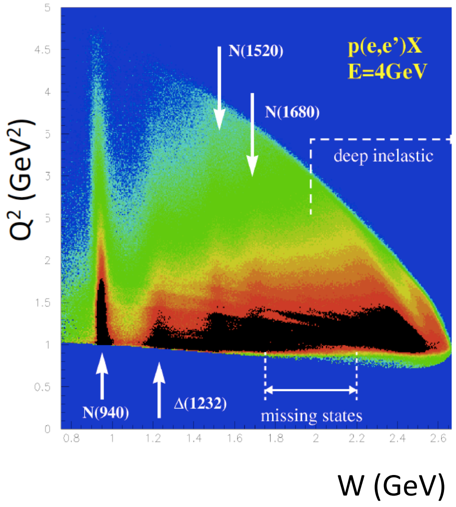
Hybrid Baryons at CLAS

Annalisa D'Angelo

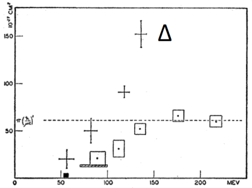
University of Rome Tor Vergata & INFN Rome Tor Vergata
Rome - Italy

Outline:

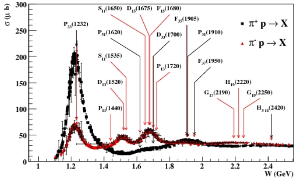
- Establishing N* states
- Identifying the effective degrees of freedom
- Search for hybrid Baryons
- Outlook & conclusions



Historical Markers

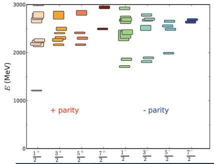


1952: First glimpse of the Δ(1232) in πp scattering shows internal structure of the proton.

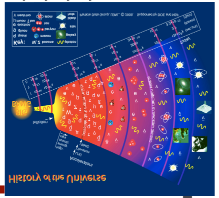


1964: Baryon resonances essential in establishing the quark model and the color degrees of freedom.

1989: Broad effort to address the missing baryon puzzle.



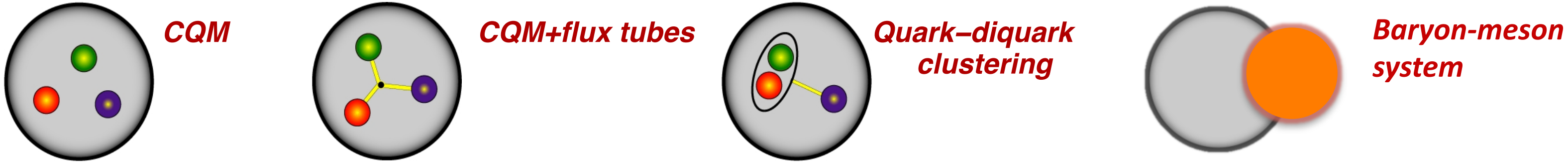
2010: First successful attempt to predict the nucleon spectrum in LQCD.



2015: Understanding of the baryon spectrum is needed to quantify the transition from QGP to the confined phase in the early universe.

What Do We Want to Learn ?

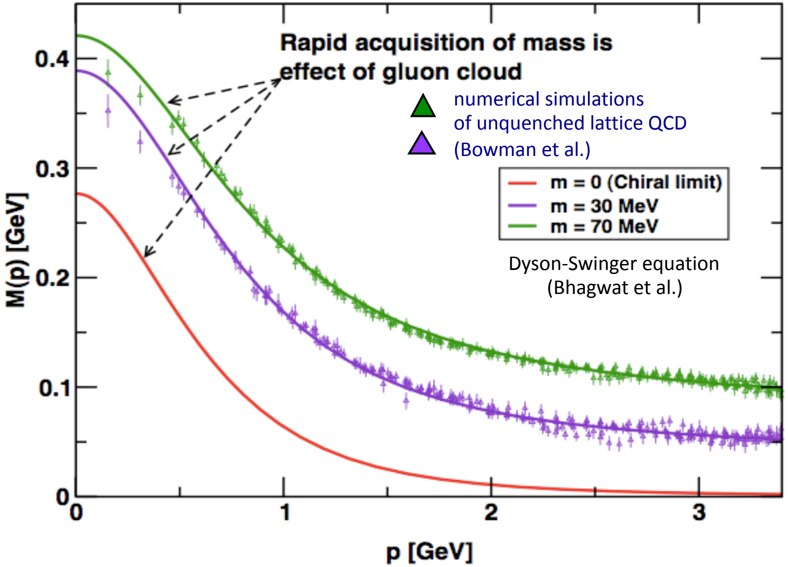
Understand the effective degrees of freedom underlying the N* spectrum and the forces.

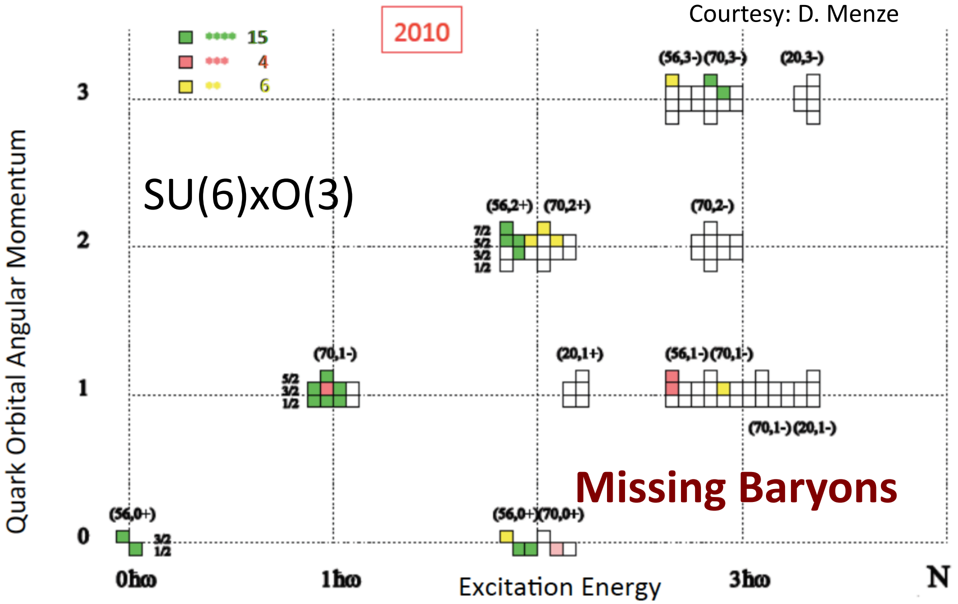


- A vigorous experimental program is worldwide underway with the aim to:
  - search for **undiscovered states** in meson **photoproduction** at CLAS, CBELSA, GRAAL, MAMI, LEPS
  - confirm or dismiss weaker candidates (*, **, ***)
  - characterize the N* and Δ spectrum systematics.

- Measure the strength of resonance excitations versus distance scale in meson **electro-production** at JLab, to reveal the underlying degrees of freedom in the Q^2 evolution of the transition amplitudes.

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





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

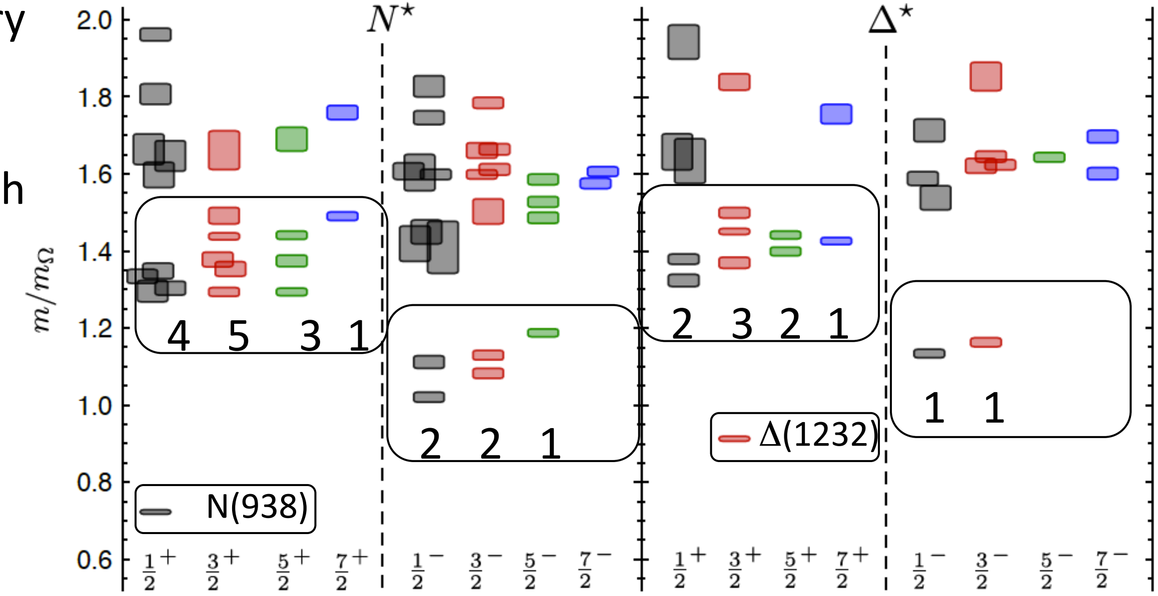
→ Connection between constituent and current quarks.

- 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

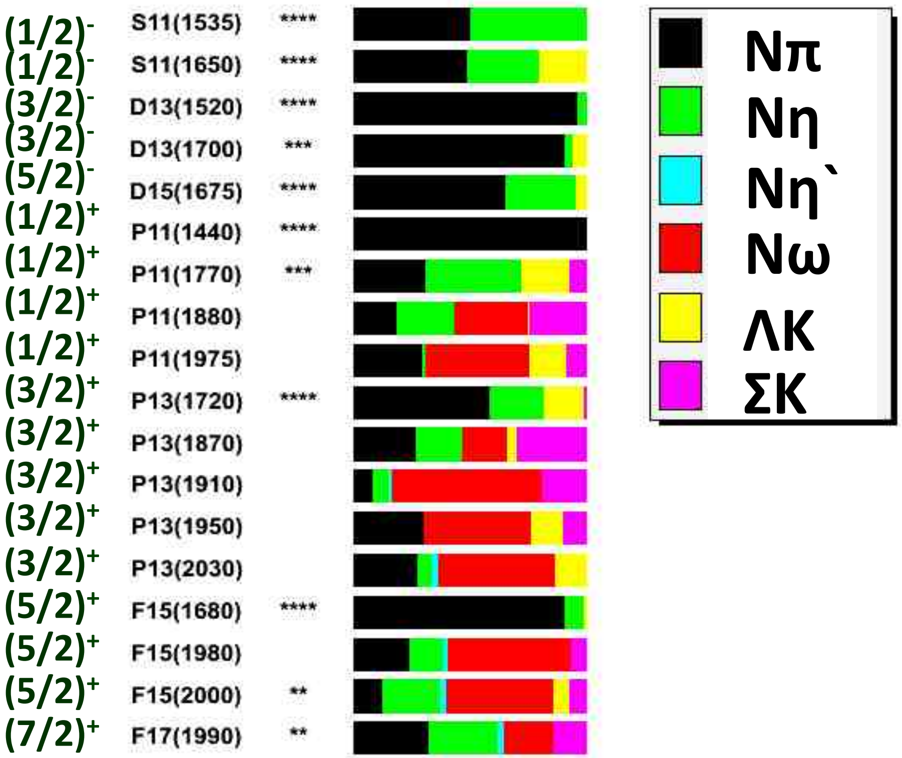
Problems are not solved!



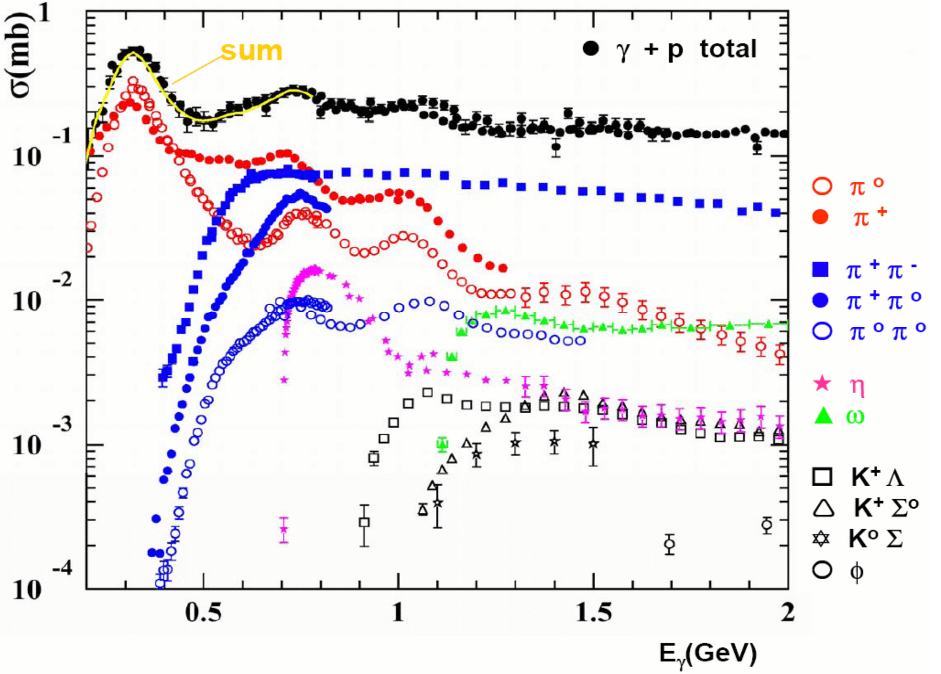
Robert G. Edwards, Jozef J. Dudek, David G. Richards, Stephen J. Wallace
Phys.Rev. D84 (2011) 074508

Establishing the N* and Δ Spectrum

Search all channels: not just πN



Photonuclear cross sections

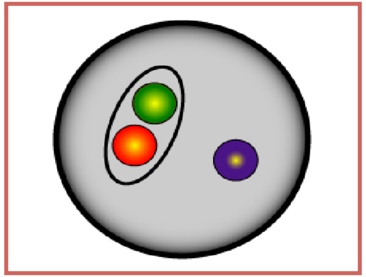


Evidence for New N* in KY Final State

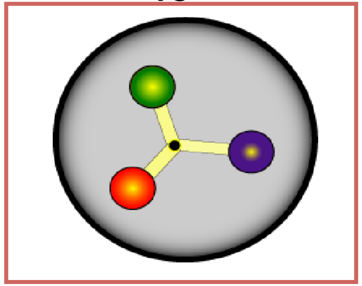
State N(mass)J^P	PDG pre 2010	PDG 2018	KΛ	KΣ	Nγ
N(1710)$1/2^+$	***	****	****	**	****
N(1880)$1/2^+$		***	**		**
N(1895)$1/2^-$		****	**	*	**
N(1900)$3/2^+$	**	****	***	**	***
N(1875)$3/2^-$		***	***	**	***
N(2150)$3/2^-$		***	**		**
N(2000)$5/2^+$	*	**	**	*	**
N(2060)$5/2^-$		***		**	**

Do New States Fit into Q^3 QM ?

