

Hadronic Multi-particle Final State Measurements with CLAS at Jefferson Lab

Will Brooks
Jefferson Lab

NuInt02, December 2002

Outline

- Overview of CLAS Physics Program
- Description of CLAS
- Samples of CLAS data and analysis
- Future nuclear target experiments
- Conclusions

CLAS: the CEBAF Large Acceptance Spectrometer in Hall B at JLAB

- International collaboration of 160 scientists
- Physics data taking began end of 1997
- 17 major production runs completed
- Wide variety of run conditions:
 - Electron/photon beams, $0.5 < E < 6$ GeV (polarized)
 - Targets: $^1,^2\text{H}$ (including polarized), $^3,^4\text{He}$, ^{12}C , ^{56}Fe , etc.
- 50 PhD theses underway or completed
- More info at <http://www.jlab.org/Hall-B>

CLAS Physics Highlights

Broad program: over 50 experiments

- Physics of excited nucleons (N^* program)
- Neutron electromagnetic form factor
- Polarized structure functions
- Deep virtual Compton scattering (GPD's)
- Quark/hadron propagation through nuclei
- Semi-inclusive deep inelastic scattering
- Exotic meson searches
- Elementary hyperon photoproduction
- Two-nucleon correlations in light nuclei

Drift Chambers

35,000 wires
 $\sigma_R = 350 \mu\text{m}$

Superconducting Toroidal Magnet

$$\int Bdl \cong 1.7 \text{ T}\cdot\text{m}$$

Cerenkov Counters

216 channels
99.5% efficient
over 50 m^2 area

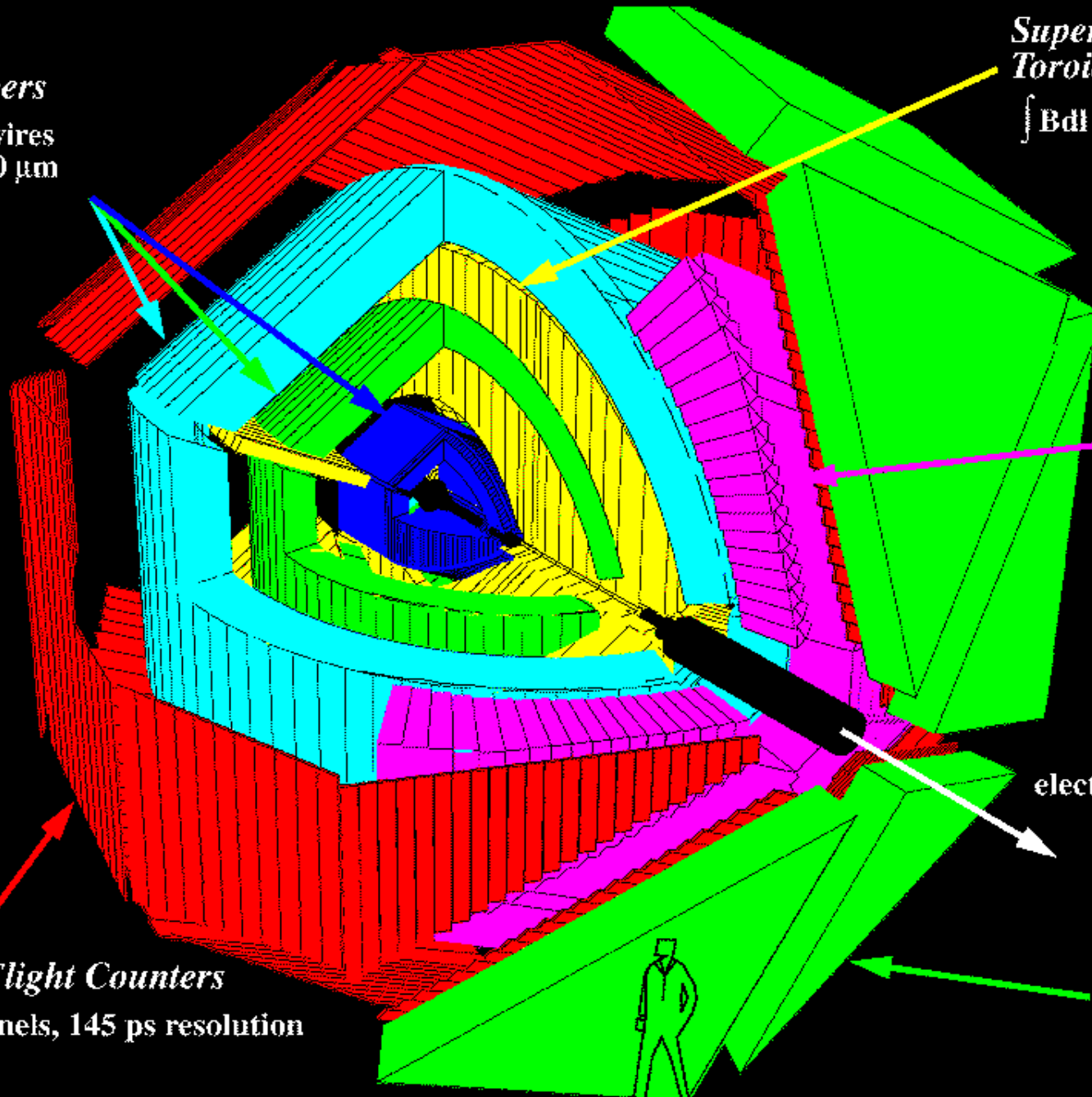
electron beam direction

Electromagnetic Shower Calorimeters

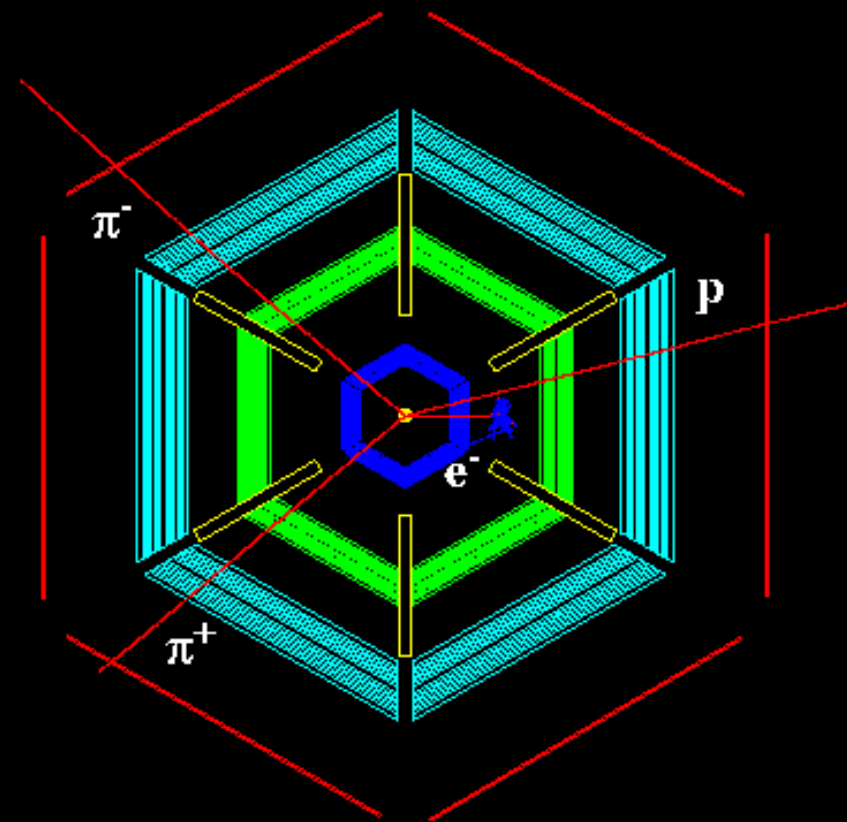
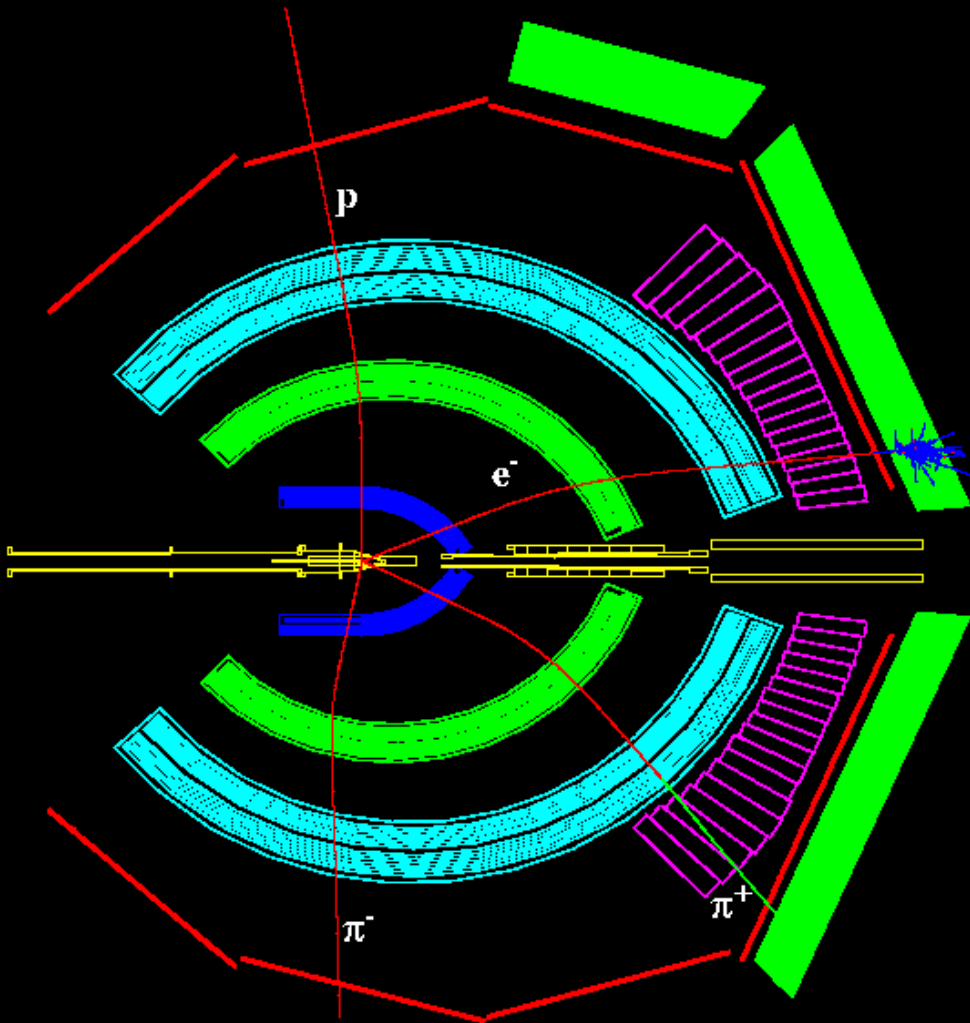
1700+ channels
 $\sigma/E = 10\%/E^{0.5}$

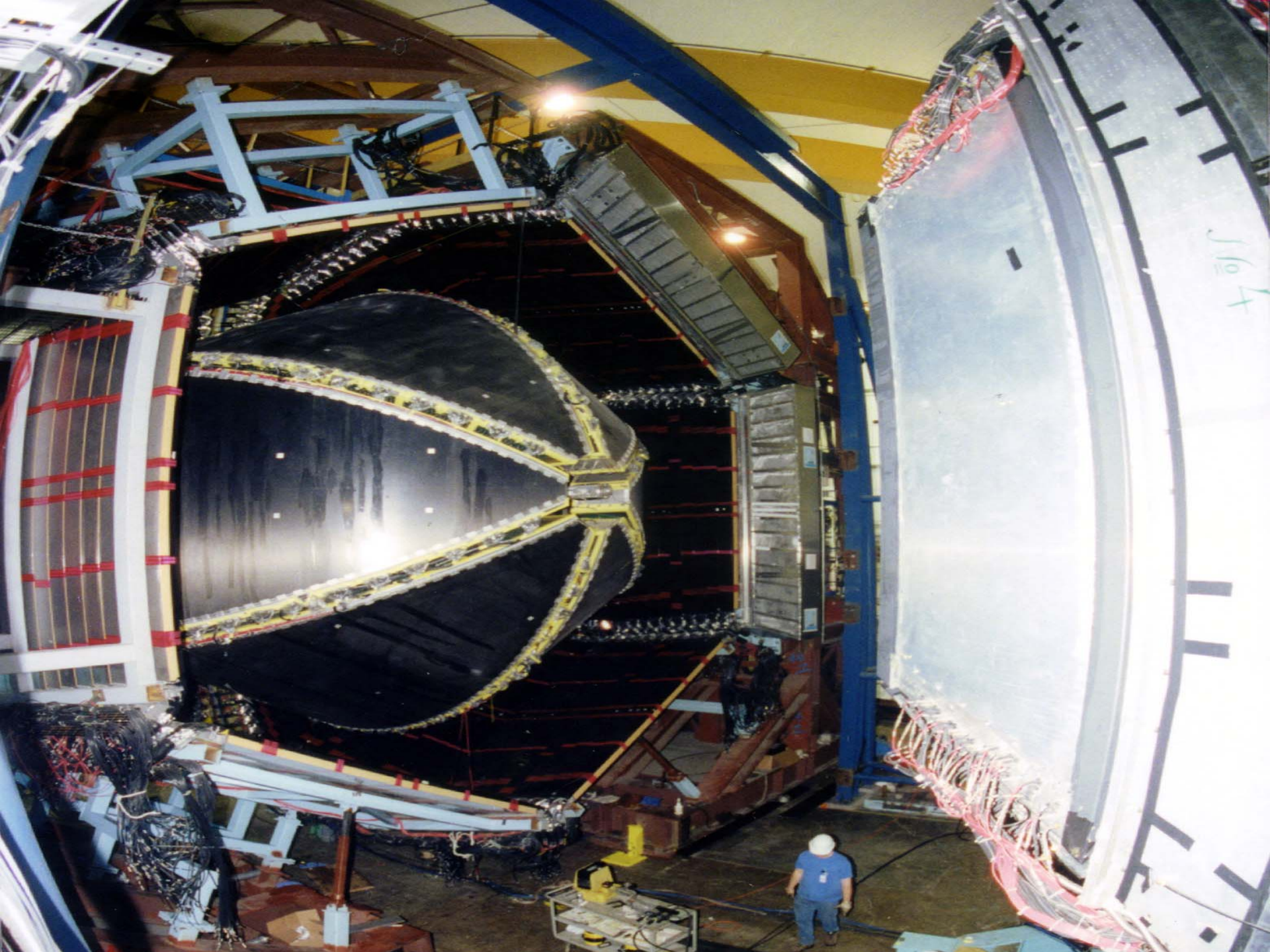
Time of Flight Counters

500+ channels, 145 ps resolution



- Charged particle angles $8^\circ - 144^\circ$
- Neutral particle angles $8^\circ - 70^\circ$
- Momentum resolution $\sim 0.5\%$ (charged)
- Angular resolution ~ 0.5 mr (charged)
- Identification of p , π^+/π^- , K^+/K^- , e^-/e^+





