Measurement of Form Factors at High Q^2

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- Pion form factor extend range from $Q^2 = 2.5 \Rightarrow Q^2 = 6$
- Proton electric form factor extend range from $Q^2 = 9.0 \Rightarrow Q^2 = 14$
- Neutron electric form factor extend range from $Q^2 = 4.3 \Rightarrow Q^2 = 8$
- Transition form factors extend range from $Q^2 = 7.3 \Rightarrow Q^2 = 15$
- Real Compton “form factors” extend range from $Q^2 = 6.0 \Rightarrow Q^2 = 17$

Hall C Summer Workshop

August 2004

Physics Motivation for measurement of Exclusive reactions

Evolution from valence quarks in hadron to complex hadronic structure

➡ Q^2 dependence of form factors

- Pion form factor:
  - Expect transition at lower Q^2 since only $q\bar{q}$
  - Exactly calculable in pQCD.
- In NΔ transition measurement of $G^{\star}_{M}$

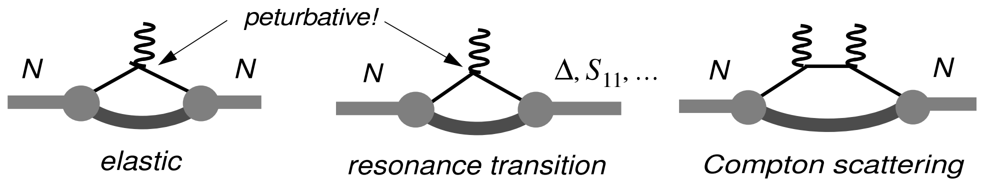
➡ Helicity conservation

- Q^2 dependence of F_2/F_1 for both proton and neutron
- Q^2 dependence of E_1/M_1 in NΔ. In pQCD, expect E_1/M_1 = 1
- Measurement of recoil proton polarization , A_{LL}, in real compton scattering.

Physics Motivation for measurement of Exclusive reactions

Constrain GPDs at high t

Factorize reaction mechanism into hard (perturbative) and soft (GPD) parts



➡Form factors related to the lowest moments of GPDs , *e.g.* the nucleon FF

$$F_1(t) = \int_{-1}^{1} \sum_q H^q(x,t)dx \quad F_2(t) = \int_{-1}^{1} \sum_q E^q(x,t)dx$$

➡Real compton access -1th moments of $H^q(x,t)$ and $E^q(x,t)$

➡$N\Delta$ FF related to isovector GPDs

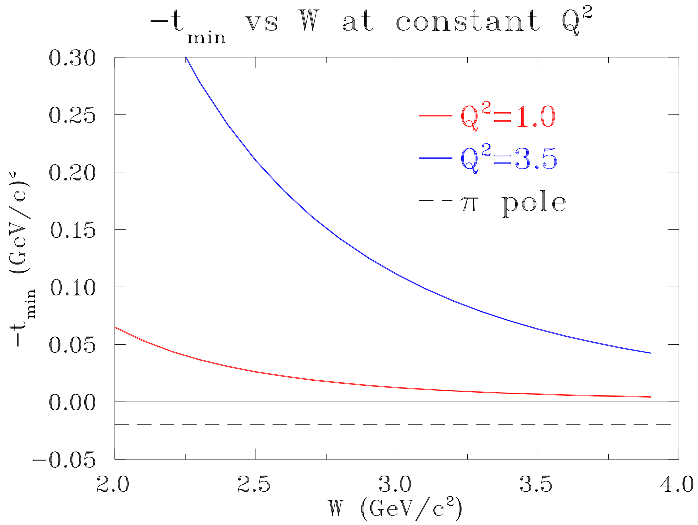
➡Provide a mapping $k_\perp$ dependence of wavefunction.

