The non-linear regime of quantum chromodynamics in the context of relativistic heavy-ion collisions

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Palaiseau

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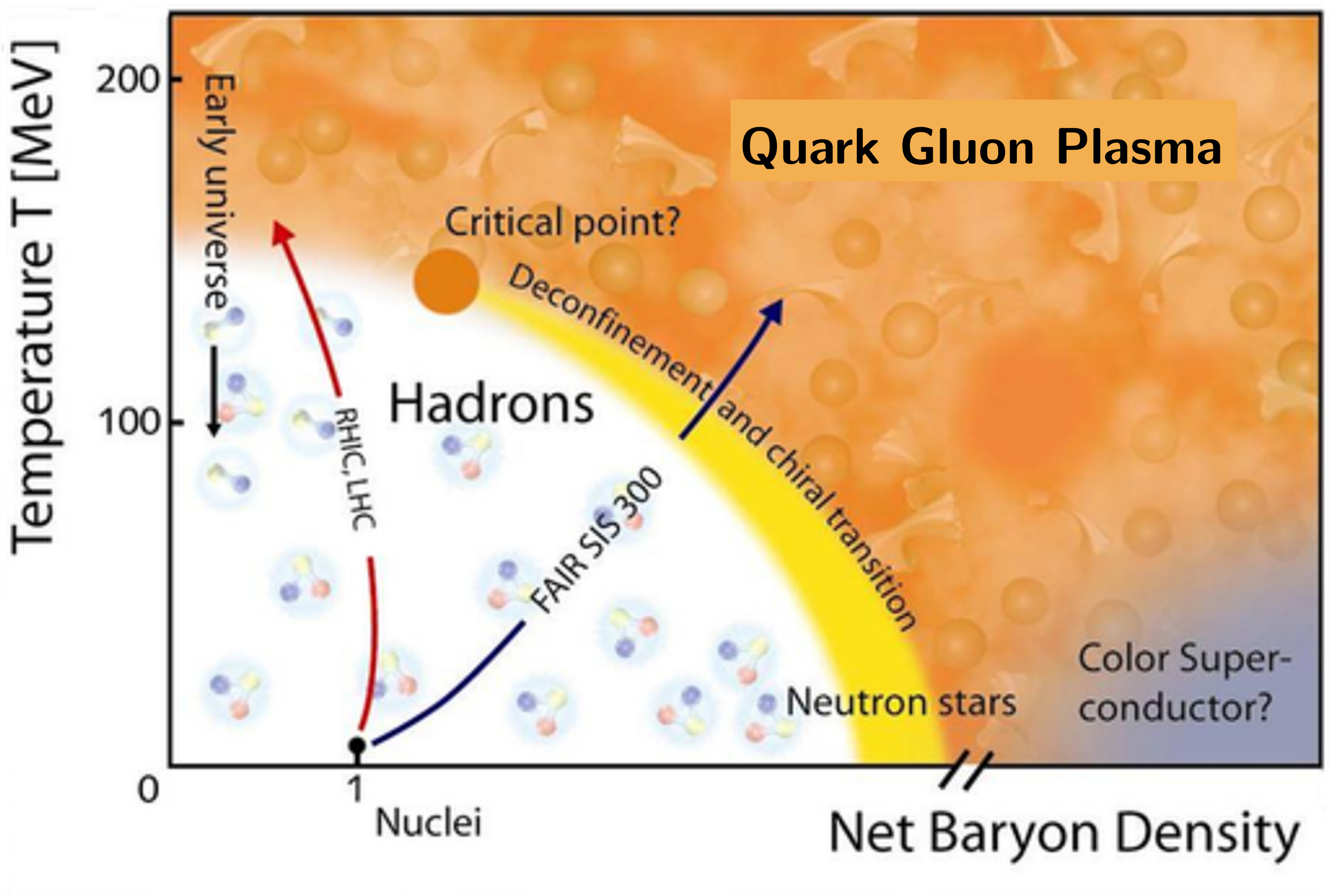
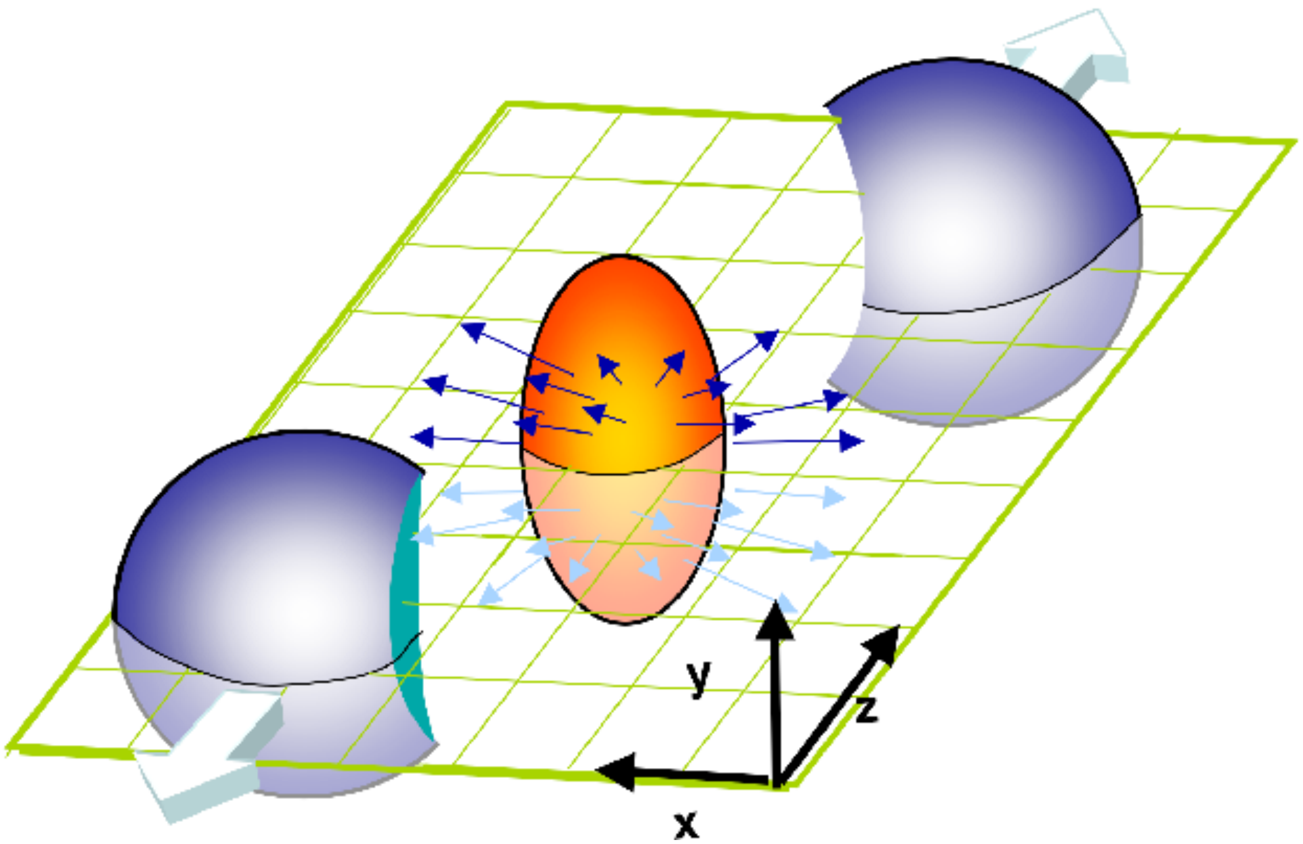
The QCD phase space

