Integrating the RIVET analysis tool into EPOS 4

Dr Johannes JAHAN - University of Houston / MUSES

in collaboration with
Pr. Klaus WERNER - Subatech / Nantes Université
Dr. Damien VINTACHE - Subatech / CNRS
Event generators are codes engineered to compute models in order to simulate collisions on an event-by-event basis, using Monte-Carlo sampling techniques.

**Advantage:** perfect knowledge of the whole event history

**Caveats:** underlying-model dependence + requires parametrisation
Event generators are codes engineered to compute models in order to simulate collisions on an event-by-event basis, using Monte-Carlo sampling techniques.

**Advantage:** perfect knowledge of the whole event history

**Caveats:** underlying-model dependence + requires parametrisation
Event generators are codes engineered to compute models in order to simulate collisions on an event-by-event basis, using Monte-Carlo sampling techniques.

**Advantage:** perfect knowledge of the whole event history

**Caveats:** underlying-model dependence + requires parametrisation

Key role in experiment: used with detector simulation to design hardware, facilities & characterise systematic errors.
Event generators are codes engineered to compute models in order to simulate collisions on an event-by-event basis, using Monte-Carlo sampling techniques.

**Advantage:** perfect knowledge of the whole event history

**Caveats:** underlying-model dependence + requires parametrisation

Key role in experiment: used with detector simulation to design hardware, facilities & characterise systematic errors.

Essential to bridge the gap between theory and experiment, being used for data interpretation and model validation.
Generalities on EPOS

**Energy conservation + Parallel scattering + factOrization + Saturation**

General-purpose event generator (simulates every steps of the collision) for hadronic physics, like Pythia\(^1\) or HIJING++\(^2\) (*see Tuesday’s talk*).

---

2. G. Biró et al., arXiv:1901.04220
Generalities on EPOS

**Energy conservation + Parallel scattering + factOrization + Saturation**

General-purpose event generator (simulates every steps of the collision) for hadronic physics, like Pythia \(^1\) or HIJING++ \(^2\) (see Tuesday’s talk).

Based on a multiple scattering approach, the parton-based Gribov-Regge Theory (PBGRT) \(^3\), and a hybrid evolution of matter including 3+1D hydrodynamics \(^4\) to reproduce the fluid behaviour of the QGP.

Developed to simulate any type of collision, from \(\sqrt{s} \approx \text{GeV}\), with the same formalism:

\[
e^+ + e^- \quad e^\pm + p \quad p + p \quad p + A \quad A + A
\]

---

2. G. Biró et al., arXiv:1901.04220
**EPOS 4** is a new version of the EG released publicly in October 2022, with a dedicated website:

https://klaus.pages.in2p3.fr/epos4/

Includes some **new developments** about the **physics**:

- new coherent treatment of saturation and factorisation (↔ binary scaling)
- possibility to use the BES EoS including a CP + 1st order phase transition, more suited for RHIC energies
- microcanonical hadronisation of the core (instead of GC Cooper-Frye), more suited for small systems

*References*

- K. Werner, arXiv:2301.12517

+ some user-oriented upgrades:

- more documentation, modularisation, simplified running mode...
**EPOS 4** is a new version of the EG released publicly in **October 2022**, with a dedicated website:

[https://klaus.pages.in2p3.fr/epos4/](https://klaus.pages.in2p3.fr/epos4/)

Includes some **new developments** about the **physics**:

- new coherent treatment of **saturation** and **factorisation** ($\leftrightarrow$ binary scaling) \(^a\)
  - possibility to use the BES EoS including a CP + 1\(^b\)st order phase transition, more suited for RHIC energies
  - microcanonical hadronisation of the core (instead of GC Cooper-Frye), more suited for small systems

\(^a\)K. Werner, arXiv:2301.12517


+ some user-oriented upgrades:
  - more documentation, modularisation, simplified running mode...
EPOS 4 is a new version of the EG released publicly in October 2022, with a dedicated website:  
https://klaus.pages.in2p3.fr/epos4/

Includes some new developments about the physics:

- new coherent treatment of saturation and factorisation (↔ binary scaling) \(^a\)
- possibility to use the BES EoS including a CP + 1\(^{st}\) order phase transition, more suited for RHIC energies \(^b\)
EPOS 4 is a new version of the EG released publicly in October 2022, with a dedicated website:

https://klaus.pages.in2p3.fr/epos4/

Includes some new developments about the physics:

- new coherent treatment of saturation and factorisation \( \leftrightarrow \) binary scaling \(^a\)
- possibility to use the BES EoS including a CP + 1\(^{st}\) order phase transition, more suited for RHIC energies \(^b\)
- microcanonical hadronisation of the core (instead of GC Cooper-Frye), more suited for small systems \(^c\)

---

\(^a\) K. Werner, arXiv:2301.12517
EPOS 4 is a new version of the EG released publicly in October 2022, with a dedicated website: https://klaus.pages.in2p3.fr/epos4/

Includes some new developments about the physics:

- new coherent treatment of saturation and factorisation (↔ binary scaling) $^a$
- possibility to use the BES EoS including a CP + 1$^{\text{st}}$ order phase transition, more suited for RHIC energies $^b$
- microcanonical hadronisation of the core (instead of GC Cooper-Frye), more suited for small systems $^c$

$^a$ K. Werner, arXiv:2301.12517

+ some user-oriented upgrades: more documentation, modularisation, simplified running mode...
**Motivations**

New version of an event generator requires intensive testing to find the best parameters tuning, covering as much system sizes and widest energy range as possible.

⇒ computationally consuming! (210Mh of CPU-time in 2022)

Hence the motivation to integrate RIVET into EPOS on-stream analysis system to help us optimising the process.
Motivations

New version of an event generator requires intensive testing to find the best parameters tuning, covering as much system sizes and widest energy range as possible.

⇒ computationally consuming! (210Mh of CPU-time in 2022)

Hence the motivation to integrate RIVET into EPOS on-stream analysis system to help us optimising the process.

For developers:
- a framework to cross-check analyses written by ourselves (via EPOS online analysis system)
- a catalogue of analyses identical to the experimental ones + associated data
New version of an event generator requires intensive testing to find the best parameters tuning, covering as much system sizes and widest energy range as possible. ⇒ computationally consuming! (210Mh of CPU-time in 2022)

Hence the motivation to integrate RIVET into EPOS on-stream analysis system to help us optimising the process.

For developers:
- a framework to cross-check analyses written by ourselves (via EPOS online analysis system)
- a catalogue of analyses identical to the experimental ones + associated data

For users:
- an independent analysis tool which is easy to handle
**RIVET** is a system for validation of MC event generators, based on a C++ framework for analysis algorithms.

https://rivet.hepforge.org/
https://gitlab.com/hepcedar/rivet

**Purpose** : offering a **simple and standardised tool** for comparison between **event generators and data** & ensuring **analysis conservation** for experimental collaborations
**RIVET** is a system for validation of MC event generators, based on a C++ framework for analysis algorithms.

https://rivet.hepforge.org/
https://gitlab.com/hepcedar/rivet

**Purpose**: offering a simple and standardised tool for comparison between event generators and data & ensuring analysis conservation for experimental collaborations

- **1 analysis** ≡ 1 publication + corresponding set of plots data, connected to HepData (900+).
  - Based on the standard HepMC library for the format of input data.
  - Contain libraries of generator-independent event analysis methods.

+ **BONUS**: comes with its dedicated histogramming & plotting tool
**RIVET** is a system for validation of MC event generators, based on a C++ framework for analysis algorithms.

https://rivet.hepforge.org/
https://gitlab.com/hepcedar/rivet

**Purpose**: offering a simple and standardised tool for comparison between event generators and data & ensuring analysis conservation for experimental collaborations

- **1 analysis** ≡ 1 publication + corresponding set of plots data, connected to HepData (900+).
  - Based on the standard **HepMC library** for the format of input data.
  - Contain libraries of generator-independent event analysis methods.
  