Typical Run Conditions

- Luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (LH2 target)
- 10^6 hadronic interactions/second
- Up to 4000 Hz event rate
- Trigger: single electron
- Data transfer rate: up to 20 MByte/s
(~ 1 TByte/day)
- Acquire 10 – 30 billion triggers/year

Physics of Excited Nucleons

N* program

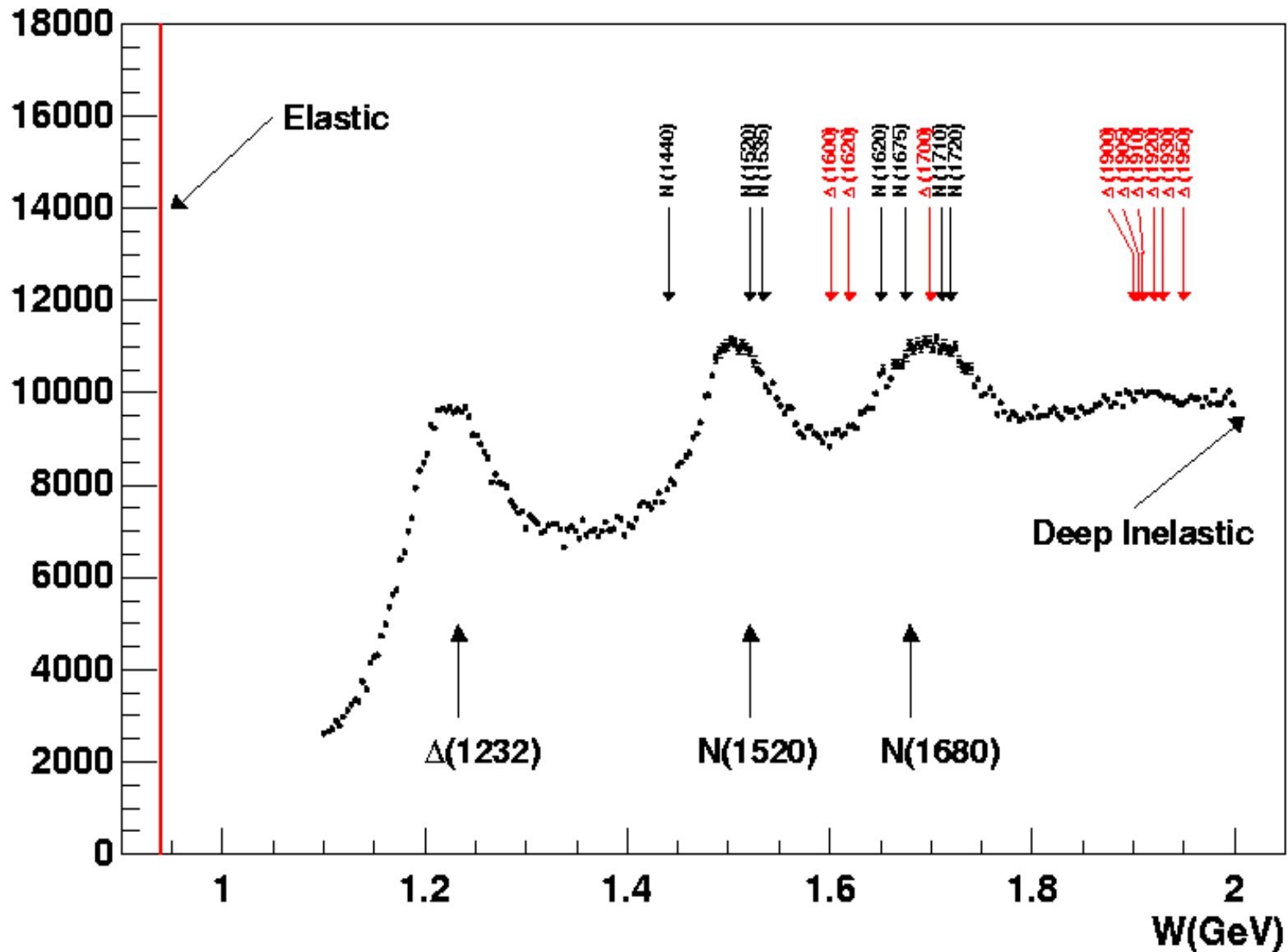
■ Resonance transition form factors

- N- Δ transition
- Second resonance region (e.g. S_{11})
- N- Δ axial form factor

■ Quark model 'missing resonances'

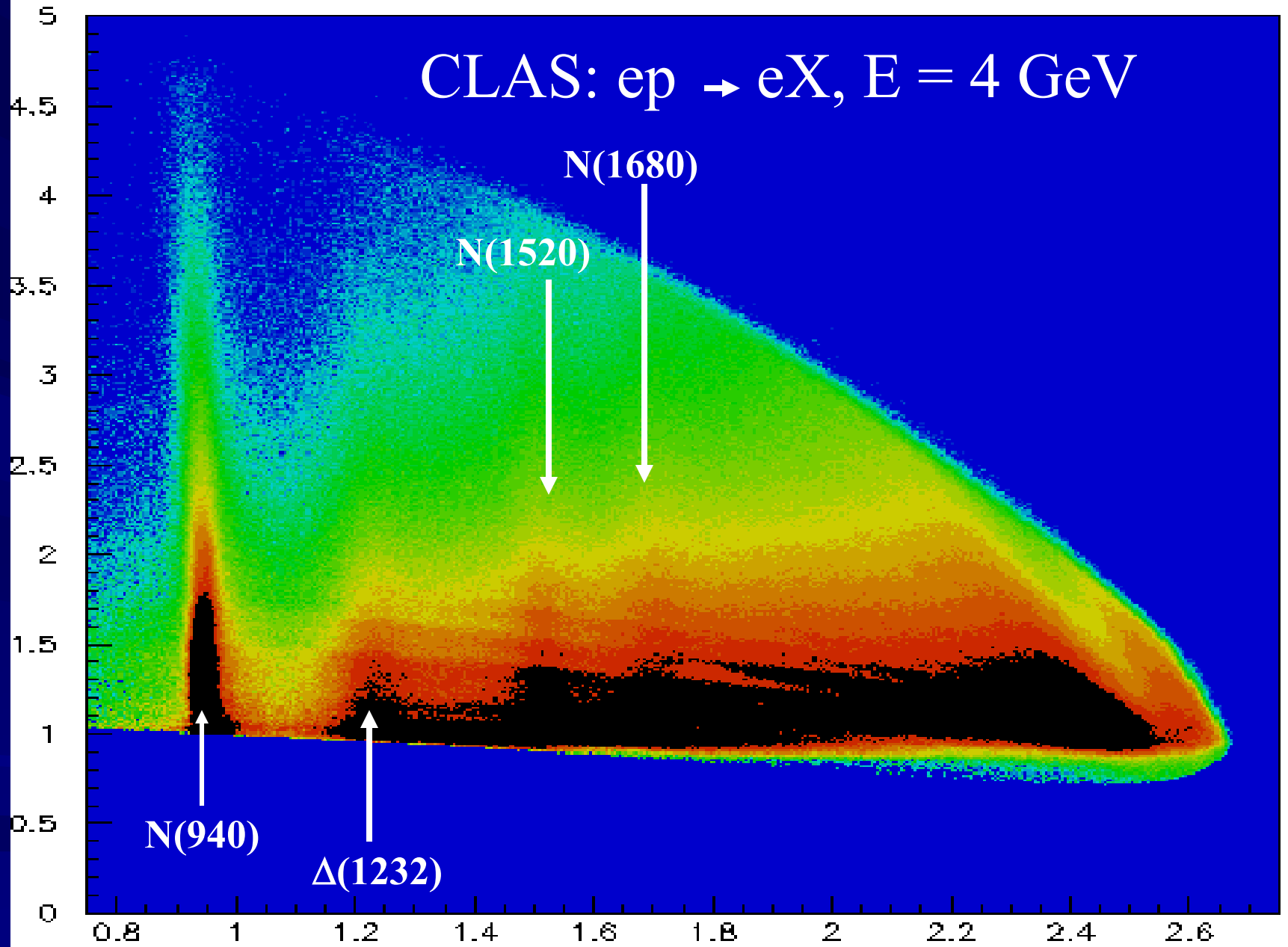
- Can find them in unexplored decay channels?
- Models have correct degrees of freedom?

