Experiment-theory interface for heavy-ion physics

(using HepMC, Rivet, mcplots)

Jan Fiete Grosse-Oetringhaus[1] Przemyslaw Karczmarczyk[1,2]
Jochen Klein[1]

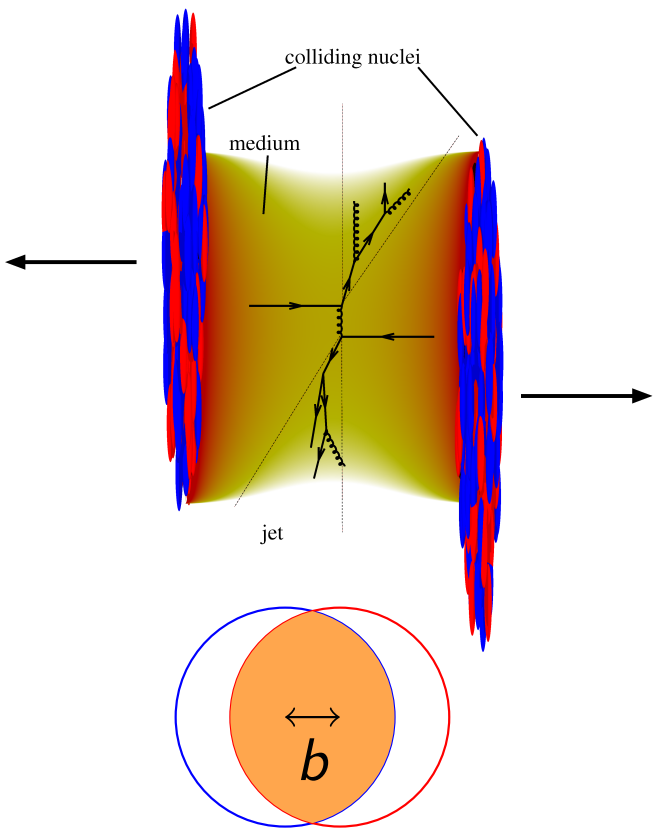
[1]CERN

[2]Warsaw University of Technology, Faculty of Physics

MCnet meeting
April 6th, 2017

heavy-ion collisions

$\sigma_{\mathrm{PbPb}} \simeq 8$ b



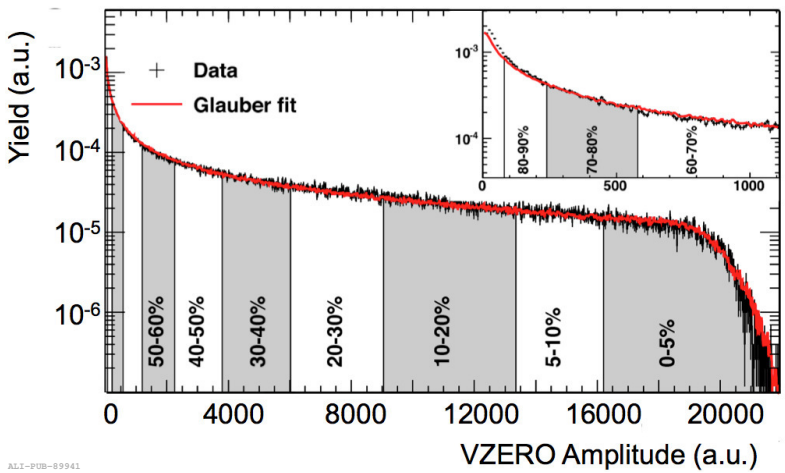
- geometric description of collision
  $\rightsquigarrow$ impact parameter b
  $\rightsquigarrow$ centrality (fraction of σ_{geom})
- high energy density in overlap region, non-trivial shape
- "**bulk matter**" (soft production)
  - collective phenomena instead of single particles
  - thermo-/hydrodynamical models
  - statistical analyses
- **hard probes**
  - more similar to HEP case

