PWA Challenge with polarized photon beam

Florida International University 2020

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Model for Intensity with polarized photon beam

$$\vec{\gamma}(\lambda, p_\gamma)\ p(\lambda_1, p_N) \to \pi^0(p_\pi)\ \eta(p_\eta)\ p(\lambda_2, p'_N)$$

Φ - angle between γ polarization vector and production plane

Ω- direction of η in helicity frame

P_γ is the degree of linear polarization

$A_{\lambda;\lambda_1\lambda_2}(\Omega)$-the reaction amplitude

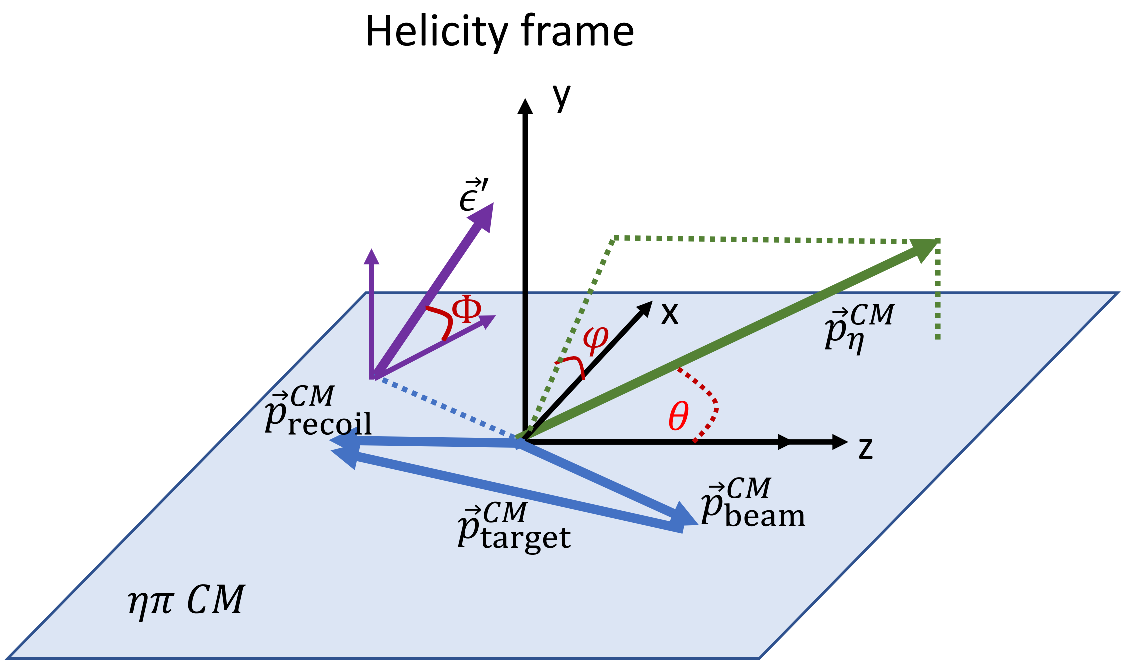
$$I(\Omega,\Phi) = \frac{d\sigma}{dt\ dm_{\eta\pi}\ d\Omega\ d\Phi}$$

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

$$I^0(\Omega) = \frac{\kappa}{2}\sum_{\lambda,\lambda_1,\lambda_2} A_{\lambda;\lambda_1\lambda_2}(\Omega) A^*_{\lambda;\lambda_1\lambda_2}(\Omega),$$

$$I^1(\Omega) = \frac{\kappa}{2}\sum_{\lambda,\lambda_1,\lambda_2} A_{-\lambda;\lambda_1\lambda_2}(\Omega) A^*_{\lambda;\lambda_1\lambda_2}(\Omega),$$

$$I^2(\Omega) = i\frac{\kappa}{2}\sum_{\lambda,\lambda_1,\lambda_2} \lambda A_{-\lambda;\lambda_1\lambda_2}(\Omega) A^*_{\lambda;\lambda_1\lambda_2}(\Omega)$$



with κ containing all kinematical factors. The partial wave amplitudes T^l are defined by:

$$A_{\lambda;\lambda_1\lambda_2}(\Omega) = \sum_{\ell m} T^\ell_{\lambda m;\lambda_1\lambda_2} Y^m_\ell(\Omega)$$

We introduce reflectivity basis which allows to trade helicity λ for the reflectivity index ϵ=$\pm$1, and express helicity amplitudes in terms of reflectivity amplitudes

$$T^\ell_{-1m;\lambda_1\lambda_2} = (-1)^m \left[{}^{(-)}T^\ell_{-m;\lambda_1\lambda_2} - {}^{(+)}T^\ell_{-m;\lambda_1\lambda_2}\right] \qquad T^\ell_{+1m;\lambda_1\lambda_2} = {}^{(-)}T^\ell_{m;\lambda_1\lambda_2} + {}^{(+)}T^\ell_{m;\lambda_1\lambda_2}$$

At high energies, natural (unnatural) exchanges contributes only to the ϵ=+(ϵ=$-$) components in the reflectivity basis

Define phase rotated spherical harmonics

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

$$\text{Re}\, Z^m_\ell(\Omega,\Phi) = \sqrt{\frac{2\ell+1}{4\pi}}\, d^\ell_{m0}(\theta)\cos(m\phi - \Phi)$$

$$\text{Im}\, Z^m_\ell(\Omega,\Phi) = \sqrt{\frac{2\ell+1}{4\pi}}\, d^\ell_{m0}(\theta)\sin(m\phi - \Phi)$$

Phys. Rev. D 100, 054017

Model for Intensity with polarized photon beam

Parity invariance implies

$$^{(\epsilon)}T^{\ell}_{m;-\lambda_1-\lambda_2} = \epsilon(-1)^{\lambda_1-\lambda_2}\ ^{(\epsilon)}T^{\ell}_{m;\lambda_1\lambda_2}$$

