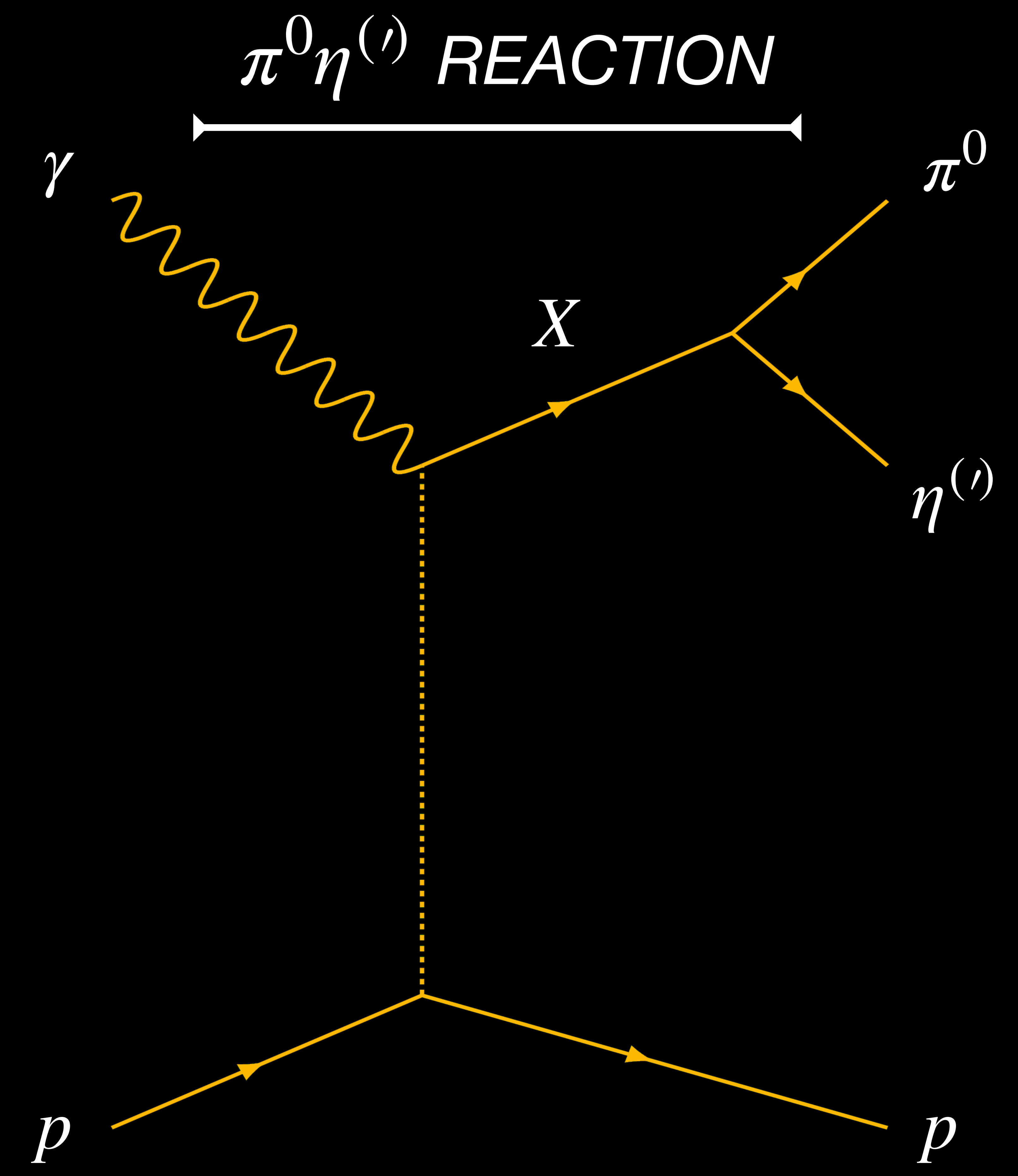
Analyzing $\pi^0\eta$ and $\pi^0\eta'$ systems in the search for exotic hybrid mesons at GlueX

9th Workshop of the APS Topical Group on Hadronic Physics

Zachary Baldwin, April 13 2021
for Carnegie Mellon University and the GlueX Collaboration

Overview

Introduction	$\pi^0\eta^{(\prime)}$	Conclusion
Motivation	Baryon Contribution	Summary
	Invariant Mass Final State	Future Work
	Angular Distributions	
	Double Regge Analysis	



Motivation

Theory

- Mesons can be characterized by quantum numbers denoted by J^{PC}

Total angular momentum | $J = 0,1,2,\ldots$

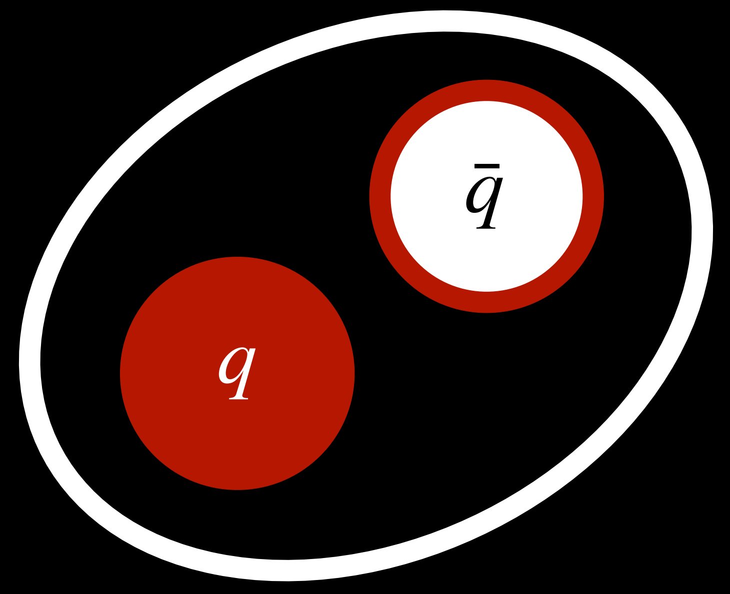
Parity | $P = (-1)^{L+1}$

Charge Conjugation | $C = (-1)^{L+S}$

L is the relative orbital angular momentum of the q and $\bar{q}$

S is the total intrinsic spin of the $q\bar{q}$ pairs

Meson



Allowed quantum numbers

$$J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{--}, 2^{-+}, \ldots$$

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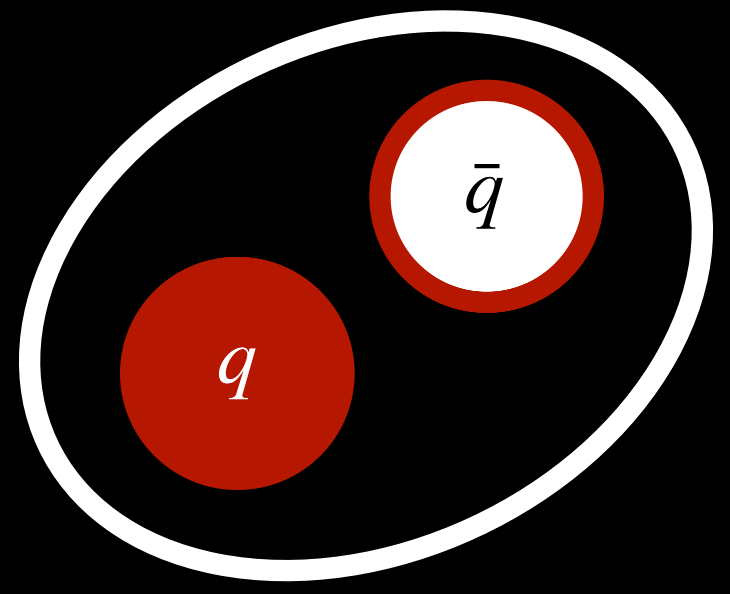


FORBIDDEN quantum numbers

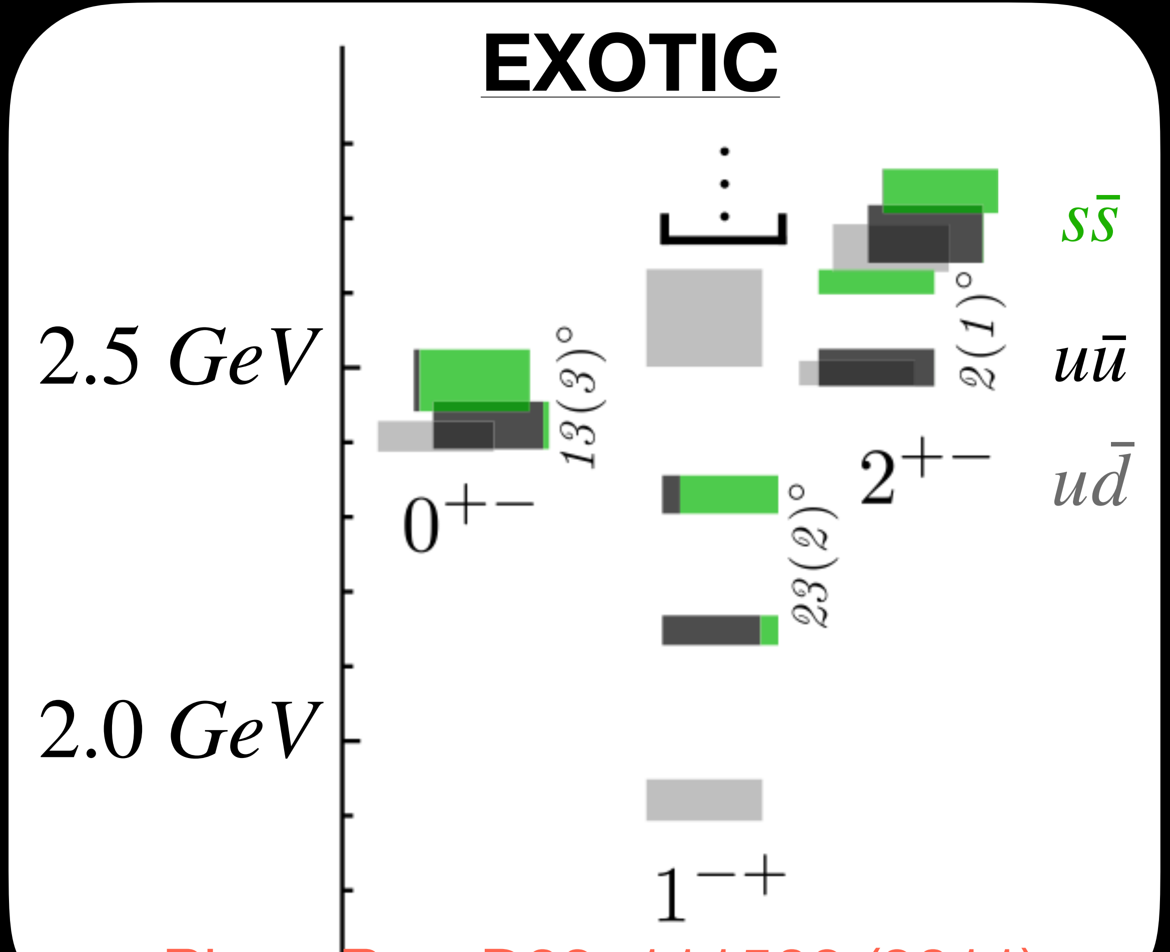
$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$$

Discovering forbidden quantum numbers would be immediate evidence of a non-$q\bar{q}$ state (i.e. new QCD states)

Motivation

Lattice QCD and Past Experiments

- Lattice QCD predicts "gluonic excitations", confirming mesons that are not in constituent quark model known as *exotic mesons*



Phys. Rev. D83, 111502 (2011).

Motivation

Lattice QCD and Past Experiments

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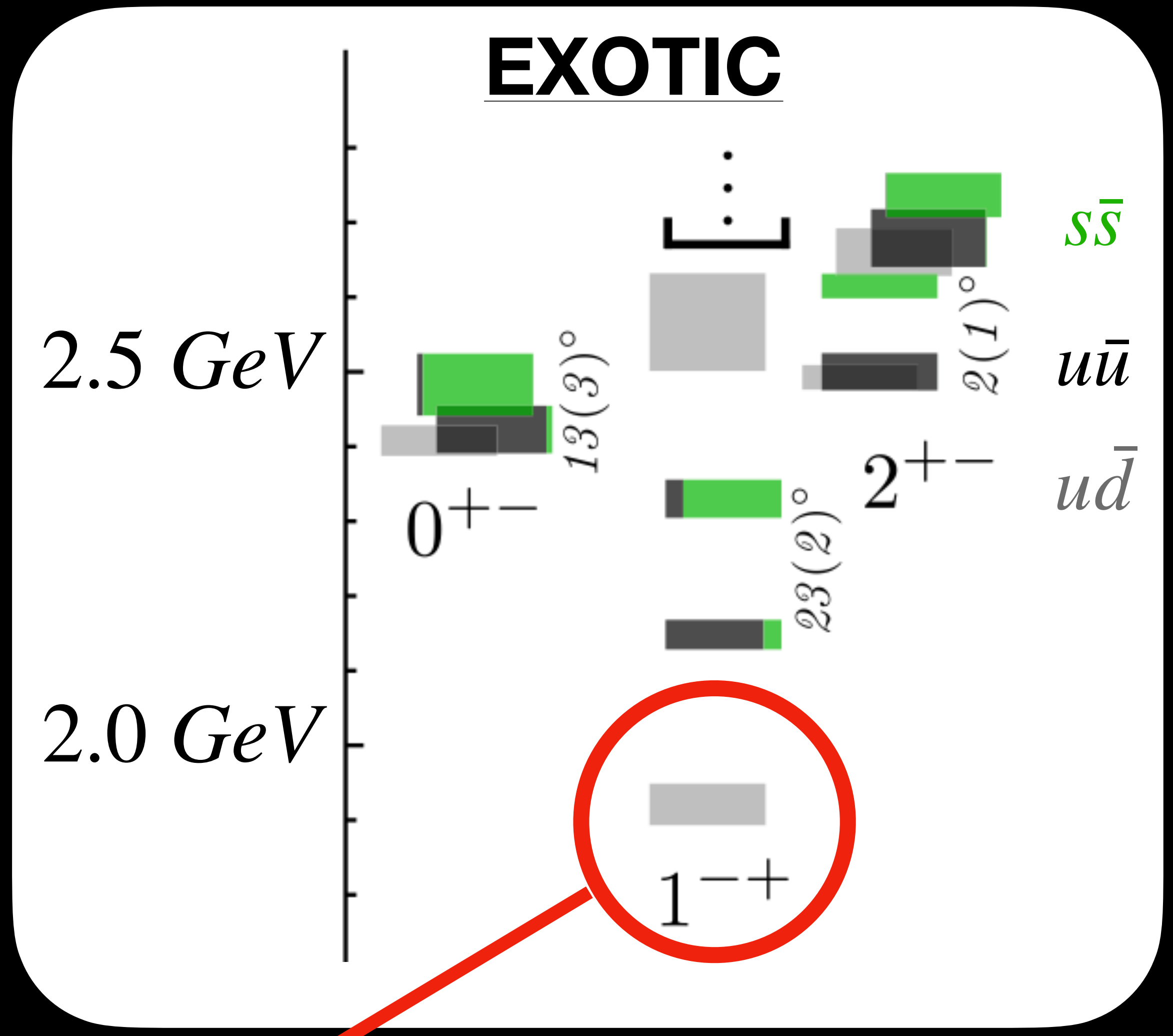


