HIJING++

Speaker: Gergely Gábor Barnaföldi, Wigner RCP of the H.A.S.

Group: GGB, **G. Bíró**, Sz.M. Harangozó, W.T. Deng, M. Gyulassy, G.Y. Ma,
P. Lévai, **G. Papp**, X.N. Wang, B.W. Zhang

ALICE PWG-MM 2019, CERN, 27th March 2019

HIJING++

a status report as of yesterday

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Outline

- Motivation for HIJING++
- Technical details of the HIJING++
  - The structure of the program
  - Simulation framework & new features
- New physics & tests
  - Code validation in proton-proton collisions
  - Adding RIVET framework
  - Fine-tuning with PROFESSOR
- Outlook…

MOTIVATION

A QUESTION
How long time does an event ‘cost’?

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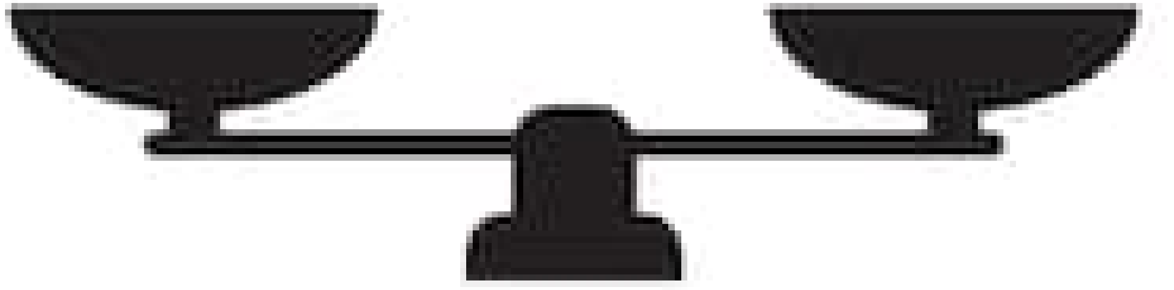
Detector event
10^{-8} s collision
10^{-6} s reconstruction

MC event
10^{-3} s with
reconstruction



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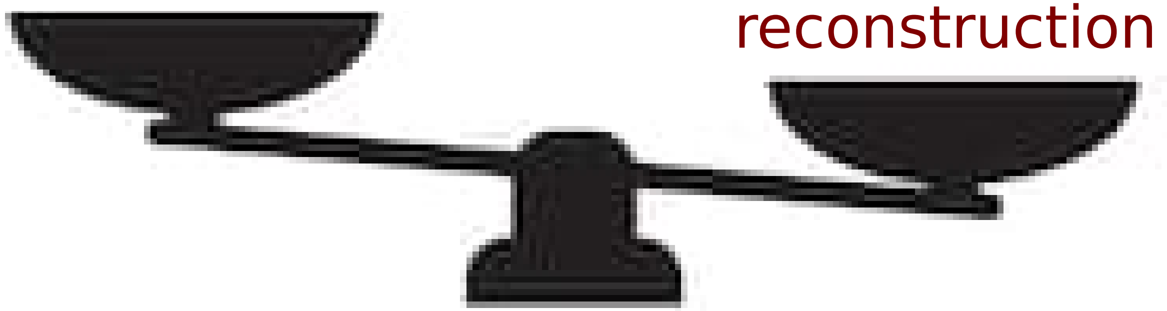
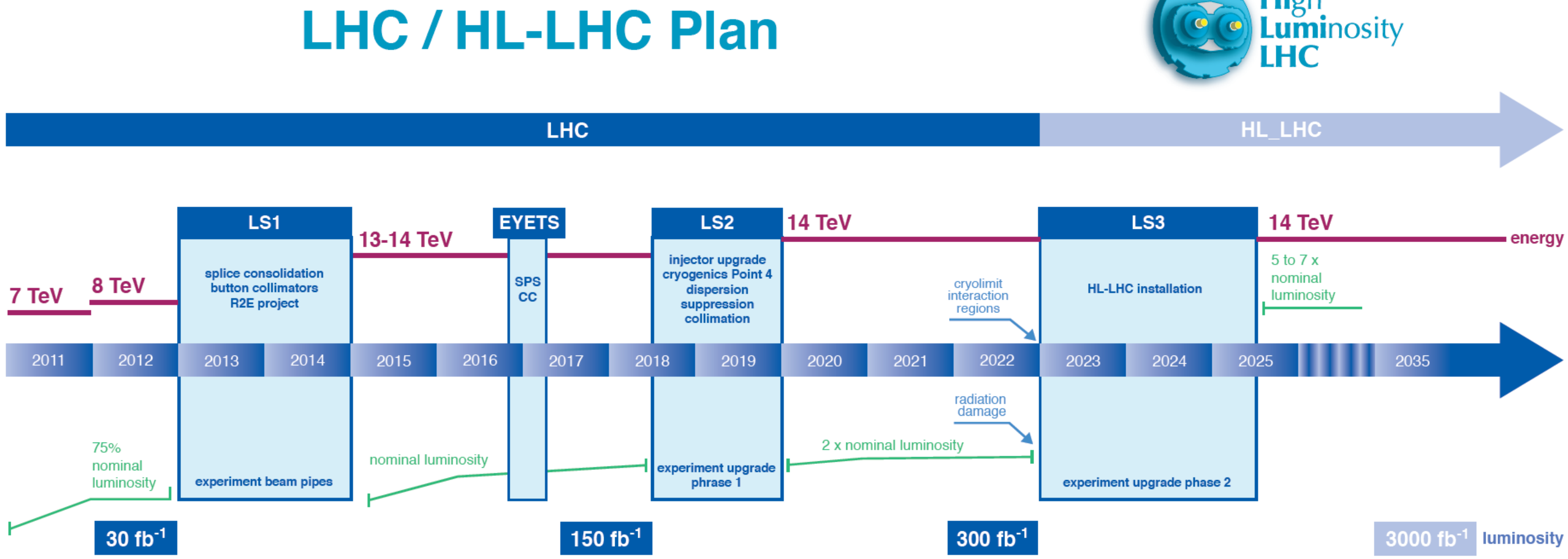


HI data from the Large Hadron Collider

- LHC upgrades & theories required more and faster HI simulations



HIJING++

(C++ based HIJING version 3.1 with parallel opportunities)

The HIJING++

HIJING(Heavy-Ion Jet INteraction Generator)

易經

Bagua (eight simbols)

fundamental principles of reality

adjoint representation 8 of *SU(3)*

The HIJING++

HIJING(Heavy-Ion Jet INteraction Generator)

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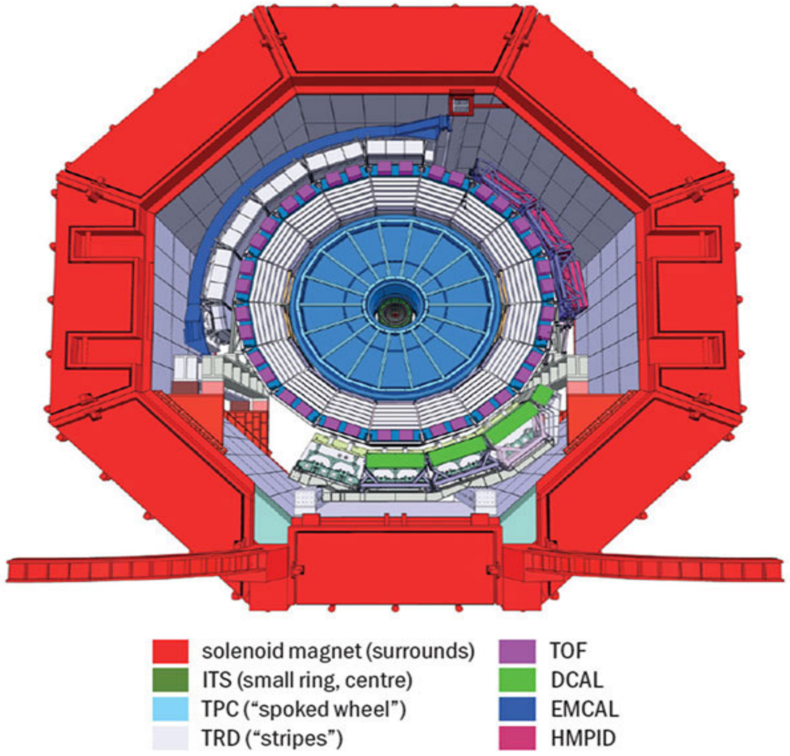


Bagua (eight simbols)

fundamental principles of reality

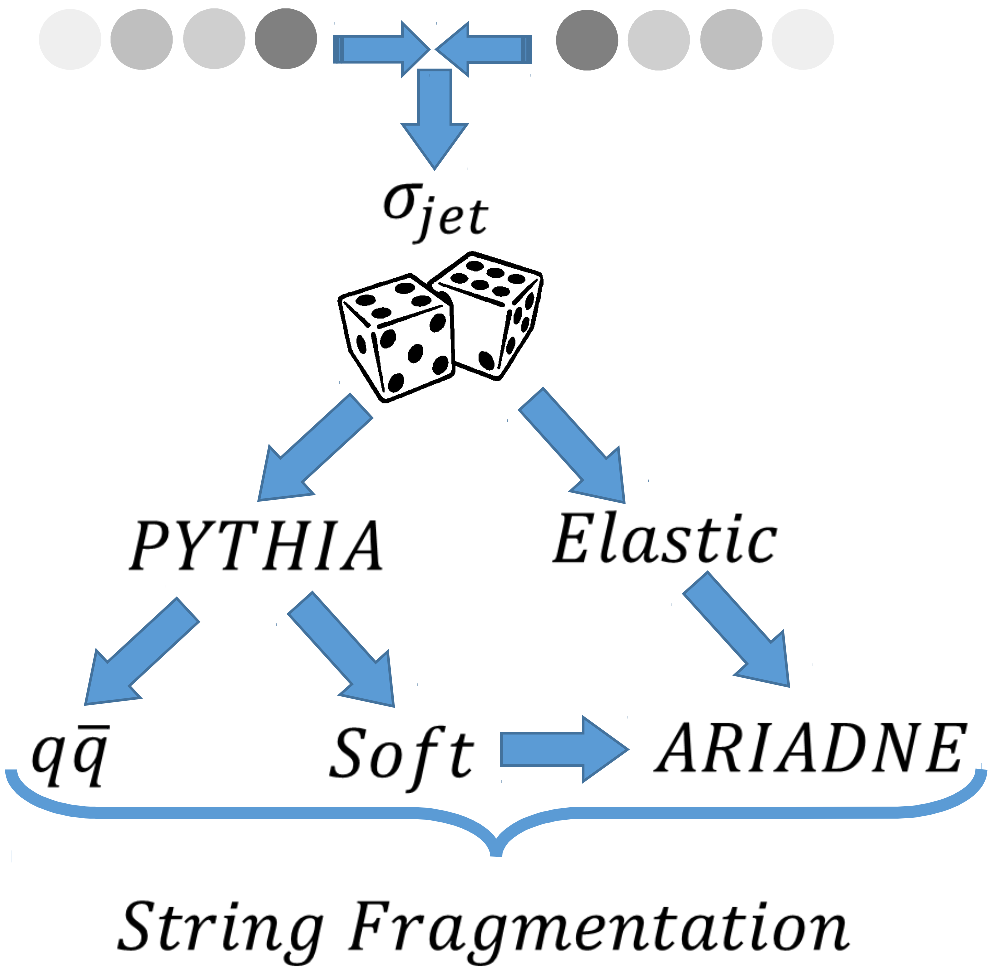
adjoint representation 8 of *SU(3)*

The HIJING++

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

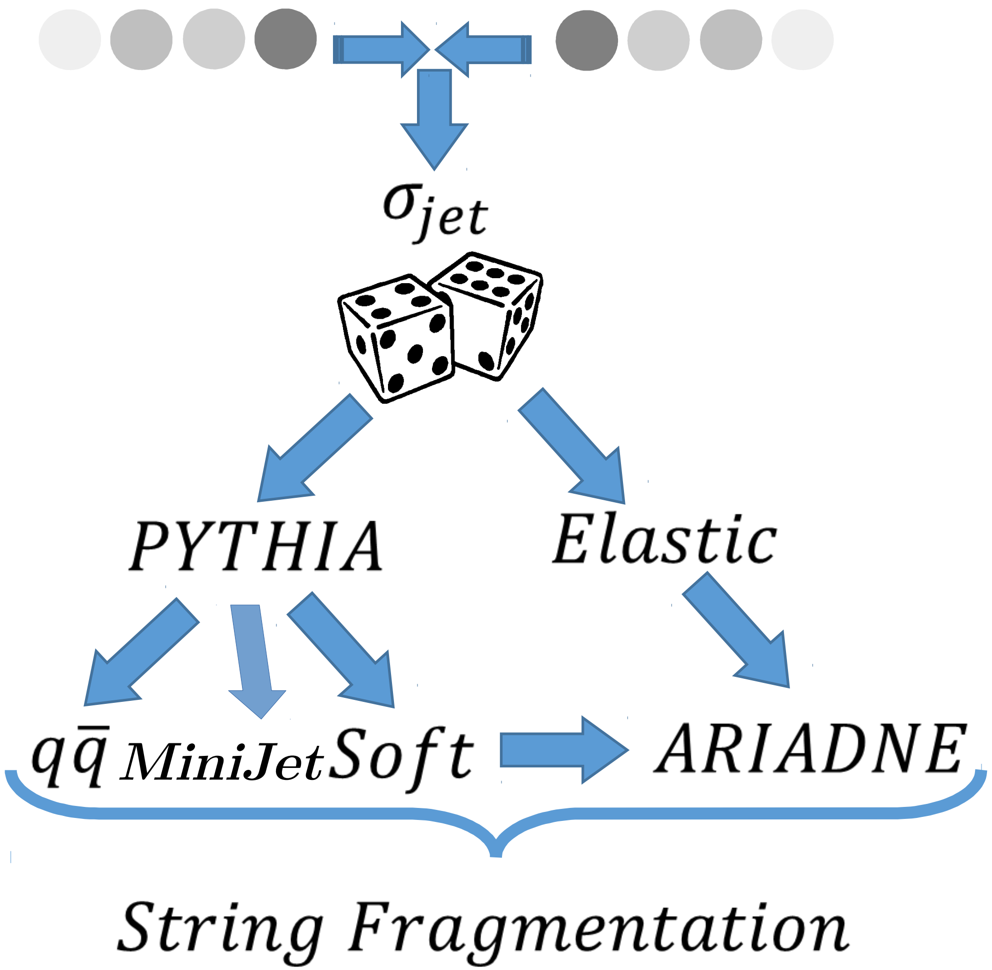
Program Flow – in general

- Pair-by-pair nucleon-nucleon events
- Multiple soft gluon exchanges between valence- and di-quarks
- String hadronization according to Lund fragmentation scheme



Program Flow – in general

- Pair-by-pair nucleon-nucleon events
- Multiple soft gluon exchanges between valence- and di-quarks
- String hadronization according to Lund fragmentation scheme
- HIJING has another feature: MiniJets



Program Flow – MiniJet

- Two component model jet+soft $p_T > p_0$
- Jet cross section: $\sigma_{jet} = \int_{p_0^2}^{s/4} \mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2 \frac{1}{2} \frac{\mathrm{d}\sigma_{jet}}{\mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2}$

$$\frac{\mathrm{d}\sigma_{jet}}{\mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2} = K \sum_{a,b} x_1 f_a(x_1, p_T^2) x_2 f_b(x_2, p_T^2) \frac{\mathrm{d}\sigma^{ab}(\hat{s}, \hat{t}, \hat{u})}{\mathrm{d}\hat{t}}$$

- Eikonal formalism:

$$\sigma_{el} = \pi \int_0^\infty \mathrm{d}b^2 \left[1 - e^{\chi(b,s)}\right]^2,$$
$$\sigma_{in} = \pi \int_0^\infty \mathrm{d}b^2 \left[1 - e^{2\chi(b,s)}\right],$$
$$\sigma_{tot} = 2\pi \int_0^\infty \mathrm{d}b^2 \left[1 - e^{\chi(b,s)}\right],$$

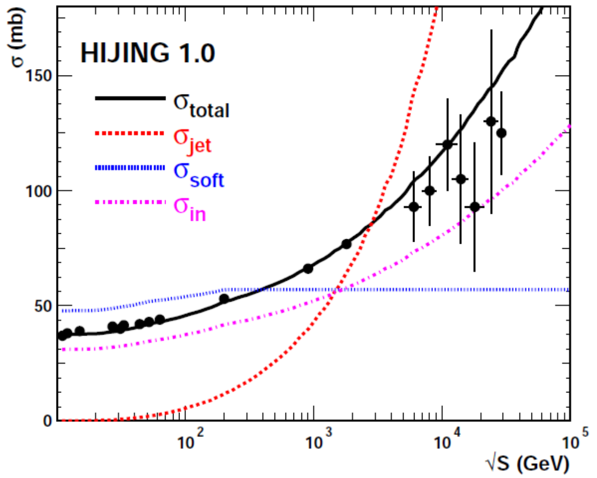
$$\chi(b,s) \equiv \chi_s(b,s) + \chi_h(b,s) = \frac{1}{2}\left[\sigma_{soft} T_{NN}(b) + \sigma_{jet} T_{NN}(b)\right],$$

Program Flow – MiniJet

- The two-components here:

$$\sigma_0 = \pi \int_0^\infty db^2 \left[1 - e^{-2\chi_s(b,s)}\right] e^{-2\chi_h(b,s)},$$

$$\sigma_j = \pi \int_0^\infty db^2 \frac{[2\chi_h(b,s)]^j}{j!} e^{-2\chi_h(b,s)}.$$



- HIJING 1.0 $p_T > p_0$

$$\frac{T_{AA}(b)\sigma_{jet}}{\pi R_A^2} \leq \frac{p_0^2}{\pi}$$

Program Flow – MiniJet

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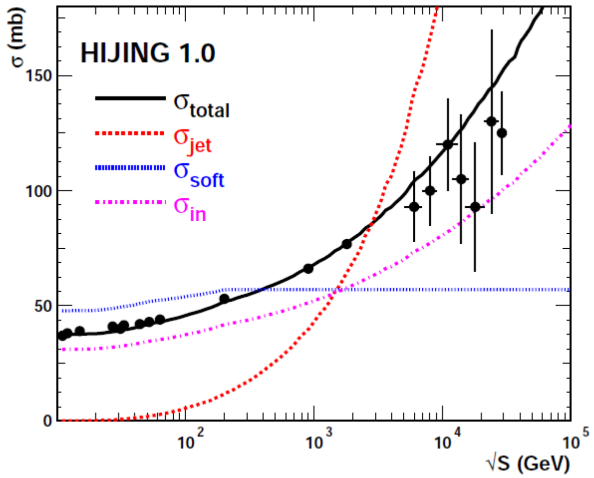
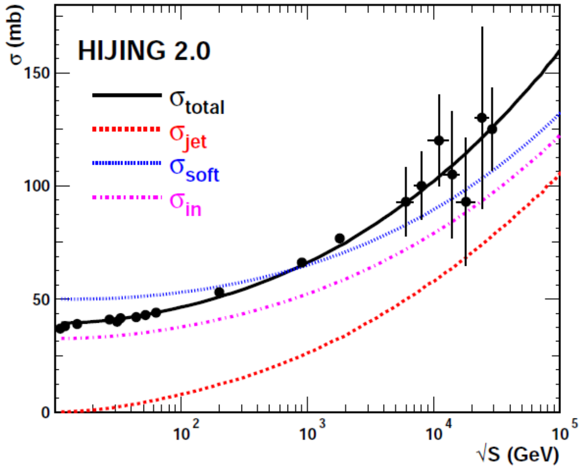
- HIJING 1.0 $p_T > p_0$

$$\frac{T_{AA}(b)\sigma_{jet}}{\pi R_A^2} \leq \frac{p_0^2}{\pi}$$

- HIJING 2.0 $p_T > p_0$

$$\begin{aligned} p_0 &= 2.62 - 1.084\log(\sqrt{s}) + 0.299\log^2(\sqrt{s}) \\ &\quad -0.0292\log^3(\sqrt{s}) + 0.00151\log^4(\sqrt{s}), \\ \sigma_{soft} &= 55.316 - 4.1126\log(\sqrt{s}) + 0.854\log^2(\sqrt{s}) \\ &\quad -0.0307\log^3(\sqrt{s}) + 0.00328\log^4(\sqrt{s}), \end{aligned}$$





Program Flow – MiniJet

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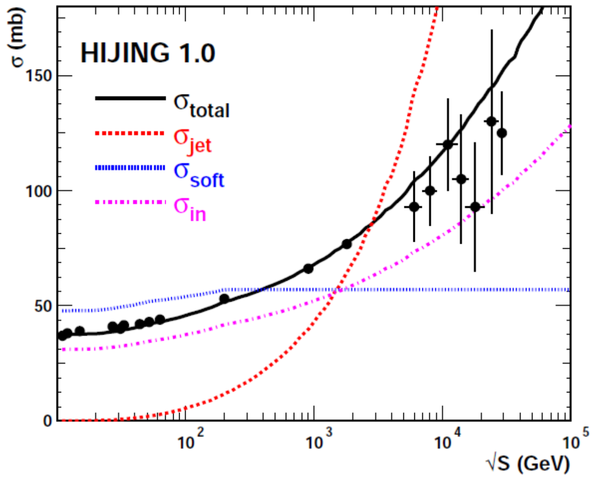
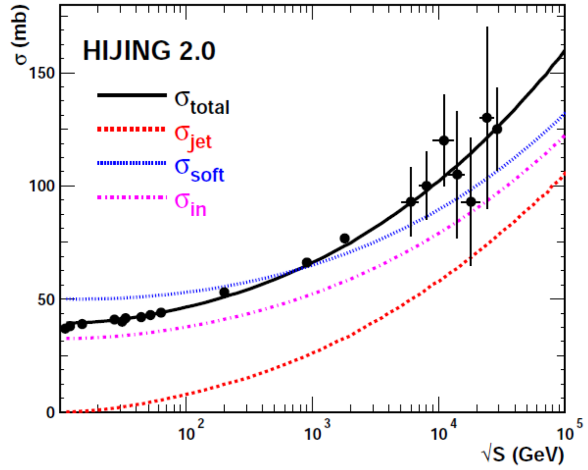
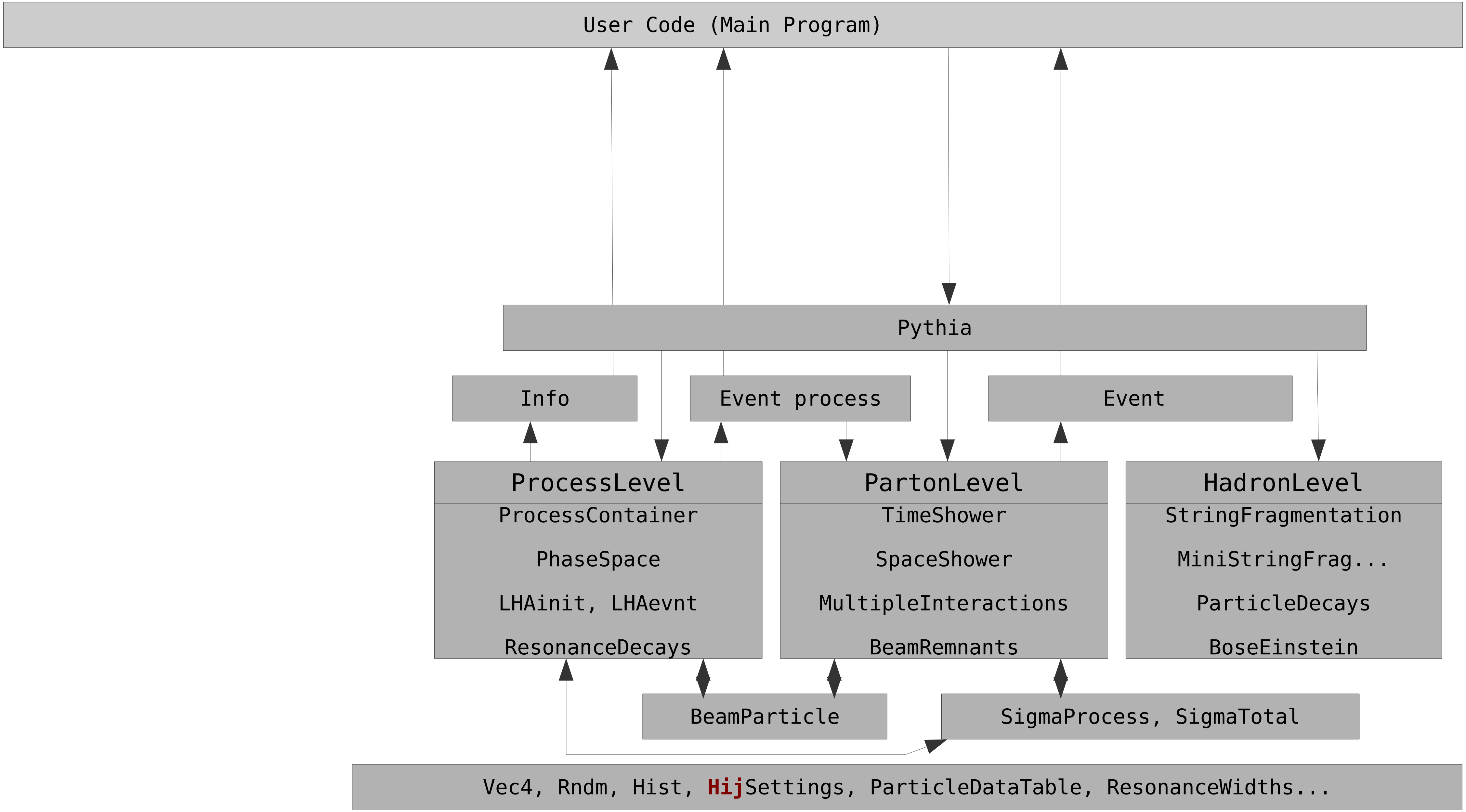
- HIJING++: new parametrization





