FLORIDA STATE UNIVERSITY

Study of the ω meson structure

HUGS 2022 – Student Seminars
16th June

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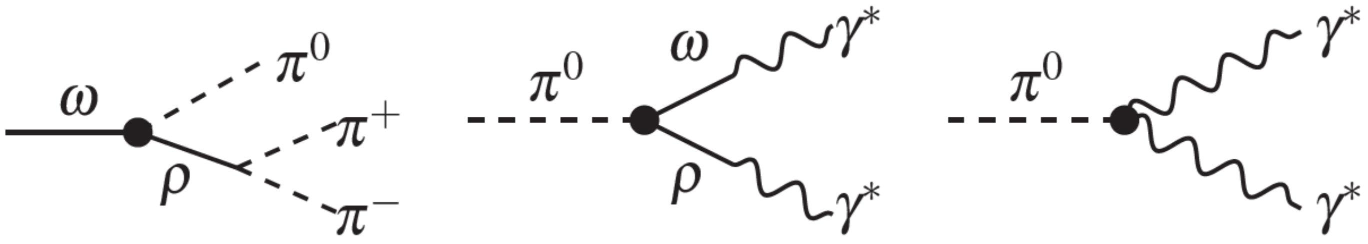
Motivation: Why study the ω meson?

Study of the decay mechanisms of a resonance can provide useful information about its internal dynamics. We study the ω decay.

- ω mesons are produced copiously in photoproduction experiments ($\Upsilon p \rightarrow p\omega$)
- The decay channel to the three-pion final state $\omega \rightarrow \pi^+\pi^-\pi^0$ has branching ratio of 89%.

$$\gamma p \rightarrow \omega p$$
$$\omega \rightarrow \pi^+\pi^-\pi^0$$
$$\pi^0 \rightarrow \gamma\gamma$$