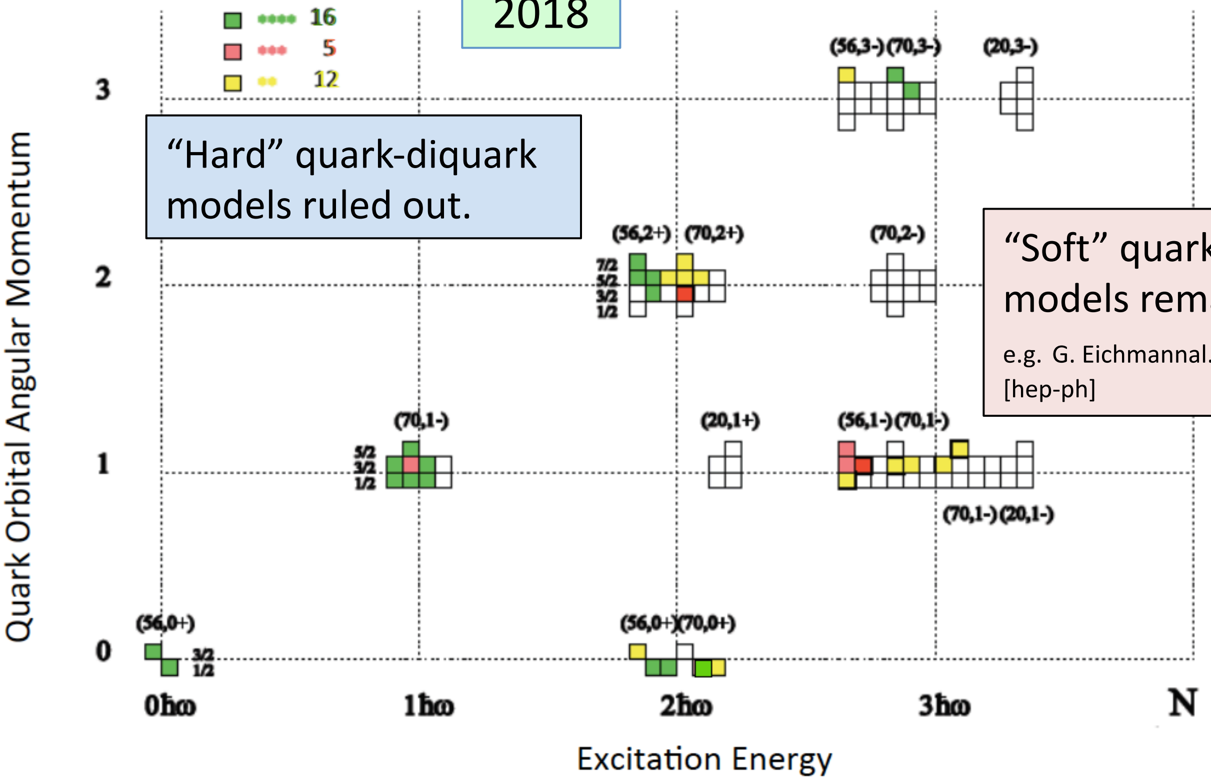
SU(6)xO(3)



vs



2018



"Hard" quark-diquark models ruled out.

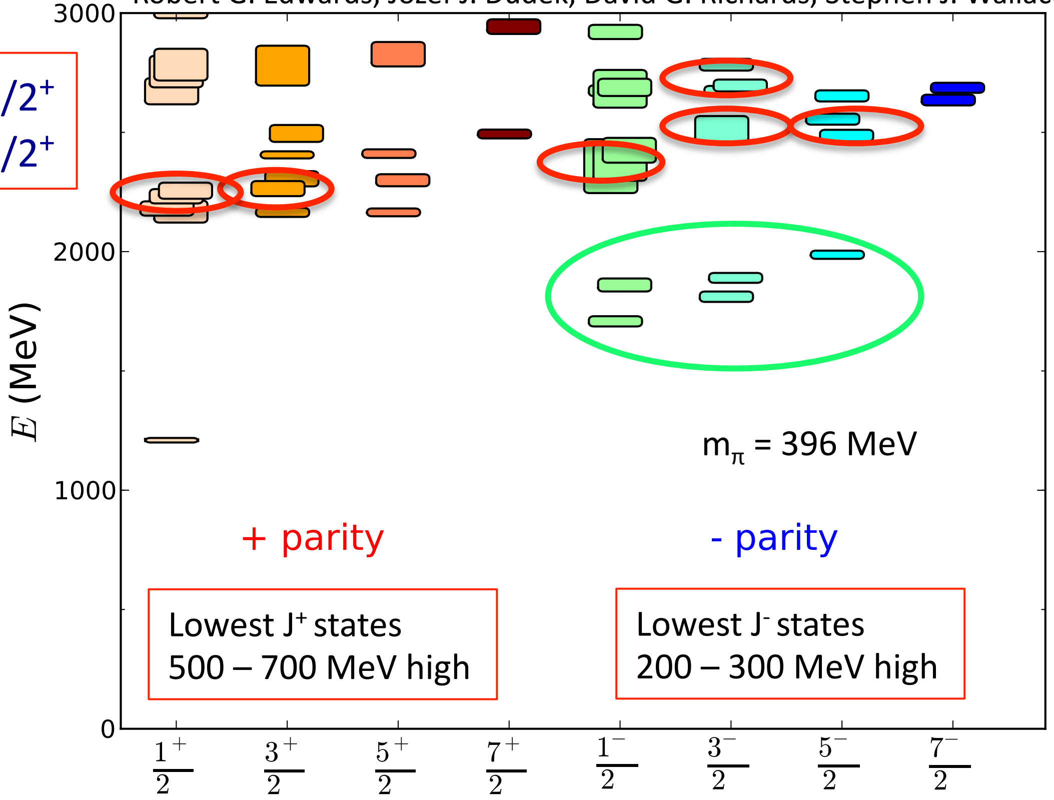
"Soft" quark-diquark models remain viable.

e.g. G. Eichmannal. et arXiv:1607.05748 [hep-ph]

Do New States Fit into LQCD Projections ?

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

N(1900)3/2+
N(1880)1/2+



N(2060)5/2-
N(2120)3/2-
N(1875)3/2-
N(1895)1/2-

Ignoring the mass scale, new candidates fit the J^P values predicted from LQCD.

The field would really benefit from more realistic Lattice masses for N* states.

Known states:
N(1675)5/2-
N(1700)3/2-
N(1520)3/2-
N(1650)1/2-
N(1535)1/2-

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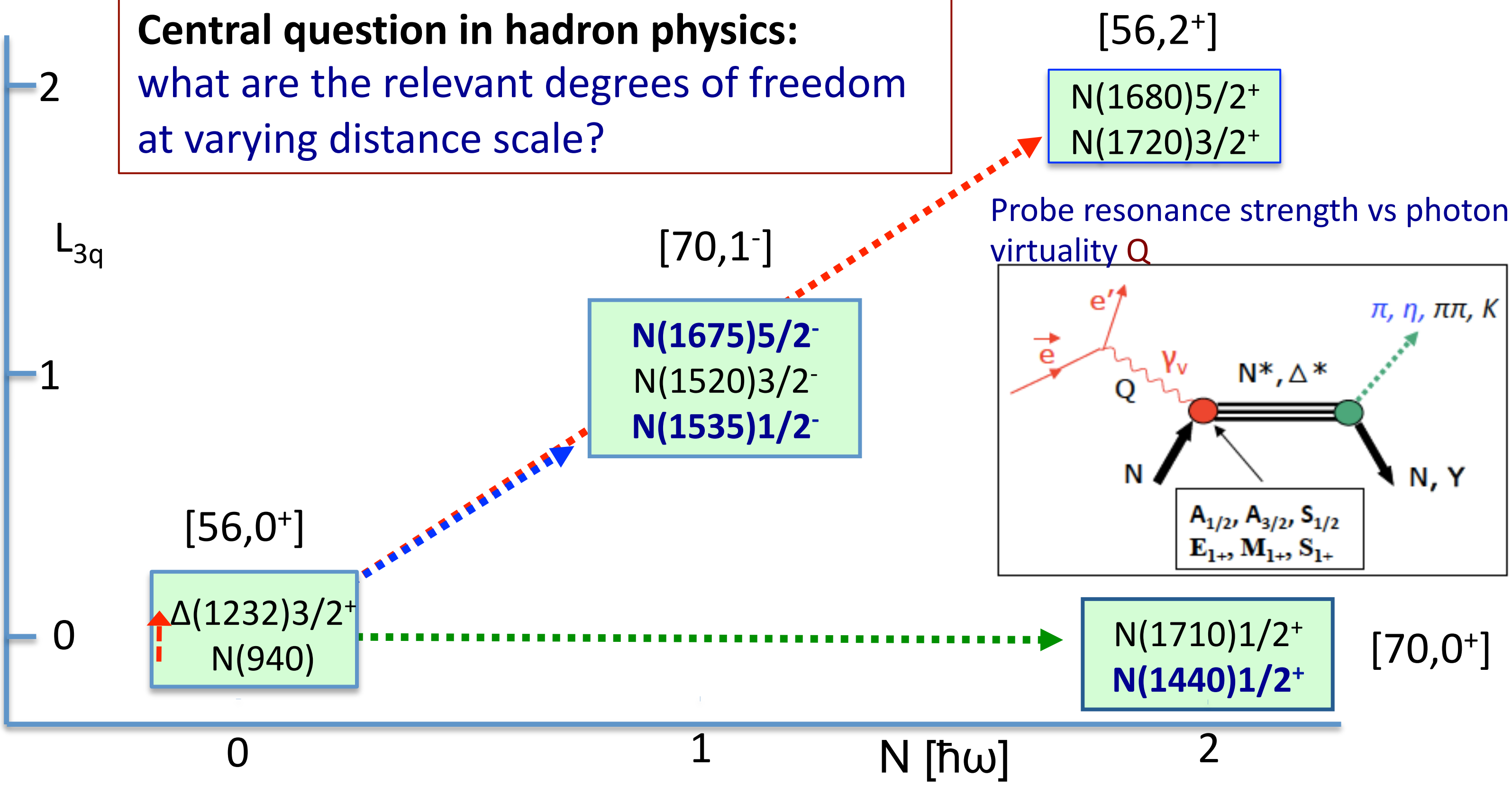
State N(mass)J^P	PDG pre 2010	PDG 2018	KΛ	KΣ	Nγ
N(1710)$1/2^+$	***	****	****	**	****
N(1880)$1/2^+$		***	**		**
N(1895)$1/2^-$		****	**	*	**
N(1900)$3/2^+$	**	****	***	**	***
N(1875)$3/2^-$		***	***	**	***
N(2150)$3/2^-$		***	**		**
N(2000)$5/2^+$	*	**	**	*	**
N(2060)$5/2^-$		***		**	**

Study these states in electroproduction and extend to higher masses

Electroexcitation of N*/Δ resonances

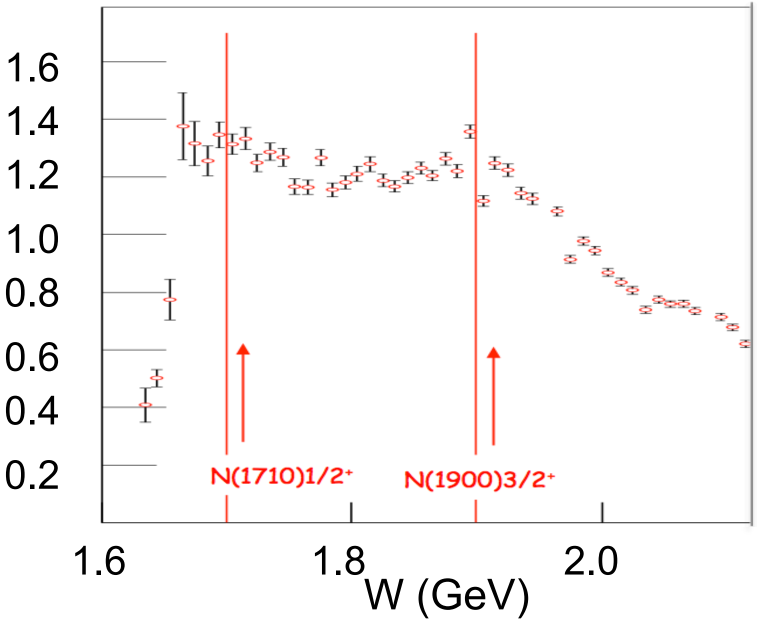
Central question in hadron physics:
what are the relevant degrees of freedom at varying distance scale?



