Isoscaling effect with Z=1 and 2 particles in Sn+Sn at 270 MeV/u

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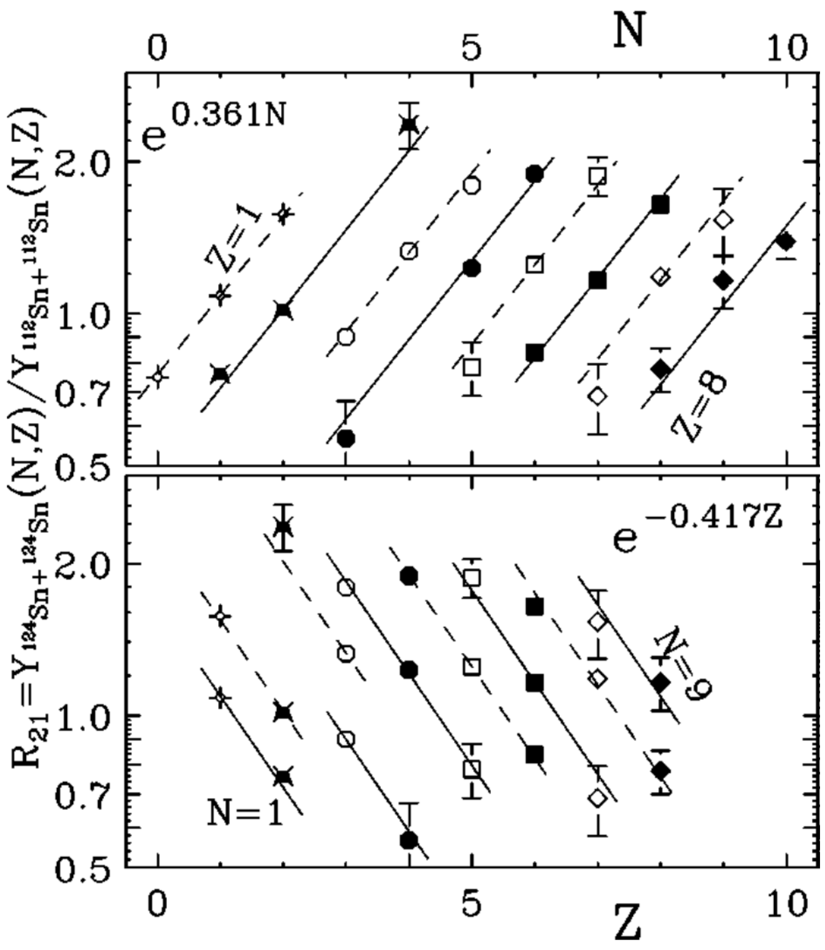
Introduction to Isoscaling

- Grand canonical ensemble, thermal equilibrium assumption in heavy-ion collision the fragment yield can be written down as:
  - $Y^{prim.}(N,Z,T) = \frac{VA^{3/2}}{\lambda_T^3}\omega(N,Z,T)\exp\left[\frac{E_B(N,Z)+N\mu_n+Z\mu_p}{T}\right].$
  - $Y^{final}(N,Z,T) \simeq f(N,Z,T)Y^{prim.}(N,Z,T).$

** S. Albergo et al. Nuovo Cimento Soc. Ital. Fis., A 89 (1985) 1*
** H. S. Xu et al. Phys. Rev. Lett. 85 (2000) 716*

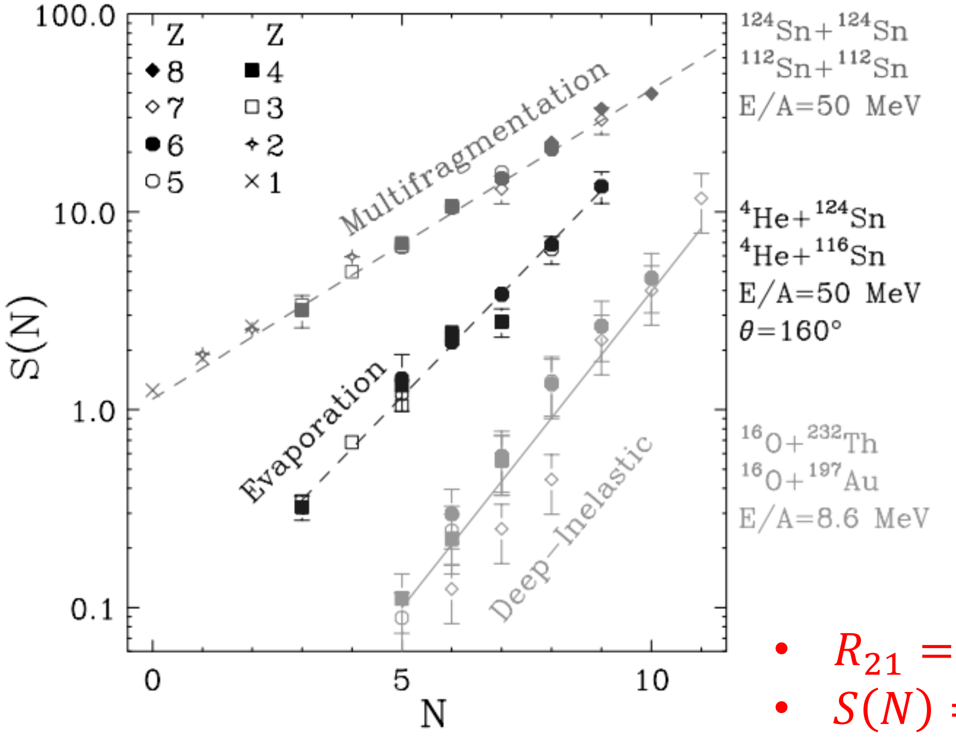
- We compare two collision system 2 and 1.
  - Two system have similar size and temperature.
  - System 2 is neutron rich system compared to system 1.
- The fragment yield ratio between two systems exhibit exponential behavior:
  - $R_{21} = Y_{system-2}(N,Z)/Y_{system-1}(N,Z).$
  - $R_{21} = C\exp(\alpha N + \beta Z)$, $\alpha = \frac{\Delta\mu_n}{T}$, $\beta = \frac{\Delta\mu_p}{T}$.