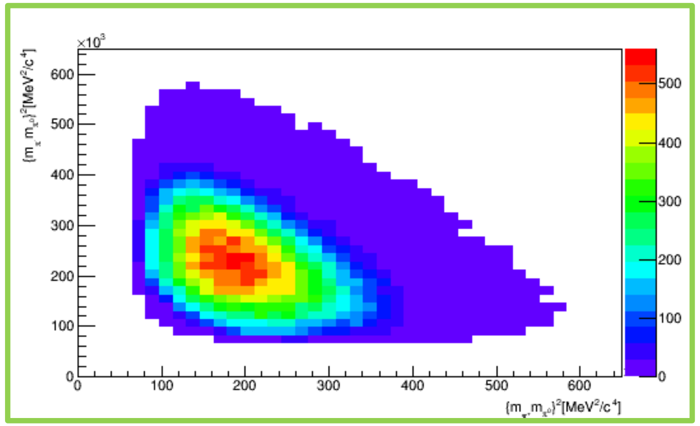
→ **DALITZ PLOT ANALYSIS**

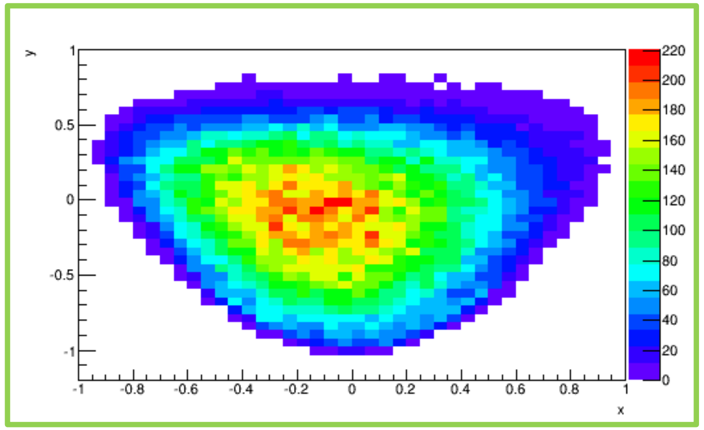


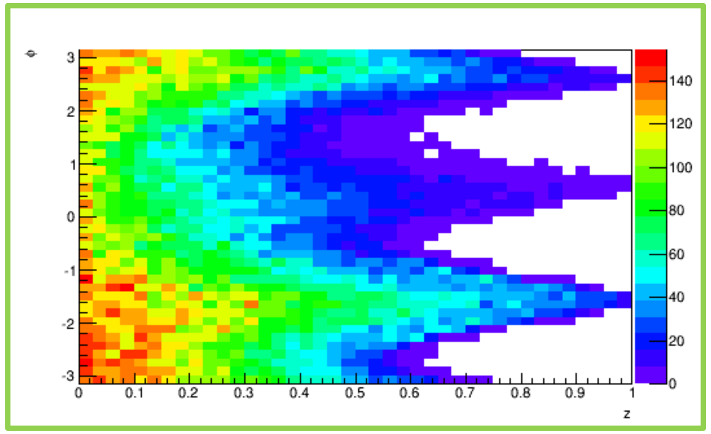
- Description of pseudoscalar transition form factors which would help to describe the intrinsic structure of hadrons.
- Hadronic contribution to anomalous magnetic moment of muon.
- Understanding the re-scattering effects between final state pions.

The Dalitz Plot Analysis

$\omega \rightarrow \pi^{+} \pi^{-} \pi^{0}$







$$m_{12}^2 = M^2 + m_3^2 - 2ME_3$$

$$m_{23}^2 = M^2 + m_1^2 - 2ME_1$$

$$X = \sqrt{3}\frac{T_- - T_+}{Q}$$

$$Y = \left(\frac{2m_+ + m_0}{m_+}\right)\frac{T_0}{Q} - 1$$

$$\varphi = \tan^{-1}\left(\frac{Y}{X}\right)$$

$$Z = X^2 + Y^2$$

Data from CLAS-g12

- For ω meson $J^{PC}=1^{--}$. Each pion pair must be in state of odd relative angular momentum.
- P-wave should describe the phase space.
- Deviation from P-wave phase space ⟹ interaction between decay products.

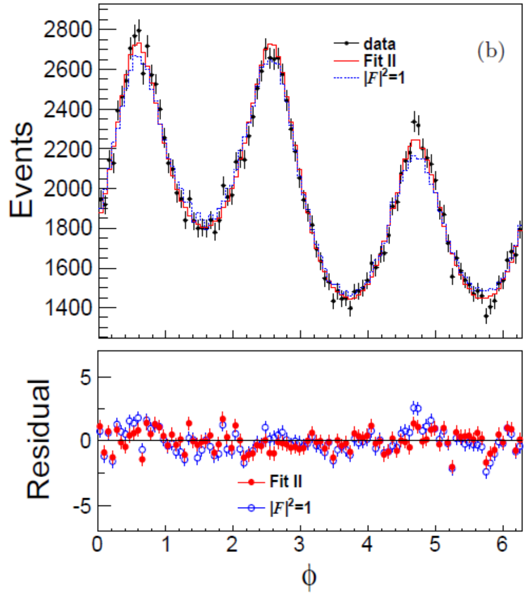
Existing Results from other experiments

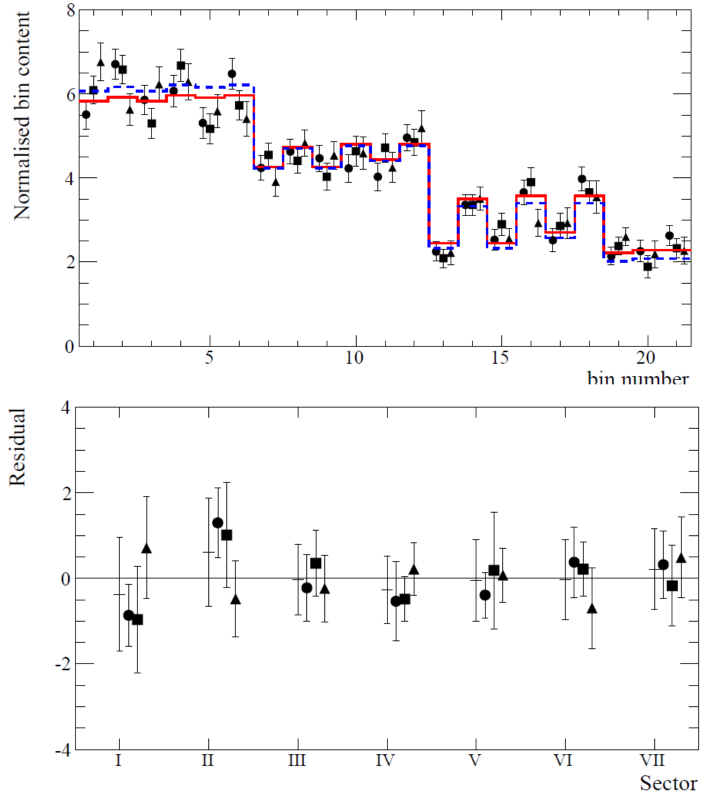
P. Adlarson *et al.*, Phys. Lett. B **770**, 418-425 (2017)

