

SIMULATING HIGH-ENERGY HEAVY-ION COLLISIONS IN HPC CLUSTERS

GPU DAY 2020: THE FUTURE OF COMPUTING, GRAPHICS AND DATA ANALYSIS

GÁBOR BÍRÓ

2020 October **20-21**

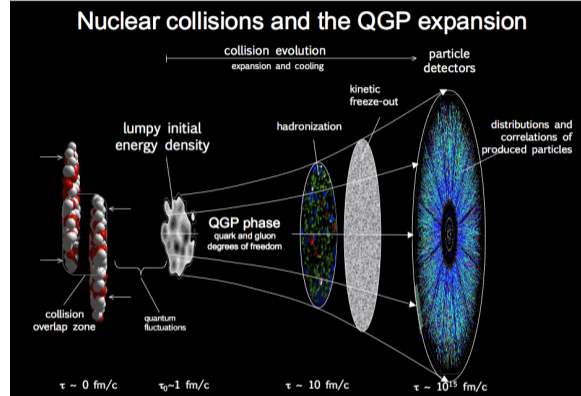
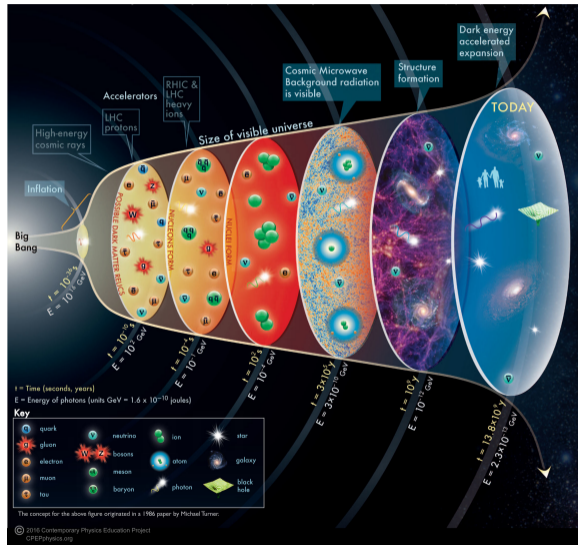
WIGNER RESEARCH **PHYSICS**
CENTRE FOR
WIGNER DATA **CENTRE**
EÖTVÖS LORÁND **UNIVERSITY**

Collaborators:

GERGELY GÁBOR BARNAFÖLDI
GÁBOR PAPP
PÉTER LÉVAI
MIKLÓS GYULASSY
XIN-NIAN WANG
BEN-WEI ZHANG



HIGH-ENERGY HEAVY-ION COLLISIONS



“Modern day HEP requires high performance computing, relying on Monte Carlo simulations”

– Alberto Di Meglio

The CERN Quantum Technology Initiative, 2020.10.20.

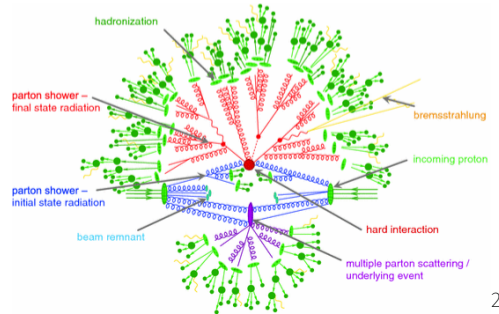
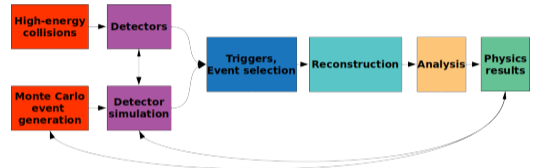
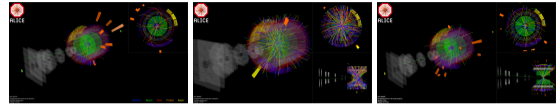
Monte Carlo Event Generators

Simulation of one proton-proton collision event: complicated...

