

# Meson electroproduction for $\eta'$ , $\omega$ , and $\rho^0$ (E'OR) in the threshold region

HKS COLLABORATION PROPOSAL IN HALL C FOR PAC54

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Ralph M. Marinaro III

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Christopher Newport University

# 1. Purpose of this presentation

## For Hall A/C collaborators:

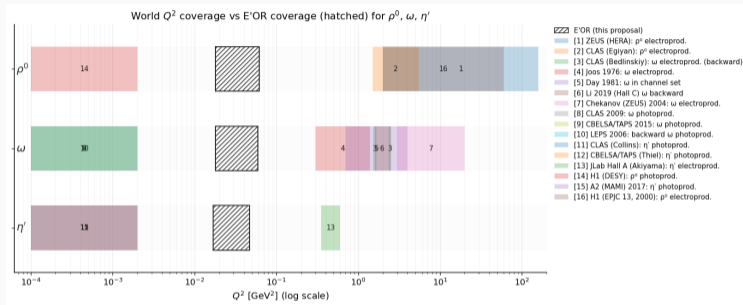
- Confirm E'OR proposal was submitted for PAC54 as a Hall C experiment using the HKS–HES apparatus.
- Introduce Hall A/C community to the E'OR experiment ahead of the PAC presentation and discuss physics case and feasibility.
- The experimental concept is unchanged from HKS meeting, HES measures  $e'$ , HKS measures  $p'$  in coincidence, and  $X$  meson is reconstructed via missing mass.

## Primary message

E'OR is an opportunistic, semi-parasitic low- $Q^2$  meson electroproduction experiment that uses the already planned HKS–HES infrastructure to fill a largely uncovered region between photoproduction and electroproduction data, and to further increase scientific return of the HKS program.

## 2. Physics gap in low- $Q^2$ exclusive meson electroproduction

- Channels:  $ep \rightarrow e'p'M$ , with  $M = \rho^0, \omega, \eta'$ , target region near threshold  $Q^2 \approx 0.015\text{--}0.06 \text{ GeV}^2$ .
- Existing data concentrated near photoproduction or at  $Q^2 > 0.1 \text{ GeV}^2$ , E'OR helps fill the data gap.



### Physics motivation

Anchor the transition from  $Q^2 = 0$  photoproduction to higher  $Q^2$  electroproduction with high-resolution missing-mass reconstruction and precision differential cross sections.

### 3. Why these three mesons?

#### $\rho^0$ : isovector reference

- Tests standard vector-meson electroproduction mechanisms.
- Sensitive to natural-parity exchange and diffractive-like production strength.
- Reference channel for comparing isospin-dependent dynamics.

#### $\omega$ : isoscalar contrast

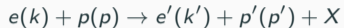
- Same vector-meson family, but different isospin structure from  $\rho^0$ .
- Near threshold,  $\omega$  production is more sensitive to pion exchange and unnatural-parity contributions.
- The ratio  $\sigma_\omega/\sigma_{\rho^0}$  constrains exchange-mechanism systematics.

#### $\eta'$ : singlet and strangeness

- Flavor-singlet pseudoscalar tied to the axial anomaly and possible gluonic dynamics.
- At  $W \approx 1.91$  GeV, production may receive contributions from  $N(1895) 1/2^-$ .
- Low- $Q^2$  dependence can probe whether near-threshold strength is compact or meson-baryon-like.

## 4. Observables and channel separation

- Reaction formalism:



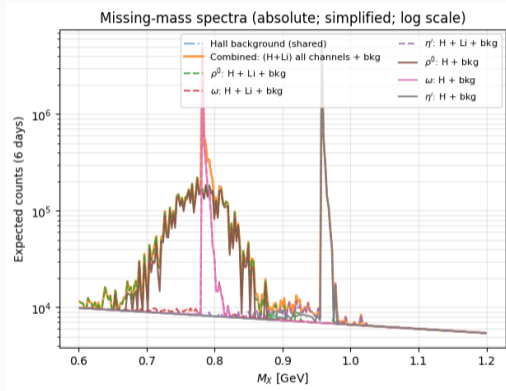
- Missing mass calculation:

$$M_X^2 = (k + p - k' - p')^2$$

- Primary observables include:

$$\frac{d\sigma}{dQ^2}, \quad \frac{d\sigma}{dt}, \quad \sigma_\omega / \sigma_{\rho^0}, \quad \sigma_{\eta'} / \sigma_\omega.$$

