Jefferson Lab

GlueX

γ $\bar{p}p$ $\bar{\Lambda}\Lambda$

Baryon-Antibaryon Photoproduction at GlueX

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

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On behalf of the GlueX Collaboration

MENU 2023

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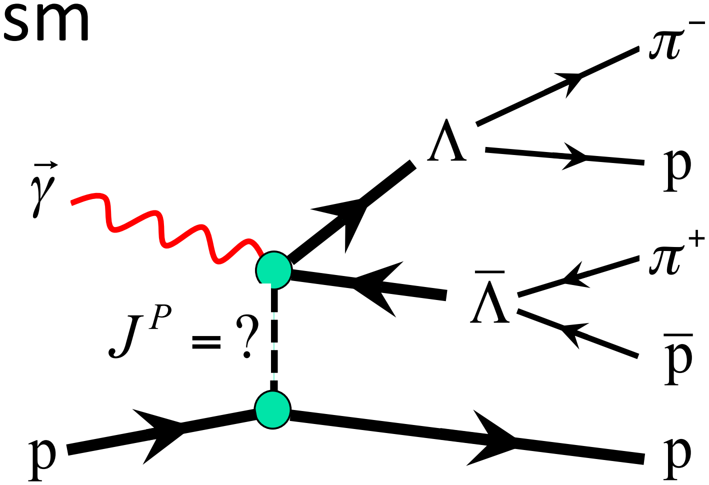
Carnegie Mellon University

Exploring Baryon-Baryon Photoproduction

- GlueX in Hall D at Jefferson Lab
  - Fully exclusive final states
  - Reactions: $\vec{\gamma}p \rightarrow \{p\overline{p}\}p$, $\vec{\gamma}p \rightarrow \{\Lambda\overline{\Lambda}\}p$, $\vec{\gamma}p \rightarrow \{p\overline{\Lambda}\}\Lambda$
- Compare phenomenology for these channels
  - What do the data suggest?
  - Model for production mechanism
  - Cross section results
  - Beam Spin observables



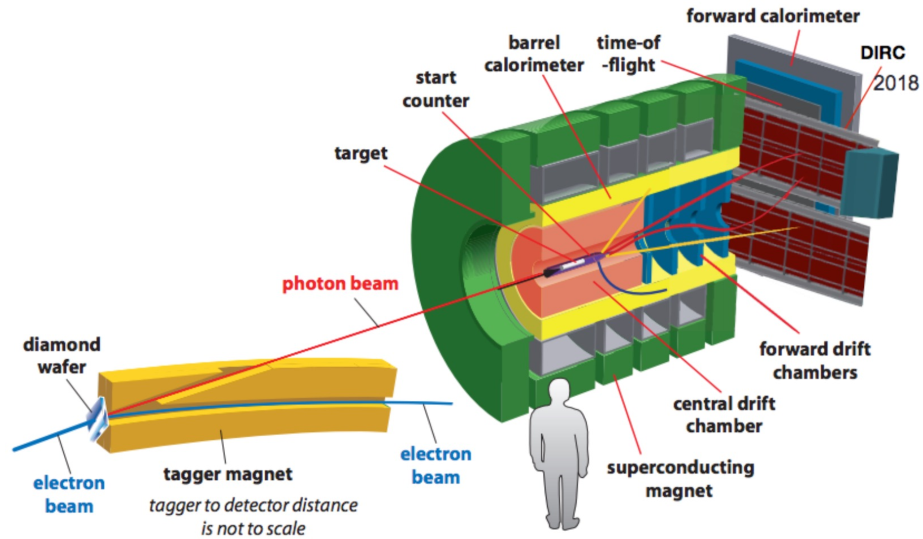
Motivation:

- Pull 3 quark-anti-quark pairs out of the vacuum at once – not sufficiently studied!
- Measure ratio of strange to non-strange production: $\{s\bar{s}\}$ vs. $\{u\bar{u}\}$.
- Mechanism via photoproduction is poorly known*
  - We have limited theory support
  - We offer a phenomenological model

* But see predictions : T. Gutsche *et al.* Physical Review D **96**, 054024 (2017)

Experimental parameters

- GlueX spectrometer
- Photon beam energy: 3.7 to 11.4 GeV
- "Phase I" data set: luminosity 429.6 pb^{-1}

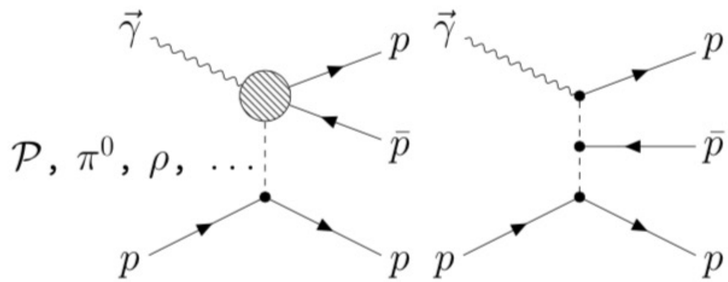


- Trigger on $\gtrsim$ 1 GeV calorimetric energy deposit by (p, π^{+-}, γ, ...)
- Exclusive reactions: kinematic fit to energy, momentum, creation/decay vertices, flight path significance (for hyperons)