Inclusive scattering in the resonance region



CLAS: $ep \rightarrow eX$, $E = 4 \text{ GeV}$

$Q^2 \text{ (GeV}^2\text{)}$



CLAS: $ep \rightarrow epX$, $E = 4 \text{ GeV}$

$W(\text{GeV})$

2.2

2

1.8

1.6

1.4

1.2

1

0.8

π^0

η

ω

-0.2

0

0.2

0.4

0.6

0.8

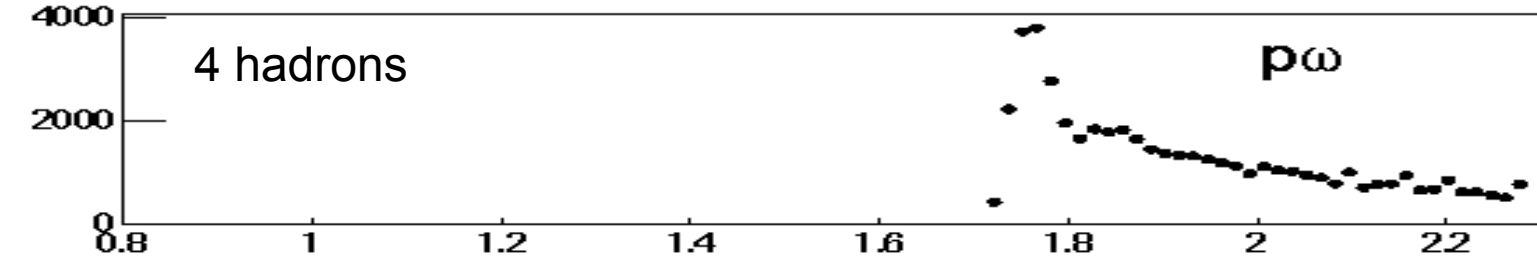
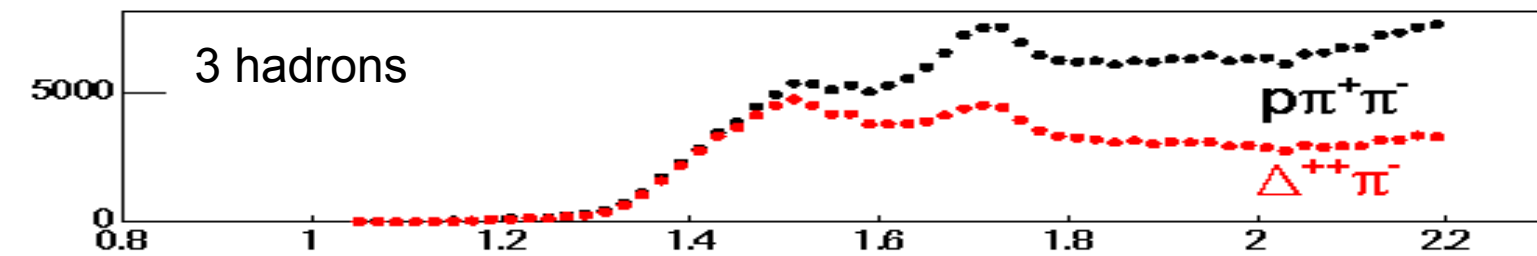
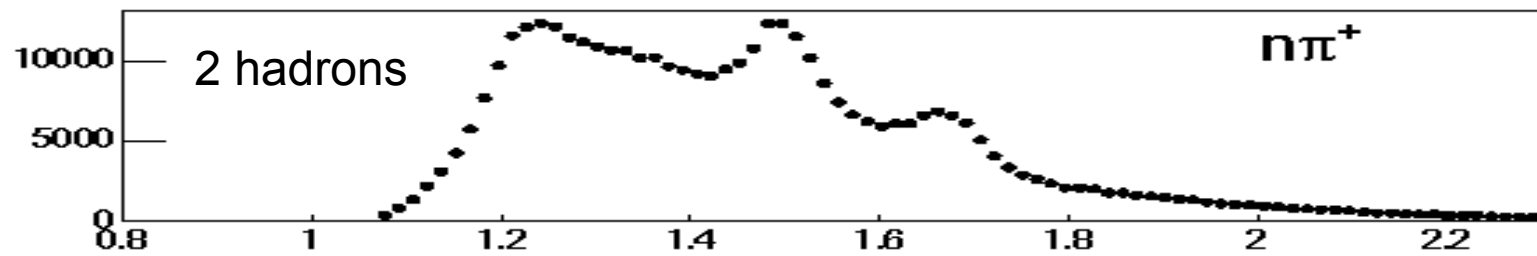
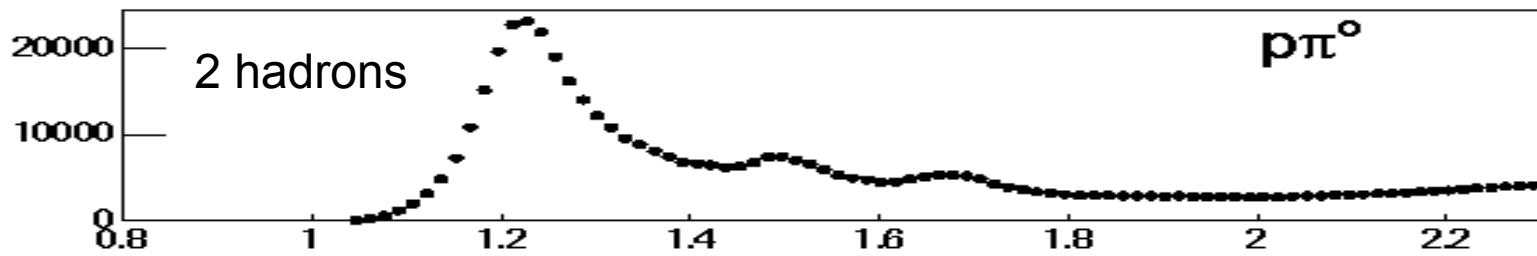
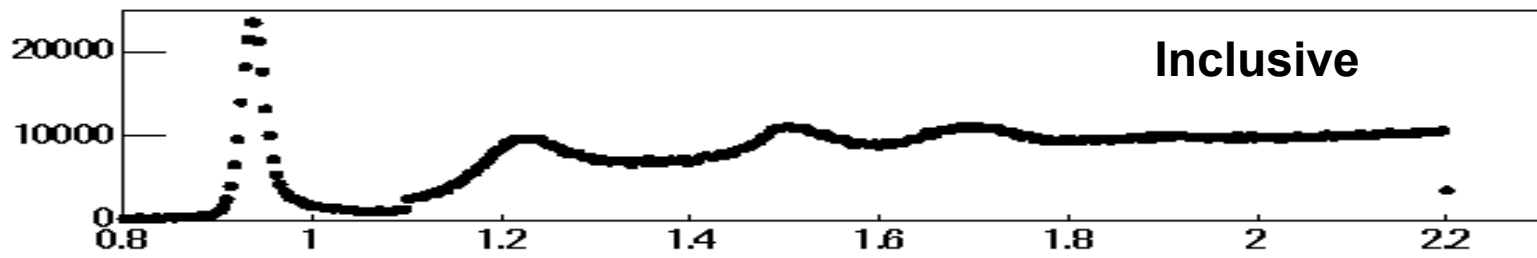
1

