Recent progress on pion analysis of Sn+Sn collision data with SπRIT-TPC

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for the SπRIT Collaboration

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Nuclear Equation of State

- An equation that describes the relations among the pressure, energy, temperature, density and isospin asymmetry of nuclear systems.

$$E(\rho,\delta) = \underline{E(\rho,\delta=0)} + \underline{E_{\mathrm{sym}}(\rho)}\delta^2 + O(\delta^4), \quad \delta = \frac{\rho_{\mathrm{n}} - \rho_{\mathrm{p}}}{\rho}$$

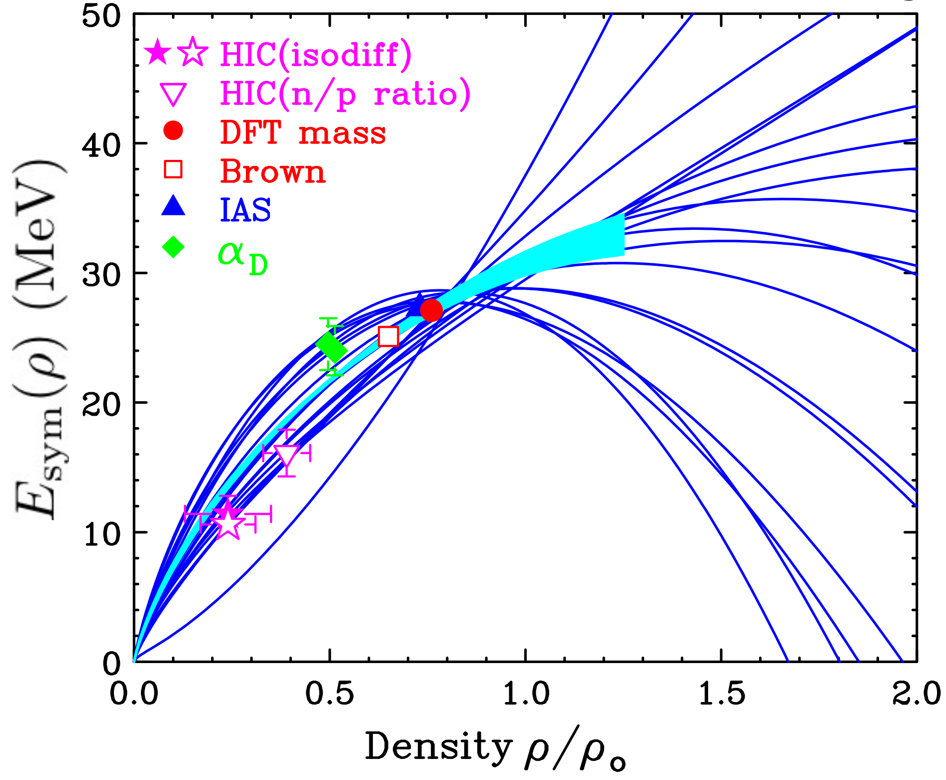
EOS of symmetric nuclear matter

- Experimentally constrained in $\rho_0 \sim 5\rho_0$
  - Collective flows
  - Isoscalar collective vibrations
  - Kaon production in HIC

Symmetry energy

- Affects the relationship between neutron star radius and mass.
- Very few laboratory constraints
- Experimental constraints are emerging in sub-saturation density.

Private communication with M. B. Tsang

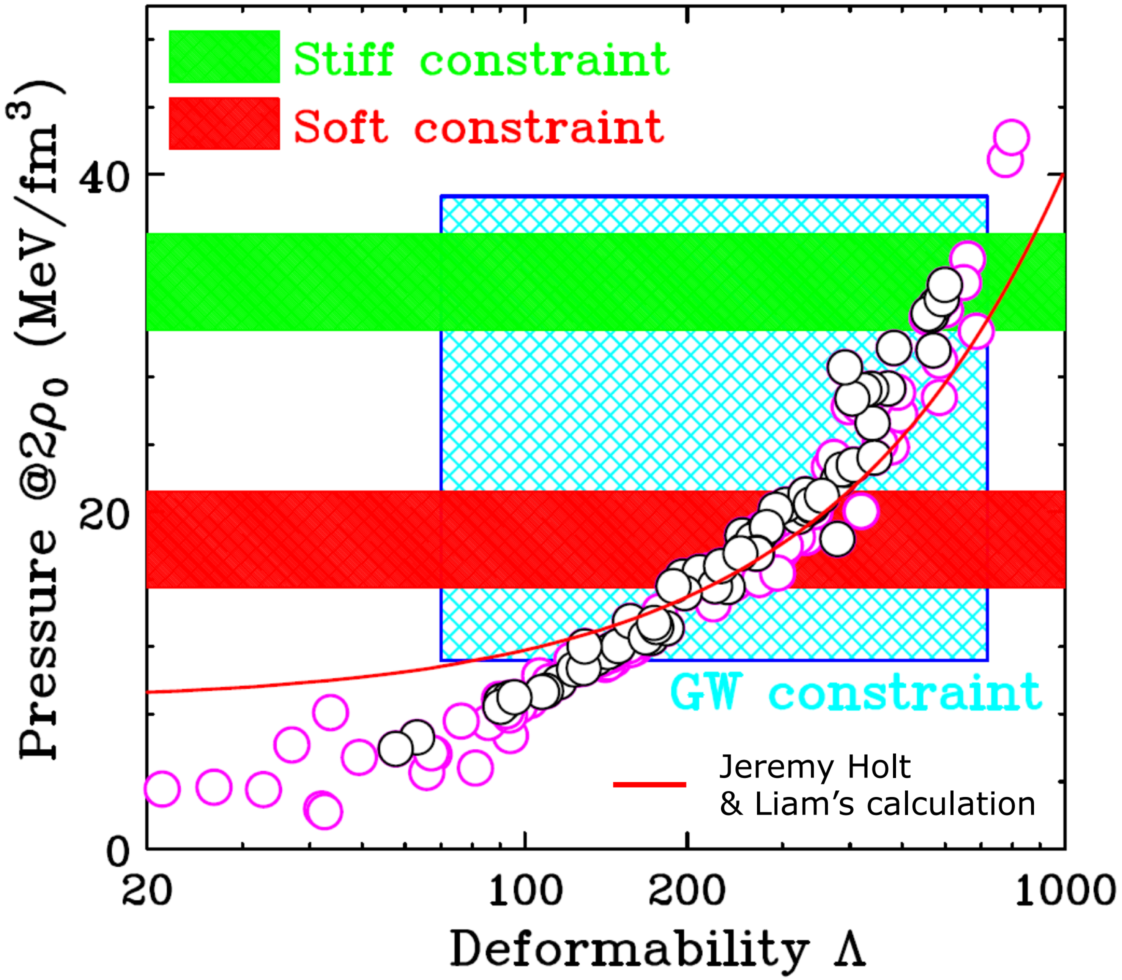


M. B. Tsang *et al.*, Phys. Rev. C **86** (2012) 015803
C. J. Horowitz *et al.*, J. Phys. G: Nucl. Part. Phys. **41** (2014) 093001

Nuclear Equation of State

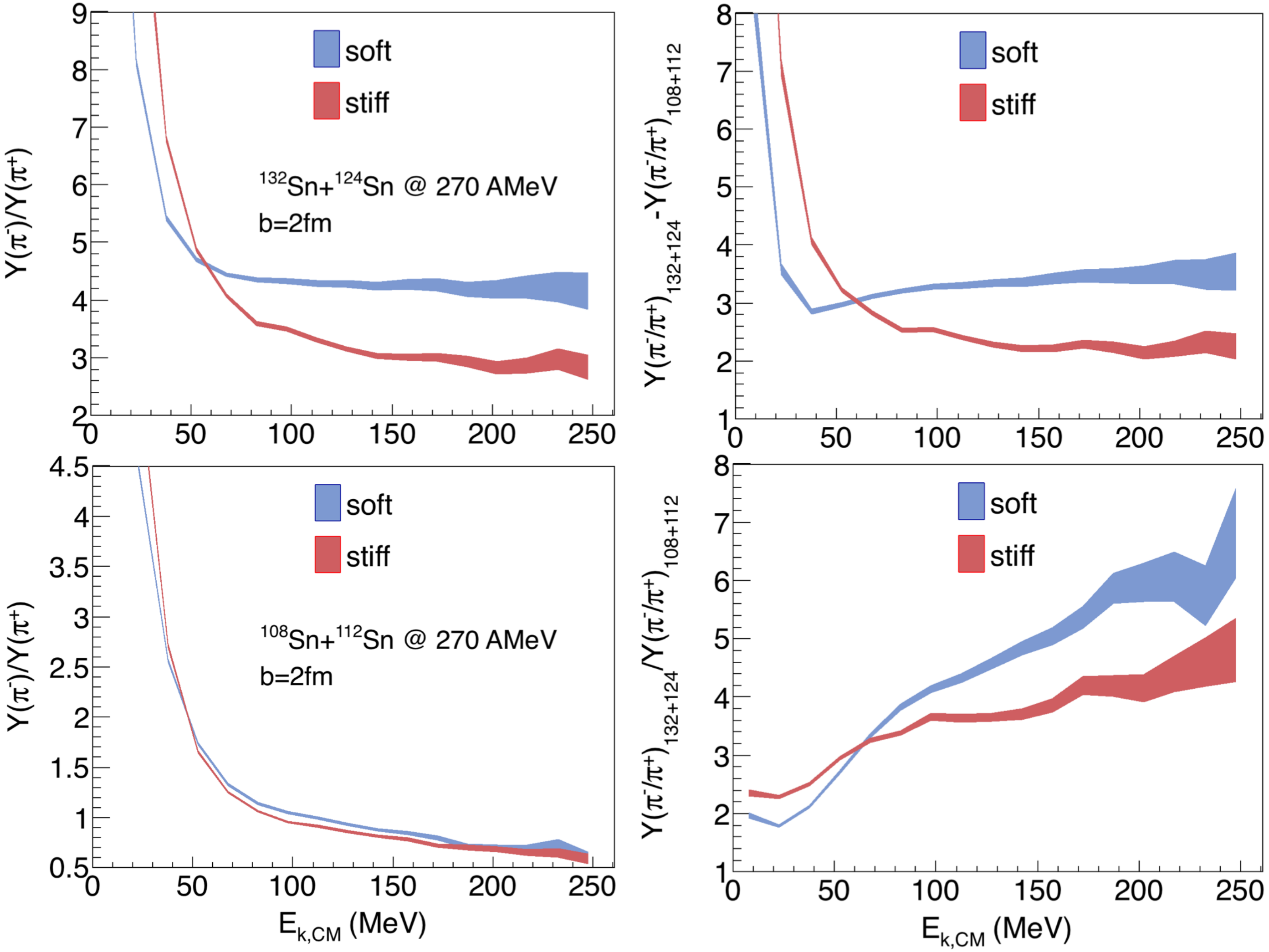
- Recent measurement of binary neutron-star merger event, GW170817, provided certain range of constraints on nuclear EOS.
- Calculation shows that laboratory heavy-ion collision experiments at around $2\rho_0$ are able to provide additional constraints on neutron stars' deformability and radii.
- Heavy-ion collision experimental data are able to provide narrower range of constraints.