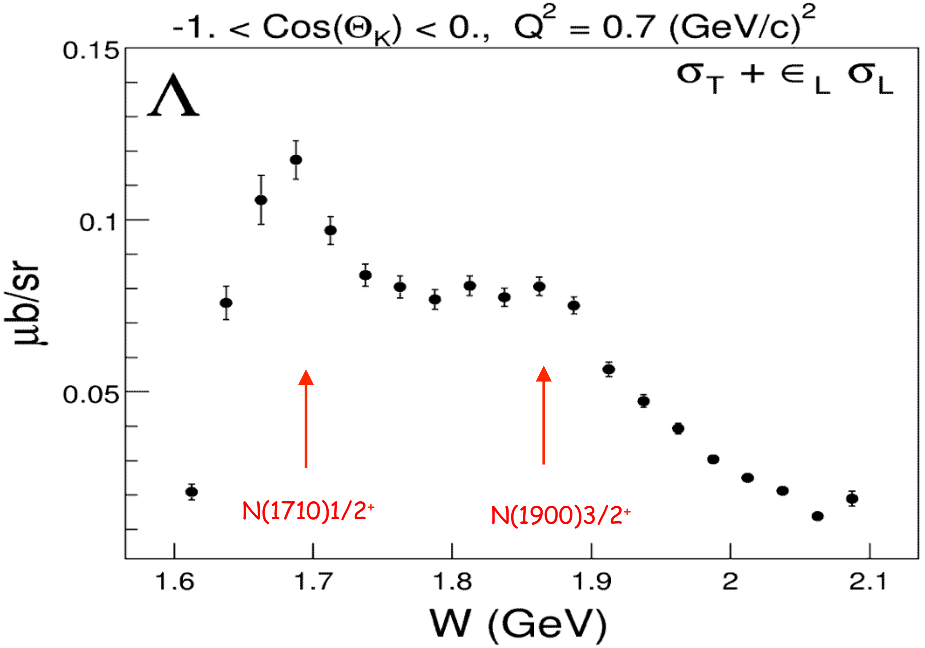
Probe resonance strength vs photon virtuality Q

Studying Baryons in γ*p → KΛ/Σ ?

Photoproduction

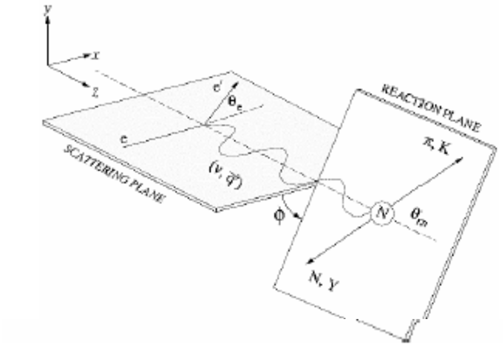


Electroproduction



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

Electroexcitation kinematics



$$\frac{d^4\sigma}{dQ^2 dW\, d\Omega_K} = \Gamma(Q^2, W) \times \frac{d\sigma}{d\Omega_K}(Q^2, W, \Theta_K, \varepsilon, \phi)$$

Virtual photon flux

Electroproduction cross section

Transverse

Transverse-tra e interference

Helicity structure

$$\frac{d\sigma}{d\Omega_K} = \sigma_T + \varepsilon_L \sigma_L + \varepsilon \sigma_{TT} \cos(2\phi) + \sqrt{2\varepsilon_L(\varepsilon+1)}\sigma_{LT}\cos(\phi) + h\sqrt{2\varepsilon_L(1-\varepsilon)}\sigma_{LT'}$$

σ_u "Unseparated"

Longitudinal (sensitive to J=0± exchange in t-channel: mesons, diquarks)

Transverse-longitudinal interference

Measured σ are decomposed using UIM or fixed-t DR to extract N* & Δ helicity amplitudes.

Hybrid Baryons: Baryons with Explicit Gluonic Degrees of Freedom

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

Experimentally:

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

- **Hybrid baryons** $|qqqg\rangle$ have the same quantum numbers J^{P} as $|qqq\rangle$ ⟶ electroproduction with CLAS12 (Hall B).

Theoretical predictions:

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

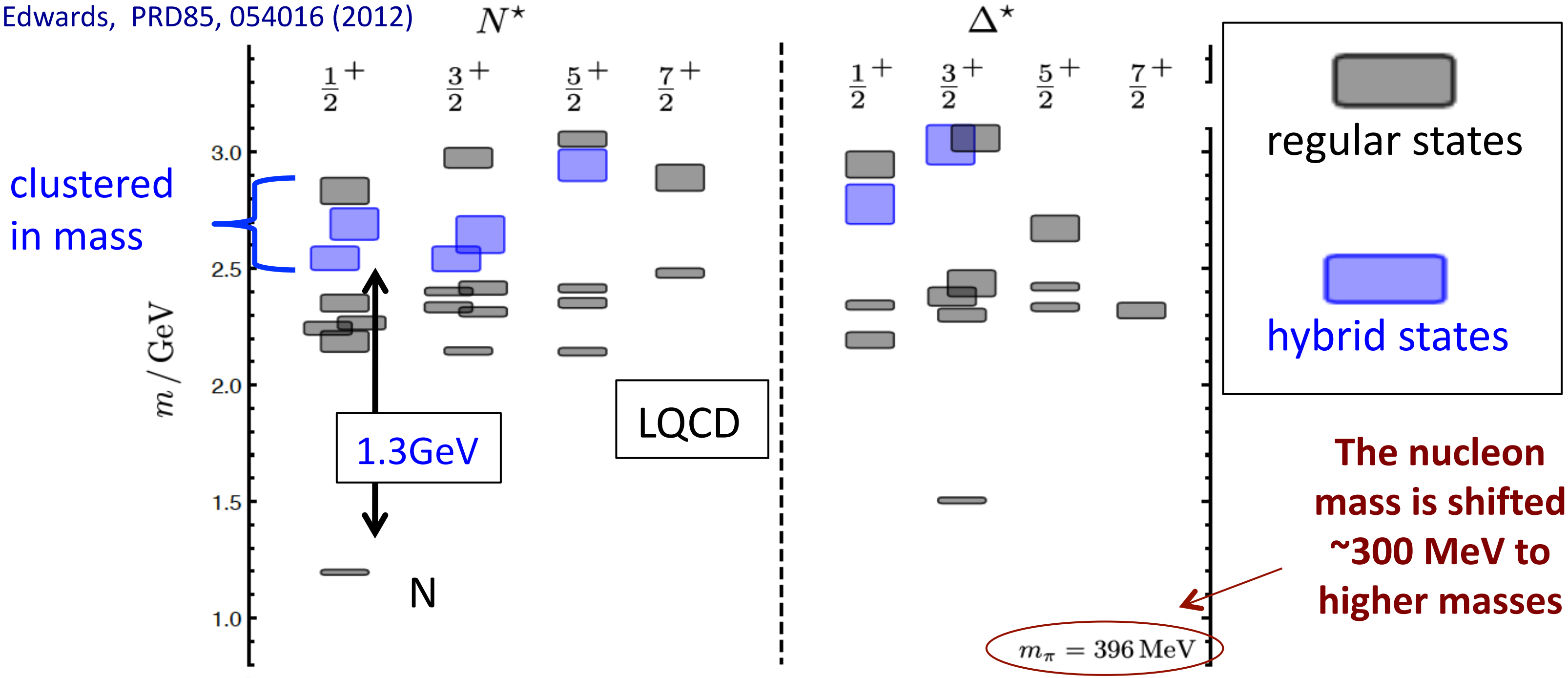
✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).

✧ 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)



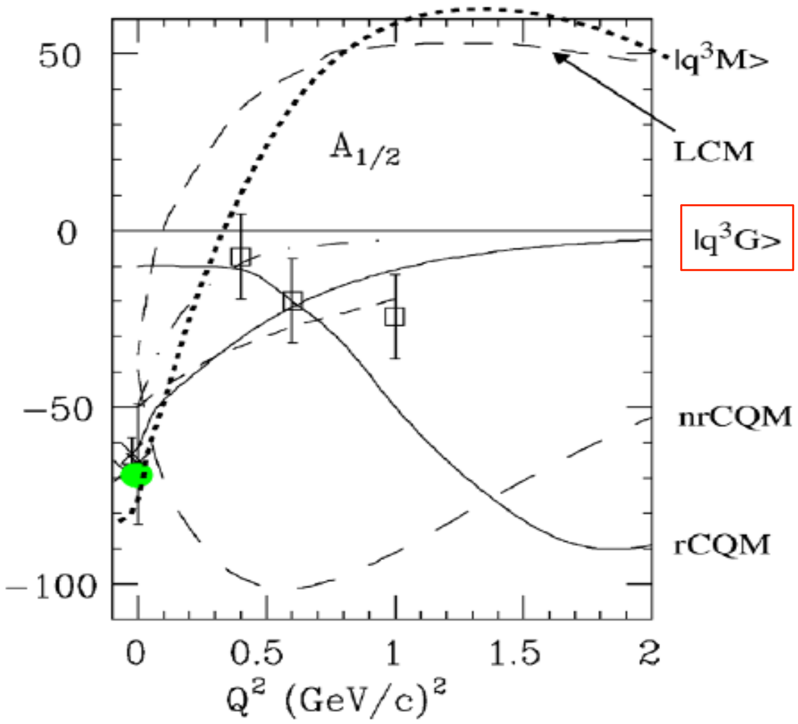
The nucleon mass is shifted ~300 MeV to higher masses

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?**

Electrocouplings of the 'Roper' in 2002

N(1440)1/2$^+$

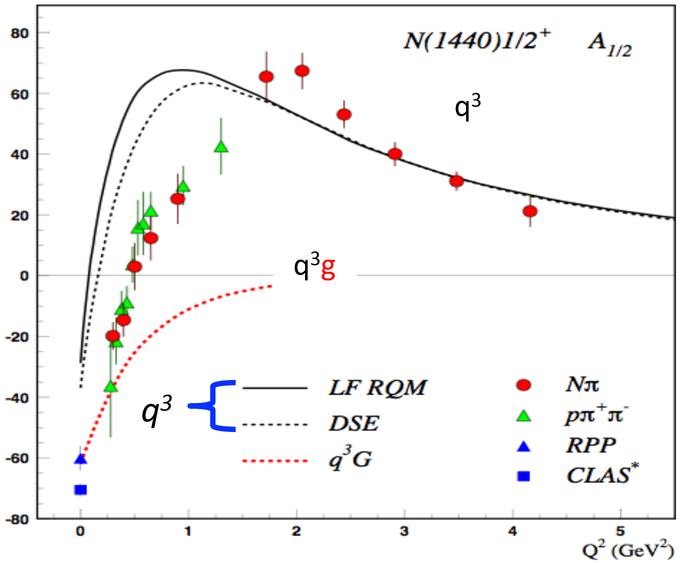


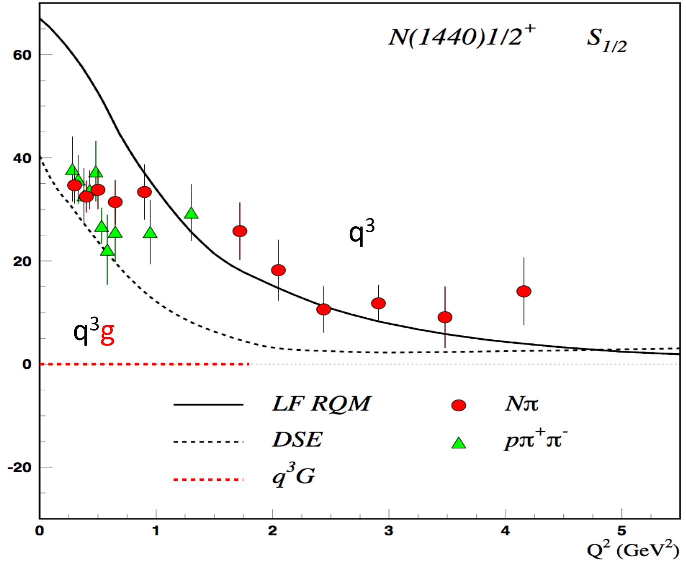
In 2002 Roper amplitude $A_{1/2}$ measurements were more consistent with hybrid state but data were limited with large uncertainties.

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

Separating q^3g from q^3 States?

Precise CLAS results on electrocouplings clarified nature of the Roper





- $A_{1/2}$ and $S_{1/2}$ amplitudes at high Q^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:

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

$$e\,p \longrightarrow e\,K^+\Lambda,\ e\,K^+\Sigma^0$$

The study will include other single meson channels.

