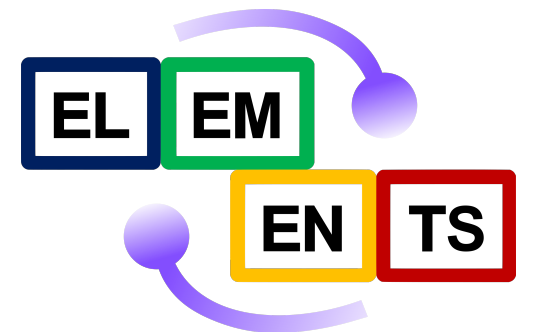




SMASH Status and Perspective: Application of HepMC and Rivet

Hannah Elfner

April 8th, 2021, Strong 2020 Workshop



A Little Advertisement

- Short workshop within RHIC-AGS users meeting on HEPMC in heavy-ion collisions:
- This is a chance to bring your perspective to the discussion about theory-experiment comparison

HEPMC in Heavy Ion Collisions


7 June 2021
US/Eastern timezone


- Overview
- Registration
- Participant List

Support

✉ christine.nattrass@utk.edu

This short workshop will focus on issues with the application of HEPMC standards in heavy ion Monte Carlo models, with an eye towards compatibility with Rivet analyses. There will be discussions of heavy ion specific issues with the goal of developing solutions which work for existing codes with feasible solutions.

 **Starts** 7 Jun 2021, 08:45
Ends 7 Jun 2021, 12:00
US/Eastern

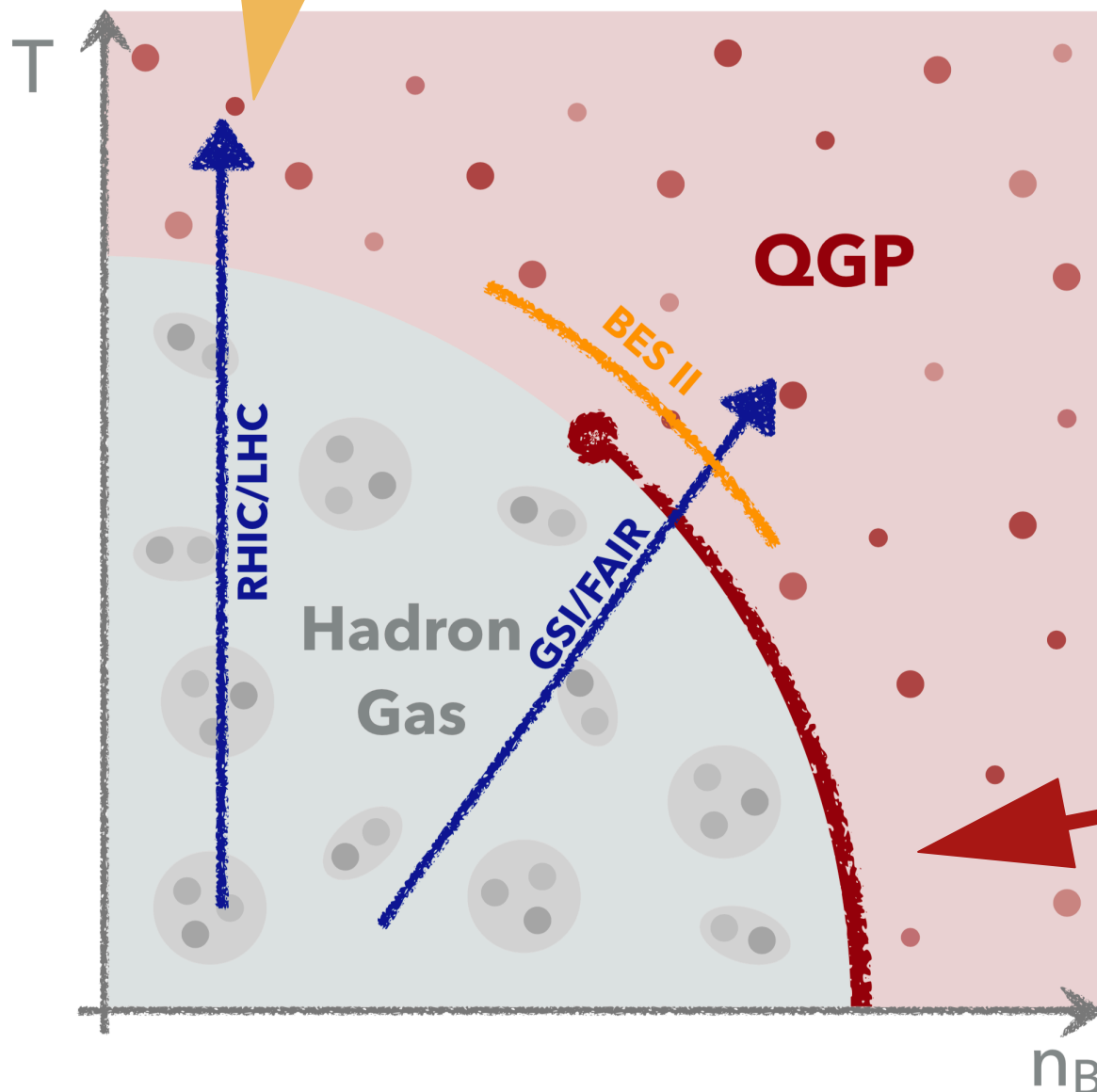
 [Christine Nattrass](#)

- Please register, if you are interested!
- There is also a Slack workspace on RIVET in heavy ions

Dynamical Modeling

Standard approach at high energies

- Non-equilibrium initial evolution
- Viscous hydrodynamics
- Hadronic rescattering



