# The impact of SRC pairs on properties of hadronic neutron stars


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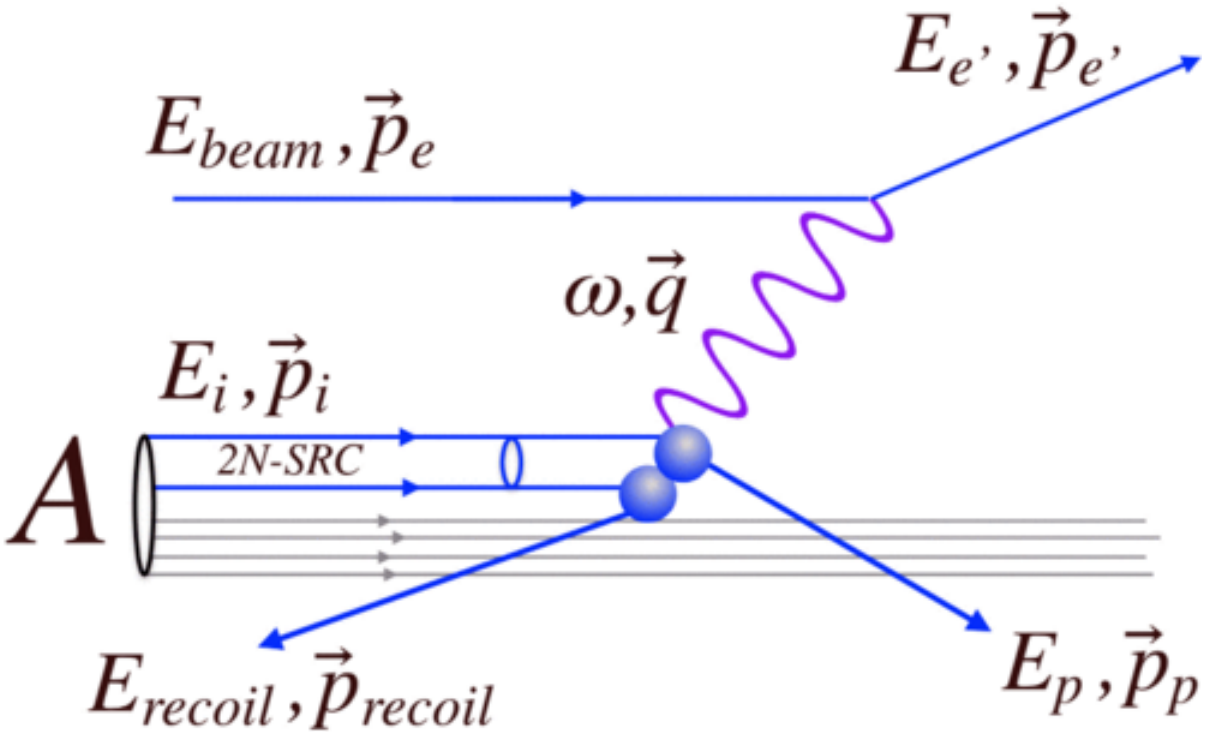
# SRC pairs : challenging the nuclear shell model

nucleon-nucleon tensor force and short-range repulsive core




$$Q^2 = \vec{q}^2 - (\frac{\omega}{c})^2$$

$$x_B = \frac{Q^2}{2m_N\omega}$$

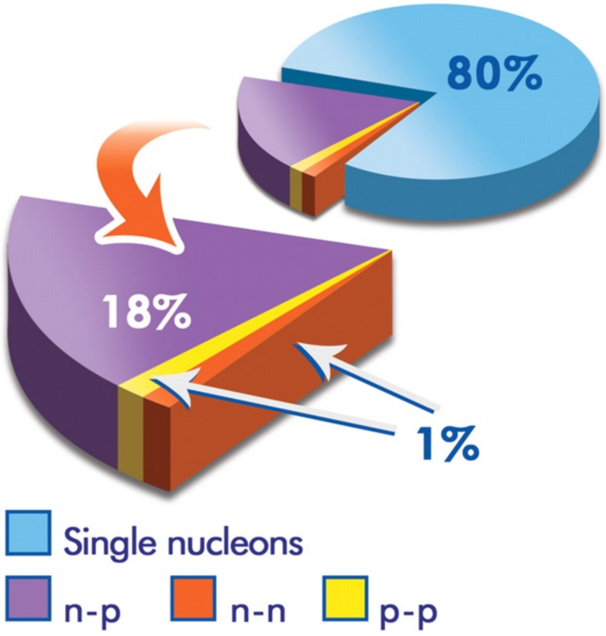
$$\vec{p}_{miss} = \vec{p}_f - \vec{q}$$

