Recent Results from the BLAST Experiment (Nucleon Electromagnetic Form Factors)

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Overview

BLAST Collaboration

- Electromagnetic structure of nucleons
- Polarization techniques
- The BLAST experiment at MIT-Bates
- Results at low Q^2
  - Proton
  - Neutron
- Concluding Remarks

Electron scattering from the nucleon

- Electron a clean probe of hadron structure
  - Electron vertex is well-known from QED
  - One-photon exchange dominates, higher-order diagrams suppressed
- Characterize structure of hadron in terms of form factors
- $G_E(Q^2)$ and $G_M(Q^2)$ related to charge and magnetization density
- One-photon exchange approximation, form factors are observables

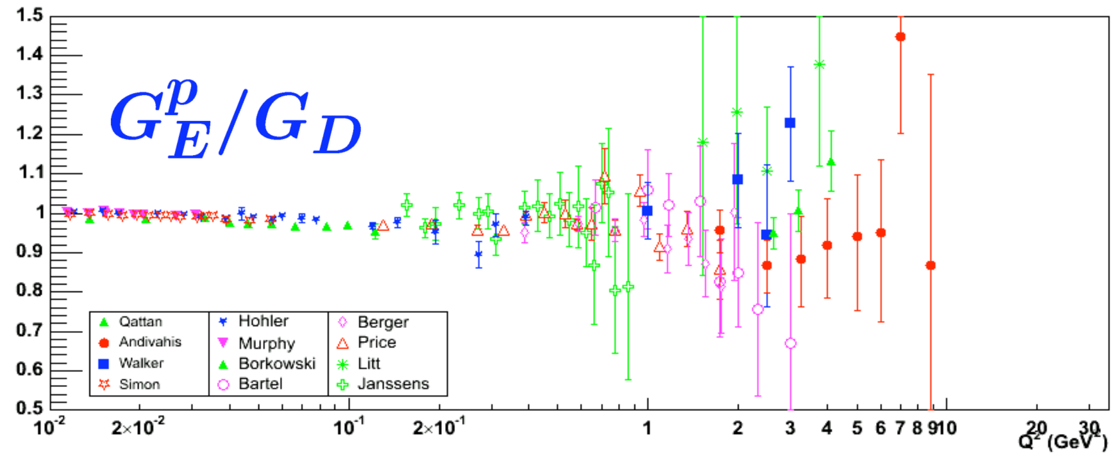
$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = S_0 = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$

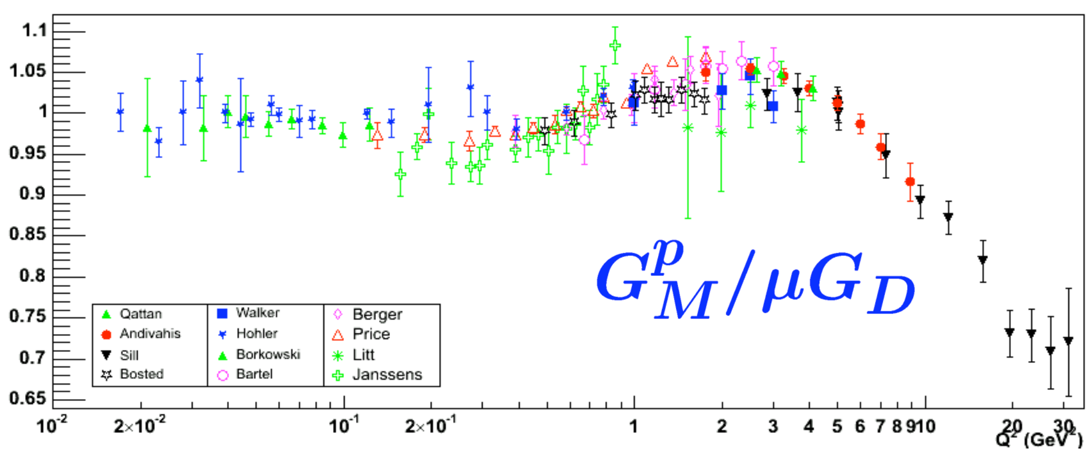
$$= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}$$

$$= \frac{\epsilon\, G_E^2 + \tau G_M^2}{\epsilon\,(1+\tau)}, \qquad \epsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$

$$\tau = \frac{Q^2}{4M^2}$$

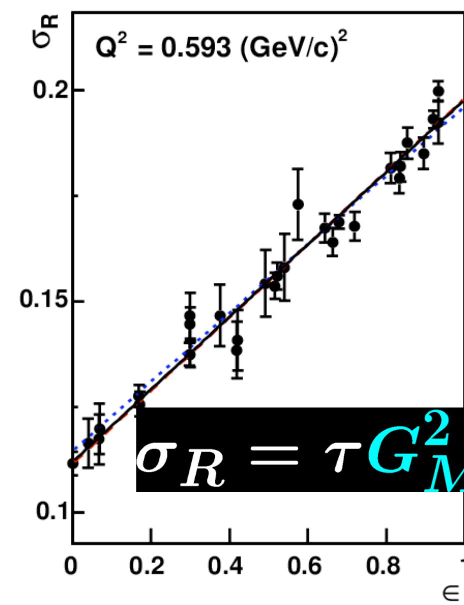
Rosenbluth Separation





$$G_D = \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

- Extract G_E and G_M from large unpolarized e-p cross section data set
- At fixed Q^2, fit $d\sigma/d\Omega$ vs. $\tan^2(\theta/2)$



$$\sigma_R = \tau G_M^2 + \epsilon G_E^2$$

–*Dominated by G_E or G_M*

- *Constrains G_E at Low Q^2*
- *Constrains G_M at High Q^2*

Polarization and Form Factors

- Double polarization in elastic ep scattering:

  Recoil polarization or polarized target

  $^1H(\vec{e},e'\vec{p})$, $^1\vec{H}(\vec{e},e'p)$

- Polarized cross section

$$\sigma = \sigma_0 \left(1 + P_e \vec{P}_t \cdot \vec{A}\right)$$

- Double spin asymmetry

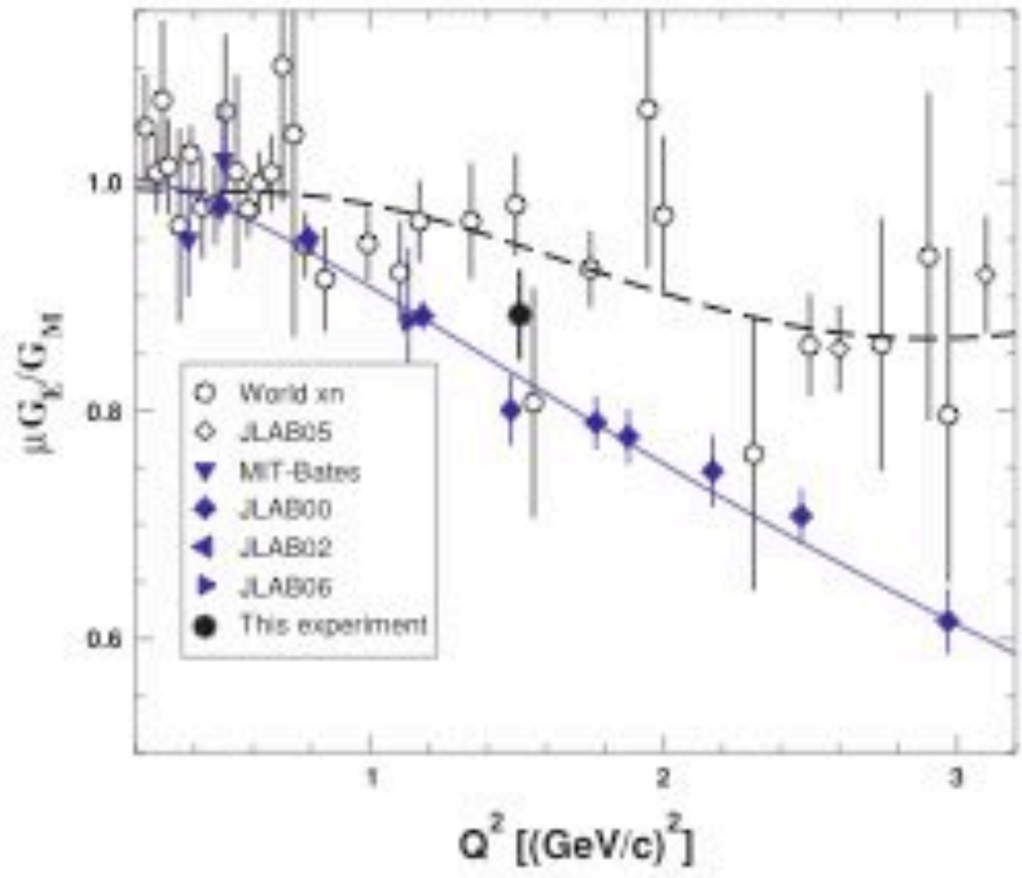
$$\frac{\vec{P}_t}{P_t} \cdot \vec{A} = -\frac{\sqrt{2\tau\epsilon(1-\epsilon)} G_E G_M \tilde{P}_x + \tau\sqrt{1-\epsilon^2} {G_M}^2 \tilde{P}_z}{\epsilon G_E^2 + \tau G_M^2}$$

