Photoproduction of the $f_1(1285)$ Meson

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Ph.D. work of Ryan Dickson, completed 2011

arXiv:1604.07425 [nucl-ex], Accepted by Phys. Rev. C

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Outline

- What are the $f_1(1285)$ and $\eta(1295)$ mesons?
- Identification of the state in CLAS/g11
- Results for:
  - Mass and Width
  - Differential cross sections - model comparisons
  - Branching ratios $\eta \pi \pi$, $\gamma \rho^0$, $K K \pi^-$
  - Dalitz plot analysis
    - spin and parity determination
Two Players:

- $f_1(1285) \quad I^G(J^{PC}) = 0^+(1^{++})$
  - Well-established axial-vector meson seen in hadronic reactions;
    - Seen in experimental PWA analyses
    - Seen in Lattice QCD
  - Possible “dynamically generated” $\bar{K}K^*$ – c.c. state

- $\eta(1295) \quad I^G(J^{PC}) = 0^+(0^{-+})$
  - A “controversial” state seen in $\pi^- p \rightarrow \eta \pi^+ \pi^- n$
    - Seen only in PWA, e.g. J. Manak et al., E852/BNL
  - Important in the enumeration of mesonic states
First Observation of $f_1(1285)$ or $\eta(1295)$ in 
$\gamma p \rightarrow p x \rightarrow p \pi^+ \pi^-(\eta)$

Which state is it? $f_1(1285)$, $\eta(1295)$, or both?

Statistics in CLAS g11 data: $\sim 1.5 \times 10^5 \ x(1280)$ events
Two $x \rightarrow K K \pi$ decay modes

- Detect $p K^+ \pi^- (K^0)$ (left)
- Detect $p K^- \pi^+ (\bar{K}^0)$ (right)
- Combine channels prior to yield extraction using Voigtian + polynomial

$W = 2.45$ GeV

$-0.2 < \cos \theta^{\text{c.m.}} < 0.0$
Cross-check $\eta'$ cross section

- Compare two CLAS analyses of $\eta'$ photoproduction
  - Same data set, using different methods
    - Red: Williams & Krahn et al.*
    - Blue: Dickson et al. (this work)
  - Good agreement between independent analyses
- Use (small) differences to quantify systematic uncertainty

(Note log scale)

Results

arXiv:1604.07425 [nucl-ex], Accepted by Phys. Rev. C
R. Dickson et al., CLAS Collaboration
Mass & Width Measurement

- Mass (GeV) vs. $\cos\theta^{c.m.}$
  - $W = 2.35$ GeV
  - $W = 2.45$ GeV
  - $W = 2.55$ GeV
  - $W = 2.65$ GeV

- Width (MeV) vs. $\cos\theta^{c.m.}$
  - $W = 2.35$ GeV
  - $W = 2.45$ GeV
  - $W = 2.55$ GeV
  - $W = 2.65$ GeV
Mass & Width Measurement

<table>
<thead>
<tr>
<th>Channel</th>
<th>Mass (MeV/c²)</th>
<th>Width (MeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta' \rightarrow \eta\pi^+\pi^- )</td>
<td>958.48 ± 0.04</td>
<td>( \Gamma \ll \sigma_{\text{exp}} )</td>
</tr>
<tr>
<td>( x \rightarrow \eta\pi^+\pi^- )</td>
<td>1281.0 ± 0.8</td>
<td>18.4 ± 1.4</td>
</tr>
<tr>
<td>( \eta' )</td>
<td>957.78 ± 0.06</td>
<td>0.198 ± 0.009</td>
</tr>
<tr>
<td>( f_1(1285) )</td>
<td>1281.9 ± 0.5</td>
<td>24.2 ± 1.1</td>
</tr>
<tr>
<td>( \eta(1295) )</td>
<td>1294 ± 4</td>
<td>55 ± 5</td>
</tr>
</tbody>
</table>

