High transverse momentum observables in heavy ion collisions at the LHC in PYQUEN model

I.P. Lokhtin, A.M. Snigirev, C.Yu. Teplov
(SINP MSU, Moscow, Russia)

- PYQUEN - model of jet quenching in heavy ion collisions
- Nuclear modification factors for jets and high-P_T hadrons
- Jet fragmentation function measured by leading hadrons
- Transverse momentum imbalance in dimuon tagged jet events
- 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)

I. Lokhtin, A. Snigirev, Eur. Phys. J. C 46 (2006) 211

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:

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

2. Radiative loss (BDMS):

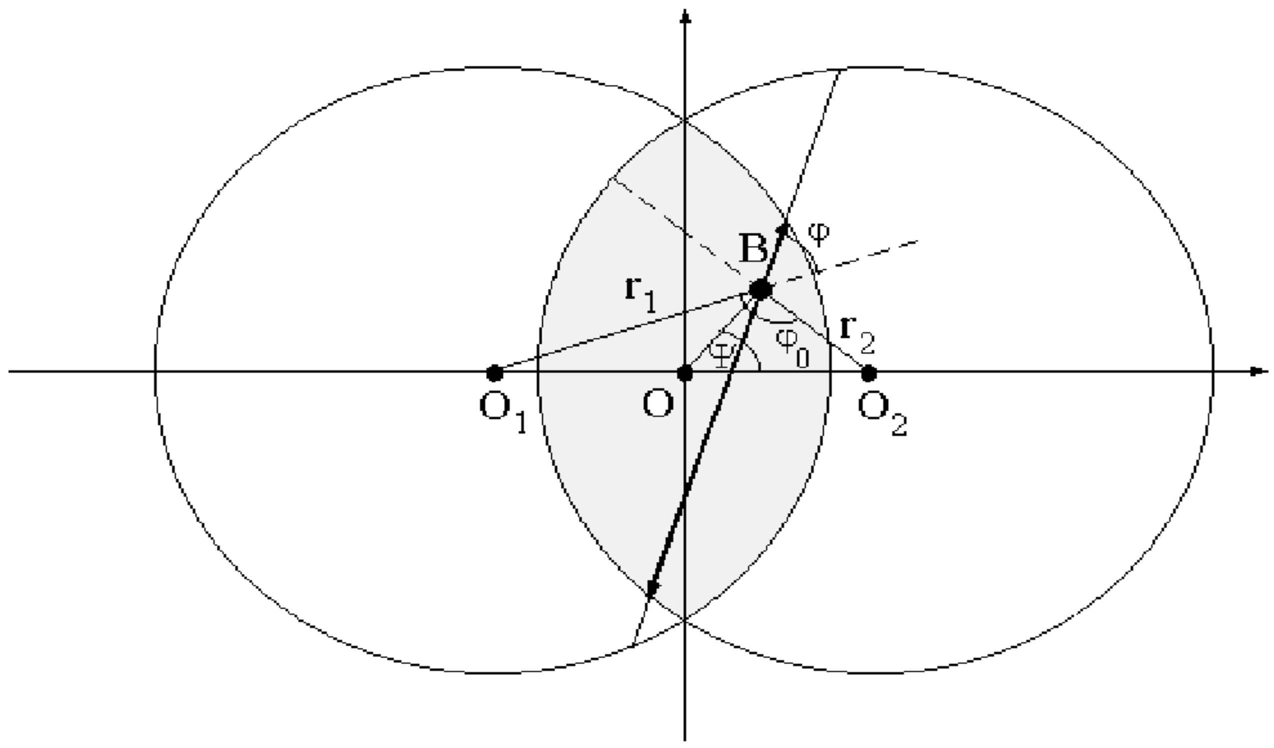
$$\frac{dE}{dx}(m_q=0)=\frac{2\alpha_s C_F}{\pi\tau_L}\int_{E_{LPM}\sim\lambda_g\mu_D^2}^{E} d\omega\left[1-y+\frac{y^2}{2}\right]\ln\left|\cos(\omega_1\tau_1)\right|,\quad \omega_1=\sqrt{i\left(1-y+\frac{C_F}{3}y^2\right)\bar{k}\ln\frac{16}{\bar{k}}},\quad \bar{k}=\frac{\mu_D^2\lambda_g}{\omega(1-y)},\quad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

"dead cone" approximation for massive quarks:

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

Nuclear geometry and QGP evolution

impact parameter b≡ |O_1O_2| - transverse distance between nucleus centers



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

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

$$\frac{dN}{d\psi\, dr}(b)=\frac{T_A(r_1)T_A(r_2)}{\int\limits_0^{2\pi} d\psi \int\limits_0^{r_{max}} rdrT_A(r_1)T_A(r_2)}$$

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

$$\frac{dP}{dl_i}=\lambda^{-1}(\tau_{i+1})\exp(-\int\limits_0^{l_i} \lambda^{-1}(\tau_i+s)ds), \quad \lambda^{-1}=\sigma\rho$$

