Carnegie Mellon University

Light Meson Spectroscopy in $K_S^0 K_S^0$ Photoproduction at GlueX

JUNE 16, 2022

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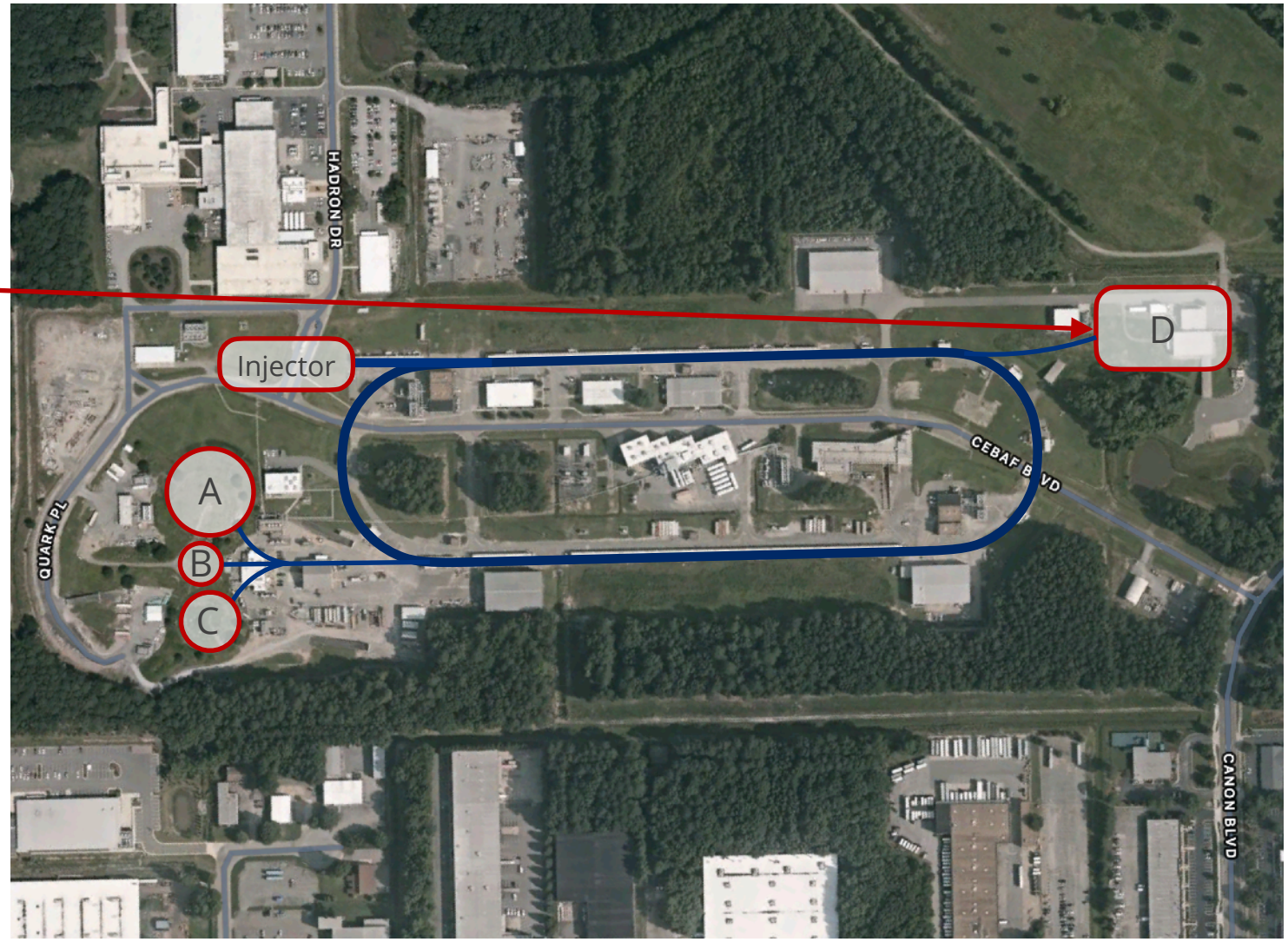
Presented to the 37th Annual HUGS Program at Jefferson Lab

Overview

- Introduction to GlueX Physics
- Motivation for the $K_S^0 K_S^0$ Channel Analysis
- Data Selection
- Partial Wave Analysis

Introduction to GlueX Physics

- Located at Hall D in Jefferson Lab



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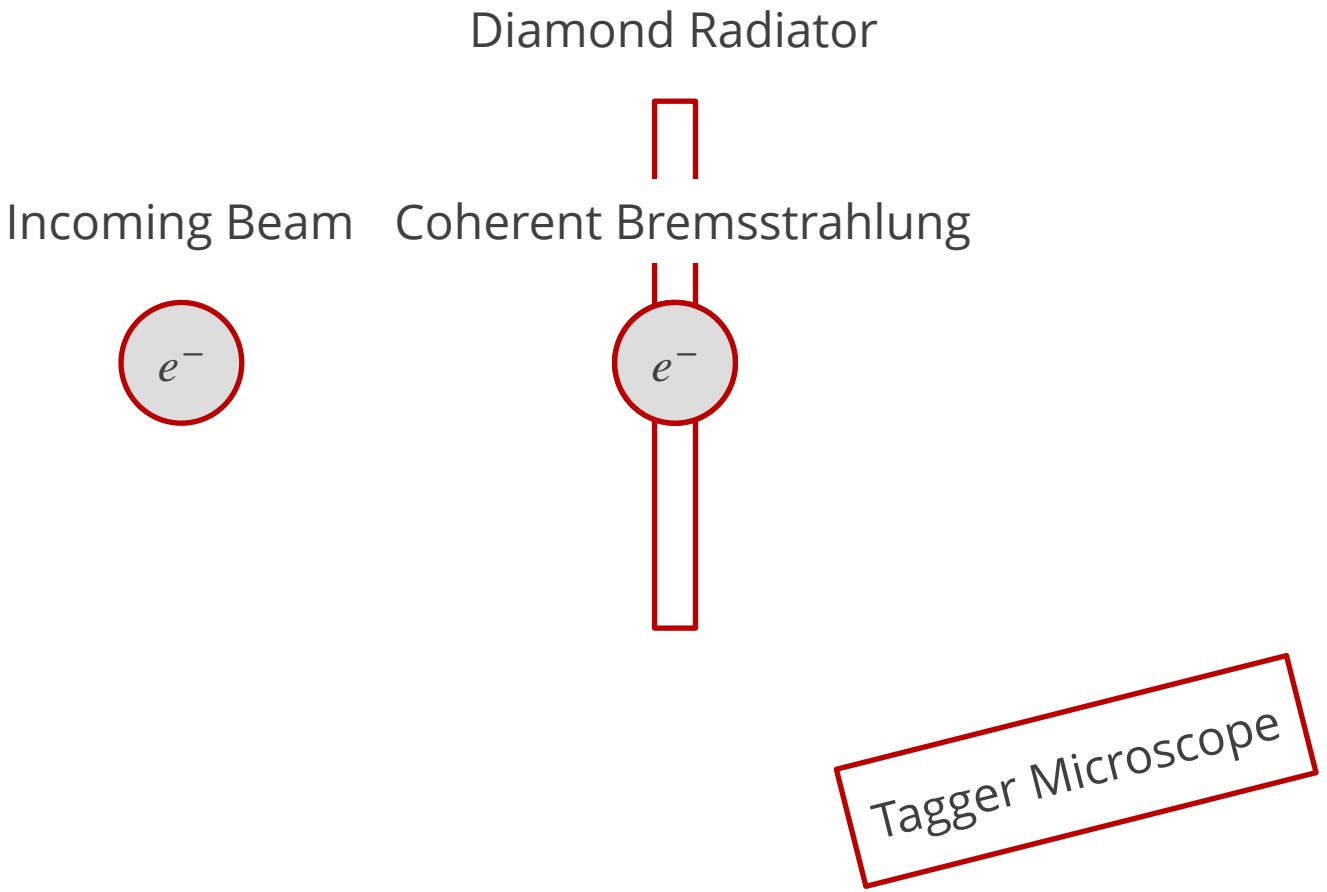

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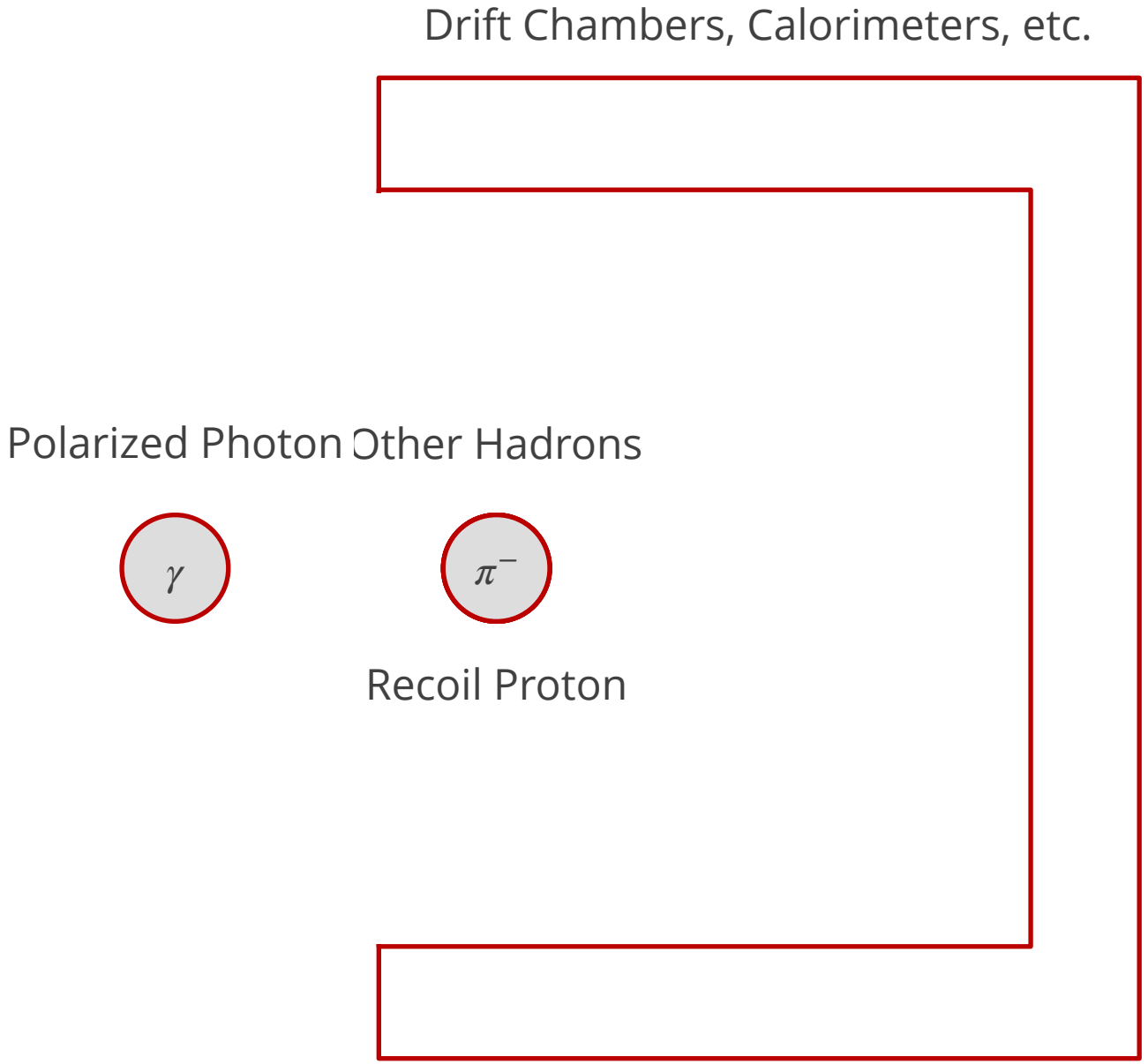

