Building a systematic primer for the rescattering of heavy flavor hadrons

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1. Motivation

- Hadronic rescattering affects observables: p_T spectra and v_n, quarkonia suppression, IMR dilepton yields [1-3]
- No agreed-upon description or *systematic* study for interactions of HF hadrons
- Precision era ⇔ controlled hadronic effects
- **Call for attention:** consequences of rescattering on HF observables with a toy-model for a system post-hadronization

Uncertainties & difficulties

- How do we determine and model the relevant channels?
- Can we treat resonances as independent and distinct?
- Interaction cross sections with HF not directly measurable
- Lack of data on resonance properties (mass, width) [4]

2. SMASH

Simulating **Ma**ny **S**trongly-interacting **H**adrons

- Evolve hadrons with Boltzmann equation [5]

$$p^\mu \partial_\mu f_i(x,p) = C_i^{\text{coll}}[f]$$

- Isotropic and elastic collision term

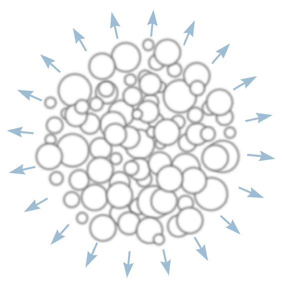
$$C^i_{2\leftrightarrow 2}[f] = \sum_j \int |\mathbf{p}'_i - \mathbf{p}'_j| \underline{\sigma_{ij}(s)} [f(\mathbf{p}'_i) f(\mathbf{p}'_j) - f(\mathbf{p}_i) f(\mathbf{p}_j)]\, \mathrm{d}^3\mathbf{p}$$

- Elastic cross sections from Additive Quark Model

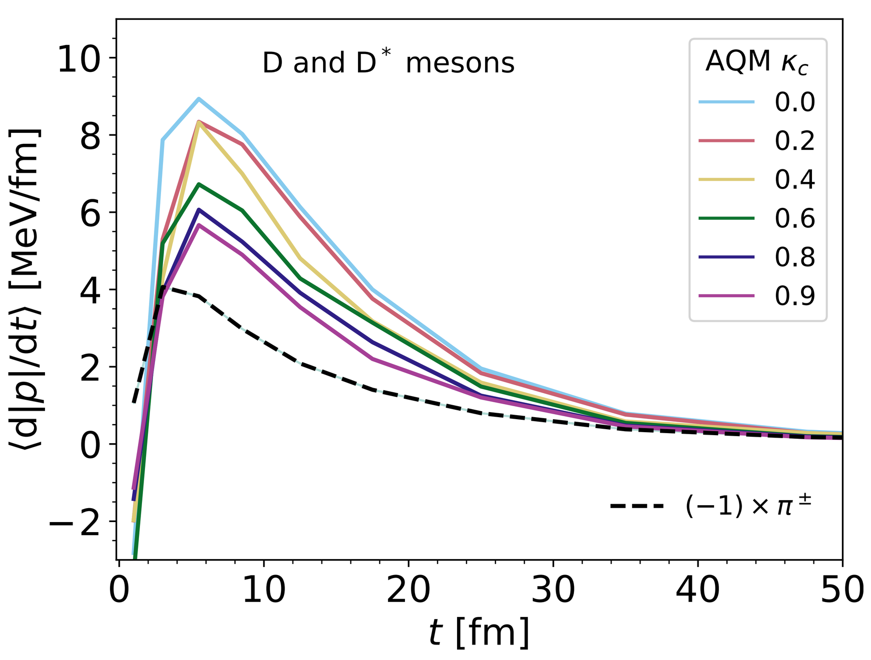
$$\underline{\sigma_{AB}} = \sigma_{pp} \frac{n_q^A}{3}\frac{n_q^B}{3}(1-0.4x_s^A)(1-0.4x_s^B)(1-\kappa_c x_c^A)(1-\kappa_c x_c^B)$$

