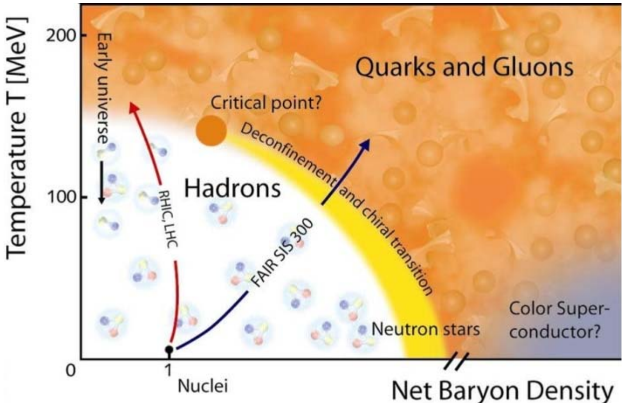

Benchmarking transport models

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26.-31. March 2017

FAIR GSI

Outline

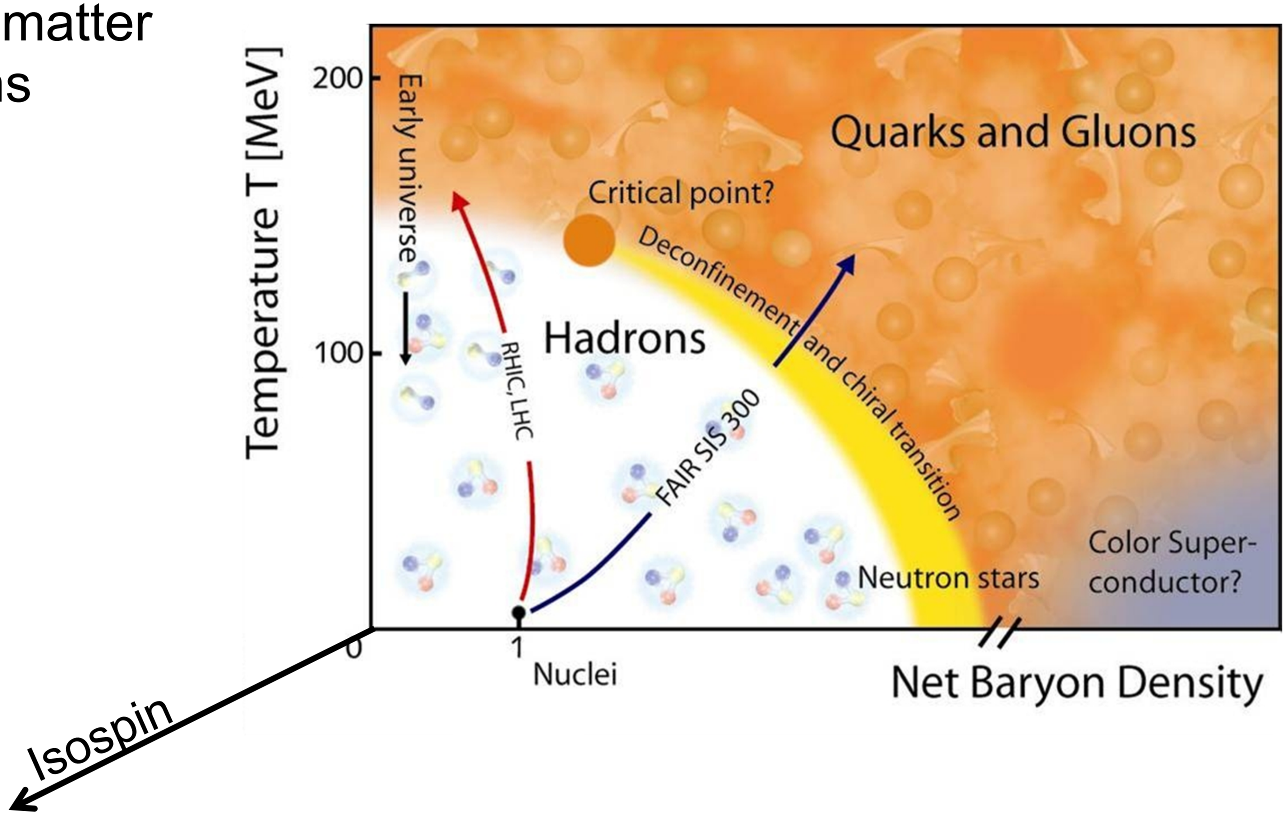
- Introduction
- Heavy ion collisions and transport models
  - succeses
  - open issues
- Benchmarking
  - vs experiment
  - vs reference data set
- Summary and Conclusion