1. Perturbative QCD calculations

$$\frac{d^2 \sigma^{lP \rightarrow hX}}{dx dQ^2} = \sum_{i=q, \bar{q}, g} \int_x^1 \frac{dz}{z} f_i(z, \mu) d\hat{\sigma}_{i \rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

2. Additional phenomenological processes: MPI, colour reconnection, hadronization scheme...
3. Compromise: computational time \leftrightarrow precision
 - Tons of random numbers
4. Empirical parameters: need to be tuned



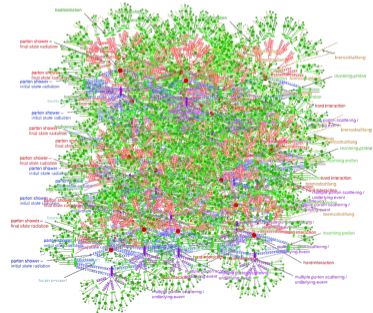
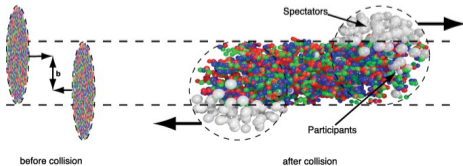
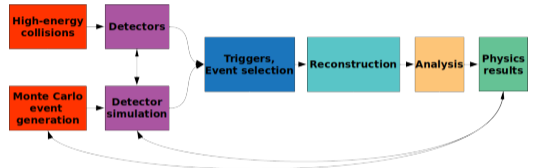
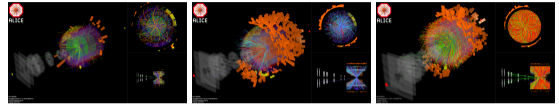
Monte Carlo Event Generators

Simulation of one **heavy-ion** collision event: **even more** complicated...

1. Perturbative QCD calculations

$$\frac{d^2\sigma^{lP\rightarrow hX}}{dx dQ^2} = \sum_{i=q,\bar{q},g} \int_x^1 \frac{dz}{z} f_i(z,\mu) d\hat{\sigma}_{i\rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

2. Additional phenomenological processes: MPI, colour reconnection, hadronization scheme...
3. Compromise: computational time \leftrightarrow precision
 - **Tons** of random numbers
4. Empirical parameters: need to be tuned
5. Multiple nucleon-nucleon interactions



Monte Carlo Event Generators

Simulation of one **heavy-ion** collision event: **even more** complicated...

1. Perturbative QCD calculations

$$\frac{d^2\sigma^{lP \rightarrow hX}}{dx dQ^2} = \sum_{i=q, \bar{q}, g} \int_x^1 \frac{dz}{z} f_i(z, \mu) d\hat{\sigma}_{i \rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

2. Additional phenomenological processes: MPI, colour reconnection, hadronization scheme...

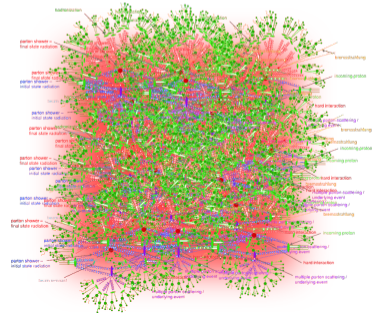
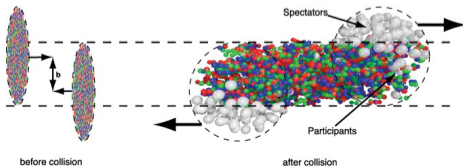
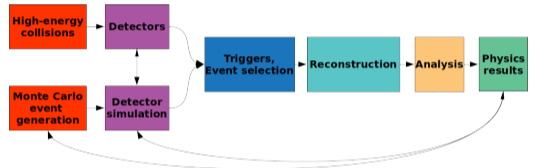
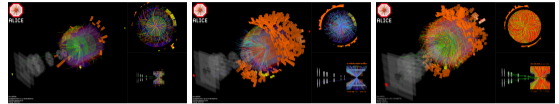
3. Compromise: computational time \leftrightarrow precision

- **Tons** of random numbers

4. Empirical parameters: need to be tuned

5. Multiple nucleon-nucleon interactions

6. Additional nuclear effects: jet quenching, Cronin enhancement, shadowing...



Monte Carlo Event Generators

Simulation of one **heavy-ion** collision event: **even more** complicated...