- Asymmetry ratio (“Super ratio”)

  independent of polarization or analyzing power

$$\frac{A_\perp}{A_\parallel} \propto \frac{G_E}{G_M}$$

Proton $\mu G_E/G_M$

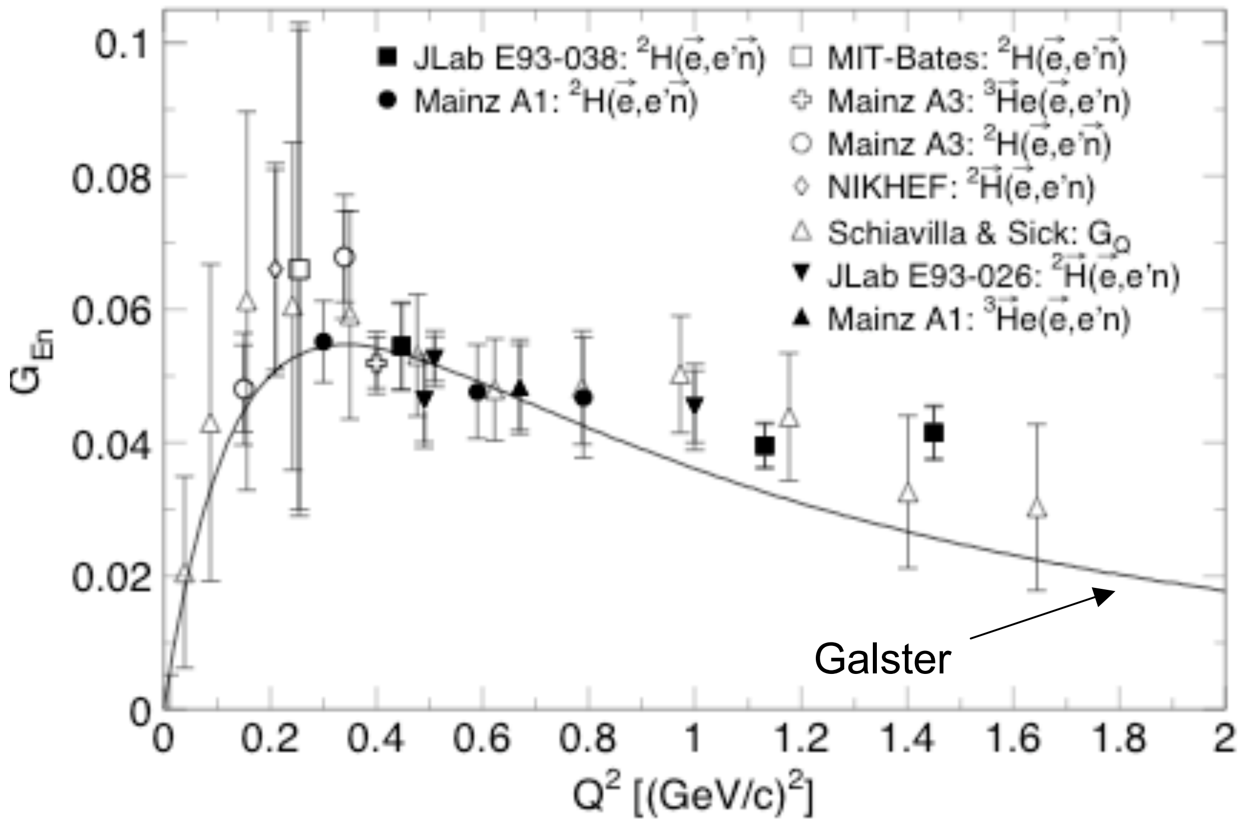


- **High Q^2 recoil polarimetry measurements**
  - Large deviation from 1
  - Discrepancy from Rosenbluth
- New polarized and unpolarized experiments confirm to high precision
- 2-photon exchange amplitudes important in discrepancy

First result from a polarized target

Jones et al, PRC 74 035201 (2006)

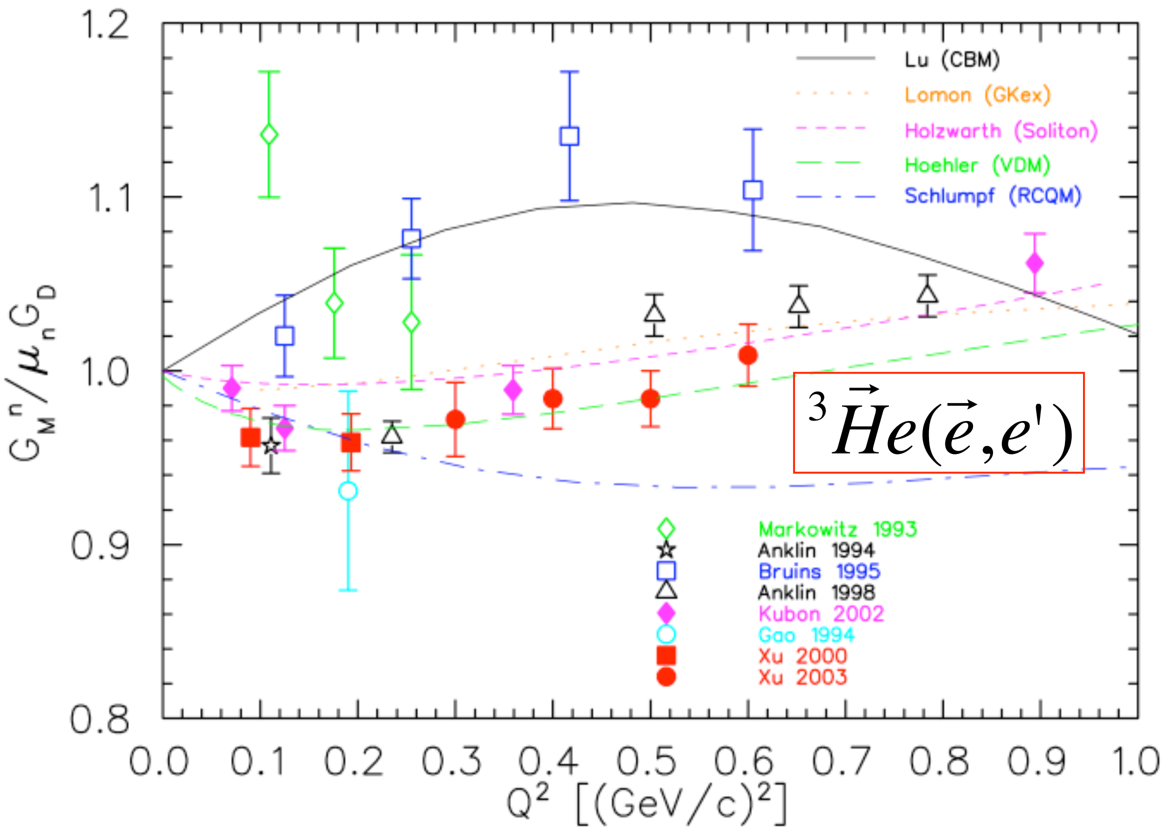
Polarization and Neutron Electric Form Factor



- No free neutron targets (^2H and ^3He)
- Cross section is dominated by G^M_n insensitive to G^E_n
- Recent precise spin-dependent experiments (multiple techniques and targets) span wide Q^2 range

- More precise G^n_E data needed at low Q^2
  - Essential for parity-violation experiments
  - Meson cloud physics

Neutron Magnetic Form Factor G^n_M

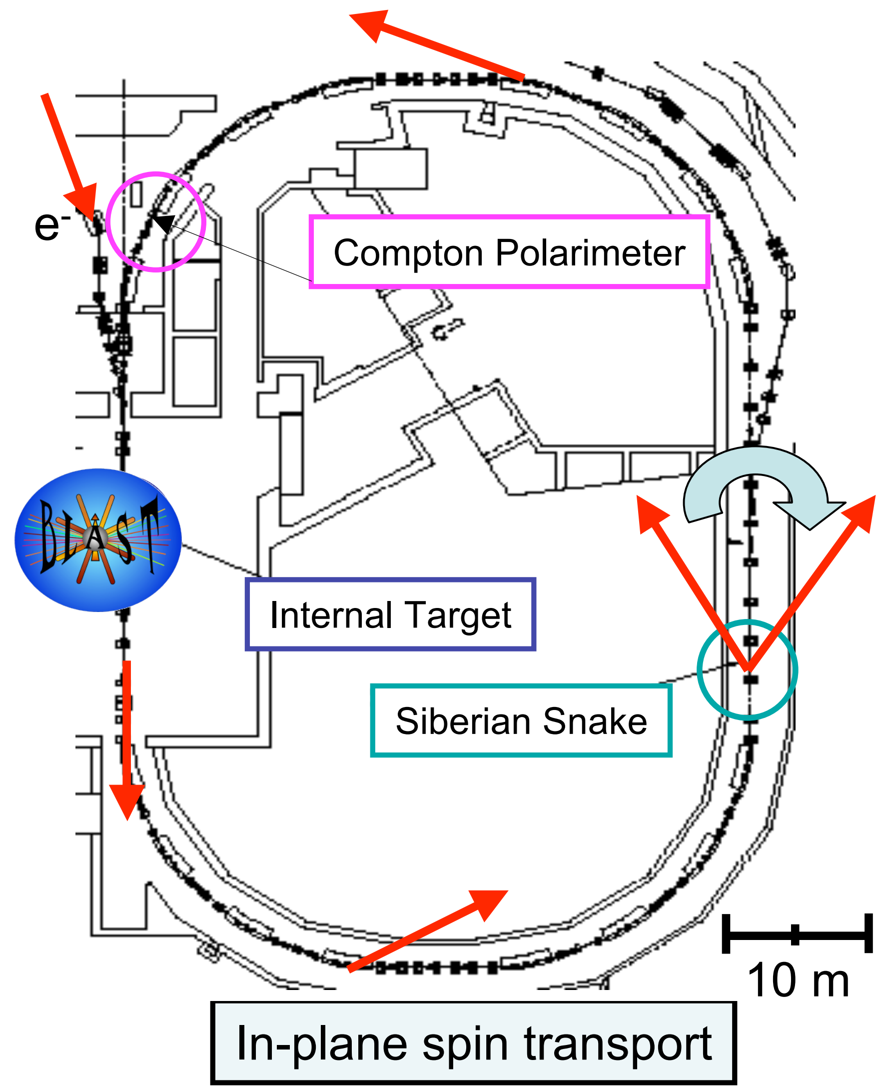


- In pre-polarization era extraction from ratio d(e,e'n) to d(e,e'p)
- Inclusive measurements polarized neutron target ^{3}He (Xu et al)
- Sensitivity in polarized Deuterium asymmetries