M. Ablikim *et al.*, Phys. Rev. D **98** 11, 112007 (2018)

BESIII Collaboration

WASA-at-COSY Collaboration





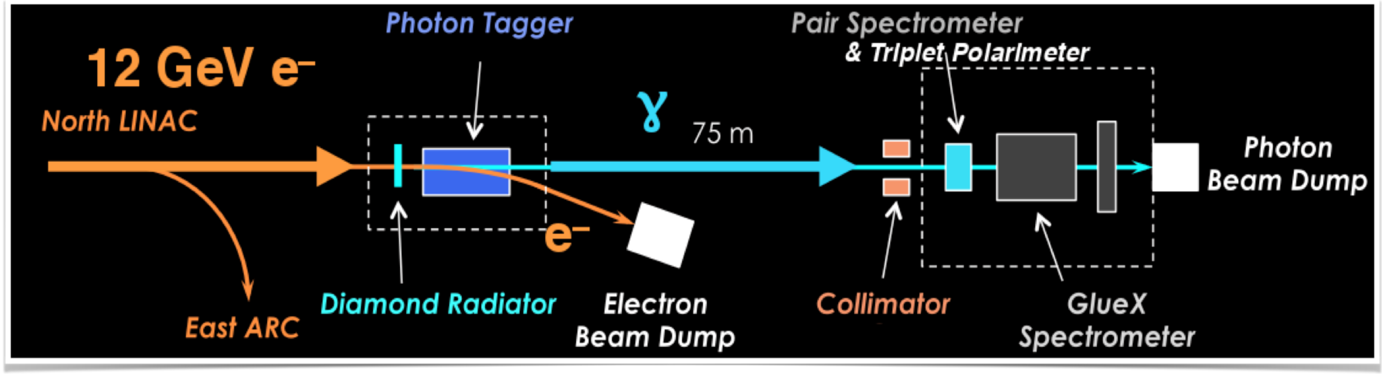
	$\alpha \times 10^3$	$\beta \times 10^3$	$\zeta \times 10^3$
Fit I	132.1 ± 6.7		
Fit II	120.2 ± 7.1	29.5 ± 8.0	
Fit III	111 ± 18	25 ± 10	22 ± 29

WASA-at-COSY: Low statistics events. ω produced in *$pd \to {}^3He\omega$ and $pp \to pp\omega$.* Least square fitting utilized to find fit parameters.

BESIII: Higher statistics, ω produced in *J/ψ* decays. Utilized unbinned maximum likelihood fit to perform the Dalitz plot analysis.

Parameters used in fit	$\alpha \times 10^3$	$\beta \times 10^3$	$\gamma \times 10^3$	$\chi^2/d.o.f.$
$\mathcal{N}^1\mathcal{N}^2$	-	-	-	84 / 40
$\mathcal{N}^1\mathcal{N}^2\alpha$	153(42)	-	-	69 / 39
$\mathcal{N}^1\mathcal{N}^2\alpha\beta$	132(48)	55(63)	-	68 / 38
$\mathcal{N}^1\mathcal{N}^2\alpha\gamma$	21(148)	-	232(252)	68 / 38