** M. B. Tsang et al. (MSU) Phys. Rev. C 64 (2001) 041603*

Introduction to Isoscaling

- Isoscaling was reported in many other experiments not only from the multi-fragmentation in heavy-ion collisions but in non symmetric collisions such as evaporation, deeply inelastic scattering and light ion induced reactions.



- $R_{21} = C\exp(\alpha N + \beta Z)$
- $S(N) = R_{21}\exp(-\beta Z)$

** M. B. Tsang et al. Phys. Rev. C 64 (2001) 041603*
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** A. S. Botvina et al. Phys. Rev. C 65 (2002) 044610*
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** Akira Ono et al. Phys. Rev. C 68 (2003) 051601*
** S. R. Souza et al. Phys. Rev. C 80 (2009) 044606*

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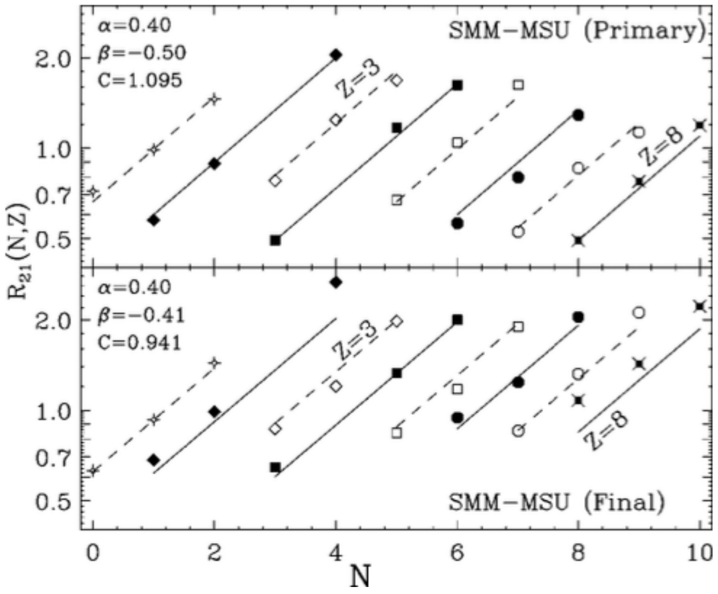
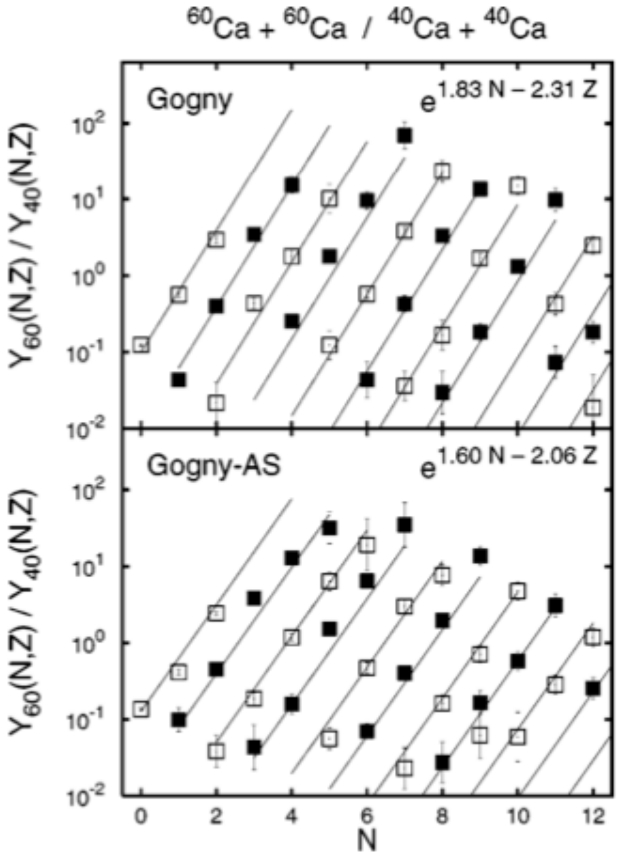
- Isoscaling was also reported in many model calculations
  - SMM (Statistical multi-fragmentation model),
  - EES (expanding emission source model),
  - AMD (antisymmetrized molecular dynamics).