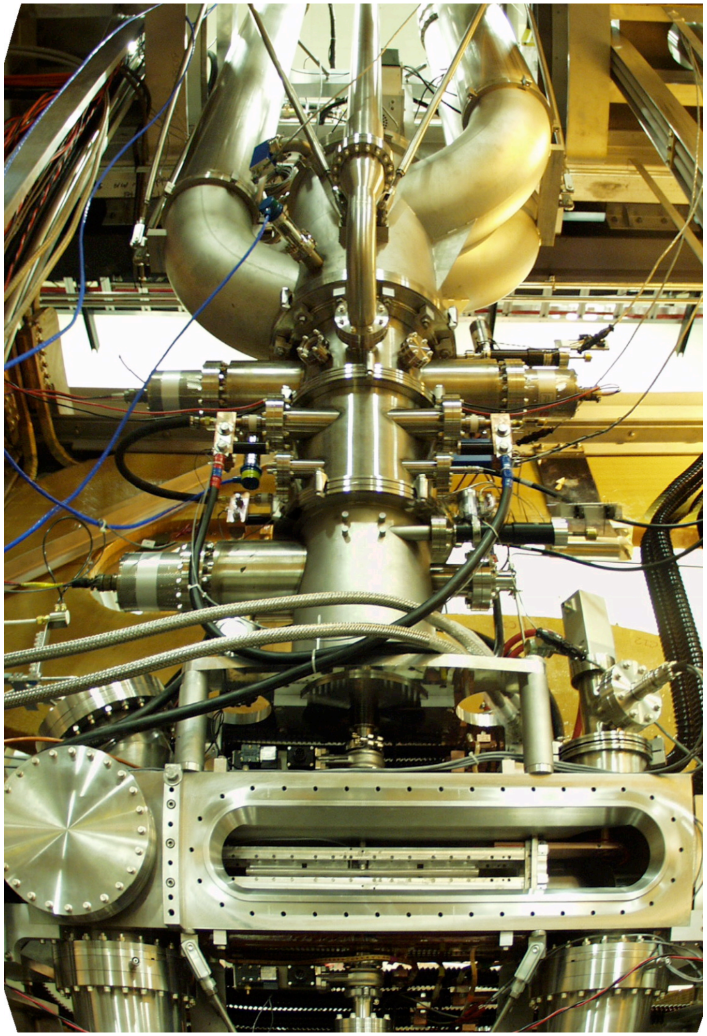
Polarized beam-target program at low Q^2 (BLAST)

BLAST Polarized Beam

- **MIT-Bates South Hall Ring**
  - Stored electron beam, 850 MeV
  - High intensity, I > 200 mA
  - Pre-polarized injection
  - Siberian Snake **(BINP)**
  - Compton polarimeter
  - Spin flipper **(Michigan)**
  - Stable longitudinal pol. (P_b ~.65)



BLAST Polarized Target

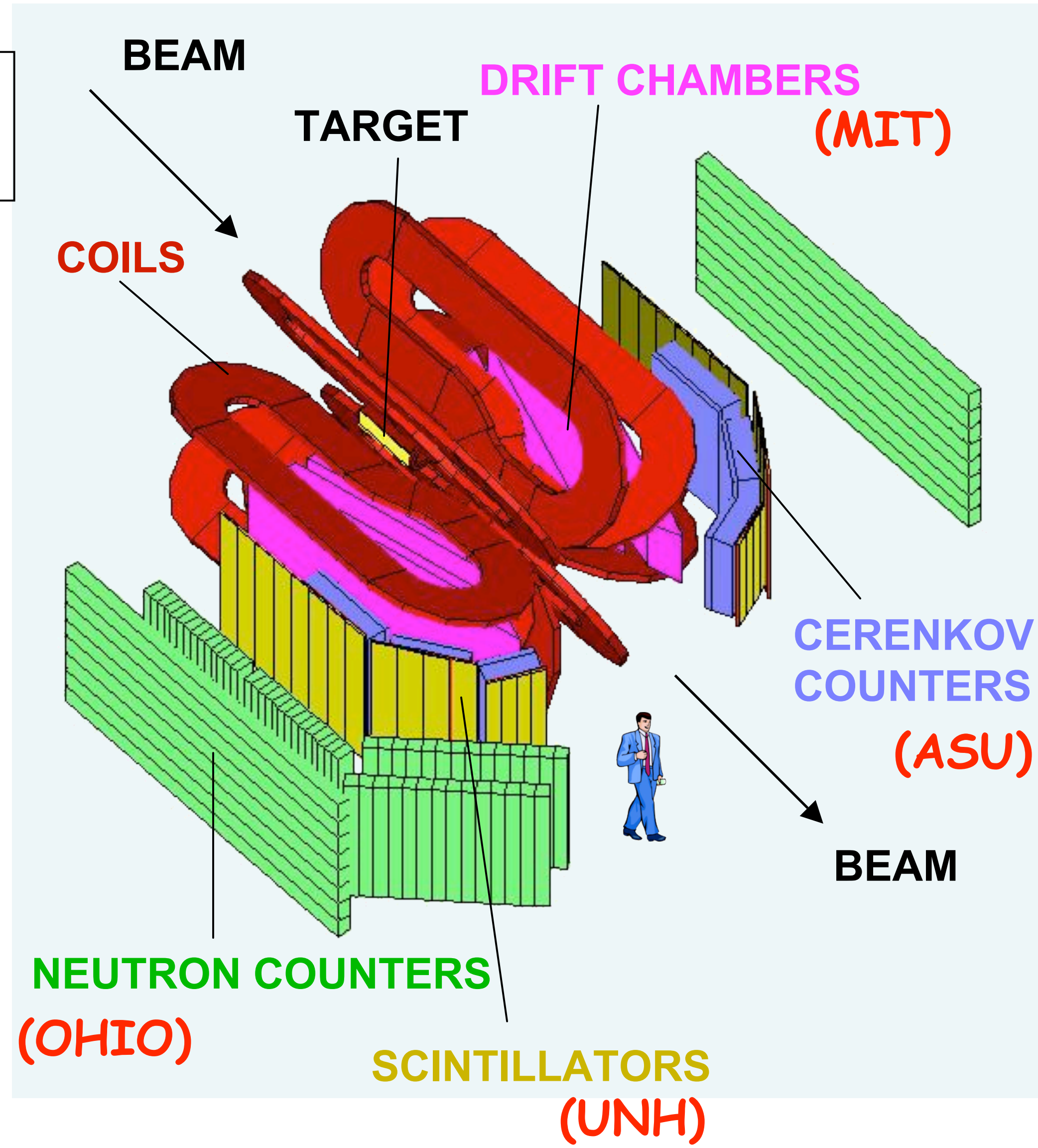


- Atomic Beam Source (NIKHEF)
  - Internal gas target
  - Isotopically pure H and D
  - Vector and tensor pol. D
  - Inside high B field
  - Thickness: 6×10^{13} atoms/cm^2
  - Vector pol. $P_t \sim .82$
- Luminosity: $6 \times 10^{31}/(cm^2 s)$

The BLAST Detector

Bates Large Acceptance Spectrometer Toroid

- Left-right symmetric
- Large acceptance
  - $20^o < \theta < 80^o$
  - $-15^o < \phi < 15^o$
  - $0.1 < Q^2/(GeV/c)^2 < 0.8$
- Detection of $e\pm$, $\pi\pm$, p, d, n.
- Extended neutron coverage on right
- Open trigger



BLAST physics program

- Polarized **Hydrogen**

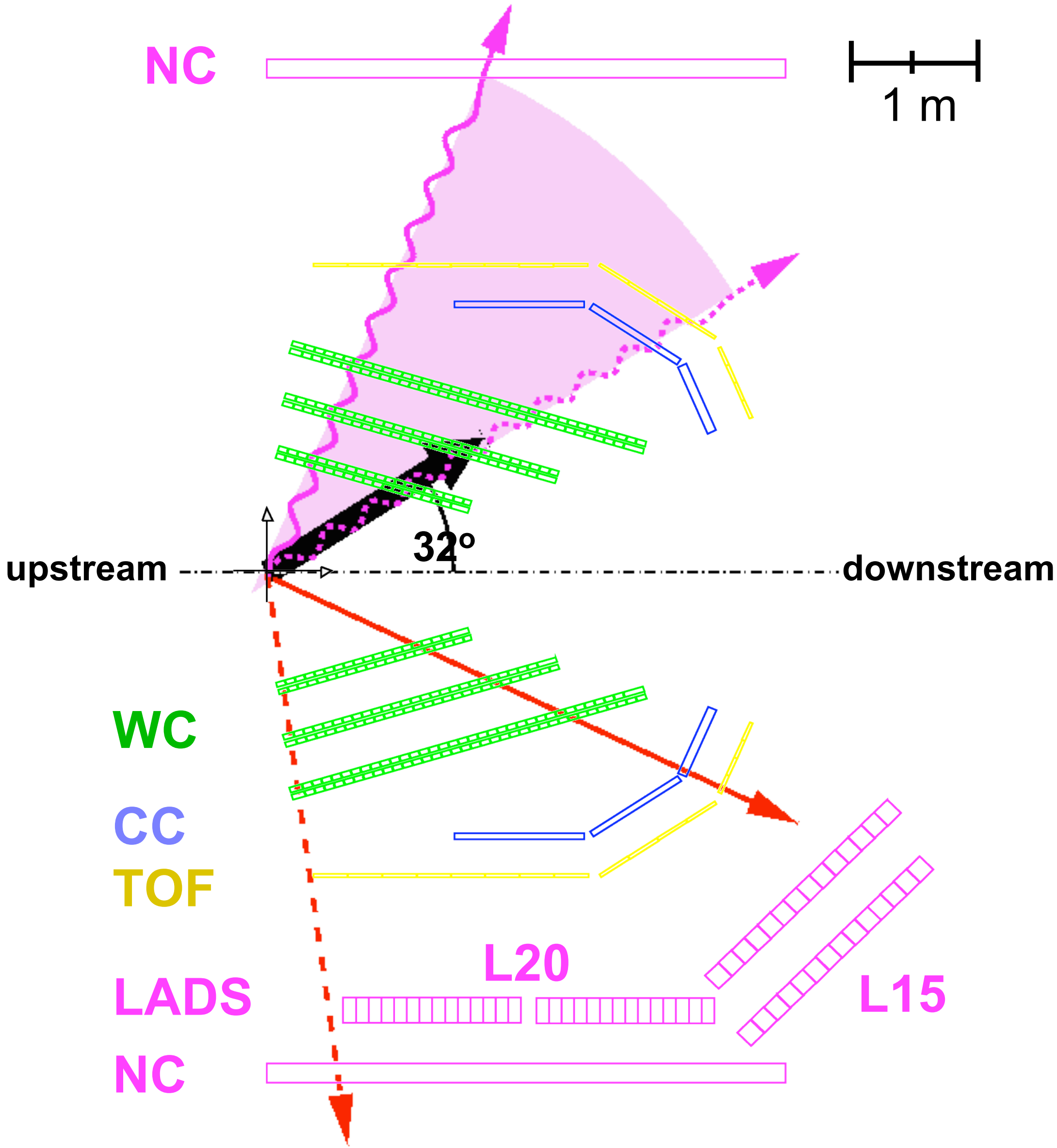
$\vec{p}(\vec{e},e')x$	$\boxed{\vec{p}(\vec{e},e'p)}$	$\vec{p}(\vec{e},e'p)\gamma,\pi^0$ $\vec{p}(\vec{e},e'\pi^+)n$	$p(\vec{\gamma},\vec{\pi}^+n)$
Inclusive	G^p_E/G^p_M	N-Δ: C2/M1	photoprod.

