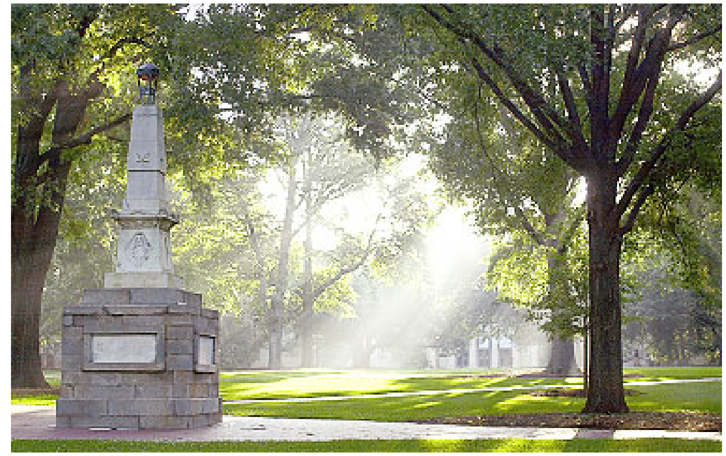
USC Summer Academy on Non-Perturbative Physics

The next workshop in our series "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities" will be held at the University of South Carolina on August 13-15, 2012. This three-day workshop will provide us extended opportunities to present and discuss in depth future developments and preliminary results on the continuous exploration of hadronic physics towards smaller distances. If you would like to participate please contact gothe@sc.edu or mokeev@jlab.org or visit www.jlab.org/conferences/EmNN2012/.

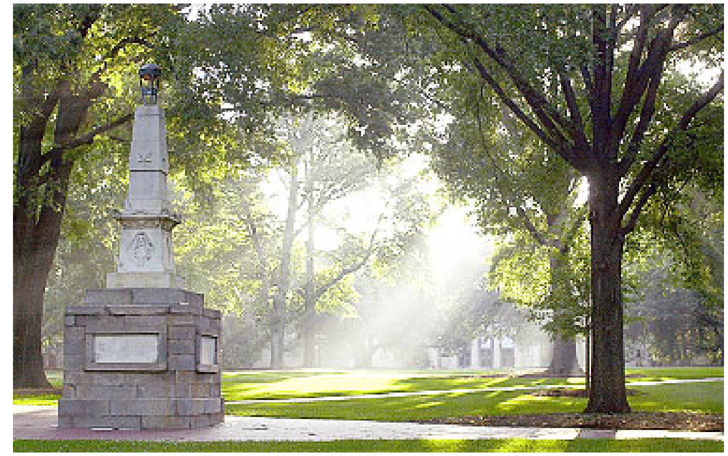


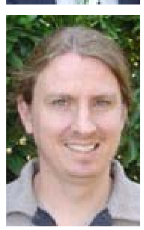
COLLEGE OF ARTS AND SCIENCES
PHYSICS AND ASTRONOMY
South Carolina

A first of its kind three-week graduate student summer school on "Dyson-Schwinger Equations (DSEs) to tackle non-perturbative physics, their applications in Quantum Chromodynamics (QCD) and condensed matter physics, and their mathematical connection to the Hopf algebras" will be held at USC from July 26 to August 10, directly preceding a three-day international workshop on "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities". The main lecturers are Piers Coleman, Ian Cloet, Craig Roberts, and Karen Yeats. There are a limited number of slots for outside graduate students available. If you would like to come or send a graduate student please contact gothe@sc.edu or webb@sc.edu and visit www.physics.sc.edu/~gothe/.

USC Summer School on Non-Perturbative Physics

A first of its kind three-week graduate student summer school on “Dyson-Schwinger Equations (DSEs) to tackle non-perturbative physics, their applications in Quantum Chromodynamics (QCD) and condensed matter physics, and their mathematical connection to the Hopf algebras” will be held at USC from July 26 to August 10, directly preceding a three-day international workshop on “Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities”. There are a limited number of slots for outside graduate students available. If you would like to come or send a graduate student please contact gothe@sc.edu or webb@sc.edu.





Karen Yeats: “The Hopf Algebraic Approach to DSEs”. DSEs are very useful in how they mirror the recursive decomposition of Feynman diagrams into subdiagrams. This simple combinatorial observation is surprisingly powerful as it gives us hints as to how to unwind the combinatorial difficulties from the analytic ones. Furthermore, the Slavnov-Taylor identities for the coupling constants correspond to certain Hopf ideals. The lectures will explain these connections without expecting prior algebraic experience.

Piers Coleman: “DSE Applications in Condensed Matter Physics”. In his lectures, he explains the relevance of DSEs for condensed matter physics and will give a short introduction to interacting electron systems followed by five lectures on: “Feynman diagrams in many body physics”, “The interacting electron plasma”, “BCS theory I and II”, and “The Kondo effect and heavy Fermions”.

Craig Roberts: “The Emergence of DSEs in Real-World QCD”. The properties of QCD are dominated by two emergent phenomena: confinement and dynamical chiral symmetry breaking (DCSB). These phenomena are not apparent in the formulae that define QCD, and DSEs play a critical role in exploring them and in predicting Nature's observable phenomena in the world of strong interactions.

Ian Cloet: “Hadron Phenomenology and QCD’s DSEs”. An understanding of how the colored quarks and gluons bind together to form the observed color singlet hadrons remains one of the most important questions in all of nuclear physics. His lectures will explore the interplay between experiment and theory using the DSEs and provide a perspective on answering key questions concerning QCD’s nonperturbative structure.

EmNN* 2012

The next workshop in our series "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities" will be held at the University of South Carolina on August 13-15, 2012. This three-day workshop will provide us extended opportunities to present and discuss in depth future developments and preliminary results on the continuous exploration of hadronic physics towards smaller distances. If you would like to participate please contact gothe@sc.edu or mokeev@jlab.org or visit www.jlab.org/conferences/EmNN2012/.

In the tradition of this workshop, we will focus on the extension of the $\gamma_v NN^*$ electrocoupling studies to high photon virtualities from 5.0 to 12.0 GeV^2. This is the kinematic area, where the N* structure is still almost unexplored, and which will be comprehensively covered by the approved experiment PR12-09-003 on N* studies in exclusive meson electroproduction off protons with the CLAS12 detector. The experiment will be carried out in the first five years after the completion of the Jefferson Lab 12-GeV Upgrade Project.

By that time ready-to-use methods for the extraction of the $\gamma_v NN^*$ electrocouplings at high photon virtualities are needed as well as general QCD-based frameworks for the theoretical interpretation of these fundamental N* parameters. Resonance electrocouplings will be measured for the first time at distance scales, where quark degrees of freedom are expected to dominate. These studies will focus on the exploration of quark interactions in the QCD running coupling regime, which are responsible for the baryon formation. They are vital in order to explore confinement in the baryon sector and to understand how the complexity of non-perturbative strong interactions emerges from QCD.

The scope of this three-day workshop focuses particularly on the development of future strategies, methods, and approaches to extract the $\gamma_v NN^*$ electrocouplings, where hard quark interactions become relevant, and on the interpretation of hadronic physics in this non-perturbative regime. The workshop aims to foster already initiated efforts and create opportunities to facilitate and stimulate further growth in this field.

Bridging the Gap between Nuclear and High-Energy Physics

Ralf W. Gothe

UNIVERSITY OF SOUTH CAROLINA

Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities

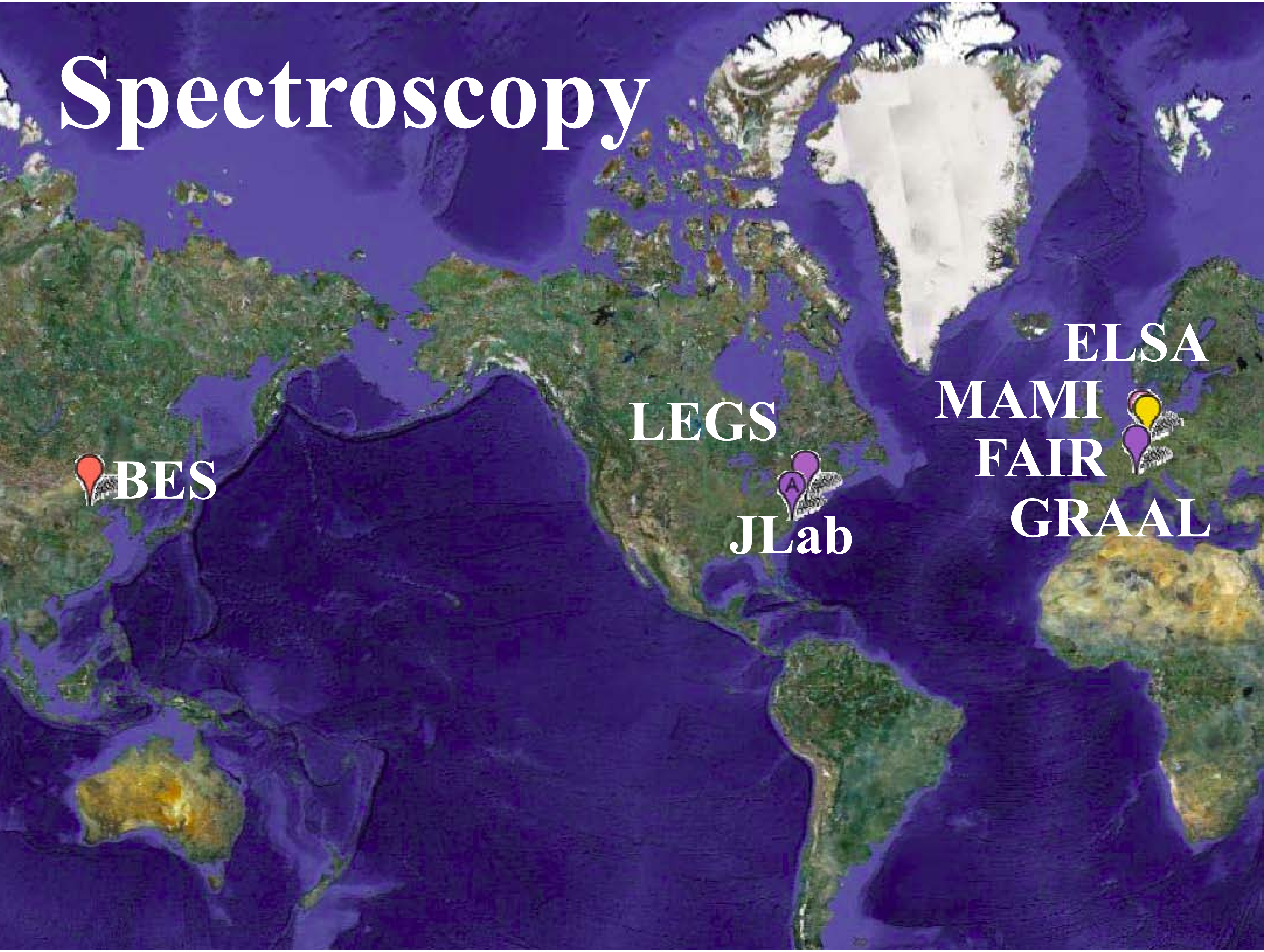
August 13 to 15, 2012

USC, Columbia, SC

- **γ_vNN* Experiments:** The Best Access to the Baryon and Quark Structure?
  - Elastic Form Factors and Transition Form Factors
- **Analysis:** Phenomenological Extraction … can you do better?
  - Consistent extraction of γ_vNN* electrocouplings in various decay channel with various models
- **QCD based Theory:** Solve Non-Perturbative QCD and Confinement?

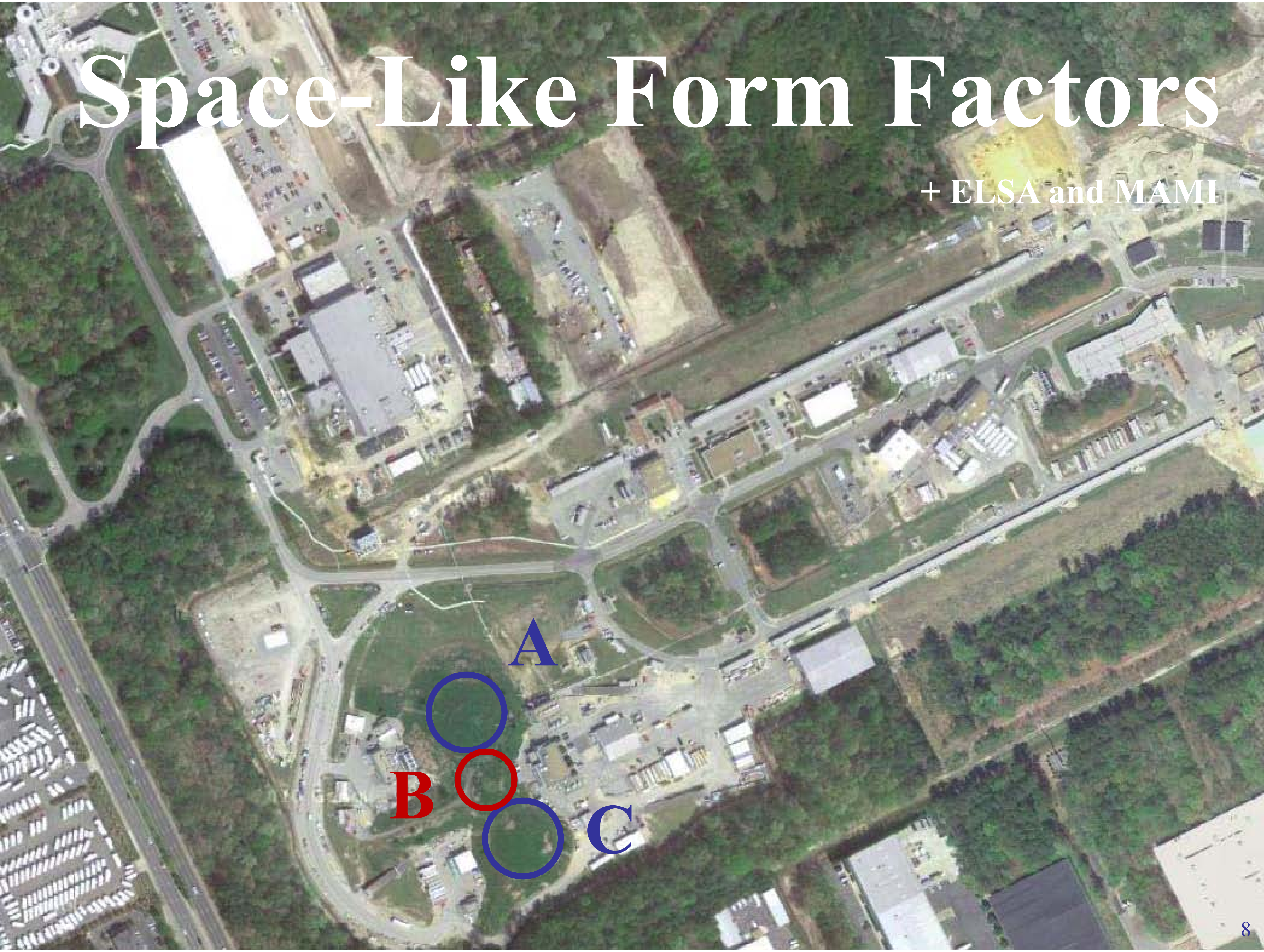
Non-perturbative QCD for Bound and Confined Quarks?

Experimental Facilities

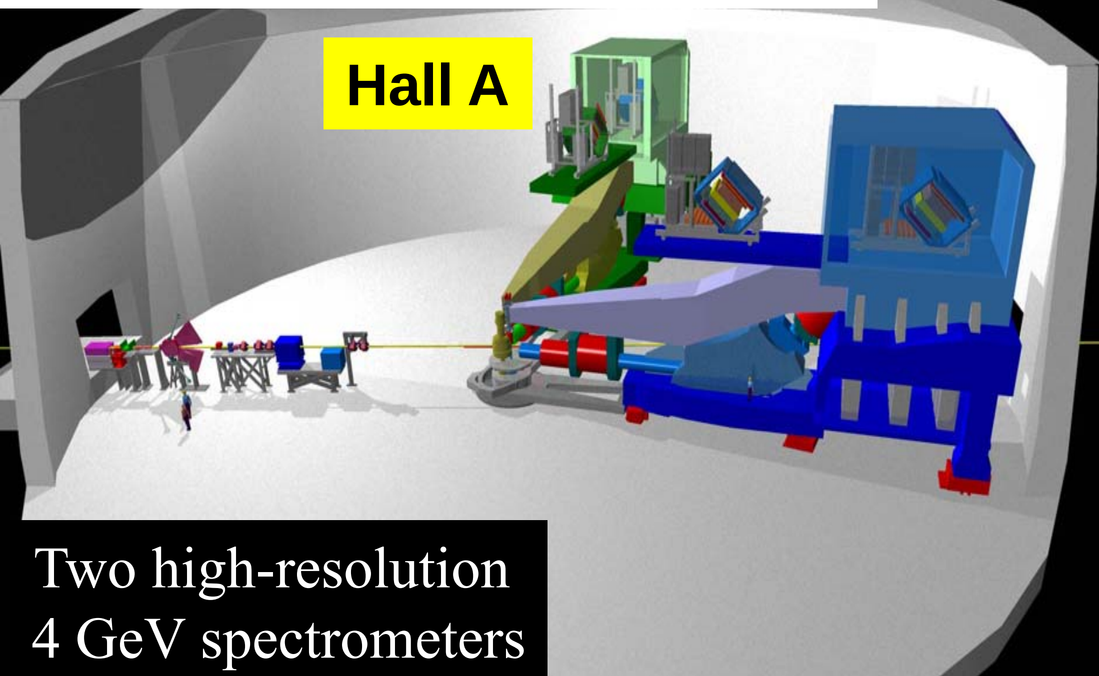

Spectroscopy
ELSA
MAMI
LEGS
BES
FAIR
JLab
GRAAL

Space-Like Form Factors

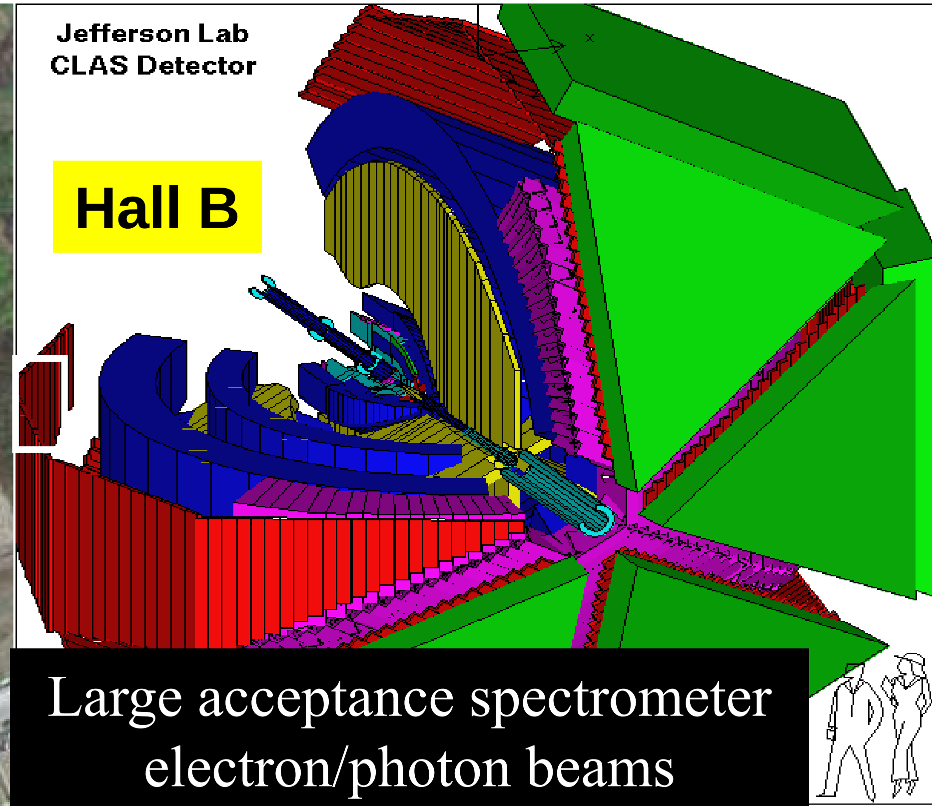
+ ELSA and MAMI



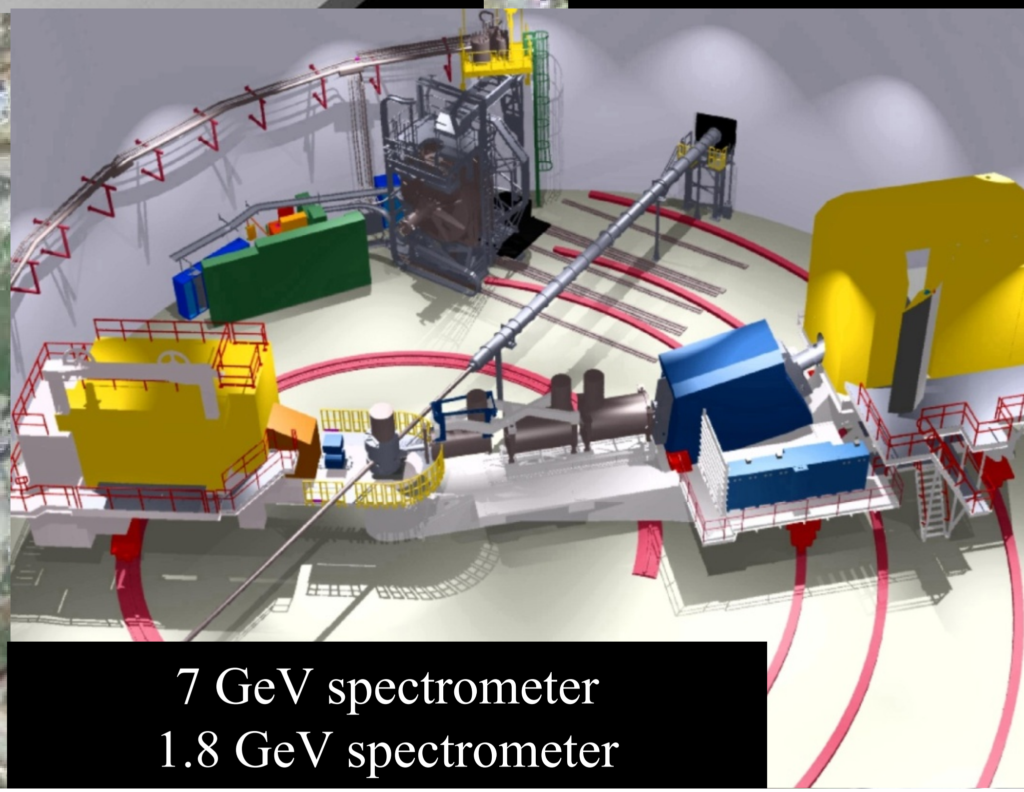
Jefferson Lab Today



Two high-resolution
4 GeV spectrometers

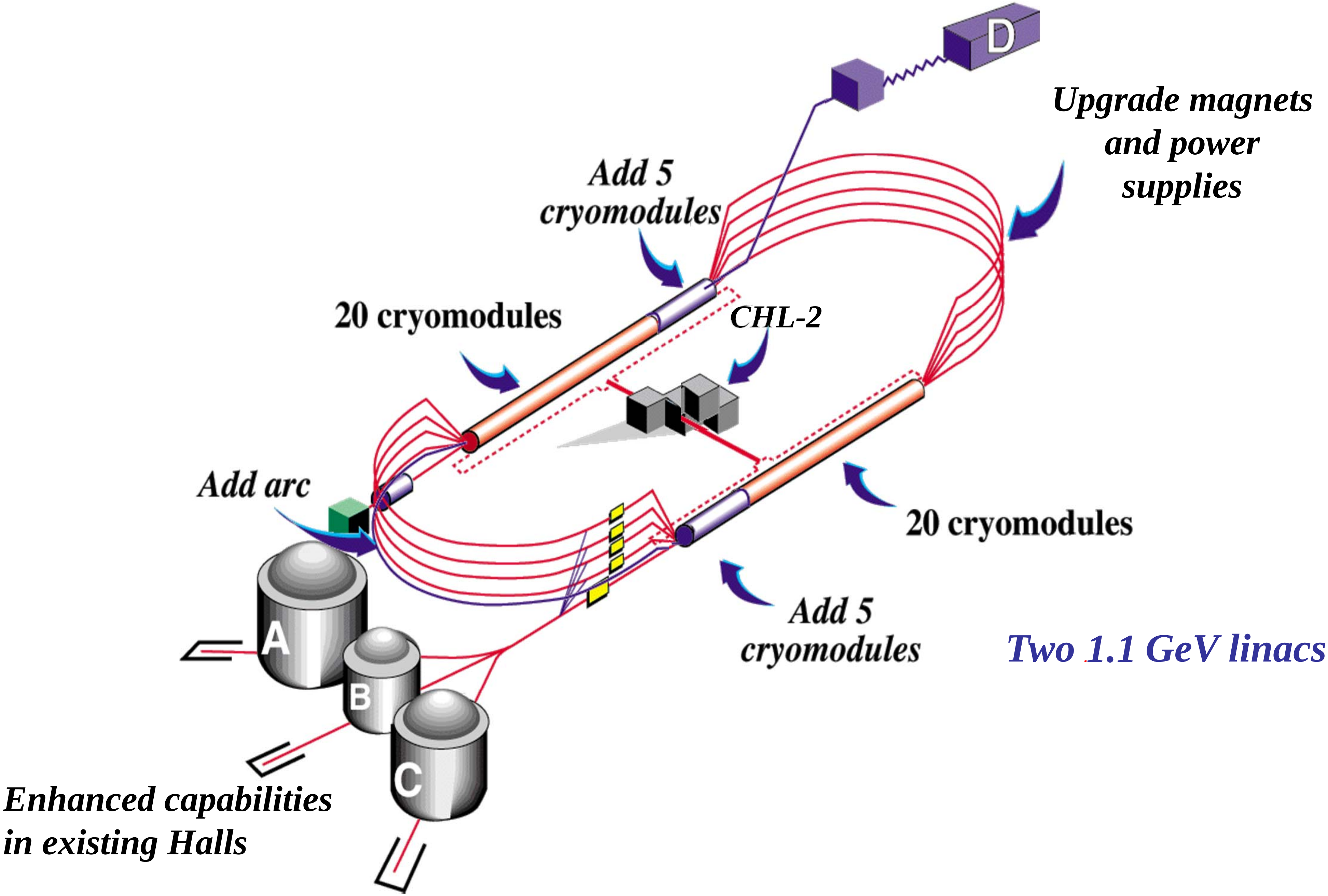


Large acceptance spectrometer
electron/photon beams

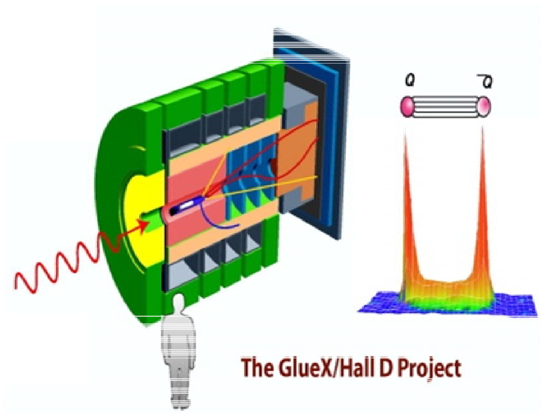


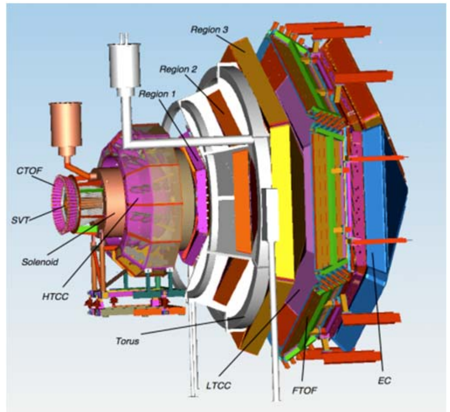
7 GeV spectrometer
1.8 GeV spectrometer

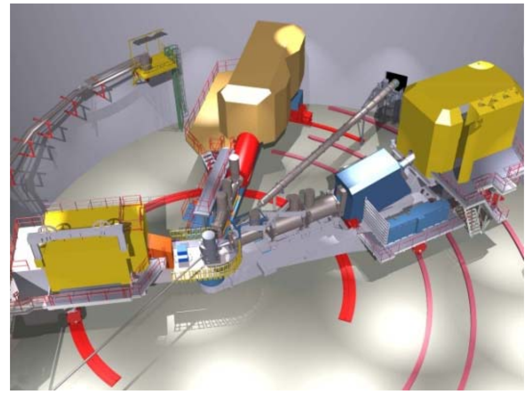
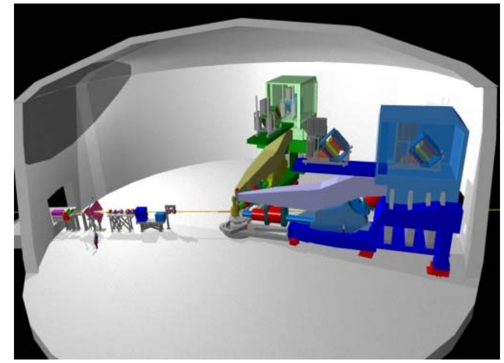
12 GeV CEBAF