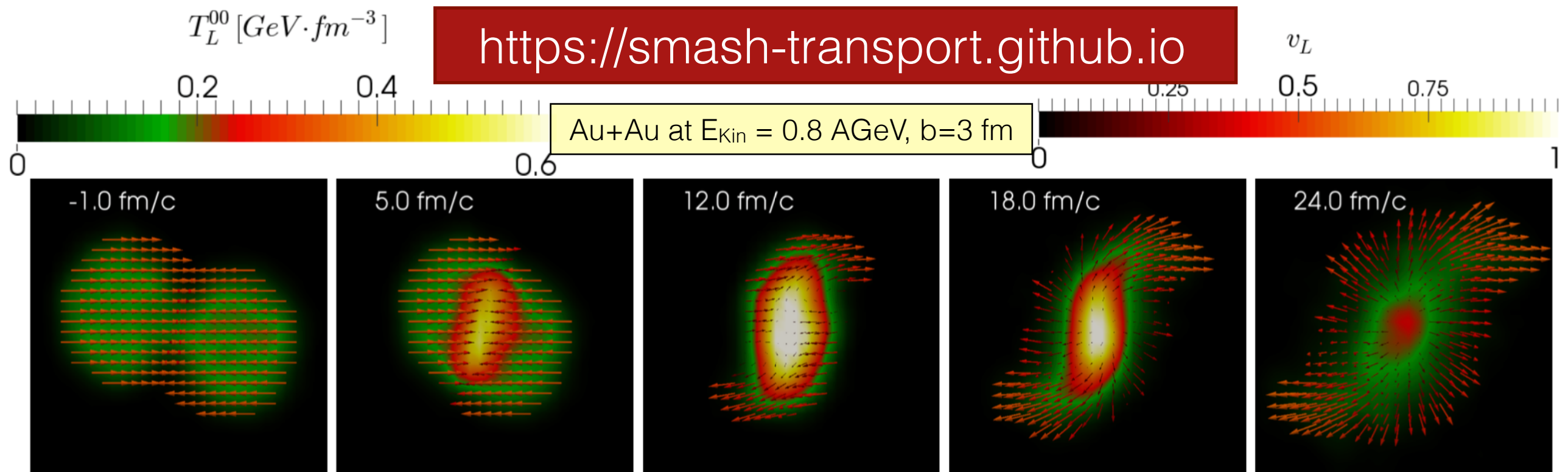
- **Status:** Two regimes with well-established approaches
- Goals:
 - Constraint on the equation of state of nuclear matter
 - Determine limit of applicability of hadronic transport approach
 - Predict qualitative signatures of first order phase transition

Standard approach at low beam energies

- Hadronic transport approaches
- Resonance dynamics
- Nuclear potentials



- Hadronic transport approach:
 - Includes all mesons and baryons up to ~ 2 GeV
 - Geometric collision criterion
 - Binary interactions: Inelastic collisions through resonance/string excitation and decay
 - Infrastructure: C++, Git, Doxygen, (ROOT)



* Simulating Many Accelerated Strongly-Interacting Hadrons

Degrees of Freedom

N	Δ	Λ	Σ	Ξ	Ω	Unflavored			Strange	
N ₉₃₈	Δ_{1232}	Λ_{1116}	Σ_{1189}	Ξ_{1321}	Ω_{1672}	π_{138}	$f_0 980$	$f_2 1275$	$\pi_2 1670$	K_{494}
N ₁₄₄₀	Δ_{1620}	Λ_{1405}	Σ_{1385}	Ξ_{1530}	Ω_{2250}	π_{1300}	$f_0 1370$	$f_2' 1525$		K^*_{892}
N ₁₅₂₀	Δ_{1700}	Λ_{1520}	Σ_{1660}	Ξ_{1690}		π_{1800}	$f_0 1500$	$f_2 1950$	$\rho_3 1690$	$K_1 1270$
N ₁₅₃₅	Δ_{1900}	Λ_{1600}	Σ_{1670}	Ξ_{1820}			$f_0 1710$	$f_2 2010$		$K_1 1400$
N ₁₆₅₀	Δ_{1905}	Λ_{1670}	Σ_{1750}	Ξ_{1950}		η_{548}		$f_2 2300$	$\phi_3 1850$	K^*_{1410}
N ₁₆₇₅	Δ_{1910}	Λ_{1690}	Σ_{1775}	Ξ_{2030}		η'_{958}	$a_0 980$	$f_2 2340$		$K_0^*_{1430}$
N ₁₆₈₀	Δ_{1920}	Λ_{1800}	Σ_{1915}			η_{1295}	$a_0 1450$		$a_4 2040$	$K_2^*_{1430}$
N ₁₇₀₀	Δ_{1930}	Λ_{1810}	Σ_{1940}			η_{1405}		$f_1 1285$		K^*_{1680}
N ₁₇₁₀	Δ_{1950}	Λ_{1820}	Σ_{2030}			η_{1475}	ϕ_{1019}	$f_1 1420$	$f_4 2050$	$K_2 1770$
N ₁₇₂₀		Λ_{1830}	Σ_{2250}				ϕ_{1680}			$K_3^*_{1780}$
N ₁₈₇₅		Λ_{1890}				σ_{800}		$a_2 1320$		$K_2 1820$
N ₁₉₀₀		Λ_{2100}					$h_1 1170$			$K_4^*_{2045}$
N ₁₉₉₀		Λ_{2110}				ρ_{776}		$\pi_1 1400$		
N ₂₀₆₀		Λ_{2350}				ρ_{1450}	$b_1 1235$	$\pi_1 1600$		
N ₂₀₈₀						ρ_{1700}				
N ₂₁₀₀							$a_1 1260$	$\eta_2 1645$		
N ₂₁₂₀						ω_{783}				
N ₂₁₉₀						ω_{1420}		$\omega_3 1670$		
N ₂₂₂₀						ω_{1650}				
N ₂₂₅₀										

As of SMASH-1.7

- ▶ + corresponding antiparticles
- ▶ Perturbative treatment of photons and dileptons
- ▶ Isospin symmetry

- Mesons and baryons according to particle data group
- Isospin multiplets and anti-particles are included