Angular Distributions Tell the Story

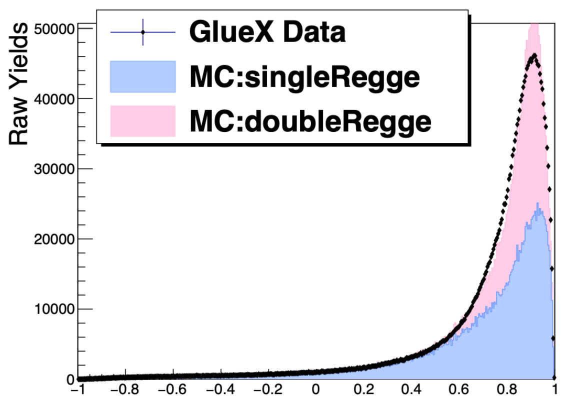
MC:singleRegge

~65%

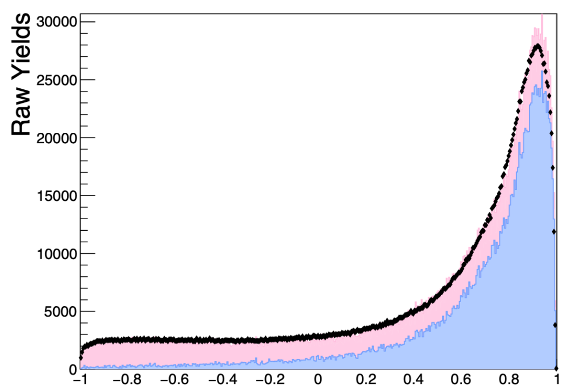


MC:doubleRegge

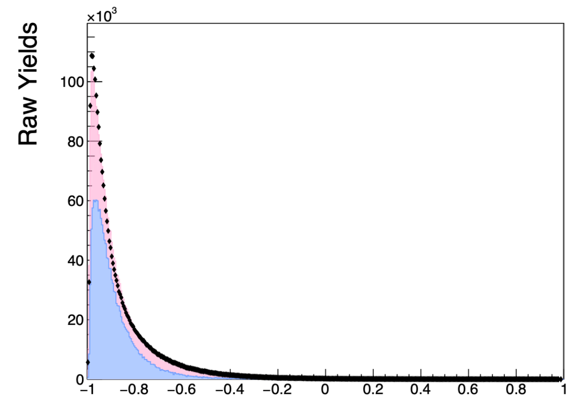
~35%



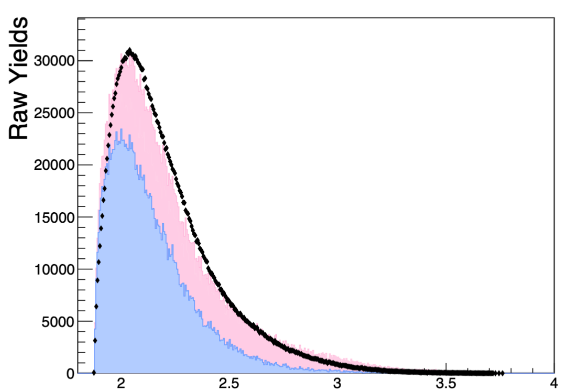
Forward Proton: $\cos(\theta_{CM})$



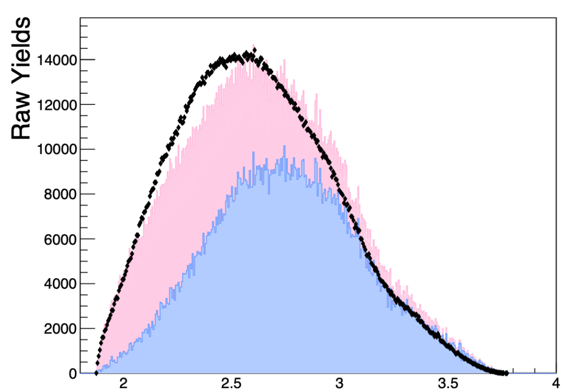
Anti-Proton: $\cos(\theta_{CM})$



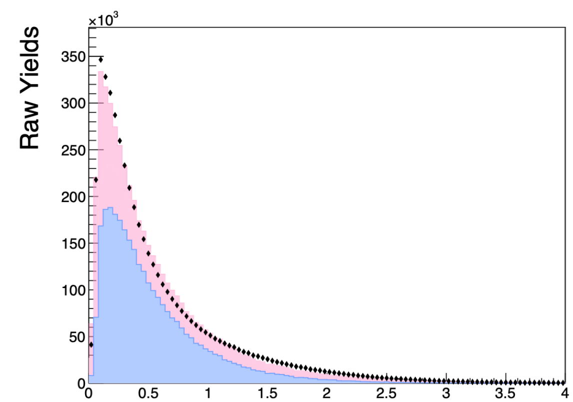
Backward Proton: $\cos(\theta_{CM})$



Invar. Mass $\{p_{fwd}\,\bar{p}\}$ GeV/c^2

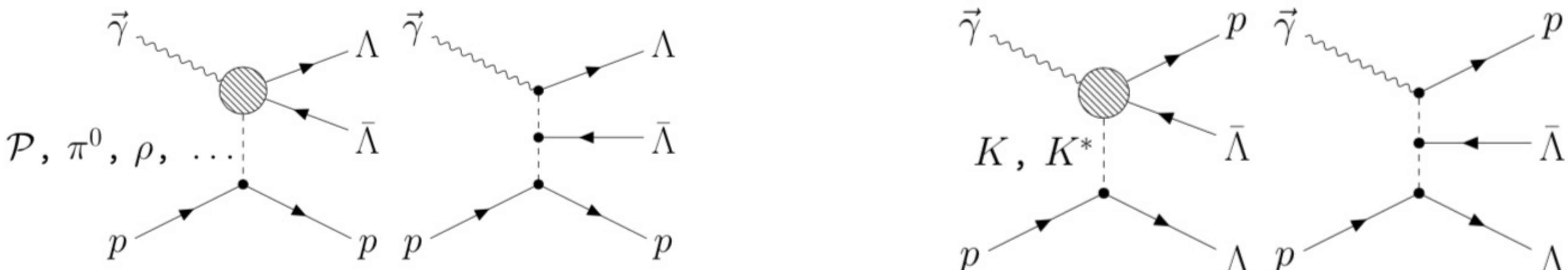


Invar. Mass $\{p_{bkwd}\,\bar{p}\}$ GeV/c^2

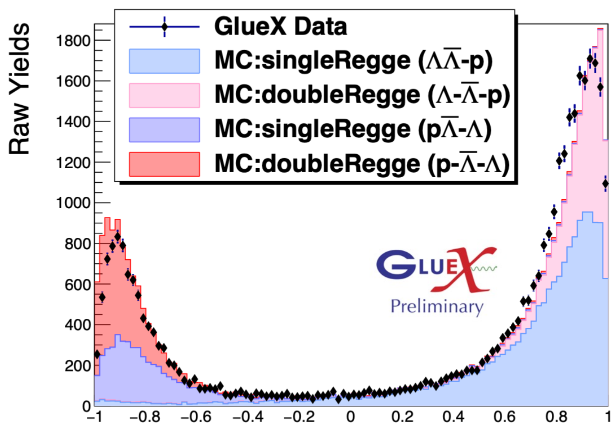


$-(t - t_{\min})$ of IM$\{p_{fwd}\,\bar{p}\}$

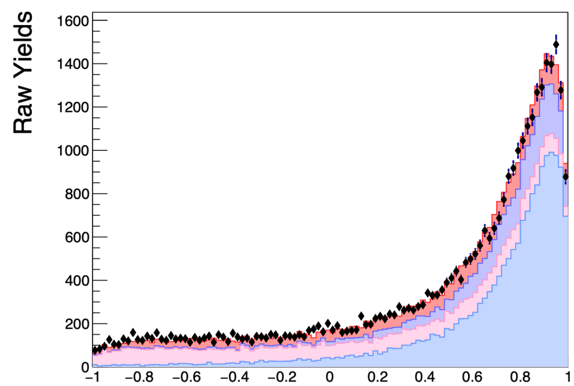
Angular Distributions Tell the Story



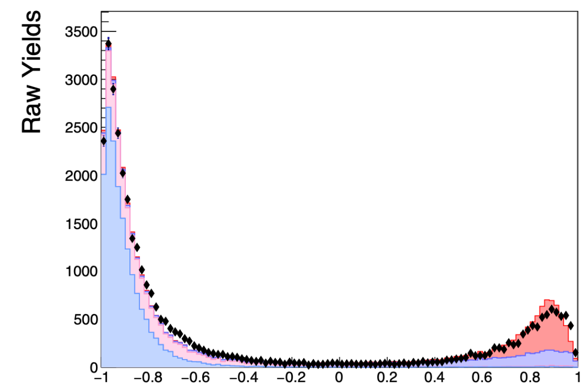
MC:singleRegge ($\Lambda\bar{\Lambda}$-p) MC:doubleRegge (Λ-$\bar{\Lambda}$-p) MC:singleRegge (p$\bar{\Lambda}$-Λ) MC:doubleRegge (p-$\bar{\Lambda}$-Λ)



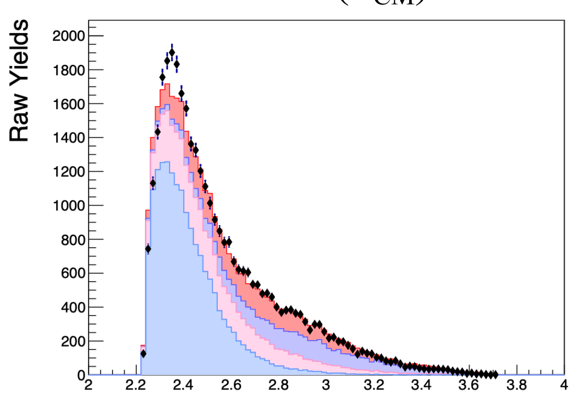
Lambda: $\cos(\theta_{CM})$.



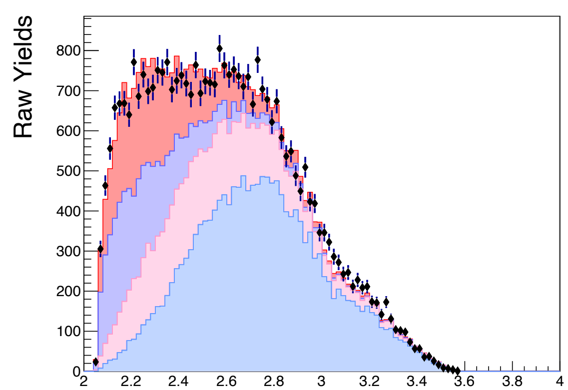
Anti-Lambda: $\cos(\theta_{CM})$



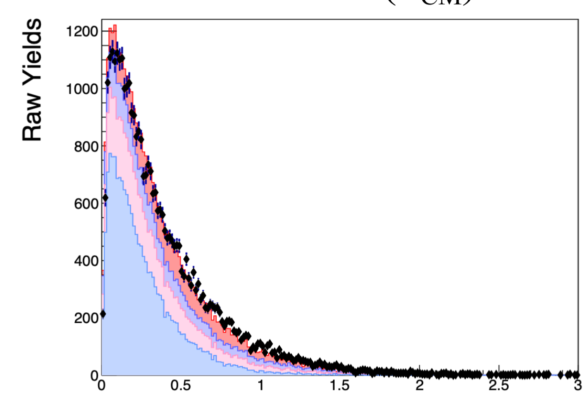
Proton: $\cos(\theta_{CM})$.



