

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

AIX-LES-BAINS

HARDPROBES2018

GÁBOR BÍRÓ

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COLLABORATORS



Gergely Gábor Barnaföldi
Gábor Papp
Péter Lévai
Miklós Gyulassy
(Szilveszter Harangozó)
Xin-Nian Wang
Ben-Wei Zhang
(Guoyang Ma)

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- Wigner Data Center, Wigner GPU Laboratory
- ÚNKP-17-3 New National Excellence Program of the Ministry of Human Capacities

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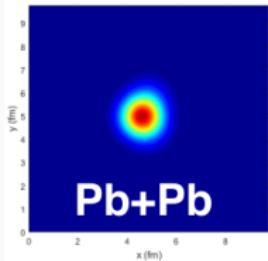
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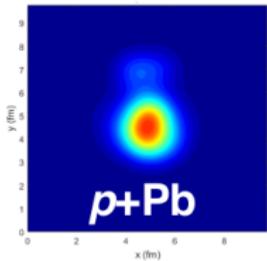
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INTRODUCTION

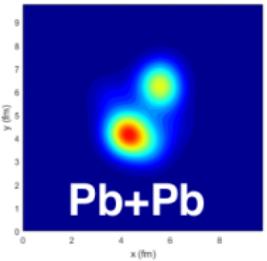
where does the QGP “begin”?



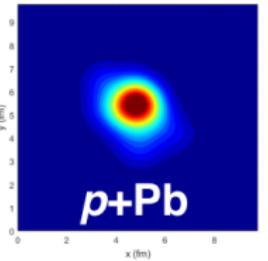
Pb+Pb



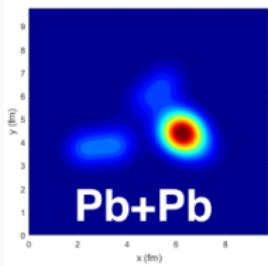
p+Pb



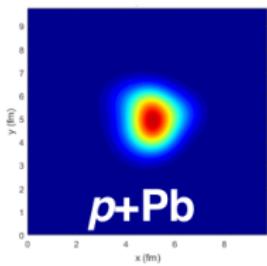
Pb+Pb



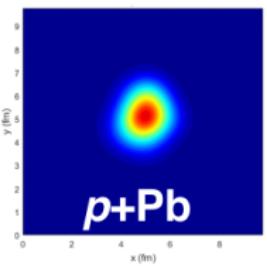
p+Pb



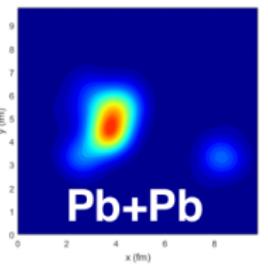
Pb+Pb



p+Pb



p+Pb



Pb+Pb

0-10% $p+A$ & 70-90% $A+A$

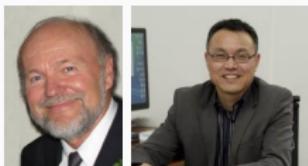
R. Weller and P. Romatschke, SuperSONIC

HIJING MONTE CARLO EVENT GENERATOR

H eavy
I on
J et
IN teraction
G enerator

核易经

[Hé – yì – jīng]



"Nuclear change theory"; Book of Changes, "Originally a divination manual in the Western Zhou period (1000–750 BC)"

First, FORTRAN version: 1991, X.N. Wang, M. Gyulassy, *Phys. Rev. D* **44**, 3501 (1991).

- 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

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- ...**is** a framework, **not** a black box.

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- ...**is not** published (yet).

HIJING++ SUMMARY

FORTRAN HIJING → HIJING++:

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 - jet energy loss:

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 - collisional: OK

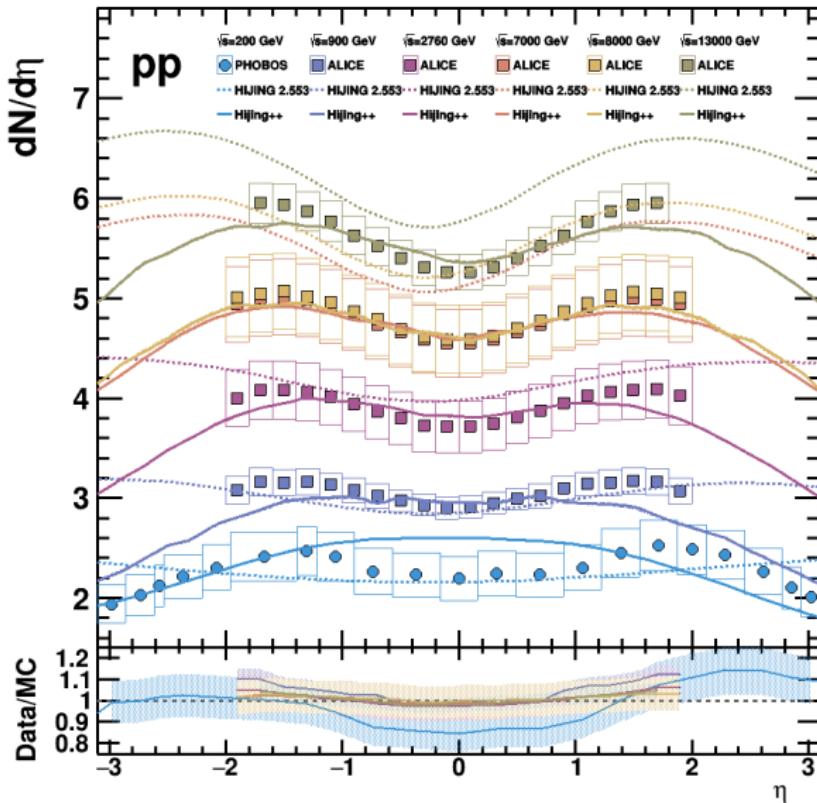
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 - jet energy loss:
 - collisional: OK
 - radiative: under development

