(e,e) from light nuclei

Ingo Sick

Form factors of A=2,3,4 nuclei

great contribution to quantitative understanding of nuclei

- Exact calculation of w.f. in terms of nucleons possible
  - standard model of nuclear physics
    - nucleonic constituents
    - interacting via NN-force
  - achieves 'initial' goal of NP
    - quantitatively understand nuclei (A<<)
- Variety of observables
  - F_{C0}, F_{M1}, F_{C2}
  - T=0, T=1
- polarization observables accessible
  - polarized targets for A=2,3
  - recoil polarimeters for A=2
- can reach large q as $F(q)$ fall slowly
  - $\longrightarrow$ small distances
  - resolution $\sim 1.5/q$
  - can/must go beyond SMNP
- best evidence for non-nucleonic d.o.f.
  - some observables especially sensitive $d(e,e')np$
  - MEC: π, ρ, Δ, ...
  - description $\pm$ consistent with V_{NN}

- provide best neutron-'target'

  decisive for study of n

Together: sets nuclei $A \leq 4$ apart from nuclei

there:

use of simplified models

no bottom-up approach

goal of talk:

show what has been achieved

point out where 12GeV opens new doors

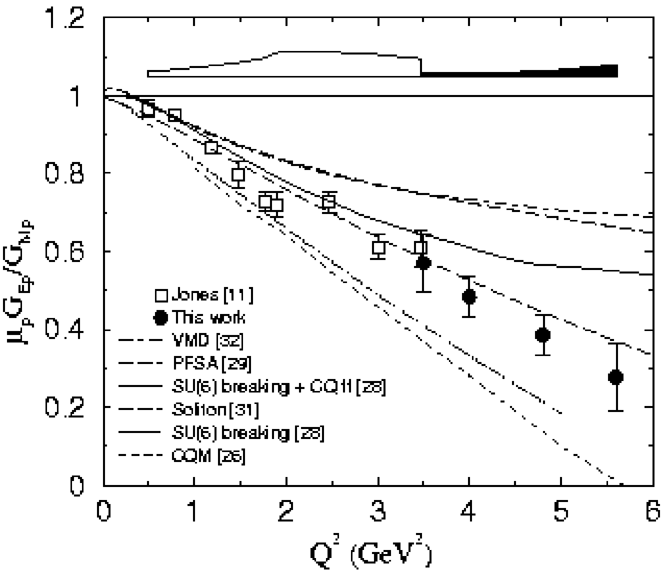
discuss new physics topics

review: Prog. Part. Nucl. Phys. 47 (01) 245

Necessary ingredients: G_{ep}, G_{mp}

G_{mp} well known

G_{ep}/G_{mp} show pronounced q-dependence $q^2 < 6GeV^2/c^2$



not topic of talk

point out

can with 12GeV reach $q^2 \sim 14 GeV^2/c^2$

enough for interpretations of *nuclear* form factors

Deuteron

only bound 2N-system

fundamental for NP

A. question of past:

to which degree can understand as 2N

explained by V_{NN} known from N-N scattering?

B. question of last 2 decades

to which degree can understand as 2N+mesons

explained using MEC consistent with V_{NN}?

in spirit of B., for future:

role of $\Delta\Delta$, other isobars

poorly identified as $\Delta\Delta$ very short ranged

importance of relativity

even at $7 fm^{-1}$ (T_{20}) basically non-relativistic

as $k \sim q/4 \sim 2 fm^{-1}$

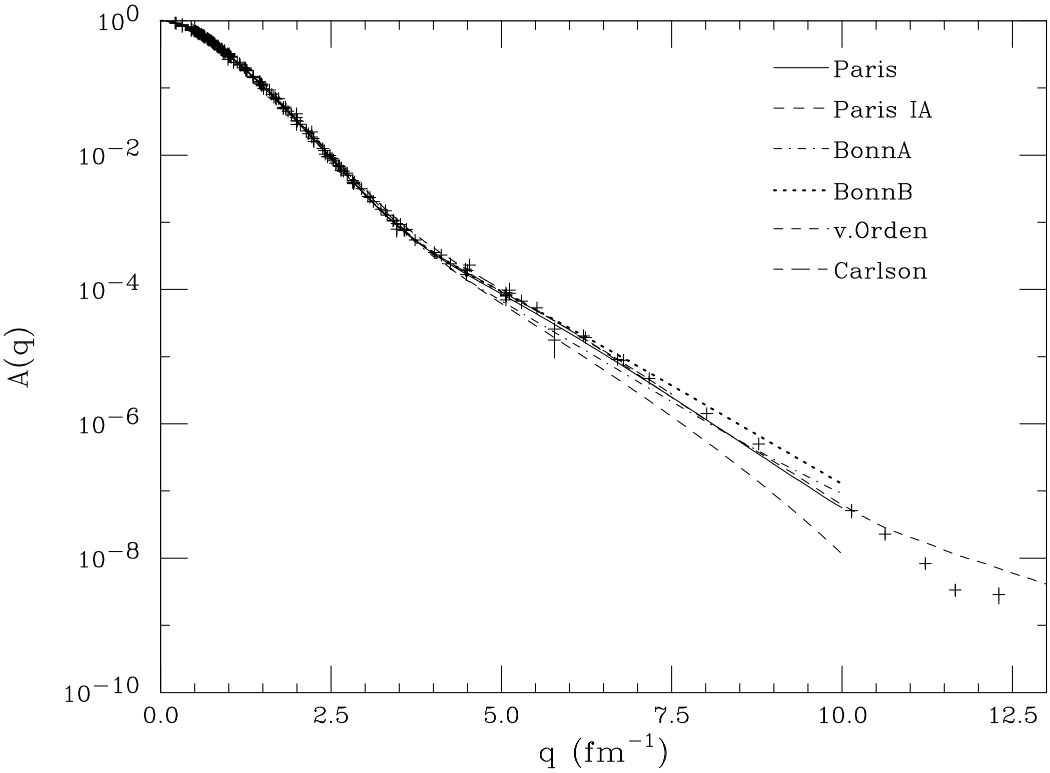
$k^2/m^2 \sim 0.2$

C. question for future: where are quark d.o.f. important

Achievements of past

A(q): known to very large q

not very sensitive



T_{20} known to $q \sim 7fm^{-1}$

to there can separate C0, C2

Data: large body

- many L/T-separations
- data with large $\delta\sigma$ dominate plots

Optimal analysis

- all data
- fit σ, T_{2i} with flexible parameterization
- statistical errors via error-matrix
- syst. errors via change, refit, quadr. sum
- include Coulomb

Monopole form factor

find

- significant effect of MEC
- sensitive due to presence of diffraction feature
- good agreement with experiment
  - despite different V_{NN}
  - relativistic/non-relativistic approach

Quadrupole form factor

find:

- not sensitive
  - for same reason $A(q)$ not sensitive
- good agreement with theory
- best use: G_{en}

M1 form factor

- sensitive in region of mini/maxi
- some calculations don't do well
  - not understood

Calculations:

Sauer et al:

- Paris, Bonn A, B
- non-relativistic, +rel. corr.
- MEC derived from Bonn pot.
- $\rho\pi\gamma$ separate

Carlson+Schiavilla

- Argonne V18
- π and ρ MEC from V_{NN}
- $\Delta, \rho\pi\gamma, \omega\pi\gamma$ separate

