Probing proton momentum in neutron-rich matter

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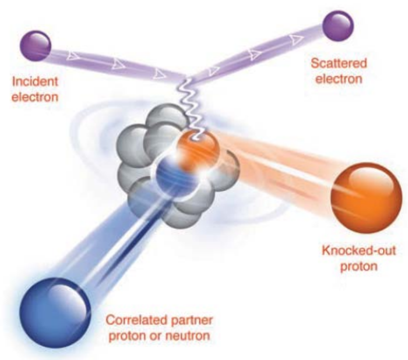
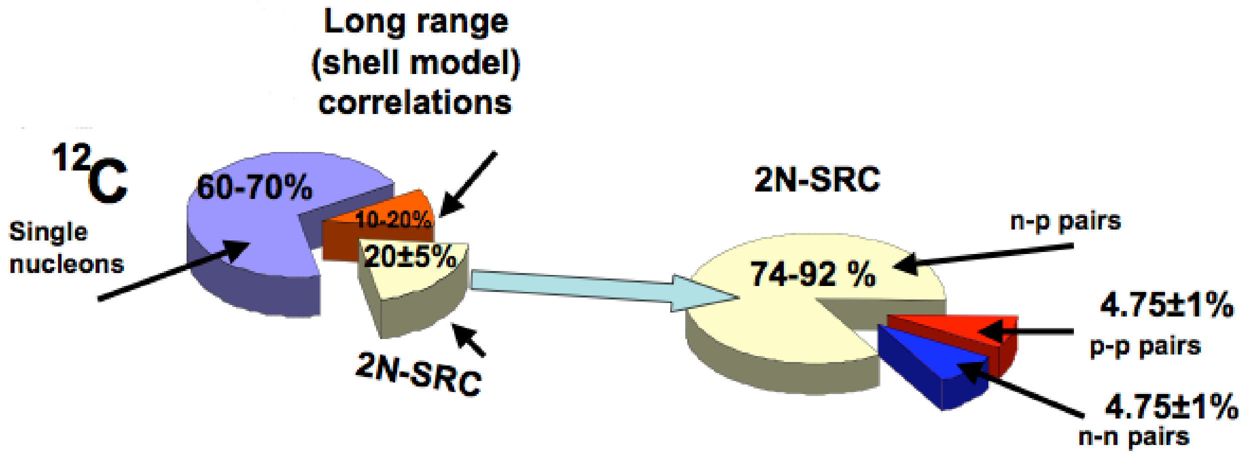
2018/4/9

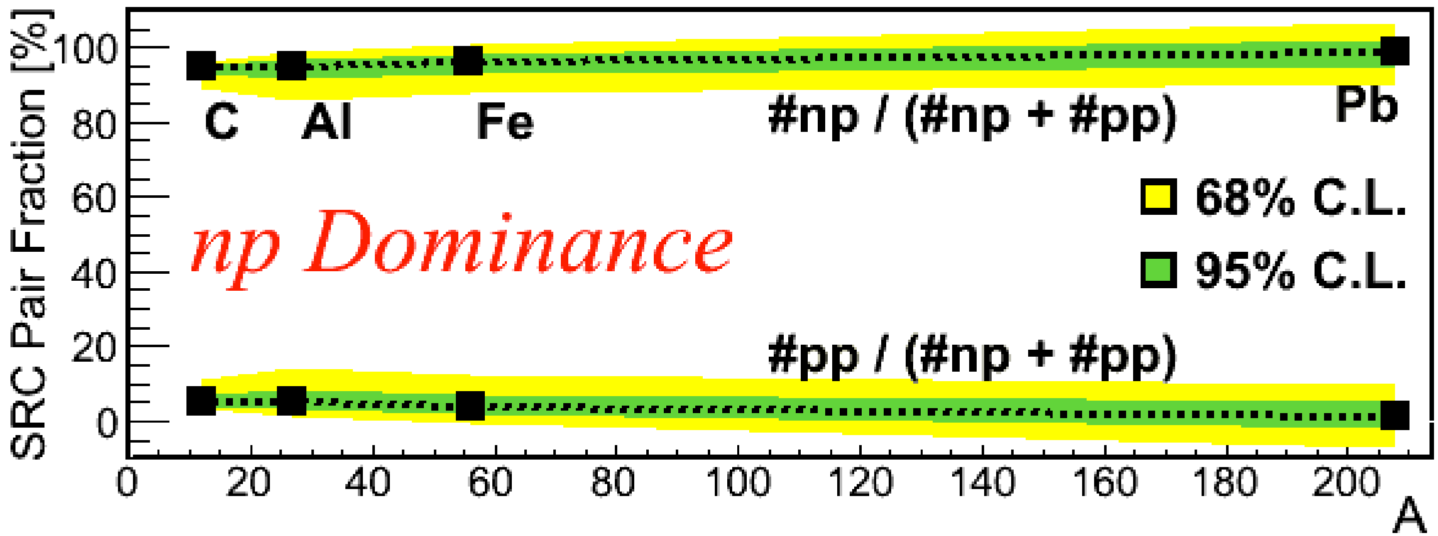
Nucleon-nucleon Short-range-Correlations



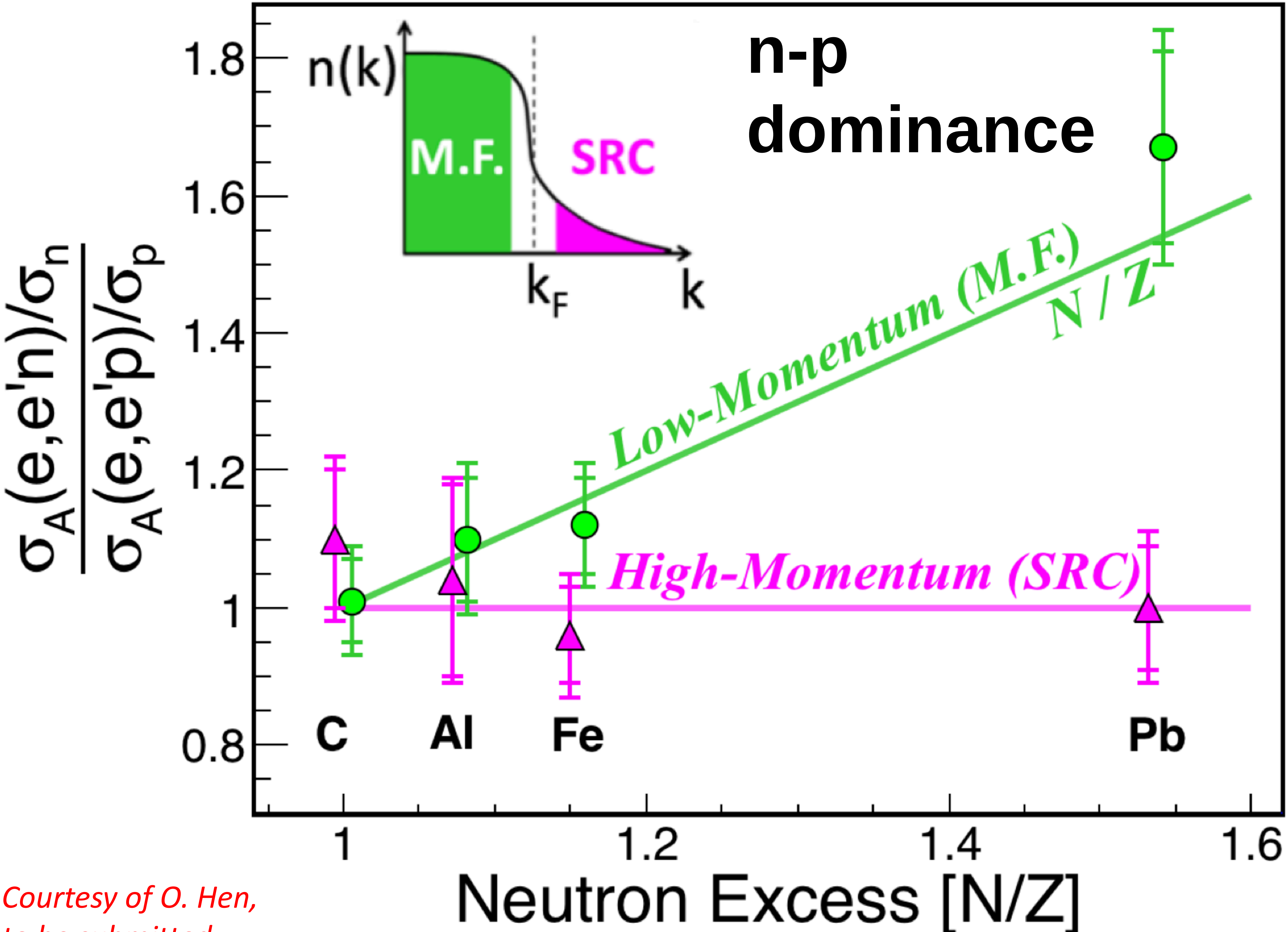
Jlab



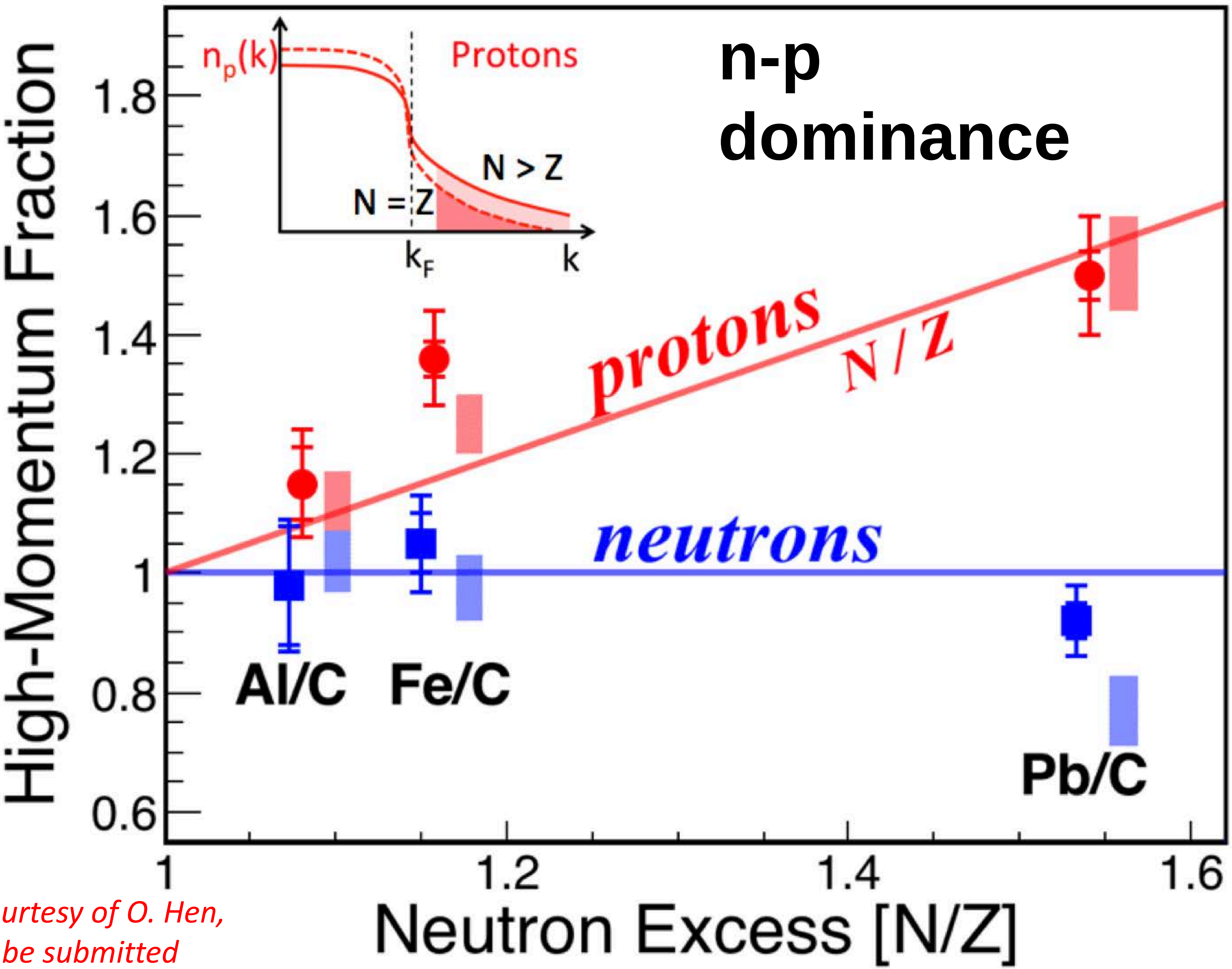
R. Subedi et al., Science 320, 1476 (2008).



