SMASH Status and Perspective: Application of HepMC and Rivet

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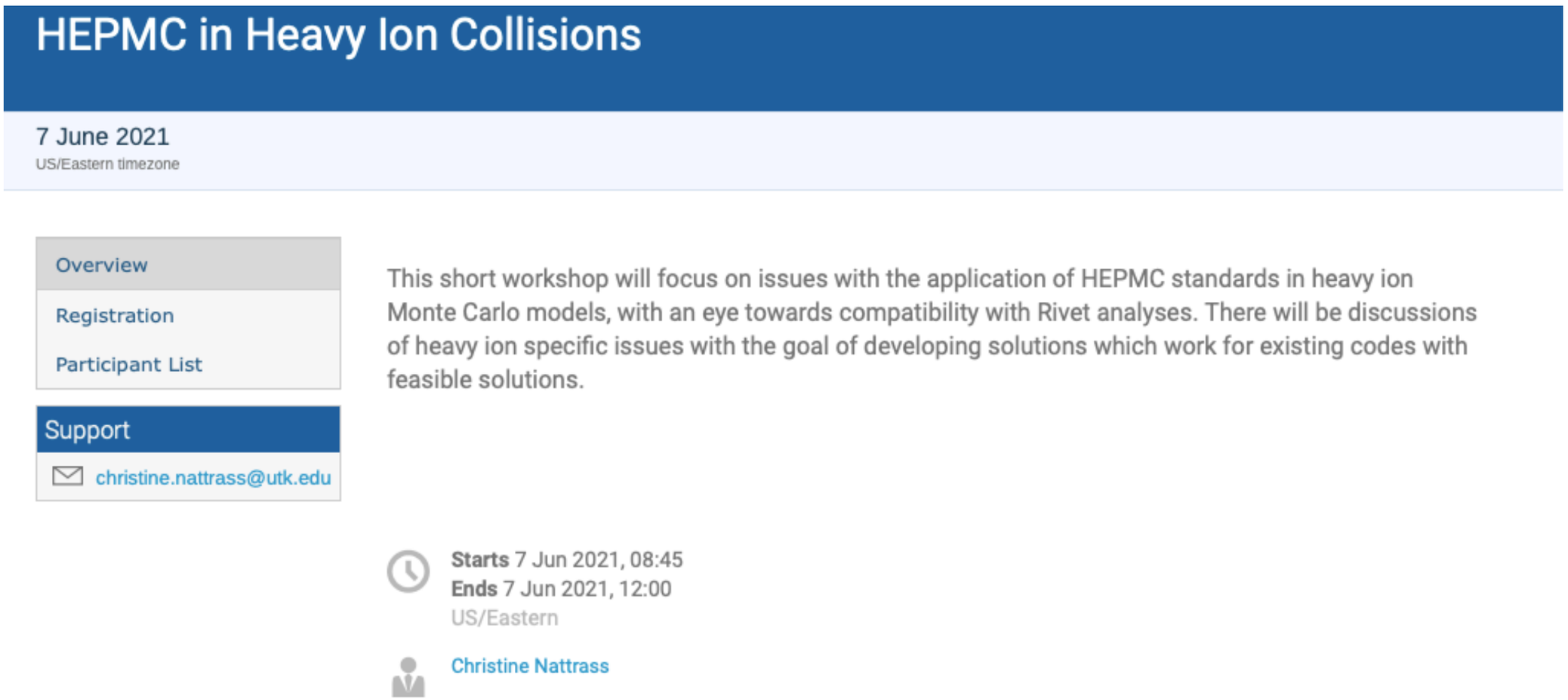
April 8th, 2021, Strong 2020 Workshop

