BM@N Analysis Note 4
Centrality evaluation for production of *p, d, t* in 3.2 A GeV argon-nucleus interactions

The number of tracks originated from the primary event vertex Ntr and the number of hits NBD in the Barrel Detector (situated around the target) are anti-correlated with the impact parameter *b* of a nucleus-nucleus collision. The correlation plots extracted from the DCM-SMM simulation of Ar + C, Al, Cu, Sn, Pb interactions are shown in Fig.1a. The narrowest correlation to the impact parameter *b* is found for the number of hits NBD in Ar+Sn and Ar+Pb interactions. The distributions of the impact parameter *b* for minimum bias Ar+C,Al,Cu,Sn,Pb collisions are given in Fig.1b. Vertical lines show the boundary of collisions with centrality 0-40% and 40-100%. The values of the boundary impact parameters are 4.23 fm (Ar+C), 4.86 fm (Ar+Al), 5.66 fm (Ar+Cu), 6.32 fm (Ar+Sn), 7.10 fm (Ar+Pb). The analysis of the *p,d,t* production in the Ar+A interactions is done for these two classes of the event centrality.

To select events, which belong to centrality classes 0-40% and 40-100% , and estimate the reconstruction efficiency for these classes of events, distributions of Ntr, NBD and 2-dimensional Ntr & NBD are used. The correlation plots between NBD and Ntr are given in Fig.1c for the experimental data and the DCM-SMM simulation.

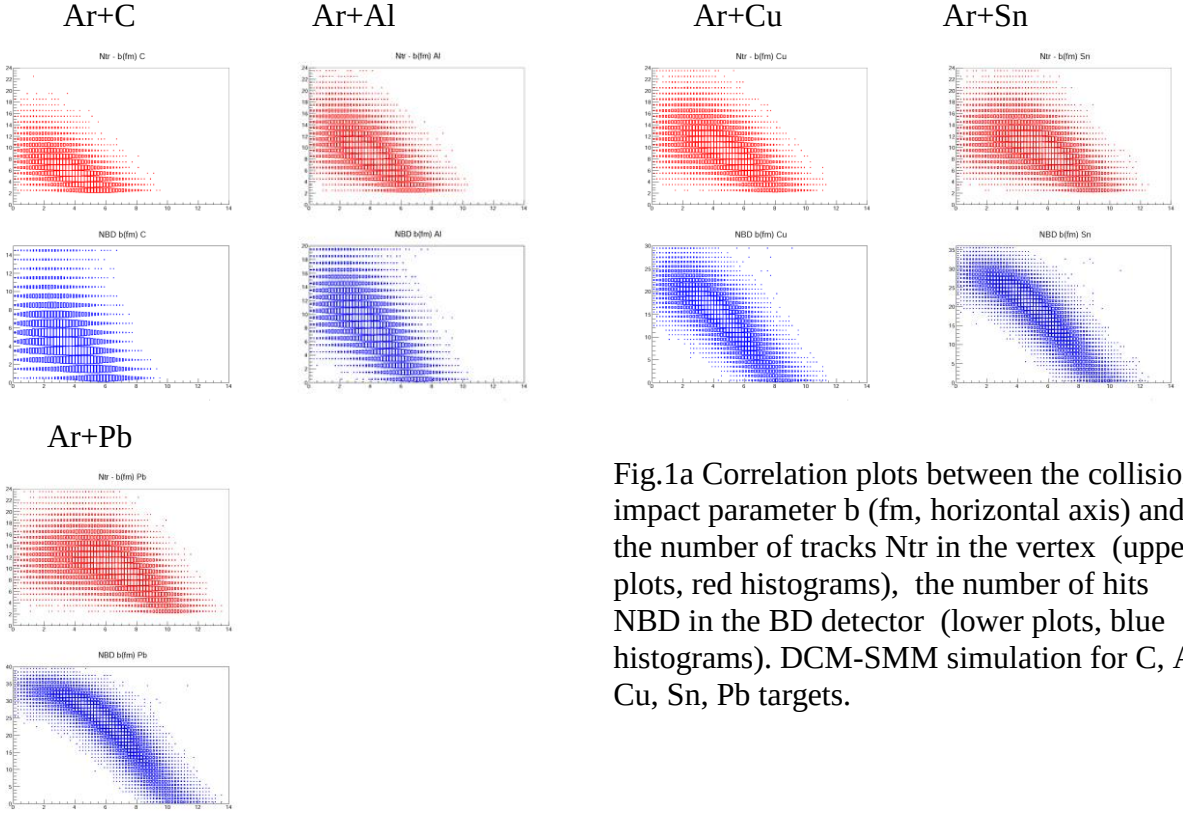
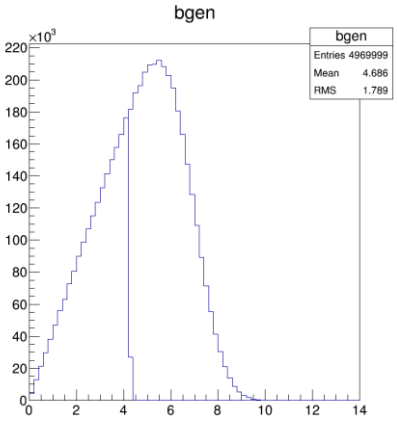
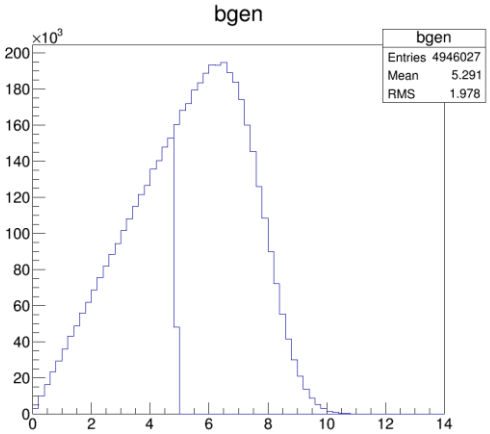


Fig.1a Correlation plots between the collision impact parameter b (fm, horizontal axis) and the number of tracks Ntr in the vertex (upper plots, red histograms), the number of hits NBD in the BD detector (lower plots, blue histograms). DCM-SMM simulation for C, Al, Cu, Sn, Pb targets.

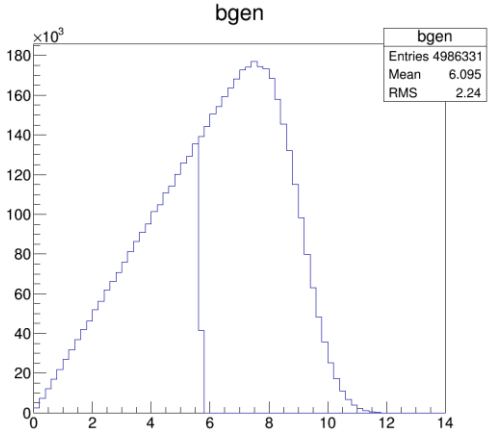
Ar+C



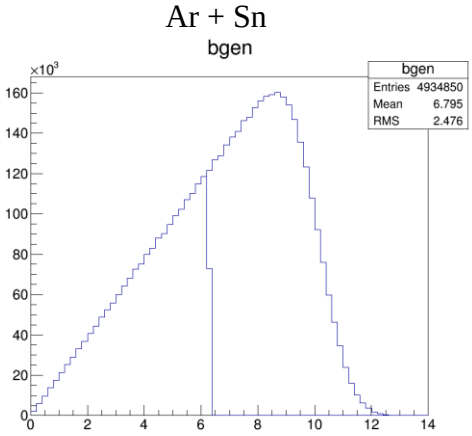
Ar+Al



Ar + Cu



Ar + Sn



Ar + Pb

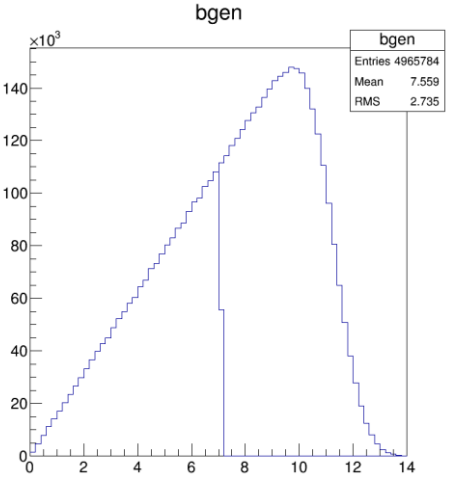


Fig.1b. Distribution of the impact parameter b (fm) of Ar+C,Al,Cu,Sn,Pb collisions. Line shows the boundary of collisions with centrality 0-40% and 40-100%. The boundary impact values are 4.23 fm (Ar+C), 4.86 fm (Ar+Al), 5.66 fm (Ar+Cu), 6.32 fm (Ar+Sn), 7.10 fm (Ar+Pb).