CURRENT STATUS RESULTS

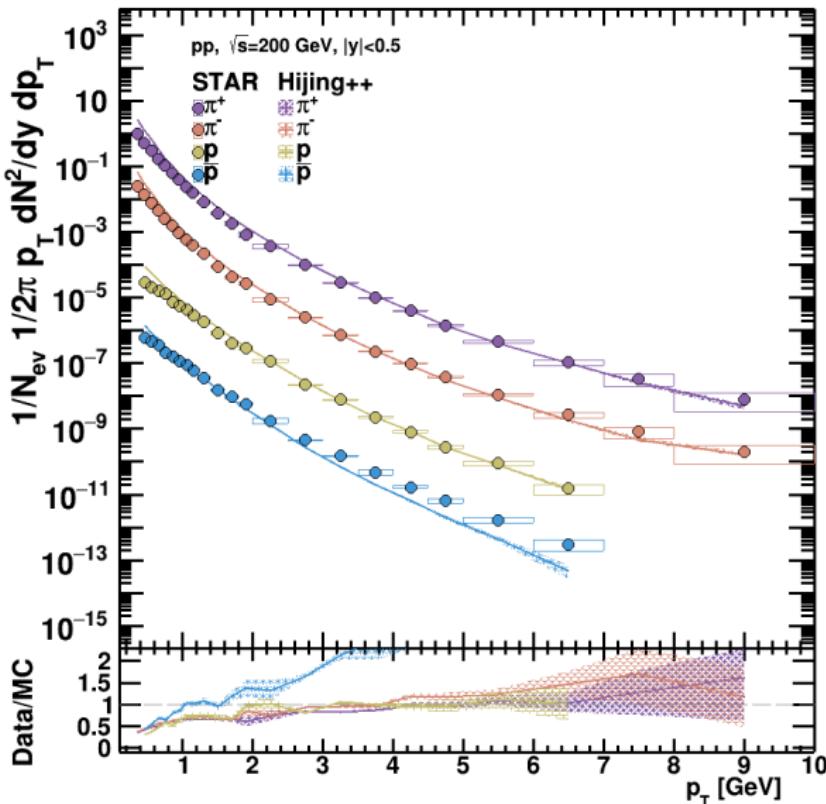
HIJING++ RESULTS



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: CT1onlo, $10^5 - 10^6$ events

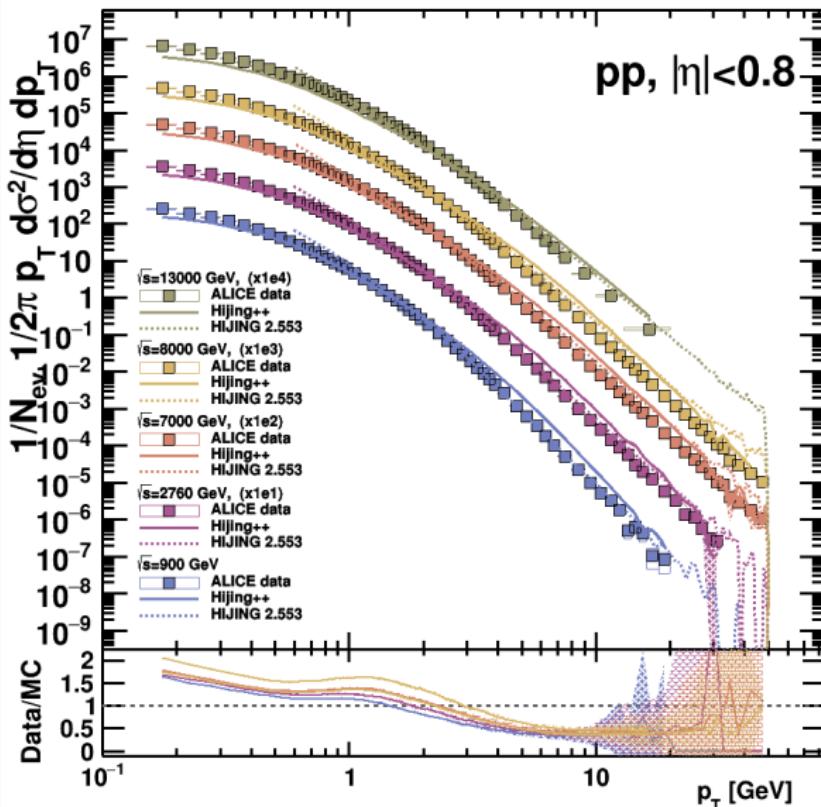
HIJING++ RESULTS



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
- At mid- p_T the agreement is good
- PDF set: CT10nlo, $(10 - 20) \times 10^6$ events

