Study of light cluster production in intermediate energetic heavy-RI collision at RIBF

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RIKEN's Programs for Junior Scientists

Contents of this talk

- Physics motivation
  - Asymmetric nuclear EOS, symmetry energy
  - Heavy-ion collision observables, pion and cluster
- Experiment
  - 270 MeV/nucleon Sn-Sn isotopic collisions at RIKEN-RIBF
- Current status of hydrogen isotopes analysis
  - Reaction system difference on the multiplicity and rapidity
- Summary

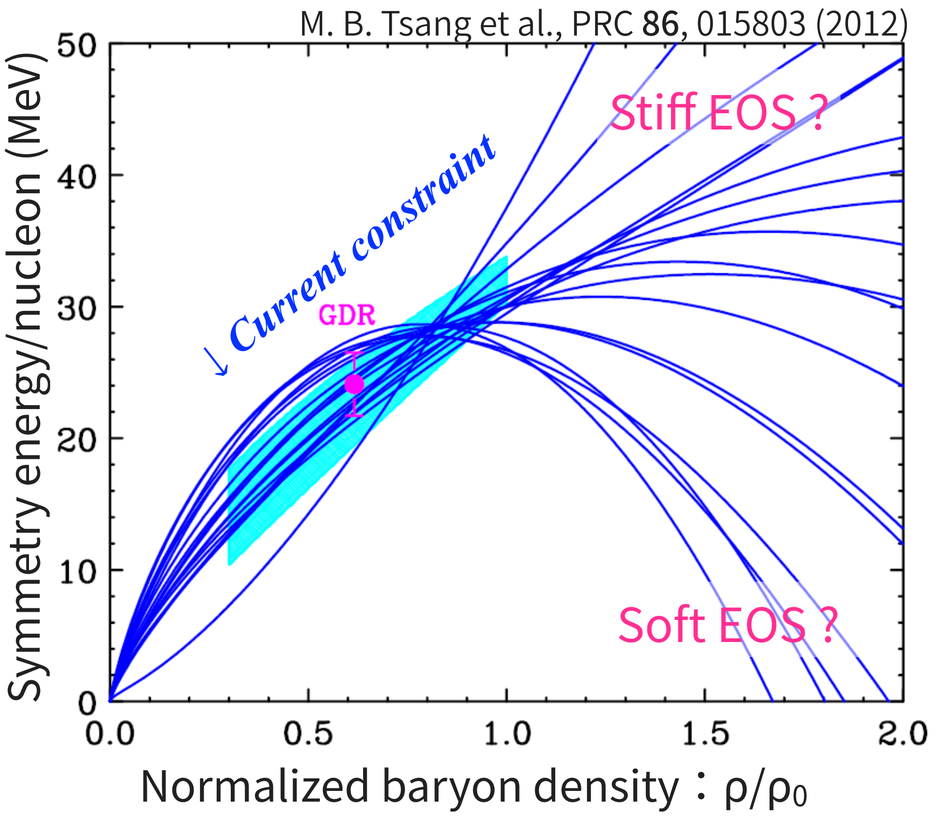
Motivation: nuclear equation of state

- **= Relationship between thermodynamic variables of the nuclear matter**

$$\mathcal{E}(\rho,\delta) = \mathcal{E}(\rho,\delta\sim 0) + \mathcal{S}(\rho)\delta^2 + \mathcal{O}(\delta^4)$$

$$\rho = \rho_n + \rho_p,\ \ \delta = (\rho_n - \rho_p)/\rho$$

- Symmetry energy: S(ρ)
  - Associated with a lot of phenomena at asymmetric matter.
  - Nuclear phys.: neutron skin/halo, exotic resonance state
  - Neutron star: mass-radius relation, BNS merger(GW170817)
  - At below saturation density, constrained by various probes.
- Poor constraint at high density.



High densities: information of neutron star interior.

➡ **Heavy-ion collision(HIC) is possible method to produce a dense matter on the earth.**

Measured reaction system set: Sn isotope collisions

- Experiment@RIKEN-RIBF in Spring of 2016

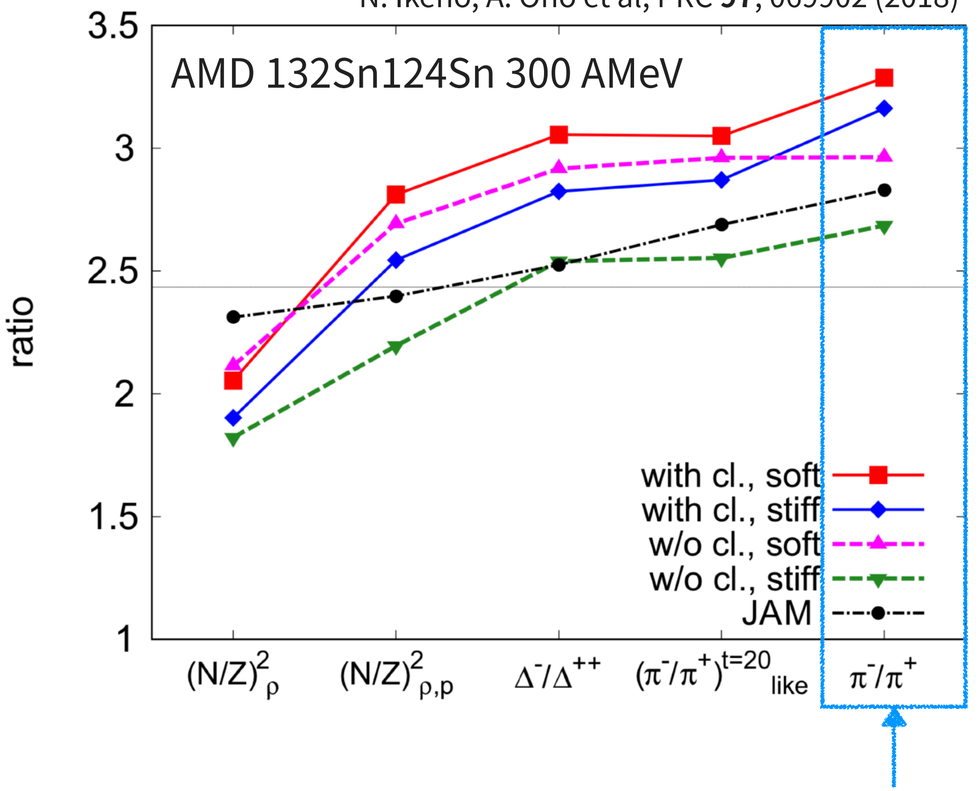
Primary beam	Secondary	Target	E_{beam} [MeV/n]	δ_{system} = (N-Z)/A
124Xe	108Sn	112Sn	270 → ~2ρ_0 matter is produced.	0.09
	112Sn	124Sn		0.15
238U	132Sn	124Sn		0.22
	124Sn	112Sn		0.15

