Studying Nucleon Structure with BLAST and Prospects at a Future Electron-Ion Collider

Motivation

Recent Results from the BLAST Experiment

Possible Future for BLAST

Prospects at a Future Electron-Ion Collider

Setting the Scale

Solar system

- scale the solar radius to 1 m

Setting the Scale

Solar system

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Gold atom

- scale the nuclear radius to 1 m

Setting the Scale

Solar system

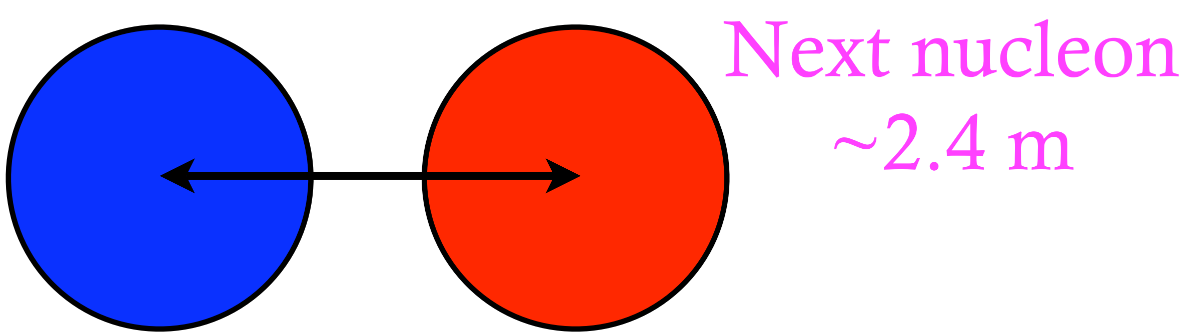
- scale the solar radius to 1 m

Gold atom

- scale the nuclear radius to 1 m

Nucleon in nucleus

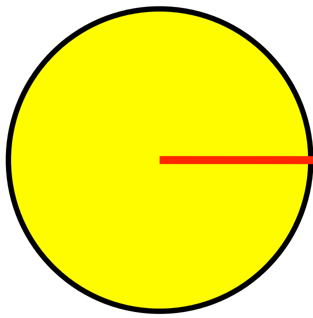
- scale nucleon radius to 1 m



Setting the Scale

Solar system

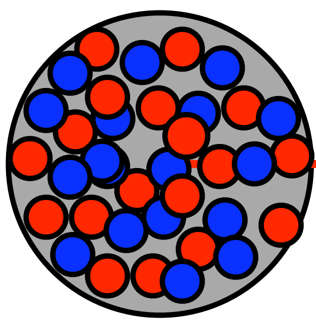
- scale the solar radius to 1 m



Plu

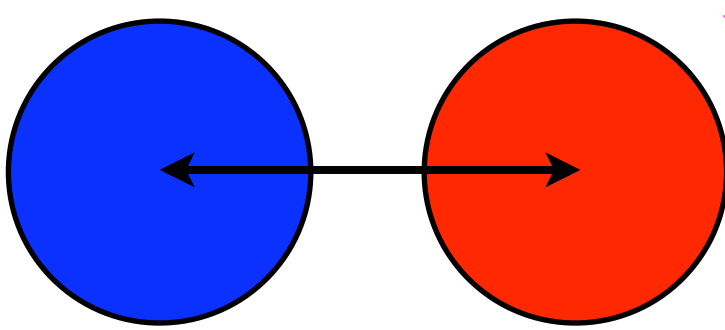
Gold atom

- scale the nuclear radius to 1 m

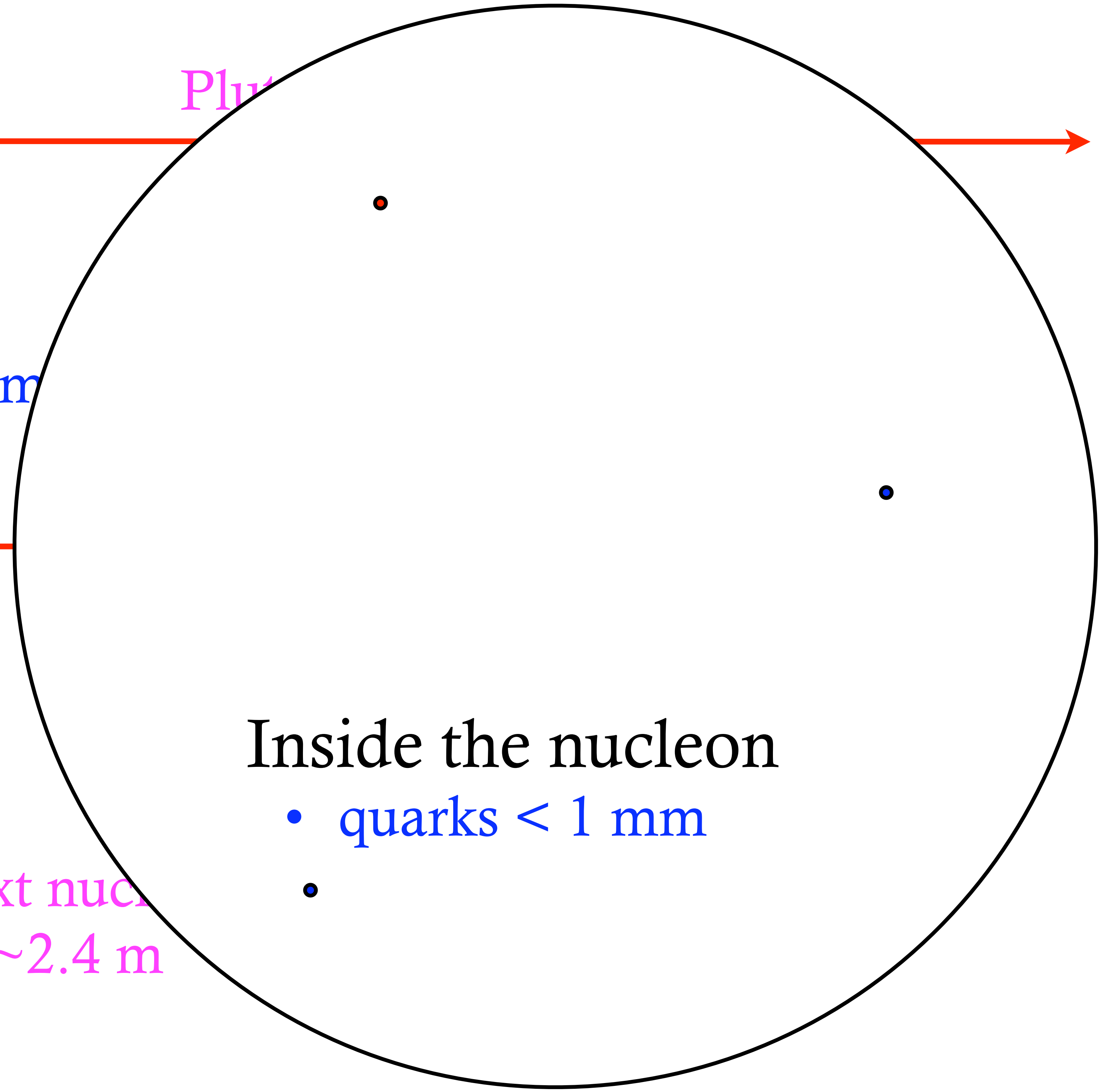


Nucleon in nucleus

- scale nucleon radius to 1 m



Next nuc
~2.4 m



Inside the nucleon

- quarks < 1 mm

Binding Energy and Nucleon Mass

$$\Delta E = \sum_{\text{constituents}} M_{\text{constituent}} - M_{\text{Whole}}$$

For stable molecules, atoms, nuclei binding energy is positive.

- e.g. gold nucleus
  - 79 * 938.2... + 118 * 939.5... - 196.9...* 931.4... = 1520 MeV
  - approximately 7.7 MeV / nucleon

For a nucleon

- up quark mass ~5 MeV
- down quark mass ~7 MeV
- proton binding energy
  - 2 * 5 + 1 * 7 - 938.2... = - 921... MeV

Nucleon binding energy negative but stable !

- constituent quarks only provide a fraction of the mass
- mass arises from kinetic energy of valence quarks, sea quarks, and gluons
- colour confinement binds them inside the nucleon

Nucleon Spin

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Site Highlights

New features
WSJ.com is introducing new search features as well as indexes to give readers quick access to businesses and people prominently mentioned in the daily Journal.

SCIENCE JOURNAL
By SHARON BEGLEY

Scientists Try to Put Right Spin on Quarks To Understand Matter

May 19, 2006; Page B1

Talk about accounting problems. In a quest that has its roots 2,400 years ago in Democritus' search for the smallest bit of matter, physicists thought they were doing pretty well when, in the 1960s, they discovered that the protons in atomic nuclei are each made of three even-smaller subatomic particles, which were given the whimsical name quarks.

But it quickly became clear that the numbers "don't add up," says physicist Douglas Beck of the University of Illinois, Urbana-Champaign. The total mass of the three quarks, for instance, is a mere 1.5% of the proton's. Try as they might to balance the books, no amount of creative accounting has turned up the sources of the missing mass, casting doubt on science's understanding of how the basic building blocks of the physical world are assembled into matter.

Wall Street Journal - 19/5/06

http://online.wsj.com/article_email/SB114798871342257010-lMyQjAxMDE2NDE3OTkxODk4Wj.html

Mass of nucleon

1.5 % attributed to valence quarks

Nucleon spin

20-30 % from quarks

Nucleon magnetic moment

1/3 from quarks

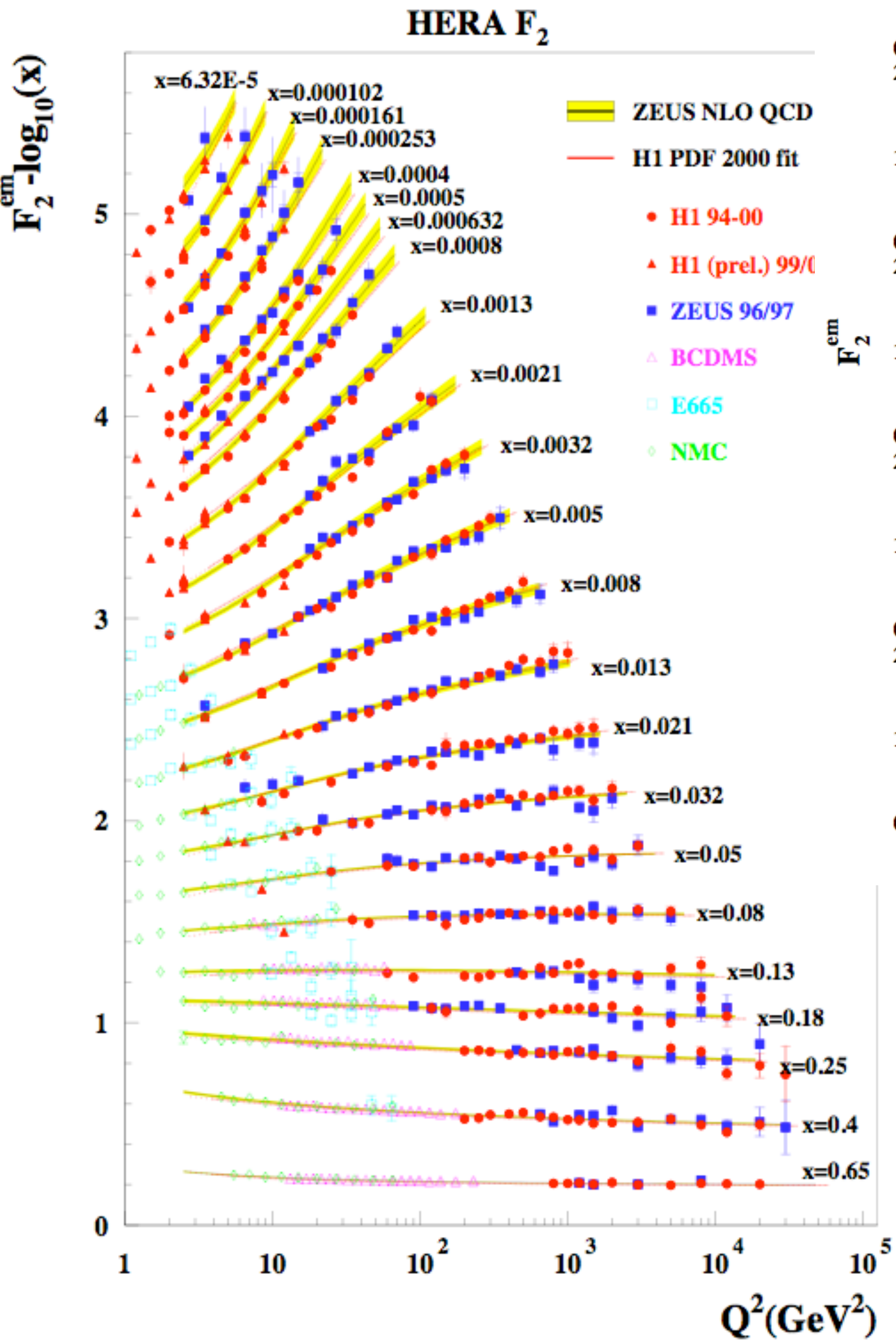
Role of sea quarks ?

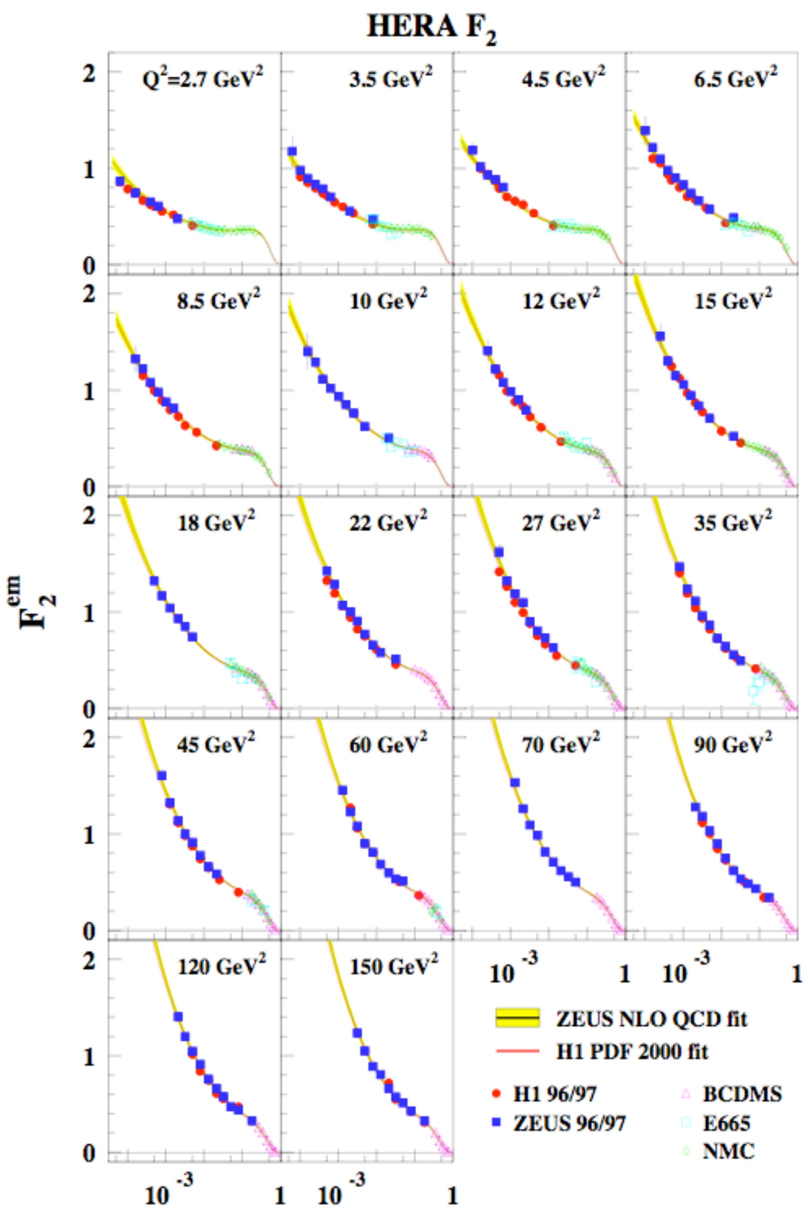
Role of gluons ?

QCD Remarkably Successful

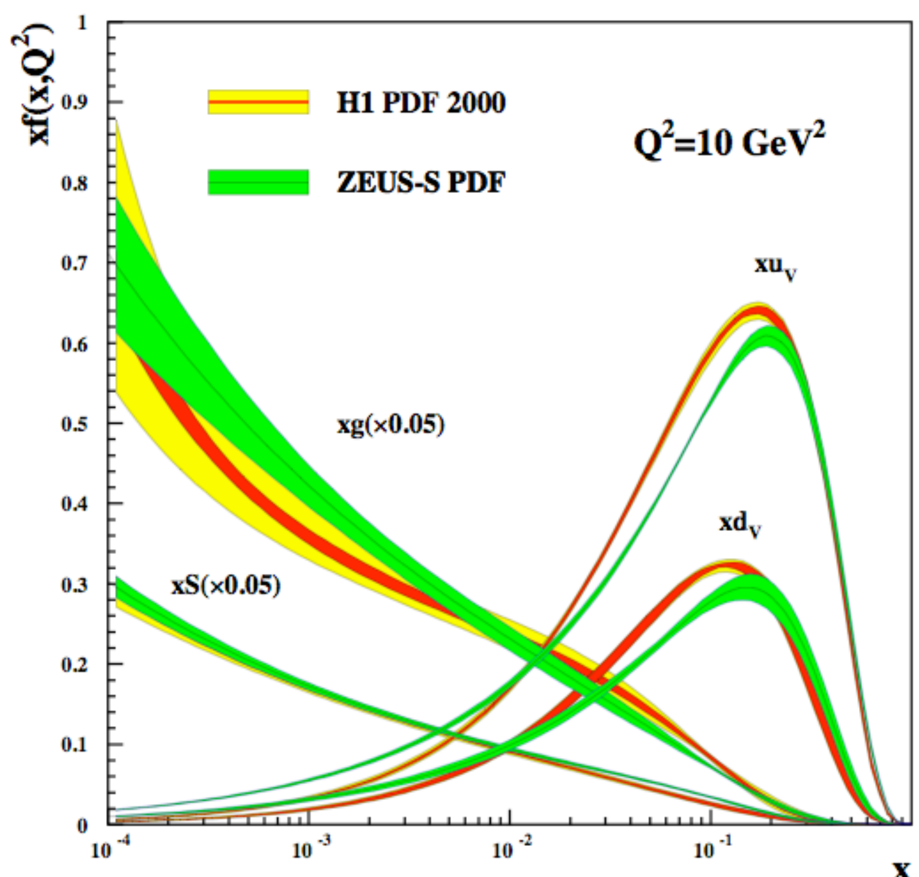
Bjorken scaling

DGLAP evolution



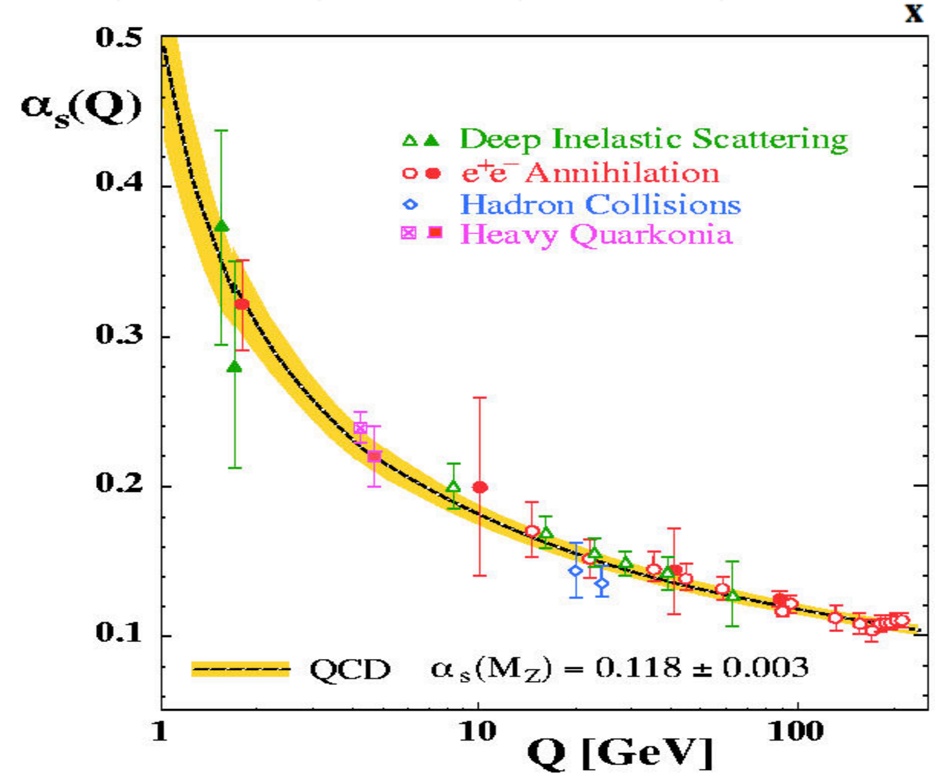


PDF's



Sea quarks

Running coupling α_s

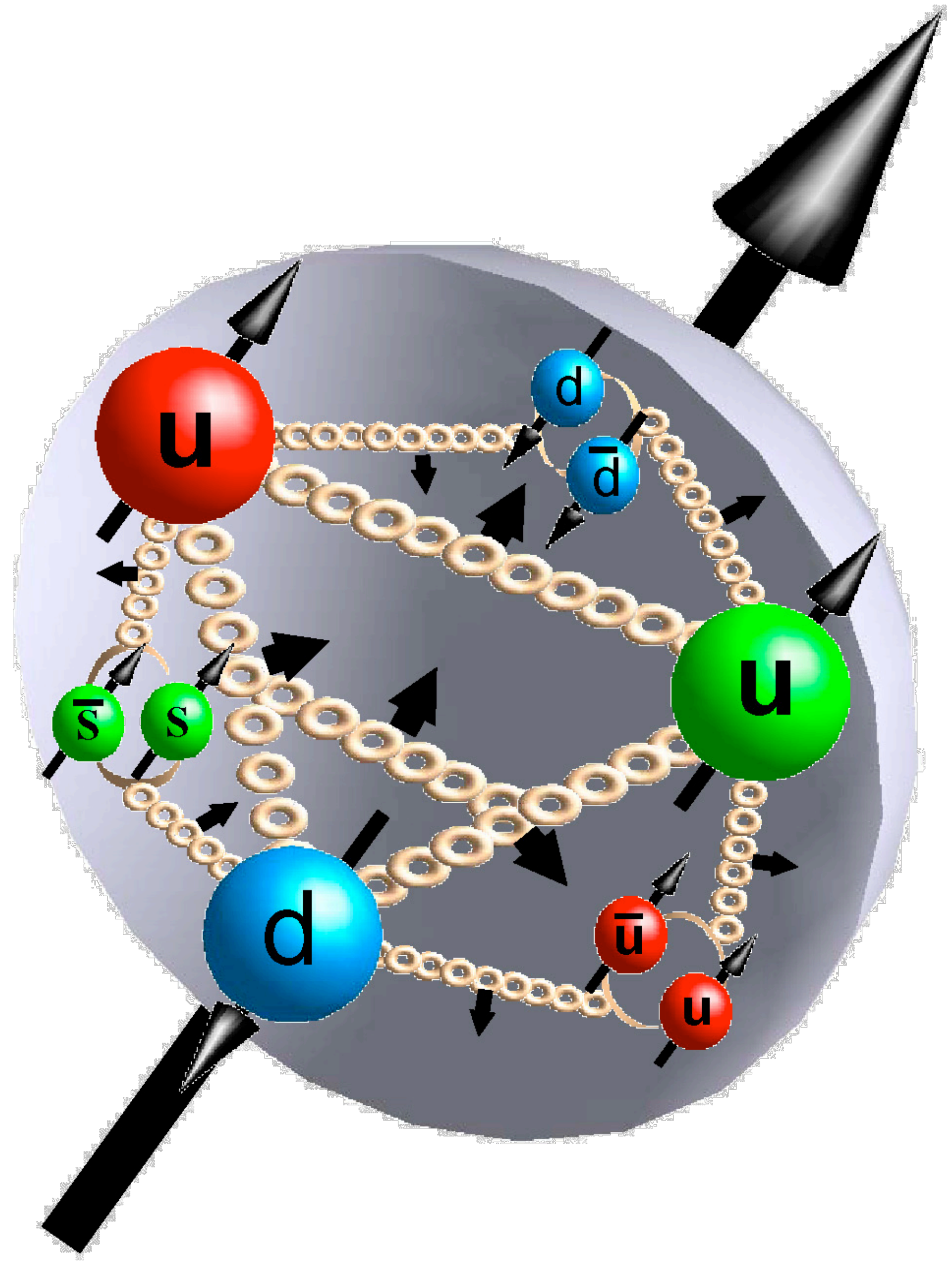


Nucleon Not Understood

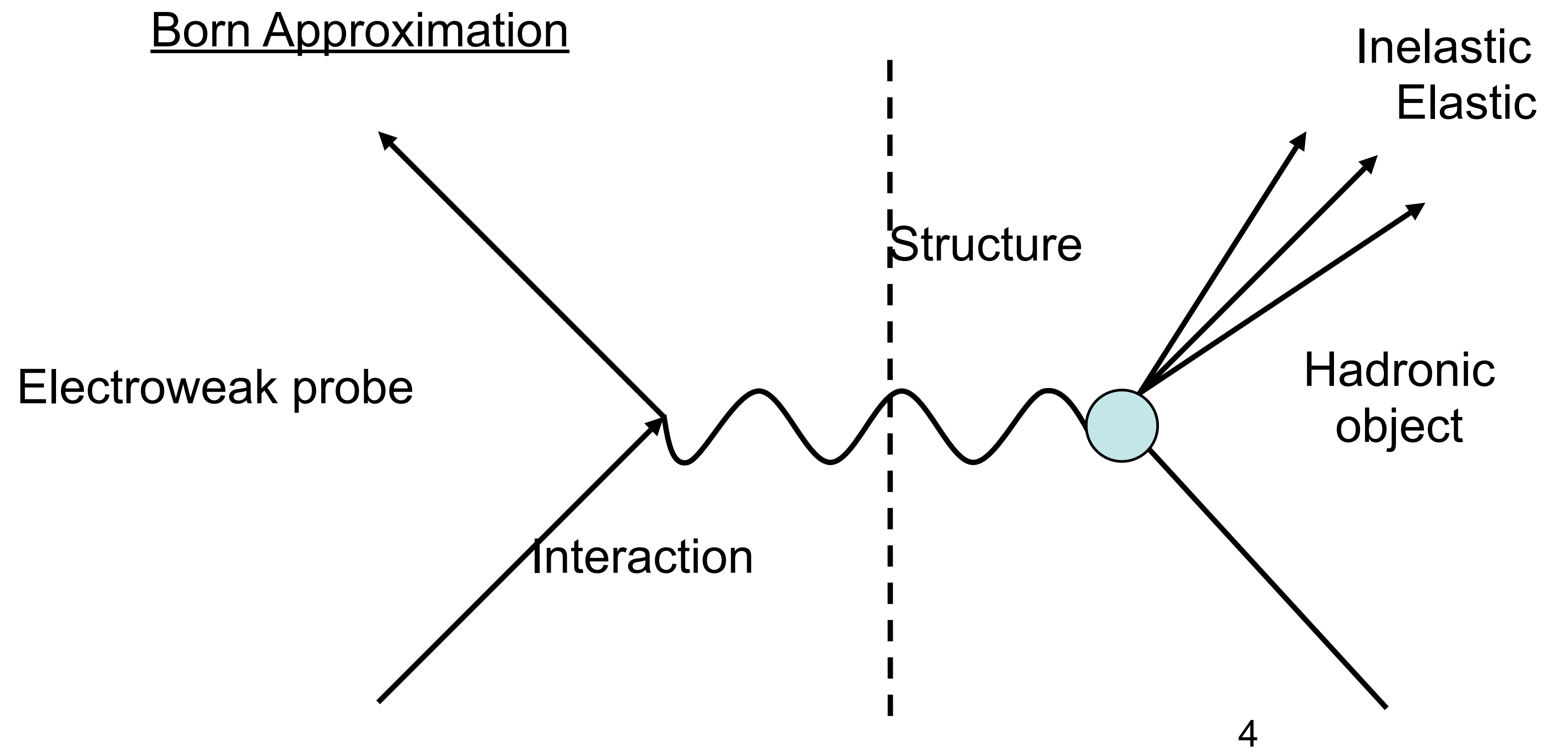
QCD describes the colour force
- very successful at high Q^2
  - asymptotic freedom
- not currently applicable to nucleon
  - pQCD not possible at confinement
- lattice QCD?

Nuclear force screened colour force
- current models phenomenological

Need to know more
- nucleon structure
- spin distribution
- flavour distribution
- distributions in nuclei
- data to test QCD



Electron Scattering as a Probe



Electron ideal

- lepton vertex know from QED
- virtual photon probes hadron
  - interacts with quarks
  - measures hadronic charge and magnetic currents

$$\bar{u}(P')\left[\gamma^{\mu} F_1^N(Q^2) + i\sigma^{\mu\nu}\frac{q_\nu}{2M} F_2^N(Q^2)\right] u(P)$$

  - ignoring parity violating term

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

- 100 MeV/c $\Rightarrow$ 12.6 fm
- 1 GeV/c $\Rightarrow$ 1.26 fm
- 10 GeV/c $\Rightarrow$ 0.126 fm

Nucleon Elastic Form Factors

- for point-like, spin=1/2 particles QED gives:

$$\sigma_{Dirac} = \sigma_{Mott}\left(1 + 2\tau\tan^2\frac{\theta}{2}\right)$$

- for extended objects, like nucleons, require form factors:

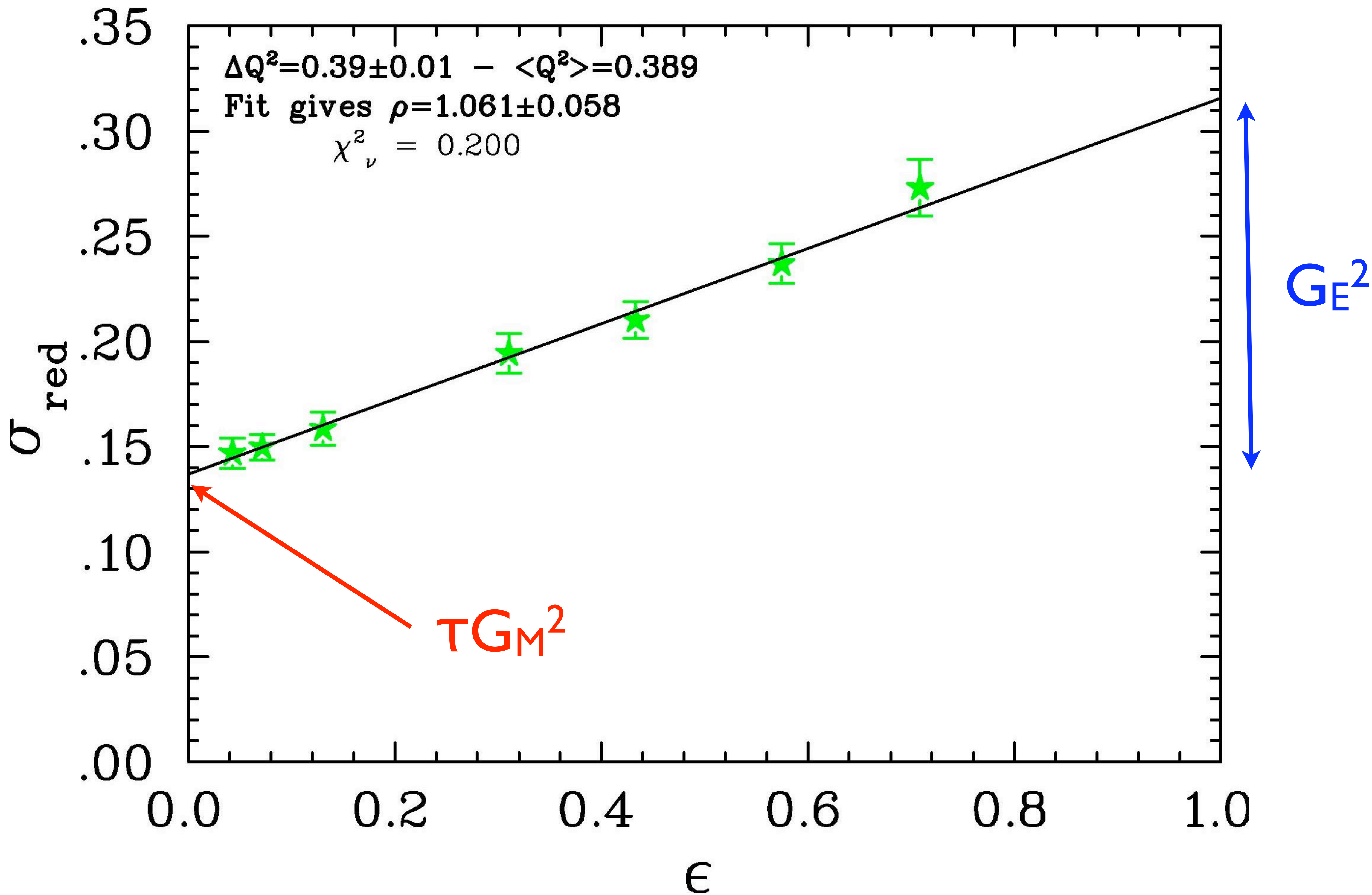
$$\sigma_{lab} = \sigma_{Mott}\left[\left(\frac{{G_E^N}^2 + \tau {G_M^N}^2}{1+\tau}\right) + 2\tau {G_M^N}^2\tan^2\frac{\theta}{2}\right]$$

$$G_E^N = F_1^N - \tau F_2^N; \qquad G_M^N = F_1^N + F_2^N$$

- traditionally measure using Rosenbluth technique

$$\sigma_{lab} = \sigma_{Mott}\left(\frac{\epsilon G_E^2 + \tau G_M^2}{\epsilon(1+\tau)}\right), \qquad \tau = \frac{Q^2}{4M^2}, \qquad \epsilon = \frac{1}{1 + 2(1+\tau)\tan^2\frac{\theta}{2}}$$

Rosenbluth Separation



Nucleon Elastic Form Factors

Usually parameterised as dipole in momentum space.

$$G_D(Q^2) = \frac{1}{\left(1 + \frac{Q^2}{0.71}\right)^2} \quad \leftrightarrow \quad \rho_D(r) = \rho_0^{-\sqrt{0.71}r}$$

- corresponds to a exponential distribution in position space
- single dipole describes G^p_E, G^p_M, and G^n_M
- G^n_E is the exception, order of magnitude smaller
  - traditionally hard to measure, small, no convenient neutron targets

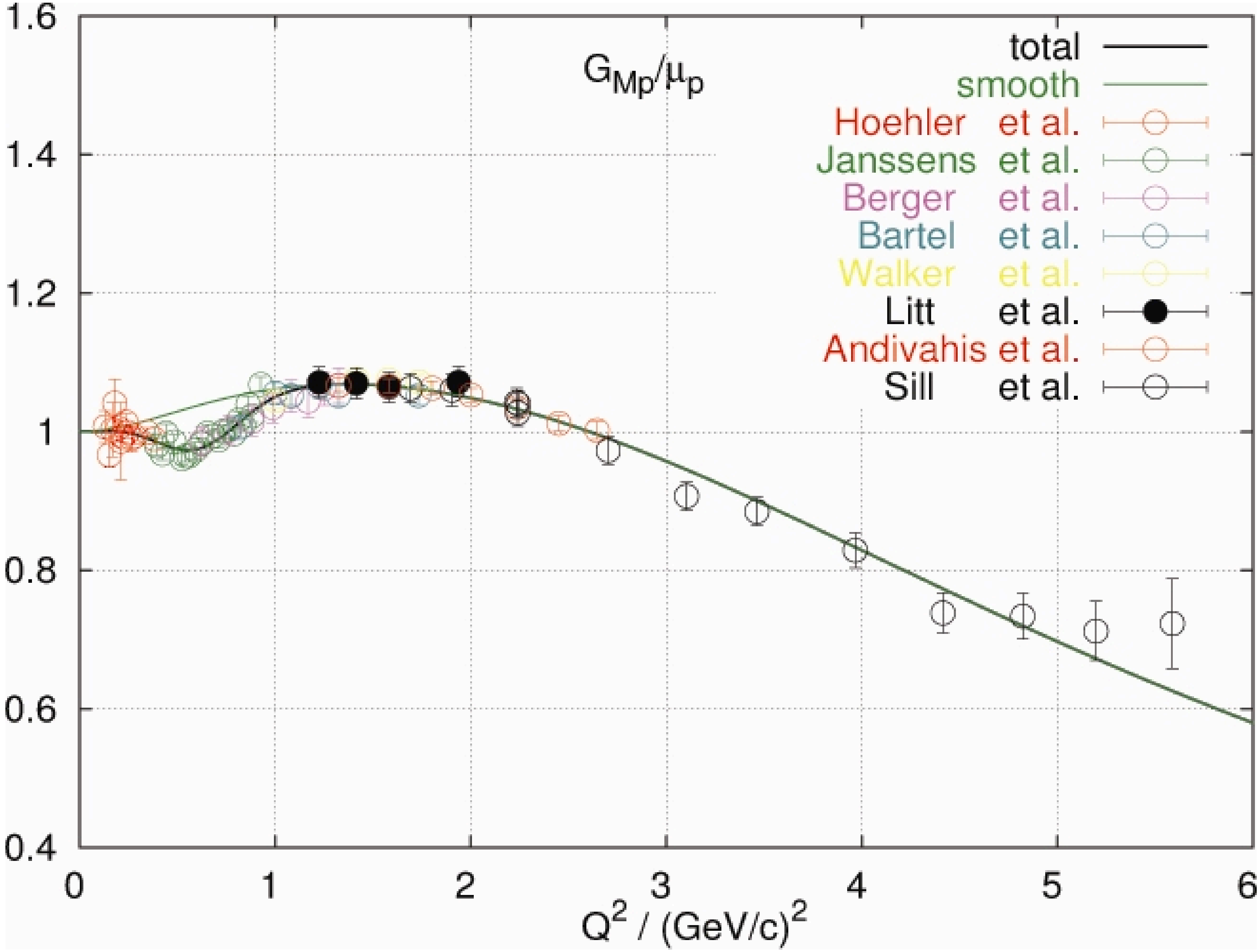
But dipole not perfect, does not describe details $Q^2 < 1$ $(GeV/c)^2$
Friedrich and Walcher have proposed a new parameterisation:

$$G^N(Q^2) = G^N_S(Q^2) + \alpha_B Q^2 G^N_B(Q^2)$$

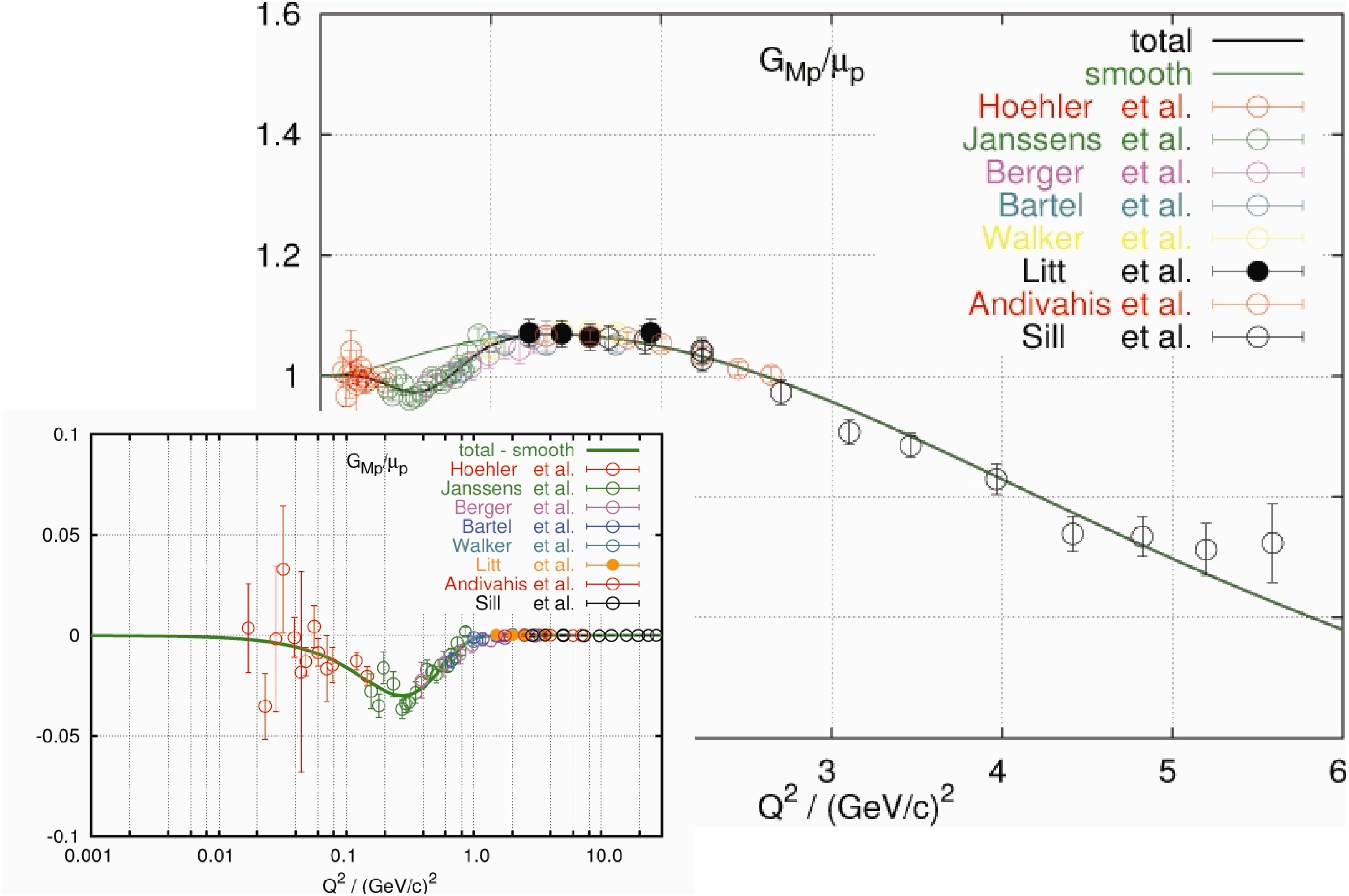
- S- smooth term of two dipoles
- B - bump part of two gaussians