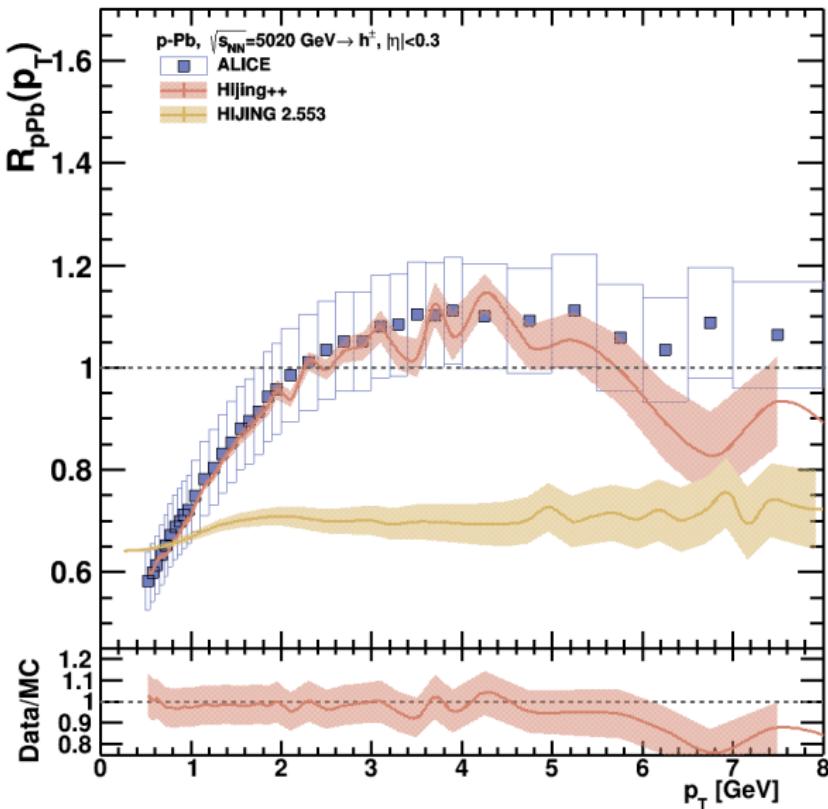
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HIJING++ RESULTS



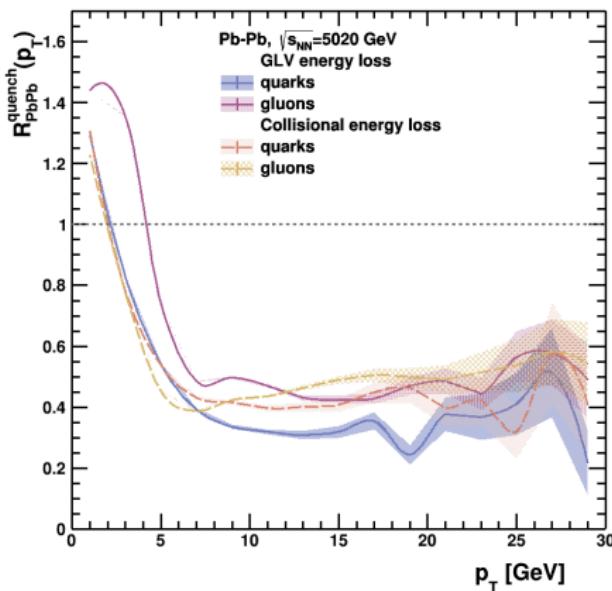
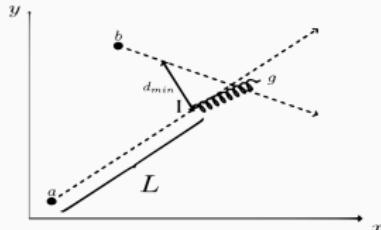
Nuclear modification factor of charged hadrons at p-Pb

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

$$\langle N_{bin} \rangle = 16.037$$

- with HIJING++ the agreement is excellent until ≈ 6 GeV
- PDF set: CT10nlo, HIJING shadowing model, 10^4 (p-Pb) and 10^6 (pp) events

JET ENERGY LOSS



Radiative energy loss: opacity expansion

(M. Gyulassy, P. Lévai, I. Vitev, Phys.Lett. B538 (2002) 282-288, Nucl.Phys. B594

(2001) 371-419)

Probability of radiating a collinear gluon:

$$p(L) = 1 - e^{-\frac{L}{\lambda_g}} \quad (1)$$

The energy loss:

$$\Delta E = \frac{C_R \alpha_S}{N(E)} \frac{(L_\mu)^2}{\lambda_g} \log \left(\frac{E}{\mu} \right) , \quad (2)$$

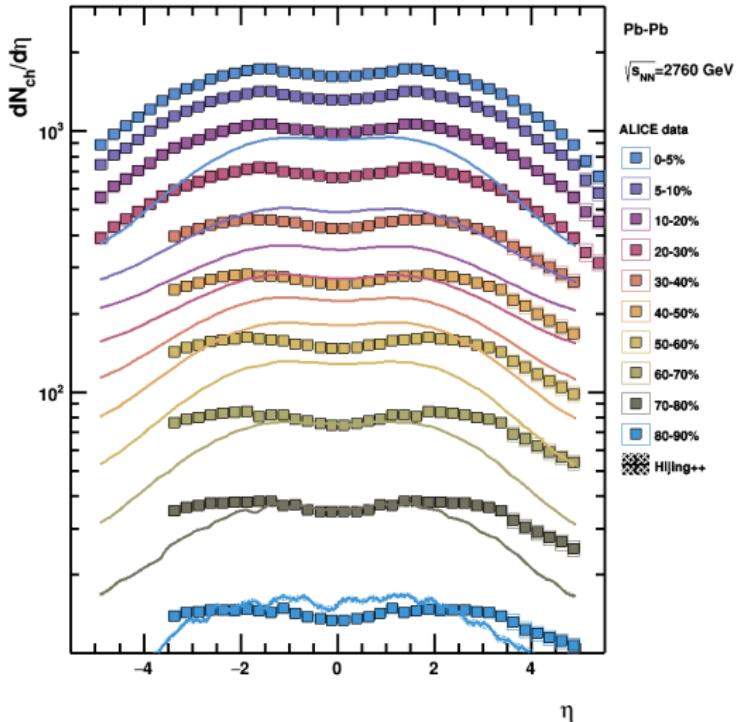
$$N(E) = \frac{1}{4 + \frac{22}{\log E}} \quad (3)$$

