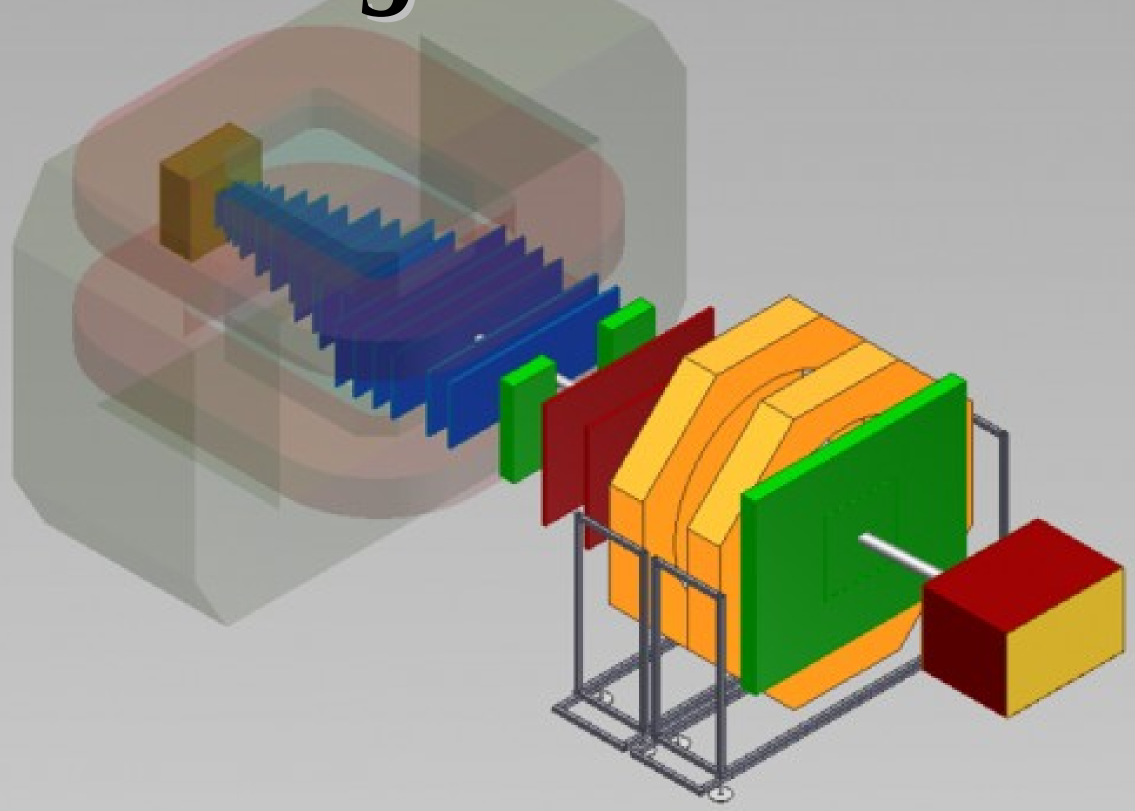
Current Progress in Fragment analysis in Argon data run 7



Lalyo Kovachev[1,2], Yuri Petukhov[1], Vasilii Plotnikov[1], Igor Rufanov[1]

1. VBLHEP Joint Intitute for Nuclear Research, Russia
2. IMech Bulgarian Academy of Sciences, Bulgaria

Outline

1) Selection criteria

2) Data – MC agreement

3) Reconstruction efficiency

4) Trigger efficiency

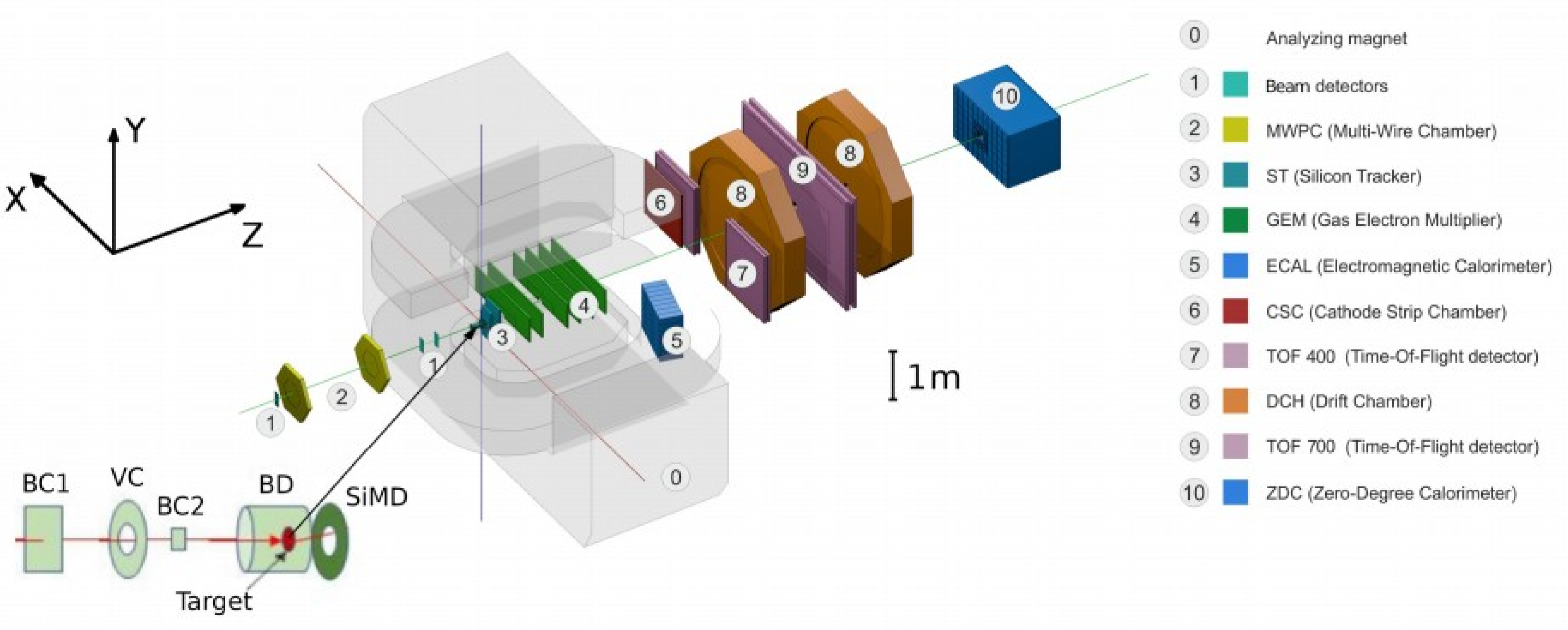
5) Cross sections and yields of protons and deuterons

6) $Helium^4$ to $(deuterium+helium^4)$ ratio

7) m_T and y spectra of protons and deuterons and extracted inverse slope parameter

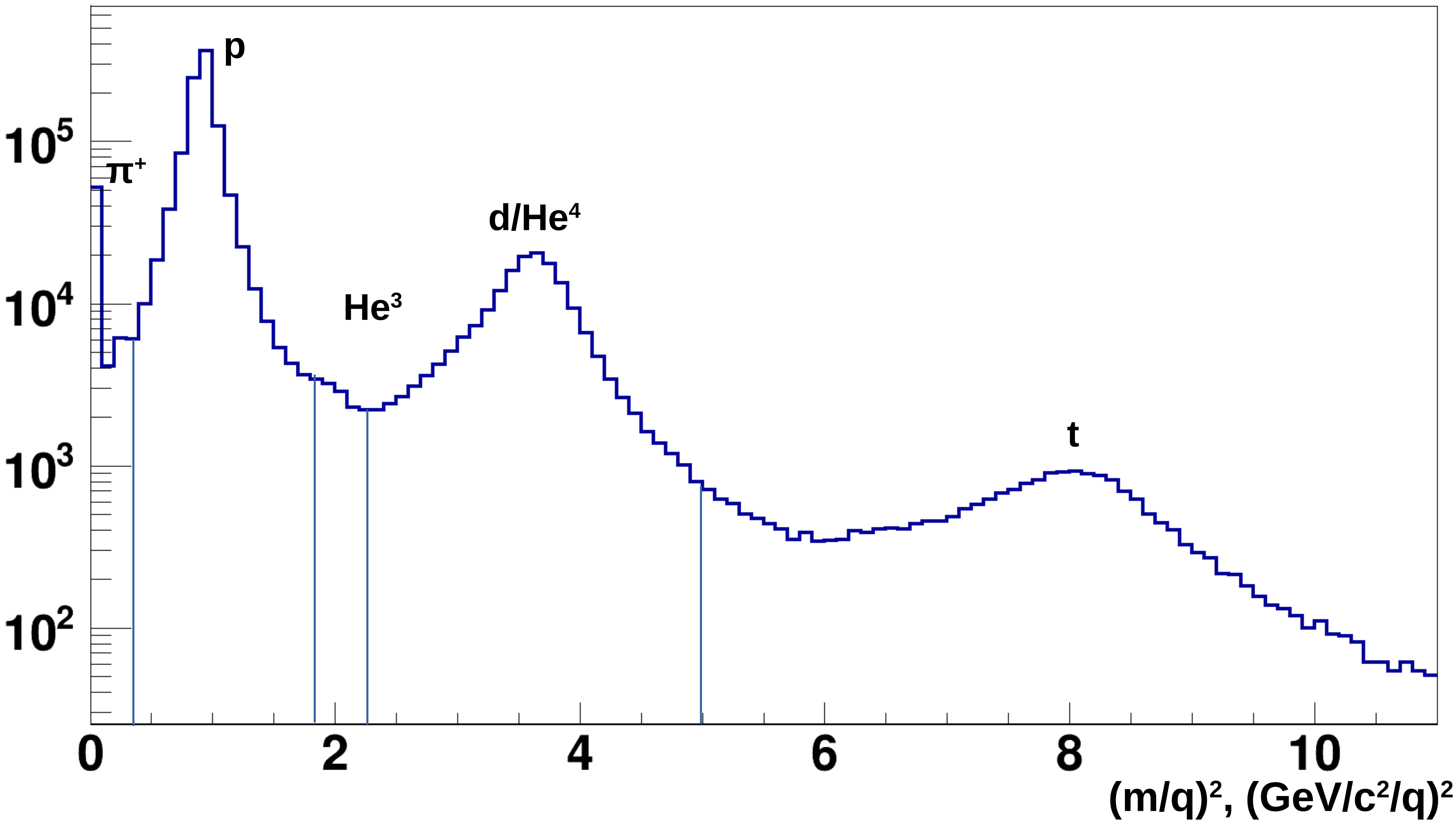
8) Conclusions

BM@N Setup
Run with argon beam (March 2018)
(Ar+C, Ar+Al, Ar+Cu, Ar+Sn, Ar+Pb at 3.2A GeV)