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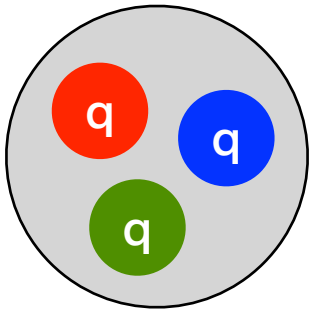
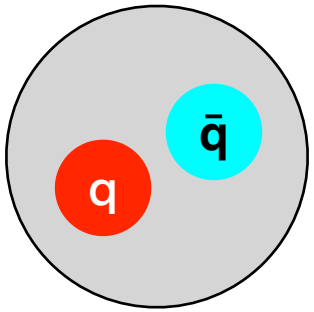
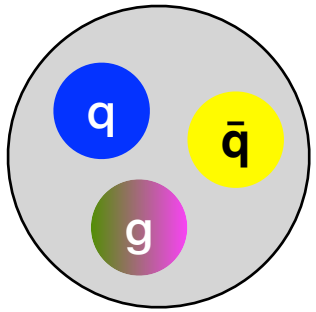
- Goal: Search for exotic mesons



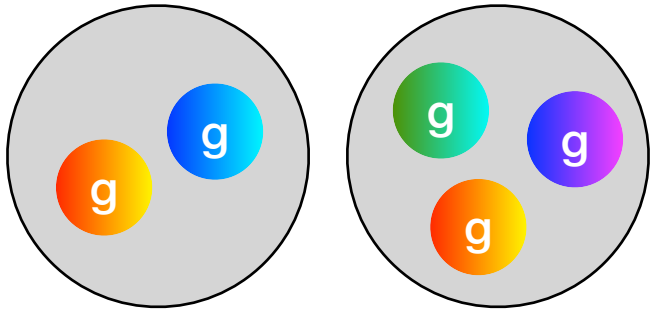
Baryon



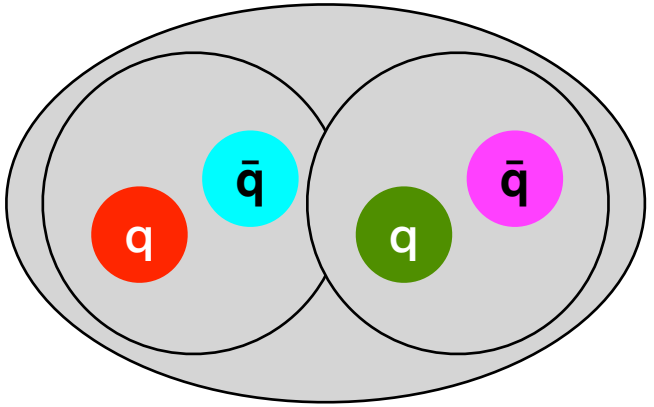
Meson



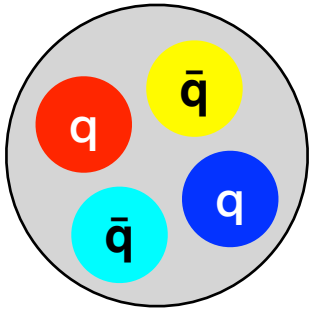
Hybrid Meson



Glueballs



Molecular Meson

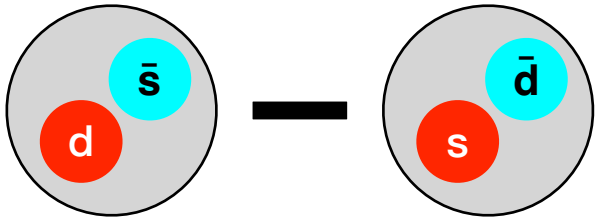


Tetraquark

Motivation for the $K_S^0 K_S^0$ Channel Analysis

- K-Short mesons are weak eigenstates of the $K\bar{K}$ system with a single strange quark

$$K_S^0 = (K^0 - \bar{K}^0)/\sqrt{2}$$



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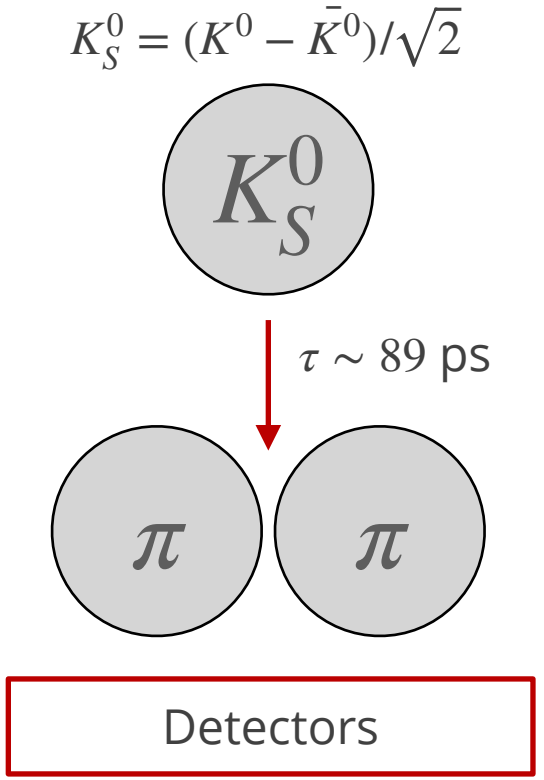

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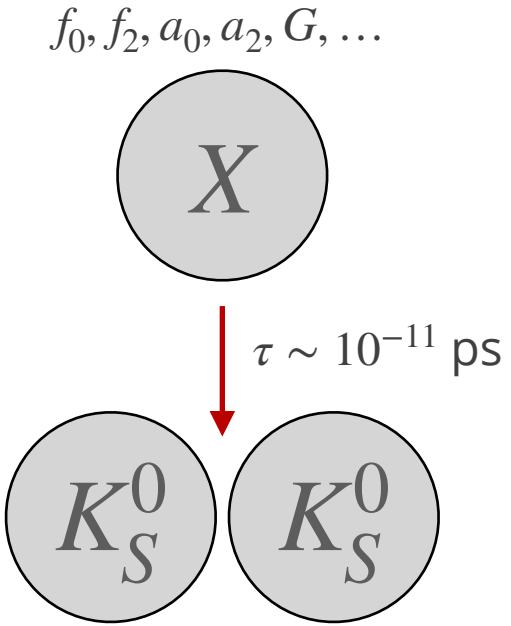

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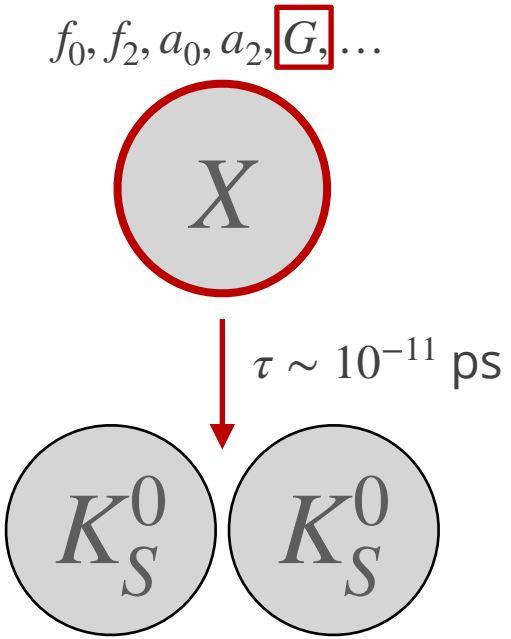

Morningstar, C. J., & Peardon, M. (1999). Glueball spectrum from an anisotropic lattice study. Physical Review D (Vol. 60, Issue 3). https://doi.org/10.1103/PhysRevD.60.034509