Collisional energy loss

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

Needs some tuning

HIJING++ JET ENERGY LOSS



Pseudorapidity density at different centralities

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

main.cc:

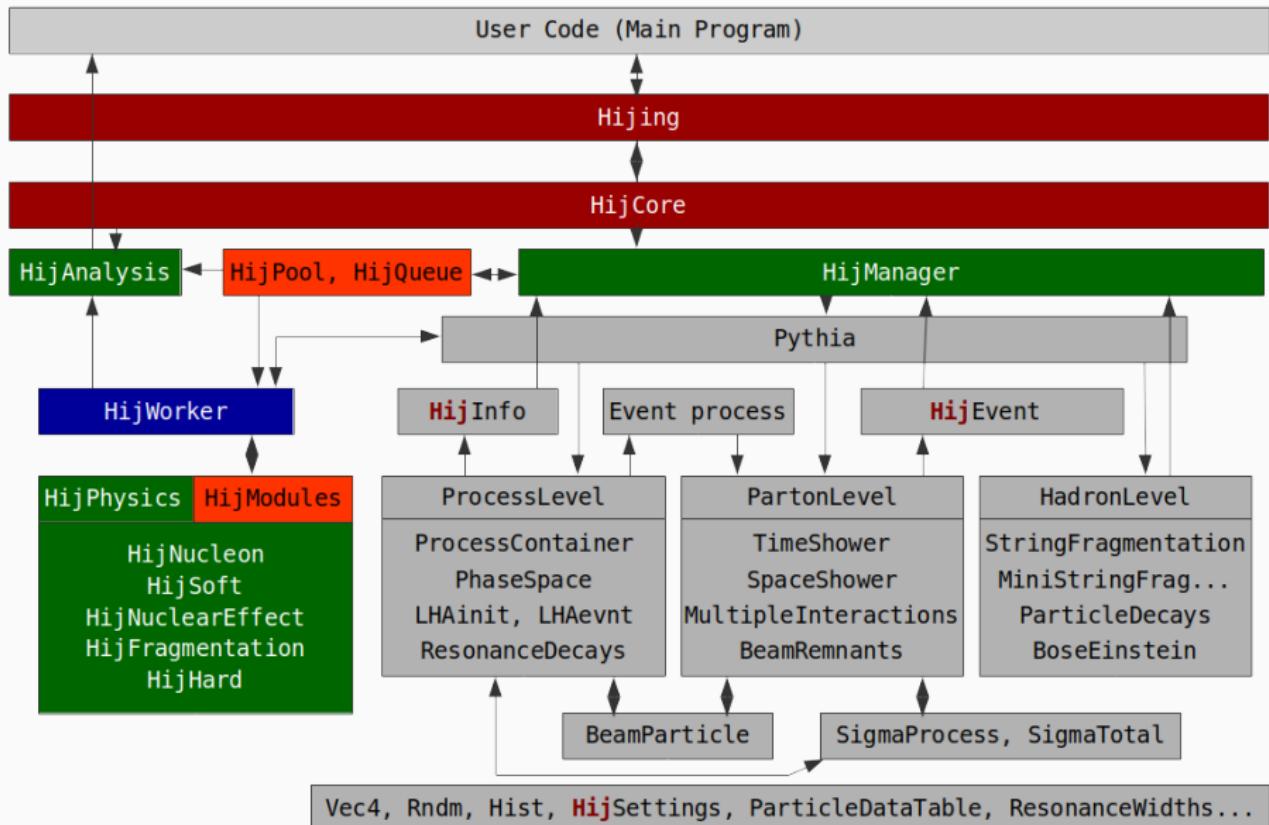
```
1 #include "Hijing.hpp"
2
3 using namespace Hijing3;
4
5 int main(int argc, char* argv[])
6 {
7     Hijing hijing;
8     hijing.readFile("testSettings.cmnd");
9
10    hijing.init();
11    hijing.newAnalysis("root", "EventEnd", "pt_cpcion",
12                      50, 0.0, 20.0);
13    hijing.analysisProperties("pt_cpcion", "final", "pT",
14                             "yw-05too-5",
15                             "ID211", "ID-211");
16    hijing.start();
17 }
```

testSettings.cmnd:

```
1 PDF:pSet = CT1onlo
2
3 Hijing:threads = 3
4 Beams:eCM   = 8160
5 Hijing:DoShadowing = off
6 Hijing:makeLog = off
7 Hijing:fileName = PbPb_5020_GLVtest
8
9 Main:numberOfEvents = 50000
10 Hijing:idA = P
11 Hijing:aproj = 1
12 Hijing:zproj = 1
13 Hijing:idB = A
14 Hijing:atarg = 208
15 Hijing:ztarg = 82
16 (...)
```