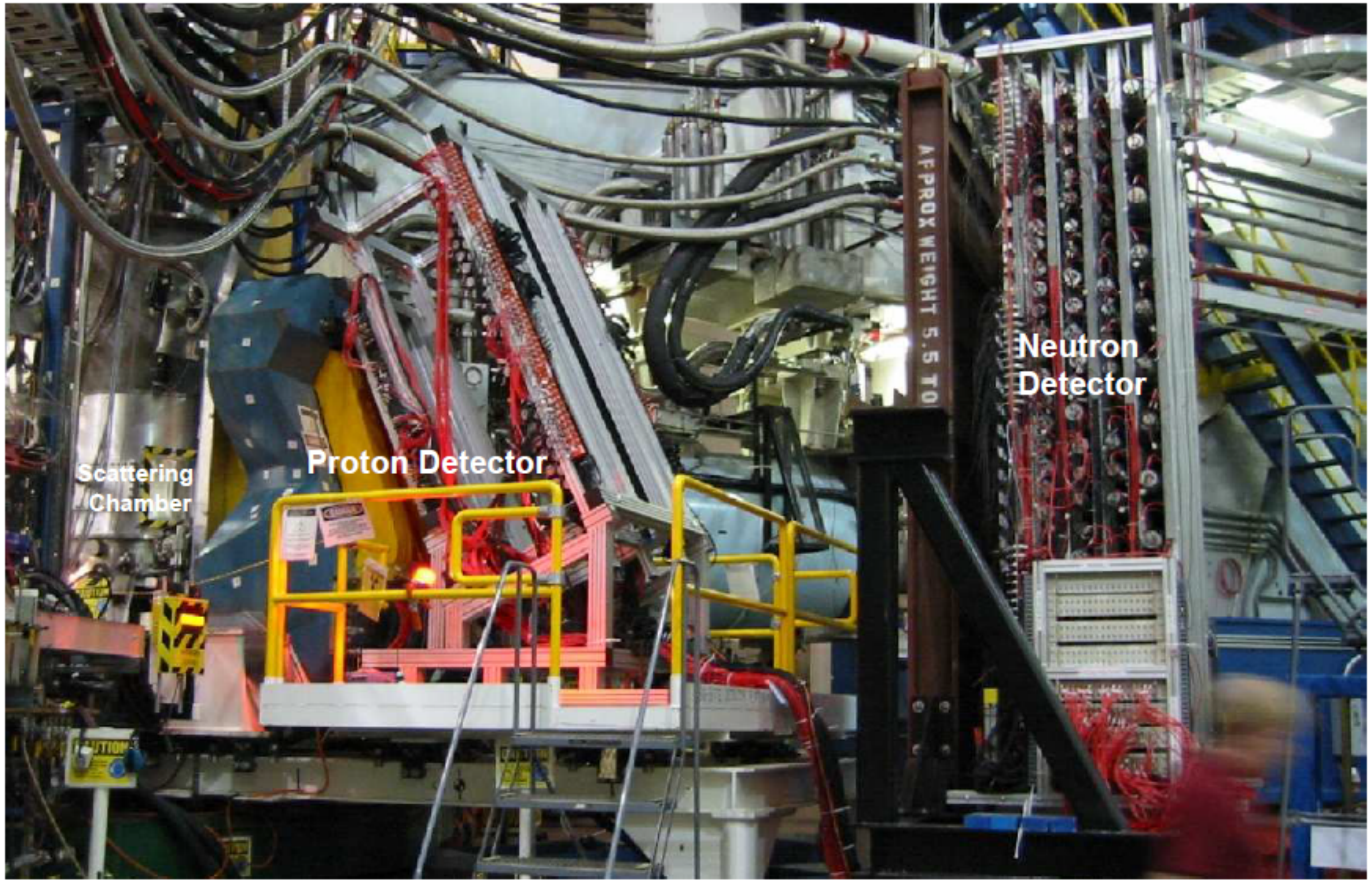
$$E_{miss} = \omega - E_f$$

$$m^2_{miss} = [(\vec{q}, \omega) + (0, m_d) - (\vec{p}_f, E_f)]^2$$

# R. Subedi (2008)

$$\frac{^{12}C(e,e'pn)}{^{12}C(e,e'pp)} = 18 \pm 5$$




R. Subedi et al., Science 320, 1476 (2008)

# O. Hen (2014)

$[A(e,e^{'}pp)/A(e,e^{'}p)]/[^{12}C(e,e^{'}pp)/^{12}C(e,e^{'}p)]$

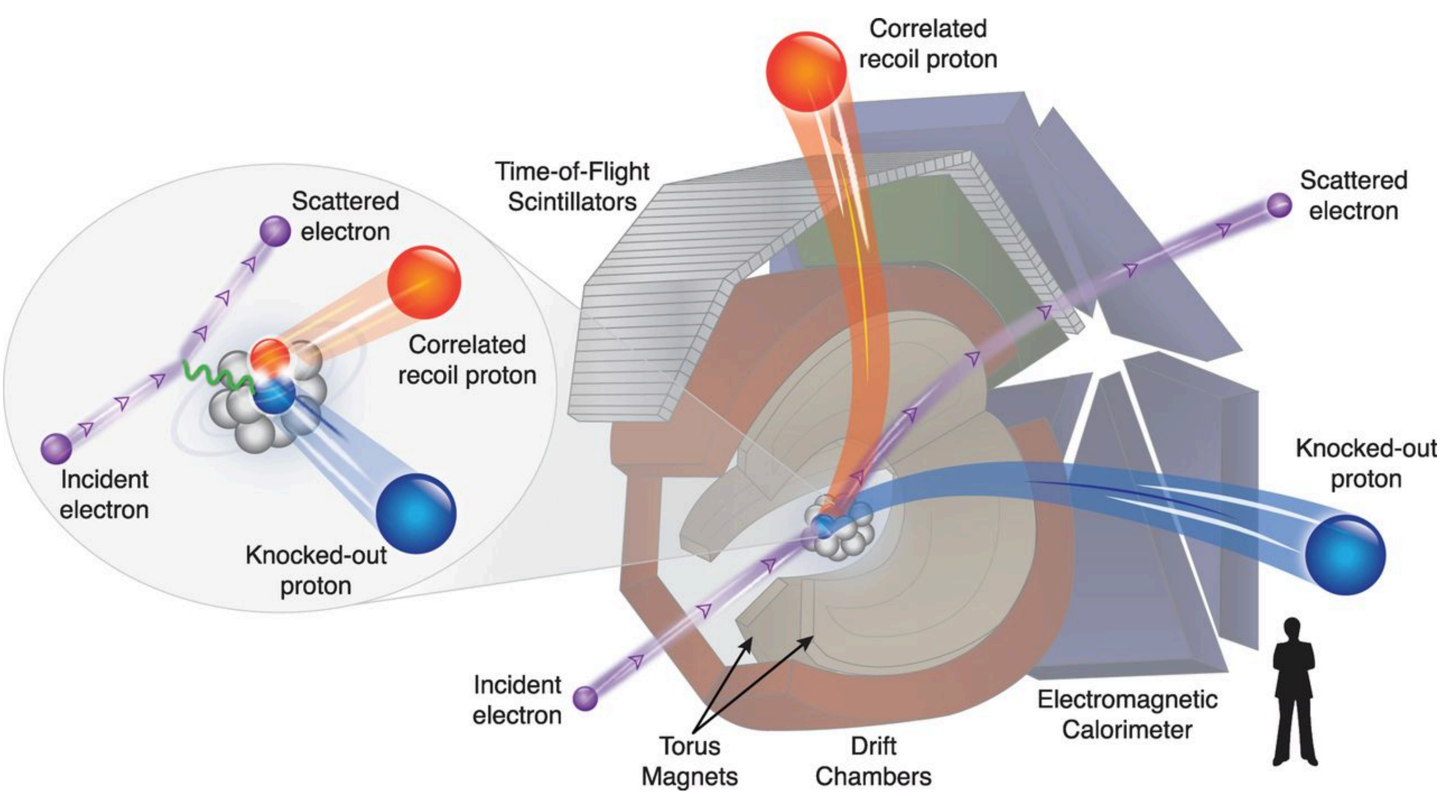
$A$ targets include $^{12}C$, $^{27}Al$, $^{56}Fe$, $^{208}Pb$ with similar average density.