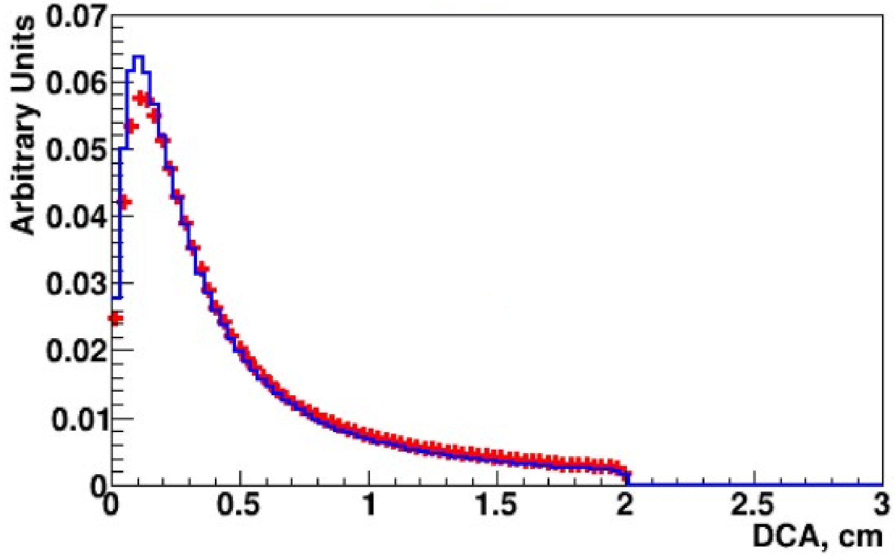


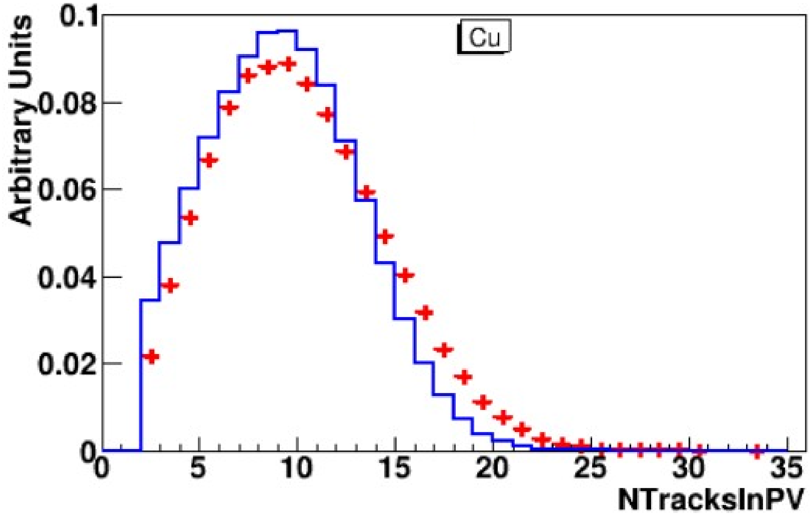
Detectors used in the analysis: Beam detectors (1), Multiplicity Detectors, ST (3), GEM (4),CSC (6), TOF 400 (7), DCH (8), TOF 700 (9)

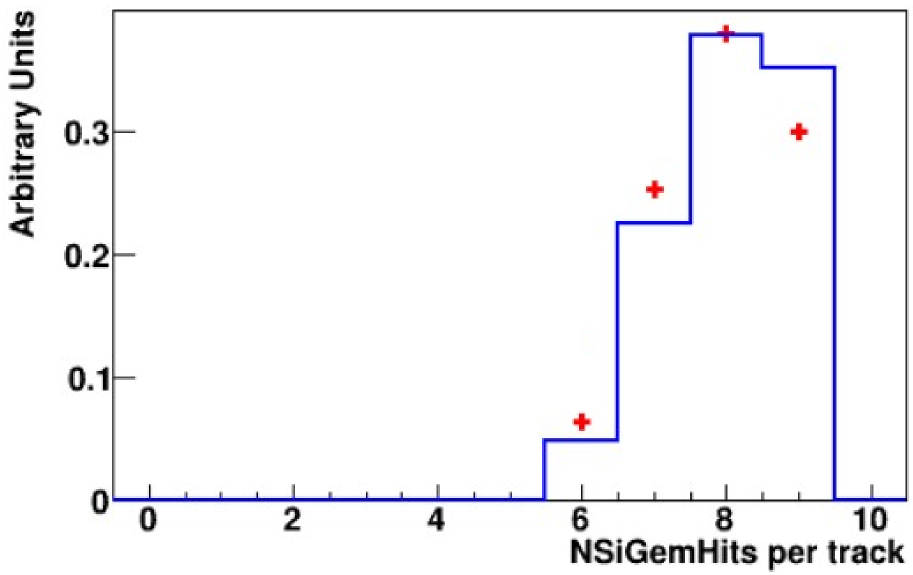
m^2 spectra of positive particles produced in argon-nucleus interactions

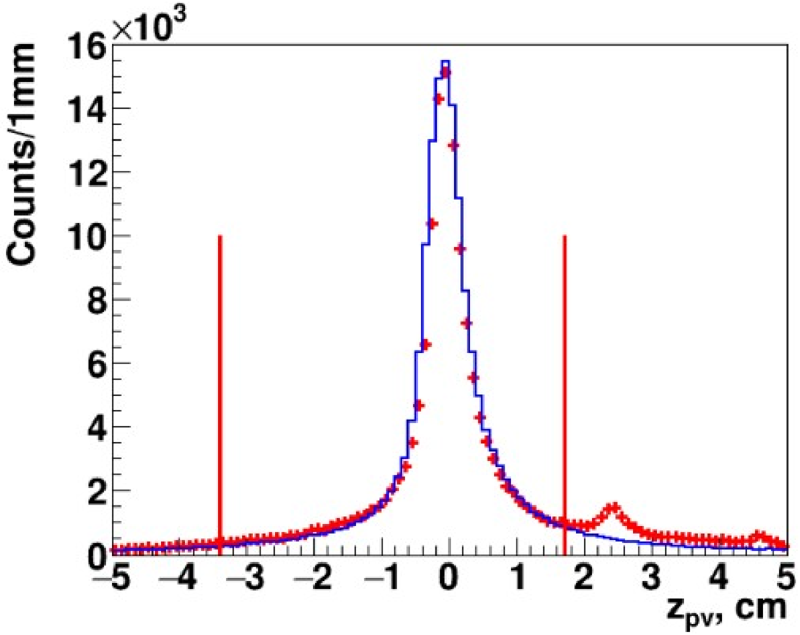


Comparison between experimental data and MC





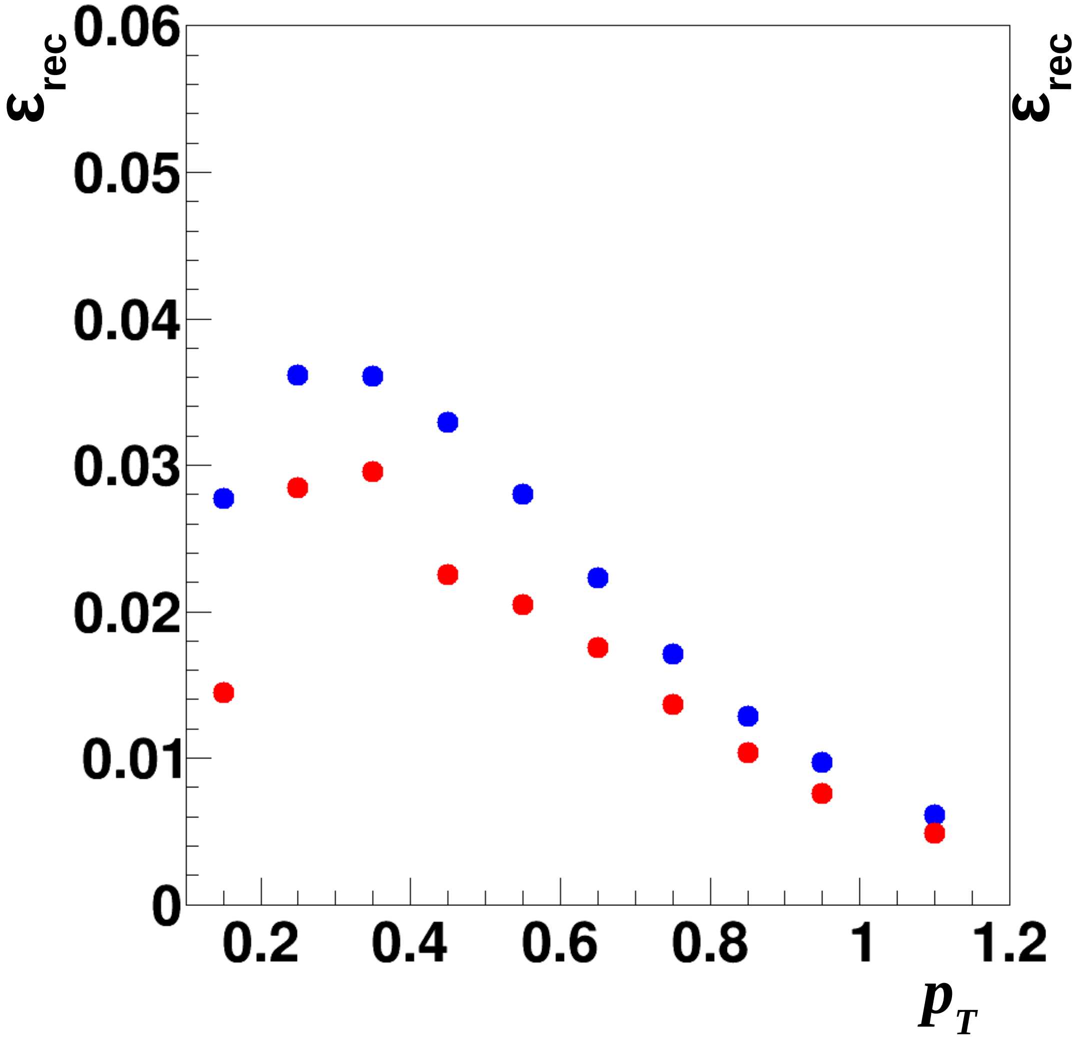


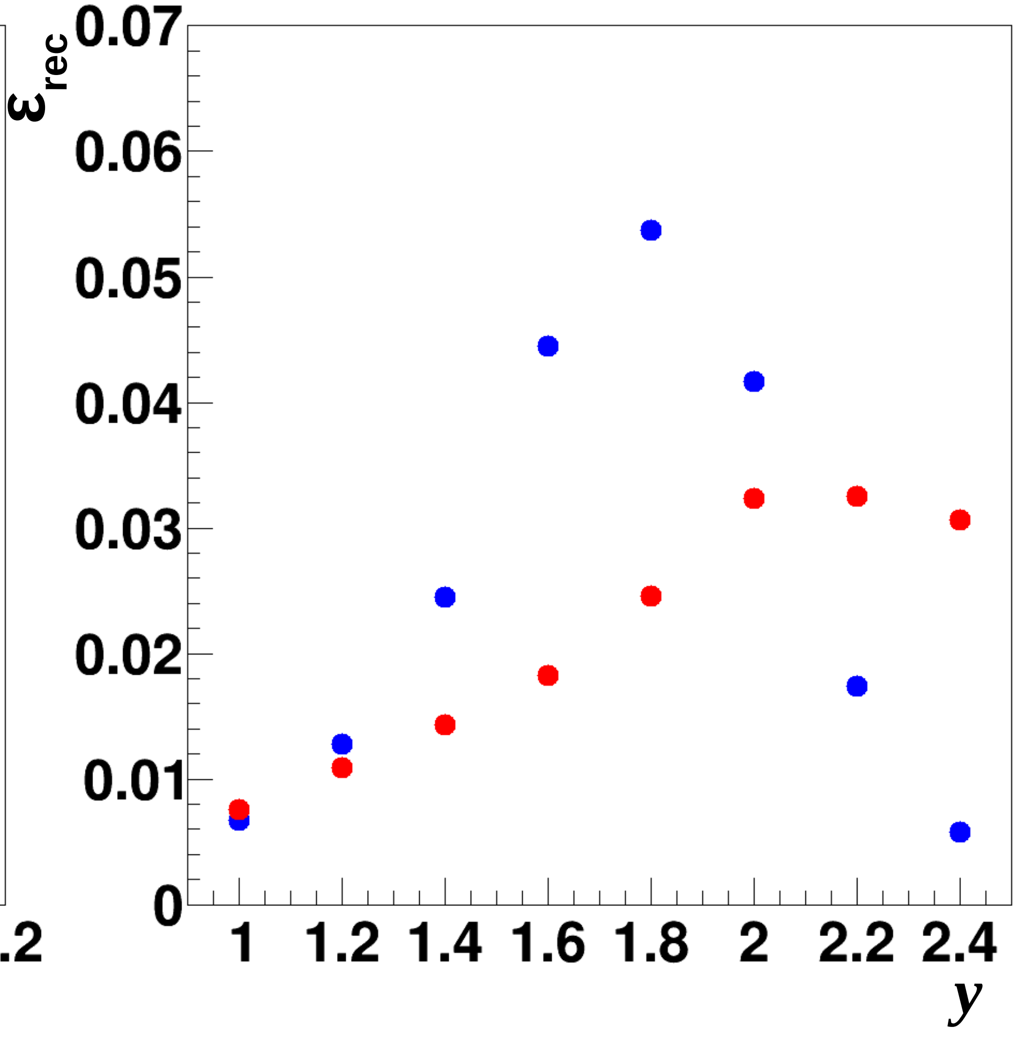


Selection Criteria for experimental data and MC

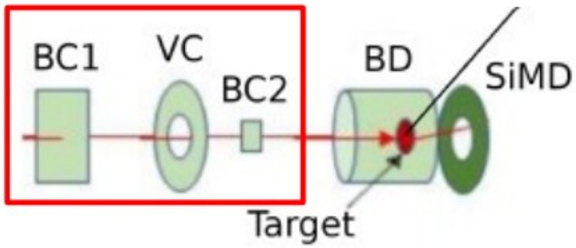
- ✔ Number of hits in 6 GEM per track > 3
- ✔ Tracks from PV: -3.4 < ZPV – Z0 < 1.7 cm
- ✔ Momentum range of tracks for ToF-400 (ToF-700):
- ✔ p > 0.5 (0.7) GeV/c
- ✔ Distance from a track to PV in the X-Y plane: dca< 1 cm
- ✔ Distance of extrapolated tracks to CSC (DCH) and ToF400 (ToF-700): |residX,Y| < 3 σ of hit-track residual distribution