- fit to a collection of the world's data

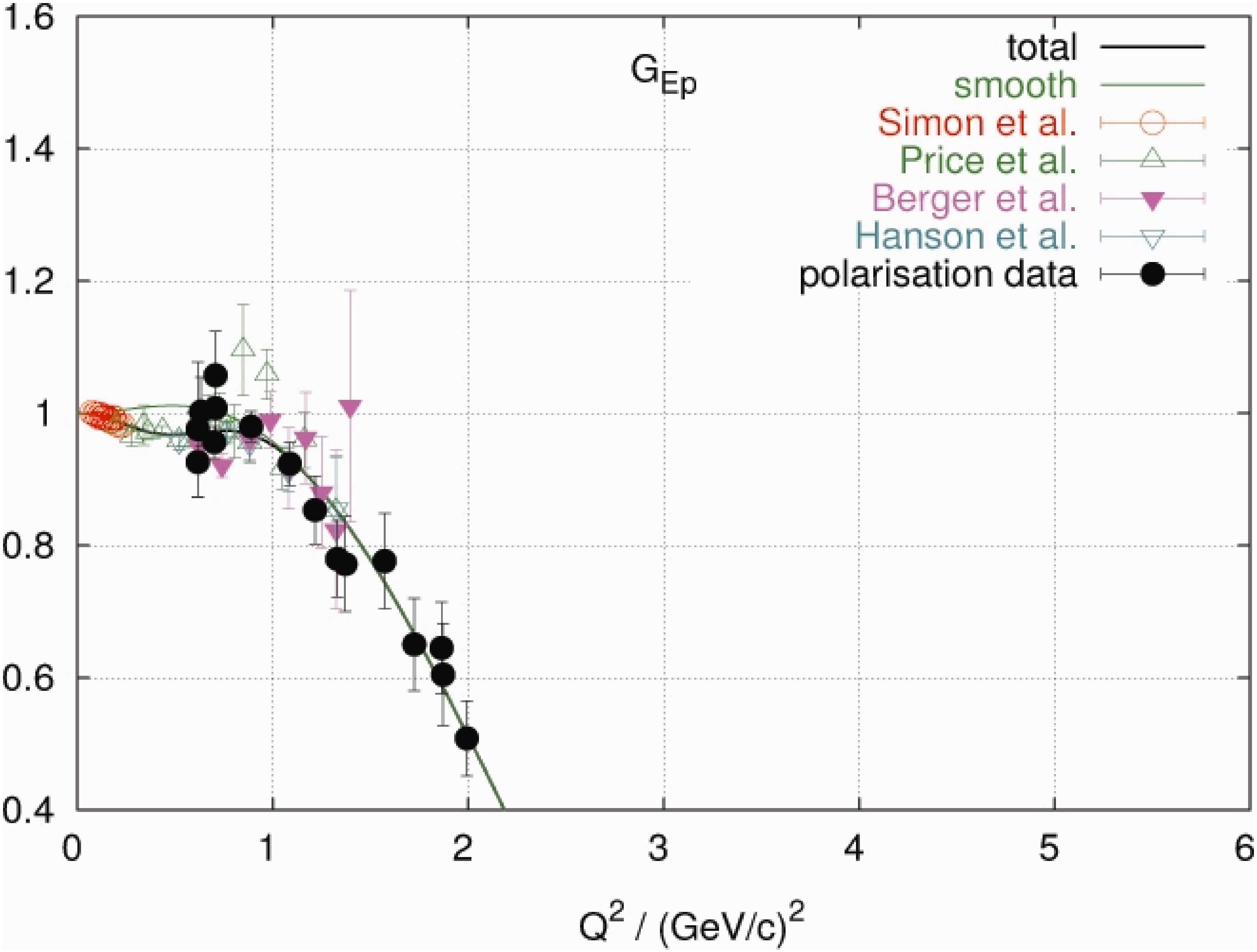
Friedrich and Walcher Fit to G^p_M



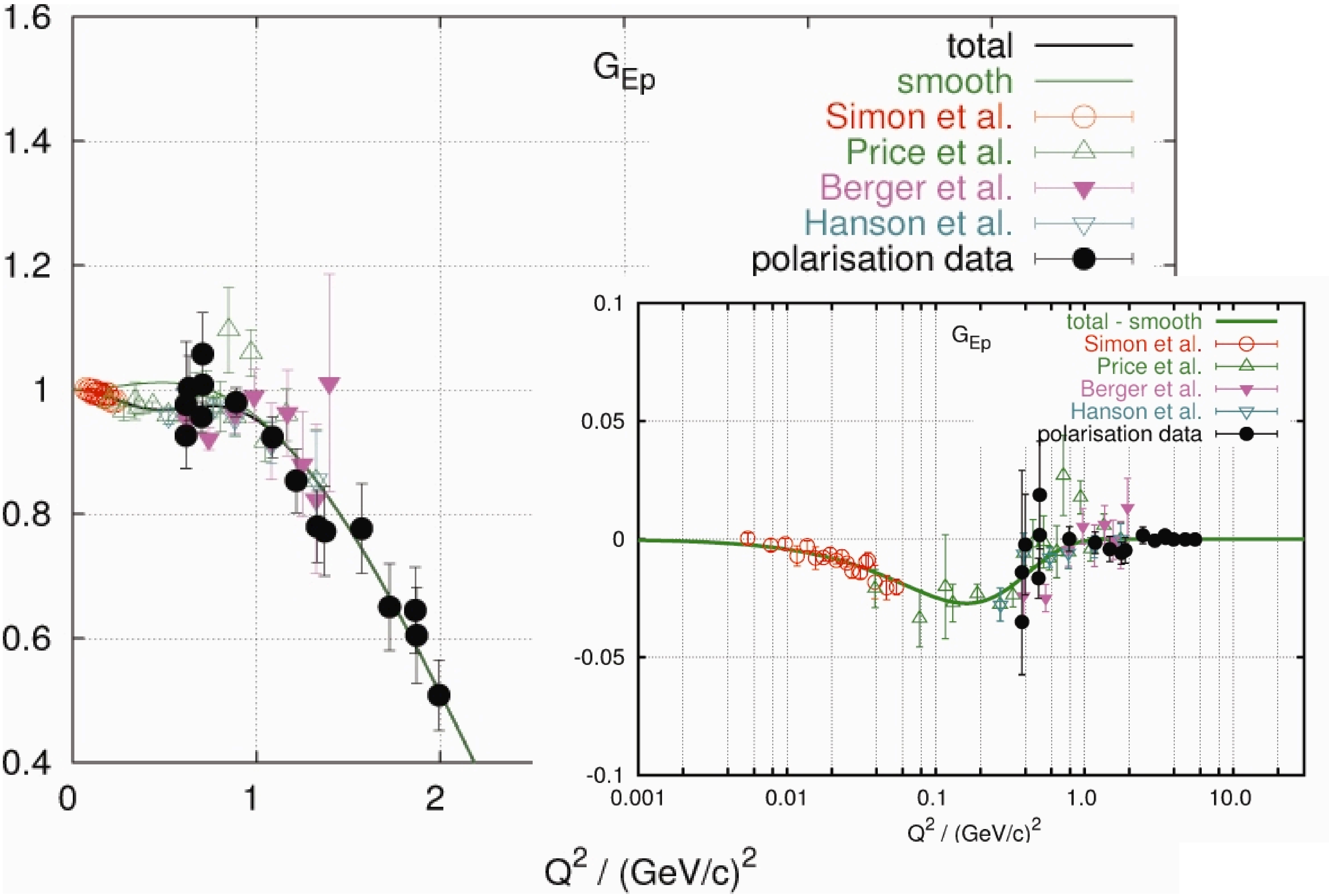
Friedrich and Walcher Fit to G^p_M



Friedrich and Walcher Fit to G^p_E



Friedrich and Walcher Fit to $G^p{}_E$



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Bates Large Acceptance Spectrometer Toroid

Systematic study of spin-dependent electromagnetic interaction

Polarized electrons in MIT-Bates SHR storage ring

- 850 MeV, 200 mA (typical), 65% polarization (typical)

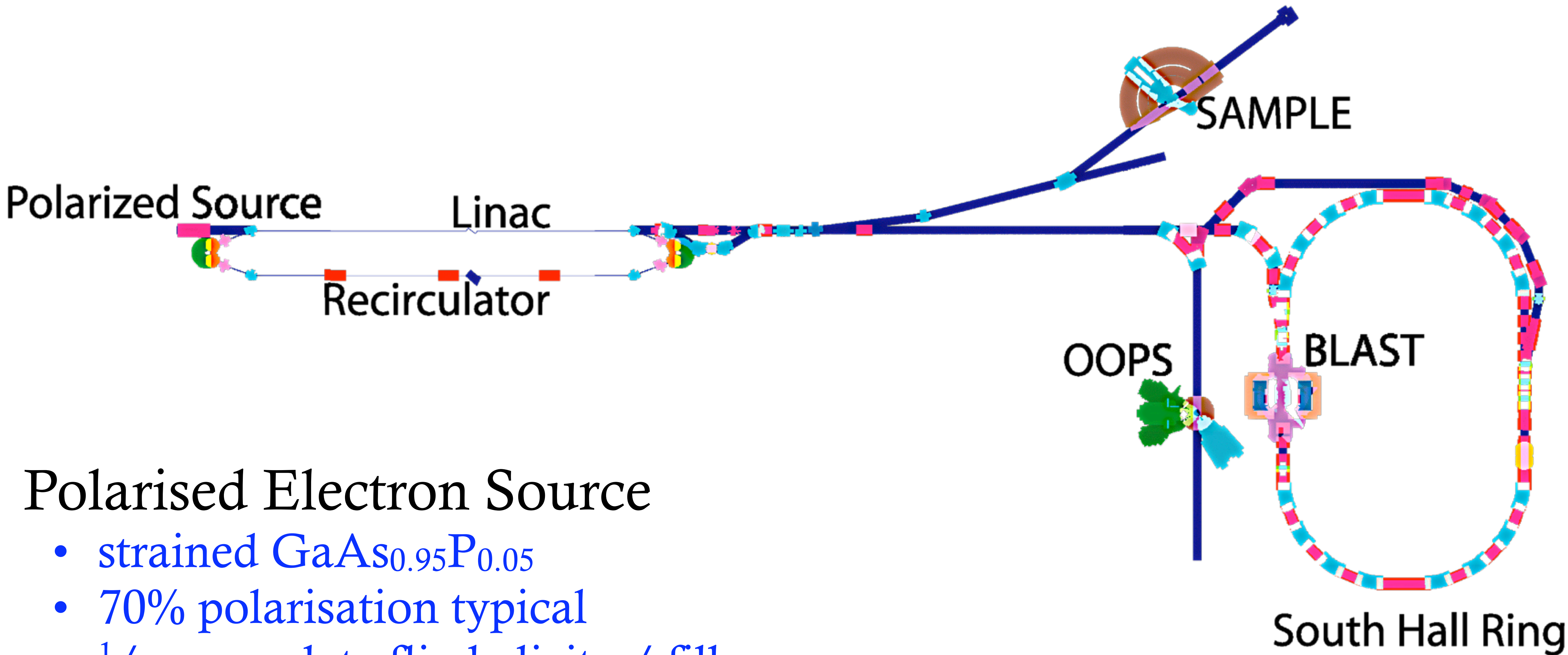
Highly polarized, internal gas target, isotopically pure H or D

- 6×10^{13} atoms/cm^2, 80% vector (H and D), 70% tensor (D) polarization

L/R Symmetric, large acceptance, general purpose detector

- 20°- 80° polar, ±15° azimuthal, $0.1 < Q^2 < 0.8$ (GeV/c)^2
- Simultaneous detection of $e^\pm$, $\pi^\pm$, p, n, d

MIT-Bates Linear Accelerator Center



Polarised Electron Source

- strained $GaAs_{0.95}P_{0.05}$
- 70% polarisation typical
- $^{1}/_{2}$ wave plate flip helicity / fill

500 MeV Linac + Recirculator

- polarised electrons up to 1 GeV

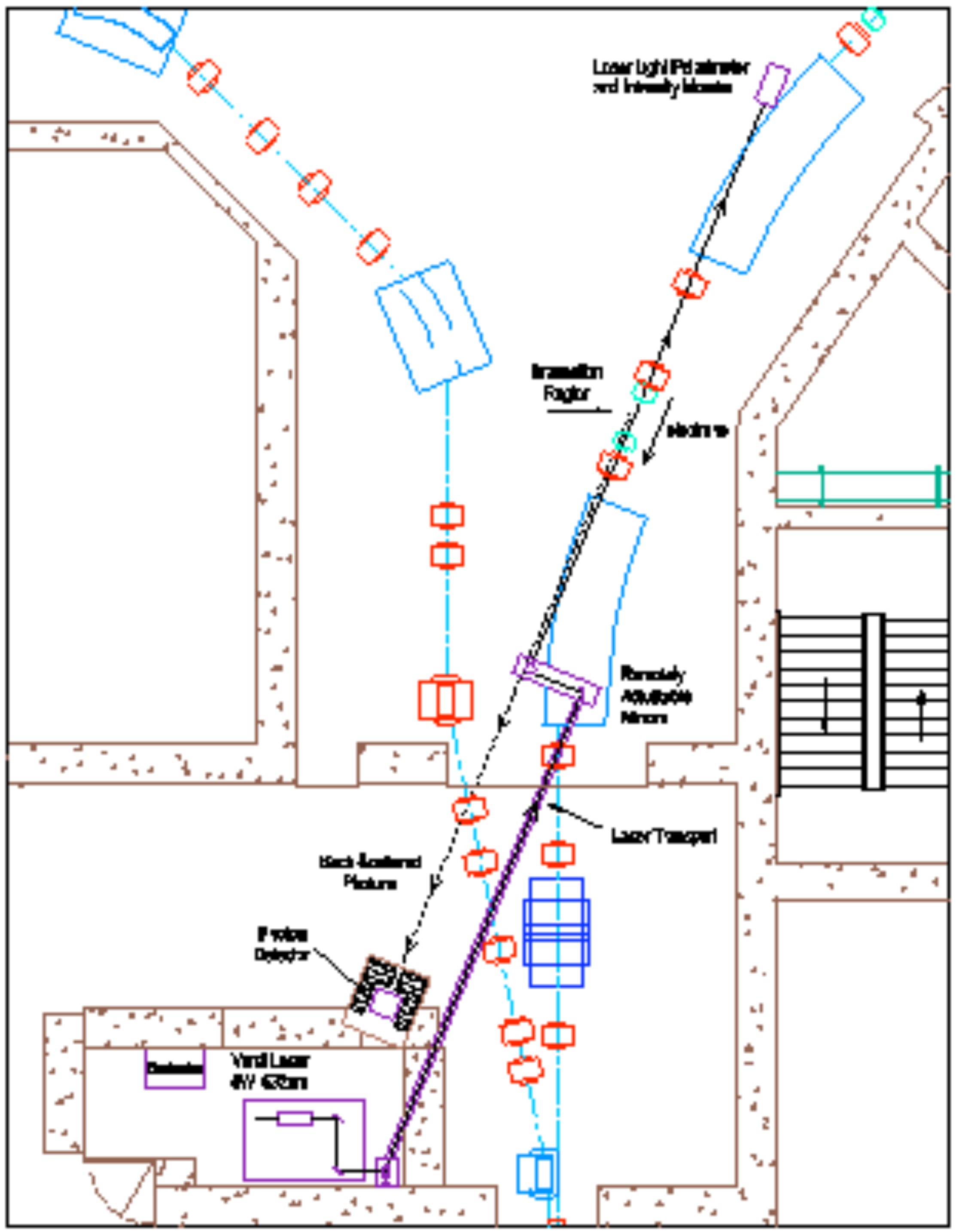
North and South Expt. Halls

- SAMPLE - north hall
- OOPS/BLAST - south hall

South Hall Ring

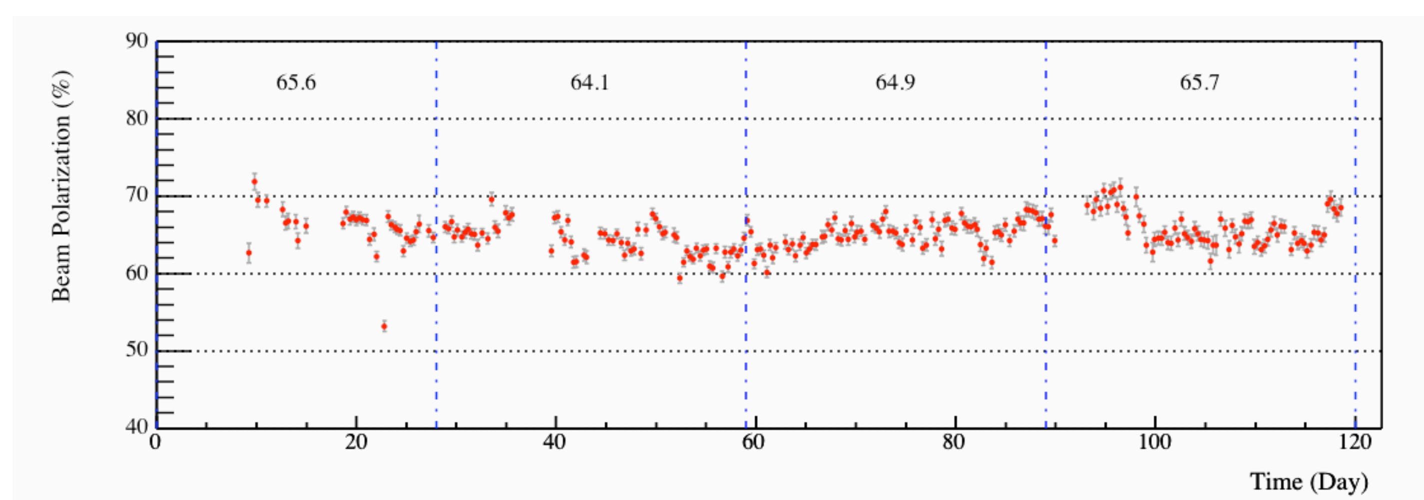
- stack to 225 mA typical
- 30 minute lifetime
- 65 % polarisation typical
- Siberian snake maintains longitudinal spin at target

Compton Polarimeter

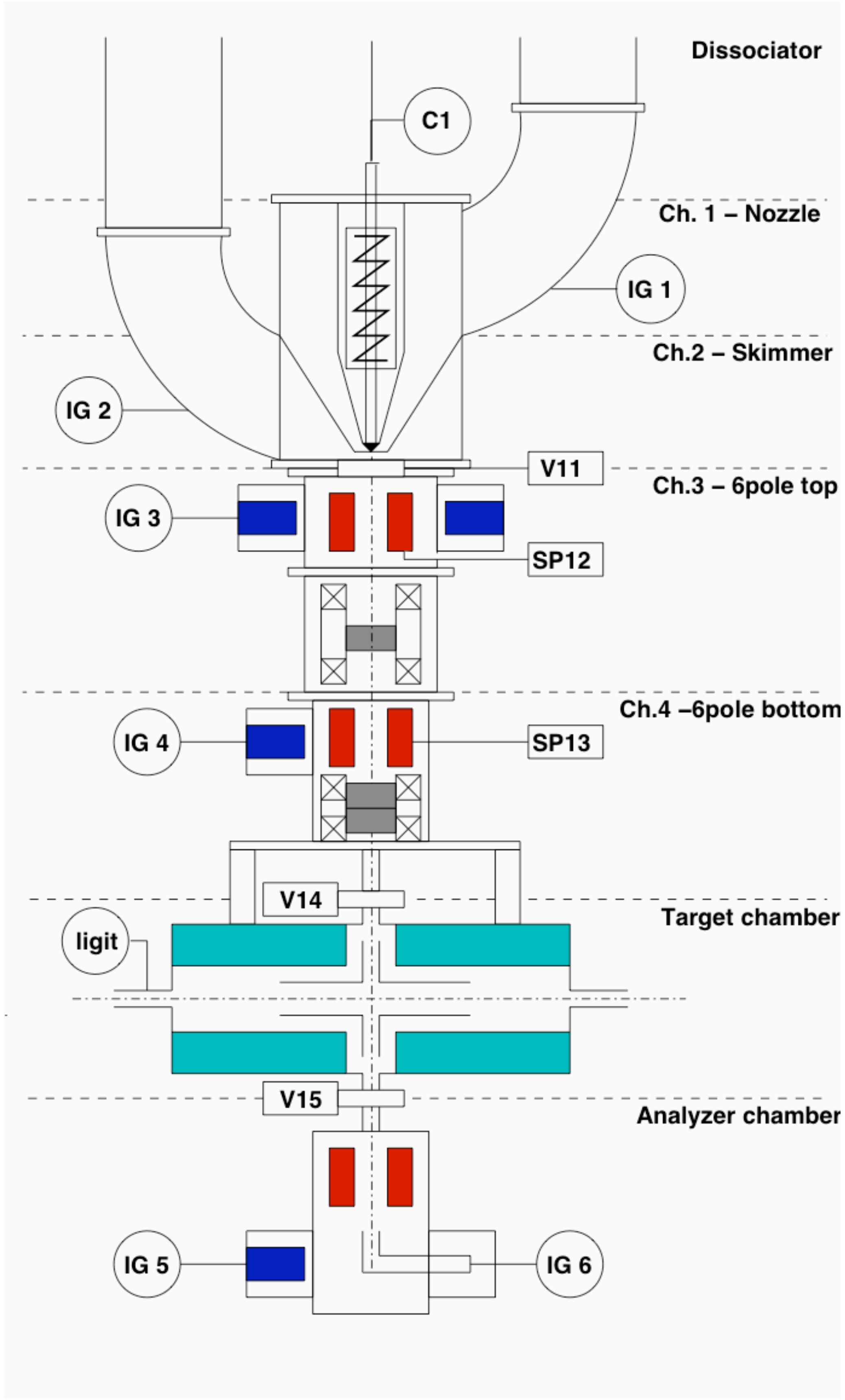


Monitor polarisation in ring

- 5 W laser, 532 nm, circularly polarised incident on oncoming electron beam
- Back-scattered photons detected in CsI
- Laser helicity flipped in Pockels cell
- Asymmetry yields beam polarisation
- Chopper wheel allows simultaneous measure of background
- Typical beam polarisation 65 %
- Systematic uncertainty <3%



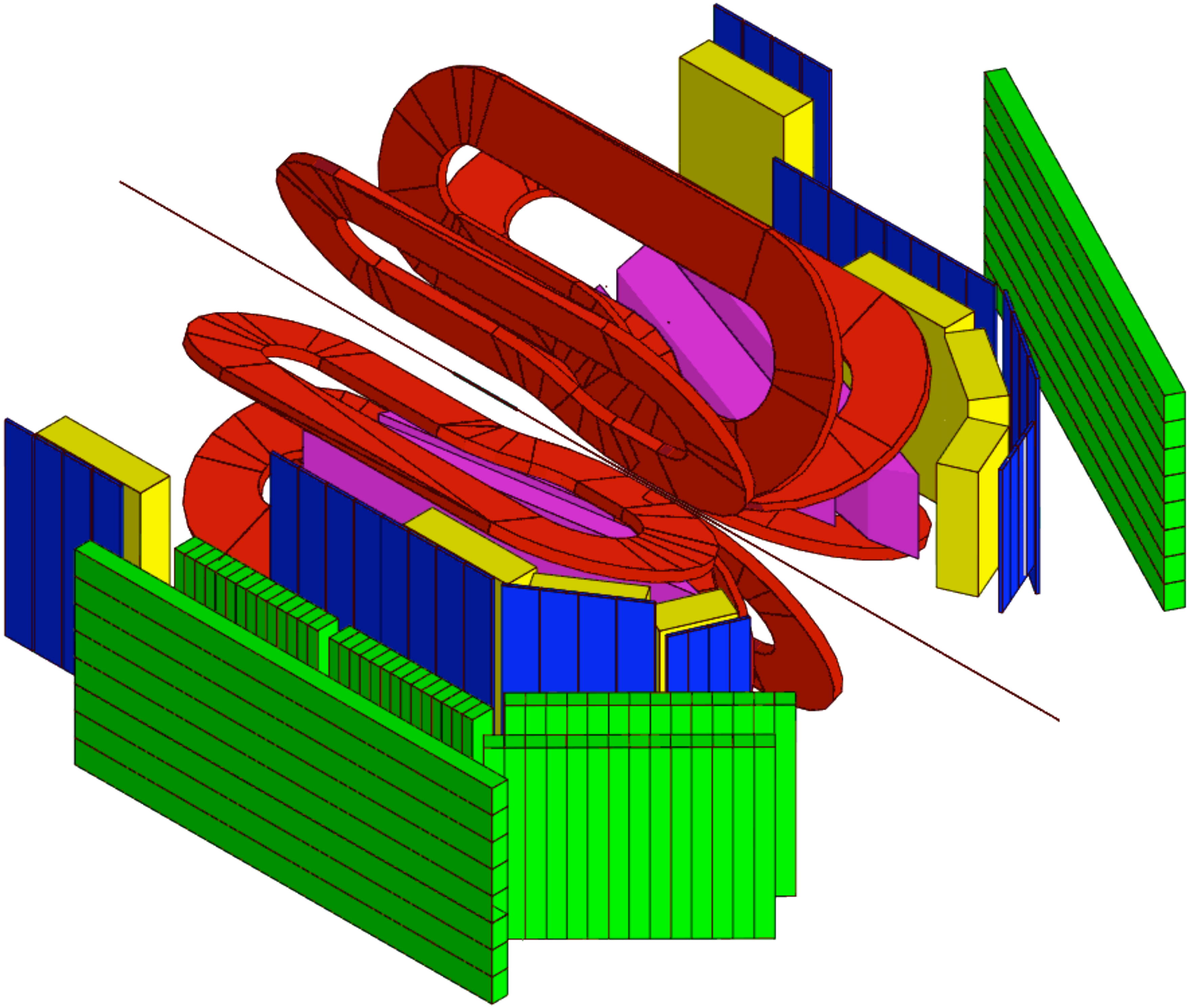
Internal, Polarised Gas Target



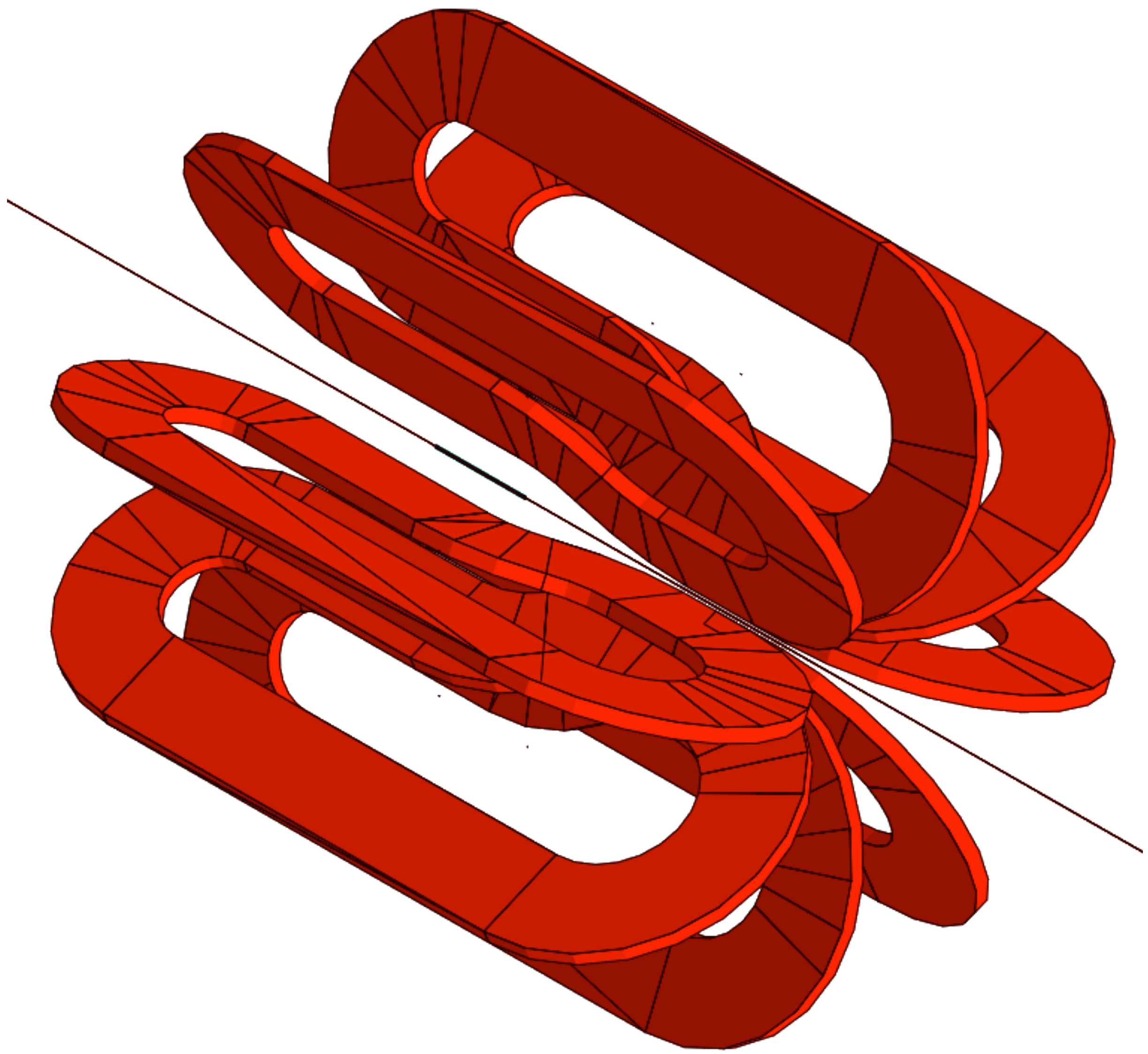
Atomic Beam Source

- series of focusing magnets and RF transition units populate and transport the desired spin state to the target cell
- target cell - thin walled, open ended tube, 60 cm long, $\varnothing$15 mm
- isotopically pure ^{1}H or ^{2}H
- vector polarised ^{1}H
- vector and tensor polarised ^{2}H
- randomly change spin state every 5′ during run
- target density 6×10^{13} atoms/cm^2
- vector polarisation 80 % typical
- tensor polarisation 68 % typical

BLAST Detector

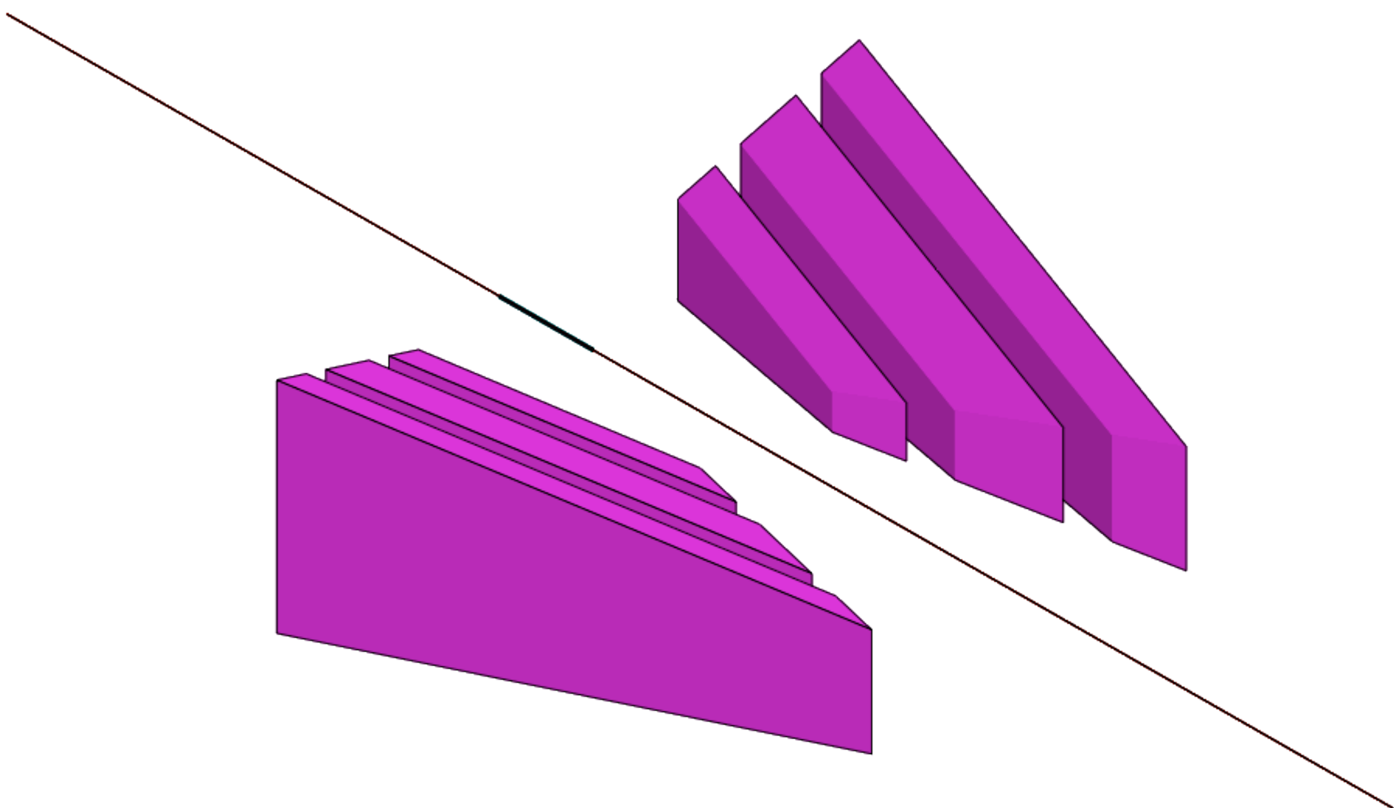


BLAST Detector



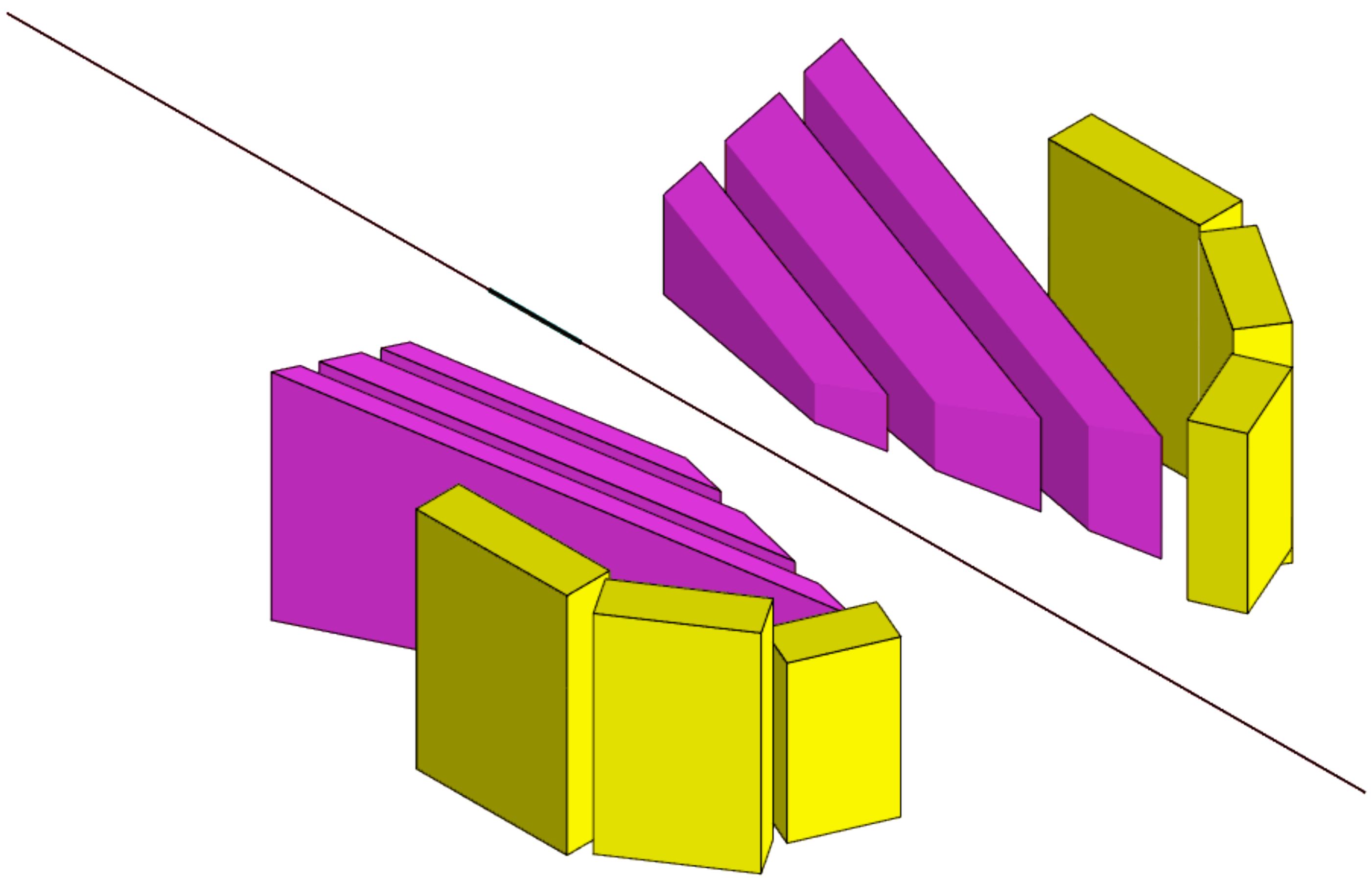
- 8 sector toroid magnet
  - minimise effect on beam and target polarisation
- 3.8 kG maximum field
- two horizontal sectors instrumented

BLAST Detector



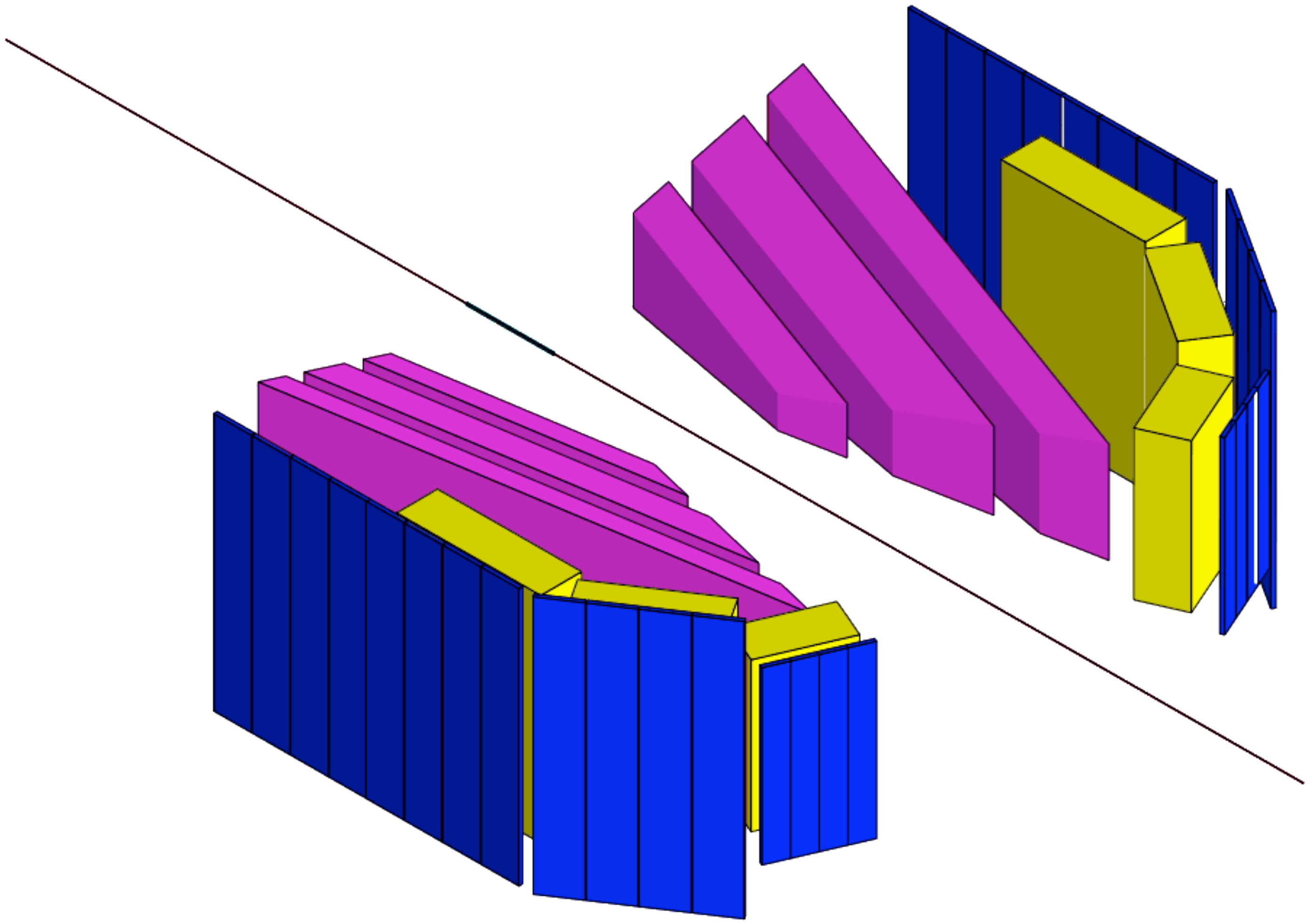
- 3 wire chambers / sector
  - single gas volume
- 2 superlayers / chamber
  - +/- 10° stereo
- 3 sense layers / superlayer
- total 18 layers of tracking
- momentum analysis
- scattering angles
- event vertex
- particle charge

BLAST Detector



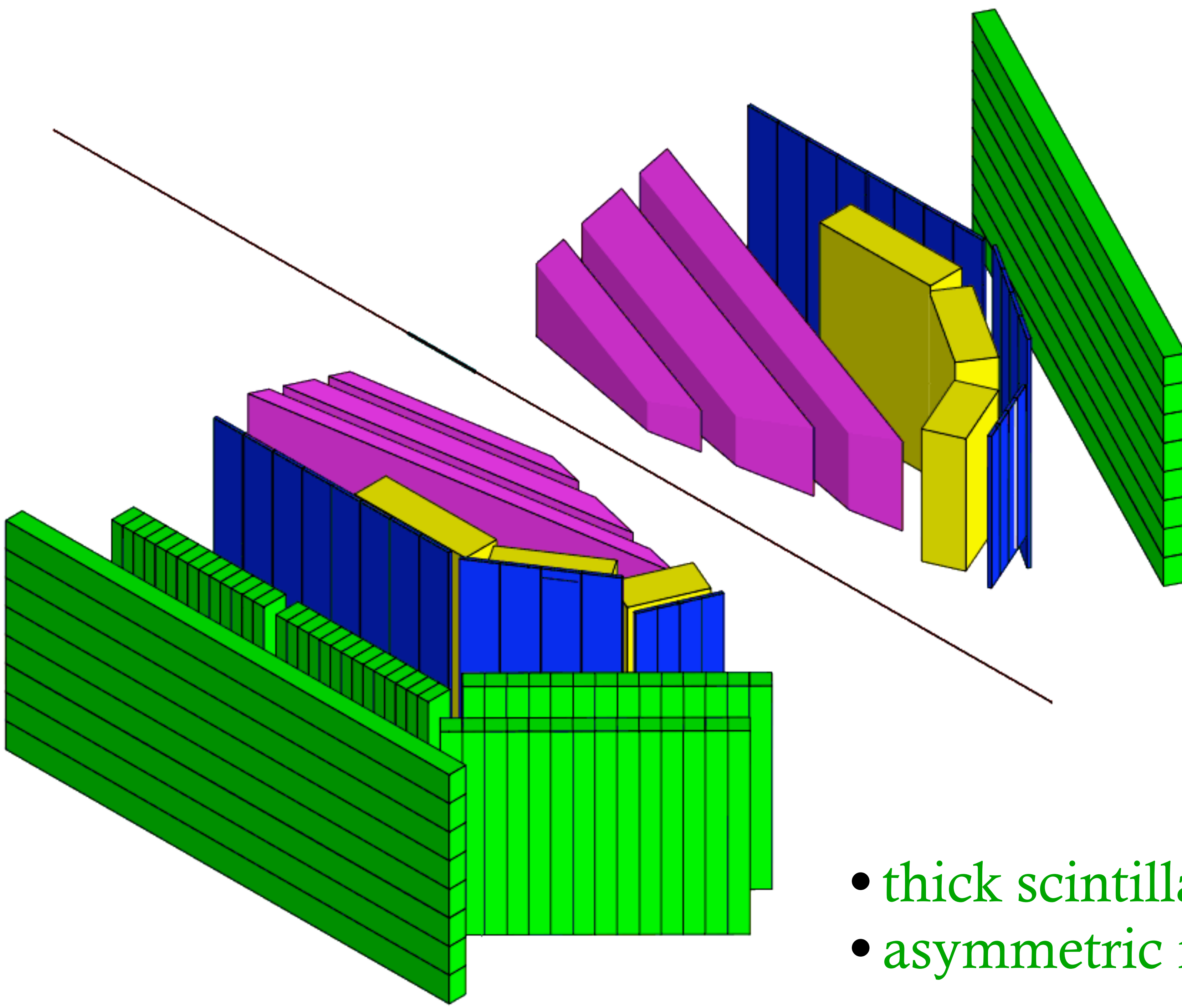
- Aerogel Cerenkov
- pion / electron separation