- Mass consistent with PDG value for \( f_1(1285) \) not \( \eta(1295) \)
- Width is smaller than PDG by several \( \sigma \)
Cross Section vs. Angle and $W$

$$\gamma p \rightarrow pf_1(1285) \rightarrow p\pi^+\pi^-(\eta)$$

- **Differential cross-sections**
  - $\eta\pi^+\pi^-$ final state
  - total rate not measured

- **Systematic uncertainty**
- Very weak forward peaking seen
  - Cross section falls at very forward angles
Compare Mesons: $f_1$ and $\eta'(958)$

- $f_1(1285)$ is produced "flatter" than the $\eta'$
- (Note logarithmic scale)
- Clue about production: not meson-exchange dominated like the $\eta'$
Comparison with Models

- **Solid red**: Effective Lagrangian with meson exchange
  - Kochelev et al.

- **Dashed**: Effective Lagrangian with meson exchange
  - Uncontrolled hadronic form factor cut-offs
  - J-J. Xie (unpublished, private comm.)

- **Dotted**: "Holographic QCD" model
  - S. Domokos: meson exchange with specific recipe to compute couplings

Event-by-event, rescale meson sidebands to lie within the Dalitz plot contour

Algebraic method developed to do this projection...
Dalitz analysis of $x \rightarrow \eta \pi^+ \pi^-$

Background-subtracted acceptance-corrected Dalitz plot reveals dominance of decay via $a_0^\pm \pi^\mp$ intermediate states.

Strong interference of bands seen. Amplitude analysis!
From decay: find spin & parity

\[ x \rightarrow a_0^\pm + \pi^\mp \]

\[ J^P \rightarrow 0^+ + 0^- + L^{-1L} \]

\( f_1 \): p-wave decay

\( \eta \): s-wave decay

Adair system
From decay: find spin & parity

\[ x \rightarrow a_0^\pm + \pi^\mp \]
\[ J^P \rightarrow 0^+ + 0^- + L^{-1L} \]

\( f_1 \): \( p \)-wave decay
\( \eta \): \( s \)-wave decay

- tests “\( s \)-channel helicity conservation”
From decay: find spin & parity

\[ x \rightarrow a_0^{\pm} + \pi^\mp \]

\[ J^P \rightarrow 0^+ + 0^- + L^{-1L} \]

Gottfried-Jackson system - tests “t-channel helicity conservation”

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Helicity system fit

- $s$-channel helicity system
- Components:
  - Blue: $L=1, m=0$
  - Green: $L=1, m=\pm 1$
  - Red: Total
- $a_0^\pm$ interference reproduced
- $p$-wave decay and negative parity demonstrated
- Decaying meson is definitely the $f_1(1285)$
Gottfried-Jackson system fit

- $t$-channel helicity system
- Components:
  - Blue: $L=1, m=0$
  - Green: $L=1, m=\pm 1$
  - Red: Total
  - Cyan: $L=0$ fit
- $a_0$ interference NOT reproduced
- Decaying meson is not aligned in this system

$M^2(\eta \pi^-)$ vs. $M^2(\eta \pi^+)$, Folded

Data

Simulation

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# Properties of $f_1(1285)$ vs. $\eta(1295)$

<table>
<thead>
<tr>
<th></th>
<th>$f_1(1285)$</th>
<th>$\eta(1295)$</th>
<th>CLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I^G(J^{PC})$</td>
<td>$0^+(1^{++})$</td>
<td>$0^+(0^{-+})$</td>
<td>$J^P = 1^+$</td>
</tr>
<tr>
<td>Mass (MeV)</td>
<td>$1281.9 \pm 0.5$</td>
<td>$1294 \pm 4$</td>
<td>$1281.0 \pm 0.8$</td>
</tr>
<tr>
<td>Width, $\Gamma$ (MeV)</td>
<td>$24.2 \pm 1.1$</td>
<td>$55 \pm 5$</td>
<td>$18.4 \pm 1.4$</td>
</tr>
<tr>
<td>Decays:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$4\pi$</td>
<td>$33 \pm 2%$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\eta \pi \pi$</td>
<td>$52 \pm 2%$</td>
<td>Seen</td>
<td>-</td>
</tr>
<tr>
<td>$\Gamma(a_0\pi ,(\text{no}KK))$</td>
<td>$69 \pm 13%$</td>
<td>-</td>
<td>$74 \pm 9%$</td>
</tr>
<tr>
<td>$\Gamma(K\bar{K}\pi)$</td>
<td>$17.1 \pm 1.3%$</td>
<td>-</td>
<td>$21.6 \pm 3.1%$</td>
</tr>
<tr>
<td>$\Gamma(\gamma\rho^0)$</td>
<td>$10.5 \pm 2.2%$</td>
<td>Not seen</td>
<td>$4.7 \pm 1.8%$</td>
</tr>
</tbody>
</table>
Conclusions: The photoproduced meson CLAS sees at 1281 MeV is the $f_1(1285)$.

