At TRIUMF: a Great Start

Willem T.H. van Oers

TRIUMF

Angela Bracco

1979: at the University of Manitoba
Ph.D. thesis work at TRIUMF

1983 : Ph.D. thesis entitled “Quasi-Free Scattering of Protons from 3He at Intermediate Energies”

“Felix, qui potuit rerum cognoscere causas”


EXIT
DIGITAL
PDP-5

Quasi-Free Scattering 3He(p,2p)pn, 3He(p,2p)d, 3He(p,pd)p

A.Bracco, Phys. Rev. Lett. 50, 1741 (1983)
M. B. Epstein, Phys. Rev. C32, 967 (1985)

Quasi-Free Scattering 2H(p,2p)n

V. Punjabi et al. Phys. Rev. C38, 2728 (1988)
M.B. Epstein et al. Phys. Rev. C42, 510 (1990)

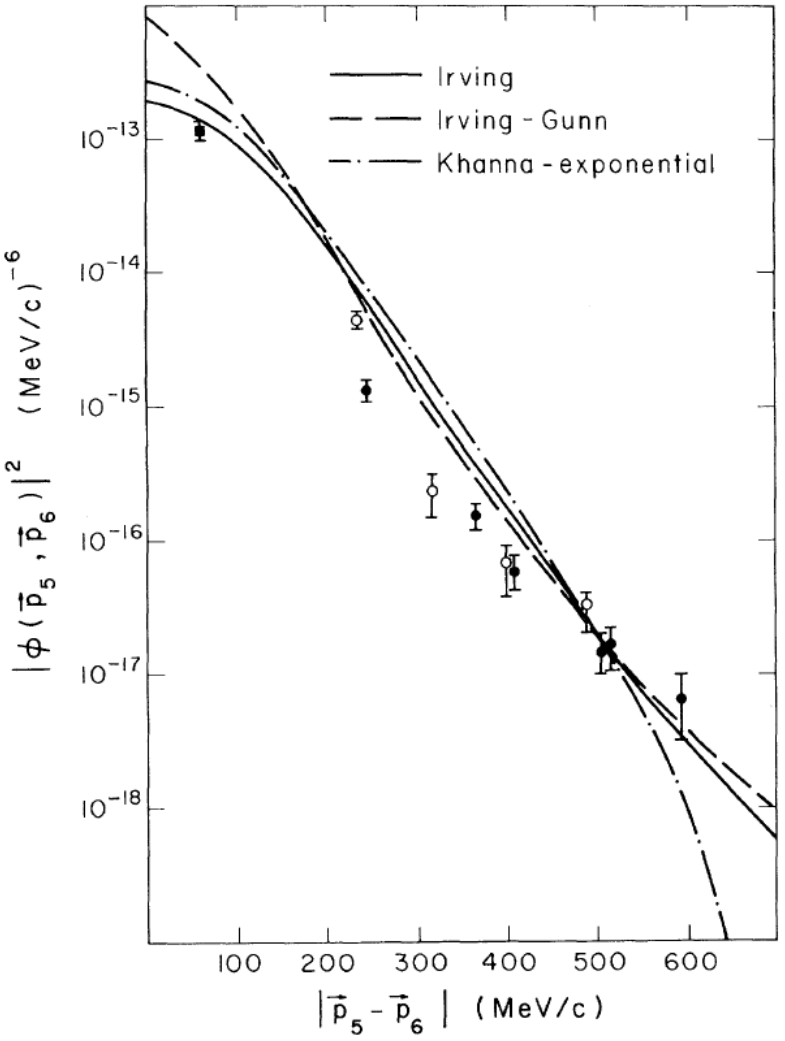


FIG. 1. Differential cross sections $d^6\sigma/d\Omega_3\, dT_3\, d\Omega_4\, dT_4$ divided by the factor $F(d\sigma/d\Omega)_{1/2}{}^{p-p} N$ as a function of the relative momentum of the unobserved p–n pair. The 250-MeV results are presented as open circles, while the 400-MeV results are presented as filled circles. The 155-MeV datum of Frascaria *et al.* is presented as a filled square. The solid, dashed, and dot-dashed curves correpond to p–n relative-motion momentum distributions as indicated.

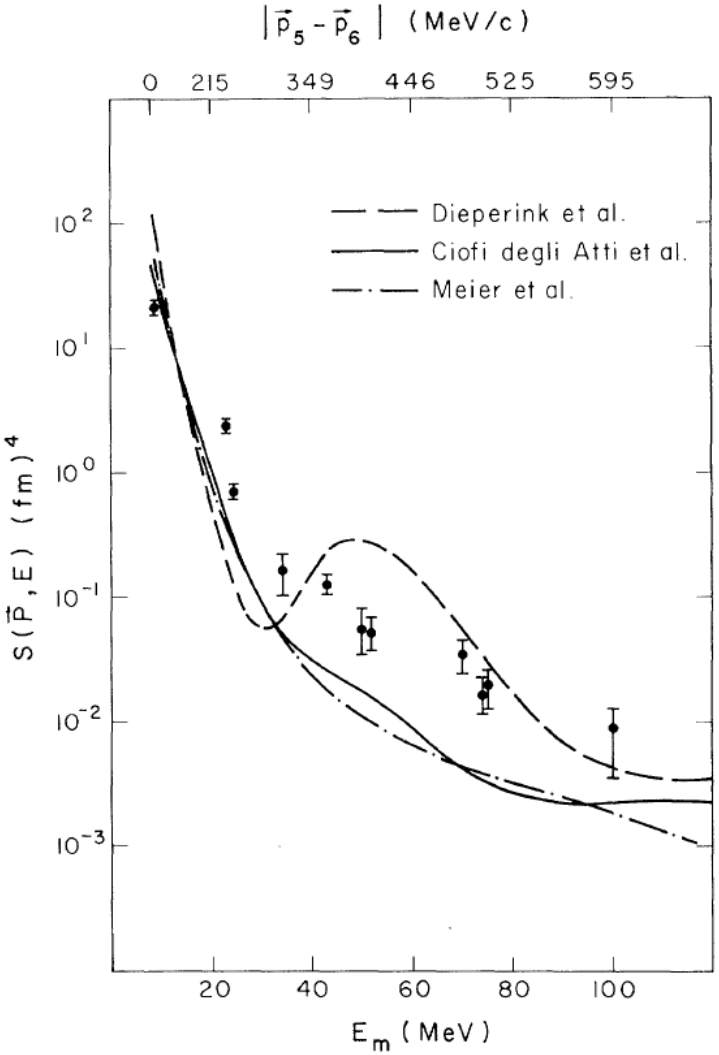


FIG. 2. Differential cross sections $d^6\sigma/d\Omega_3\, dT_3\, d\Omega_4 dT_4$ divided by the factor $F'(d\sigma/d\Omega)_{1/2}{}^{p-p}$ as a function of the relative momentum of the unobserved p–n pair and the missing energy E_m. The quantity $E_m = E - m_2 + m_4 = E_x - Q$, with E_x the excitation energy of the p–n pair and Q the reaction Q value. The calculated spectral functions are as indicated.