BLAST Detector



- time of flight scintillator walls
- relative timing
- trigger timing

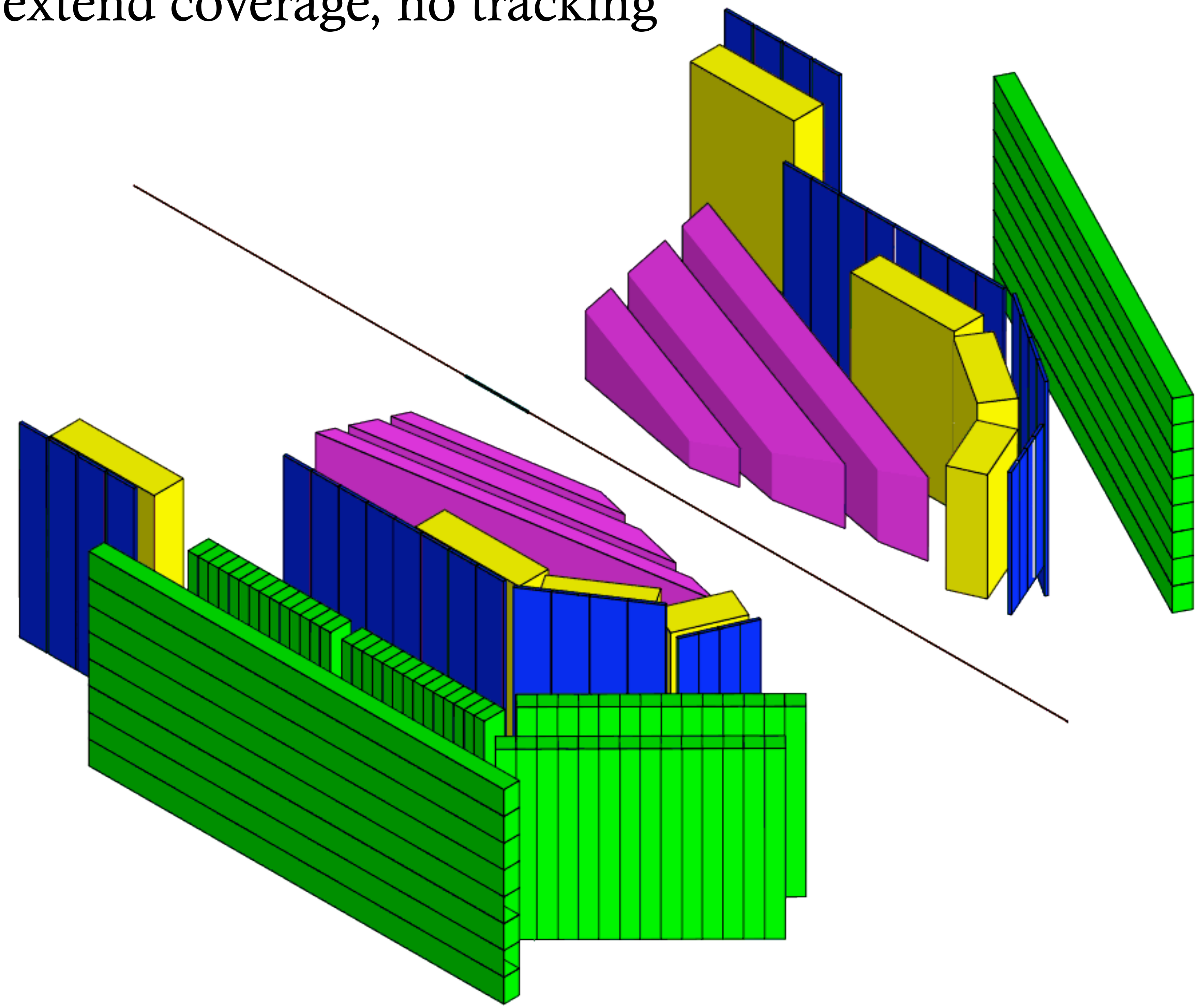
BLAST Detector



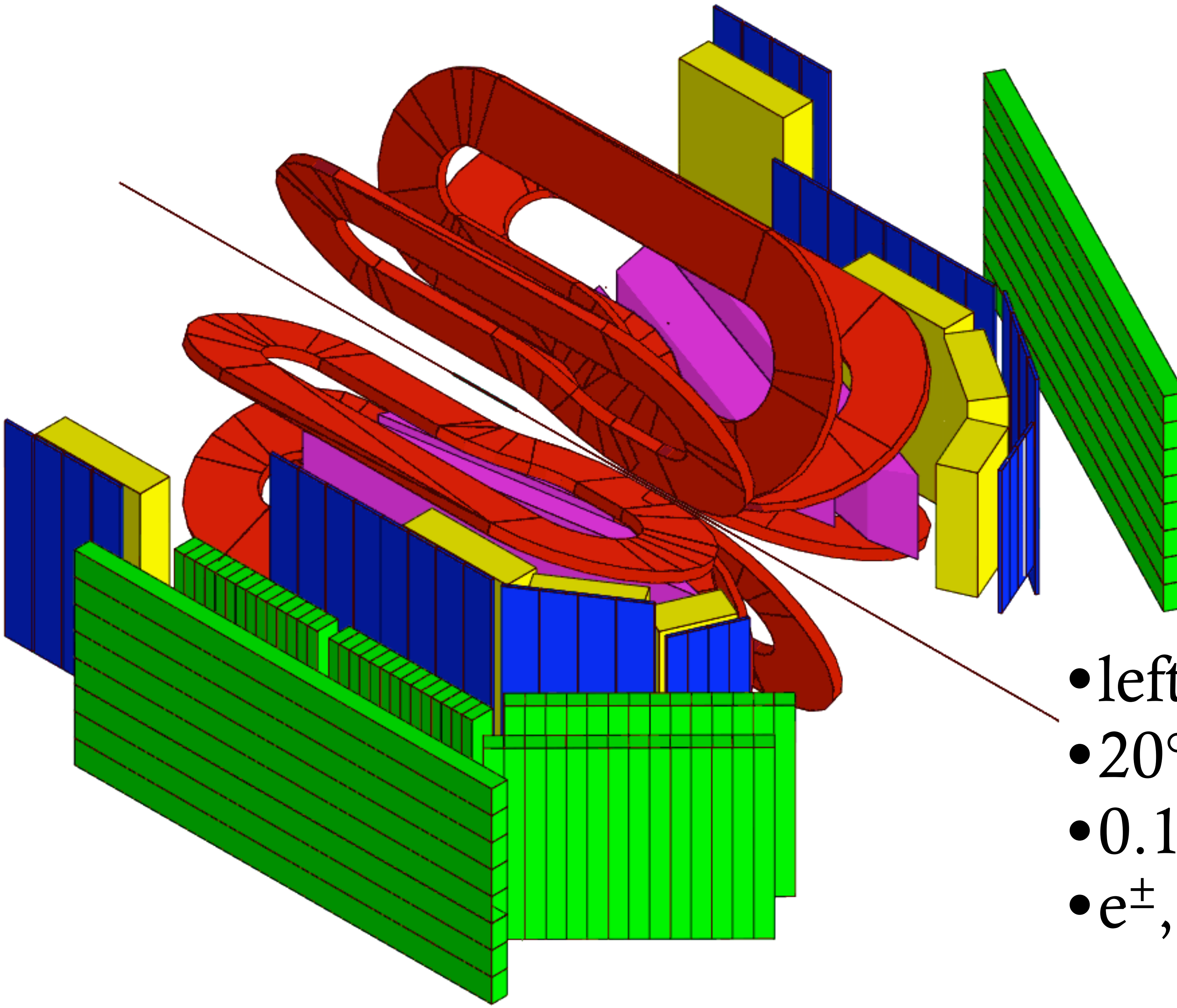
- thick scintillators for neutron detector
- asymmetric favouring right sector

BLAST Detector

- back angle detectors
- extend coverage, no tracking

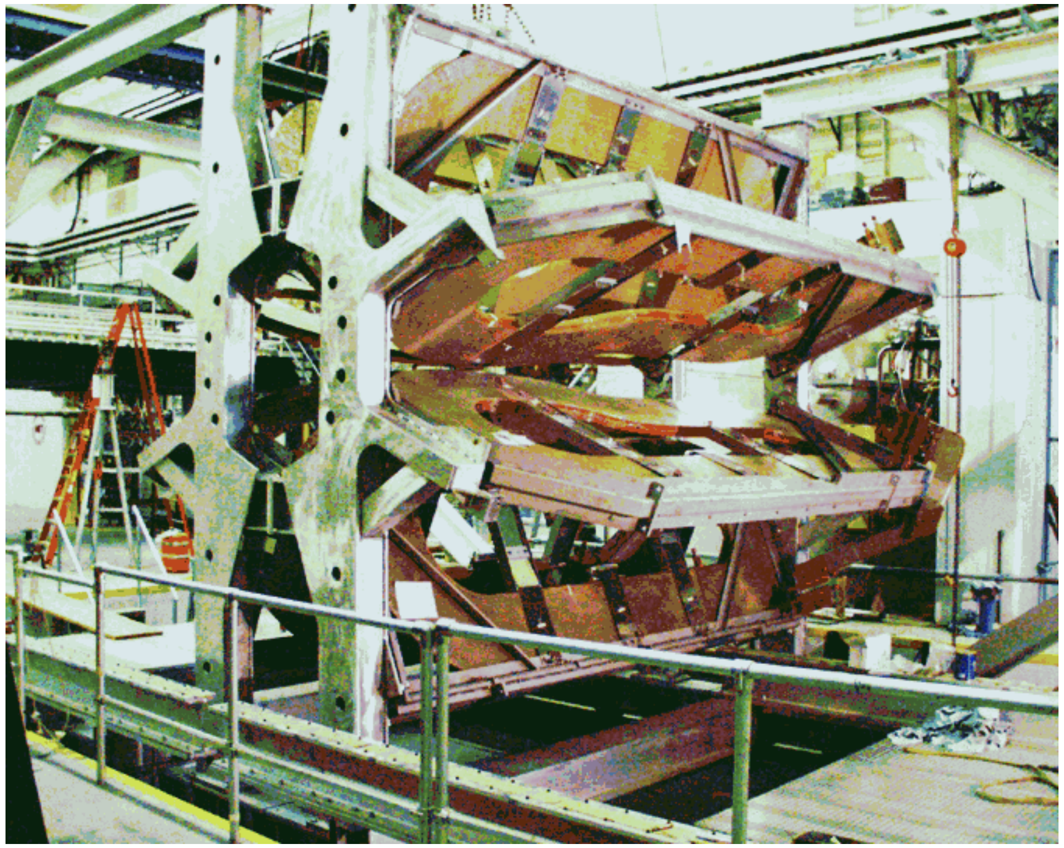


BLAST Detector

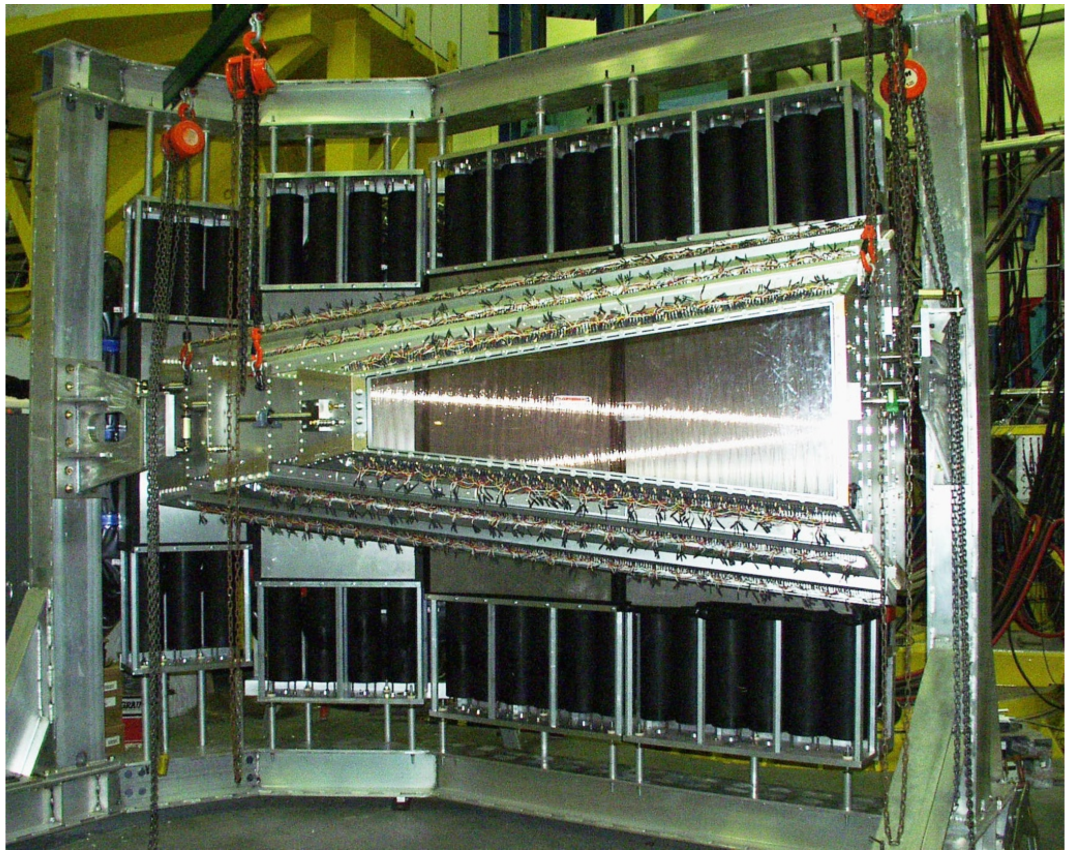


- left-right symmetric
- 20°- 80° θ, ±15° ϕ
- $0.1 < Q^2 < 0.8\ (\mathrm{GeV/c})^2$
- $e^{\pm}$, $\pi^{\pm}$, p, n, d

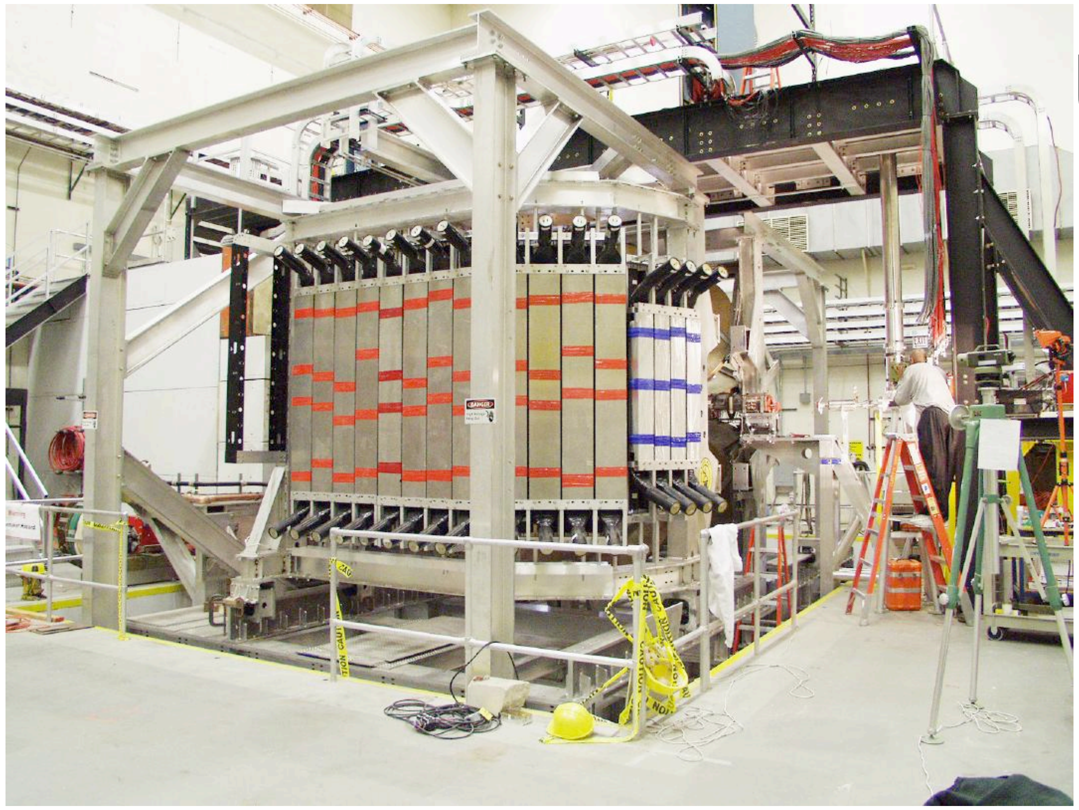
BLAST Detector Components



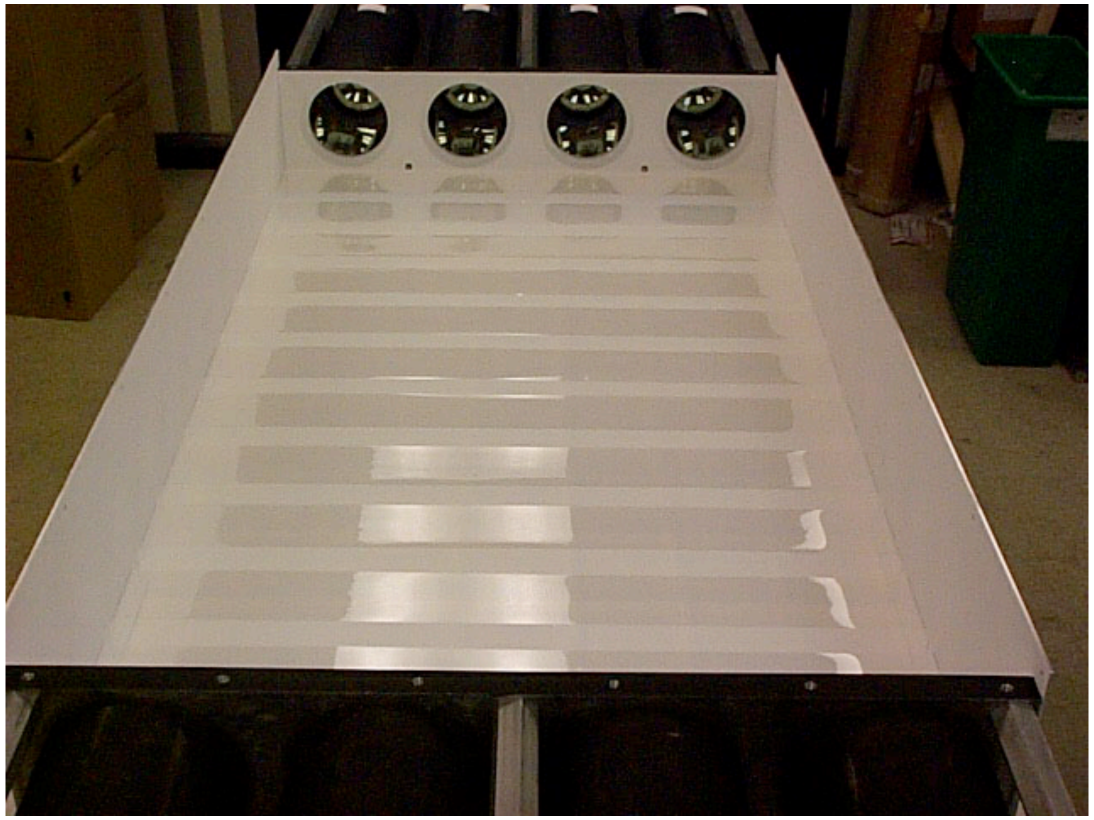
Bates



MIT



UNH



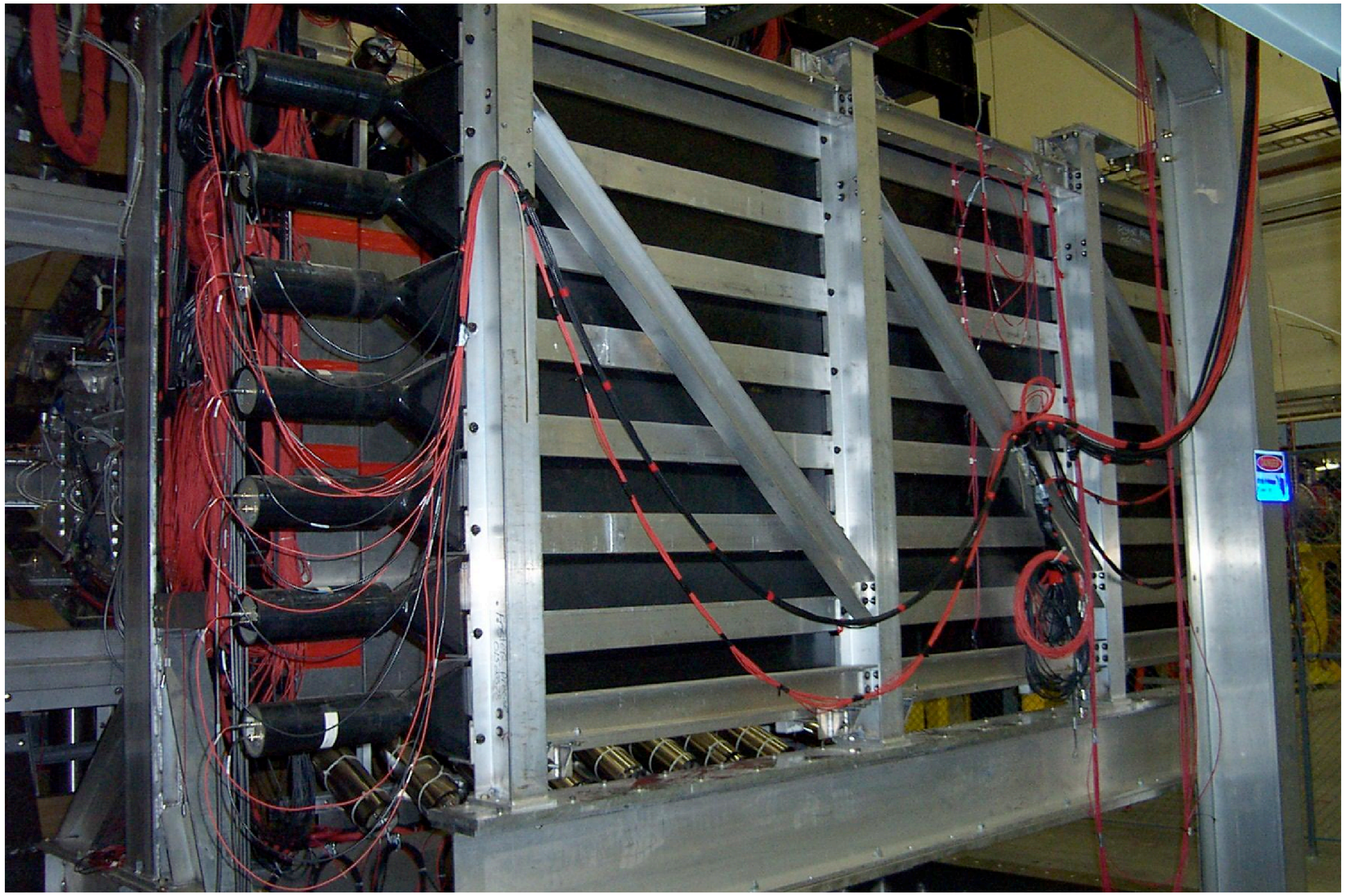
ASU

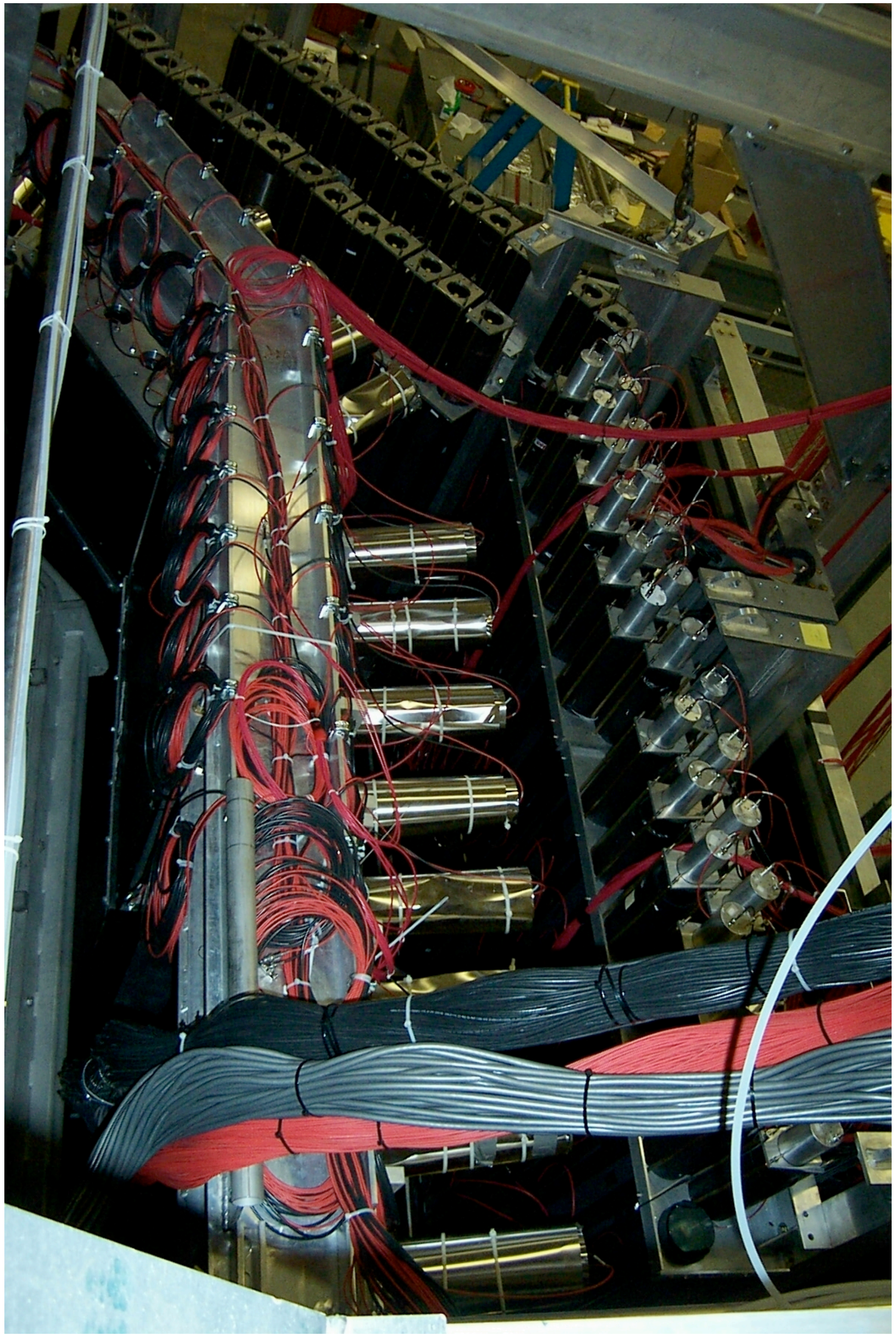
BLAST Detector Components

Neutron Detectors

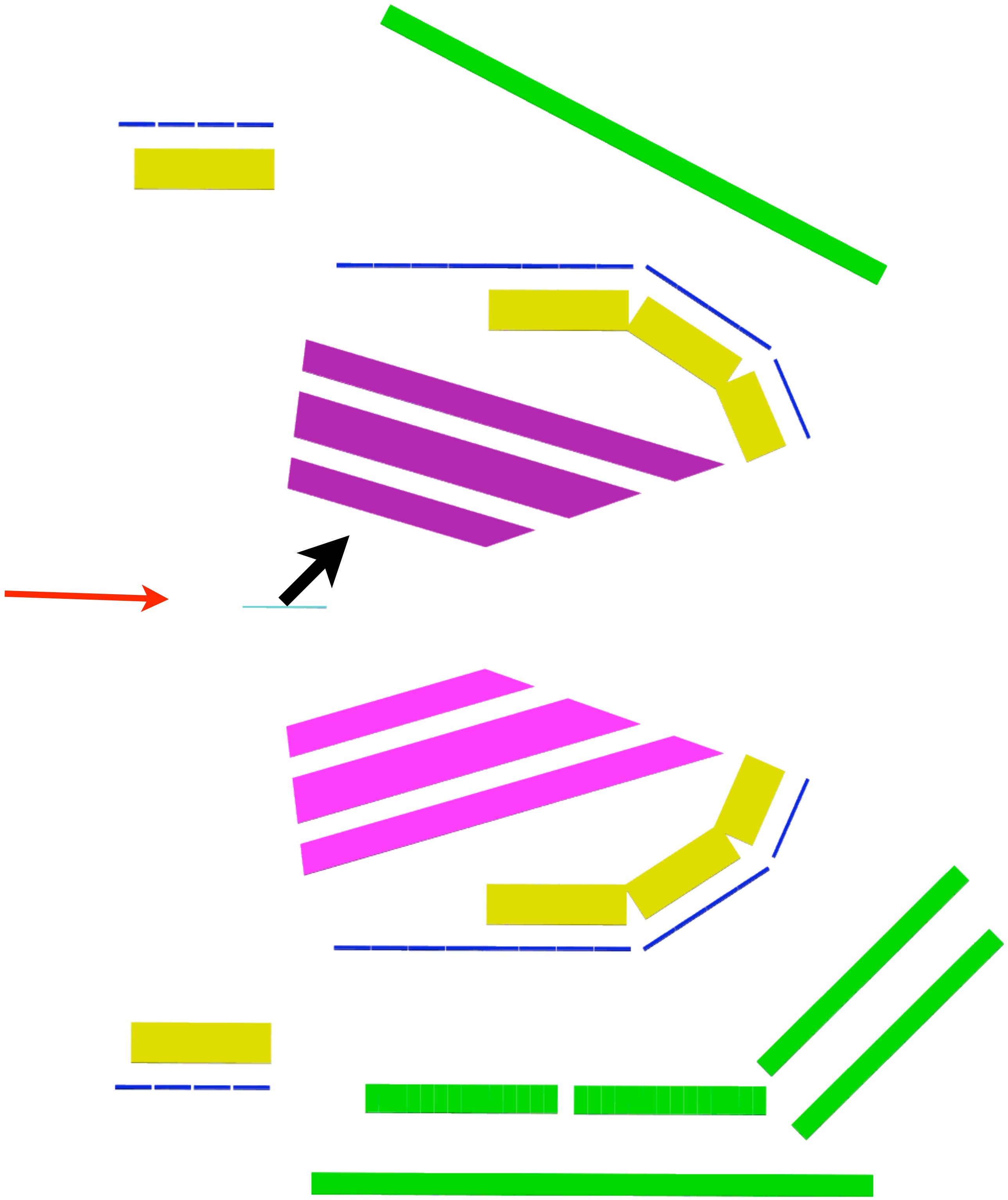
MIT

Ohio University





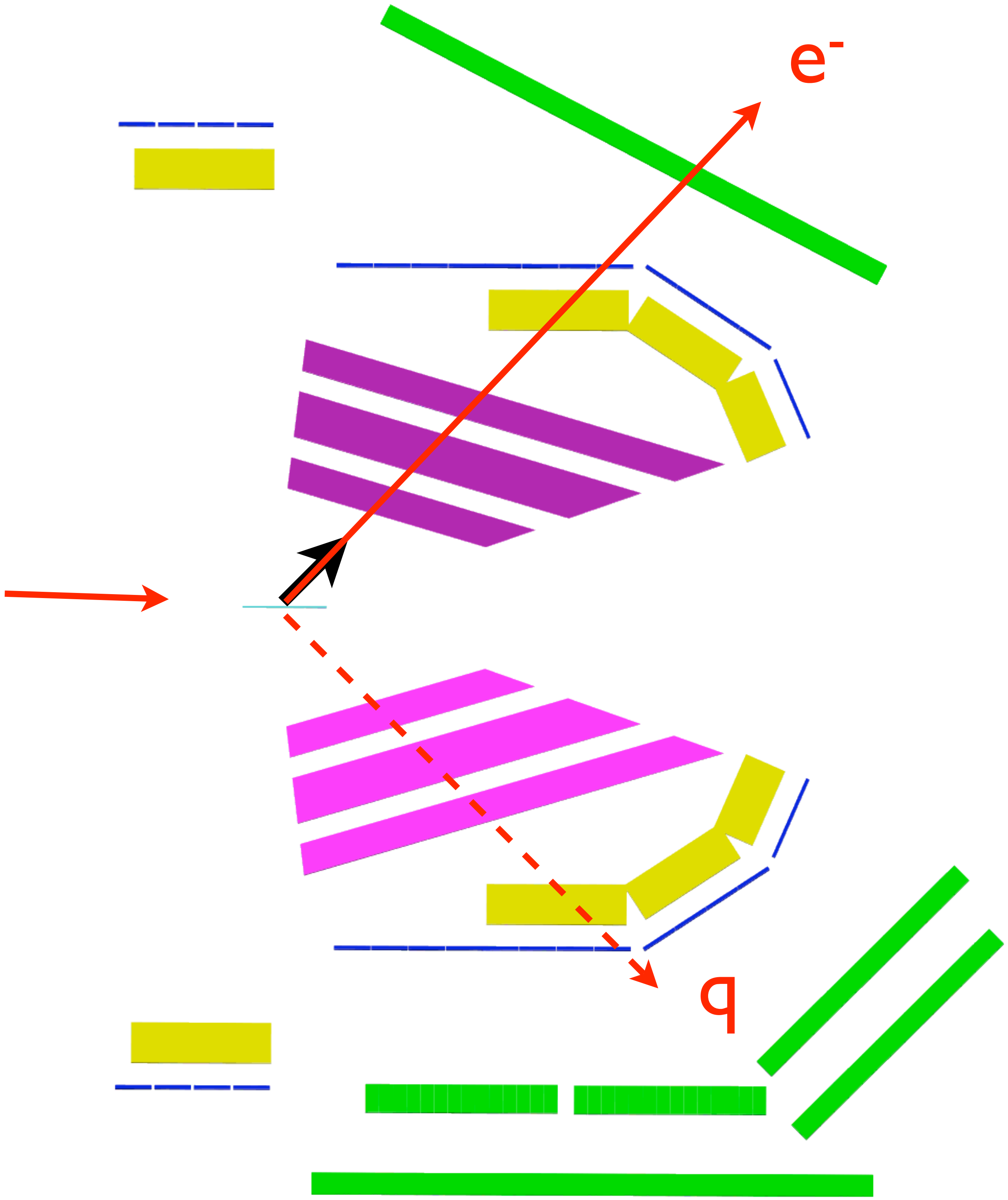
Orientation of Target Spin



Target spin angle

- 32° (2004) / 45° (2005)
- horizontal into the left sector

Orientation of Target Spin



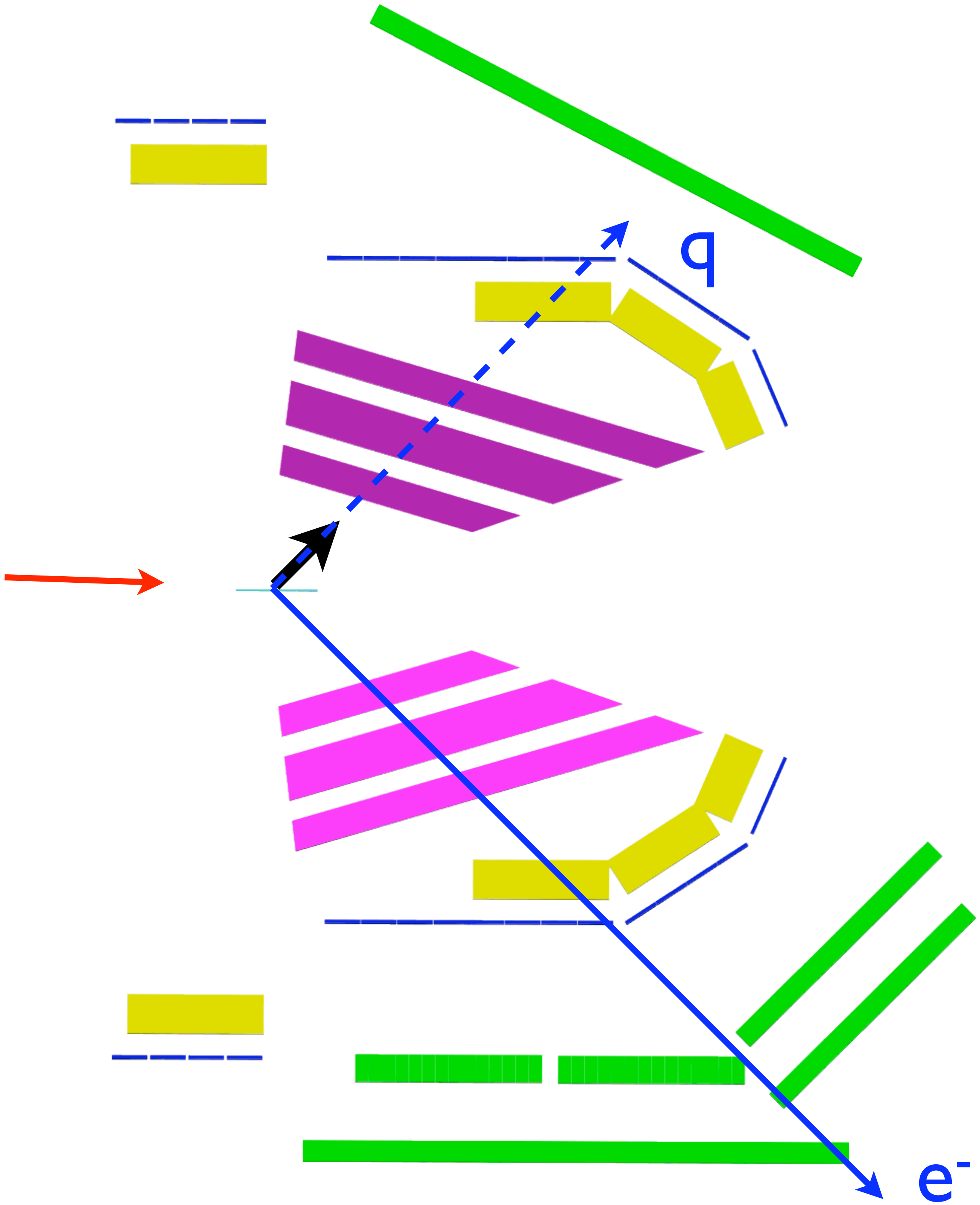
Target spin angle

- 32° (2004) / 45° (2005)
- horizontal into the left sector

Electron scatters to left sector

- q ≈ perpendicular to target spin
- θ* ≈ 90°
- "spin perpendicular" kinematics

Orientation of Target Spin



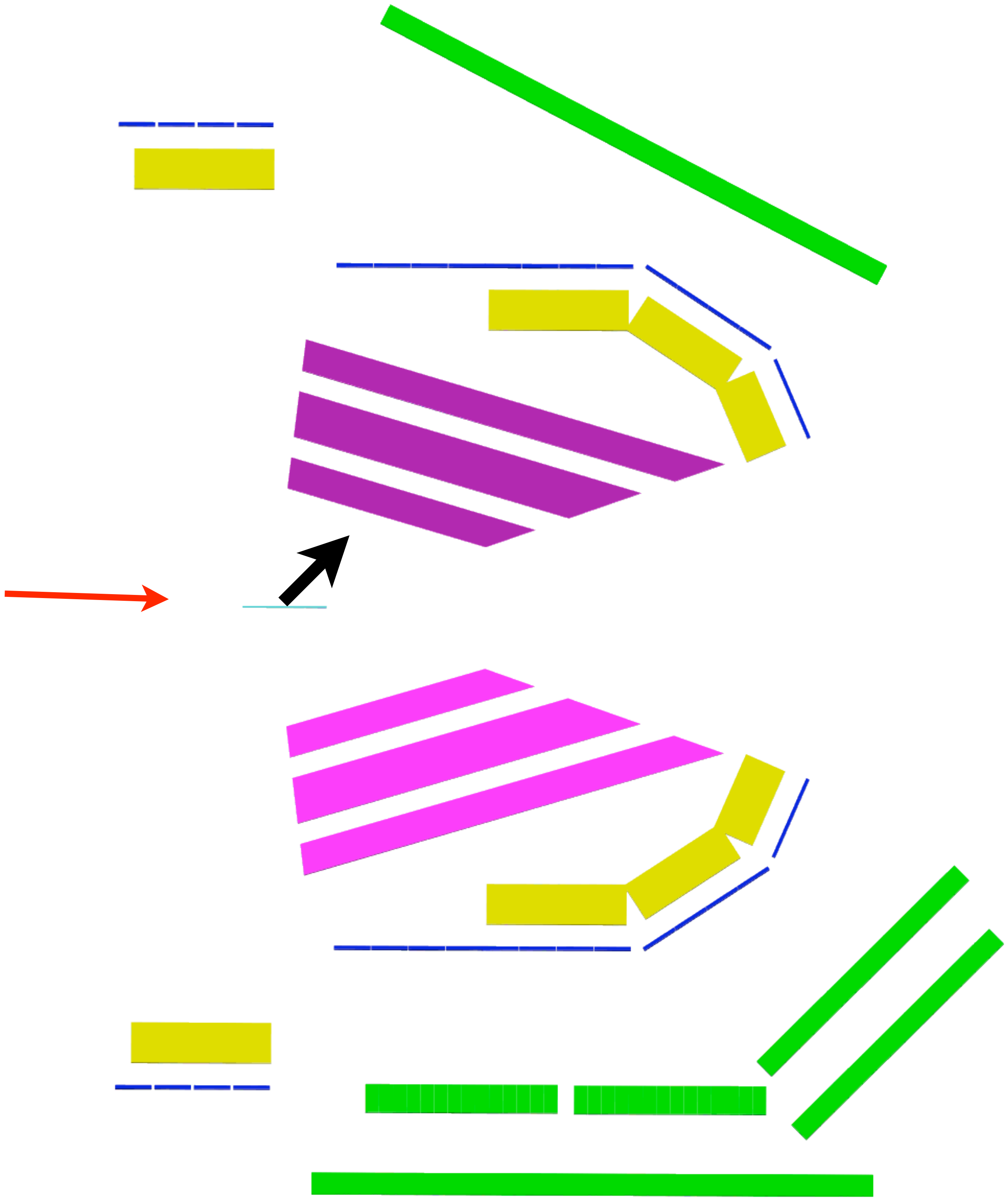
Target spin angle

- 32° (2004) / 45° (2005)
- horizontal into the left sector

Electron scatters to right sector

- q ≈ parallel to target spin
- $\theta^* \approx 0°$
- "spin parallel" kinematics

Orientation of Target Spin



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Electron scatters to right sector

- q ≈ parallel to target spin
- $\theta^* \approx 0°$
- "spin parallel" kinematics

BLAST Physics

Polarised Hydrogen

$^1\vec{H}(\vec{e},e')$	$^1\vec{H}(\vec{e},e'p)$	$^1\vec{H}(\vec{e},e'p)\gamma,\pi^0$	$^1\vec{H}(\vec{e},e'\pi^+)n$	$^1\vec{H}(\vec{e},e'\pi^+n)$
Inclusive	G^p_E/G^p_M	N-Δ : EMR, CMR		Photoprod.