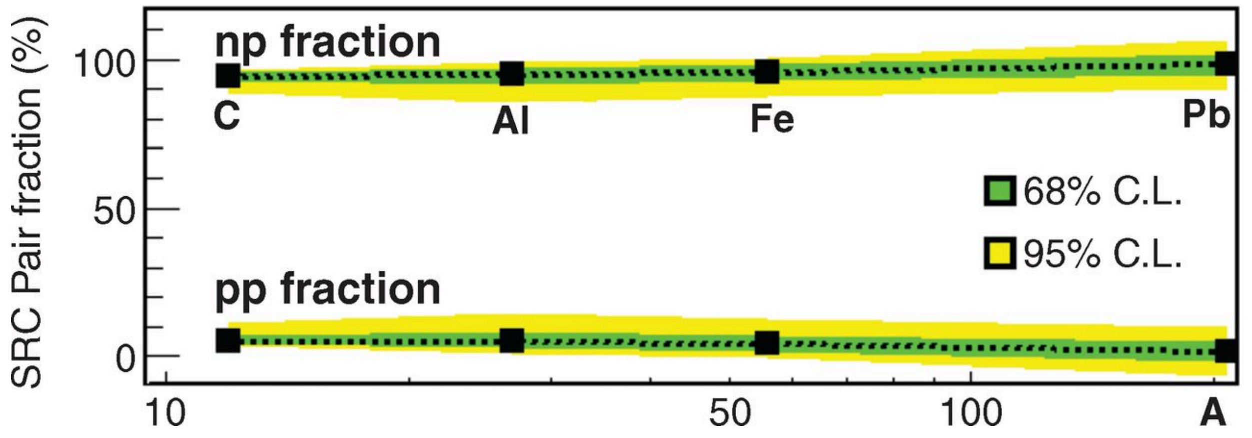
Final-State Interaction (FSI) effects were also taken into account,

mainly the single-charge exchange (SCX).

[Hence $[A(e,e^{'}pp)]$ was detected as $[A(e,e^{'}pn)$.]

O. Hen et al. (Jefferson Lab CLAS Collaboration), Science 346, 614 (2014)



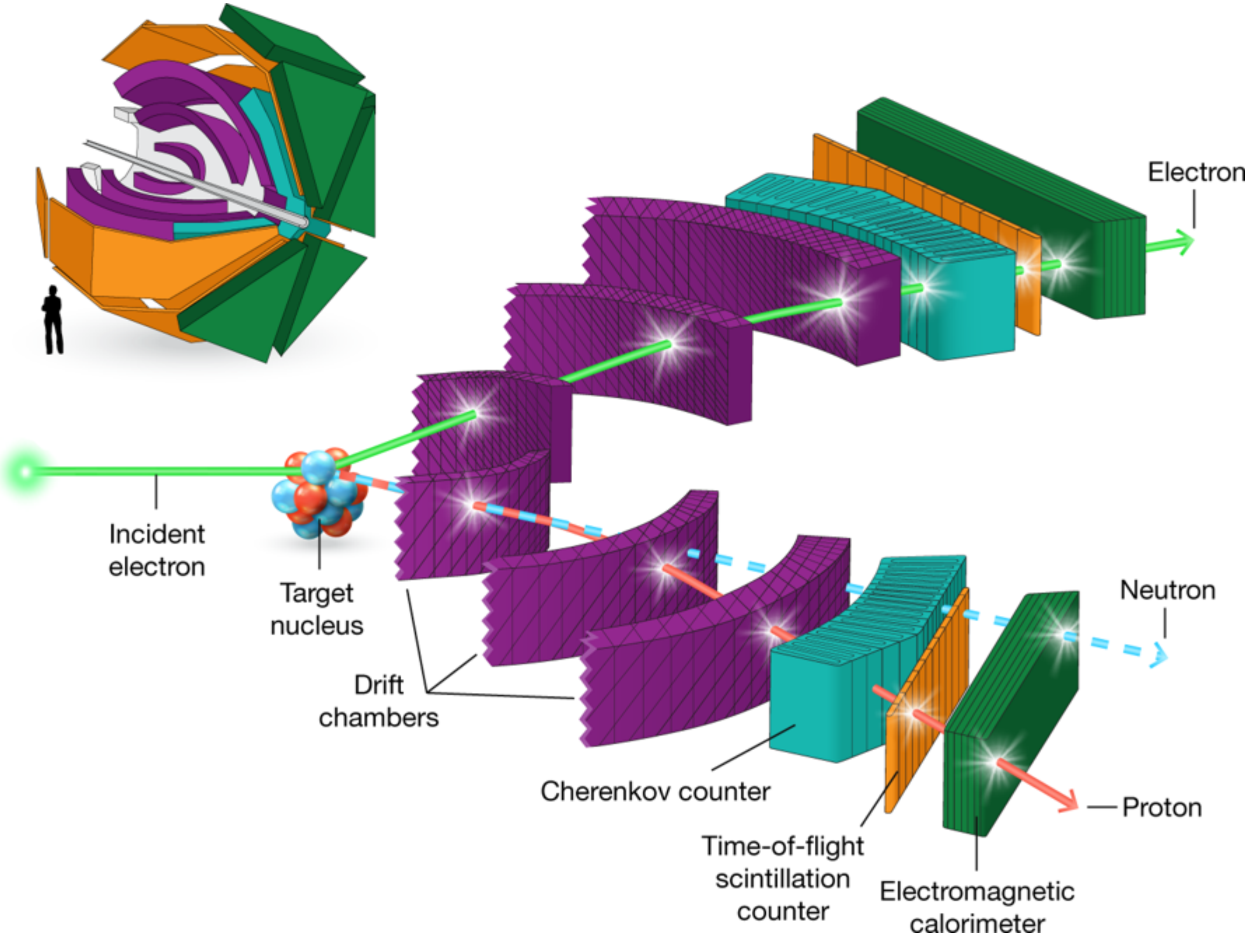
# The CLAS Collaboration (2018)

