RHIC Physics with the Parton Cascade Model

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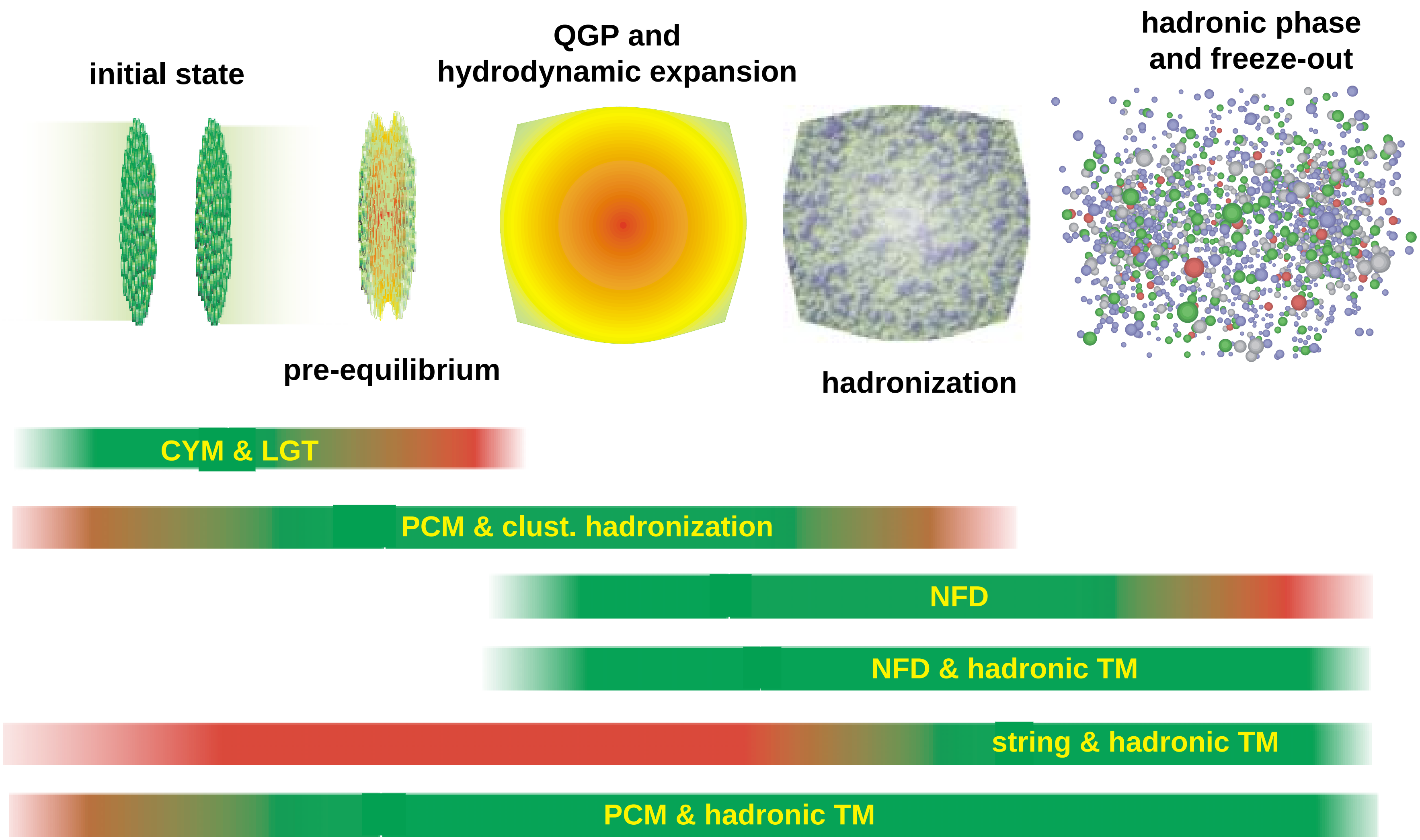
- Motivation
- The PCM: Fundamentals & Implementation
- Tests: comparison to pQCD minijet calculations
- Application: Reaction Dynamics @ RHIC, v_2
- Outlook & Plans for the Future

Transport Theory at RHIC



Aims of the Parton Cascade Model

provide a microscopic space-time description of relativistic heavy-ion collisions based on perturbative QCD

- discover novel phenomena associated with the collective behaviour of highly compressed and/or heated QCD matter
- map the route to kinetic and chemical equilibration from a partonic initial state to a Quark-Gluon-Plasma
- identify probes of the partonic phase
- prepare the ground for a study of hadronization and comparison to hadronic observables
- provide initial conditions for other model calculations, e.g. hydrodynamics or hadronic cascades

Basic Principles of the PCM

- degrees of freedom: quarks and gluons
- classical trajectories in phase space (with relativistic kinematics)
- initial state constructed from experimentally measured nucleon structure functions and elastic form factors
- an interaction takes place if at the time of closest approach d_{min} of two partons

- system evolves through a sequence of binary (2Æ2) elastic and inelastic scatterings of partons and initial and final state radiations within a leading-logarithmic approximation (2ÆN)
- binary cross sections are calculated in leading order pQCD with either a momentum cut-off or Debye screening to regularize IR behaviour
- guiding scales: initialization scale Q_0, p_T cut-off p_0 / Debye-mass $_{—D}$, intrinsic k_T / saturation momentum Q_S, virtuality >

Initial State in the PCM

the initial phase-space distribution can be constructed either from known data on hadrons and nuclei or taken from a model of the initial state of heavy-ion collisions (e.g. a Color-Glass-Condensate)

- for partons of flavour *a* in a nucleus the distribution is given by:

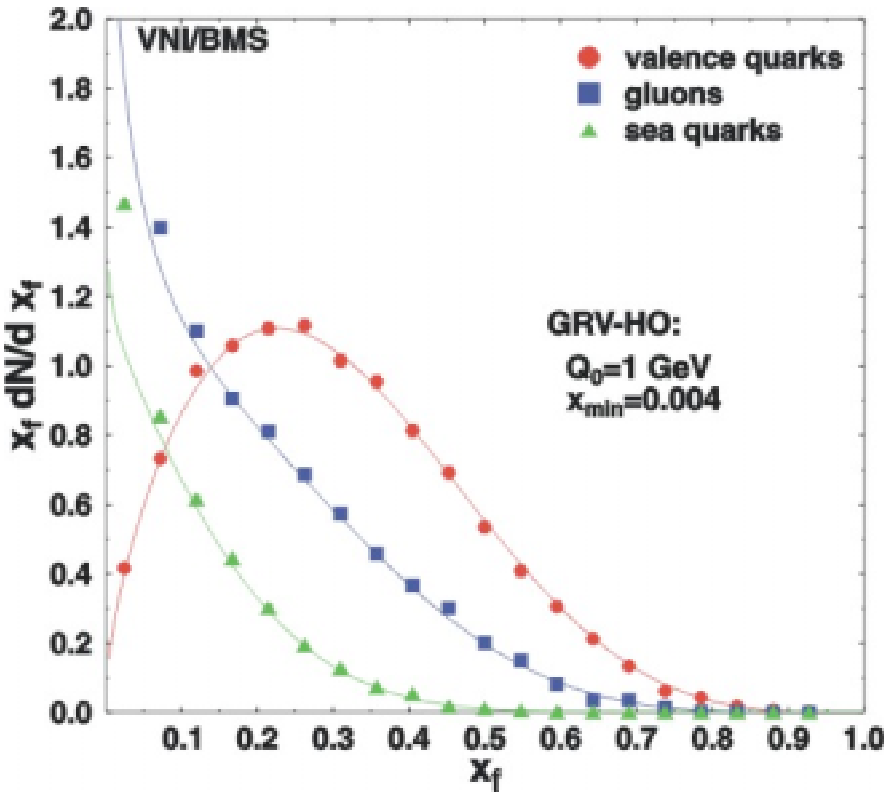
ÿ with the initial momentum distribution:

(Q_0: initial resolution scale, $\_^A$ optional shadowing, g: opt. primordial k_T)

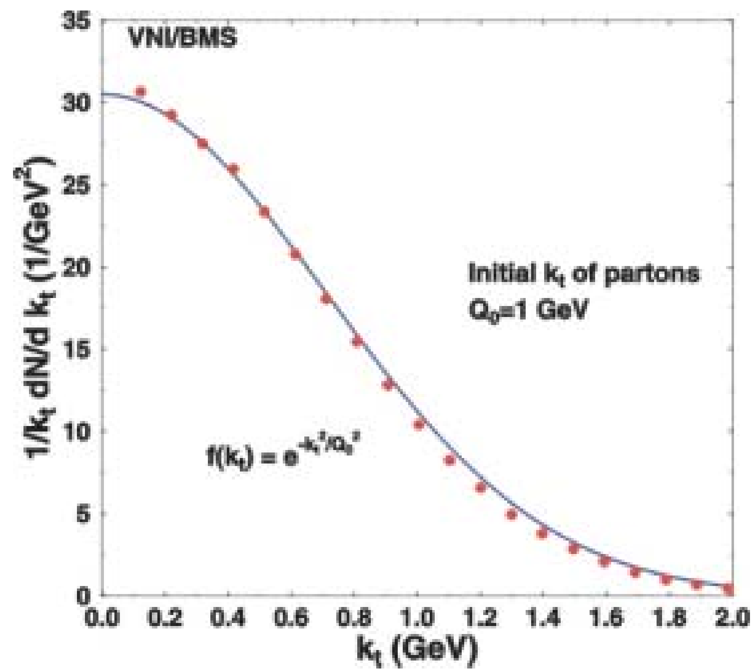
ÿ and the initial spatial distribution:

- H_N: distribution of nucleons in nucleus (e.g. Fermi-Distribution)
- h_a: distribution of partons in hadron (based on elastic form factor)

Initial State II: Parton Momenta



- flavour and x are sampled from PDFs at an initial scale Q_0 and low x cut-off x_{min}
- initial k_t is sampled from a Gaussian of width Q_0 in case of no initial state radiation



- virtualities are determined by:

Binary Processes in the PCM

- the total cross section for a binary collision is given by:

  with partial cross sections:

- now the probability of a particular channel is:

- finally, the momentum transfer & scattering angle are sampled via

Parton-Parton Scattering Cross-Sections

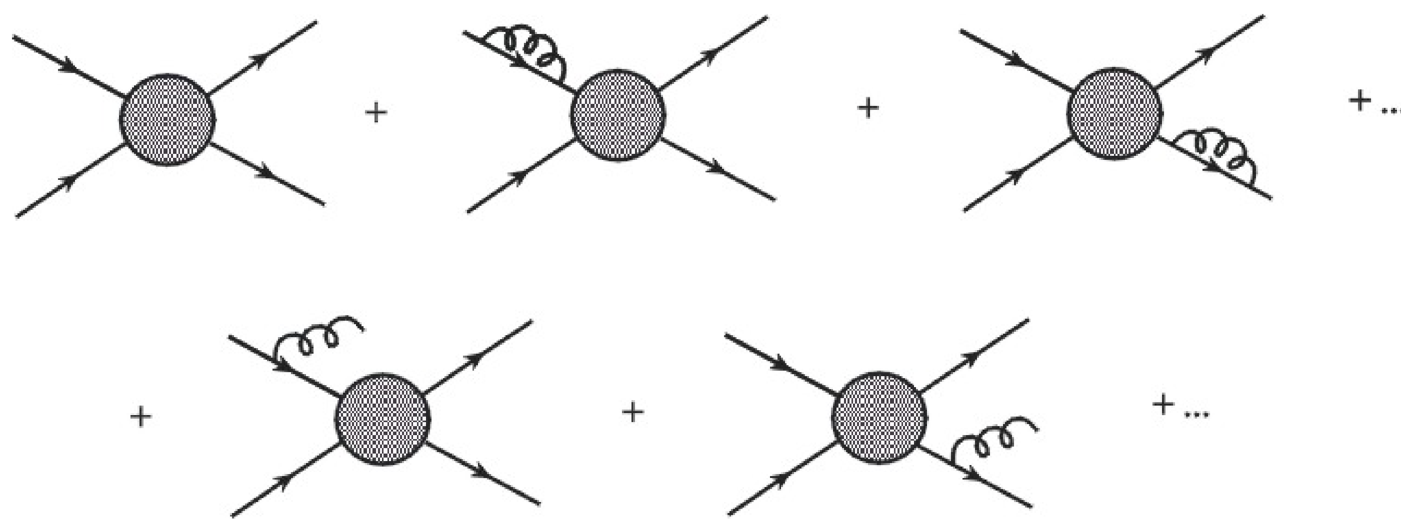
g g Æ g g	[illegible]	q q' Æ q q'	[illegible]
q gÆ q g	[illegible]	q qbarÆ q' qbar'	[illegible]
g g Æ q qbar	[illegible]	q g Æq _	[illegible]
q q Æ q q	[illegible]	q qbar Æ g _	[illegible]
q qbar Æ q qbar	[illegible]	q qbar Æ _ _	[illegible]
q qbar Æ g g	[illegible]		

- a common factor of $\pi\_{s}^{2}(Q^2)/s^2$ etc.
- further decomposition according to color flow

Scale Evolution and Branching

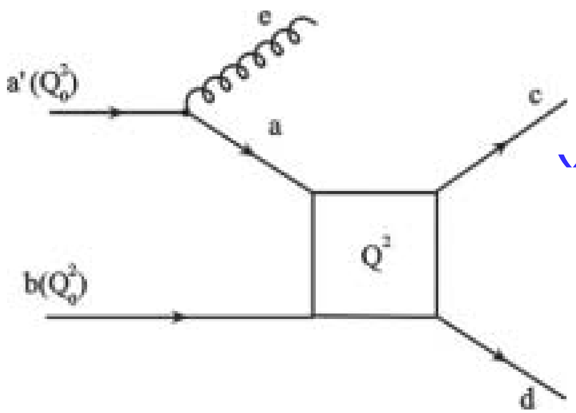
- higher order corrections describing the evolution of the factorization scale and branching processes are treated in the collinear (LLA) approximation
- the differential cross section is modified by a factor of

for each initial state parton

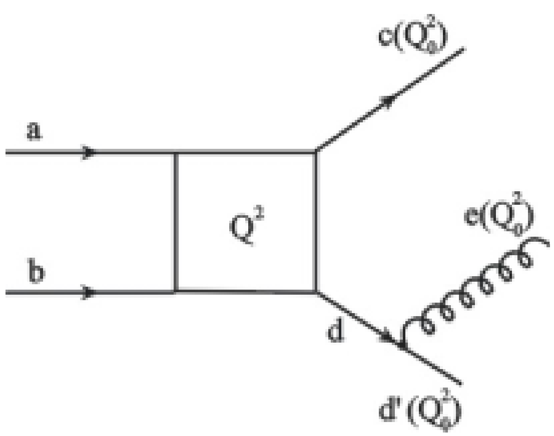


Initial and final state radiation

Probability for a branching is given in terms of the Sudakov form factors:



space-like branchings:

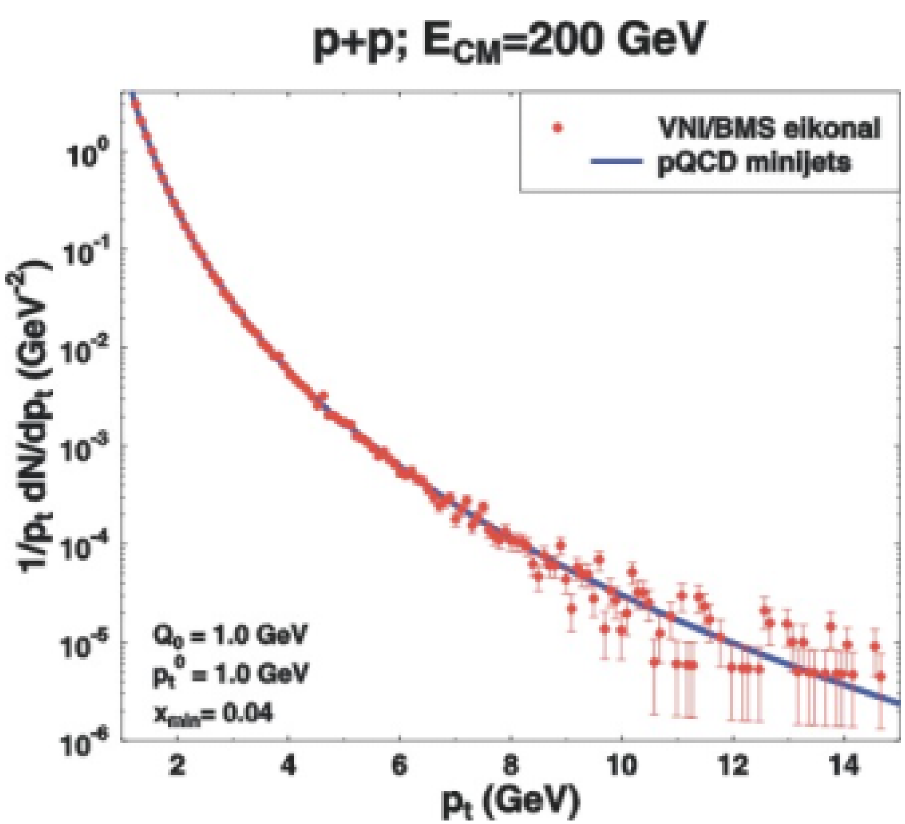


time-like branchings:

• Altarelli-Parisi splitting functions included:
$P_{qÆqg}$, $P_{gÆgg}$, $P_{gÆqqbar}$ & $P_{qÆq\_}$

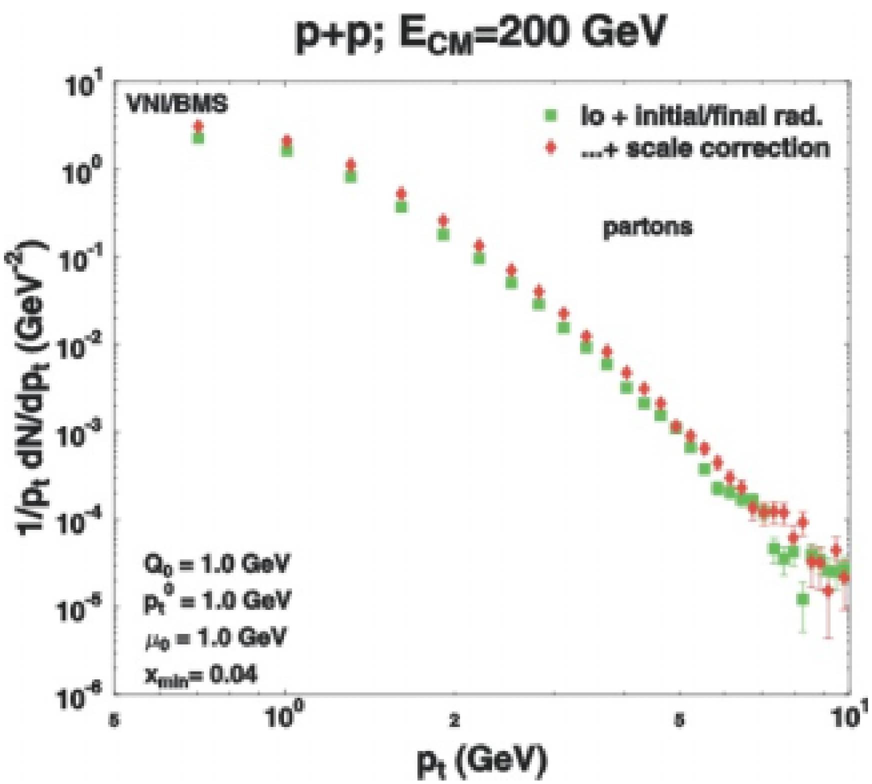
Testing the PCM Kernel: p_t distribution

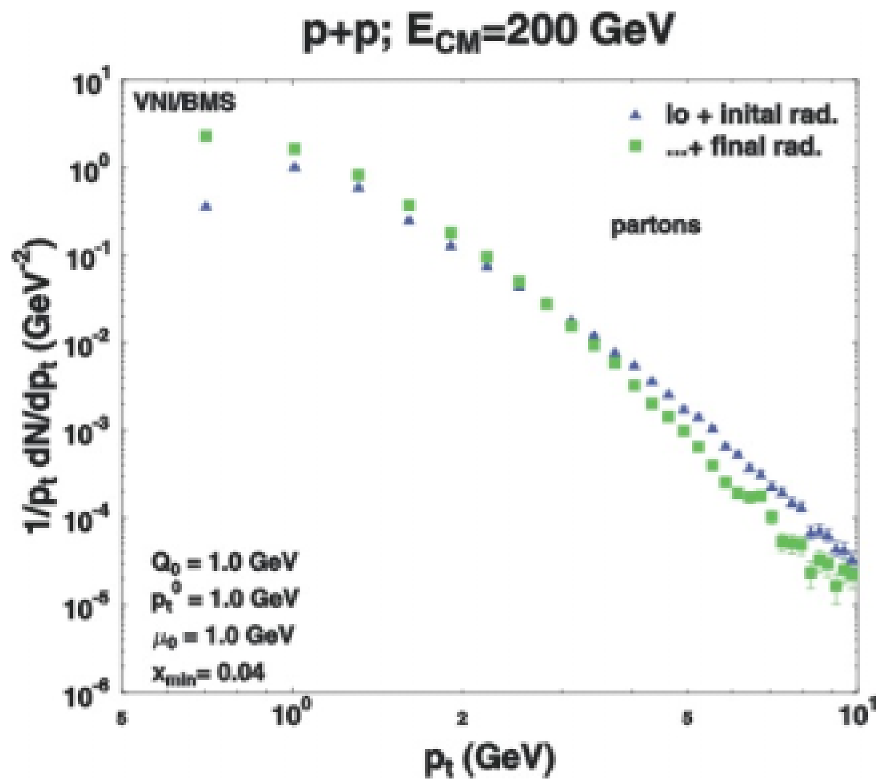
- the minijet cross section is given by:



- equivalence to PCM implies:
  - ÿ keeping the factorization scale $Q^2 = Q_0^2$ with _s evaluated at Q^2
  - ÿ restricting PCM to eikonal mode, without initial & final state radiation
- results shown are for b=0 fm

Corrections for Q_0 & Initial/Final Radiation





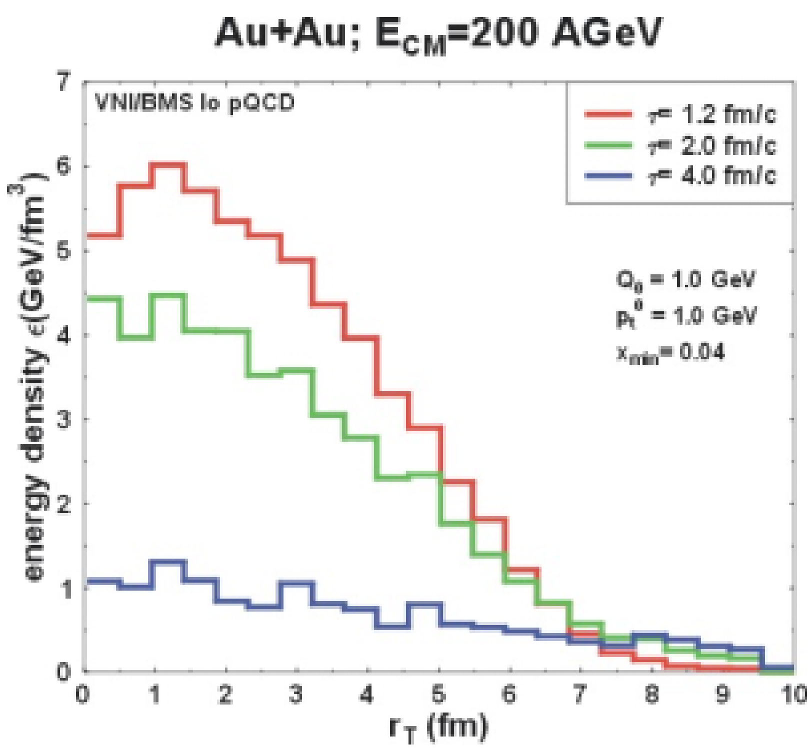
•dynamic factorization scale correction increases cross section by ~40%

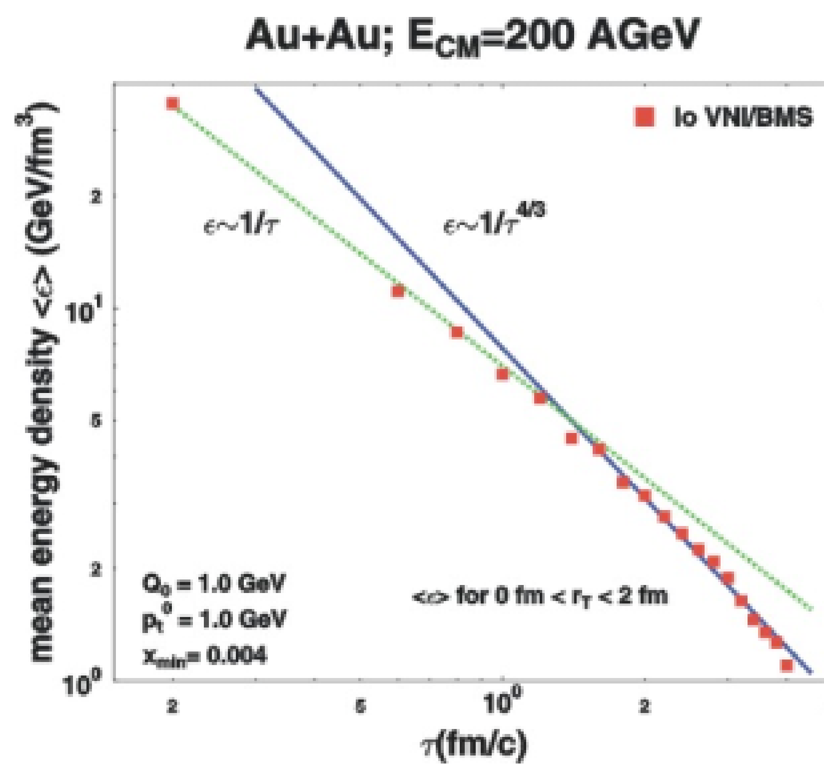
•final state radiation suppresses p_t-distribution by a factor of ~2 at p_tª5 GeV

ÿ jets vs. leading partons

Space-Time Evolution of Energy Density

energy-density at y_{CM} is calculated from:

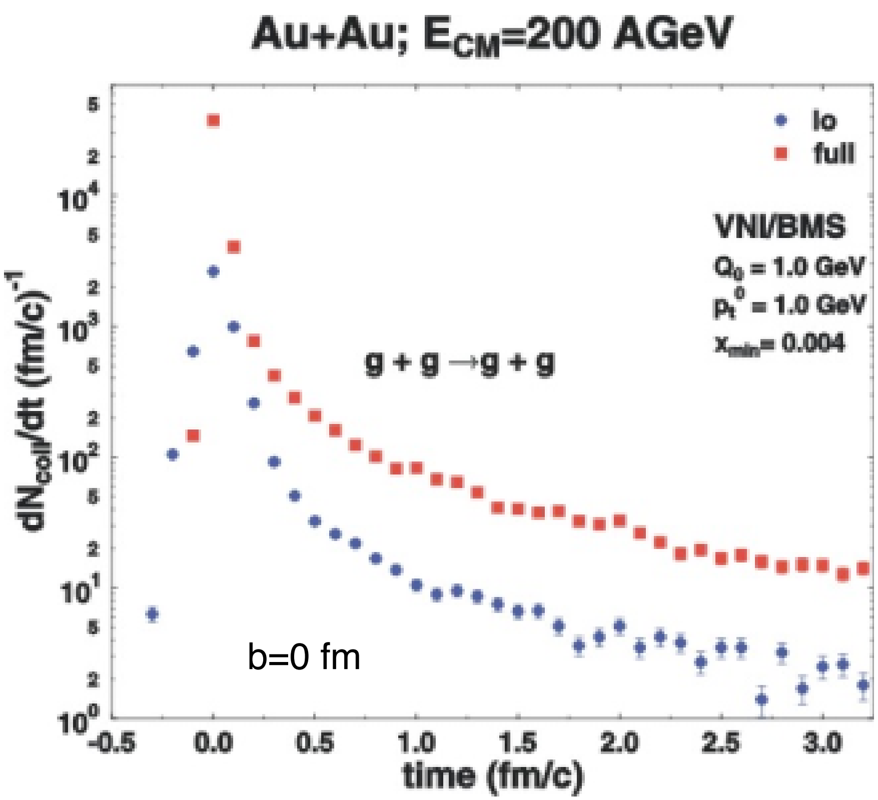




•hints of transverse expansion?

•conditions for hydrodynamics reached?

Collision Rates & Numbers

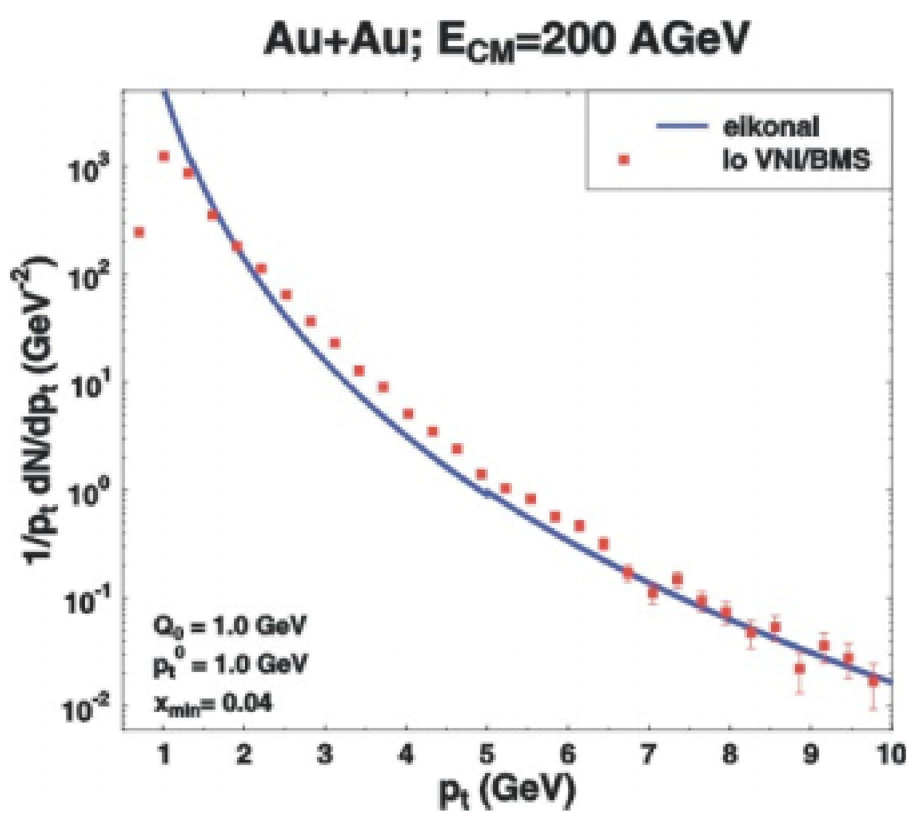


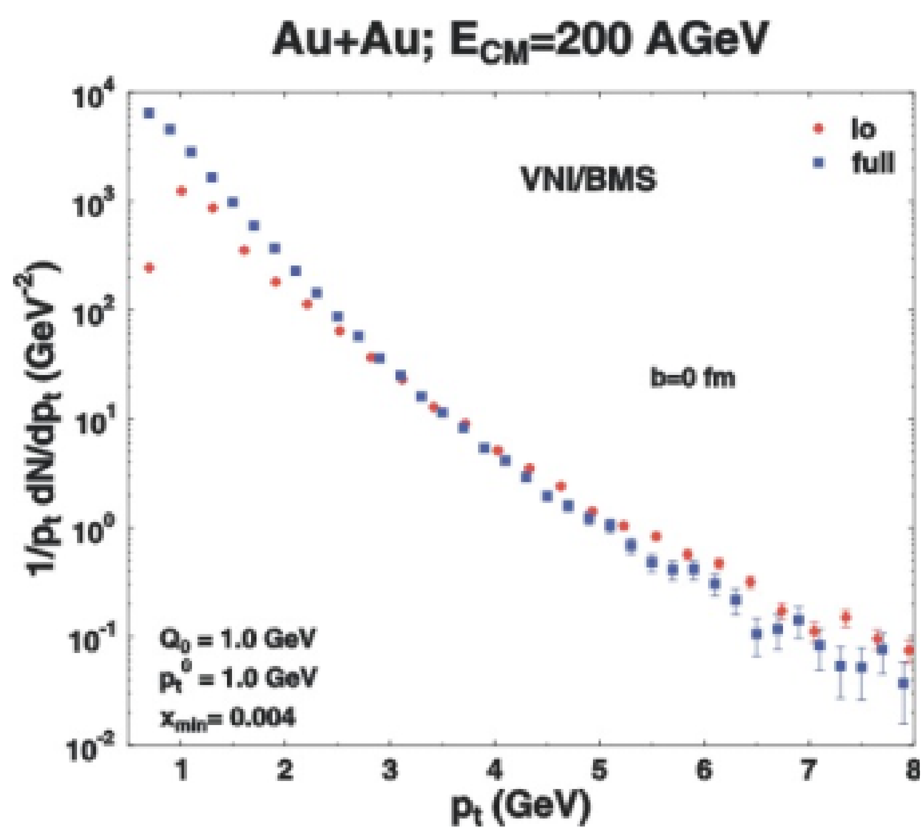
# of collisions	lo	full	sat
q + q	70.6	274	90.6
q + qbar	1.3	38.52	21.0
q + g	428.3	2422.6	747.7
g + g	514.4	4025.6	1265.8