- Scaling parameter α and symmetry energy C_{sym} :
  - $\alpha = \frac{4C_{sym}}{T}\left[\left(\frac{Z_1}{A_1}\right)^2 - \left(\frac{Z_2}{A_2}\right)^2\right]$, (T < 5 MeV).





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SπRIT Experiment

- Sn + Sn collisions at 270 MeV/u measured with SπRIT-TPC inside the SAMURAI magnet producing 0.5 T at RIBF RIKEN (2015-2016).
  - $^{132}Sn + ^{124}Sn$ (N/Z = 1.56)
  - $^{108}Sn + ^{112}Sn$ (N/Z = 1.20)
  - $^{124}Sn + ^{112}Sn$ (N/Z = 1.36)
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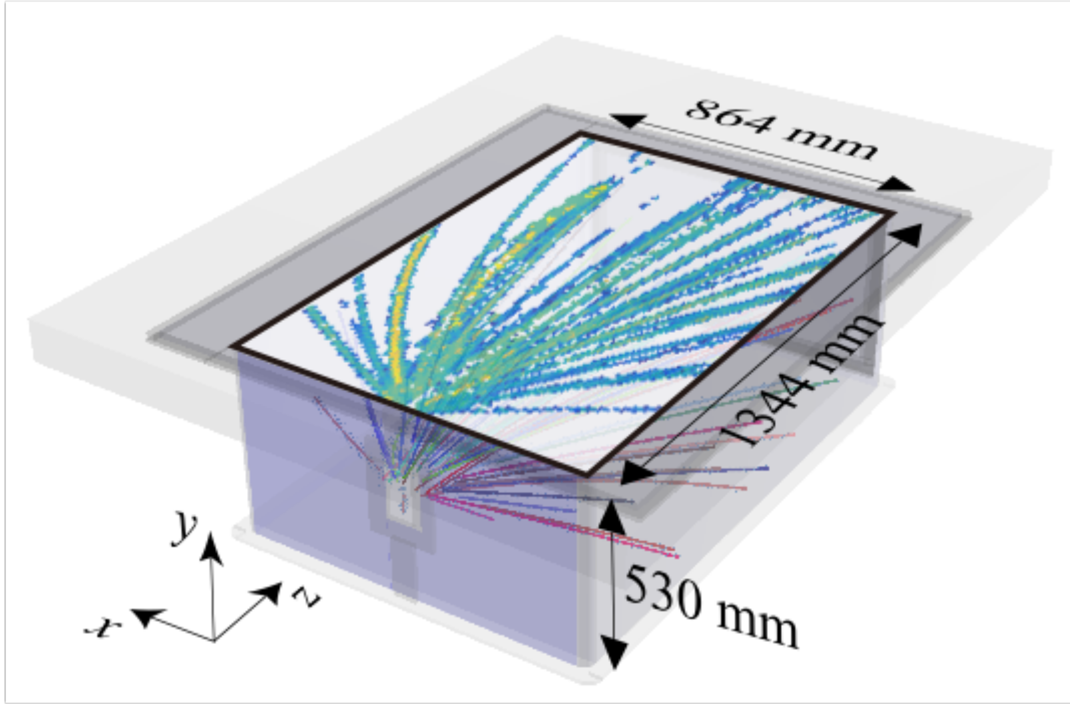