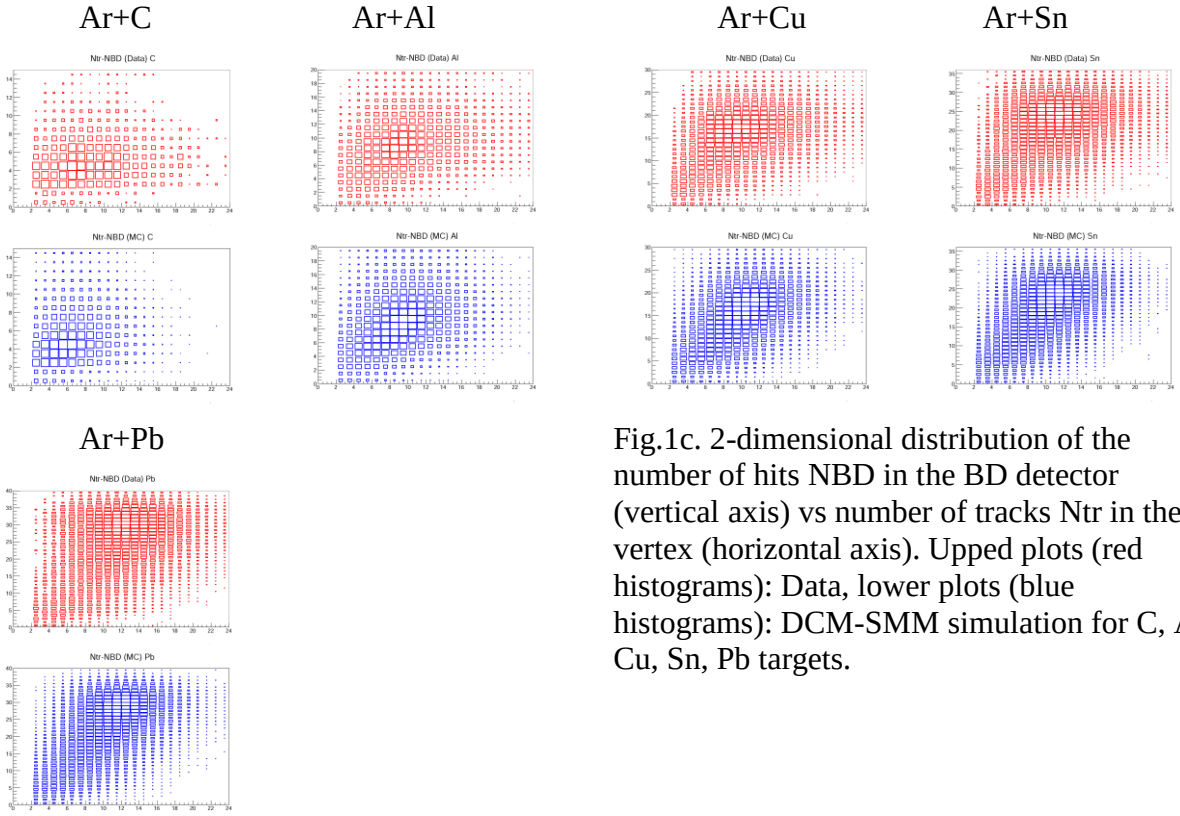


Fig.1c. 2-dimensional distribution of the number of hits NBD in the BD detector (vertical axis) vs number of tracks Ntr in the vertex (horizontal axis). Upped plots (red histograms): Data, lower plots (blue histograms): DCM-SMM simulation for C, Al, Cu, Sn, Pb targets.

The shape of the NBD and Ntr distributions in data and simulation are in reasonable agreement. All the data distributions shown below are corrected for the trigger efficiency [1].
The probability density function (PDF) distributions for NBD hits in experimental and simulated events with identified deuterons are presented in Fig.2a for 10 bins in p_T and 8 bins in rapidity y. Data and simulated distributions are normalized to 1 in every p_T and y bin. The PDF distributions for Ntr tracks in experimental and simulated events with identified deuterons are presented in Fig.2b for 10 bins in p_T and 8 bins in y.

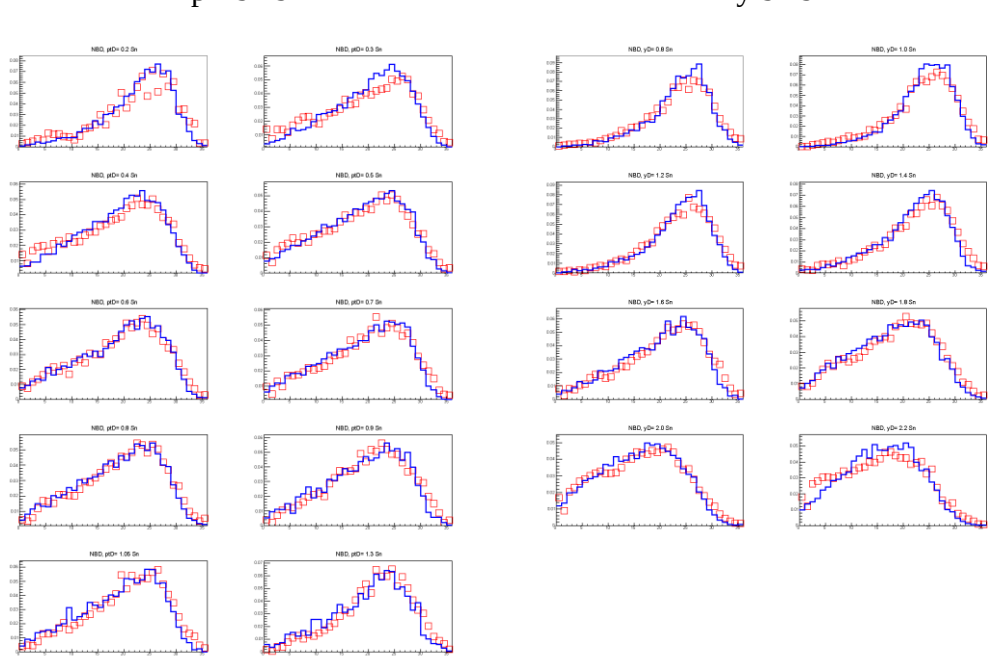


Fig.2a Ar+Sn: PDF distributions of the number of hits in the BD detector NBD in events with

identified deuterons (ToF-700) for 10 bins in p_T (left set of plots) and 8 bins in y (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

pT bins y bins

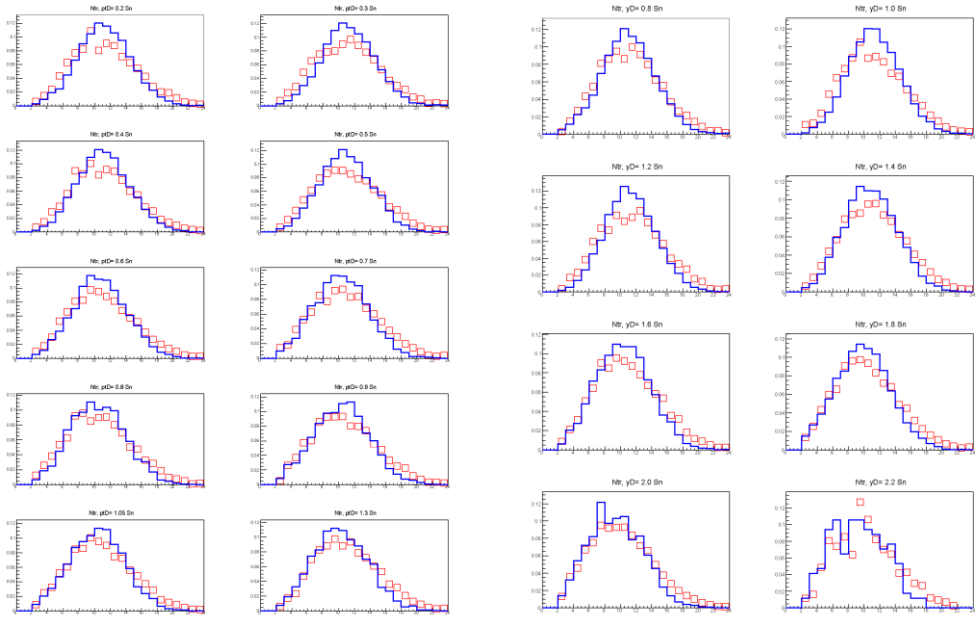


Fig.2b Ar+Sn: PDF distributions of the number of tracks Ntr in the vertex in events with identified deuterons (ToF-400) for 10 bins in p_T (left set of plots) and in y (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