  + **BONUS**: comes with its dedicated histogramming & plotting tool

⇒ **RIVET fulfills all the condition we’re seeking**
Adding the HepMC output

In addition to the **ROOT** format (only standard output so far), implemented the **ASCII standard HepMC** output format.

```
E 1 -1 -1.000000000000000e+00 -1.000000000000000e+00 -1.000000000000000e+00 0 -1 235 10001 10002 0 0
U GEV MM
C 8.4970962524414062e+10 0.000000000000000e+00
H 0 11 16 44 235 154 0 0 0 1.3447725296020509e+01 0 0 0
V -1 0 0 0 0 2 2451 0
P 10001 1000822080 0 0 -2.8703993462420581e+05 2.870400000000000e+05 1.937290160000000e+02 4 0 0 -1 0
P 10002 1000822080 0 0 2.8703993462420581e+05 2.870400000000000e+05 1.937290160000000e+02 4 0 0 -1 0
P 10384 -211 4.1446900367736816e-01 1.5941139459609985e+00 2.2229127883911133e+01 2.2290594482655265e+01 1.3956999778747559e-01 1 0 0 0 0
P 10385 2212 2.4639999866485596e-01 -2.7039399743080139e-01 1.3799184570312500e+03 1.3799188245081380e+03 9.3826997280128850e-01 1 0 0 0 0
P 10386 2212 -5.7721109747585297e-02 -8.2814702764153481e-03 1.2756362304687500e+03 1.275635768648102e+03 9.3826997280128850e-01 1 0 0 0 0
```
Adding the HepMC output

In addition to the **ROOT** format (only standard output so far), implemented the **ASCII standard HepMC** output format.

- Modification of the code to implement **HepMC 2.06.09** libraries
  - Take into account user's choice for HepMC recording (ON/OFF) or additional features like reference frame boost
Adding the HepMC output

In addition to the **ROOT** format (only standard output so far), implemented the **ASCII standard HepMC** output format.

1. **modification of the code to implement HepMC 2.06.09 libraries**
   + take into account **user’s choice** for HepMC recording (ON/OFF) or additional features like **reference frame boost**

2. **decision on what to record**: keep **all information** VS. **save memory space** *(10k Au+Au @ 39GeV/A ≡ 2.1GB)*
Adding the HepMC output

In addition to the **ROOT** format (only standard output so far), implemented the **ASCII standard HepMC** output format.

1. modification of the code to implement **HepMC 2.06.09** libraries
   + take into account user’s choice for HepMC recording (ON/OFF) or additional features like reference frame boost

2. decision on what to record: keep all information **VS.** save memory space *(10k Au+Au @ 39GeV/A ≡ 2.1GB)*
   - Light Mode: records only final-state particles
     → fine for centrality determination / charged particles distributions
Adding the HepMC output

In addition to the **ROOT** format (only standard output so far), implemented the **ASCII standard HepMC** output format.

- **Modification of the code to implement** HepMC 2.06.09 libraries
  - + take into account user's choice for HepMC recording (ON/OFF) or additional features like reference frame boost

2. **Decision on what to record:** keep all information **VS. save memory space** (10k Au+Au @ 39GeV/A ≡ 2.1GB)
   - **Light Mode:** records only final-state particles
     - → fine for centrality determination / charged particles distributions
   - **Default Mode:** records **complete decay history** for particles with $\tau > 10^{-20}$ s (+ some exception like quarkonia)
     - → necessary for feed-down corrections + reconstructed particles + jets...
Once we have ensured compatibility with RIVET by adding the HepMC event recording, we need to integrate it into EPOS analysis framework.

**Calculation Center**

- job $i-1$ ($n$ events)
- job $i$ ($n$ events)
- job $i+1$ ($n$ events)

EPOS analyses (e-by-e)

- $i-1$.histo
- $i$.histo
- $i+1$.histo
How we use RIVET with EPOS

Once we have ensured compatibility with RIVET by adding the HepMC event recording, we need to integrate it into EPOS analysis framework.

- develop the architecture to call RIVET directly from EPOS user’s input (mainly Python)


Dr Johannes JAHAN
Integrating the RIVET analysis tool into EPOS 4
May 11, 2023 7/12
How we use RIVET with EPOS

Once we have ensured compatibility with RIVET by adding the HepMC event recording, we need to integrate it into EPOS analysis framework.

- develop the architecture to call RIVET directly from EPOS user’s input (mainly Python)
- develop the converters to put analyses results into EPOS output files (for hybrid cases EPOS / RIVET analyses)

Still room for improvements:

- give more freedom to the user regarding particle species recorded in the HepMC format
- use FIFO pipes to run RIVET, to avoid temporary storage of HepMC files

Once we have ensured compatibility with RIVET by adding the HepMC event recording, we need to integrate it into EPOS analysis framework.

- develop the architecture to call RIVET directly from EPOS user’s input (mainly Python)
- develop the converters to put analyses results into EPOS output files (for hybrid cases EPOS / RIVET analyses)
- allow to save/remove HepMC event records
How we use RIVET with EPOS

Once we have ensured compatibility with RIVET by adding the HepMC event recording, we need to integrate it into EPOS analysis framework.