Heavy ion reactions

Access **QCD phase diagram**

- EOS of nuclear matter

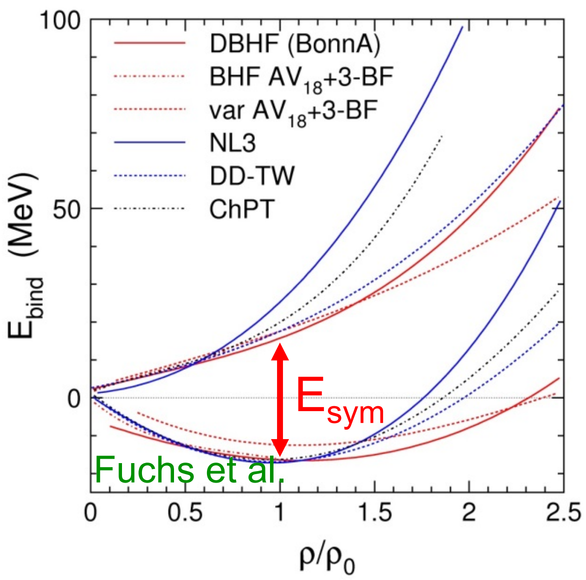
by heavy ion collisions

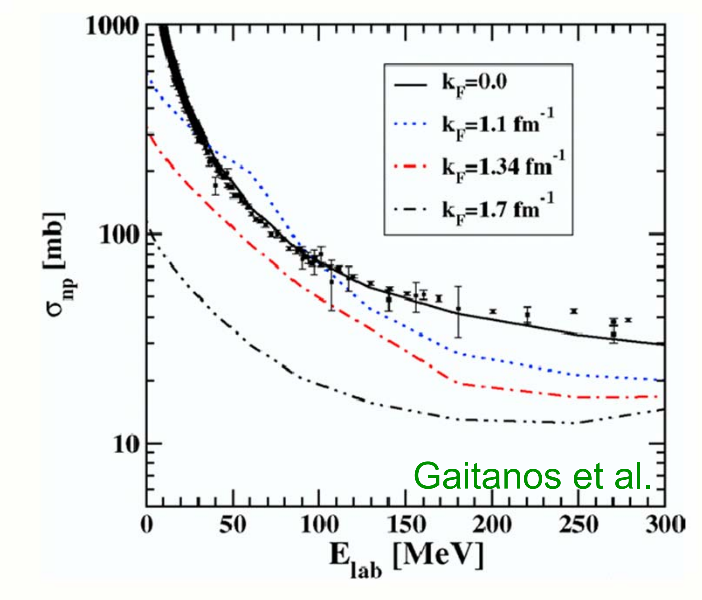


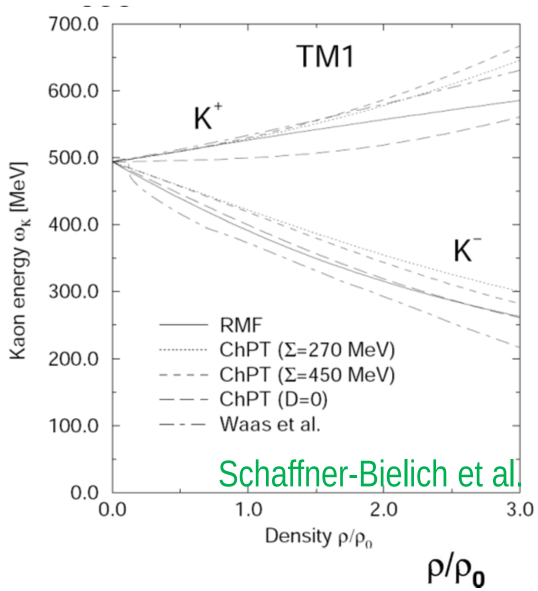
- finite system
- extract information via modeling the hadronic phase

➡ microscopic transport models

Heavy ion reactions







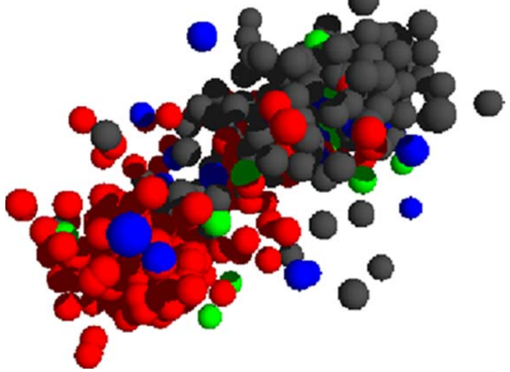
Not only nuclear matter equation of state

- in-medium cross sections
- in-medium potentials
- in-medium characteristics of particles
- in-medium correlations (3/4body interactions, clustering)

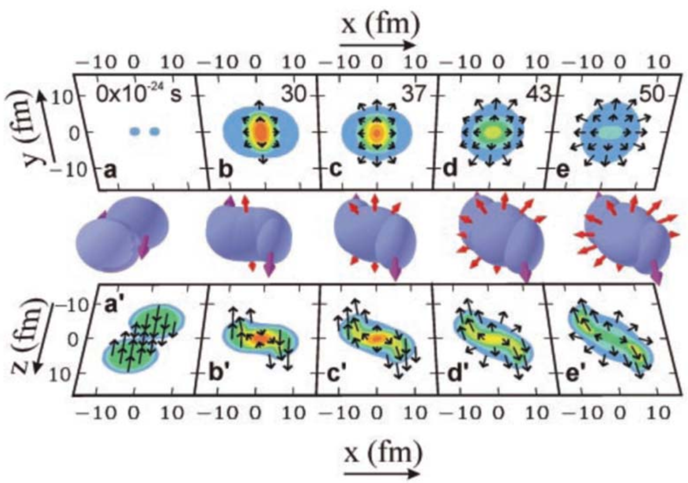
Heavy ion reactions and transport models

Various approaches
QMD/AMD

C. Hartnack



BUU



P. Danielewicz et al.
Science 298, 1592 (2002)

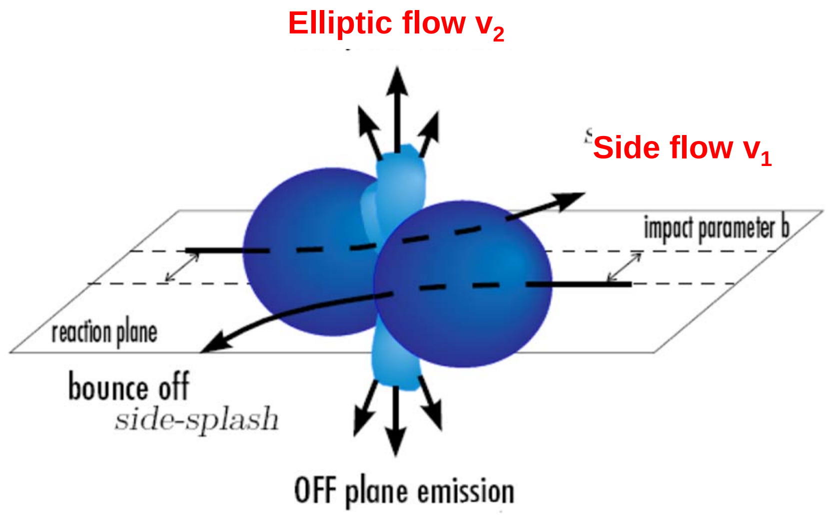
Transport models:
Solving the Boltzmann Equation in the presence of many particles

Very successful

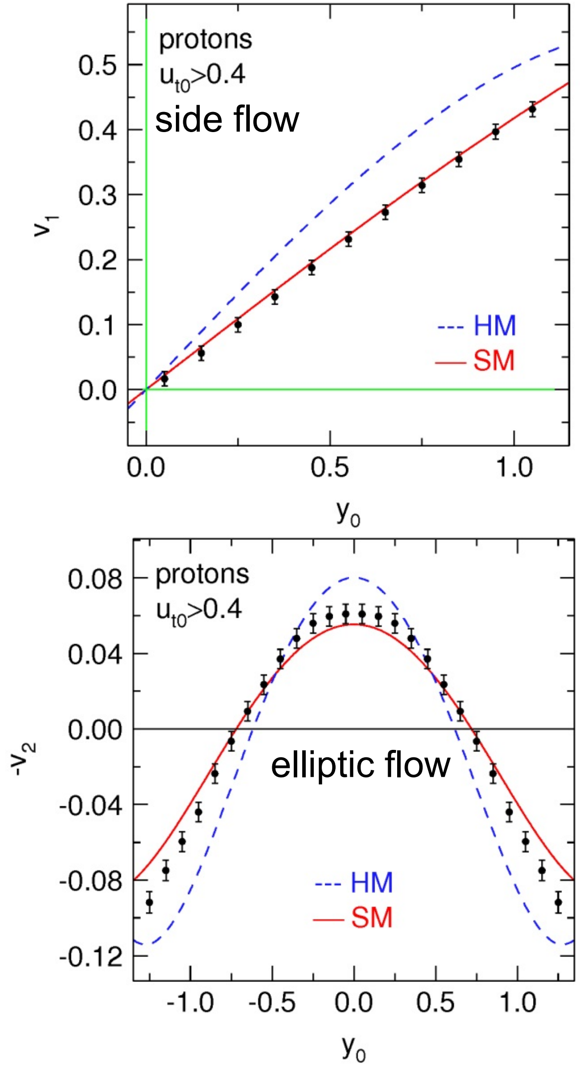
- **describing** experimental data
- **understanding** mechanisms of HI collisions, e.g.
  - particle production
  - collective flow
  - heavy fragments