We take advantage of this constraint to define

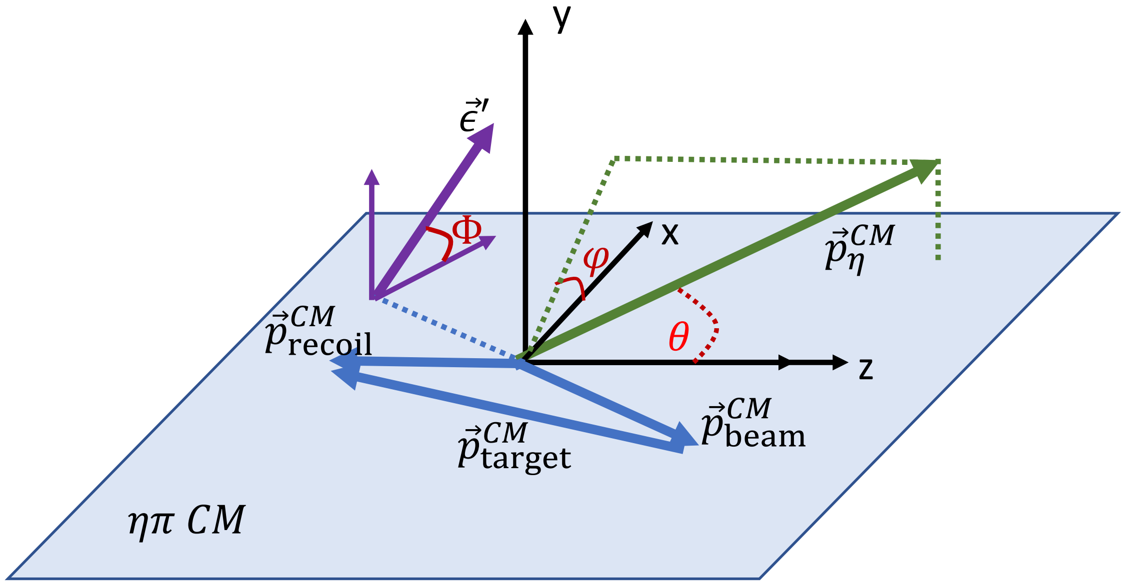
$$[\ell]^{(\epsilon)}_{m;0} = {}^{(\epsilon)}T^{\ell}_{m;++} \qquad [\ell]^{(\epsilon)}_{m;1} = {}^{(\epsilon)}T^{\ell}_{m;+-}$$

Are partial wave amplitudes for spin flip k=1 and spin non-flip k=0.
For each l , there are 2*2*(2l+1) complex partial waves with $\epsilon=\pm1$, k=0,1 corresponding to target and recoil helicities and m=-l,.....l.
There is no interference between $\epsilon=+$and $\epsilon=-$ intensities.

Intensity that involves four coherent sums for each configuration of nucleon spin:

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

Helicity frame



Helicity-non-flip amplitudes dominate and we set the helicity-flip amplitudes to zero. This is not restrictive as the target is not polarized in GlueX, and the measured intensities are not sensitive to the details of the nucleon helicity structure.
Natural parity exchanges (corresponding to the amplitudes with $\epsilon=+1$) dominate in the energy range of interest.

Phys. Rev. D 100, 054017

Generated 2*10^6 ($p\eta'\pi^0$)events with AmpTools

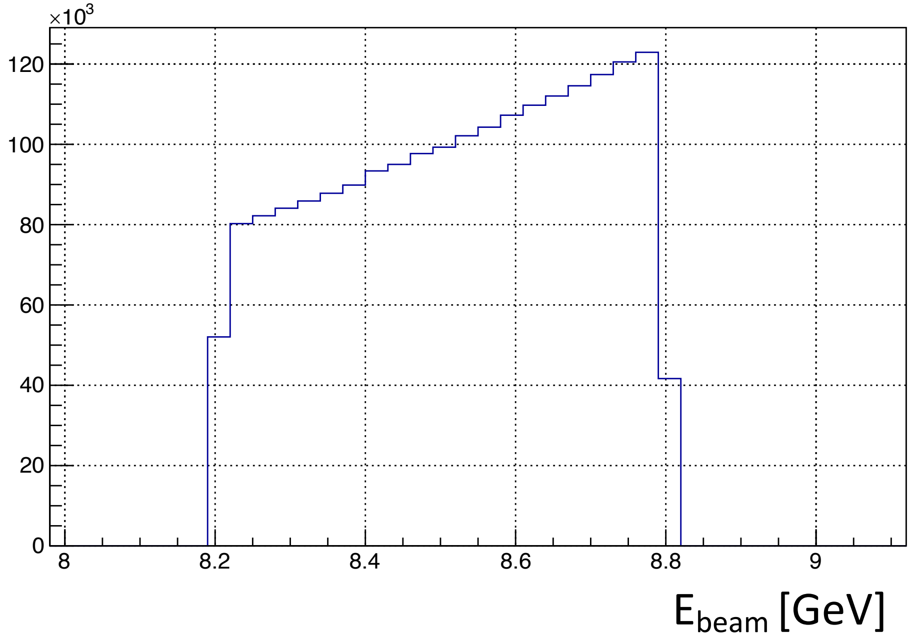
Generated amplitudes are

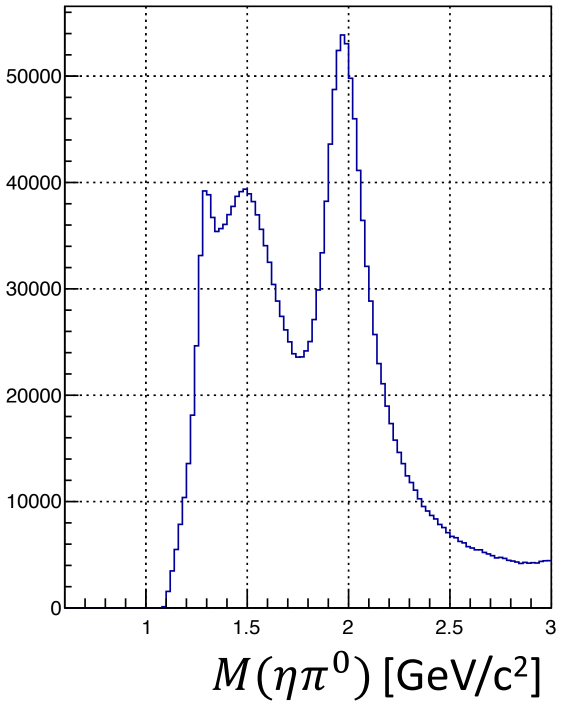
- P1/π_1(1600 MeV) (exotic)
- D1/a2 (1320 MeV)
- G1/a_4 (1995)

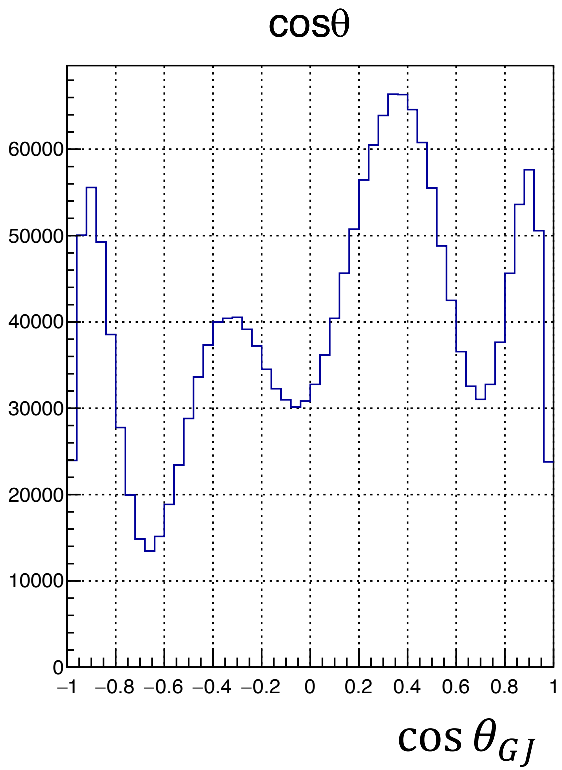
Φ=1.77 Deg.