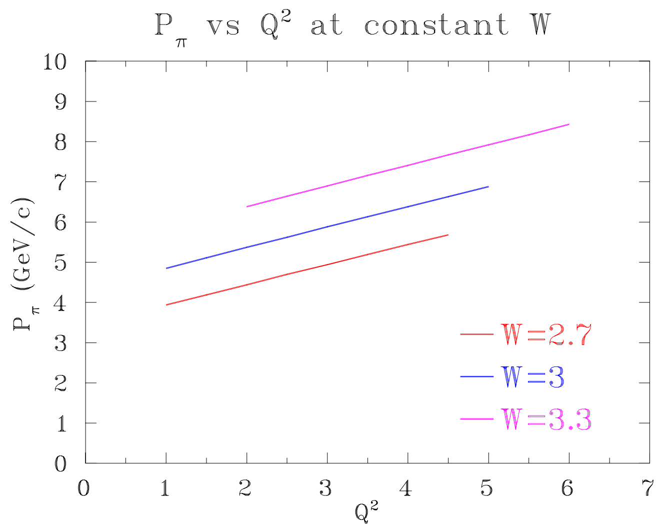
Pion Form factor

- Pick kinematics to maximize sensitivity to proton's pion field.
- Measure p(e,e$'\pi^+$)n at parallel kinematics at two epsilon, ϵ points.

  $\sigma_{cm} \propto \epsilon\sigma_L + \sigma_T + \sigma_{LT}\cos\phi + \sigma_{TT}\cos 2\phi$
- $\sigma_L \propto F_\pi$.
- In practice measure σ_L as a function of t and fit with a model to extract F_π