$\rightsquigarrow$ **different concepts than HEP analyses**

heavy-ion collisions

impact parameter $\leftrightarrow$
multiplicity

$\rightsquigarrow$ **experimental concept**



$\rightsquigarrow$ multiplicity percentiles

- geometric description of collision
  $\rightsquigarrow$ impact parameter b
  $\rightsquigarrow$ centrality (fraction of σ_{geom})
- high energy density in overlap region, non-trivial shape
- "**bulk matter**" (soft production)
  - collective phenomena instead of single particles
  - thermo-/hydrodynamical models
  - statistical analyses
- **hard probes**
  - more similar to HEP case

$\rightsquigarrow$ **different concepts than HEP analyses**

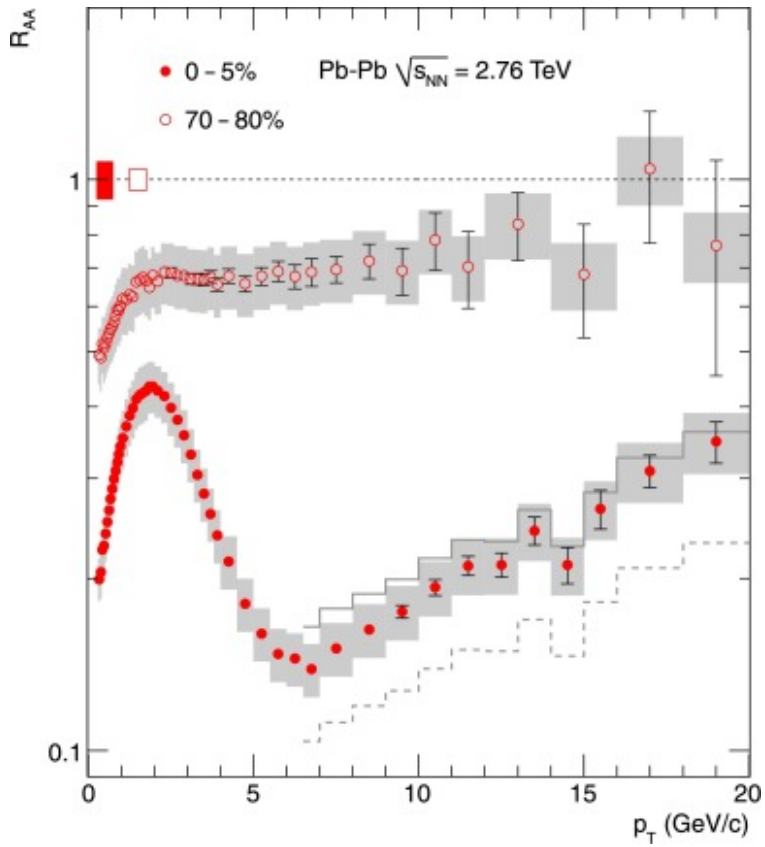
analyses to showcasing heavy-ion needs

- nuclear modification factor
  - compare yields in Pb–Pb with scaled yields in pp:

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}/\mathrm{d}p_{\perp}}{\langle N_{\mathrm{coll}} \rangle \, \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\perp}}$$

  $\rightsquigarrow$ ratio of Pb–Pb and pp analyses

- $\langle \mathrm{d}N/\mathrm{d}\eta \rangle$ vs centrality
- near-side peak widths