π_1 → $\pi_1(1400)$ → $\pi\eta$

π_1 → $\pi_1(1600)$ → $\pi\eta'$

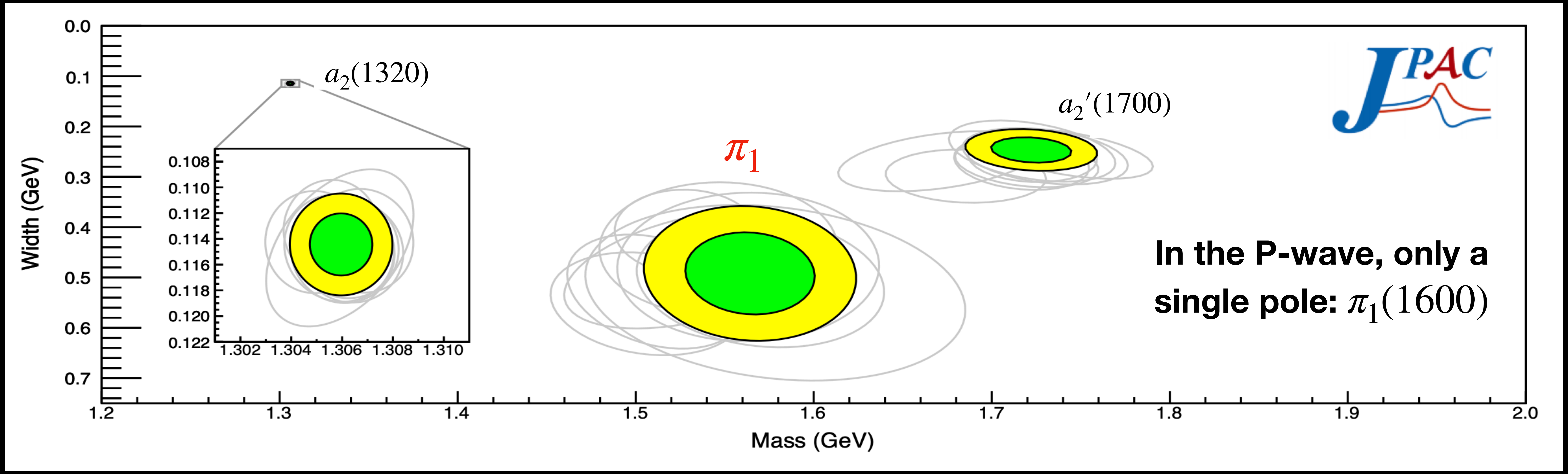
- Multiple experiments have looked for resonances in the P-wave: E852, Crystal Barrel, CLEO, etc.

L	S	P	D	F	…
J^{PC}	0^{++}	1^{-+}	2^{++}	3^{-+}	…

COMPASS

Combined analysis for both $\pi\eta$ and $\pi\eta'$

$\pi^- p \to n\pi^-\eta^{(\prime)}$



In the P-wave, only a single pole: $\pi_1(1600)$

A. Rodas et al. [Joint Physics Analysis Center], PRL 122, 042002 (2019)

Motivation

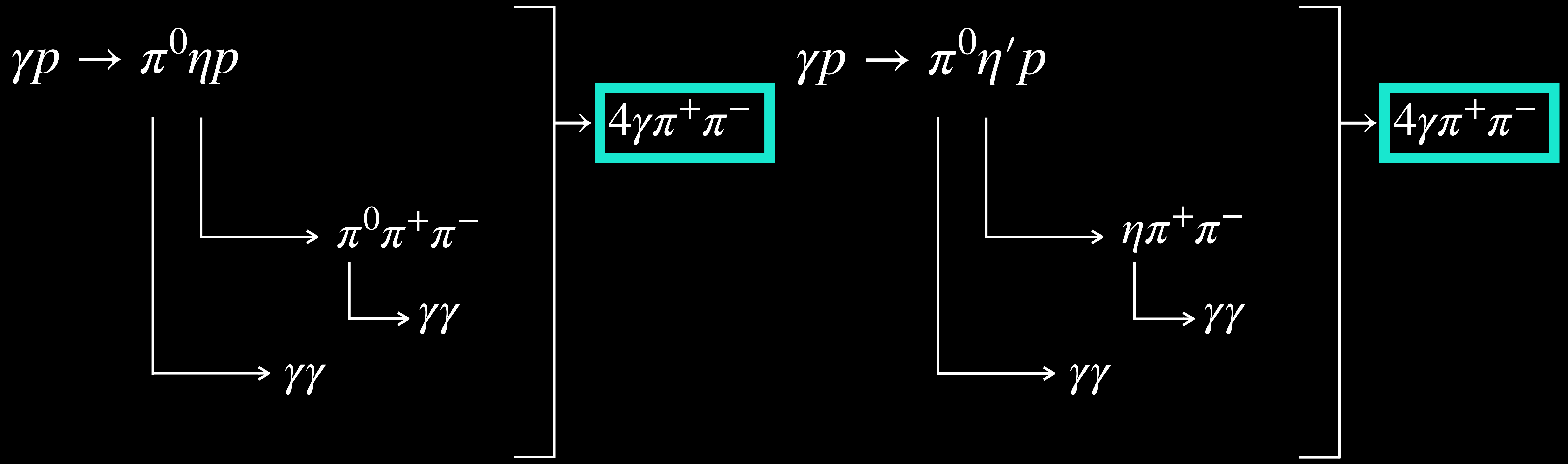
$\pi^0\eta^{(\prime)}$ Introduction

There are several decay modes associated with the π^0, η and η'

$$BR(\pi^0 \to 2\gamma) = (98.823 \pm 0.034)\,\%$$

$$BR(\eta \to \pi^0\pi^+\pi^-) = (22.98 \pm 0.2)\,\%$$

$$BR(\eta' \to \eta\pi^+\pi^-) = (42.9 \pm 0.7)\,\%$$



Other final states are being studied and will be shown during the APS meeting

Background

Baryon Contributions

- Major contributions to background involves Δ^+ baryons and multiple N* states
- Removal of the Δ^+ is relatively simple, but this is not the case for the $N*$ region

Is there a clear way to reject each $N*$?

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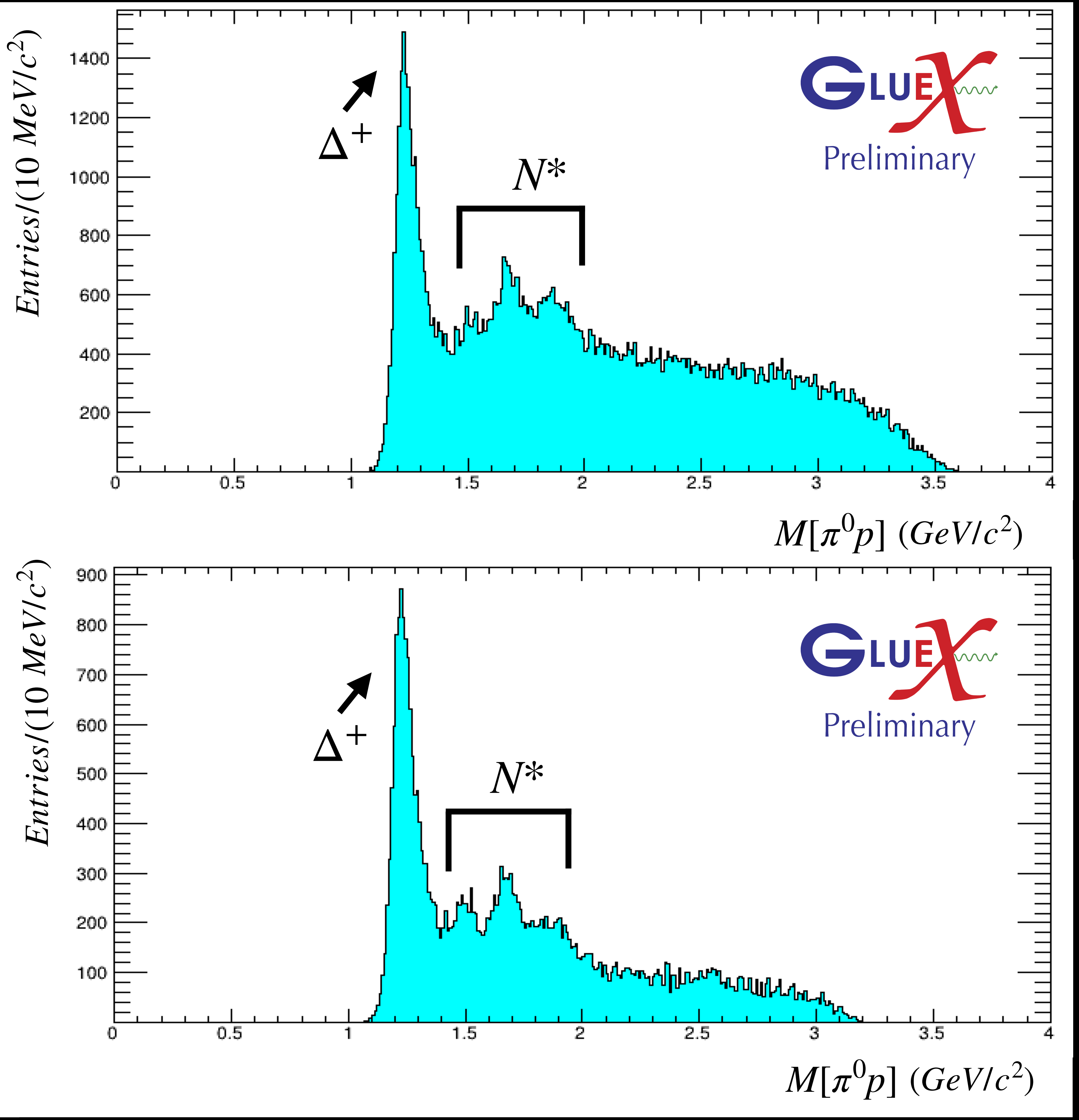
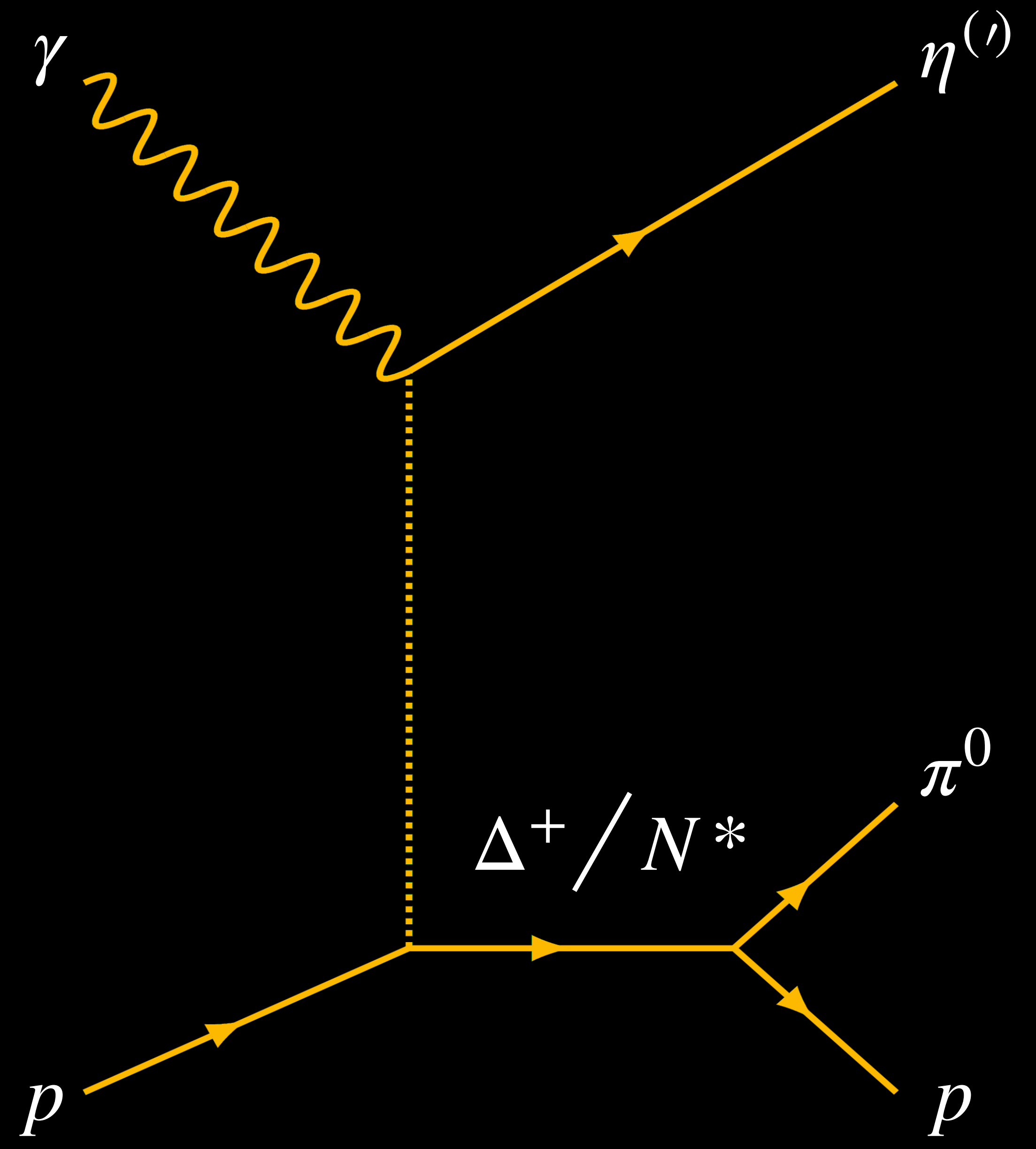
$\pi^0\eta$ system

