Spoke 2 Annual Meeting CINECA, 19 - 12 -2023

Simulating lattice QCD at high temperatures:
High Performance Computing for theoretical particle physics

Pietro Rescigno

Università degli studi di Milano - Bicocca
INFN sezione di Milano - Bicocca

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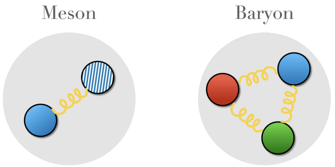

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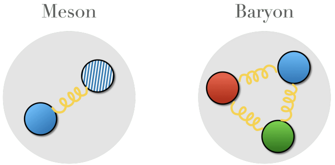

The Nobel Prize in Physics 2004

David J. Gross, H. David Politzer and Frank Wilczek

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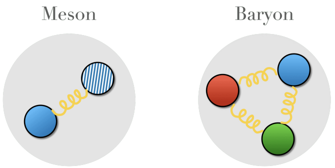

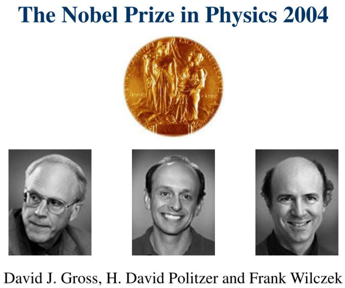

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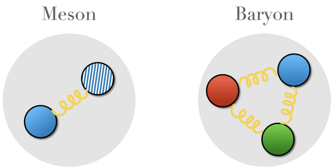
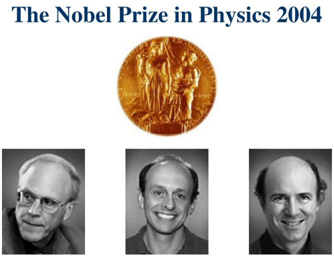
- Perturbative expansions may show slow convergence or be **ill defined**
- Need for **non-perturbative**, **model independent** approach to study the properties of QCD





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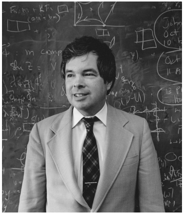
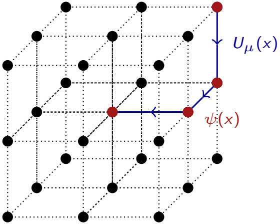
Lattice Field Theory



"I saw from this that to understand quantum field theories, I would have to understand quantum field theories on a lattice" - from K. G. Wilson's Nobel Lecture, 1982



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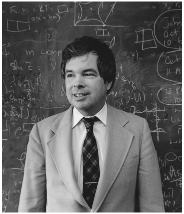

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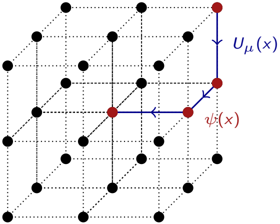

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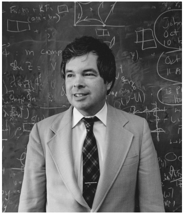

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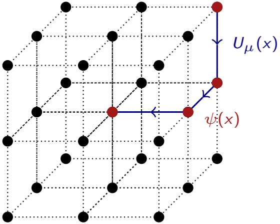

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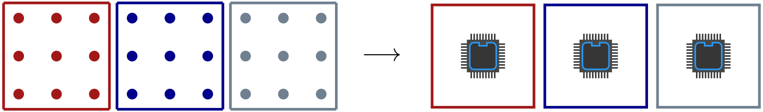
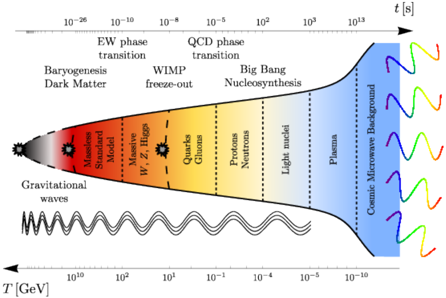
- By construction amenable to **numerical simulation** via Monte Carlo integration: $\mathcal{O}(10^{10})$ variables
- Subdivisions of the lattice are mapped to different processors and treated in parallel: **HPC** and **efficient algorithms** are essential!