P_γ =0.3

J	M	ε	Real	Imaginary	BW Mass	BW Width
1	1	± 1	200	200	1.564	0.492
2	1	± 1	50	50	1.306	0.114
4	1	± 1	5	0	1.996	0.255







Config file for fitting with generated amplitudes

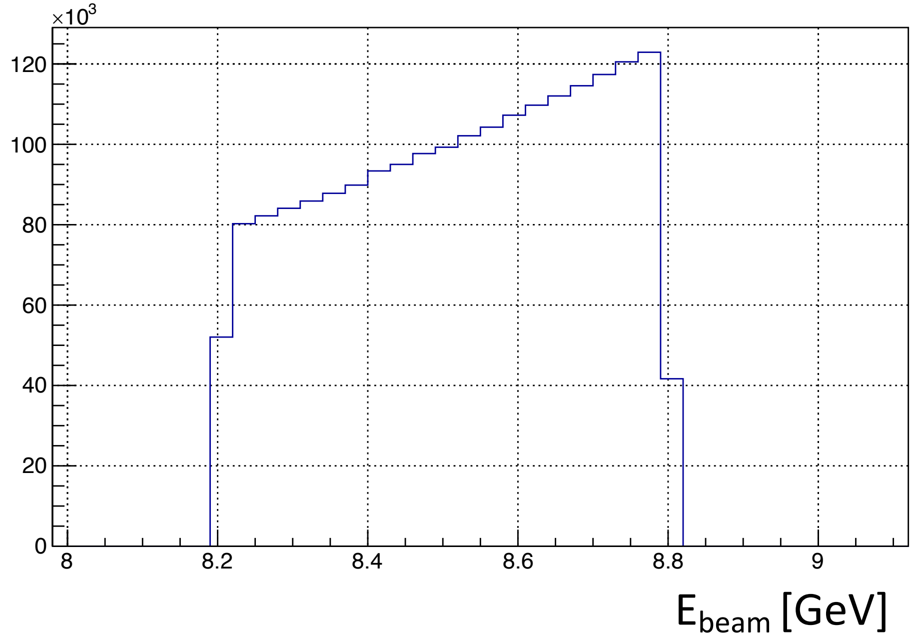
```
#define beamConfig beamconfig.cfg
define polVal 0.3

# definition of resonances
define atwolight 1.306 0.114
define pione 1.564 0.492
define afour 1.996 0.255

reaction EtaPrimePi0 Beam Proton EtaPrime Pi0

sum EtaPrimePi0 NegativeRe
sum EtaPrimePi0 NegativeIm
sum EtaPrimePi0 PositiveRe
sum EtaPrimePi0 PositiveIm

parameter polAngle 1.77 fixed
# a2(1320)
amplitude EtaPrimePi0::NegativeRe::D1- Zlm 2 1 +1 -1 polAngle polVal
amplitude EtaPrimePi0::NegativeRe::D1- BreitWigner atwolight 2 2 3
amplitude EtaPrimePi0::PositiveIm::D1+ Zlm 2 1 -1 -1 polAngle polVal
amplitude EtaPrimePi0::PositiveIm::D1+ BreitWigner atwolight 2 2 3
amplitude EtaPrimePi0::PositiveRe::D1+ Zlm 2 1 +1 +1 polAngle polVal
amplitude EtaPrimePi0::PositiveRe::D1+ BreitWigner atwolight 2 2 3
amplitude EtaPrimePi0::NegativeIm::D1- Zlm 2 1 -1 +1 polAngle polVal
amplitude EtaPrimePi0::NegativeIm::D1- BreitWigner atwolight 2 2 3

#pi1(1600)
amplitude EtaPrimePi0::NegativeRe::P1- Zlm 1 1 +1 -1 polAngle polVal
amplitude EtaPrimePi0::NegativeRe::P1- BreitWigner pione 1 2 3
amplitude EtaPrimePi0::PositiveIm::P1+ Zlm 1 1 -1 -1 polAngle polVal
amplitude EtaPrimePi0::PositiveIm::P1+ BreitWigner pione 1 2 3
amplitude EtaPrimePi0::PositiveRe::P1+ Zlm 1 1 +1 +1 polAngle polVal
amplitude EtaPrimePi0::PositiveRe::P1+ BreitWigner pione 1 2 3
amplitude EtaPrimePi0::NegativeIm::P1- Zlm 1 1 -1 +1 polAngle polVal
amplitude EtaPrimePi0::NegativeIm::P1- BreitWigner pione 1 2 3
```

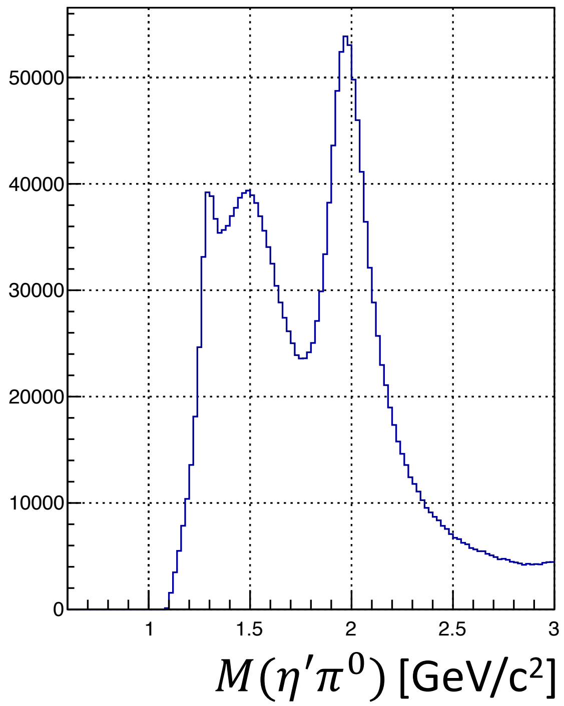
Zlm as suggested in GlueX doc-4094 (M. Shepherd)
argument 1 : j
argument 2 : m
argument 3 : real (+1) or imaginary (-1) part
argument 4 : 1 + (+1/-1) * P_gamma
argument 5 : polarization angle (in Deg.)
argument 6 : beam properties config file or fixed polarization

