
15th International Workshop on the Physics of Excited Nucleons

# Hybrid Baryon Spectroscopy with CLAS12 at Jefferson Lab
# Exotic Hadron Spectroscopy with CLAS/CLAS12 at Jefferson Lab


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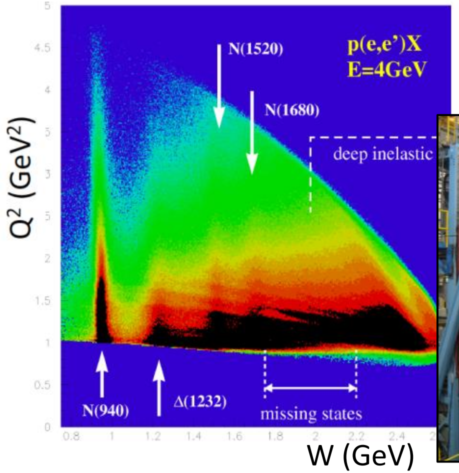
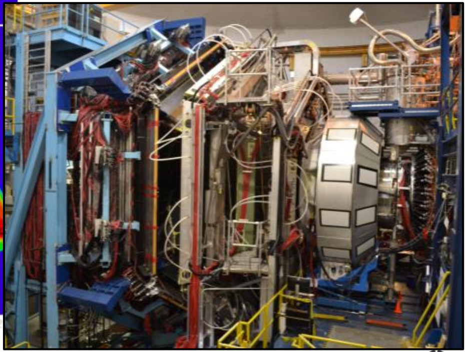
**Outline:**

- Physics case: hybrid baryons and the role of the glue
- Hybrid baryons signature
- KY and ππ electroproduction in CLAS12
- Current Status
- Outlook & conclusions



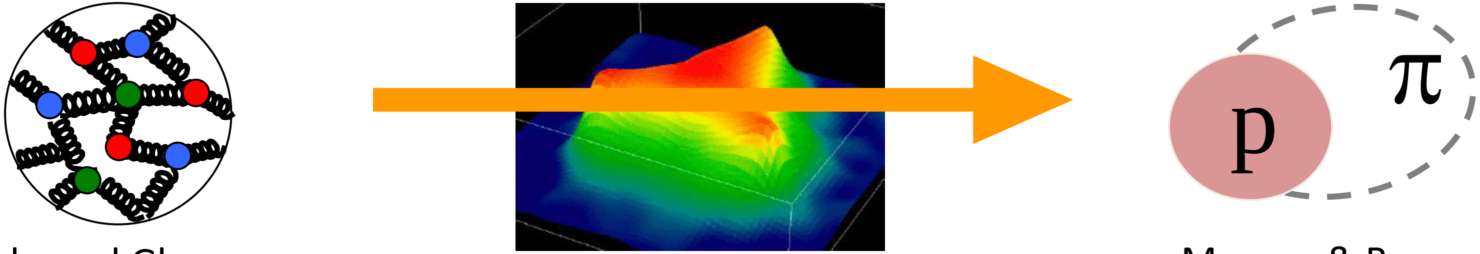
Jefferson Lab

clas

# Critical QCD Question Addressed in Hadron Spectroscopy

1. **What is the nature of the mass of hadrons?** Plenary Talk by Craig Roberts on Monday
   Quarks accounts only for a small fraction of the mass of the proton ($m_u$=1.7-3.3 MeV, $m_d$=4.1-5.8 MeV): what leads to the ~GeV mass??
2. **What are the relevant degrees of freedom?** Plenary Talk by Victor Mokeev and Ralf Gothe on Monday
   At high energy, phenomena can be described in terms of quark and gluons; at low energy, we observed baryons and meson: what are the real degrees of freedom and how the transition from small to large distances occurs??
3. **What is the origin of confinement?**
   Are quarks confined within colorless objects? Can we prove and explain it?
4. **Do quark configuration beyond qqq and $q\bar{q}$ exist?** Plenary Talk by Qian Wang on Tuesday
   The theory of strong interactions does not prohibit hadronic states with different quark configurations (4q, gg, 2qg, 3qg). Can we find evidence of the existence of such states?

**<< 0.1 fm** **0.1 – 1 fm** **> 1 fm**

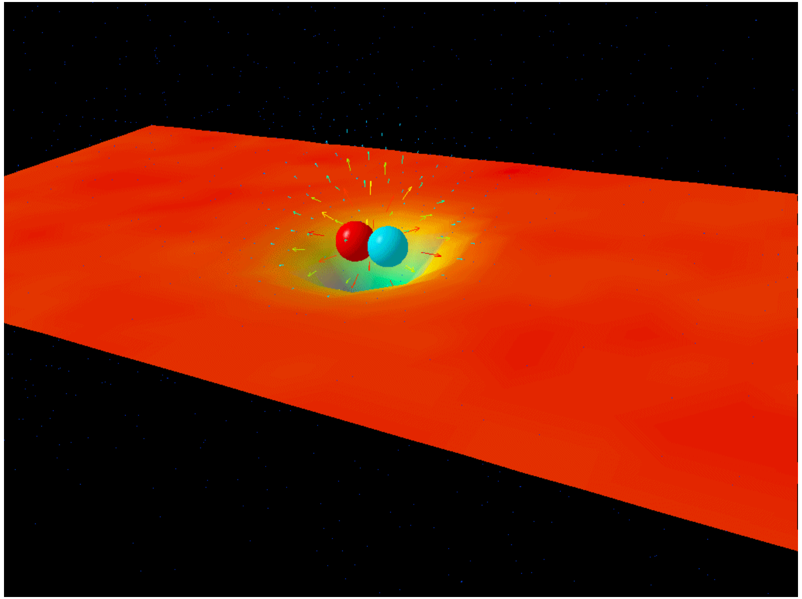



Quarks and Gluons Effective Degrees of Freedom Mesons & Baryons

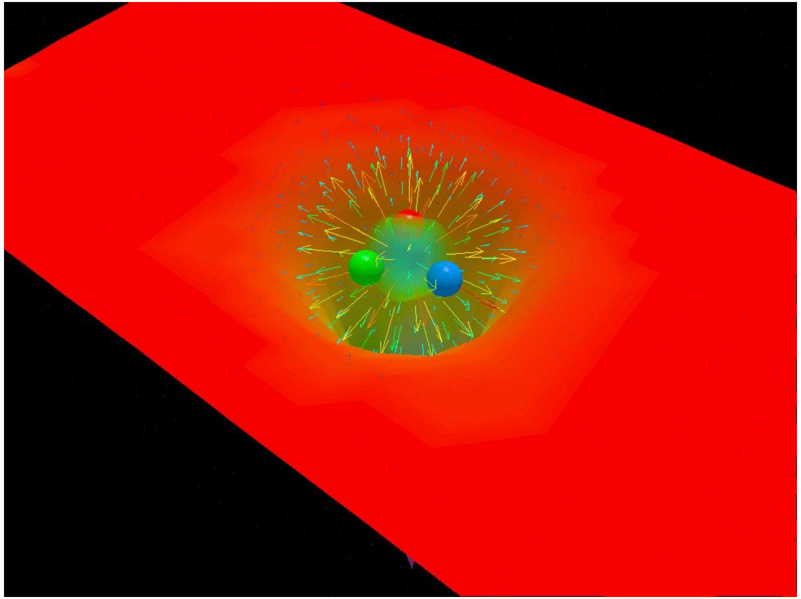
# Critical QCD Question Addressed in Hadron Spectroscopy

- The light meson and N* spectrum: what is the role of glue?

→ **Search for hybrid hadronic states**



Mesons



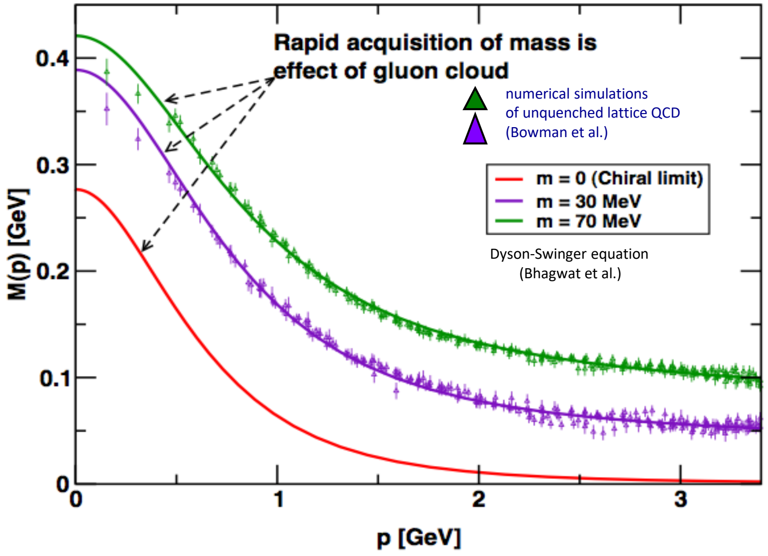
Baryons

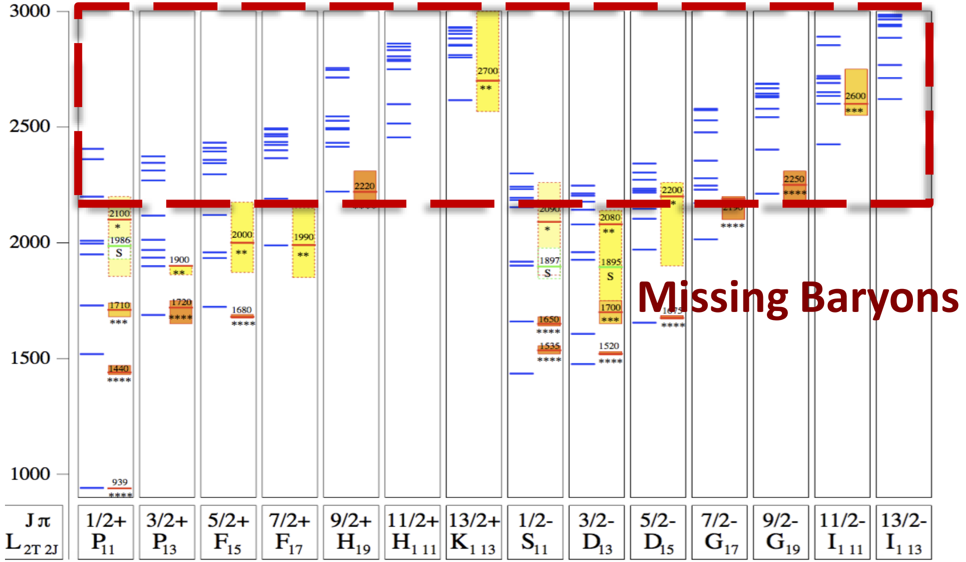
Derek B. Leinweber – University of Adelaide

# Constituent quark models and SU(6)xO(3)

- Current-quarks of perturbative QCD evolve into constituent quarks at low momentum

  → Connection between constituent and current quarks.