Highly customizable through run parameters stored in **xml** files

HIJING++ STRUCTURE



HIJING++ MODULARITY

In the xml:

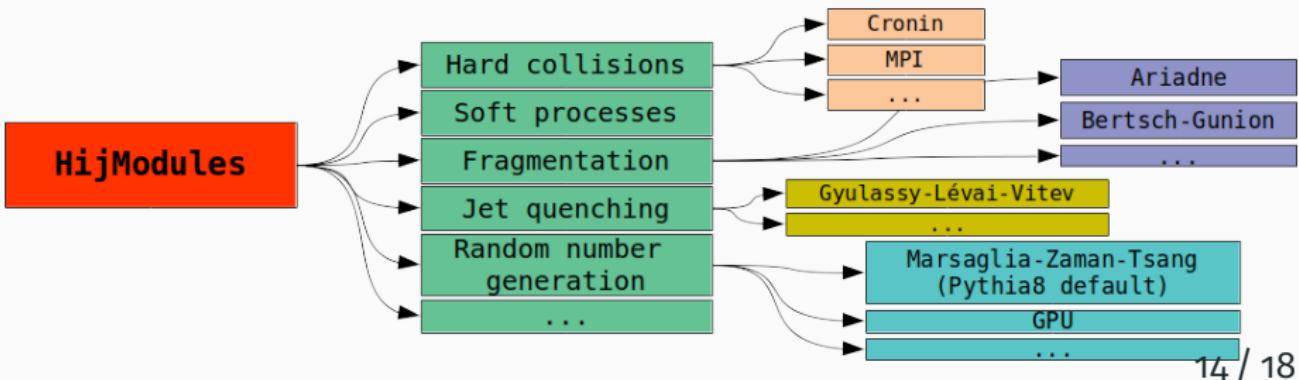
```
1 <word name="Hijing:Quenching" default="HijQuenching_GLV0">
2 Select the jet quenching definition: GLV model version 0.
3 </word>
```

Building the HijModules:

```
1 unique_ptr<IHijQuenching> ModuleFactory::makeQuenching(const string &name) {
2     if (name == "HijQuenching_GLV0")
3         return move(make_unique<HijQuenching_GLV0>());
4     if (name == "HijQuenching_GLV1")
5         return move(make_unique<HijQuenching_GLV1>());
6 }
```

At user level, in testSettings.cmnd:

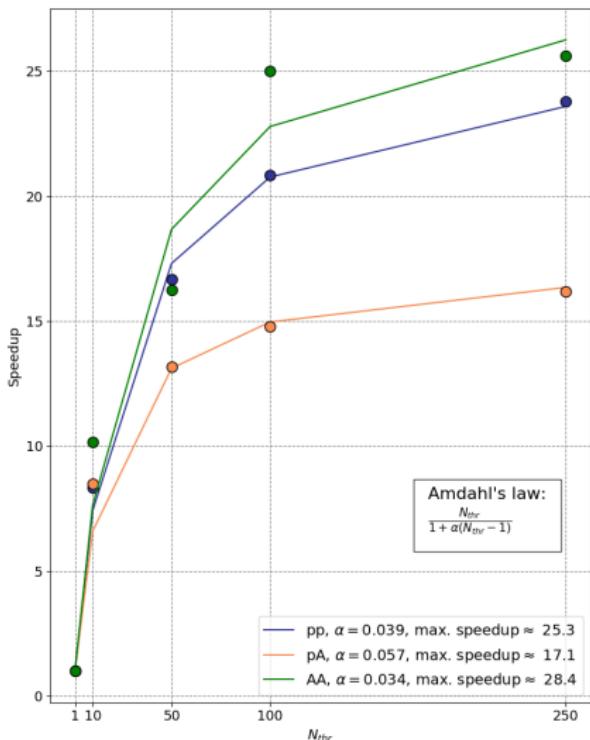
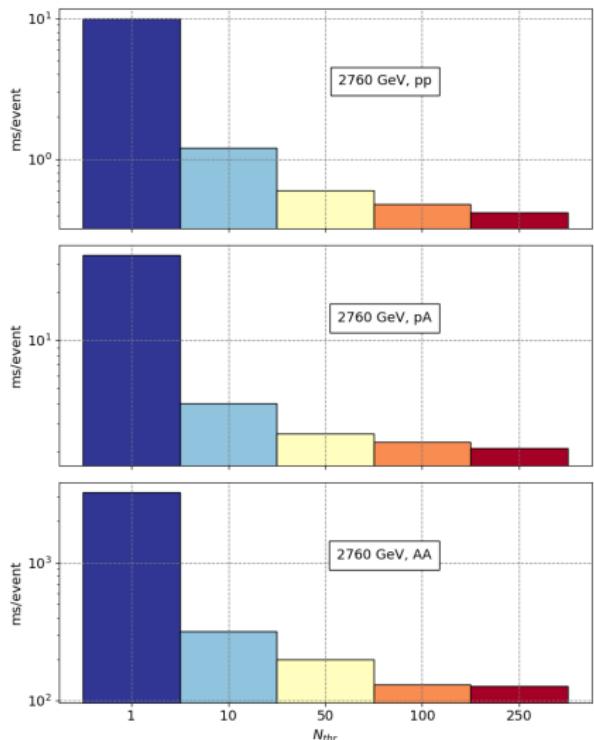
```
1 Hijing:Quenching = HijQuenching_GLV0
```



