Some aspects of heavy ion jets

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TIFR

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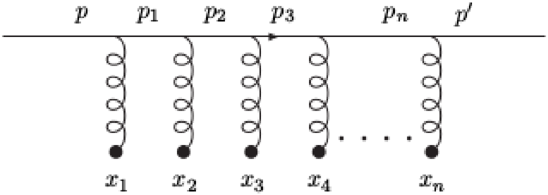
Jet observable zeal

- Work in progress with collaborators Faizan Bhat, Rajiv Gavai, Ambar Jain
- We study a new jet observable "zeal" and how it can be useful for heavy ion physics

Basic physics of quenching of energetic partons

Effect of the medium: momentum broadening



- An energetic parton with momentum $k_{||}$ traversing the medium gets kicks transverse to its motion
- $k_{\perp} \ll k_{||}$
- *(BDMPS-Z (1995/7))*

Momentum broadening

- In certain approximate scenarios,

$$\mathrm{P}(k_\perp) \approx \exp(-\frac{k_\perp^2}{\hat{q}L}) \,, \qquad (1)$$

  which corresponds to diffusion in momentum space.
- $\hat{q} = (\Delta k_\perp)^2/L$
- For randomly located static scatterers $\hat{q} = \frac{\mu^2}{\lambda}$, where $\mu \sim gT$ *(Gyulassy, Levai, Vitev (1999))*
- Transverse kicks drive the parton offshell, and it radiates gluons: leading to energy loss

Models of energy loss

- GLV *Gyulassy, Levai, Vitev (1999, 2001)*. Momentum broadening occurs due to screened gluon exchange with stationary charge centres. Density of scatterers determined by the medium T
- AMY *Arnold, Moore, Yaffe (2001, 2002)*. An effective theory with $p_{\rm parton} \gg T \gg gT$
- ASW *Armesto, Salgado, Wiedemann (2000, 2003)*. $\hat{q}$ is treated as a parameter. Sometimes estimated using AdS/CFT techniques *Rajagopal, Liu, Wiedemann (2005). Somewhat larger values*
- HT *Wang, Guo, Majumder et. al. (2000)*. $\hat{q}$ is a non-perturbative parameter written in terms of gluon correlators

Jet observables

- Models predict a specific distribution of partons in jets
- Can we use the distribution of particles in the reconstructed jets to analyze quenching?
- For other examples see *Vitev, Wicks, Zhang (2008), Renk (2009), Leeuwen (2015)*

Jet observables

- Few splittings of energetic partons can give rise to a similar suppression as many splittings carrying a small fraction of the energetic particle
- Can distinguish these scenarios
- Can also lead to insight on the qualitatively different behaviours of jet R_{AA} and single particle R_{AA} as a function of p_T

A proposed observable

Z

- We define a new observable

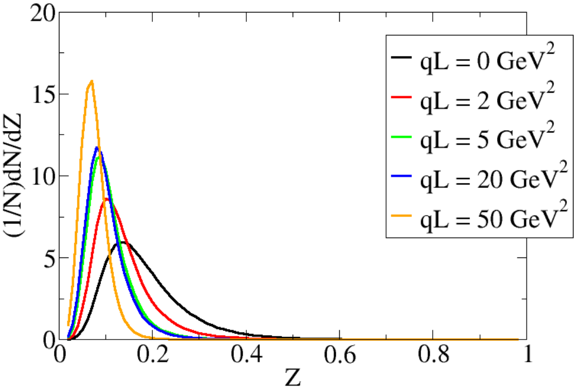
$$Z = -1/\log(\sum_i \exp(-p_T^{\mathrm{jet}}/(\hat{n}_T^{\mathrm{jet}} \cdot \vec{p}_i)))$$

- The form is reminiscent of the thrust distribution
- p_T^{jet} and $\hat{n}^{\mathrm{jet}}$ are found using a jet algorithm (fastjet)
- Proposed with Ambar Jain and Rajiv Gavai (1509.04671)

Jet observables

- The most energetic particles in the jet play the most important role
- Stray, low energy background particles do not contribute. Useful for the heavy-ion environment
- No branching gives $Z = 1$
- More branching lowers Z towards $Z = 0$

