Photoproduction of Excited η Resonances $\gamma p \to p\pi^+\pi^-\eta$ at CLAS

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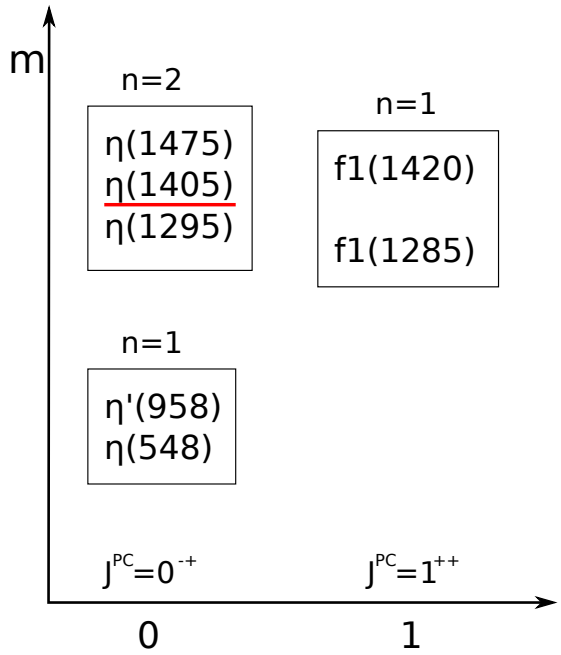
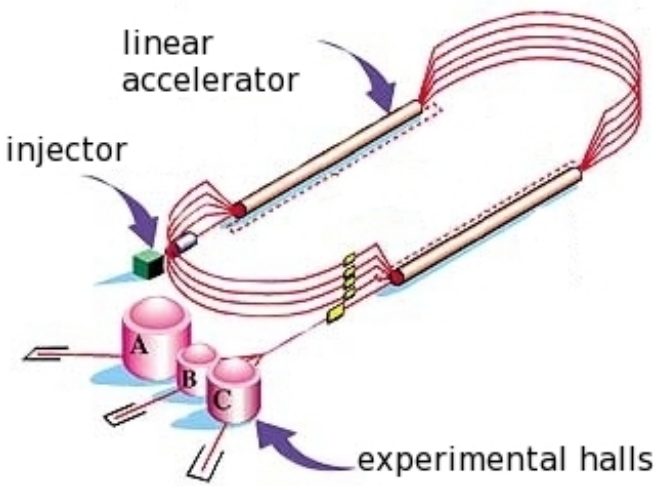
Motivation

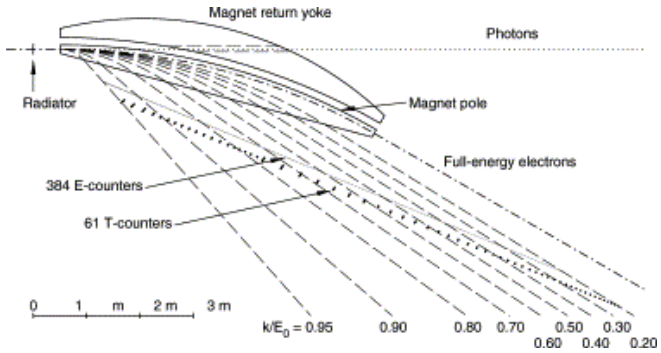
- Supernumerous resonance with $J^{PC} = 0^{-+}$
- $\eta(1295)$
  - Seen in $\pi^- p$ scattering experiments
  - Seen by DM2 in $J/\psi \to \gamma\pi^-\pi^+\eta$
  - No further observation
  - Interference with $f_1(1285)$
  - Artifact of f_1?
- $\eta(1405)$
  - Only seen in gluon rich processes like $\overline{p}p$ annihilations and radiative J/ψ decays
  - Not seen in photoproduction or $\gamma\gamma$ fusion
  - Decays to $K\overline{K}\pi$ and $\pi\pi\eta$
  - Glueball candidate
- $\eta(1475)$
  - Strong coupling to $K\overline{K}\pi$
  - Not yet seen in $\pi\pi\eta \to$ weak coupling



