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Monte Carlo Generator DQGSM

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Content

- Motivation
- LAQGSM – Los Alamos Quark String Model
- DQGSM – Dubna Quark-Gluon-String-Model
- Prospects
- Conclusion

Motivation

- LAQGSM – commercial code
  - Licensing rights (*K. Gudima)*
  - Many new implementations – new code
  - Problems of usage of his code (licensing and techniclal)

Our task

- Recollect the components of Gudima's code
- Verify each component comparing it with experiment
- Create on the base of components the new code, DQGSM
- Make it available for common usage
- Prepare the manual

LAQGSM

- LAQGSM – components
  - DCM – Dubna Cascade Model
  - QGSM – Quark Gluon String Model
  - Coalescence
  - Preequilibrium
  - Equilibrium

DQGSM

DQGSM – Dubna Quark-Gluon-String-Model

- DCM+Coalescence+Multifragmentation
- QGSM
- Extended yield of hyperons and strange mesons
- Multifragmentation
- Hyperfragments
- Hyperon Polarization
- Helicity and Vorticity

DCM-QGSM

DCM

V. D. Toneev andK.K.Gudima, Nucl. Phys.A400, 173c (1983)

- 3-step process:
  - intranuclear cascade of binary collisions;
  - coalescence of protons and neutrons with forming light fragments.
  - preequilibrium emission of particles from excited remnants; - i) statistical equilibrated decay of excited remnants including fission;
- Based on the Monte Carlo solution of a set of the BUU relativistic kinetic equations with the collision terms, including cascade-cascade interactions.
- Nucleons, pions and low mass resonances (adjusted to exp.data)
- Is relevant up to 10 GeV

DCM-QGSM

QGSM

V. D. Toneev, N. S. Amelin, K. K. Gudima, and S. Yu. Sivoklokov, Nucl. Phys. A 519, 463c (1990)

N. S. Amelin, E. F. Staubo, L. S. Csernai, V. D. Toneev, and K. K. Gudima, Phys. Rev. C 44, 1541 (1991)

- Binary collisions
  - ✓ formation quark-gluon strings between quark and di-quarks
  - ✓ hadronization of strings in the framework of DPM (*A. B. Kaidalov, Sov. J. Nucl. Phys. 45 (1987) 902-907*)
  - ✓ ends of strings - leading particles
  - ✓ Formation time concept

DQGSM: DCM-QGSM + modifications

Coalescence

V. D. Toneev and K. K. Gudima, Nucl. Phys. A400 (1983) 173c-190c.

H. Schulz, G. Ropke, K. K. Gudima, and V. D. Toneev, Phys. Lett. B 124 (1983) 458-460.

- Light fragments formation (d, t, ^{3}He, ^{4}He)
- Final state interations
- Coalescence criteria: $(p_i - p_0) < p_c$ and $(r_i - r_0) < r_c$

DQGSM: DCM-QGSM + modifications

Multifragmentation

A. Botvia et al, Nucl. Phys. A584 (1995) 737-756.

- Statistical break-up of excited nuclear residuals
- Light and medium mass fragments formation

DQGSM: DCM-QGSM + modifications

Hyperfragment production

*A.S. Botvina, K. K. Gudima, J. Steinheimer, M. Bleicher, and I. N. Mishustin, PHYSICAL REVIEW C **84**, 064904 (2011)*

*J. Steinheimer, K.K. Gudima, A.S. Botvina, I.N. Mishustin, M. Bleicher, H. Stocker, Phys. Lett. **B714**, 85 (2012).*

Generalized Statistical Fragmentation model

- Coalescence mechanism in central region
- Multifragmentation in forward and backward regions:

  - capture of hyperons by spectator fragments in non-central heavy ion collisions

  - capture criterium: $E_H < |V_\Lambda|$

$$V_\Lambda(\rho) = -\alpha \frac{\rho}{\rho_0}\left[1 - \beta\left(\frac{\rho}{\rho_0}\right)^{2/3}\right],$$