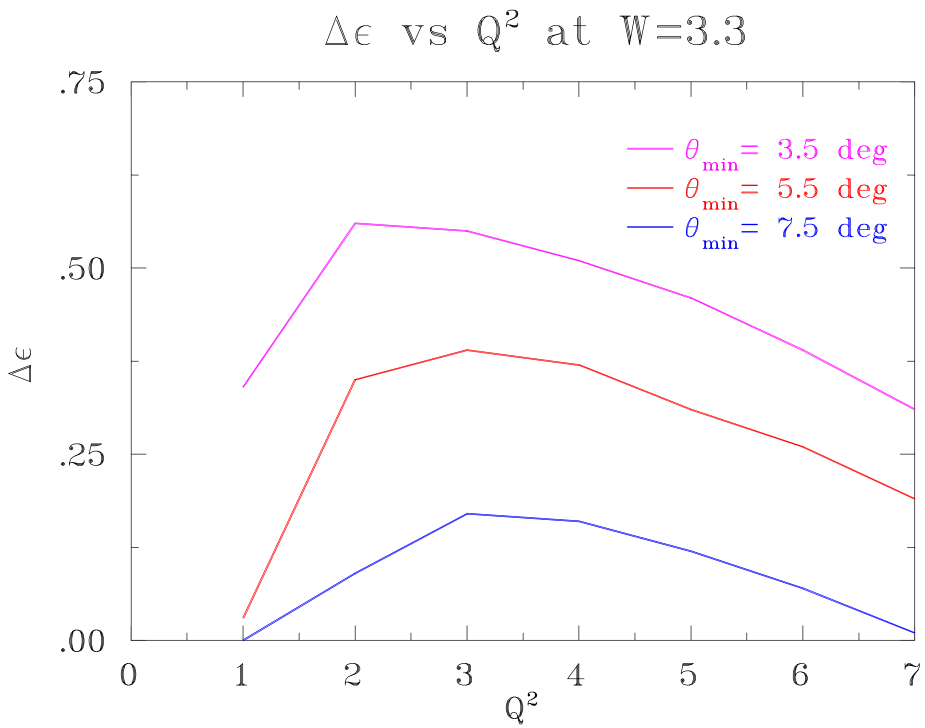
Higher W get closer to the pion pole





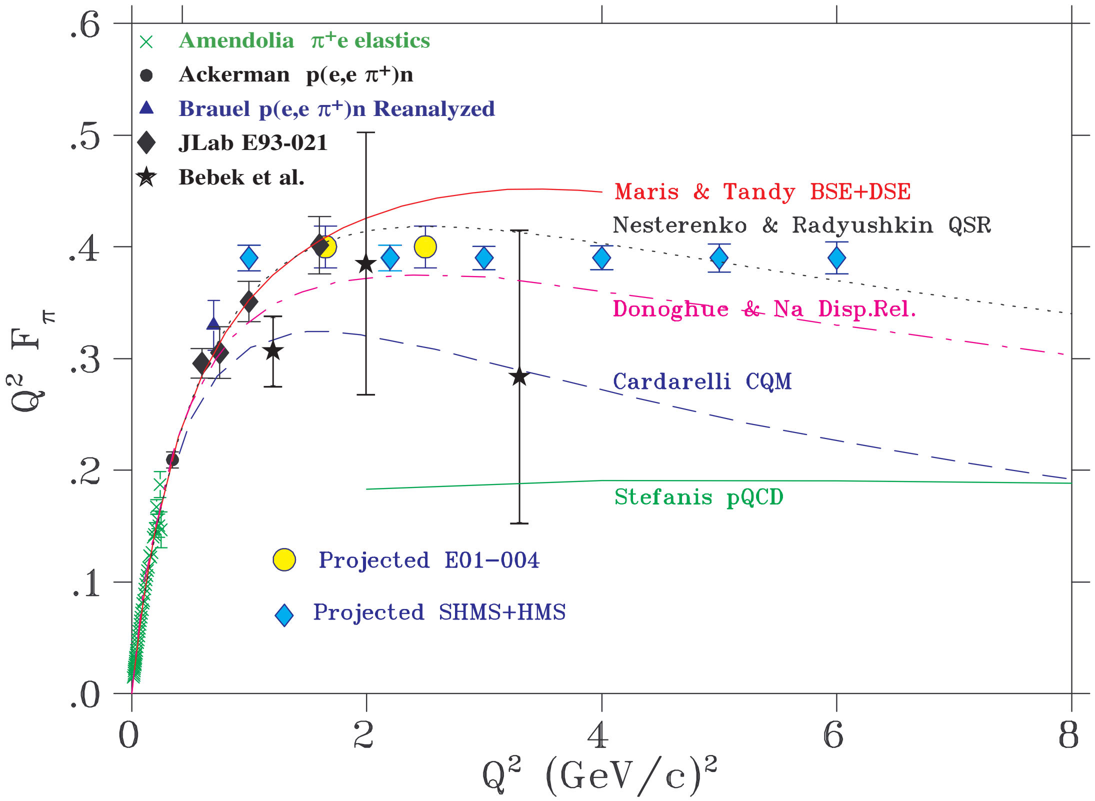
High p_π to reach high W at given Q^2

F_π experiment matched to SHMS/HMS combination



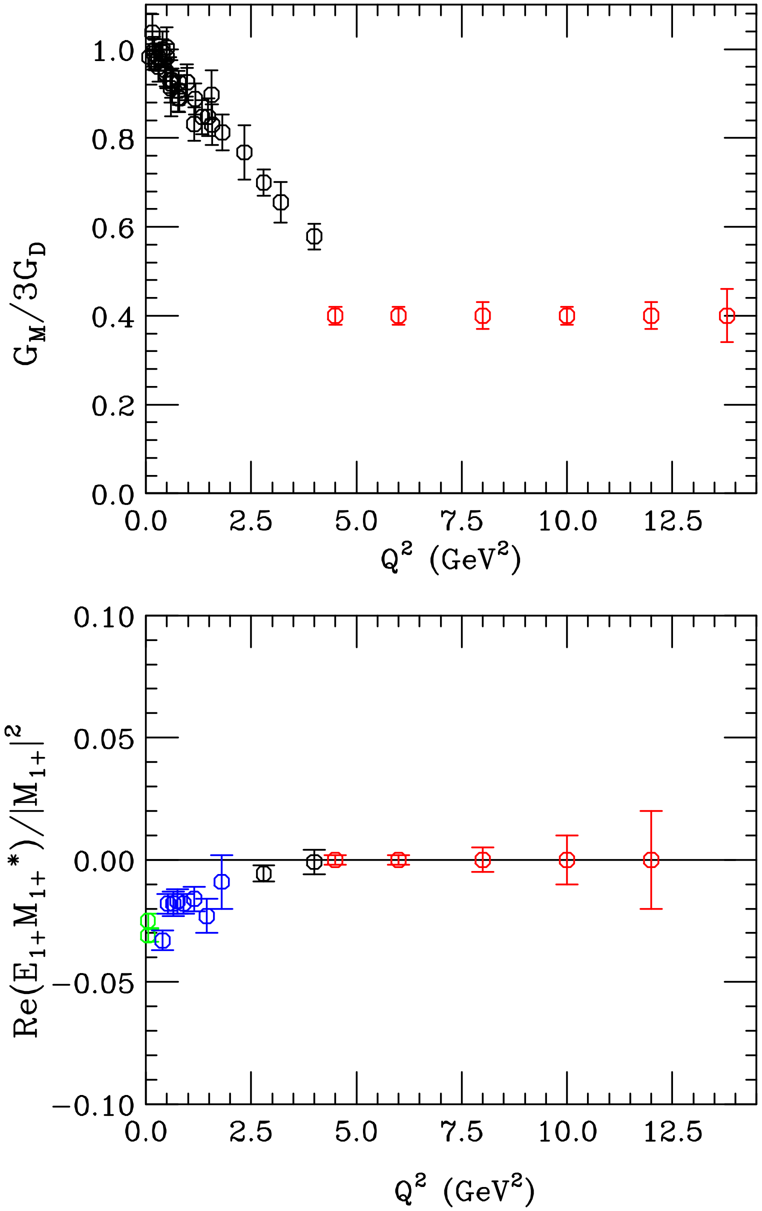
- Need spectrometer like SHMS which:
  - accepts high momentum ➡ high W
