Discovering Exotic Mesons @GlueX

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Jefferson Lab
Joint Physics Analysis Center

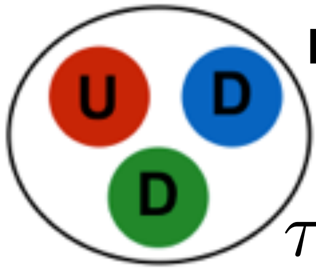
Cake Seminar
JLab, February 2019

Jefferson Lab
Thomas Jefferson National Accelerator Facility

JPAC
Joint
Physics
Analysis
Center

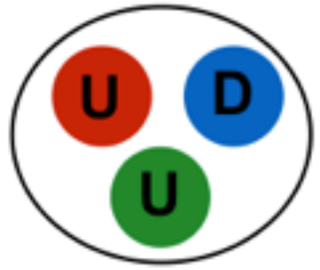
Ordinary and Exotic Hadrons

Ordinary baryons:



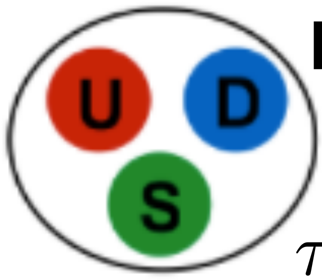
neutron

$\tau \sim 10^3 s$



proton

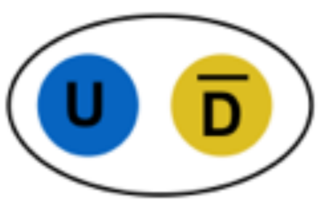
stable



baryon Λ

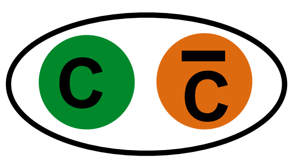
$\tau \sim 10^{-10} s$

Ordinary mesons



pion

$\tau \sim 10^{-8} s$



J/ψ

$\tau \sim 10^{-20} s$

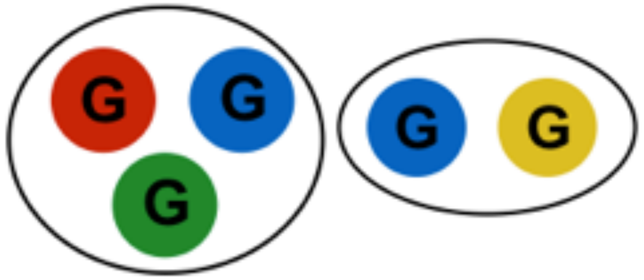
kaon

$\tau \sim 10^{-8} s$

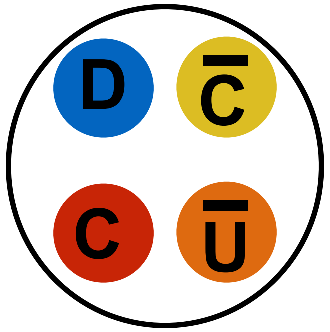
Exotic matter

hybrid mesons

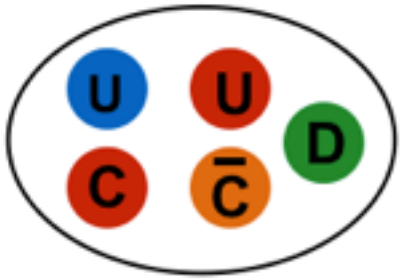
glueballs



tetraquarks

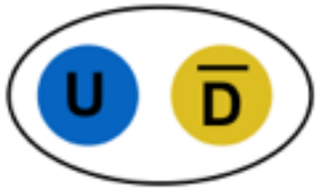


pentaquarks



Hybrid Mesons Production

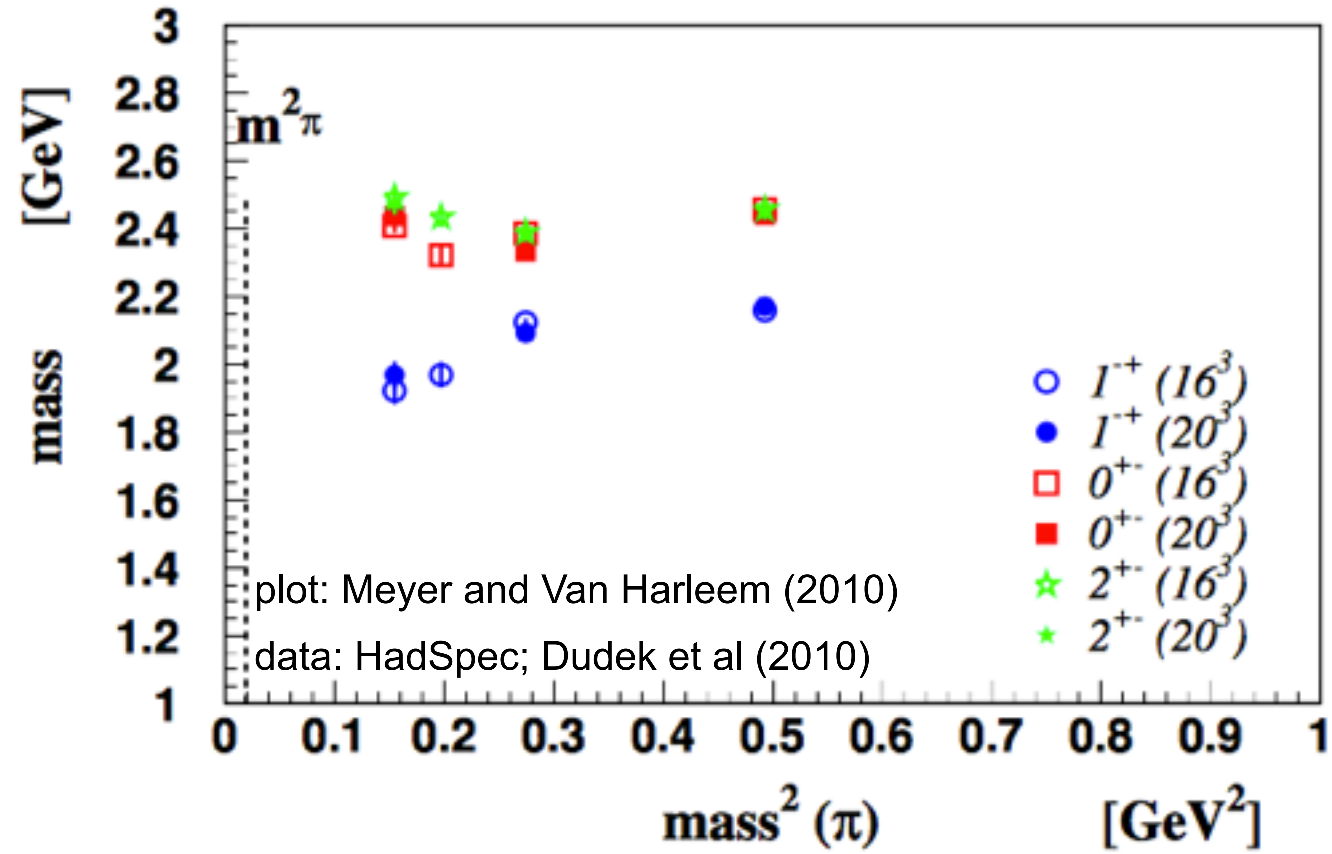
Ordinary mesons



$$\vec{J} = \vec{L} \oplus \vec{S}$$

$$P = -(-1)^L$$

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



Examples of quantum numbers

QNs J^{PC}	(I^G)		Names (I^G)		
1^{++}	(1^-)	a_1	(0^+)	f_1	f_1'
1^{--}	(1^+)	ρ_1	(0^-)	ω_1	ϕ_1
0^{-+}	(1^-)	π_0	(0^+)	η_0	η_0'
$\mathbf{1^{-+}}$	$\mathbf{(1^-)}$	π_1	$\mathbf{(0^+)}$	η_1	η_1'
2^{-+}	(1^-)	π_2	(0^+)	η_2	η_2'
$\mathbf{0^{+-}}$	$\mathbf{(1^+)}$	$\mathbf{b_0}$	$\mathbf{(0^-)}$	$\mathbf{h_0}$	$\mathbf{h_0'}$
1^{+-}	(1^+)	b_1	(0^-)	h_1	h_1'
$\mathbf{2^{+-}}$	$\mathbf{(1^+)}$	$\mathbf{b_2}$	$\mathbf{(0^-)}$	$\mathbf{h_2}$	$\mathbf{h_2'}$

Meyer and Van Harleem (2010)

hybrid mesons

$$\eta_1 \to \eta\eta', a_2\pi, K_1 K, \ldots$$

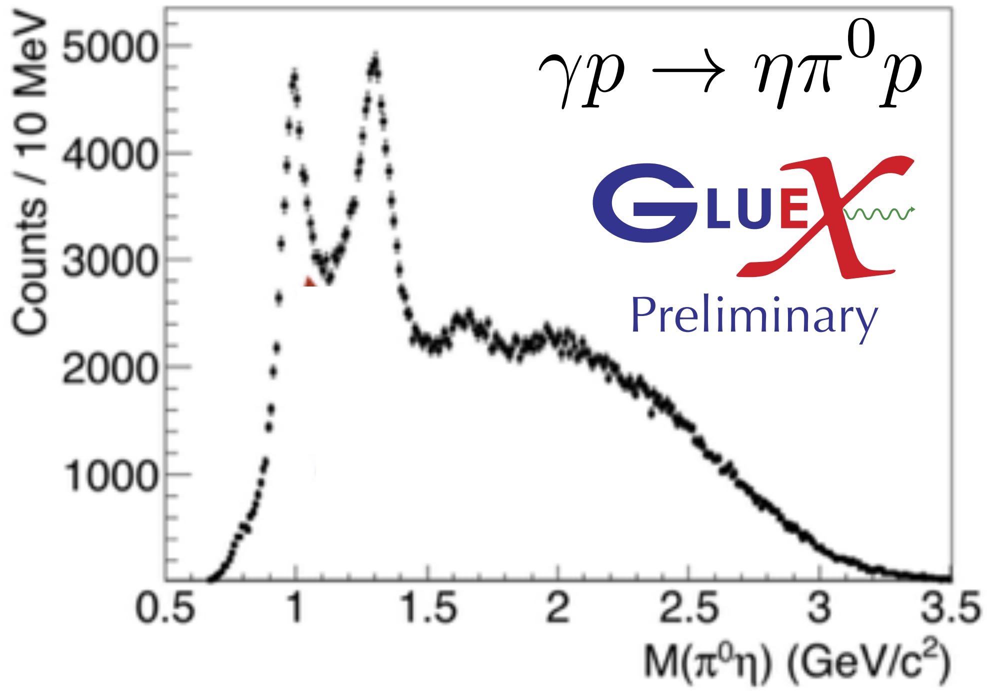
$$\pi_1 \to \eta\pi, \eta'\pi, \rho\pi, b_1\pi, \ldots$$