Reconstruction Efficiency for protons for TOF400 and TOF700





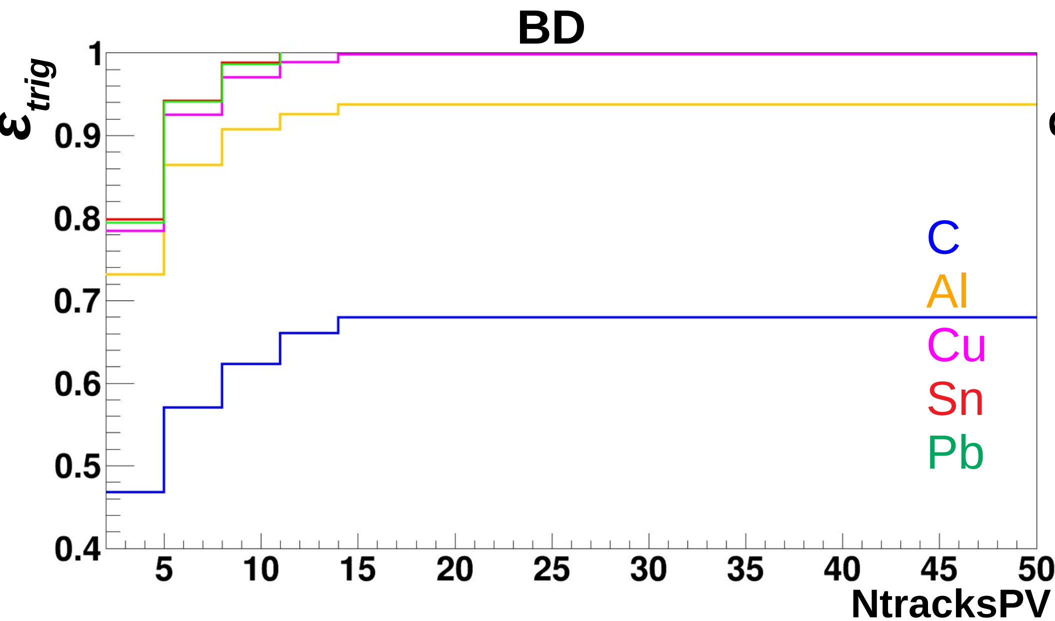
Trigger Efficiency

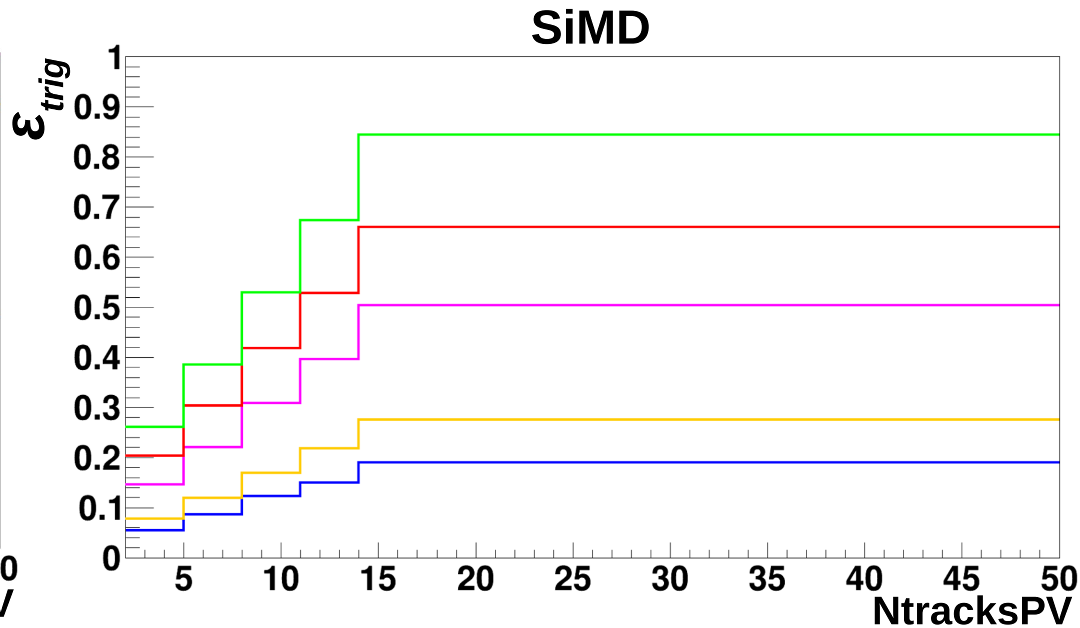


The efficiency to get a trigger signal based on multiplicities of fired channels in the BD (SiMD) detectors εtrig was calculated for events with reconstructed protons and deuterons using experimental event samples recorded with an independent trigger based on the SiMD(BD)detectors:

$$\varepsilon trig(BD \geq m) = N(BD \geq m, SiMD \geq n)/N(SiMD \geq n),$$

where **m** and **n** are the minimum number of fired channels in BD and SiMD varied in the range from 2 to 4. The dependences of the trigger efficiency on the track multiplicity in the primary event vertex and the X/Y vertex position were taken into account. The efficiency for the combined BD and SiMD triggers was calculated as a product of the BD and SiMD trigger efficiencies.





Cross sections and yields of protons and deuterons

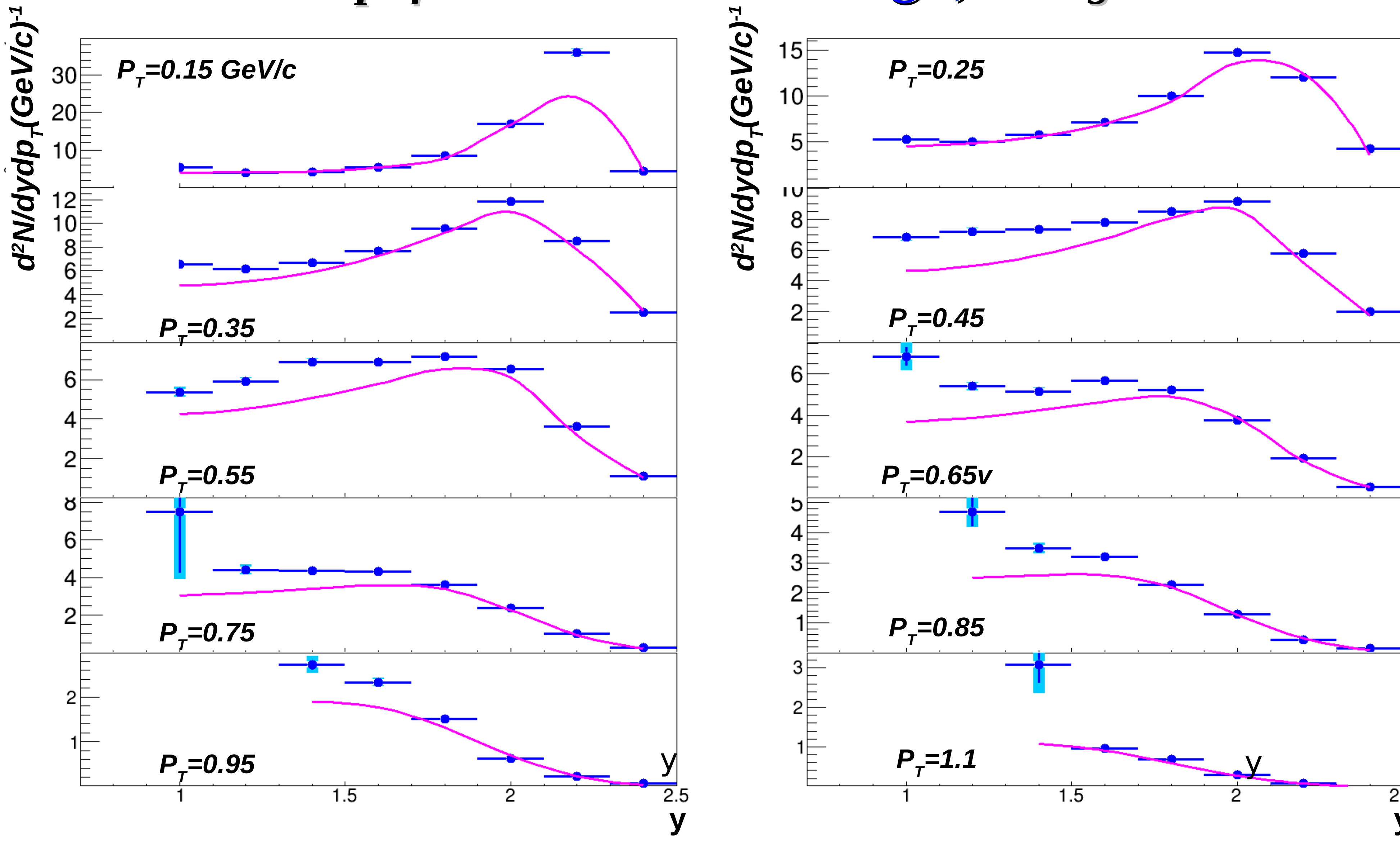
The differential cross sections **$d^2\sigma(y, pT)/dydp_T$** and yields **$d^2N(y, pT)/dydp_T$** of protons and deuterons production in Ar+C, Al, Cu, Sn, Pb interactions are calculated in bins of (y, pT) according to the formulae:

$$d^2\sigma(y,pT) / dydp_T = d^2n(y,p_T) / dydp_T / (\varepsilon rec(y,p_T) \cdot \varepsilon trig \cdot L)$$

