Monte Carlo Generator DCM-SMM

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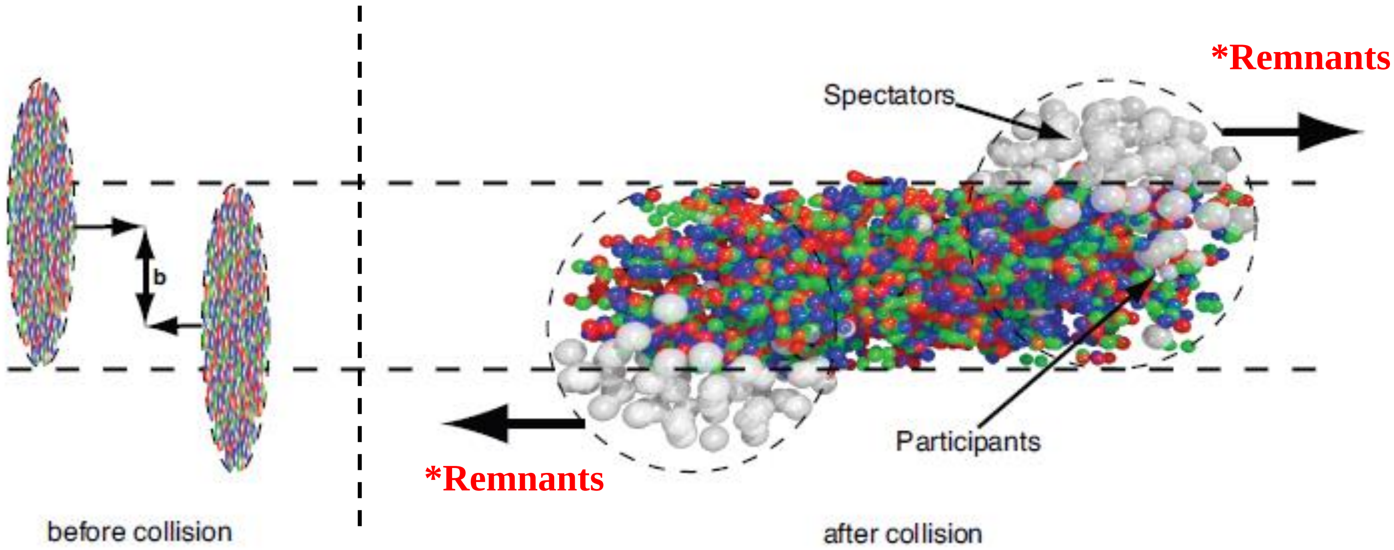
Content

- Motivation
- DCM–QGSM – previous version
- DCM–SMM: modified DCM-QGSM + SMM
- Comparison to data
- Further Development

Motivation

Heavy Ion Collision



Motivation

- Kinetic Monte-Carlo models of heavy ion collisions

  URQMD, pHSD, LAQGSM, …

- Description of interaction/participant zone

  URQMD, pHSD, LAQGSM

- Description of spectator/remnant zone

  LAQGSM

  DCM-QGSM basic component LAQGSM

of

Motivation

- Kinetic Monte-Carlo models of heavy ion collisions

  URQMD, pHSD, LAQGSM, DCM-QGSM, …

- Description of interaction/participant zone

  URQMD, pHSD, LAQGSM, DCM-QGSM

- Description of spectator/remnant zone

  LAQGSM – commercial code

  DCM-QGSM basic component LAQGSM

- Modification of DCM-QGSM → DCM-SMM

DCM-QGSM

Main ingredients

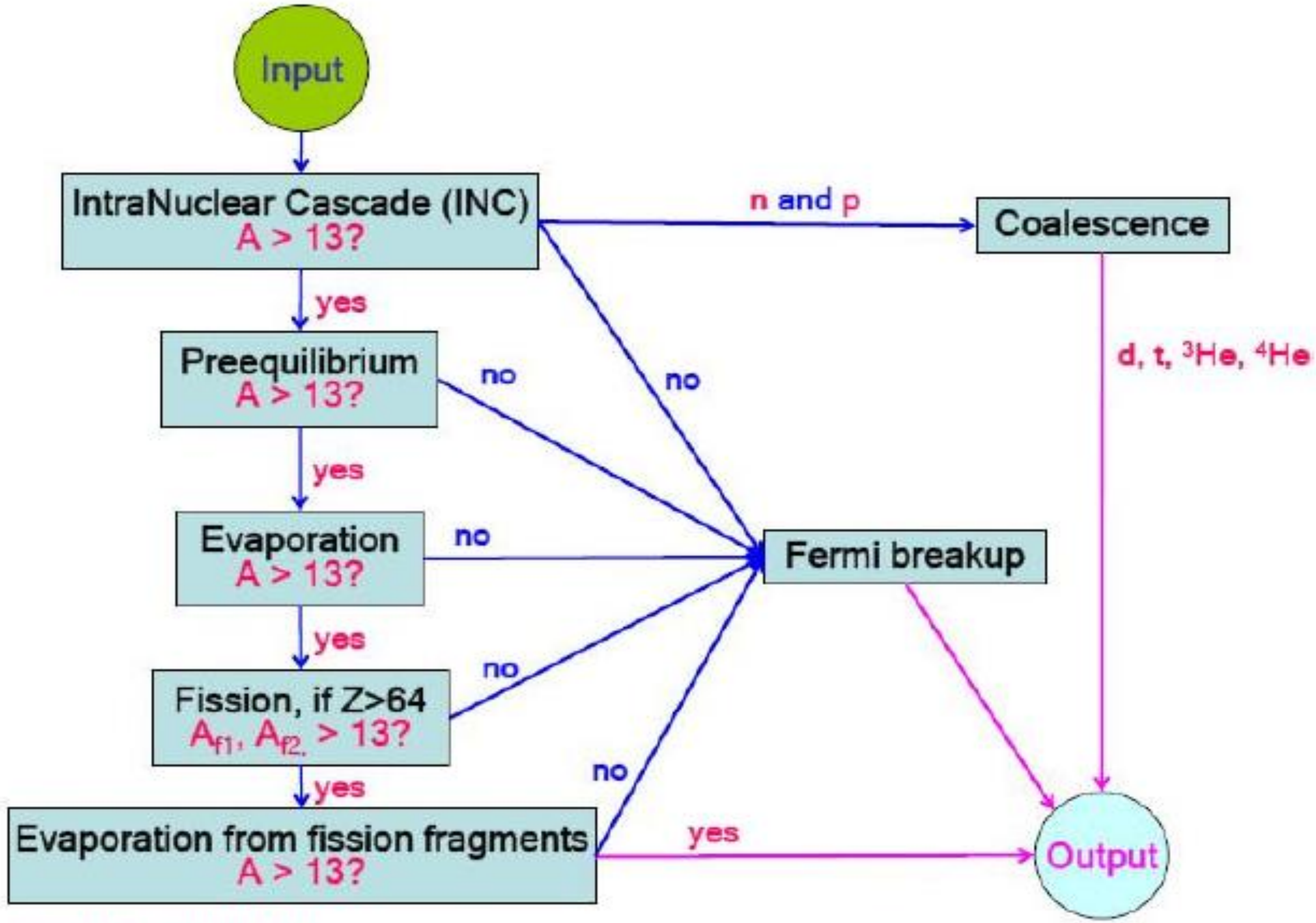
- **DCM –** Monte-Carlo solution of BUU relativistic kinetic equation
- **Nucleus-nucleus collisions –** incoherent superposition of binary interactions
- **Black disk appr.** – criterion of binary interaction cross section
- **Nucleus –** Fermi gas of nucleons confined in Woods-Saxon potential
- **Nucleon momenta:** $0 < p < p_F$, p_F - boundary Fermi momentum
- **Pauli (exclusion) principle**

DCM-QGSM

DCM-QGSM – 4-stage model

- **Fast binary collisions** with particle production
- **Coalescence** of secondary nucleons
- **Pre-equilibrium emission** of highly excited remnants
- **Sequential evaporation and/or fision**

Scheme of DCM calculations



DCM-QGSM

N + N → BB
N + N → BBX
B: p, n, N*, Δ, Λ, Σ, Ξ, Ω
X ⟶ M: ρ, ω, η, φ
M + B → BX
M + M → X

Fast, binary interaction stage

- **DCM**

  E_{Lab} < 4.5AGeV

  hadrons → hadrons (nucleons, deltas, hyperons, mesons)
- **QGSM**

  ELab > 4.5AGeV

  hadrons → quark-gluon strings → hadrons

DCM+QGSM
E_{Lab} > 4.5 AGeV

QGSM

N.S. Amelin, L.V. Bravina, L.I. Sarycheva, and L.N. Smirnova, Sov. J. Nucl. Phys. 50 (1989) 1058;
N.S. Amelin, K.K. Gudima, V.D. Toneev, Sov. J. Nucl. Phys. 51 (1990) 327;
N.S. Amelin and L.V. Bravina, Sov. J. Nucl. Phys. 51 (1990) 133;
N.S. Amelin, L.V. Bravina, L.P. Csernai, V.D. Toneev, K.K. Gudima, and S.Yu. Sivoklokov, Phys. Rev. C 47, 2299 (1993).