SUCCESS OF TRANSPORT MODELS
EOS OF NUCLEAR MATTER

Heavy ion collisions – collective flows



Au+Au 1A GeV 3.5<b<6.3 fm

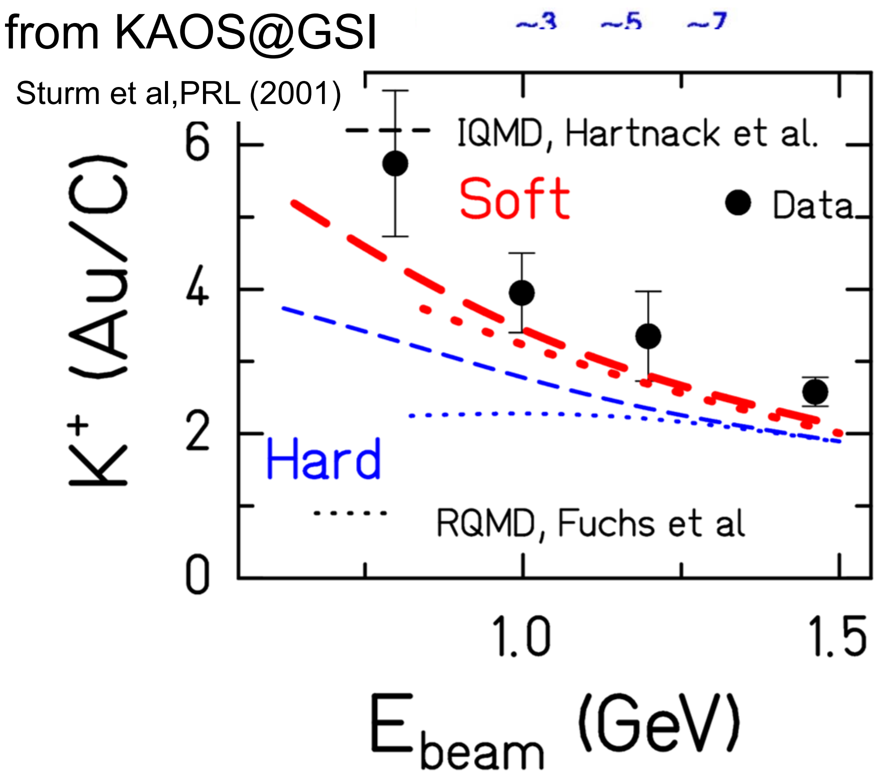


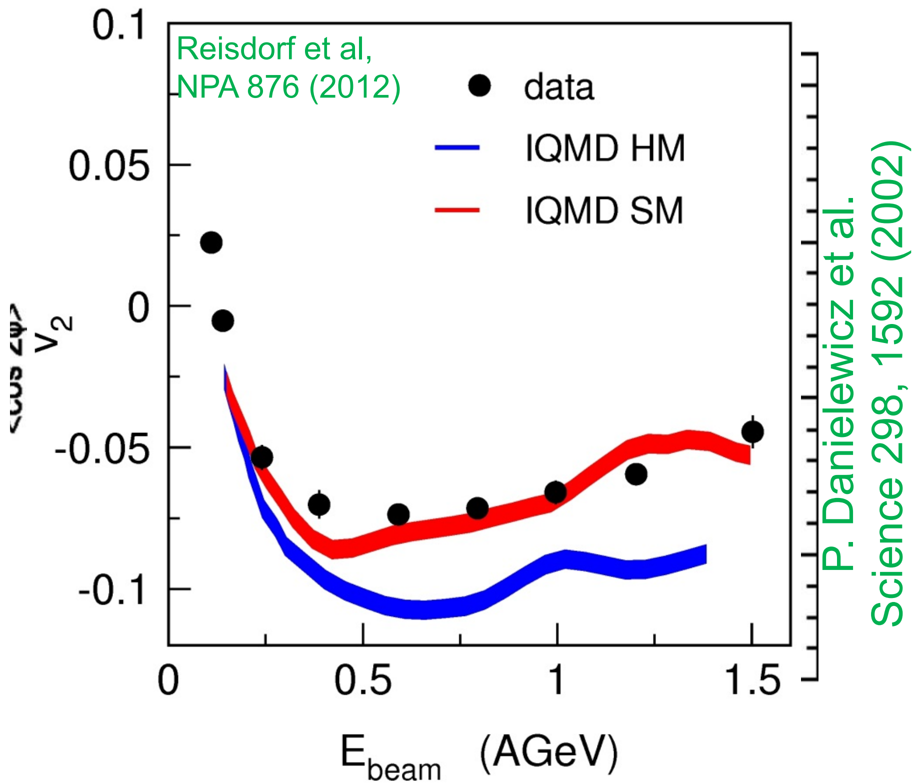
W. Reisdorf et al, Nucl. Phys. A 876 (2012) 1

$$\frac{dN}{d\phi} \sim 1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi); \phi = \phi_R - \varphi$$

- reaction dynamics described
- collective flows Au+Au between 0.4 – 1.5AGeV described by one model
- consistent description of flow and strangeness production possible

Heavy ion collisions, strangeness and collective flows





- additional constraints needed on momentum dependence of NN potential and in-medium cross sections
- newer data on elliptic flow in agreement with a soft EOS (SM)

  → most available data and Kaon production is reasonably described by IQMD model (input parameters constrained with experimental data)

