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 Centre for **Physics**
Wigner Data **Centre**
Eötvös Loránd **University**

Collaborators:

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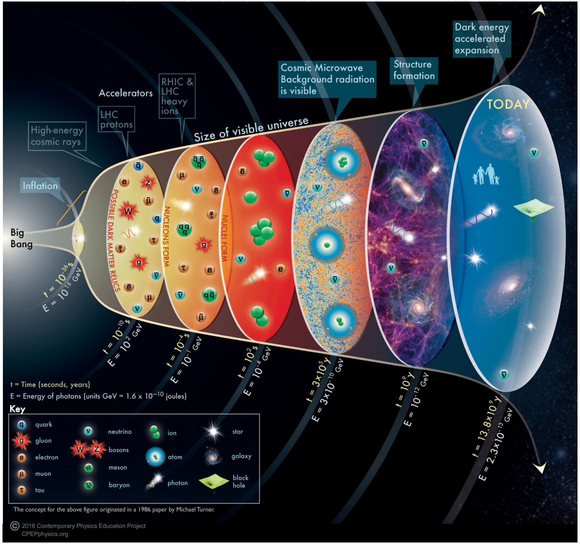
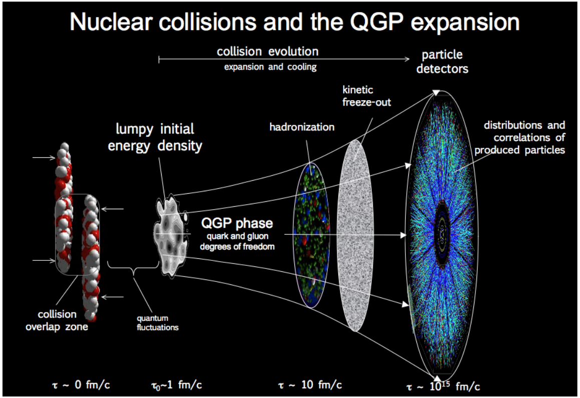
Gábor Papp
Péter Lévai
Miklós Gyulassy
Xin-Nian Wang
Ben-Wei Zhang





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

— Alberto Di Meglio

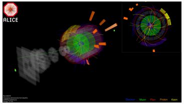
The CERN Quantum Technology Initiative, 2020.10.20.

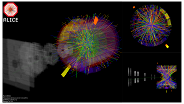
Simulation of one proton-proton collision event: complicated...

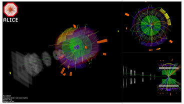
1. Perturbative QCD calculations

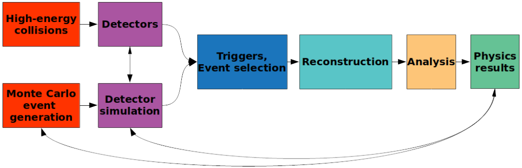
$$\frac{d^2\sigma^{lP\to hX}}{dx dQ^2} = \sum_{i=q,\bar{q},g} \int_x^1 \frac{dz}{z} f_i(z,\mu)\, d\hat{\sigma}_{il\to iX}\left(\frac{x}{z},\frac{Q}{\mu}\right) D_i^h(z)$$

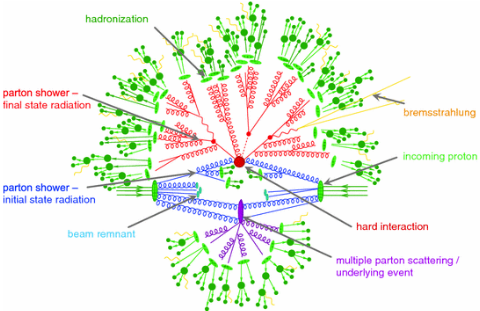
2. Additional phenomenological processes: MPI, colour reconnection, hadronization scheme...
3. Compromise: computational time $\longleftrightarrow$ precision
   - Tons of random numbers
4. Empirical parameters: need to be tuned