$$\gamma p \to \eta\pi^0 p$$

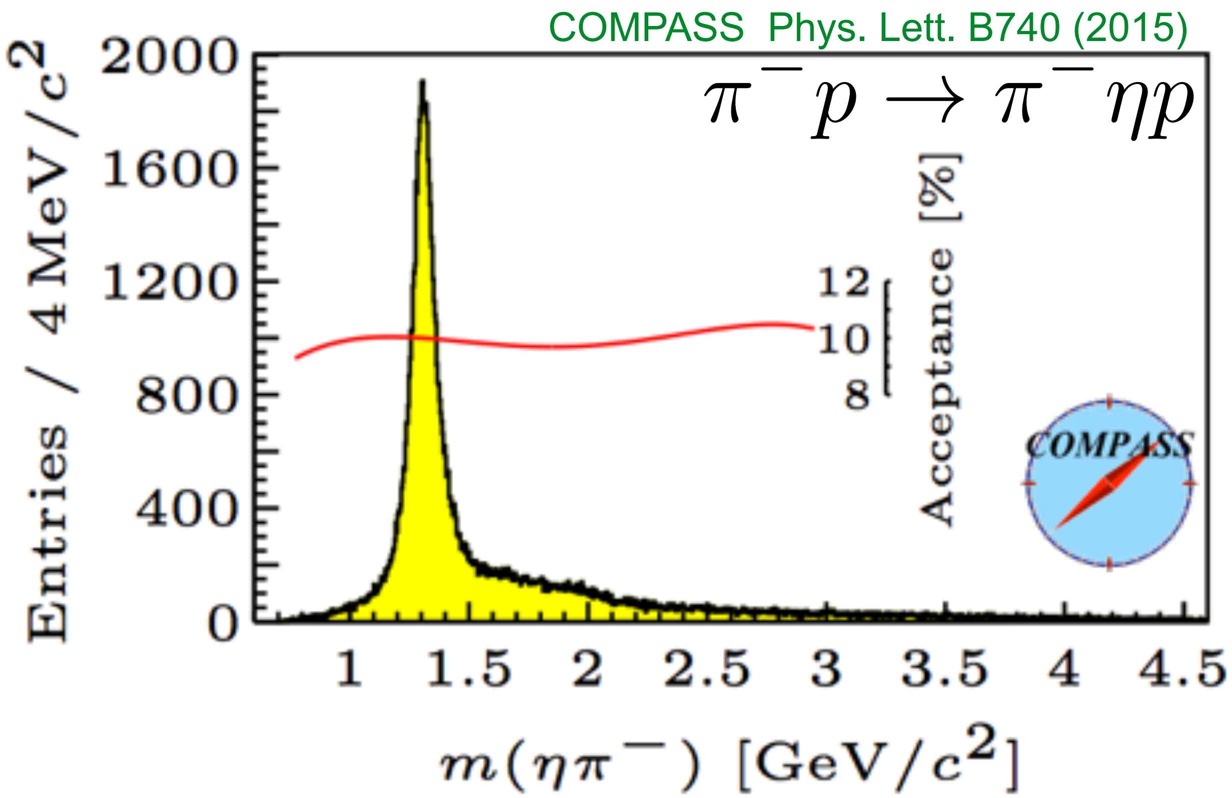
$$\gamma p \to \eta\pi^- \Delta^{++}$$

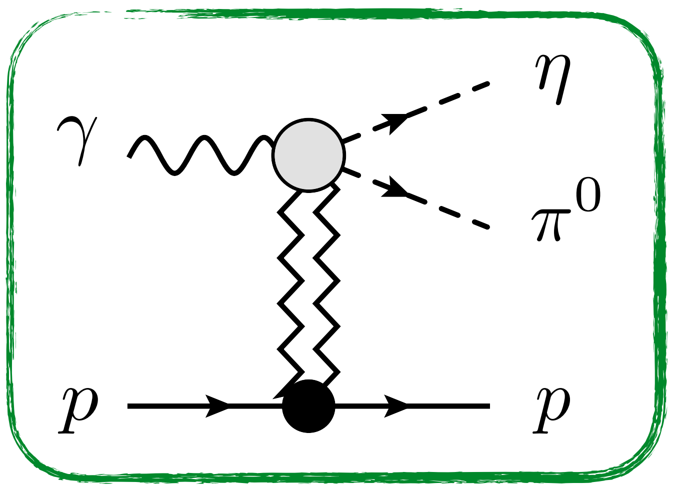
Eta-Pi Production

$E_{\text{beam}} = 9$ GeV

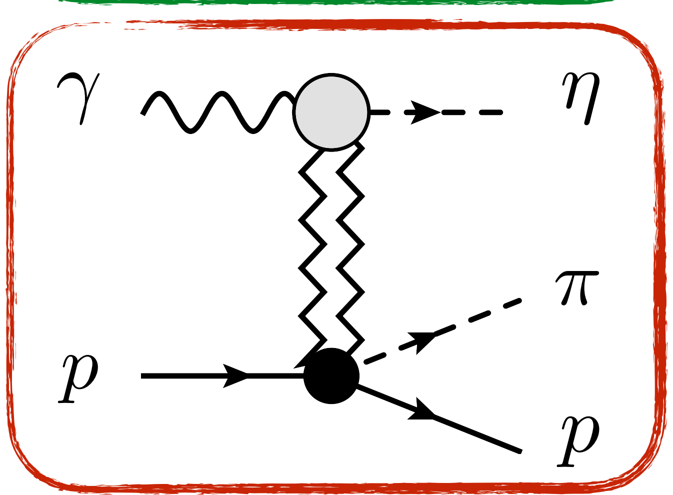


$E_{\text{beam}} = 190$ GeV

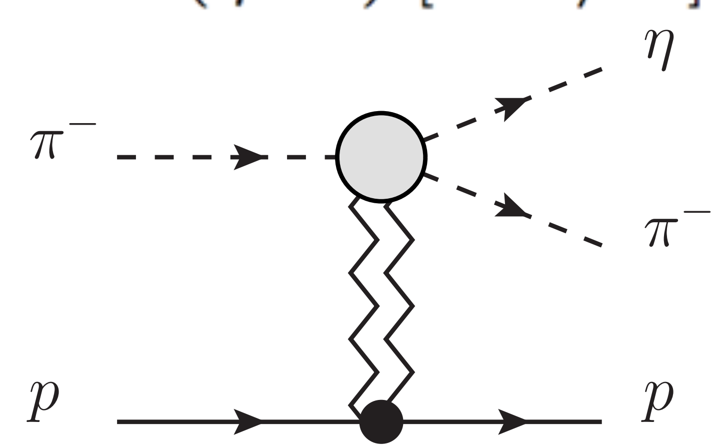




"signal"

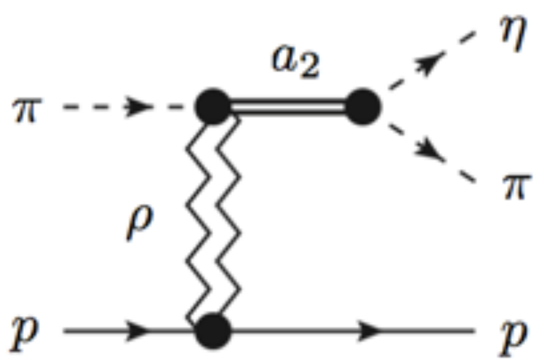


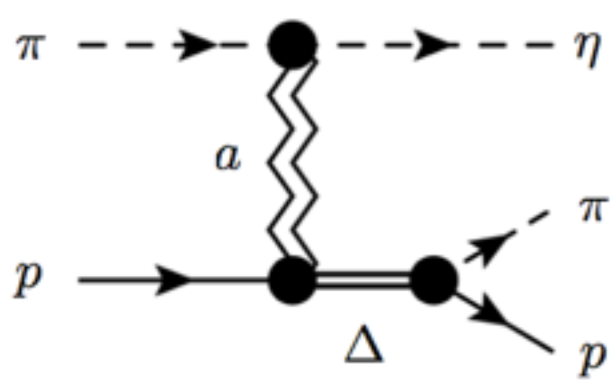
"background"