HIJING++ BUILT-IN ANALYSIS

```
1 hijing.newAnalysis("root", "EventEnd", "multiplicity_root", 100, 0.0, 100.0, "<dN_{ch}/d#eta>", "Prob");
2
3 hijing.newAnalysis("ascii","EventEnd", "eta_charged_ascii", 20, -5.0, 5.0);
4
5 hijing.newAnalysis("root", "raw","EventEnd","raw data");
6
7 auto myEventFilter = [&](const Event &event) {
8     return true;
9 };
10
11 auto myHadronFilter = [&](const Particle &particle , const Event &event) {
12     return particle.isFinal() && abs(particle.id()) == 211;
13 };
14
15 hijing.analysisBranches("raw data", "eta", "pT");
16
17 hijing.analysisFilter("raw data", myEventFilter, myParticleAccept);
18
19 hijing.analysisProperties("multiplicity_root", "charged", "final", "multiplicity", "nonorm",
20                         "yw=0.5to0.5", "png");
21
22 hijing.analysisProperties("eta_charged_ascii","final","eta", "charged");
```

HIJING++ PERFORMANCE TESTS



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: $\sim 70\%*$

HIJING++ DOCUMENTATION (BASED ON THE XML FILES)



Hijing++

RC 3.0-1

A Heavy Ion Jet INteraction Generator, C++ version

Home Installation Downloads Documentation Classes Files List of example mains

Hijing++
Installation
Downloads
Documentation
Examples
Glossary
Update history
Bibliography
Example results
Classes
Files
List of example mains

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 -jN
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 1:*

```
sed -i '/80000\ METAv10LHC\ 2/a 80060 GRV98lo 1' /path/to/install/LHAPDF6/share/LHAPDF/pdfsets.index
```

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

Pythia8

Download and install the latest version from the official webpage:

SUMMARY

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

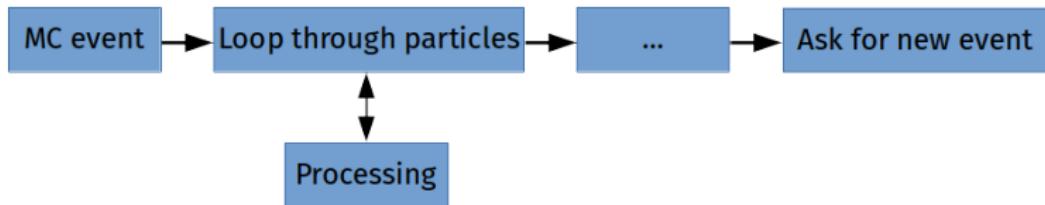
hijing@wigner.mta.hu

wigner.mta.hu/~hijing (Soon!)

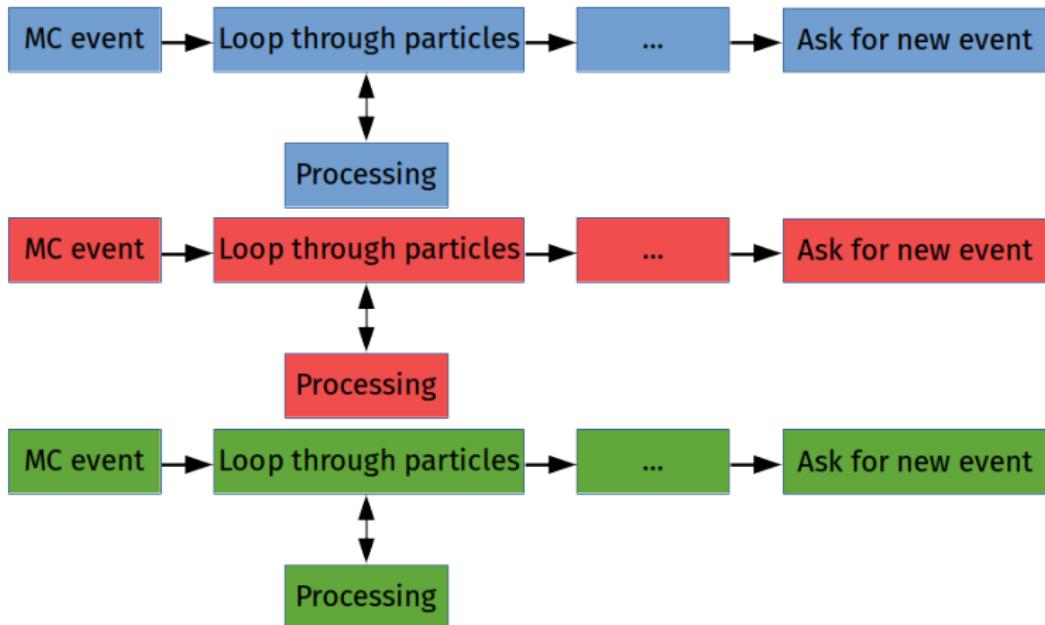
Thank you for your attention!