A Little Advertisement

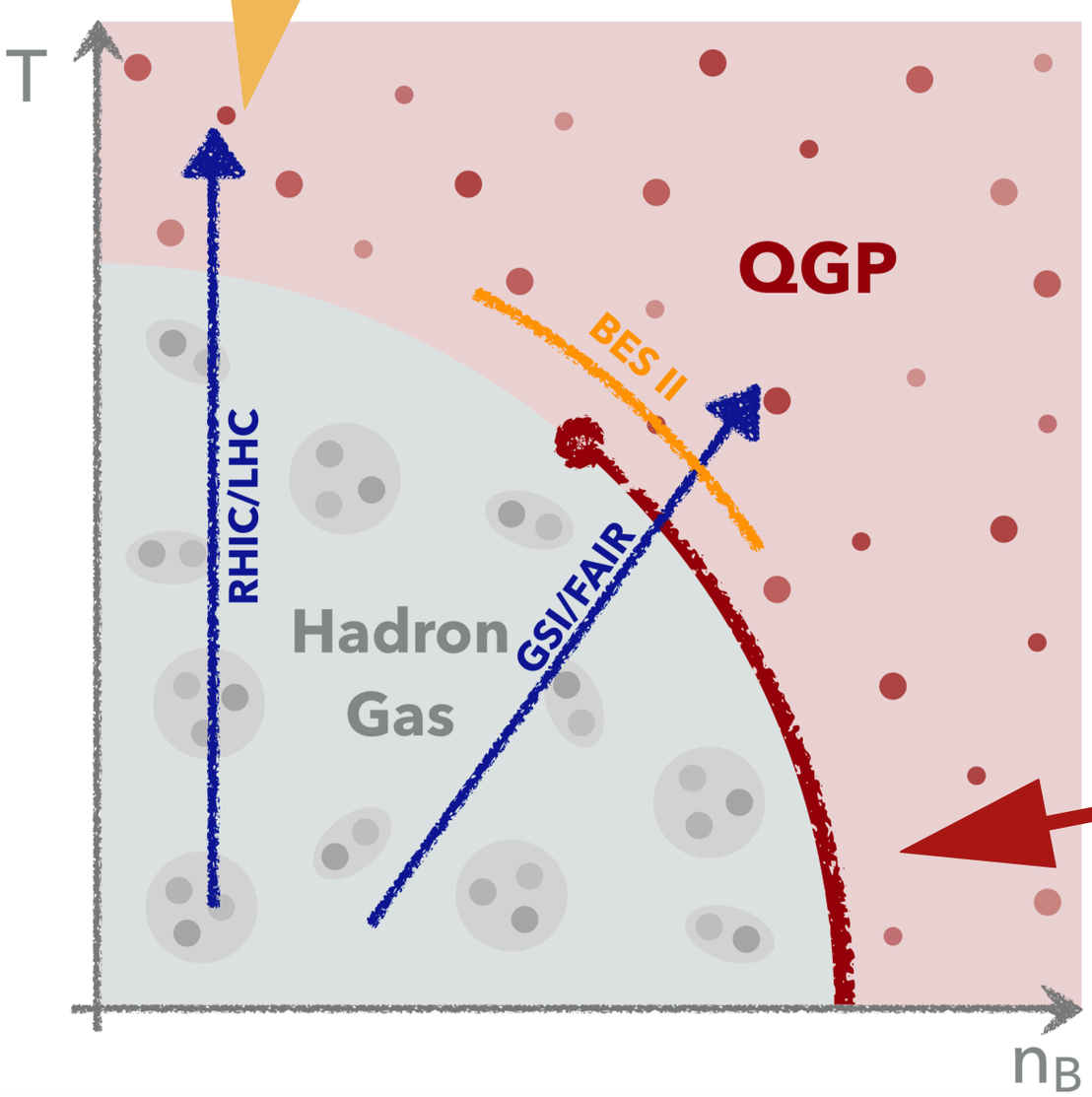
- Short workshop within RHIC-AGS users meeting on HEPMC in heavy-ion collisions:
- This is a chance to bring your perspective to the discussion about theory-experiment comparison



- 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

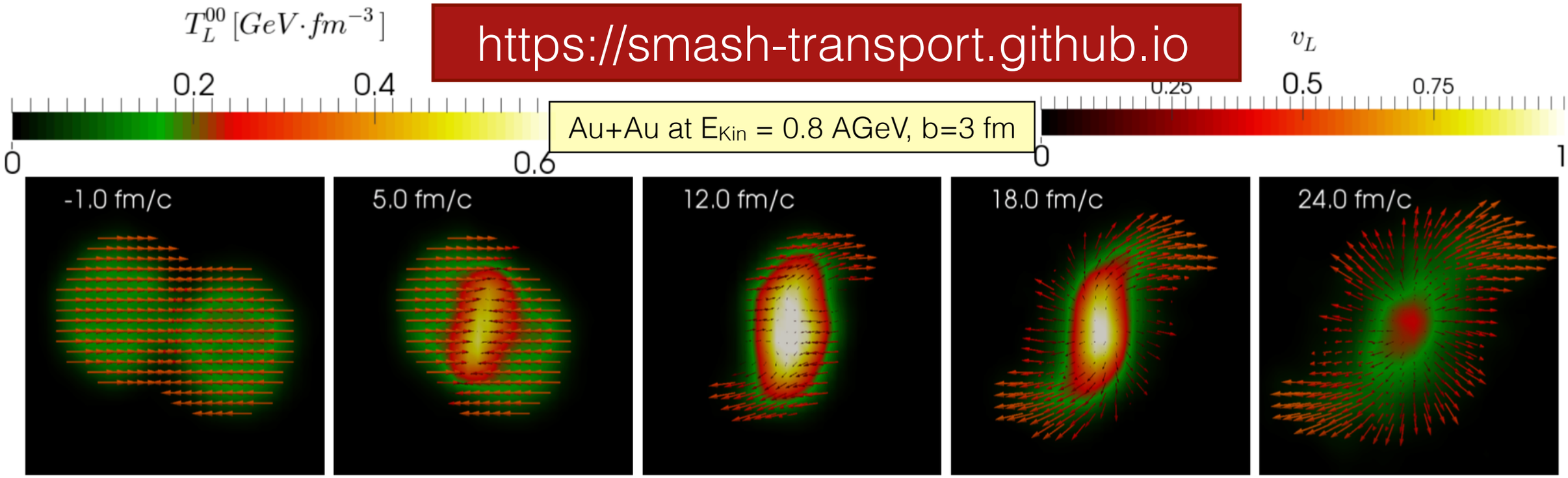
smash

SMASH*

J. Weil et al, PRC 94 (2016)

- 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)