- Radiative and collisional energy loss per scattering

$$\Delta E_{tot,i}=\Delta E_{rad,i}+\Delta E_{col,i}$$

- Transverse momentum kick per scattering

$$\Delta k_{t,i}^2=\left(E-\frac{t_i}{2m_{0i}}\right)^2-\left(p-\frac{E}{p}\frac{t_i}{2m_{0i}}-\frac{t_i}{2p}\right)^2-m_q^2$$

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

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

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

↓

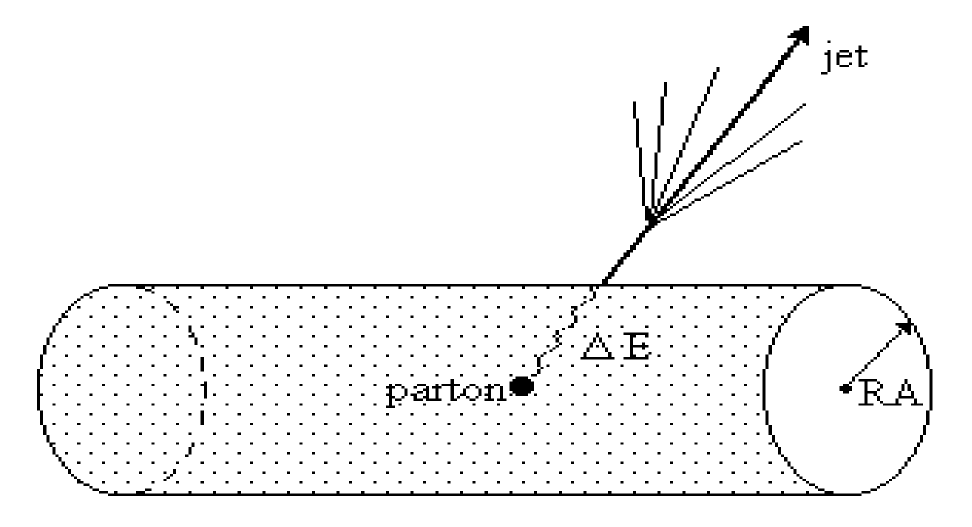
Parton hadronization and final particle formation

PYTHIA6.4 with hadronization: mstp(111)=1, call PYEXEC

More details on PYQUEN physics can be found in:

I.Lokhtin, A.Snigirev, EPJ C45 (2006) 211; ; and references therein.

Jet quenching in heavy ion collisions at the LHC



$\Delta E \propto T_0^{\,3}$ (temperature), g (number degrees of freedom) $\Rightarrow \Delta E_{QGP} >> \Delta E_{HG}$

LHC, central Pb+Pb:

$$T_{0,\,QGP} \sim 1 \text{ GeV} >> T_{0,\,HG}^{max} \sim 0.2 \text{ GeV},$$

$$g_{QGP} > g_{HG}$$

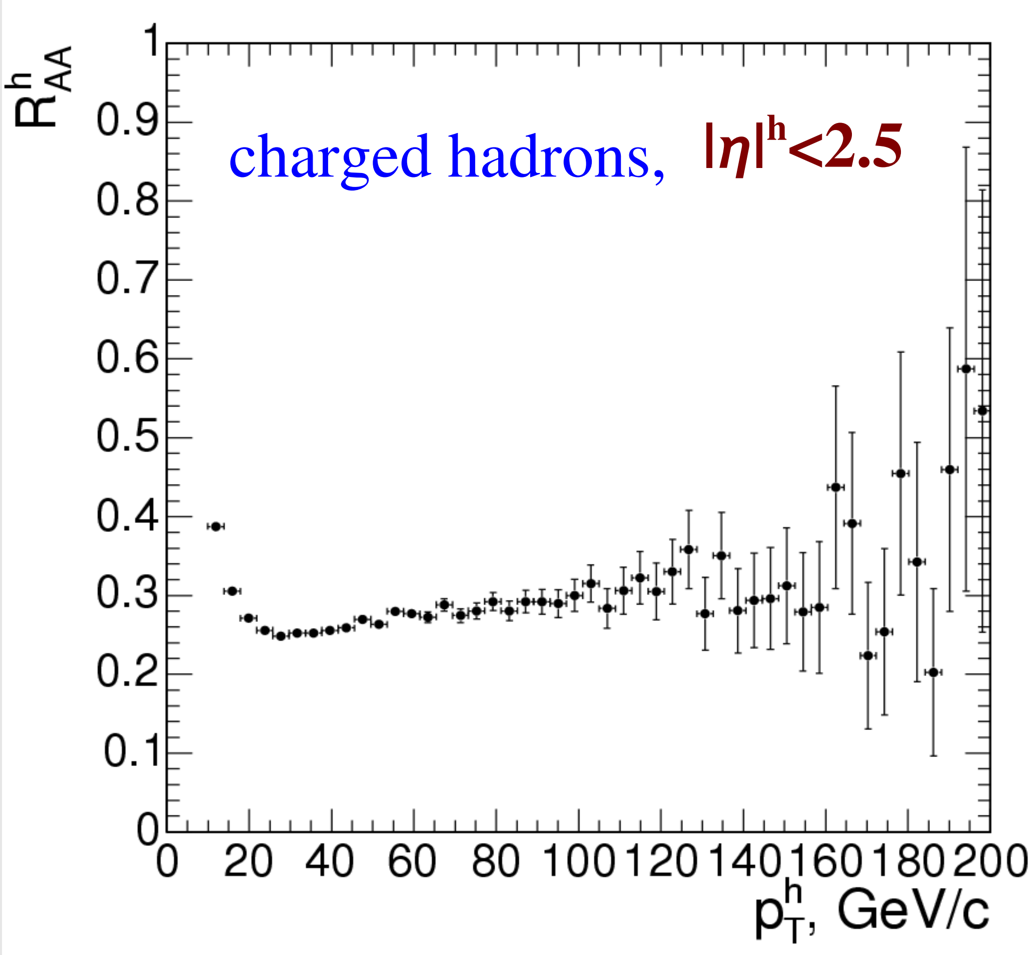
$$\Downarrow$$

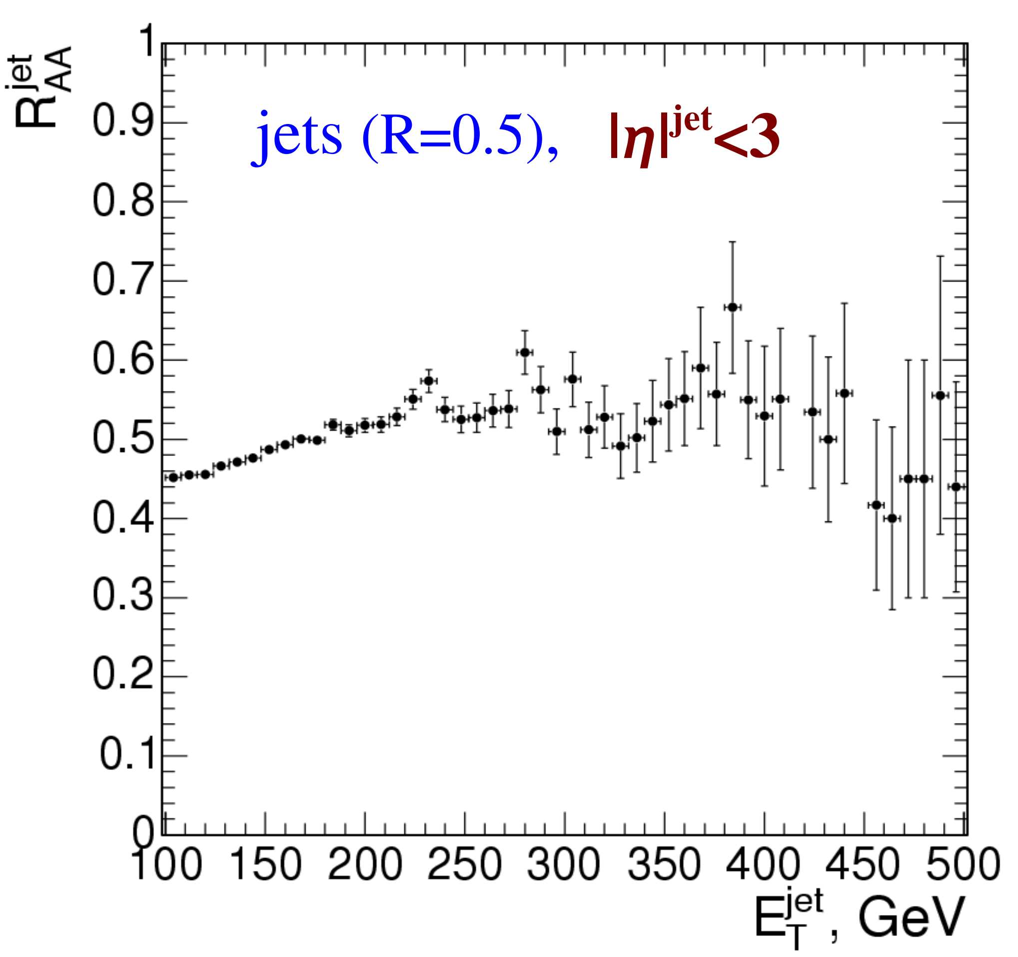
$$\Delta E_{QGP} / \Delta E_{HG} \geq (1 \text{ GeV} / 0.2 \text{ GeV})^3 \sim 10^2$$