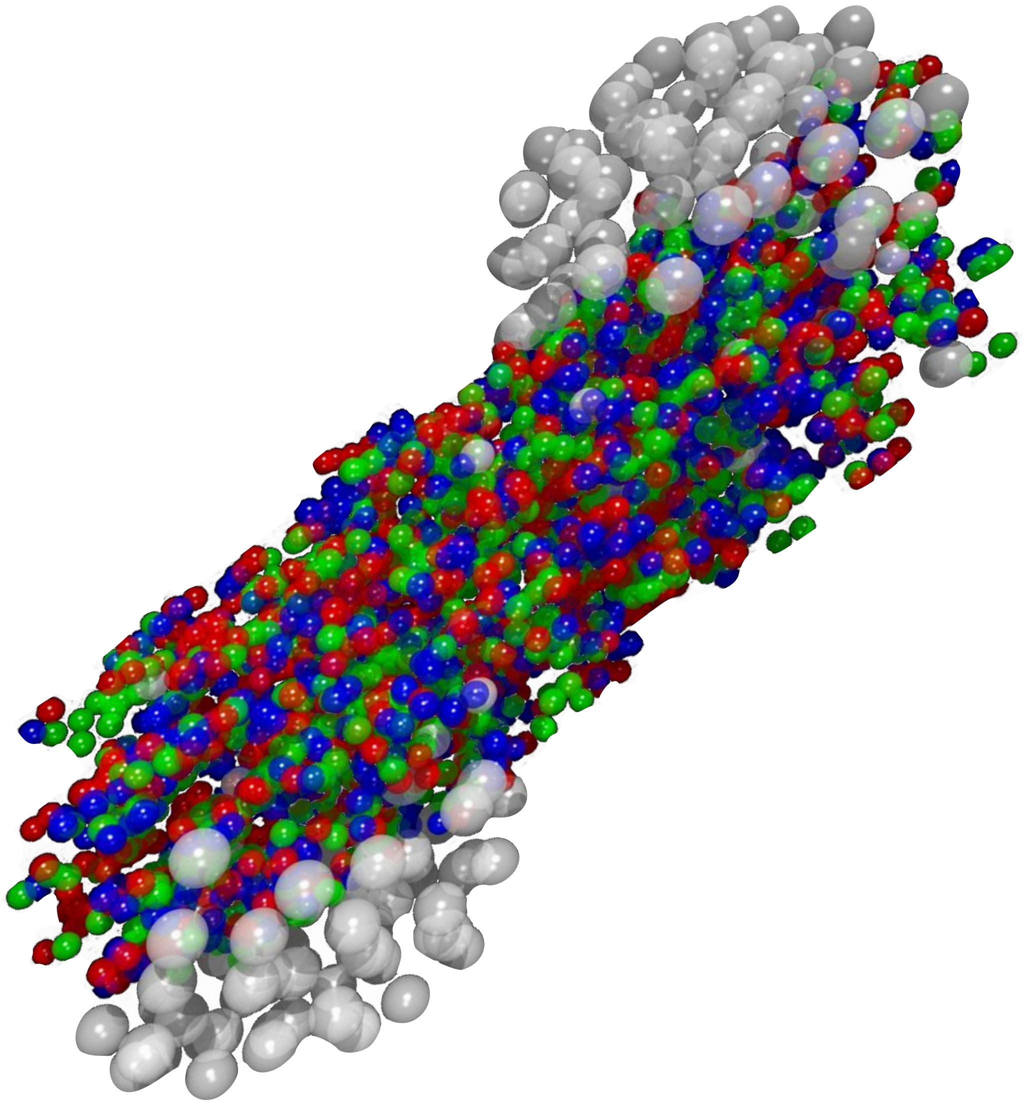


- QCD behaves differently depending on conditions of temperature of density of matter
- Low temperature and densities: **hadronic phase (confinement)**
- Transition at high temperature to a **deconfined phase:** The **QUARK-GLUON PLASMA**

