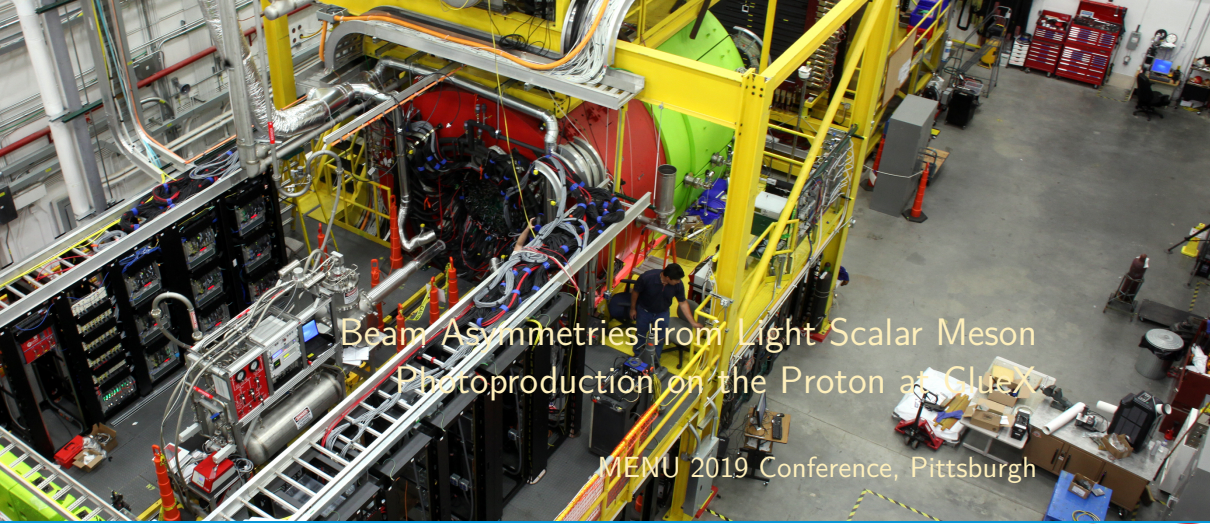


Beam Asymmetries from Light Scalar Meson Photoproduction on the Proton at GlueX

MENU 2019 Conference, Pittsburgh

THE GEORGE WASHINGTON UNIVERSITY

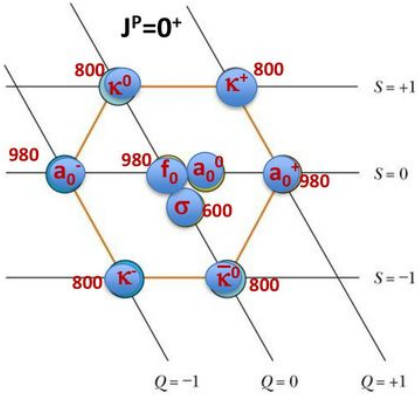
WASHINGTON, DC

Stuart Fegan

George Washington University

June 3rd, 2019

Light Scalar Mesons



- The structure of light scalar meson states (spin 0, even parity) is poorly understood
- Large widths mean states have significant overlap with background
- Further complicated by proximity to $K\bar{K}$ and $\eta\eta$ thresholds

Light Scalar Mesons

$f_0(980)$ [j] $I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 990 \pm 20$ MeV
Full width $\Gamma = 10$ to 100 MeV

$f_0(980)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	dominant	476
$K\overline{K}$	seen	36
$\gamma\gamma$	seen	495

$a_0(980)$ [j] $I^G(J^{PC}) = 1^-(0^{++})$

Mass $m = 980 \pm 20$ MeV
Full width $\Gamma = 50$ to 100 MeV

$a_0(980)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\pi$	dominant	319
$K\overline{K}$	seen	†
$\gamma\gamma$	seen	490

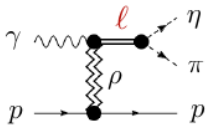
Chin. Phys C40, 100001 (2016)

- Phenomenological models describe the light scalars as anything from $q\bar{q}$ to glueballs and tetraquarks
- Precision measurements of the properties of observed states is the key to understanding their nature in quark-gluon terms
- Specifically, photoproduction data of light scalars could provide helpful insights