CEBAF and Tagger

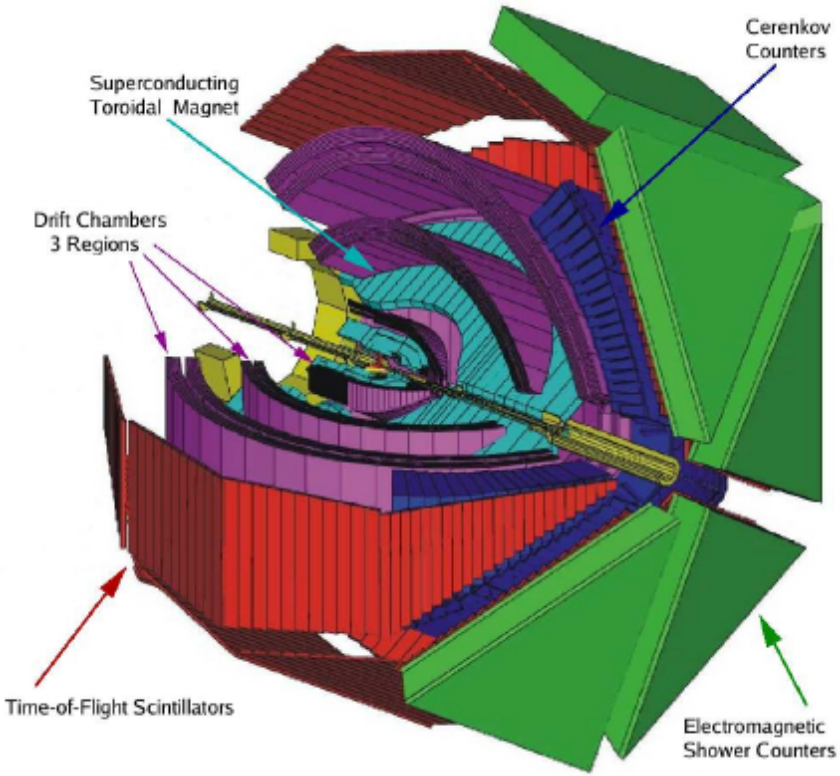


- Electron bunches of 90 μm length, seperated by 667 ps in time
- Electron kinetic energy up to 6 GeV
- Beam switchyard delivers beam bunches to any experimental area each 2.004 ns



- Energetically tagged photons ranging from 20% to 95% of incident electron beam energy
- 384 overlapping E-counters for energy measurement
  - $\Delta E_\gamma / E_\gamma \approx 10^{-3}$
- 61 T-counters provide timing information
  - 110 ps timing resolution

CEBAF Large Acceptance Spectrometer - CLAS



- Target: 40 cm in length, 4 cm in diameter, unpolarized liquid hydrogen
- Toroidal magnet (2.5 T)
- Start-Counter: timing resolution 350 ps
- Drift Chambers: $\delta p/p \leq 0.5\,\%$ for 1 GeV/c, spatial resolution 330 μm
- TOF: timing resolution 80-160 ps
- Cerenkov counter: covers polar angle from 8° to 45°, pion lepton separation up to 2.5 GeV/c