https://smash-transport.github.io



* Simulating Many Accelerated Strongly-Interacting Hadrons

Degrees of Freedom

N	Δ	Λ	Σ	Ξ	Ω
N_{938}	Δ_{1232}	Λ_{1116}	Σ_{1189}	Ξ_{1321}	Ω^-_{1672}
N_{1440}	Δ_{1620}	Λ_{1405}	Σ_{1385}	Ξ_{1530}	Ω^-_{2250}
N_{1520}	Δ_{1700}	Λ_{1520}	Σ_{1660}	Ξ_{1690}	
N_{1535}	Δ_{1900}	Λ_{1600}	Σ_{1670}	Ξ_{1820}	
N_{1650}	Δ_{1905}	Λ_{1670}	Σ_{1750}	Ξ_{1950}	
N_{1675}	Δ_{1910}	Λ_{1690}	Σ_{1775}	Ξ_{2030}	
N_{1680}	Δ_{1920}	Λ_{1800}	Σ_{1915}		
N_{1700}	Δ_{1930}	Λ_{1810}	Σ_{1940}		
N_{1710}	Δ_{1950}	Λ_{1820}	Σ_{2030}		
N_{1720}		Λ_{1830}	Σ_{2250}		
N_{1875}		Λ_{1890}			
N_{1900}		Λ_{2100}			
N_{1990}		Λ_{2110}			
N_{2060}		Λ_{2350}			
N_{2080}					
N_{2100}					
N_{2120}					
N_{2190}					
N_{2220}					
N_{2250}					

As of SMASH-1.7

Unflavored				Strange
π_{138}	$f_{0\ 980}$	$f_{2\ 1275}$	$\pi_{2\ 1670}$	K_{494}
π_{1300}	$f_{0\ 1370}$	$f_{2}'_{1525}$		K^*_{892}
π_{1800}	$f_{0\ 1500}$	$f_{2\ 1950}$	$\rho_{3\ 1690}$	$K_{1\ 1270}$
	$f_{0\ 1710}$	$f_{2\ 2010}$		$K_{1\ 1400}$
η_{548}		$f_{2\ 2300}$	$\phi_{3\ 1850}$	K^*_{1410}
η'_{958}	$a_{0\ 980}$	$f_{2\ 2340}$		$K_0^*{}_{1430}$
η_{1295}	$a_{0\ 1450}$		$a_{4\ 2040}$	$K_2^*{}_{1430}$
η_{1405}		$f_{1\ 1285}$		K^*_{1680}
η_{1475}	ϕ_{1019}	$f_{1\ 1420}$	$f_{4\ 2050}$	$K_{2\ 1770}$
	ϕ_{1680}			$K_3^*{}_{1780}$
σ_{800}		$a_{2\ 1320}$		$K_{2\ 1820}$
	$h_{1\ 1170}$			$K_4^*{}_{2045}$
ρ_{776}		$\pi_{1\ 1400}$		
ρ_{1450}	$b_{1\ 1235}$	$\pi_{1\ 1600}$		
ρ_{1700}				
	$a_{1\ 1260}$	$\eta_{2\ 1645}$		
ω_{783}				
ω_{1420}		$\omega_{3\ 1670}$		
ω_{1650}				