PAC 44 E12-16-010

A Search for Hybrid Baryons in Hall B with CLAS12

Spokespersons:

Annalisa D'ANGELO

University of Rome "Tor Vergata" and INFN Rome Tor Vergata

Volker BURKERT, Daniel S. CARMAN, Victor MOKEEV

Thomas Jefferson National Accelerator Facility

Evgeny GOLOVACH

Skobeltsyn Institute of Nuclear Physics and Lomonosov Moscow State University

Ralf GOTHE

University of South Carolina

for the CLAS Collaboration

A New Experiment Run Group Proposal Submitted to Jefferson Lab PAC44

A Search for Hybrid Baryons in Hall B with CLAS12

Volker Burkert *(Spokesperson)*, Daniel S. Carman *(Spokesperson)*, Valery Kubarovsky, Victor Mokeev *(Spokesperson)*, Maurizio Ungaro, Veronique Ziegler
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA

Annalisa D'Angelo *(Contact Person, Spokesperson)*, Lucilla Lanza, Alessandro Rizzo
Università di Roma Tor Vergata and INFN Roma Tor Vergata, 00133 Rome, Italy

Gleb Fedotov, Evgeny Golovach *(Spokesperson)*,
Boris Ishkhanov, Evgeny Isupov, Igor T. Obukhovsky[‡]
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

Ralf W. Gothe *(Spokesperson)*, Iuliia Skorodumina
University of South Carolina, Columbia, South Carolina 29208, USA

Vincent Mathieu[†], Vladyslav Pauk, Alessandro Pilloni, Adam Szczepaniak[†]
Theory Center, Jefferson Laboratory, Newport News, Virginia 23606, USA
([†]Joint with Indiana University, Bloomington, Indiana 47405, USA)

Simon Capstick[‡], Volker Crede, Johnathan Gross[‡]
Florida State University, Tallahassee, Florida 32306, USA

Jan Ryckebusch[‡]
Ghent University, B-9000 Ghent, Belgium

Michael Döring
The George Washington University, Washington, DC 20052, USA

Vincenzo Bellini, Francesco Mammoliti, Giuseppe Russo, Concetta Sutera, Francesco Tortorici
INFN, Sezione di Catania, 95125 Catania, Italy

Ilaria Balossino, Luca Barion, Giuseppe Ciullo, Marco Contalbrigo, Paolo Lenisa, Aram Movsisyan, Luciano Libero Pappalardo, Matteo Turisini
INFN, Sezione di Ferrara, 44100 Ferrara, Italy

Philip Cole
Idaho State University, Pocatello, Idaho 83209, USA

Marco Battaglieri, Andrea Celentano, Raffaella De Vita, Erica Fanchini, Mikhail Osipenko, Marco Ripani, Elena Santopinto, Mauro Taiuti
INFN, Sezione di Genova, 16146 Genova, Italy

Alessandra Filippi
INFN, Sezione di Torino, 10125 Torino, Italy

César Fernández-Ramírez[‡]
Universidad Nacional Autónoma de México, 04510 Mexico City, Mexico

Inna Aznauryan[‡]
Yerevan Physics Institute, 375036 Yerevan, Armenia

Valery E. Lyubovitskij[‡]
Institut für Theoretische Physik, Universität Tübingen, Kepler Center for Astro and Particle Physics Auf der Morgenstelle 14, D-72076 Tübingen, Germany
Department of Physics, Tomsk State University, 634050 Tomsk, Russia

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

and the CLAS Collaboration

June 2, 2016

[‡] **Experiment theory support member**

Analysis Tools for Electromagnetic Excitation of Baryons

Single Meson Analysis

- **Unitary Isobar Model & Fixed-t Dispersion Relations approaches**
- **Regge-and Resonance Model (Gent Group)**

Double Meson Analysis

- **J-M Reaction Model**

Multi-channel Analysis

- **Bonn-Gatchina multi-channel PWA**
- **Argonne-Osaka dynamically coupled-channel model**
- **JPAC Analysis Tools for high mass states using Regge & Veneziano Approach**

CLAS12 Equipment

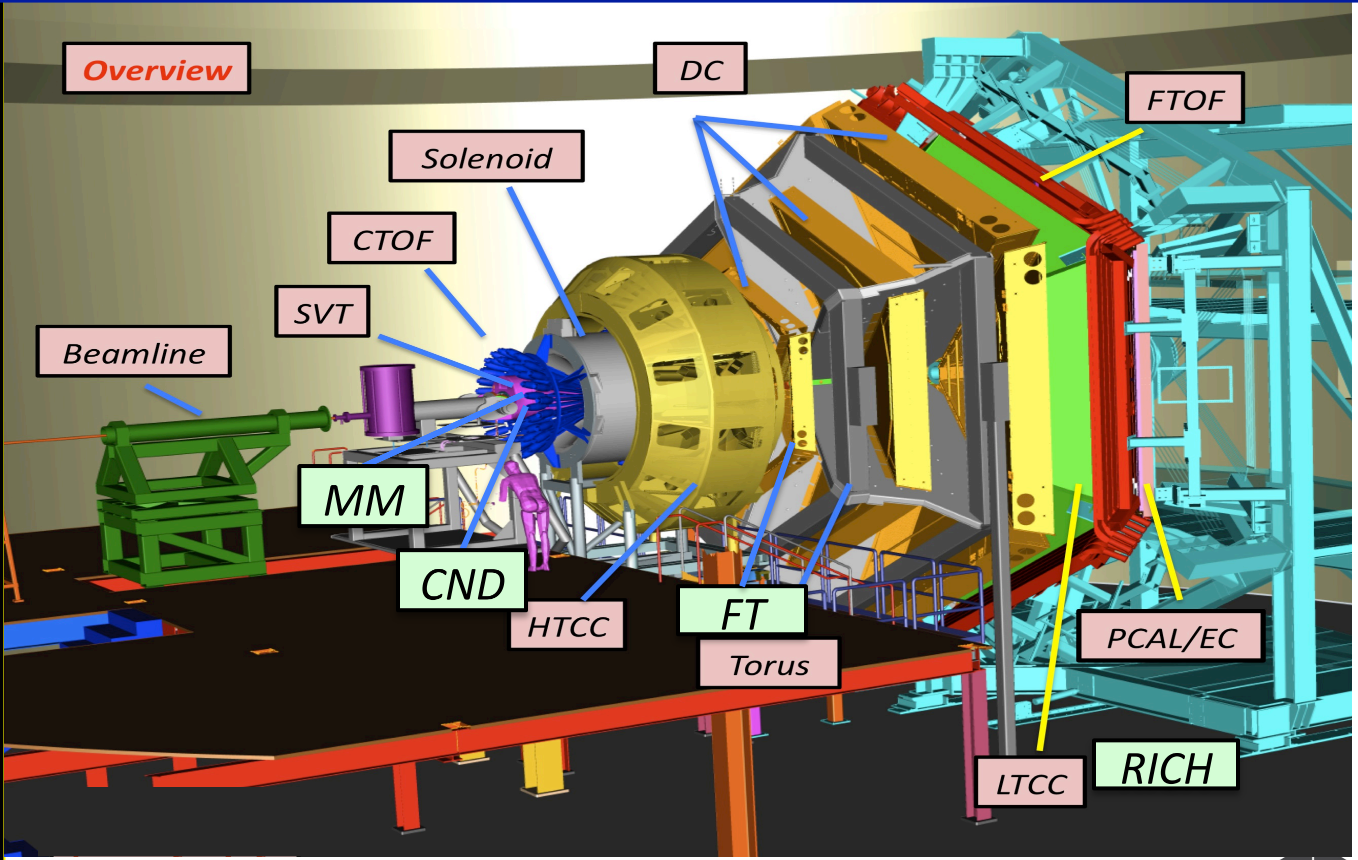
Hall B

<u>Forward Detector (FD)</u>
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward TOF System
- Pre-shower calorimeter
- E.M. calorimeter

<u>Central Detector (CD)</u>
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

<u>Beamline</u>
- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

<u>Upgrade to the baseline</u>
- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



Forward Tagger

FT designed to detect electrons and photons at small angles

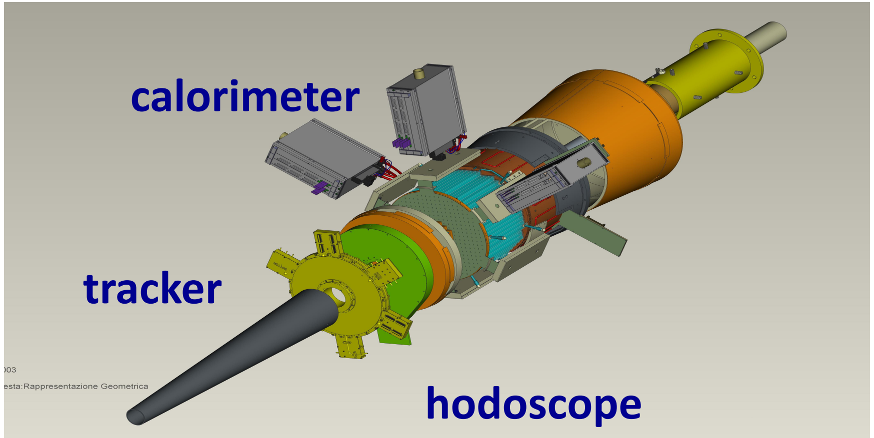
$$\theta = 2.5^\circ \rightarrow 4.5^\circ$$

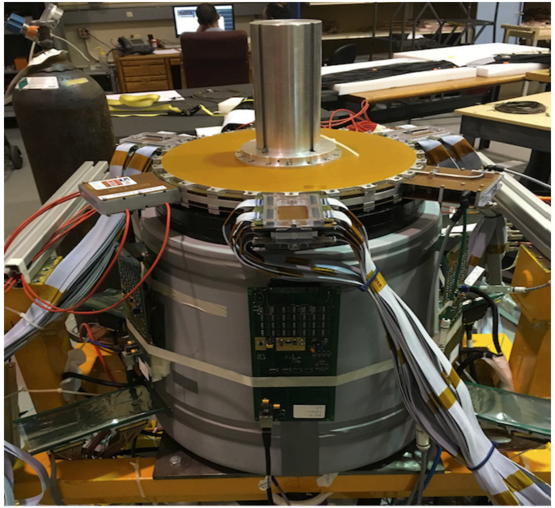
FT-Cal: calorimeter to measure electron energy/momentum

FT-Hodo: scintillation hodoscope to veto photons & backsplash

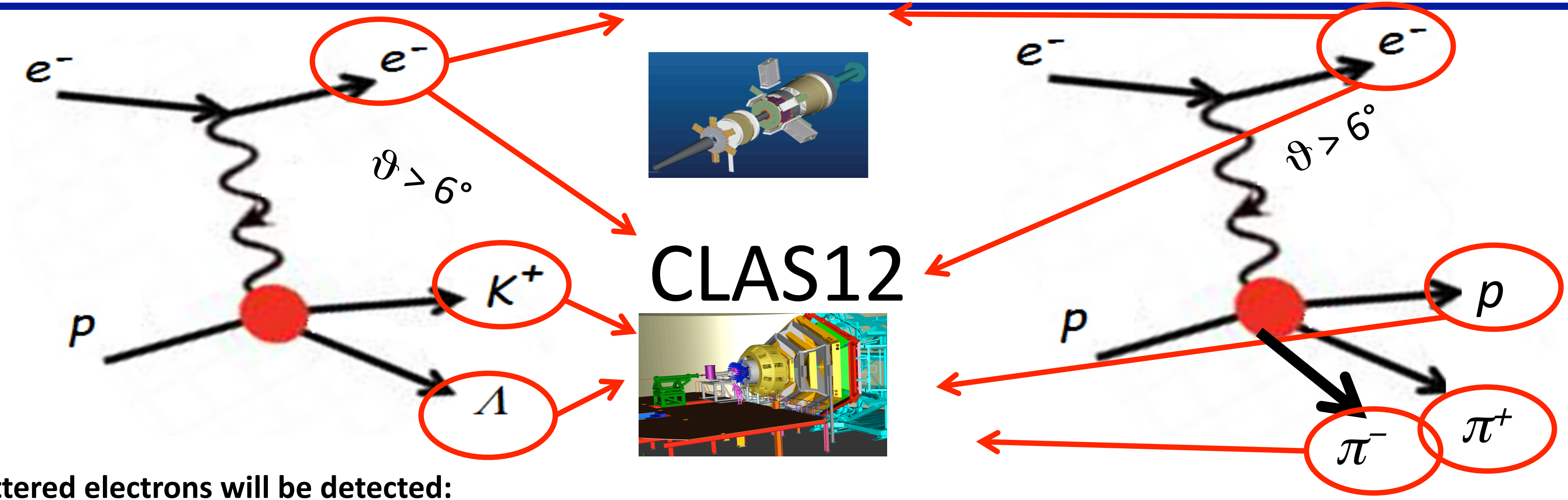
FT-Trk: micro-mega detector to measure electron angles, polarization plane

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





The Experiment



Scattered electrons will 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 will be measured in the full range from 6° to 130°

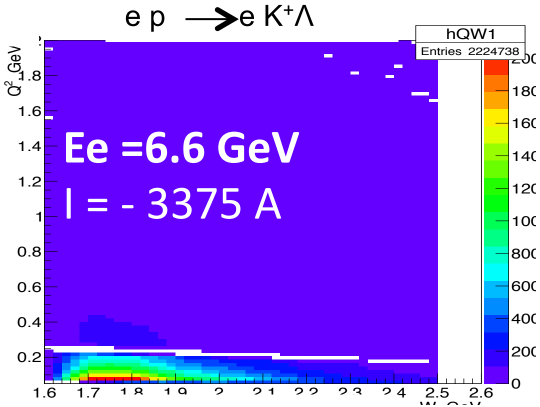
$$Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \quad \Rightarrow \quad \vartheta < 5°$$

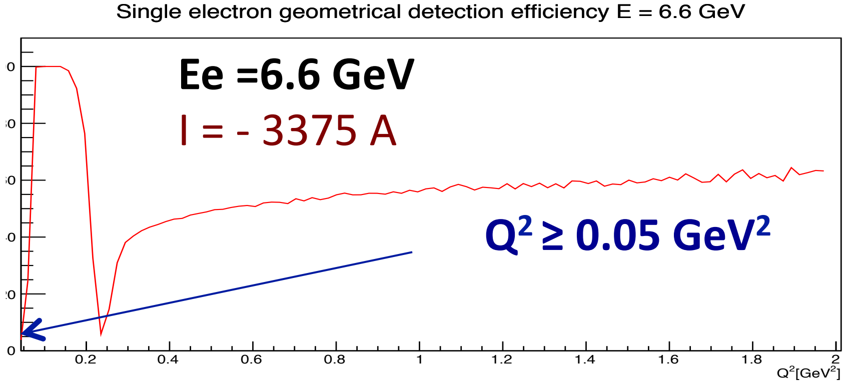
W < 3 GeV Q^2 range of interest: **0.05 - 2 GeV^2**

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.