Systems with the same charge: Z=50+50 and wide range of asymmetry
➡ **Cancel out coulomb effect and reduce uncertainties like detector efficiency to strongly focus on the symmetry energy.**

Heavy-ion collision observables and cluster

- Toward extraction of symmetry energy…
  - Charged pion observables are predicted as good probes.
  - **BUT pion production is not so simple, influenced by dense in-medium effects in HIC.**
- In order to understand HIC correctly…
  - There are available multi-observables.
  - AMD calculation w./w.o. cluster correlation suggests that treatment of cluster in HIC influences pion ratio.
    - Cluster production affects the p-n dynamics in HIC.
  - **Cluster property should be also well-known to understand pion observables.**
  - **Ex.) deuteron is the most simple cluster.**

N. Ikeno, A. Ono et al, PRC **97**, 069902 (2018)

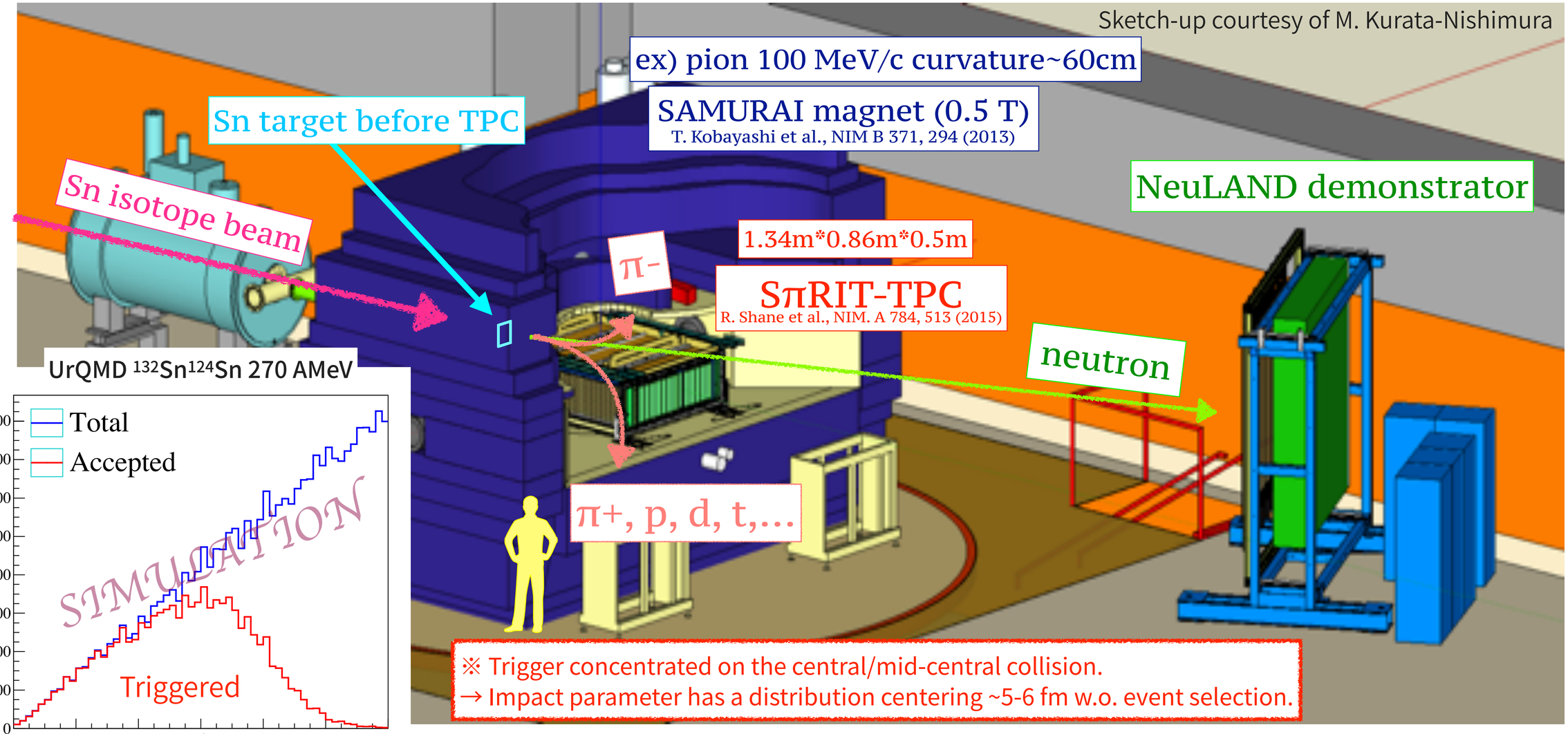


Pion ratio for different options.

