New measurements of the elastic ^{3}He form factors

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Some Ancient History …

"It is pointed out that the finite size of the nucleus will give rise to large deviations from Mott scattering when the change in wave-length of the electrons is of order of the nuclear dimensions. This deviation from Mott scattering at large scattering angles therefore provides a possibility for determination of the shape of the charge distribution and size of nuclei. In the case of a spherically symmetric charge distribution the nuclear charge density is immediately obtained from the observed angular distribution by a Fourier transform. ....”

The Charge Distribution in Nuclei and the Scattering of High Energy Electrons
M.E. Rose
Phys. Rev. 73, 279 (1948)
https://doi.org/10.1103/PhysRev.73.279
(Scattering of electrons with up to 50 MeV is envisioned in this work)

… 70 years later we are still trying to measure and understand the charge and current distributions in nuclei complicated by the fact that we now know the involved objects (p, n, π, …) and interactions are emergent from QCD – what are the relevant “effective” DoF?

Mathematical machinery …. (1γ, unpol., [½, ½], lab)

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

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{(Z\alpha)^2 E' \cos^2(\theta/2)}{4E^3 \sin^4(\theta/2)}$$

$$A(Q^2) = \frac{F_C^2(Q^2) + \mu^2 \tau F_M^2(Q^2)}{1+\tau}$$

$$B(Q^2) = 2\tau\mu^2 F_M^2(Q^2)$$

$$\tau = Q^2/4M^2$$

$$Q^2 = 4EE' \sin^2\left(\frac{\theta}{2}\right)$$

F_C and F_M are the "charge" and "magnetic" form factors,

Yennie, Levy & Ravenhall - Rev. Mod. Phys. 29, 144 (1957)

Ernst, Sachs & Wali – Phys Rev 119, 1105 (1960)

Sachs – Phys. Rev. 126, 2256 (1962)

Hand, Miller & Wilson – Phys. Rev. Lett. 8, 110 (1962)

Separating F_C and F_M, requires at least two measurements at different Θ and same Q^2

$$
\begin{aligned}
F_{exp} &= (1+\tau)\left(\frac{d\sigma}{d\Omega}\right)\left(\frac{d\sigma}{d\Omega}\right)^{-1}_{Mott} \\
&= F_C^2 + \mu^2 \tau F_M^2 \; \underbrace{[1 + 2(1+\tau)\tan^2(\theta/2)]}_{\epsilon^{-1}}
\end{aligned}
$$

Need large luminosity and solid angles to get reasonable kinematic enhancement of F_M. For this experiment,

Θ_{forw} ~20-30 deg; Θ_{back}~140 deg; (three Θ for most pts)