Light Scalar Mesons

- The $\pi\pi$ decay of $f_0(980)$, and the $\eta\pi$ decay of $a_0(980)$, both accessible through the four photon final state, are thought to be a powerful tool to discriminate between models
- Both states lie close to $K\bar{K}$ threshold, which has so far made accurate determination of resonance properties difficult
- For the purposes of this talk, we will focus on the $\eta\pi$ final state

Theoretical Insights (JPac)



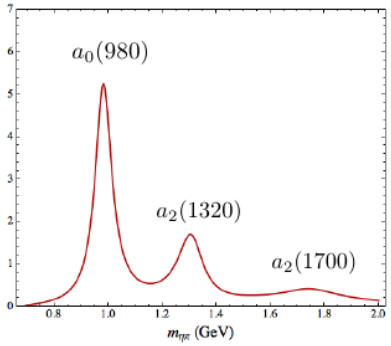
$$R = \{\underbrace{a_0(980)}_{S_0^{(+)}}, \underbrace{\pi_1(1600)}_{P_{0,1}^{(+)}}, \underbrace{a_2(1320), a_2(1700)}_{D_{0,1,2}^{(+)}}\}$$

production: natural exchanges

line shape: Breit-Wigner form

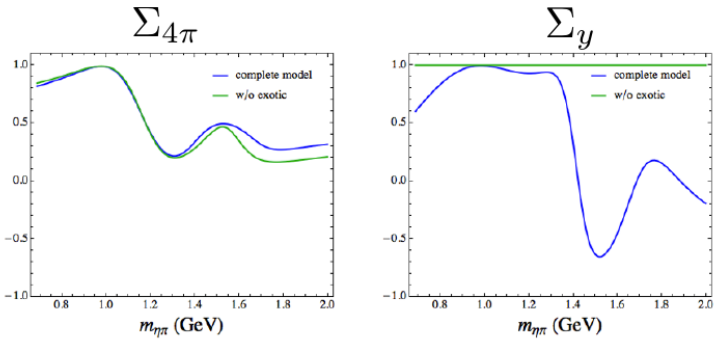
parameters: arbitrary

Small exotic wave,
not apparent in the diff. cross. section



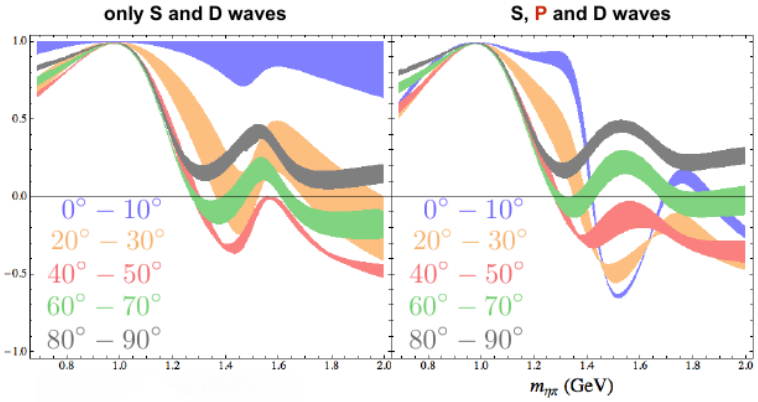
VM et al (JPAC), in preparation

Theoretical Insights (JPac)



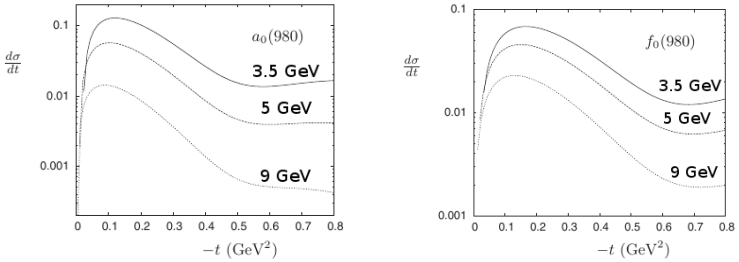
- Contributing waves in the model can be expressed in terms of the beam asymmetry
- Possible influence of an exotic state is more pronounced at small angles in the Gottfried-Jackson frame

