Jet quenching and charmonia suppression from Effective Quenching model

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Introduction

- Physics of the suppression = **parton** energy loss in **fluctuating** hot nuclear matter

- => Some observables ($I_{AA}$, $R_{AA}$ of particles, ...) result from a **complicated convolution** of: hard parton spectra, dependence of the loss on the flavor and parton shower shapes, path-length...

- => All observables are convolutions of (non-trivial) initial conditions and (non-trivial) energy loss
Introduction

Two paths:
• Be as realistic as one can:
  – MC generators
  – Model full evolution of medium (JETSCAPE Collaboration)
  – theory calculations of parton energy loss
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  – theory calculations of parton energy loss
  – parametric modeling of parton energy loss
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arXiv:1702.01931
arXiv:1908+ε.XXXX
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This talk
This talk ... 

... use a simple model with minimal assumptions on the quenching physics to extract basic properties of the jet quenching
The simplest modeling of parton energy loss

\[
\frac{dN}{dp_T^{\text{jet}}} = A \left[ f_{q_0} \left( \frac{p_{T_0}}{p_T^{\text{jet}}} \right)^{n_q} + (1 - f_{q_0}) \left( \frac{p_{T_0}}{p_T^{\text{jet}}} \right)^{n_g} \right]
\]

Jet spectra parameterized by a power law

\[
f_q \left( p_T^{\text{jet}} \right) = \frac{1}{1 + \left( \frac{1 - f_{q_0}}{f_{q_0}} \right) \left( \frac{p_{T_0}}{p_T^{\text{jet}}} \right)^{n_g - n_q}}
\]

Fraction of jets of a given flavor (i.e. quark or gluon initiated)
The simplest parametric modeling of parton energy loss

\[
\frac{dn_Q(p_T^{\text{jet}})}{dp_T^{\text{jet}}} = \frac{dn \left( p_T^{\text{jet}} + S(p_T^{\text{jet}}) \right)}{dp_T^{\text{jet}}} \times \left( 1 + \frac{dS}{dp_T^{\text{jet}}} \right)
\]

Yield of quenched jets of a given flavor at given pt

\[ R_{AA} \text{ in the approximation of fractional energy loss} \]

\[ S_q \equiv spT \]
\[ S_g = c_F \times S_q \]

\begin{align*}
R_{AA} &= f_q \left( \frac{1}{1 + S_q/p_T^{\text{jet}}} \right)^{n_q} \times \left( 1 + \frac{dS_q}{dp_T} \right) + \\
&\quad (1 - f_q) \left( \frac{1}{1 + S_g/p_T^{\text{jet}}} \right)^{n_g} \times \left( 1 + \frac{dS_g}{dp_T} \right)
\end{align*}
Jet $R_{AA}$ in the simplest model

\[ \text{rapidity} \]

\[ 2.76 \text{ TeV} \]
The simplest model does not work because:

\[\rightarrow\] jet spectra are not a simple power law

\[\rightarrow\] fractional energy loss is not realized in the nature
Realistic parametric model

\[ \frac{dN}{d p^\text{jet}} = A \left( \frac{p_T^\text{jet}}{p_T} \right)^{n+\beta \log \left( \frac{p_T^\text{jet}}{p_T^0} \right)} \]

Realistic parameterization of input jet spectra

General modeling of jet energy loss

\[ S = s' \left( \frac{p_T^\text{jet}}{p_T^0} \right) \]
Jet $R_{AA}$ in realistic model
Jet $R_{AA}$ in realistic model

$\rightarrow$ Slow evolution with $p_T$ and no rapidity dependence of jet $R_{AA}$ can be interpreted as a result of different energy loss of quark and gluon initiated jets.
-> Flatness and no rapidity dependence of jet $R_{AA}$ can be interpreted to be a result of different energy loss of quark and gluon initiated jets
Quantifying the parton energy loss, fixed $c_F$

\[ S_q = s' \left( \frac{p_{T,jet}}{p_{T,0}} \right)^\alpha \]
\[ S_g = c_F \times S_q \]

Fixed to $9/4$
Quantifying the parton energy loss, fixed $c_F$

\[ S_q = s' \left( \frac{p_T^\text{jet}}{p_{T,0}} \right)^\alpha \]

\[ S_g = c_F \times S_q \]

Quark with $p_T = 40 \text{ GeV}$ ($p_{T,0}$) looses \( \sim 5 \text{ GeV} \).