SMASH code

- SMASH is a ~30.000 lines C++ code
- Development started in 2012
- Publication happened in November 2018
- Developers:
 - 2019-2020 Agnieszka Wergieluk
 - 2014-2016, 2019-2020 Janus Weil
 - 2016 Joseph Tindall
 - 2015-2020 Vinzent Steinberg
 - 2015- Jan Staudenmaier
 - 2020- Agnieszka Sorensen
 - 2017- Anna Schäfer
 - 2017-2019 Sangwook Ryu
 - 2017-2019 Jonas Rothermel
 - 2016-2019 Jean-Bernard Rose
 - 2013-2018 Hannah Petersen
 - 2019 Lukas Prinz
 - 2015-2017 Longgang Pang
 - 2014- Dmytro Oliinychenko
 - 2017- Justin Mohs
 - 2019- Damjan Mitrovic
 - 2017 Markus Mayer
 - 2014-2015, 2020 Matthias Kretz
 - 2016-2018 Feng Li
 - 2020- Natey Kübler
 - 2015 Thomas Kehrenberg
 - 2019- Jan Hammelmann
 - 2014 Andy Goldschmidt
 - 2019-2020 Leon Geiger
 - 2020- Oscar Garcia-Montero
 - 2018- Hannah Elfner
 - 2016 Niklas Ehlert
 - 2012-2014 Bjørn Bäuchle
 - 2012-2014 Jussi Auvinen
 - 2012-2014 Maximilian Attems

The SMASH Team

- In Frankfurt:
 - Oscar Garcia-Montero
 - Gabriele Inghirami
 - **Jan Staudenmaier**
 - Anna Schäfer
 - **Justin Mohs**
 - Jan Hammelmann
 - Niklas Götz
 - **Natey Kübler**
 - Philip Karan
 - **Martha Ege**
 - Jannis Gebhard
 - Marco Müller
 - Antonio Bozic
- In US/China:
 - Dmytro Oliinychenko
 - Agnieszka Sorensen
 - Xiang-Yu Wu



Group excursion in September 2020

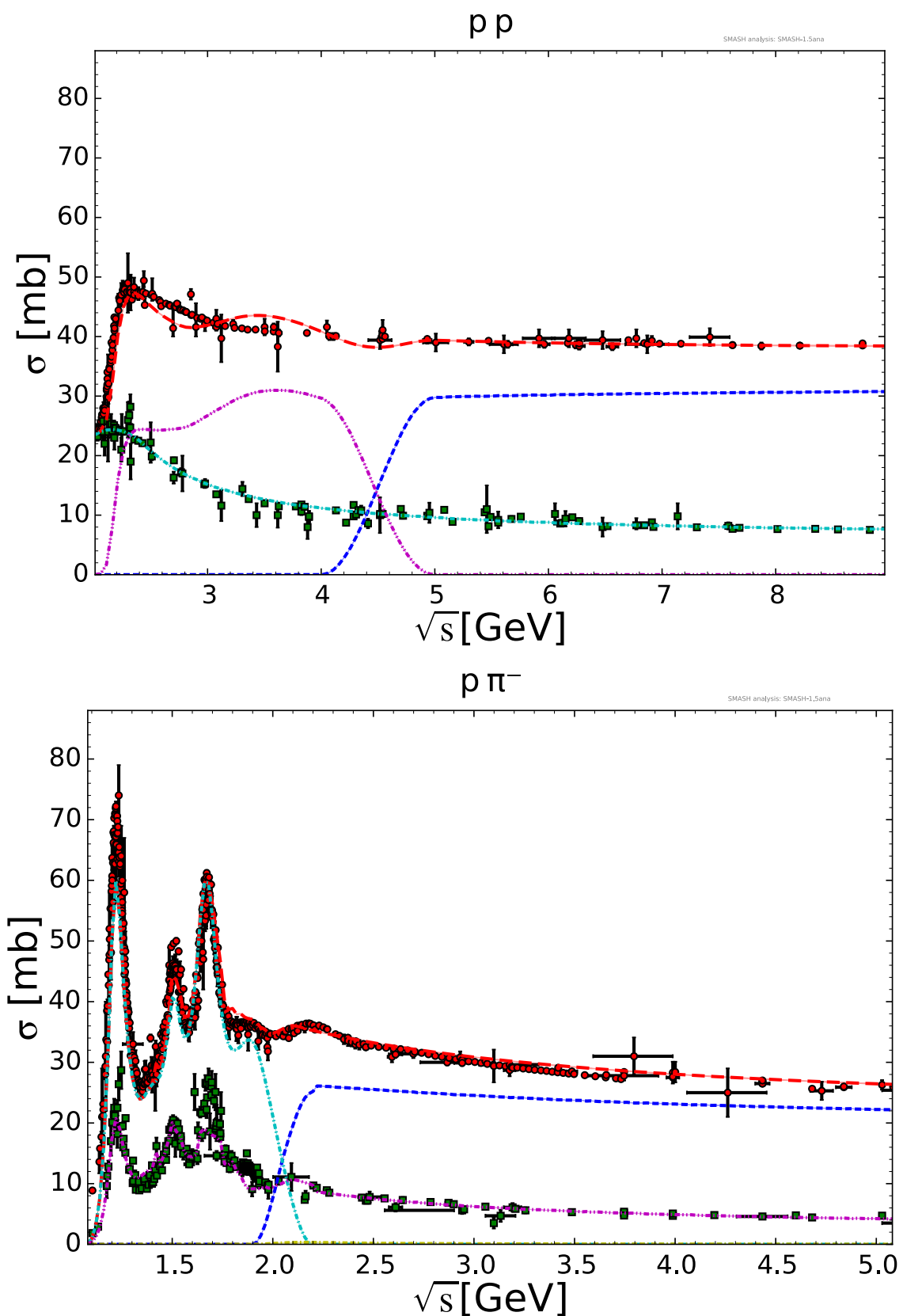
Versions

- Every 6-9 months a new release is finished
- Issues („to-dos“) are assigned to these milestones
- Explain in release notes in detail what is new and if there are any (breaking) changes to in- or output
- Semantic versioning (MAJOR.MINOR.FIX)
- Crucial to include version numbers when citing results or plotting them in comparison to experimental data
- Zenodo DOI assigned to each code version
- Versioning is crucial for reproducibility and transparency, allows for tracking of changes

Tests

- Test suite contains mostly unit and run tests - nothing is broken
 - Has to pass on every change before merged into main branch (+ code is reviewed by someone else)
 - Automatically ensured by CI Service
- Physics analysis suite compares observables against previous versions and experimental data
 - Run for every new release/version
 - Results are public and code is also open source
 - Based on make and Python scripts
 - -> Rivet could be the future!