O. Hen et al., Science 346, 614 (2014).



Courtesy of O. Hen, to be submitted



Courtesy of O. Hen,
to be submitted

$$^{40}_{20}Ca_{20}$$

$$HMT\_nucleon = 40 * 20\% = 8$$

$$HMT\_proton = 8 \div 2 = 4$$

$$HMT\_neutron = 8 \div 2 = 4$$

$$HMT\_proton / Z = 4/20 = 20\%$$

$$HMT\_neutron / N = 4/20 = 20\%$$

$$^{208}_{82}Pb_{126}$$

$$HMT\_nucleon = 208 * 20\% = 41.6 \approx 42$$

$$HMT\_proton = 42 \div 2 = 21$$

$$HMT\_neutron = 42 \div 2 = 21$$

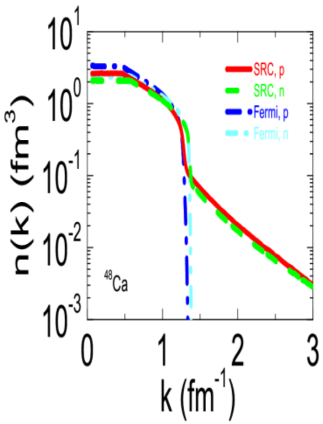
$$HMT\_proton / Z = 21/82 = 25.6\%$$

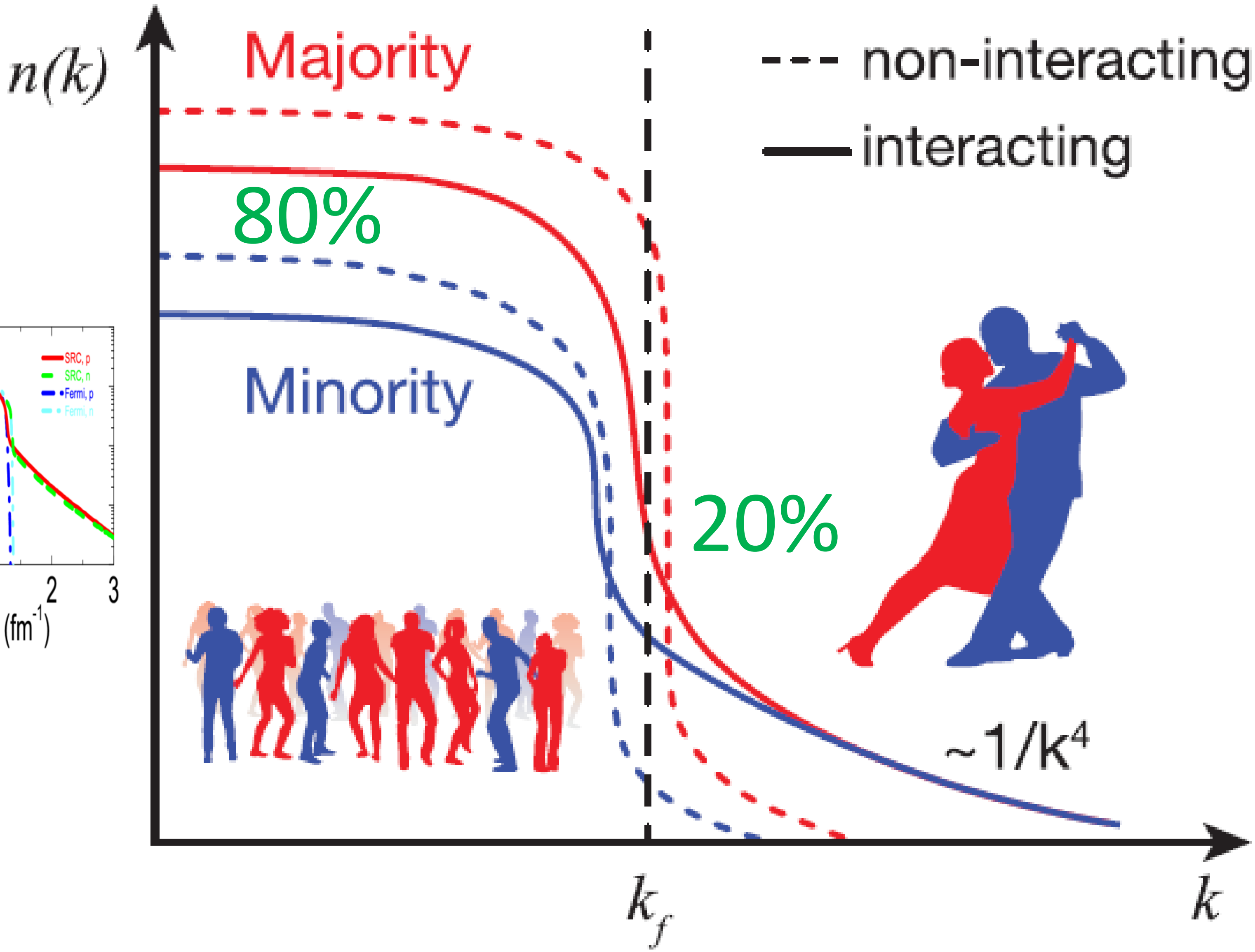
$$HMT\_neutron / N = 21/126 = 16.7\%$$

Proton increase

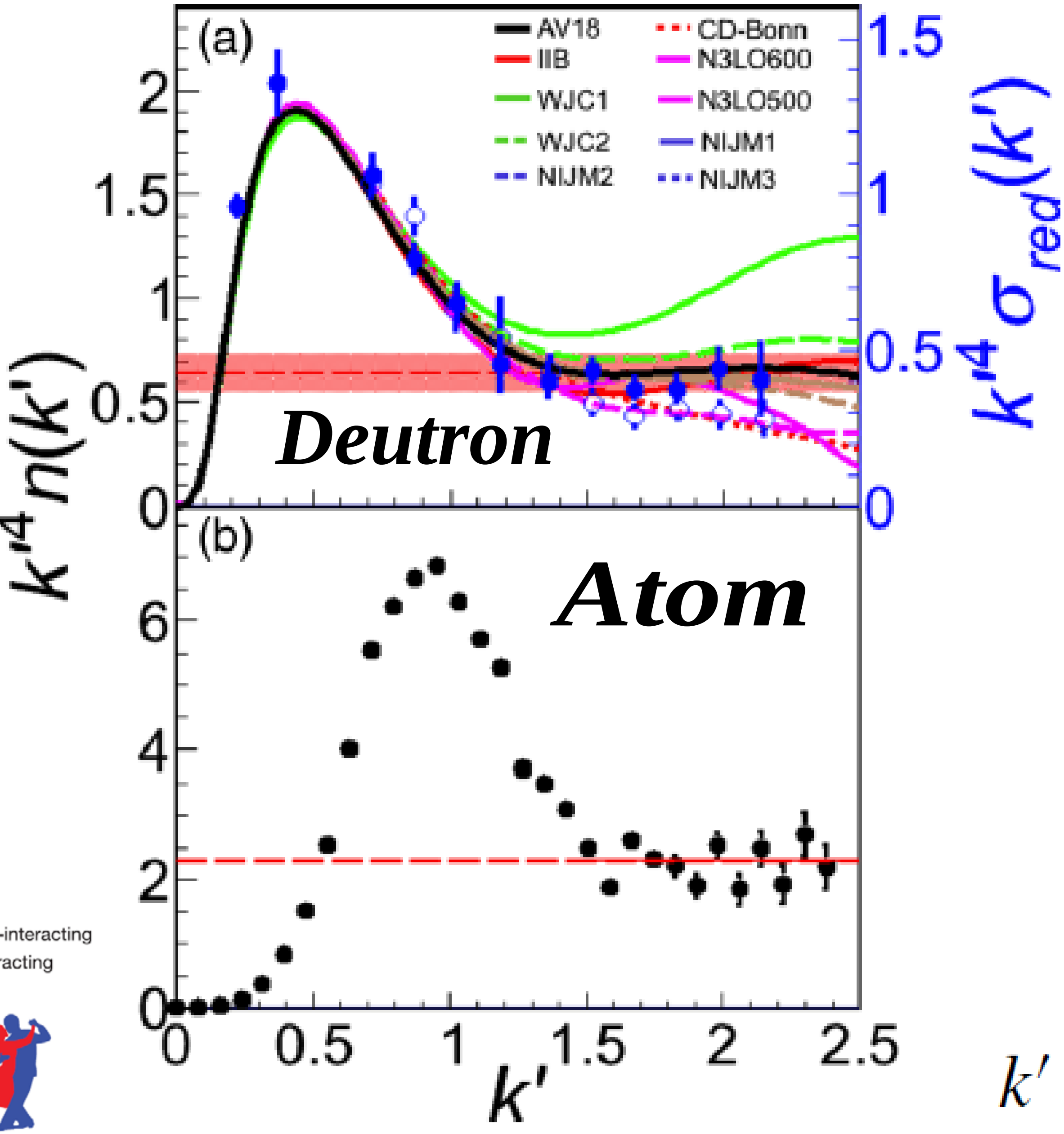
Neutron decrease

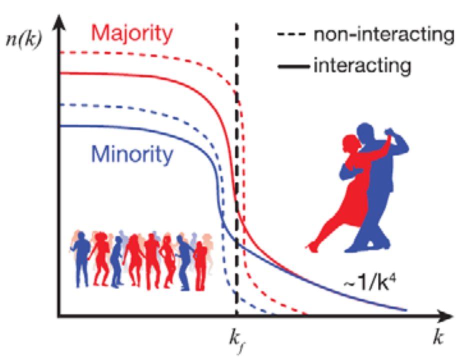
Nucleon momentum distribution





O. Hen et al., Science 346, 614 (2014).





$$k' = k / k_F$$

O. Hen, et al, PRC 92, 045205 (2015)

Neutron-rich matter:

$$n_p^{\rm HMT}(k)/n_n^{\rm HMT}(k) \simeq \rho_n/\rho_p$$
$$\int_{k_F}^{\lambda k_F} n^{HMT}(k)k^2dk / \int_0^{\lambda k_F} n(k)k^2dk \simeq 20\%$$
$$\int_0^{\lambda k_F} n(k)k^2dk = 1$$

respective – transition – momentum

A)

$$n(k)\_n = \begin{cases} C_1, k \le k_{F_n} \\ \downarrow \\ C_2/k^4, \underline{k_{F_n}} < k \le \lambda k_{F_n} \end{cases}$$

$$\boxed{n(k)\_p = \begin{cases} C_1, k \le k_{F_p} \\ \downarrow \\ C_2/k^4, \underline{k_{F_p}} < k \le \lambda k_{F_p} \end{cases}}$$

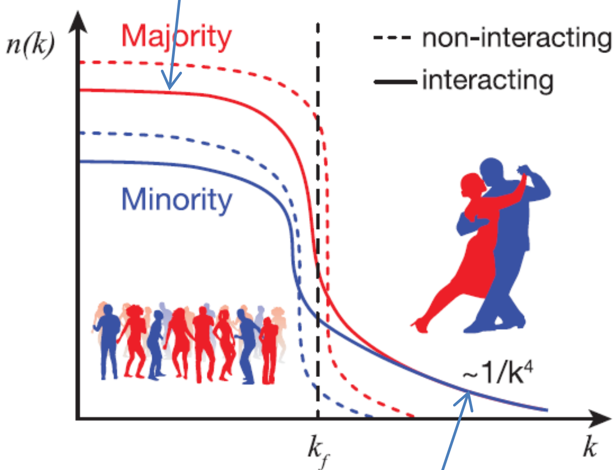
majority – transition – momentum

B)

$$n(k)\_n = \begin{cases} C_1, k \le k_{F_n} \\ \downarrow \\ C_2/k^4, \underline{k_{F_n}} < k \le \lambda k_{F_n} \end{cases}$$

$$\boxed{n(k)\_p = \begin{cases} C_1, k \le k_{F_p} \\ \downarrow \\ C_2/k^4, \underline{k_{F_n}} < k \le \lambda k_{F_n} \end{cases}}$$