Highly Energetic Heavy Ion Collisions

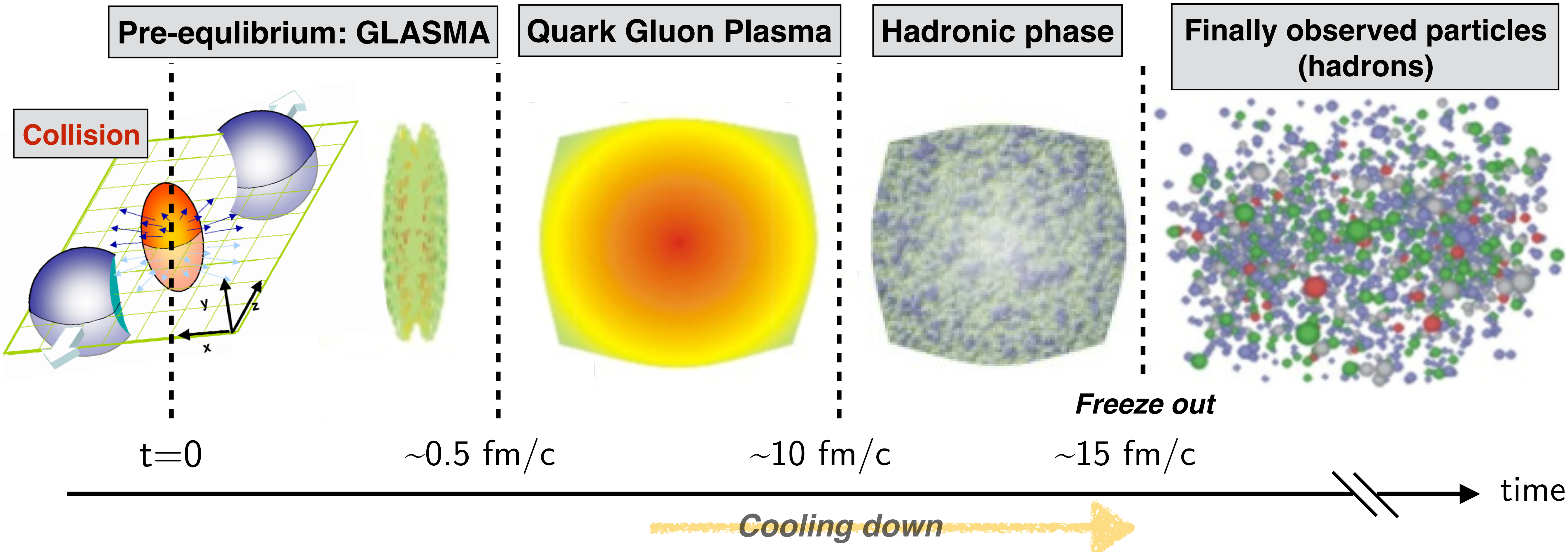
- This state of matter can be accessed in particle colliders through **Heavy Ion Collision** experiments





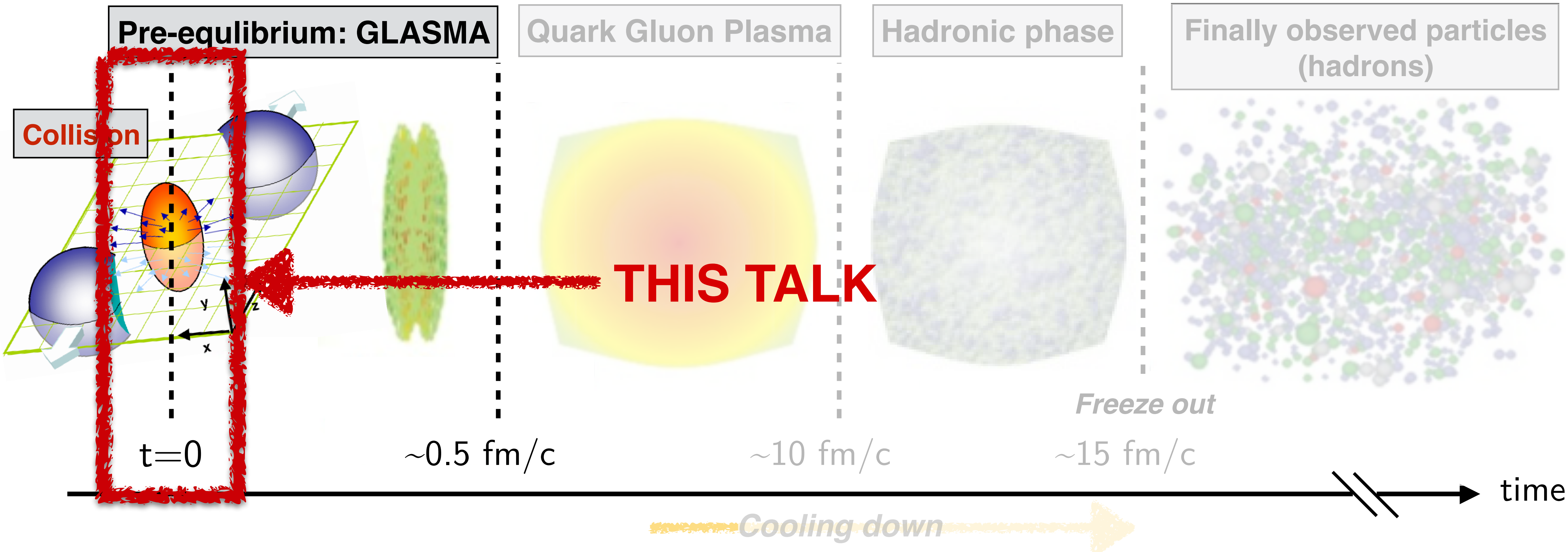
- Performed at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (**RHIC**) and CERN's Large Hadron Collider (more specifically the **ALICE** experiment)

Stages of a heavy ion collision



- After the collision, matter goes through different phases as it cools down
- In the last part, it reaches the hadronic phase, and this is how it appears in the detectors