Validation



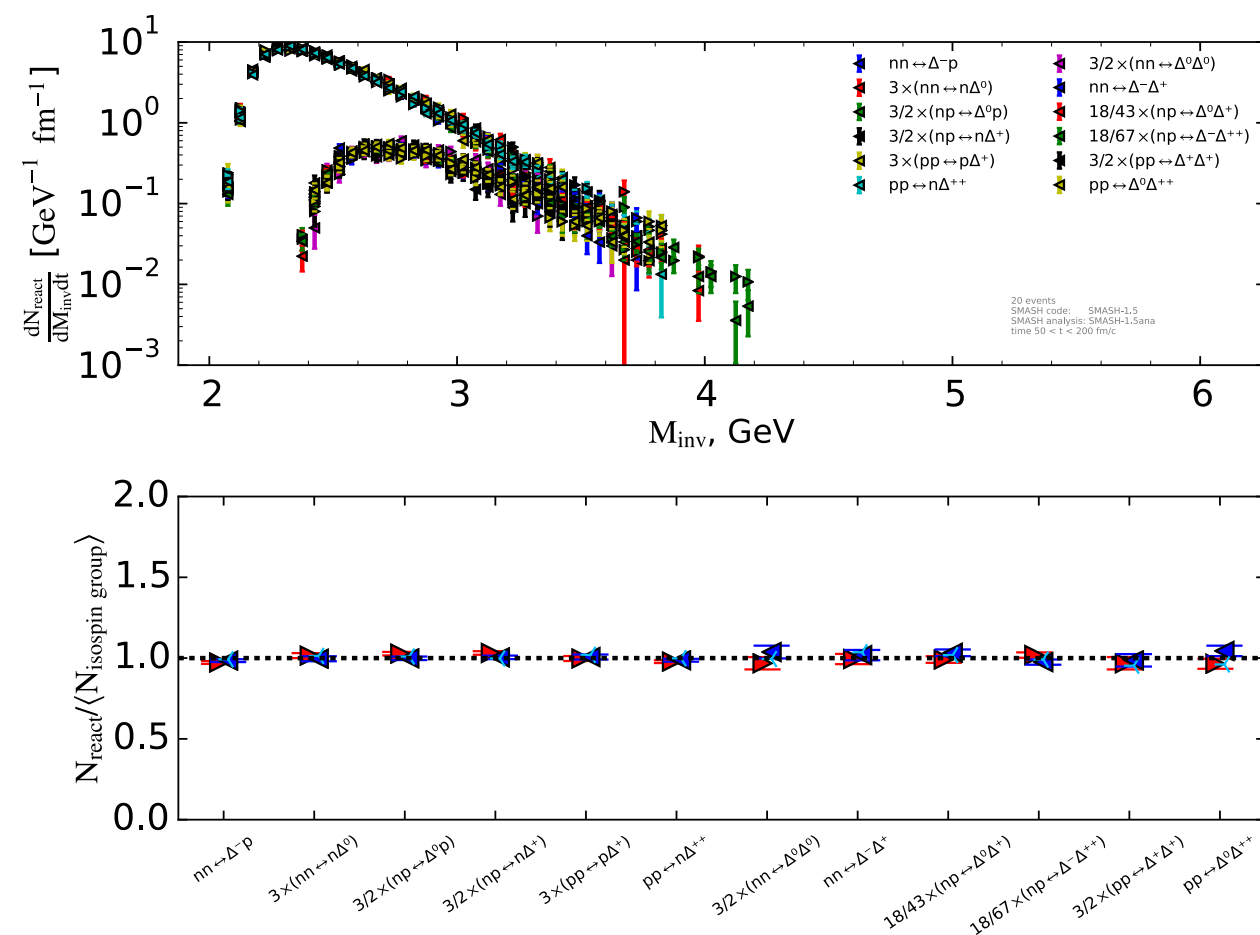
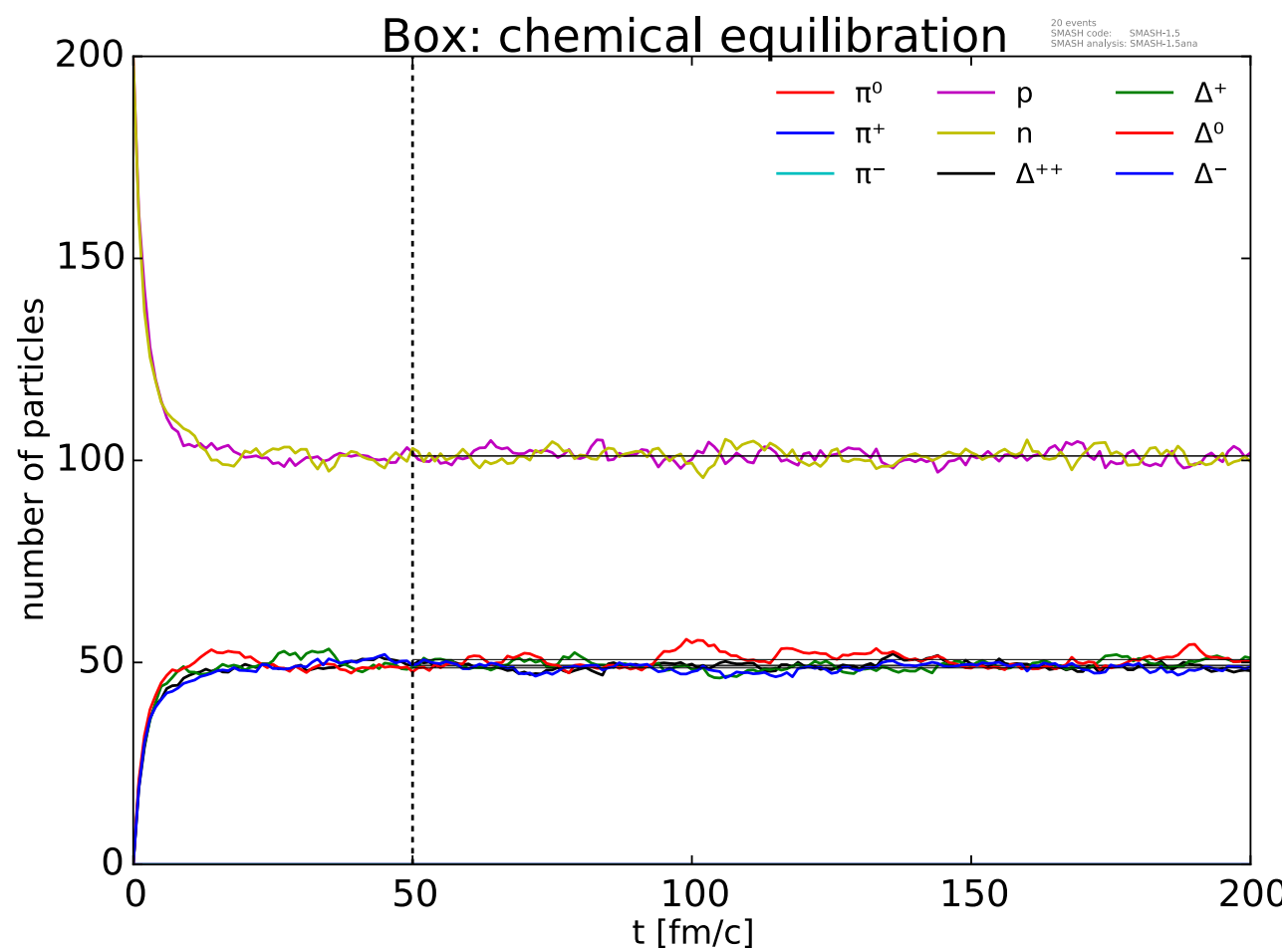
- Total cross section for $pp/p\pi$ collisions
- Parametrized elastic cross section
- Many resonance contributions to inelastic cross section
- Reasonable description of experimental data
- Soft strings à la UrQMD and hard strings via Pythia 8