DQGSM: DCM-QGSM + modifications

Hyperon Polarization in Production plane

K. Gudima, D. Suvarieva, A. Zinchenko, Phys. Part. Nucl. Lett., 15, 182 (2018).

Hyperon production

$B + B \rightarrow BYK$, $M + B \rightarrow YK$, $Y = \Lambda, \Sigma$

Hyperon polarization

- *DeGrand–Markkanen–Miettinen* mechanism

T. A. Degrand, J. Markkanen, and H. I. Miettinen, Phys. Rev. D: Part. Fields 32, 2445 (1985).

- Depends on p_t and x_F
- Depolarization due to rescatterings

DQGSM: DCM-QGSM + modifications

Nuclear Vorticity and Global Hyperon Polarization

O. V. Rogachevsky, A. S. Sorin, and O. V. Teryaev, Phys. Rev. C 82, 054910 (2010)

A. Sorin, O. Teryaev, Phys.Rev. C95 (2017) no.1, 011902

- Noncentral heavy ion collisions
- relativistic kinematic vorticity

$$\omega_{\mu\nu} = \frac{1}{2}(\partial_\nu u_\mu - \partial_\mu u_\nu),$$

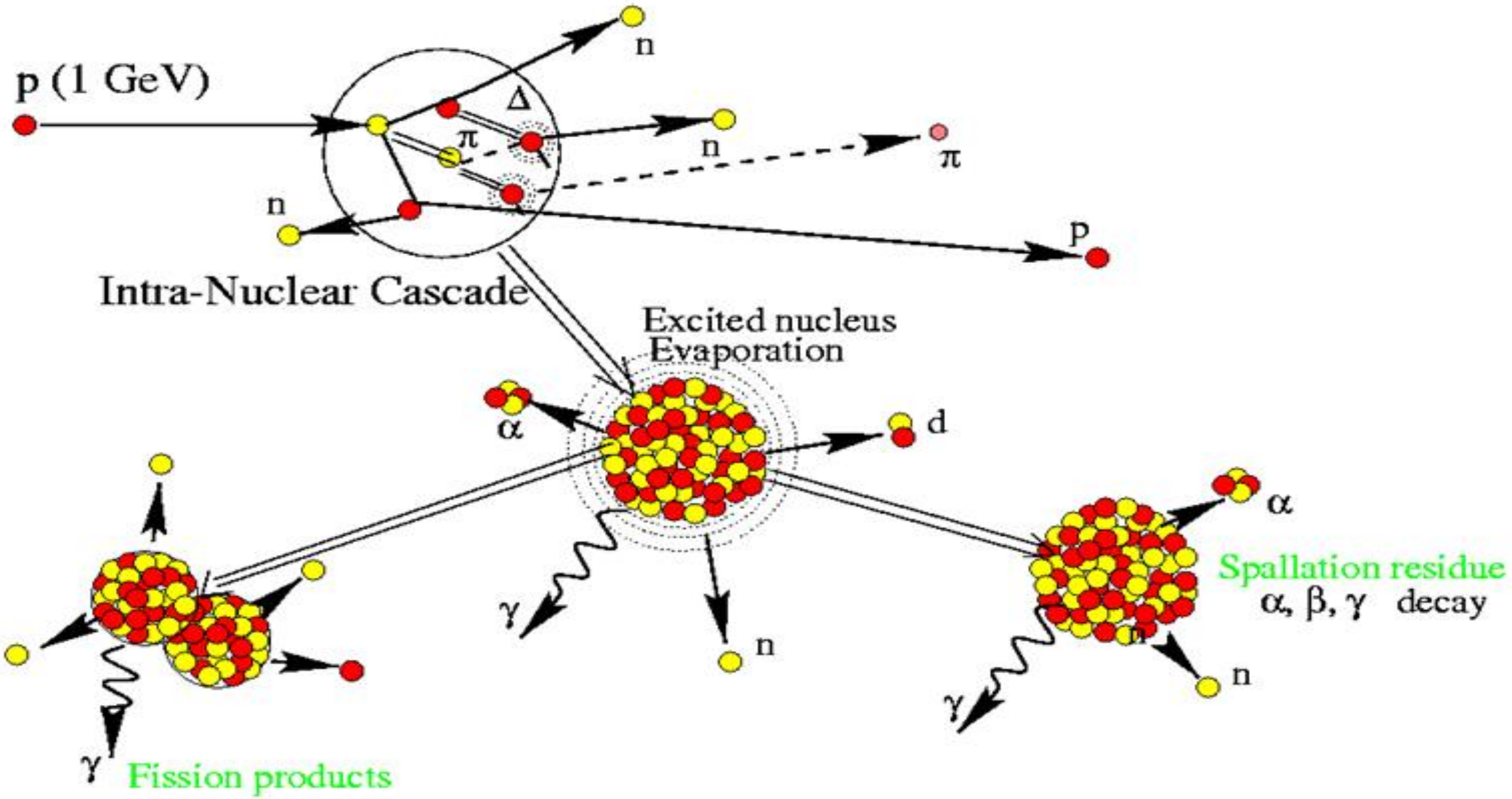
- thermal vorticity in hydrodynamic approach

$$\varpi_{\mu\nu} = -\frac{1}{2}(\partial_\mu \beta_\nu - \partial_\nu \beta_\mu)$$

where $\beta_\mu = \frac{u_\mu}{T}$ and T is a temperature in the comoving system.

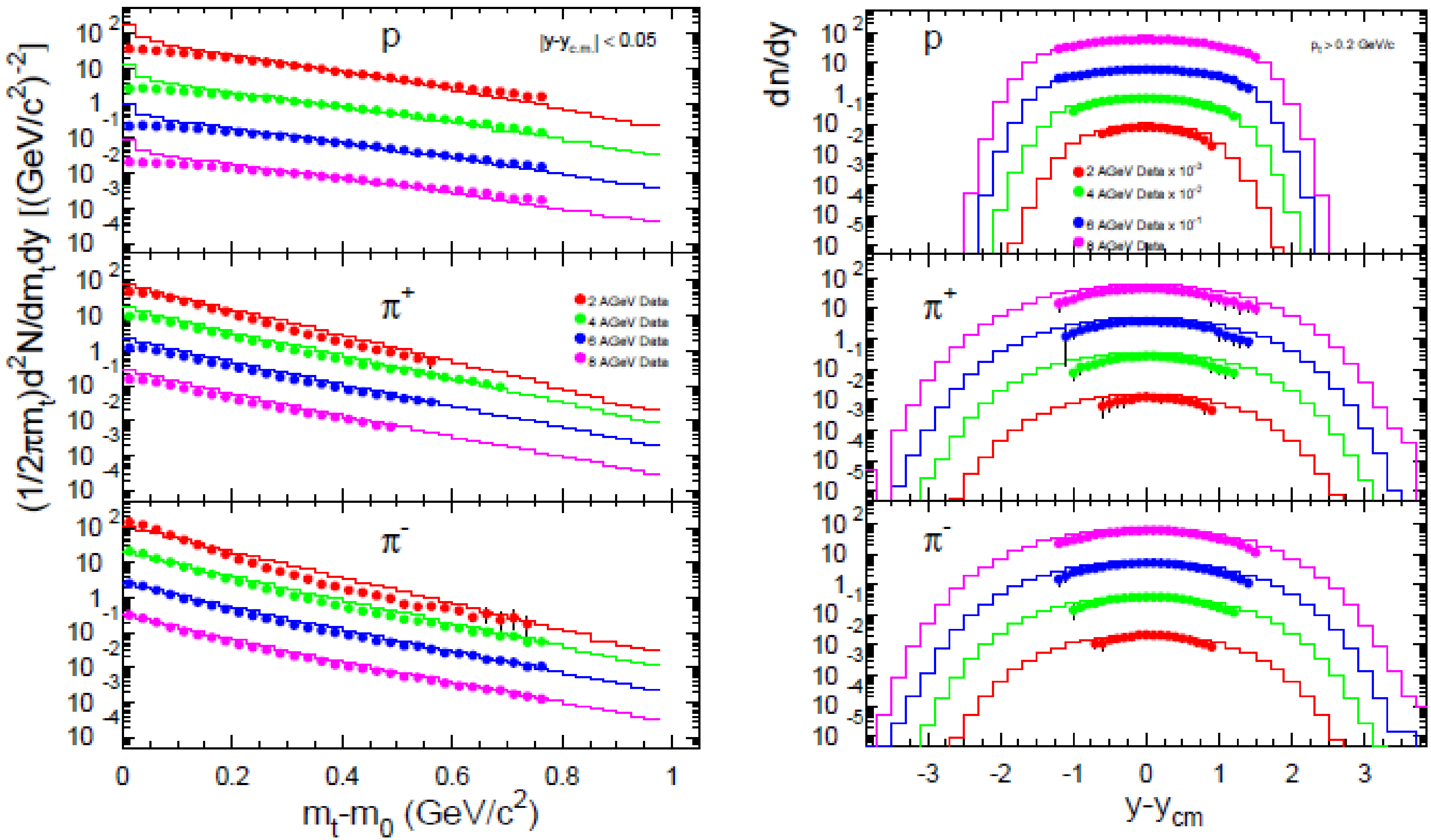
- Hyperon polarization
  - due to the chiral vortical effect
  - due to vorticity and temperature gradients