Vector Polarised Deuterium

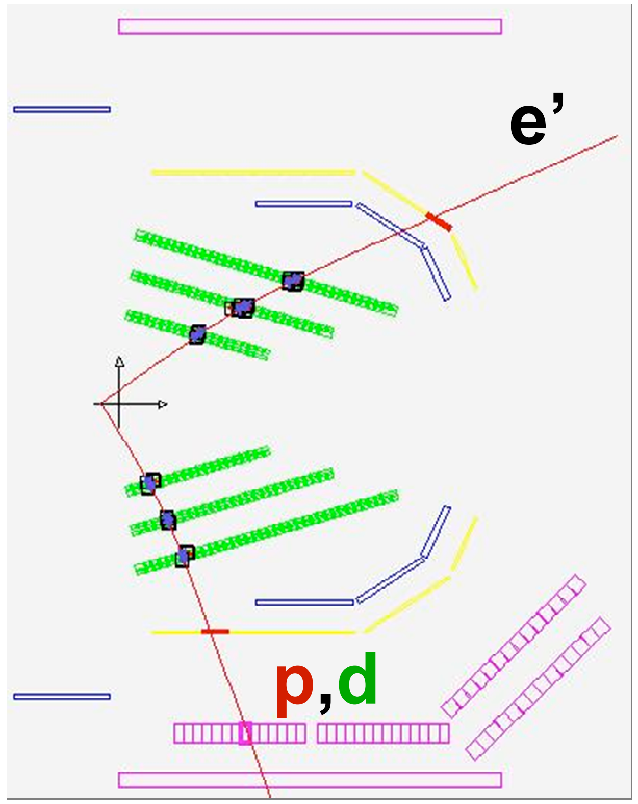
$^2\vec{H}(\vec{e},e')$	$^2\vec{H}(\vec{e},e'd)$	$^2\vec{H}(\vec{e},e'p)n$	$^2\vec{H}(\vec{e},e'n)p$	$^2\vec{H}(\vec{e},e'\pi^{\pm,0})$
G^n_M	T^e_{11} : G^d_M	A^v_{ed} : L=2	G^n_E	N-Δ

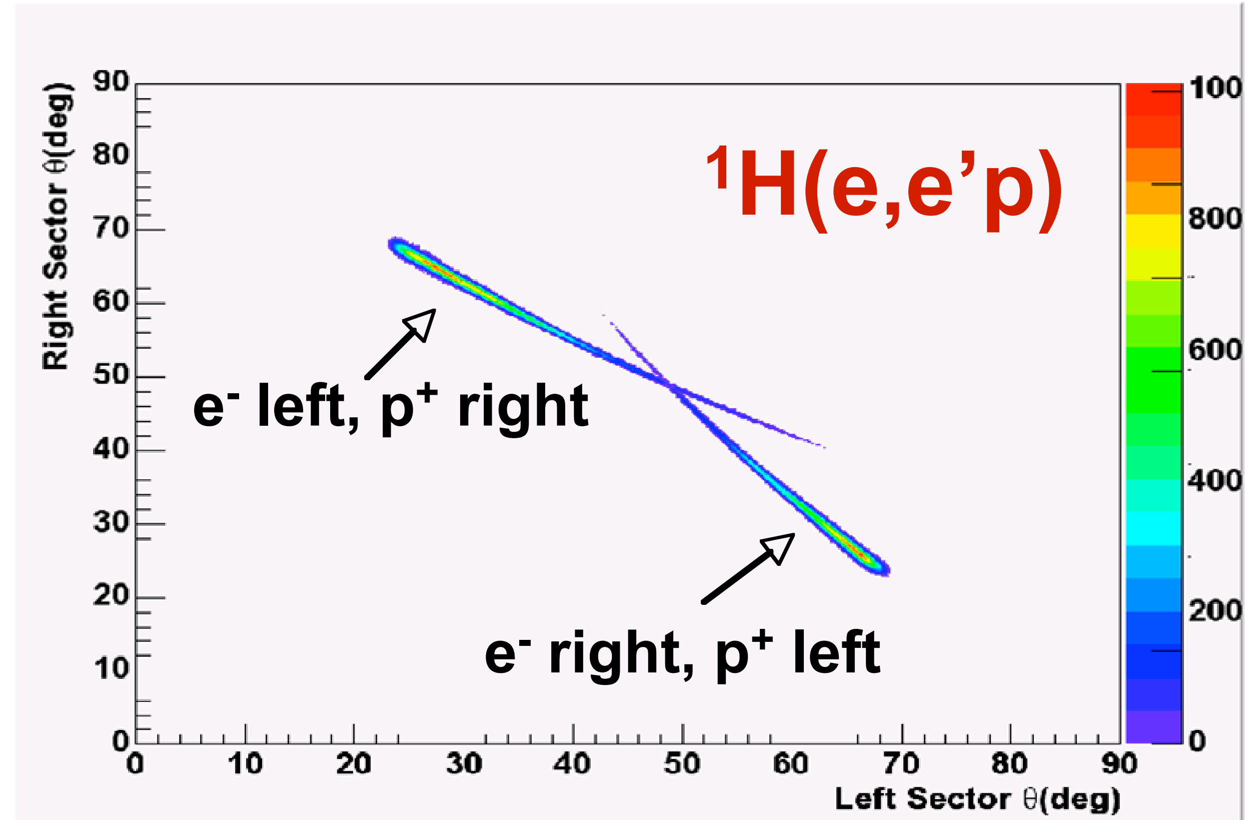
Tensor Polarised Deuterium

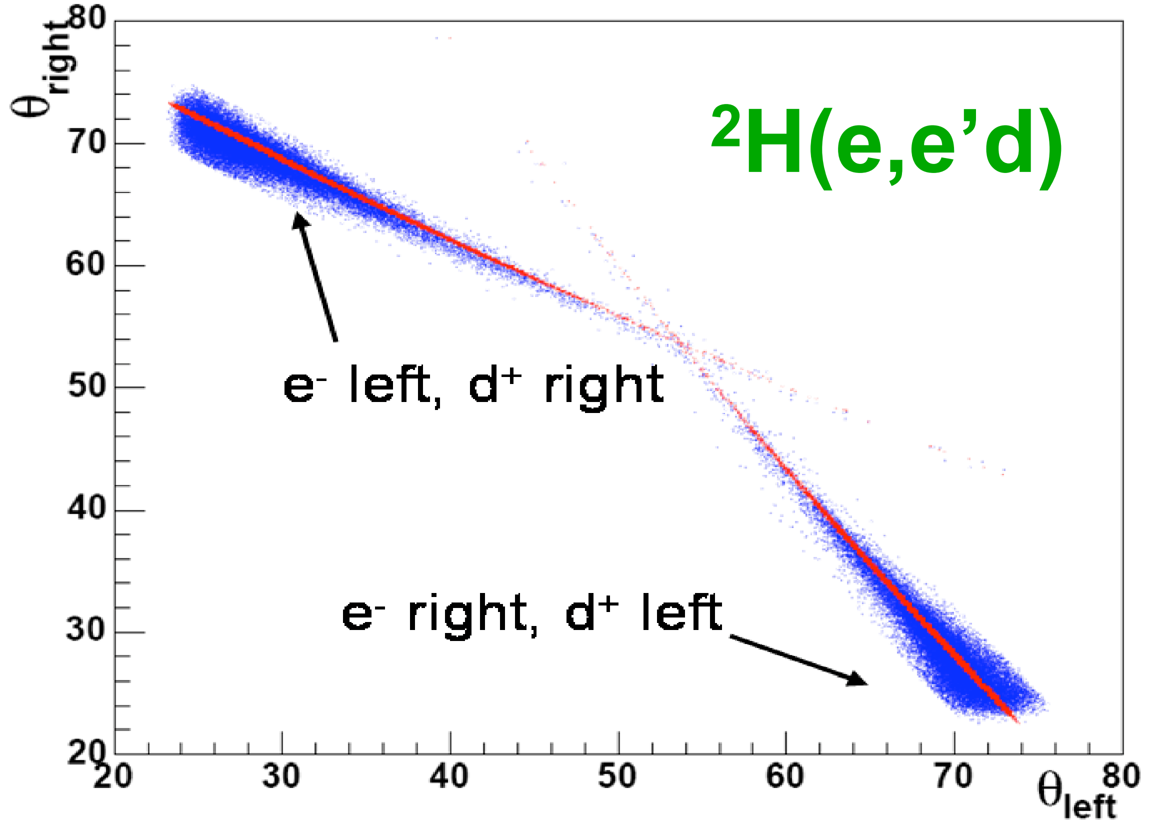
$^2\overleftrightarrow{H}(e,e'd)$	$^2\overleftrightarrow{H}(e,e'p)n$	$^2\overleftrightarrow{H}(e,e'n)p$	$^2\overleftrightarrow{H}(\gamma,pn)$	$^2\overleftrightarrow{H}(\vec{e},e'\pi^{\pm})$
T_{20} : G^d_Q	A^T_d : L=2		photodisint.	$^1S_0$

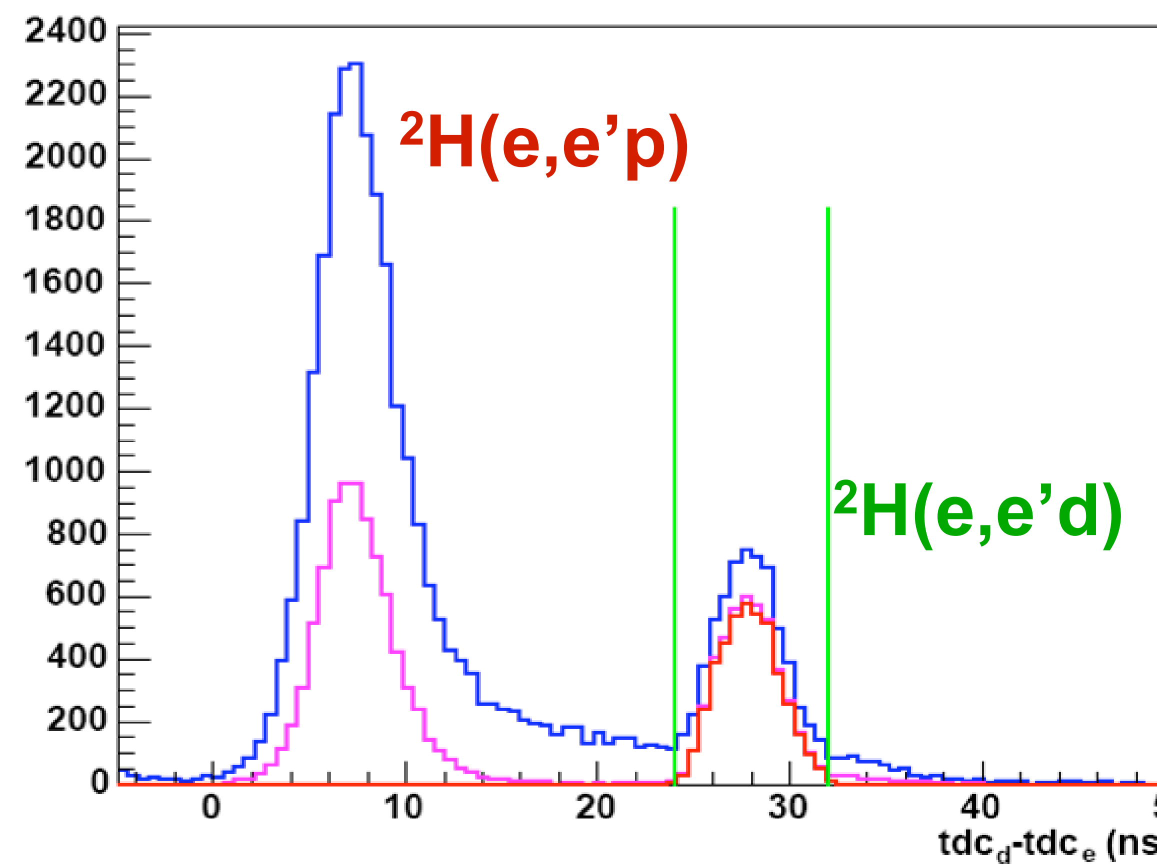
Event Selection

Charge+/-
Coplanarity
Kinematics
Timing









Elastic Scattering from Hydrogen

With polarized beam and target can measure asymmetries

$$A_{exp} = P_b P_t \frac{-2\tau v_{T'} \cos\theta^* {G_M^p}^2 + 2\sqrt{2\tau(1+\tau)} v_{TL'} \sin\theta^* \cos\phi^* G_M^p G_E^p}{(1+\tau) v_l {G_E^p}^2 + 2\tau v_T {G_M^p}^2}$$

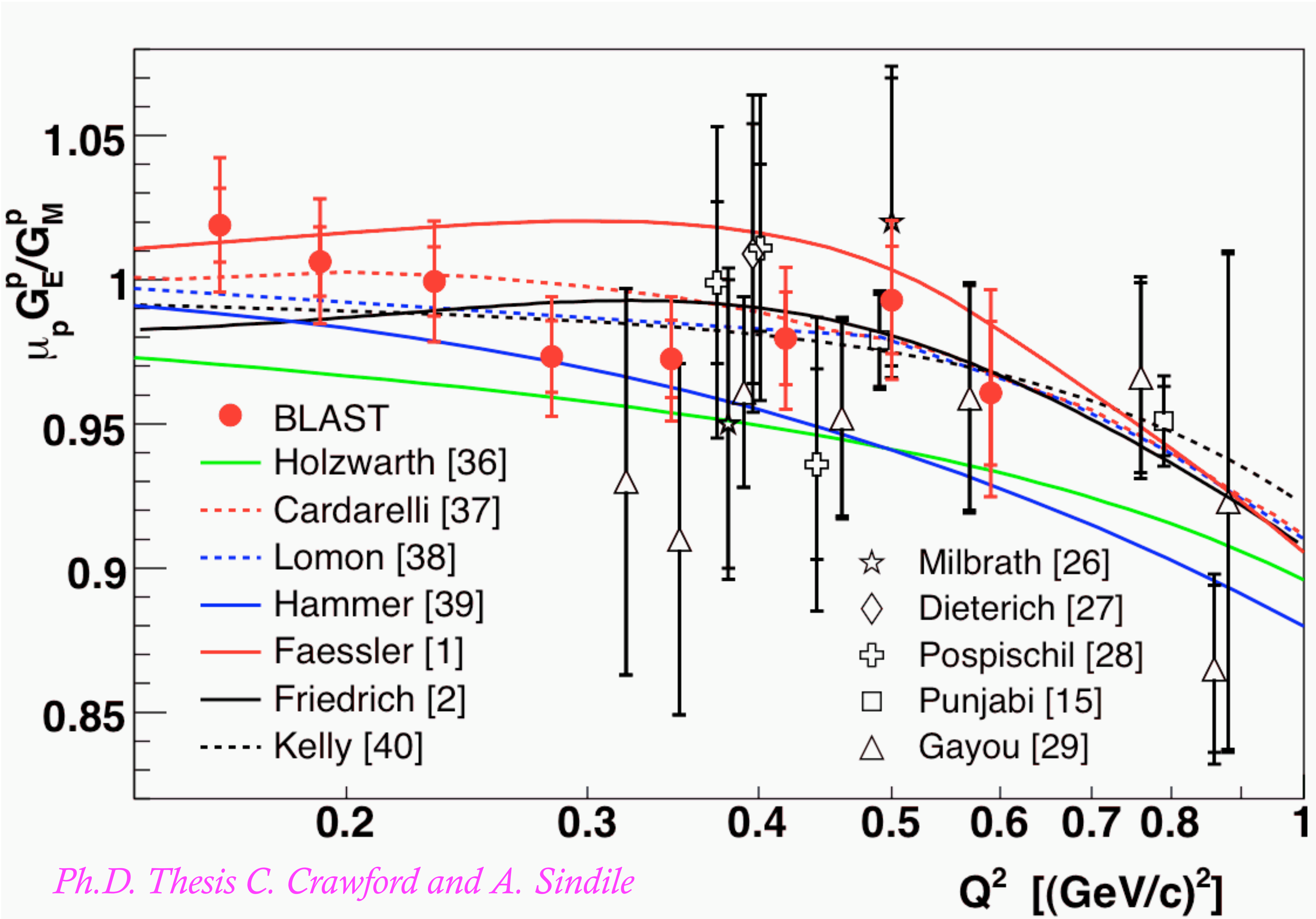
- note some terms vanish in perpendicular or parallel kinematics

With symmetric detector can form ratio of left/right asymmetries

$$R_A = \frac{A_L}{A_R} = \frac{z_L^* - x_L^* G_E^p / G_M^P}{z_R^* - x_R^* G_E^p / G_M^P}$$

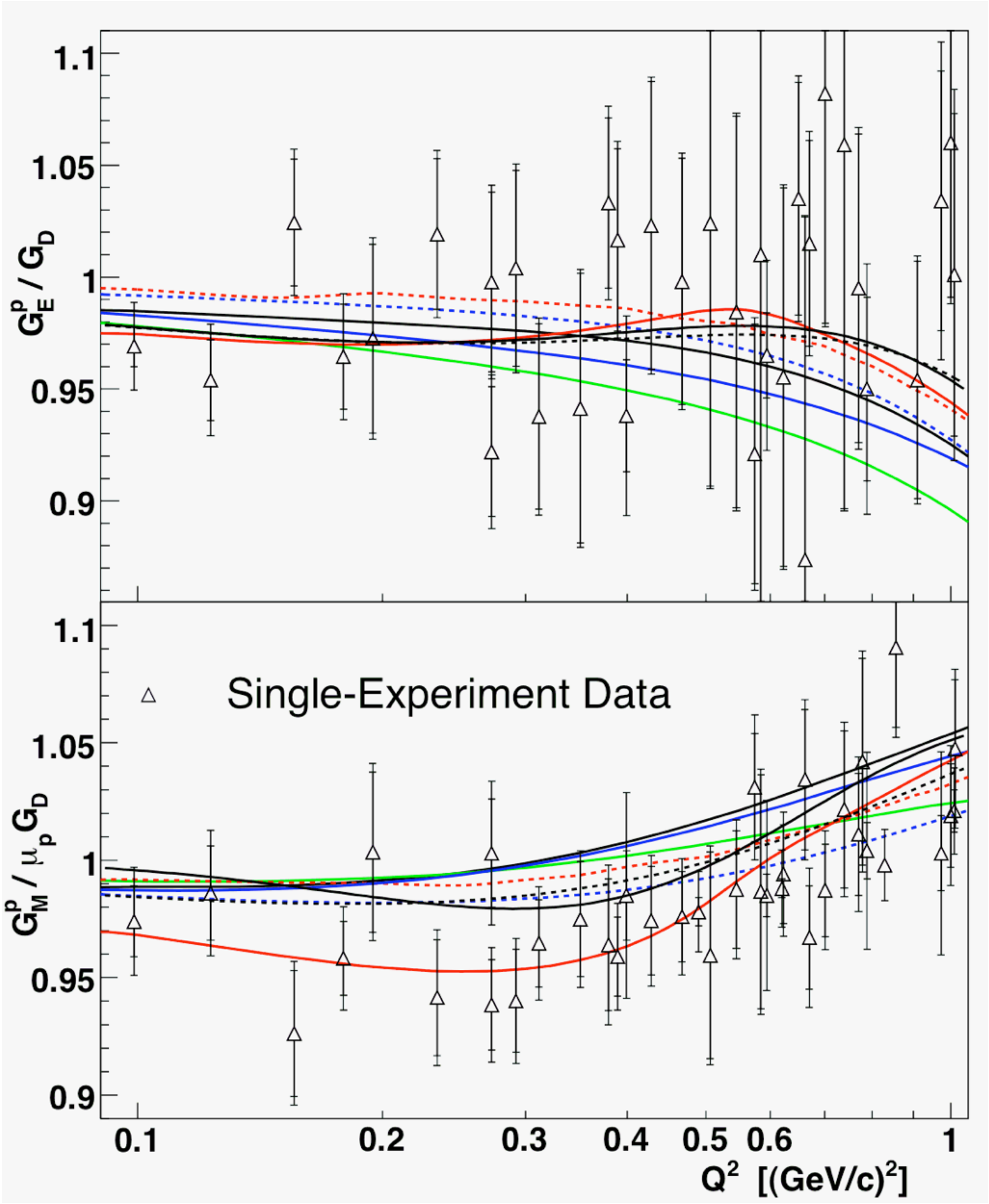
- beam and target polarisations cancel
- all that remains is kinematic terms

Ratio of Proton Elastic Form Factors



Ph.D. Thesis C. Crawford and A. Sindile

Impact of BLAST Results on World Data



Proton elastic form factors

- $G^p{}_E$ and $G^p{}_M$
  - divided by dipole
  - collection of unpolarised data

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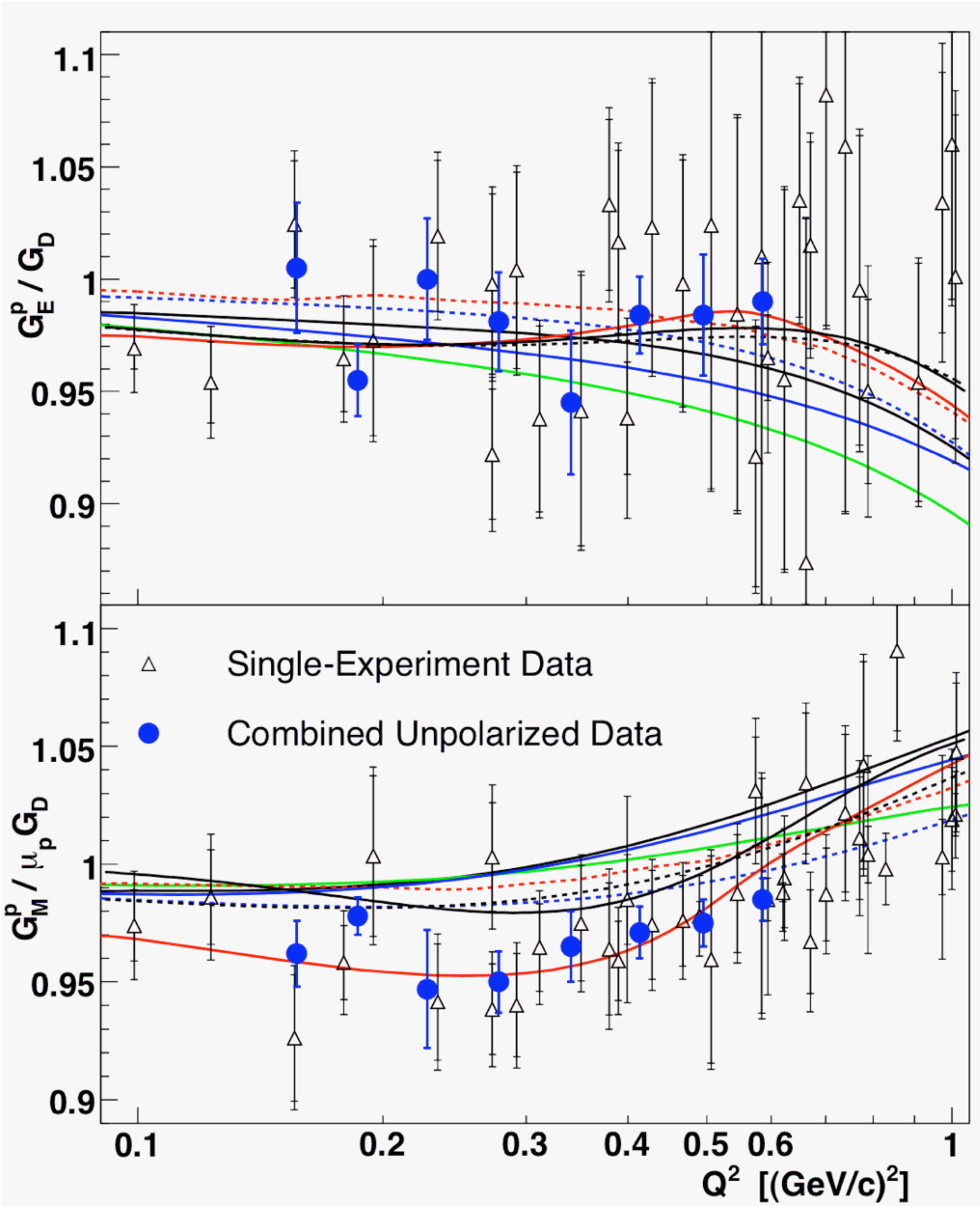
PRL 98 (2007) 52301

Impact of BLAST Results on World Data



Proton elastic form factors

- G^p_E and G^p_M
  - divided by dipole
  - collection of unpolarised data

World data combined

- averaged and rebinned
- over BLAST range

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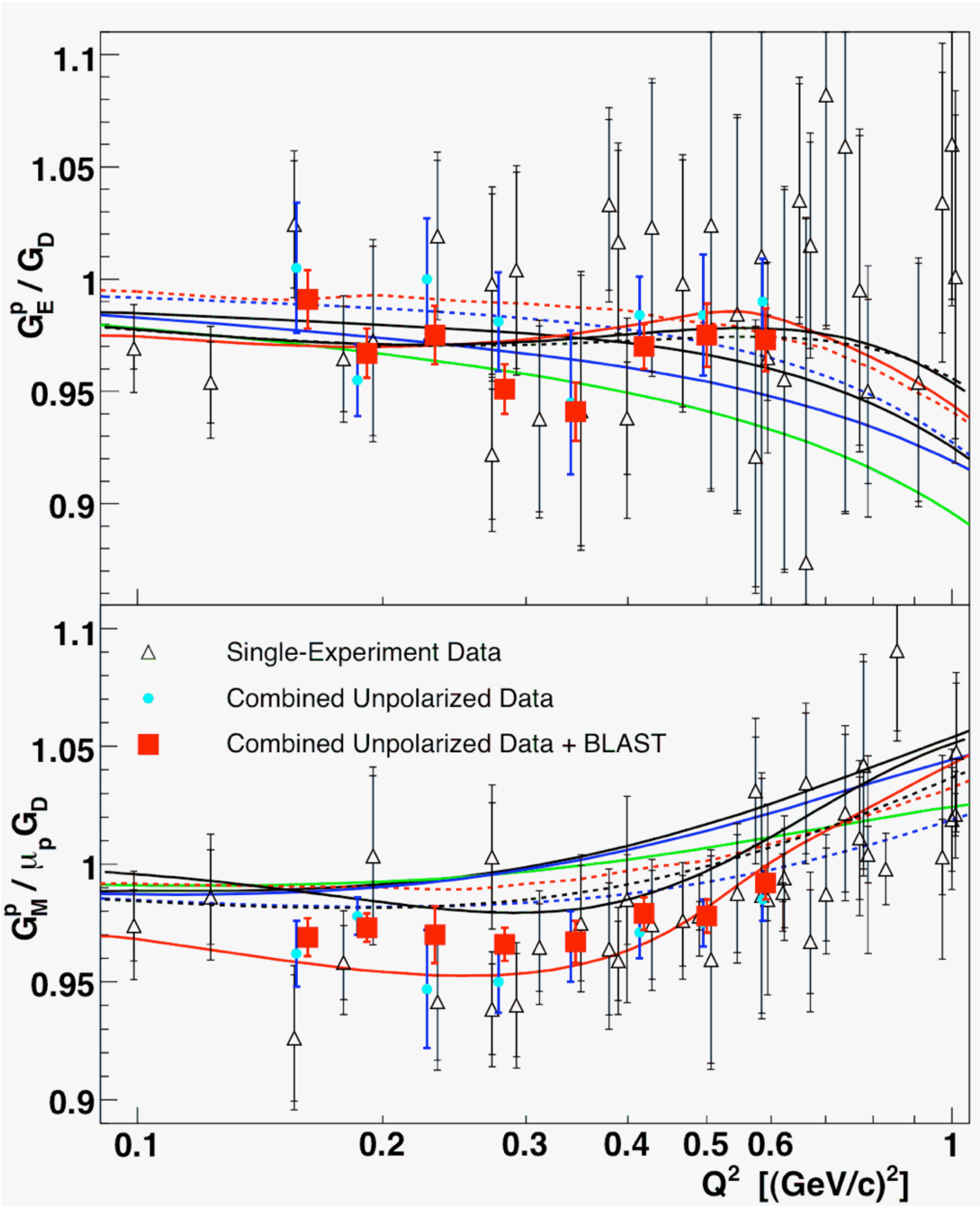
PRL 98 (2007) 52301

Impact of BLAST Results on World Data



Proton elastic form factors

- $G^p{}_E$ and $G^p{}_M$
  - divided by dipole
  - collection of unpolarised data

World data combined

- averaged and rebinned
- over BLAST range

Constraining with BLAST

- uncertainties reduced factor 2

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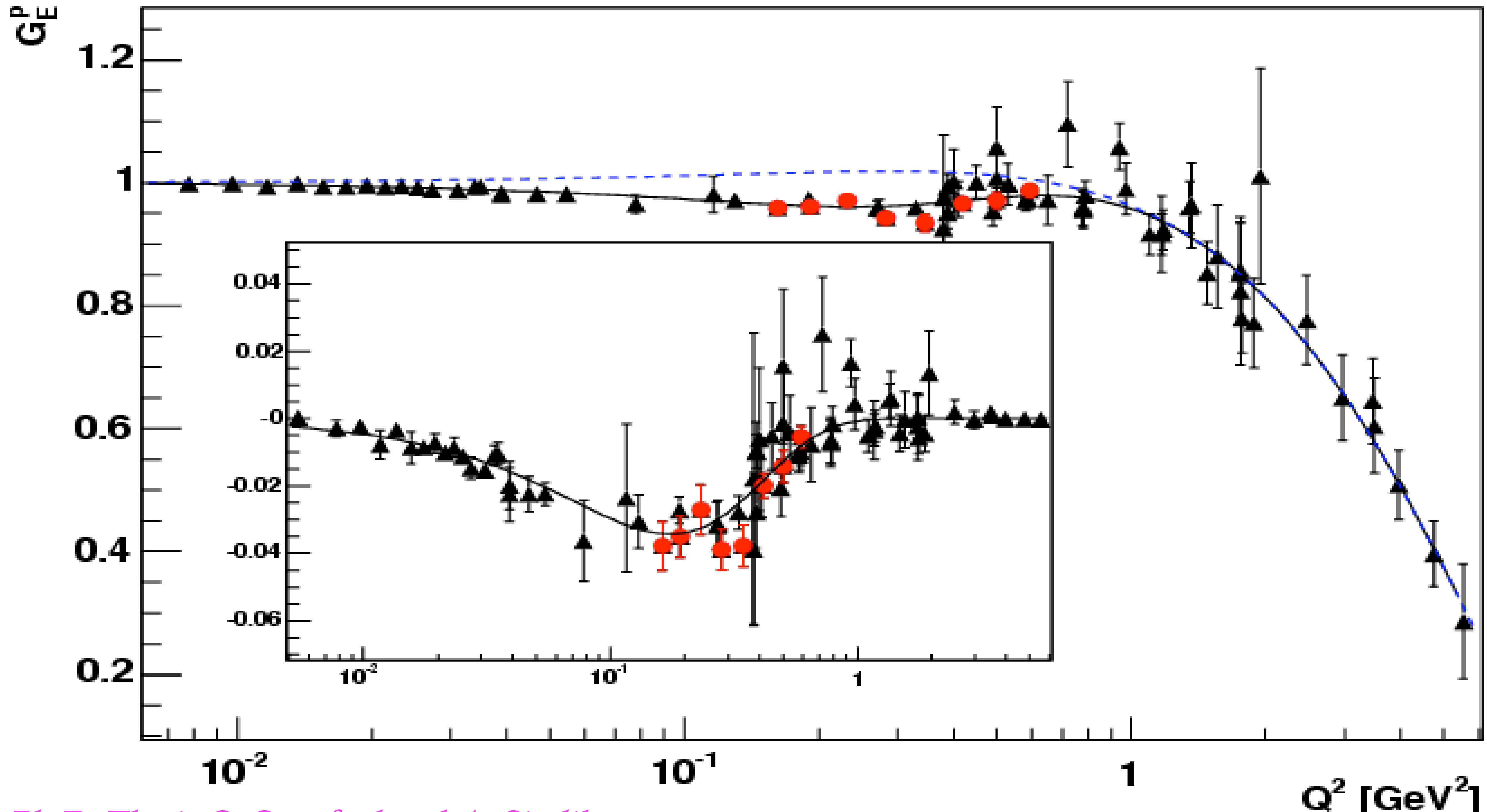
PRL 98 (2007) 52301

BLAST Data with Friedrich and Walcher



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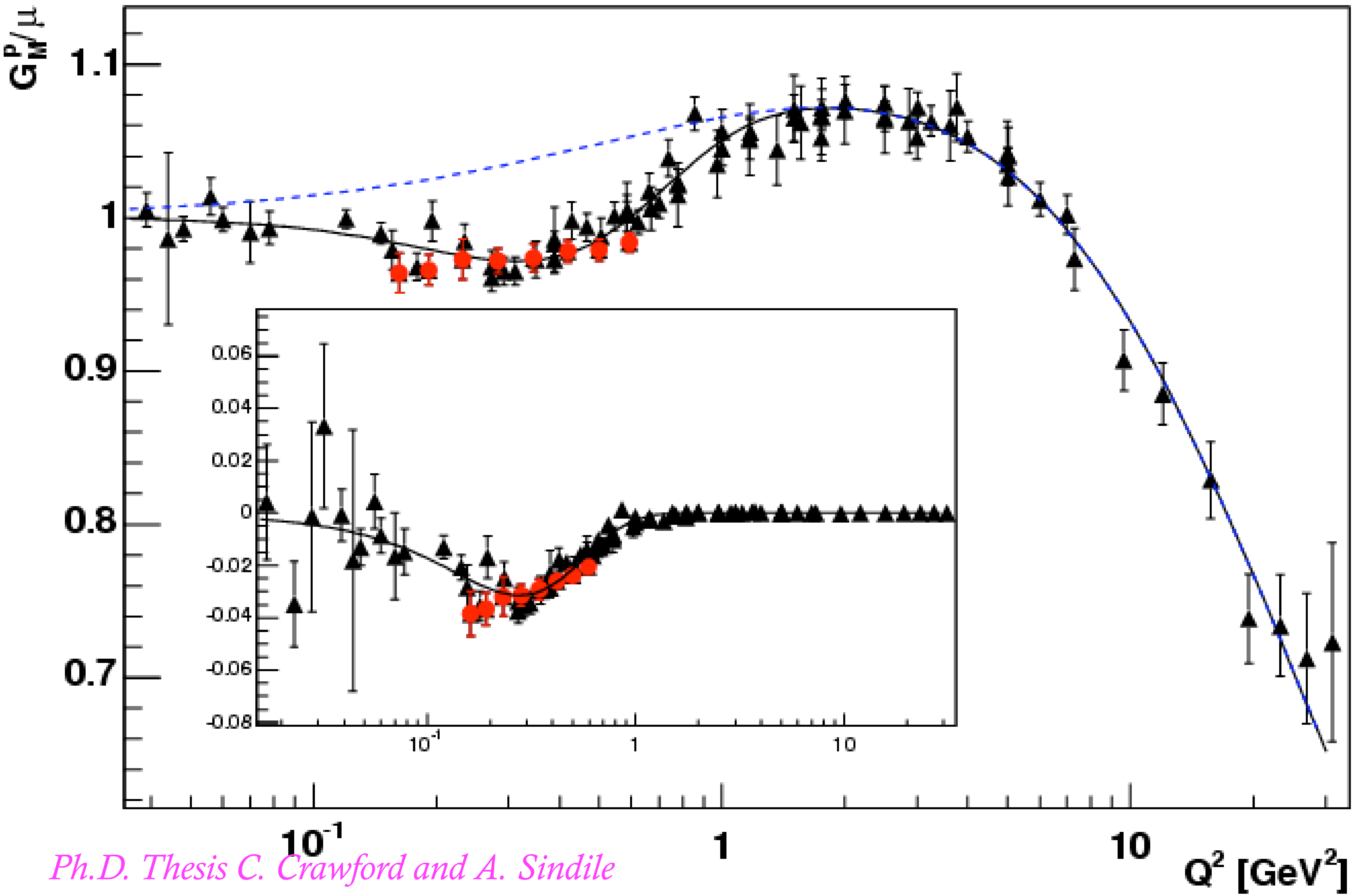
BLAST Data with Friedrich and Walcher



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Elastic Electron - Deuteron Scattering

Deuteron spin S = 1

- three form factors G^d_C, G^d_M, and G^d_Q
- G^d_Q arises from tensor force, D-wave
- normalisation $G^d_Q(0)=M^2_d\, Q_d$

Unpolarised elastic cross section - insufficient

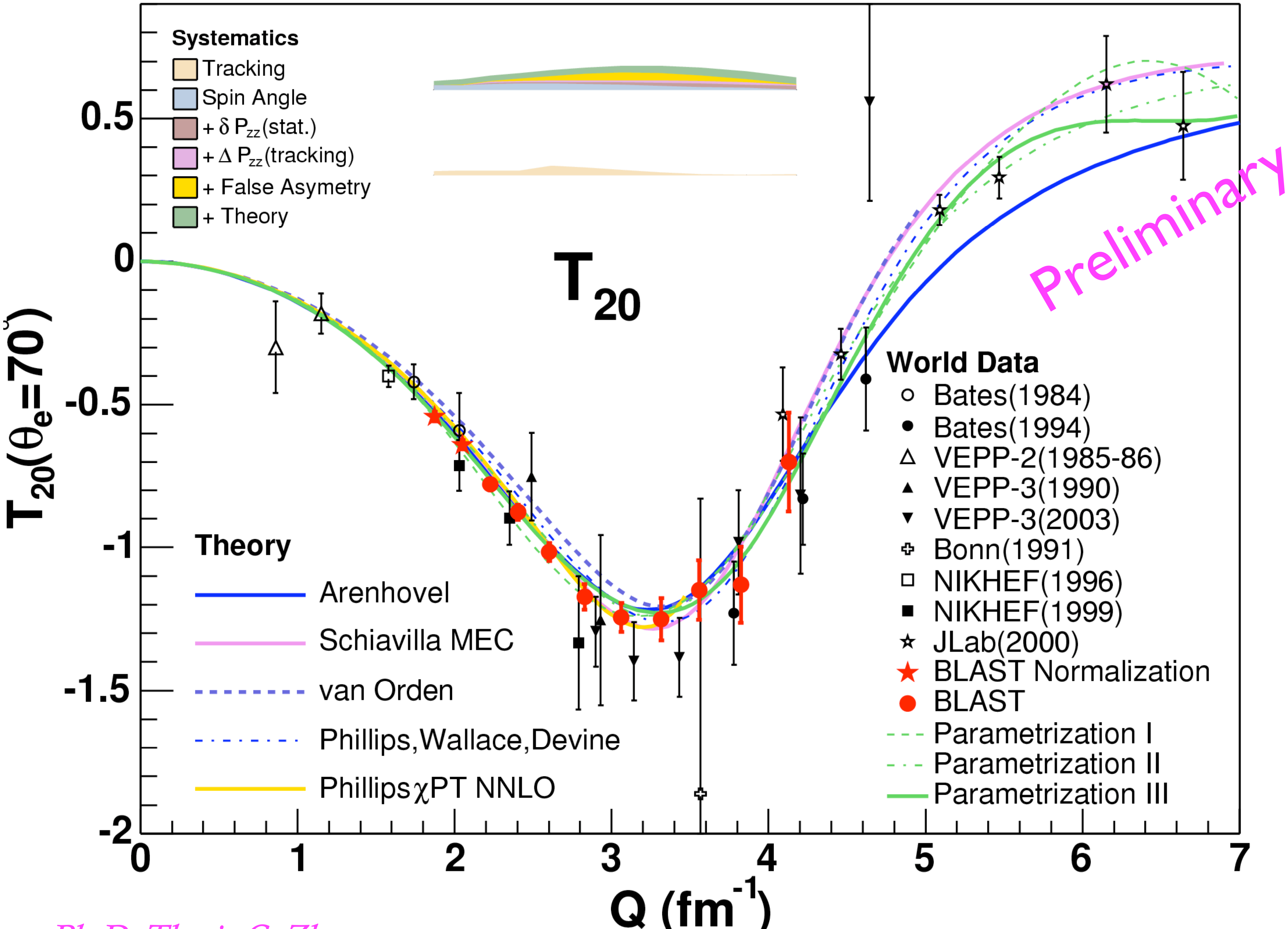
$$A(Q^2) = {G_C^d}^2 + \frac{8}{9}\eta^2 {G_Q^d}^2 + \frac{2}{3}\eta {G_M^d}^2$$

$$B(Q^2) = \frac{4}{3}\eta(1+\eta){G_M^d}^2; \qquad \eta = Q^2/(4M_d^2)$$

Need additional measurement - tensor asymmetry

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

T_{20}



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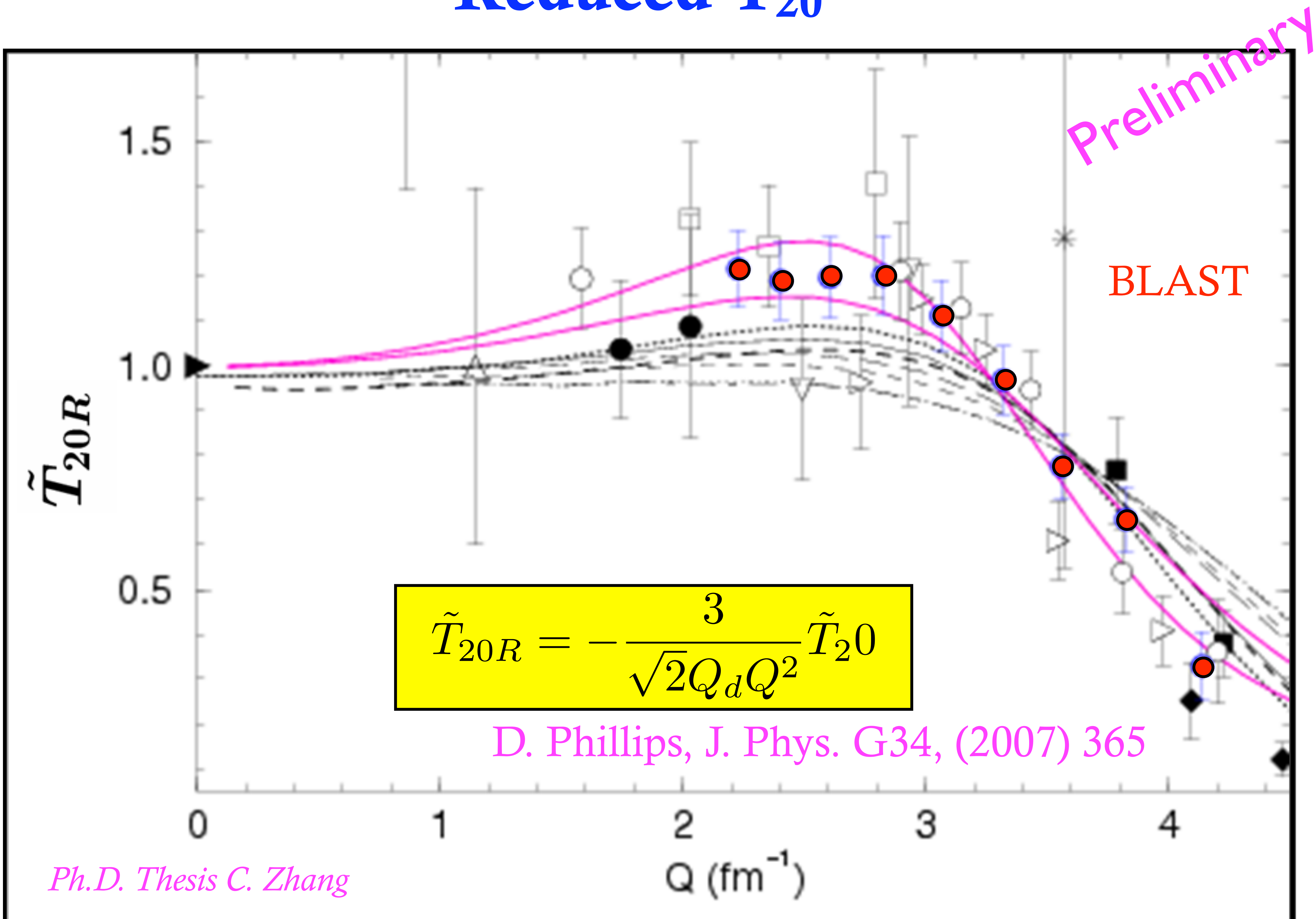
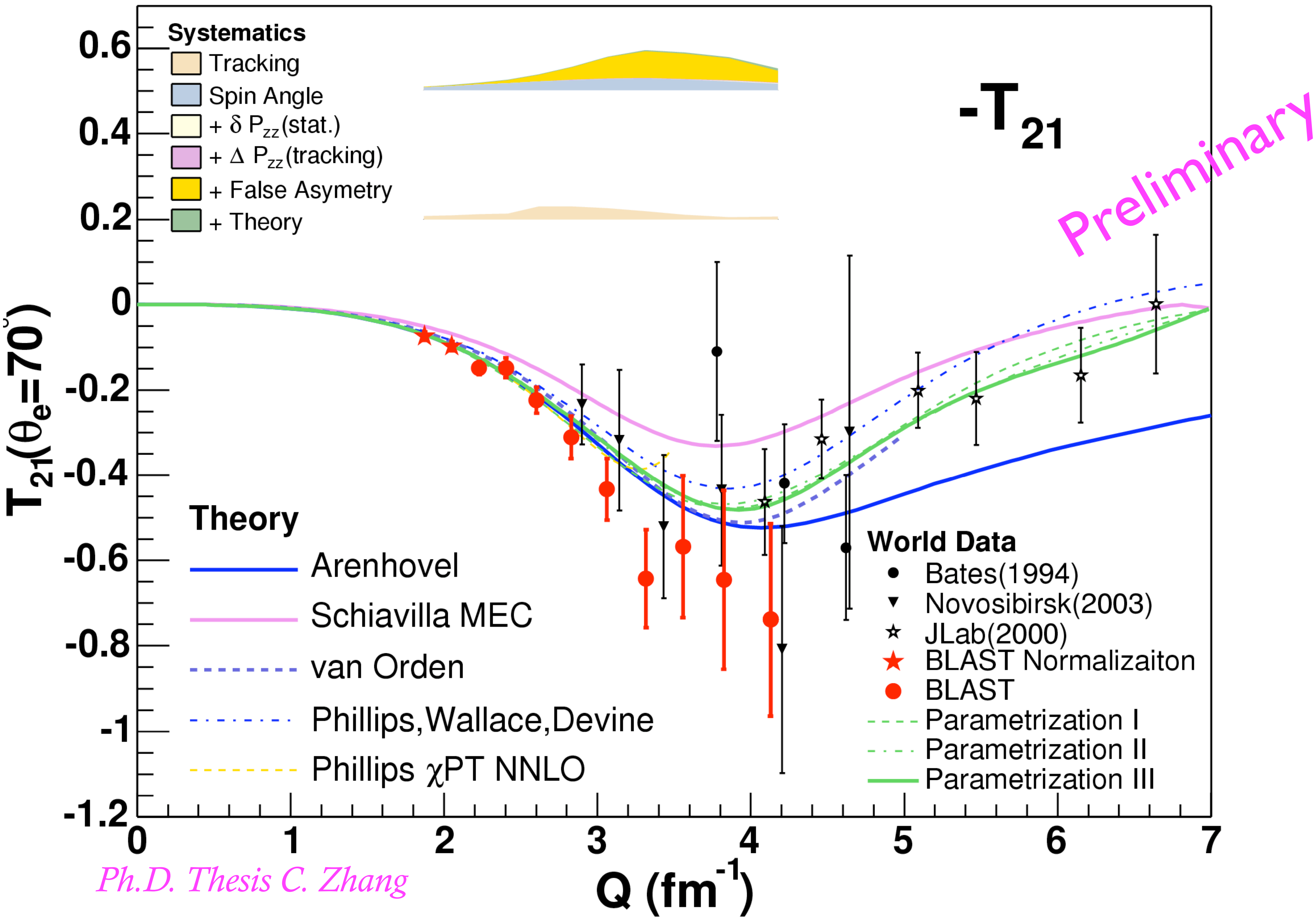
Reduced T_{20}