Binary collisions

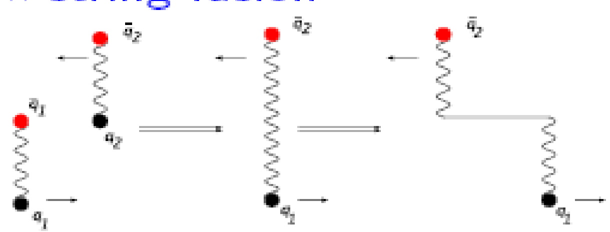
- ✓ formation quark-gluon strings between quark and di-quarks
- ✓ hadronization of strings in the framework of DPM (*A. B. Kaidalov, Sov. J. Nucl. Phys. 45 (1987) 902-907*)
- ✓ ends of strings - leading particles
- ✓ Formation time concept

QGSM

- Particularities of space-time evolution

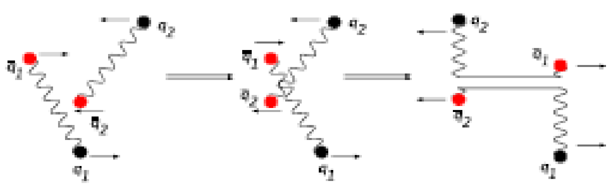
CLASSICAL STRING THEORY

⋆ string fusion



time ⇒

⋆ string rearrangement

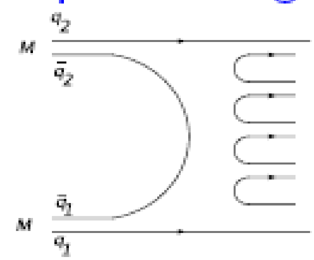


⋆ leading particle effect

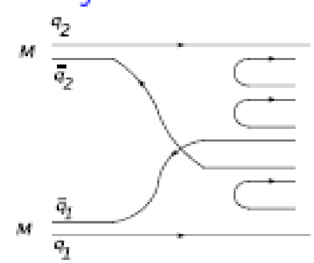
⋆ color rope formation

DUAL TOPOL. MODEL

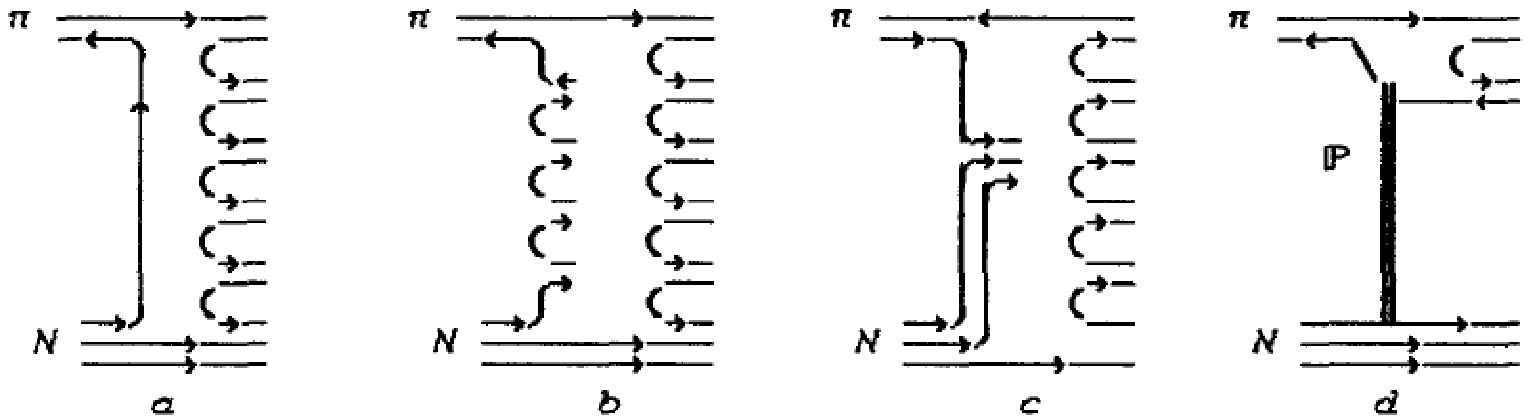
⋆ planar diagram



⋆ cylindrical diagram



QGSM



Topological diagrams for the multiparticle production in πN collisions: a - planar, b - cylindrical, c - "undeveloped" cylindrical, d - diffractive.

$$\sigma_{tot} = \sigma_{pl} + \sigma_{cyl} + \sigma_{und} + \sigma_{dif} + \sigma_{el}.$$

String extends between constituents.

String breaks by q-qbar pair according to u : d : s : qq = 1 : 1 : 0.27 : 0.1

At break -> new string + hadron

QGSM

The longitudinal momentum distribution of the constituent quark

$$u_B(x) \sim x^{-1/2}(1-x)^a,$$

$$u_M(x) \sim x^{-1/2}(1-x)^{-0.5},$$

a=1.5 for *u*-quark
a= 2.5 for *d*-quark

The transverse momentum distribution of the constituent quark

$$\omega(p_\perp) = (\pi\sigma_\perp^2)^{-1/2}\exp(-p_\perp^2/\sigma_\perp^2) \qquad \sigma_\perp = 0.51 \text{ GeV/c}$$

The fragmentation functions:

$$\begin{aligned} f_{q\to M}(z) &= 1-a+2a(1-z), \\ f_{qq\to B}(z) &= 0.4+0.6\exp[-20(1-z)]/[1+\exp(-20)], \\ f_{qq\to M}(z) &= 3a(1-z)^2, \end{aligned}$$

Particle in QGSM

Particle	*PDG ID*	*Particle*	*PDG ID*	*Particle*	*PDG ID*
γ	22	K^0_L	130	Σ^+	3222
e^-	11	K^0_S	310	Σ^0	3212
ν_e	12	K^0	311	Σ^-	3112
μ^-	13	K^+	321	Σ^{*+}	3224
ν_μ	14	K^-	-321	Σ^{*0}	3214
π^0	111	K^{*0}	313	Σ^{*-}	3114
π^+	211	K^{*+}	323	Ξ^0	3322
π^-	-211	p	2212	Ξ^-	3312
ρ^0	113	n	2112	Ξ^{*0}	3324
ρ^+	213	Δ^{++}	2224	Ξ^{*-}	3314
ρ^-	-213	Δ^+	2214	Ω^-	3334
η	221	Δ^0	2114		
η'	331	Δ^-	1114		
ω	223	Λ	3122		
φ	333				