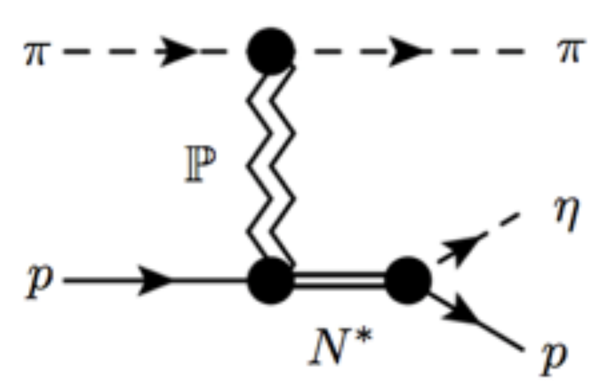


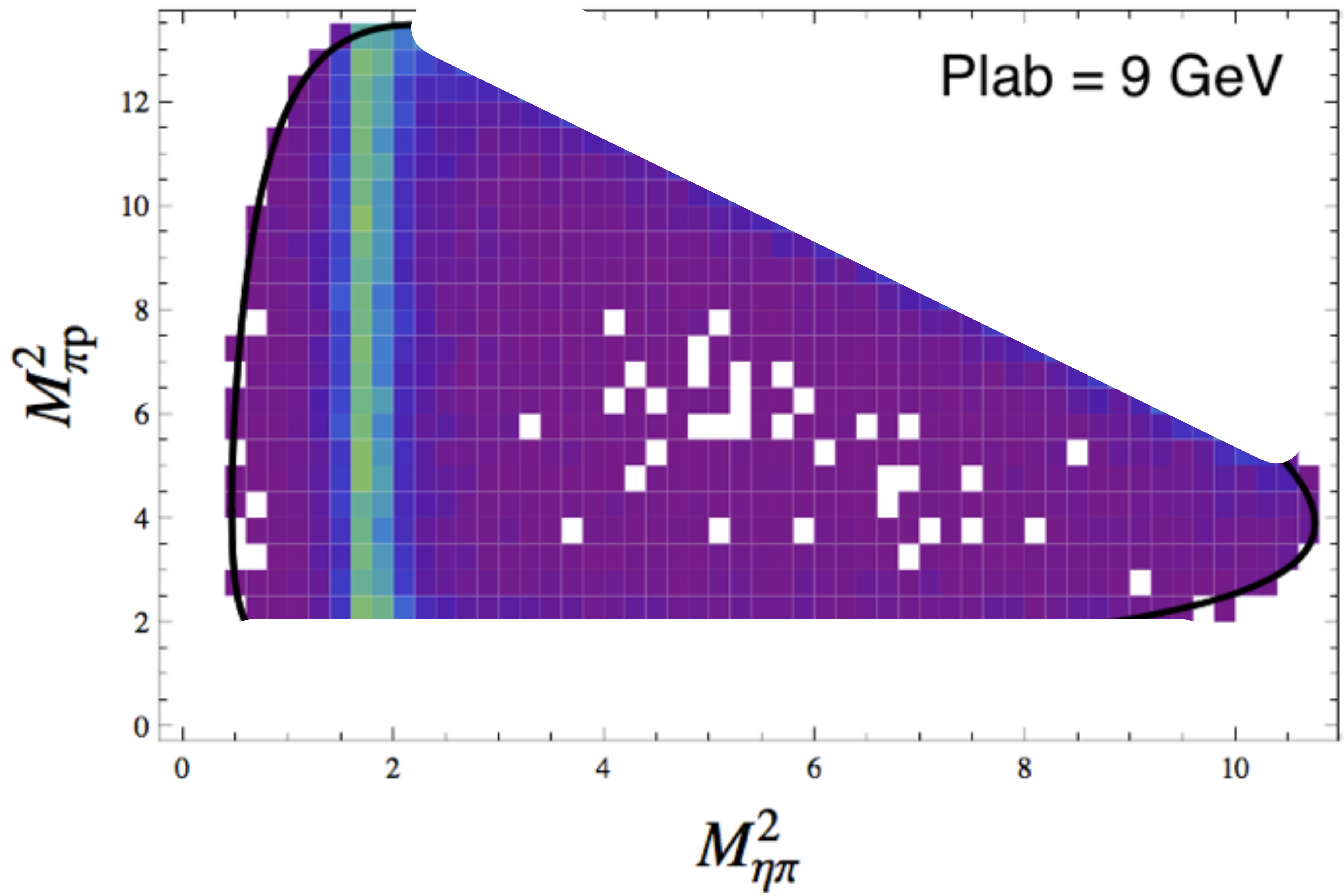
only "signal" at high energy

Eta-Pi Production: toy model



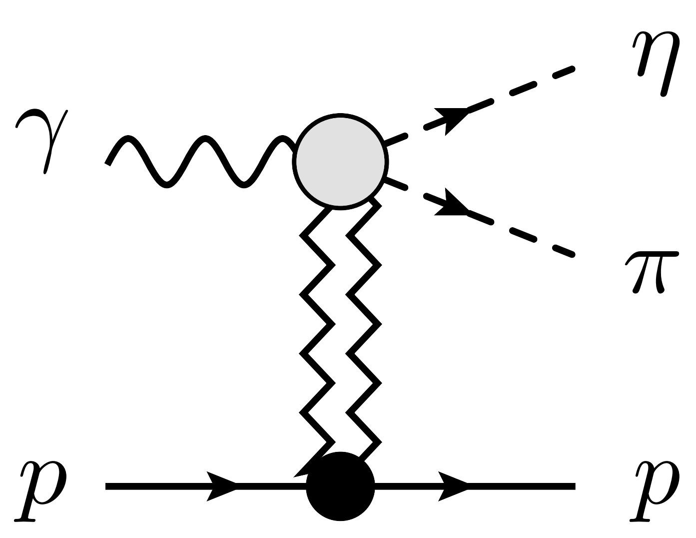


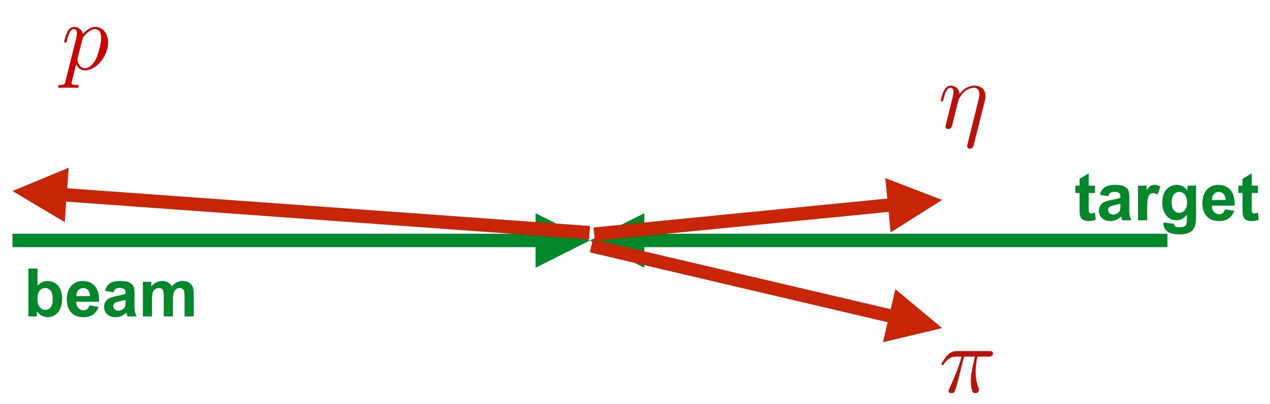


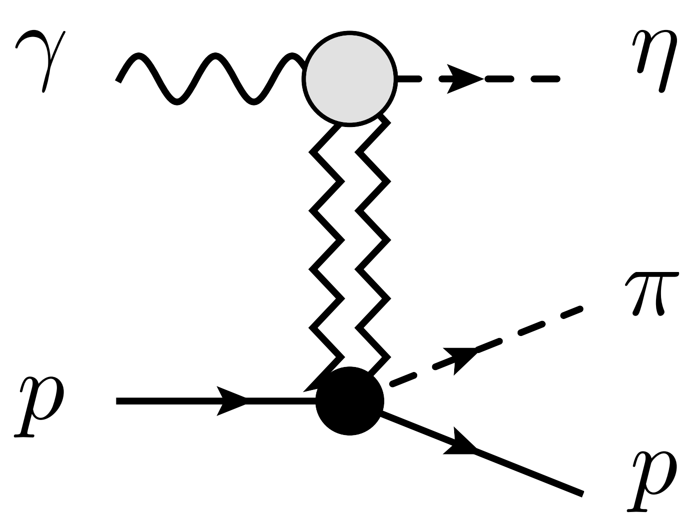


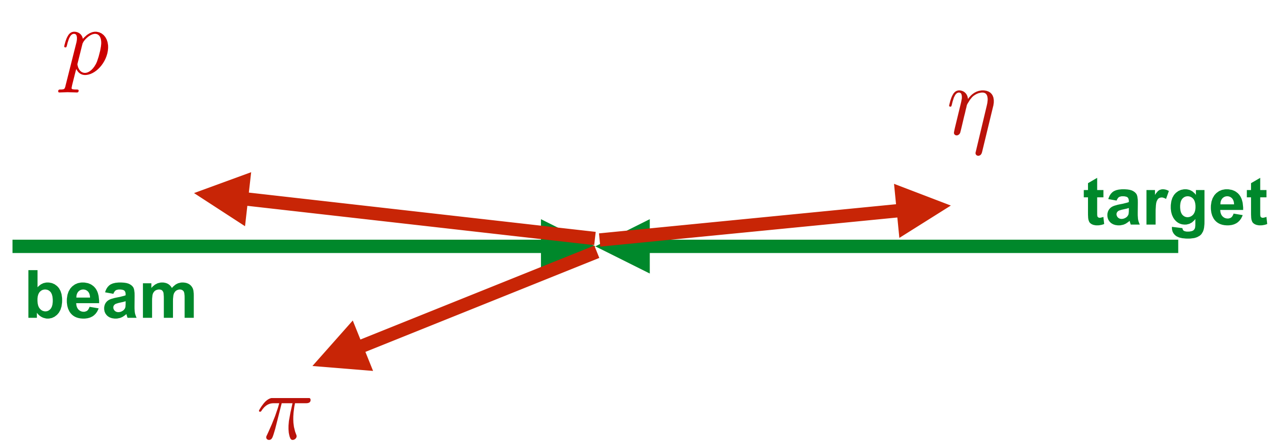
Longitudinal Plot

How do we select beam fragmentation ? → Boost in the rest frame



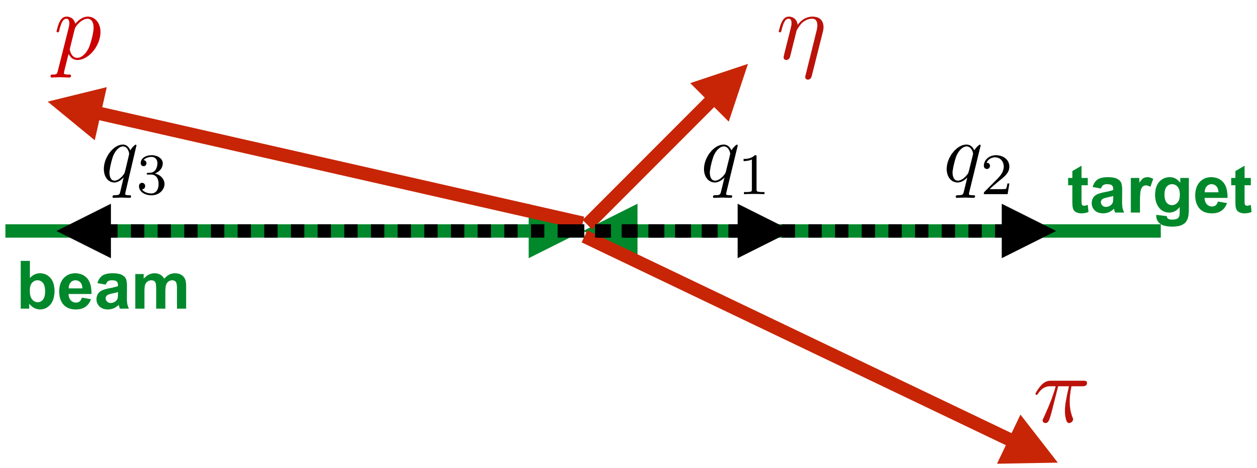






Van Hove NPB9 (1969) 331
Shi et al (JPAC) PRD91 (2015) 034007
Pauli et al PRD98 (2018) 065201

Longitudinal Plot



only 2 variables since $q_1 + q_2 + q_3 = 0$

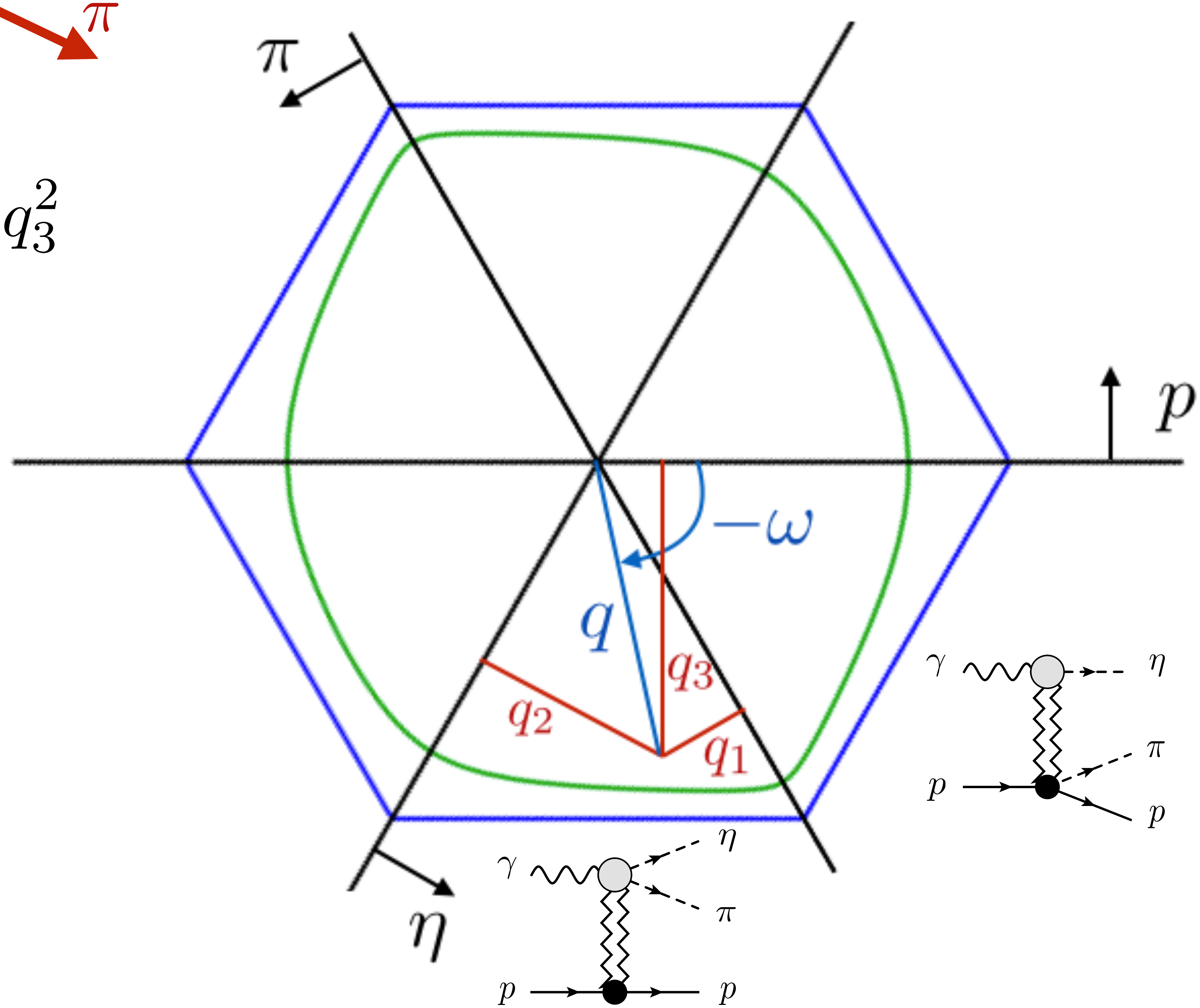
radius: $q^2 = q_1^2 + q_2^2 + q_3^2$

longitudinal angle: ω

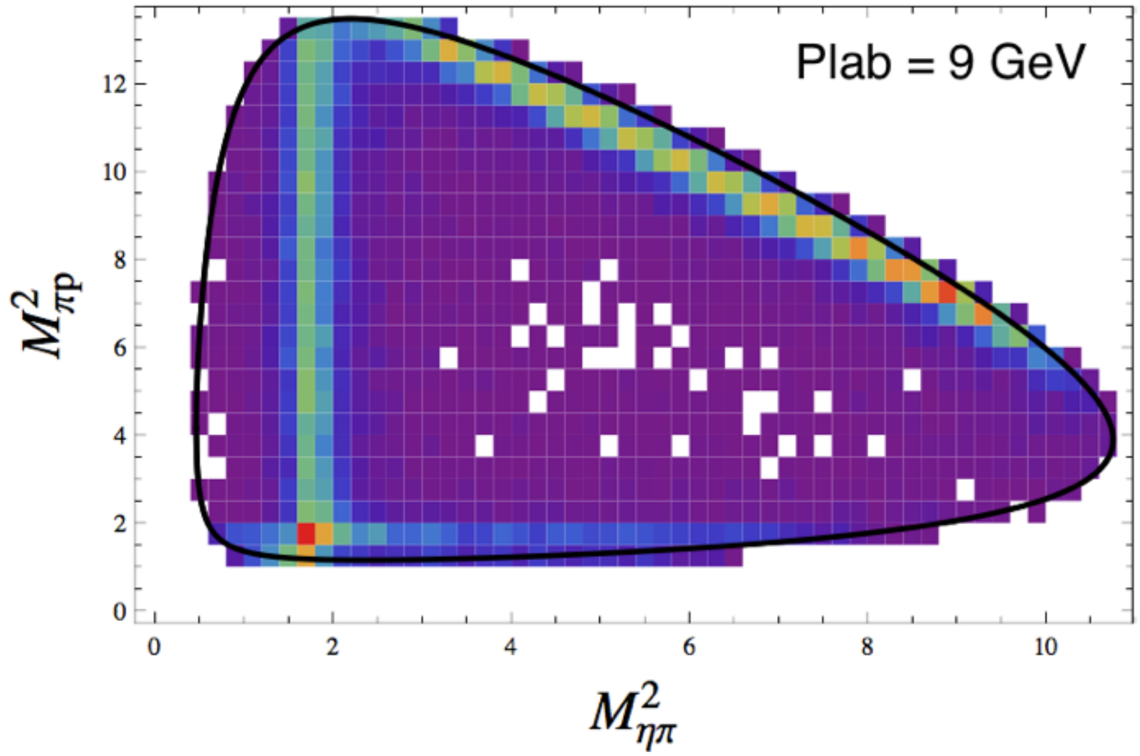
$$q_3 = \sqrt{\frac{2}{3}} q \sin\omega$$

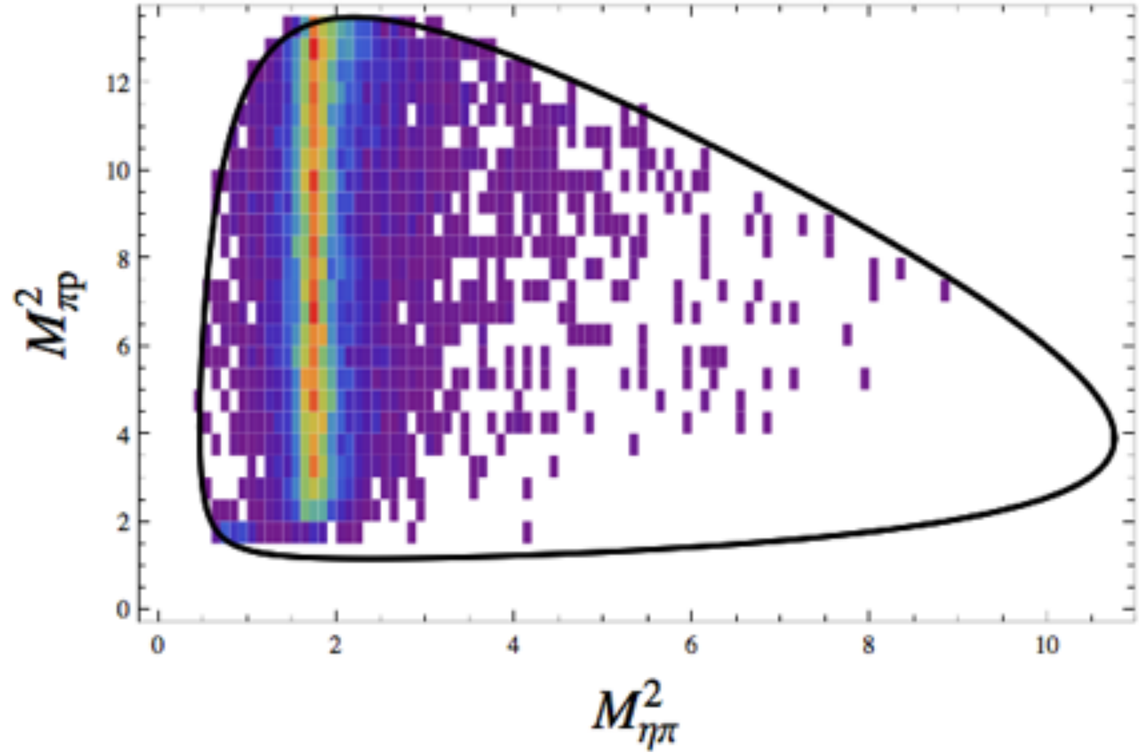
$$q_2 = \sqrt{\frac{2}{3}} q \sin\left(\omega + \frac{2\pi}{3}\right)$$

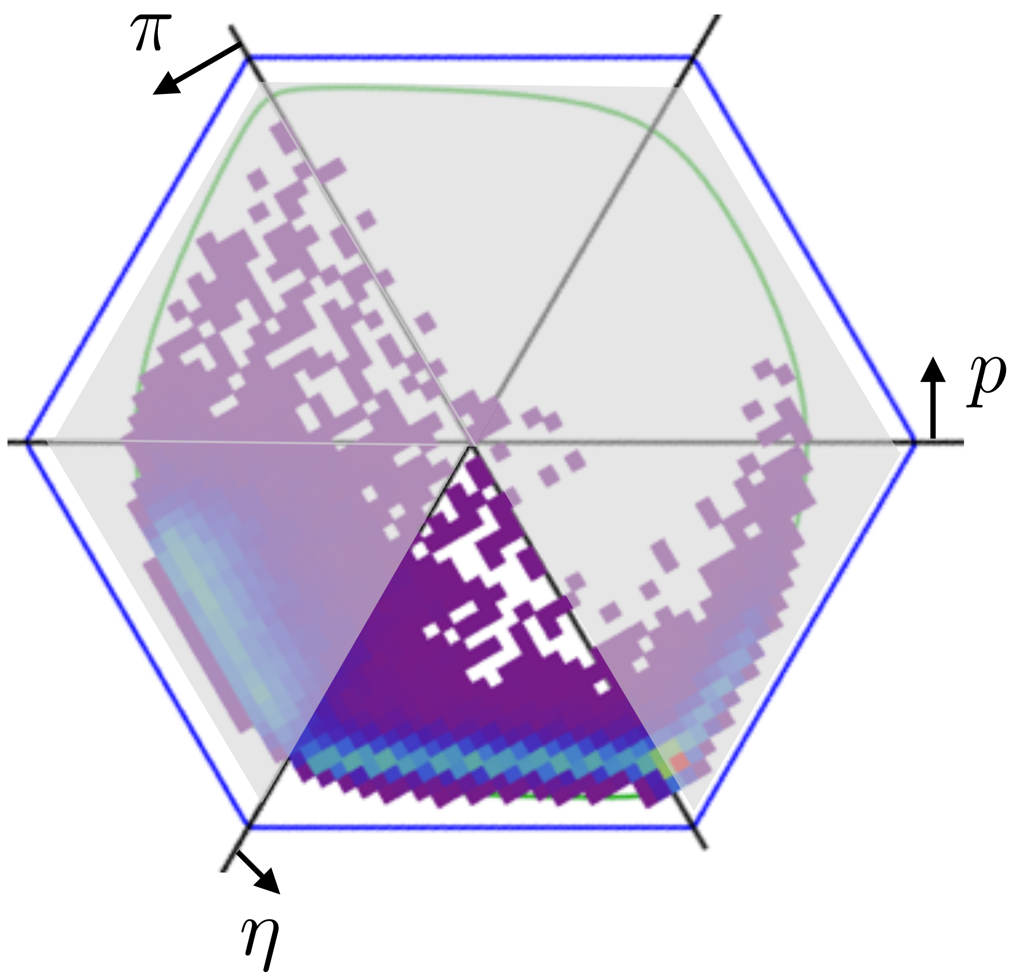
$$q_1 = \sqrt{\frac{2}{3}} q \sin\left(\omega + \frac{4\pi}{3}\right)$$