Arenhövel et al

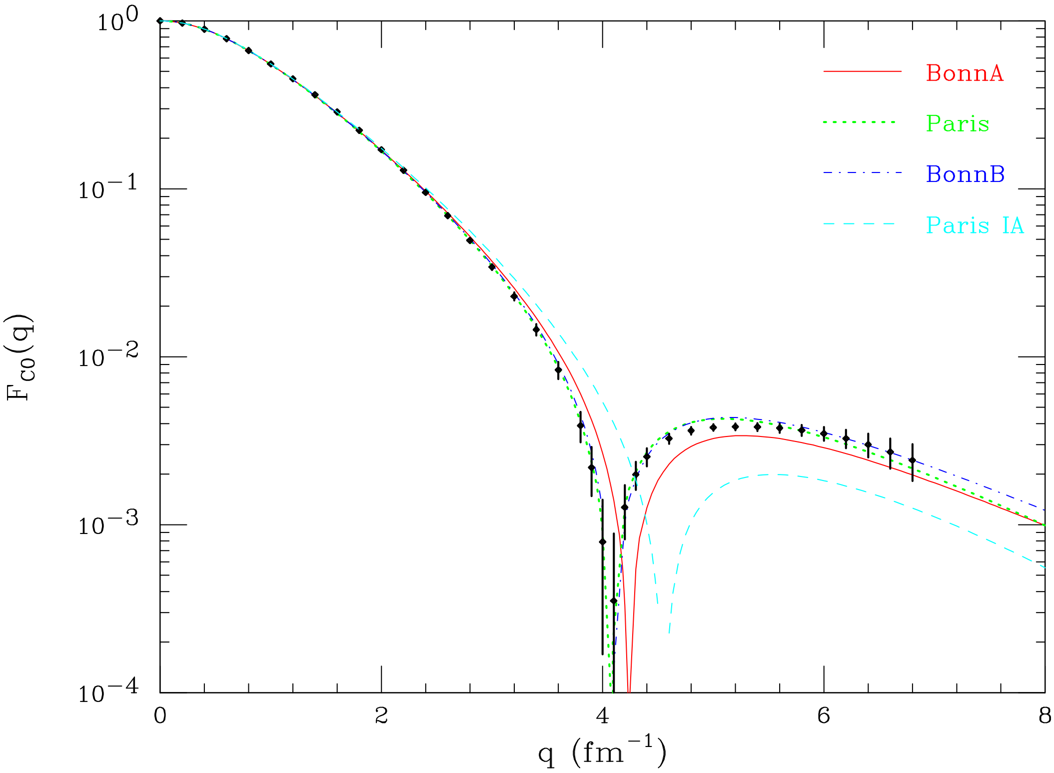
- coupled N+meson fields
- Foldy-Wouthuysen trans. $\rightarrow$ non-rel. limit
- OBEPQ-B
- $\rho\pi\gamma$ separate

Hummel+Tjon

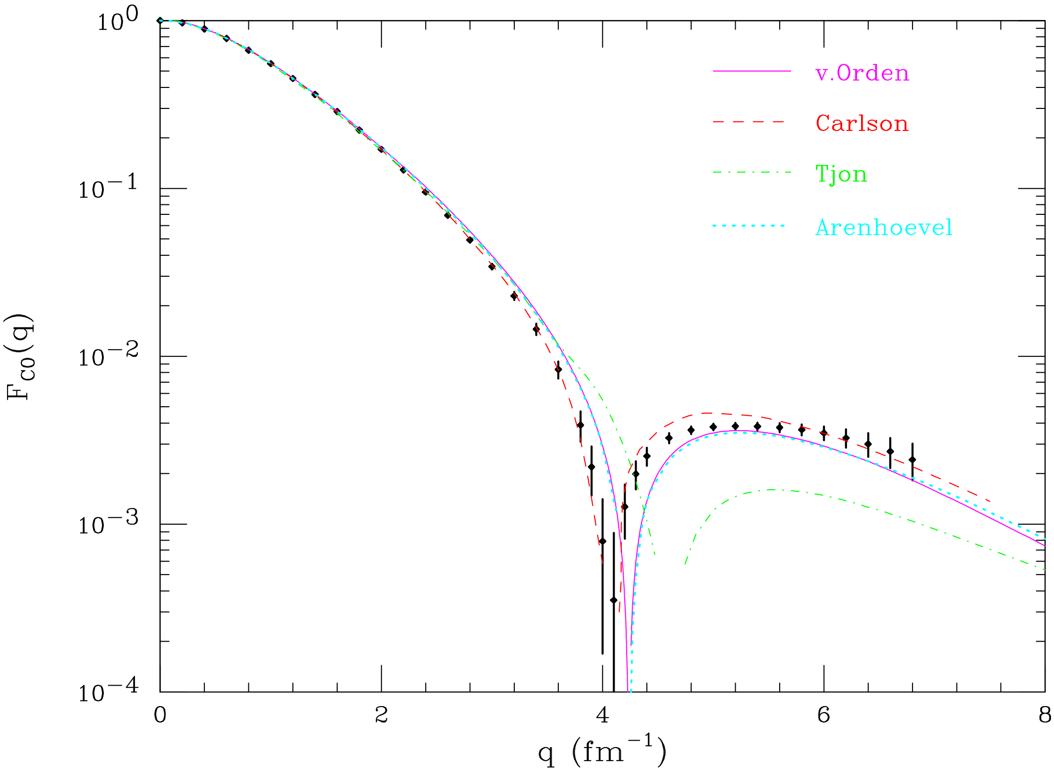
- Blankenbecler-Sugar eq.
- OBE
- $\rho\pi\gamma, \omega\epsilon\gamma$ separate

v.Orden et al

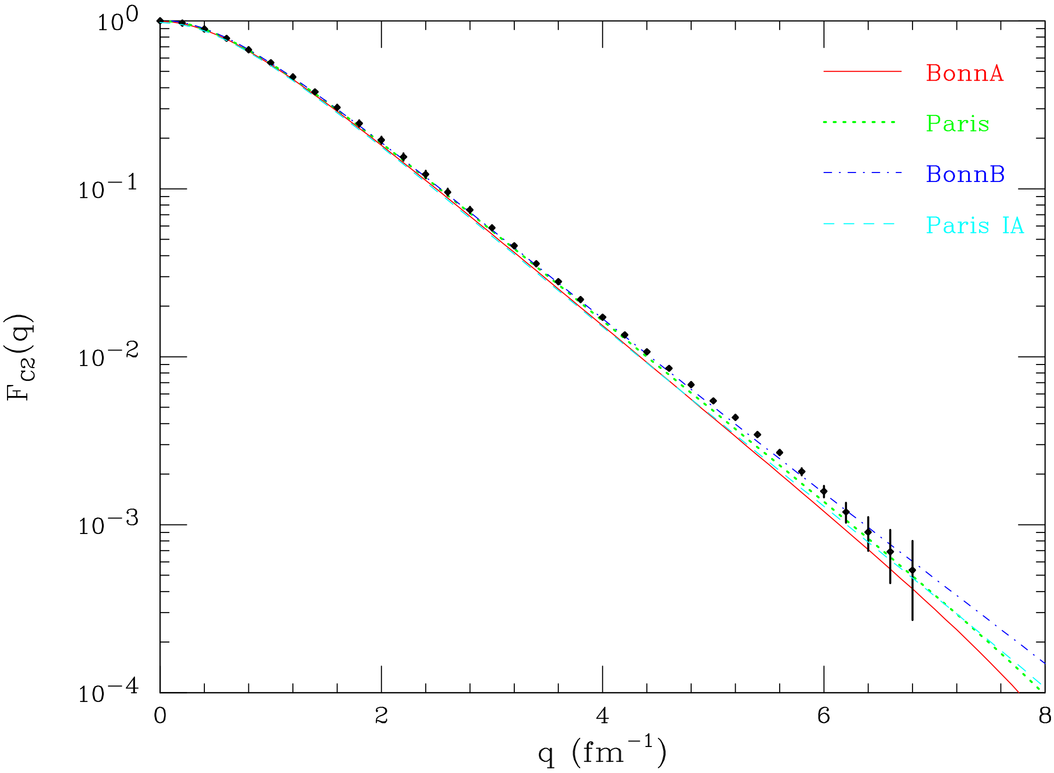
- Bethe-Salpeter eq., quasi-potential
- OBE
- $\rho\pi\gamma$ separate