The spallation reaction



E895 Collaboration

Charged Particle Production in 2 to 8 AGeV Central Au+Au Collisions



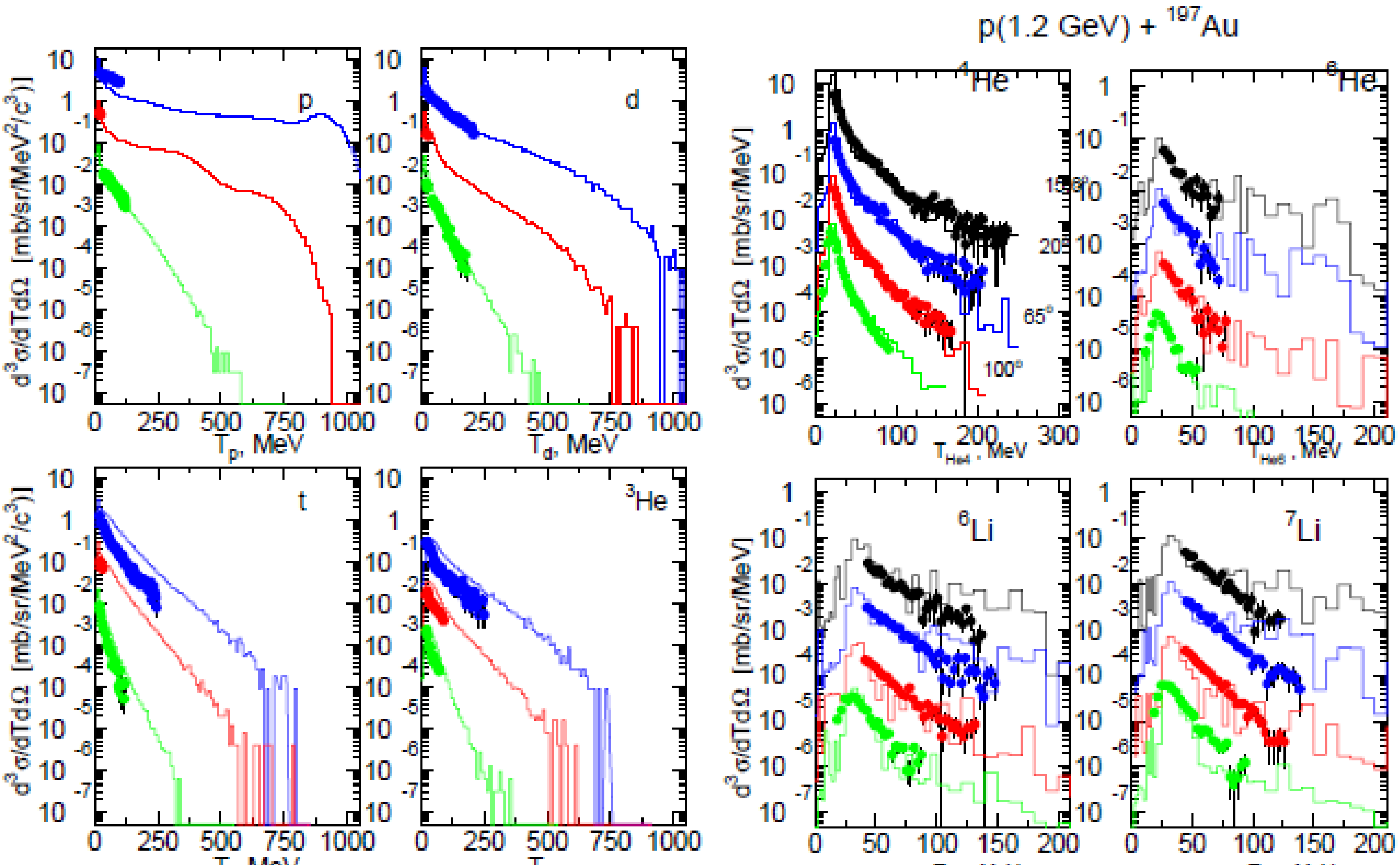
PISA Collaboration. *p* + Au collisions at 1.2, 1.9 and 2.5 GeV, PHYSICAL REVIEW C **76**, 014618 (2007)

The energy and angular dependence of double differential cross sections $d2\sigma/ddE$ wasmeasured for reactions induced by 2.5 GeV protons on Au target with isotopic identification of light products (H, He, Li, Be, and B) and with elemental identification of heavier intermediate mass fragments (C, N, O, F, Ne, Na, Mg, and Al). It was found that two different reactionmechanisms give comparable contributions to the cross sections. The intranuclear cascade of nucleon-nucleon collisions followed by evaporation from an equilibrated residuum describes the low energy part of the energy distributions whereas another reaction mechanism is responsible for the high energy part of the spectra of composite particles.