$$d^2N(y,p_T) / dydp_T = d^2\sigma(y,pT) / dydp_T / \sigma inel$$

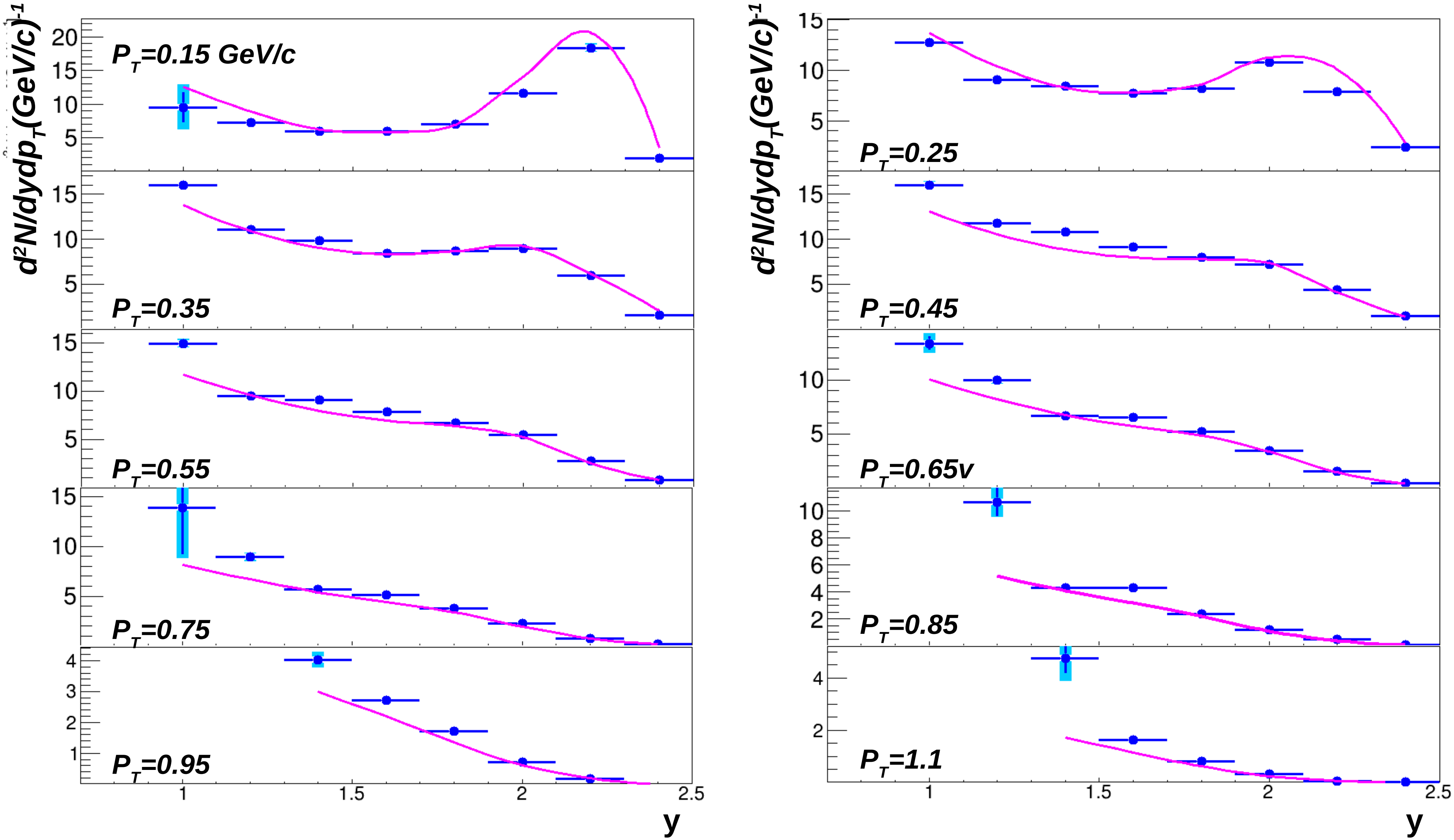
where **L** is the luminosity,
n – the number of reconstructed protons(deuterons) in intervals dy and dp_T ,
ε rec – the efficiency of the protons(deuterons) reconstruction,
ε trig– the trigger efficiency,
σinel– the cross section for minimum bias inelastic Ar+A interactions. The cross sections for inelastic Ar+C, Al, Cu, Sn, Pb interactions are taken from the predictions of the DCM-SMM model
The cross sections in (y, pT) bins are calculated as weighted averaged of the results obtained with ToF-400 and ToF-700 data taking into account the statistical uncertainties

Rapidity spectra for protons in different intervals on p_T for DCM-SMM and BM@N, Al target



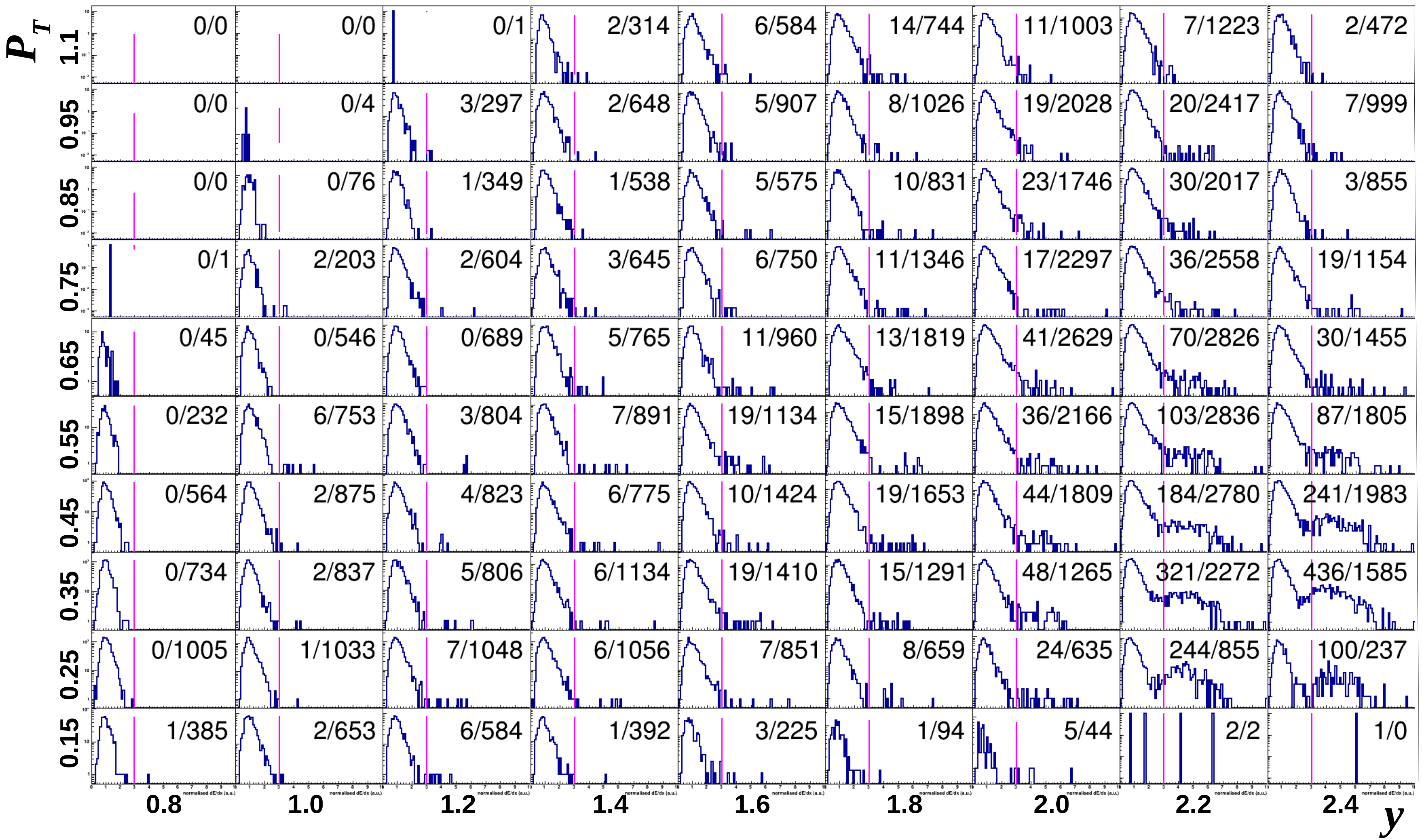
DCM-SMM reasonable describes the normalization and shape of the proton spectra

Rapidity spectra for protons in different intervals on p_T for DCM-SMM and BM@N, Pb target

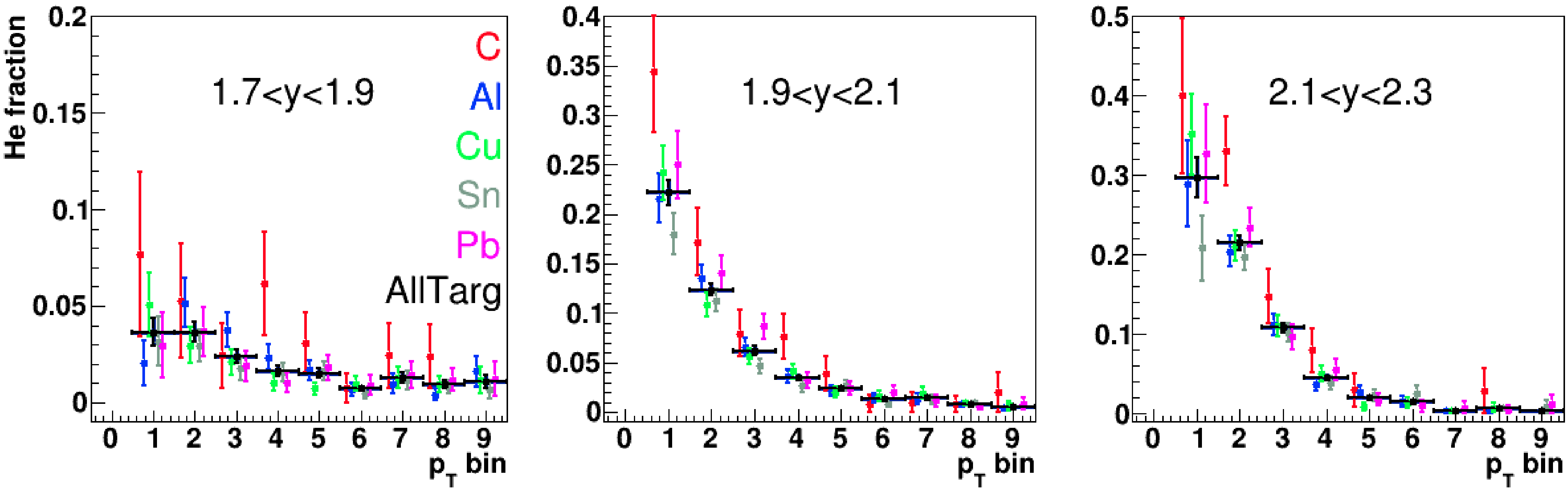


DCM-SMM reasonable describes the normalization and shape of the proton spectra

Determining helium⁴ to (deuterium+helium⁴) ratio using Dedx method in different intervals of transverse momentum and rapidity

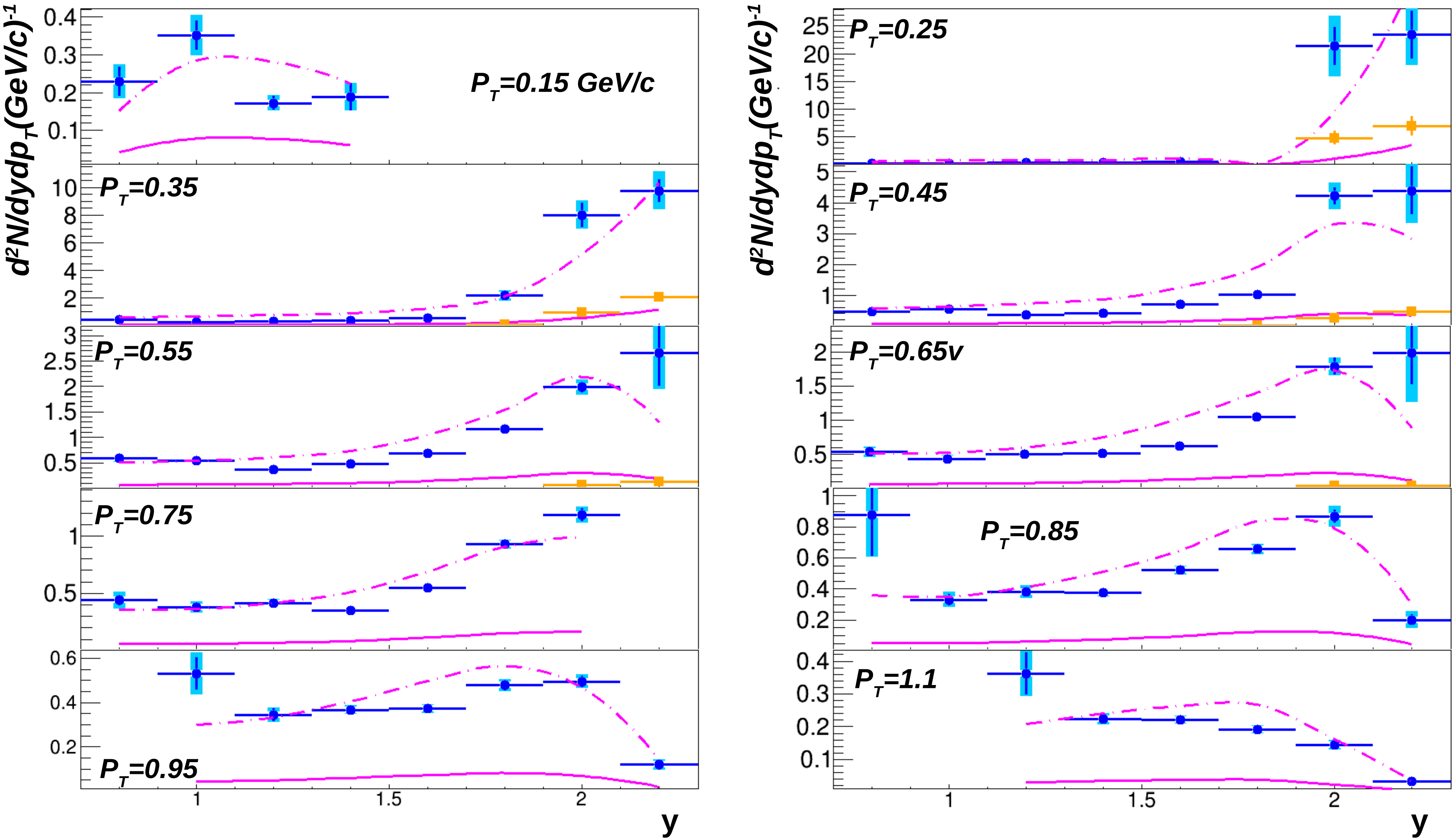


Measuring helium[4] to (deuterium+helium[4]) ratio in different intervals of p_T and rapidity for different targets