- For missing mass, mesons  $\omega$  and  $\eta'$  have sharp peaks and  $\rho^0$  is broader with large intrinsic decay width ( $\Gamma \approx 149$  MeV)



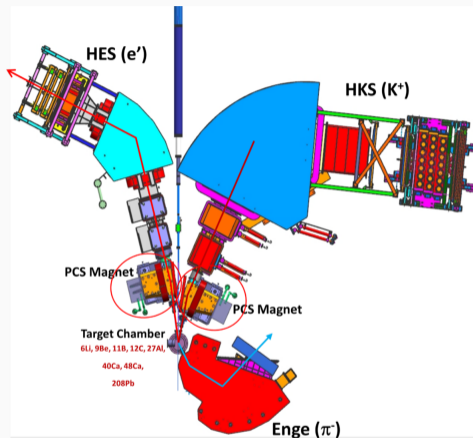
Projected missing-mass spectra including signal, Li, continuum, and hall background.

## 5. Why HKS–HES is the enabling apparatus

- HES selects forward-angle scattered electrons at low momentum transfer, HKS detects recoil hadron, for E'OR this is used as a proton arm rather than a kaon arm.
- High-resolution magnetic spectrometer is essential for clean missing-mass reconstruction.
- E'OR requires no new detector resources and uses existing HKS–HES installation plan.
- Projected DAQ performance lowers concerns to suppress scattered protons at the online trigger level, separate kaon-proton trigger possible.

### Strategic motivation

E'OR is an opportunistic high-resolution experiment enabled by a configuration that is already approved for the Hall C HKS program.



HKS–HES layout planned for hypernuclear program in JLab Hall C.

## 6. Baseline kinematics and run conditions

Quantity	Beam / target	HES	HKS
Beam energy	2.24 GeV	–	–
Current	30 $\mu$ A	–	–
Target	LiH, 150 mg/cm <sup>2</sup>	–	–
Central angle	–	8.5°	11.5°
Central momentum	–	0.740 GeV/c	channel dependent
Solid angle	–	3.4 msr	7.0 msr
Momentum bite	–	$\pm 4\%$	$\pm 6\%$

### $\rho^0$ and $\omega$ setting

$p_{0,\text{HKS}} \approx 1.20$  GeV/c, measured simultaneously.

### $\eta'$ setting

$p_{0,\text{HKS}} \approx 0.75$  GeV/c, scale HKS magnet by  $\sim 60\%$ .

## 7. Beamtime request submitted to PAC54

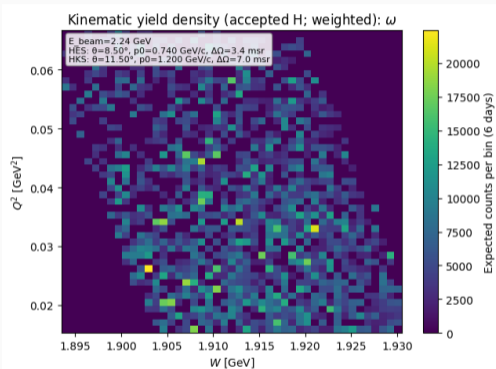
Setting	$E_b$	$I$	Target	Beamtime
$\rho^0 + \omega$ , HKS $p_0 \approx 1.20$ GeV/c	2.24 GeV	30 $\mu$ A	LiH	6.0 d
$\eta'$ , HKS $p_0 \approx 0.75$ GeV/c	2.24 GeV	30 $\mu$ A	LiH	6.0 d
HKS momentum retuning	–	–	–	0.5 d
Elastic/optics/timing calibration	–	–	–	0.5 d
<b>Total</b>				<b>13 d</b>

- The spectrometer angles stay fixed, only the HKS field setting changes between the two production periods.
- Overlap with hypernuclear program  $\Lambda - \Sigma$  calibrations may reduce the effective E'OR-specific overhead.
- Beamtime request is stated as beam-on-target time at 100% availability.