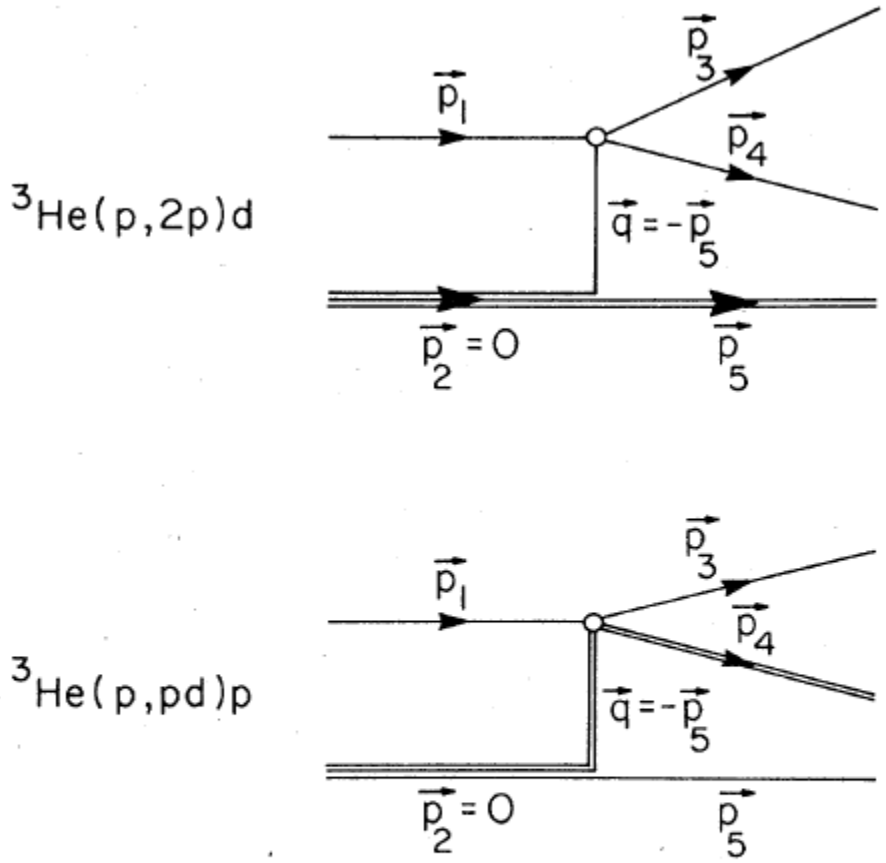


FIG. 1. First-order diagram for the ^{3}He(p,2d)d and ^{3}He(p,pd)p reactions. Particles 1—5 represent, in order, the incident proton, the target nucleus ^{3}He, the scattered proton, the ejected proton or deuteron, and the recoiling particle.

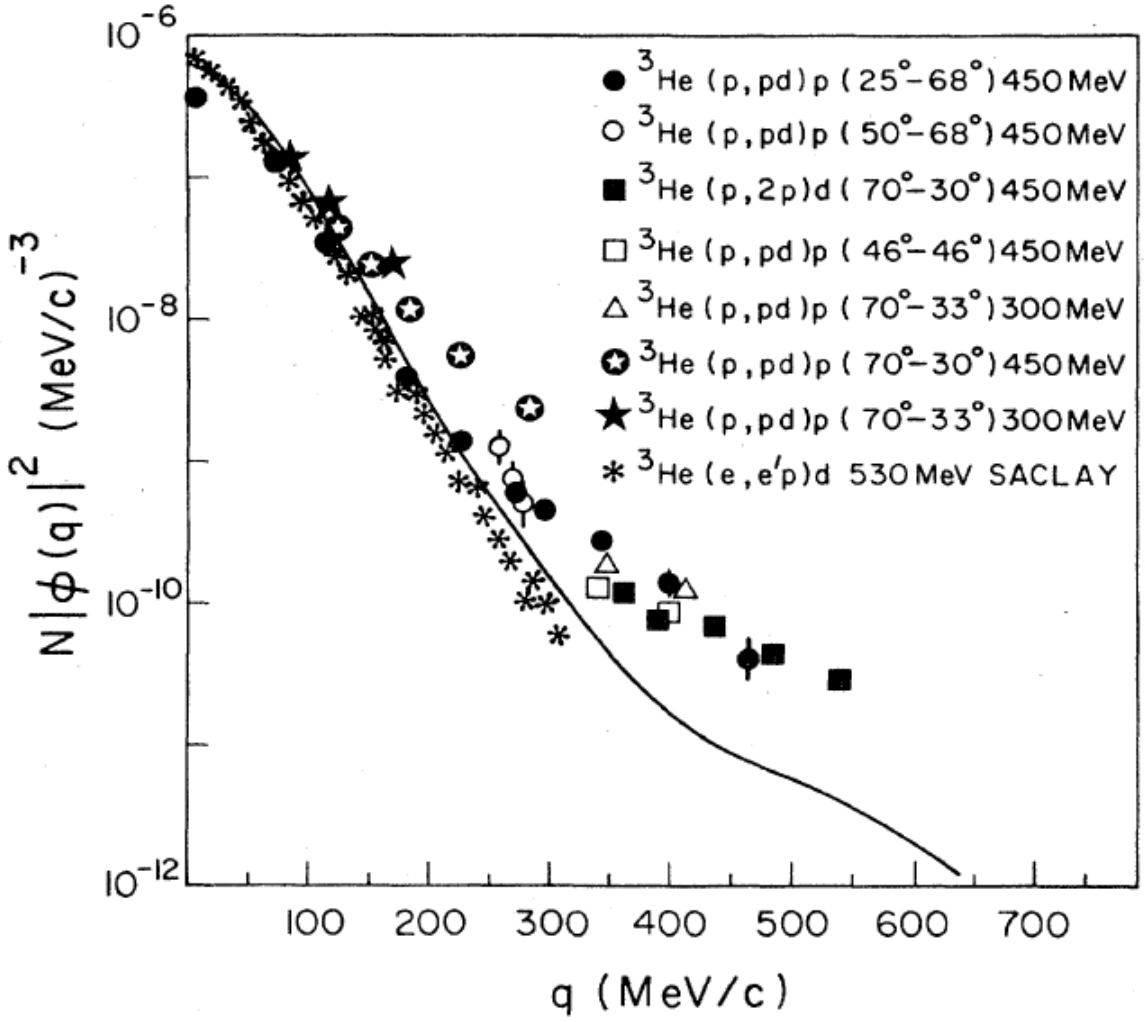


FIG. 4. Experimental spectral functions from the present measurements and from the ^{3}He(e,e′p)d Saclay results at 530 MeV. The curve is the spectral function of Ciofi degli Atti *et al.*