Stages of a heavy ion collision



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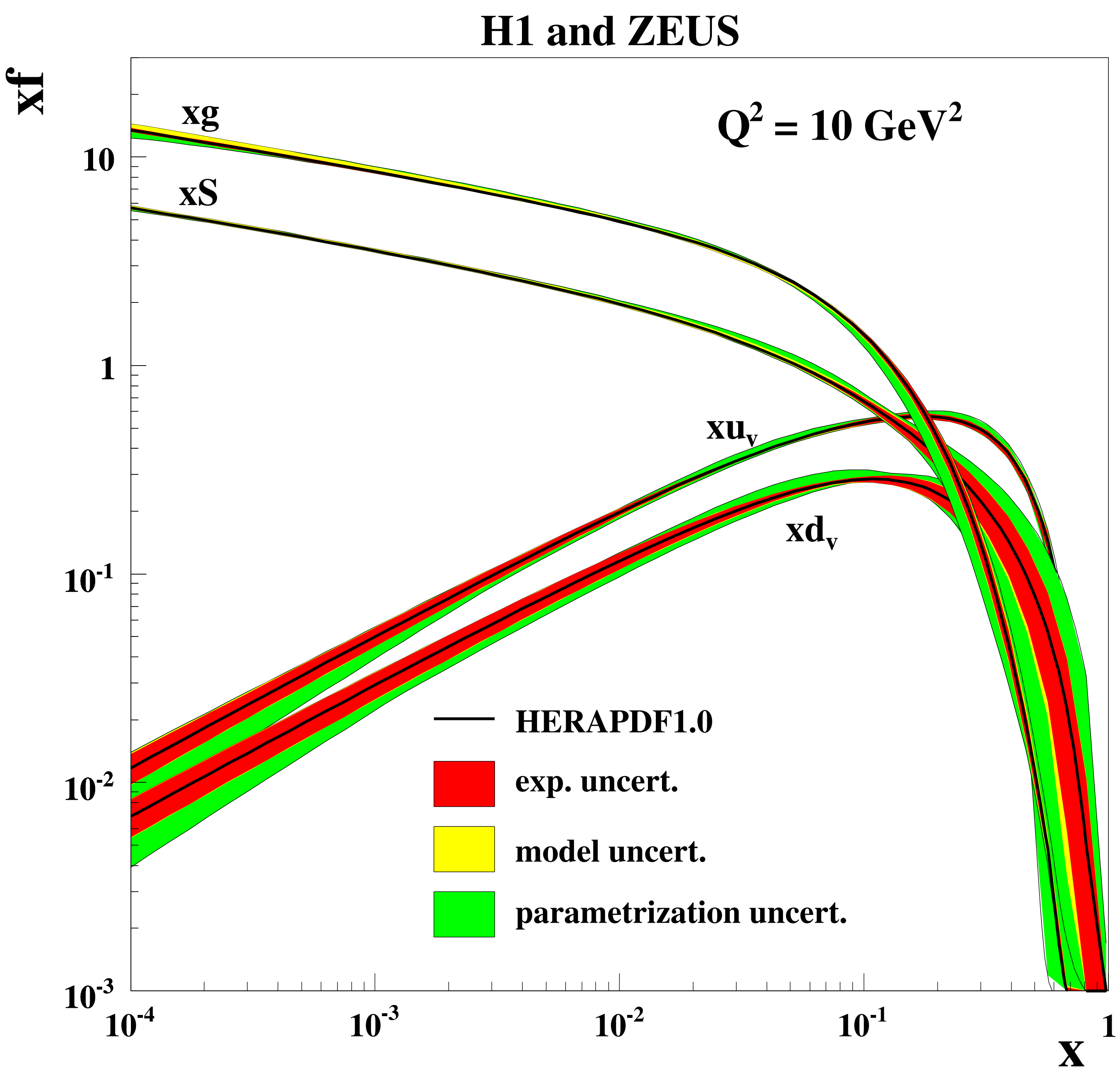
- **We are interested in studying the matter generated immediately after the collision** ($\tau = 0^+$)

Highly Energetic Heavy Ion Collisions

- At high energies the partonic content of protons and neutrons is **vastly dominated by a high density of gluons**



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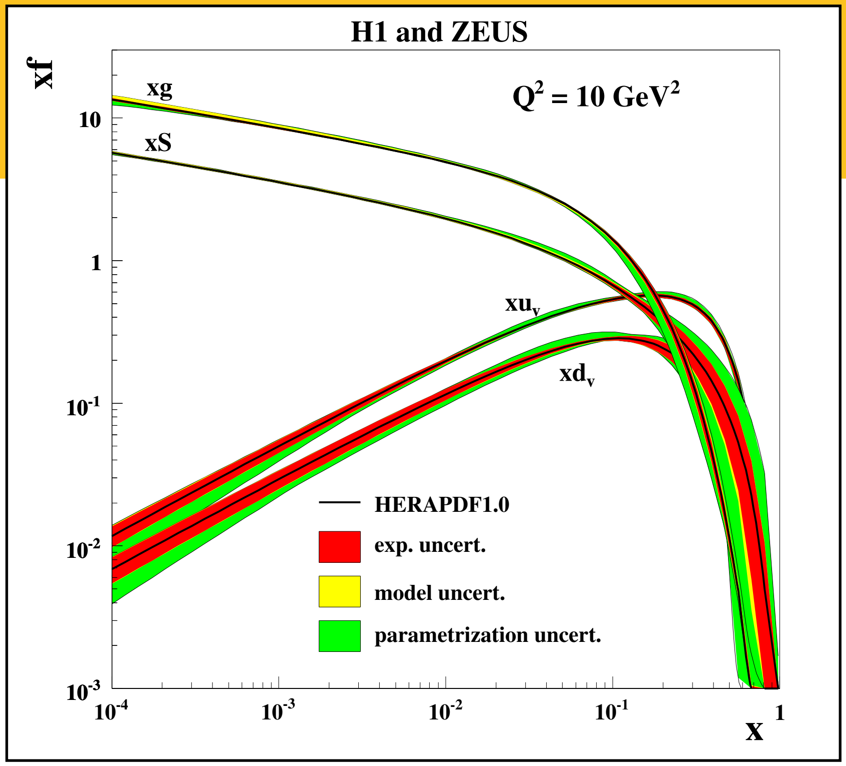
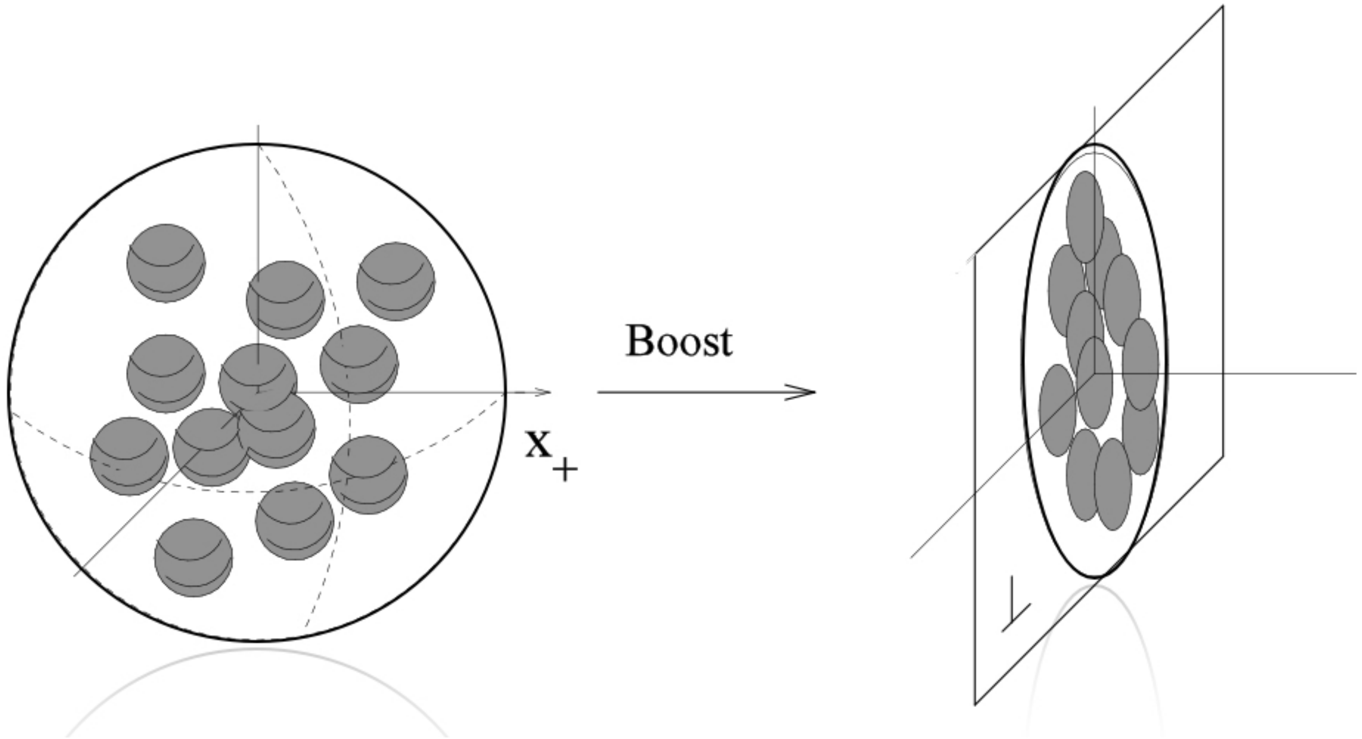