100GeV hadronized jets

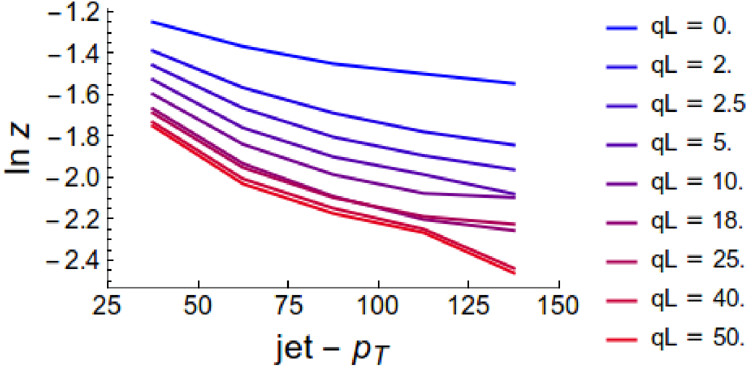


- Inject 100GeV gluon into the medium
- Z depends on $\hat{q}L$ and $\hat{q}L^2$ but the prominent dependence is on $\hat{q}L$. Useful to compare results for different $\hat{q}L$
- Using *QPYTHIA* (*Armesto et. al. (2009)*) to split, hadronize

100GeV hadronized parton

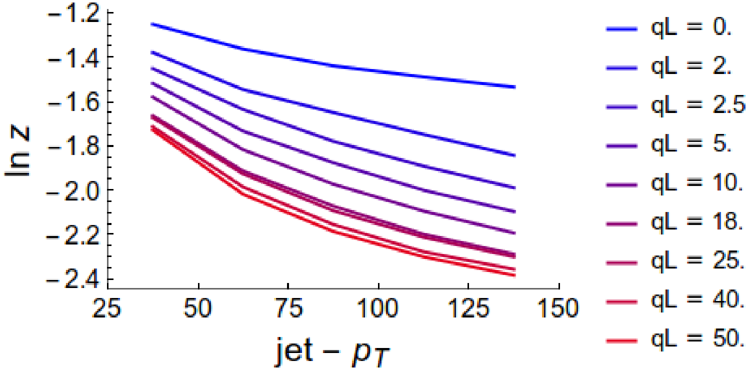
- An idealized test problem
- The main feature is that increasing qL shift the zeal distribution left
- This is because additional medium splitting distributes the jet momentum between more particles
- Suggests mean $\log(Z)$ as a variable
- Also makes the distribution narrower
- Standard deviation of $\log(Z)$ as a variable
- A method to extract $\hat{q}$
- In progress with *Faizan Bhat, Ambar Jain, Rajiv Gavai, and RS*

Using reconstructed jets



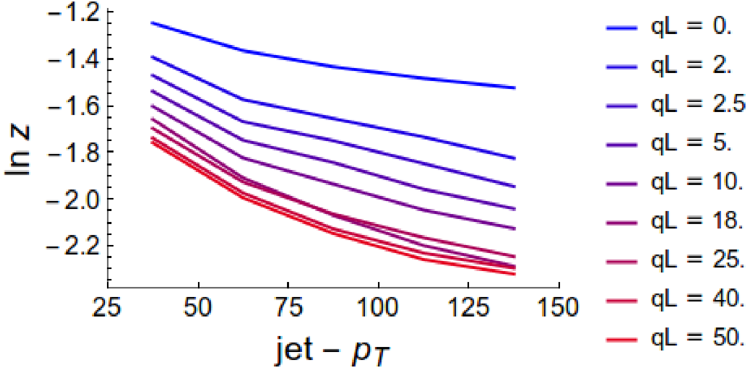
- Injecting a gluon with momentum 150 GeV

Using reconstructed jets



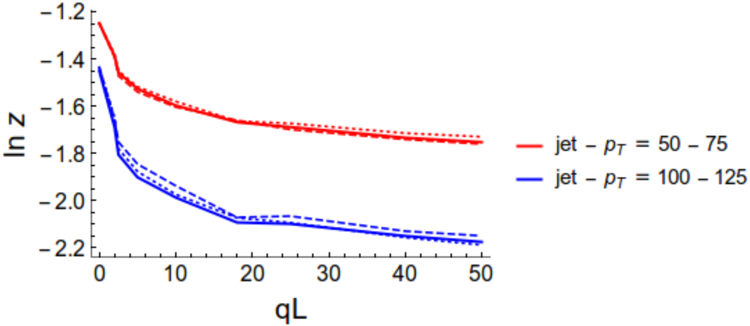
- Injecting a gluon with momentum 175 GeV

Using reconstructed jets



- Injecting a gluon with momentum 200 GeV

Insensitive to the injected gluon energy



- Lower the jet energy, the lower the mean zeal
- Quite insensitive to the injected gluon energy

Using mean $\log(Z)$ of reconstructed jets

- Insensitivity to the injected energy is a bonus since the injected energy is unobservable
- A very specific dependence on the reconstructed jet energy and $\hat{q}L$
- Suggests a way to extract $\hat{q}$ if L is known