DCM-QGSM

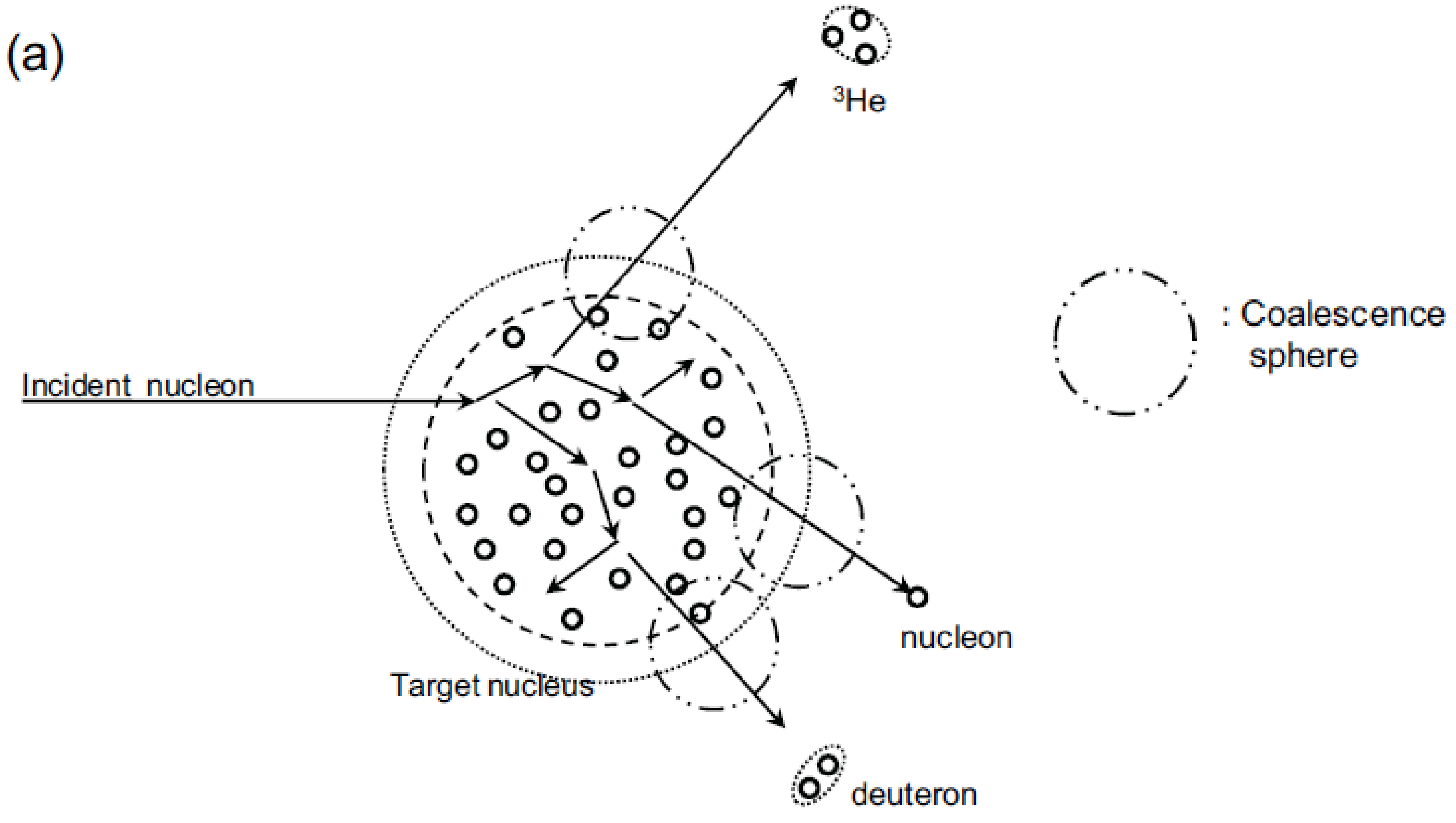
Coalescence Stage

Coalescence of secondaries

- light fragments formation (d, ^3H, ^3He, ^4He)
- hyperfragments formation ($^3H_\Lambda$, $^3He_\Lambda$, $^4He_\Lambda$,$^5He_\Lambda$)
- coalescence criteria: $(p_i - p_0) < p_c$ and $(r_i - r_0) < r_c$
- p_c , r_c – parameters

DCM-QGSM

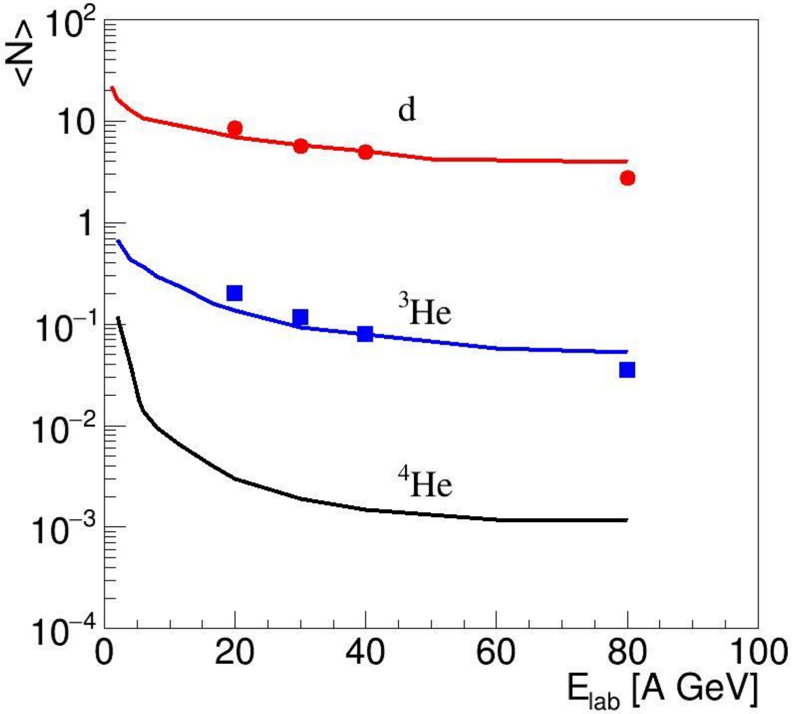
Coalescence stage

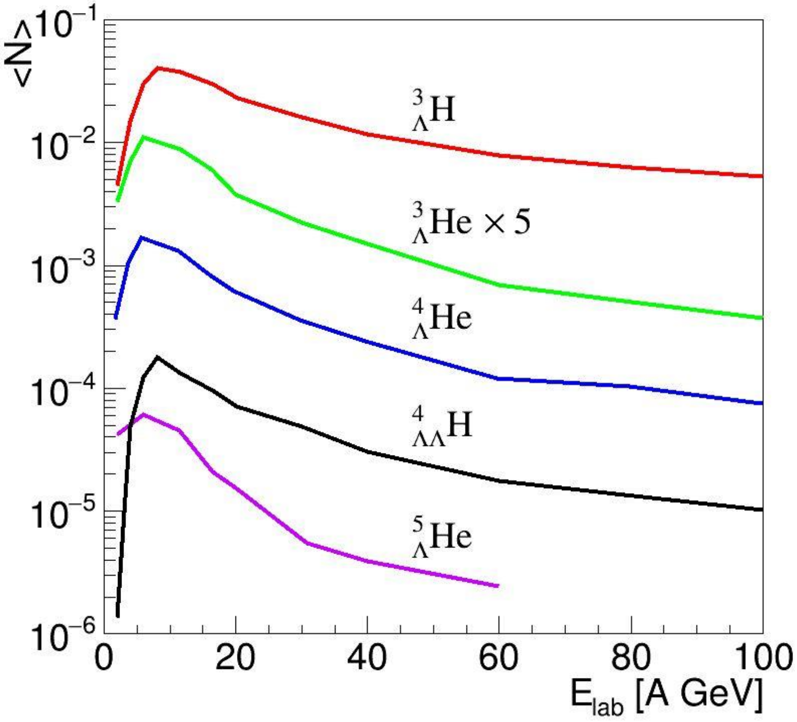


Schematic representation of the surface coalescence model

Coalescence

Data are from NA49





DCM-QGSM
Spallation of excited remnants

Pre-equilibrium Stage

emission of particles from excited remnants with $A \leq 13$

Spallation of remnants

Fermi break-up

(sequential) evaporation and/or fission

DCM-QGSM

3-th stage: Preequilibrium emission

- Pre-equilibrium particles – particles emitted after coalescence stage but before equilibration of a residual nucleus.
- Initial configuration for pre-equilibrium decay – number of excitons n_0 (particles p_0 and holes h_0)

$$n_0 = p_0 + h_0$$

- Subsequent emissions of **n, p, d, t, 3He**, and **4He**.

DCM-QGSM
If $A_{residual} \leq 13$ → **Fermi Break-Up**

- Input for Fermi Break-up of residual:

$E = U + M(A, Z)$ – its total energy
U – its excitation energy

- Break-up probability

$$W(E,n) = (V/\Omega)^{n-1}\rho_n(E)$$

where V – volume of decaying A, $\Omega = (2\pi h)^3$

$A_{residual}$ → $p, n, d, t, {}^3He, {}^3He, \ldots$

DCM-QGSM
Spallation of excited remnants

Evaporation

nucleons and light fragments emission (p, n, d, ^{3}H, ^{3}He, ^{4}He)