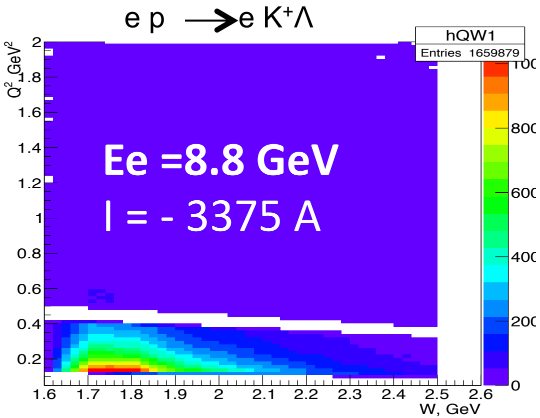
Kinematical Coverage: Full Q^2 Range

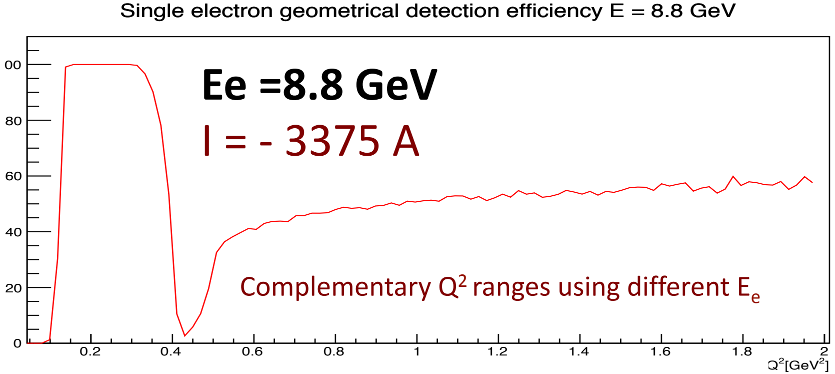
Q^2 vs W





Q^2 as low as 0.05 GeV^2 may be reached



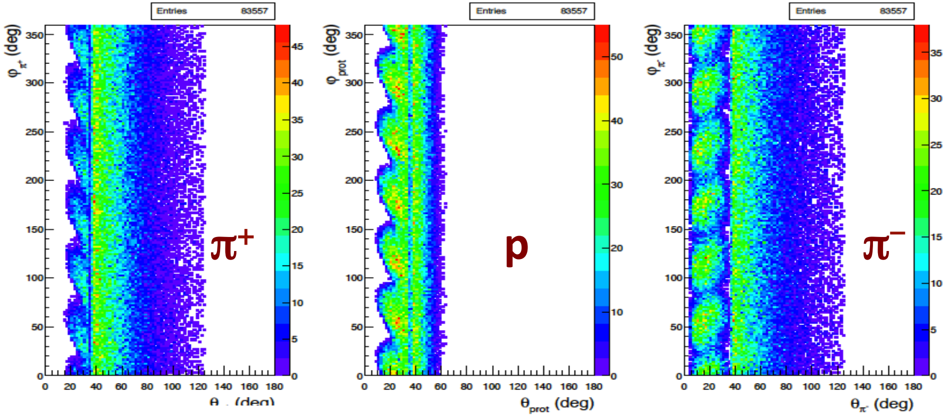


Ee = 8.8 GeV provides enough statistics for 2.5 < W < 3 GeV

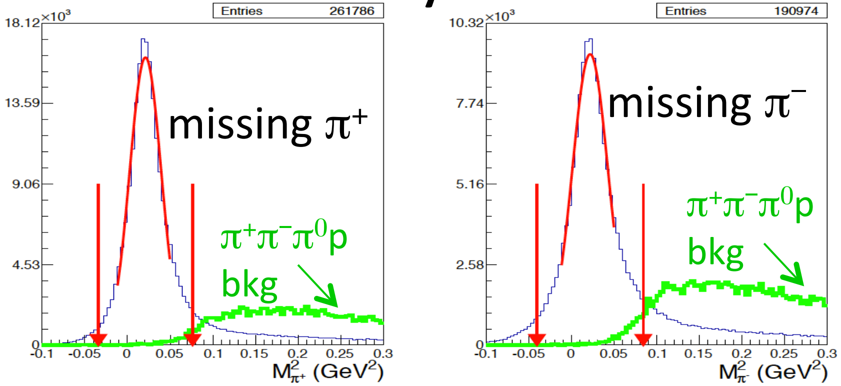
Event Simulation in **CLAS12**

Results for e p $\longrightarrow$ e p $\pi^+ \pi^-$

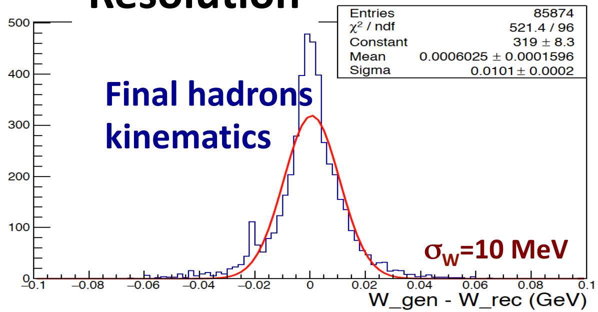
ϕ vs. θ angular acceptance for final hadrons



Exclusivity cuts



Resolution



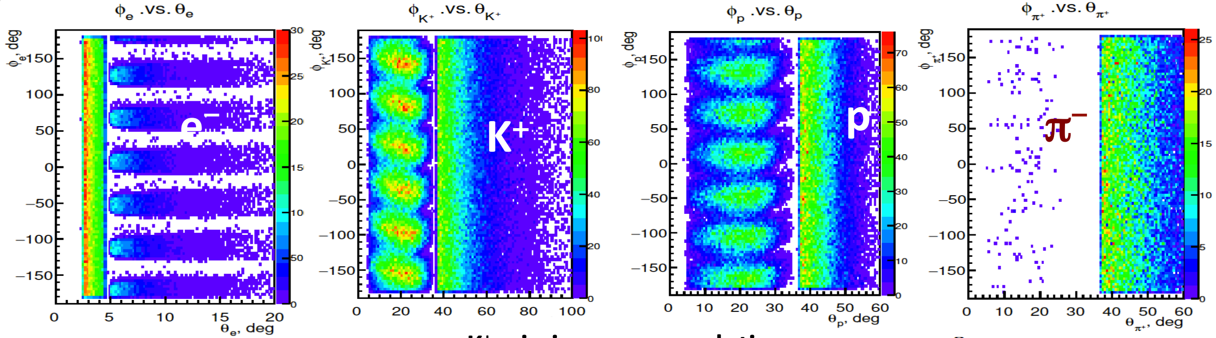
Acceptance

Ee	$p\pi^+\pi^-$ detected	one missing hadron
Ee = 6.6 GeV	8.7 %	13%
Ee = 8.8 GeV	8.3 %	13 %

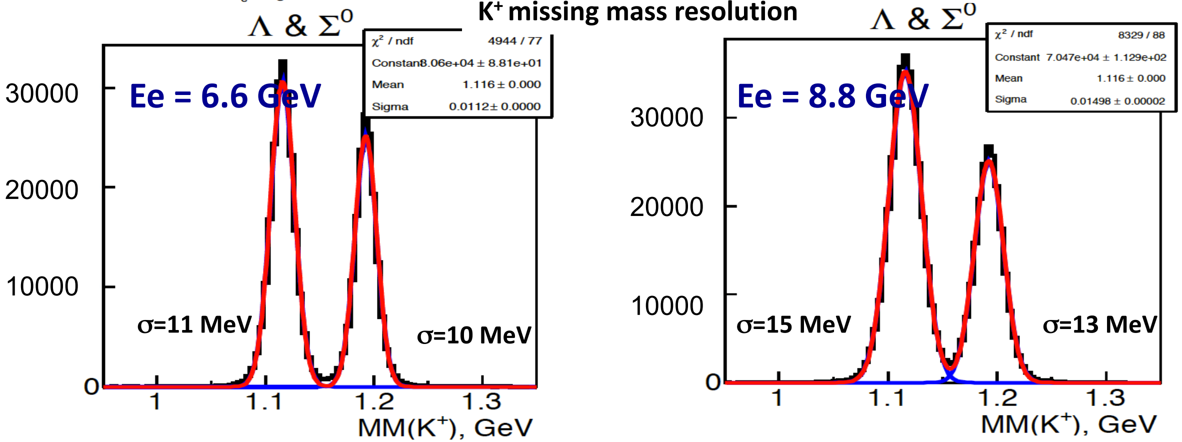
Event Simulation in **CLAS12**

ϕ vs θ angular acceptance for final particles

Results for e p ⟶ e K^+ Y



K^+ missing mass resolution



Minimum measurable Q^2

Ee = 6.6 GeV	0.05 GeV^2
Ee = 8.8 GeV	0.1 GeV^2

Acceptance

Ee	one missing hadron
Ee = 6.6 GeV	10 %
Ee = 8.8 GeV	8 %

Quasi – Data Analysis

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

M_R = 2.2 GeV Γ_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 (50 days at 6.6 GeV & 50 days at 8.8 GeV)

2. The Legendre moments of the unseparated and polarization interference components of the cross section.
   → Search for distinctive structures due to the added resonance.

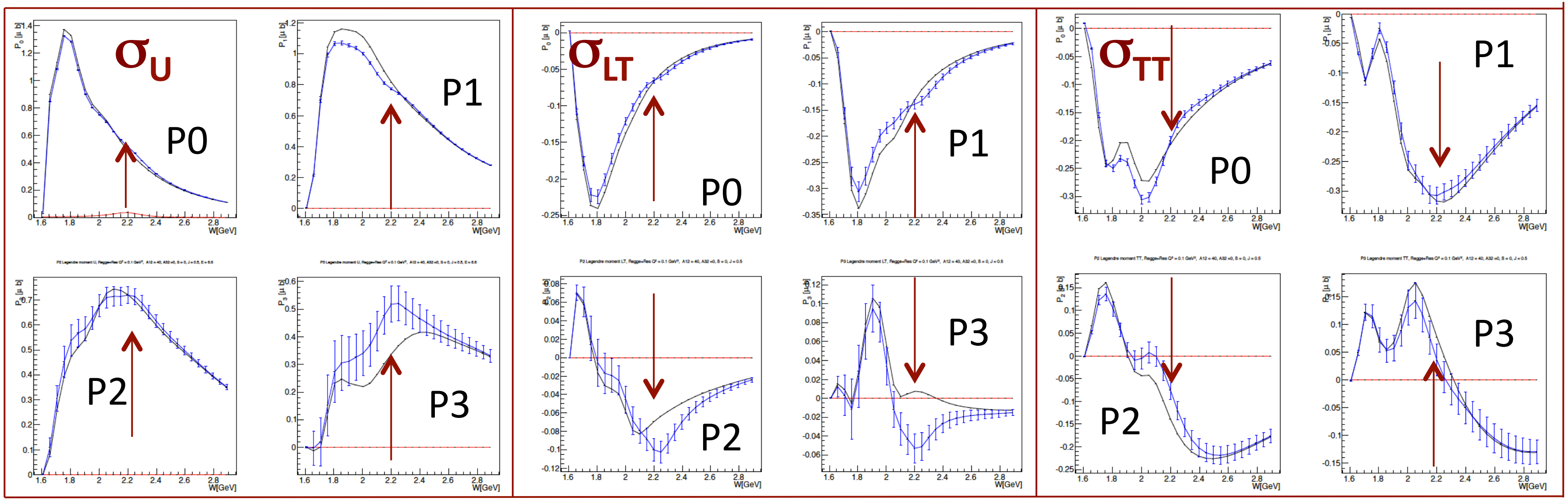
3. The statistical sensitivity to hybrid baryons electrocouplings.
   → Minimum electrocoupling values with 100 days of beam time.

