Measurements of the Invariant Cross Sections for Forward Production of the Secondary Light Nuclei in CC-collisions at Beam Energy 20.5 GeV/n on the Accelerator U-70 IHEP.

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Abstract

M.Yu. Bogolyubsky, A.A. Volkov, D.K. Elumakhov, A.A. Ivanilov, A.Yu. Kalinin, A.N. Krinitsyn, V.I. Kryshkin, N.V. Kulagin, D.I. Patalakha, K.A. Romanishin, V.V. Skvortsov, V.V. Talov, L.K. Turchanovich,

"Measurements of the Invariant Cross Sections for Forward Production of the Secondary Light Nuclei in CC-collisions at Beam Energy 20.5 GeV/n on the Accelerator U-70 IHEP".

The mesurements of the invarinat cross sections for forward production of the secondary light nuclei in CC-collisions at beam energy 20.5 GeV/n have been made on the accelerator U-70 (National Research Center Kurchatov Institute - Institute for High Energy Physics, Protvino, Moscow region, Russia) with employing the beamline no. 22 together the detectors of the FODS setup as spectrometer with verying beam line rigidity from 7 to 70 GeV/c. In the experiment observation of secondary light nuclei with momenta above kinematic limit of NN-interactions have been obtained. Recalculations of the observed yields of particles to the invariant cross section were performed with detailed simulation for propagation of particles and nuclei through the beam line no. 22 and the FODS detectors in the framework of Geant4. This approach allows to estimate both the angular aperture of the experiment and the loss of particles and nuclear fragments due to its decays and interactions in the material of the setup. A wide class of theoretical models introduced in Geant4 (like QGSP-FTFP-BERT-EMV) allows one to compare their predictions related to invariant cross section directly with experimental results and select models that are more appropriate to reality with possibility of refinement and adjustment of the model parameters.

Introduction

Recently U-70 provided ^{12}C beam. It opens new possibilities in study CA-scattering.

The aim of this experiment is to mesure production at angle 0 charged particles and nuclear fragments. For this the combined spectrometer for 2ry particles is used consisting of beam line no. 22 and detectors of the modified setup FODS (with varying beam line rigidity from 7 to 70 GeV).

Sumulation for beam-line 22: M.Yu.Bogolyubsky, «Selection and Transportation of Light High-energy Nuclei by Beamline 22 of the U-70 Accselerator: The Monte Carlo Simulation», Instruments and Experimental Techniques, 2014, vol. 57, pp. 519-530

1st results demonstrated that the experiment is successfully launched: M.Yu. Bogolyubsky et al. «Forward Particle Production in Proton-Nucleus Interactions at momenta 25 and 50 GeV/c and Proton-Nucleus Interactions at Energy 25 GeV/n», Phisics of Atomoc Nuclei, 2017, Vol. 80., No. 3, pp. 455-460; ISNN 1083-7788.

In this work we transfer from yelds of prticles to invarint cross section. This is more usefull for comparison with predictions of theoretical models. Such transfer was made on the base detailed simulation for passing of particles and nuclei through used combined spectrometer to define acceptance in framework of Geant4 (version 10.4.p02).

The FODS setup

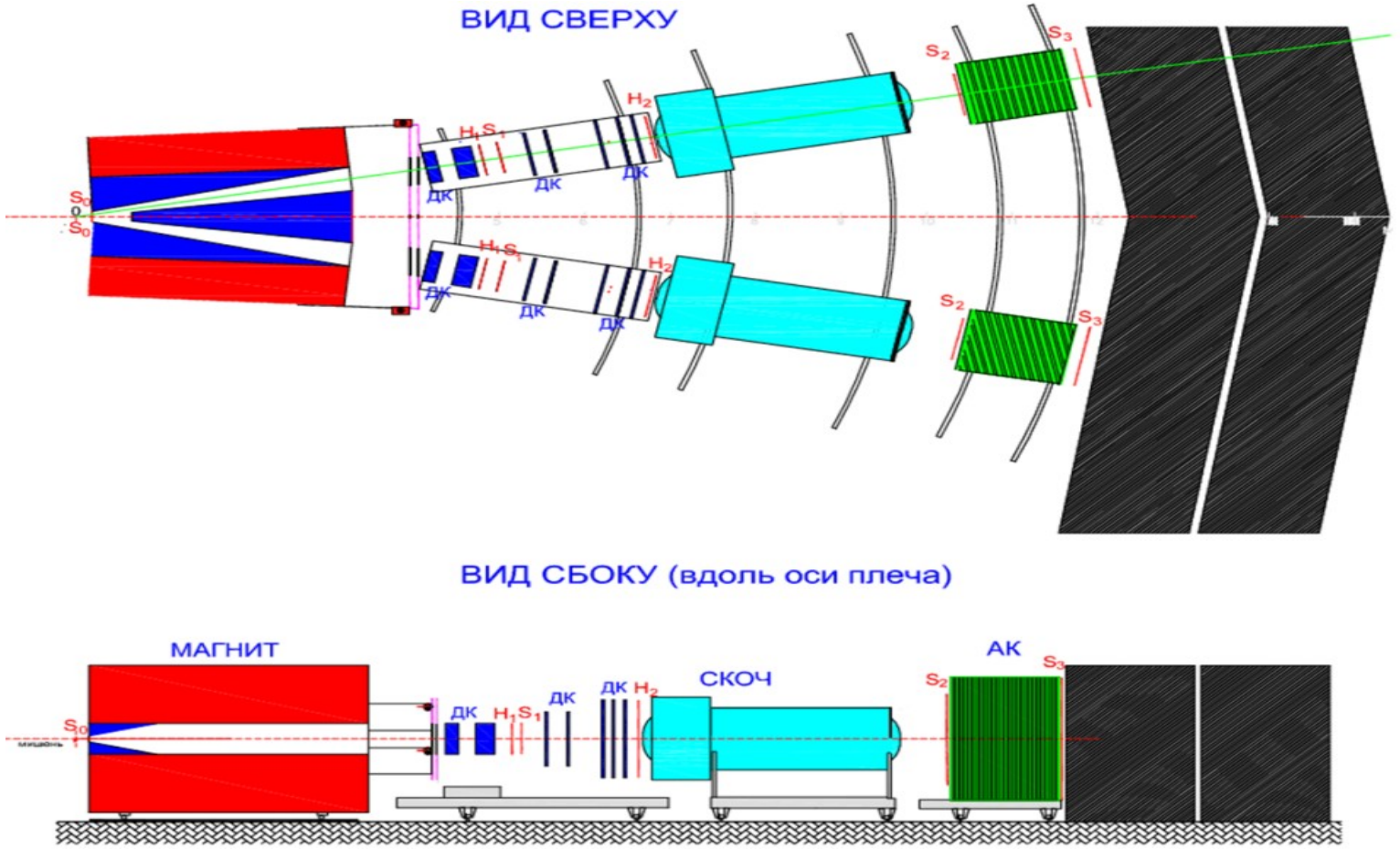


Fig. 1. The FODS setup: Notations: МАГНИТ — magnet, Si - scintillating counters, ДК - drift chambers and drift tubes, Hi - hodoskopes, СКОЧ - ring image cherenkov counters, АК - hadron calorimeters. The arms can be rotated with center of rotation in point O. In our measurements one of arms (South) was ajusted on angle 0 relatively to the beam propagation.

Experimental setup

Beam: ^{12}C, 20 A GeV.

Beam extraction:

Stochastic slow extraction (10^9 per spill)

Extraction with bent crystal (10^7 per spill)

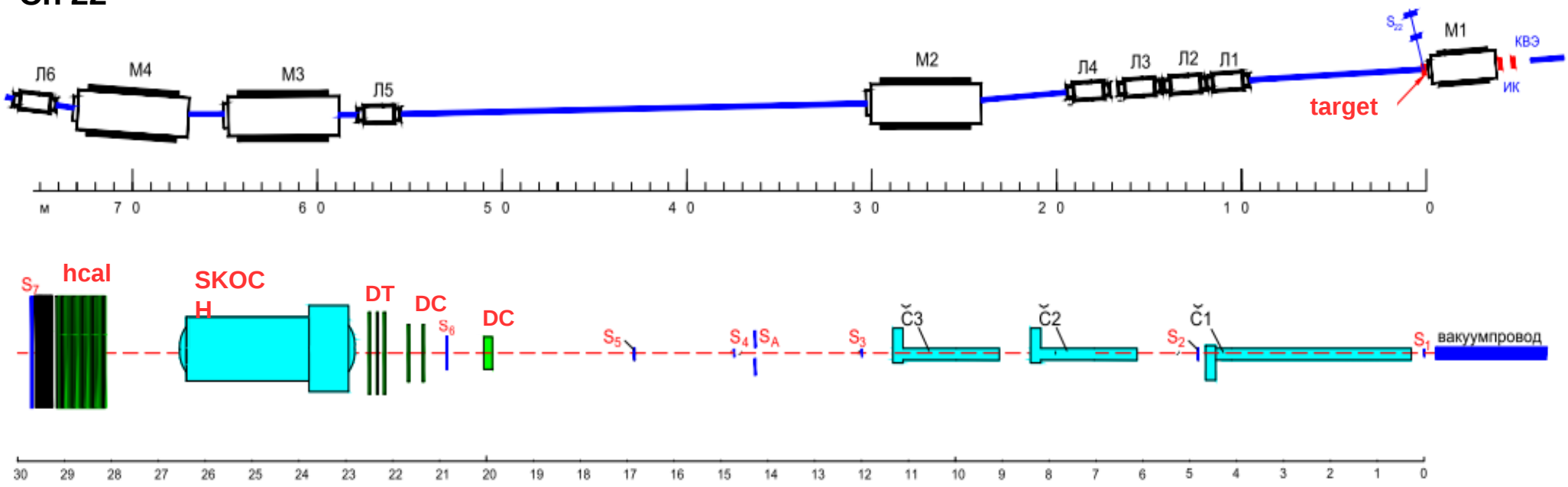
Targets: Carbon, Lead (~1.8 cm length) and empty target.

Total length of the setup ~120m.

Angular acceptance: ~6 mrad.

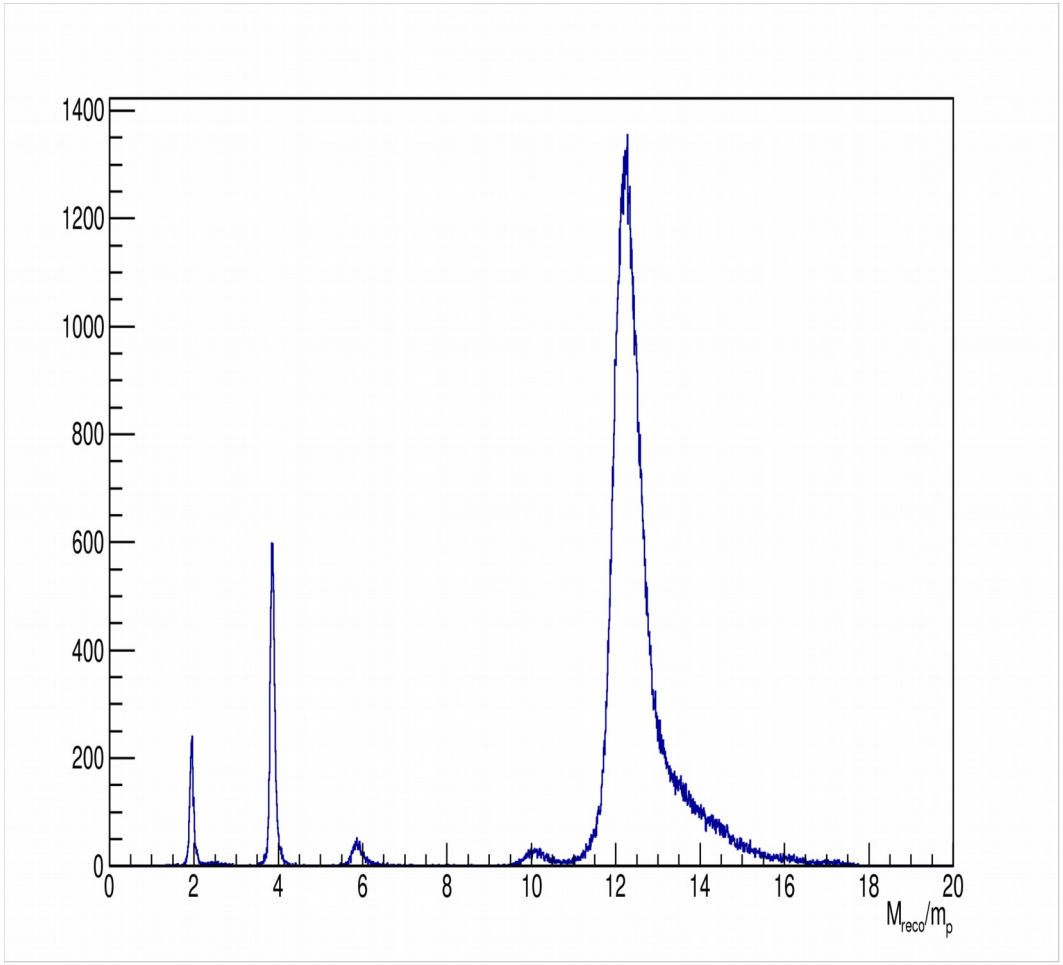
Beam direction

Ch 22



S_i-scintillator counters, $\check{C}_i$- Cherenkov counters, SCOCH – RICH detector, hadron calorimeter, DT – drift tubes, DC – drift chambers.

