A Monte Carlo Model for Jet Quenching

Jet Quenching from Soft QCD Scattering in the Quark-Gluon Plasma

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HERA - LHC Workshop

DESY 14. 3. 2007

project with

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Outline

Introduction

Our Model
- Description
- Results

Summary & Outlook

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Our Model

- Description
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Summary & Outlook

What is so Exciting about Jet Quenching?

jet quenching: suppression of high-$p_\perp$ particles (jet particles) in collisions of ultra-relativistic heavy nuclei

- origin: energetic quarks and gluons interact with the QGP and lose energy
- jet quenching carries information about the QGP

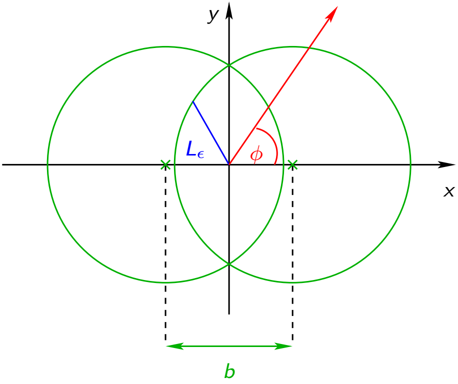
$\Rightarrow$ want to use jet quenching as probe to determine QGP parameters

But then we have to understand the energy loss mechanism.

- induced gluon radiation (QCD bremsstrahlung)
- elastic collisions
- but there must be more to it

Some Nomenclature

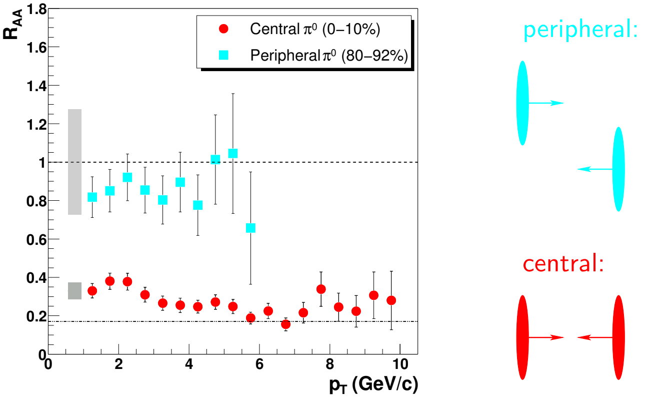
A + A collision in the transverse plane



centrality: fraction of geometrical cross section ($\sim b^2$)

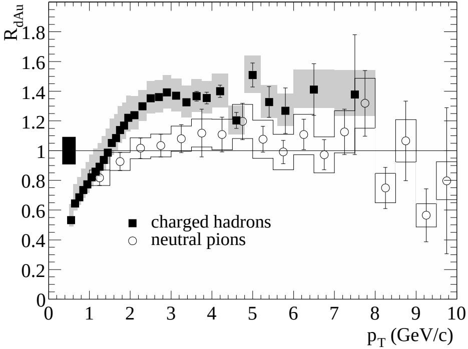
The Nuclear Modification Factor

$$R_{AB}(p_\perp,\eta) = \left(\frac{1}{N_{evt}}\frac{d^2N^{AB}}{dp_\perp d\eta}\right)\cdot\left(\frac{\langle N_{coll}\rangle}{\sigma_{inel}^{pp}}\frac{d^2\sigma^{pp}}{dp_\perp d\eta}\right)^{-1}$$



Adler *et al.*, PHENIX Collaboration, PRL **91** (2003) 072301

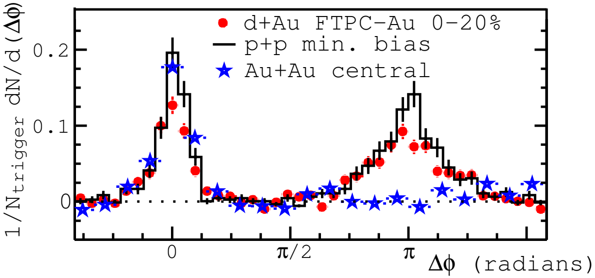
Origin of Jet Quenching



Adler *et al.*, PHENIX Collaboration, PRL **91** (2003) 072303

- no suppression in d+Au collisions → jet quenching final state effect
- small enhancement due to initial state rescattering → Cronin effect

