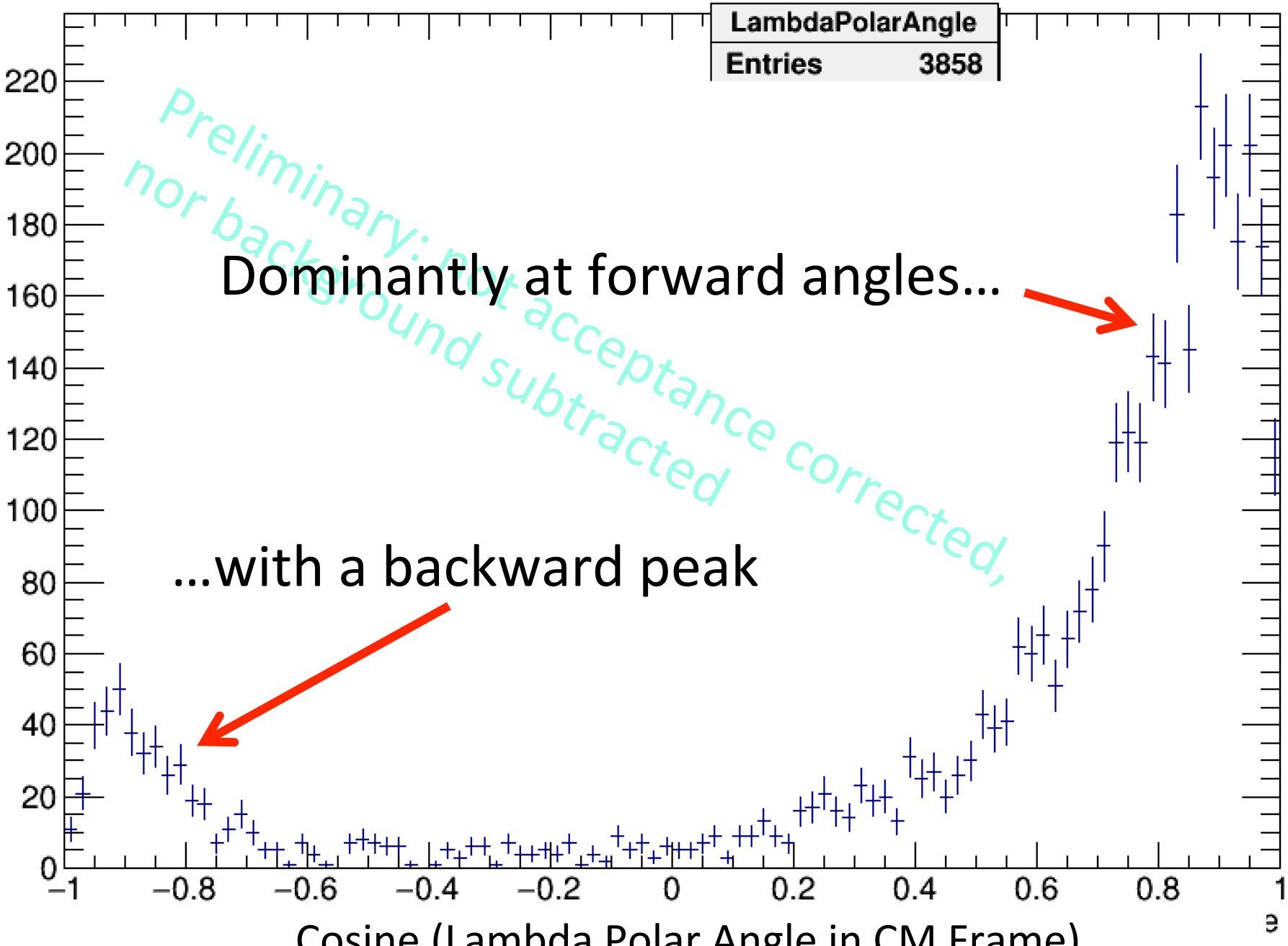


Quiz:

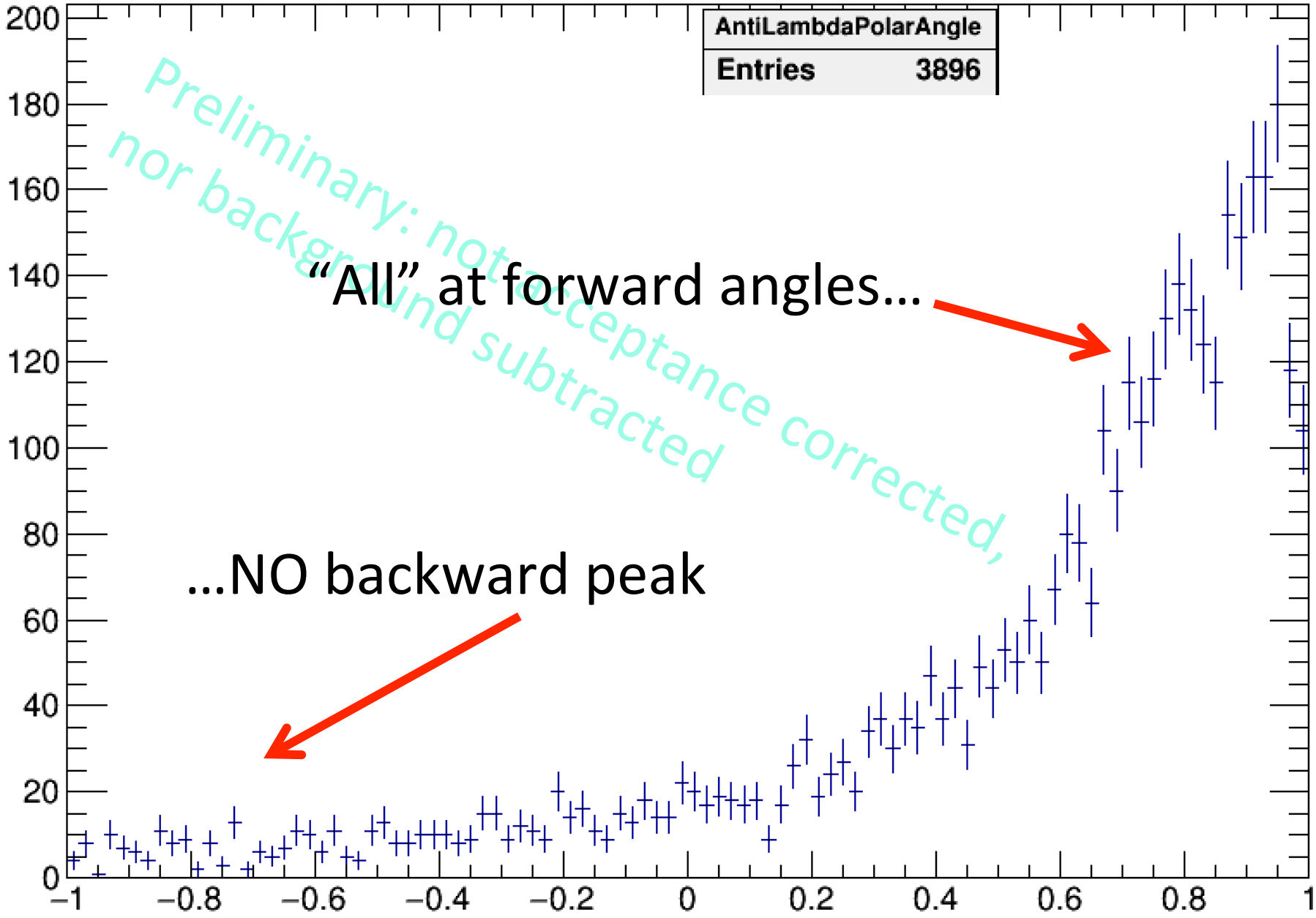
- How would you suppose that the Lambda particles are distributed in (γp) C.M. angle?
  - uniformly?
  - forward?
  - backward?