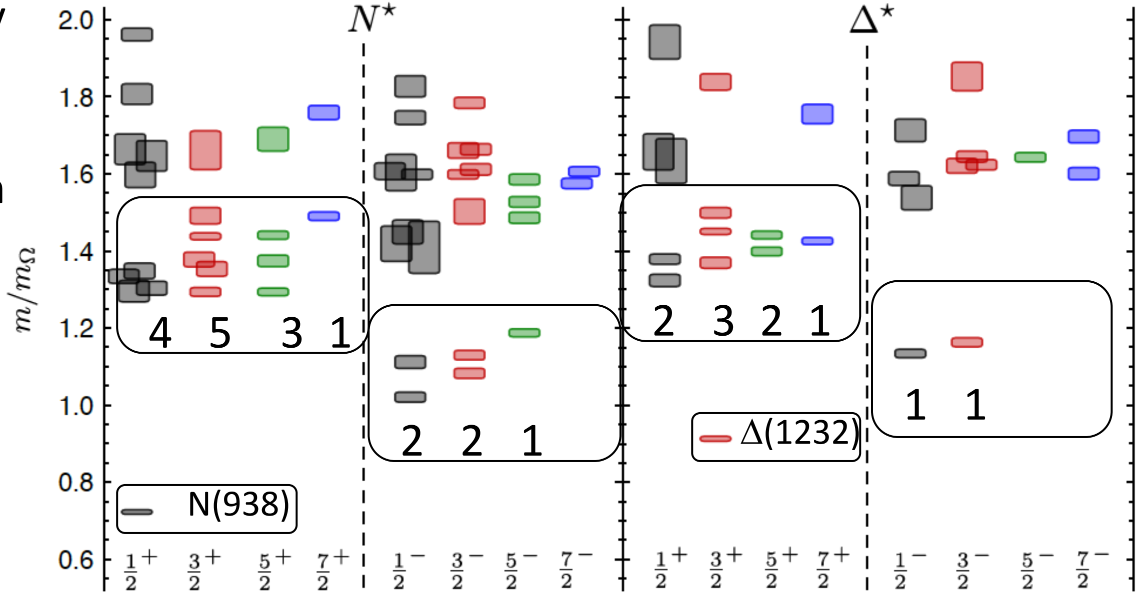

U. Löring, B. Metsch, H.R. Petry, Eur. Phys. J. A 10, 395 (2001)

- QCD-inspired Constituent Quark models: states classified by isospin, parity and spin within each oscillator band. Many projected $q^3$ states are still missing or uncertain.

# LQCD N* & Δ Spectra

- Exhibit the SU(6)×O(3)-symmetry features
- Counting of levels consistent with non-rel. quark model
- Striking similarity with quark model
- No parity doubling

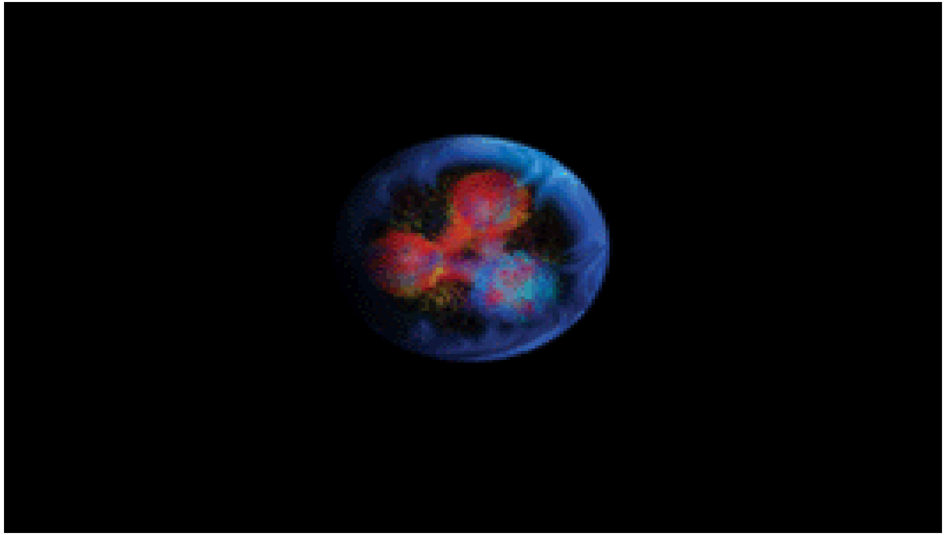
**Problems are not solved!**

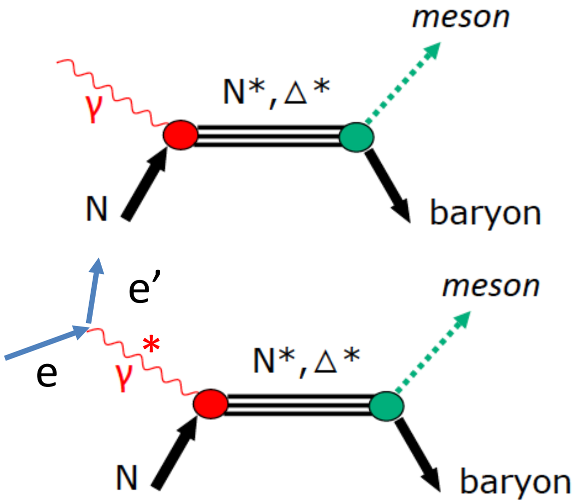



Robert G. Edwards, Jozef J. Dudek, David G. Richards, Stephen J. Wallace
**Phys.Rev. D84 (2011) 074508**

# How to access light baryon excited states

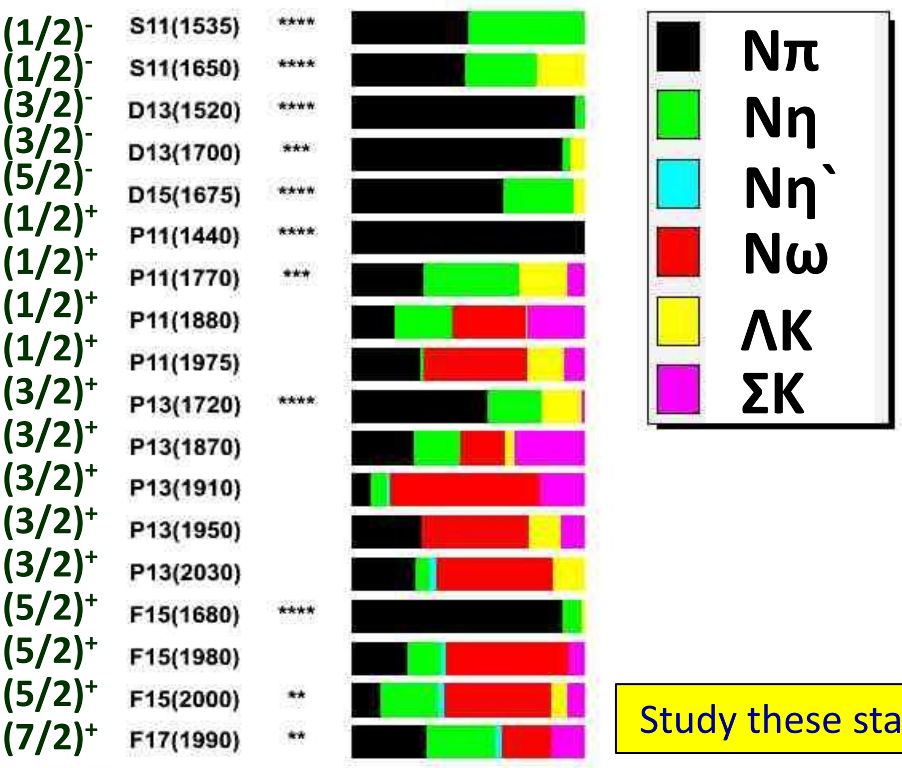
Light Baryons can be studied in different reactions: starting from $\pi$N, $\gamma$N, eN initial states they appear as intermediate resonances that may decay in different final states as $\pi$N, $\pi\pi$N, ηN, $\omega$ N $\rho$N, K$\Lambda$, KΣ, K*Y … Once formed, **their properties are independent from the reaction channel**.



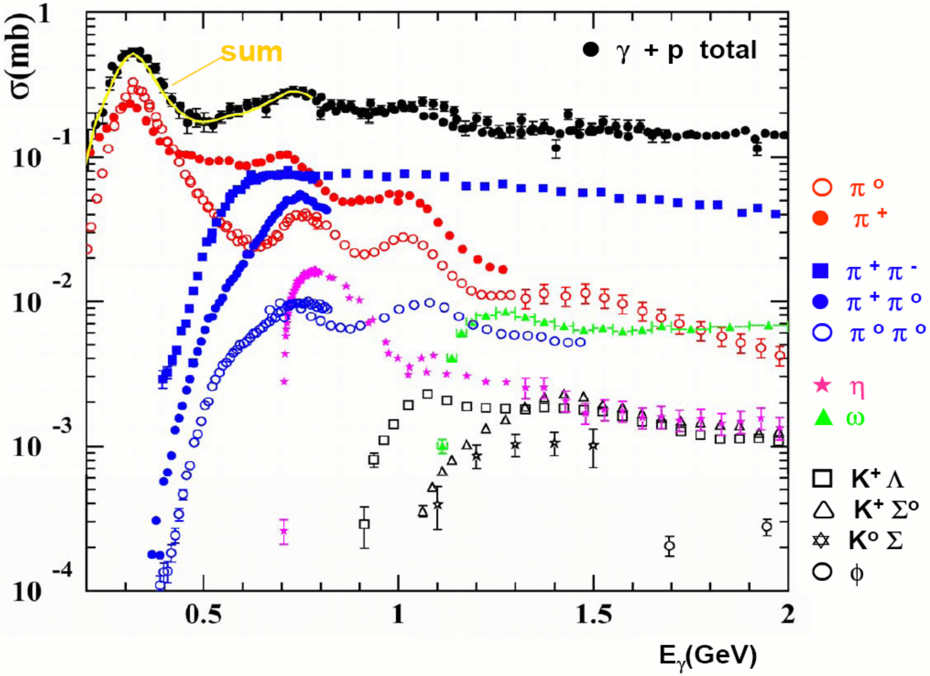


# Establishing the N* and Δ Spectrum

## Search all channels: not just πN



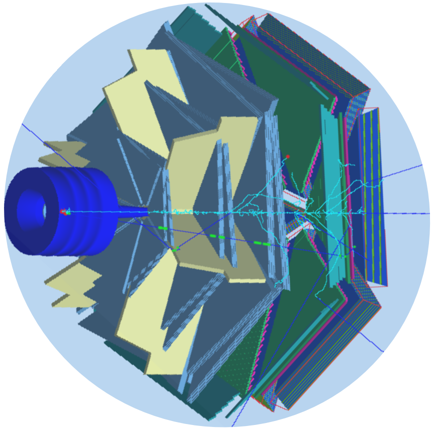

## Photonuclear cross sections




Study these states in electroproduction and extend to higher masses

# CLAS12 N* Program – meson electro-production

## The N* program is one of the key physics foundations of Hall B



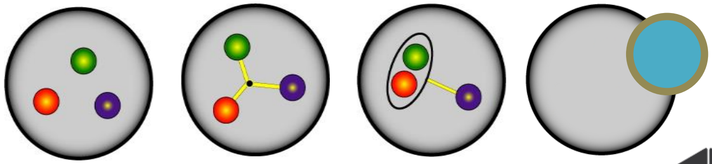
- CLAS12 was designed to measure cross sections and spin observables over a broad kinematic range for exclusive reaction channels:

πN, ωN, ϕN, ηN, η□N, ππN, KY, K*Y, KY*

  - N* parameters do not depend on how they decay
  - Different final states have different hadronic decay parameters and different backgrounds
  - Agreement offers model-independent support for findings

- The program goal is to probe the *spectrum* of N* states and their *structure*
  - Probe the underlying degrees of freedom of the nucleon through studies of the $Q^2$ evolution of the production amplitudes

N* degrees of freedom??