  - goes small angle (5.5°) ➡ large ϵ coverage
  - attached to pivot ➡ LT separation
- Combined with HMS can do good LT separation

F_π at 11 GeV



- Assume 50 μA on 4cm LH_2 target for 100 days.
- In 2003, measurement at Q^2 = 2.5 .

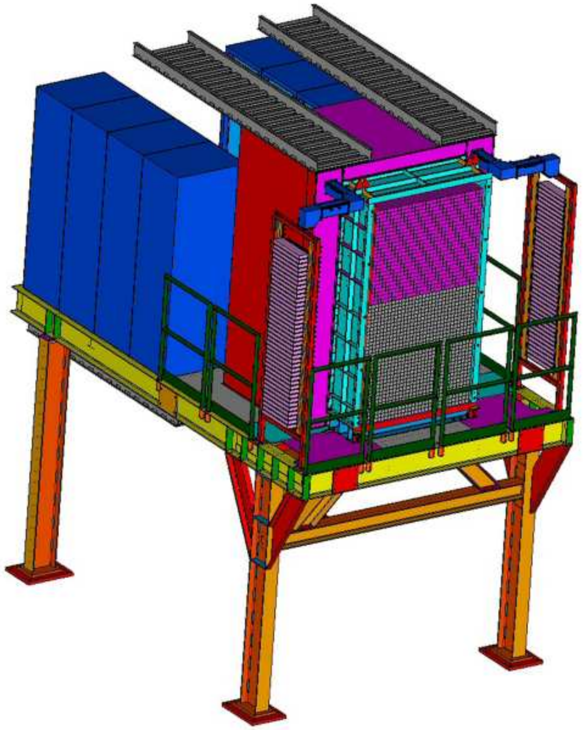
Transition amplitudes in p(e,e′p)π° or η