J. Weil et al, PRC 94 (2016), updated SMASH-1.5

Detailed Balance

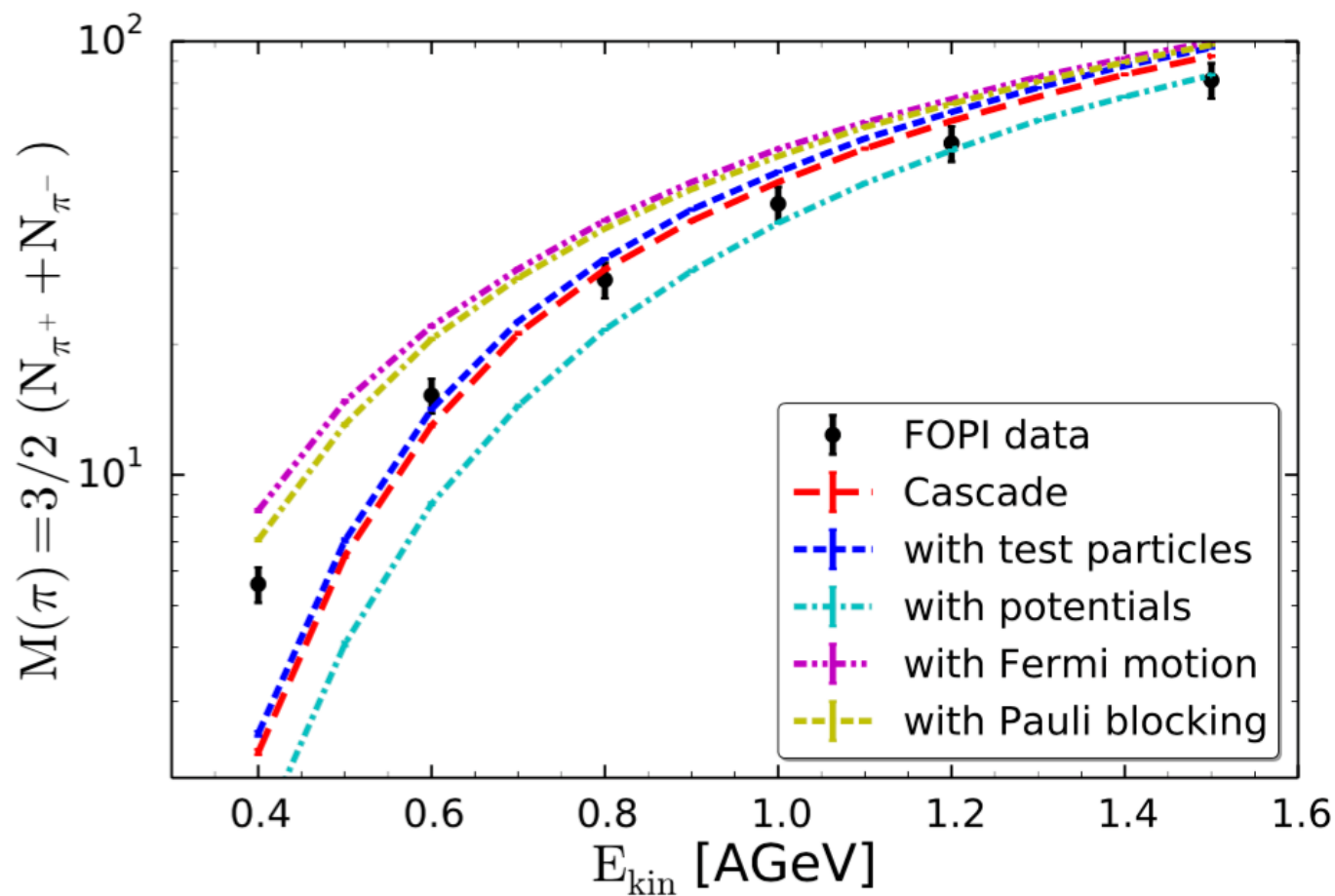
- Inverse absorption cross section calculated from production cross section
- Conservation of detailed balance (only $1 \leftrightarrow 2$ or $2 \leftrightarrow 2$ processes)

