Theory and phenomenology of radiative energy loss processes in nuclear collisions

François Arleo

LLR Palaiseau

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Context

Hard QCD processes in pA collisions allow for probing nuclear effects:

- nuclear Parton Distribution Functions (nPDF)
  - PDF modified in nuclei $f_i^{\mathrm{A}}(x, Q^2) \neq A\, f_i^{p}(x, Q^2)$
  - nPDF extracted from data global fits, assuming collinear QCD factorization in pA collisions to be valid for all observables

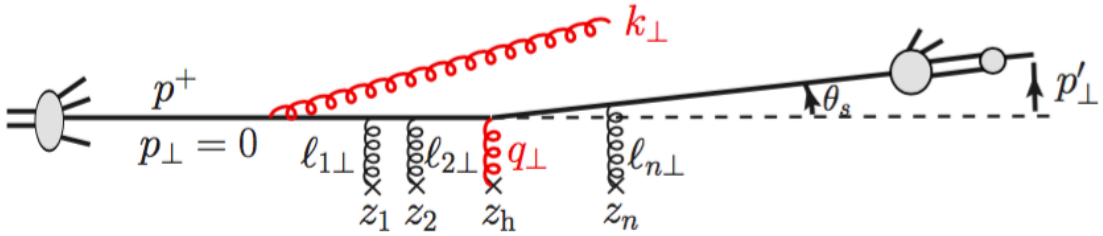
    cf. Ingo Schienbein, Mon 7, 11:40
- Energy loss processes
  - Multiple scattering in nuclei induce radiation, leading to energy loss
  - Affects hadron production in pA collisions at all energies
  - Effect beyond collinear factorization

☞ How to study separately both effects ?

Fully Coherent Energy Loss (FCEL)

Energy loss in nuclear matter revisited: **fully coherent regime**

[FA Kolevatov Munier Peigné Rustamova Sami 2010-2020]



- New regime predicted from first principles in QCD
  - Better understanding of in-medium QCD radiation
- FCEL affects the production of **all hadron species** in pA collisions
- Important consequences for the phenomenology of pA collisions
  - quarkonia, light hadrons, open-heavy flavour hadrons. . . and even neutrinos from hadron decays in cosmic ray air showers
- FCEL spoils a clean extraction of nuclear parton densities
  - consequences on the prediction of hard processes in heavy-ion collisions

Some highlights (1/2)

- Rigorous calculation of the medium-induced gluon spectrum for a generic $ab \to (cd)_R$ hard process

$$\omega \left.\frac{dI}{d\omega}\right|_{ab\to(cd)_R} = (C_a + C_R - C_b)\,\frac{\alpha_s}{\pi}\left[\ln\left(1 + \frac{\hat{q}L}{M_\xi^2}\frac{E^2}{\omega^2}\right) - \text{pp}\right]$$

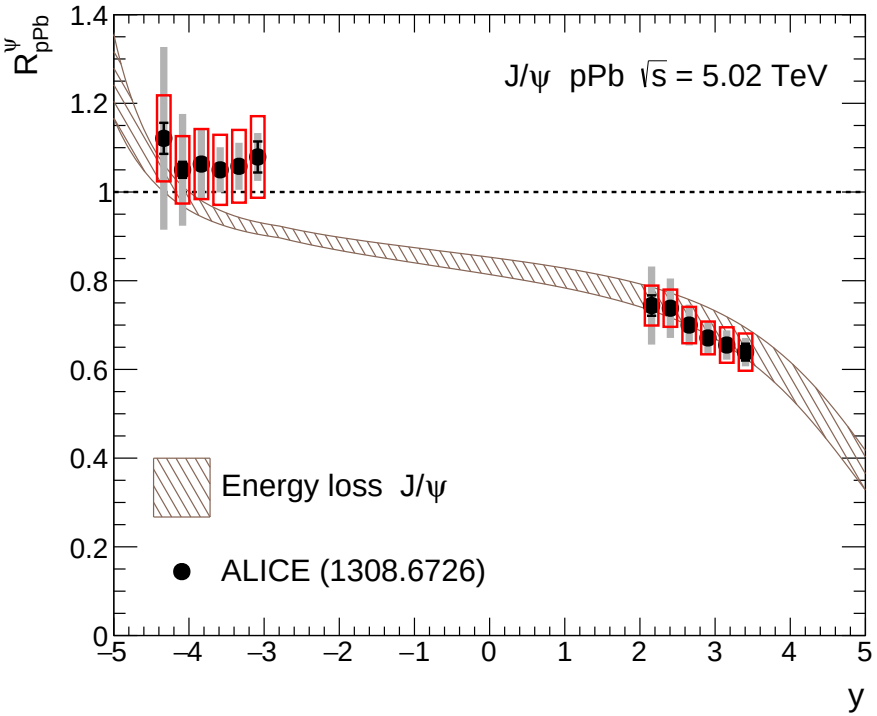
  - Derived in the opacity expansion and saturation formalisms
  - Leads to energy loss **proportional to parton energy** E