- lifetime of interacting phase: ~ 3 fm/c
- partonic multiplication due to the initial & final state radiation increases the collision rate by a factor of 4-10

ÿ are time-scales long enough for thermalization?

Multiple Scattering and Radiation



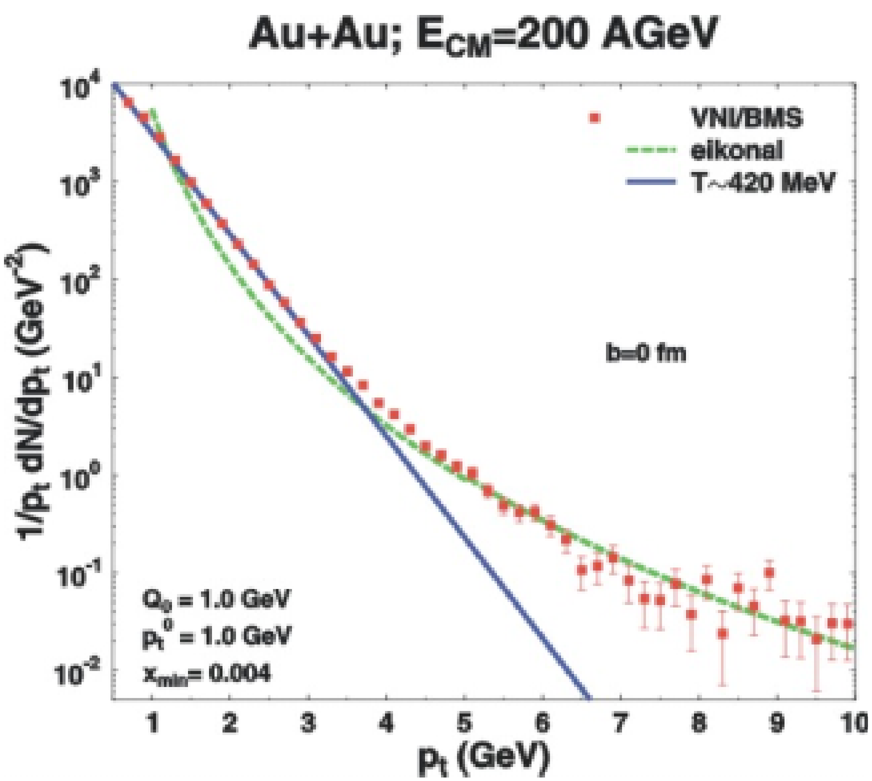


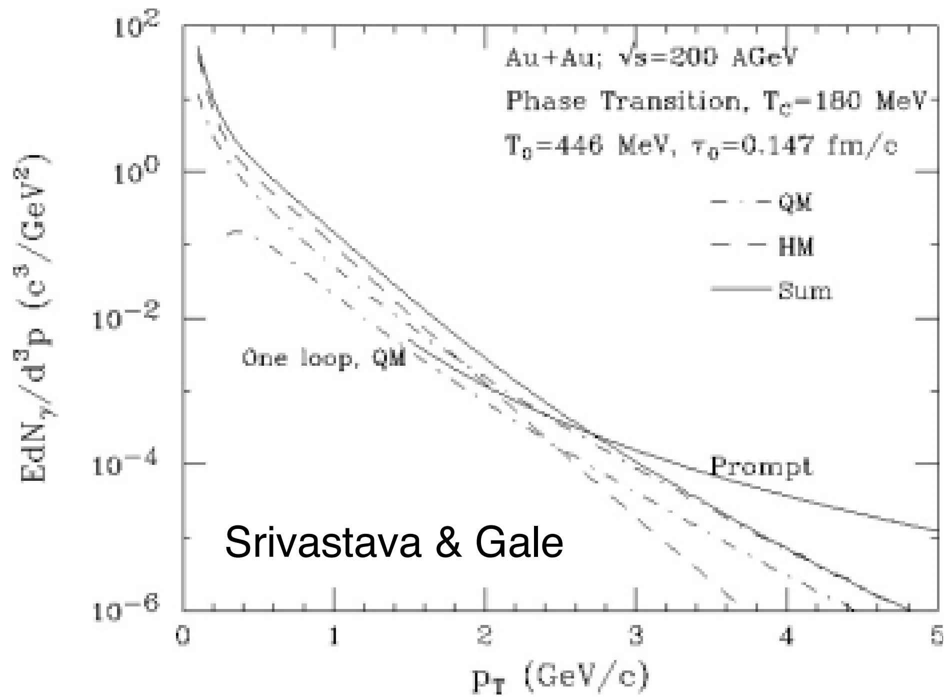
•multiple scattering broadens momentum distribution at intermediate p_t

•radiation enhances low p_t domain and leads to suppression at high p_t

ÿJet Quenching at p_t > 5 GeV?