Using results of the DCM-SMM simulation, fractions of reconstructed events which belong to two centrality classes (0-40% and 40-100%) are calculated. The fractions of events with centrality 0-40% and 40-100% are presented as functions of the NBD hits in Fig.3a and 3b, respectively. Fig.3c and 3d show the fractions of events with centrality 0-40% and 40-100% as functions of the Ntr tracks in Fig.3c and 3d, respectively.
To transform the distribution of the fraction (probability) of events of centrality classes 0-40% and 40-100% from the simulation into data, cumulative distributions for every p_T and y bin are build from the distributions Ntr and NBD shown in Fig.2a and 2b. As an example, the cumulative distributions $\Sigma(Ntr<=i)/\Sigma(Ntr\ all)$ and $\Sigma(NBD<=i)/\Sigma(NBD\ all)$ integrated over all p_T and y bins are given in Fig.2c. To produce the fraction distributions for data (open symbols in Fig.3a-3d) the fraction of events with centrality 0-40% or 40-100% is taken from the simulated distribution cell1 (blue histogram in Fig.3a-3d) and placed in the data cell2 with the same commulant value (see in Fig.3e, horizontal transition from the histogram bins to the bins of open symbols. The event fraction in Fig.3a-3d was transformed from cell1 simulation (hystogram) to cell2 data (open symbols).

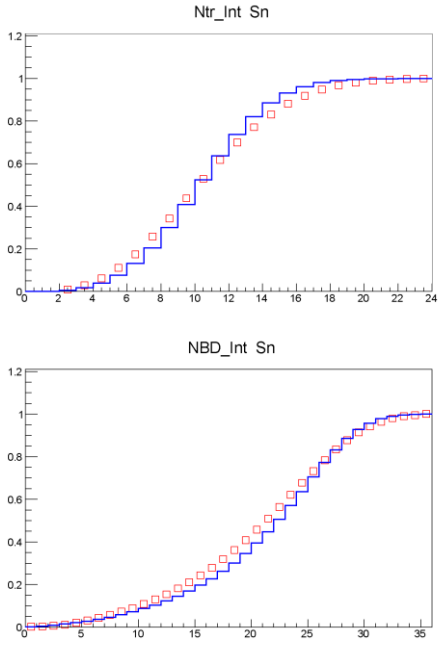


Fig.2c. Ar+Sn: Cumulative distributions for Ntr and NBD from Fig.2a and 2b in events with identified deuterons integrated over all p_T and y bins. Blue histogram – DCM-SMM simulation, red open symbols – data.

pT bins y bins

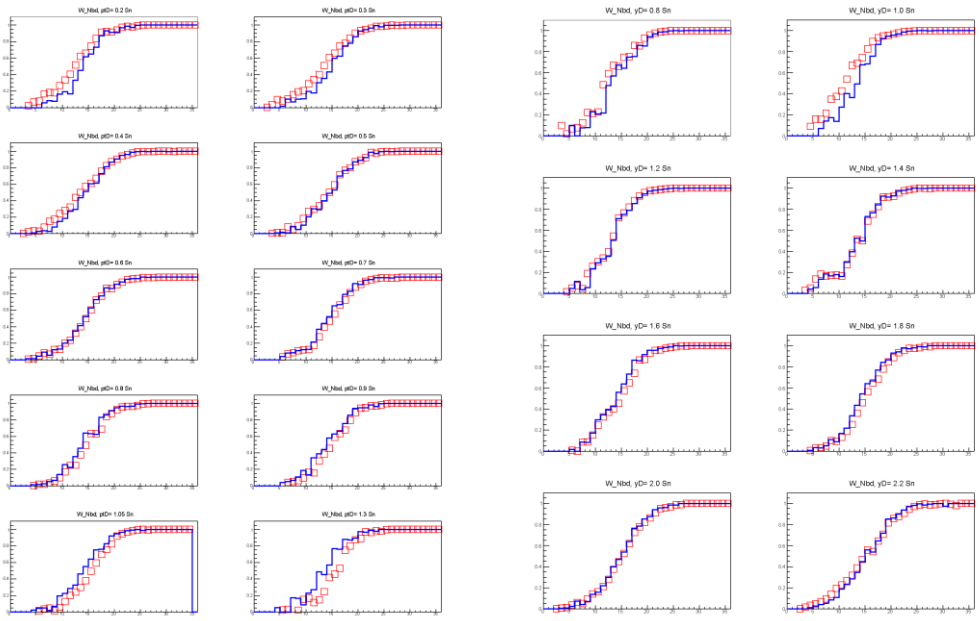


Fig.3a Ar+Sn: Fraction (probability) of events with identified deuterons of centrality class 0-40% as a function of the NBD hits for 10 bins in p_T (left set of plots) and *y* (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

pT bins y bins

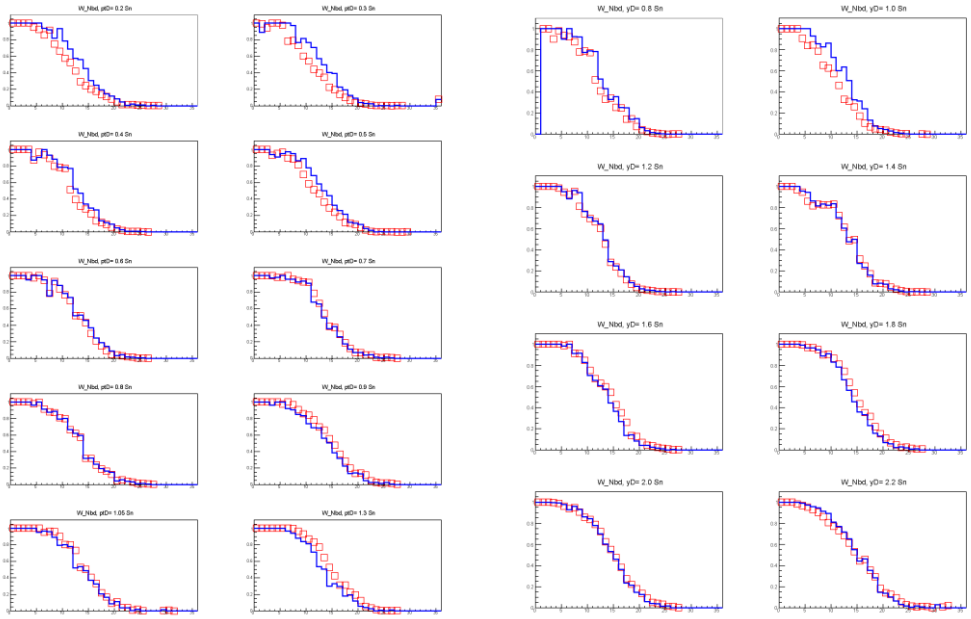


Fig.3b Ar+Sn: Fraction (probability) of events with identified deuterons of centrality class 40-100% as a function of the NBD hits for 10 bins in p_T (left set of plot) and y (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

pT bins y bins

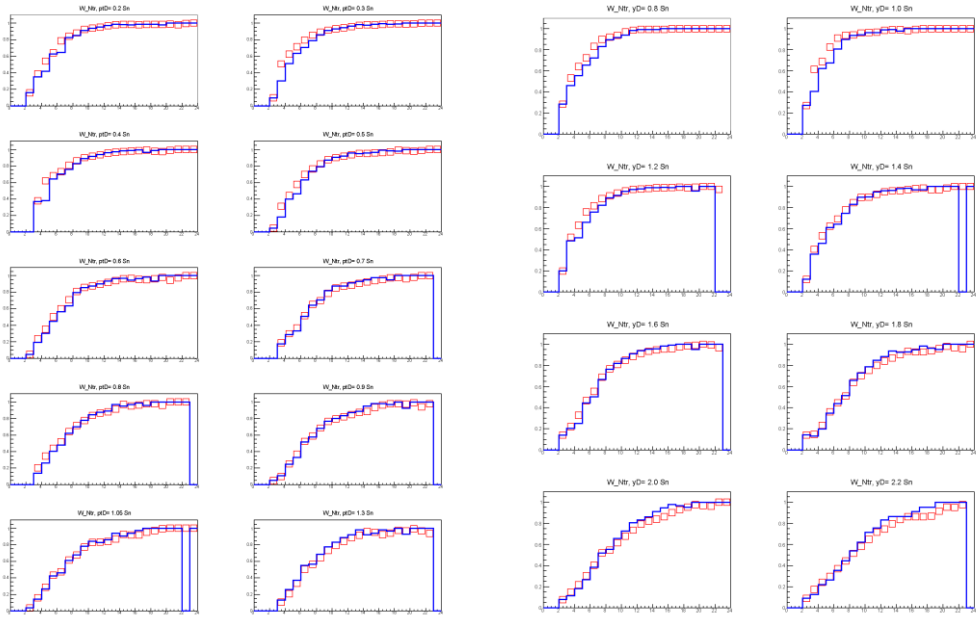


Fig.3c Ar+Sn: Fraction (probability) of events with identified deuterons of centrality class 0-40% as a function of the Ntr tracks for 10 bins in p_T (left set of plots) and y (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