SUCCESS OF TRANSPORT MODELS
SYMMETRY ENERGY AT HIGH DENSITIES

Symmetry energy at supra-normal densities

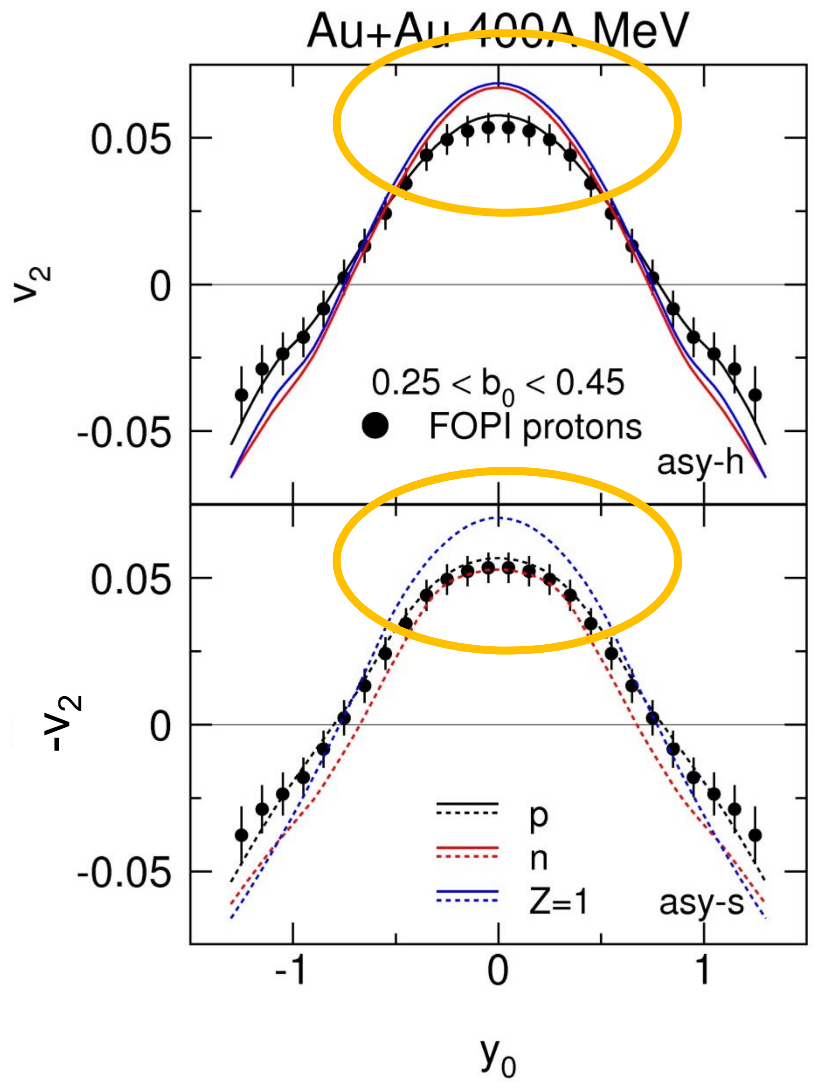
Differential elliptic flow v_2 of n/p
UrQMD (Q. Li et al.) predicts

"hard" E_{sym} → "soft" E_{sym}: protons unchanged; neutron and proton flow inverted

Towards model invariance:
tested stability with different models:

- soft vs. hard EOS **190<K<280 MeV**
- density dependence of $\sigma_{NN,elastic}$
- asymmetry dependence of $\sigma_{NN,elastic}$
- optical potential
- momentum dependence of isovector potential

M.D. Cozma et al., arXiv:1305.5417
P. Russotto et al., PLB 267 (2010)
Y. Wang et al.,PRC 89, 044603 (2014)



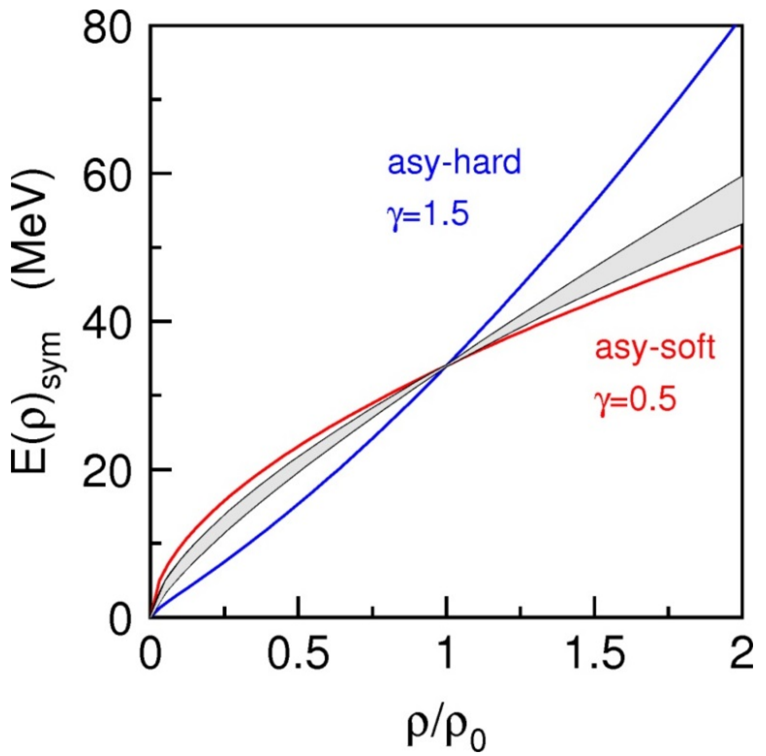
Constraining the symmetry energy at high densities

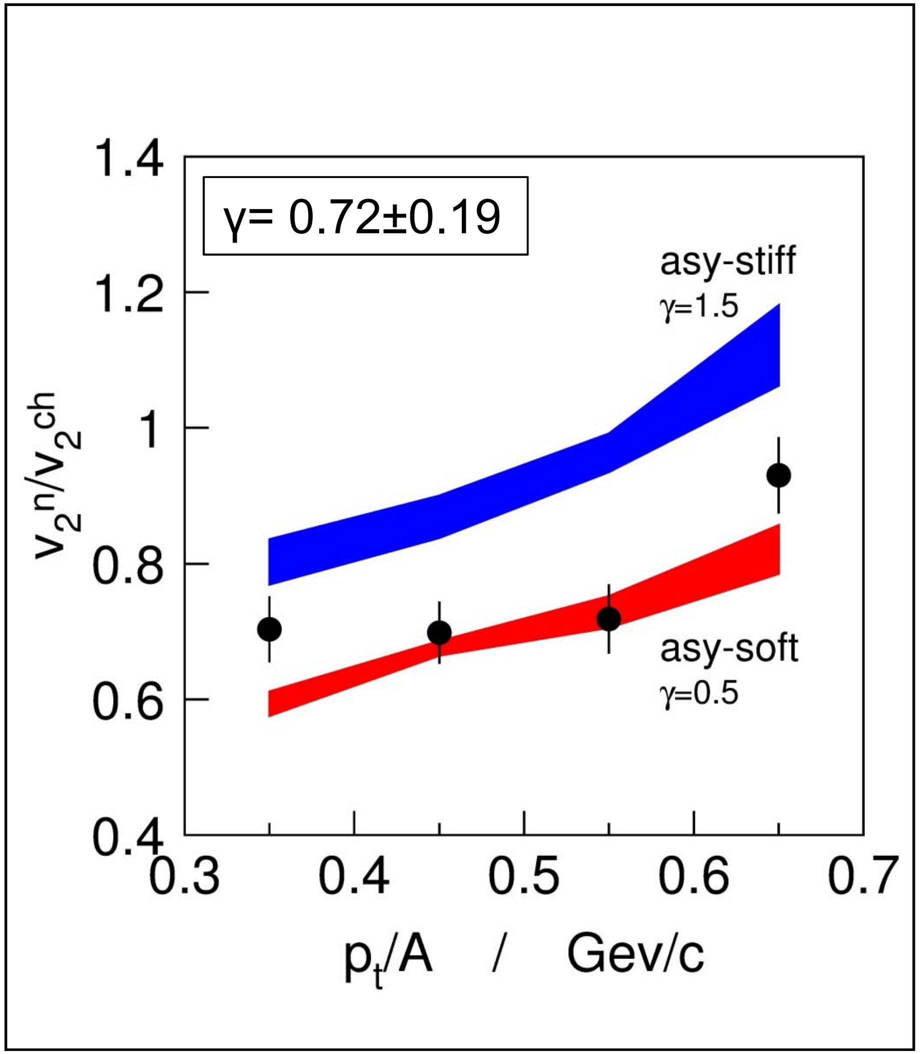
Comparison to models:

parameterization of $E_{sym:}$

$E_{sym} = E_{sym}^{pot} + E_{sym}^{kin}$

$= 22\ MeV \cdot (\rho/\rho_0)^{\gamma} + 12\ MeV \cdot (\rho/\rho_0)^{2/3}$

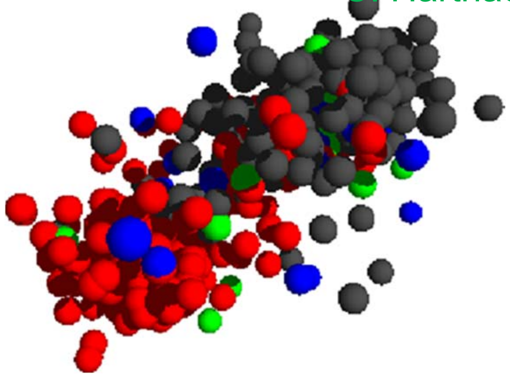




HOWEVER....

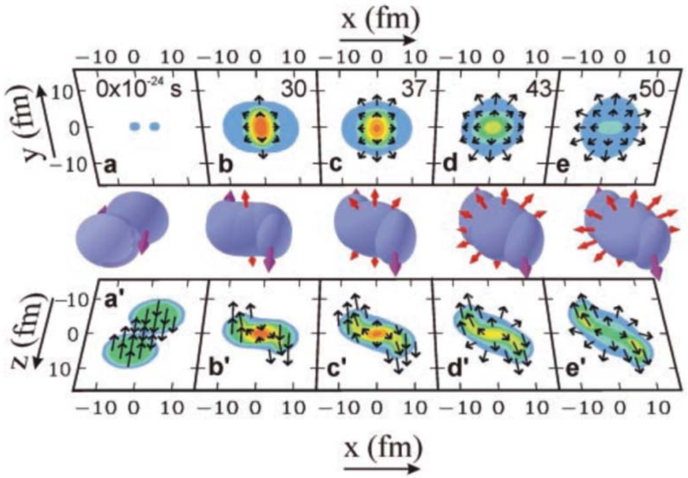
Heavy ion reactions and transport models

Various approaches
QMD



C. Hartnack

BUU



P. Danielewicz et al.
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Very successful
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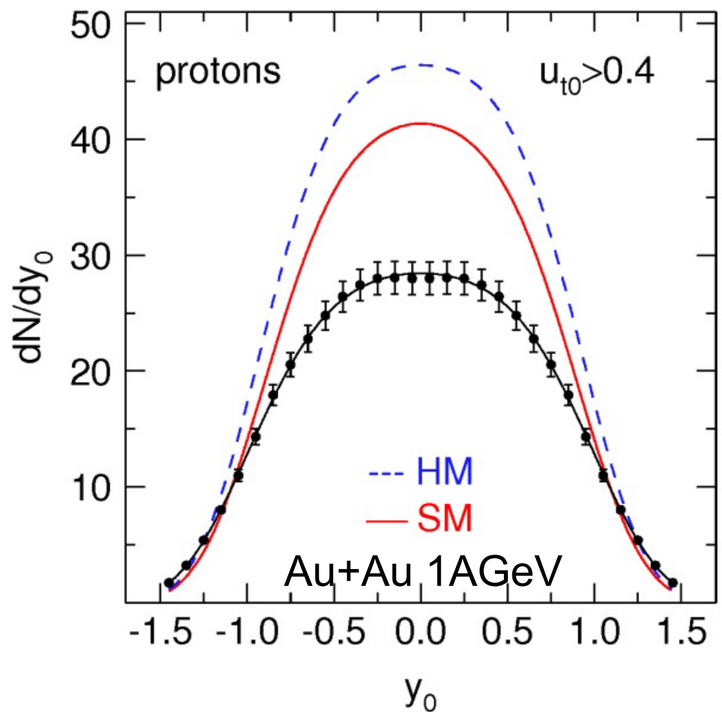
Heavy ion reactions and transport codes