Invar. Mass $\{\Lambda\bar{\Lambda}\}$ GeV/c^2



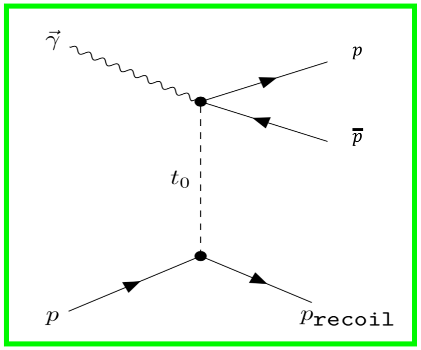
Invar. Mass $\{p\bar{\Lambda}\}$ GeV/c^2



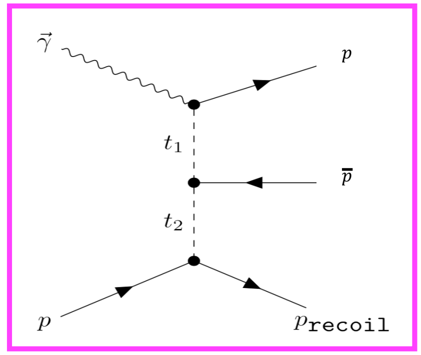
$-(t - t_{min})$ of IM$\{\Lambda\bar{\Lambda}\}$ GeV^2

Elements of the Model

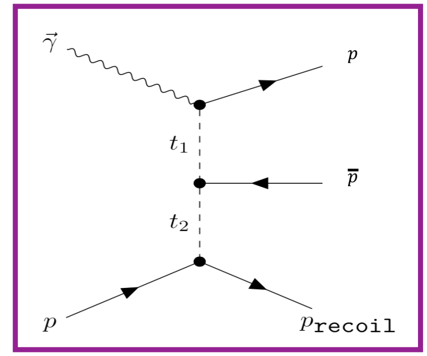
w_1



$+w_2$



$+w_3$



Single Regge:

a_1: t_0 slope
$d\sigma/dt_0 \sim \exp(a_1 t_0), \forall t_0 > a_3$

a_2: $p\bar{p}$-clustering.
$d\sigma/dM_{p\bar{p}} \sim \exp[-(M_{p\bar{p}} - 2m_p)/a_2]$

a_3: low-t cutoff
$d\sigma/dt_0 \sim (\exp(a_1 a_3)/a_3) * t_0, \forall t_0 \leq a_3$

Double Regge I:

a_4: t_1-slope
$d\sigma/dt_1 \sim \exp(a_4 t_1), \forall t_1 > a_6$

a_5: t_2-slope
$d\sigma/dt_2 \sim \exp(a_5 t_2)$

a_6: low-t cutoff
$d\sigma/dt_1 \sim (\exp(a_4 a_6)/a_6) * t_1, \forall t_1 \leq p_6$

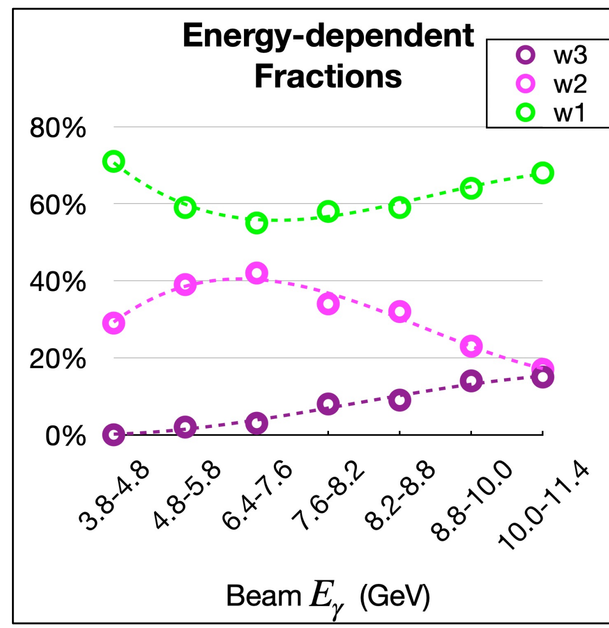
Double Regge II:

a_7: t_1-slope
$d\sigma/dt_1 \sim \exp(a_7 t_1), \forall t_1 > a_9$

a_8: t_2-slope
$d\sigma/dt_2 \sim \exp(a_8 t_2)$

a_9: low-t cutoff
$d\sigma/dt_1 \sim (\exp(a_7 a_9)/a_9) * t_1, \forall t_1 \leq p_9$

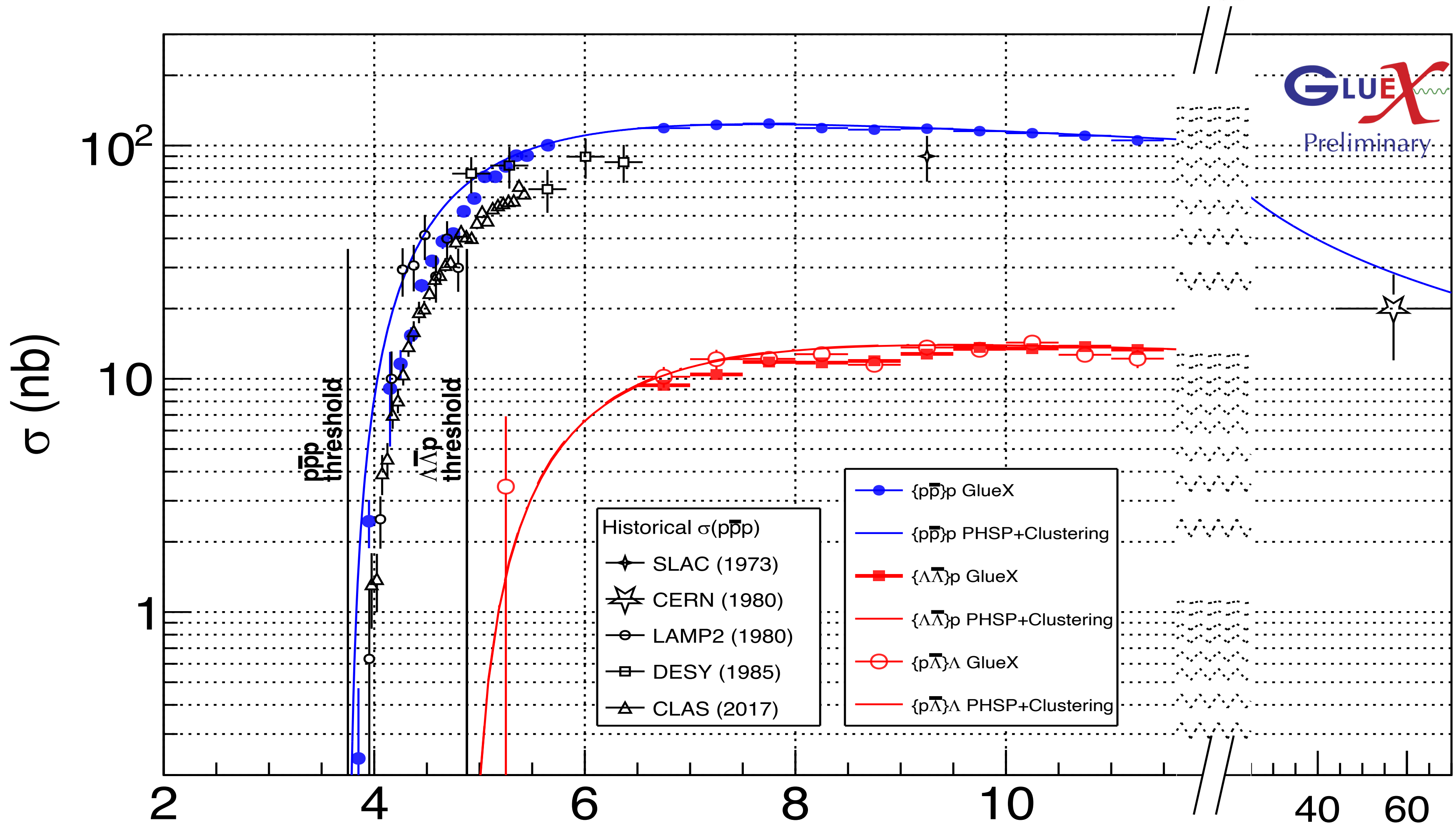
- Accounts for large-angle asymmetry between anti-baryons and baryons : double-Regge diagram(s)
- Match Monte Carlo simulations to all angular, momentum transfer, and mass distributions
  - Use incoherent sum of model terms fitted to data
  - New few parameters in each beam energy interval
    - 6 for hyperons (one double-Regge diagram)
    - 6+3 = 9 for protons (two double-Regge diagram needed)
- Stochastic Gradient Descent fitting algorithm



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

Total Cross Sections

Compare to (3-body phase space)x(mass clustering): $\sigma_{TOT} \sim \frac{p_{CM}q}{p_{\gamma p}s}\left\|\mathcal{M}(c_m)\right\|^2$