1.2

1.4

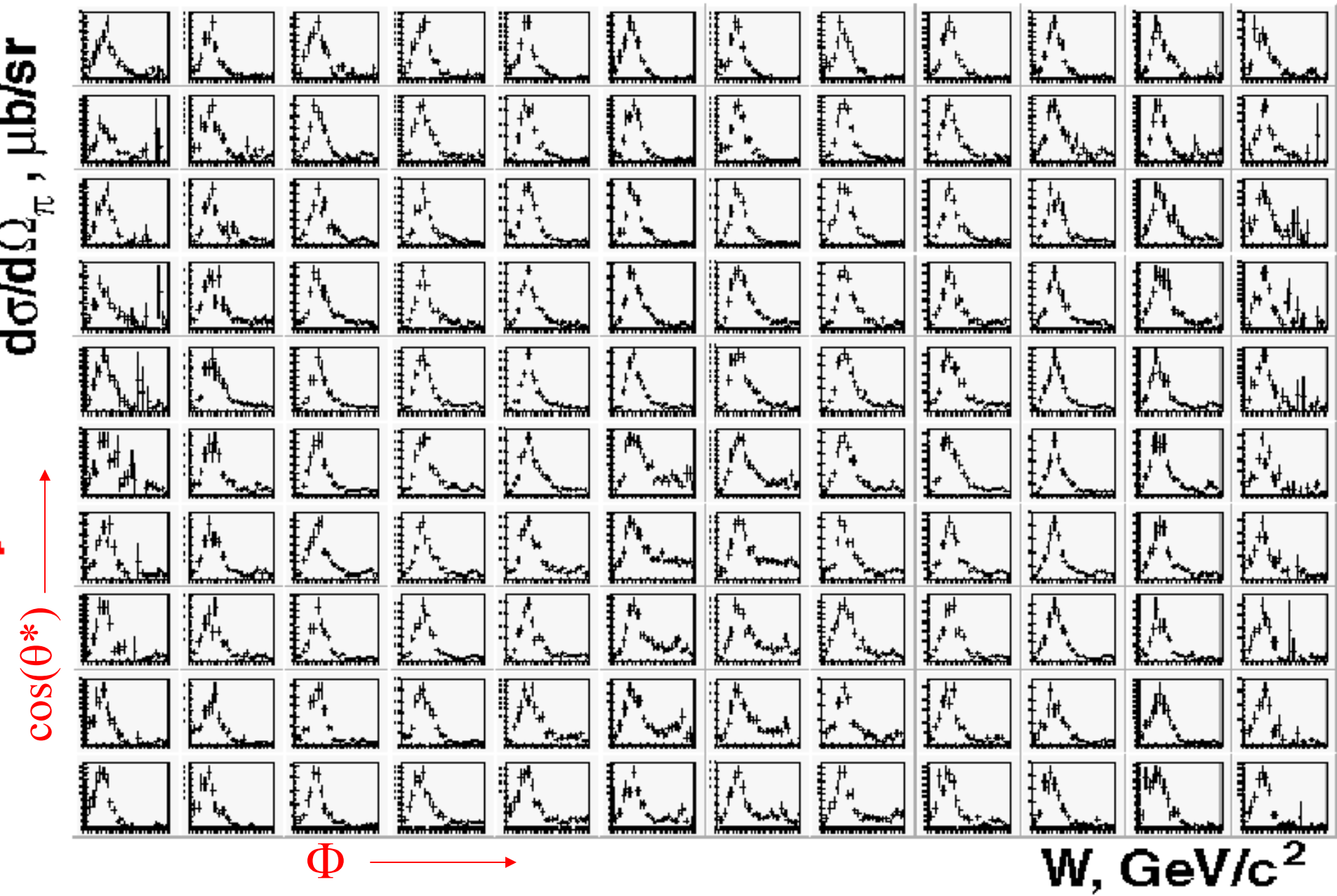
Missing Mass (GeV)

$ep \rightarrow eX, E = 4 \text{ GeV}$



W(GeV)

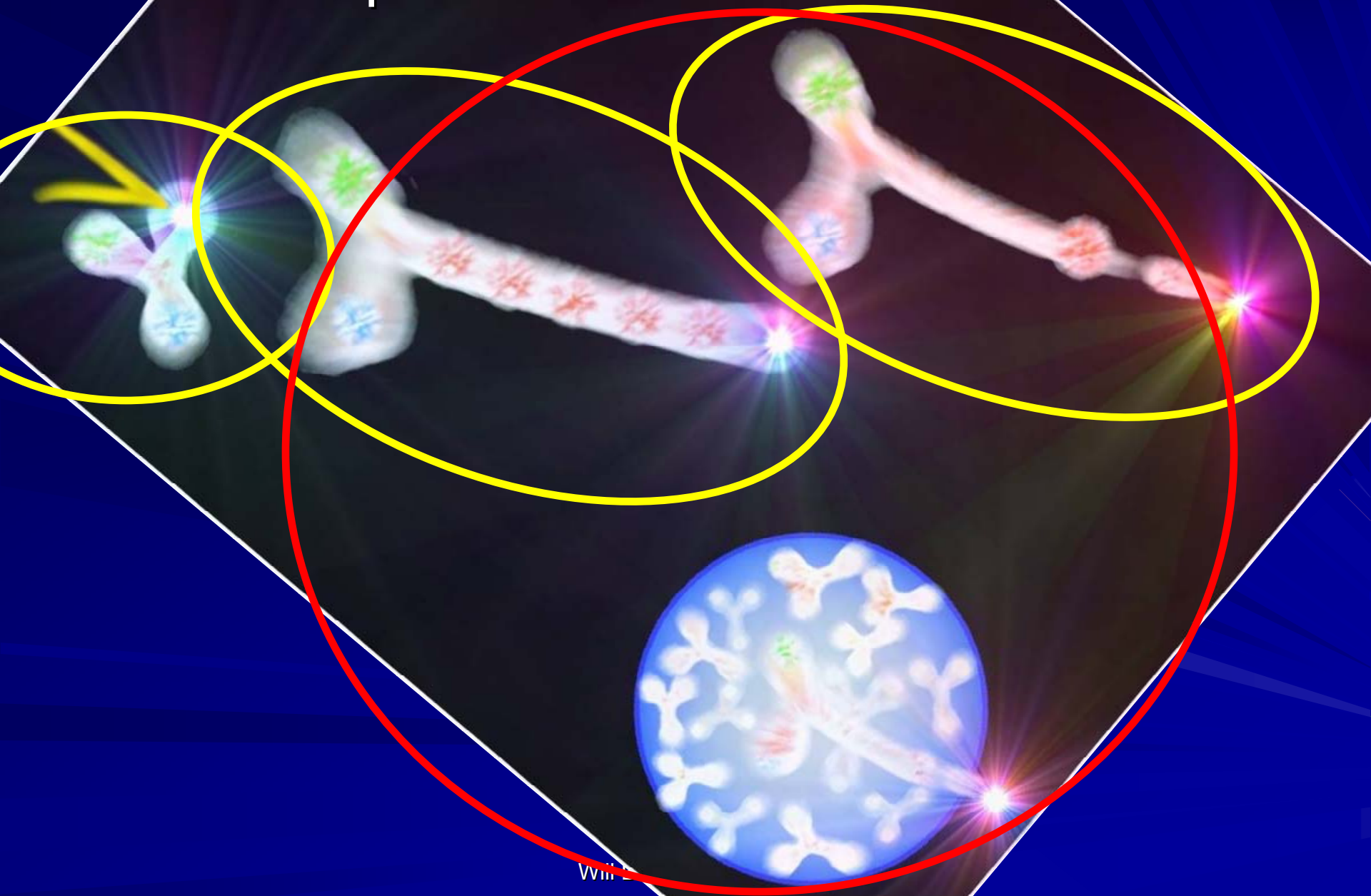
$$Q^2 = 0.40 (\text{GeV}/c)^2, \Delta Q^2 = 0.100 (\text{GeV}/c)^2$$



Quark/Hadron Propagation through Nuclei

- Space-time properties of hadronization
 - Mass, size, p_T , v , z , Q^2 , and flavor dependences of **hadron formation lengths**
 - Gluon emission
- Transverse momentum broadening
 - Quark-gluon correlations
 - Quark energy loss
- 6 GeV experiment coming in June 2003
 - *New collaborators welcome*
- 11 GeV experiment (in 2010-2012?)