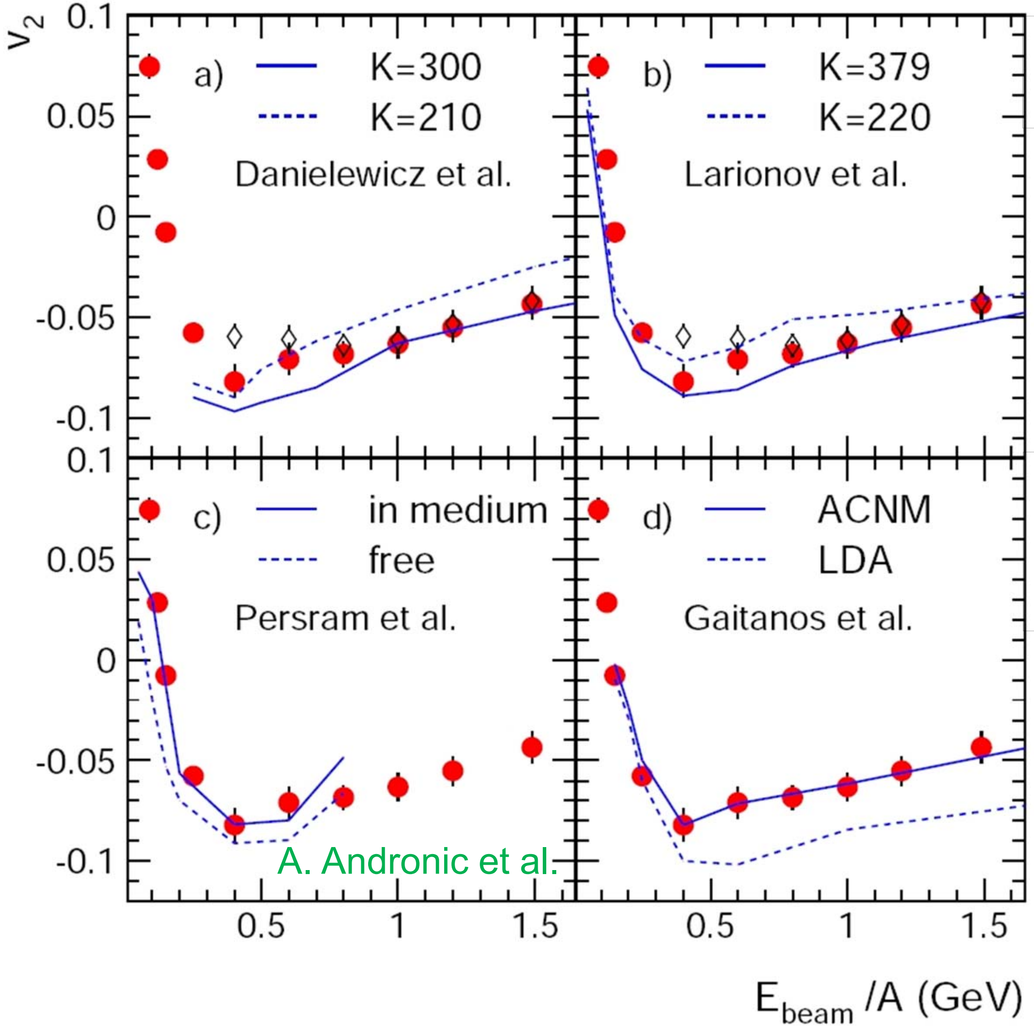


W. Reisdorf et al, Nucl. Phys. A 876 (2012) 1

- yields of composite particles (d, t, 3He, α ...) emitted from the mid-central source are under predicted by most models (model -> cluster reconstruction algorithm)
- momentum dependence and neutron/proton effective masses
- .... others see E. Di Filippos

Heavy ion reactions and transport models

Au+Au elliptic flow in mid-central collisions
compared to predictions from BUU models



Influence of the EOS

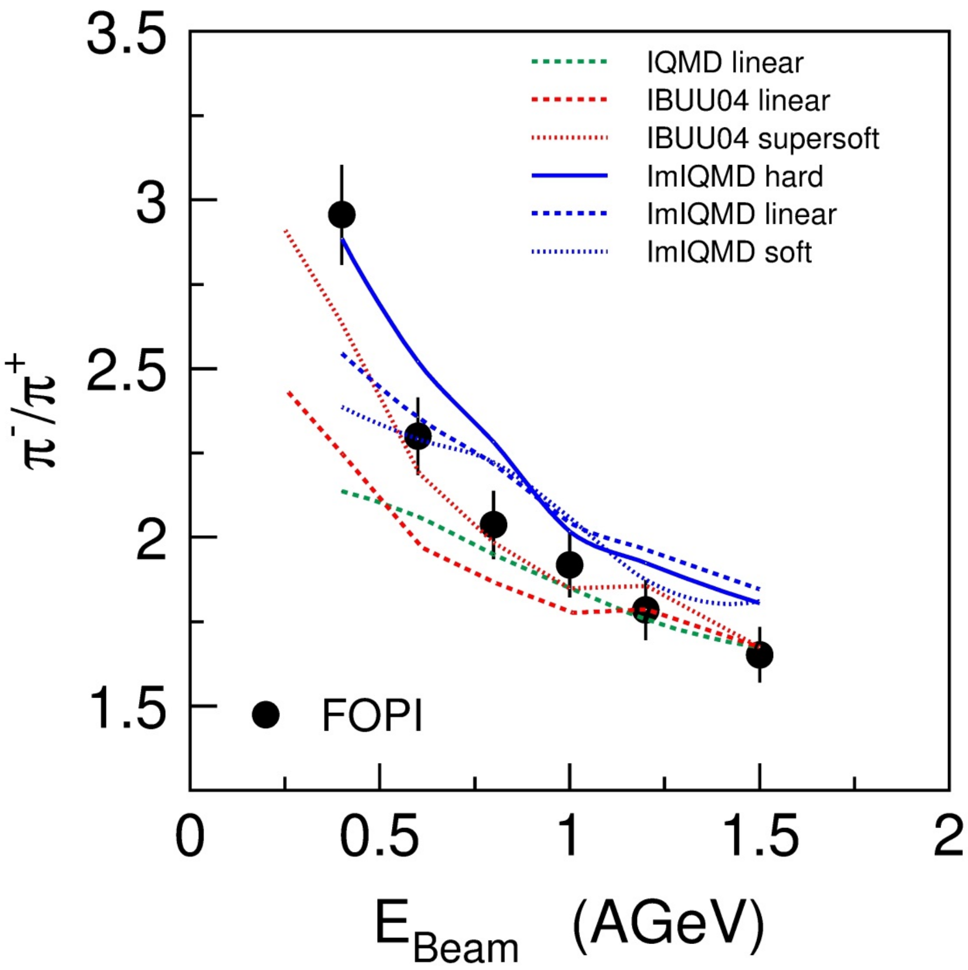
In-medium effects with soft EOS

Constraining input parameters with experimental data
→ more rigorously
(see talk of B. Barker)

Heavy ion reactions and transport models

Density dependence of the symmetry energy:

- IQMD and IBUU04 yield – in a sense – compatible results: a soft density dependence of the symmetry term leads to a higher π^-/π^+ ratio
  - in IQMD small sensitivity to the symmetry energy, most due to secondary effects
  - agreement with n/p flow data needing a slightly stiffer SE (see talks of J. Lukasik, E.. di Filippo or D. Cozma)
- whereas others predict a higher π^-/π^+ ratio for a hard density dependence of the symmetry energy
- or no dependence at all



IQMD: C. Hartnack
IBUU04: X. Zhang et al.
ImIQMD: Z. Feng, G. Jing, PRC 82 (2010) 044615

Transport models

Existing codes differ in

- initialization
- description of particle properties/resonances
- model dependent cross sections (e.g. NN-in-medium)
- numerical methods
- physics concepts....

Drawing conclusions

- on EOS
- in-medium effects etc.

is difficult when models yield different results on specific observables

Need to control

numerical methods

standard input parameters

BENCHMARKING TRANSPORT MODELS

Benchmarking of transport models

Performance evaluation

What is being evaluated?

Predictions of transport codes

How does one define performance?

Deviation of code predictions from (experimental) data?
But... not describing experimental data may also be a result!

Benchmark:

Set of experimental data
Needs to be defined
Criteria?

Benchmarking = Performance evaluation

How?

Describing experimental data?