Preliminary
BLAST
1.5
1.0
0.5
$\tilde{T}_{20R}$
0
1
2
3
4
Q (fm^{-1})
$\tilde{T}_{20R} = -\frac{3}{\sqrt{2}Q_d Q^2}\tilde{T}_20$
D. Phillips, J. Phys. G34, (2007) 365
Ph.D. Thesis C. Zhang

T_{21}



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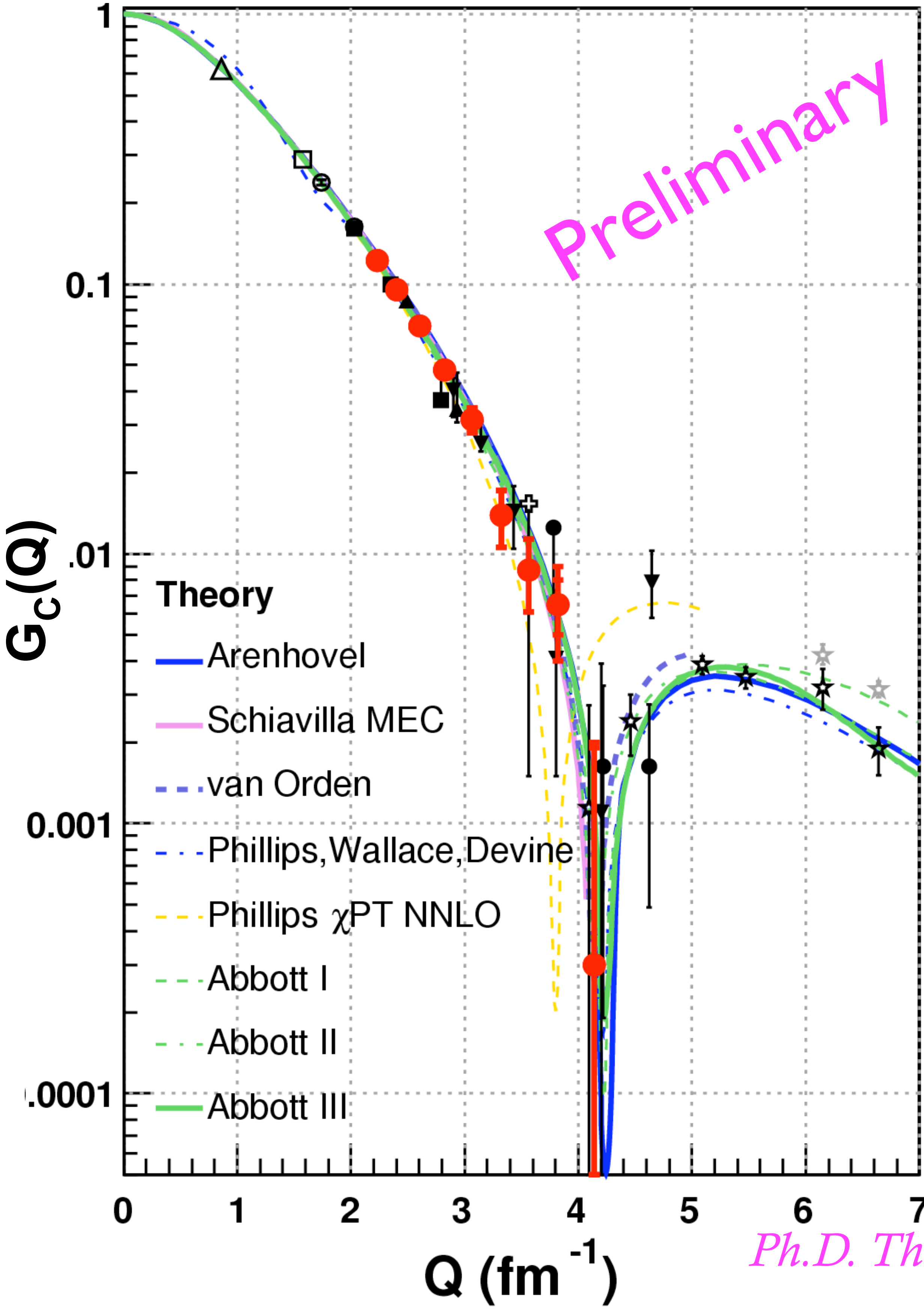
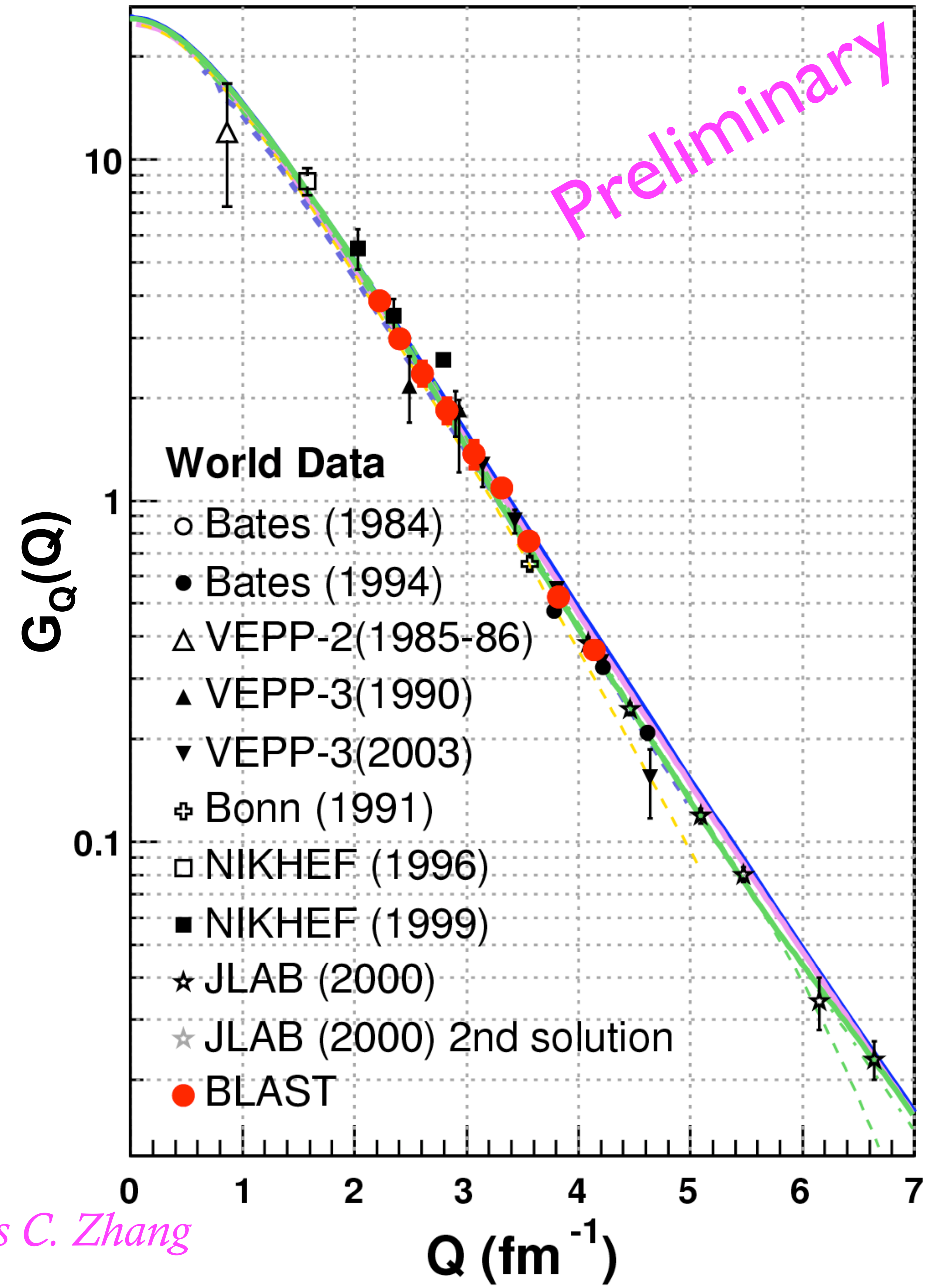
G_C and G_Q





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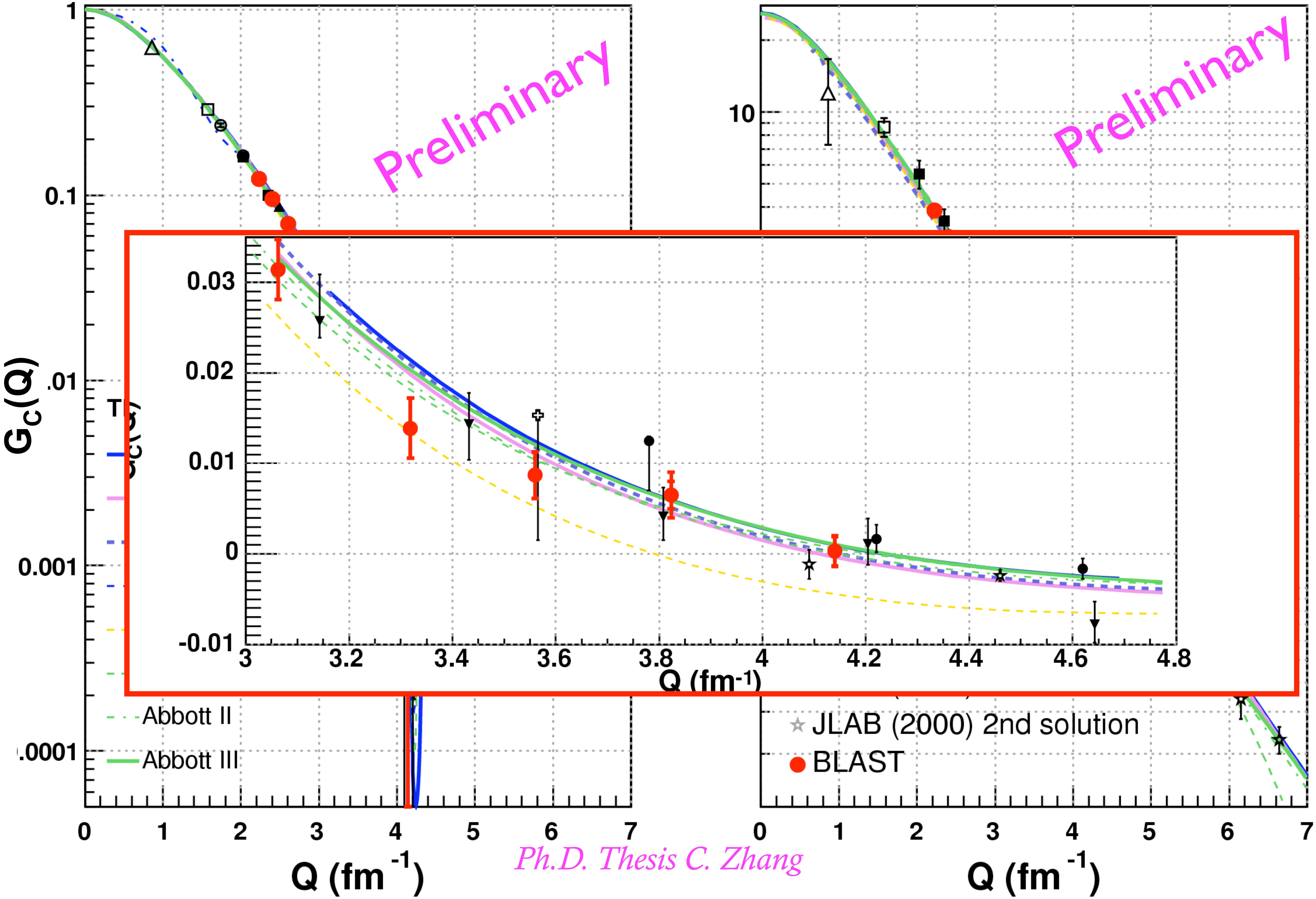
G_C and G_Q



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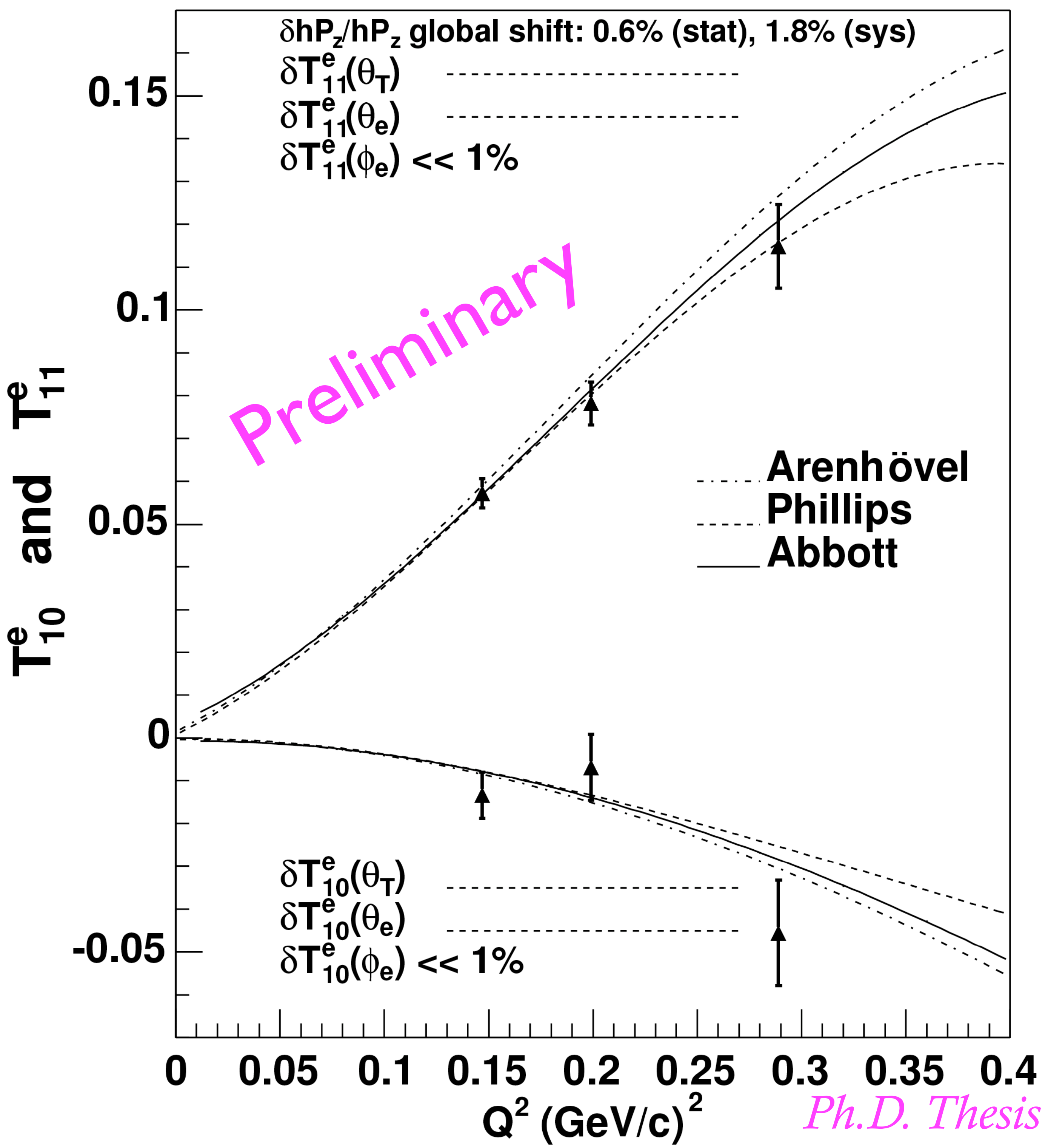
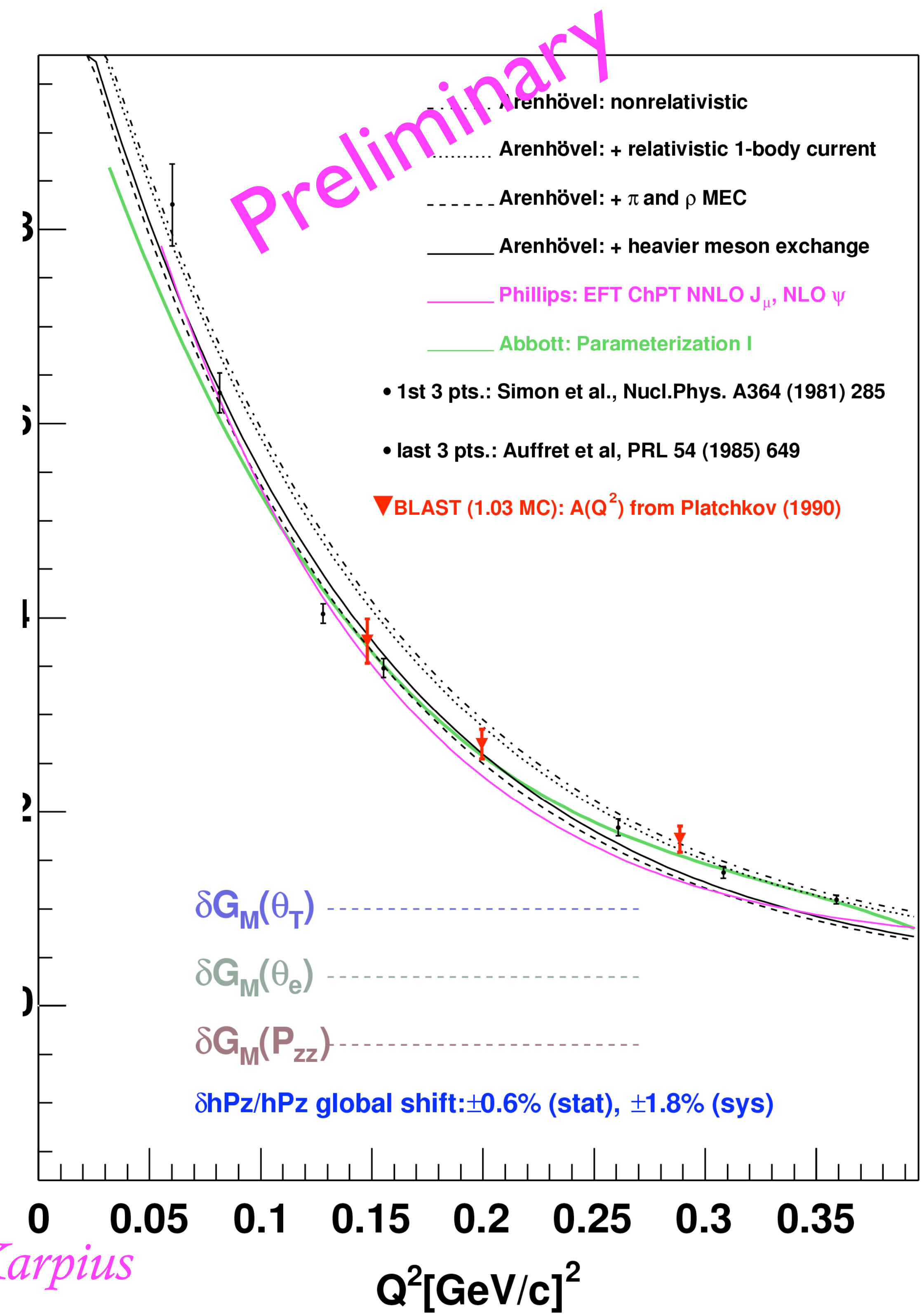
T^e_{10} and T^e_{11} and G^d_M



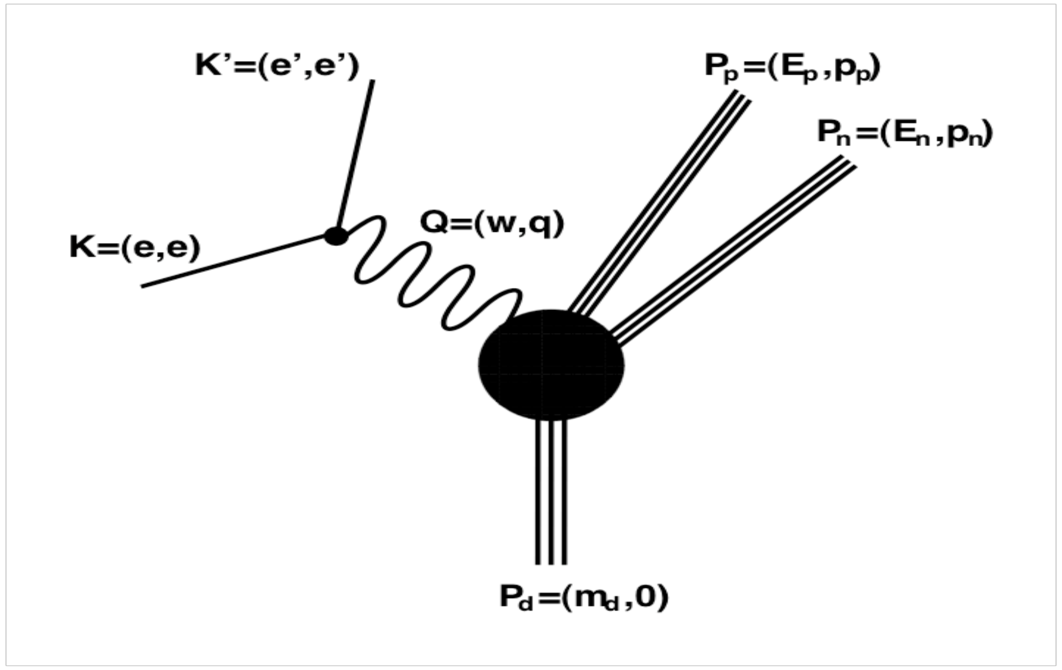
Ph.D. Thesis P. Karpius



Quasi-Elastic Scattering from Deuterium

Deuteron readily breaks up

- e + d → e′ + p + n
- electro-disintegration



Spin-dependent d(e,e′N) cross section can be written as:

$$S(h, P_Z, P_{ZZ}) = S_0\left[1 + P_Z A_d^V + P_{ZZ} A_d^T + h(A_e + P_Z A_{ed}^V + P_{ZZ} A_{ed}^T)\right]$$

In the Born approximation

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

Yielding:

$$S(h, P_Z, P_{ZZ}) = S_0\left[1 + P_{ZZ} A_d^T + h P_Z A_{ed}^V\right]$$

A_{ed}^V: $\propto G_E/G_M$

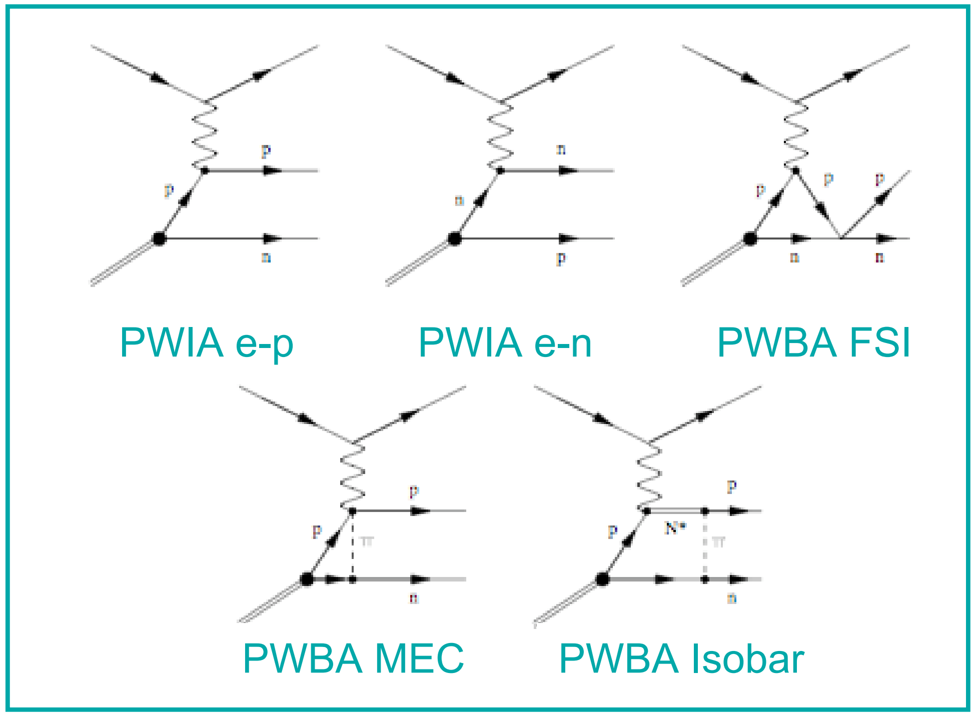
A_d^T: = 0 for S state

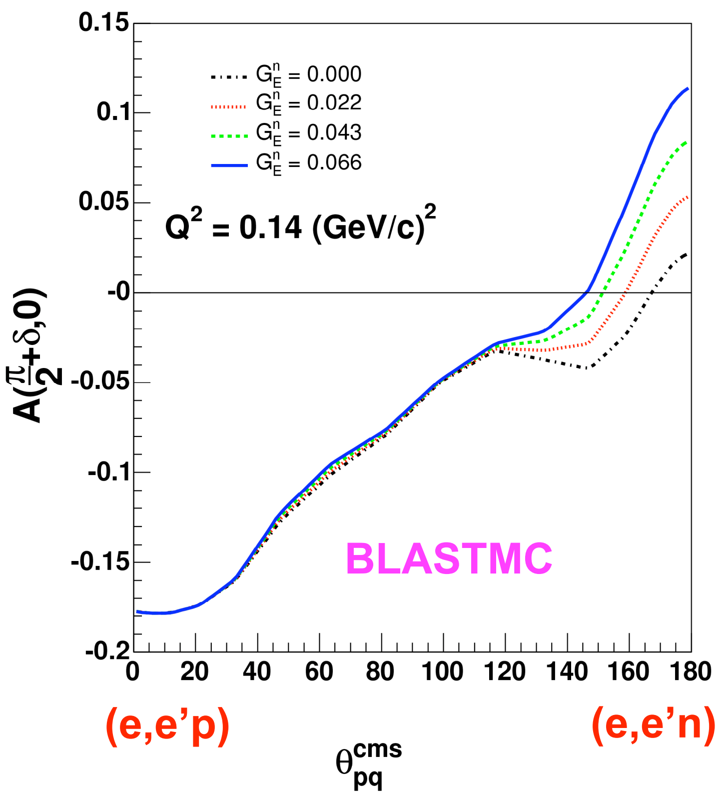
Extracting G^n_E from A^V_{ed}

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

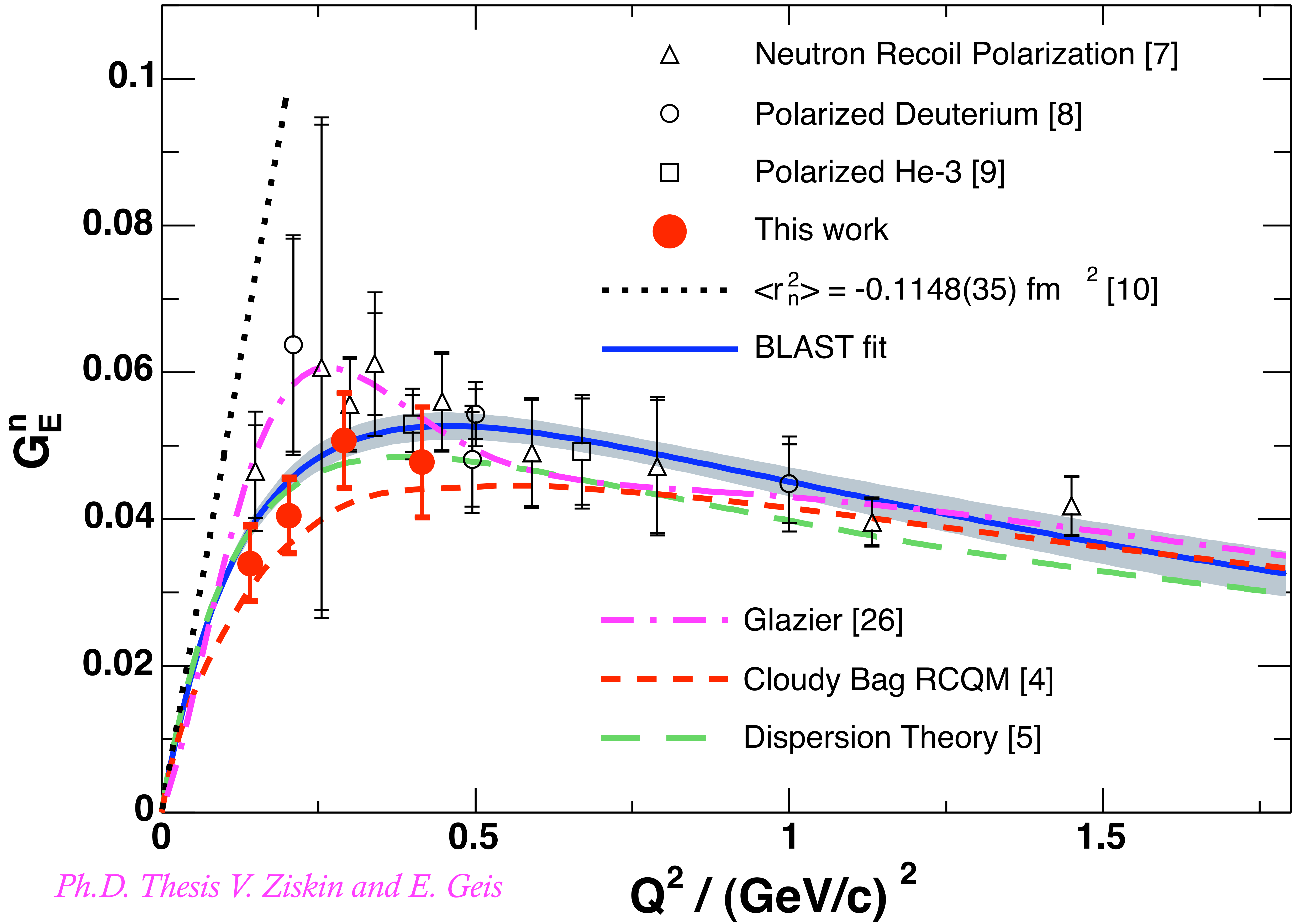
Beam-Target vector asymmetry gives G^n_E assuming G^n_M known

- full Monte Carlo simulation
- deuteron electro-disintegration by H. Arenhovel
- account for FSI, RC, IC, MEC
- "spin-perpendicular" kinematics shows largest effect



