PR05-004: A(Q) at low Q in ed elastic scattering

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- Jeopardy update of E02-004, approved by PAC 21 for 5 days at B+ priority

Physics motivation

Some experimental details

Run plan and time request

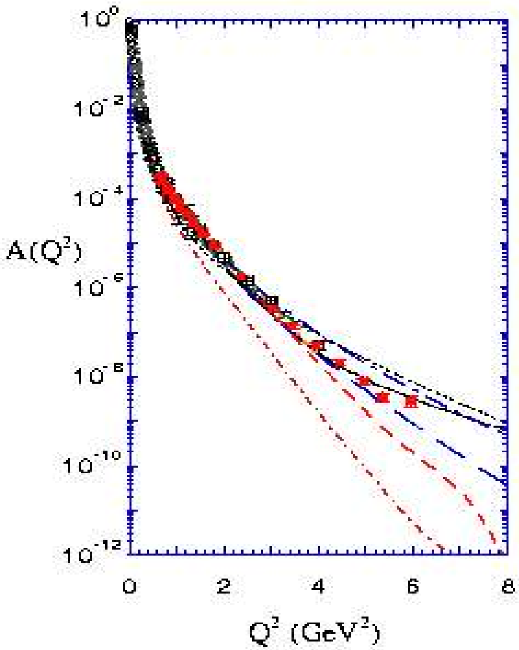
Overview

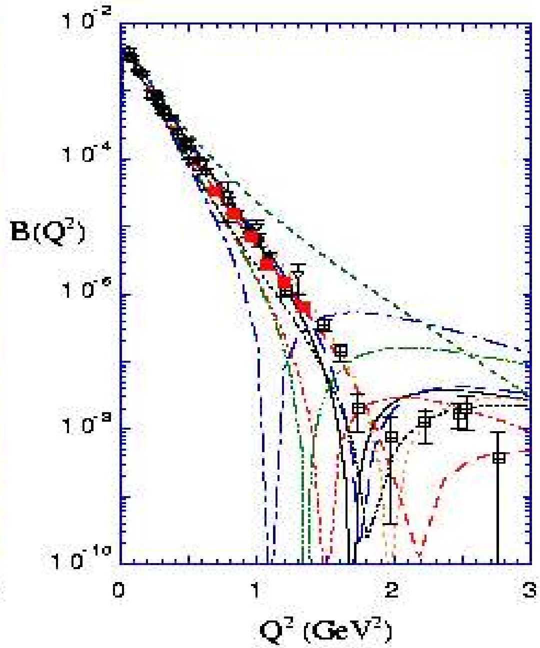
- Deuteron elastic scattering is a primary test case for predicting nuclear structure from NN interaction
- Many theoretical tools: conventional theory (NR, rel), no-π EFT, χPT, pQCD ...
- Spin 1 deuteron has 3 form factors:

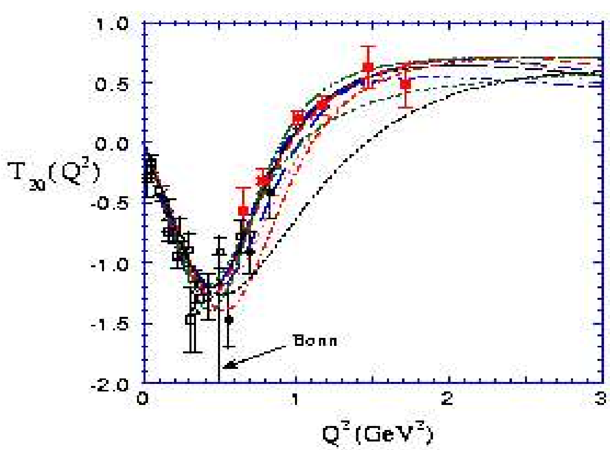
$$\sigma = \sigma_{NS}\,[A(G_C,G_Q,G_M) + B(G_M)\tan^2(\theta/2)]$$

- Goal: high precision, low Q, improved A data base to test χPT, rel. corrections to see if we understand the deuteron to the few % level

Overview of Data







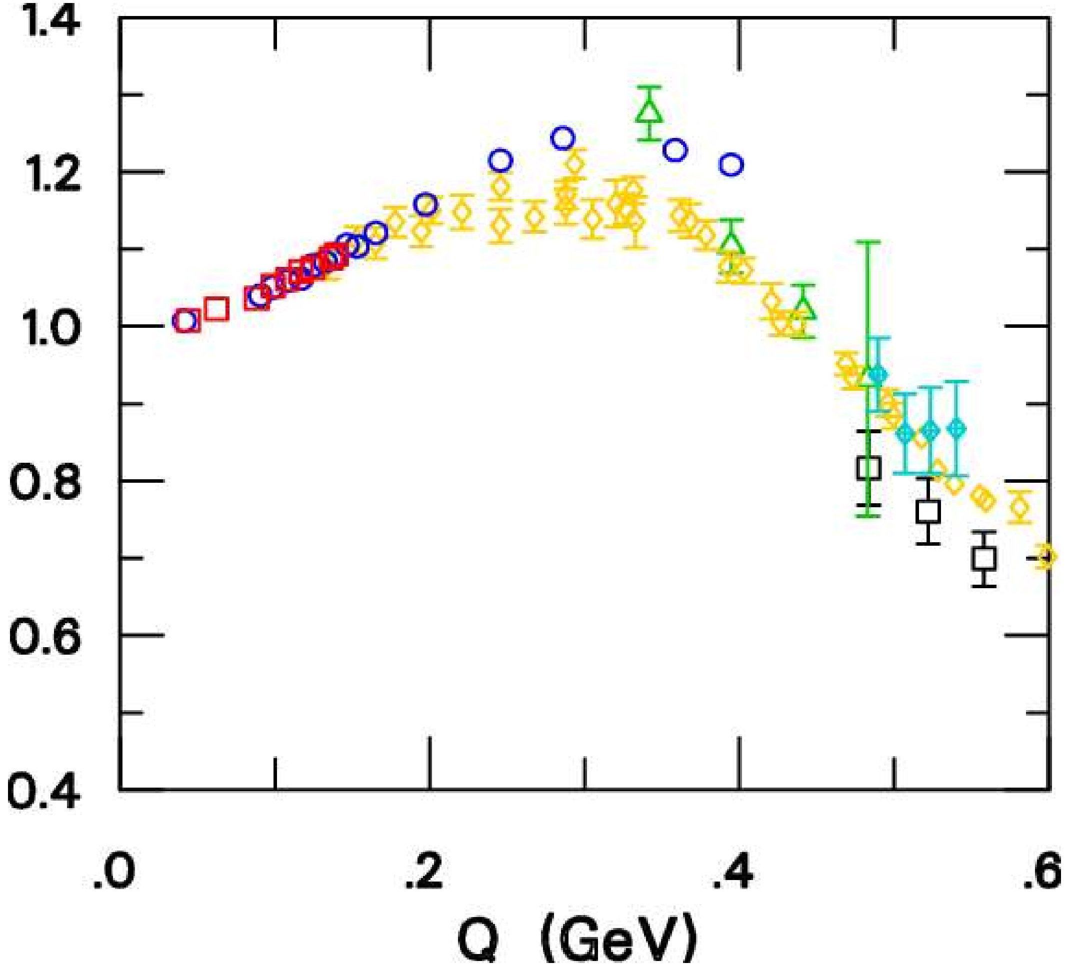
Overview suggests good agreement at low Q, need to better determine minimum of B and push all observables to higher Q - but semi-log plots hide problems. Critical look indicates only ~3 good calculations.