Jet quenching at LHC (I): jet nuclear modification factors

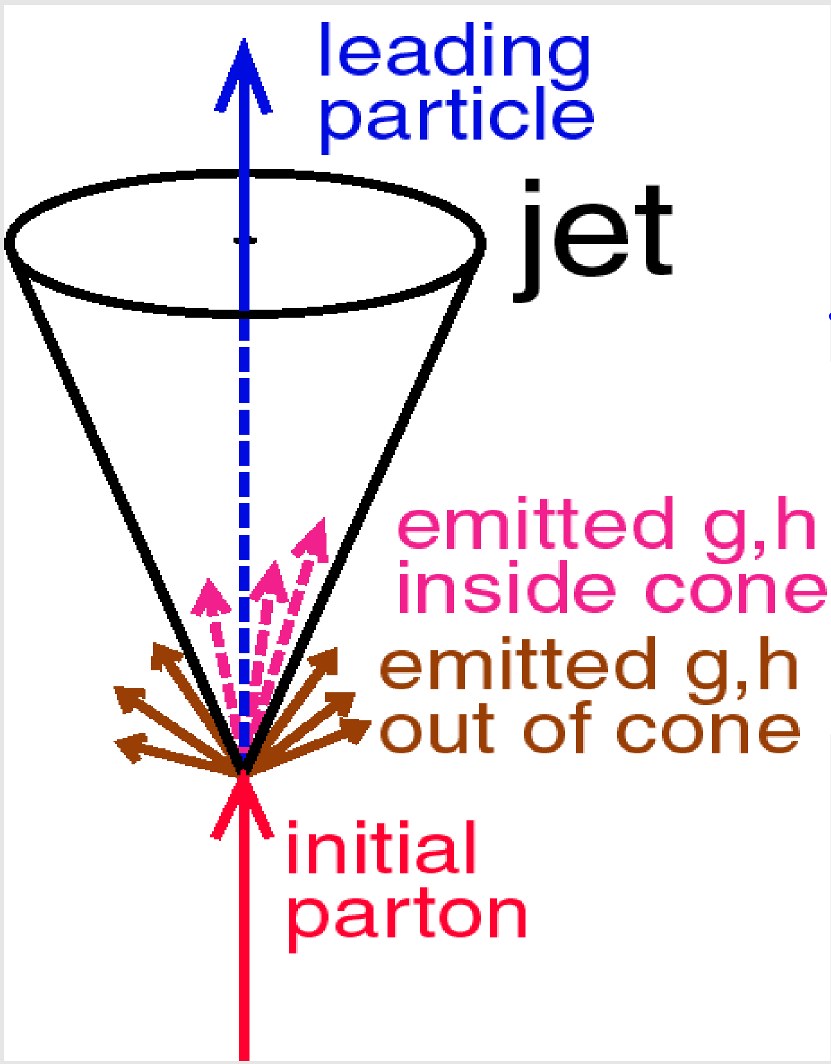
PYQUEN, Pb+Pb (b=0), √s=5.5A TeV (T_0=1 GeV, τ_0=0.1 fm/c, n_f=0)

(~10^6 events with E_T^{jet} > 100 GeV is expected for 1 month LHC run, L=0.5 nb^{-1})





Jet quenching at LHC (II): jet fragmentation function



Jet fragmentation function *D(z)*:

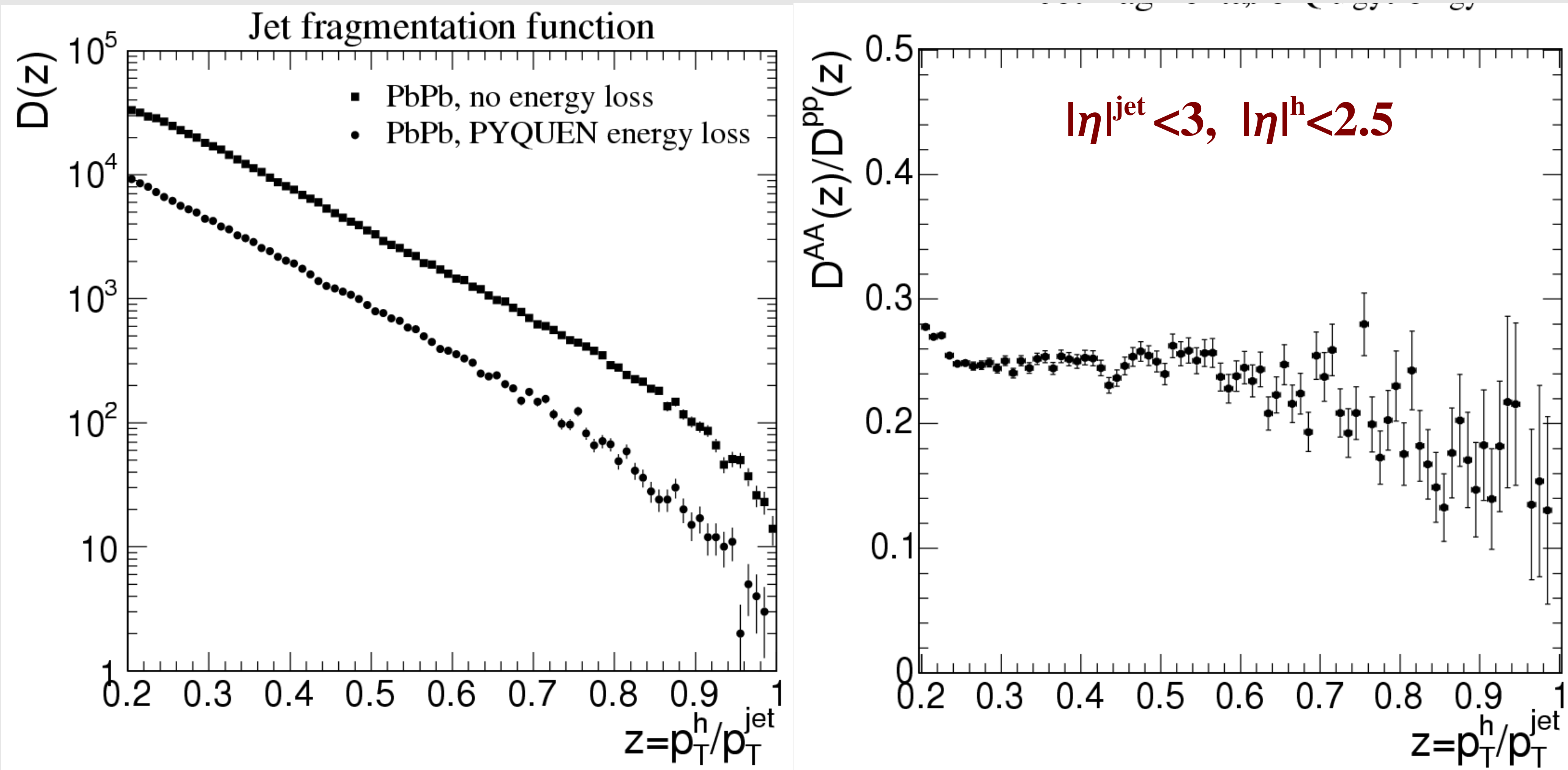
probability distribution for leading hadron in the jet to carry fraction $z(\equiv p_T^{h}/p_T^{jet})$ of jet transverse momentum:

$$D(z) = \int\limits_{z \cdot p_{T\,\min}^{jet}} d(p_T^h)^2 dy dz' \frac{dN_{AA}^h}{d(p_T^h)^2 dy dz'} \delta(z - p_T^h/p_T^{jet}) \Bigg/ \int\limits_{p_{T\,\min}^{jet}} d(p_T^{jet})^2 dy \frac{dN_{AA}^{jet}}{d(p_T^{jet})^2 dy}$$

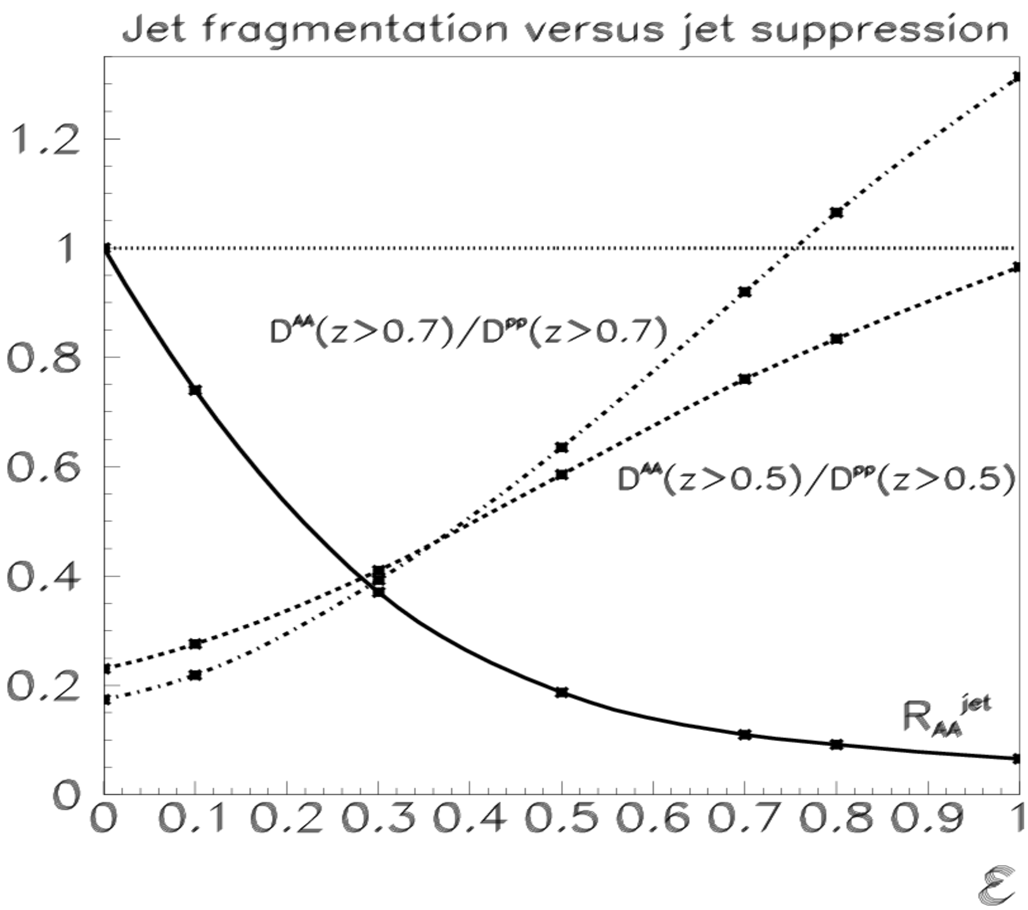
In the jet induced by heavy quark, the energetic muon can be produced ("b-tagging")