Quantifying the relative fractions of high-momentum ($k > k_F$) protons and neutrons

Showing that adding neutrons to the nucleus increases the fraction of high-momentum protons

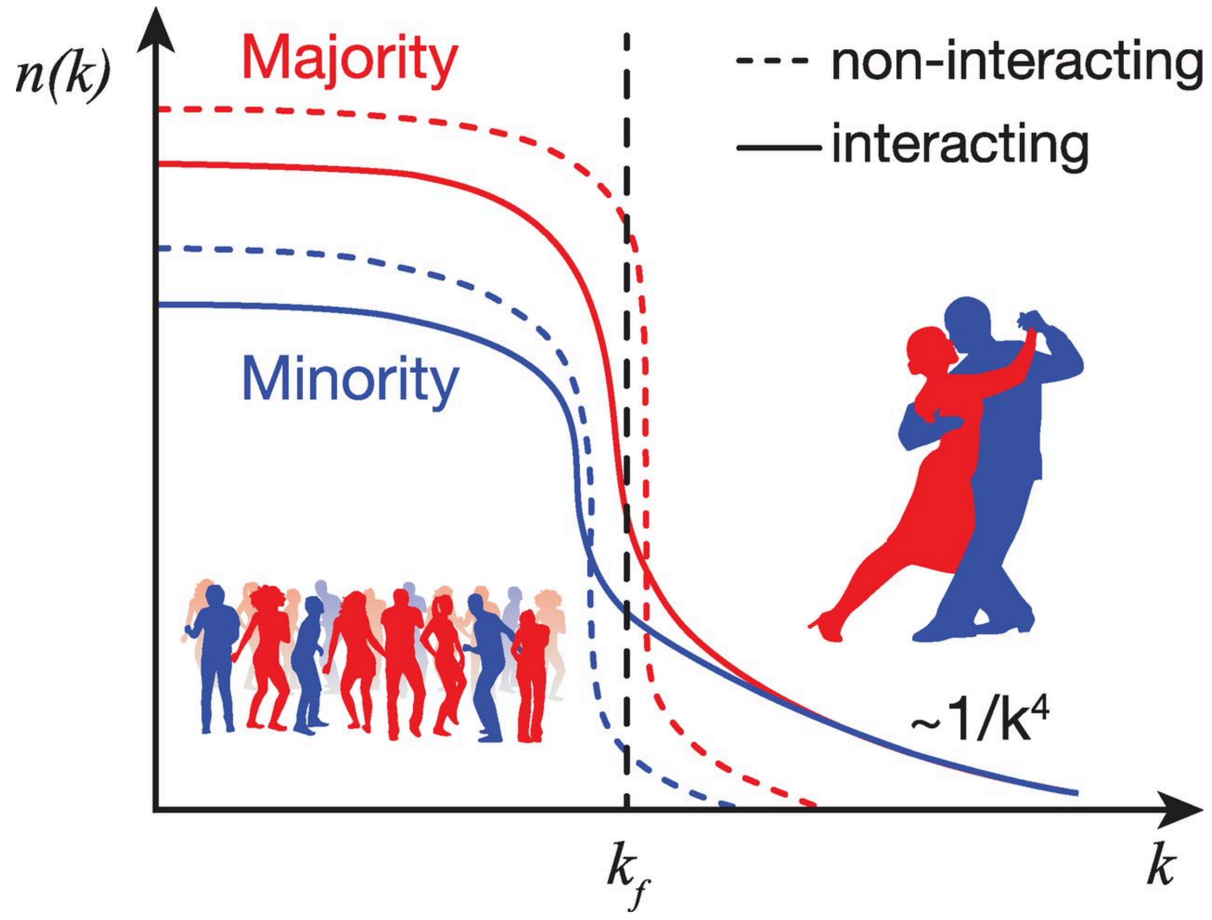
Helping confirm the np dominance of the high-momentum tail in medium and heavy nuclei

Supporting momentum-sharing inversion in heavy nuclei




The CLAS Collaboration, Nature 560, 617 (2018)