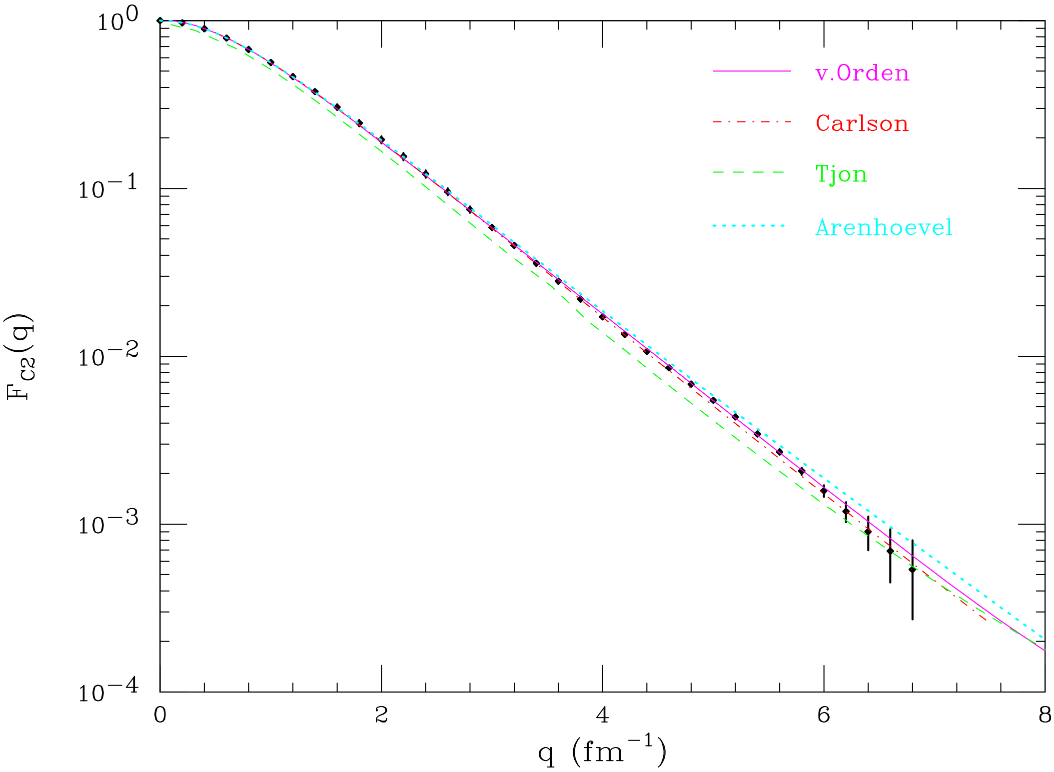
BonnA
Paris
BonnB
Paris IA
$F_{C0}(q)$
$q\ (fm^{-1})$



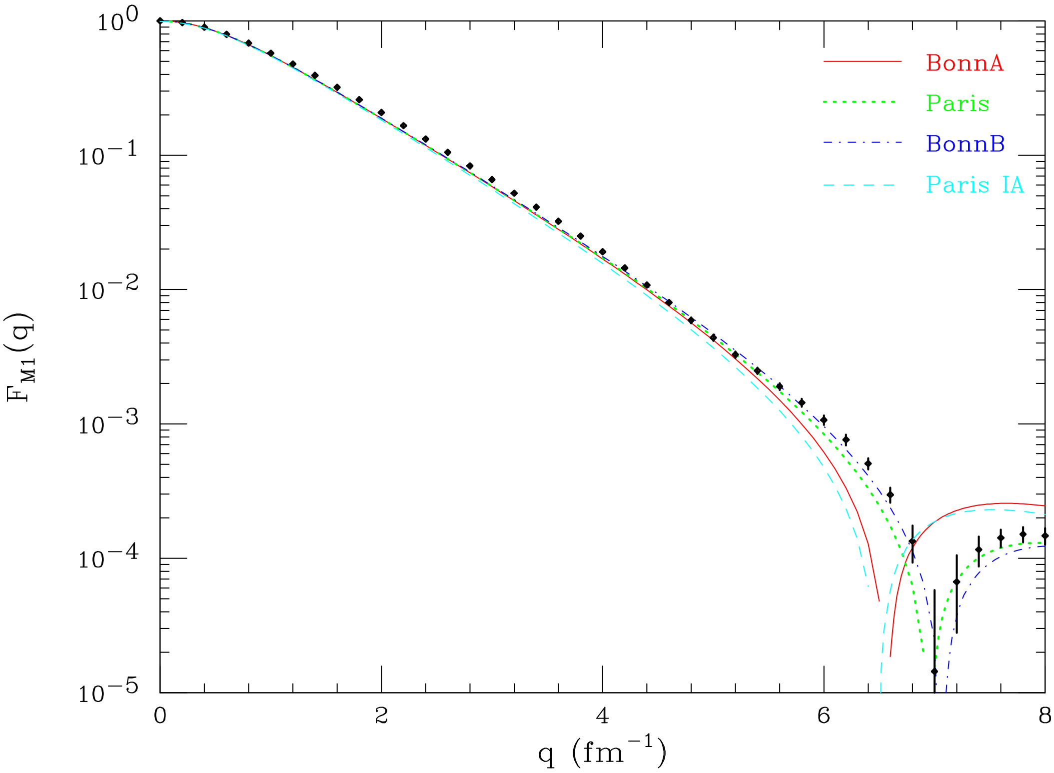
v.Orden
Carlson
Tjon
Arenhoevel
$F_{C0}(q)$
$q\ (fm^{-1})$

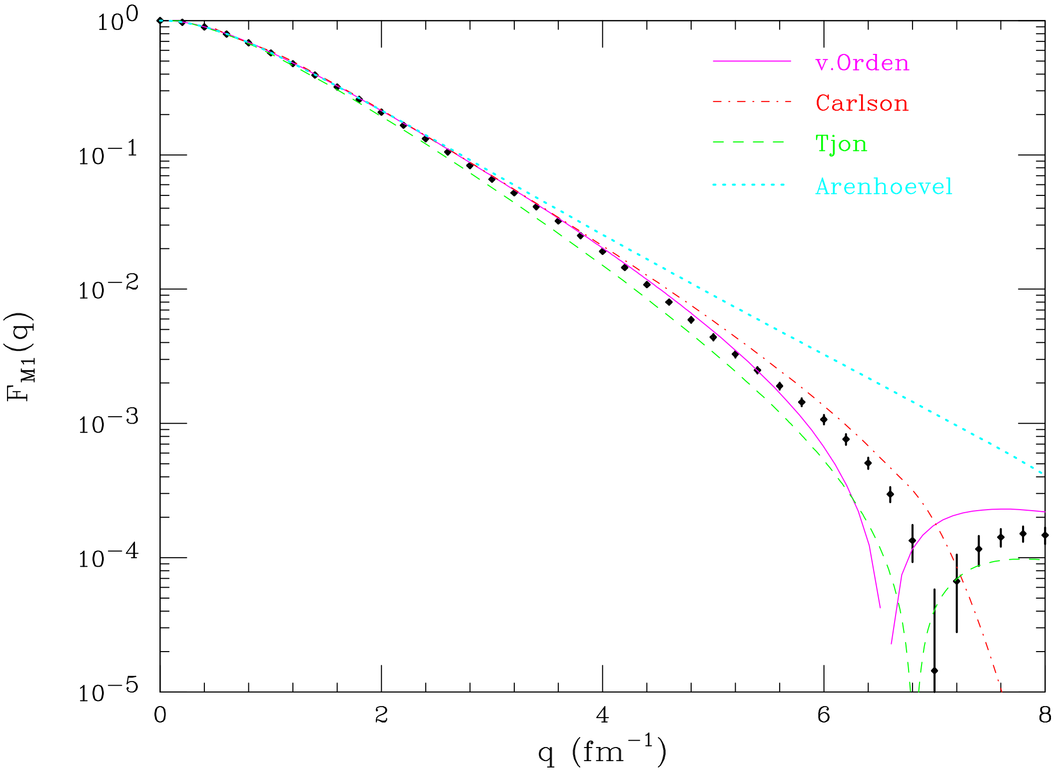


BonnA
Paris
BonnB
Paris IA
$F_{C2}(q)$
$q\ (fm^{-1})$



v.Orden
Carlson
Tjon
Arenhoevel
$F_{C2}(q)$
$q\ (fm^{-1})$


BonnA
Paris
BonnB
Paris IA
$F_{M1}(q)$
q (fm^{-1})


v.Orden
Carlson
Tjon
Arenhoevel
$F_{M1}(q)$
q (fm^{-1})