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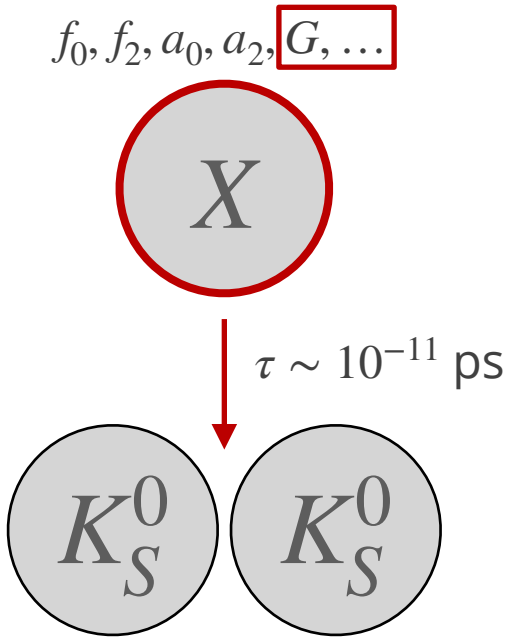
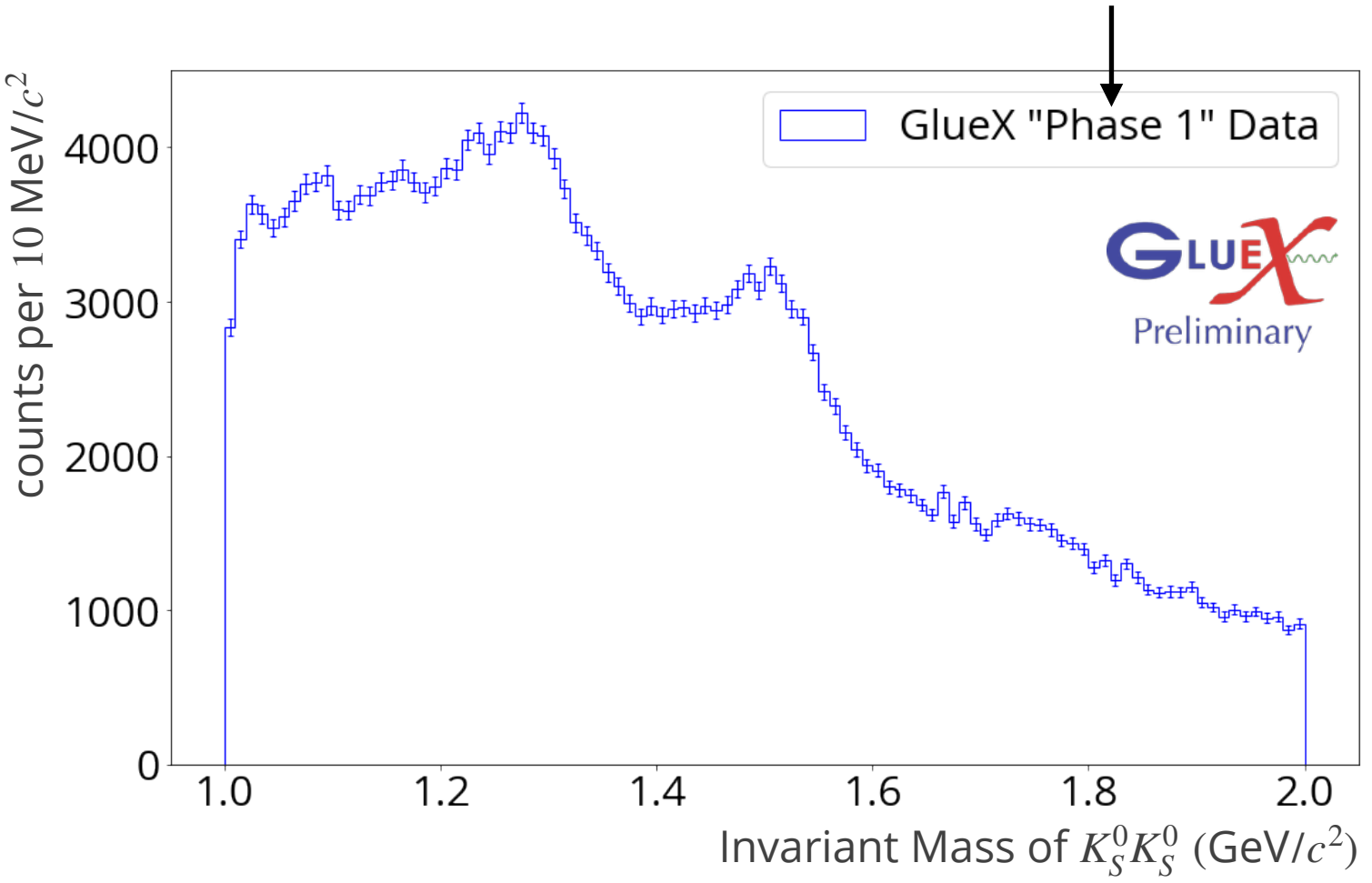
- Lightest glueballs are predicted as 0^{++} and 2^{++} with scalar mass ~1500 MeV (above $K_S^0 K_S^0$ threshold)
- Important in understanding other light mesons which don't fit into $q\bar{q}$ model (potential light tetraquarks, molecular mesons)



Amsler, C., & Törnqvistb, N. A. (2004). Mesons beyond the naive quark model. Physics Reports, 389(2), 61–117. https://doi.org/10.1016/j.physrep.2003.09.003

Data Selection

- GlueX reconstruction
  - Kinematic fit for energy-momentum conservation and vertex constraints on decays
- Basic particle identification cuts (clean-up selections on pions/ proton in detectors)
- Selection on the χ^2/NDF of the kinematic fit



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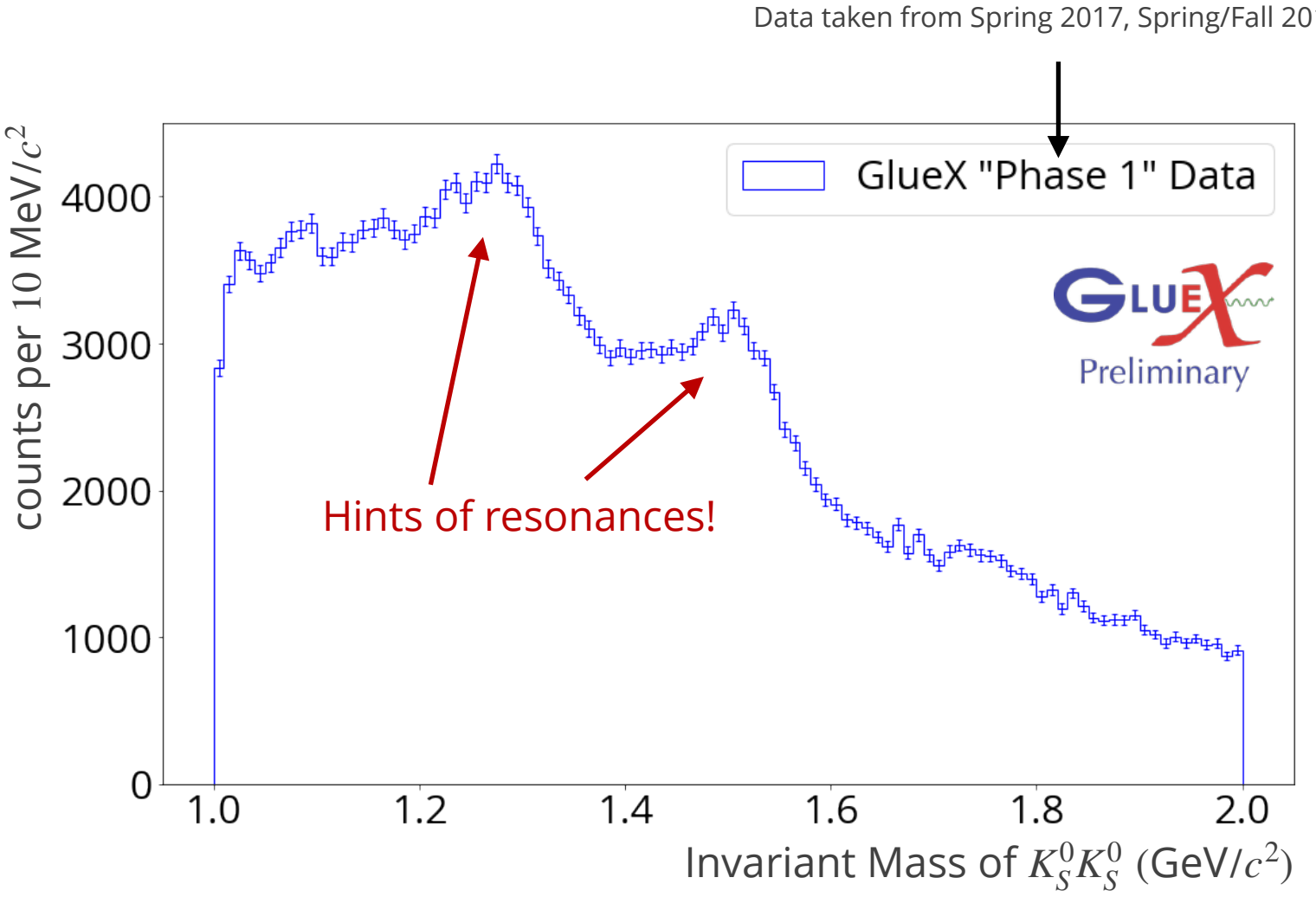