pT bins y bins

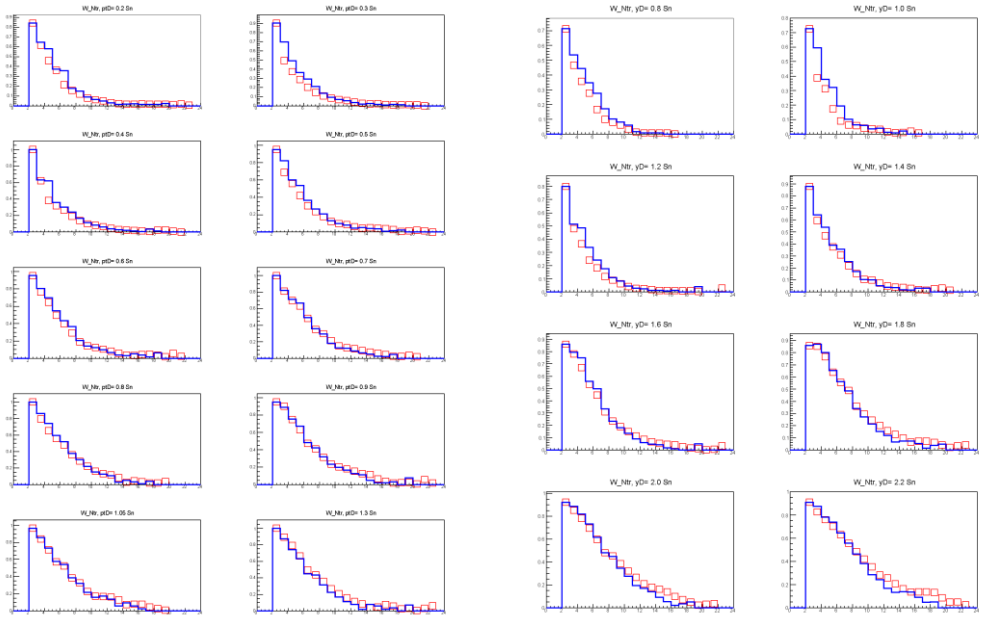


Fig.3d Ar+Sn: Fraction (probability) of events with identified deuterons of centrality class 40-100% as a function of the Ntr tracks for 10 bins in p_T (left set of plots) and y (right set of plots). Blue histogram - DCM-SMM simulation, open red symbols – data.

Probablities of events with centralities 0-40% and 40-100% extracted from the Ntr, NBD and 2-dimensional Ntr & NBD distributions are illustrated in Fig.4a. To be short, all distributions are integrated over all p_T and y bins. Probabilities of events with centralities 0-40% and 40-100% extracted from the Ntr and NBD distributions are compiled in Fig.4b for Ar+C,Al,Cu,Sn,Pb interactions.

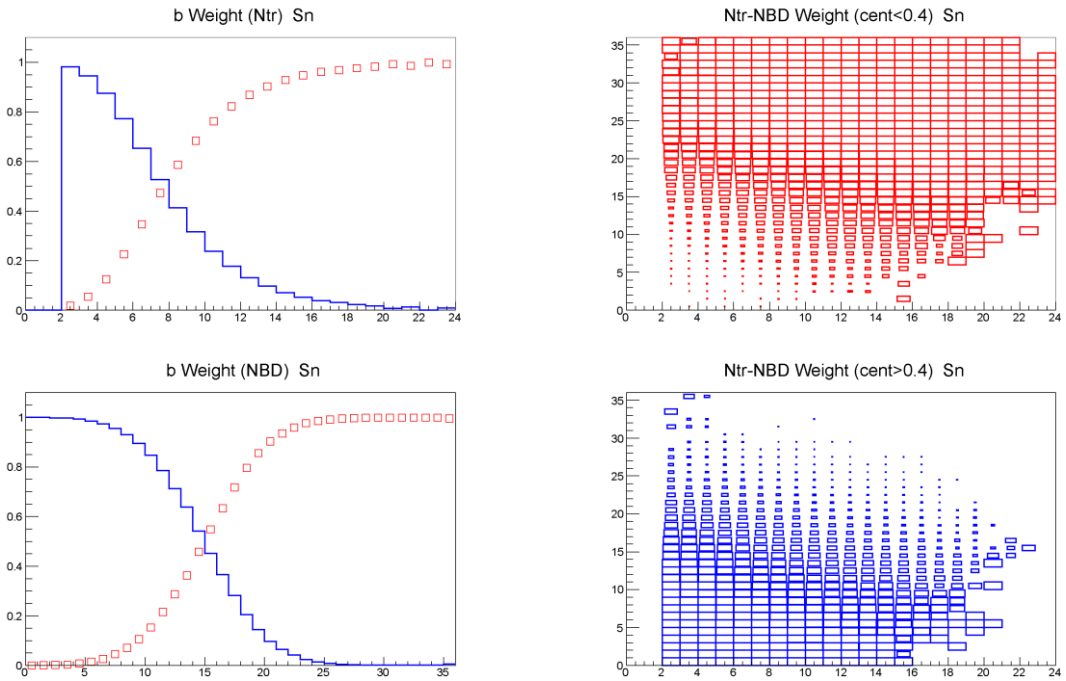
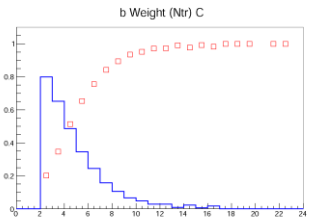
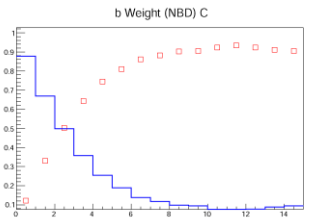


Fig.4a. Ar+Sn, Left plots: Fraction (probability) of events with the centrality 0-40% (red open

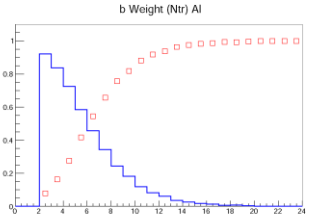
symbols) and 40-100% (blue histogram) as a function of the number of tracks Ntr in the vertex (upper plot) and number of hits NBD in the BD detector (lower plot). Right plots: 2-dimensional distribution of the fraction (probability) of events with centrality 0-40% (upper red histogram) and 40-100% (lower blue histogram) as a function of the number of tracks Ntr in the vertex (horizontal axis) and the number of hits NBD in the BD detector (vertical axis).

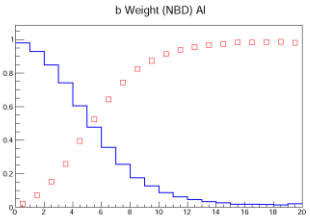
Ar + C



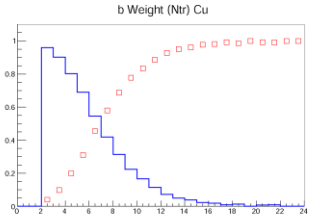


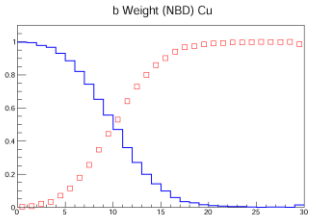
Ar+Al



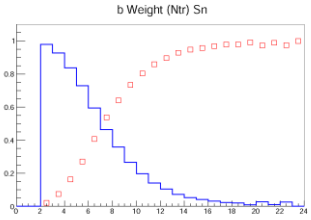


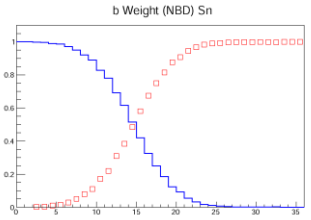
Ar+Cu



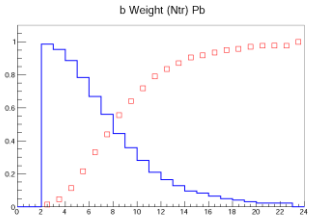


Al+Sn





Al+Pb



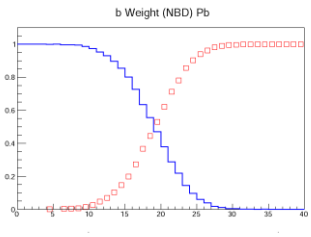


Fig.4b Fraction (probability) of events with centrality 40-100% (blue histograms) and 0-40% (red open symbols) as a function of the number of tracks Ntr in the vertex (upper plots), as a function of the number of hits NBD in the BD detector (lower plots). DCM-SMM simulations for C, Al, Cu, Sn, Pb targets.