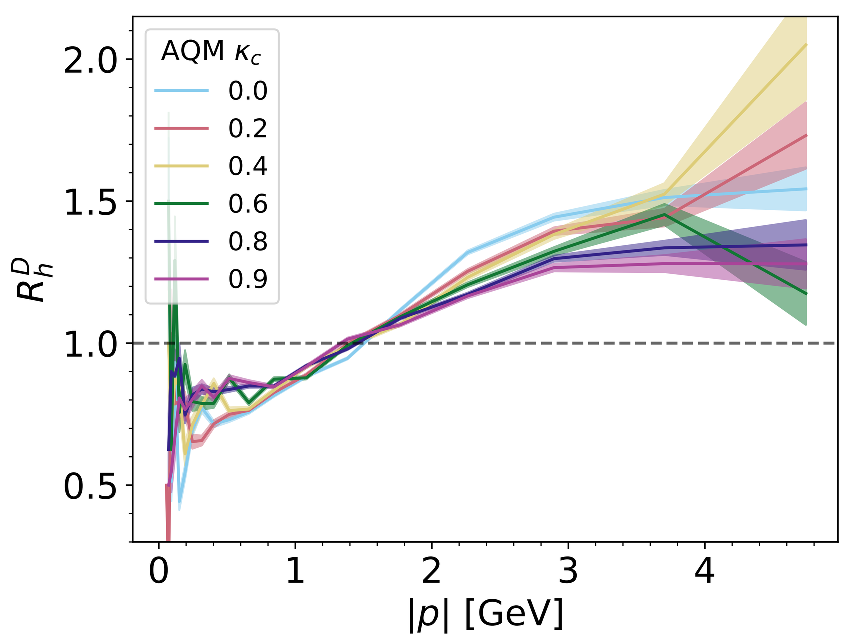
- $\kappa_s = 0.4$ from experimental fits, no known value for κ_c

3. Thermalized sphere



- Simplest toy-afterburner
- Mimic late stage thermodynamics of Pb+Pb at $\sqrt{s_{NN}} = 2.76$ TeV:
  - ⋆ SHM: $T = 157$ MeV and $r = 10.9$ fm [6]
  - ⋆ Blast wave: $u_0 = 0.65$ [7]





- Change in momentum increases with cross section
- Pion wind: D mesons pushed by lower mass particles
- Kinetic freezeout at $t_{kf} \sim 45$ fm

"Hadronic" modification factor

Multiplies R_{AA} in frameworks without rescattering

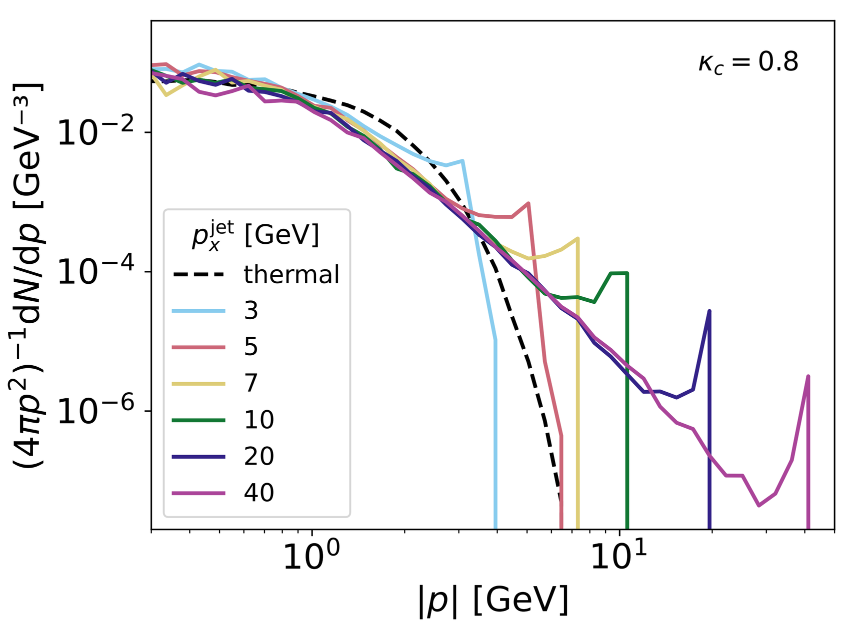
$$R_h \equiv \frac{\mathrm{d}N}{\mathrm{d}p}(t_{kf}) \Big/ \frac{\mathrm{d}N}{\mathrm{d}p}(t_{sw})$$