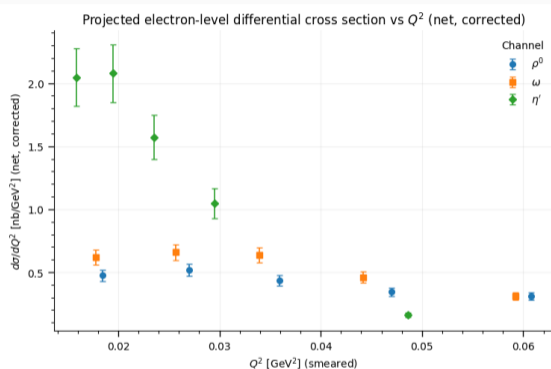
## 8. Simulation and analysis chain used for projections

- **Event generation:** two-body reaction in CM frame, boosted to lab frame.
- **Acceptance modeled:**  $(\theta, \phi, p)$  windows for HES and HKS consistent with spectrometer settings.
- **Detector effects:** track smearing, efficiency slightly varying with  $Q^2$ , and simple radiative tail model.
- **Physics content:** extracted differential cross sections  $(-t, Q^2, W)$ , subtracted out background and Li contributions.
- **Outputs used for projections:**
  - kinematic coverage plots ( $Q^2$  vs.  $W$ ) as heat maps.
  - $-t$  ranges separated into bins with corresponding yields.
  - missing-mass spectra including signals vs background vs Li contribution.
  - binned yields used to calculate projected differential cross sections, with corrections for efficiency, acceptance, bin centering, radiative tail.

## 9. Projected kinematic coverage and reconstructed spectra

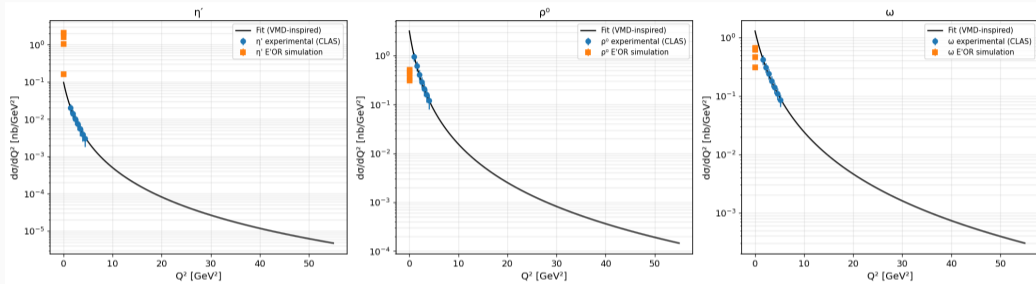


Example  $Q^2$  vs  $W$  heat map for  $\omega$  meson projected kinematic coverage.



Projected cross sections for E'OR particles, binning dependent on requested days and beam current.

# 10. Projected E'OR cross sections in context with CLAS data



- Orange data markers are E'OR projected  $d\sigma/dQ^2$  from simulation and blue are CLAS electroproduction data used as closest available benchmark.
- CLAS data are generally at higher  $Q^2$  and somewhat different  $W$ , so the comparison is not direct.
- Projected E'OR cross sections are realistic in magnitude compared with existing electroproduction data, while adding uniquely low- $Q^2$  coverage for  $\rho^0$ ,  $\omega$ , and  $\eta'$ .

## 11. Feasibility risks and controls

- **Finalize LiH target:** parameters, implementation, and production capabilities:
  - **Beam-current/areal-density:** current values in proposal are pending final target design.
  - **Risks:** handling and chemical stability, avoid melting or significant damage,
    - LiH is water reactive and must be well sealed/handled in controlled conditions,
    - Encapsulation integrity (vacuum compatibility, leak tightness),
    - Thermal conduction path to target frame, raster size and verified spot stability.
- **Data Acquisition Trigger Rates:** estimates are plausible for running conditions.
  - Current anticipated raw proton acceptance rate  $\sim 500$  Hz.
  - Estimate total DAQ trigger rate with HKS-HES coincidence  $\sim 300$ -350 Hz.
- **Analysis software:** additional analysis software will be required, there is significant overlap with analysis software already being developed for HKS program.