Event Selection

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

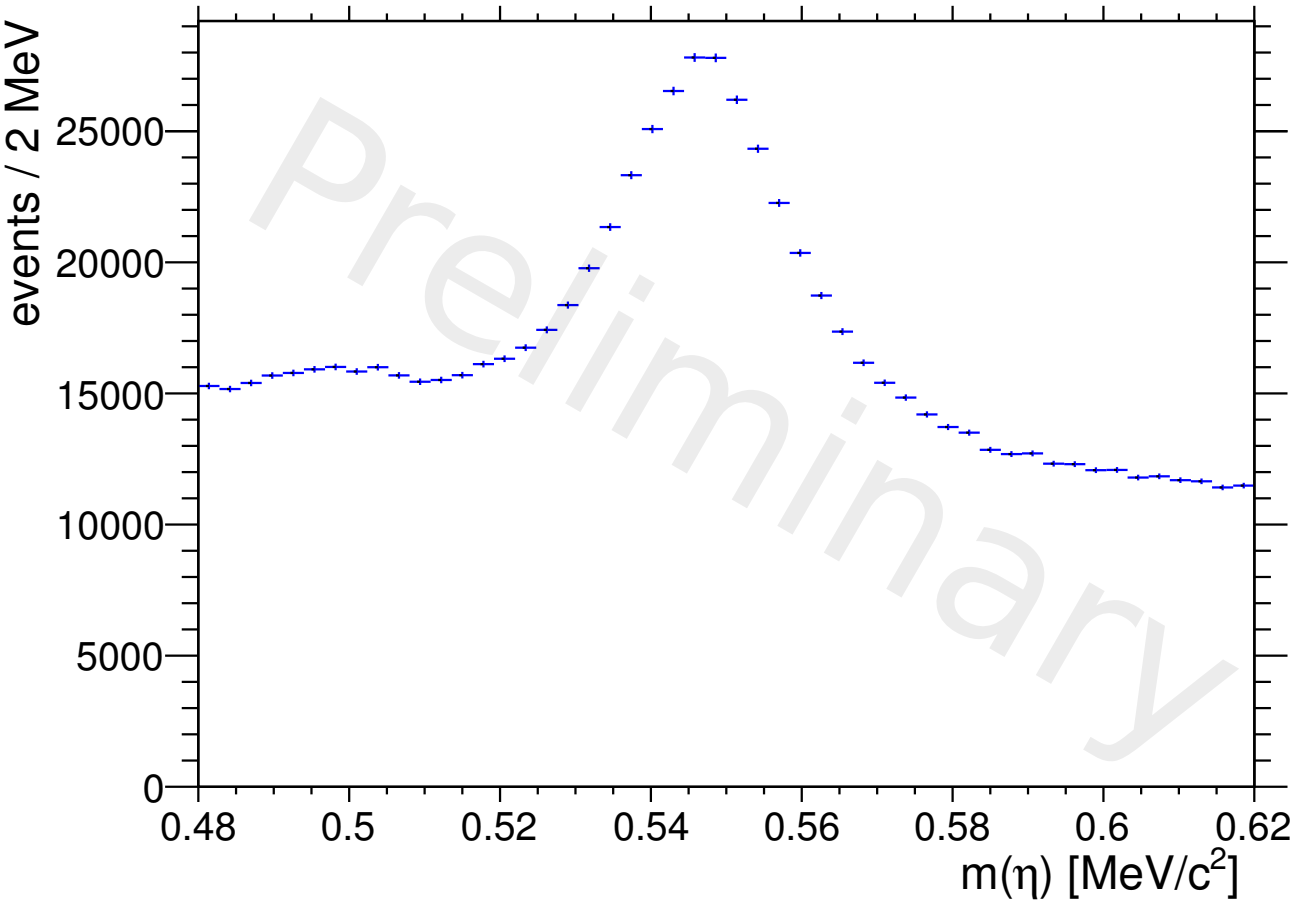
- Subset of data taken in 2009 (g12)
- Photon energy 1.5 to 5.5 GeV
- Trigger Conditions: 3 charged tracks in 3 different sectors
  or 2 charged tracks in 2 different sectors and photon energy > 3.2 GeV
- Require:
  - 3 charged particles (2 positive, 1 negative)
  - PID: p, π^+, π^-
  - η reconstruction via missing mass method

$\rightarrow \approx 81 \cdot 10^6$ events

- Origin in target: $r < 2$ cm, $-110\,\text{cm} < z < -70\,\text{cm}$
- Timing: $\Delta t = t_{Tagger} - t_{StartCounter}$, $|\Delta t| < 0.5$ ns
- Minimal momentum: $p_p > 0.3\,\text{GeV/c}$, $p_{\pi^+,\pi^-} > 0.1\,\text{GeV/c}$
- Fiducial volume cut
- PID: $\beta_{calc} = \frac{p}{\sqrt{m_{PDG}^2 + p^2}}$
  $\Rightarrow d = \beta_{calc} - \beta_{meas.} \Rightarrow |d| < 0.04$
- Cut on missing mass: $480\,\text{MeV/c}^2 < m_{miss} < 620\,\text{MeV/c}^2$