Disappearance of the away-side jet



Adams *et al.*, STAR Collaboration, PRL **91** (2003) 072304

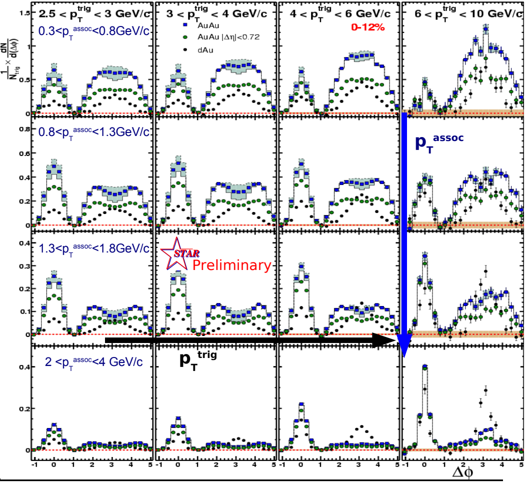
trigger particles: $4\,\text{GeV} < p_\perp < 6\,\text{GeV}$
associated particles: $2\,\text{GeV} < p_\perp < p_\perp(\text{trig})$

- disappearance of the away-side jet in central Au + Au collisions
- again no suppression in d + Au

Reappearance of the away side jet

Associated p_T Dependence

- Centrality : 0 - 12%
- Associated p_T (rows):
  - 0.3 – 0.8 GeV/c
  - 0.8 – 1.3 GeV/c
  - 1.3 – 1.8 GeV/c
  - 2.0 – 4.0 GeV/c
- Triggers (columns):
  - 2.5 – 3.0 GeV/c
  - 3.0 – 4.0 GeV/c
  - 4.0 – 6.0 GeV/c
  - 6.0 – 10.0 GeV/c
- Detailed cases:
  - 3rd row
  - right column



Mark Horner Quark Matter 2006, Shanghai, Nov 14 - 20 7/16

Mark Horner's talk at Quark Matter 2006

Conclusions

- The strong suppression and modification of jets in heavy ion collisions may reveal information about the properties of the Quark - Gluon Plasma.
- There is a wealth of exciting data (mainly differential observables)
  - $R_{AA}(p_\perp,\phi,\eta)$ for identified particles and different beam energies and nuclei
  - two particle correlations in ϕ and η in different $p_\perp$ bins
  - three particle correlations
  - azimuthal anisotropy (v_2) as function of $p_\perp$ and particle species
  - R_{AuAu} and v_2 for electrons from heavy flavour decays
  - ...
- We are dealing with a very complex system (geometry, expansion, etc.), fluctuations may be important.

$\Rightarrow$ We would like to have a MC.

Outline

Overview

our code:
- choose impact parameter
- ↓ pick position of hard scattering
- ↓ increase width of $k_\perp$ distribution ← Cronin effect

PYTHIA:
- ↓ pdf (p + p)
- ↓ initial state parton shower
- ↓ matrix element
- ↓ final state parton shower

our code:
- ↓ interactions with the QGP

PYTHIA:
- ↓ hadronisation ← independent fragmentation

Modelling of the QGP

Geometry: N_{part}, N_{coll} etc. from simple Glauber - model (sharp sphere or Woods - Saxon potential)

Eskola, Kajantie, Lindfors, Nucl. Phys. B **323** (1989)

EOS: ideal relativistic gluon gas

$$\Rightarrow n = \frac{g}{\pi^2}\zeta(3)T^3 \quad \& \quad \epsilon = \frac{\pi^2 g}{30}T^4$$