- + 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

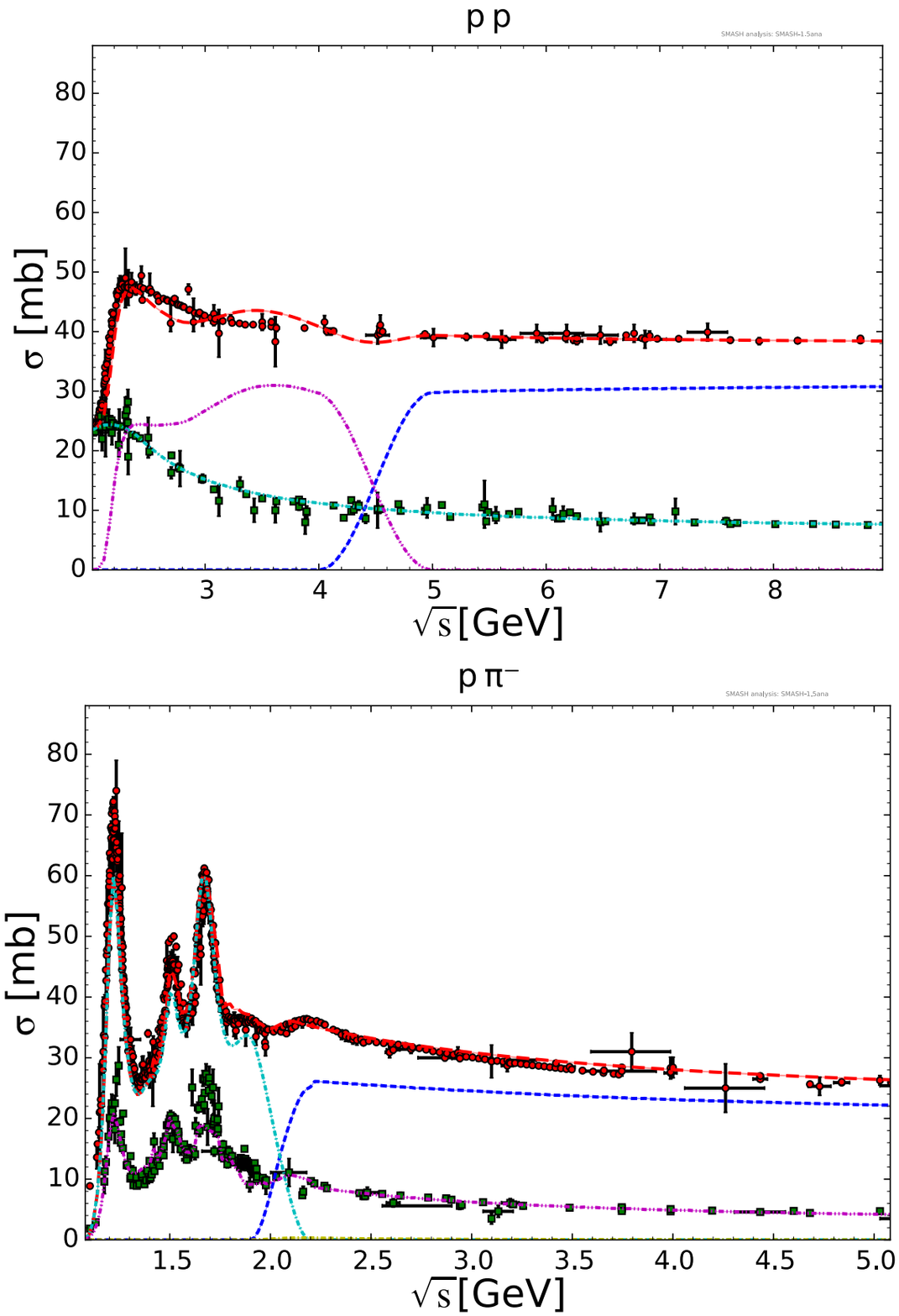
Versions

- 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 transparence, 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



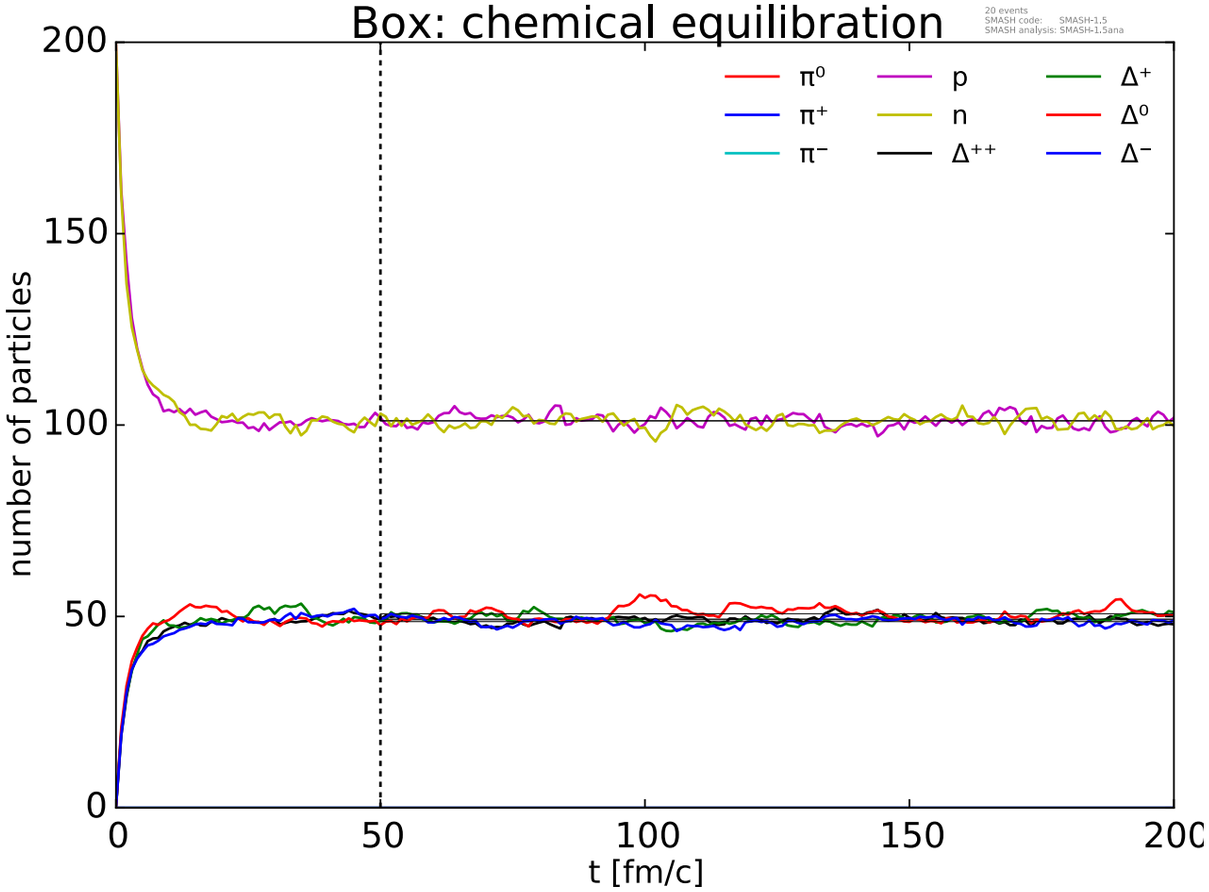
- Total cross section for pp/pπ collisions
- Parametrized elastic cross section
- Many resonance contributions to inelastic cross section
- Reasonable description of experimental data
- Soft strings à la UrQMD and hard strings via Pythia 8