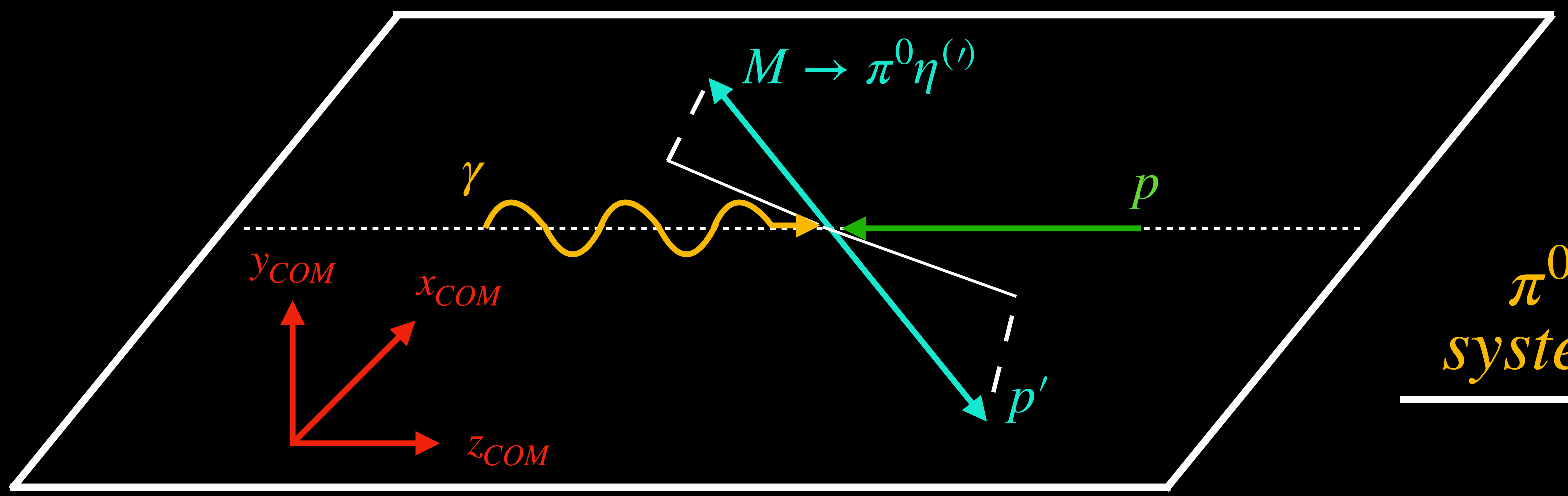
$\pi^0\eta'$ system





Center of Mass Frame

Baryon Contributions



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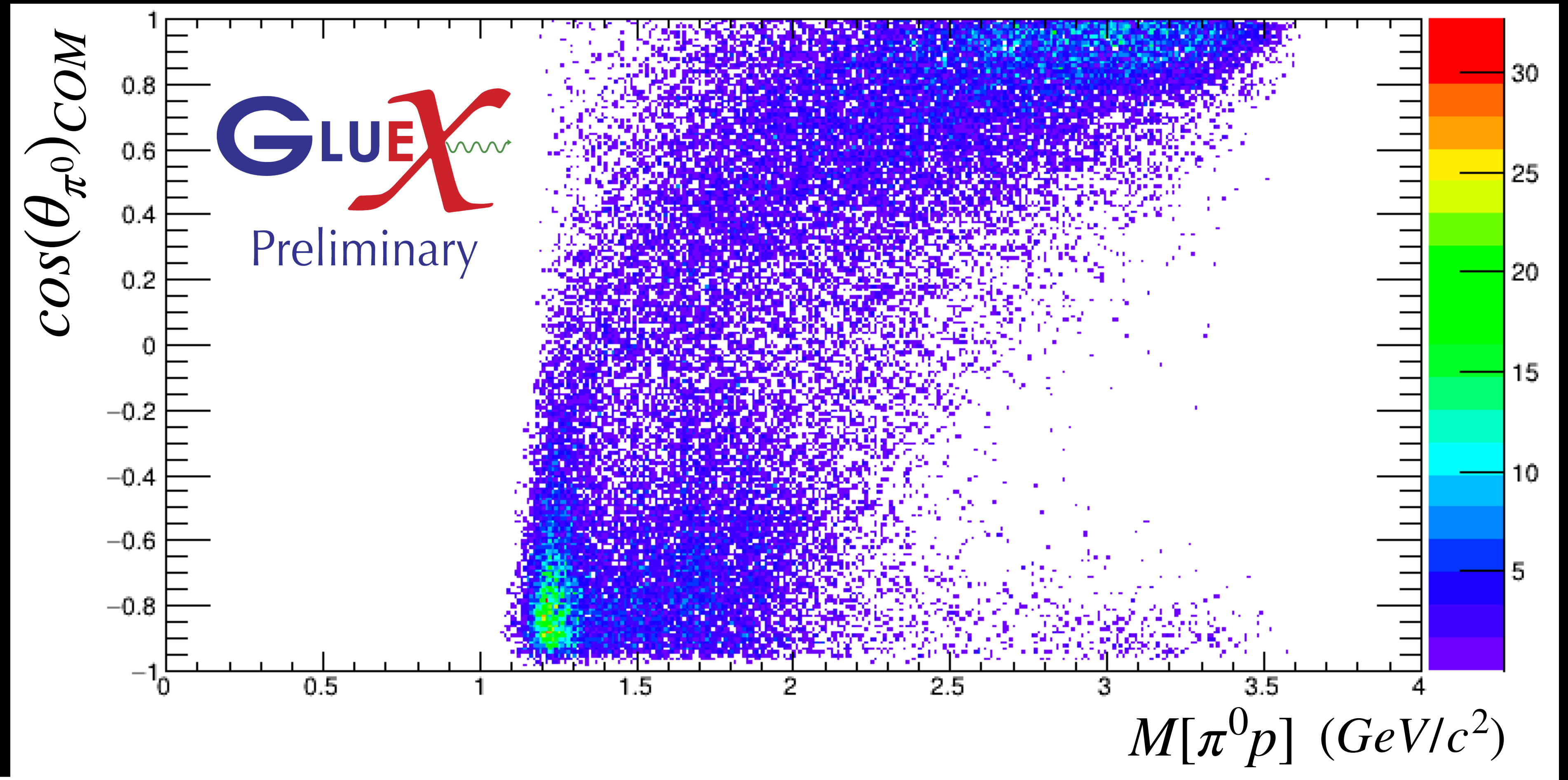
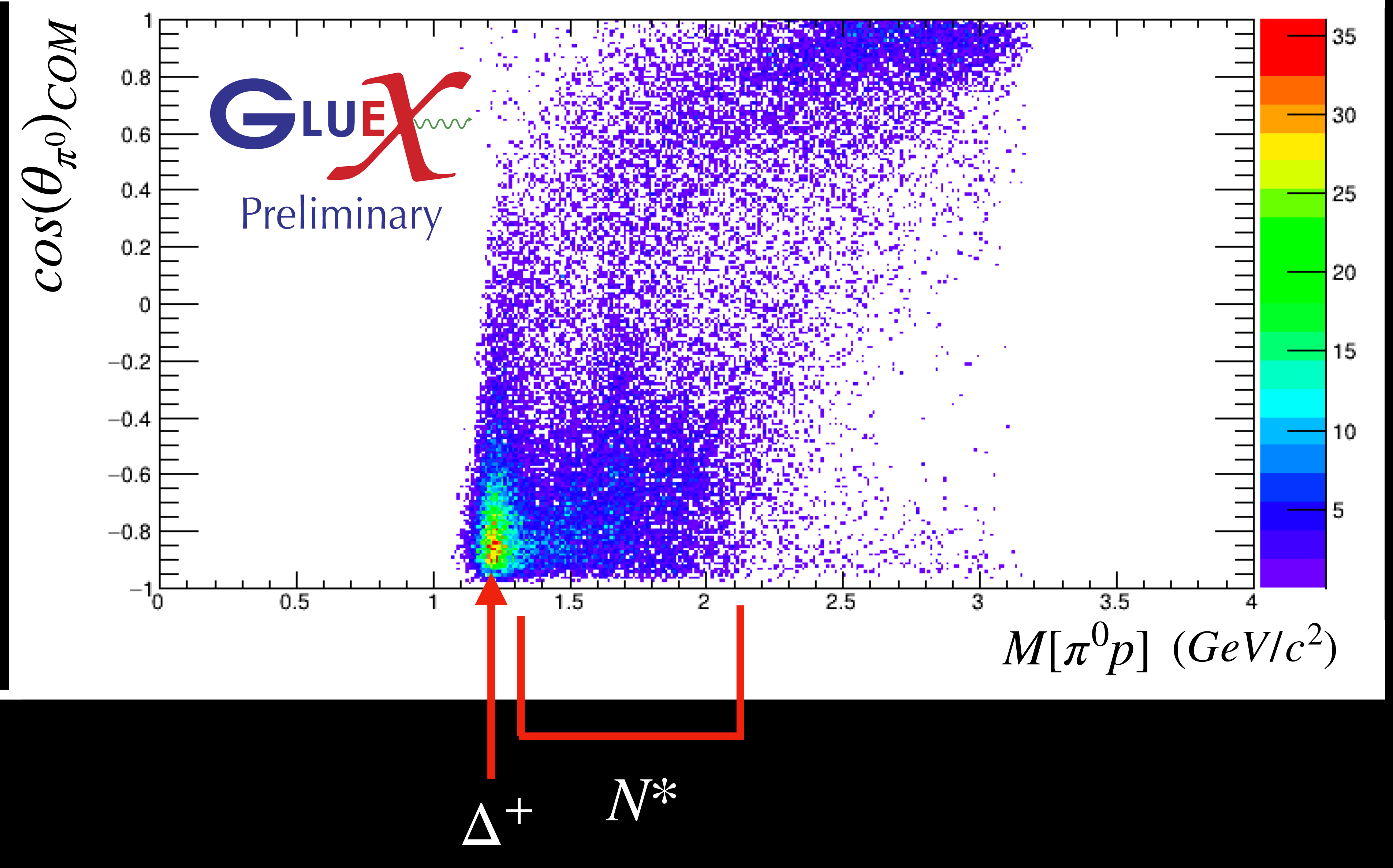
$\pi^0\eta$ system



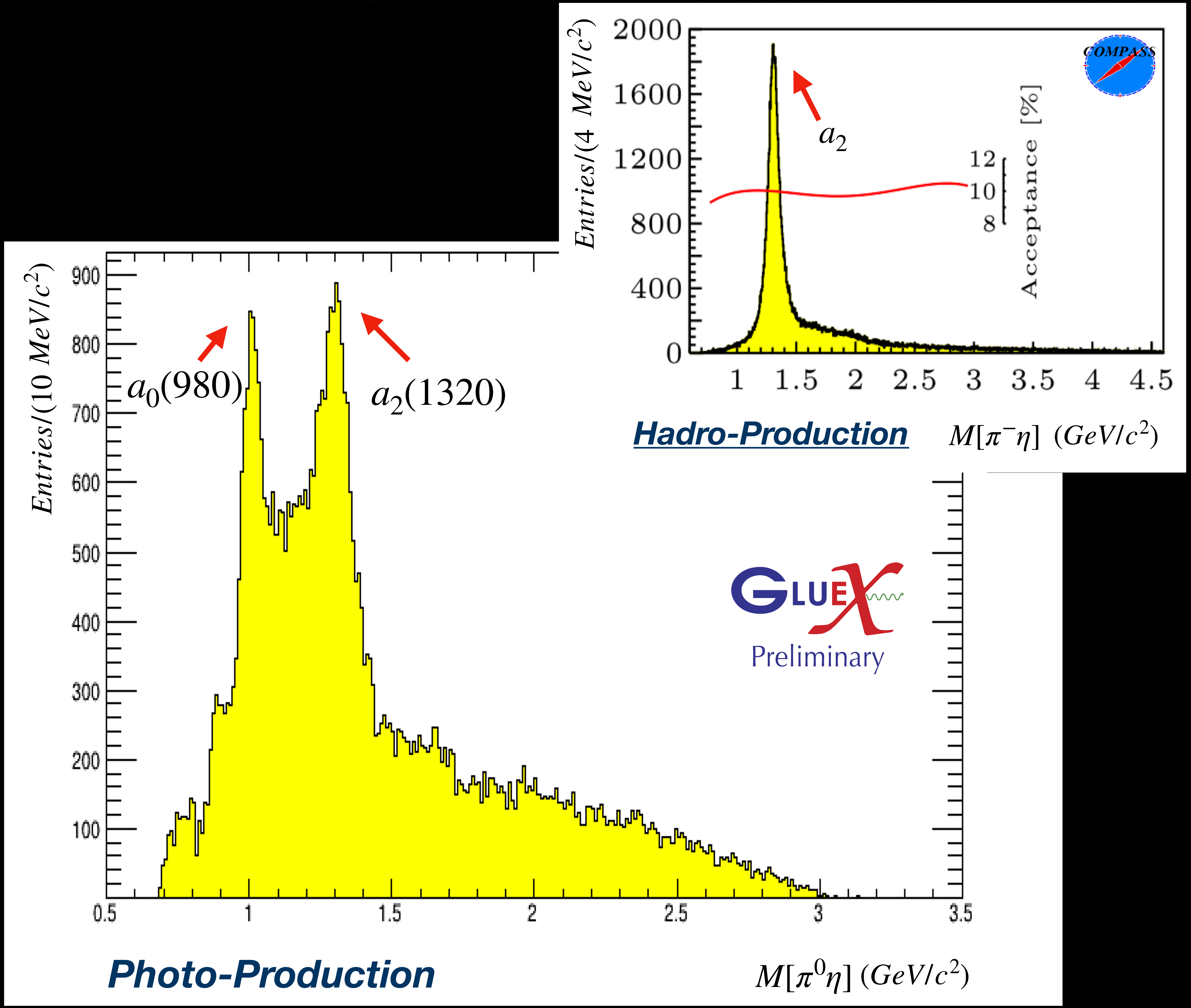
$\pi^0\eta'$ system



- By looking in the center of mass frame, it becomes apparent that the baryon contributions will tend to go backwards in θ_{π^0}

Studies still on-going, so only the removal of the Δ^+ structure is shown going forward