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

1. Perturbative QCD calculations

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

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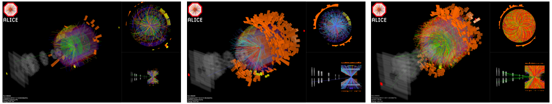
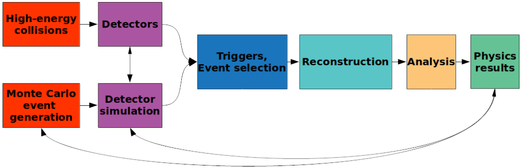
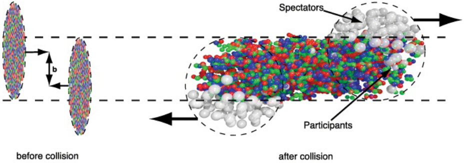
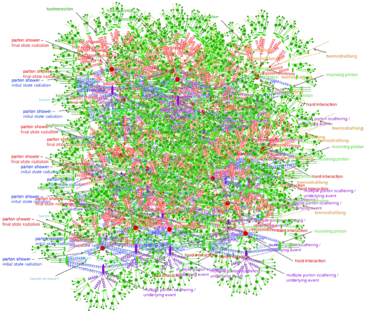
5. Multiple nucleon-nucleon interactions









Monte Carlo event generators

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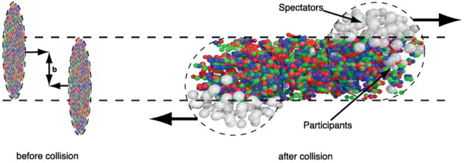

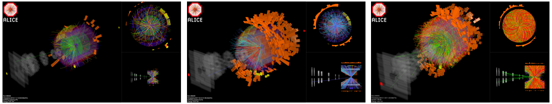

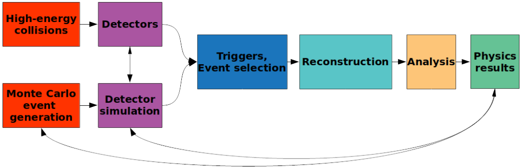

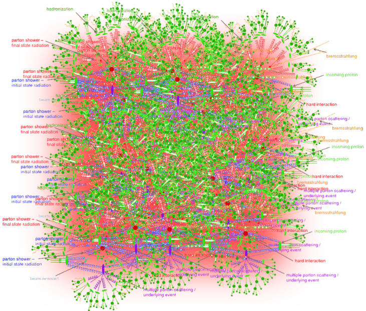

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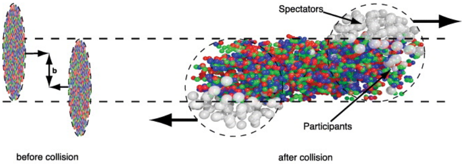
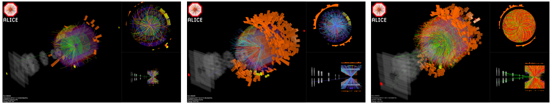
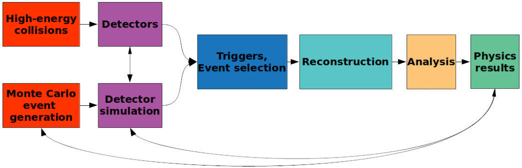
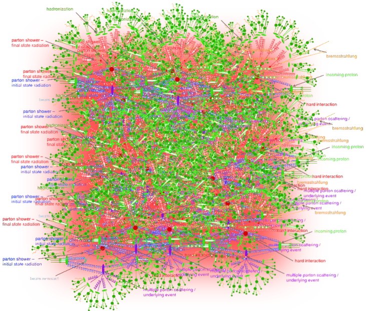