- Production mechanism is more consistent with $s$-channel process ($N^*$-decay...) than $t$-channel process (meson-exchange)
  - Cross section is much "flatter" than $\eta'$ production
  - The $f_1(1285)$ is aligned in the $s$-channel helicity system, seen via $\eta\pi^+\pi^-$ Dalitz-plot amplitude analysis

- $\Gamma \sim 18.2$ MeV; narrower than PDG average

- Branching ratios measured:
  - $K K \pi / \eta \pi \pi$, $a_0 \pi / \eta \pi \pi$ and $\gamma \rho^0 / \eta \pi \pi$
Backup Slides
CLAS Experiment

- **Photoproduction:**
  - **Targets:** unpolarized LH$_2$, polarized p, & HD-ice
  - **Beams:** unpolarized, circular, linear, to $\sim$5 GeV
  - **Reconstructed** $K^+p\pi^-(\pi^0)$ or $K^+\pi^+\pi^-(n)$
  - $20 \times 10^9$ triggers $\rightarrow 1.41 \times 10^6$ KY$\pi$ events in g11a

- **Electroproduction:**
  - $Q^2$ from $\sim$0.5 to $\sim$3 (GeV/c)$^2$
  - Structure functions from Rosenbluth and beam-helicity separations
### Quark Model for Mesons

Table 15.2: Suggested $q\bar{q}$ quark-model assignments for some of the observed light mesons. Mesons in bold face are included in the Meson Summary Table. The wave functions $f$ and $f'$ are given in the text. The singlet-octet mixing angles from the quadratic and linear mass formulae are also given for the well established nonets. The classification of the $0^{++}$ mesons is tentative: The light scalars $a_0(980)$, $f_0(980)$, and $f_0(500)$ are often considered as meson-meson resonances or four-quark states, and are omitted from the table. Not shown either is the $f_0(1500)$ which is hard to accommodate in the nonet. The isoscalar $0^{++}$ mesons are expected to mix. See the “Note on Scalar Mesons” in the Meson Listings for details and alternative schemes.