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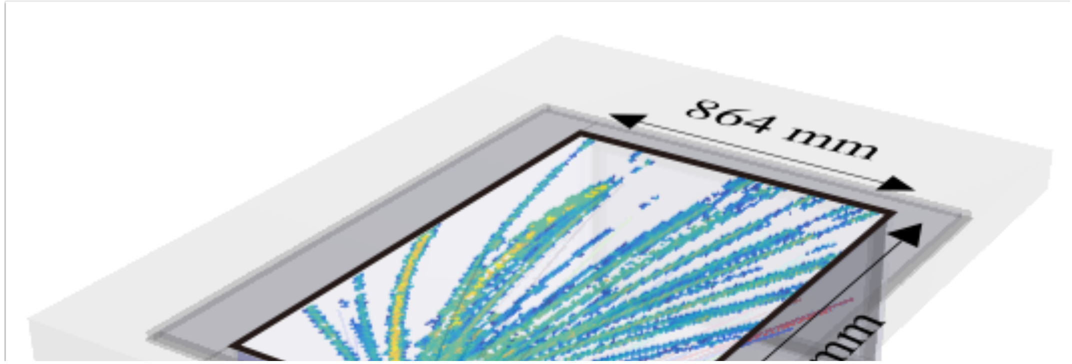
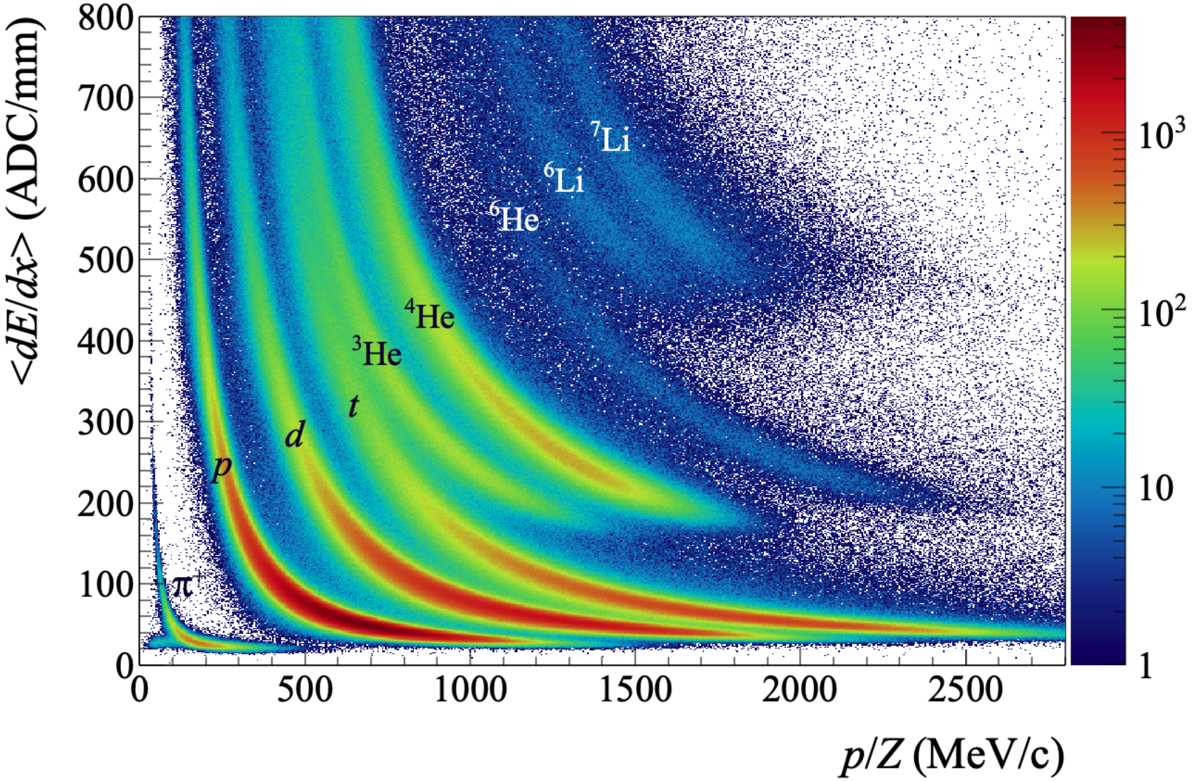


- Pions, Hydrogen and Helium isotopes are found.