D
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
Two 1.1 GeV linacs
A
B
C
Enhanced capabilities in existing Halls

Overview of Upgrade Technical Performance Requirements



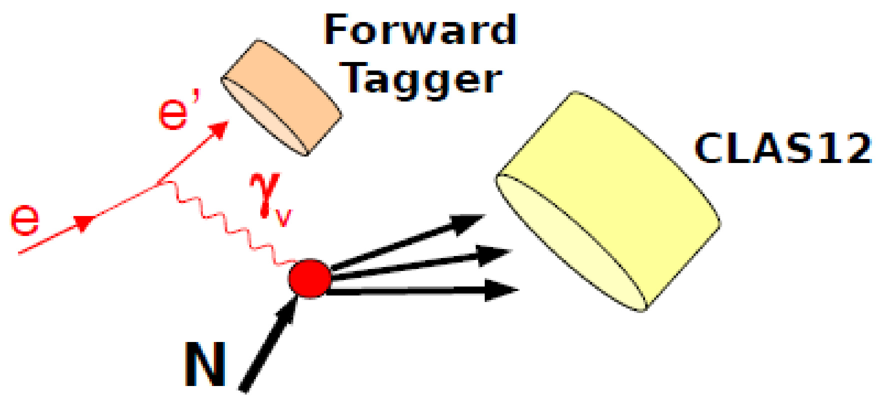


Hall D	Hall B	Hall C	Hall A
4π hermetic detector GlueEx	luminosity 10^{35} CLAS12	High Momentum Spectrometer SHRS	High Resolution Spectrometer HRS
polarized photons	hermeticity	precision	space
$E_\gamma \sim 8.5$-9.0 GeV	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution		excellent momentum resolution	
high multiplicity reconstruction		luminosity up to 10^{38}	

Forward Photon Tagger for Spectroscopy

M. Battaglieri



$E_{scattered}$	0.5 - 4.5 GeV
θ	2.5^o - 4.5^o
ϕ	0^o - 360^o
ν	6.5 - 10.5 GeV
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 >$ 0.1 GeV^2)
W	3.6 - 4.5 GeV

Calorimeter + hodoscope + tracker

Electron energy/momentum

Photon energy (ν=E-E')

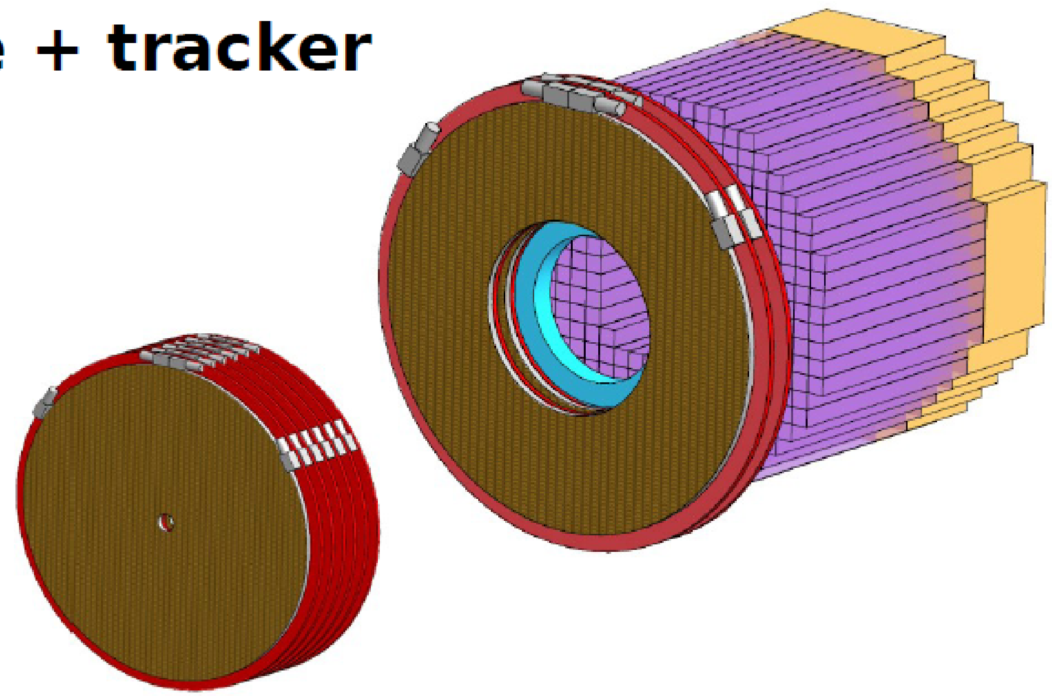
Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles

$Q^2 = 4\, E\, E' \sin^2 \vartheta/2$

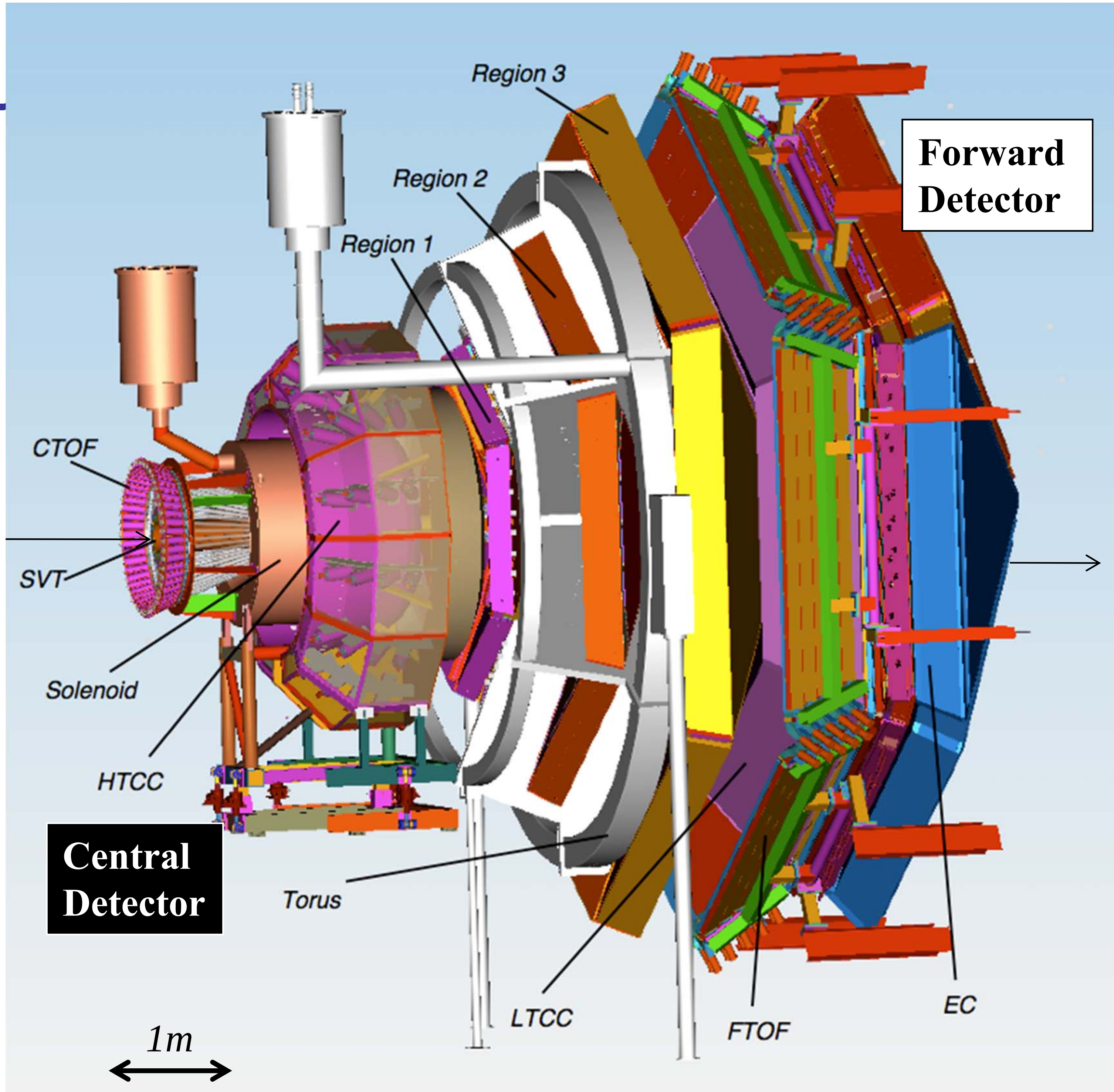
Scattering plane



Rates in the forward tagger

$L_e \sim 10^{35}$ cm^{-2} s^{-1} ($N_\gamma \sim 5\ 10^8\ \gamma$/s)

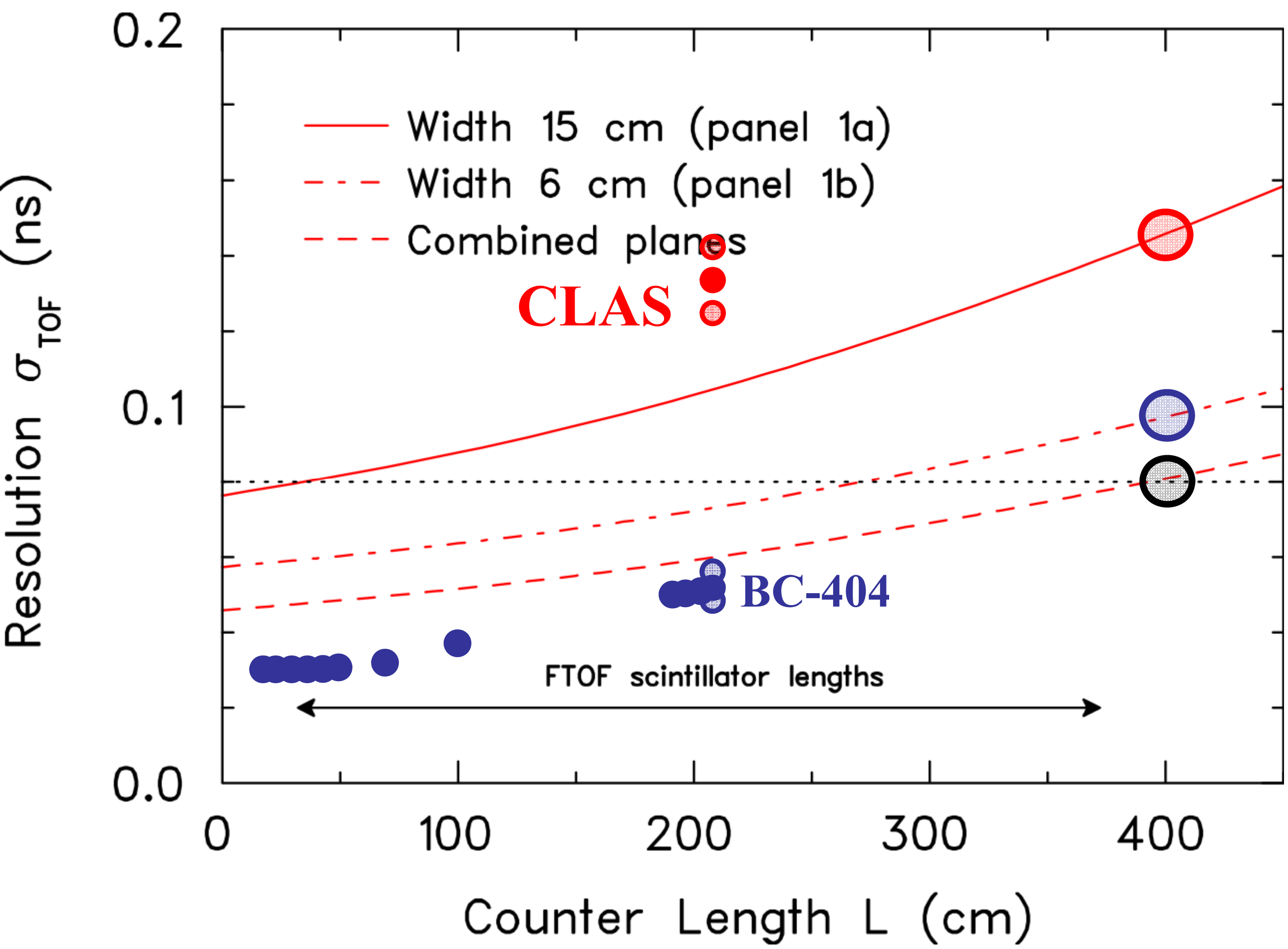
CLAS12

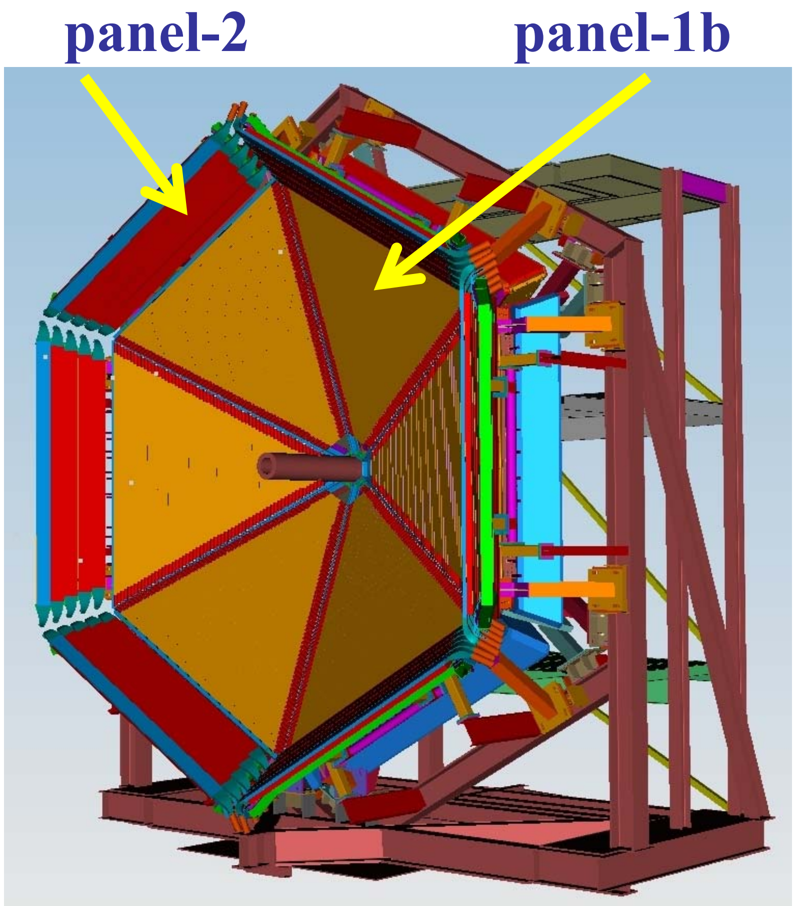


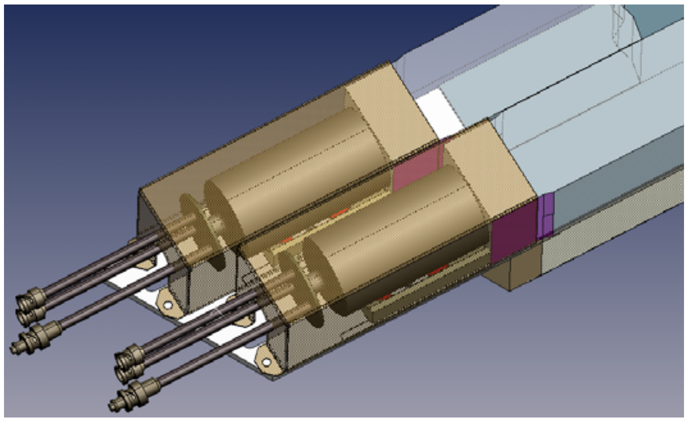
- Luminosity > 10^{35} $cm^{-2}s^{-1}$
- Hermeticity
- Polarization

- Baryon Spectroscopy
- Elastic Form Factors
- N to N* Form Factors
- GPDs and TMDs
- DIS and SIDIS
- Nucleon Spin Structure
- Color Transparency
- …

New Forward Time of Flight Detector for CLAS12



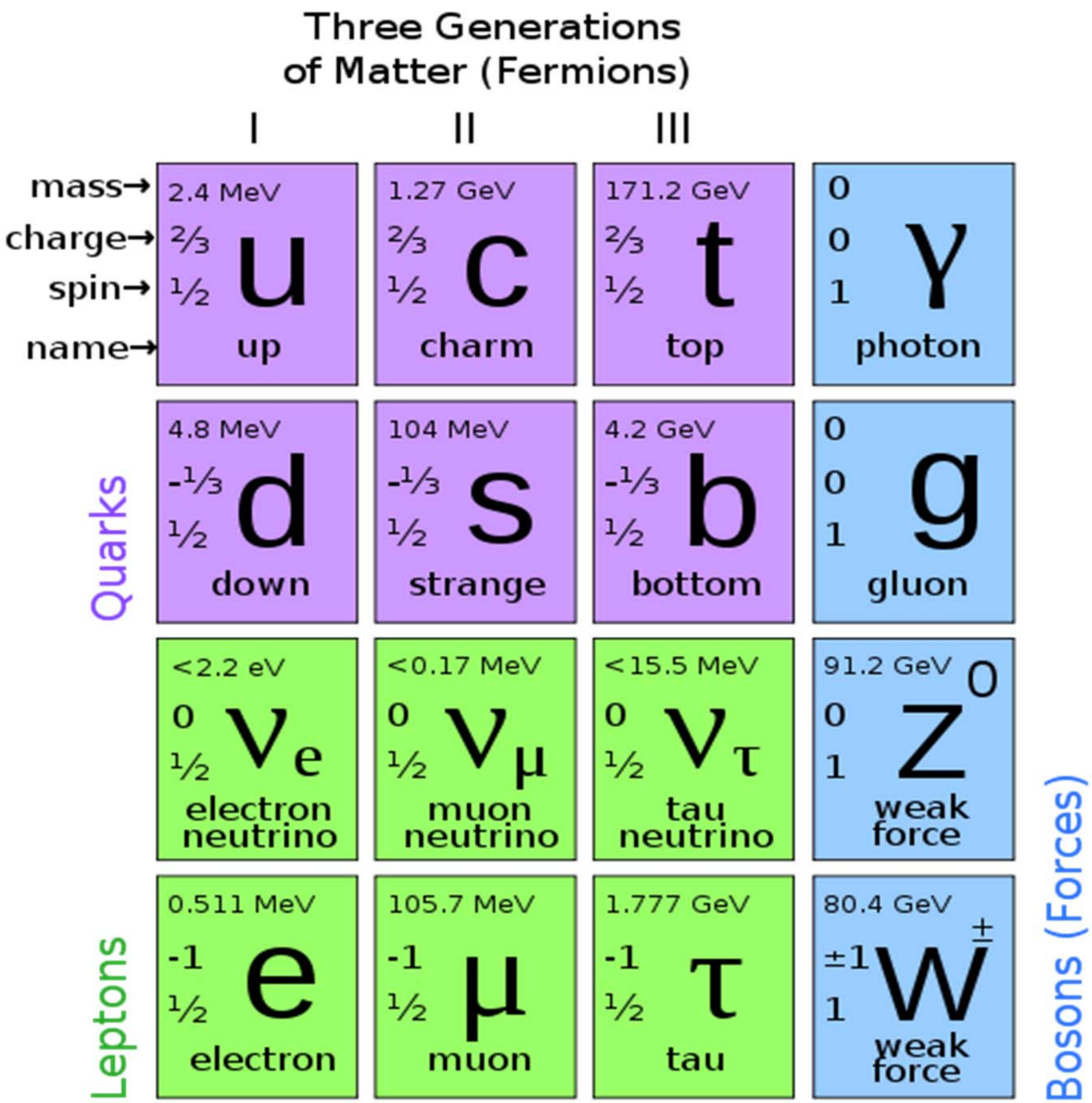


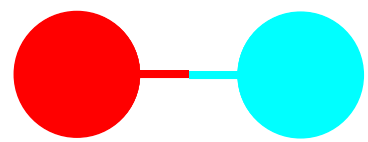


World-record time resolution of 44 ns
averaged over the full length of 210 cm

Spectroscopy

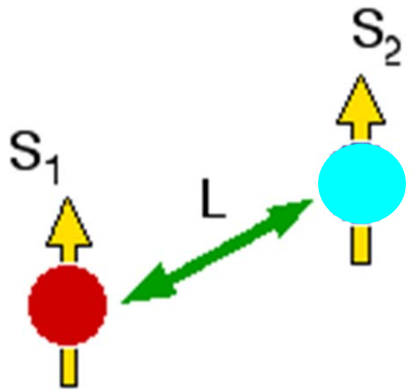
Build your Mesons…





Meson Spectroscopy

Search for mesons with 'exotic' quantum numbers (not compatible with quark-model)

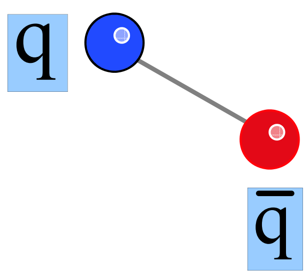


$S = S_1 \oplus S_2 \quad J = L \oplus S \qquad P = (-1)^{L+1} \qquad C = (-1)^{L+S}$

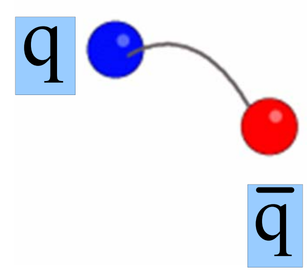
Not-allowed: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$

Unambiguous experimental signature for the presence of gluonic degrees of freedom in the spectrum of mesonic states

Normal meson:
flux tube in
ground state
m=0
$CP = (-1)^{S+1}$



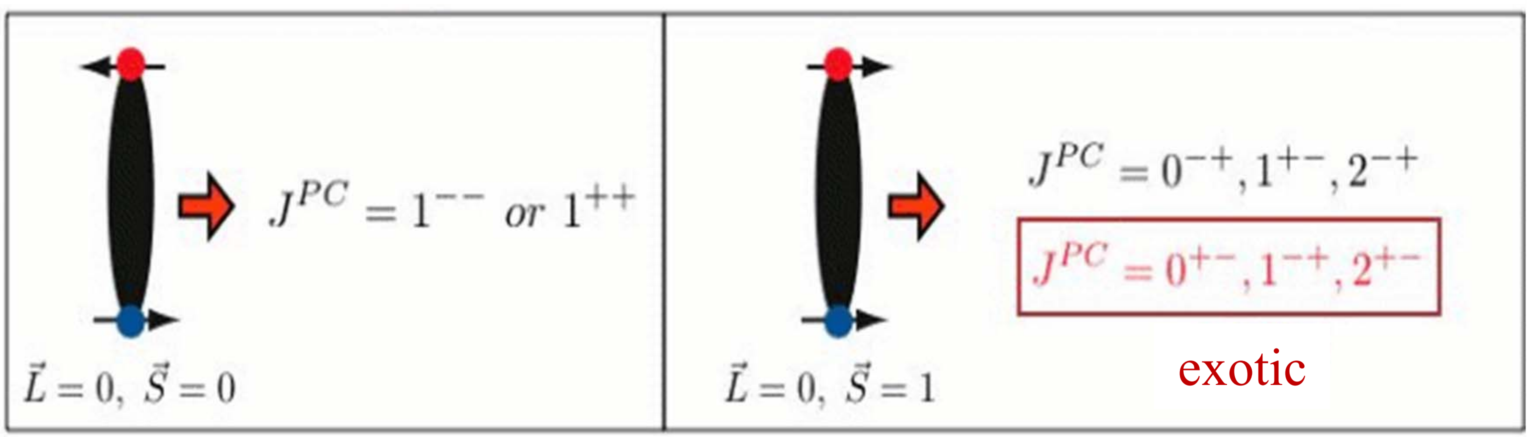
Hybrid meson:
flux tube in
excited state
m=1
$CP = (-1)^{S}$