$\rightarrow \approx 1.4 \cdot 10^6$ events

Missing Mass Spectrum



- Broad η peak
- Neutral kaon contribution

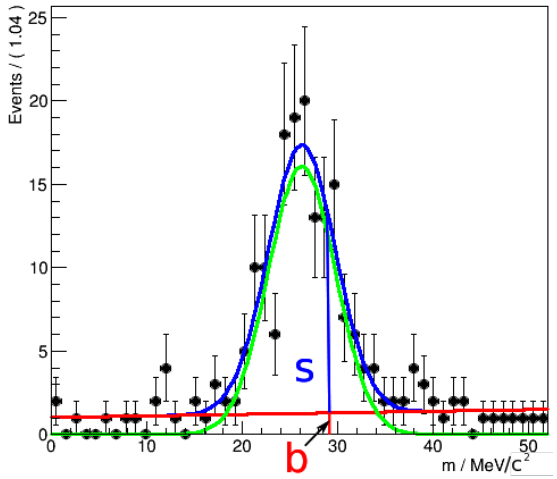
Event-based Background Suppression

Assumption: Distribution of background events in a small cell of the phasespace has to be different compared to signal events.

→ Event-by-event procedure:

- First step: find N nearest neighbours B of seed event A in phasespace
  - Define metric to calculate distances in phasespace
  - Choose N events with smallest distance to seed event
- Second step: fit invariant mass spectrum $m(\eta)$ of nearest neighbours with appropriate functions for signal and background

- Metric contains:
  - Angular distributions
  - $cos(\theta)$ of the η production angle
  - Beam energy
  - $\mathrm{m}^2(\pi\,\pi\,\mathrm{m}_{\mathrm{miss}})$

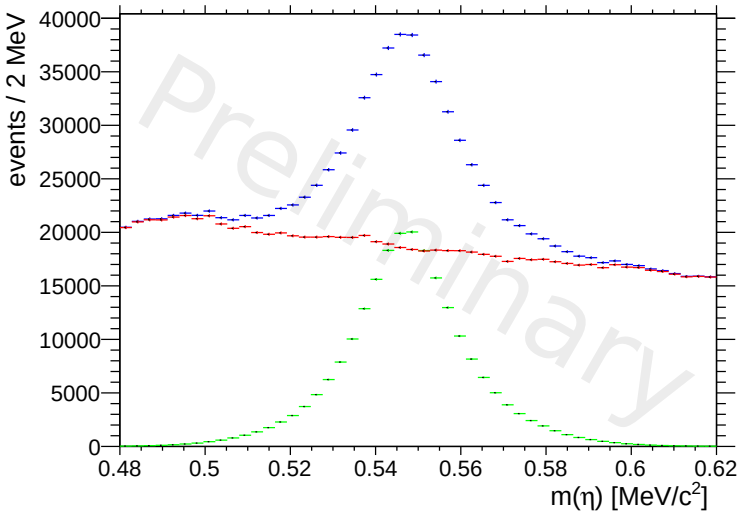


Event-based Background Suppression

- Third step: calculate signal to background ratio

$$Q = \frac{f_s s}{f_s s + (1 - f_s) b}$$
$$s = S(m_{\text{seed}})$$
$$b = B(m_{\text{seed}})$$

- Fourth step: normalize S/B and assign it as probabilistic weight for each event