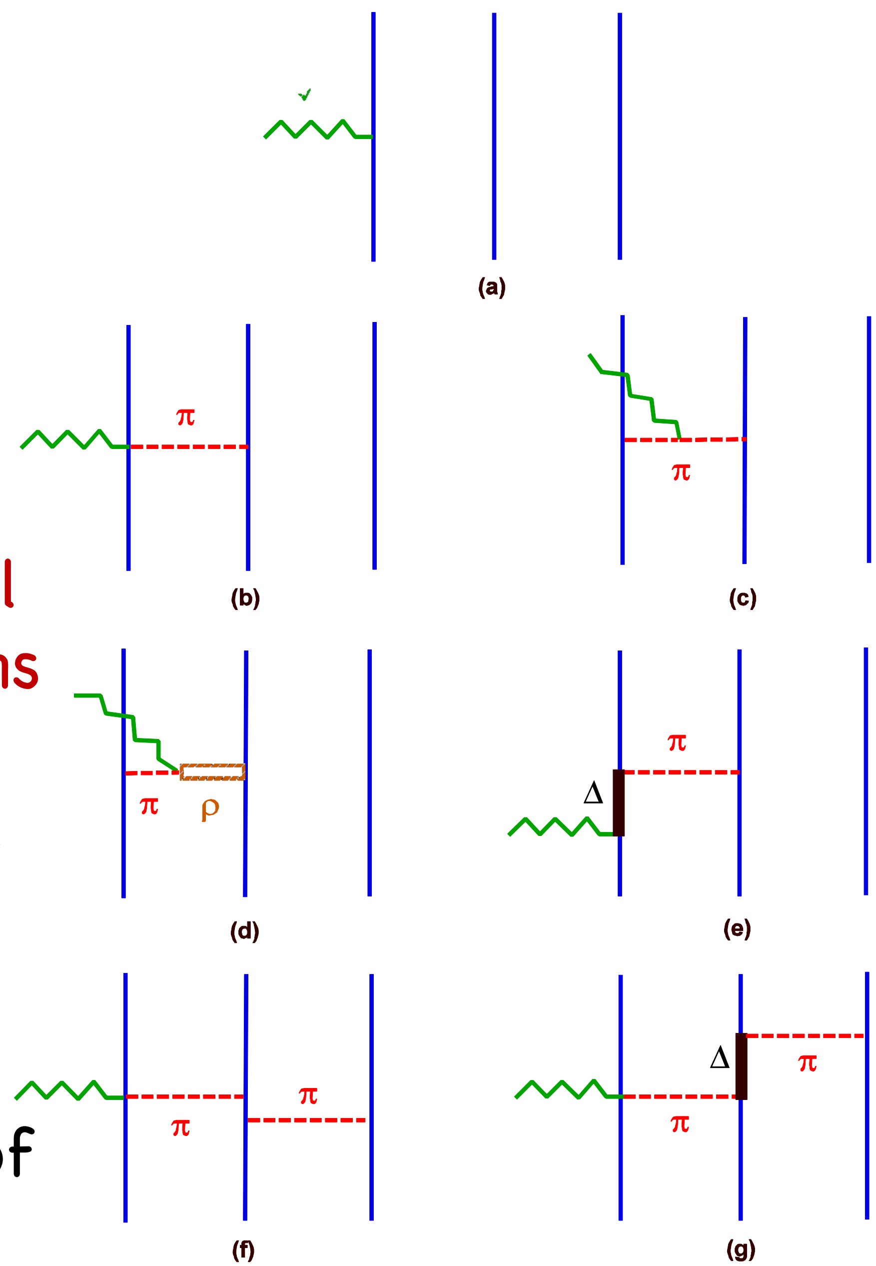
^{3}He: 20cm long, 13.7-14.2atm, 7.1-7.8K (0.057-0.070 g/cm^2)

0.688 </= E (GeV) </= 3.304

29 </= I (uA) </= 99

Why the interest in the elastic form factors of the few-body nuclei (besides curiosity)?

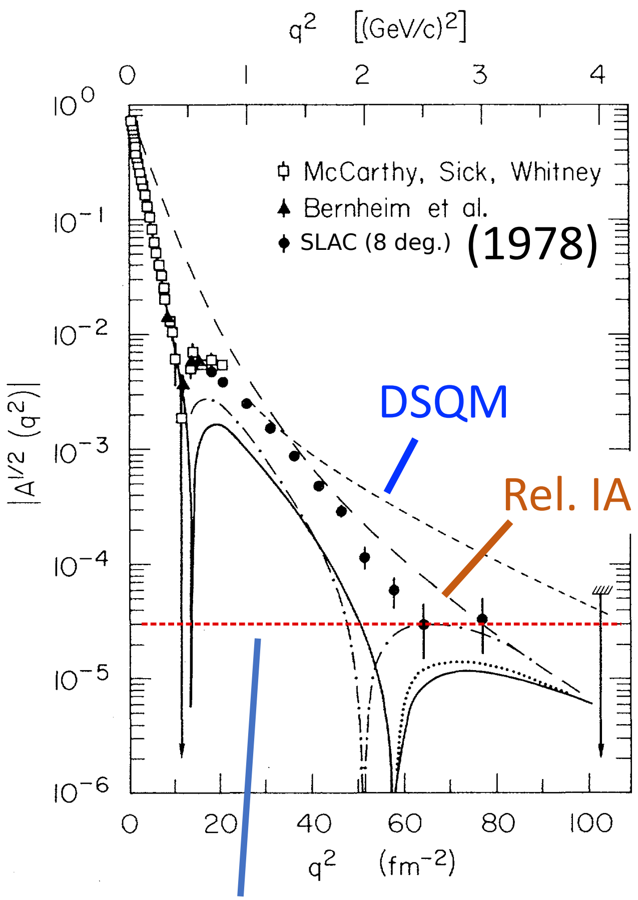
- We can calculate them ……
  - Faddeev, Hyperspherical Harmonics, ….
  - Argonne AV18 N-N potential
  - Urbana UIX 3-N interactions
  - Add Meson Exchange Currents (MECs) to Impulse Approximation (IA)