Medium-modified jet fragmentation function measured with leading $h^{\pm}$, h^{o}

Pb+Pb (b=0), $\sqrt{s}$=5.5A TeV, E_T^{jet} > 100 GeV (~0.6 millions unquenched jets with z>0.2 for 1 month LHC run)



JFF softening vs. jet rate suppression



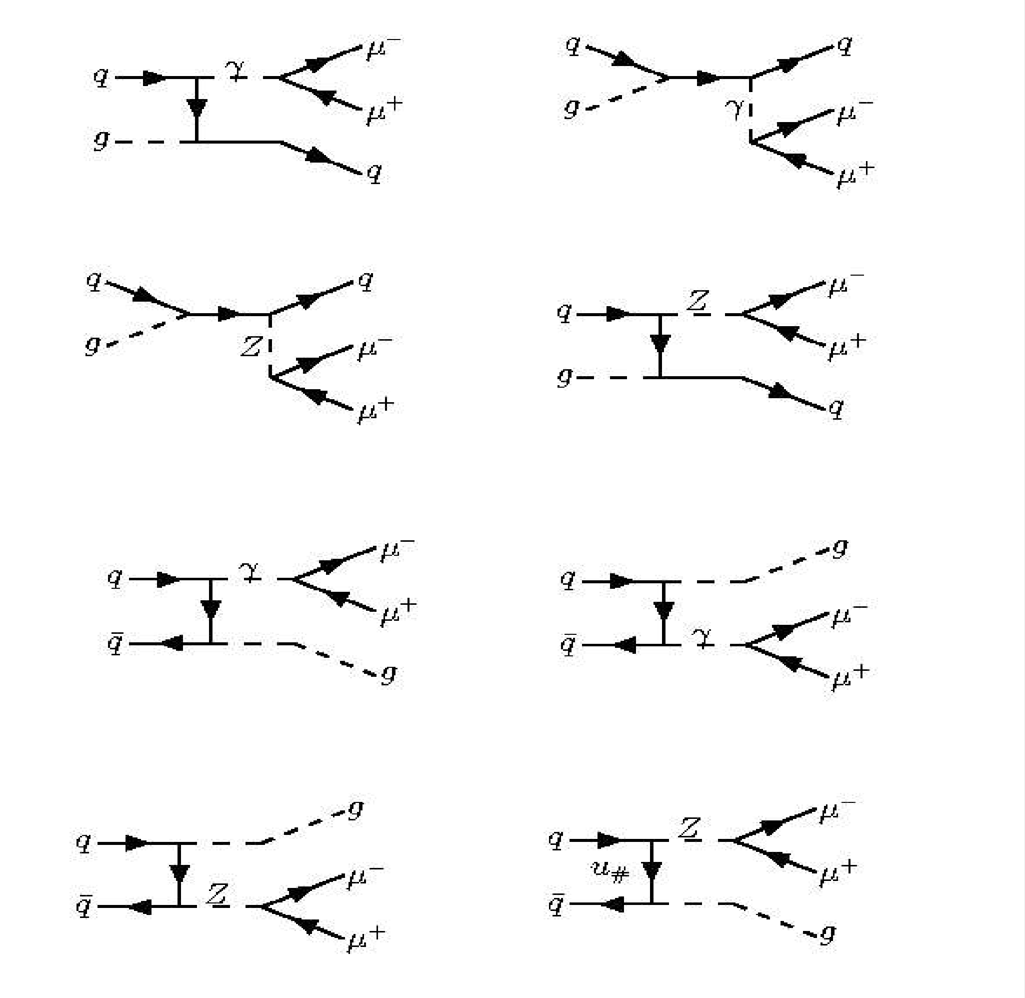
Medium-modified JFF softening and jet rate suppression depends on the fraction ε of jet energy loss falling outside the jet cone

The anti-correlation between two effects can be carried out in order to differentiate between various energy loss mechanisms (small-angular radiation vs. wide-angular radiation and collisional loss).

