Correlated spectral function from (e,e'p)

Ingo Sick

historical development of nuclear physics

strongly influenced by shell model
existence of Independent Particle states, IP orbits
explains many features of nuclei

tacit assumption

(2j+1) particles in 'filled' shell
depletion only due to configuration mixing near ϵ_F
can limit space to ±1 or ±2 shells
effective N-N interaction compensates
    fitted to selected nuclear properties

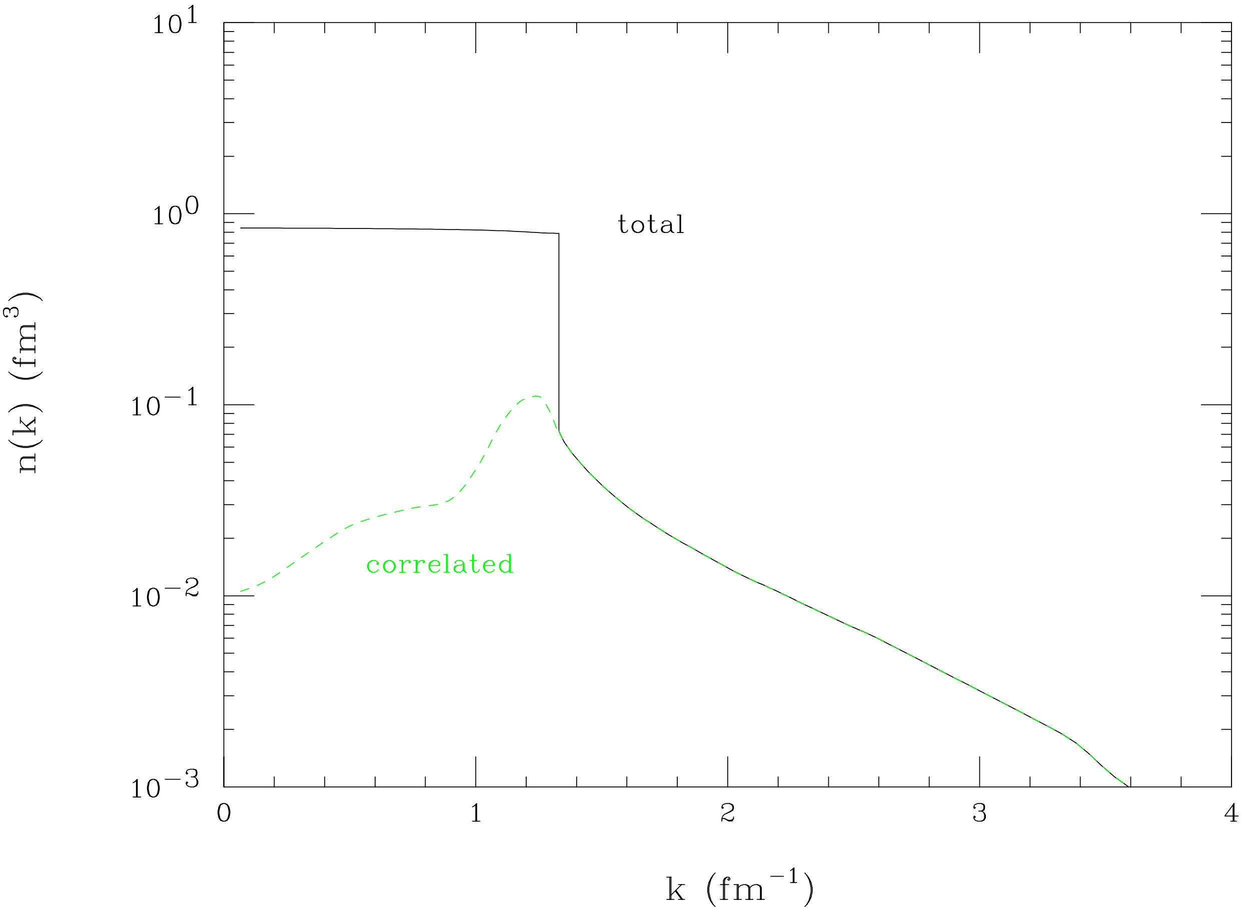
today highly developed technique

several groups worldwide
quite successful

parallel line of thought: study of NM

initially Bethe-Bruckner-Goldstone
later Correlated Basis Function theory, MC
indicate strength way above Fermi edge
indicate tail of $n(k)$ to large k

momentum distribution:



~20% in correlated region
little impact on theory of finite nuclei
spectroscopic factors seem to agree with SM

change: initiated by (e,e) and (e,e'p)

- magnetic scattering
- density differences of isobars

  measure $R^2(r)$

  do so in nuclear interior

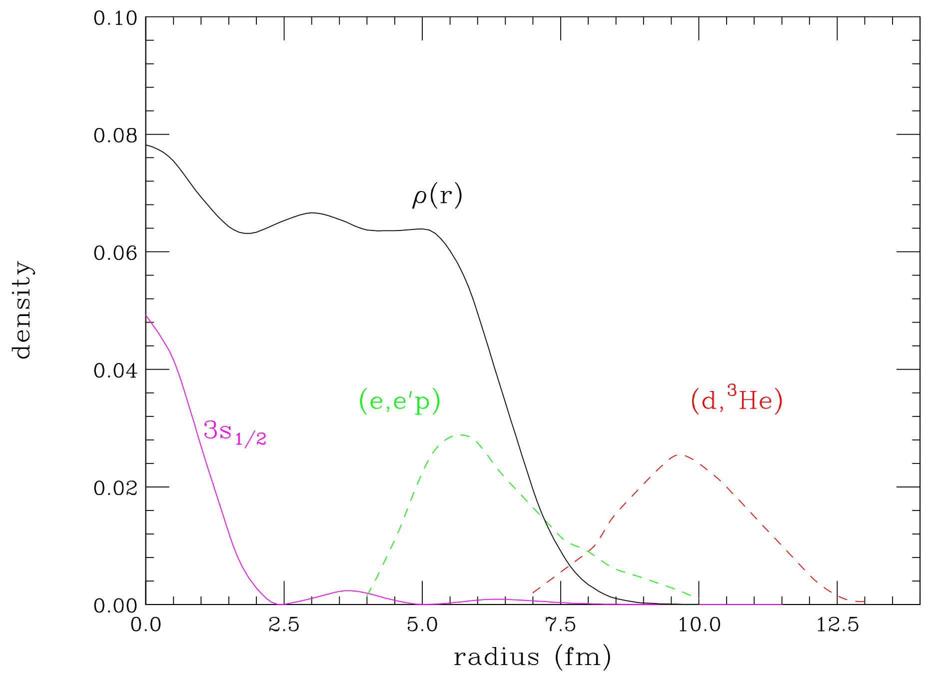
  not only in large-r region

  there spect. factor sensitive to assumed $R(r)$

  $\Delta s/s \sim 10 * \Delta rms/rms$

  can determine genuine *integral* property

  find depletion



- (e,e'p) reactions

  measure $R^2(k)$

  not as far inside nucleus, but still....