Centrality

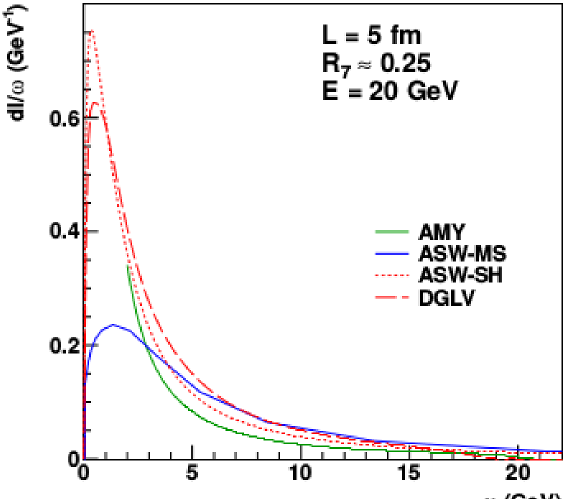
Centrality	b mean (fm)	b RMS (fm)	N_{part} mean	N_{part} RMS	N_{coll} mean	N_{coll} RMS
0–10%	3.4 ± 0.1	1.2	355 ± 3	33	1484 ± 120	241
10–20%	6.0 ± 0.2	0.8	261 ± 4	30	927 ± 82	183
20–30%	7.8 ± 0.2	0.6	187 ± 5	23	562 ± 53	124
30–50%	9.9 ± 0.3	0.8	108 ± 5	27	251 ± 28	101
50–100%	13.6 ± 0.4	1.6	22 ± 2	19	30 ± 5	35

- *(CMS (2011))*

Can we distinguish different models of quenching?

Gluon distribution

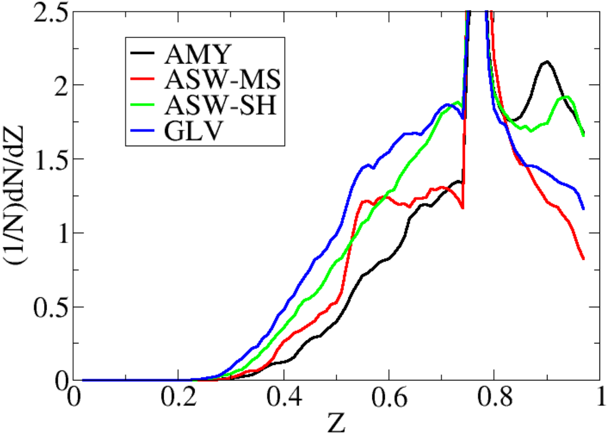
- In a particular model, the emission spectrum of gluons parton is given *(Armesto et. al. (2009))*
- Shown here for a 20GeV injected particle



Repeated emission

- We partitioned the energy of the leading gluon into multiple gluons chosen from the gluon distribution. Simulated $200,000$ events
- This gives a parton level distribution of the jet energy

Models



- All the different models tuned such that R_{AA} is 0.25 for $L = 5$fm. (*Armesto et. al. (2012)*)

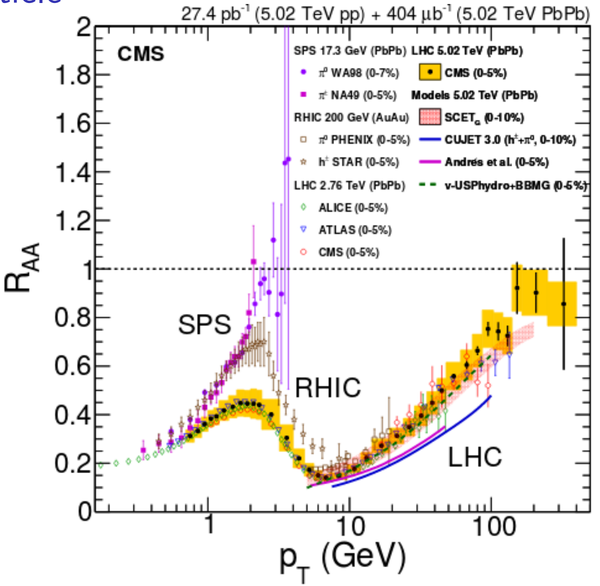
Not yet under quantitative control

- Too many features
- Hadronization will wash away some of the features but can it distinguish the global features
- Low injected energy (20 GeV injection energy is too low)

Conclusions for Z

- Within a model one can extract medium parameters like $\hat{q}$
- Various systematic dependencies on L and jet energy expected in a model
- Seems capable of distinguishing models, but eventually will boil down to error bars
- To do
  1. Hadronization systematics
  2. Background event subtraction
  3. Experimental data
  4. Comparison with other analyses (eg. jet cone radius dependence)

Single particle



- *(CMS (2016))*