Want and can extend F_{M1} to larger q

proposal already on the books

can be done at 6GeV

Challenge for future

role of quarks

explicit in w.f. and MEC

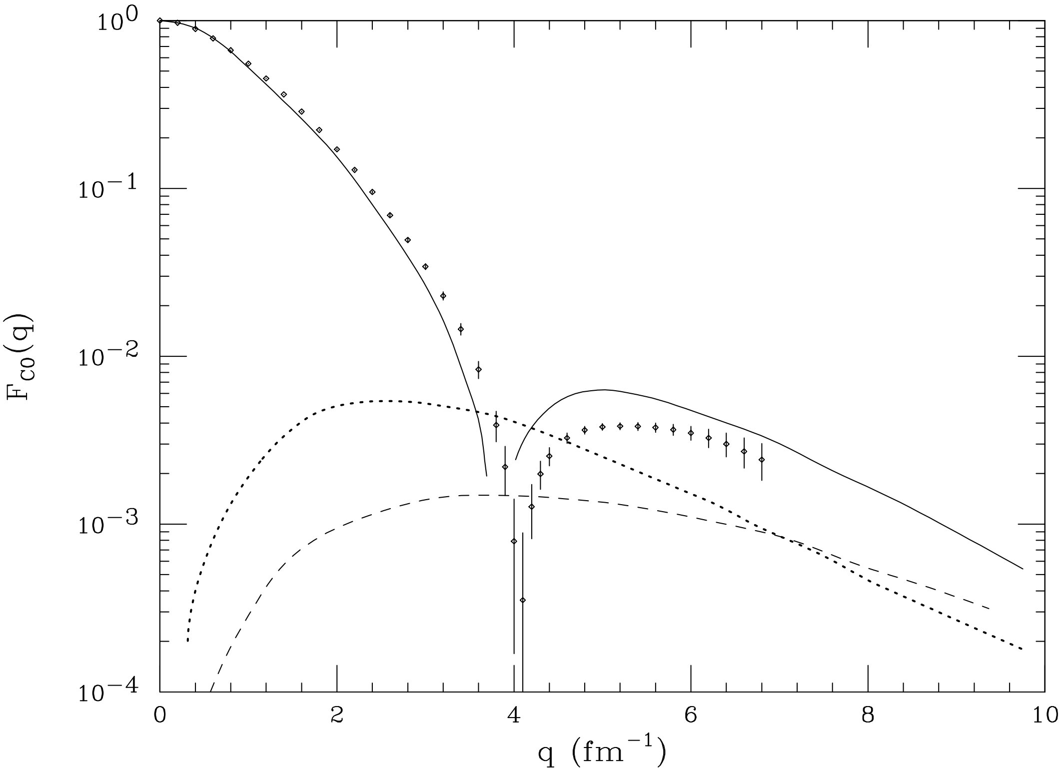
example: calculation of Buchmann

q cluster model, res. group technique

$\pi + g$ exchange on 1+2-N level

add. exchange-contribution - - -

not sufficiently sensitive at present q



much more sensitive at larger q

T_{20} at 12GeV

can gain factor 4 from energy

can gain factor 2 from analyzing power

new polarimeter (d-p elastic scattering)

can gain factor 2 from design for limited q-range

$\longrightarrow$ can get important extension in q-range

$\longrightarrow$ very worthwhile effort

A(q) to higher q?

estimation in proposal to $10GeV^2/c^2$

doubles q^2-range

Cited interest:

verification/confirmation pQCD

$$F_D \sim \sqrt{A} \sim q^{2(N-1)} \sim q^{-10}$$

bad reason

pQCD only valid if $q/N \gg k_F$

is (at $q^2 = 10$) $0.4GeV/c \gg 0.6GeV/c$??

If apply same thinking to nucleonic form factor

(N=2, k_F=80MeV/c)

expect: asymptotic behavior of F_{C0} at $q \sim 100MeV/c$

obviously ridiculous

F has diffraction zero at 100 times larger q^2 !!

non-applicability similarly shown by G_{ep}

has zero or kink at $Q^2 \sim 8GeV^2/c^2$!

need real calculation of wave function!

Early calculations available

e.g. Dijk+Bakker, Buchmann *et al.*
quark cluster model
antisymmetrized q-wave function of N
large-r behavior described by V_{NN}
still too phenomenological

A=3 nuclei

unique systems
4 form factors
C0, M1, T=0, T=1
best chance to disentangle physics
valid approaches must explain *all* form factors

achievements of past: maximum q's:

^3H charge: $7 fm^{-1}$
^3H magnetic: $7 fm^{-1}$
^3He charge: $10\ fm^{-1}$
^3He magnetic: $8 fm^{-1}$

Comparison to theory

large effect of MEC
in both C0 and M1
small effect of Δ
calculations do amazingly well
T=1 more sensitive than T=0
need both H and He to separate

Calculations

Marcucci et al

pair-correlated hyperspherical harmonics approach
AV18, UIX 3-body force
π and ρ MEC from V_{NN}
$\rho\pi\gamma, \omega\rho\gamma$ separate