I.P.Lokhtin and A.M.Snigirev, Phys.Lett. B567 (2003) 39

Jet quenching at LHC (III): $\gamma^*/Z(\rightarrow\mu^+\mu^-)$+jet production

COMHEP + PYTHIA



$|\eta|^{\mu}<2.5$, $p_T^{\mu}>5$ GeV/c

$|\eta|^{jet}<3$, $E_T^{jet}, P_T^{\mu\mu}>50$ GeV

$\sqrt{s}$=5.5 A TeV:

$\sigma(pp\rightarrow\mu^+\mu^-+jet) \approx 18$ pb,

$\sigma(Pb+Pb\rightarrow\mu^+\mu^-+jet) \approx 0.8\ \mu b$

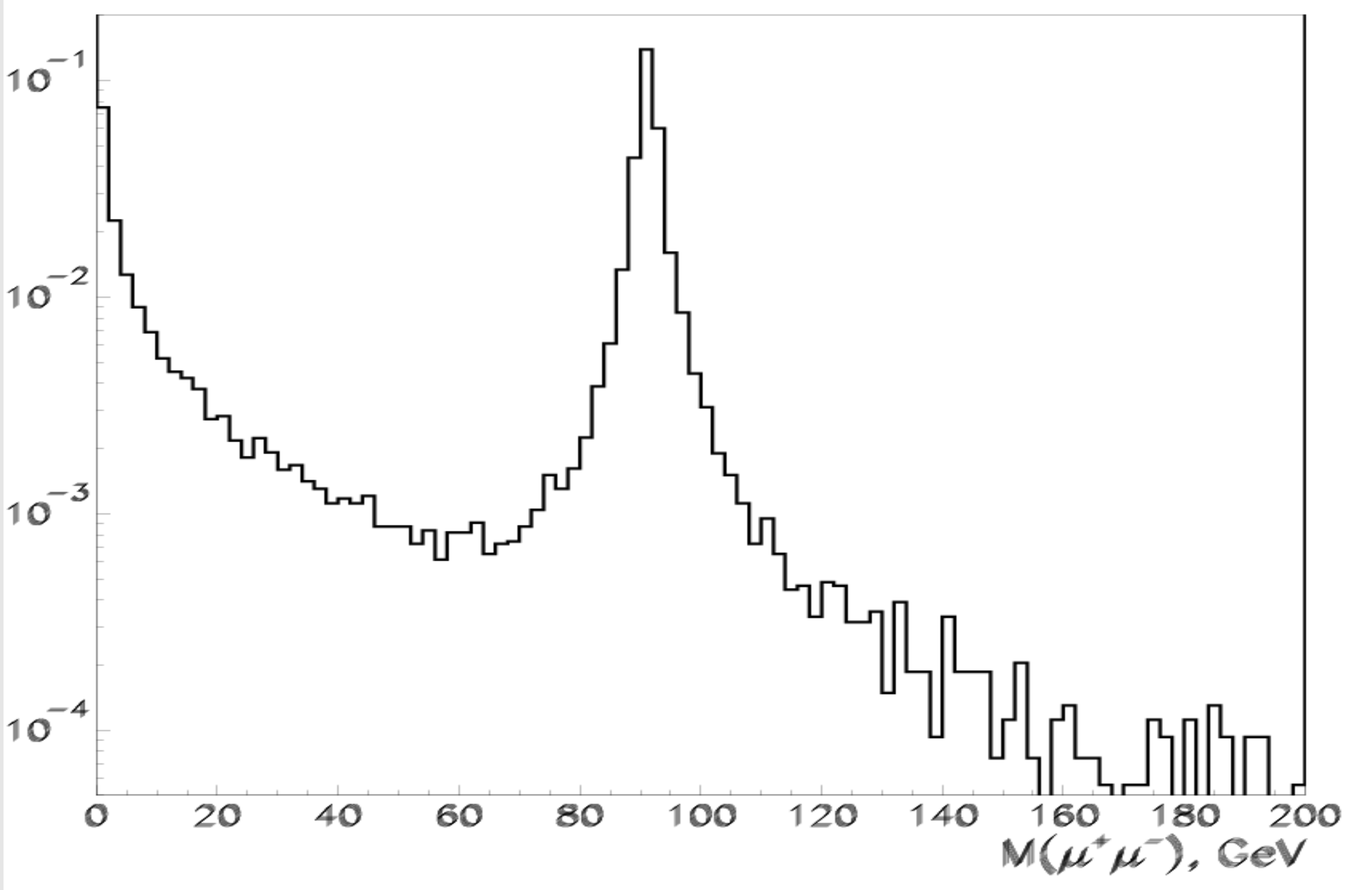
Events per 1 month:

($T=1.3\times10^6$ s, $L=4.2\times10^{26}$ $sm^{-2}s^{-1}$)

