Spin-Dependent Electron Scattering from Deuterium at BLAST

MIT-Bates Linear Accelerator Laboratory

Atomic beam source internal target

Symmetric BLAST detector

Spin-dependent electron scattering from deuterium

- elastic scattering
- quasi-elastic scattering
- inclusive

BLAST Collaboration

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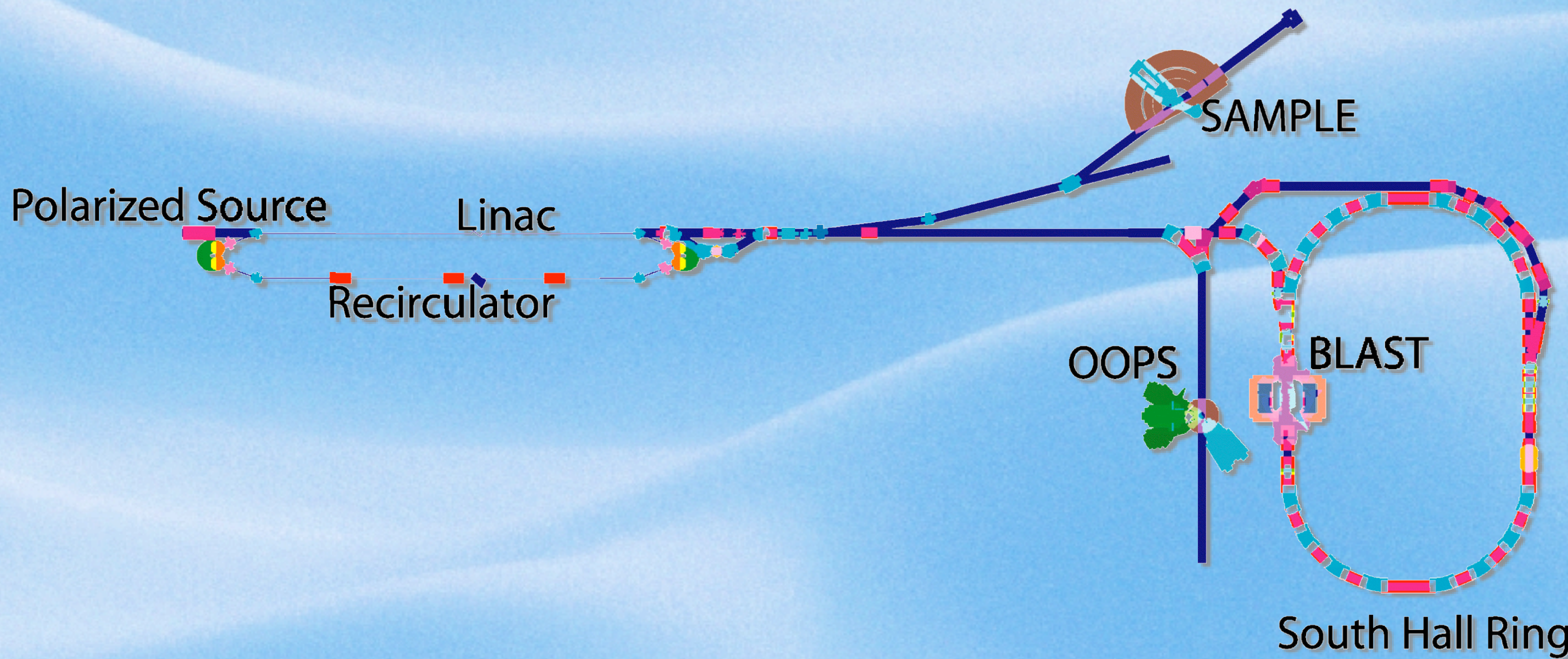
MIT-Bates Linear Accelerator Laboratory



Polarised electron source

- photoemission on HGD GaAs
- 70 % polarisation

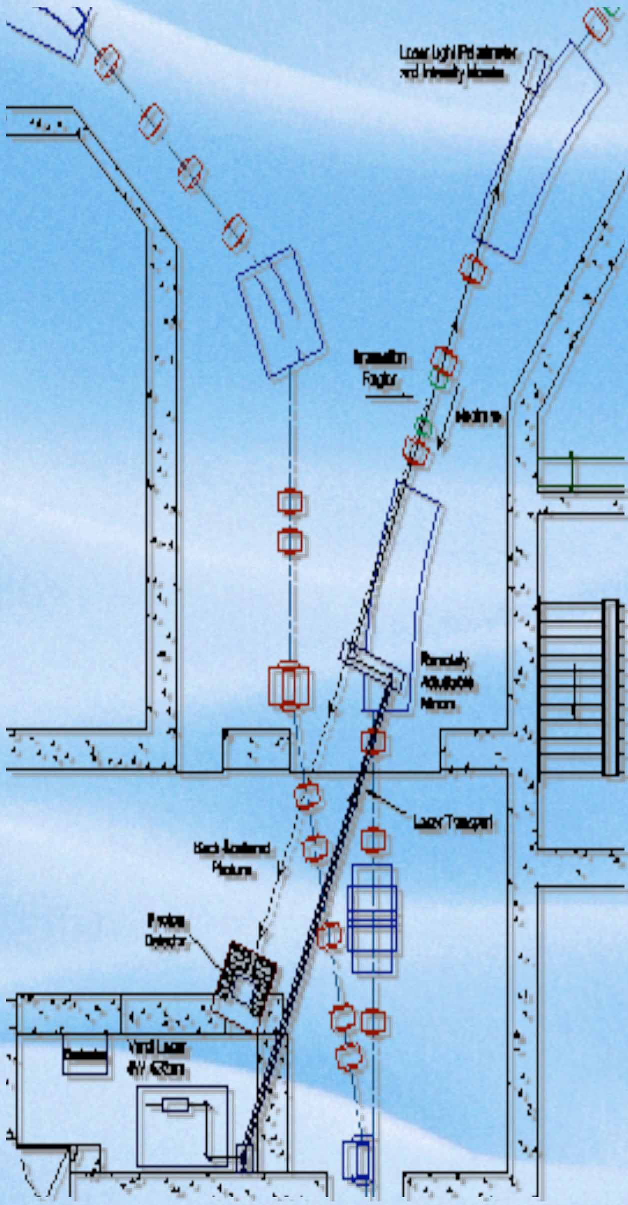
500 MeV linac with recirculator

- polarised electrons up to 1 GeV

South hall electron storage ring

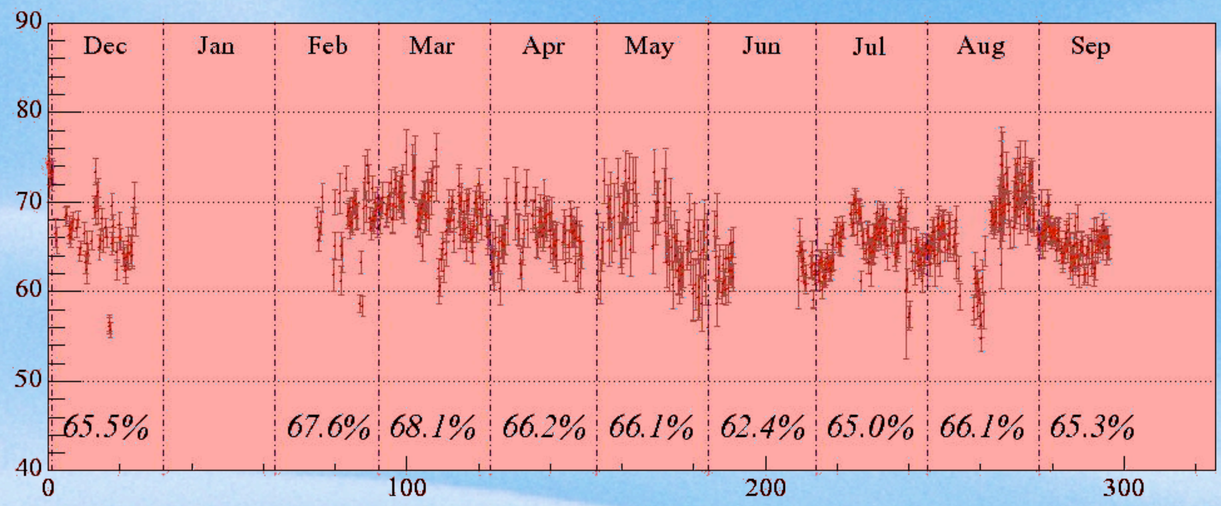
- siberian snake
- 65% polarisation in ring
- stack to 225 mA, 30' lifetime
- reverse beam helicity each fill

Compton Polarimeter

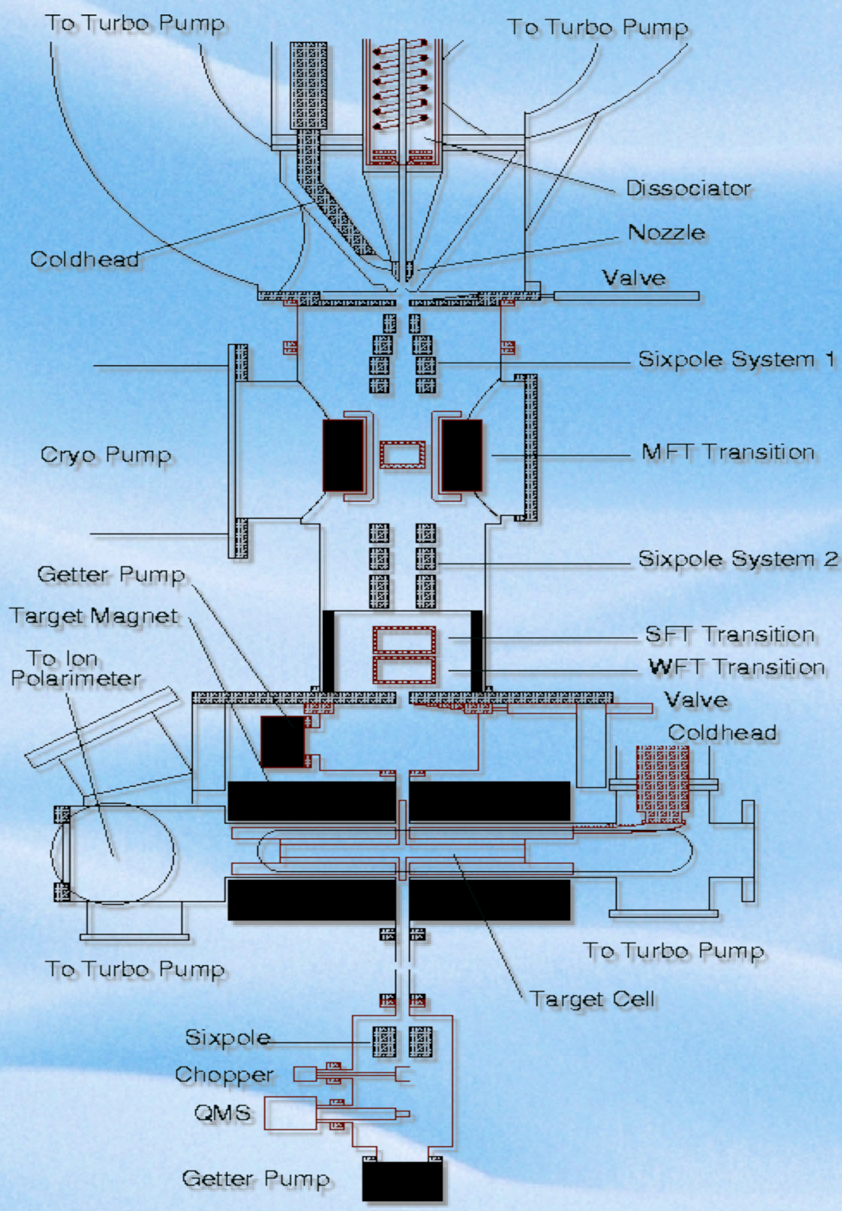


Online monitor of beam polarisation in ring

- 5 W laser, 532 nm, circularly polarised incident on oncoming electron beam
- backscattered photons detected in CsI
- laser helicity flipped in Pockels cell
- asymmetry yields beam polarisation
- chopper wheel to measure background simultaneously
- typical polarisation 65 %
- systematic uncertainty <3%



Internal Gas Target



Atomic Beam Source (ABS)