100 GeV quark looses 8 GeV

Effective power \( \sim 0.55 \)

Linear dependence of \( s' \) on \( N_{\text{part}} \)
Quantifying the parton energy loss, fixed $c_F$

$$S_q = s' \left( \frac{p_T^{\text{jet}}}{p_{T,0}} \right)^\alpha$$

$$S_g = c_F \times S_q$$

Energy loss does not extrapolate to zero. Hot medium even in peripheral? Some other physics? (nPDFs?, limits of Glauber?, …)

Effective power $\sim 0.55$

Quark with $p_T = 40$ GeV ($p_{T,0}$) looses $\sim 5$ GeV. 100 GeV quark looses 8 GeV

Linear dependence of $s'$ on $N_{\text{part}}$
Quantifying the parton energy loss, free $c_F$

$$S_q = s' \left( \frac{p_{T}^{\text{jet}}}{p_{T,0}} \right)^{\alpha}$$

$$S_g = c_F \times S_q$$

- Use rapidity differential jet $R_{AA}$ measurement to perform a **multidimensional fit** and extract $\alpha$, $s'$ and $c_F$ simultaneously (Input: NLO spectra – POWHEG+PYTHIA8 + 3 variations of PDFs)

- Vacuum value of $c_F$ measured and evaluated in pQCD (MLLA calculations)

- In vacuum, $c_F = 1.7-1.8$ for $Q=20-100$ GeV

- In-medium: $c_F = 1.78 \pm 0.12$ – consistent with the value **in the vacuum** (Useful discussion on $c_F$ also in arXiv:1812.06019)
Quantifying the parton energy loss

\[ S_q = s' \left( \frac{p_T^{\text{jet}}}{p_T,0} \right)^\alpha \]

\[ S_g = c_F \times S_q \]

- Use rapidity differential jet R_{AA} measurement to perform a **multidimensional fit** and extract \( \alpha \), \( s' \) and \( c_F \) simultaneously
  (Input: NLO spectra – POWHEG+PYTHIA8 + 3 variations of PDFs)

- Full result:

| \( s' = x \cdot N_{\text{part}} + y \) | \( x = (12.3 \pm 1.4) \cdot 10^{-3} \text{ GeV}, \)  
| \( y = 1.5 \pm 0.2 \text{ GeV} \) |
|---|---|
| \( \alpha \) | 0.52 \( \pm 0.02 \) |
| \( c_F \) | 1.78 \( \pm 0.12 \) |

- **Average** jet quenching encapsulated **in 4 parameters**.
5.02 TeV versus 2.76 TeV

- Same jet $R_{AA}$ ... but that does not imply same energy loss.
- Spectra shape and flavor admixture are different
  => energy loss must be different.
- About 10% larger energy loss at 5.02 TeV compared to 2.76 TeV.
Note

• ... jet $R_{\text{AA}}$ ... as a result of different energy loss of quark- and gluon-initiated jets

• Alternative: **shower shape** – wide jets lose more than narrow.

• How to **distinguish**?

• Do as **many comparisons** with data as possible (in the kinematic region insensitive to in-cone radiation / recoil effects). Here:
  – Rapidity dependence of the $R_{\text{AA}}$,
  – Behavior of the $R_{\text{AA}}$ in the forward region,
  – Jet fragmentation,
  – Jet shapes.

• More info in the **backup**: charged particle $R_{\text{AA}}$, b-jet $R_{\text{AA}}$, $z_g$, high-$p_T$ charmonia, ... and more to come

• Do as many comparisons as possible ... and **look for a failure** (by seeing a failure of the model one can learn new stuff)
Predictions for the forward region

![Graph showing jet $R_{AA}$ vs. $p_{T,\text{jet}}$ in two regions: $2.1 < |\eta| < 2.8$ and $2.8 < |\eta| < 3.5$.](image)

$\rightarrow$ The jet $R_{AA}$ should decrease in the forward region
Measurement in the forward region

$|y| < 0.3$

ATLAS

anti-$k_t$, $R = 0.4$ jets, $\sqrt{s_{NN}} = 5.02$ TeV

$0 - 10\%$, $158 < p_T < 200$ GeV

$0 - 10\%$, $316 < p_T < 562$ GeV

2015 Pb+Pb data, 0.49 nb$^{-1}$

2015 $pp$ data, 25 pb$^{-1}$

--> The jet $R_{AA}$ does decrease in the forward region
Modification of longitudinal structure of jet (fragmentation function)
Modifications of fragmentation functions

- How is the parton shower modified by the QCD medium?
- Basic picture ...