C. Y. Tsang *et al.*, arxiv:1807.06571



Pions as an observable

- π^-/π^+ yield ratio is one of observables sensitive to symmetry energy.
- pBUU calculations estimate there will be a large difference in between two different scenarios of symmetry energy.

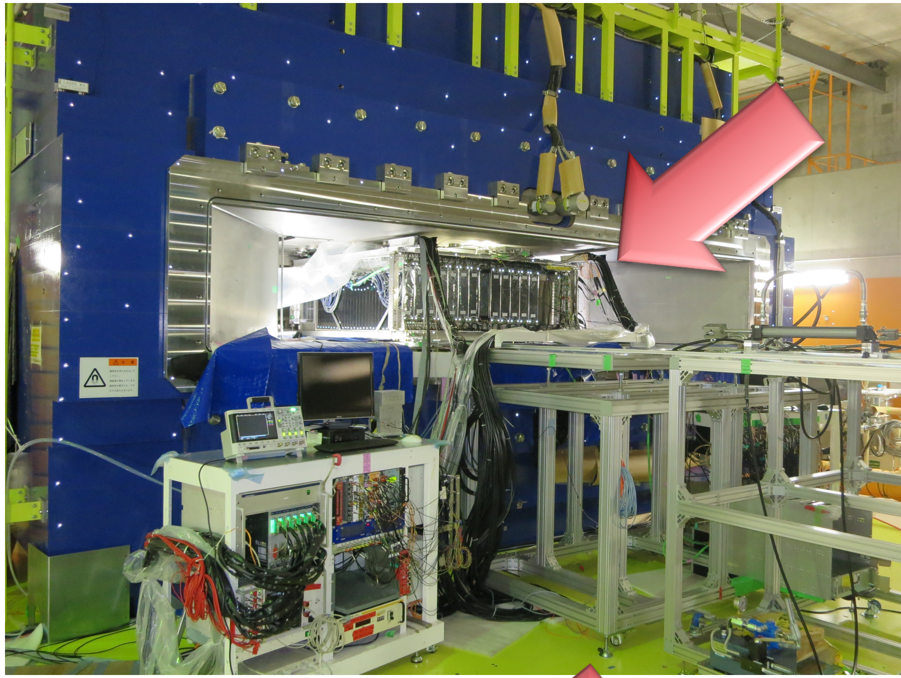


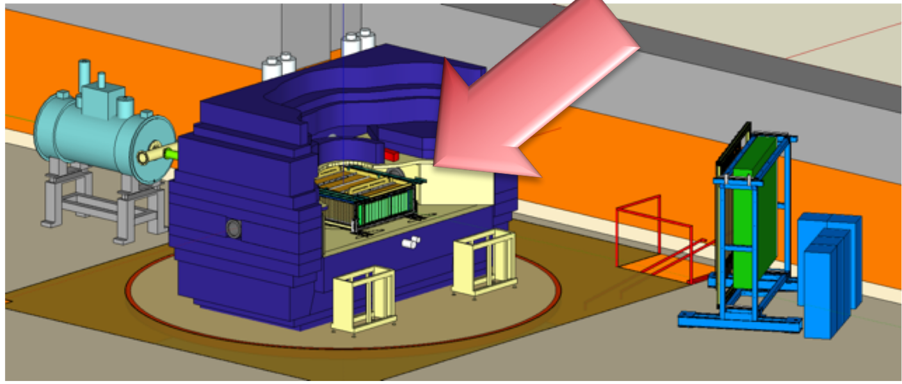
SπRIT Experiment

- SAMURAI Pion Reconstruction and Ion Tracker Time Projection Chamber is specifically designed to work with SAMURAI superconducting magnet at RIBF/RIKEN.
- During more than two weeks of beam time, we collected ~250TB of raw data.

  - E_{beam}=270 AMeV

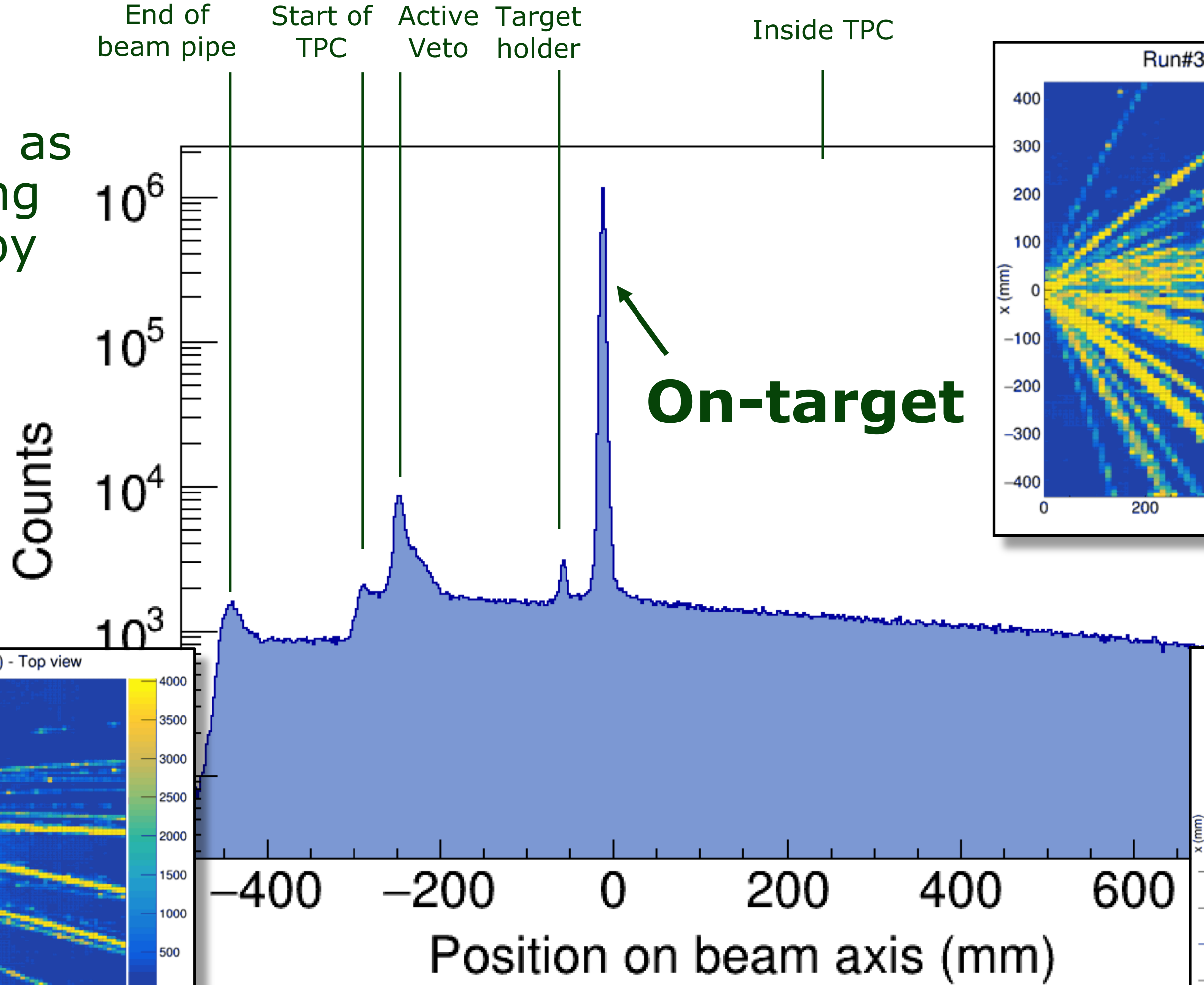
System	δ=(N-Z)/A	#events
^{132}Sn+^{124}Sn	0.22	3.8×10^{6}
^{108}Sn+^{112}Sn	0.09	2.4×10^{6}
^{112}Sn+^{124}Sn	0.15	1.8×10^{6}
^{124}Sn+^{112}Sn	0.15	2.5×10^{5}