PISA Collaboration

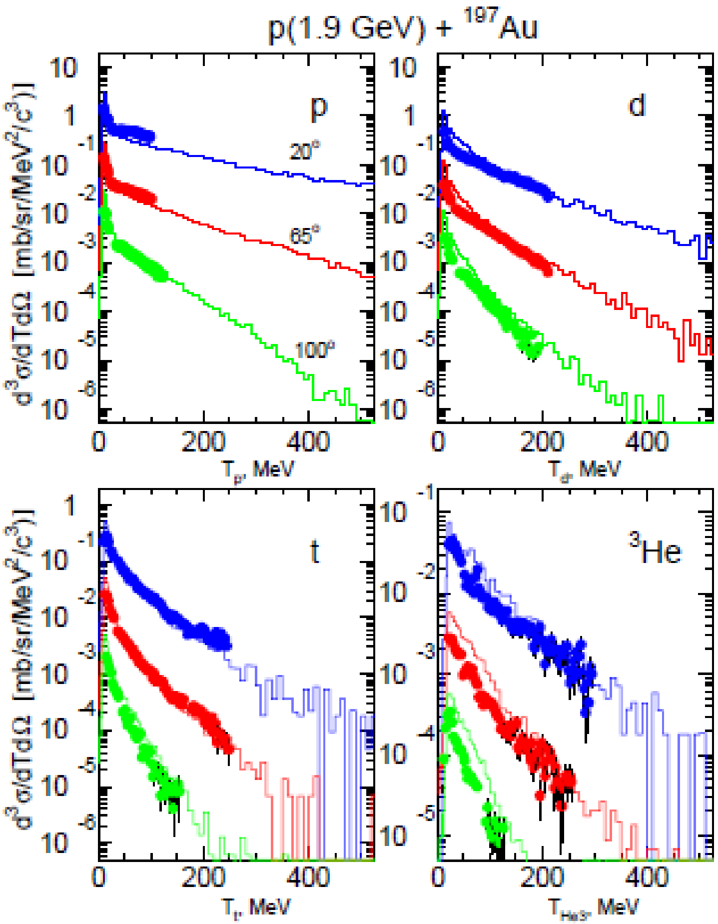
p + Au collisions at 1.2 GeV

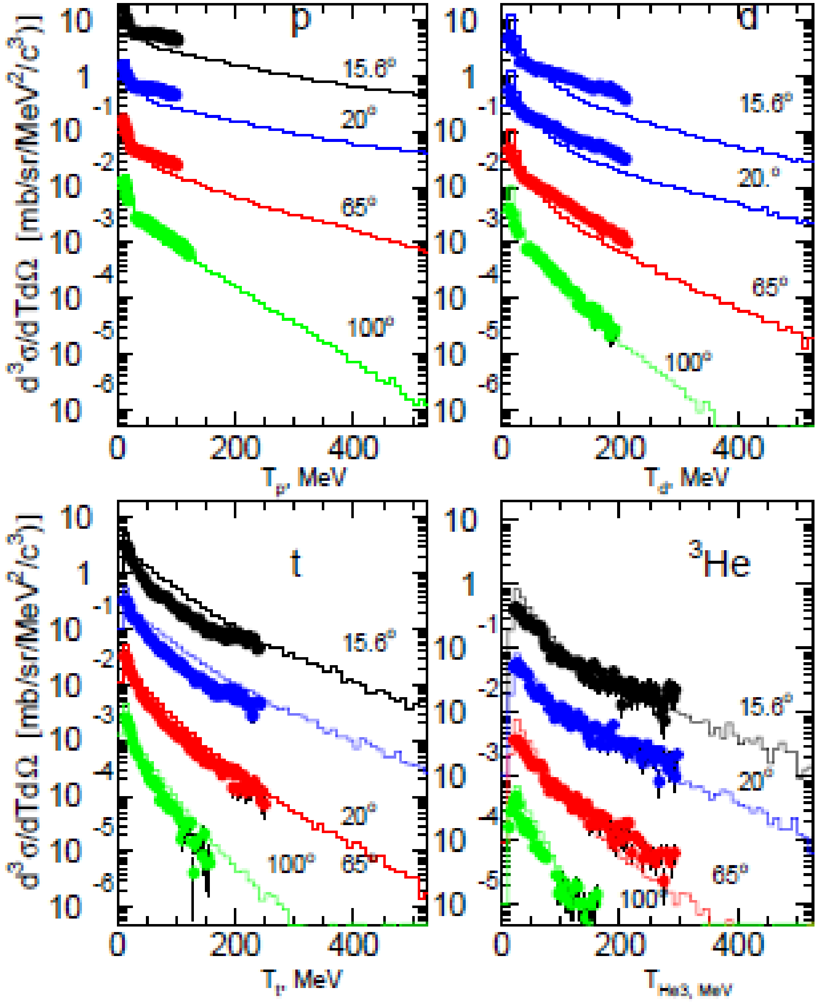
Light fragment yield



PISA Collaboration

p + Au collisions at 1.9(left) and 2.5 GeV(right)