A Note on Different Theories

- There are many ways to formulate relativistic deuteron theory: point / front / instant form methods, or Bethe-Salpeter, Gross eq., and equal-time field theories. χPT also includes relativistic corrections at each order.
- As different methods of including the same physics, all should give the same prediction if carried out completely and consistently.
- Only two calculations have complete/consistent MEC. Their variation better indicates the theoretical uncertainty.

A Data at Low Q

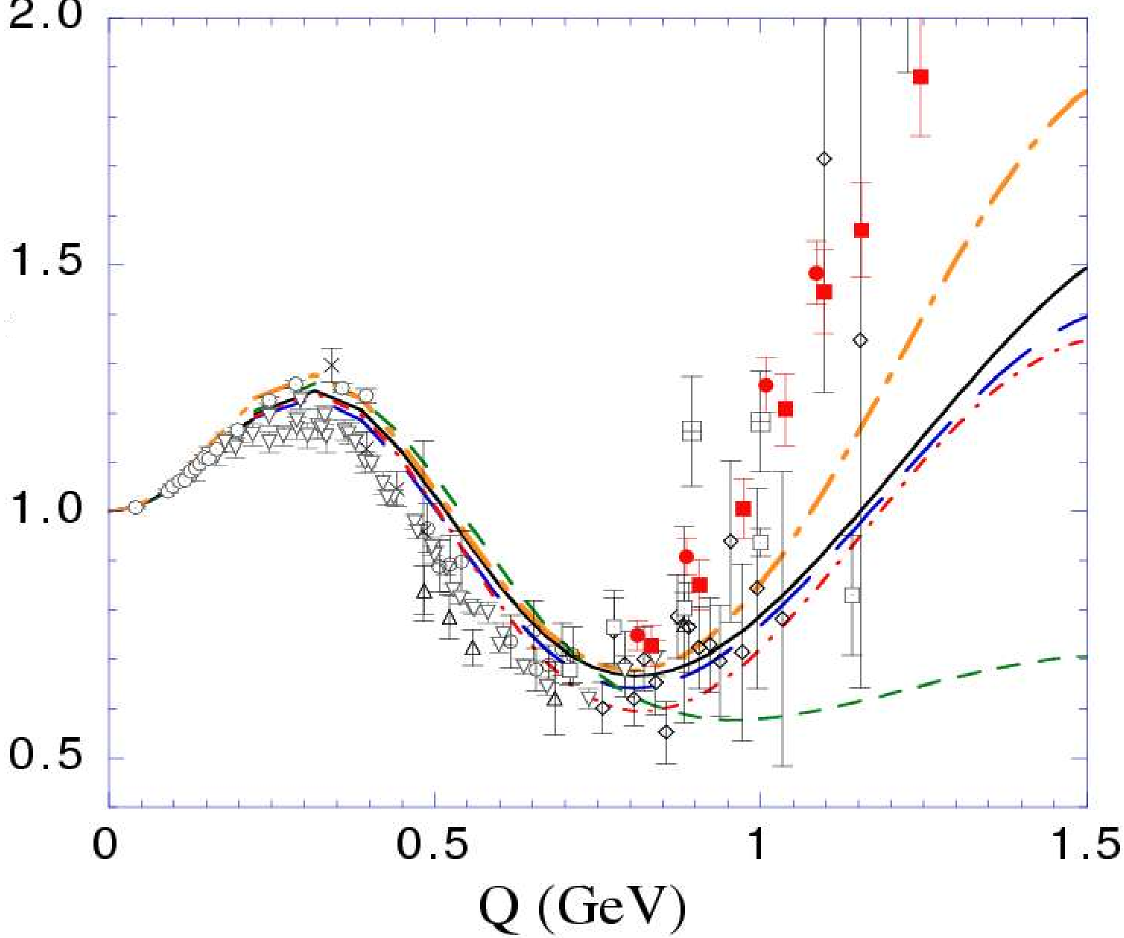
$A/A_{\text{"fit"}}$ vs. Q



- Mainz and Saclay consistent in A for Q ≤ 0.2 GeV, B, and ep elastic to < 1%, but not in A for Q ≥ 0.25 GeV
- Hints of problems in each data set, but only at ~2% level
- Improved data important