To estimate systematics in the measurement of yields of events with centrality classes 0-40% and 40-100% due to migration from one class to another, the probabilities of events calculated for one class (0-40% or 40-100%) are applied to events simulated in another class (i.e. 40-100% instead of 0-40%). If classes of events with centralities 0-40% and 40-100% are completely separeated in the Ntr and NBD distributions, the fraction of events migrated to the "wrong" centrality class will be negligable relative to the number of selected events in the "true" centrality class. PDFs of NBD hits and Ntr tracks in events with identified deuterons are presented in Fig.5a-5d for "true" centrality class (red histogrames) and migrated from "wrong" centrality class (blue histograms).

pT bins y bins

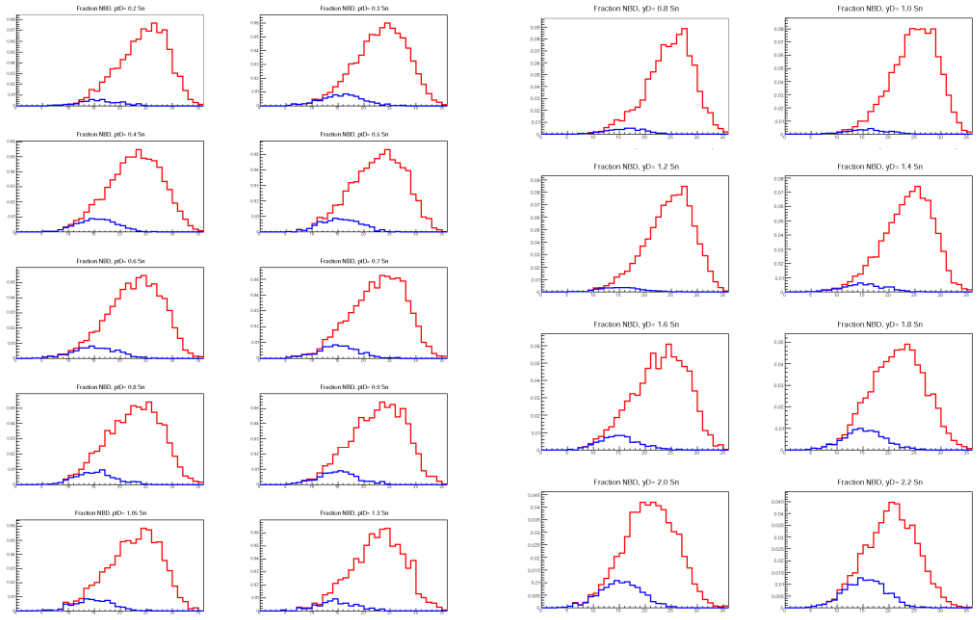


Fig.5a Ar+Sn: PDF distributions of the number of hits in the BD detector NBD in events with identified deuterons (ToF-700) for 10 bins in p_T (left set of plots) and 8 bins in y (right set of plots). Blue histograms – simulated events from centrality class 0-40%, red histograms – simulated events from centrality class 40-100%, but migrated to centrality class 0-40%.

pT bins y bins

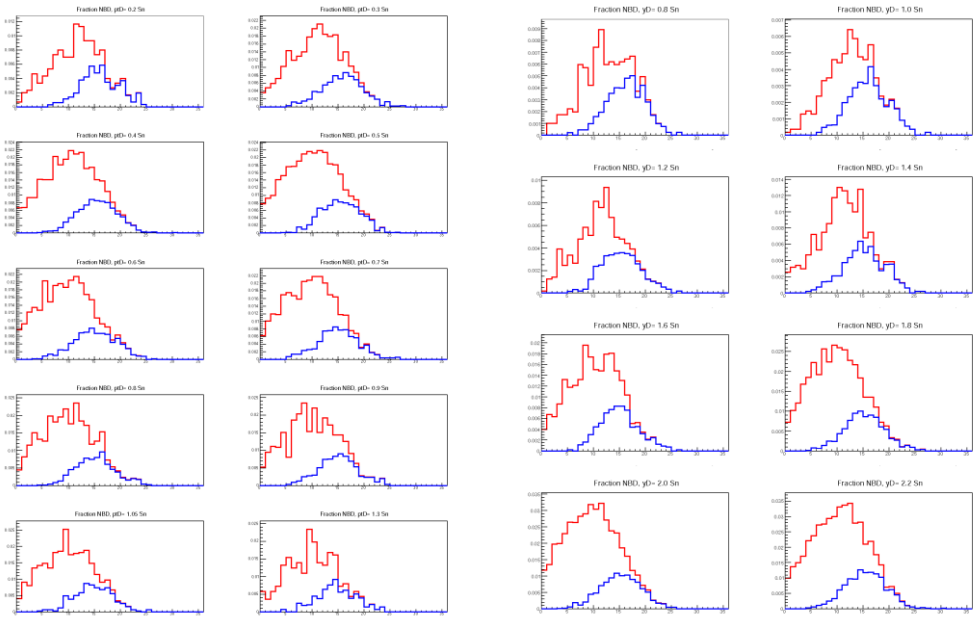


Fig.5b Ar+Sn: PDF distributions of the number of hits in the BD detector NBD in events with identified deuterons (ToF-700) for 10 bins in p_T (left set of plots) and 8 bins in y (right set of plots). Red histograms – simulated events from centrality class 40-100%, blue histograms – simulated events from centrality class 0-40%, but migrated to centrality class 40-100%.

pT bins y bins

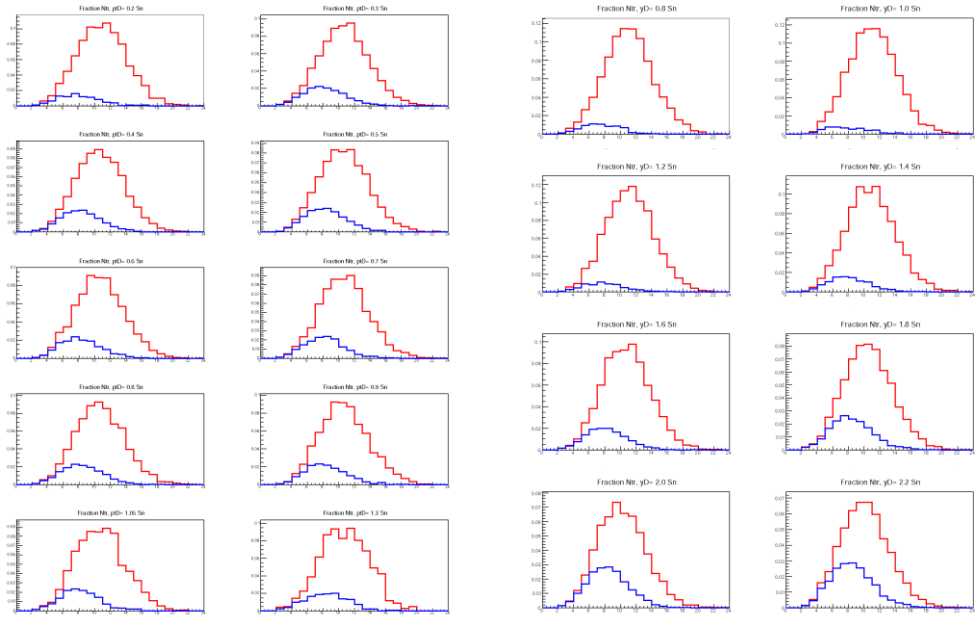


Fig.5c Ar+Sn: PDF distributions of the number of tracks Ntr in the vertex in events with identified deuterons (ToF-700) for 10 bins in p_T (left set of plots) and 8 bins in y (right set of plots). Red histograms – simulated events from centrality class 0-40%, blue histograms – simulated events from centrality class 40-100%, but migrated to centrality class 0-40%.