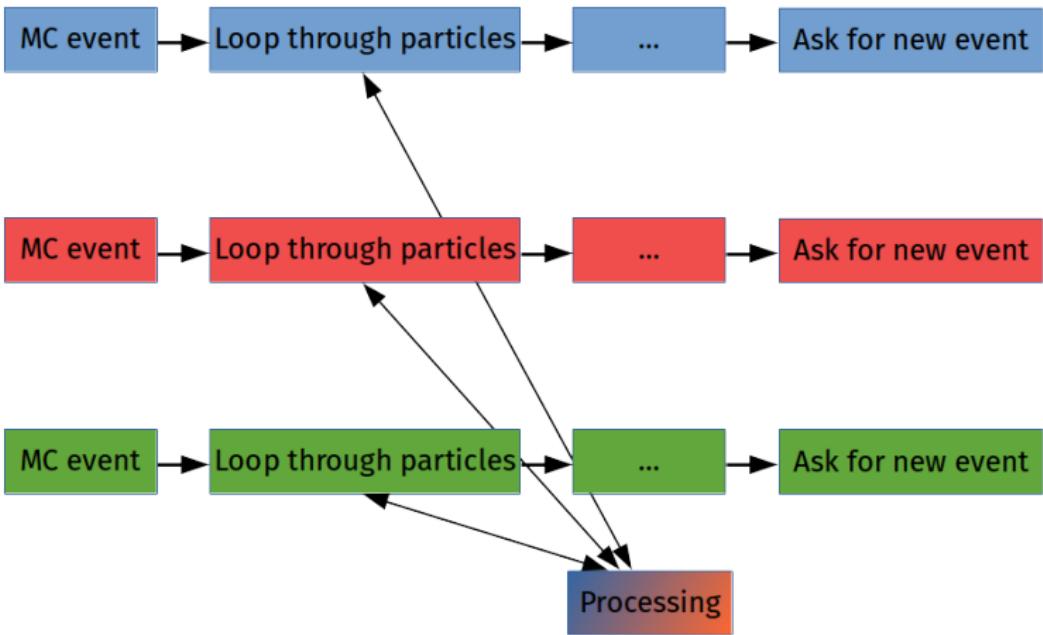
HIJING++ MULTITHREADING



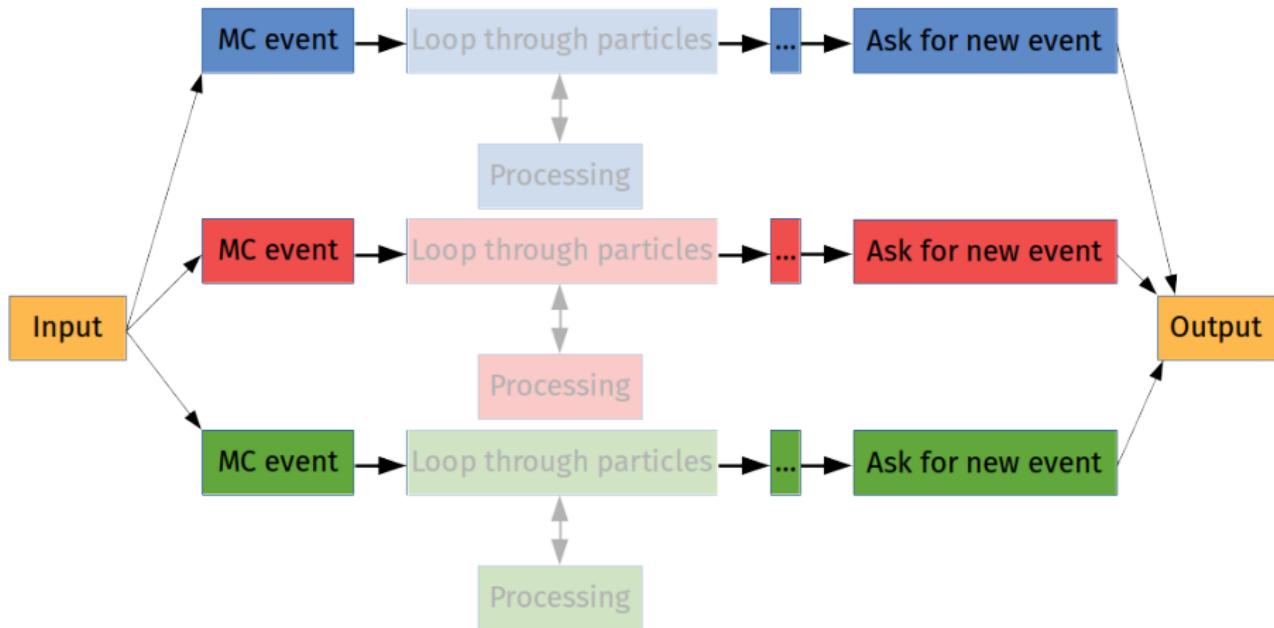
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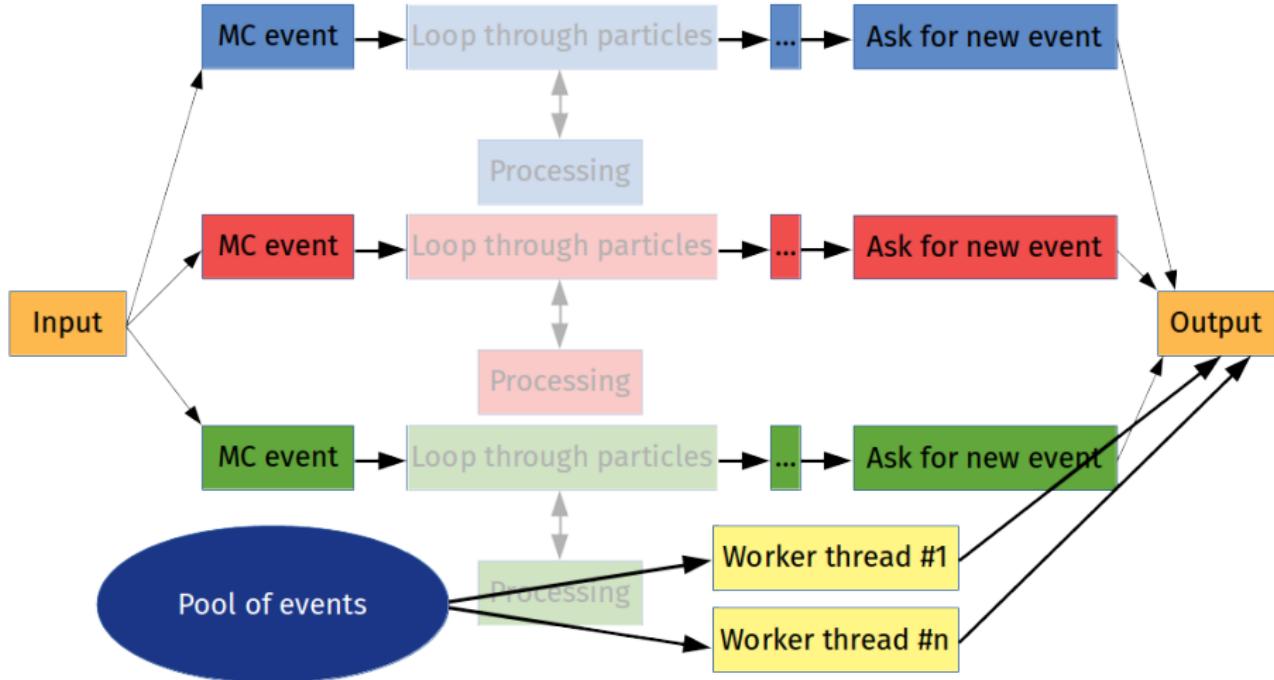
HIJING++ MULTITHREADING