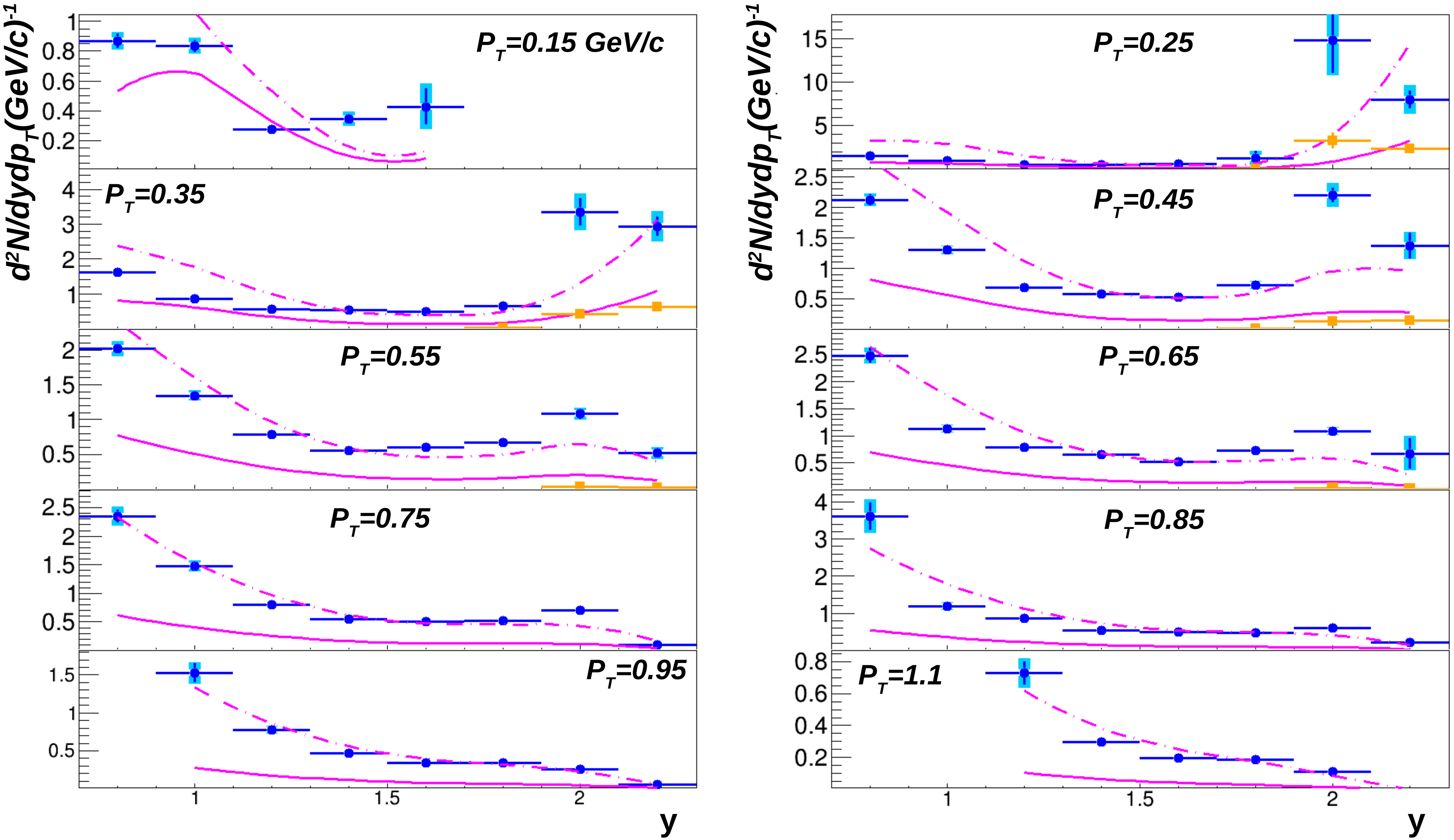
The histograms presented depict only those cases in which the helium content is above 2%

Rapidity spectra for deuterons/helium[4] in different intervals on p_T for DCM-SMM-original, DCM-SMM-normalized and BM@N, Al target



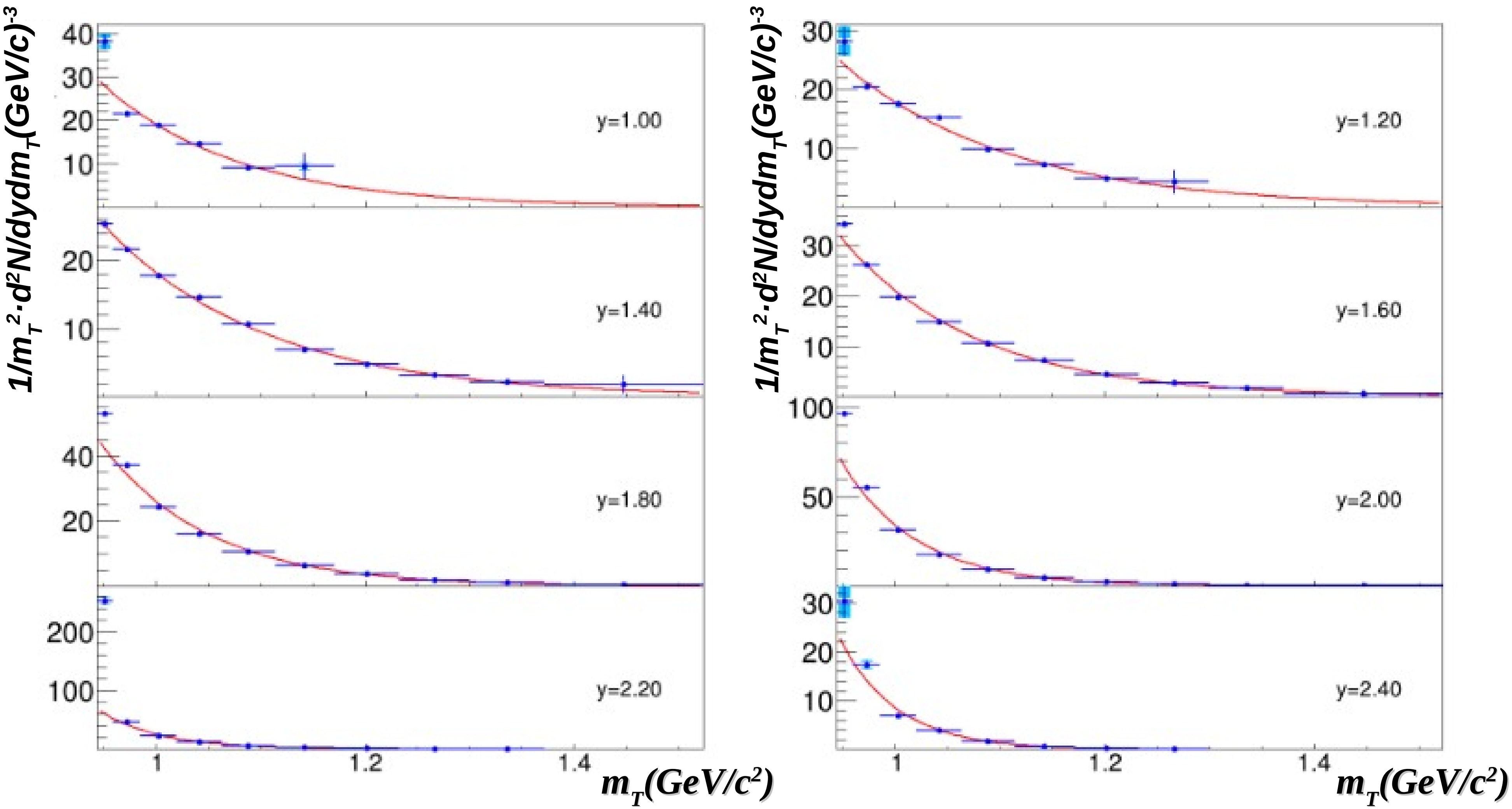
DCM-SMM reasonable describes the shape of the proton spectra (see normalized DCM-SMM), but underestimates much the noramlization of the deuteron and He4 yields

Rapidity spectra for deuterons/helium[4] in different intervals on p_T for DCM-SMM-original , DCM-SMM-normalized and BM@N, Pb target



DCM-SMM reasonable describes the shape of the proton spectra (see normalized DCM-SMM) , but underestimates much the noramlization of the deuteron and He4 yields

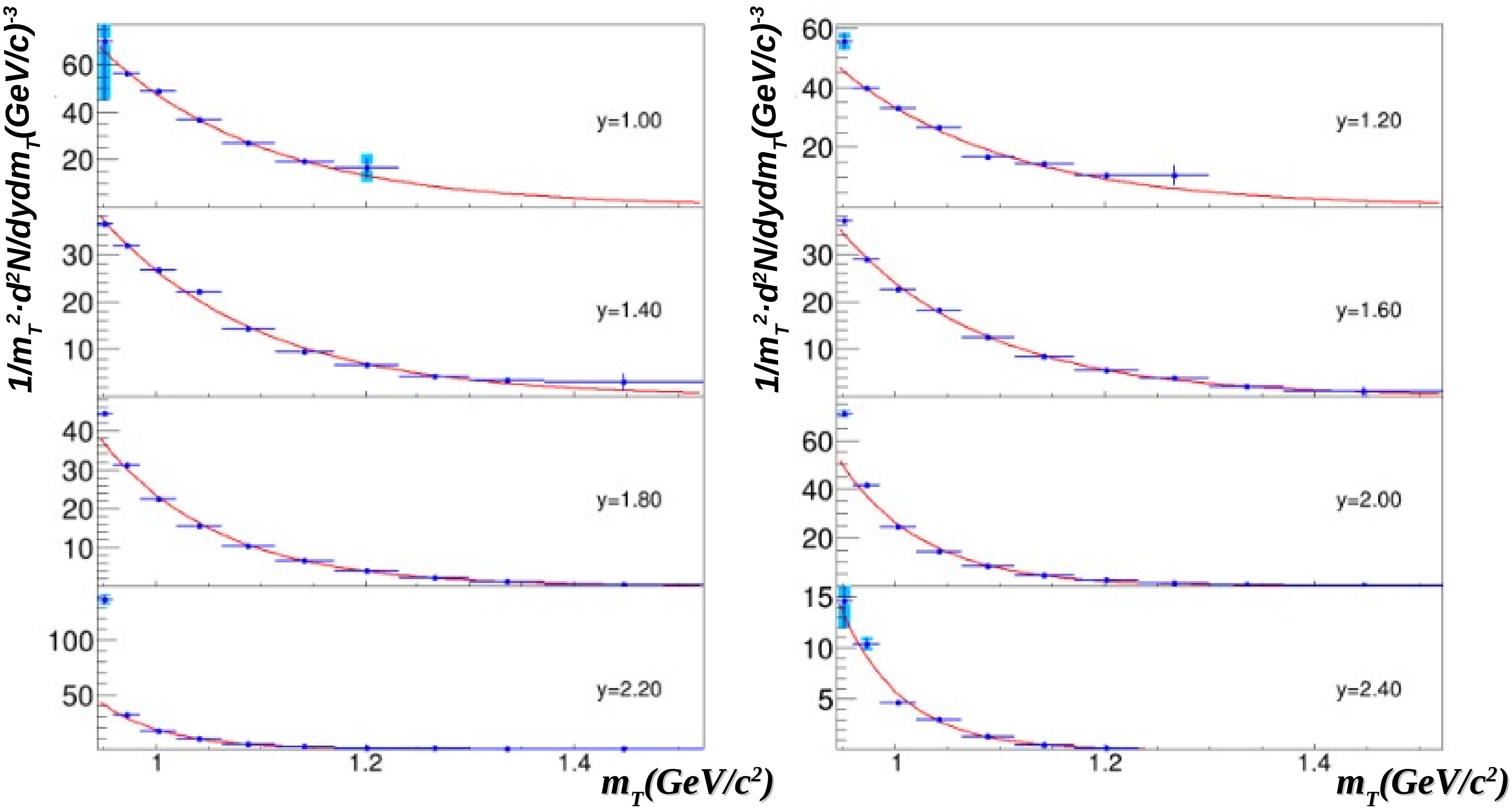
Transverse mass m_T spectra of protons in different intervals on rapidity for Al target



$$1/m_T^2 \cdot d^2N/dm_T dy = C \cdot \exp(-(m_T - m)/T_0)$$

where **m** is mass of proton $m_T = \sqrt{(m^2 + p_T^2)}$ is the transverse mass, **C** – normalization (free parameter), T_0 – inverse slope (free parameter) **dm_T** and **dy** corresponds to the measured m_T and ylab range