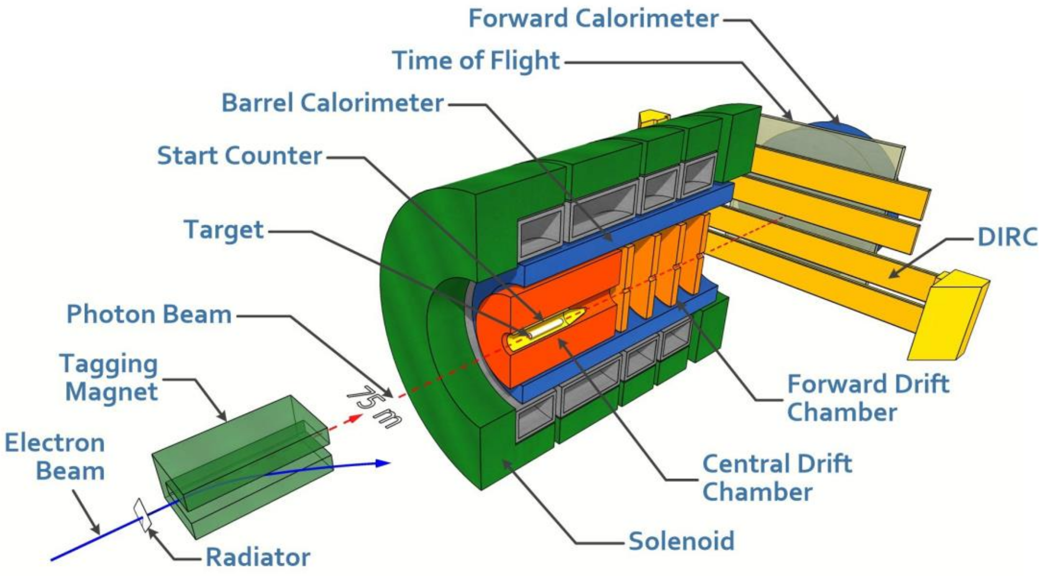
What makes GlueX a good candidate to study the Dalitz decay $\omega \rightarrow \pi^+\pi^-\pi^0$



- We produce ω in photoproduction reactions $\Upsilon p \rightarrow p\omega$: more statistics.

- Initial indications from Dalitz Plot analysis* of CLAS-g12 data have given different values of the Dalitz plot parameters. It will be interesting to perform the full analysis using GlueX data.

- We wish to perform the Dalitz Plot analysis using event-based likelihood fitting in the AmpTools fitting framework.



*Courtesy of Angelica Goncalves

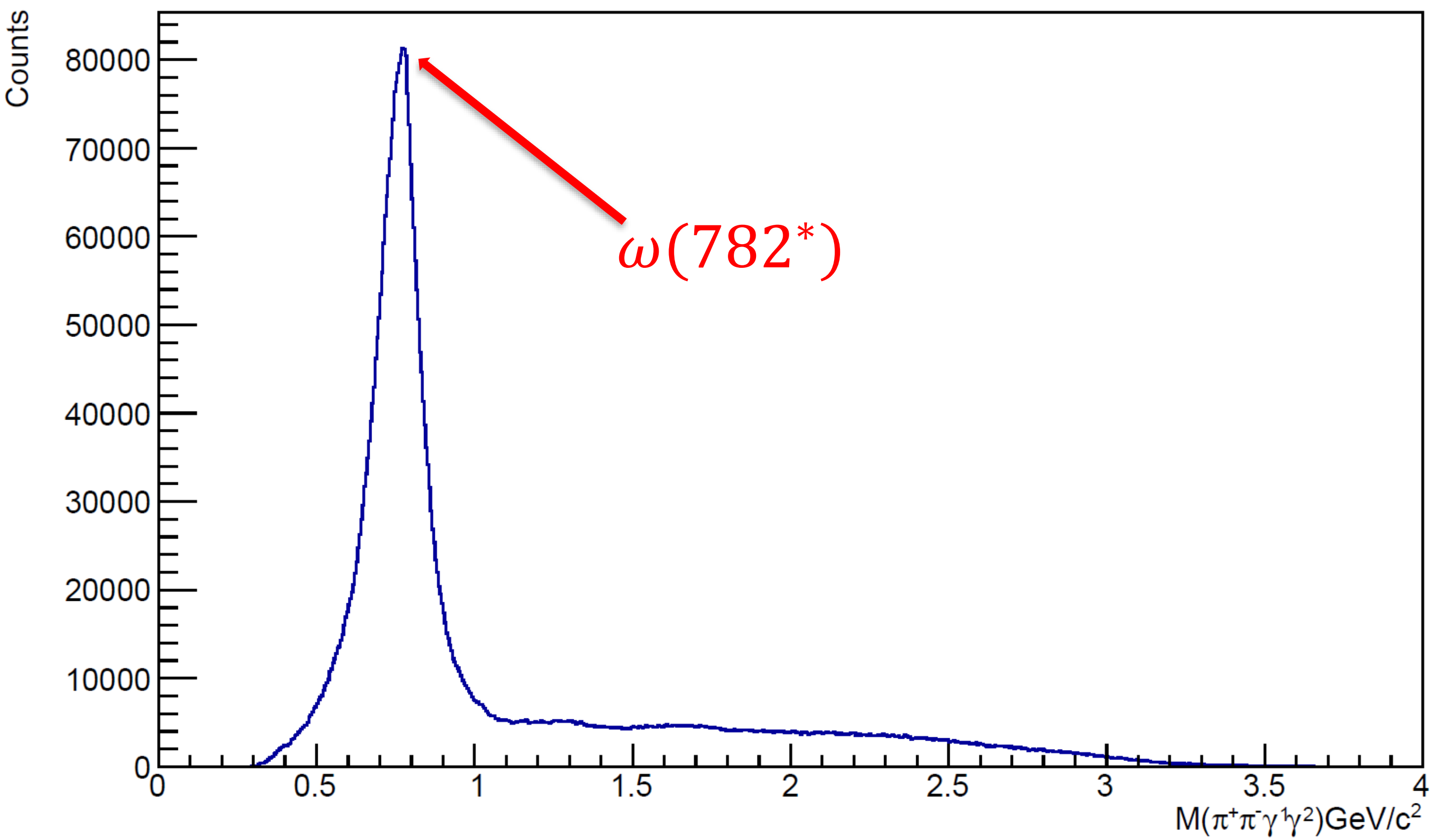
http://inspirehep.net/search?p=find+collaboration+gluex

