Brief overview about SMASH and HepMC

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SMASH: Simulating Many Accelerated Strongly-interacting Hadrons

SMASH: (Phys.Rev.C 94 (2016) 5, 054905, arXiv:1606.06642 [nucl-th])

- effectively solves the relativistic Boltzmann equation $p_\mu \partial^\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C^i_{coll}$
- is suitable for the study of low-energy heavy-ion collisions (GSI, FAIR, NICA, low-end RHIC energies) and late, dilute stages of high-energy heavy-ion collisions (RHIC, LHC)
- its basic degrees of freedom are the hadrons listed by the PDG up to m $\approx$ 2.35 GeV
- uses a geometric collision criterion: $d_{coll} < \sqrt{\frac{\sigma_{tot}}{\pi}}$ (stochastic criterion underway)
- models inelastic collisions through resonance/string excitation and decay
- relies on Pythia for string fragmentation in the high-energy region
- respects Detailed Balance, modeling multi-particle decays by intermediate resonances
- uses test particles method for mean field potentials ($\sigma \to \sigma/N_{test}$; $N \to N \cdot N_{test}$)
- can produce perturbatively photons and dileptons
- does not perform weak decays

Technical info about SMASH

Website: https://smash-transport.github.io/

- project started and lead by Prof. Hannah Elfner, ≈ 30 contributors from 2012 to now
- written in C++ (reference standard: C++11, moving to C++14)
- license: GPLv3 for all C++ programs, BSD 3-clause for cmake script
- version control: git, repositories on GitHub
- public repository open to external contributions: https://github.com/smash-transport/smash
- private development repository, personal branches for new features and bug fixing
- pull requests merged only after passing code review and tests
- continuous integration system, with 97 tests (more planned)
- use of Doxygen, issue tracking, developers' wiki
- extensive "real world" runs before new releases, results compared with previous versions
- external libraries: Pythia, GSL, Boost, Eigen, Root, HepMC3, Rivet
- outputs: Oscar1999/2013 (also with collisions), Root, VTK, HepMC3 (also with coll.), YODA, +others

SMASH and HepMC3

- HepMC3 output already available in the current public version
- refactoring by Christian Holm Christensen (*thanks!*), in merging phase
- weak decays are not included
- 1 vertex approach (incoming: the two ions, outgoing: the final hadrons)

```
HepMC::Version 3.02.03
HepMC::Asciiv3-START_EVENT_LISTING
E 0 1 2085
U GEV MM
A 0 GenCrossSection 1.00000000e+00 1.00000000e+00 -1 -1
A 0 GenHeavyIon v0 -1 -1 -1 -1 -1 -1 -1 -1 -1 2.1e-12 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0
P 1 0 1000791970 9.43689570933138306e-16 -1.9186041644303486e-15 1.3754382917006133e+03 1.3882799553220250e+03 1.8838986191571570e+02 4
P 2 0 1000791970 -1.4988010832439613e-15 2.1163626406917047e-16 -1.3735989449357155e+03 1.3864234356511674e+03 1.8813793183267410e+02 4
V -1 0 [1,2]
P 3 -1 2112 6.6331694115931883e-01 -2.4379008979486039e-01 4.5099025679659137e+00 4.6603098764842530e+00 9.3799999999999539e-01 1
P 4 -1 2112 -4.5270668544997568e-02 -3.0088272223290868e-01 2.3815951469717733e+00 2.5776771112861088e+00 9.3799999999999917e-01 1
P 5 -1 211 -4.0329720685159098e-01 -3.8188323481948450e-01 7.1480025528005464e-01 9.1567835343886384e-01 1.3800000000000062e-01 1
P 6 -1 111 3.0641641017577714e-01 -1.3783349192318975e-01 -2.3272903494970720e-01 4.3138833042790137e-01 1.3800000000000023e-01 1
P 7 -1 2212 6.0989232038425856e-01 -7.4725583561518949e-01 -2.8262176919375155e+00 3.1301294491674407e+00 9.3799999999999917e-01 1
P 8 -1 2212 4.0731373777449856e-02 8.1187804084078707e-01 -1.3079581189504912e+00 1.8031648396466085e+00 9.3799999999999550e-01 1
P 9 -1 22 -9.2386651843253093e-02 1.0898872803301661e-01 -2.5383219003143254e-01 2.9128099315474498e-01 -3.7252902984619141e-09 1
• • •
P 2084 -1 -211 3.7504676390887565e-01 4.5226506152572912e-02 3.8179598143172866e-01 5.5454276968932303e-01 1.3800000000000043e-01 1
P 2085 -1 -211 7.6023702285501787e-02 -2.0728952588888874e-01 -1.5970500743862019e+00 1.6181351893304243e+00 1.3800000000000023e-01 1
E 1 1 2142
U GEV MM
A 0 GenCrossSection 1.00000000e+00 1.00000000e+00 -1 -1
A 0 GenHeavyIon v0 -1 -1 -1 -1 -1 -1 -1 -1 -1 2.1e-12 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0
P 1 0 1000791970 2.0816668171721685e-16 -2.4980018054066022e-16 1.3773932707329091e+03 1.3902531868511953e+03 1.8865762982080454e+02 4
P 2 0 1000791970 -1.1796119636642288e-16 1.3877787807814457e-16 -1.3772711678013673e+03 1.3901299439159295e+03 1.8864090573034147e+02 4
V -1 0 [1,2]
P 3 -1 3112 -3.3033684447684913e-01 3.1916832849818394e-01 -3.8019160813222846e-02 1.2752087316687368e+00 1.1890000000000001e+00 1
P 4 -1 2112 1.0289398340740465e+00 3.5691784808330568e-01 7.3723862022617348e-01 1.6153861196561448e+00 9.3800000000000028e-01 1
P 5 -1 -211 2.9797826949558187e-01 -1.8485137056841505e-01 -1.2968877447887999e+00 1.3505268975018536e+00 1.3799999999999943e-01 1
```