4. The capability of extracting the added resonance parameters from expected data.
   → Blind analysis of quasi-data.

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 → e p $\pi^+ \pi^-$
JLab - Moskow (JM) model

e p → e K^+Y
Regge + Resonance (RPR-2011) Gent model

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

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

$p\pi^+\pi^-$

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

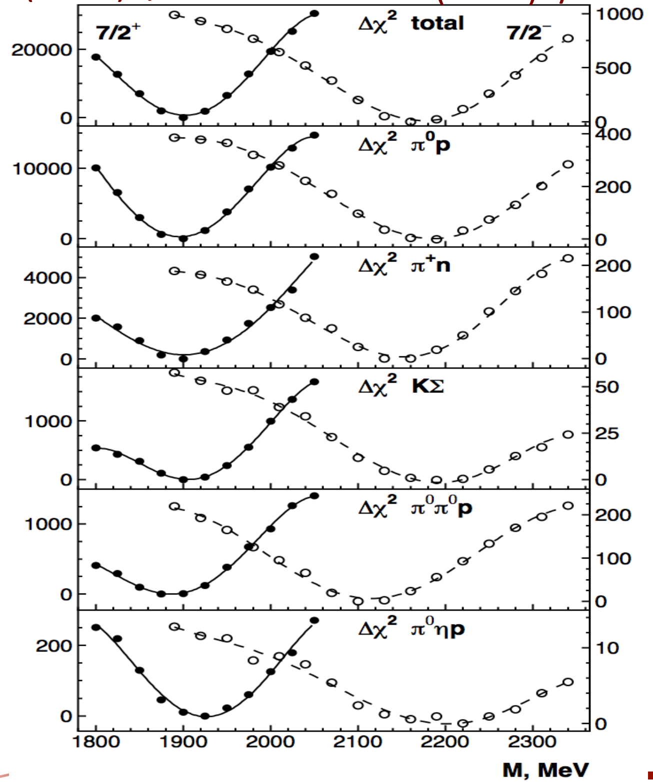
$K^+\Lambda$

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

Δ(1950)7/2$^+$ Δ(2200)7/2$^-$



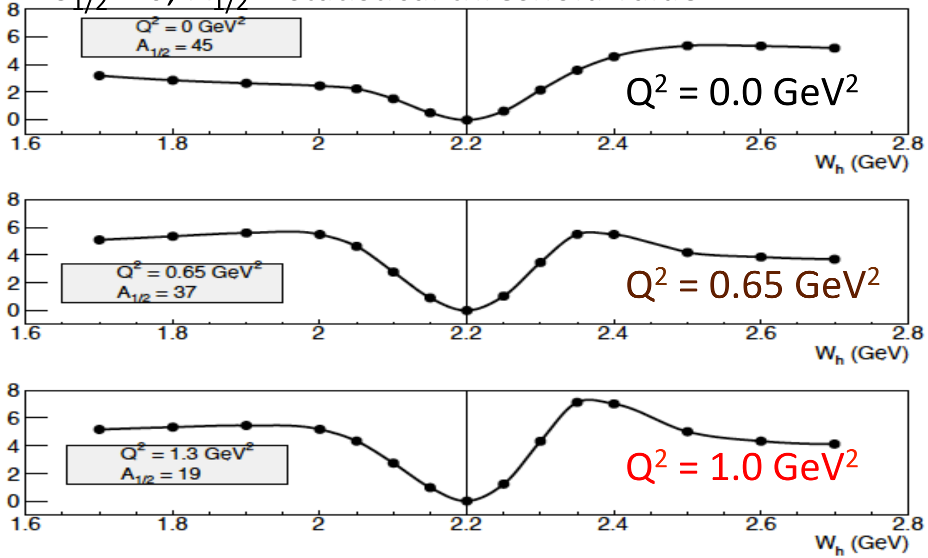
ep ⟶ e p $\pi^+\pi^-$

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

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

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

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



χ^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 ⟶ 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 Γ_{res}^1 $A_{1/2}^1$
M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

Searching the minimum of the quantity:

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

$d\sigma_{th}$ 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 $\longrightarrow$ e $K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated $\longrightarrow$ $d\sigma_{q.d.}$

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

7 unknown parameters: M_{res}^1 Γ_{res}^1 $A_{1/2}^1$
M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

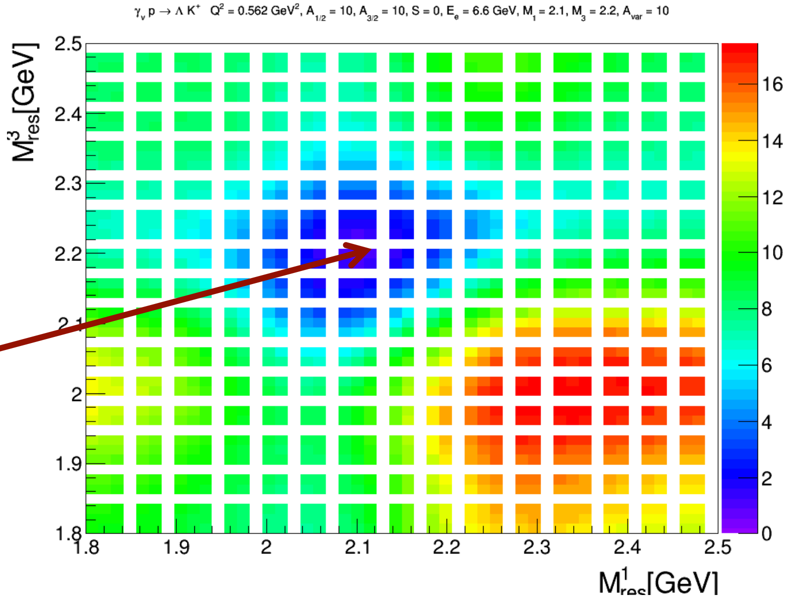
Iterative procedure:

- The algorithm calculates the χ^2 value over a 7-dim parameters coarse grid, covering the full range
- The combination of parameters corresponding to the minimum χ^2 value is found
- χ^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 ⟶ e $K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated ⟶ $d\sigma_{q.d.}$

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



χ^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 ⟶ 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 Γ_{res}^1 $A_{1/2}^1$ M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

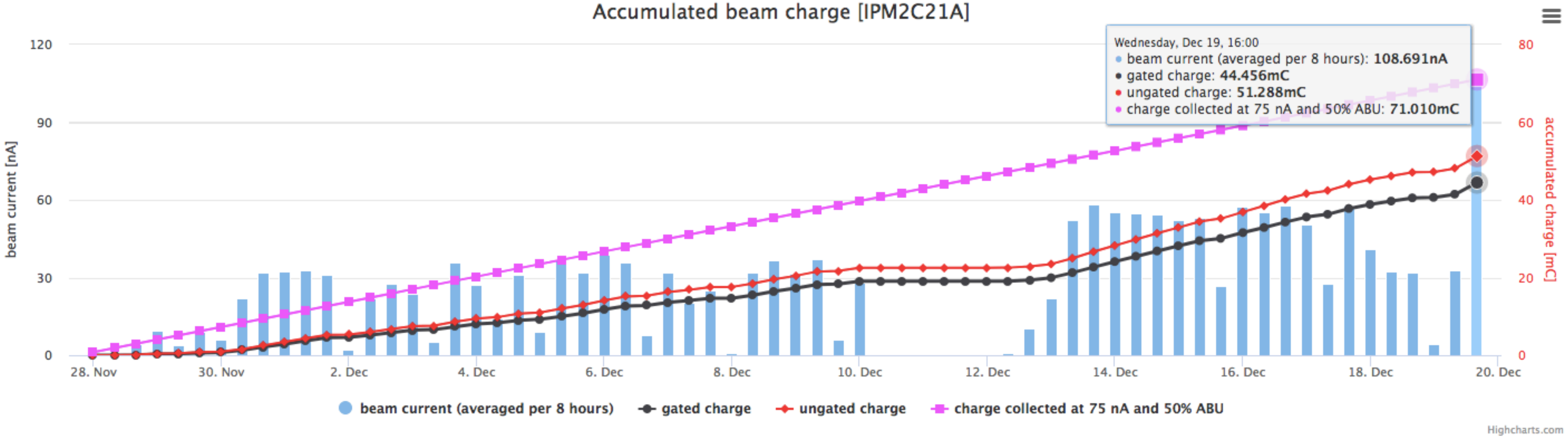
Hybrid Baryons parameters are well reconstructed.

Blind Resonance Parameters	Extracted Resonance Parameters
M_{res}^1 = 2.30 GeV	M_{res}^1 = 2.32 GeV
Γ_{res}^1 = 0.30 GeV	Γ_{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
Γ_{res}^2 = 0.35 GeV	Γ_{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 $GeV^{-1/2}$

Data Taking has Started !

First 3 weeks of data taking: November 29th – December 21st

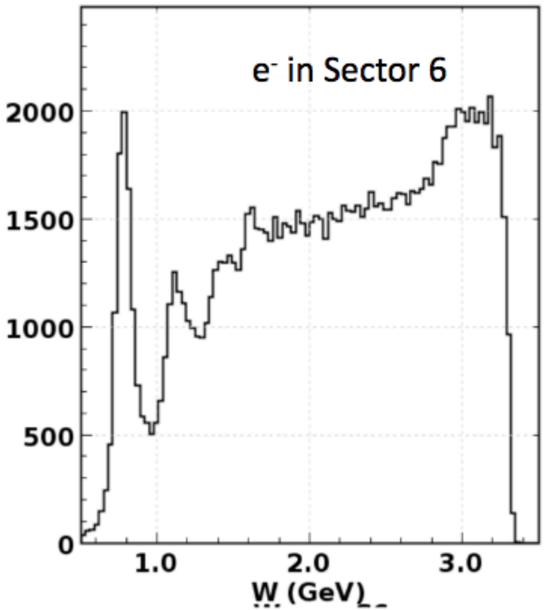
start date: 11/28/2018 end date: 12/20/2018

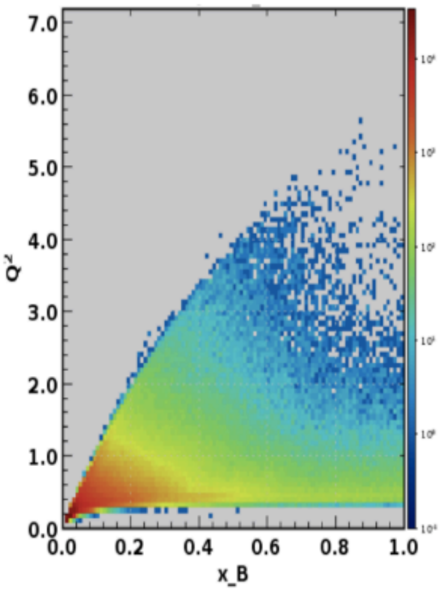


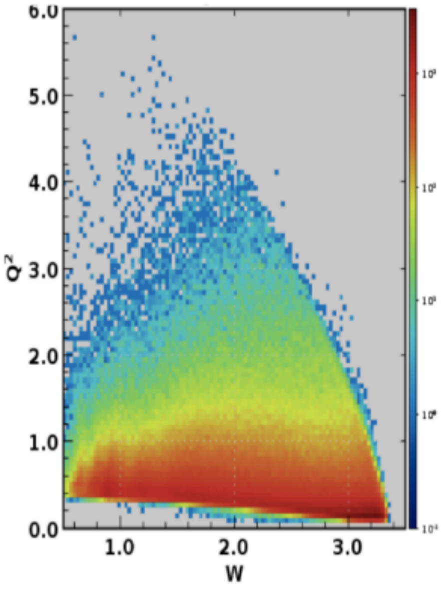
Accumulated gated charge = 44.5 mC

Integrated luminosity = 58 fb^{-1}

Early data analysis at 6.5 GeV!







Number of events corresponds to about **0.003%** of expected RG-K 6.5GeV data of 2018

Light Baryon Spectroscopy at EIC?

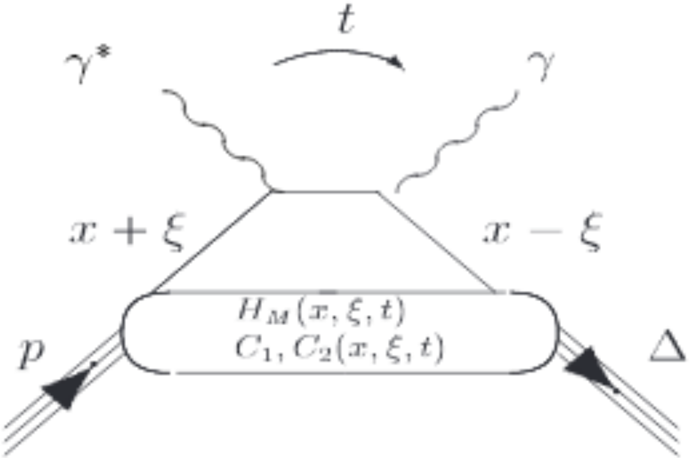
GENERALIZED PARTON DISTRIBUTIONS AND NUCLEON RESONANCES

M. GUIDAL, S. BOUCHIGNY, J.-P. DIDELEZ, C. HADJIDAKIS, E. HOURANY
Institut de Physique Nucléaire Orsay, F-91406 Orsay, France

M. VANDERHAEGHEN
Institut für Kernphysik, Johannes Gutenberg-Universität, D-55099 Mainz, Germany

arXiv: hep–ph/0304252

L. L. Frankfurt, M. V. Polyakov, M. Strikman, and M. Vanderhaeghen Phys. Rev. Lett. 84, 2589



"Transition" GPDs may be measured from hard exclusive electro-production of photons and mesons (π, ρ, ϕ, ω ..) and may give insight on the quark and gluon content of the excited states of the nucleon.

Summary

- Major progress made in the last years in the search for N* and Δ states.

  All states can be accommodated in CQM and LQCD schemes.

  - Naïve (non-dynamical) di-quark models are ruled out.

- Knowledge of Q^2-dependence of electrocouplings is absolutely necessary to understand the nature (the internal structure) of the excited states.

  - Roper IS the first radial excitation of the q^3 core, obscured at large distances by meson-cloud effects.