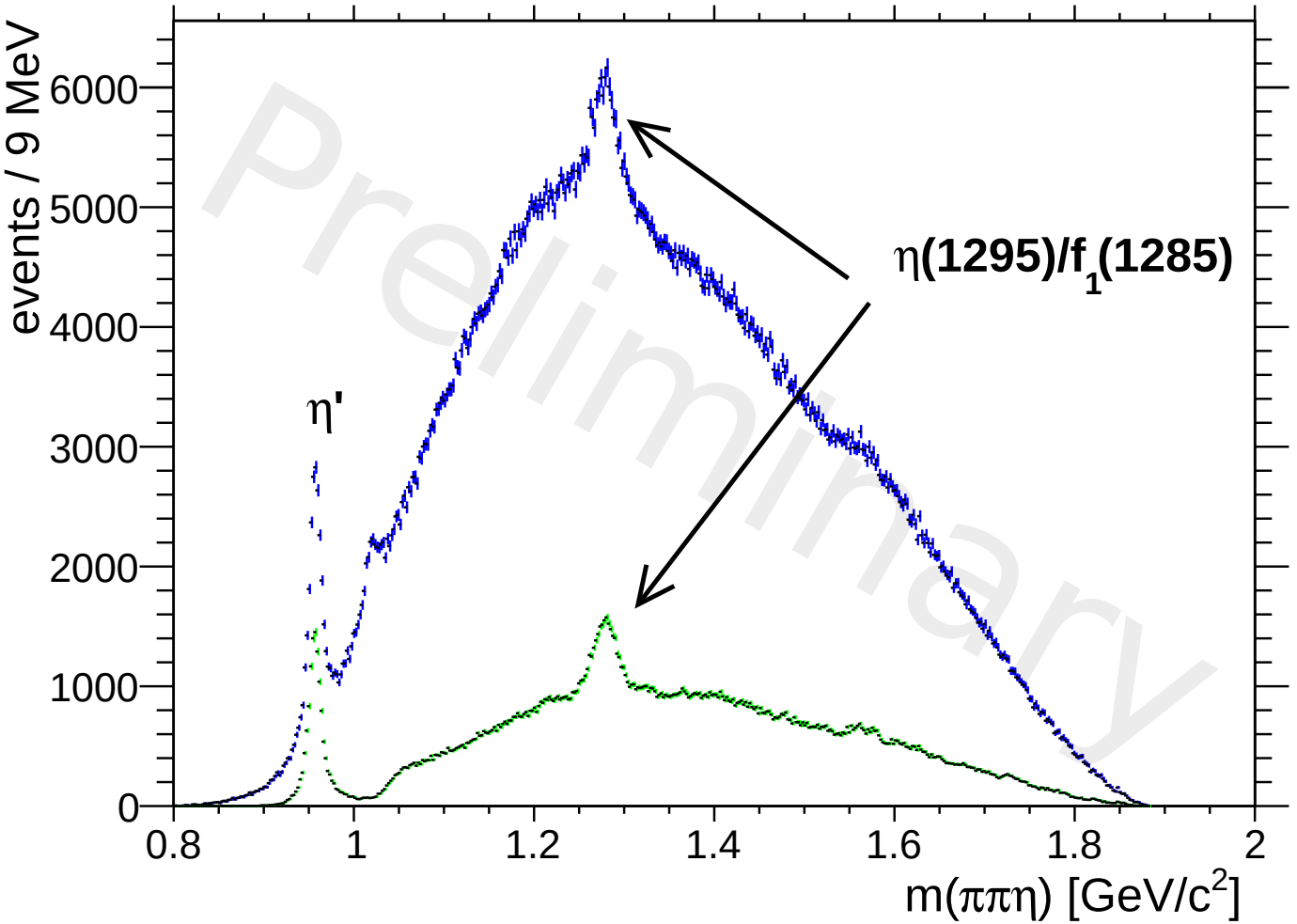


Unweighted 1-Q weighted Q weighted

- Benefit: No knowledge on the origin of background is needed!