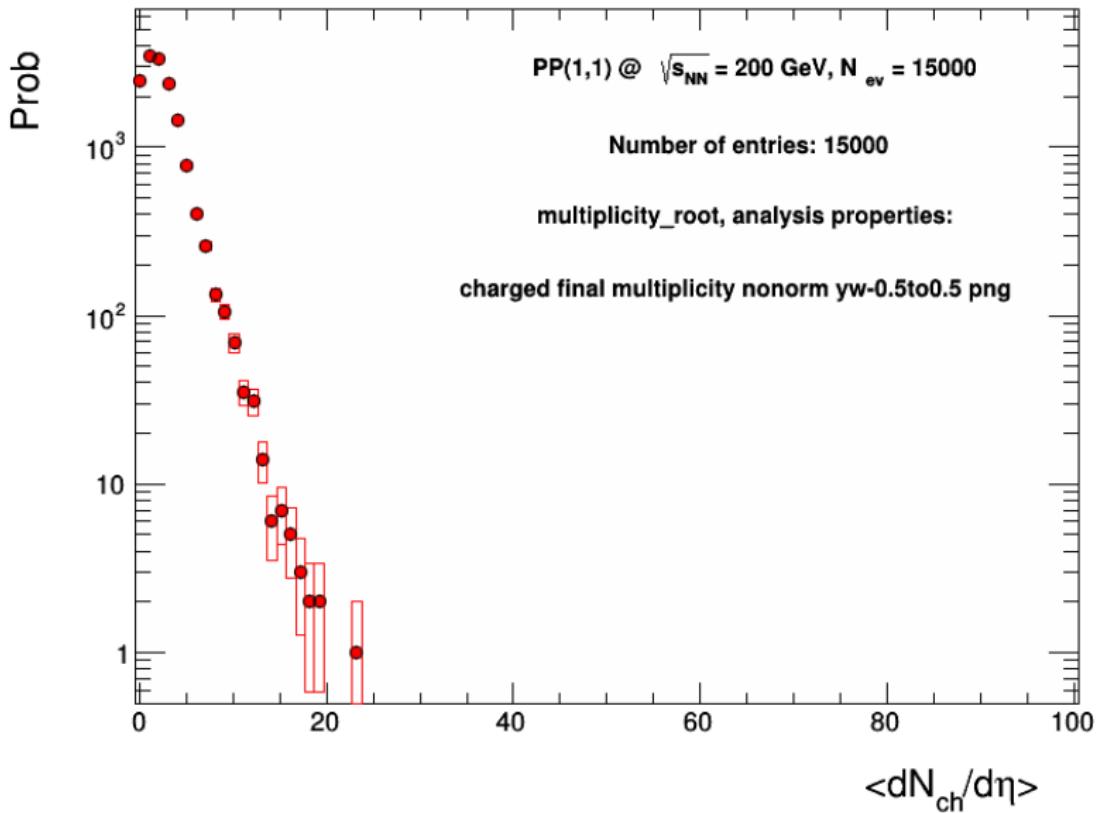
HIJING++ MULTITHREADING



HIJING++ MULTITHREADING



HIJING++ ANALYSIS EXAMPLE OUTPUTS



HIJING++ ANALYSIS EXAMPLE OUTPUTS

```
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 0.39507 0.0050667
```