➡ **Hydrogen isotopes are good benchmark to discuss the cluster property in HIC.**

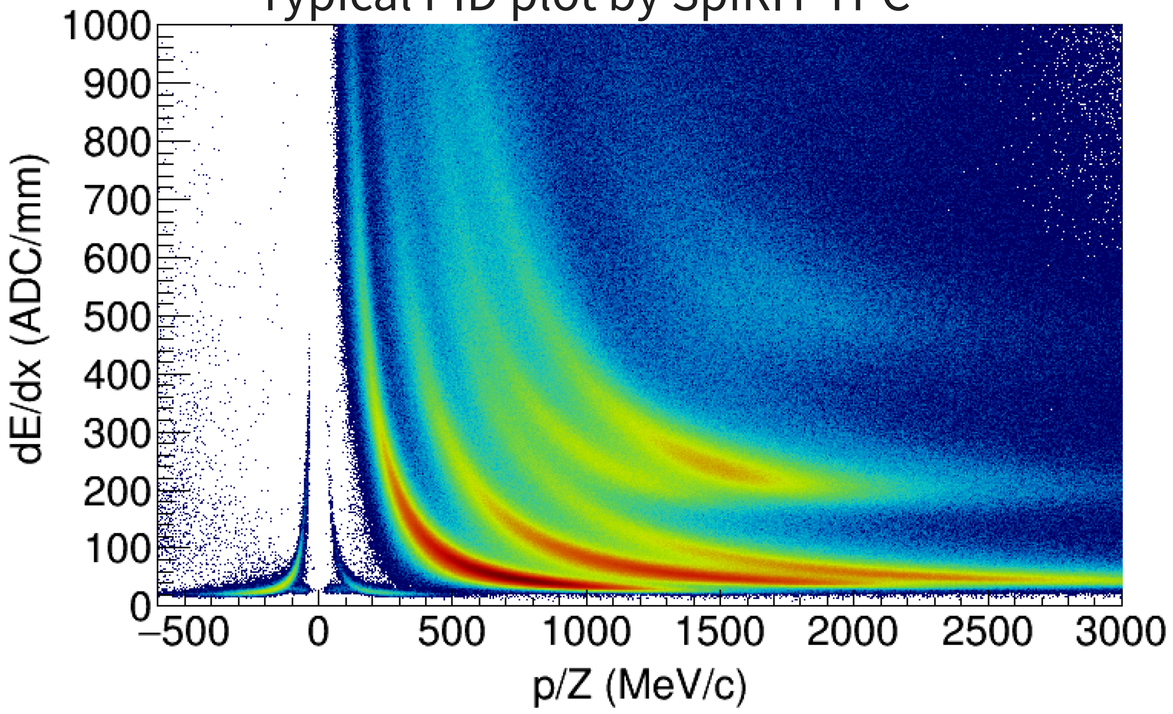
Experimental setup @ RIBF - SAMURAI spectrometer

Charged particles are detected by large volume Time-Projection-Chamber inside the dipole magnet.