1. Perturbative QCD calculations

$$\frac{d^2\sigma^{lP\rightarrow hX}}{dx dQ^2} = \sum_{i=q,\bar{q},g} \int_x^1 \frac{dz}{z} f_i(z,\mu) d\hat{\sigma}_{i\rightarrow iX} \left(\frac{x}{z}, \frac{Q}{\mu} \right) D_i^h(z)$$

2. Additional phenomenological processes: MPI, colour reconnection, hadronization scheme...

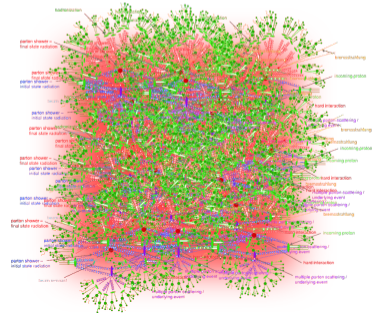
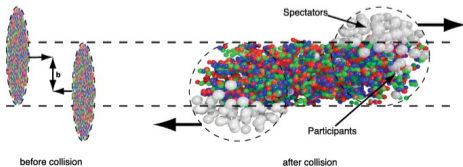
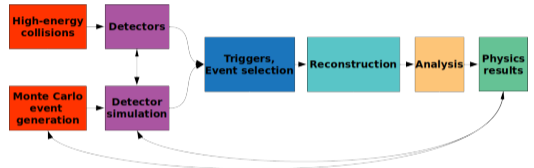
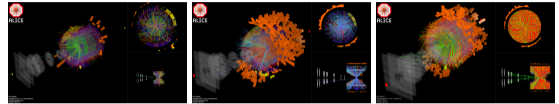
3. Compromise: computational time \leftrightarrow precision

• **Tons** of random numbers

4. **Empirical parameters: need to be tuned**

5. Multiple nucleon-nucleon interactions

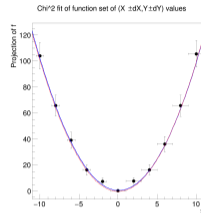
6. Additional nuclear effects: jet quenching, Cronin enhancement, shadowing...



Monte Carlo Event Generators – Tuning

Tuning: set the empirical parameters to fit the experimental data
→ basically „just” an iterative χ^2 minimization

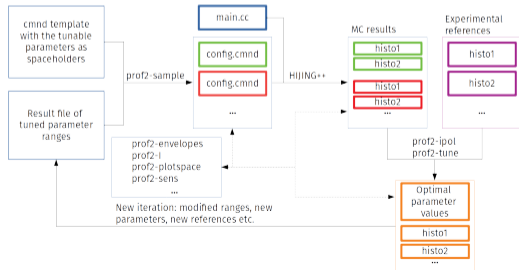
$$\chi^2 = \sum_i \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2$$



YODA (YODA .. *Yet more Objects for Data Analysis*)

Rivet (*Rivet – Robust Independent Validation of Experiment and Theory*)

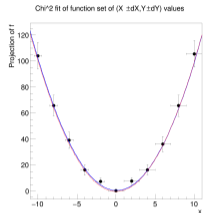
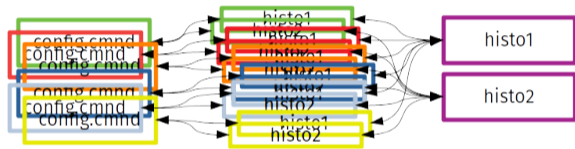
Professor (Tuning tool for Monte Carlo event generators)



Monte Carlo Event Generators – Tuning

Tuning: set the empirical parameters to fit the experimental data
 → basically „just“ an iterative χ^2 minimization