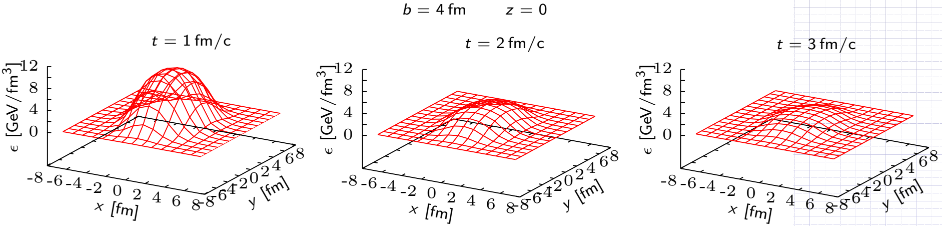
expansion: boost-invariant longitudinal expansion

$$T(\tau) \propto \tau^{-1/3} \quad \Rightarrow \quad n(\tau) \propto \tau^{-1} \quad \& \quad \epsilon(\tau) \propto \tau^{-4/3}$$

$$(\tau = \sqrt{t^2 - z^2})$$

Bjorken, Phys. Rev. D **27** (1983)

local energy density: $\epsilon(x,y,\tau) \propto N_{\text{part}}(x,y) \cdot \tau^{-4/3}$



Interactions with the Plasma

Basic idea

soft colour interactions with background important in p+p collisions (SCI Model by G. Ingelman et al.)

Edin, Ingelman, Rathsman, Phys. Lett. B **366** (1996) 371

Enberg, Ingelman, Timneanu, Phys. Rev. D **64** (2001) 114015

$\Rightarrow$ should occur also in a QGP
much more interactions $\rightarrow$ even small momentum transfer may be important $\rightarrow$ jet quenching?

Soft colour interactions with (small) momentum transfer

- treated as elastic scattering
- successive scatterings assumed to be independent
- momentum transfer t Gaussian distributed
- interaction probability is 0.5 for quarks and 0.75 for gluons

The model can be applied to heavy quarks without changes.

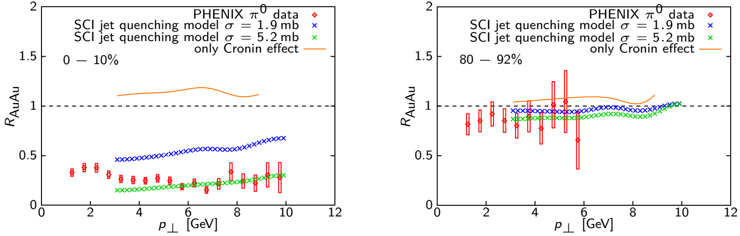
Model Parameters

default values:		
Cronin parameter	α	$0.5\,\mathrm{GeV}^2$
QGP formation time	τ_i	$0.2\,\mathrm{fm}$
initial energy density $\epsilon(\tau = 1\,\mathrm{fm})$	ϵ_0	$5.5\,\mathrm{GeV\,fm}^{-3}$
critical temperature	T_c	$0.175\,\mathrm{GeV}$
gluon mass	m_g	$0.2\,\mathrm{GeV}$
interaction probability quark	p_q	0.5
interaction probability gluon	p_g	0.75
width of t - distribution	σ_t	$0.5\,\mathrm{GeV}^2$
screening radius	R_{scr}	$0.3\,\mathrm{fm}$
$\Rightarrow$ scattering cross section: $\sigma = 1.9\,\mathrm{mb}$		

alternative:		
screening radius	R_{scr}	$0.5\,\mathrm{fm}$
$\Rightarrow$ scattering cross section: $\sigma = 5.2\,\mathrm{mb}$		