Fission

fission of heavy excited nucleus (A > 100) into 2 or 3 fragments

Shortcoming of DCM-QGSM

Poor description of intermediate mass fragments

DCM-SMM: DCM-QGSM + SMM

We need to improve intermediate mass fragments production

SMM – Statistical Multifragmentation Model

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

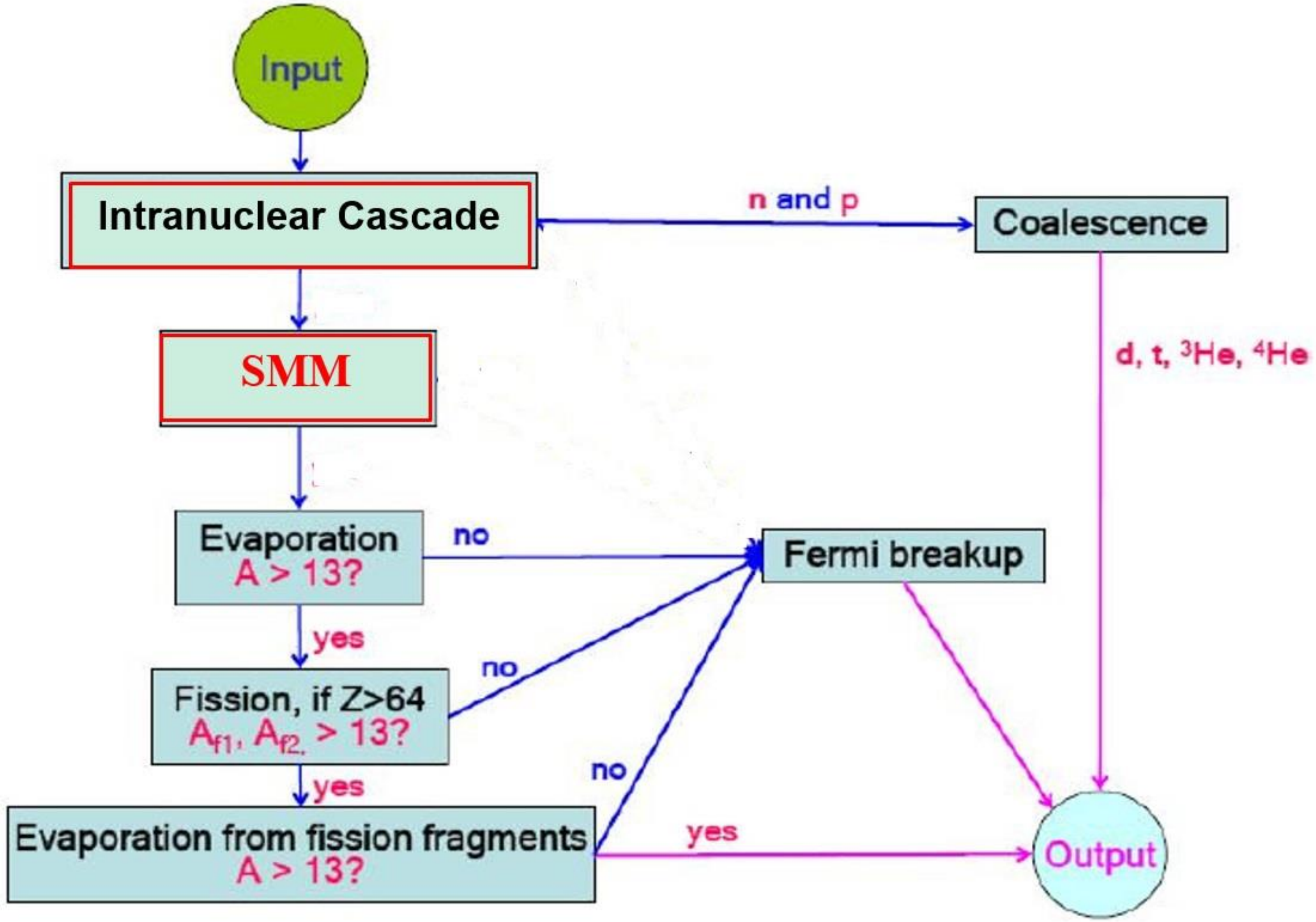
J.P. Bondorf, A.S. Botvina, A.S. Ilinov, I.N. Mishustin, K. Sneppen, Phys.Rep. 257 (1995) 133-221

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

DCM-SMM: DCM-QGSM + SMM

- DCM-QGSM + coalescence – preequilibrium
- SMM + Fermi break-up + Evaporation + fission

Scheme of DCM-SMM

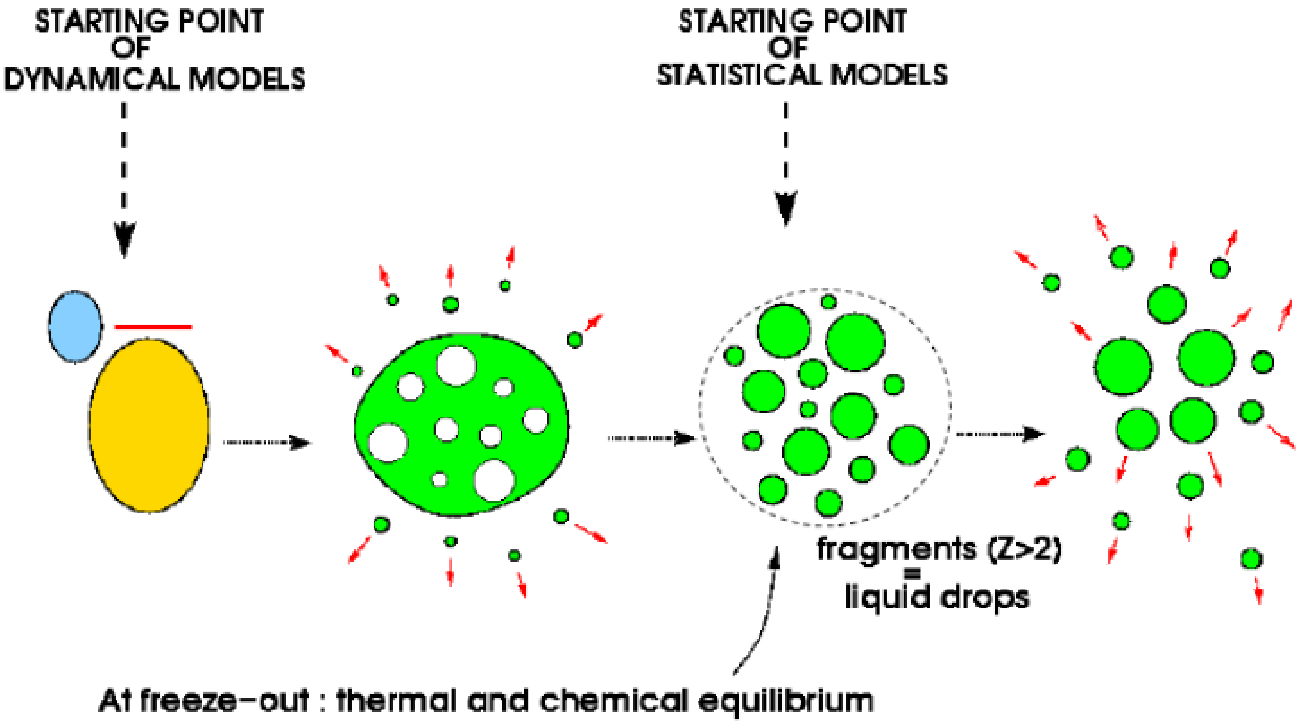


SMM

Multifragmentation in intermediate and high energy nuclear reactions

Experimentally established:

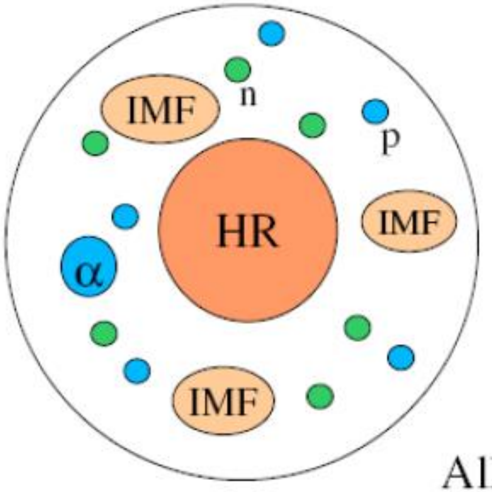
1) few stages of reactions leading to multifragmentation,
2) short time ~100fm/c for primary fragment production,
3) freeze-out density is around $0.1\rho_0$,
4) high degree of equilibration at the freeze-out,
5) primary fragments are hot.



SMM

Statistical Multifragmentation Model (SMM)

J.P.Bondorf, A.S.Botvina, A.S.Iljinov, I.N.Mishustin, K.Sneppen, Phys. Rep. **257** (1995) 133