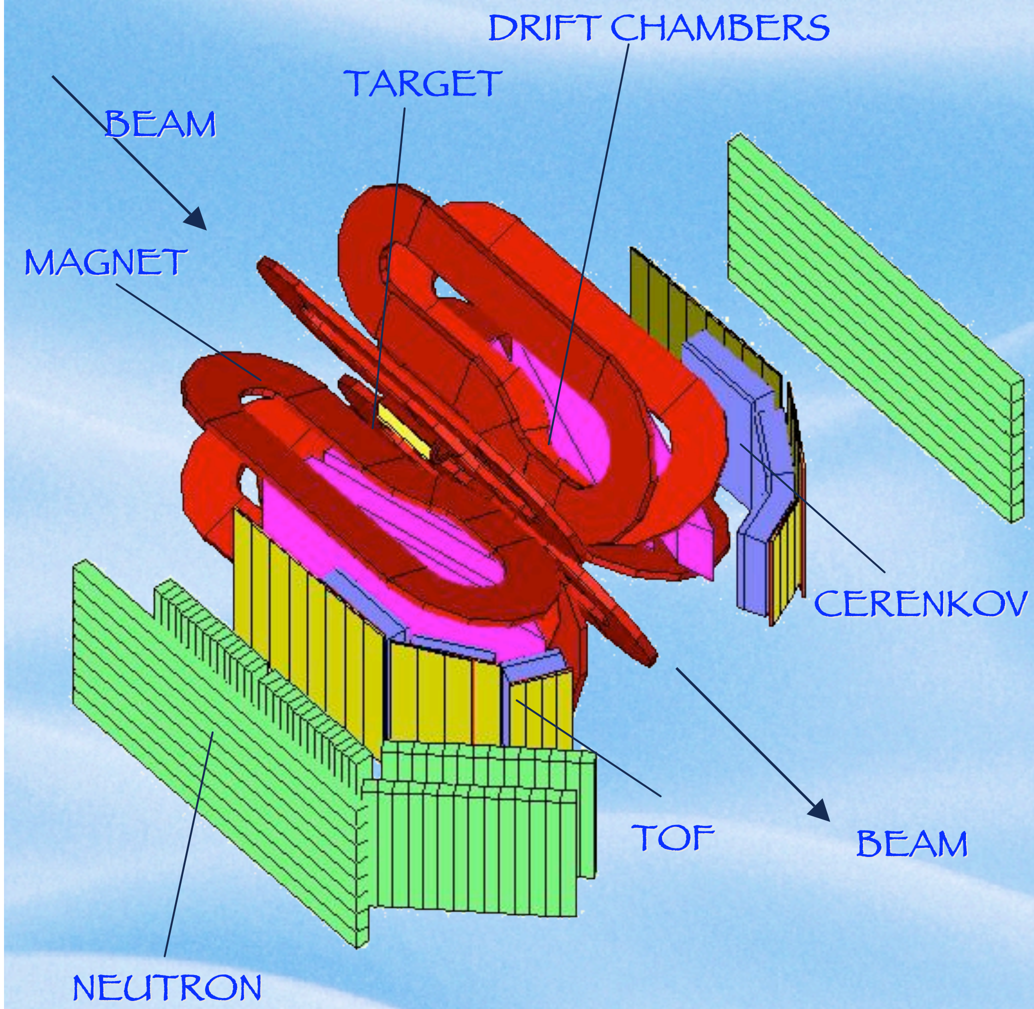
- focusing magnets and RF transitions populate and transport desired spin states to target cell
- 60 cm long, open ended target cell
- isotopically pure H and D
  - vector polarised H
  - vector and tensor polarised D
- rapidly change spin states (5'/state)
- typical D target density
- typical D polarisations (e'p and T_{20})

$$6 \times 10^{13} \text{atoms/cm}^2$$

$$P_Z \approx 80\%$$

$$P_{ZZ} \approx 68\%$$

BLAST Detector



Toroidal magnetic field
- 3.8 kG max

Drift Chambers
- 3 chambers/sector
- 2 superlayers/chamber (±5°)
- 3 sense layers/superlayer
- 18 tracking layers/sector
- 954 sense wires

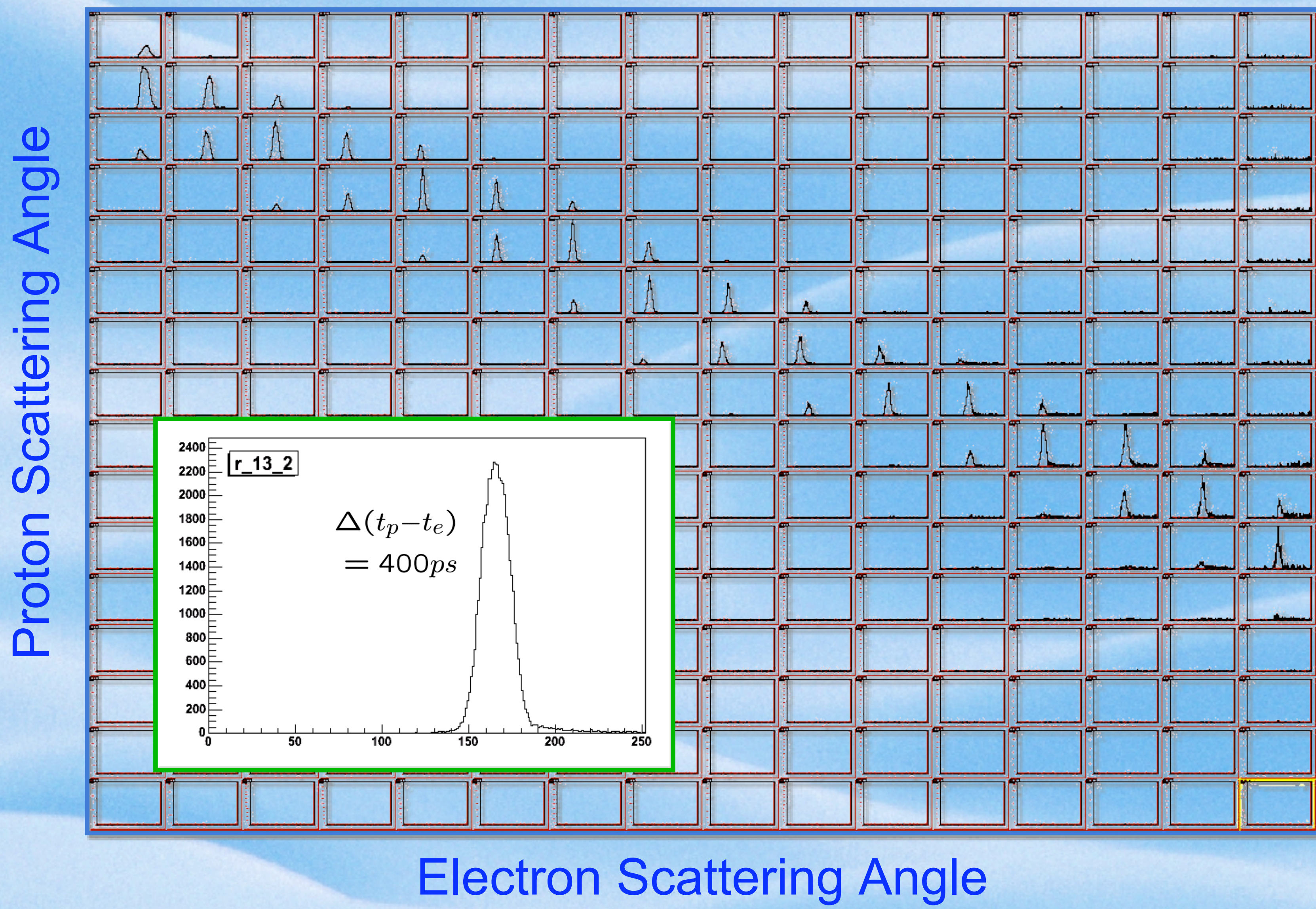
Cerenkov Detectors
- 1 cm thick aerogel
- electron identification

Time of flight scintillators
- 16 vertical bars, 2.5 cm thick
- trigger and relative timing

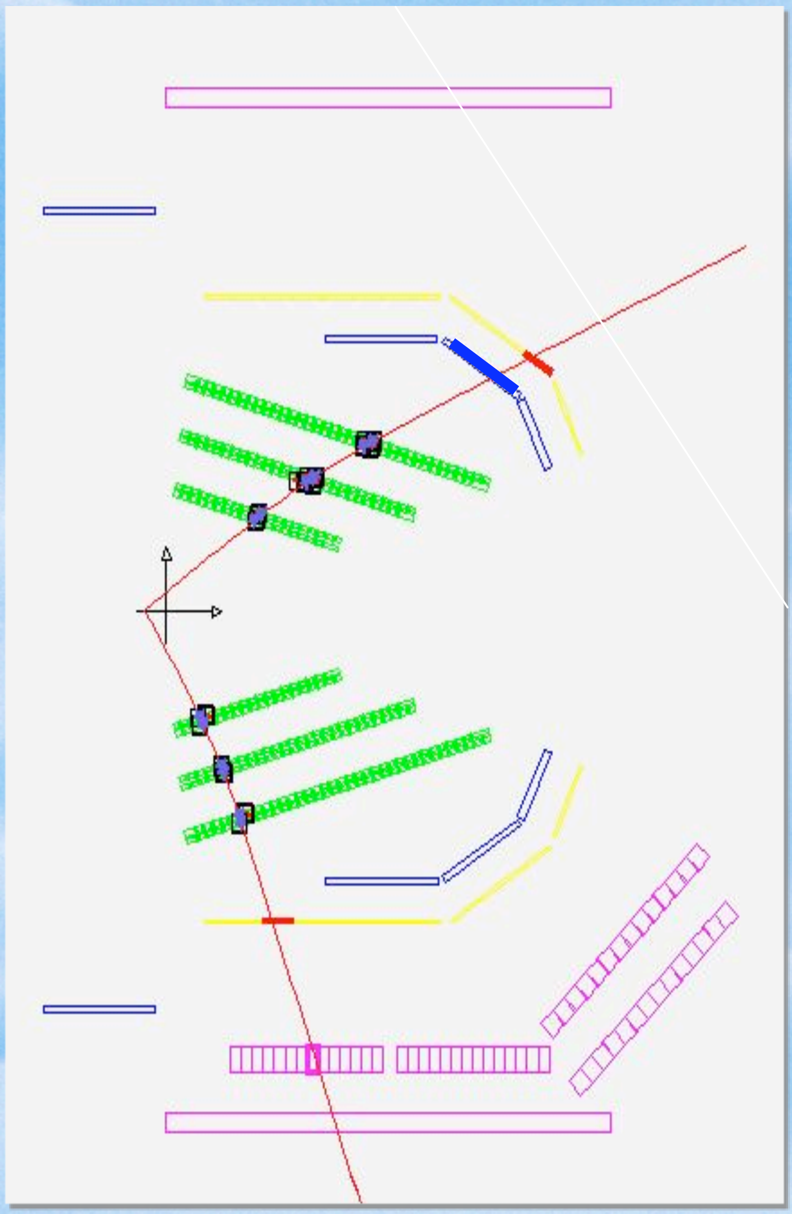
Neutron detectors
- 10 cm thick in left sector
- 25-30 cm thick in right sector

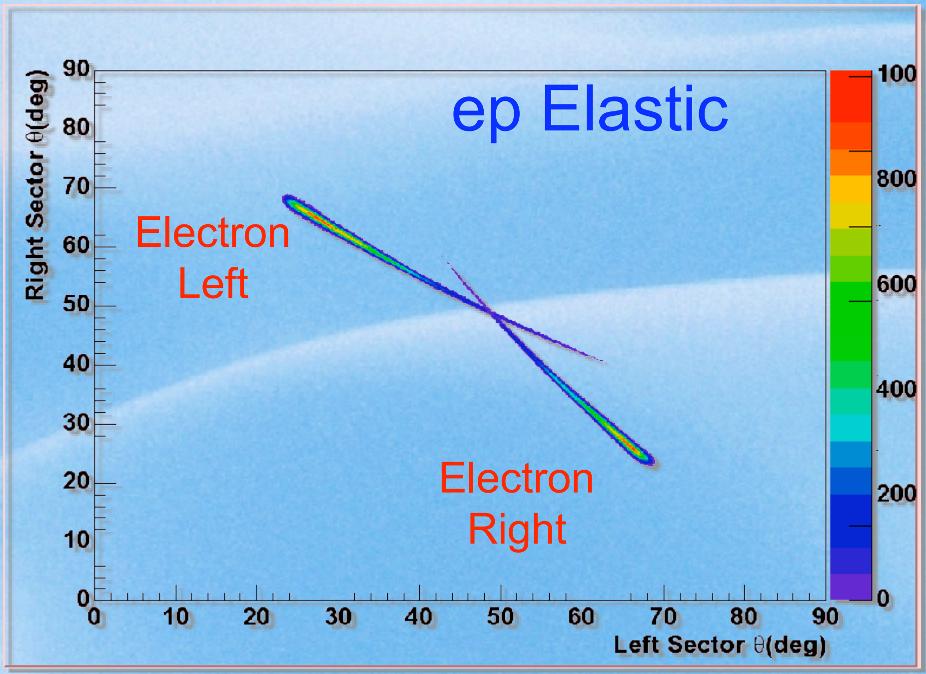
2 level, 8 channel trigger, buffered DAQ
- concurrent data acquisition