Marcucci et al

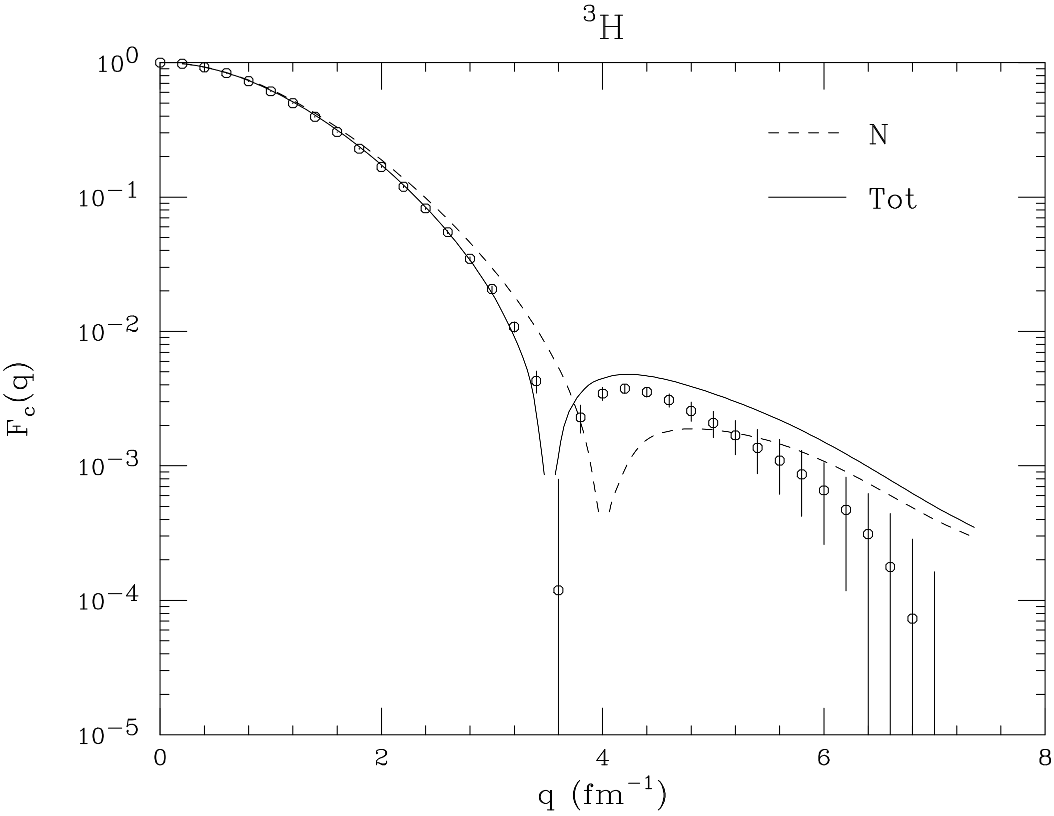
include Δ
AV28Q NN-interaction

Sauer et al

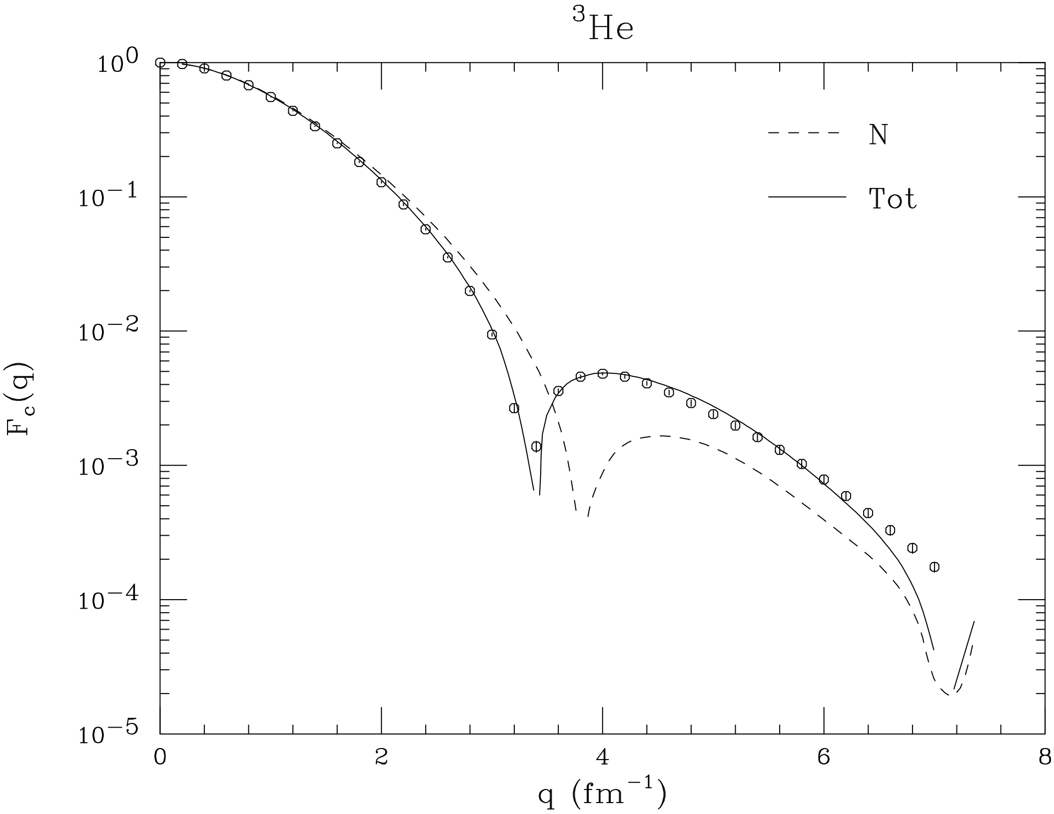
coupled N-Δ Faddeev
Paris, refitted to include Δ
(includes important 3-body piece)
$\pi, \rho, \rho\pi\gamma$ added

Schiavilla et al

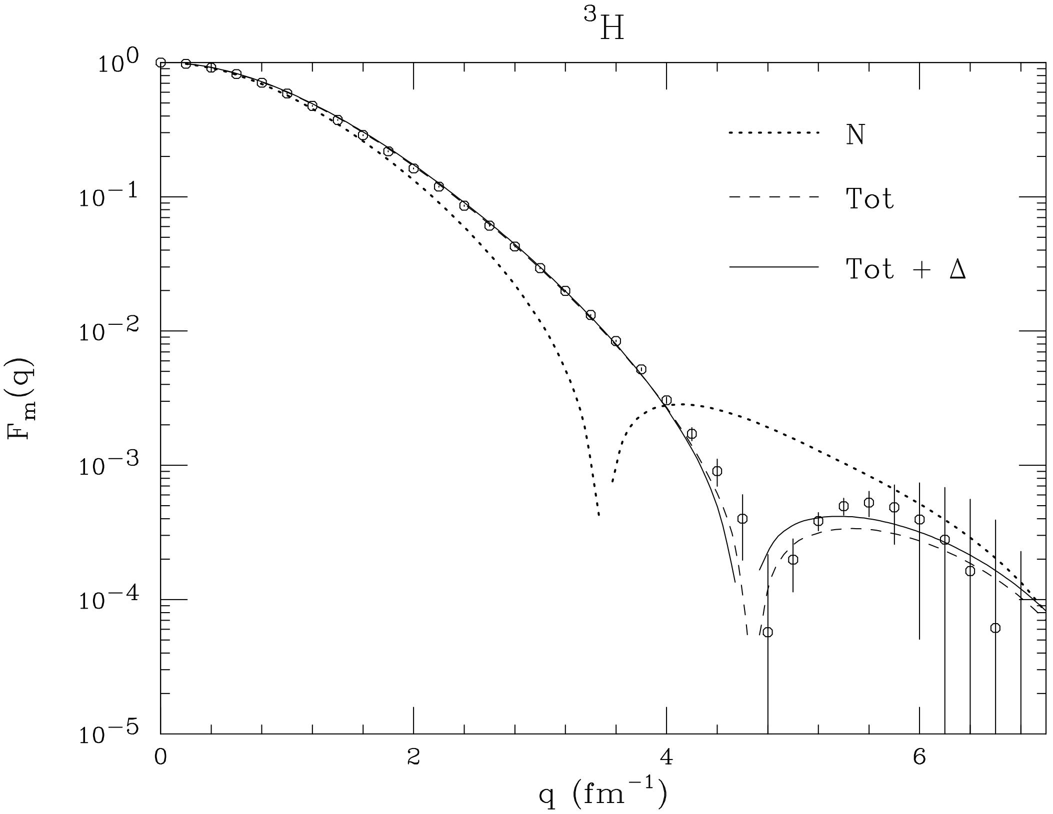
Variational wave function
Argonne V14, Urbana 3N
π and ρ MEC from V_{NN}
$\rho\omega\gamma$ separate



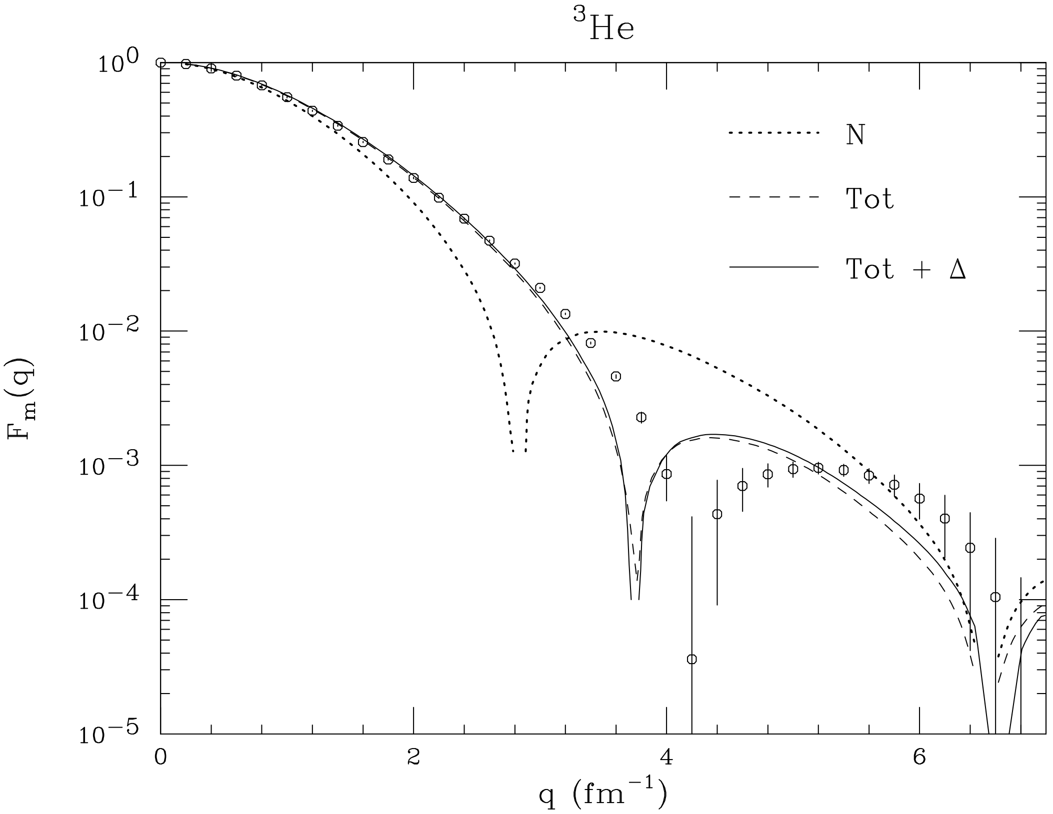
^{3}H
N
Tot
$F_c(q)$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
2
4
6
8
q (fm^{-1})