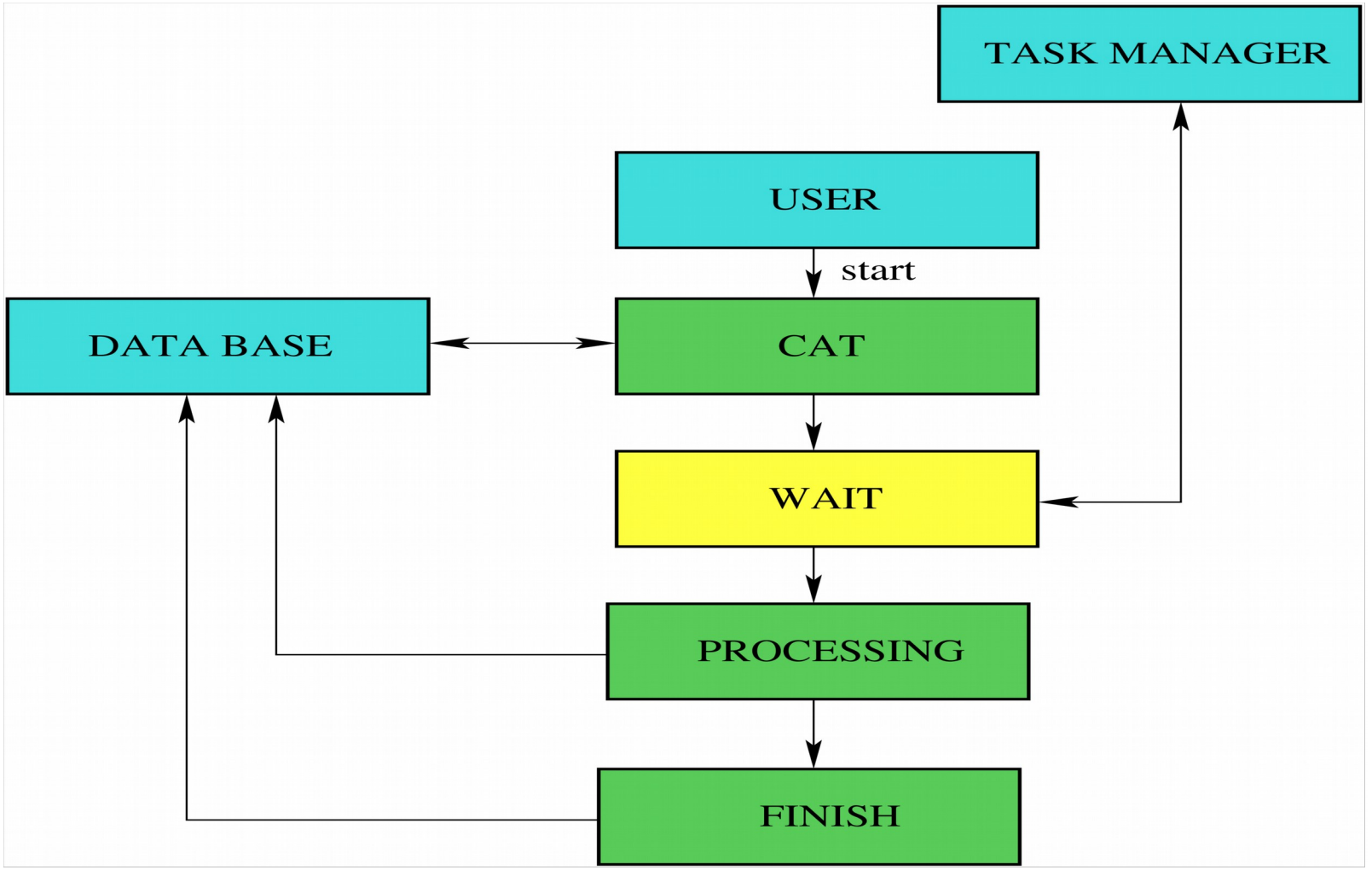
Mass reconstruction in SCOCH



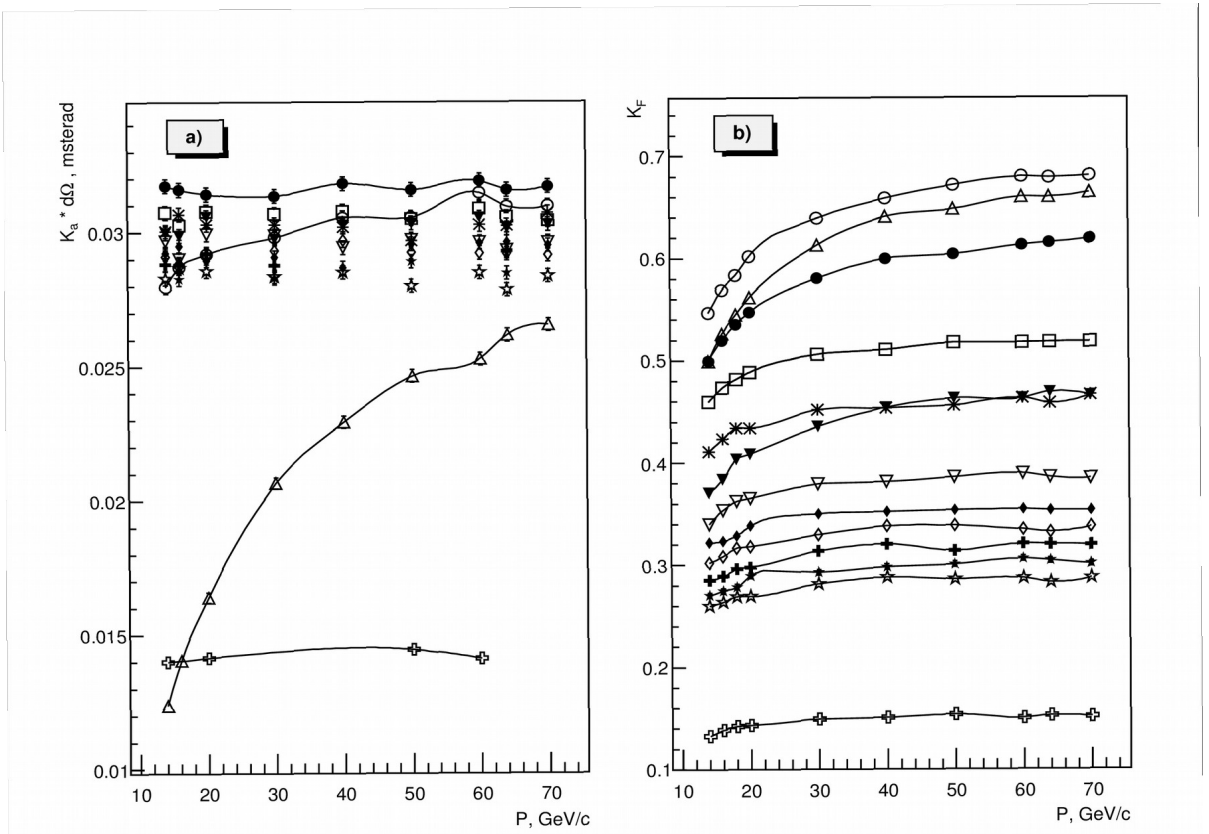
P=41 GeV/c, empty target
Beam extraction with bent crystal

Determination acceptance dΩ and attenuation coefficients Ka (beam line 22), Kf (FODS setup) by Monte-Carlo simulation in Geant4 v. 10.02.p02

Organization of mass calculations on computer cluster IHEP, up to 3000 parallel jobs



Determination acceptance dΩ and attenuation coefficients Ka , Kf by Monte-Carlo sumulation in Geant4

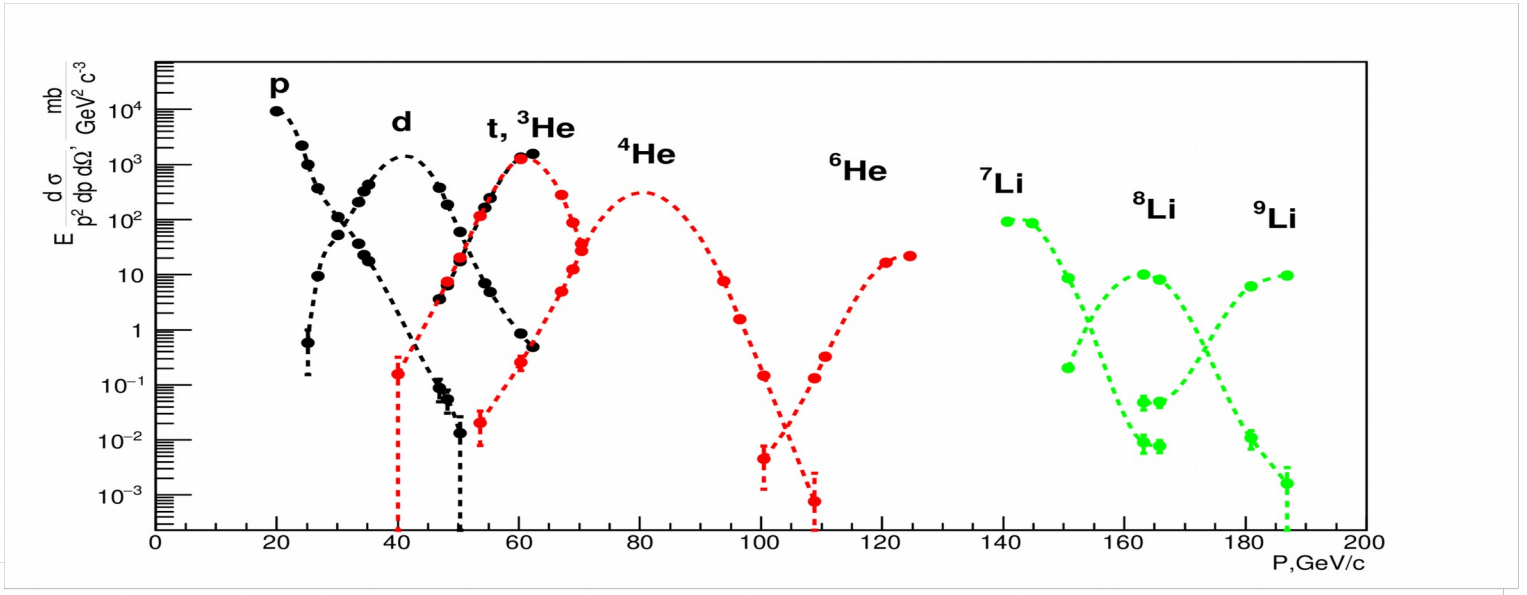


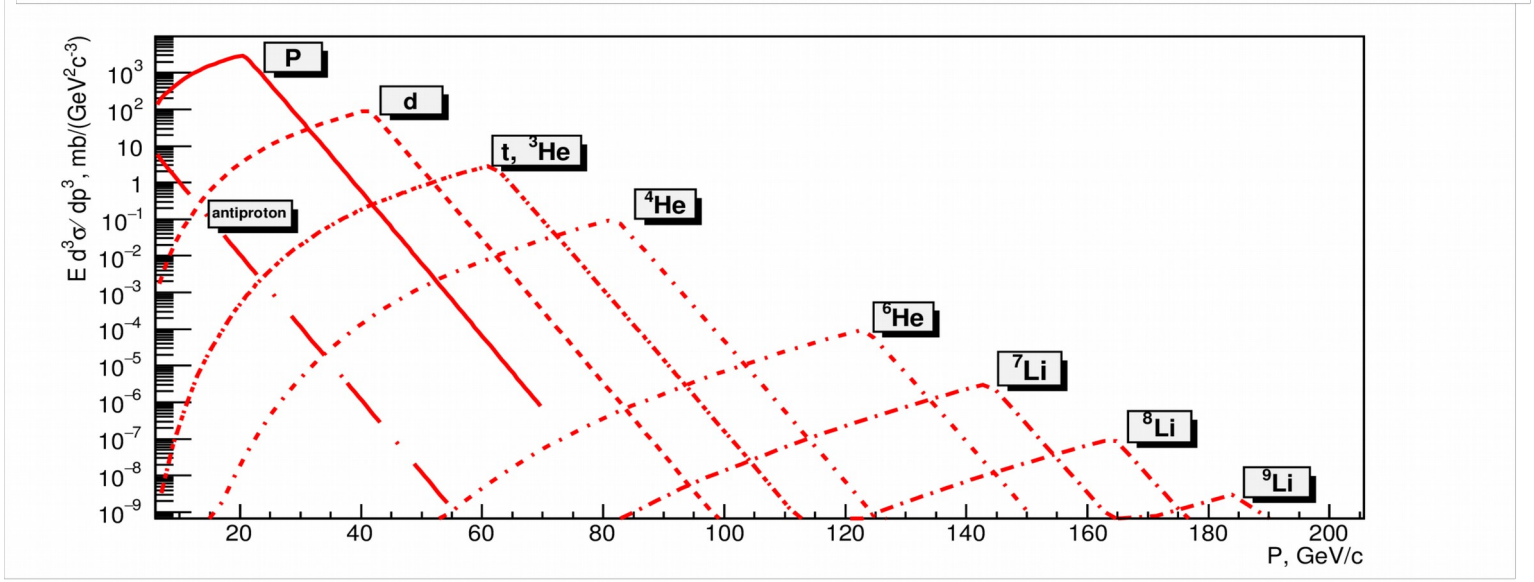
The dependences: a) - Ka *dΩ and b) - KF in CC interactions on beam-line rigidity P for positive particles and nuclear fragments, transport code is - QGSP-FTFP-BERT-EMV, notations: white points - π+ mesons, white triangles - K+ mesons, black points - protons, white squares - deuterons, black triangle (inverted) - Triton and He3, the six-pointed star - He4, white triangle (inverted) - He6, black diamond - Li6, white diamond - Li7, black cross - Li8, white cross - Li9, black five-pointed star - B10, light five-pointed star - C12, solid lines - spline between computed points, a) - contains for simplicity splines only for protons, π+, K+ mesons and Li9.