Nonrelativistic Theory Precision

$A/A_{\text{"fit"}}$ vs. Q

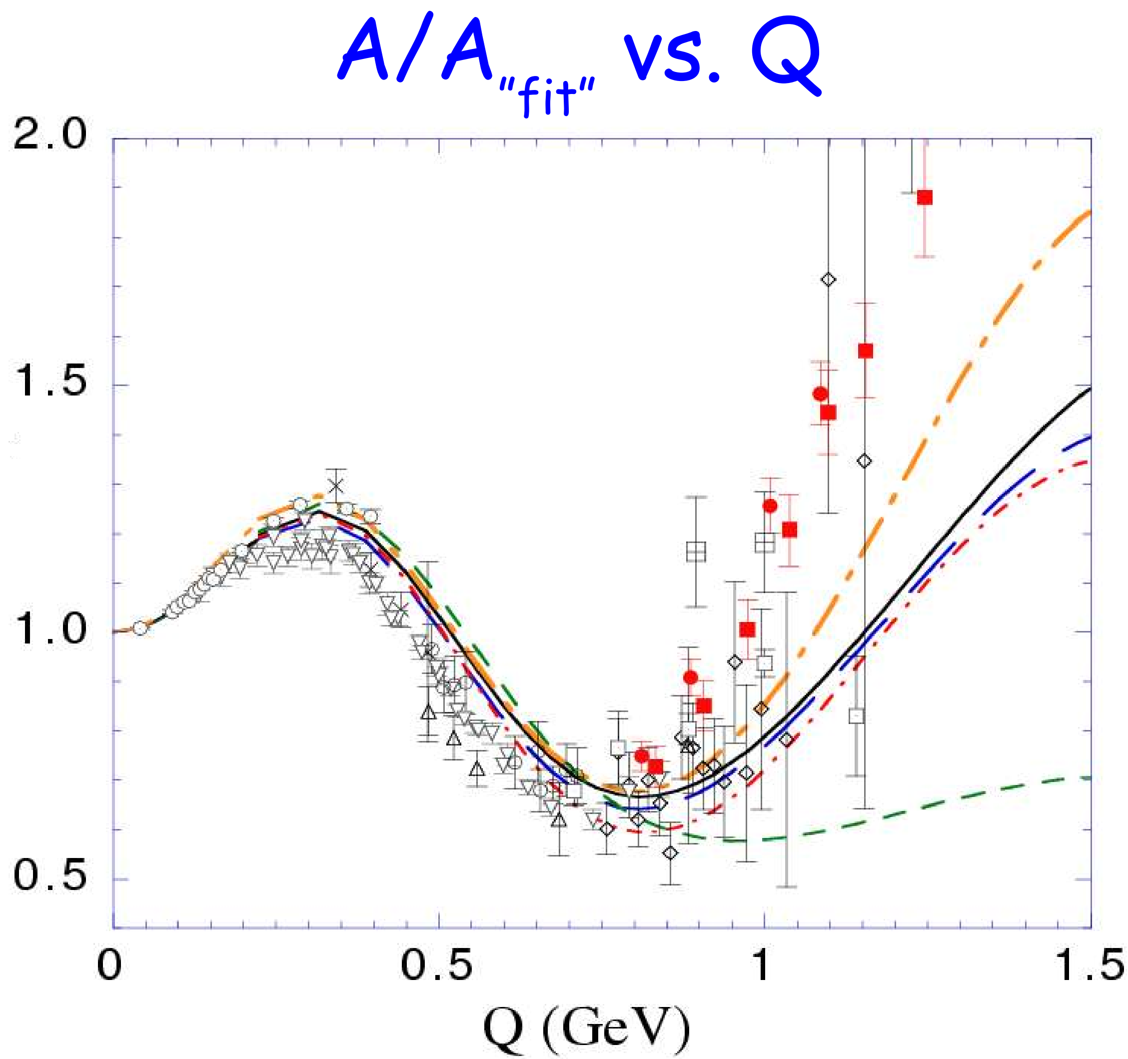


NN force uncertainties small, lead to NR theories consistent to ~±2% or better at low Q

In order from largest at 0.35 GeV: W16,CD-Bonn,AV18,IIB, and Paris.

