Fragments formation within PHQMD and do we really we need it?

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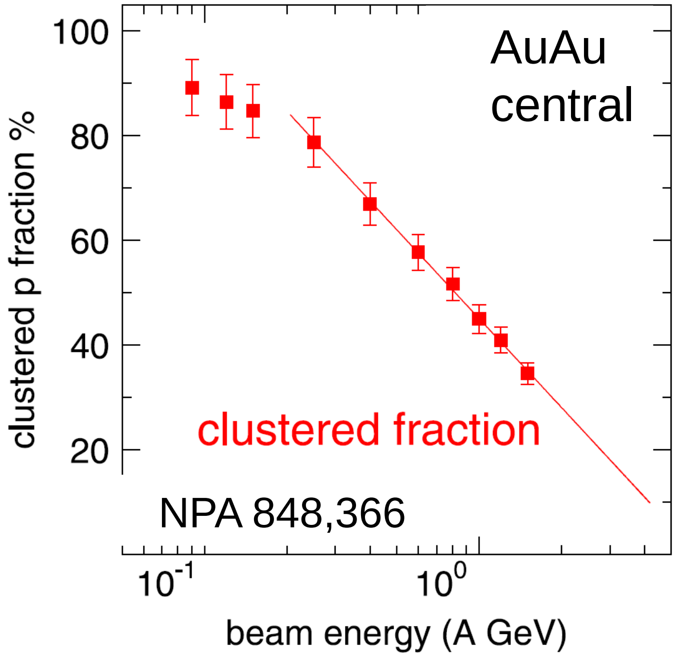
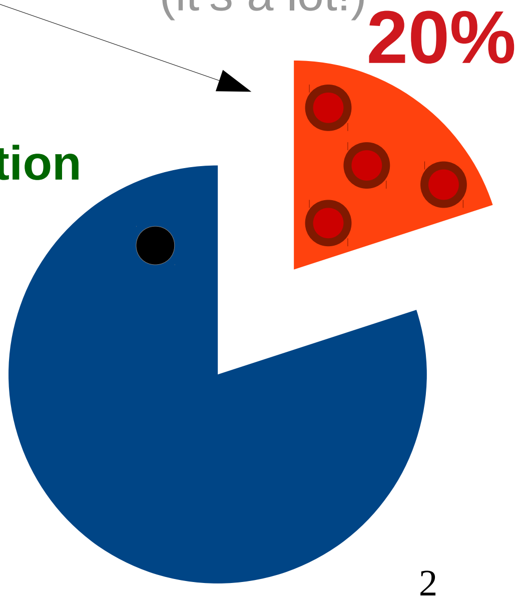
Introduction



At 3 A.GeV even in central collisions almost 20% of the baryons are bound in the clusters

(it's a lot!)

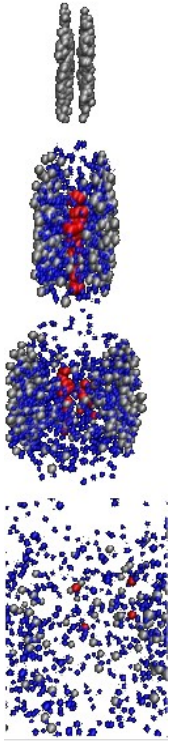


Without dynamical fragments formation we cannot properly describe observables like v1, v2, p_T spectra,

Many present transport models fail to describe fragments at NICA/FAIR (and higher) energies. We made a new one.

PHSD

E.L. Bratkovskaya, W. Cassing, Nucl.Phys. A856 (2011) 162-182.



Initial A+A collisions – HSD: string formation and decay to pre-hadrons

Fragmentation of pre-hadrons into quarks: using the quark spectral functions from the Dynamical QuasiParticle Model (DQPM) approximation to QCD

DQPM: Peshier, Cassing, PRL 94 (2005) 172301; Cassing, NPA 791 (2007) 365: NPA 793 (2007)

Partonic phase: quarks and gluons (= „dynamical quasiparticles“) with off-shell spectral functions (width, mass) defined by DQPM

elastic and inelastic parton-parton interactions:
using the effective cross sections from the DQPM

- ✓ q + qbar (flavor neutral) <=> gluon (colored)
- ✓ gluon + gluon <=> gluon (possible due to large spectral width)
- ✓ q + qbar (color neutral) <=> hadron resonances

Hadronization: based on DQPM - massive, off-shell quarks and gluons with broad spectral functions hadronize to off-shell mesons and baryons:
gluons → q + qbar; q + qbar → meson (or string);
q + q +q → baryon(or string)(strings act as ‚doorway states‘ for hadrons)
Hadronic phase: hadron-string interactions – off-shell HSD

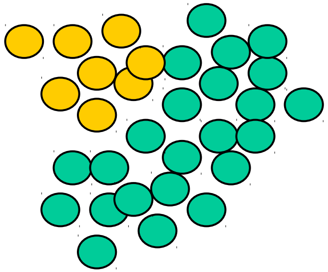
FRIGA

A. Le Fèvre et al., J. Phys.: Conf. Ser. 668 (2016) 012021.

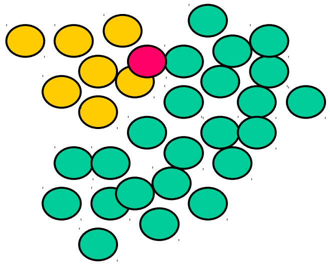
1) Pre-select good «candidates» for fragments according to proximity criteria: real space coalescence = Minimum Spanning Tree (MST) procedure.

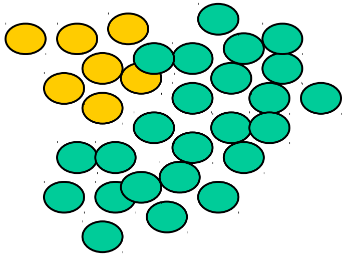
2) Take randomly 1 nucleon out of one fragment

3) Add it randomly to another fragment



$$E=E^{1}_{kin}+E^{2}_{kin}+V^{1}+V^{2}$$





$$E'=E^{1'}_{kin}+E^{2'}_{kin}+V^{1'}+V^{2'}$$

<u>If E′ < E</u> take the new configuration
<u>If E′ > E</u> take the old with a probability depending on E′-E
Repeat this procedure very many times...
It leads automatically to the most bound configuration.