- Vector and Tensor Polarized **Deuterium**

$\vec{d}(\vec{e},e')$	$\vec{d}(\vec{e},e'd)$	$\vec{d}(\vec{e},e'p)n$	$\vec{d}(\vec{e},e'n)p$	$\vec{d}(\vec{e},e'\pi^{\pm,0})$
G^n_M	T^e_{11}: G^d_M	A^V_{ed}: L=2	G^n_E	N-Δ

$\overleftrightarrow{d}(e,e'd)$	$\overleftrightarrow{d}(e,e'p)n$, $\overleftrightarrow{d}(e,e'n)p$	$\overleftrightarrow{d}(\gamma,pn)$
T_{20}: G^d_Q	A^T_d: L=2	photodisint.

Target Spin Orientation



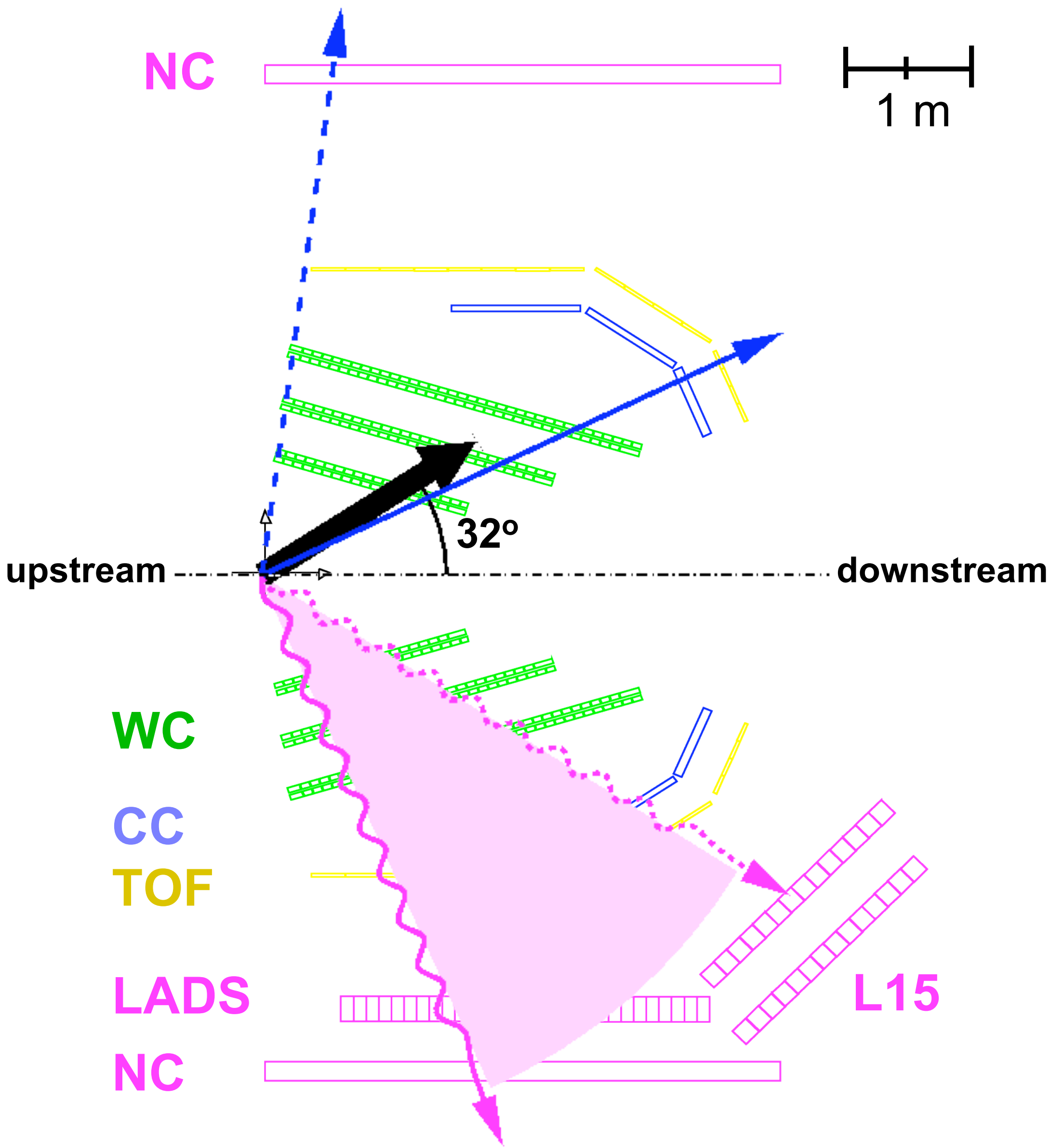
Freedom of in-plane spin angle

32° (2004) / 47° (2005)

e- right → θ* ≈ 0°

“spin-parallel”

Target Spin Orientation



Freedom of in-plane spin angle

32° (2004) / 47° (2005)

e- left → θ* ≈ 90°

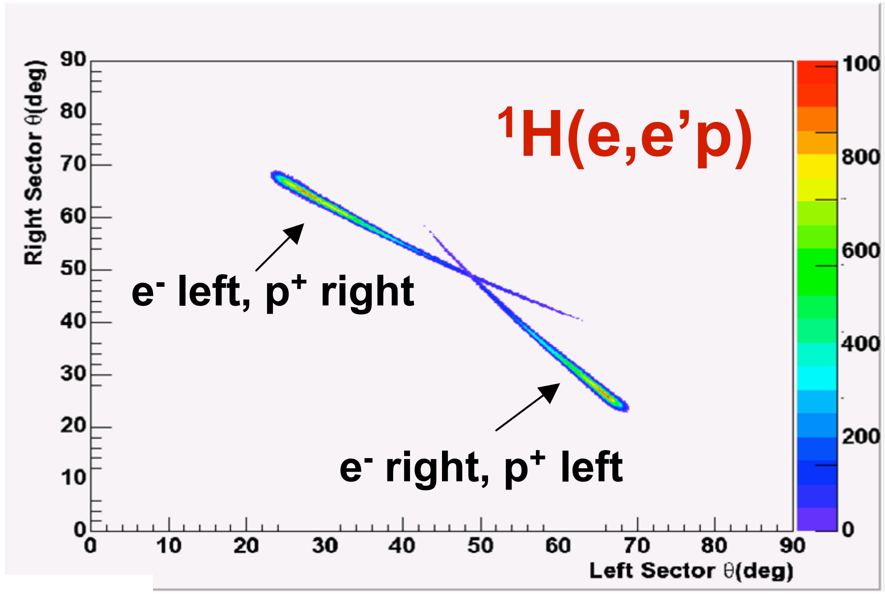
"spin-perpendicular"

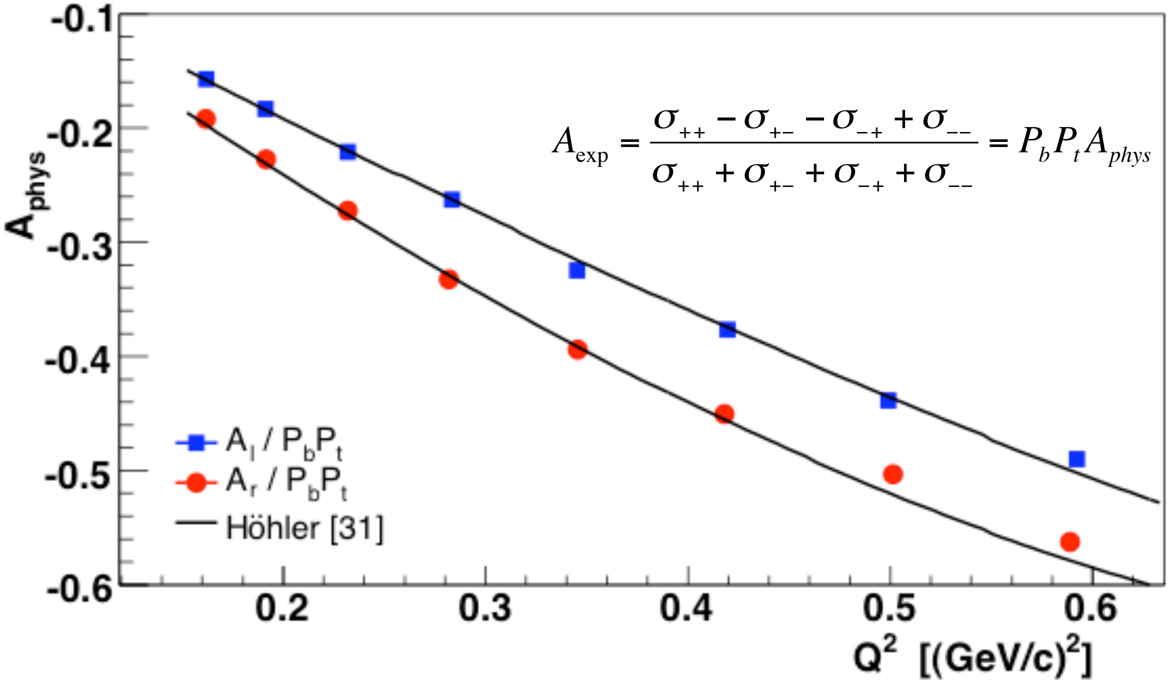
e- right → θ* ≈ 0°

"spin-parallel"

BLAST Elastic Hydrogen Data H(e,e'p)