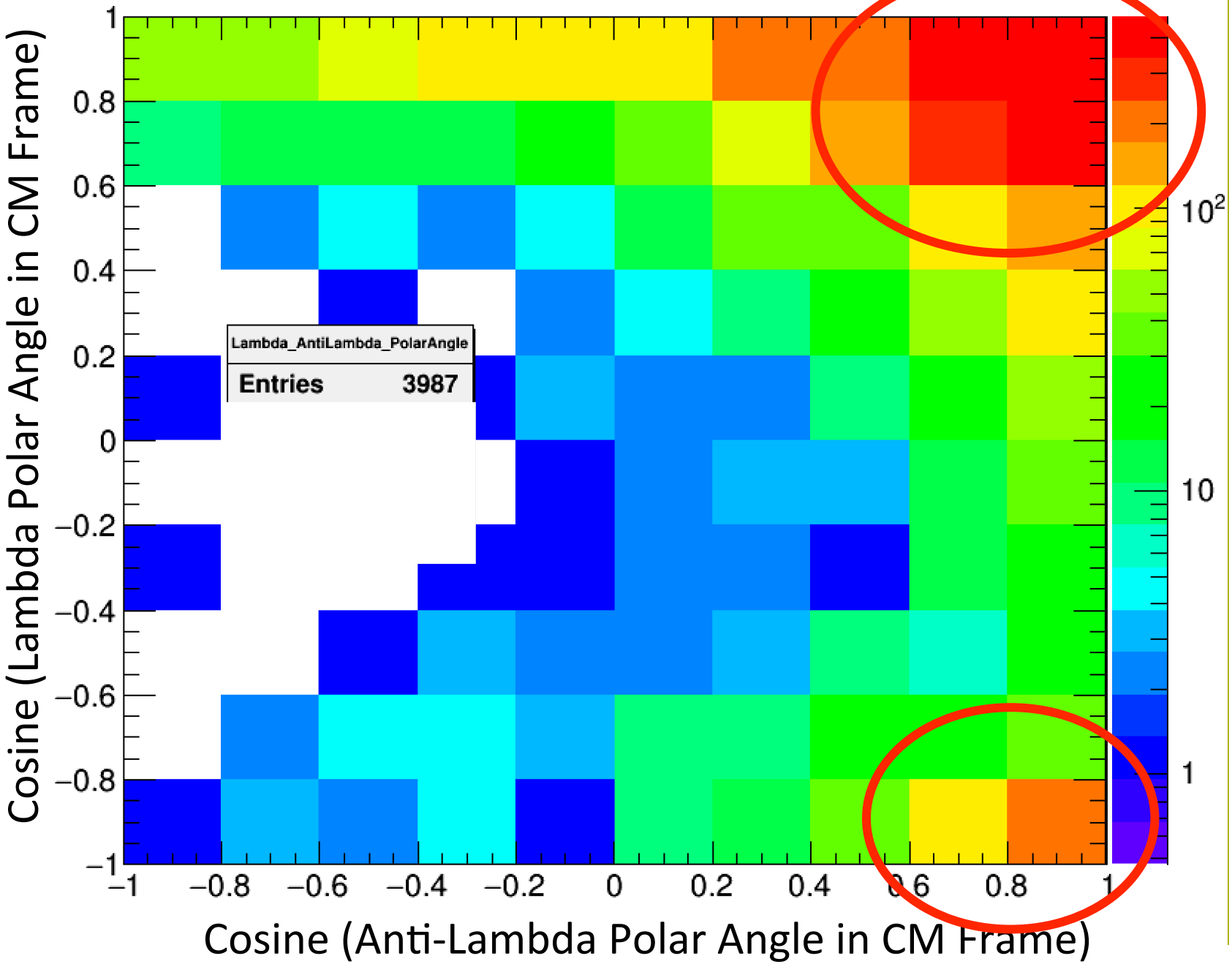
Lambda Polar Angle in C.M.



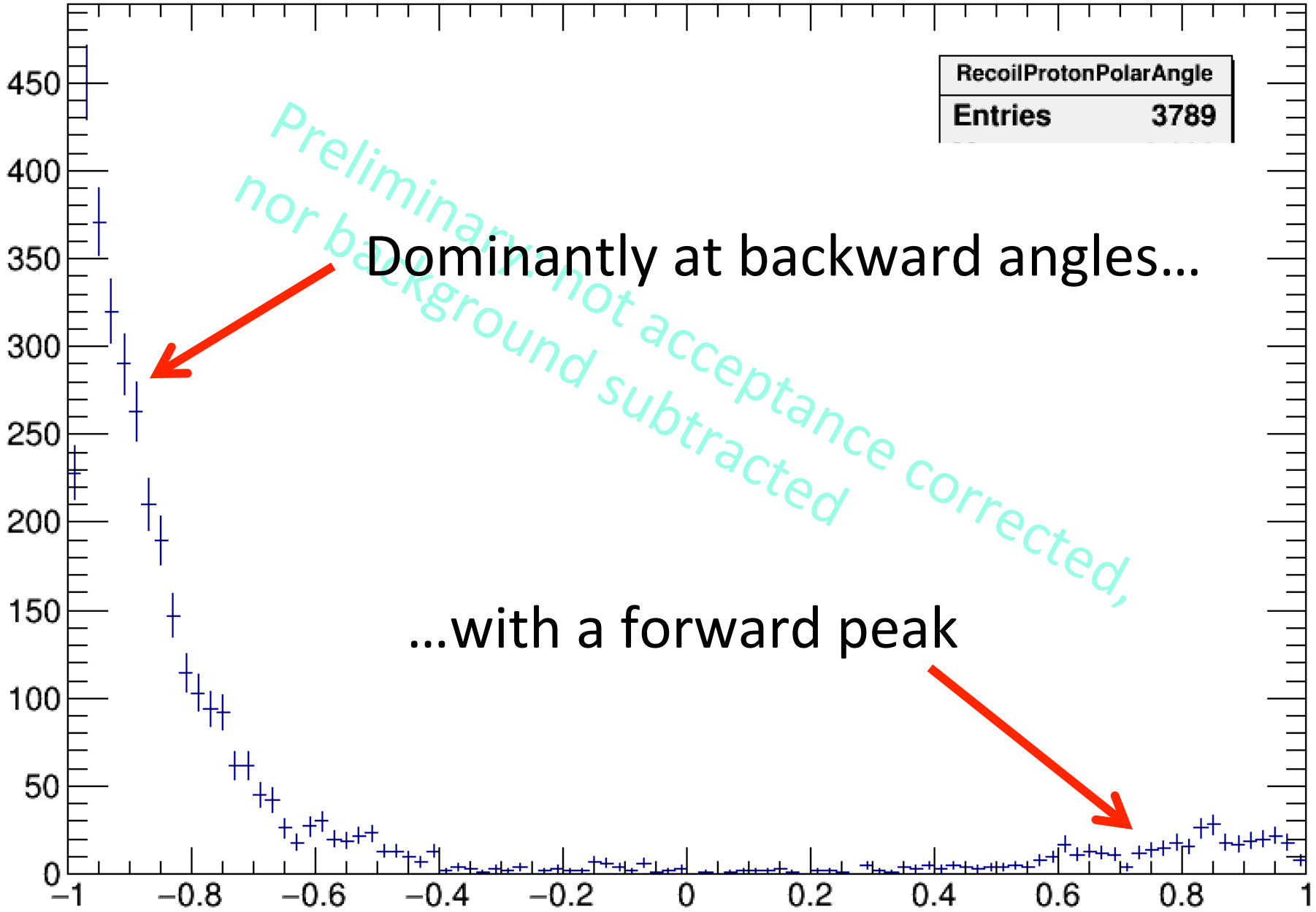
AntiLambda Polar Angle in C.M.