**Black** = vacuum component of PS  
**Red** = medium induced radiation

\[ c) = a \land b \]
For some configurations medium resolves parton shower
\[ d) = a \lor b \lor c + \text{more} \]

in-cone radiation  
+ jet excites medium \(\Rightarrow\) “recoiling” particles from the medium

- Medium resolves parton shower
- Emission is coherent

**Examples:**
- JHEP 12 (2001), 009
Modifications of fragmentation functions

- How is the parton shower modified by the QCD medium?
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Medium resolves parton shower

Emission is coherent

e.g.: Phys. Lett. B345 (1995), 277
JHEP 12 (2001), 009

e.g.: Phys. Rev. Lett. 106 (2011)

e.g.: Phys. Rev. C80 (2009) 054913

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c) = a && b
For some configurations medium resolves parton shower

! (d) = a || b || c + more

in-cone radiation
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Medium resolves parton shower
Emission is coherent

a)

b)

Medium resolves parton shower

Emission is coherent

JHEP 12 (2001), 009

e.g.: Phys. Rev. Lett. 106 (2011)

e.g.: Phys. Rev. C80 (2009) 054913
Modifications of fragmentation functions

→ Subtract the energy from the jet / initial parton and then let it fragment as in the vacuum

[a) Medium resolves parton shower
e.g.: Phys. Lett. B345 (1995), 277
     JHEP 12 (2001), 009

[b) Emission is coherent
e.g.: Phys. Rev. Lett. 106 (2011)

Red = medium induced radiation

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\[ \langle d \rangle = a \parallel b \parallel c + \text{more} \]

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Modifications of fragmentation functions

→ Subtract the energy from the jet / initial parton and then let it fragment as in the vacuum

(Ratio of fragmentation functions)
Modifications of fragmentation functions

Subtract the energy from the jet / initial parton and then let it fragment as in the vacuum

Structure seen at intermediate and high-z is due to the difference in quenching of quark and gluon initiated jets

→ Speaks in favor of presence of color coherence effects in the data

Excess of low-z not due to flavor effects (due to in-cone radiation or recoil effects)

Some level of disagreement? Will get back to it ...
Transverse structure of jet (jet shape)

**ATLAS** Preliminary

\[ \text{Pb+Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV, } 0.49 \text{ nb}^{-1} \]

\[ pp \ \sqrt{s} = 5.02 \text{ TeV, } 25 \text{ pb}^{-1} \text{ anti-} k_t \ R=0.4 \]

- \( 1.6 < p_T < 2.5 \text{ GeV} \)
- \( 4.0 < p_T < 6.3 \text{ GeV} \)
- \( 6.3 < p_T < 10.0 \text{ GeV} \)
- \( 10.0 < p_T < 25.1 \text{ GeV} \)
- \( 25.1 < p_T < 63.1 \text{ GeV} \)

\[ 126 < p_T^\text{jet} < 158 \text{ GeV} \]

\[ 0 - 10\% \]
Modification of the jet shape

→ Subtract the energy from the jet / initial parton and then let it fragment as in the vacuum
Modification of the jet shape

126 < \( p_{T,\text{jet}} \) < 158 GeV

- \( r < 0.05 \): values well reproduced (for all \( p_{T}^{\text{ch}} \) bins)
- \( r > 0.05 \): trends similar but magnitude very different ...

... two particular possibilities:

1) **Input spectra** are not well modeled (sub-dominant contributions to jet \( p_T \))

2) **Coherent picture** breaks for \( \sim 100 \) GeV jets at \( r \sim 0.05 \)
Modification of the jet shape

$126 < p_{T,\text{jet}} < 158 \text{ GeV}$

1) **Input spectra** are not well modeled (sub-dominant contributions to jet $p_T$)

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Modification of the jet shape

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... two particular possibilities:

1) Input spectra are not well modeled (sub-dominant contributions to jet $p_{T}$)

2) Coherent picture breaks for ~100 GeV jets at $r \sim 0.05$
Modifications of fragmentation functions – a detail

Excess of low-$z$ not due to flavor effects (due to in-cone radiation or recoil effects)

- These low-$z$ hadrons contribute to the measured jet energy. Parameter $s'$ contains this soft part.
- Soft part contributes to the measured fragmentation via denominator of $z$.
Modifications of fragmentation functions – a detail

Excess of low-$z$ not due to flavor effects (due to in-cone radiation or recoil effects)

- These low-$z$ hadrons contribute to the measured jet energy. Parameter $s'$ contains this soft part.
- Soft part contributes to the measured fragmentation via denominator of $z$.