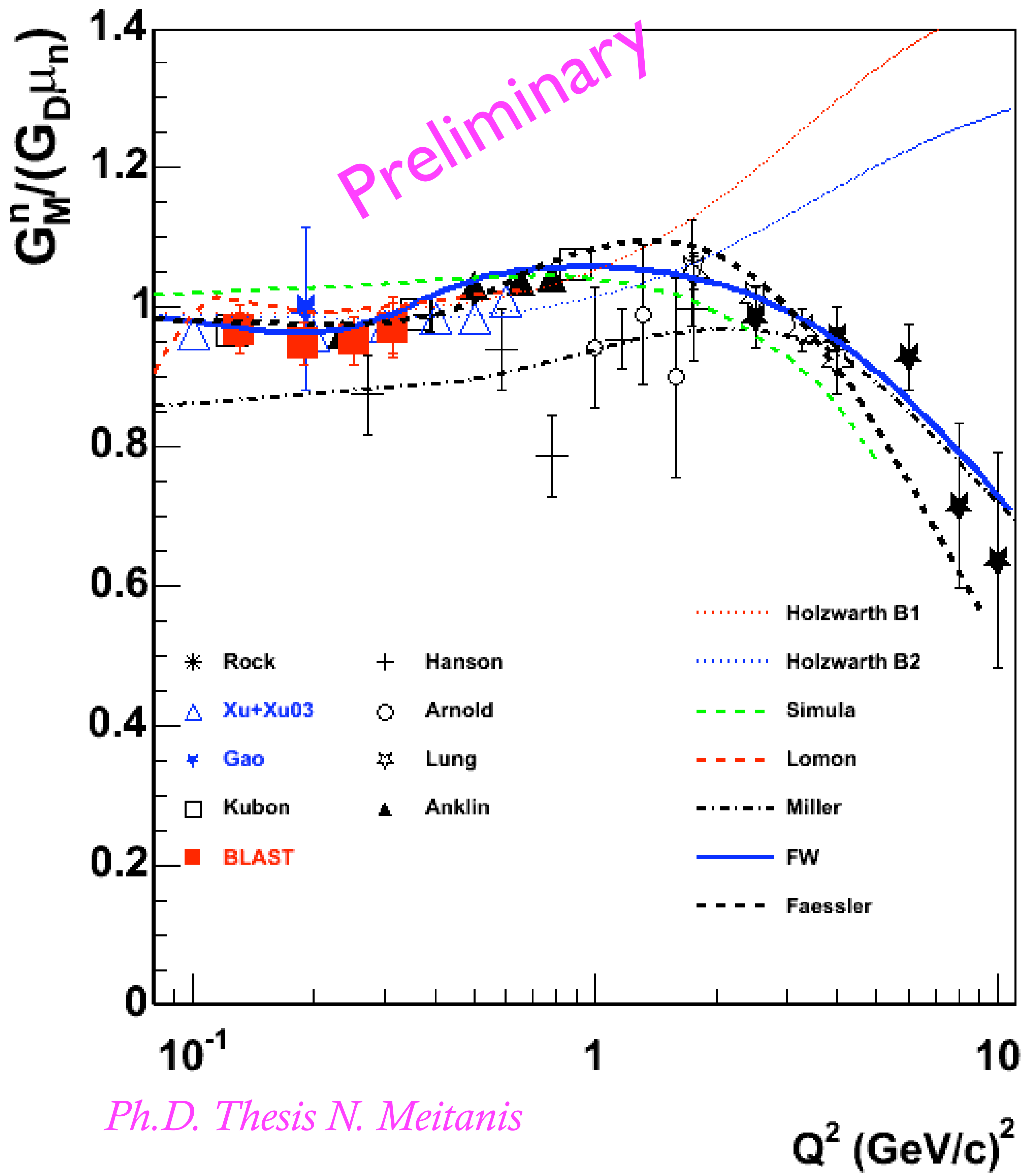


G^n_E from BLAST



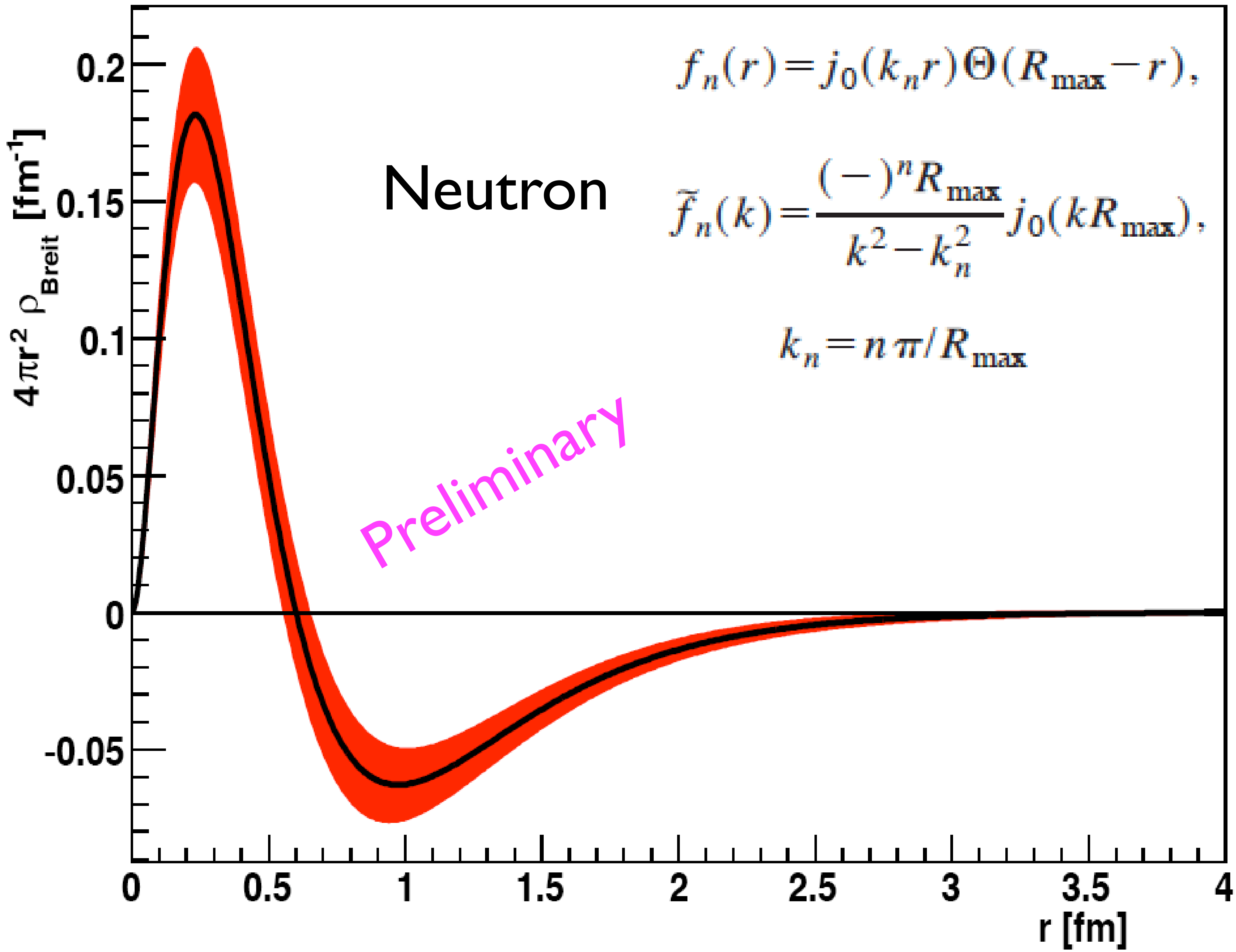
Ph.D. Thesis V. Ziskin and E. Geis

G^n_M from Inclusive Scattering

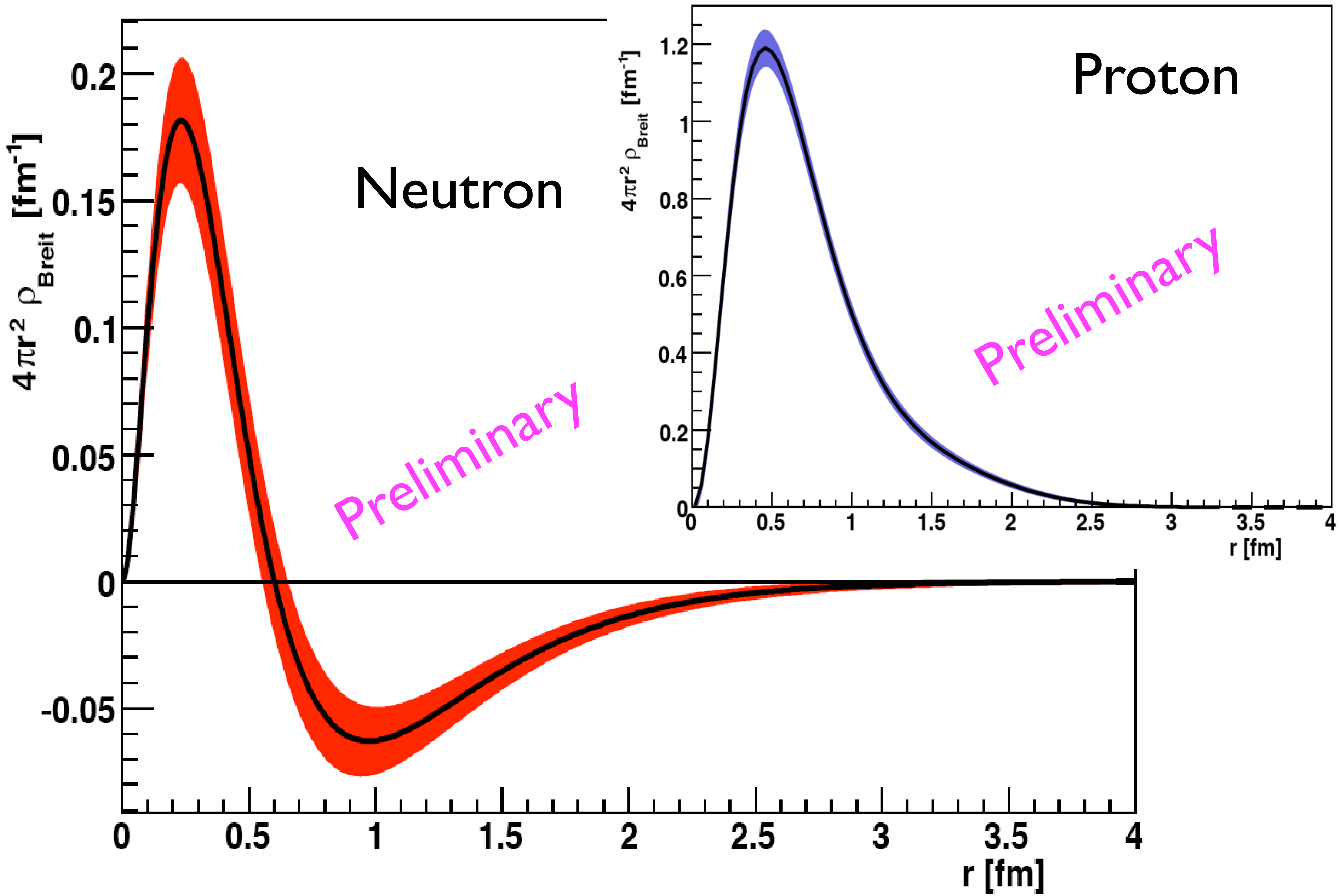


Ph.D. Thesis N. Meitanis

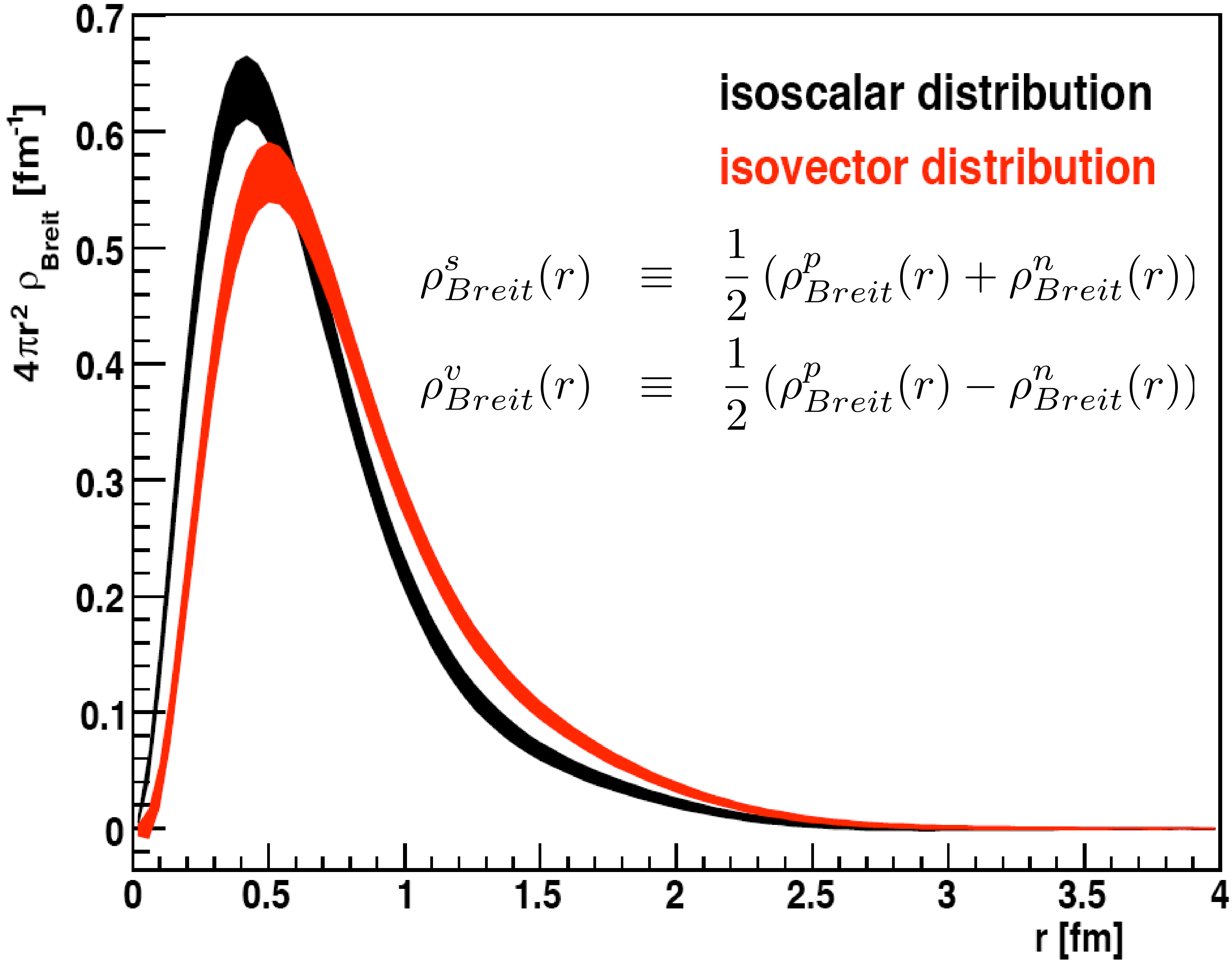
Breit Frame Distributions



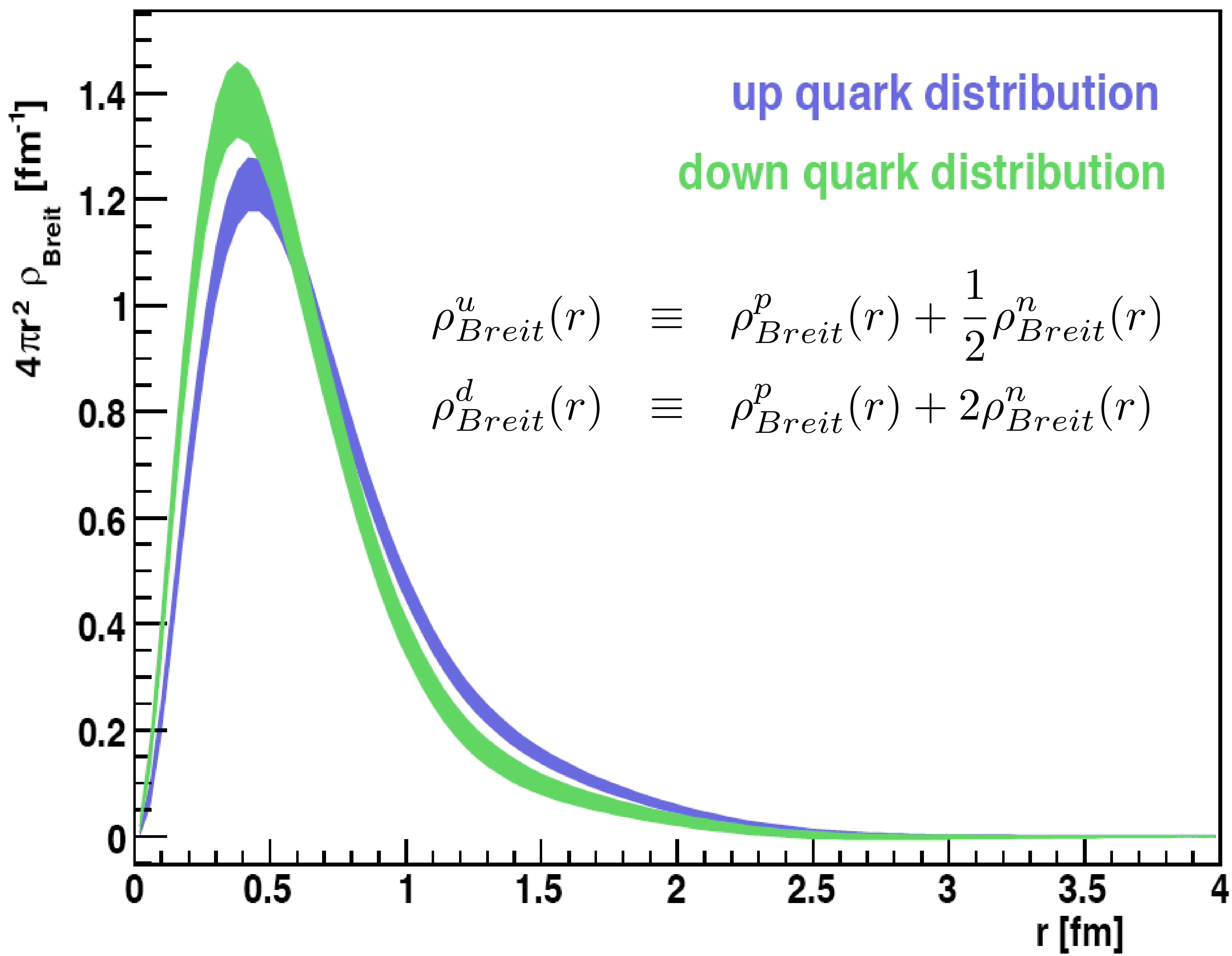
Breit Frame Distributions



Isoscaler and Isovector Distributions



Up and Down Quark Distributions



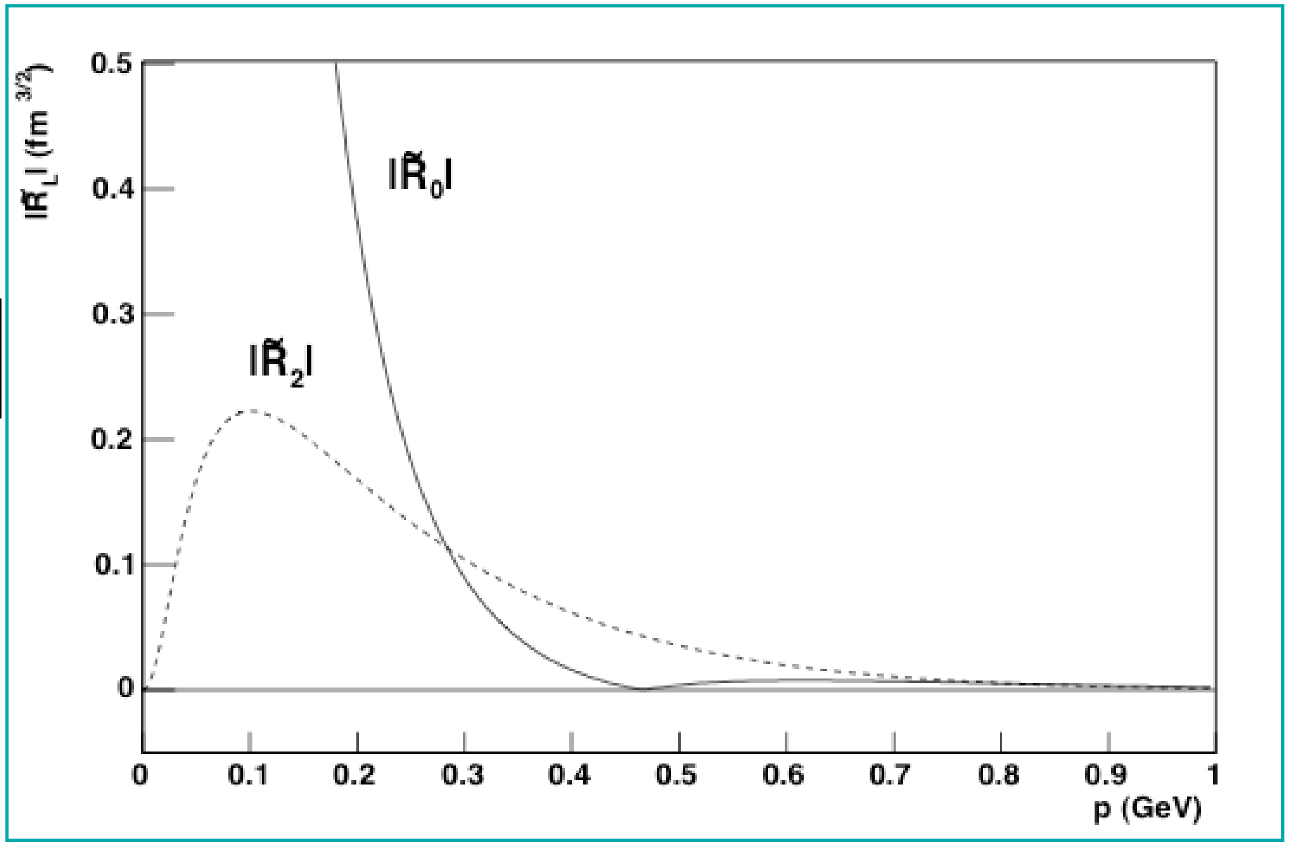
Deuteron Wavefunction

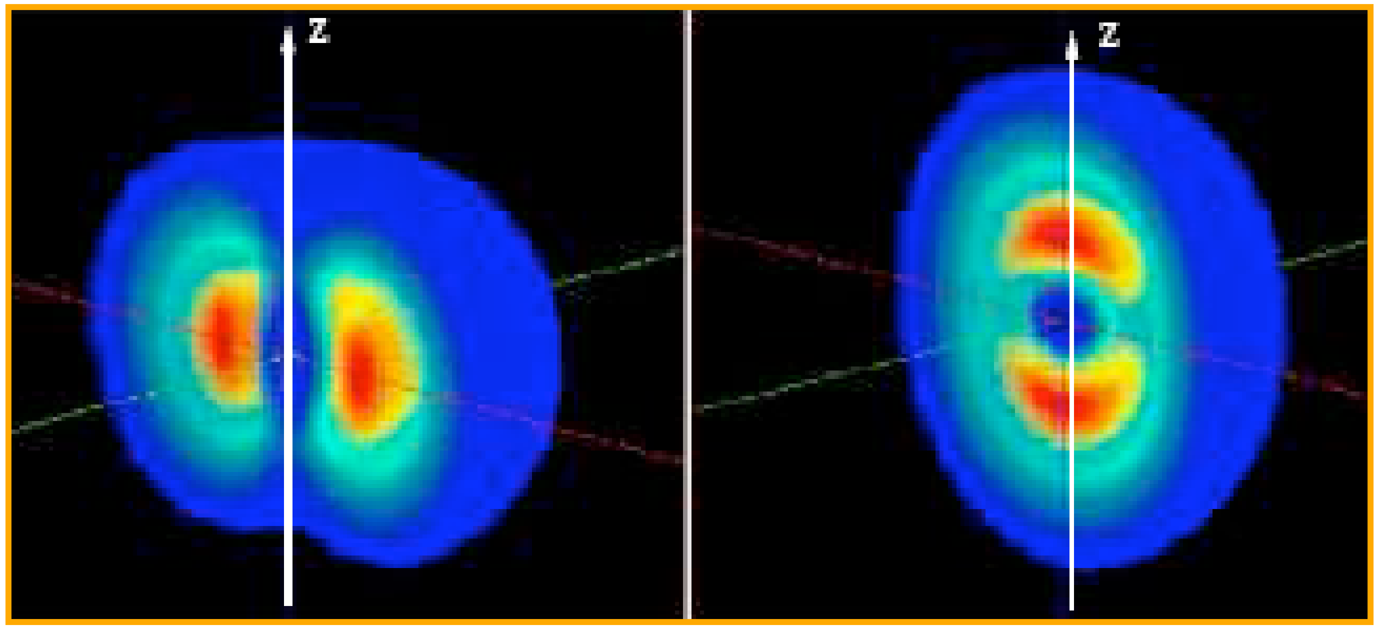
Deuteron wavefunction:

- L=0, 2 admixture

$$\psi^{m_d}(\vec{r}) = R_0(r)Y_{110}^{m_d}(\Omega_r) + R_2(r)Y_{112}^{m_d}(\Omega_r)$$

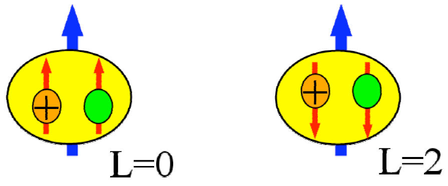
- S state minimum at p ~ 0.45 GeV
- D state significant at p > 0.3 GeV



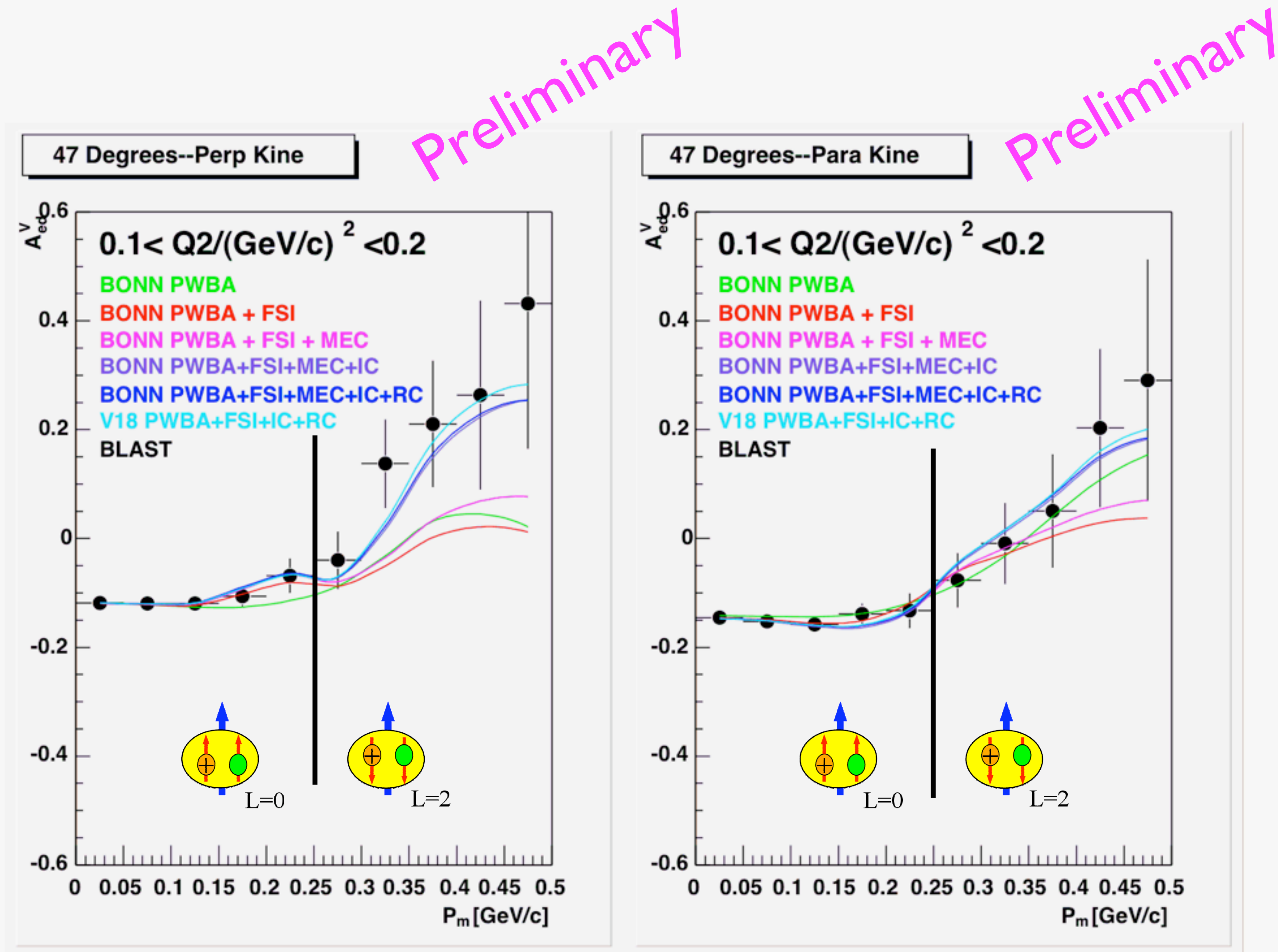


D state normally 4-6 %

- but beyond 0.3 GeV dominant
- region to study tensor force
- in D state nucleon spins flip

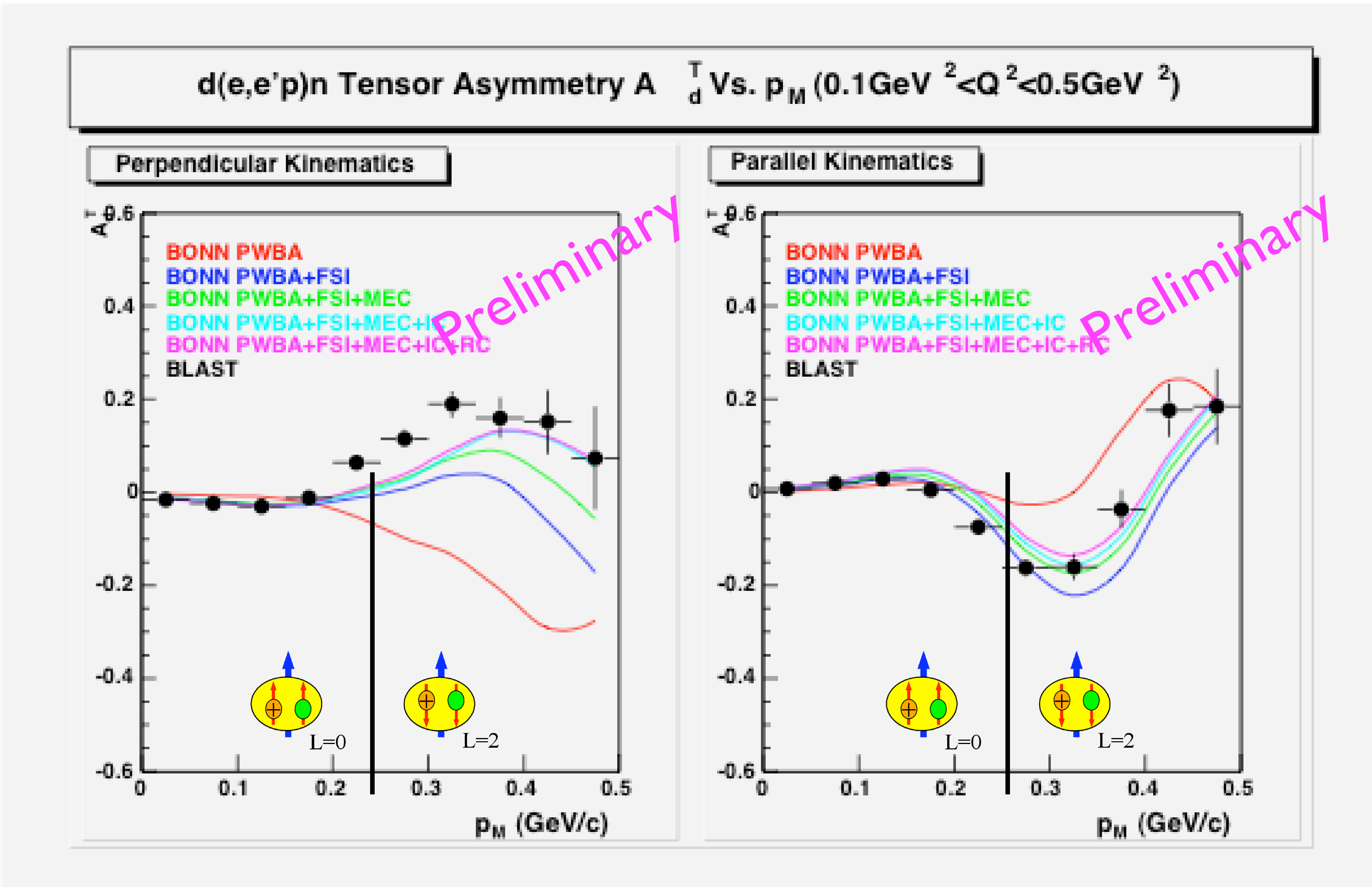


Quasi-Elastic e′p Scattering from Deuterium



Ph.D. Thesis A. DeGrush

Quasi-Elastic e′p Scattering from Deuterium

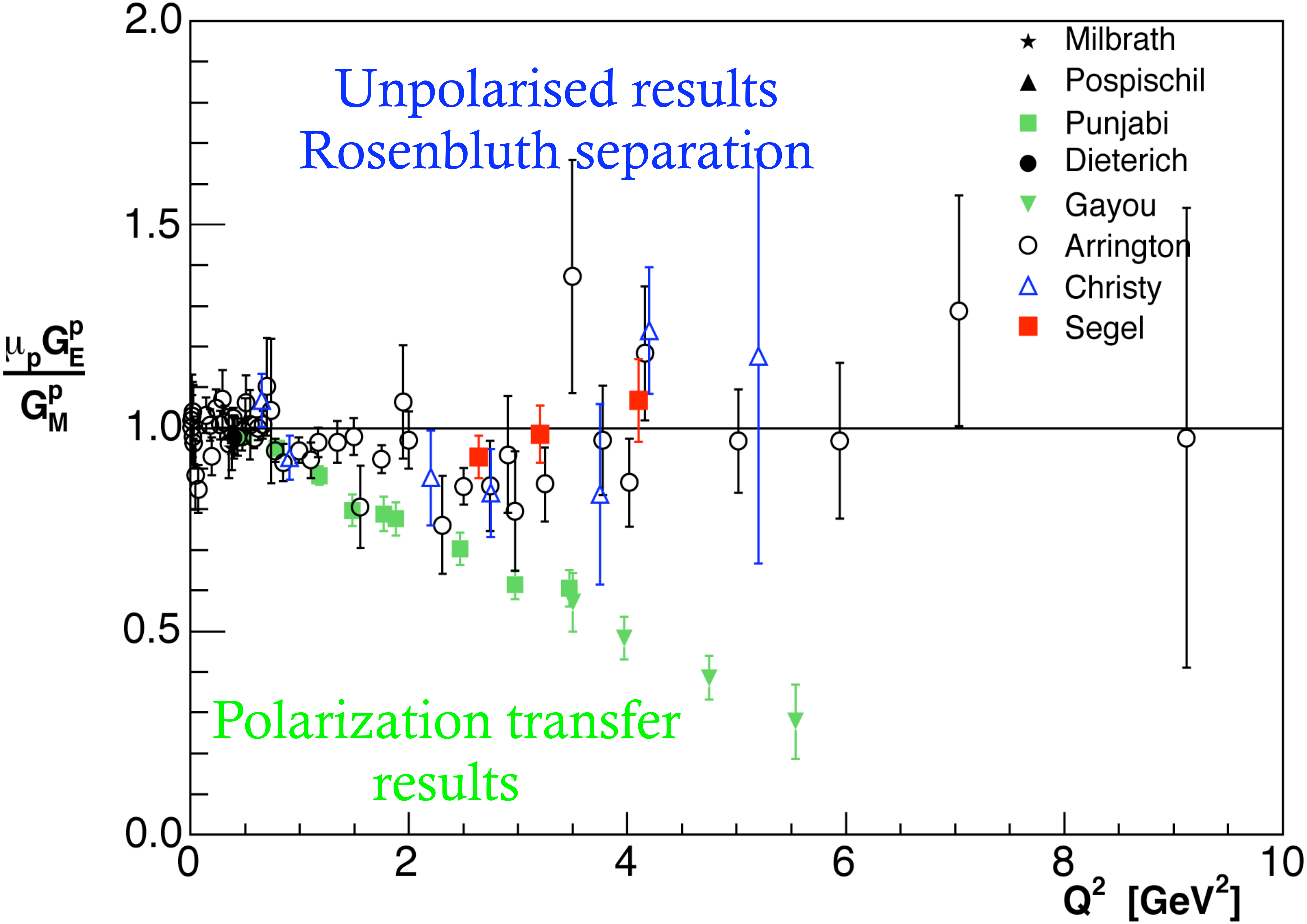


Ph.D. Thesis A. Maschinot

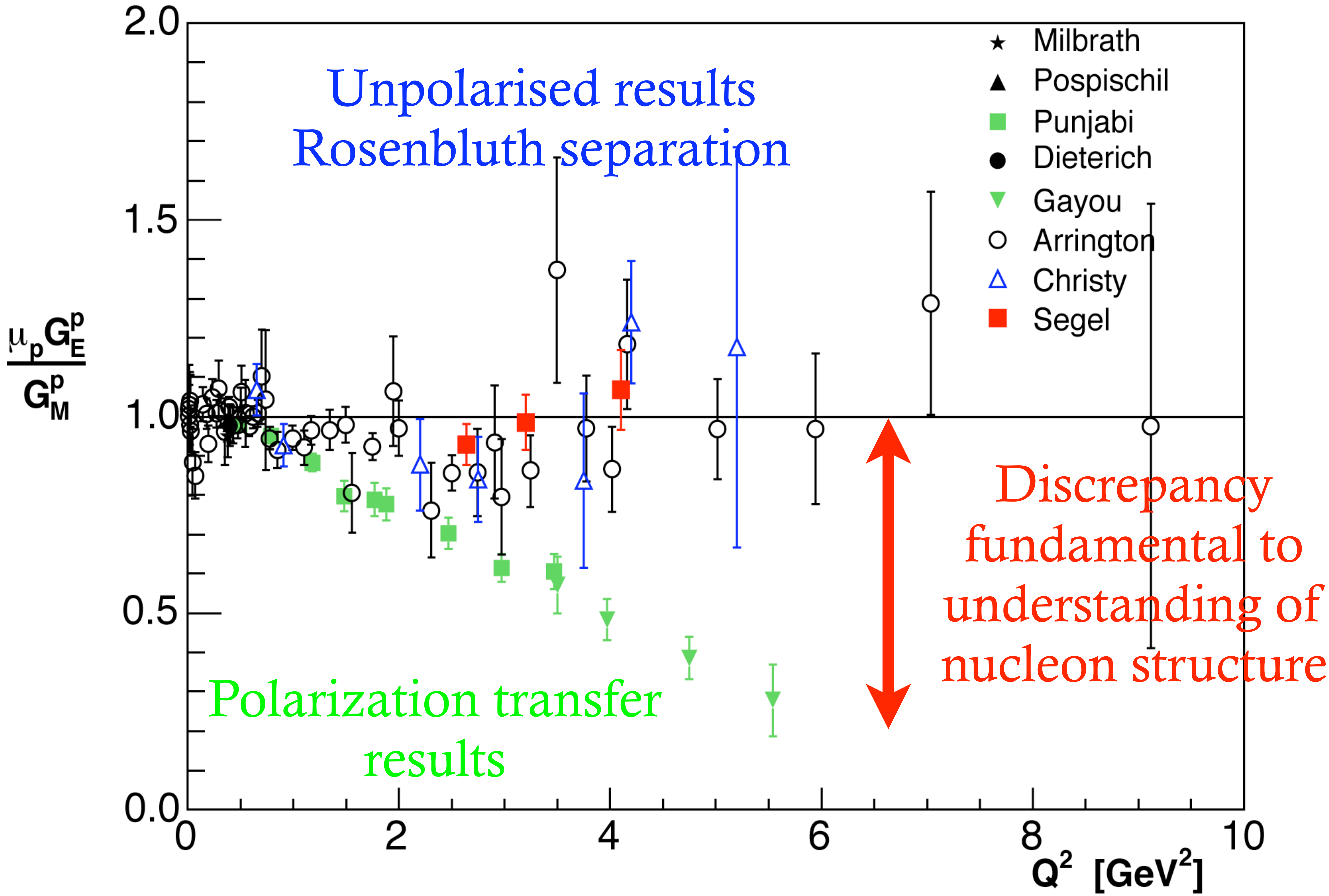
BLAST Collaboration

Possible Future for BLAST

Discrepancy in Proton Form Factor Ratio

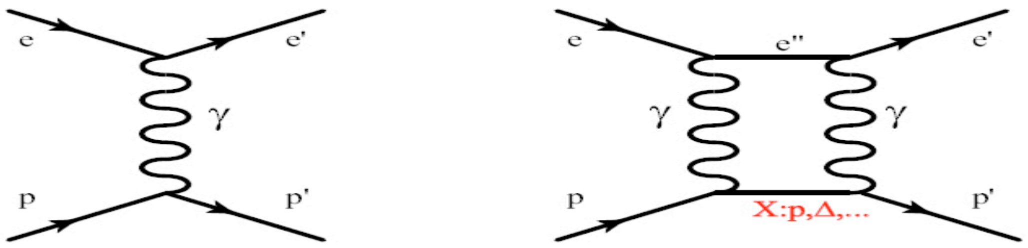


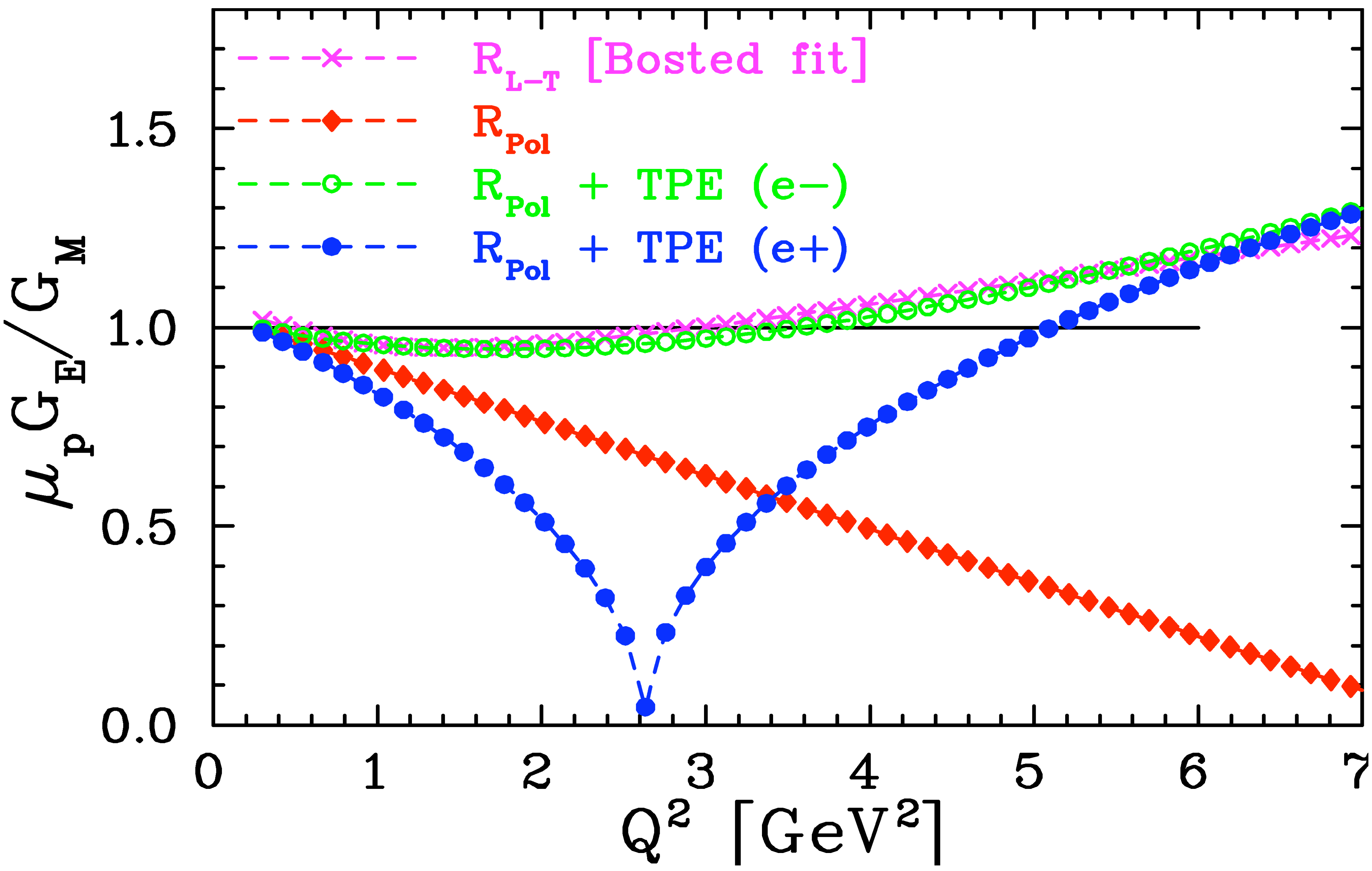
Discrepancy in Proton Form Factor Ratio



Two Photon Effect

Possible explanation of discrepancy and consequence





Seminar at DESY and DESY-Zeuthen, R. Milner, May, 2007

An Experiment to Definitively Determine the Contributions of Multiple Photon Exchange in Elastic Lepton-Nucleon Scattering

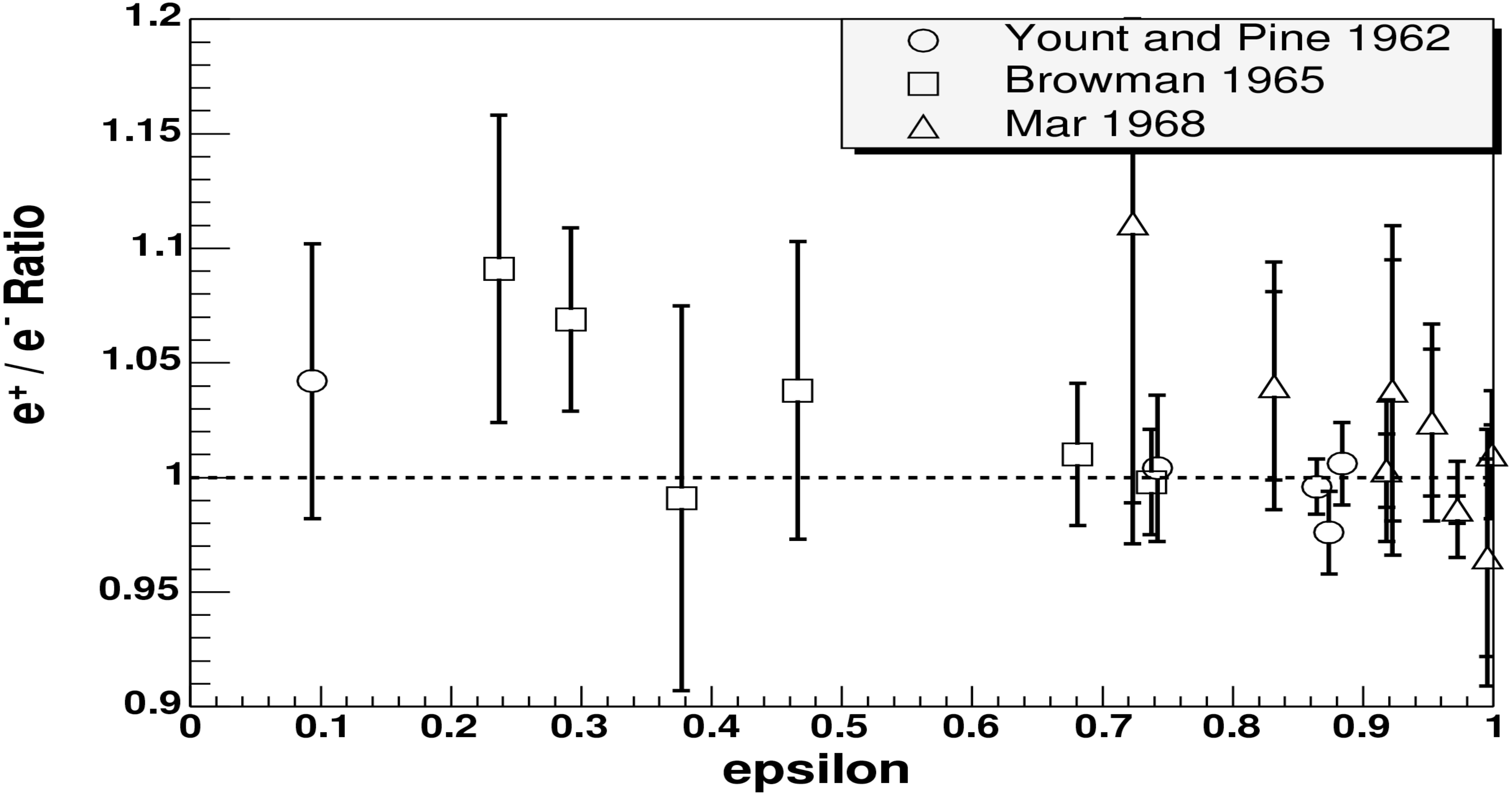
Measure ratio of e^+p / e^-p elastic scattering

- BLAST detector on DORIS storage ring
- 2-4 GeV electrons and positrons (change daily with toroid polarity)
- unpolarised, internal hydrogen gas target
- systematics cancel (to first order)

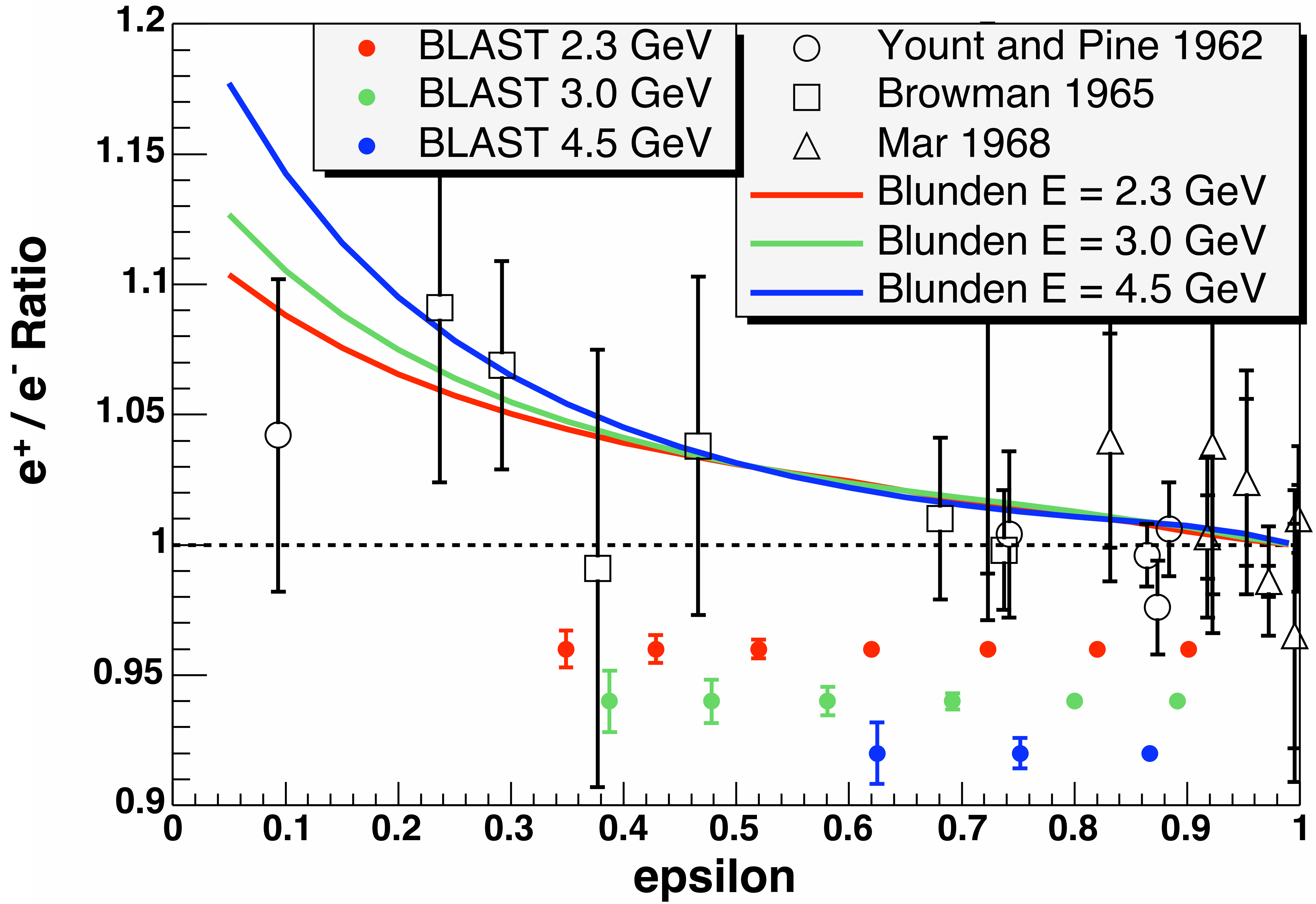
R. Heuer suggested presentation to DESY PRC

DESY PRC requested a brief document for review

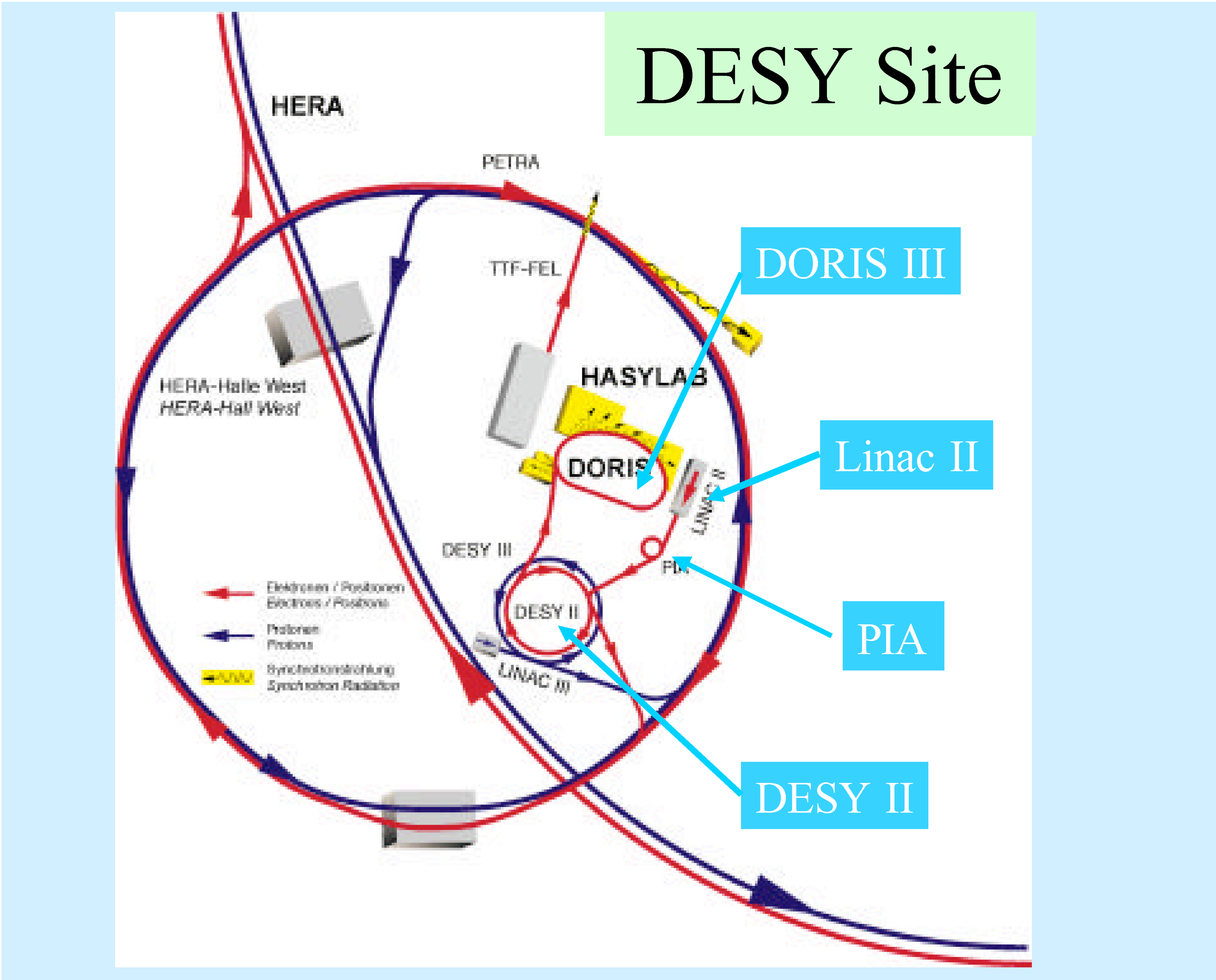
Interference in e⁺p/e⁻p Cross Section Ratio