Space-time Picture of Hadronization

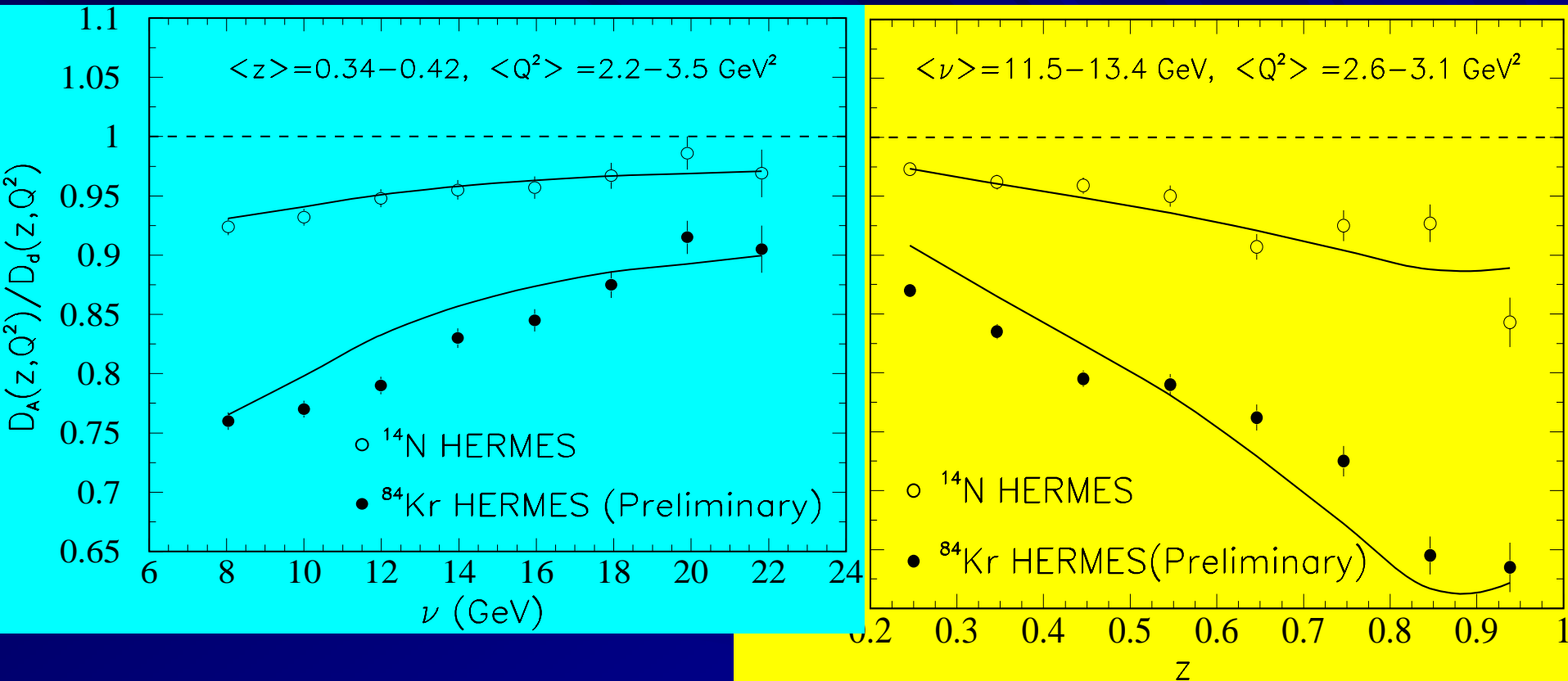


Nuclear Quark/Hadron Propagation

Experimental Method

- Use a range of targets, light to heavy
 - ^1H , ^2H , ^{14}N , ^{56}Fe , ^{84}Kr , ^{197}Au
- DIS kinematics + measure hadrons
- Single electron trigger
- Nuclear medium modifies fragmentation functions and p_T distributions
- 6 GeV beam: $Q^2 \leq 4 \text{ GeV}^2$, $\nu \leq 5 \text{ GeV}$
- 12 GeV beam: $Q^2 \leq 9 \text{ GeV}^2$, $\nu \leq 9 \text{ GeV}$
- Measure $\pi^{+,-,0}$, η , ω , η' , ϕ , $K^{+,-,0}$, ρ , Λ , $\Sigma^{+,0}$, $\Xi^{0,-}$

Recent Data from HERMES at HERA

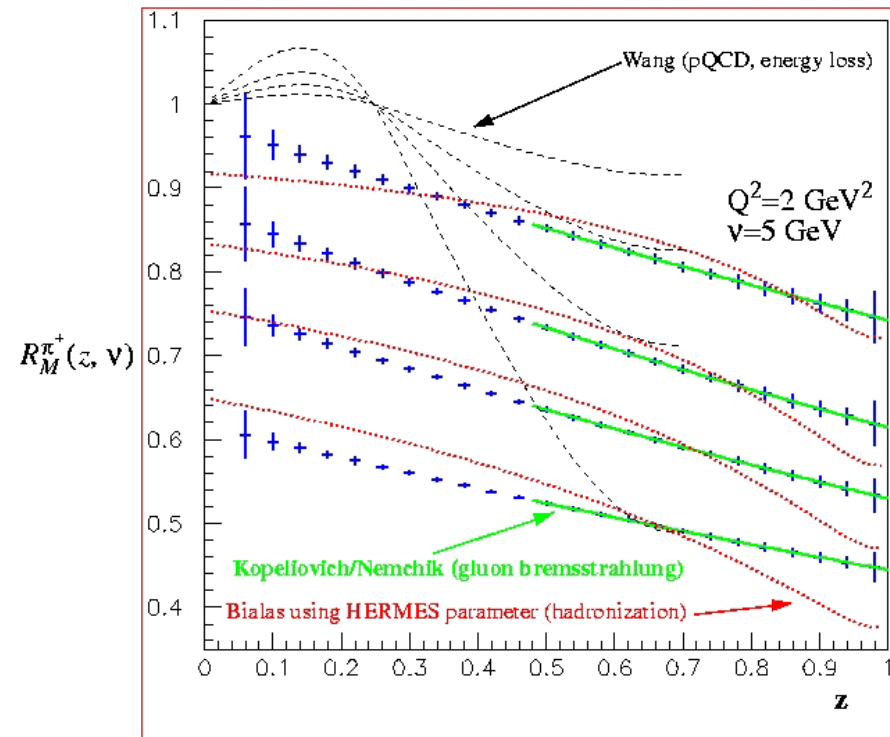
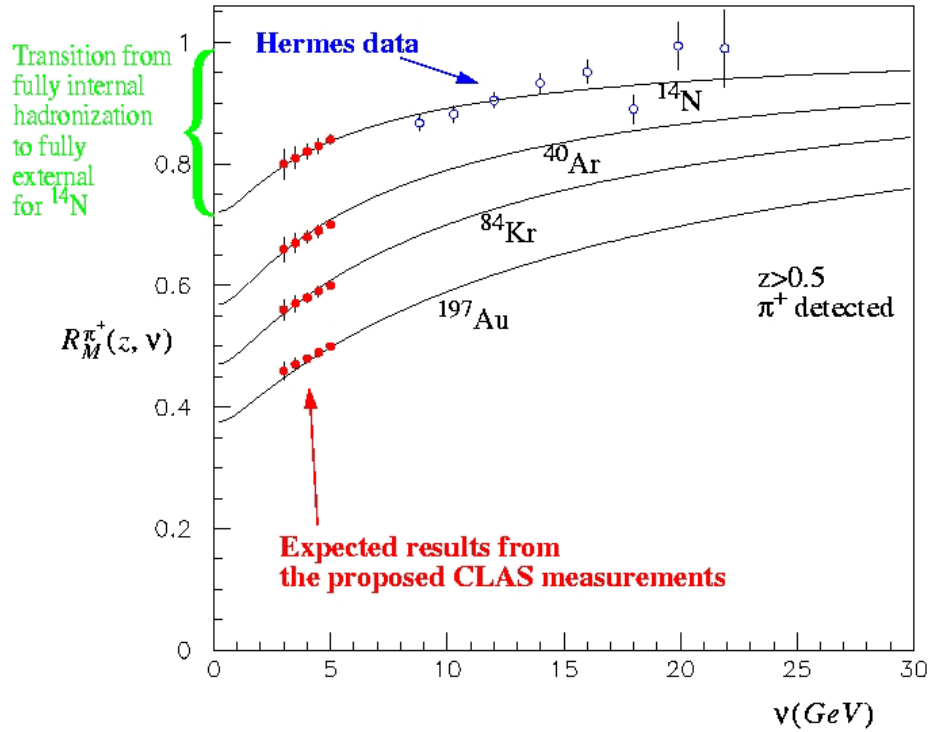