Note: $\Lambda\bar{\Lambda}$ & $p\bar{\Lambda}$ are equal size

Suppression of strangeness

- Strange states suppressed compared to non-strange states in photoproduction.
- We measure: $\sigma_{\gamma p \to \{\Lambda\bar{\Lambda}\}p + \{p\bar{\Lambda}\}\Lambda} / \sigma_{\gamma p \to p\bar{p}p} = 0.22 \pm 0.01$
- Relate to quark creation probabilities (GlueX):

$$\boxed{\frac{P(s\bar{s})}{P(u\bar{u})} \simeq 0.22}$$

- Compare to single-meson ΛK^+ / $N\pi$ electroproduction* case (CLAS):

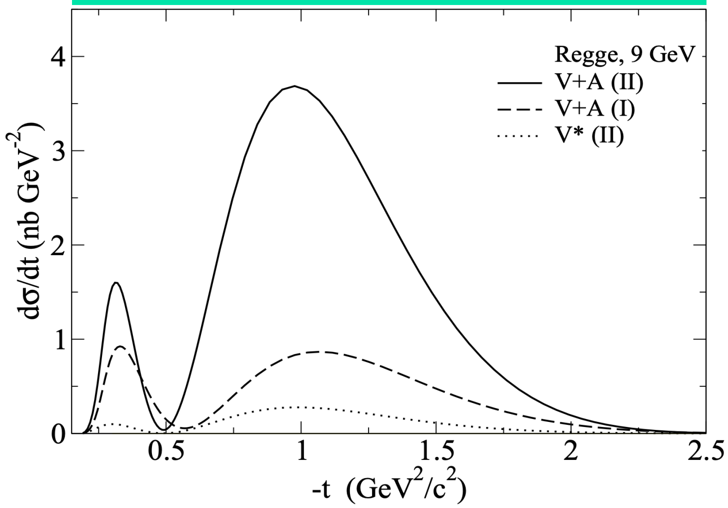
$$P(s\bar{s})/P(d\bar{d}) = 0.21 \pm 0.03$$

- Consistent suppression by factor of ~5 relative to lightest quarks.

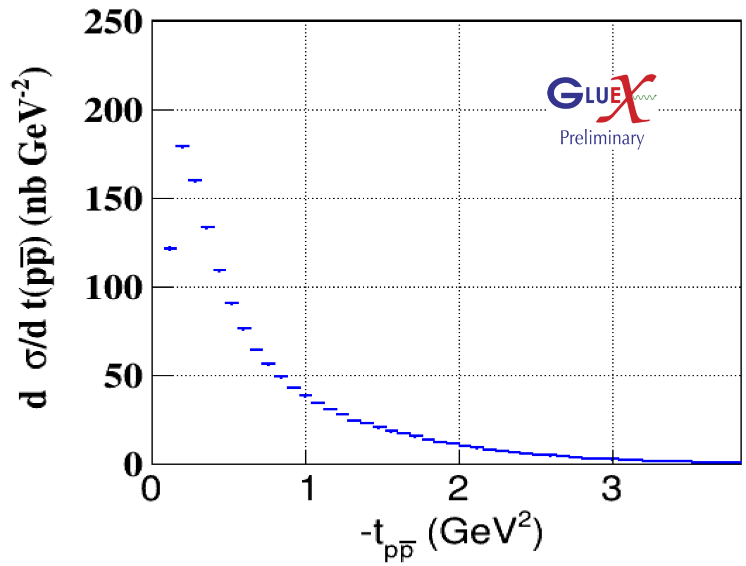
* M. Mestayer *et al.* (CLAS), Strangeness Suppression of $q\bar{q}$ Creation Observed in Exclusive Reactions, Phys. Rev. Lett. **113**, 152004 (2014), arXiv:1412.0974 [nucl-ex].

Differential cross sections @$E_\gamma = 8.75 GeV$

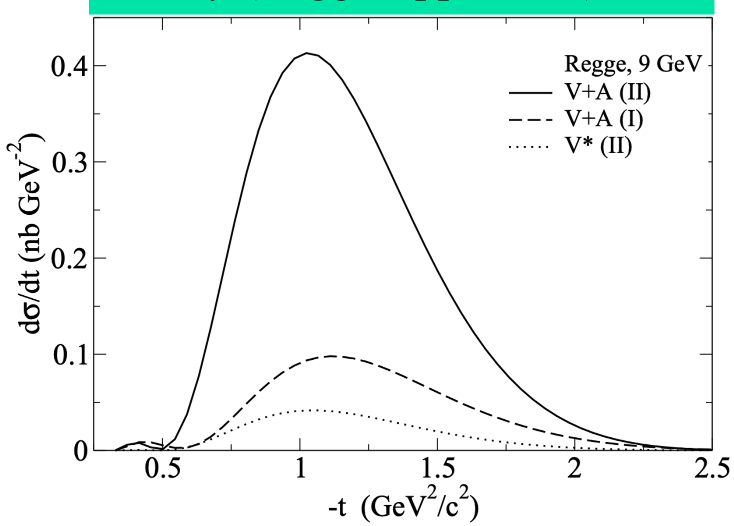
Theory (Regge Approach)*: $p\bar{p}$



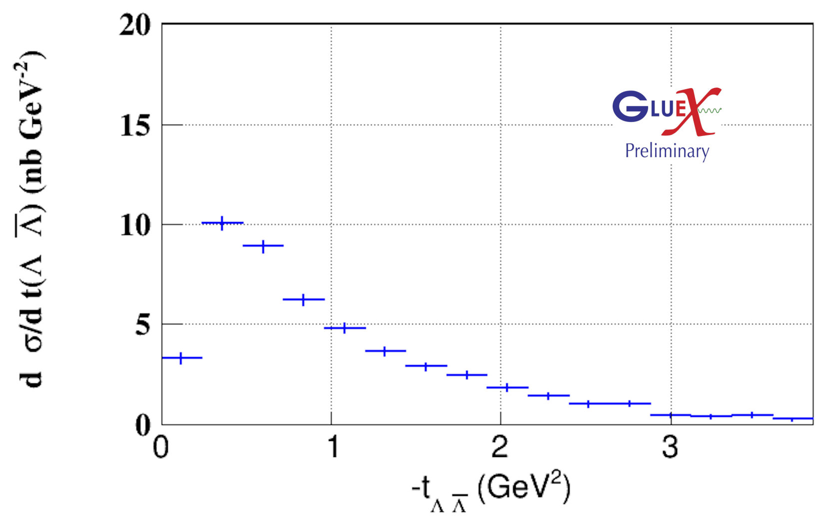
GlueX data: $p\bar{p}$



Theory (Regge Approach*): $\Lambda\bar{\Lambda}$



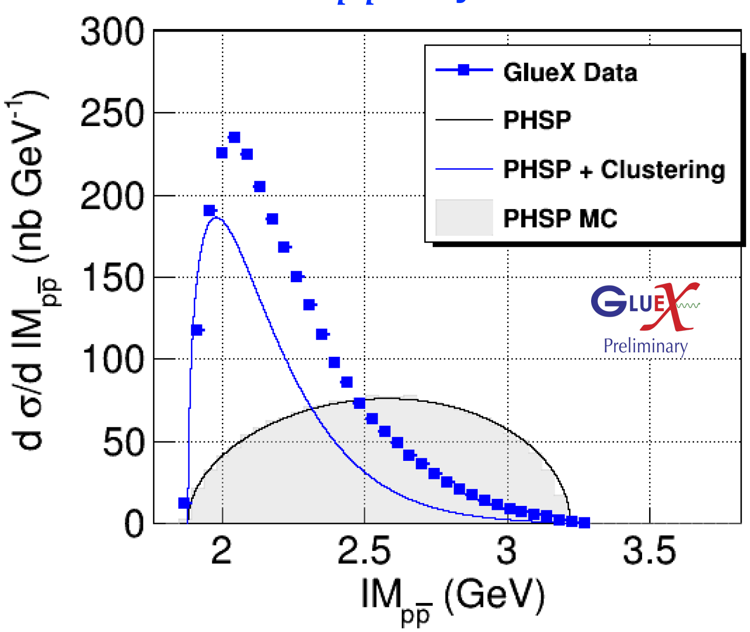
GlueX data: $\Lambda\bar{\Lambda}$



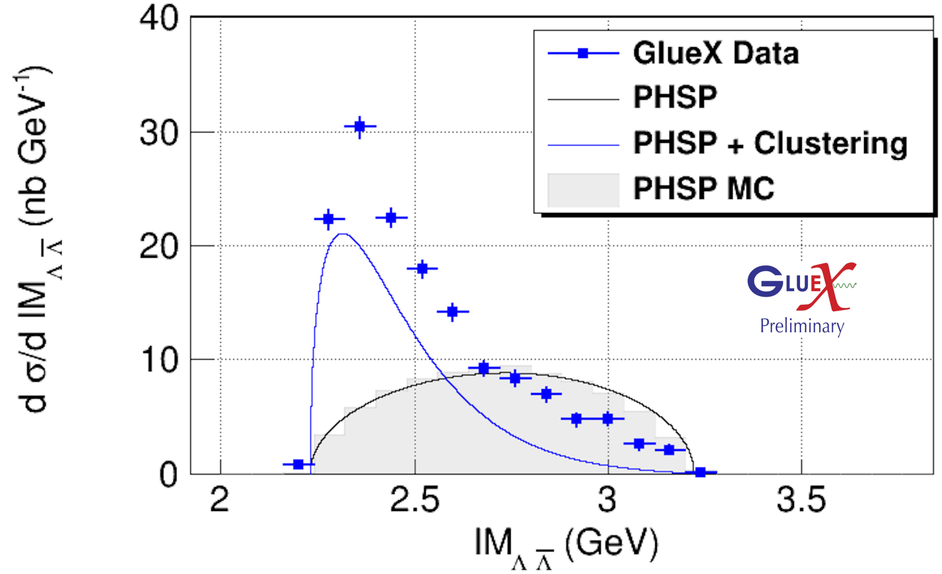
* T. Gutsche *et al.* Physical Review D **96**, 054024 (2017)