Light nuclei: Finv(P) cross-section of forward production (experimemt - top) in comparison with Stavinsky formula (down)

P — momentum of inclusive particle GeV/c

Fugure shows strong population in regions kinematically forbidden by NN-interaction above P1=20.5*A

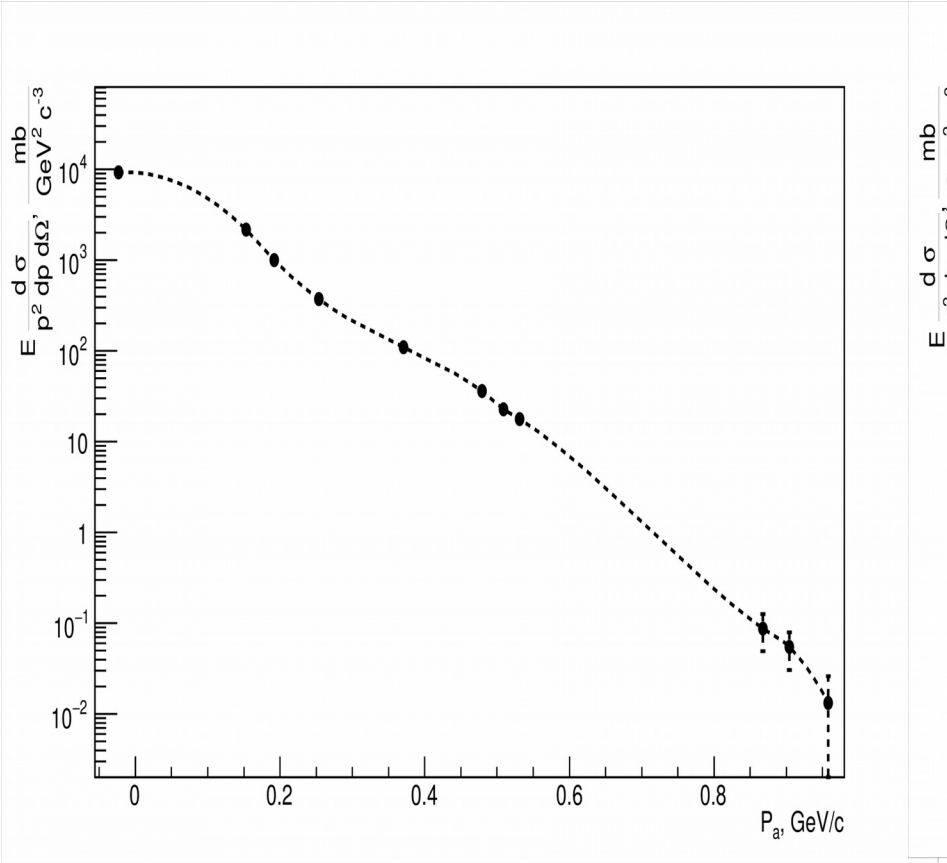


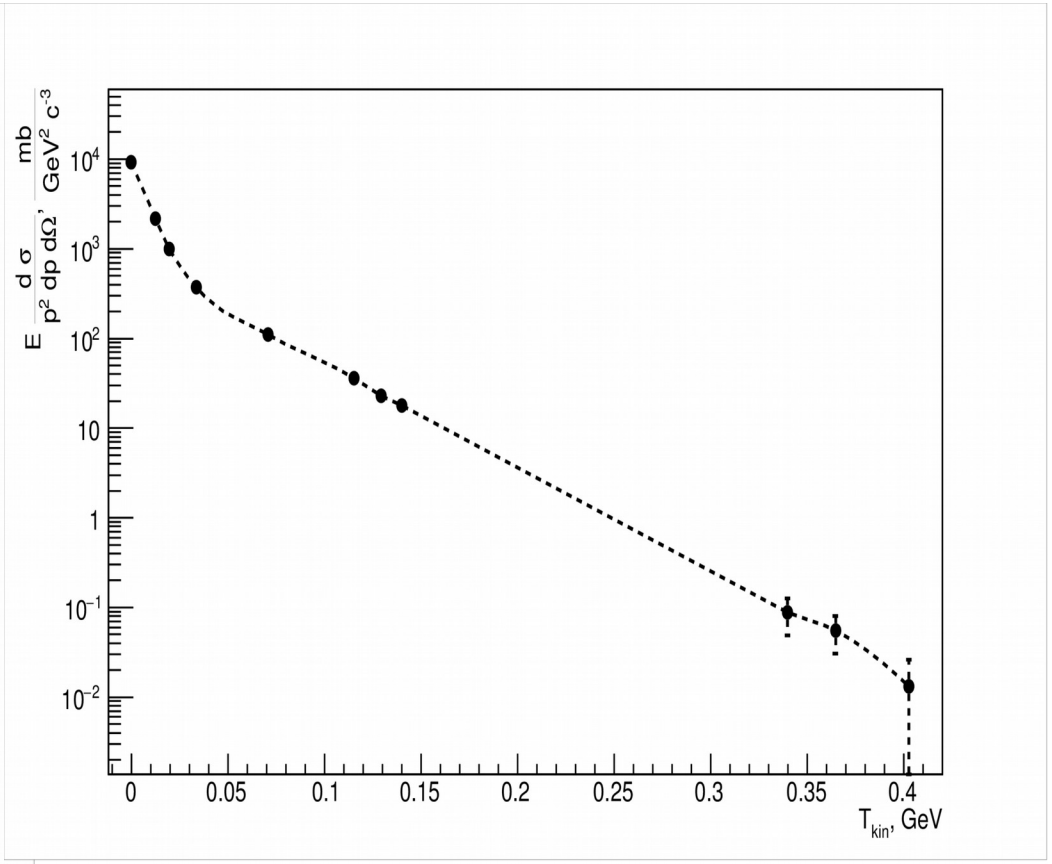


Protons: Finv cross-section for forward production in antilab. sys.

P — momentum of proton in antilab. sys,

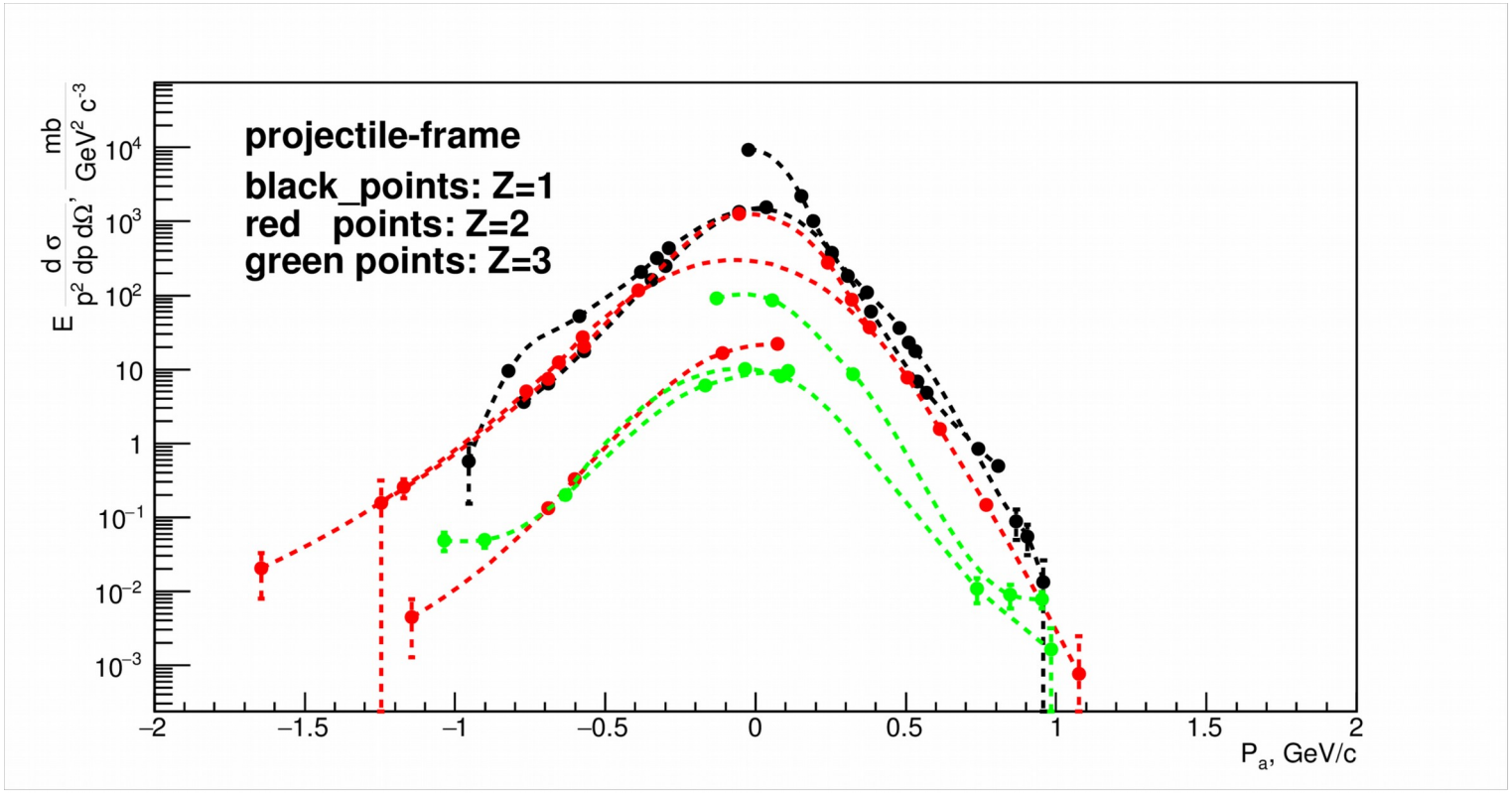
Tkin — kinetic energy of proton in antilab. sys.





Light nuclei: Finv cross-section for forward production in antilab. sys.

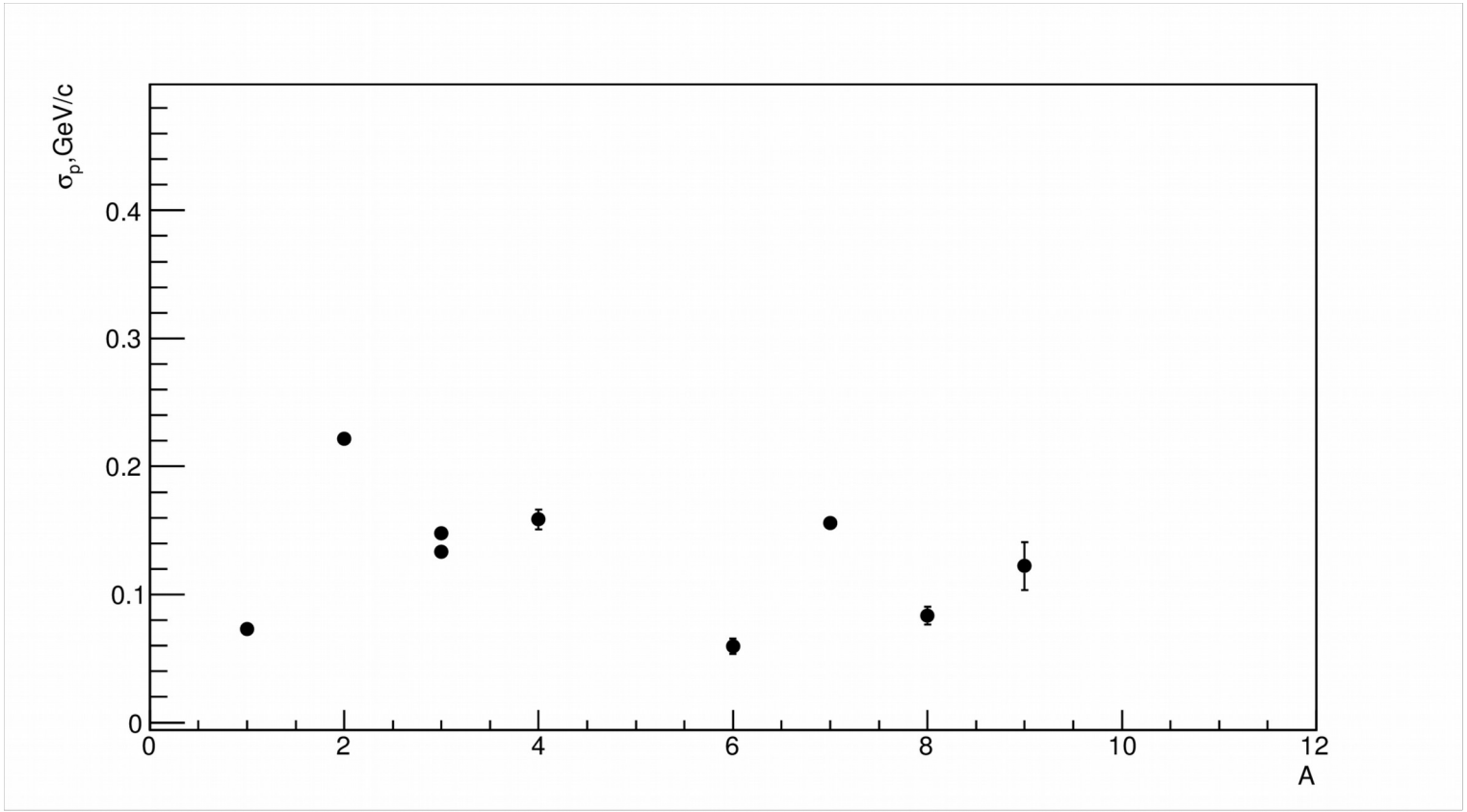
(P — momentum of inlusive particle in antilab. sys)