C_1

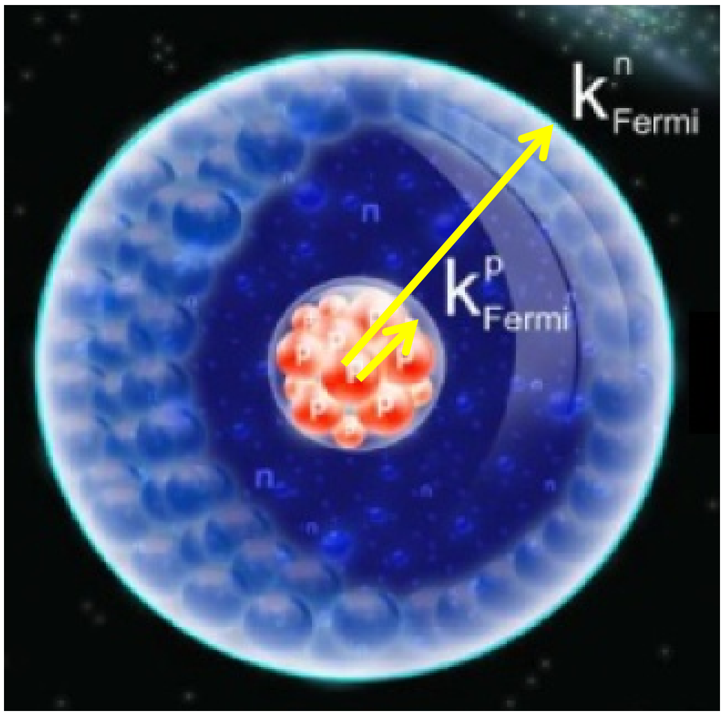


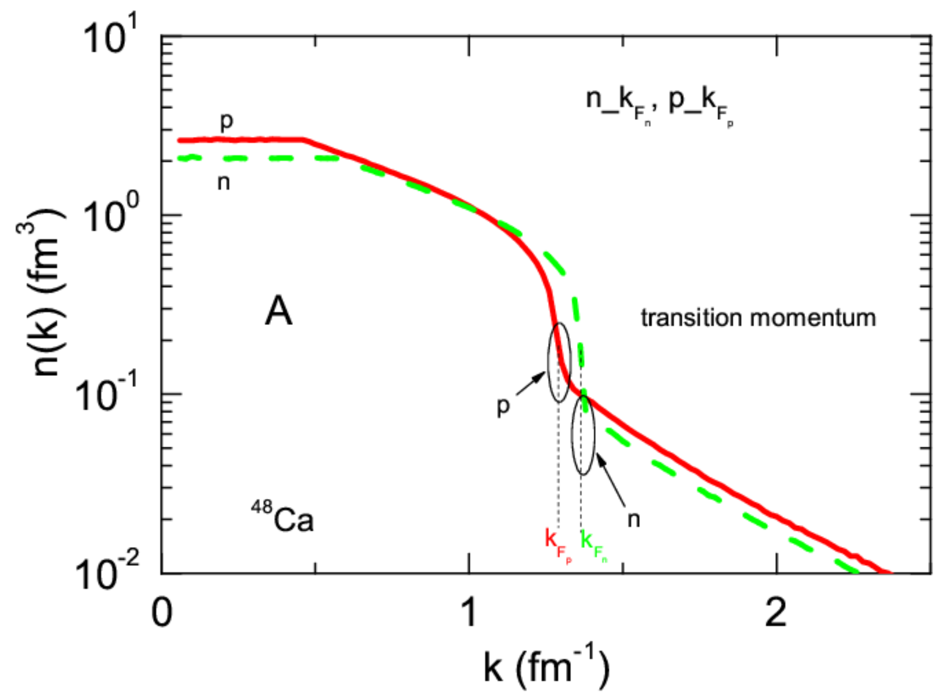
C_2/k^4

Transition momentum

Neutron-star matter

$$k_{F_{n,p}}(r) = [3\pi^2\hbar^3\rho(r)_{n,p}]^{\frac{1}{3}}$$

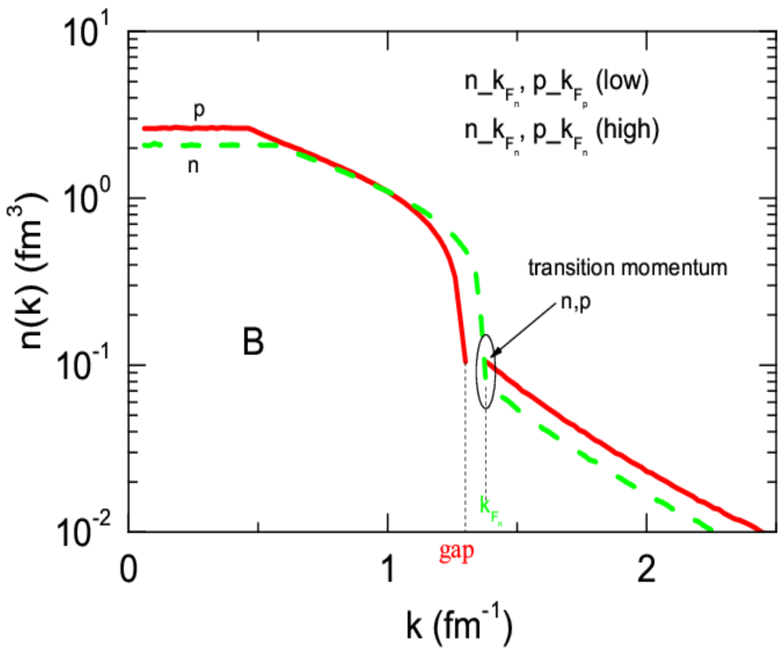


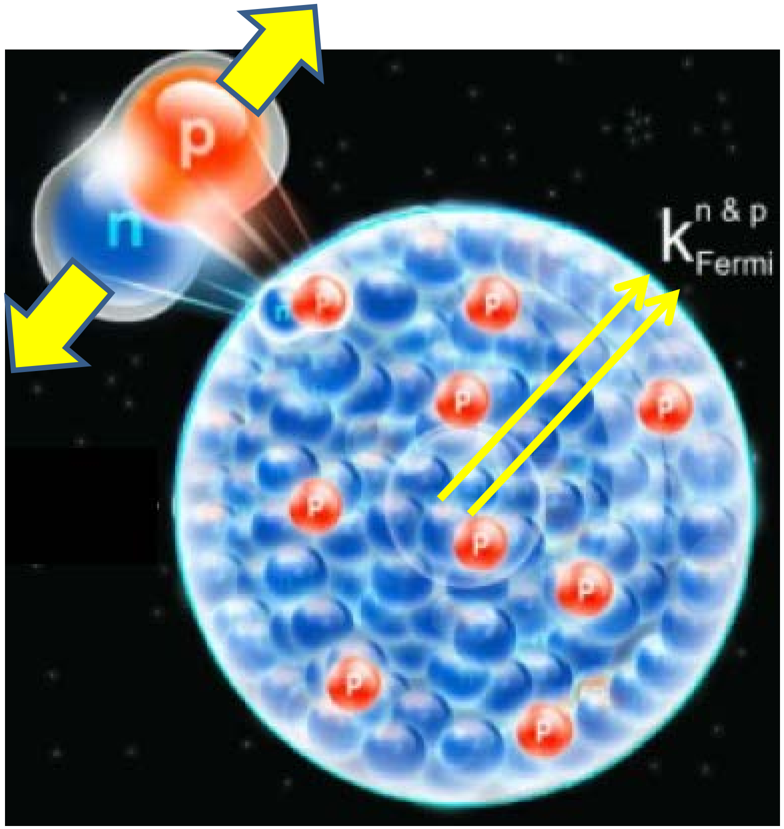


k_proton: small

Transition mom. = Respective Fermi mom.

Neutron-star matter

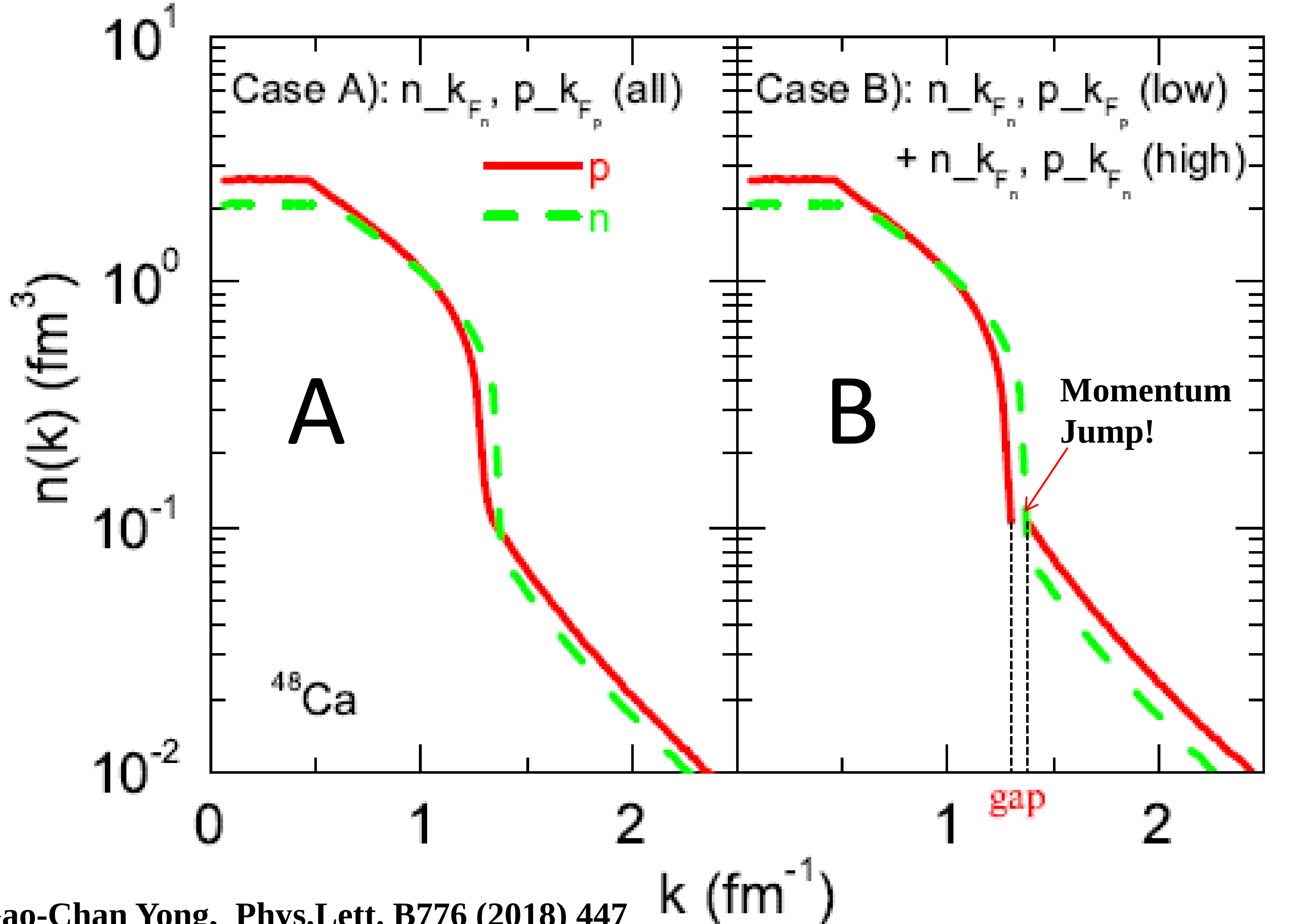




k_proton: large

Minority transition mom.
= majority transition mom.