Invariant Mass Comparisons



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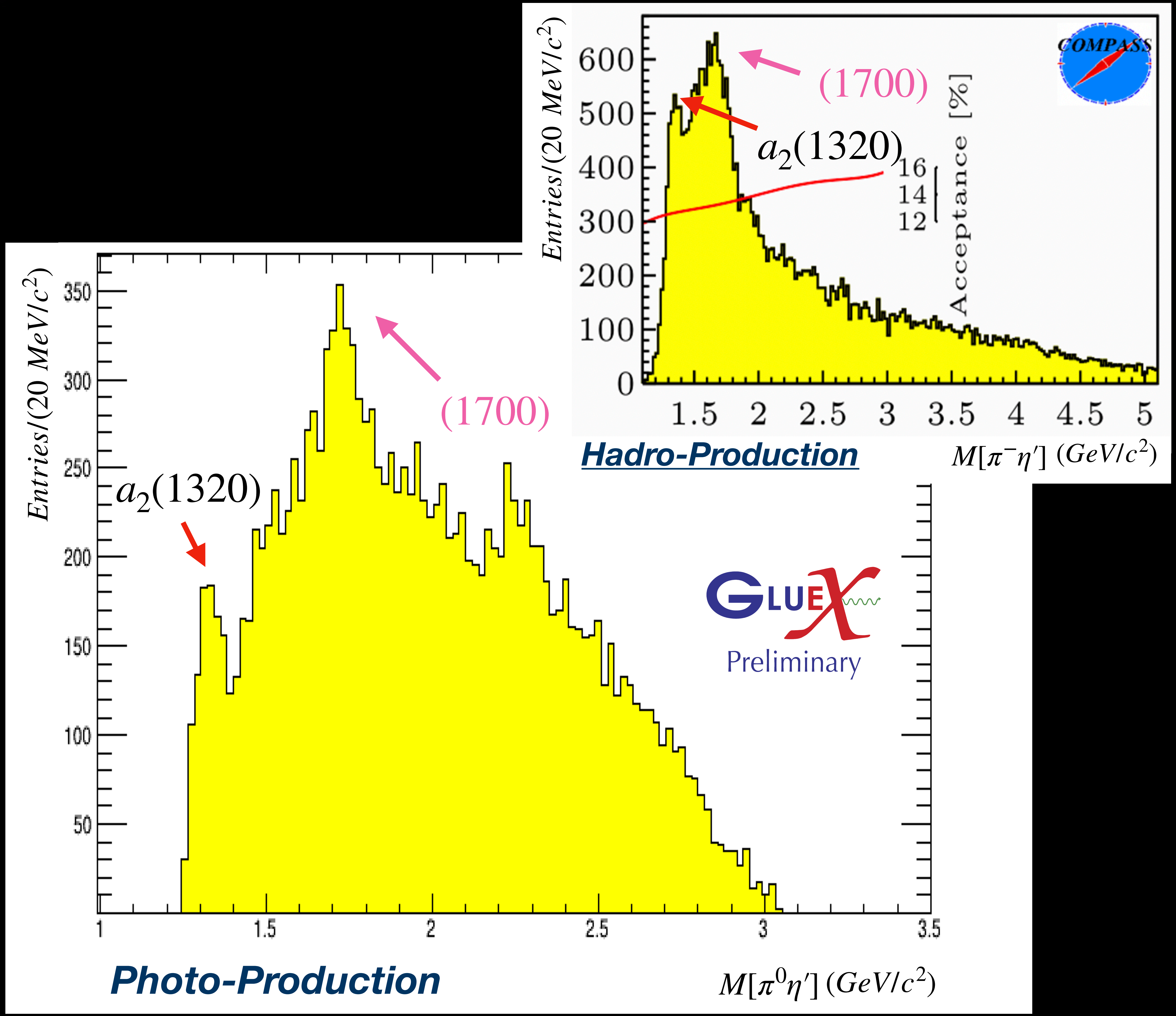

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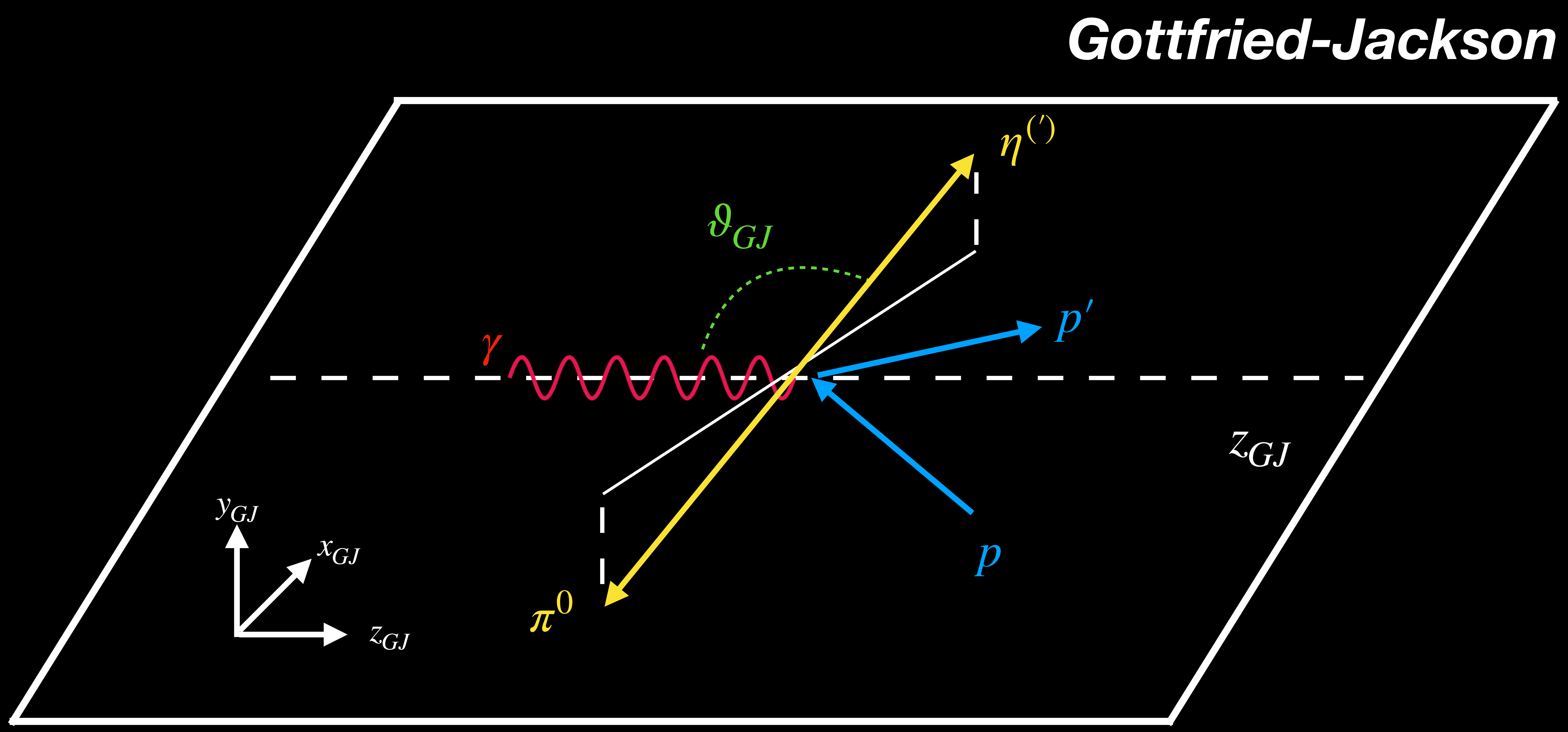
Angular Distributions

Gottfried-Jackson Reference Frame



- Gottfried-Jackson viewed in the center of mass of the $\pi^0\eta^{(\prime)}$ system
- Z_{GJ} is taken as the direction of the incident photon
- ϑ_{GJ} is the angle between the directions of $\eta^{(\prime)}$ and the incident γ

Angular Distributions

Gottfried-Jackson vs. Invariant Mass

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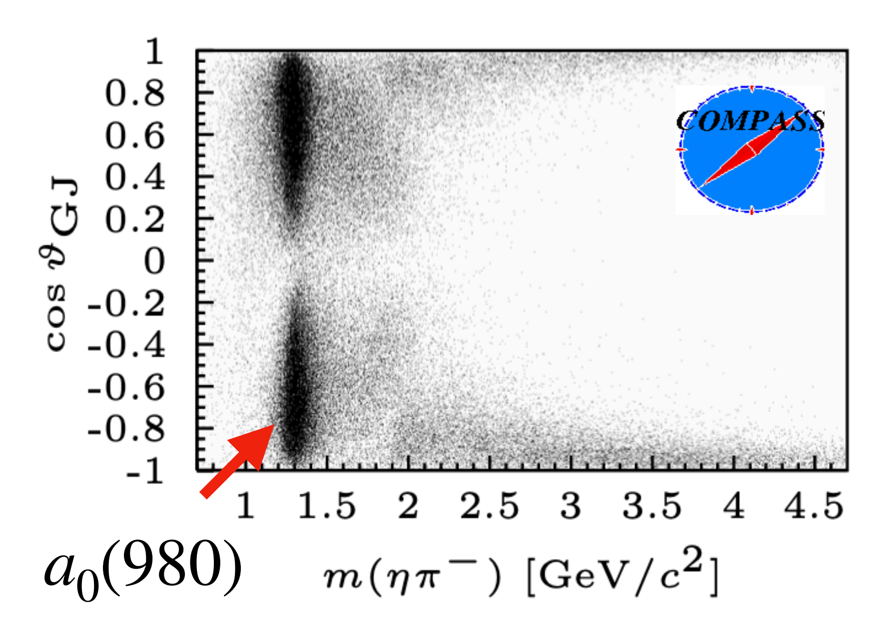
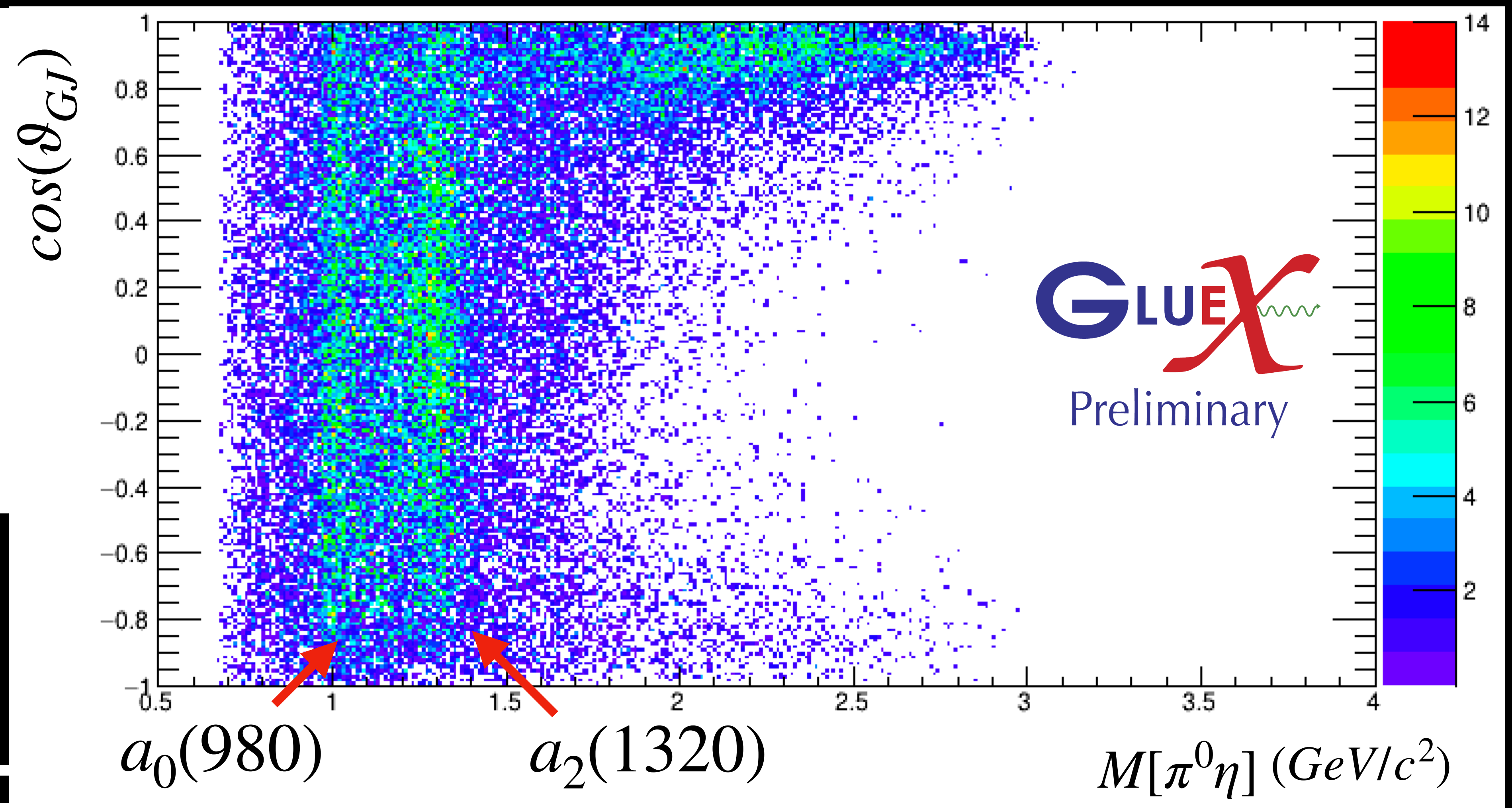
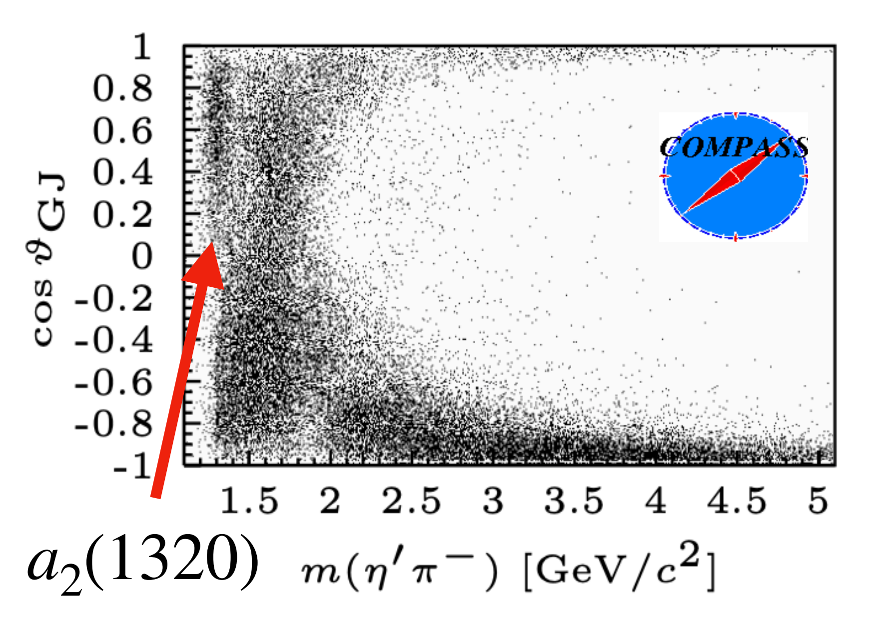
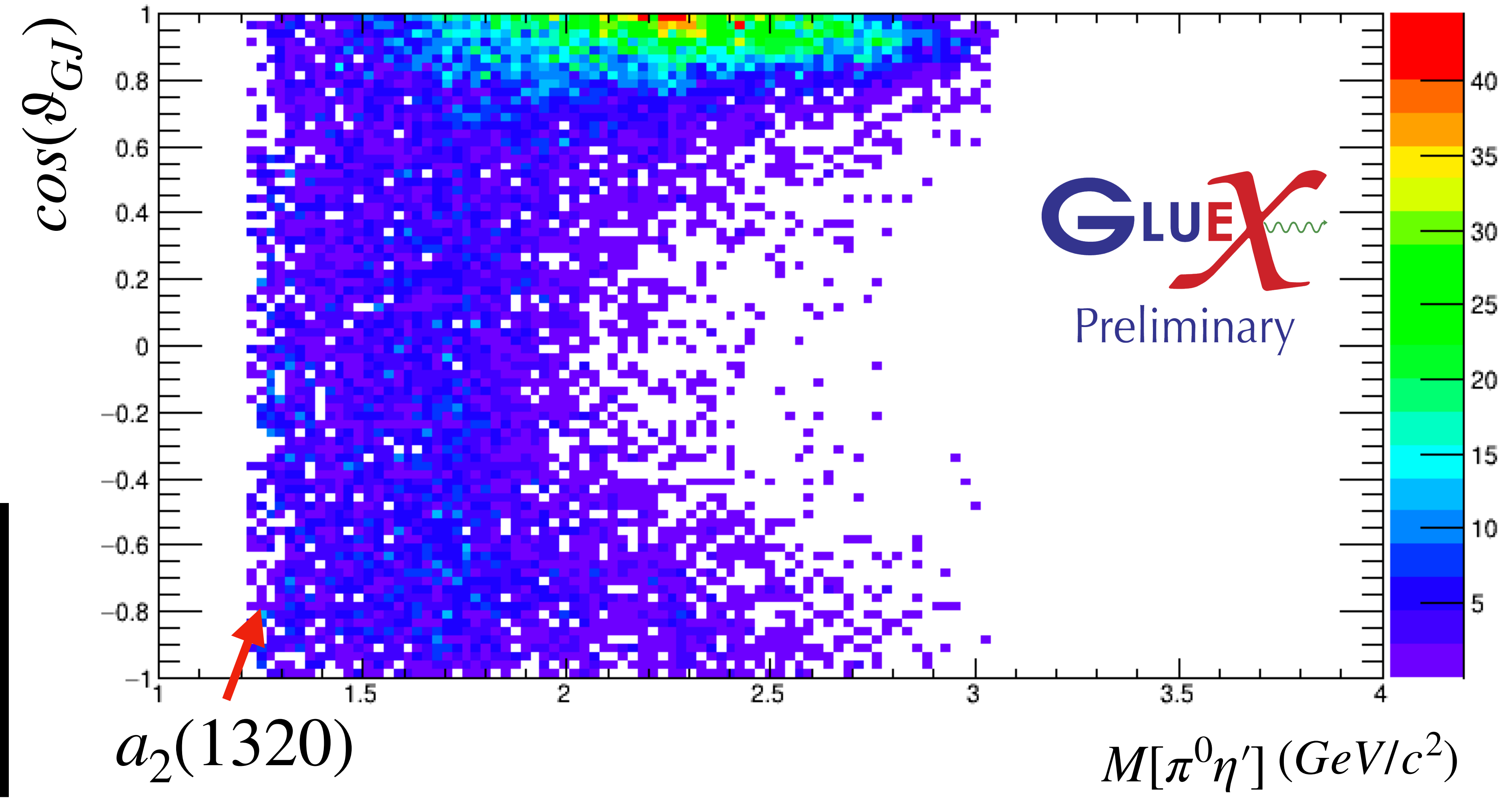