# Updated Spectrum of Baryon Resonances

- From 2000 to 2010 no new Baryon resonances in PDG. πN- scattering data and π-photoproduction only.

| State $N(mass)J^P$ | PDG 2010 | PDG 2026 | $\pi N$ | $K\Lambda$ | $K\Sigma$ | $\gamma N$ |
|---|---|---|---|---|---|---|
| $N(1710)1/2^+$ | *** | **** | **** | ** | * | **** |
| $N(1875)3/2^-$ | | *** | ** | * | * | ** |
| $N(1880)1/2^+$ | | *** | * | ** | ** | ** |
| $N(1895)1/2-$ | | **** | * | ** | ** | **** |
| $N(1900)3/2^+$ | ** | **** | ** | ** | ** | **** |
| $N(2000)5/2^+$ | * | ** | * | | | ** |
| $N(2060)5/2^-$ | | *** | ** | * | * | *** |
| $N(2100)1/2^+$ | * | *** | *** | * | | ** |
| $N(2120)3/2^-$ | | *** | ** | ** | * | *** |
| $\Delta(1600)3/2^+$ | *** | **** | *** | | | **** |
| $\Delta(1900)1/2^-$ | ** | *** | *** | | ** | *** |
| $\Delta(2200)7/2^-$ | * | *** | ** | | ** | *** |

Multi-channel models now include many photoproduction data. e.g. Bonn-Gatchina PWA analysis PRL 119, 062004, (2017)

**Naming scheme has changed:**
**$L_{2I\ 2J}(E) \rightarrow J^P(E)$**

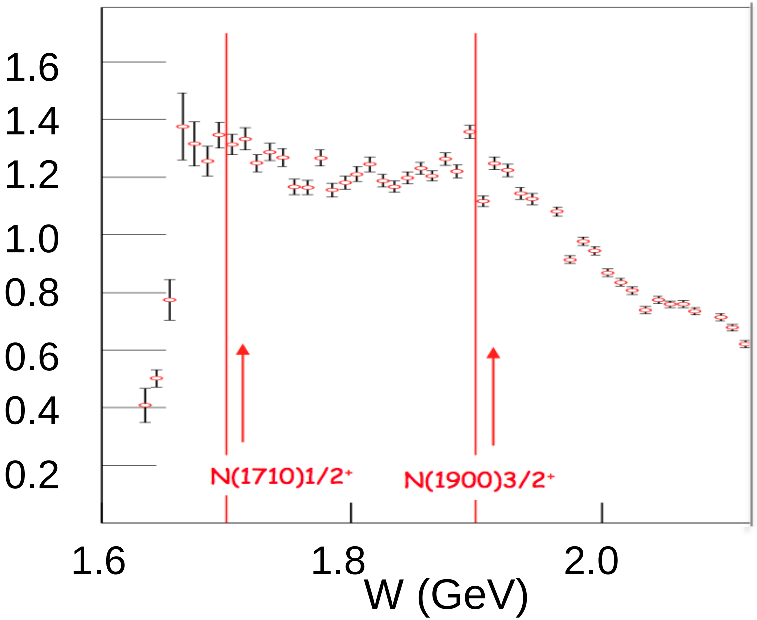
- Results from photoproduction now add to the PDG tables and determine properties of baryon resonances

Decisive impact from CLAS KY photoproduction data

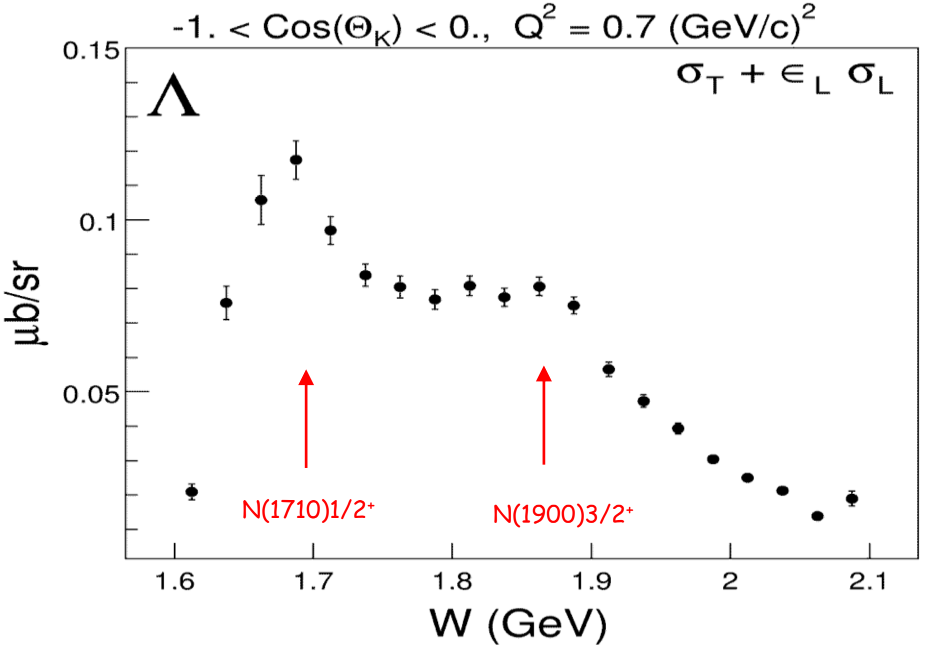
- Extend studies to KY electroproduction and to higher masses

# Studying Baryons in $\gamma^* p \rightarrow K\Lambda/\Sigma$ ?

## Photoproduction




## Electroproduction




- **Strangeness electroproduction is a fertile ground in studying S=0 baryon states with masses above 1.6 GeV.**

# Hybrid Baryons: Baryons with Explicit Gluonic Degrees of Freedom

**Hybrid hadrons** with dominant gluonic contributions are predicted to exist by QCD.

**Experimentally:**

- **Hybrid mesons** $|q\bar{q}g>$ states may have exotic quantum numbers $J^{PC}$ not available to pure $|q\bar{q}>$ states → $0^{--}$, $1^{-+}$, ….GlueX, MesonEx, COMPASS, PANDA ….

- **Hybrid baryons** |qqqg> have the same quantum numbers $J^P$ as |qqq> →

electroproduction with CLAS12 (Hall B).

**Theoretical predictions:**

✧ MIT bag model - T. Barnes and F. Close, Phys. Lett. 123B, 89 (1983).

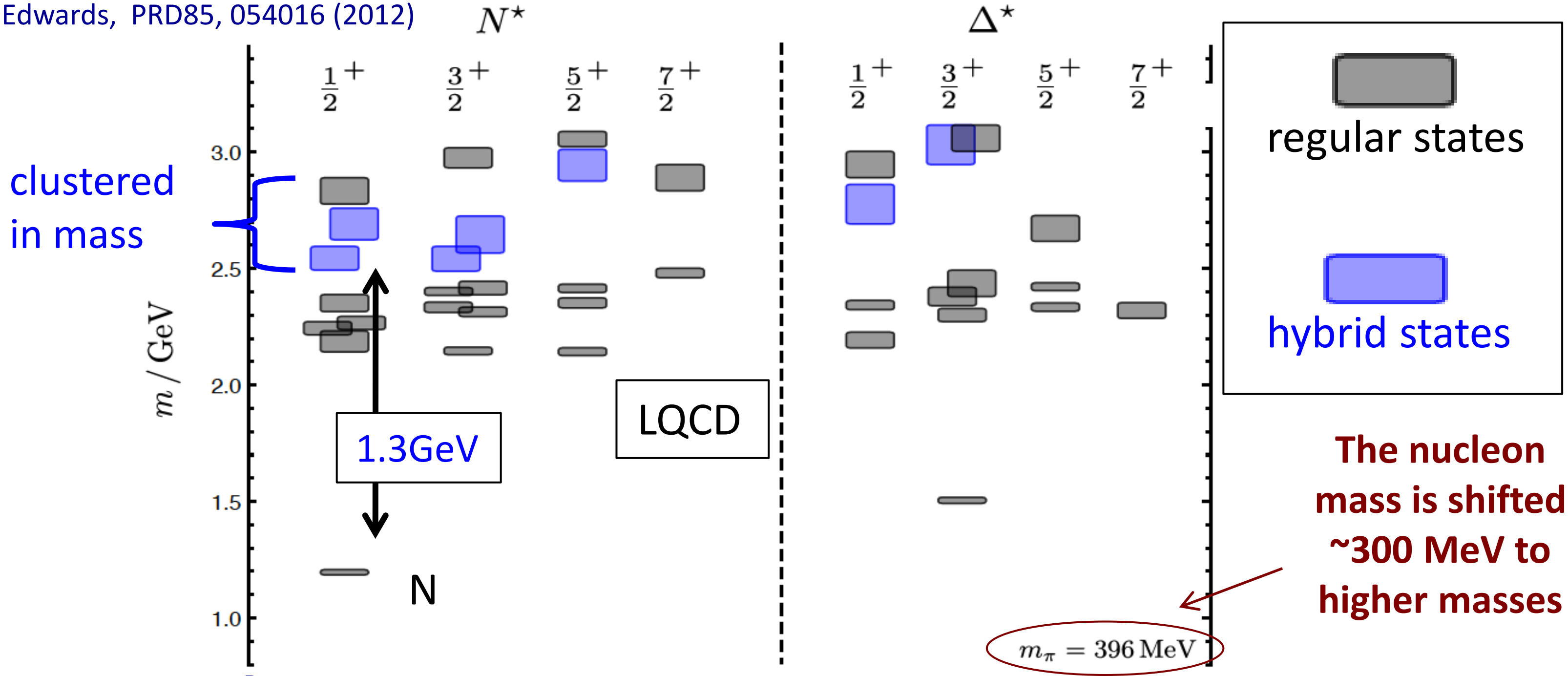
✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).

✧ Flux Tube model - S. Capstick and P. R. Page, Phys. Rev. C 66, 065204 (2002).

✧ LQCD - J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012).

# Hybrid Baryons in LQCD

J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012)




**The nucleon mass is shifted ~300 MeV to higher masses**

**Hybrid states have same $J^P$ values as qqq baryons. How to identify them?**

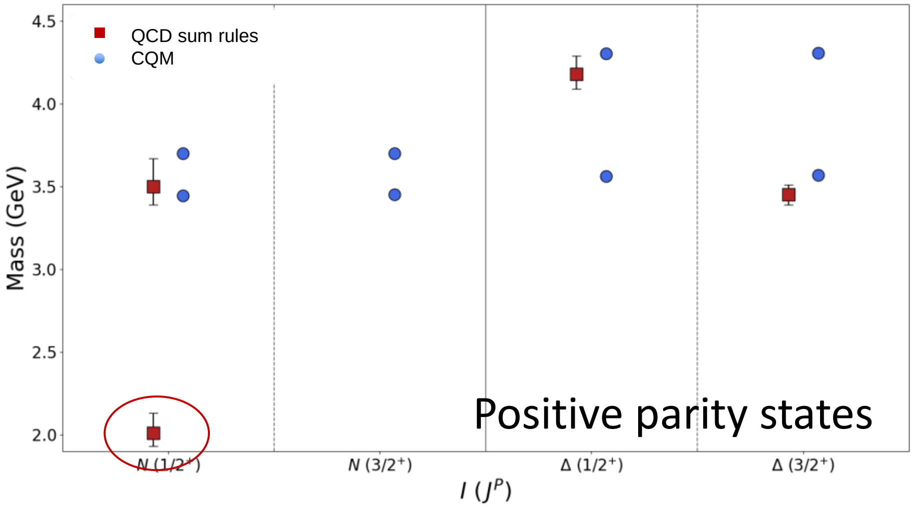
- Overpopulation of N $1/2^+$ and N $3/2^+$ states compared to QM projections.
- **$A_{1/2}$ ($A_{3/2}$) and $S_{1/2}$ show different $Q^2$ evolution. Can we do it?**