Which one is correct?

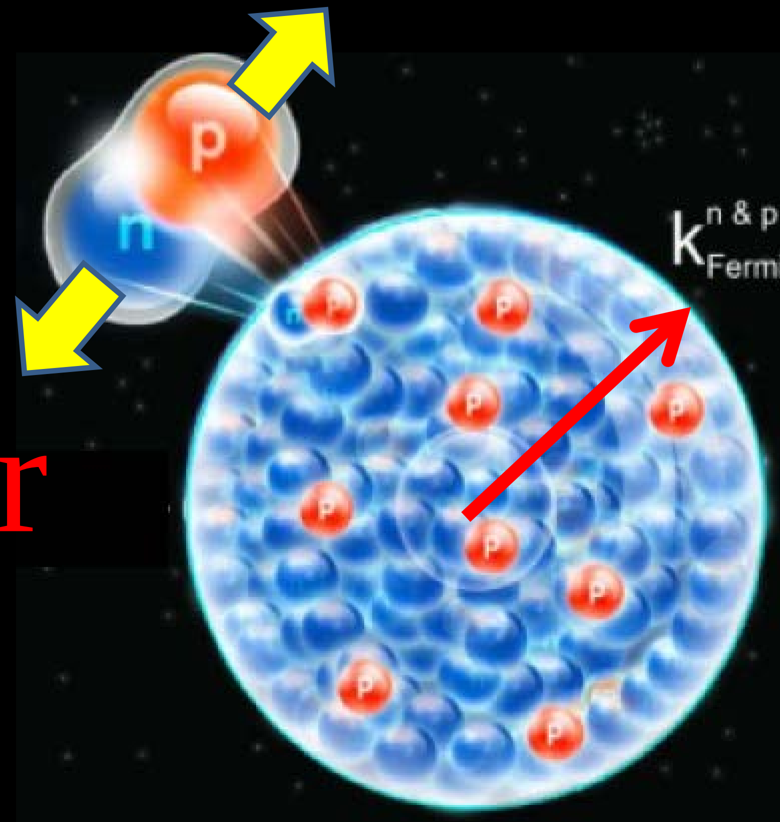


Gao-Chan Yong, Phys.Lett. B776 (2018) 447

Neutron-star matter

$$k_{F_{n,p}}(r) = [3\pi^2\hbar^3\rho(r)_{n,p}]^{\frac{1}{3}}$$

or



k_proton: small

k_proton: large

<u>**Respective Fermi momenta**</u>

<u>**Majority's(i.e., neutron's) Fermi momenta**</u>

How about microscopic approach?

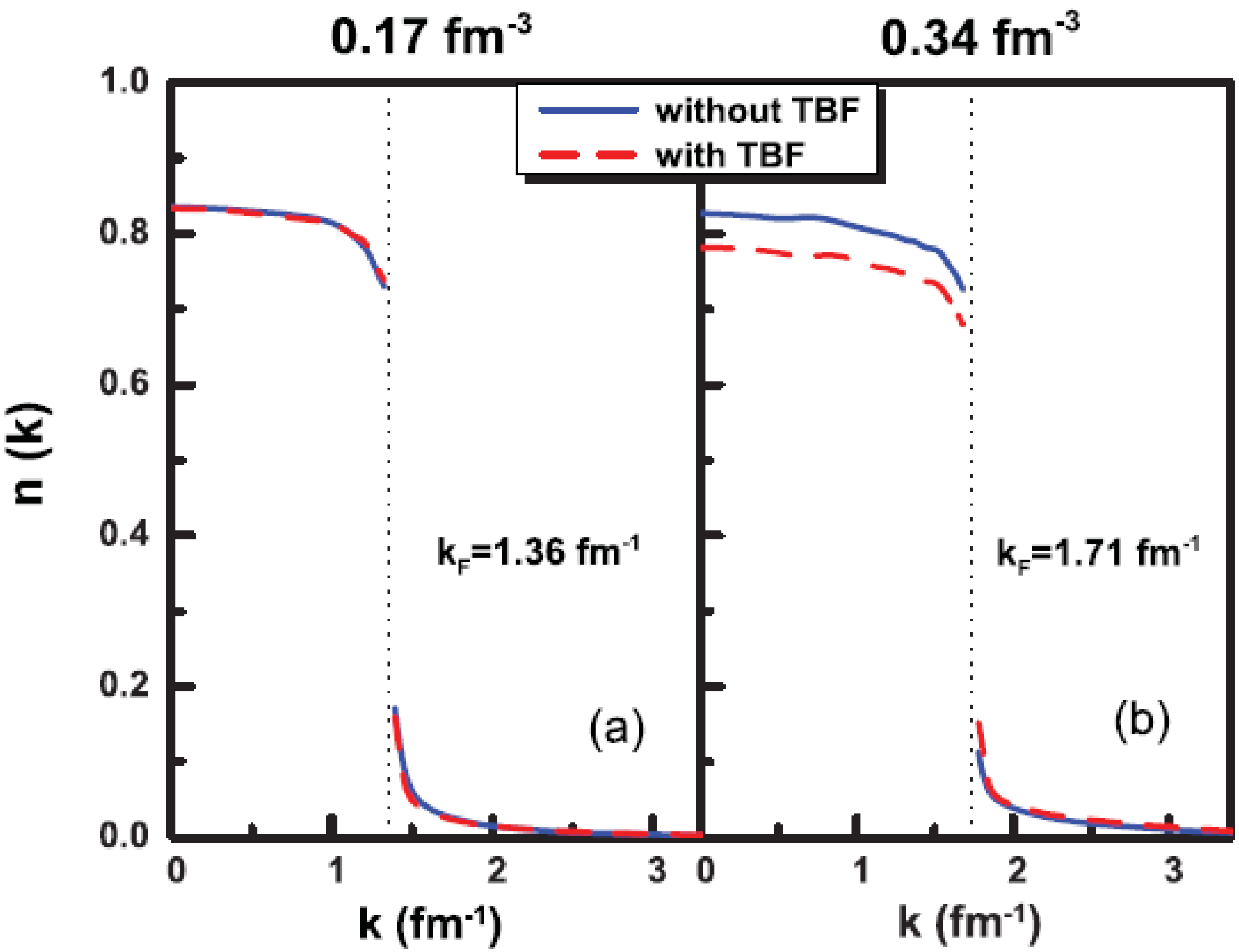


FIG. 7. (Color online) Nucleon momentum distribution in symmetric nuclear matter at two densities, $\rho = 0.17\ \mathrm{fm}^{-3}$ (left panel) and $\rho = 0.34\ \mathrm{fm}^{-3}$ (right panel).

P. Wang, S.X. Gan, P. Yin, W. Zuo , Phys. Rev. C 87,014328 (2013).

BUU Equation

$$\partial_t f_1 + \frac{\vec{p}}{E}\overrightarrow{\nabla}_r f_1 - \overrightarrow{\nabla}_r \underline{\underline{U}}\,\overrightarrow{\nabla}_p f_1$$

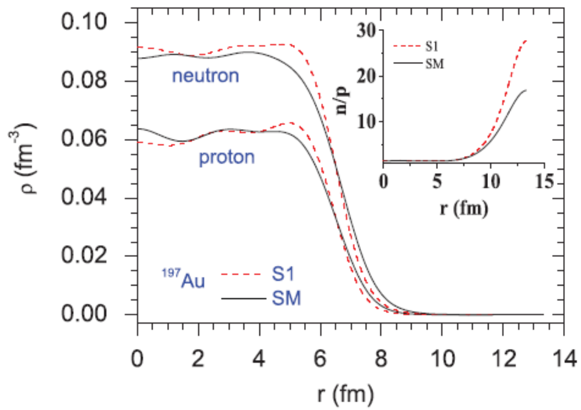
$$= \int \frac{d^3 p_{1'} d^3 p_2 d^3 p_{2'}}{(2\pi)^9} \underline{\underline{\sigma_{12}}} v_{12} (2\pi)^3 \delta^3(\overrightarrow{p_1} + \overrightarrow{p_2} - \overrightarrow{p_{1'}} - \overrightarrow{p_{2'}})$$

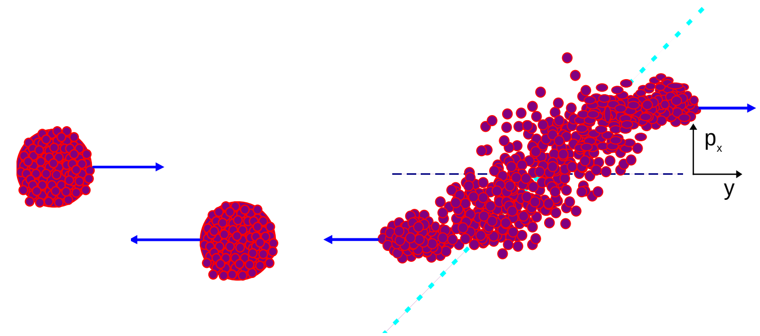
$$\times \left\{ f_{1'} f_{2'} (1 - f_1)(1 - f_2) - f_1 f_2 (1 - f_{1'})(1 - f_{2'}) \right\}$$

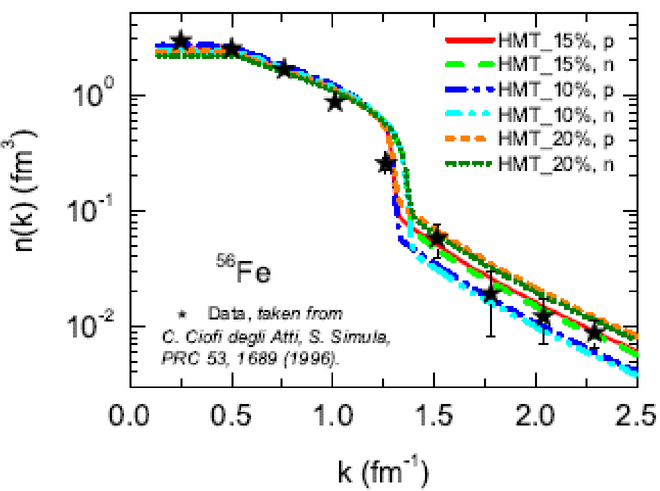
G.F. Bertsch, S.D. Gupta, Phys. Rep. 1988, 160, No.4, 189-233
W. Cassing, V. Metag, U. Mosel, K. Niita, Phys. Rep. 1990, 188, No.6, 363-449

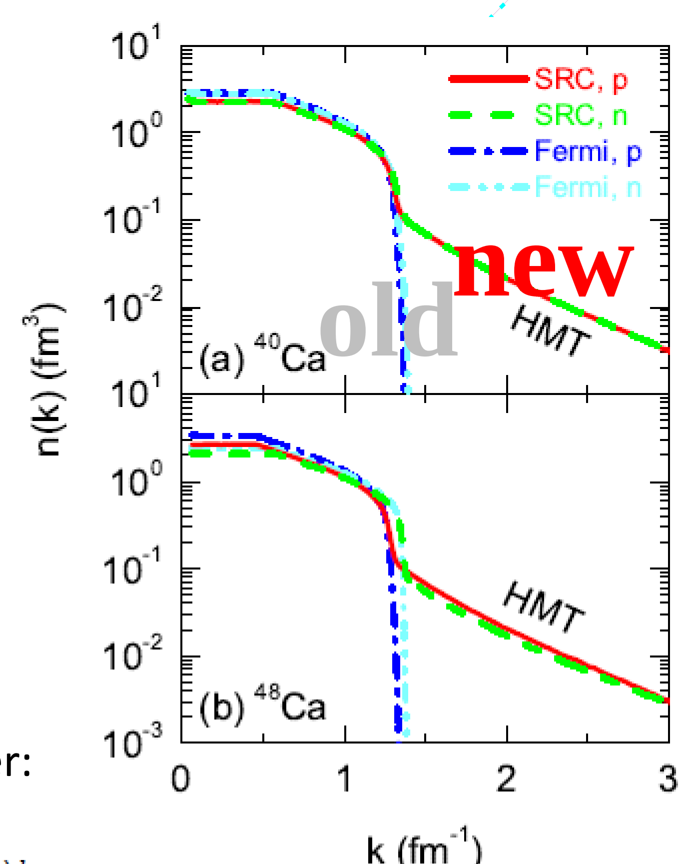
(1) Initialization:

(1) Nucleons in coordinates, RMF, SHF
(2) Momentum-space: localThomas-Fermi







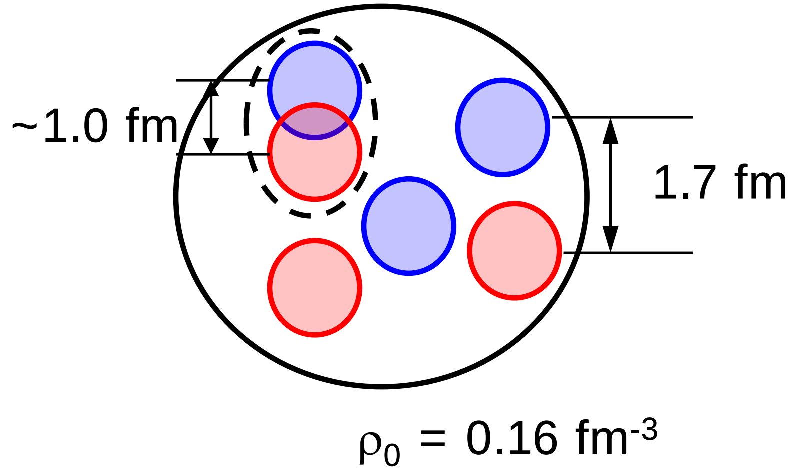


Gao-Chan Yong, Bao-An Li, PRC96, 064614(2017).

For nuclear matter:

$$n(k) = \begin{cases} C_1, & k \le k_F; \\ C_2/k^4, & k_F < k < \lambda k_F \end{cases}$$

(2) Mean-field:



$$U(\rho,\delta,\vec{p},\tau) = A_u(x)\frac{\rho_{\tau'}}{\rho_0} + A_l(x)\frac{\rho_\tau}{\rho_0}$$

$$+B\left(\frac{\rho}{\rho_0}\right)^\sigma(1-x\delta^2) - 8x\tau\frac{B}{\sigma+1}\frac{\rho^{\sigma-1}}{\rho_0^\sigma}\delta\rho_{\tau'}$$

$$+\frac{2C_{\tau,\tau}}{\rho_0}\int d^3\vec{p'}\frac{f_\tau(\vec{r},\vec{p'})}{1+(\vec{p}-\vec{p'})^2/\Lambda^2}$$

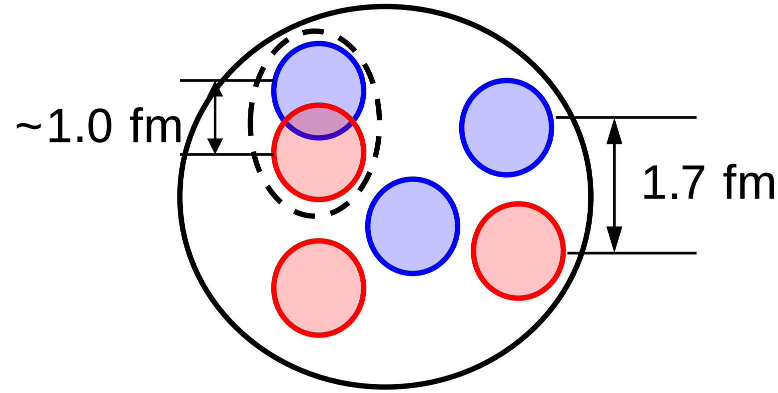
$$+\frac{2C_{\tau,\tau'}}{\rho_0}\int d^3\vec{p'}\frac{f_{\tau'}(\vec{r},\vec{p'})}{1+(\vec{p}-\vec{p'})^2/\Lambda^2}$$

Considering n-p correlations:

The parameters A, B, C, et al., are re-adjusted

Gao-Chan Yong, PRC93, 044610 (2016)

Symmetry potential:



ρ_0 = 0.16 fm^{-3}

$$U = U_0 + Usym$$

$$Usym = \partial Wsym \big/ \partial \rho_\tau$$

$$Wsym = Esym^{pot} \times \rho \times \delta^2$$

$$Esym = Esym^{kin} + Esym^{pot} \approx 31.6 MeV(\rho_0)$$

$$Esym^{kin} = \langle E^{kin}_{pure-n} \rangle - \langle E^{kin}_{n=p} \rangle = \frac{3}{5}\left[\frac{\hbar^2}{2m_n} k^2_{F_n}\right] - \frac{3}{5}\left[\frac{\hbar^2}{2m_n} k^2_{F_{n=p}}\right] \approx 12.5 MeV(\rho_0)$$

$$Esym^{pot} \approx 31.6 - 12.5 = 19.1(MeV)$$

old

$$Esym^{kin} \approx 0$$

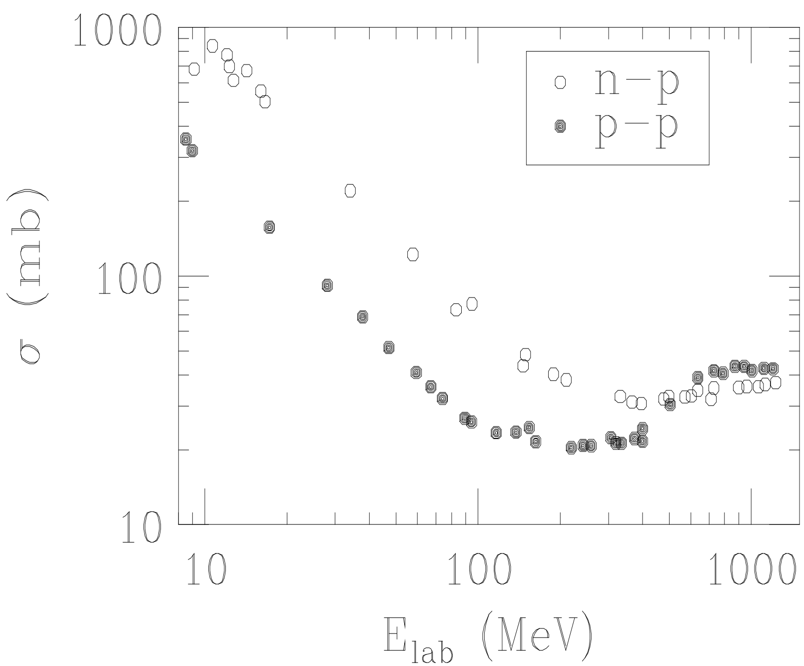
$$Esym^{pot} \approx 31.6 - 0 = 31.6(MeV)$$

new

(3) Baryon-baryon scatterings:

$$R^{BB}_{\text{medium}}(\rho,\delta,\vec{p}) \equiv \sigma^{\text{medium}}_{BB_{\text{elastic,inelastic}}}/\sigma^{\text{free}}_{BB_{\text{elastic,inelastic}}}$$
$$= (\mu^*_{BB}/\mu_{BB})^2,$$

$$U_B^{\Delta^-} = U_n,$$
$$U_B^{\Delta^0} = \tfrac{2}{3}U_n + \tfrac{1}{3}U_p,$$
$$U_B^{\Delta^+} = \tfrac{1}{3}U_n + \tfrac{2}{3}U_p,$$
$$U_B^{\Delta^{++}} = U_p$$



$$\frac{m_B^*}{m_B} = 1\bigg/\left(1 + \frac{m_B}{p}\frac{dU}{dp}\right)$$

Bao-An Li, Lie-Wen Chen, Phys.Rev.C72:064611,2005

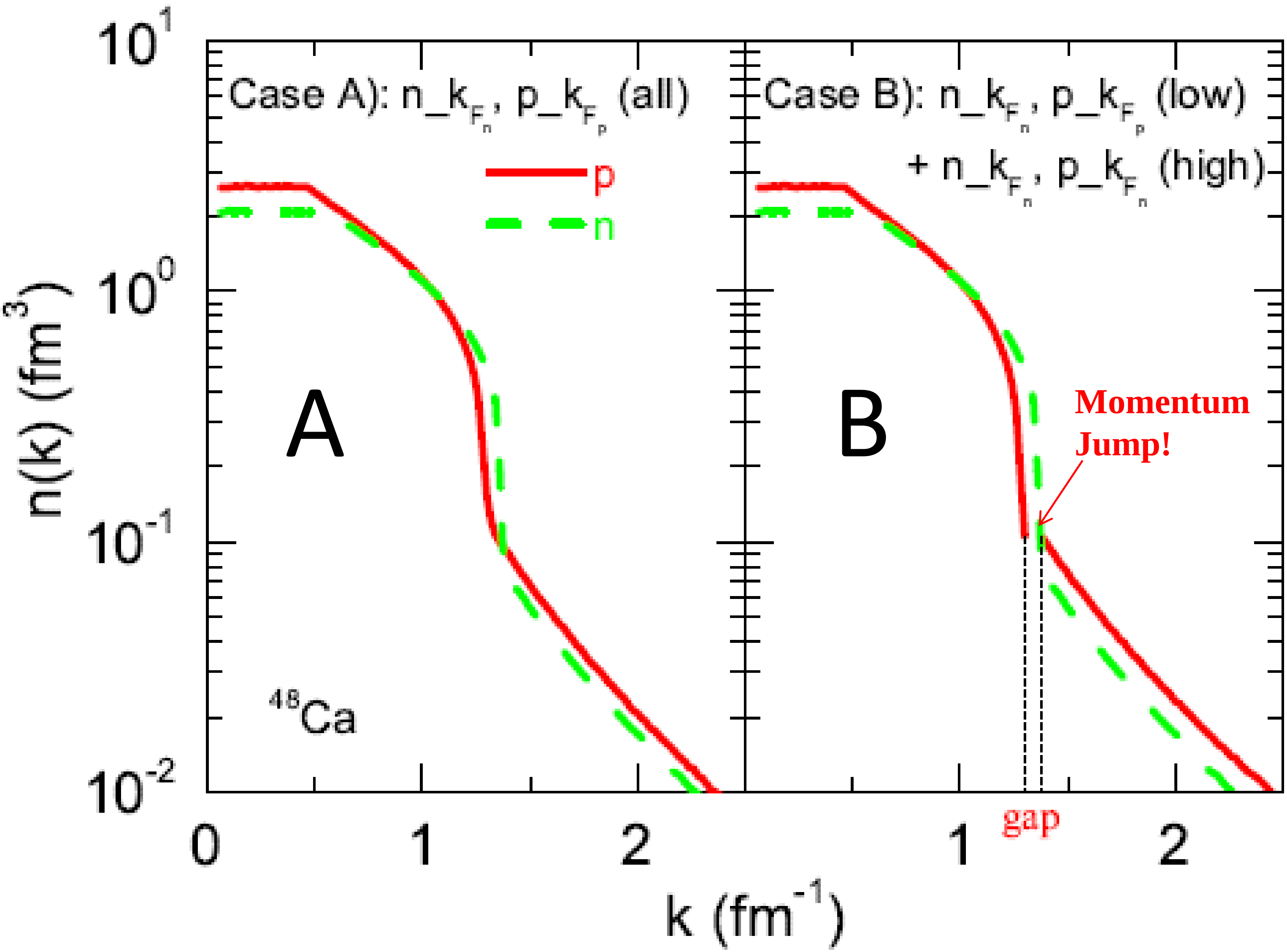
M.D. Cozma, Phys.Lett. B753 (2016) 166-172