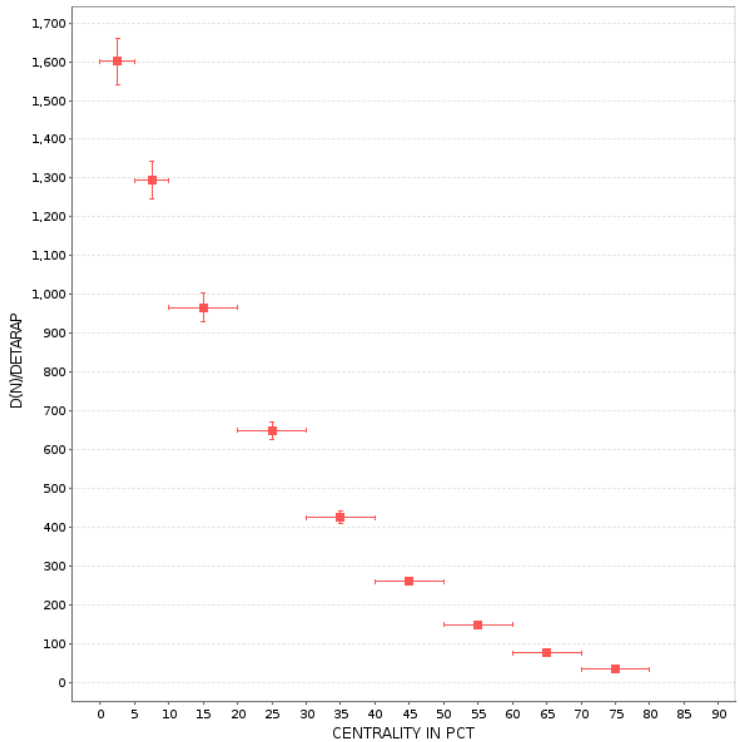
analyses to showcasing heavy-ion needs

- nuclear modification factor
  - compare yields in Pb–Pb with scaled yields in pp:

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}/\mathrm{d}p_{\perp}}{\langle N_{\mathrm{coll}} \rangle \, \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\perp}}$$

  $\rightsquigarrow$ ratio of Pb–Pb and pp analyses

- $\langle \mathrm{d}N/\mathrm{d}\eta \rangle$ vs centrality
- near-side peak widths

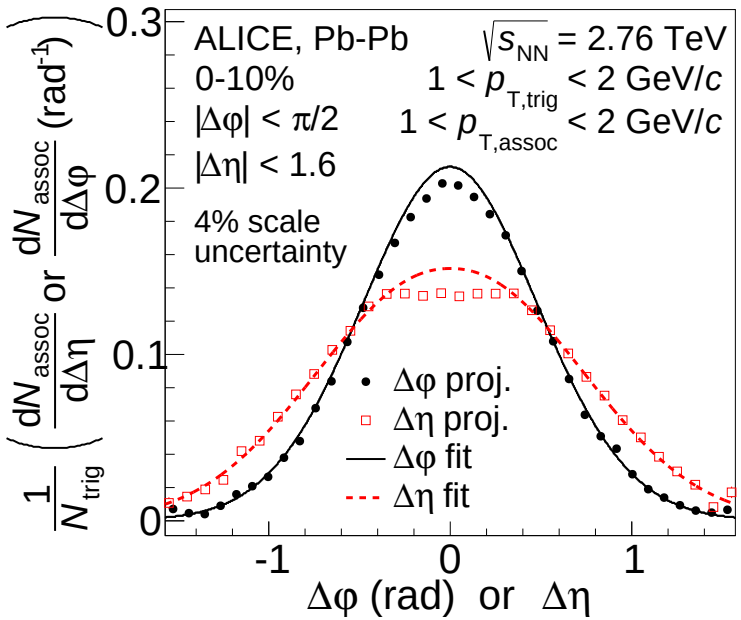


analyses to showcasing heavy-ion needs

- nuclear modification factor
  - compare yields in Pb–Pb with scaled yields in pp:

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}/\mathrm{d}p_{\perp}}{\langle N_{\mathrm{coll}} \rangle \, \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\perp}}$$

  $\rightsquigarrow$ ratio of Pb–Pb and pp analyses
- $\langle \mathrm{d}N/\mathrm{d}\eta \rangle$ vs centrality
- near-side peak widths



resulting requirements

typical needs of heavy-ion analyses:

- comparison **Pb–Pb to pp**
  also p–Pb to pp
- classification of events according to
  - **centrality** (multiplicity)
  - event plane
  - spherocity
  - ...
- characterization of distributions
  (e.g. invariant mass, correlation functions)
  - yield extraction
  - peak widths
  - ...
- event generation computing intense: $\mathcal{O}(10\ \mathrm{s/event})$

$\rightsquigarrow$ **need for more complex processing**

resulting wishlist for HepMC and Rivet

- common projections for global event properties, e.g. for
  - centrality
  - multiplicity classes

  $\rightsquigarrow$ need for calibration
- post-processing, e.g. for
  - combination of results (e.g. Pb–Pb and pp)
  - processing of merged results (e.g. fitting)
- tools for further processing of histograms, e.g. for
  - peak width
  - fitting
  - background subtraction

---

started implementation and interaction with Rivet team

main contributors

- Benedikt Völkel (summer student project 2016)
- Przemyslaw Karczmarczyk (CERN doctoral student 2016 – 2019)

implementation

- added analyses and functionality to Rivet (our version)
  in order to really understand the needs and technical issues

---

$\rightsquigarrow$ following discussion
based on existing implementations

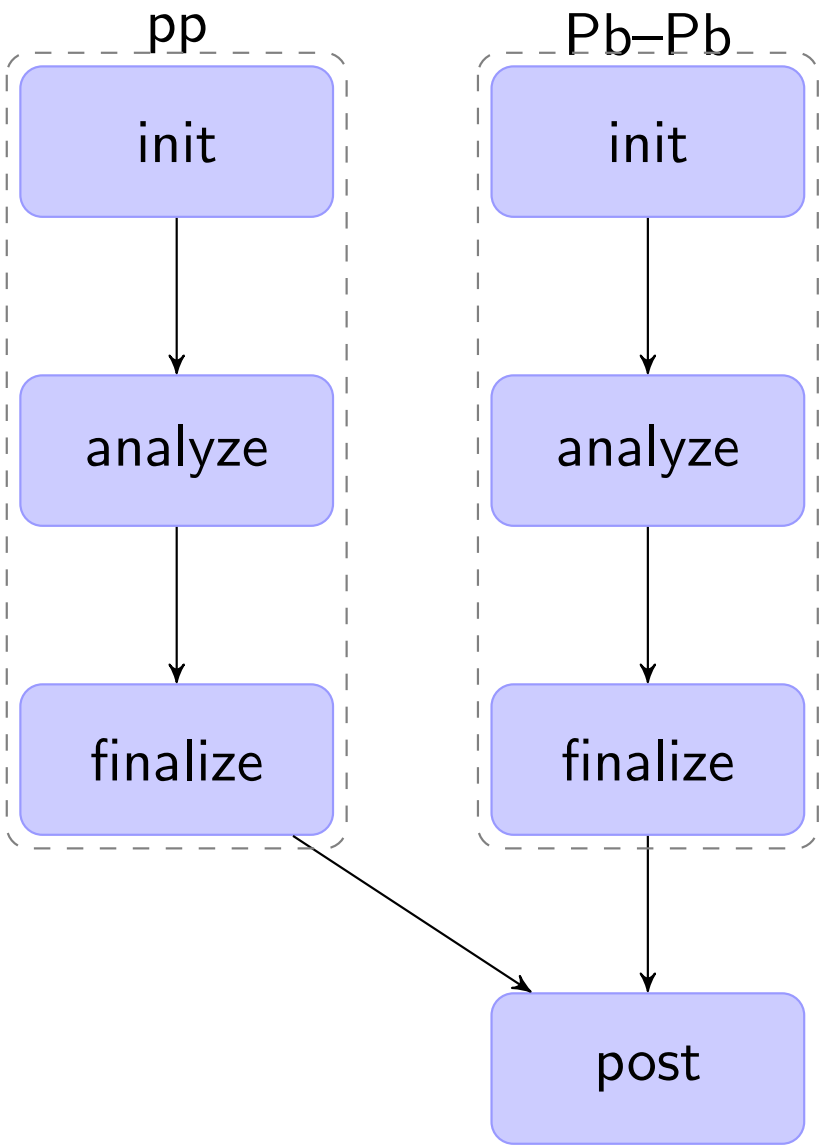
nuclear modification factor

- nuclear modification factor (e.g. for charged hadrons):