Ensemble of nucleons and fragments in thermal equilibrium characterized by

neutron number N_0

proton number Z_0, $N_0+Z_0=A_0$

excitation energy $E^*=E_0-E_{CN}$

break-up volume $V=(1+\kappa)V_0$

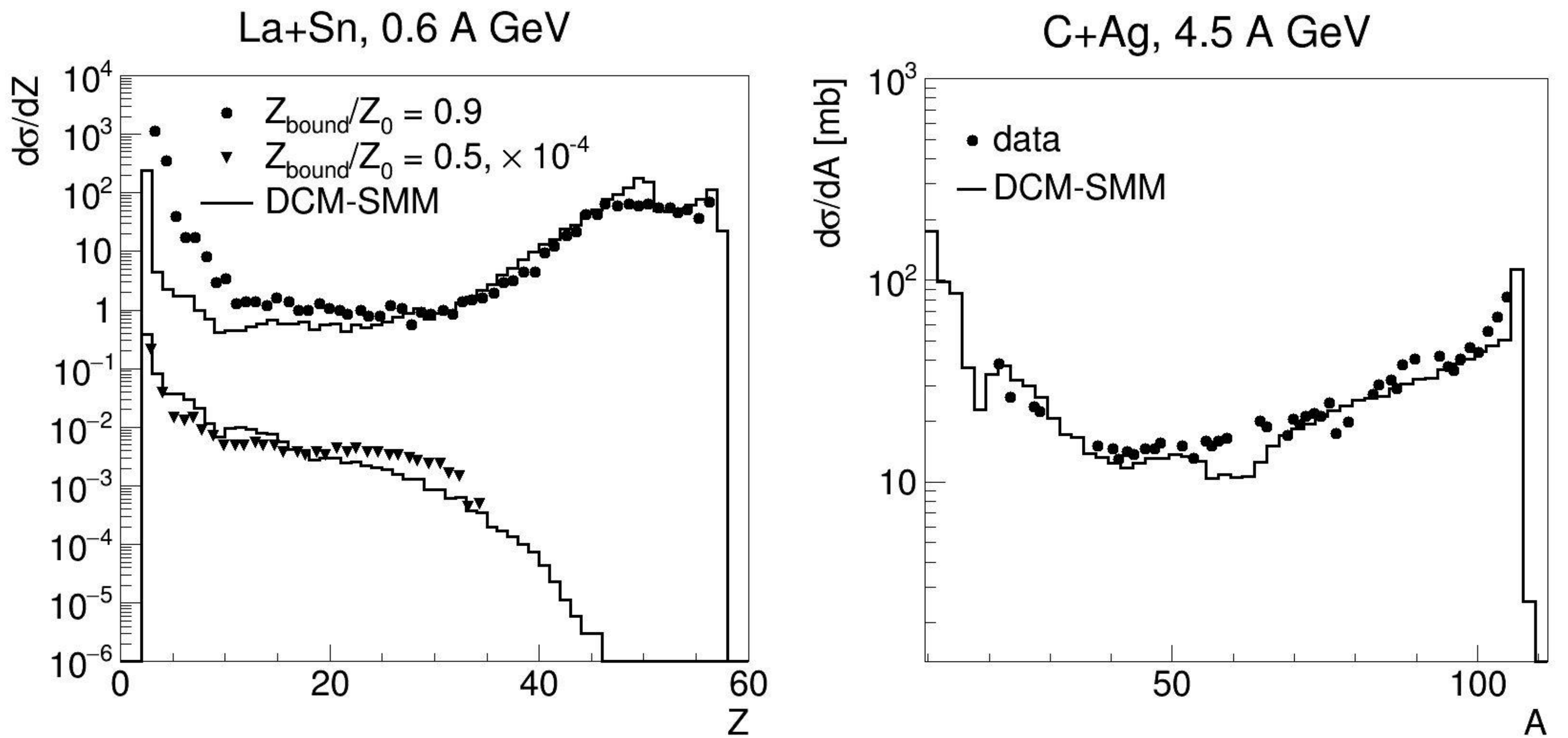
All break-up channels are enumerated by the sets of fragment multiplicities or partitions, $f=\{N_{AZ}\}$

Statistical distribution of probabilities: $W_f \sim \exp\{S_f(A_0, Z_0, E^*, V)\}$

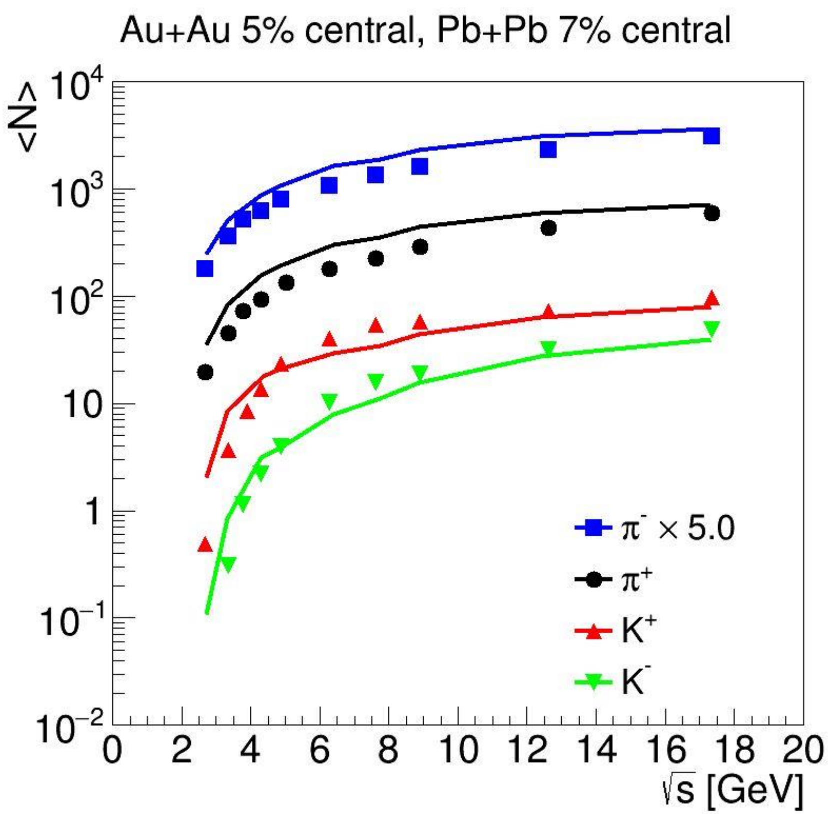
under conditions of baryon number (A), electric charge (Z) and energy (E*) conservation, including compound nucleus.

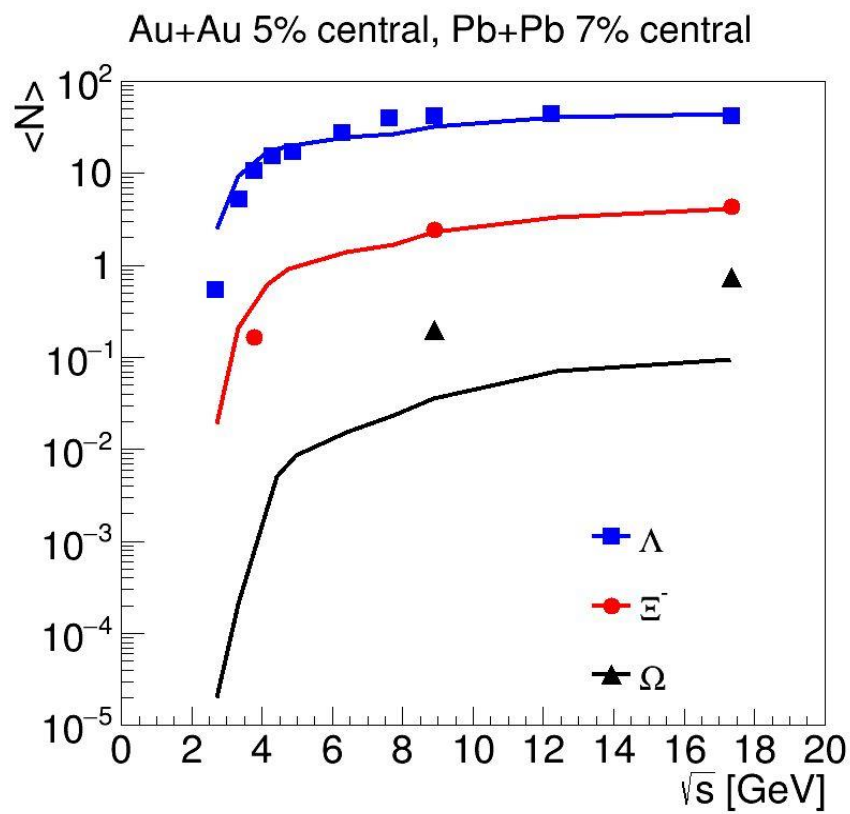
DCM-SSM vs Experiment

Nuclear Fragmentation



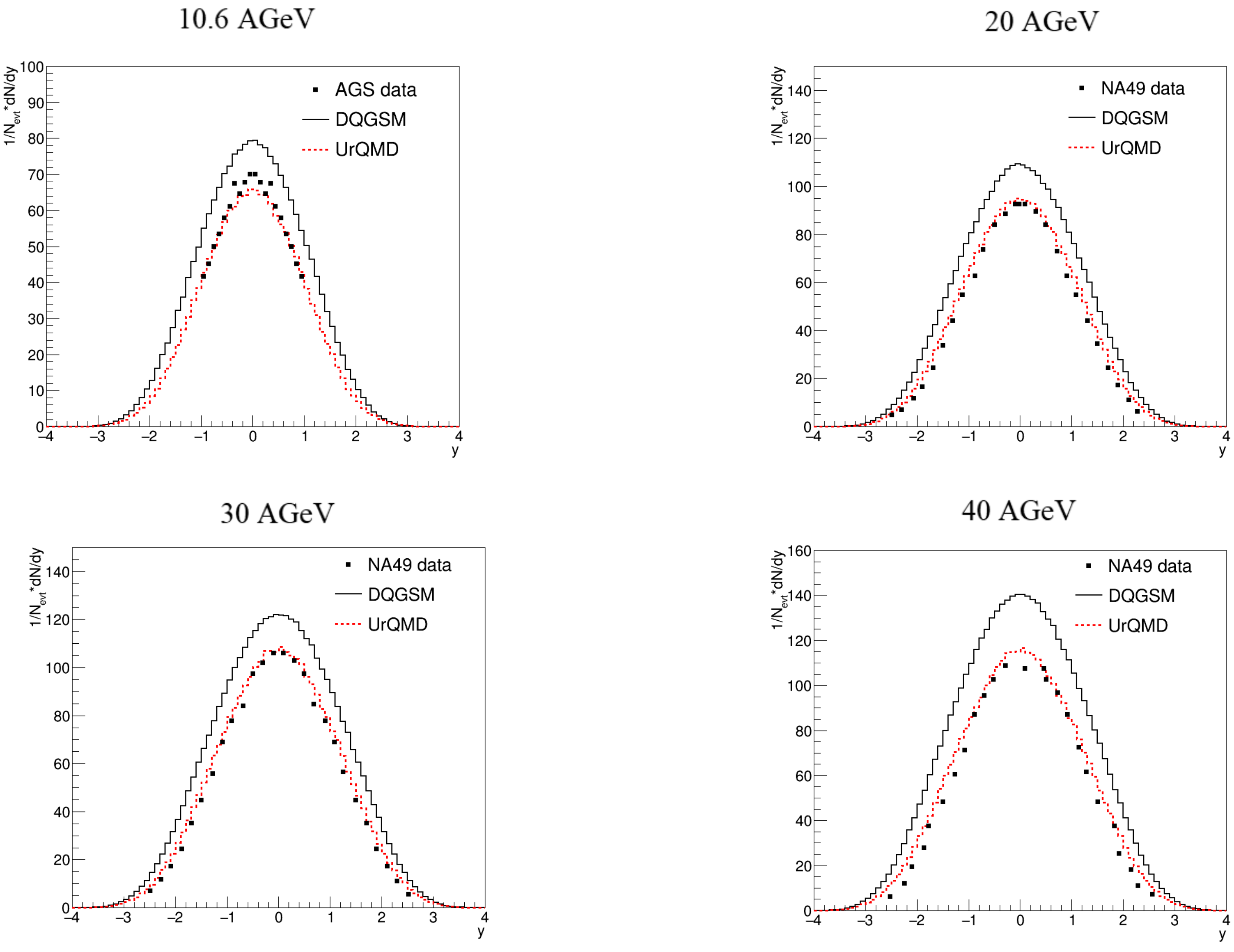
DCM-SSM vs Experiment: **AGS**, Au+Au; **NA49**, Pb+Pb
Particle Production