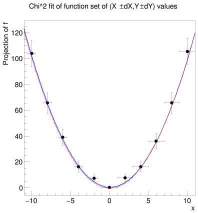


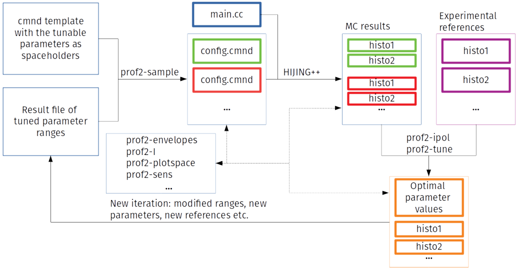


Tuning: set the empirical parameters to fit the experimental data
→ basically „just" an iterative χ^2 minimization

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

*sample→**calculate**→minimize→repeat*





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)

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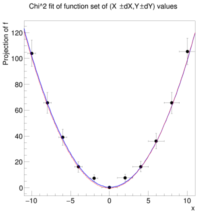

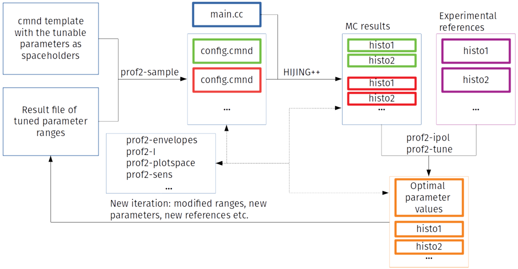

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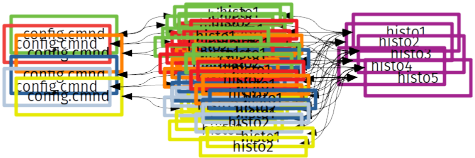

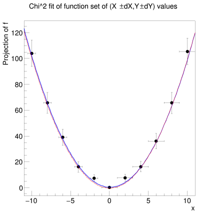

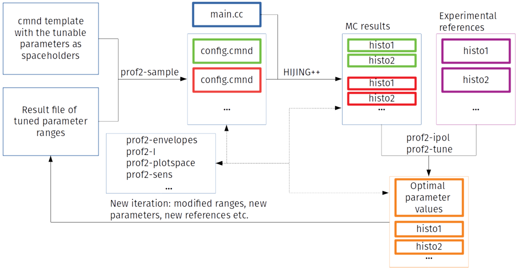

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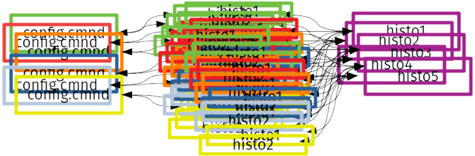

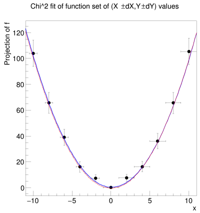

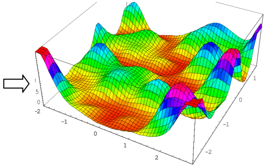

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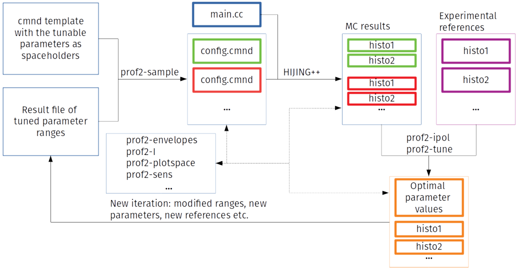

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→ basically ~~„just"~~ an iterative χ^2 minimization ⇨ **very serious business**

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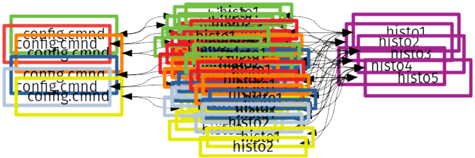