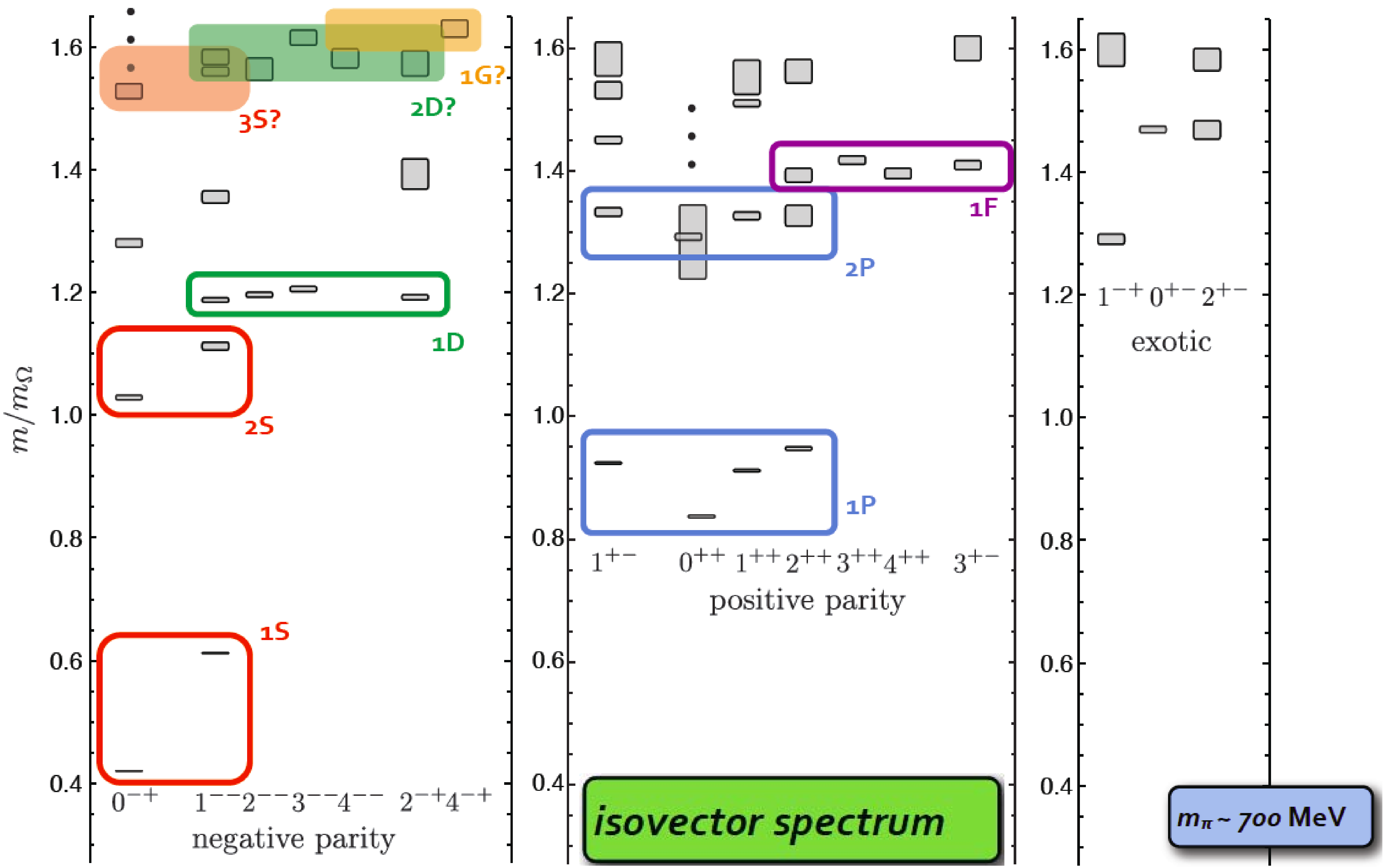
Flux tubes
$J^{PC}\ 1^{-+}, 1^{+-}$

Combine excited glue quantum number with those of the quarks

M.Battaglieri

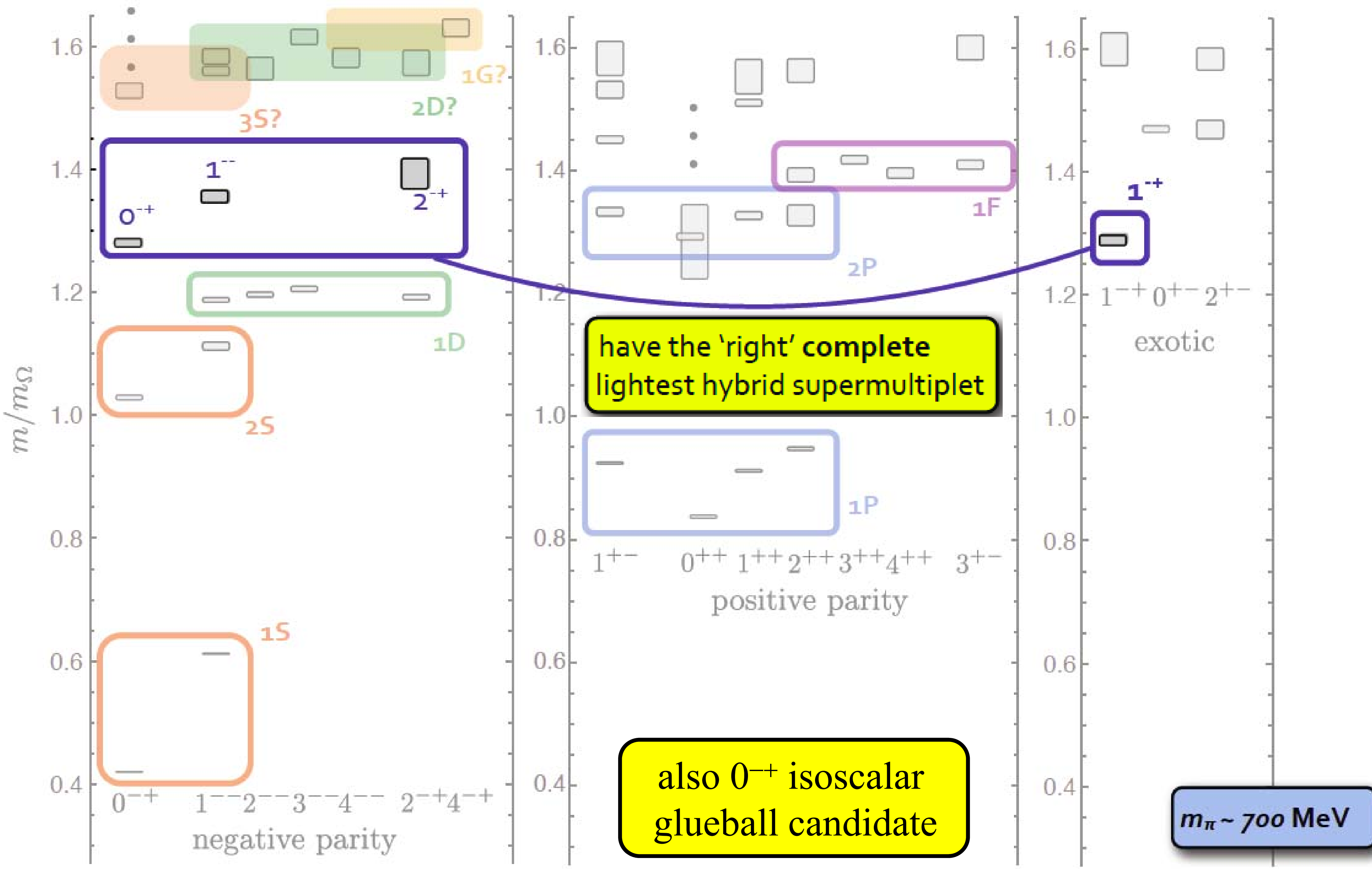


Meson Spectrum in QCD Lattice Calculations



J. Dudek et al. Phys. Rev. D82 (2010) 034508

Meson Spectrum in QCD Lattice Calculations



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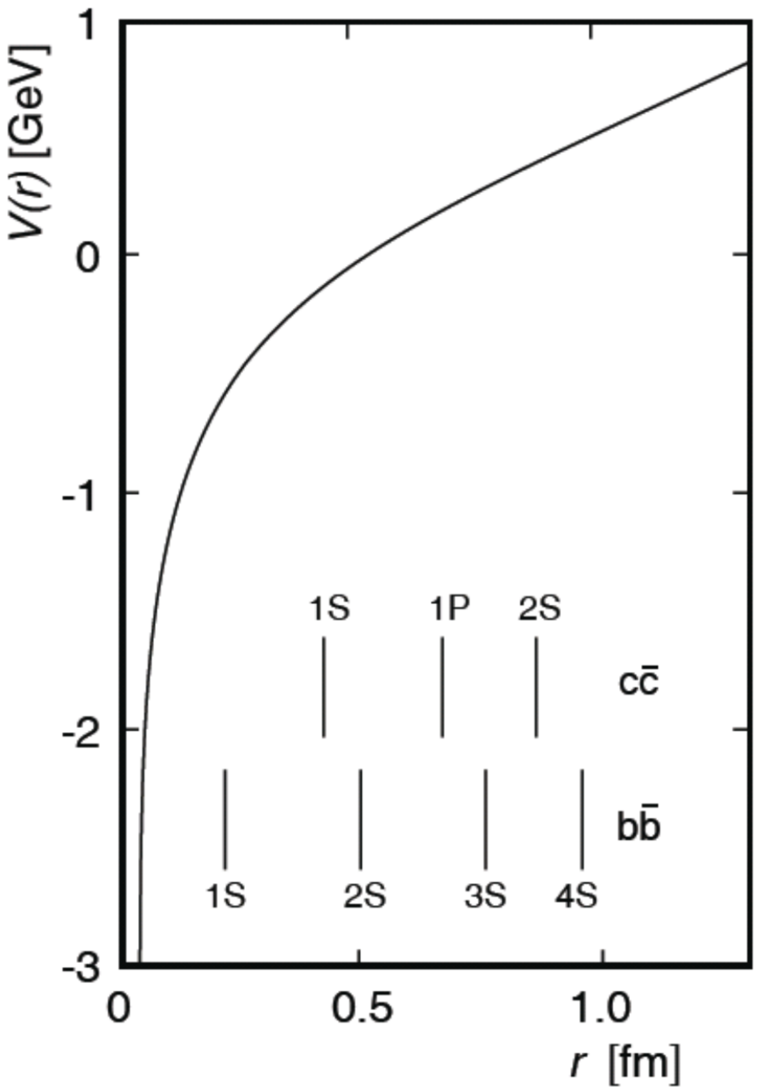
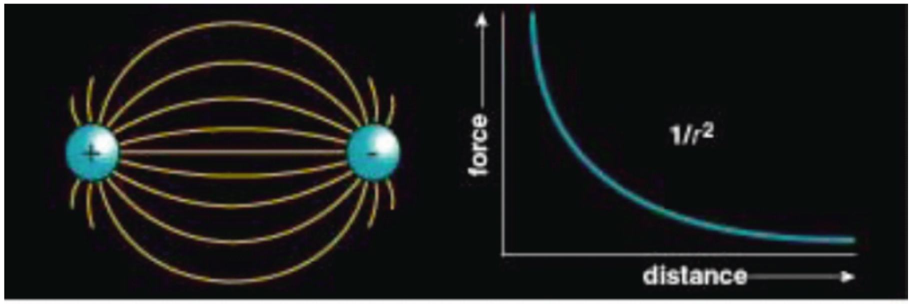
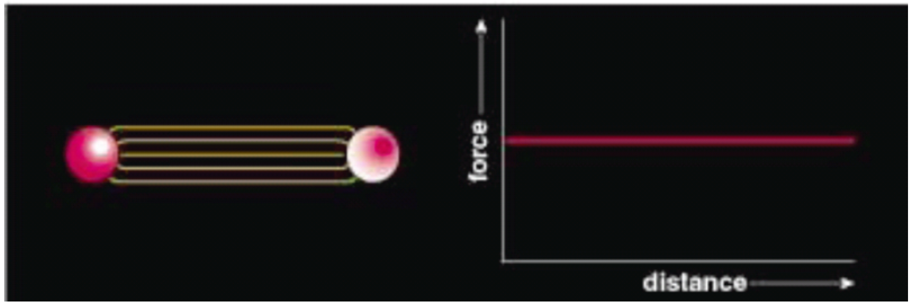
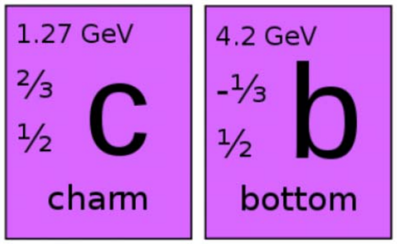
Heavy Quark Systems



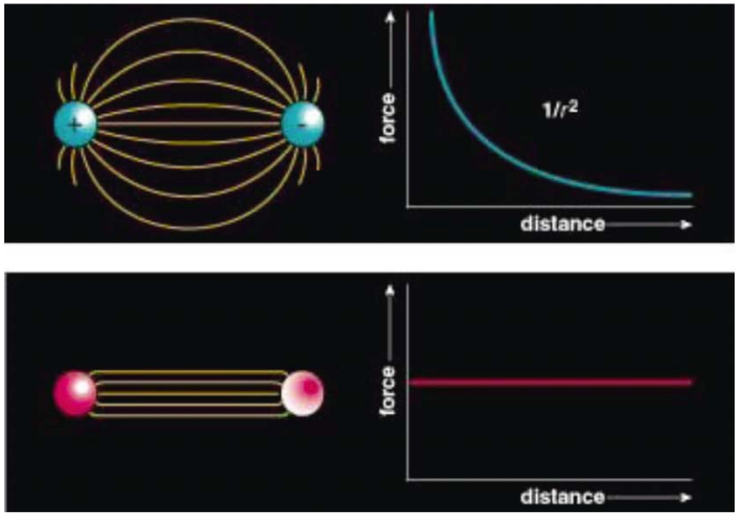
$$V = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$





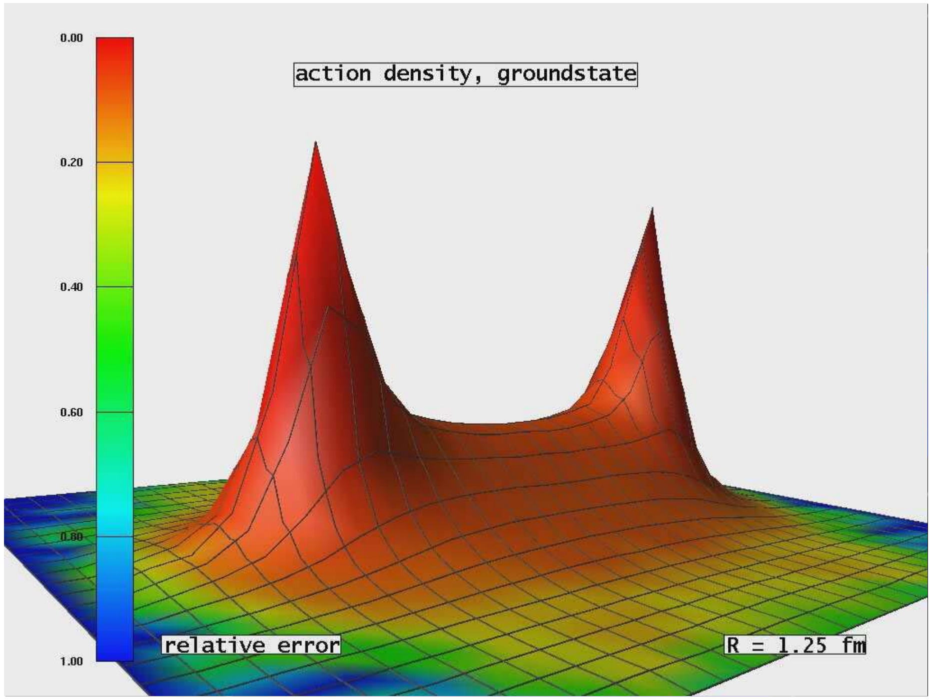


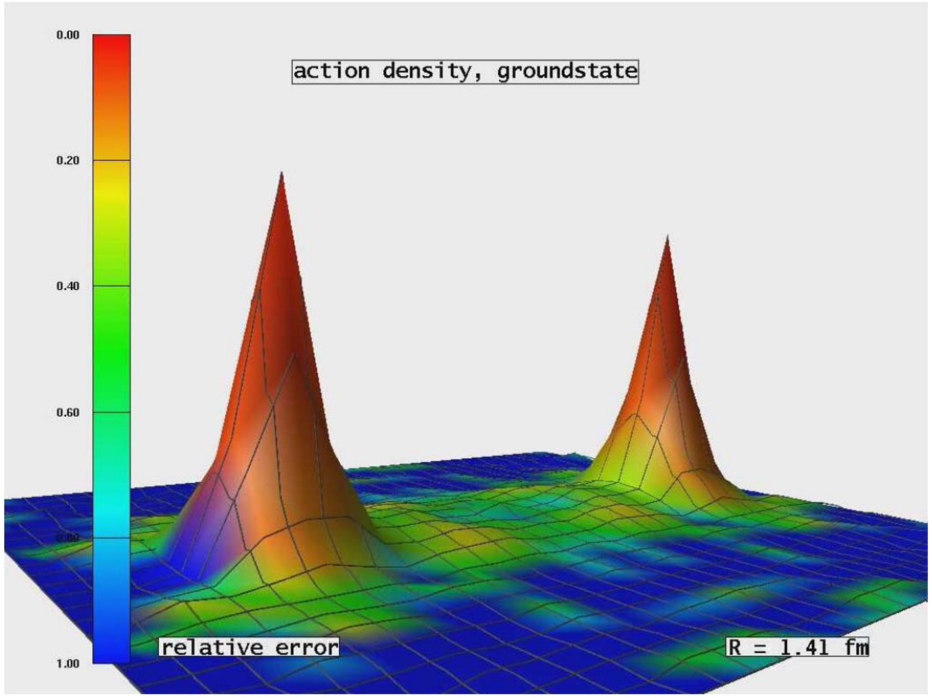
Heavy Quark Systems



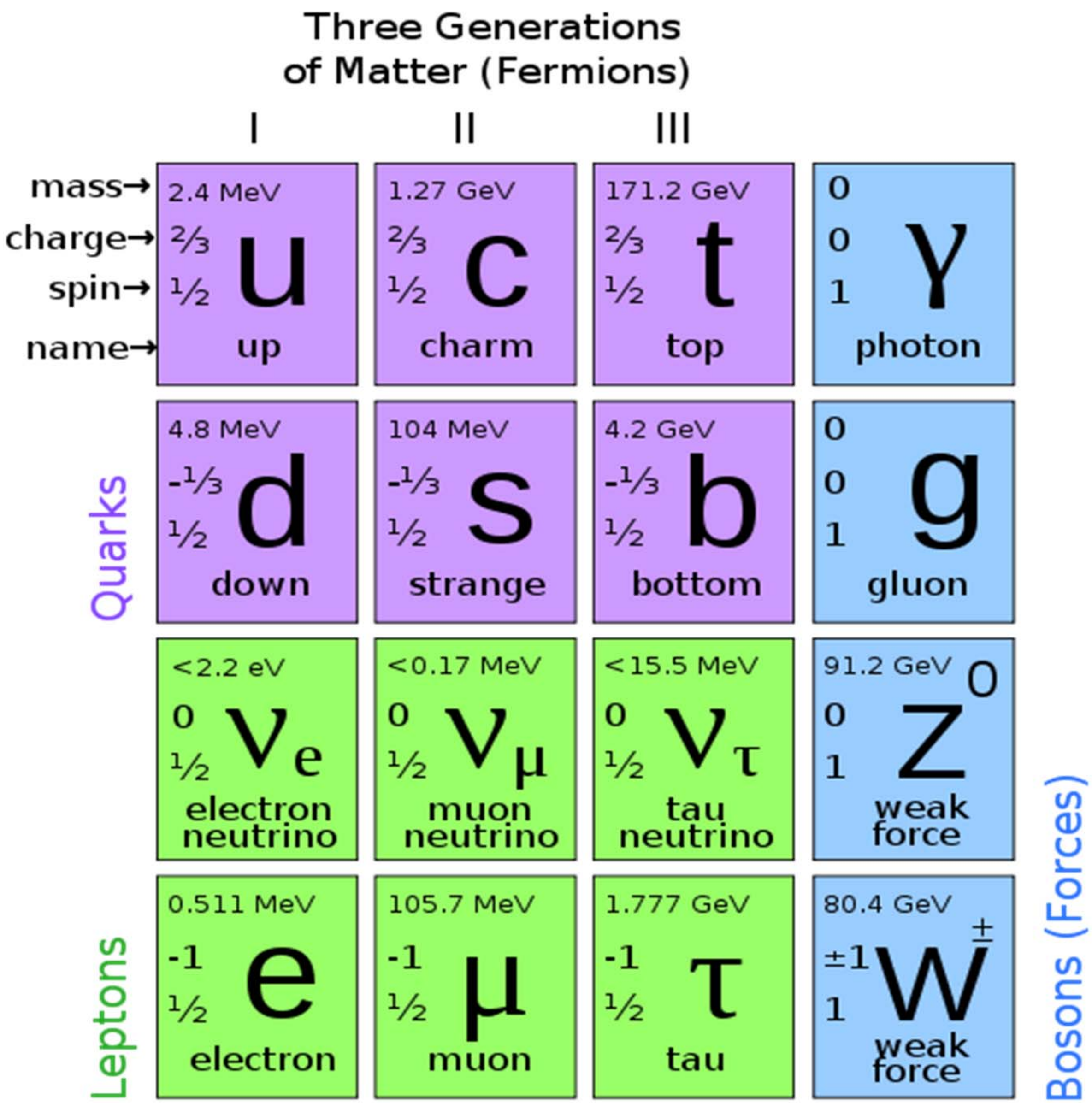
$$V = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$

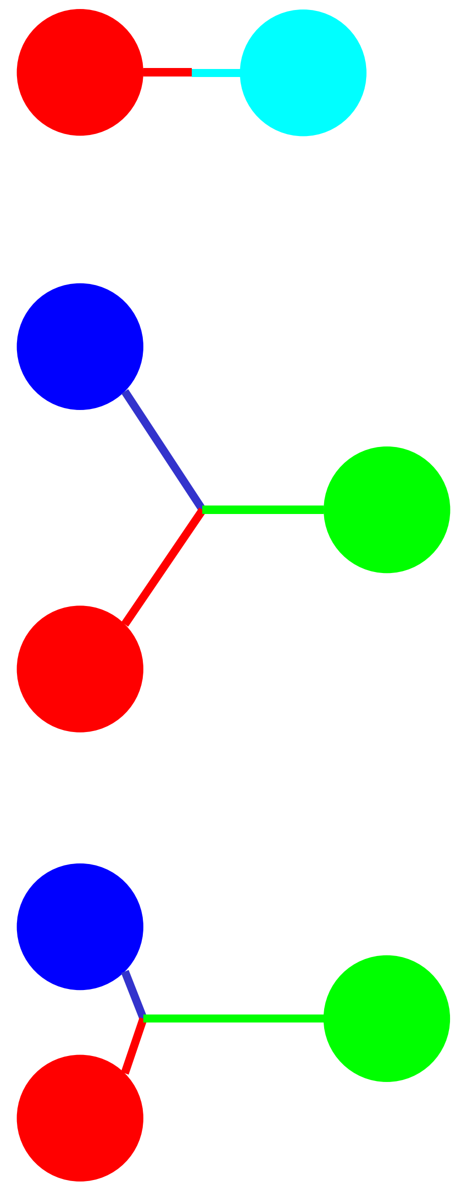
Bali *et al.* he-la/0512018





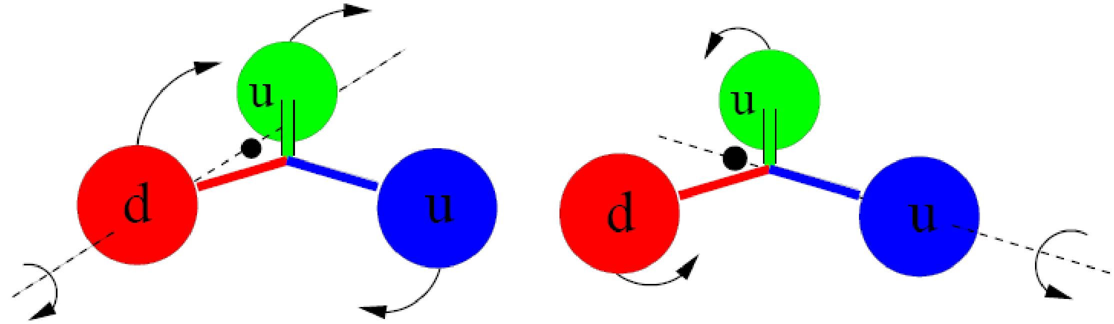
Build your Mesons and Baryons …



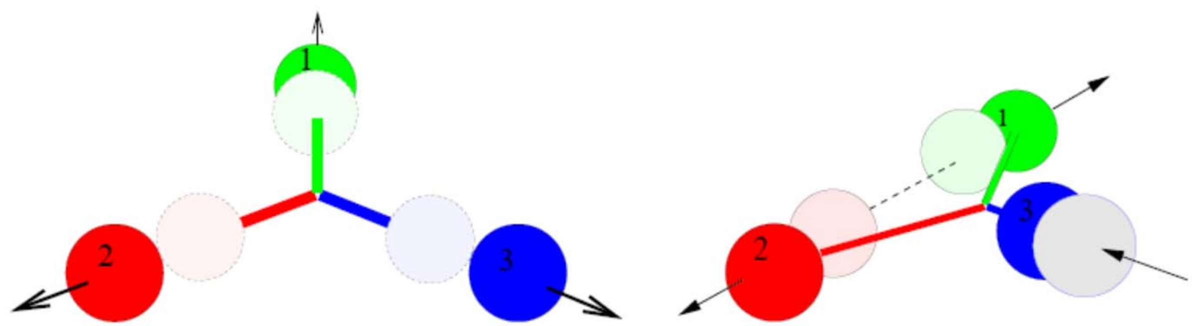


N and Δ Excited Baryon States …

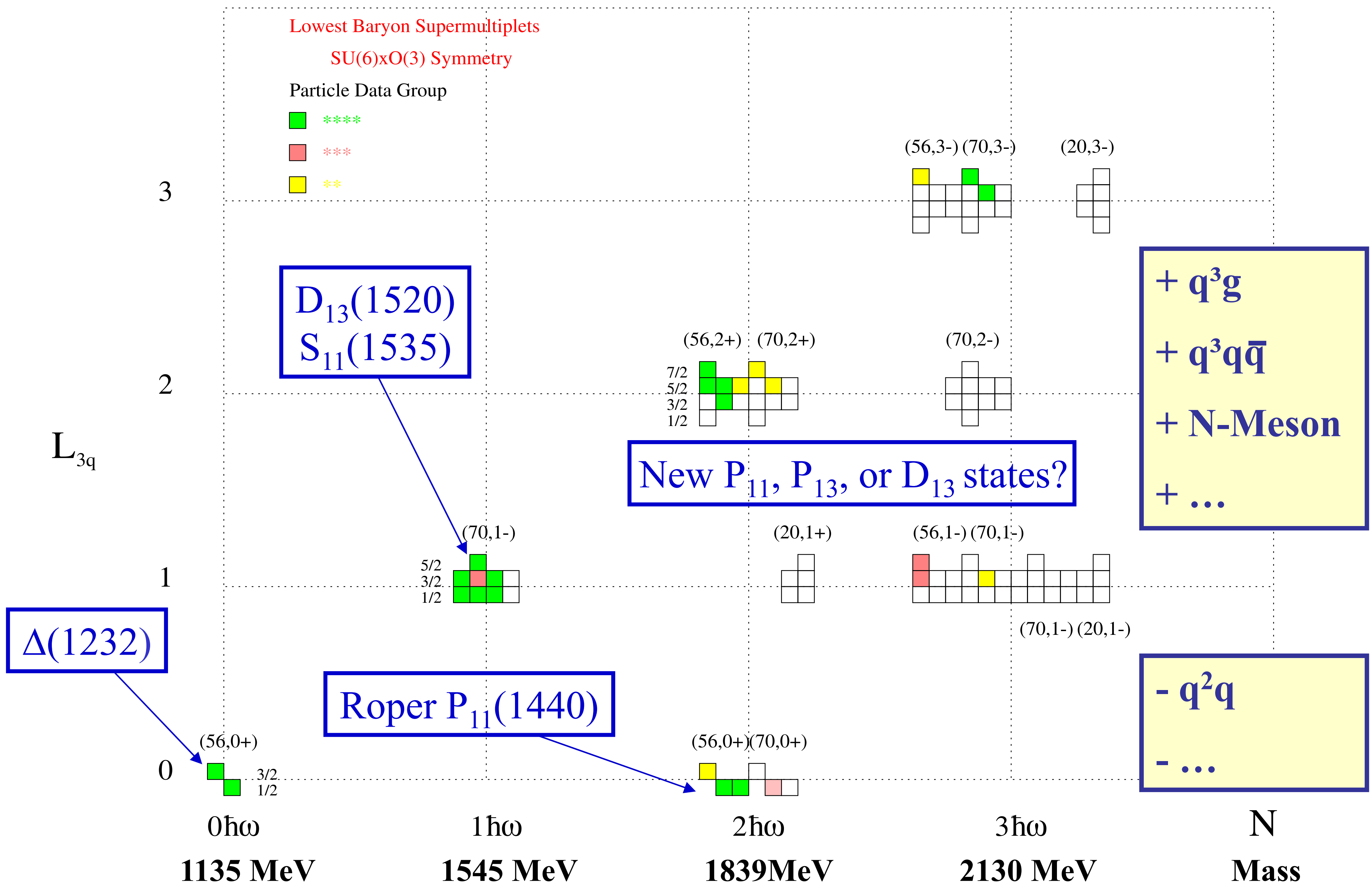
- Orbital excitations (two distinct kinds in contrast to mesons)