$\pi^0\eta$ system





$\pi^0\eta'$ system

$cos(\vartheta_{GJ}) \approx 1$

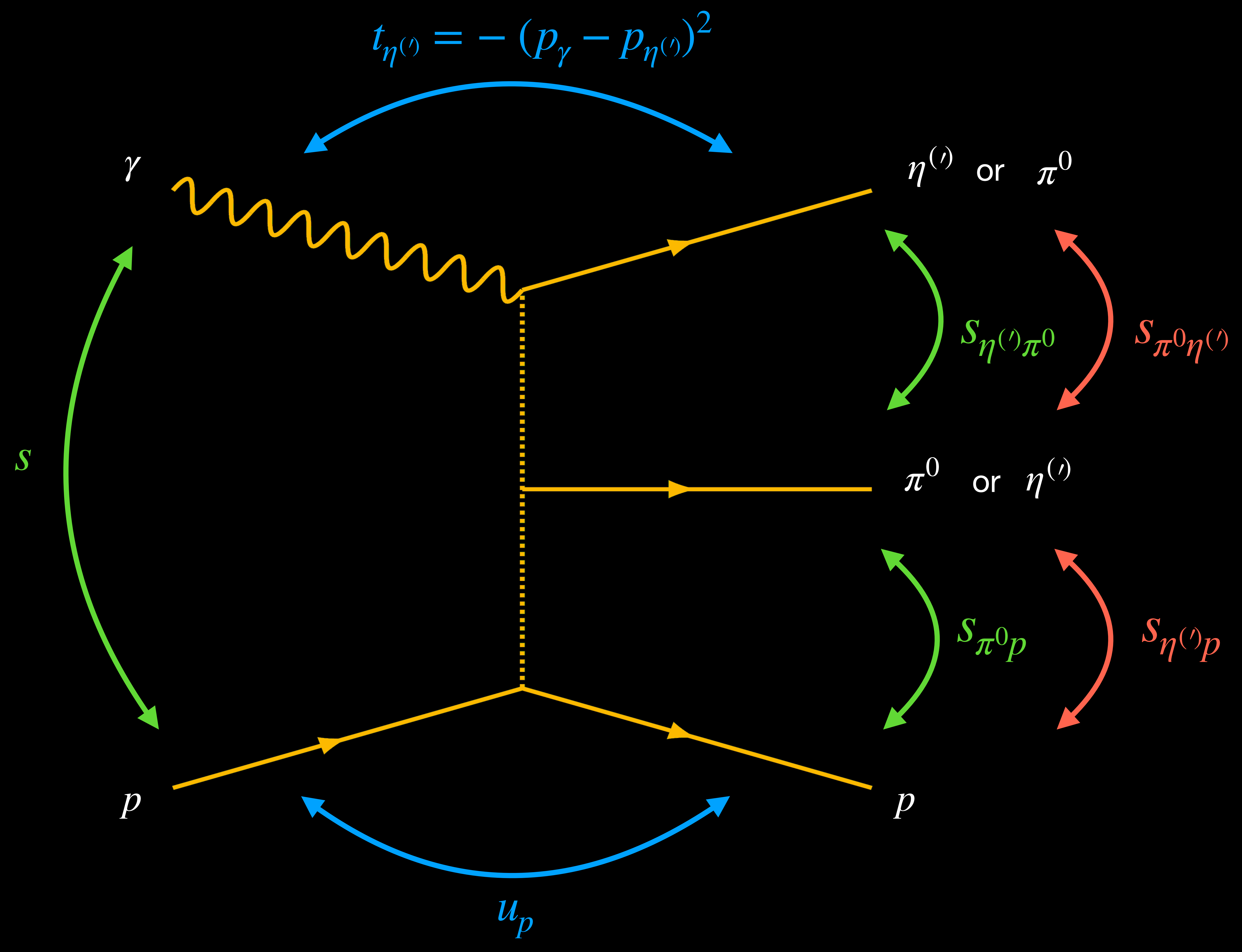
Forward $\eta^{(\prime)}$ Particles

$cos(\vartheta_{GJ}) \approx -1$

Backward $\eta^{(\prime)}$ Particles

Double Regge Analysis

Vertex Exchange Diagrams



- The exotic hybrid signature in $\pi\eta^{(\prime)}$ systems would be observed as odd partial waves, which may be enhanced by other processes
- Understanding and modeling this type of exchange is crucial
- Closely working with JPAC

Double Regge Analysis

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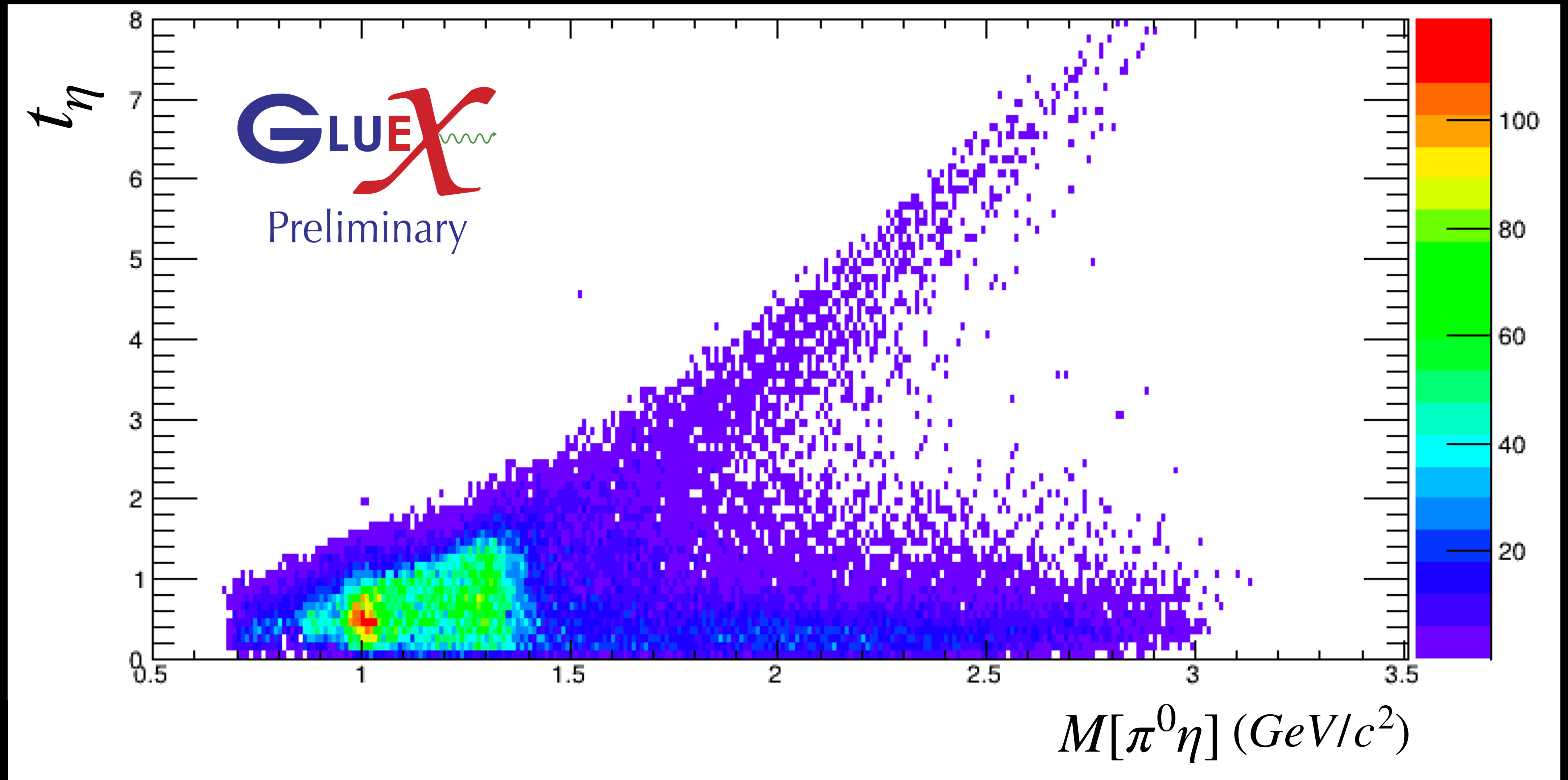
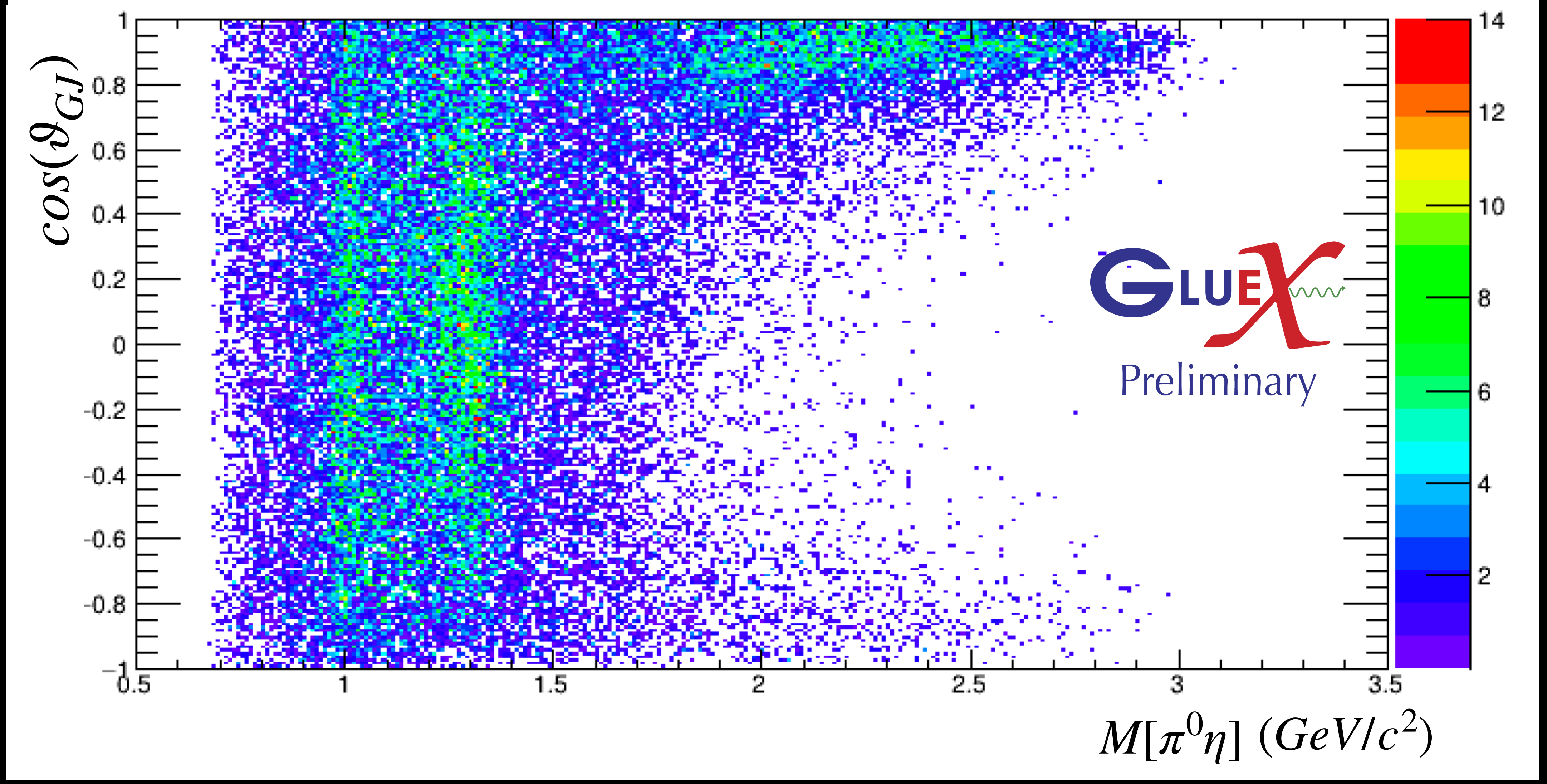
Similar in the $\pi^0\eta'$ system