Contribution of soft hadrons to the jet energy can be estimated from the measurement at low-$z$ => fragmentation distributions w/ correct soft contribution
Modifications of fragmentation functions – a detail

→ Prediction: detailed measurement of fragmentation at the highest-\(z\) (or lowest-\(\xi\)) should exhibit a depletion

\[ p_{T,\text{jet}}^{\text{measured}} = p_{T,\text{jet}}^{\text{quenched}} + p_{T}^{\text{soft}} \]
Modifications of fragmentation functions – a detail

→ Prediction: detailed measurement of fragmentation at the highest-$z$ (or lowest-$\xi$) should exhibit a depletion

\[ p_{T,\text{jet}}^{\text{measured}} = p_{T,\text{jet}}^{\text{quenched}} + p_{T}^{\text{soft}} \]

Seems observed in the data
Example of other observables: non-groomed jet mass

A hint of possible shift to lower jet mass values seen in the data
Example of other observables: non-groomed jet mass

... but rather complicated observable: significant flavor dependence + dependence on recoil at low-$p_T$

A hint of possible shift to lower jet mass values seen in the data
What about other objects?

Data tell us that the medium largely sees a jet as one object => what about other objects with a structure that are suppressed?

\[ R_{D(z)} \]

\[ \sqrt{s_{NN}} = 5.02 \text{ TeV} \]

\[ \text{pp } 25.8 \text{ pb}^{-1} \]

\[ \text{PbPb } 404 \text{ \mu}b^{-1} \]
What about other objects?

Data tell us that the medium largely sees a jet as one object
=> what about other objects with a structure that are suppressed?
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\[ J/\Psi \ & \ \Psi(2S) \]
What about other objects?

Data tell us that the medium largely sees a jet as one object => what about other objects with a structure that are suppressed?

\[
\text{J/}\Psi \ & \ \psi(2S)
\]

... check the differences between the suppression of jets and charmonia at high-\(p_T\) (at the LHC at mid-rapidity)

Input:

- Measured pp spectra of charmonia (cannot rely on out of the box PYTHIA or other generator)
- Energy loss extracted from jets
Charmonia
Charmonia

... suppression of both charmonia at $p_T>6.5$ GeV is similar to the suppression of light quark jets
Summary

• **Flavor** dependence of the jet quenching seems to drive quite a lot of what we see in the data.

• Average jet quenching can be **quantified** from the data as follows:

<table>
<thead>
<tr>
<th>$s = x \cdot N_{\text{part}} + y$</th>
<th>$x = 12.3 \pm 1.4$ GeV, $y = 1.5 \pm 0.2$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>$0.52 \pm 0.02$</td>
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<tr>
<td>$c_F$</td>
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\[ S_q = s' \left( \frac{p_T^{\text{jet}}}{p_T^{\text{0}}} \right)^\alpha \]

\[ S_g = c_F \times S_q \]

• **Coherence** effects seem to be important, but for jets with $p_T \sim 100$ GeV they seem to **break at $r \sim 0.05$**.

• **Recoil** (or in-cone radiation) can modify kinematic regions where one would not expect that (e.g. high-z fragmentation).

• **Precision** is really needed:
  - precision **data** are needed **to understand details** (recoil via high-z fragmentation, jet shapes at low $r$; flavor via V-jets).
  - precision **MC** is needed to have the **reference under the control**.

• Suppression of **charmonia** at $p_T > 6.5$ GeV at midrapidity behaves like the suppression of light quark jets.
Slides with more information
• Same jet $R_{AA}$ … but that does not imply same energy loss.

• Spectra shape and flavor admixture are different

=> energy loss must be different.
5.02 TeV versus 2.76 TeV

- Same jet $R_{AA}$ … but that does not imply same energy loss.
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- About 10% larger energy loss at 5.02 TeV compared to 2.76 TeV.
Groomed $z_g$ ... checking the impact of jet flavor

Using PYTHIA:

$z_g$ does not depend much on the flavor or jet $p_T$
Groomed $z_g$ … checking the impact of jet flavor

Same procedure as for modeling fragmentation functions => no modification seen => measured modification not due to a flavor
Modifications of fragmentation functions
From jet internal structure to charged particle $R_{AA}$

Each particle of a given $p_T$ must be in a jet of the same or higher $p_T$

$\Rightarrow$ Charged particle $R_{AA}$ (at high-$p_T$) = convolution of flavor dependent jet suppression and fragmentation functions
From jet internal structure to charged particle $R_{AA}$
Jets at RHIC versus LHC