Sign of Two Reaction Amplitudes

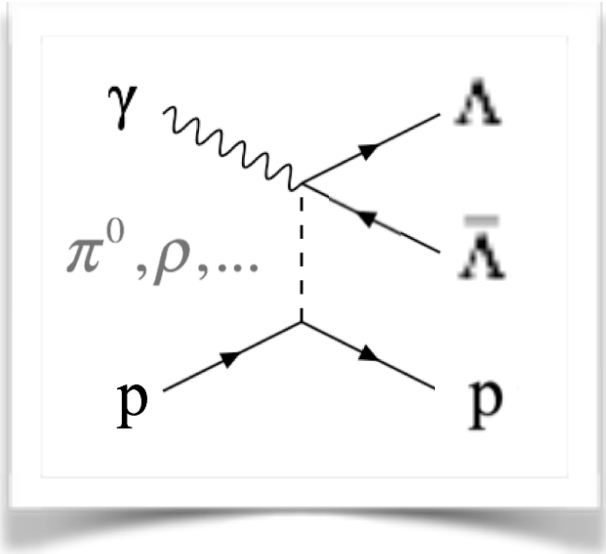


Proton C.M. angle

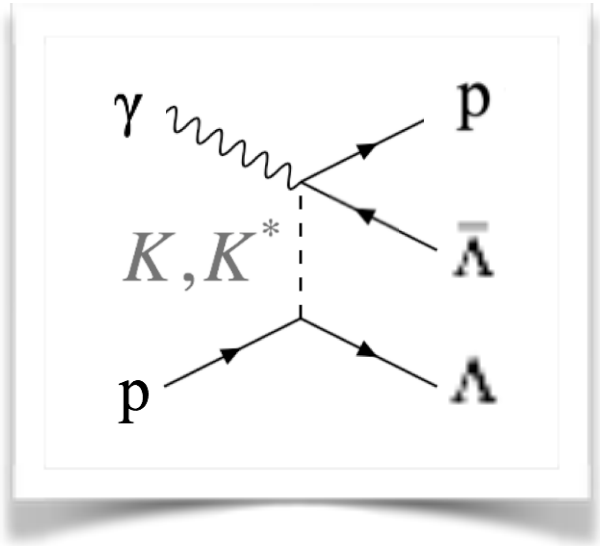


Consistent with two t-channel Amplitudes:

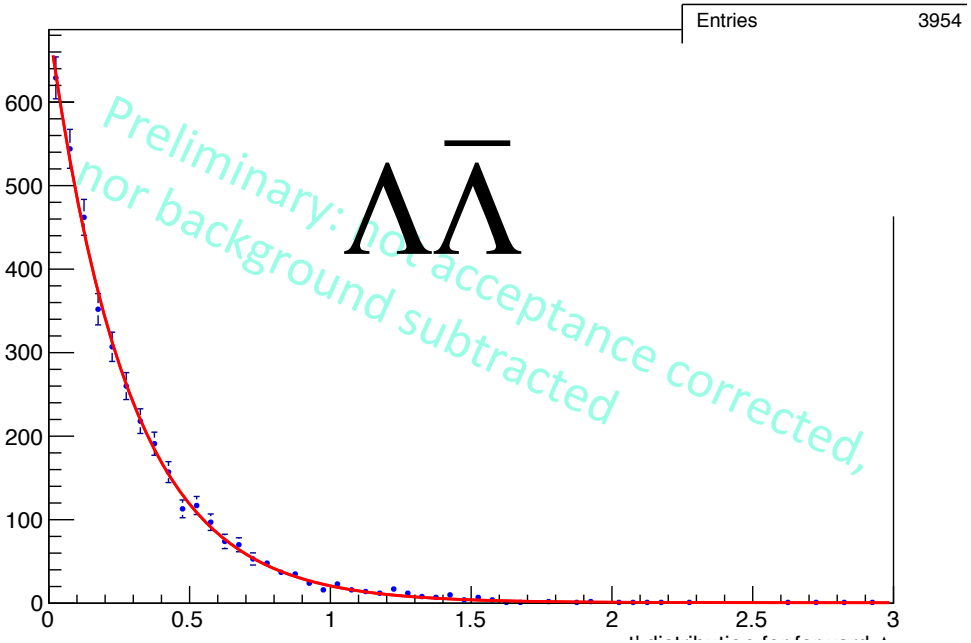
- Nonstrange exchange:
  - recoiling proton goes backward in C.M. frame
  - π, ρ, Pomeron…



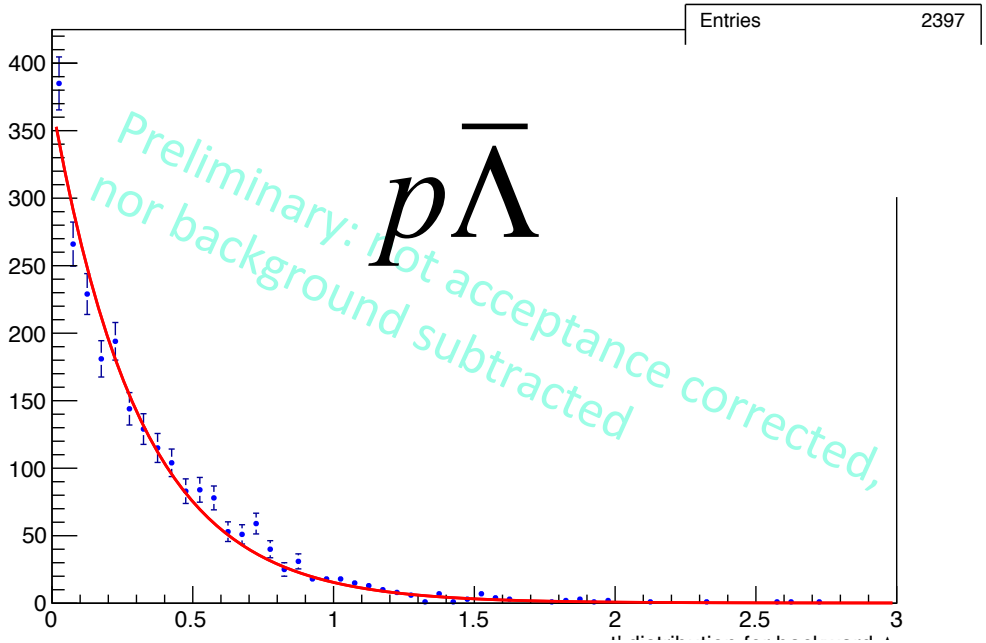
- Strange exchange:
  - recoiling Λ goes backward in C.M. frame
  - K, K^* exchange…



t-t_{min} Distribution ~ Cross Section



- t' of $\Lambda\bar{\Lambda}$ pairs (GeV^2)

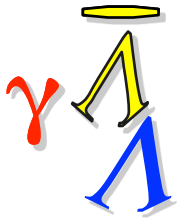


- t' of $p\bar{\Lambda}$ pairs (GeV^2)

Distribution for $\Lambda\bar{\Lambda}$ forward track pairing

-does not resemble the model prediction!