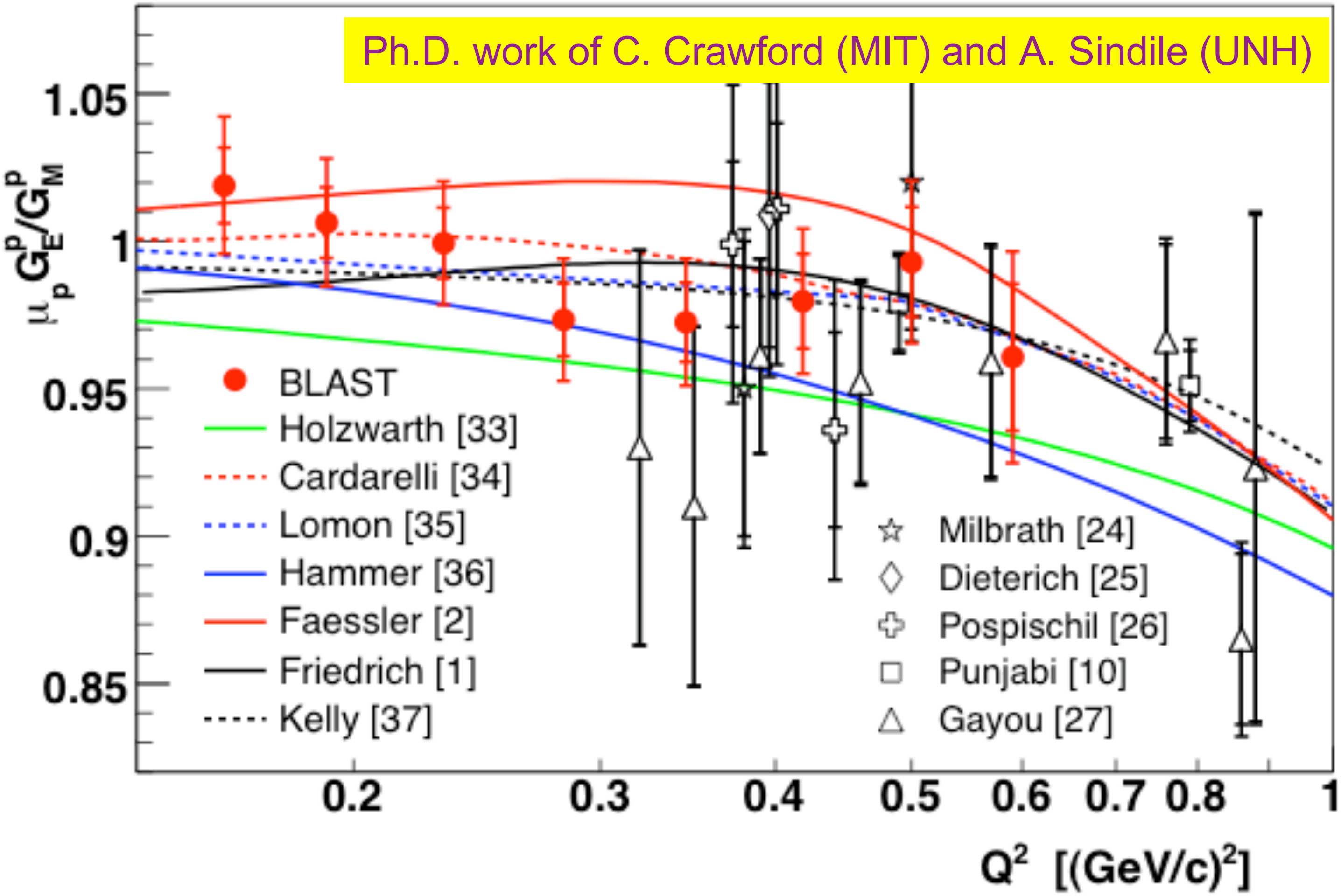
- Extensive polarized H data set
  - 300 kC int e^-, 90 pb^{-1} int. lum
- Elastic scattering well determined
  - Multiple cuts
  - Clean kinematic correlation





- Beam and target spin varied
- Single spin asymmetries used as systematic checks
- Radiative corrections small (MASCARAD)
- BLAST left and right sectors

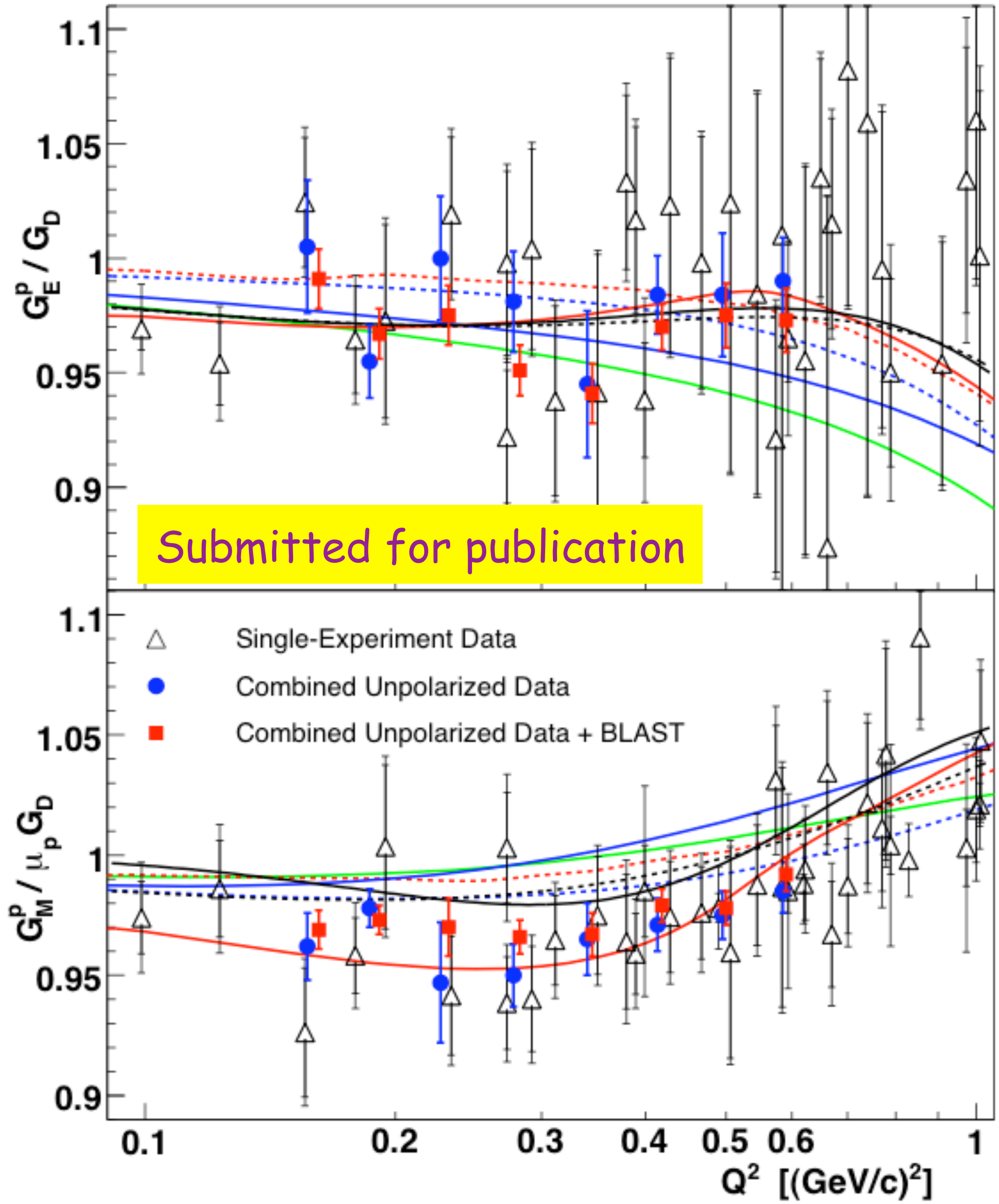
Proton Form Factor Ratio $\mu_p G^p_E / G^p_M$



- First polarized target data at $Q^2 < 1$ (GeV/c)^2
- Very precise data statistically and systematically

G^p_E and G^p_M

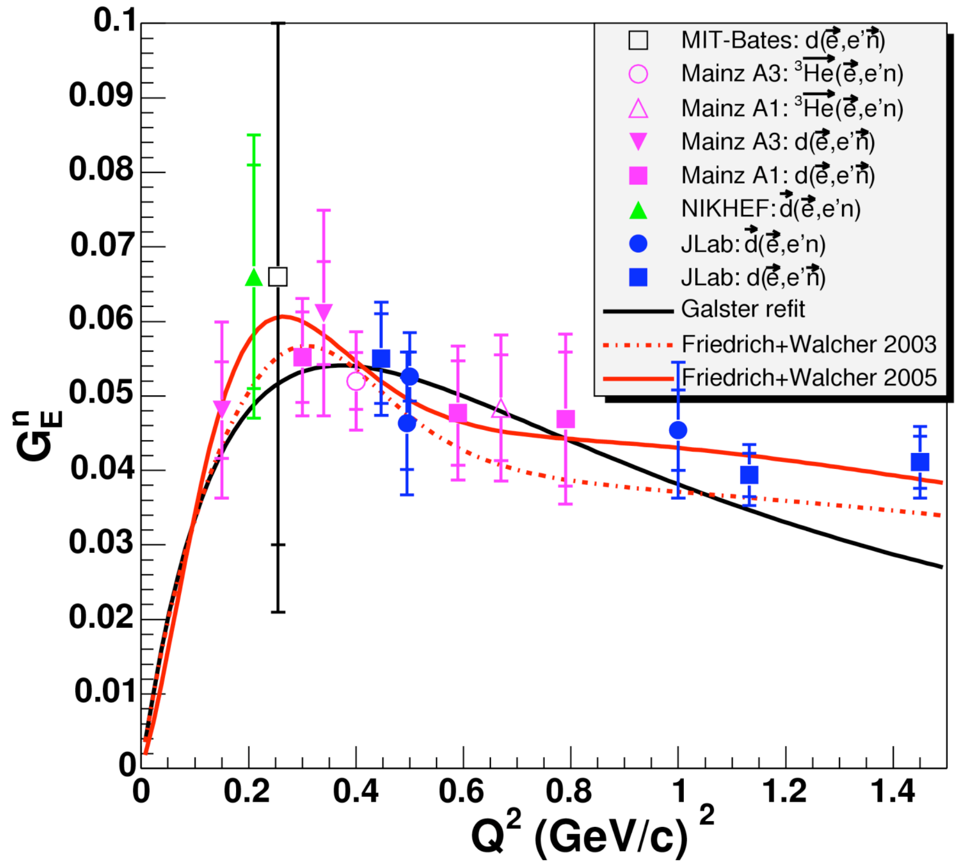
- Previous unpolarized data to for local Rosenbluth at each BLAST Q^2
- Addition of BLAST data significantly shrinks errors
- Smoothing of G_E and G_M
- Hints of structure at low Q^2