- Search for hybrid baryons with explicit gluonic degrees of freedom would be possible investigating the low Q^2 evolution of high-mass resonance (2-3 GeV) electrocoupligs:

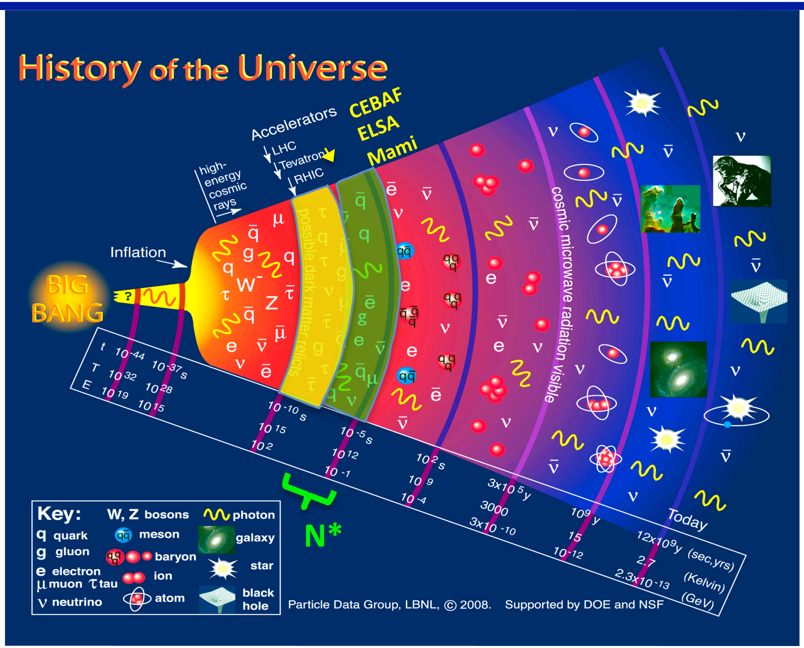
  - Looking for suppressed $A^{1/2}$, $A^{3/2}$, $S^{1/2}$ at low $Q^{2.}$

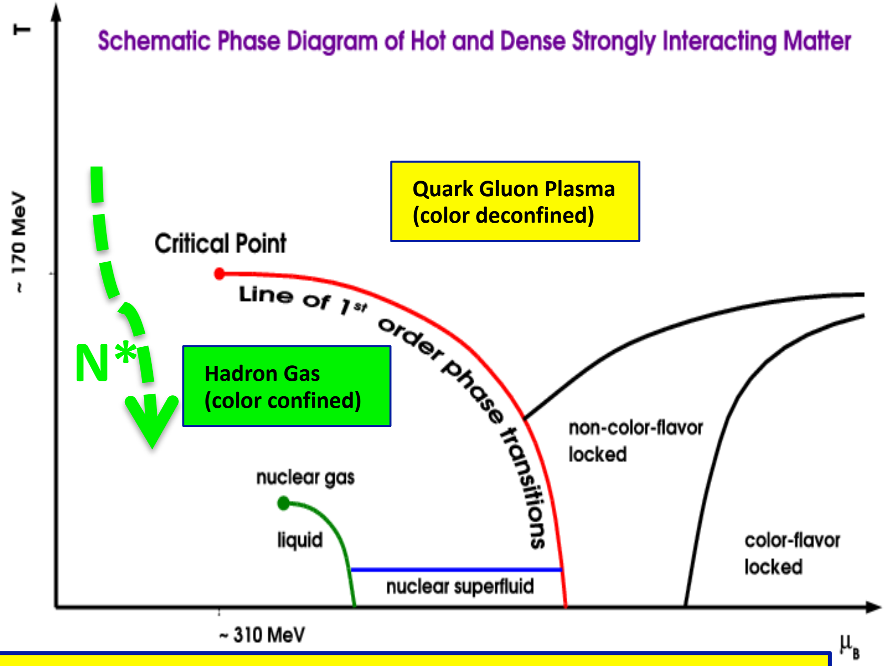
- "Transition" GPDs may be considered at EIC :

  - N* longitudinal, transverse momentum and impact parameter partons distributions

Backup Slides

N* in the History of the Universe



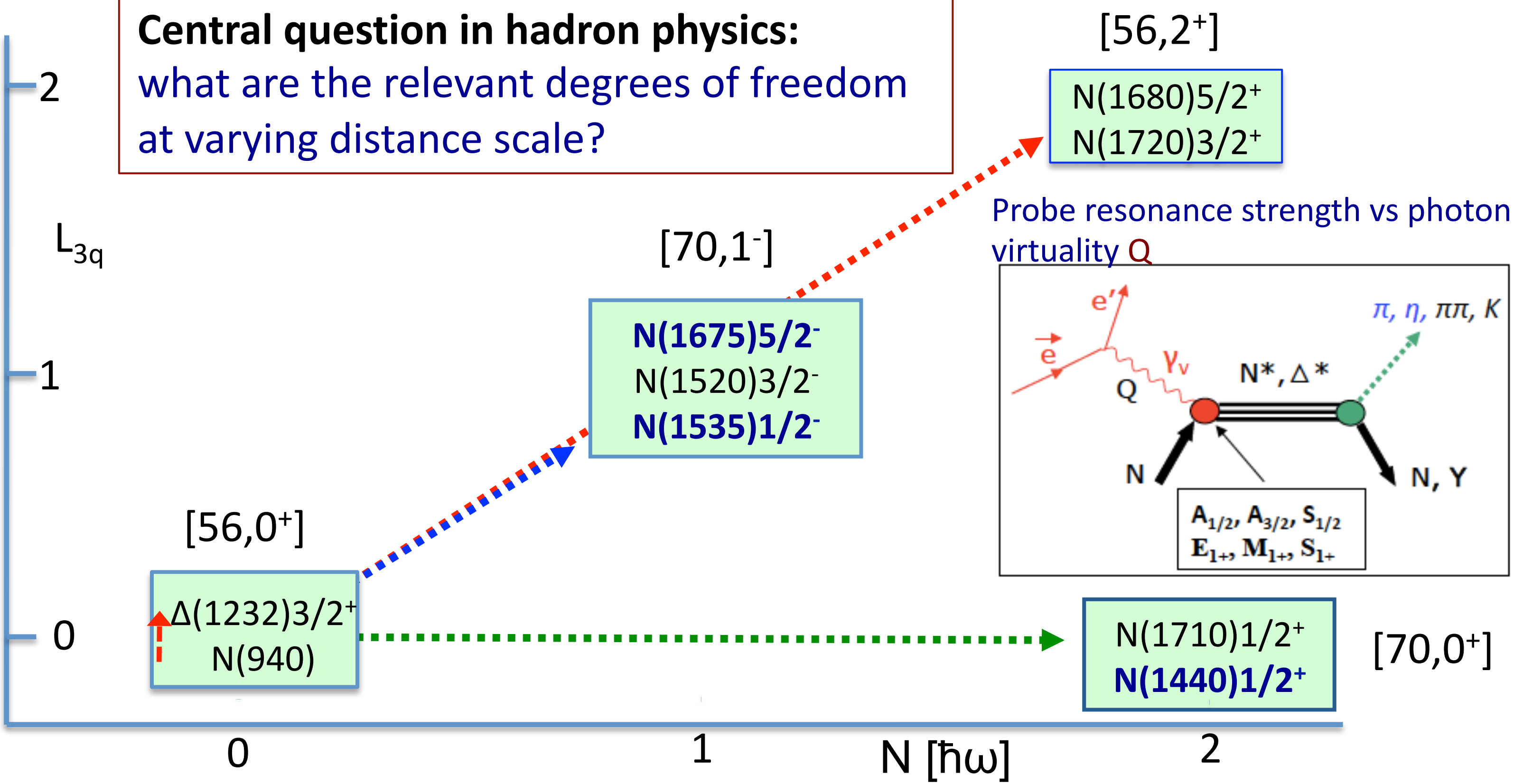


Dramatic events occur in the microsecond old Universe.

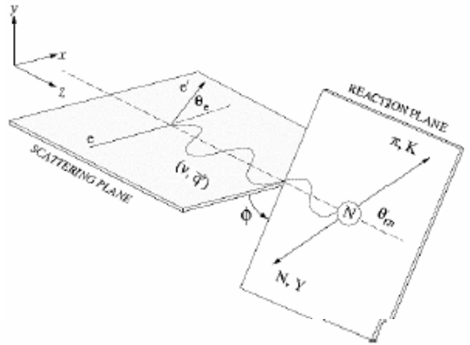
- The transition from the QGP to the baryon phase is dominated by excited baryons. A quantitative description requires more states than found to date => **missing baryons.**
- During the transition the quarks acquire **dynamical mass** and the **confinement of color** occurs.

Electroexcitation of N*/Δ resonances

Central question in hadron physics:
what are the relevant degrees of freedom at varying distance scale?



Electroexcitation kinematics



$$\frac{d^4\sigma}{dQ^2 dW\, d\Omega_K} = \Gamma(Q^2, W) \times \frac{d\sigma}{d\Omega_K}(Q^2, W, \Theta_K, \varepsilon, \phi)$$

Virtual photon flux

Electroproduction cross section

$$\frac{d\sigma}{d\Omega_K} = \sigma_T + \varepsilon_L \sigma_L + \varepsilon \sigma_{TT} \cos(2\phi) + \sqrt{2\varepsilon_L(\varepsilon+1)}\,\sigma_{LT} \cos(\phi) + h\sqrt{2\varepsilon_L(1-\varepsilon)}\,\sigma_{LT'}$$

Transverse

Transverse-tra e interference

Helicity structure

σ_u "Unseparated"

Longitudinal (sensitive to J=0$^{\pm}$ exchange in t-channel: mesons, diquarks)

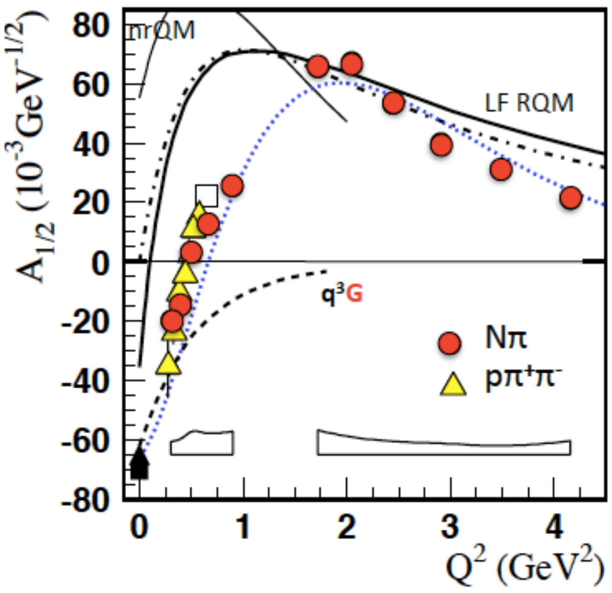
Transverse-longitudinal interference

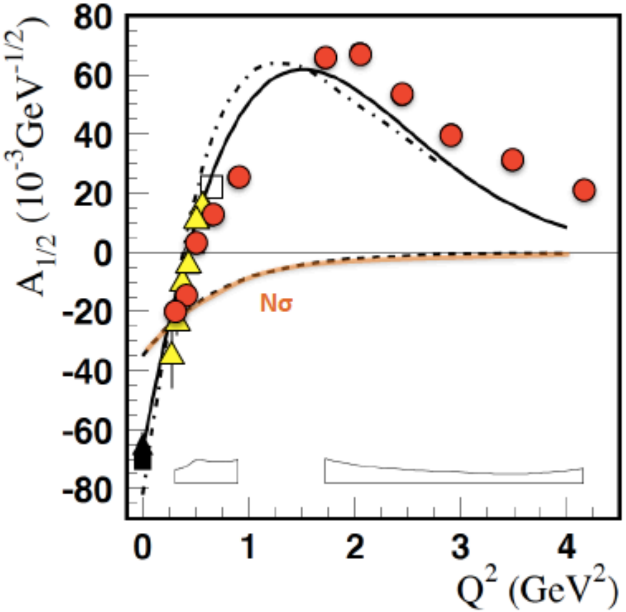
Measured σ are decomposed using UIM or fixed-t DR to extract N* & Δ helicity amplitudes.

Electrocouplings of the 'Roper' in 2012

N(1440)1/2+

I. Aznauryan et al. (CLAS), PRC 80, 055203 (2009)
V. Mokeev et al. (CLAS), PRC 86, 035203 (2012)





L. Tiator et al., Chin Phys C33, (2009) 1069 (MAID fit)
I. Aznauryan et a.l. PRC 76, (2007) 025212
Z.P. Li et al. PRD 46, (1992) 70

I. T. Obukhovsky et a.l. PRD 84, (2011) 014004

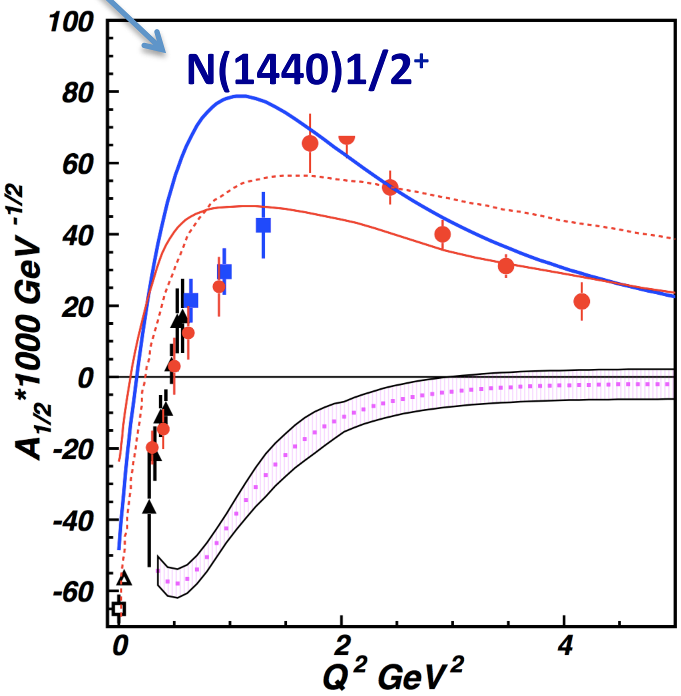
Electrocouplings of the 'Roper' in 2016

Nπ loops to model MB cloud: **running quark mass** in LF RQM.
I. G. Aznauryan, V.D. Burkert PR C 85 (2012) 055202.