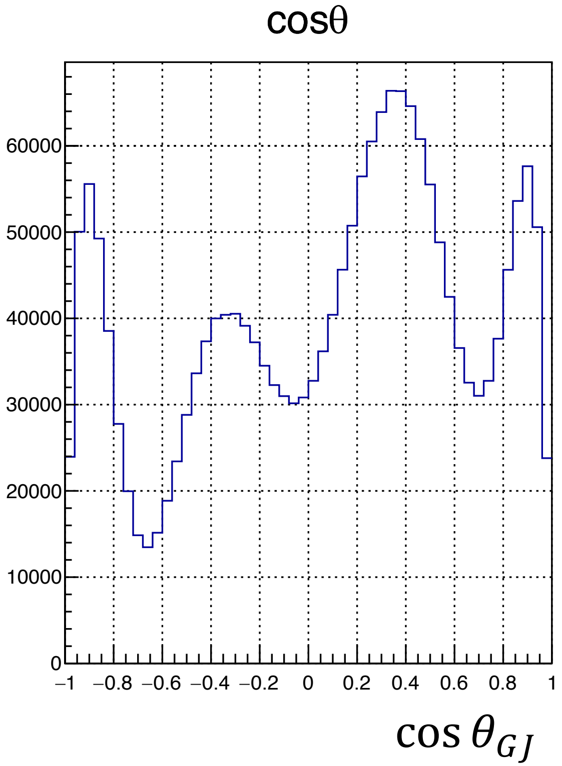
Config file for fitting with generated amplitudes

```
#a4(1996)
amplitude EtaPrimePi0::NegativeRe::G1- Zlm 4 1 +1 -1 polAngle polVal
amplitude EtaPrimePi0::NegativeRe::G1- BreitWigner afour 4 2 3
amplitude EtaPrimePi0::PositiveIm::G1+ Zlm 4 1 -1 -1 polAngle polVal
amplitude EtaPrimePi0::PositiveIm::G1+ BreitWigner afour 4 2 3
amplitude EtaPrimePi0::PositiveRe::G1+ Zlm 4 1 +1 +1 polAngle polVal
amplitude EtaPrimePi0::PositiveRe::G1+ BreitWigner afour 4 2 3
amplitude EtaPrimePi0::NegativeIm::G1- Zlm 4 1 -1 +1 polAngle polVal
amplitude EtaPrimePi0::NegativeIm::G1- BreitWigner afour 4 2 3

# initialize production coefficients
initialize EtaPrimePi0::NegativeRe::P1- cartesian 20.0 20.0
initialize EtaPrimePi0::PositiveIm::P1+ cartesian 20.0 20.0
#initialize EtaPrimePi0::PositiveRe::P1+ cartesian 20.0 20.0
#initialize EtaPrimePi0::NegativeIm::P1- cartesian 20.0 20.0

initialize EtaPrimePi0::NegativeRe::D1- cartesian 50.0 50.0
initialize EtaPrimePi0::PositiveIm::D1+ cartesian 50.0 50.0
#initialize EtaPrimePi0::PositiveRe::D1+ cartesian 50.0 50.0
#initialize EtaPrimePi0::NegativeIm::D1- cartesian 50.0 50.0

initialize EtaPrimePi0::NegativeRe::G1- cartesian 100.0 0.0 real
initialize EtaPrimePi0::PositiveIm::G1+ cartesian 100.0 0.0 real
#initialize EtaPrimePi0::PositiveRe::G1+ cartesian 100.0 0.0 real
#initialize EtaPrimePi0::NegativeIm::G1- cartesian 100.0 0.0 real

constrain EtaPrimePi0::NegativeRe::P1- EtaPrimePi0::NegativeIm::P1-
constrain EtaPrimePi0::PositiveIm::P1+ EtaPrimePi0::PositiveRe::P1+
constrain EtaPrimePi0::NegativeRe::D1- EtaPrimePi0::NegativeIm::D1-
constrain EtaPrimePi0::PositiveIm::D1+ EtaPrimePi0::PositiveRe::D1+
constrain EtaPrimePi0::NegativeRe::G1- EtaPrimePi0::NegativeIm::G1-
constrain EtaPrimePi0::PositiveRe::G1+ EtaPrimePi0::PositiveIm::G1+
```

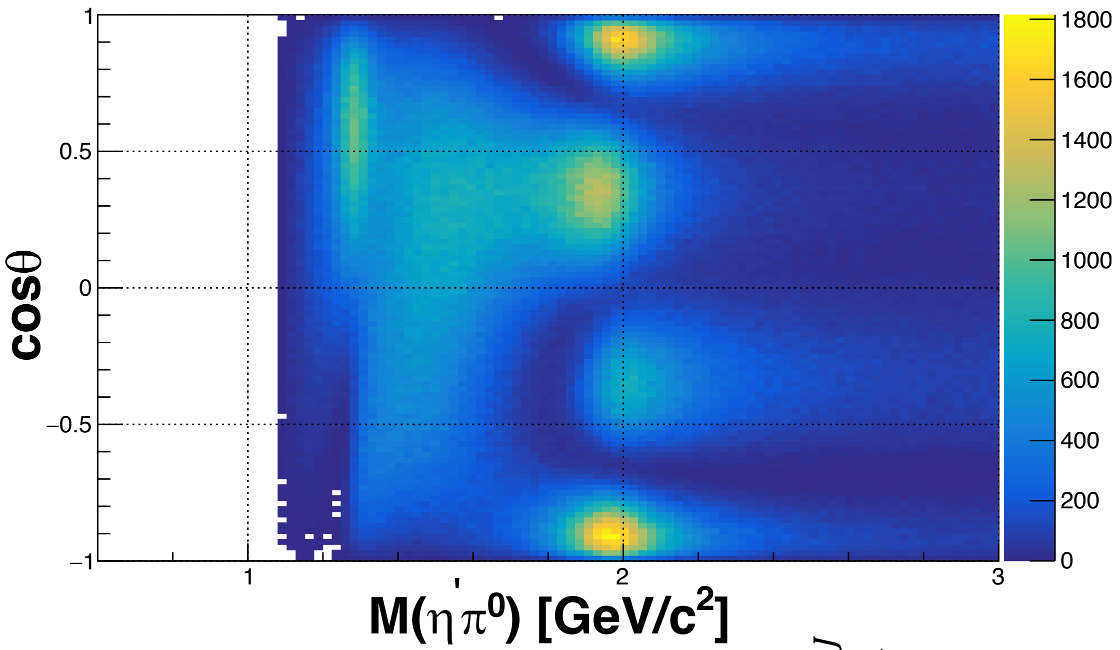
Generated 2*10⁶ $(p\eta'\pi^0)$events with AmpTools