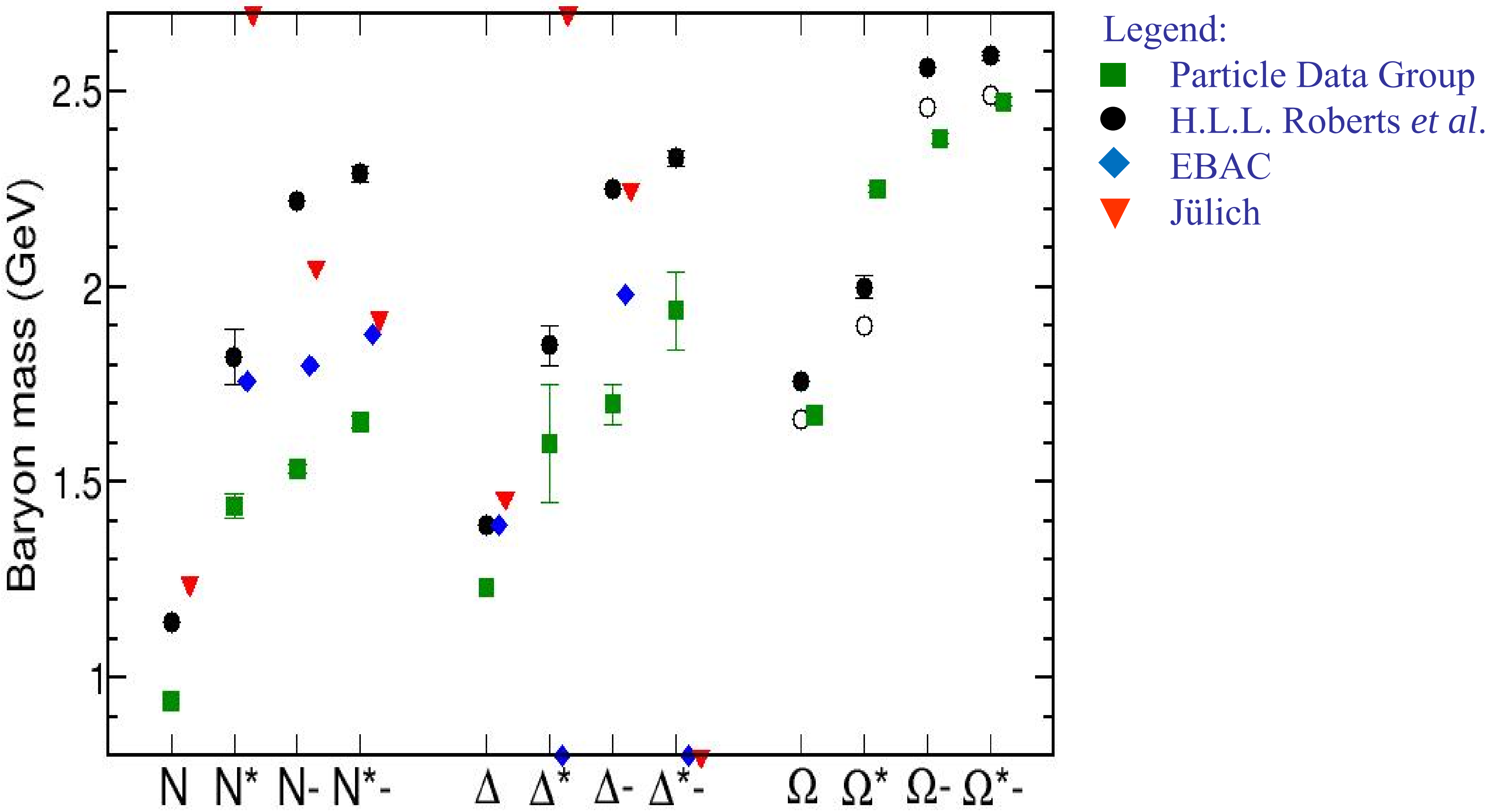
- Radial excitations (also two kinds in contrast to mesons)



Quark Model Classification of N*

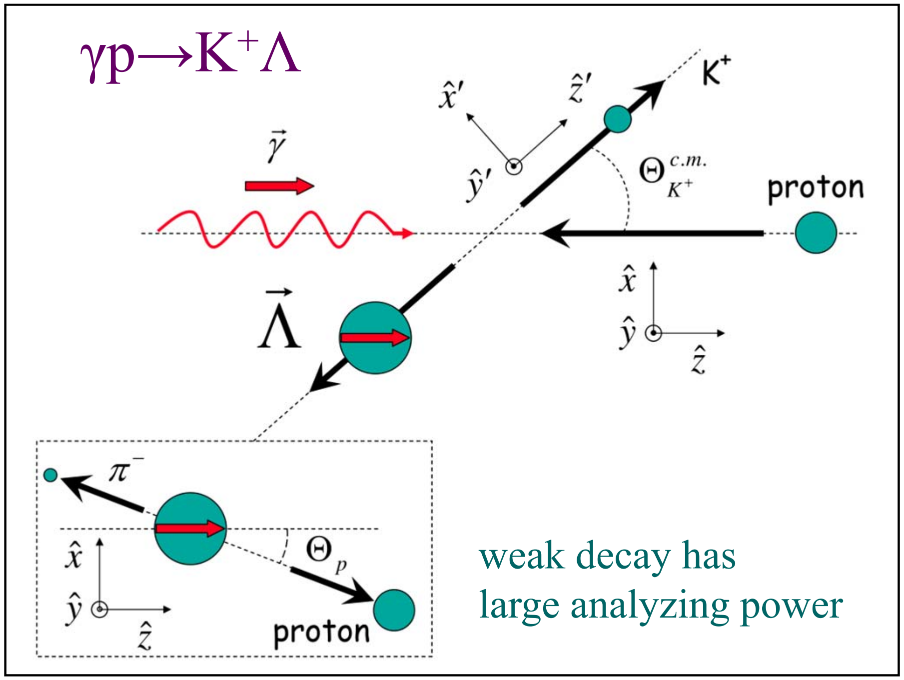


Baryon Spectrum in QCD DSE Calculations



H.L.L. Roberts *et al.*, arXiv:1101.4244 [nucl-th], *Few Body Systems* (2011) pp. 1-25

FROST/HD $\vec{\gamma}\vec{N} \rightarrow \pi N, \eta N, K\vec{\Lambda}, K\vec{\Sigma}, N\pi\pi$

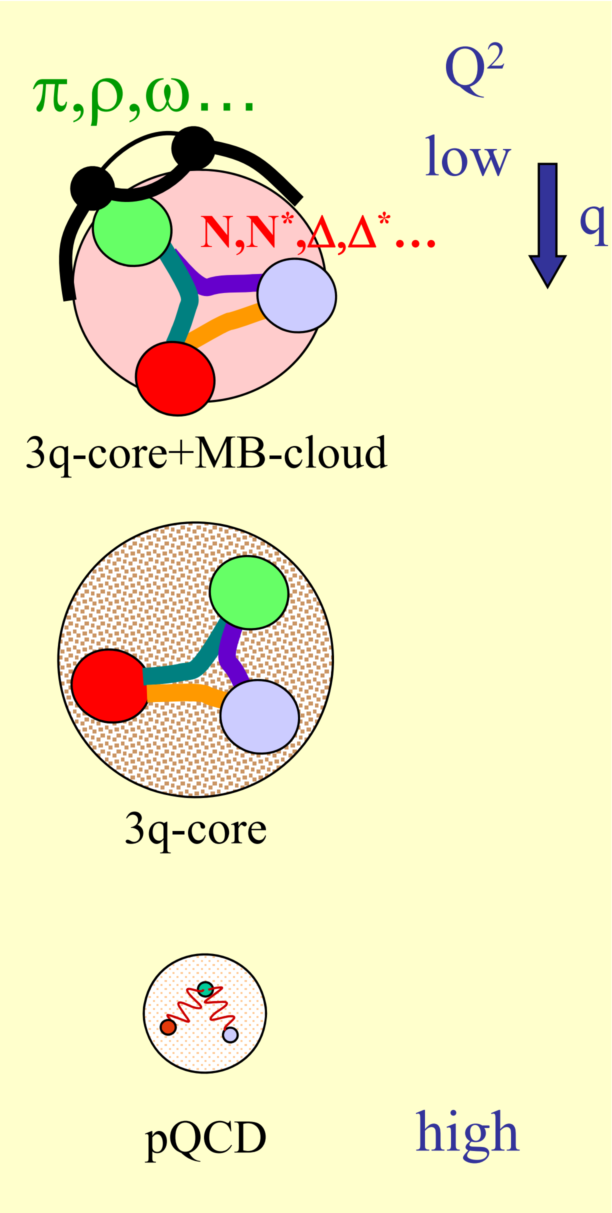


- Process is described by 4 complex, parity conserving amplitudes
- 8 well-chosen measurements are needed to determine amplitude
- For hyperon finals state 16 observables are measured in CLAS ➠ large redundancy in determining the photo-production amplitudes ➠ allows many cross checks and increased accuracy
- 8 observables measured in reactions without recoil polarization

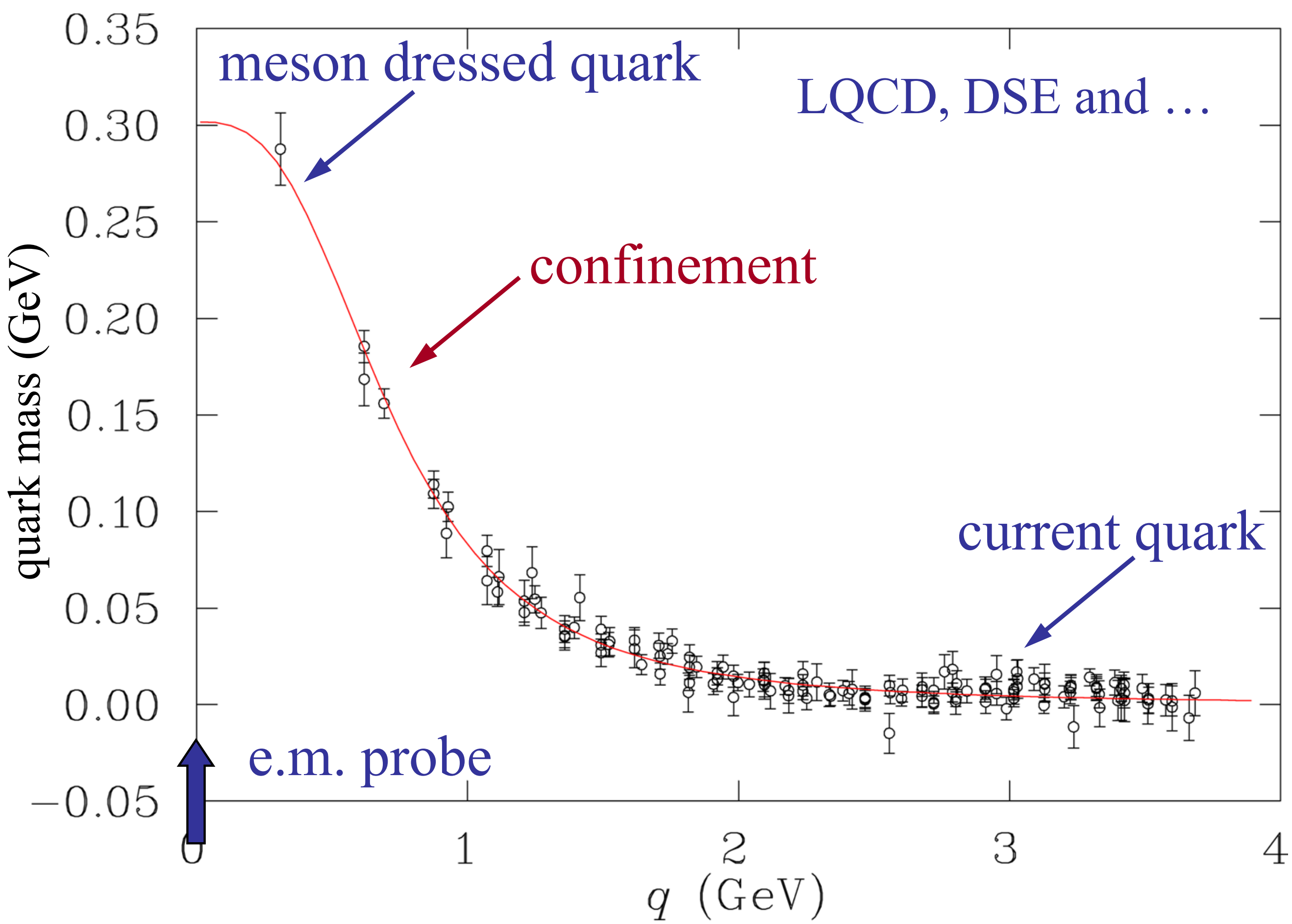
Photon beam		***Target***			***Recoil***			***Target - Recoil***								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

Space-Like Form Factors

Hadron Structure with Electromagnetic Probes

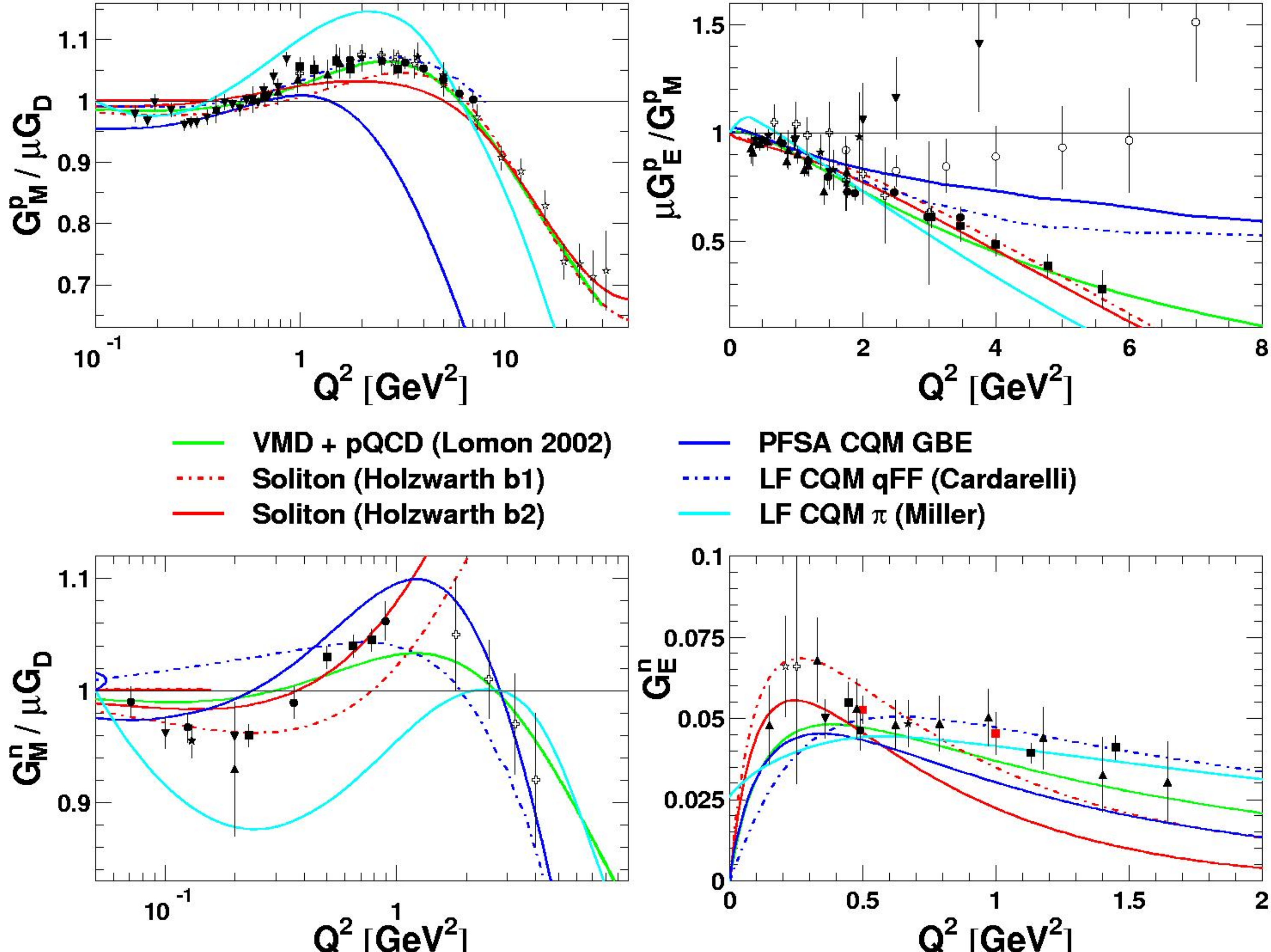


- Study the structure of the nucleon spectrum in the domain where dressed quarks are the major active degree of freedom.
- Explore the formation of excited nucleon states in interactions of dressed quarks and their emergence from QCD.

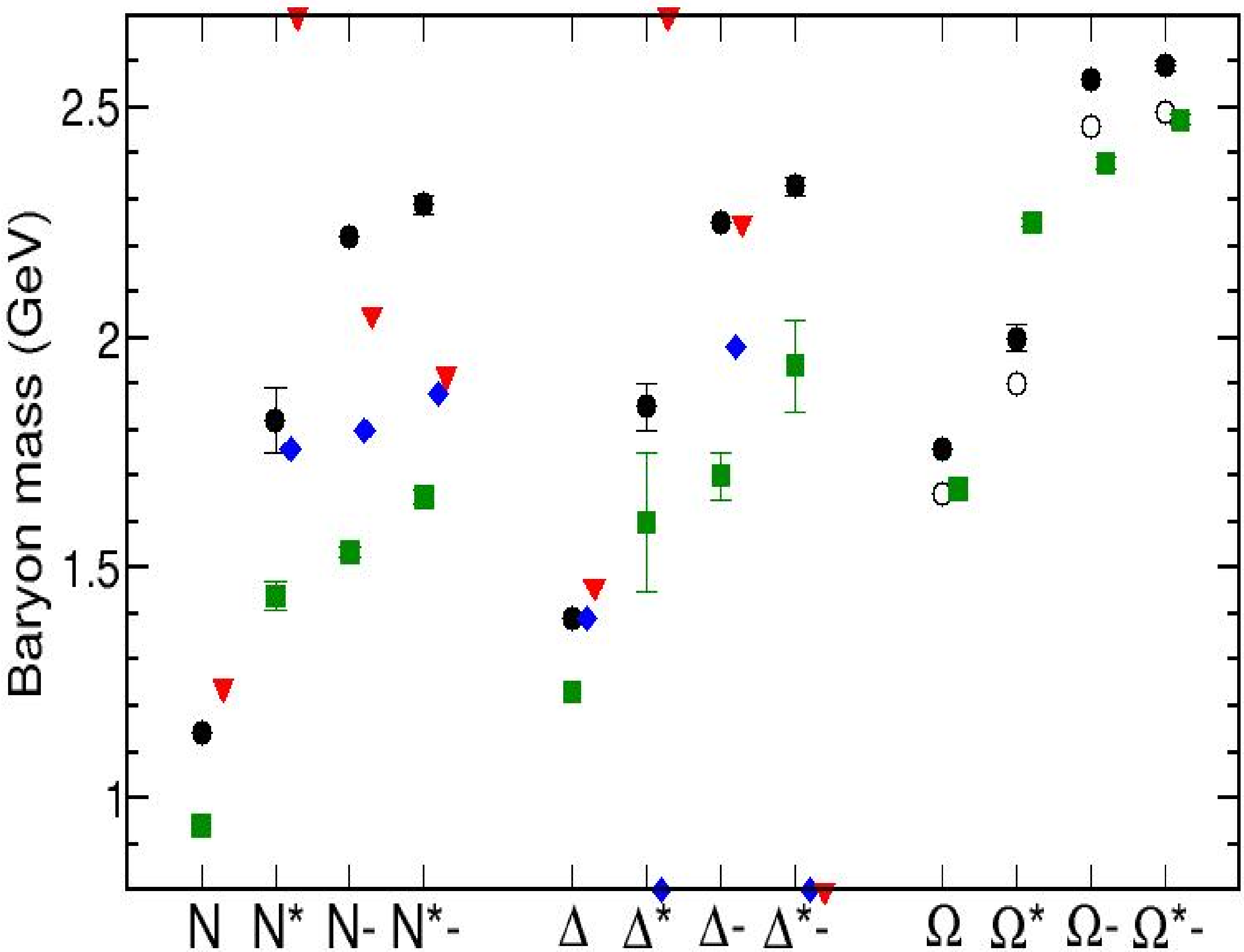


Small Sample of Recent Calculations

J. Arrington



Baryon Spectrum in QCD DSE Calculations

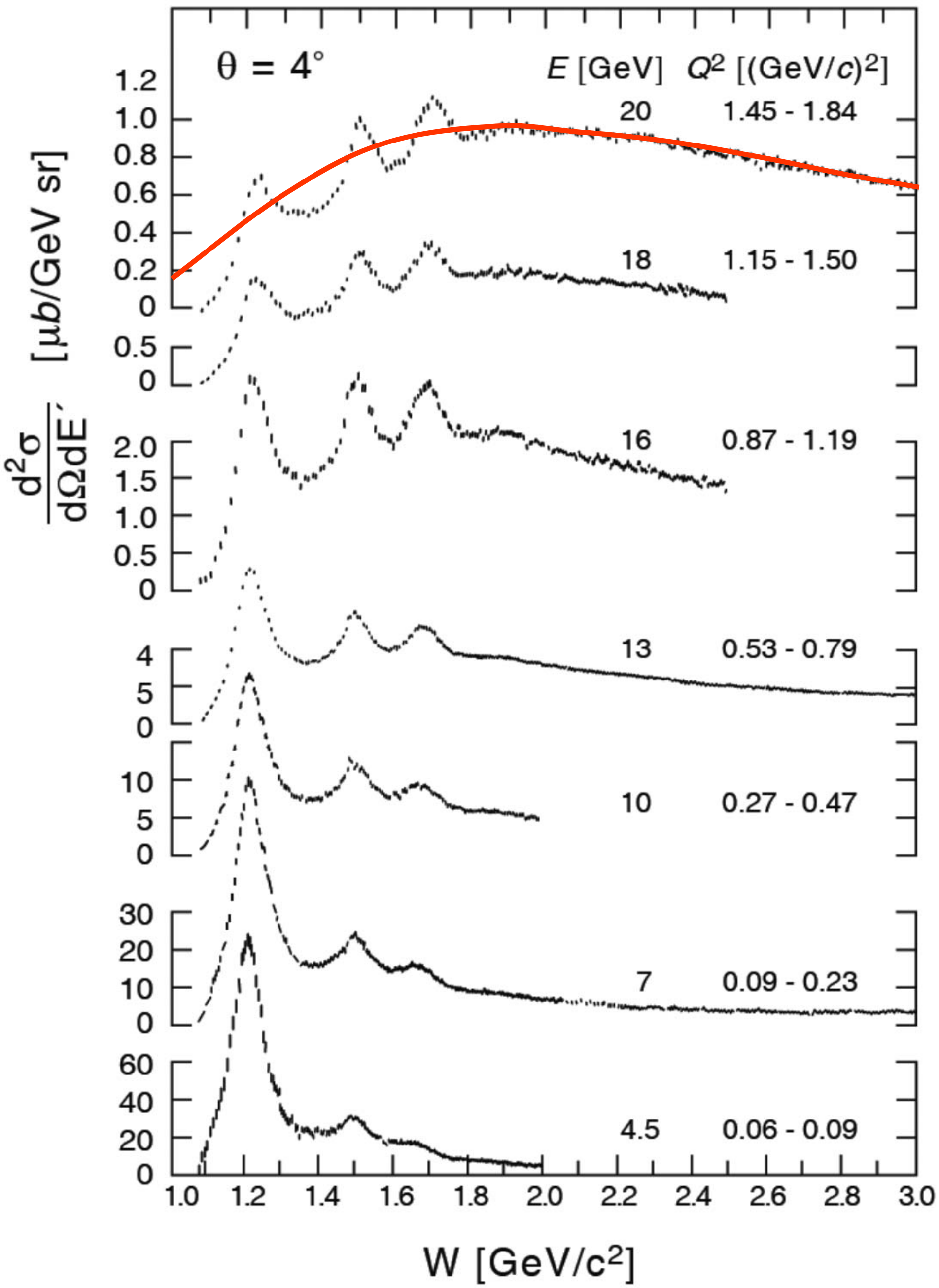


Legend:
Particle Data Group
H.L.L. Roberts *et al.*
EBAC
Jülich

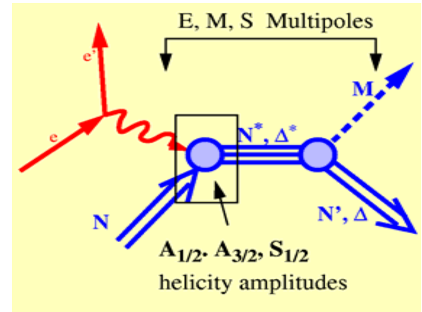
H.L.L. Roberts *et al.*, arXiv:1101.4244 [nucl-th], *Few Body Systems* (2011) pp. 1-25