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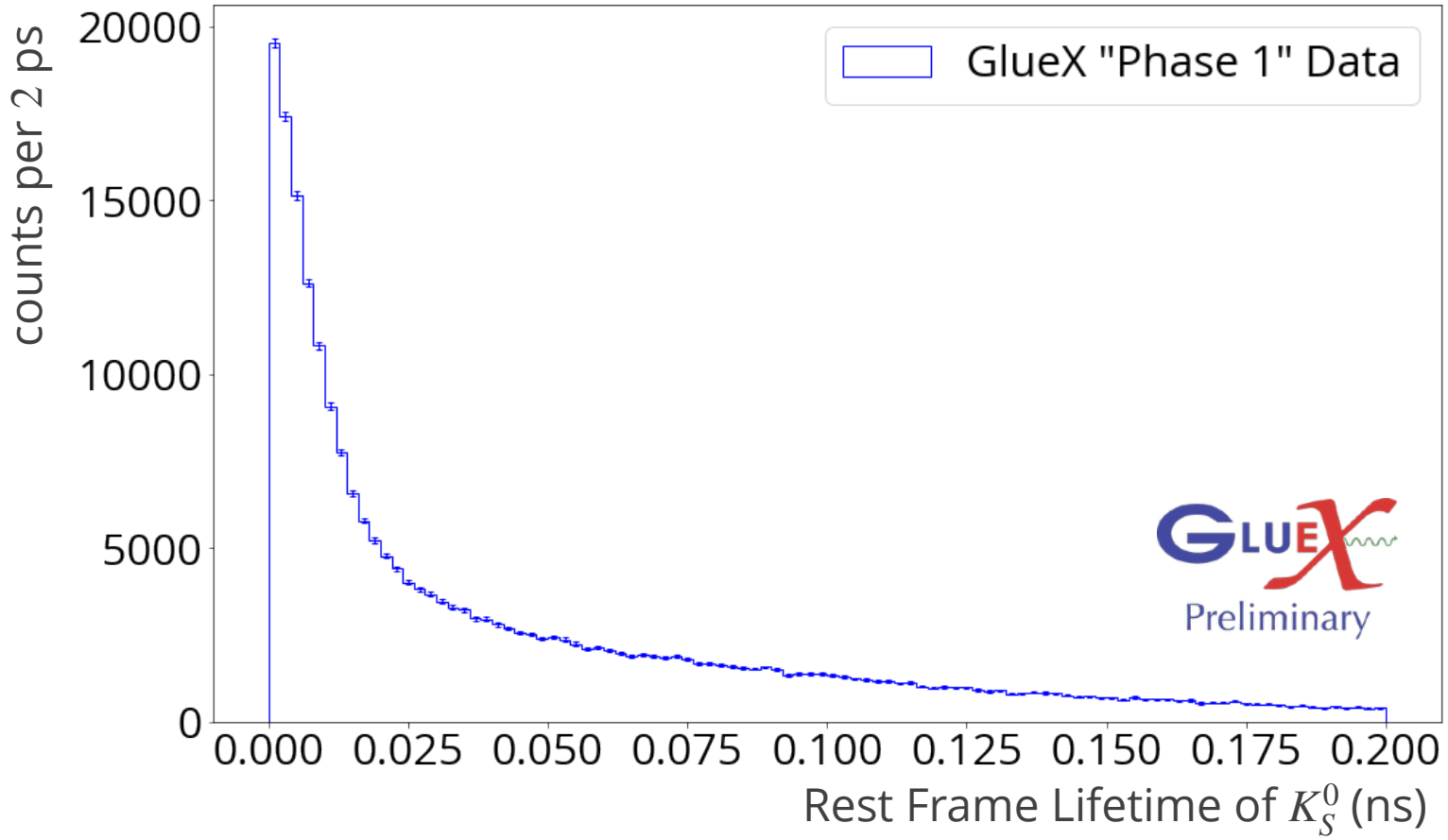

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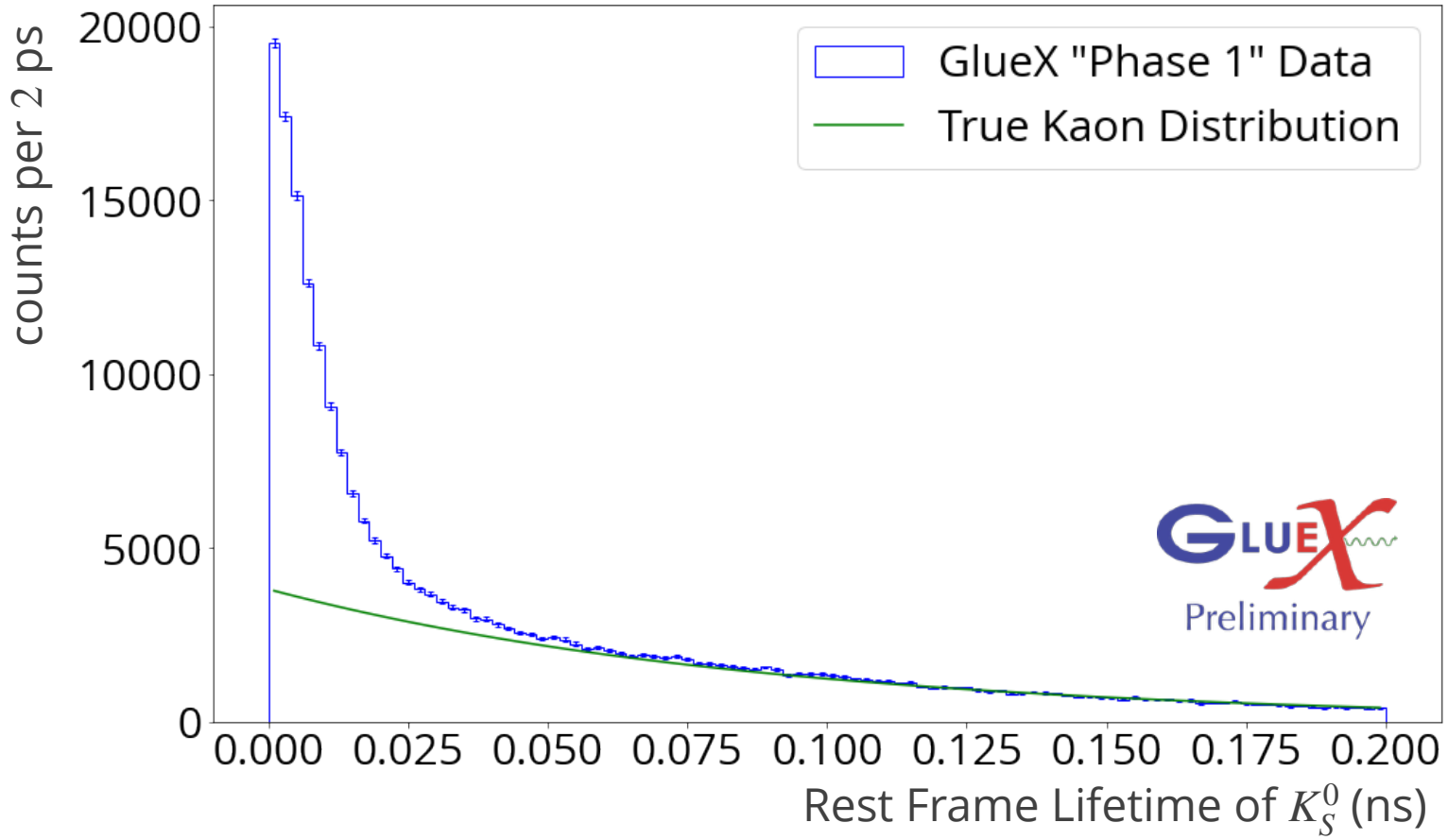
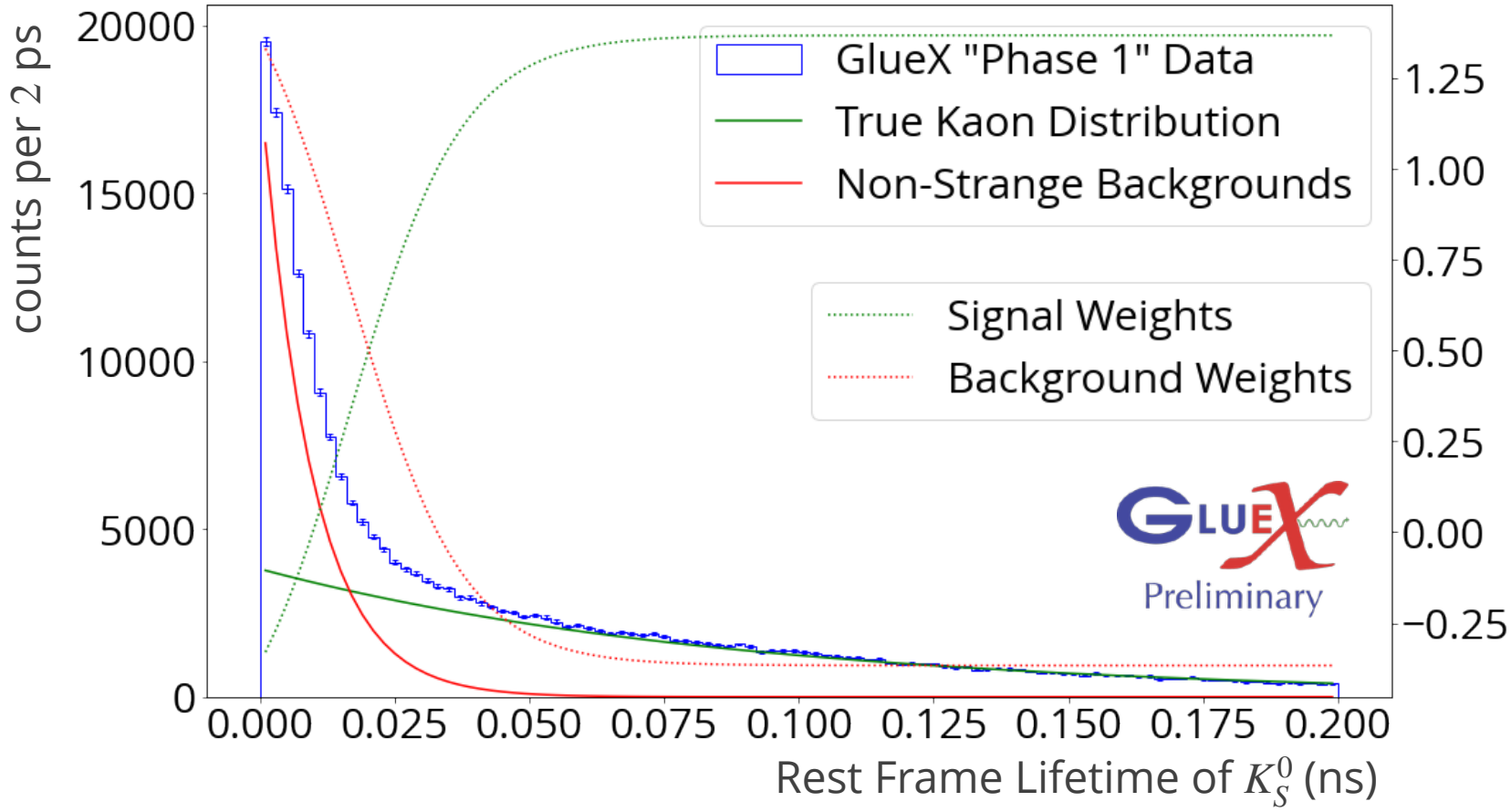


Data Selection

- We can do better: look at the kaon lifetimes in the rest frame!
- Many events decay faster than expected
- Using these signal and background probability distributions, we can construct weights based on the probability that an event is a signal
  - This method is called sPlot and includes proper error propagation



Pivk, M., & Diberder, F. R. le. (2004). *sPlot: a statistical tool to unfold data distributions*. https://doi.org/10.1016/j.nima.2005.08.106

Data Selection

- Most significant non-strange background has been removed!