Results for $\omega \rightarrow \pi^+\pi^-\pi^0$

- Data from Spring 2017
- Most of the background suppressed using kinematic fitting and preliminary cuts

Invariant Mass of ω

*mass in MeV/c²



$$\gamma p \rightarrow \omega p$$
$$\omega \rightarrow e^+e^-\pi^0$$
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Theoretical Motivation

- Electromagnetic transition form factors (TFFs)
- Contributions to the hadronic light by-light (HLbL) scattering cross sections
- Anomalous magnetic moment of muon $(g-2)_\mu$
- Precision calculation of decay rates of mesons in rare dilepton modes e^+e^- and $\mu^+\mu^-$

Experimental challenges

- Smaller signal compared to background contributions. Non-resonant contributions e.g., $\pi^0\pi^0$ and $\pi^0\eta$
- Low branching ratio (~2000) smaller than $\omega \rightarrow \pi^0\pi^+\pi^-$
- PID: $\omega \rightarrow \pi^0\pi^+\pi^-$ can mimic $\pi^0e^+e^-$ final state which cannot be differentiated by e/m calorimeter

For a pointlike meson A

$A \to l^+l^-B$

$A \to \gamma^*B$ (From QED)

$\gamma^* \to l^+l^-$

Deviation from pure QED dependence described by e/m TFF

TFFs parameterized in pole approximation from Vector Meson Dominance (VMD) assumption

$$F(m_{ll}) = \left(1 - \frac{m_{ll}^2}{\Lambda^2}\right)^{-1}$$

Λ^{-2} → TFF slope at $m_{ll} = 0$

What we can measure in experiment

TFFs are determined by measuring the **decay rate of $A \to l^+l^-B$** as a function of **dilepton invariant mass m_{ll}**

$$\frac{d\Gamma(\omega \to \pi^0 l^+l^-)}{dm_{ll}\Gamma(\omega \to \pi^0\gamma)} = \frac{2\alpha}{3\pi m_{ll}}\left(1 - \frac{4m_l^2}{m_{ll}^2}\right)^{\frac{1}{2}}\left(1 + \frac{2m_l^2}{m_{ll}^2}\right) \times \left[\left(1 + \frac{m_{ll}^2}{m_\omega^2 - m_{\pi^0}^2}\right)^2 - \left(\frac{4m_\omega^2 m_{ll}^2}{m_\omega^2 - m_{\pi^0}^2}\right)\right]^{\frac{3}{2}} \left|F_{\omega\pi^0}(m_{ll})\right|^2$$