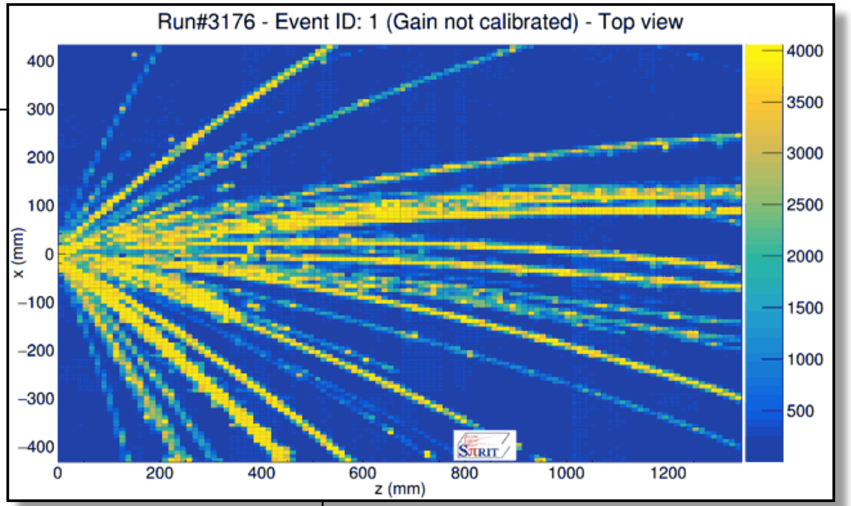


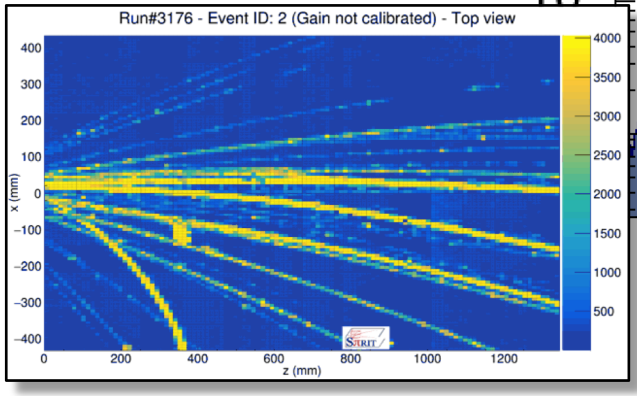


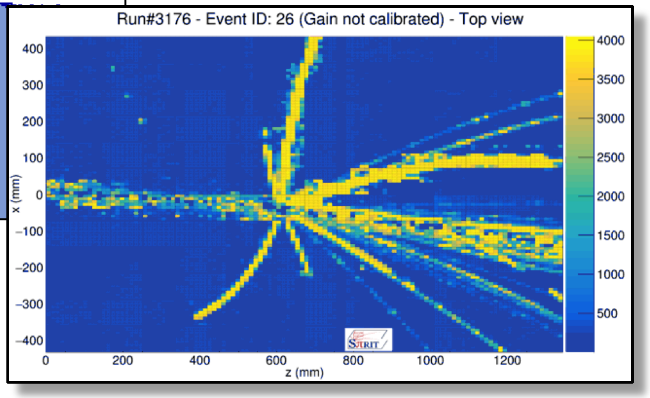
Reconstructed Vertex Distribution

- Vertices are reconstructed as 3D points at the converging point of the tracks event by event.
- Vertexing efficiency **93.4%**

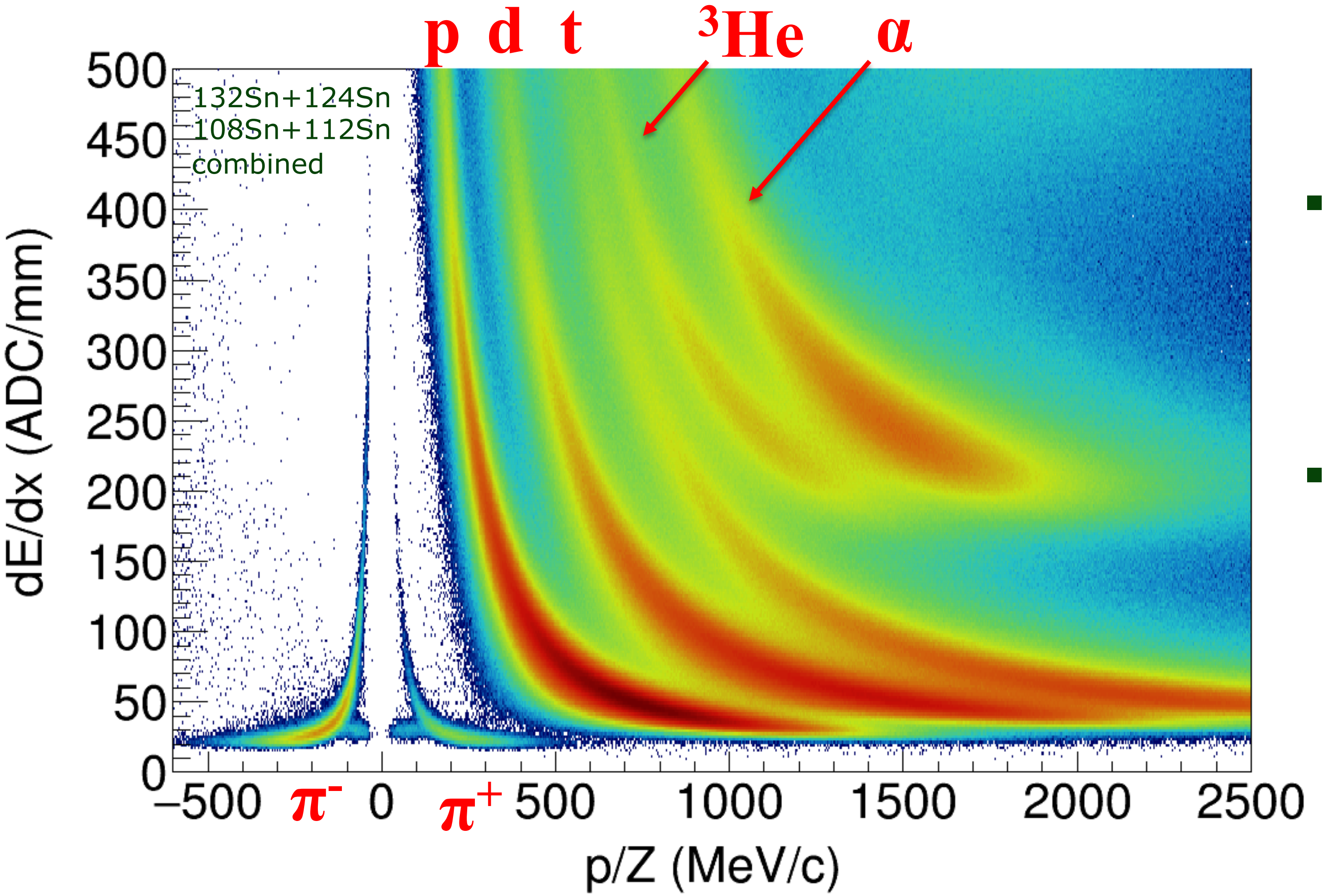








TPC Particle Identification



- Different particles are identified by particles' the energy loss inside the TPC and their momentum.
- SπRIT TPC can clearly identify particles up to alpha with pion detection settings.

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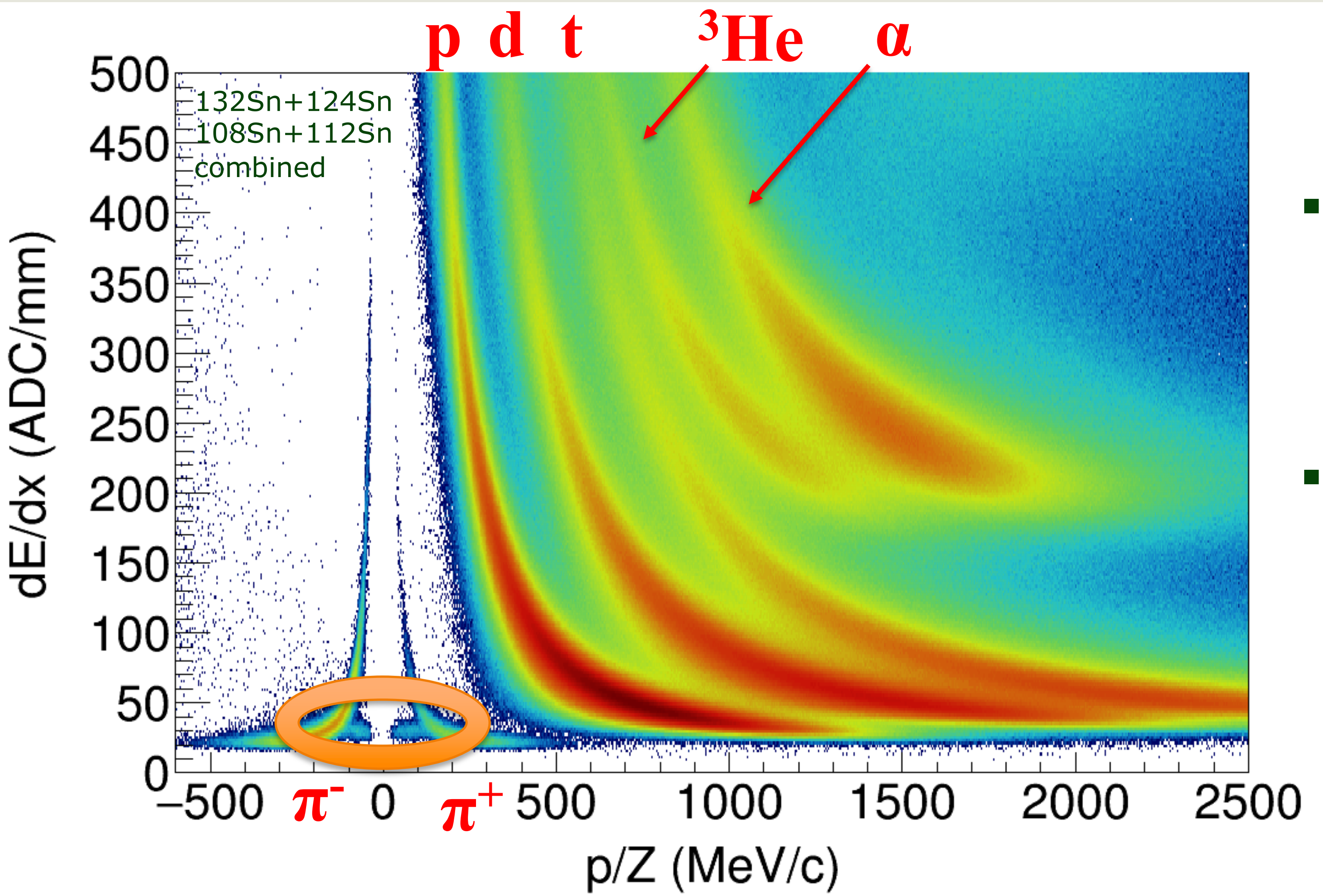