# Isospin-dependent nucleon momentum distribution




$$n(k,\delta)_p = \begin{cases} C_1^p & 0 \le k < k_F^p \\ C_2^p(1+\delta)k^{-4} & k_F^p \le k < \lambda k_F^p \\ 0 & k > \lambda k_F^p \end{cases}$$

$$n(k,\delta)_n = \begin{cases} C_1^n & 0 \le k < k_F^n \\ C_2^n(1-\delta)k^{-4} & k_F^n \le k < \lambda k_F^n \\ 0 & k > \lambda k_F^n \end{cases}$$

$$C_1^p = 1 - 0.25(1+\delta)$$

$$C_2^p = \frac{0.25(k_F^p)^4}{3(1-\lambda^{-1})}$$

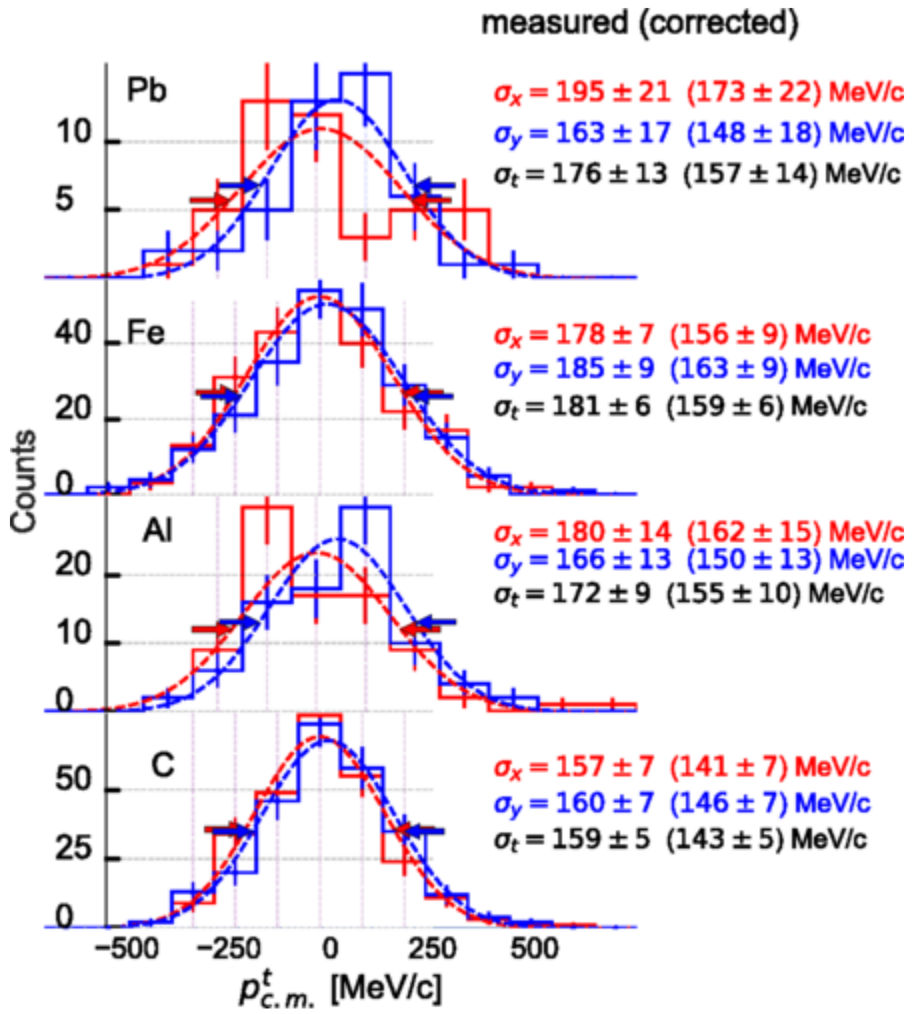
$$C_1^n = 1 - 0.25(1-\delta)$$

$$C_2^n = \frac{0.25(k_F^n)^4}{3(1-\lambda^{-1})}$$

O. Hen et al. (Jefferson Lab CLAS Collaboration), Science 346, 614 (2014)

B. J. Cai, B. A. Li, and L. W. Chen, Phys. Rev. C 94, 061302(R) (2016)

# Our isospin-independent nucleon momentum distribution




E. O. Cohen et al. (CLAS Collaboration), Phys. Rev. Lett. 121, 092501 (2018)

$$n(k,\delta)_p = \begin{cases} C_1^p & 0 \le k < k_F^n \\ C_2^p(1-\delta)k^{-4} & k_F^n \le k < \lambda k_F^n \\ 0 & k > \lambda k_F^n \end{cases}$$

$$n(k,\delta)_n = \begin{cases} C_1^n & 0 \le k < k_F^n \\ C_2^n(1-\delta)k^{-4} & k_F^n \le k < \lambda k_F^n \\ 0 & k > \lambda k_F^n \end{cases}$$