* Ph.D. work of C. Crawford (MIT) and A. Sindile (UNH)

Form Factor Parameterizations

- Structure at low Q^2 in analysis of Friedrich-Walcher
- G^n_E world data from double pol. experiments
- Phenomenological fit with bump → effects of meson cloud
- Consistent bump seen in all 4 form factors at low Q^2 with broad width

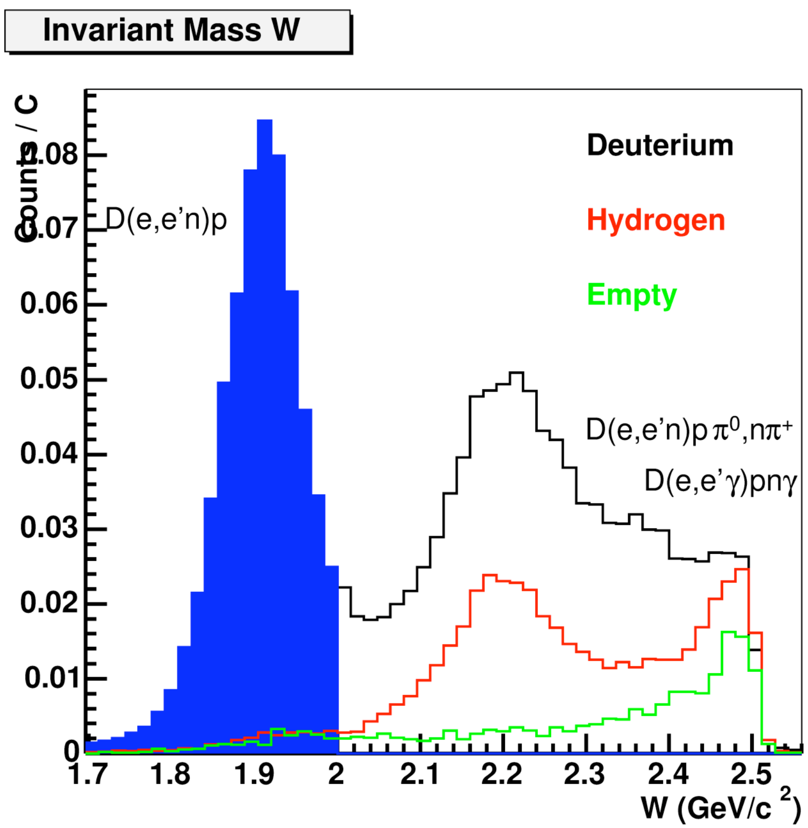


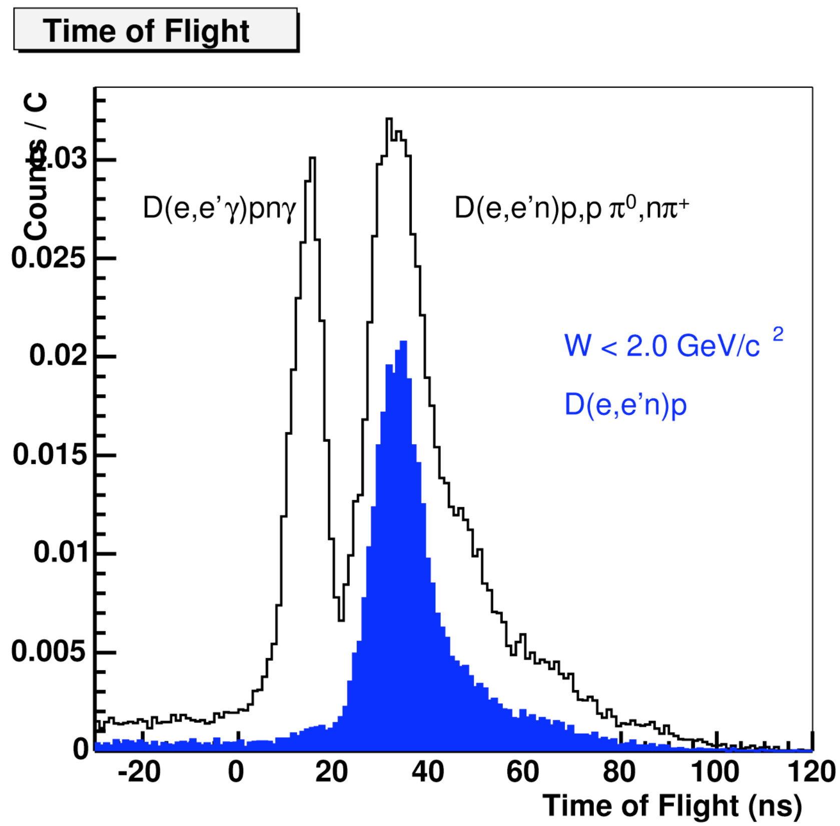
$$G_{FW} = \frac{a_{10}}{(1+Q^2/a_{11})^2} + \frac{a_{20}}{(1+Q^2/a_{21})^2} + a_b\,Q^2\left(\mathrm{e}^{-\frac{1}{2}\left(\frac{Q-Q_b}{\sigma_b}\right)^2} + \mathrm{e}^{-\frac{1}{2}\left(\frac{Q+Q_b}{\sigma_b}\right)^2}\right)$$

"smooth part" "bump part"

BLAST Neutron Data

- Large deuterium data set (Q > 2 MC in 2004 and 2005)
- Very clean quasielastic ^{2}H(e,e'n) spectra
- Highly efficient **proton veto** (drift chambers + TOF)

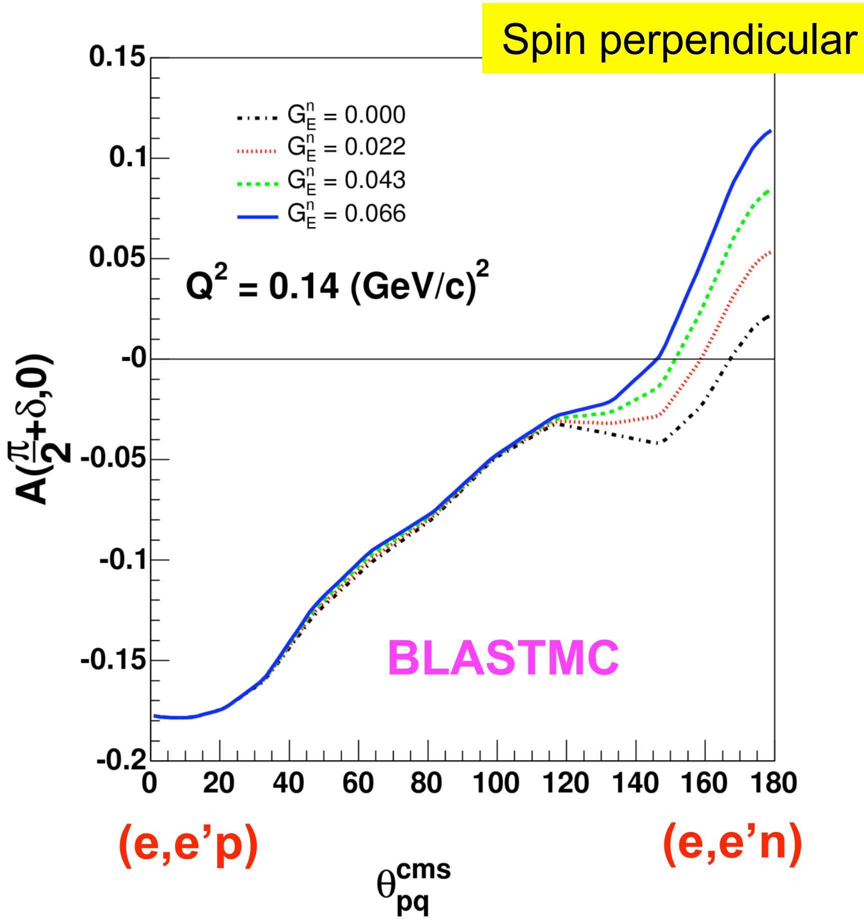




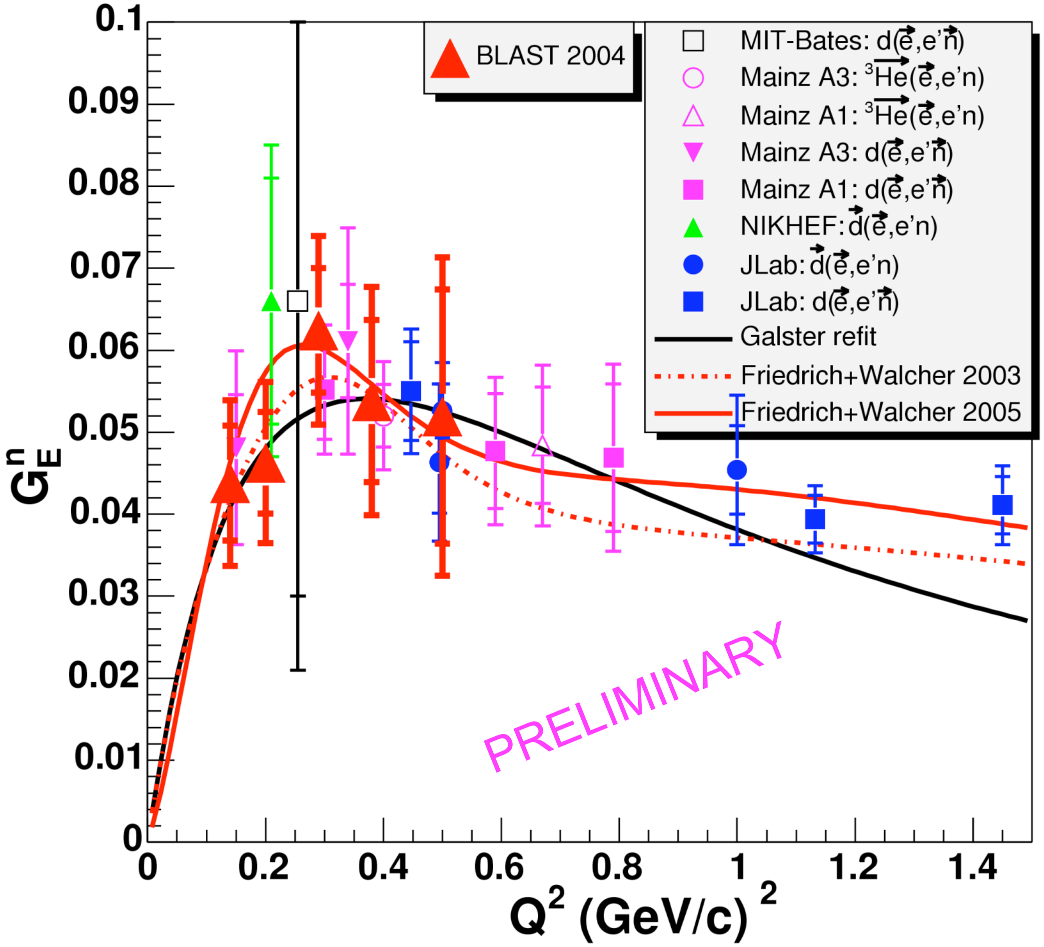
Extraction of G^n_E

$$A^V_{ed} = \frac{a\, {G^n_M}^2 \cos\theta^* + b\, G^n_E G^n_M \sin\theta^* \cos\phi^*}{c\, {G^n_E}^2 + {G^n_M}^2} \approx a \cos\theta^* + b\, \frac{G^n_E}{G^n_M} \sin\theta^* \cos\phi^*$$