J. Weil et al, PRC 94 (2016), updated SMASH-1.5

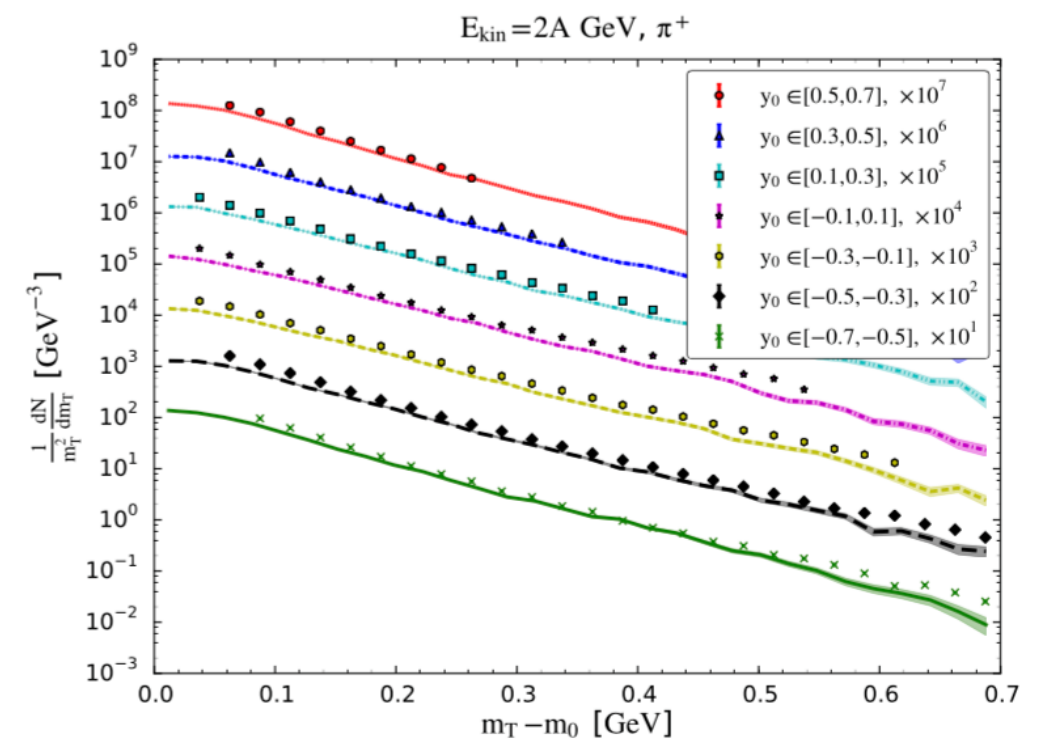
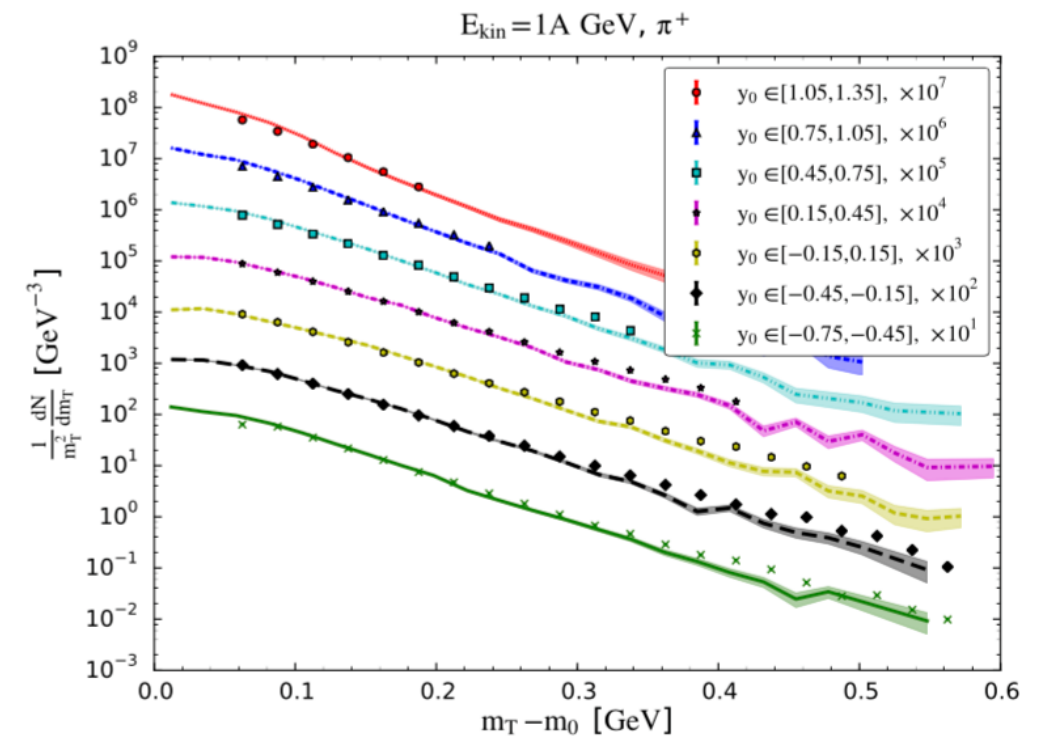


Pion Production in Au+Au

- Potentials decrease pion production, while Fermi motion increases yield
- Nice agreement with SIS experimental data