PHQMD

Parton-Hadron Quantum Molecular Dynamics

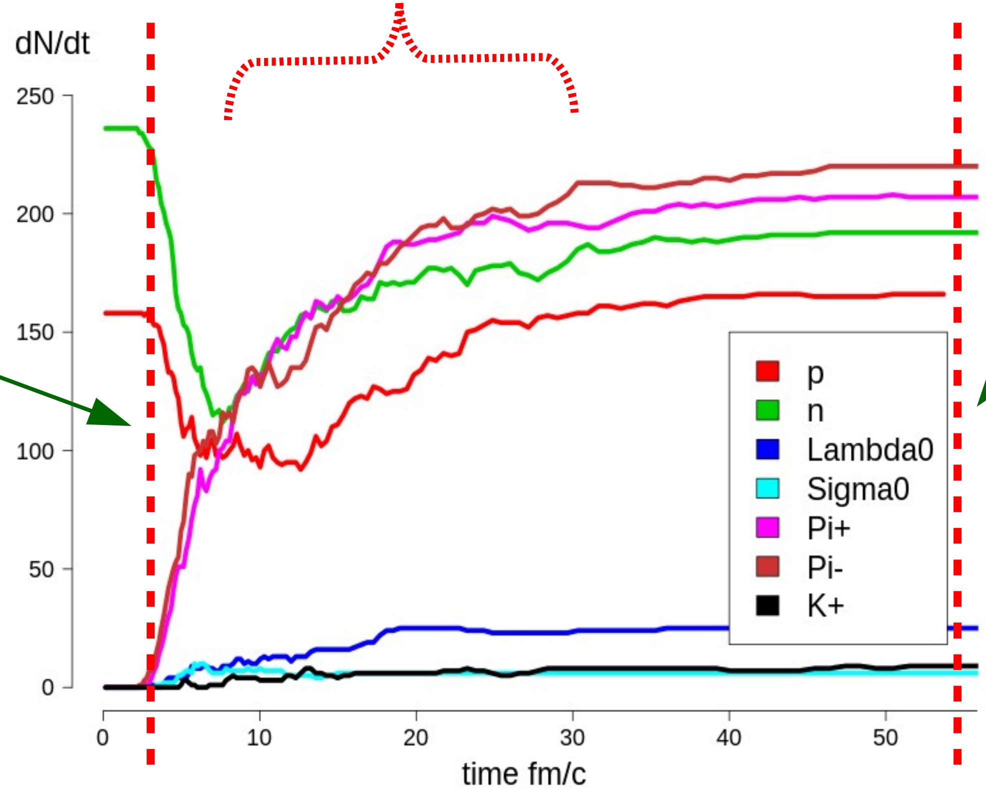
= PHSD + QMD* + FRIGA

* J. Aichelin and H. Stöcker, Phys. Lett. 176 B (1988) 14

Clusterization time

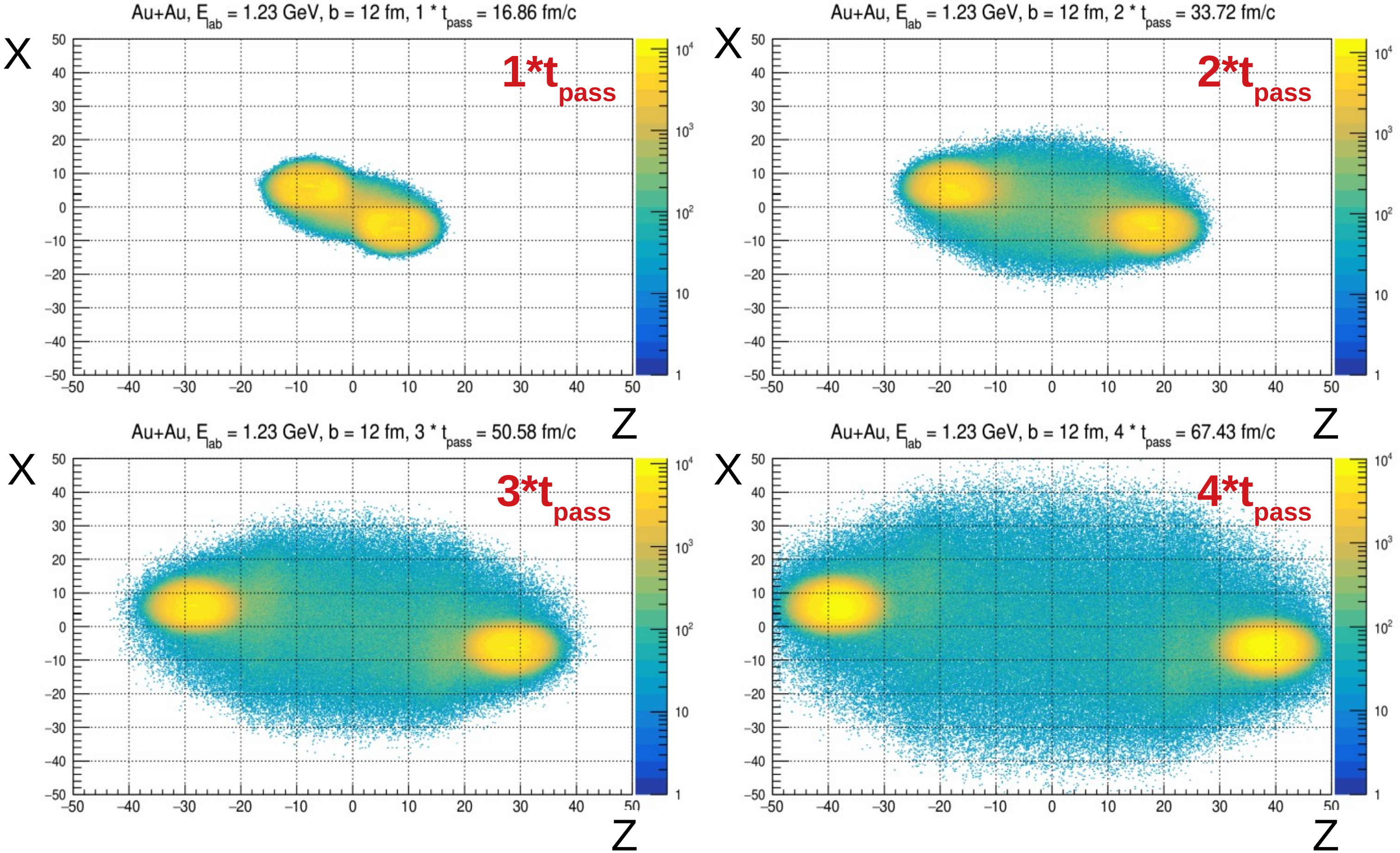
Maybe here..?

Too early

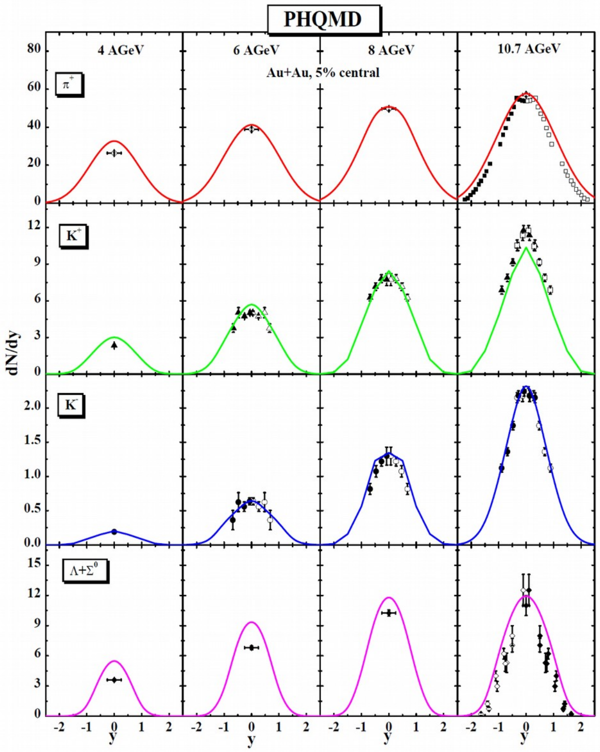


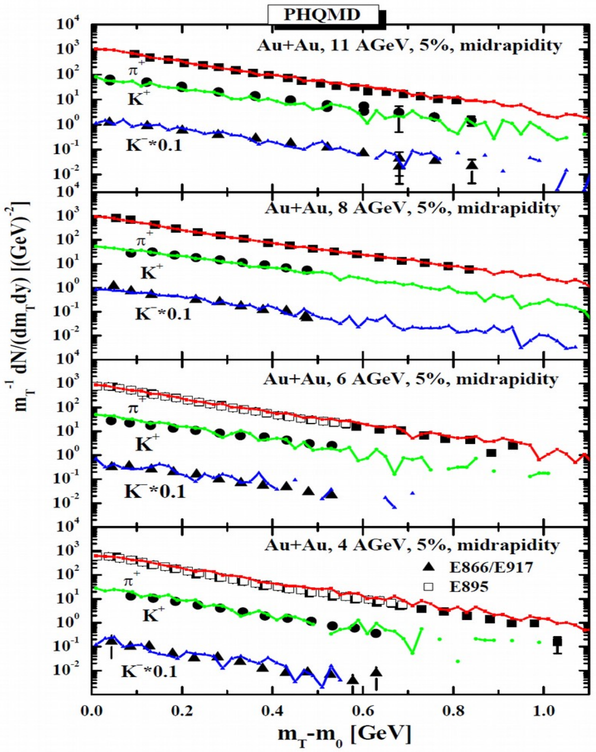
Oops...