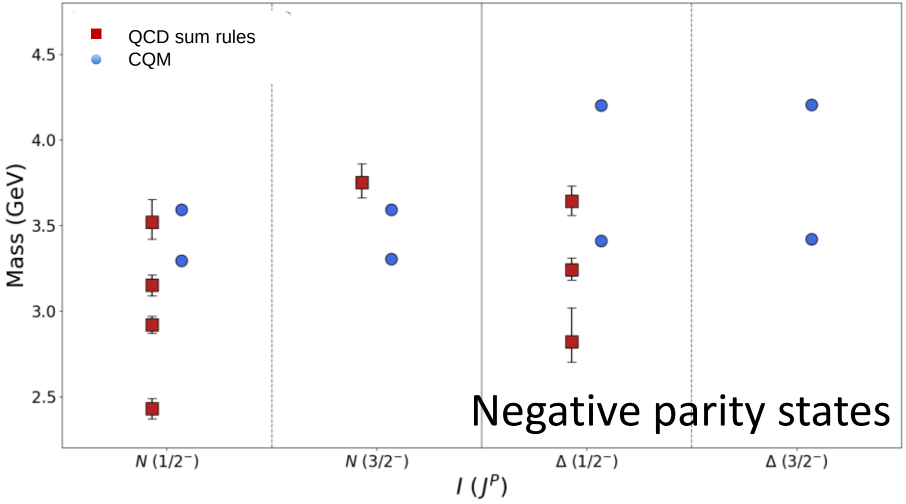
# Hybrid Baryons in QCD Sum Rules and CQM

- qqqg light hybrid baryons spectra have been calculated within the QCD sum rules and the CQM frameworks

Talk by Joachin Viseur on Wednesday

the lowest-lying hybrid baryon is predicted to be the positive-parity N $1/2^+$ of 2.01 GeV mass decaying into conventional baryon plus meson final states: N $f_0(980)/a_0(980)$, $\Delta(1232)\ \pi/\rho$



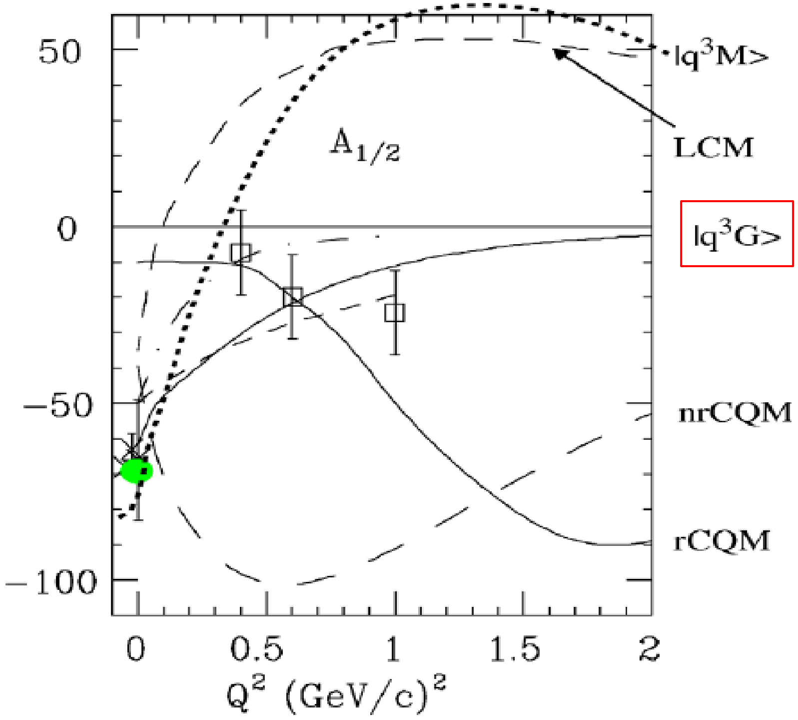




QCD Sum Rules — Qi-Nan Wang, et al. PRD 113, 014033 (2026) *Predictions of masses for light hybrid baryons*

CQM — Joachim Viseur M. et al., arXiv:2606.14451 [hep-ph] *Light hybrid baryons in the constituent model of QCD*

# Electrocouplings of the 'Roper' in 2002

N(1440)1/2$^+$




In 2002 Roper amplitude $A_{1/2}$ measurements were more consistent with hybrid state but data were limited with large uncertainties.

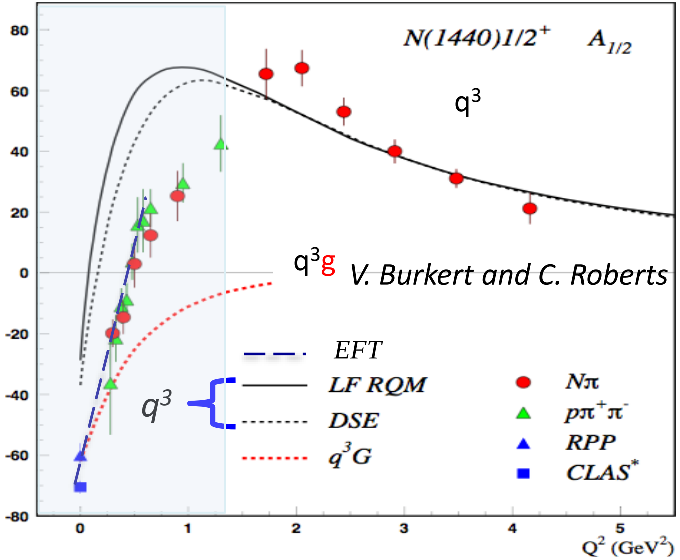
Lowest mass hybrid baryon should be $J^P = 1/2^+$ (same as Roper)

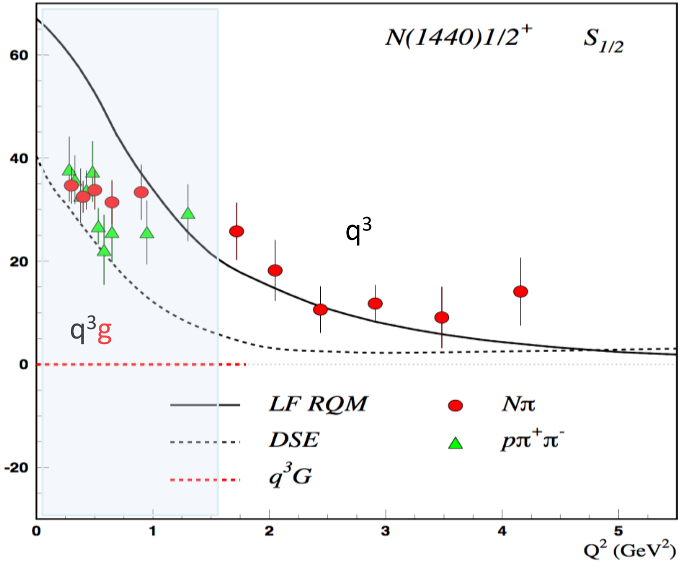
# Separating $q^3g$ from $q^3$ States?

## Precise CLAS results on electro-couplings clarified nature of the Roper

V.D. Burkert et al, *Prog.Part.Nucl.Phys.* 146 (2026) 104214
G. Ramalho, Mod. Phys. 91, 011003 (2026)

J. Segovia et al., PRL 115, 171801 (2015)
V. Burkert C.D. Roberts, Rev. Mod. Phys. 91, 011003 (2019)




- $A_{1/2}$ and $S_{1/2}$ amplitudes at high $Q^2$ >2 $GeV^2$ indicate 1st radial $q^3$ excitation
- Significant meson-baryon coupling at small $Q^2$

**For hybrid “Roper”, $A_{1/2}(Q^2)$ drops off faster with $Q^2$ and $S_{1/2}(Q^2)$ ~ 0.**

# Hybrid Baryon Signatures

Based on available knowledge, the ***signatures*** for hybrid baryons consist of***:***

- **Extra resonances** with $J^p$=1/2$^+$ and $J^p$=3/2$^+$, with masses > 1.8 GeV and decays into $N\pi\pi$ or KY final states.
- A **drop** of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure.
- A **suppressed** longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude ($J^P$=1/2$^+$).

**We focused on:**

$$e\,p \rightarrow \quad e\,p\,\pi^+\,\pi^-$$

$$e\,p \rightarrow \quad e\,K^+\Lambda,\ e\,K^+\Sigma^0$$

**The study will include other multi meson channels.**

A New Experiment Run Group Proposal Submitted to Jefferson Lab PAC44

# A Search for Hybrid Baryons in Hall B with CLA 12


Volker Burkert (Spokesperson), Daniel S. Carman (Spokesperson), V
Victor Mokeev (Spokesperson), Maurizio Ungaro, Ver
*Thomas Jefferson National Accelerator Facility, Newport N*

Annalisa D'Angelo (Contact Person, Spokesperso
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Boris Ishkhanov
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Ilaria Contalbrigo, Paolo Lenisa,
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*44100 Ferrara, Italy*

*Idaho State U*

Marco Battaglieri, And
Mikhail Osipenko, M
*INFN, Se*

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*Craig D. Roberts*‡
*Argonne National Laboratory, Argonne, IL 60439, USA*

*and the CLAS Collaboration*


*June 2, 2016*

‡ **Experiment theory support member**

**Approved with A- Rating**

**100 PAC days Assigned to Run Group K**

**50 PAC DAYS data taken in Fall 2018 and Spring 2024**

# Analysis Tools for Electromagnetic Excitation of Baryons

**Single Meson Analysis**

- **Unitary Isobar Model & Fixed-t Dispersion Relations approaches (Kaon-MAID)**
- **Regge-and Resonance Model (Gent Group)**
- **Prague Isobar Model** http://www.ujf.cas.cz/en/departments/department-of-theoretical-physics/isobar-model.html

**Double Meson Analysis**

- **J-M Reaction Model**

**Multi-channel Analysis**

- **Bonn-Gatchina multi-channel PWA**

- **Julich-Bonn-Washington coupled-channel framework**

- **Argonne-Osaka dynamically coupled-channel model**

- **JPAC Analysis Tools for high mass states using Regge & Veneziano Approach**

# CLAS12 Equipment

Hall B

Forward Detector (FD)

- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward TOF System
- Pre-shower calorimeter
- E.M. calorimeter

Central Detector (CD)

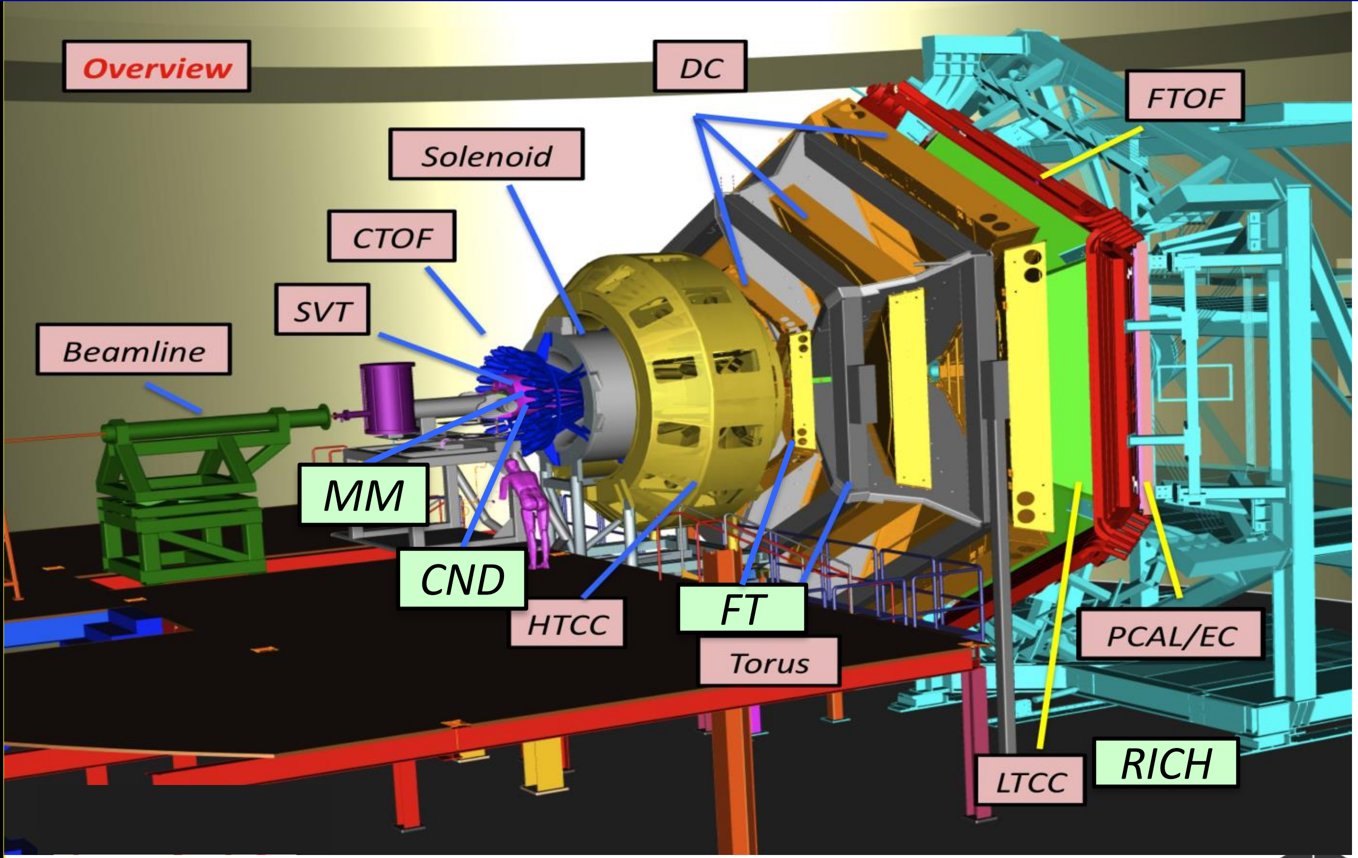
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