  give better integral than transfer reactions

  find significant depletion

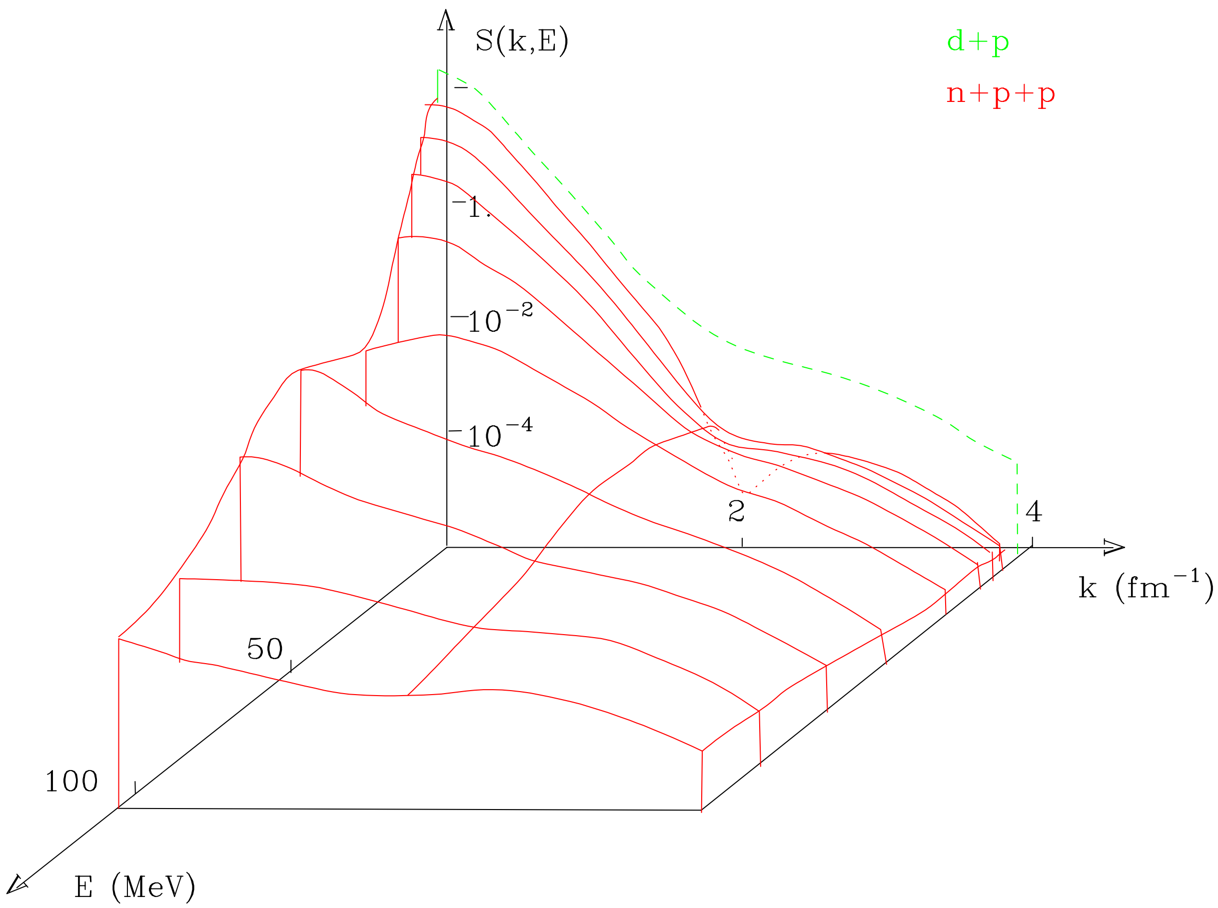
Where correlated strength in finite nuclei?

→ $S(k,E)$ of ^{3}He

- first microscopic spectral function $S(k,E)$
  - calculated by Dieperink et al
  - *exact* Faddeev wave function
    - includes all NN-correlations
    - use RSC interaction
  - 2B-breakup ∼ shell-model $n(k)$
  - 3B-breakup ∼ correlated strength
    - due to short-range N-N interaction

for long time only microscopic calculation

^{3}He spectral function



many things to be said:

- shows that correlations give strength at *both* large k and E
- strength *very* spread out, hard to identify experimentally
- explains failure of sum rules $\int ...dE = 2j+1$

  cannot include large E in integral
- failure of Koltun sumrule $\not\rightarrow$ 3BF's
- high l have only 8% probability, give 50% to kinetic energy!
- played many games to understand effect of large k, E

  in data lacking info on them

- taught me how to think about effects of correlations

  A=3 not too "pathological" to teach us

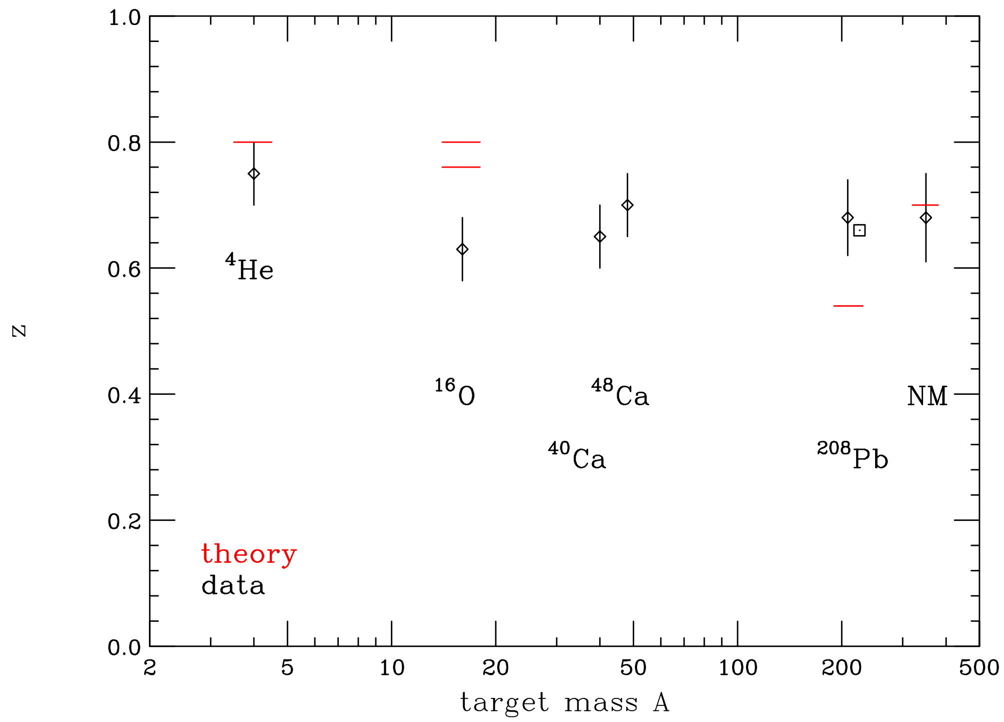
Convincing data on s.p. strength:

(e,e'p), mainly NIKHEF ($\rightarrow$ talk Louk)

high-quality experiments due to large duty factor
increased sophistication treating FSI, ..
dedicated effort

comes together with other information form (e,e)

density difference $Pb - Tl$
confirmation of SM orbitals in nuclear interior
BUT: Δoccupation 3s only 0.7
together with $(e, e'p)$, $(d,^3 He)$:
$\rightarrow$ absolute occupation



main message

in nuclei find orbits $\sim$ independent-particle states

$R(r)$, $R(k)$ as given by IPSM

observed in transitions to *low* E^*

but

single particle states have *partial occupation*

rest of strength at *very large* E^*

Similar to ∞ nuclear matter

overall

shell-model describes only 70% of nucleons

rest outside model space

how can ever get quantitative??

simply use enough parameters?

not satisfactory!

insight for time being lost on SM-community

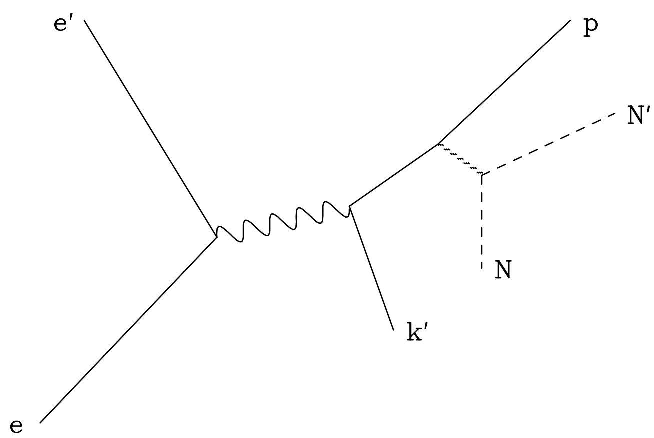
calculations of ever increasing sophistication
ignoring 20-30% of nucleons!
e.g. review Talmi, 50y of SM, 2002, 275p
not *one* word on 30%

unsatisfactory:

have identified *missing* strength
have fair theoretical understanding
have not seen *correlated* strength

