Open heavy-flavor and heavy-jet study from the LIDO transport model

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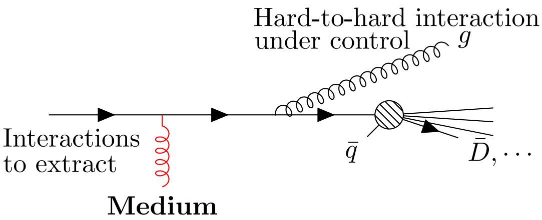
Transport of heavy quark

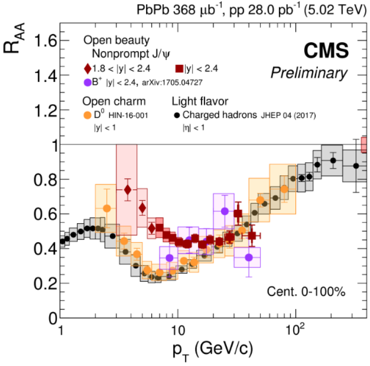


- Production from hard vertices.
- Flavor-tagged hadronization and decay channels.
- Hard-to-hard splitting under theoretical control.
- The interest: interaction between the heavy-quark and the deconfined QGP medium? Transport parameters $D_s, \hat{q}, \cdots$.

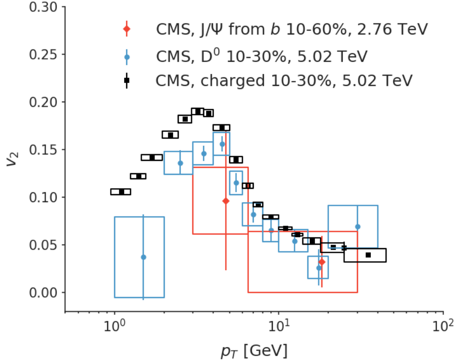
Nuclear modification and momentum anisotropy

If we focus on inclusive production of a heavy-flavor particle.

Suppressed yield at fixed p_T.



Non-zero momentum anisotropy.



Bayesian extraction of transport parameter in a transport model

How does these observables converts into the knowledge of HQ-medium interaction?

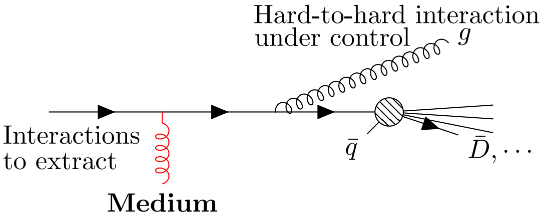
Qualitatively:

- R_{AA}: energy-dependence of energy loss.
- High-p_T v_2: geometry (path) dependence of energy loss.
- Low-p_T v_2: need rather strong coupling to the medium so that charm meson can almost flow with the medium.

Quantitatively:

- Couple transport models to realistic medium evolution.
- Use Bayesian method to extract transport model parameters $(\alpha_s, \hat{q}, \cdots)$.
- Propagation of experimental / theory uncertainty.

A brief review of the LIDO linearized partonic transport model [1]



- Elastic process: small-angle diffusion plus large-angle collisions.

- Diffusion dynamics solved by a Langevin equation

$$\hat{q}_S \sim \alpha_s C_R m_D^2 T \ln\left(1 + \frac{Q_{\rm cut}^2}{m_D^2}\right) + \cdots$$

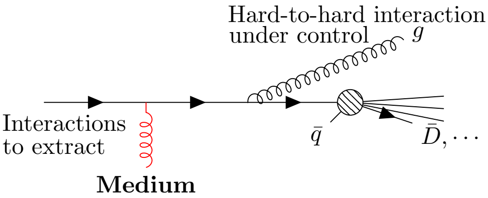
- Large-q processes treated in a linearized Botlzmann equation.

$$\frac{dP}{dt} \sim \int_{Q_{\rm cut}^2}^{6ET} \frac{\alpha_s m_D^2 T}{q^4} dq^2$$

- Interpolate between the two descriptions by tuning $Q_{\rm cut}$.