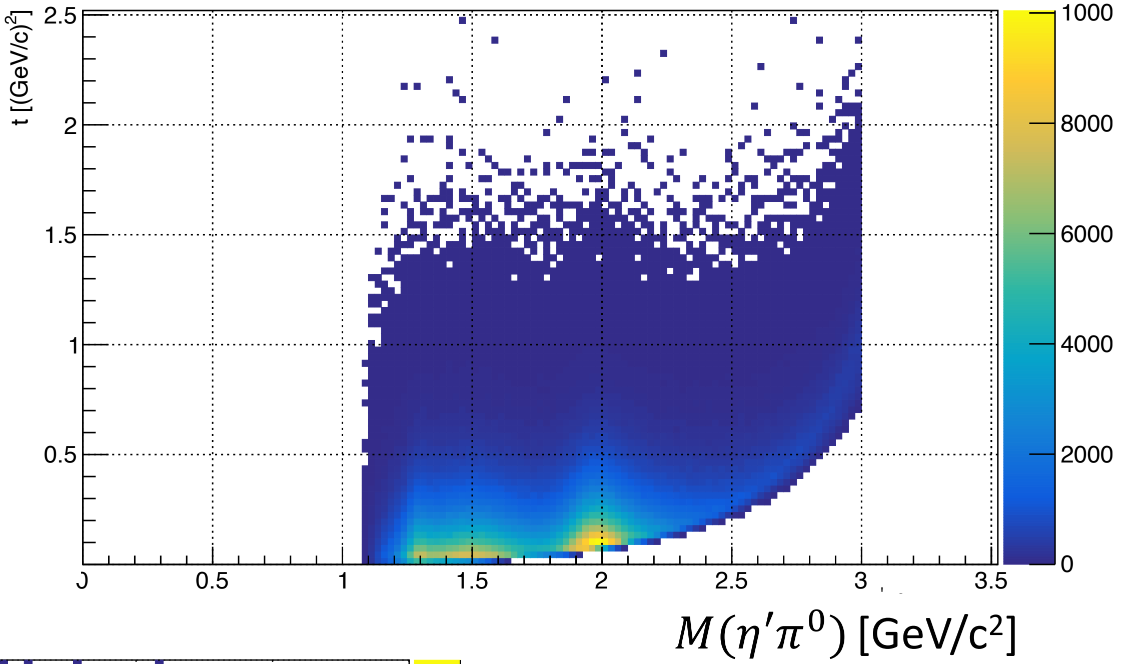


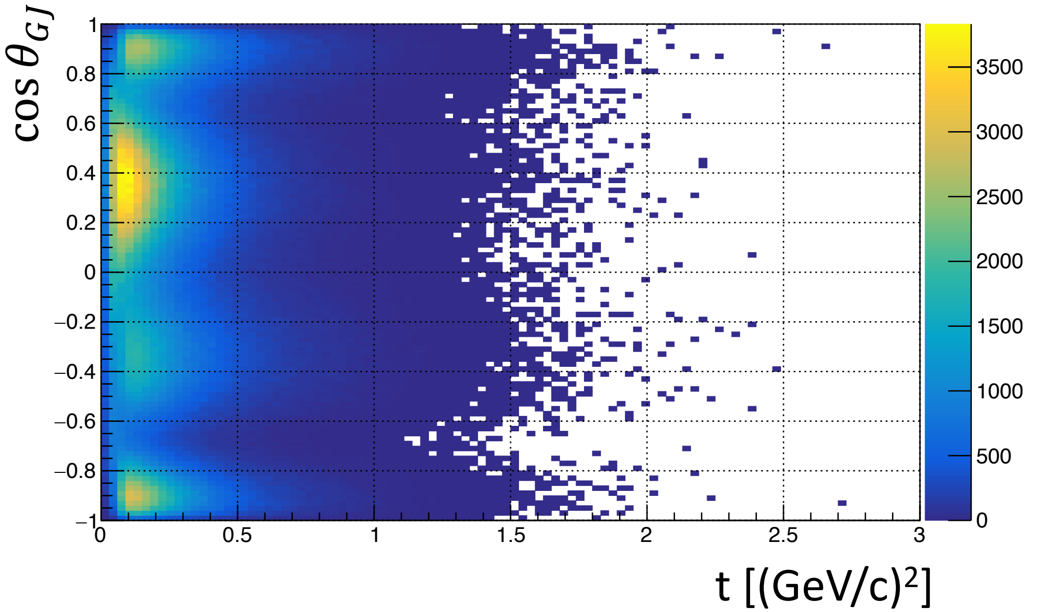




Generated 2*10⁶ $(p\eta'\pi^0)$ events with AmpTools

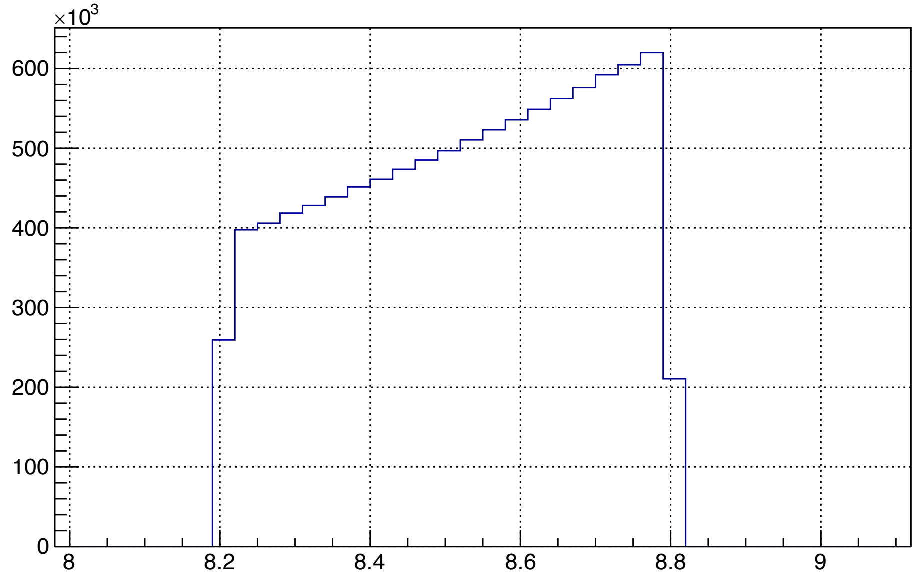




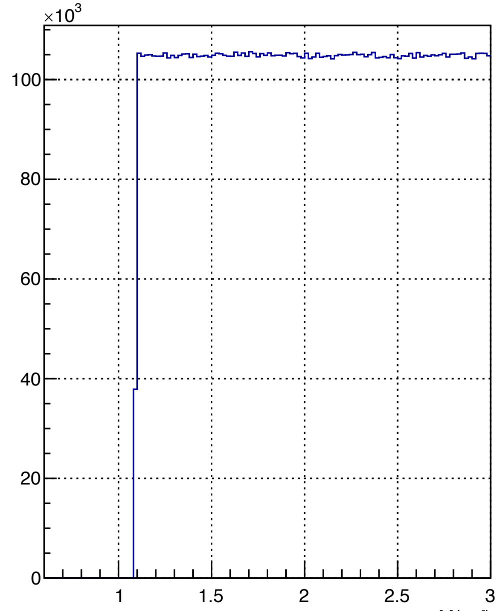