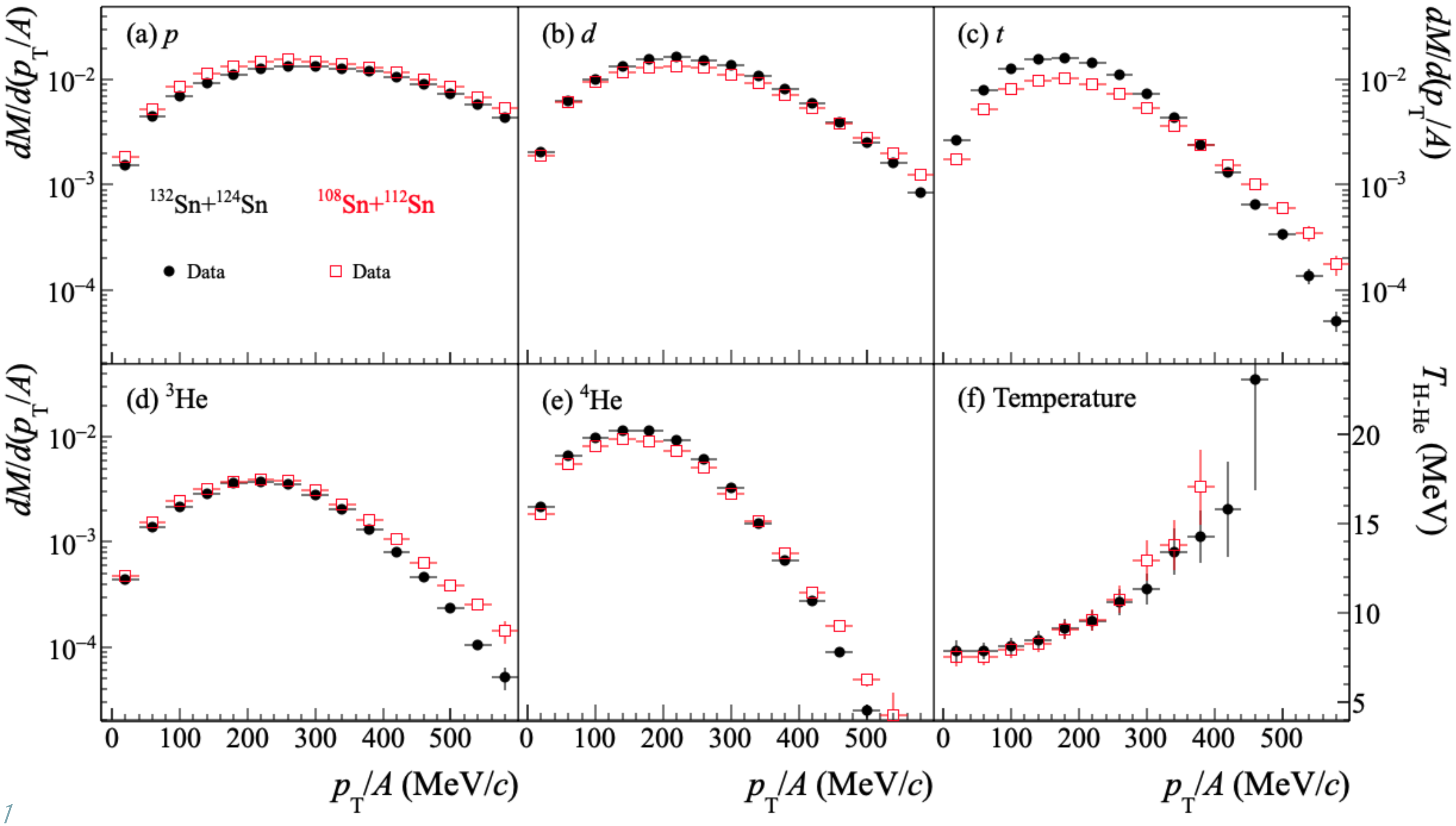


- Cut
    - Rapidity y_0 = 0 - 0.4
    - Impact factor b < 1.5 fm

p_T/A Spectra

- Different trend of p_T/A is shown for (N-Z) groups.
- N-Z=1 (p, ^{3}He) particles show more yield in neutron deficient system.
- N-Z=0 (d, ^{4}He) particles show little more yield is shown for neutron rich system.
- N-Z=1 (t) particle show larger yield is shown for neutron rich system.

- H-He double ratio temperature was calculated for reference.
  - $T = 1.43 \ln^{-1}\left[1.6 \frac{Y(d)\, Y(^4He)}{Y(t)\, Y(^3He)}\right]$