Clusterization time



Model predictions



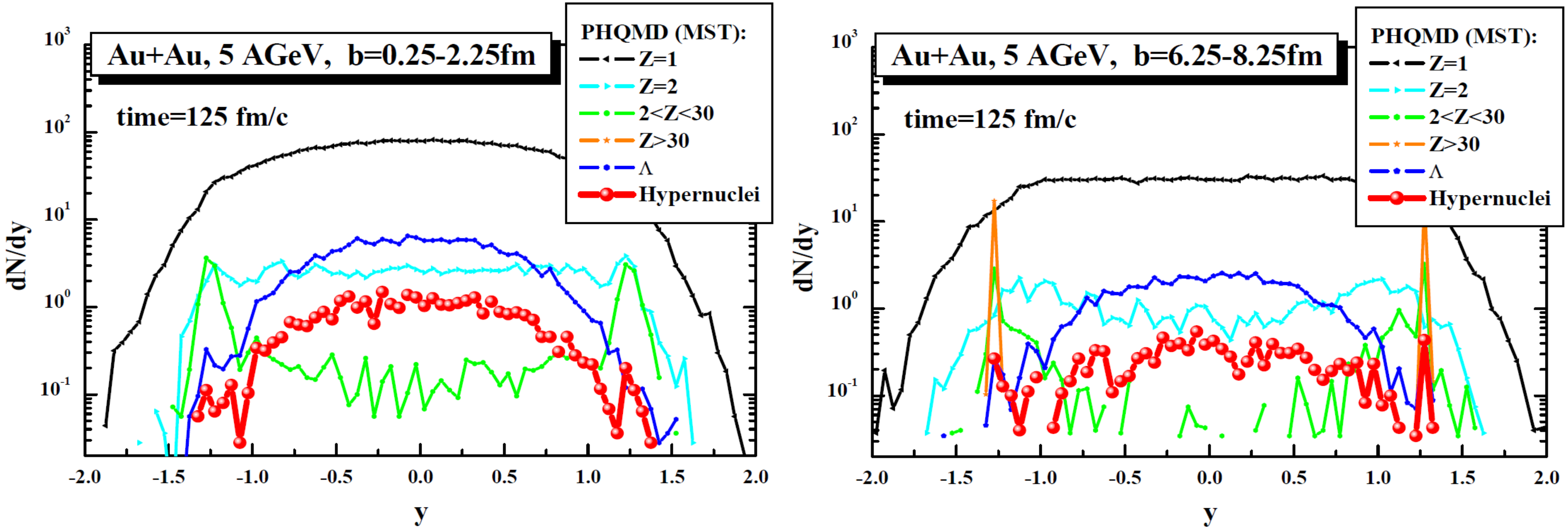


Single particle spectra still the same as in PHSD

Produced particles are well reproduced at NICA/FAIR energies

Model predictions

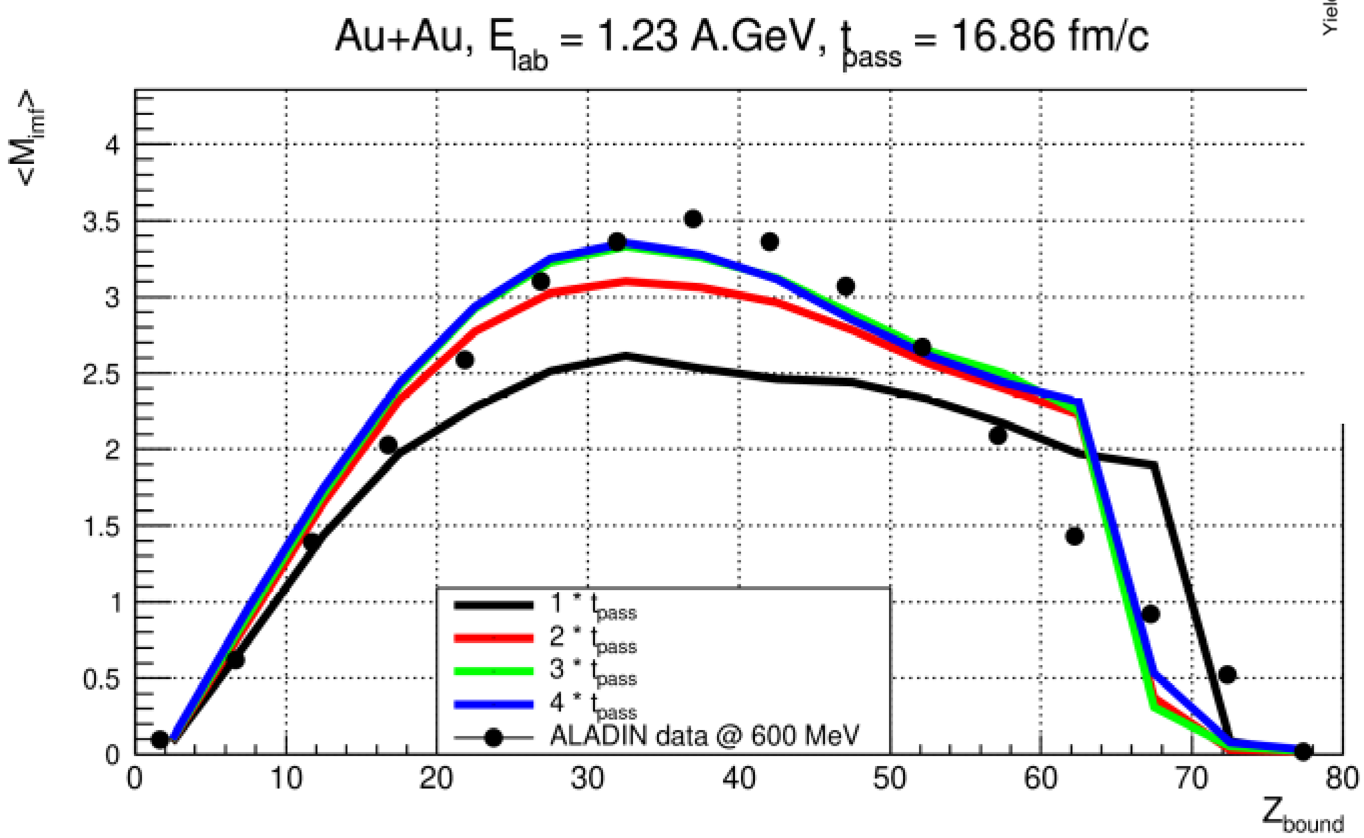
(preliminary results at NICA energies)

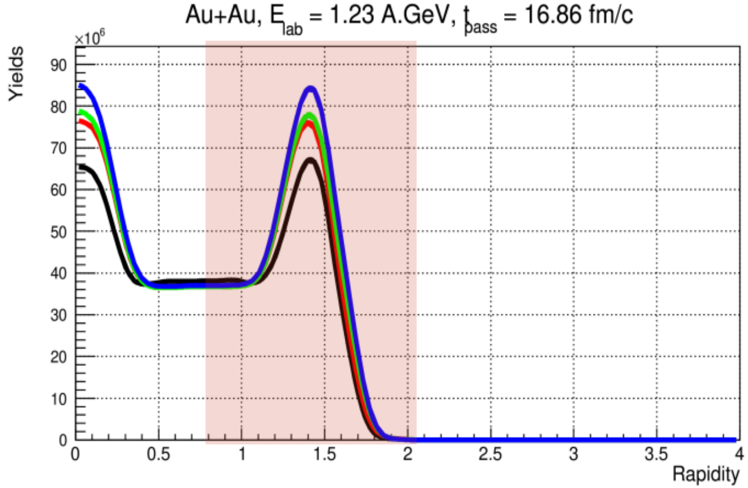


Central collisions: light clusters;
Semi-peripheral collisions: existence of heavy clusters – remnants from spectators

M_{imf} vs Z_{bound} @ 1.23 GeV

Courtesy of the ALADIN Collaboration for the new S254 data



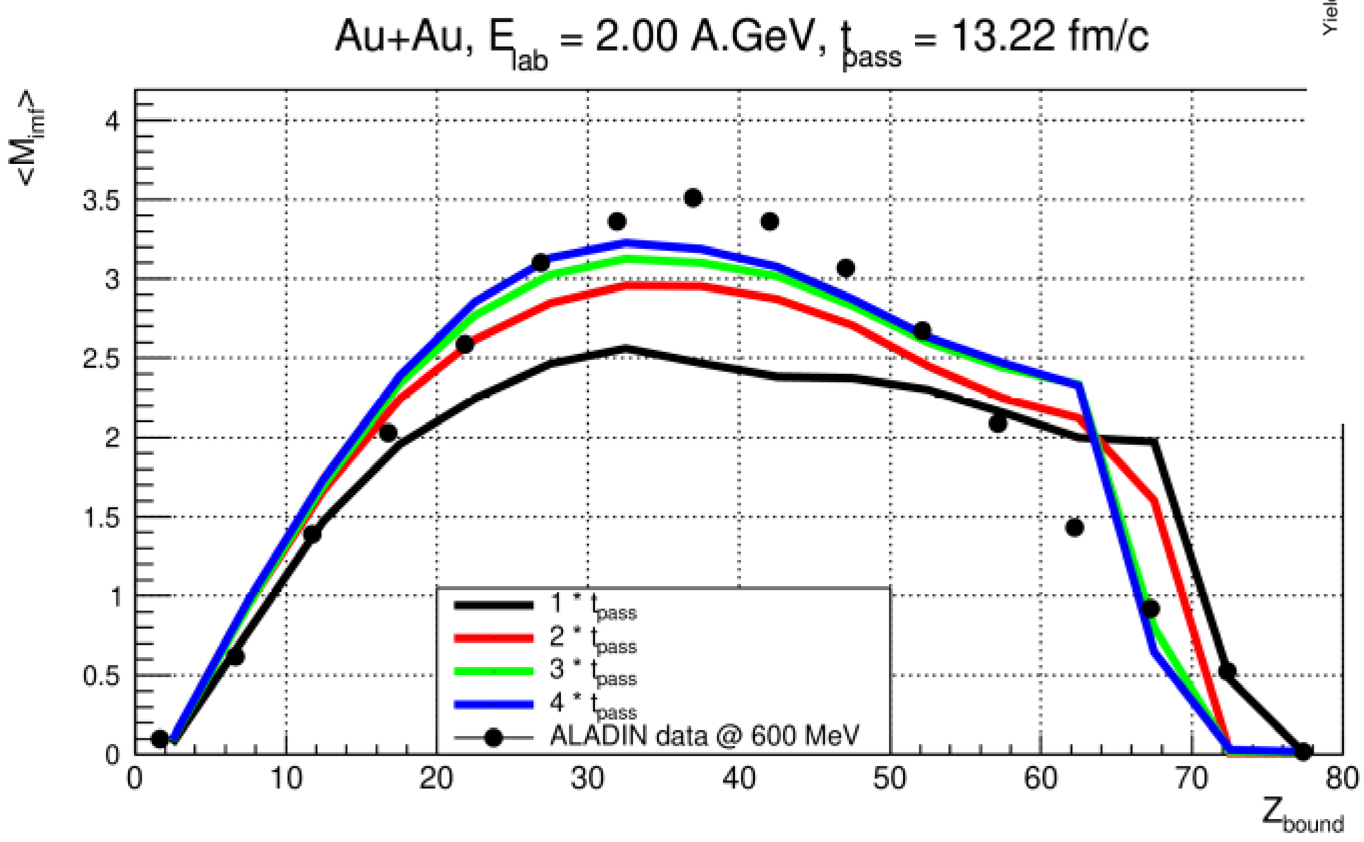


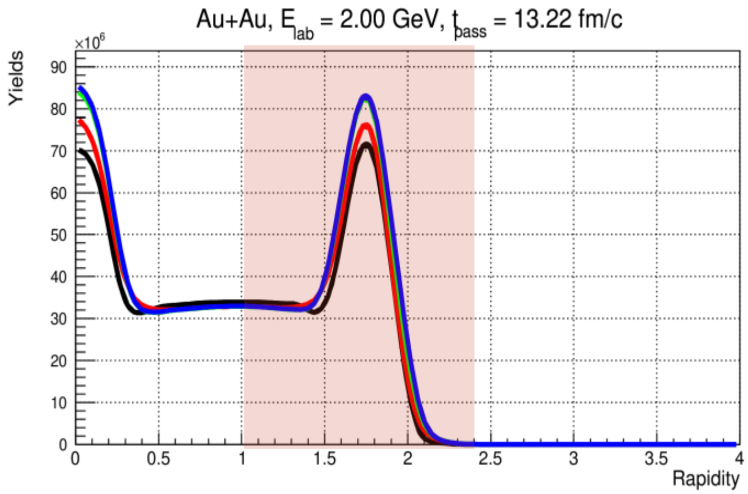
$\langle M_{IMF} \rangle$ – average number of medium mass fragments (2<Z<30)