Data: Eur. Phys. J. C20 (2001) 479.

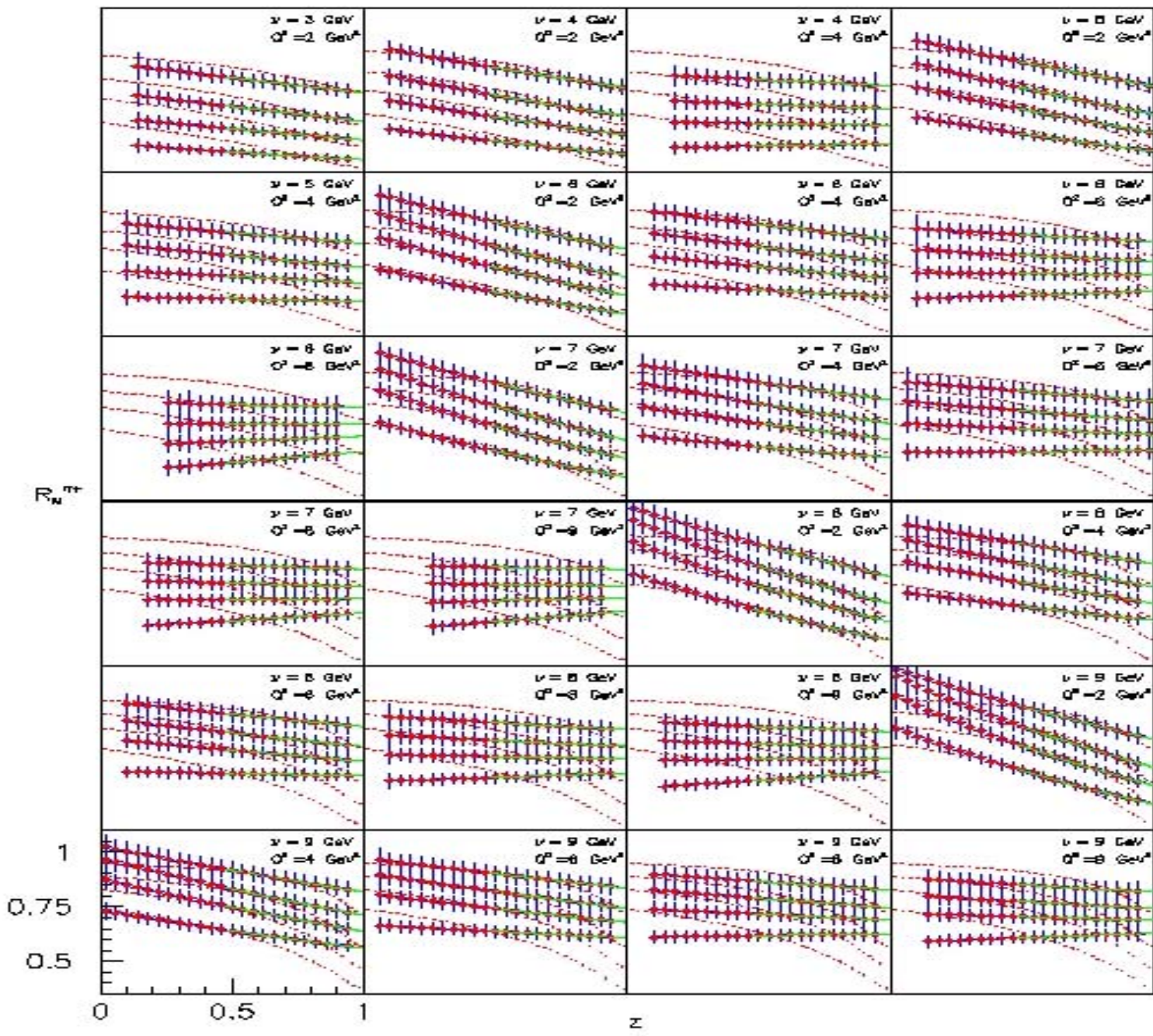
Theory: nucl-th/9607036 for gluon bremsstrahlung model,
Phys. Rev. Lett. 89 (2002) for twist-4 pQCD model.