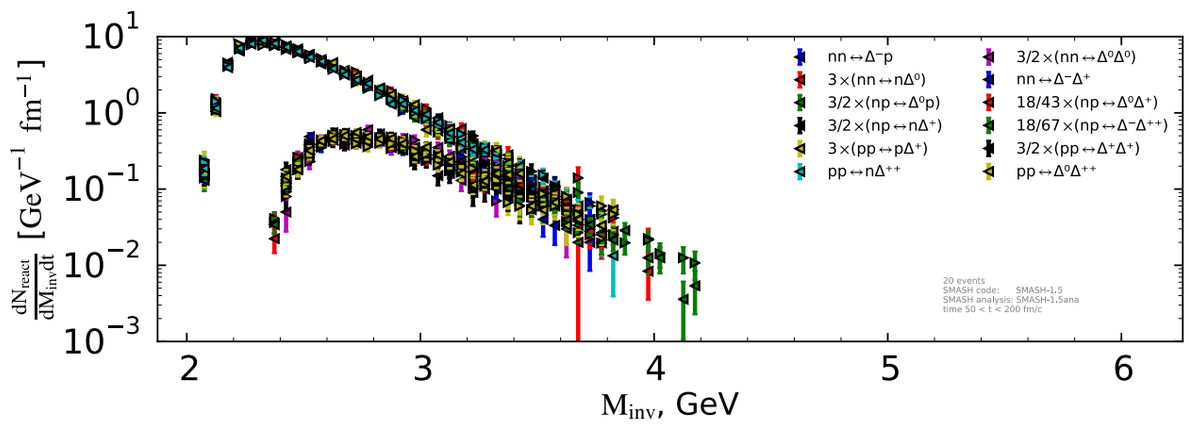
J. Weil et al, PRC 94 (2016), updated SMASH-1.5

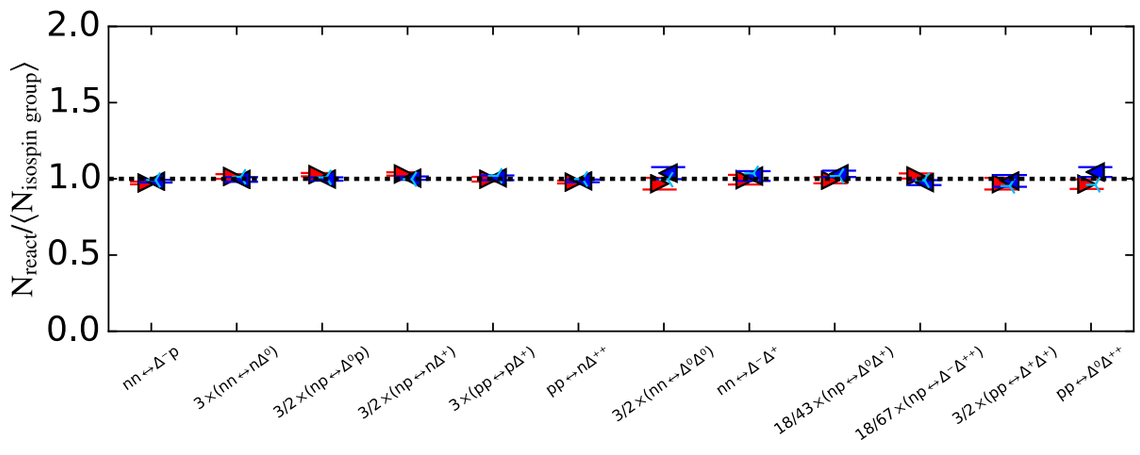
Detailed Balance

- Inverse absorption cross section calculated from production cross section
- Conservation of detailed balance (only 1 <—> 2 or 2 <—> 2 processes)