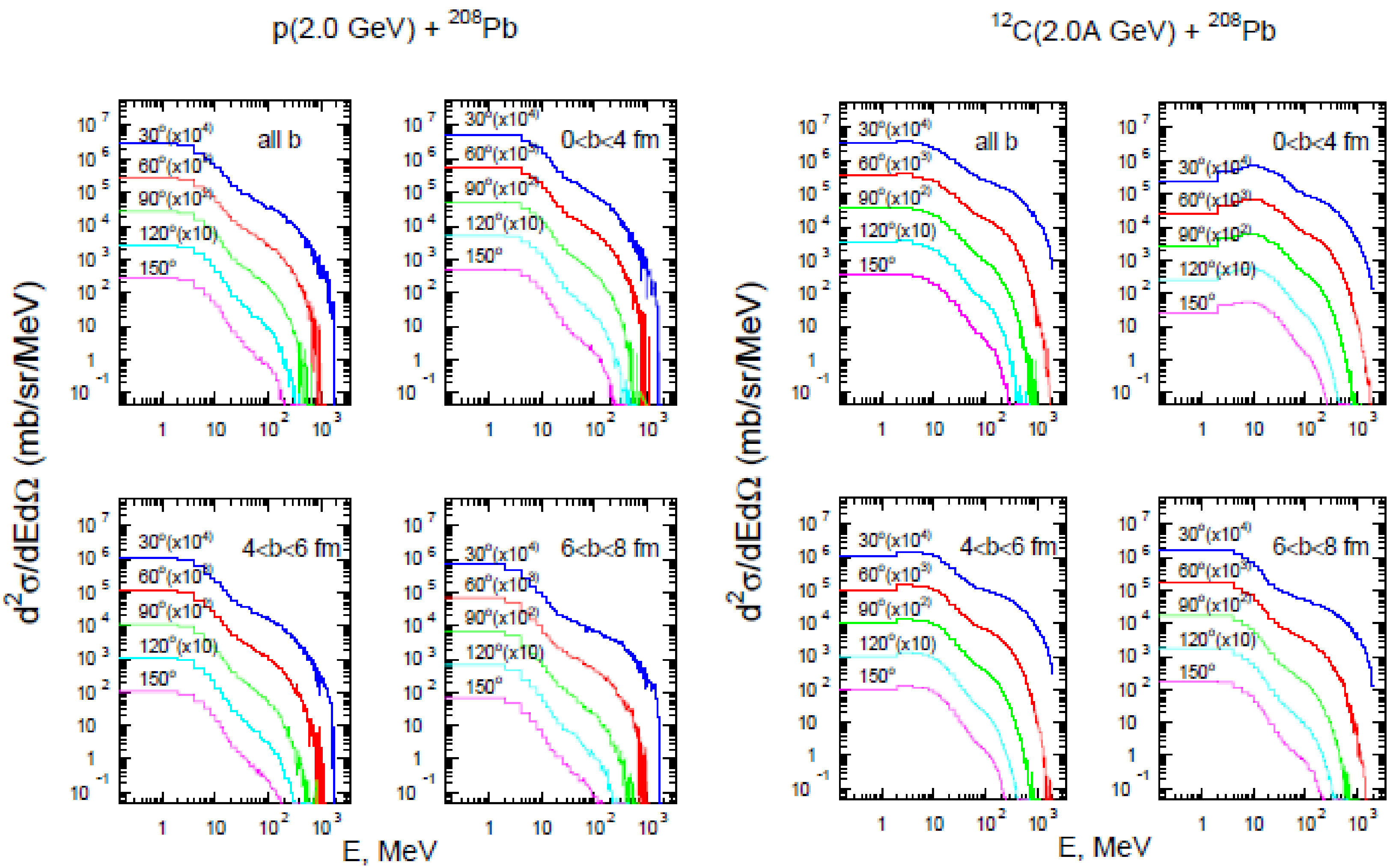




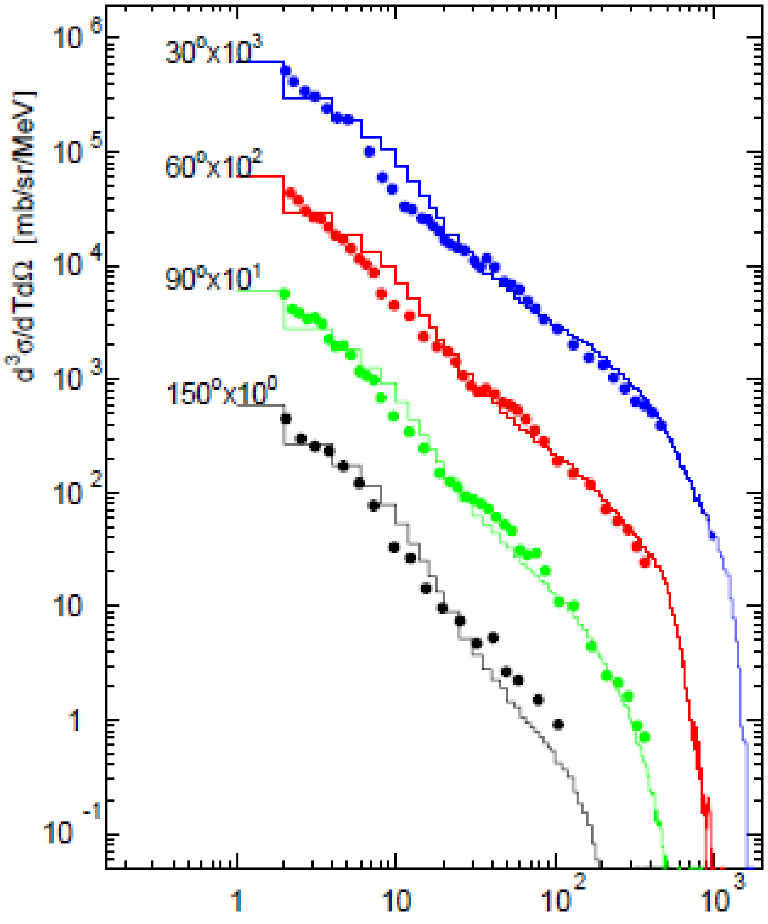
Yurevich V. I. et al. PEPAN LETTERS 2006. v. 3, №3(132). p. 49-72

Results on the neutron double-differential cross section and yields obtained in the time-of-light measurements with different lead targets and beams of protons and 12C at energy of about 2 GeV are discussed. The neutron spatial-energy distribution for the extended lead target was studied by the threshold detector method in energy range of protons and deuterons 1-3.7 GeV. A dependence of the mean neutron multiplicity, energy of neutrons, and process of neutron multiplication in lead on target dimension, and type and energy of beam particle was analyzed.

DQGSM: Neutron spectra in ^{12}C + ^{208}Pb reactions at different centralities



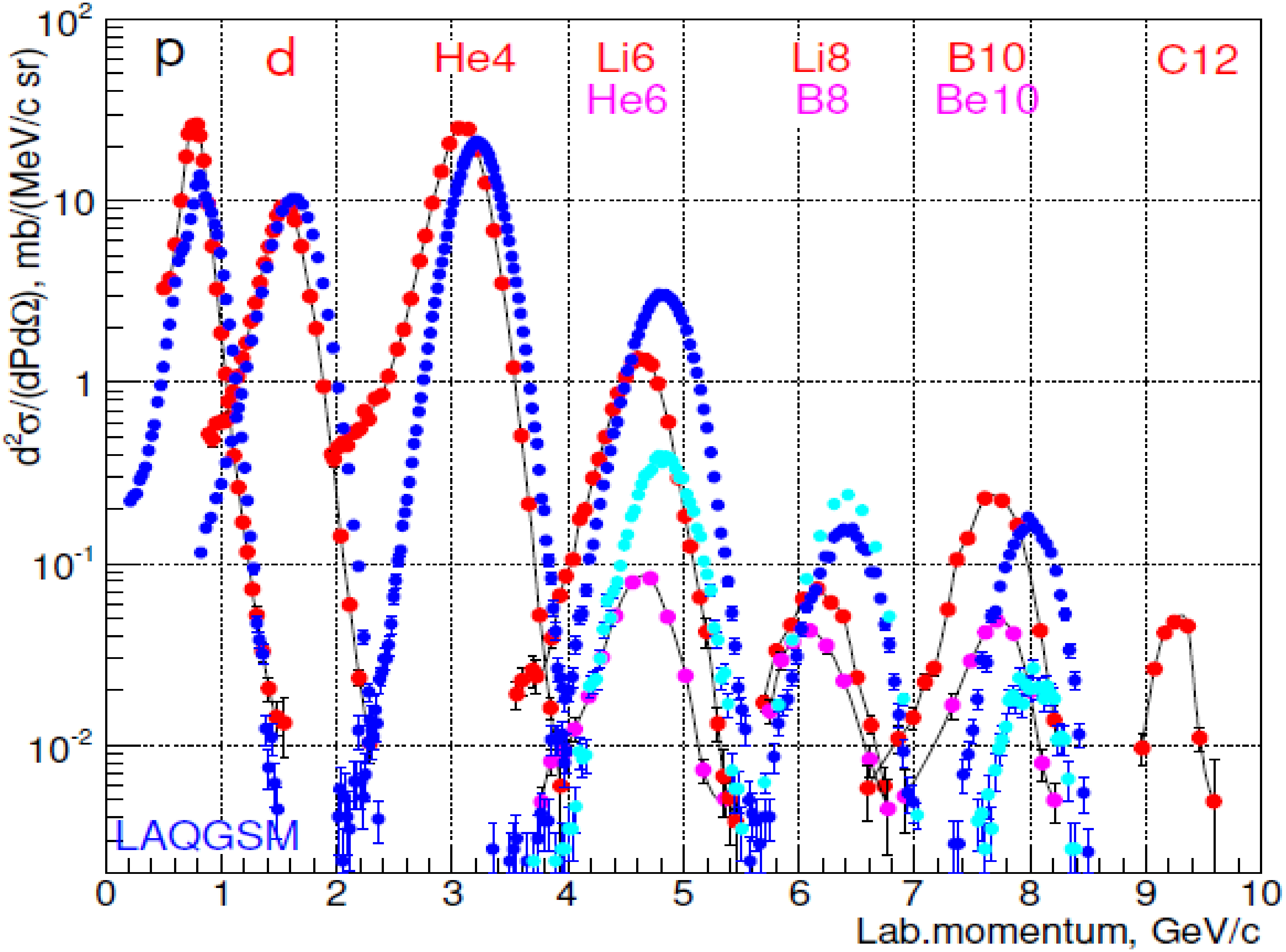
Neutron spectra in P(2.0 GeV) +208Pb at different centralities