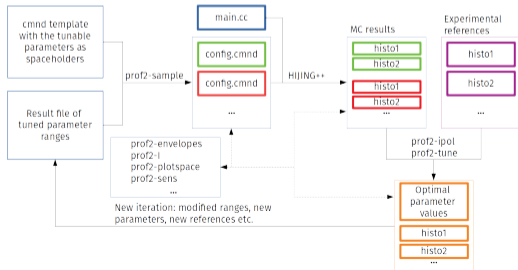
$$\chi^2 = \sum_i \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2$$



YODA (YODA .. *Yet more Objects for Data Analysis*)

Rivet (*Rivet – Robust Independent Validation of Experiment and Theory*)

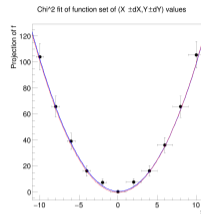
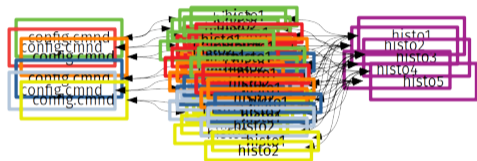
Professor (Tuning tool for Monte Carlo event generators)



MONTE CARLO EVENT GENERATORS – TUNING

Tuning: set the empirical parameters to fit the experimental data
→ basically „just“ an iterative χ^2 minimization

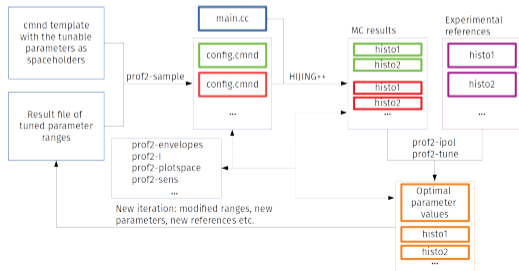
$$\chi^2 = \sum_i \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2$$



YODA (YODA .. *Yet more Objects for Data Analysis*)

Rivet (*Rivet – Robust Independent Validation of Experiment and Theory*)

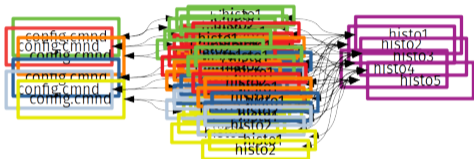
Professor (Tuning tool for Monte Carlo event generators)



Monte Carlo Event Generators – Tuning

Tuning: set the empirical parameters to fit the experimental data
 → basically „just“ an iterative χ^2 minimization

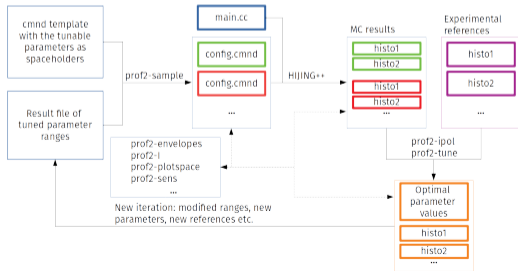
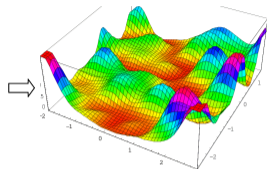
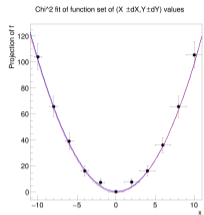
$$\chi^2 = \sum_i \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2$$