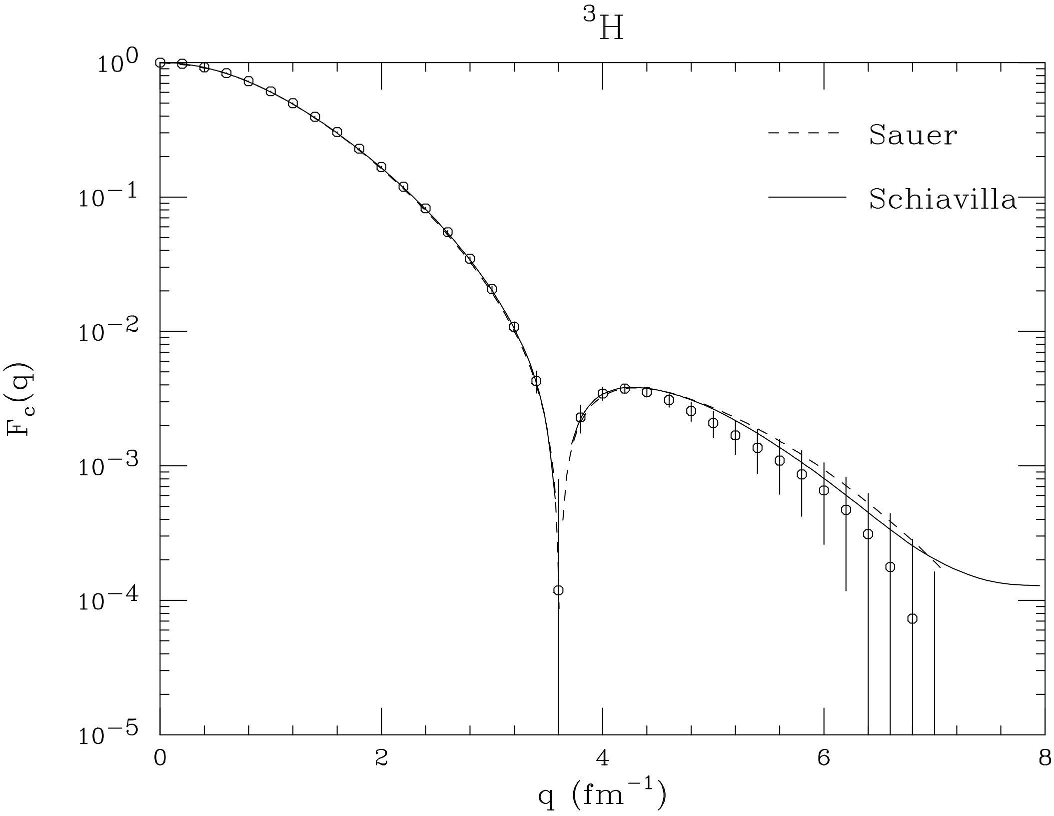
^{3}He
N
Tot
$F_c(q)$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
2
4
6
8
q (fm^{-1})



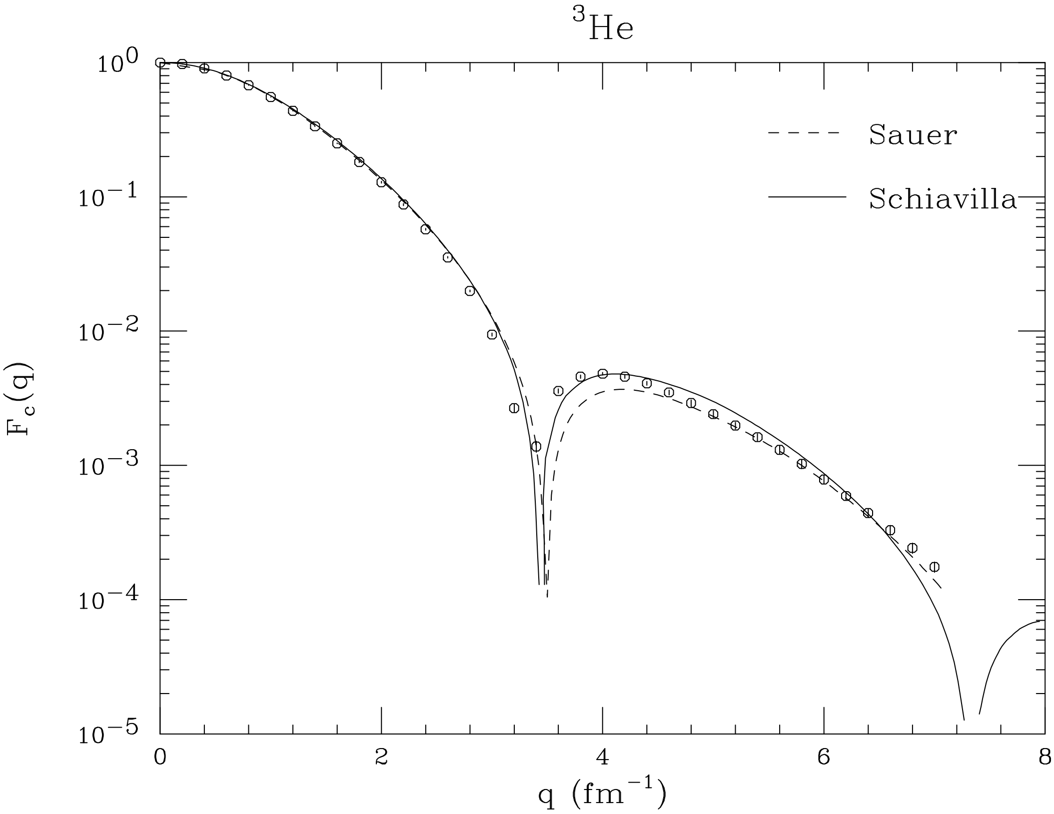
^{3}H
N
Tot
Tot + Δ
$F_m(q)$
q (fm^{-1})



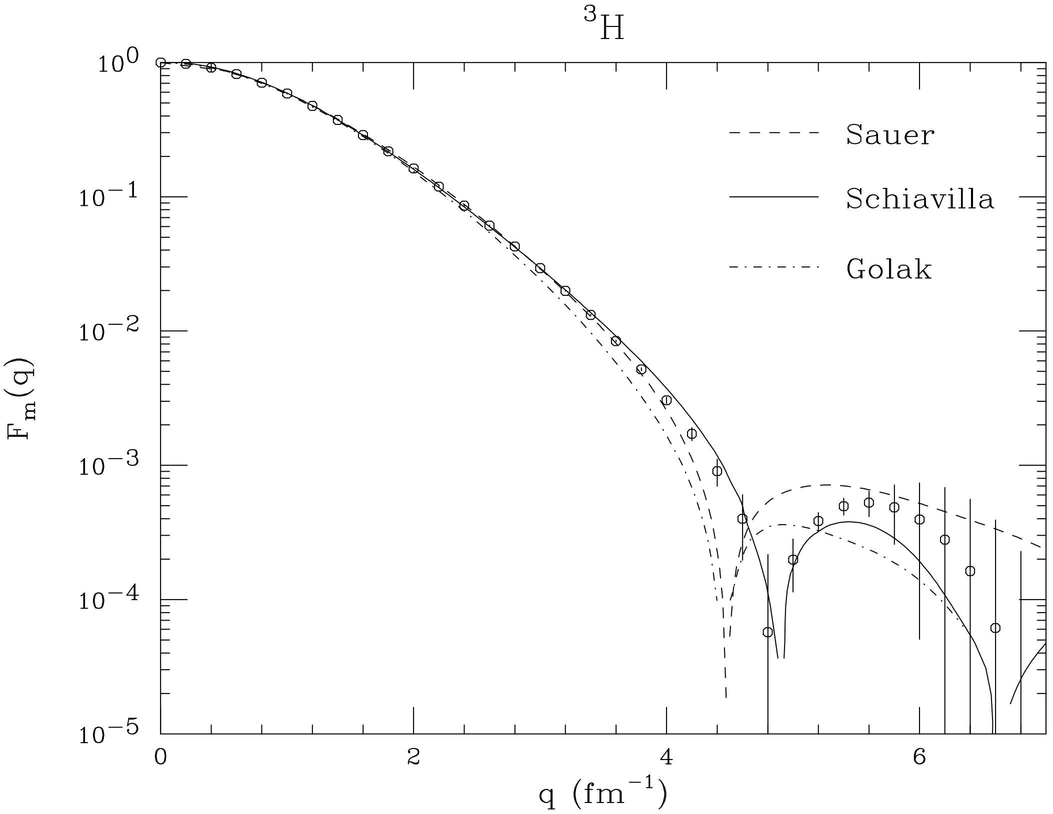
^{3}He
N
Tot
Tot + Δ
$F_m(q)$
q (fm^{-1})