Time of Flight Coincidence for ep Elastic



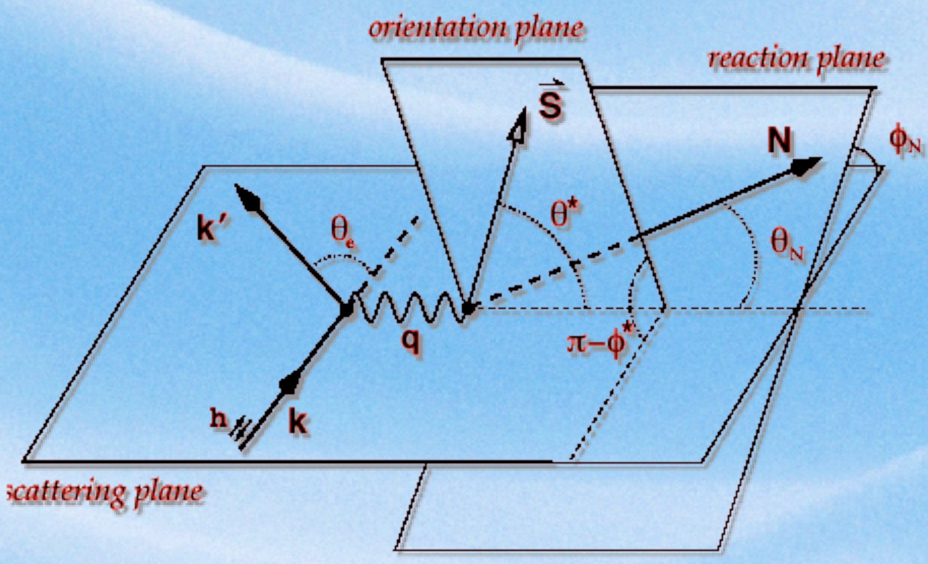
Event Reconstruction

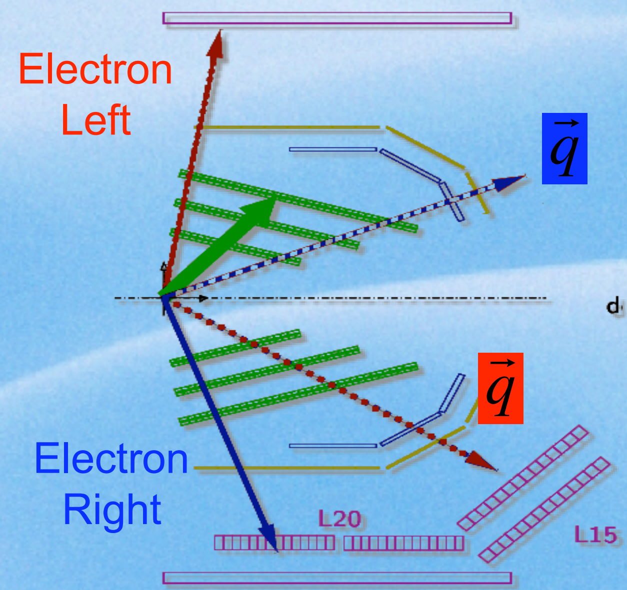




	current	goal
σ_p	3%	2%
σ_θ	0.5°	0.3°
σ_ϕ	0.5°	0.5°
σ_z	1cm	1cm

Kinematics for Spin-Dependent Electron Scattering





Scattering plane
- incident and scattered electron
- q vector

Orientation plane
- direction of target spin vector

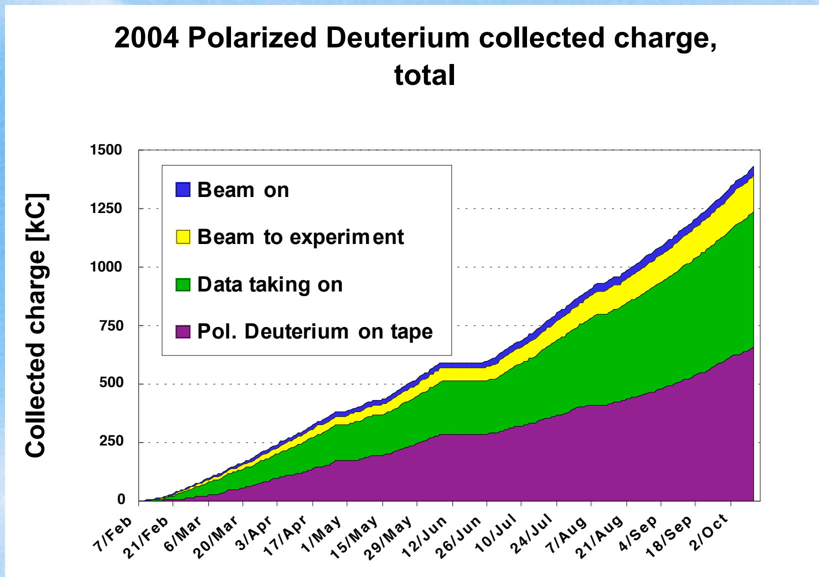
Reaction plane
- reaction product momenta

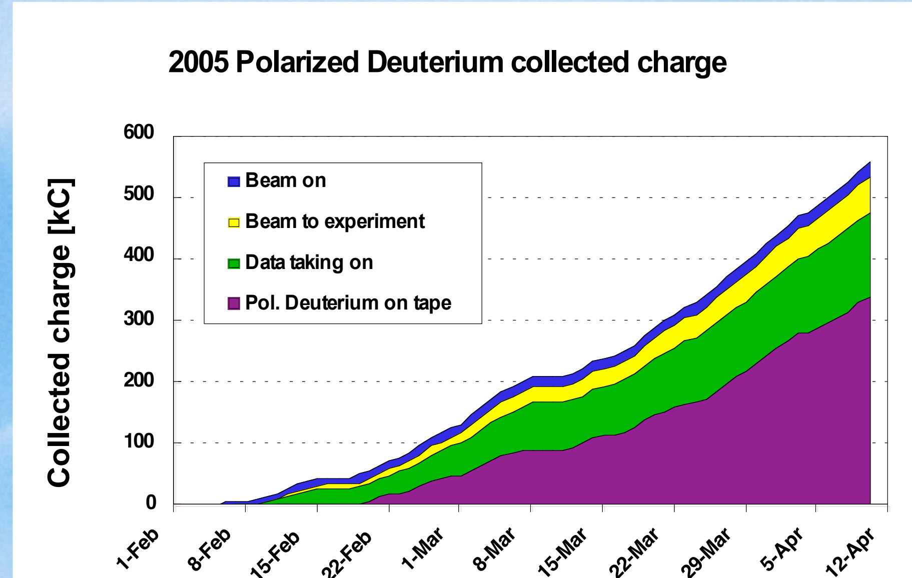
For BLAST
- target polarisation 32° or 47° horizontal into the left sector (T_{20} and G_E^n)

Electron scattering into left sector
- q vector ~perpendicular to target spin
- enhanced neutron detection in right

Electron scattering into right sector
- q vector ~parallel to target spin

BLAST Data





2004 - Polarised Deuterium
- 170 pb^{-1} on deuterium

2004 - Polarised Hydrogen
- 94 pb^{-1} on hydrogen

2004 data, in general, all analysed
Working on details and systematics

2005
- 120 pb^{-1} on deuterium to date
- expect additional 120 pb^{-1}
- more than double 2004 statistics

Data presented covers 2004 and some of 2005 depending on channel

BLAST Physics Analyses

All Results Preliminary

Results from theses work of

Chi Zhang (MIT) - T_{20}

Aaron Maschinot (MIT) - *e′p*

Vitaly Ziskin (MIT) - *e′n*

Nikolas Meitanis (MIT) - inclusive

Deuteron Form Factors from Elastic Scattering

Electromagnetic structure of deuteron has 3 form factors

$$G_C\,,\ G_M\,,\ \text{and}\ G_Q$$

- G_Q arises from D state contribution → tensor force

Unpolarised experiments unable to resolve G_Q

- Rosenbluth separation insufficient

$$A(Q^2) = G_C^2(Q^2) + \frac{8}{9}\eta^2 G_Q^2(Q^2) + \frac{2}{3}\eta G_M^2(Q^2)$$

Need additional measure

$$B(Q^2) = \frac{4}{3}\eta(1+\eta)G_M^2(Q^2)$$

asymmetry

Tensor Asymmetry

BLAST can measure directly

- single spin (target) asymmetry
- both vector and tensor polarised deuterium target
- polarised electron as well (not needed for T_{20})

Measure T_{20} in *ed* elastic scattering

$$A = \frac{3\cos^2\theta_d^* - 1}{2}T_{20} - \sqrt{\frac{3}{2}}\sin 2\theta_d^* \cos\phi_d^* T_{21} + \sqrt{\frac{3}{2}}\sin^2\theta_d^*\cos\phi_d^* T_{22}$$

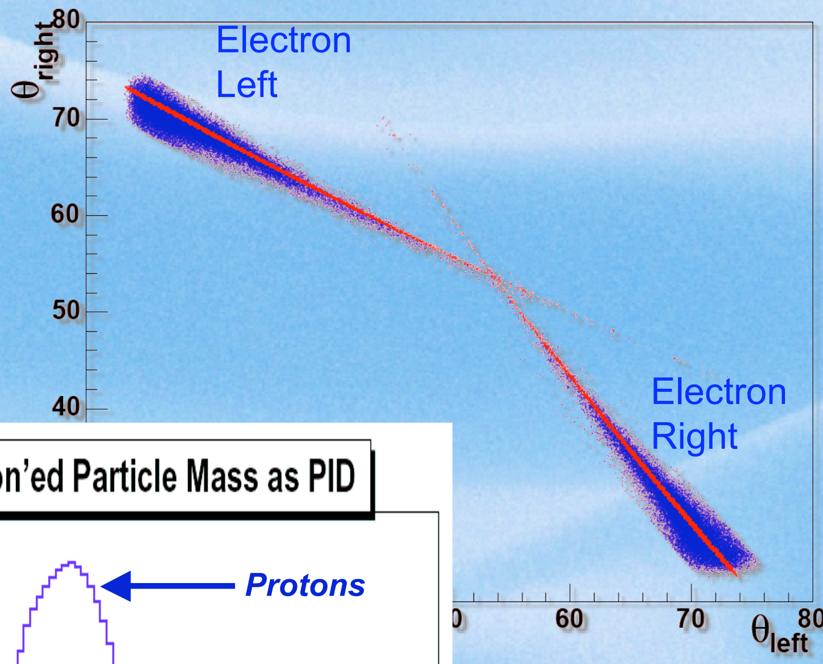
$T_{22} \propto$

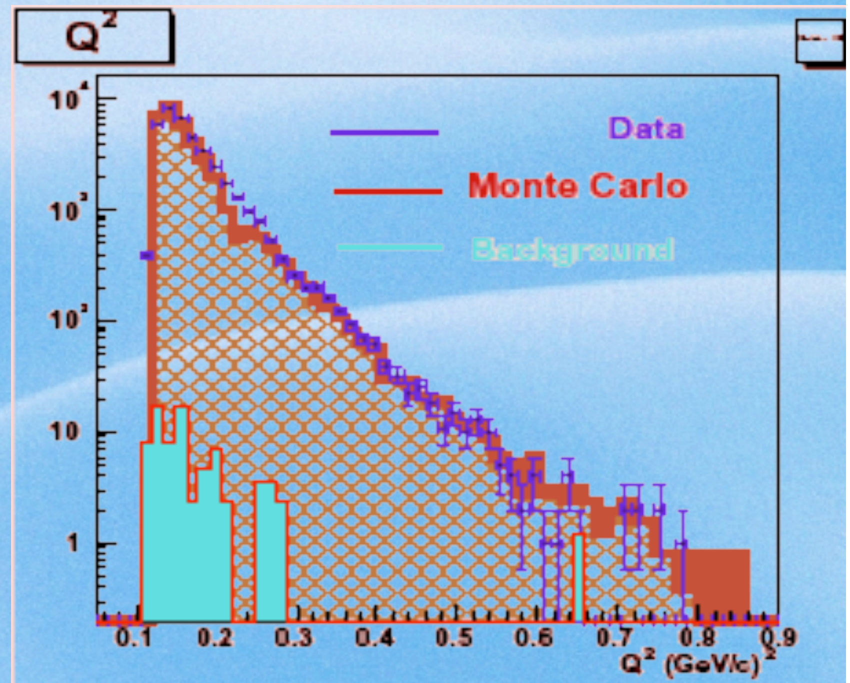
$$T_{20} = -\frac{1}{\sqrt{2}S}[\frac{8}{3}\eta G_C G_Q + \frac{8}{9}\eta^2 G_Q^2 + \frac{1}{3}\eta[1 + 2(1+\eta)\tan^2\frac{\theta_e}{2}]G_M^2]$$