Theoretical Insights (JPac)



Theoretical Insights (Donnachie, Kalashnikova)

- Model using reggeised ρ and ω exchange employed to calculate photoproduction amplitudes for $a_0(980)$ and $f_0(980)$
- Cross section predictions available for light scalar meson production

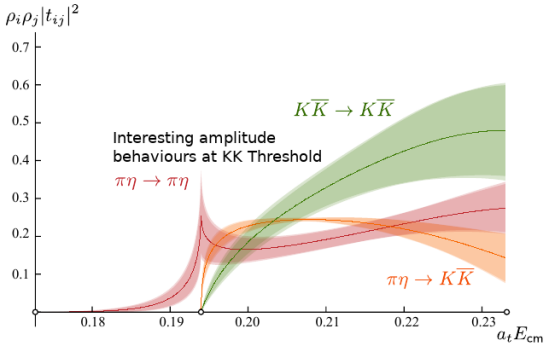


Phys Rev C93 (2016) 025203

- Model also provisionally predicts beam asymmetry for these mesons

Theoretical Insights (Lattice QCD)

- S-wave scattering amplitude from a coupled-channel lattice calculation
- Usual caveats about unphysical quark masses
- Suggestions that something significant happens at $K\bar{K}$ threshold
- Possibly an $a_0(980)$-like resonance, coupled to $K\bar{K}$ and $\eta\pi$



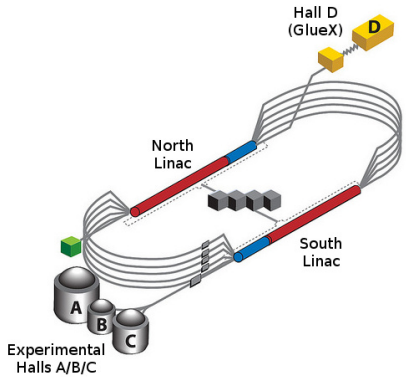
Phys. Rev. D93, 094506 (2016)

Jefferson Lab

- Jefferson Lab - US DoE facility in Newport News, VA
- Superconducting RF accelerator with primary electron beam of up to 12 GeV
- Four experimental halls, with simultaneous beam delivery
- Real photon beam experiments in Hall D, using a secondary bremsstrahlung photon beam in the GlueX experiment

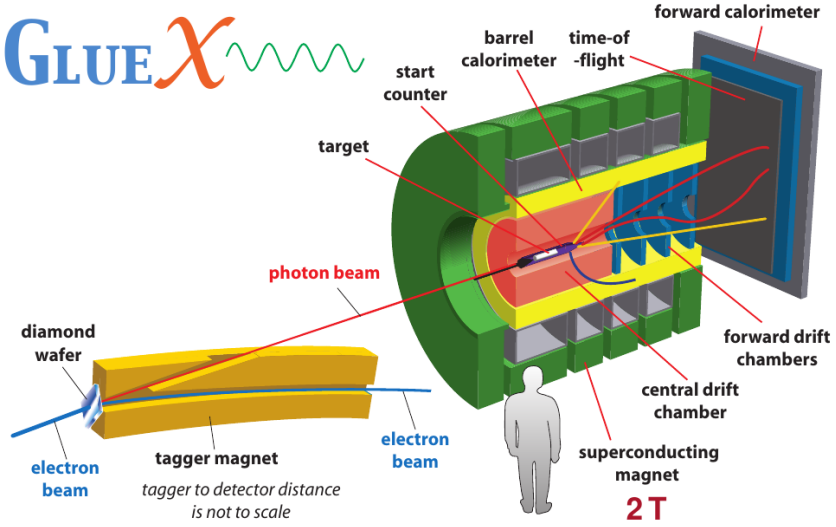
Jefferson Lab

- Jefferson Lab - US DoE facility in Newport News, VA
- Superconducting RF accelerator with primary electron beam of up to 12 GeV
- Four experimental halls, with simultaneous beam delivery
- Real photon beam experiments in Hall D, using a secondary bremsstrahlung photon beam in the GlueX experiment