Dependence of σ_p on A

obtained by gauss approximation of Finv cross-section

in antilab-system



Summary

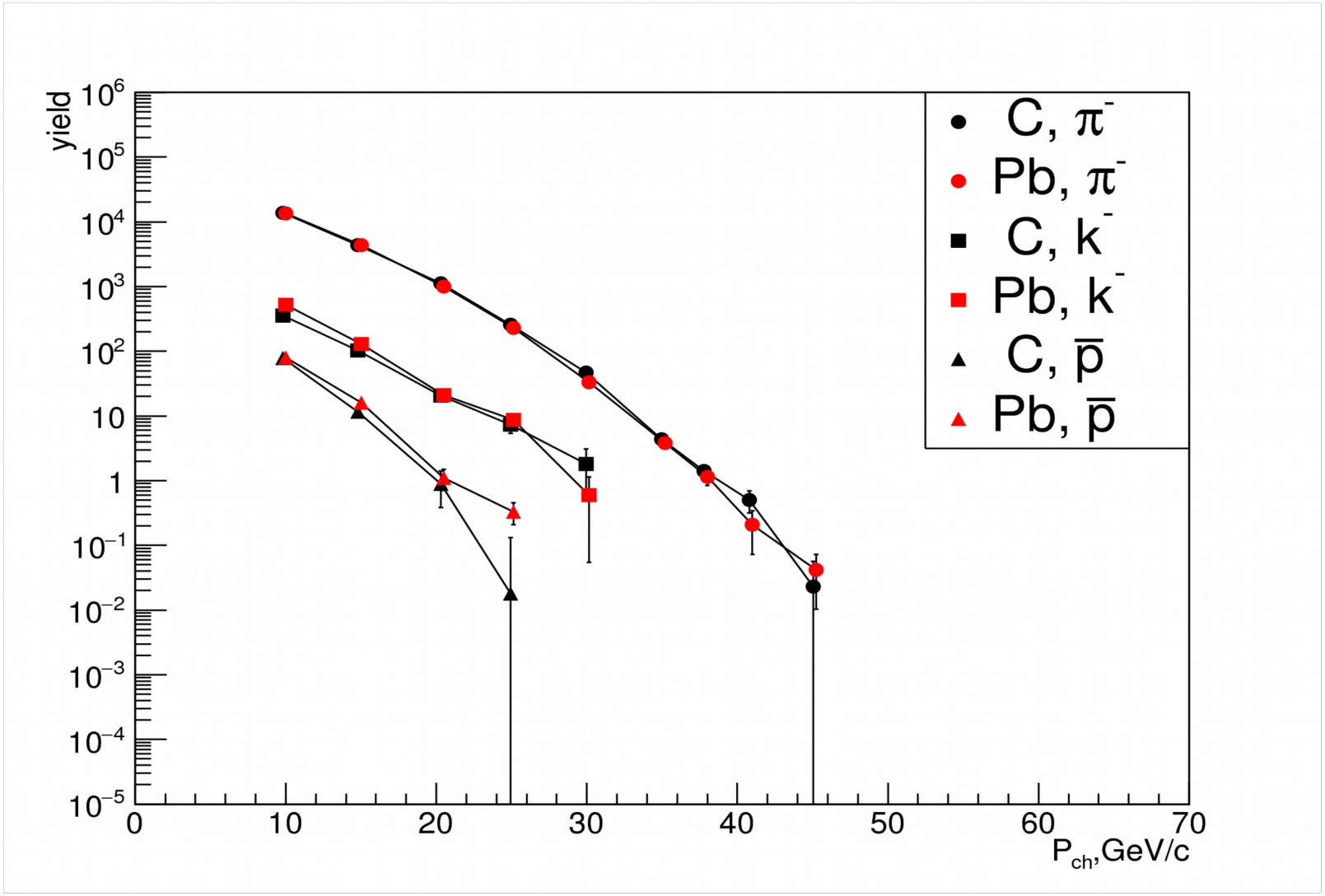
Preliminary results for the invariant cross sections of light nuclei fragments produced at zero angle in the carbon-carbon interactions with energy of 20 A GeV/c are presented.

Essential dicripancy with Stavinsky formula based on scailing variable Smin — minimal squared energy of colliding constituents to produce observed particle in framework of nuclear scaling hypothesis is observed. It may point out on need to subtract from scailing variable mass of inlusive particle and/or add new parametee in this formula.

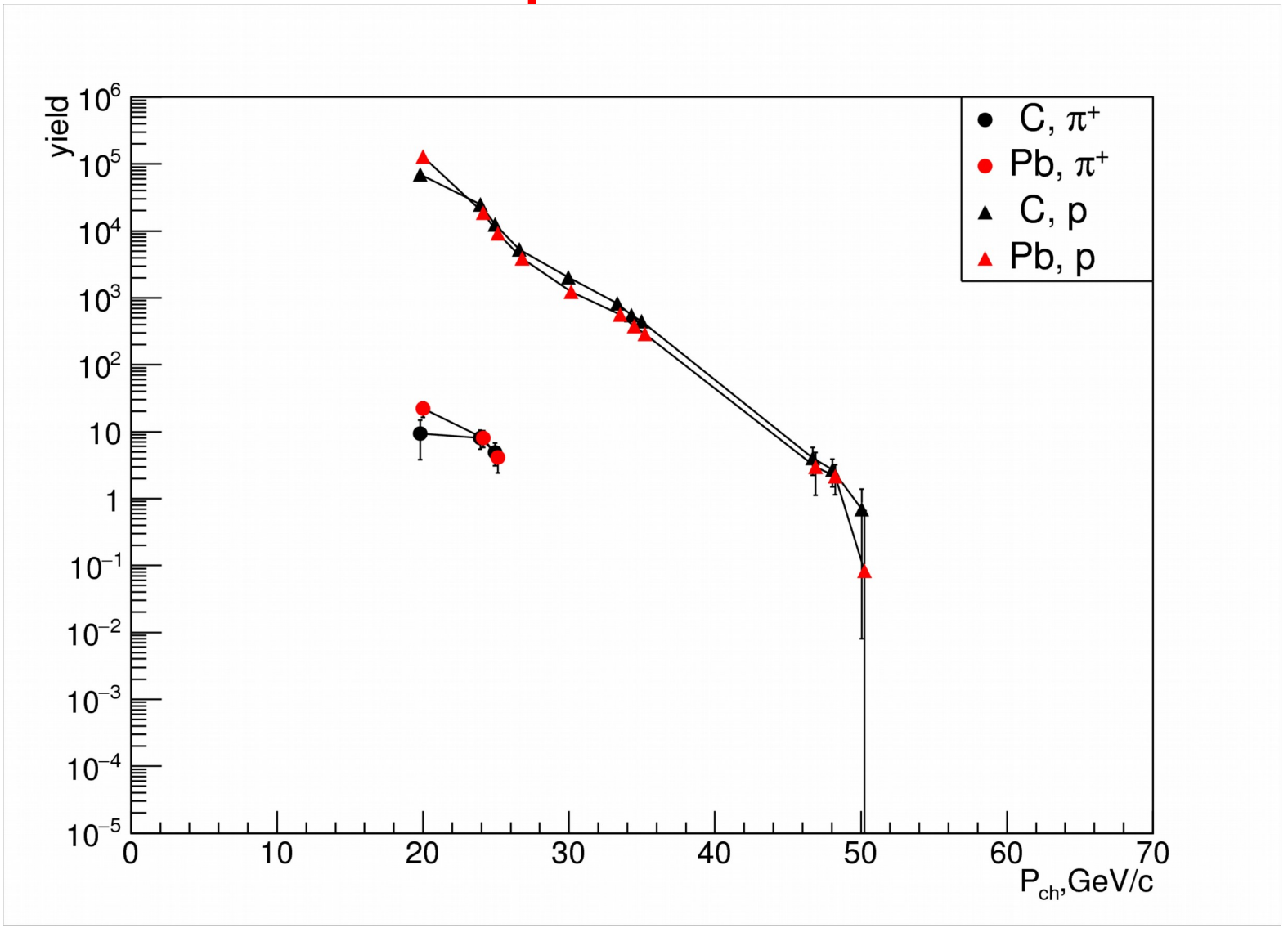
Comparison of presented results on invariant cross sections with models included in Genat4 QGSP-FTFP-BERT-EMV and also with model UrQMD is now in progress.

