The SMASH Project
(A next-generation hadronic transport model)
Status and Progress

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(and the SMASH team)

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FIAS Frankfurt Institute for Advanced Studies

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HIC for FAIR
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Outline

Idea: give an overview over the current status and recent progress of the SMASH project

- motivation: starting a new transport code from scratch
- SMASH: what it is, what it does
- particles, resonances
- "actions", cross sections, decays
- various tests and checking
- hadronic potentials, Fermi motion
- physics case: pion multiplicities in the 1 AGeV regime

Disclaimer

1. all work presented here is not just my personal achievement, but stems from a highly collaborative effort (i.e. several other people have been involved in doing all the work)

2. the views and opinions expressed here are primarily my own ;)

The SMASH Team

currently:

- group leader (Hannah Petersen)
- 3 postdocs (LongGang Pang, Matthias Kretz, J.W.)
- 1 PhD student (Dima Oliinychenko)
- 1 master student (Thomas Kehrenberg)
- 1 bachelor student (Marcel Lauf)

previous contributors:

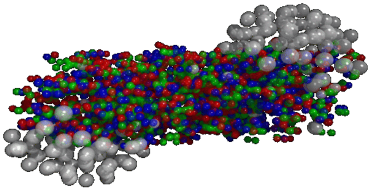
- Max Attems, Jussi Auvinen, Björn Bäuchle

"consulting":

- Kai Gallmeister, Jochen Gerhard

Physics Motivation

- transport models are an essential tool to understand high-energy heavy-ion collisions
- complementary to hydro approaches
- important for understanding non-equilibrium phenomena and 'microscopic' physics
- however much QGP you create, it will always freeze out into hadrons
- you need to have the hadronic phase under control!



Technical Motivation

- most (hadronic) transport models at present are still based on Fortran(77)
- an ancient language, designed for punchcards!
- codes are historically grown, typically badly structured
- become increasingly unmaintainable
- carry a lot of historic 'dead fright'
- do not take full advantage of modern hardware (multi-core, GPU, distributed-memory)
- hard to find students which are 'fluent' in Fortran
- hard to find any computer scientists which are enthusiastic about F77
- often codes are not open and results not reproducible

Going Forward ...

- bite the bullet: start a new implementation from scratch!
- for sure: major effort, will take time
- but: opens up many opportunities

- ingredients:
    - an appropriate programming language (C++)
    - proper version control (git)
    - collaborative tools: redmine, doxygen, ...
    - motivated people with physics and CS skills
    - proper physics

- long-term aim: create an open platform for transport-based research

WHY C++?

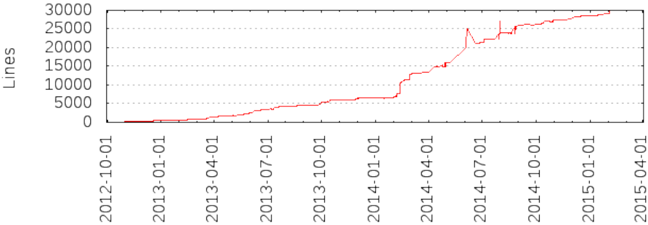
language options for modern scientific codes:
C++, Fortran2008, Python, ...

advantages of C++:

- modern general-purpose language
- built on concepts like object orientation ('classes') and generic programming ('templates')
- good performance
- numerous libraries available
- commonly taught at universities
- widely used also in industry and non-academic areas

SMASH: current status

- SMASH: **S**i**M**ul**A**tor for **S**mashing **H**eavy ions
- project is roughly two years old
- $\sim$ 30k loc, 7 active contributors
- internal release 0.6 (yesterday!)
- most infrastructure work is done
- we're starting to do some actual physics!