## 12. Projected statistical and systematic precision

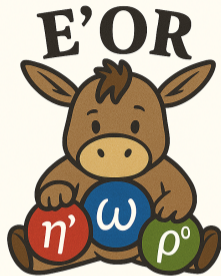
Source of uncertainty	Estimate
Beam charge / current normalization	2–3%
LiH target areal density and composition	3–5%
Acceptance and optics modeling	4–5%
Tracking efficiency and reconstruction	2–3%
Timing and coincidence cuts	1–2%
Proton PID cuts: TOF + Cherenkov vetoes	2–3%
Background subtraction / missing-mass fit	3–5%
Radiative and bin-centering corrections	1–3%
Accidental coincidence subtraction	$\lesssim 1\%$
<b>Total projected systematic</b>	<b><math>\sim 7\text{--}10\%</math></b>

- Projected background-subtracted yields are large in all channels, raw counting uncertainties are well below 1% per bin.
- Cross-section precision is driven mainly by controlled systematic effects, acceptance, optics, target normalization, background subtraction, and reconstruction efficiency.
- E'OR is not statistics-limited, proposal-level expectation is a conservative  $\sim 7\text{--}10\%$  total uncertainty per cross-section bin.

## 13. Run Plan, Collaboration Needs, and Next Steps

### Run plan (baseline, submitted)

- 6 days:  $\rho^0 + \omega$  @ HKS  $p_0 \approx 1.20$  GeV/c
- 6 days:  $\eta'$  @ HKS  $p_0 \approx 0.75$  GeV/c
- 1 day total: momentum retuning, adjust magnets, system calibrations



### Future experiment needs

- Contingency plans, and HKS magnet adjustment procedure
- Implement proton trigger and proton PID using Cherenkov + TOF
- Improve analysis and simulation software, integrate with HKS infrastructure
- Agree on schedule and consider student theses (one per reaction channel?)

# Backup: What does the $\rho^0$ benchmark mean?

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Slide 3 topic	Meaning for E'OR
Standard vector-meson electroproduction mechanisms	The reference reaction is $\gamma^* p \rightarrow p\rho^0$ . Standard descriptions include vector-meson dominance / hadronic photon coupling, $t$ -channel exchange, diffractive or Pomeron-like exchange, and possible near-threshold baryon-exchange contributions.
Natural-parity exchange	Natural-parity exchange means exchanged trajectories with $P = (-1)^J$ , such as Pomeron-like or tensor-meson exchange. This contrasts with unnatural-parity exchange, $P = -(-1)^J$ , such as pion exchange, which is especially important for $\omega$ production.
Diffractive-like production strength	A diffractive-like contribution gives a smooth, forward-enhanced cross section with a relatively simple momentum-transfer dependence, often locally parameterized as $d\sigma/dt \sim e^{-b(-t)}$ .
Reference channel for isospin-dependent dynamics	The $\rho^0$ is dominantly isovector, $\rho^0 \sim (u\bar{u} - d\bar{d})/\sqrt{2}$ , while the $\omega$ is dominantly isoscalar, $\omega \sim (u\bar{u} + d\bar{d})/\sqrt{2}$ . Measuring both in the same acceptance makes $\sigma_\omega/\sigma_{\rho^0}$ a direct test of isospin-dependent production mechanisms.

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**Bottom line:**  $\rho^0$  anchors the vector-meson sector. It is the baseline channel for checking whether the E'OR results are consistent with established vector-meson electroproduction systematics.