Program Structure – HIJING 3.1



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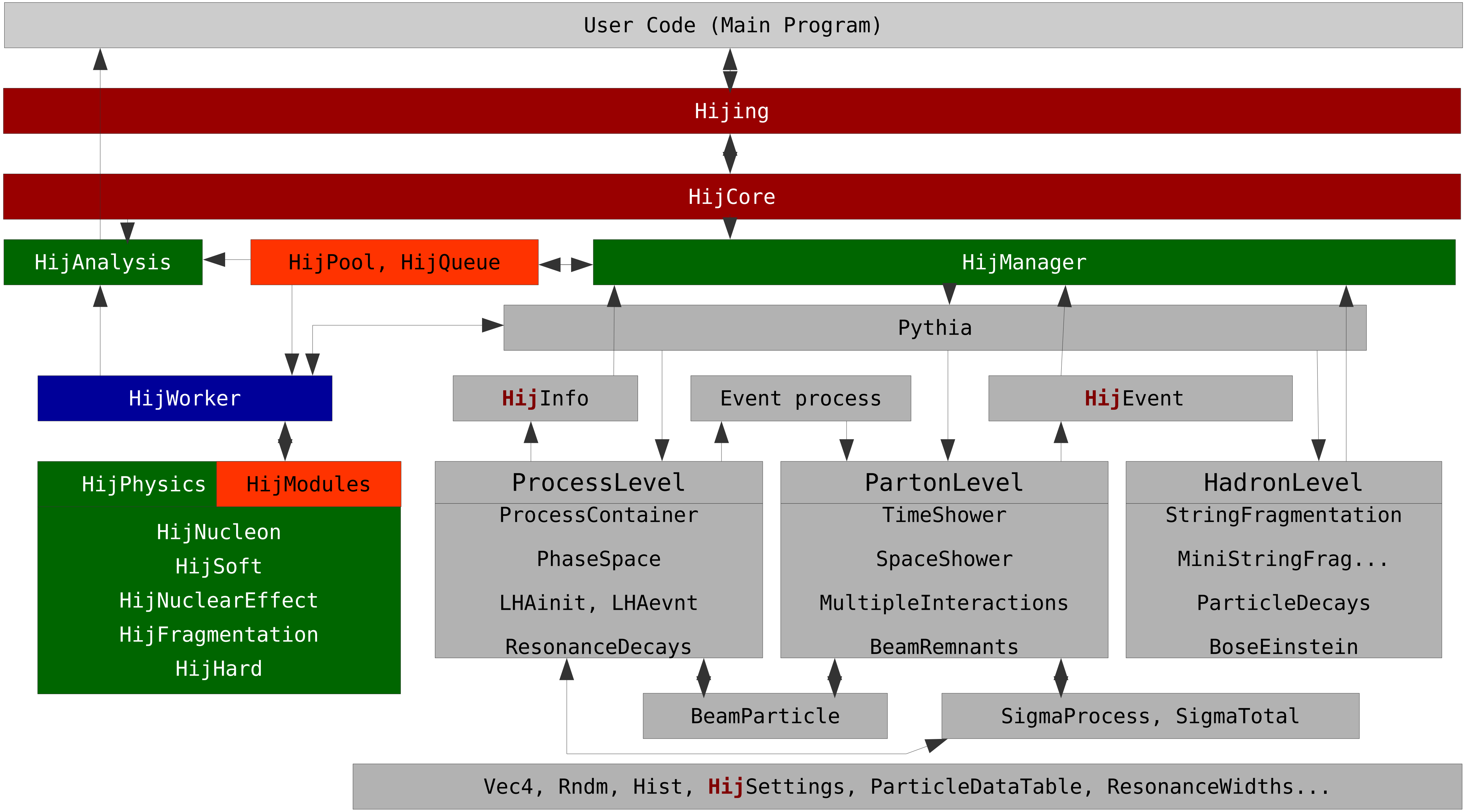

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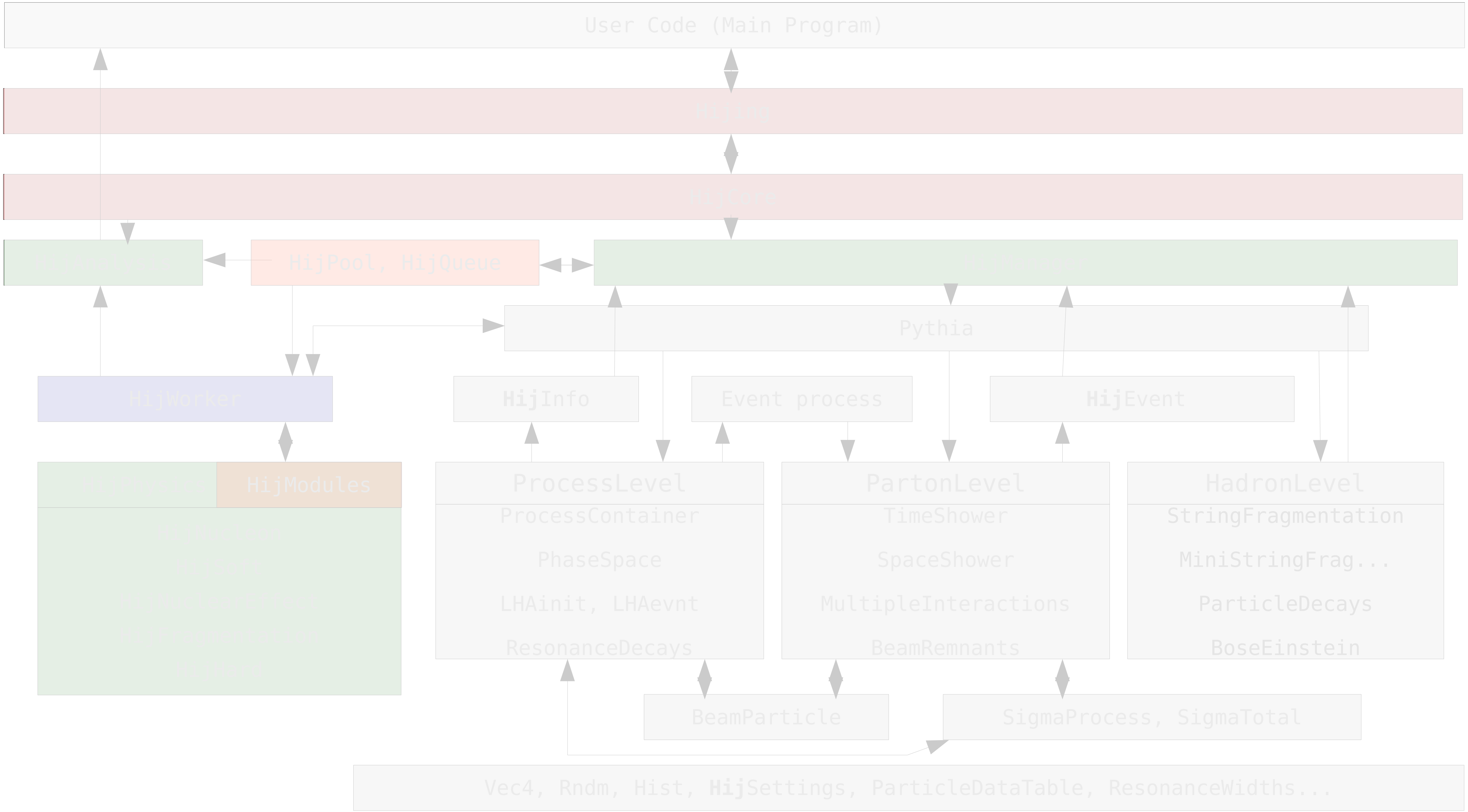

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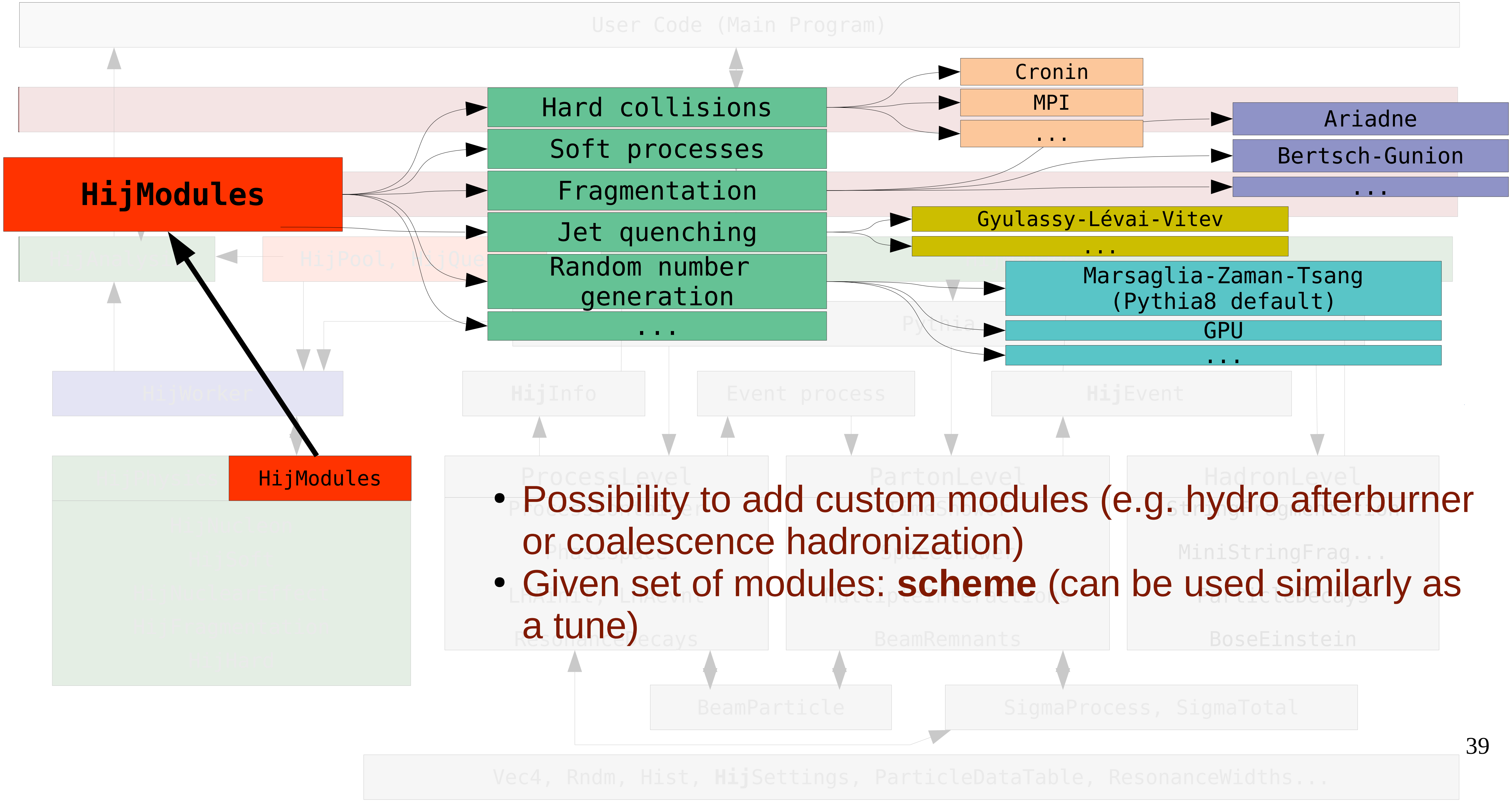
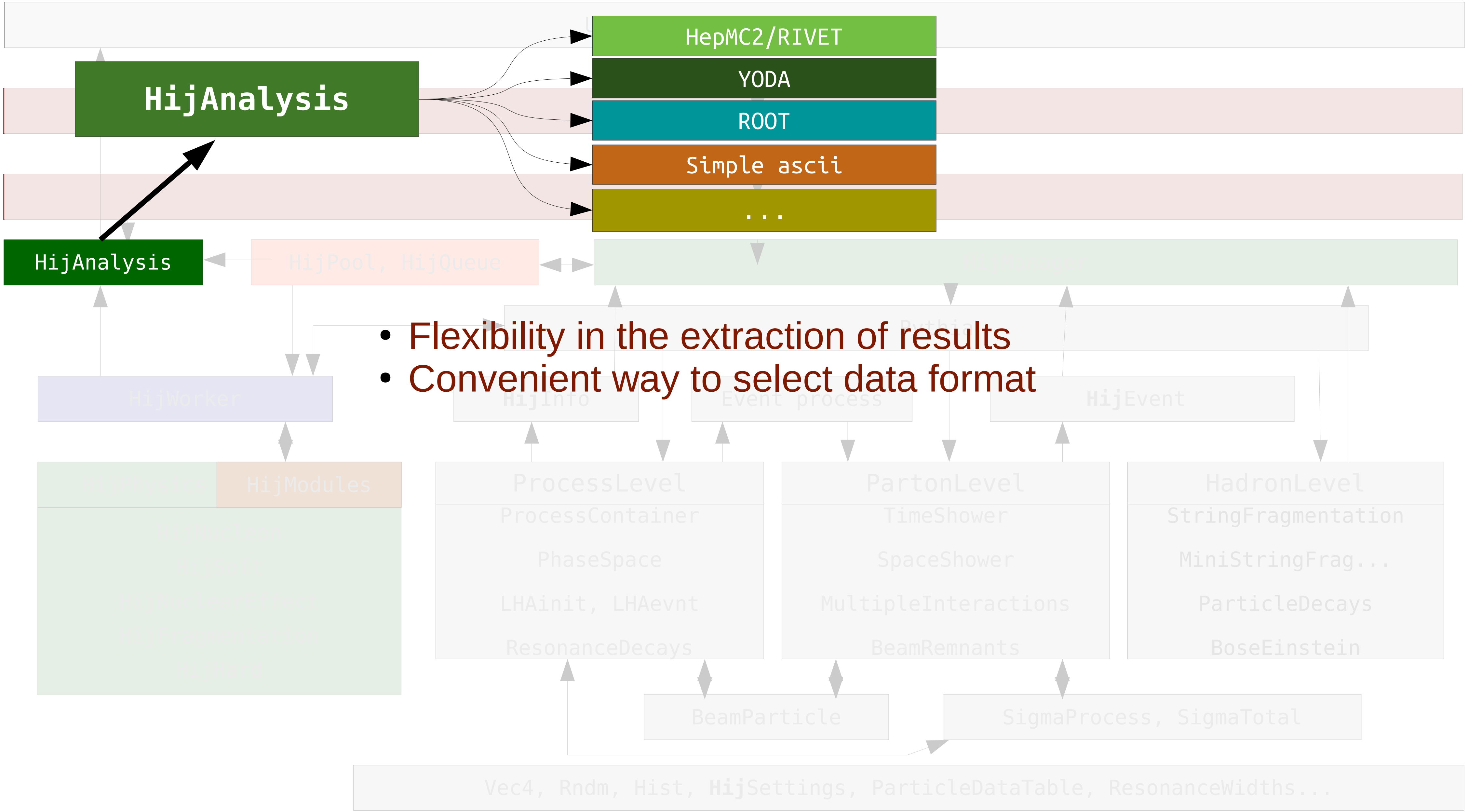


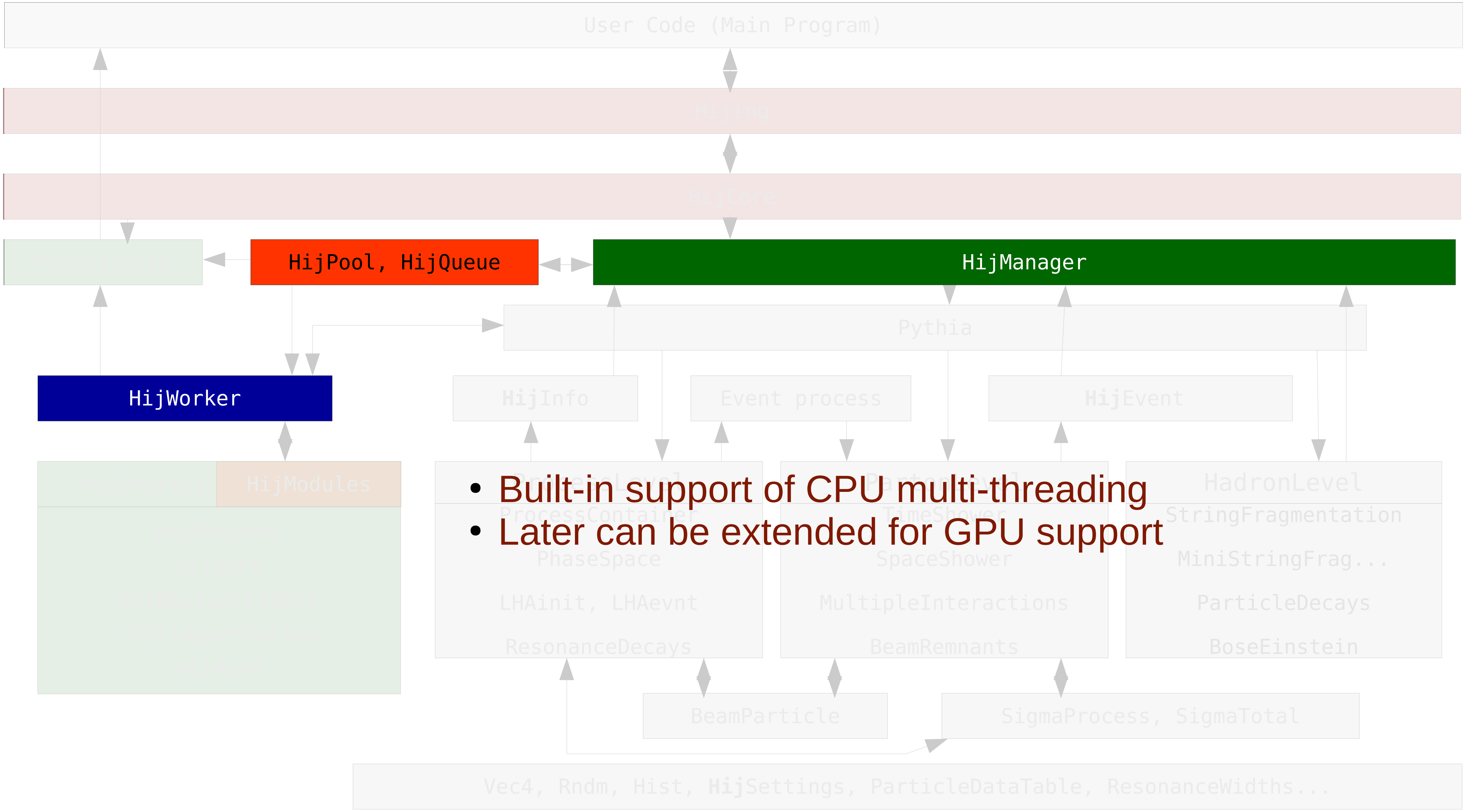
- Possibility to add custom modules (e.g. hydro afterburner or coalescence hadronization)
- Given set of modules: **scheme** (can be used similarly as a tune)

Program Structure – HIJING 3.1



- Flexibility in the extraction of results
- Convenient way to select data format

Program Structure – HIJING 3.1



- Built-in support of CPU multi-threading
- Later can be extended for GPU support

Dependencies & External packages

- C++ v14+

Native multi-threading support of the C++

- LHAPDF 6

./configure –prefix=$HOME/…/share/LHAPDF

make all

insert downloaded PDF library to $HOME/…/share/LHAPDF

optionally modify **pdfsets.index**, add set if needed

export LD LIBRARY PATH=<library path>

- Pythia 8.x

*./configure --with-lhapdf6-lib=$HOME/…/lib *
--with-boost-lib=/usr/lib/x86_64-linux-gnu
make –j4

- RIVET McNET2

Data analysis using YODA

HIJING vs. HIJING++

	FORTRAN HIJING	HIJING++:
Precision	single	double
Pythia version	5.3*	8.2+**
PDF	GRV98lo	LHAPDF6.2+
Colour reconnection	✗	✓
Jet quenching	(✓)	(✓)
Multithreading	✗	✓
Analysis interface	✗	✓***
Module management******	✗	✓

*Was modified and hardwired into HIJING

**Default tune for HIJING++ is Monash, for that re-tuning of the parameters is needed

***Includes: simple ascii, ROOT and HepMC2 (Rivet)

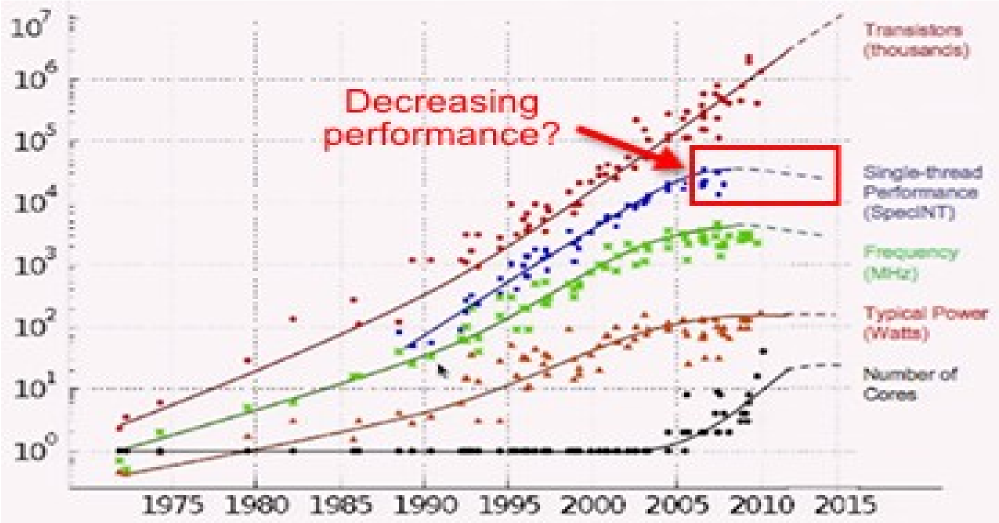
****In Backup

Performance tests with HIJING++

Fast computing = parallel computing

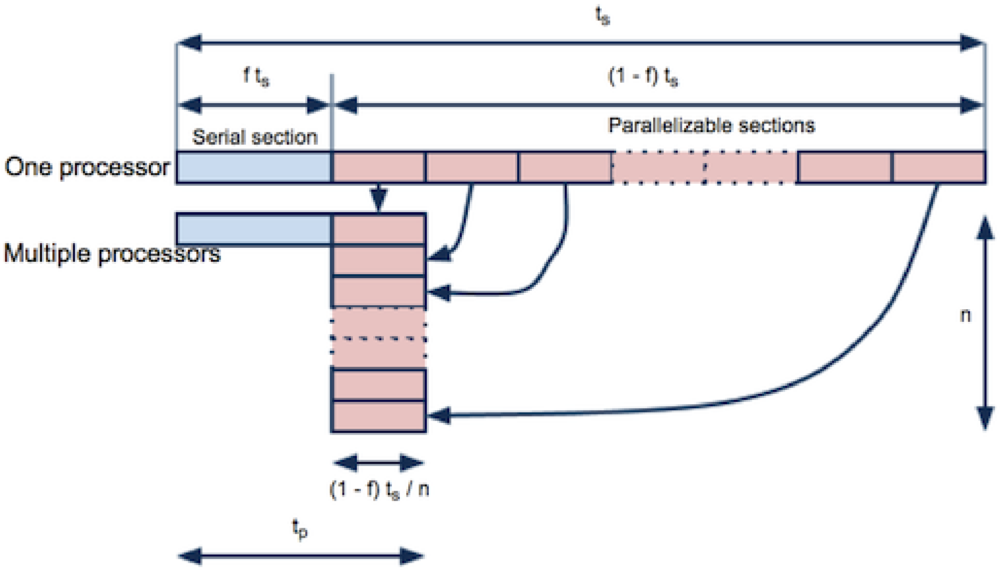
- Moore's law:

Every 2nd year the number of transistors (integrated circuits) are doubled in computing hardwares.