FRAGM experiment at the ITEP TWA

heavy- ion accelerator. Carbon fragmentation at 300 MeV/nucleon in the reaction

$$12C + 9Be \rightarrow f + X$$



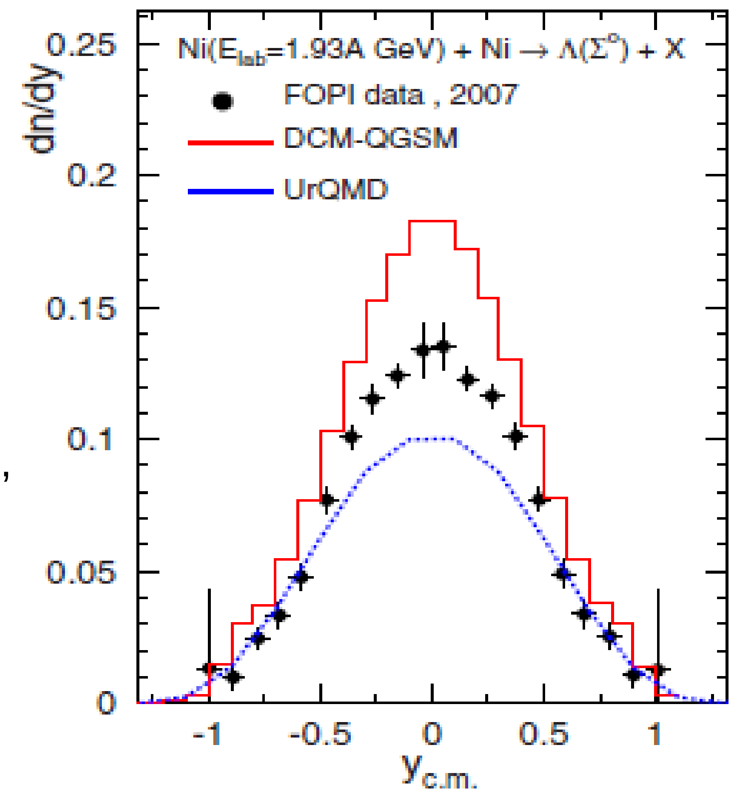
Spectra of the fragments emitted at 3.5*o* from the carbon fragmentation at 300 MeV/nucleon. B.M.Abramov, Web of Conferences **138**, 03002 (2017)

Strange particle production and formation of hypernuclei in heavy-ion collisions

In all transport models the production of hyperons is associated with nucleon-nucleon collisions, e.g., $p + n \rightarrow n + \Lambda + K^+$, or collisions of secondary mesons with nucleons, e.g., $\pi^+ + n \rightarrow \Lambda + K^+$, and some other binary collisions. Strange particles may be produced in the participant zone, however, the particles can rescatter and undergo secondary interactions. As a result the produced hyperons populate the whole momentum space around the colliding nuclei, including the vicinity of nuclear spectators, and can be captured by the spectator residues. The hyperon capture can be described by both the potential and the coalescence approach. The capture of produced Λ hyperons by nuclear spectator residues can be easily obtained within the potential criterion: It takes place if a hyperon kinetic energy in the rest frame of the residue is lower than the attractive hyperon potential, which is around 30 MeV in matter at normal nuclear density $\rho_0 \approx 0.15\ \mathrm{fm}^{-3}$. The coalescence criterion uses the proximity of baryons in momentum and coordinate space. the coalescence of baryons can be applied after the dynamical stage of reaction.

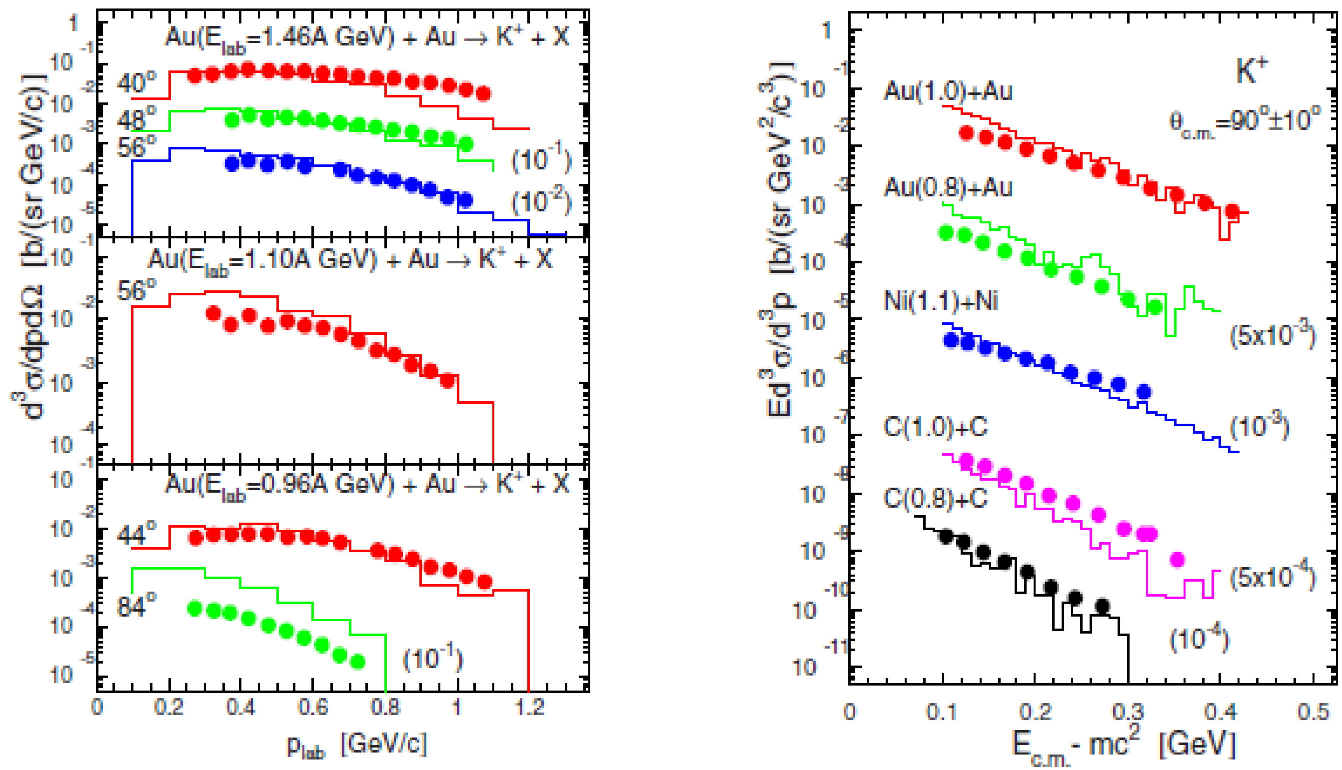
Rapidity distributions of Λ and Σ^0 hyperons

A. S. Botvina, K. K. Gudima, J. Steinheimer et. al,
PRC **84**, 064904 (2011).
A. S. Botvina, K. K. Gudima, J. Steinheimer, et. al,
PR C **95**, 014902 (2017).