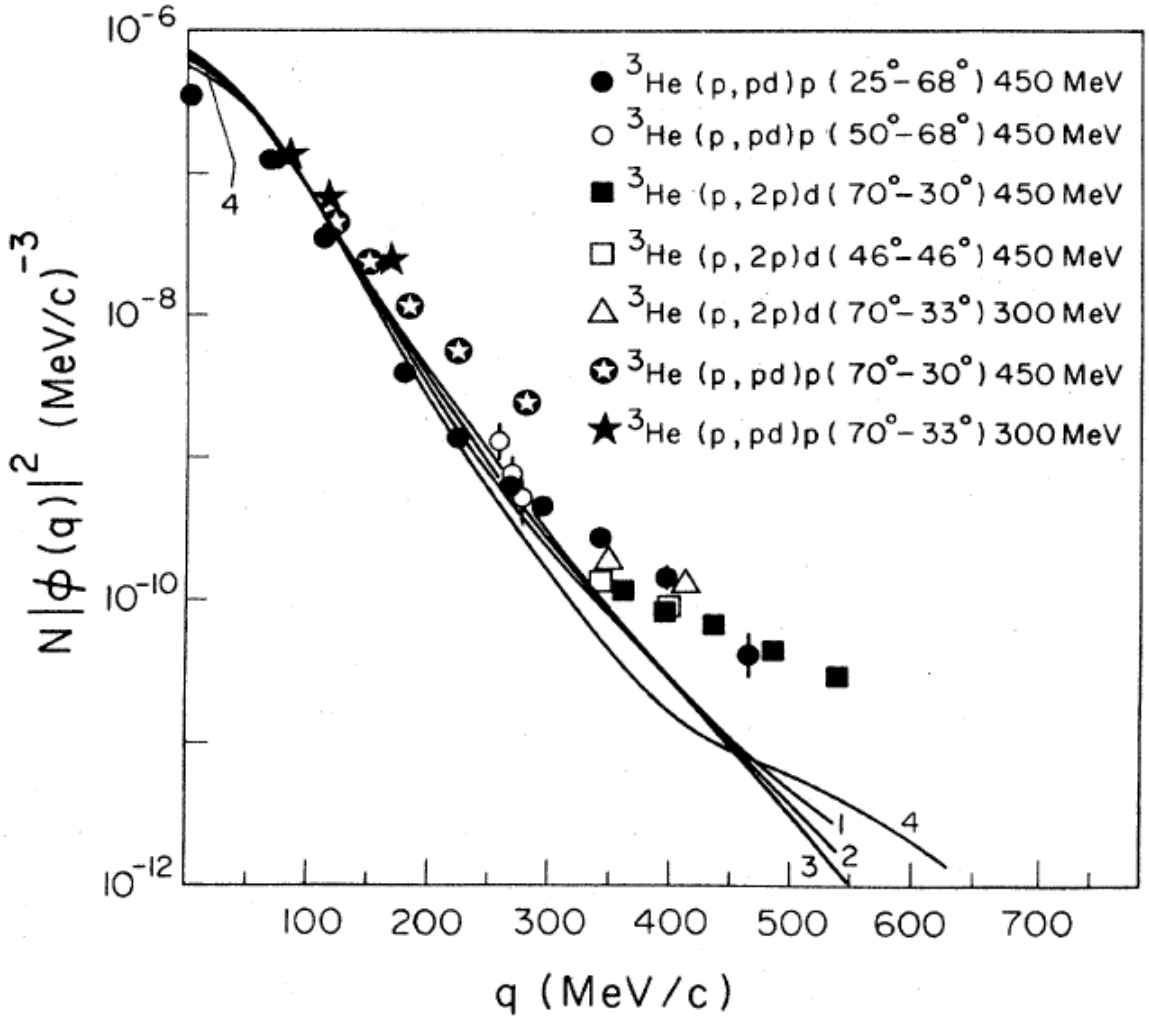


FIG. 6. The experimental spectral function from the present measurements compared to the spectral function calculated using an Irving-Gunn wave function (1) and the spectral functions calculated by Gibson and Lehman (2 and 3) using 7% and 4% *D* state in the deuteron, respectively. Curve 4 is the spectral function of Ciofi degli Atti *et al.*

Quasi-Elastic Scattering ^{3}He(e,e'p)d and ^{3}He(e,e'p)pn

- **M.M. Rvachev et al. Phys.Rev.Lett. 94, 192302 (2005)**
- **F.Benmokhtar et al. Phys.Rev.Lett. 94, 082305 (2005)**

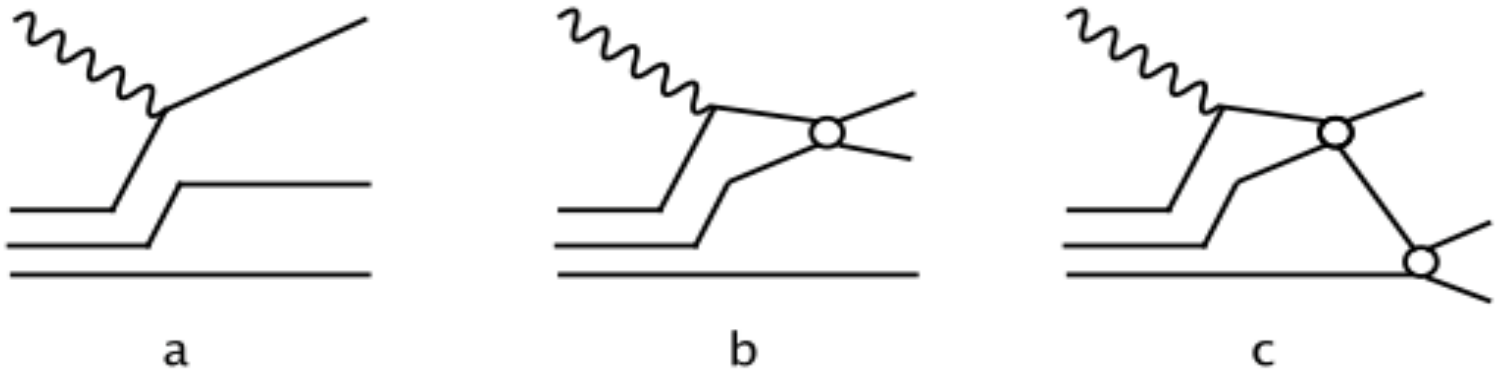


FIG. 1. Feynman diagrams for (a) direct disintegration, (b) rescattering, and (c) rescattering with the spectator nucleon.