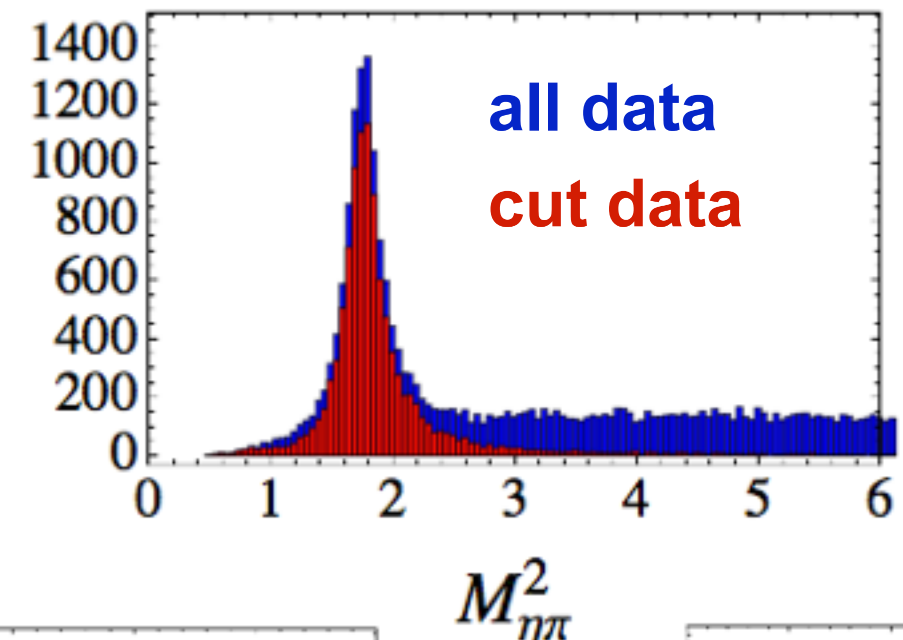


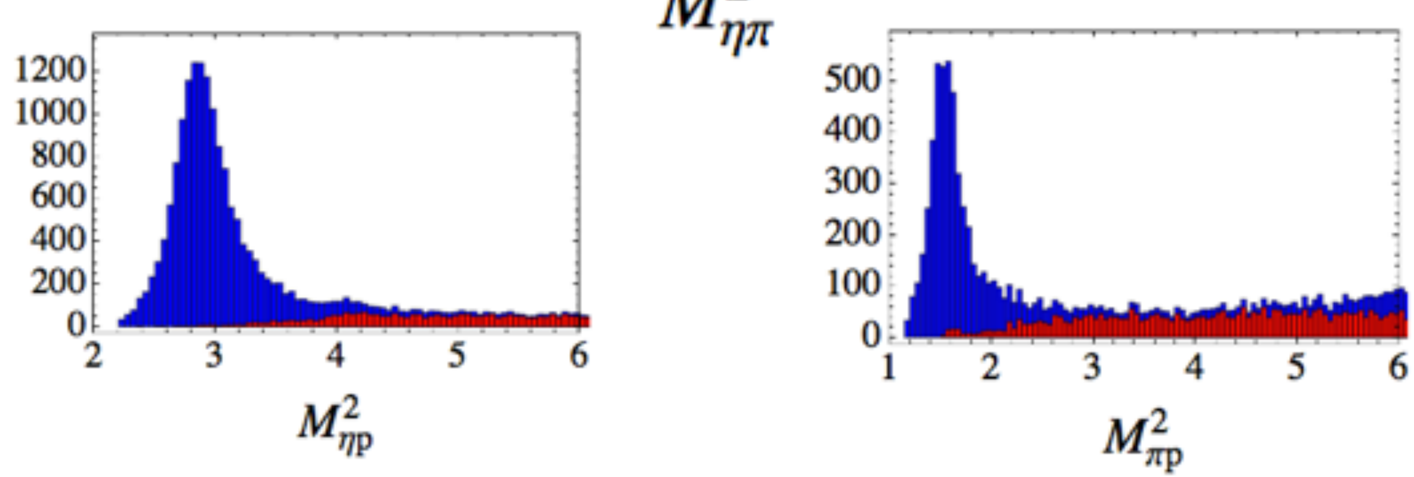
Cut in Longitudinal Angle



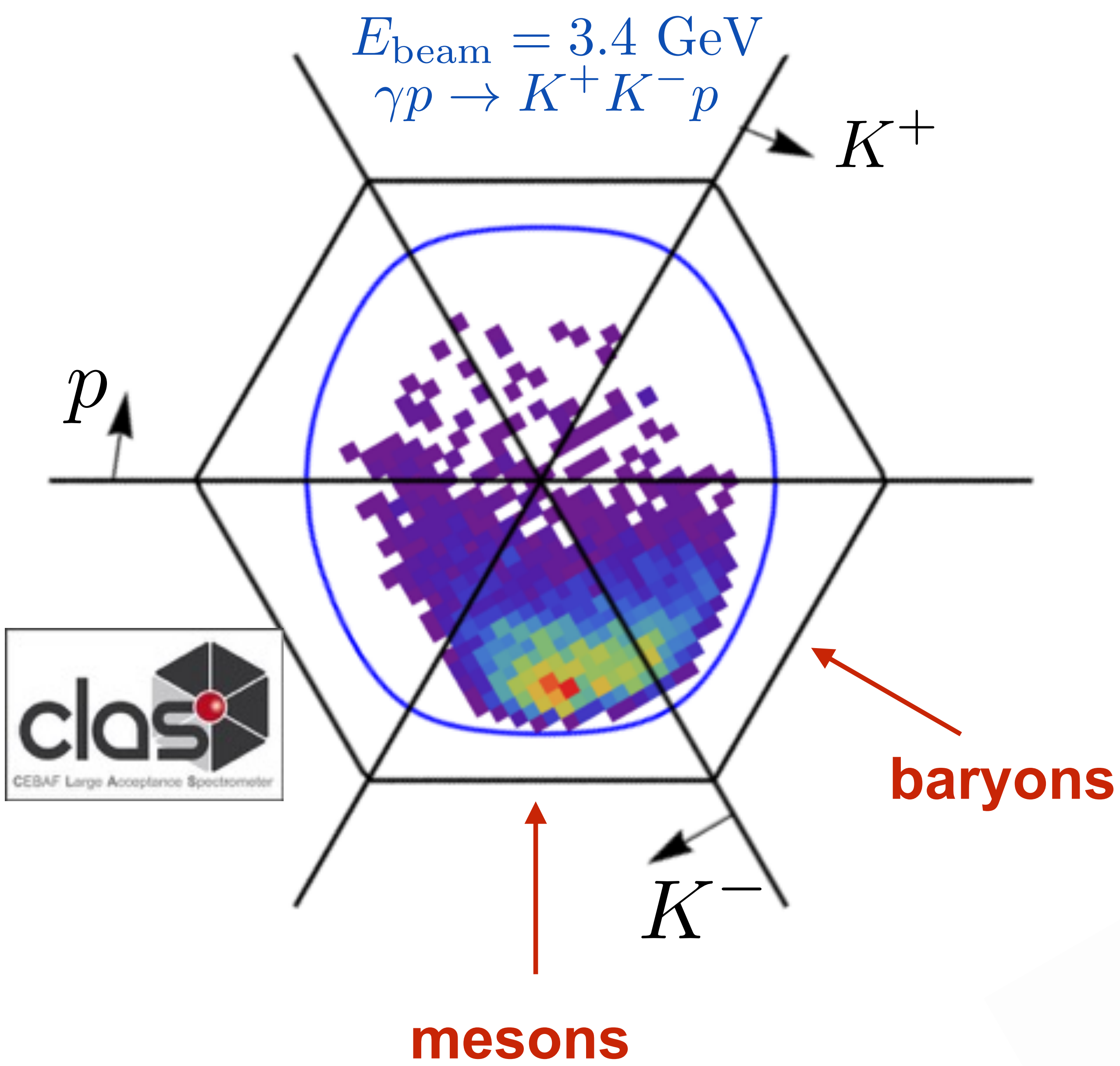


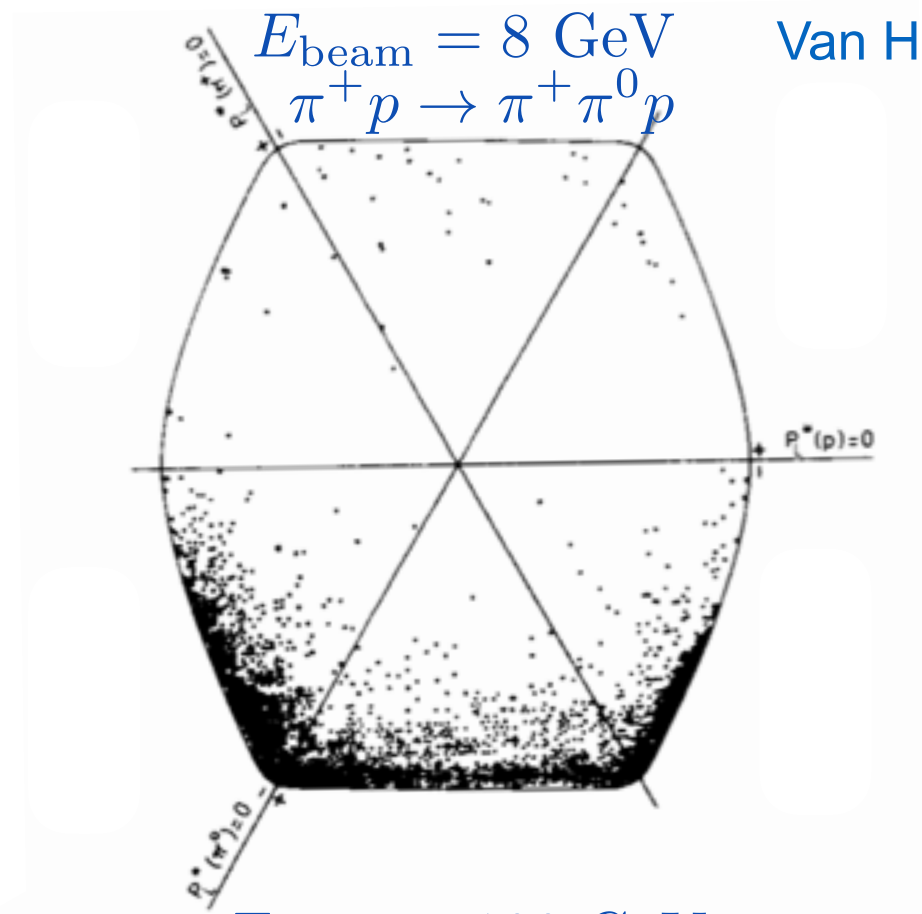




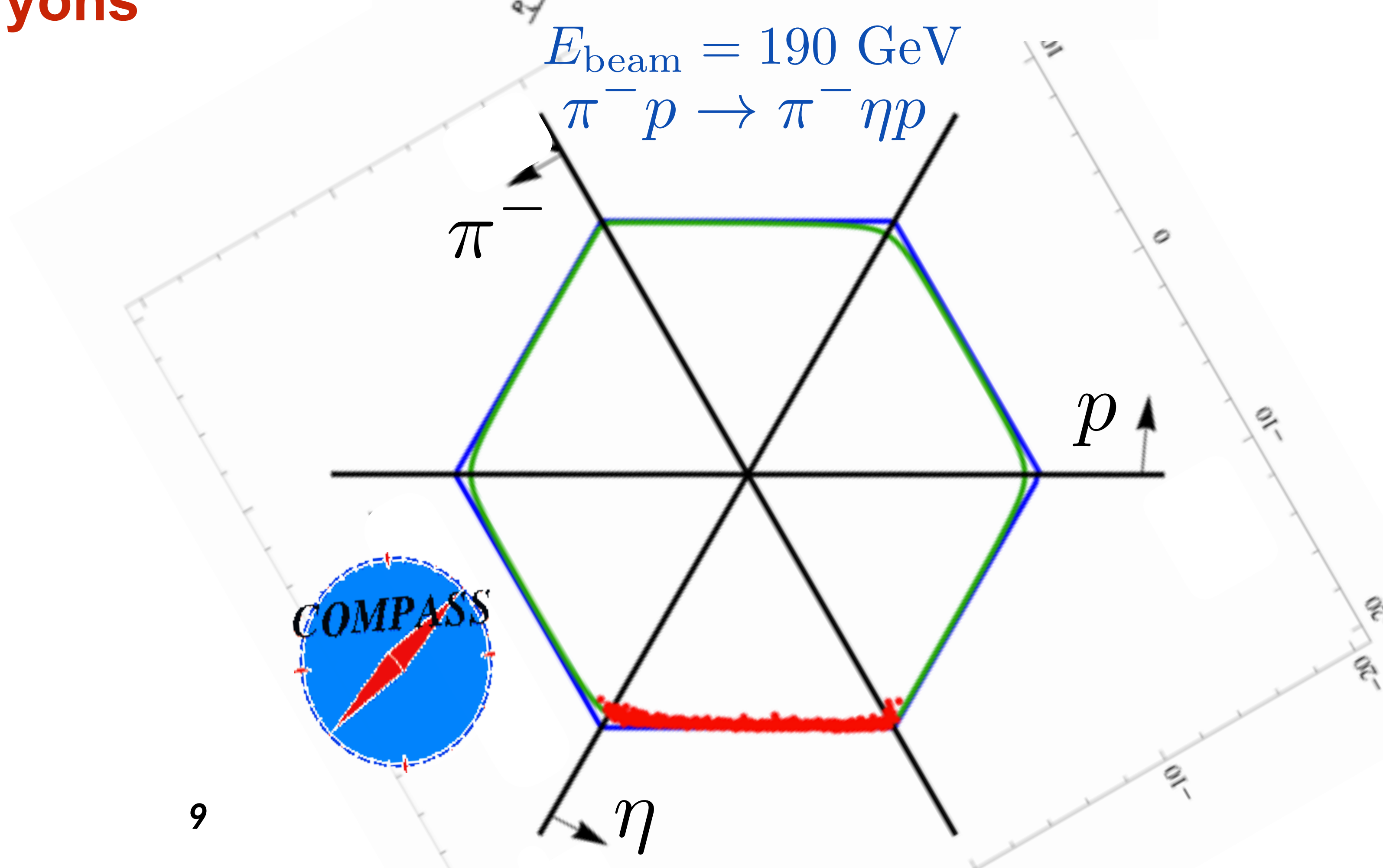


Longitudinal Plot: Energy Evolution





Van Hove (1969)