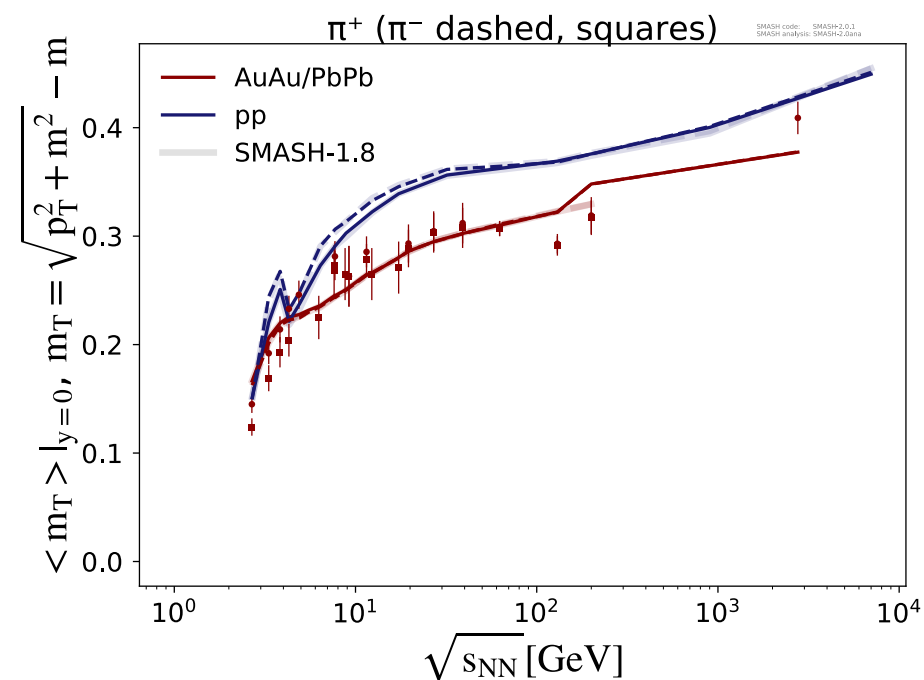
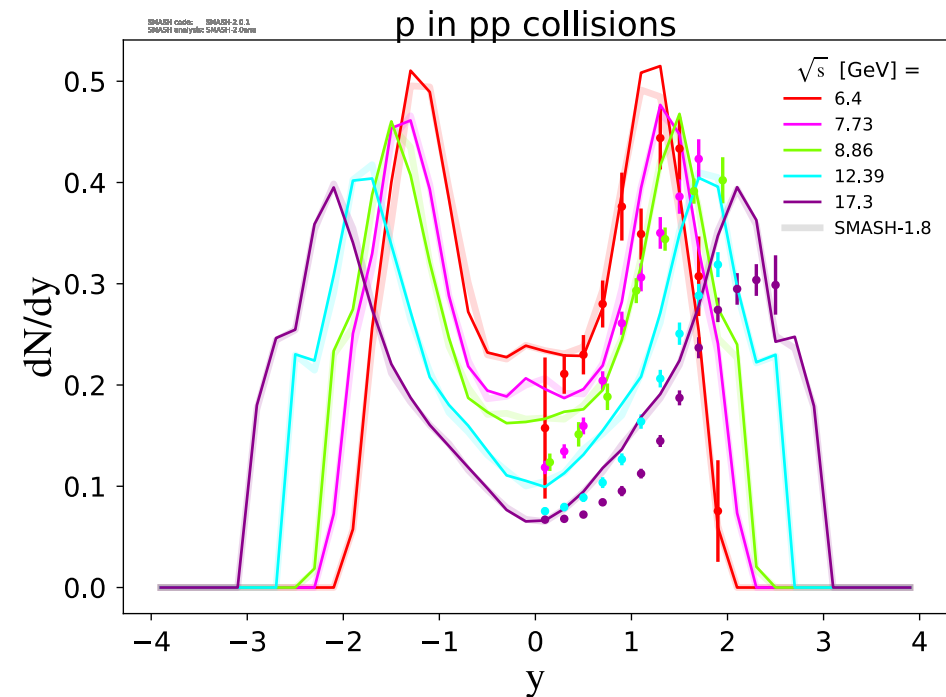
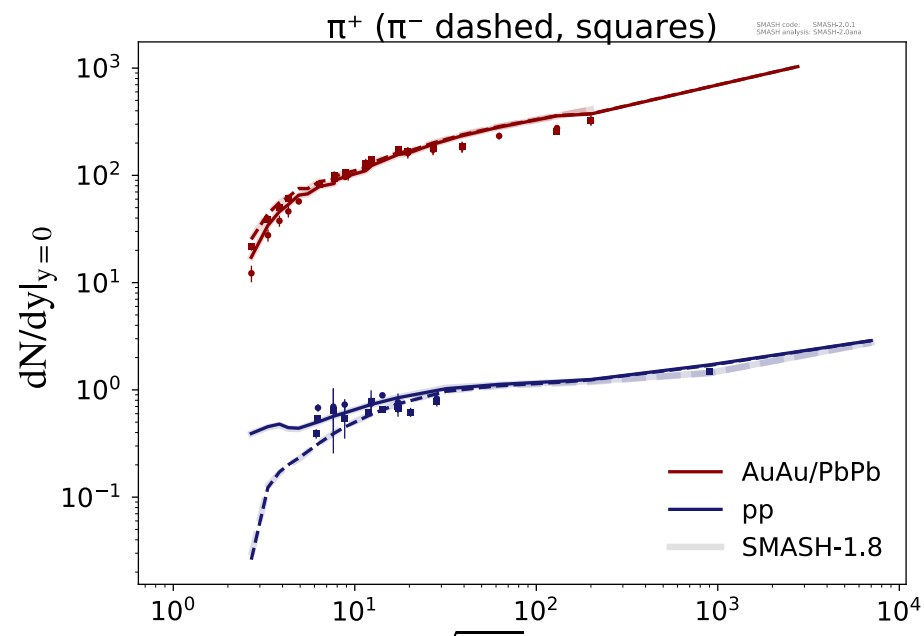
Note: consecutive addition of features