- Amdalh's law:

The theoretical speedup is given by the portion of parallelizable program, p, & number of processors, N, is:



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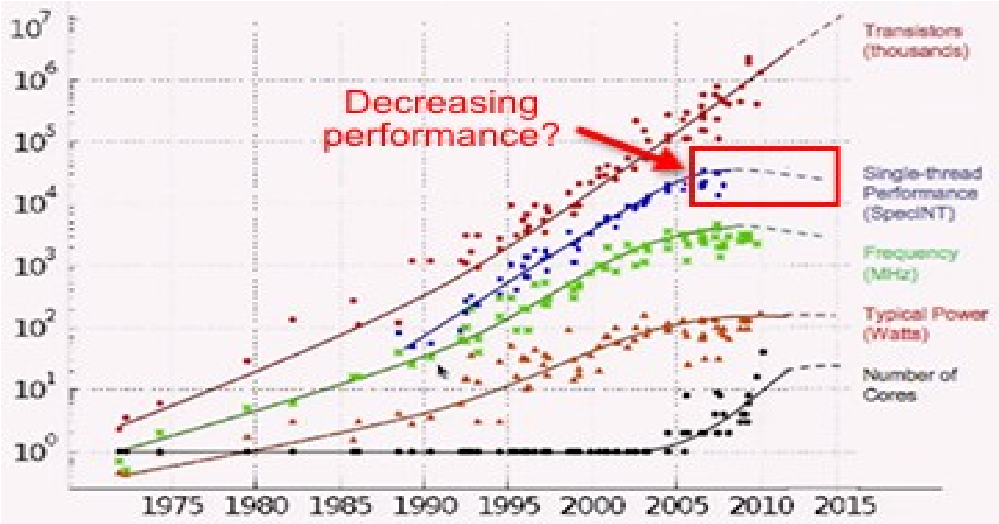


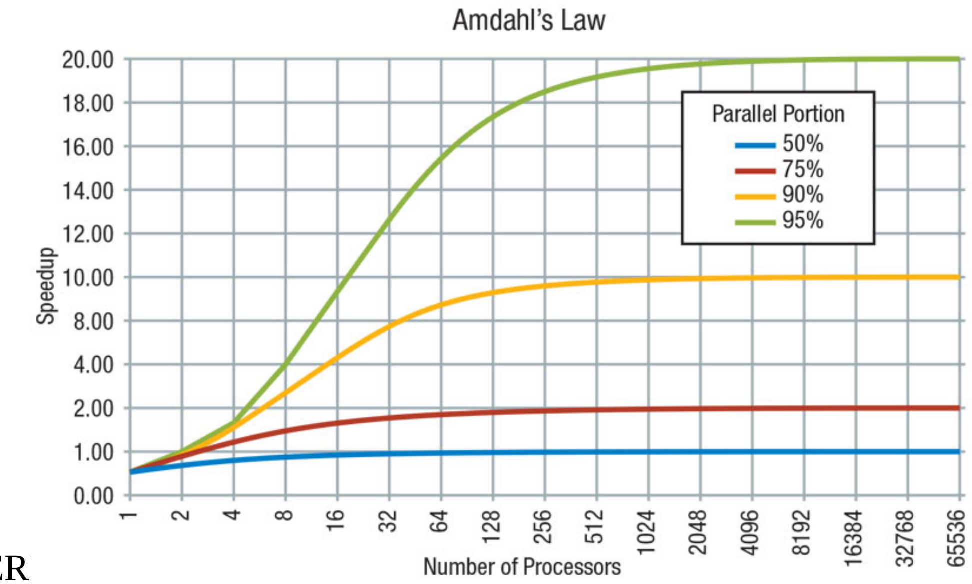
- Amdalh's law:

The theoretical speedup is given by the portion of parallelizable program, p, & number of processors, N, is:

$$\text{Speedup}(N) = \frac{1}{(1-P)+\frac{P}{N}}$$

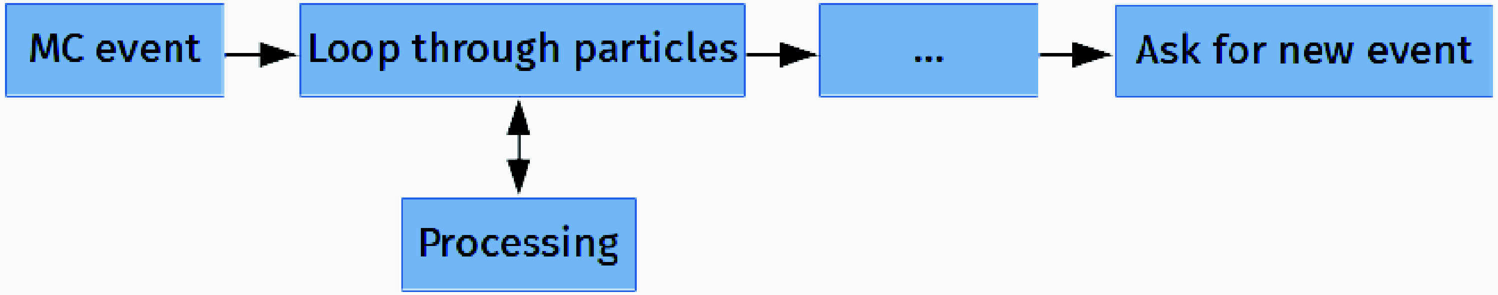
Serial part of job = 1 (100%) - Parallel part

Parallel part is divided up by N workers



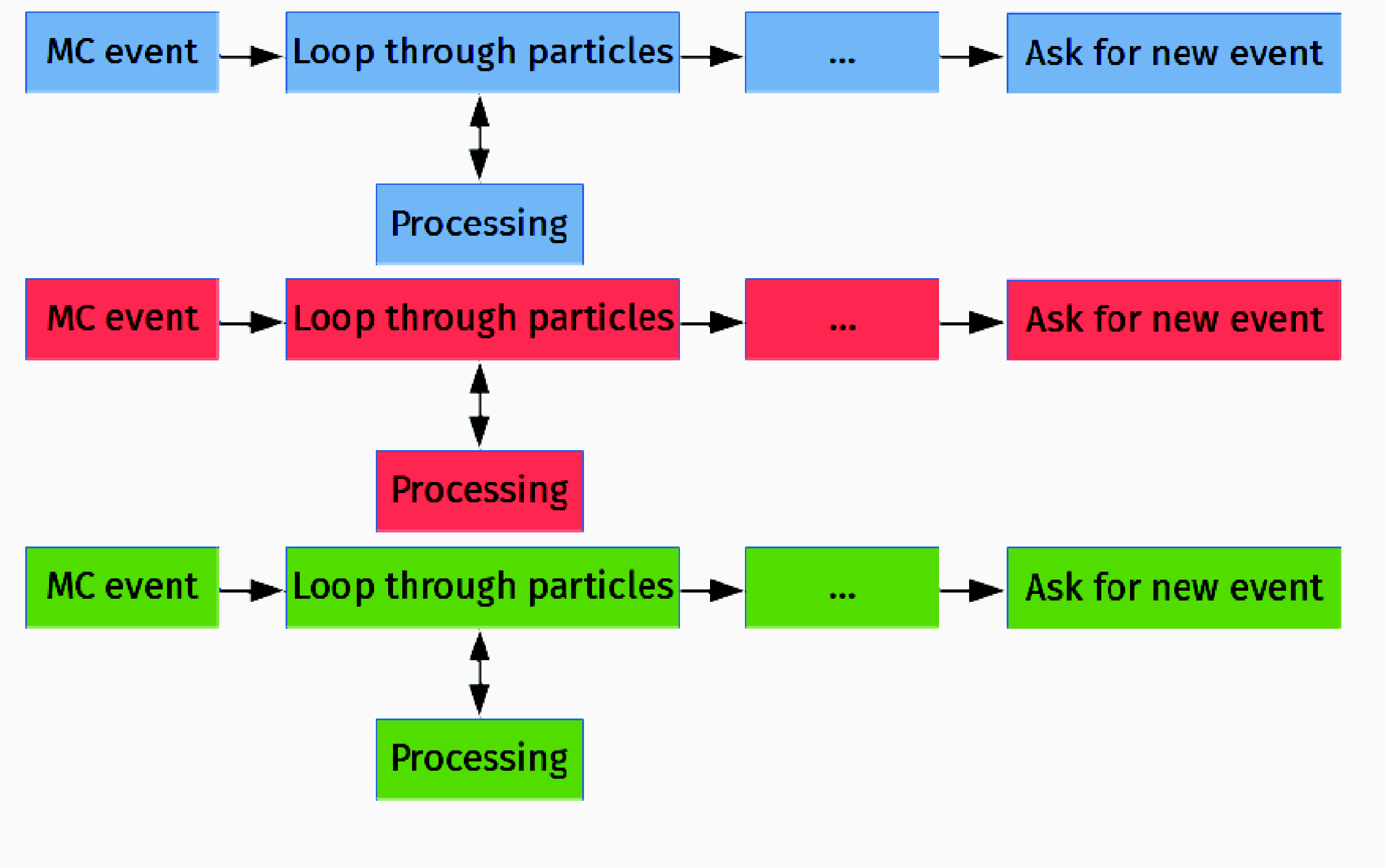
Multi-thread features

What is in the DO LOOP?



Multi-thread features

What is ongoing in a "mass" production of using MC in data analysis?



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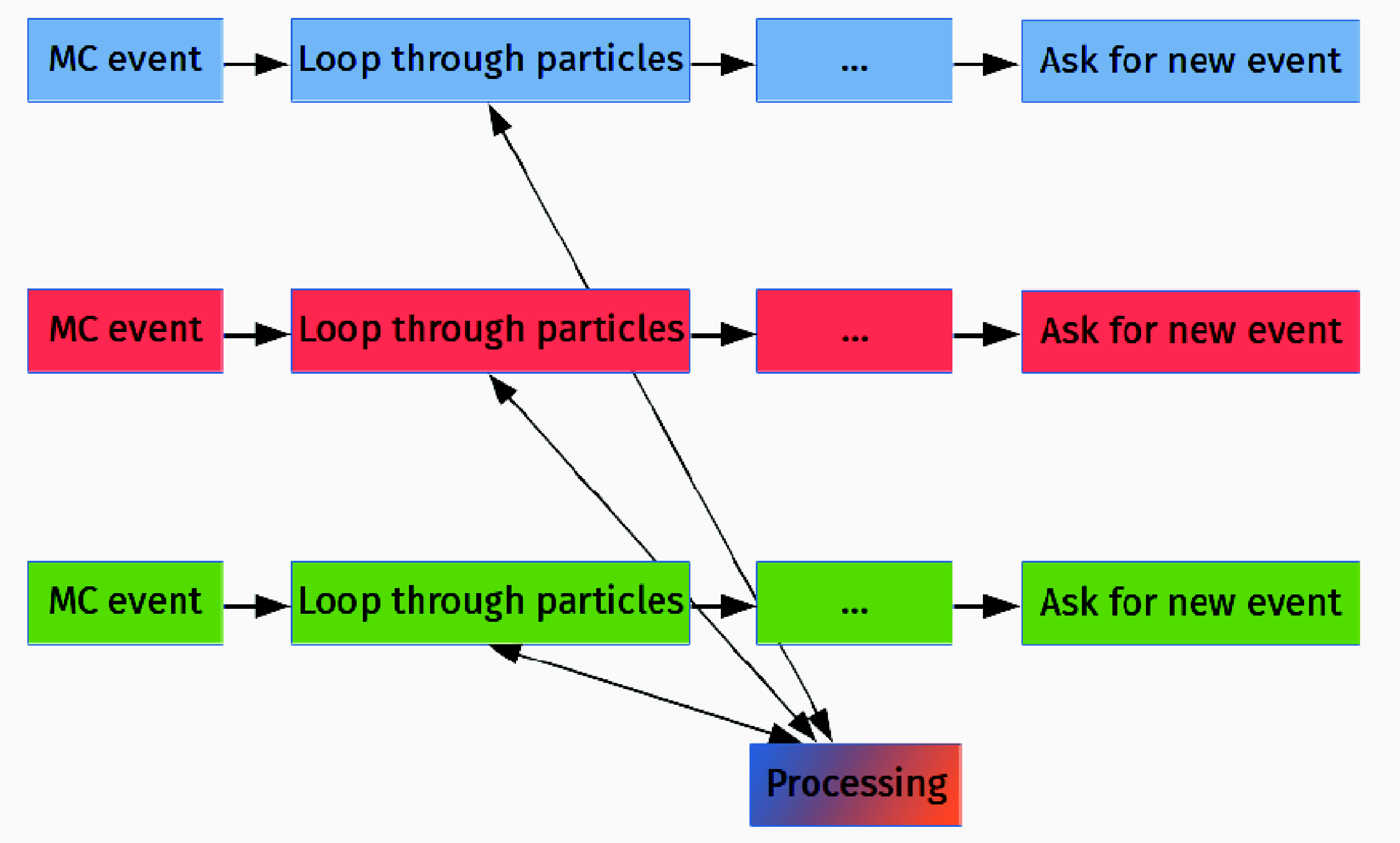

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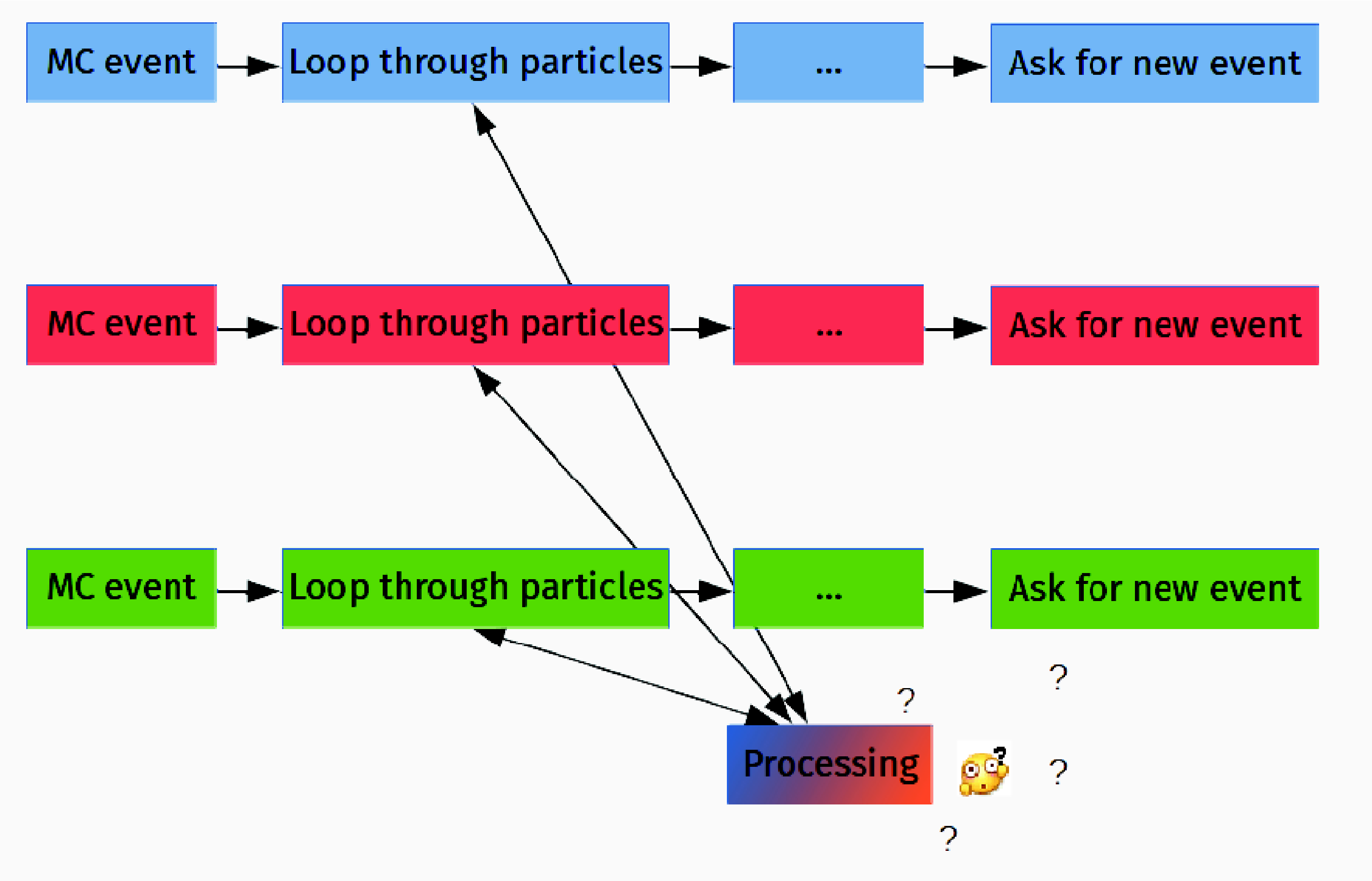
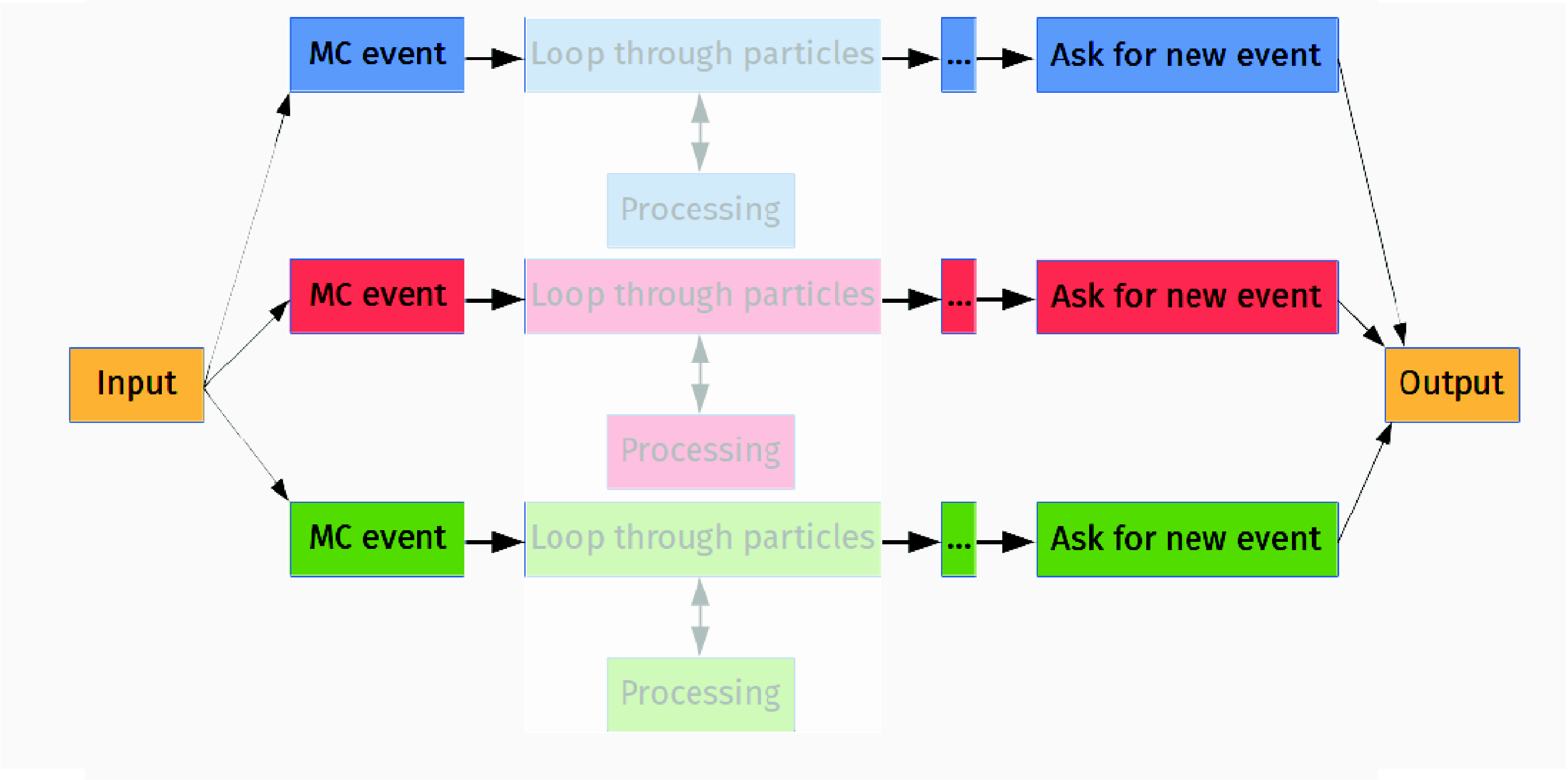