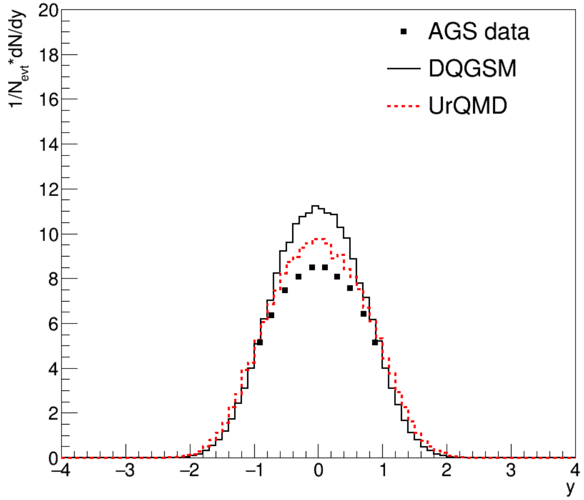
DCM-SSM vs Experiment: **AGS**, Au+Au; **NA49**, Pb+Pb

π^- - rapidity distributions

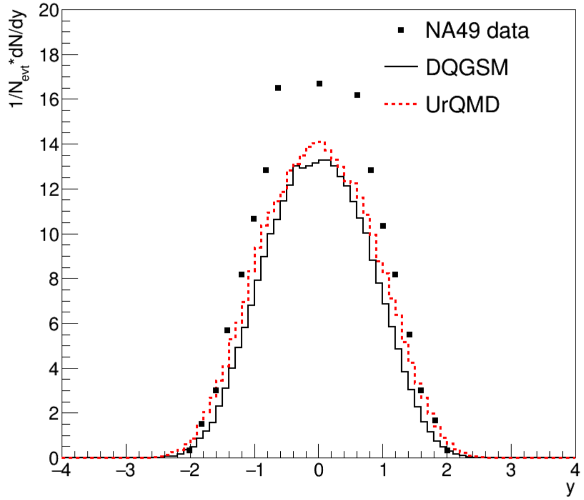


DCM-SSM vs Experiment: **AGS**, Au+Au; , **NA49,** Pb+Pb
K^+- rapidity distributions

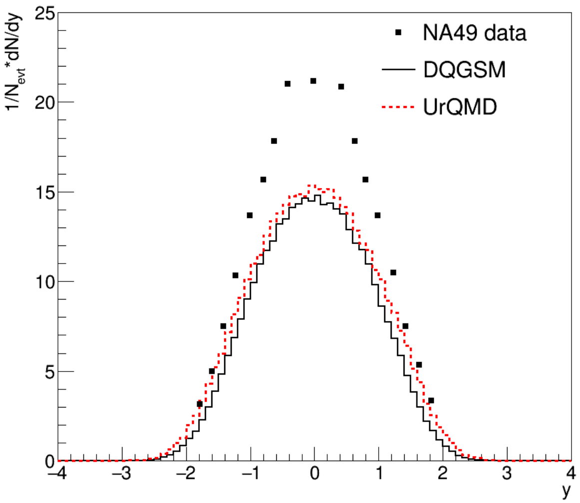
10.6 AGeV



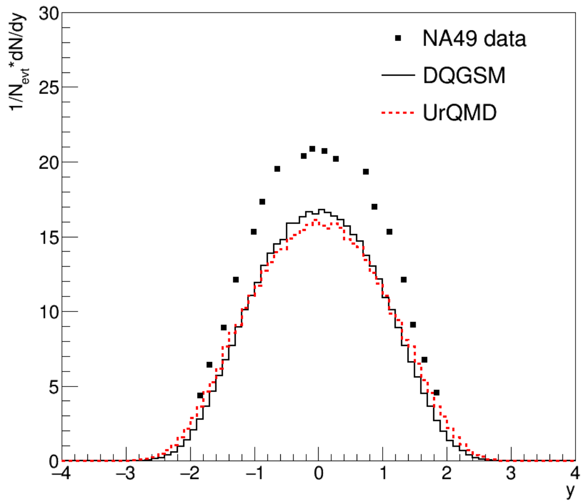
20 AGeV



30 AGeV

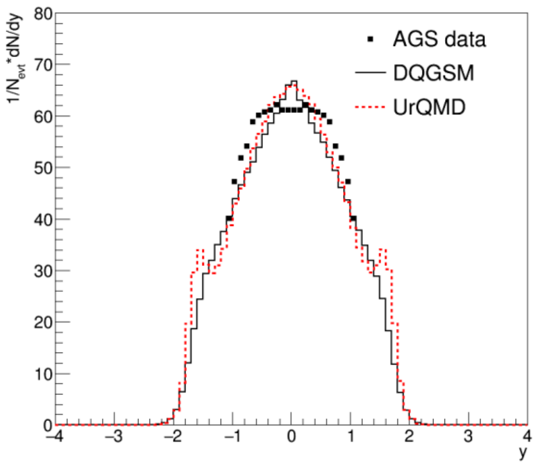


40 AGeV

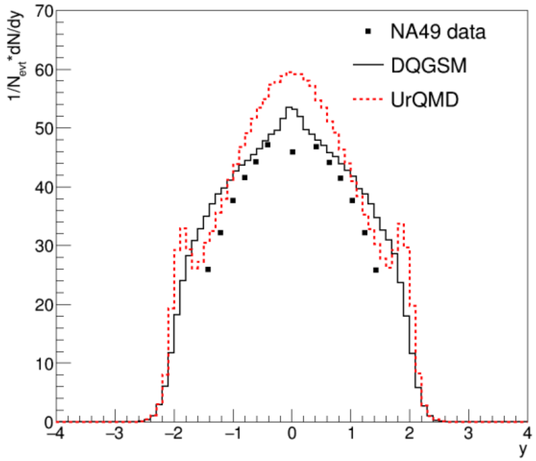


DCM-SSM vs Experiment: **AGS**, Au+Au; , **NA49,** Pb+Pb
proton - rapidity distributions