- At high energies the partonic content of protons and neutrons is **vastly dominated by a high density of gluons**

- Relativistic kinematics: at high energies, the nuclei appear almost two-dimensional in the laboratory frame due to **Lorentz contraction**



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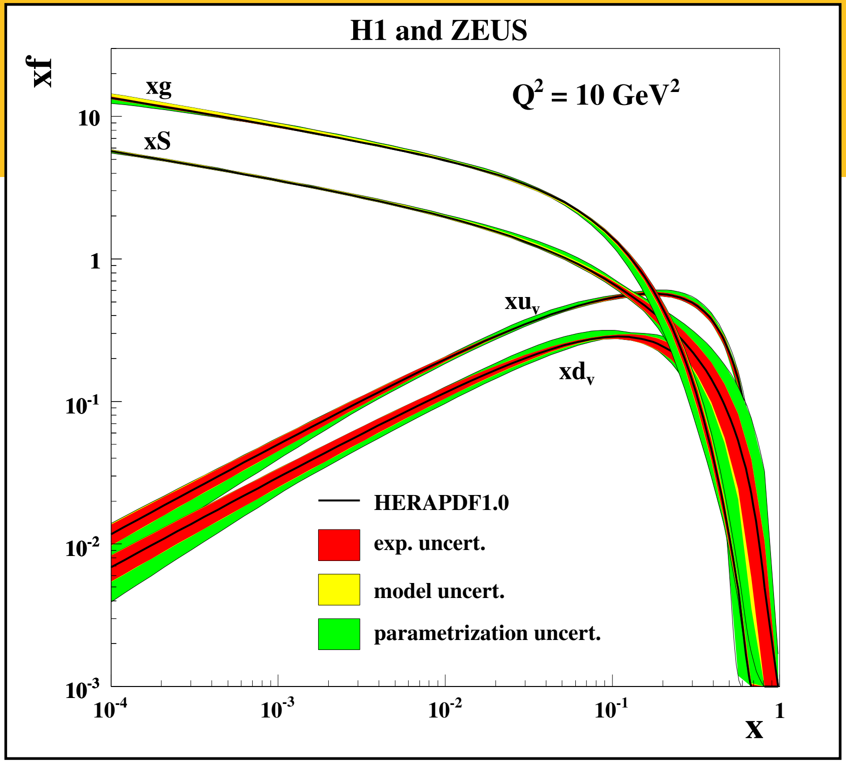