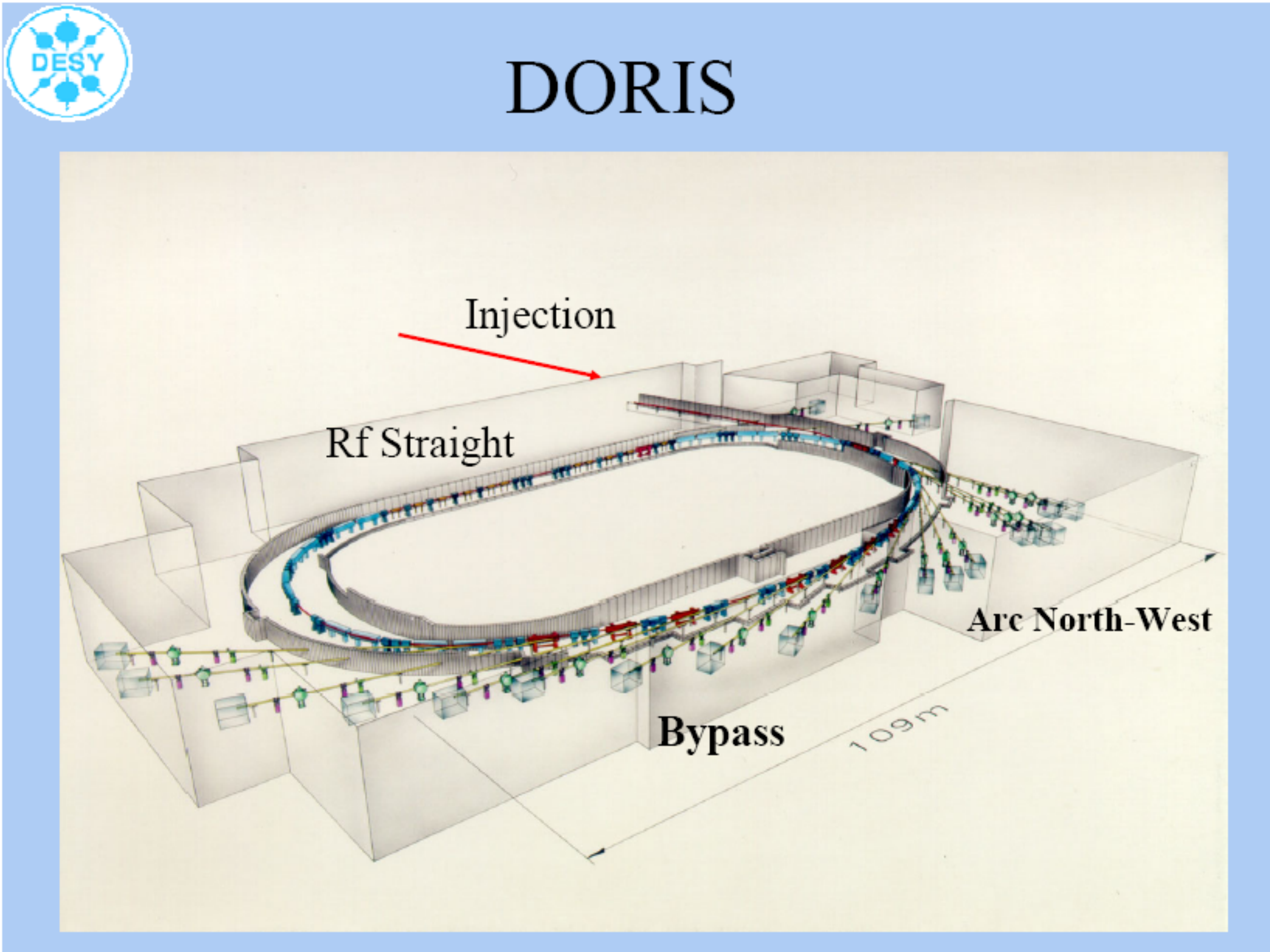
Interference in e^+p/e^-p Cross Section Ratio



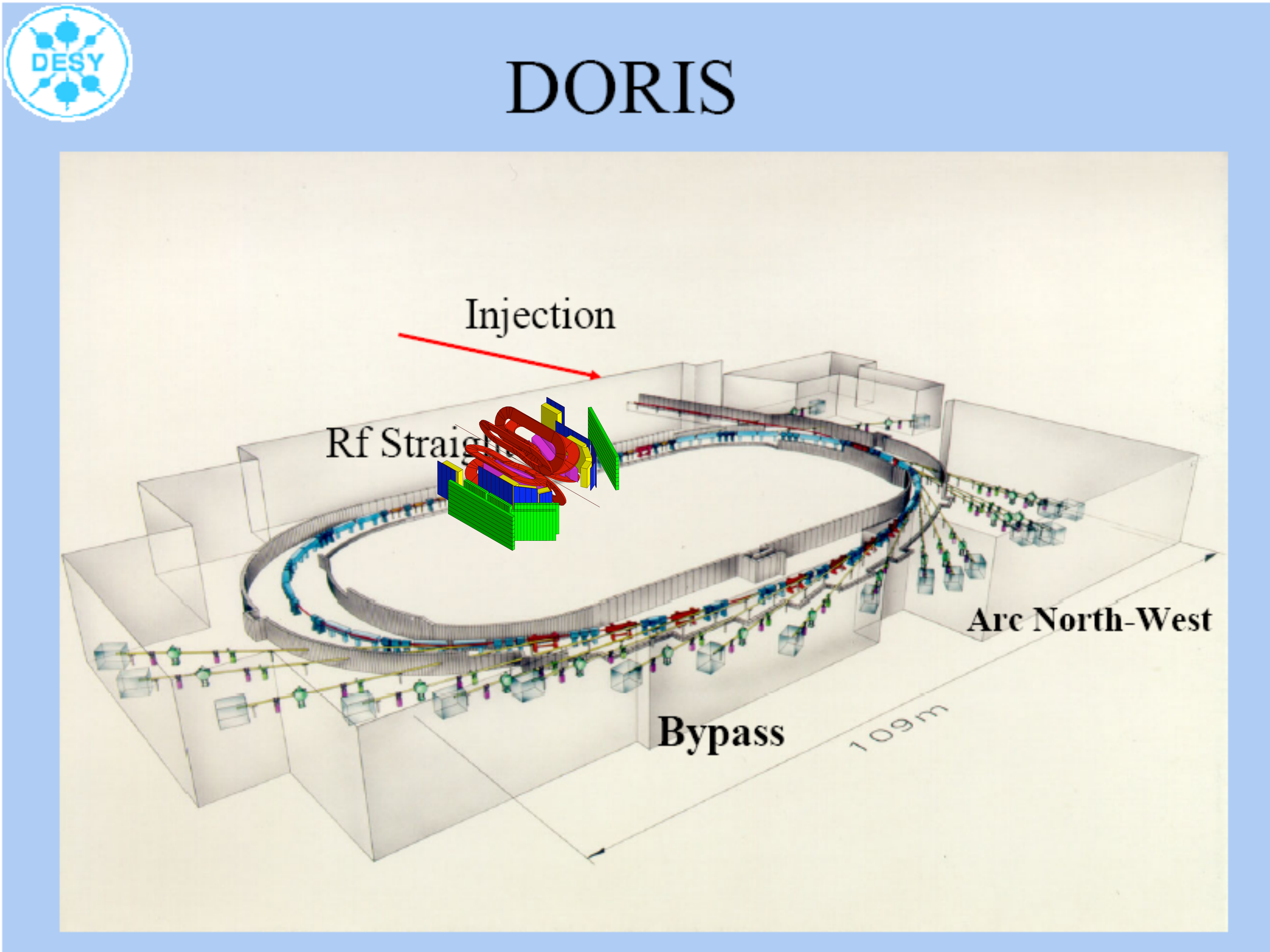
Proposed Experiment - BLAST@DORIS



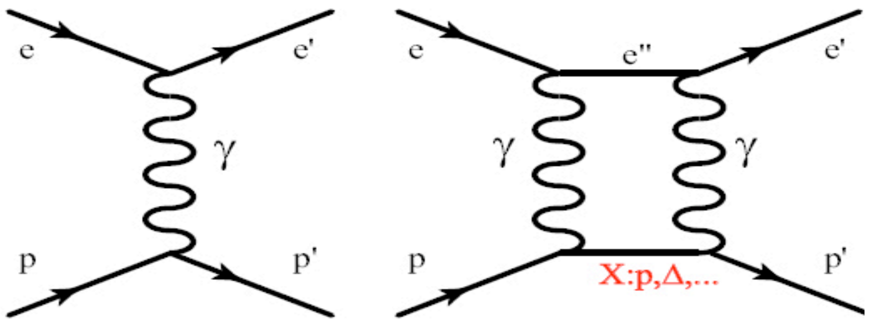
DORIS Electron/Positron Storage Ring

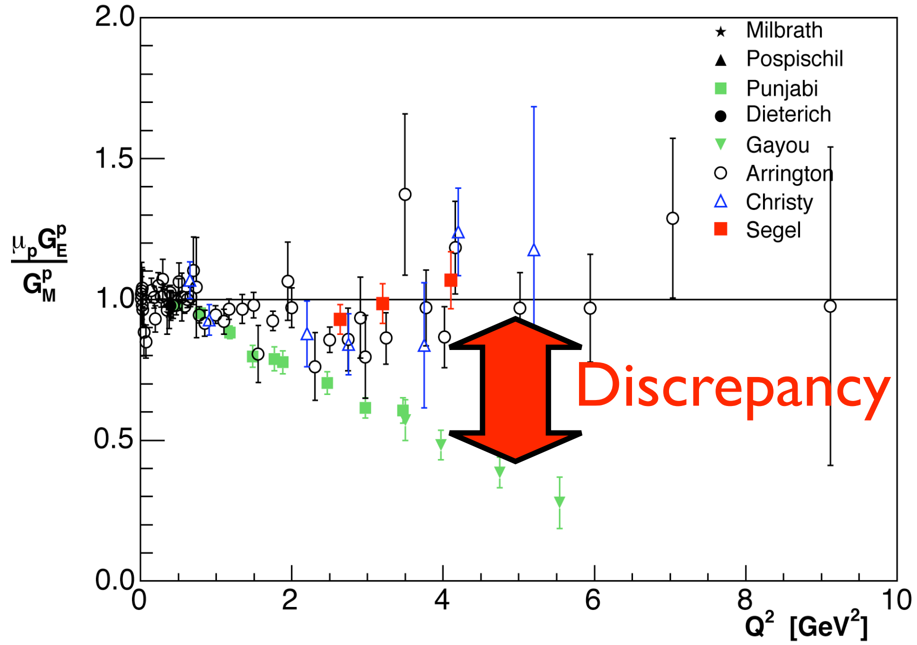


DORIS Electron/Positron Storage Ring

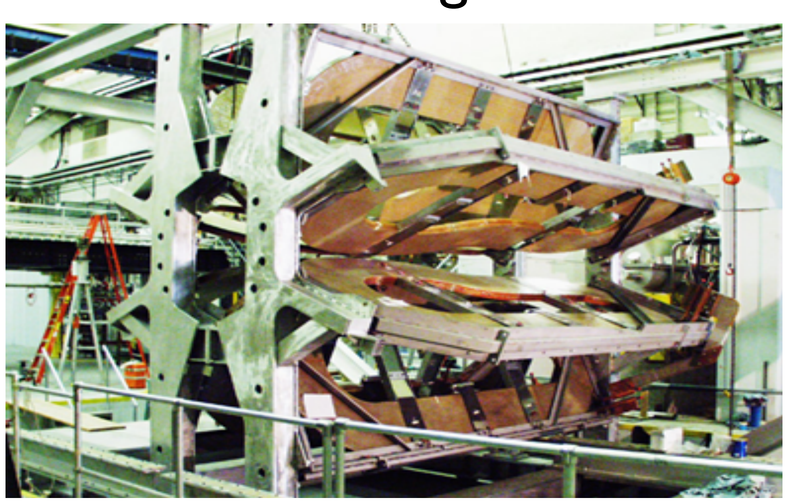


Internal Target Experiment at DORIS





Detector & Target Exist



Young-Kee Kim, on behalf of PRC

PRC64 Meeting: Findings / Recommendations

DESY Extended Scientific Council Meeting, November 19-20

- Proposal of a new experiment at DORIS using the available MIT-BLAST detector and an unpolarized hydrogen gas target.
- The goal is to determine the contribution of multiple photon exchange processes and to resolve the existing discrepancy in lepton-nucleon scattering data. Dedicated data taking for one month per year for several years would be sufficient.
- External referees to review. They strongly support the physics case. The PRC recommends DESY management discuss with the accelerator group.
- Formal proposal for fall, 2008
- Looking for collaborators !

Future for Studying Nucleon Structure

A High Luminosity Electron - Ion Collider

References / Acknowledgements

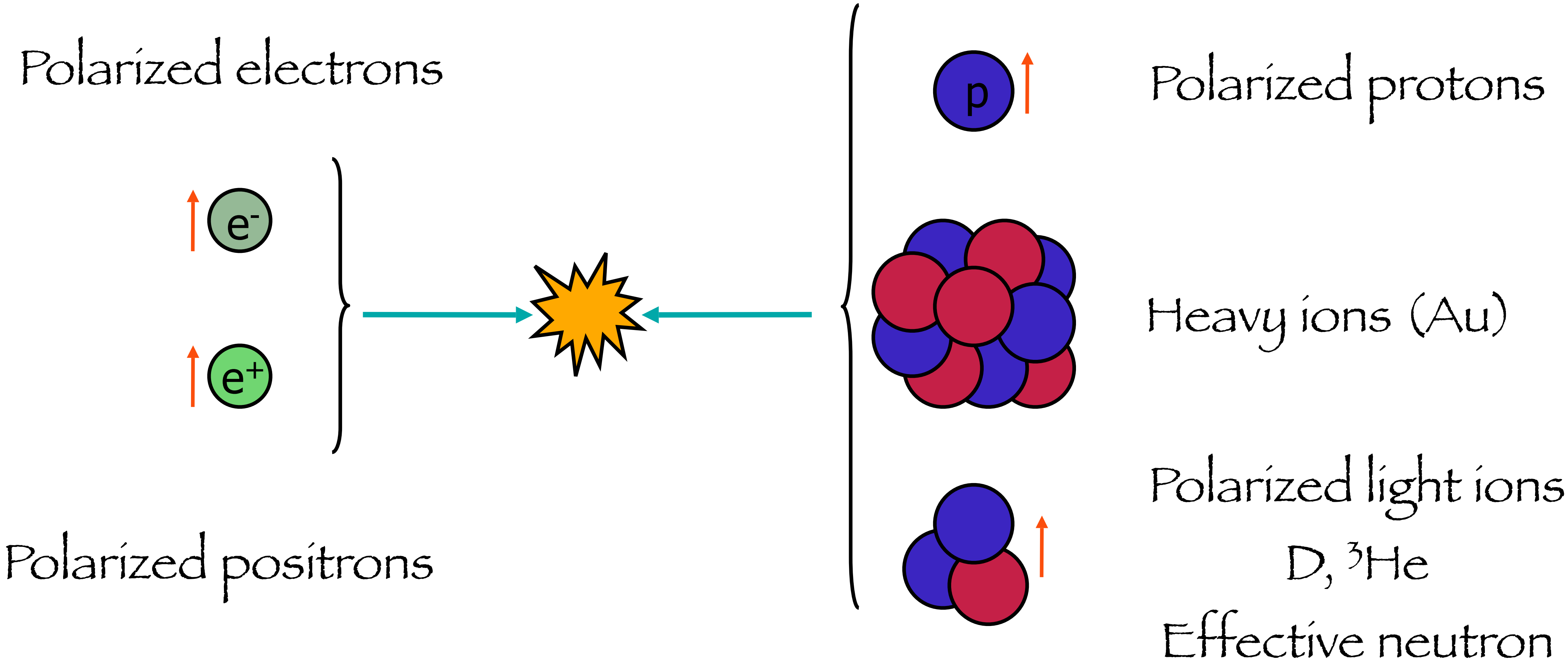
Study of the Fundamental Structure of Matter with an Electron-Ion Collider, Ann. Rev. Nucl. Part. Sci. 55 (2005) 165, A. Deshpande, R. Milner, R. Venugopalan, W. Vogelsang

eRHIC - Zeroth Order Design Report, C-A/AP/142 March, 2004, BNL, MIT-Bates, BINP, DESY

http://casa.jlab.org/research/elic/elic.shtml

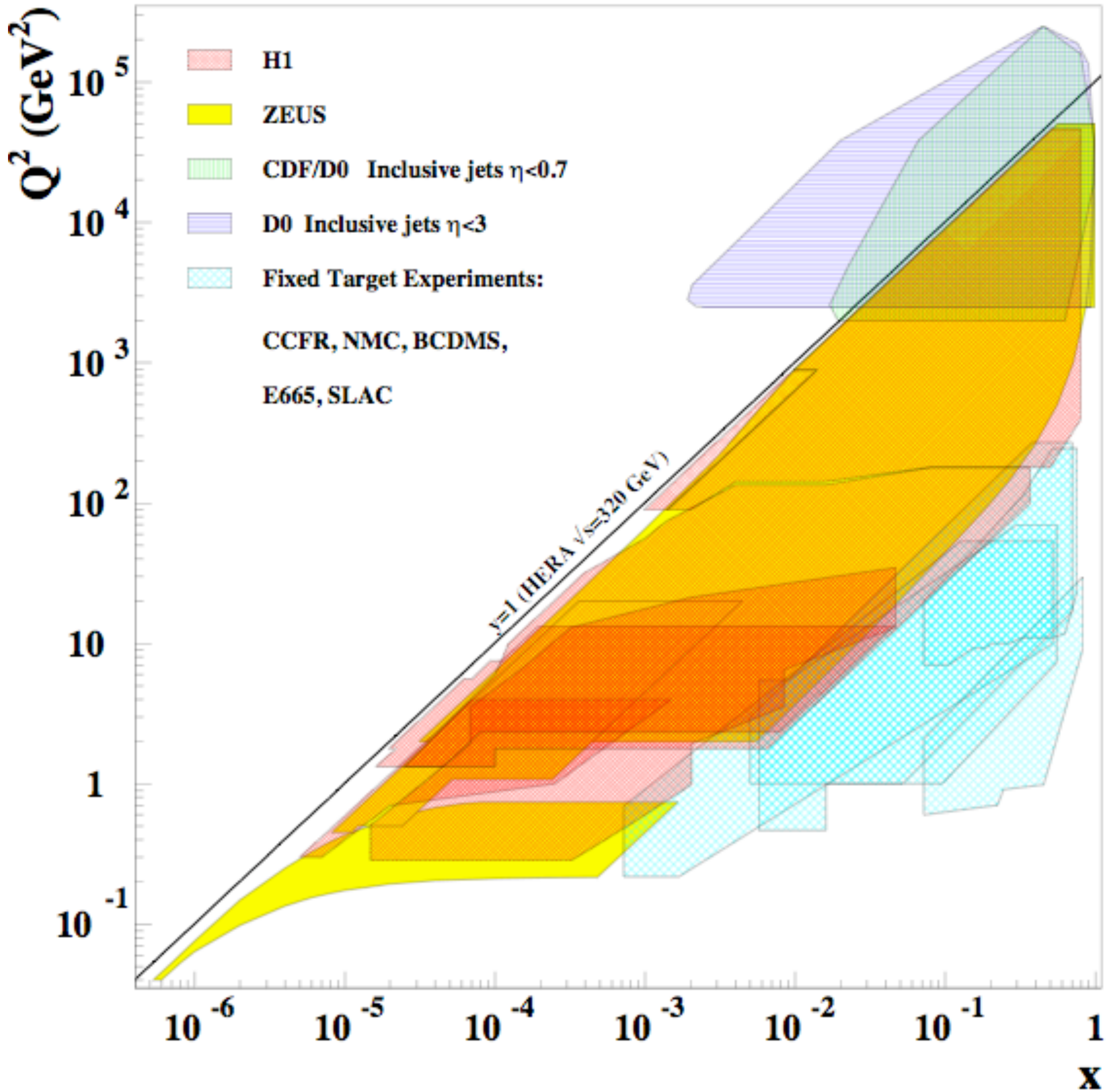
Deep Inelastic Electron-Nucleon Scattering at the LHC, DESY 06-006, J.B. Dainton, M. Klein, P. Newman, E. Perez, F. Willike

Electron-Ion Collider Concept

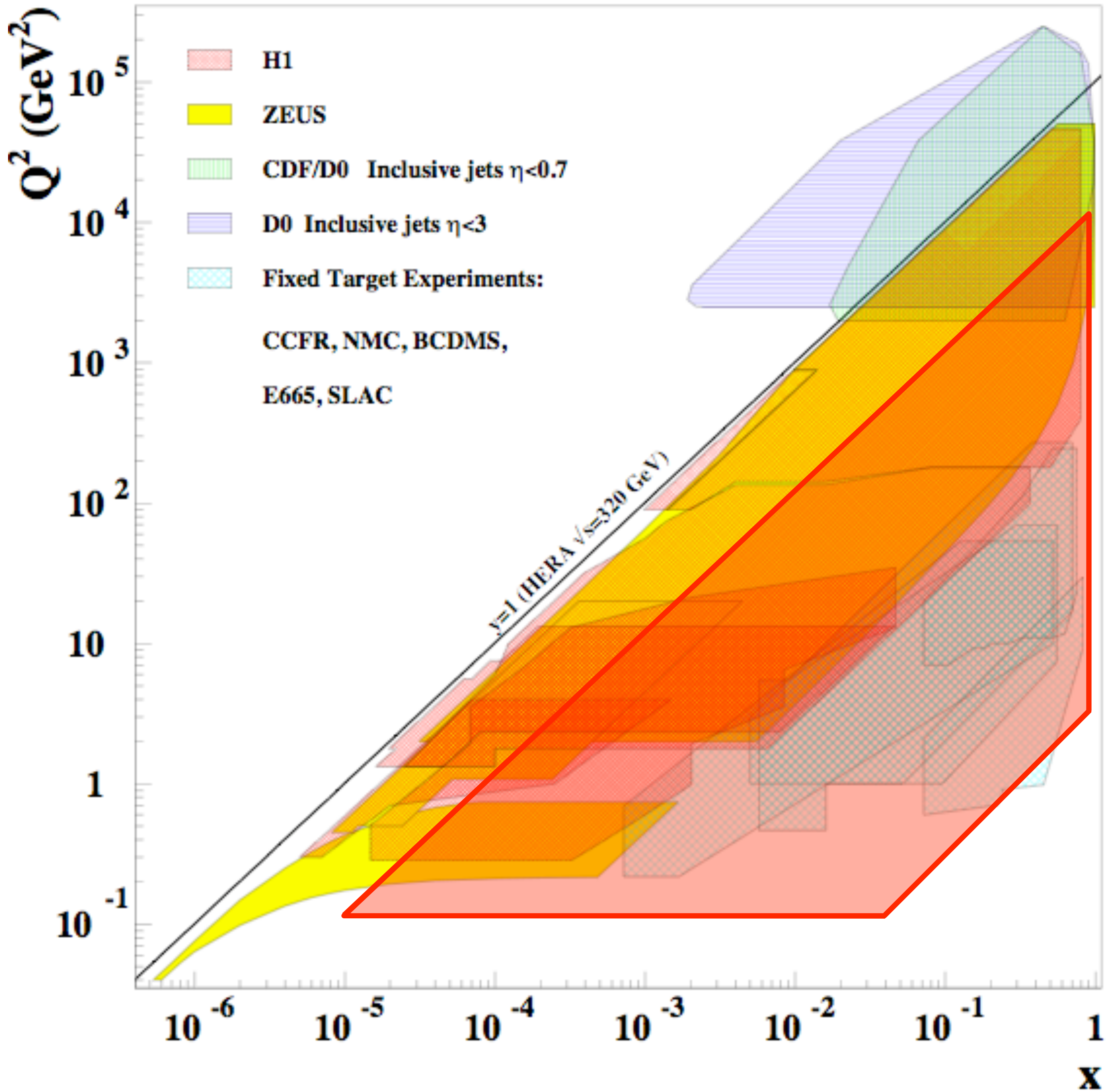


Range of centre of momentum energies

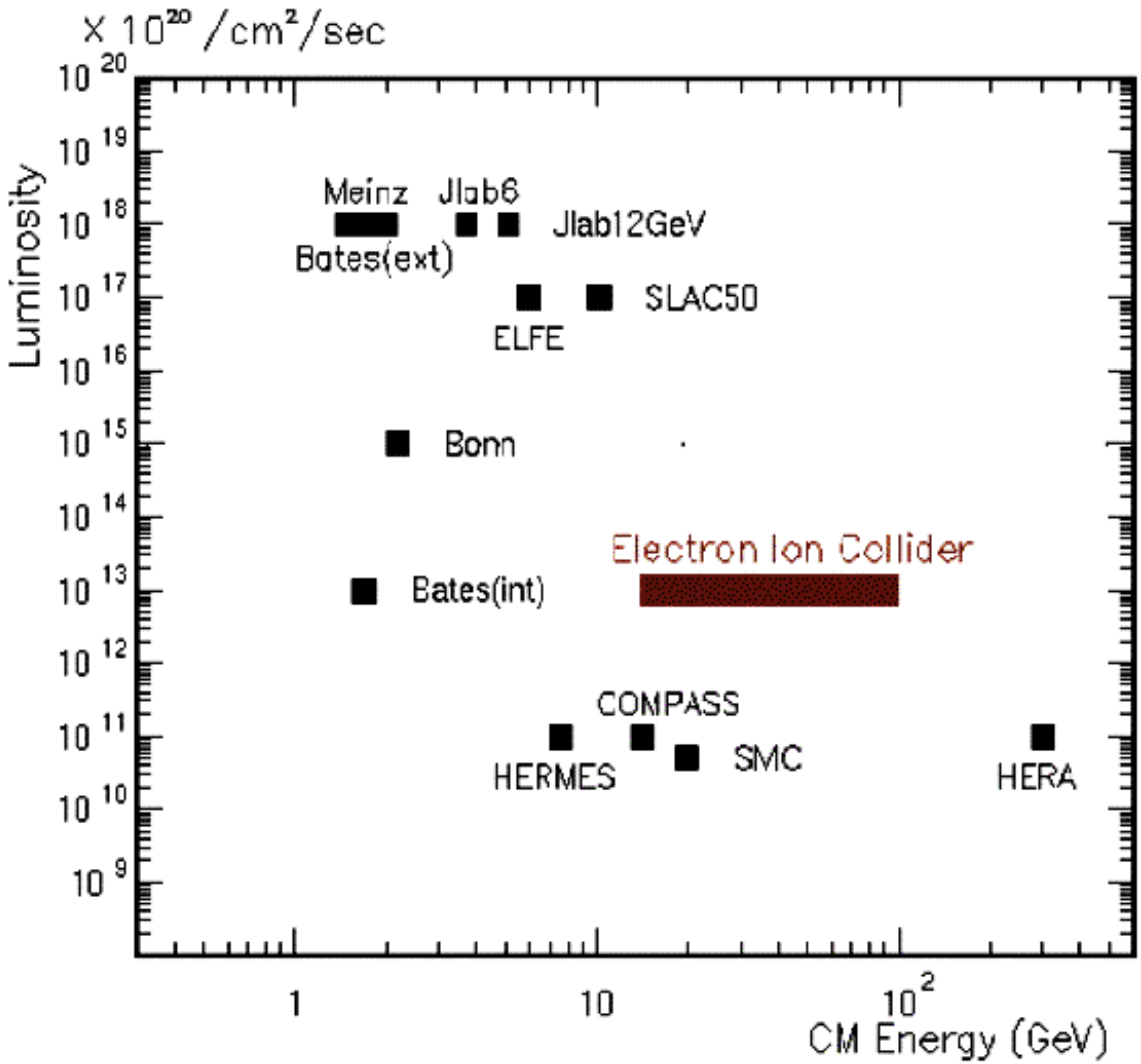
Existing Kinematics - Mostly Unpolarised



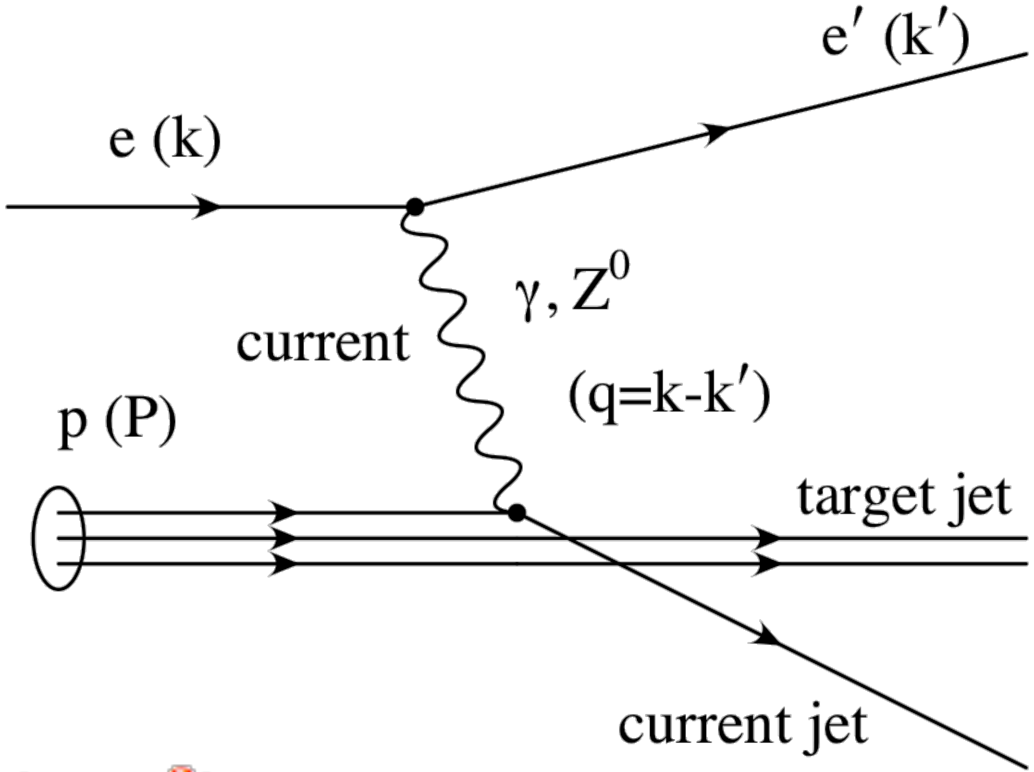
Polarized Electron - Ion Collider Coverage



Luminosity versus Q^2



Why Lepton - Ion Collider



$$\frac{d^2\sigma}{dxdy} \propto \mathcal{L}_{\mu\nu}(k,q,s)\mathcal{W}^{\mu\nu}(P,q,S)$$

$$\begin{aligned}
\mathcal{W}^{\mu\nu}(P,q,S) \quad = \quad & -g^{\mu\nu}F_1(x,Q^2) + \frac{P^\mu P^\nu}{Pq}F_2(x,Q^2) \\
& -\imath\epsilon^{\mu\nu\rho\sigma}\frac{q_\rho P_\sigma}{2Pq}F_3(x,Q^2) \\
& +\imath\epsilon^{\mu\nu\rho\sigma}q_\rho\left[\frac{S_\sigma}{Pq}g_1(x,Q^2) + \frac{S_\sigma(Pq) - P_\sigma(Sq)}{(Pq)^2}g_2(x,Q^2)\right] \\
& + \left[\frac{P^\mu S^\nu + S^\mu P^\nu}{2Pq} - \frac{Sq}{(Pq)^2}P^\mu P^\nu\right]g_3(x,Q^2) \\
& + \frac{Sq}{(Pq)^2}P^\mu P^\nu g_4(x,Q^2) - \frac{Sq}{Pq}g^{\mu\nu}g_5(x,Q^2)
\end{aligned}$$

Unpolarized DIS at EIC

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha_{em}^2}{Q^4}\left[\left(1+(1-y)^2\right)F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

$$F_2(x,Q^2) = \sum_q e_q^2\left(xq(x,Q^2) + x\bar{q}(x,Q^2)\right)$$

Measurements will add to F_2 data set

Variable CM energy allows measure of longitudinal structure function F_L

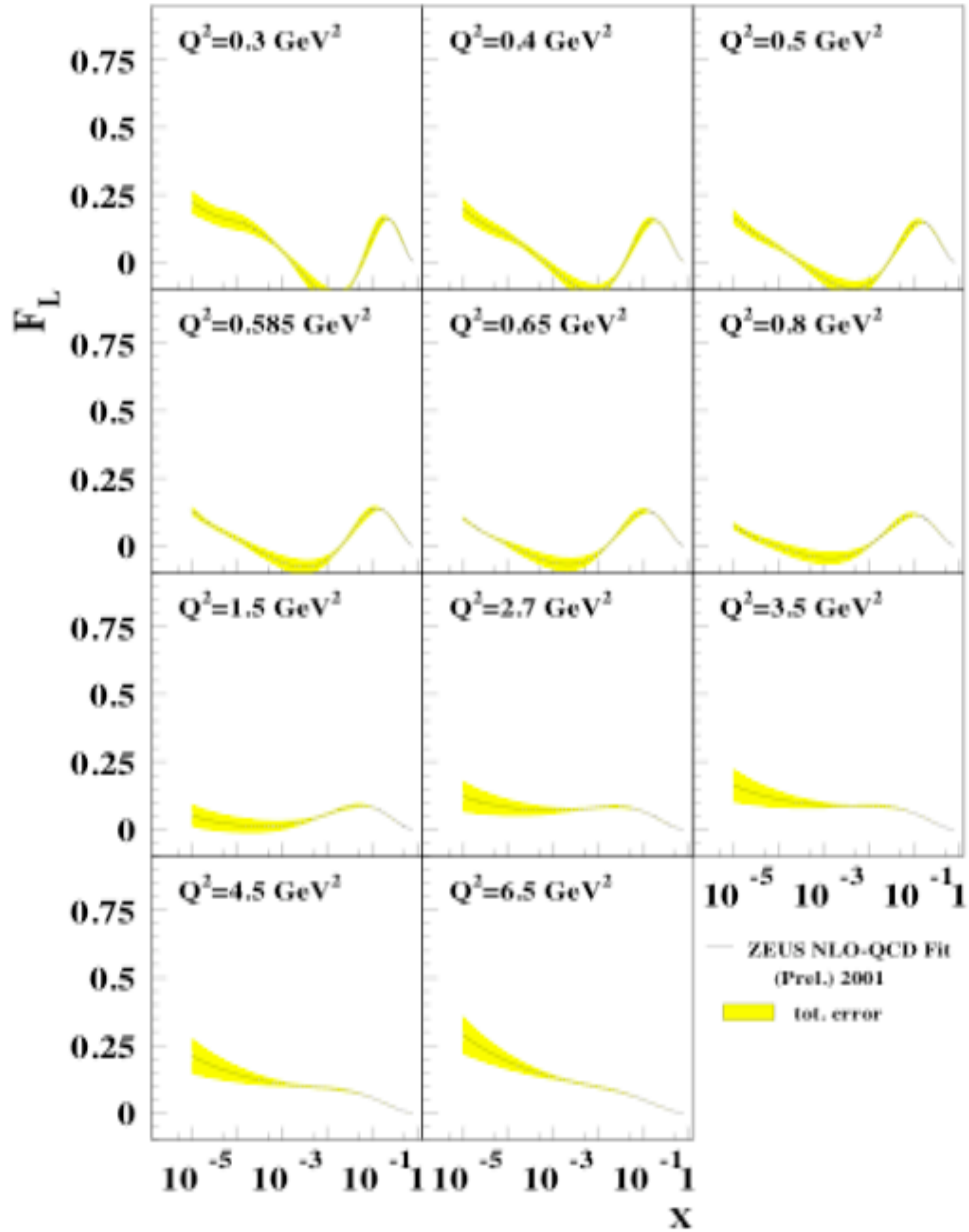
$$F_L = F_2 - 2xF_1$$

Can be determined from scaling violations

$$F_L \propto \alpha_S x G(x,Q^2)$$

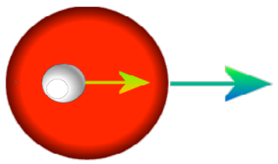
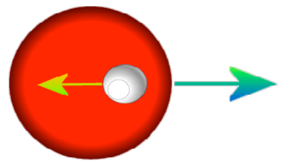
Negative gluon distributions at low Q^2

Possible direct measurement at EIC by varying centre of momentum energy

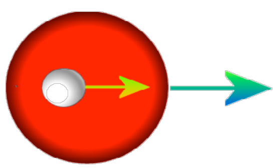
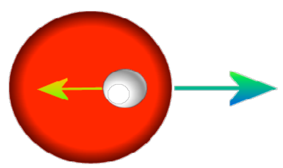


Spin Structure of Nucleons

$$F_1(x) = \frac{1}{2}\sum_q e_q^2\,(q(x) + \bar{q}(x))$$

$q(x) \approx$  + 

$$g_1(x) = \frac{1}{2}\sum_q e_q^2\,(\Delta q(x) + \Delta\bar{q}(x))$$

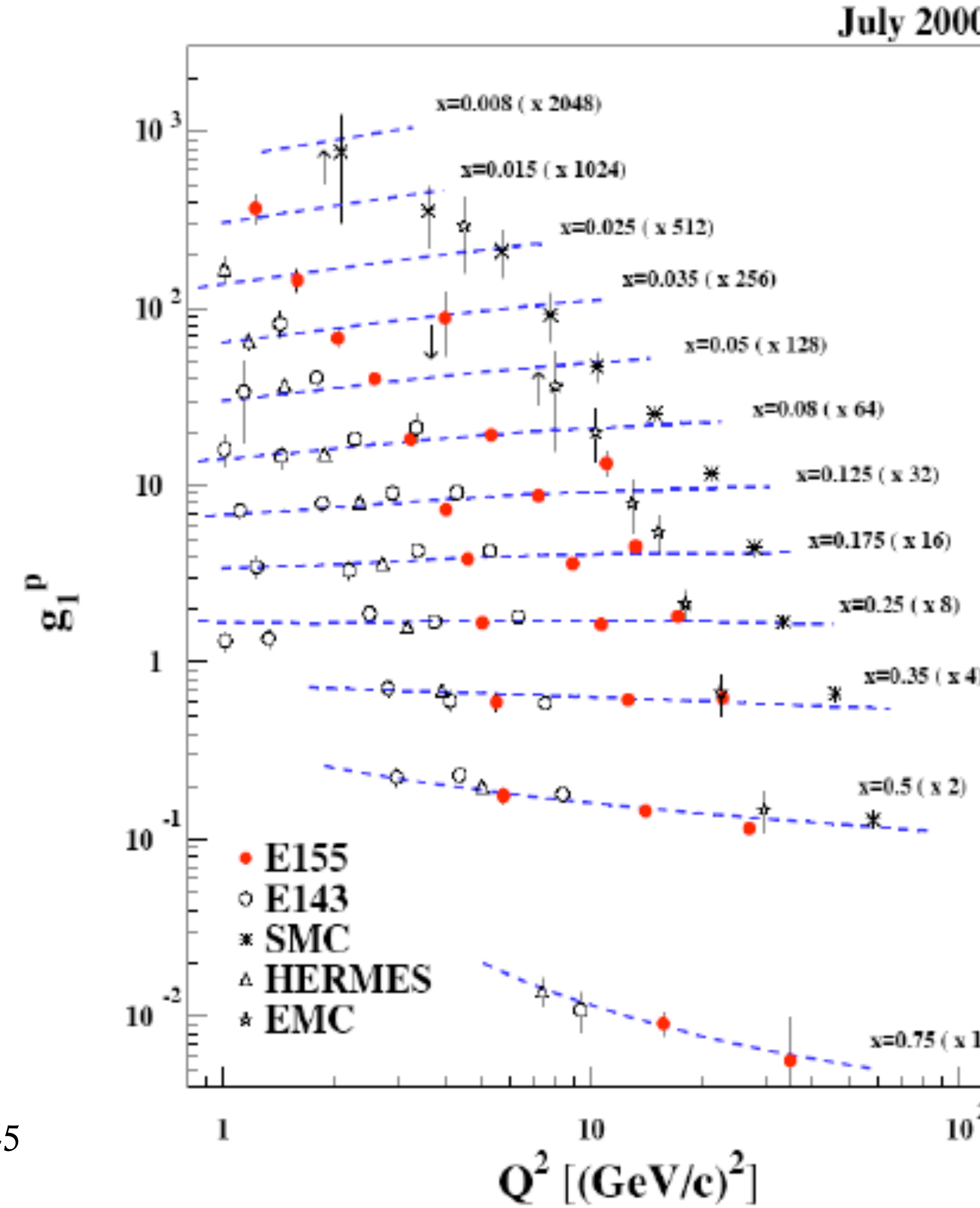
$\Delta q(x) \approx$  – 

Analogous to unpolarised DIS

QCD predicts evolution

Able to extract polarised parton densities including gluon

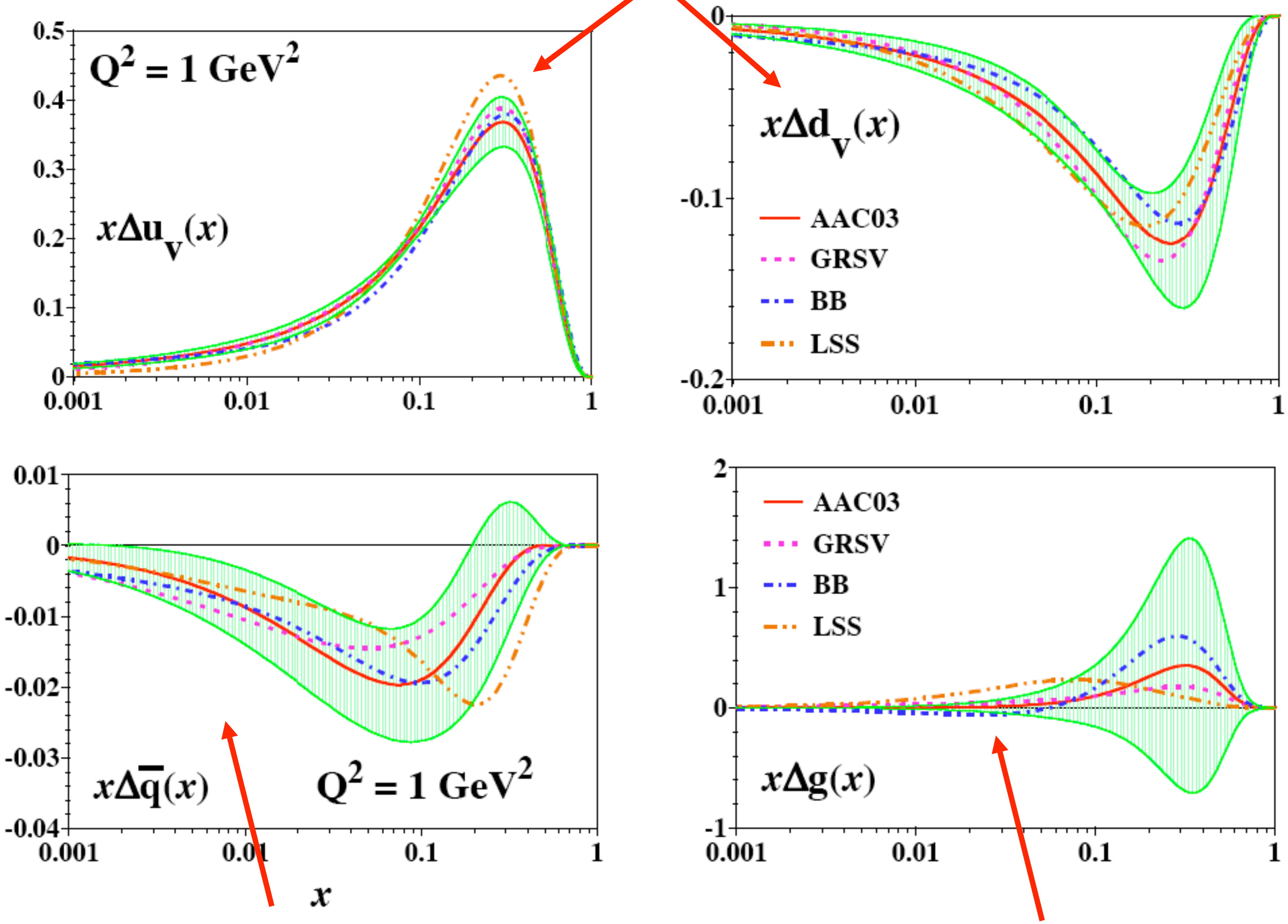
EIC will extend range $Q^2 \rightarrow 3000$, $x \rightarrow 5\text{x}10^{-5}$