Beamline

- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

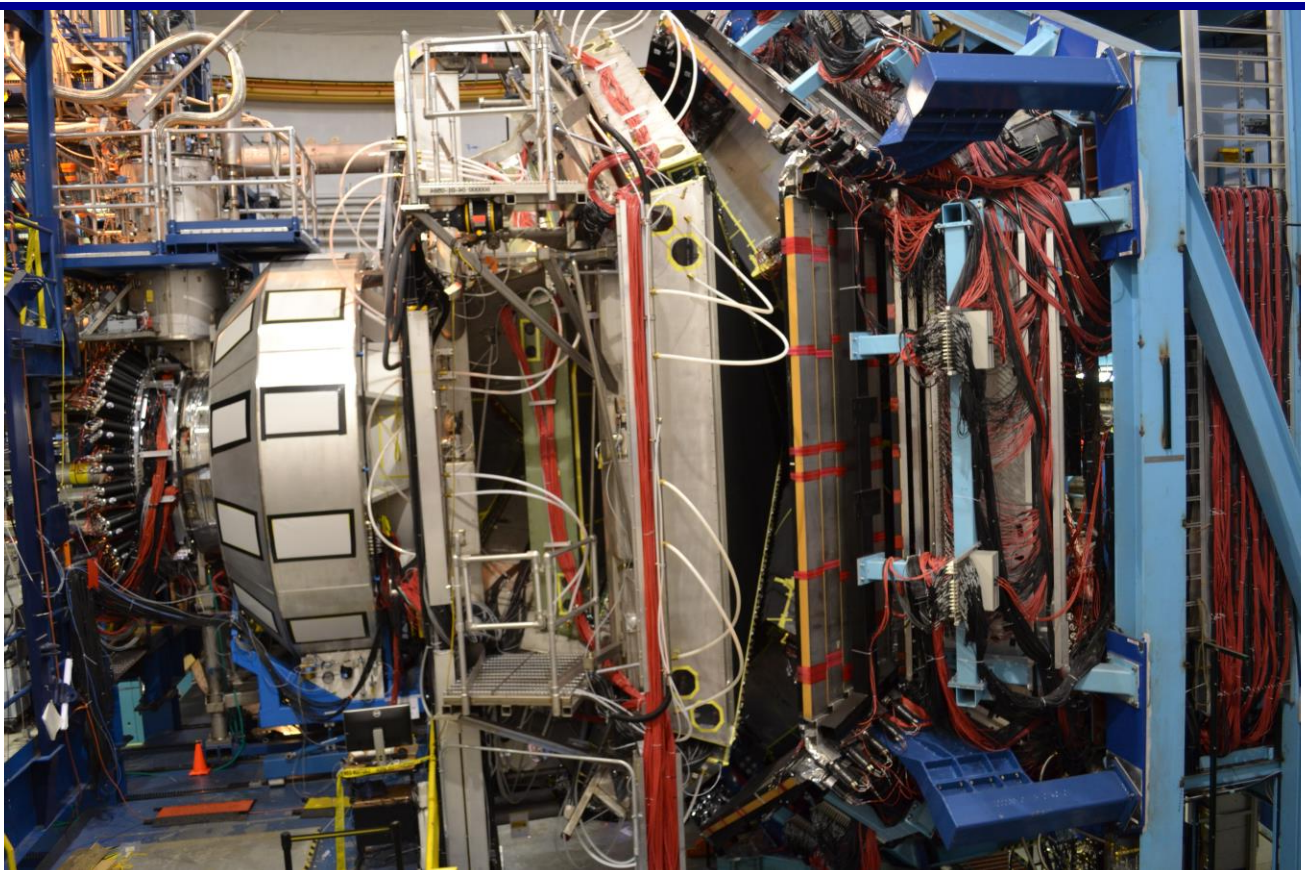
Upgrade to the baseline

- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



# CLAS12 Spectrometer

beam



# Forward Tagger



FT designed to detect electrons and photons at small angles

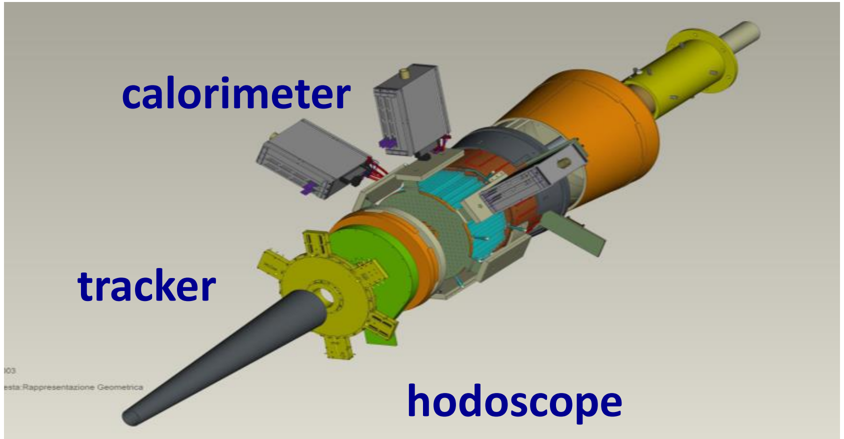
$$\theta = 2.5^\circ \rightarrow 4.5^\circ$$

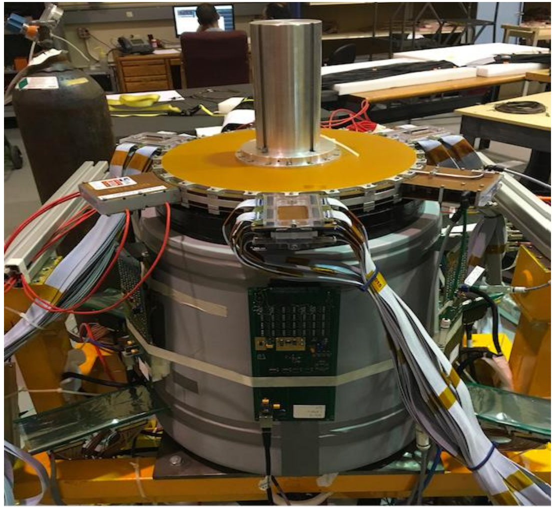
FT-Cal: calorimeter to measure electron energy/momentum

FT-Hodo: scintillation hodoscope to veto photons & backsplash

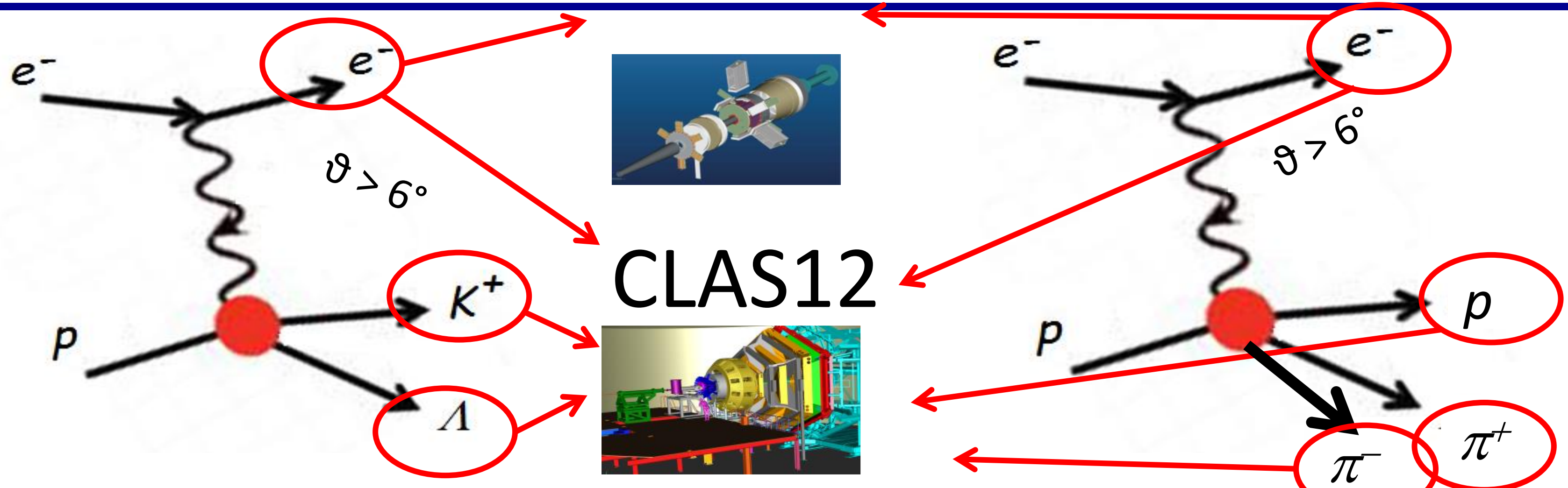
FT-Trk: micro-mega detector to measure electron angles, polarization plane

$$\frac{\sigma(E)}{E} \leq \frac{0.02}{\sqrt{E\ (\mathrm{GeV})}} + 0.01$$



# The Experiment




**Scattered electrons are be detected:**

- in the Forward Tagger for angles from 2.5° to 4.5°
- in the Forward Detector of CLAS12 for scattering angles greater than about 6°

**Charged hadrons are measured in the full range from 6° to 130°**

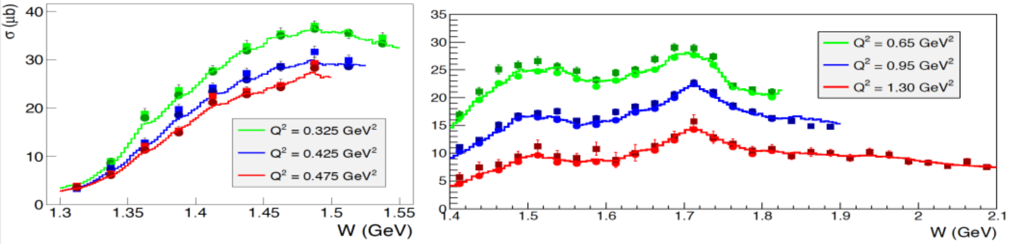
**W < 3 GeV**   $Q^2$ range of interest: **0.05 - 2 GeV²**   $Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\theta}{2} \Rightarrow \theta < 5^o$

FT allows to probe the **crucial $Q^2$ range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}(Q^2)$ amplitude.