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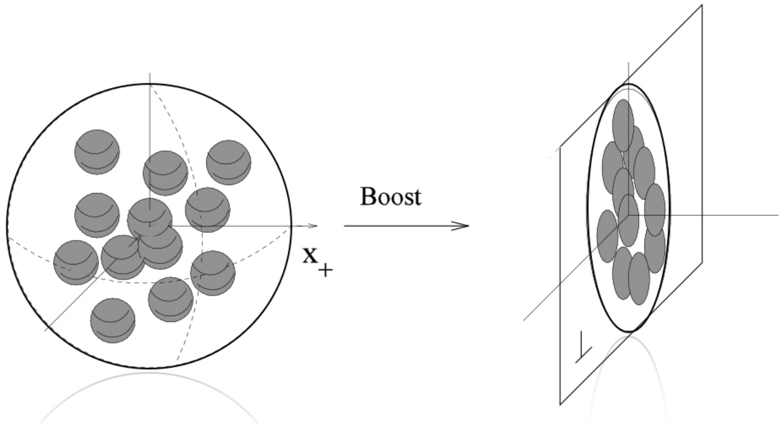
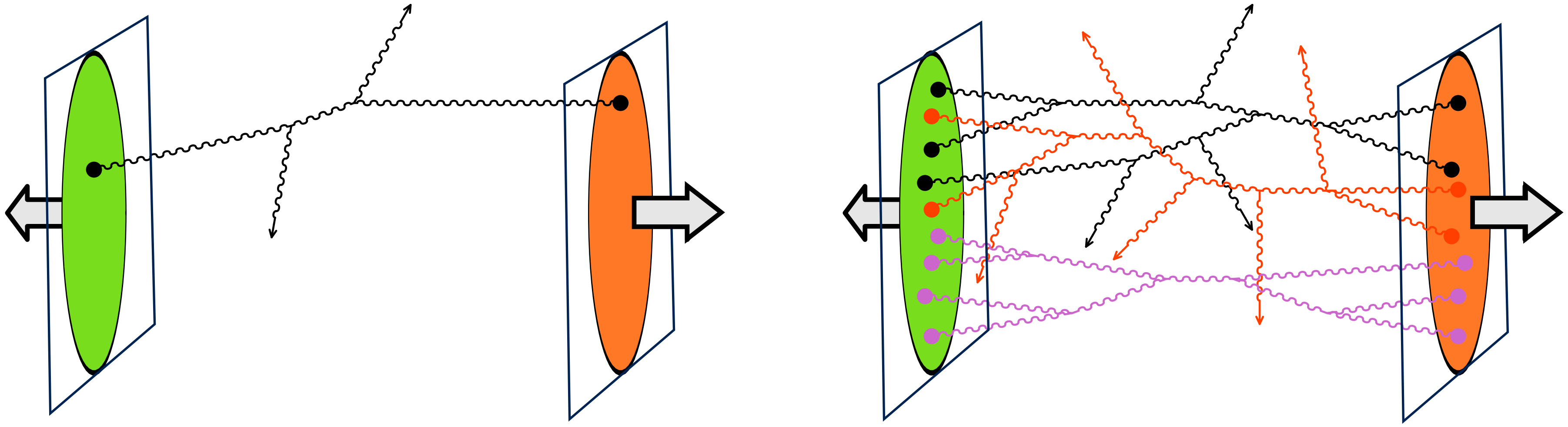
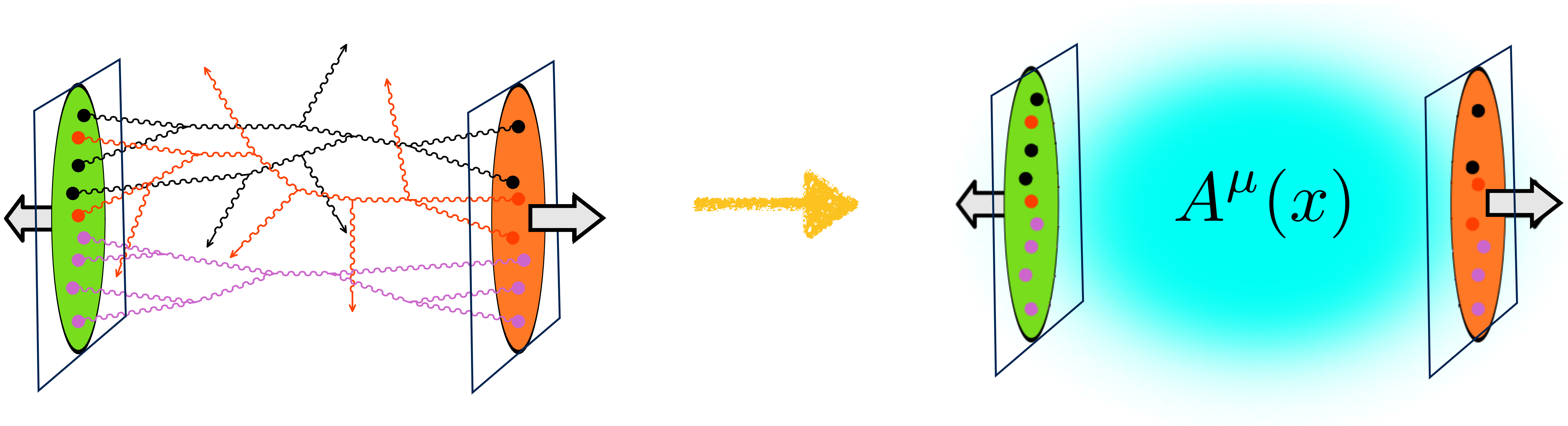


- QCD becomes **non-linear** and **non-perturbative**!



Color Glass Condensate

- We use an approximation of QCD for high gluon densities where we replace the gluons with a **classical field** generated by the valence quarks



- Dynamics of the field described by **Yang-Mills** classical equations:

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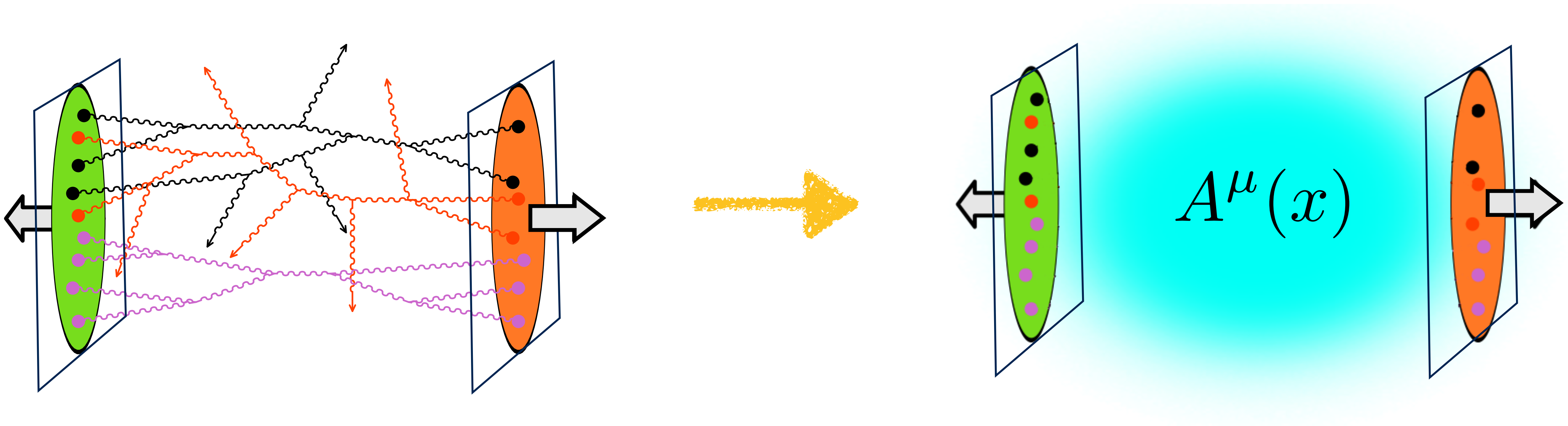