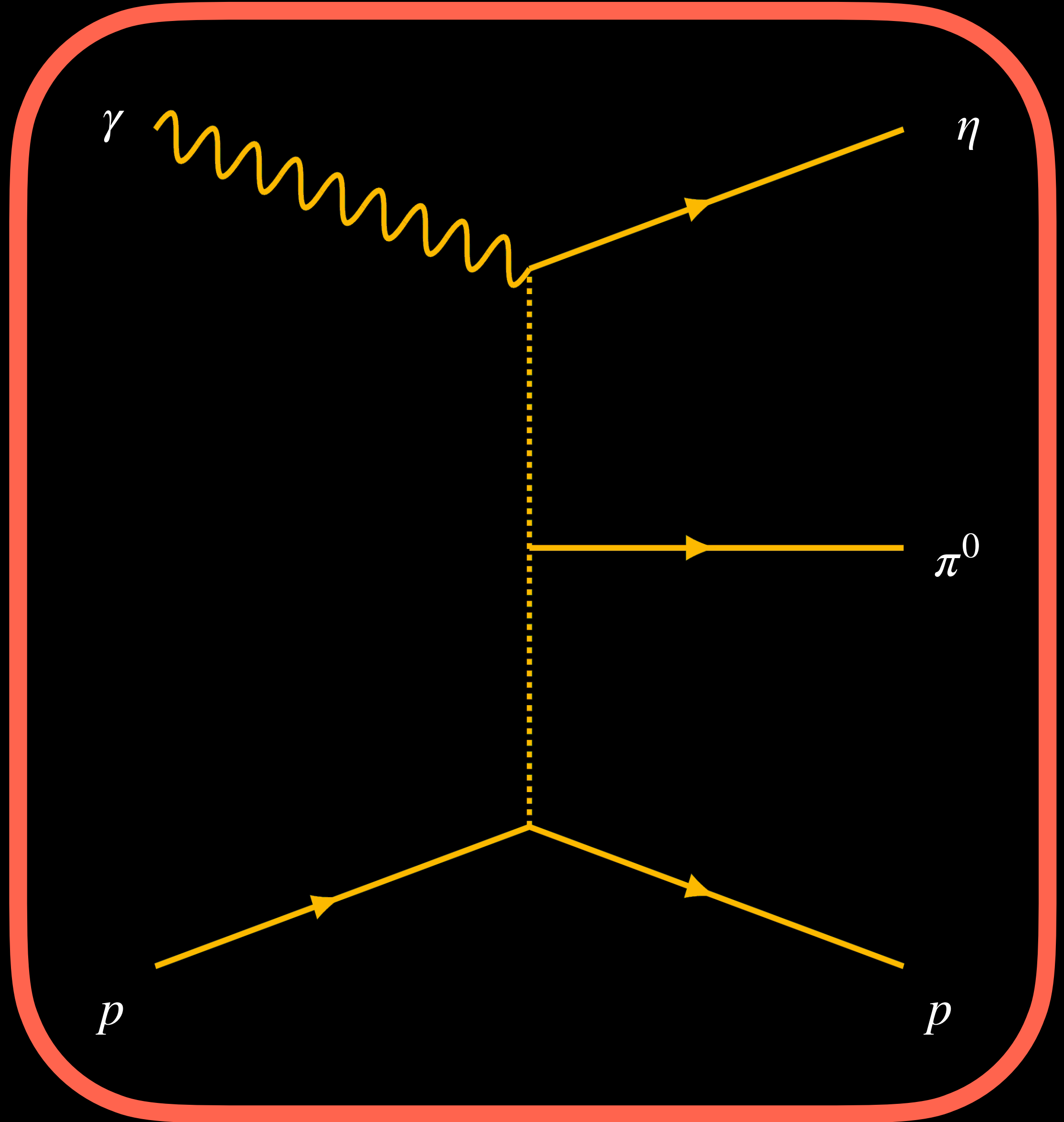


$t_\eta \approx < 1$

Faster η Particles

$cos(\vartheta_{GJ}) \approx 1$

Forward η Particles



Double Regge Analysis

Similar in the $\pi^0\eta'$ system

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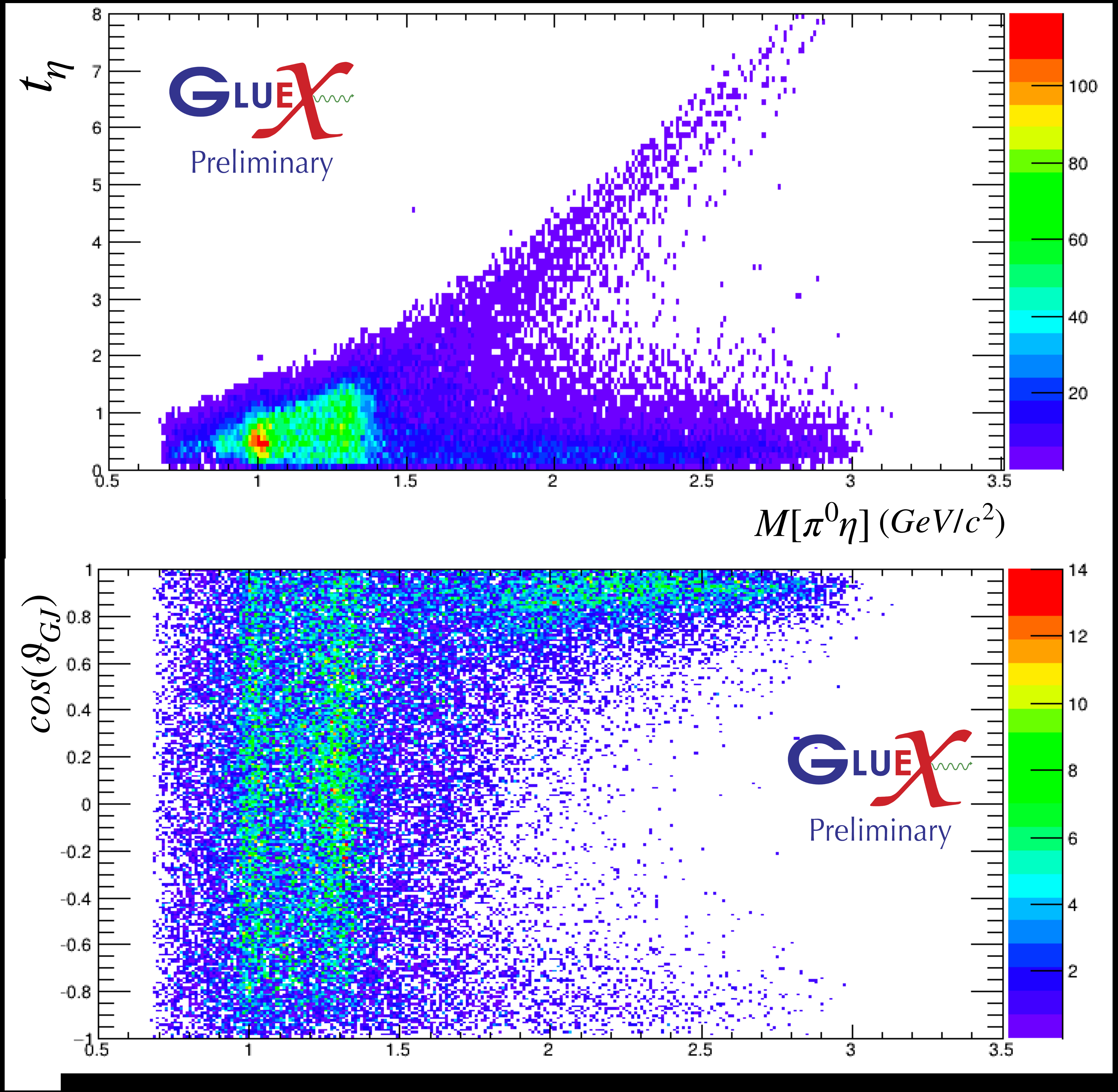


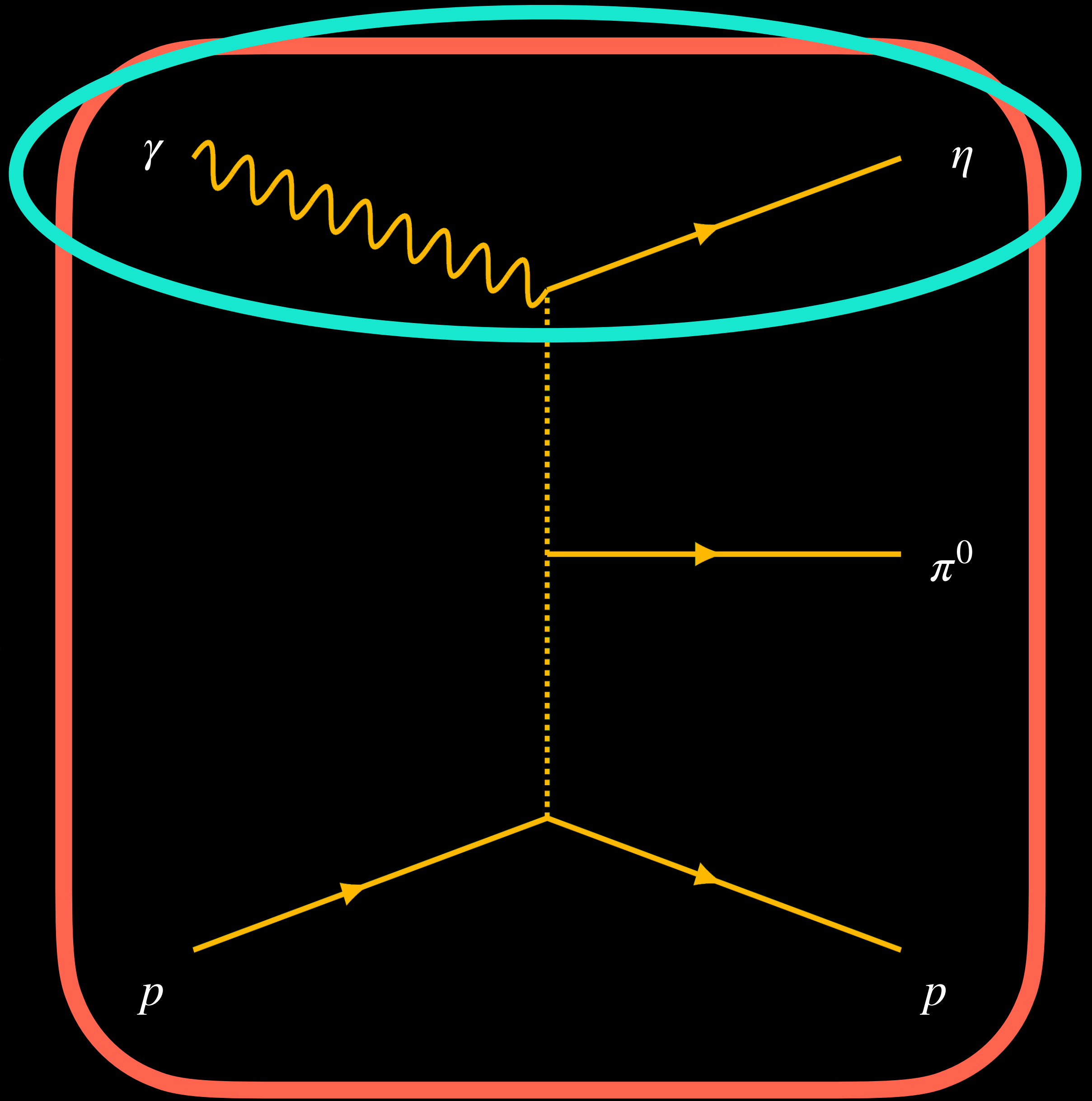
- Can study the upper vertex exchange through a beam asymmetry

$t_\eta \approx < 1$

Faster η Particles

$cos(\vartheta_{GJ}) \approx 1$

Forward η Particles



- This observable is sensitive to the naturally of the exchange particle

Double Regge Analysis

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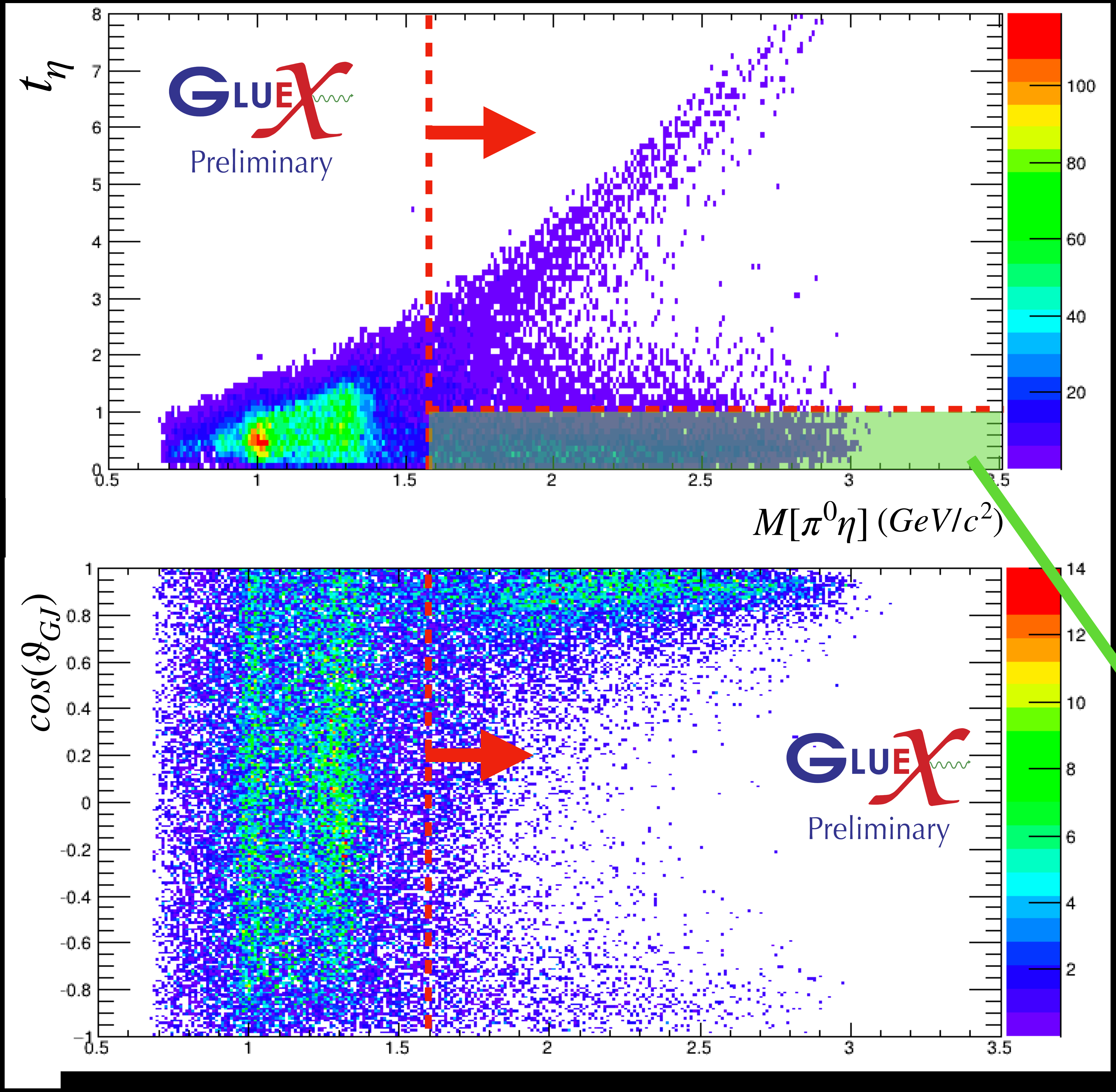