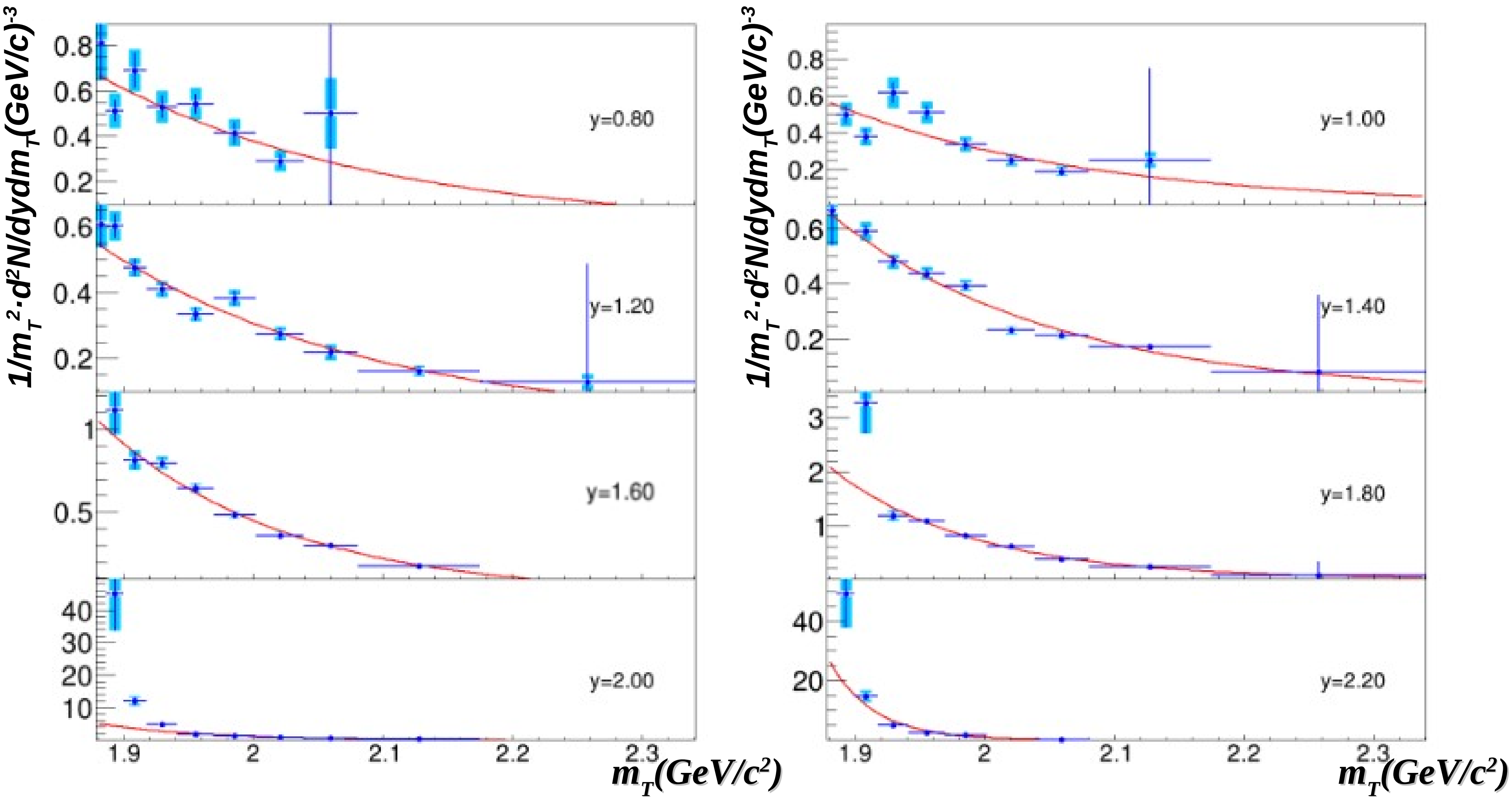
Transverse mass m_T spectra of protons in different intervals on rapidity for Pb target



$$1/m_T^2 \cdot d^2N/dm_T dy = C \cdot \exp(-(m_T - m)/T_0)$$

where **m** is mass of proton $m_T = \sqrt{(m^2 + p_T^2)}$ is the transverse mass, **C** – normalization (free parameter), T_0 – inverse slope (free parameter) **dm_T** and **dy** corresponds to the measured m_T and ylab range

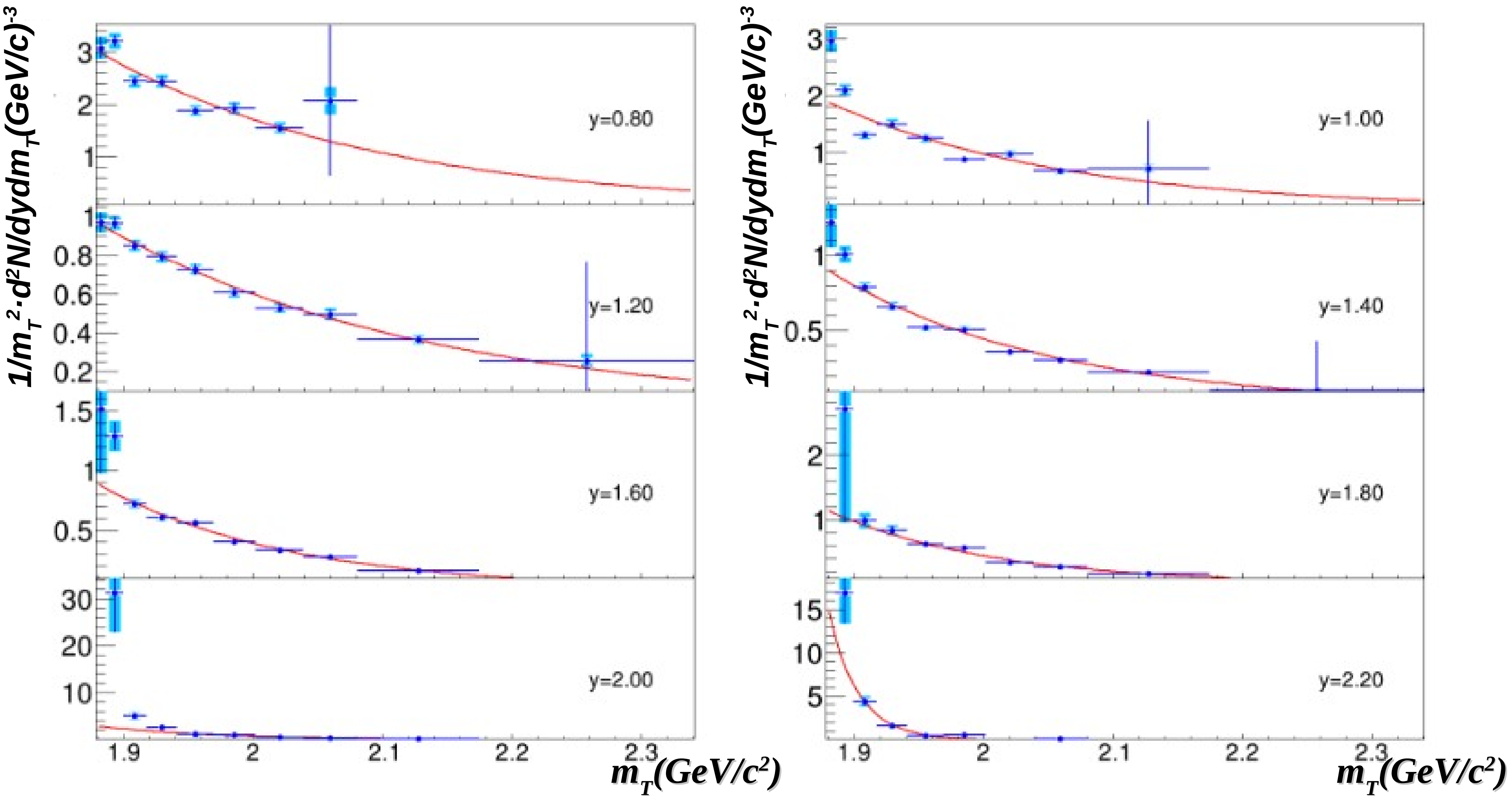
Transverse mass m_T spectra of deuterons in different intervals on rapidity for Al target



$$1/m_T^{2}\cdot d^2N/dm_T dy = C\cdot \exp(-(m_T - m)/T_0)$$

where **m** is mass of deuteron $m_T=\sqrt{(m^2+p_T^2)}$ is the transverse mass,**C** – normalization (free parameter), $\mathbf{T_0}$ – inverse slope (free parameter) $\mathbf{dm_T}$ and **dy** corresponds to the measured m_T and ylab range

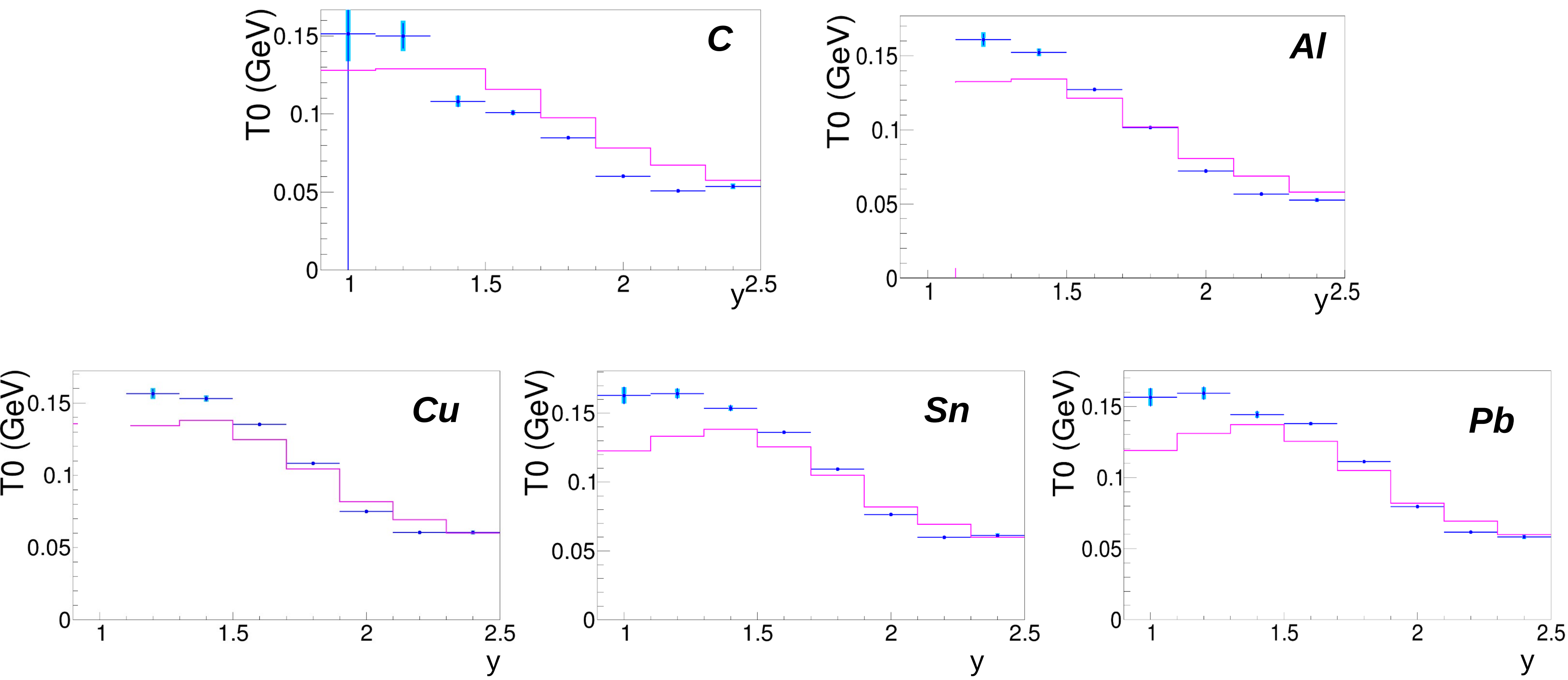
Transverse mass m_T spectra of deuterons in different intervals on rapidity for Pb target