Parton Spin Distributions

Hirai, Kumano, Saito

Valence distributions q-$\bar{q}$



Limited information on sea

Weak constraints from scaling violation

Valence quark spin distributions reasonably well known

Need sea and gluon data

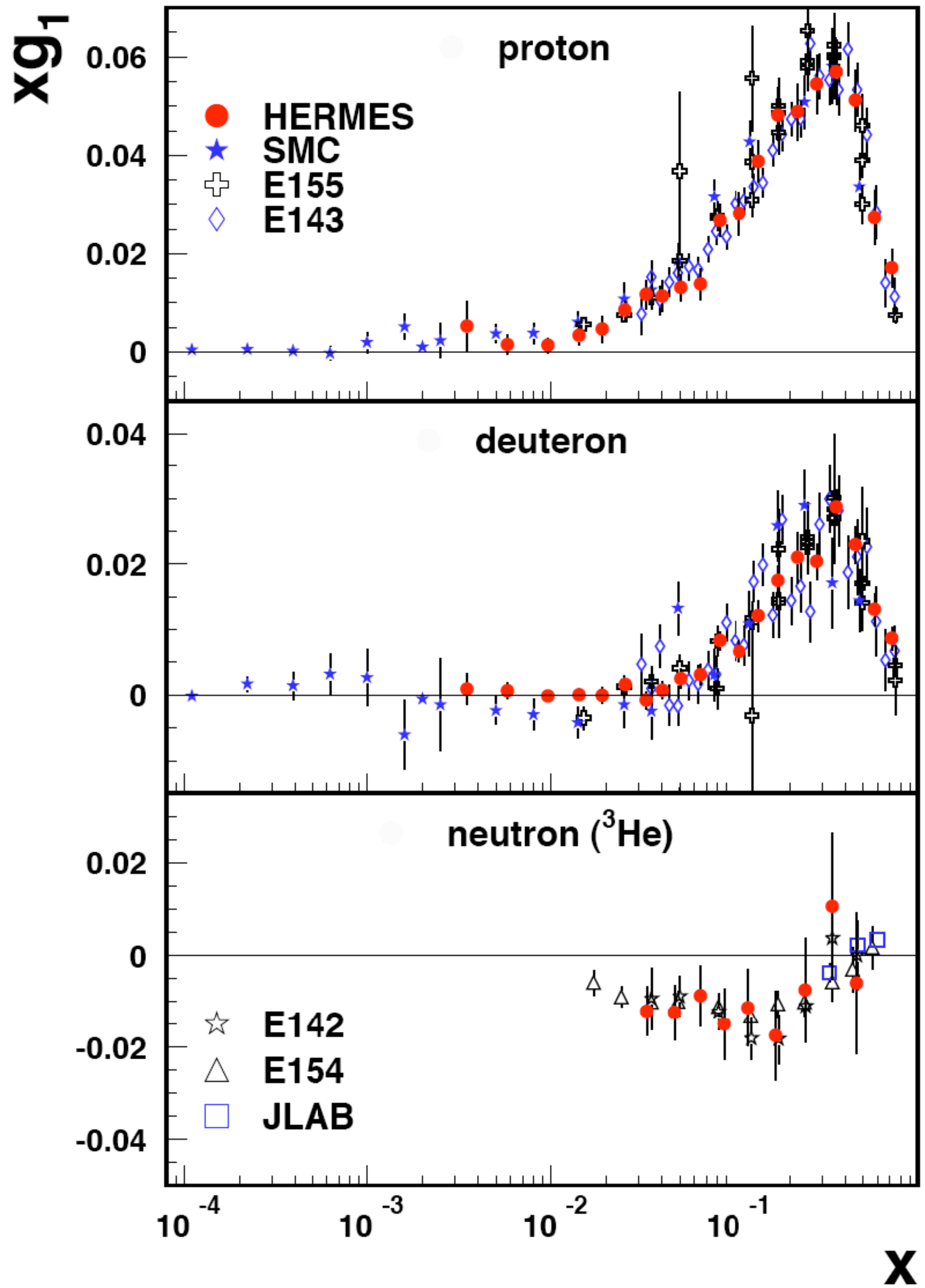
Results limited by range of Q^2

EIC extend range

$5 \times 10^{-5} < x < 0.7$

$0.5 < Q^2 < 3000$

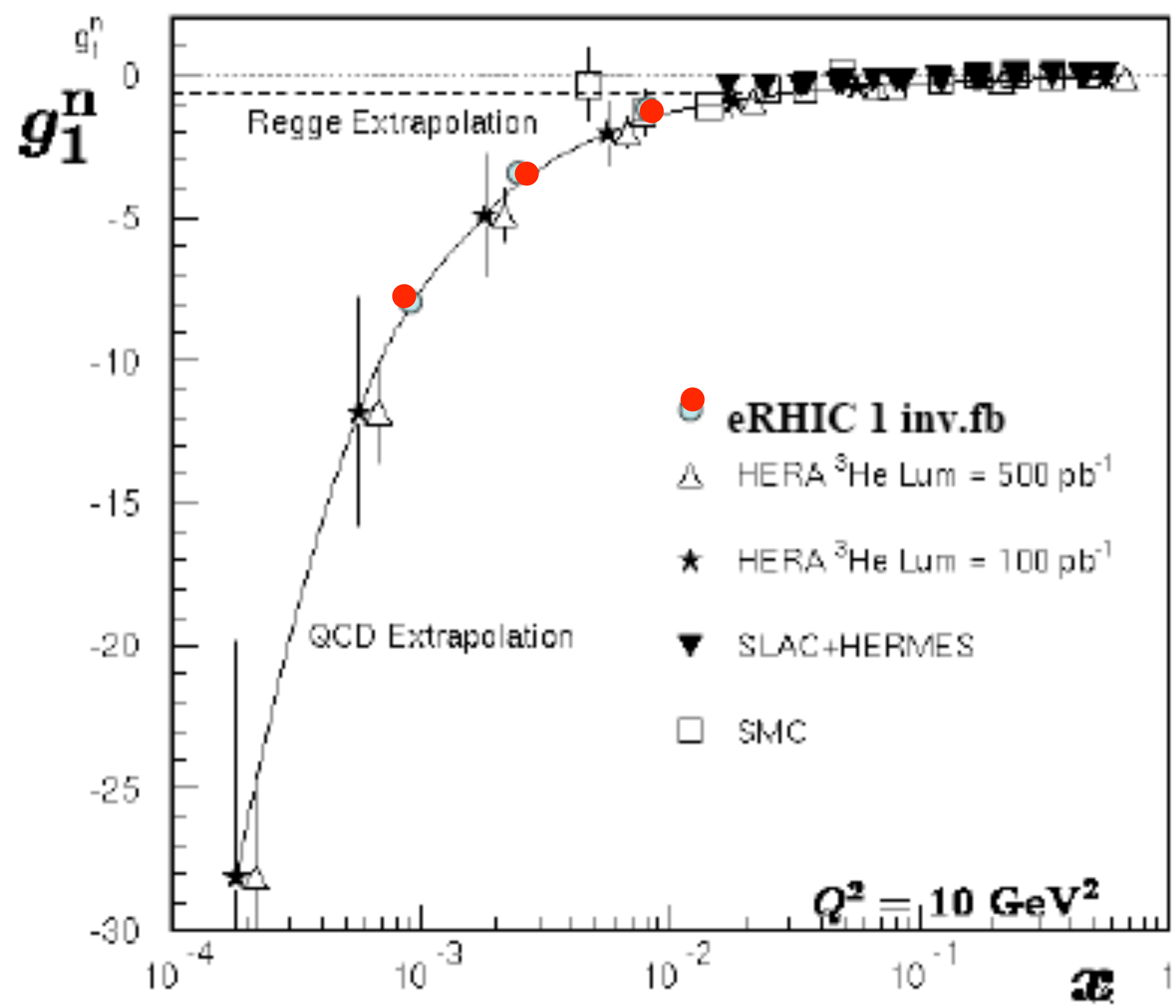
p, n, d Spin Structure Functions



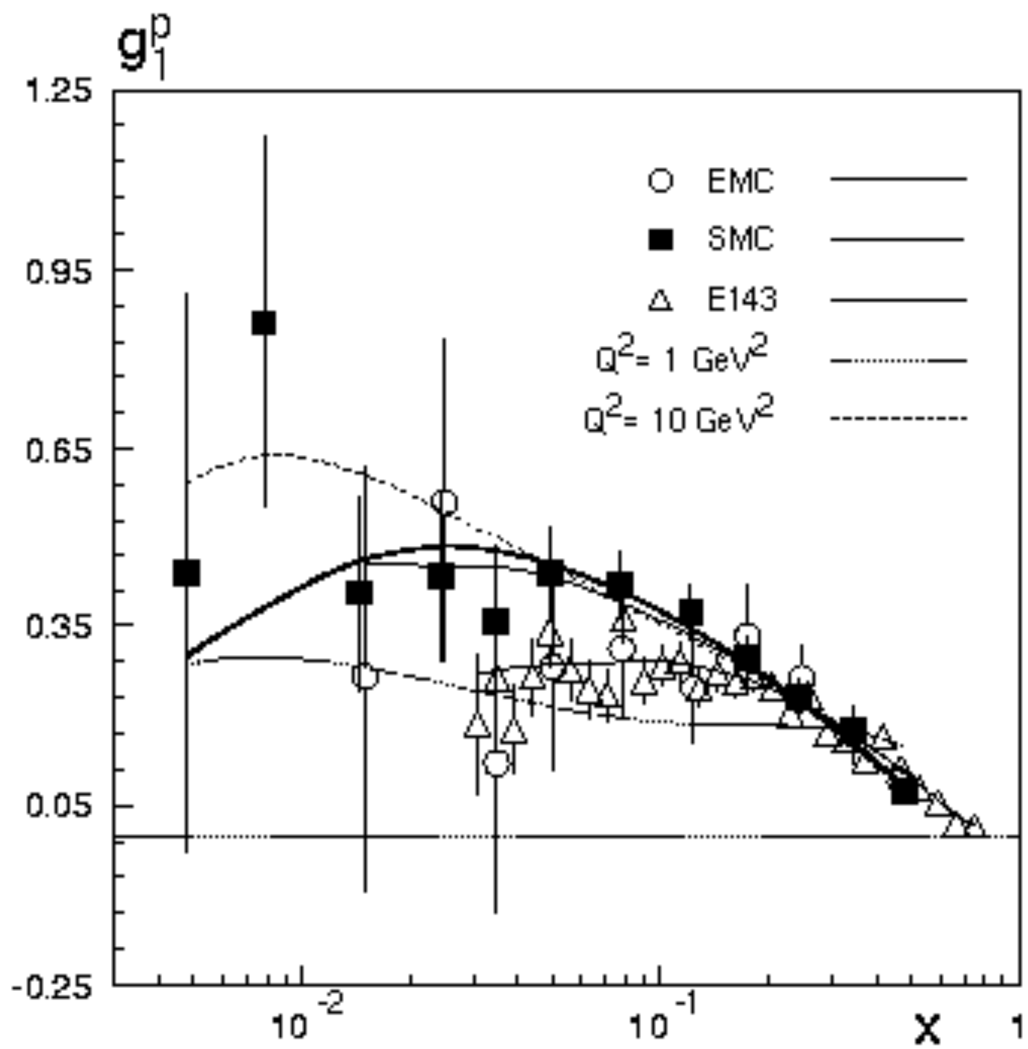
Available data limited in range, Q^2

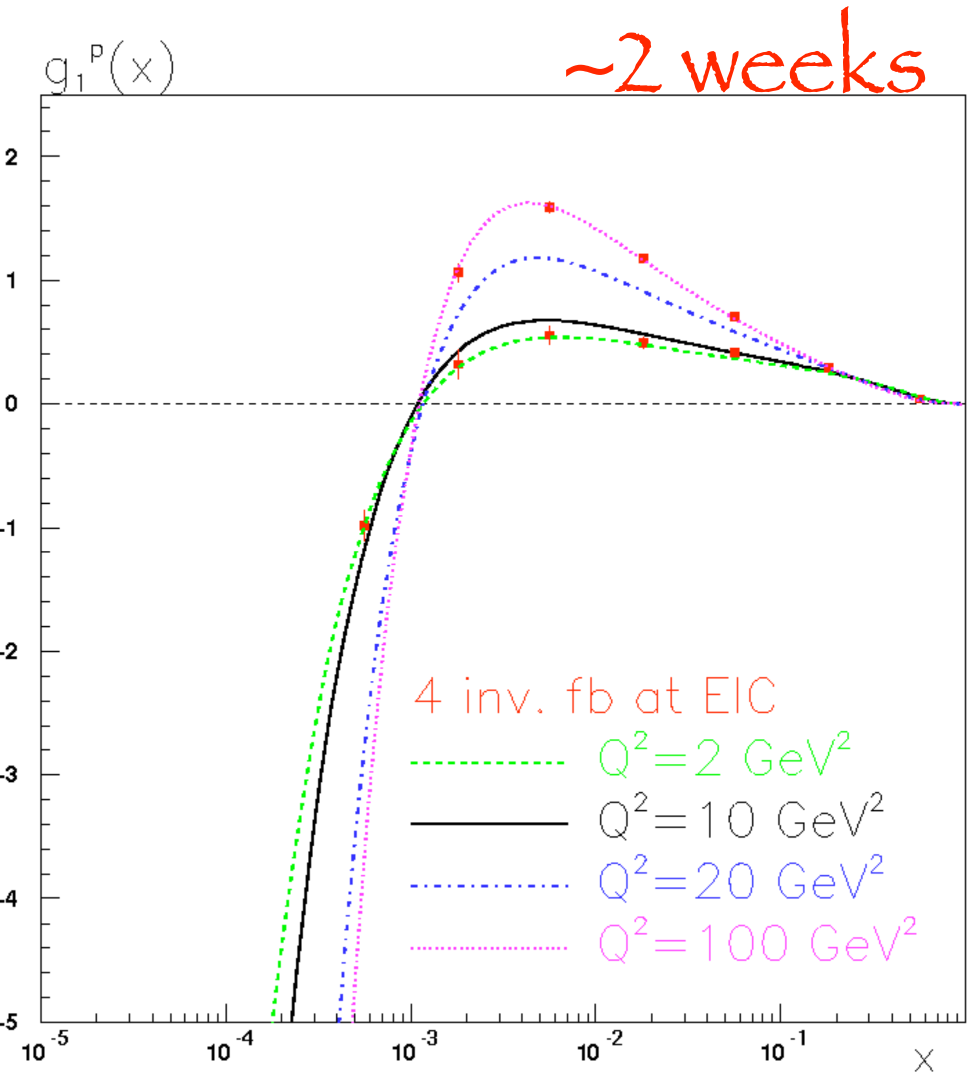
Particularly g^n

At EIC - p, d, ^{3}He
After just ~2 weeks at 10^{33} cm^{-2}s^{-1}



Spin Structure Function g_1^p at Low x





Bjorken sum rule

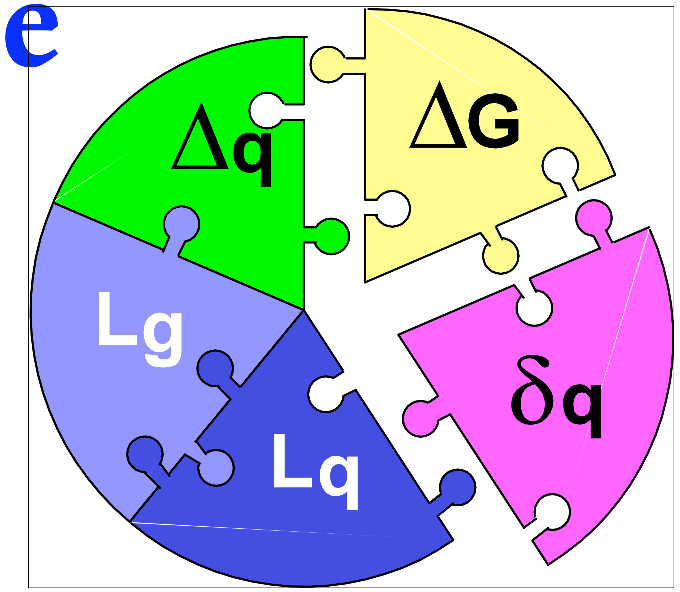
$$\int_0^1 dx(g_1^p - g_1^n) = \frac{1}{6}g_A[1 + O(\alpha_S)]$$

Currently known to ~10%

EIC would verify to ~1%

Improved measure of α_s

Nucleon Spin Puzzle



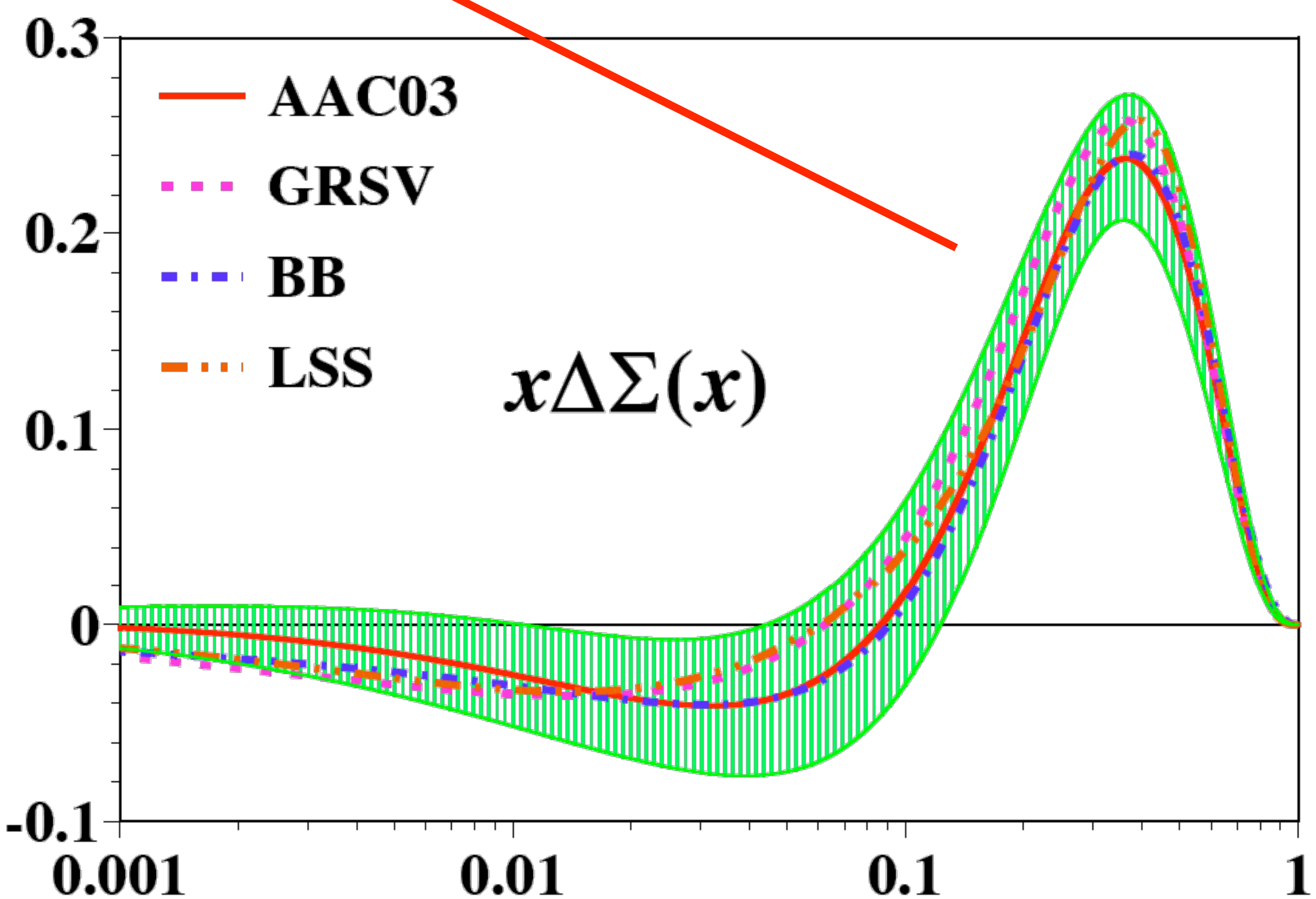
Nucleon spin = $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$

Quark contribution

$$\Delta\Sigma = \int_0^1 dx(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})$$

$\Delta\Sigma \approx 0.2$

Hirai, Kumano, Saito



Gluon contribution

$$\Delta G = \int_0^1 dx \Delta g(x)$$

$\Delta g(x) =$

Currently

$1.0 \pm 1.0(\text{stat}) \pm 0.4(\text{sys}) \pm 1.4(\text{th})$

Many experiments underway on ΔG

COMPASS, STAR

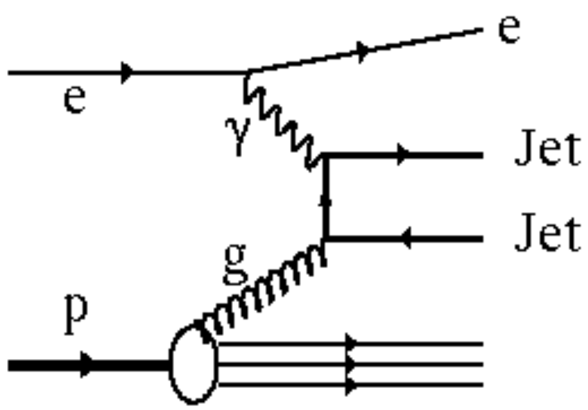
ΔG at EIC

Best determination from scaling violations of $g_1(x,Q^2)$

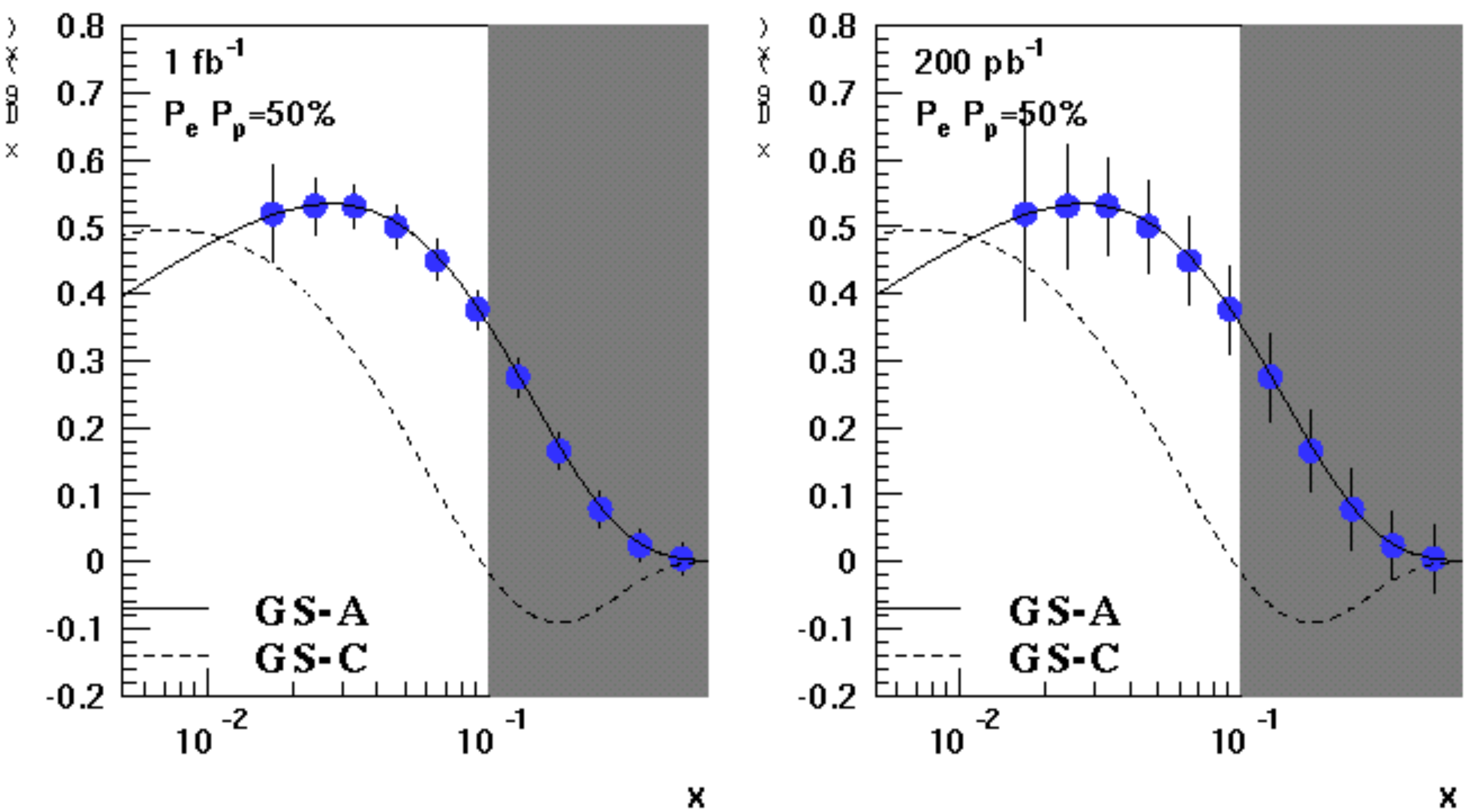
- EIC will extend range in x and Q^2
- improve existing measurement factor of 3 in 1 week

Direct measure via photon-gluon fusion

- di-jets, high P_T hadrons
- Successfully used at HERA
- NLO calculations exist
- Constrains shape in mid x region



A.De Roeck, A.Deshpande, V. Hughes, J. Lichtenstadt, G. Radel



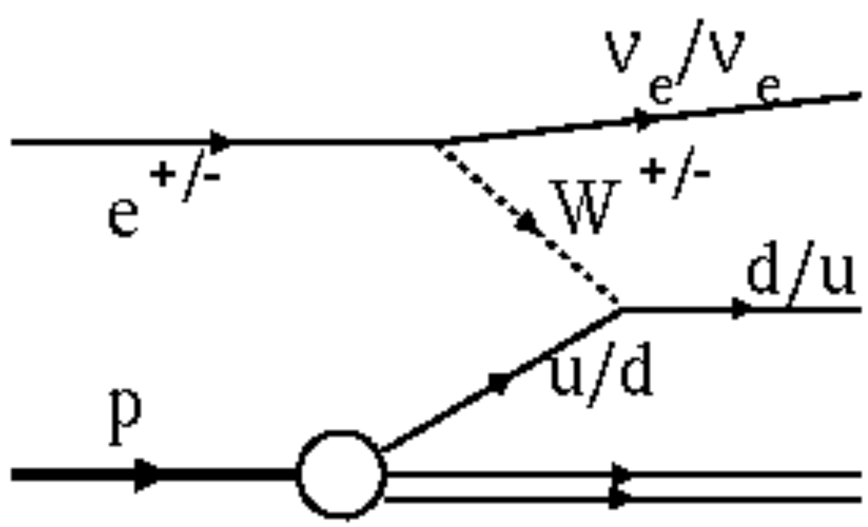
1 fb^{-1} in 2 week at EIC

Scaling violation data plus di-jet analysis will yield total uncertainty 5-10% after 1 year

Parity Violating Structure Function g_5

Use asymmetry between electrons and positrons in CC reactions

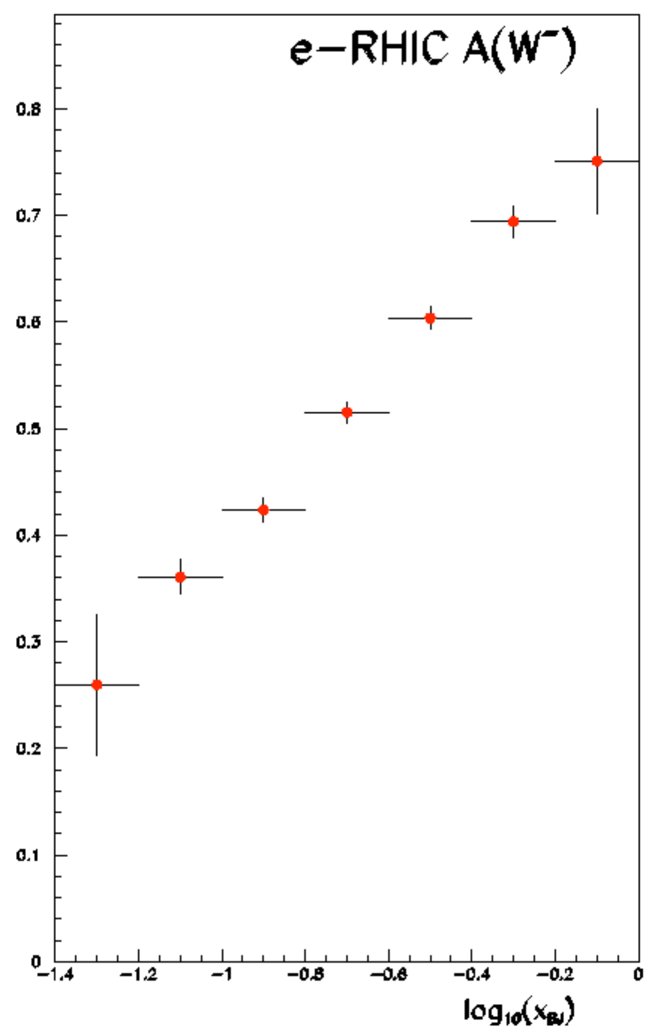
J. Contreras, A. De Roeck

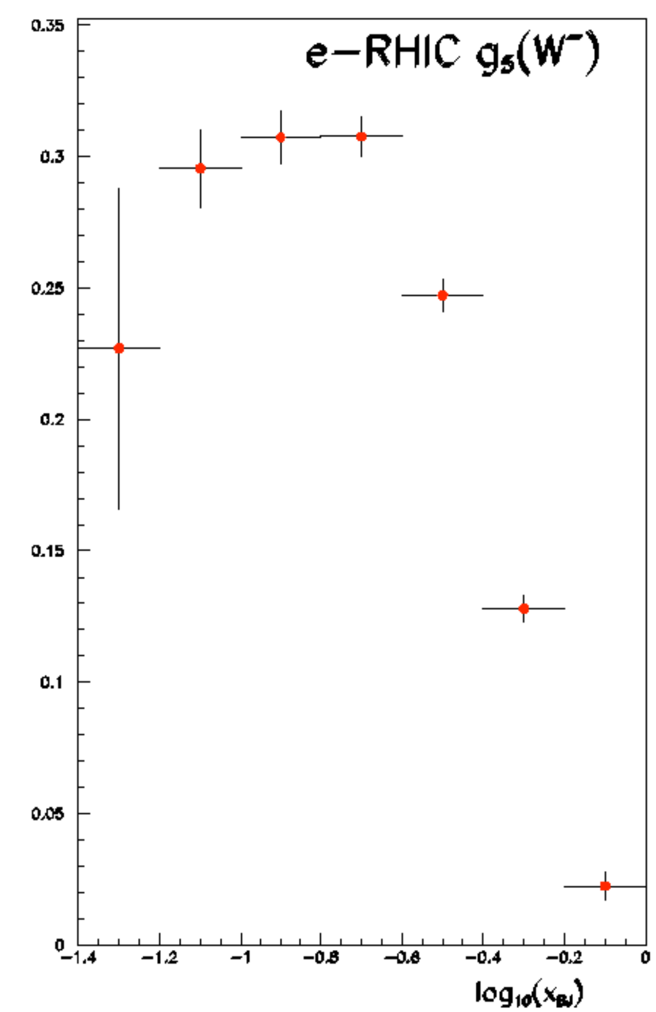


$$A^{W^+} = \frac{-2bg_1 + ag_5}{aF_1 - bF_3}$$

Extract g_5

$$A^{W^-} = \frac{2bg_1 + ag_5}{aF_1 + bF_3}$$





Unique measurement at EIC

eRHIC

C-A/AP/142
March 2004

eRHIC

Zeroth-Order Design Report

BNL
L. Ahrens, D. Anderson, M. Bai, J. Beebe-Wang, I. Ben-Zvi, M. Blaskiewicz, J.M. Brennan,
R. Calaga, X. Chang, E.D. Courant, A. Deshpande, A. Fedotov, W. Fischer,
H. Hahn, J. Kewisch, V. Litvinenko, W.W. MacKay, C. Montag,
S. Ozaki, B. Parker, S. Peggs, T. Roser, A. Ruggiero,
B. Surrow, S. Tepikian, D. Trbojevic,
V. Yakimenko, S.Y. Zhang

MIT-Bates
W. Franklin, W. Graves, R. Milner, C. Tschalaer, J. van der Laan,
D. Wang, F. Wang, A. Zolfaghari and T. Zwart

BINP
A.V. Otboev, Yu.M. Shatunov

DESY
D.P. Barber

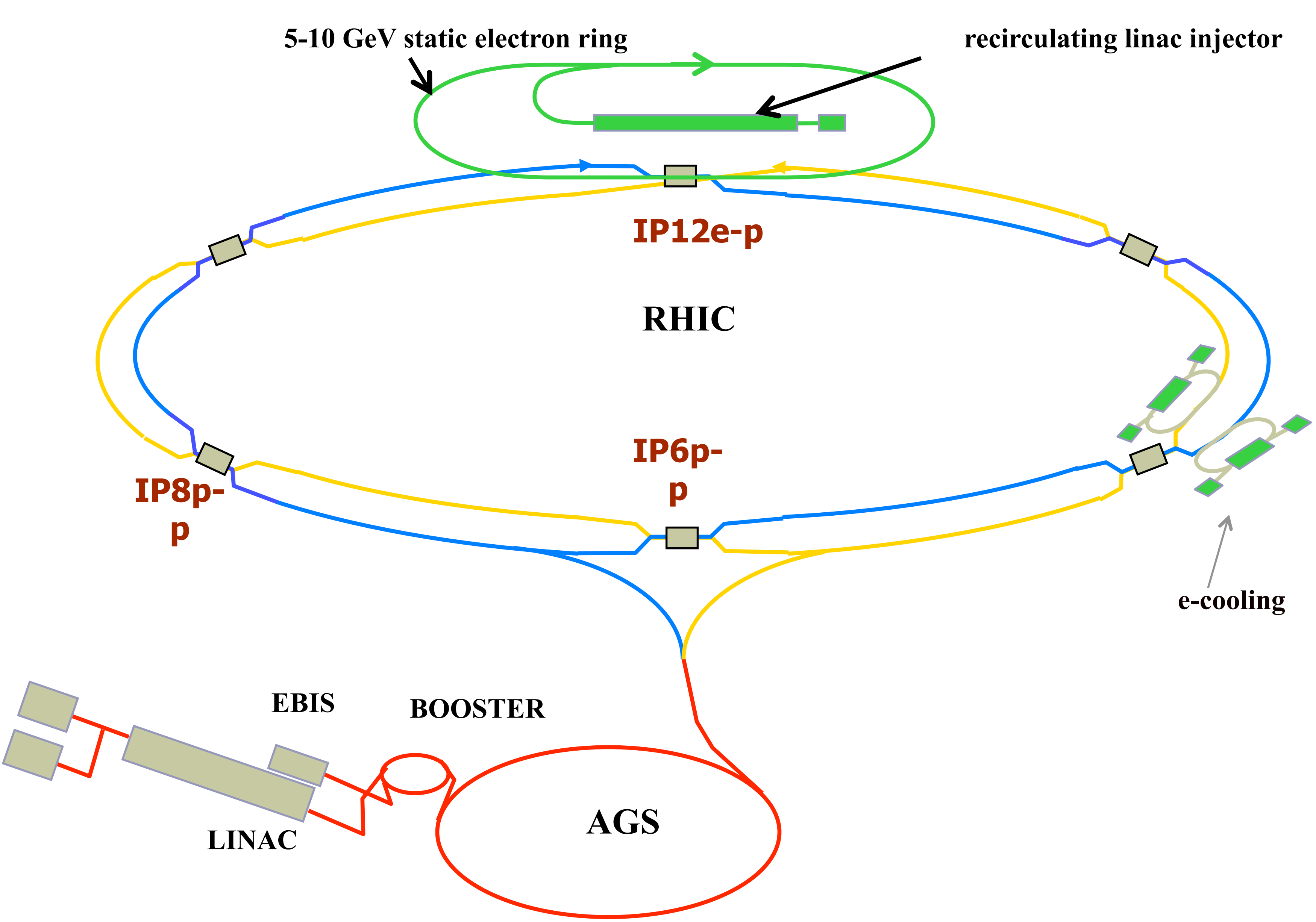
Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

Detailed design report on accelerators and interaction region for both
Ring-ring
Linac-ring

Joint effort by BNL, MIT-Bates, Novosibirsk, and DESY

www.agsrhichome.bnl.gov/eRHIC/eRHIC_ZDR.htm

eRHIC - Ring-Ring Design



Linac injects into electron storage ring at full energy
2-10 GeV
0.5 A

RHIC can run in parallel

Polarized electrons and positrons

Similar to PEP II
Same components ?

Single interaction point

Requires spin rotators

±3 m IP to nearest magnet

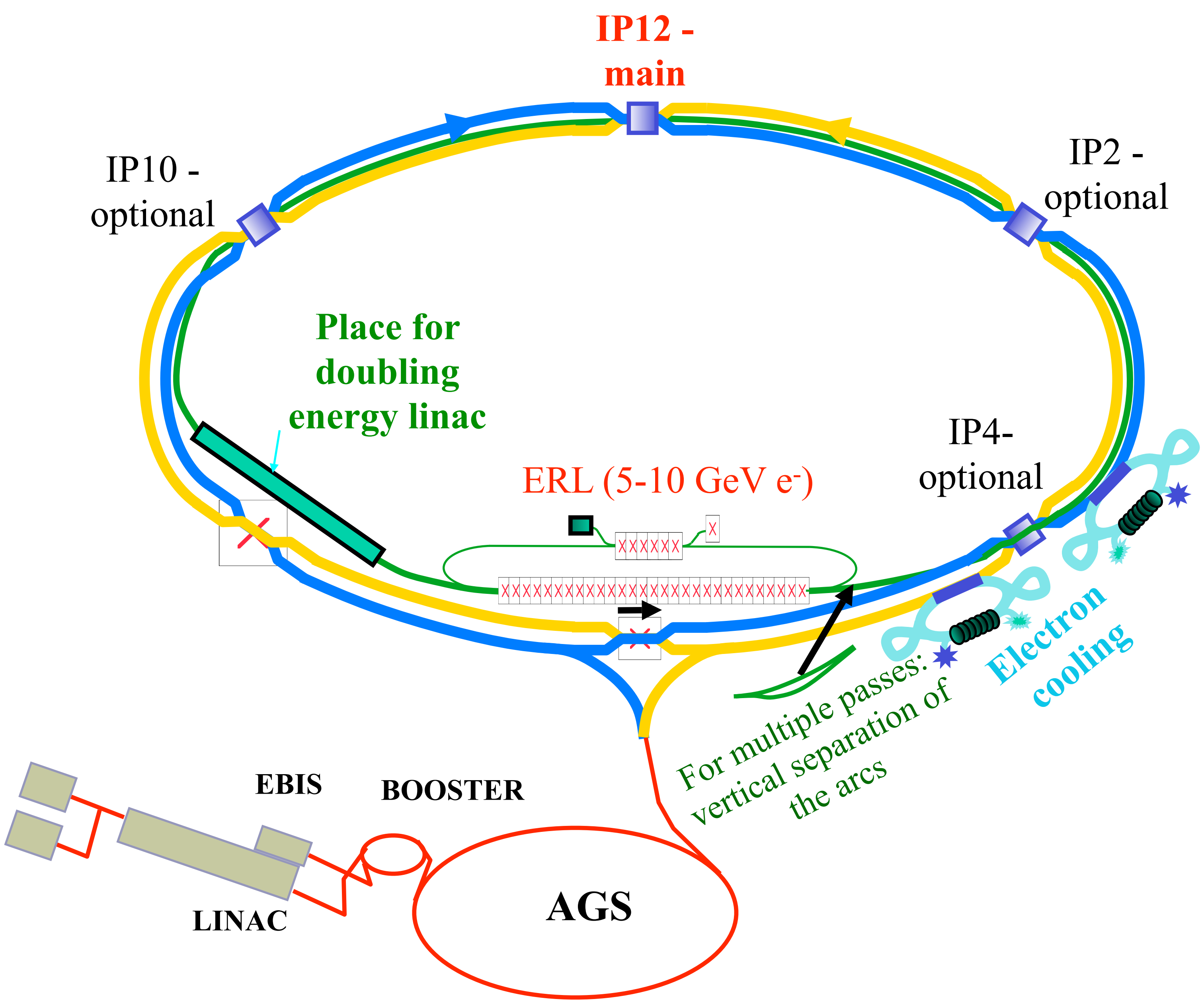
Luminosity limited by beam-beam tune shifts

High luminosity requires cooling

and

increase of 120 ⇒ 360 bunches

eRHIC - Linac-Ring Design



Superconducting, energy recovery linac feeds directly into IP

Possible multiple IP's

Rapid reversal of polarisation

No depolarizing energy regions

Spin rotators not needed

±5 m IP to nearest magnet

No positrons

Luminosity not limited by beam-beam interaction

But need high intensity ion source

kW IR laser ERL-FEL (significant R&D)

eRHIC - Linac-Ring Design

Superconducting, energy recovery linac feeds directly into IP

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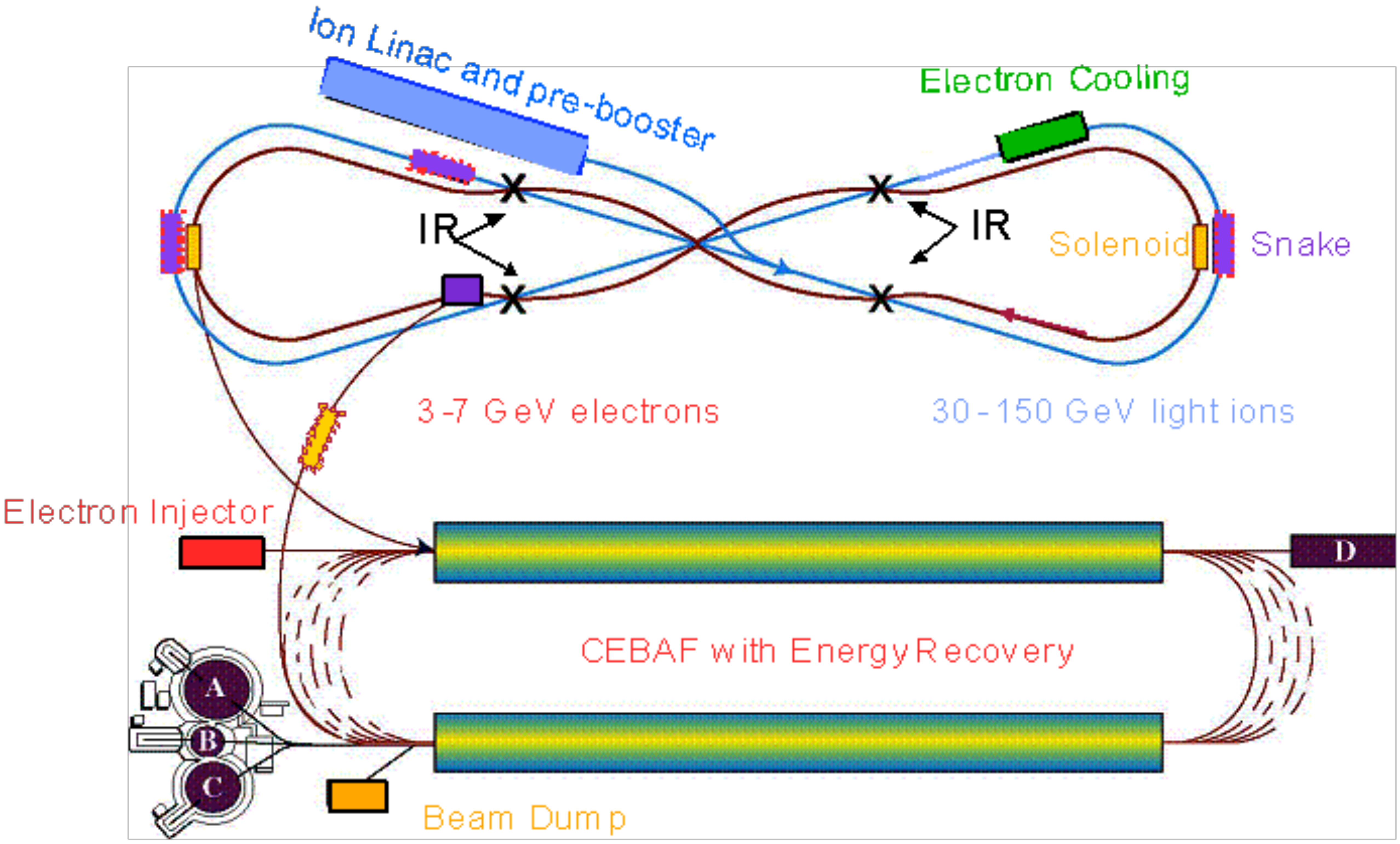
kW IR laser ERL-FEL (significant R&D)

ELIC

http://casa.jlab.org/research/elic/elic.shtml



LHeC

DESY 06-006
Cockcroft-06-05

Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology, Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA/Spp, Gif-sur-Yvette, France

Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\text{cm}^{-2}\text{s}^{-1}$, and high energy, $\sqrt{s} = 1.4$ TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond $10^6\,\text{GeV}^2$ and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

*Contributed to the Open Symposium on European Strategy for Particle Physics Research, LAL Orsay, France, January 30th to February 1st, 2006.

70 GeV electron/positron ring on top of LHC ring

Assumes nominal LHC parameters

Possible multiple IP's

74 mA electron current

25 ns bunch spacing

10^{33} cm^{-2}s^{-1} luminosity

Conclusion

BLAST provides new precision data on nucleon form factors, deuteron structure, and other data to constrain nuclear models.

We hope to study two photon effect with BLAST@DORIS.

Unpolarised DIS region has been well explored at HERA

More spin dependent data is needed to understand the nucleon structure, mass, spin, etc.

A new, polarised electron-ion collider can best address these issues in an efficient, comprehensive manner.