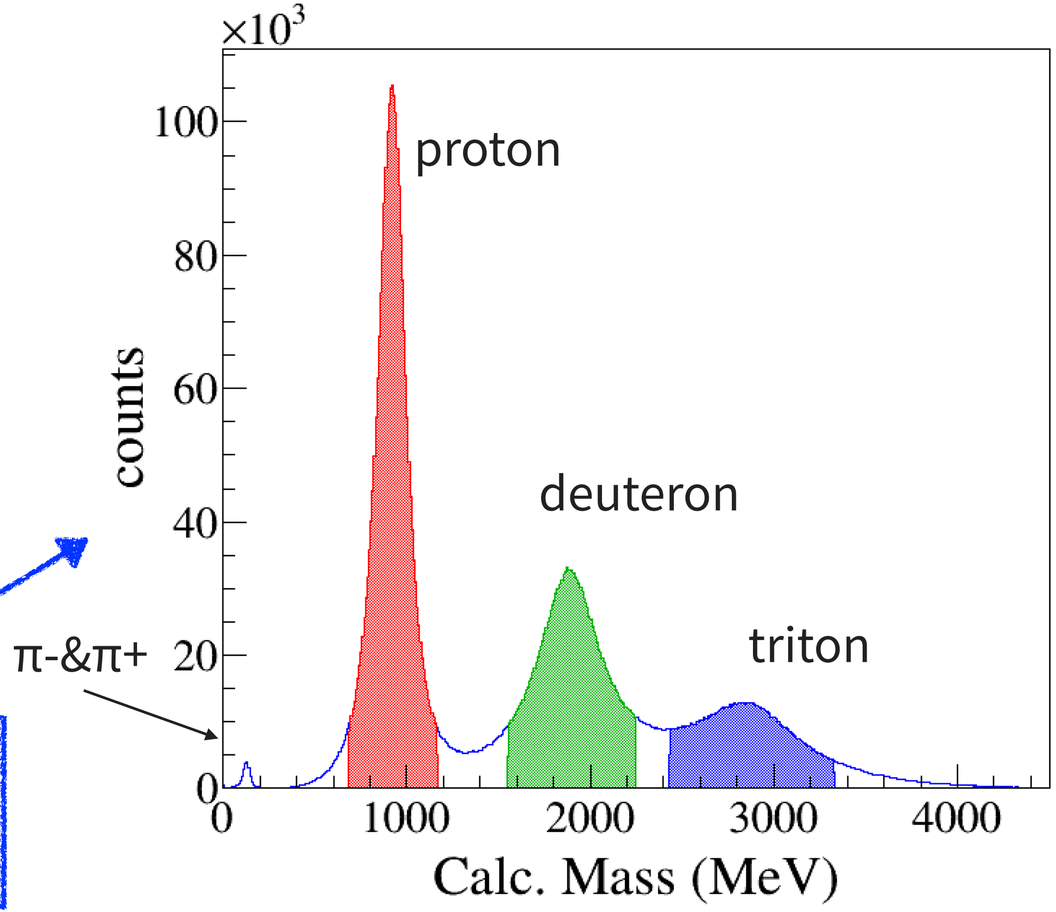


Particle identification in TPC, hydrogen isotope selection

Typical PID plot by SpiRIT-TPC



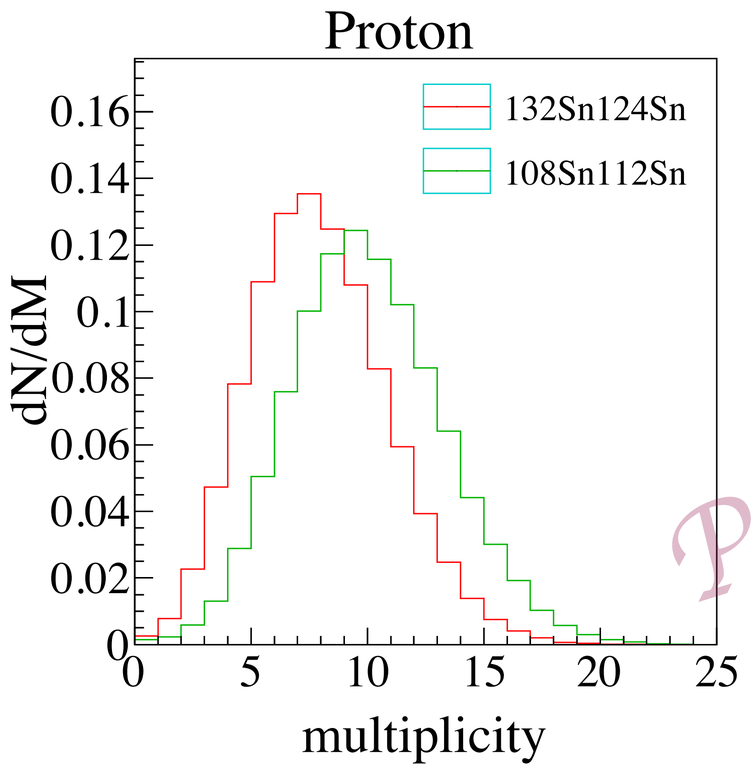
Mass spectrum with cut of helium isotopes or heavier one.

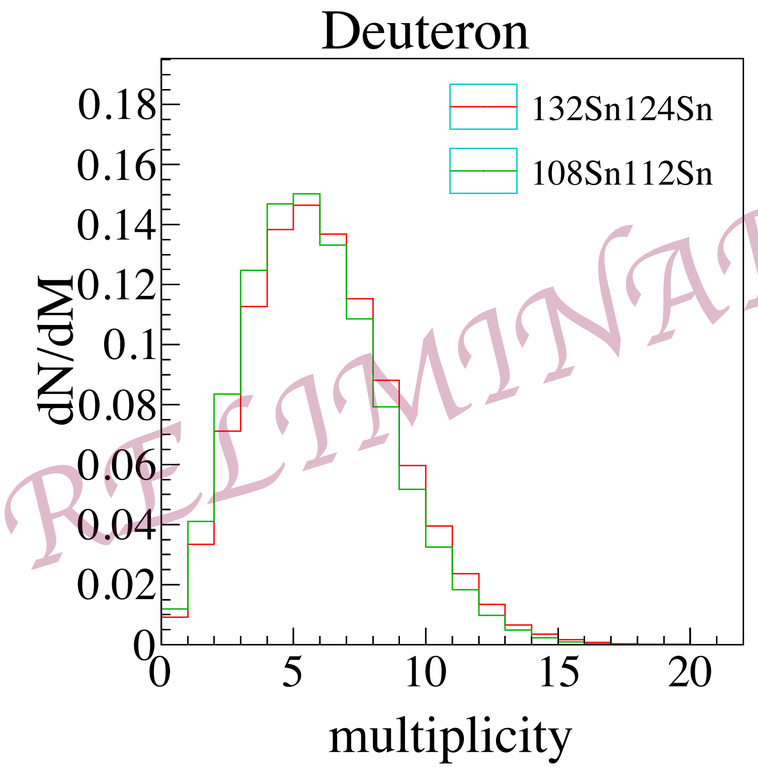


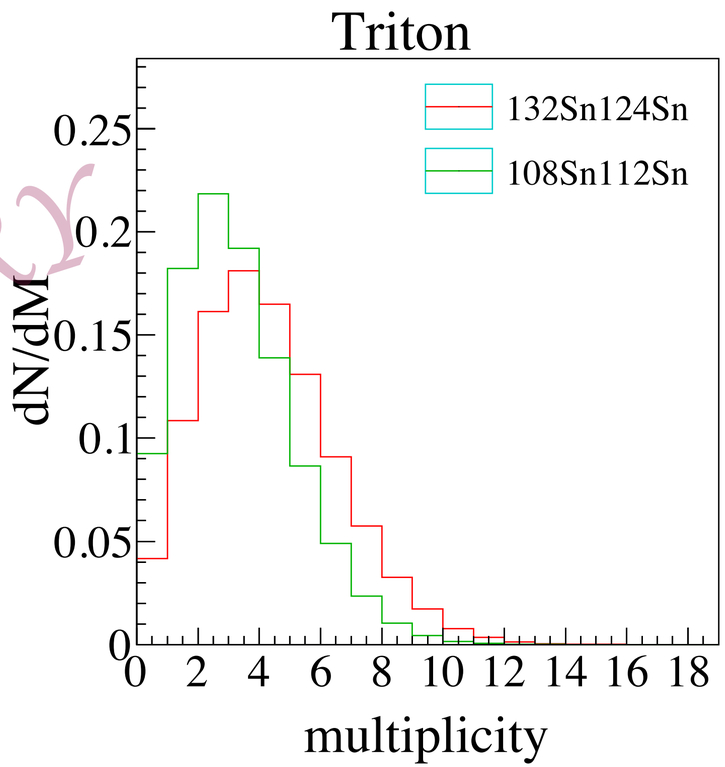
By using Bethe-Bloch equation, we can calculate the particle mass from two variables, dE/dX and momentum/charge which are observed in TPC.

Multiplicity of hydrogen isotope for each system

Efficiency is NOT corrected.