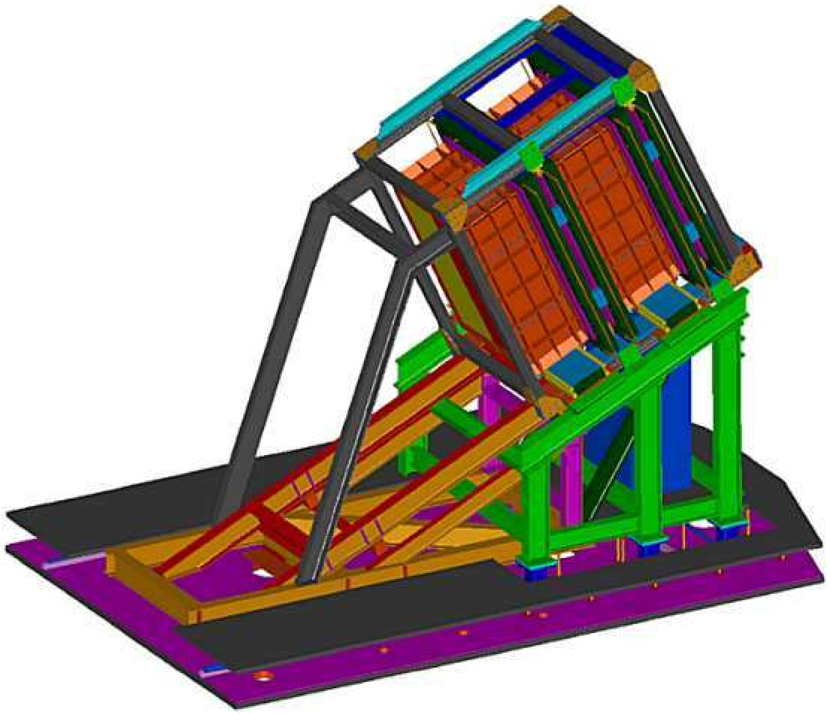
- In 35 days at 100μA beam
- SHMS needed for :
  - good angular resolution
  - tied to pivot
    (known central angle)
  - forward angle
  - high momentum
- SIMC has SHMS included.
  Used to study resolutions