Distribution for $p\bar{\Lambda}$ forward track pairing

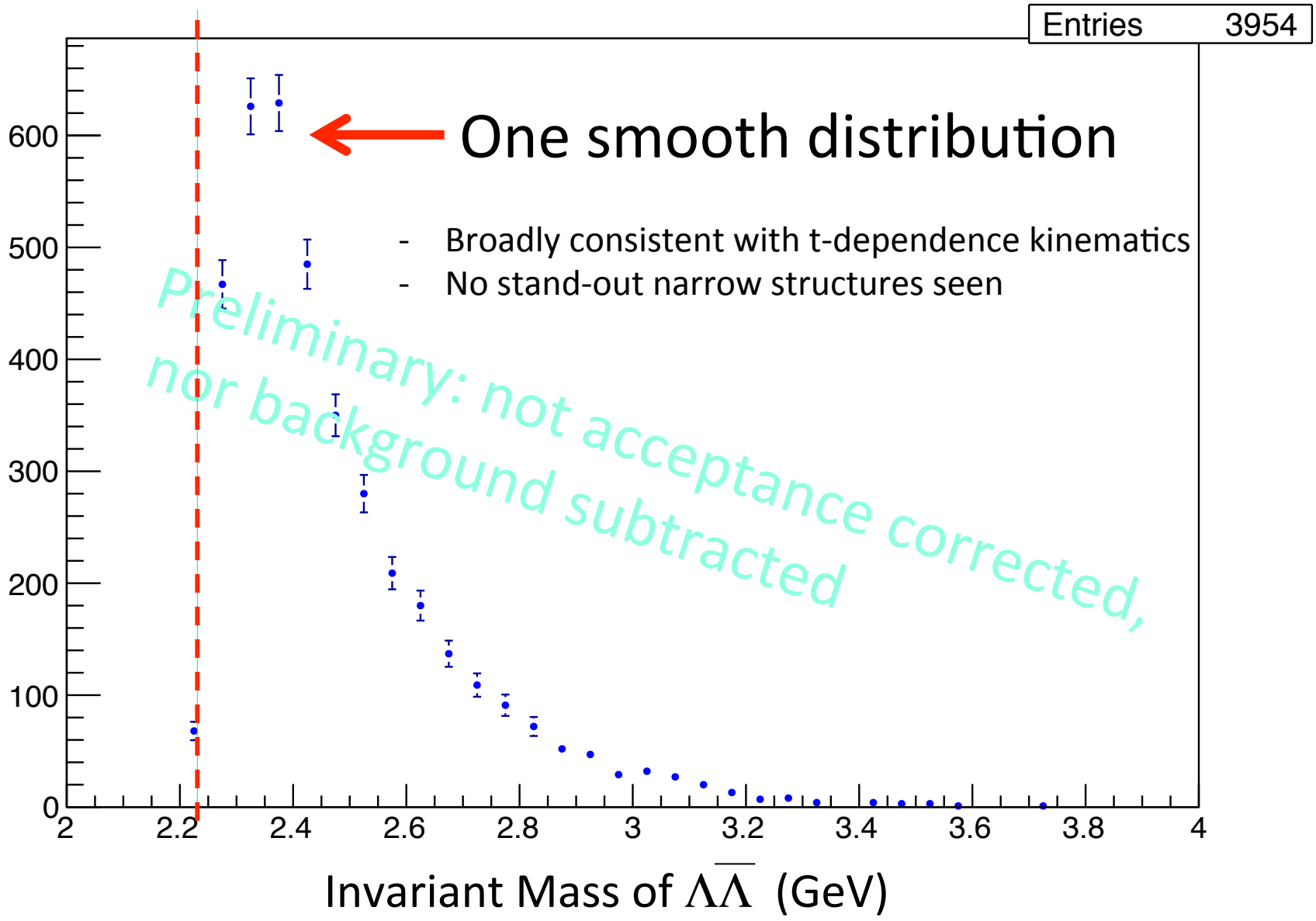


Continuum Resonances

- Baryon-(anti-)baryon interactions
  - $\bar{p}p$ resonance searches came up empty… after years of work at CERN & elsewhere
- Look for resonant quasi-bound states in invariant masses of $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$
  - First-ever search for baryon-anti-baryon resonances in this reaction

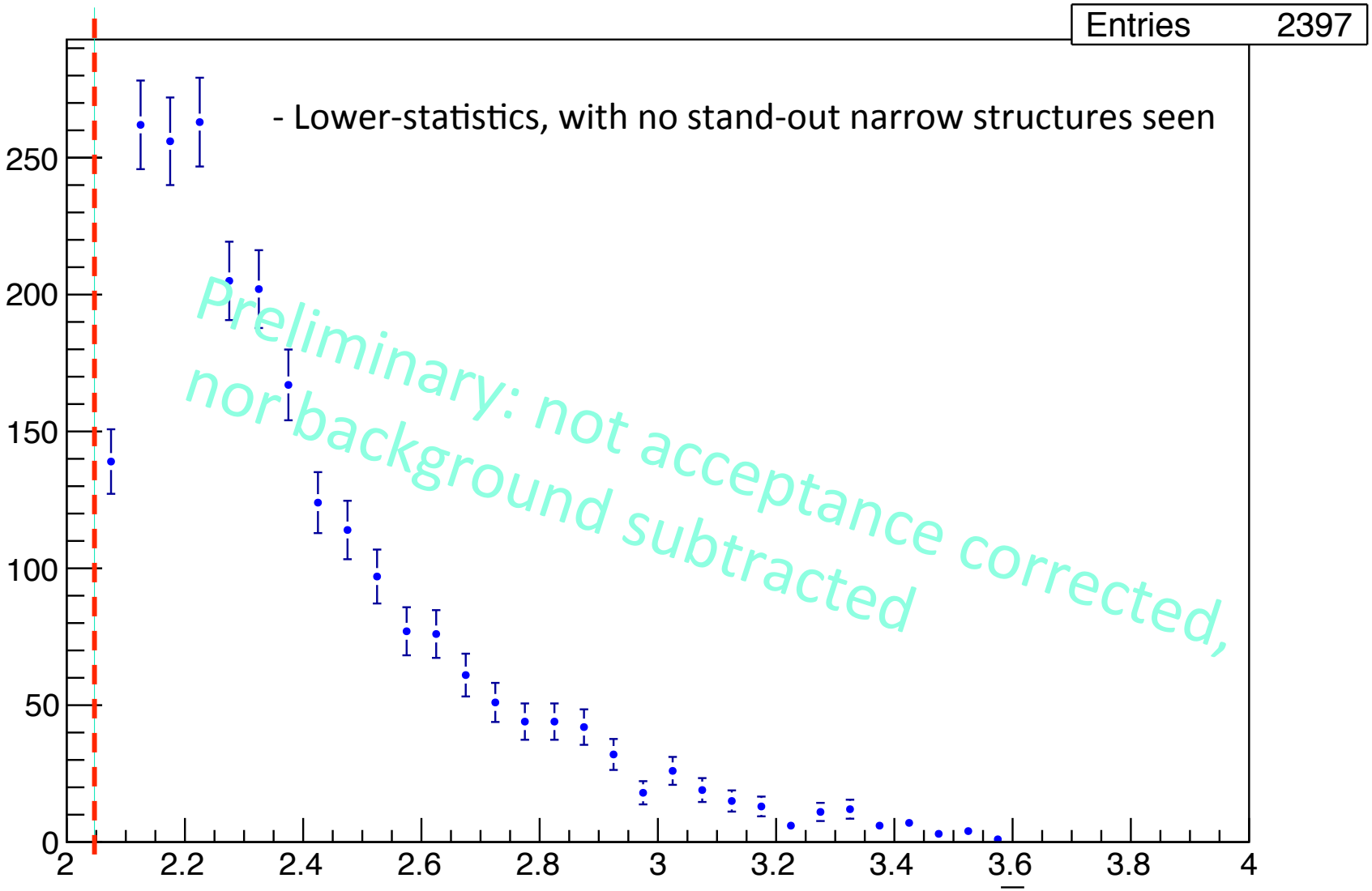
Looking for $\Lambda\bar{\Lambda}$ -onium