$$= \left[QED_{\omega\pi^0}\right]\left|F_{\omega\pi^0}(m_{ll})\right|^2$$

TFF for $\omega \to \gamma^*\pi^0$

$$f(\cos\theta^*) = 1 + cos^2\theta^* + \frac{2m_l^2}{m_{ll}^2} sin^2\theta^*$$

Angle b/w decaying lepton in rest frame of virtual photon & direction of dilepton system in CM frame

Results from other experiments

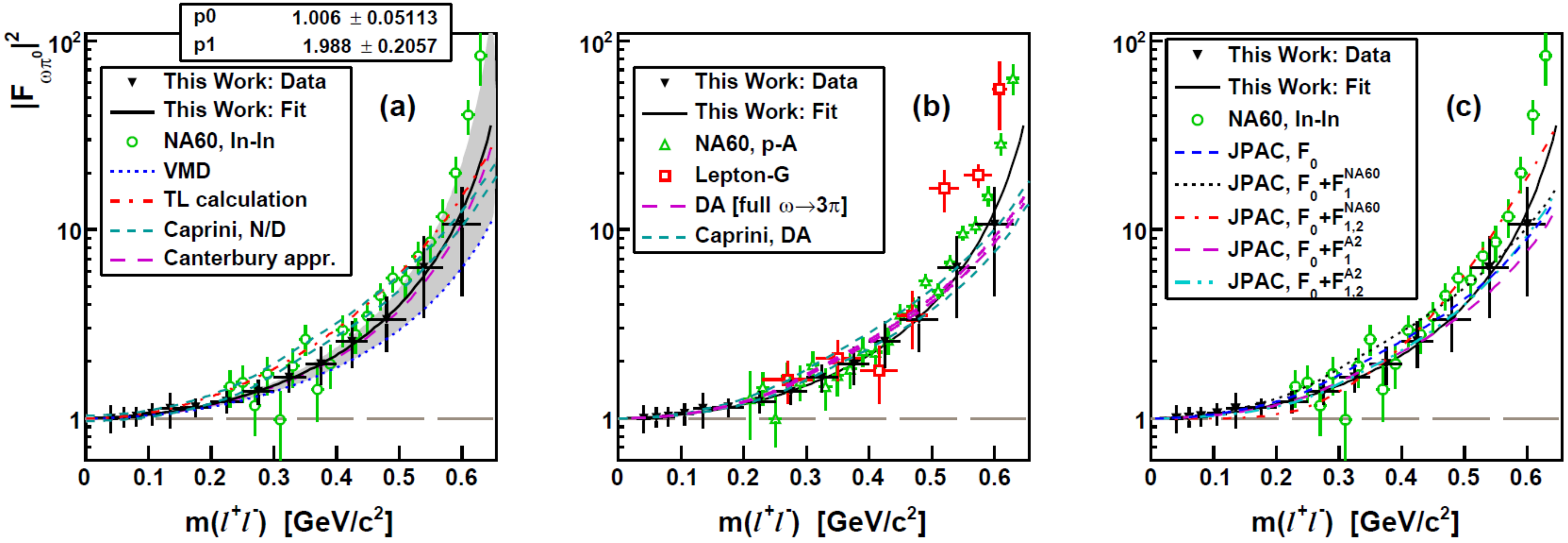
P. Adlarson *et al.*, Phys. Rev. C **95**, 035208 (2017)
https://arxiv.org/abs/1609.04503v2

Data for the decay

$$\omega \rightarrow e^+e^-\pi^0$$

only available from A2 at MAMI with electron beam energies ~ 1.5 GeV

Expt.	$\Lambda^{-2}_{\omega\pi^0}$(GeV^{-2})
A2 at MAMI	$1.99 \pm 0.21_{tot}$
Lepton-G	$2.36 \pm 0.21_{tot}$
NA60	$2.223 \pm 0.026_{stat} \pm 0.037_{syst}$



Discrepancy of $\Lambda^{-2}_{\omega\pi^0}$ value predictions from dispersion theory and experimental data