Proton Electric Form Factor by $p(\vec{e}, e\vec{p})$

BigCal for electron



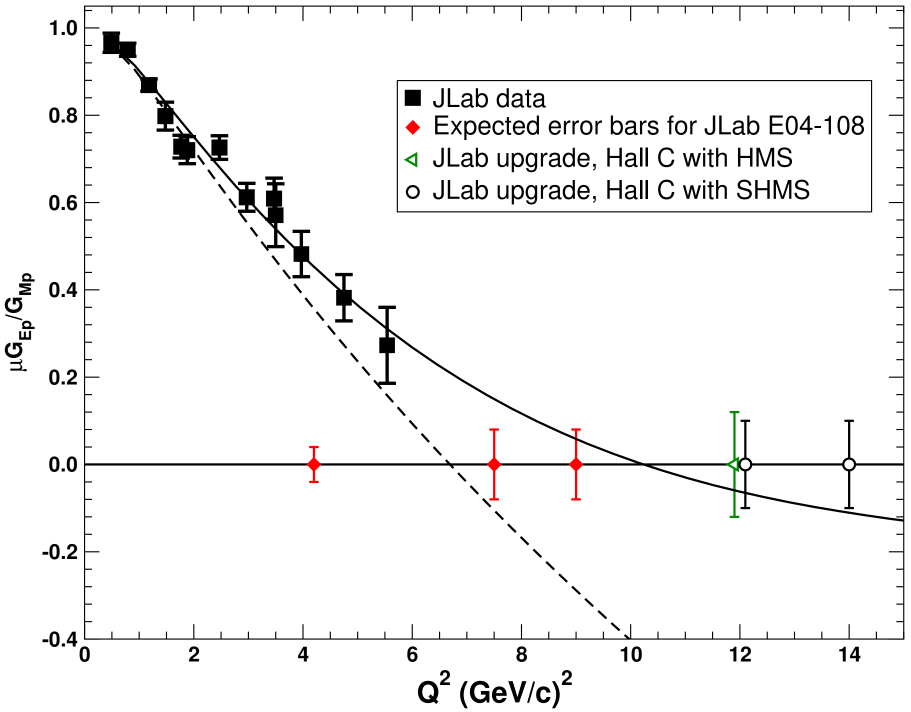
FPP in HMS or SHMS

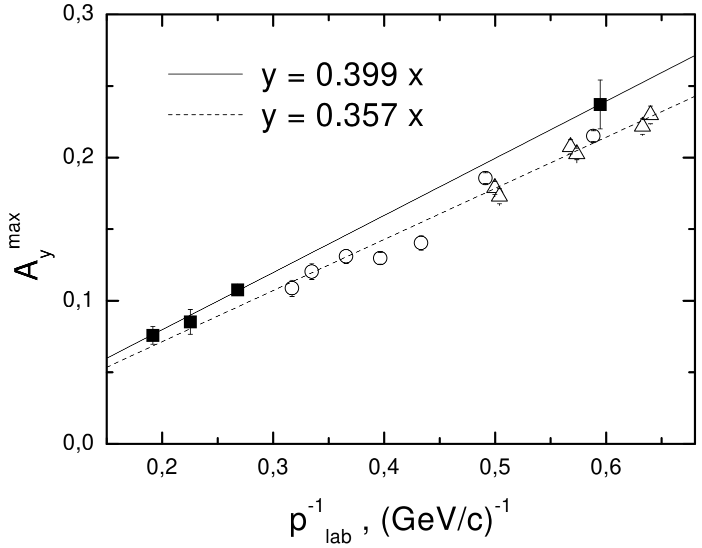


Q^2	E'_e	θ_e	p_p	θ_p
12	4.6	28	7.27	17
14	3.5	35	8.35	14

Proton Electric Form Factor

Measured A_y in CH_2 (solid) at Dubna compared to A_y in ^{12}C data (open points)



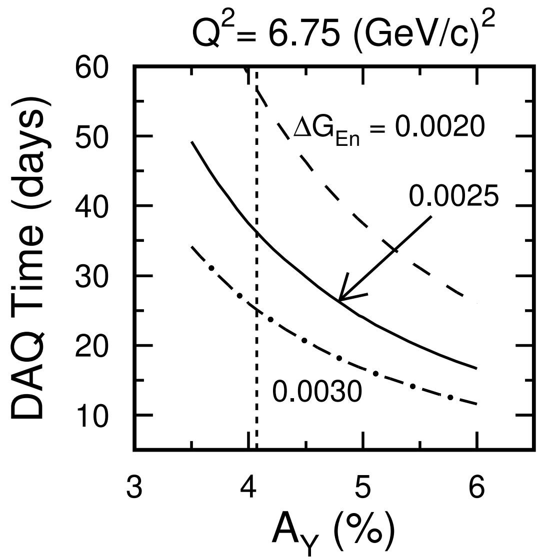


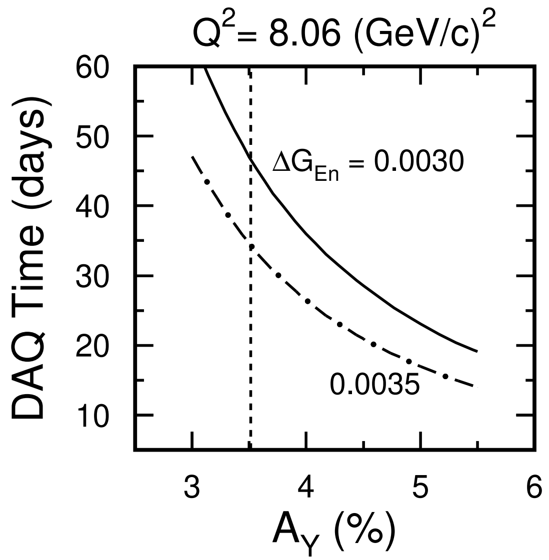
- Use extrapolation to estimate A_y (Better to have measurement at Dubna!)
- Assumed 100μA and 60 days at Q^2 = 12 and 120 days at Q^2 = 14
- χ = 350° is for HMS versus χ = 259°, 295° for SHMS at Q^2 = 12 and 14
- Systematic error probably better in HMS (QQQD) versus SHMS (combined function)

G_E^n with the 12-GeV Upgrade

[HMS maximum central momentum $P_e^{;} = 7.3$ GeV/c]