Space-Like Transition Form Factors

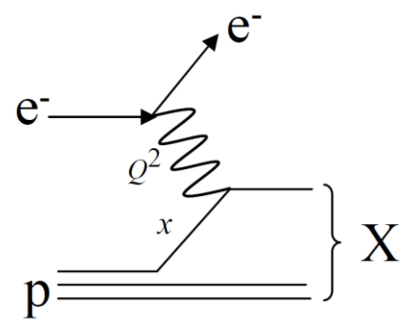
Baryon Excitations and Quasi-Elastic Scattering



hard and confined

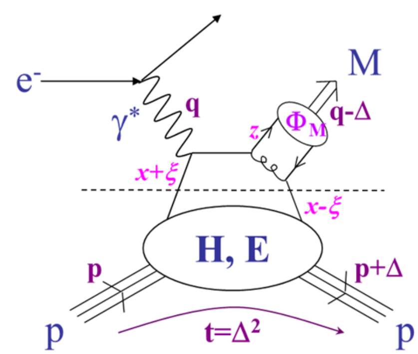


quasi-elastic



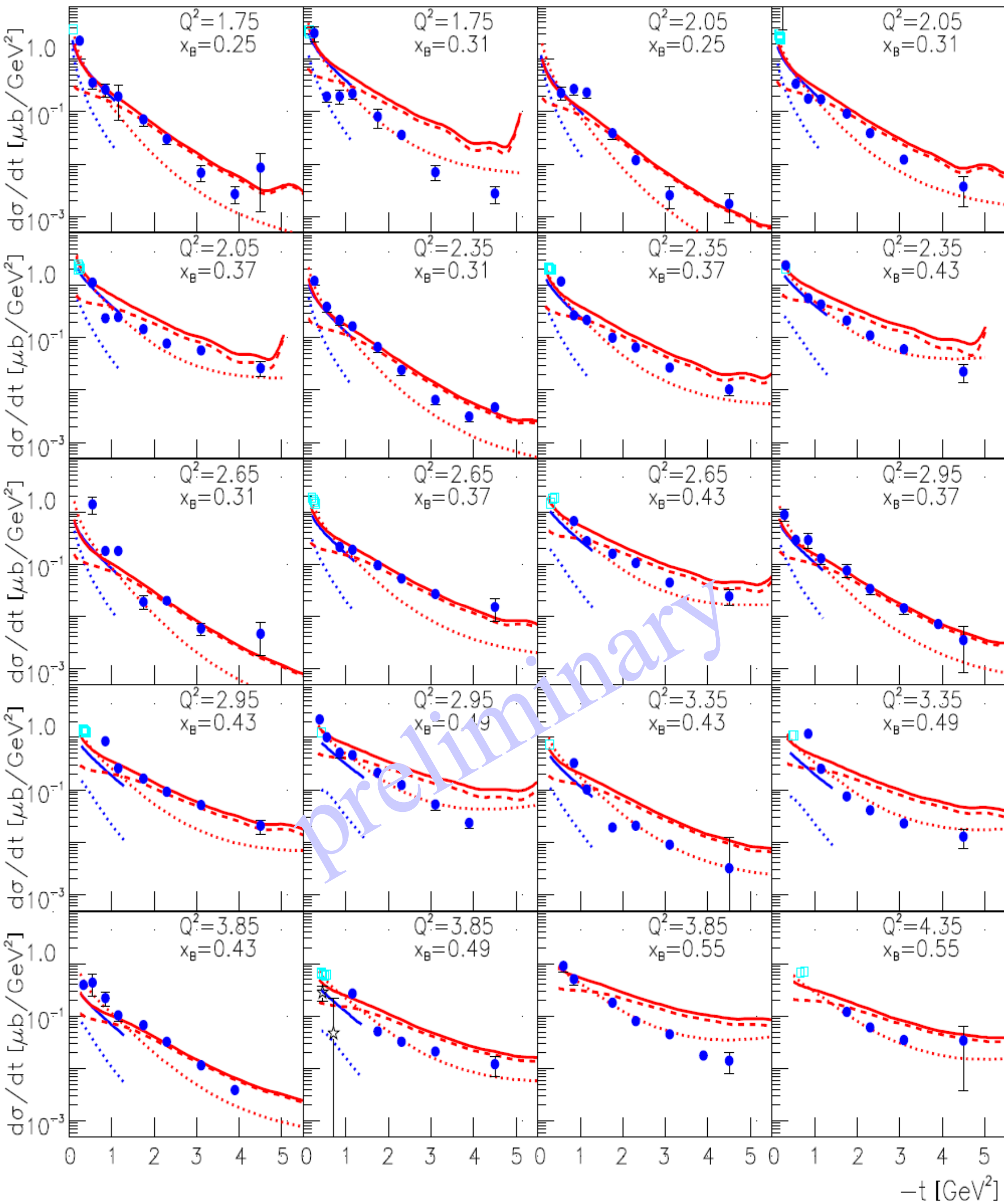
hard

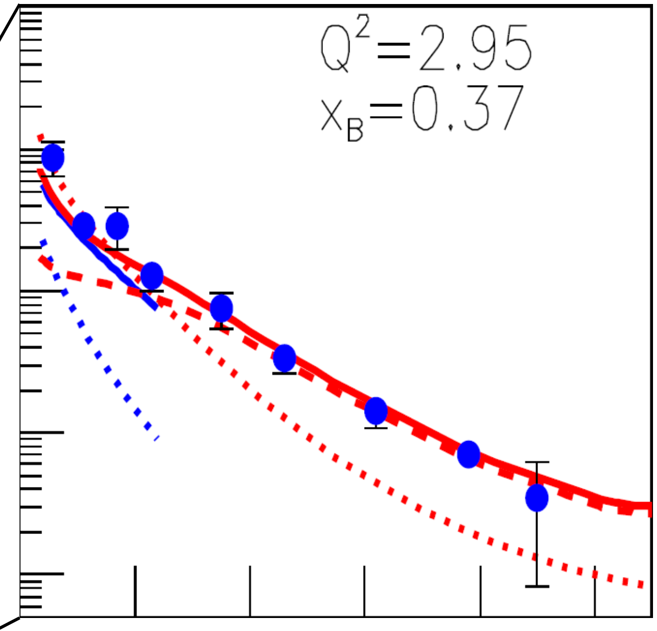
soft



Deep Inelastic Scattering
S. Stein et al., PR **D22** (1975) 1884

Deep exclusive π^+ electroproduction off the proton

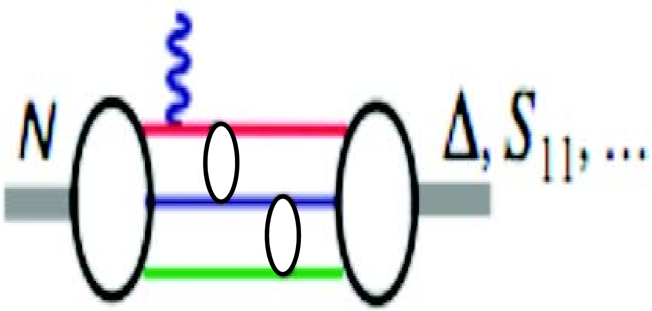




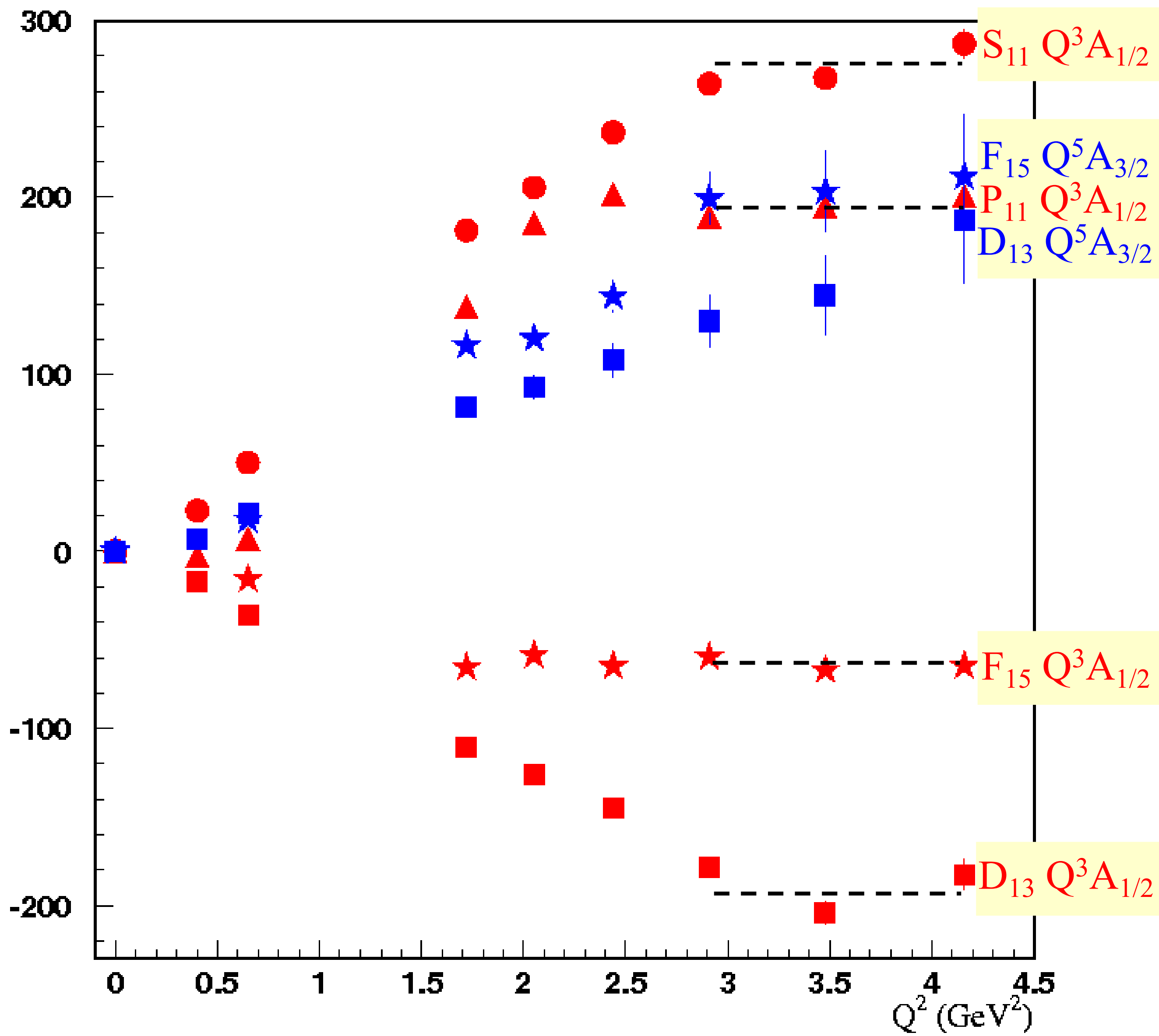
Kijun Park

The red solid ($d\sigma/dt$), dotted ($d\sigma_L/dt$), and dashed ($d\sigma_T/dt$) curves are the calculations from the hadronic model (Regge phenomenology) with (Q^2, t)-dependent form factors at the photon-meson vertices. The blue solid and dotted curves are the calculations of $d\sigma/dt$ and $d\sigma_L/dt$, respectively, of the partonic model (handbag diagrams).

Evidence for the Onset of Scaling?

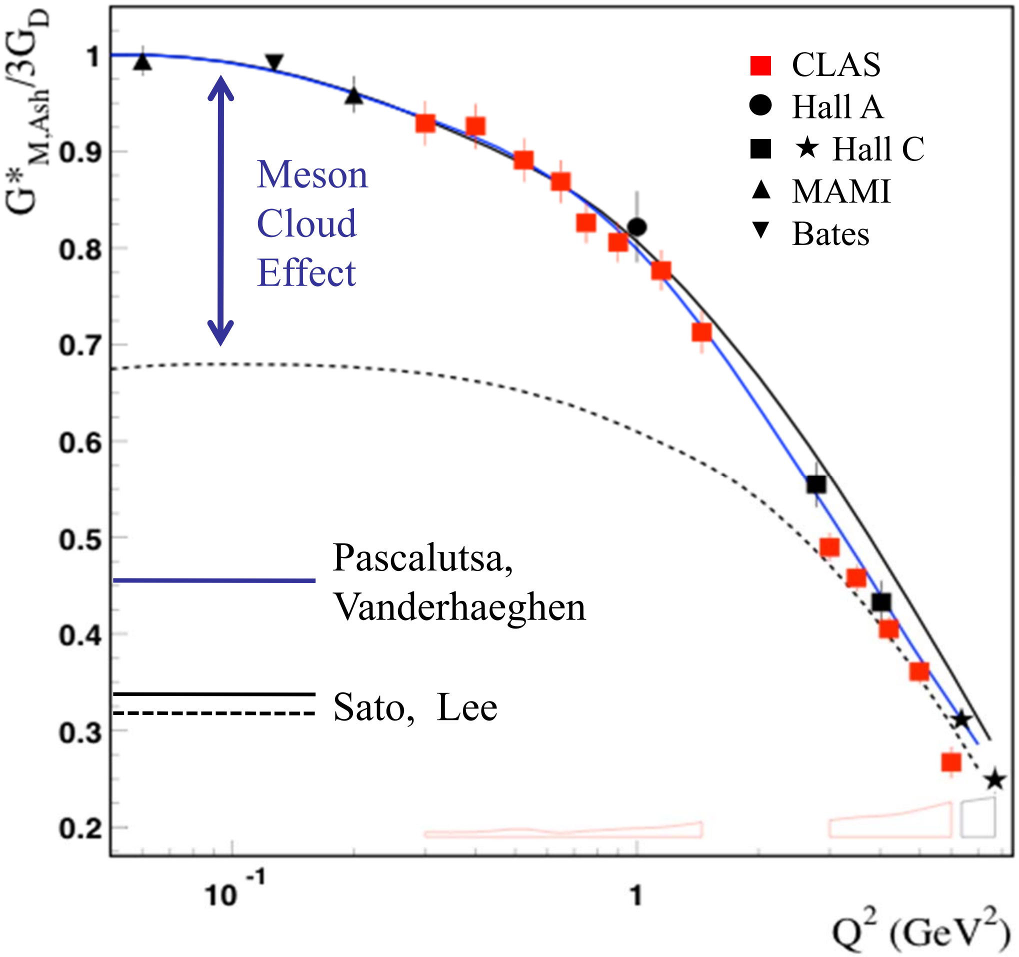


Phys. Rev. C80, 055203 (2009)

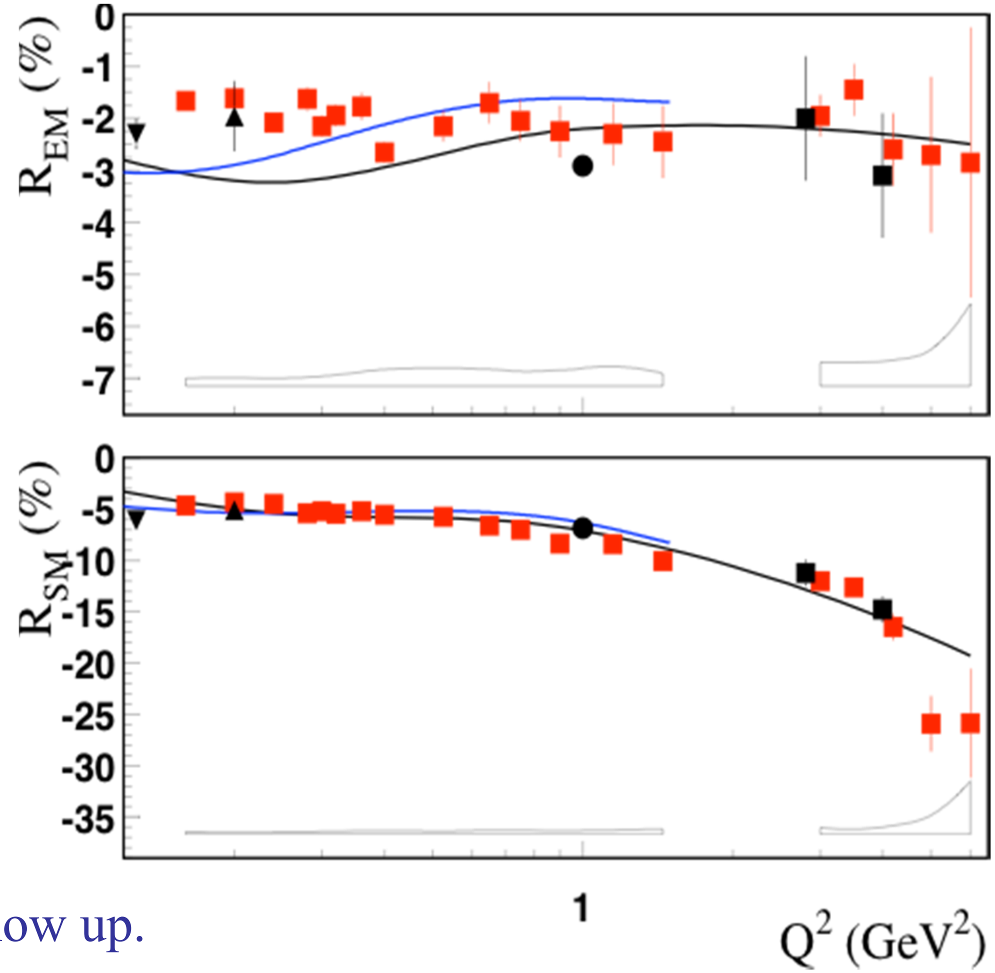


- $A_{1/2} \propto 1/Q^3$
- $A_{3/2} \propto 1/Q^5$
- $G^*_M \propto 1/Q^4$

$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

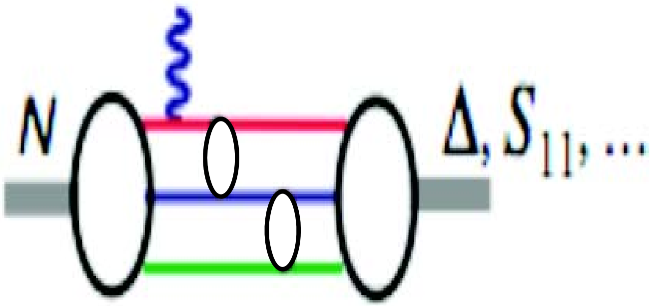


Phys. Rev. Lett. 97, 112003 (2006)



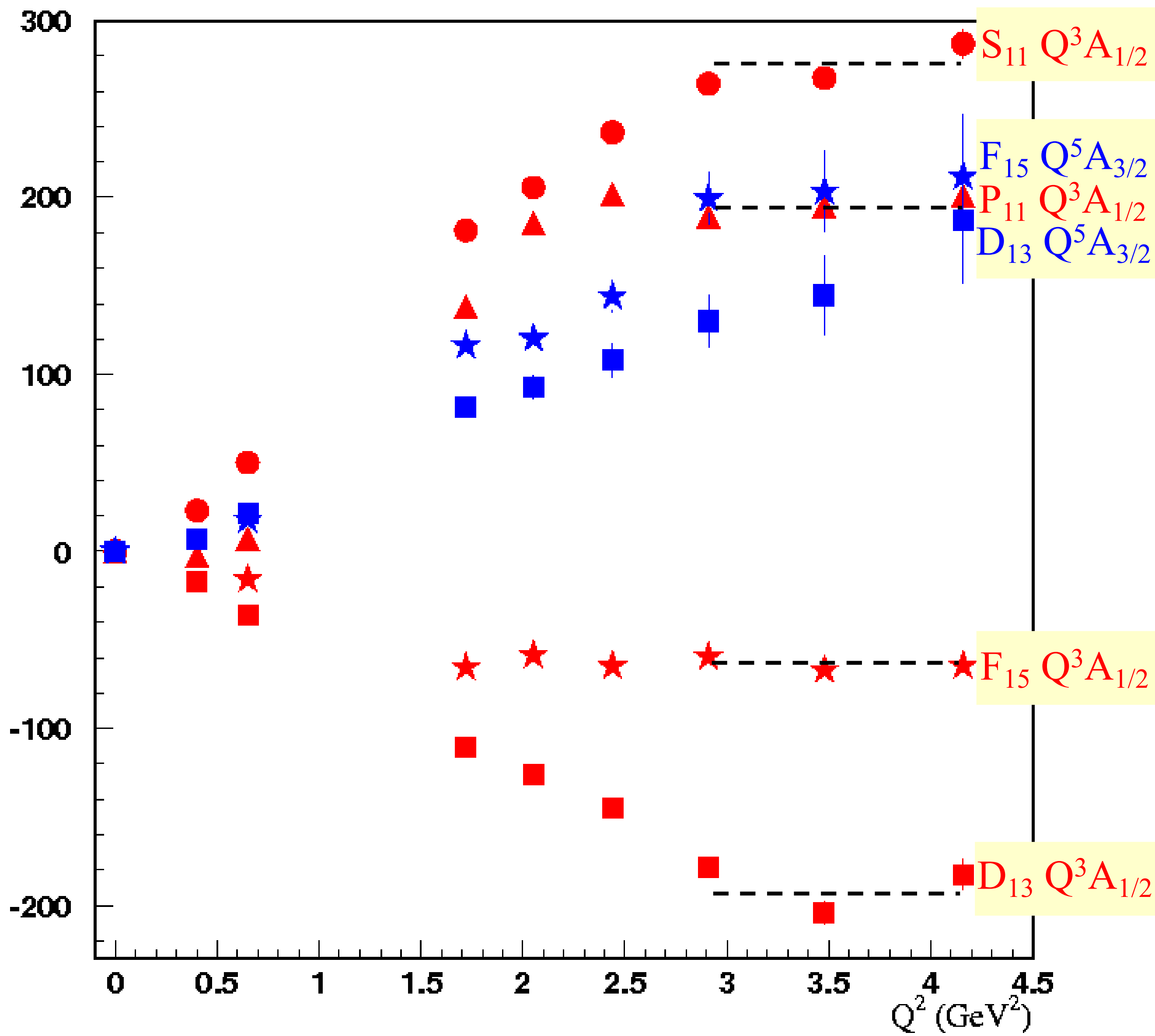
- New trend towards pQCD behavior does not show up.
  - $R_{EM} \rightarrow +1$
  - $G^*_M \rightarrow 1/Q^4$
- CLAS12 can measure G^*_M, R_{EM}, and R_{SM} up to Q^2~12 GeV^2.

Dominance of the Three-Quark Core?

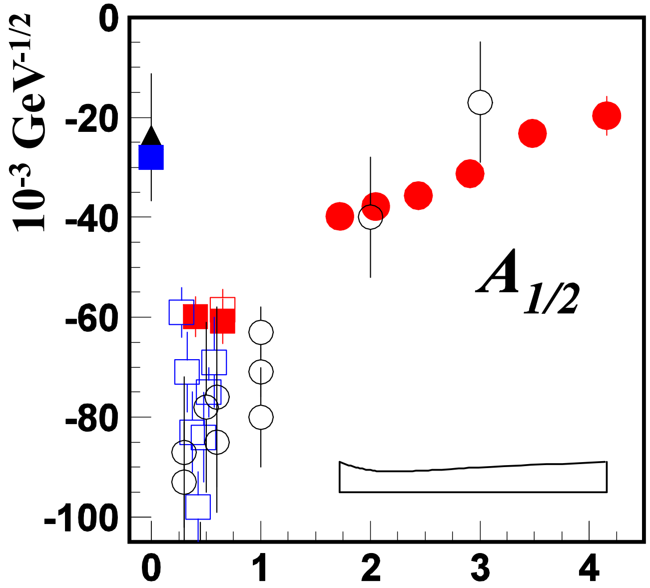


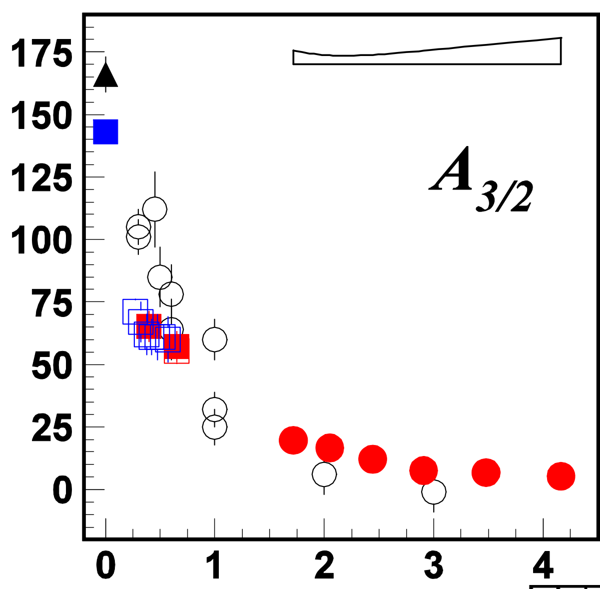
- $A_{1/2}$ α $1/Q^3$
- $A_{3/2}$ α $1/Q^5$

Phys. Rev. C80, 055203 (2009)



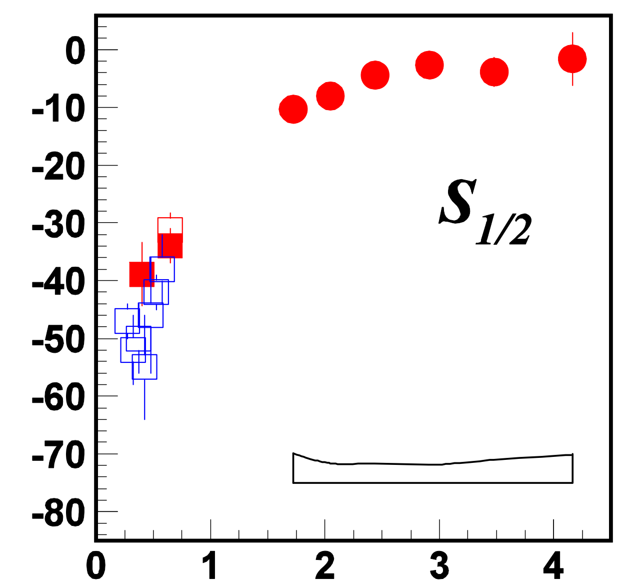
$N(1520)D_{13}$ Helicity Asymmetry

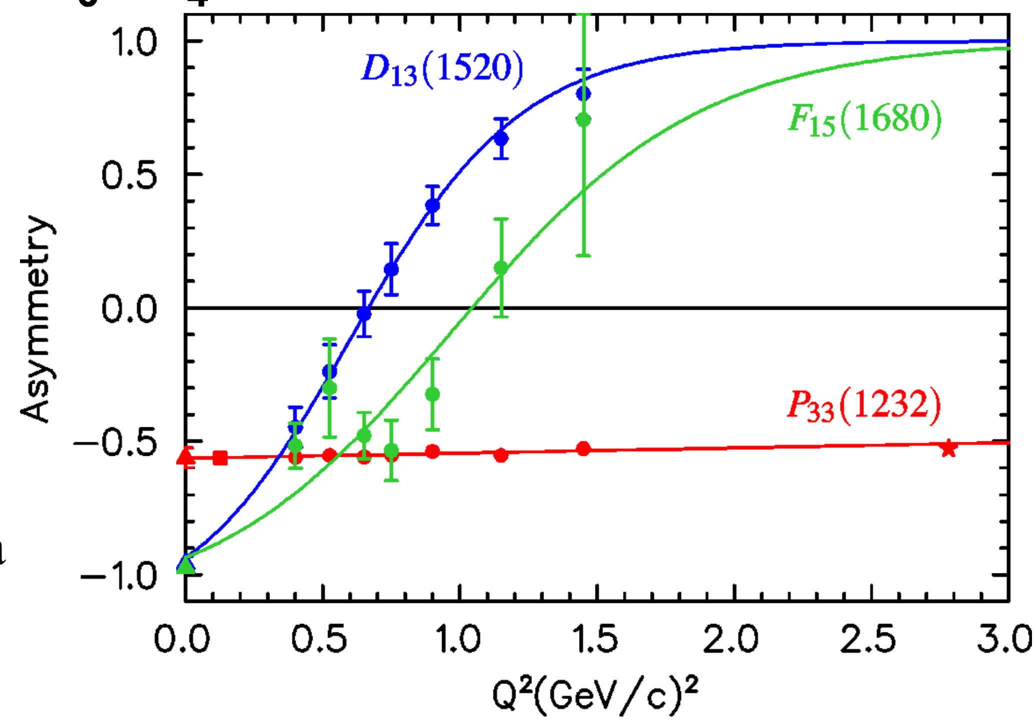




$$A_{hel} = \frac{A_{1/2}^2 - A_{3/2}^2}{A_{1/2}^2 + A_{3/2}^2}$$

L. Tiator





○ world data

▲ PDG estimation ● ■ Nπ (UIM, DR)

$\gamma_v NN^*$ Extraction

Phenomenological Analyses

- Unitary Isobar Model (UIM) approach in single pseudoscalar meson production
- Fixed-*t* Dispersion Relations (DR)
- Isobar Model for Nππ final state (JM)

see White Paper Sec. VII

- Coupled-Channel Approach (EBAC)

see White Paper Sec. VIII

Phenomenological Analyses in Single Meson Production

Unitary Isobar Model (UIM)

Nonresonant amplitudes: gauge invariant Born terms consisting of *t*-channel exchanges and *s*- / *u*-channel nucleon terms, reggeized at high W.

πN rescattering processes in the final state are taken into account in a K-matrix approximation.