Z_{bound} – number of charges bounded in clusters (Z>1)

M_{imf} vs Z_{bound} @ 2 GeV

Courtesy of the ALADIN Collaboration for the new S254 data



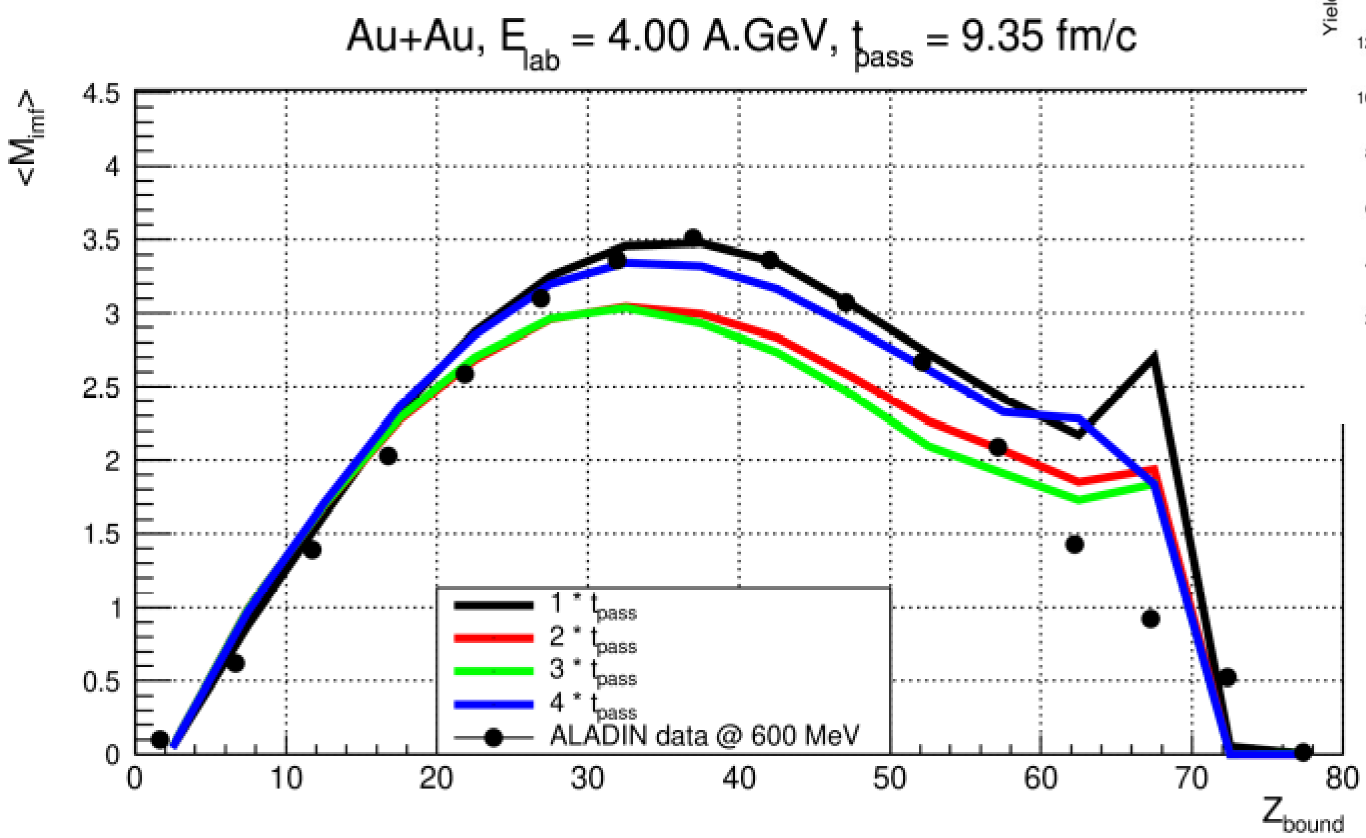


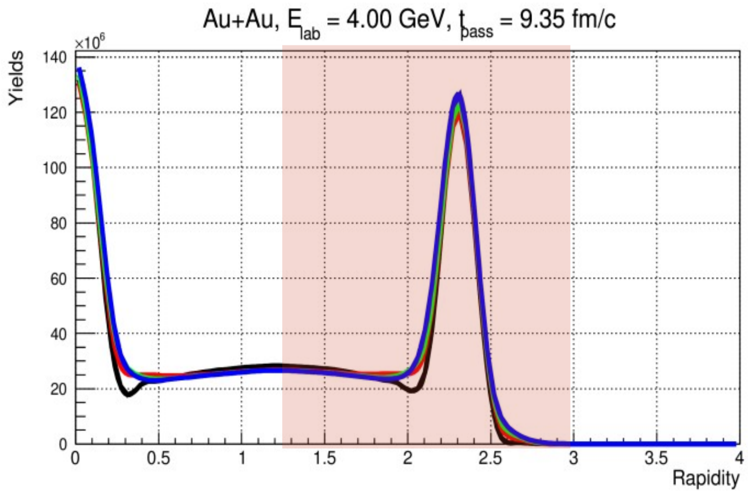
$<M_{IMF}>$ – **average number of medium mass fragments (2<Z<30)**