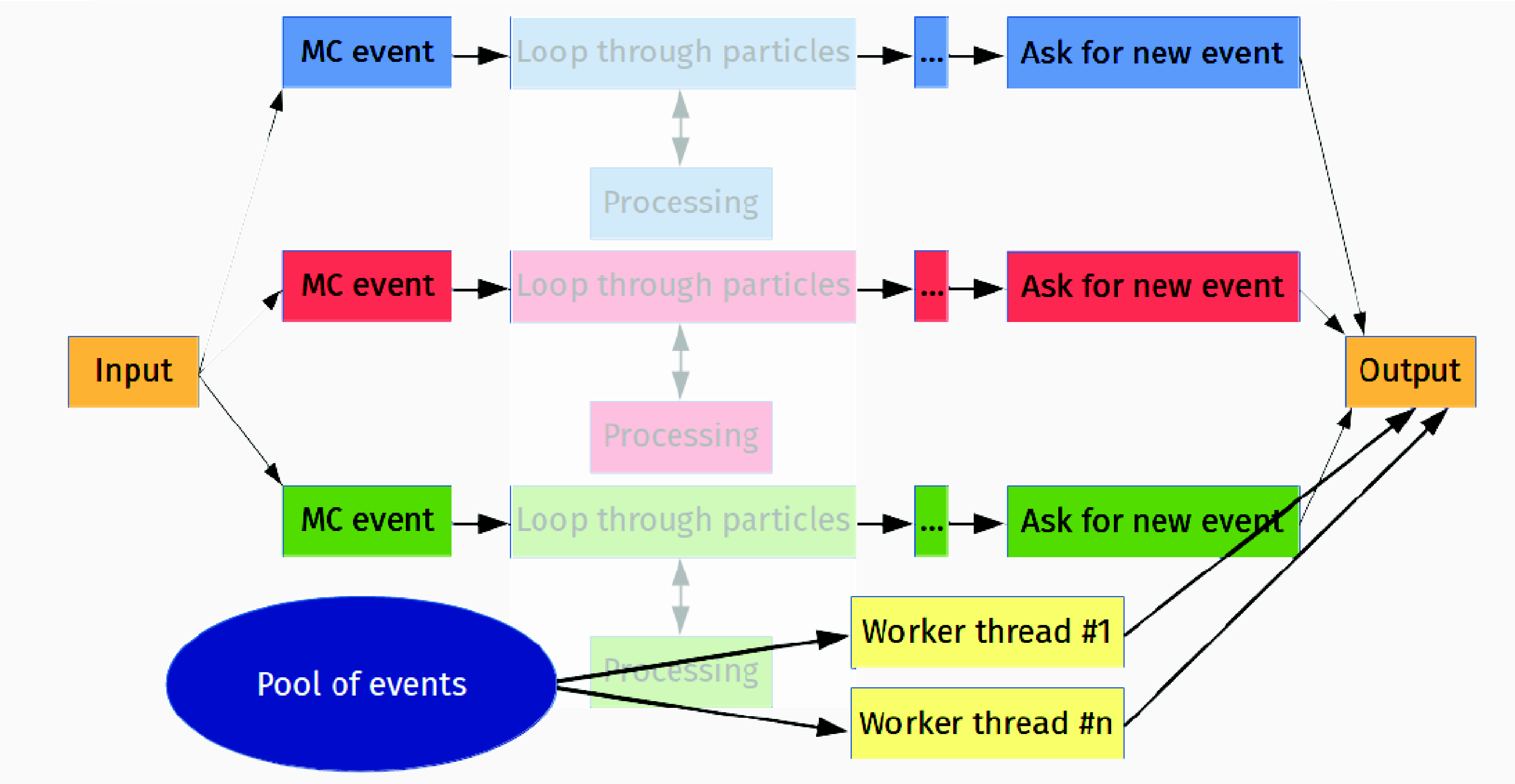
Multi-thread features

Multi-threading is not just running the same code multiple….



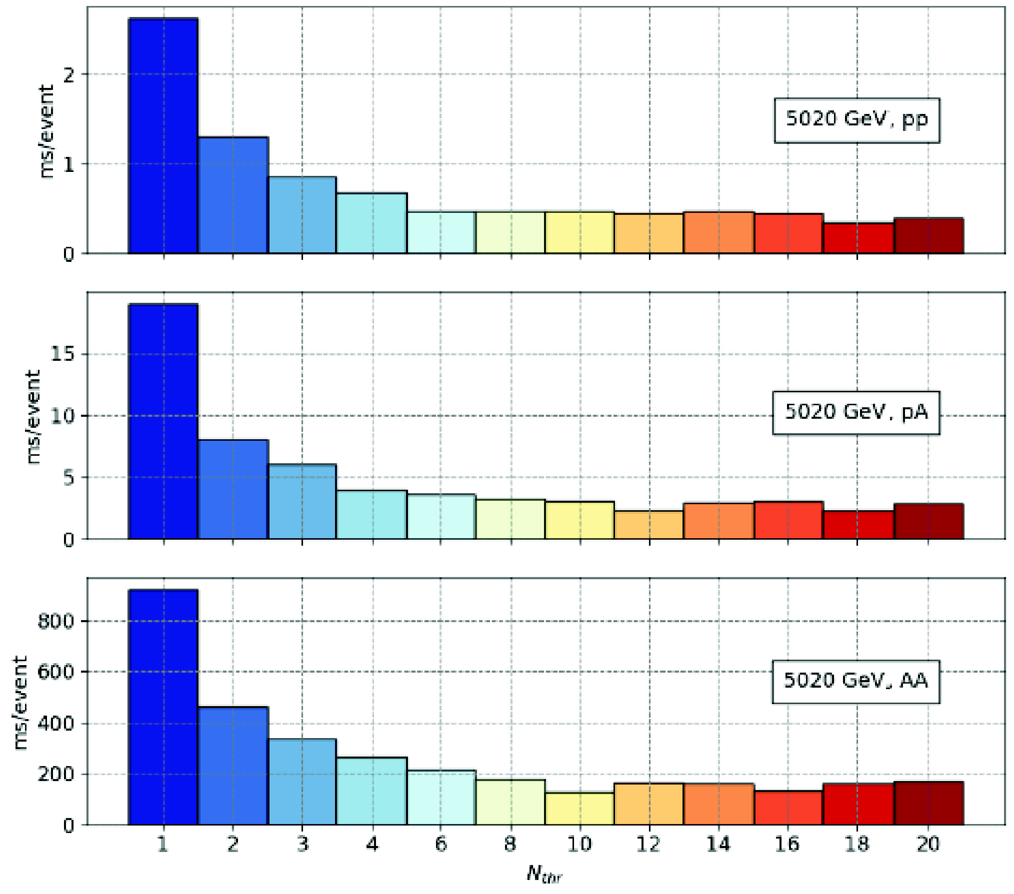
Multi-thread features

...but redistribute pool of events among multiple threads!



Multi-thread features

How much does a pp/pA/AA collision event cost in time?



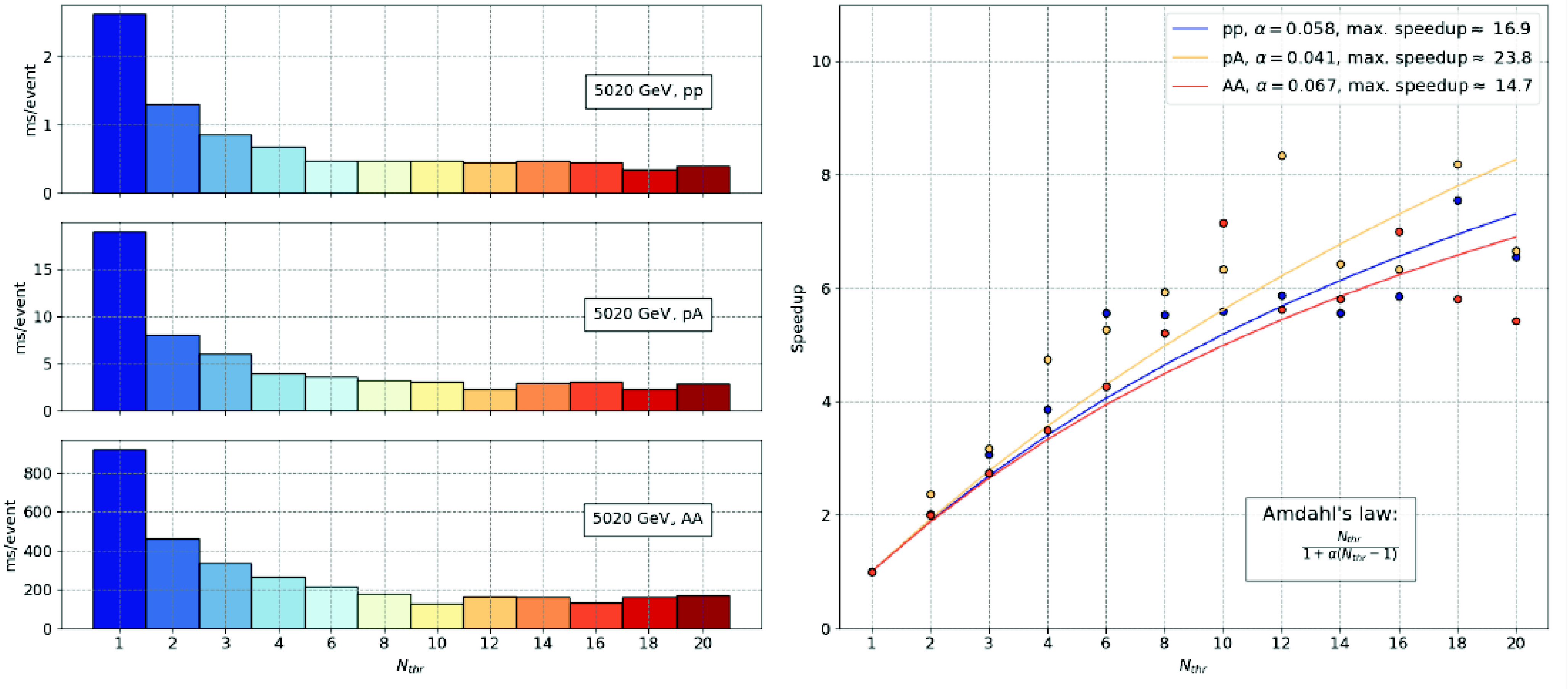
Multi-thread features

How much does a pp/pA/AA collision event cost in time?

pp: 17x

pA: 24x

AA: 15x

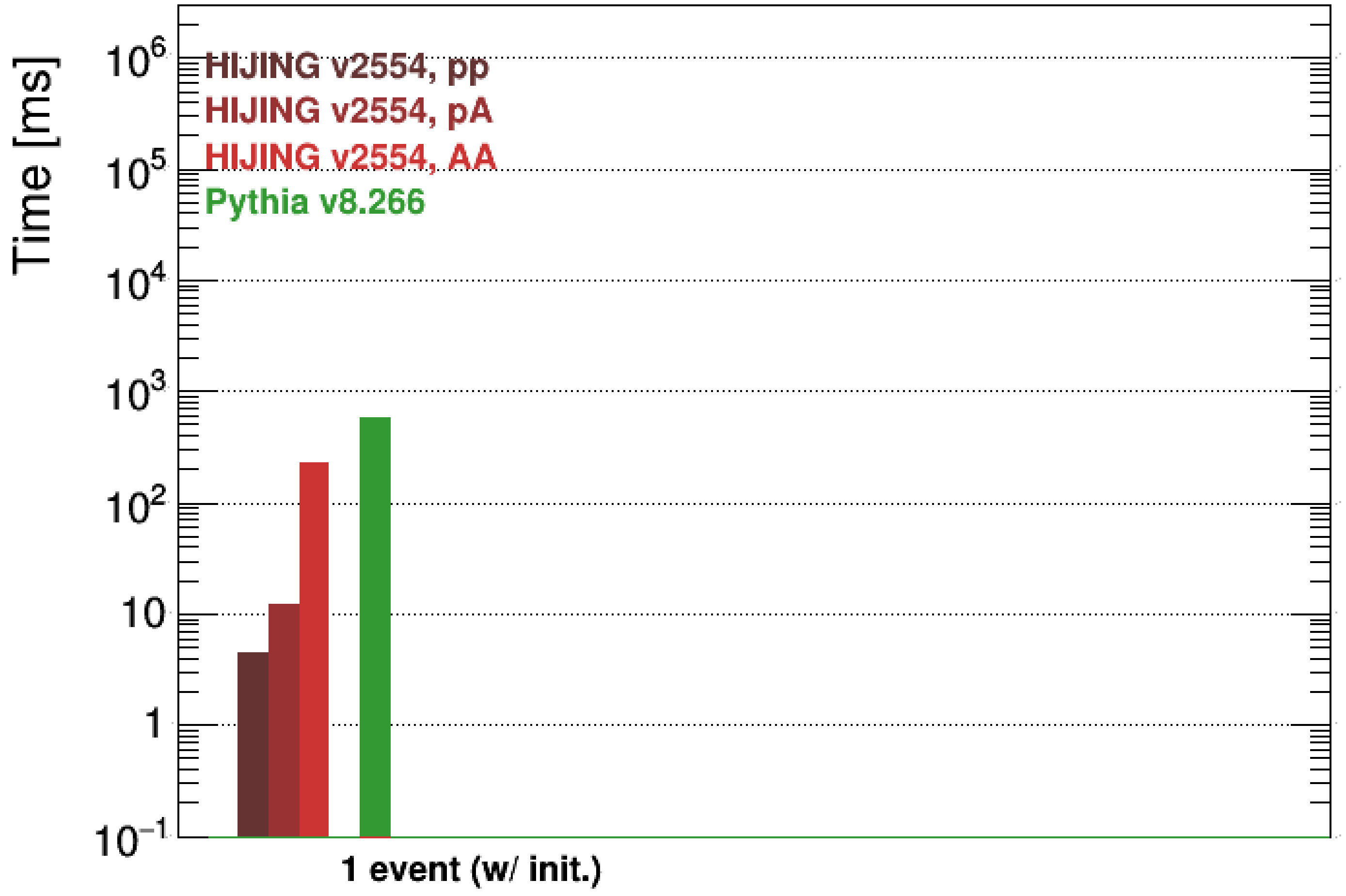


Performance tests: runtime

- Runtime new vs. old

  Single core run & 1 event:

  – Old HIJING pp is faster, than PYTHIA8, but less physics



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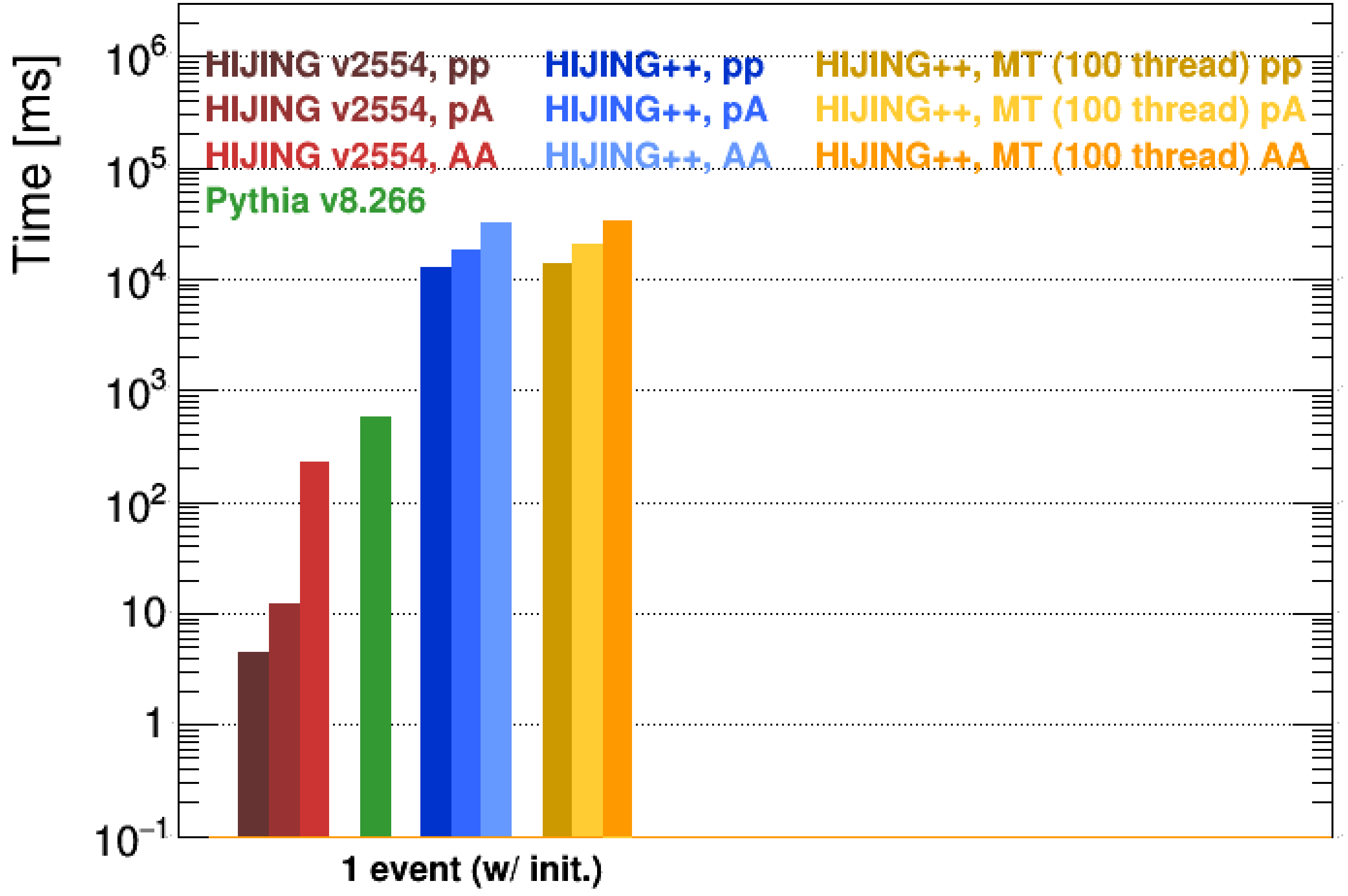
  - HIJING++ pp is slower, than PYTHIA8: this is the effect of minijets + nuclear effects
  - Init: is longer for HIJING++



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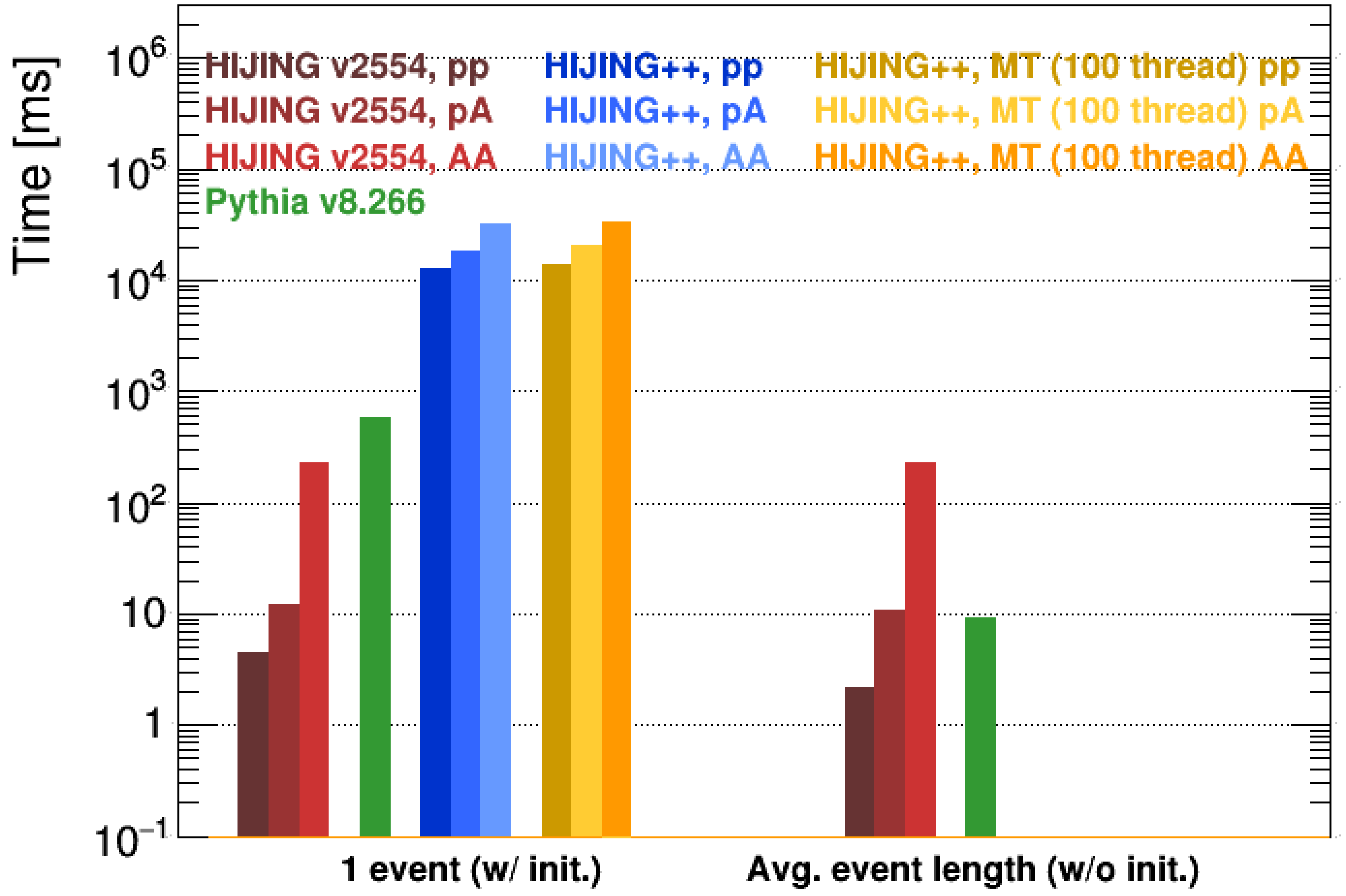
  Multi- event & multi-core run:



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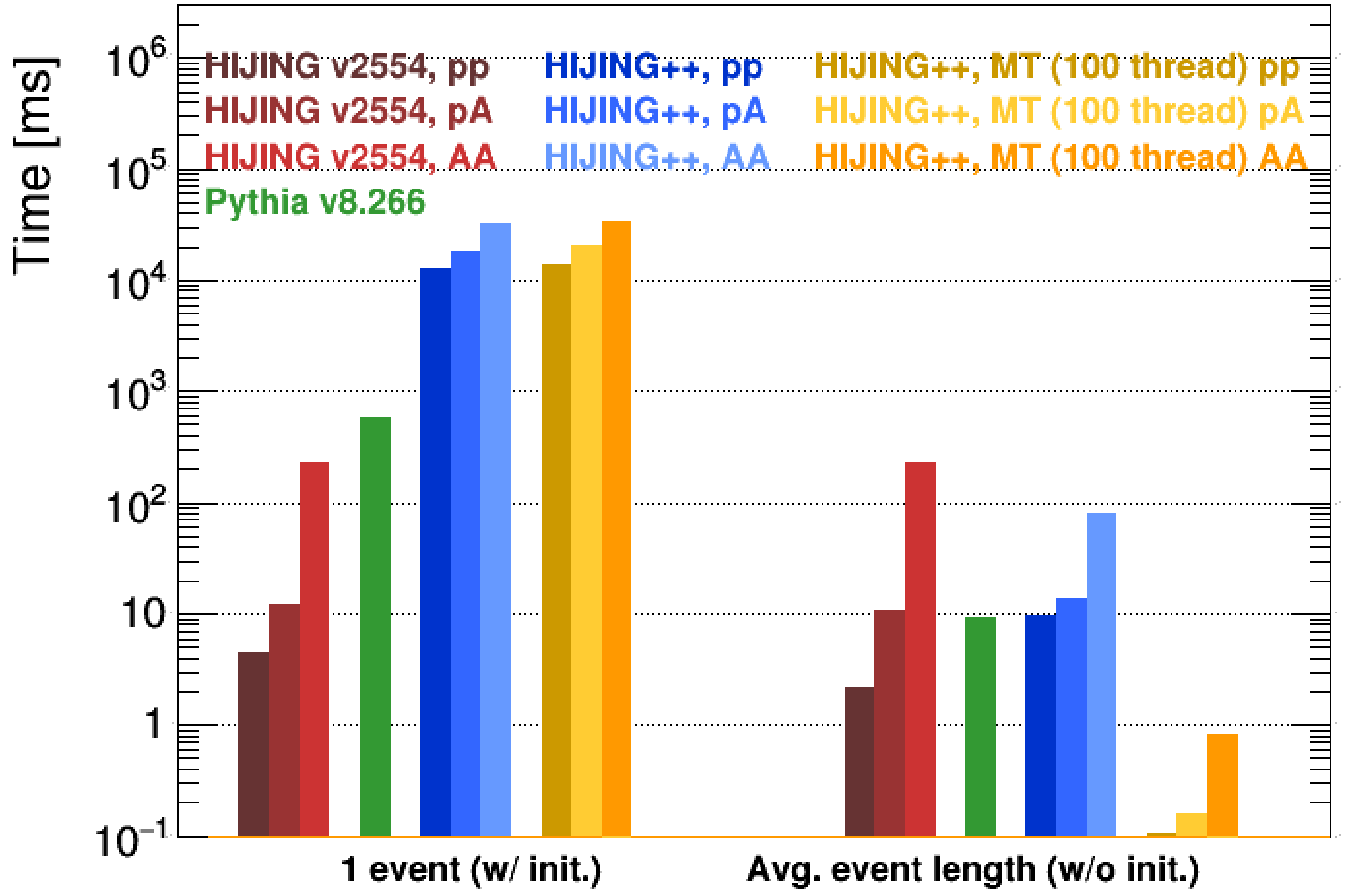
  Multi- event & multi-core run:

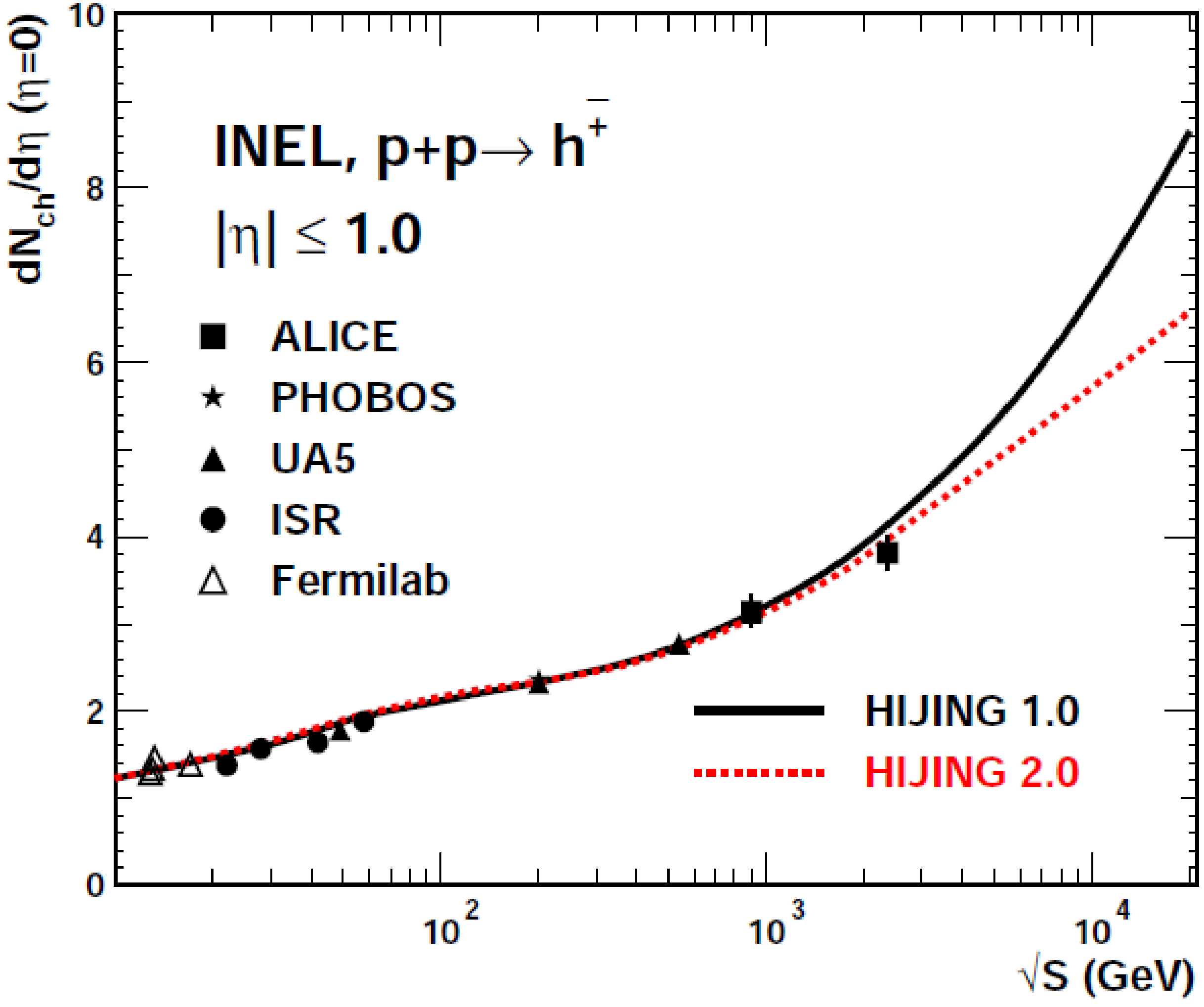
  - Due to the MPI support several times faster
  - Better performance in HIC than in small systems (100 evts)



Physics tests with HIJING++

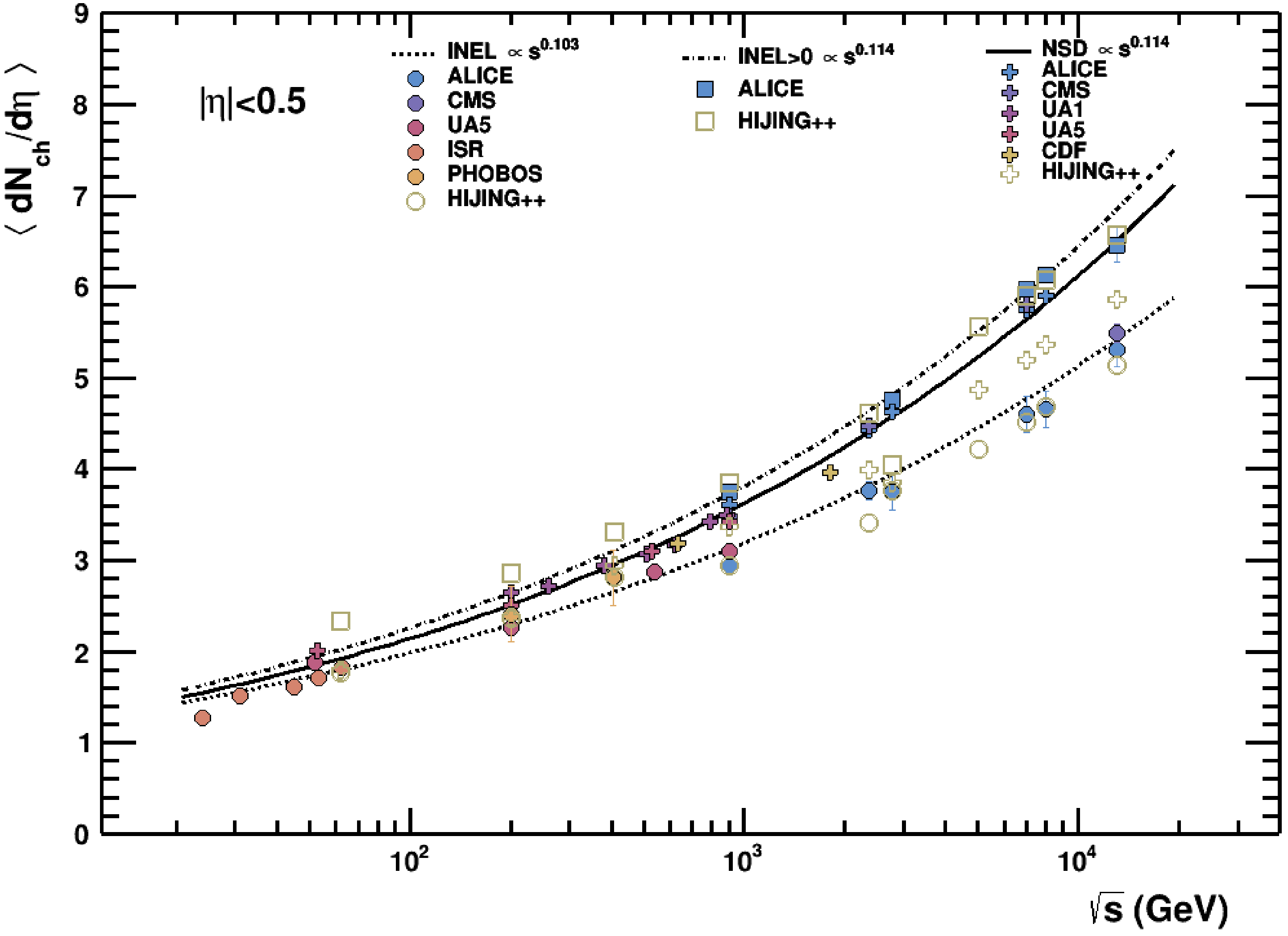
Physics tests: global observables in pp

- Total ch. multiplicity
  - In HIJING 1.0 and 2.0 this has been changed a lot at LHC



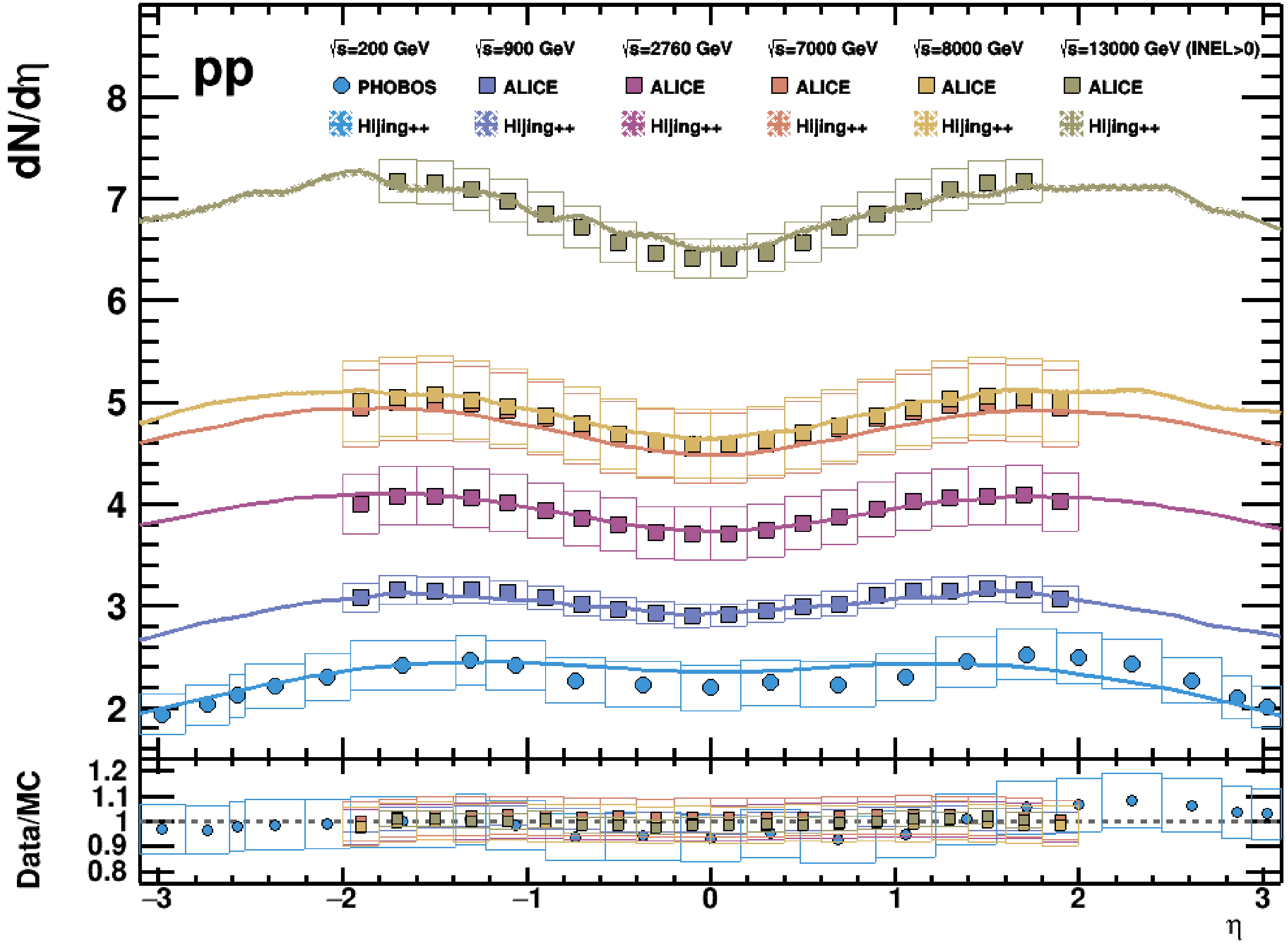
Physics tests: global observables in pp

- Total ch. multiplicity
  - All pp data in a wide center of mass energy range 10 GeV to 13 TeV
  - HIJING++ ch. multiplicity trend is similar than the data



Physics tests: global observables in pp

- (Pseudo) rapidity
  - pp data 200 GeV - 13 TeV
  - In this set PHOBOS & ALICE
  - Perfect agreement up to 5-10% in wide pseudo-rapidity range.



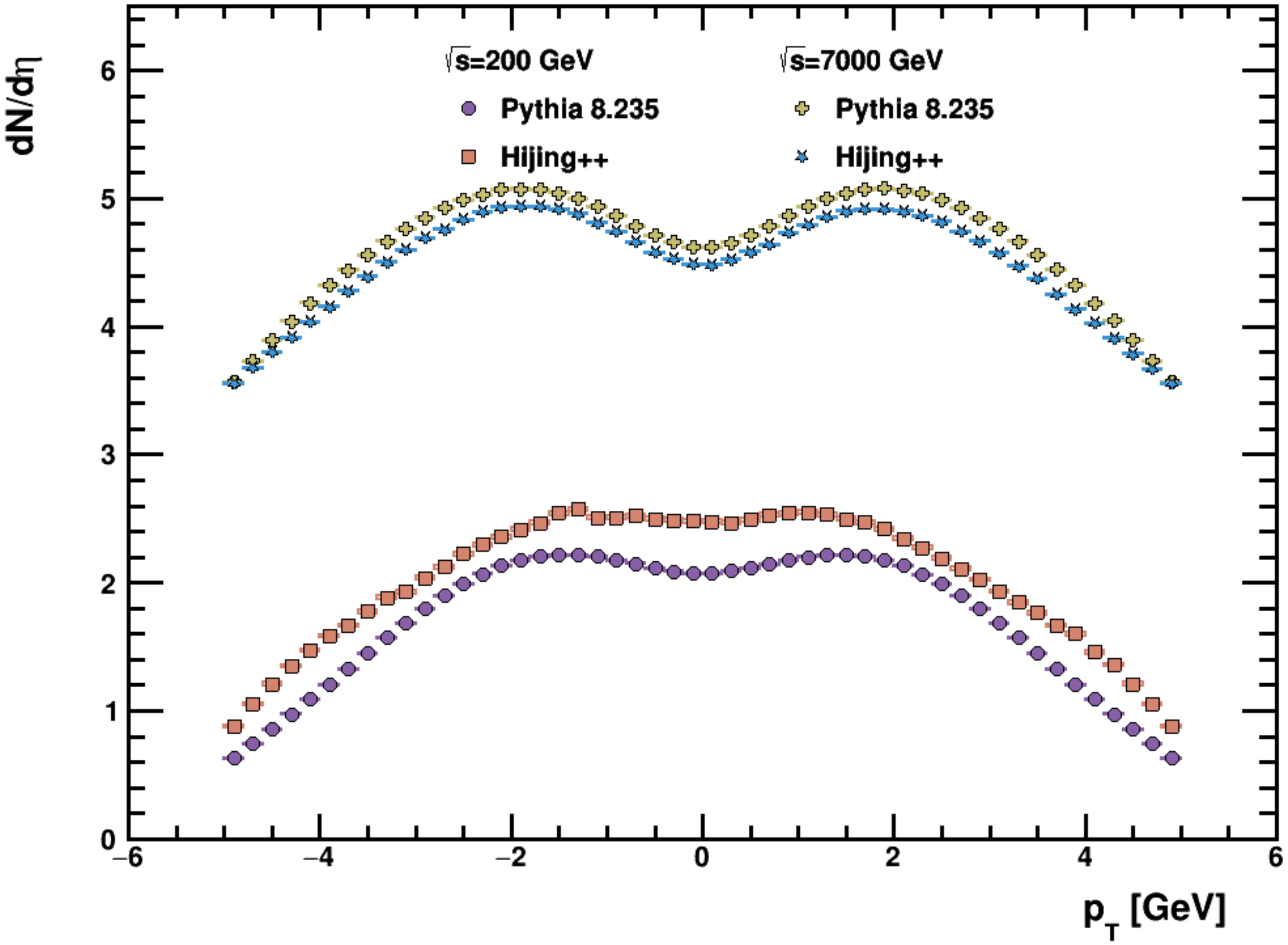
Physics tests: global observables in pp

- (Pseudo) rapidity
  - pp data 200 GeV vs. 7 TeV
  - PYTHIA 8.235 (Monash) vs. HIJING++

  - Change in the trends

    @ 200GeV HIJING++ > PYTHIA

    @ 7TeV PYTHIA > HIJING++
  - At 200 GeV curves are less paralle especially around mid-rapidity.

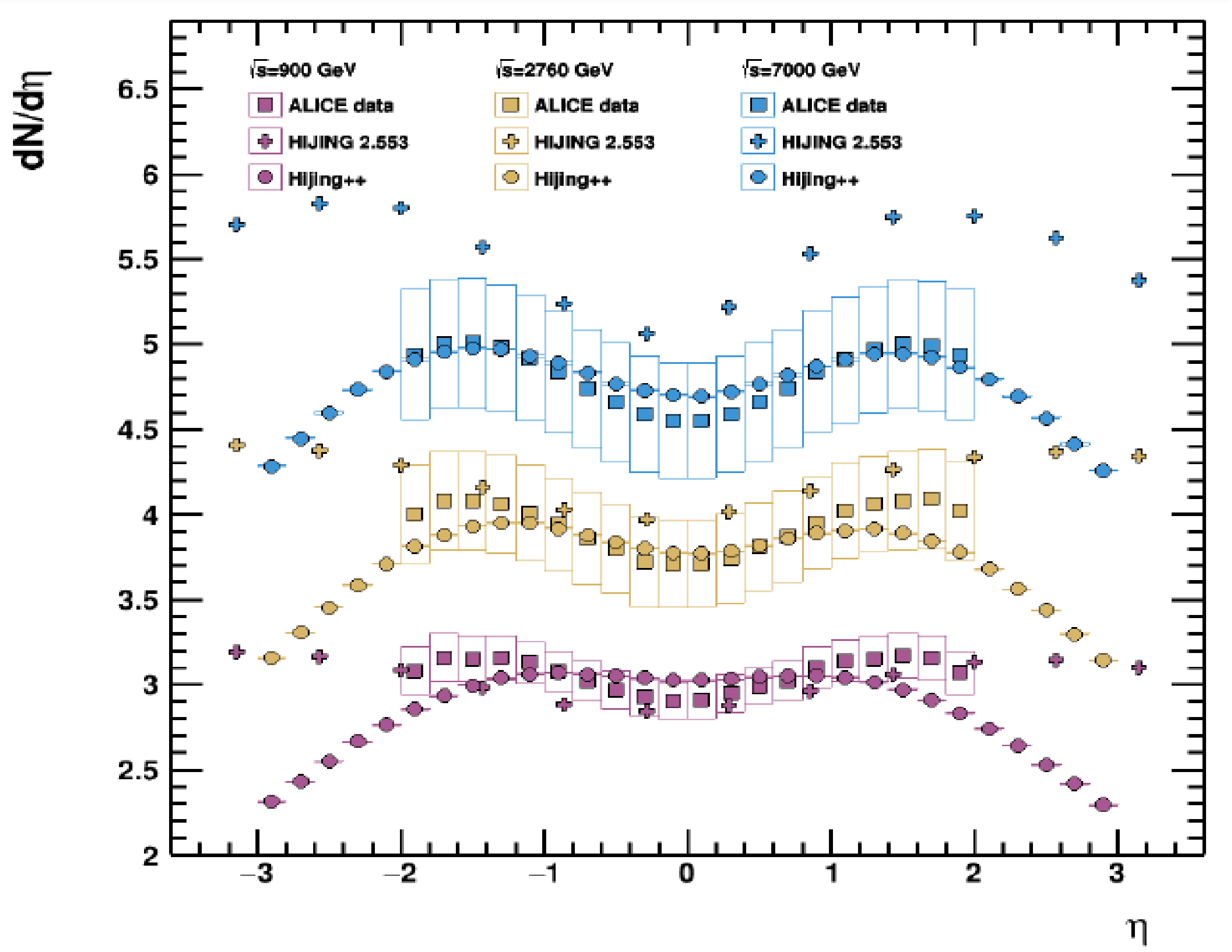


Physics tests: global observables in pp

- (Pseudo) rapidity
  - pp data 900 GeV vs. 7 TeV
  - HIJING 2.553 vs. HIJING++
  - Change in the trends