Backup

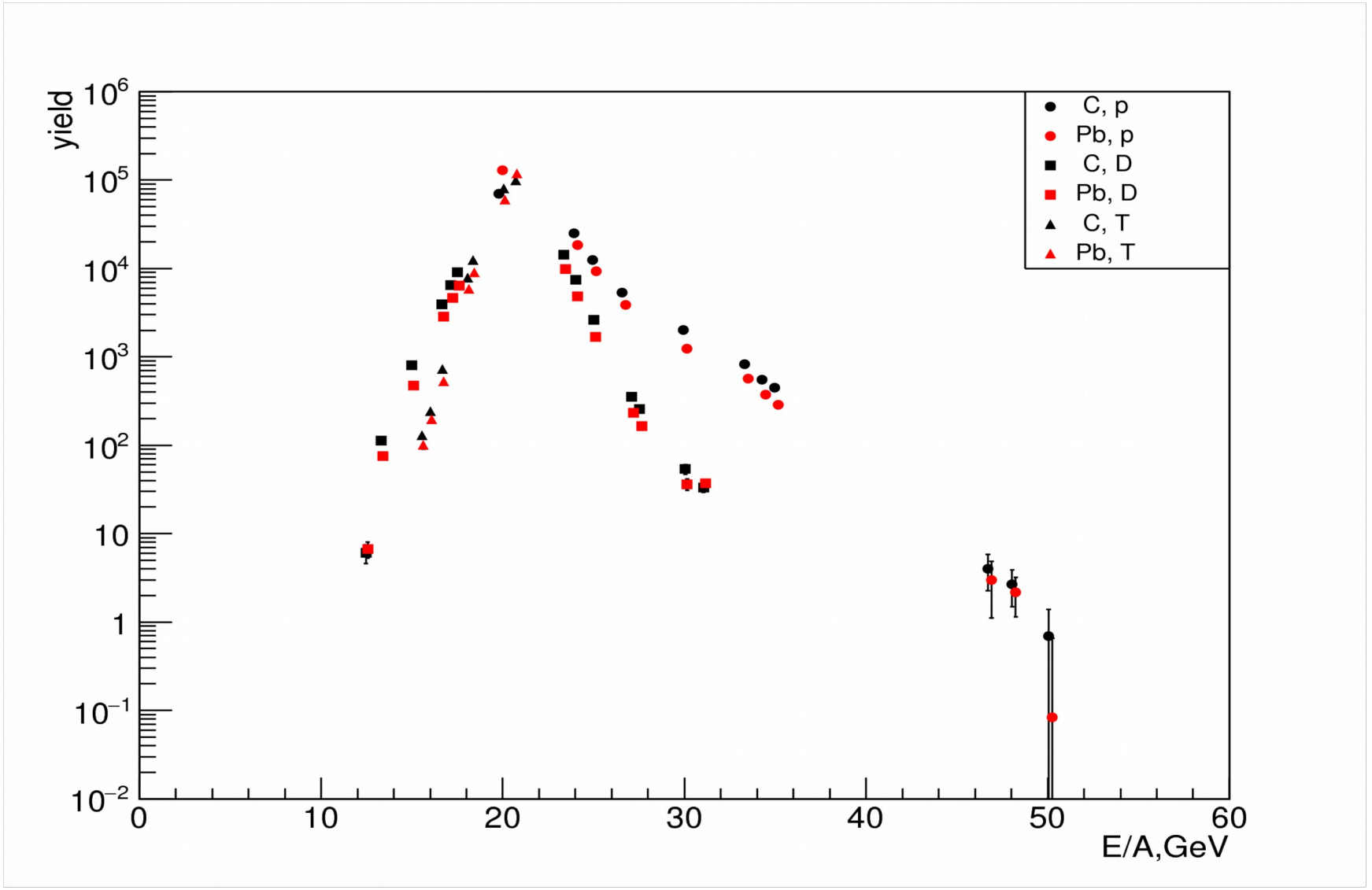
Yields, p, π^-, κ^-



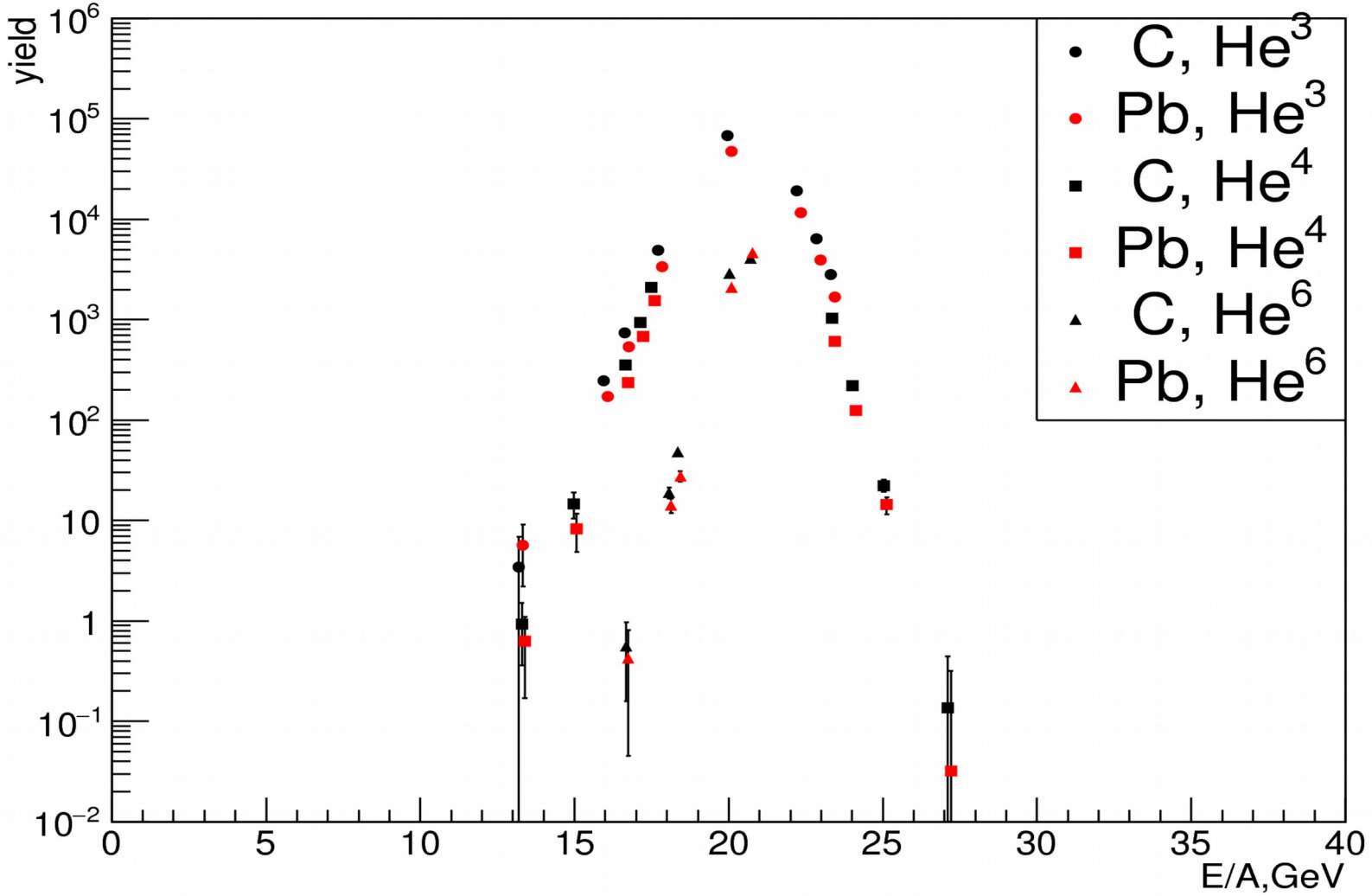
p, π^+


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60
70
P_{ch},GeV/c
C, π^+
Pb, π^+
C, p
Pb, p

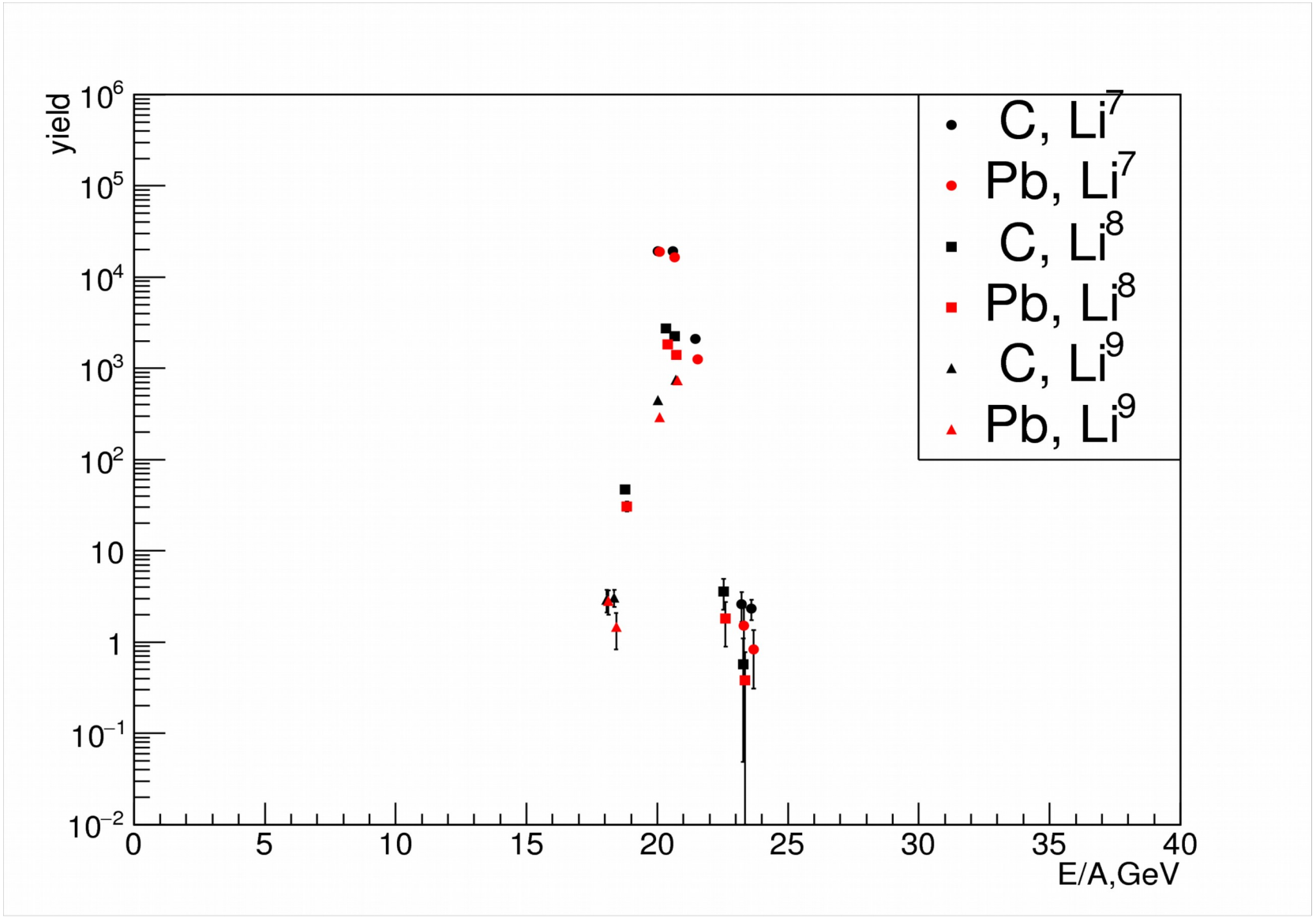
p,D,T


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
10
20
30
40
50
60
E/A,GeV
C, p
Pb, p
C, D
Pb, D
C, T
Pb, T

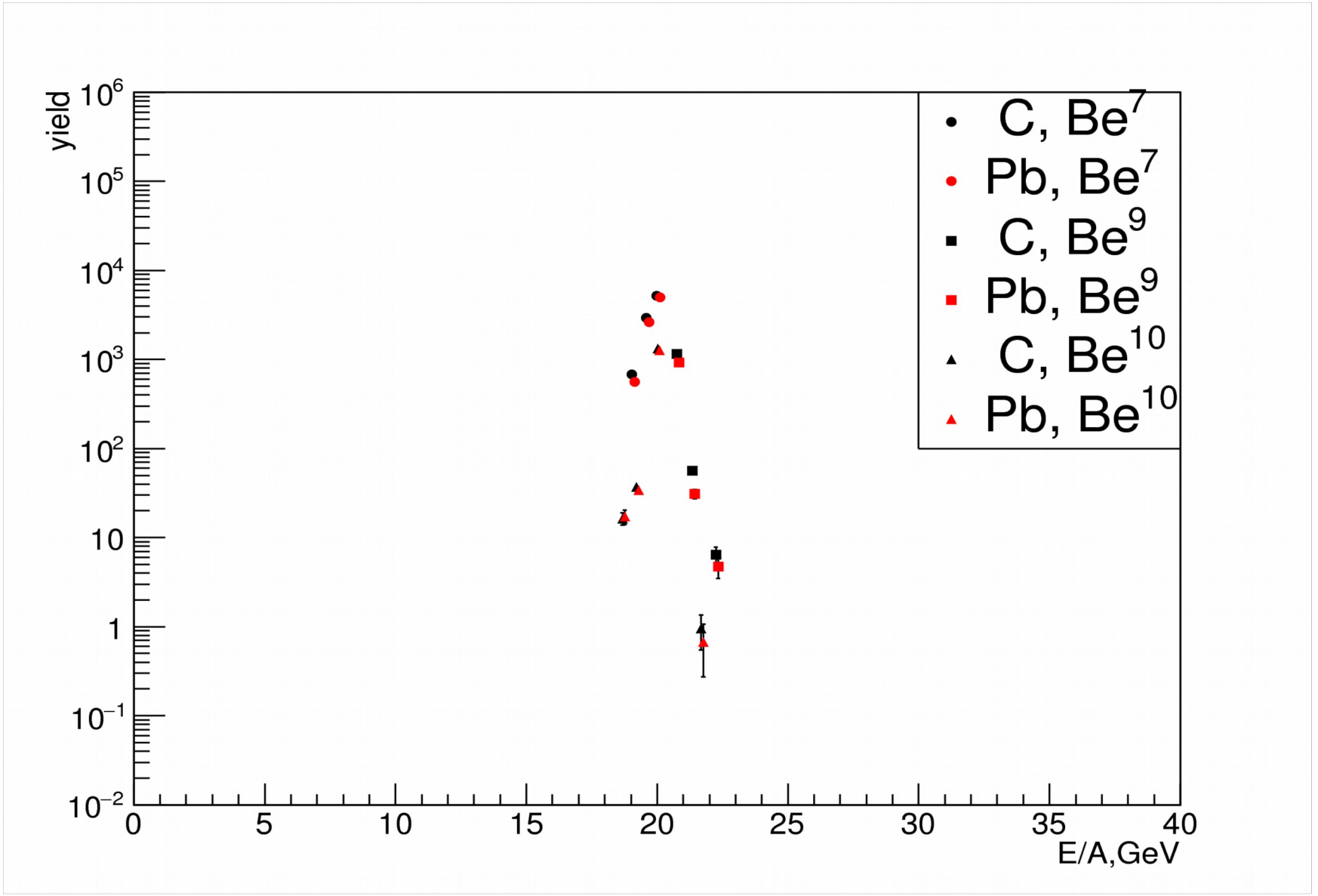
He


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40
E/A,GeV
C, He^3
Pb, He^3
C, He^4
Pb, He^4
C, He^6
Pb, He^6