Differential cross sections $@E_\gamma = 8.75 GeV$

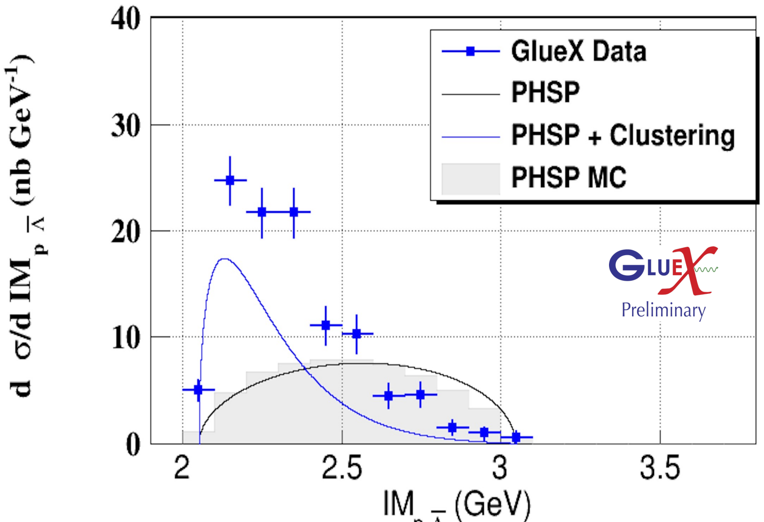
$p\bar{p}$ - system



$\Lambda\bar{\Lambda}$ - system



$p\bar{\Lambda}$ - system

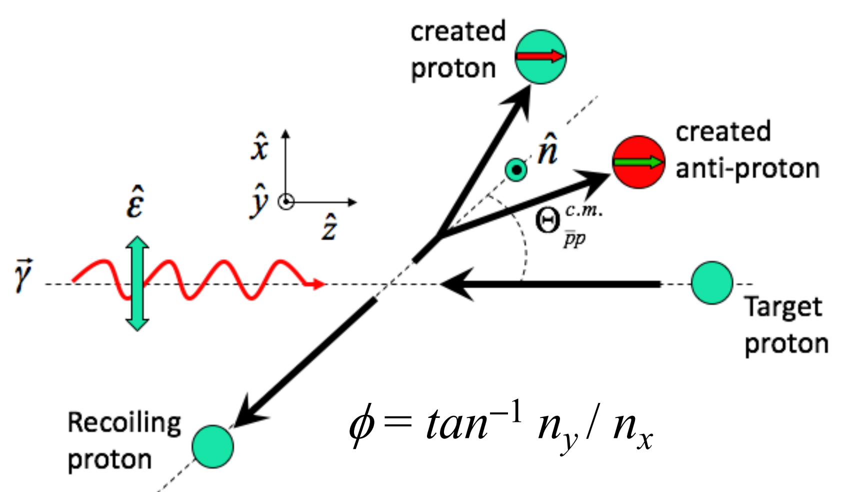


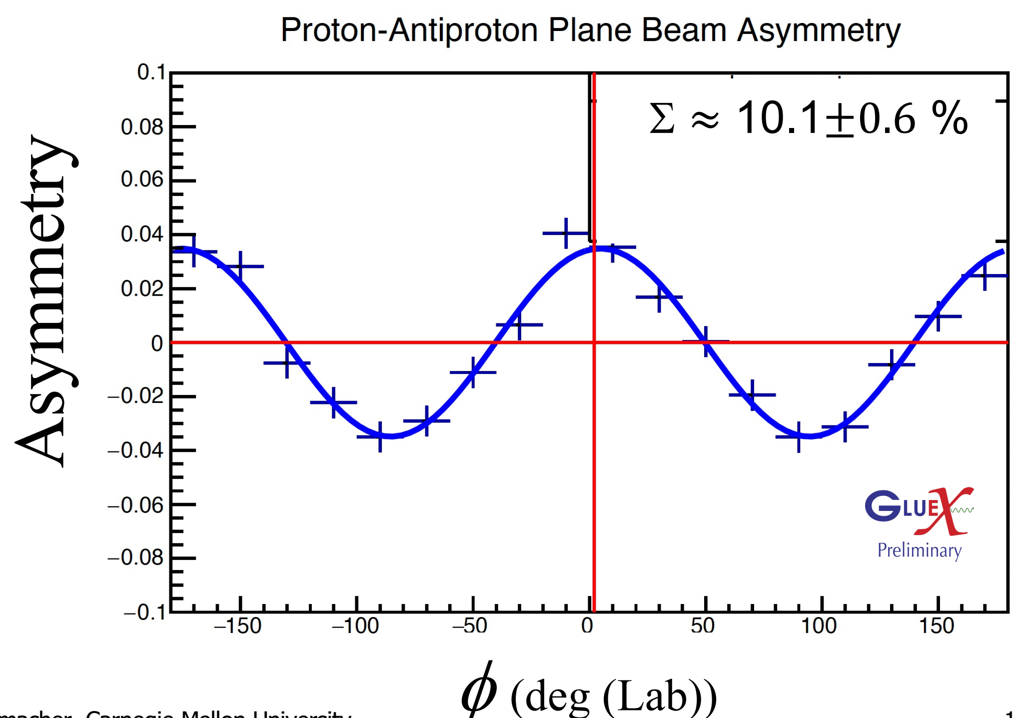
- No hints of threshold "-onium states"
- Attractive interaction:
  - Baryons and anti-baryons tend to "cluster"
- Model parameterization (single Regge):

  $d\sigma/dIM_{p\bar{p}} \sim \exp[-(IM_{p\bar{p}} - 2m_p)/c_m]$
  - Each channel gets a fitted clustering parameter, c_m
- Single-Regge component: blue curves

Spin Observables

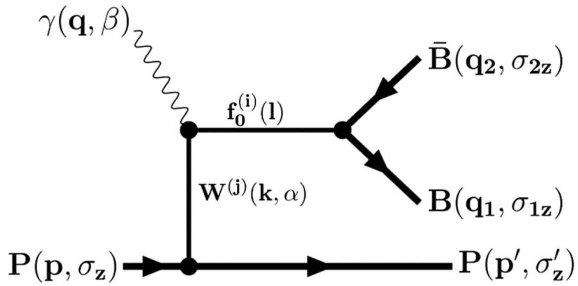
- Beam linear polarization ~35% for 8.2 < E_γ < 8.8 GeV
  - Coherent bremsstrahlung off diamond radiator
- Beam Spin Asymmetry (BSA), Σ, sensitive to exchanges
  - Insensitive to experimental acceptance: $A(\phi)$