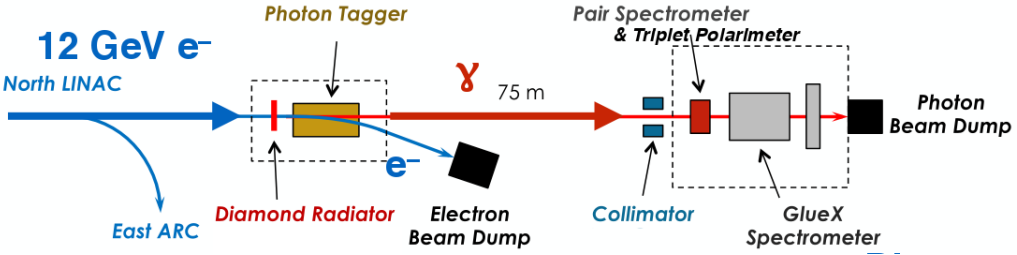


GlueX collaboration

GlueX

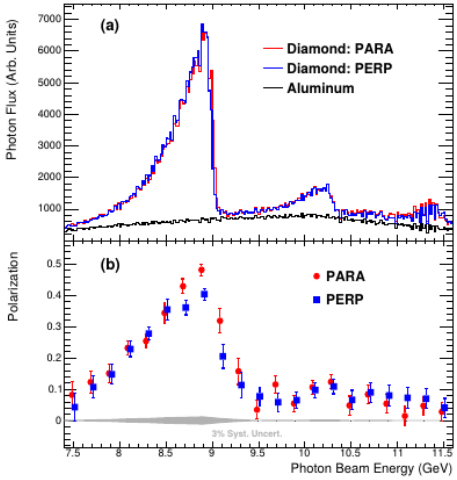

GLUEX
forward calorimeter
barrel calorimeter
time-of -flight
start counter
target
photon beam
diamond wafer
forward drift chambers
central drift chamber
electron beam
tagger magnet
electron beam
superconducting magnet
2 T
tagger to detector distance is not to scale

GlueX Beamline

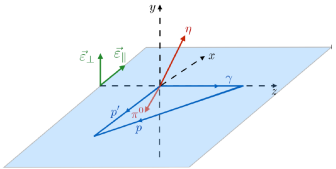


- 12 GeV electron beam produces real photon beams via bremsstrahulng radiation off a radiator (Aluminium or Diamond) up to 9 GeV
- Photon energy tagged by detecting energy-degraded electron in one of two devices in the tagger focal plane
- Ancillary devices to determine flux and polarisation
- Polarised photon beams from coherent remsstrahlung off diamond radiators

GlueX Beamline

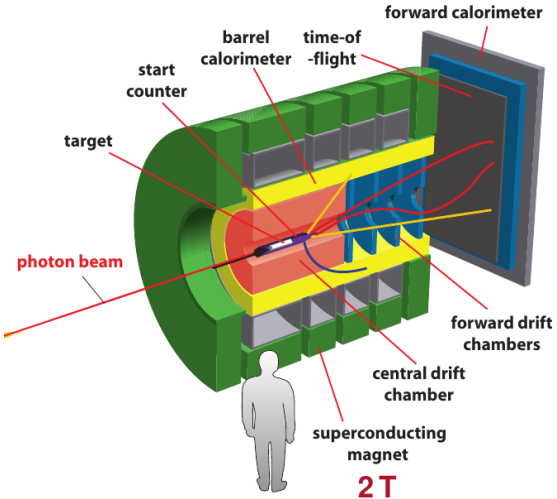


- Beam is collimated to enhance polarised component (typically around 40% polarisation at 9 GeV)
- Polarisation planes rotated by 90 degrees to constrain systematics
- Referred to as PARA (parallel) and PERP (perpendicular)



GlueX Detectors

- Real photon beam interacts with target
- Charged and neutral particle detection in a hermetic solenoid- based detector
- Uniform acceptance over 4π solid angle
- Recent upgrade has added a DIRC