pT bins y bins

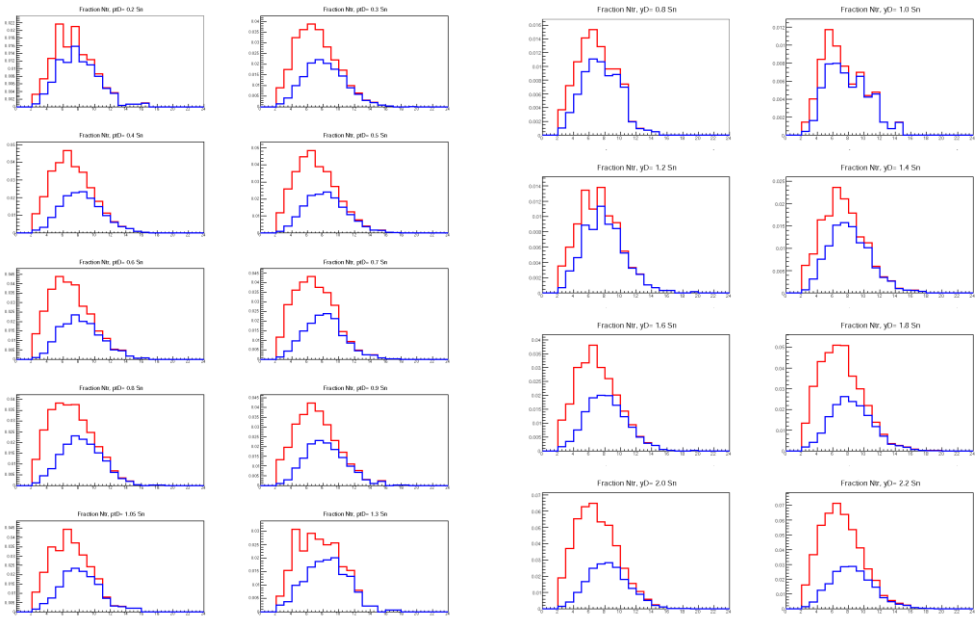


Fig.5d Ar+Sn: PDF distributions of the number of tracks Ntr in the vertex in events with identified deuterons (ToF-700) for 10 bins in p_T (left set of plots) and 8 bins in y (right set of plots). Red histograms – simulated events from centrality class 40-100%, blue histograms – simulated events from centrality class 0-40%, but migrated to centrality class 40-100%.

The fractions of events migrated from one centrality class extracted from the Ntr, NBD and

Ntr&NBD distributions to another centrality class are given in Fig.6a-6e for different bins in p_T and y for events with reconstructed deuterons and protons . These fractions are derived as the ratios of the integrals of the blue and red histograms shown in Fig.5a-5e.

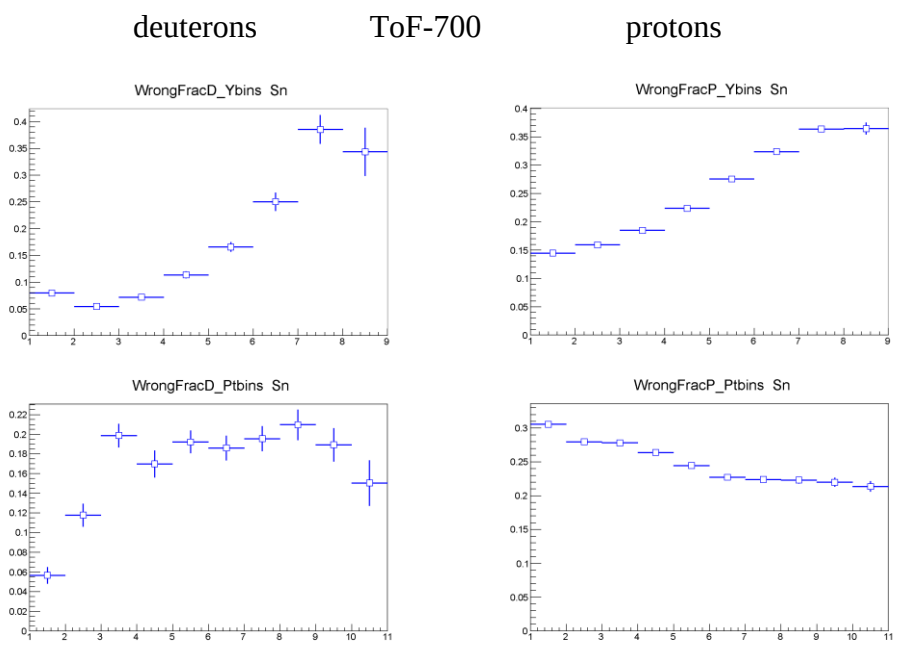


Fig.6a. Ar+Sn: Fraction of events migrated from the centrality class 40-100% defined from Ntr(vertex) to the centrality class 0-40% for 8 bins in y (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

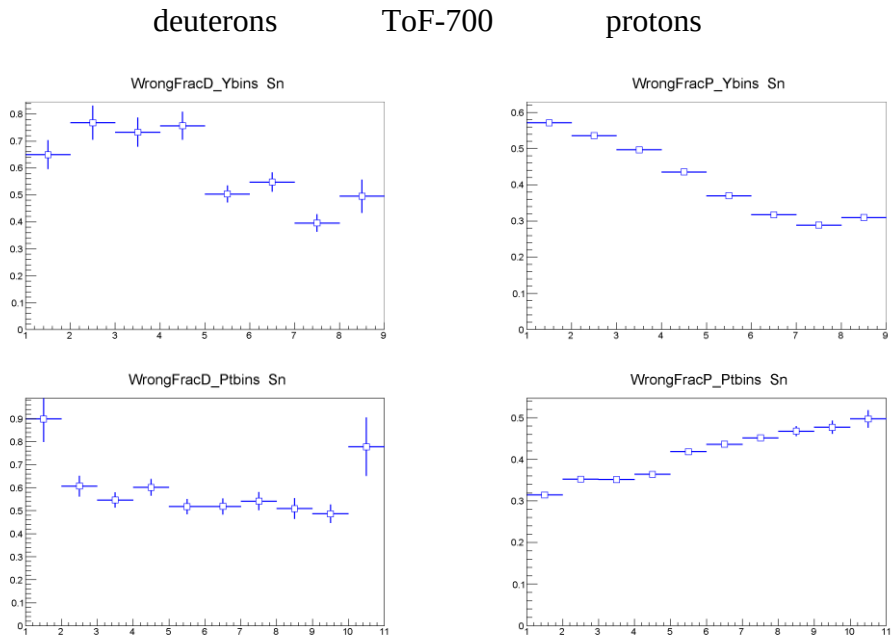


Fig.6b. Ar+Sn: Fraction of events migrated from the centrality class 0-40% defined from Ntr(vertex) to the centrality class 40-100% for 8 bins in y (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

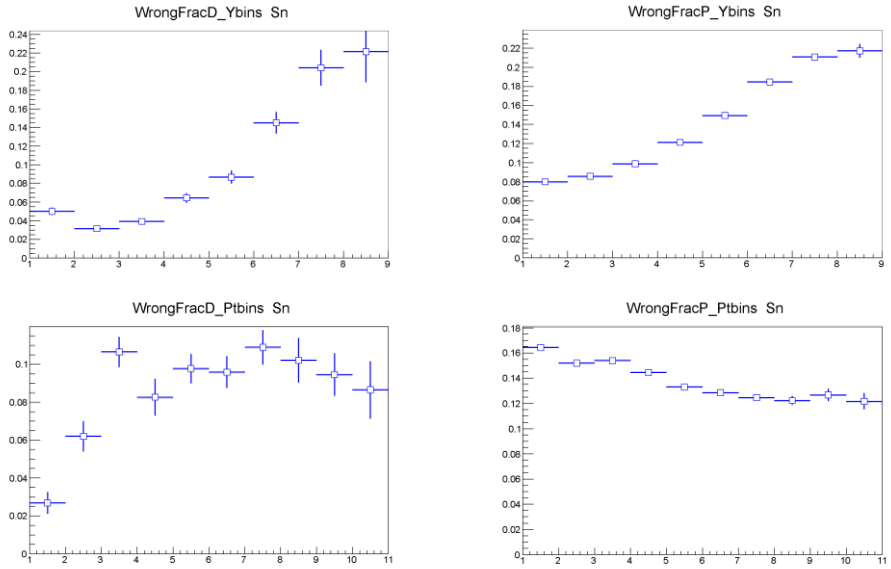


Fig.6c. Ar+Sn: Fraction of events migrated from the centrality class 40-100% defined from the NBD hits to the centrality class 0-40% for 8 bins in y (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