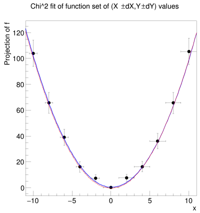

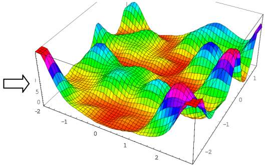

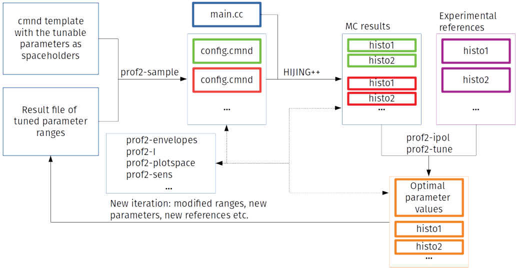

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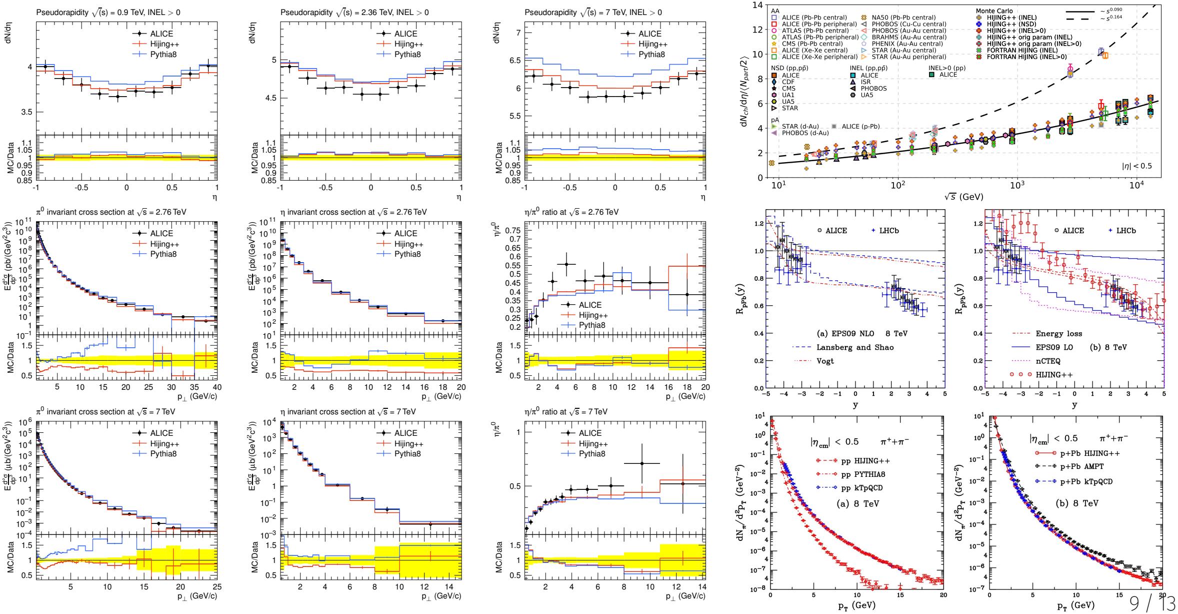
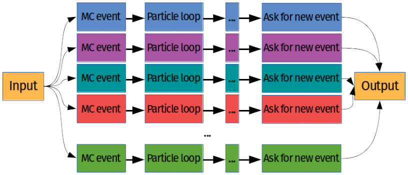


Heavy
Ion
Jet
INteraction
Generator
核易经
[Hé –yì –jīng]

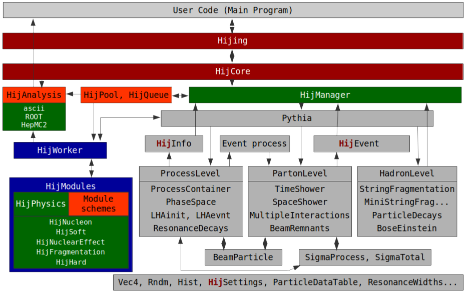
"Nuclear change theory"; Book of Changes, "Originally a divination manual in the Western Zhou period (1000–750 BC)"