- develop the architecture to call RIVET directly from EPOS user’s input (mainly Python)
- develop the converters to put analyses results into EPOS output files (for hybrid cases EPOS / RIVET analyses)
- allow to save/remove HepMC event records

Still room for improvements:
- give more freedom to the user regarding particle species recorded in the HepMC format
- use FIFO pipes to run RIVET, to avoid temporary storage of HepMC files

Physics level: data are well reproduced at mid-rapidity overall

Analysis level: RIVET and EPOS analyses give identical results

(except for some cases because of normalisation)
**Physics level:** common particles production is well reproduced at forward rapidity

**Analysis level:** RIVET and EPOS analyses give identical results again
Physics level: strange and charmed particles well reproduced

Analysis level: some discrepancies appear between RIVET and EPOS analyses
Physics level: strange and charmed particles well reproduced

Analysis level: some discrepancies appear between RIVET and EPOS analyses

- Impact of particle’s selection in the HepMC recording process for some analyses
  → let the user choose more precisely the content of event records
**Physics level:** strange and charmed particles well reproduced

**Analysis level:** some discrepancies appear between RIVET and EPOS analyses

- Impact of particle’s selection in the HepMC recording process for some analyses
  → *let the user choose more precisely the content of event records*
- Feed-down corrections? Normalisation? Event selection?
Summary

- made EPOS 4 compatible with RIVET, useful for both users and developers
- to go further: RIVET integrated into the online EPOS4 analysis system
  (saves memory space + enables cross-check with pre-existent analyses)

BUT...
Summary

- made EPOS 4 compatible with RIVET, useful for both users and developers
- to go further: RIVET integrated into the online EPOS4 analysis system
  
  (saves memory space + enables cross-check with pre-existent analyses)

BUT...

- further improvement might be necessary + some tricky questions regarding event recording
  
  → user’s feedback
made EPOS 4 compatible with RIVET, useful for both users and developers

to go further: RIVET integrated into the online EPOS4 analysis system
(saves memory space + enables cross-check with pre-existent analyses)

BUT...

further improvement might be necessary + some tricky questions regarding event recording

→ user's feedback

limited catalogue (VERY limited for heavy-ions) restrain use of systematic tuning tools (e.g. Professor)

<table>
<thead>
<tr>
<th>Key</th>
<th>ALICE</th>
<th>ATLAS</th>
<th>CMS</th>
<th>LHCb</th>
<th>Forward</th>
<th>HERA</th>
<th>$e^+e^-$ ($\leq 12$ GeV)</th>
<th>$e^+e^-$ ($\leq 12$ GeV)</th>
<th>Tevatron</th>
<th>RHIC</th>
<th>SPS</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rivet wanted (total):</td>
<td>278</td>
<td>334</td>
<td>447</td>
<td>269</td>
<td>17</td>
<td>479</td>
<td>703</td>
<td>560</td>
<td>1131</td>
<td>469</td>
<td>64</td>
<td>2</td>
</tr>
<tr>
<td>Rivet REALLY wanted:</td>
<td>36</td>
<td>37</td>
<td>89</td>
<td>8</td>
<td>0</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rivet provided:</td>
<td>26/304 = 9%</td>
<td>189/523 = 36%</td>
<td>103/550 = 19%</td>
<td>17/286 = 6%</td>
<td>8/25 = 32%</td>
<td>34/513 = 7%</td>
<td>192/895 = 21%</td>
<td>325/885 = 37%</td>
<td>58/1189 = 5%</td>
<td>8/477 = 2%</td>
<td>4/68 = 6%</td>
<td>112/114 = 98%</td>
</tr>
</tbody>
</table>
Complementary material
Event generation with EPOS

**Primary interactions treated with PBGRT**

Exchange of multiple Pomerons $\equiv$ parton ladders in parallel

**Core-corona separation**

Dynamical separation of the system into 2 parts at early time of evolution $^a$:

- **core** = high energy-density region ($> \varepsilon_c$)
- **corona** = low energy-density region ($< \varepsilon_c$)

---


---

**Core evolution**

Viscous 3+1D hydrodynamics expansion based on a cross-over transition Equation of State (EoS)

**Corona evolution**

Strings evolution following dynamics of a gauge invariant Lagrangian $+$ string fragmentation

**Hadronic cascades**

Re-scatterings between formed hadrons simulated using UrQMD$^b$.

---


---

K. Werner (2018)

---

MADAI collaboration