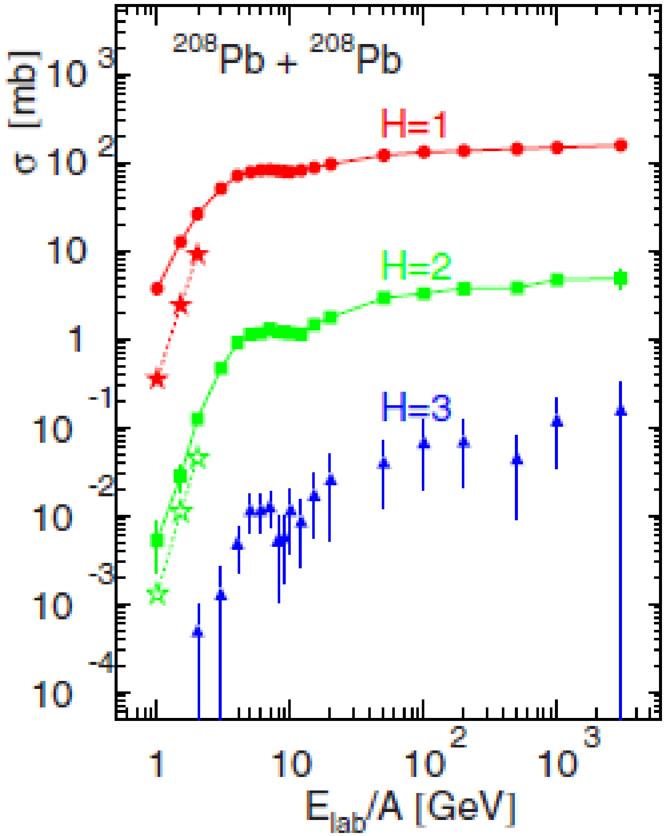
$$V_\Lambda(\rho) = -\alpha \frac{\rho}{\rho_0}\left[1 - \beta\left(\frac{\rho}{\rho_0}\right)^{2/3}\right],$$

Double-differential cross sections as functions of the laboratory particle momenta for the production of K⁺ mesons in the gold on-gold collisions at subthreshold energies under different angles and invariant cross sections for the production of of K⁺ mesons in the center-of-mass system versus their kinetic energy under the angle of 90◦ degree, in the gold, nickel, and carbon symmetric ion collisions. The The DQGSM calculations are given by histogram, the experimental data (solid circles) are taken from Ref. [C. Sturm *et al.*, Phys. Rev. Lett. **86**, 39 (2001). and A. Forster *et al.* (KaoS Collaboration), Phys. Rev. C **75**, 024906 (2007)].



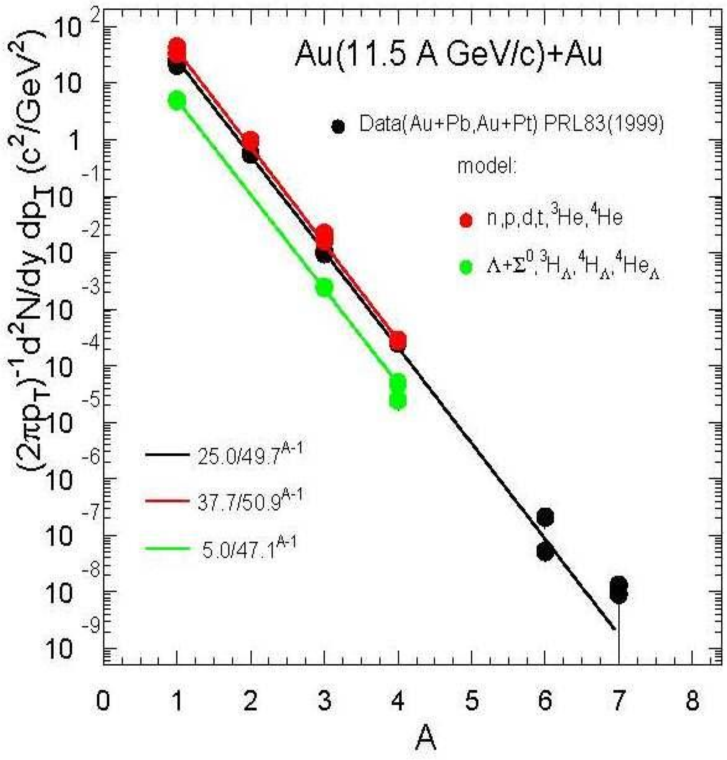
Yields of spectator residues after the capture of one, two, and three Λ hyperons.

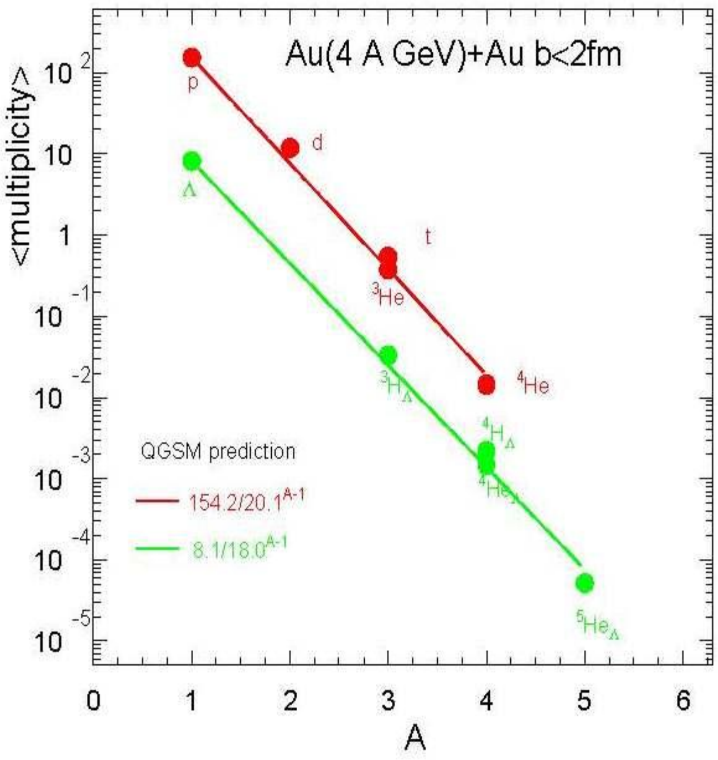
Absolute yields (in mb) of the hyperspectator residues (projectiles or targets) in lead on lead collisions versus the laboratory energies. The numbers of captured Λ hyperons (H) are shown in the figure. The circles and squares (connected by solid lines) and triangles are DQGSM calculations. UrQMD results are noted by stars and connected by dashed lines