Complications:

- strength spread out over 100-200MeV
  very hard to observe
- reaction mechanism
  – at low E, $k_{p'}$ optical potential for FSI OK
  – at large E, $k_{p'}$ more complicated
  p' not 'swallowed' by Im(V)
  p' reappears at lower $k_{p'}$
  simulates large missing energy E
  covers small genuine strength



Complications largely ignored

could not do much about

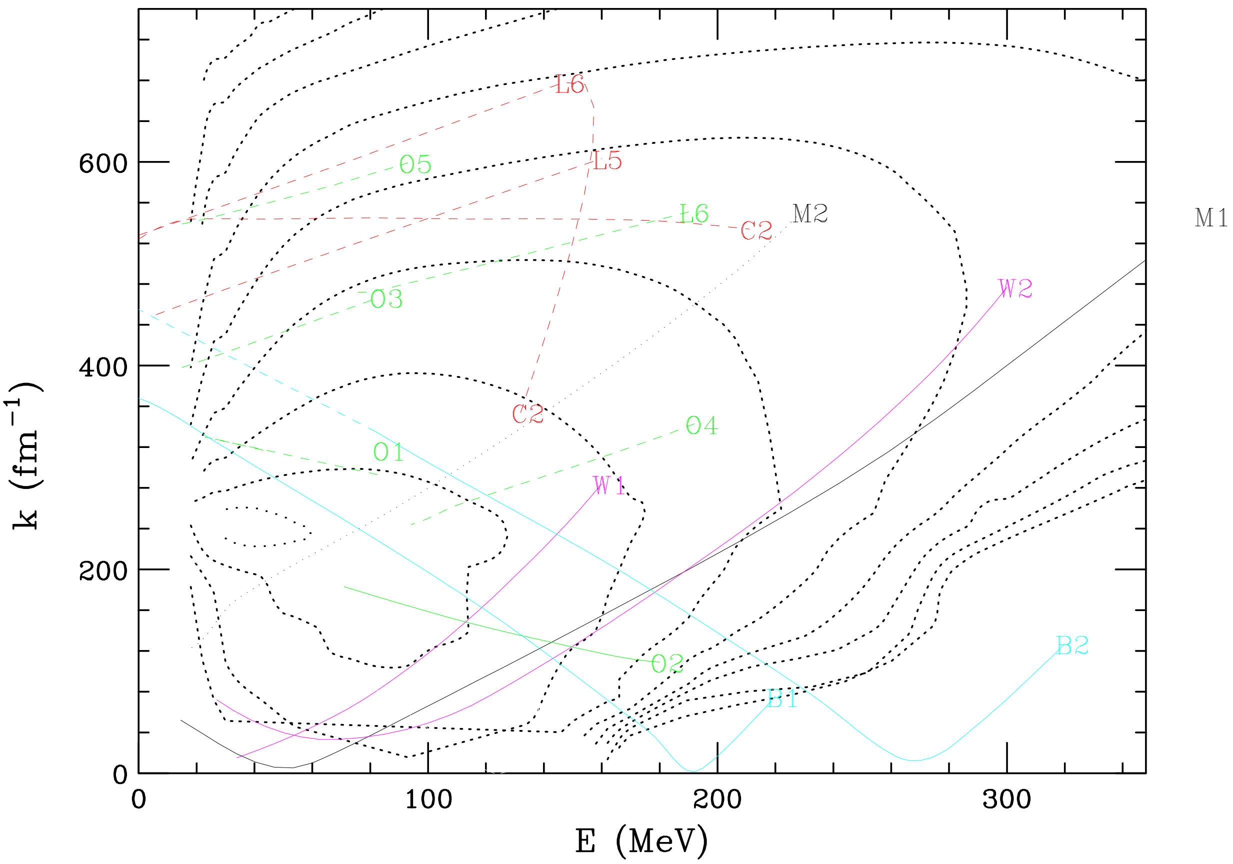
kinematics too constrained by facilities available

not enough energy/momentum available

study of all available data

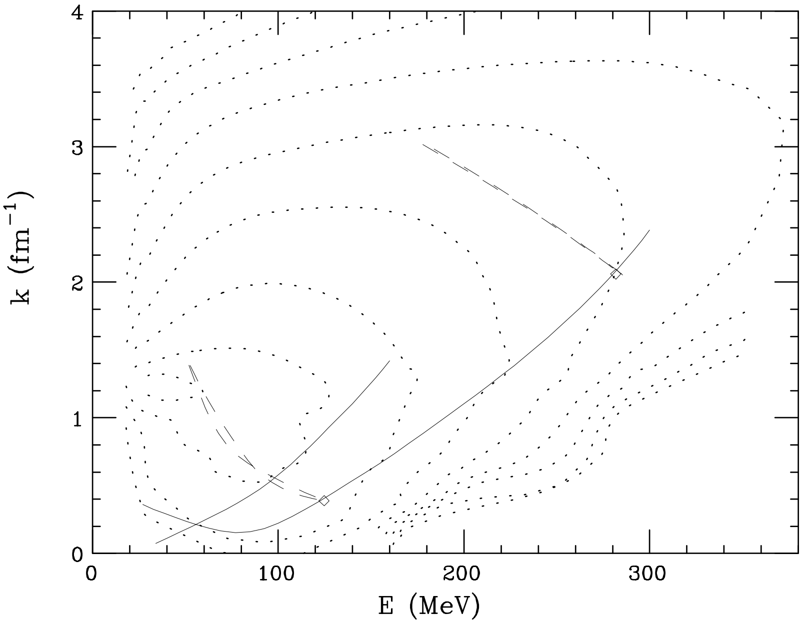
compare experimental $d\sigma/d\omega dE$ to IA using realistic S (IPSM + NM(ρ) in LDA)

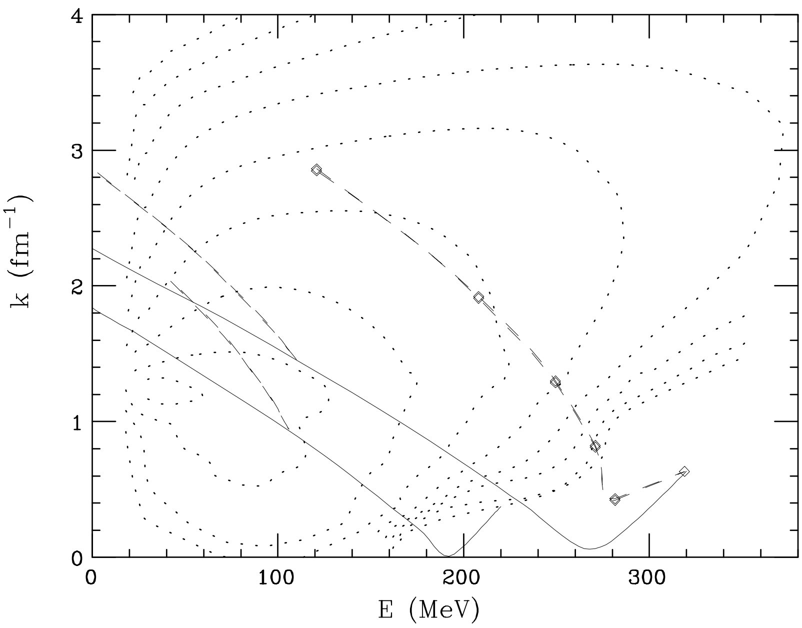
look if exp. $\simeq$ or $>>$ theory



find

- most experiments give $\sigma_{exp} \gg \sigma_{IA}$
- standard perpendicular kinematics worst, // kinematics best
- understand how $(p, 2p)$ moves strength





consequence:

must do experiment in *parallel* kinematics, at large q,
(available data are for perpendicular kinematics)
above ridge $E \sim k^2/2m$
to have chance

similar study for π-production contribution

Δ excitation

can give large contribution
mainly from low E' as m_π small

L/T - separation?