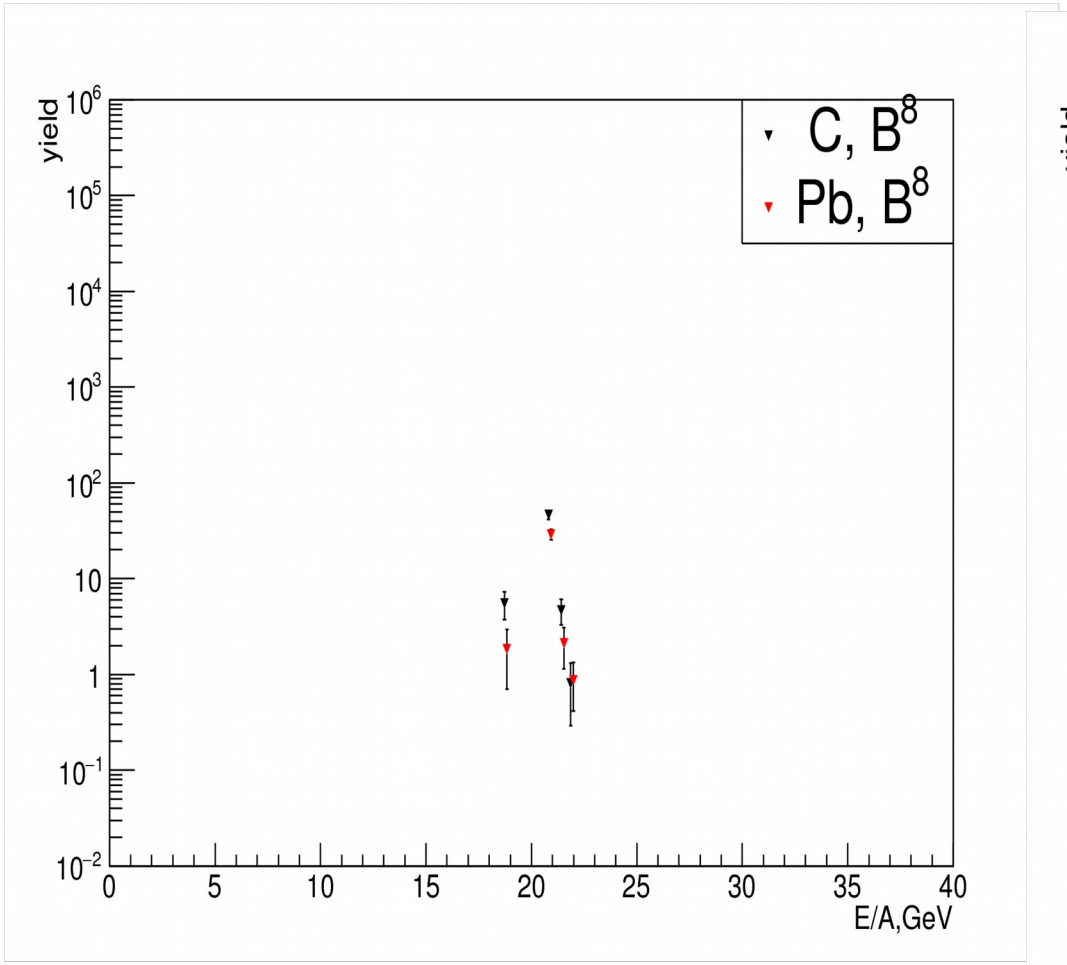
Li

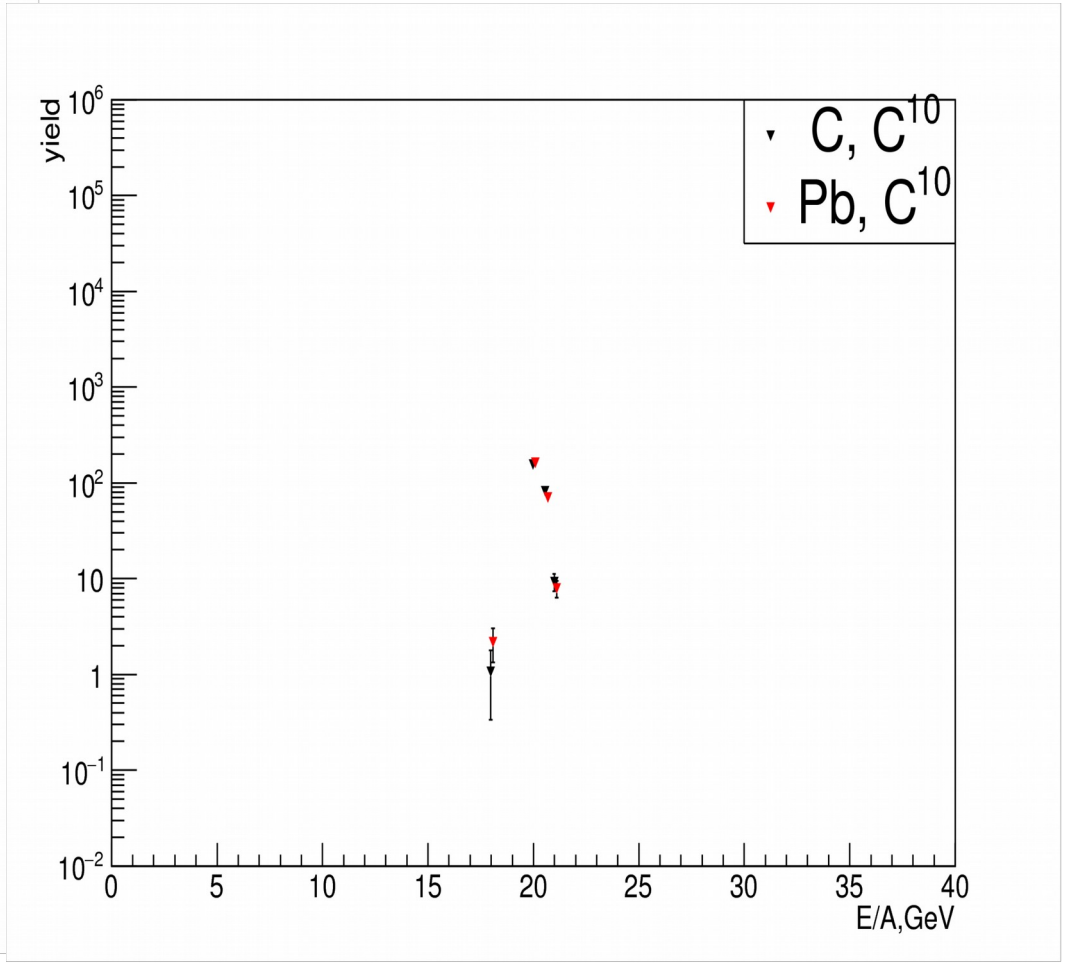

yield
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40
E/A,GeV
C, Li^{7}
Pb, Li^{7}
C, Li^{8}
Pb, Li^{8}
C, Li^{9}
Pb, Li^{9}

Be


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40
E/A,GeV
C, Be^7
Pb, Be^7
C, Be^9
Pb, Be^9
C, Be^{10}
Pb, Be^{10}

B and C


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40
E/A,GeV
C, B^8
Pb, B^8


yield
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
5
10
15
20
25
30
35
40
E/A,GeV
C, C^{10}
Pb, C^{10}

Summary

Preliminary results for the yields of hadrons and nuclear fragments in the carbon beam with an energy of 20 A GeV/c are presented.

Observed production of hadrons above kinematic limit of nucleon-nucleon interaction at an energy of carbon beam 20 A GeV.

Mesons yields are strongly suppressed in relation to protons with a momentum greater than 20 GeV/c.

A-dependence of the proton and meson production is consistent with the chosen cross section parameterization for the nuclear-nuclear interactions.

Important corrections for the yields of the nucleus fragments yet to be done.

Normalization

Secondary emission detector was used to measure beam intensity.
It can measure intensity from 10^8 to 10^{11} carbon nuclei per spill.

Ratio background(empty target) to signal(C or Pb target) ~ 0.5.

Empty target background is a main source of systematic error (~15%).

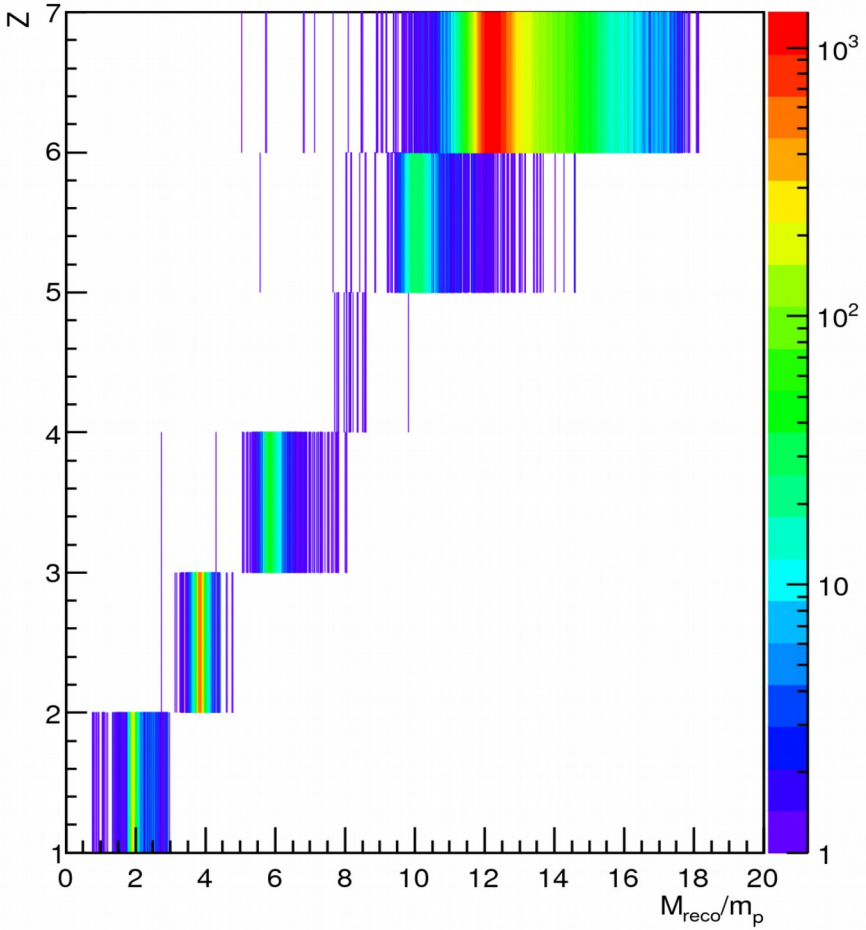
For the target length correction following parameterization was used:

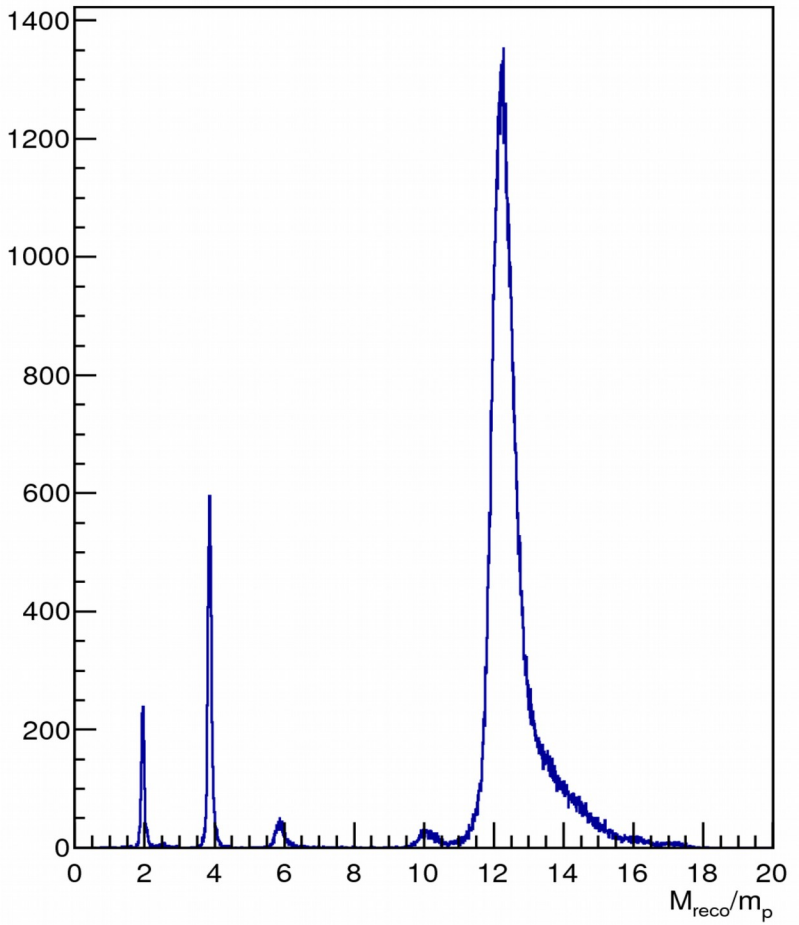
(Measurement of ^{19}F Nuclear Interaction at 4 GeV/c per Nucleon, Golovin V.M. et al., JINR Rapid Communications №17-86.)

Applied corrections:

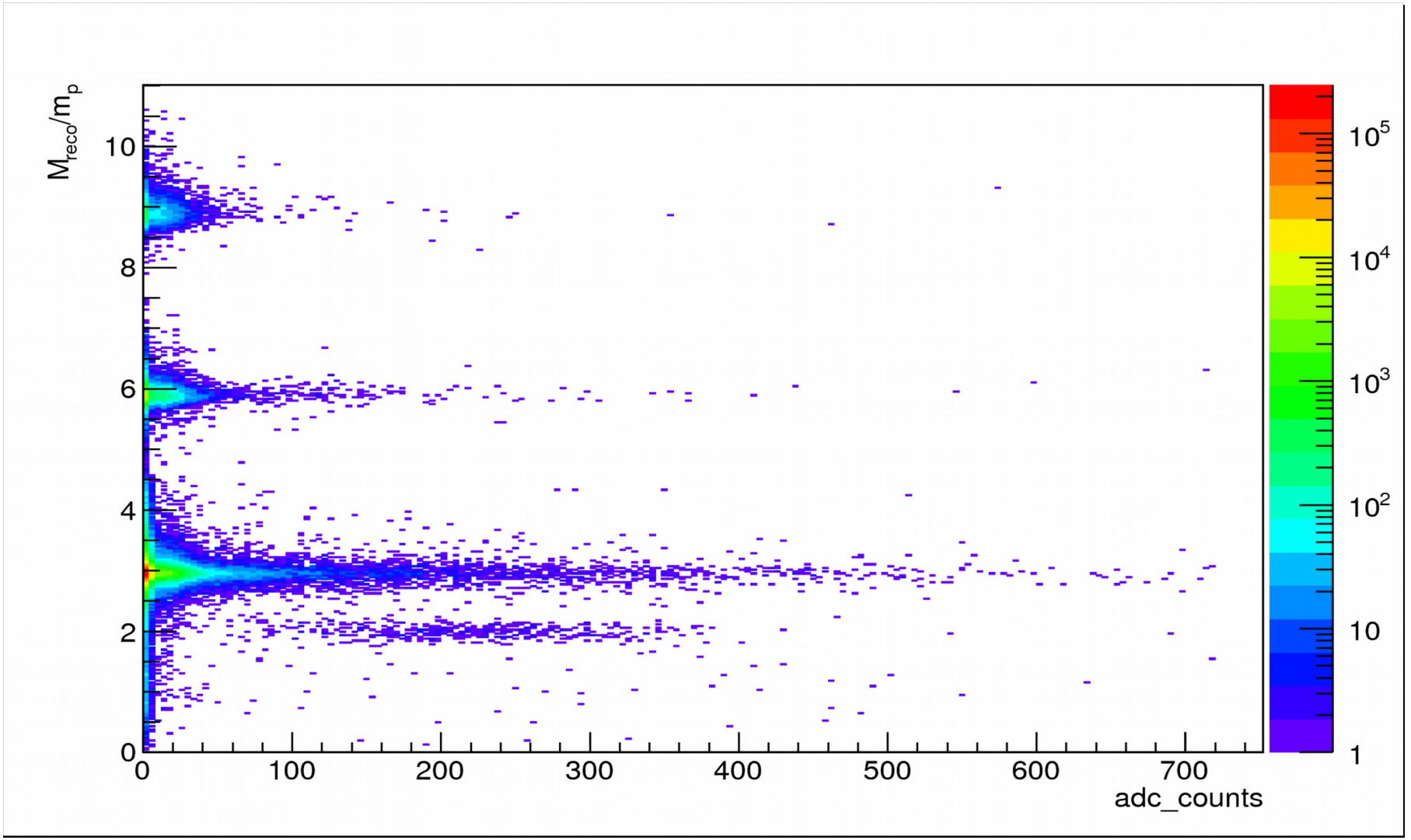
- Cherenkov ring reconstruction efficiency
- Lifetime of the particles
- Identification and transmission efficiency (a.t.m. done only for p,k,π !)