# Event Simulation in **CLAS12**

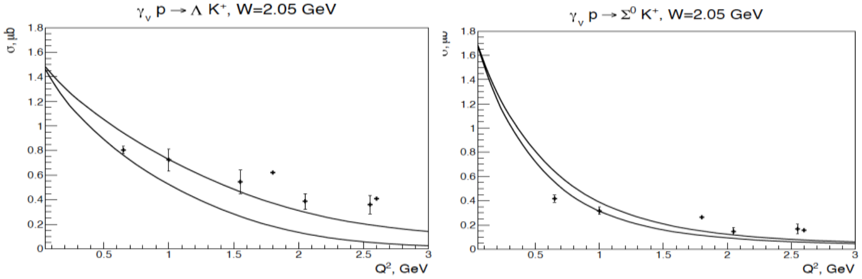
## $e\,p \longrightarrow e\,p\,\pi^+\,\pi^-$

## JLab - Moscow (JM) model




## $e\,p \longrightarrow e\,K^+Y$

## Regge + Resonance (RPR) Gent model




- Development of a realistic event generator using the available models.
- Simulation of *quasi-data* events.
- Full MC events reconstruction to determine final resolutions and efficiencies.

# Quasi – Data Analysis

A hypothetical hybrid baryon contribution added at the amplitude level to the model RPR-2011:

$M_R$ = 2.2 GeV $\Gamma_R$=0.25 GeV $J^P = 1/2^+$ ($J^P = 3/2^+$)

The reaction cross section has been calculated with and without the hybrid baryon resonance contribution to determine:

1. Minimum beam time needed to obtain statistical uncertainty for cross sections comparable with CLAS photoproduction data.
   → 100 days of beam time
2. The Legendre moments of the unseparated and polarization interference components of the cross section.
   → Search for distinctive structures due to the added resonance.
3. The statistical sensitivity to hybrid baryons electro-couplings.
   → Minimum electro-coupling values with 100 days of beam time.
4. The capability of extracting the added resonance parameters from expected data.
   → Blind analysis of quasi-data.

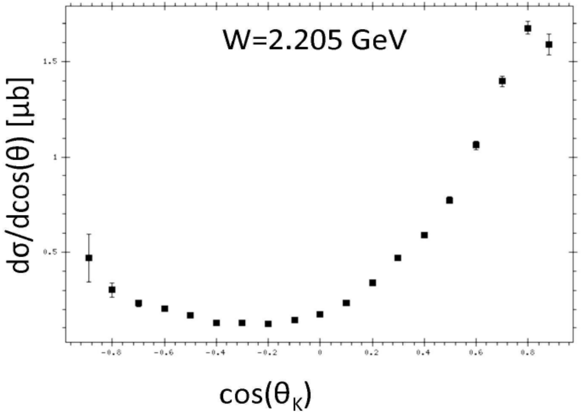
# Statistics and Binning Requirements

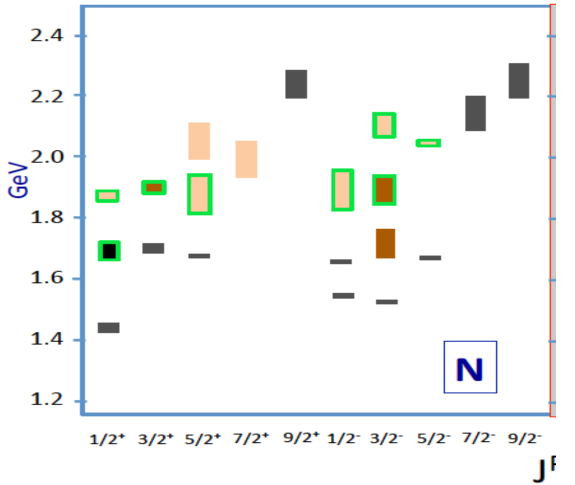
Samples of **$\gamma p \to K^+\Lambda$** cross section used in BnGa analysis that discovered new baryon states in the W range 1.85 – 2.2 GeV mass region.

**Statistical precision ranges from**
**2% - 7%.**

Similar statistics needed to:
- Separate structure functions in $\phi$
- Find new excited baryon states
- Map $Q^2$ dependence of amplitudes

$\Delta W$=10 MeV, $\Delta\cos\theta^*$ = 0.1




| | Range | Bin | #bins |
|---|---|---|---|
| W (GeV) | 1.8-3.0 | 0.01 | 120 |
| cos $\theta^*$ | -1 to +1 | 0.1 | 20 |
| $\phi$ [°] | 0 - 360 | 18 | 20 |
| $Q^2$($GeV^2$) | 0.05 - 2 | 0.02/0.1 | 5/15 |

Total KΛ data in **50+50** days:
**$518.4\times10^6$ events**
Number of bins: $960\times10^3$
<N> = **540 evts/bin**
**$\sigma_N/N$ = 4.3%**

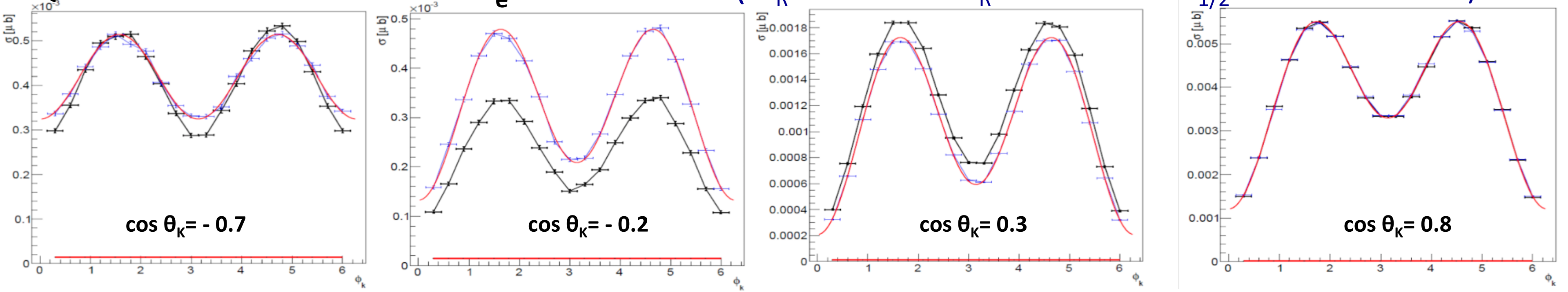
# Simulation of Model + Hybrid Contributions

**e p $\longrightarrow$ e $K^+Y$**

$$\frac{d^2\sigma}{d\Omega_K^*} = \underbrace{\frac{d^2\sigma_T}{d\Omega_K^*} + \epsilon\frac{d^2\sigma_L}{d\Omega_K^*}}_{\sigma_U = \sigma_T + \varepsilon\sigma_L} + \epsilon\frac{d^2\sigma_{TT}}{d\Omega_K^*}\cos 2\phi_K^* + \sqrt{\epsilon(1+\epsilon)}\frac{d^2\sigma_{LT}}{d^2\Omega_K^*}\cos\phi_K^*$$

Black points RPR 2011 model — Blue points RPR 2011 + hybrid resonance

**$Q^2 = 0.1$ GeV$^2$ W=2.2 GeV $E_e = 6.6$ GeV** ($M_R = 2.2$ GeV $\Gamma_R$=0.25 GeV $A_{1/2} = 15\ 10^{-3}$ GeV$^{-1/2}$)

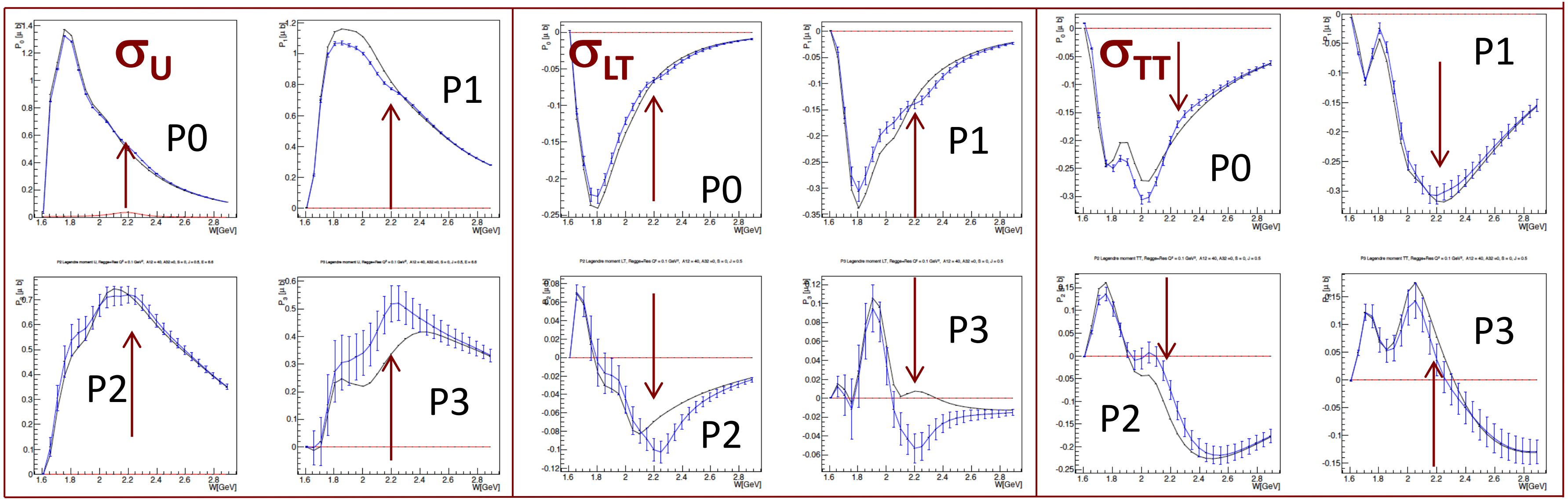



The extraction of the **unseparated cross section d$\sigma_U$** and the **interference cross sections d$\sigma_{TT}$** and **d$\sigma_{LT}$** rely on a **fit of the azimuthal dependence** of the differential cross section at fixed bins of: W, $Q^2$, cos θ*.