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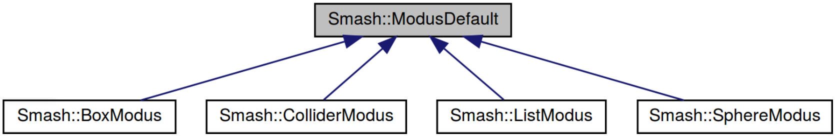


SMASH can be run in different setups:

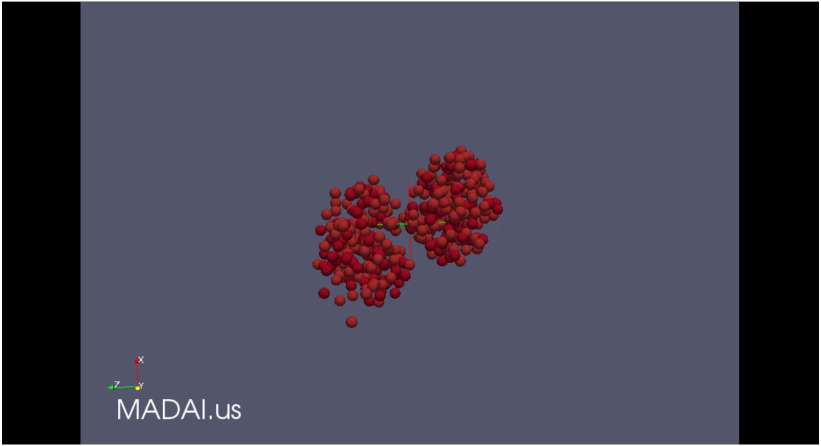
- Collider: nucleus+nucleus, hadron+hadron, hadron+nucleus
- Box: box with periodical boundary conditions (inifinte-matter simulations, checks for equilibration and detailed balance)
- Sphere: simple expanding sphere with given initial particle distribution (testing)
- List: initialize with a list of externally specified particles (e.g. for interfacing with hydro)

I/O and Analysis

- input in YAML format (to specify simulation parameters and options)
- output formats: OSCAR, VTK, ROOT, binary, ...

- separate analysis repository collects scripts (mainly Python) that directly work on Smash output
- perform all sorts of tests and physics analyses
- plus: unit tests that check correctness of the code

Movies (via VTK output)

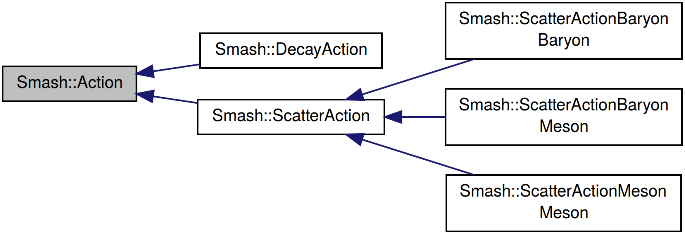


DEGREES OF FREEDOM: HADRONS

name	mass	width	PDG IDs	decays
π	0.138	0.0	211,111,-211	
ρ	0.776	0.149	213,113,-213	$\pi\pi$
η	0.548	1.0e-6	221	3π
ω	0.783	0.0085	223	$\pi\rho$
σ	0.800	0.400	9000221	$\pi\pi$
N	0.938	0.0	2212,2112	
Δ	1.232	0.117	2224,2214,2114,1114	πN
N*(1440)	1.462	0.391	202212,202112	πN, $\pi\Delta$, σN
N*(1520)	...	...	...	...

- up to now: only a few non-strange mesons and baryons
- plus antiparticles
- assume isospin symmetry
- more to come soon!