Nσ loops to model MB cloud in LF RQM: **frozen constituent quark mass** in LF RQM .
I. T. Obukhovsky et al. PRD 89, (2014) 0140032.

Quark-core contributions from DSE/QCD
J. Segovia et al. PRL 115 (2015) 171801.

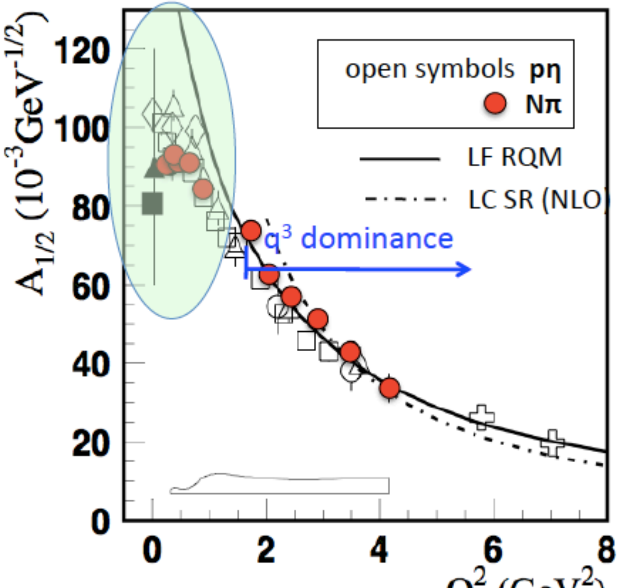
***Meson Baryon cloud** inferred from CLAS data as the difference between data and the quark-core evaluation in DSE/QCD.*
V. Mokeev et al., PR C 93 (2016) 025206.



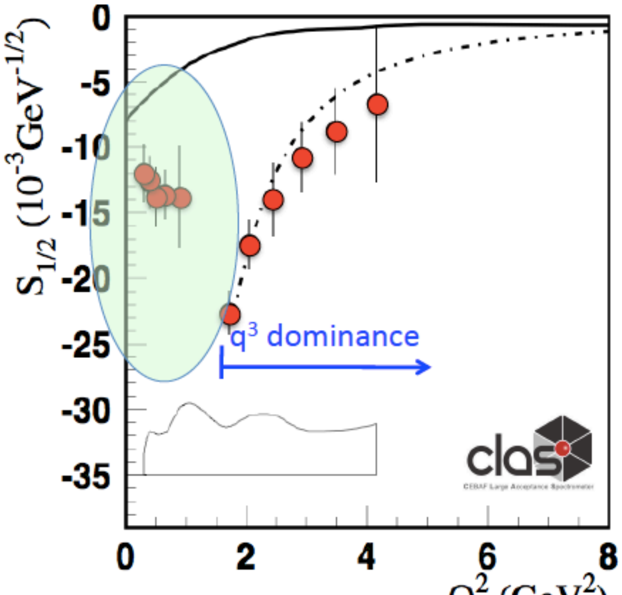
The structure of the Roper is driven by the interplay of the core of three dressed quarks in the 1st radial excitation and the external meson-baryon cloud.

MB Contribution to electro-excitation of N(1535)1/2⁻

Is it a 3-quark state or a hadronic molecule?



I.G. Aznauryan, V.D. Burkert, PR C85 (2012) 055202



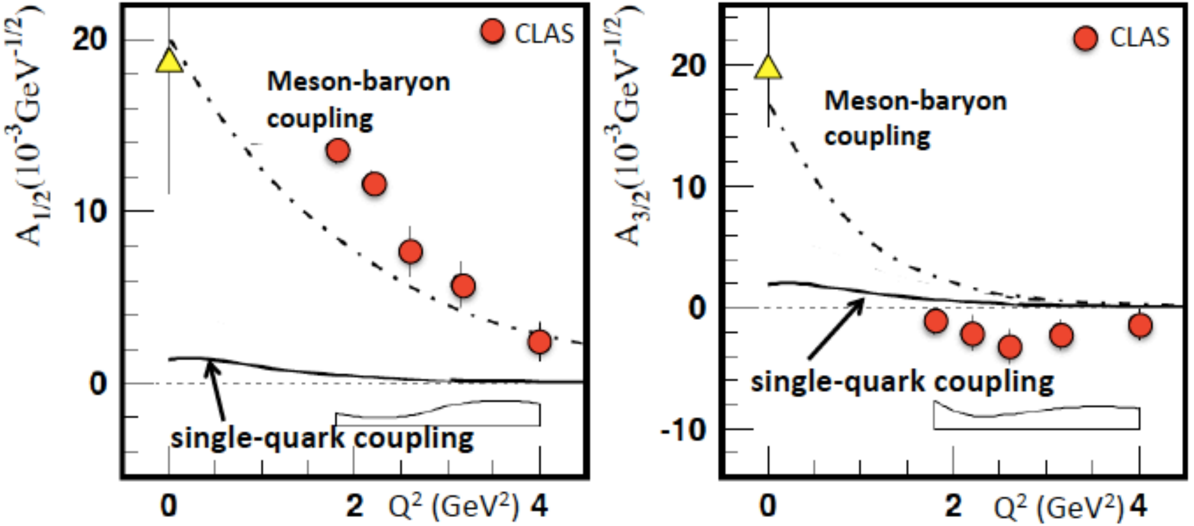
I.V. Anikin, V.M. Braun, N. Offen, PR D92 (2015) 1, 014018

- Meson-baryon cloud may account for discrepancies at low Q^2.

MB Contribution to electro-excitation of N(1675)5/2⁻

Quark components to the helicity amplitudes of the N(1675) 5/2⁻ are strongly suppressed for **proton target.**

Single Quark Transition:
$A^p_{1/2} = A^p_{3/2} = 0$



- Measures the meson-baryon contribution to the γ* p N(1675)5/2⁻ directly.
- Can be verified on γ* n N(1675)5/2⁻ which is not suppressed

——— *E. Santopinto and M. M. Giannini, PRC 86, 065202 (2012)*

– · – · *B. Juliá-Díaz, T.-S.H. Lee, et al., PRC 77, 045205 (2008)*

Baryon Spectroscopy Status Today

- Major progress made in the last ~ 5 years in the search for N* and Δ states.
  All states can be accommodated in CQM and LQCD schemes.
  - Naïve (non-dynamical) di-quark models are ruled out.

- Knowledge of Q^2-dependence of electrocouplings is absolutely necessary to understand the nature (the internal structure) of the excited states.
  - Roper IS the first radial excitation of the q^3 core, obscured at large distances by meson-cloud effects.

- Leading electrocoupling amplitudes of prominent low-mass states (e.g. $N(1535)1/2^-$) is well modeled by DSE/QCD, LC SR and LF RQM for $Q^2 > 2$ GeV.

- Search for hybrid baryons with explicit gluonic degrees of freedom would be possible investigating the low Q^2 evolution of high-mass resonance (2-3 GeV) electrocoupligs:
  - Looking for suppressed $A^{1/2}$, $A^{3/2}$, $S^{1/2}$ at low Q^2.

Event Simulation

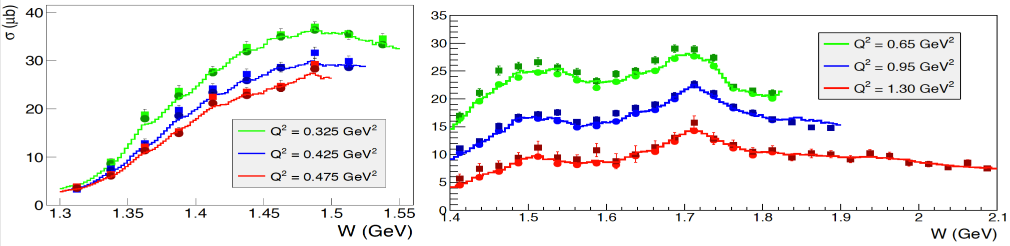
1. $e\,p \longrightarrow e\,p\,\pi^+\,\pi^-$

2. $e\,p \longrightarrow e\,K^+Y$

Event Simulation in **CLAS12**

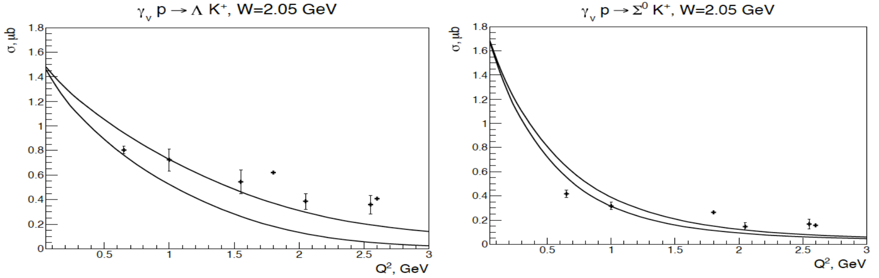
$e\,p \longrightarrow e\,p\,\pi^+\,\pi^-$

JLab - Moscow (JM) model



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

Regge + Resonance (RPR) Gent model



- Development of a realistic event generator using the best presently available models.
- Simulation of *quasi-data* events.
- Selection of trigger conditions:

  scattered electron (FT or CLAS12) + at least 1 hadron in CLAS12.
- Events reconstruction to determine final resolutions and efficiencies.

Simulation of Model + Hybrid Contributions

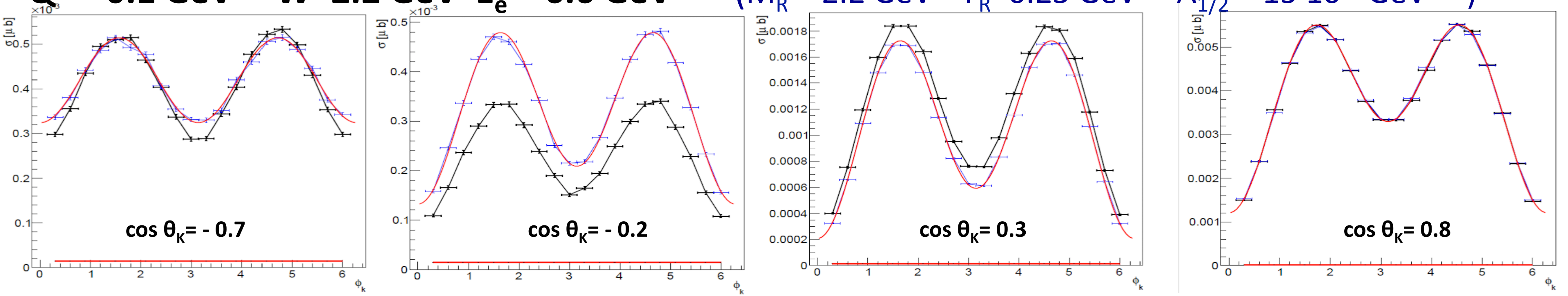
e p ⟶ e K^+Y

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

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 Γ_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*.

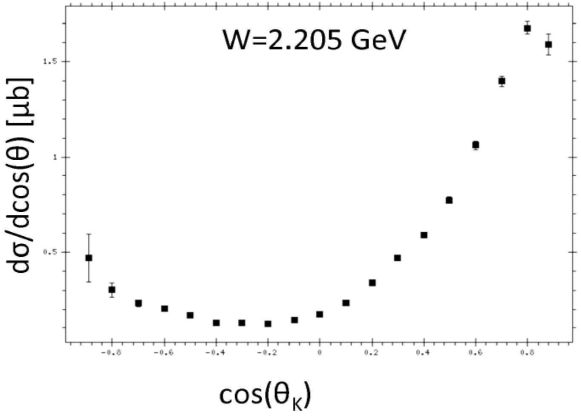
Statistics and Binning Requirements

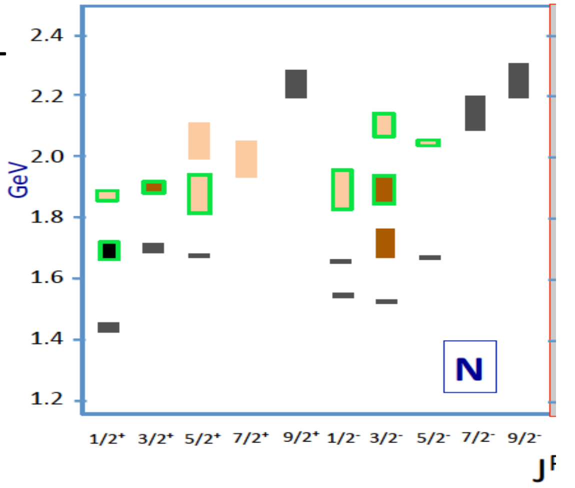
Samples of **γp -> K⁺Λ** cross section used in BnGa analysis that discovered new baryon states in the W range 1.85 – 2.2 GeV mass region.

Statistical precision ranges from 2% - 7%.

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

ΔW=10 MeV, Δcos θ* = 0.1





	Range	Bin	#bins
W (GeV)	1.8-3.0	0.01	120
cos θ*	-1 to +1	0.1	20
ϕ [°]	0 - 360	18	20
Q^2(GeV²)	0.05 - 2	0.02/0.1	5/15

Total KΛ data in **50+50** days:

518.4x10⁶ events

Number of bins: 960x10³

<N> = **540 evts/bin**

σ_N/N = 4.3%