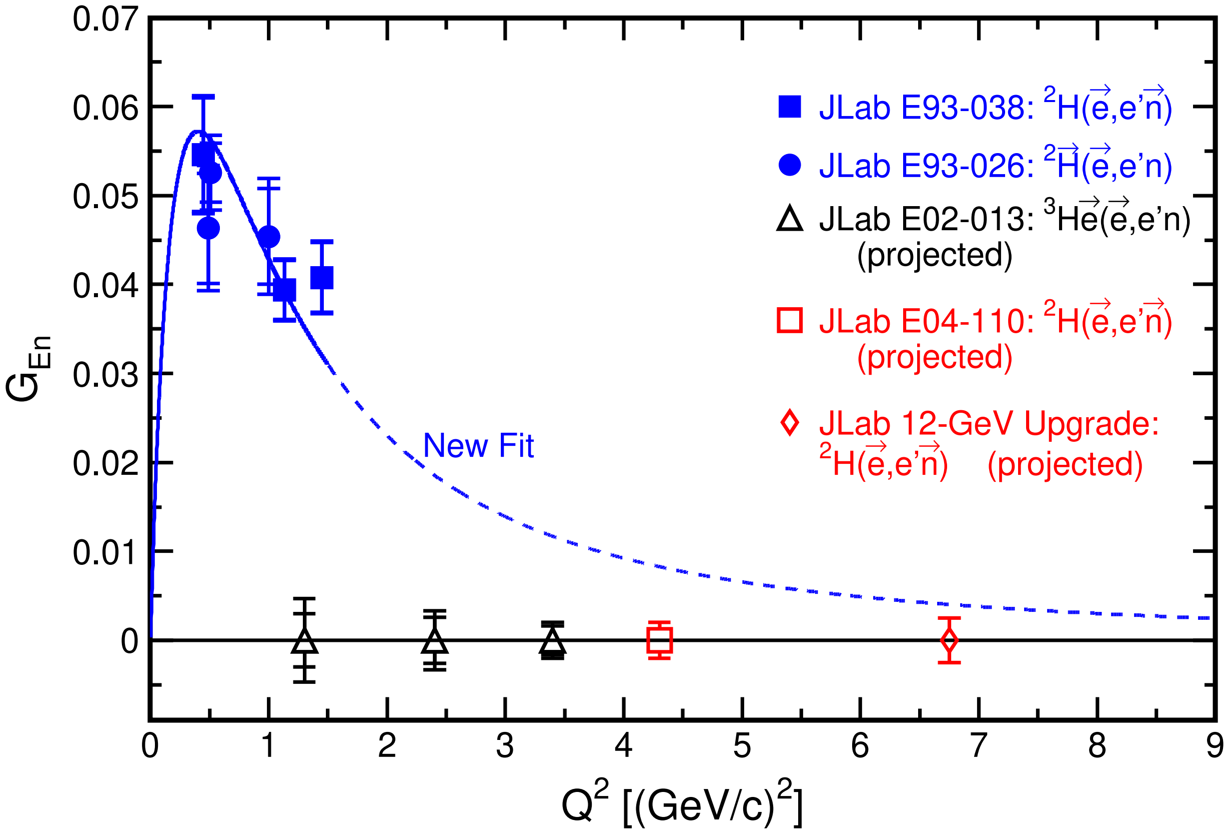
Four-Momentum Transfer, Q^2 (GeV/c)^2	**6.75**	**8.06**
Beam Energy, E_0 (GeV)	10.9	10.9
Electron Scattering Angle, θ_e (deg)	16.76	19.27
Scattered Electron Momentum, $P_e^{;}$ (GeV/c)	*7.295*	*6.600*
Neutron Scattering Angle, θ_n (deg)	28.2	25.0
Neutron Momentum, P_n (GeV/c)	4.444	5.153
Polarization Transfer $D_{LL'}$	0.448	0.530
Polarization Transfer $D_{LS'}$	0.075	0.082
MCEEP Coincidence Rate (Hz) @100μA	27.3	9.1