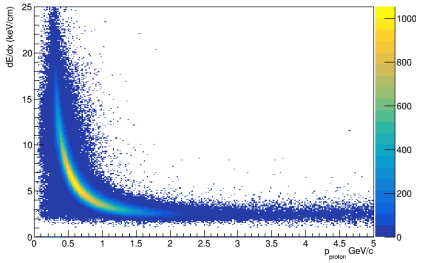


The $\eta\pi$ Channel

- This work focuses on studying beam asymmetries of the $\eta\pi$ channel, where η and π each decay to a pair of photons

$$\gamma p \rightarrow p\eta\pi \rightarrow p\gamma\gamma\gamma\gamma$$

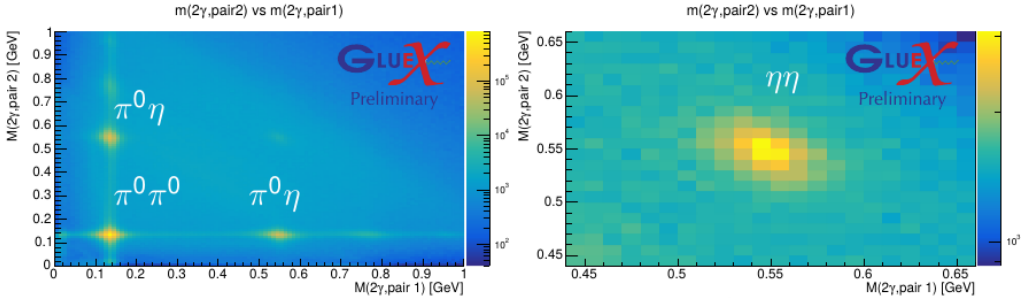
- This will later lead to asymmetry measurements of the $a_0(980)$ and $a_2(1320)$ mesons, both of which are seen in the four photon final state of $\eta\pi$



- Kinematic fit used to identify particles and filter data
- Cuts applied on vertex position, $\frac{dE}{dx}$ cut in the drift chamber for proton, and photon beam energy

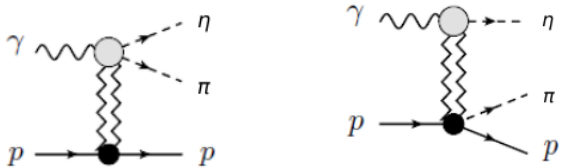
η and π^0 Identification

- π^0 and η distributions from diphoton invariant masses



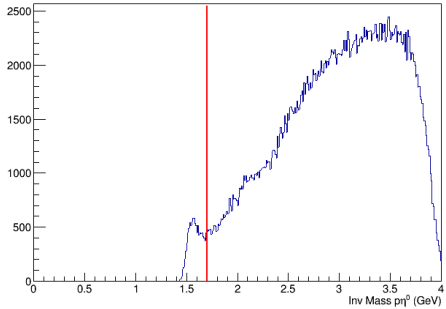
Competing Production Mechanisms

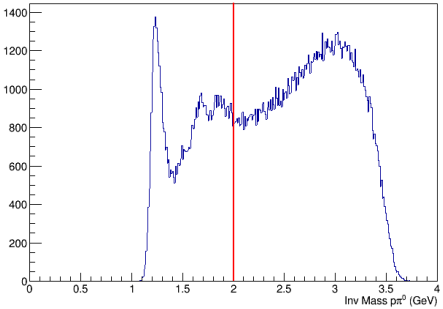
- Even assuming perfect particle identification, different processes can result in the same final state
- This is particularly true as the number of particles in the final state increases
- In the reaction $\gamma p \to p\eta\pi$, the final state particles could arise from the production of an intermediate meson ($a_0(980) \to \eta\pi$), or baryon ($\Delta^+ \to p\pi^0$)



Selecting Meson Events

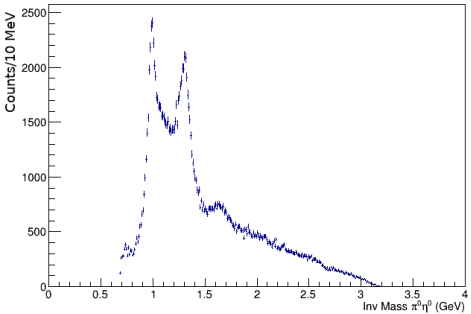
- With further event selection processes, e.g. vetoing baryon resonances, produce cleaner meson samples