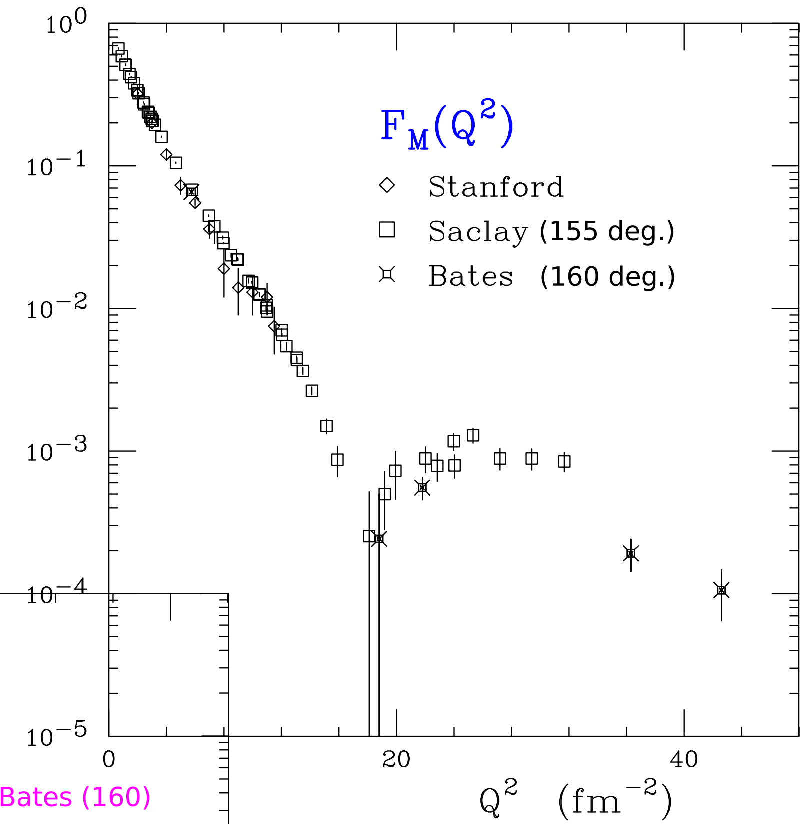
some MECs …

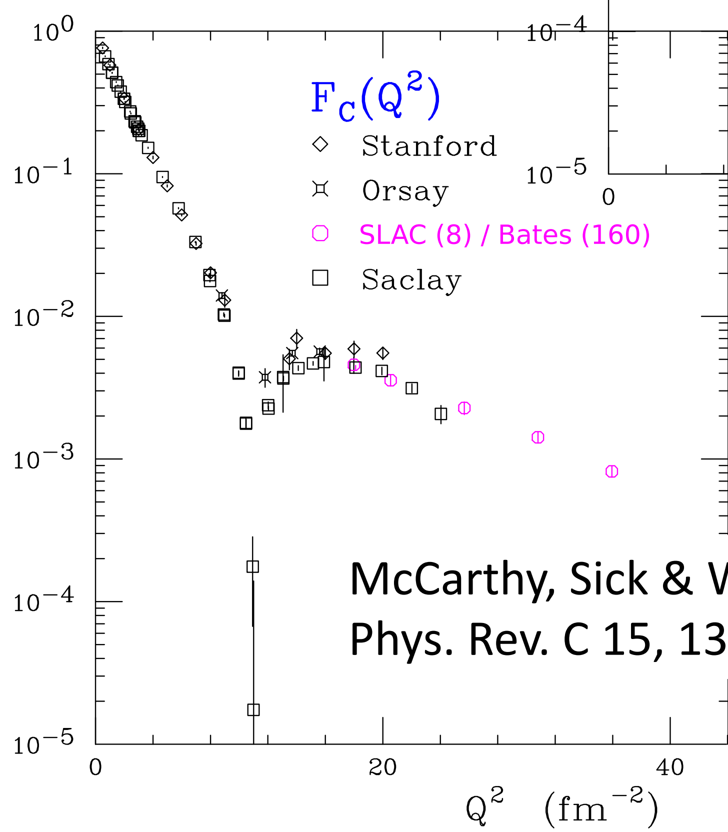
Location of diffraction minimum and strength of $F_{C,M}$ coming out of the minimum sensitive to chosen MECs