* S. Albergo et al. Nuovo Cimento Soc. Ital. Fis., A 89 (1985) 1

p_T/A Spectra + AMD

AMD : Soft symmetry energy

** M. Kaneko et al. Phys. Lett. B 822 (2021) 136681*

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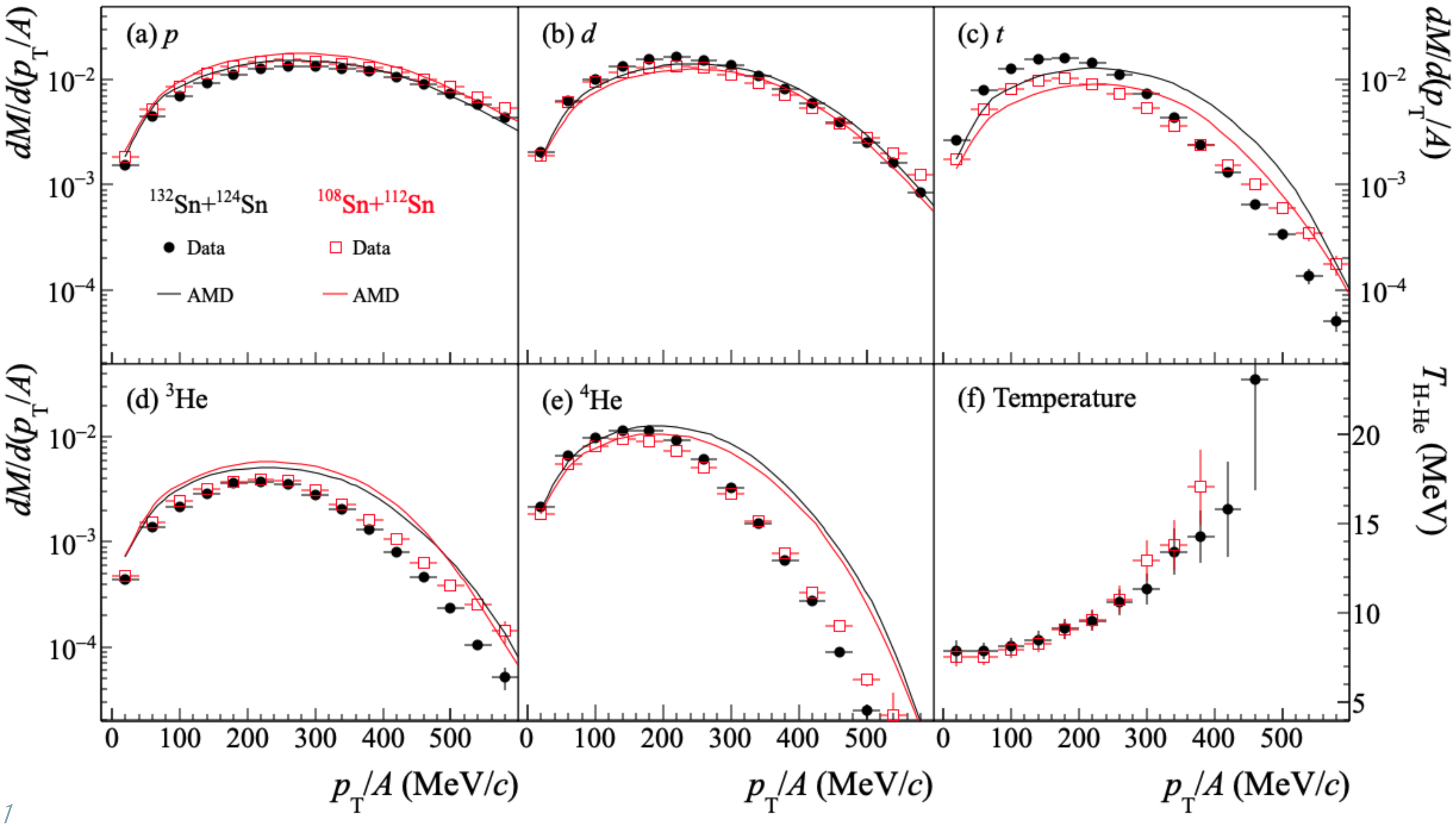
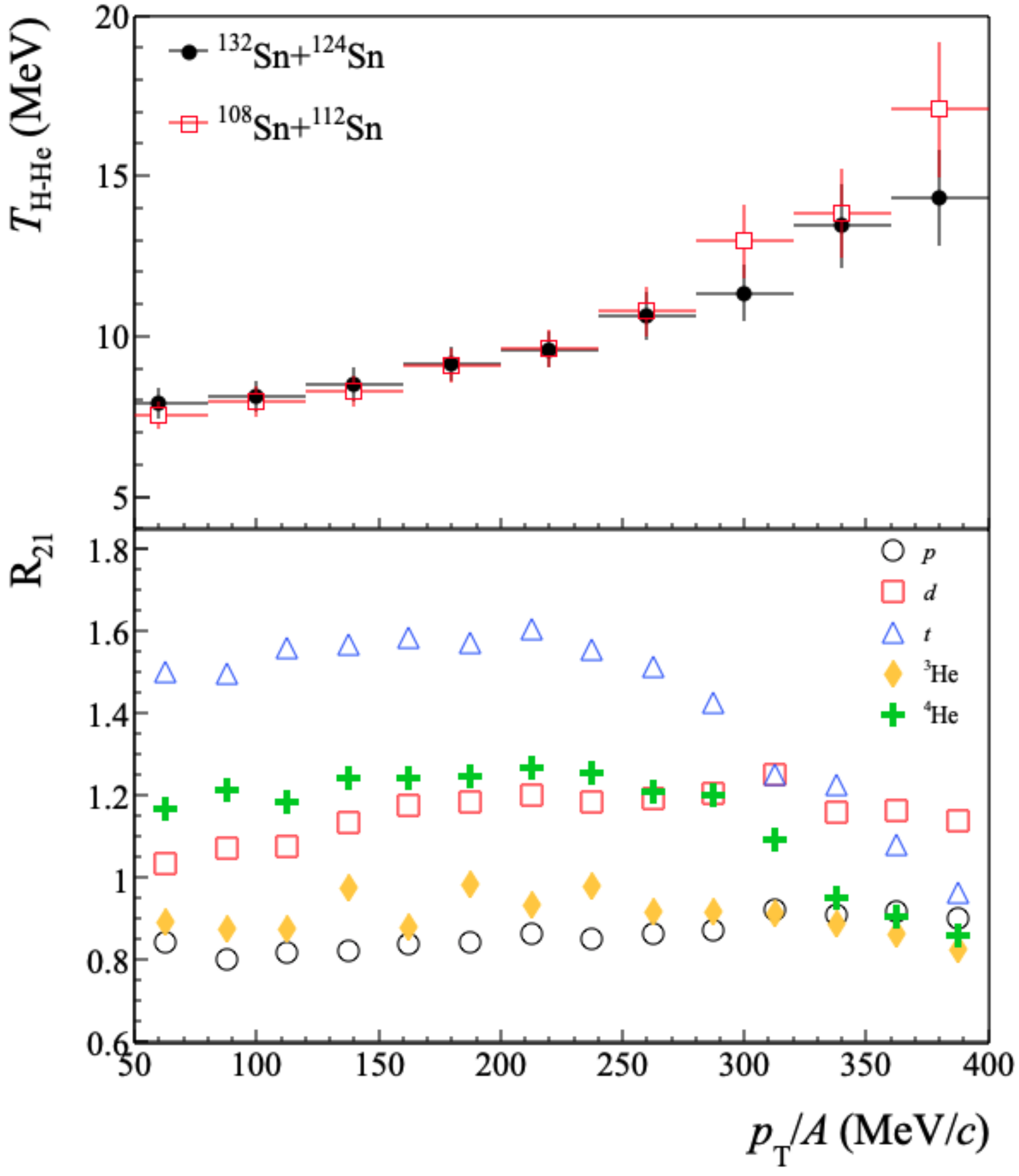


Spectral Yield Ratio

- N-Z group is clearly shown in the spectra.
  - $R_{21} = C\exp(\alpha N + \beta Z)$.
  - $\alpha \simeq -\beta$
- Valid at p_T/A below 250 MeV/c and temperature exceed over 10 MeV at this point.