$$1/m_T^{2} \cdot d^2N/dm_T dy = C \cdot \exp(-(m_T - m)/T_0)$$

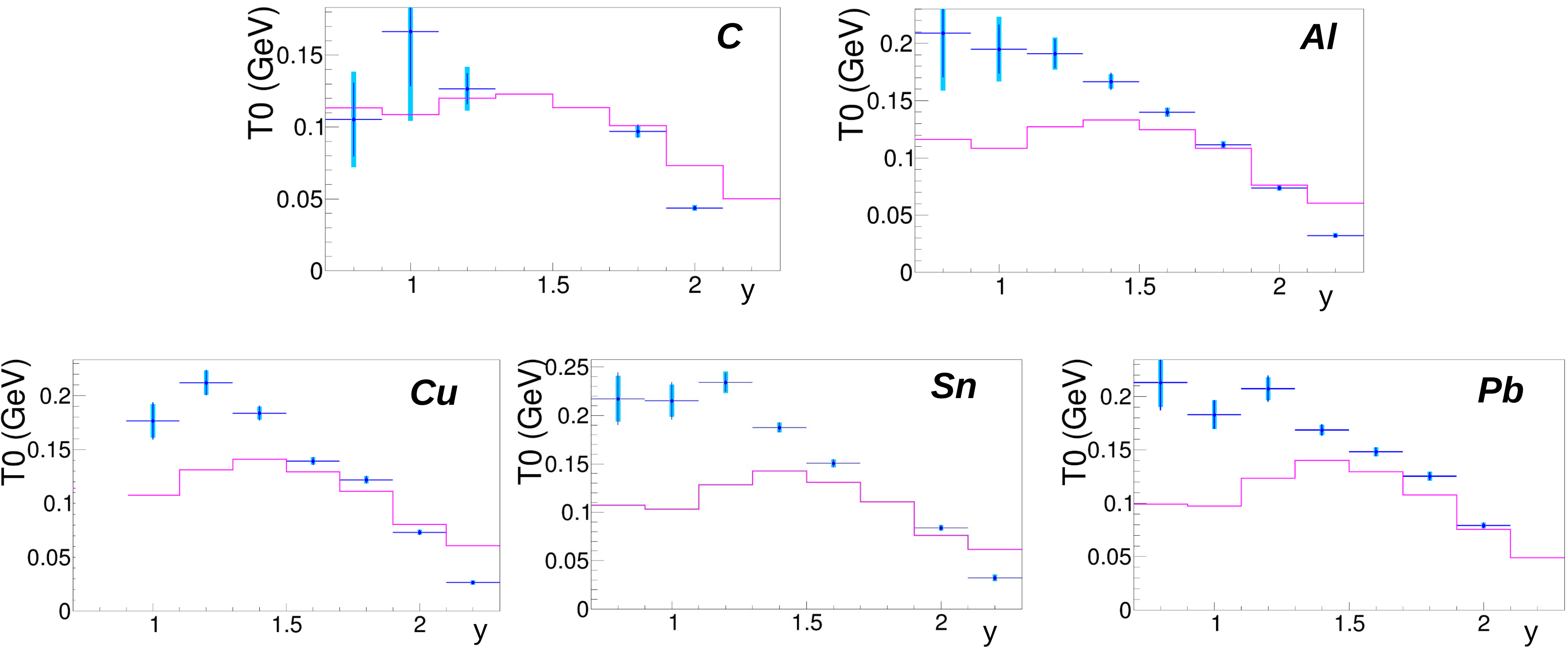
where **m** is mass of deuteron $m_T = \sqrt{(m^2 + p_T^2)}$ is the transverse mass, **C** – normalization (free parameter), $\mathbf{T_0}$ – inverse slope (free parameter) $\mathbf{dm_T}$ and **dy** corresponds to the measured m_T and ylab range

Rapidity dependence of the inverse slope T0 for protons for DCM-SMM and BM@N



DCM-SMM describes the inverse slope of protons in the forward rapidity range, but underestimates data in the central rapidity range (y_{CM}^{NN} ~ 1.08)

Rapidity dependence of the inverse slope T0 for deuterons for DCM-SMM and BM@N



DCM-SMM describes the inverse slope of deuterons in the forward rapidity range, but underestimates data by a factor 2 in the central rapidity range (y_{CM}^{NN} ~ 1.08)

Conclusions

Spectra of protons, deuterons and He^4 are measured in bins of rapidity and transverse momentum (transverse mass)

Inverse slopes are extracted from fits of the transverse mass spectra of protons and deuterons

Data are compared with predictions of the DCM-SMM model

He^3, He^4 and t spectra will be analyzed in details on the next step

Thank you for your attention !

BACKUP

Reconstruction Efficiency

Reconstruction efficiency	$\varepsilon rec = \varepsilon acc \cdot \varepsilon cuts$
protons(deuterons) geometrical acceptance in detectors	$\varepsilon acc = Nacc\ (y,pT) / Ngen\ (y,pT)$
Efficiency of reconstruction of protons(deuterons within the detector geometrical acceptance after applying kinematic and spatial cuts	$\varepsilon cuts = Ncuts(y,pT) / Nacc(y,pT)$

Event selection criteria

- ✓ Beam halo, pile-up suppression within the readout time window, number of signals in the start detector: BC1=1, number of signals in the beam counter: BC2=1, number of signals in the veto counter around the beam: Veto=0;

Trigger condition in the multiplicity detectors: number of signals BD≥m, m ∈ [2;4], SiMD≥n, n ∈ [2;4] and combinations of SiMD and BD triggers (run dependent).

Number of triggered events, beam fluxes and integrated luminosities collected for the argon beam of 3.2A GeV (*ToF-400* (*ToF-700*)).

Interactions (target thickness)	**Number of triggers / 10^6**	**Integrated beam flux / 10^7**	**Integrated luminosity / 10^{30} cm^{-2}**
Ar+C (2mm)	11.7 (11.3)	10.9 (8.7)	2.06 (1.97)
Ar+Al (3.33mm)	30.6 (29.2)	15.4 (10.2)	2.30 (2.05)
Ar+Cu (1.67mm)	30.9 (28.7)	15.9 (11.3)	1.79 (1.60)
Ar+Sn (2.57mm)	30.0 (25.9)	15.1 (9.5)	1.11 (0.91)
Ar+Pb (2.5mm)	13.7 (13.7)	7.0 (4.9)	0.50 (0.40)

Trigger Efficiency

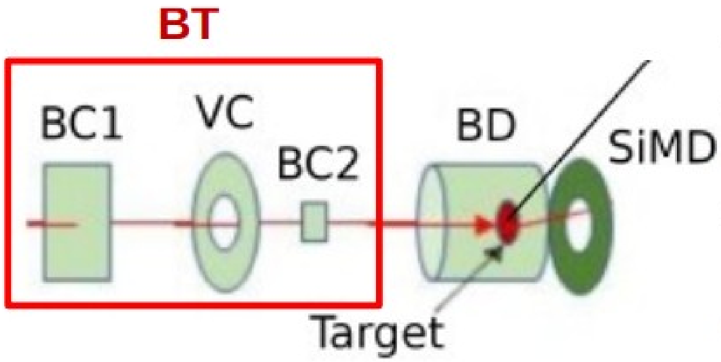
The following logic conditions were applied to generate the trigger signal: 1)BT$\otimes$(BD$\geq$m); 2) BT$\otimes$(SiMD$\geq$n); 3)BT$\otimes$(BD$\geq$2)$\otimes$(SiMD$\geq$3). The trigger conditions were varied to find the optimal ratio between the event rate and the trigger efficiency for each target. Condition 1 was applied for 60% of data collected with the carbon target. This trigger fraction was continuously reduced with the atomic weight of the target down to 26% for the Pb target. The fraction of data collected with trigger condition 2 was rising from 6% for the carbon target up to 34% for the Pb target. The rest of data were collected with trigger condition 3.

The systematic errors evaluated in the analysis cover the differences in the protons and deuterons signals obtained by using the mean values of the trigger efficiency values instead of the efficiency dependences on the number of vertex tracks and primary vertex position. The systematic errors also include the following checks made on limited statistics:

$$\varepsilon_{trig}(BD \geq m) = N(BD \geq m, BT)/N(BT),$$
$$\varepsilon_{trig}(SiMD \geq n) = N(SiMD \geq n, BT)/N(BT),$$
$$\varepsilon_{trig}(BD \geq m \,\&\, SiMD \geq n) = N(BD \geq m \,\&\, SiMD \geq n)/N(BT).$$

where runs with only BT in online trigger are used.

Differential cross sections



where L is the luminosity, $n_{\pi,K}$ is the number of reconstructed π^+ and K^+ mesons in intervals dy and dp_T, ε_{rec} is the efficiency of the π^+ and K^+ meson reconstruction, ε_{trig} is the multiplicity trigger (BD, SiMD) efficiency, ε_{BT} is the beam trigger efficiency, σ_{inel} is the cross section for the minimum bias inelastic argon-nucleus interactions.

$$d^2\sigma_{\pi,K}(y,p_T)/dydp_T = n_{\pi,K}(y,p_T)/(\varepsilon_{rec}(y,p_T)(\varepsilon_{trig}\varepsilon_{BT})(L/\varepsilon_{BT})dydp_T)=$$
$$=n_{\pi,K}(y,p_T)/(\varepsilon_{rec}(y,p_T)\varepsilon_{trig}Ldydp_T),$$

$$d^2N_{\pi,K}(y,p_T)/dydp_T = d^2\sigma_{\pi,K}(y,p_T)/(\sigma_{inel}dydp_T),$$

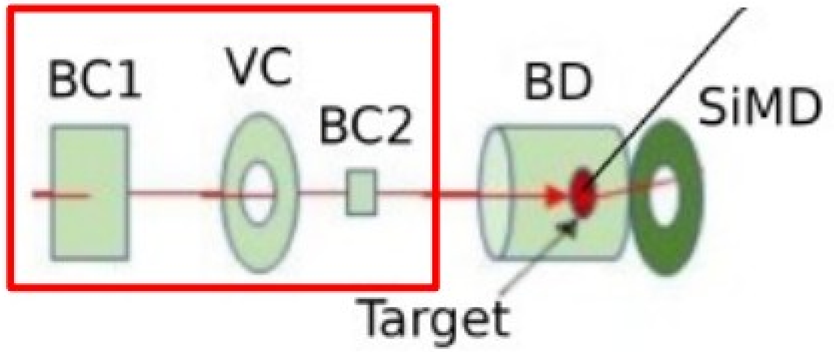
$$\varepsilon_{FullTrig}=\varepsilon_{trig}\varepsilon_{BT},\ L_{full}=L/\varepsilon_{BT},$$

ε_{BT} is cancelled in the numerator and denominator.