previous data …



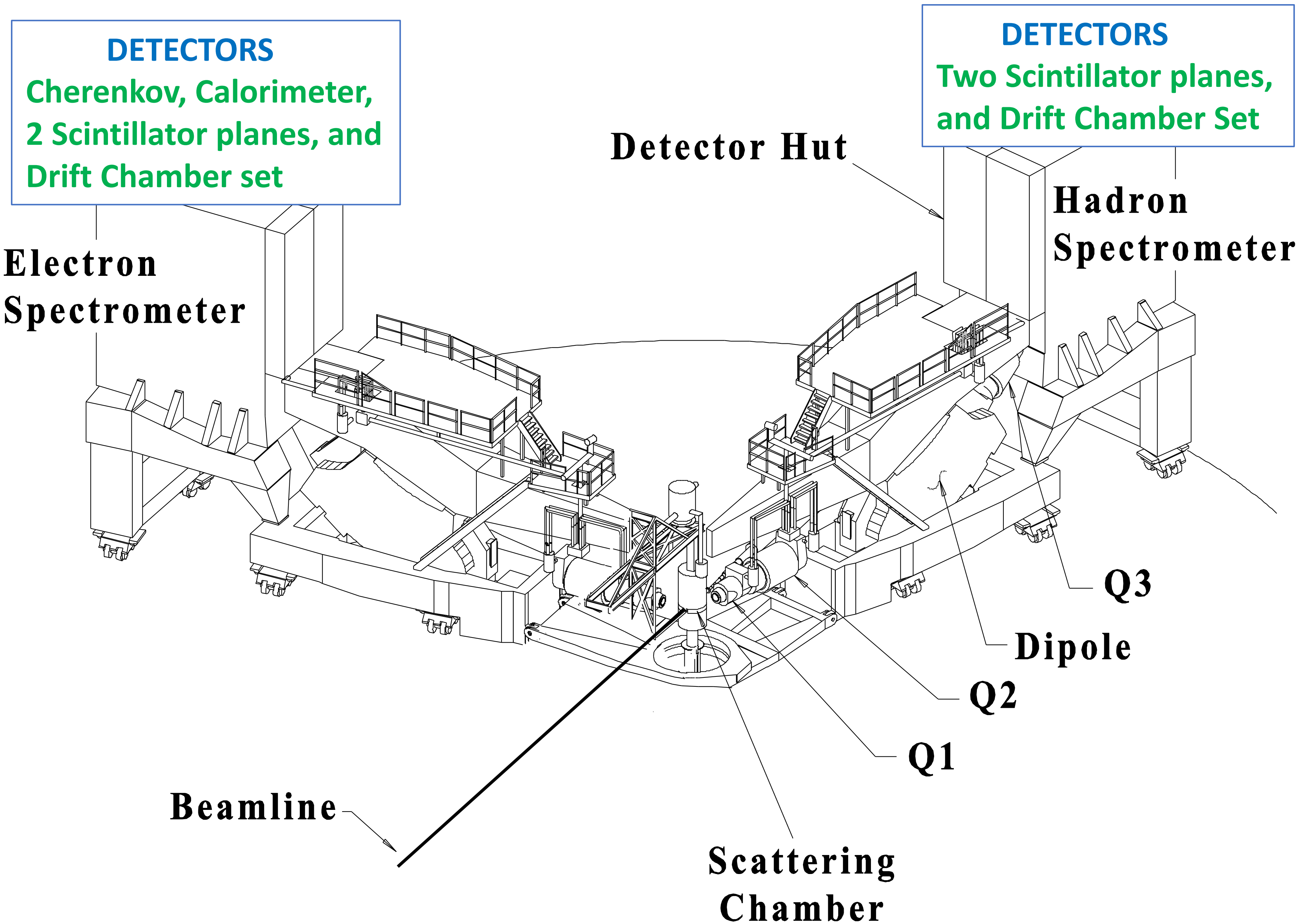
~ 1 evt / 5 C
(~ 6 days @ < 10 uA >)