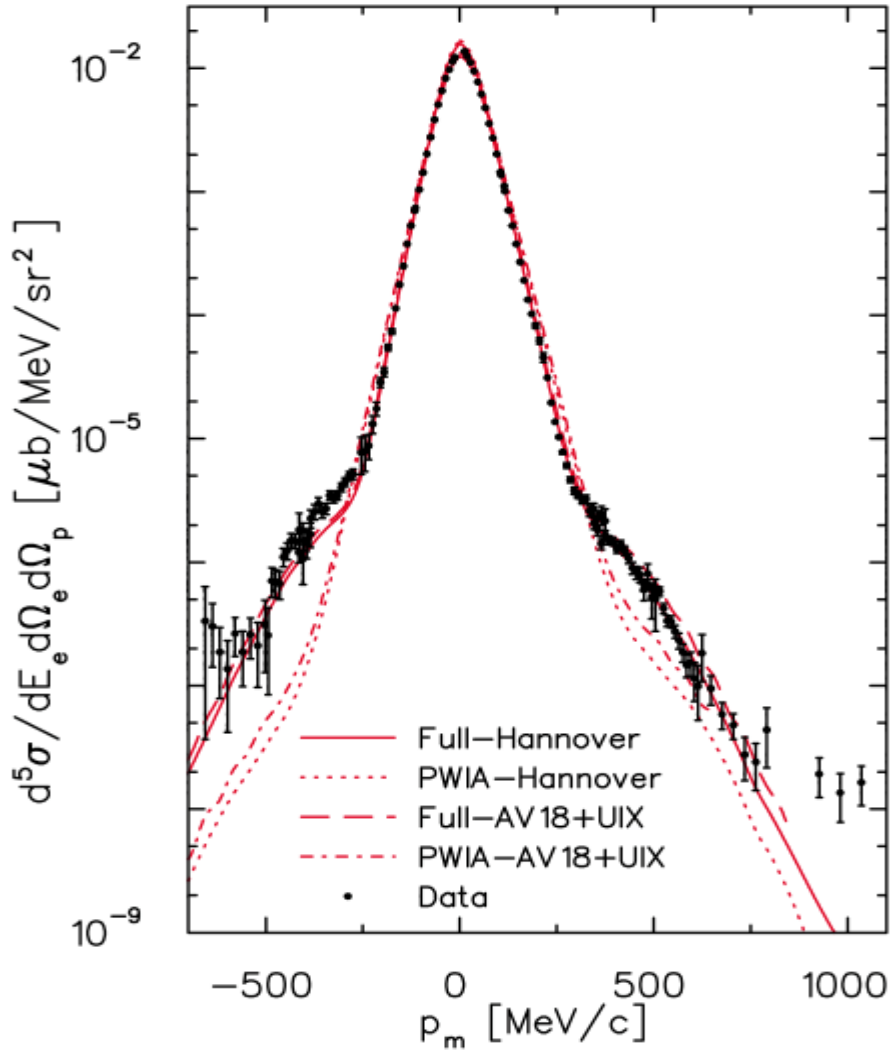


FIG. 1 (color online). Measured ^{3}He$(e, e'p)^2$H cross section as a function of the missing momentum, p_m. Also displayed are PWIA and full calculations in the diagrammatic approach for two different ground-state wave functions.

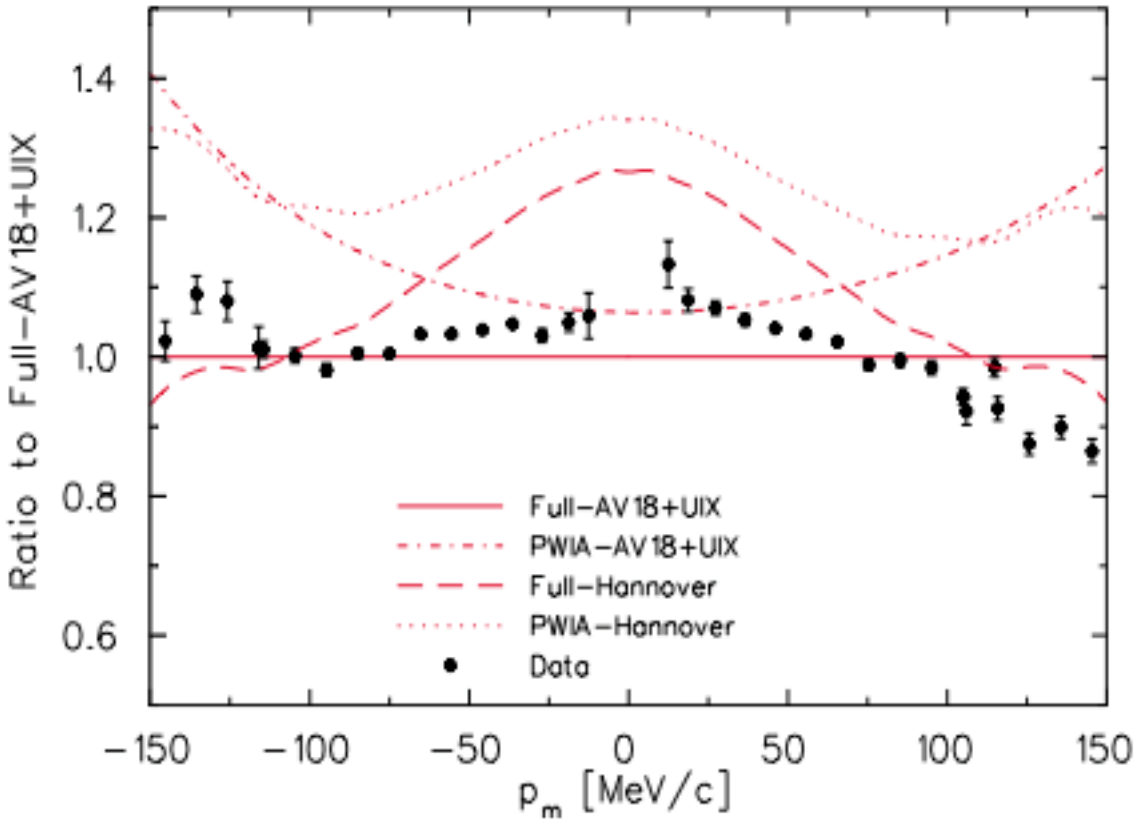


FIG. 2 (color online). Same data as in Fig. 1 for low p_m only, but shown as a ratio to the full calculation that uses the ground-state wave function generated from the AV18 *NN* potential and the Urbana IX three-nucleon force. Also shown are the ratios to this calculation of the full calculation that uses the Hannover GSWF, as well as of the two corresponding PWIA curves.