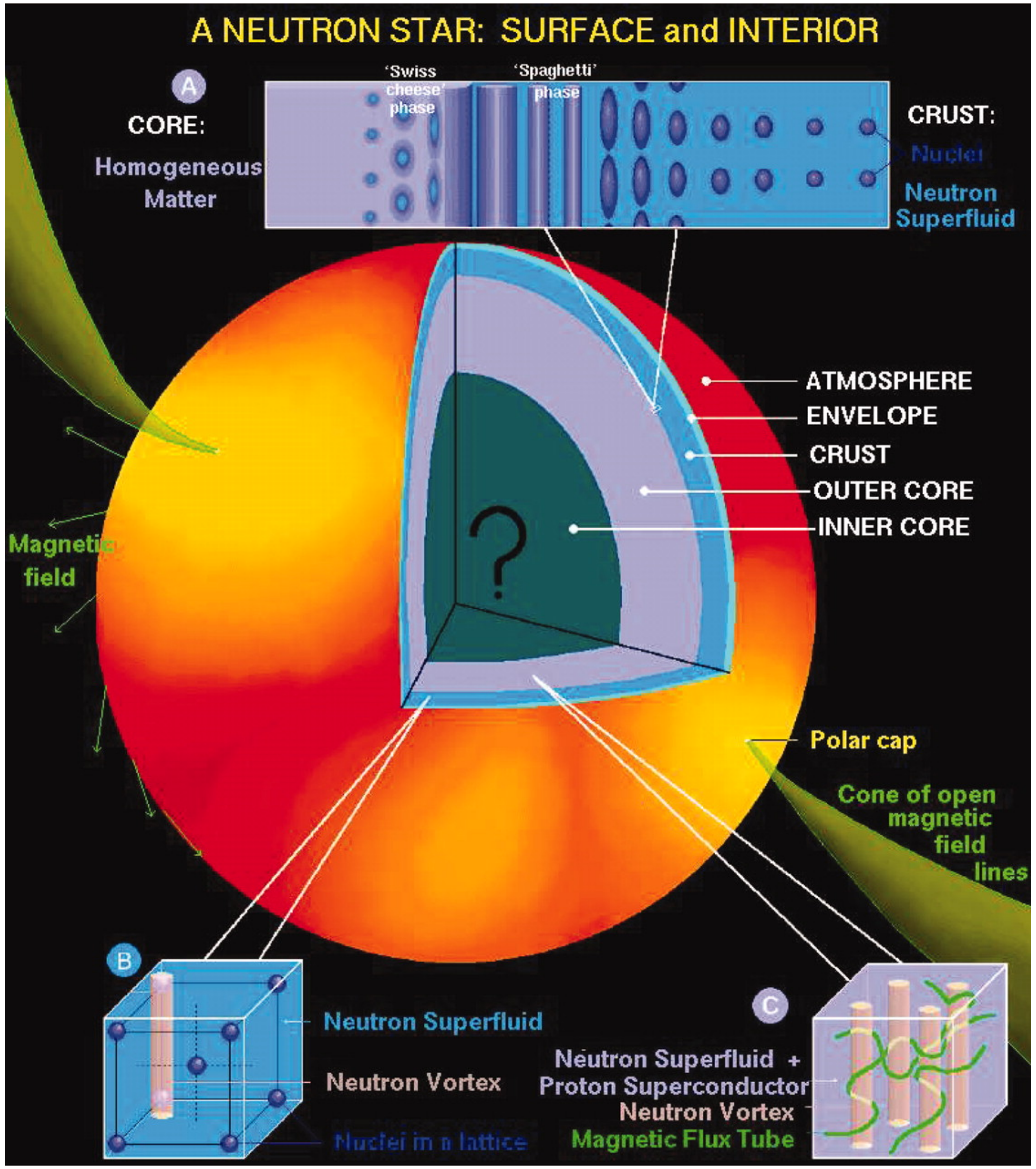
$$C_1^p = [1 - 0.25(1+\delta)]\frac{1-\delta}{1+\delta}$$

$$C_2^p = C_2^n$$

$$C_1^n = 1 - 0.25(1-\delta)$$

$$C_2^n = \frac{0.25(k_F^n)^4}{3(1-\lambda^{-1})}$$

# Internal Structure and Composition




the core-crust interface

3D nuclei, meatballs, 肉丸

2D cylindrical nuclei, spaghetti, 意粉

1D slabs of nuclei, lasagna, 千层面

2D cylindrical voids, ziti, 通心粉

3D voids, ravioli, 方形饺

the outer core

a soup of nucleons, electrons, and muons

the inner core

Exotic particles and/or Bose condensates (pions or kaons) may become abundant.

J. M. Lattimer and M. Prakash, Science 304, 536 (2004)

# Method: nonlinear relativistic mean field model

$$\mathcal{L} = \sum_B \bar{\psi}_B[\gamma_\mu(i\partial^\mu - g_{\omega B}\omega^\mu - \frac{g_{\rho B}}{2}\boldsymbol{\tau}\cdot\boldsymbol{\rho}^\mu) - (m_B - g_{\sigma B}\sigma)]\psi_B$$
$$+\sum_l \bar{\psi}_l(i\gamma_\mu\partial^\mu - m_l)\psi_l$$
$$+\frac{1}{2}(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2) - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4$$
$$-\frac{1}{4}\omega_{\mu\nu}\omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu - \frac{1}{4}\boldsymbol{\rho}_{\mu\nu}\boldsymbol{\rho}^{\mu\nu} + \frac{1}{2}m_\rho^2\boldsymbol{\rho}_\mu\boldsymbol{\rho}^\mu$$

$\bar{\sigma} \to \sigma$, $\bar{\omega}_\mu \to \omega_0$ and $\bar{\boldsymbol{\rho}}_\mu \to \rho_{03}$

$$\int_0^{k_F^J}(\cdots)\Theta(k_F^J - k)dk \to \int_0^{\lambda k_F^n}(\cdots)n_J(k)dk$$

$\rho_0 = 0.153\ \mathrm{fm}^{-3}$, $B/A = -16.3$ MeV,

$K = 300$ MeV, $a_{sym} = 32.5$ MeV and $m_N^* = 0.7\, m_N$

$U_\Lambda^{(N)} = -30$ MeV, $U_\Sigma^{(N)} = 30$ MeV and $U_\Xi^{(N)} = -18$ MeV