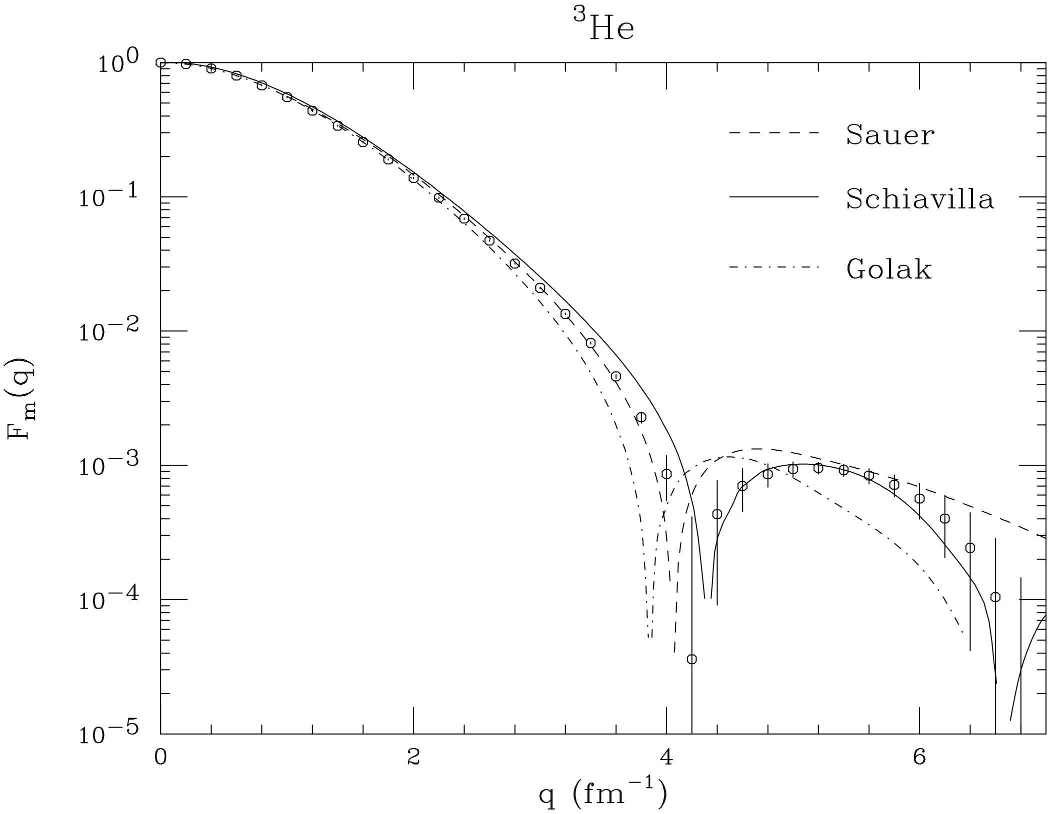
^{3}H
Sauer
Schiavilla
$F_c(q)$
q (fm^{-1})



^{3}He
Sauer
Schiavilla
$F_c(q)$
q (fm^{-1})



^{3}H
Sauer
Schiavilla
Golak
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$F_m(q)$
0
2
4
6
q (fm^{-1})



^{3}He
Sauer
Schiavilla
Golak
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$F_m(q)$
0
2
4
6
q (fm^{-1})

What can do in future

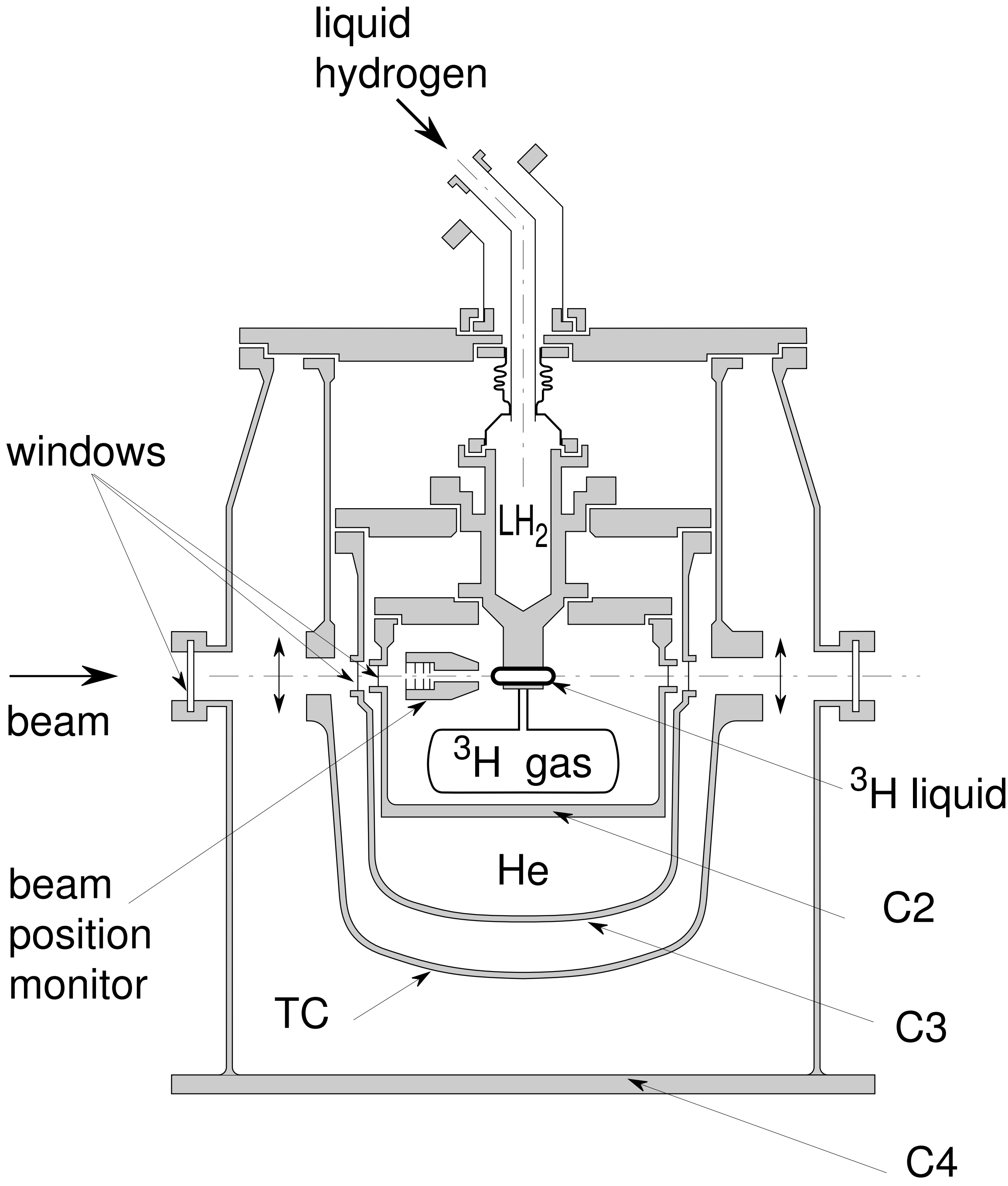
^3H to large q

- presently limited by E$\sim$700MeV
- at 10GeV can gain factor 200 in σ
  - need to detect recoil
- can push to similar q as ^3He
- can double q^2-range of T=0,1 separation

^3H target: safe design available

Saclay liquid target

- multiple enclosures
- high thickness
- well known density
- low pressure (3 bars)
- good utilization of ^3H (98%)
- closed system
  - no manipulation of ^3H on site
- only 10kC