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

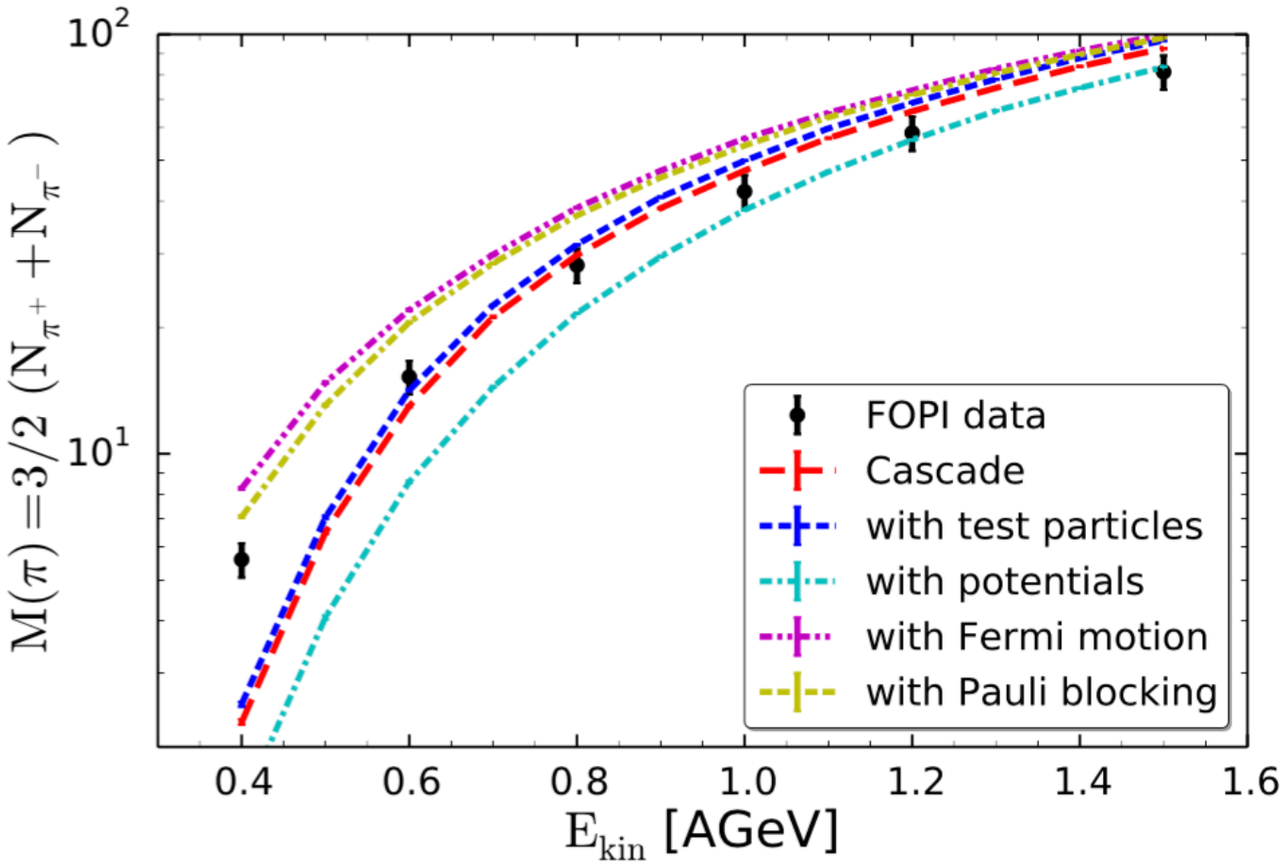


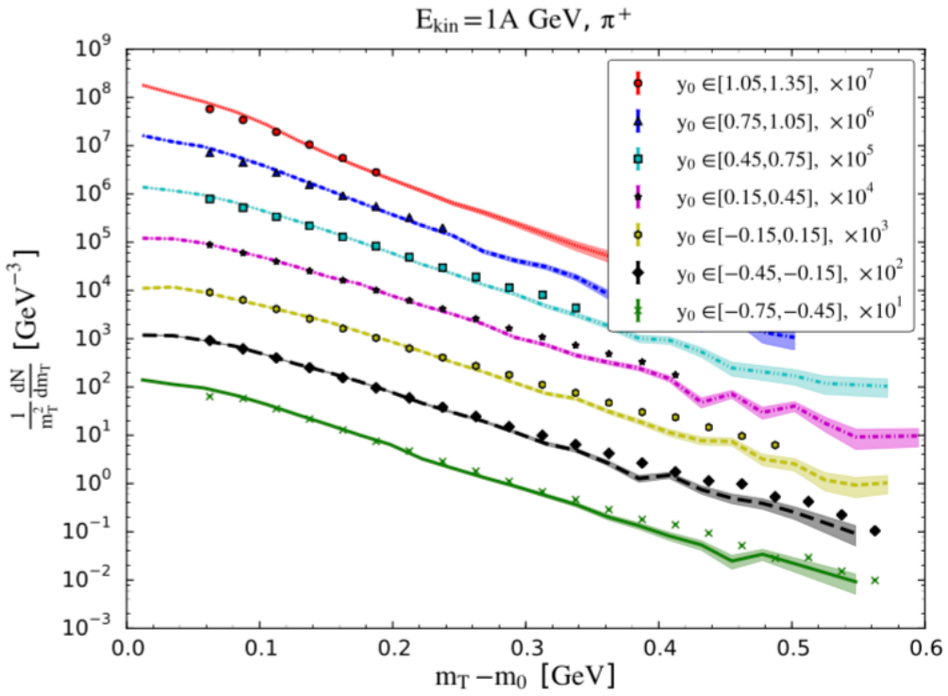


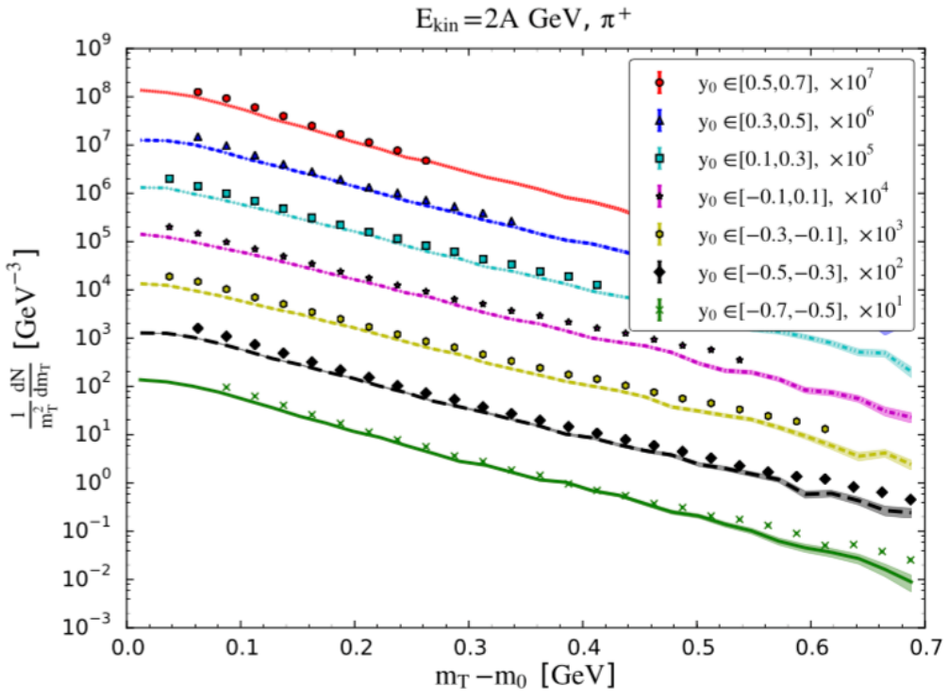


Pion Production in Au+Au