    @ 900GeV HIJING++ = HIJING

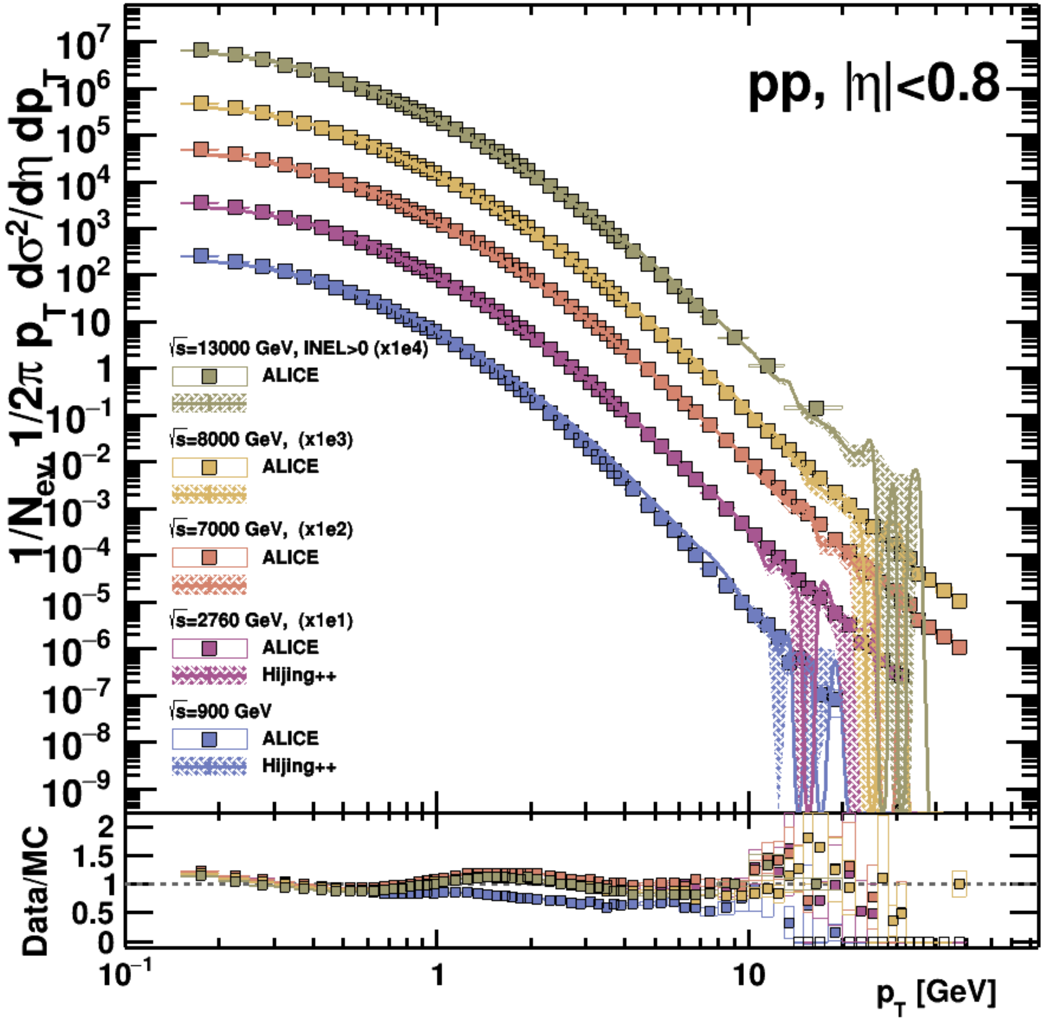
    @ 7TeV HIJING > HIJING-
  - Differences are stronger at high energies and higher pseudorapi



Physics tests: global observables in pp

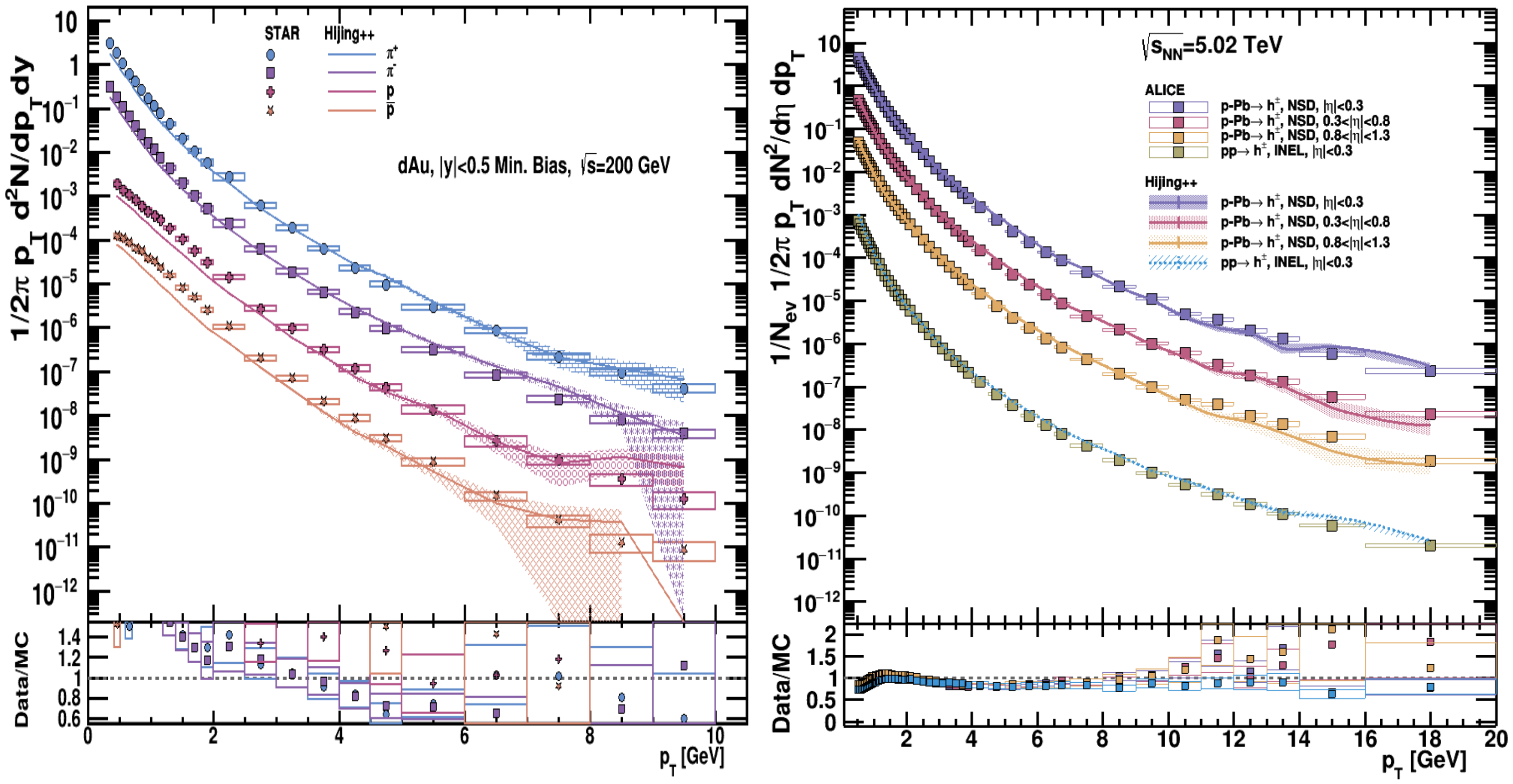
- Charged hadron spectra
  - pp data 900 GeV - 13 TeV

    In this set ALICE data
  - Perfect agreement up to 50% in wide transverse momentum and center of mass energy range.



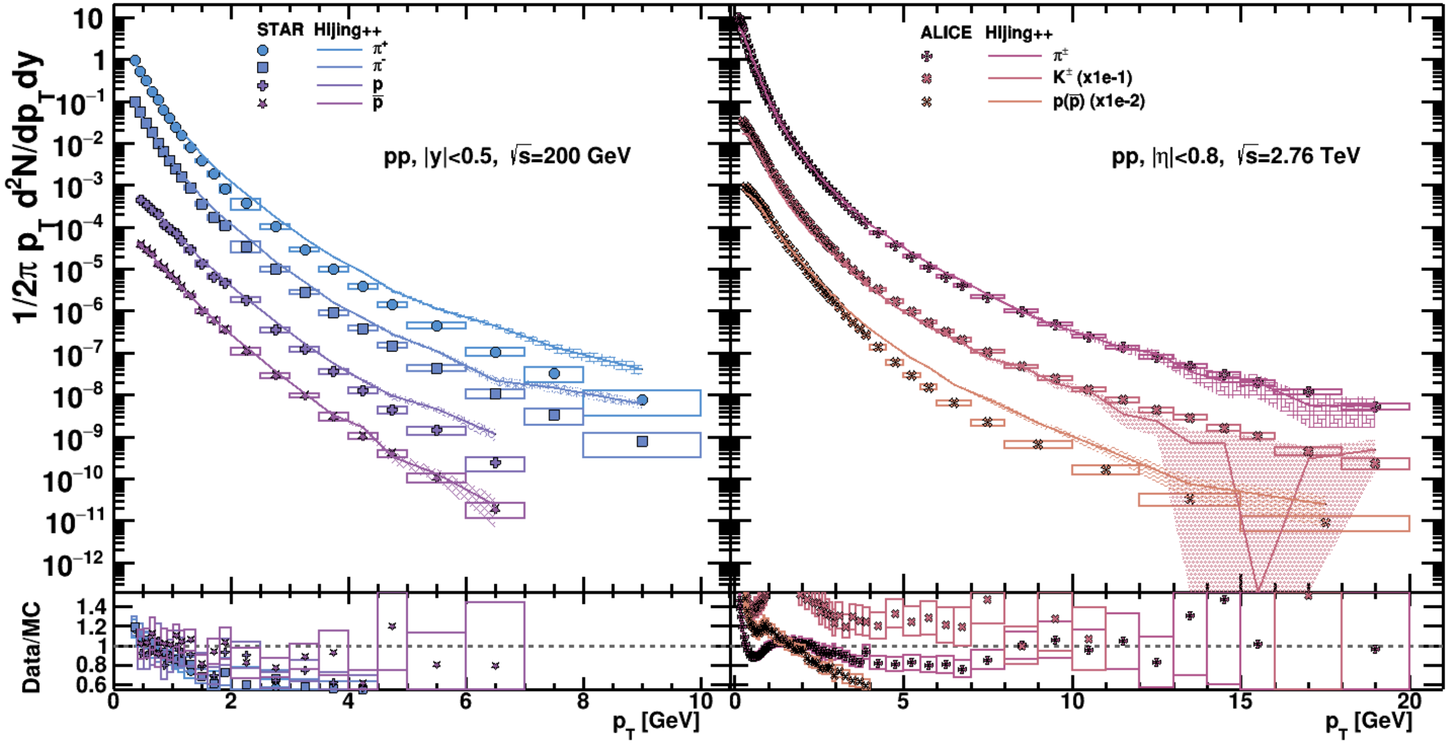
Physics tests: global observables in pA

- Charged hadron spectra
  - pp & pA data dAu at 200 GeV and pPb 5.02 TeV
  - In this set STAR & ALICE data
  - Perfect agreement up to 50% in wide transverse momentum and center of mass energy range.



Physics tests: global observables in pA

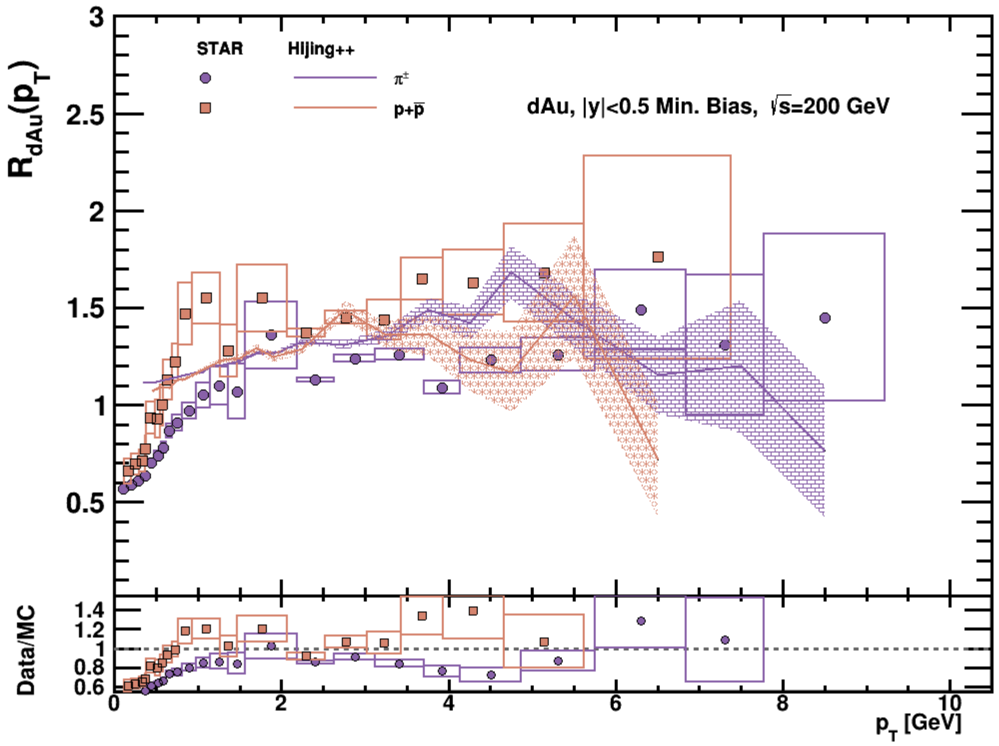
- Identified hadron spectra
  - pp data at 200 GeV and 2.76 TeV
  - In this set STAR & ALICE data
  - Perfect agreement up to 50% in wide transverse momentum and center of mass energy range.
  - High-pT proton production has to be improved.

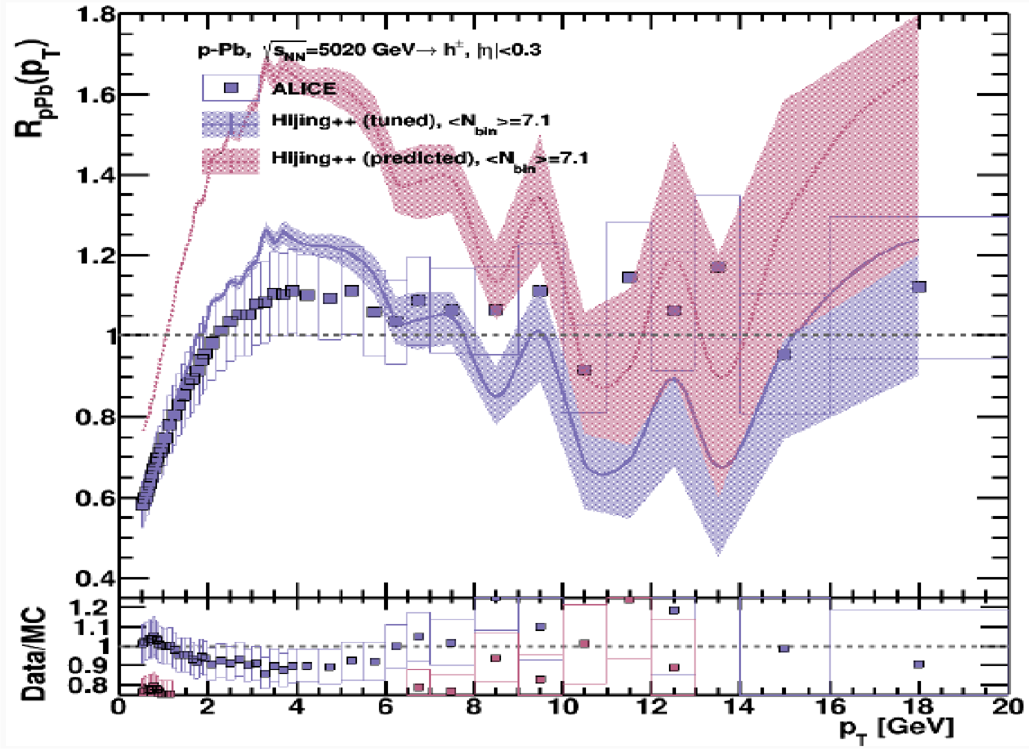


Physics tests: global observables in pA

- Nuclear Modification

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

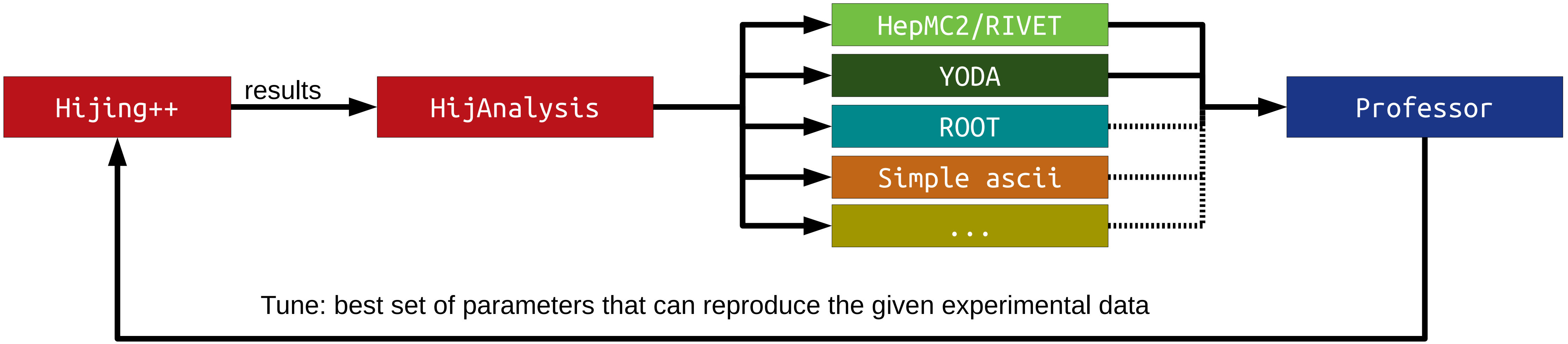




What is the next ???

HIJING++ with fine tuning

- Fine-tuning: optimizing numerical parameters (~10) for an initial, general purpose “tune” (like Monash 2013 for PYTHIA)
- HijAnalysis interface: different data structures for convenient usage
- The general steps of tuning:



HIJING++ with fine tuning

- Iterative process

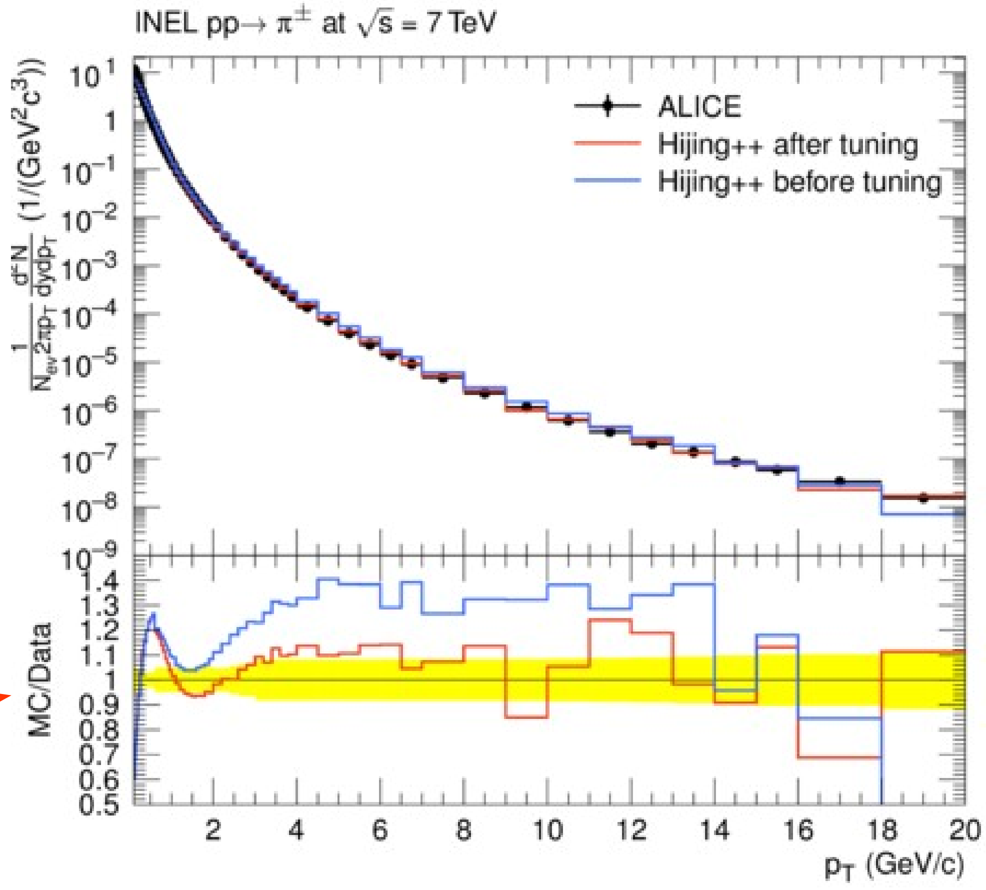
  → finding the most general parametrization

  - The input of PROFESSOR is the YODA format
  - The goal is to find the optimal set for each possible setup for any HI
  - In principle, many dataset available in the HepData database can be used

HIJING++ with fine tuning

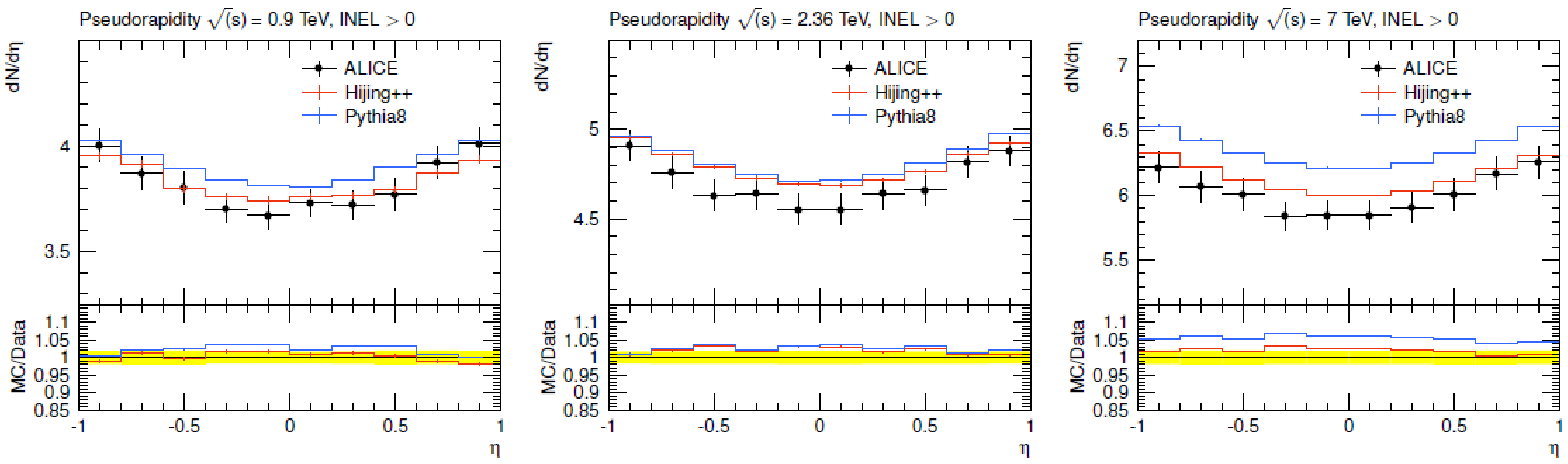
- Iterative process
  - → finding the most general parametrization
    - The input of PROFESSOR is the YODA format
    - The goal is to find the optimal set for each possible setup for any HI
    - In principle, many dataset available in the HepData database can be used