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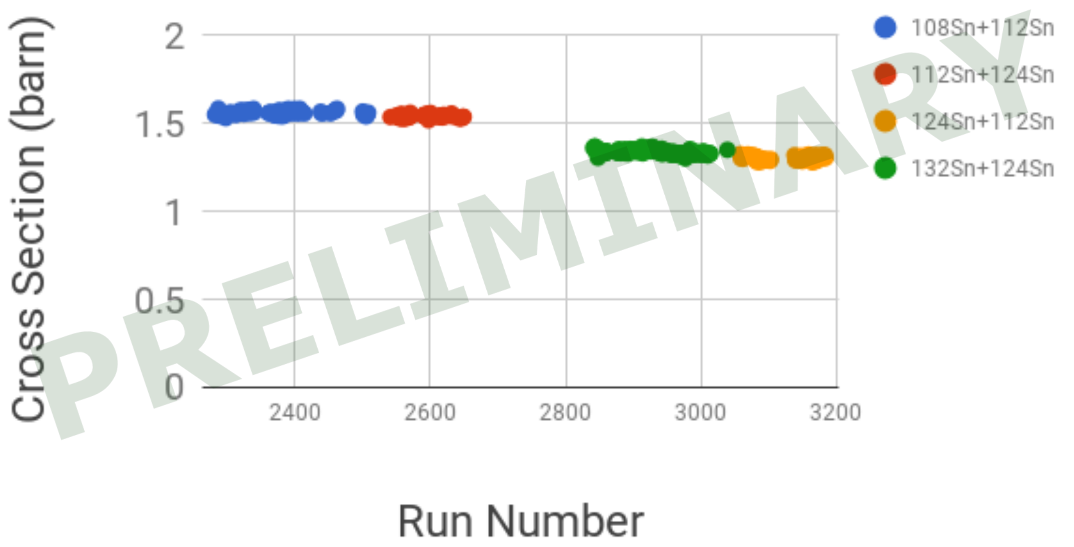
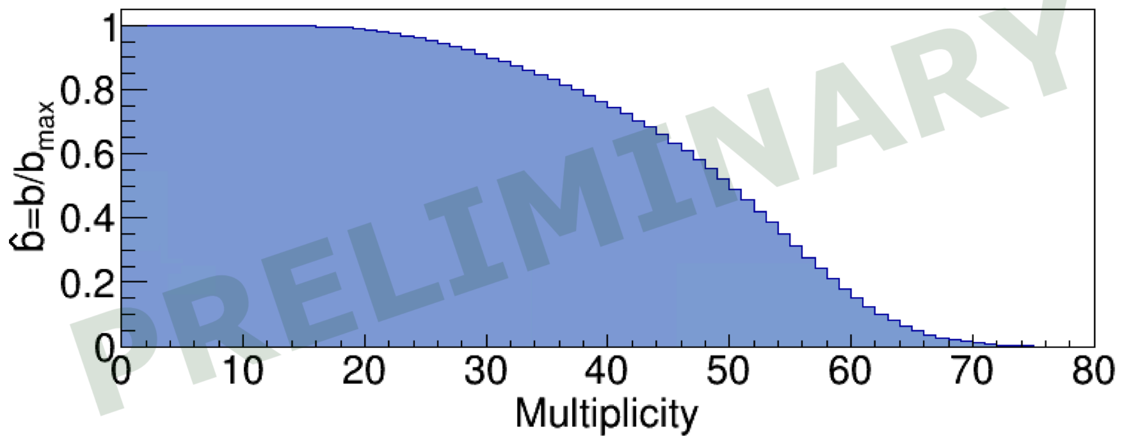
Impact parameter determination

(Courtesy of Jon Barney)

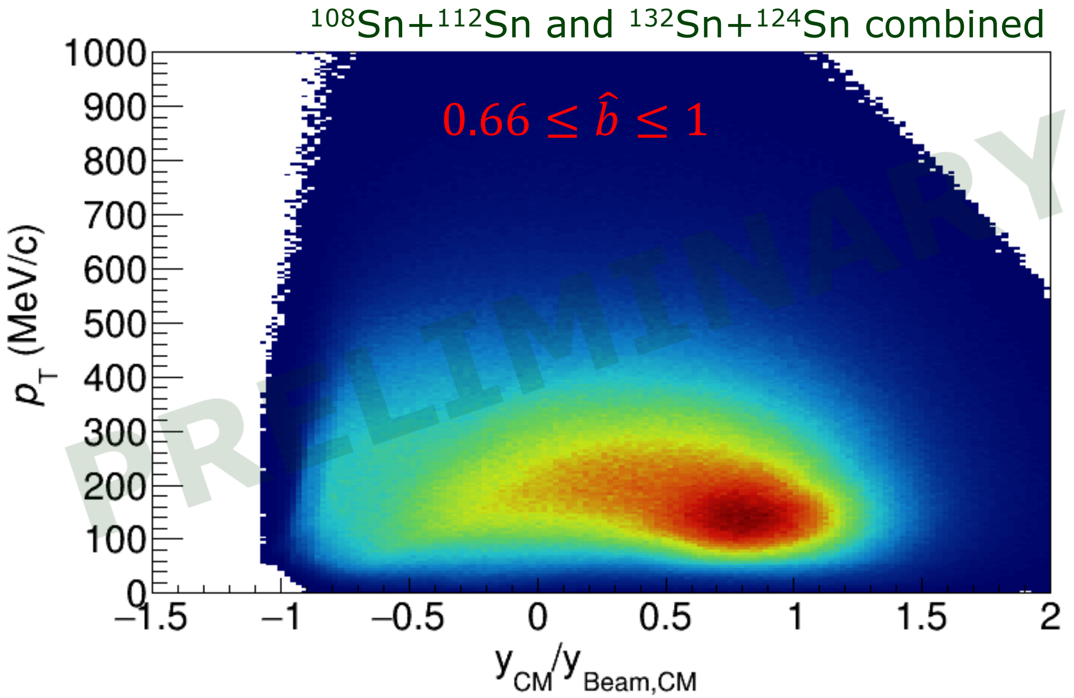
- Total cross section is calculated using scaler information and beamline data analysis.
- Associating cross section information with the other parameters, i.e. charged particle multiplicity, is on-going to obtain criteria to select the desired impact parameter.

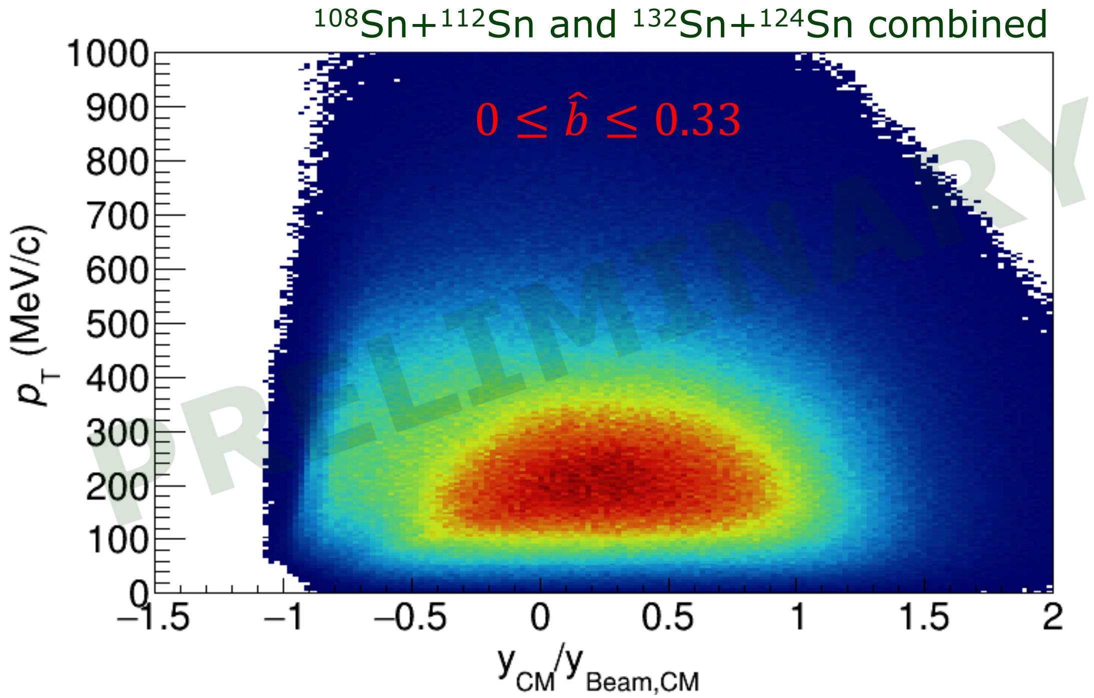




Stopping of protons depending on b

- Gating on the data based on $\hat{b}$ selects the overlapping of projectile and target system as expected.
- Continuing study to the relation between $\hat{b}$ and b is promising.