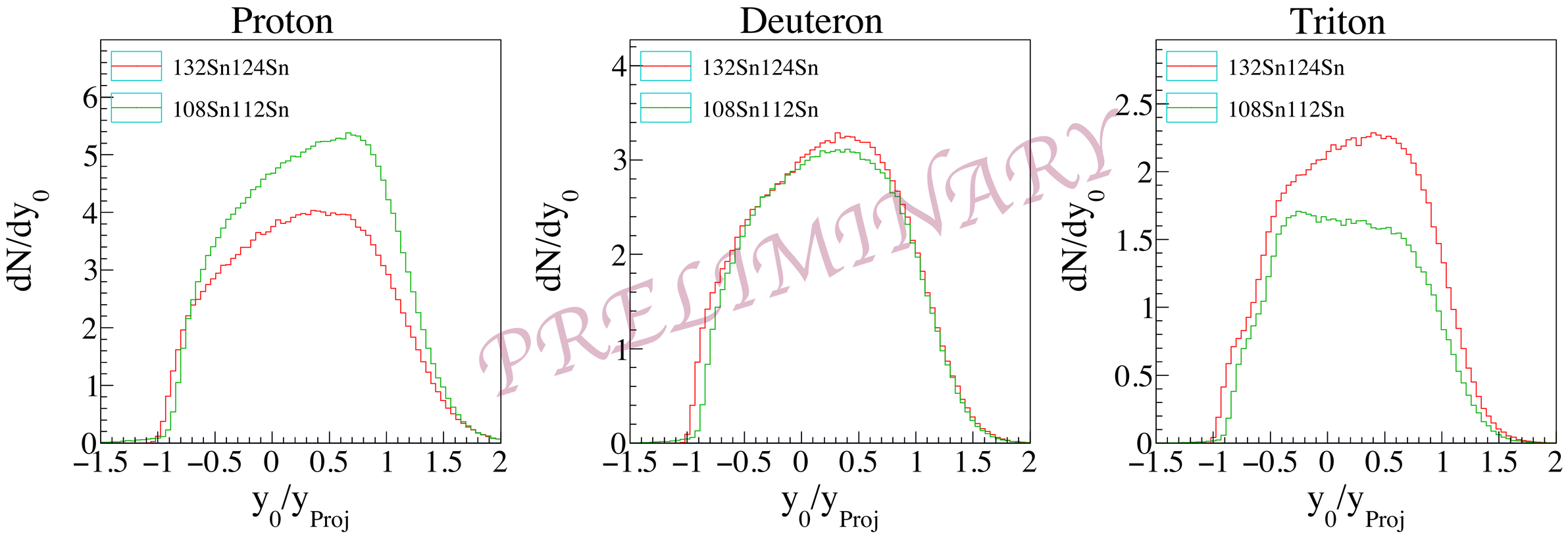




- Neutron-rich system produced more triton, less proton.
  - Protons are more likely to be caught by surrounding neutrons in n-rich environment.
  - How about deuteron ?
    - For d production, p+n→d and d+n→t (and d+p→3He) competes, which might result in similar for two reaction systems.

Rapidity of hydrogen isotope for each system

$$\text{rapidity} = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$$



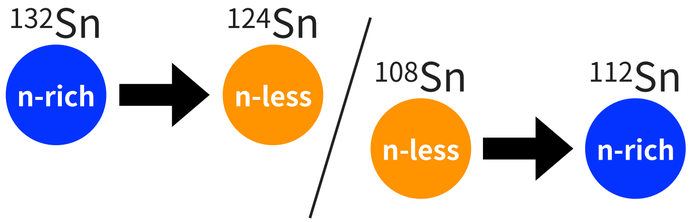
- Rapidity distributions in center of mass frame.(No correction)
  - Rapidity is normalized by projectile rapidity. → beam rapidity for 1, target rapidity for -1.
  - The number difference on proton and triton is seen as same as multiplicity spectra.
  - Triton spectra difference is considered to reflect the projectile-target asymmetry.

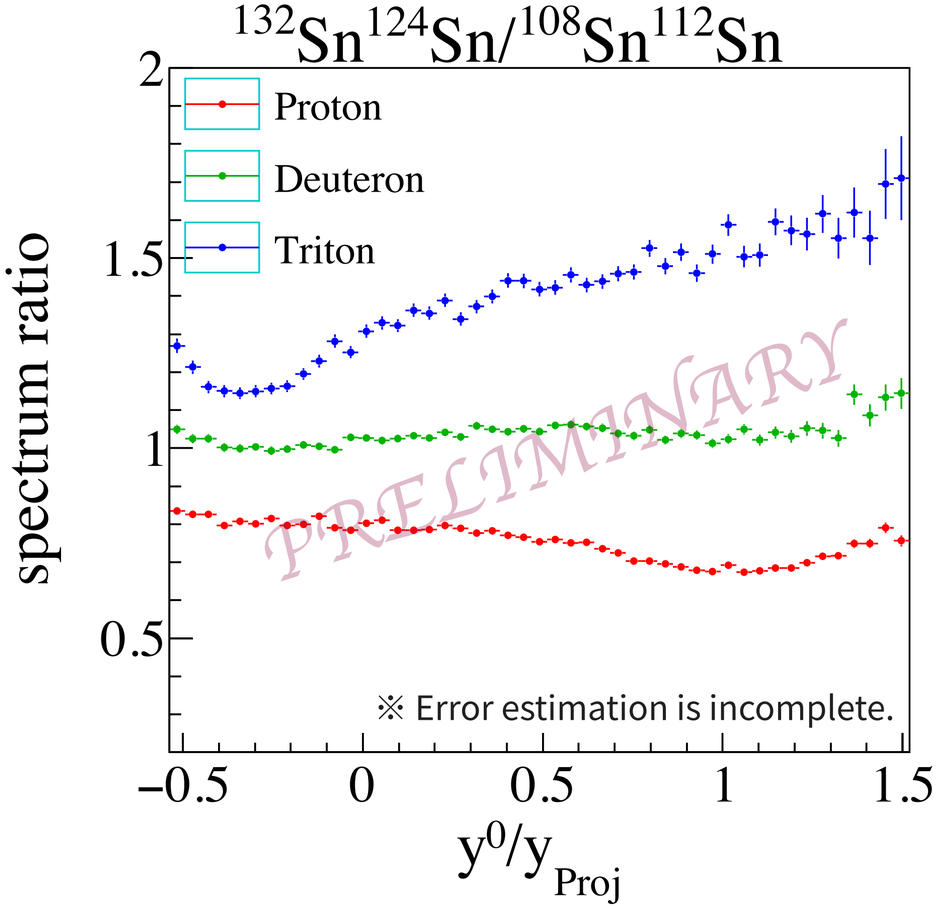
Rapidity of hydrogen isotope for each system