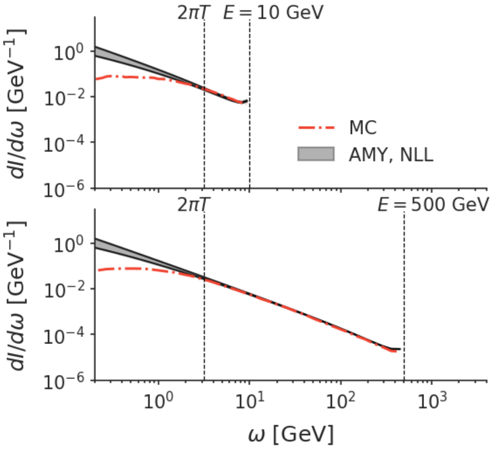
[1] PhysRevC.100.064911

A brief review of the LIDO linearized partonic transport model



- Medium-induced parton radiations.
- Implementation of LPM and finite size effect.

- Implementation well tested in simple medium.

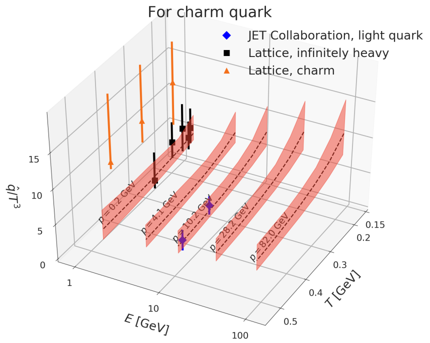


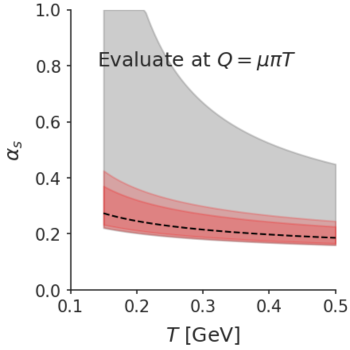
$\alpha_s = 0.3$

What has been learned from Bayesian analysis on HF?

From calibration to open-heavy-flavor R_{AA}, v_2,

- The temperature and momentum dependence of $\hat{q}$ with uncertainty.
- The perturbative coupling strength $\alpha_s(Q, T)$ for radiative and large-q elastic processes.





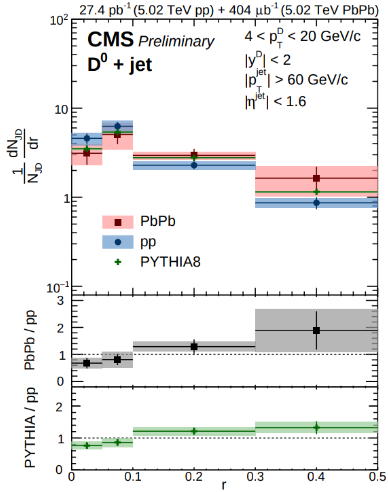
Things remain to be improved / answered:

- To further reducing the uncertainty, it is useful to have a handle on the relative contribution from radiative v.s. elastic energy loss.
  - Elastic energy loss: $\Delta E/\Delta t \sim \hat{q}(E,T)/T$.
  - Radiative energy loss depends on both $\alpha_{s,\mathrm{rad}}$ and $\hat{q}(E,T)$.
- Can we ask more details of the interaction beyond a $\hat{q}$ number.
  - Diffusion dominated or large-q process dominated.

The tool to be examined: heavy flavor jet.

Heavy-flavor – jet correlation

- The heavy flavor jet provides a preferred direction and hard scale of the hard event where the heavy quark is created.
- Energy-energy correlation: heavy-flavor jet fragmentation function.
- Angular correlation: heavy-flavor radial distribution around jet.
- Do they contain additional information on HF transport properties?



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An ideal case: heavy-flavor correlation with its initial momentum

Before considering HF-jet correlation, investigate a simpler problem: **HF correlation with its initial momentum.**

- Initial charm quark momentum obtained form pythia.
- Medium: Pb+Pb 0-10% event-averaged hydrodynamics.
- Including hadronization effect.
- Compare the change in the distribution of $x = p_T^D / p_T^{c,\mathrm{init}}$ and $\Delta r = \sqrt{(\phi_D - \phi_c)^2 + (\eta_D - \eta_c)^2}$

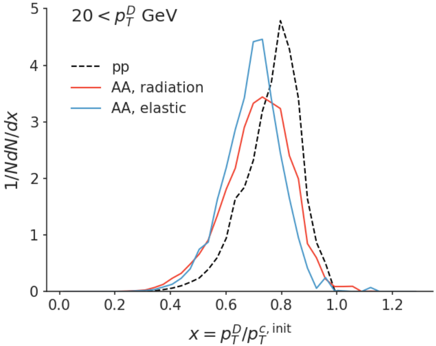
Initial charm-quark momentum is not an observable, but this shall provide insights on what information may / may not survive in HF-jet correlations.