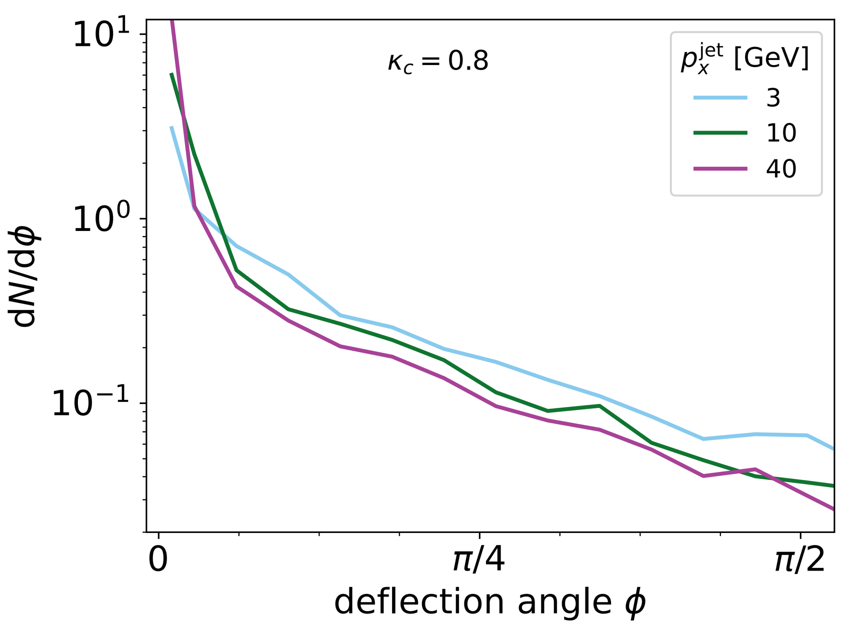
4. "Jets"

- In reality: HF is not thermal!
- Charmed hadrons start off faster than light hadrons
- Here: one per SMASH event

Our *jet*

A single D meson propagates fast in the x-direction from the origin, only scatters elastically without radiating





Hint of thermalization

- Rescattered particles from jets follow universal curve
- *Slow* particles insensitive to initial condition

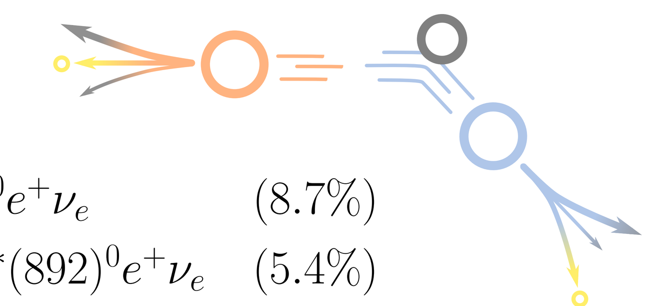
- Little deflection even though most momentum is lost
- Slower jets more likely to be deflected to larger angles
- Similar results if inelastic interactions are included

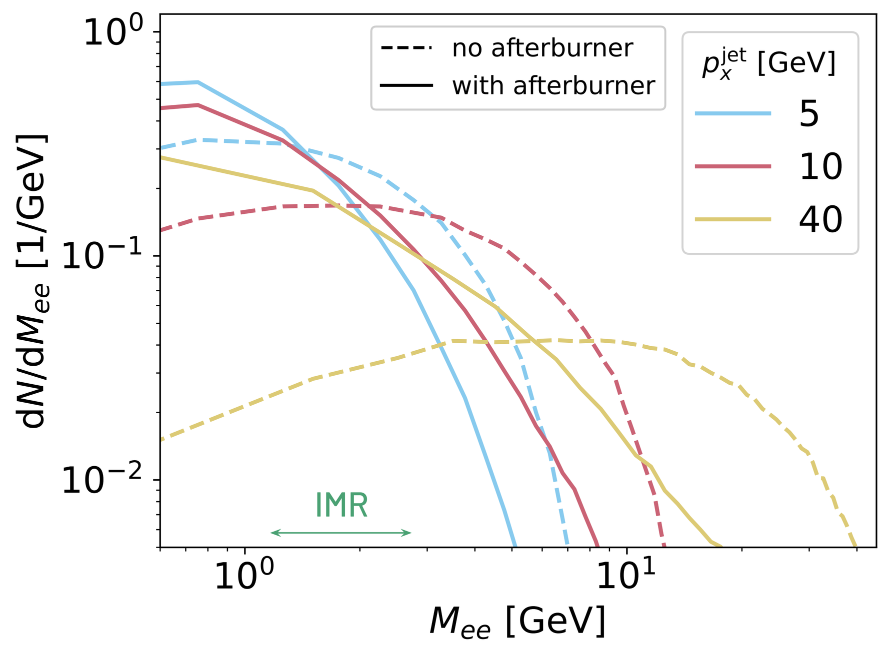
Hadronic jet quenching may modify extraction of $\hat{q}$!