$$\text{rapidity} = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$$

- Rapidity spectrum system ratio
  - 132Sn124Sn system has n-rich projectile
    - → more tritons are expected in forward rapidity region.
  - 108Sn112Sn system has n-rich target
    - → more tritons in target rapidity region.
  - Spectrum ratio shows a trend which is consistent with a simple expectation above.
  - **Triton has a positive slope w.r.t. rapidity, and an inverse slope is seen on proton.**
  - **Deuteron spectrum shows ~1 w.r.t rapidity.**

➡ Rapidity spectra look to be informative how much cluster will be produced for different kind of reaction system.





Summary & future prospect

- We have measured Sn-Sn collision in 270 MeV/nucleon at RIBF.
- Analysis algorithm is under development, a lot of studies are ongoing.
- Raw multiplicity and rapidity distributions for hydrogen isotopes in n-rich system and n-deficient system are presented.
  - **System dependence and projectile-target asymmetry effect seems to be observed.**
- Next step
  - Efficiency studies are necessary for further understanding on the spectra.
    - Ex.) Stopping and/or temperature using the rapidity, cluster property using the multiplicity (d/p, t/p etc.)
  - He isotopes are also measured in SpiRIT-TPC, which will be available.

SπRIT collaboration

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Thank you for your attention !!

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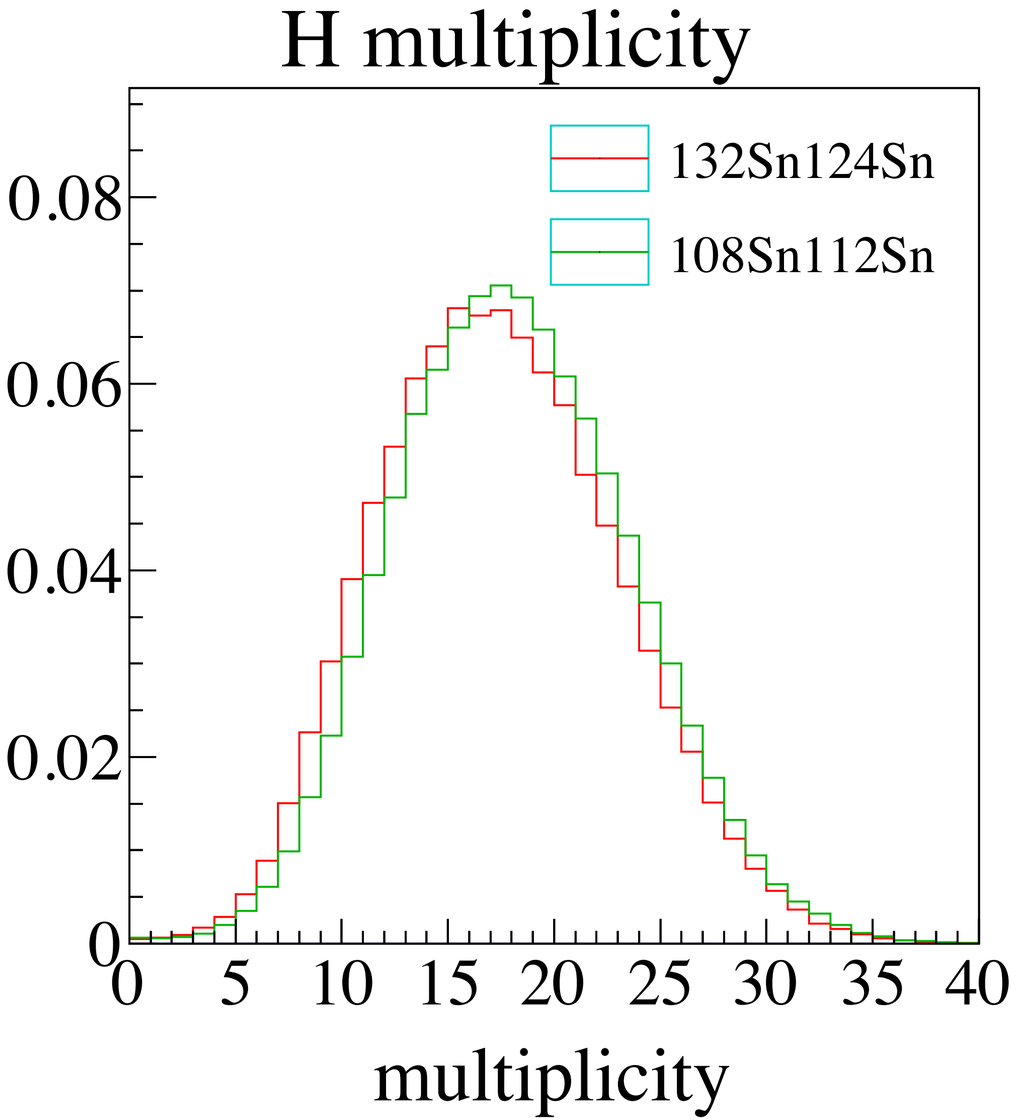
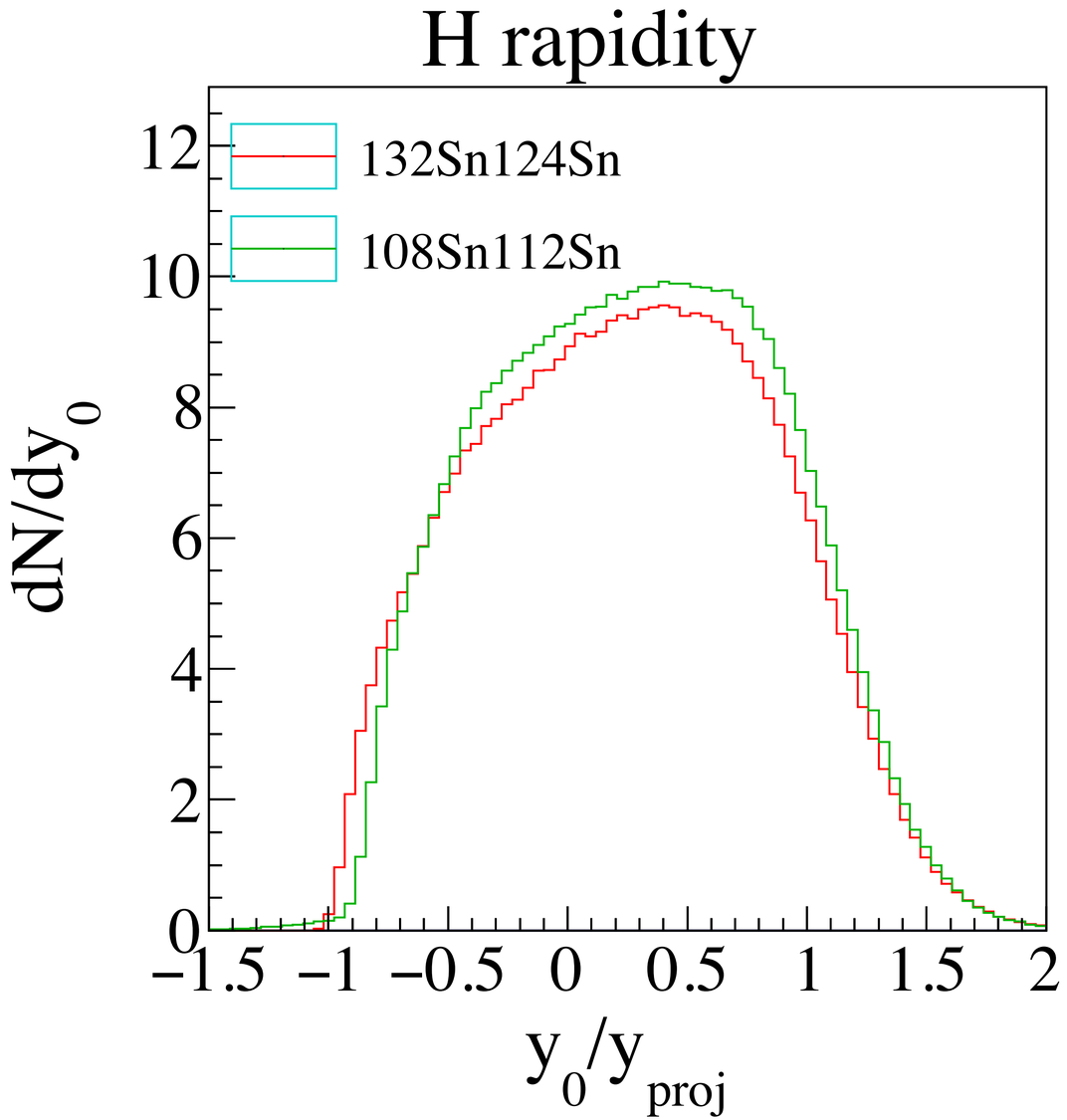
Total hydrogen multiplicity for different system