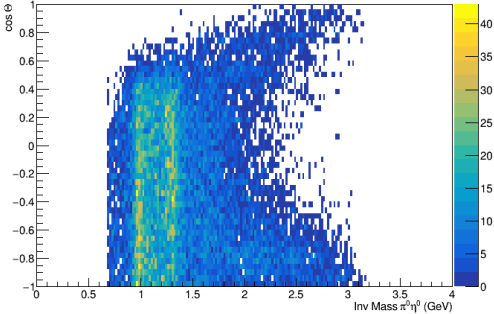




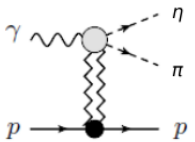
Invariant Mass Distributions

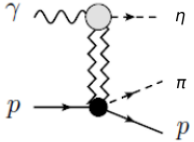
- Invariant Mass of $\eta\pi$, showing clear signals of $a_0(980)$ and $a_2(1320)$
- Also suggestions of a higher mass state, possibly $a_2(1700)$
- Events with small GJ angles ($cos\Theta_{GJ}$ close to 1) are severely suppressed





Reaction Kinematics



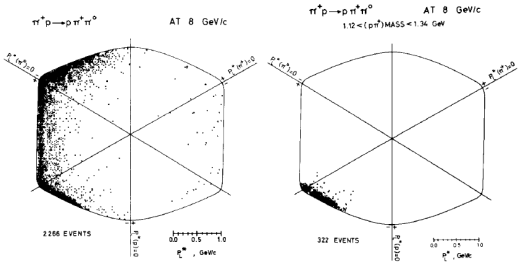


- The competing baryonic and mesonic processes have very different reaction kinematics
- In the centre of mass frame, it is possible to separate them

Longitudinal Phase Space

- This isn't a new idea, it was first proposed and studied fifty years ago by Leon Van Hove

- His basic premise is that at sufficiently high centre-of-mass energy, phase space is dominated by longitudinal components of particle momenta
- Transverse components can be neglected, reducing dimensionality of phase space



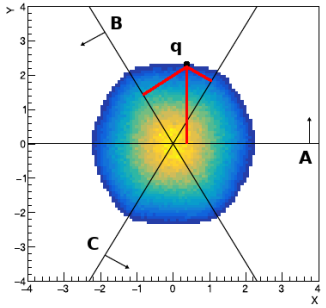
Nucl. Phys. B 9, 331 (1969)

Van Hove Plots

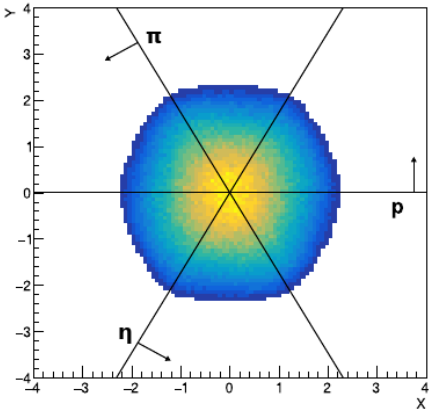
- This gave rise to the Longitudinal Phase Space plot, a way of visualising reaction kinematics of an n-particle final state in an n-1 dimensional plane
- For example, in a three particle final state, the longitudinal phase space can be represented on a two dimensional plane

- We can define co-ordinates on the van Hove plot analogously to polar co-ordinates via the longitudinal momentum components of the final state particles