→Result of tuning may differ a lot

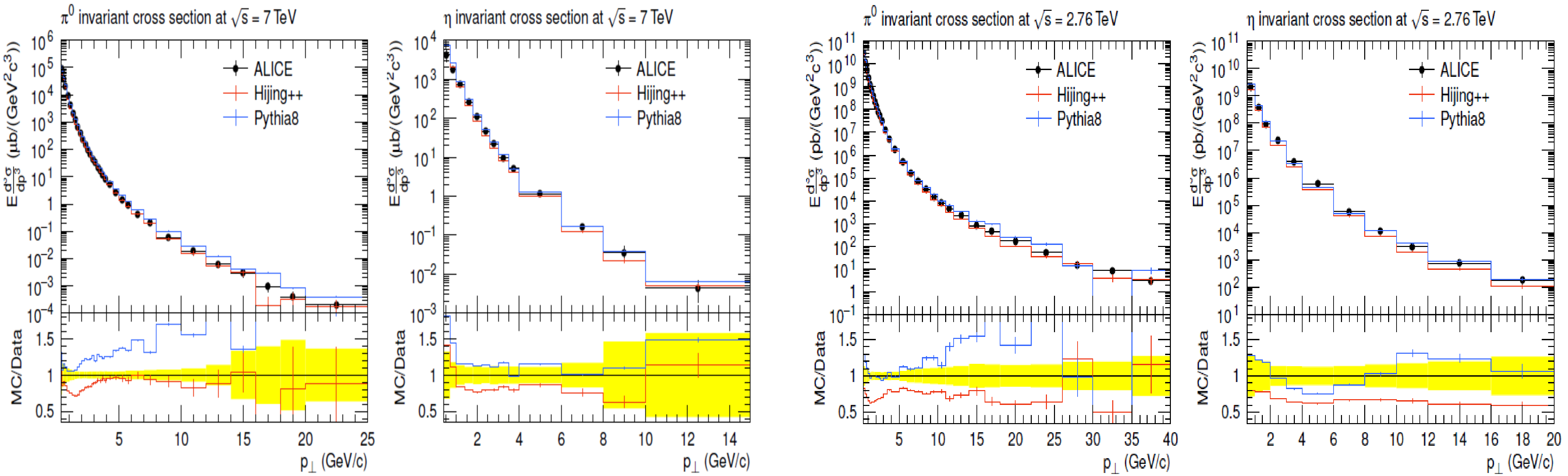


Test & tunes within RIVET framework

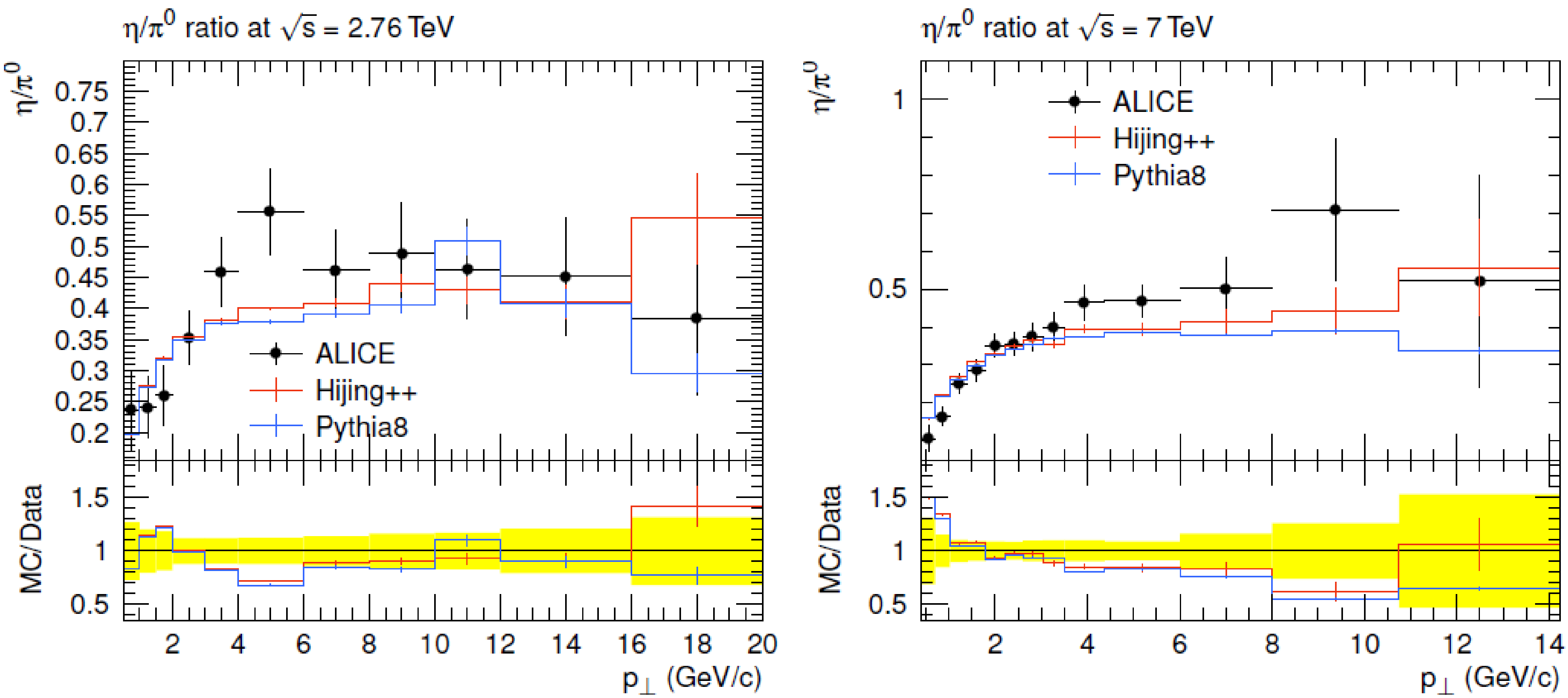
Predictions for ALICE pp collisions at LHC energies



Test & tunes within RIVET framework



Test & tunes within RIVET framework

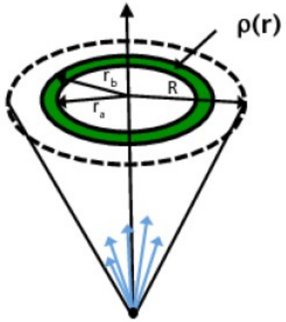


In a real physics analysis

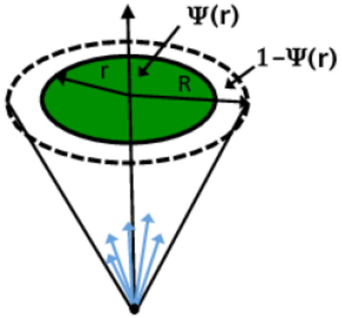
- Z Varga, R Vértesi, GGB: Adv. In HEP 2019 6731362

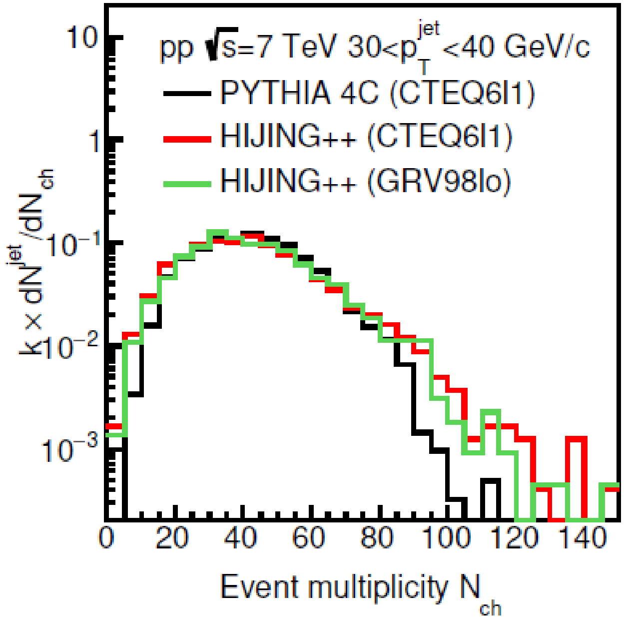
  Modification of Jet Structure in High-Multiplicity pp Collisions due to Multi-parton Interactions and Observing a Multiplicity-Independent Characteristic Jet Size

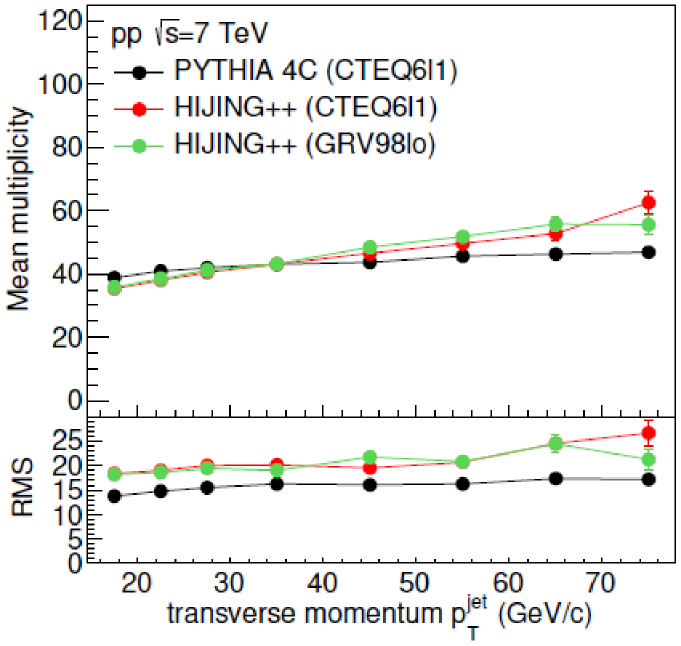
$$\rho(r) = \frac{1}{\delta r}\frac{1}{p_{\mathrm{T}}^{jet}}\sum_{r_a<r_i<r_b} p_{\mathrm{T}}^{i}$$



$$\psi(r) = \frac{1}{p_{\mathrm{T}}^{jet}}\sum_{r_i<r} p_{\mathrm{T}}^{i}$$







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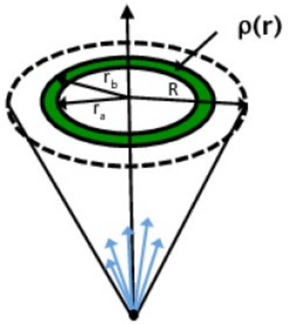
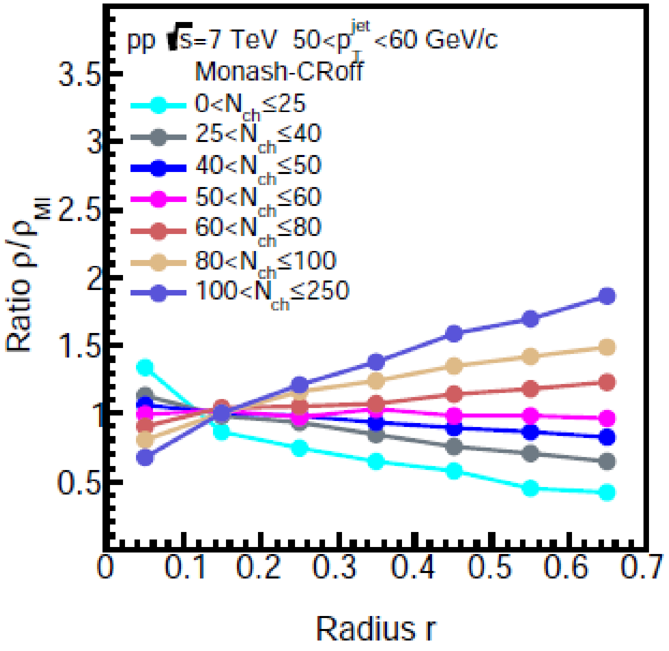
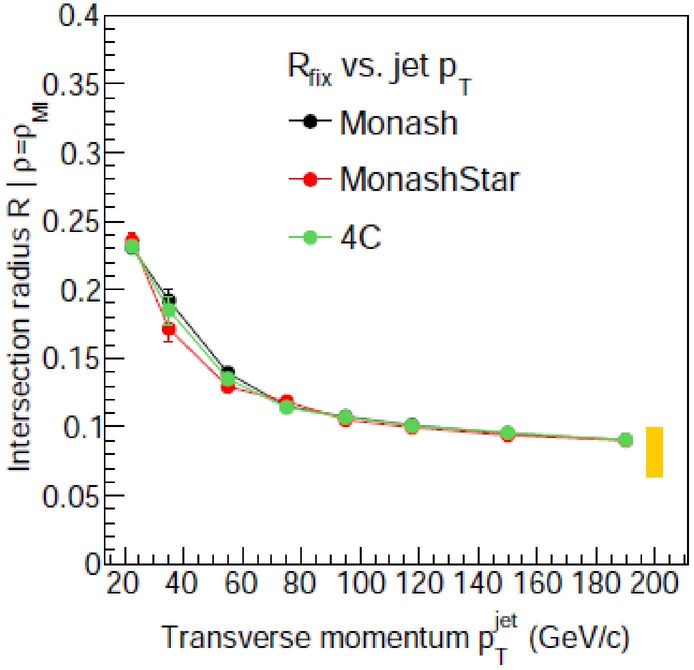
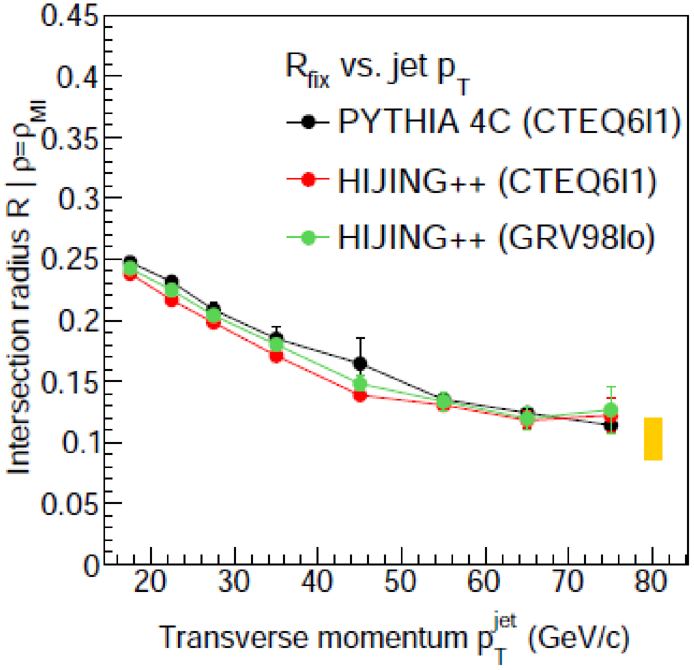






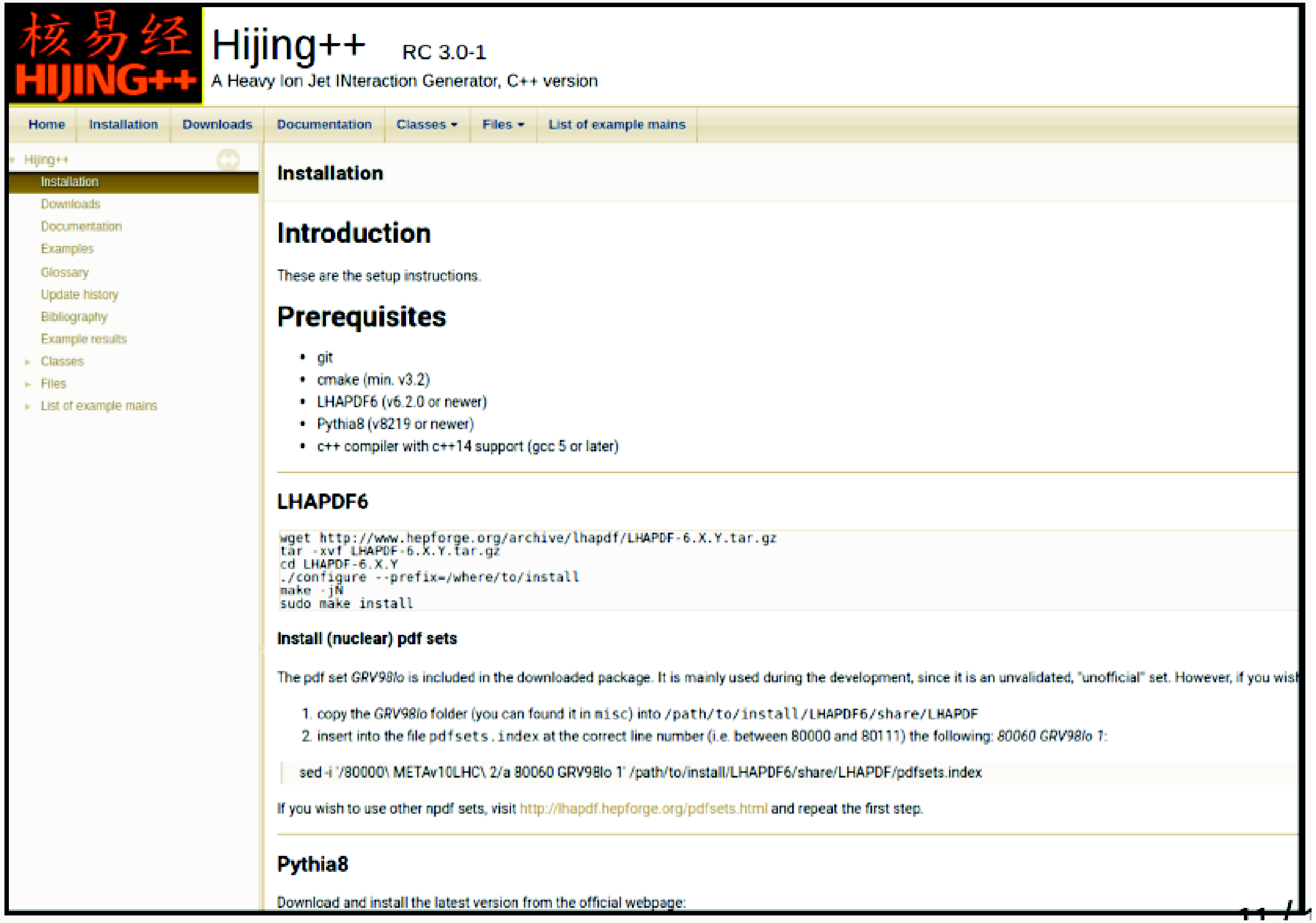


Summary

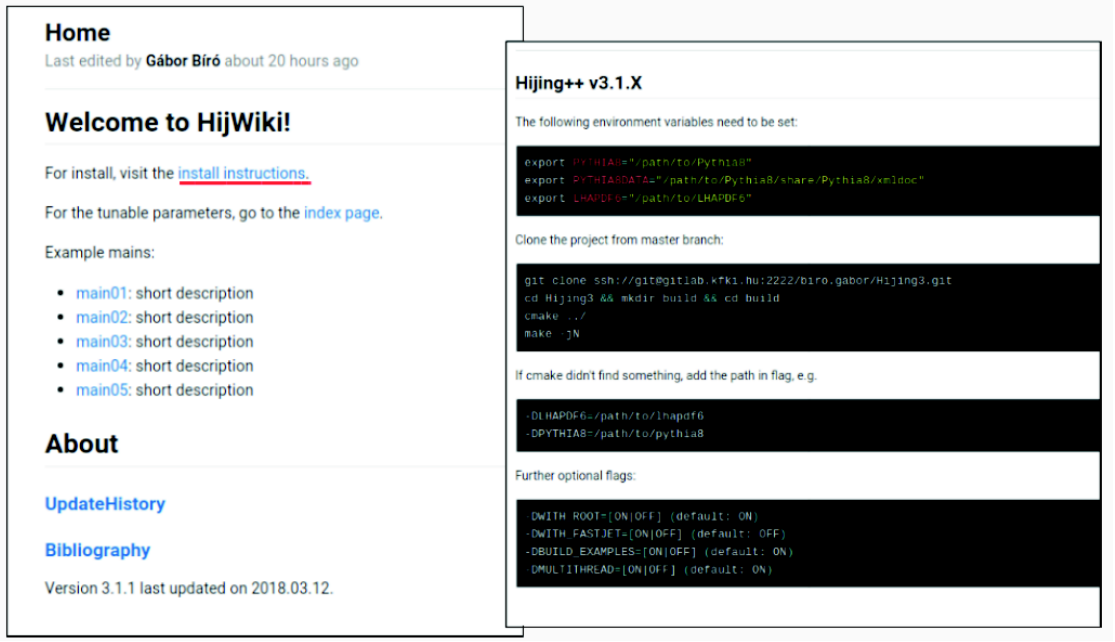
- HIJING++
  - Coding from FORTRAN → C++ has been done
  - One more step HijCore & HijManager were introduced
  - Performance (parallel) tests are ongoing and promising
- First PHYSICS
  - Physics tests has been started
  - Comparison to data is ongoing: RIVET & YODA support is available
  - Tunes are running, and using PROFESSOR
  - Documentation, documentation, documentation....
- Next
  - Step-by-step reconsidering of nuclear effect (shadowing with Q^2, jet quenching)

BACKUP

Stay tuned… (web page is ready)



Documentation is ongoing…



Home

Last edited by **Gábor Bíró** about 20 hours ago

Welcome to HijWiki!

For install, visit the install instructions.

For the tunable parameters, go to the index page.

Example mains:

- main01: short description
- main02: short description
- main03: short description
- main04: short description
- main05: short description

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Version 3.1.1 last updated on 2018.03.12.