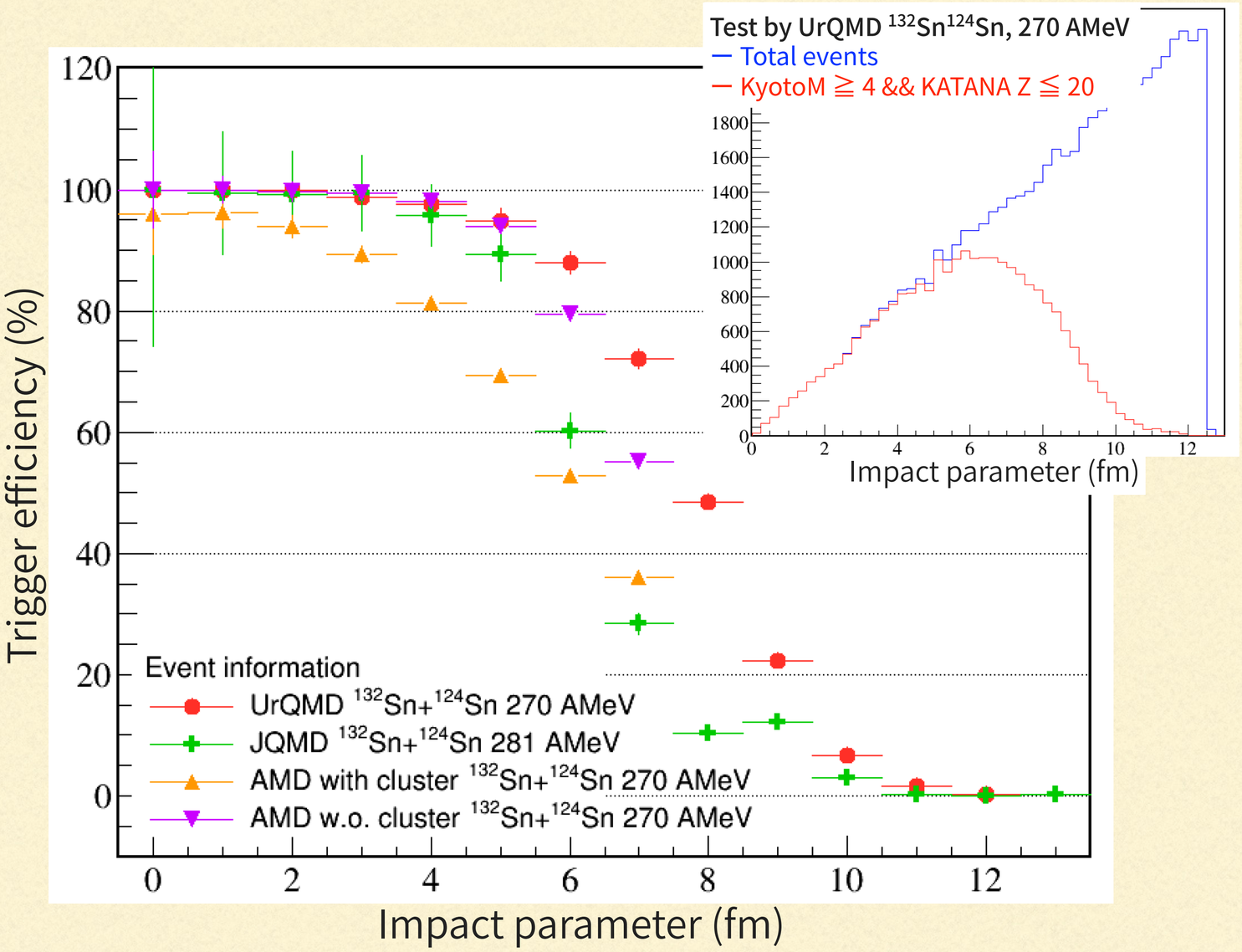
132Sn124Sn yields a little bit less.
→ Heavy cluster is produced more than 108Sn112Sn?