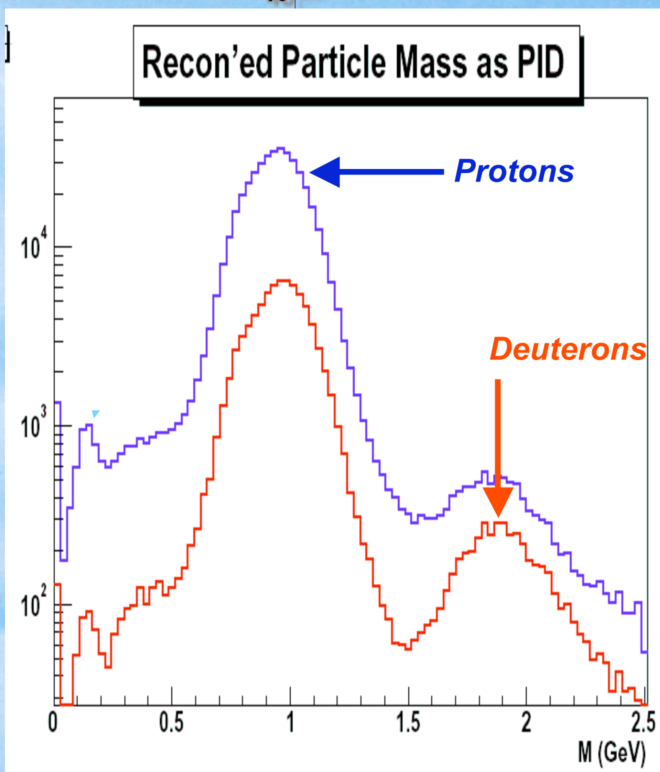
Test

- D state contribution

ed Elastic Event Selection







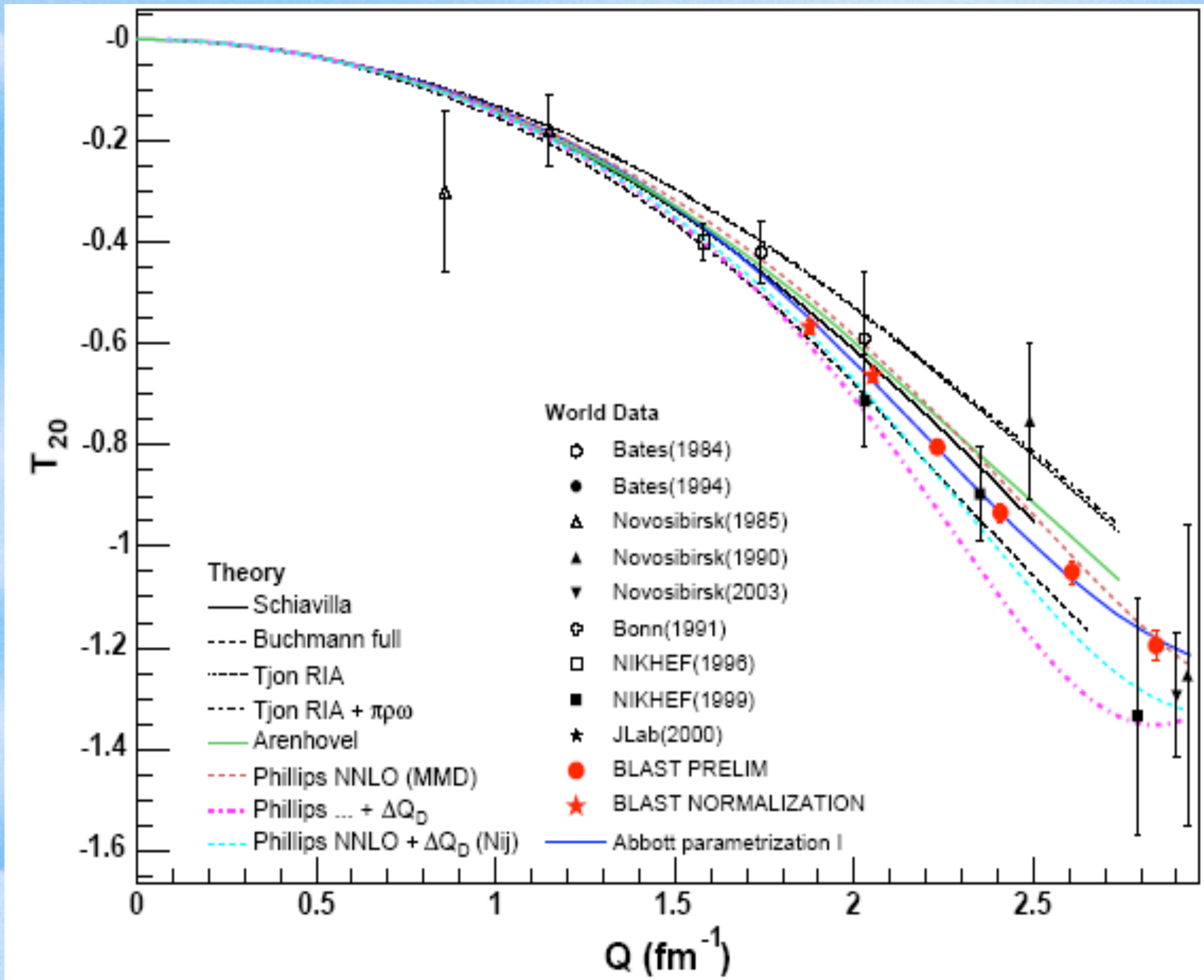
Event selection

- basic timing cuts, both e^- and *d* tracked
- oppositely charged tracks, coplanarity
- mass from deuteron momentum and energy (timing)

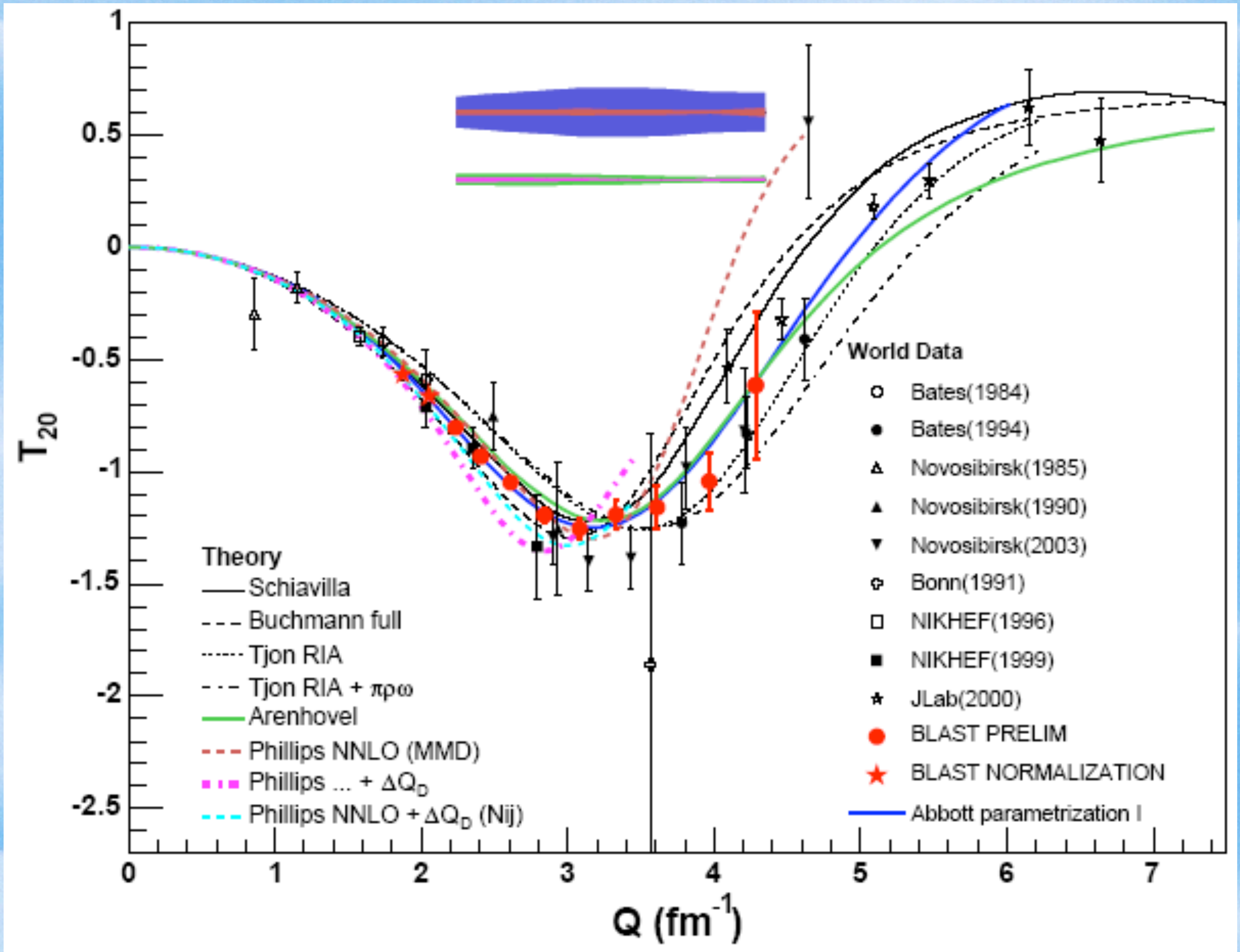
Background negligible

- cell walls, positrons, misidentified protons
- study with empty and H runs

Normalisation - Determining Tensor Polarisation



Preliminary T_{20} Result

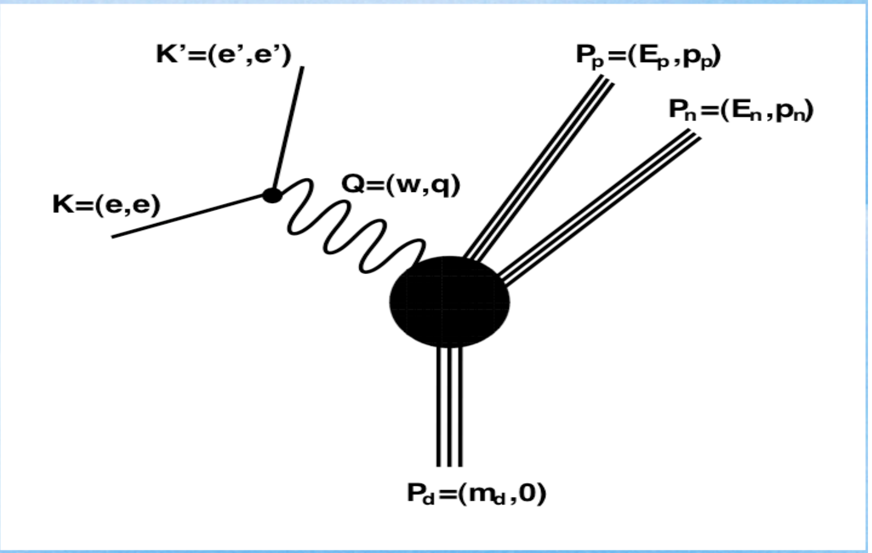


Quasi-Elastic Scattering from Deuterium

Deuterium readily breaks up into two nucleons

- $e + d \rightarrow e' + p + n$
- electro-disintegration

d(e,e'N)N cross section can be written as:



In $S(h,P_z,P_{zz}) = S_0\left(1+P_zA_d^V+P_{zz}A_d^T+h\left(A_e+P_zA_{ed}^V+P_{zz}A_{ed}^T\right)\right)$

$A_e = A_d^V = A_{ed}^T = 0$

$S = S_0(1 + P_{ZZ}A_d^T + hP_ZA_{ed}^V)$

$\sim G_EG_M$

= 0 for S state

Deuteron Wave Function

Deuteron is a spin = 1 nucleus

- ground state an admixture of L=0 and L=2

$$\Psi^{m_d}(\vec{r}) = R_0(r) Y^{m_d}_{110}(\Omega_r) + R_2(r) Y^{m_d}_{112}(\Omega_r)$$

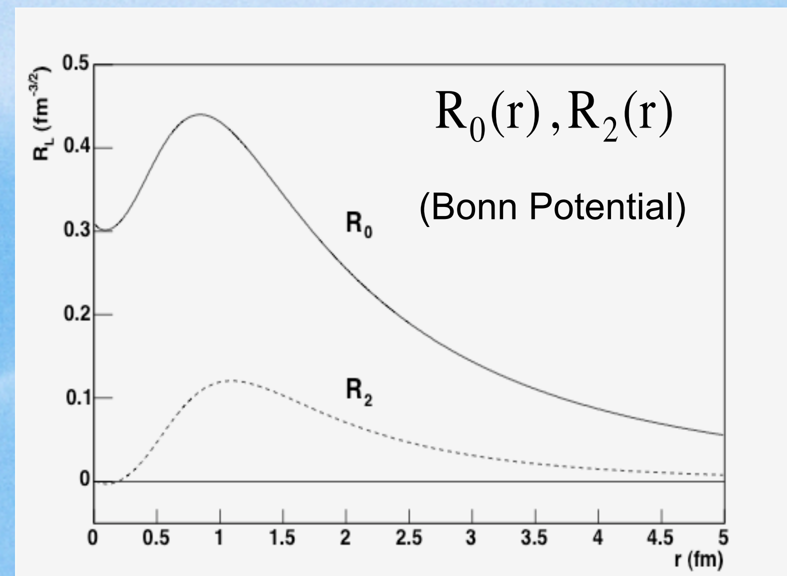
Tensor component required for ΔL = 2

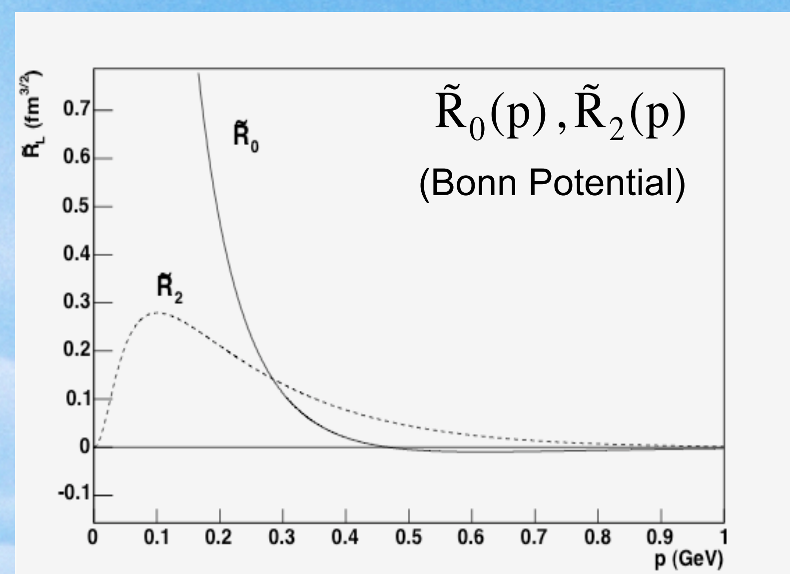
Fourier transform to momentum space

$$\vec{r} \equiv \vec{r}_p - \vec{r}_n \rightarrow \vec{p} \equiv \frac{1}{2}\left(\vec{p}_p - \vec{p}_n\right) \equiv \vec{p}_M$$