- Jets very different between LHC and RHIC
- Jet spectra for a given flavor more steep at RHIC
- Flavor composition also different

→ Will impact charged particle $R_{AA}$

→ Apply the effective quenching factors extracted at the LHC to RHIC jets
b-jets suppression

- b-jet $R_{AA}$ ... comparable with inclusive jet $R_{AA}$ ... but again, spectral shapes are different
- Moreover, just one flavor => direct comparison misleading
$b$-jets suppression

- $b$-jet $R_{AA} \ldots$ comparable with inclusive jet $R_{AA} \ldots$ but again, spectral shapes are different
- Moreover, just one flavor $\Rightarrow$ direct comparison misleading
- Use the model + $b$-jet cross-section measurement to quantify the difference between inclusive jets and $b$-jets.
- Results of minimization wrt to (statistically limited) data + including role of gluon splitting: $b$-jets are suppressed by $1.5\pm0.4$ more than light quark jets.
Charged particle $R_{AA}$

RHIC vs LHC

- Underlying jet spectra very different between RHIC and LHC
- Effective quenching factors from LHC applied to RHIC parton/jet spectra
- Same quenching leads to smaller $R_{AA}$ in the case of RHIC

$N_{\text{part}} = 260$
- 200 GeV
- 2.76 TeV

$R_{AA}$ vs charged particle $p_T$ [GeV]

$=>$ Initial parton spectra and flavor composition are very important for the extraction of the size of jet quenching
Dijet asymmetry

→ The subleading jet is quenched very differently than the leading jet → quantify

→ The subleading jet in the maximum of the $x_J$ is suppressed by a factor of ~3 larger than the leading jet
Unused slides, technical details
Modifications of fragmentation functions – prediction

... central rapidity – higher yields at high-z (but not by much)
Modifications of fragmentation functions – prediction

... central rapidity – higher yields at high-z (but not by much)
Modifications of fragmentation functions – prediction

... central rapidity – higher yields at high-z (but not by much)
Start: Two basic questions

• Why do have the jet and charge particle $R_{AA}$ almost **no rapidity dependence** given quite different input parton spectra and flavor composition at different rapidities?

• What is responsible for the **enhancement** (= not suppression) at high $z$ seen in the fragmentation?
Start: Two basic questions

• Why do have the jet and charge particle \( R_{AA} \) almost **no rapidity dependence** given quite different input parton spectra and flavor composition at different rapidities?

• What is responsible for the **enhancement** (= not suppression) at high \( z \) seen in the fragmentation?

\[ \rightarrow \] Use a simple model with minimal assumptions on the quenching physics to extract basic properties of the jet quenching
Dijet asymmetry

\[ x_J = \frac{p_{T,\text{subleading}}}{p_{T,\text{leading}}} \]

\text{ATLAS} \quad \text{anti-}k_t \quad R = 0.4 \text{ jets}

100 < p_{T1} < 126 \text{ GeV} \quad 0 \text{ - 10%}
Dijet asymmetry

\[ x_J = \frac{p_{T,\text{subleading}}}{p_{T,\text{leading}}} \]

\( \frac{1}{N} \frac{dN}{dx_J} \)

\( 100 < p_{T,1} < 126 \text{ GeV} \)

\( 0 - 10\% \)

\( \text{ATLAS} \quad \text{anti-} k_t \quad R = 0.4 \text{ jets} \)

\( \text{Pb+Pb} \)

\( pp \)

Source ??
Dijet asymmetry

- Test the role of path-length dependence

\[ S(p_{T,ini}, l) = \]
\[ = \frac{c_F s}{\langle l \rangle} \left( \frac{p_{T,ini}}{p_{T,0}} \right)^\alpha f(l) \]

\[ l^k \]
\[ k = 0.5, 1, 2, 3 \]

\[ l = \int d\tau \tau \rho(\vec{r}) \]
Dijet asymmetry

- Test the role of path-length dependence

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\[ l^k \]
\[ k = 0.5, 1, 2, 3 \]

\[ l = \int d\tau \tau \rho(\vec{r}) \]

Path-length or fluctuations in IC have no major impact (similar conclusions in EPJC 76 (2016) no.5, 288)
Dijet asymmetry

• Test the role of flavor

\[ S(p_{T,\text{ini}}, l) = \frac{c_{F}S}{\langle l^{k(c_{F})} \rangle} \left( \frac{p_{T,\text{ini}}}{p_{T,0}} \right)^{\alpha} f(l^{k(c_{F})}) \]