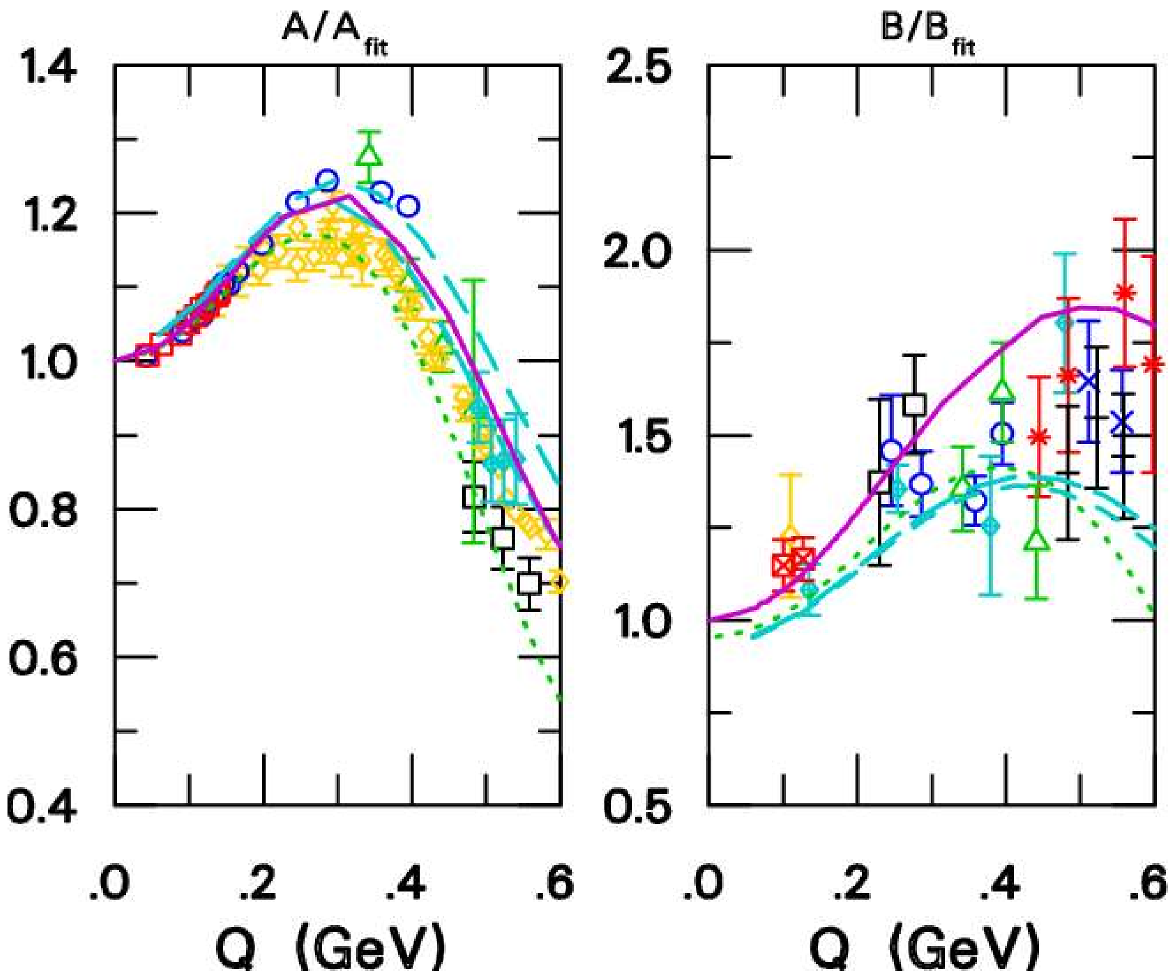
Only CD-Bonn and AV18 are χ^2 = 1 fits to phase shifts.

Nonrelativistic Theory Precision



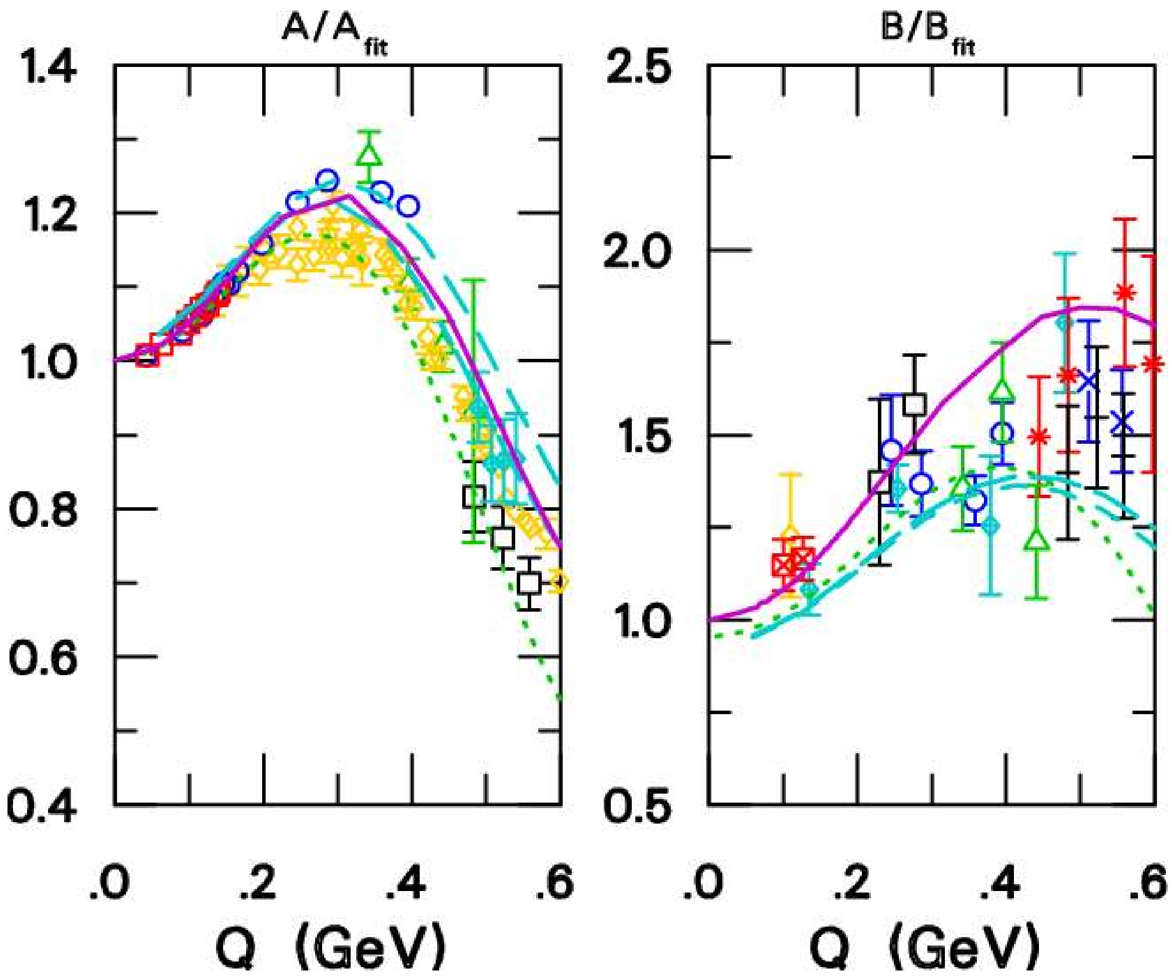
It is less clean to investigate relativistic corrections at high Q, due to large uncertainties in the NN force, the $\rho\pi\gamma$ MEC, and the off-shell current of nucleons in nuclei