$$X = q\ cos(\omega)$$
$$Y = q\ sin(\omega)$$



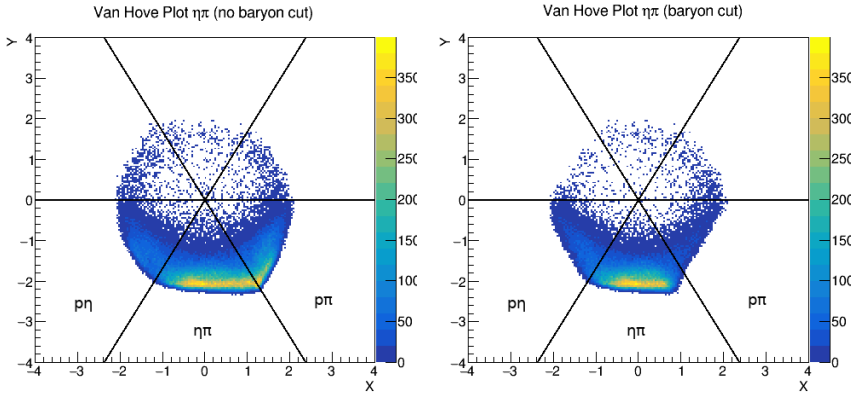
Interpretation



- The axes divide the longitudinal phase space into six sectors
- Each sector corresponds to specific directions of travel of the final state particles in the CM frame
- The arrows on the axes show the forward travel of each labelled particle
- For example, the bottommost sector has $\eta\pi$ going forward and proton going backward

Insights from Van Hove

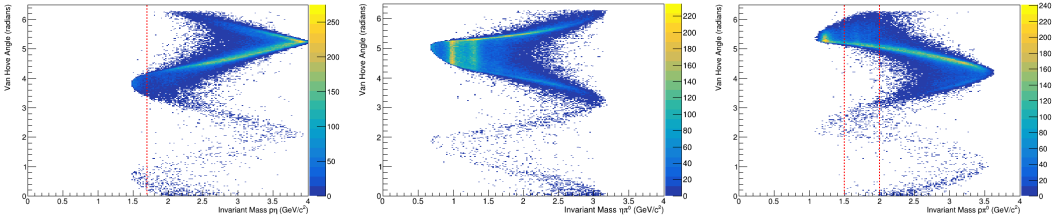
- Can also visualise the event samples in a Van Hove plot



- Cuts have removed much of the unwanted baryon processes, but at a cost of signal

Optimising $p\eta\pi^0$ Selection

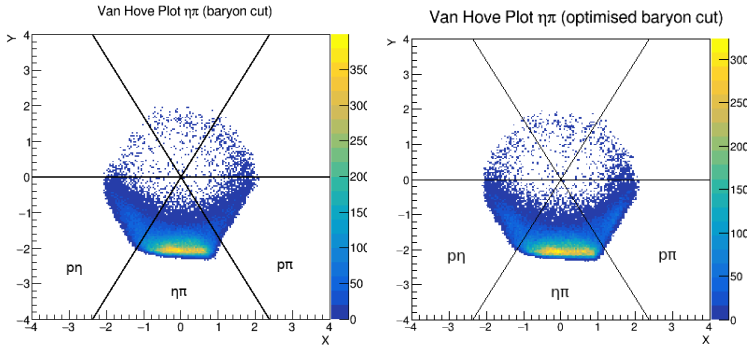
- Van Hove angle against invariant mass of particle pairs



- Here, the $a_0(980)$ and $a_2(1320)$ can be seen, and the baryon processes are also visible
- Rather than cut on Van Hove angle, we can use these plots to inform baryon veto cuts, and verify them by examining the Van Hove plot

Optimising $p\eta\pi^0$ Selection

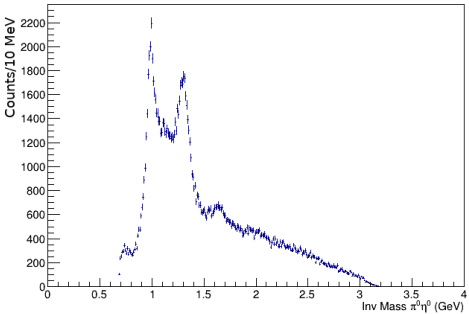
- Loosen the Baryon cuts, and re-examine VH distribution

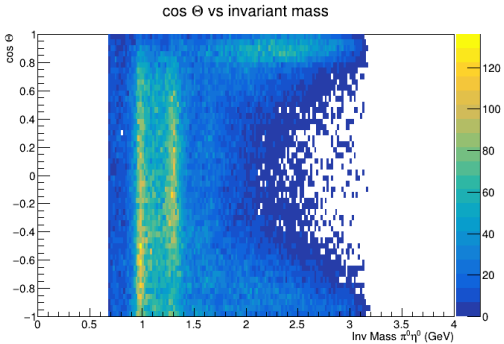


- Van Hove plots can be a useful tool to verify event selection

Invariant Mass Distribution, post optimisation

- Invariant Mass of $\eta\pi$, with looser baryon cuts
- The $a_0(980)$ and $a_2(1320)$ remain, as does the hint of something else at 1.7 GeV
- *cos* θ_{GJ} vs invariant mass preserves more small angle events using the new cuts