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}/\mathrm{d}p_{\perp}}{\langle N_{\mathrm{coll}} \rangle \, \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\perp}}$$

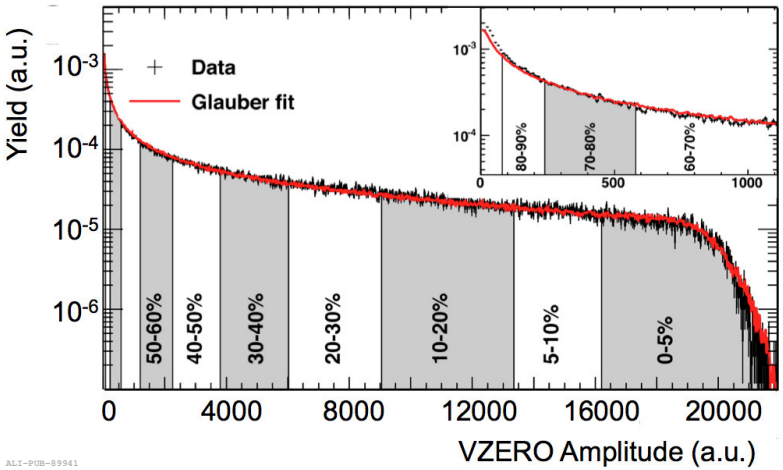
- need $p_{\perp}$ spectra in pp and Pb–Pb typically in different generator runs
- potentially both samples split into subjobs (computing intense)
- division of (individually merged) results

$\rightsquigarrow$ covered by **post-processing** and read-in of previous results



centrality

- characterized by impact parameter, typically not directly measured
- use centrality instead, i.e. relate to measured multiplicity (using e.g. tracks around mid-rapidity)
- classify in percentiles of multiplicity
- requires calibration data to know the binning



$\rightsquigarrow$ covered by **projection** operating on FinalState
(e.g. charged particles with $|\eta| < 0.9$)
and **calibration handling**

existing features proposed for inclusion

- **HepMC**: extend heavy-ion block to contain centrality
- **Rivet**: add `post()` method for post-processing
- **Rivet**: add option to read-in previous results
- **Rivet**: add projection for centrality
  operating on FinalState (defined in analysis)
- **Rivet**: add handling and management of calibration data
  (for centrality based on FinalState used)

$\rightsquigarrow$ already **existing implementations**,
proposed for upstream integration

thanks to Benedikt, Przemek!

remaining open items

- further processing of histograms,
  s.a. invariant mass distributions, correlation functions
  - fitting,
    e.g. of Fourier components
  - yields, peak widths
  - background subtraction
- further projections for event classification,
  e.g. event shapes
- post-processing and merging of results from sub-jobs

---

more things likely to come up
as we implement analyses

conclusions & outlook

- also heavy-ion analyses benefit from systematic comparisons of data and Monte Carlo (wish to use Rivet)
- many heavy-ion analyses difficult to implement with current functionality of tools
- many common needs for typical heavy-ion analyses
  $\rightsquigarrow$ try to generalize solutions
- first extensions for heavy-ion analyses are implemented aiming at inclusion in official Rivet distribution
- other items remain to be addressed

$\rightsquigarrow$ **looking forward to fruitful collaboration**

References

modified sources:

- `https://gitlab.cern.ch/pkarczma/Rivet-2.5.2-hi`
- `https://gitlab.cern.ch/pkarczma/mcplots`
- `https://gitlab.cern.ch/pkarczma/HepMC-2.06.09-hi`