ChiPT and Rel. Theory vs A and B



- FSR: IA, MEC
- VOG CIA
- DP χPT
- Rel. theory uncertainty large (20%) for B, but small (2%) for A

Disagreement in A not from B

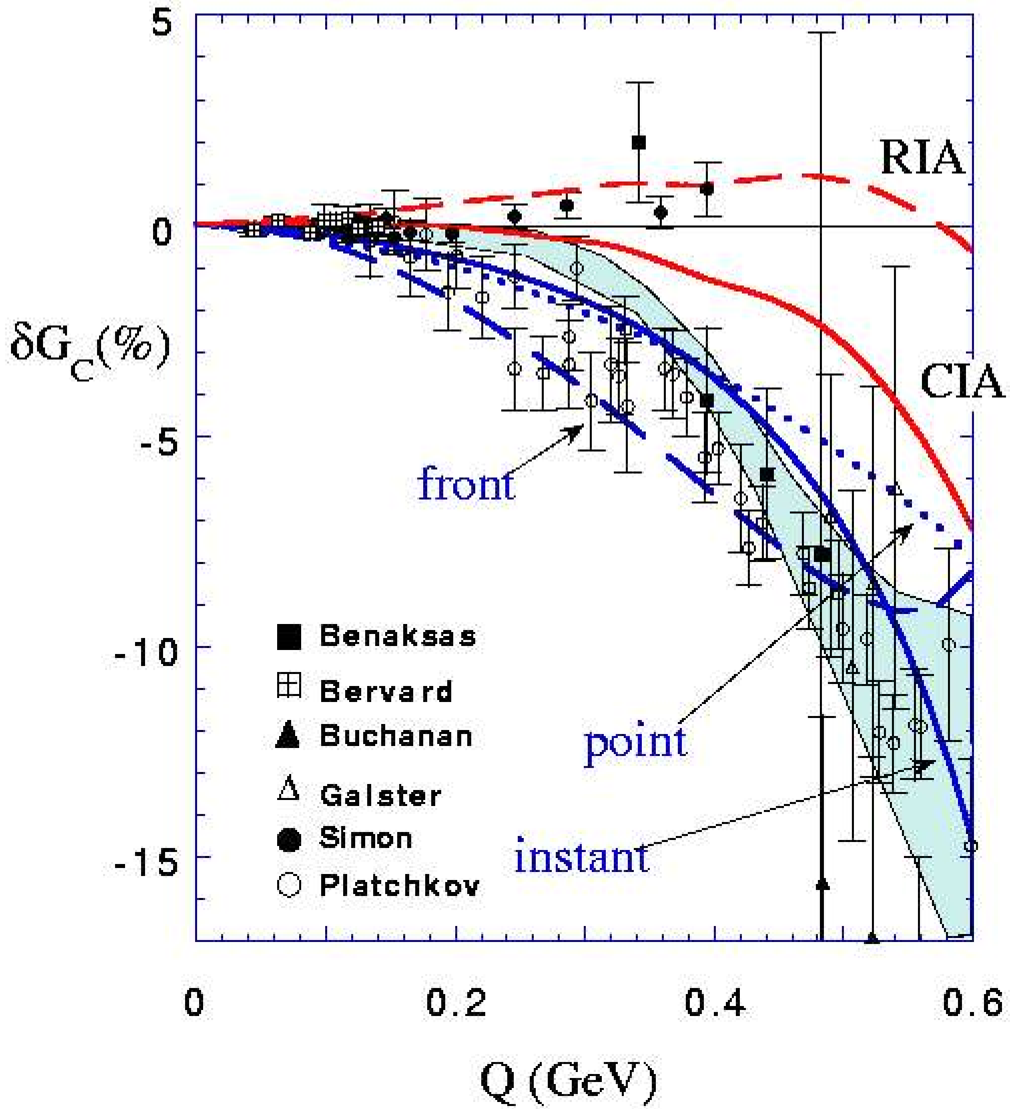


- Mainz and Saclay A data disagree for Q=0.25-0.4, but B agrees
- B poorly determined, but small effect on σ

Why High Precision, Low Q A(Q)?

- Only know “reality” at Q~0.4 GeV to ~10%
- Theories vary about 10%, but two best theories agree much better, sit in middle of data range.
- Conventional ambiguities here small (NN force, $\rho\pi\gamma$ MEC, off-shell form factor)
- Don't know how well χPT converged without better precision data
- Goal: determine rel. corr, how well we understand deuteron
- Results will be of great interest to many theorists

Relativistic theory vs G_C



- Small corrections convert A to G_C
- Plot wrt NR AV18
- What are the rel. corrections, at low Q where small?
- F/P/I incomplete, poor at high Q, overestimate theory uncertainty

Experimental Overview

- Attempt high precision absolute measurement (2-3%), and even higher precision relative measurement (<1%)
- Use multiple cross checks to ensure small, under control, known systematics
  - Measure ep, ed, $e^{12}C$ vs θ (Q) at fixed E_e
  - $^{12}C(e,e')$ known to 1% to Q~0.45 GeV: Offermann, Cardman, de Jager et al.
  - Measure with both HRS-L and HRS-R (each measures ang. dist. with other fixed luminosity monitor)
  - Measure at 2 beam energies