Z_{bound} – **number of charges bounded in clusters (Z>1)**

M_{imf} vs Z_{bound} @ 4 A.GeV

Courtesy of the ALADIN Collaboration for the new S254 data



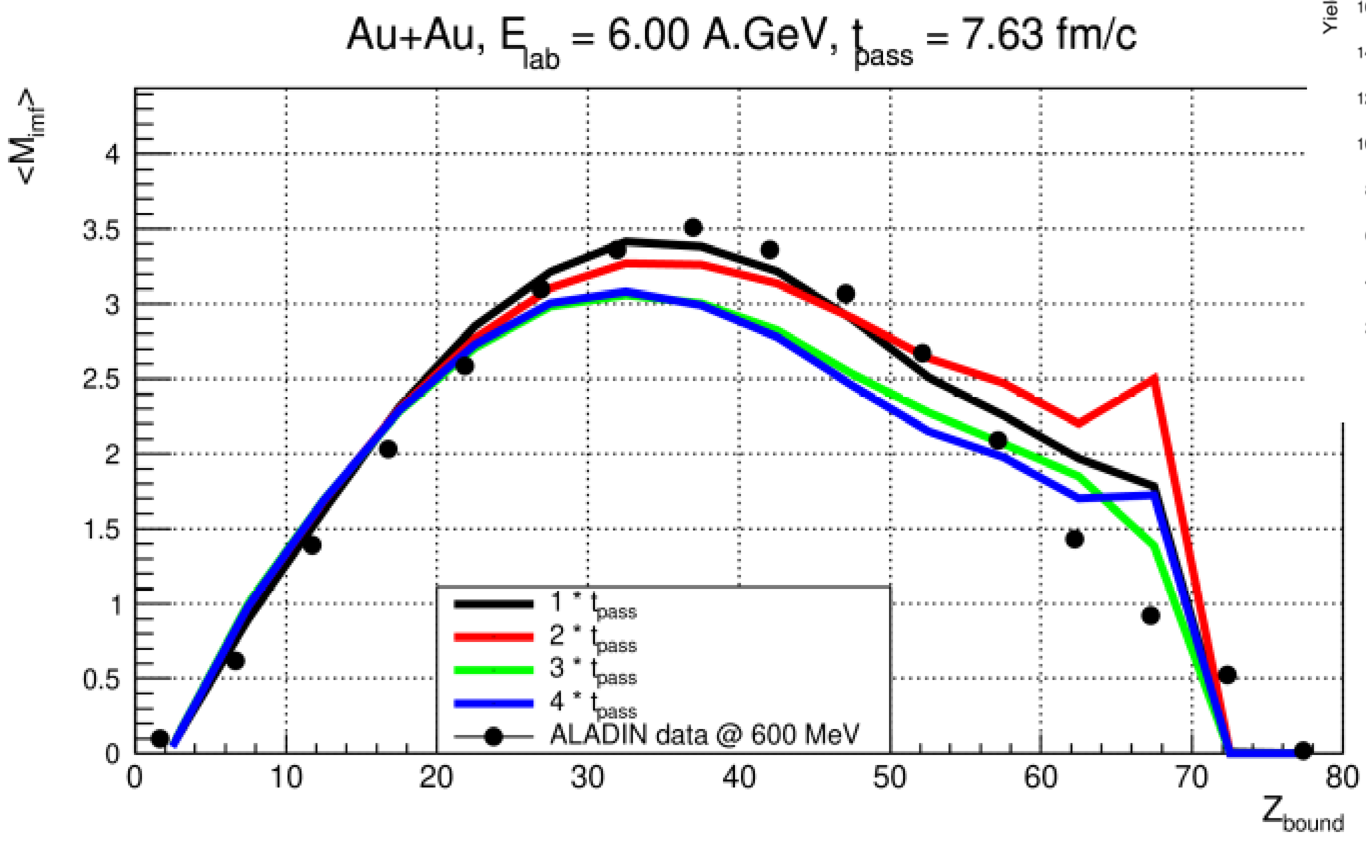


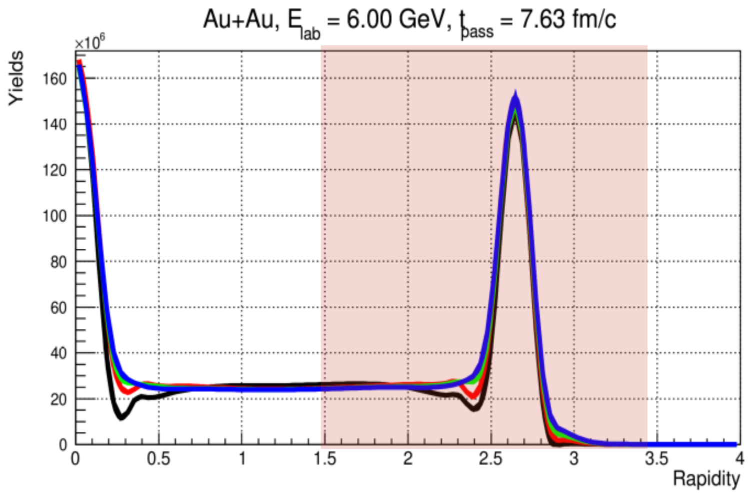
$<M_{IMF}>$ – average number of medium mass fragments (2<Z<30)

Z_{bound} – number of charges bounded in clusters (Z>1)

M_{imf} vs Z_{bound} @ 6 A.GeV

Courtesy of the ALADIN Collaboration for the new S254 data



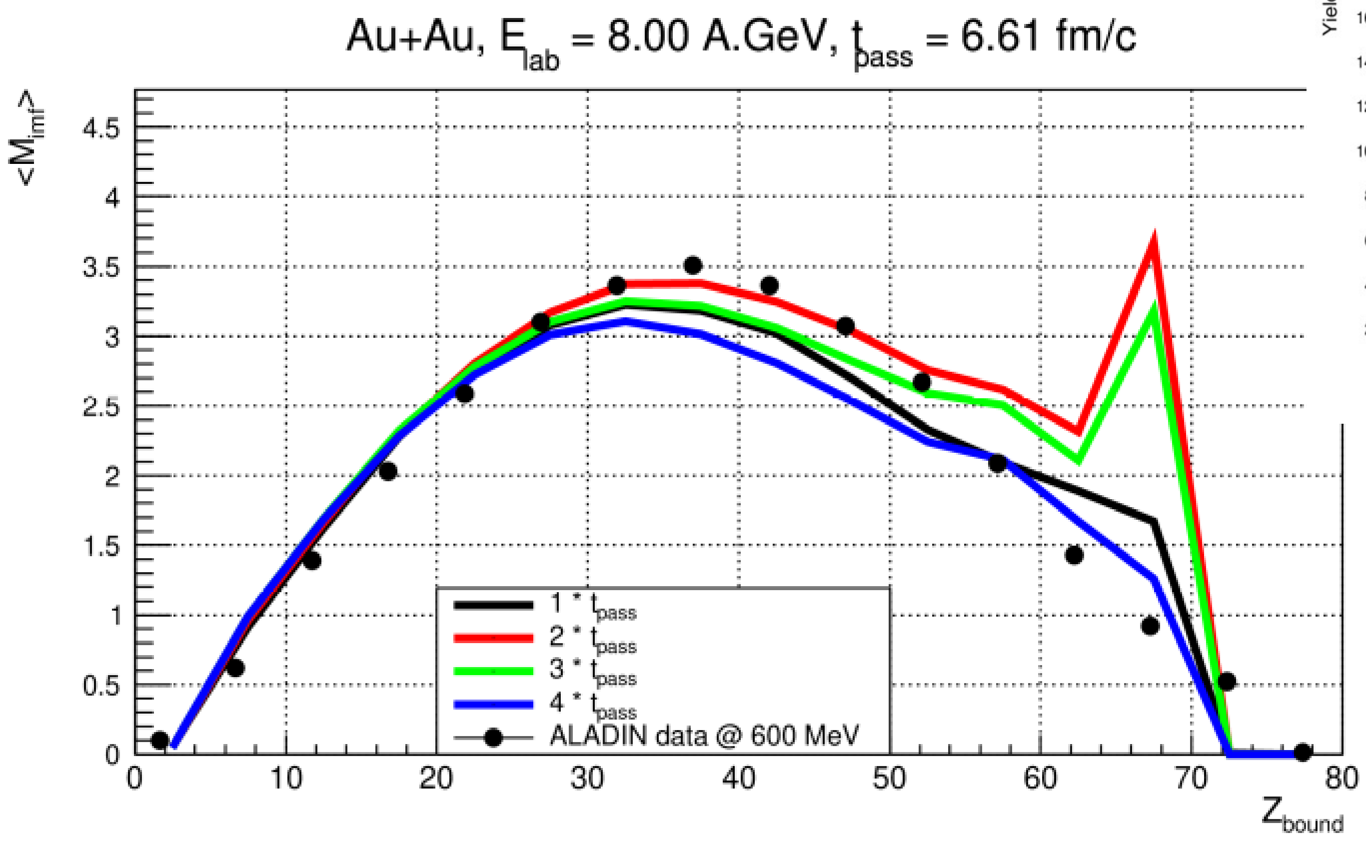


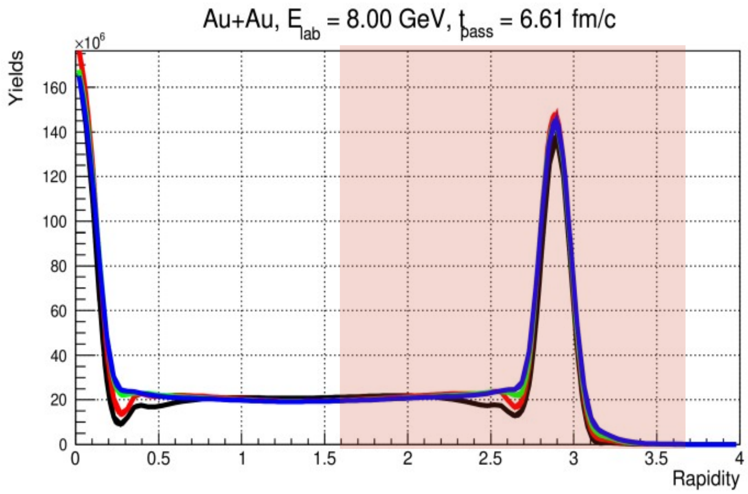
$\langle M_{IMF} \rangle$ – average number of medium mass fragments (2<Z<30)

Z_{bound} – number of charges bounded in clusters (Z>1)

M_{imf} vs Z_{bound} @ 8 A.GeV

Courtesy of the ALADIN Collaboration for the new S254 data





$<M_{IMF}>$ – **average number of medium mass fragments (2<Z<30)**

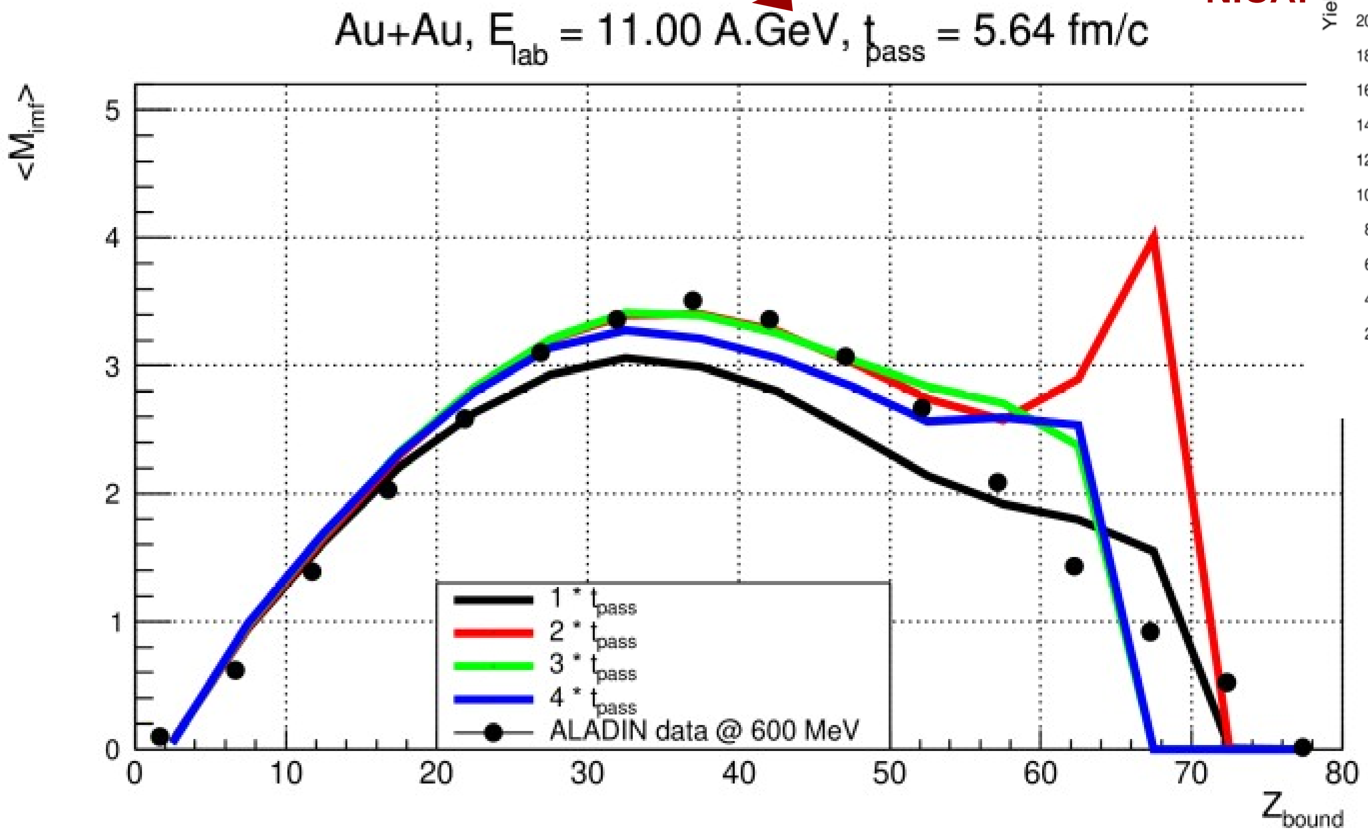
Z_{bound} – **number of charges bounded in clusters (Z>1)**