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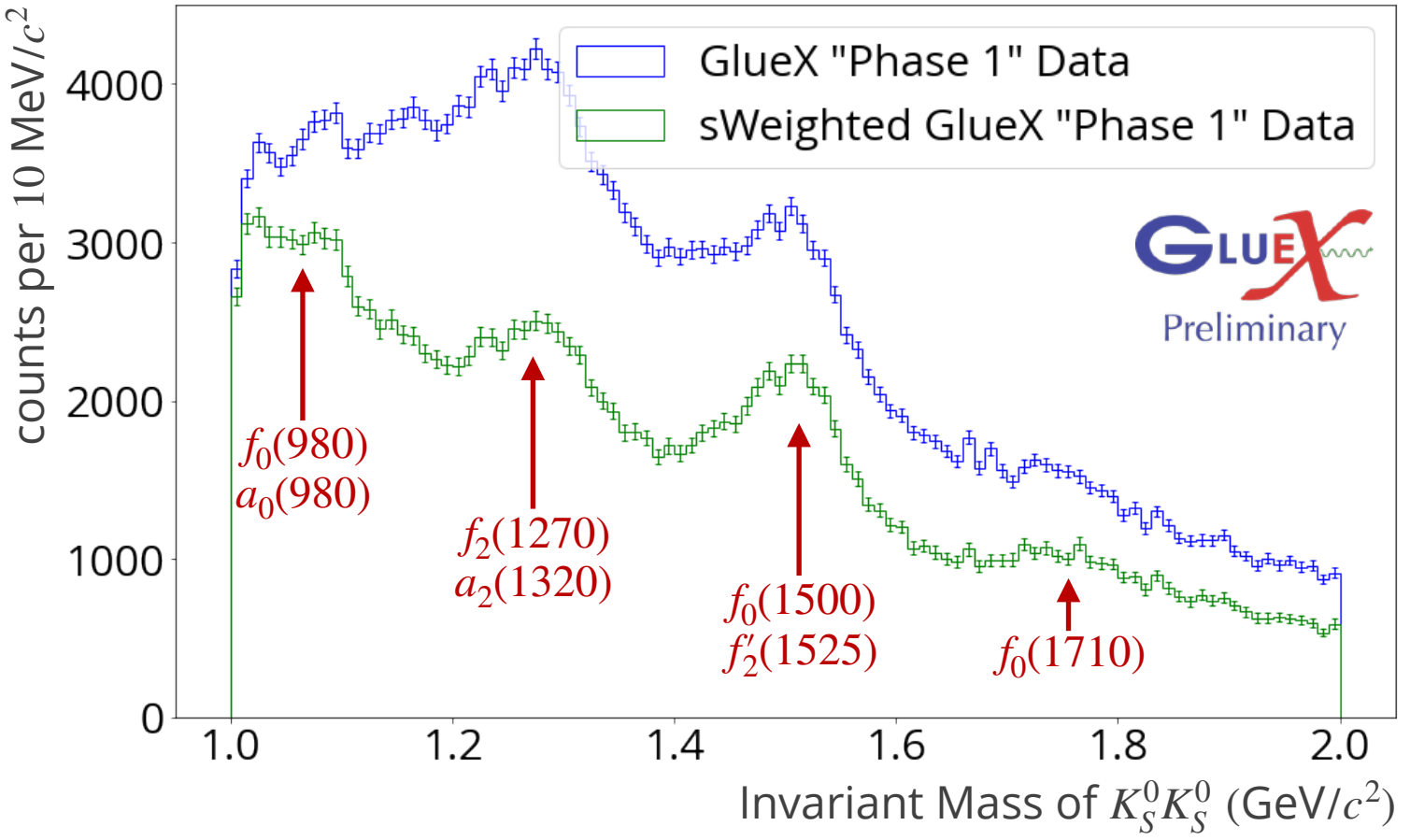
- Clear peaks at known resonances



Partial Wave Analysis

- Looking at decay products from X, we can fit angular distributions to $Y_{\ell,m}(\theta,\phi)$ functions and extract components with $\ell = 0,2,\ldots$ to obtain spin

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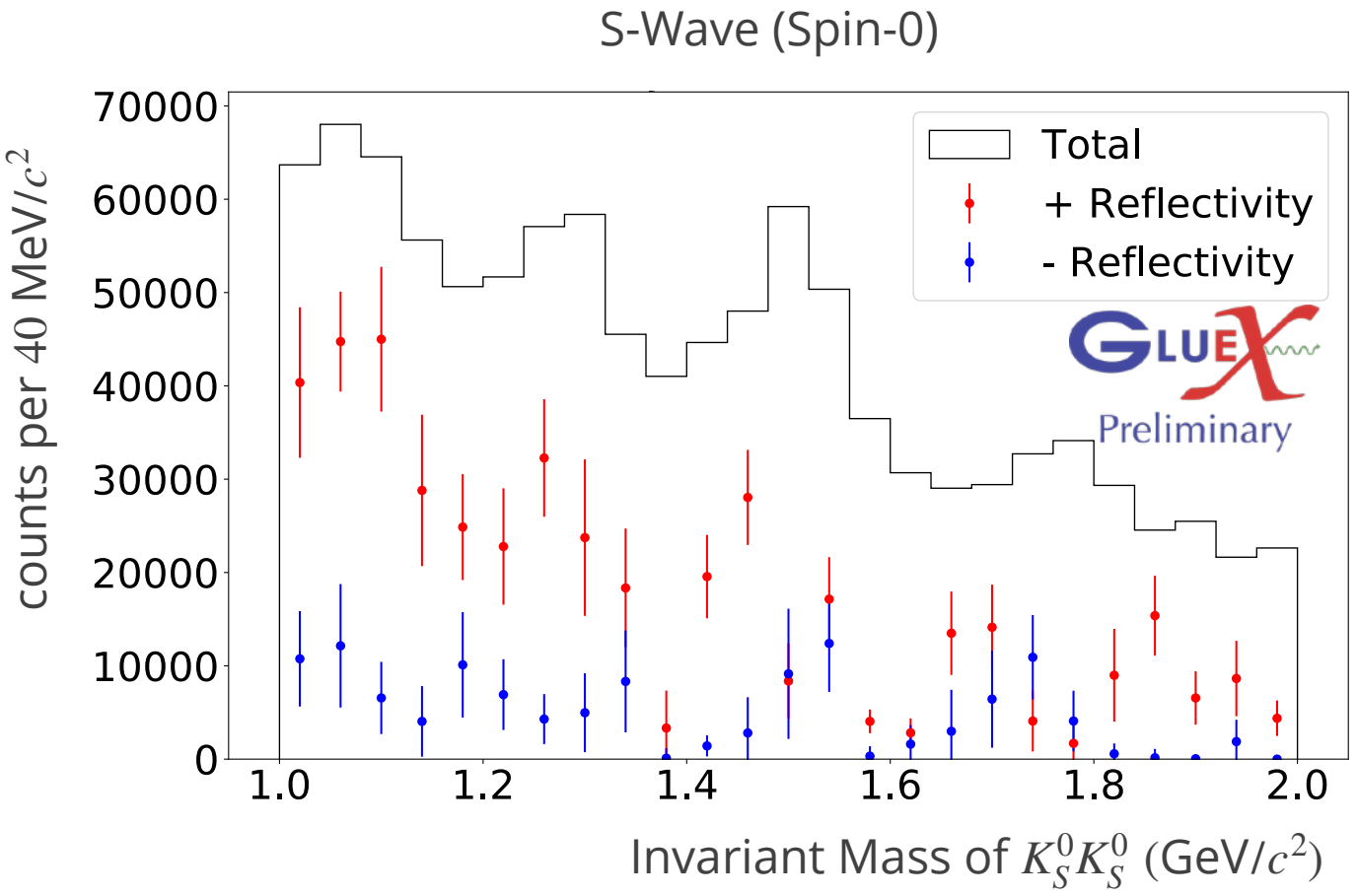
- Adding in photon polarization, we can get another observable, reflectivity ($\varepsilon = \pm 1$) which tells us about the parity of the interaction
- Choice of z-axis just mixes m moments (helicity frame is recommended for photoproduction)

In the helicity frame, the z-axis is set as the boost axis from the center of mass frame to the X rest frame