Δ-excitation transverse
can suppress by extracting L?

2-step processes:

L/T not possible
do not know intermediate state
cannot reconstruct momentum,..
e.g.: could be out-of-plane
do L/T as were in-plane

L/T extremely limited

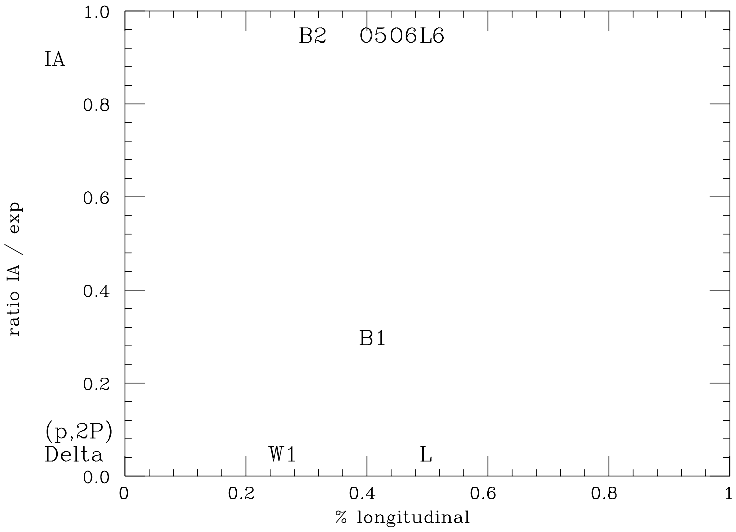
if T factor 5 larger than L error on L huge
known from (e,e'), Coulomb sumrule!
more true for (e,e'p) as more difficult

L/T in existing data

plot σ_{IA}/σ_{exp} versus %L

if T problem, expect ratio closer to 1 for large L

Data:



show *no* correlation

L/T not efficient for reasons mentioned

Conclusion: understand why

some experiments measure ± S(k,E)

others measure multistep reactions

no obvious need for new mechanism

conventional (p,pN)+Δ-excitation enough

lesson for future

kinematics for measurement of S(k>>,E>>)

such that k'>>k, E'>E

parallel kinematics!

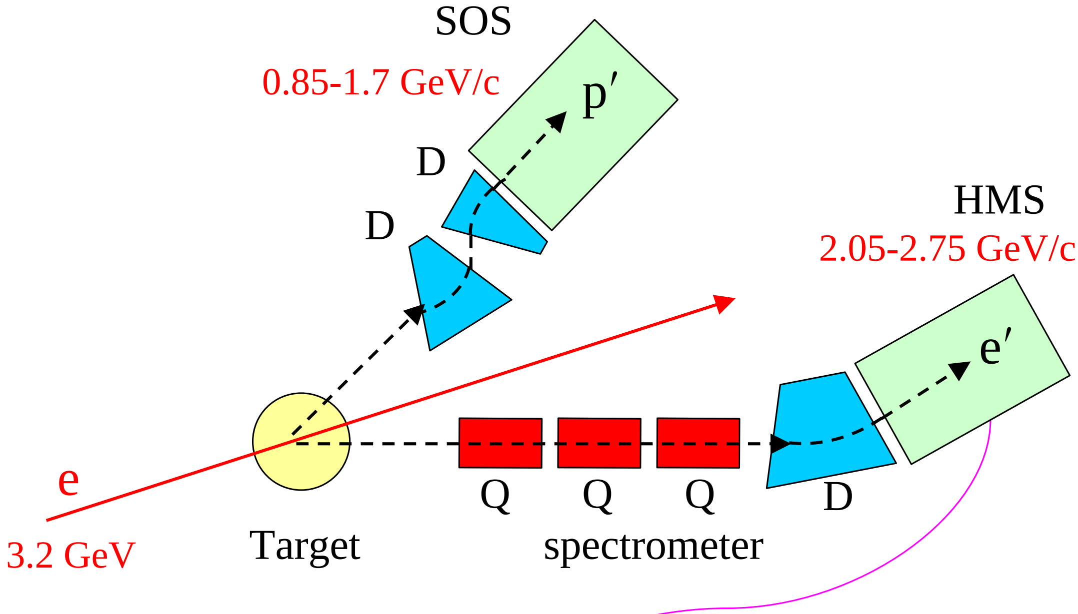
not antiparallel, not perpendicular

not L/T

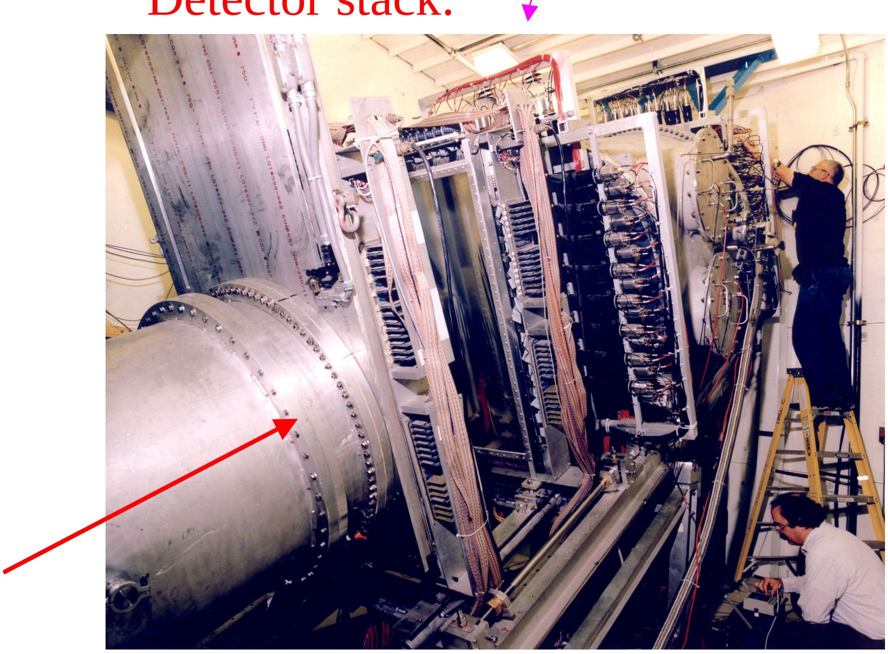
not dip vs. other kinematics

JLAB experiment

Setup in Hall C at Jlab: (e,e′p)



Detector stack:

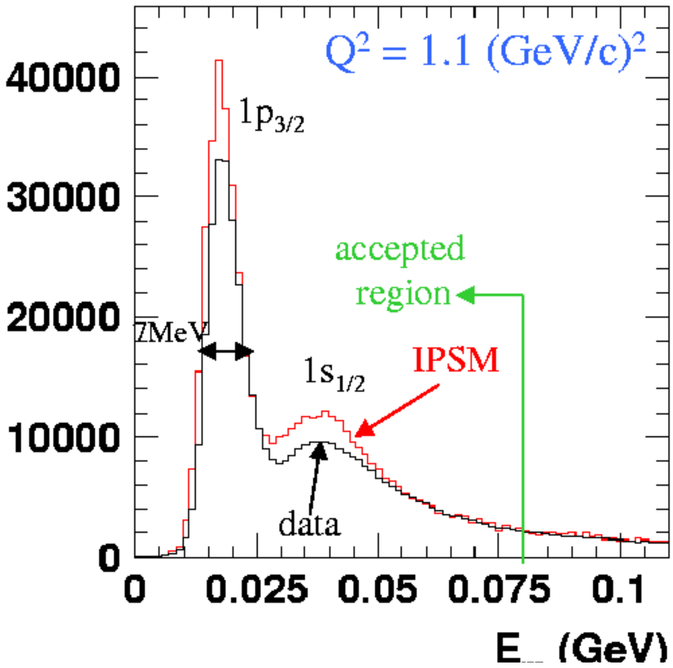


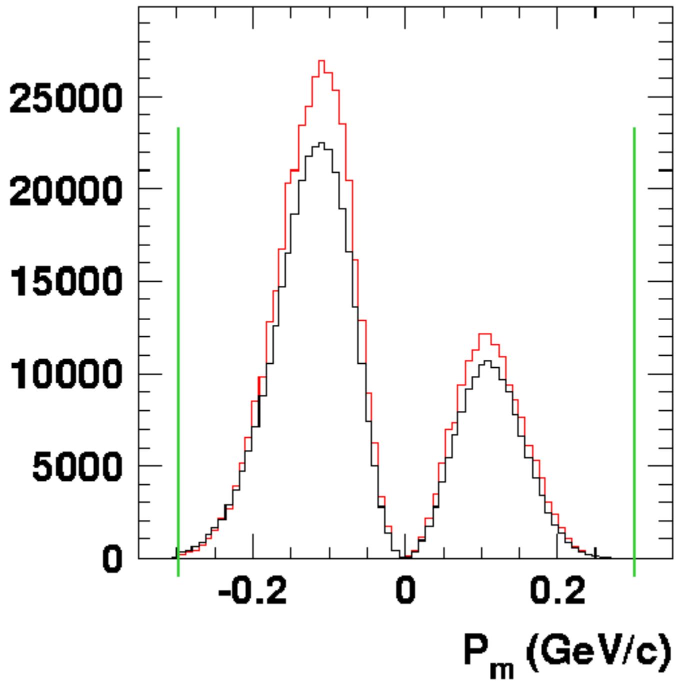
2 drift chambers | 4 scintillator planes | 1 Cerenkov

Results from Daniela Rohe

test: s.p.-region

kinematics with same $E_{p'}$ as production runs





use:

T=0.6.. (Benhar+Pieper)

integrate over E <80MeV

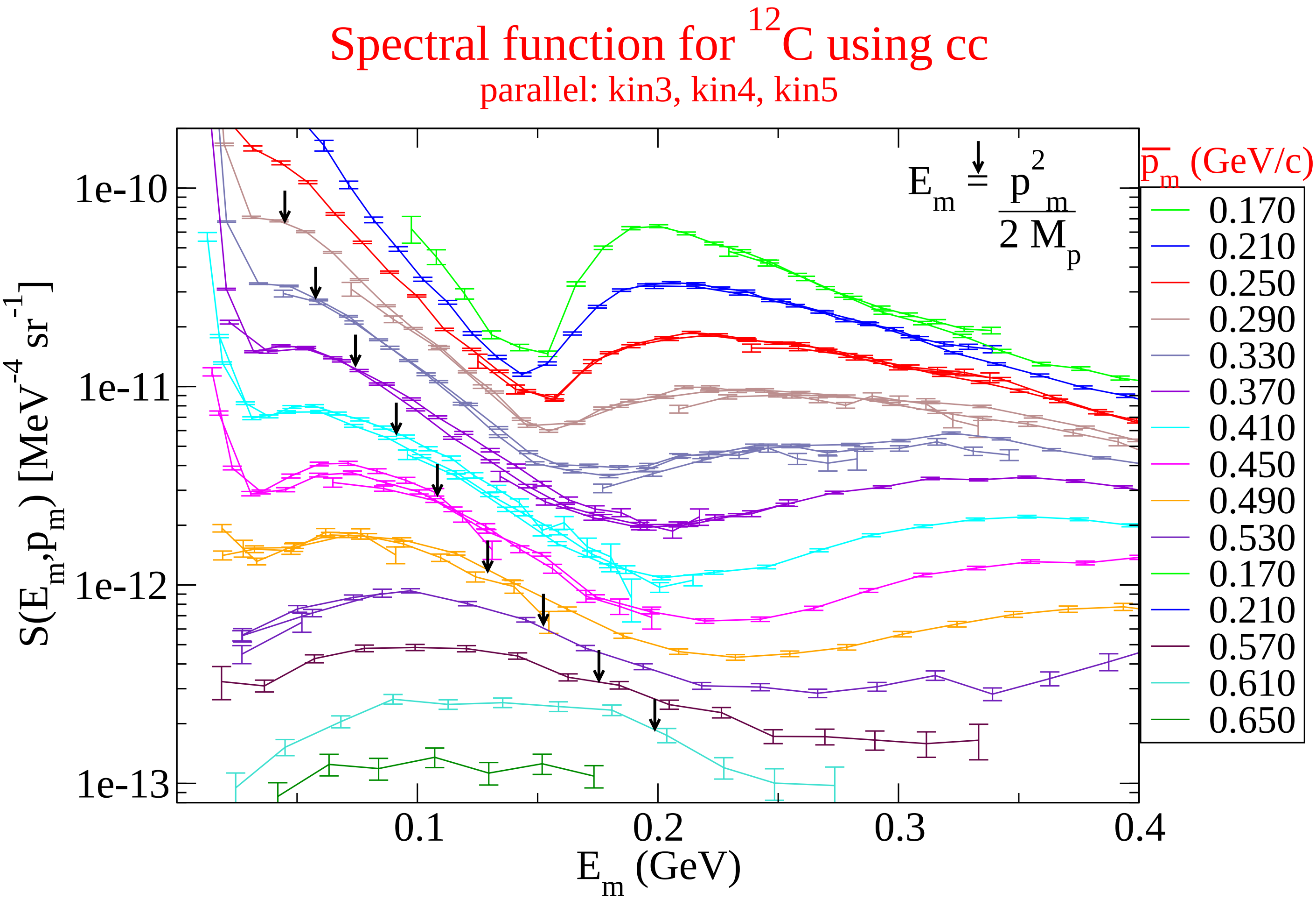
find:

occupation agrees with Benhar $S(k, E)$

(significantly larger than values from low-q (e,e'p))

overall syst. error 3%

correlated region

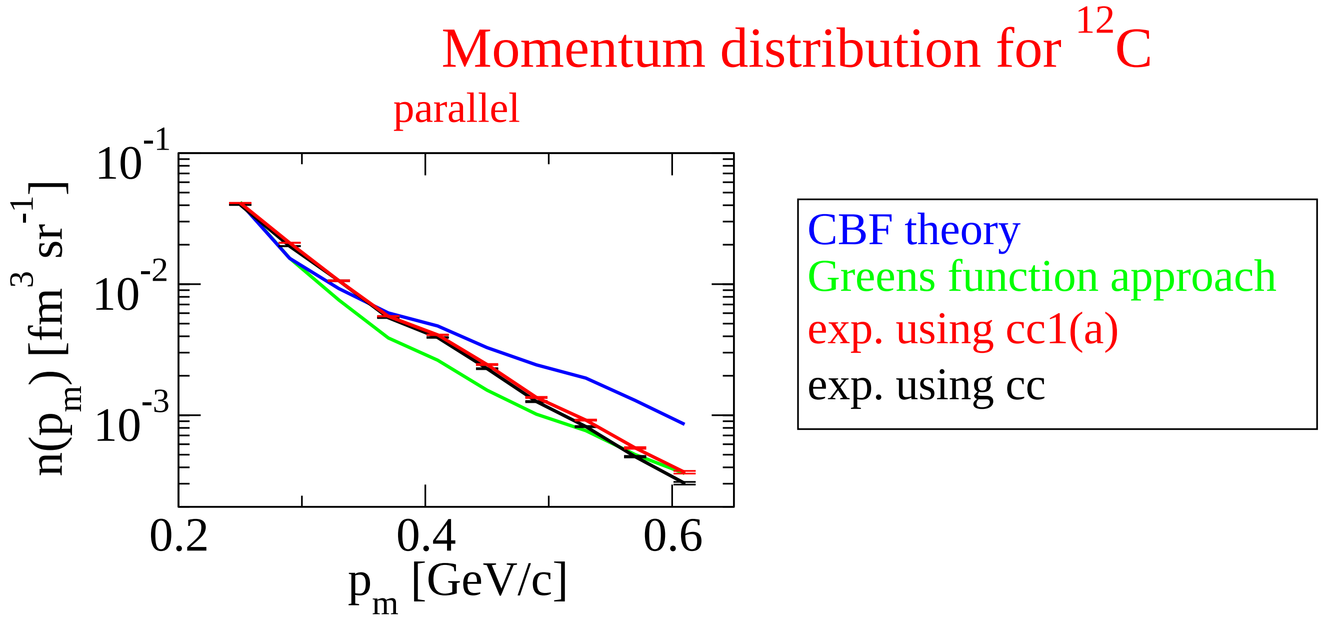


main observation on E-dependence

maximum of $S(k,E)$ of theories at too large E

understood by recent calculation of Müther+Polls?