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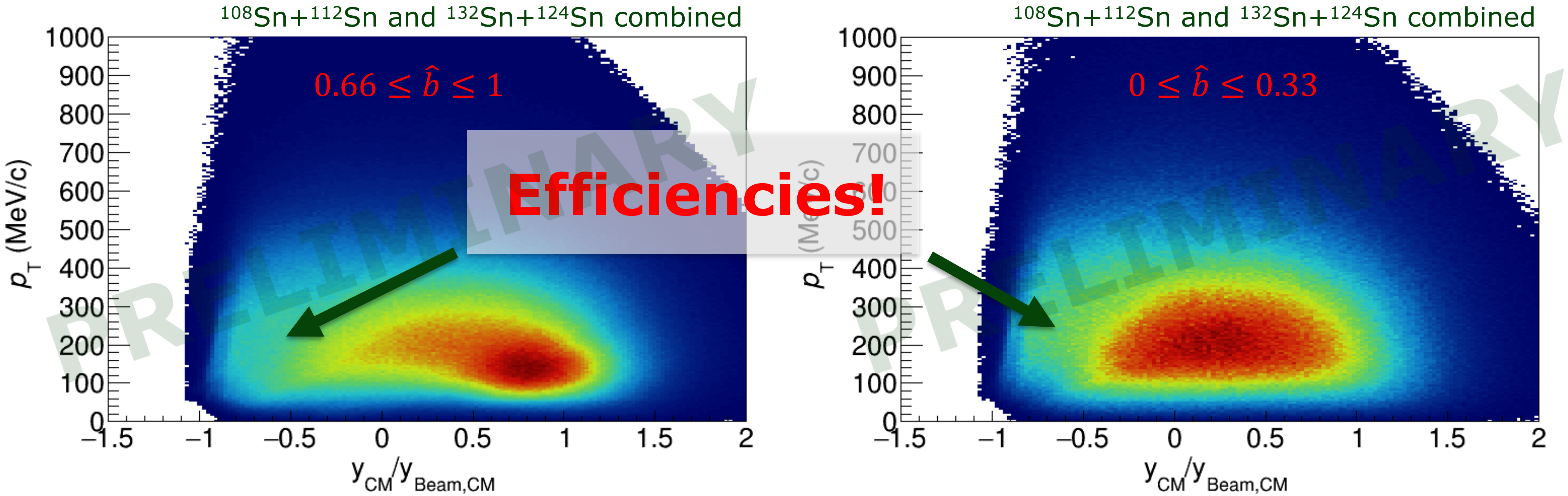
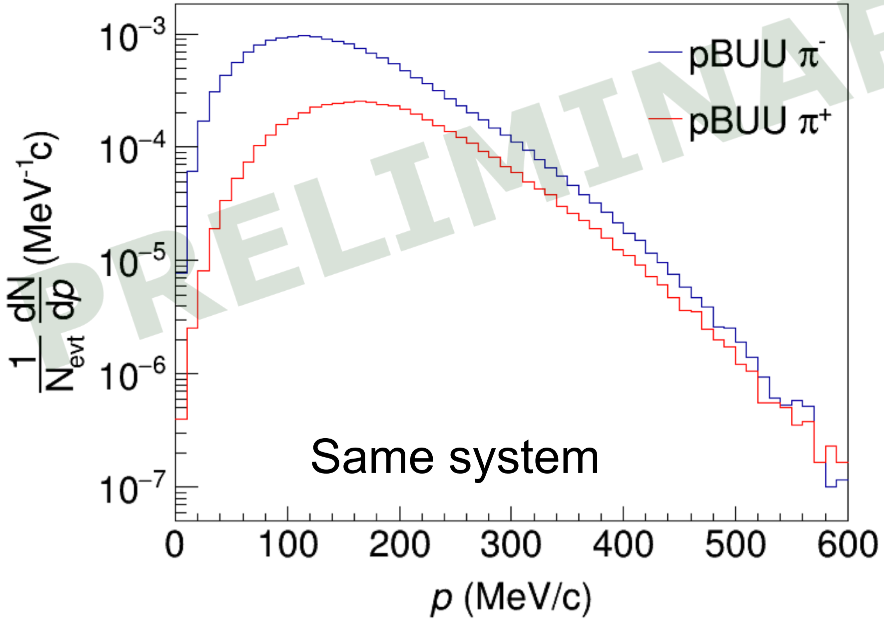
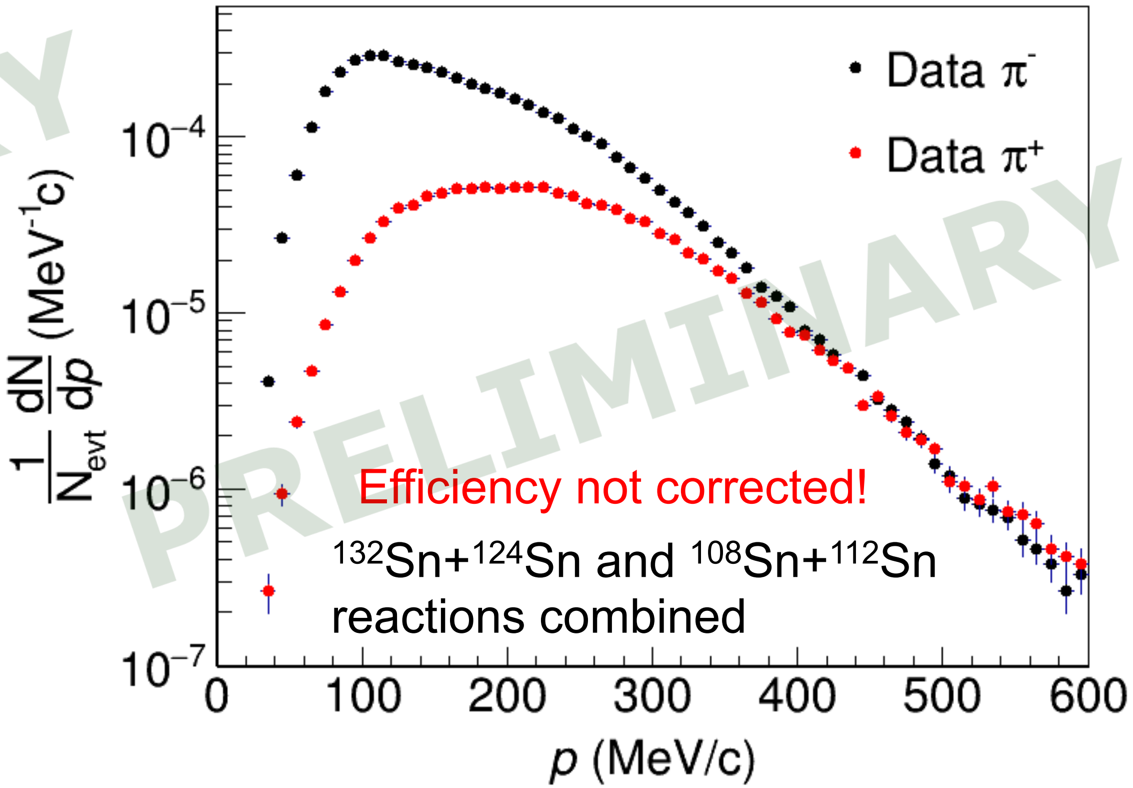


Experimental pion spectra

- Pion spectra from the entire on-target events qualitatively reasonable compared to pBUU calculation.





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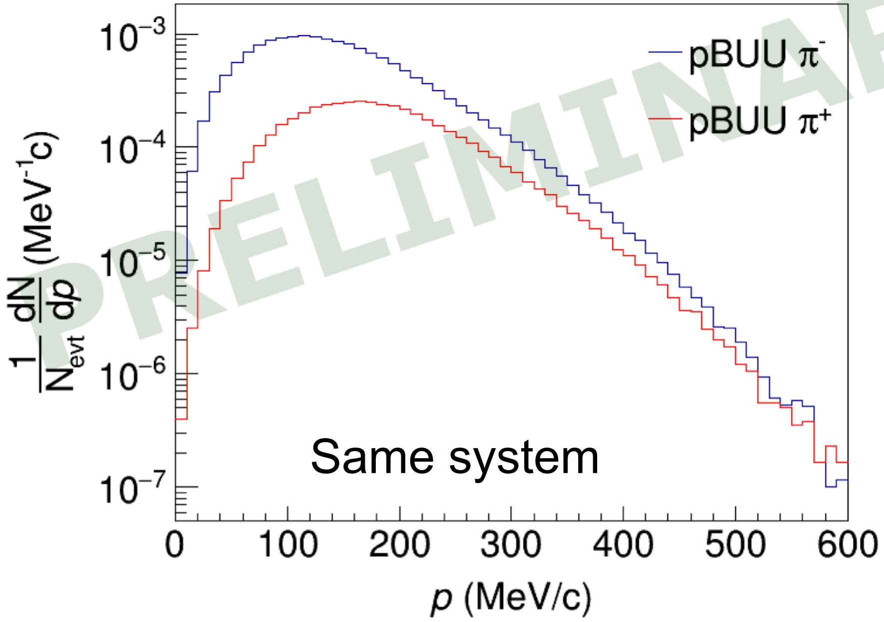