L=2 component dominant above 0.3 GeV

$$R_0(r) \rightarrow \tilde{R}_0(p) \;,\; R_2(r) \rightarrow \tilde{R}_2(p)$$





Quasi-Elastic e′p – Missing Mass and Momentum

Only the e^- and *p* are measured

- actually measure d(e,e′p)X

Define "missing" energy, momentum, and mass:

$$E_M \equiv m_d + \omega - E_p$$

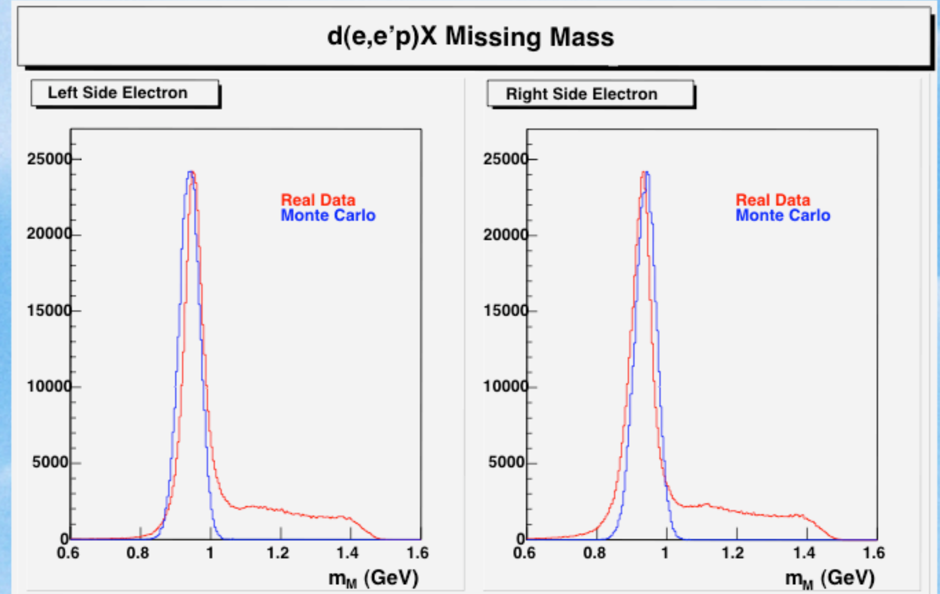
$$\vec{p}_M \equiv \vec{q} - \vec{p}_p$$

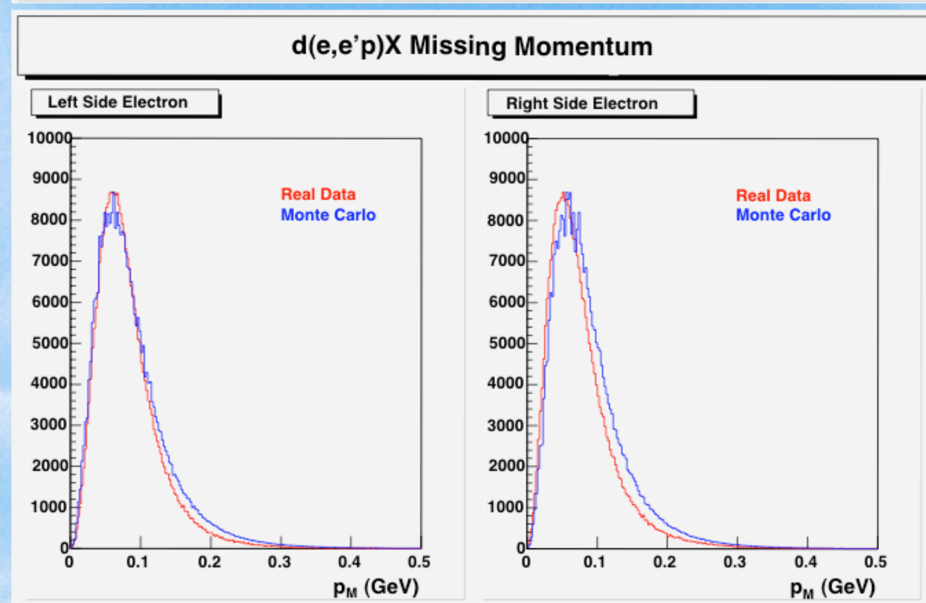
$$m_M \equiv \sqrt{E_M^2 - p_M^2}$$

Demand $m_M \approx m_n$ to ensure X = n

Radiative effects

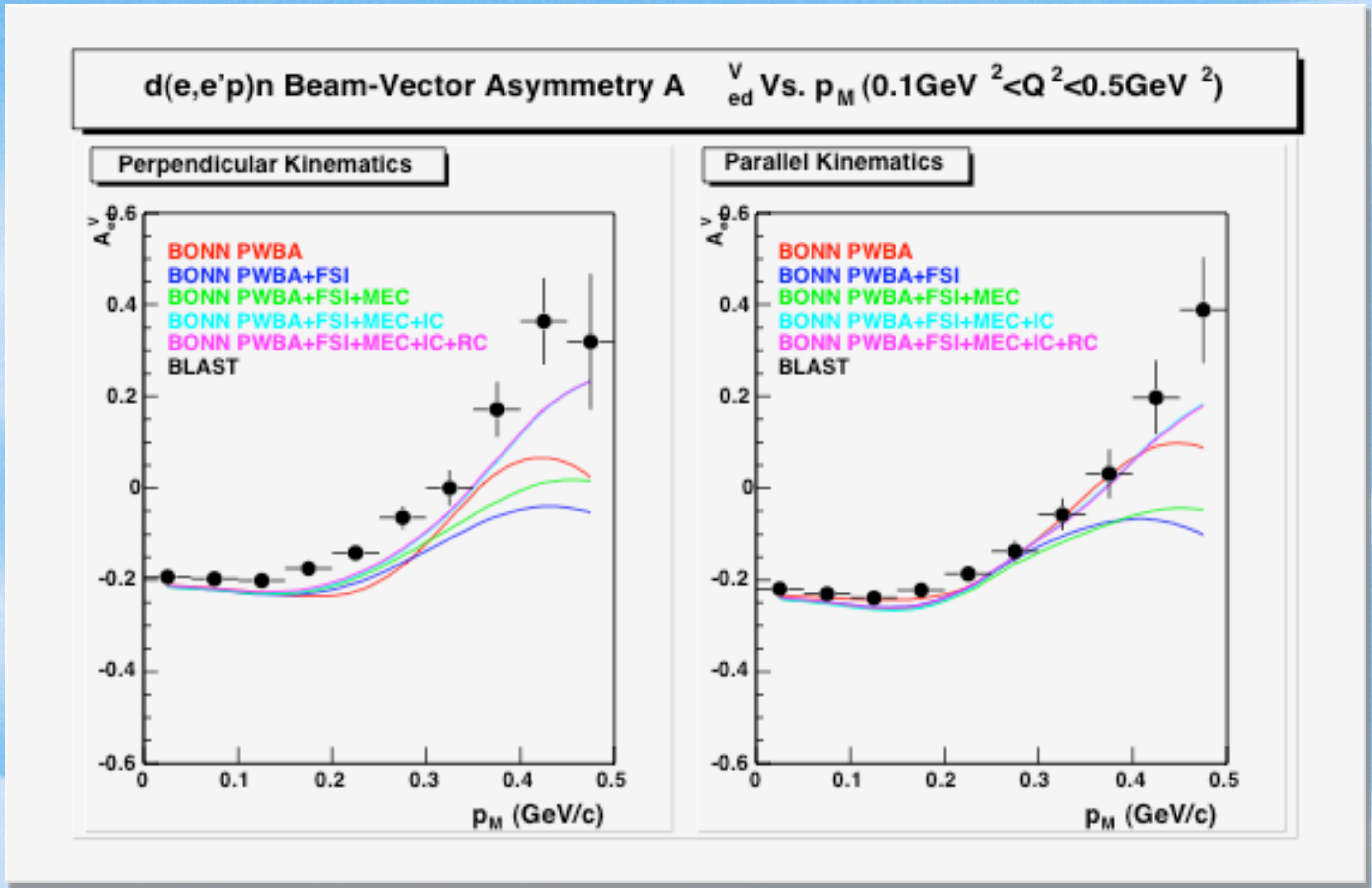
Fermi motion





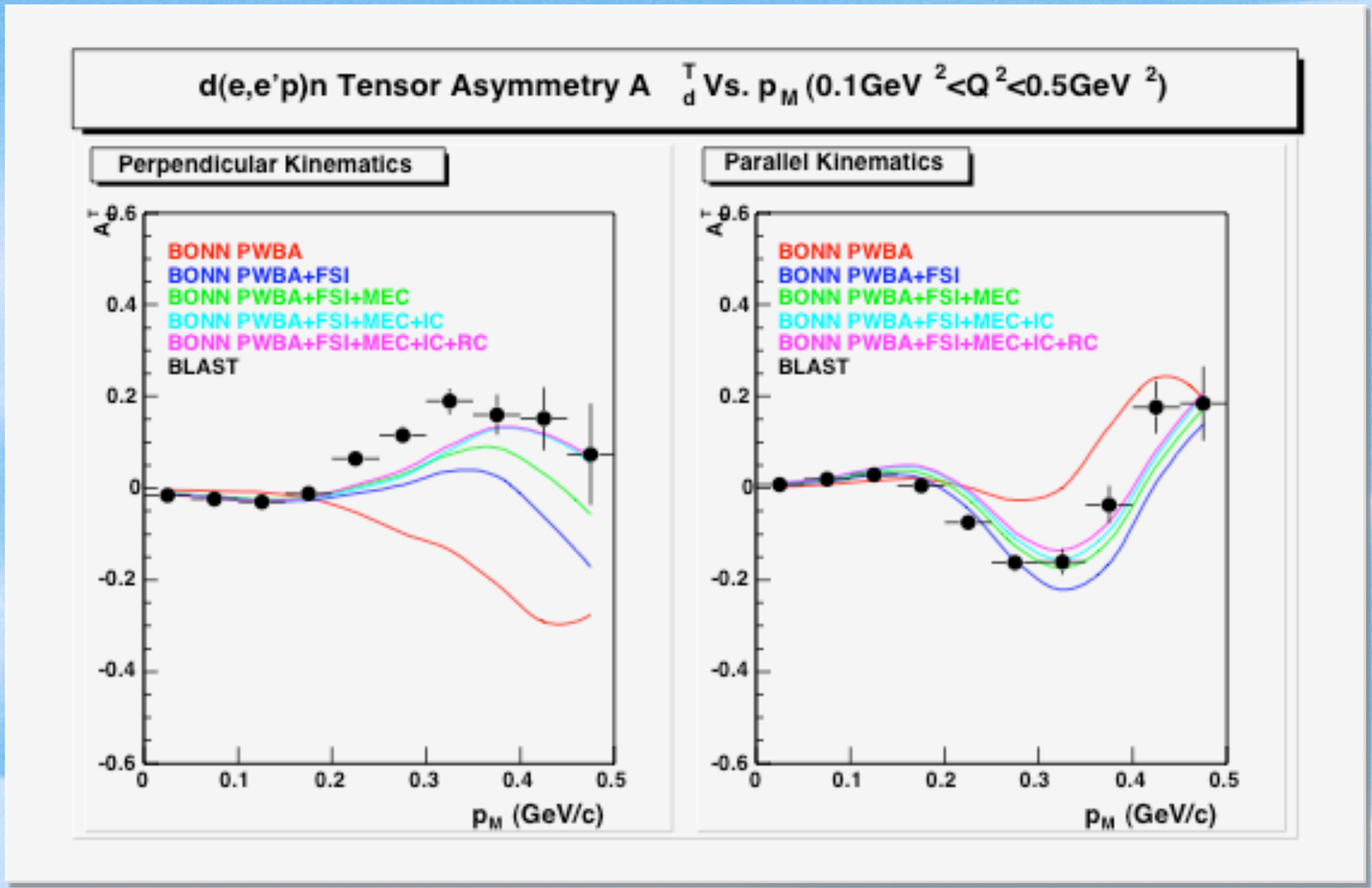
Vector Asymmetry

- Vector polarisation determined from low P_M bins at low Q^2, model independent
- Full theory with all terms needed to agree with data
- Effect of D state at P_M > 0.2 GeV/c