momentum dependence



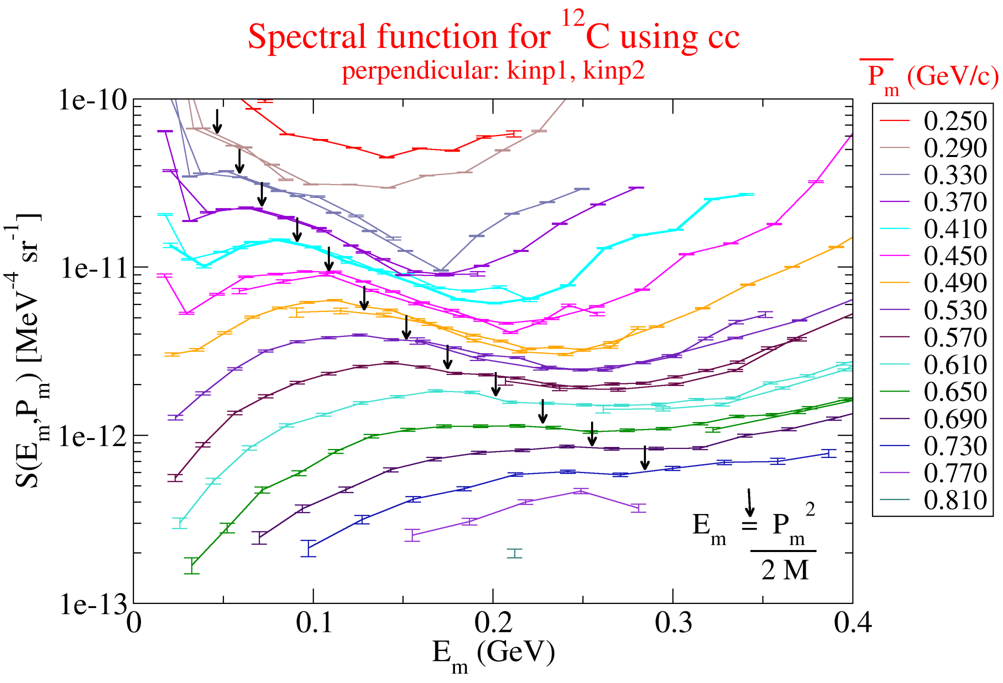
theory and experiment $\pm$ agree

how about standard perpendicular kinematics?

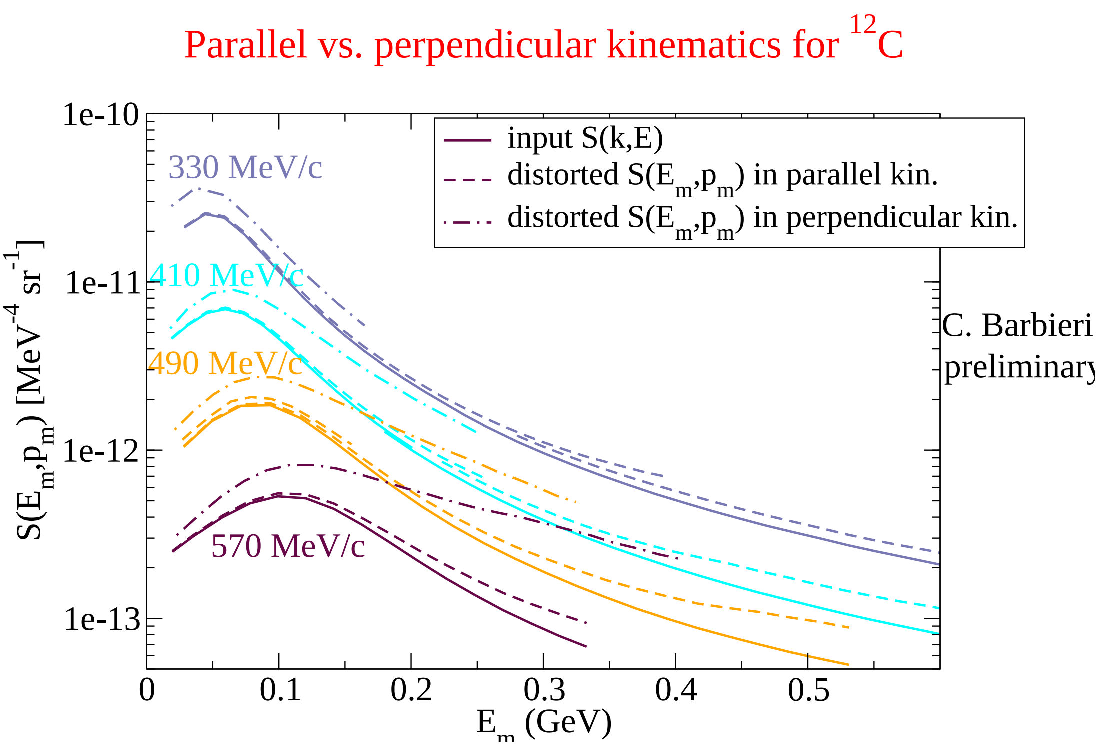
(used for overwhelming majority of experiments)

find

experimental (distorted) $S(k,E) >> S$ from parallel kinematics



confirmed by calculation (→ talk Barbieri)
include (p,p'N) via Glauber



lesson

use parallel kinematics

not perpendicular, not antiparallel

there 2-step manageable in size

can be corrected for

use perp. kinematics to check FSI-calculation

(improvements needed)

note

parallel kinematics → 'dip'region

used as argument to avoid

excess strength in single-arm (e,e') in dip

not understood by most

difference missing energy ... energy loss

(e,e') in dip

large energy loss

large missing energy

(energy not accounted for)

(e,e'p) in dip

large energy loss of electron

energy recovered via outgoing proton

no large 'missing' energy

unaccounted energy loss →

problematic out-of-control reaction mechanisms

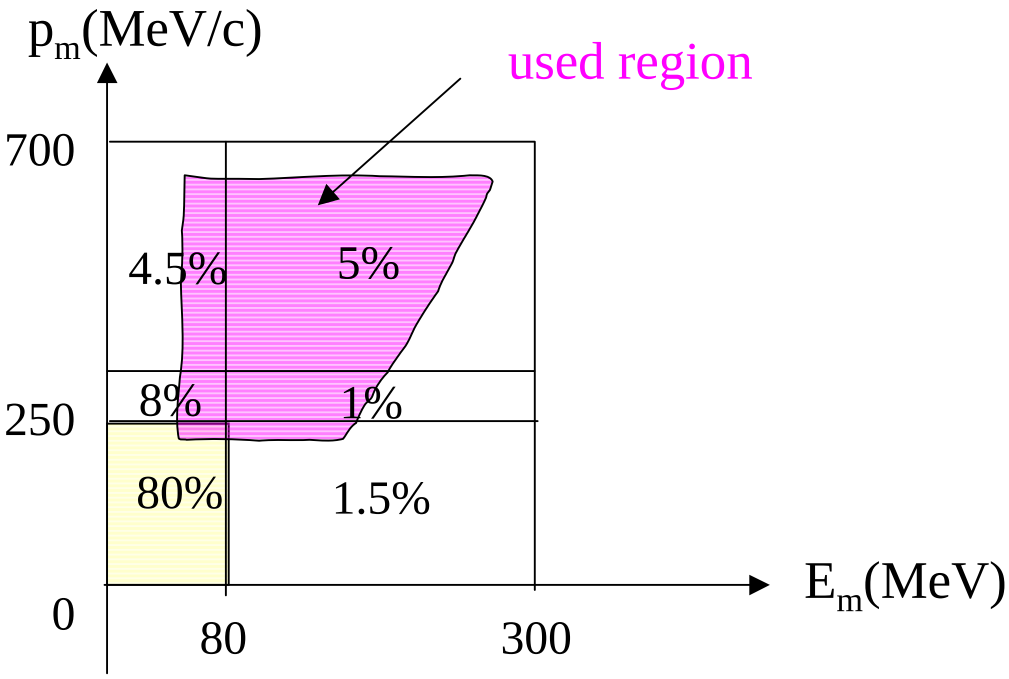
How much correlated strength??