Hijing++ v3.1.X

The following environment variables need to be set:

```
export PYTHIA8="/path/to/Pythia8"
export PYTHIA8DATA="/path/to/Pythia8/share/Pythia8/xmldoc"
export LHAPDF6="/path/to/LHAPDF6"
```

Clone the project from master branch:

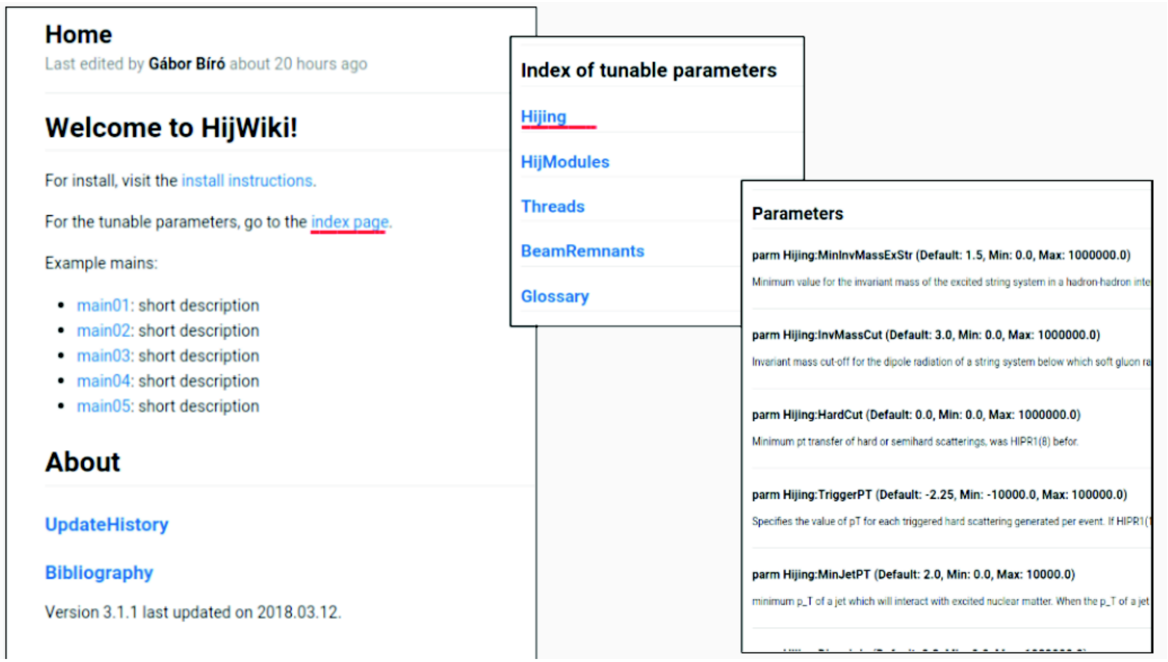
```
git clone ssh://git@gitlab.kfki.hu:2222/biro.gabor/Hijing3.git
cd Hijing3 && mkdir build && cd build
cmake ../
make -jN
```

If cmake didn't find something, add the path in flag, e.g.

```
-DLHAPDF6=/path/to/lhapdf6
-DPYTHIA8=/path/to/pythia8
```

Further optional flags:

```
-DWITH_ROOT=[ON|OFF] (default: ON)
-DWITH_FASTJET=[ON|OFF] (default: OFF)
-DBUILD_EXAMPLES=[ON|OFF] (default: ON)
-DMULTITHREAD=[ON|OFF] (default: ON)
```



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Threads

BeamRemnants

Glossary

Parameters

parm Hijing:MinInvMassExStr (Default: 1.5, Min: 0.0, Max: 1000000.0)

Minimum value for the invariant mass of the excited string system in a hadron-hadron inte

parm Hijing:InvMassCut (Default: 3.0, Min: 0.0, Max: 1000000.0)

Invariant mass cut-off for the dipole radiation of a string system below which soft gluon ra

parm Hijing:HardCut (Default: 0.0, Min: 0.0, Max: 1000000.0)

Minimum pt transfer of hard or semihard scatterings, was HIPR1(8) befor.

parm Hijing:TriggerPT (Default: -2.25, Min: -10000.0, Max: 100000.0)

Specifies the value of pT for each triggered hard scattering generated per event. If HIPR1(

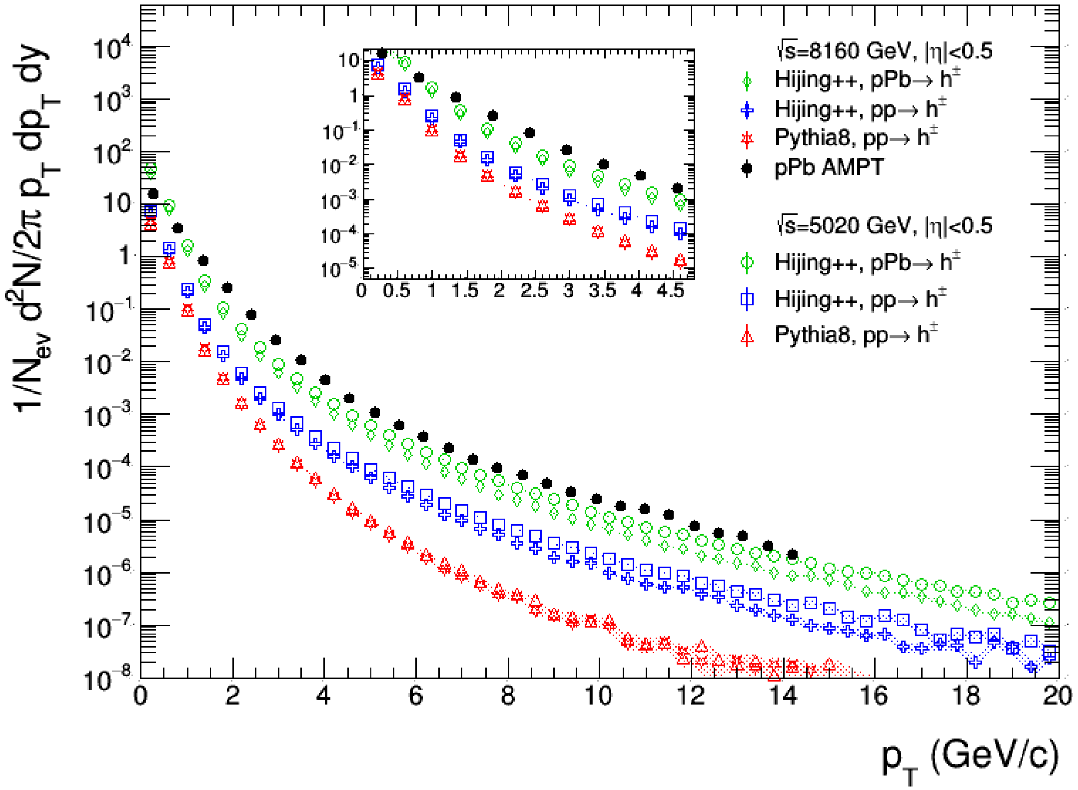
parm Hijing:MinJetPT (Default: 2.0, Min: 0.0, Max: 10000.0)

minimum p_T of a jet which will interact with excited nuclear matter. When the p_T of a jet

First calculations: pp & pPb

HIJING++ pPb comparison (y=0)

- Test: hadron spectra az 5.02 & 8 TeV
- HIJING++ to Theory (kTpQCD, AMPT)
  - PYTHIA8 on pp
  - AMPT pPb



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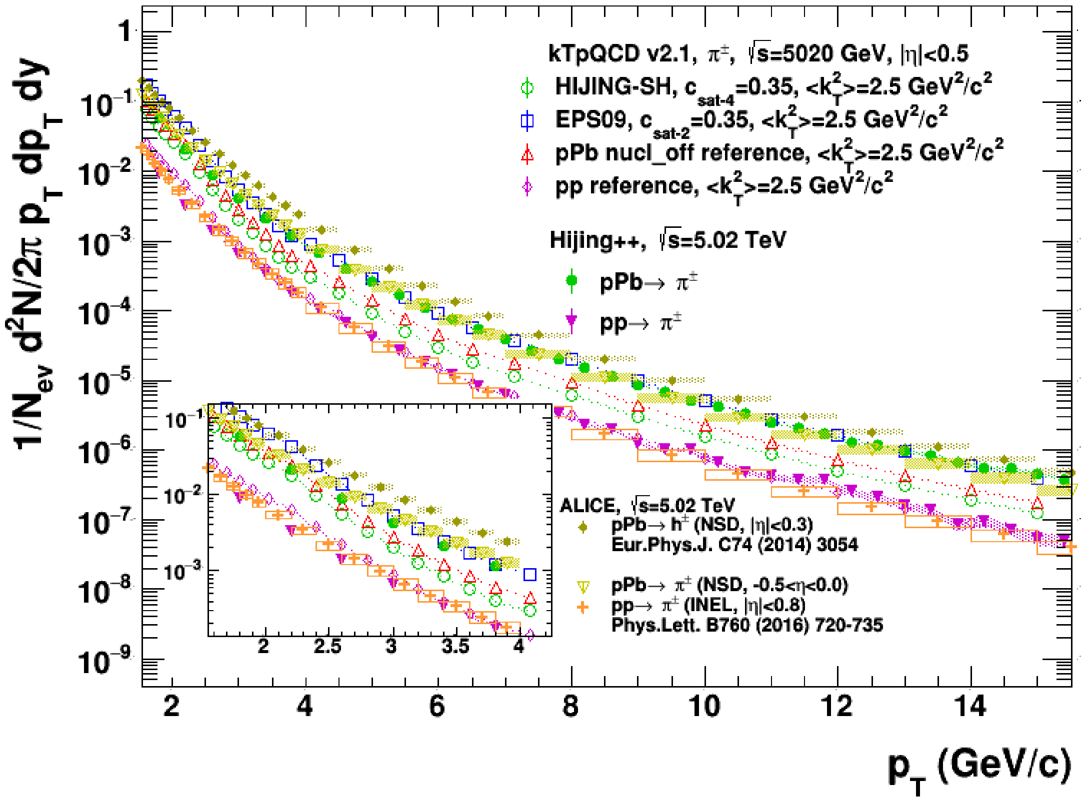
  - kTpQCD_v21 with HIJING & EPS09
- HIJING++ to LHC data:
  - ALICE data @ 5.02 TeV pp & pPb

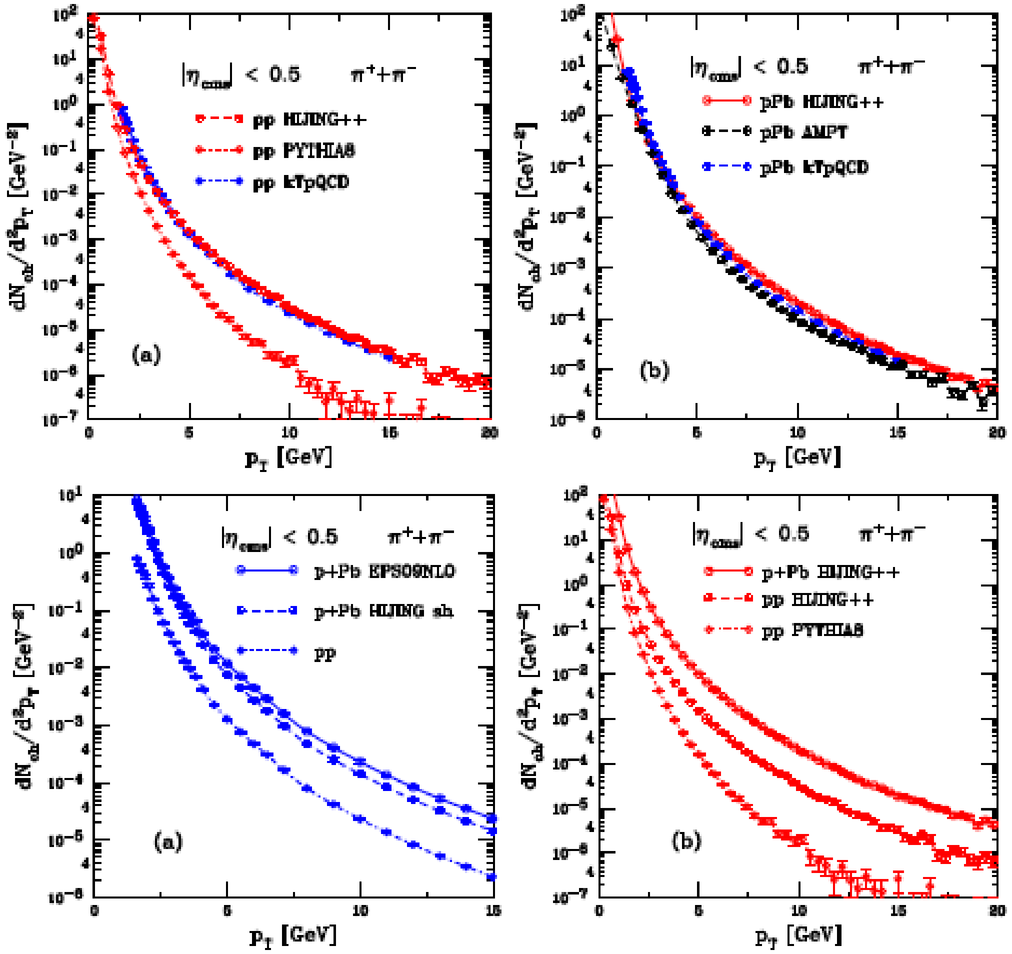


First predictions: pp & pPb

HIJING++ pp & pPb comparison

by R. Vogt: NPA 972 (2018) 18

- Prediction: hadron spectra 8 TeV
- HIJING++ to Theory at 8 TeV
  - PYTHIA8 on pp
  - EPS09NLO
  - AMPT on pPb
  - kTpQCD_v21 on pp & pPb
- Results:
  - Differences at pp level
  - Similar spectra in pPb



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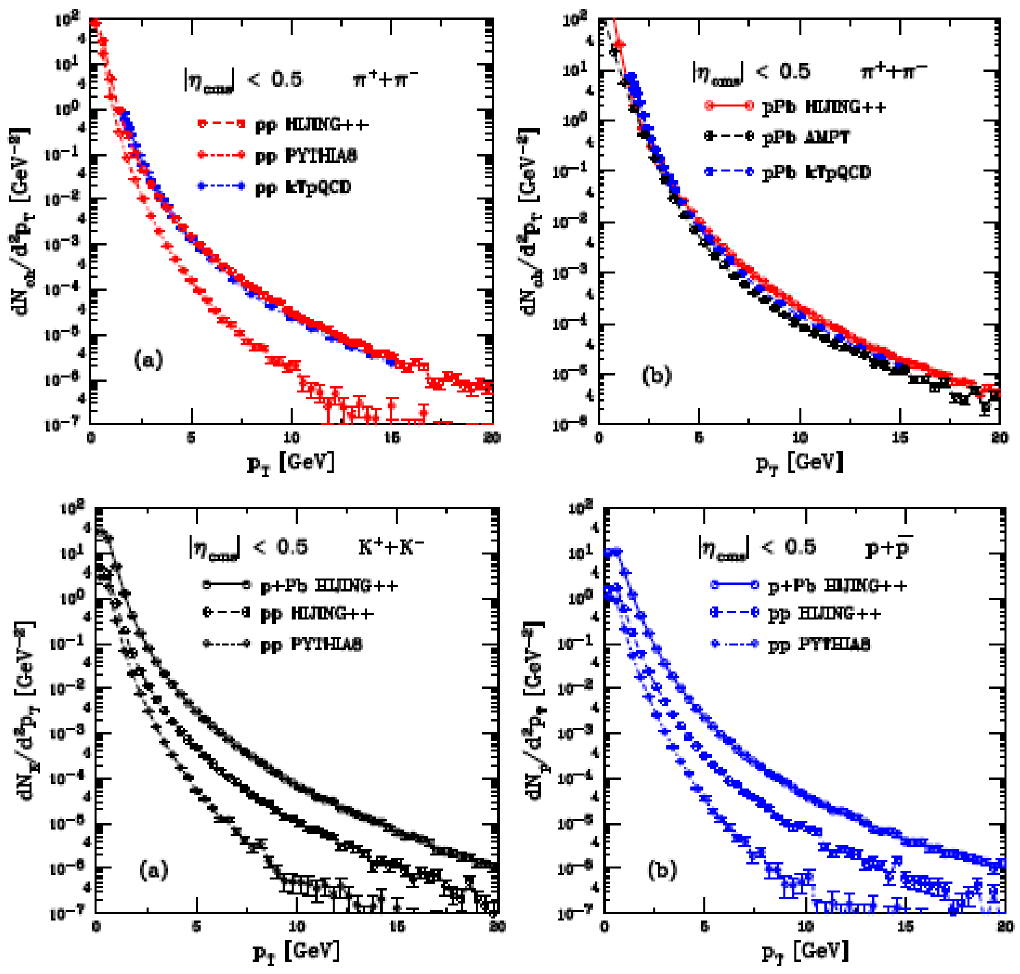
  - EPS09NLO
  - AMPT on pPb
  - kTpQCD_v21 on pp & pPb
- Results:
  - Major differences for K & p

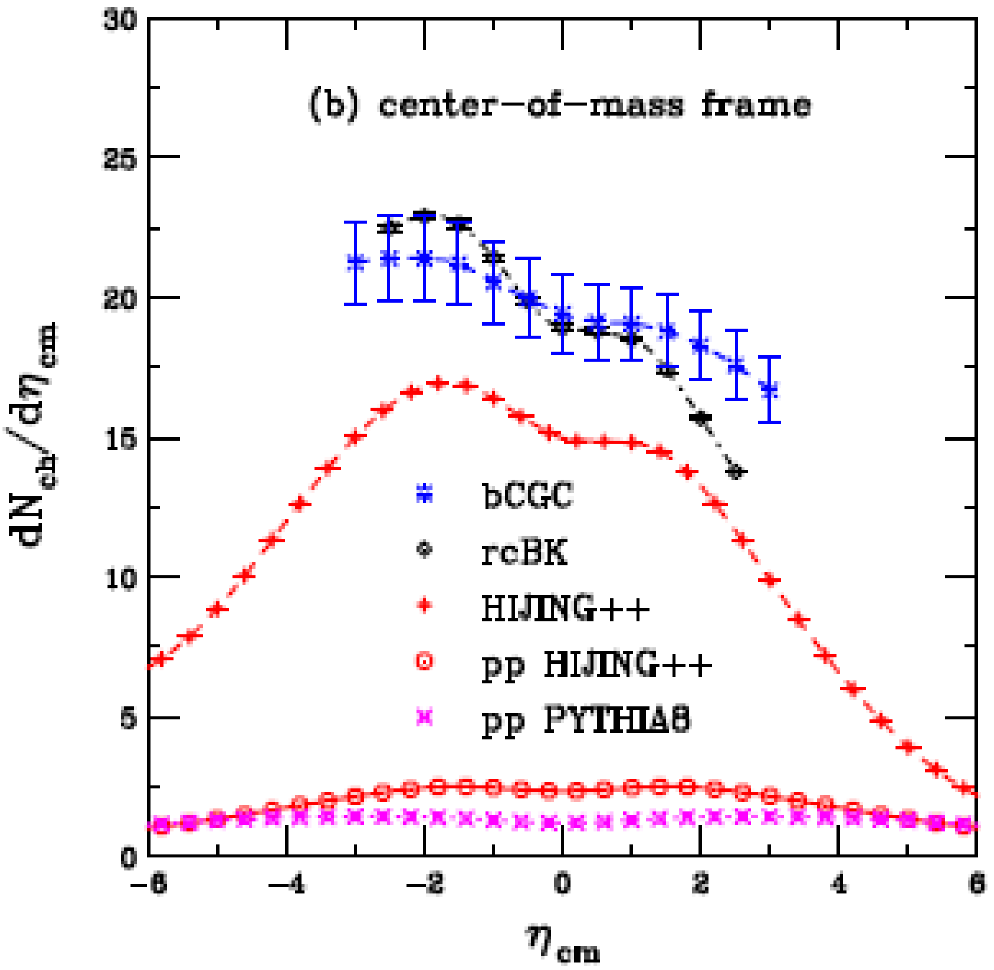


First predictions: pp & pPb

HIJING++ pp & pPb comparison

by R. Vogt NPA 972 (2018) 18

- Prediction: rapidity distribution 8 TeV
- HIJING++ to Theory at 8 TeV
  - PYTHIA8 on pp
  - rcBK
  - bCGC
- Results:
  - Major deviance for PYTHIA8 at midrapidity is coming from minijets

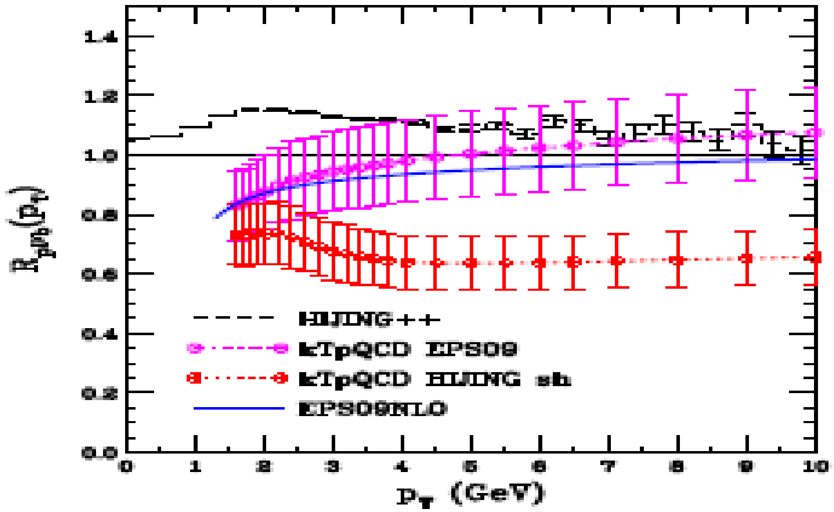


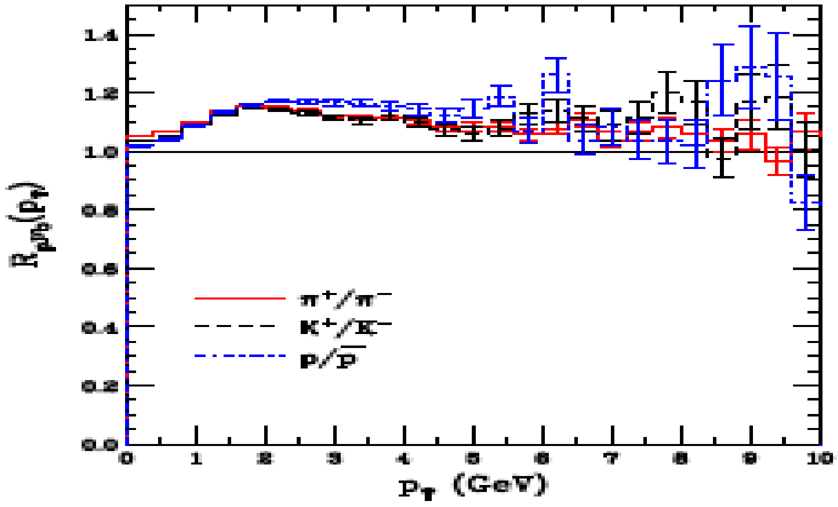
First predictions: pp & pPb

HIJING++ pp & pPb comparison

by R. Vogt NPA 972 (2018) 18

- Prediction: $$R_{pA}(p_T) = \frac{dN_{pA}/dyd^2p_T}{\langle N_{\rm bin}\rangle dN_{pp}/dyd^2p_T}$$
- HIJING++ to Theory at 8 TeV
  - kTpQCD_v21 with EPS09 & HIJING
  - EPS09NLO
- Results:
  - Better agreement with EPS09
  - No relevant difference between π, K, p





First predictions: pPb → heavy hadrons

HIJING++ pPb rapidity dependence

- Prediction at various rapidity:

$$R_{pA}(p_T) = \frac{dN_{pA}/dyd^2p_T}{\langle N_{\text{bin}}\rangle dN_{pp}/dyd^2p_T}$$

- Results:
  - To the y>0 similar trends
  - On the y<0 yields increase with mass