- Quasielastic $^2\vec{H}(\vec{e},e'n)$
- Full Montecarlo simulation of the BLAST experiment
- Deuteron electrodisintegration by H. Arenhövel
- Accounted for FSI,MEC,RC,IC
- Compare measured A^V_{ed} with BLASTMC, vary G^n_E



Neutron Electric Form Factor G^n_E*



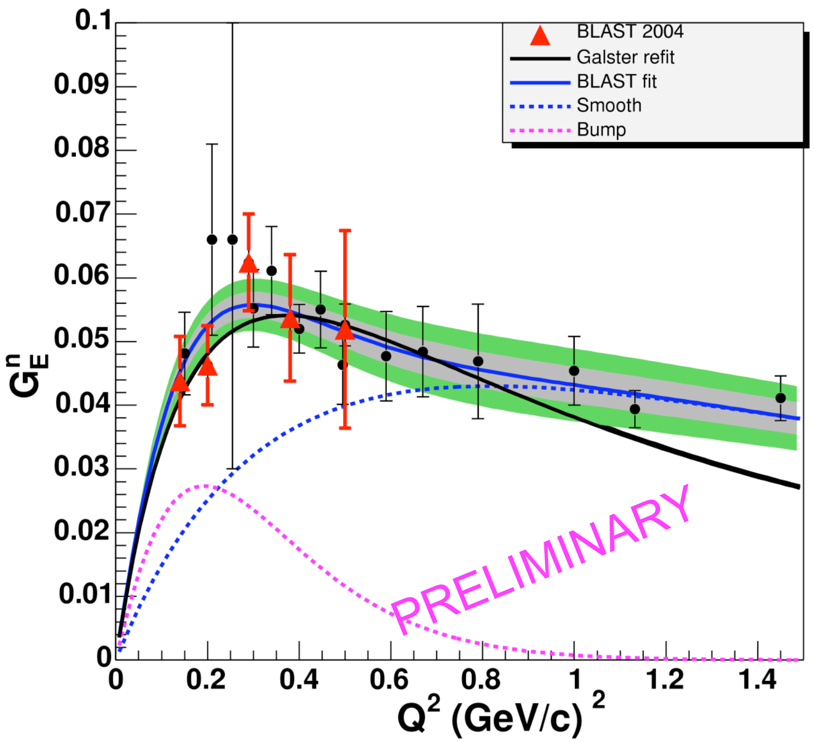
- BLAST 2004 complete
- Final results including 2005 run expected soon
- Mostly consistent with other data at low Q^2
- BLAST fit
  - Includes BLAST 2004
  - Modified F&W
  - Slope as Q^2 nears 0 from $\langle r^2_n \rangle = -0.115\ \mathrm{fm}^2$

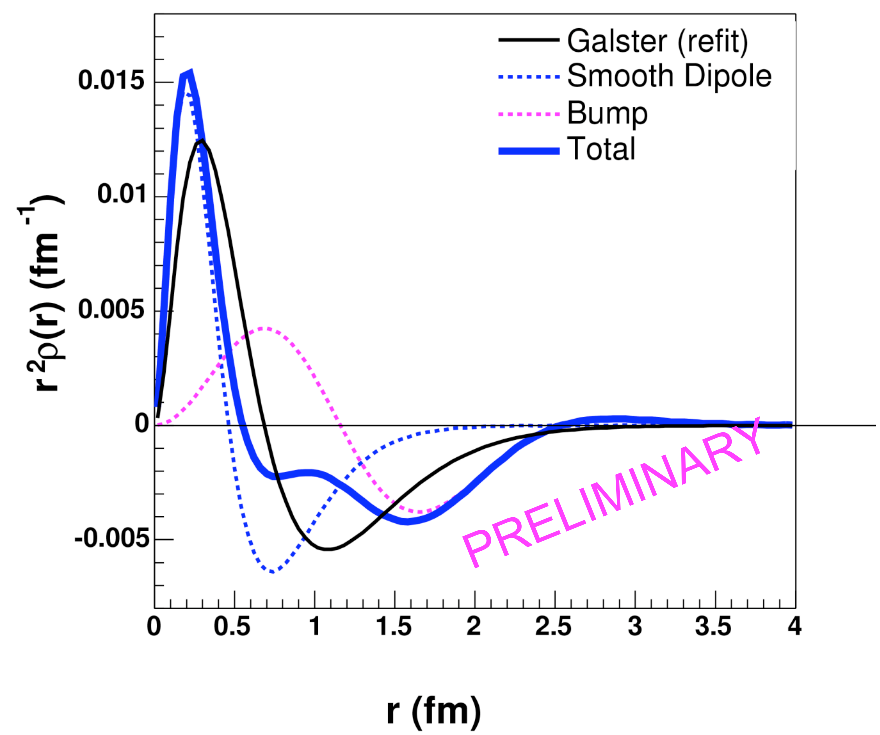
*Ph.D. work of V. Ziskin (MIT) and E. Geis (ASU)

Neutron Electric Form Factor G^n_E*

- Bump contributes at lower Q^2
- Pion cloud effect?

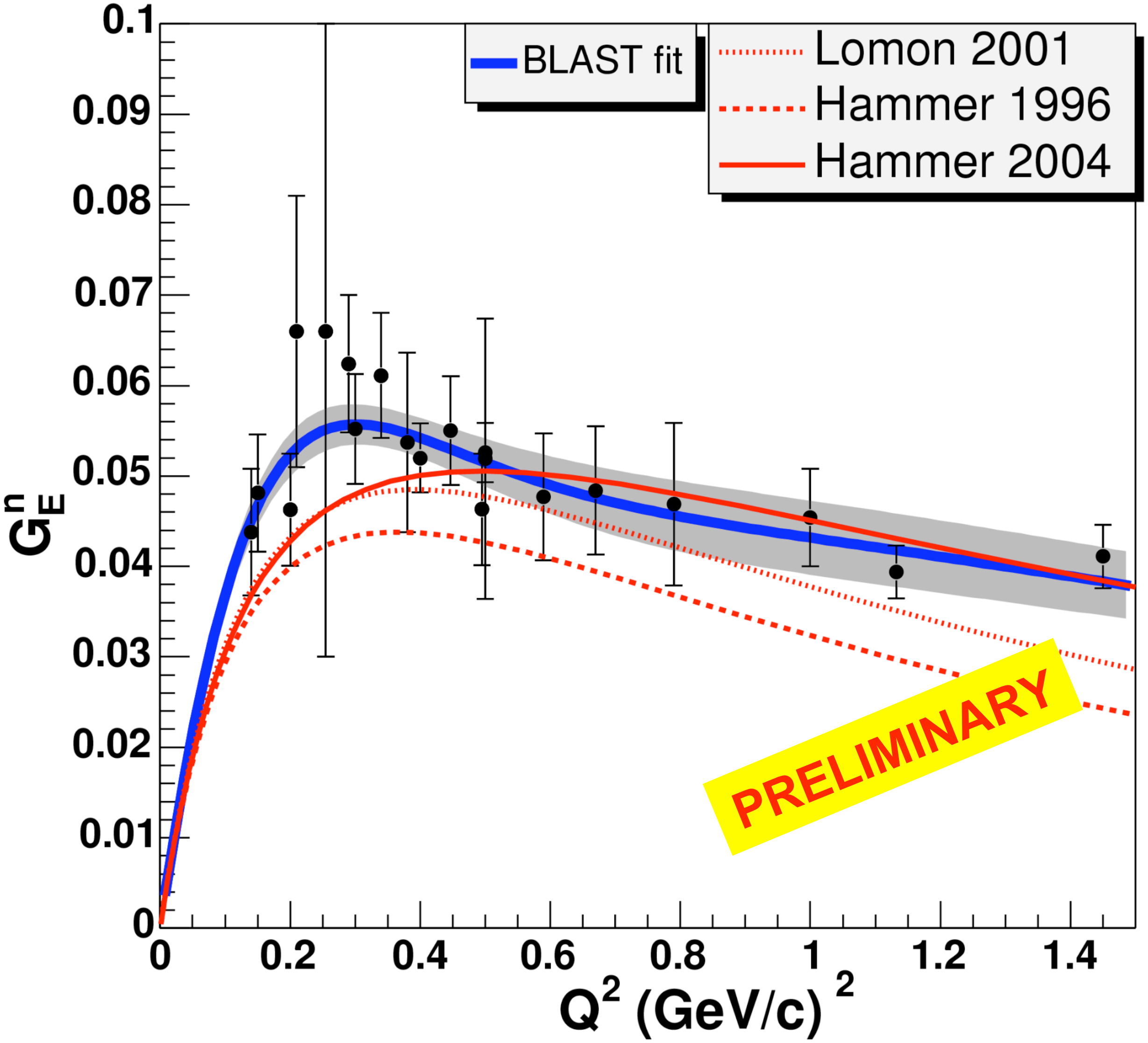
*Ph.D. work of V. Ziskin (MIT) and E. Geis (ASU)





