Double Soft Gluon Emission in a Dense Quark–Gluon Plasma: Interference and Correlations

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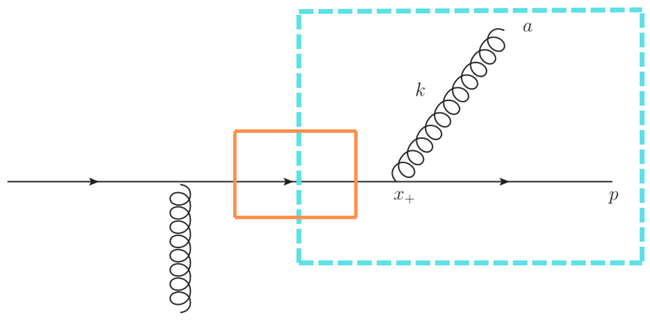
What we know

Gluonstrahlung: the basic unit

In vacuum, the most basic interaction one can think of is a quark emmitting a gluon



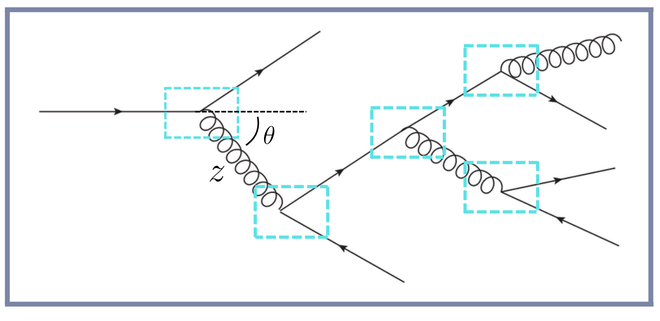
Soft Gluon approximation: $k \ll p$

$$\mathcal{M}_0^a \sim g_s \int dx_+ dx_\perp e^{ix_\perp \cdot (p+k)_\perp} \frac{\varepsilon_\perp(k) \cdot k_\perp}{|k_\perp|^2} T^a$$

QCD gauge coupling — Color algebra

Parton showers in vacuum

One can approach the parton shower behavior as multiple and sequential gluonstrahlung events

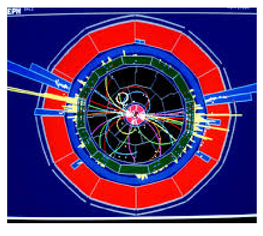


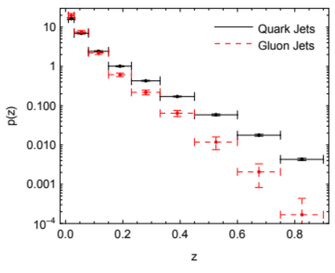
One can compute observables like the energy spectrum:

Stong Coupling constant — Casimir in Fundamental rep.

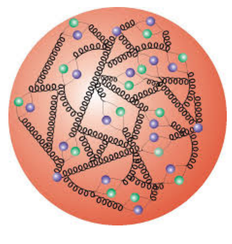
$$\frac{d^2N}{dzd\theta^2} \sim \frac{\alpha_s C_F}{\pi} \frac{1}{z\theta^2}$$

Azymuthal angle — Gluon Energy Fraction





The factorization of this process provides an accurate description of many properties observed in QCD jets, whose dynamics in vacuum are by now firmly established

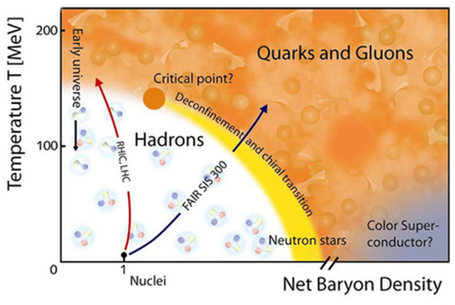


Quarks radiate gluons, evolving the parton shower, while they are enough energetic. Otherwise they get bound to each other in a process called Hadronization, which we know little

Problem: A colorful medium

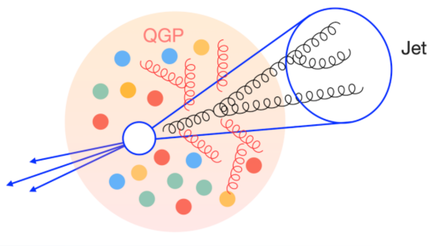
Quark-Gluon Plasma (QGP)

A state of matter from the early Universe where quarks and gluons moved freely, recreated today in heavy-ion collisions at the LHC



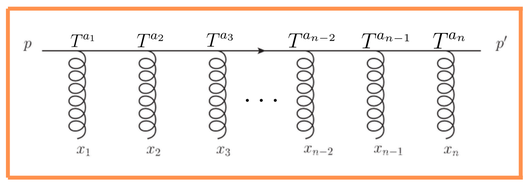
By studying how energetic particles traverse this medium, we can uncover its properties and test the strong force under extreme conditions

Jet Quenching



Parton Propagation in the QGP

Quarks and gluons scatter off the medium constituents → Need to redefine propagators → Wilson Line