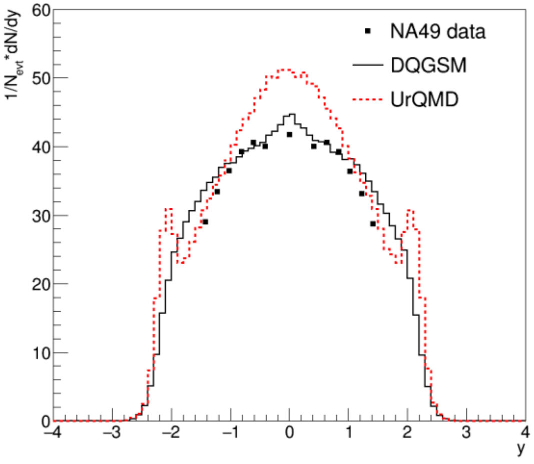
10.6 AGeV



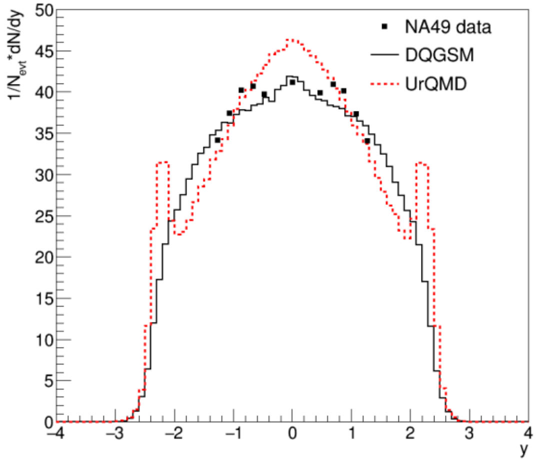
20 AGeV



30 AGeV

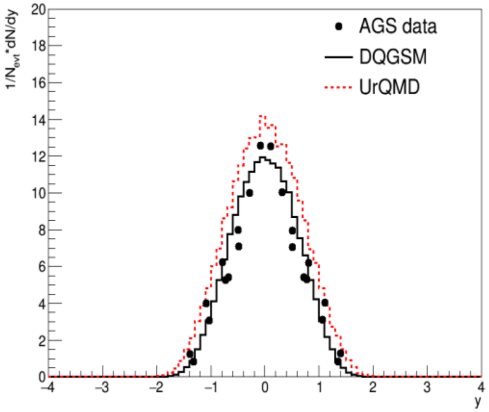


40 AGeV

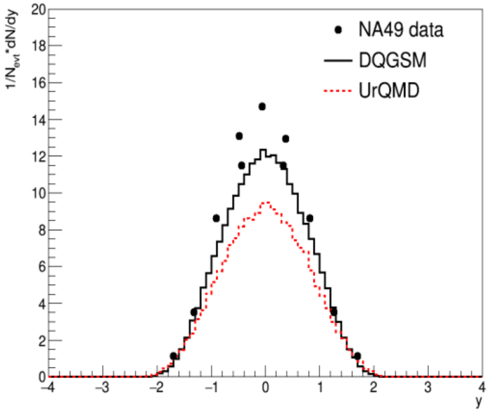


DCM-SSM vs Experiment: AGS, Au+Au; **NA49,** Pb+Pb
Λ - rapidity distributions

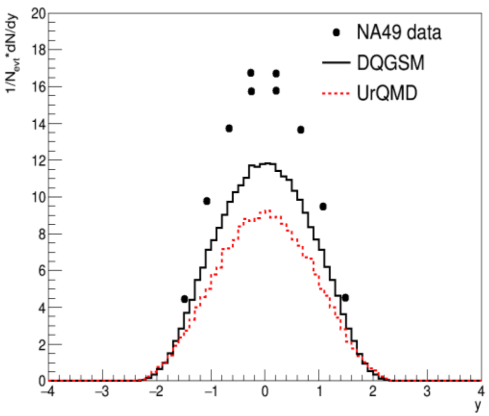
10.6 AGeV



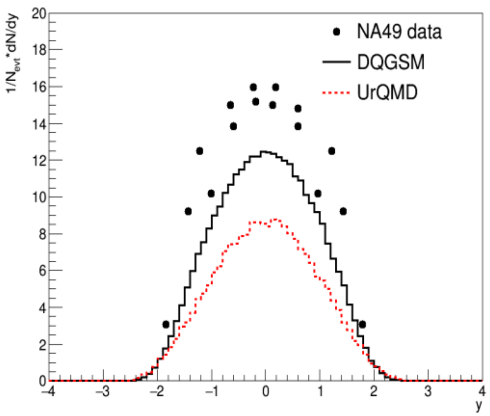
20 AGeV



30 AGeV

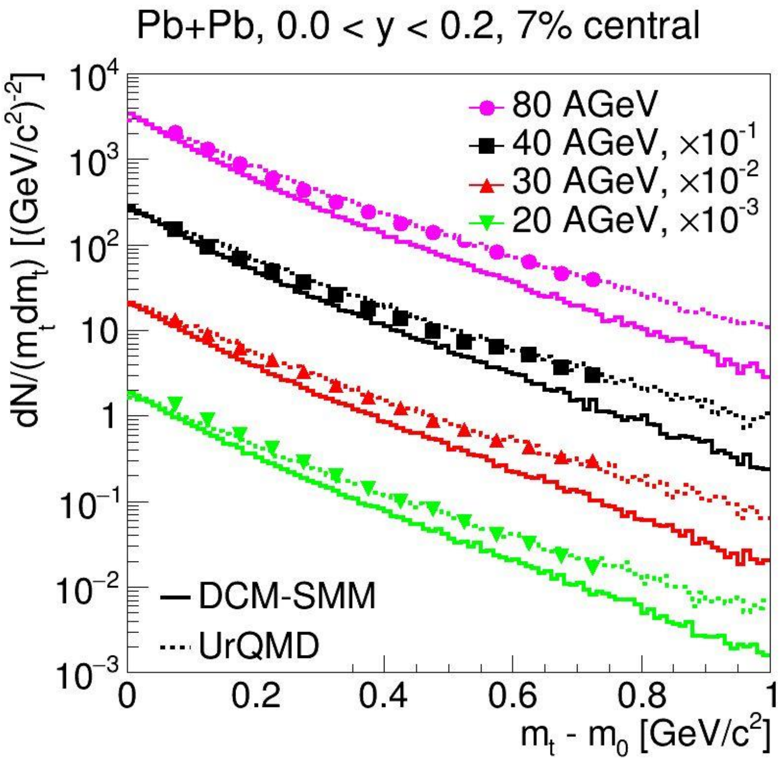


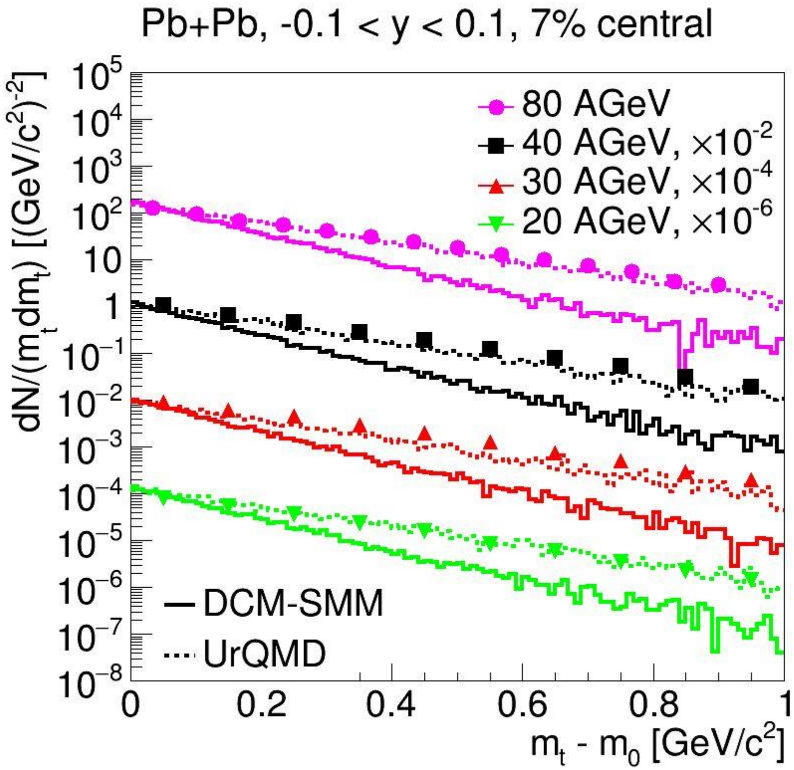
40 AGeV



DCQGSM vs Experiment: NA49, Pb+Pb

m_t - distributions

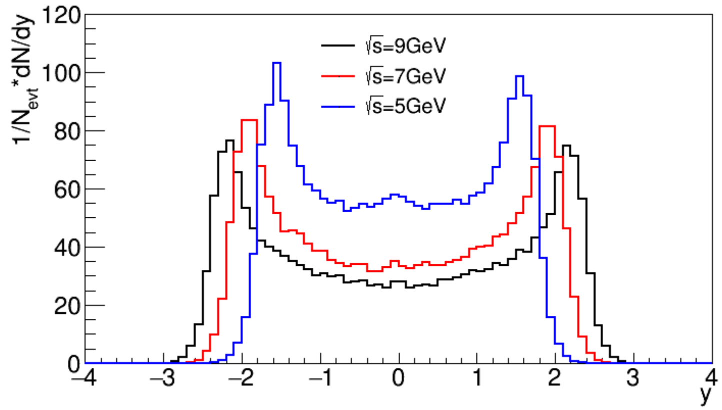




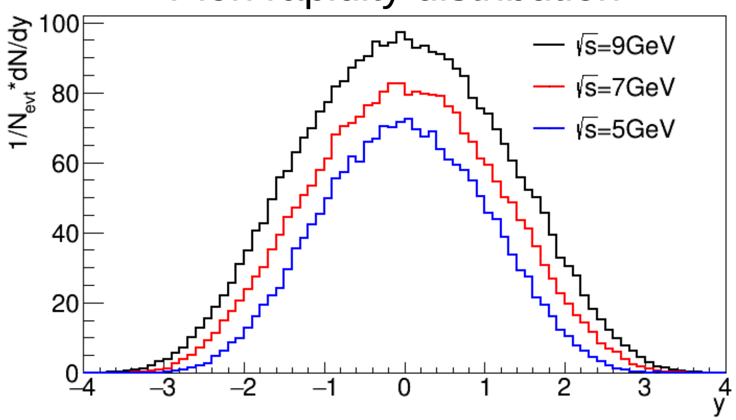
AuAu min bias collisions

DCM-SMM

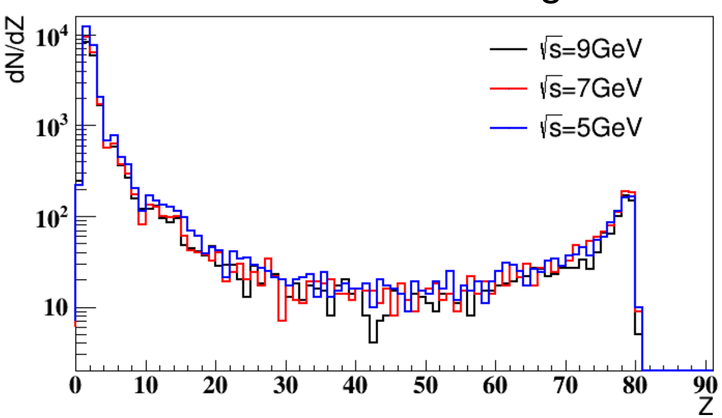
Proton rapidity distribution



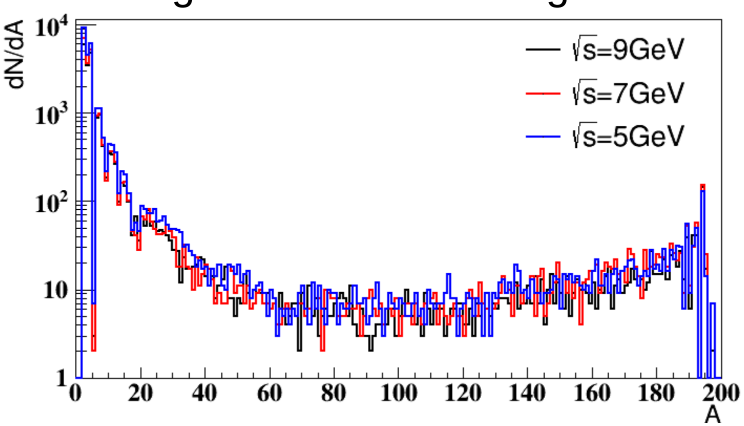
Pion rapidity distribution



Mass distribution of fragments



Charge distribution of fragments



Determination of Number of Participants in Carbon-Nucleus Collisions

- DCM-SMM
- Glauber model
- pHSD

Number of participants

Reaction	DCM-SMM	pHSD	Glauber
CC	5.1	8.3	6.9
CAl	8.3	10.1	9.4
CCu	13.9	17.1	13.6