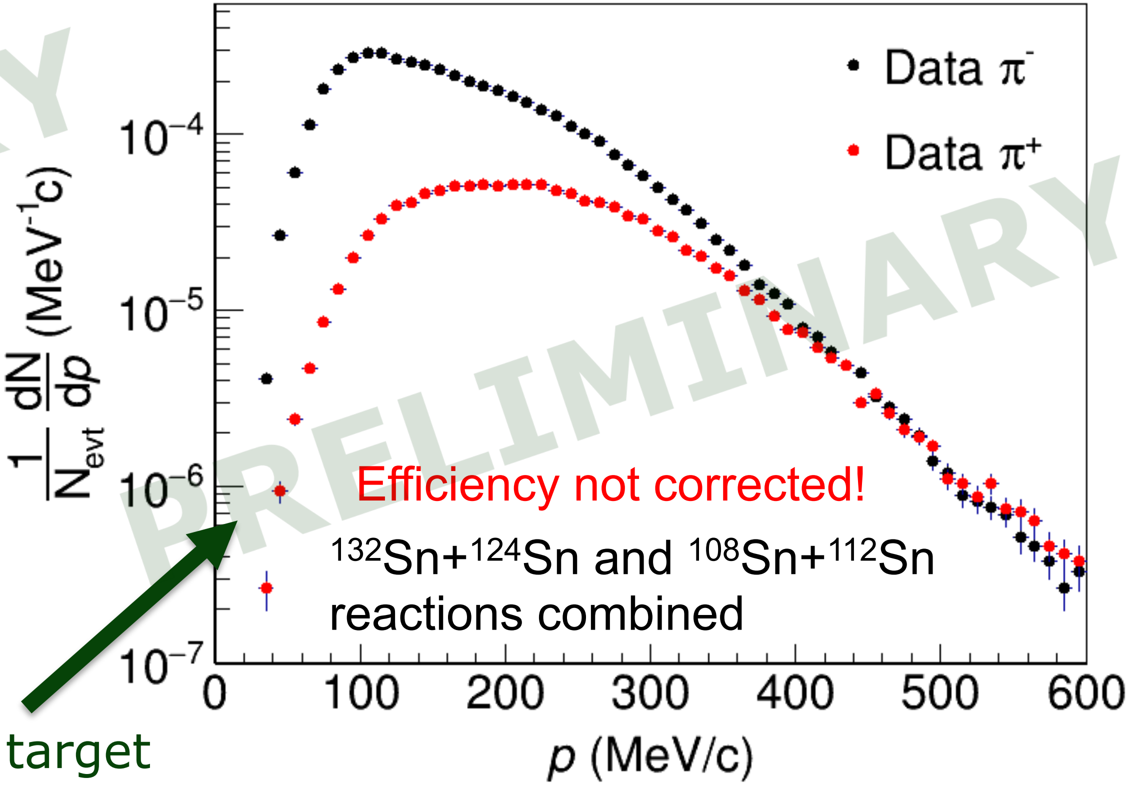

- Energy loss through target
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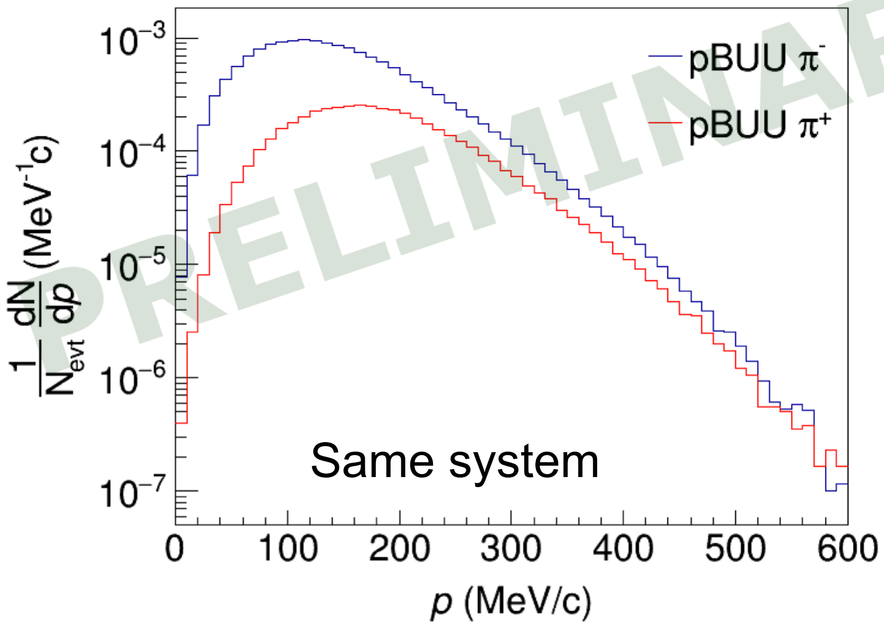

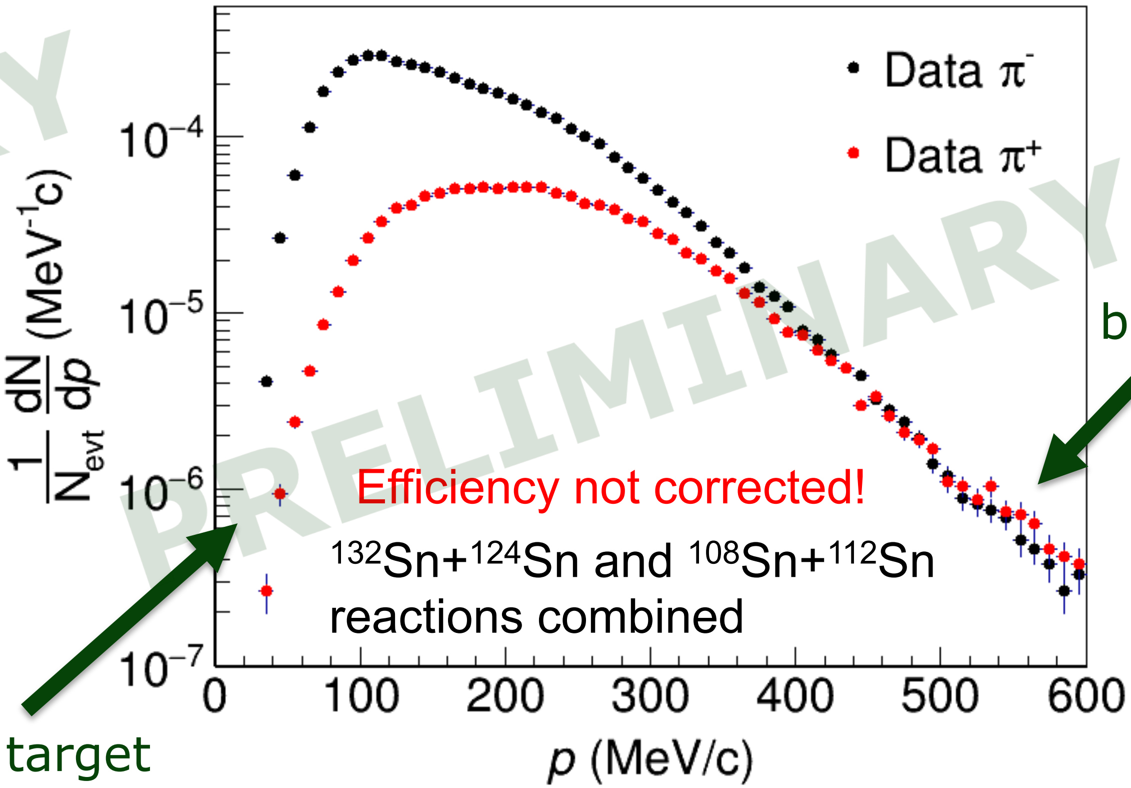

Proton background

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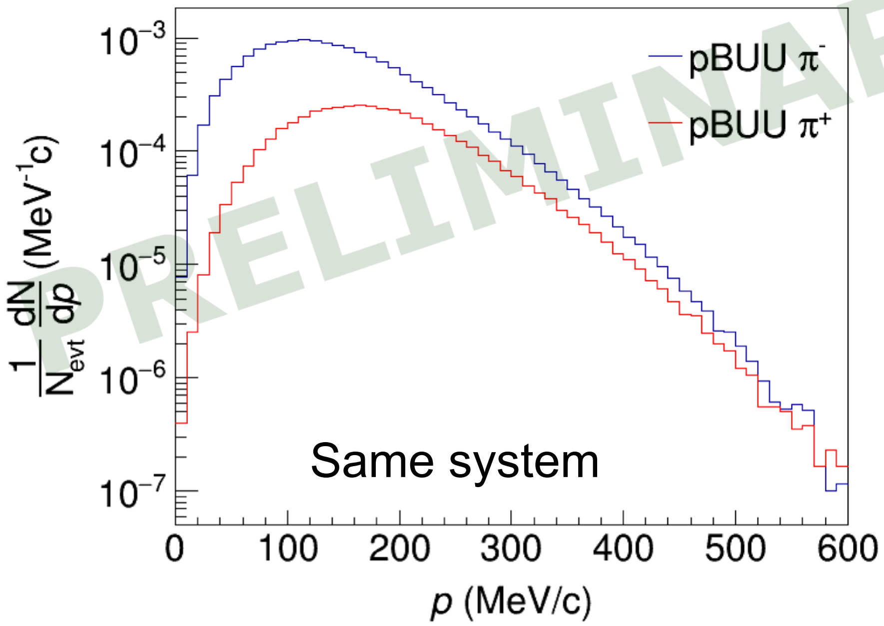
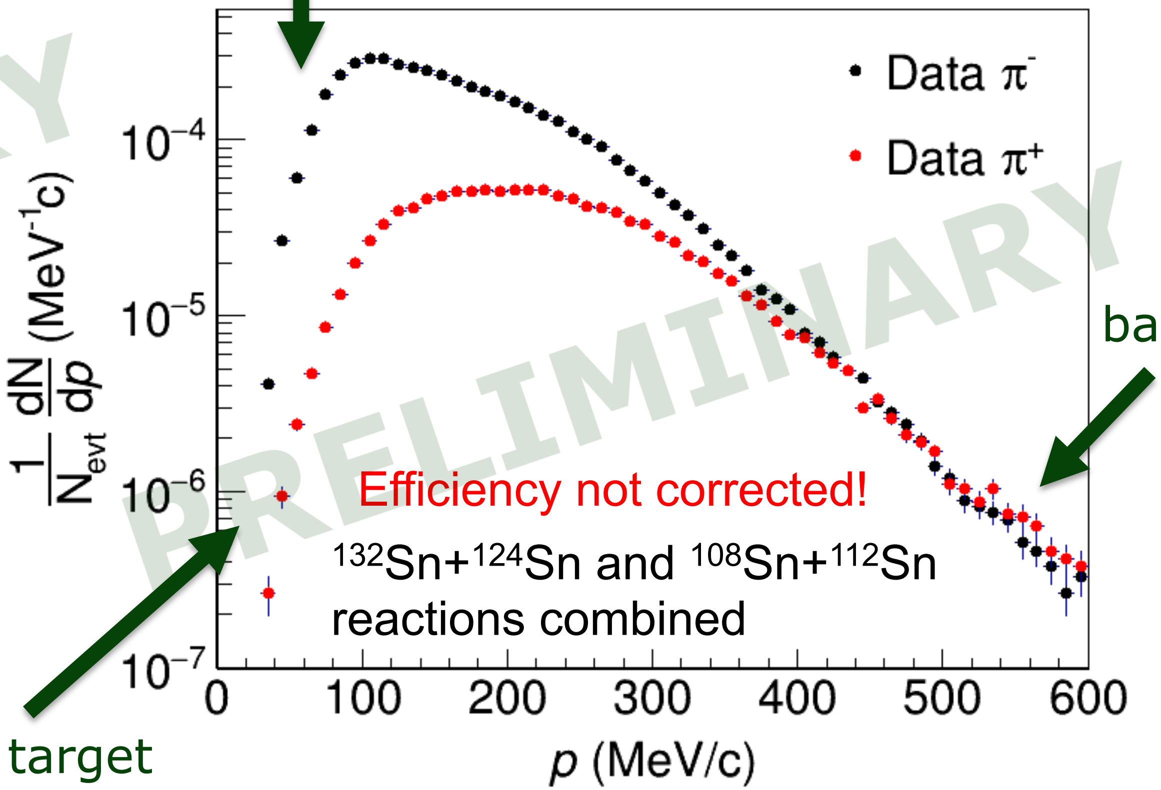
e+/e- contamination