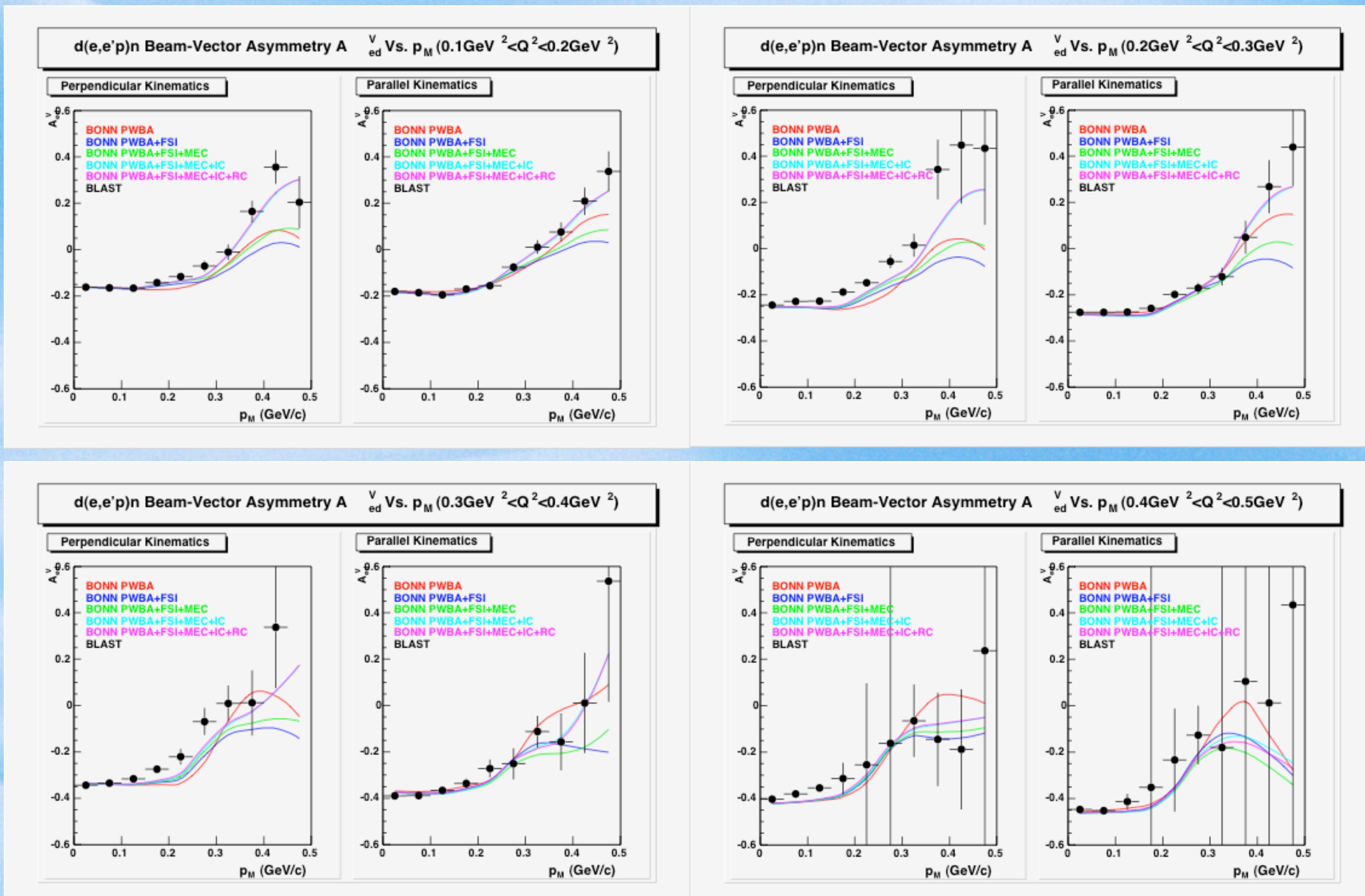


Tensor Asymmetry

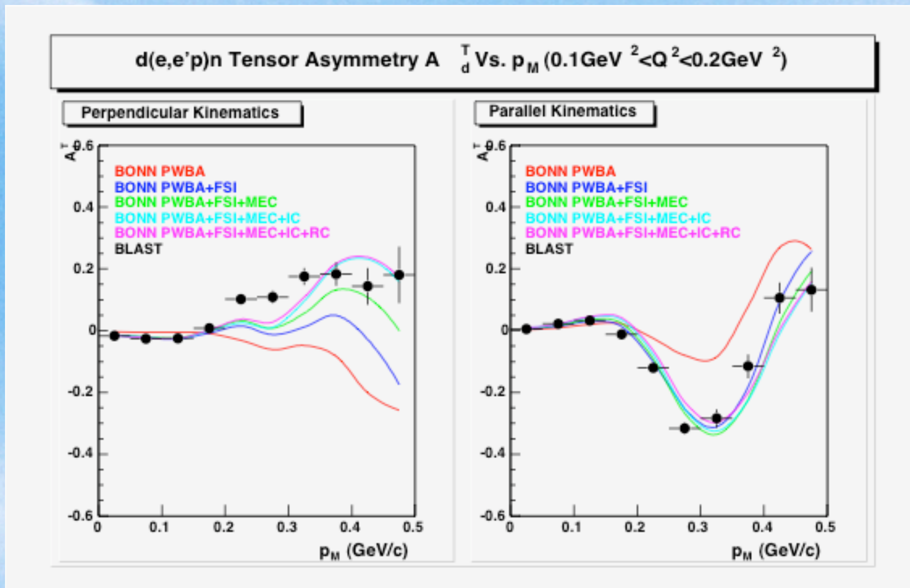
Target tensor polarisation determined from T_{20} measurements
Should be zero but effect of D state starting at $P_M > 0.2$
Full theory needed to match data but even then D state effects start too late

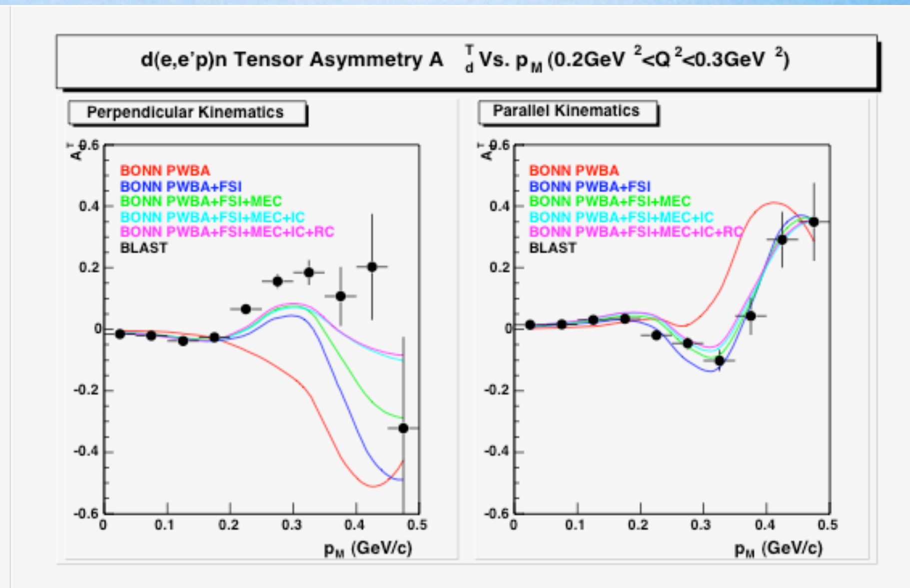


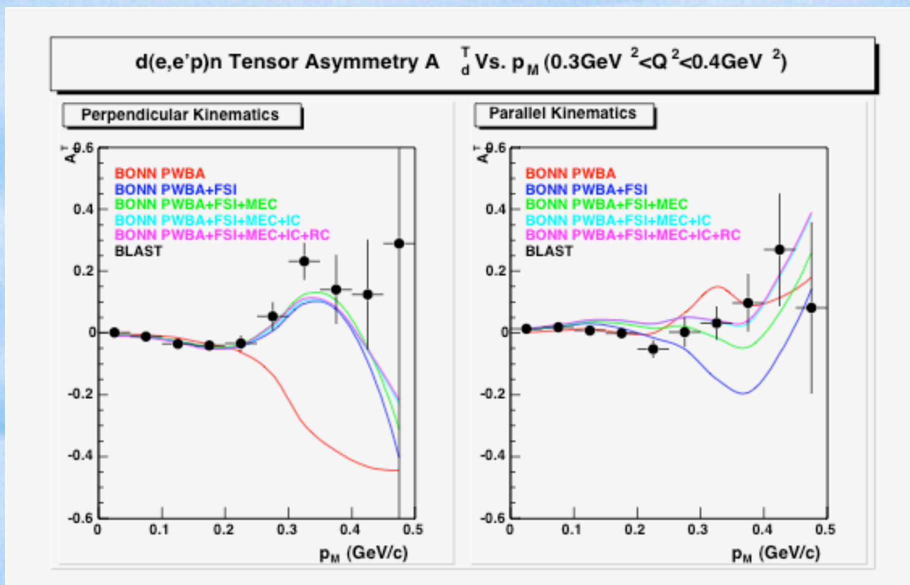
Beam-Vector Asymmetry with Q^2

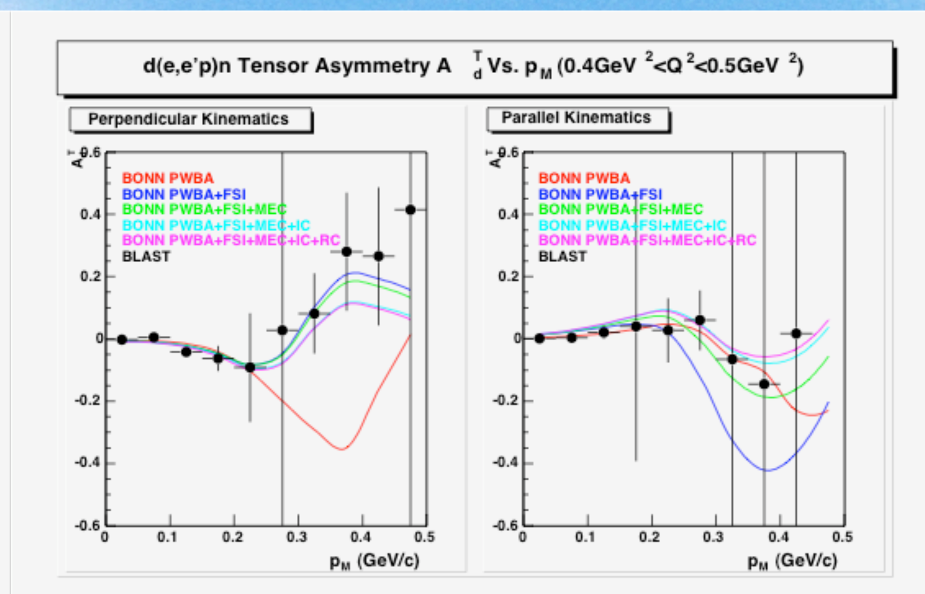


Tensor Asymmetry with Q^2









Quasi-Elastic e'n - Neutron Charge Form Factor G_E^n

Difficult to measure G_E^n

- no free neutron targets, must unfold from deuterium or ^{3}He
- electric form factor small; cross sections dominated by G_M^n
- neutron detection efficiency usually low

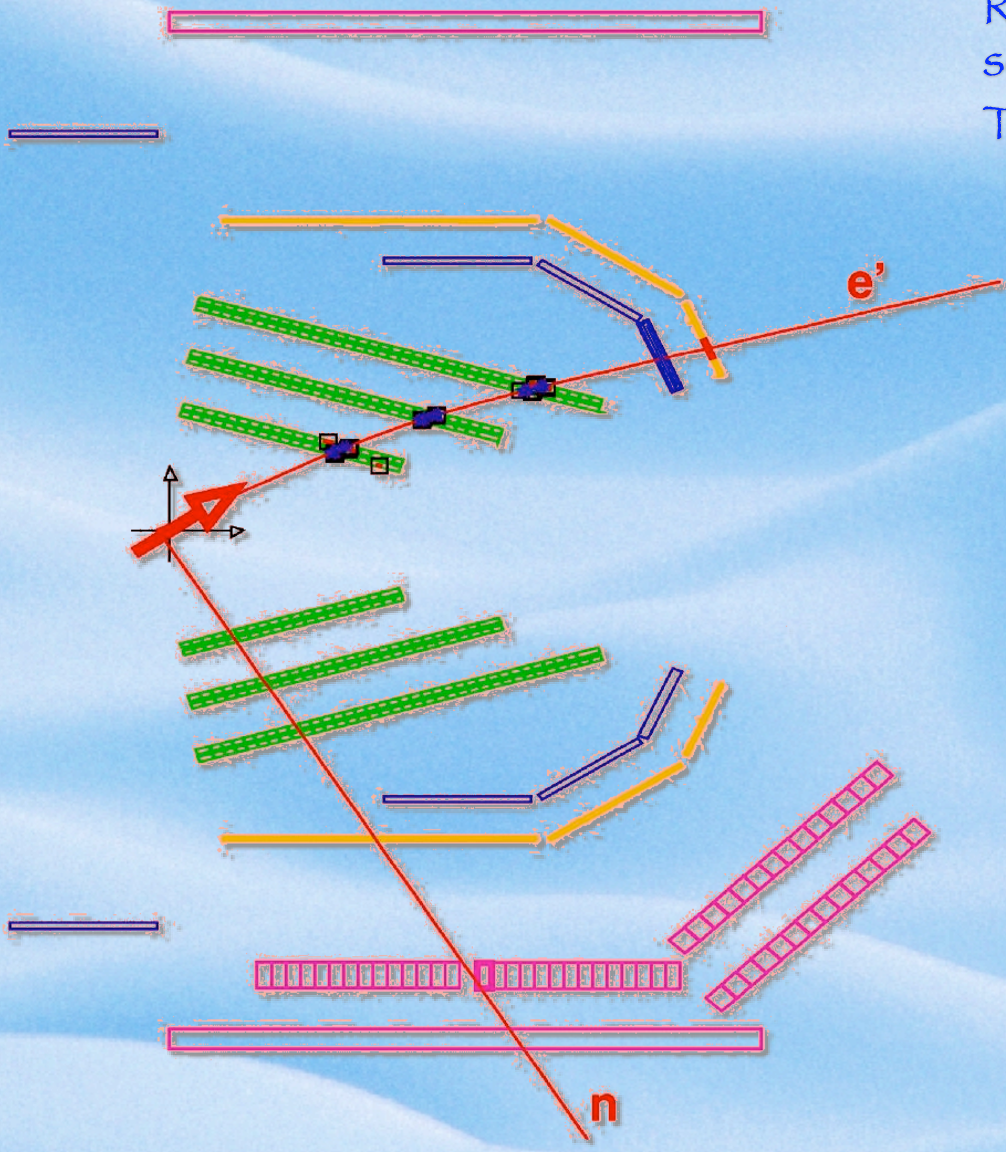
Least known of nucleon form factors but important