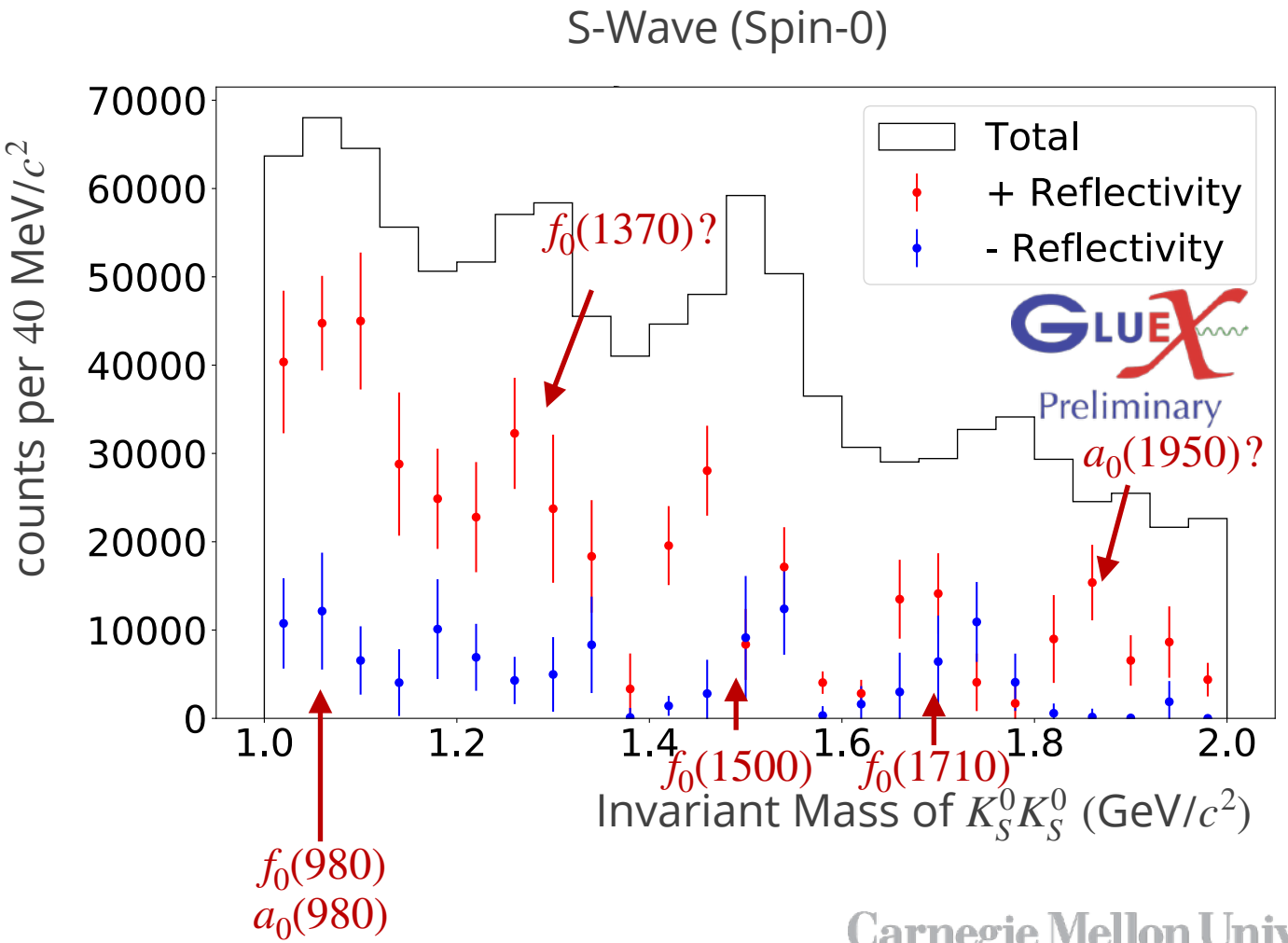
Partial Wave Analysis

- "Model-independent" fits in each bin (no Breit-Wigners or other mass-dependent amplitudes)



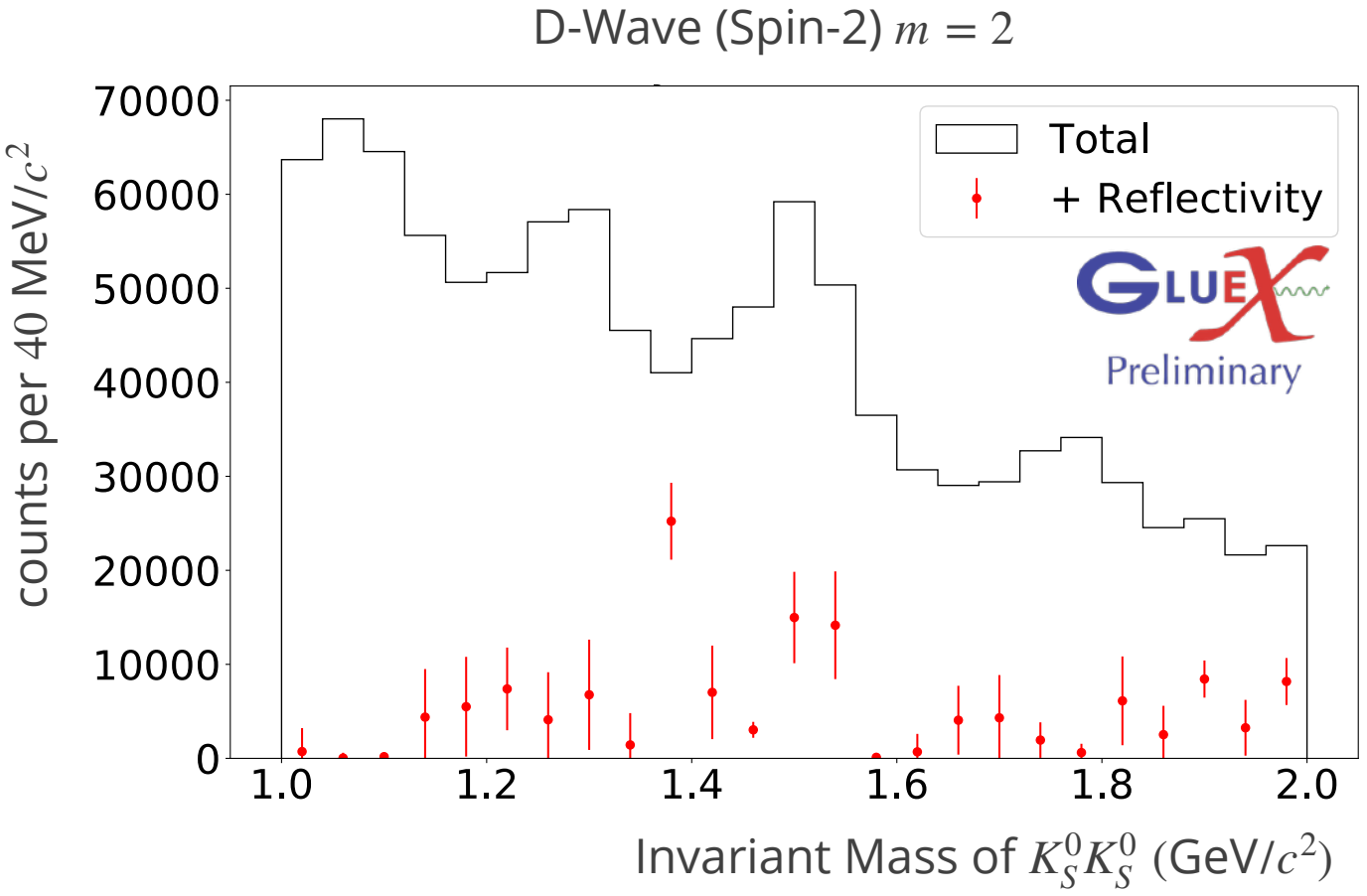
Partial Wave Analysis

- "Model-independent" fits in each bin (no Breit-Wigners or other mass-dependent amplitudes)
- Qualitative evidence of multiple resonances



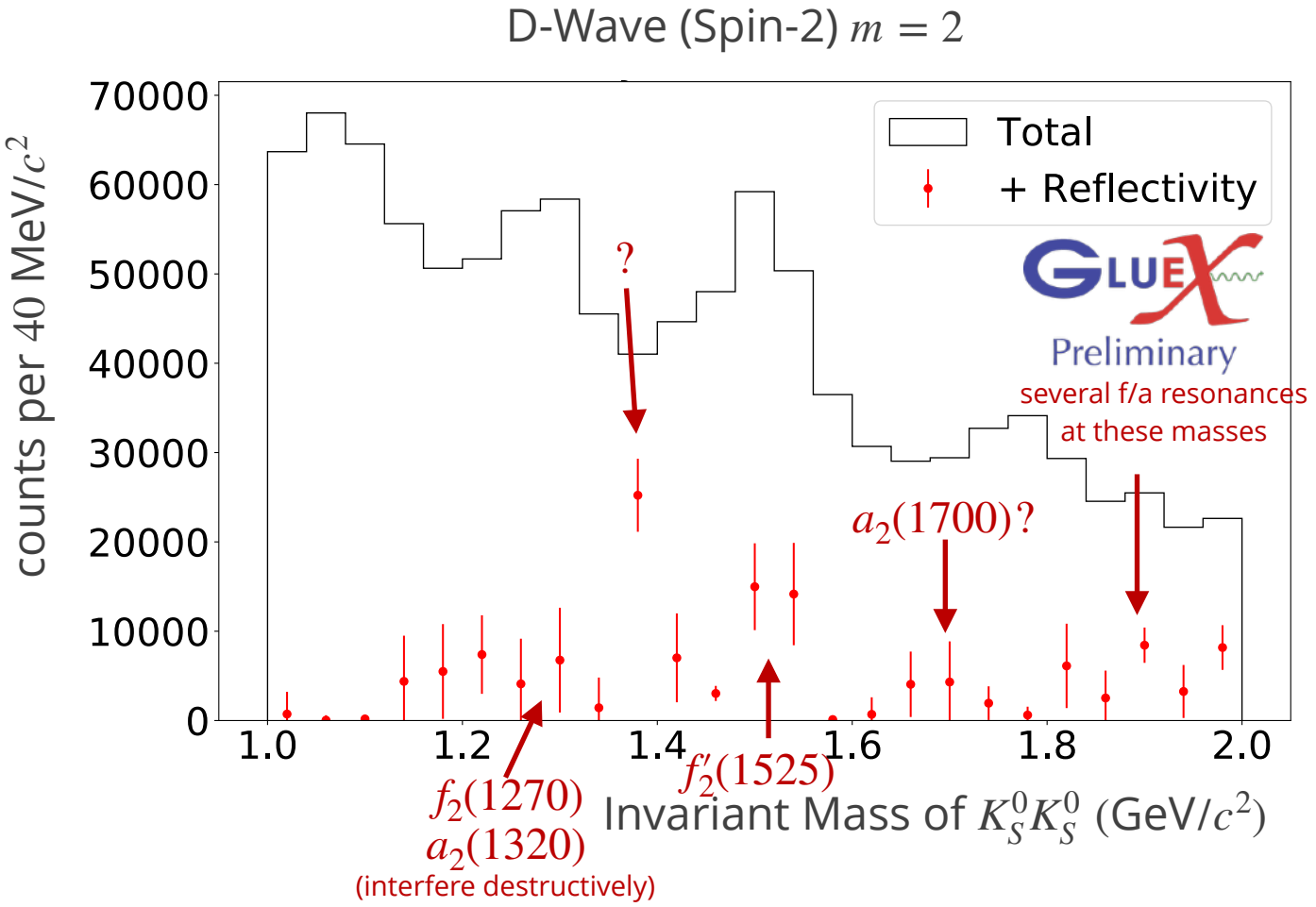
Partial Wave Analysis

- 5 possible m moments for $\ell = 2$



Partial Wave Analysis

- 5 possible m moments for $\ell = 2$
- Most are close to zero, but some show interesting features



Thanks for Listening!