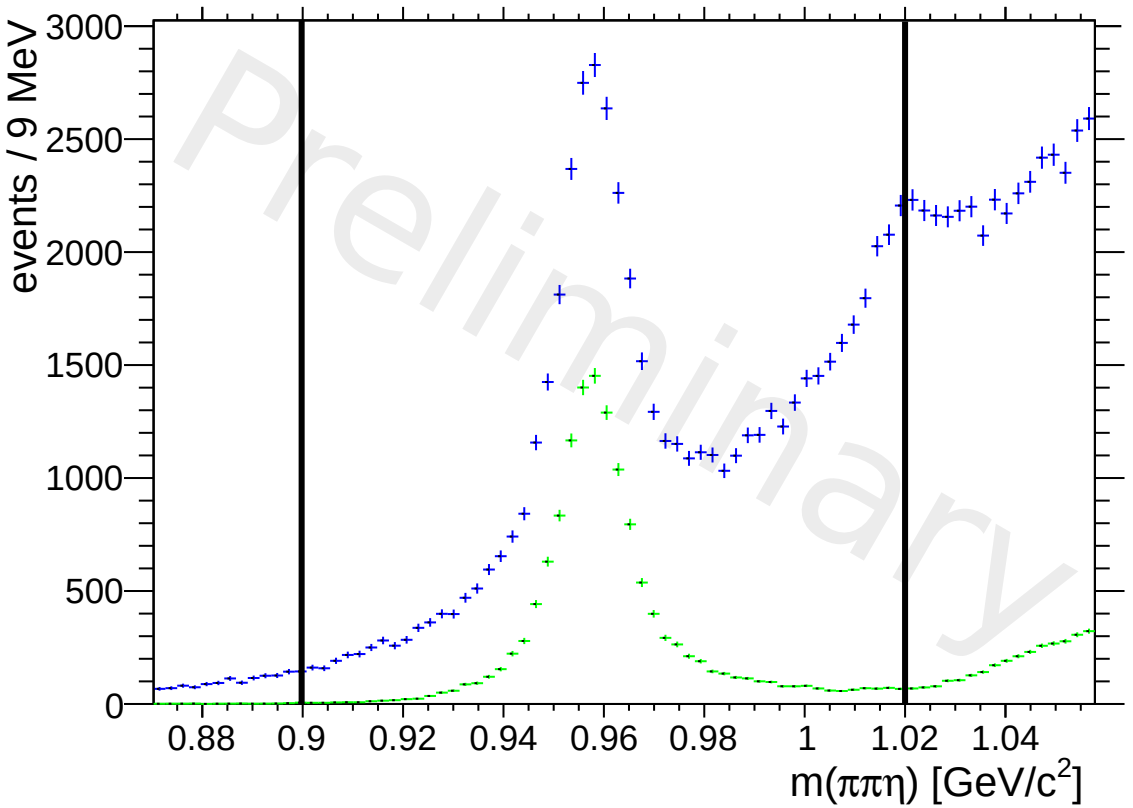
CLAS Collaboration Phys.Rev. C80 (2009) 065208, Crystal Barrel Collaboration, Eur.Phys.J. C75 (2015) 3, 124