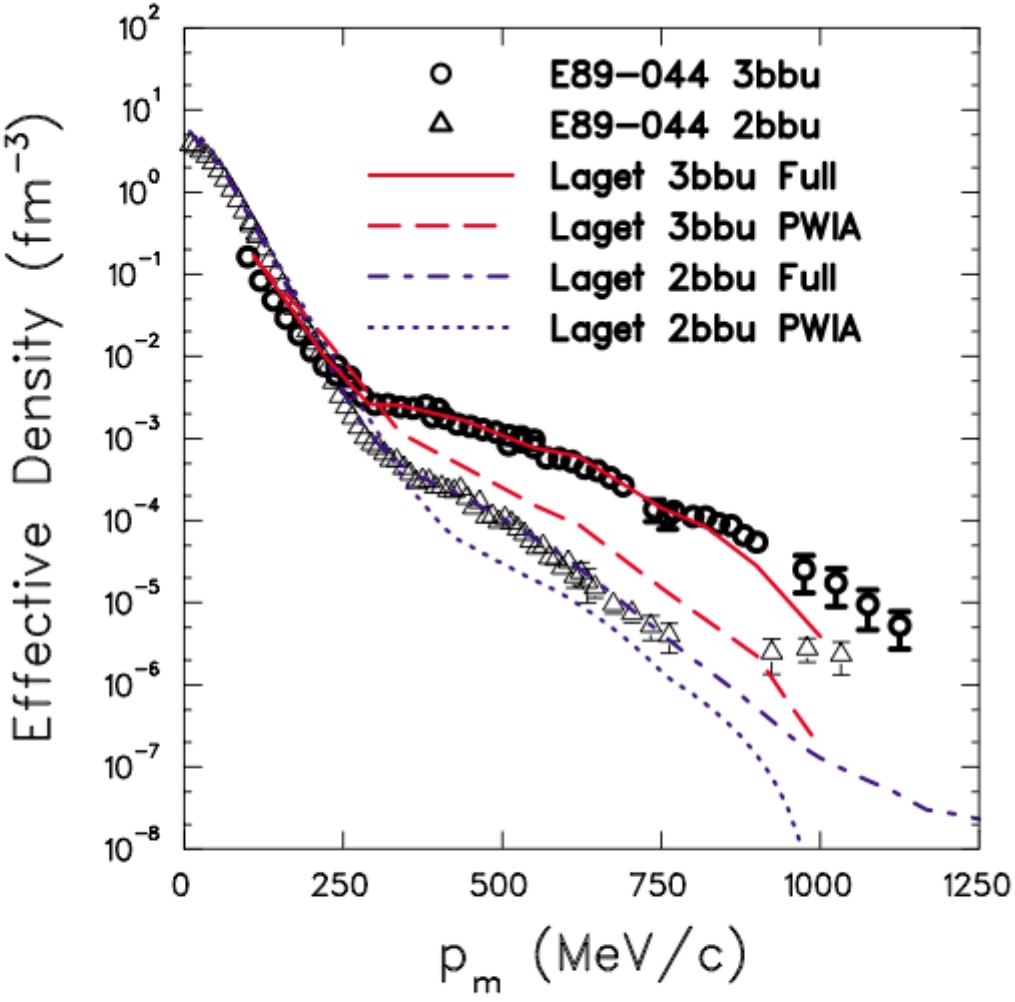


FIG. 3 (color online). Proton effective momentum density distributions in ^{3}He extracted from $^3\mathrm{He}(e, e'p)pn$ (open black circles) and $^3\mathrm{He}(e, e'p)d$ (open black triangles), compared to calculations from Laget [19]. The 3bbu integration covers E_M from threshold to 140 MeV.

The nucleon has a complex structure

the magnetic moments of the proton and neutron:

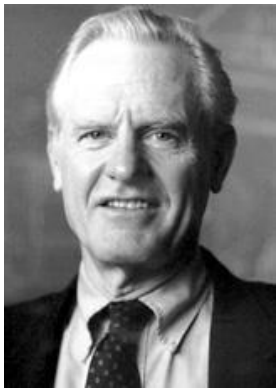
Otto Stern (1933) $\mu_p = 2.793\ \mu_N$, $\mu_n = -1{,}913\ \mu_N$

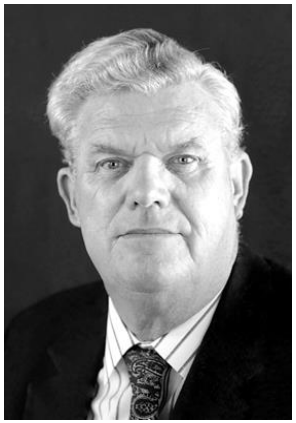
Nobel Prize in 1943

electron scattering from atomic nuclei show the structure of the nucleons

Robert Hofstadter (1956)

Nobel Prize in 1961





deep inelastic scattering of electrons on protons and bound neutrons gives the evidence for the quarks and gluons