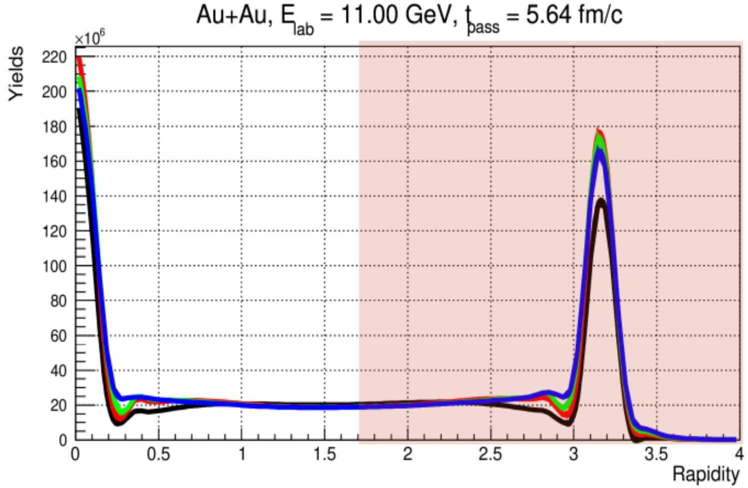
M_{imf} vs Z_{bound} @ 11 A.GeV

Courtesy of the ALADIN Collaboration for the new S254 data

$\sqrt{S_{NN}} \approx 5$ GeV

NICA!

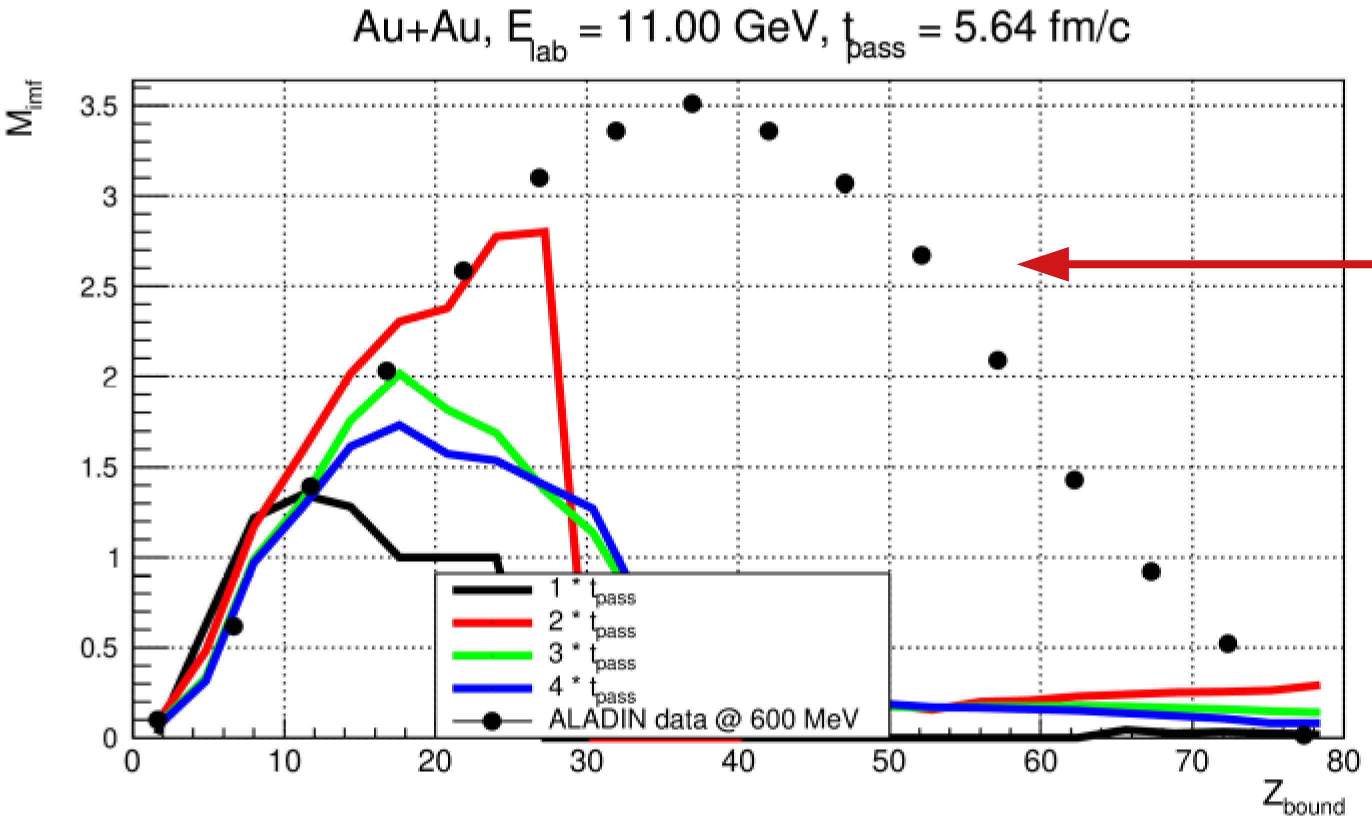




$\langle M_{IMF} \rangle$ – average number of medium mass fragments (2<Z<30)

Z_{bound} – number of charges bounded in clusters (Z>1)

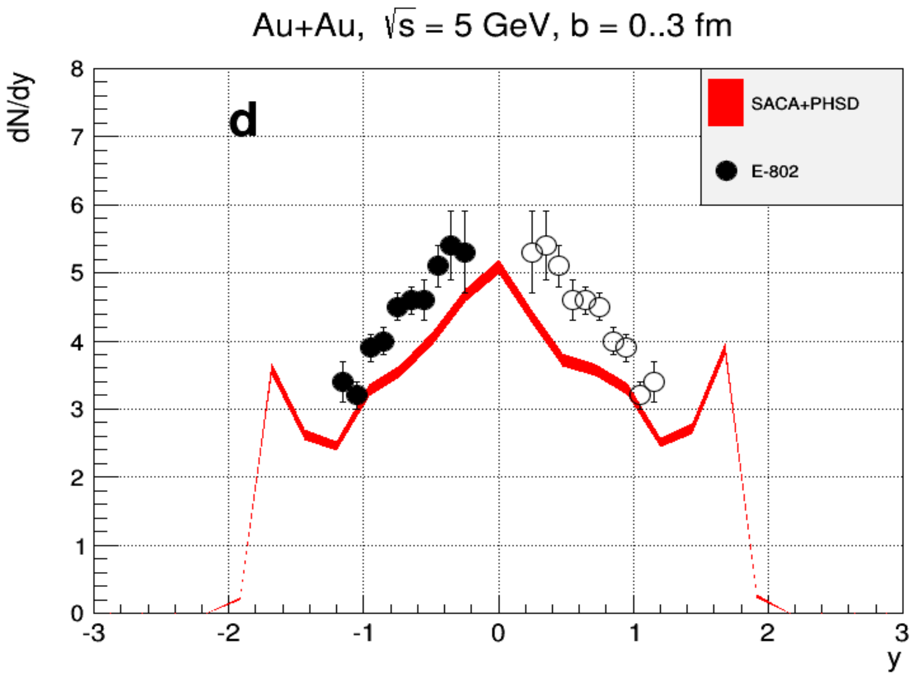
Why not to use just coalescence?