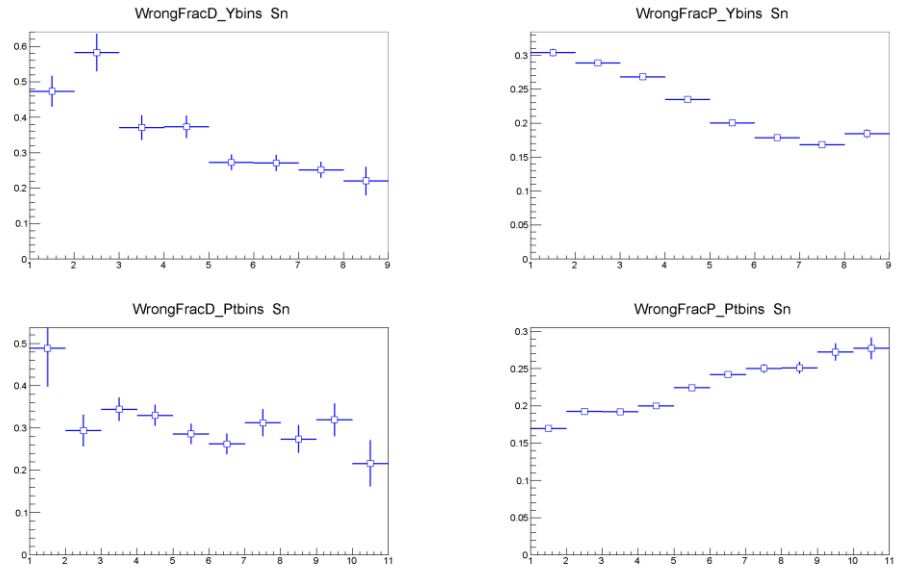


Fig.6d. Ar+Sn: Fraction of events migrated from the centrality class 0-40% defined by NBD to the centrality class 40-100% for 8 bins in y (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

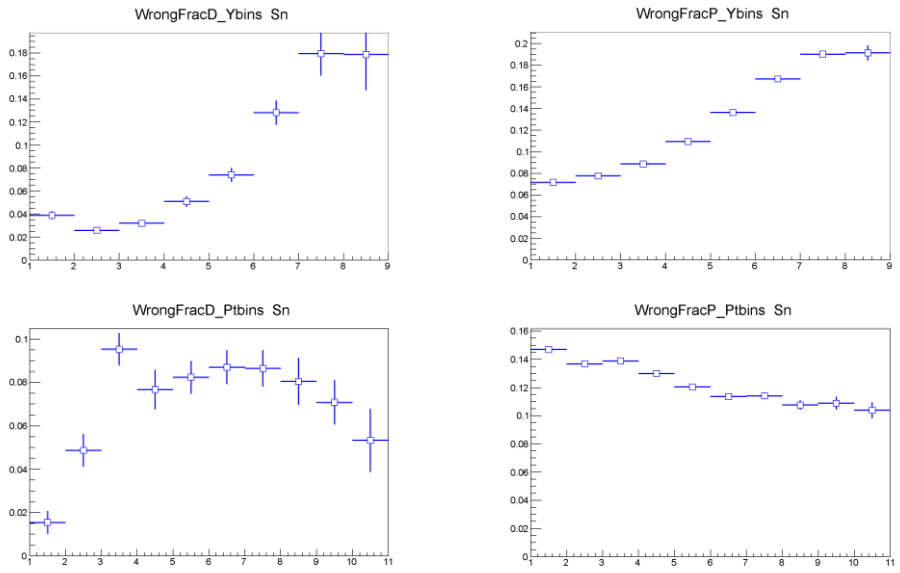


Fig.6e. Ar+Sn: Fraction of events migrated from the centrality class 40-100% to the centrality class 0-40% difined from the 2-dimensional Ntr & NBD distribution for 8 bins in *y* (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

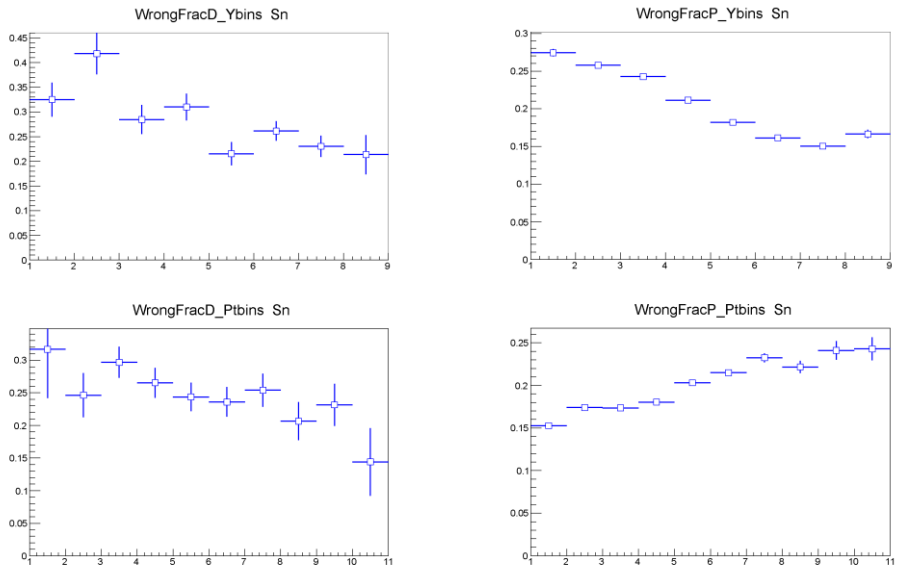


Fig.6f. Ar+Sn: Fraction of events migrated from the centrality class 0-40% to the centrality class 40-100% defined from the 2-dimensional Ntr & NBD distribution for 8 bins in *y* (upper plots) and 10 bins p_T (lower plots). Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

Table 1. Average fraction of migrated events between centrality classes in Ar+ Sn interactions

Centrality classes Selected distributions / events	40-100% →0-40% deuterons / protons	0-40% →40-100% deuterons / protons
Ntr distribution	0.17 / 0.25	0.60 / 0.41
NBD distribution	0.10 / 0.14	0.33 / 0.23
Ntr & NBD distribution	0.08 / 0.12	0.26 / 0. 20

The definition of the centrality class from the 2-dimensional Ntr & NBD distribution gives somewhat better separation of the centrality classes compared to the NBD distribution. The usage of the Ntr distribution gives large migration between the centrality classes compared to the NBD distribution. Based on these results, the Ntr & NBD distributions are used to define the centrality classes 0-40% and 40-100% in the analysis of the Ar+A data.

a) In simulation, it is possible to reconstruct "true" y (pT) spectra of particles originated from events of the centralities 0-40% and 40-100% by analysing events in the two ranges of the impact parameter presented in Fig.1b. Below these spectra are designated as "true" spectra y(pT).
b) In data, it is nessesary to apply event weights equivalent to the probabilities of events occuring in the centrality classes 0-40% and 40-100%. These probablilities are shown in Fig. 3a-3d and 4a for three methods for choosing centrality in Ar+Sn collisions and in Fig.4b for interactions with different targets. Below the reconstructed spectra are designated as "rec" spectra y(pT).
To assess the systematic uncertainty of the reconstructed spectra y(pT) in the centrality classes 0-40% and 40-100% , the ratio Rec/True of the spectra y(pT) is formed for centrality determined by the NBD, Ntr and NBD&Ntr distributions. The Rec/True ratios of the y and pT spectra for deuterons and protons identified in ToF-700 are given in Fig.7a-7b for centralities 0-40% and 40-100% determined by the NBD distribution. The values of the ratio Rec/True extracted from the two-dimensional y-pT intervals are shown in Fig.7c and 7d. The "Pool" distributions (Rec/True-1)/StatError, also shown in Fig.7c and 7d illustrate the systematical shifts in the Rec/True ratios in terms of statistical errors. The shifts of Rec/True relative to 1 and the pool distribution illustrate the reasonable agreement of the Rec and True spectra.

deuterons ToF-700 protons

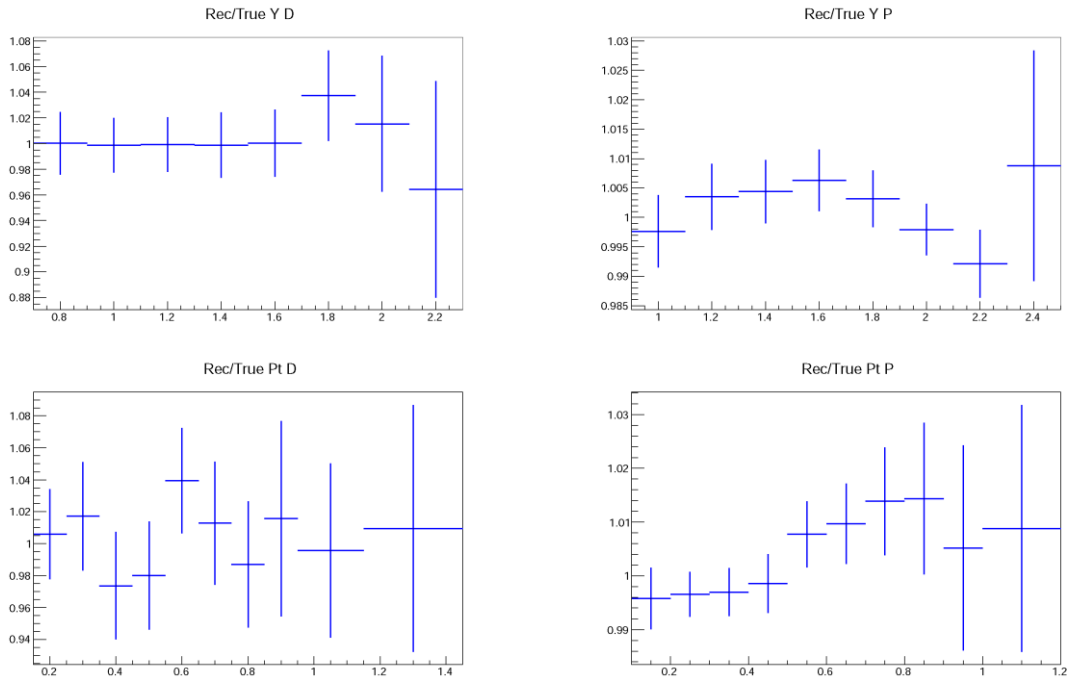


Fig.7a. Ar+Sn: Ratio Rec/True of y (pT) spectra reconstructed in the centrality class 0-40% defined by NBD to the "true" y (pT) spectra in the centrality class 0-40%. Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