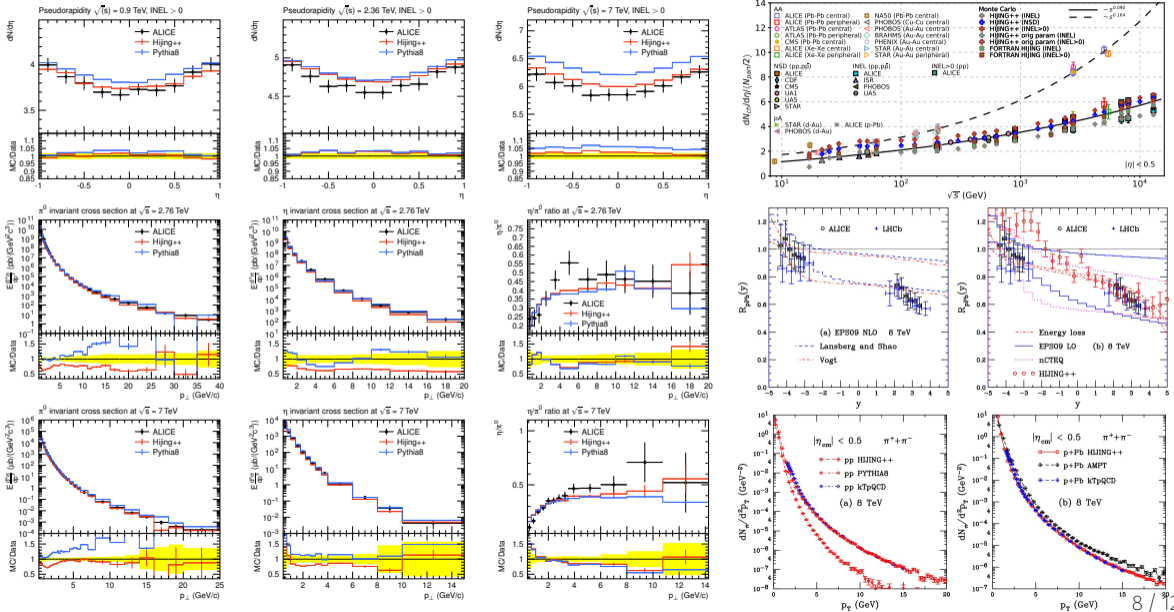
YODA (YODA .. *Yet more Objects for Data Analysis*)

Rivet (*Rivet – Robust Independent Validation of Experiment and Theory*)

Professor (Tuning tool for Monte Carlo event generators)



Monte Carlo Event Generators – Tuning



HIJING++ – A NEW GENERATION OF HEAVY-ION MONTE CARLO

Heavy
Ion
Jet
Interaction
Generator

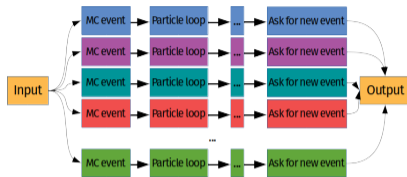
核易经

[Hé -yì -jīng]

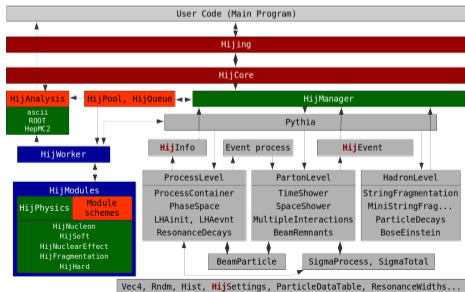
“Nuclear change theory”; Book of Changes, “Originally a divination manual in the Western Zhou period (1000–750 BC)”

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

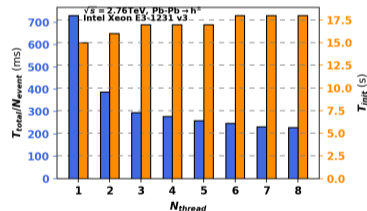
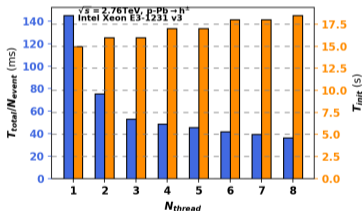
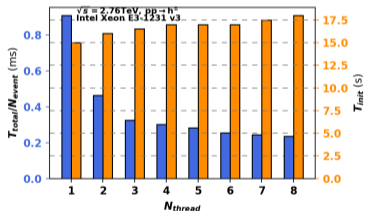
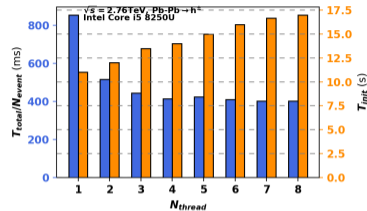
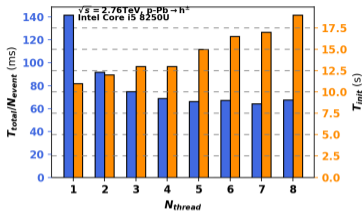
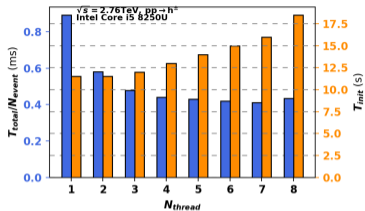
- Computational challenge: more than 600 million collision in **each second** → HiLumiLHC: even more
- Requirements for a new version: multithreaded mode, maintainability, intuitive usage



