R.H.I.C. THEORY

OPEN PROBLEMS

RHIC Winter Workshop at LBNL, 7-9 Jan 1999

- KKG
- ENTROPY
- HARD vs. SOFT PHYSICS
- HADRONIC FREEZE-OUT
- SECOND-GENERATION MODELS FOR RHIC


KKG '95

Cucurullo '86

http://rhic.phys.columbia.edu/rhic/vni

VNI

MC-simulation program to study high-energy particle collisions in QCD by space-time evolution of parton-cascades and parton-hadron conversion

BNL-63632, hep-ph/9701226

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VNI is a general-purpose Monte-Carlo event-generator, which includes the simulation of lepton-lepton, lepton-hadron, lepton-nucleus, hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions. On the basis of renormalization-group improved parton description and quantum-kinetic theory, it uses the real-time evolution of parton cascades in conjunction with a self-consistent hadronization scheme that is governed by the dynamics itself. The causal evolution from a specific initial state (determined by the colliding beam particles) is followed by the time-development of the phase-space densities of partons, pre-hadronic parton clusters, and final-state hadrons, in position-space, momentum-space and color-space. The parton-evolution is described in terms of a space-time generalization of the familiar momentum-space description of multipl (semi) hard interactions in QCD, involving 2 -> 2 parton collisions, 2 -> 1 parton fusion processes, and 1 -> 2 emission processes. The formation of color-singlet pre-hadronic clusters and their decays into hadrons, on the other hand, is treated by using a spatial criterion motivated by confinement and a non-perturbative model for hadronization. This article gives a brief review of the physics underlying *VNI*, which is followed by a detailed description of the program itself. The latter program description emphasizes easy-to-use pragmatism and explains how to use the program (including a simple example), annotates input and control parameters, and discusses output data provided by it.

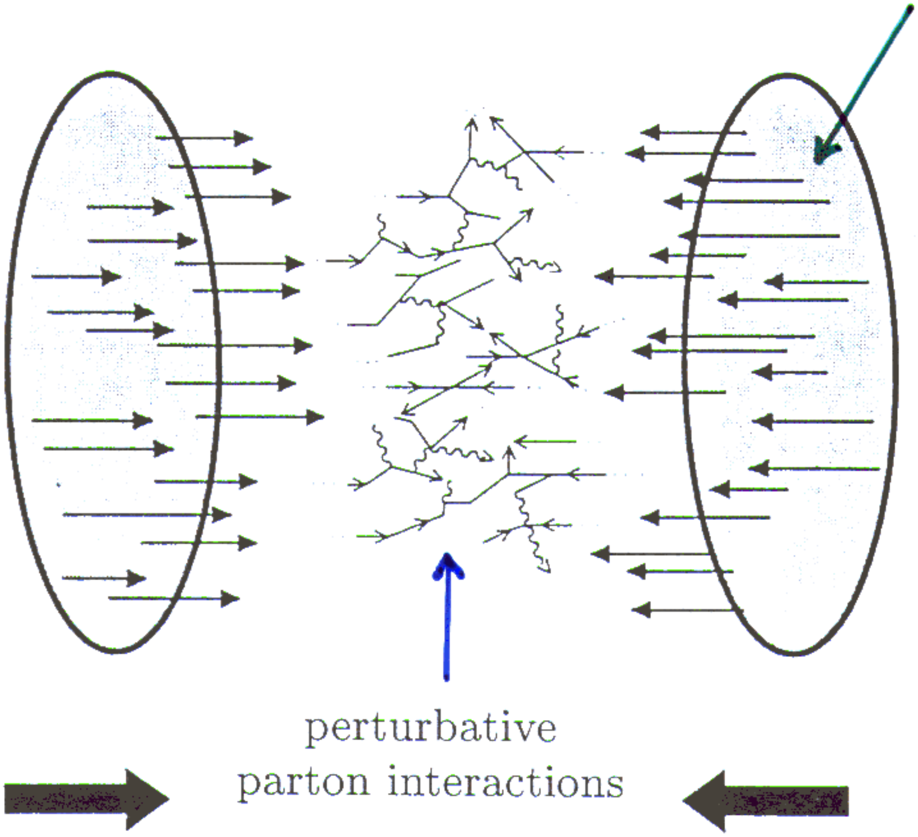
Comp. Phys. Comm.
<u>104</u> (1997) 70

You may want also to visit the *Wunderbar World of KKG* .