Previous High Precision p,C Data

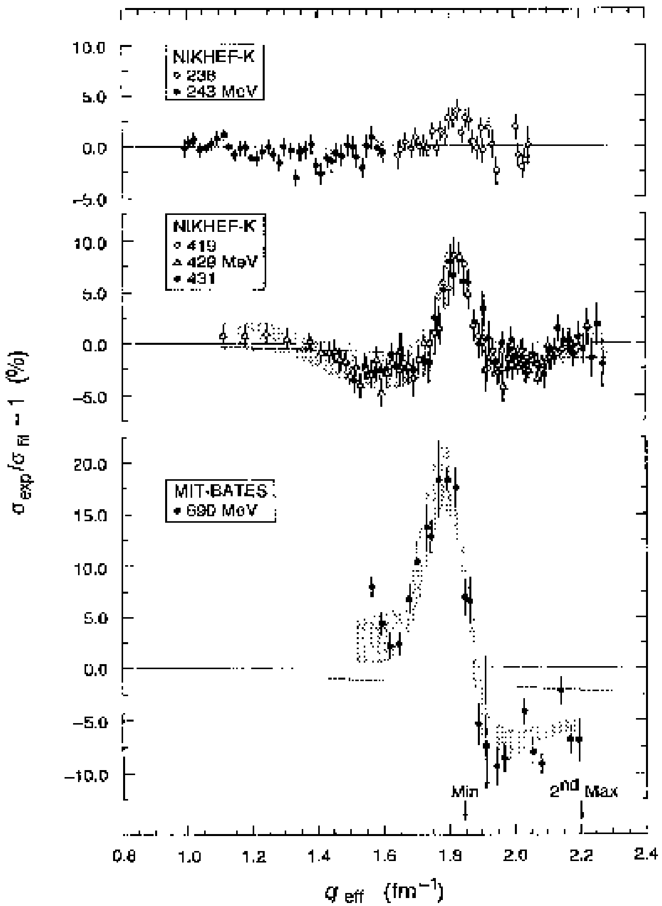


FIG. 11. The differences between the cross sections measured at six incident electron energies (from 238 to 690 MeV) and the values predicted by the ground-state charge density parameters obtained from the data at lower energies (see text). The dashed curves indicate the energy dependence of the dispersive contribution according to Friar and Rosen [12] between 240 MeV and the energy under consideration.

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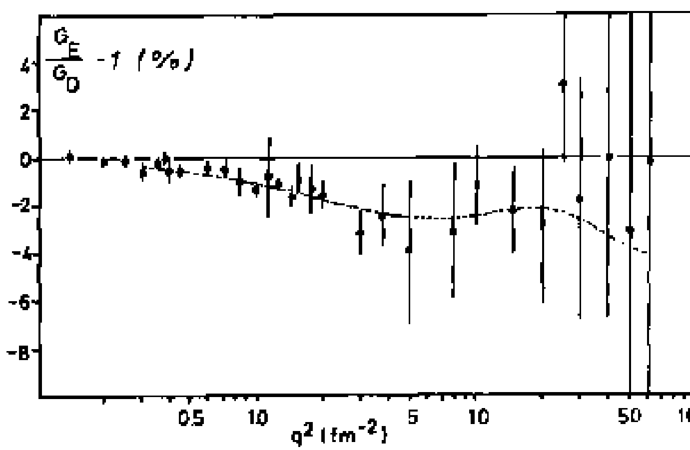


Fig. 3. The ratio G_E/G_D versus q^2. The dashed line is the best fit calculated with a monopole ansatz.

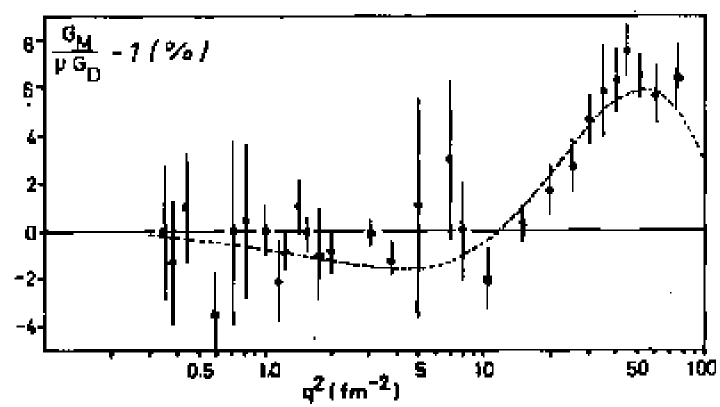


Fig. 4. The same as in fig. 3, but for the magnetic form factor G_M.

E01-001 "Super-Rosenbluth"

- Recent high-precision Hall A experiment
- "Published" leading uncertainties (Note we have much higher, and much wider range of, singles rates):

Item	absolute (%)	relative (%)
Solid Angle	2	0.0
Radiative Correction	1	0.2
Background Subtraction	1	0.2
Luminosity	1	0.0
Tracking efficiency	0	0.2
Scattering Angle	0	0.2
Total	3	0.45

Kinematic Sensitivity

- Uncertainty in cross section and A due to knowledge of Q dominated by knowledge of scattering angle
- At 857 MeV, 0.3 mr uncertainty leads to 0.8% (0.3%) at Q=0.2 (0.8) GeV
- At 600 MeV, 0.3 mr uncertainty leads to 0.5% (0.2%) at Q=0.2 (0.8) GeV
- Knowing Q is largest systematic uncertainty in determining $A(Q_1)/A(Q_2)$