<table>
<thead>
<tr>
<th>$n^{2s+1}L_J$</th>
<th>$J^{PC}$</th>
<th>$l = 1$</th>
<th>$l = \frac{1}{2}$</th>
<th>$l = 0$</th>
<th>$l = 0$</th>
<th>$\theta_{\text{quad}}$</th>
<th>$\theta_{\text{lin}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^1S_0$</td>
<td>$0^{-+}$</td>
<td>$\pi$</td>
<td>$K$</td>
<td>$\eta$</td>
<td>$\eta'(958)$</td>
<td>$-11.4$</td>
<td>$-24.5$</td>
</tr>
<tr>
<td>$1^3S_1$</td>
<td>$1^{--}$</td>
<td>$\rho(770)$</td>
<td>$K^*(892)$</td>
<td>$\phi(1020)$</td>
<td>$\omega(782)$</td>
<td>$39.1$</td>
<td>$36.4$</td>
</tr>
<tr>
<td>$1^1P_1$</td>
<td>$1^{++}$</td>
<td>$b_1(1235)$</td>
<td>$K_{1B}^*$</td>
<td>$h_1(1380)$</td>
<td>$h_1(1170)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3P_0$</td>
<td>$0^{++}$</td>
<td>$a_0(1450)$</td>
<td>$K_0^*(1430)$</td>
<td>$f_0(1710)$</td>
<td>$f_0(1370)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3P_1$</td>
<td>$1^{++}$</td>
<td>$a_1(1260)$</td>
<td>$K_{1A}^*$</td>
<td>$f_1(1420)$</td>
<td>$f_1(1285)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3P_2$</td>
<td>$2^{++}$</td>
<td>$a_2(1320)$</td>
<td>$K_2^*(1430)$</td>
<td>$f_2(1525)$</td>
<td>$f_2(1270)$</td>
<td>$32.1$</td>
<td>$30.5$</td>
</tr>
<tr>
<td>$1^1D_2$</td>
<td>$2^{-+}$</td>
<td>$\pi_2(1670)$</td>
<td>$K_2(1770)^*$</td>
<td>$\eta_2(1870)$</td>
<td>$\eta_2(1645)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3D_1$</td>
<td>$1^{--}$</td>
<td>$\rho(1700)$</td>
<td>$K^*(1680)$</td>
<td>$\omega(1650)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3D_2$</td>
<td>$2^{--}$</td>
<td>$K_2(1820)$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3D_3$</td>
<td>$3^{--}$</td>
<td>$\rho_3(1690)$</td>
<td>$K_3^*(1780)$</td>
<td>$\phi_3(1850)$</td>
<td>$\omega_3(1670)$</td>
<td>$31.8$</td>
<td>$30.8$</td>
</tr>
<tr>
<td>$1^3F_4$</td>
<td>$4^{++}$</td>
<td>$a_4(2040)$</td>
<td>$K_4^*(2045)$</td>
<td>$f_4(2050)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3G_6$</td>
<td>$5^{--}$</td>
<td>$\rho_6(2350)$</td>
<td>$K_6^*(2380)$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^3H_6$</td>
<td>$6^{++}$</td>
<td>$a_6(2450)$</td>
<td></td>
<td></td>
<td></td>
<td>$f_6(2510)$</td>
<td></td>
</tr>
<tr>
<td>$2^1S_0$</td>
<td>$0^{-+}$</td>
<td>$\pi(1300)$</td>
<td>$K(1460)$</td>
<td>$\eta(1475)$</td>
<td>$\eta(1295)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2^3S_1$</td>
<td>$1^{--}$</td>
<td>$\rho(1450)$</td>
<td>$K^*(1410)$</td>
<td>$\phi(1680)$</td>
<td>$\omega(1420)$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The $1^{±±}$ and $2^{±}$ isospin $\frac{n}{2}$ states mix. In particular, the $K_{1A}^*$ and $K_{1B}^*$ are nearly equal (45°) mixtures of the $K_1(1270)$ and $K_1(1400)$. The physical vector mesons listed under $1^3D_1$ and $2^3S_1$ may be mixtures of $1^3D_1$ and $2^3S_1$, or even have hybrid components.
The $J^{PC} = 1^{++}$ mesons, including the $f_1(1285)$, are ‘seen’ in recent lattice calculations...

Dynamically Generated Mesons

- The $f_1(1285)$ as a $\{\bar{K}K^* + \text{c.c.}\}$ composite state
  - Chiral Lagrangian + unitarization of the pseudoscalar – vector meson nonet interaction
  - Lattice calculations
  - Expect “non-standard” production mechanisms, if true