J. Weil et al, PRC 94 (2016)

Energy Scan

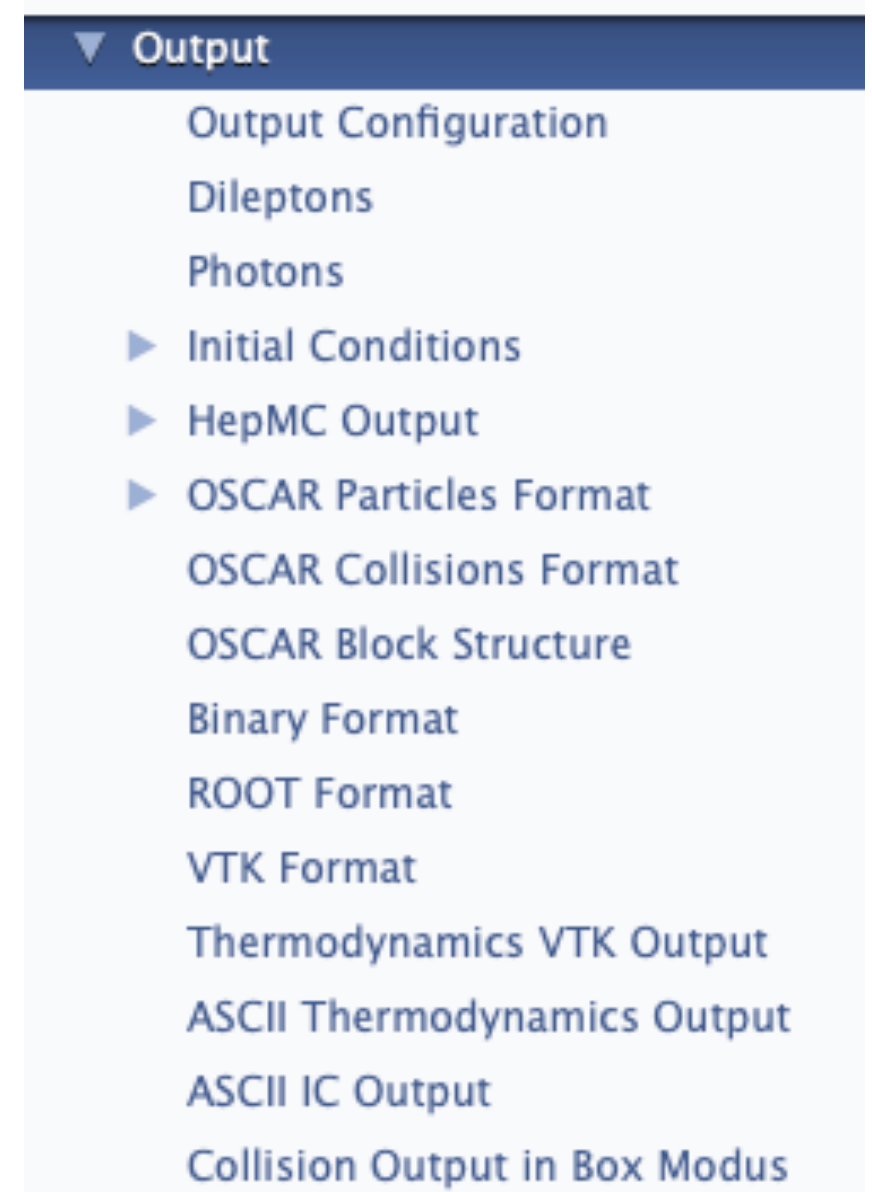
- For the main hadronic species, particle production and spectra for all beam energies are included



- Simplification of inclusion of more data points?
- Joint validation suite for event generators?

Output Formats

- SMASH provides:
 - OSCAR 1999 and 2013 particles and collision history output (ASCII and binary)
 - Root tree
 - VTK for visualization
 - Initial conditions for input to hydro
 - HepMC output:
 - First step: only one vertex with final particles
 - New (by C. Holmes): Full history directly connected to Rivet
 - Each additional third party library introduces extra overhead for maintenance



How to Use SMASH?

- Visit the webpage to find publications and link to SMASH-2.0 results <https://smash-transport.github.io>
- Download the code at <https://github.com/smash-transport/smash>
- Checkout the Analysis Suite at <https://github.com/smash-transport/smash-analysis>
- Find user guide and documentation at <https://github.com/smash-transport/smash/releases>
- Animations and Visualization Tutorial under <https://smash-transport.github.io/movies.html>

The screenshot displays the GitHub repository for SMASH. The repository name is "Simulating Many Accelerated Strongly-interacting Hadrons". It shows 6,590 commits, 1 branch, 2 releases, 13 contributors, and GPL-3.0 license. The commit history table is as follows:

Commit	Message	Time
elfnerhannah Merge pull request #132 from smash-transport/schaefer/fix_bug_nuclear...	Latest commit f068109 on 4 Dec 2018	
3rdparty	Adjustments for running with JetScape	4 months ago
bin	Updated benchmark decaymodes	3 months ago
cmake	Use lightweight tags for version	4 months ago
doc	Updated links in README.md and CONTRIBUTING.md to link to the correct...	3 months ago
examples/using_SMASH_as_library	Update pythia version in README.md and removed trailing whitespace.	4 months ago
input	Fix parity for light nuclei decays	3 months ago
src	Merge pull request #132 from smash-transport/schaefer/fix_bug_nuclear...	2 months ago

The right side of the screenshot shows the "Releases" section for SMASH-1.5.1, released on 4 Dec 2018. The release title is "First public version of SMASH". It includes a "Latest release" badge and a "Draft a new release" button. The release description mentions that elfnerhannah released this on 27 Nov 2018 with 6 commits to master since this release. Useful extras include links to an overview of Physics results, a User Guide, and HTML Documentation.

Summary and Outlook

- SMASH has been developed as a new hadronic transport approach
 - Source code is public and ready to use for low beam energies and late stage rescattering at high beam energies
 - Integrated into JETSCAPE framework
- HepMC Output is available and exploration of Rivet in progress
 - Clarification of header information is required
 - Community standard for primary particle information and inclusion of weak decays needed
- Wish for the future:
 - Employ Rivet for regular code validation procedure
 - Avoid many hours/days/weeks to re-implement experimental analysis
 - Simplify large Bayesian multi-parameter, multi-observable analysis