Assuming including Short-range correlations information

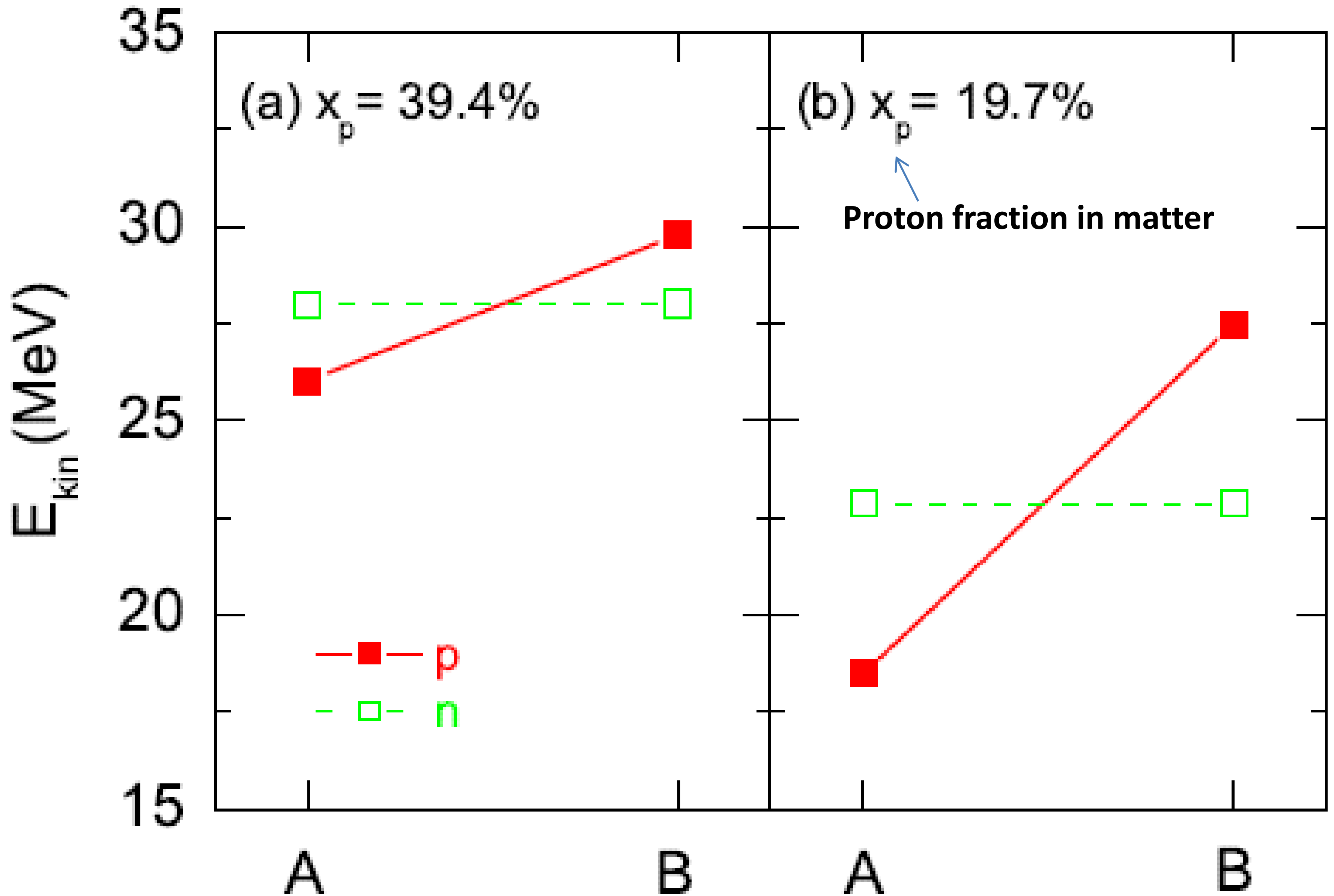
Gao-Chan Yong, Phys. Rev. C 93, 044610 (2016)

Two inputs:

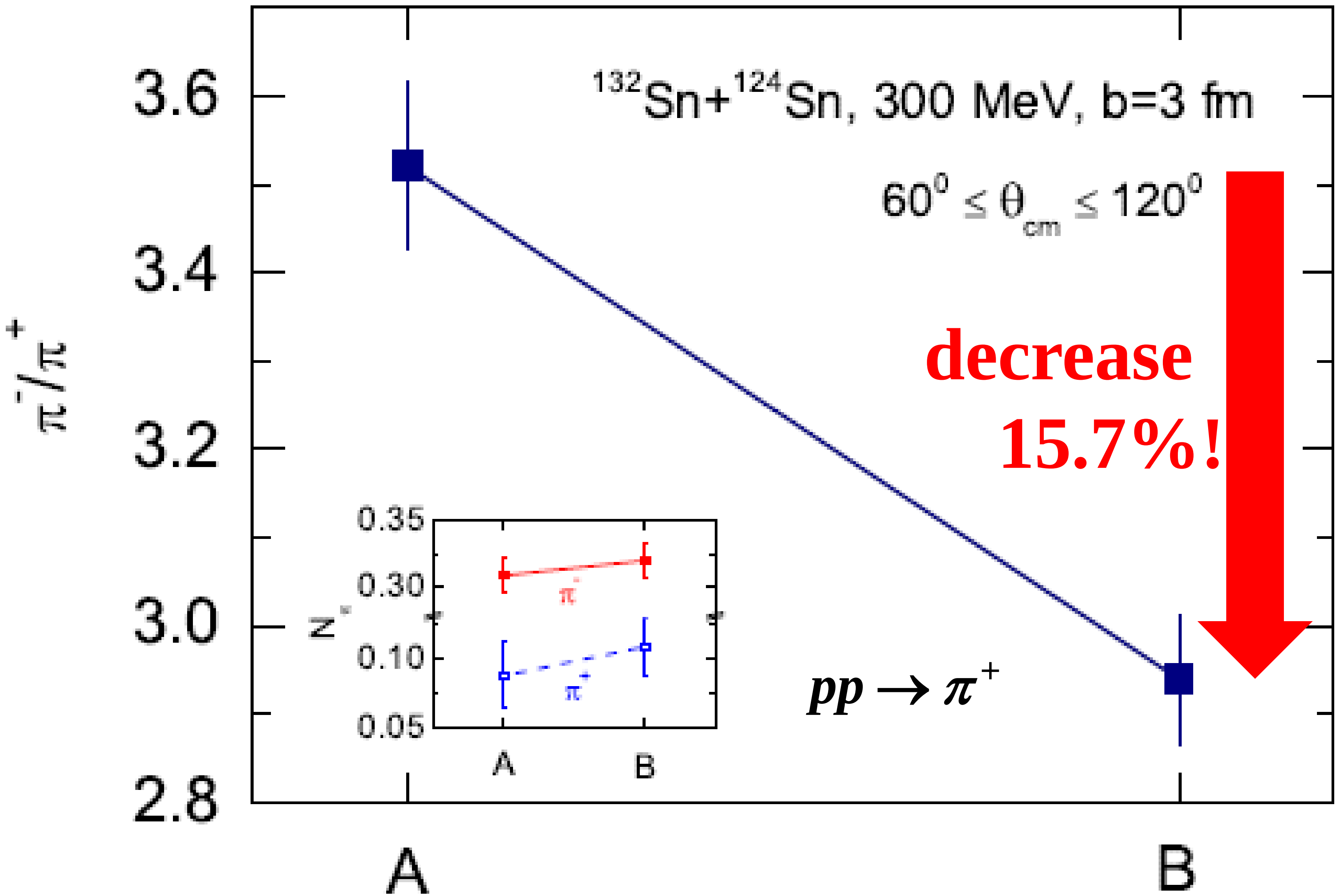
Gao-Chan Yong, Phys.Lett. B776 (2018) 447



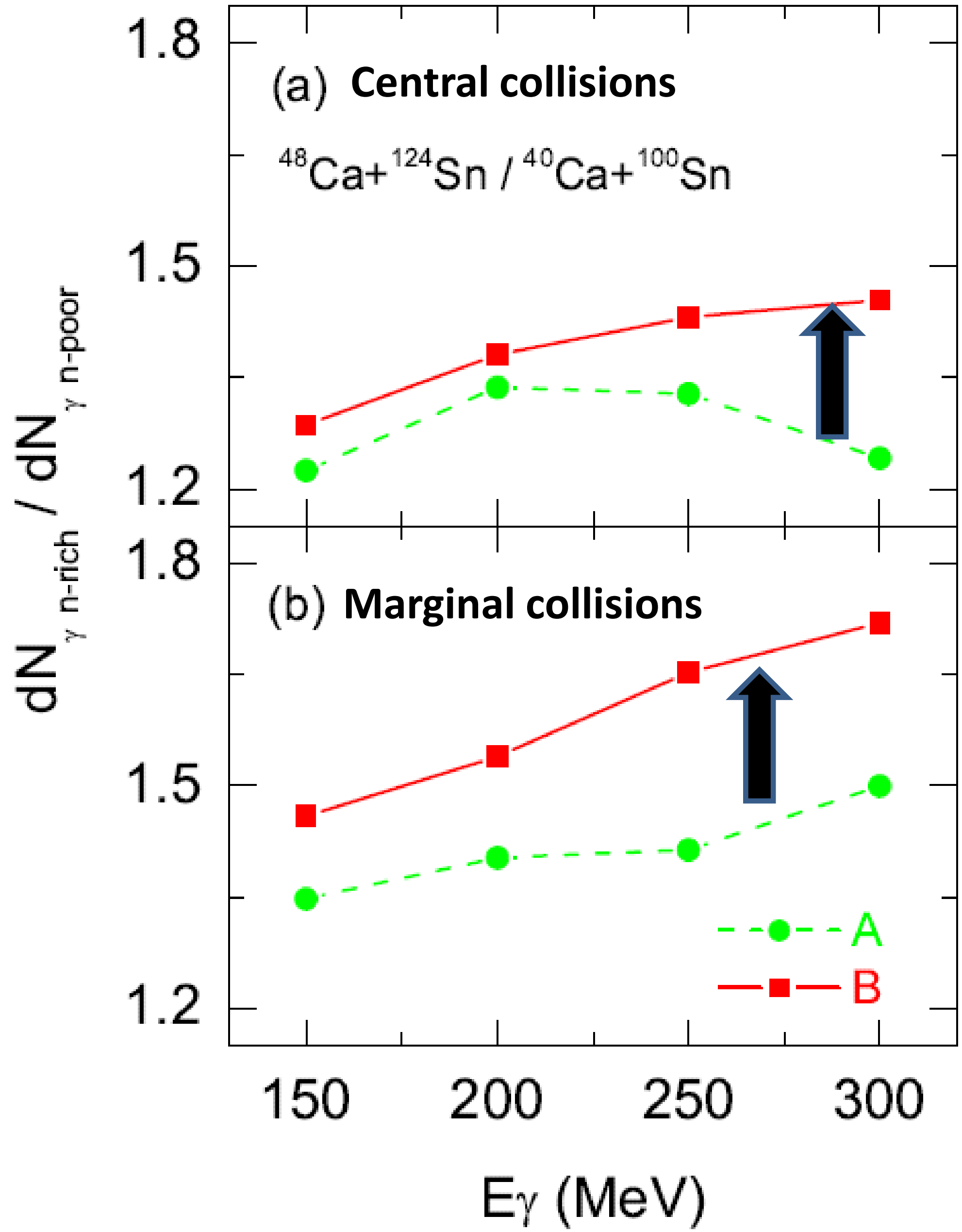
On Nucleon kinetic energy



On pion ratio



On photon production

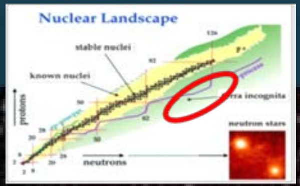


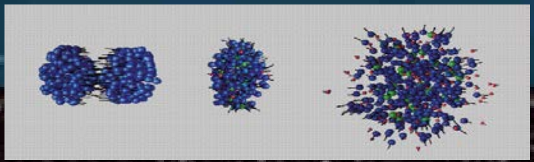
increase 15%!