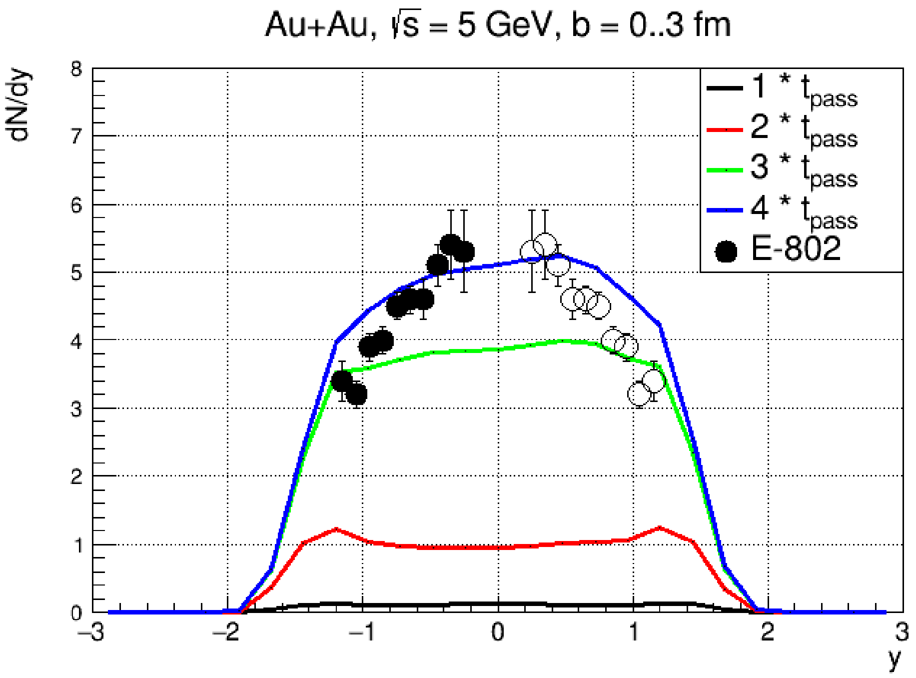
It fails to describe spectators

Some yields

Old



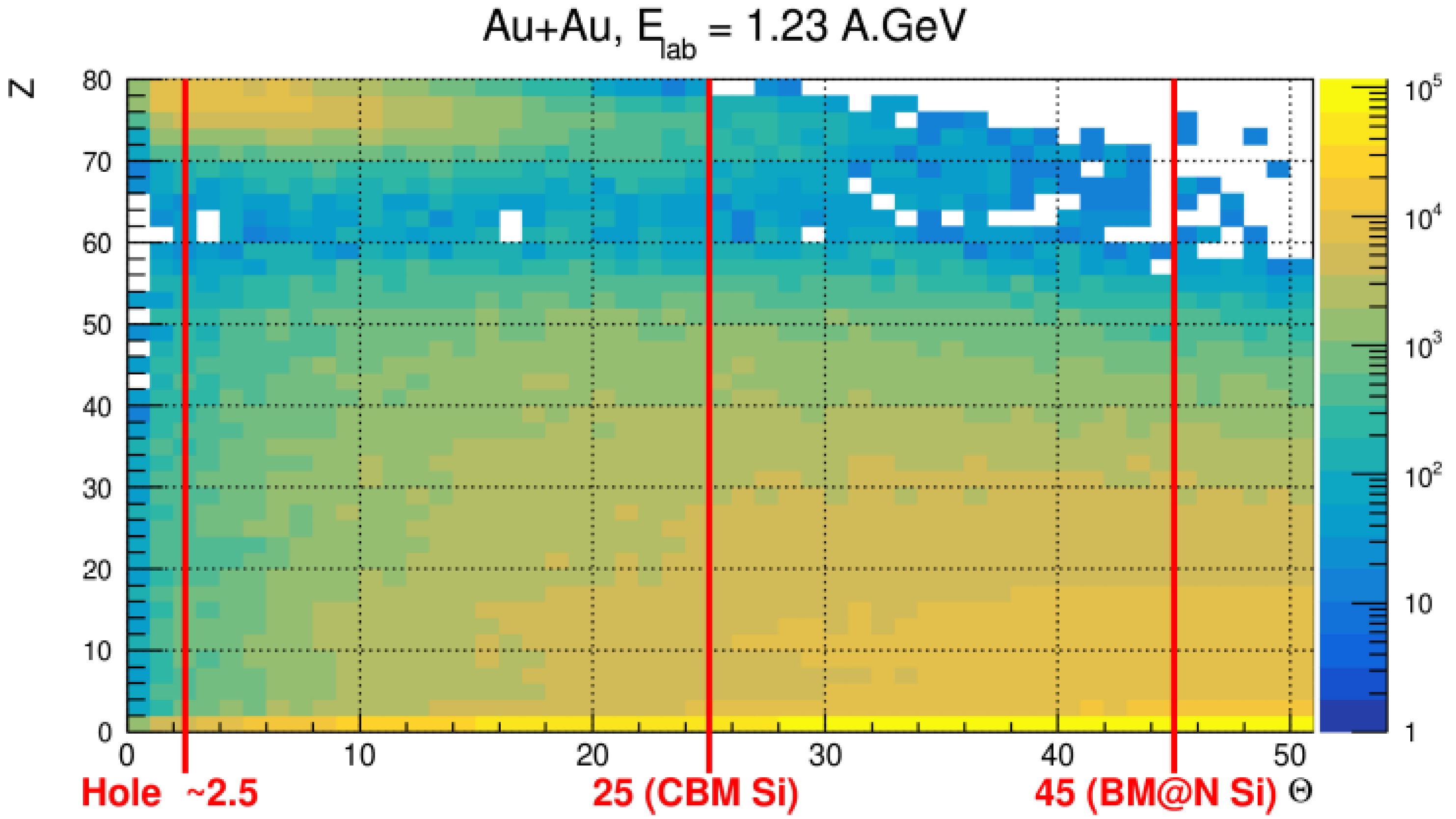
New



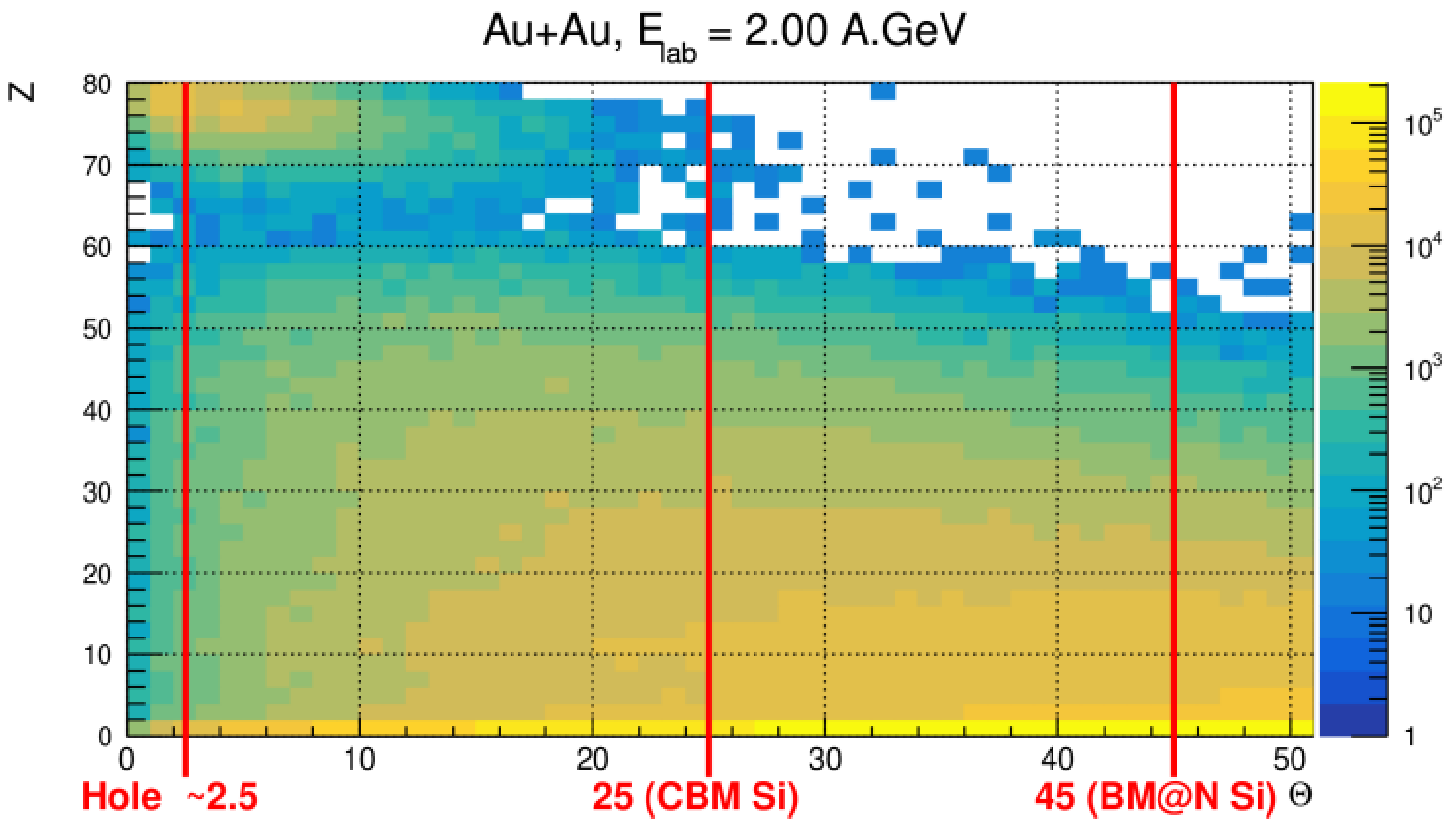
PHQMD+FRIGA
may be also used for engineering stuff