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





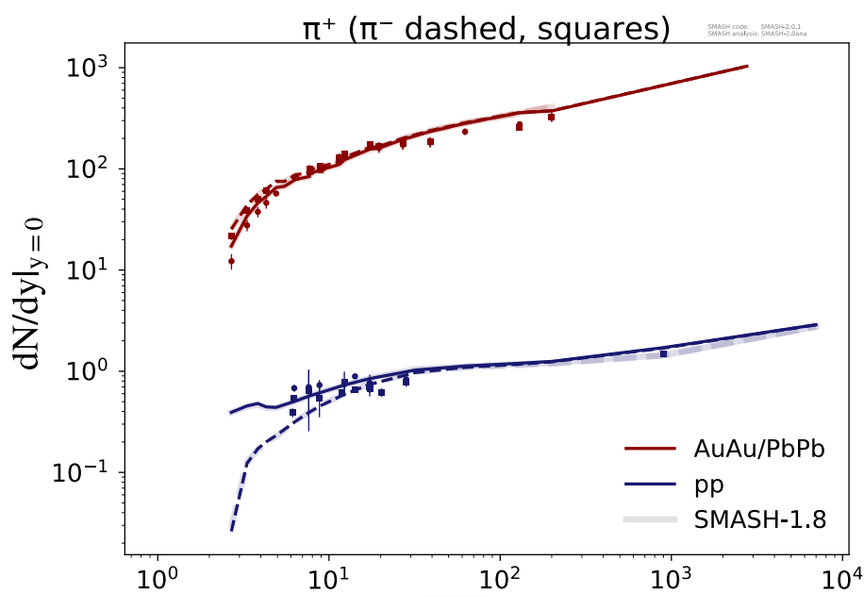


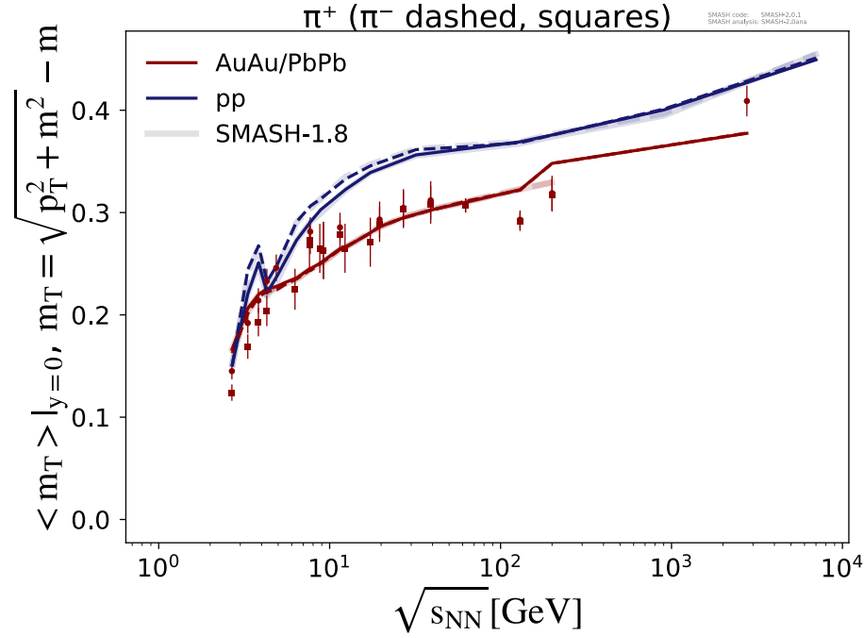
Note: consecutive addition of features

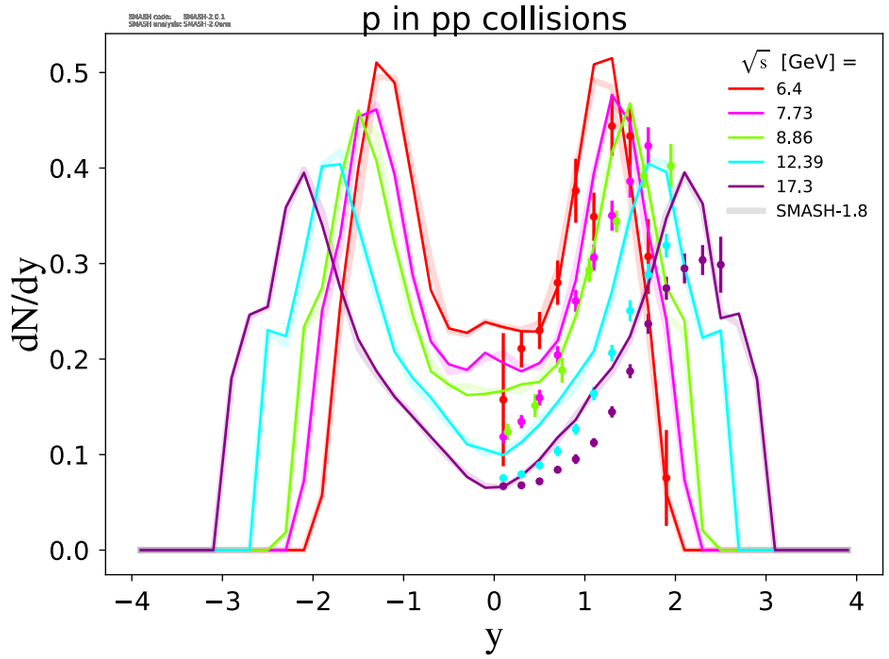
J. Weil et al, PRC 94 (2016)