SMASH HepMC3 output with collision history

- possibility to print also the full collision history in merging phase
- number of participants included (nucleons that had at least one collision with a nucleon of the other ion)
- but the centrality measure should be based on experimentally measured quantities
- or obtained by using a conversion formula from the impact parameter

```
HepMC::Version 3.02.03
HepMC::Asciiv3-START_EVENT_LISTING
E 0 5112 10192
U GEV MM
A 0 GenHeavyIon v0 1 46 46 46 -1 -1 -1 -1 -1 4.2 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0
V -1 0 [395,396]
P 1 -1 2112 7.8712677104819856e-02 -1.4960615824082379e-01 9.9302965090654300e+00 9.9759315578084067e+00 9.3799999999999994e-01 101
P 2 -1 2112 1.3485950653406700e-01 2.2996876456971248e-02 8.6835327366161170e+00 8.7351188160615880e+00 9.3799999999999994e-01 103
P 3 -1 2112 -7.7601246997128184e-02 4.9847926832582413e-02 1.1581805908283506e+01 1.1620093754634501e+01 9.3799999999999994e-01 1
P 4 -1 2112 1.0505546339754430e-01 1.2451620185023873e-01 8.2721792642073293e+00 8.3267841760246544e+00 9.3799999999999994e-01 145
. . .
P 393 -1 2212 -1.2883198621432670e-01 -1.4113531862347004e-01 -8.9471437691271269e+00 8.9982077373366547e+00 9.3799999999999994e-01 101
P 394 -1 2212 3.3250214432509702e-02 1.0800846316361748e-01 -9.0130866175903694e+00 9.0624690775230441e+00 9.3799999999999994e-01 102
P 395 0 1000791970 -1.5404344466674047e-15 -1.3461454173580023e-15 1.9602481827322265e+03 1.9692894892850316e+03 1.8848913683155308e+02 4
P 396 0 1000791970 -4.3715031594615539e-16 4.9960036108132044e-16 -1.9599808731101930e+03 1.9690209467434863e+03 1.8846343347403226e+02 4
. . .
V -6 0 [144,204] @ -1.0951630927022127e+00 2.2452028597848011e+00 8.6662028923993273e-02 1.4736666838563284e-01
P 440 -6 3114 -3.3404249576053757e-01 -8.6156288650605450e-01 2.8598273591145187e+00 3.2923344543640414e+00 1.3850000000000000e+00 145
P 441 -6 211 1.4298777068454666e-01 5.0628771555056296e-01 2.1958424089527160e+00 2.2621981872590236e+00 1.3800000000000001e-01 1
P 442 -6 321 7.5820895921327469e-01 2.9823003688399513e-01 4.4106236850031326e+00 4.5123673688477242e+00 4.9399999999999999e-01 145
P 443 -6 2112 4.9846305057026599e-02 5.5321112474797252e-01 -4.5787555749966469e+00 4.7067370670386541e+00 9.3799999999999994e-01 145
P 444 -6 111 -5.0963324451302439e-01 -3.8360544631963001e-01 -6.2565636471300827e+00 6.2905096655953594e+00 1.3800000000000001e-01 101
```

SMASH and Rivet

In merging phase:
interface with Rivet using the AnalysisHandler (by Christian Holm Christensen (*thanks!*))

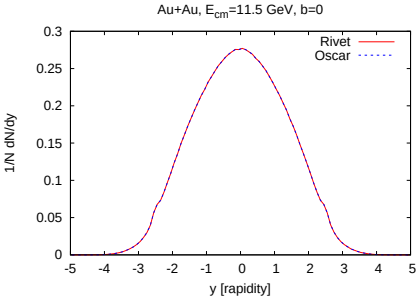
So far only tests with:

- MC_FSPARTICLES
- one *toy* own analysis

Caveats: *ignore_beam* must be used if Fermi motion is enabled. (the additional random momentum of nucleons leads to different total energies in the two ions)

However:

- consistency between results directly from the handler and Rivet on HepMC3 output
- consistency between Rivet results and post-processing with Python from Oscar output
- $\Rightarrow$ HepMC3 and Rivet can be used with SMASH



Answers to some questions

- Q: How do you handle decays? Do you have any information on particles' parentage? Would it be possible to add at least information from the freezeout surface onward to the HEPMC?
  A: Basically, so far we have only strong decays, with branching ratios according to PDG data. If strictly necessary, it should be possible to add also this information in the HepMC output, as well as weak decays.
- Q: Do you include the impact parameter in the HEPMC?
  A: Yes.
- Q: Do you have logistical issues with file sizes?
  A: The typical size in binary output for a study with SMASH is of order 1 TB (with broad variance). ASCII HepMC requires ≈ 1.5X more space. So file sizes can be an issue if one needs to save all the data. If this is not the case, the disk space issue can be solved by doing the post-processing of the results in intermediate steps or by using the Rivet handler.

Regarding Rivet, we have some resources to spend on a 1-time investment to include new infrastructure, but for steady maintenance and more efforts (e.g. implementing Rivet analysis from the theory side or similar) there are no resources (this "infrastructure work" would need more recognition and funding to be feasible).