INTRODUCING HIJING++: THE HEAVY ION JET
INTERACTION GENERATOR FOR THE
HIGH-LUMINOSITY LHC ERA

AIX-LES-BAINS

GÁBOR BÍRÓ
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1. **Introduction**

2. **Current status results**

3. **Jet energy loss**

4. **Tech features**

5. **Summary**
INTRODUCTION
where does the QGP “begin”?

\[ 0-10\% \ p+A \& \ 70-90\% \ A+A \]

R. Weller and P. Romatschke, SuperSONIC
"Nuclear change theory"; Book of Changes, "Originally a divination manual in the Western Zhou period (1000–750 BC)"


- Pairwise nucleon interactions ((in)elastic scattering (Pythia), diffraction, gluon radiation, Lund fragmentation...), wounded nucleon model
- Up to date, the community still uses the (more-or-less) original FORTRAN code
- Challenge: software simulation of 600 million real collision in each second (HiLumiLHC: multiple of this)
HIJING++ FAQ

HIJING++ ...

• HIJING++ is a framework, not a black box.
• HIJING++ is not a direct port of the old FORTRAN code.
• HIJING++ is a direct port of the old FORTRAN code after all (regarding the physics).
• HIJING++ is not a wrapper for Pythia8.
• HIJING++ is not published (yet).
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FORTRAN HIJING → HIJING++:

- **Computational level:**
  - Single precision
  - Double precision
  - Multithreading
  - Module management
  - Analysis interface

- **Physics level:**
  - Parameters of the wounded nucleon model tuned for:
    - LHC energies
    - Pythia8 tunes
  - PDF distributions via LHAPDF6 (FORTRAN HIJING: GRV98)
  - Colour reconnection is included
  - Agreement with experimental pp/pA data is good, especially at mid-$p_T$
  - Jet energy loss:
    - Collisional: OK
    - Radiative: Under development
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Current status results
HIJING++ RESULTS

Pseudorapidity of charged hadrons from RHIC to LHC energies in pp collisions

- Agreement with experimental data is much better for HIJING++ and for higher energies compared to FORTRAN HIJING
- PDF set: CT10nlo, $10^5 - 10^6$ events
HIJING++ RESULTS

$p_T$ spectra of identified and charged hadrons from RHIC to LHC energies in pp collisions

- At higher energies, at very low $p_T$ Hijing++ underestimates, while at high $p_T$ overestimates
- Az mid-$p_T$ the agreement is good
- PDF set: CT10nlo, (10 – 20)x10^6 events
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Nuclear modification factor of charged hadrons at p-Pb

\[ R_{pPb} = \frac{d^2 N_{pPb} / d\eta dp_T}{\langle N_{bin} \rangle d^2 N_{pp} / d\eta dp_T}, \]

\[ \langle N_{bin} \rangle = 16.037 \]

- with Hijing++ the agreement is excellent until \( \approx 6 \text{ GeV} \)
- PDF set: CT10nlo, HIJING shadowing model, \( 10^4 \) (p-Pb) and \( 10^6 \) (pp) events
Jet energy loss
**Radiative energy loss: opacity expansion**


Probability of radiating a collinear gluon:

\[ p(L) = 1 - e^{-\frac{L}{\lambda g}} \]  

(1)

The energy loss:

\[ \Delta E = \frac{C_R \alpha_S}{N(E)} \left( \frac{L \mu}{\lambda g} \right)^2 \log \left( \frac{E}{\mu} \right) \]  

(2)

\[ N(E) = \frac{1}{4 + \frac{22}{\log E}} \]  

(3)

**Collisional energy loss**

No gluon radiation, only elastic scattering of the partons in the dense medium

Needs some tuning
Peripheral: reasonable agreement
Central: too few final state hadrons
PDF set: nCTEQ15, HIJING
shadowing turned off
**Problem:** the implementation of the collinearity, Pythia8 merge the partons that are too close in the phase space
Tech features
HIJING++  Monte Carlo Event Generator

**Solid C++ foundations**

- User friendly usage (C++14 compiler, cmake, LHAPDF6, Pythia8)
- Many optional extension (ROOT, FastJet, Rivet, ...)
- Easily parallelizable

```c++
#include "Hijing.hpp"

using namespace Hijing3;

int main(int argc, char* argv[])
{
    Hijing hijing;
    hijing.readFile("testSettings.cmnd");

    hijing.init();
    hijing.newAnalysis("root", "EventEnd", "pt_cpi", 50, 0.0, 20.0);
    hijing.analysisProperties("pt_cpi", "final", "pT", "yw—0.5to0.5",
        "ID211", "ID—211");

    hijing.start();
}
```

```ini
[main]
PDF:pSet = CT1onlo
Beams:eCM = 8160
Hijing:threads = 3
Hijing:DoShadowing = off
Hijing:makeLog = off
Hijing:fileName = PbPb_5020_GLVtest
Main:numberOfEvents = 50000
Hijing:idA = P
Hijing:aprot = 1
Hijing:zproj = 1
Hijing:idB = A
Hijing:atarg = 208
Hijing:ztarg = 82
(...)```

Highly customizable through run parameters stored in xml files
HIJING++ Modularity

In the xml:

```xml
<word name="Hijing:Quenching" default="HijQuenching_GLV0"></word>
```

Select the jet quenching definition: GLV model version 0.

Building the HijModules:

```cpp
unique_ptr<IHijQuenching> ModuleFactory::makeQuenching(const string &name) {
    if (name == "HijQuenching_GLV0")
        return move(make_unique<HijQuenching_GLV0>());
    if (name == "HijQuenching_GLV1")
        return move(make_unique<HijQuenching_GLV1>());
}
```

At user level, in testSettings.cmnd:

```cmnd
Hijing:Quenching = HijQuenching_GLV0
```
hijing.newAnalysis("root", "EventEnd", "multiplicity_root", 100, 0.0, 100.0, "<dN_{ch}/d\#eta>", "Prob");

hijing.newAnalysis("ascii","EventEnd", "eta_charged_ascii", 20, -5.0, 5.0);

hijing.newAnalysis("root", "raw","EventEnd","raw data");

auto myEventFilter = [&](const Event &event) {
    return true;
};

auto myHadronFilter = [&](const Particle &particle, const Event &event) {
    return particle.isFinal() && abs(particle.id()) == 211;
};

hijing.analysisBranches("raw data", "eta", "pT");

hijing.analysisFilter("raw data", myEventFilter, myParticleAccept);

hijing.analysisProperties("multiplicity_root", "charged", "final", "multiplicity", "nonorm", "yw-0.5to0.5", "png");

hijing.analysisProperties("eta_charged_ascii","final","eta", "charged");
Wigner GPU Laboratory, Intel(R) Xeon Phi(TM) CPU 7250 (272 CPU threads)
1 event, 1 thread, Pythia 8.2: \(\sim 200\%\)
1 event, 1 thread, FORTRAN HIJING: \(\sim 70\%\)*
**Installation**

**Introduction**
These are the setup instructions.

**Prerequisites**
- git
- cmake (min. v3.2)
- LHAPDF6 (v6.2.0 or newer)
- Pythia8 (v8219 or newer)
- c++ compiler with c++14 support (gcc 5 or later)

**LHAPDF6**

```
wget http://www.hepforge.org/archive/lhapdf/LHAPDF-6.X.Y.tar.gz
tar -xvf LHAPDF-6.X.Y.tar.gz
cd LHAPDF-6.X.Y
./configure --prefix=/where/to/install
make -j8
sudo make install
```

**Install (nuclear) pdf sets**

The pdf set GRV98lo is included in the downloaded package. It is mainly used during the development, since it is an unvalidated, "unofficial" set. However, if you wish

1. copy the GRV98lo folder (you can find it in misc) into /path/to/install/LHAPDF6/share/LHAPDF
2. insert into the file pdfsets.index at the correct line number (i.e. between 80000 and 80111) the following: 80060 GRV98lo T :

```
    sed -i /80000\ META*10LHC\ /a 80060 GRV98lo T
```

If you wish to use other npdf sets, visit http://lhapdf.hepforge.org/pdfssets.html and repeat the first step.

**Pythia8**

Download and install the latest version from the official webpage:
Summary

- Brand new framework in C++
- Good agreement with pp/pA data, tuning for heavy-ion is under progress
- Default jet energy loss with GLV+collisional model, under development
- CPU parallelization and analysis is included in the standard accessory
- Modules: room for any new model
- Only a little polishing is needed, release soon...

Stay tuned!

Contacts:

biro.gabor@wigner.mta.hu

or

hijing@wigner.mta.hu

wigner.mta.hu/~hijing (Soon!)
Thank you for your attention!
MC event → Loop through particles → ... → Ask for new event

Processing
HIJING++ MULTITHREADING

1. MC event → Loop through particles → ... → Ask for new event
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HIJING++ ANALYSIS EXAMPLE OUTPUTS

PP(1,1) @ $\sqrt{s_{NN}} = 200$ GeV, $N_{ev} = 15000$

Number of entries: 15000

multiplicity_root, analysis properties:

charged final multiplicity nonorm yw-0.5to0.5 png
```
1 | # Name: eta_charged_ascii
2 | # System: PP(1,1) @ sqrt{s_{NN}} = 200 GeV
3 | # Event number: 15000
4 | # Entries: 251506
5 | # Analysis properties: final eta charged
6 | # bincenter  binwidth  value  stat.error
7 | -4.9  0.1  0.20273  0.0036764
8 | -4.7  0.1  0.23273  0.003939
9 | -4.5  0.1  0.25573  0.004129
10 | -4.3  0.1  0.26953  0.004239
11 | -4.1  0.1  0.28187  0.0043349
12 | -3.9  0.1  0.29753  0.0044537
13 | -3.7  0.1  0.3106   0.0045505
14 | -3.5  0.1  0.30907  0.0045392
15 | -3.3  0.1  0.32467  0.0046524
16 | -3.1  0.1  0.328    0.0046762
17 | -2.9  0.1  0.3472   0.0048111
18 | -2.7  0.1  0.35693  0.0048781
19 | -2.5  0.1  0.36413  0.004927
20 | -2.3  0.1  0.37133  0.0049755
21 | -2.1  0.1  0.3744   0.004996
22 | -1.9  0.1  0.3822   0.0050478
23 | -1.7  0.1  0.3864   0.0050754
24 | -1.5  0.1  0.38933  0.0050947
25 | -1.3  0.1  0.3928   0.0051173
26 | -1.1  0.1  0.39893  0.0051571
27 | -0.9  0.1  0.38507  0.0050667
```