Energy Scan

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







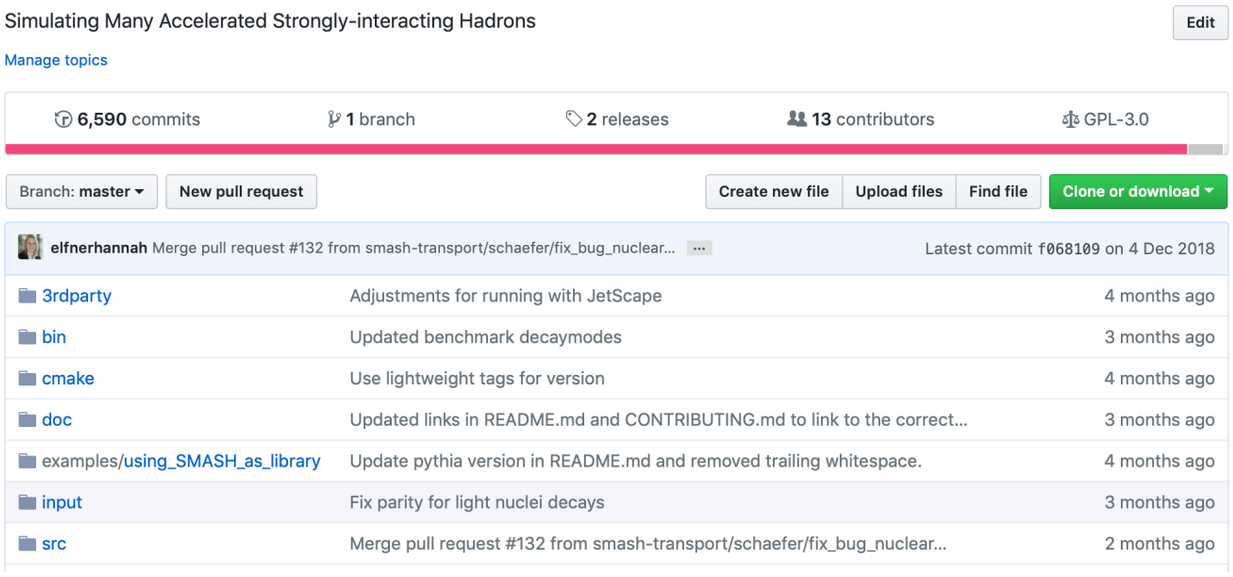
- Simplification of inclusion of more data points?
- Joint validation suite for event generators?

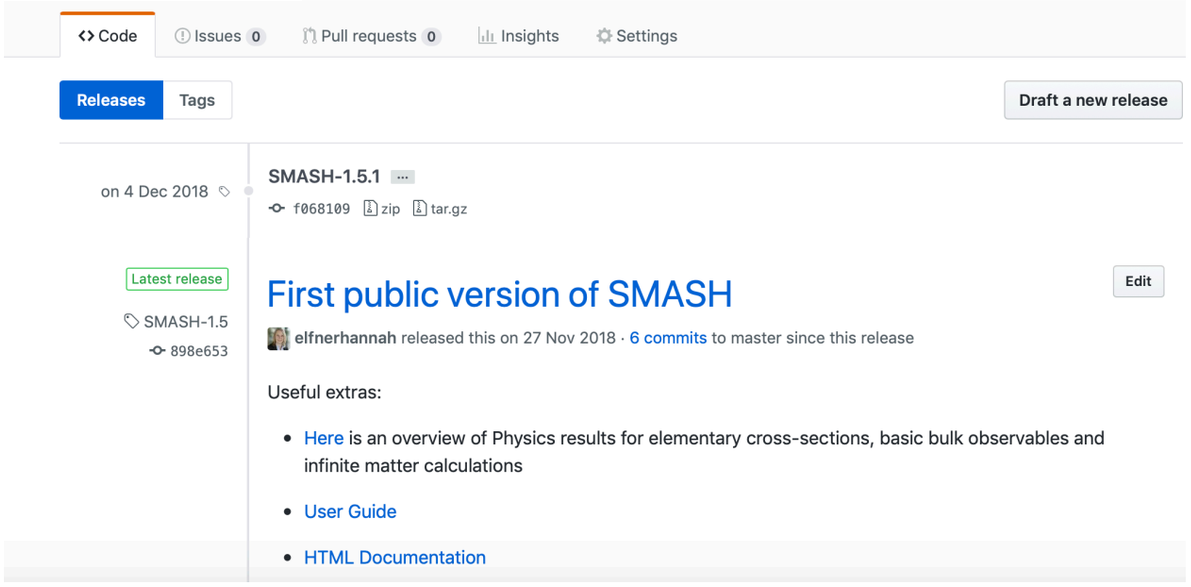
Output Formats

- 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





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