Generated 10*10⁶ $(p\eta'\pi^0)$ flat events with AmpTools

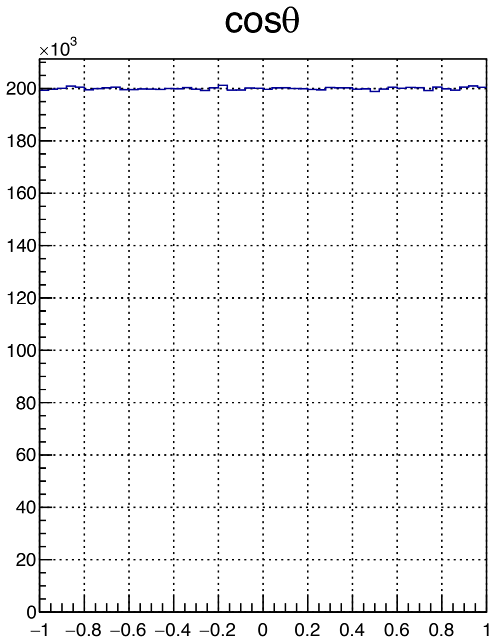
- Flat in $\cos\theta_{GJ}$
- Flat in $M(\eta\pi^0)$



E_{beam} [GeV]

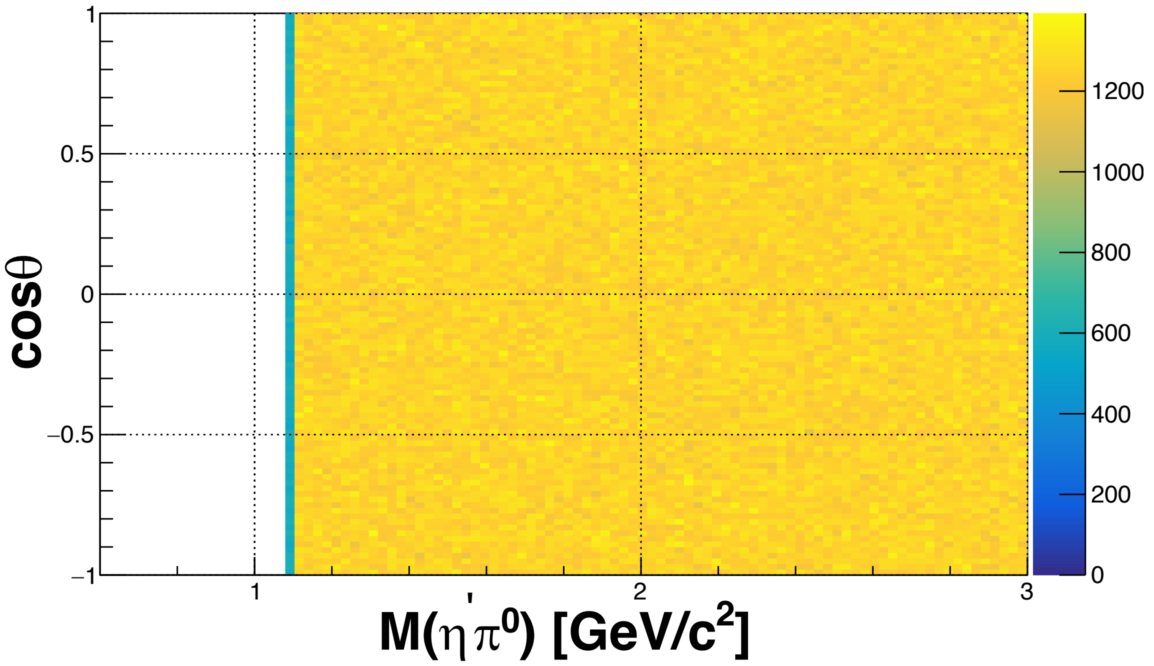


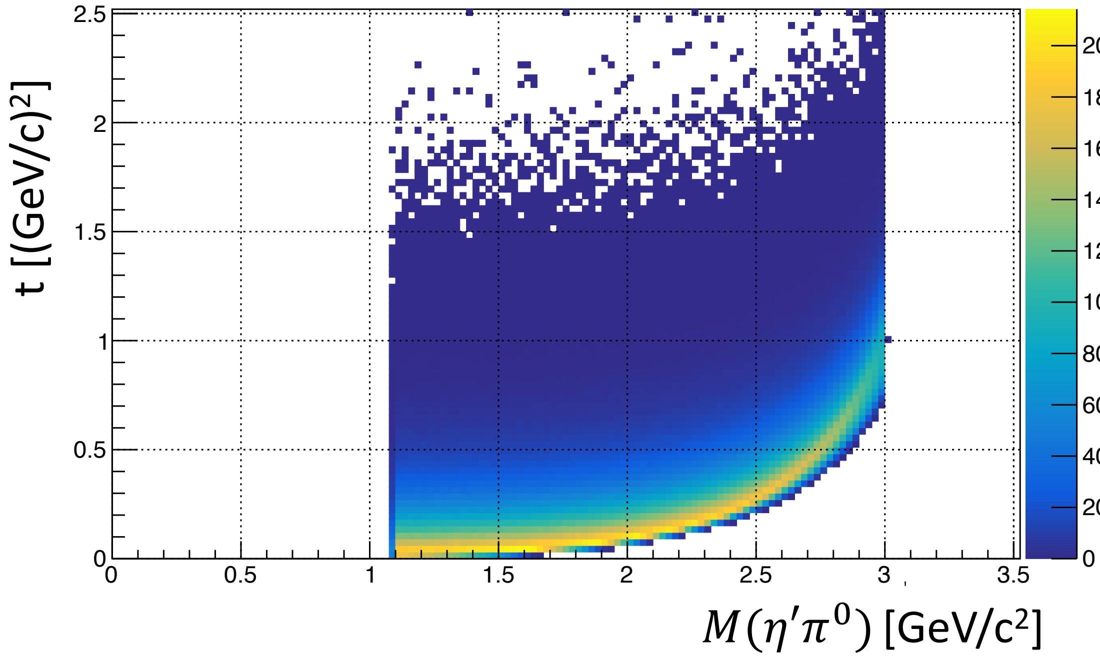
$M(\eta\pi^0)$ [GeV/c²]