H rapidity for different system



No weight was applied.
→ Proton rapidity could dominate this spectrum.

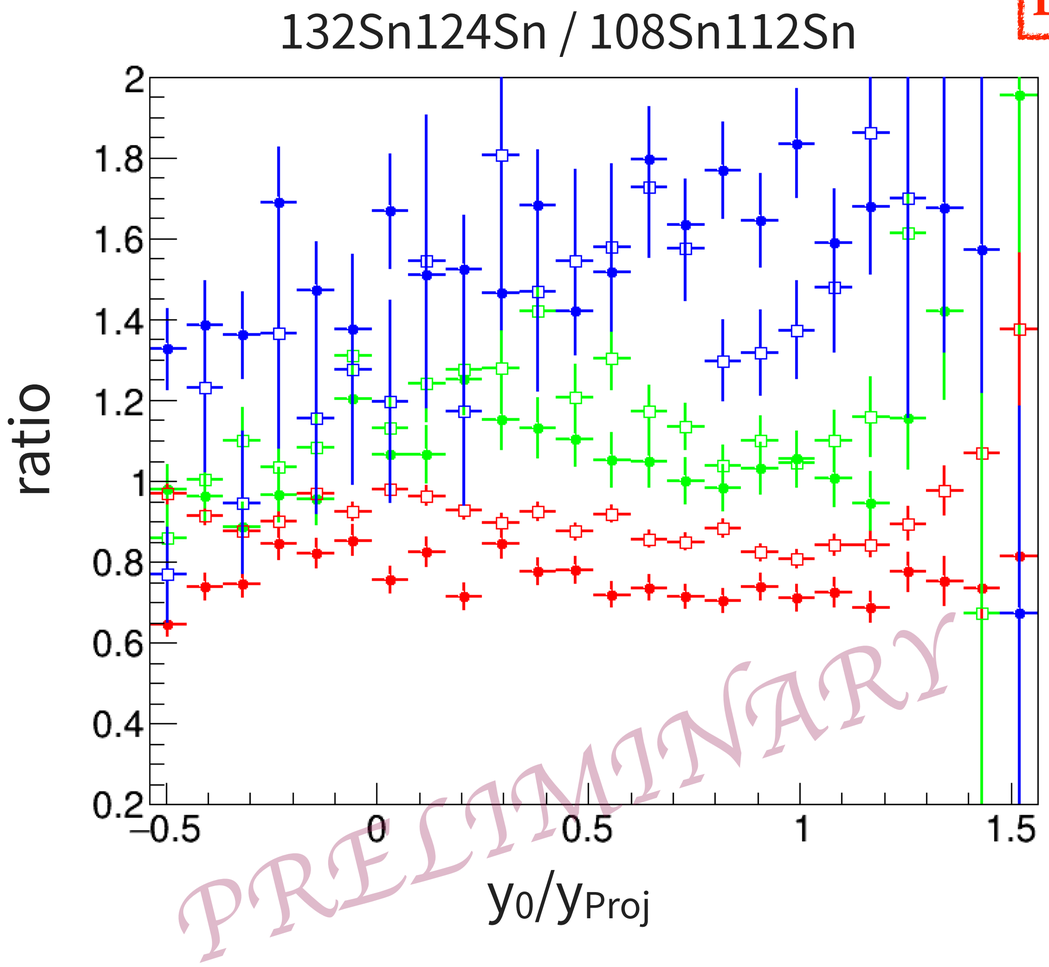
Trigger efficiency vs. impact parameter



- Trigger efficiency: how much events will be triggered by the SpiRIT trigger system?
  - ex) UrQMD case
  - Mean of b ~ 6 fm, width ~ 4 fm.
  - ~ 40 % of events will be triggered in total.
  - On mid-peripheral region, models look to have a discrepancy.
  - On the central collision, almost all of events can be triggered. On the other hand, there seems to be a model dependency how much peripheral events are included in our data.

Spectrum ratio: AMD w./w.o. cluster-correlation

Detector & impact parameter acceptance is NOT considered.



● : with cluster-cluster correlation
□ : without correlation
- Proton
- Deuteron
- Triton

Proton spectrum ratio:
→ With cluster-cluster correlation is further from 1 than without correlation.

Deuteron:
→ With correlation is closer to 1 than without correlation.

Calculation with cluster correlation looks to favor the preliminary result.