Nuclear Modification Factor

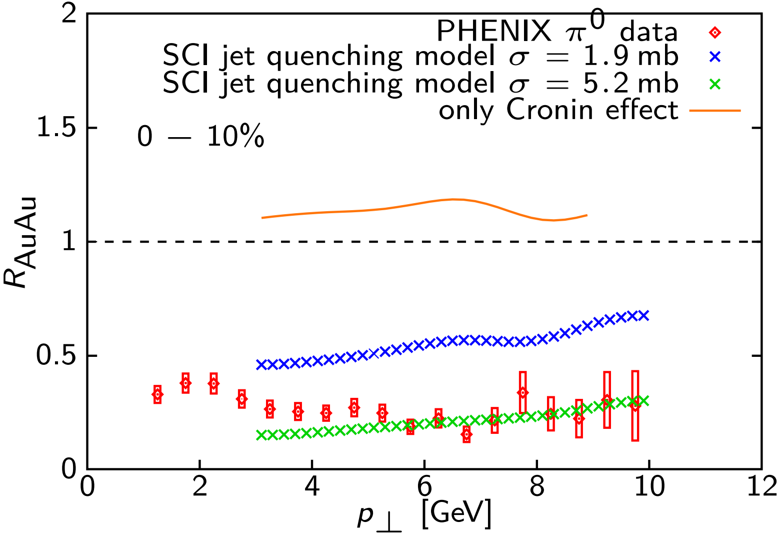
π^0 suppression



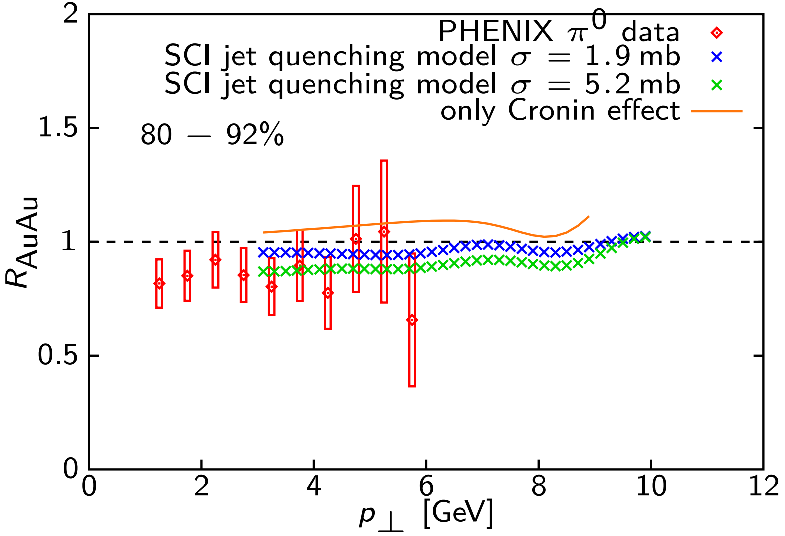
- most central collisions: large cross section scenario consistent with data
- most peripheral collisions: two scenarios are similar and in agreement with data

Adler *et al.*, PHENIX Collaboration, PRL **91** (2003)

Nuclear Modification Factor

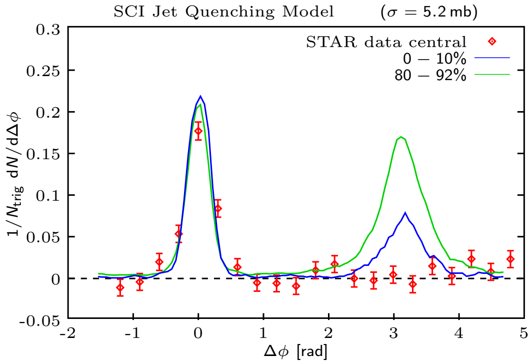


Nuclear Modification Factor



Azimuthal Correlation

trigger particles: $4\,\text{GeV} < p_\perp < 6\,\text{GeV}$
associated particles: $2\,\text{GeV} < p_\perp < p_\perp(\text{trig})$

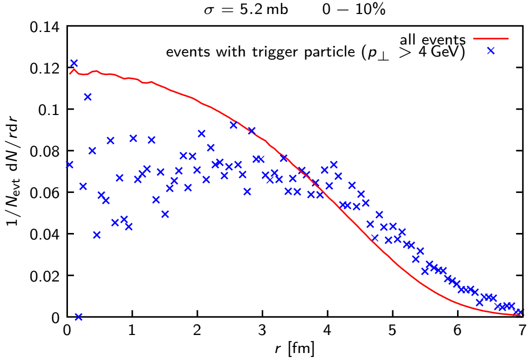


- We see a suppression of the away-side jet but no disappearance.