cannot integrate over entire correlated region

FSI and Δ-excitation and part of s.p.strength limit

integrate over 'clean' region

both data and theories



result

integral over S from experiment	0.55
integral over S from CBF	0.59
integral over S from GF approach	0.53

good agreement

heavier nuclei

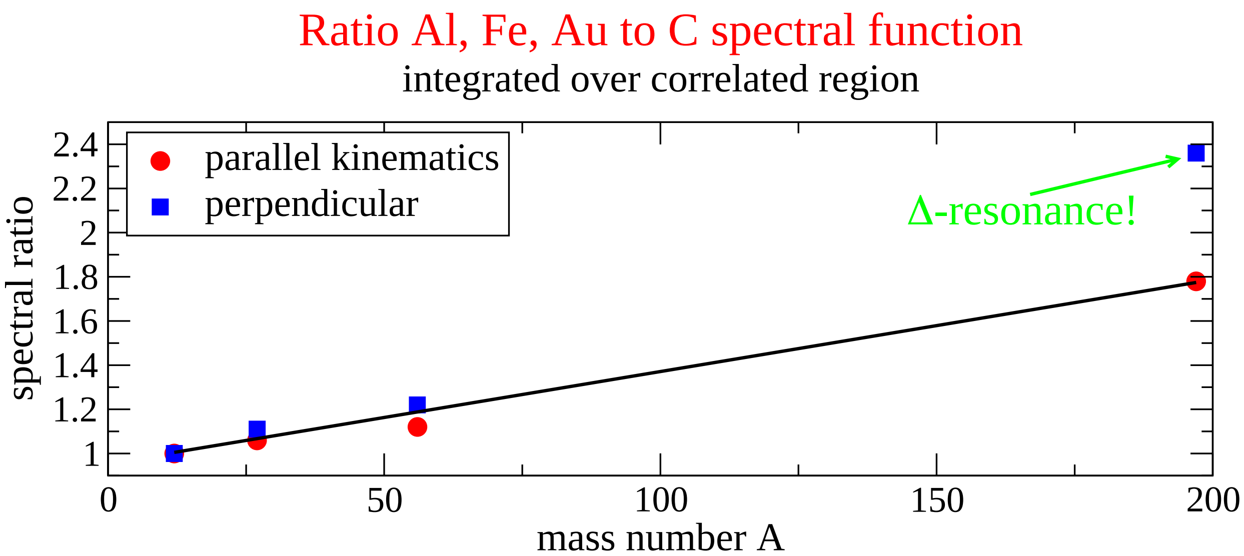
experiment performed for C, Al, Fe, Au

interest in A>>

→ nuclear matter

study of FSI of recoil-p

ratio to C of correlated strength



enhancement for Au

not yet understood

consequence of tensor correlations as $N > Z$??

effect of rescattering ??

Summary

- perform experiment with optimized kinematics
  to minimize multi-step contributions
- identify strength at large k, E
- theory produces $S(k, E)$, $\pm$ correct strength (BHF, CBF+LDA)
  E-dependence does not entirely agree
    strength at too low E
    enhancement for large A not understood
- would want kinematics more strictly parallel
  rather restrictive kinematics
  unfavorable true/accidental
  but it's worth it!

for details:

see habilitation work of Daniela Rohe

Problem with disagreeing occupation numbers: ^{12}C

Lapikas, low-q (e,e'p):

summed s+p strength = 3.40

(add 0.12 for weakly excited states)

Rohe, high-q (e,e'p)

(similar for analyses of SLAC, JLAB data)

integrated strength (E=80) = 4.68

(uses T from Benhar+Pieper)

includes $\int_{40}^{80} = 0.3$ (n_{corr}=1.26!)

noted in paper by Lapikas et al

question: which is true occupation? is q-dependent??

open: quality optical potentials

role MEC's

coupled-channel effects

effect relativity

value of T

. . . . .

test

- use $n(k)$ from (e,e'p)
  transform to r-space
  calculate s.p.-contribution to (point) density

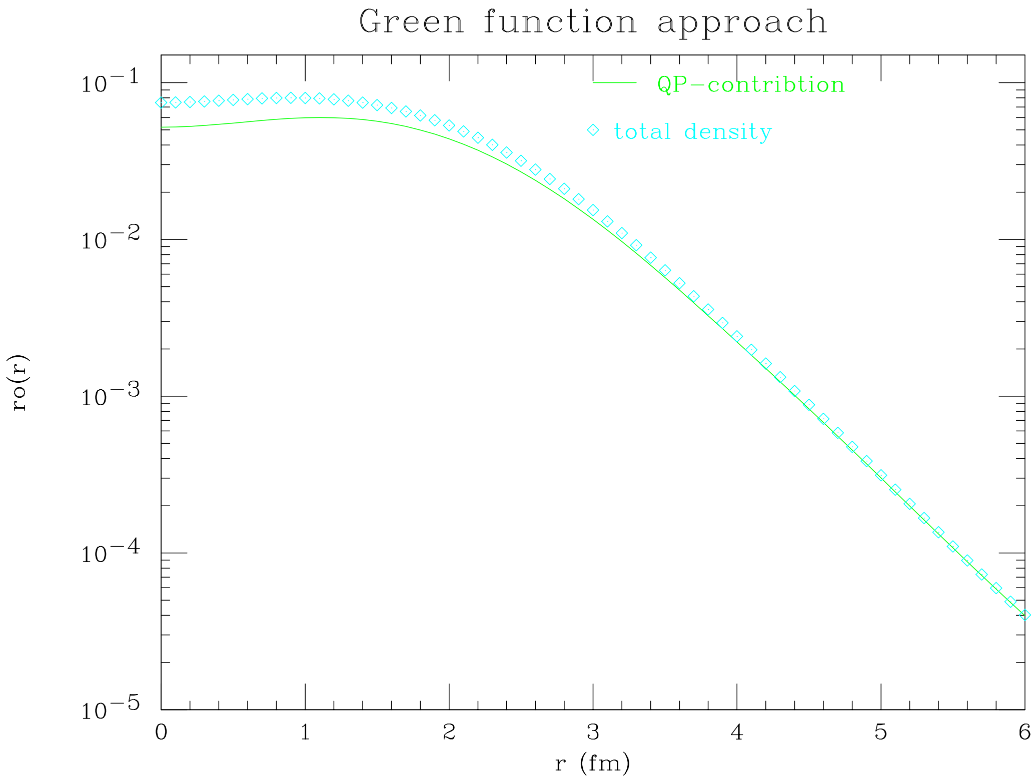
- use charge density from (e,e)
  unfold n+p-size to get ρ_{point}
  compare

expectations

at large r asymptotic tail of $R^2(r)$
dominated by *single*-nucleon properties
expect $(n_s R_s^2 + n_p R_p^2) = \rho_{point}$

