Investigation of Signatures of Short-Range Correlations in Intermediate Energy Heavy Ion Collisions

- K. Hagel, et al.

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THE MOMENTUM DISTRIBUTION IN A DILUTE FERMI GAS AT ZERO TEMPERATURE

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Abstract: The momentum distribution at zero temperature in a dilute Fermi gas with repulsive interactions is calculated to second order in the small parameter $p_F a$, the quantity p_F being the Fermi momentum, and a the free-space scattering length.

TABLE 1

Calculated values

p/p_F	0.2	0.6	0.8	1−0	1+0	1.1	1.2	1.5	2.0	3.0
$\lvert\delta n(p)\rvert/\zeta^2$	1.14	1.36	1.66	2.06	0.720	0.392	0.266	0.112	0.036	0.006

According to (11), $n(p)$ varies as p^{-4} when $(p/p_F) \rightarrow \infty$. The expressions given above are not, however, expected to be valid when $pa > 1$, since the detailed structure of the interparticle force, and not just the S-wave scattering length, comes into play for such large momenta. Therefore the p^{-4}-dependence should only be taken seriously when the inequalities $p \gg p_F$ and $pa < 1$ are satisfied simultaneously.

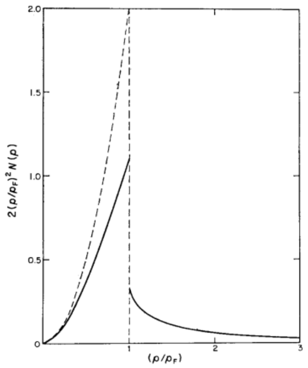

Fig. 1. The momentum distribution in an idealized dilute nucleon gas.

† Whether a discontinuity is also a property of the exact solution has been the subject of rather extensive but as yet inconclusive discussions. The interested reader is referred to ref. [4]).

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Realistic model of the nucleon spectral function in few- and many-nucleon systems

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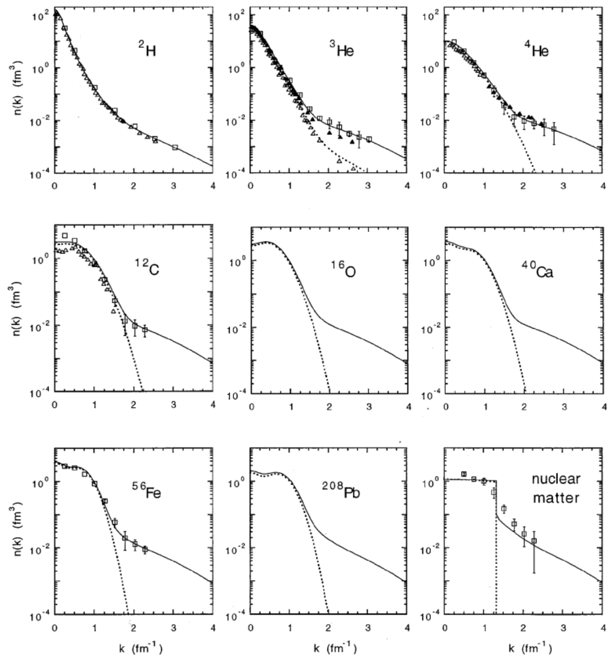

FIG. 1. The many-body nucleon momentum distribution $n(k)$ [Eq. (19)] corresponding to the parametrization described in the Appendix (solid lines). Considering the representation (22), the momentum distribution $n_0(k)$ [Eq. (25) for $A=3,4$ and Eq. (26) for complex nuclei] is given by the dotted lines. The deuteron momentum distribution has been calculated using the Paris potential [31] and the many-body results for the momentum distributions $n_0(k)$ and $n(k)$ have been taken from Refs. [20] (^{3}He) [23], (^{4}He) [24], (^{12}C and ^{40}Ca) [25], (^{16}O) [26], (^{56}Fe) [27], (^{208}Pb), and [22] (infinite nuclear matter). The normalization of $n(k)$ is $\int_0^\infty dk\, k^2 n(k)=1$. The theoretical calculations are compared with the experimental values of $n_0(k)$ and $n(k)$ extracted from the experimental data on inclusive $A(e,e')X$ and exclusive $A(e,e'p)X$ reactions. The open squares represent the results obtained within the y-scaling analysis of inclusive data for ^{2}H, ^{3}He, ^{4}He, ^{12}C, ^{56}Fe and nuclear matter performed in Ref. [2], and the full triangles are the results for $n(k)$ in ^{4}He extracted from the exclusive reaction ^{4}He$(e,e'p)X$ [6]. The open triangles represent the values of $n_0(k)$ obtained from the exclusive experiments off ^{2}H [33], ^{3}He [5], ^{4}He [34], and ^{12}C [35].