- test QCD models at low Q^2 which predict charge distribution from quark distribution and interactions
- needed to reduce systematics in parity violation experiments

Measure G_E^n from vector asymmetry $A^V_{ed} \propto G_E^n G_M^n$

- perpendicular kinematics has largest asymmetry
  - hence BLAST put additional neutron detectors in right sector

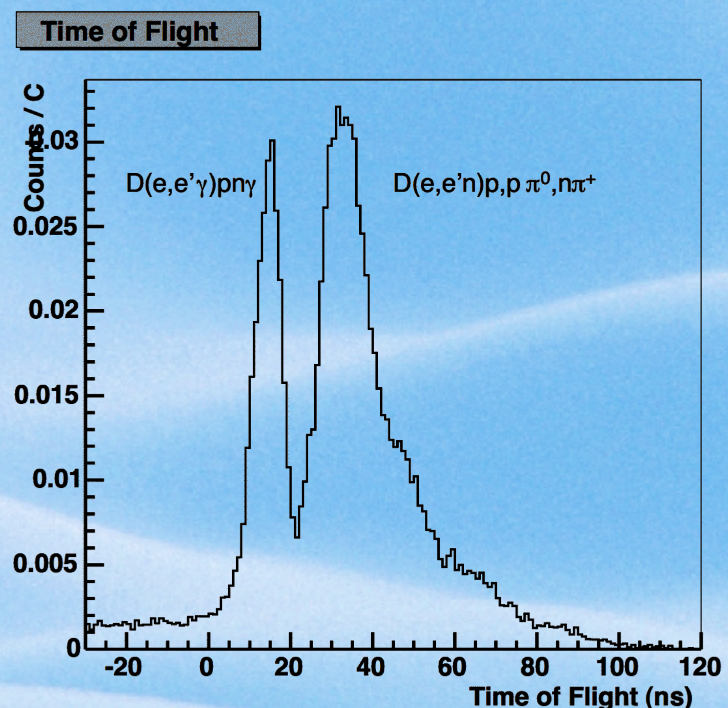
G_E^n Event Selection



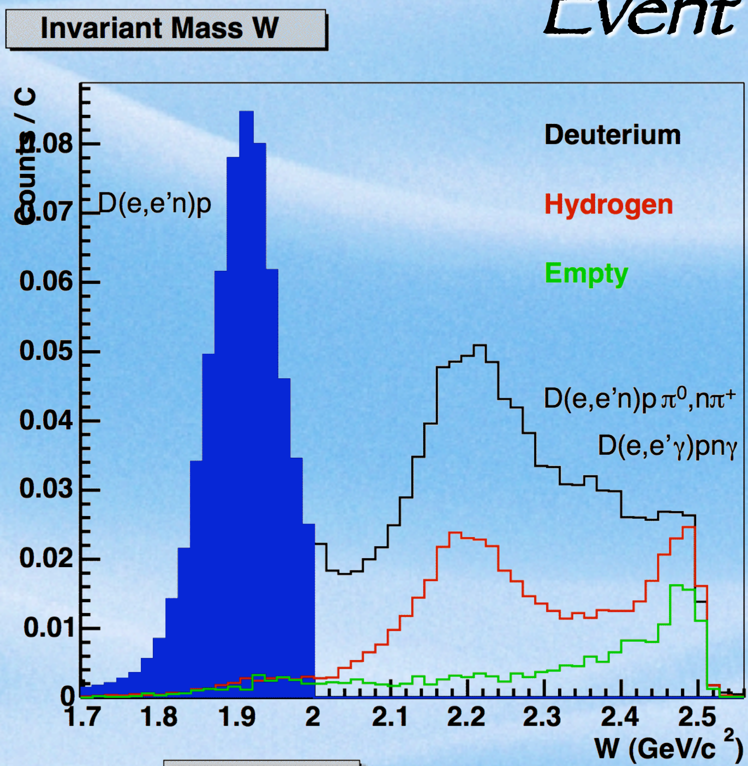
Require electron and neutron in opposite sector with NO wire chamber track

Timing cut in neutron detector

- distinguish neutrons from photons
- timing resolution 5 ns
- 5% neutron momentum resolution



Event Selection for G_E^n



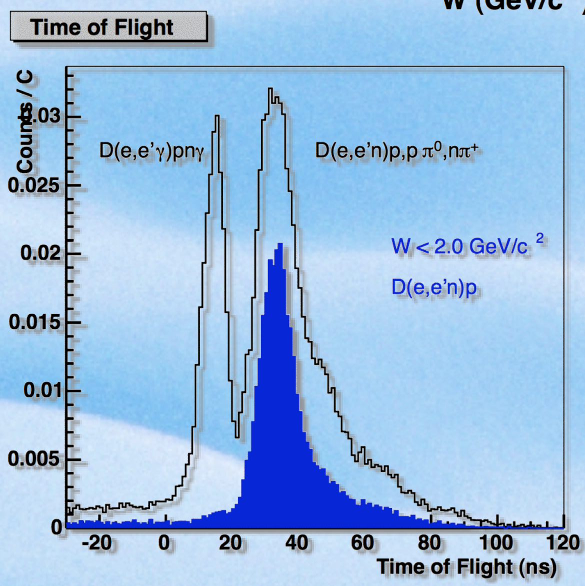
Calculate invariant mass

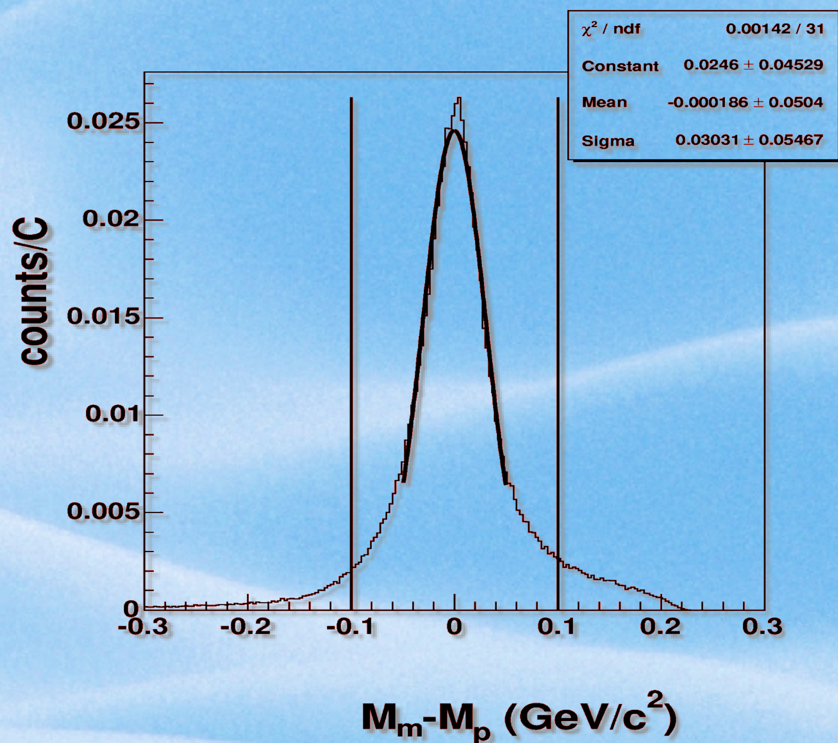
- cut $W<2\ GeV/c^2$

Background from empty target and H

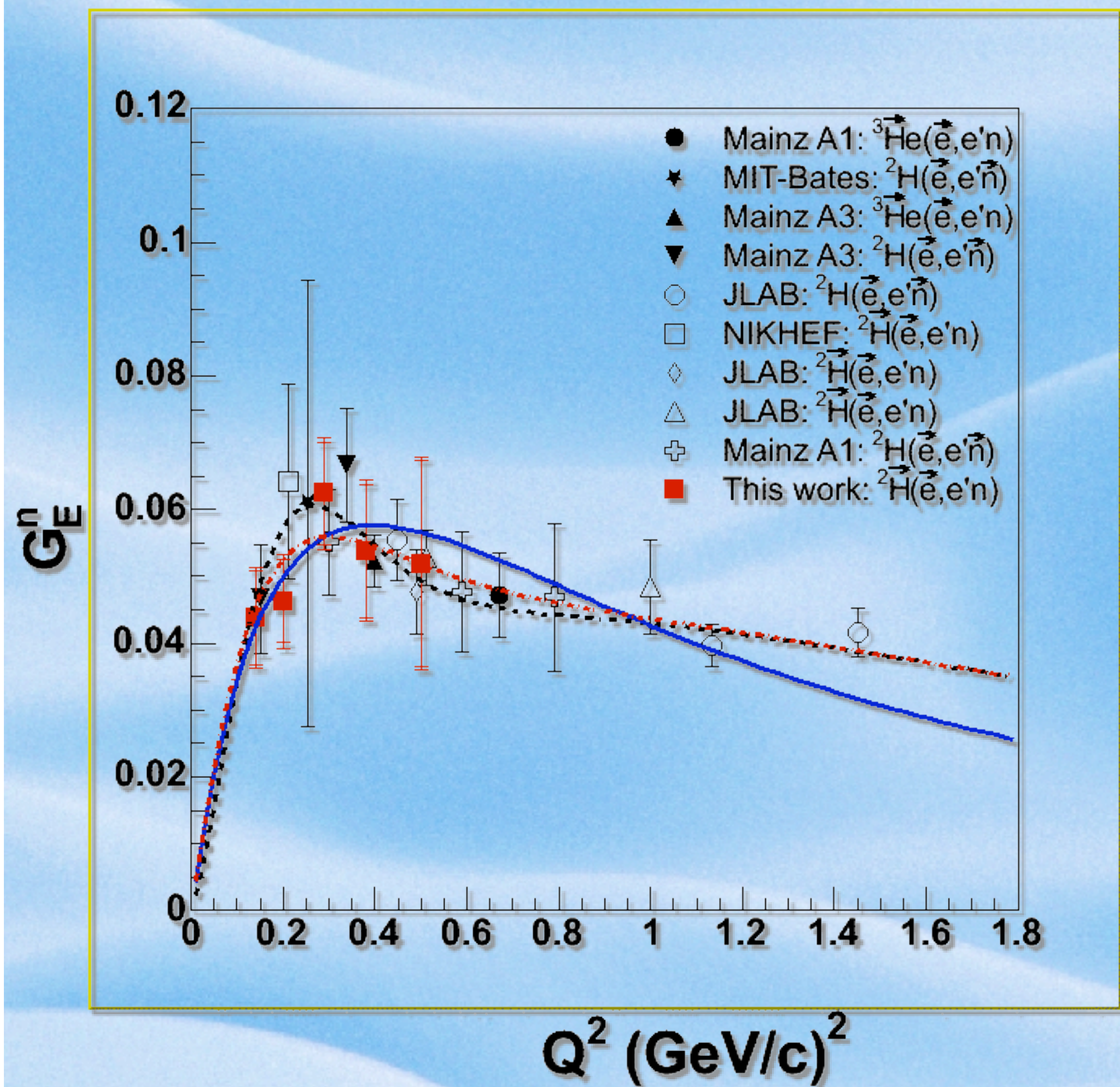
Form missing mass

- cut around proton mass





G^n_E World Plot



Blue curve

- Galster parameterisation with Platchkov modification
- under shoots high Q^2

$$-\frac{a\mu_n\tau}{1+b\tau}G_D \qquad a = 0.906 \quad b = 3.53$$

Black curve

- A1 Collaboration following Friedrich and Walcher
- non-relativistic constituent quark model
- charge radius wrong

Red curve - BLAST fit

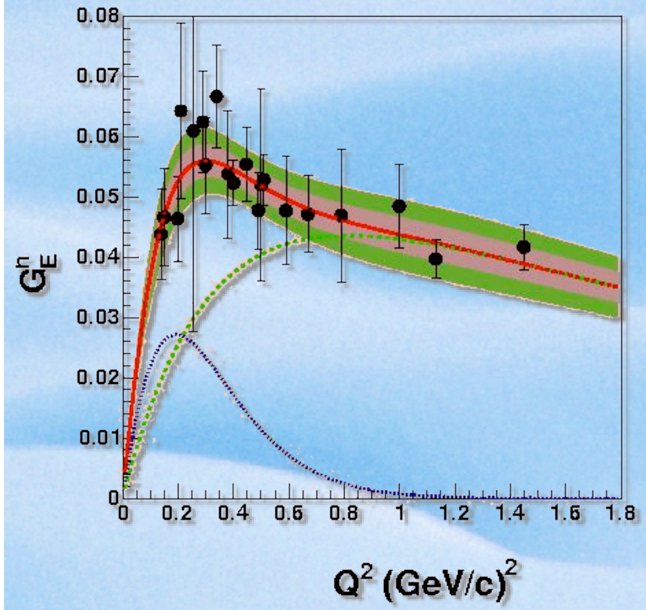
- form as A1 Collaboration
- constrain to get charge radius