Mass reconstruction.

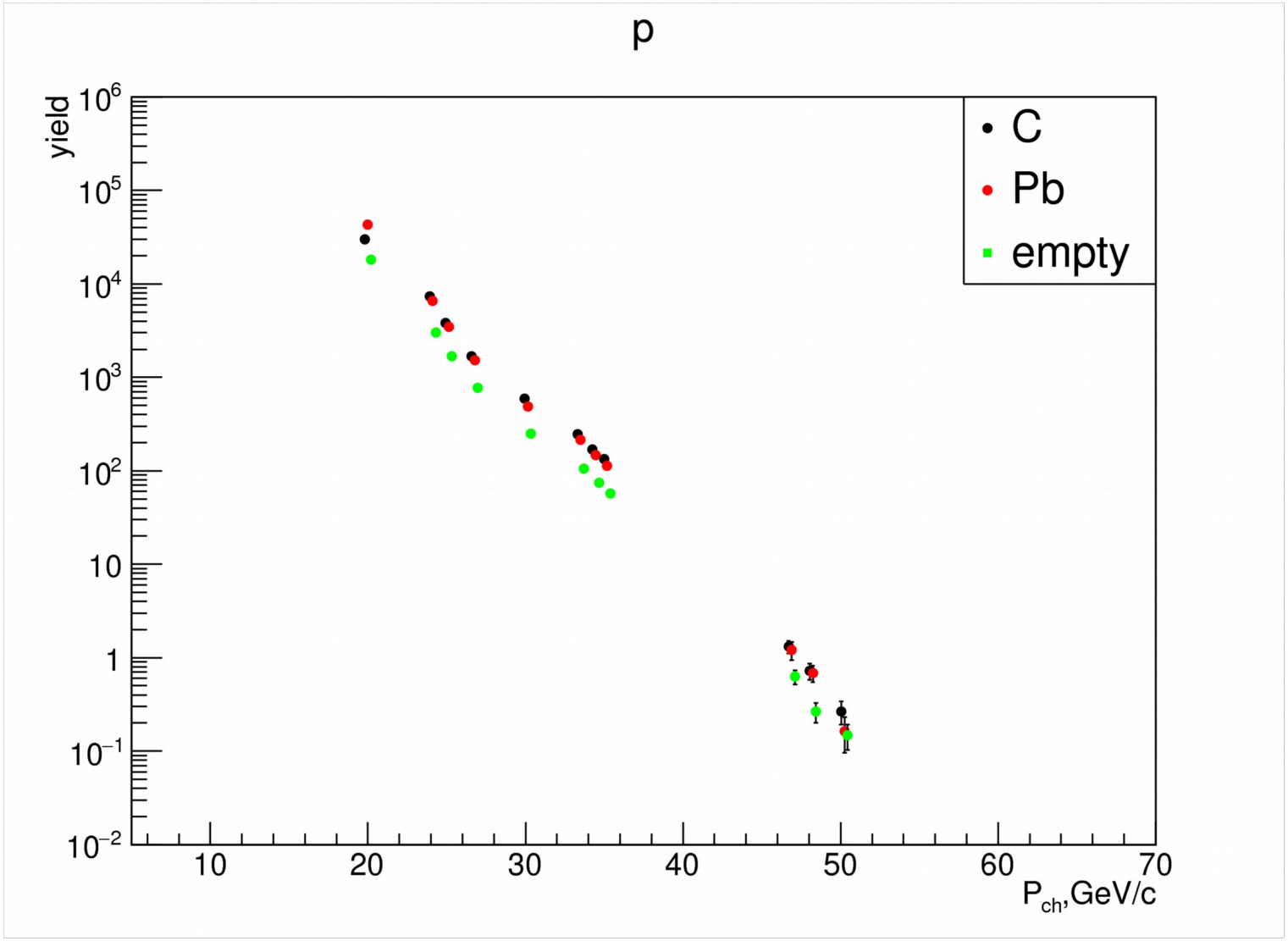




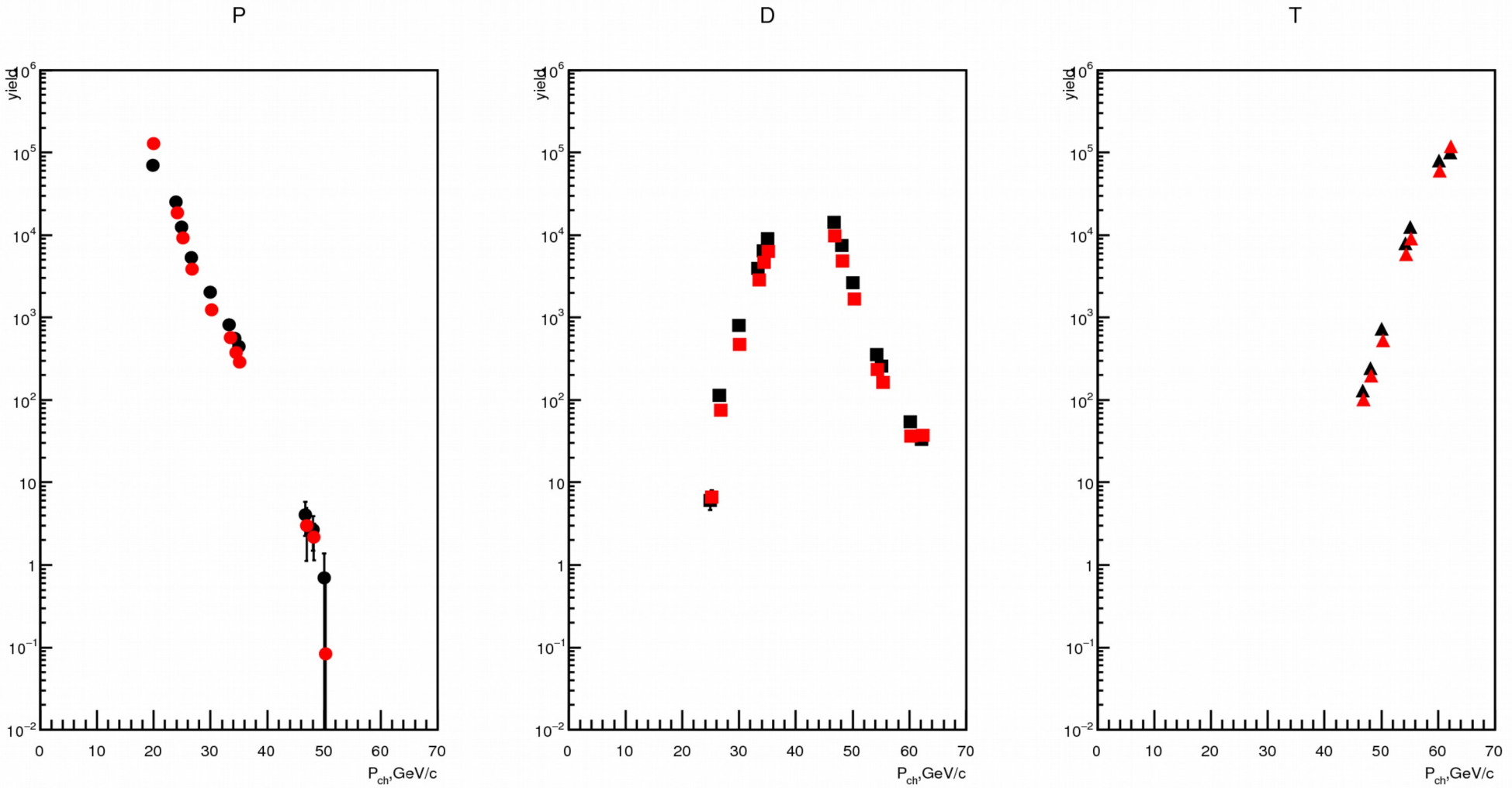
Mass reconstruction.