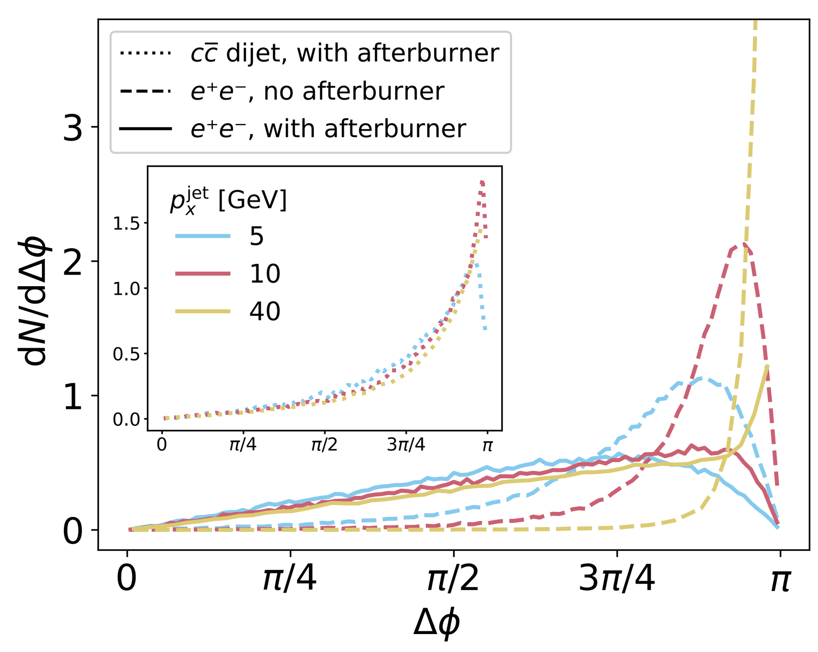
5. IMR Dileptons

- $1.2 < M_{ee} < 2.6$ GeV: large background from semileptonic decays of correlated HF pairs
- Back-to-back D^+D^- jets
- Isotropic and unpolarized decays

$$\begin{cases} D^+ \to \bar{K}^0 e^+ \nu_e & (8.7\%) \\ D^+ \to \bar{K}^*(892)^0 e^+ \nu_e & (5.4\%) \end{cases}$$







Vacuum

- Independent Dalitz decays: indirect dilepton and large spread in M_{ee}
- Distribution of opening angle sensitive to jet momentum