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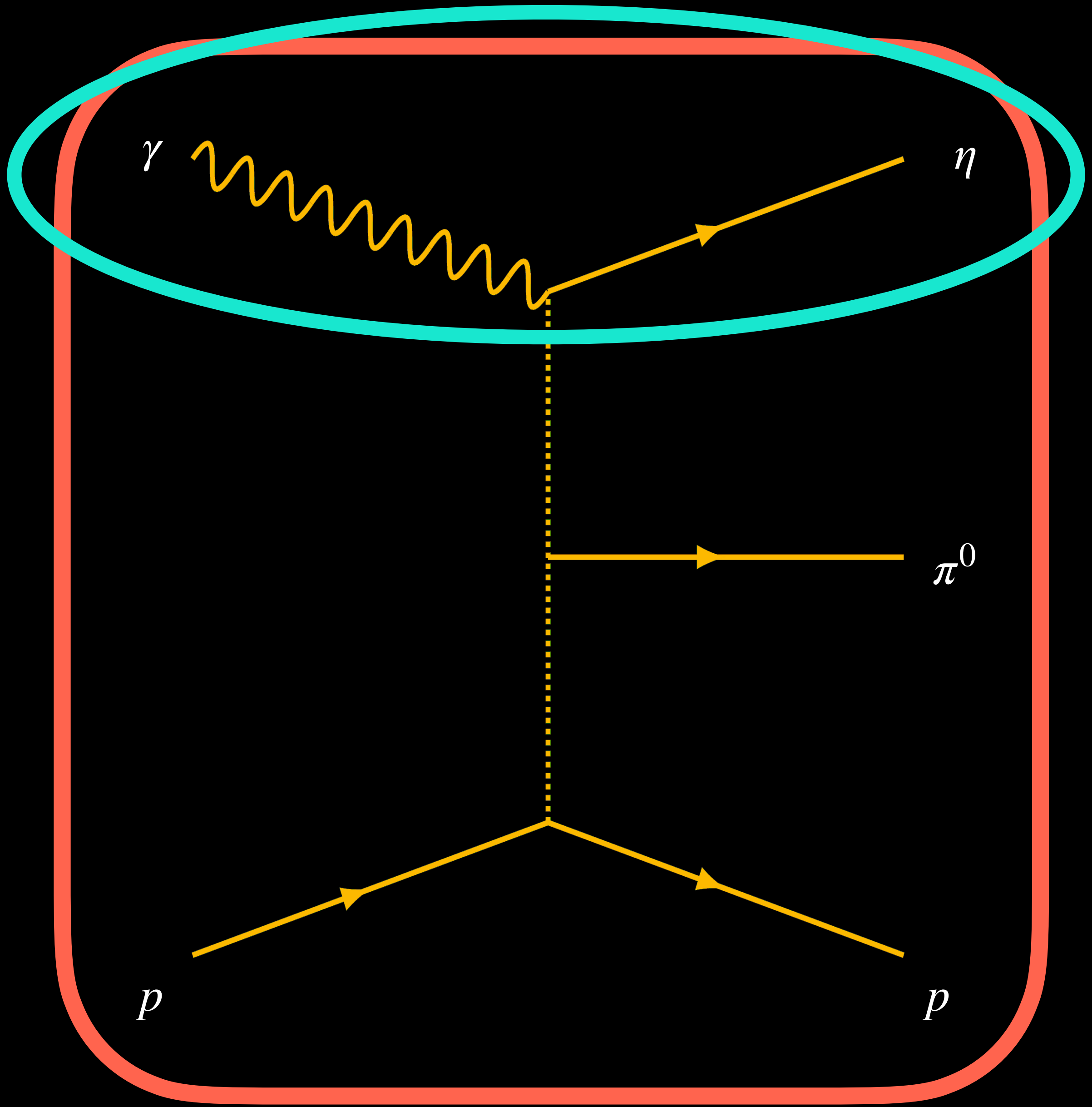
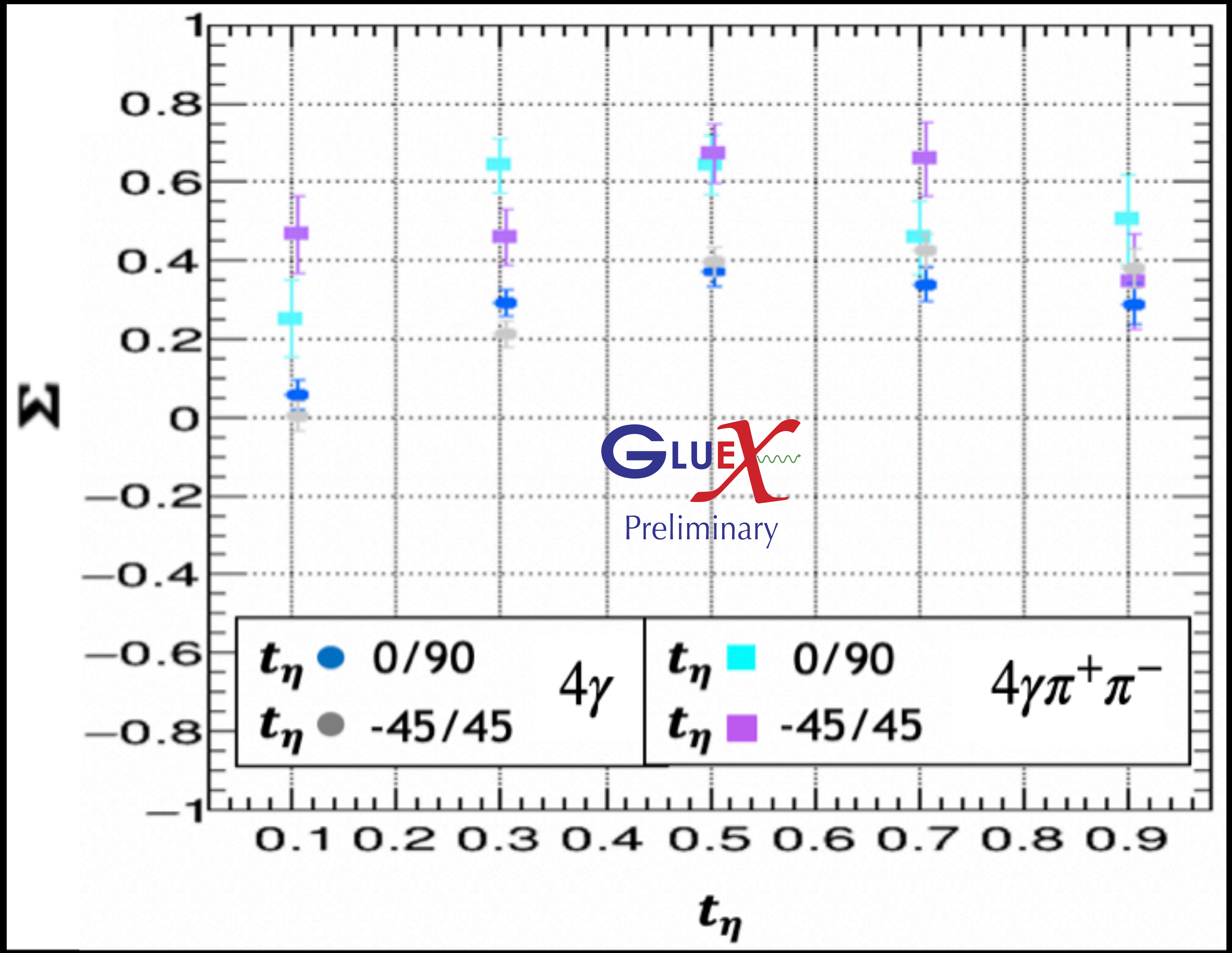


- Can divide in bins of $M[\pi^0\eta]$ where we see the fast η events and the double Regge process is dominant

Double Regge Analysis

Σ Beam Asymmetry



- Beam asymmetries for different decays modes will behave the same!

$\gamma p \rightarrow 4\gamma\pi^+\pi^- p$

$\gamma p \rightarrow 4\gamma p$

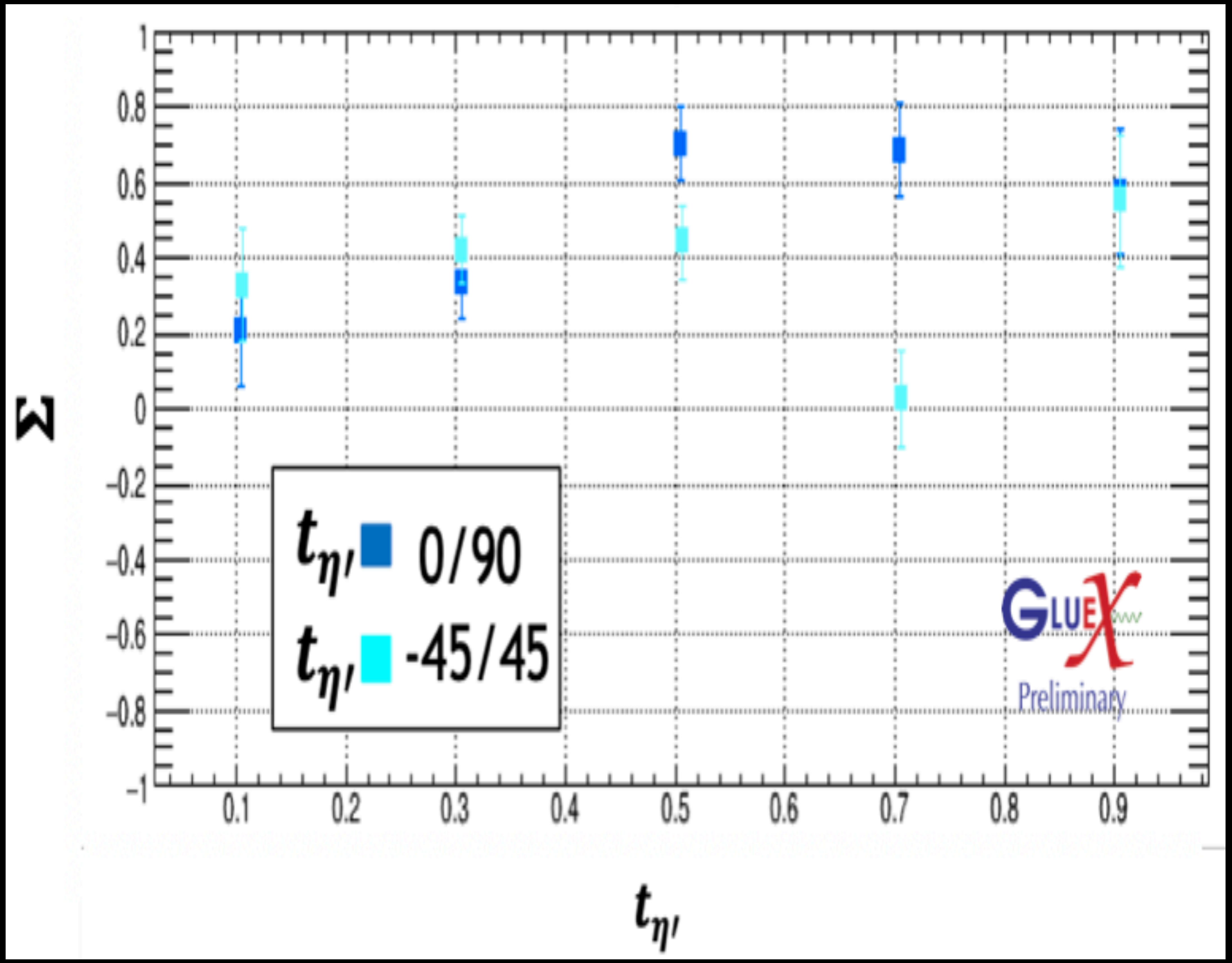
HIGHER Σ FOR $4\gamma\pi^+\pi^-$?

- For the more complicated reaction, there seems to be something that we don't understand yet and that's ok!

- Σ is integrated over multiple variables mentioned previously so in both channels the different acceptances for these variables will ultimately affect their overall contribution

Double Regge Analysis

Beam Asymmetry Comparison



- **Currently no analysis being performed on the different decay modes of $\pi^0\eta'$**
- **Once we understand what we are missing in $\pi^0\eta$ we can apply it to the $\pi^0\eta'$ channel**

Summary/Future Work

Summary

- Resonance can be seen for: $a_0(980)$, $a_2(1320)$ as well as possible higher mass resonances
- Baryon contributions finally being understood with removal possible
- Elementary double Regge analysis shown with further work underway to understand other observables and their contributions to the different vertex exchanges

Future Work

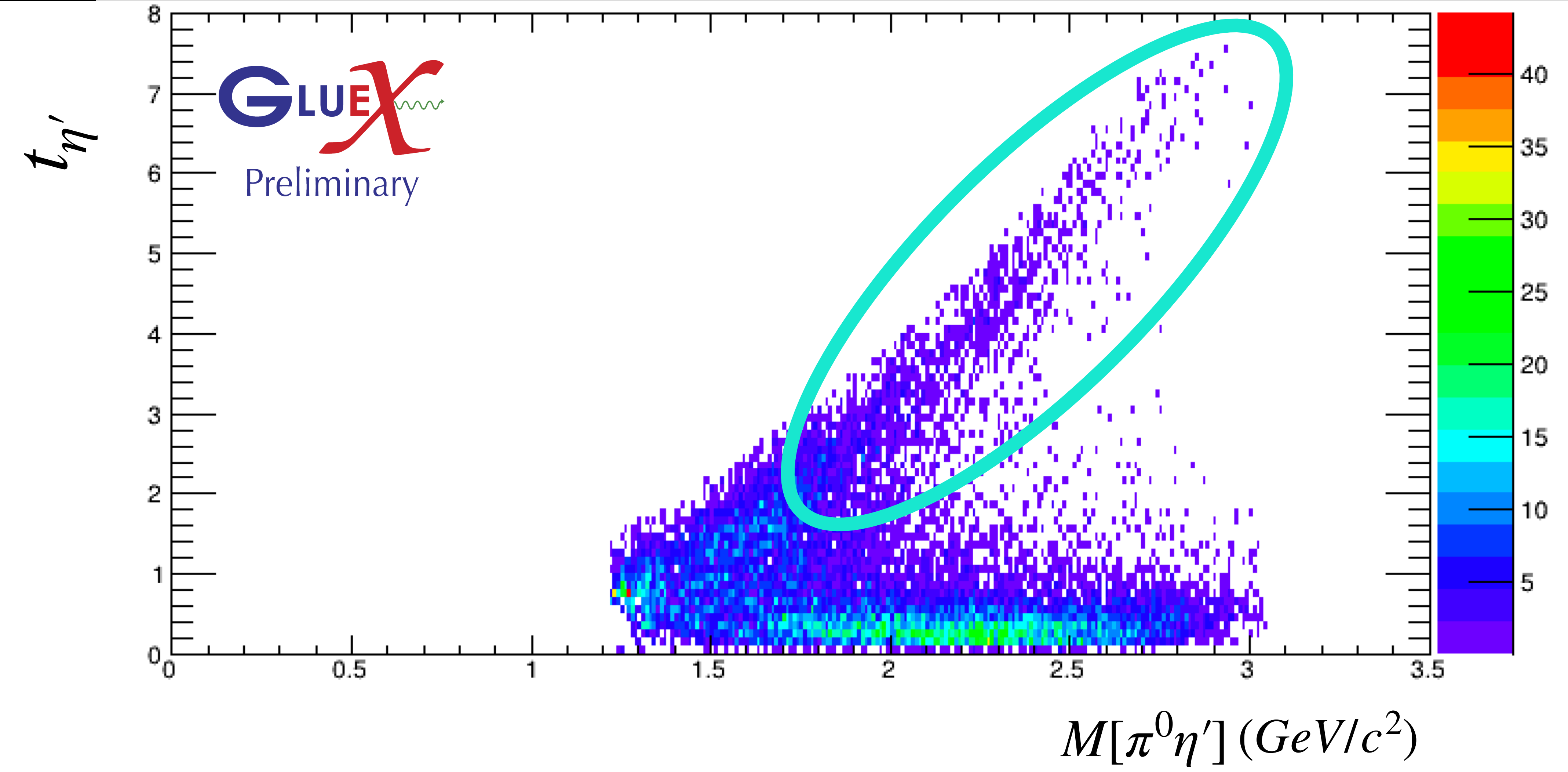
- Continue Monte Carlo simulations to further understand detector acceptance for backward $\eta^{(\prime)}$ particles
- Partial wave analysis will be performed to understand the odd and even angular momentum characteristics in each system