# Backup: What does the $\omega$ contrast mean?

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Slide 3 topic	Meaning for E'OR
Same vector-meson family, different isospin	The $\rho^0$ and $\omega$ are both neutral light vector mesons with $J^{PC} = 1^{--}$ , but they differ in isospin: $\rho^0 \sim (u\bar{u} - d\bar{d})/\sqrt{2}$ is isovector, while $\omega \sim (u\bar{u} + d\bar{d})/\sqrt{2}$ is isoscalar. This makes $\omega$ the controlled contrast to the $\rho^0$ benchmark.
Near-threshold sensitivity to pion exchange	Near threshold, $\omega$ production can receive stronger contributions from $\pi$ exchange and other hadronic exchange mechanisms than $\rho^0$ production. This tests whether the same production picture that describes $\rho^0$ is sufficient for $\omega$ .
Unnatural-parity contributions	Pion exchange is an unnatural-parity exchange, $P = -(-1)^J$ . This contrasts with natural-parity exchange, $P = (-1)^J$ , associated with Pomeron-like or tensor-meson exchange. A different $\omega$ strength or $t$ dependence relative to $\rho^0$ can indicate enhanced unnatural-parity dynamics.
$\sigma_\omega/\sigma_{\rho^0}$ constrains exchange mechanisms	The ratio $R_{\omega/\rho} = \sigma_\omega/\sigma_{\rho^0}$ cancels several common normalization and acceptance effects. Because the two mesons have similar masses but different isospin and exchange sensitivity, this ratio directly constrains the reaction mechanism.

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**Bottom line:**  $\omega$  tests how vector-meson production changes when the produced meson is isoscalar and more sensitive to pion-exchange dynamics.

# Backup: What does the $\eta'$ motivation mean?

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Slide 3 topic	Meaning for E'OR
<b>Flavor-singlet pseudoscalar tied to the axial anomaly</b>	The $\eta'$ is not an ordinary octet pseudoscalar. Its large mass is tied to the axial $U(1)$ anomaly, and its wave function contains a significant flavor-singlet component. This makes $\eta'$ production sensitive to singlet dynamics not isolated by $\rho^0$ or $\omega$ .
<b>Possible gluonic dynamics</b>	Because the axial anomaly is connected to nonperturbative gluon topology, $\eta'$ production can test whether conventional hadronic exchange mechanisms are sufficient, or whether singlet-specific and gluonic contributions are needed in the reaction amplitude.
<b><math>N(1895) 1/2^-</math> contribution near threshold</b>	E'OR targets $W \approx 1.91$ GeV, close to the region where $\eta'$ production may couple to $N(1895) 1/2^-$ . This gives sensitivity to near-threshold baryon-excitation dynamics and possible hidden-strangeness components.
<b>Low-<math>Q^2</math> dependence as a structure probe</b>	The measured $Q^2$ dependence can help distinguish compact resonance-like strength from more extended meson-baryon dynamics in the near-threshold $\eta'$ production amplitude.

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**Bottom line:**  $\eta'$  is a theory-rich channel that extends E'OR to flavor-singlet QCD, possible hidden strangeness, and near-threshold baryon structure.

# Backup: How is the simulation implemented?

Simulation step	Implementation in the E'OR MC
Event generation	HES electron sampled in $(\theta, \phi, p)$ bite; compute $q^\mu$ , $Q^2$ , $W$ ; generate $\gamma^* p \rightarrow p' M$ in CM; boost final state to lab.
Acceptance model	Rectangular HES/HKS cuts in $(\theta, \phi, p)$ ; HES: $8.5^\circ$ , $0.740 \text{ GeV}/c$ , $\pm 4\%$ ; HKS: $11.5^\circ$ , $\pm 6\%$ ; channel-dependent HKS $p_0$ .
Detector effects	Momentum and angular smearing applied after acceptance; one-sided radiative tail applied to $e'$ momentum; recompute reconstructed $Q^2$ , $W$ , $t$ , and $M_X$ .
Weights	Accepted events weighted by input $d\sigma/dt$ , low- $Q^2$ scaling, and $ dt/d \cos \theta^* $ ; separate signal, continuum, and Li components.
Outputs	Weighted events produce missing-mass spectra, $Q^2$ - $W$ coverage, binned yields, acceptance corrections, and projected differential cross sections.

**Bottom line:** this is an analysis-level MC with two-body kinematics, HKS–HES acceptance, smearing, radiative migration, backgrounds, and weighted yield extraction. Improvements to the simulation are ongoing.