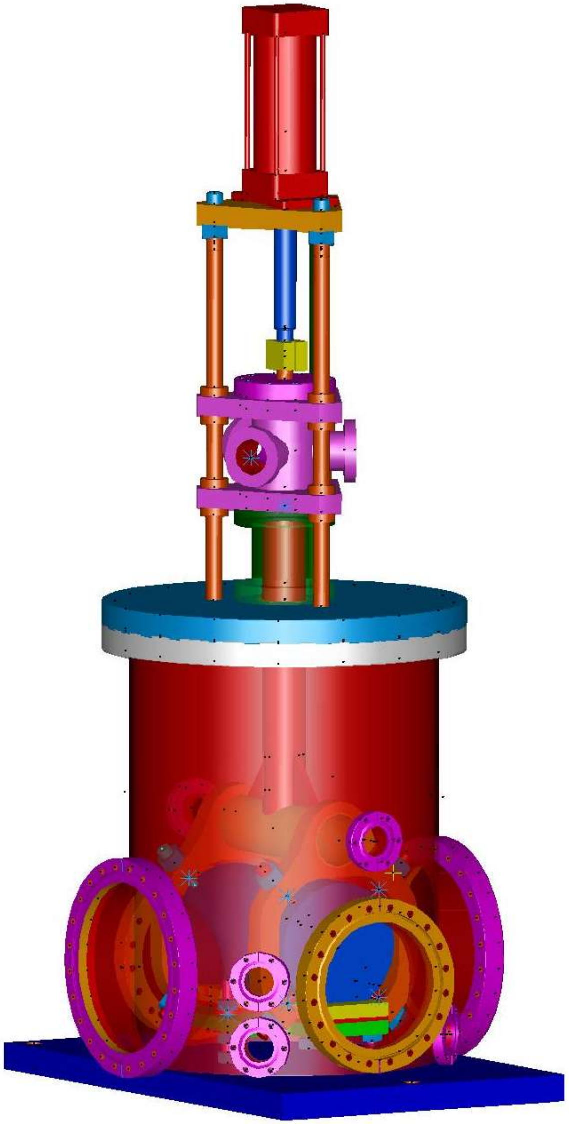
Luminosity

- Target areal density known to ~0.2%
- Relative luminosity good to ~0.1% (with monitor spectrometer, rate dependences understood)
- Hall A at present has no mechanism for calibrating absolute beam current at small currents (or even verifying relative current)
- We are building beam calorimeter for these calibrations, copying and improving upon 1% SLAC silver calorimeter

Beam Calorimeter

- Uncertainty estimate, from May 2004 design review

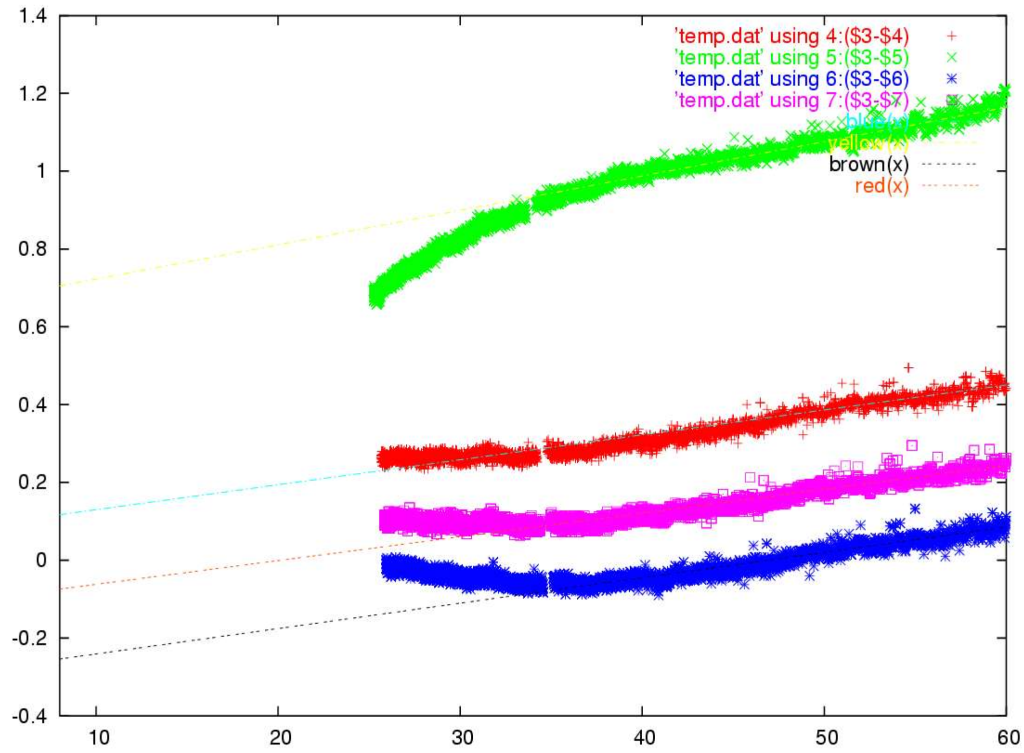
Item	Loss (%)	Uncertainty (%)
Beam Energy	0.0	0.02
Thermometry	0.0	0.2
Heat Capacity	0.0	0.2
Heat Losses	0.4	0.1
EM showers	0.15	0.05
Hadronic loss	0.3	0.15
TOTAL	0.85	0.34



Beam Calorimeter

- First cross comparison of four small surface mount RTDs to high precision NIST-traceable Omega probe (10 mK)

$T_{RTD} - T_{Omega}$ vs T_{Omega}



Beam Calorimeter

- Currently working with aluminum slug
- RTDs come good to ~200 mK (abs), good enough for <1% current determination, but not good enough for our ambitions
- Working on cross-calibration procedure, have just obtained more robust RTDs
- Spending $$, expect to build and install ~end of year, commission during 2006 facility development time

Systematic Uncertainties

- Estimated leading systematics

Systematic	Absolute (%)	Relative-d (%)	Relative-p (%)
Angle	0.5	0.7	0.1
Charge	0.5	0.1	0.1
Areal density	0.2	0.1	0.3
Solid angle	1.0	0.1	0.1
Rad. corr.	1.0	0.1	0.1
det. eff.	0.7	0.2	0.2
...			
Total	1.8	0.8	0.4

