Dynamical energy loss as a tool for QGP Tomography

Magdalena Djordjevic
Suppression
– a traditional probe of QCD matter

Light and heavy flavour suppressions are considered as excellent probes of QCD matter.

Suppression for a number of observables at RHIC and LHC has been measured.

Comparison of theory with the experiments allows testing our understanding of QCD matter.
1) Initial momentum distributions for partons
2) Parton energy loss
3) Fragmentation functions of partons into hadrons
4) Decay of heavy mesons to single $e^-$ and $J/\psi$. 

Suppression scheme
Energy loss

Initially, most of the energy loss calculations assumed only radiative energy loss, and a QCD medium composed of static scattering centers. (e.g. GW, DGLV, ASW, BDMPS...)

However, these calculations lead to an obvious disagreement with the experimental data.

Is collisional energy loss also important?

Yes, collisional and radiative energy losses are comparable!
Non-zero collisional energy loss - a fundamental problem

With such approximation, collisional energy loss has to be exactly equal to zero!

Static QCD medium approximation (modeled by Yukawa potential).

Introducing collisional energy loss is necessary, but inconsistent with static approximation!

However, collisional and radiative energy losses are shown to be comparable.

Static medium approximation should not be used in radiative energy loss calculations!

Dynamical QCD medium effects have to be included!
The dynamical energy loss

- Finite size medium of dynamical (moving) partons
- Based on finite T field theory and HTL approach

Includes:
- Same theoretical framework for both radiative and collisional energy loss
- Finite magnetic mass effects (M. D. and M. Djordjevic, PLB 709:229 (2012))
  - Running coupling (M. D. and M. Djordjevic, PLB 734, 286 (2014)).

Integrated in a numerical procedure including parton production, fragmentation functions, path-length and multi-gluon fluctuations

- No free parameters
- Treats both light and heavy flavor partons

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Understanding the existing data

(200 GeV at RHIC and 2.76TeV at LHC)
• **Provide joint predictions across diverse probes**
  charged hadrons, pions, kaons, D mesons, non-photonic single electrons, non-prompt J/ψ  
  M. D. and M. Djordjevic, PLB 734, 286 (2014)

• **Puzzles (apparently surprising data)**
  Measured charged hadron vs. D meson suppression  
  M.D., PRL 112, 042302 (2014)

• **Concentrate on all centrality regions**
  M. D., M. Djordjevic and B. Blagojevic, PLB 737 298 (2014)

• **All predictions generated**
  ➢ By the same formalism
  ➢ With the same numerical procedure
  ➢ No free parameters in model testing
Comparison with LHC data (central collision)

Very good agreement with diverse probes!

M. D. and M. Djordjevic, PLB 734, 286 (2014)
Comparison with LHC data (central collision)

Very good agreement with diverse probes!
Heavy flavor puzzle at LHC

Significant gluon contribution in charged hadrons

\[ R_{AA} (h^\pm) < R_{AA} (D) \]

Much larger gluon suppression

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Charged hadrons vs D meson $R_{AA}$

$R_{AA} (h^\pm) = R_{AA} (D)$

ALICE data
Charged hadrons vs D meson $R_{AA}$

$R_{AA} (h^\pm) = R_{AA} (D)$

Excellent agreement with the data!

Disagreement with the qualitative expectations!

M.D., PRL 112, 042302 (2014)
D meson is a genuine probe of bare charm quark suppression

Distortion by fragmentation

Charged hadron $R_{AA} = \text{(bare) light quark } R_{AA}$

M.D., PRL 112, 042302 (2014)
Puzzle summary

\[ R_{AA} (h^\pm) = R_{AA} \text{(light quarks)} \]
\[ R_{AA} (D) = R_{AA} \text{(charm)} \]

\[ R_{AA} \text{(light quarks)} = R_{AA} \text{(charm)} \]

\[ R_{AA} (h^\pm) = R_{AA} (D) \]

Puzzle explained!

M.D., PRL 112, 042302 (2014)
Comparison with RHIC data (central collisions)

Very good agreement!

M.D. and M. Djordjevic, PRC 90, 034910 (2014)
$R_{AA}$ vs. $N_{part}$ for RHIC and LHC

Excellent agreement for both RHIC and LHC and for the whole set of probes!

M. D., M. Djordjevic and B. Blagojevic, PLB 737 298 (2014)
Predictions for the upcoming 5.1 TeV Pb+Pb at LHC

Comparison with the suppressions at lower beam energies
5.1 TeV Pb+Pb at LHC

The same suppression as at 2.76 TeV for all types of probes!

5.1 TeV Pb+Pb at LHC

The same suppression as at 2.76 TeV for all types of probes!

In line with BES energy scan, which shows similar suppressions between RHIC and LHC.

Why the same suppression?
An interplay between initial distribution and energy loss effects.

(see poster 671, board 0570)

The two effects cancel!

Energy loss summary

Dynamical energy loss formalism.

Tested on angular averaged $R_{AA}$ data

Good agreement for wide range of probes, centralities and beam energies.

Can explain puzzling data.

Clear predictions for future experiments.

Largely not sensitive to the medium evolution.

The dynamical energy loss formalism can well explain the jet-medium interactions in QGP.
Outlook

Dynamical energy loss model + Bulk medium evolution models (Huovinen/Niemi, BAMPS)

Predictions of angular differential $R_{AA}$ observables (e.g. elliptic flow) for high pt observables.

Presumably highly sensitive to the medium evolution.

A new sophisticated tool for precision QGP tomography.
Backup
**Numerical procedure**

- **Light flavor production**  Z.B. Kang, I. Vitev, H. Xing, PLB 718:482 (2012)
- **Heavy flavor production**  M. Cacciari et al., JHEP 1210, 137 (2012)
- **Multi-gluon fluctuations**
- **DSS and KKP fragmentation for light flavor**
- **BCFY and KLP fragmentation for heavy flavor**
- **Decays of heavy mesons to single electron and J/$\psi$ according to**
  M. Cacciari et al., JHEP 1210, 137 (2012)
- **Temperature $T=304$ MeV for LHC and $T=221$ MeV for RHIC.**
What about jets?

The dead cone effect

Good agreement at the low energy!

As well as for jets!

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At high momentum, all types of particles have the same suppression. Good agreement between our model and the data. The model is in agreement with the jet data as well!
Non central collisions @ LHC
(fixed centrality and charged hadrons)

M. D., M. Djordjevic and B. Blagojevic, PLB 737 298 (2014)

An excellent agreement for different centrality regions!
Non central collisions \@ RHIC
(fixed centrality and neutral pions)

Also a very good agreement for RHIC!

M. D., M. Djordjevic and B. Blagojevic, PLB 737 298 (2014)