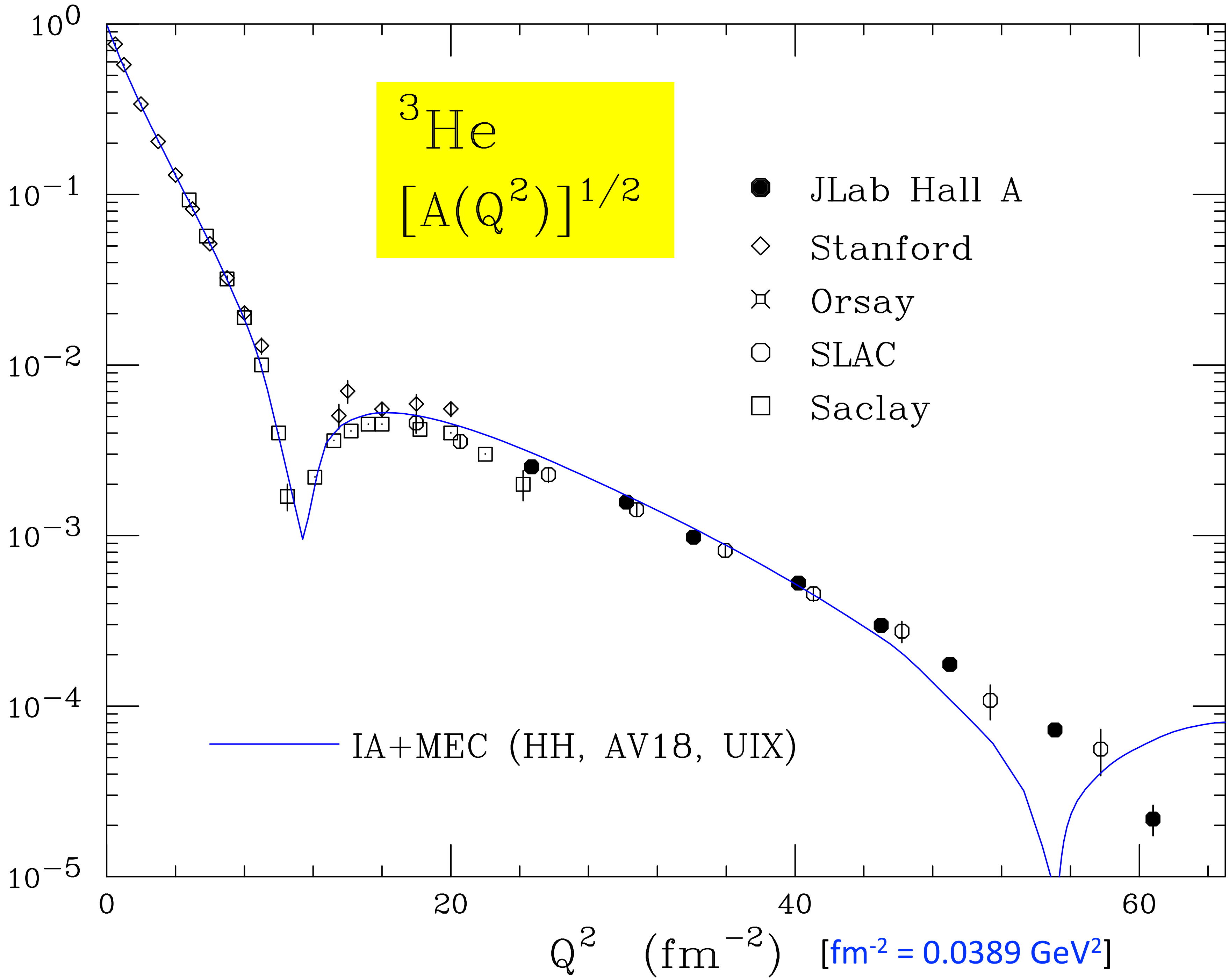


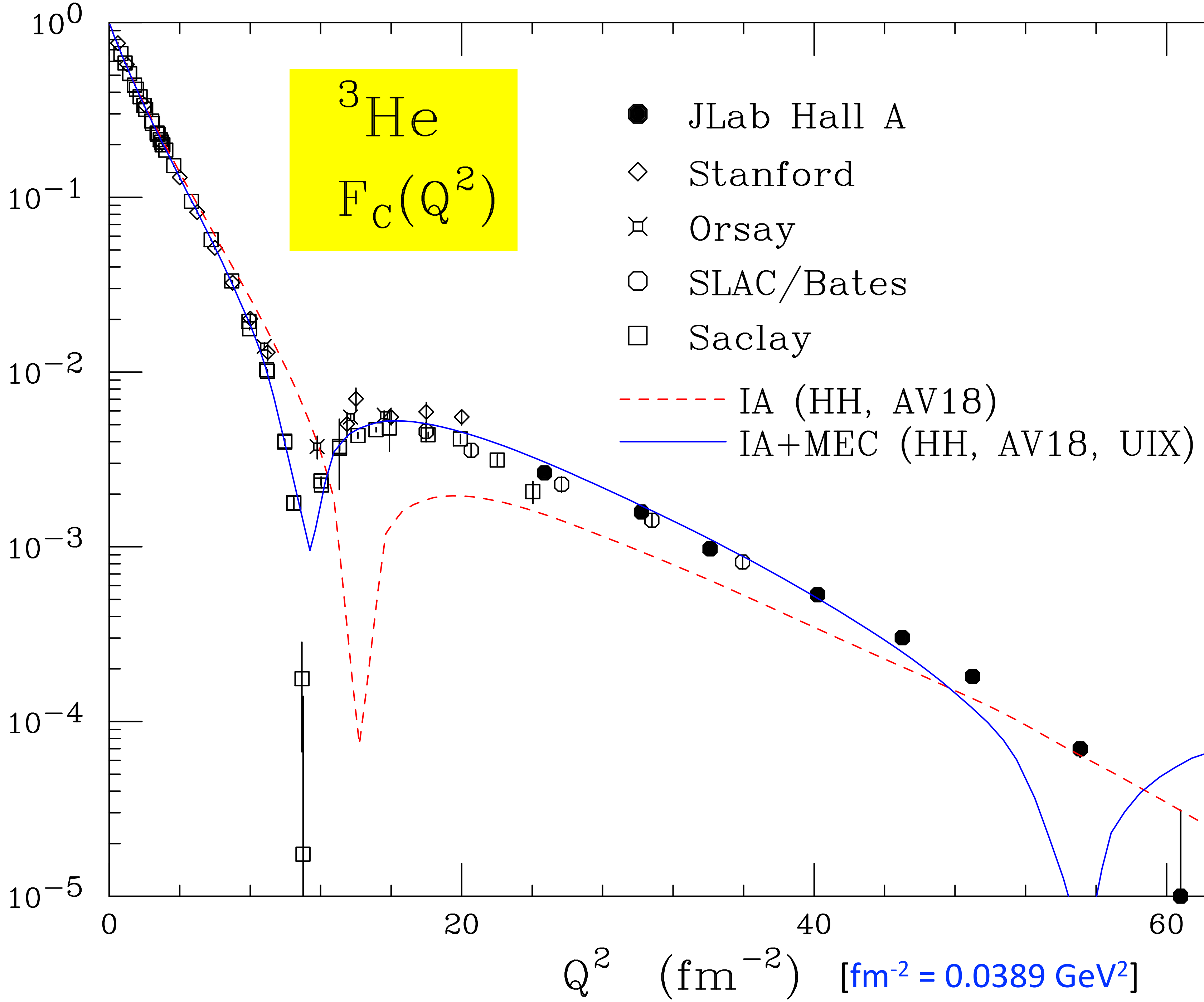


McCarthy, Sick & Whitney
Phys. Rev. C 15, 1396 (1977)