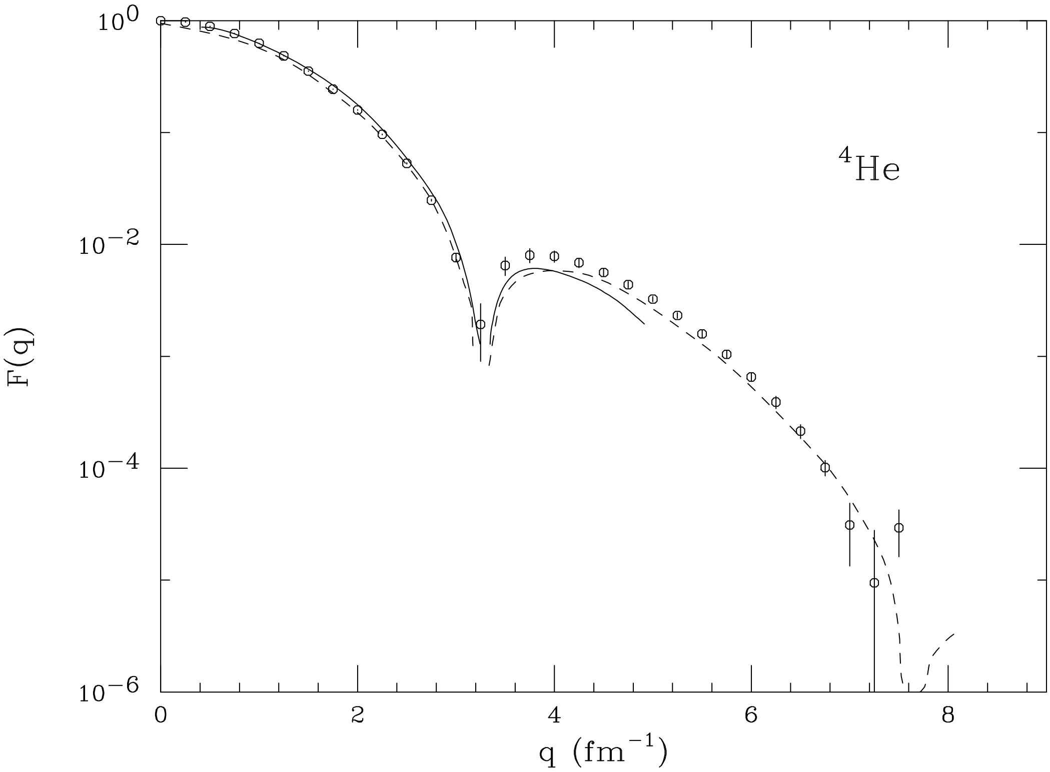

liquid
hydrogen
windows
LH_2
beam
beam
position
monitor
^3H gas
^3H liquid
He
C2
TC
C3
C4

^3He magnetic form factor

can go to much larger q

proposal on table for hall-A

A=4



at 10GeV can get factor 100 relative to SLAC experiment

current

solid angle spectrometer

need to detect ^4He in coincidence?

can explore second minimum+maximum

there usually sensitive to new physics

Overall

can push maximum q to $10 fm^{-1}$ and beyond
with $1.5/q$ do reach resolution where quark d.o.f. relevant

Needed

calculations of nuclear w.f. in terms of q, g
calculations of MEC in terms of q

not yet available
can expect to become available on time-scale of
finished experiments with upgraded machine

Study of correlated strength

not F(q), not A¡¡, but highly interesting!

strength in $S(k,E)$ due to s.r. correlations

large k

large E

main problem

multi-step reactions (e,e'p) + (p,pn)

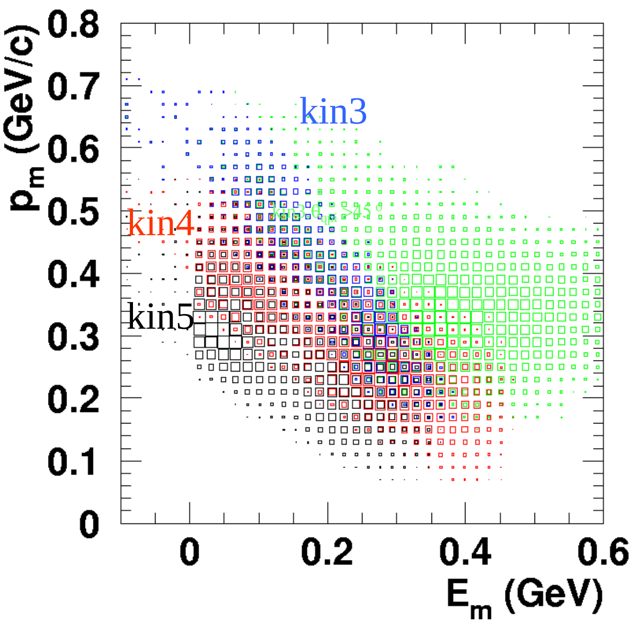
Δ excitation (e,e'Δ) + $\Delta \rightarrow p + \pi$

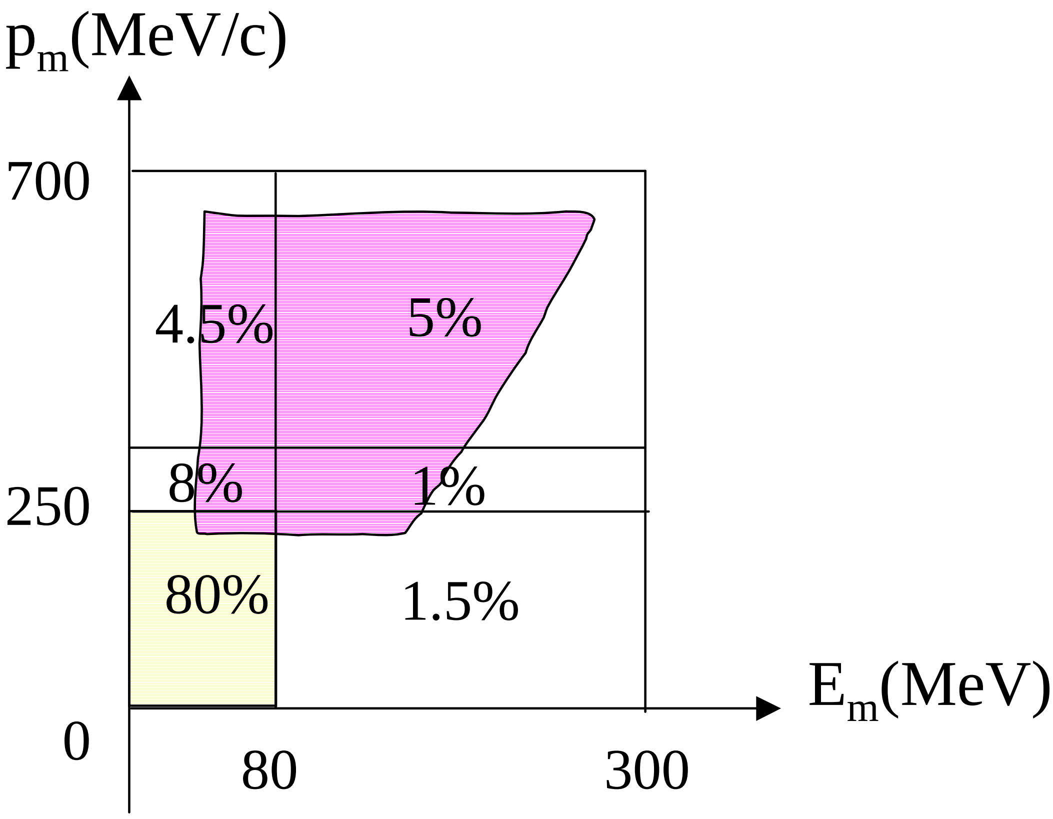
To minimize

use larger q

use strictly parallel kinematics $\vec{q} \parallel \vec{k}$

Hall-C experiment Rohe et al, only $\pm$ parallel





Results

Experiment	0.61 ±0.06
Greens function theory	0.46
CBF theory	0.64

12GeV

have kin. freedom for strictly parallel kinematics
have high q
have 2 high-momentum spectrometers
$k + q$ very large

cleanest way I know of to get at correlations!