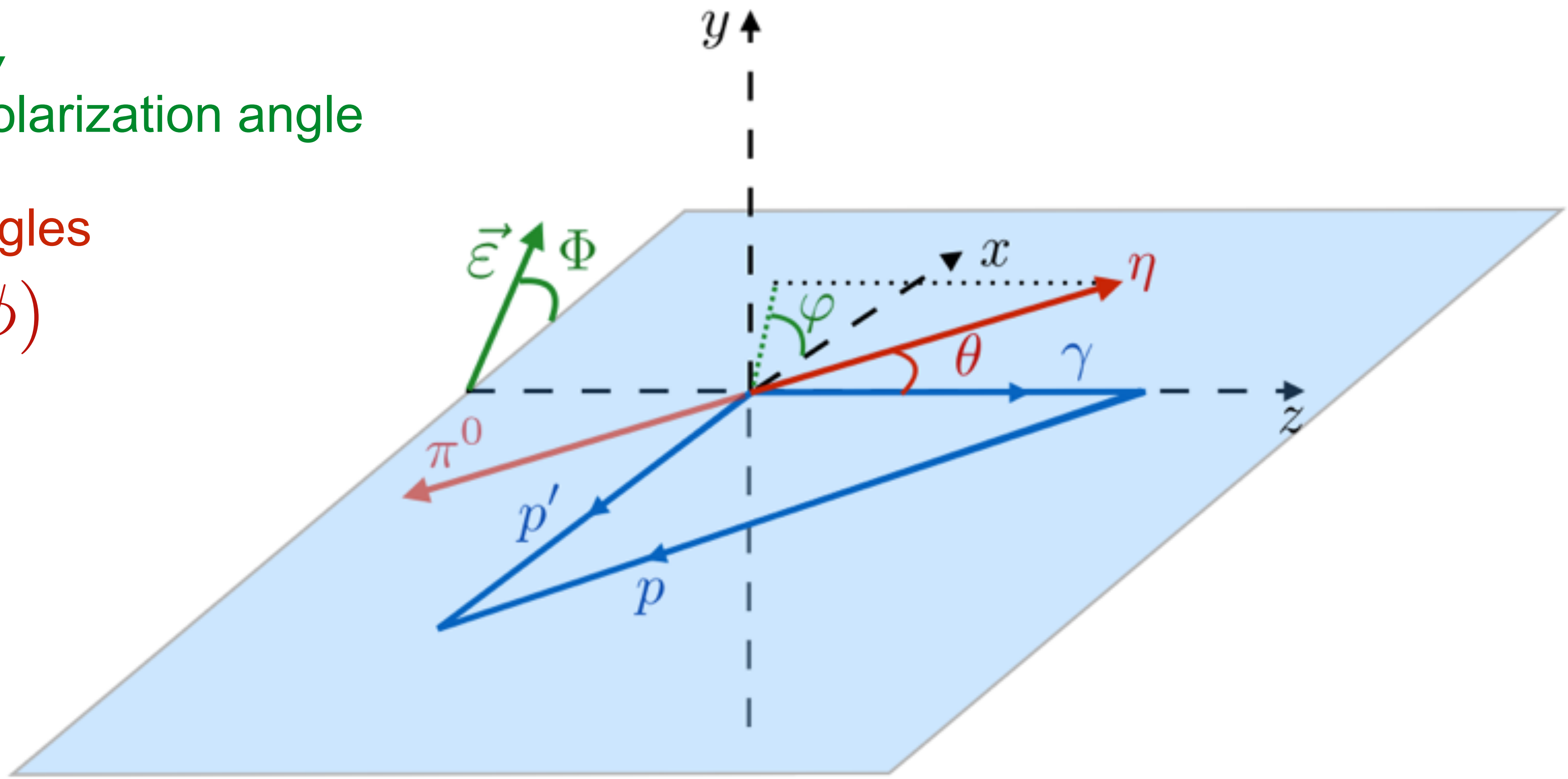
Measured Intensities

$$I(\Omega, \Phi) = I^0(\Omega) - P_\gamma I^1(\Omega)\cos 2\Phi - P_\gamma I^2(\Omega)\sin 2\Phi$$

polarization angle

η decay angles

$\Omega = (\theta, \phi)$

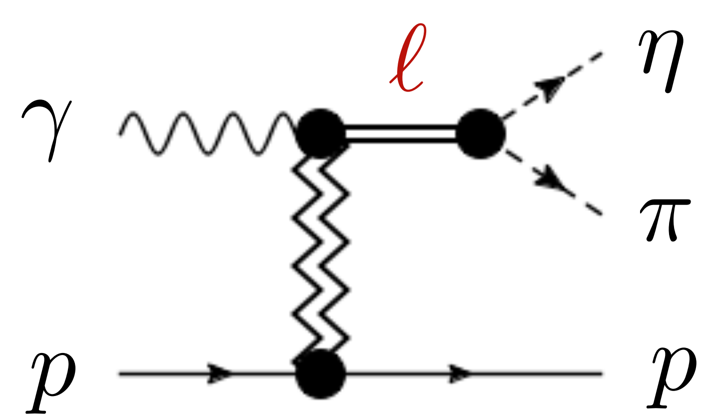


Implicit variables

Beam energy (fixed)

momentum transfer (integrated)

$\eta\pi$ invariant mass (binned)



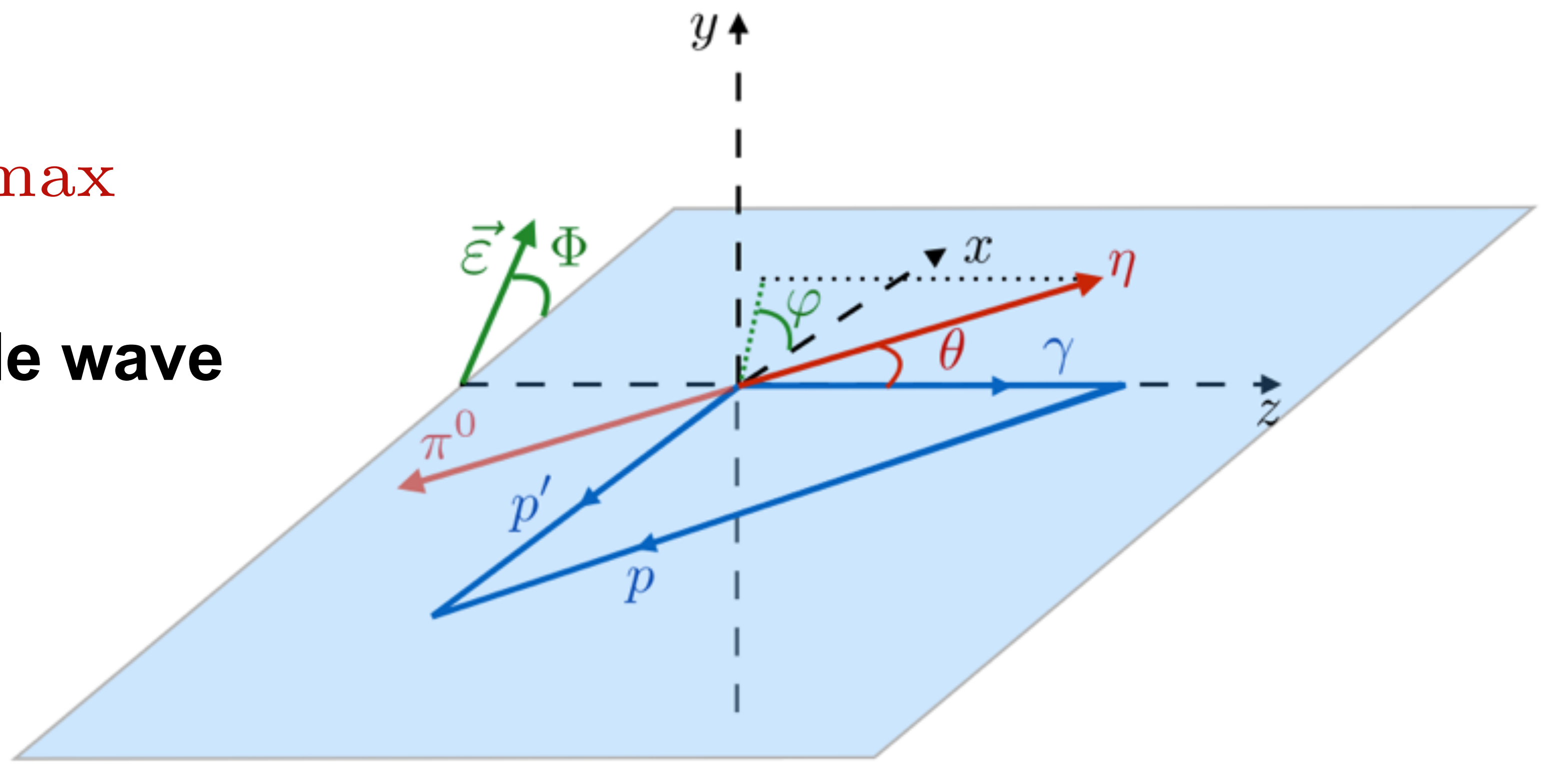
Observables: Moments of Angular distribution

$$I(\Omega, \Phi) = I^0(\Omega) - P_\gamma I^1(\Omega)\cos 2\Phi - P_\gamma I^2(\Omega)\sin 2\Phi$$

$$H^0(LM) = \frac{1}{2\pi}\int I(\Omega, \Phi)\, d^L_{M0}(\theta)\cos M\phi \,\mathrm{d}\Omega \mathrm{d}\Phi$$

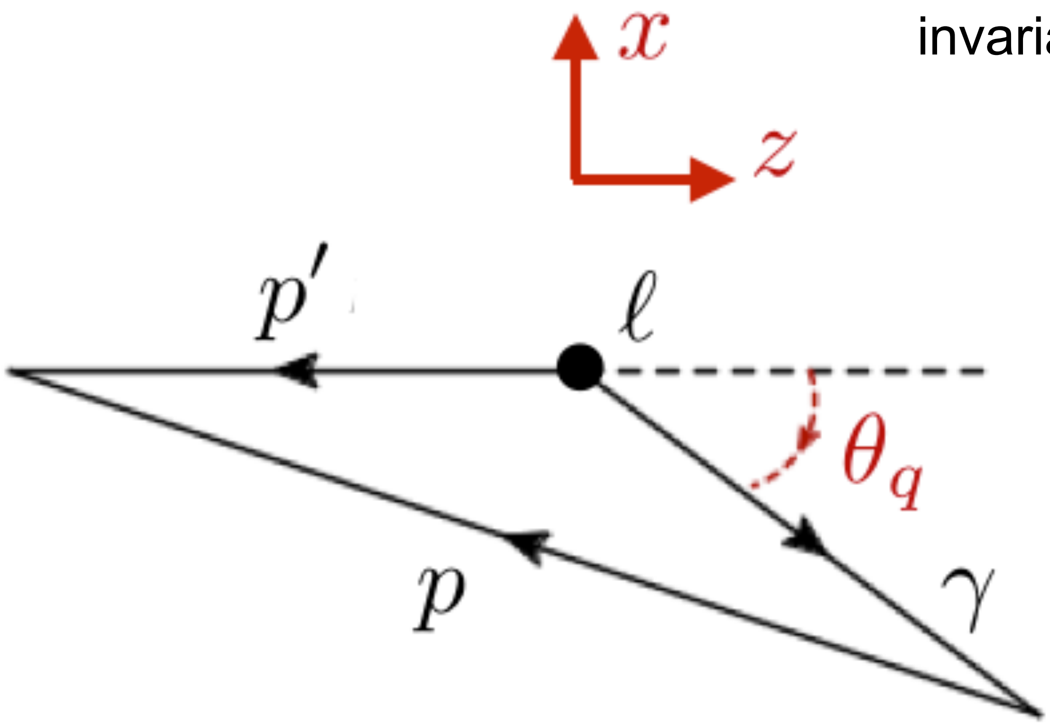
Extract moments up to $L \leq 2\ell_{\max}$