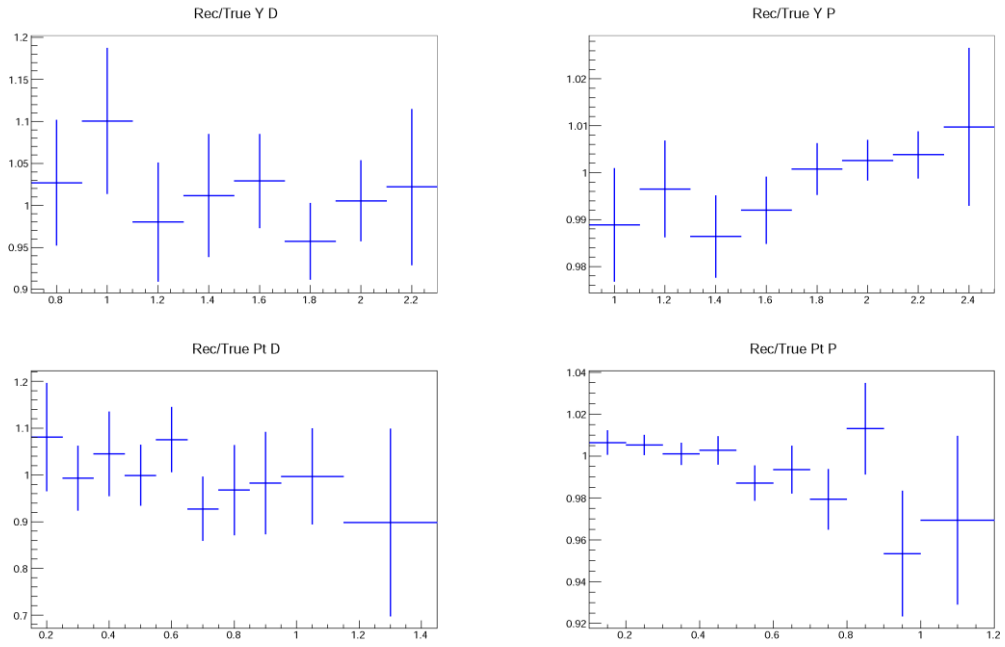


Fig.7b. Ar+Sn: Ratio Rec/True of y (pT) spectra reconstructed in the centrality class 40-100% defined by NBD to the "true" y (pT) spectra in the centrality class 40-100%. Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

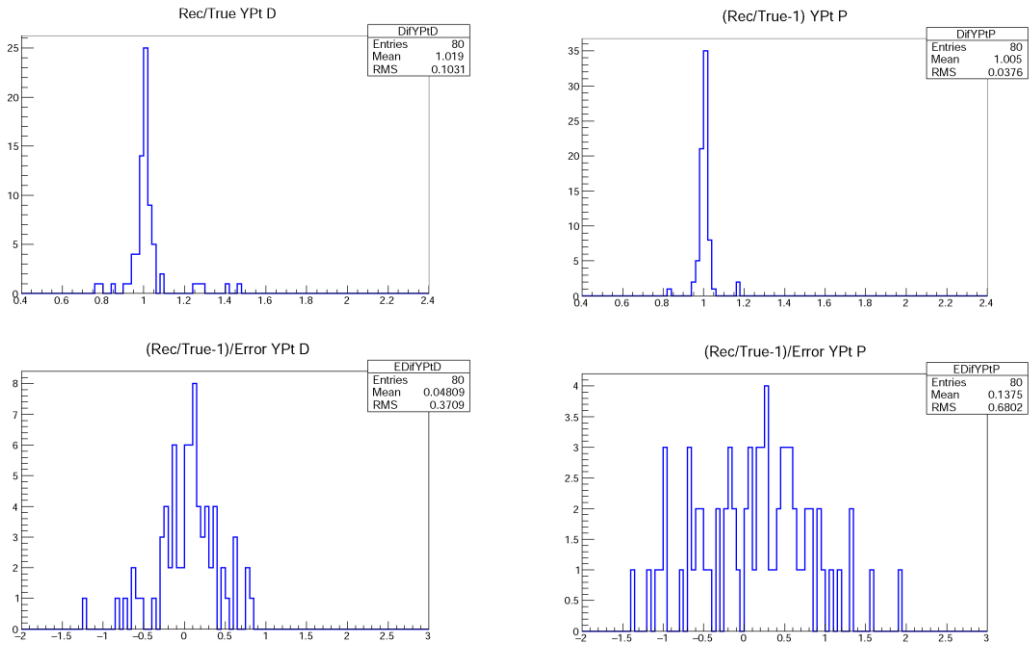


Fig.7c. Ar+Sn: Upper plots: Rec/True ratio values extracted from 2D y-pT spectra reconstructed at the centrality class 0-40% defined by NBD. Lower plots: "Pool" distribution (Rec/True-1)/StatError of 2D y-pT spectra reconstructed in the centrality class 0-40% defined by NBD. Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons detected in ToF-700.

deuterons ToF-700 protons

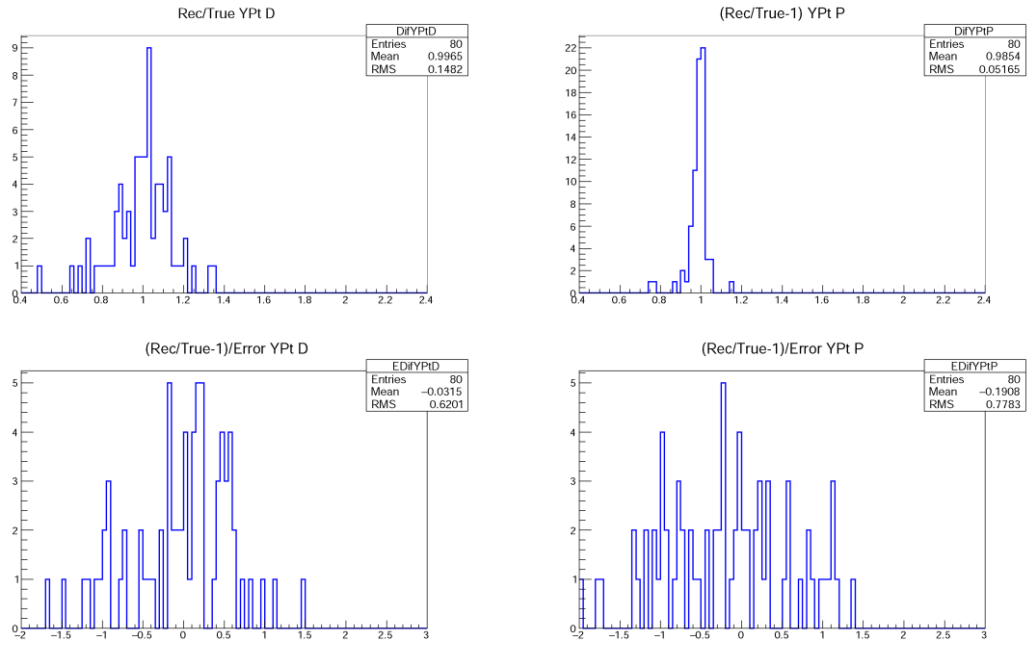


Fig.7c. Ar+Sn: Upper plots: Rec/True ratio values extracted from 2D y-pT spectra reconstructed at the centrality class 40-100% defined by NBD. Lower plots: "Pool" distribution (Rec/True-1)/StatError of 2D y-pT spectra reconstructed in the centrality class 40-100% defined by NBD. Left plots - for events with deuterons detected in ToF-700, right plots – for events with protons

detected in ToF-700.

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