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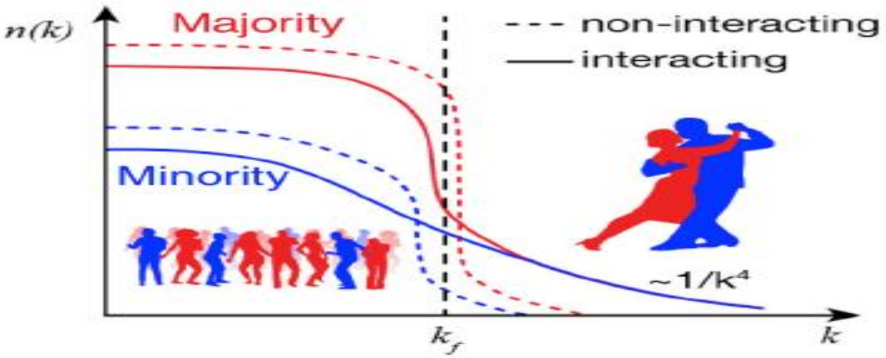

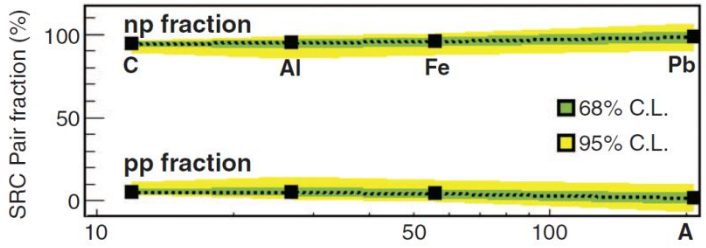

Fig. 3. The extracted fractions of np (top) and pp (bottom) SRC pairs from the sum of pp and np pairs in nuclei. The green and yellow bands reflect 68 and 95% confidence levels (CLs), respectively (9). np-SRC pairs dominate over pp-SRC pairs in all measured nuclei.

Importance of SRC in Extracting EOS Information?

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Imprints of high-momentum nucleons in nuclei on hard photons from heavy-ion collisions near the Fermi energy

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- **Theoretical study of the role of SRC**
- **Strong effect on hard photon spectrum is predicted**
- **Similar effects on pion ratios. Beam energy dependence?**

Despite of the impressive progresses in the field, many interesting questions regarding the nature, size, range, and shape of the HMT and SRC need to be more thoroughly studied. For example, within the neutron-proton dominance model using a contact force, the nucleon HMT naturally reduces asymptotically to the $n(k) \sim 1/k^4$ as for the ultra cold atoms near the unitary limit [23], and it is consistent with predictions of dilute Fermi gas models [10,11,24]. On the other hand, there are indications from both theories and experiments that the HMT may not scale as $n(k) \sim 1/k^4$. For example, earlier analyses of scaling functions, e.g., y scaling and superscaling in the quasielastic region of inclusive electron-nucleus scatterings [25], found that the $n(k)$ scales as $n(k) \sim 1/k^{4+m}$ with $m \approx 4$–4.5 for momenta k up to $(1.59$–$1.97)k_F$ with $k_F = 250\,\mathrm{MeV}/c$. Different powers in the HMT mean different short range behavior of nuclear forces. For example, the nuclear force from an inverse Fourier transform for $m = 4$ and $m = 5$ behaves as $V_{NN}(r) \sim 1/r$ and $V_{NN}(r) \sim (1/r)^{1/2}$, respectively. Therefore, determining the shape of the HMT has important ramifications for our understanding about the nature of strong interactions at short distances.

