High-mass dimuon and secondary charmonium spectra in heavy ion collisions at the LHC

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• PYQUEN - model of jet quenching in heavy ion collisions
• Mechanisms of heavy quark production
• Medium-induced energy loss of b-quarks and dimuon spectra
• Summary
Monte-Carlo models to simulate jet quenching and flow effects in HIC

- **PYQUEN** - fast code to simulate jet quenching (modify PYTHIA6.4 jet event), http://cern.ch/lokhtin/pyquen

- **HYDJET** - merging soft part (with including flow effects) and multijets generated with PYQUEN
  http://cern.ch/lokhtin/hydro/hydjet.html

HydjetRHIC and PyquenRHIC are also available by web

The codes are included in LHC generator database GENSER

*(HYDJET1_1 and PYQUEN 1_1 are latest versions)*

Medium-induced partonic energy loss

General kinetic integral equation:

\[ \Delta E(L, E) = \int_0^L dx \frac{dP}{dx}(x) \lambda(x) \frac{dE}{dx}(x, E), \quad \frac{dP}{dx}(x) = \frac{1}{\lambda(x)} \exp(-x/\lambda(x)) \]

1. Collisional loss and elastic scattering cross section:

\[
\frac{dE}{dx} = \frac{1}{4T} \frac{\lambda}{\sigma} \int_{t_{\text{max}}}^{t_{\text{max}}} dt \frac{d\sigma}{dt} = \frac{2\pi \alpha_s^2(t)}{t^2}, \quad \alpha_s = \frac{12\pi}{(33 - 2N_f) \ln(t/\Lambda_{\text{QCD}}^2)}, \quad C = 9/4 \ (gg), \ 1 \ (gq), \ 4/9 \ (qq) 
\]

2. Radiative loss (BDMS):

\[
\frac{dE}{dx}(m_q = 0) = \frac{2\alpha_s C_F}{\pi \tau_L} \int_{E_{\text{phys}}}^E d\omega \left(1 - y + \frac{y^2}{2}\right) \ln|\cos(\omega_1 \tau_1)|, \quad \omega_1 = \sqrt{i\left(1 - y + \frac{C_F}{3} y^2\right)} k \ln \frac{16}{k}, \quad \bar{k} = \frac{\mu_D^2 \lambda_g}{\omega(1 - y)}, \quad \tau_1 = \frac{\tau_L}{2\lambda_g}, \quad y = \frac{\omega}{E}, \quad C_F = \frac{4}{3} 
\]

"dead cone" approximation for massive quarks:

\[
\frac{dE}{dx}(m_q \neq 0) = \frac{1}{(1 + (l\omega)^{3/2})^2} \frac{dE}{dx}(m_q = 0), \quad l = \left(\frac{\lambda}{\mu_D^2}\right)^{1/3} \left(\frac{m_q}{E}\right)^{4/3} 
\]

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Nuclear geometry and QGP evolution

impact parameter $b \equiv |O_1 O_2|$ - transverse distance between nucleus centers

Space-time evolution of QGP, created in region of initial overlapping of colliding nuclei, is described by Lorenz-invariant Bjorken's hydrodynamics J.D. Bjorken, PRD 27 (1983) 140

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Monte-Carlo simulation of parton rescattering and energy loss in QGP

- Distribution over jet production vertex $V(r \cos \psi, r \sin \psi)$ at im.p. $b$

\[
\frac{dN}{d \psi dr}(b) = \frac{T_A(r_1) T_A(r_2)}{2\pi r_{\text{max}} \int_0 d \psi \int_0 r dr T_A(r_1) T_A(r_2)}
\]

- Transverse distance between parton scatterings $l_i = (\tau_{i+1} - \tau_i) E/p_T$

\[
\frac{dP}{dl_i} = \lambda^{-1}(\tau_{i+1}) \exp(-\int_0 \lambda^{-1}(\tau_i + s) ds), \quad \lambda^{-1} = \sigma \rho
\]

- Radiative and collisional energy loss per scattering

\[
\Delta E_{\text{tot},i} = \Delta E_{\text{rad},i} + \Delta E_{\text{col},i}
\]

- Transverse momentum kick per scattering

\[
\Delta k^2_{t,i} = \left( E - \frac{t_i}{2 m_{0i}} \right) - \left( p - \frac{E}{p} \frac{t_i}{2 m_{0i}} \right)^2 - m_q^2
\]

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Angular spectrum of gluon radiation

Medium-modified jet fragmentation depends on fraction of partonic energy loss falling outside the jet cone

But full treatment of angular spectrum of emitted gluons is sophisticated and model-dependent

Two simple parameterizations of gluon angular distribution:

Small-angular radiation: \( \frac{dN^g}{d\theta} \propto \sin \theta \exp \left( \frac{-(\theta - \theta_0)^2}{2\theta_0^2} \right), \quad \theta_0 \sim 5^\circ \)

Broad-angular radiation: \( \frac{dN^g}{d\theta} \propto \frac{1}{\theta} \)

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PYQUEN (PYthia QUENched)

Initial parton configuration
PYTHIA6.4 w/o hadronization: mstp(111)=0

↓

Hard parton rescattering and energy loss + emitted gluons
PYQUEN rearranges partons to update ns strings: ns call PYJOIN

↓

Parton hadronization and final particle formation
PYTHIA6.4 with hadronization: mstp(111)=1, call PYEXEC

More details on PYQUEN physics can be found in:

I.Lokhtin, "Monte-Carlo simulation of jet quenching and high transverse momentum observables at LHC"
Mechanisms of heavy quark production at high energy

- Pair creation
- Flavour excitation
- Gluon splitting

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Spectrum of $\mu^+\mu^-$ - pairs of high invariant mass from BB decays

Contribution of showering b-quarks in $BB \rightarrow \mu^+\mu^-$ is comparable with pair creation

Contribution of showering b-quarks in $B \rightarrow J/\psi \rightarrow \mu^+\mu^-$ is dominant (\sim 80\%)

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Medium-modified high-mass dimuons and secondary J/ψ spectra

\[ \sim 5 \times 10^4 \] events for each unquenched channels is expected for 1 month LHC run (with showering b-bbar production)

In-medium energy loss of b-quark (collisional+radiative) affects significantly the dimuon spectra

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Nuclear modification factors for high-mass dimuons and secondary $J/\psi$

~$5 \times 10^4$ events for each unquenched channels is expected for 1 month LHC run (with showering b-bbar production)

Nuclear modifications factors are slightly dependent on kinematics and above EKS shadowing (~15%)

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Summary on PYQUEN predictions for dimuons in PbPb events at the LHC

Medium-induced rescattering and energy loss of b-quark (collisional+radiative) will affect the dimuon spectra, and can result in significant suppression of rates of high-mass dimuons (by a factor ~2.5) and secondary charmonia (by a factor ~2) above nuclear shadowing effect.

Showering mechanism of heavy quark production for dimuon spectra will be important.