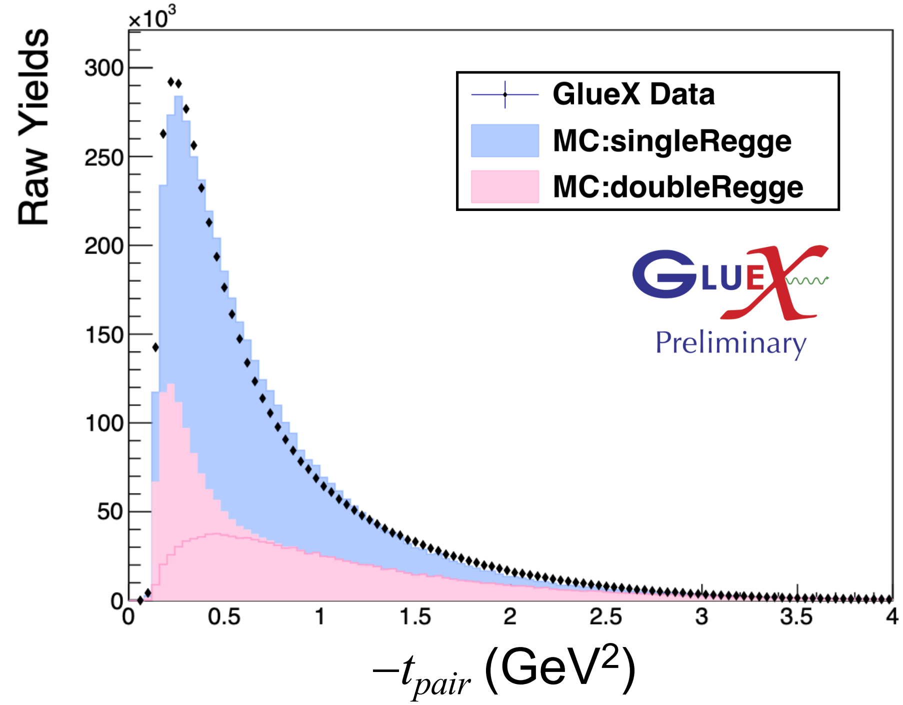




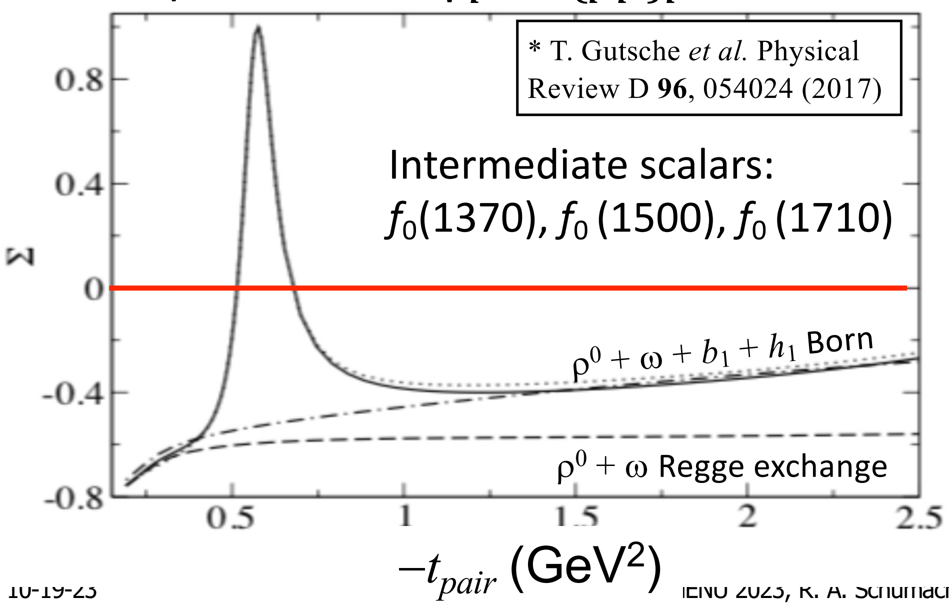
BSA, Σ, for $\{p\bar{p}\}$ pairs

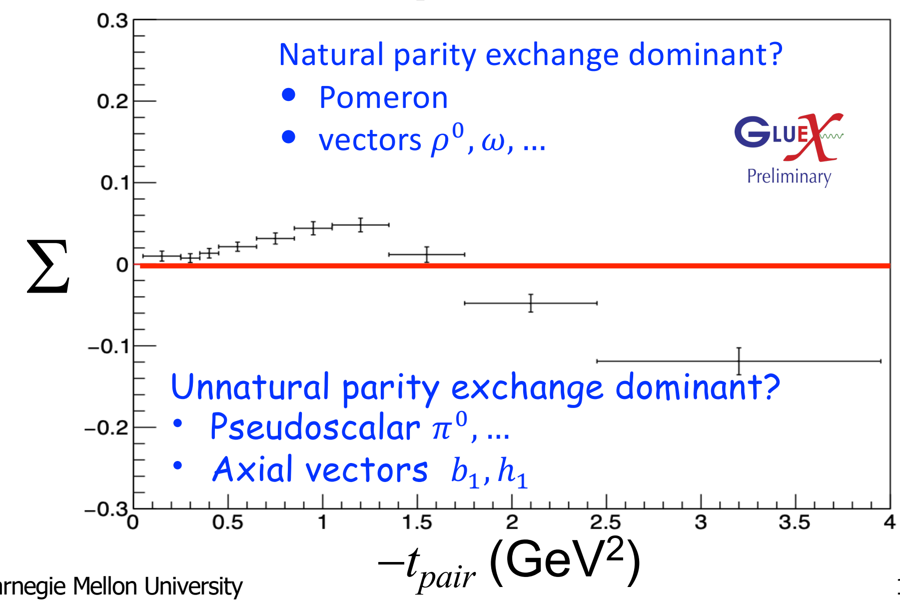
- $t_{pair} = [p^{\mu}(\gamma) - p^{\mu}(p\bar{p})]^2$
  - Mild t-dependence seen; Σ is small
  - Theory deals only with decay of scalar mesons to pairs – not what we see!





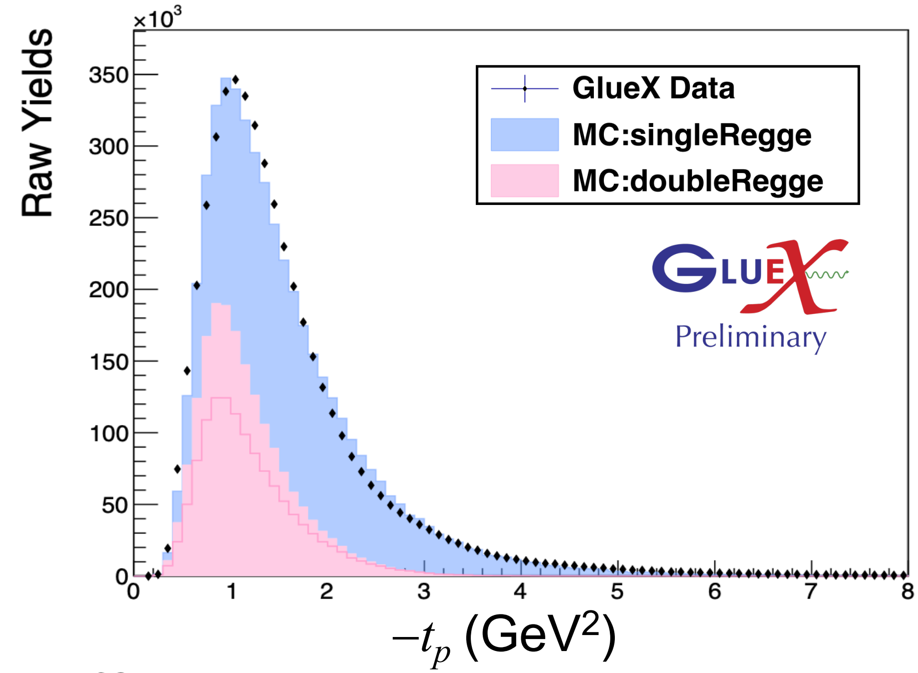
Σ prediction of $\gamma p \rightarrow \{p\bar{p}\}p$ at 9 GeV