QCD at high temperature

The properties of QCD in the **high temperature** regime play a crucial role in many fascinating topics:

- Heavy Ion Collision experiments
- Neutron Star structure (**Equation of State**)
- Early Universe Dynamics



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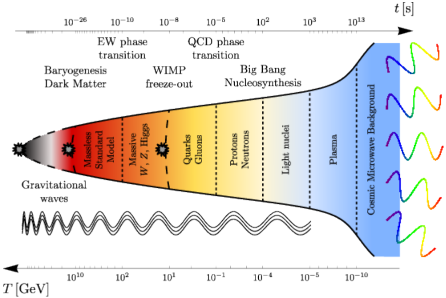

Perturbation theory is **severely limited** at high temperatures [Linde 1980]

Lattice studies mostly limited to $T \lesssim 1$ GeV: how to accomodate both an **hadronic scale** and the **temperature** on the same lattice?

Shifted Boundary Conditions

- Formally, finite temperature is obtained with a **compact Euclidean time** direction ⇒ Periodic Boundary conditons : $\phi(x_0 + L_0, \boldsymbol{x}) = \phi(x_0, \boldsymbol{x})$

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$$\phi(x_0 + L_0, \mathbf{x}) = \phi(x_0, \mathbf{x} - \boldsymbol{\xi} L_0)$$

  Proved crucial for a precise determination of SU(3) E.O.S. [Giusti and Pepe 2017], and enter a recently proposed strategy that allowed to explore unprecedented temperatures up to $\gtrsim$ 100 GeV in QCD [Giusti, Pepe et al. 2021]
- Description of the thermal theory from a **moving frame**

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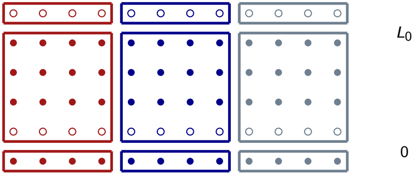

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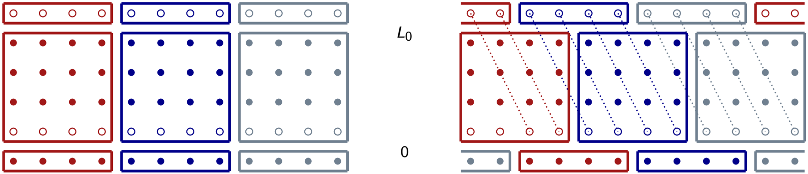

BC relate sites assigned to the **same processor**

BC may relate sites assigned to **different processors!**

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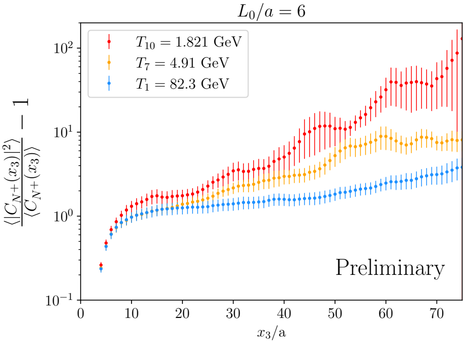
- At high temperature we demonstrated that the loss is greatly reduced.



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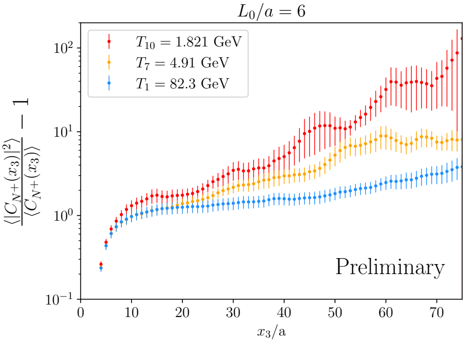

Goals and outlook

- Study the properties of **baryons** and **mesons** in the high temperature regime from first principles
- Lattice sizes of the order $10 \times (288)^3$
- Run highly parallelized simulations on $\sim 5000 - 10000$ cores

Thank you for your attention!