Thermalization?

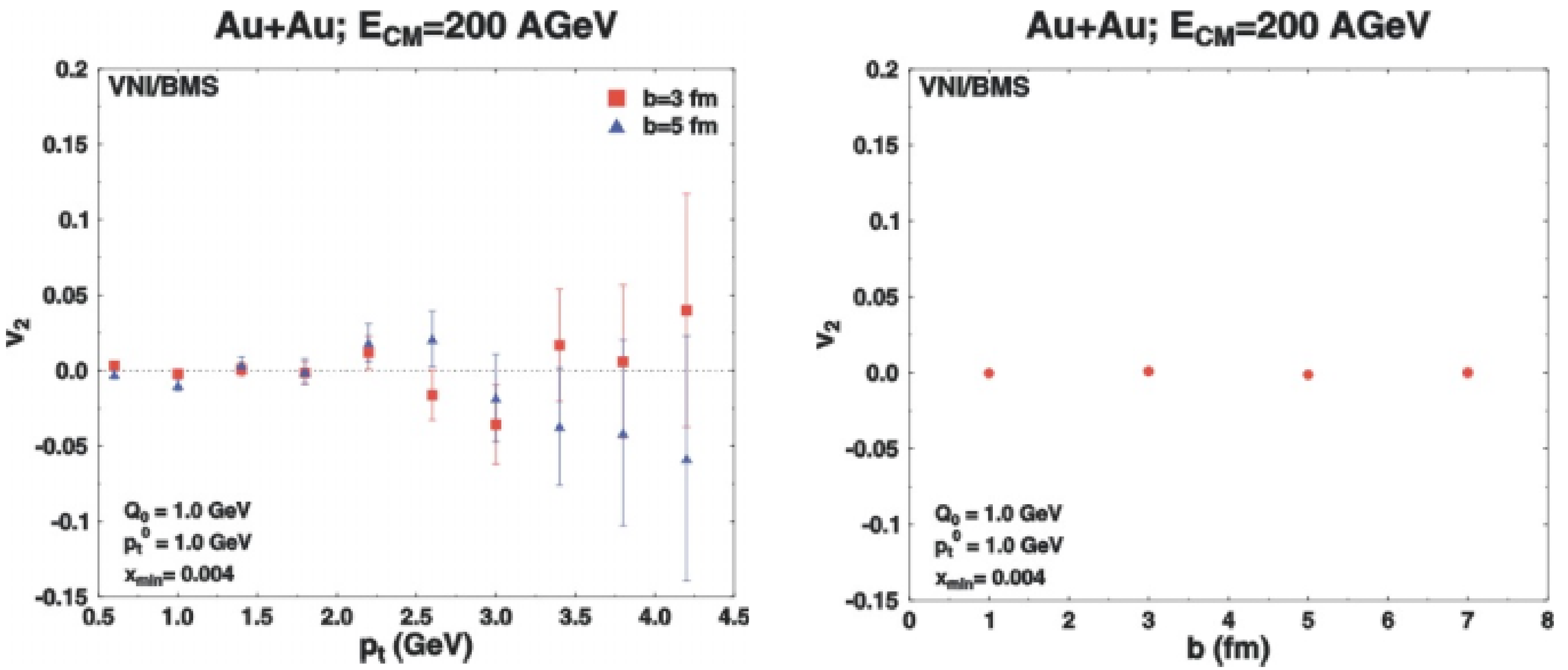




- spectrum exhibits thermal behaviour for $p_t < 4$ GeV
- thermalization due to radiation and rescattering?

- initial temperature estimated from measured dN/dy and Bjorken's formula: 446 MeV

Elliptic Flow in VNI/BMS



- v_2 calculated as:

Elliptic Flow in VNI/BMS II

The following parameters may influence v_2 calculation:

- physics input:
  - cut-off parameters p_0 & x_{min} influence cross-section
  - lack of soft, non-perturbative, processes
- analysis method:
  - idealized reaction plane & averaging over events
  - no susceptibility for jet correlations

•unscreened pQCD cross sections with a cut-off p_0=1 GeV are on the order of 0.4 mbarn – a factor of 10 too small for generating sizable elliptic flow

ÿ V_2 is soft, non-perturbative physics!

Novel Features in VNI/BMS

- initialization in quantitative agreement with PDFs & virtualities
- proper treatment of renormalization scale in transport cross sections
- vastly improved algorithm for sampling t from d_/dt
- consistent treatment for propagation of space- & time-like partons
- proper treatment of p_t generation in parton showers
- introduction of a fast cascade algorithm
- introduction of factorization scale correction in cross sections
- improved algorithm for the LPM effect
- possibility to simulate eikonal approximation
- incorporation of saturation physics
- output & documentation conforming to OSCAR standards

Limitations of the PCM Approach

Fundamental Limitations:

- lack of coherence of initial state
- range of validity of the Boltzmann Equation
- parton saturation is input, not result of dynamics
- interference effects are included only schematically
- hadronization has to be modeled in an ad-hoc fashion

Limitations of present implementation (as of May 2002)

- lack of detailed balance: (no N Æ 2 processes)
- no 2 Æ 1 processes involving space-like partons
- lack of selfconsistent medium corrections
- heavy quarks?

Future Directions …

The VNI/BMS approach provides an ideal framework for:

- study of event by event fluctuations
- investigating the detailed dynamics of jet-quenching
- study of medium modification of QCD processes
- studying the transition of a shattered Colour Glass to a QGP
- study of propagation & recombination of heavy quarks
- investigating models of hadronization
- dovetailing to hydrodynamics & hadronic cascades

• suggestions and collaborative endeavours on these and related issues are most welcome!

The End