Weighted $\pi\pi\eta$ Invariant Mass Spectrum



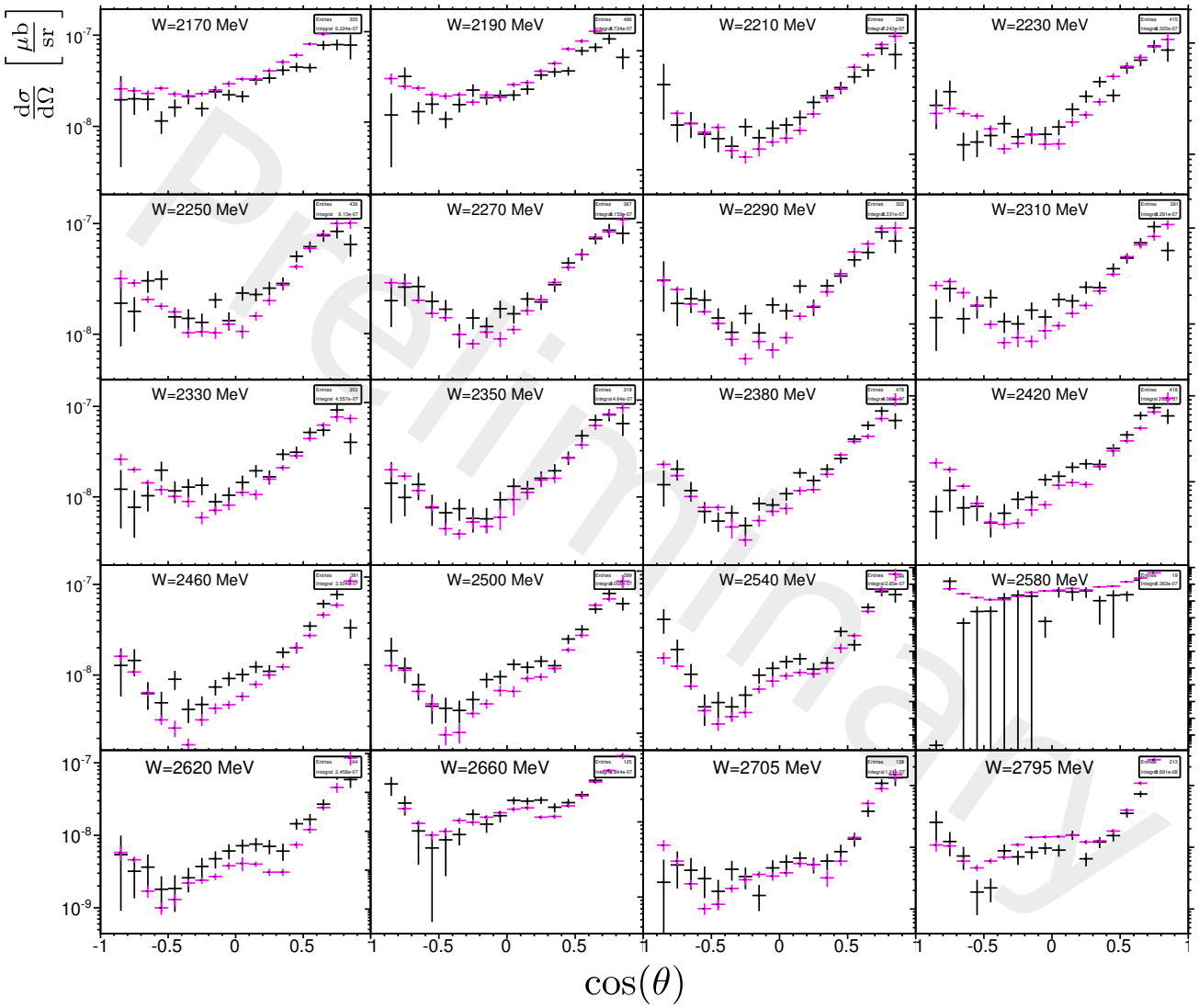
Weighted $\pi\pi\eta$ Invariant Mass Spectrum

Unweighted
Q weighted



Cut on invariant $\pi\pi\eta$ mass in η' region:
$0.9\,\mathrm{GeV/c^2} < \mathrm{m}(\eta') < 1.02\ \mathrm{GeV/c^2}$