CPb	34.0	32.5	23.1

Further Development of DCM-SMM.

- Correction of formation time concept
- Improvement of transverse mass description
- Implementation of mechanism of hyperfragment production by residuals
- Implementation of the mechanism of enhancement of strangeness
- Implementation of the mechanism of enhancement of dilepton yield

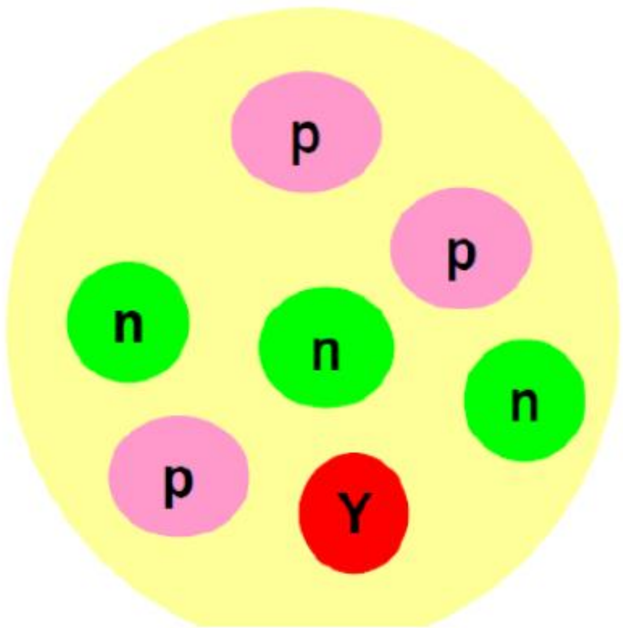
Thank you!

Backups

Hyperfragment production in DCM-SMM

Hypernucleus: Hyperons Bound in Nuclei

Hypernucleus: consists of nucleons (n, p) + hyperon (Y)



Notation:

$$_{Y}^{A}Z$$

Y = Hyperon

$Z = Z_p + (N_Y \cdot q_Y)$

$A = N_n + N_p + N_Y$

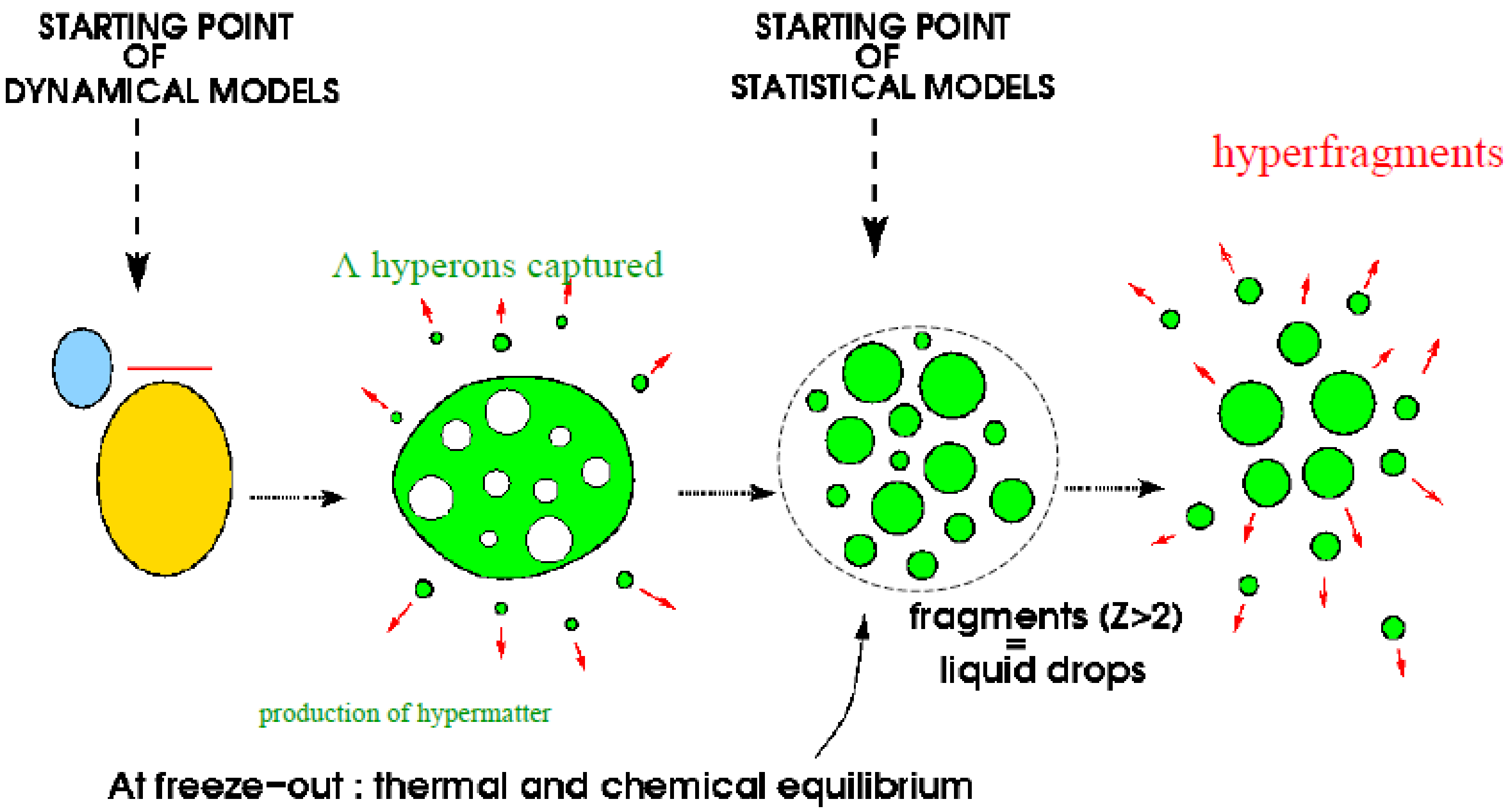
A.S.Botvina and J.Pochodzalla, Phys. Rev.C76 (2007) 024909

Generalization of the statistical de-excitation model for nuclei with Lambda hyperons

In these reactions we expect analogy with

multifragmentation in intermediate and high energy nuclear reactions

+ nuclear matter with strangeness



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: $E_H < |V_\Lambda|$

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