We can estimate damage caused to detector

Z vs Θ @ 1.23 A.GeV

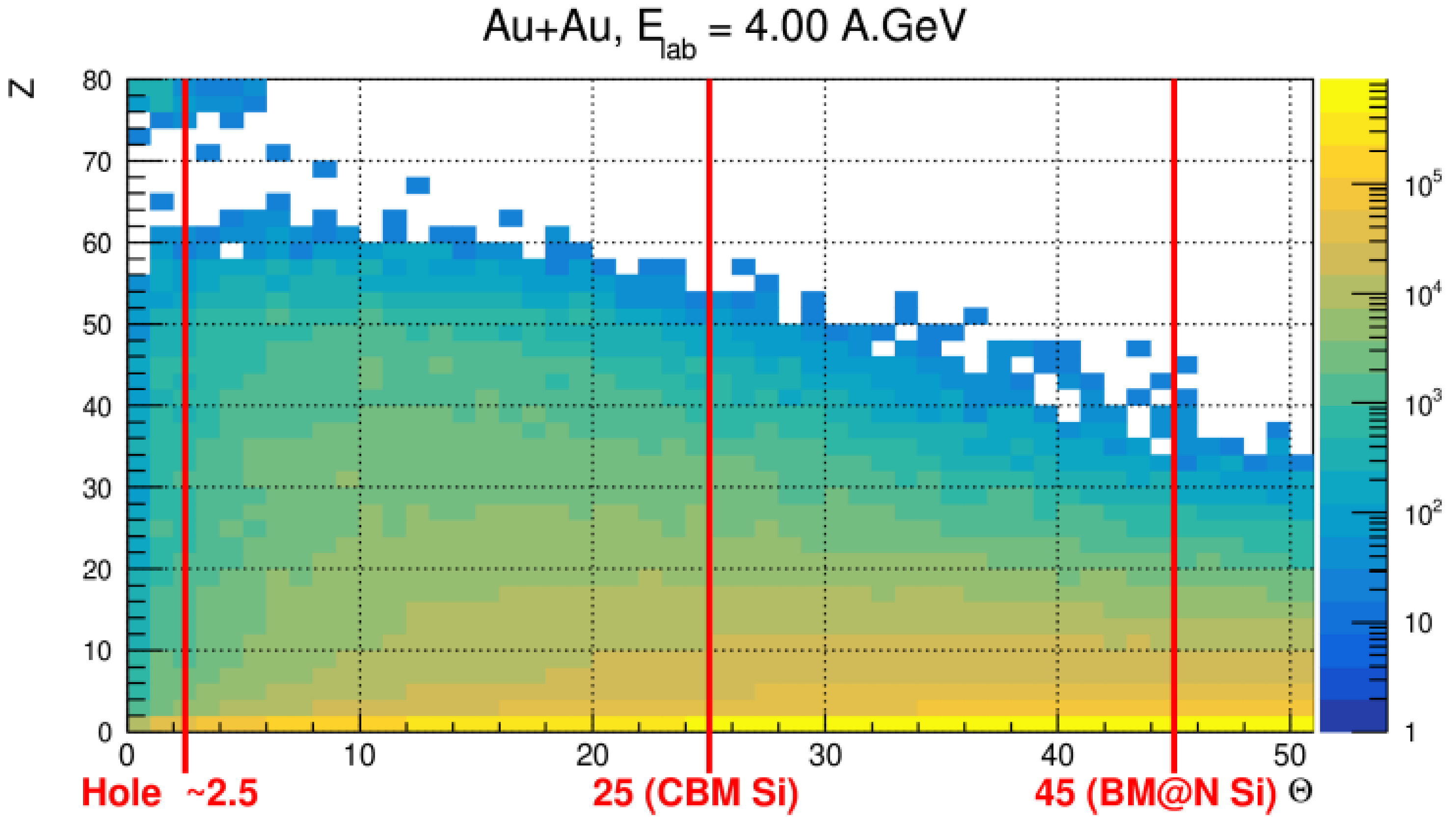


Z vs Θ @ 2 A.GeV



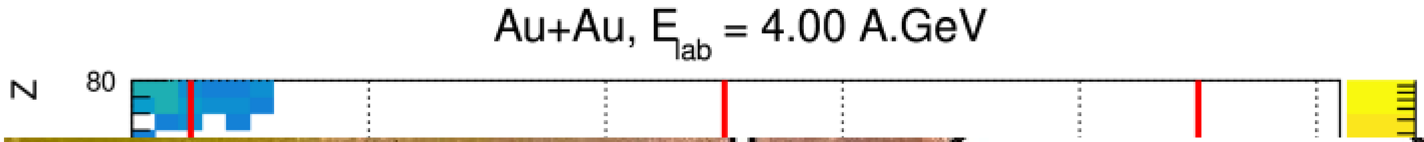
Au+Au, E_{lab} = 2.00 A.GeV
Z
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
Θ
10^5
10^4
10^3
10^2
10
1
Hole ~2.5
25 (CBM Si)
45 (BM@N Si)

Z vs Θ @ 4 A.GeV



Au+Au, E_lab = 4.00 A.GeV
Z
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
Θ
10^5
10^4
10^3
10^2
10
1
Hole ~2.5
25 (CBM Si)
45 (BM@N Si)

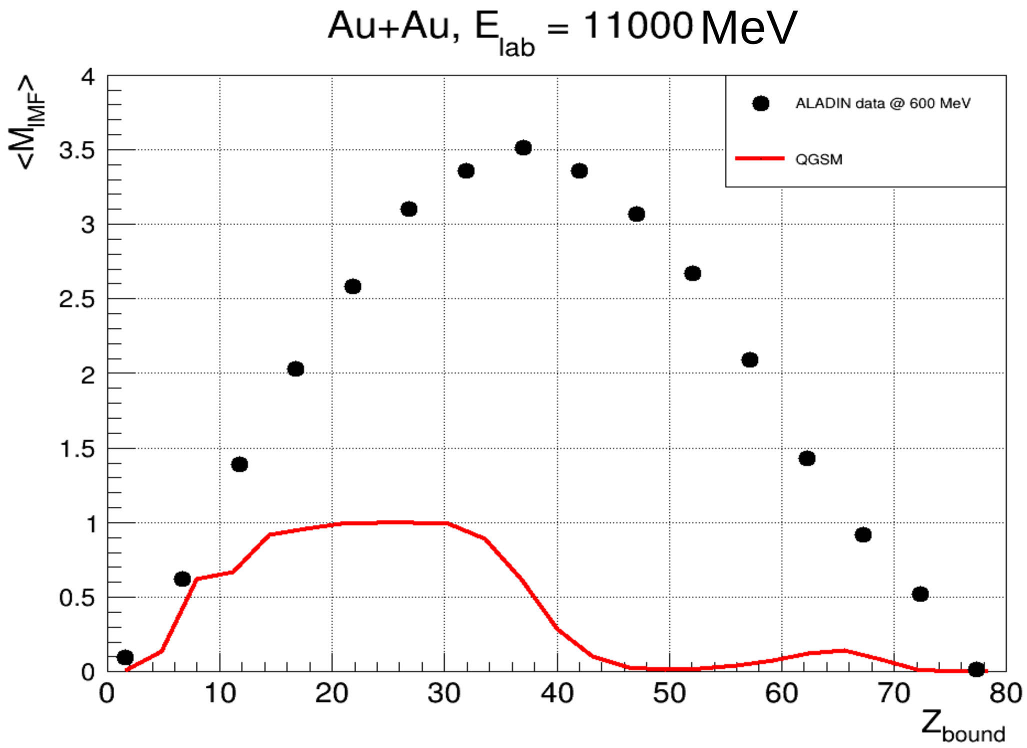
Z vs Θ @ 4 A.GeV



Summary

- PHQMD can produce clusters and hypernuclei;
- Model reproduce experimental data;
- Model`s predictions can be used for analysis, feasibility and engineering studies;
- Model is actively developing.

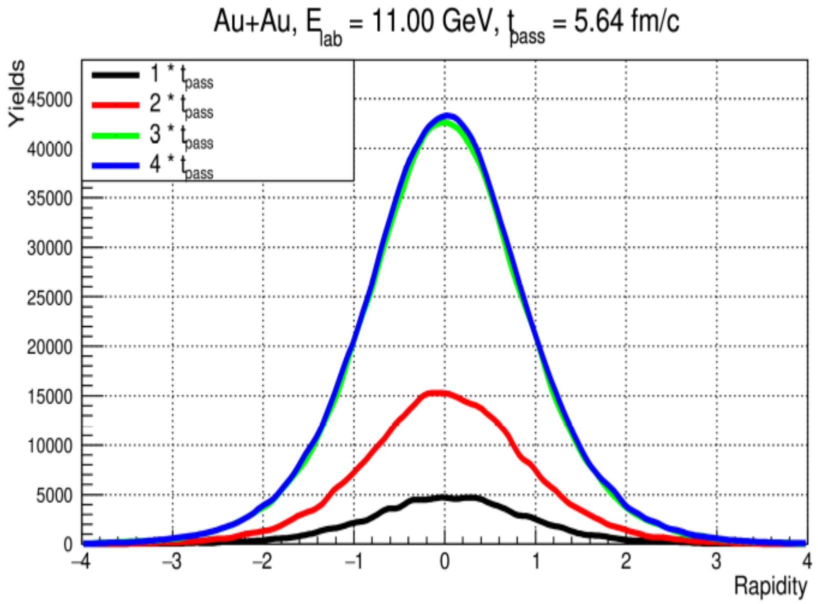
Backup



DCM-QGSM

Some yields

Fragments Z >= 2



Hypernuclei