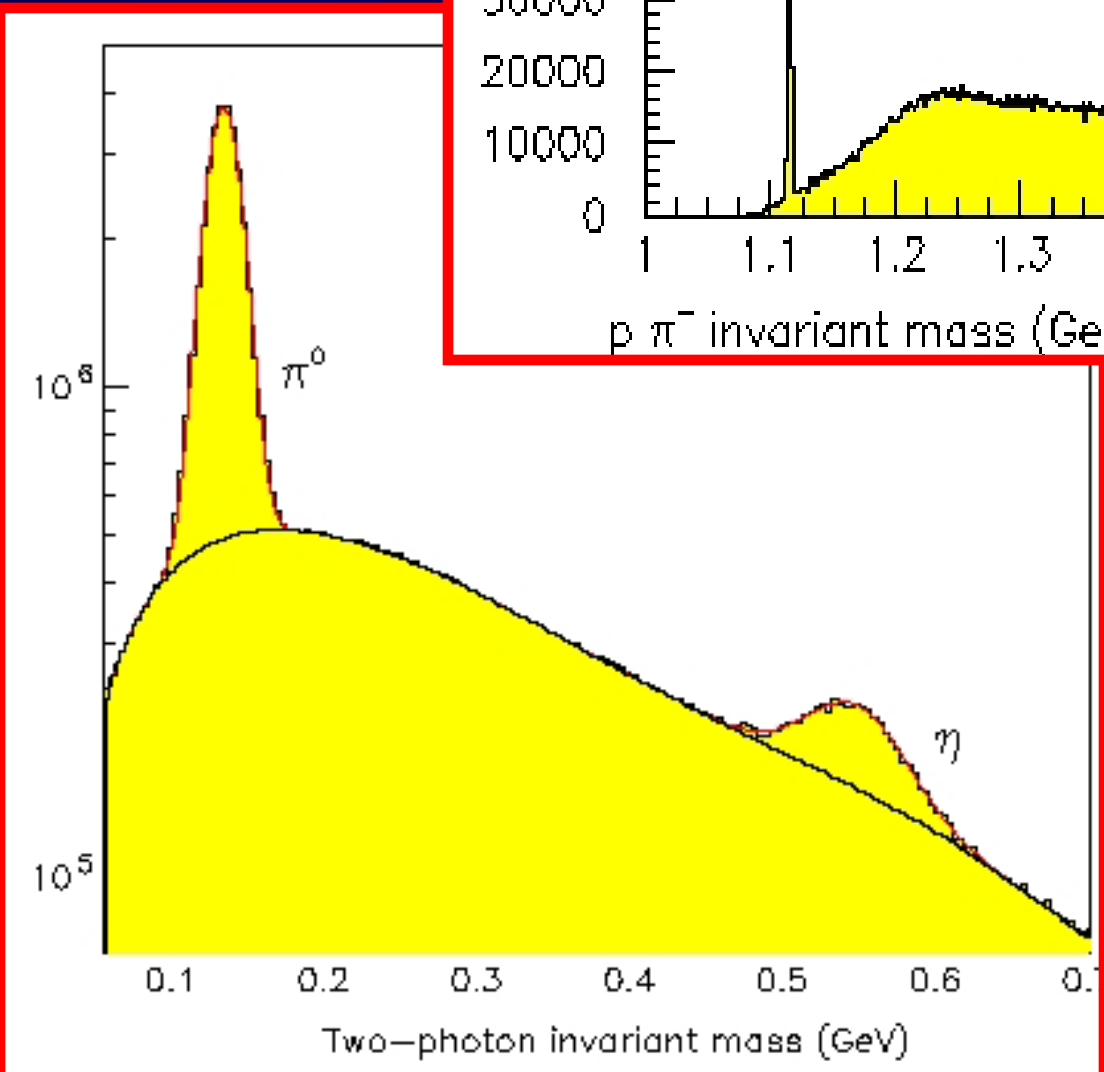
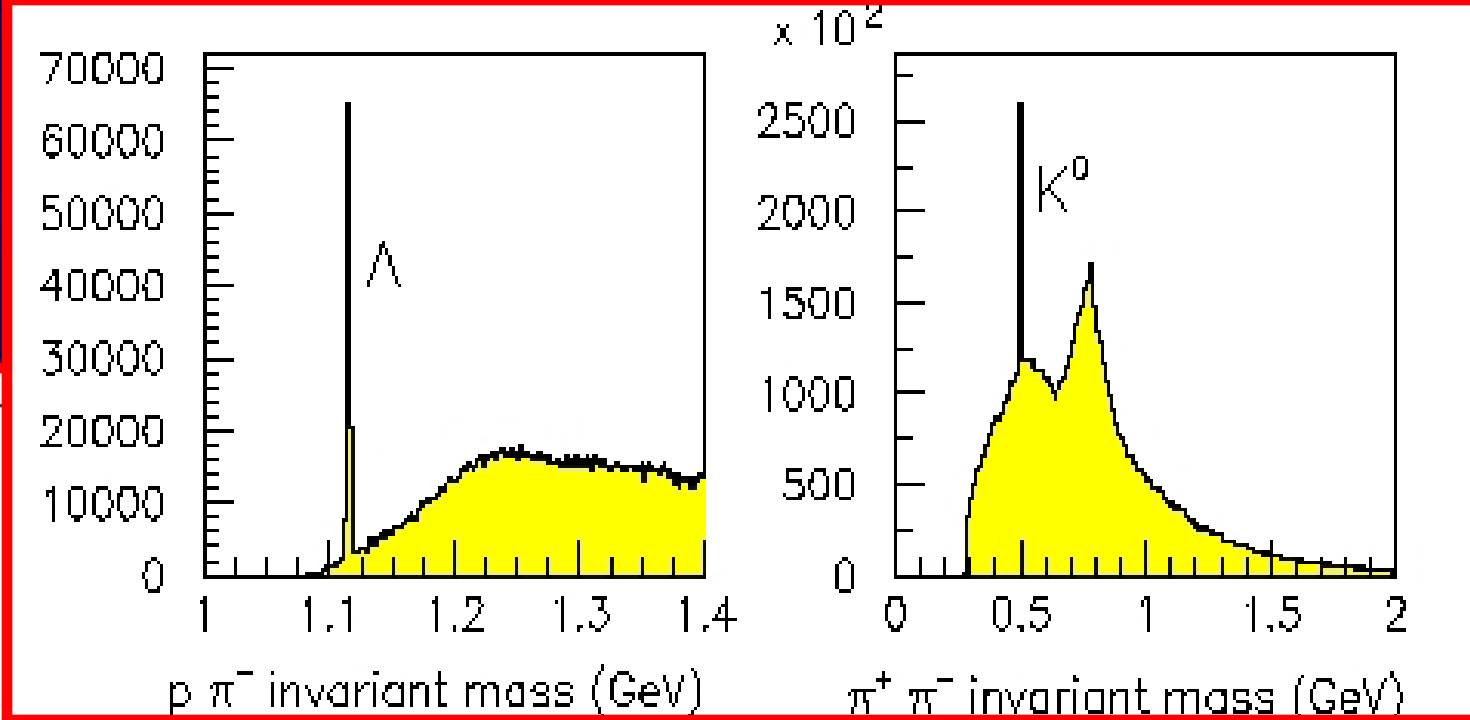
See also David Gaskell talk tomorrow morning.

Anticipated CLAS Data at 6 GeV



Kinematic Coverage, 12 GeV





■ Neutral particle detection for fragmentation events at 11 GeV (LEPTO simulation, no vertex cut)

Conclusion

- CLAS has taken a huge volume of new data including multi-hadron final states
- N^* and nuclear data likely to be of interest to neutrino community
- Collaborative connection likely to be most fruitful – many potential opportunities for collaboration

Hadrons accessible for formation length studies

CLAS at 11 GeV

hadron	$c\tau$	mass (GeV)	flavor content	detection channel	production rate per 1k DIS events
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	$\gamma\gamma$	1100
π^+	7.8 m	0.14	$u\bar{d}$	direct	1000
π^-	7.8 m	0.14	$d\bar{u}$	direct	1000
η	0.17 nm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	$\gamma\gamma$	120
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\pi^0$	170
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\eta$	27
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	K^+K^-	0.8
K^+	3.7 m	0.49	$u\bar{s}$	direct	75
K^-	3.7 m	0.49	$\bar{u}s$	direct	25
K^0	27 mm	0.50	$d\bar{s}$	$\pi^+\pi^-$	42
p	stable	0.94	$u\bar{d}$	direct	1100
\bar{p}	stable	0.94	$\bar{u}d$	direct	3
Λ	79 mm	1.1	uds	$p\pi^-$	72
$\Lambda(1520)$	13 fm	1.5	uds	$p\pi^-$	-
Σ^+	24 mm	1.2	us	$p\pi^0$	6
Σ^0	22 pm	1.2	uds	$\Lambda\gamma$	11
Ξ^0	87 mm	1.3	us	$\Lambda\pi^0$	0.6
Ξ^-	49 mm	1.3	ds	$\Lambda\pi^-$	0.9