Additional benchmark data

- pion production → inelastic cross sections, momentum dependence
- stopping → elastic cross section

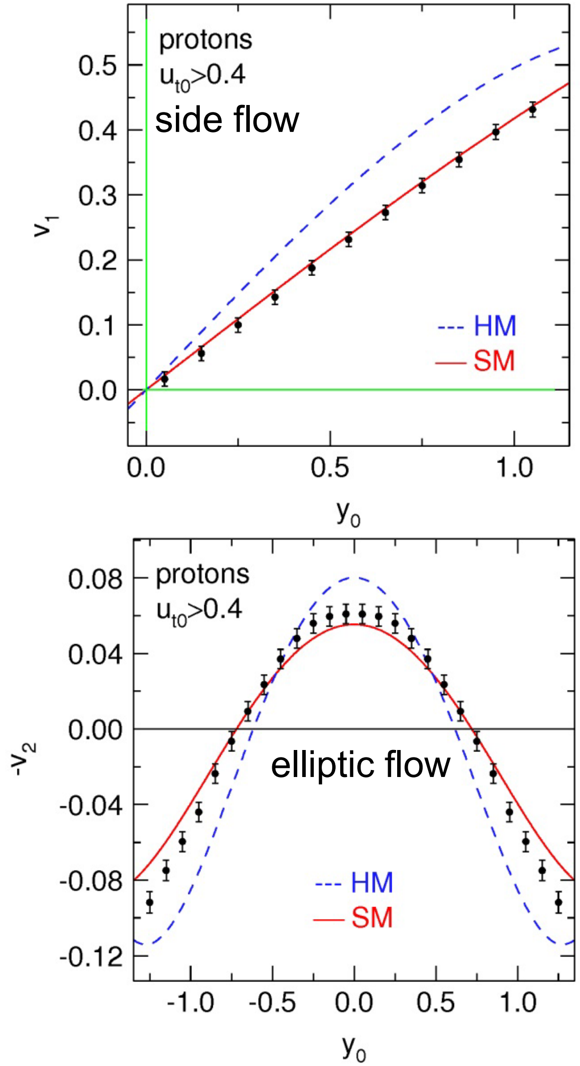
Calculations done with IQMD (UrQMD)

- input parameters *selected* but not fitted
- same input parameters for all comparisons
- also describing kaon data

Problems:

- Clusterization
- FOPI filter for ERAT
- particle acceptance
- analysis method
- reaction plane determination

Au+Au 1A GeV 3.5<b<6.3 fm



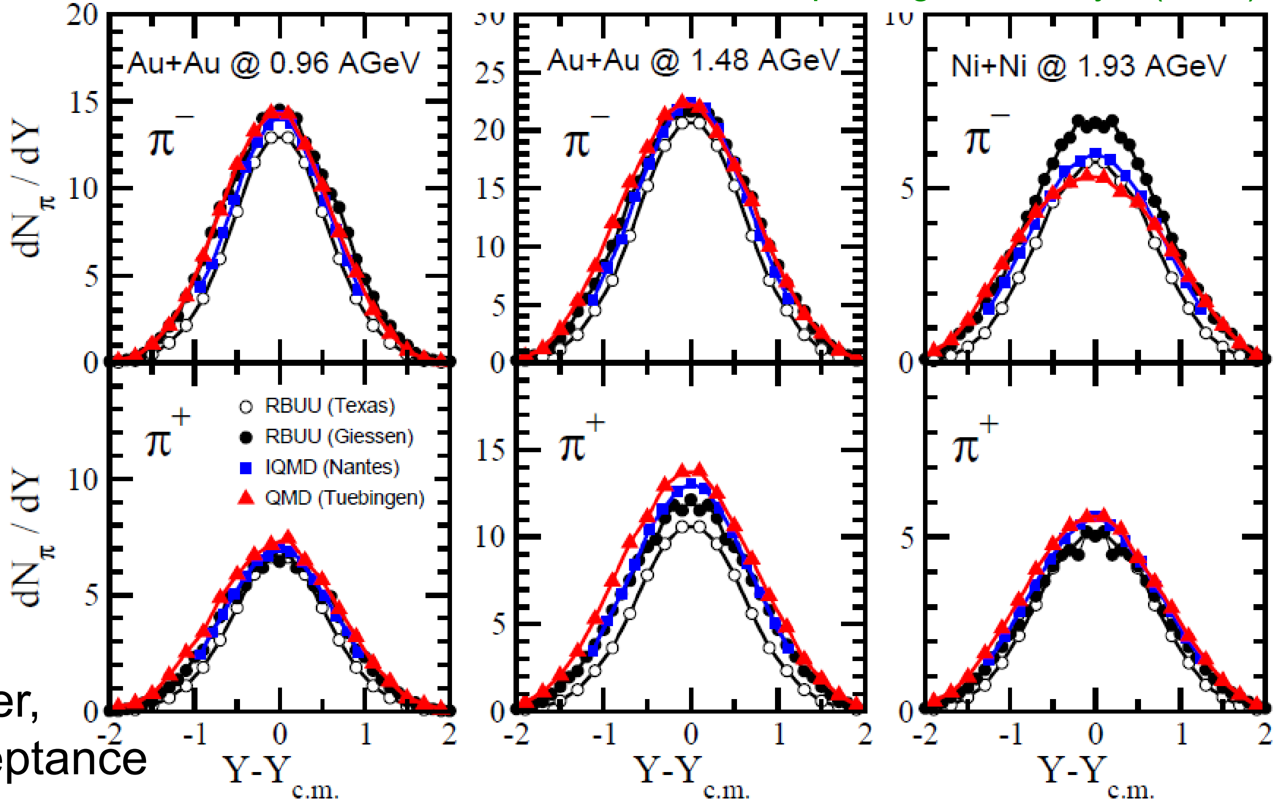
W. Reisdorf et al, Nucl. Phys. A 876 (2012) 1

Benchmarking = Performance evaluation

C. Fuchs, Rep. Prog. Nucl. Phys. (2005)

How?

Comparison to
a reference model!



- same impact parameter,
- same cuts, same acceptance
- standard output
- standard analysis routine
- agreement on cross sections, Delta lifetimes, detailed balance (Trento 2001/2003)

E.E. Kolomeitsev, C. Hartnack, H.W. Barz, M. Bleicher, E. Bratkovskaya, W. Cassing, L.W. Chen, P. Danielewicz, C. Fuchs, T. Gaitanos, C.M. Ko, A. Larionov, M. Reiter, Gy. Wolf, J. Aichelin, J. Phys. G 31 (2005) 741.

Benchmarking = Performance evaluation

Select the reference model

Define a set of observables sensitive to certain input parameters

- yields
- stopping
- flow ....

and a set of systems, energies and impact parameters

- Au+Au, Sn+Sn, C+C
- 100... 2 AGeV
- central, half central

Generate appropriate number of events for all systems/energies/ impact parameters with standard output

Analyze with standard analysis tool

Publish in comparison to reference data set

Finally:

- publish the code

Benchmarking – How I do it!