Sensitivity to the relative contribution of elastic v.s. inelastic process

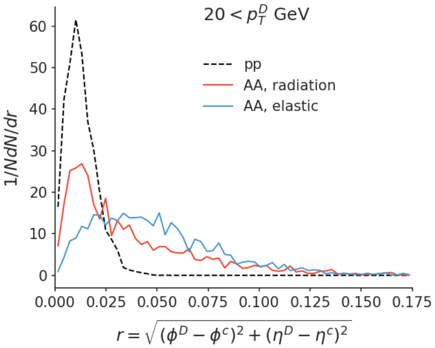
Red: Radiative energy loss only, Blue: Elastic energy loss only

Both cause $\sim$ 3.5 GeV loss in energy for considered p_T range.

Similar p_T correlations



Different angular correlations:



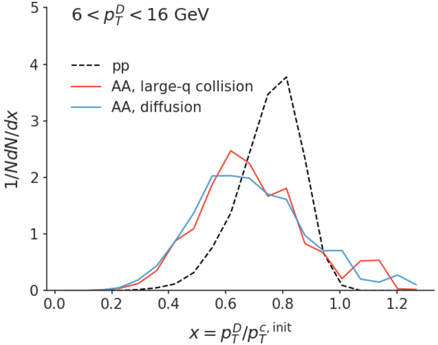
To cause similar energy loss, radiation is more collinear than elastic recoil.

This difference may survive in realistic HF-jet correlation to provide information on elastic v.s. radiative contribution.

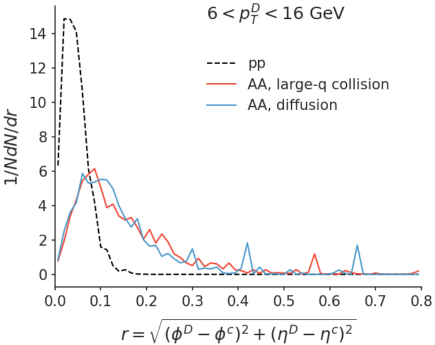
Sensitivity to the nature of the elastic interaction

Red: large-q, Blue: diffusion.
Both cause ~ 5 GeV loss in energy for considered p_T range.

Very similar p_T correlations



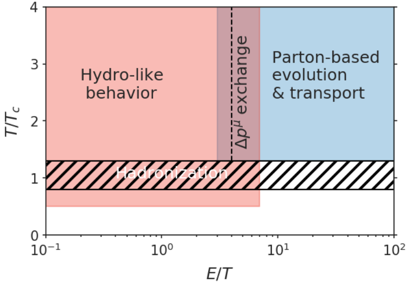
Very similar angular correlations



Not likely to tell the nature of elastic collision from HF-jet correlation

Inclusive jet

- Initialize all partons momentum from pythia.
- In-medium partonic transport, including hard recoil particles, $\alpha_s(\max\{Q, 2\pi T\})$.
- Soft recoil particles $(E < 5T)$ and energy-momentum loss due to diffusion process are propagated by a simple ansatz for medium excitation.



- Medium excitation is important for the energy-momentum conservation of model prediction.

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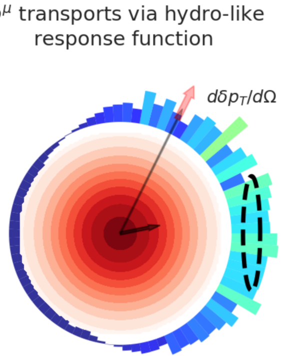

- Medium excitation is important for the energy-momentum conservation of model prediction.
- A simple ansatz to redistribute energy momentum deposition in the solid angle Ω in the Bjorken frame.

$$\frac{de}{d\Omega} \sim \frac{\delta p^0 + \hat{\Omega}\cdot\delta\vec{p}/c_s}{4\pi}, \quad \frac{d\vec{p}}{d\Omega} \sim \frac{3(c_s\delta p^0 + \hat{\Omega}\cdot\delta\vec{p})\hat{\Omega}}{4\pi}$$

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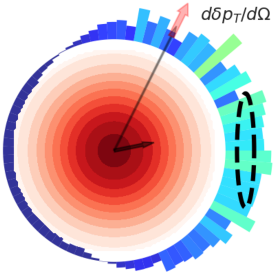
δp^μ transports via hydro-like response function



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- $\Delta p_T/\Delta\eta\Delta\phi$ by freezeout with avg. $v_{\mathrm{radial}} \sim 0.6$.