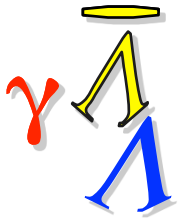
Forward Lambda particles selected



Looking for $p\bar{\Lambda}$-onium

Backward Lambda particles selected





(Possible) CPT Symmetry Test

- Lifetimes for particle and anti-particle must be the same:

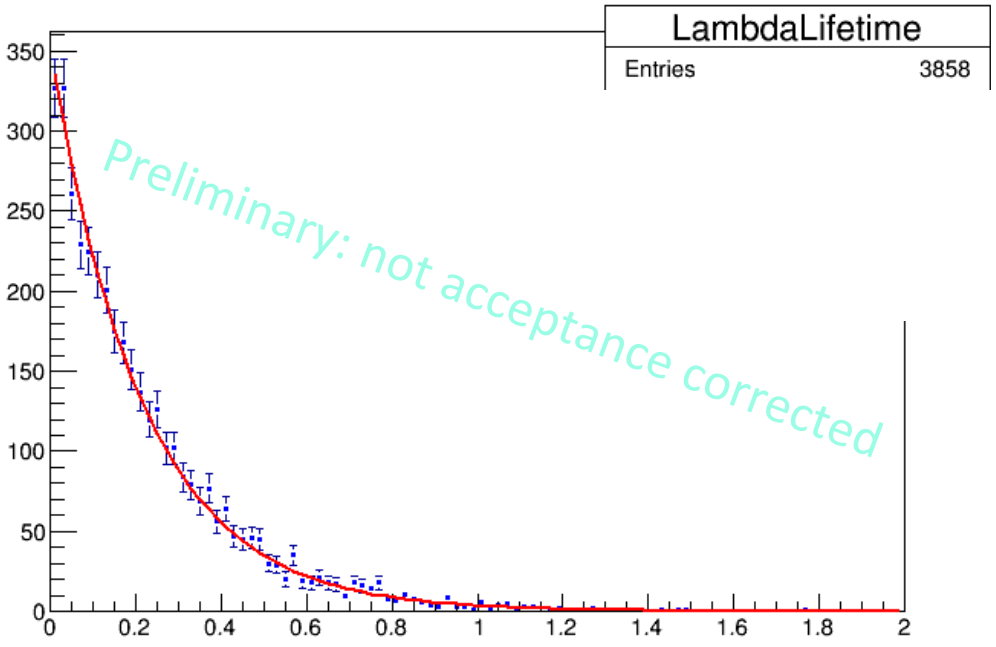
$$\tau_{\Lambda} = \tau_{\bar{\Lambda}} \quad \text{(by CPT)}$$

$$\tau_{\Lambda} = 263.2 \pm 2.0\, ps$$

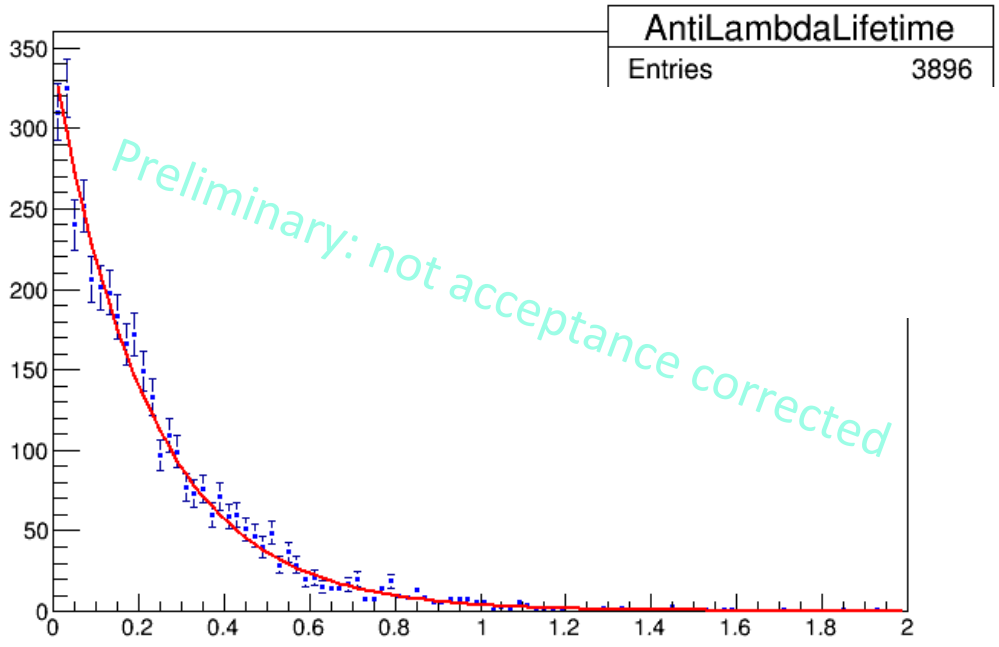
$$\left(\tau_{\Lambda} - \tau_{\bar{\Lambda}}\right) / \tau_{\Lambda} = -0.001 \pm 0.009 \text{ (PDG)}$$

Reconstructed Lifetimes

Lifetimes consistent, within uncertainties



Rest Frame Lambda Lifetime (ns)



Rest Frame anti-Lambda Lifetime (ns)

PRELIMINARY: GlueX needs about x10 events to be statistically competitive. It could happen…

Spin Correlations (in-progress work)

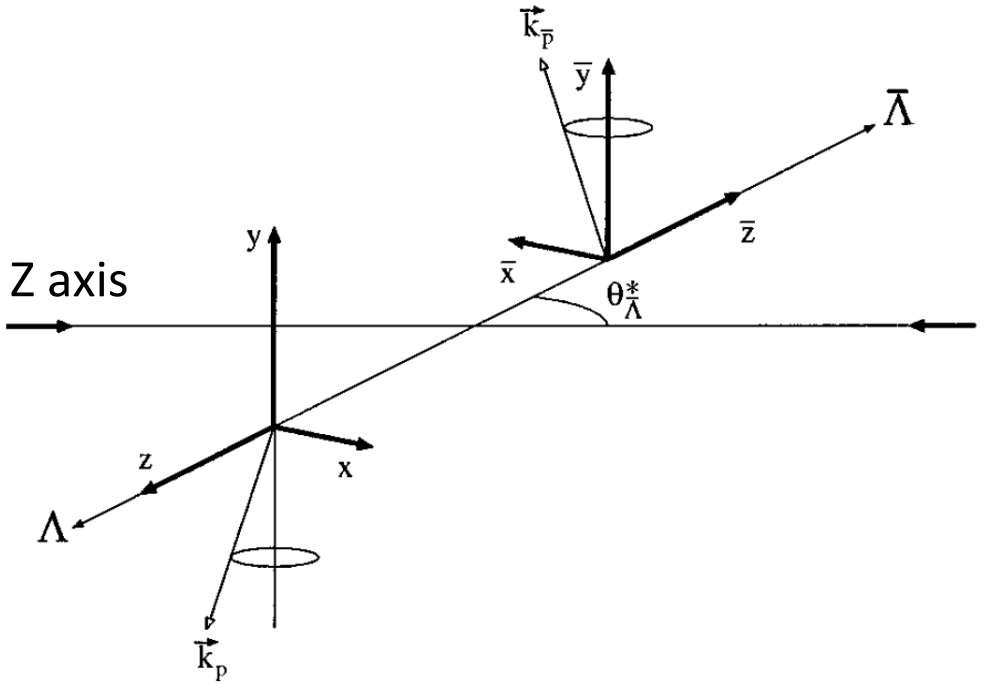
- Beam spin asymmetry, Σ, coming
  (recall GlueX uses linear photon beam polarization...)
- The Lambdas can be produced polarized