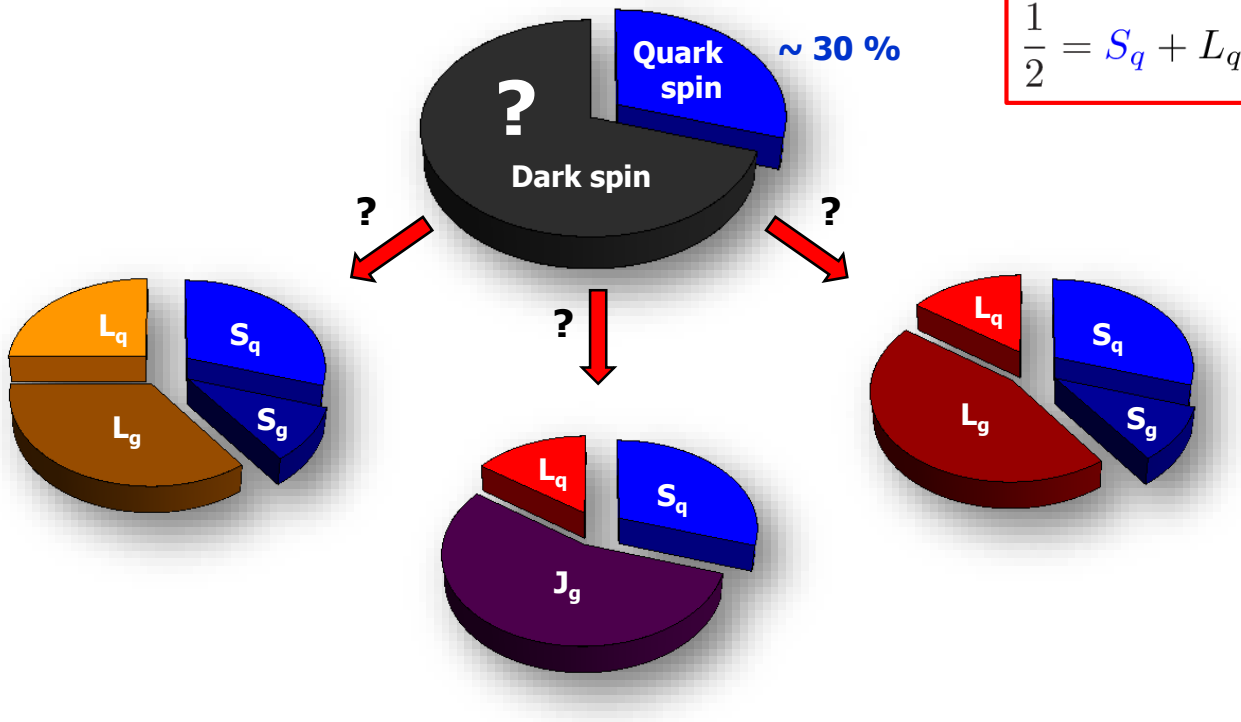
Jerome I. Friedman, Henry W. Kendall, Richard E.Taylor (early 1970's)

Nobel Prize in 1990

- **1) The Structure of the Proton: electric and magnetic form factors, generalized parton distributions (quarks and gluons), longitudinal and transverse momentum distributions, where resides the spin?**

- **2) The 3He Wave Function: Faddeev equations, N-N potentials, 3N potentials**
  In Quasi-Free Scattering : FSI, MEC, multiple scattering

Angular momentum decomposition



$$\frac{1}{2} = S_q + L_q + S_g + L_g$$

Many questions/issues :

- **Frame dependence ?**
- **Gauge invariance ?**
- **Uniqueness ?**
- **Measurability ?**
- **…**

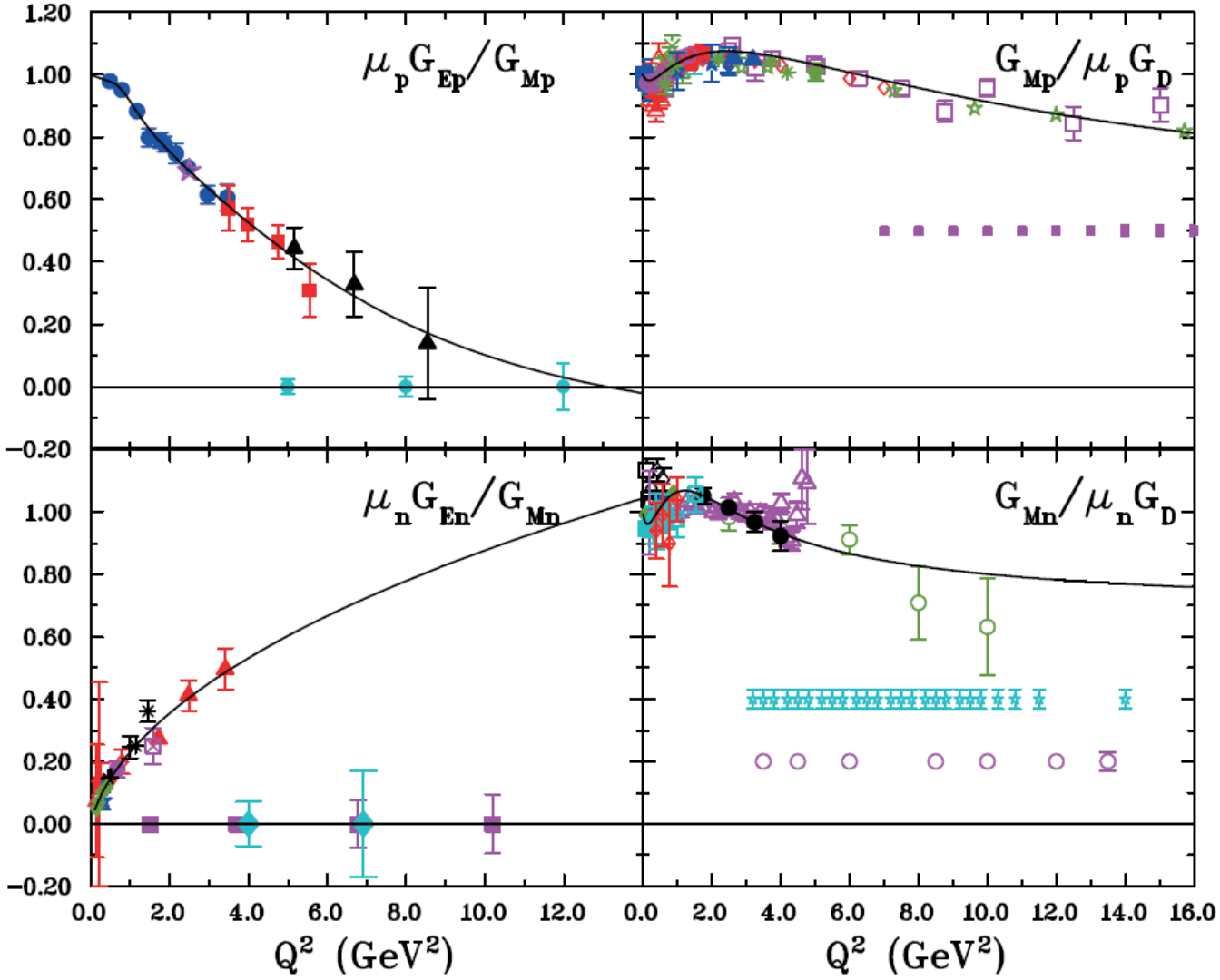
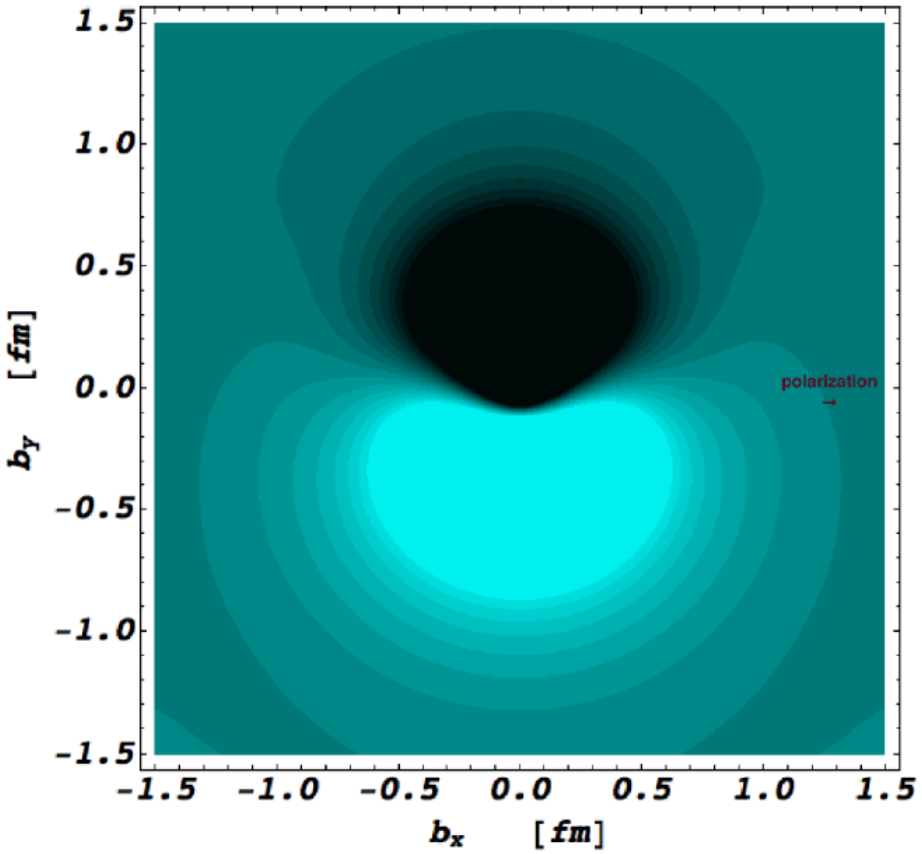