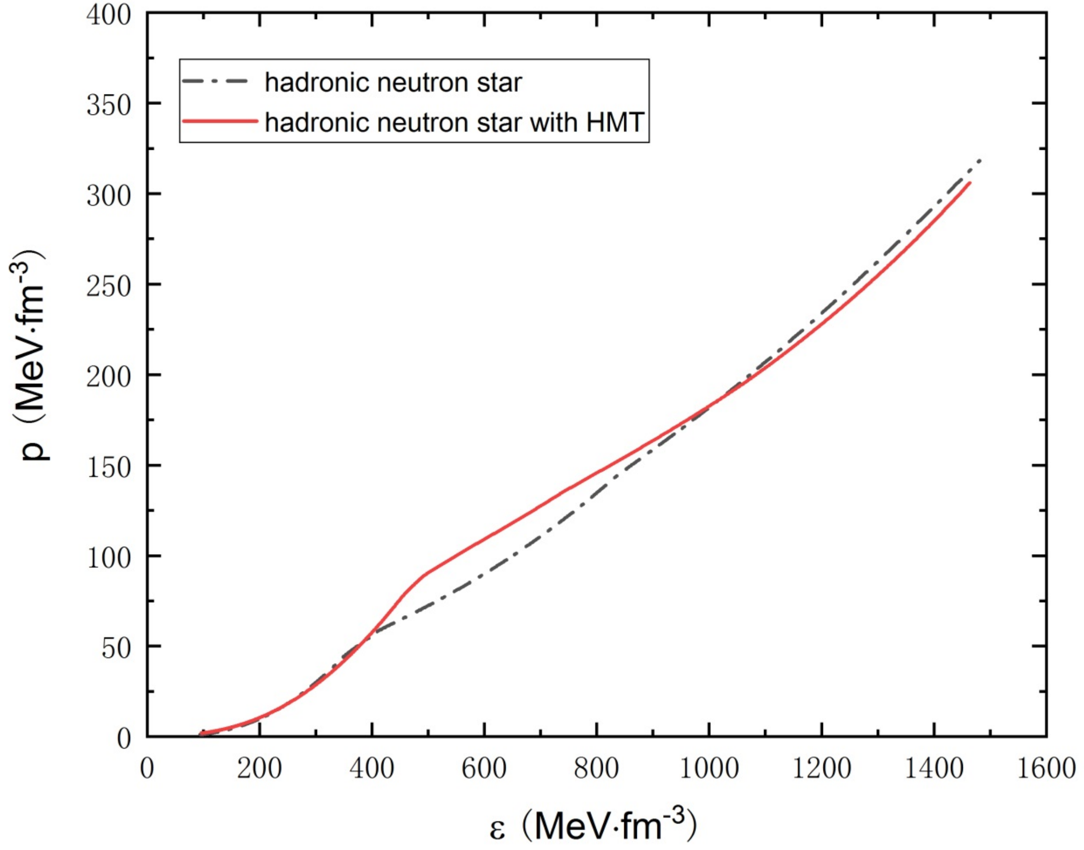
TABLE I. Model parameters, $g_{\sigma N}$, $g_{\omega N}$, $g_{\rho N}$, $g_2$ and $g_3$ used in the calculation without (the upper line)/with incorporating SRC pairs. $\lambda = 2.75$ and $x$ are assigned to different values here, 15%, 20% and 25% respectively.

| x | $g_{\sigma N}$ | $g_{\omega N}$ | $g_{\rho N}$ | $g_2$ | $g_3$ |
|---|---|---|---|---|---|
| | 8.702 | 10.604 | 8.198 | 9.206 | -6.125 |
| 15% | 8.938 | 10.033 | 14.527 | 12.564 | -14.742 |
| 20% | 9.020 | 9.835 | 15.261 | 13.760 | -17.869 |
| 25% | 9.103 | 9.633 | 15.962 | 14.996 | -21.126 |

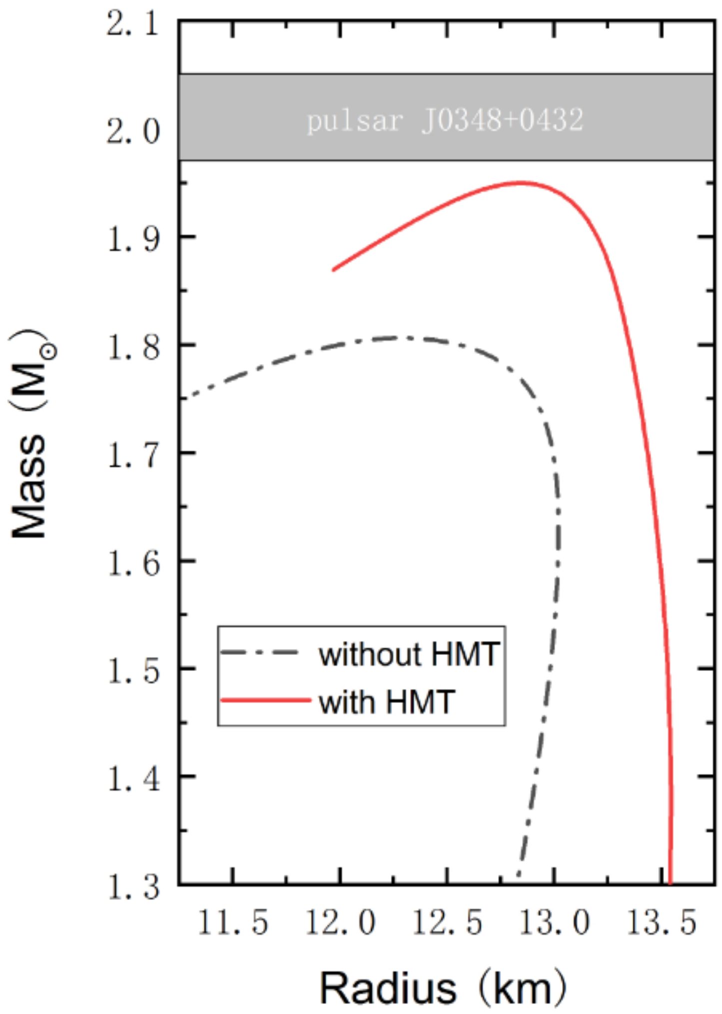
TABLE II. Model parameters, $g_{\omega N}$ and $x_{\sigma Y}(= g_{\sigma Y}/g_{\sigma N})$ used in the calculation without (the upper line)/with incorporating SRC pairs. $Y$ denotes hyperons, i.e., $\Lambda$, $\Sigma$ and $\Xi$. $\lambda = 2.75$ and $x$ are assigned to different values here, 15%, 20% and 25% respectively.

| x | $g_{\omega N}$ | $x_{\sigma\Lambda}$ | $x_{\sigma\Sigma}$ | $x_{\sigma\Xi}$ |
|---|---|---|---|---|
| | 10.604 | 0.618 | 0.405 | 0.320 |
| 15% | 10.033 | 0.564 | 0.351 | 0.293 |
| 20% | 9.835 | 0.547 | 0.334 | 0.284 |
| 25% | 9.633 | 0.529 | 0.316 | 0.275 |