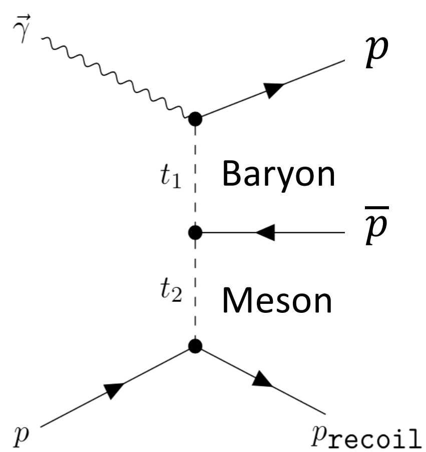


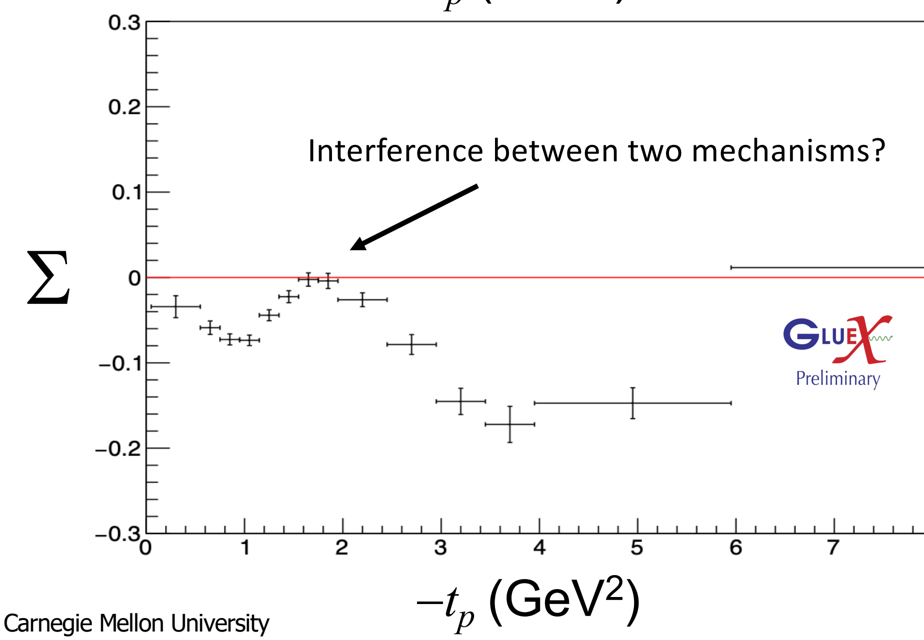


BSA, Σ, for proton alone

- $t_p = [p^\mu(\gamma) - p^\mu(p)]^2$
  - Significant negative beam asymmetry
  - Baryon & meson exchange present in double Regge picture
  - Appears that multiple reaction mechanisms interfere here
  - No theory guidance available here

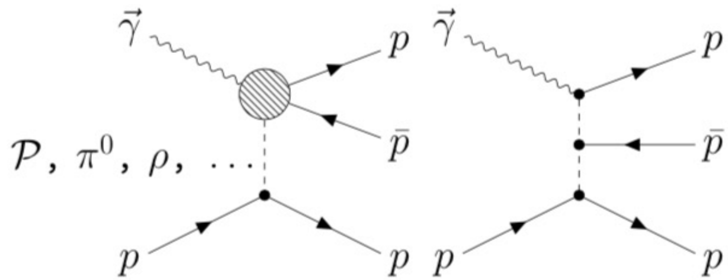






Summary / Conclusions

- We examine 3 baryon-anti-baryon reactions!
- Evidence for at least two exchange mechanisms:

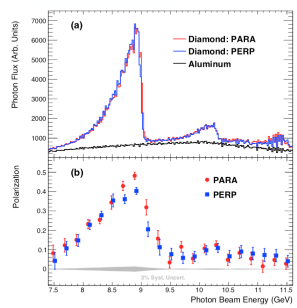


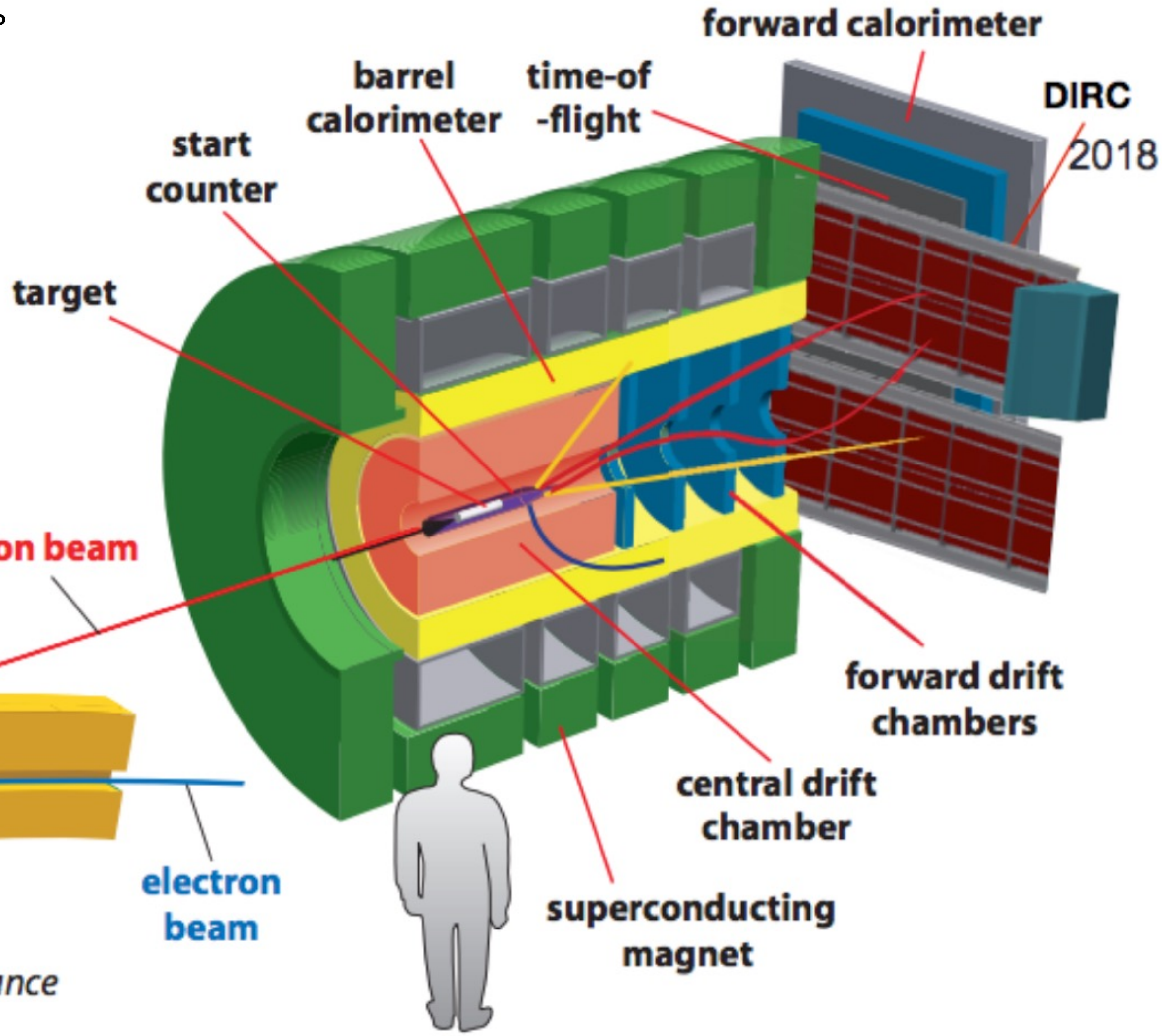
  - Single Regge
  - Double Regge – with anti-baryon “in the middle”
  - A Monte-Carlo based reaction model fits GlueX data well.
- We see non-vanishing spin observables
  - More available, e.g. for hyperons
- We would welcome more theory support!