Fig. 37. The projected error bars for the approved nucleon form factors experiments at Jefferson Lab in the 12 GeV era. For the Hall A SBS experiment E12-07-108 [333], the anticipated error bars on the ratio $\mu_p G_{Ep}/G_{Mp}$ are shown as filled circles (cyan). The anticipated error bars on the ratio G_{En}/G_{Mn} are shown as filled squares (magenta) for the Hall A SBS experiment E12-09-016 [334] and as filled diamonds (cyan) for the Hall C experiment E12-11-009 [335]. The anticipated error bars for $G_{Mp}/\mu_p G_D$ from the Hall A experiment E12-09-019 [332] are shown with square symbols (magenta). Finally the ratio $G_{Mn}/\mu_n G_D$ will be measured in two experiments: E12-09-019 in Hall A [337] and E12-07-104 in Hall B [336]. The expected error bars are shown as empty circles (magenta) and filled stars (cyan), respectively.



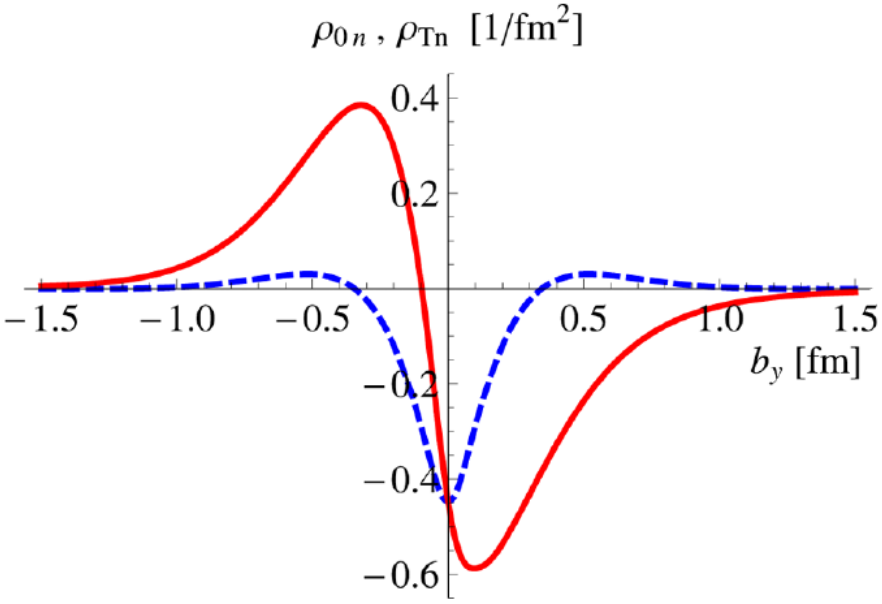


Fig. 26. Left: the 2D projected charge density ρ^n_T for a neutron polarized in the *x*-direction (to the right, in the figure). Dark areas represent negative charge, light areas, positive charge. Right: the charge densities along the *y*-axis for a neutron polarized along the *x*-direction: ρ_{0n} is given by the dashed curve (blue), and ρ_{Tn} is given by the solid curve (red).