Adams *et al.*, STAR Collaboration, PRL **91** (2003) 072304

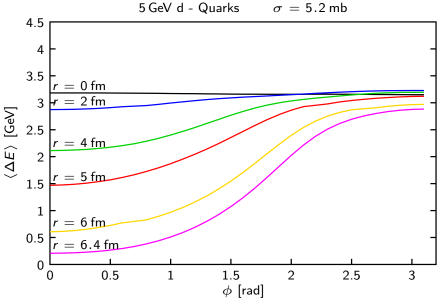
Surface Bias

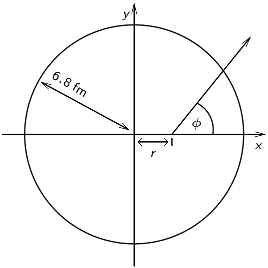
r: distance of hard scattering from centre



We see a moderate surface bias in accordance with the two particle correlation.

Energy Loss and Geometry

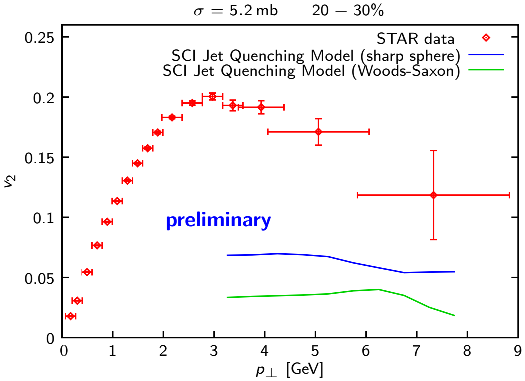




- It is difficult to get a strong suppression due to the rapid expansion, emission from the surface does not help.

Azimuthal Anisotropy

$$v_2 = \langle \cos(2\phi) \rangle$$

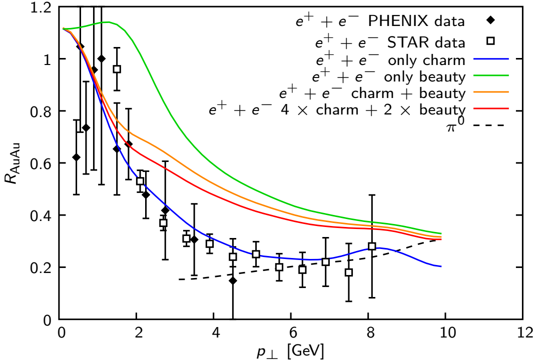


Adams *et al.*, STAR Collaboration, Phys. Rev. C 72 (2005) 014904

- effect weaker than in data
- big difference between potentials, although $R_{\mathrm{AuAu}}(p_\perp)$ is practically the same

Electron/Positron R_{AuAu}

now we are looking at heavy flavours



- The suppression of electrons is somewhat too weak even with the large cross section.

Adler *et al.*, PHENIX Collaboration, PRL **96** (2006)
Abelev *et al.*, STAR Collaboration, nucl-ex/0607012

Outline

Summary & Outlook

Summary

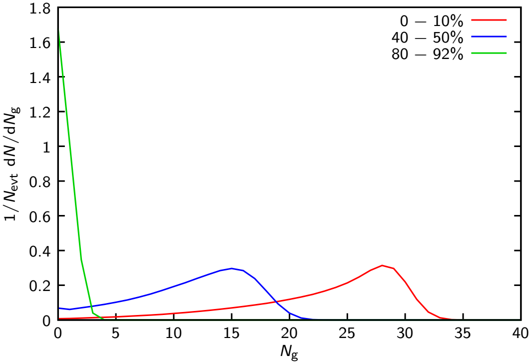
- Energy loss through scattering is important, although it cannot account for the whole jet quenching.
- The expansion as well as geometrical aspects turned out to be crucial.
- Furthermore, with a MC one has access to practically all observables.

Outlook

- How does the medium affect the other processes, especially parton showers and hadronisation? – project with Hans Jürgen Pirner

Zapp, Ingelman, Rathsman, Stachel, PLB 637 (2006) 179
Zapp, Ingelman, Rathsman, Stachel, hep-ph/0702201

Number of Gluons Encountered by a Hard Parton



looks like expected $\surd$