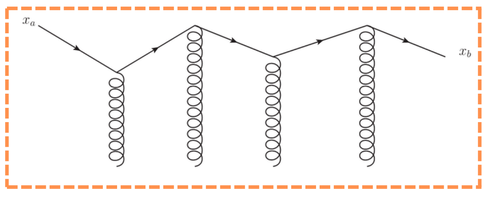


$$W(x_\perp) = \sum_{k=1}^{n} \frac{1}{k!} \mathcal{P} \left[ig \int dx_{k+} A_-^{a_k}(x_{k+}, x_\perp) T^{a_k} \right]^k$$

Eikonal Approximation

$$S(p,p') \sim \delta(p'_\perp - p_\perp) p_+ \int dx_\perp e^{-ix_\perp \cdot (p'-p)_\perp} W(x_\perp)$$

Relaxing the approximation



$$G(x_a, x_b) = \int_{x_a}^{x_b} \mathcal{D}r(x_+) \exp\left[i \frac{p_+}{2} \int dx_+ \left(\frac{dr}{dx_+} \right)^2 \right] W(r)$$

Allows variations in the transverse plane

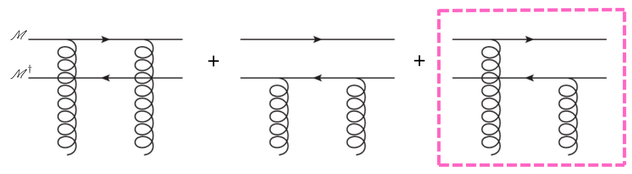
One can repeat the calculation of the emission of one soft gluon in the medium using these objects

Color Interference

In order to compute observables one needs to average over the ensemble

$$Tr \left\langle W^\dagger(x_\perp) W(y_\perp) \right\rangle$$

Local correlators measure optical-like interference patterns between partons



Interference Cross-section

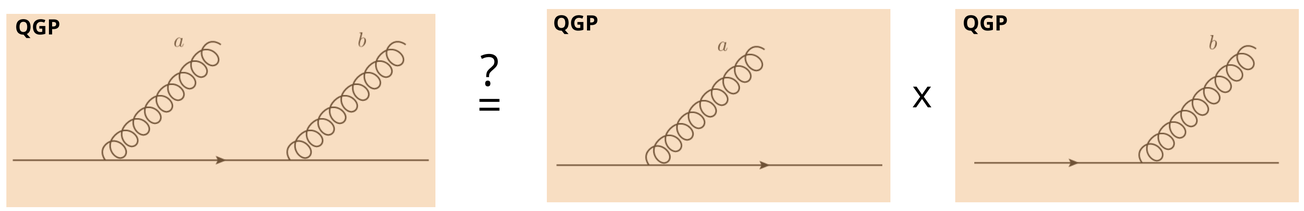
$$Tr \left\langle W^\dagger(x_\perp) W(y_\perp) \right\rangle \simeq \exp\left[-\frac{C_F}{2} \int dx_+ n(x_+) \sigma(x_\perp - y_\perp) \right]$$

Medium Configuration

$$\mathrm{Tr} \left\langle W^\dagger(s_1) W(s_2) \ldots W(s_n) \right\rangle \xrightarrow[N_c \gg 1]{} \mathrm{Tr} \left\langle W^\dagger(s_i) W(s_j) \right\rangle \ldots \mathrm{Tr} \left\langle W^\dagger(s_k) W(s_l) \right\rangle$$

One can simplify any n-point function by taking the large N_c limit

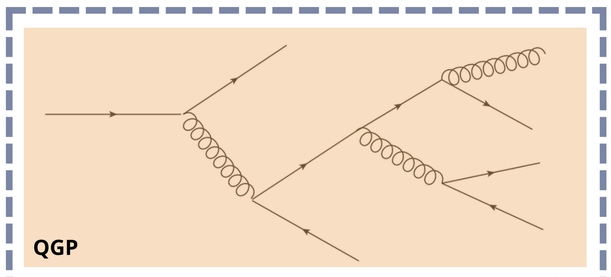
Double Gluon emission



When two gluons are emitted inside the QGP, they can either behave like independent emissions or interfere with each other

Understanding when interference matters is crucial allow us to check if (or when) interferences can be neglected

If so, parton showers in the QGP could be treated much like those in vacuum, greatly simplifying their description



Future work

- Calculating the parton correlators and evaluate the leading order
- Simplifying the n-point functions and computing observables like the energy spectrum
- Considering if parton showers in QGP can be factorized like the ones in vacuum

$$? \; |\mathcal{M}_{\text{double}}|^2 \simeq |\mathcal{M}_a|^2 \times |\mathcal{M}_b|^2 \; ?$$

References

- Apolinário, L., Armesto, N., Milhano, J. G., & Salgado, C. A. (2015). Medium-induced gluon radiation and colour decoherence beyond the soft approximation. JHEP, 2015(2), Article 119
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