Requires improved measurement of $\left|F_{\omega\pi^0}\right|^2$

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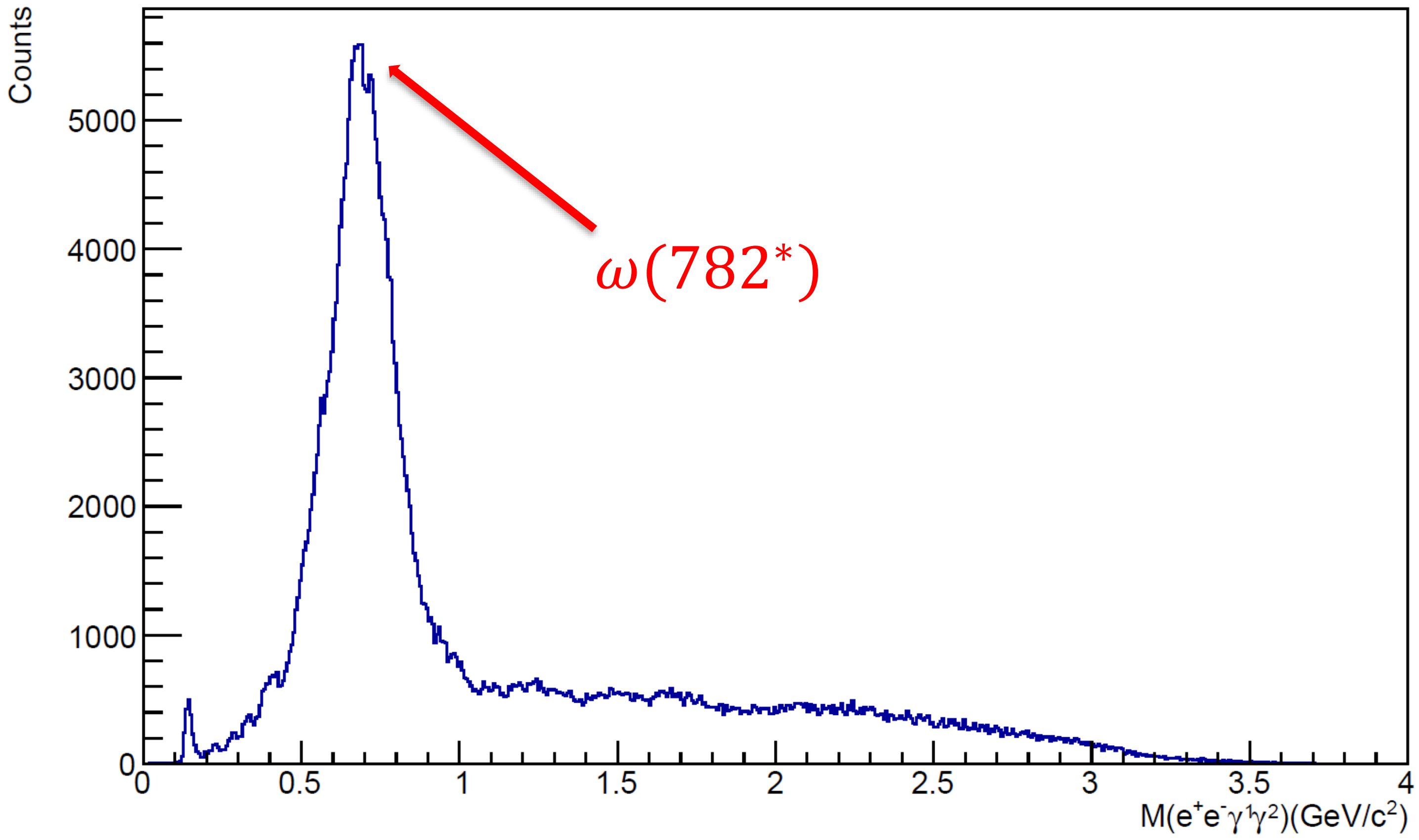

"Tapestries are made by many artisans working together. The contributions of separate workers cannot be discerned in the completed work, and the loose and false threads have been covered over. So it is in our picture of particle physics."

— Sheldon L. Glashow

Thank you for your attention!