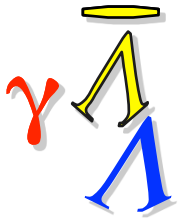
$$I(\theta_p) = \frac{1}{4\pi}\left(1 - \alpha P_\Lambda \cos(\theta_p)\right) \quad I(\theta_{\bar{p}}) = \frac{1}{4\pi}\left(1 - \bar{\alpha} P_{\bar{\Lambda}} \cos(\theta_{\bar{p}})\right)$$

  - Expect:

$$P_\Lambda = P_{\bar{\Lambda}} \text{ (by C)}$$

$$\alpha = -\bar{\alpha} \text{ (by CP)}$$





Spin Correlations (in-progress work)

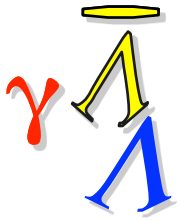
- The $\Lambda\bar{\Lambda}$ spin correlations: $C_{\bar{m}n} = \left\langle \vec{\sigma}_{\bar{m}} \otimes \vec{\sigma}_{n} \right\rangle$
  - Observables:

$$C_{\bar{z}x} = C_{\bar{x}z} \text{ (by C)} \qquad C_{\bar{x}y} = C_{\bar{y}x} = C_{\bar{z}y} = C_{\bar{y}z} = 0 \text{ (by P)}$$

  - Singlet Fraction:

$$S_F \equiv \frac{1}{4}\left(1 - \left\langle \vec{\sigma}_{\Lambda} \bullet \vec{\sigma}_{\bar{\Lambda}} \right\rangle\right) = \frac{1}{4}\left(1 + C_{\bar{x}x} - C_{\bar{y}y} + C_{\bar{z}z}\right)$$

    - $S_F = 0$ - hyperons produced in spin triplet state
    - $S_F = 1$ - hyperons produced in spin singlet state
    - $S_F = ¼$ - statistical mixture of singlet & triplet

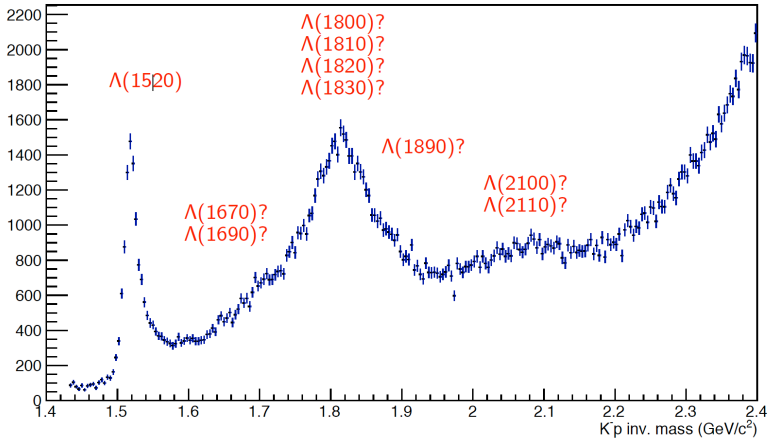


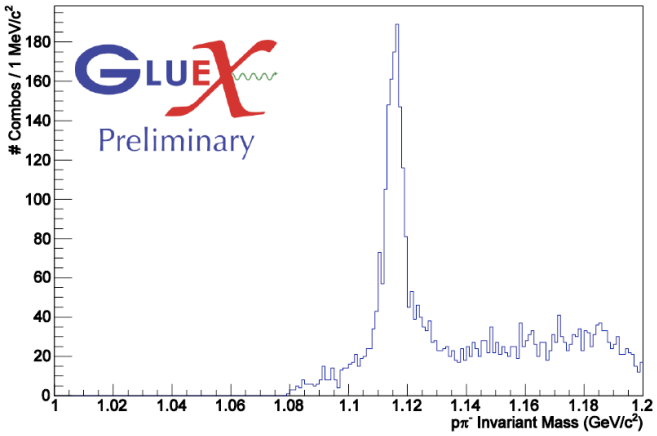
Spin Correlations

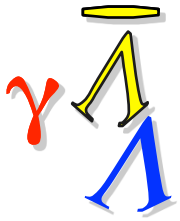
- This is the leading edge of our work…
  - No results yet

Other Strangeness Physics at GlueX

- $K^+\Lambda$: beam asymmetry and Λ polarization at GlueX energies
- $\Lambda(1520)$: beam asymmetry & and higher-lying $p\,K^-$ states
- Ξ's: ground state observed and evidence for excited states
- K/π Cerenkov separator (DIRC) being installed 2018

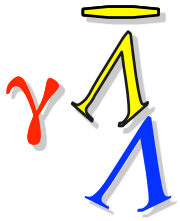






Summary / Conclusions

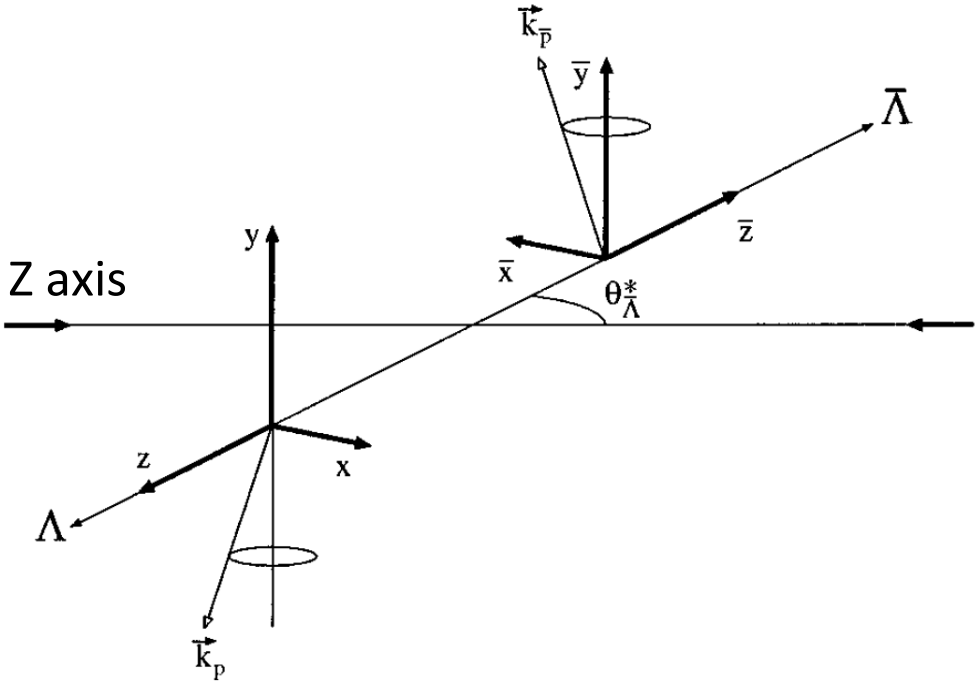
- We see the $\Lambda\bar{\Lambda}$ reaction!
- Interesting angular distributions shown
  - Evidence for at least two exchange mechanisms
- Acceptances have not been applied yet: all very preliminary
- Have ~twice the statistics from 2018 run
- Cross sections & spin observables coming, compare $p\bar{p}$ & $\Lambda\bar{\Lambda}$
- We would welcome some theory support!