The Action concept



- "Action": any event that transforms N particles into M others
- currently implemented:
  - collisions ($2 \to 1$, $2 \to 2$)
  - decays ($1 \to 2$)
  - box-wall crossings ($1 \to 1$)
- in future:
  - multi-particle production ($2 \to X$)
  - multi-particle interaction ($X \to Y$)

use Manley/Saleski ansatz:

$$\Gamma_{R\to ab} = \Gamma^0_{R\to ab}\frac{\rho_{ab}(m)}{\rho_{ab}(M_0)}$$

$$\rho_{ab}(m) = \int dm_a^2 dm_b^2 \mathcal{A}_a(m_a^2)\mathcal{A}_b(m_b^2)\frac{p_f}{m}B_L^2(p_f R)\mathcal{F}_{ab}^2(m)$$

example: $L = 1$ decays with stable daughters ($\Delta \to \pi N$, $\rho \to \pi\pi$):

$$\Gamma(m) = \Gamma_0 \frac{m_0}{m}\left(\frac{q}{q_0}\right)^3 \frac{q_0^2+\Lambda^2}{q^2+\Lambda^2}$$

CROSS SECTIONS

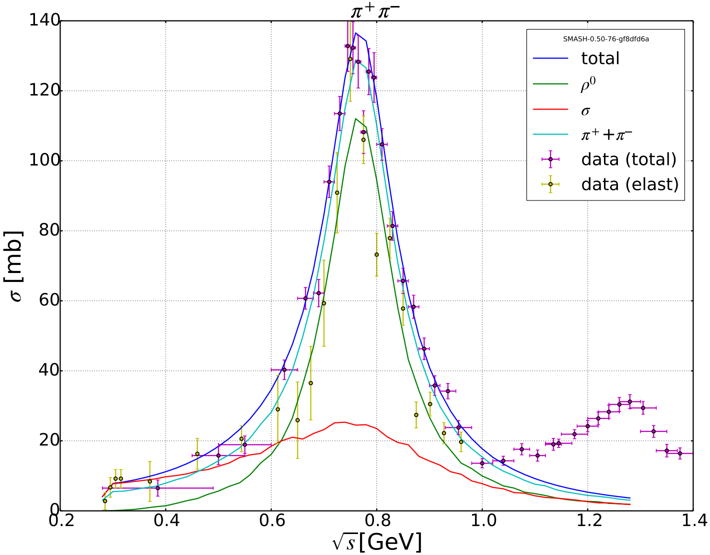
$2 \to 1$ resonance production (Breit-Wigner):

$$\sigma_{ab\to R}(s) = \frac{2J_R+1}{(2J_a+1)(2J_b+1)}\mathcal{S}_{ab}\frac{4\pi}{p_{cm}^2}\frac{s\Gamma_{ab\to R}(s)\Gamma_R(s)}{(s-M_0^2)^2+s\Gamma_R(s)^2}$$

$2 \to 2$ (e.g. $NN \to N\Delta$):

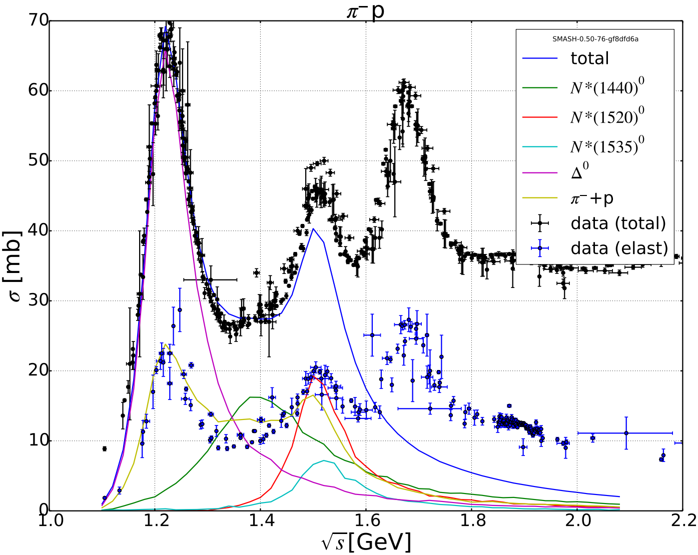
$$\sigma_{ab\to Rc}(s) = C_I^2\frac{|M|^2_{ab\to Rc}}{64\pi^2 s}\frac{4\pi}{p^i_{cm}}\int dm^2\mathcal{A}(m^2)p^f_{cm}$$

with the spectral function $\mathcal{A}(m) = \frac{1}{\pi}\frac{m\Gamma(m)}{(m^2-M_0^2)^2+m^2\Gamma(m)^2}$