$\ell_{\max}$ **is the highest non-negligible wave**



Frame

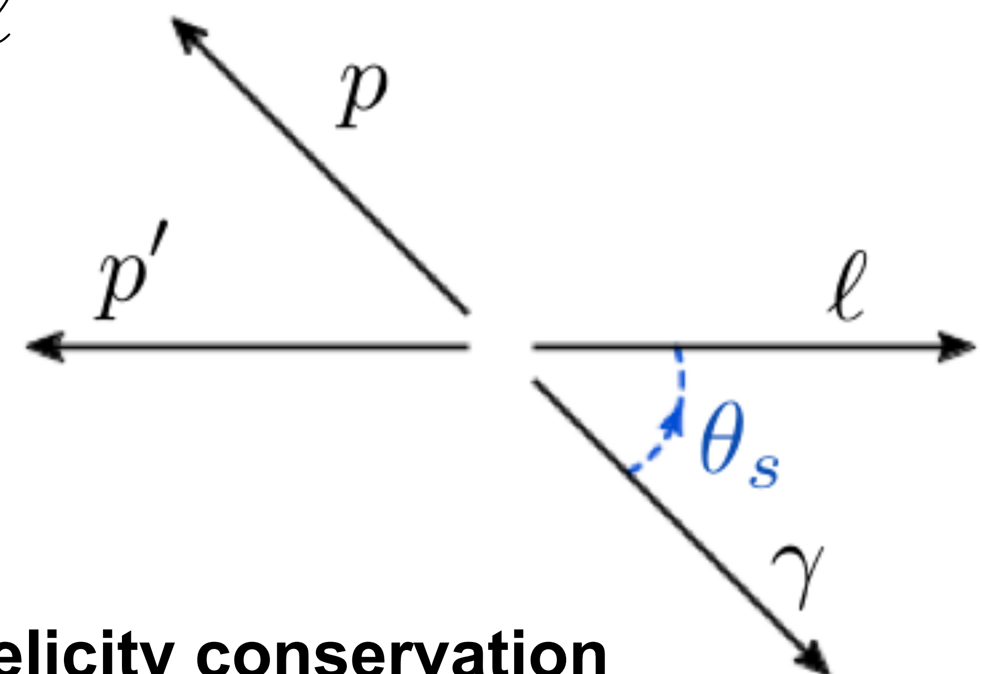
Helicity frame



boost

invariant helicity ℓ

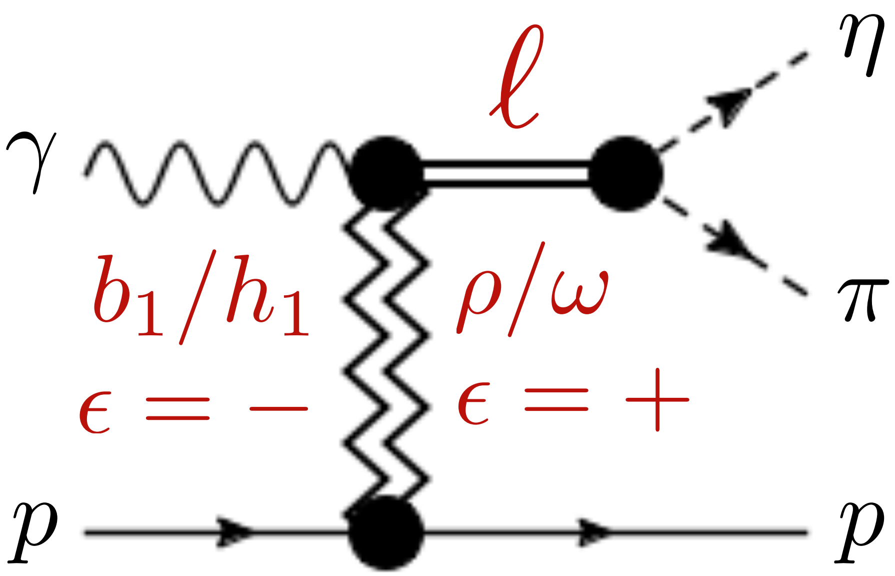
s-channel



helicity conservation

between γ **and** ℓ

$$T_{\lambda_\gamma m} \simeq \delta_{\lambda_\gamma, m} T_{\lambda_\gamma m} + \dots$$

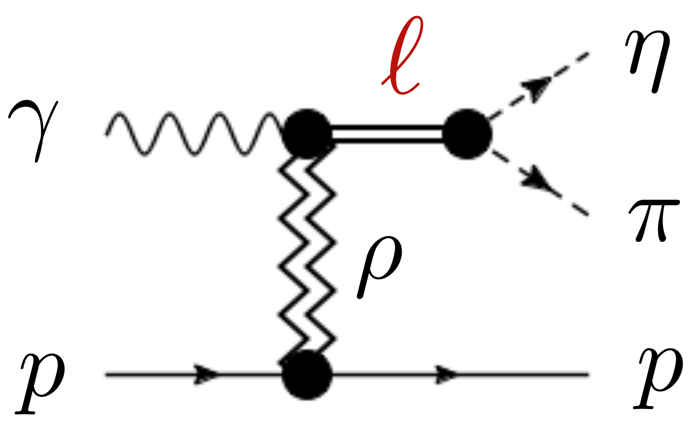


Reflectivity basis:

$$[\ell]_m^{(\epsilon)} = T_{1m} - \epsilon \, T_{-1-m}$$

Dominant: $(\epsilon = +, m = 1)$

Model



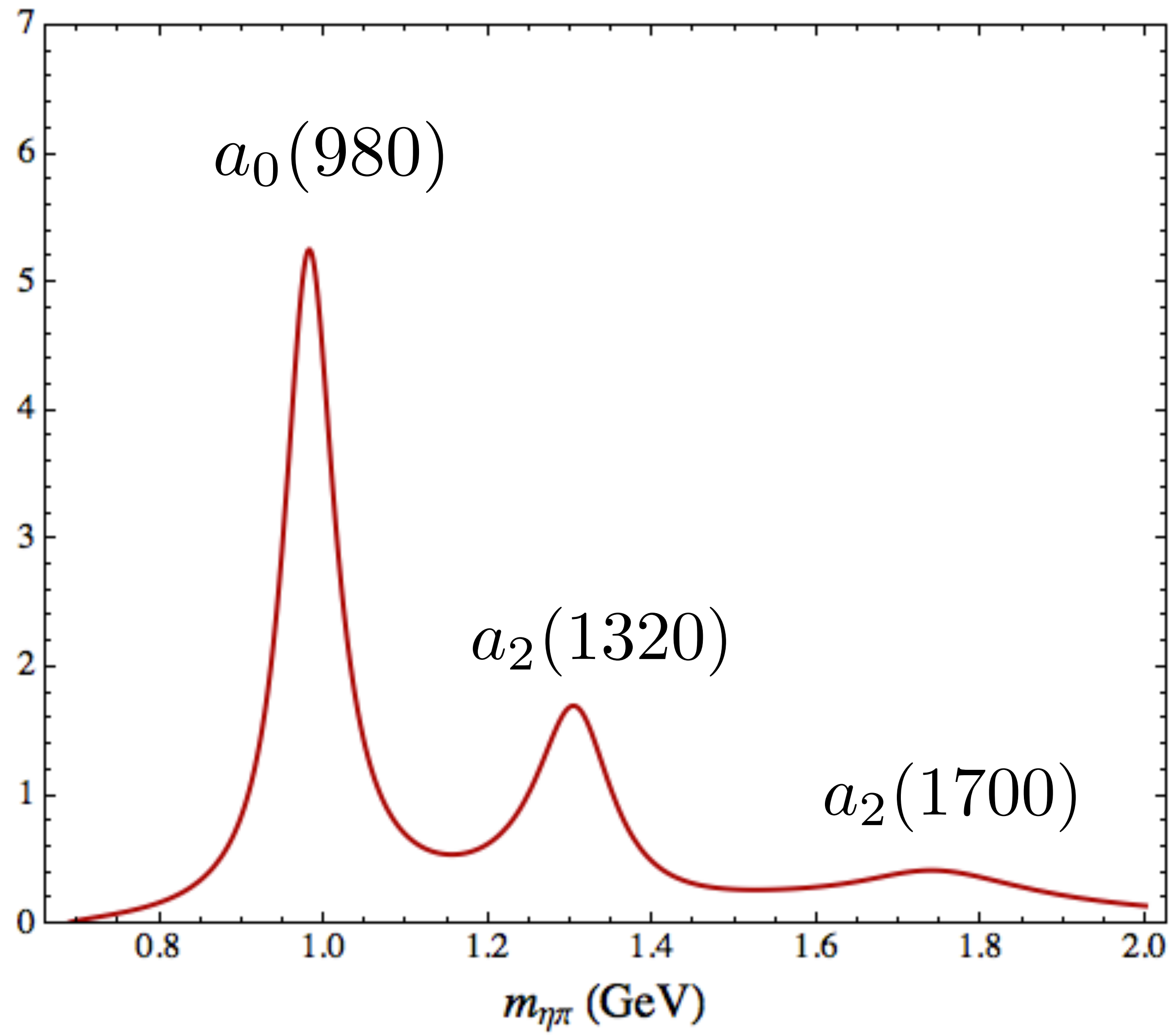
$$R = \{\underbrace{a_0(980)}_{S_0^{(+)}}, \underbrace{\pi_1(1600)}_{P_{0,1}^{(+)}}, \underbrace{a_2(1320), a_2(1700)}_{D_{0,1,2}^{(+)}}\}$$

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

Observables: Moments of Angular distribution

$$H^0(LM) = \frac{1}{2\pi}\int I(\Omega,\Phi)\, d^L_{M0}(\theta)\cos M\phi\, \mathrm{d}\Omega \mathrm{d}\Phi$$

$$H^1(LM) = \frac{-1}{\pi P_\gamma}\int I(\Omega,\Phi)\cos 2\Phi\, d^L_{M0}(\theta)\cos M\phi\, \mathrm{d}\Omega \mathrm{d}\Phi$$

$$\mathrm{Im}\, H^2(LM) = \frac{1}{\pi P_\gamma}\int I(\Omega,\Phi)\sin 2\Phi\, d^L_{M0}(\theta)\sin M\phi\, \mathrm{d}\Omega \mathrm{d}\Phi$$

$m' = m - M$

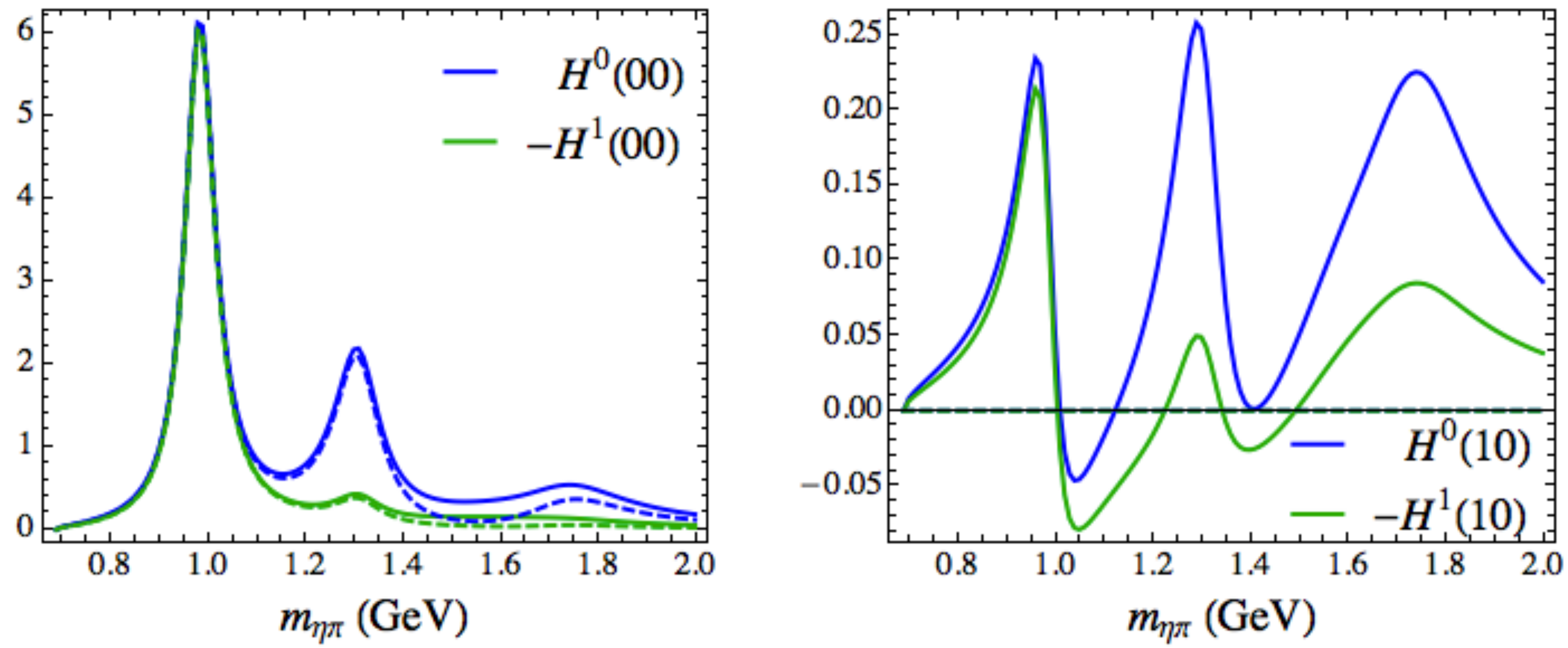
$$H^1(LM) + \mathrm{Im}\ H^2(LM) \propto \sum_{\epsilon,\, \substack{\ell\ell' \\ mm'}} \left(\frac{2\ell'+1}{2\ell+1}\right)^{1/2} \epsilon(-1)^m C^{\ell 0}_{\ell' 0 L 0} C^{\ell m}_{\ell' m' L M}\, [\ell]^{(\epsilon)}_{-m} [\ell']^{(\epsilon)*}_{m'}$$