Fixed-*t* Dispersion Relations (DR)

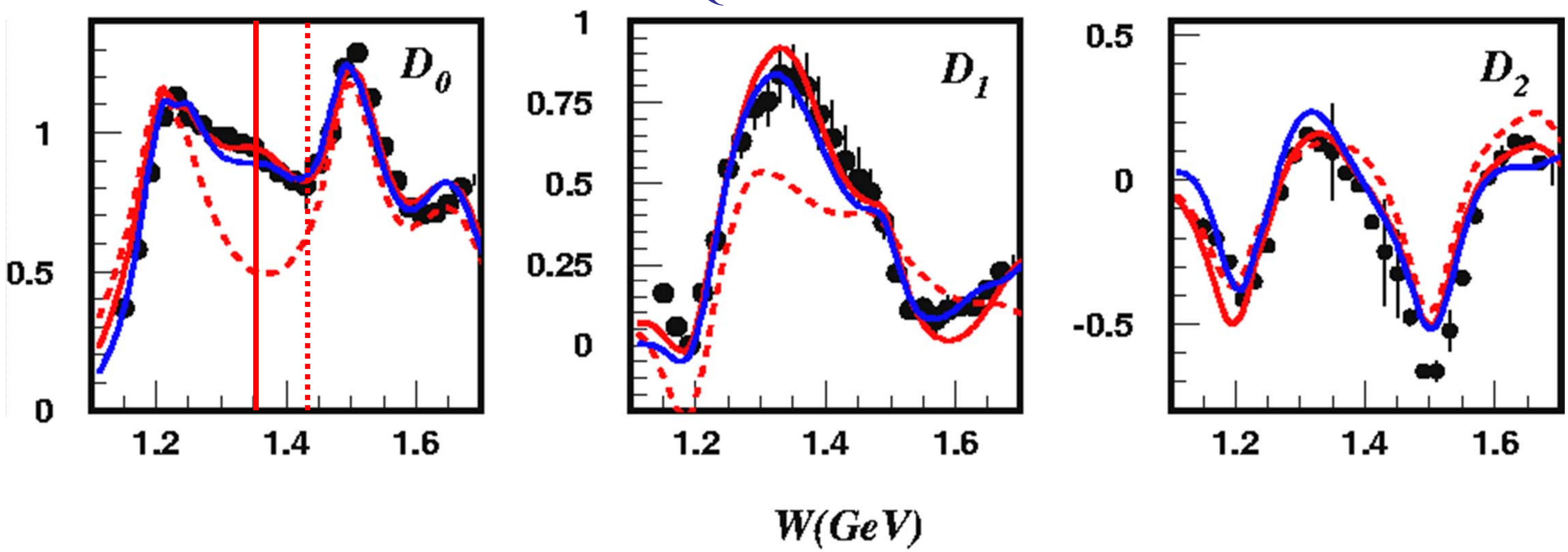
Relates the real and the imaginary parts of the six invariant amplitudes in a model-independent way. The imaginary parts are dominated by resonance contributions.

see White Paper Sec. VII

Legendre Moments of Unpolarized Structure Functions

K. Park *et al.* (CLAS), Phys. Rev. C77, 015208 (2008)

Q^2=2.05GeV^2



$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$

I. Aznauryan —— DR fit

I. Aznauryan - - - DR fit w/o P_{11}

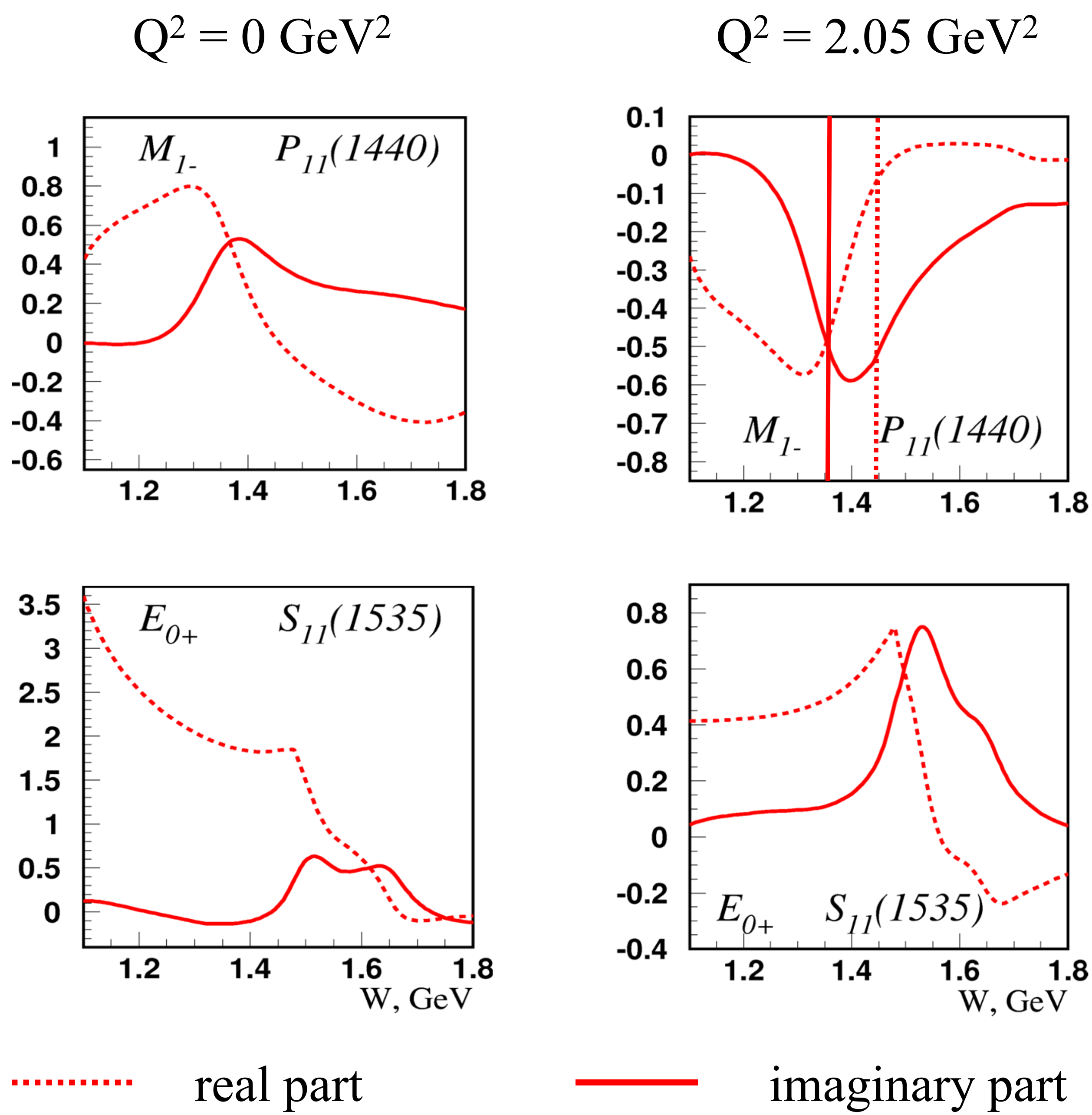
I. Aznauryan —— UIM fit

Two conceptually different approaches DR and UIM are consistent. CLAS data provide rigid constraints for checking validity of the approaches.

Energy-Dependence of π^+ Multipoles for P_{11}, S_{11}

The study of some baryon resonances becomes easier at higher Q^2.

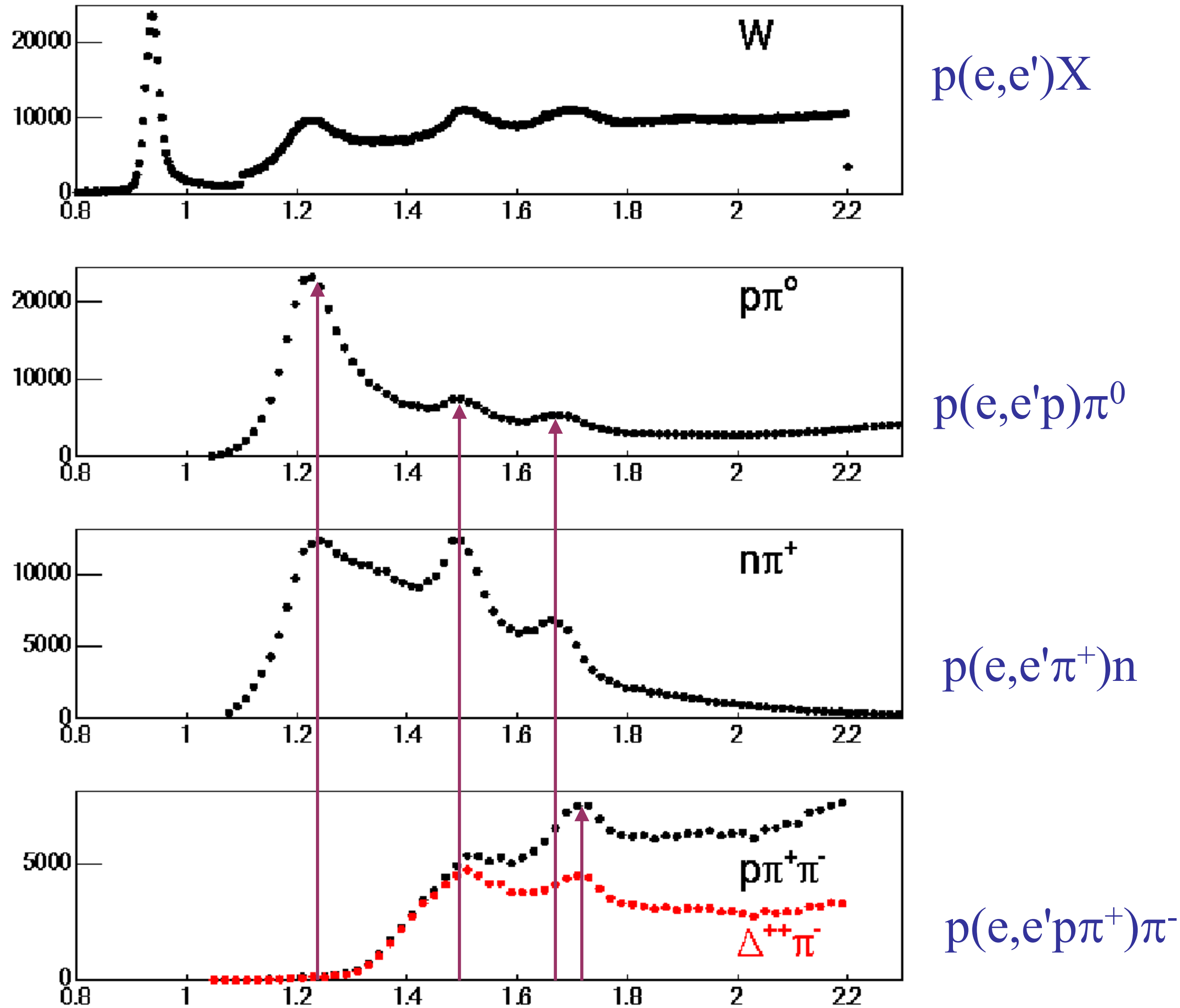
Cross sections are extracted in the $p\pi^0$, $p\pi^+$, $p\eta$, and more are currently under analysis in the $p\omega$ and $p\pi^-$ final states.



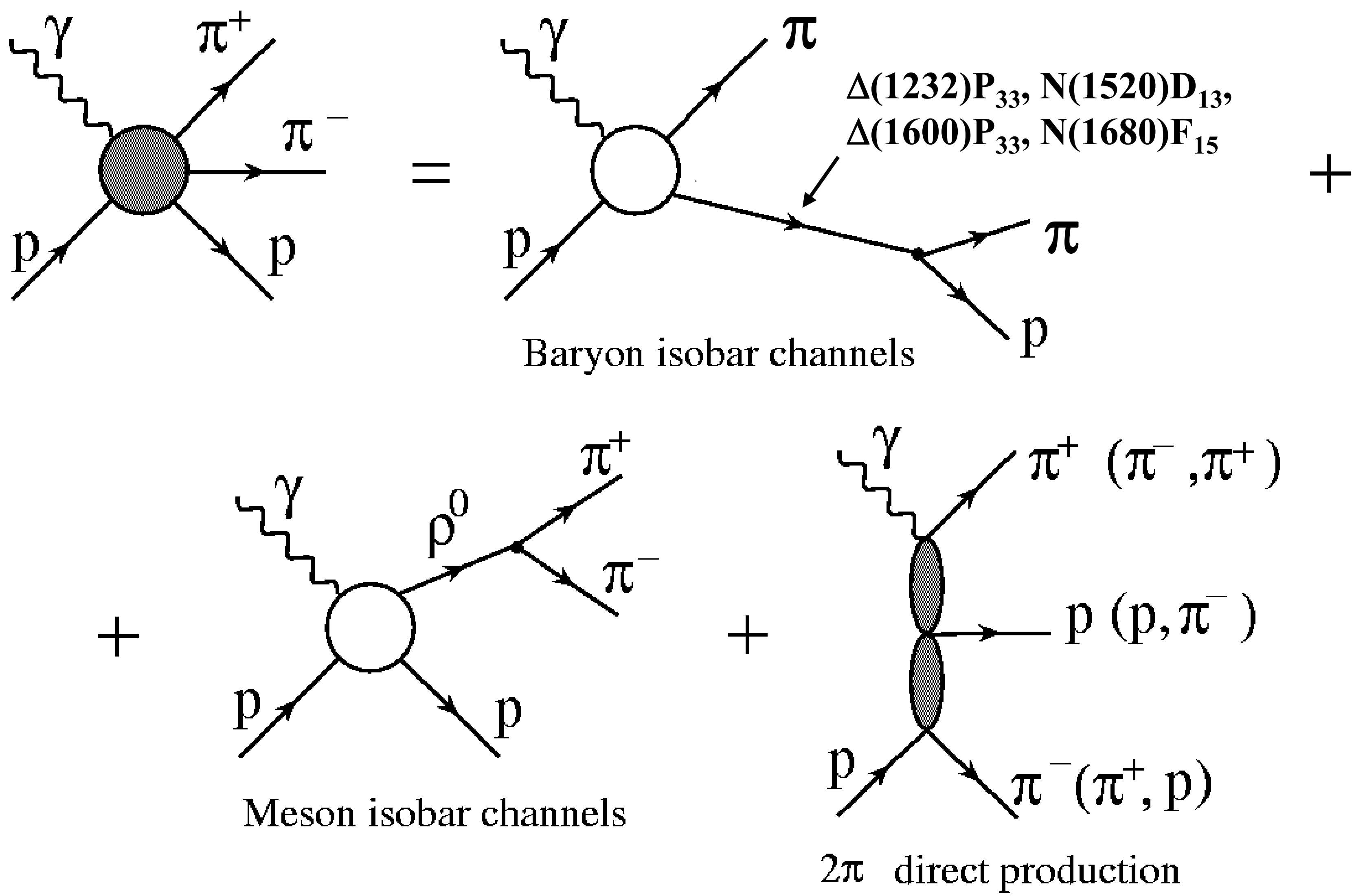
Nucleon Resonances in Nπ and Nππ Electroproduction

- Nππ channel is sensitive to N*s heavier than 1.4 GeV
- Provides information that is complementary to the Nπ channel
- Many higher-lying N*s decay preferentially into Nππ final states

$Q^2 < 4.0\,GeV^2$



JM Model Analysis of the $p\pi^+\pi^-$ Electroproduction

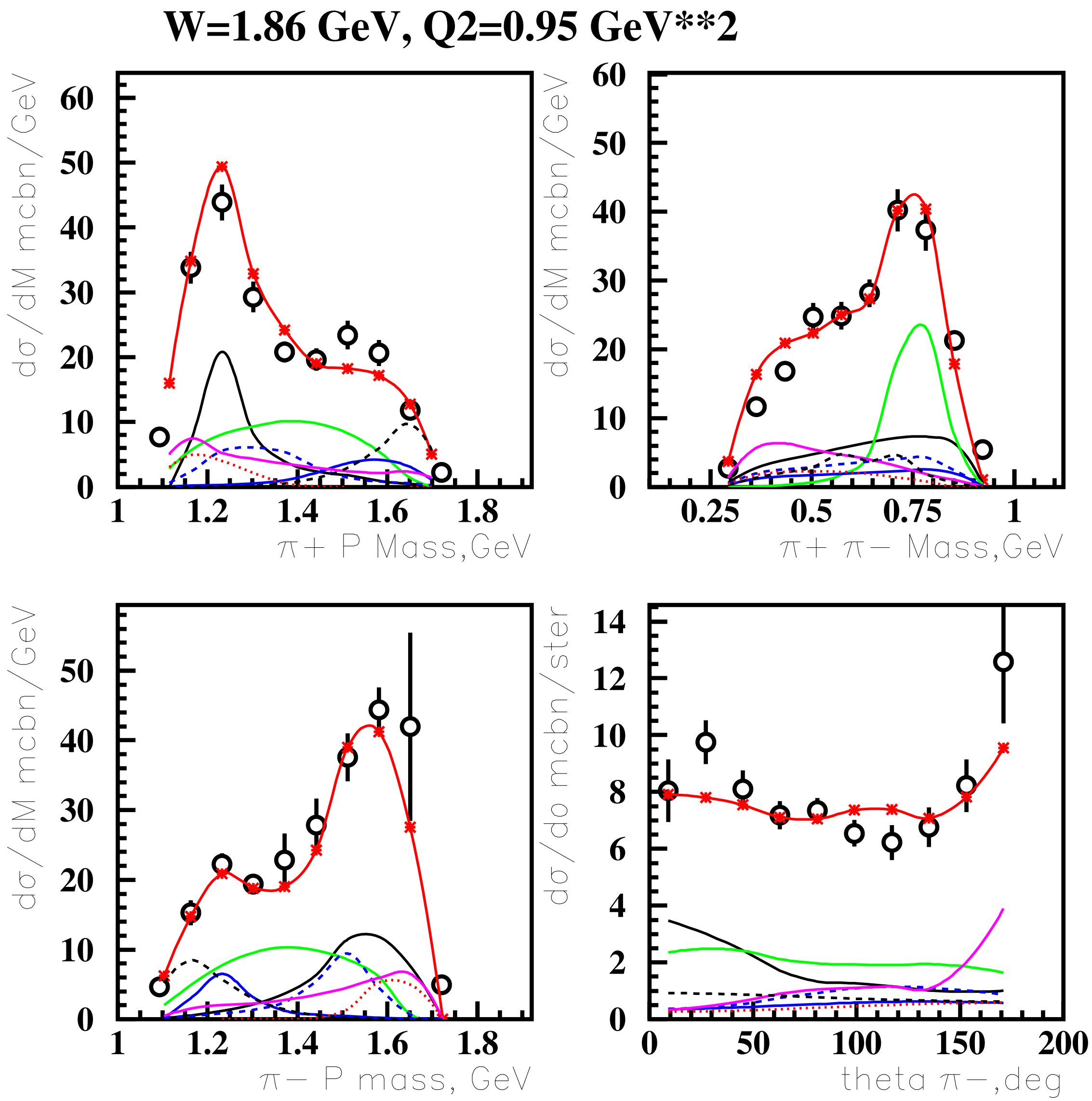


see White Paper Sec. VII

Contributing Mechanisms to $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

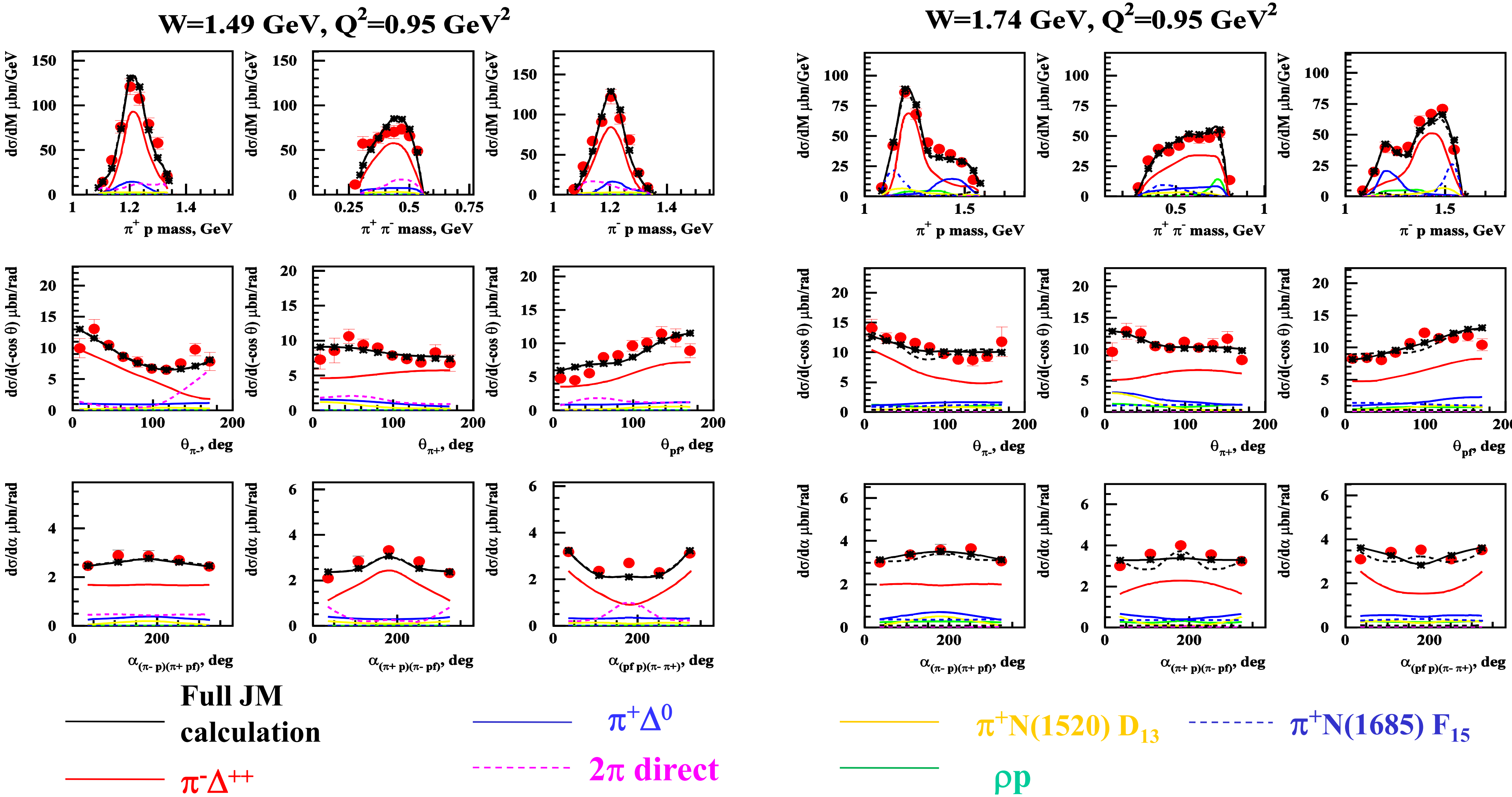
Isobar Model JM05

- Full calculations
- $\gamma p \rightarrow \pi^- \Delta^{++}$
- $\gamma p \rightarrow \pi^+ \Delta^0$
- $\gamma p \rightarrow \pi^+ D_{13}(1520)$
- $\gamma p \rightarrow \rho p$
- $\gamma p \rightarrow \pi^- \Delta^{++}(1600)$
- $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$
- direct 2π production



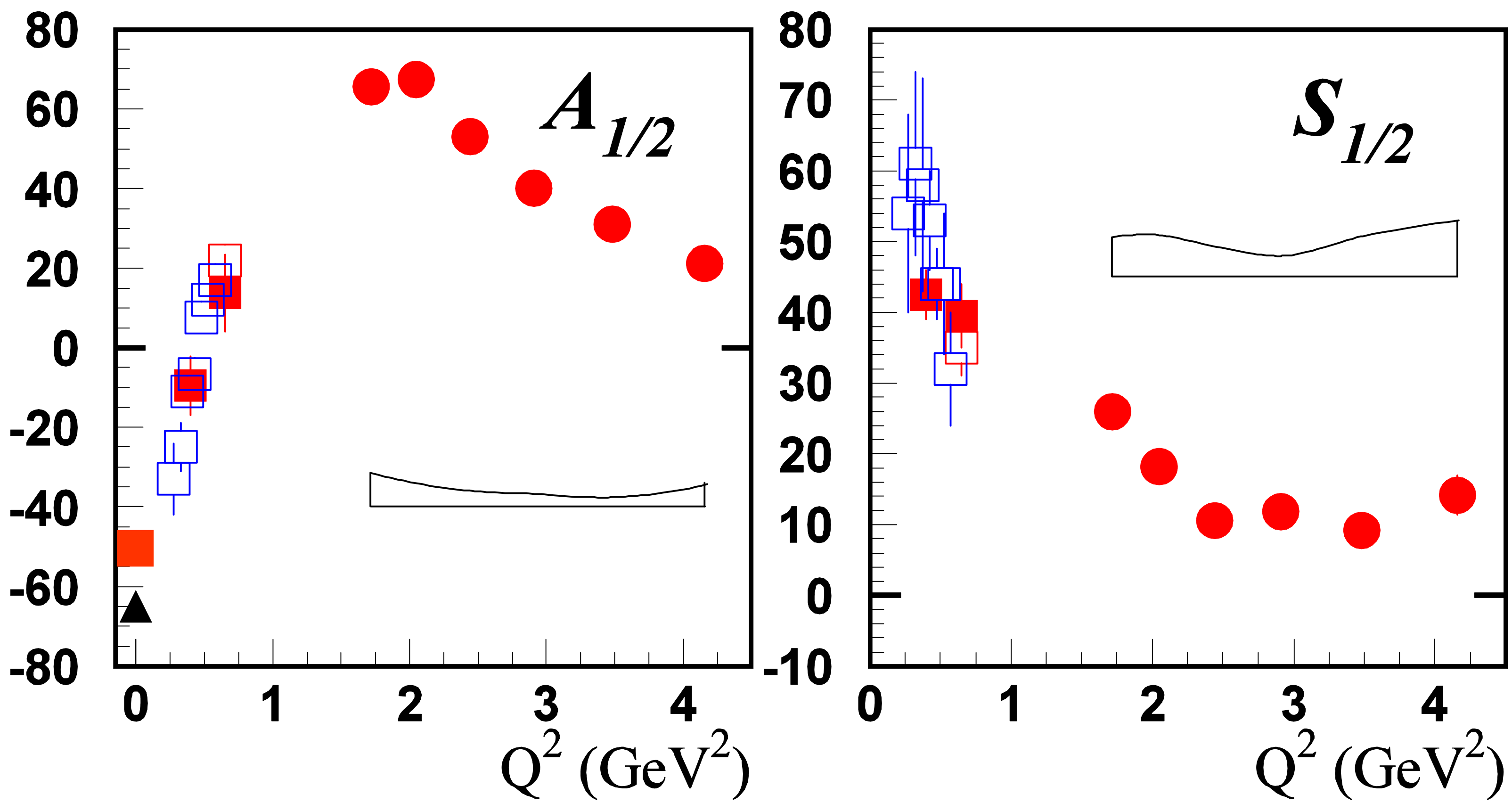
➢ The combined fit of nine single differential cross sections allowed to establish all significant mechanisms.

JM Mechanisms as Determined by the CLAS 2π Data



Each production mechanism contributes to all nine single differential cross sections in a unique way. Hence a successful description of all nine observables allows us to check and to establish the dynamics of all essential contributing mechanisms.