Supplemental Slides

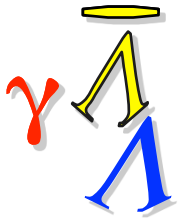
Spin Correlations

- The $\Lambda\bar{\Lambda}$ spin correlations:



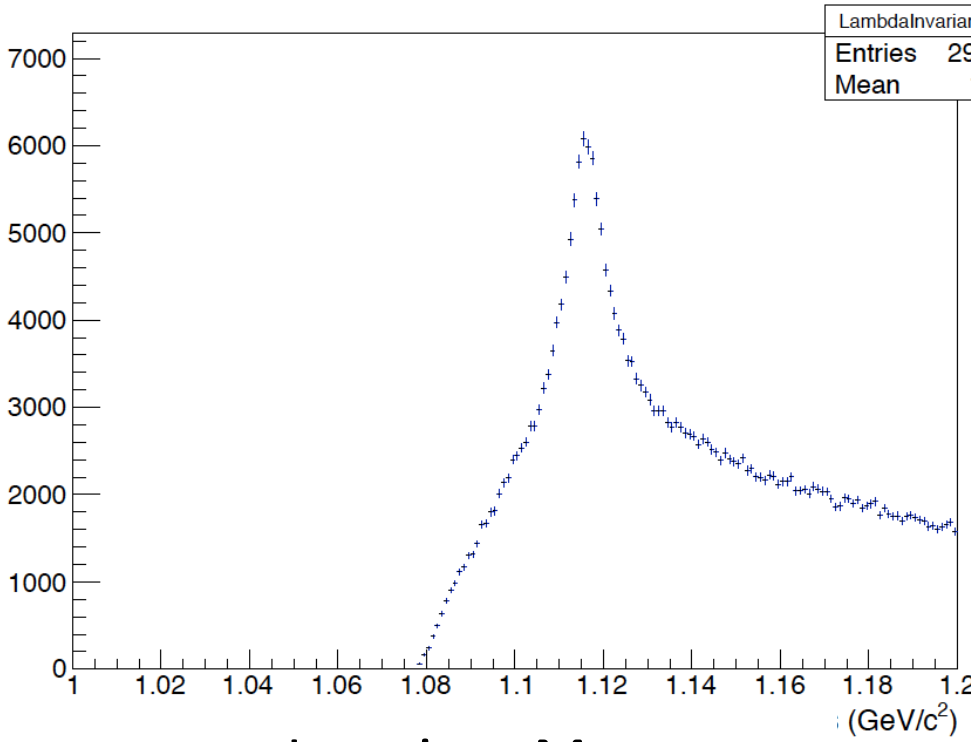
$$P_{\bar{y}} = \frac{3}{\bar{\alpha}} \frac{1}{N} \frac{\sum_{k=1}^{N} \eta_k \cos\theta^k_{\bar{m}}}{\sum_{k=1}^{N} \eta_k}$$

$$C_{\bar{m}n} = \frac{9}{\alpha\bar{\alpha}} \frac{1}{N} \frac{\sum_{k=1}^{N} \eta_k \cos\theta^k_{\bar{m}} \cos\theta^k_{n}}{\sum_{k=1}^{N} \eta_k}$$



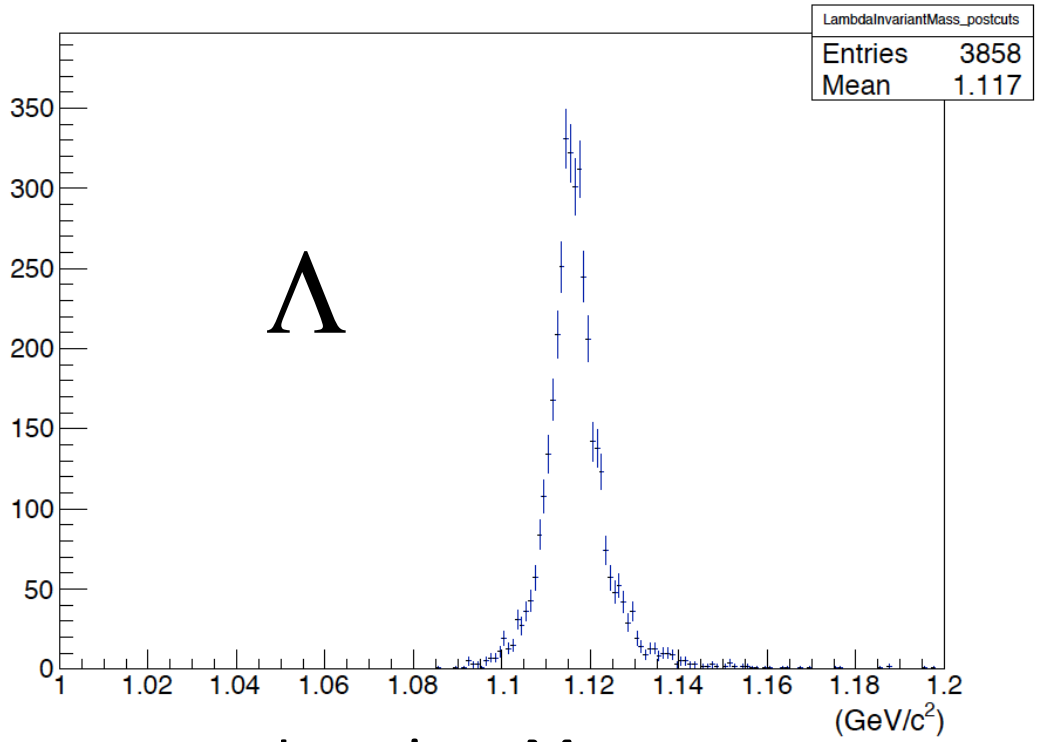
$\pi^- p \leftarrow \Lambda$ Invariant Mass Constrained

KINFIT to 5 tracks,
No PID cuts



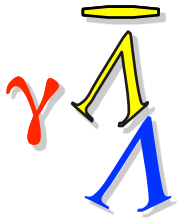
Invariant Mass π^-p

After C.L. cut &
dE/dx & timing cuts



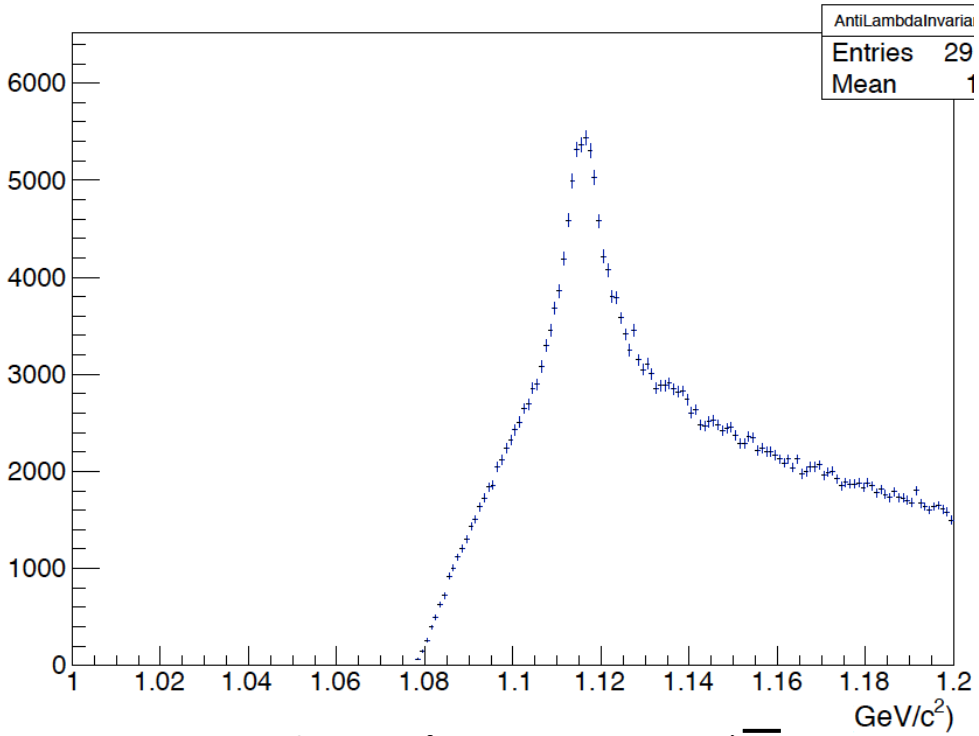
Invariant Mass π^-p

(Plotted here using pre-KINFIT variables;
it's really a delta function)