Beam Asymmetry

- Yields of PARA and PERP data are used to compute an asymmetry

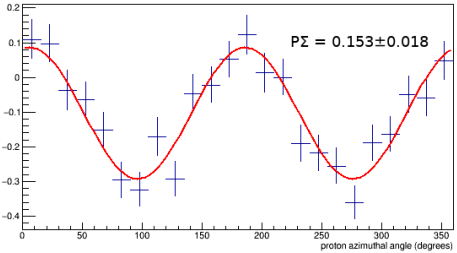
$$A(\phi) = \frac{N(PARA) - N(PERP)}{N(PARA) + N(PERP)} \approx P_{lin} \Sigma cos(2\phi)$$

- To account for differing fluxes and beam polarisations, the PARA/PERP asymmetry distributions can be fit in each bin with a function of the form

$$A(\phi) = \frac{F_R - 1 + \frac{F_R P_R + 1}{P_R + 1} 2\overline{P}\Sigma cos(2(\phi - \phi_0))}{F_R + 1 + \frac{F_R P_R + 1}{P_R + 1} 2\overline{P}\Sigma cos(2(\phi - \phi_0))}$$

- PARA/PERP flux and beam polarisation ratios are parameters of the fit, along with $\overline{P}\Sigma$ and ϕ_0

Beam Asymmetry

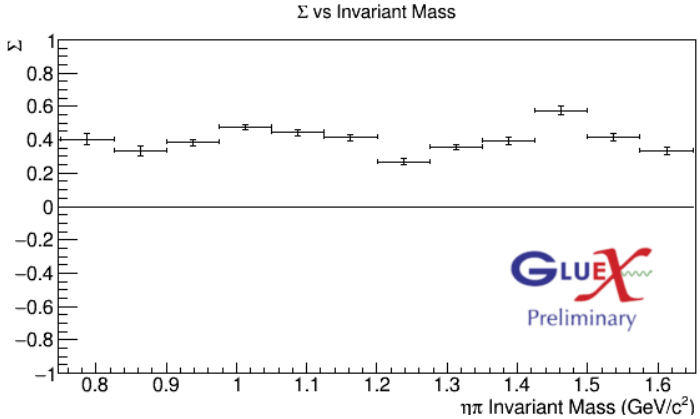


- Example fit for mass bin spanning the $a_0(980)$ meson
- Magnitude of the cosine term gives us a measurement of $P_\gamma \Sigma$

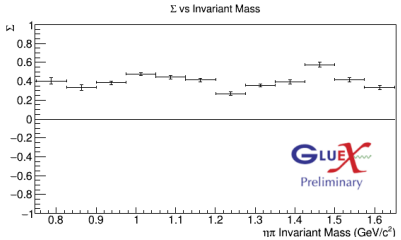
- We measure values of F_R and P_R using detectors in our beamline (Pair Spectrometer and Triplet Polarimeter)
- Use them to constrain fit parameters
- The value of ϕ_0 is reaction independent and measured from reactions with higher statistics

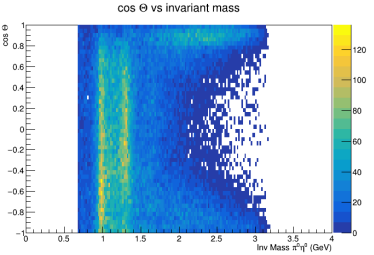
Beam Asymmetry on $\eta\pi$

- Beam Asymmetries with $\eta\pi$ invariant mass
- All *cos* θ_{GJ}, statistical errors only



Summary





- Beam asymmetry of $\eta\pi$ is a useful first measurement to make in this system
- Possible to inform models of the mesons producing this final state
- Partial Wave Analysis envisioned on full phase 1 GlueX data (with tools developed and tested on smaller subsample of the phase I data)
- Beam asymmetry measurements of the $a_0(980)$ and $a_2(1320)$ mesons, binned in $-t$, also underway