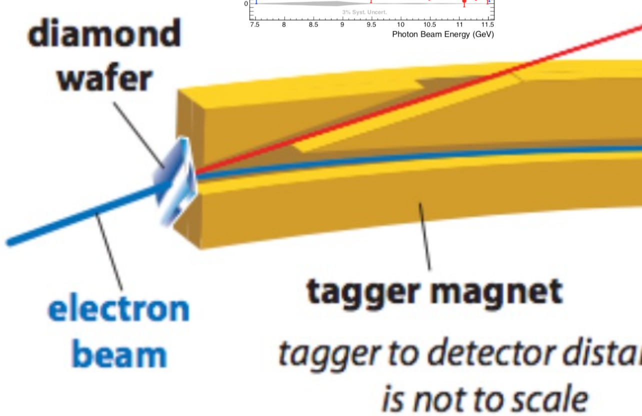
Supplemental Slides

GlueX Detector at JLab

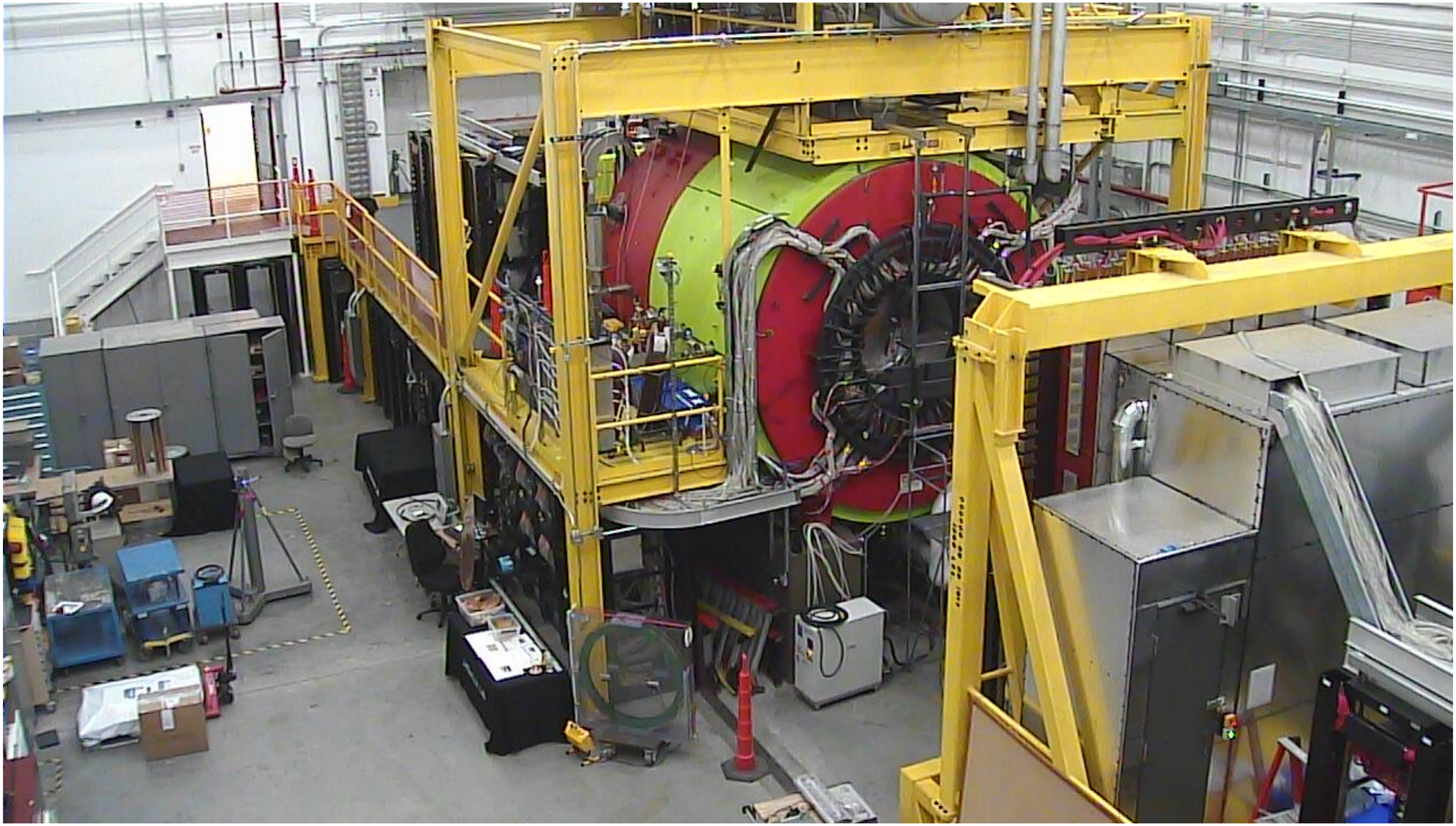
- **~12 GeV e⁻ beam** converted to:
  - 4 - 11.6 GeV photon beam
  - Linear coherent peak 8-9 GeV (~40%)
  - Four orientations: 0°, 90°, 45°, 135°
- **Solenoidal magnet**
- **Drift chambers**
- **Start counter/Time of flight**
- **Electromagnetic Calorimeters**







GlueX Experiment in Hall D / JLab

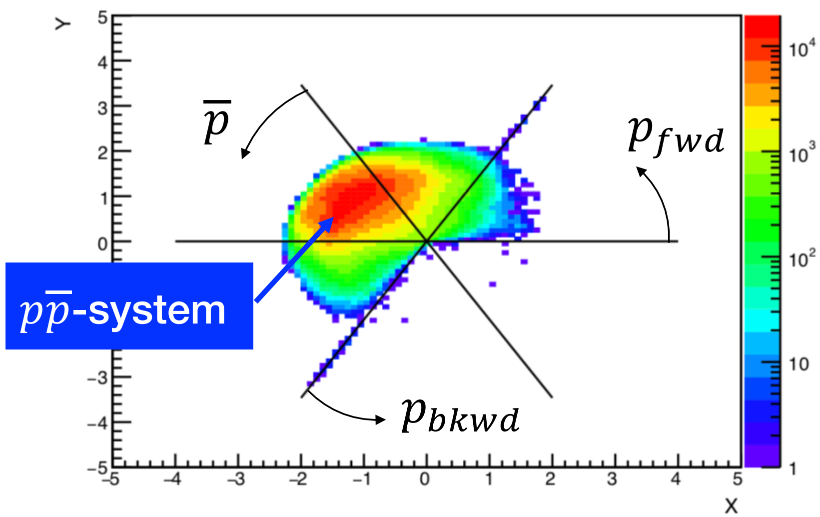


- **Physics-quality data runs in 2016, <u>2017, 2018</u>, 2020**

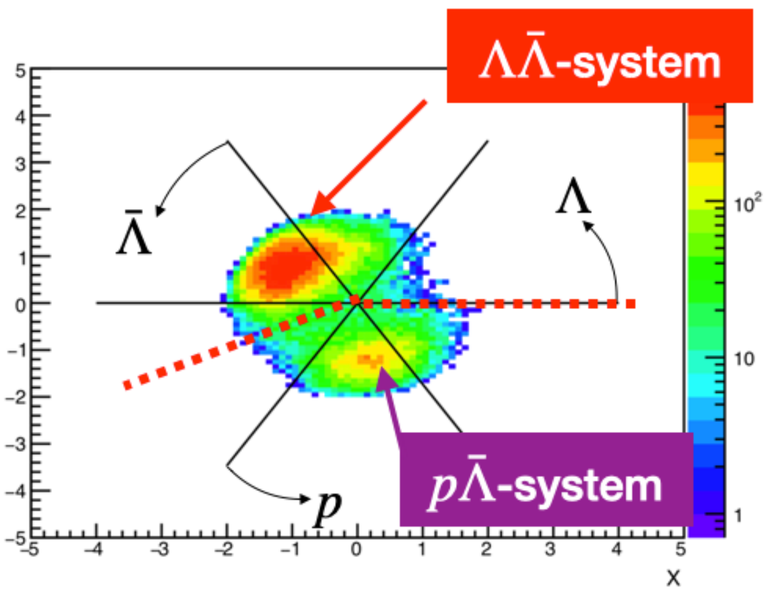
(this talk)

Van Hove view of the Kinematics

Van Hove Plot of $p\bar{p}p$



Van Hove Plot of $\Lambda\Lambda p$



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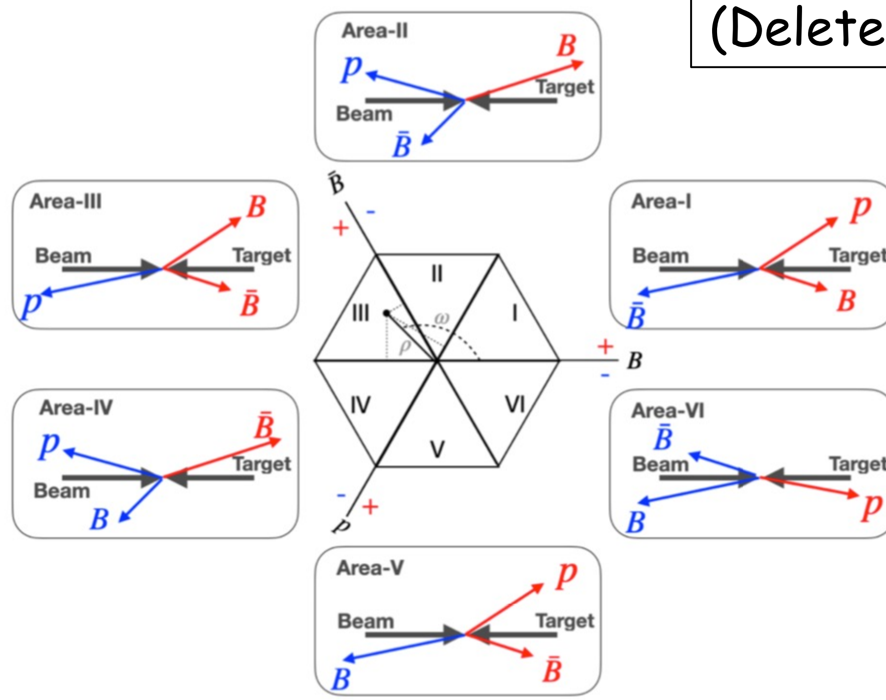

- Use longitudinal momenta to exhibit 3-body angular correlations
- Clean separation of two $\Lambda\bar{\Lambda}p$ reaction mechanisms
- Each grouping contains both single and double Regge components