Proposal for NICA
(Gudima: NICA-White Paper)

Fragments and HyperFragments Yield in Au + Au



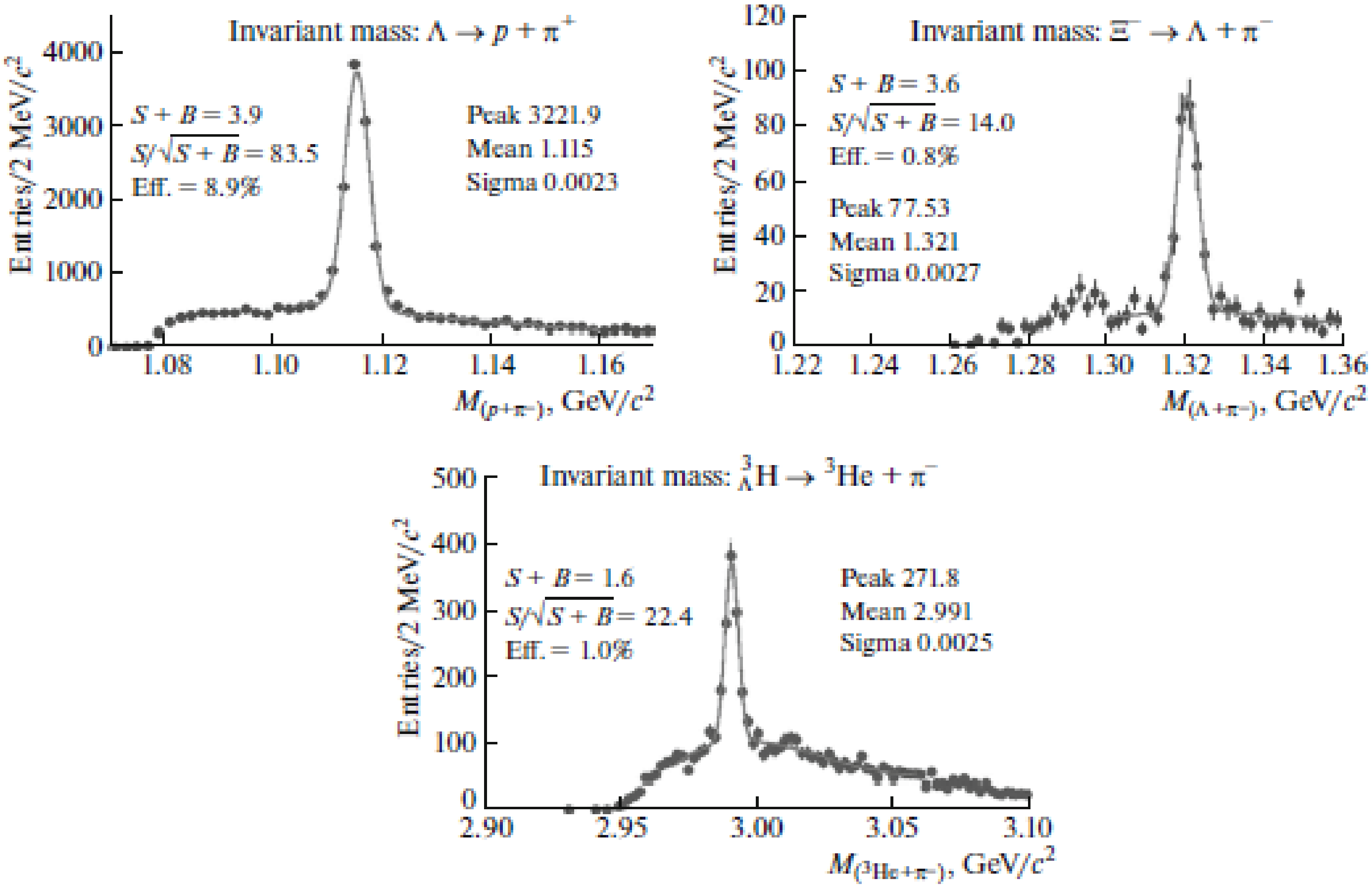


Usage of DQGSM at NICA

The Fixed Target Experiment for Studies of Baryonic Matter at the Nuclotron (BM@N)

M. N. Kapishin (for BM@N collaboration)

- Simulation of C+C, C+Al, C+Ar, C+Kr, Ar+C, Ar+Al, Ar+Ar, Ar+Kr, Kr+C, Kr+Al, Kr+Ar, Kr+Kr, Kr+Pb reactions
- The simulation aimed for optimization of BM@N The interactions of Au + Au nuclei are generated using the and DQGSM models describing collisions of heavy nuclei.
- The collision products are transported through the BM@N setup using the GEANT program and are reconstructed by applying the track reconstruction algorithm for multiparticle events.



Distributions of invariant mass of products of Λ-hyperon, Ξ^--hyperon, and hypertritium decay reconstructed in the GEM (Gaseous Electron Multiplier) tracker in central collisions of Au + Au at the beam kinetic energy of 4.5 AGeV. The statistics of the simulated events are ~ 10^6 events. With the same statistics C+C, C+Al, C+Ar, C+Kr reactions were calculated and data files were prepared.

A MONTE CARLO STUDY OF LAMBDA HYPERON POLARIZATION AT BM@N

D. Suvarieva, K.Gudima, A. Zinchenko

Physics of Particles and Nuclei Letters, 2018, Vol. 15, No. 2, pp. 182–188.

The polarization of the lightest strange hyperon Λ, is studied. Its decay $\Lambda \rightarrow p + \pi^-$ is fully reconstructible and the polarization can be extracted from the angular distribution of the final state particles. The polarization is measured with respect to the production plane of the Λ hyperon:

$\boldsymbol{n} = \boldsymbol{p}_{beam} \times \boldsymbol{p}$, where $\boldsymbol{p}_{beam}$ is aligned with the direction of the incoming beam and is the momentum. In the rest frame, the angle between the decay proton and the analyzing direction ***n*** will follow the probability distribution:

$$w(\cos(\theta))=1/2(1+\alpha P w(\cos(\theta)),$$

where ***α =0.642*** is the decay asymmetry of the parity violating weak decay $\Lambda \rightarrow p + \pi^-$ and ***P*** is transverse Λ polarization. The production of hyperons in heavy-ion collisions at NICA energies was simulated with the DQGSM code.

Thank your for attention!