Branching Ratios

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Stat. Uncert.</th>
<th>Syst. Uncert.</th>
<th>PDG $f_1(1285)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta\pi^+\pi^-$ Event Yield</td>
<td>$1.33\times10^5$</td>
<td>$4.9\times10^3$</td>
<td>$2.9\times10^3$</td>
<td></td>
</tr>
<tr>
<td>$\eta\pi^+\pi^-$ Acceptance</td>
<td>$0.0652$</td>
<td>$9.7\times10^{-5}$</td>
<td>$0.0072$</td>
<td></td>
</tr>
<tr>
<td>$K^\pm K^0\pi^+$ Event Yield</td>
<td>$6570$</td>
<td>$180$</td>
<td>$340$</td>
<td></td>
</tr>
<tr>
<td>$K^\pm K^0\pi^+$ Acceptance</td>
<td>$0.0149$</td>
<td>$3.18\times10^{-5}$</td>
<td>$0.0016$</td>
<td></td>
</tr>
<tr>
<td>$\gamma\rho^0$ Event Yield</td>
<td>$3790$</td>
<td>$790$</td>
<td>$850$</td>
<td></td>
</tr>
<tr>
<td>$\gamma\rho^0$ Acceptance</td>
<td>$0.0248$</td>
<td>$6.4\times10^{-5}$</td>
<td>$0.0050$</td>
<td></td>
</tr>
<tr>
<td>Isospin C.G. $\Gamma(K^\pm K^0\pi^+)/\Gamma(K\bar{K}\pi)$</td>
<td>$2/3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isospin C.G. $\Gamma(\eta\pi^+\pi^-)/\Gamma(\eta\pi\pi)$</td>
<td>$2/3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma\rho^0$ correction from $\eta'$ $d\sigma/d\Omega$</td>
<td>$0.95$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Branching Fraction $\Gamma(K\bar{K}\pi)/\Gamma(\eta\pi\pi)$ | $0.216$         | $0.010$       | $0.031$       | $0.171 \pm 0.013$ |
| Branching Fraction $\Gamma(\gamma\rho^0)/\Gamma(\eta\pi\pi)$ | $0.047$         | $0.010$       | $0.015$       | $0.105 \pm 0.022$ |

TABLE III. Relative branching fractions of the $f_1(1285)$ meson, with estimated uncertainties from all sources.

- $K\bar{K}\pi / \eta\pi\pi$ ratio agrees with PDG average
  - (isospin factors applied)
- $\gamma\rho^0 / \eta\pi\pi$ ratio smaller than PDG average by 55%
Dalitz analysis of $x \rightarrow \eta \pi^+ \pi^-$

- Subtract huge multi-pion background to reveal...
- ... dominance of decay via $a_0^{\pm} \pi^{\mp}$ intermediate state.
- Strong interference of bands seen. Amplitude analysis!

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Dalitz analysis of $\chi \rightarrow \eta \pi^+ \pi^-$

\[ A_{m=\pm 1} (m_{a_0^+ \pi^-}, m_{a_0^+ \pi^+}) = BW(m_{a_0^+ \pi^-}) W_{1,\pm 1}(\Theta_{a_0^+ \pi^-}, \phi_{a_0^+ \pi^-}) + BW(m_{a_0^- \pi^+}) W_{1,\pm 1}(\Theta_{a_0^- \pi^+}, \phi_{a_0^- \pi^+}) \]

\[ A_{m=0} (m_{a_0^+ \pi^-}, m_{a_0^- \pi^+}) = BW(m_{a_0^+ \pi^-}) \left( W_{1,0}(\Theta_{a_0^+ \pi^-}, \phi_{a_0^+ \pi^-}) + W_{0,0} \right) + BW(m_{a_0^- \pi^+}) \left( W_{1,0}(\Theta_{a_0^- \pi^+}, \phi_{a_0^- \pi^+}) + W_{0,0} \right) \]

\[ BW(m | m_0, \Gamma_0) = \frac{\sqrt{m_0 \Gamma_0}}{m_0^2 - m^2 - im_0 \Gamma_0} \frac{q(m)}{q(m_0)} \quad - \text{a Breit–Wigner for each } a_0 \]

\[ f_1 : \quad W_{L=1, m=0, \pm 1}(\Theta_H, \phi) = a Y_{1,+1}(\Theta_H, \phi) + b Y_{1,0}(\Theta_H, \phi) + a Y_{1,-1}(\Theta_H, \phi) \]

\[ \eta : \quad W_{L=0, m=0}(\Theta_H, \phi) = c Y_{0,0} \quad - \text{angular distribution in the selected system} \]

\[ T(m_{a_0^+ \pi^-}, m_{a_0^- \pi^+}) = \frac{q(m_{a_0^+ \pi^-})}{q(m_0)} \frac{q(m_{a_0^- \pi^+})}{q(m_0)} \left( \left| A_{m=\pm 1} (m_{a_0^+ \pi^-}, m_{a_0^+ \pi^+}) \right|^2 + \left| A_{m=0} (m_{a_0^+ \pi^-}, m_{a_0^- \pi^+}) \right|^2 \right) \]