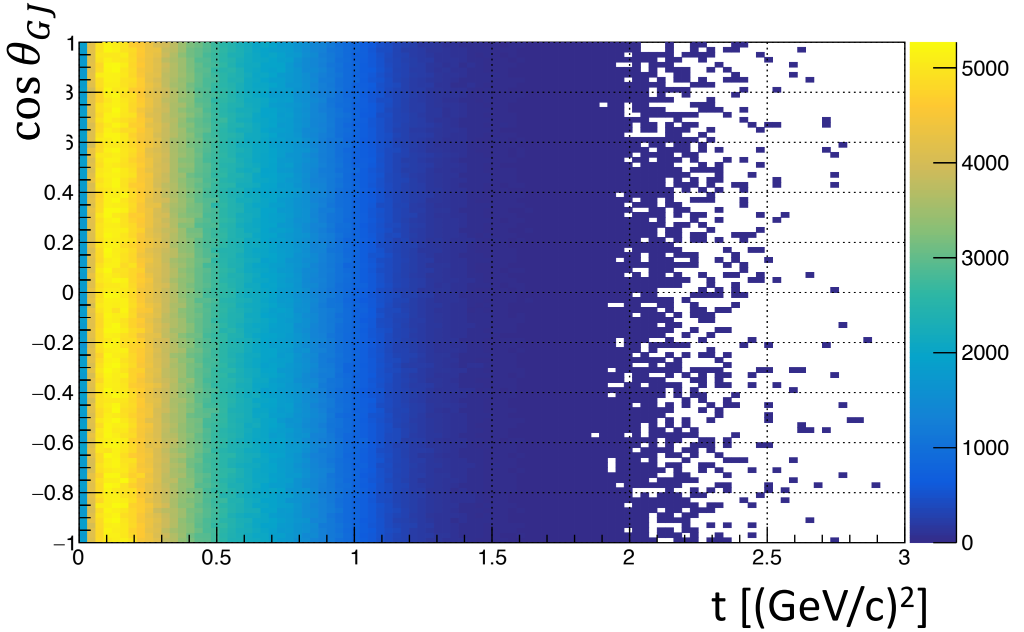


$\cos\theta_{GJ}$

Generated $24*10^6$ $(p\eta'\pi^0)$ flat events with AmpTools



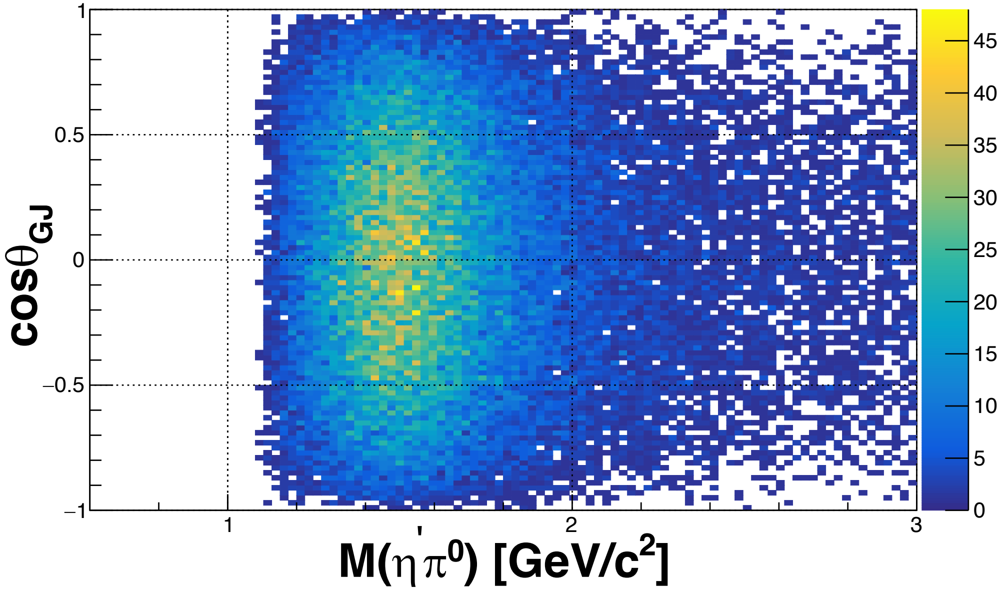


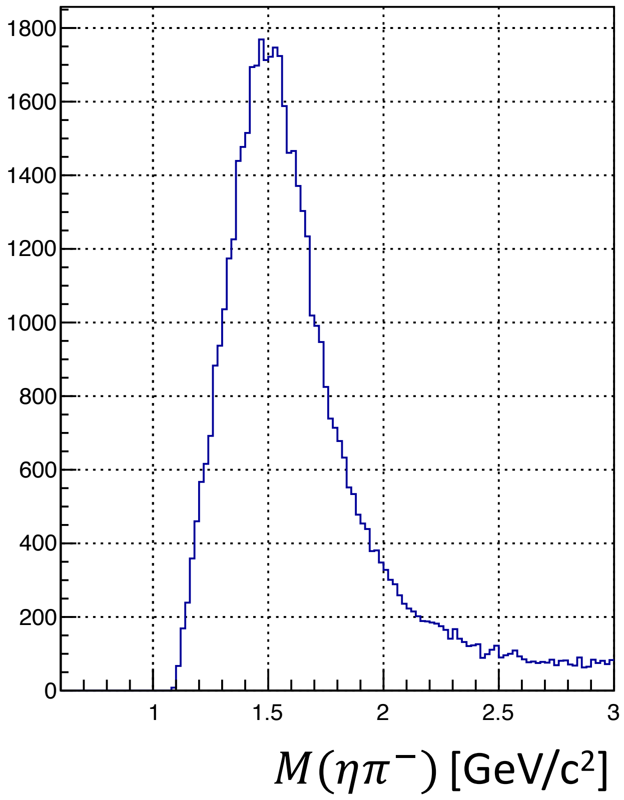


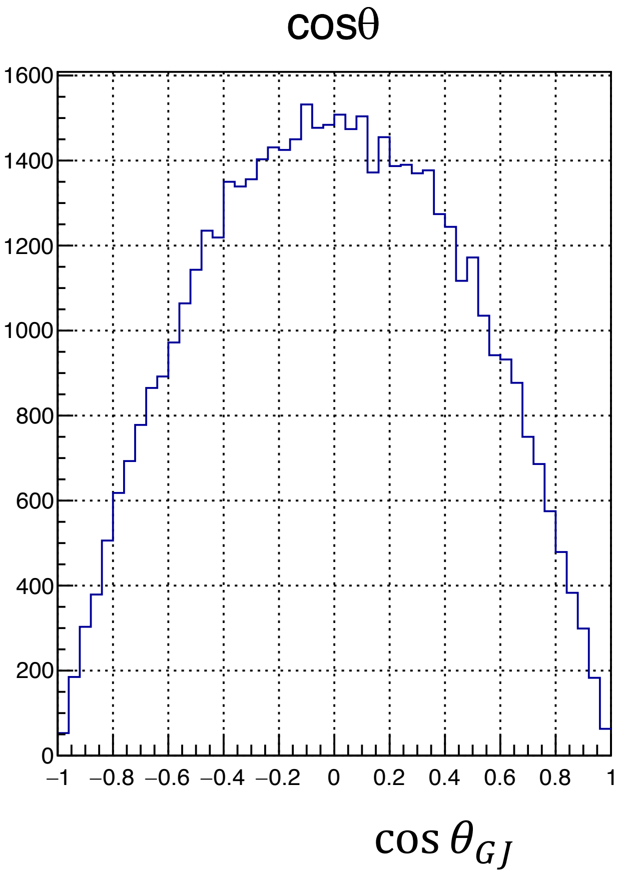
Generated single wave 50*10^3 events with AmpTools