Inclusive jet

- Initialize all parton's momenta from pythia.
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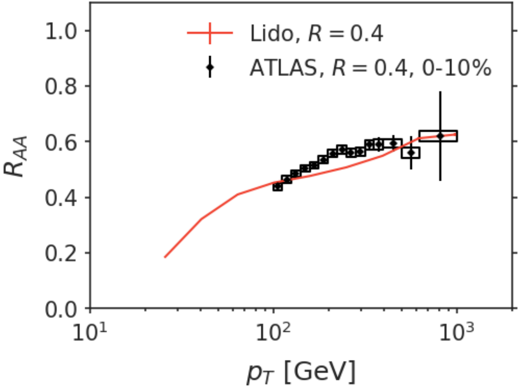
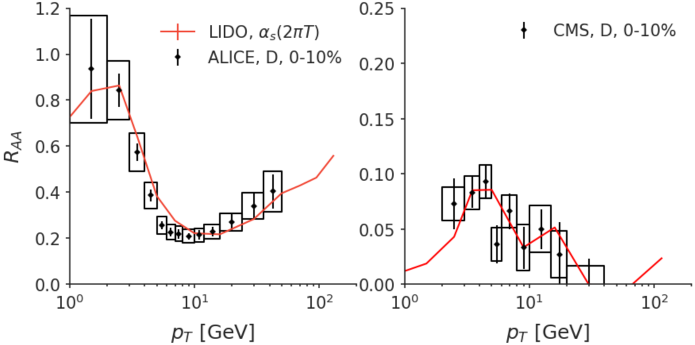


ATLAS, Phys.Lett. B790 (2019) 108-128

The open heavy-flavor transport sector

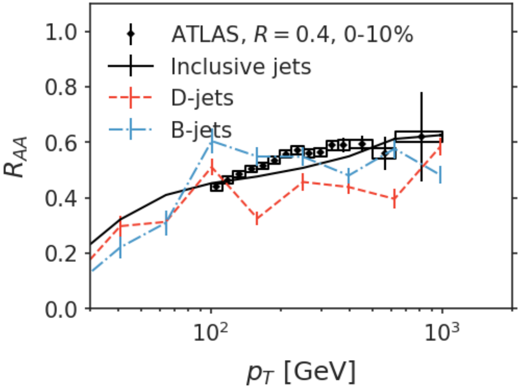
- Initialize heavy quark momenta from Pythia.
- In-medium transport using coupling constant $\alpha_s(\max\{Q, 2\pi T\})$ (not the best tune parameter from Bayesian analysis).



ALICE, JHEP10(2018)174

Heavy-jet

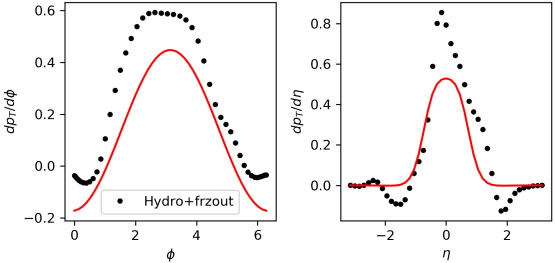
- Initialize all partons momentum from pythia.
- Currently only consider fragmentation hadronization of heavy quarks.
- Work in-progress:
  - Use the best-fit transport coefficients for both heavy and light flavors.
  - D-jet, b-jet angular correlation.



Summary and work in-progress

- Bayesian analysis on open-heavy-flavor observables extracts the T & p dependence of heavy quark $\hat{q}$.
- Relative contribution of elastic & radiative energy loss have additional constrain.
- HF angular correlation with the initial production direction (or jet) may help to provide this additional information.
- Using the Lido model, we perform a preliminary study on inclusive jet and heavy-flavor jet production in Pb+Pb at 5TeV.
- Work in-progress: look for the signal of elastic versus radiative energy loss for bottom and charm flavor in realistic HF-jet correlation.

Back-up



0.6
0.4
0.2
0.0
−0.2
$dp_T/d\phi$
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Hydro+frzout
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0.0
$dp_T/d\eta$
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2
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