Electrocouplings of N(1440)P_{11} from CLAS Data

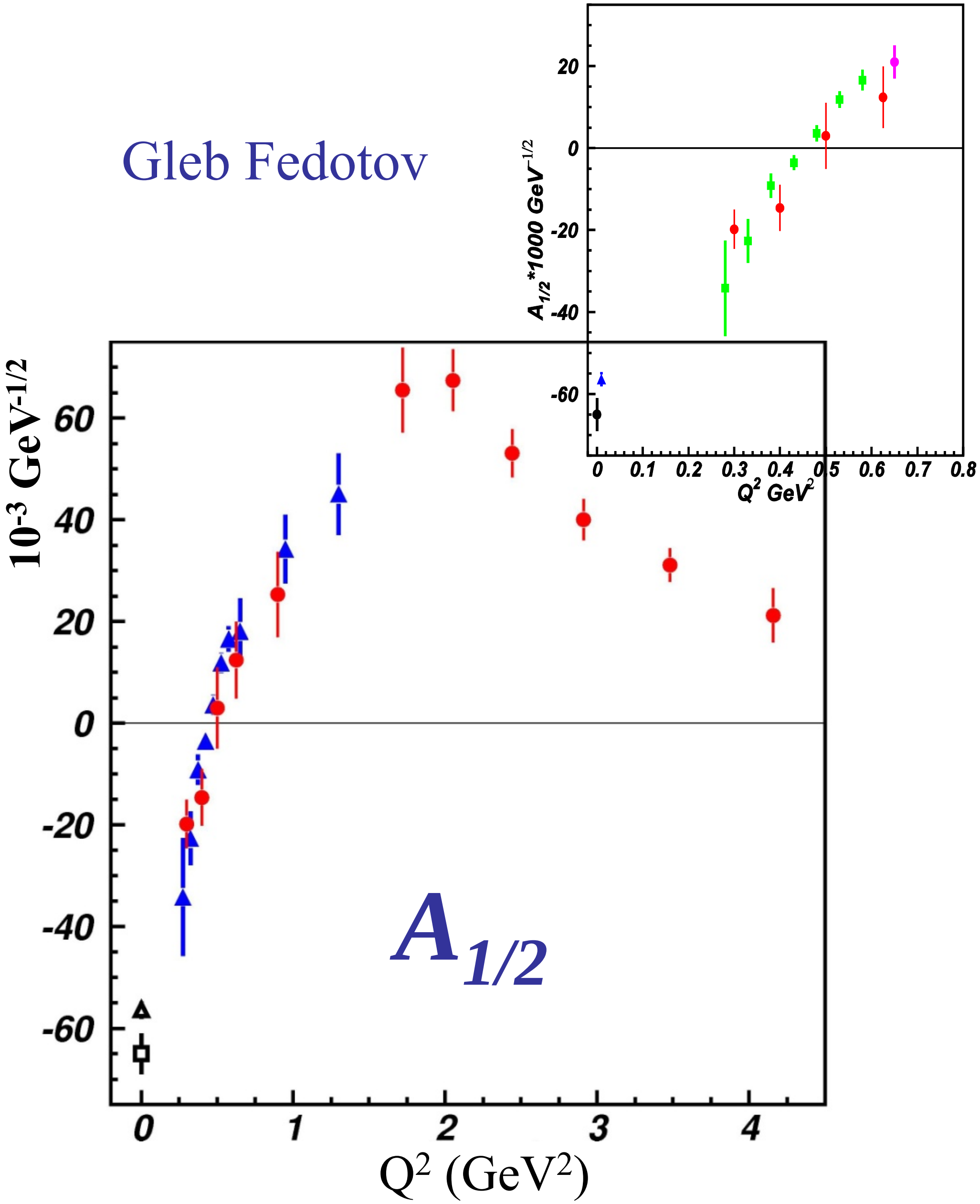


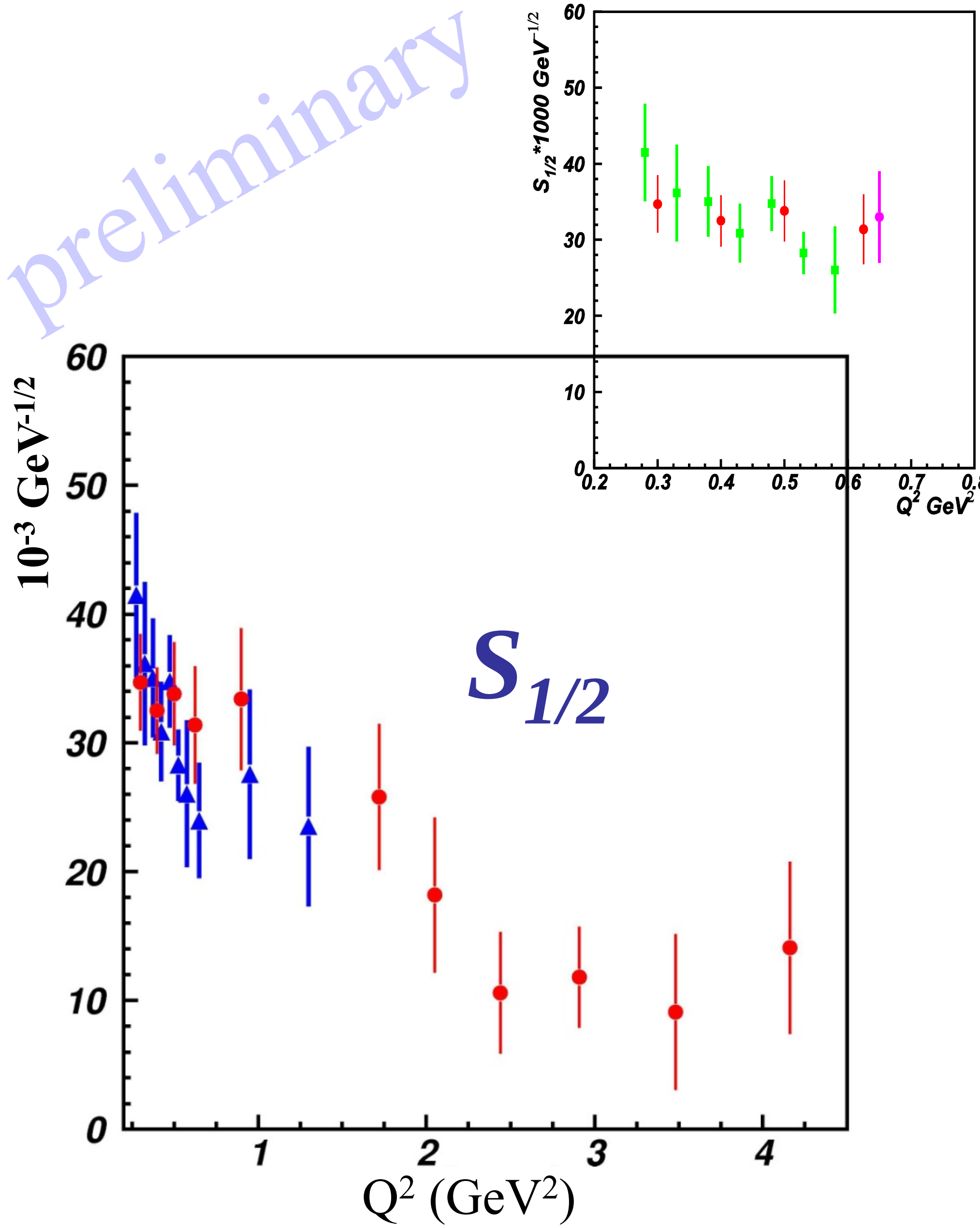
▲ PDG estimation ●■ Nπ (UIM, DR) □ Nπ, Nππ combined analysis □ Nππ (JM)

The good agreement on extracting the N* electrocouplings between the two exclusive channels (1π/2π) – having fundamentally different mechanisms for the nonresonant background – provides evidence for the reliable extraction of N* electrocouplings.

Most recent Electrocouplings of N(1440)P_{11}

Gleb Fedotov

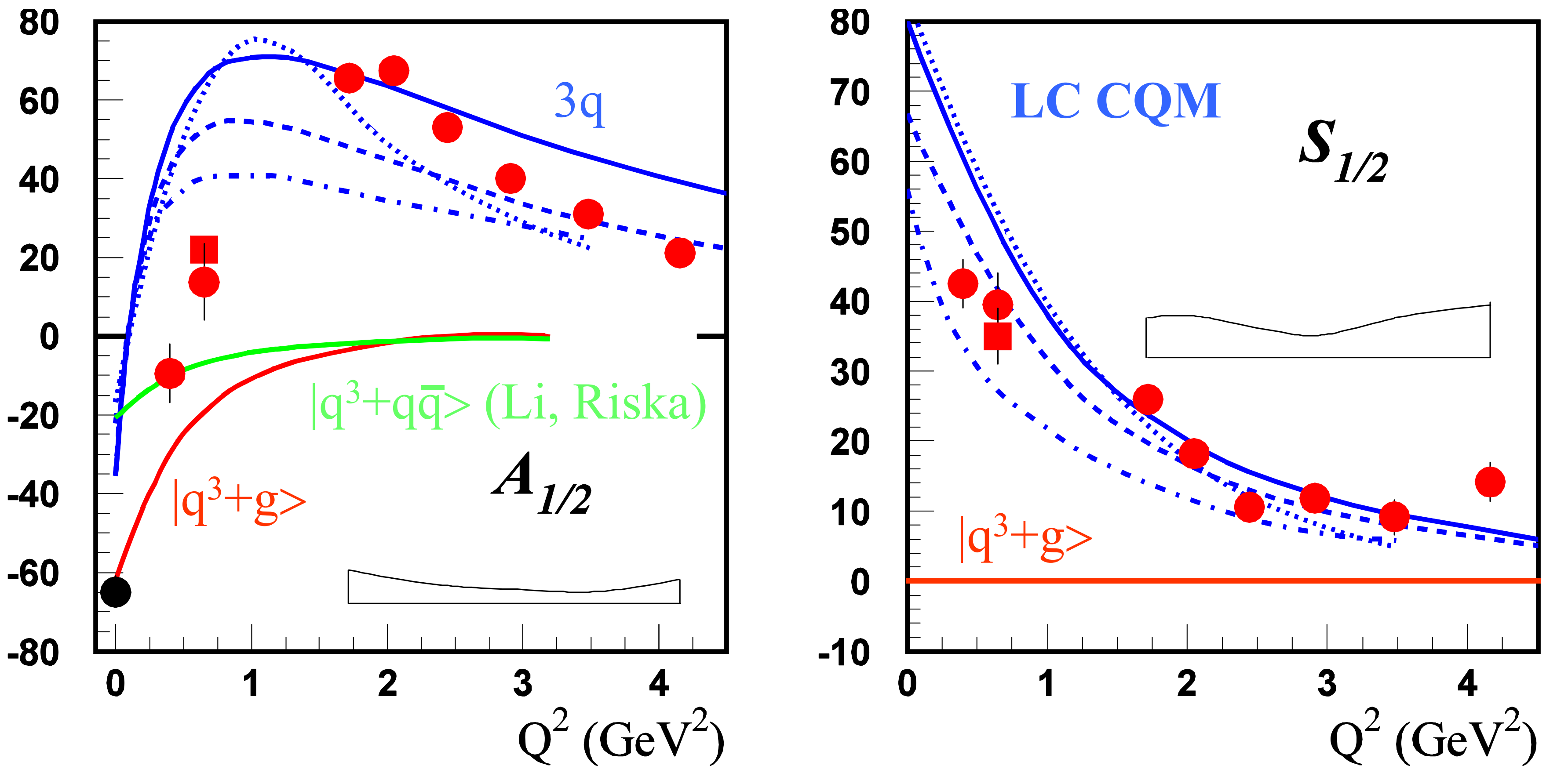




… and beam-helicity dependent 2π cross sections are currently under analysis.

QCD-Based Models and Theory?

Constituent Quark Models (CQM)



N(1440)P_{11}: ● PDG value ● Nπ ■ Nπ, Nππ combined analysis

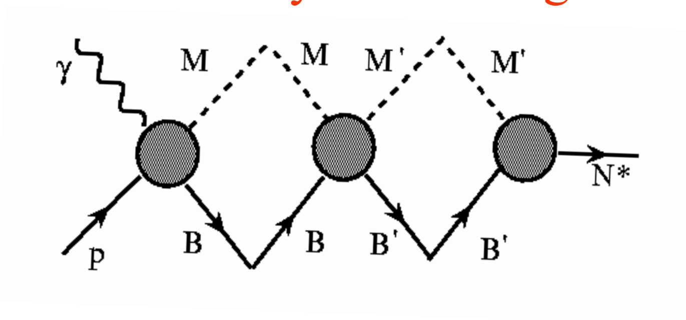
Relativistic CQM are **currently** the only available tool to study the electrocouplings for the majority of excited proton states.

This activity represent part of the commitment of the Yerevan Physics Institute, the University of Genova, INFN-Genova, and the Beijing IHEP groups to refine the model further, e.g., by including qq̄ components.

see White Paper Sec. VI

Progress in Experiment and Phenomenology

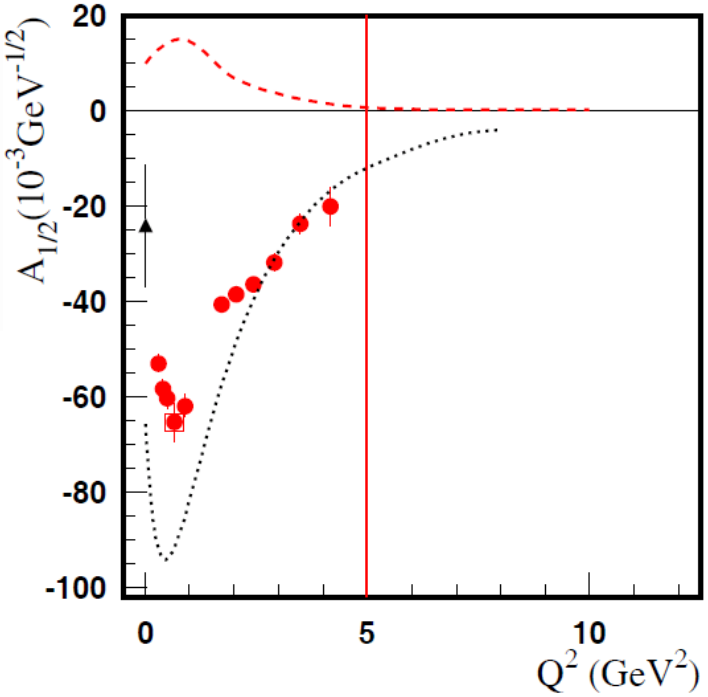
Meson-Baryon Dressing



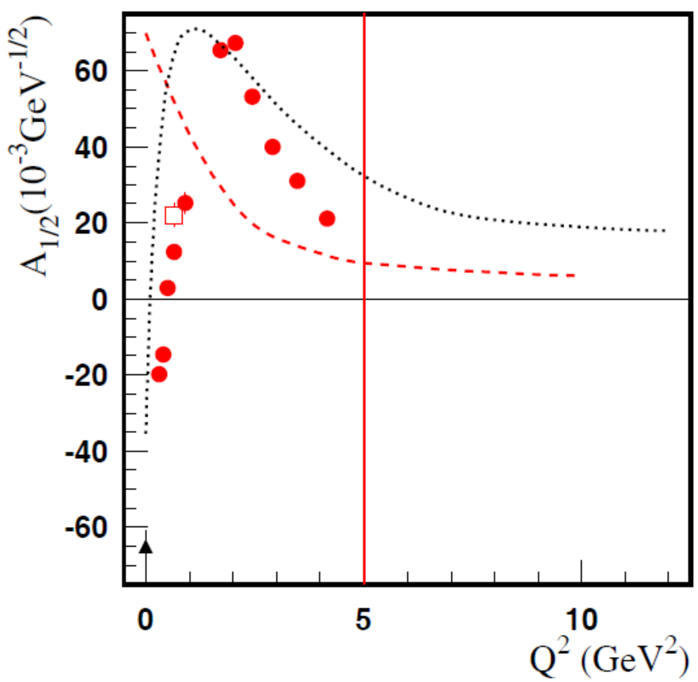
absolute meson-baryon cloud amplitudes (EBAC)

quark core contributions (constituent quark models)

$D_{13}(1520)$



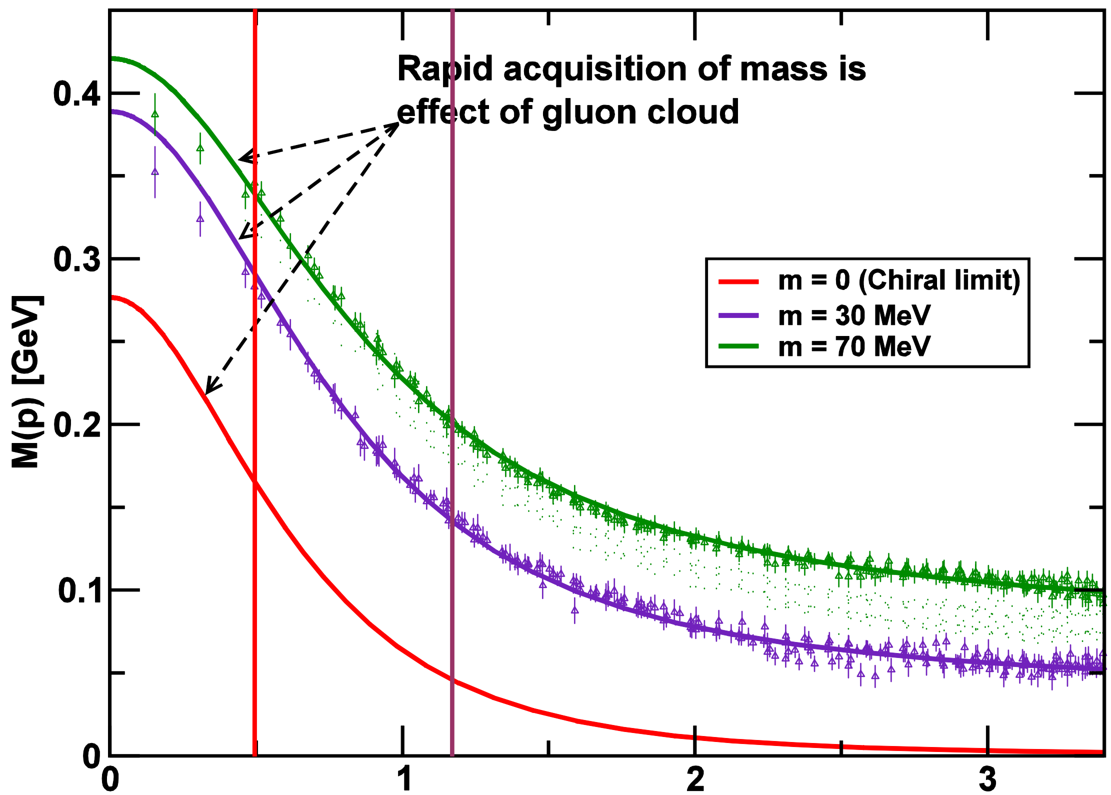
$P_{11}(1440)$



CLAS: Nπ and Nπ/Nππ combined (Phys. Rev. C80, 055203, 2009)

- Resonance structures can be described in terms of an internal quark core and a surrounding meson-baryon cloud whose relative contribution decreases with increasing Q^2.
- Data on $\gamma_v NN^*$ electrocouplings from this experiment ($Q^2 > 5$ GeV^2) will afford for the first time direct access to the non-perturbative strong interaction among dressed quarks, their emergence from QCD, and the subsequent N* formation.

Dynamical Mass of Light Dressed Quarks



$Q^2 = 2.75\ GeV^2$ p [GeV] per dressed quark

DSE and LQCD predict the dynamical generation of the momentum dependent dressed quark mass that comes from the gluon dressing of the current quark propagator.

These dynamical contributions account for more than 98% of the dressed light quark mass.

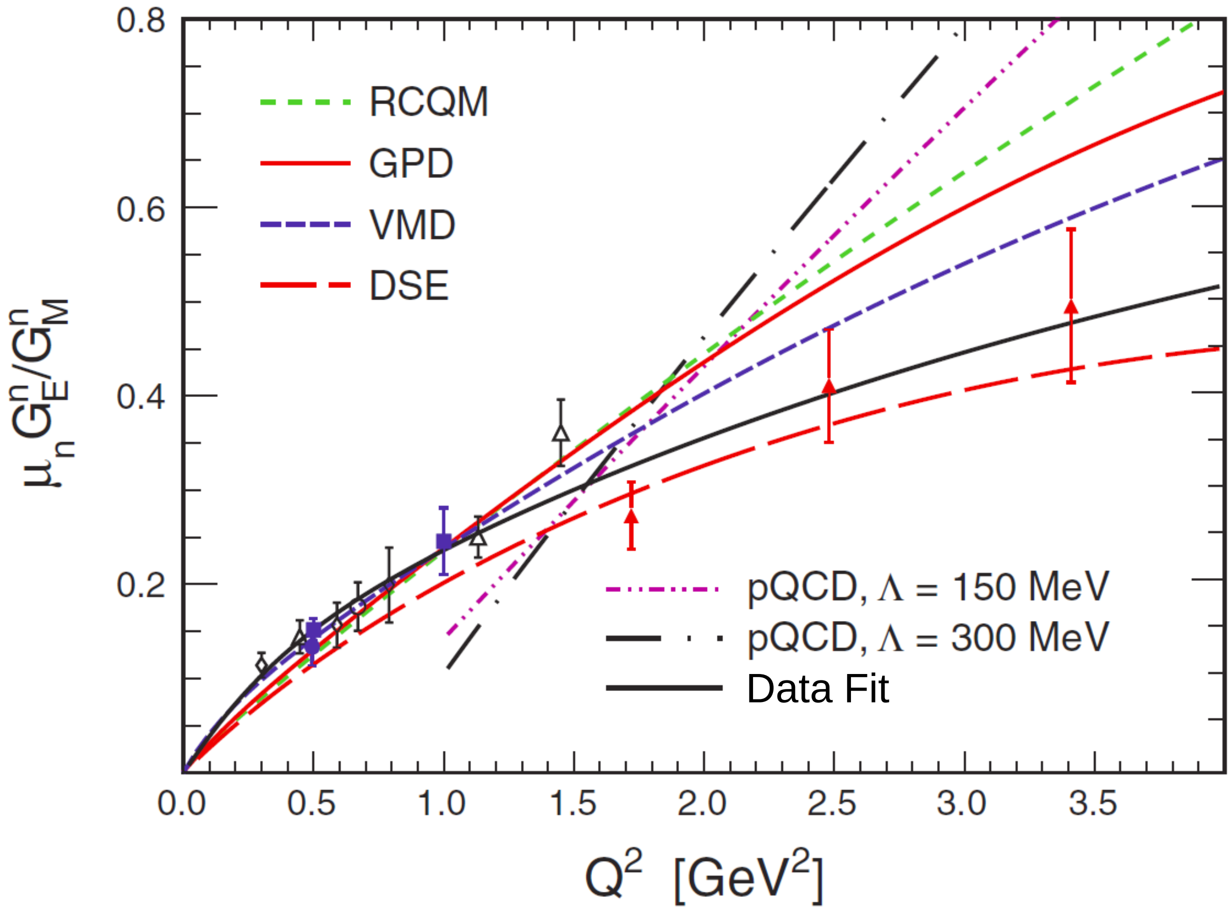
DSE: lines and LQCD: triangles

$Q^2 = 12\ GeV^2 = (\text{p times number of quarks})^2 = 12\ GeV^2 \rightarrow p = 1.15\ GeV$

The data on N* electrocouplings at $5\ GeV^2 < Q^2 < 12\ GeV^2$ will allow us to chart the momentum evolution of dressed quark mass, and in particular, to explore the transition from dressed to almost bare current quarks as shown above.

Dyson-Schwinger Equation (DSE) Approach

DSE approaches provide links between dressed quark propagators, form factors, scattering amplitudes, and QCD.



N* electrocouplings can be determined by applying Bethe-Salpeter / Faddeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

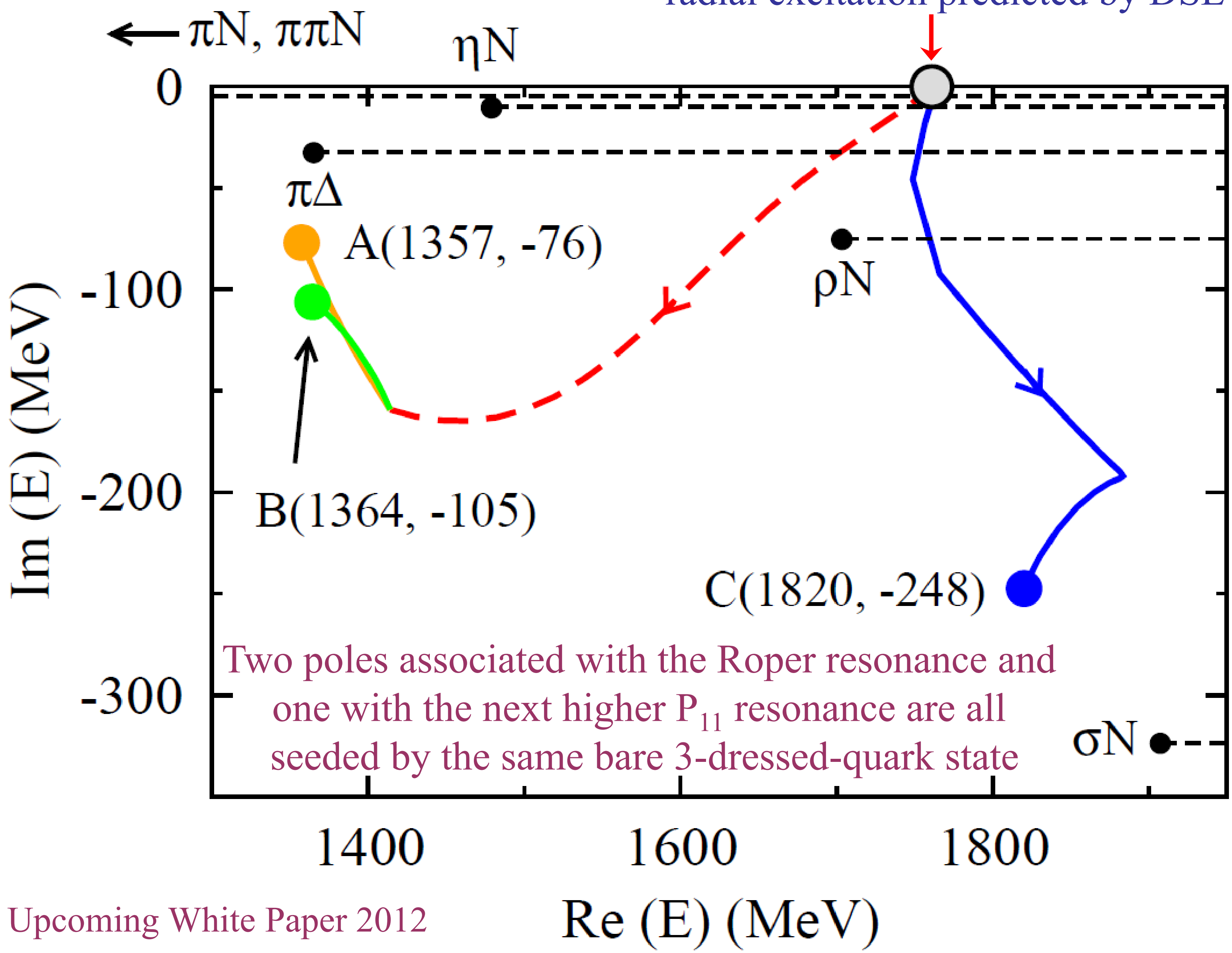
The Faddeev-DSE calculation is very sensitive to the momentum dependence of the dressed-quark propagator.