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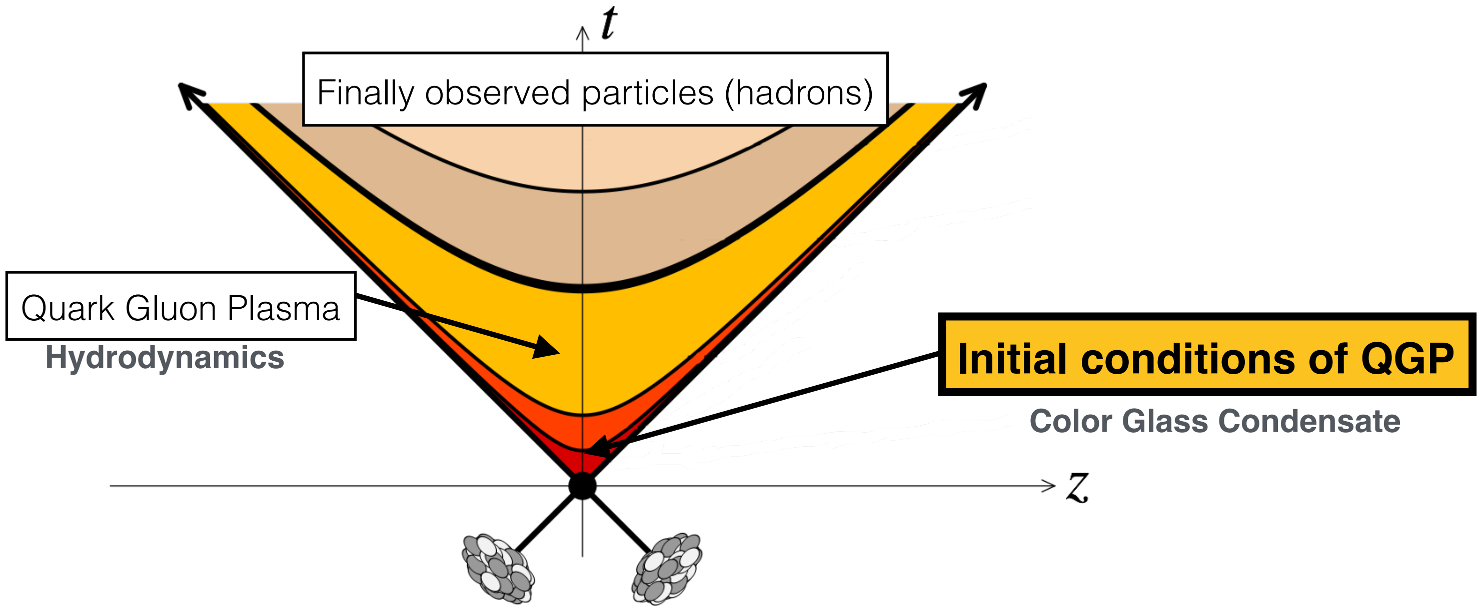
- Calculation of observables: **average** over background classical fields

$$\langle \mathcal{O}[\rho] \rangle = \int [d\rho] \exp\left\{ - \int dx \,\mathrm{Tr}\left[\rho^2\right] \right\} \mathcal{O}[\rho]$$

Computation of observables in the Color Glass Condensate



- Energy-Momentum Tensor:

$$T^{\mu\nu} = \frac{1}{4} g^{\mu\nu} F^{\alpha\beta} F_{\alpha\beta} - F^{\mu\alpha} F^{\nu}_{\ \alpha}$$

- Correlators:

$$\langle T^{\mu\nu} \rangle \propto \langle \epsilon_0 \rangle$$

$$\langle T^{\mu\nu} T^{\sigma\rho} \rangle \propto \langle \epsilon_0 \epsilon_0 \rangle$$

- Covariance:

$$\mathrm{Cov}[\epsilon_0] = \langle \epsilon_0(x_\perp) \epsilon_0(y_\perp) \rangle - \langle \epsilon_0(x_\perp) \rangle \langle \epsilon_0(y_\perp) \rangle$$

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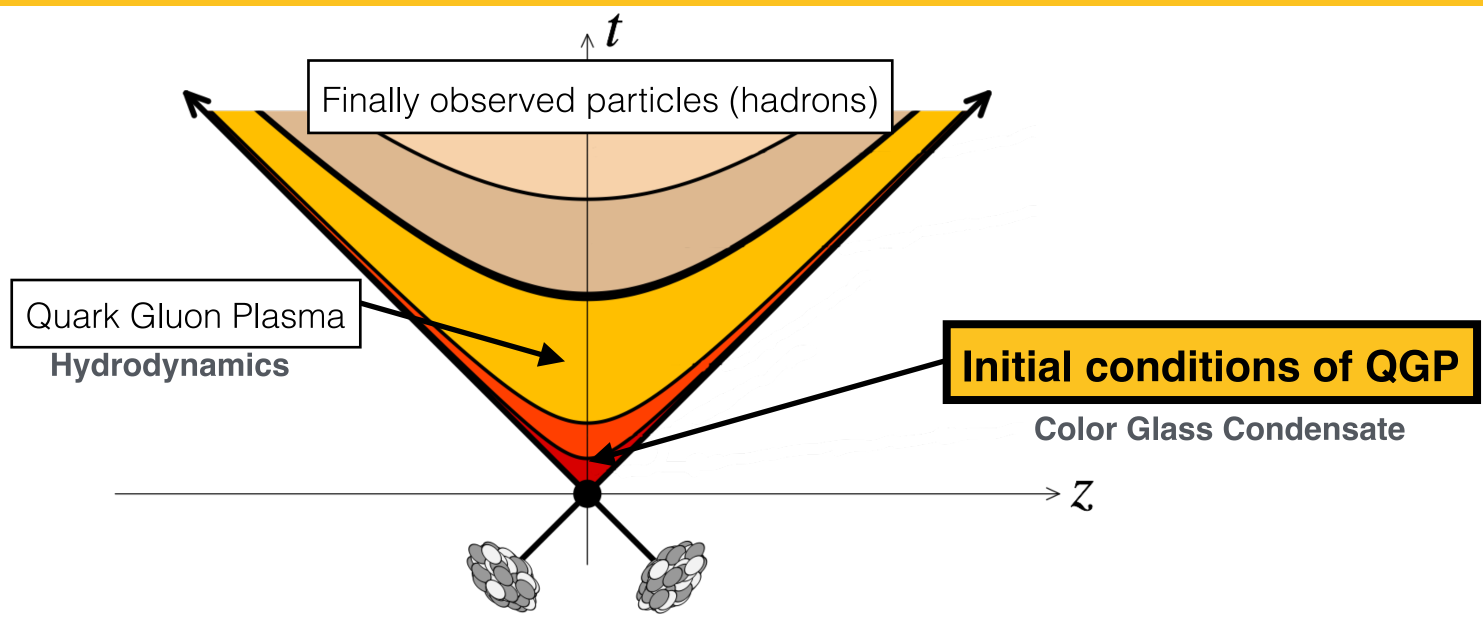