http://www.gluex.org/thanks.html

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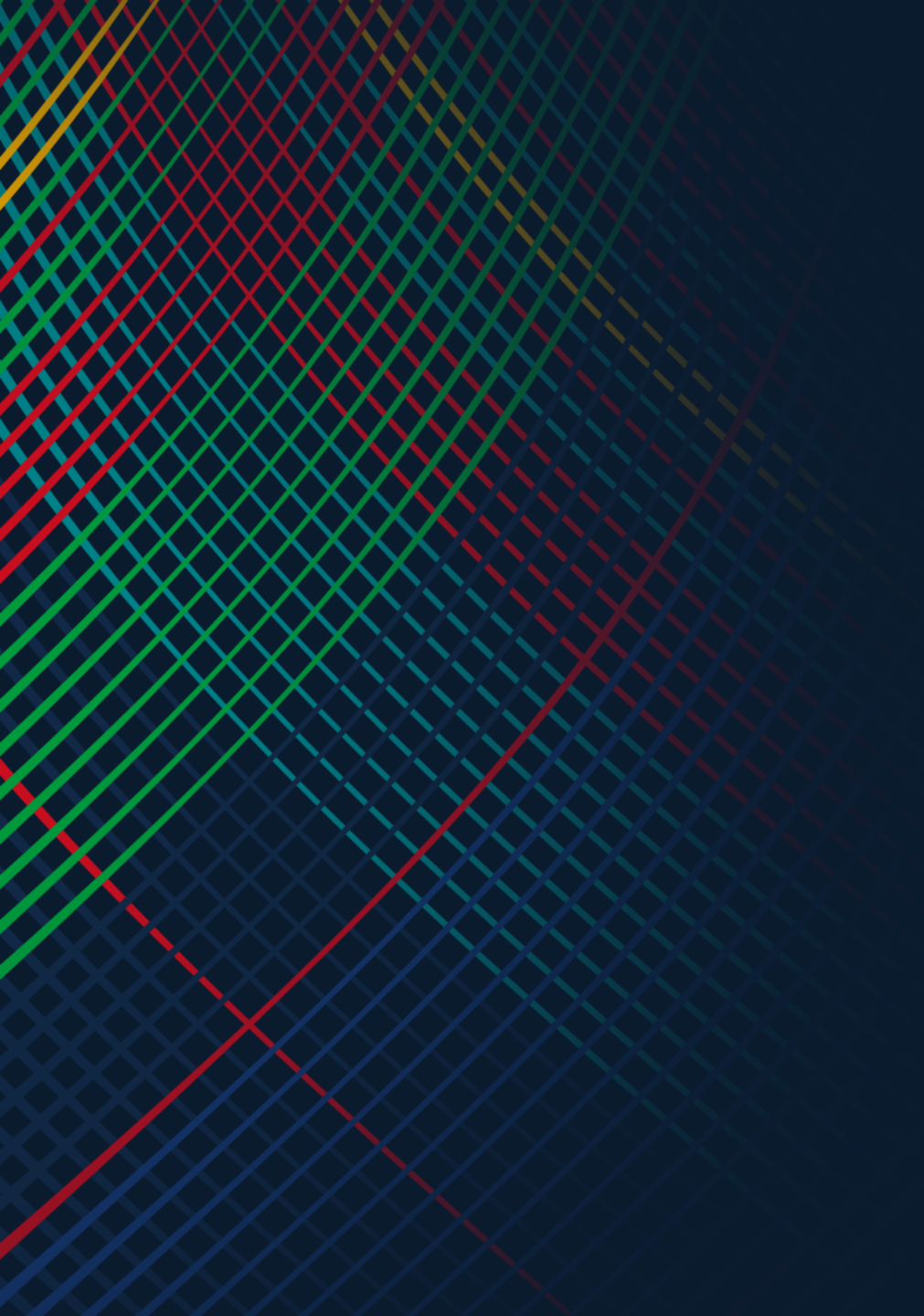
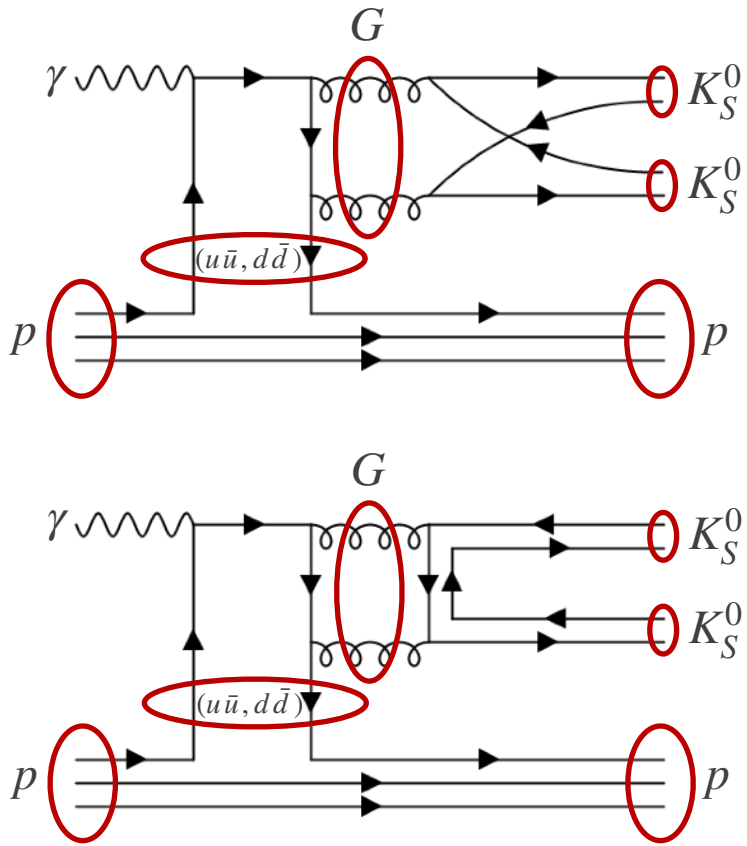
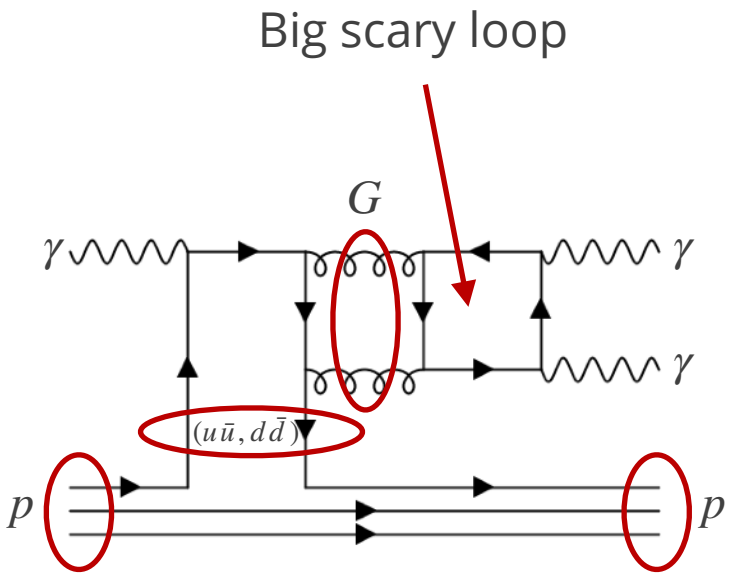


Backup

Loop Suppression for Diphoton Glueball Decays





Partial Wave Analysis

Constant related to masses of initial and final states

$$I(\Omega,\Phi) = 2\kappa \sum_k \left\{ (1-P_\gamma) \left| \sum_{\ell,m} [\ell]^{(-)}_{m;k} \Re[Z^m_\ell(\Omega,\Phi)] \right|^2 + (1-P_\gamma) \left| \sum_{\ell,m} [\ell]^{(+)}_{m;k} \Im[Z^m_\ell(\Omega,\Phi)] \right|^2 + \right.$$
$$\left. (1+P_\gamma) \left| \sum_{\ell,m} [\ell]^{(+)}_{m;k} \Re[Z^m_\ell(\Omega,\Phi)] \right|^2 + (1+P_\gamma) \left| \sum_{\ell,m} [\ell]^{(-)}_{m;k} \Im[Z^m_\ell(\Omega,\Phi)] \right|^2 \right\}$$

Total intensity (counts)

Proton polarization (not known)

Beam polarization angle

Beam polarization fraction

Complex amplitudes

$$Z^m_\ell(\Omega,\Phi) \equiv Y^m_\ell(\Omega) e^{-\imath\Phi}$$

Derived from: Mathieu, V., Albaladejo, M., Fernández-Ramírez, C., Jackura, A. W., Mikhasenko, M., Pilloni, A., & Szczepaniak, A. P. (2019). Moments of angular distribution and beam asymmetries in $\eta\pi^0$ photoproduction at GlueX. https://doi.org/10.1103/PhysRevD.100.054017