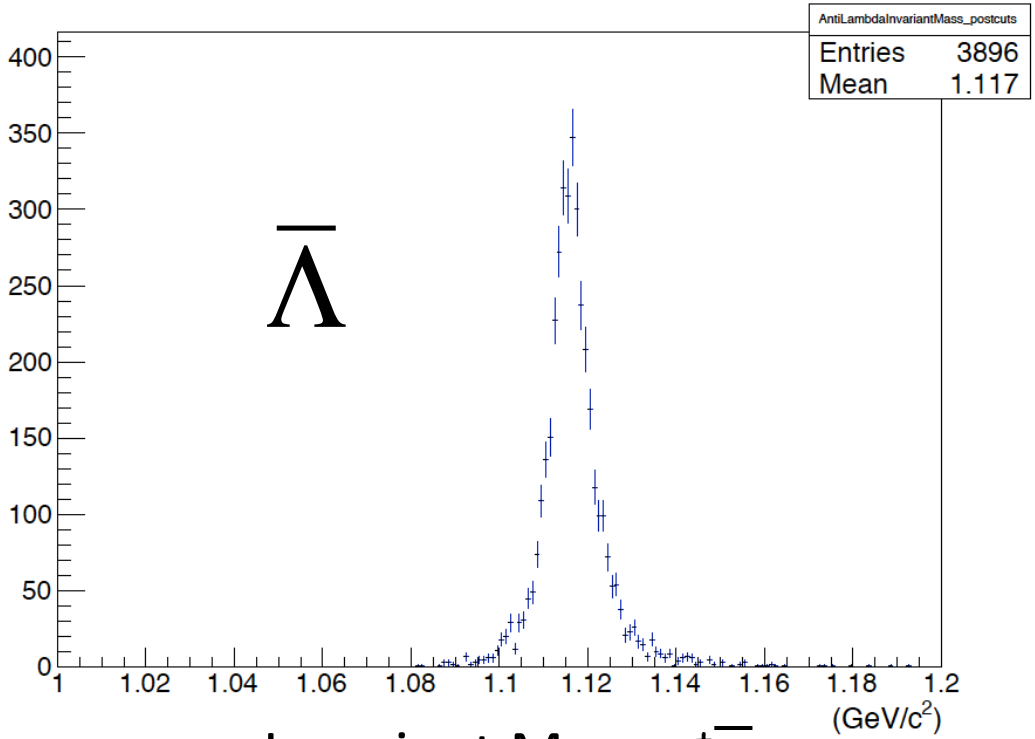
$\pi^+\bar{p} \leftarrow \bar{\Lambda}$ Invariant Mass Constrained

KINFIT to 5 tracks,
No PID cuts



Invariant Mass $\pi^+\bar{p}$

After C.L. cut &
dE/dx & timing cuts

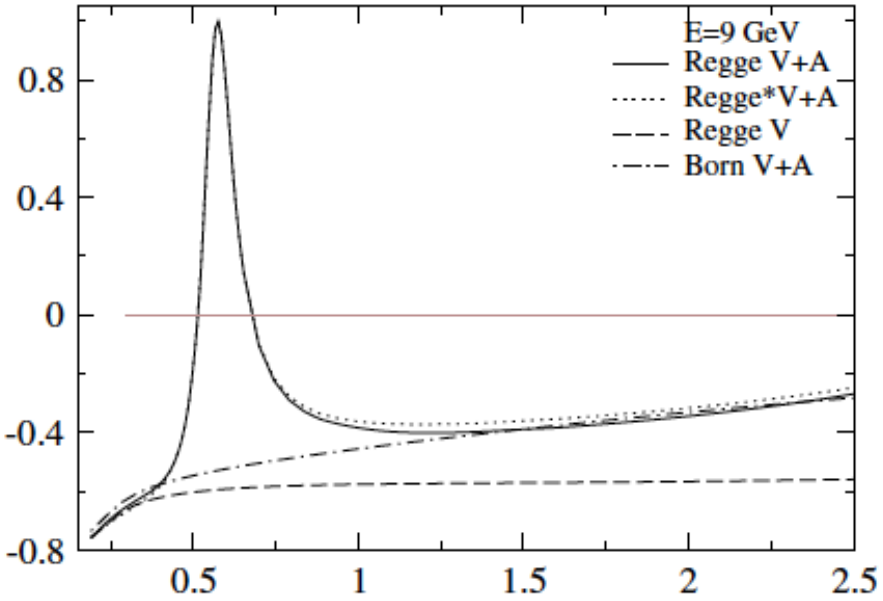


Invariant Mass $\pi^+\bar{p}$

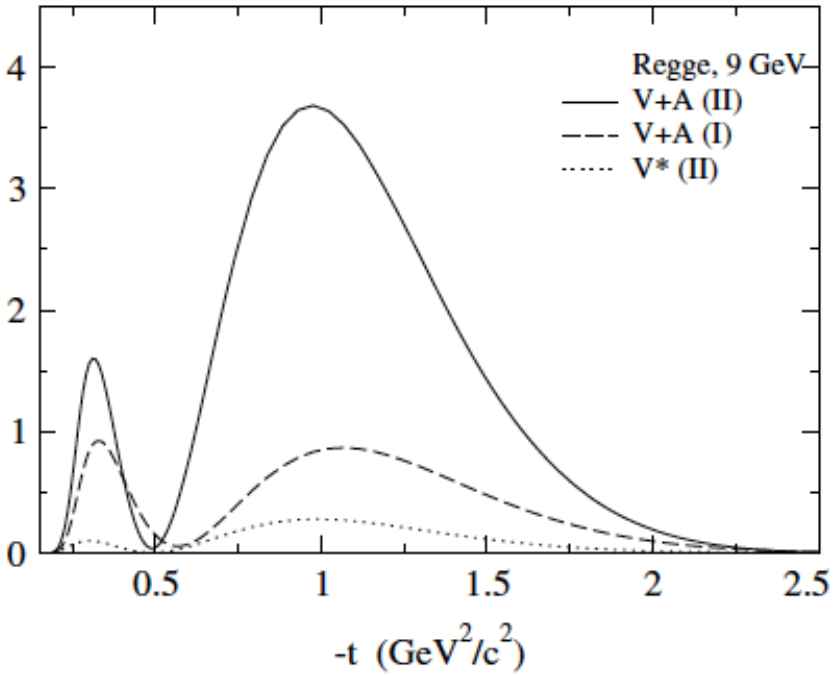
(Plotted here using pre-KINFIT variables;
it's really a delta function)

Theory Predictions

Σ



$\frac{d\sigma}{dt}$



$$\vec{\gamma}\, p \rightarrow \{p\bar{p}\}\, p$$

$$E_\gamma = 9\ \mathrm{GeV}$$

Large beam asymmetry predicted

- Peak in Σ for Regge model when meson trajectories cross zero

T. Gutsche, S. Kuleshov, V. Lyubovitskij, I. Obukhovsky, Phys. Rev. D **96**, 054024 (2017)