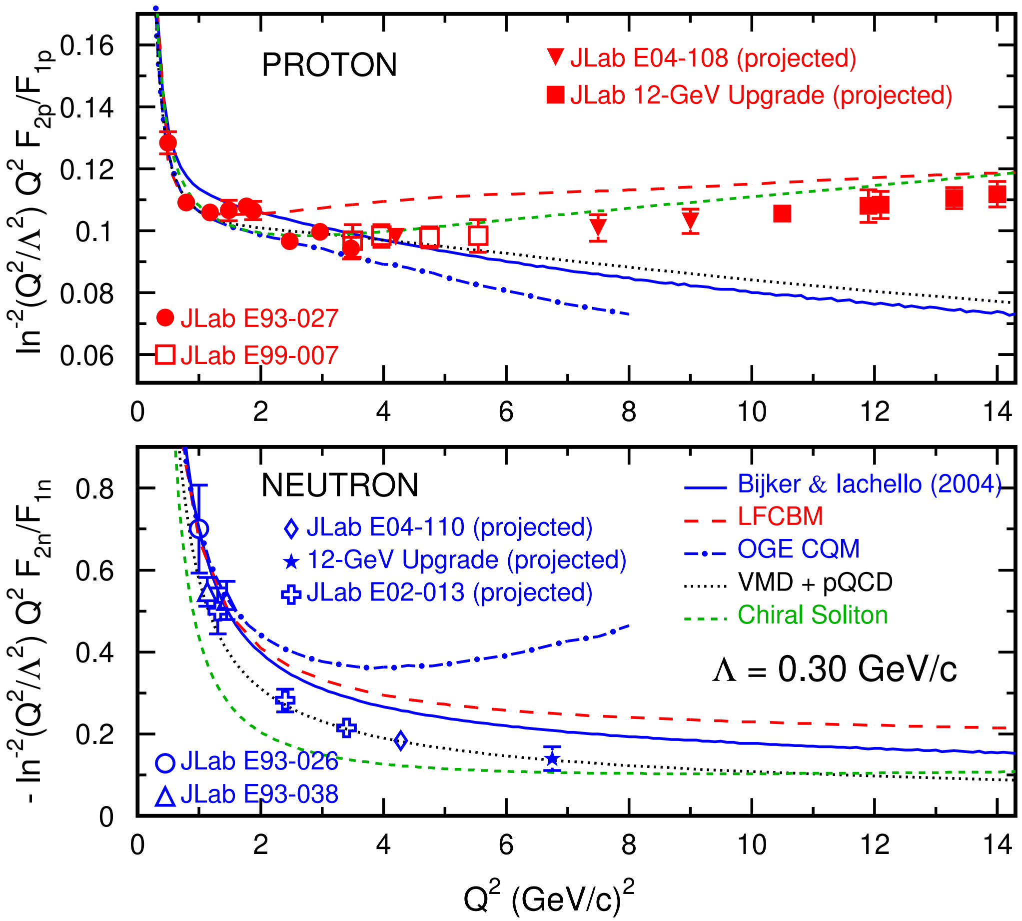
INITIAL ESTIMATE!

Neutron Electric Form Factor



- 35 days at 100 μA ➡ ΔG_E = 0.0025
- Estimated A_y at Q^2 = 6.75 by extrapolating from A_y at Q^2 = 1.43 using c/p_n .
- Will have A_y measurement at Q^2 = 4.3 in near future.
- Measurement at Dubna for p_n = 4.4?

Pertubative QCD



Belitsky,Ji and Yuan (PRL 91 (2003) 092003) calculate that the leading contribution to $F_2 \propto Q^{-6}$.

Derived $F_2/F_1 \sim \log^2(Q^2/\Lambda^2)/Q^2$, Λ is the soft scale related to size of nucleon.

Summary

- Both pion form factor and resonance transition FF need SHMS and HMS combination
  - SHMS provides high momentum and forward angle detection of pions and protons.
  - Both connected to pivot so known central angles for LT separation and measurement of ϕ_{cm} distributions
  - Both have relatively flat acceptance and good resolution
- Proton FF and Real compton experiments need BigCal in combination with HMS or SHMS.
- Neutron polarimeter for G_{En} can be used for higher Q^2 points at 11 GeV.

➡ Combined with Hall B measurement of G_{Mn} to Q^2 = 14 , will have nucleon EM form factors over a wide range in Q^2

➡ Pion form factor will provide a test of applicability of pQCD.

➡ Through GPDs can relate the various form factor measurements.