$0 \leqslant -m \ ; \ 0 \leqslant m'$

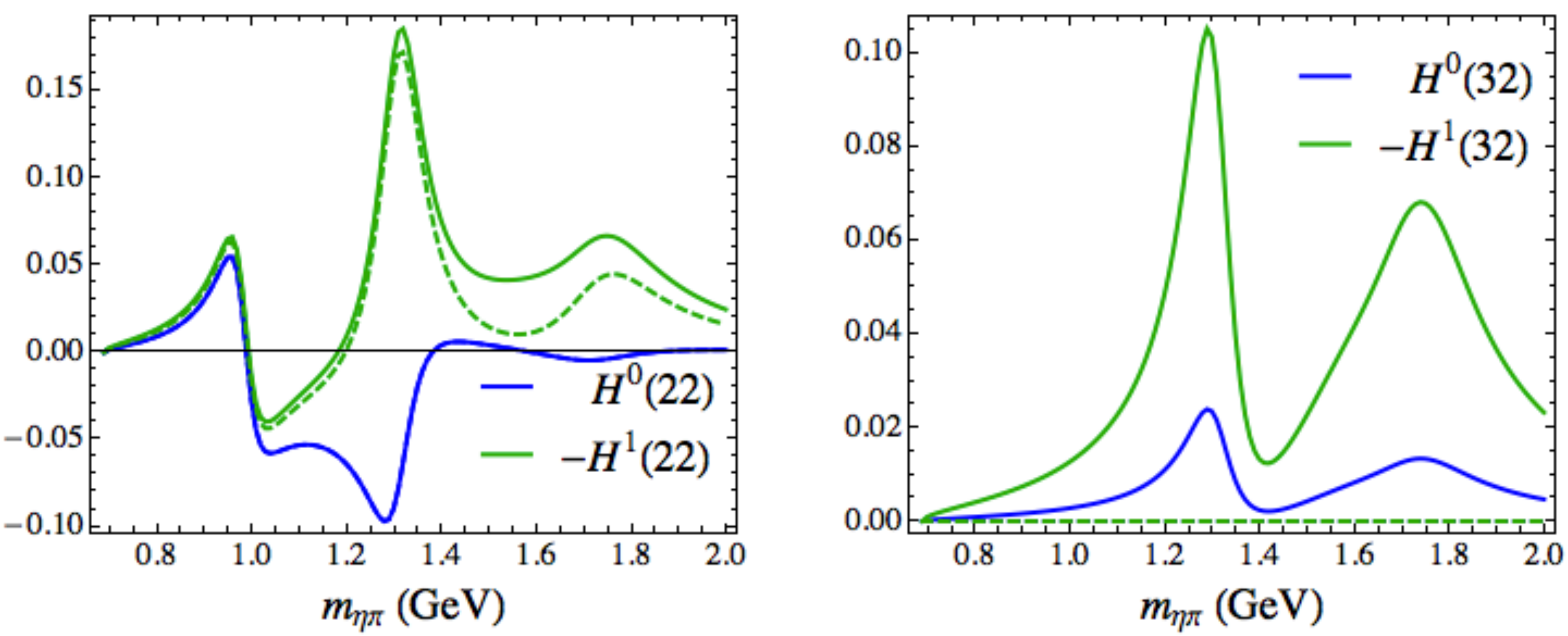
The model features only positive projections

$$H^1(LM) + \mathrm{Im}\ H^2(LM) = 0 \qquad M \geqslant 1$$

Moments



P- wave apparent in odd moments but not in even moments



$a_2(1700)$ **more apparent in odd moments than in even moments**

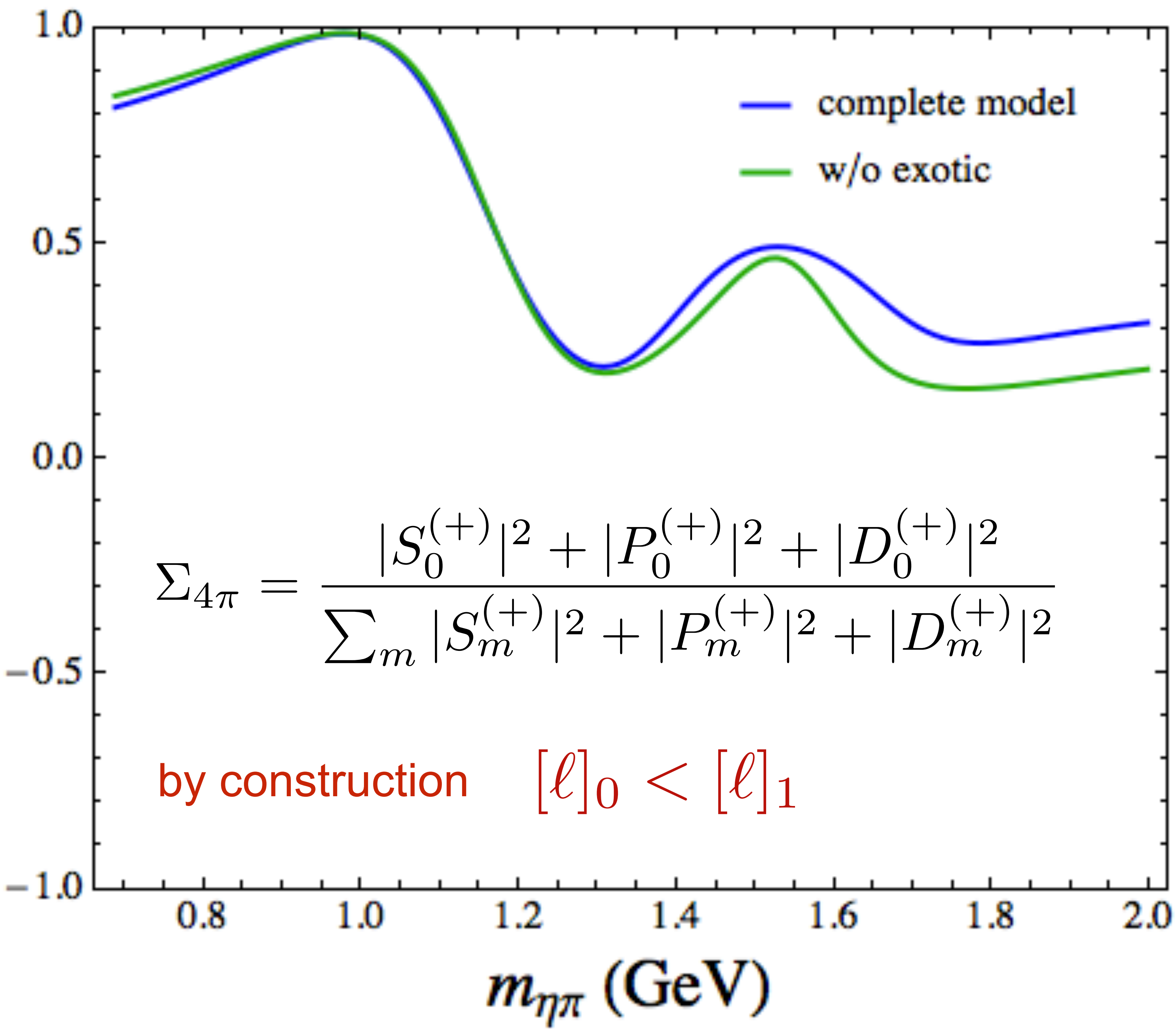
solid lines: *S* + *P* + *D* waves

dashed lines: *S* + *D* waves

Beam Asymmetries

$$\Sigma_{\mathcal{D}} = \frac{1}{P_\gamma} \frac{\int_{\mathcal{D}} I^{\parallel}(\Omega) - I^{\perp}(\Omega) \mathrm{d}\Omega}{\int_{\mathcal{D}} I^{\parallel}(\Omega) + I^{\perp}(\Omega) \mathrm{d}\Omega}$$

$\Sigma_{4\pi} =$ fully integrated

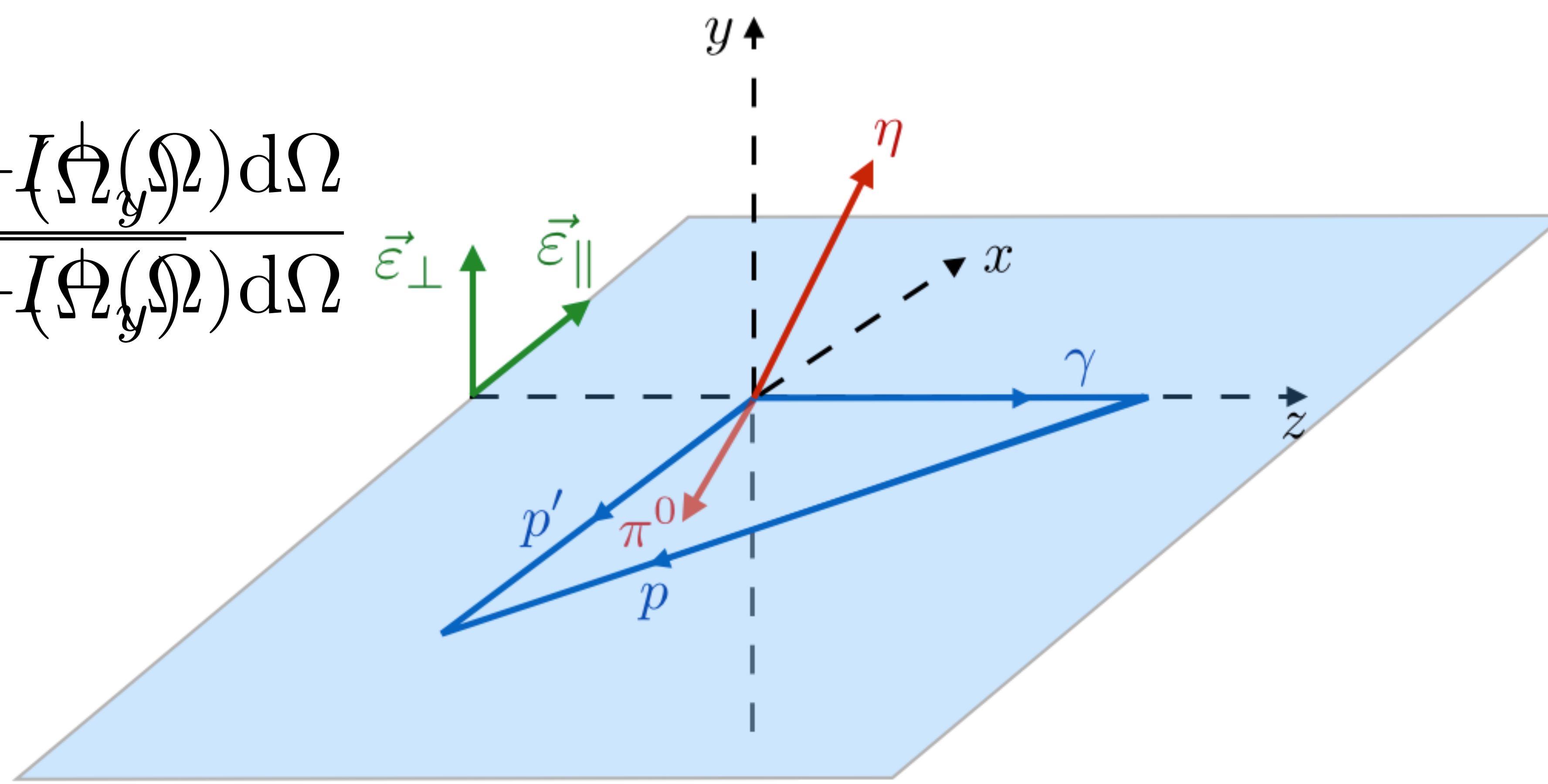


$$\Sigma_{4\pi} = \frac{|S_0^{(+)}|^2 + |P_0^{(+)}|^2 + |D_0^{(+)}|^2}{\sum_m |S_m^{(+)}|^2 + |P_m^{(+)}|^2 + |D_m^{(+)}|^2}$$

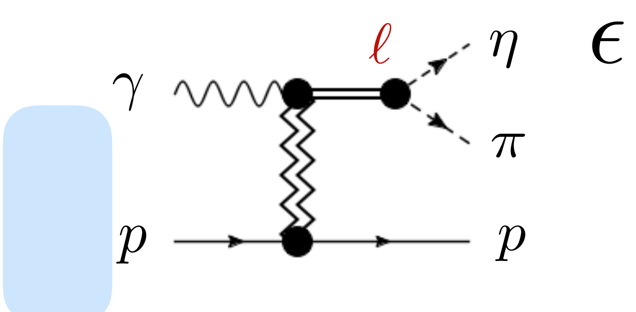
by construction $[\ell]_0 < [\ell]_1$

Beam Asymmetries

$$\Sigma_y = \frac{1}{P_\gamma}\frac{\int I_y^{\parallel}(\Omega) - I_y^{\perp}(\Omega)\,\mathrm{d}\Omega}{\int I_y^{\parallel}(\Omega) + I_y^{\perp}(\Omega)\,\mathrm{d}\Omega}$$



amplitude:
production x decay



Beam asymmetry sensitive to reflection through the reaction plane

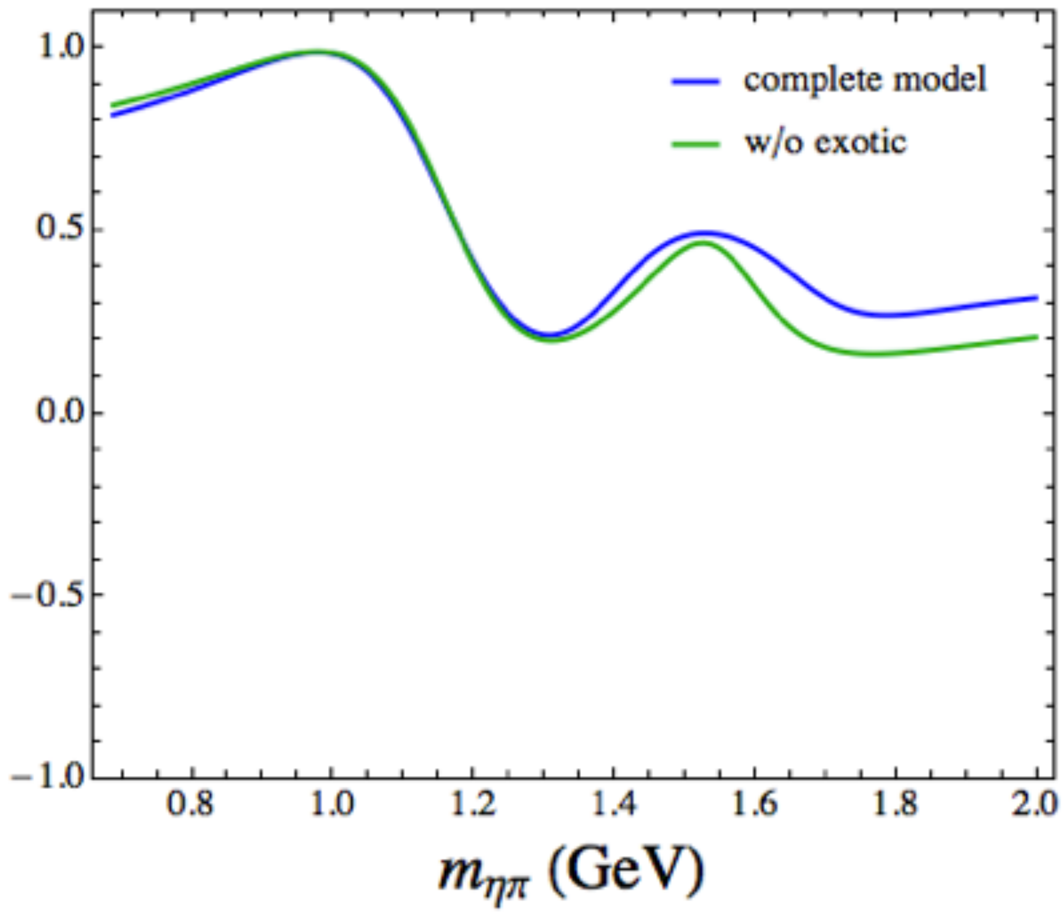
use reflection operator = parity followed by 180° rotation around Y-axis