- total decay-weighted magnitude squared
One Reaction Topology
(example)

\[ \gamma \rightarrow p \pi^+ \pi^- \]

\( m_x \)

\( \alpha_0^- \)

\( \pi^+ \)

\( \pi^- \)

\( \eta \)

\( \text{red} = \text{measured particles} \)
Two yield extraction methods

- **Voigtian lines shape using known CLAS resolution**
  - Convolution of BW and Gaussian

- **Monte Carlo fitting using signal and estimated multi-pion backgrounds**
  - $p\rho\pi\pi$ (green)
  - $p\phi_1(1370)$ (purple)
  - $p\pi(1280)$ (red) - signal
  - Total (blue)
Looking for $\gamma\rho^0$ decays

- Kinematic fit to $\gamma p \rightarrow p\pi^+\pi^-(\gamma)$
- Select $p_{\text{perp}} > 40$ MeV/c
- 2nd kin. fit to $\gamma p \rightarrow p\pi^+\pi^-(\pi^0)$ to reject $\pi^0$ background
- Very small signal: only extract branching ratio to $\eta\pi^+\pi^-$
  - Sum over all kinematics

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Comparison with Models

- N. Kochelev model
  - Effective Lagrangian
  - $t$-channel $\rho$ and $\omega$ exchange
  - Solid: $f_1(1285)$
  - Dashed: $\eta(1295)$
  - Dotted: sum

Poor match to data
Dalitz analysis of $x \rightarrow \eta \pi^+ \pi^-$

- Fold data on symmetry axis
- Generate “phase space” Monte Carlo events with finite width of meson and CLAS resolution included
- “Weight” the events with amplitude-based intensity

\[ x(1280) \rightarrow \eta\pi\pi \text{ Dalitz Analysis} \]

\[ M(\eta\pi^\pm)^2 \text{ vs. } M(\pi^\pm)^2 \]

\[ M(\eta\pi^\pm)^2 \text{ vs. } M(\pi^\pm)^2 \text{ Folded} \]

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Dalitz analysis of $\chi \to \eta \pi^+ \pi^-$

- Fit to full plot did not converge, so trim data to focus on 'bands'.
- Structure in unweighted Monte Carlo due to finite width and resolution effects
The $f_1(1285)$ is “aligned” in the helicity system.

The mix of $m = 0$ and $m = \pm 1$ is a property of the production mechanism in the range $2.30 < W < 2.80$ GeV.

$$P_\pm : P_0 = 31.8 : 69.2, \pm 1.4\%.$$  

- Discuss later...

- We also measure the ratio

$$\frac{\Gamma(a_0\pi(noKK))}{\Gamma(\eta\pi\pi(total))} = 74 \pm 2(stat) \pm 9(syst)\%$$

- Consistent with PDG value
Speculation re $f_1(1285)$ production

- Alignment in helicity system suggests $s$-channel $N^*$ production decays to $f_1(1285)p$
  - Can we infer $J^P$ of the $N^*$ baryon resonance?
  - $3/2^+ \rightarrow 1^+ + 1/2^+$ in $s$-wave leads to $P_\pm : P_0 = 1 : 2$ as seen in the data
  - $1/2^+ \rightarrow 1^+ + 1/2^+$ in $s$-wave leads to $P_\pm : P_0 = 2 : 1$, opposite to what data show

- But there are no known $N^*$ states with low $J$ at $W \sim 2.5$ GeV, so the question remains open
Compare meson types

At equal $W$

\[
\frac{d\sigma}{d\Omega} \text{ (nb/sr)} \rightarrow \eta \pi^+ \pi^-
\]

- $W = 2.35$ GeV
- $W = 2.45$ GeV
- $W = 2.55$ GeV
- $W = 2.65$ GeV
- $W = 2.75$ GeV
Compare meson types

At equal excess energy above threshold