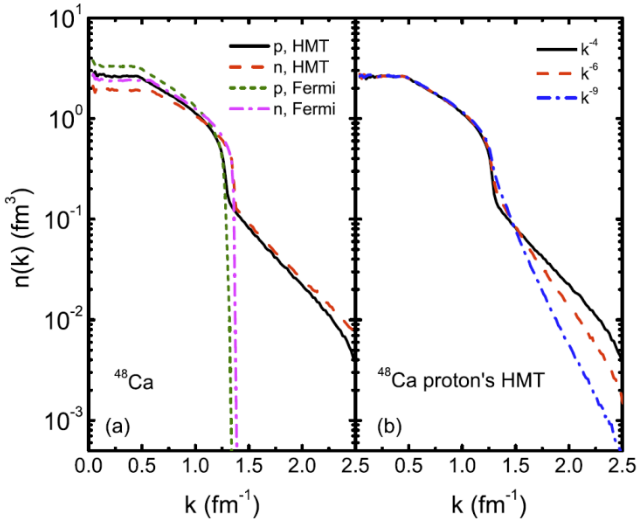


FIG. 1. Left: Nucleon momentum distributions $n(k)$ in $^{48}_{20}$Ca with a HMT in the shape of $n(k) \sim 1/k^4$. The distributions without the HMT are also shown for a comparison. Right: Momentum distributions for protons with HMT in the form of $n(k) \sim 1/k^4$, $1/k^6$, and $1/k^9$, respectively.

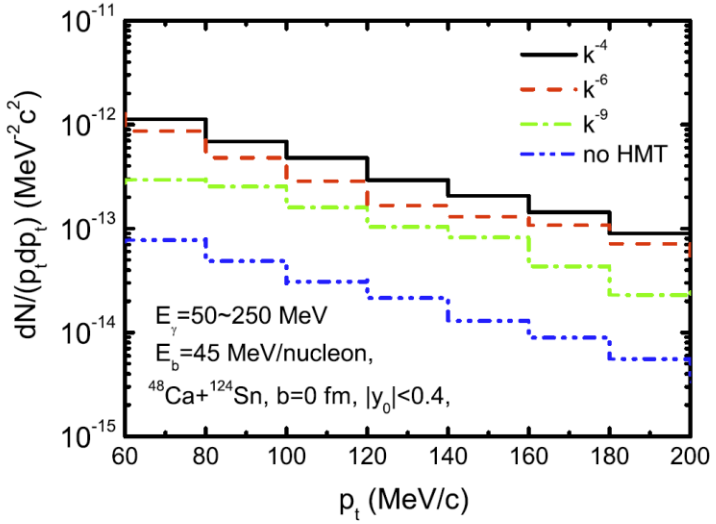
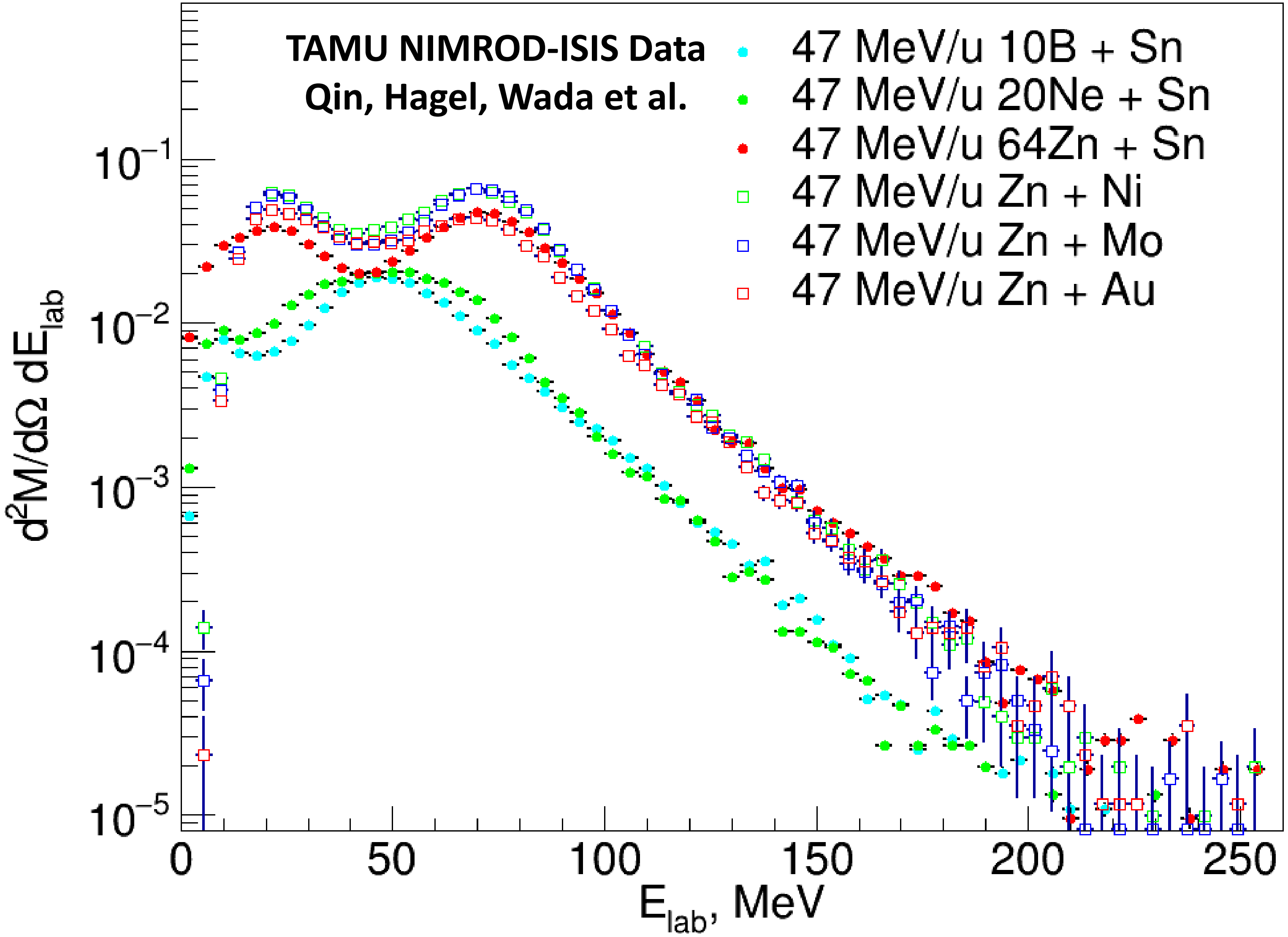
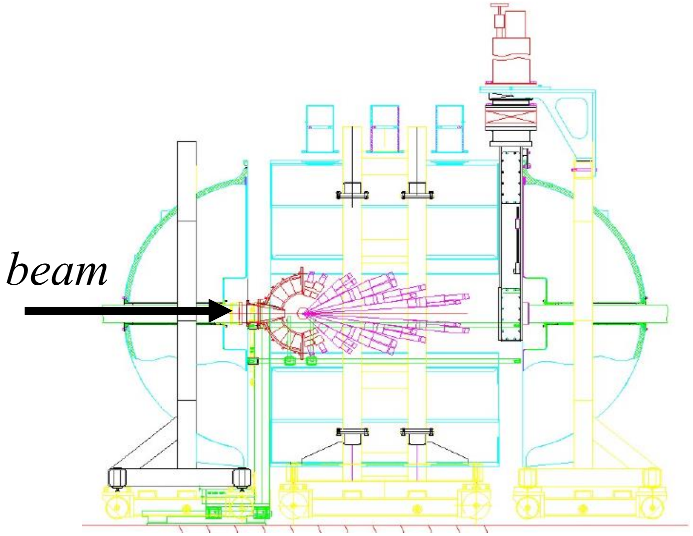