confirmed by Greens-function calculations

Müther+Polls

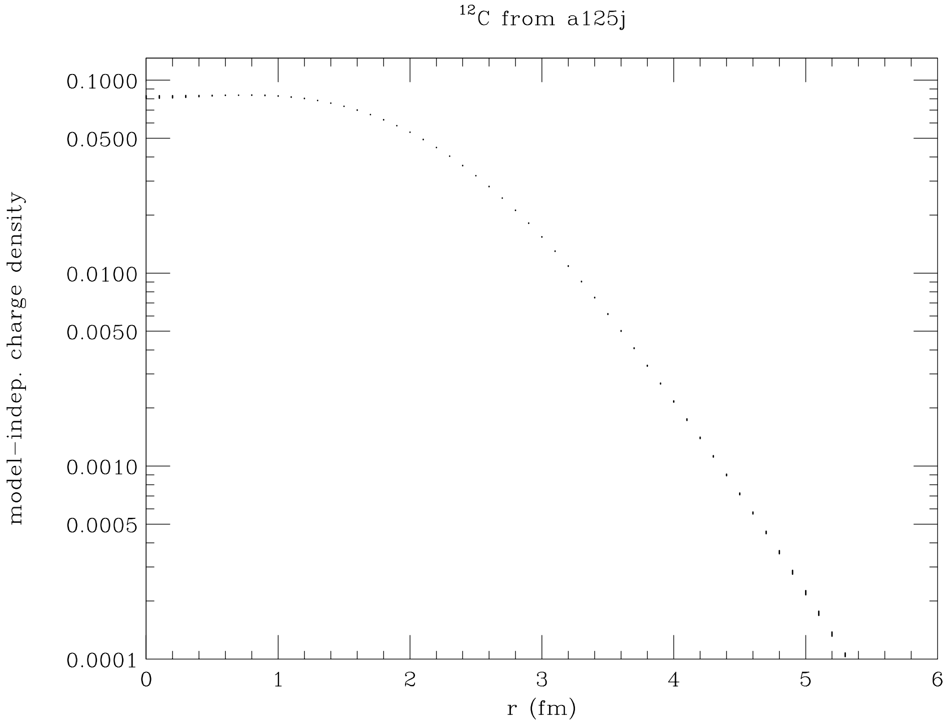


^{12}C charge density

world data (e,e)+μ-X

model-independent analysis

$\longrightarrow$ large-r tail accurately known



fall-off of $\rho(r)$ accurately given by SE$_{1p}$=15.9MeV

ρ particularly good check for ^{12}C

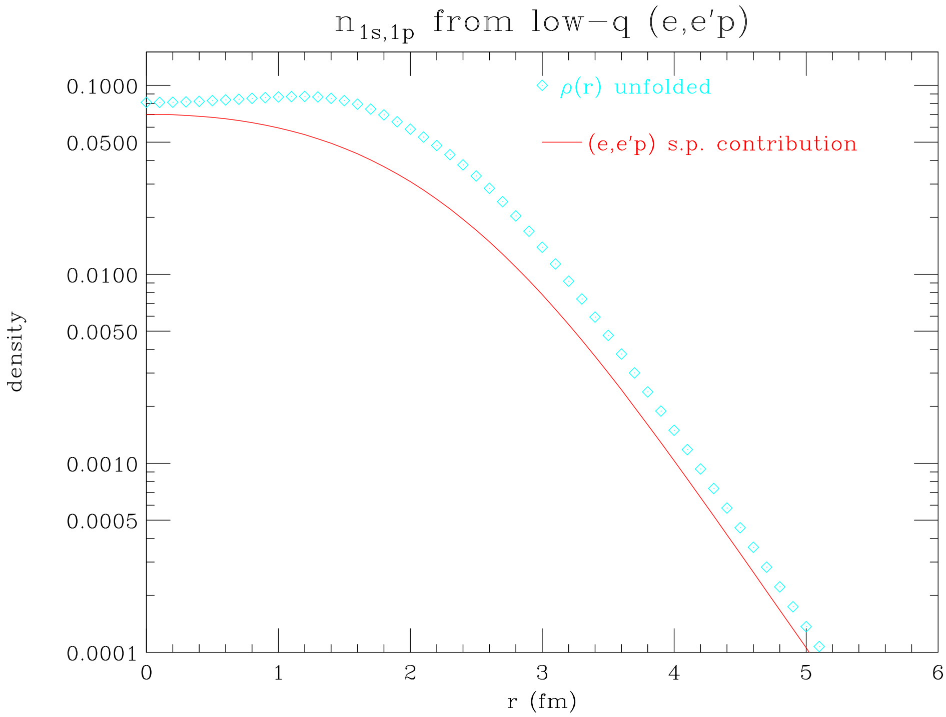
large-r density given by one shell, $p_{3/2}$, only

occupation of $p_{3/2}$ from low-q (e,e'p) particularly low

particularly clean

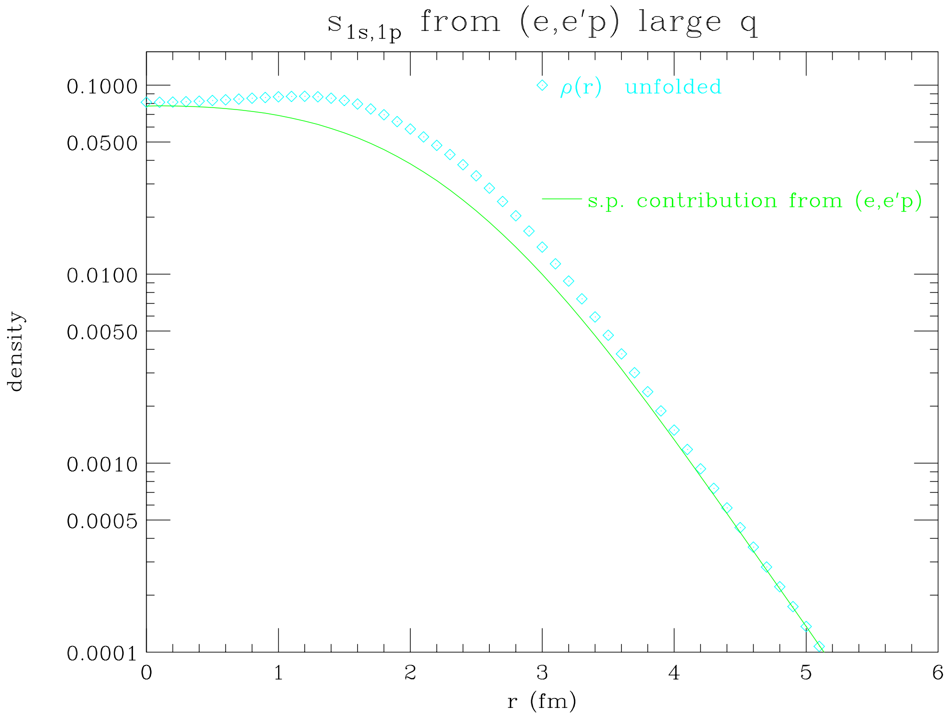
low-medium-q, ∼no MEC, only single-particle

result for low-q occupation



tail *not* explained!

result for high-q occupations



(e,e'p) and (e,e) agree!

my conclusion:

need care in comparing low-q / high-q results

spectroscopic factors of some valence states

$\neq$ occupation

with careful comparison

no significant discrepancy low-q / high-q

depletion of QP-states of $\sim$ 20% supported by

comparison s+p $\leftrightarrow$ ρ_{point}

JLAB measurement of *correlated* strength $\simeq$ theory $\pm$10%

(depletion due to correlations $\sim$ 20%)

$F_{M\Lambda}(q)$: $\overline{\alpha_\Lambda}$= 0.84 for A=49, 51, 87, 91

$^{206}Pb -^{205}Tl \rightarrow n_{3s} = 0.84$ (CERES)