Kinematics / Rates

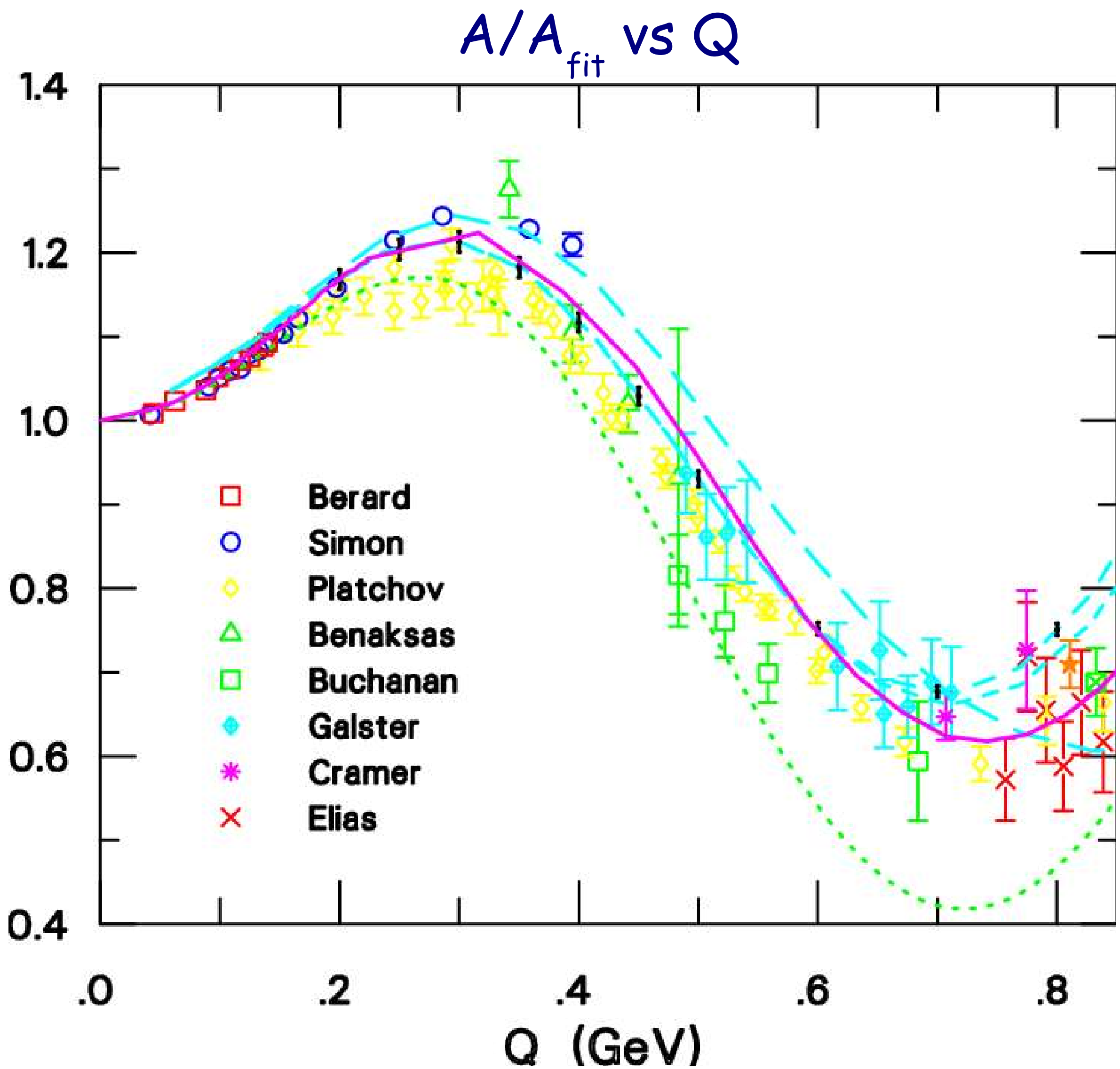
- Mostly 0.1% statistics for each point and for monitor spectrometer in Kin-4

Kin	Q (GeV)	I (muA)	Rate (Hz)	T (hrs)
1	0.20	1	70 k	0.5
2	0.25	1	16 k	0.5
3	0.30	1	4000	0.5
4	0.35	1	1300	0.5
5	0.40	3	1200	0.5
6	0.45	10	1400	0.5
7	0.50	10	500	1
8	0.60	50	350	1.5
9	0.70	50	60	3
10	0.80	50	11	4

Run Plan

- For each kinematic point, take data on elastic ^{181}Ta (low Q points only), C, C optics, Al empty cell, d, p targets
- Multiple nuclei calibrate E', θ
- Thin targets calibrate pointing, C optics calibrates y_{target}, sieve slit calibrates $\Delta\Omega$
- High precision C, d, p angular distributions (C(e,e') and p(e,e') known to ~1% up to Q~0.45 GeV)
- Repeat 4 times, with both HRS-L&R, at 2 beam energies

Projected Data



- 10 black points, on FSR full curve, with +/-1% uncertainty
- Bin size in Q: ±0.01-0.02

Time Request

Item	Time (hrs, 0.85 GeV)	Time (hrs, 0.6 GeV)
p,d data	34	17
empty cell	8	4
Carbon	15	7.5
Ta	2	1
Target changes	8	4
Angle/field changes	8	4
Access (<15°)	6	6
Ee measurements	5	5
Q calibration	1	1
TOTAL	83	46.5

PAC 21 Report

- "The measurement requires an improved knowledge of the HRS spectrometer, reduced uncertainties in the scattering angle and acceptance, as well as a more precise determination of the beam intensity."
- All these facets either demonstrated by existing experimental results or under development by us.

Summary

- Technical goal: improve Hall A systematics – some needed elements demonstrated by others, some in process by us
- Physics goal: Improved low Q A data set to allow determination of relativistic corrections and quality of NNLO χPT, not allowed with current data: how well is deuteron understood?
- 6 days at ~850 and ~600 MeV