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

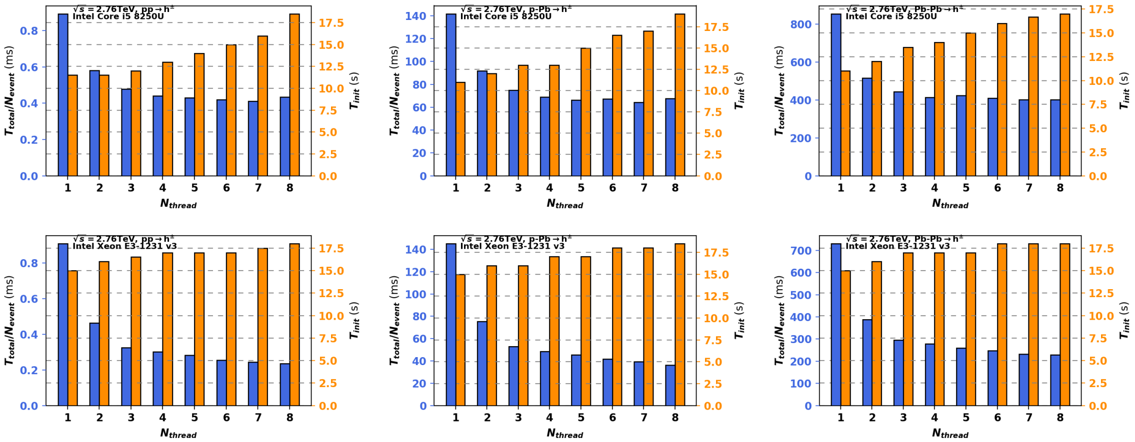
- Computational challenge: more than 600 million collision in **each second** → HiLumiLHC: even more
- Requirements for a new version: multithreaded mode, maintainability, intuitive usage



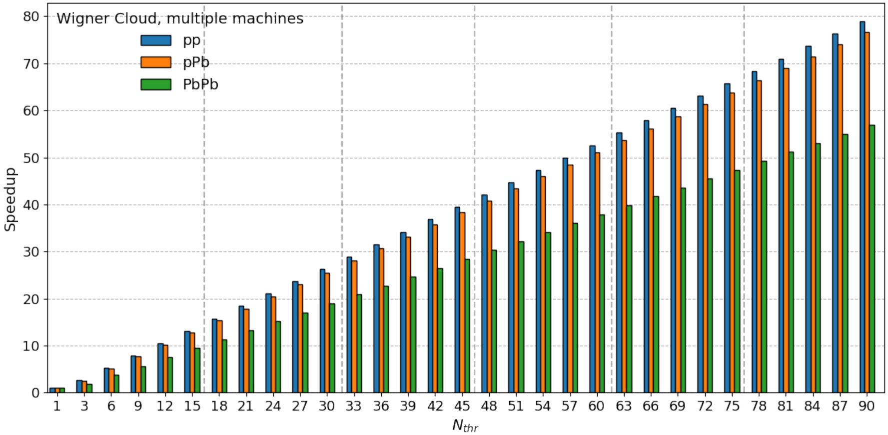
	FORTRAN HIJING	HIJING++ v3.0	HIJING++ v3.1
Precision	simple	double	double
Pythia version	5.3	8.2	8.2+
(n)PDF	GRV98lo	LHAPDF6.2	LHAPDF6.2+
Jet quenching	(✓)	(✓)	(✓)
Multithreading	✗	✗	✓
Analysis interface	✗	✗	✓
Module management	✗	✗	✓
Dependencies, build system	Makefile	Makefile	CMake



HIJING++ – MULTITHREADING



CPU	Release year	Cores (threads)	Base (turbo) frequency	TDP	RAM	Speedup pp	Speedup p-Pb	Speedup 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



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 were/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 $\longrightarrow$ 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!