Not sensitive to the symmetry energy at this energy range due to SRC.

$$pn \to pn\gamma$$

Rare isotope facilities worldwide





Neutron-rich nuclei

HIC at intermediate energy

Neutron star matter

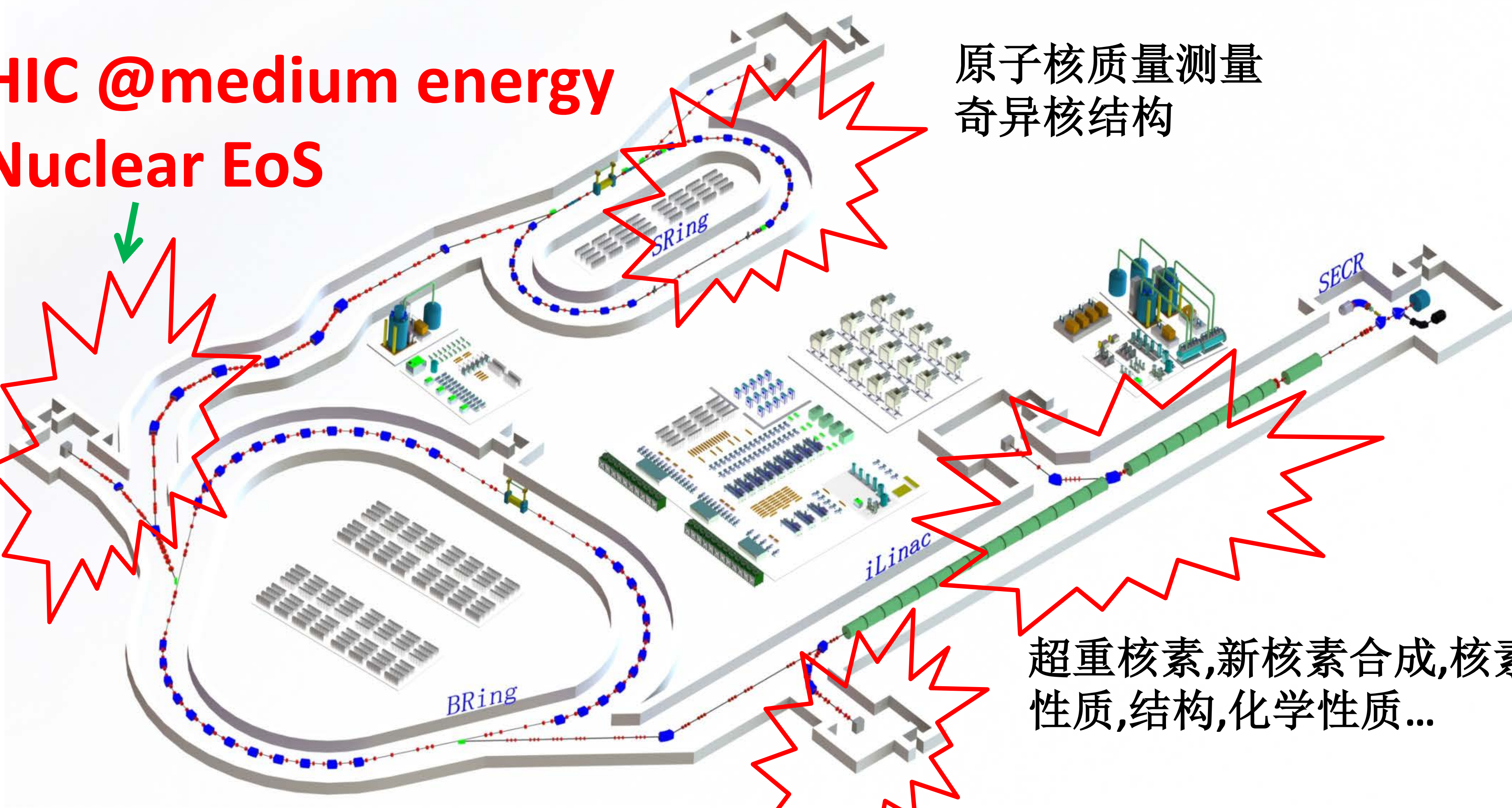
HIAF实验测量装置

High Intensity Heavy-ion Accelerator Facility

HIC @medium energy

Nuclear EoS

原子核质量测量
奇异核结构



超重核素,新核素合成,核素性质,结构,化学性质...

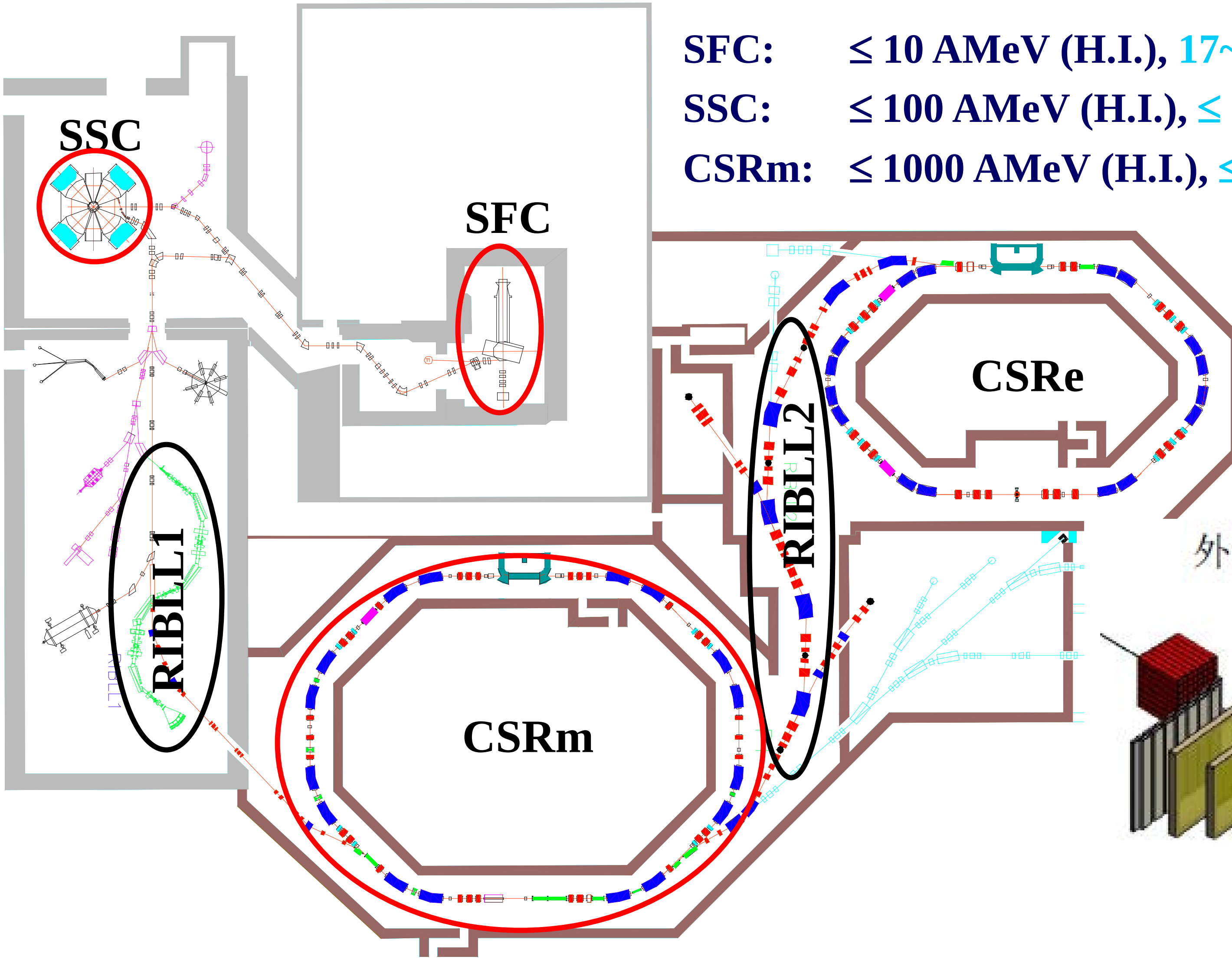
天体核反应

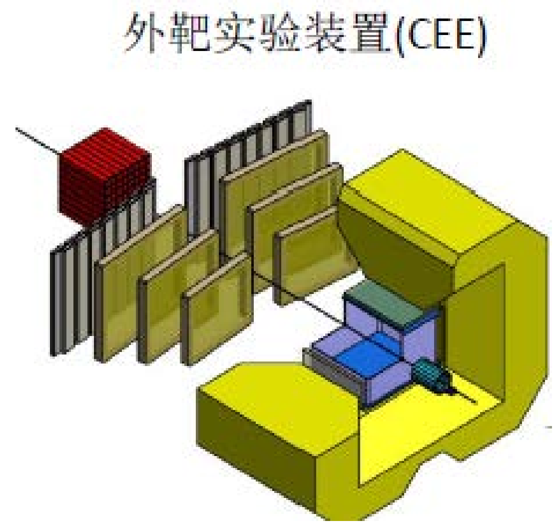
HIRFL-CSR heavy-ion beams

SFC: ≤ 10 AMeV (H.I.), 17~35 MeV (p)

SSC: ≤ 100 AMeV (H.I.), ≤ 110 MeV (p)

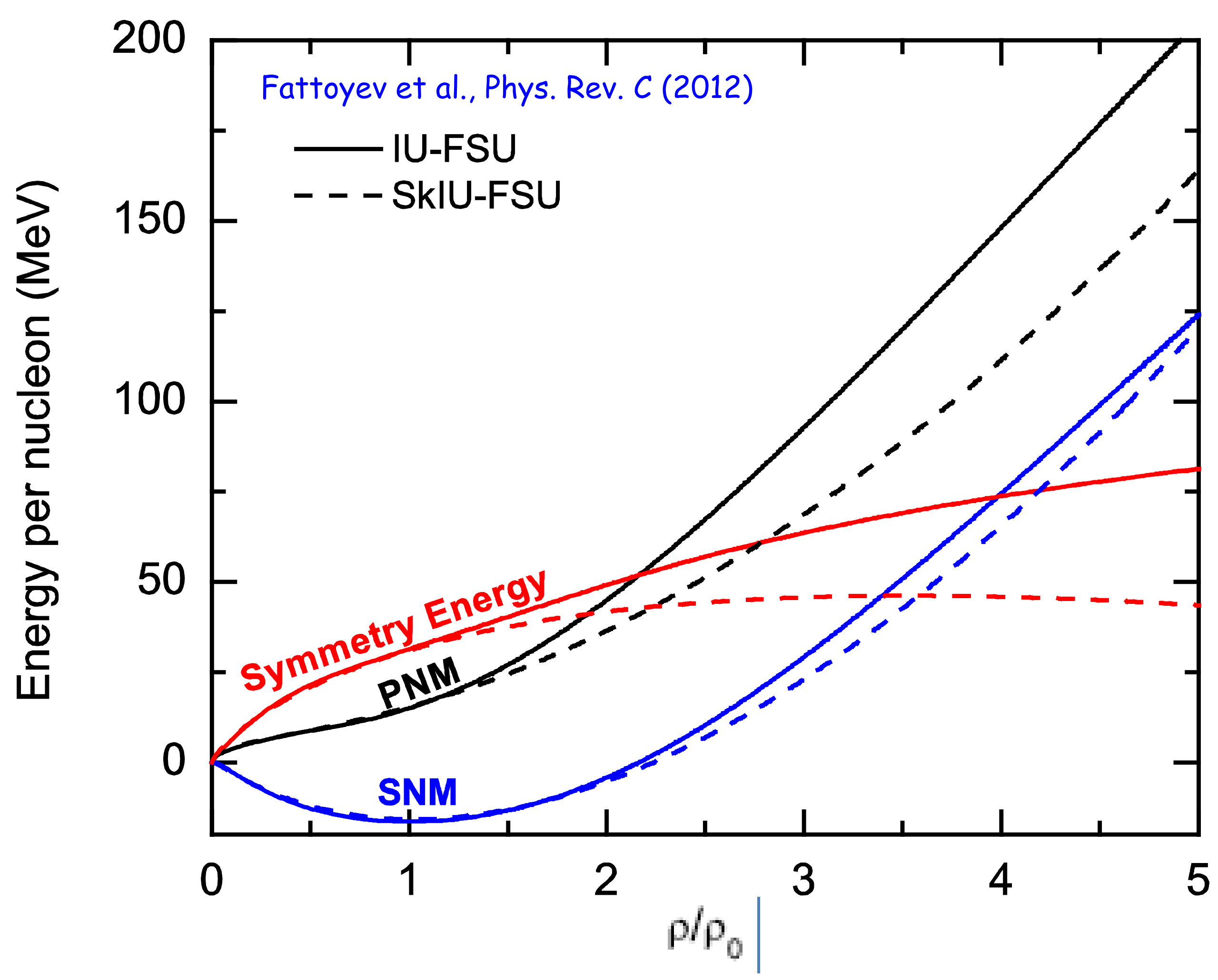
CSRm: ≤ 1000 AMeV (H.I.), ≤ 2.8 GeV (p)