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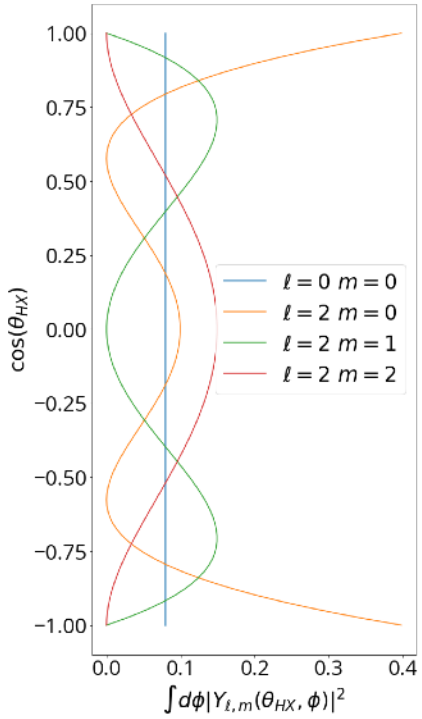
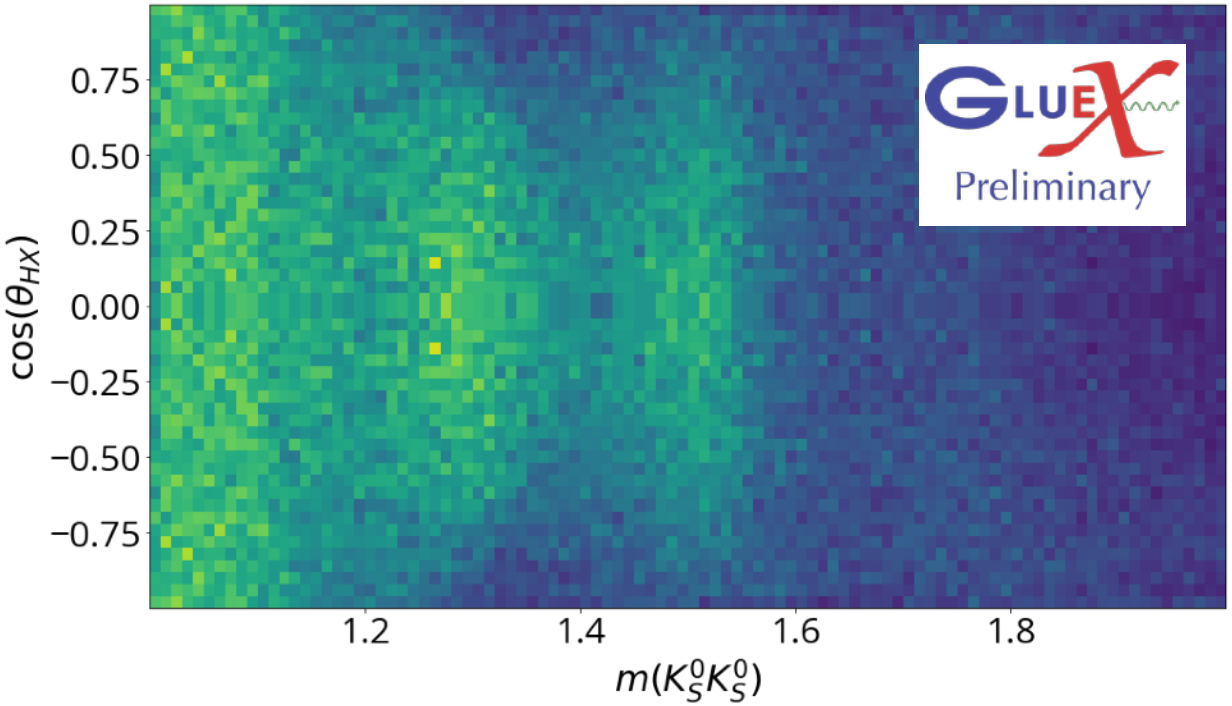
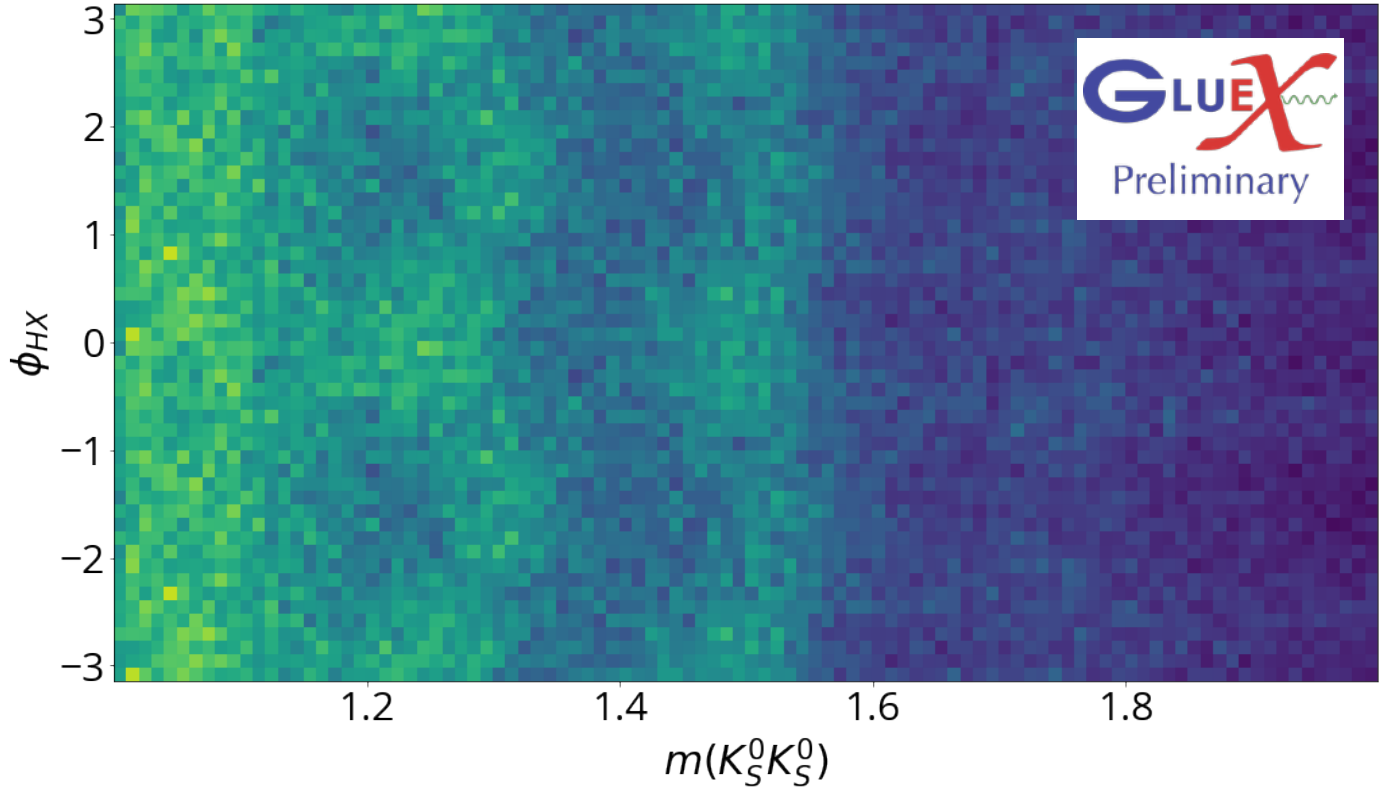


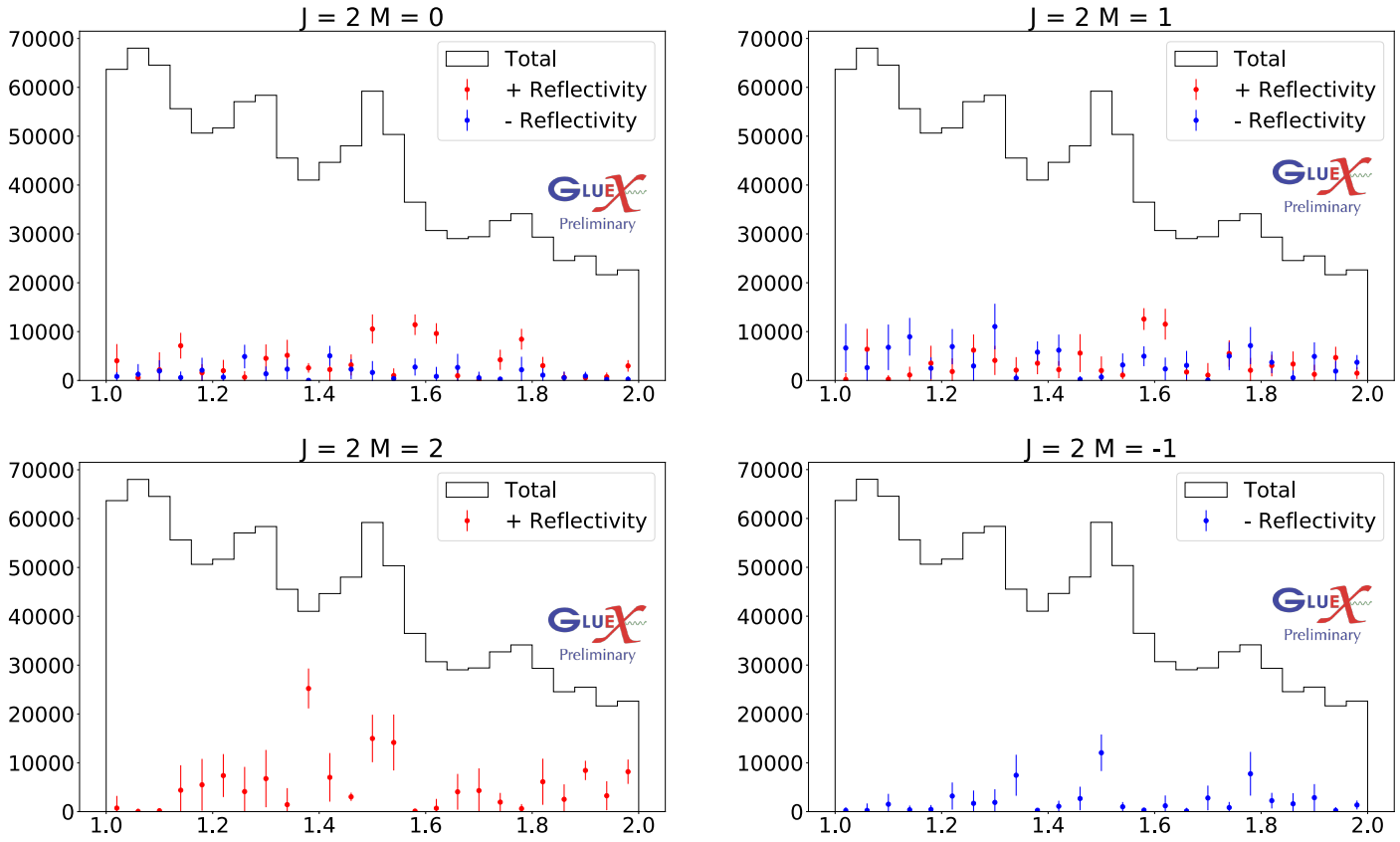


Partial Wave Analysis

Integration over $\cos(\theta_{HX})$ yields constants, fluctuations only show up when waves interfere!



Partial Wave Analysis (other D-Waves)



Baryons?

- You can identify $\Sigma^+ \to \bar{K}p$ baryons in this channel
- They are very difficult to remove without losing acceptance in the forward and backward θ_{HX} angles