High-$p_T$ phenomena in partonic transport simulations

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What is it all about?

- investigating the properties of a new state of matter, the QGP
- finding and to understanding suitable observables

high energy particles considered to be promising probes of the medium created in AA-collisions

nuclear modification factor

$$R_{AA} = \frac{d^2N_{AA}/dp_Tdy}{T_{AA}d^2\sigma_{NN}/dp_Tdy}$$

relative to pp (binary collision scaling)

$$T_{AA} = \frac{\langle N_{coll} \rangle}{\sigma_{NN}}$$

experiments show approx. factor 5 of suppression in hadron yields

K. Reygers, hep-ex/0512015

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What is our approach?

- microscopic transport simulations with **full** dynamics
  - attack various problems within **one** model
    (thermalization, $R_{AA}$, jet tomography, $v_2$, initial conditions, ...)

- investigation of jet quenching within our stochastic parton cascade model
  (Z. Xu, C. Greiner, Phys. Rev. C71)

How does it work?

- LO pQCD cross sections
- calculate **transition probabilities** for (test)particles within spatial cells
  - no geometric interpretation of cross sections
- simulate gluon plasma including the processes
  \[ gg \leftrightarrow gg \quad gg \leftrightarrow ggg \]
Some more details

- Transition probabilities

\[ P_{22} = v_{rel} \frac{\sigma_{22}}{N_{test}} \frac{\Delta t}{\Delta V} \quad P_{23} = v_{rel} \frac{\sigma_{23}}{N_{test}} \frac{\Delta t}{\Delta V} \quad P_{32} = \frac{1}{8E_1E_2E_3} \frac{I_{32}}{N_{test}^2} \frac{\Delta t}{\Delta V} \]

- \( gg \to gg \) cross section (in small-\( t \) (small angle) approximation)

\[ \frac{d\sigma_{gg \to gg}}{dt} \approx \frac{9\pi \alpha_s^2}{(q_{\perp}^2 + m_D^2)^2} \]

- \( gg \to ggg \)

\[ |M_{gg \to ggg}|^2 = \left( 72\pi^2 \alpha_s^2 \frac{s^2}{(q_{\perp}^2 + m_D^2)^2} \right) \left( 48\pi \alpha_s \frac{q_{\perp}^2}{k_{\perp}^2 \left[ (k_{\perp} - q_{\perp})^2 + m_D^2 \right]} \right) \]

- Debye screening

\[ m_D^2 = 16\pi \alpha_s \int \frac{d^3p}{(2\pi)^3} \frac{1}{p} \left( N_c f_g + N_f f_q \right) \]

thermal case:

\[ m_D^2 = (3 + N_f) \frac{8}{\pi} \alpha_s T^2 \]
Why is that difficult?

- obtain total cross section for $gg \rightarrow ggg$ via integration of the matrix element

$$
\sigma_{gg \rightarrow ggg} \sim \int_0^{s/4} dq_{1 \perp} \int_{s/4}^{s/4} dk_{2 \perp} \int_{ym}^{ym} dy \int_0^{\pi} d\phi \cdots
$$

**LPM cutoff**

**LPM-effect** (Landau-Pomeranchuk-Migdal)

- incoherent treatment of $gg \rightarrow ggg$ processes
  - parent gluon must not scatter during formation time of emitted gluon

$$
\lambda''_g > \tau''(k_{\perp}) \quad \text{with} \quad \tau''(k_{\perp}) = \frac{1}{k_{\perp}}
$$

$$
\Theta(k_{\perp} - \frac{1}{\lambda''_g}) \Theta(B - (\cosh y + A \sinh y))
$$

- discard all possible interference effects (Bethe-Heitler regime)

$$
A = \beta' \cos \theta
$$

$$
B = k_{\perp} \lambda_g \sqrt{1 - \beta'^2}
$$

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Energy loss in a static medium

- gluon jet in a static, thermal medium of gluons
- $T = 400$ MeV

LPM cutoff increases due to boost

dominant process is $2\to3$

preliminary
Au+Au – Setup

- central \((b=0\ \text{fm})\) Au-Au collision at 200 AGeV
- sampling of initial \textit{gluon plasma}:
  - initial momentum distribution (mini-jets) according to
    \[
    \frac{d\sigma_{jet}}{dp_T^2dy_1dy_2} = K \sum_{a,b} x_1 f_a(x_1, p_T^2) x_2 f_b(x_2, p_T^2) \frac{d\sigma_{ab}}{dt}
    \]
  - Glück-Reya-Vogt parameterization for structure functions; \(K = 2\)
  - lower cut-off: \(p_0 = 1.4\ \text{GeV}\) (reproduces \(dE_T/dy\))
  - particle production via standard nuclear geometry
    (Wood-Saxon density profile, Glauber-Model)
    \[
    N = 2T_{ab} \sigma_{jet}
    \]
  - each parton is given a formation time \(\Delta t_f = \cosh(y)/p_T\)
  - 35 testparticles
  - simulate evolution of fireball up to \(~5\ \text{fm/c}\)
  - when energy density in a cell drops below \(\varepsilon = 1\ \text{GeV}\)
    \(\Rightarrow\) free streaming (in the respective cell)
Au-Au – Thermalization

Time evolution of $p_T$ spectra
(central region, $x_T < 1.5$ fm, $|\eta| < 0.5$)
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Au-Au – Nuclear modification factor

RAA higher?

preliminary

old:

new:

$R_{AA} \sim 0.04–0.05$
Summary and to-do list

- possibility to examine $v_2$ and $R_{AA}$ (and various other observables) within one framework, consistently including inelastic processes
- rapid thermalization (on the order of 1-2 fm/c)
- non-perturbative transport simulations of jet events up to $p_T=35$ GeV
- $R_{AA}$ (w/o boost) very low – full results w/ boost yet to come

- energy loss depends crucially on the modeling of the LPM effect
  - Abelian vs. non-Abelian LPM effect? How to incorporate?

- no quarks included so far (smaller energy loss $\rightarrow$ higher $R_{AA}$?)
  - include quark degrees of freedom and examine quark jets
- incorporate hadronization scheme
  - effects on shape of $R_{AA}$?
- simulate LHC-energies

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Backup slides
Gluon-Quark-Ratio

$N_x / (N_g + N_q)$ vs. $p_T$ (GeV)

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Elliptic flow

Au+Au at 200 GeV
minijets $p_0 = 1.4$ GeV
$-0.5 < y < 0.5$

time evolution of $v_2$ at midrapidity for different impact parameters

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Experimental $v_2$ vs. centrality

![Graph showing experimental $v_2$ vs. centrality](image)

- $v_2$ vs. 200 GeV STAR charged particles
- $v_2$ vs. 130 GeV STAR charged particles
- $v_2$ vs. 17 GeV NA49 pions

STAR White Paper, nucl-ex/0501009

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