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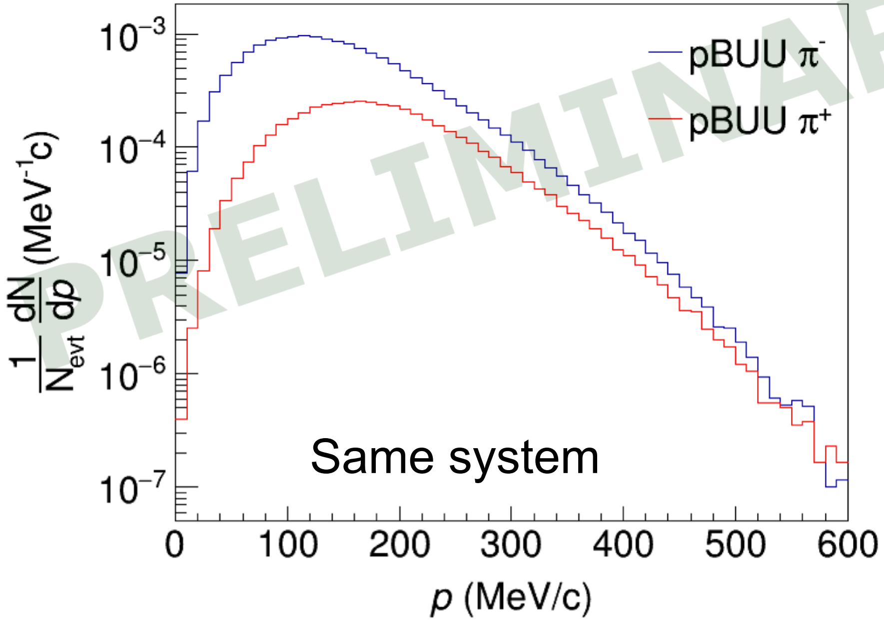
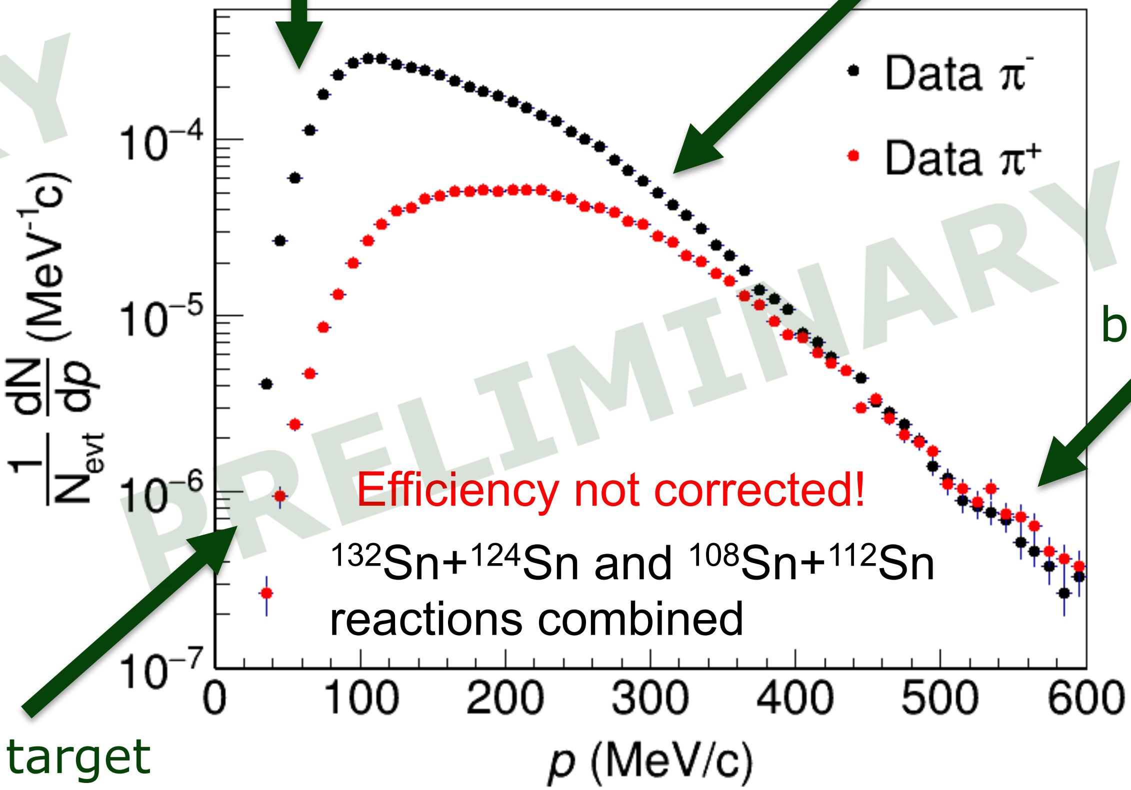