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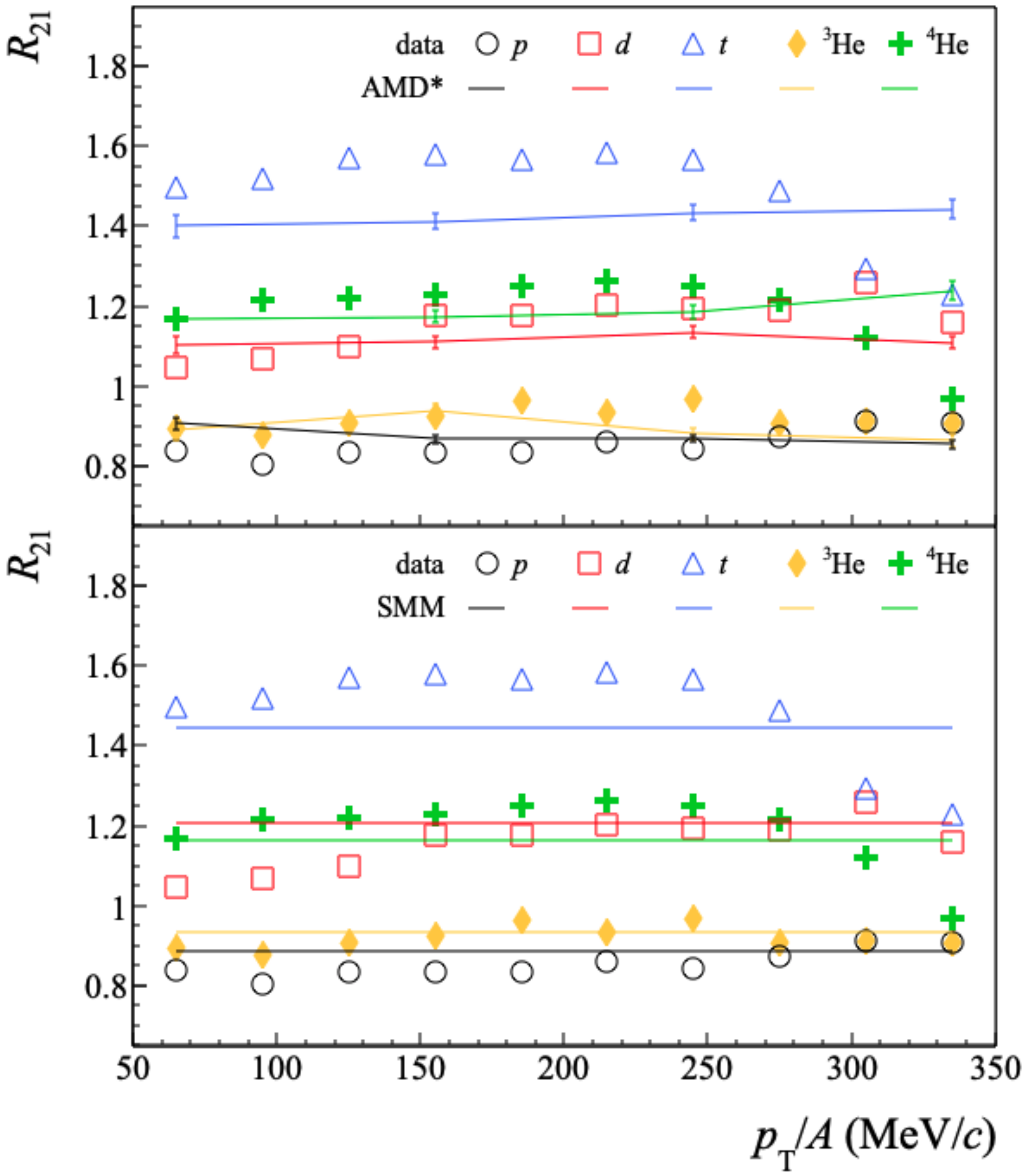
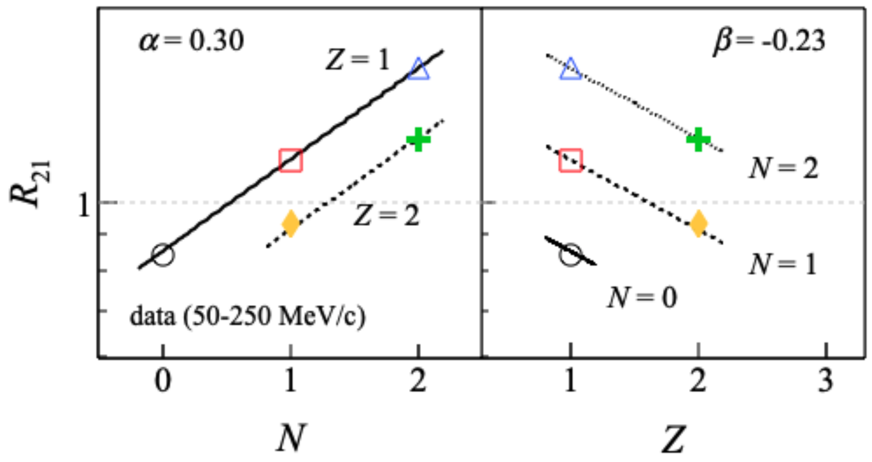
** S. R. Souza et al. Nucl. Phys. A 989 (2019) 69*