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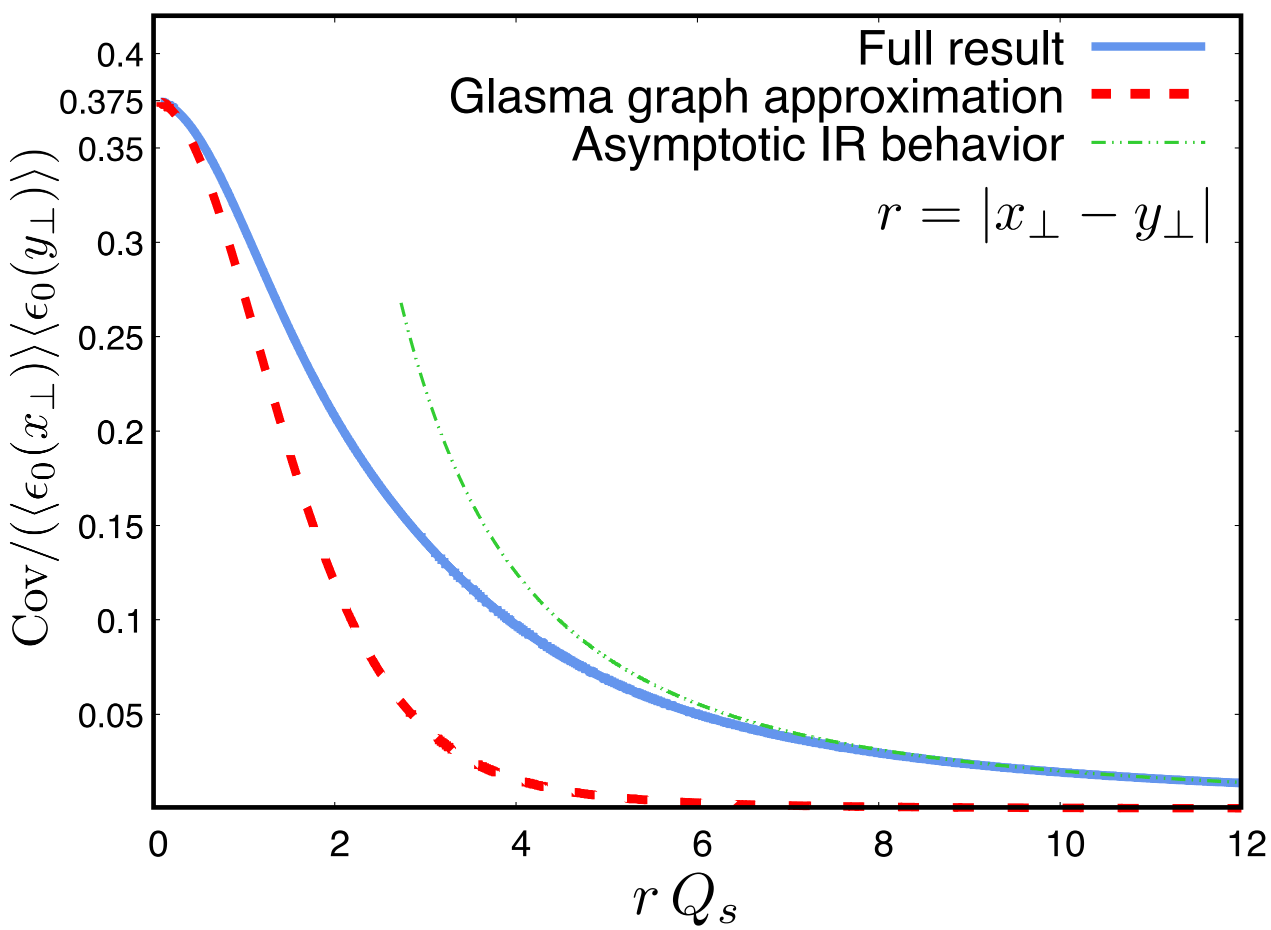

Glasma Graph result:

T. Lappi and, S. Schlichting, Phys.Rev. D 97, 034034 (2018)

What we find:

- Contrary to expectations, we obtain relatively large-range correlations ($1/r^2$ decay in the $r \to \infty$ limit).
- We show that, although the Glasma Graph result yields a good approximation in the $r \to 0$ limit, it quickly becomes unacceptable at larger distances.
- These results could have an impact in both physical interpretations and numerical results for any observable built from this quantity.

Future prospects

- The study just described presents a wide variety of applications and potential follow-up projects. Currently we are exploring the following lines of research:

  - Applying our results to the analytical calculation of **fluctuation eccentricities**.

  - Computing the **dilute-dense limit** of our expressions, which would have a direct application in the theoretical characterization of **proton-nucleus** collisions.

  - Applying the same framework in the calculation of **correlators of the divergence of the Chern-Simons current**, thus characterizing the generation of **axial charge** in the early stages of heavy ion collisions.

  - Computing the **time evolution** of our result towards thermalization time $\tau \sim 1/Q_s$, where it can serve as input for hydro QGP simulations.

$$T^{\mu\nu} = T_0^{\mu\nu} + T_1^{\mu\nu}\tau + T_2^{\mu\nu}\tau^2 + \dots$$

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thanks for your attention