FIG. 11. The transverse momentum dependence of hard photon spectra in the midrapidity region of $-0.4 \leqslant y_0 \leqslant 0.4$ in the head-on reaction of ^{48}Ca + ^{124}Sn at a beam energy of $E_b = 45$ MeV/nucleon with different shapes of HMT.

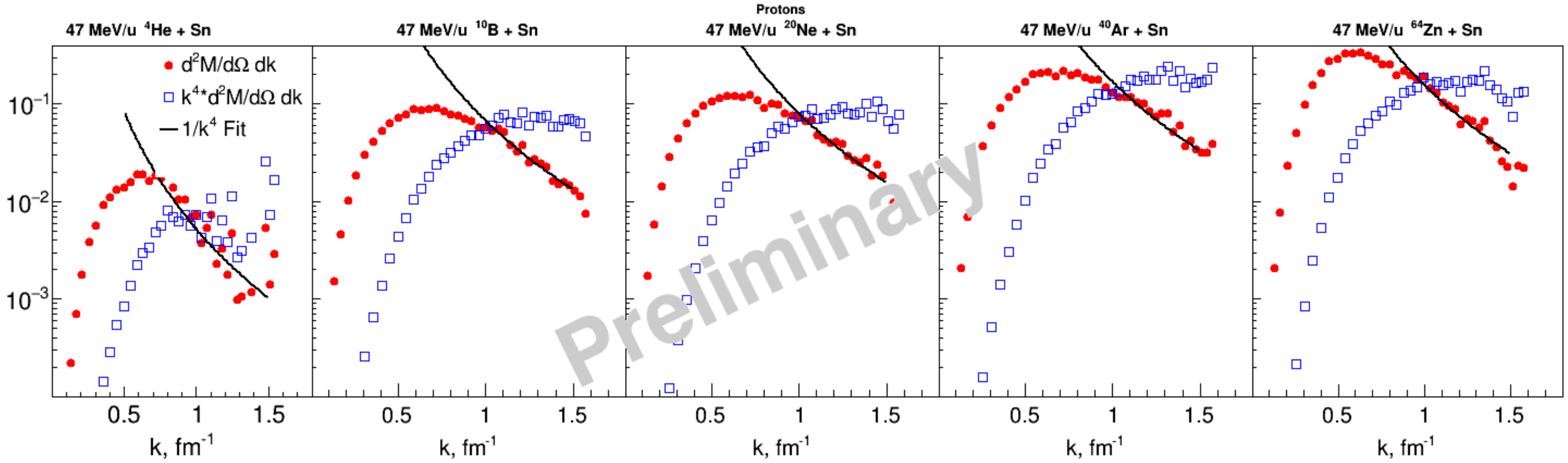
PROTON SPECTRA FROM FERMI ENERGY COLLISIONS DISPLAY VERY HIGH ENERGY TAILS at FORWARD ANGLES

- Here we focus on proton energy spectra at 4.3°

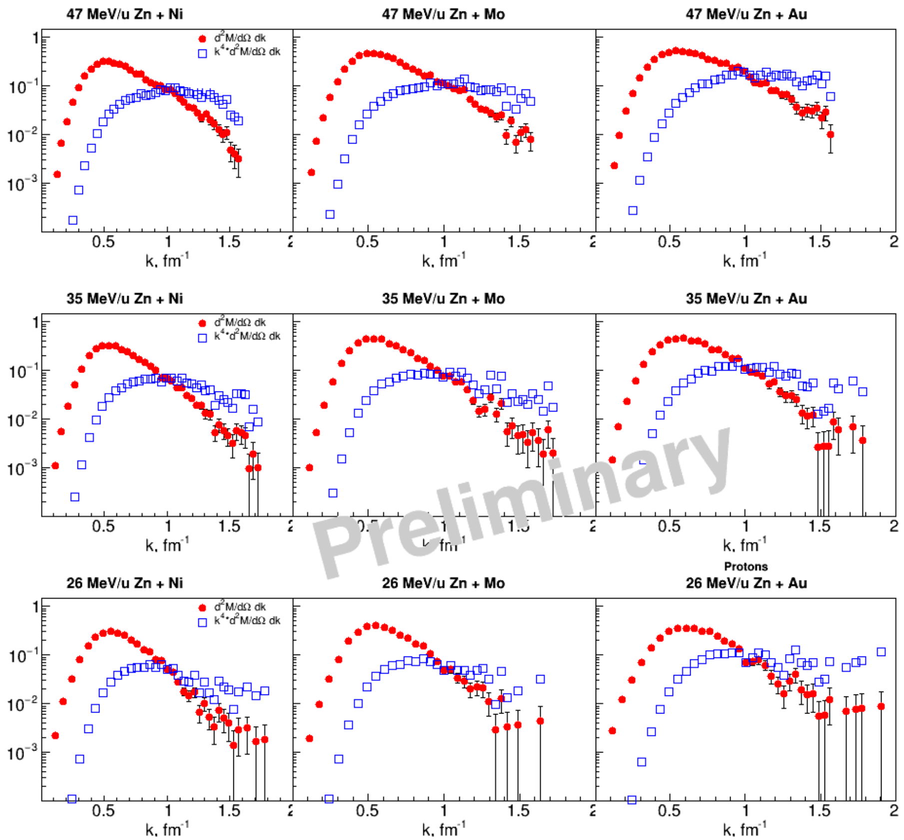




S. Wuenschel et al.,
Nucl. Instrum. Methods
A604, 578–583 (2009).



Forward Angle
Momentum Spectra
In Projectile Frame



$1/K^4$ dependence observed
Clearest when Rproj well below Rtgt
Cross section increase with Aproj

Conclusions

- High k forward proton distributions from collisions induced by ^{4}He to ^{67}Zn appear consistent with $1/k^4$ dependence. Intensity increases with projectile mass
- "Fermi jets" from projectile.

Collaborators

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