	FORTRAN HIJING	HIJING++ v3.0	HIJING++ v3.1
Precision	simple	double	double
Pythia version	5.3	8.2	8.2+
(n)PDF	GRV98lo	LHAPDF6.2	LHAPDF6.2+
Jet quenching	(✓)	(✓)	(✓)
Multithreading	X	X	✓
Analysis interface	X	X	✓
Module management	X	X	✓
Dependencies, build system	Makefile	Makefile	CMake

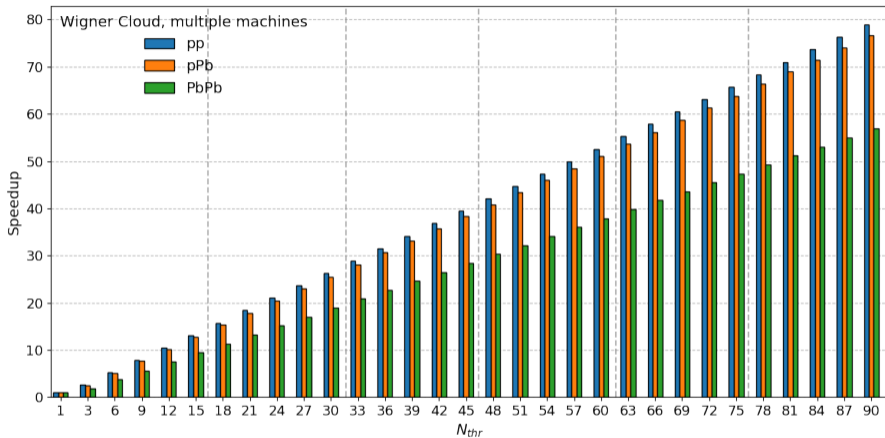


HIJING++ - MULTITHREADING



CPU	Release year	Cores (threads)	Base (turbo) frequency	TDP	RAM	Speedup		
						pp	p-Pb	Pb-Pb
Intel [®] Core [™] i5-8250U	Q3'17	4 (8)	1.6 GHz (3.4 GHz)	15 W	8 GB	2.6x	2.7x	2.6x
Intel [®] Xeon [™] E3-1231 v3	Q2'14	4 (8)	3.4 GHz (3.8 GHz)	80 W	32 GB	6.4x	6.6x	4.5x

HIJING++ – MULTITHREADING



Tuning with WDC machines: very effective

⇒ one iteration needs 2-3 days (instead of weeks)

Less time ⇒ less electricity ⇒ less money ✓

SUMMARY

- Monte Carlo event generators was/are/will be crucial in high-energy physics
- Computationally very demanding (both to operate and to develop)
- HIJING++: the next generation of high-energy heavy-ion simulations
 - Multithreaded, modular, intuitive,
 - Needs to be tuned → time consuming
 - Room for future improvements

SUPPORT

The research is supported by: **Wigner Data Center**, **Wigner GPU Laboratory**, OTKA K120660, K123815, K135515, THOR COST CA15213, Hungarian-Chinese 12 CN-1-2012-0016, MOST 2014DFG02050, 2019-2.1.11-TÉT-2019-00050 Tét, Wigner HAS-OBOR-CCNU, ÚNKP-17-3.

Thank you for your attention!