e⁺/e⁻ contamination

Tracking efficiency

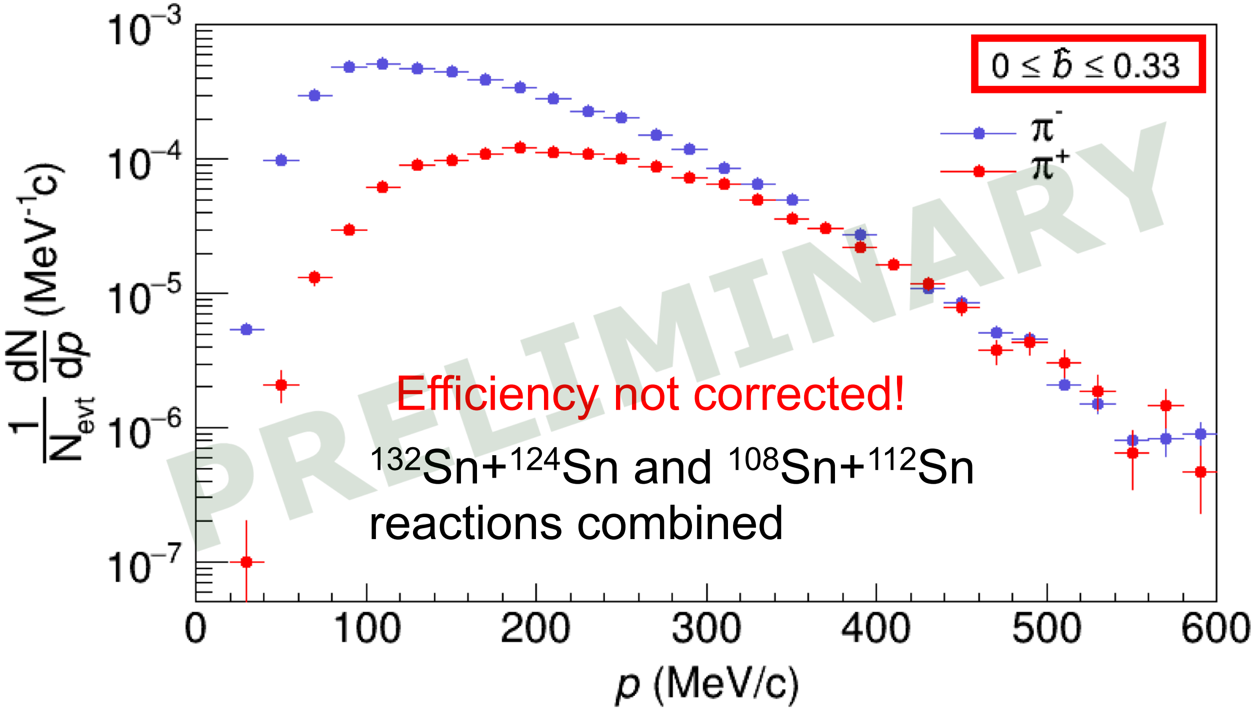
Proton background

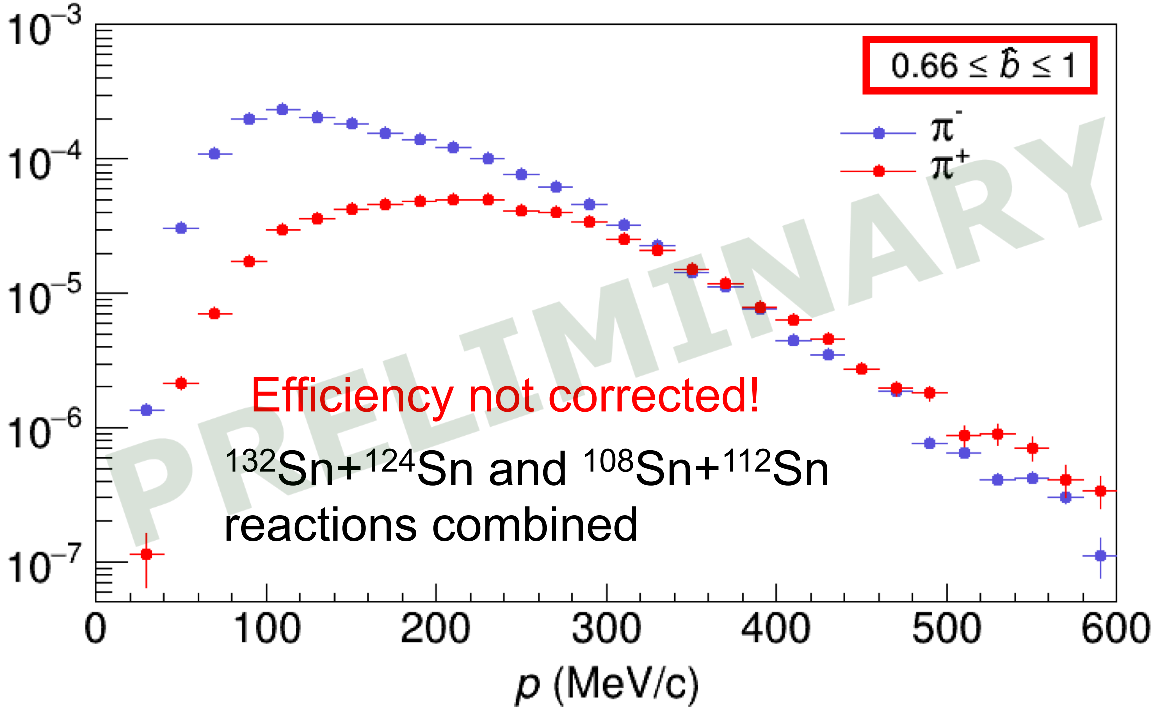


- Energy loss through target
- Detection efficiency

b dependence of pion yield

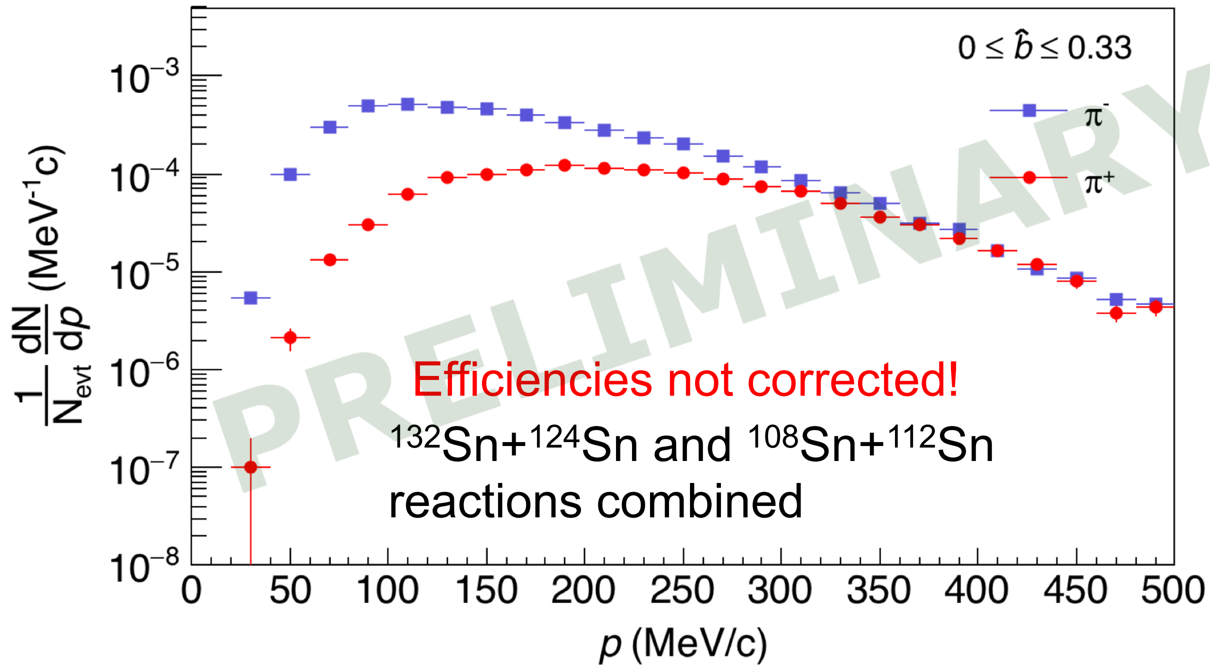
- As we select the centrality from the most to the least central collision, both pion yields decrease as they're expected.
- Pion yield trends are not affected much by the impact parameter selection.

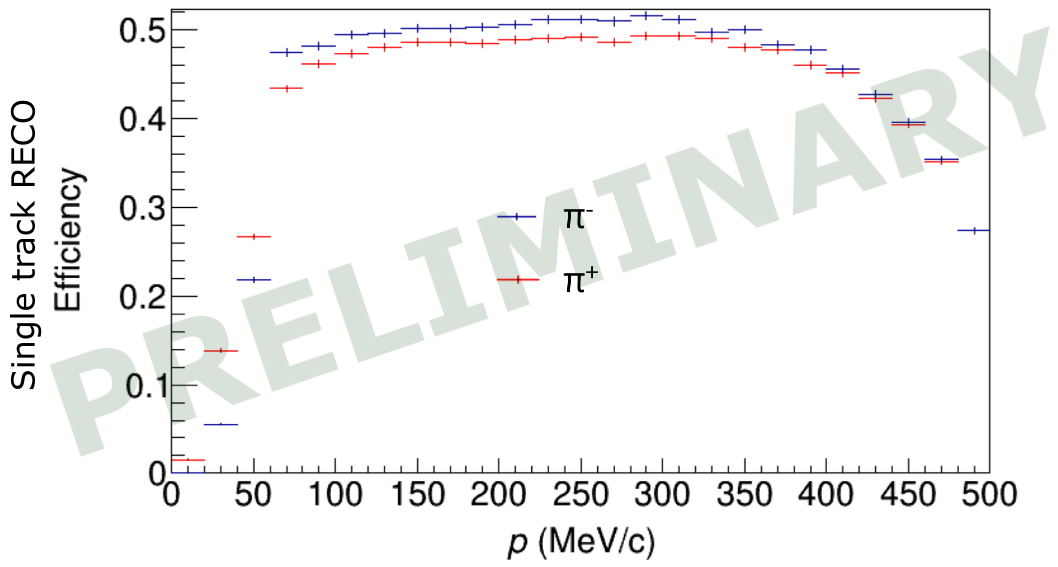




Importance of efficiency corrections

- Yield spectra need efficiency corrections, e.g. detection, tracking, etc..
- Each efficiency is not a single constant, but a function of momentum, angle, rapidity and so on.
- Preliminary result of single track Reco. efficiency corrects largely at high and low momentum yields.





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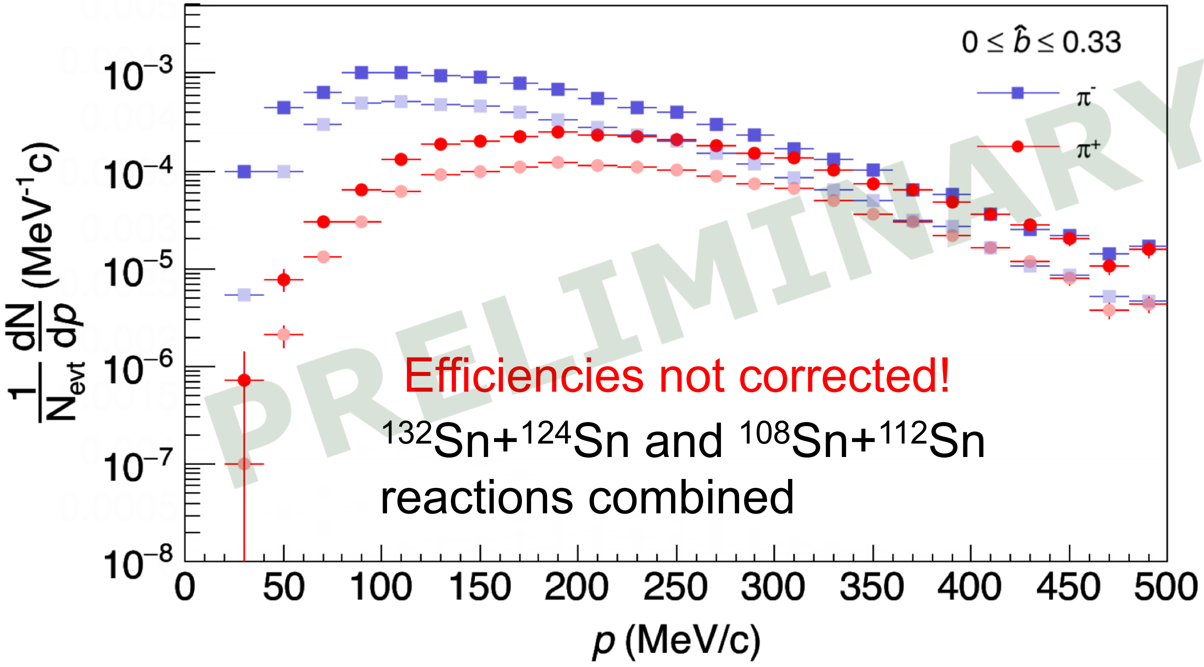

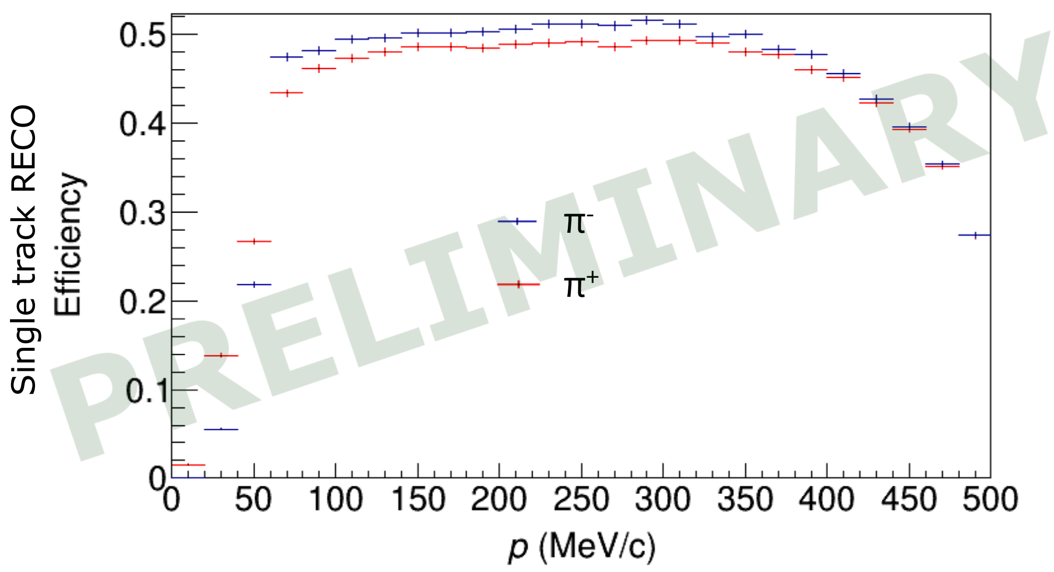

Things to do for publication

- Quantify efficiencies
  - Tracking efficiency
  - Detection efficiency
  - Trigger efficiency

  (Tracking and detection efficiency) → embedding
  - Detector effect
  - Effect by the other tracks in the TPC
- Completing the analysis of impact parameter determination
- Estimating the contamination by electron/positron to pions
- Estimating the contamination of protons to π^+
- Systematic uncertainty estimation
- Collecting enough statistics of theoretical model to compare pion yield spectra

U.S. Department of Energy Office of Science
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Michigan State University

Summary

- π^-/π^+ yield ratio is a sensitive observable to symmetry energy near $2\rho_0$.
- A series of SπRIT experiment is successfully performed in Spring 2016 at RIBF/RIKEN.
- Active development of software to assure the quality of analyzed data and analysis to extract physical observables are ongoing.
- Preliminary results look promising qualitatively.
- To produce quality physical results, the data need some corrections.

- We hope to publish the results in near future.