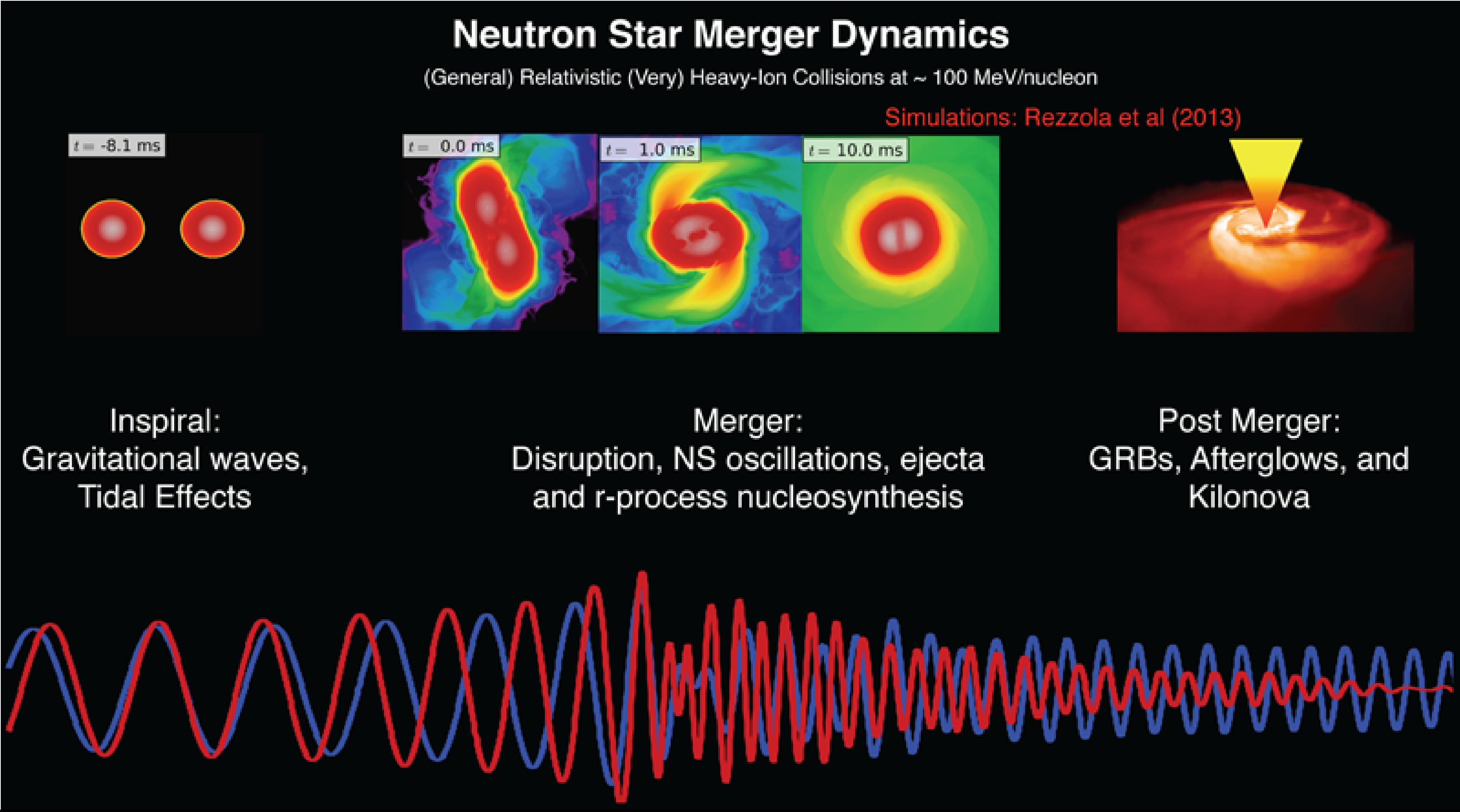




The Nuclear Equation of State

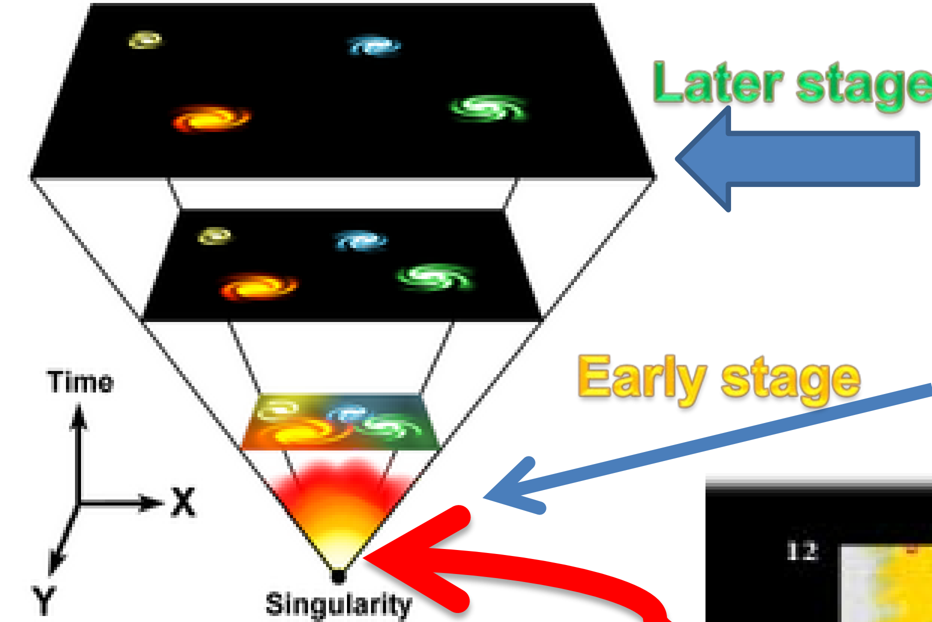
$$E(\rho,\alpha) = E_0(\rho) + S(\rho)\alpha^2 + \mathcal{O}(\alpha^4),$$





EoS of neutron-rich matter is important !

Why HIC

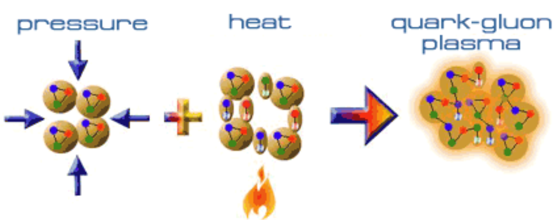


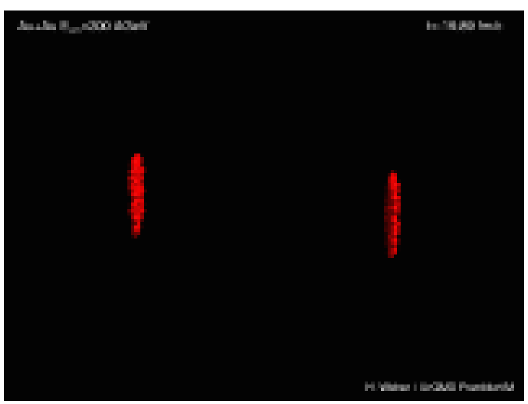
HIC @ medium energy, several GeV

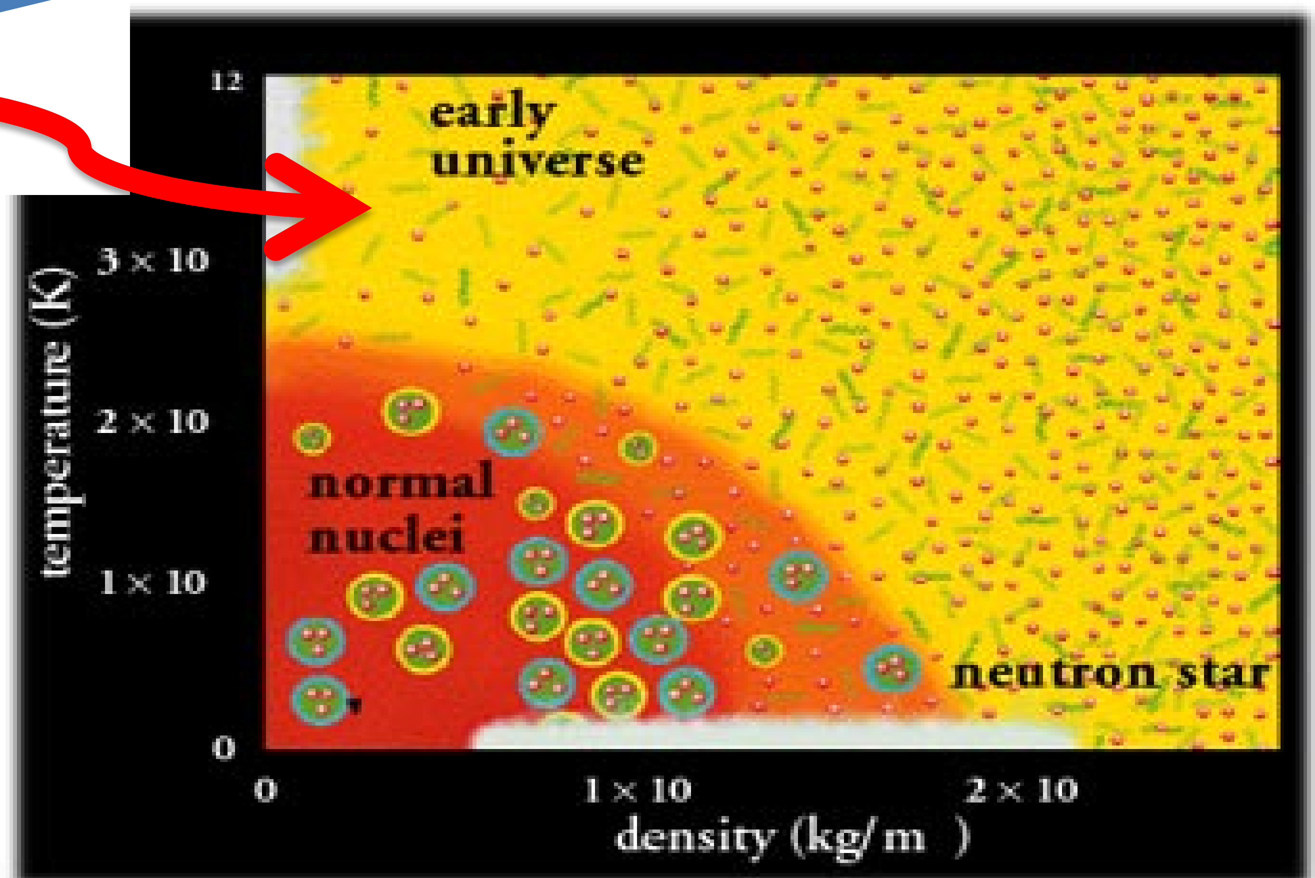
<u>Baryon matter's EoS</u> is important for violent events in the universe!

HIC @ high energy, above tens of GeV

<u>Quark matter's EoS</u>







Conclusions

- **Proton mom. distribution may have a jump** in neutron-rich nuclei or neutron-rich matter,

- Could be checked through rare isotope reaction.

Conclusions

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Thanks for your attention!