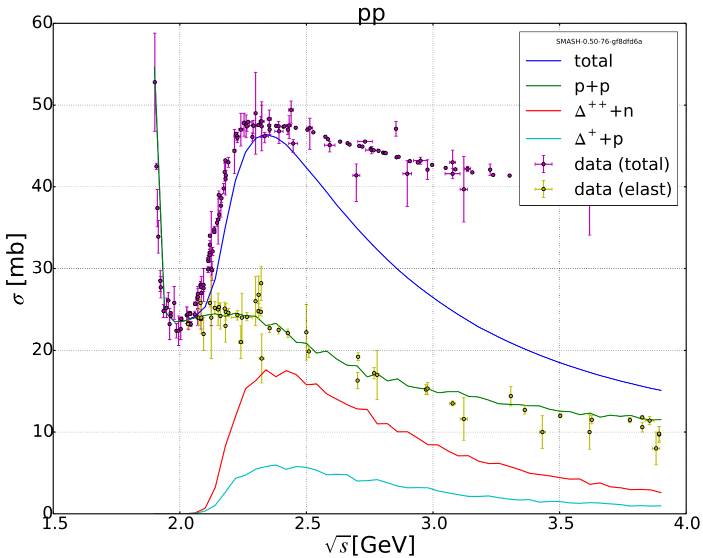


$\pi^+\pi^-$
SMASH-0.50-76-gf8dfd6a
total
ρ^0
σ
$\pi^+ + \pi^-$
data (total)
data (elast)
σ [mb]
$\sqrt{s}$[GeV]
0
20
40
60
80
100
120
140
0.2
0.4
0.6
0.8
1.0
1.2
1.4

πN CROSS SECTION



NN cross section



COLLISION CRITERION

time of closest approach in calc. frame [Bass et al., PPNP41, 1998]:

$$t_{coll} = -\frac{(\mathbf{x}_a - \mathbf{x}_b) \cdot (\mathbf{v}_a - \mathbf{v}_b)}{(\mathbf{v}_a - \mathbf{v}_b)^2} < \Delta t$$

transverse distance (in c.o.m. frame):

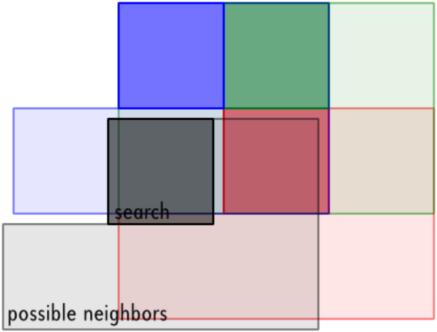
$$d_{coll}^2 = (\mathbf{x}_a - \mathbf{x}_b)^2 - \frac{((\mathbf{x}_a - \mathbf{x}_b) \cdot (\mathbf{p}_a - \mathbf{p}_b))^2}{(\mathbf{p}_a - \mathbf{p}_b)^2} < \frac{\sigma_{tot}}{\pi}$$

time ordering of actions in calc. frame!

testparticles:

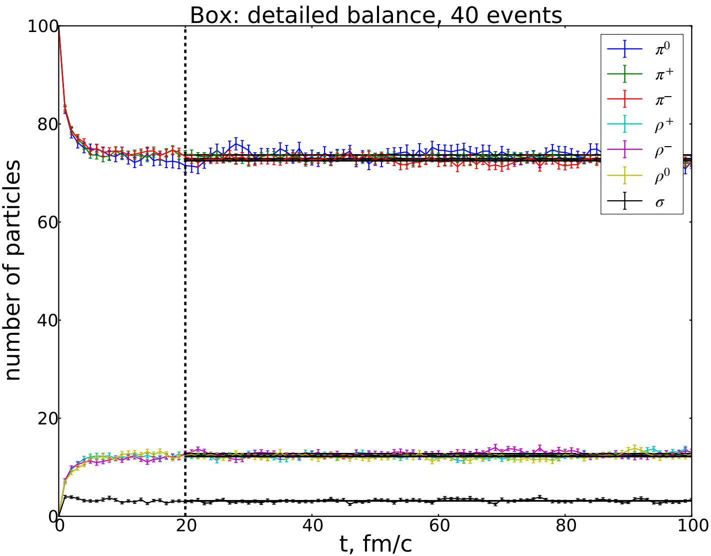
- represent each physical particle by a number of testpart. N_{test}
- divide cross sections by N_{test}

The Grid

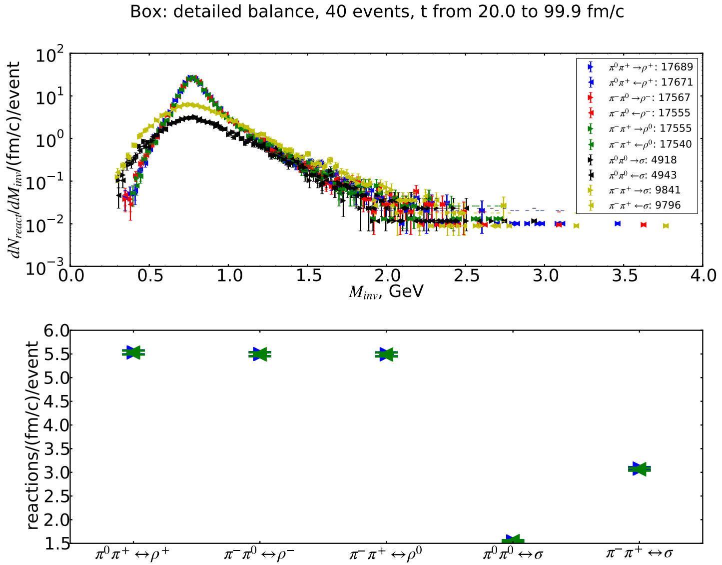


- for a particle in a given grid cell, look for collision partners only in direct neighborhood
- min. grid size connected to max. cross section ($\sim$ 200mb)
- dynamical optimization of grid parameters (Δx, Δt, ...): current master-thesis project

Checks: $\pi - \rho - \sigma$ system (1)



Checks: $\pi - \rho - \sigma$ system (2)



Skyrme potentials

standard Skyrme-type potential (without mom-dep.):

$$
\begin{aligned}
U &= a(\rho/\rho_0) + b(\rho/\rho_0)^\tau + 2S_{pot}\frac{\rho_p - \rho_n}{\rho_0} \cdot \frac{I_3}{I} \\
H_i &= \sqrt{\mathbf{p_i}^2 + m_i^2} + U(\mathbf{r_i})
\end{aligned}
$$

parameters:

$a = -209.2$ MeV, $b = 156.4$ MeV, $\tau = 1.53$, $S_{pot} = 18$ MeV

[Shanghai WS 2014]

$\Rightarrow$ rather soft EOS: $K = 240$ MeV

equations of motion:

$$
\begin{aligned}
\frac{d\mathbf{r_i}}{dt} &= \frac{\partial H_i}{\partial \mathbf{p_i}} = \frac{\mathbf{p_i}}{\sqrt{\mathbf{p_i}^2 + m_i^2}} \\
\frac{d\mathbf{p_i}}{dt} &= -\frac{\partial H_i}{\partial \mathbf{r_i}} = -\frac{\partial U}{\partial \mathbf{r_i}}
\end{aligned}
$$