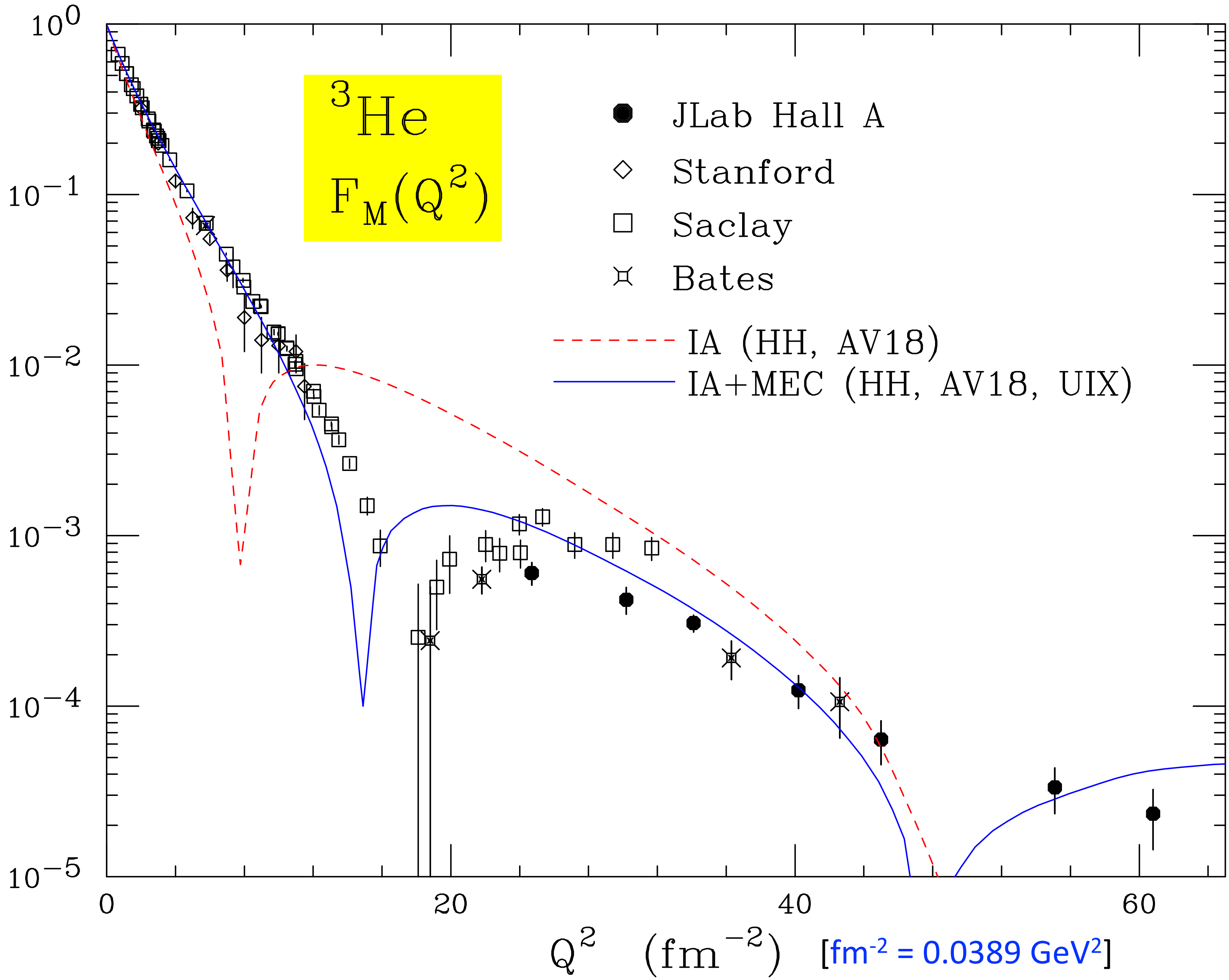
Hall A High Resolution Spectrometers




^{3}He
$[A(Q^2)]^{1/2}$
JLab Hall A
Stanford
Orsay
SLAC
Saclay
IA+MEC (HH, AV18, UIX)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
20
40
60
Q^2 (fm^{-2})
[fm^{-2} = 0.0389 GeV^2]



^{3}He
$F_C(Q^2)$
JLab Hall A
Stanford
Orsay
SLAC/Bates
Saclay
IA (HH, AV18)
IA+MEC (HH, AV18, UIX)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
20
40
60
Q^2 (fm^{-2})
[fm^{-2} = 0.0389 GeV^2]



^{3}He $F_M(Q^2)$
JLab Hall A
Stanford
Saclay
Bates
IA (HH, AV18)
IA+MEC (HH, AV18, UIX)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
20
40
60
Q^2 (fm^{-2})
[fm^{-2} = 0.0389 GeV^2]

Summary

- The F_C data appears to indicate a diffraction minimum at about $Q^2 = 62$ fm^{-2} – at the edge of our Q^2 range and farther away that present day calculations expect it.
- Behavior of cross-section within acceptance of neighboring points indicates presence of second diffraction minimum at $Q^2 \sim 50$ fm^{-2} in F_M but due to beam time constraints no actual measurement was performed.
- Strength of F_M for $Q^2 > 55$ fm^{-2} seems to be running below theoretical expectations.
- Difficulty of theoretical calculations to reproduce first minimum of F_M continues.