# EOS

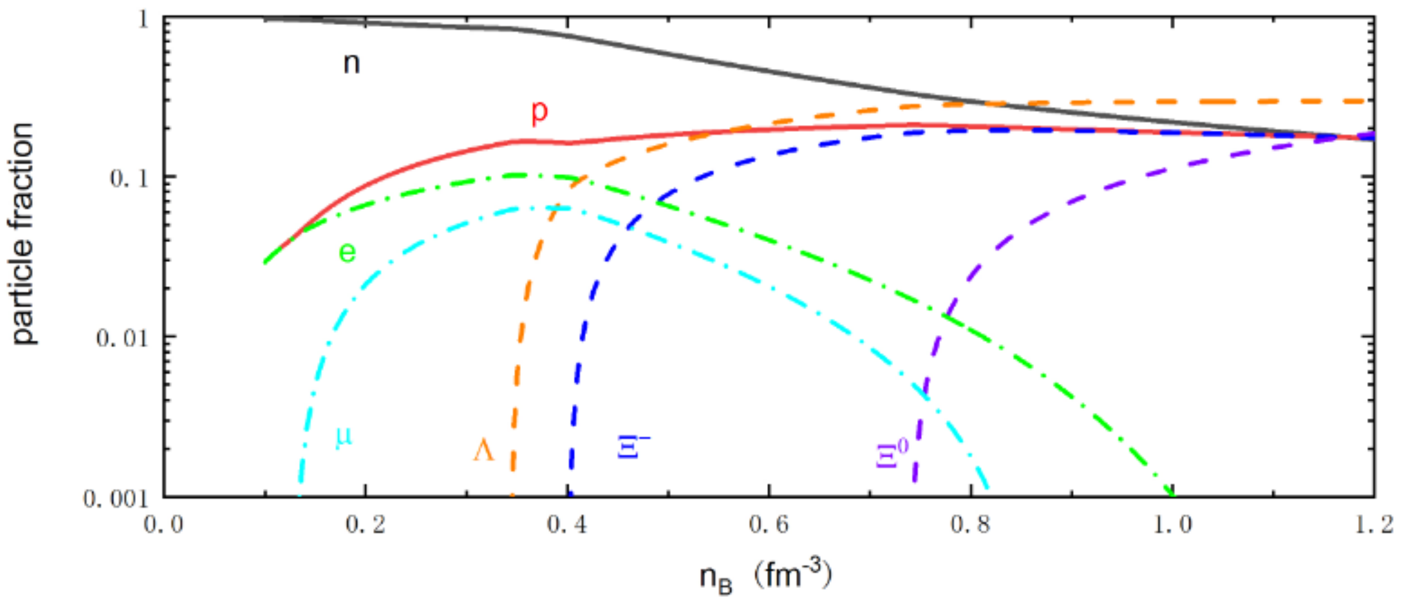


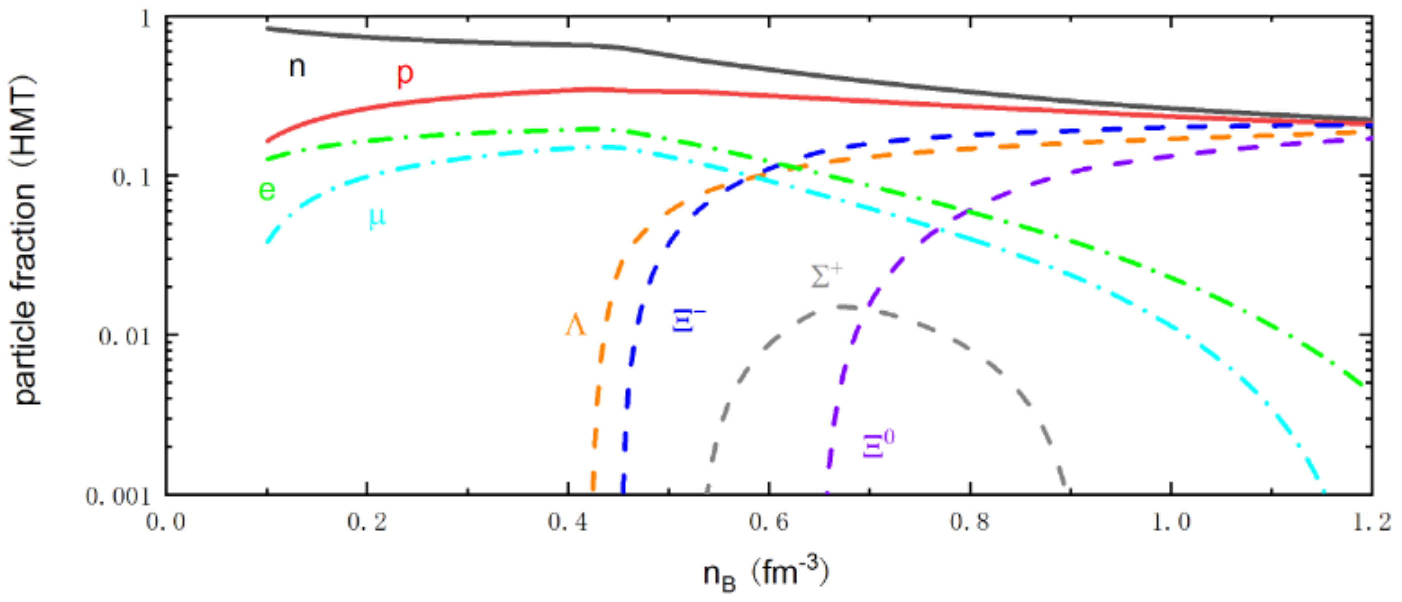

# M-R relation




J. Antoniadis et.al., Science 340, 448 (2013)

# Particle fraction



## Summary

We postulate an isospin-independent nucleon momentum distribution with HMT and recalculate the properties of hadronic neutron stars.

Our results are not suitable for quark matter stars.

## Disadvantage

Actually, the SRC can not coexist with RMFT.