Targets comparison

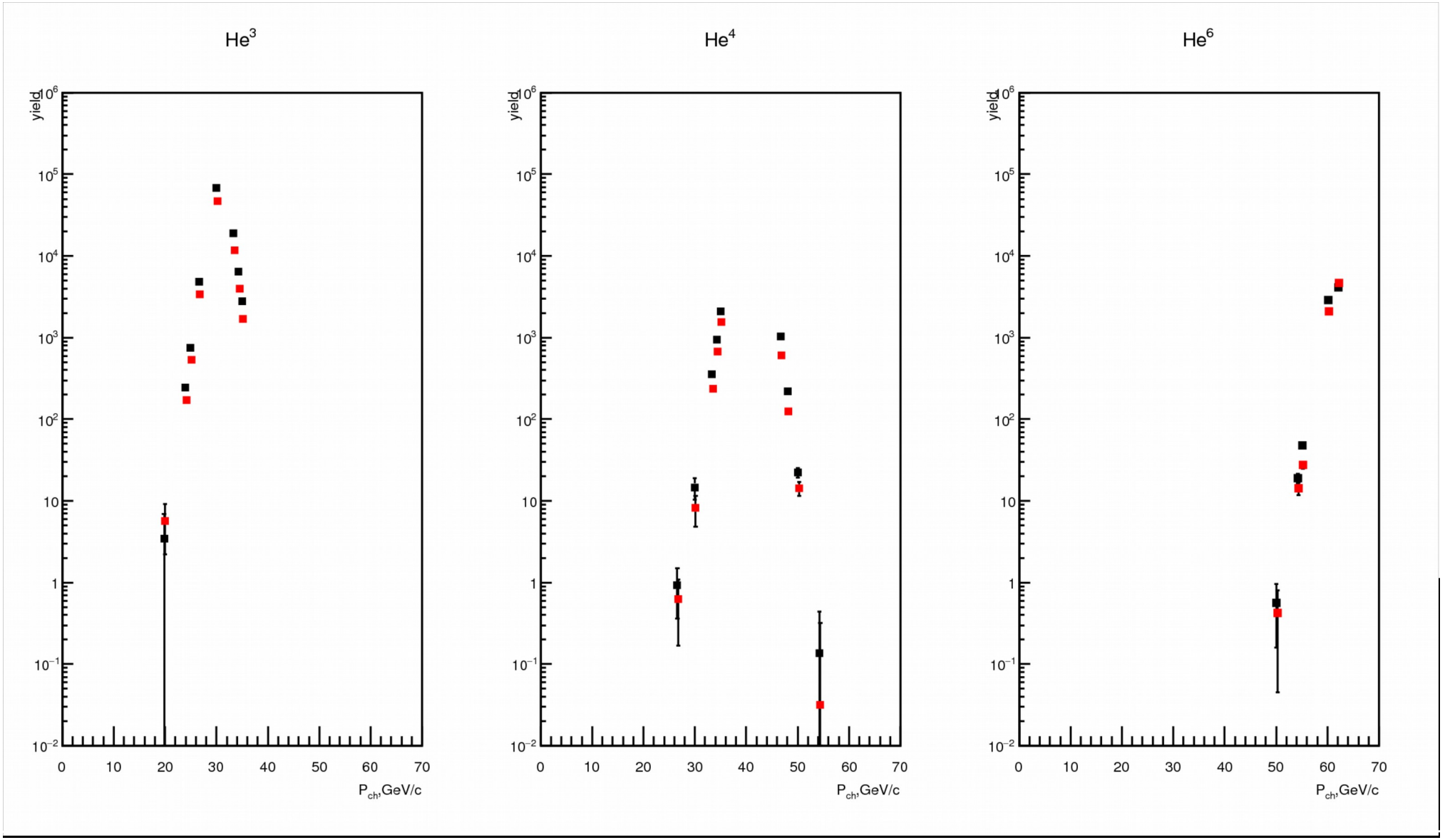


p,D,T



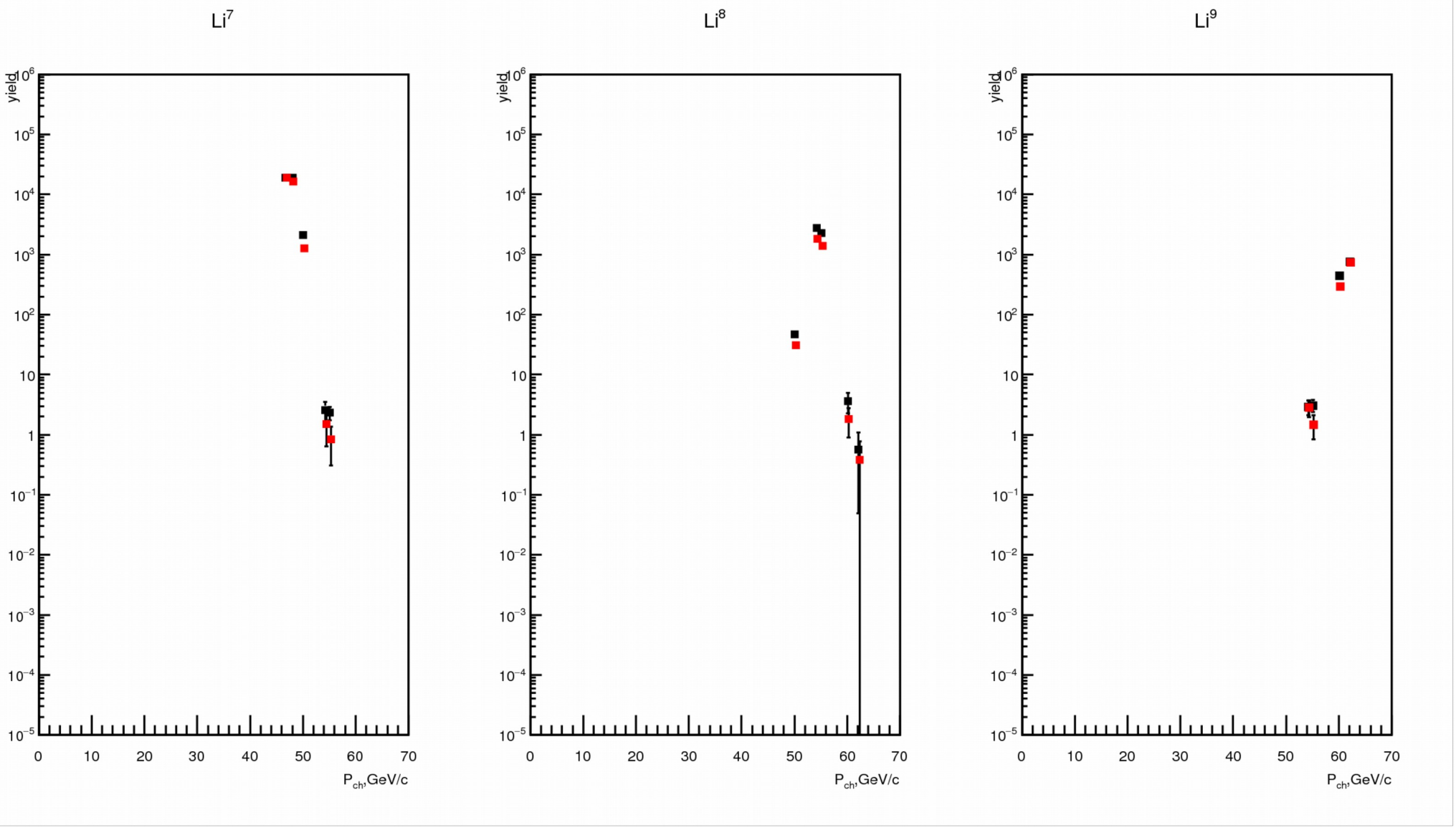
Черные точки – углеродная мишень, красные – свинцовая.

He



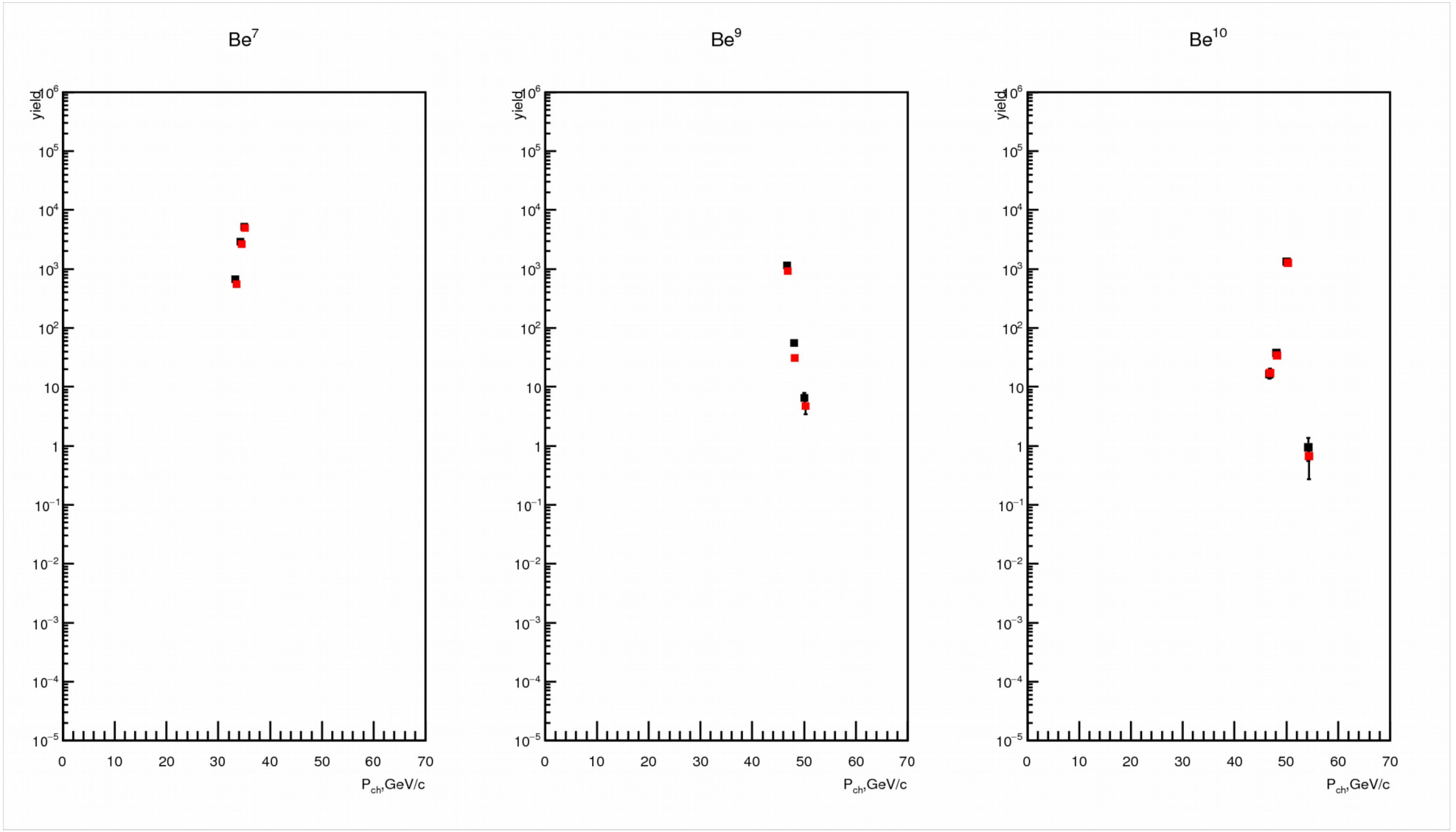
Черные точки – углеродная мишень, красные – свинцовая.

Li



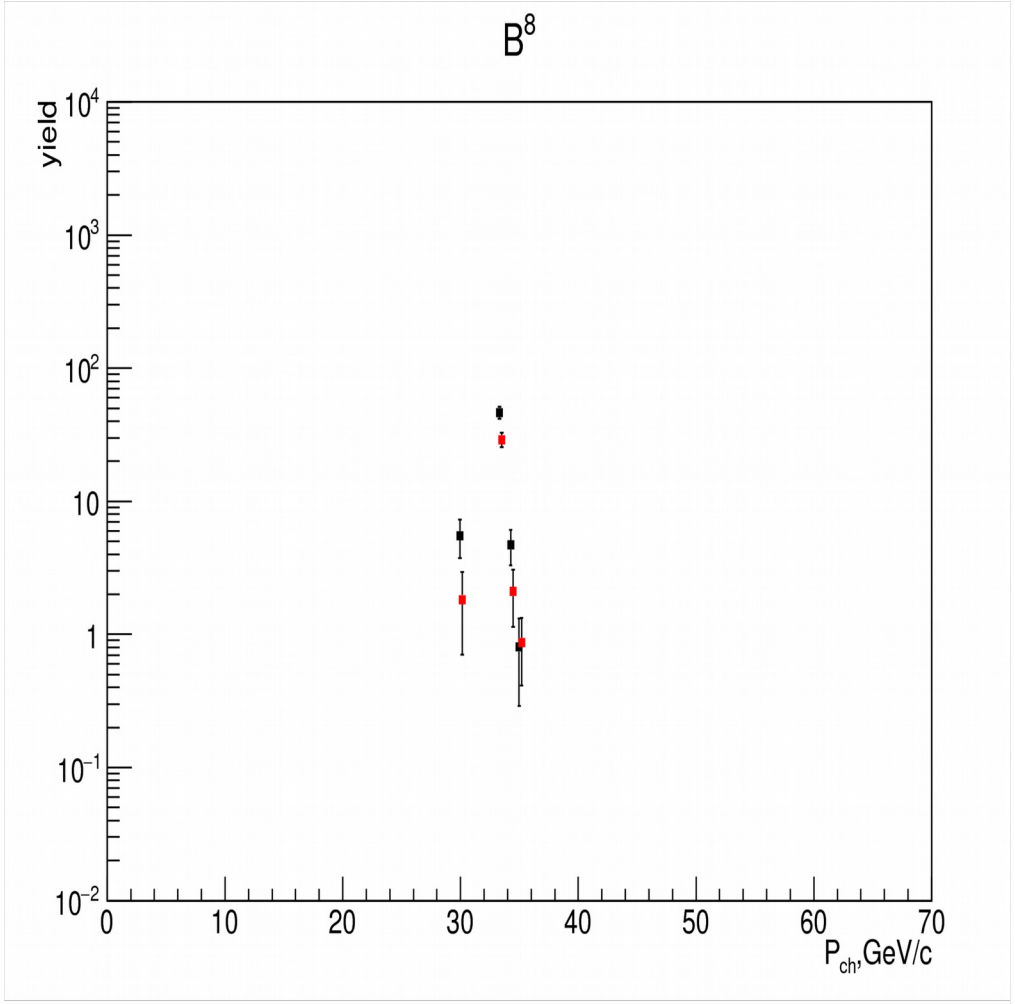
Черные точки – углеродная мишень, красные – свинцовая.

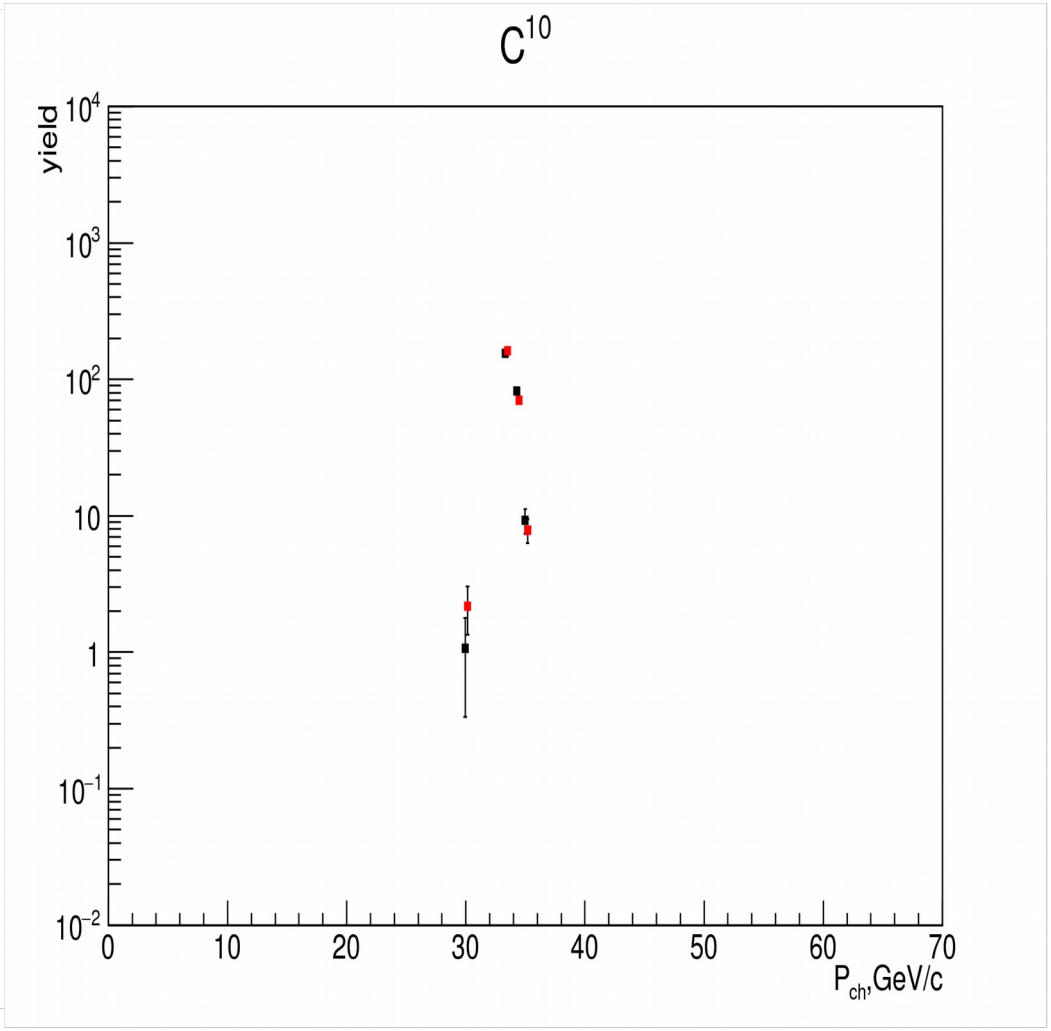
Be



Черные точки – углеродная мишень, красные – свинцовая.

B and C


B8
yield
10^4
10^3
10^2
10
1
10^-1
10^-2
0
10
20
30
40
50
60
70
P_ch,GeV/c


C10
yield
10^4
10^3
10^2
10
1
10^-1
10^-2
0
10
20
30
40
50
60
70
P_ch,GeV/c