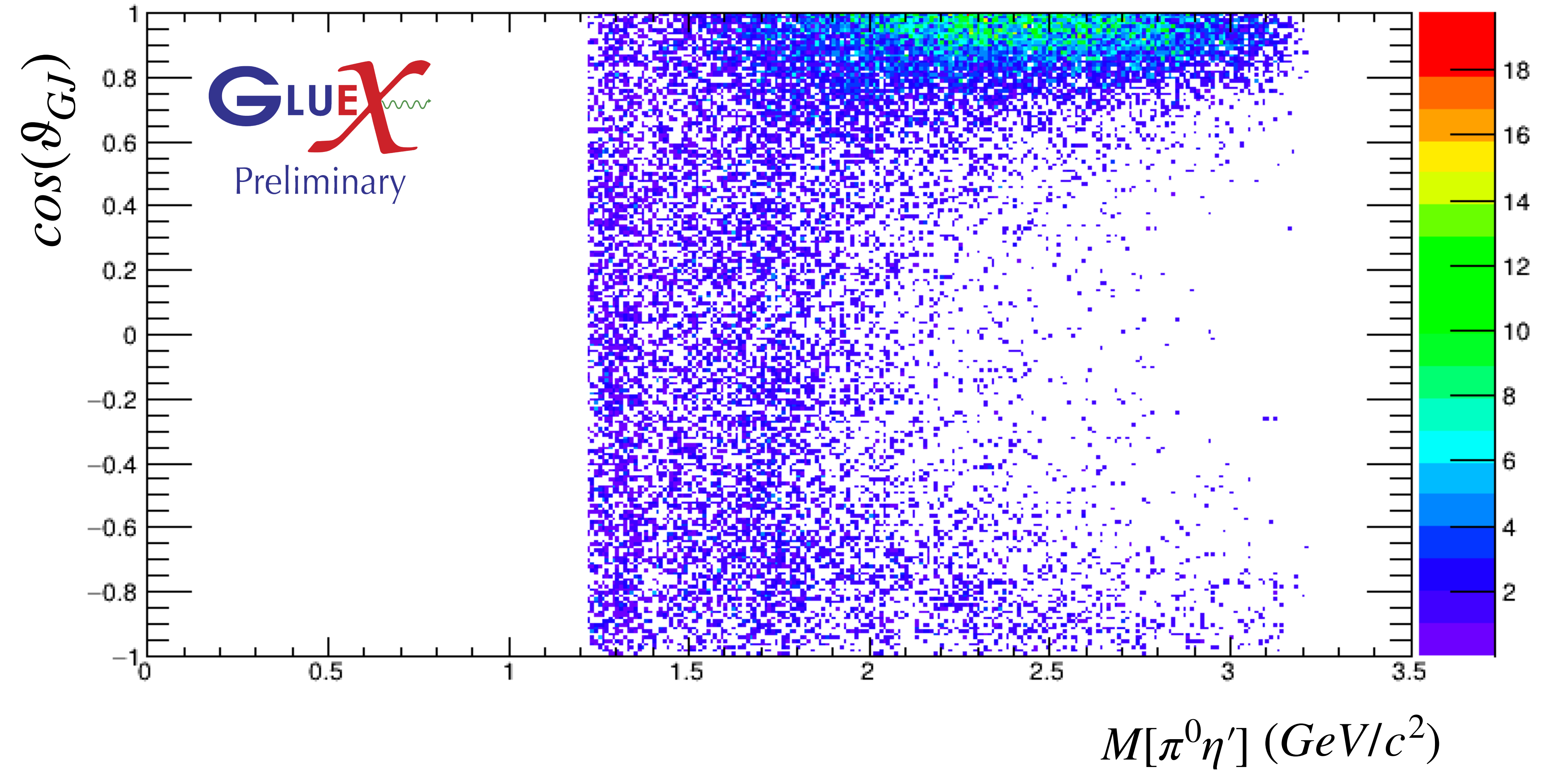
GlueX acknowledges the support of several funding agencies and computing facilities
gluex.org/thanks

Back Up Slides

Double Regge Analysis

Back Up Slide



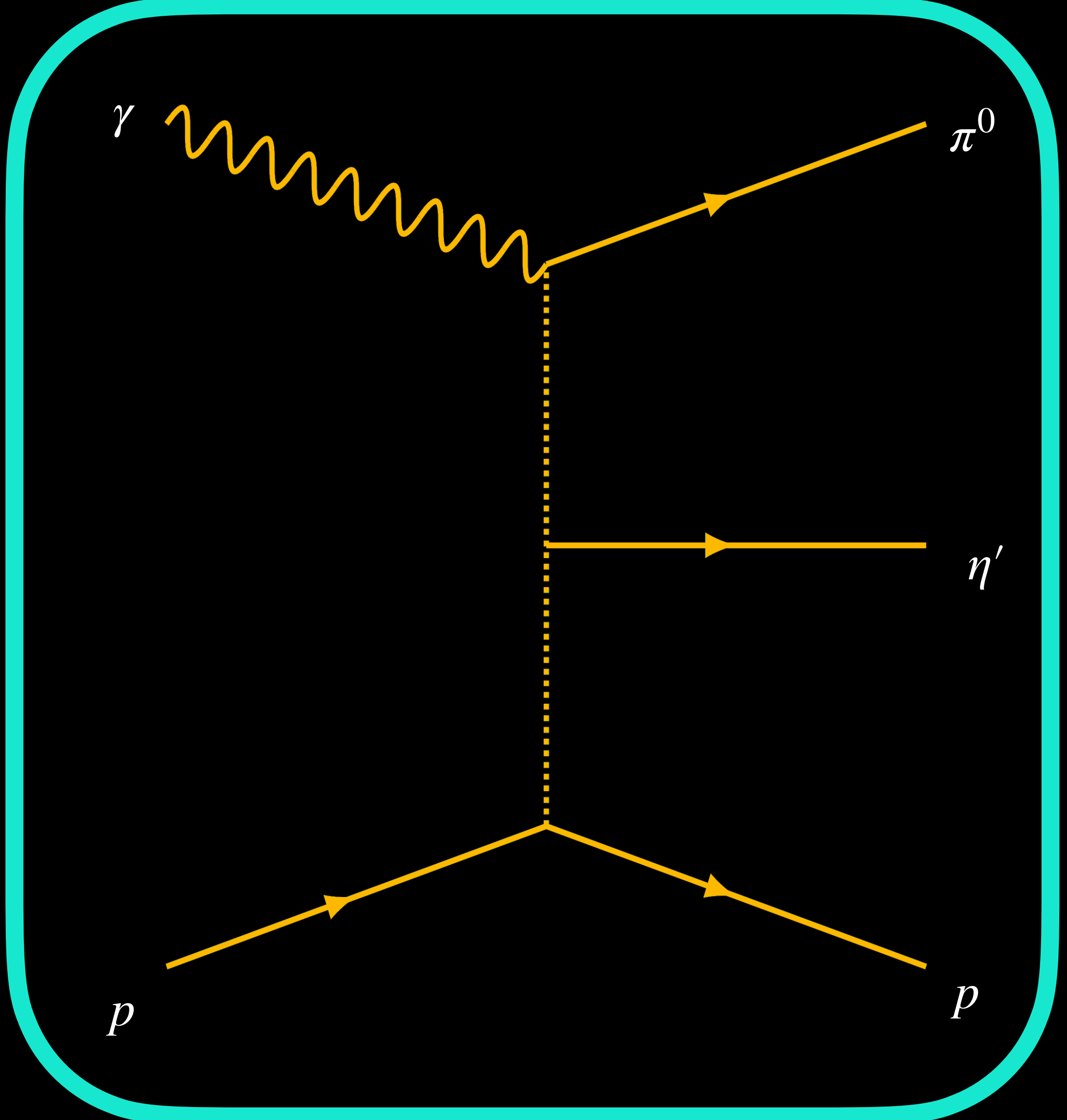


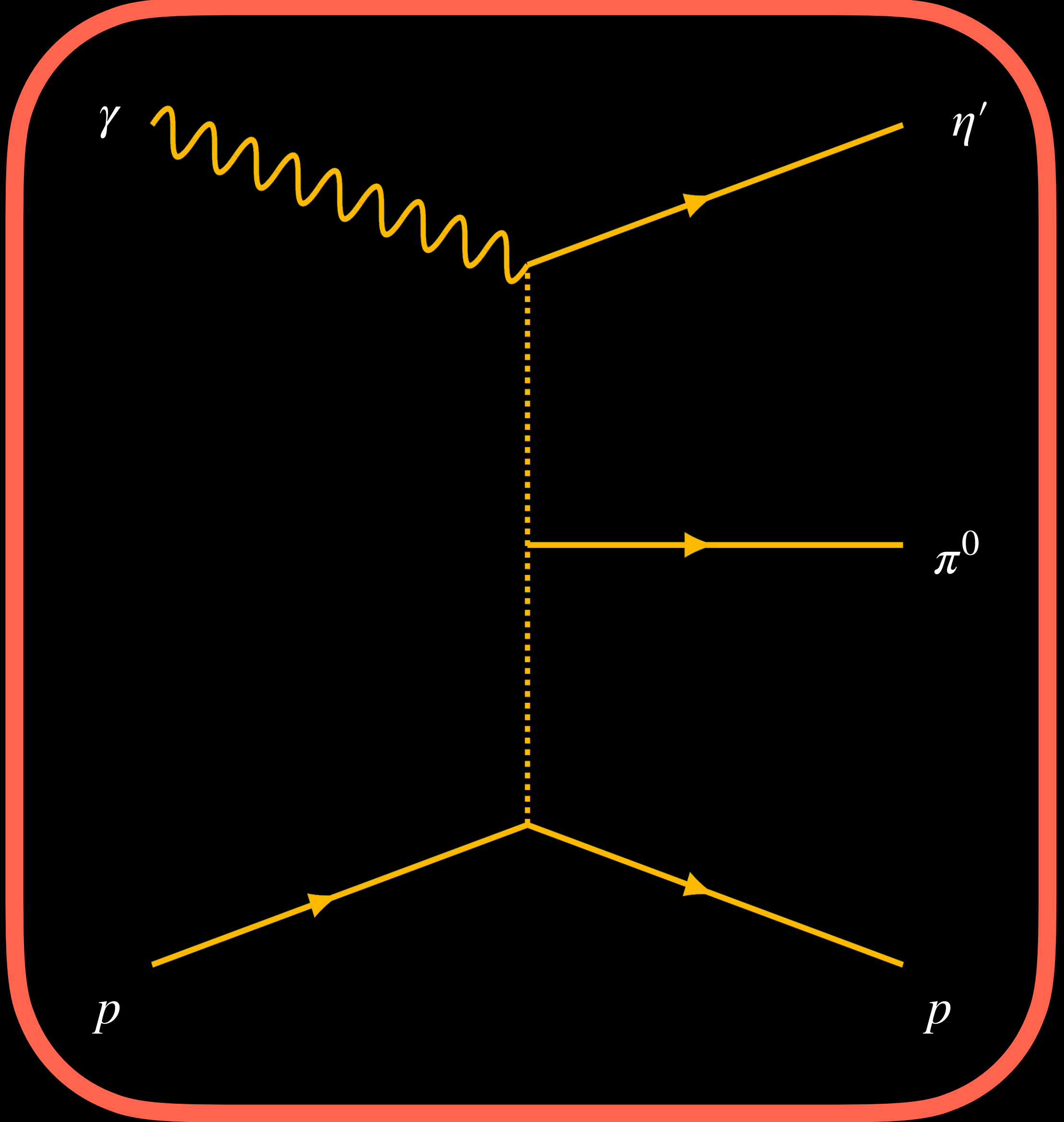
$t_{\eta'} \approx > 1$
Slower η′ Particles

$t_{\eta'} \approx < 1$
Faster η′ Particles

$cos(\vartheta_{GJ}) \approx 1$
Forward η′ Particles

$cos(\vartheta_{GJ}) \approx -1$
Backward η′ Particles





Double Regge Analysis

Back Up Slide

Beam Asymmetry description

- The first observable that has been looked at to understand the double Regge effect is the beam asymmetry Σ

$$\frac{(\frac{d\sigma_{\perp}}{d\phi}) - (\frac{d\sigma_{||}}{d\phi})}{(\frac{d\sigma_{\perp}}{d\phi}) + (\frac{d\sigma_{||}}{d\phi})} = \frac{Y(\phi)_{\perp} - F_R Y(\phi)_{||}}{Y(\phi)_{\perp} + F_R Y(\phi)_{||}} = \frac{(P_{\perp} + P_{||})\Sigma cos2(\phi)}{2 + (P_{\perp} - P_{||})\Sigma cos2(\phi)}$$

$$Y(\phi)_{\perp} \approx N_{\perp}[\sigma_{unpol}A(\phi)(1 + P_{\perp}\Sigma cos2(\phi))]$$

$$Y(\phi)_{||} \approx N_{||}[\sigma_{unpol}A(\phi)(1 - P_{||}\Sigma cos2(\phi))]$$

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