Differential Cross Section of $\gamma p \rightarrow p\eta'$



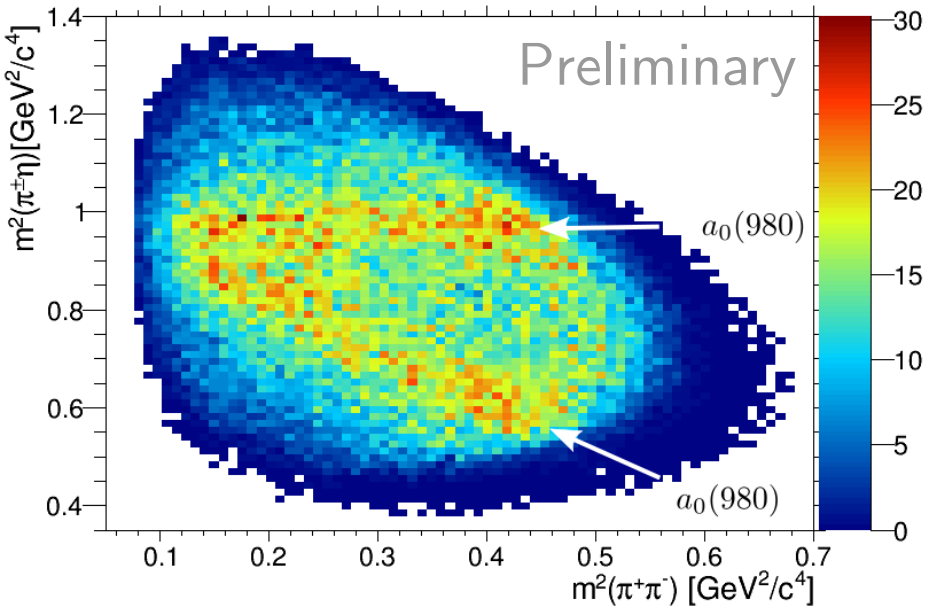
Differential cross section of $\gamma p \rightarrow p\eta'$:

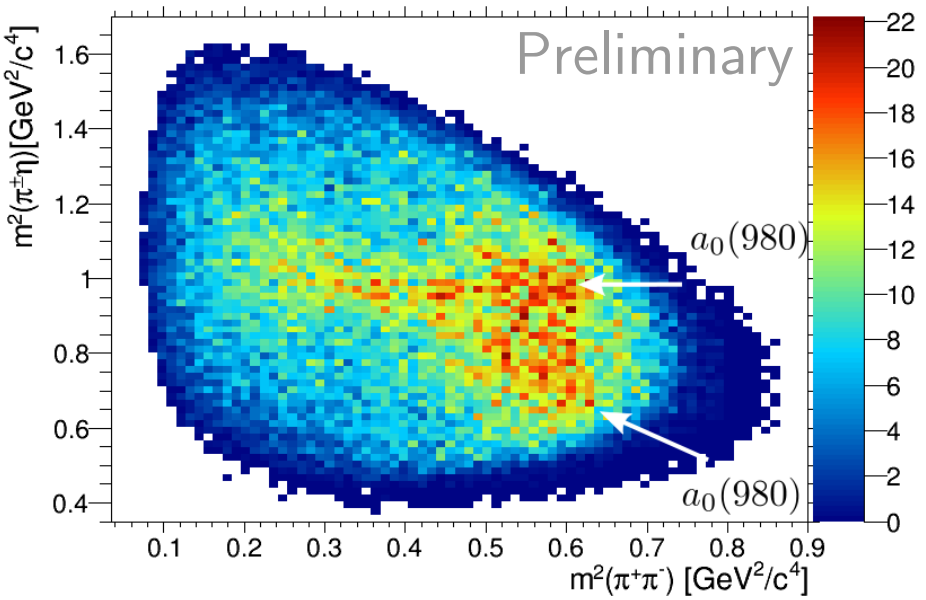
CLAS g11 run
(CLAS ,Phys.Rev. C80 (2009) 045213)

This work (g12 run)

Dalitz Plot $m^2(\pi^{\pm}\eta)$ vs. $m^2(\pi^+\pi^-)$

Not efficiency corrected.





$1270\ MeV/c^2 < m(\pi^+\pi^-\eta) < 1310\ MeV/c^2$

$1385\ MeV/c^2 < m(\pi^+\pi^-\eta) < 1425\ MeV/c^2$

Summary

- Study of excited η mesons in $\gamma p \to p\pi\pi\eta$
  - Clean sample of $810 \cdot 10^3$ reconstructed events
  - Successfully applied event-based background suppression to missing η
  - Observed η' signal and an additional enhancement at $\approx 1295\,\mathrm{MeV/c^2}$
- Extracted $\gamma p \to p\eta'$ differential cross section from g12 data subset
  - Good agreement with previous study
  - Small discrepancies (under investigation)
- Next steps:
  - Use full data set
  - Further investigation of the nature of the enhancement at $1290\ \mathrm{MeV/c^2}$
  - Extract upper limit of $\eta(1405)$ production in photoproduction