$T\times L\times\sigma(Pb+Pb\rightarrow\mu^+\mu^-+jet) \sim 500$

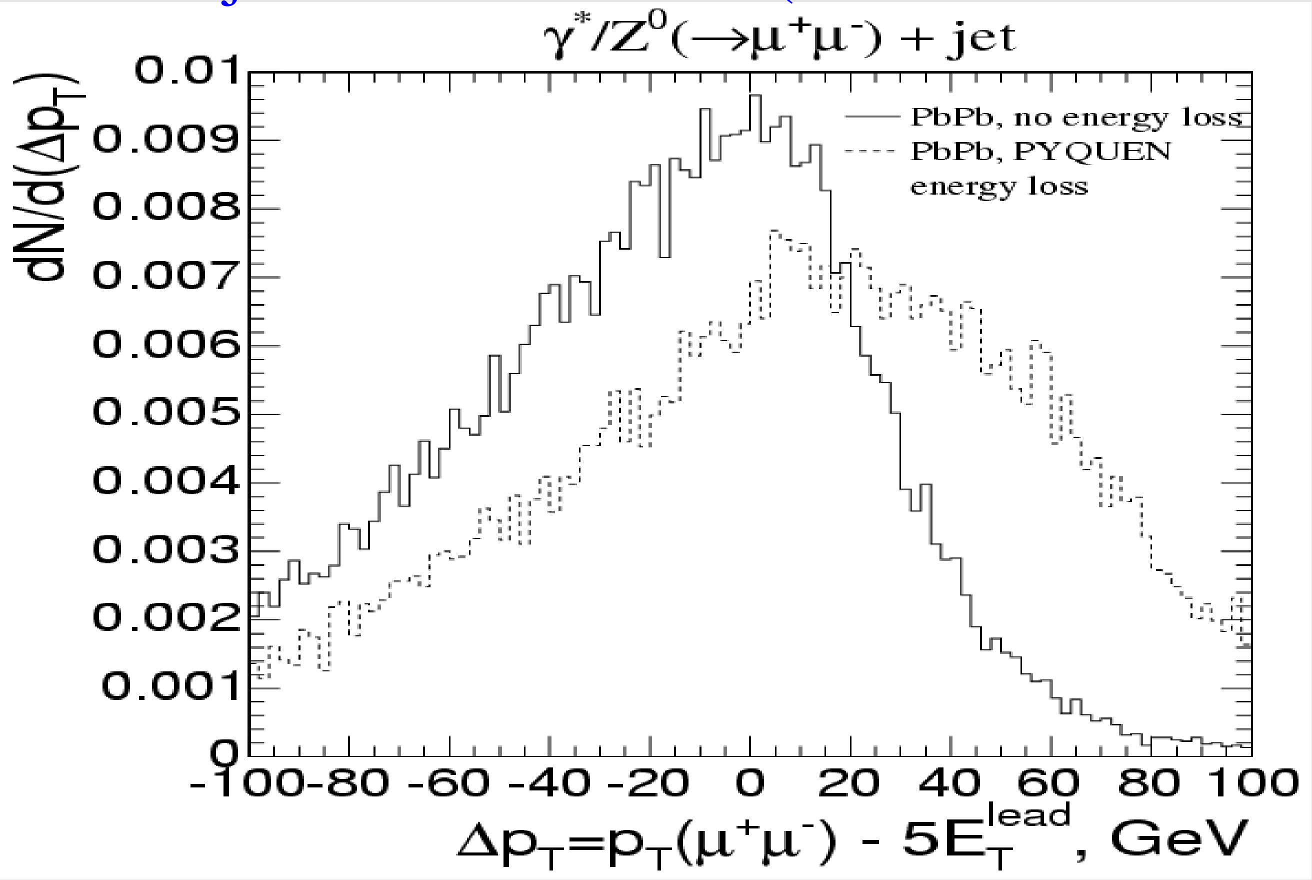
I. Lokhtin, A. Sherstnev, A. Snigirev, Phys. Lett. B 599 (260) 2004

Invariant mass spectrum of $\mu^+\mu^-$-pairs from γ^*/Z+jet production



Imbalance of transverse momentum in $\gamma^*/Z(\rightarrow\mu^+\mu^-)$+jet channel in HIC

Dimuon-jet leader correlation (minimum bias PbPb)



Advantage in using P_T-imbalance between leading hadron in a jet (but not jet itself) and muon pair: week dependence on dispersion of jet energy determination

Summary on PYQUEN predictions for high-P_T jets in PbPb events at the LHC

Strong suppression of high-p_T hadrons (by a factor of ~4 for jet triggered central events and ~6 for central events without jet trigger, R_{AA} slightly increases with p_T) and significant suppression of the absolute jet rates (due to in-medium gluon bremsstrahlung out of jet cone and collisional loss: by a factor of ~2 and almost independent on E_T).

Strong softening of the jet fragmentation function D(z) measured with leading hadron (by a factor of ~ 4 and slightly increasing with z). The anti-correlation between softening of the D(z) and jet rate suppression allows one to differentiate between various energy loss mechanisms (small-angular radiation vs. wide-angular radiation and collisional loss).

Significant P_T-imbalance between the muon pair and a leading particle in a jet for $\gamma^*/Z(\rightarrow\mu^+\mu^-)$+jet production.