- P1/π_1(1600 MeV) (exotic)

J	M	ε	Real	Imaginary	BW Mass	BW Width
1	1	−1	200	200	1.564	0.492





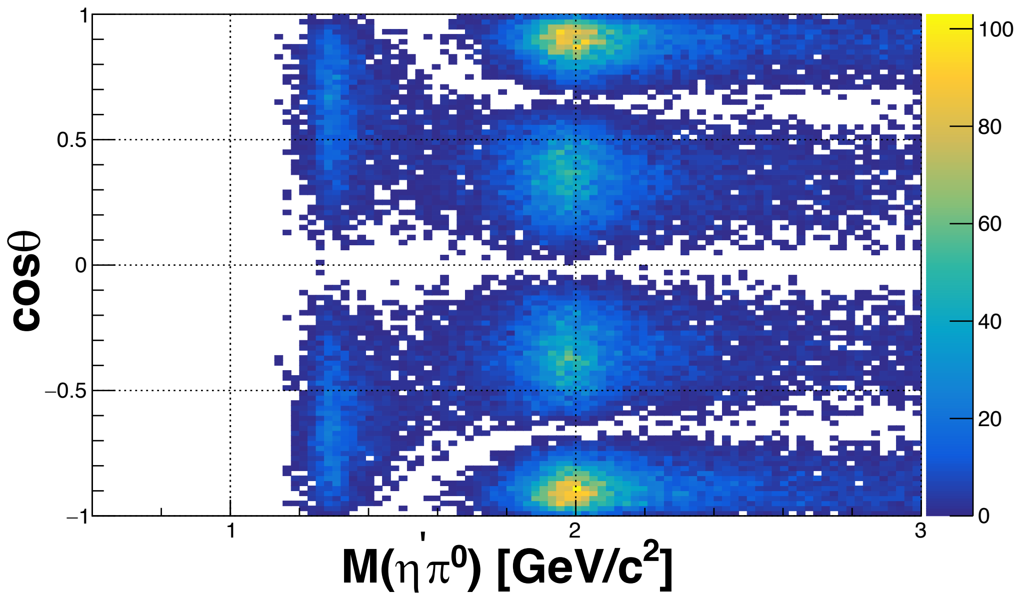


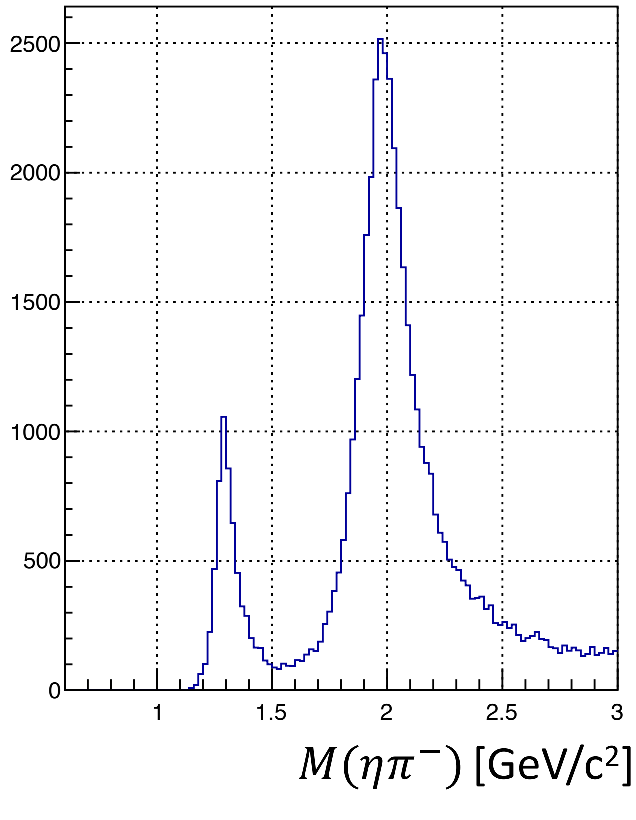
Generated even wave 50*10^3 events with AmpTools

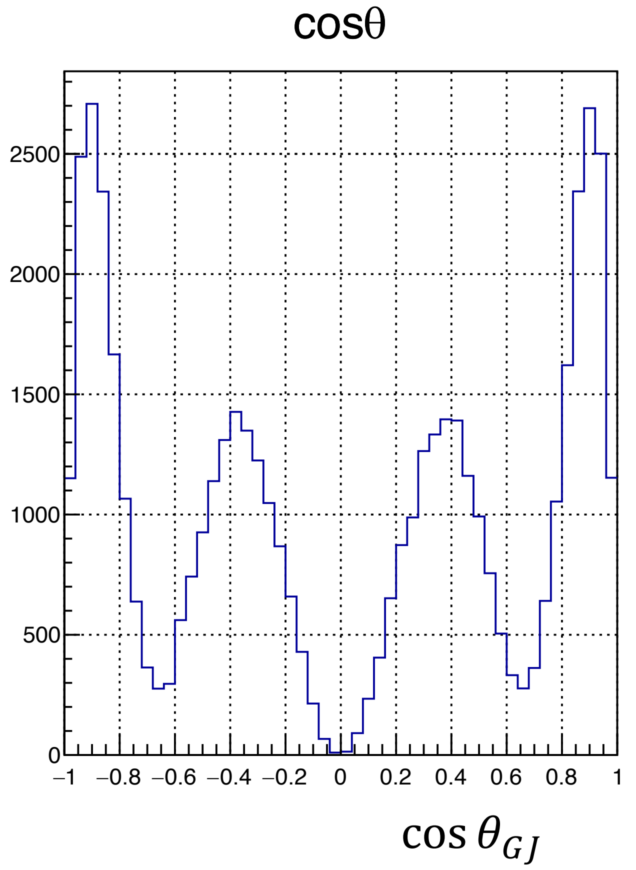
Generated amplitudes are

- D1/a2 (1320 MeV)
- G1/a_4 (1995)

J	M	ε	Real	Imaginary	BW Mass	BW Width
2	1	±1	50	50	1.306	0.114
4	1	±1	5	0	1.996	0.255







Generated odd wave $50*10^3$ events with AmpTools

Generated amplitudes are

- P1/π_1(1600 MeV) (exotic)

J	M	ε	Real	Imaginary	BW Mass	BW Width
1	1	±1	200	200	1.564	0.492