Charge form factor ↔ Charge Distribution

Model calculations of G_E^N



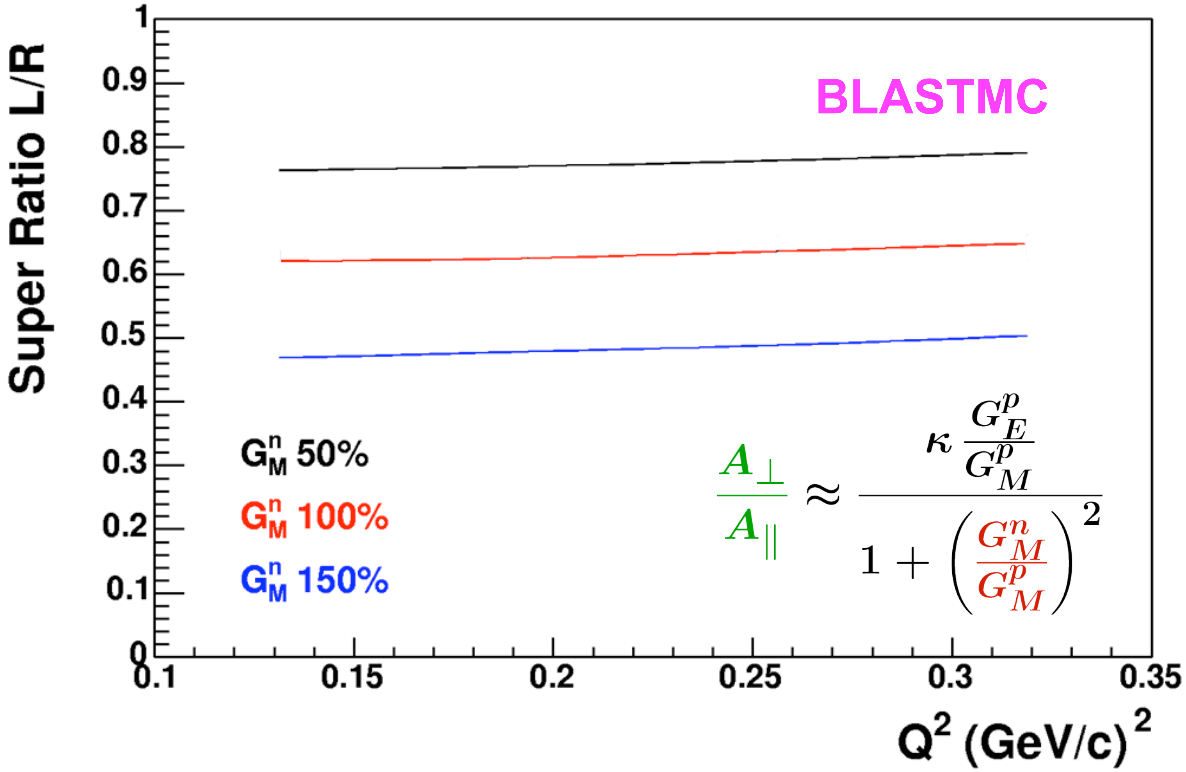
Extraction of G^n_M

- Quasielastic $^2\vec{H}(\vec{e},e')$ inclusive
- Beam-target vector asymmetry A^V_{ed}

$$A_\perp \approx \frac{c\ (G^p_E/G^p_M)}{a + b\left(1 + (G^n_M/G^p_M)^2\right)}$$

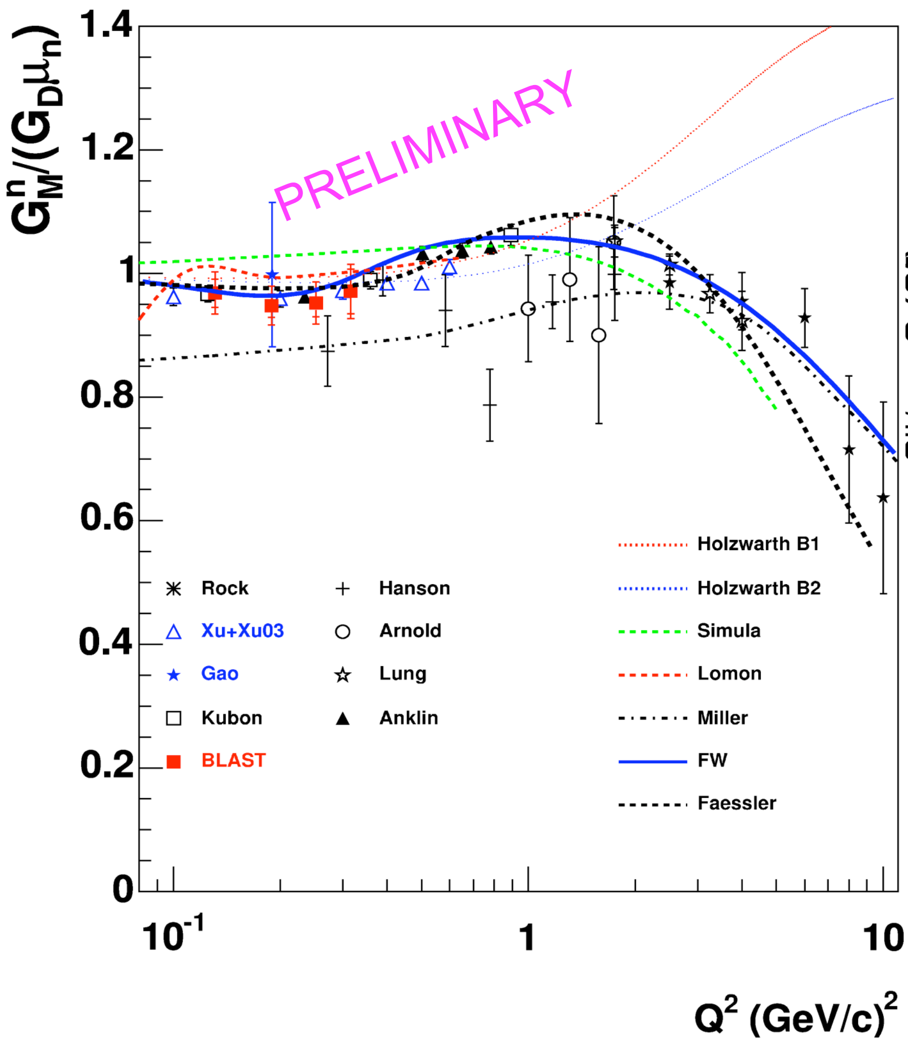
PWIA

$$A_\parallel \approx \frac{d\left(1 + (G^n_M/G^p_M)^2\right)}{a + b\left(1 + (G^n_M/G^p_M)^2\right)}$$



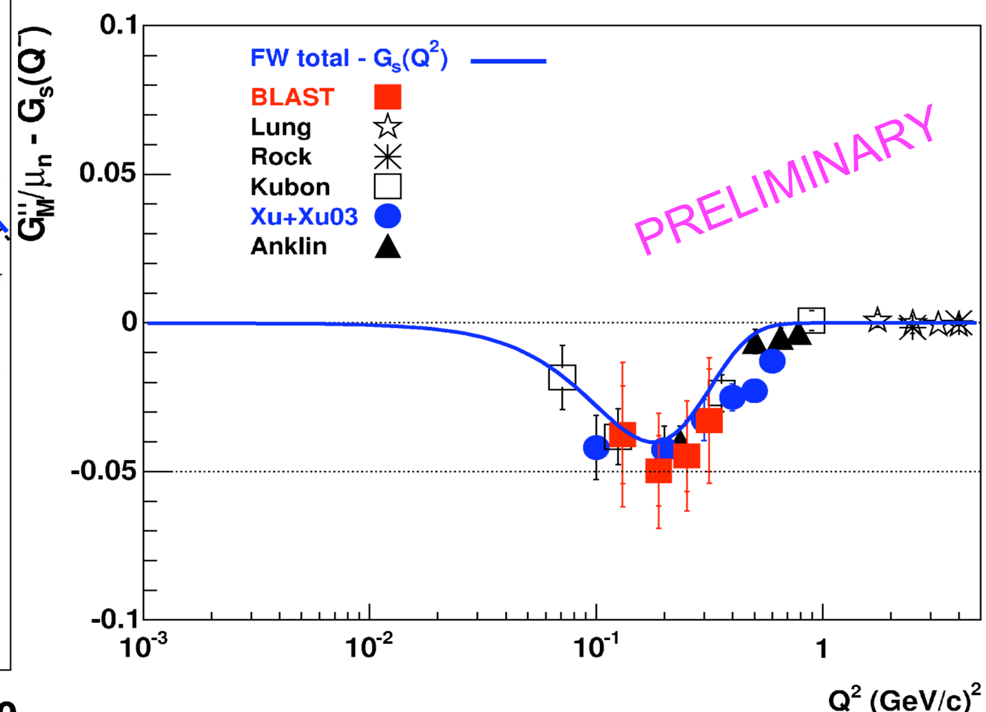
- Full Montecarlo simulation of BLAST
- Spin-parallel & perp. show sensitivity to G^n_M
- Enhanced sensitivity in super ratio

Neutron Magnetic Form Factor G^{n}_{M}*



G^n_M world data + ^{3}He + BLAST

*Ph.D. work of N. Meitanis (MIT)



Final result expected soon

Summary

- **Significant improvement in nucleon form factor data from polarization**
  - Multiple facilities and techniques
  - High precision, low systematics
- **Consistent and precise determination of elastic nucleon form factors at low momentum transfer**
  - Evidence for structure at low Q^2
  - Improvement in calculations
- **Polarization to play important role in addressing further open areas**
  - G_E^N at high Q^2
  - Transverse pol. observables with e^+,e^- (2 photon effects)
- **BLAST program coming to conclusion**
  - Final stage analysis on many channels (e-d elastic, pions)
  - Detector could play role in future experimental program

MIT-Bates

- Concluded NP operations in 2005
  - Polarization experiments
  - Polarization technique
- Facility
  - MIT ownership (interdisciplinary mission)
  - Experiments decommissioned
  - Accelerator intact and operable
- SHR has unique features for select beam studies
  - Optical stochastic cooling
  - Coherent THz radiation
  - Polarization studies
- Continued involvement of MIT faculty and Bates staff in spin physics
  - RHIC SPIN, Q-weak experiments
  - Polarized electron-ion collider design, source and target development
- Expect to continue to participate in future SPIN conferences