Define a set of observables sensitive to certain input parameters

- yields: pions, p, (n,) t
- stopping/spectra (rapidity distribution, apparent temperature): pions, p, t
- flow v1 and v2: p, t

and a set of systems, energies and impact parameters

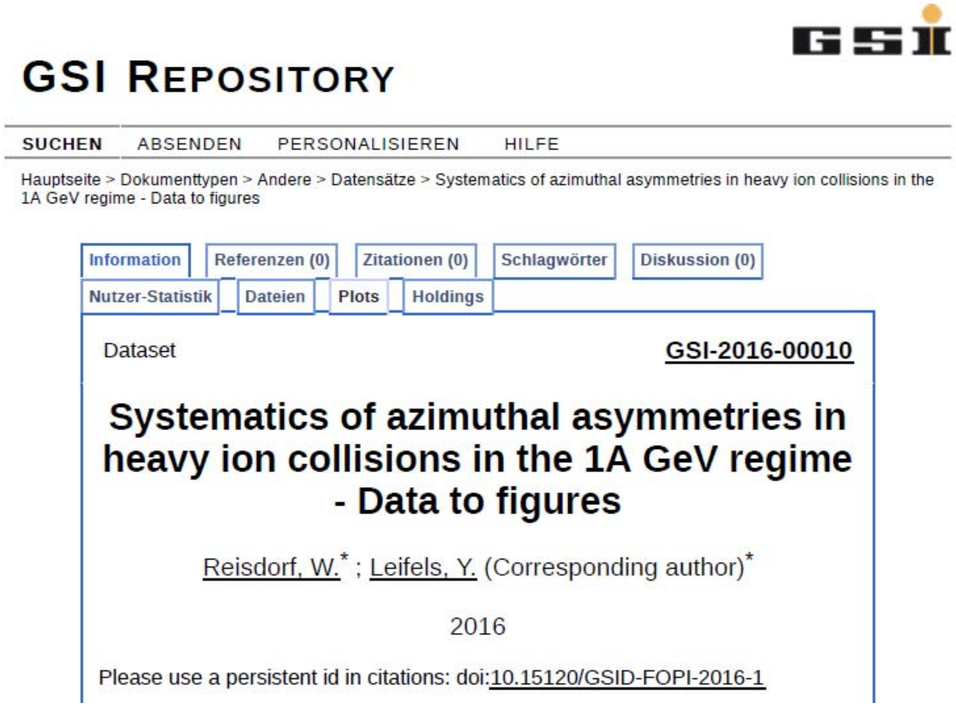
- Au+Au, Ni+Ni, Ar+Ar
- energy: 250, 400, 1000, 2000 AMeV
- central, half central (inclusive): b_{max}

Generate appropriate number of events for all systems/energies/ impact parameters with standard output

Analyze with standard analysis tool

Publish the result in comparison to reference data set in a repository providing also the input parameter set and the version number of the code

Benchmarking = Performance evaluation


GSI REPOSITORY

SUCHEN ABSENDEN PERSONALISIEREN HILFE

Hauptseite > Dokumenttypen > Andere > Datensätze > Systematics of azimuthal asymmetries in heavy ion collisions in the 1A GeV regime - Data to figures

Information | Referenzen (0) | Zitationen (0) | Schlagwörter | Diskussion (0)

Nutzer-Statistik | Dateien | Plots | Holdings

Dataset GSI-2016-00010

Systematics of azimuthal asymmetries in heavy ion collisions in the 1A GeV regime - Data to figures

Reisdorf, W.* ; Leifels, Y. (Corresponding author)*

2016

Please use a persistent id in citations: doi:10.15120/GSID-FOPI-2016-1

- comparisons should be stored on a common or institutes archive
  - persistency
- every group should assign a version number to certain releases of the code (in particular when writing publications) and save this version
  - reproducible

Benchmarking

... does not solve the problem when results of transport codes differ and drawing conclusions is model dependent

- it just elucidates the differences in a structured way
- differences have to be understood and removed
- two programs using the same theoretical approach and the same input parameters should give the same results
- **community has to survey program codes and should decide on the most suitable ones to solve certain problems (as it was done for the higher energies)**

FINALLY

Summary and conclusions

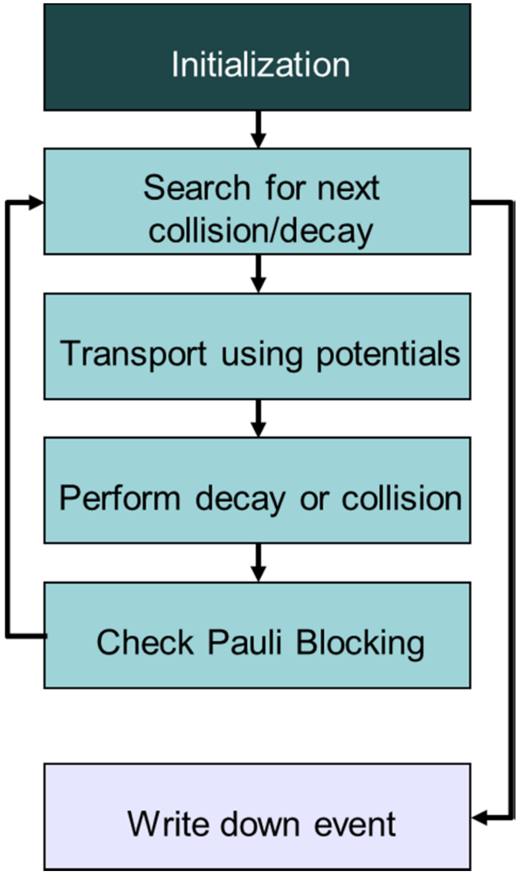
- transport codes are necessary not only to reproduce data but also to study unknown quantities
  - nuclear EOS
  - density dependence of symmetry energy
  - in-medium masses and cross sections
- which can only be obtained by transport models
- **conclusions are only accepted if all programs give the same results**
- at energies > 400 AMeV choosing input parameters and approaches let to a relatively good agreement between various theoretical models Trento 2001/2003
- Benchmarking is a tool to evaluate and document the performance of program
  - benchmark data is needed
    - necessary to select appropriate observables which are sensitive to the critical input parameters
    - availability of experimental data
  - setting up tools
- Critical evaluation of codes and inputs
  - General frame work for transport

Common transport frame work

- open source code available to all experimentalists and theoreticians
- modular in order to test different theoretical propositions (e.g. different realizations of in-medium modifications of particle properties) without changing the rest of the program
- transparent with respect to implemented effects and assumptions
- incorporate all presently available information on particle properties and cross sections consistently
- avoid averaging and approximations whenever possible
- employ state of the art mathematical tool

Achievement

- like GEANT3/4 for transport
- standardized environment to test new approaches



FAIR in 2025