$\sigma_{inel} = \pi R_0^2 (A_P^{1/3} + A_T^{1/3})^2$, where R_0 = 1.2 fm is an effective nucleon radius, A_P and A_T are atomic numbers of the beam and target nucleus.

Interaction	*Ar+C*	*Ar+Al*	*Ar+Cu*	*Ar+Sn*	*Ar+Pb*
σ_{inel}, mb	1470±50	1860±50	2480±50	3140±50	3970±50

Luminosity and fluxes



$L = N_b \cdot N_A \cdot \rho \cdot l / A \cdot corr = N_b \cdot coeff$

- ✓ N_b – integrated ion flux through the target
- ✓ N_A – Avogadro number
- ✓ $\rho \cdot l$ – target thickness (g/cm²)
- ✓ A – target atomic weight
- ✓ corr = 0.865±0.02 – correction (see below)
- ✓ coeff – transformation coefficient

- ✓ To count the beam flux (N_b) we use BT
- ✓ BT = BC1⊗VC⊗BC2
- ✓ Beam halo, pile-up suppression within the readout time window, number of signals in the start detector: BC1=1, number of signals in the beam counter: BC2=1, number of signals in the veto counter around the beam: VC=0;
- ✓ Beam flux for active (not busy) time of DAQ was integrated spill by spill for each target (C, Al, Cu, Sn, Pb)

Systematic errors

The systematic error of the protons and deuterons yields in every pT and y bin is calculated as a root square of quadratic sum of uncertainties coming from the following sources:

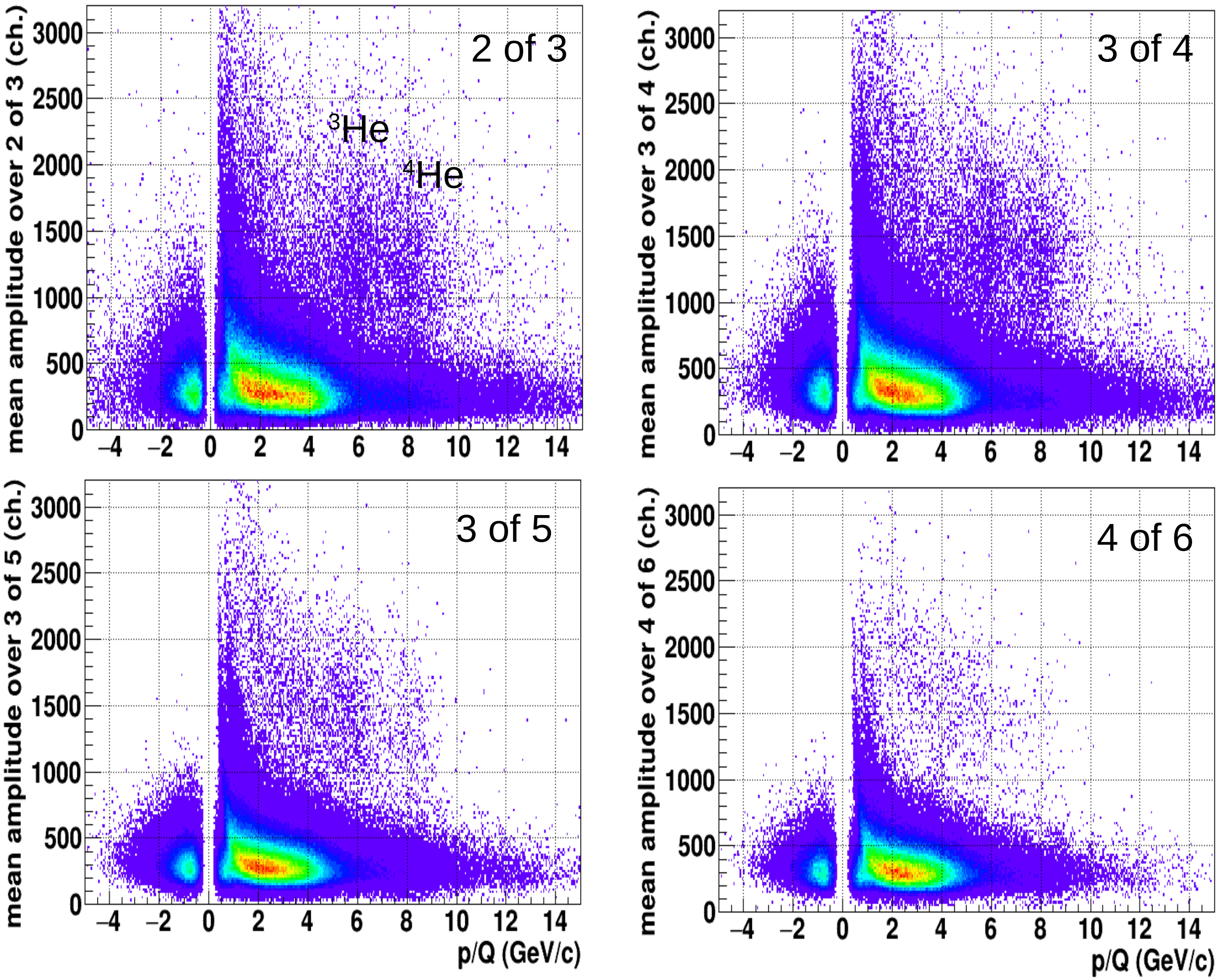
Sys1: systematic errors of the reconstruction efficiency due to the remaining difference in the X/Y primary vertex distribution in the simulation relative to the experimental data.

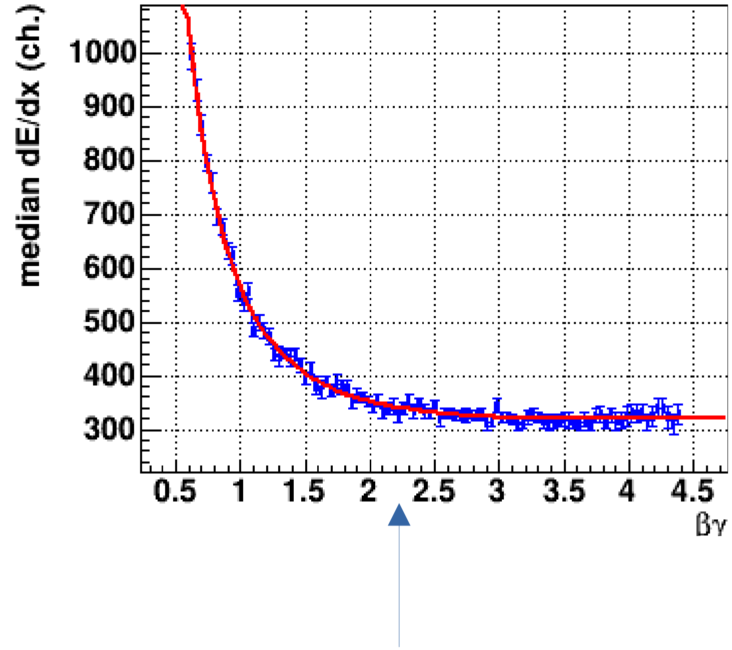
Sys2: systematic errors of the background subtraction under the protons and deuterons signals in the mass squared spectra of identified particles.

Sys3: systematic error of the trigger efficiency evaluated as a function of the number of tracks from the primary vertex and the X/Y primary vertex position

The protons and deuterons yield normalization uncertainties are calculated for the whole measured (y, pT) range as a quadratic sum of the statistical uncertainty of the trigger efficiency, uncertainties of the tracking detector efficiency, efficiency of the track matching to the CSC (DCH) outer detectors and to ToF-400 (ToF-700), uncertainties of the luminosity and inelastic nucleus-nucleus cross section

Truncated mean dE/dx for 3, 4, 5 and 6 hits tracks

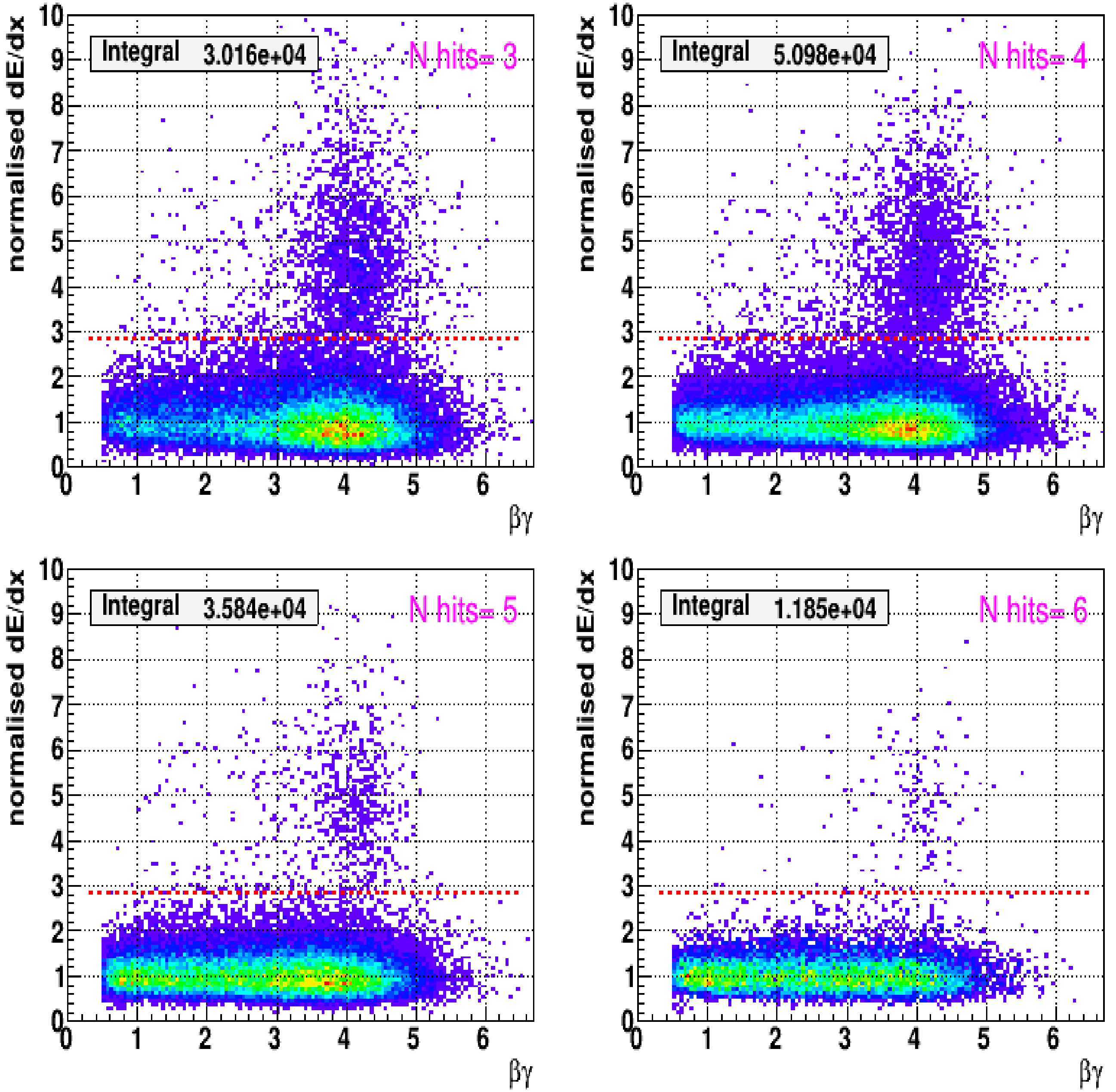




Slices in energy loss in βγ - distributions are fit and the the median value from the fit is used for normalisation

deff = sqrt[eff*(1-eff)/N(denominator)], where eff = N(numerator)/N(denominator
this is the formula obtained from the variance of the binomial distribution

Normalised dE/dx for d/^{4}He tracks (TOF-700 2.5 < m^2 < 4.5 $(GeV/c^2)^2$)



Using βγ allows us to analyze energy losses independently of particle type
Unit of dE/dx is a median value for deuterons.