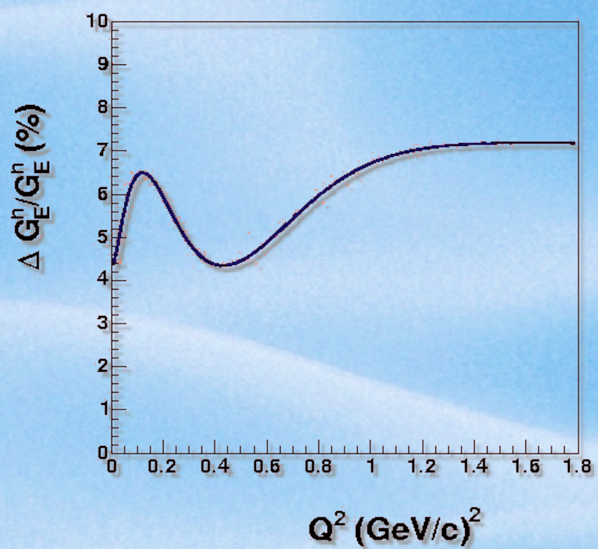
BLAST Fit

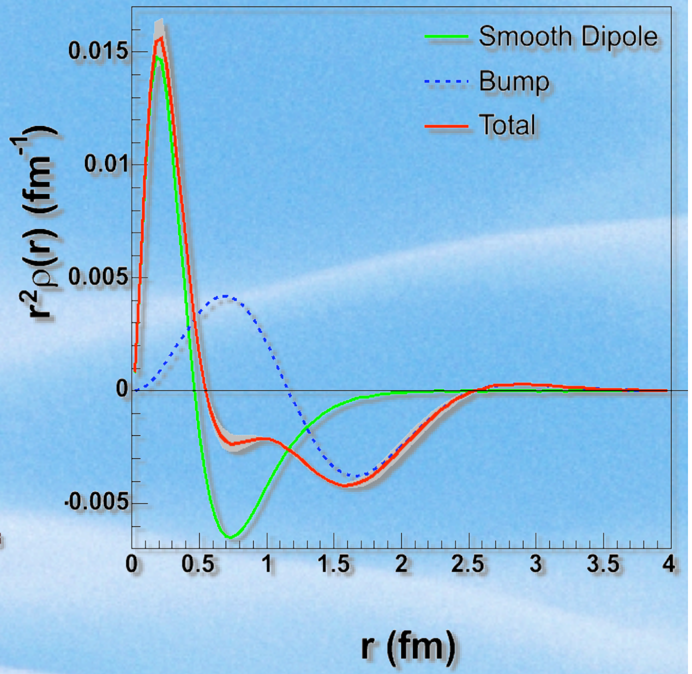
BLAST fit ← A1 Collaboration ← Friedrich and Walcher

$$G_E^n = \frac{a}{(1+Q^2/a_1)^2} - \frac{a}{(1+Q^2/a_2)^2} + a_b Q^2 \left(e^{-\frac{1}{2}(\frac{Q-Q_b}{\sigma_b})^2} + e^{-\frac{1}{2}(\frac{Q+Q_b}{\sigma_b})^2} \right)$$

- smooth dipole term (sum of 2 dipoles) normalised so $G_E^n(Q^2=0)=0$
  - corresponding to a constituent quark core (dominates high Q^2, small r)
- bump term (sum of 2 gaussians)
  - describing a pion cloud around the core (dominates low Q^2, large r)
  - bump term determines charge radius







Inclusive Electron Scattering from Deuterium - G_M^n

Why ?

- fundamental quantity
- test for theoretical models
  - N-N interaction
  - lattice QCD
  - effective field theory
- data needed for parity violation experiments

Part of systematic study at BLAST

- G_e^p, G_M^p, G_E^n, G_M^n
- deuteron form factors: G_C, G_M, and G_Q

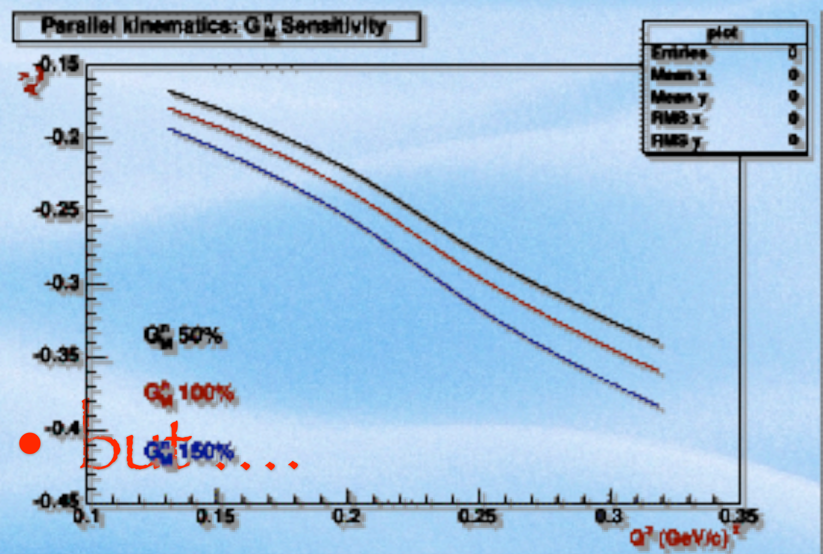
Inclusive Electron Scattering from Deuterium

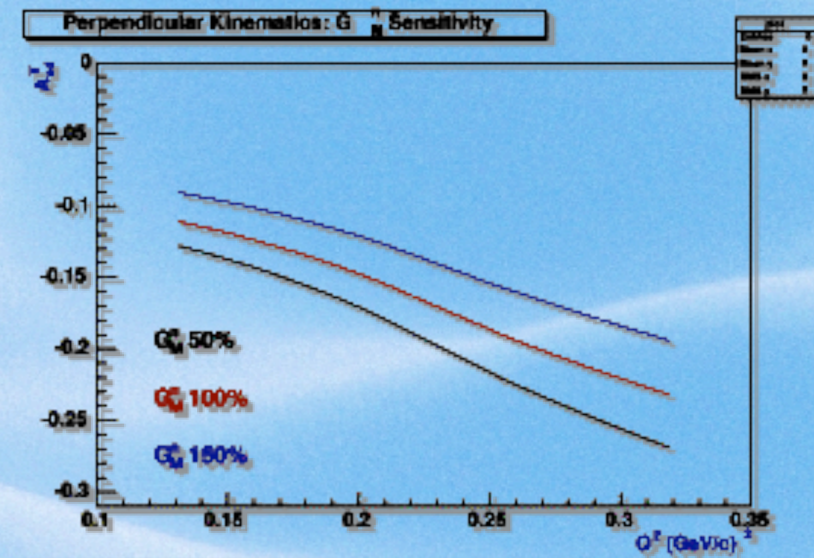
Measuring G_M^n from vector asymmetry

$$A_N = -\frac{2\sqrt{2\tau(1+\tau)}\,v_{TL'}(G_E^N G_M^N)\sin\theta^*\cos\phi^* \;-\; 2\tau v_{T'}(G_M^N)^2\cos\theta^*}{(1+\tau)v_L(G_E^N)^2 \;+\; 2\tau v_T(G_M^N)^2}$$

Parallel kinematics greatest sensitivity

- slightly





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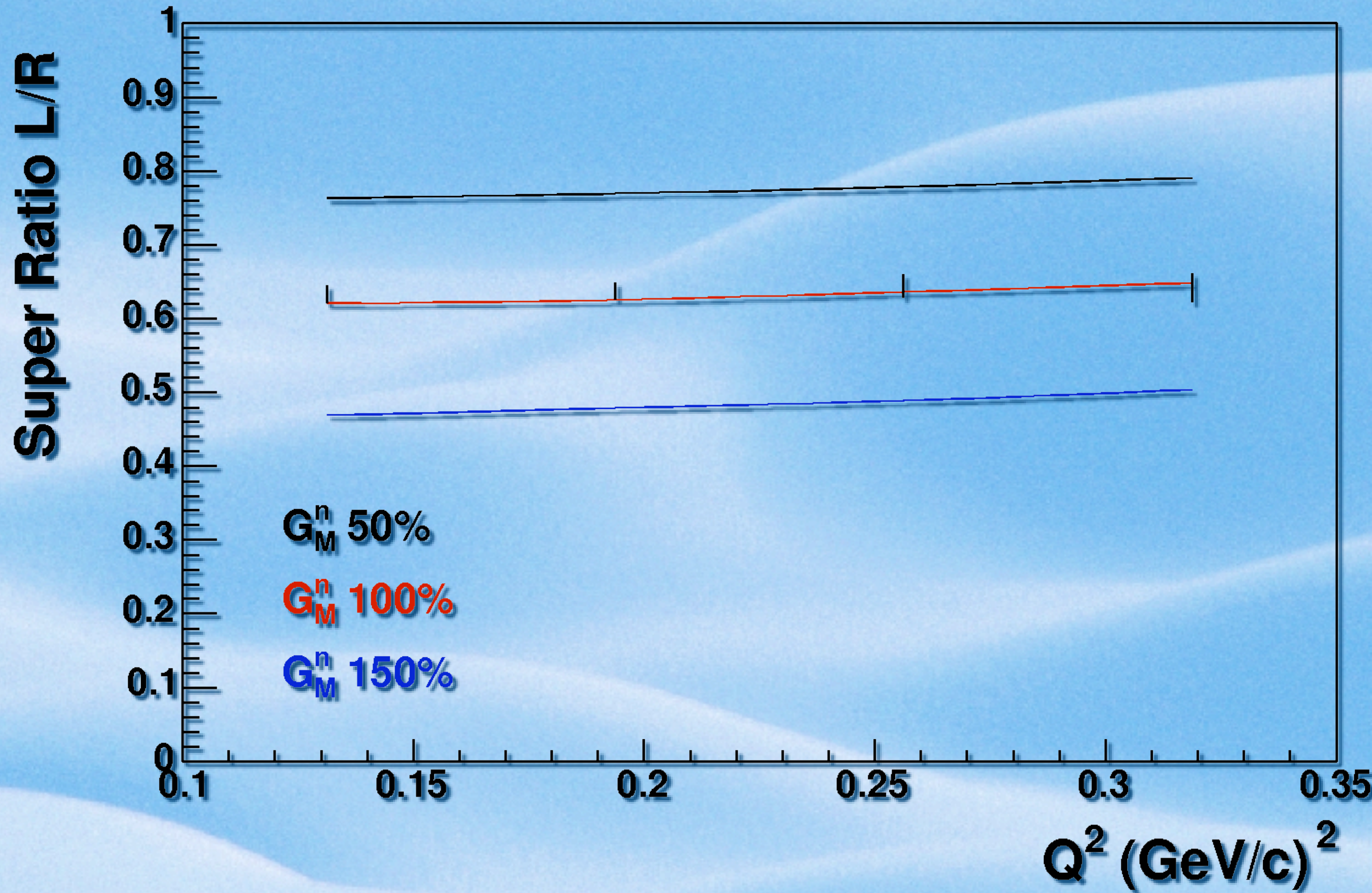
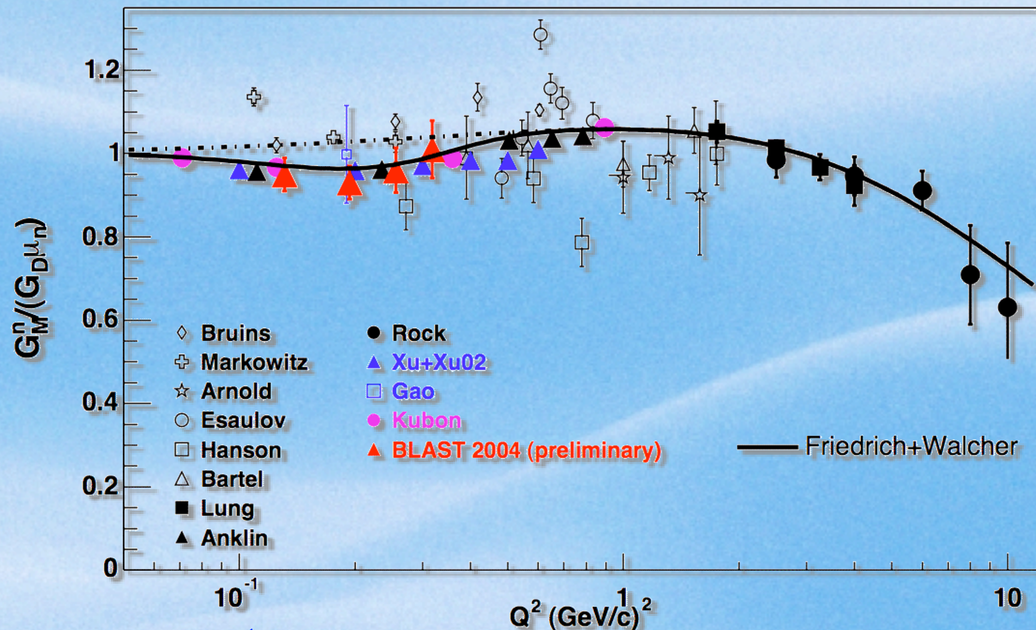
Inclusive ed Scattering - G_M^n

Super ratio, A_L/A_R, even more sensitive



G_M^n from Inclusive Scattering



Preliminary BLAST result

Fit with Friedrich and Walcher parameterisation

$$G_E^n = \frac{a_0^{in}}{(1+Q^2/a_1^{in})^2} + \frac{a_0^{out}}{(1+Q^2/a_1^{out})^2} + a_0^\pi \left(1 - \frac{1}{6}\frac{Q^2}{a_1^\pi}\right) e^{-\frac{Q^2}{4a_1^\pi}}$$

- Inn
- Gaussian dip region

Conclusions

Preliminary results from BLAST

T_{20}

quasi-elastic e'p

quasi-elastic e'n

Inclusive

Factor of two more data to analyse

Also collecting data on H, π production, Δ resonance, ..

Systematic study of the spin-dependent interaction in few-body systems

BLAST Collaboration

Ratio of G_E^p/G_M^p at BLAST