By the time of the upgrade DSE electrocouplings of several excited nucleon states will be available as part of the commitment of the Argonne NL and the University of Adelaide.

see White Paper Sec. III

DSE and EBAC Approaches

Location of the first 3-dressed-quark core radial excitation predicted by DSE



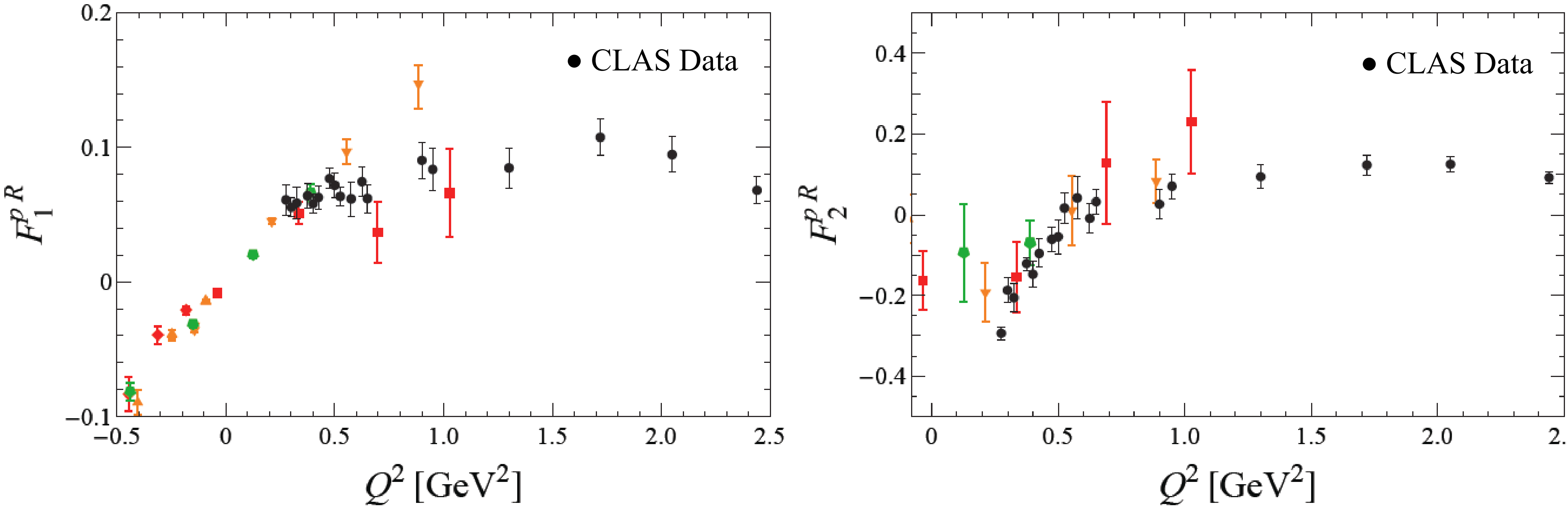
Two poles associated with the Roper resonance and one with the next higher P_{11} resonance are all seeded by the same bare 3-dressed-quark state

Upcoming White Paper 2012

Roper Transition Form Factors in LQCD

p(1440)P_{11}

Huey-Wen Lin and S.D Cohen



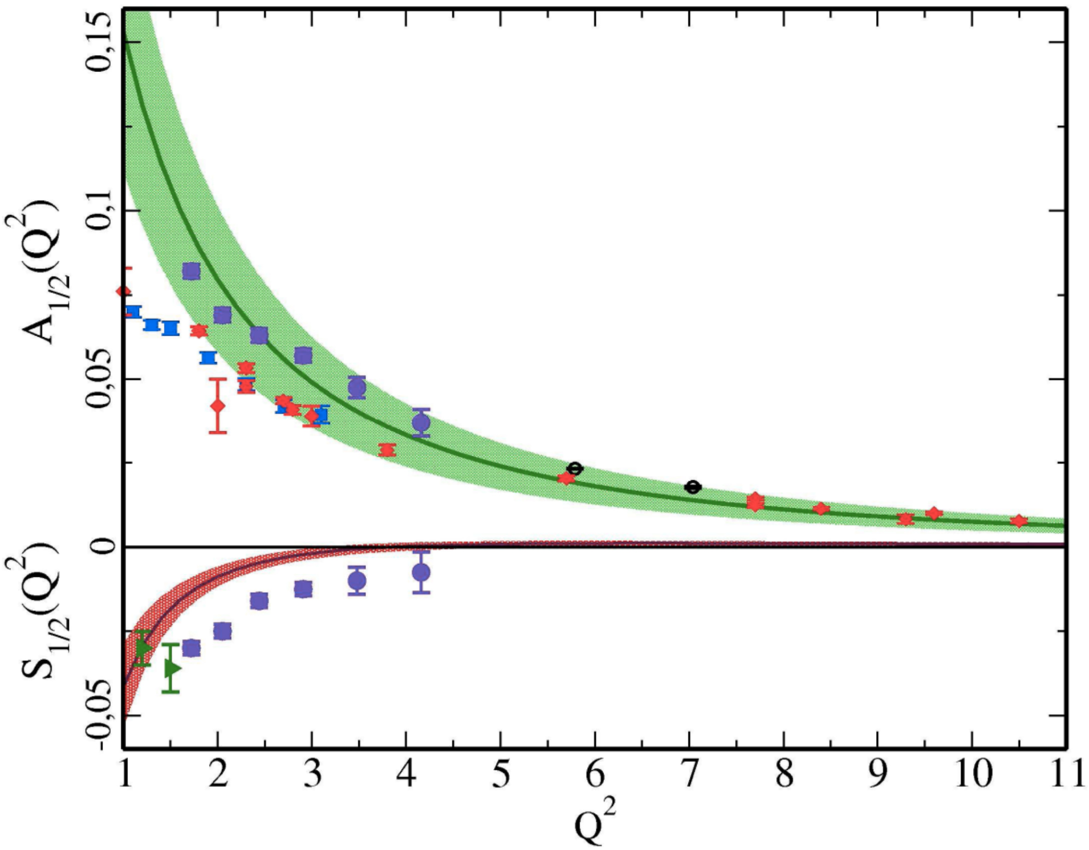
Latice QCD calculations of the p(1440)P_{11} transition form factors have been carried out with various pion masses, m_π= 390, 450, and 875 MeV. Particularly remarkable is the zero crossing in F_2 that appears at the current statistics in the unquenched but not in the quenched calculations. This suggests that at low Q^2 the pion-cloud dynamics are significant in full QCD.

By the time of the upgrade LQCD calculations of N* electrocouplings will be extended to $Q^2 = 10$ GeV^2 near the physical π-mass as part of the commitment of the JLab LQCD and EBAC groups in support of this proposal.

Upcoming White Paper 2012

LQCD & Light Cone Sum Rule (LCSR) Approach

N(1535)S_{11}



LQCD is used to determine the moments of N* distribution amplitudes (DA) and the N* electrocouplings are determined from the respective DAs within the LCSR framework.

Calculations of N(1535)S_{11} electrocouplings at Q^2 up to 12 GeV^2 are already available and shown by shadowed bands on the plot.

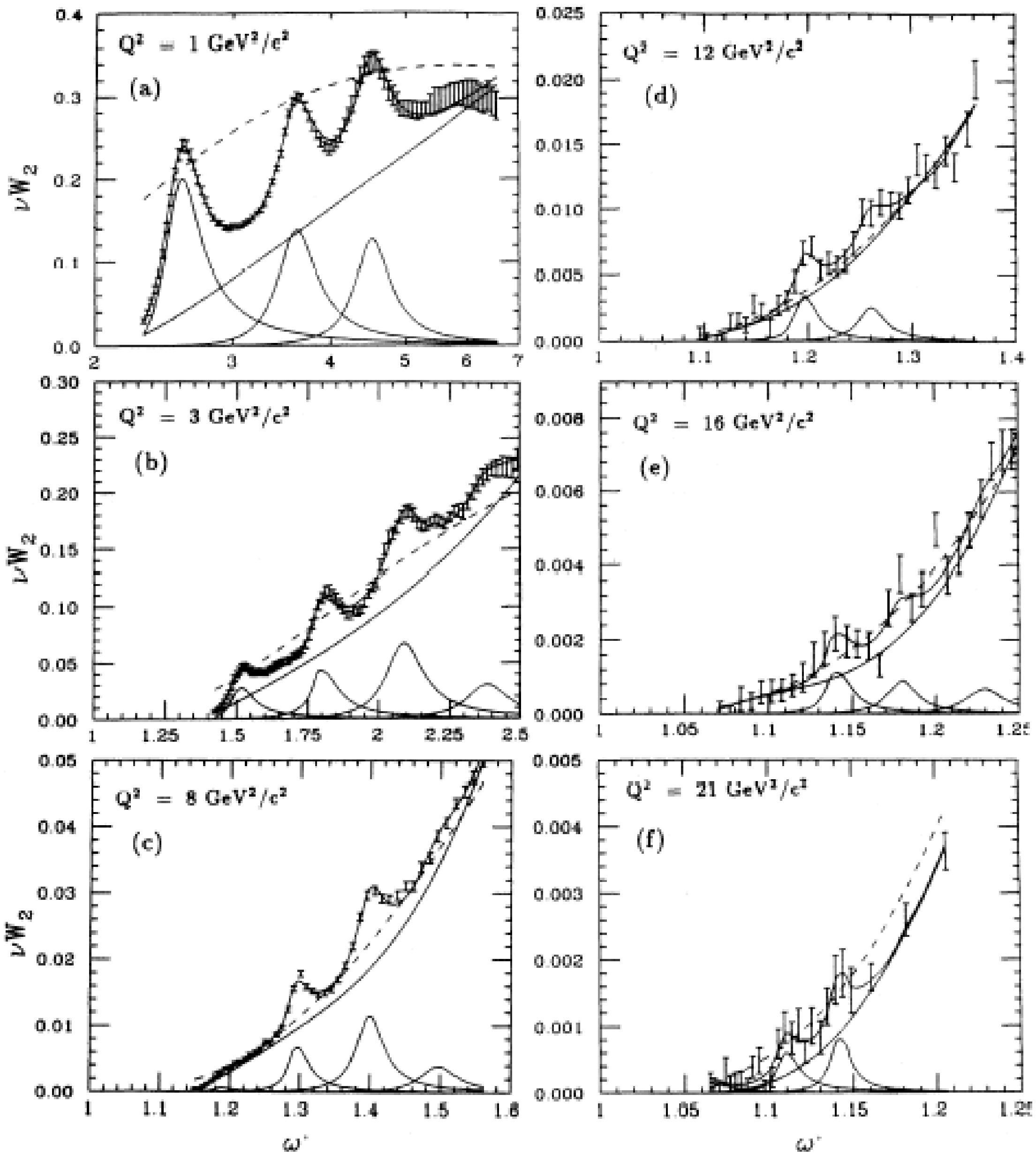
By the time of the upgrade electrocouplings of others N*s will be evaluated. These studies are part of the commitment of the Univ. of Regensburg group in support of this proposal.

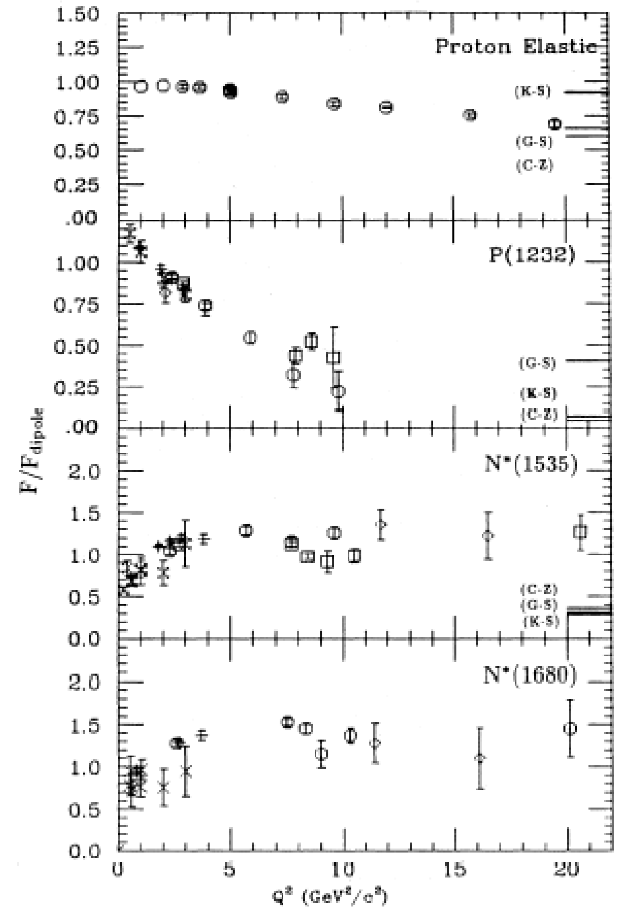
Upcoming White Paper 2012

E-09-003

… and more?

Inclusive Structure Function in the Resonance Region





P. Stoler, PRPLCM 226, 3 (1993) 103-171

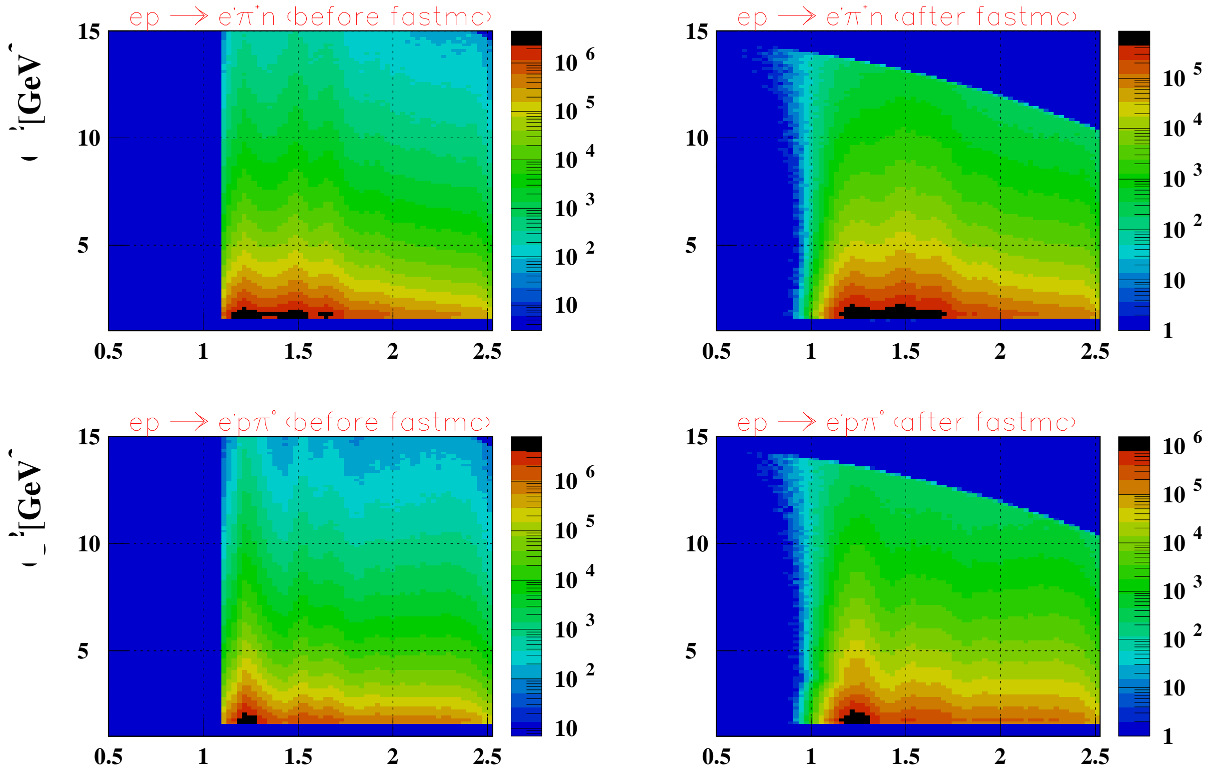
CLAS 12 Kinematic Coverage and Counting Rates

Genova-EG

(e',π+) detected

Genova-EG

(e',p) detected



(E,Q^2)	(5.75 GeV, 3 GeV^2)	(11 GeV, 3 GeV^2)	(11 GeV, 12 GeV^2)
$N^{n\pi+}$	$1.41*10^5$	$6.26*10^6$	$5.18*10^4$
$N^{p\pi 0}$	-	$4.65*10^5$	$1.45*10^4$
$N^{p\eta}$	-	$1.72*10^4$	$1.77*10^4$

L=10^{35} cm^{-2} sec^{-1}, W=1535 GeV, ΔW= 0.100 GeV, ΔQ^2 = 0.5 GeV^2

40 days

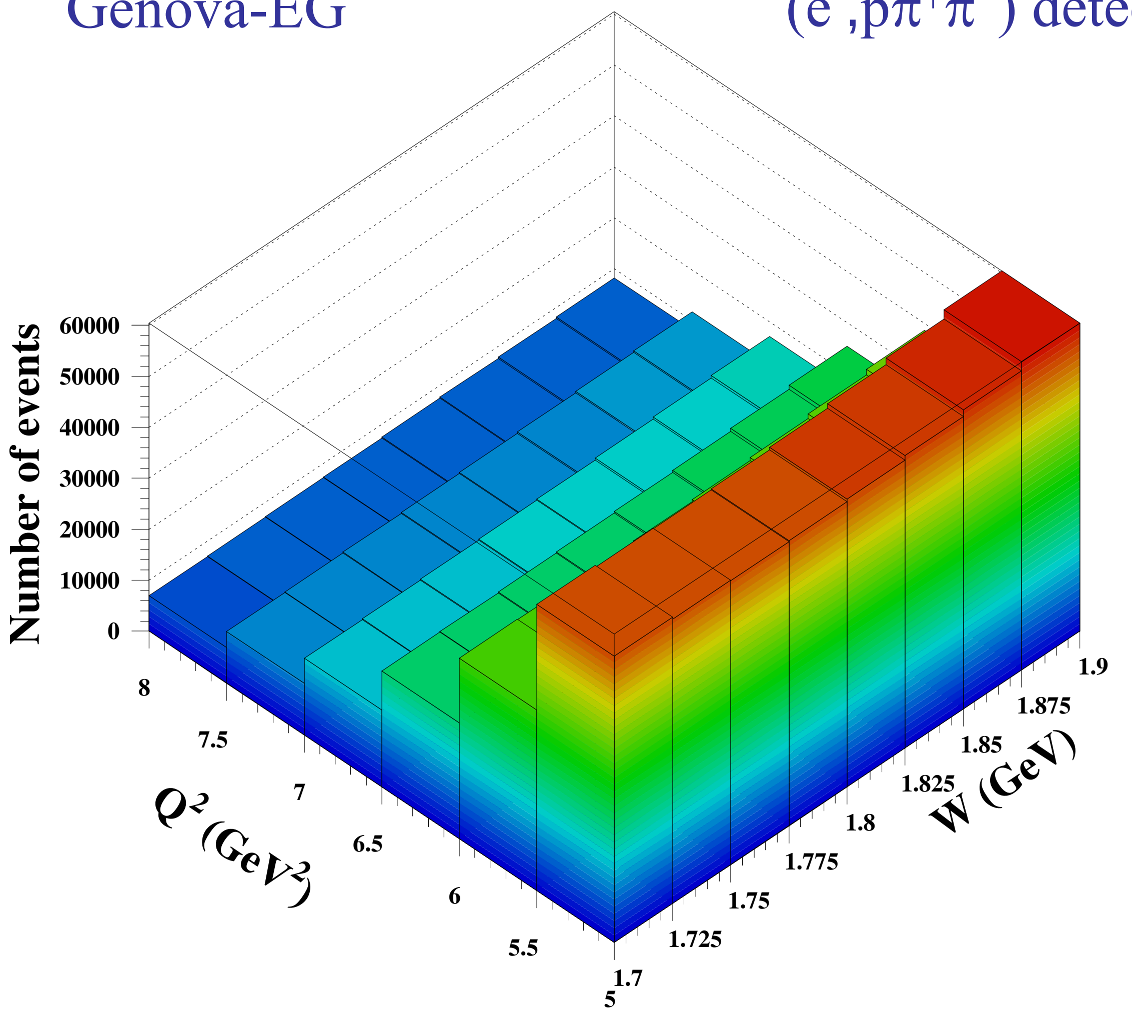
PAC35

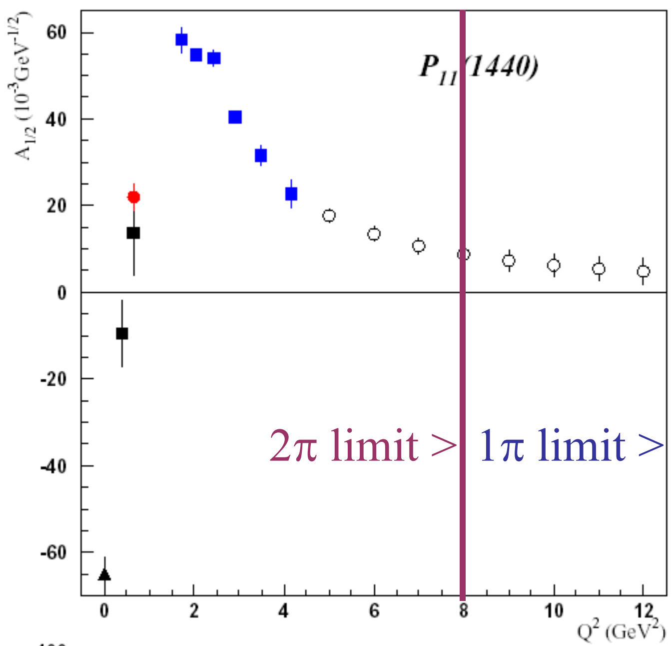
Kinematic Coverage of CLAS12

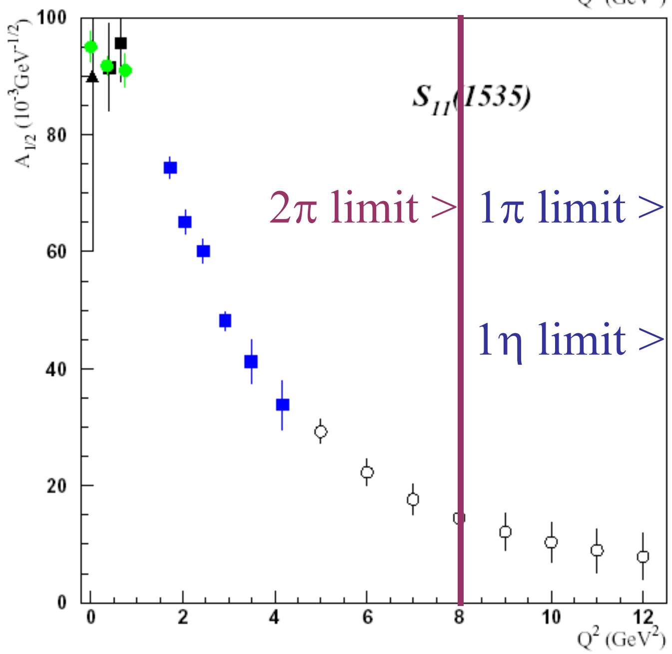
60 days

L= 10^{35} cm^{-2} sec^{-1}, $\Delta W = 0.025$ GeV, $\Delta Q^2 = 0.5$ GeV^2

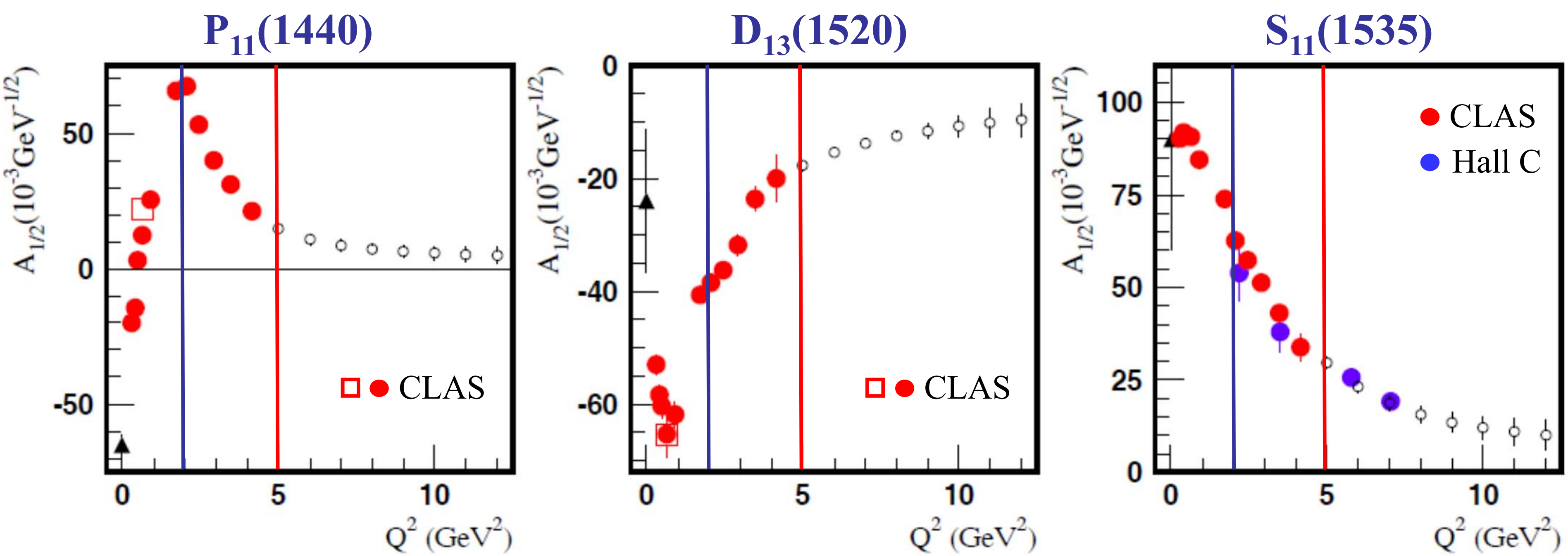
Genova-EG (e',p$\pi^+\pi^-$) detected







Anticipated N* Electrocouplings from a Combined Analysis of Nπ & Nππ



Open circles represent projections and all other markers the available results with the 6-GeV electron beam

- Examples of published and projected results obtained within 60d for three prominent excited proton states from analyses of Nπ and Nππ electroproduction channels. Similar results are expected for many other resonances at higher masses, e.g. $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, $P_{13}(1720)$, …

- This experiment will – for the foreseeable future – be the only experiment that can provide data on $\gamma_v pN^*$ electrocouplings for almost all well established excited proton states at the highest photon virtualities ever achieved in N* studies up to Q^2 of 12 GeV^2.

- Are more experimental data needed on $\gamma_v nN^*$ at high and both $\gamma_v pN^*$ and $\gamma_v nN^*$ at low Q^2?

Summary

- We will measure and determine the electrocouplings $A_{1/2}$, $A_{3/2}$, $S_{1/2}$ as a function of Q^2 for prominent nucleon and Δ states,
  - see our Proposal http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.
- Comparing our results with DSE, LQCD, LCSR, and rCQM will gain insight into
  - the strong interaction of dressed quarks and their confinement in baryons,
  - the dependence of the light quark mass on momentum transfer, thereby shedding light on dynamical chiral-symmetry breaking, and
  - the emergence of bare quark dressing and dressed quark interactions from QCD.
- This unique opportunity to understand origin of 98% of nucleon mass is also an experimental and theoretical challenge. A wide international collaboration is needed for the:
  - theoretical interpretation on N* electrocouplings, see our previous White Paper arXiv:0907.1901v3 [nucl-th], and
  - development of reaction models that will account for hard quark/parton contributions at high Q^2.
- Any constructive criticism, help, or participation is very welcomed, please contact:
  - Viktor Mokeev mokeev@jlab.org or Ralf Gothe gothe@sc.edu.