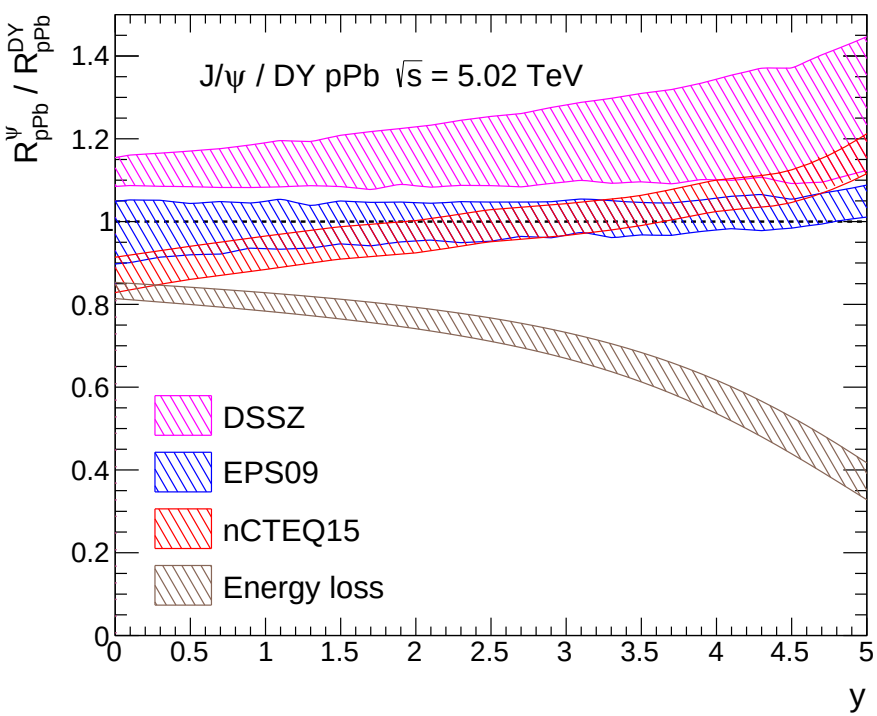
$$\Delta E_{\text{FCEL}} \propto \alpha_s \,\frac{\sqrt{\hat{q}L}}{M_\xi}\, E \quad (\gg \Delta E_{\text{LPM}})$$

  - Depends on the global color charge of the final state R

Some highlights (2/2)

- Successful phenomenology of hadron production in pA collisions
  - Solves mystery of quarkonium suppression observed at all energies
  - Extension to light and open heavy-flavour hadron production
- Suggesting Drell-Yan as a golden process to disentangle nPDF/FCEL





Collaboration

- F. Arleo, G. Jackson, R. Kolevatov, S. Munier, S. Peigné, M. Rustamova, T. Sami, K. Watanabe [red = student/postdoc]
- Strong links with experimental groups: CMS (LLR), LHCb (LLR), ALICE (Subatech)
- Exchanges with nPDF groups: nCTEQ15 (e.g. J.-P. Lansberg, I. Schienbein, H.-S. Shao in France), EPPS16 (Finland/Spain)
  - preliminary discussions on feasibility with I. Schienbein

Projects

- nPDF global fits including FCEL
  - Crucial need for reliable extraction of parton densities
  - Interesting theoretical, phenomenological and numerical aspects
- Explore FCEL effects on cosmic ray air showers
  - Preliminary results on FCEL effects on prompt and conventional neutrino flux to be compared with IceCube upper limits
- Collaboration with S. Peigné and K. Watanabe (Subatech) and G. Jackson (INT Seattle)