Nucleus Initialization / Fermi motion

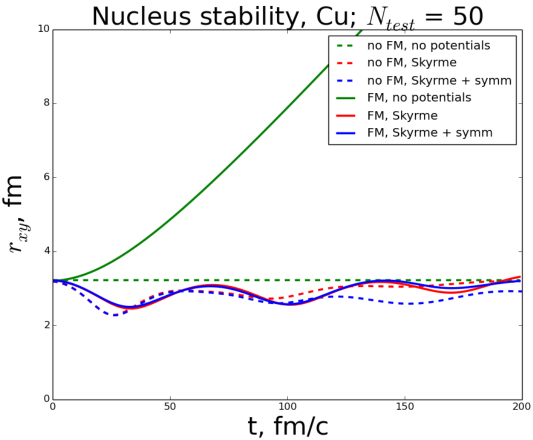
- spatial distribution: Woods-Saxon

$$\frac{dN}{d^3r} = \frac{\rho_0}{\exp\left(\frac{r-r_0}{d}\right) + 1}$$

- momentum distribution: local Thomas-Fermi approximation
- determine local Fermi momentum

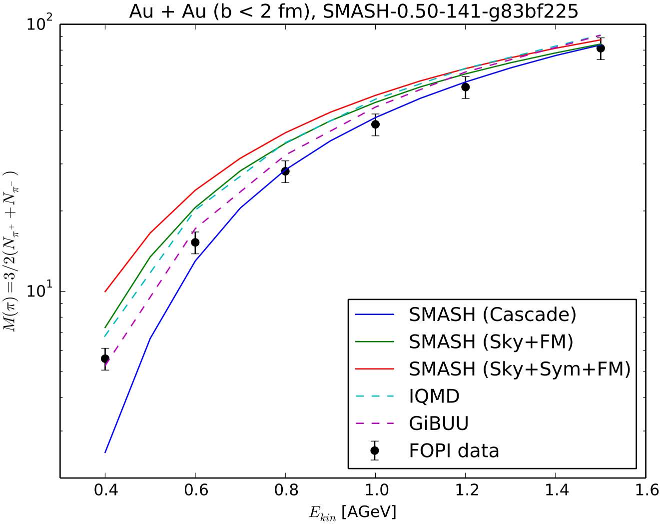
$$p_F = (3\pi^2\rho(\mathbf{r}))^{1/3}$$

- momentum distributed randomly inside Fermi sphere

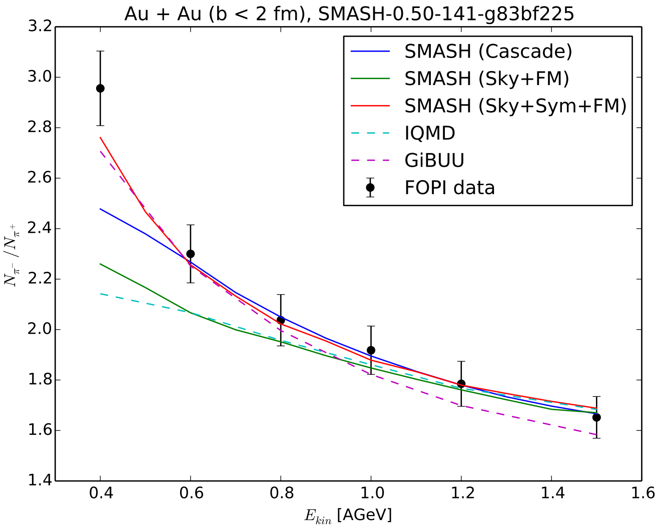


- nucleus is reasonably stable with Skyrme+FM
- with small fluctuations in avg. radius (as expected)

Pion yields around 1AGeV: FOPI data



FOPI: PION RATIO



Conclusions/Outlook

- SMASH is starting to provide a clean and future-proof implementation of hadronic transport

- still much work to be done:
  - strangeness
  - string fragmentation ($\Rightarrow$ Pythia 8)
  - interface to hydro phase
  - parallelization
  - ...