$$[\ell]_m^{(\epsilon)} \longrightarrow \Sigma_y = \epsilon(-1)^\ell$$

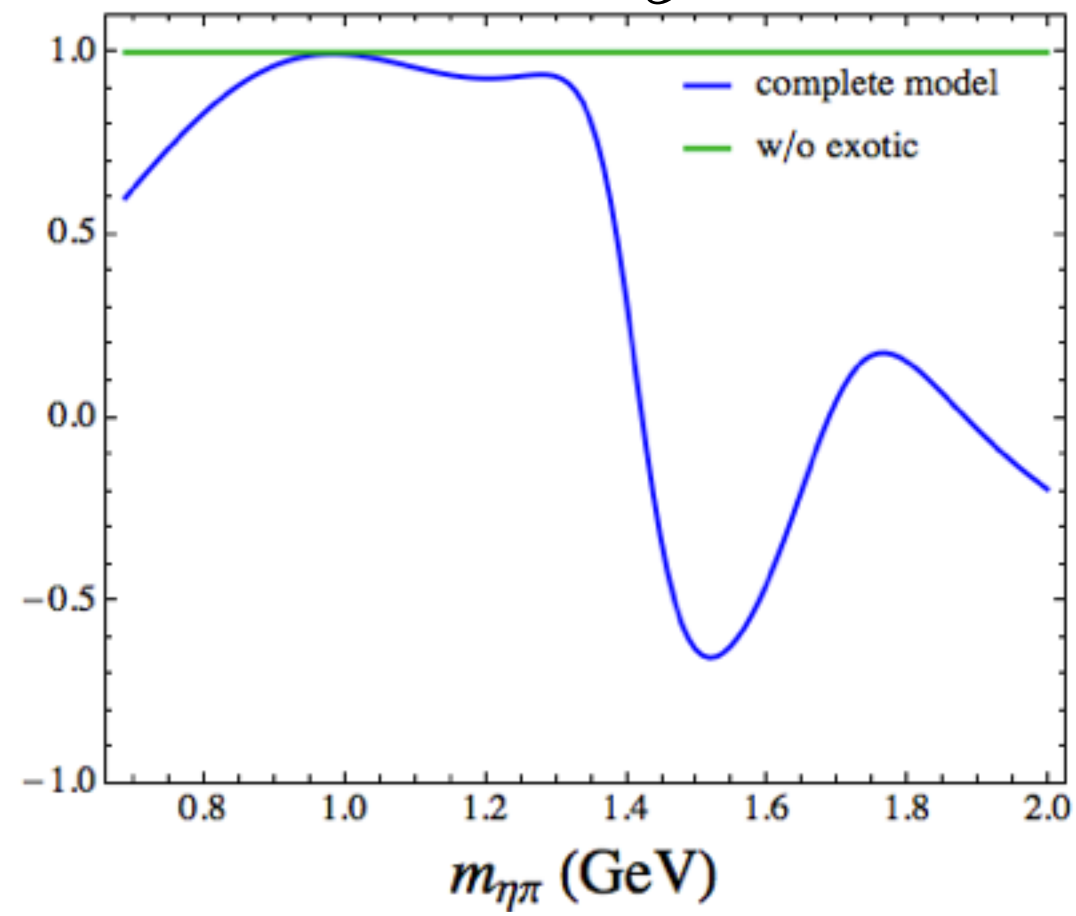
Odd waves change sign!!!

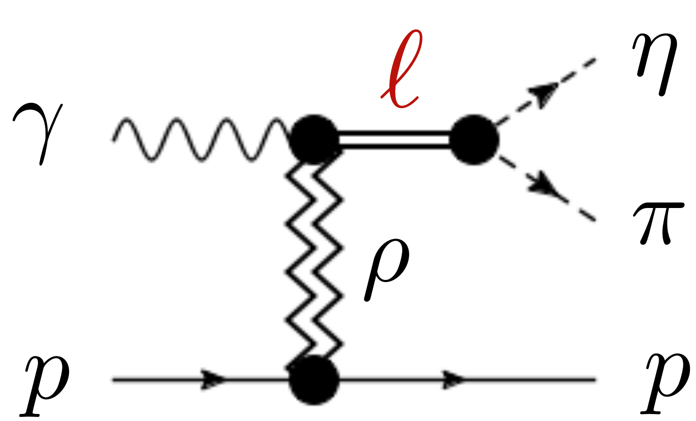
Beam Asymmetries

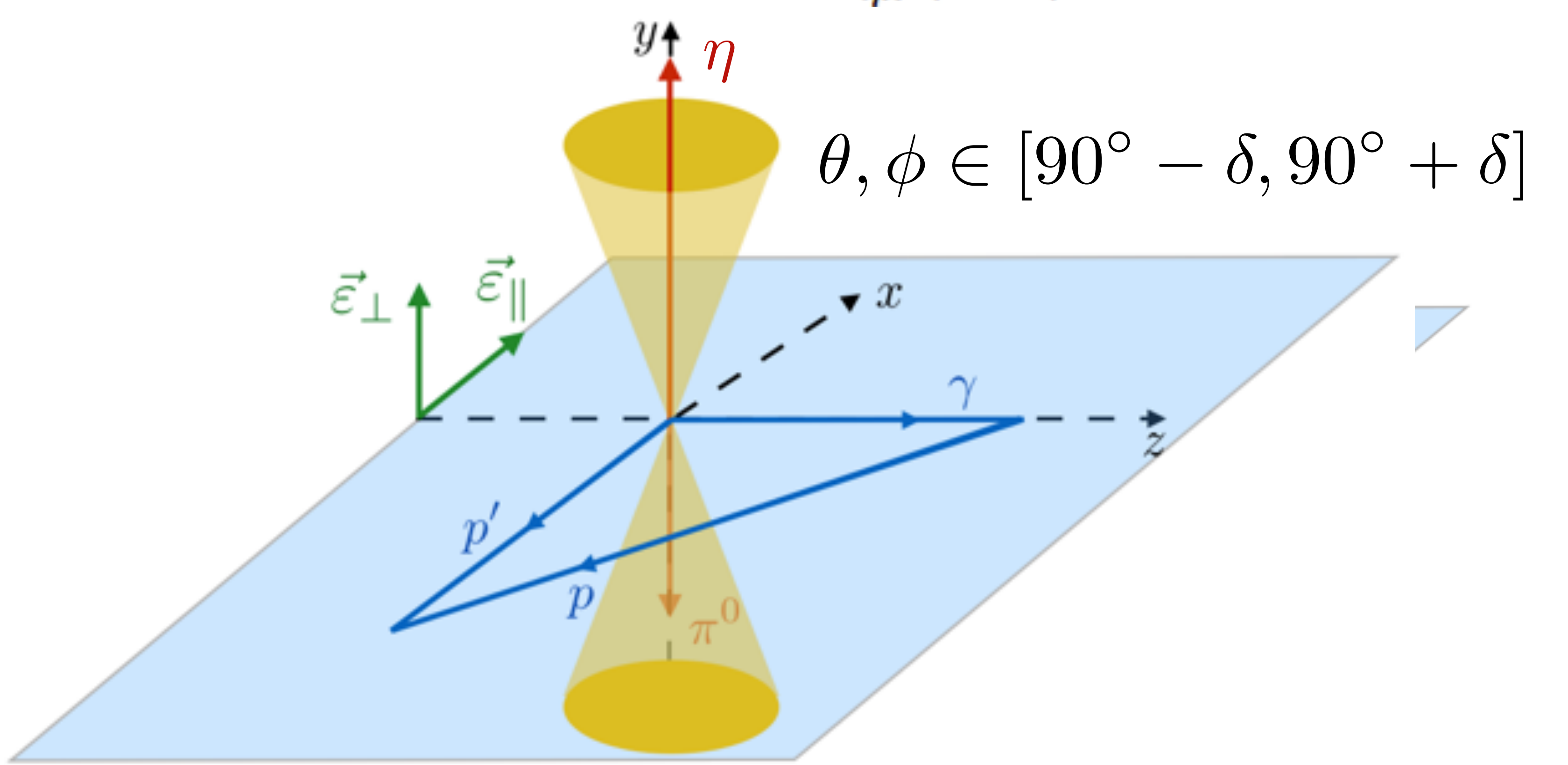
$\Sigma_{4\pi}$



Σ_y

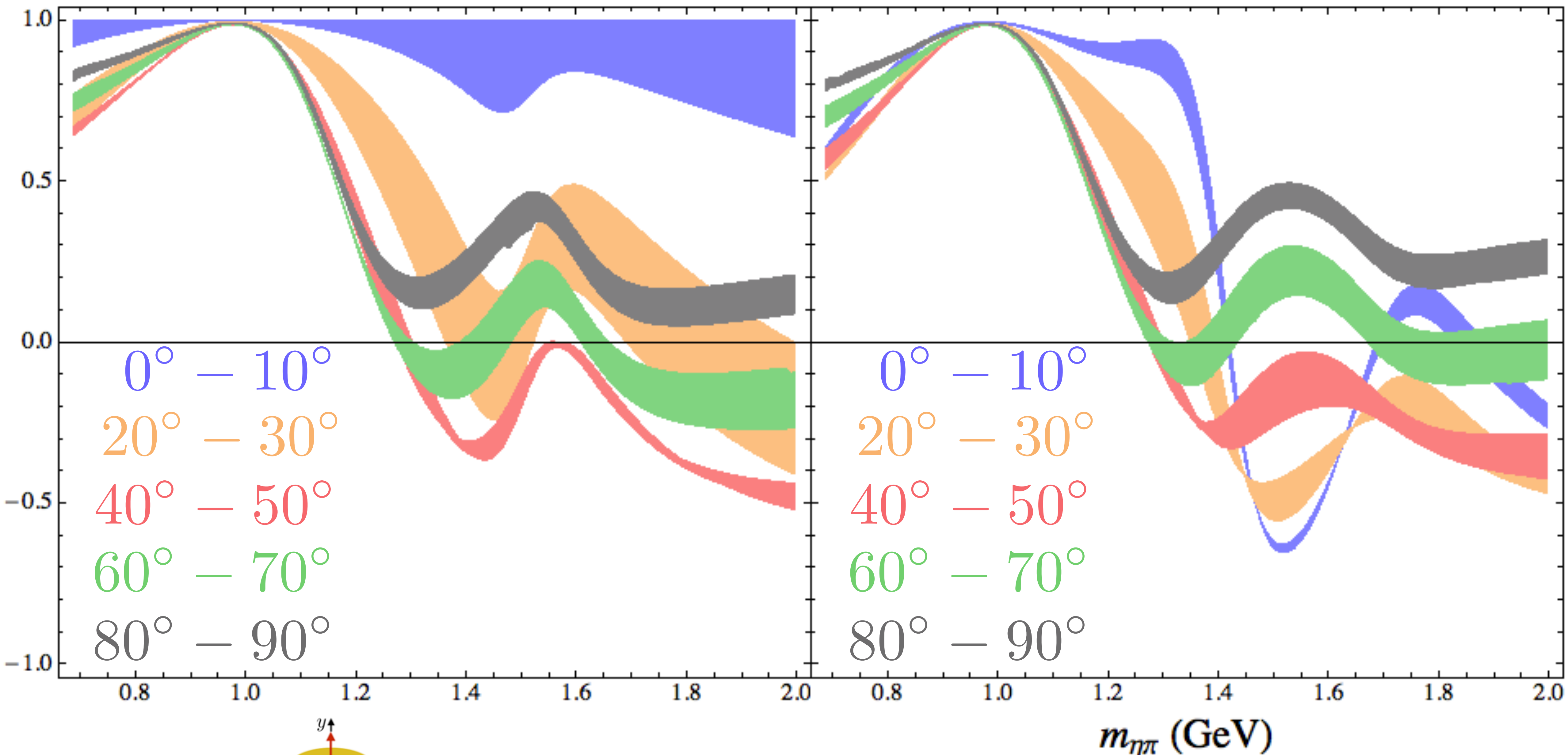


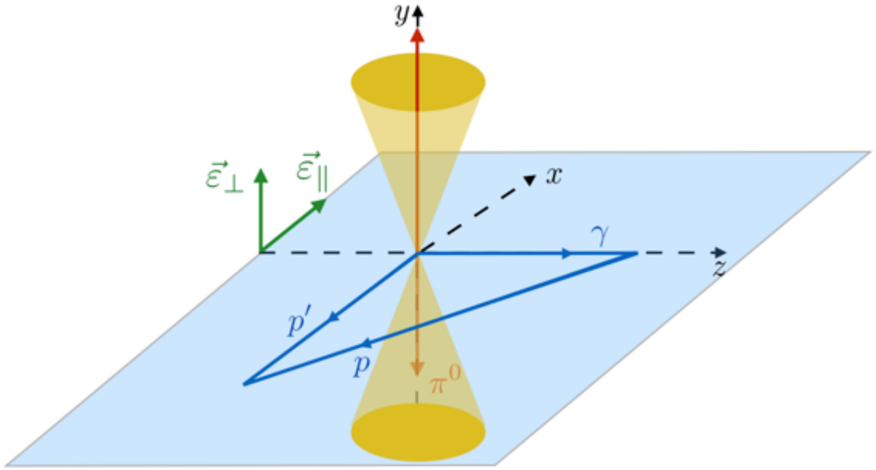




Beam Asymmetries: $\Sigma_{y\pm\delta^\circ}$

only S and D waves | **S, P and D waves**





with an opening angle greater than 30°
the observables is not sensitive to the P-wave
(with our model)

Conclusions

Moments of angular distribution and beam asymmetries provides info on wave content and production mechanism

Current/future applications @GlueX:

$$\gamma p \to \eta \pi^0 p$$

$$\gamma p \to \eta \pi^- \Delta^{++}$$

$$\gamma p \to \eta \eta p$$

$$\gamma p \to \eta \eta' p$$

Future plan: partial wave analysis