# Extraction of Legendre Moments

## $e\,p \longrightarrow e\,K^+\Lambda$ First Legendre Moments

Black curves RPR 2011 model
Blue points RPR 2011 + Resonance




- $J = ½$ Regge + Res. $Q^2 = 1\ GeV^2$ $M_{res} = 2.2\ GeV$ $A_{1/2} = 0.04\ GeV^{-1/2}$ $S_{1/2} = 0$

**Significant structures appear** in most of the Legendre moments at the value of W = 2.2 GeV, corresponding to the mass of the added hybrid baryon

# Statistical Sensitivity of Resonance Electrocouplings

**$e\,p \longrightarrow e\,p\,\pi^+\pi^-$**

**JLab - Moskow (JM) model**

**$e\,p \longrightarrow e\,K^+Y$**

**Regge + Resonance (RPR-2011) Gent model**

Fixing the resonance parameters: $M_{res}$ = 2.2 GeV, $\Gamma_{res}$ = 0.25 GeV, $S_{1/2}$ = 0
**and varying $A_{1/2,\,3/2}$** ⟶ **Minimum values for hybrid baryons electrocouplings**

$$\chi^2/\mathrm{d.p.} = \frac{1}{\mathrm{N_{d.p.}}} \sum_{W,\cos\theta*,\phi} \frac{(\mathrm{d}\sigma_{\mathrm{mod}} - \mathrm{d}\sigma_{\mathrm{mod+res}})^2}{(\mathrm{d}\sigma_{\mathrm{mod}} - \mathrm{d}\sigma_{\mathrm{mod+res}})/\mathrm{N_{ev}}}$$

**$p\pi^+\pi^-$**

| $Q^2$ ($GeV^2$) | 0. | 0.65 | 1.3 |
|---|---|---|---|
| $A_{1/3} \times 10^{-3}$ ($GeV^{-1/2}$) | 22 | 20 | 11 |

**To be compared with $N(1440)1/2^+$**

| $Q^2$ ($GeV^2$) | 0. | 0.65 | 1.3 |
|---|---|---|---|
| $A_{1/3} \times 10^{-3}$ ($GeV^{-1/2}$) | -70 | 10 | 30 |

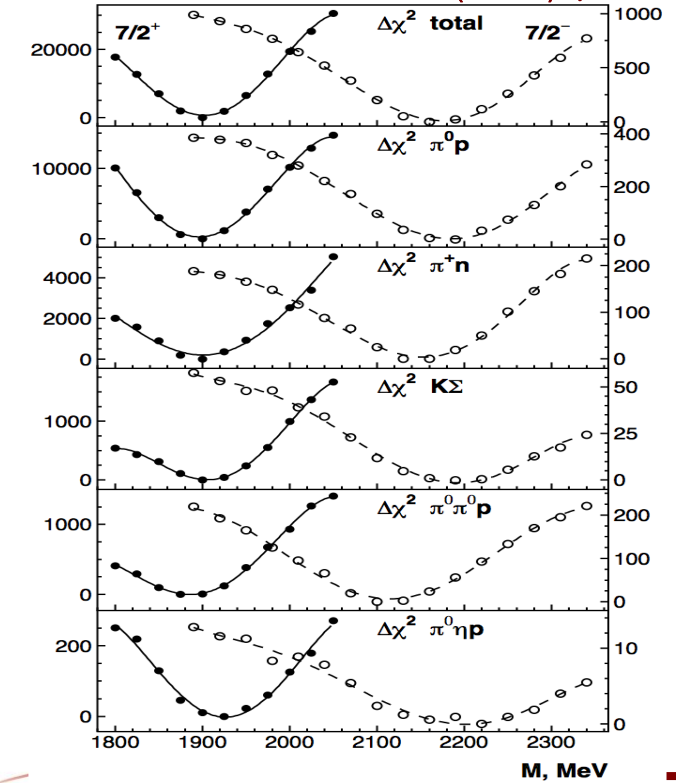
**$K^+\Lambda$**

| $Q^2$ ($GeV^2$) | $J_R$ = 1/2 | | $J_R$ = 3/2 | | |
|---|---|---|---|---|---|
| X $10^{-3}$ ($GeV^{-1/2}$) | $A_{1/2}$ | $S_{1/2}$ | $A_{1/2}$ | $A_{3/2}$ | $S_{1/2}$ |
| 0.1 | 9.5 | 9.5 | 13 | 8.5 | 8.5 |
| 0.5 | 14 | 16 | 15 | 15 | 10 |
| 1.0 | 13 | 19 | 14 | 14 | 7.5 |

# Resonance Parameters Extraction: Resonance Mass

## Bonn-Gatchina Analysis Example

$\Delta(1950)7/2^+$ $\Delta(2200)7/2^-$



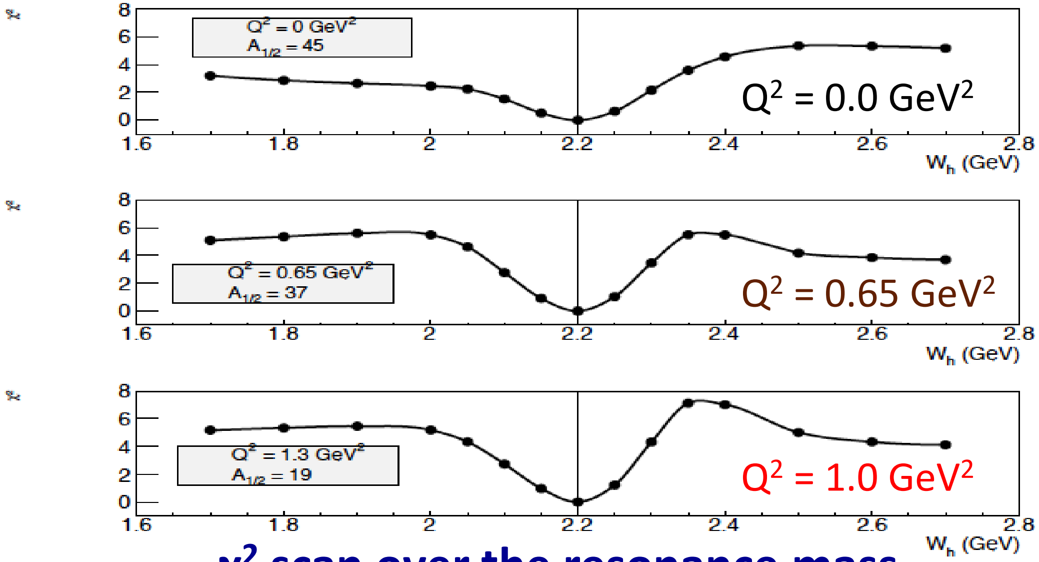

## $ep \rightarrow e\, p\, \pi^+\pi^-$

$d\sigma_{q.d.}$ = JM model + "hybrid resonance"

$d\sigma_{th}$ = JM model + variable mass resonance

$J^+ = ½^+$ $M_{res}$ = 2.2 GeV $\Gamma_{res}$ = 0.25 GeV

$S_{1/2} = 0$, $A_{1/2}$ = statistical threshold value




**$\chi^2$ scan over the resonance mass**

# Blind Extraction: $J^P=1/2^+$ + $J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \rightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated → $\mathbf{d\sigma_{q.d.}}$

**A blind analysis has been then attempted trying to extract the resonances $J^P$ spin-parities and**

**7 unknown parameters:** $M_{res}^1$ $\Gamma_{res}^1$ $A_{1/2}^1$
$M_{res}^2$ $\Gamma_{res}^2$ $A_{1/2}^2$ $A_{3/2}^2$

Searching the minimum of the quantity:

$$\chi^2/\mathrm{d.p.} = \frac{1}{\mathrm{N_{d.p.}}} \sum_{\mathrm{W},\cos\theta*,\phi} \frac{\left(\mathrm{d}\sigma_{\mathrm{th}} - \mathrm{d}\sigma_{\mathrm{q.d}}\right)^2}{\left(\mathrm{d}\sigma_{\mathrm{q.d.}}\right)/\mathrm{N_{ev}}}$$

$\mathbf{d\sigma_{th}}$ were calculated using the **Gent RPR2011** amplitudes including two resonances $J^p = 1/2^+$ and $J^p = 3/2^+$, whose parameters values were scanned in the range:

| | |
|---|---|
| $2.0 < W < 2.5$ GeV | $-0.05 < A_{1/2} < +0.05$ GeV$^{-1/2}$ |
| $0.1 < \Gamma < 0.4$ GeV | $-0.05 < A_{3/2} < +0.05$ GeV$^{-1/2}$ |

at a fixed $Q^2 = 0.5$ GeV$^2$

$S_{1/2} = 0$

# Blind Extraction: $J^P=1/2^+ + J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \rightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated → $d\sigma_{q.d.}$

**A blind analysis has been then attempted trying to extract the resonances $J^P$ spin-parities and**

**7 unknown parameters:** $M_{res}^1$ $\Gamma_{res}^1$ $A_{1/2}^1$
$M_{res}^2$ $\Gamma_{res}^2$ $A_{1/2}^2$ $A_{3/2}^2$

**Iterative procedure:**

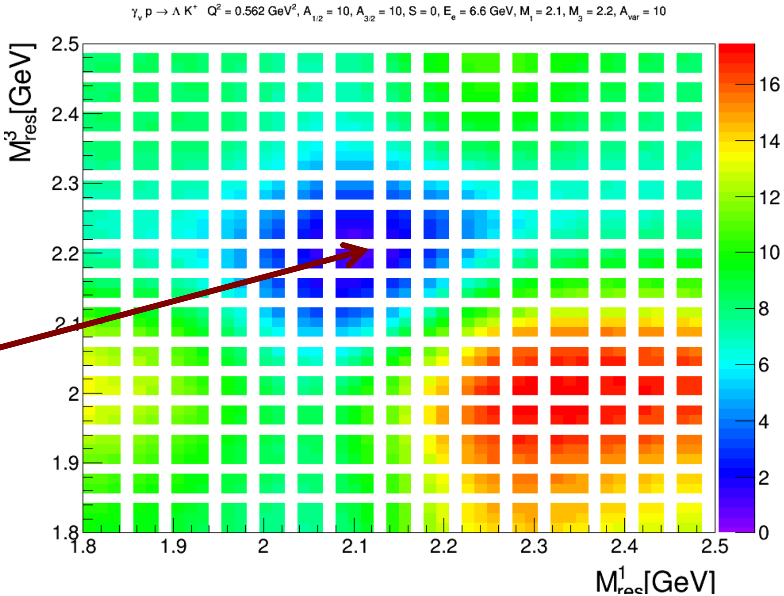
- The algorithm calculates the $\chi^2$ value over a 7-dim parameters coarse grid, covering the full range
- The combination of parameters corresponding to the minimum $\chi^2$ value is found
- $\chi^2$ value is calculated over a finer 7-dim parameters grid, around the minimum
- The procedure is repeated three times.

# Blind Extraction: $J^P=1/2^+$ + $J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \rightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated → $\mathbf{d\sigma_{q.d.}}$

**Typical 3-dim map of $\chi^2$ as a function of the two resonance masses, evolving in time for increasing $A_{1/2}$ ($A_{3/2}$) strength.**

$\chi^2$ minimum



# Blind Extraction: $J^P=1/2^+$ + $J^P=3/2^+$

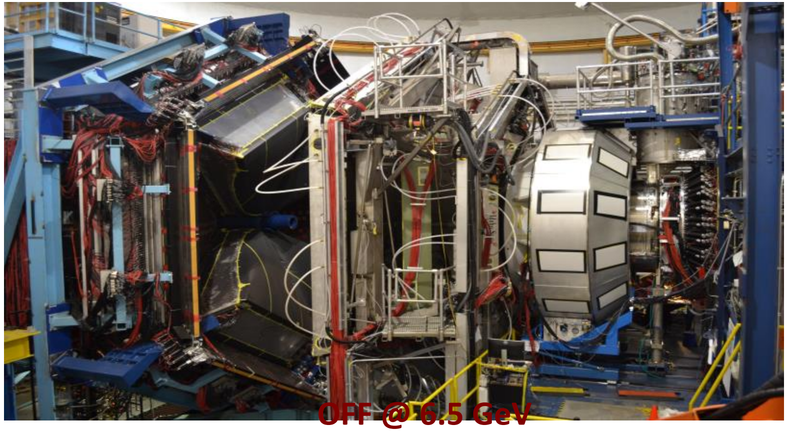
Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \rightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated → $\mathbf{d\sigma_{q.d.}}$

**A blind analysis has been then attempted trying to extract the resonances $J^P$ spin-parities and 7 unknown parameters:** $M_{res}^1$ $\Gamma_{res}^1$ $A_{1/2}^1$ $M_{res}^2$ $\Gamma_{res}^2$ $A_{1/2}^2$ $A_{3/2}^2$