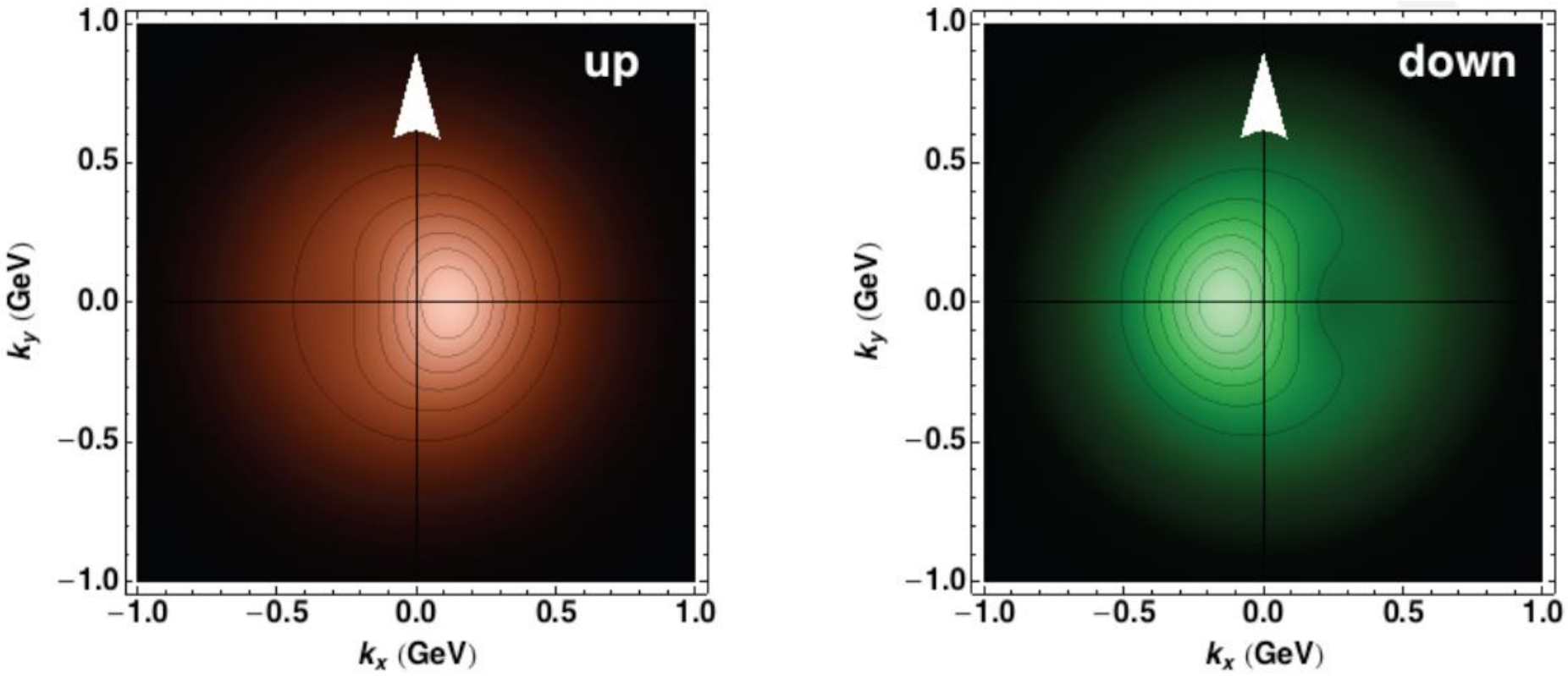


Figure 1.2: The up and down quark density distortion in transverse-momentum space, obtained by studies of the Sivers function [22].

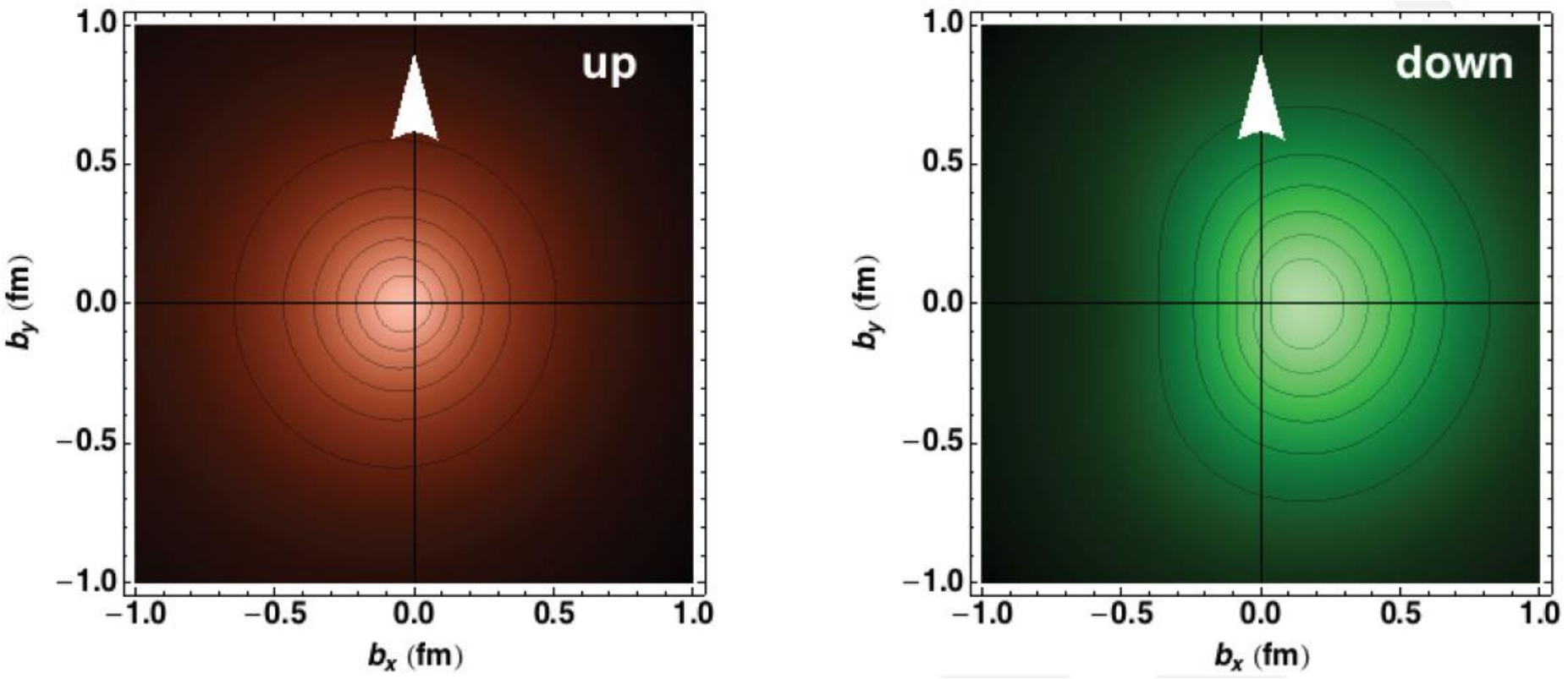


Figure 1.3: The up and down quark density distortion in impact parameter space, obtained by studies of the Pauli form factor.

What is then the latest?

Deep inelastic scattering off the tritium and 3He mirror nuclei at Jefferson Laboratory

The measurement of the ratios of the structure functions F_2^n/F_2^p and d/u : charge symmetry breaking of the d and u distributions

As next research tool: an electron-ion collider
It will get the highest priority for new facility construction by NSAC

- **This is another flight in physics then what you have followed from what we will hear today.**

- **We are expressing our best wishes in any further endeavors you may be undertaking.**