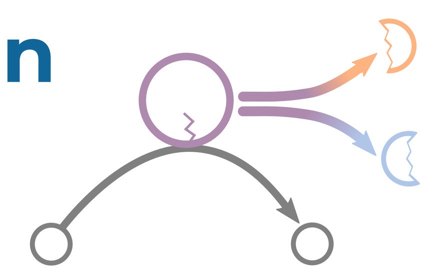
Afterburner

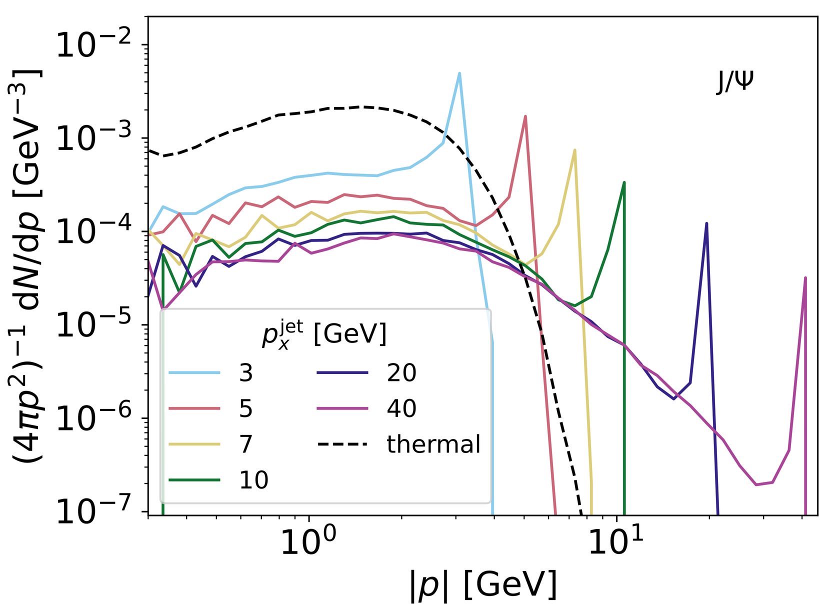
- Available phase space shrinks
- Lower M_{ee} enhanced for fast jets
- Decorrelated away from $\Delta\phi \approx \pi$
- May worsen track reconstruction and signal-to-background ratio

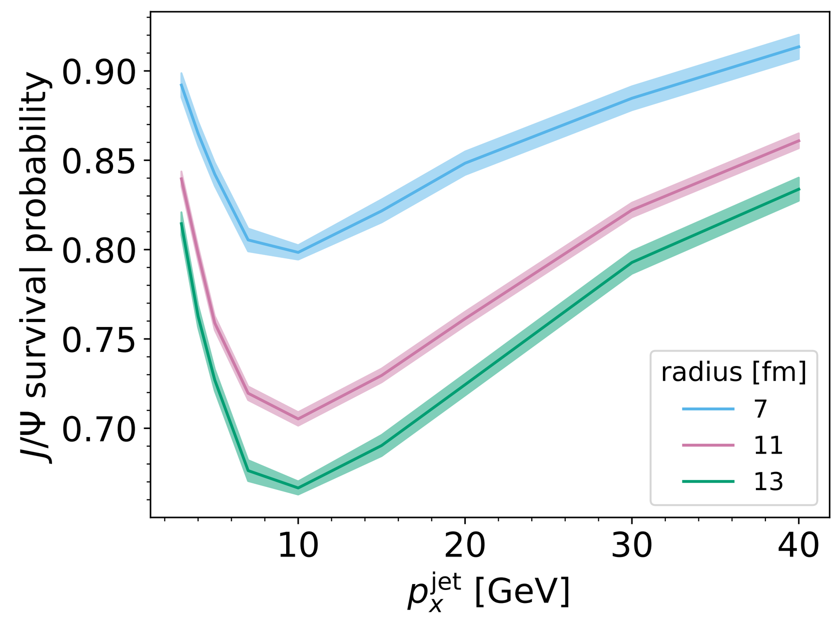
Rescaling p+p won't include rescattering effects!

6. Charmonia depletion

- $J/\Psi + N \to D^*\bar{D}N,\ D^*\bar{D}^*N$, or $\bar{D}^*\Lambda_c$ [8]
- $J/\Psi + \pi \to D^*\bar{D}$, and $J/\Psi + \rho \to D\bar{D},\ D^*\bar{D}^*$ [9]







- Leaving equilibrium: open charm is unlikely to recombine into J/Ψ
- Radius can be understood as centrality or initial jet position

A fragile bound state

$20-35\%$ suppression at 10 GeV: slow particles comove with the system, fast jets leave it earlier

Further complexities

- Properly distribute jets in phase space (with PYTHIA)
- Radiative energy loss via pions
- Response to initial anisotropy
- Feed-down from higher resonances
- Go to lower beam energies

References

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