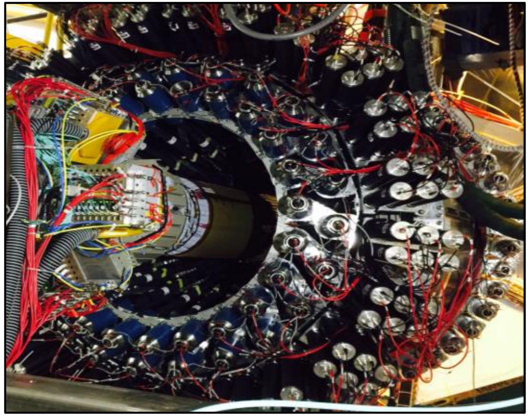
Hybrid Baryons parameters are well reconstructed.

| Blind Resonance Parameters | Extracted Resonance Parameters |
|---|---|
| $M_{res}^1$ = 2.30 GeV | $M_{res}^1$ = 2.32 GeV |
| $\Gamma_{res}^1$ = 0.30 GeV | $\Gamma_{res}^1$ = 0.30 GeV |
| $A_{1/2}^1$ = 0.020 $GeV^{-1/2}$ | $A_{1/2}^1$ = 0.019 $GeV^{-1/2}$ |
| $M_{res}^2$ = 2.45 GeV | $M_{res}^2$ = 2.45 GeV |
| $\Gamma_{res}^2$ = 0.35 GeV | $\Gamma_{res}^2$ = 0.31 GeV |
| $A_{1/2}^2$ = - 0.015 $GeV^{-1/2}$ | $A_{1/2}^2$ = - 0.014 $GeV^{-1/2}$ |
| $A_{3/2}^2$ = 0.04 $GeV^{-1/2}$ | $A_{3/2}^2$ = 0.038 $GeV^{-1/2}$ |

# Run Group K - Run Conditions

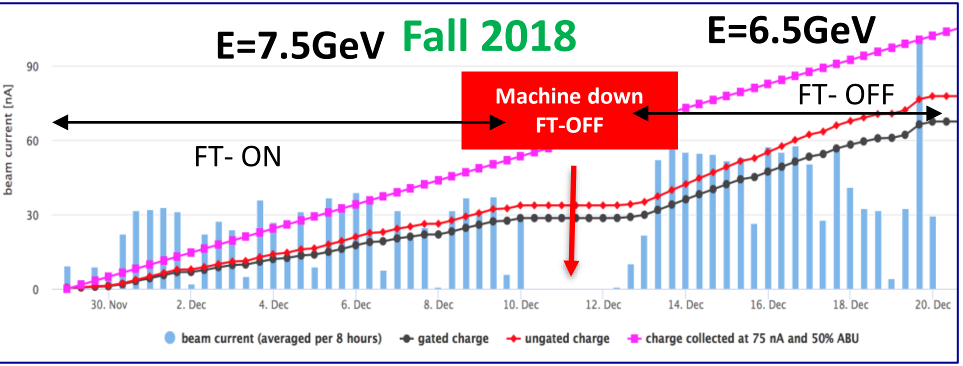


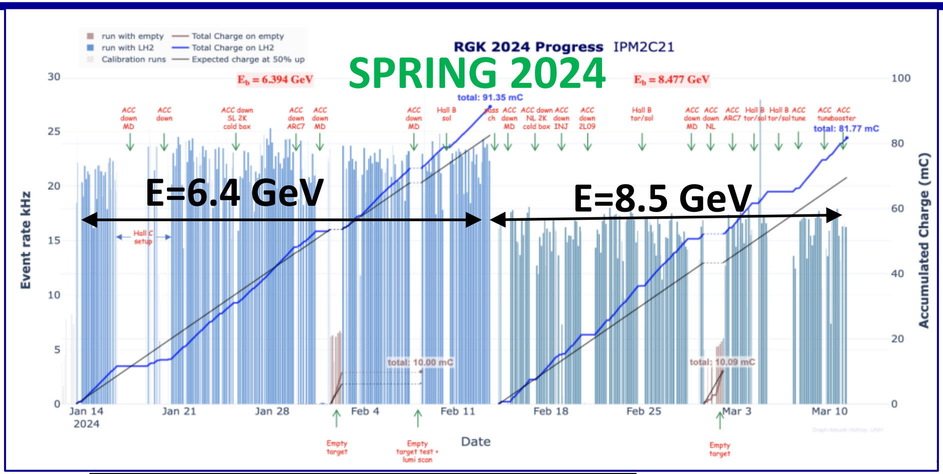
OFF @ 6.5 GeV



| | |
|---|---|
| **Torus Current** | 100% (3375 A) - **negative outbending** |
| **Solenoid** | -100 % |
| **FT** | **ON @ 7.5 GeV -> OFF @ 6.5 GeV, 8.5 GeV** |
| **MM RICH** | ON |
| **FMT** | OFF |
| **Beam/Target** | Polarized electrons, unpolarized $LH_2$ target |
| **Luminosity** | ~ 5 $10^{34}$ $cm^{-2}s^{-1}$ @ 7.5 GeV<br>$10^{35}$ $cm^{-2}s^{-1}$ @ 6.5, 8.5 GeV **FULL LUMINOSITY** |

# Run Group K  Production




45mC of accumulated charge

| Fall 2018 | | |
|---|---|---|
| Beam Energy | Beam Current | Collected Events |
| 7.5 GeV | 35 nA | 3.5 G |
| 7.5 GeV | 45 nA | 4.3 G |
| 6.5 GeV | 60 nA | 7.8 G |

**EVENTS**
**15.6 G**

Statistics increased by a factor 4

193mC of accumulated charge

| Spring 2024 | | |
|---|---|---|
| Beam Energy | Beam Current | Collected Events |
| 6.4 GeV | 65 nA | 38.3 G |
| 8.5 GeV | 75 nA | 21.7 G |

**EVENTS**
**60 G**

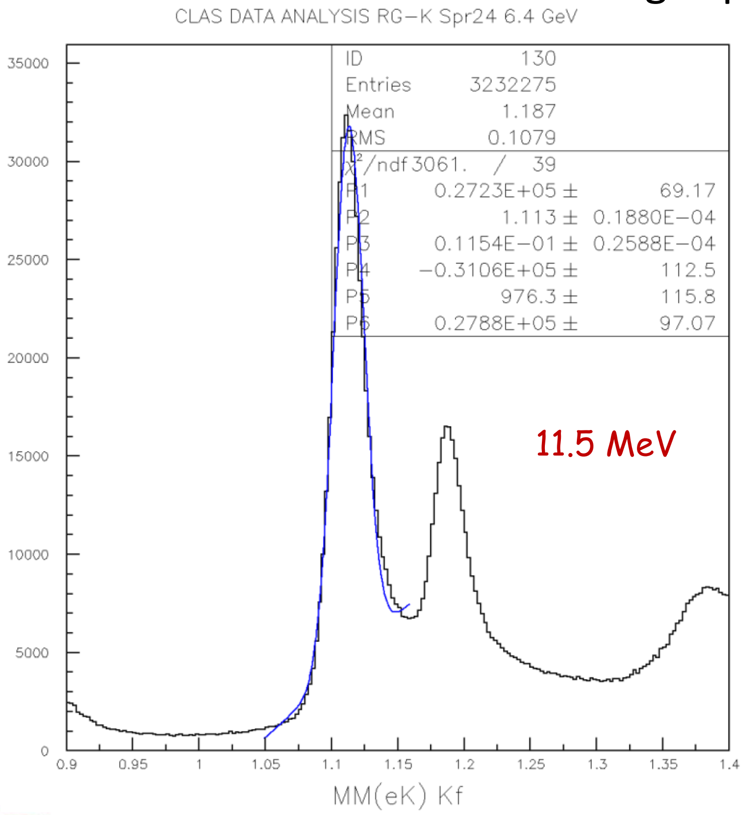
Total of 75.6 G events

# RG-K Spr24 KY Validation Studies

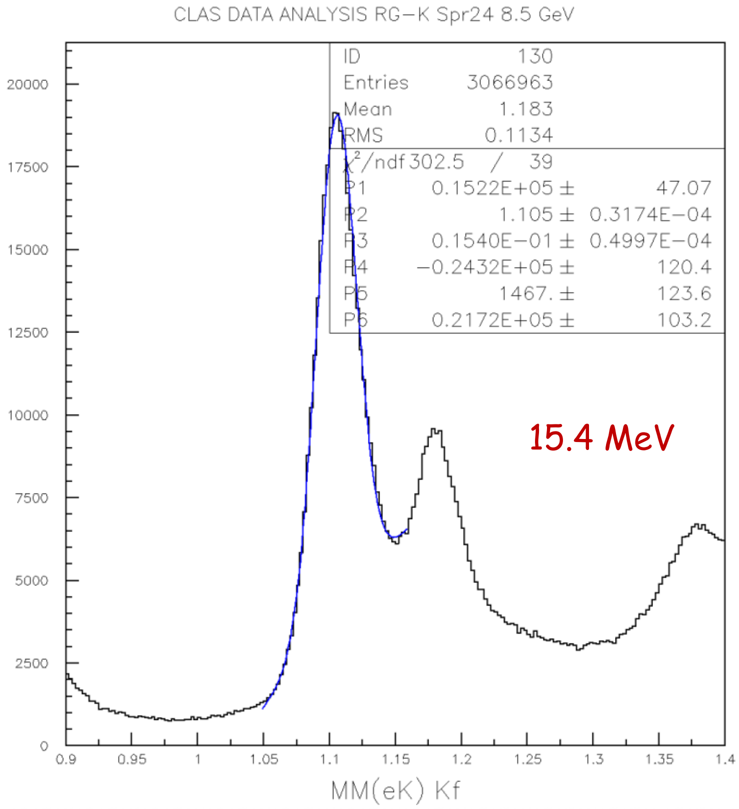
By: Daniel Carman

High-quality data available

6.4 GeV




8.5 GeV



# Run Group K  On-going analyses

| Student/Scientist | Topic |
|---|---|
| Chiara Ammendola - Roma | $ep \rightarrow e'K^+\Lambda(1520)$ |
| Joshua Artem Tan - JLAB/ Sangbaek Lee | DVCS Beam Spin Asymmetry |
| Story Frantzen - MIT | DV$\pi^0$p |
| Bianca Gualtieri - FIU | $ep \rightarrow e'K^+K^+\Xi^-$ |
| Tatsuhiro Ishige | $ep \rightarrow e'K^+\ \Lambda(1405)$ |
| Maggie Kerr | TCS |
| Anastasya Pavlova – MSU | $ep \rightarrow e'\pi^0 p$ |
| Stepan Savkin – MSU | $ep \rightarrow e'\pi^+\pi^- p$ |
| Yijie Wang - MIT | DVCS Cross Section and Elastic Scattering xsec |
| Harut Avagyan | SIDIS |
| Dan Carman/Lucilla Lanza | $ep \rightarrow e'K^+Y$ $[\Lambda(1116), \Sigma(1193)]$ |
| Krishna Neupane/Bhawani Singh | DV $K^+K^-$p |

Dan Carman plenary talk on Monday

Most analyses profit from the availability of data at 6.5, 8.5 and 10.5 GeV combining RGK and RGA data

# Summary

- We started a program to search for new states of baryonic matter: **hybrid baryons.**
- Complementing the international program to search for **hybrid mesons.**
- Identification of hybrid baryons will verify fundamental expectations of **strong QCD on the role of glue.**
- Search for these states in exclusive channels covers the kinematical range: $Q^2 > 0.05$ $GeV^2$, $W < 3$ GeV.
- **100 days** beam time with CLAS12 are expected to provide the statistical sensitivity to measure the baryon resonances electro-couplings for two major electroproduction channels $\mathbf{p\pi^+\pi^-}$ and $\mathbf{K^+Y}$ and eventually find new excited states.
- **The experiment has been approved with A- rating** and **has been assigned 100 PAC days, 50 of which have been accumulated during fall 2018 and spring 2024**
- Amplitude analysis will be developed with the **theoretical support groups** to establish the existence and properties of new resonances in the 1.8 GeV < M < 3.0 GeV mass region.