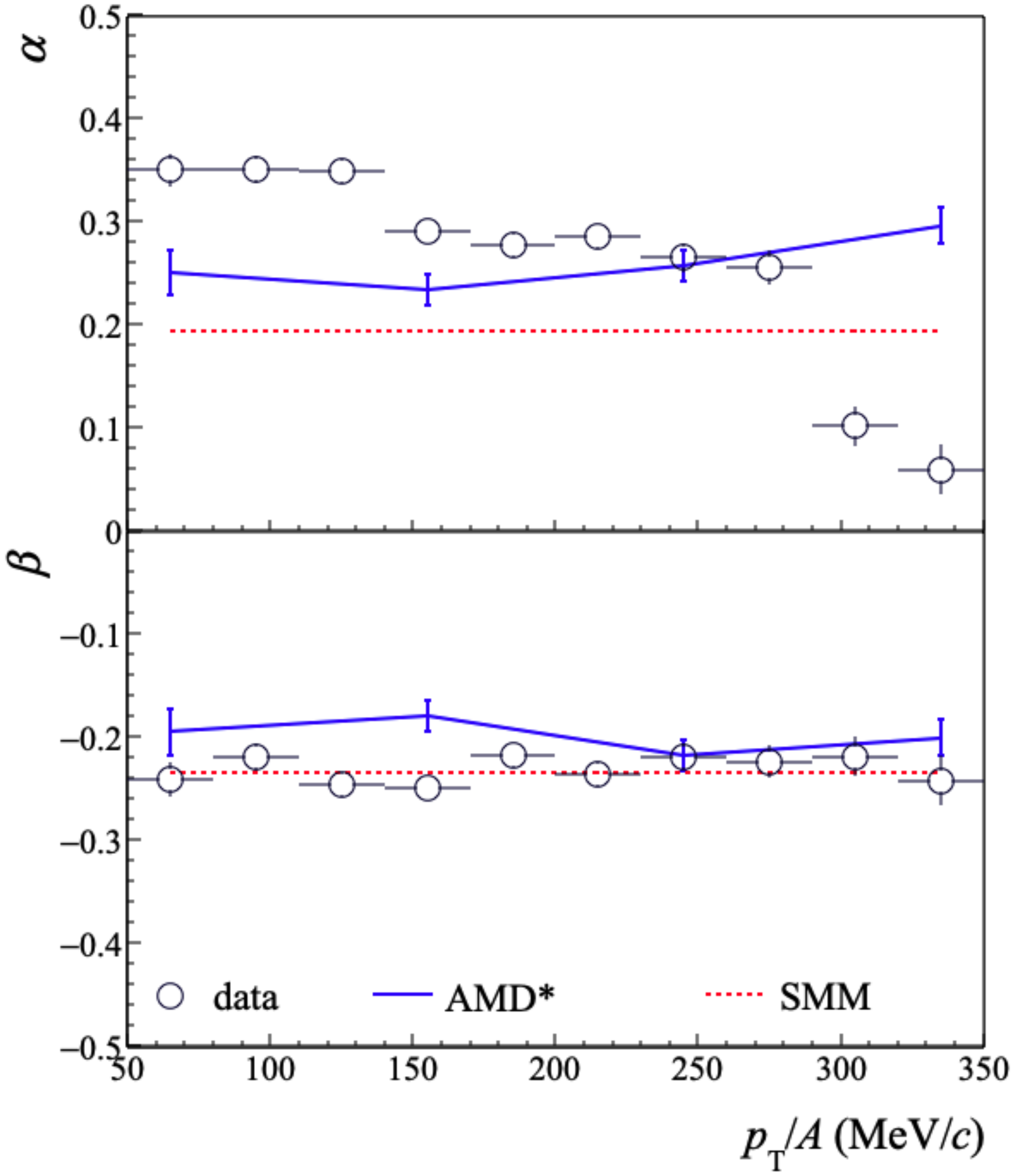
- SMM calculation where provided with A and Z of the source:
  - Neutron-rich system : A=172, Z=79
  - Neutron-deficient system : A=142, Z=72
- Compared AMD and SMM calculation explain the data up to 250 MeV/c.
- The overall trend breaks above 250 MeV/c.



Isoscaling with data

- Isoscaling fit to data, AMD and SMM where performed to get the α and β values through p_T/A.
- Nice isoscaling is given below 250 MeV/c.
- Isoscaling above 250 MeV/c is shown to break down.
- α from data decrease even below 250 MeV/c while AMD stays constant. β values stay constant for all cases.





Conclusion

- Isoscaling properties are studied in $^{132}Sn+^{124}Sn$ and $^{108}Sn+^{112}Sn$ systems at 270 MeV/u. compared to the previous studies on isoscaling, we explored collision systems with comparably large energy (270 MeV/u) and large isospin difference (N/Z_2 = 1.56 and N/Z_1 = 1.20).
- Since temperature increase as a function of p_T/A, we performed isoscaling fit for different p_T/A bins.
- The spectral yield ratio R21 show constant trend up to $p_T/A = 250\ MeV/c$ but triton and ^4He starts to decrease above this region. Consequently, isoscaling breaks above this boundary ($p_T/A = 250\ MeV/c$).
- In the reliable p_T/A region ($50\text{–}250\ MeV/c$), we obtained $\alpha = 0.30$ and $\beta = -0.23$.

- Thermal equilibrium approximation might not be appropriate for high energy particles in heavy-ion collisions at energy range around 270 MeV/u.
- The temperature of the systems for AMD (H-He temperature) show constant trend through pT/A and temperature for SMM is fixed to 8 MeV. This means that calculations is assuming thermal equilibrium through out the system and this might be the reason for different scaling trend compared to data.

- For the feature studies, more cases are needed be explored in other similar systems, and include other produced particles (neutrons, ^6He, Li isotopes) if possible.