Peaking in the configurations when the loss of quark jets is more non-linear than the loss of gluon jets

… contra-intuitive
Flavor fractions and fit parameters

Fit type | Parameter | $|y| < 2.1$ | $|y| < 0.3$ | $0.3 < |y| < 0.8$ | $1.2 < |y| < 2.1$
---|---|---|---|---|---
All | $f_{q_0}$ | 0.34 | 0.28 | 0.29 | 0.40
Power law | $n_q$ | 5.66 | 5.37 | 5.40 | 6.15
 | $n_g$ | 6.25 | 5.97 | 6.09 | 6.92
Extended power law | $n_q$ | 4.19 | 4.34 | 4.27 | 3.75
 | $\beta_q$ | 0.71 | 0.49 | 0.54 | 1.2
 | $n_g$ | 4.69 | 4.55 | 4.57 | 4.60
 | $\beta_g$ | 0.80 | 0.71 | 0.76 | 1.2
D(z) parameterization

\[ D(z) = a \cdot \frac{(1 + dz)^b}{(1 + ez)^c} \cdot \exp(-fz) \]

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark</td>
<td>318</td>
<td>2.51</td>
<td>1.44</td>
<td>-0.85</td>
<td>52.4</td>
<td>0</td>
</tr>
<tr>
<td>Gluon</td>
<td>574</td>
<td>1.87</td>
<td>2.32</td>
<td>9.09</td>
<td>32.0</td>
<td>10.3</td>
</tr>
</tbody>
</table>
\[ R_{AA} \text{ – full analytic expression} \]

\[
R_{AA} = f_q \left( \frac{1}{1 + S_q / p_T^{jet}} \right)^{n_q + \beta_q \log((p_T^{jet} + S_q) / p_T^{jet})} \times \left( \frac{p_{T0}^{jet}}{p_T^{jet}} \right)^{\beta_q \log(1 + S_q / p_T^{jet})} \left( 1 + \frac{dS_q}{dp_T^{jet}} \right) \\
+ (1 - f_q) \left( \frac{1}{1 + S_g / p_T^{jet}} \right)^{n_g \beta_g \log((p_T^{jet} + S_g) / p_T^{jet})} \times \left( \frac{p_{T0}^{jet}}{p_T^{jet}} \right)^{\beta_g \log(1 + S_g / p_T^{jet})} \left( 1 + \frac{dS_g}{dp_T^{jet}} \right),
\]

\[
f_q \left( p_T^{jet} \right) = \frac{1}{1 + \left( \frac{1 - f_{q0}}{f_{q0}} \right) \left( \frac{p_{T0}^{jet}}{p_T^{jet}} \right)^{n_g - n_q + (\beta_g - \beta_q) \log \left( \frac{p_T^{jet}}{p_T^{jet}} \right)}}.
\]
Minimization in (I.)

10-20%

60-70%

$N_{\text{part}}=261$

$N_{\text{part}}=15$
Modifications of fragmentation functions – a detail

How is the soft excess estimated:

Measured
(at least partially)

\[ \Phi_{\text{inc}}^{\text{soft}} = f_q^{\text{int}} \Phi_q^{\text{soft}} + (1 - f_q^{\text{int}}) \Phi_g^{\text{soft}} \]

\[ \Phi_g^{\text{soft}} = c_F \Phi_q^{\text{soft}} \]

\[ D^{\text{meas}}(z) = f_q^{\text{int}} D_q(z[1 + \Phi_q^{\text{soft}}]) + (1 - f_q^{\text{int}}) D_g(z[1 + \Phi_g^{\text{soft}}]) \]
Charmonia in p+Pb
Feed down
Feed down

ATLAS, JHEP 07 (2014) 154
Introduction

Two paths:

• Be as realistic as one can:
  - MC generators
  - JETSCAPE Collaboration
  - theory calculations of parton energy loss

• Be simple and try to identify what plays a major role for a given observable (e.g. flavor, coherence, path length, fluctuations, …):
  - MC generators
  - parametric modeling of parton energy loss

The Jet Energy-loss Tomography with a Statistically and Computationally Advanced Program Envelope (goal provide modular software which includes: modeling of initial state + dynamical evolution of QGP + jet energy loss + advanced statistical tools; http://jetscape.wayne.edu/)

- Phys.Lett B767 (2017) 10
- arXiv:1702.01931