You are visitor number 000317

Last modified on January 25, 1997 by Klaus Kinder-Geiger

K. Geiger, B.M. (1991)



known parton distributions

perturbative parton interactions

Relativistic Boltzmann equation

$$p^{\mu}\frac{\partial}{\partial x^{\mu}}F_i(x,p) = C_i(x,p;F_k) \quad \leftarrow \text{collision terms}$$

↑

parton distributions

↓

$$p^{2}\frac{\partial}{\partial p^{2}}F_i(x,p) = S_i(x,p;F_k) \quad \leftarrow \text{splitting functions}$$

THE PARTON CASCADE MODEL (PCM)

K. GEIGER + B.M. (1992) , K. GEIGER (1992-97)

∴ INITIAL STATE = INCOHERENT ENSEMBLE OF PARTONS GIVEN BY NUCLEAR PARTON DISTRIBUTIONS $q_f(x, Q^2)$, $g(x, Q^2)$ WITH $x = p_z / P$, AS BASIS FOR PHASE SPACE DISTRIBUTIONS

$$q_f(x, p) \qquad g(x, p)$$

AT SCALE $Q_0^2 = \langle p_T^2 \rangle_{COLL.}$

∴ TRANSPORT EQUATION = RELAT. BOLTZMANN EQ.

WITH LEADING-LOG. IMPROVED LO COLLISIONS

BINARY COLLISIONS (BUT n- PARTICLE FINAL STATES

LLA - IMPROVEMENT $\Longleftrightarrow$ DGLAP EVOLUTION

SPACE-TIME PICTURE ⟶ OFF-SHELL PROPAGATION

$$\langle Q^2 \rangle \sim \tau_f^{-2}$$

∴ HADRONIZATION = MODELED AS CLUSTERING

TRANSITION OCCURS WHEN $\langle Q^2 \rangle \leq Q^2_{crit} \sim 1 \text{ GeV}^2$

Nuclear Physics B 369 (1992) 600–654
North-Holland

NUCLEAR
PHYSICS B

Dynamics of parton cascades in highly relativistic nuclear collisions

Klaus Geiger * and Berndt Müller

Department of Physics, Duke University, Durham, North Carolina 27706, USA

Received 2 May 1991
(Revised 13 August 1991)
Accepted for publication 18 September 1991

PHYSICAL REVIEW D **VOLUME 46, NUMBER 11** **1 DECEMBER 1992**

Thermalization in ultrarelativistic nuclear collisions.
I. Parton kinetics and quark-gluon plasma formation

Klaus Geiger
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 10 March 1992)

PHYSICAL REVIEW D **VOLUME 46, NUMBER 11** **1 DECEMBER 1992**

Thermalization in ultrarelativistic nuclear collisions.
II. Entropy production and energy densities at the BNL Relativistic Heavy Ion Collider and the CERN Large Hadron Collider

Klaus Geiger
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 5 May 1992)

PHYSICAL REVIEW D **VOLUME 47, NUMBER 11** **1 JUNE 1993**

Chemical equilibration of partons in high-energy heavy-ion collisions?

K. Geiger and J. I. Kapusta
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 12 January 1993)

VOLUME 70, NUMBER 13 PHYSICAL REVIEW LETTERS 29 MARCH 1993

Dilepton Radiation from Cascading Partons in Ultrarelativistic Nuclear Collisions

K. Geiger and J. I. Kapusta
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455

(Received 27 October 1992)

PHYSICAL REVIEW D VOLUME 47, NUMBER 1 1 JANUARY 1993

Particle production in high-energy nuclear collisions: Parton cascade–cluster hadronization model

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(Received 19 August 1992)

PHYSICAL REVIEW D VOLUME 52, NUMBER 3 1 AUGUST 1995

Real-time description of parton-hadron conversion and confinement dynamics

John Ellis* and Klaus Geiger†
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(Received 2 March 1995)

PHYSICAL REVIEW D VOLUME 54, NUMBER 1 1 JULY 1996

Quantum field kinetics of QCD: Quark-gluon transport theory for light-cone-dominated processes

Klaus Geiger*
CERN TH-Division, CH-1211 Geneva 23, Switzerland

(Received 20 July 1995)

PHYSICAL REVIEW C VOLUME 56, NUMBER 5 NOVEMBER 1997

Parton cascade description of relativistic heavy ion collisions at the CERN Super Proton Synchrotron at 158*A* GeV?

Klaus Geiger[1] and Dinesh Kumar Srivastava[2]
[1]*Physics Department, Brookhaven National Laboratory, Upton, New York 11973*
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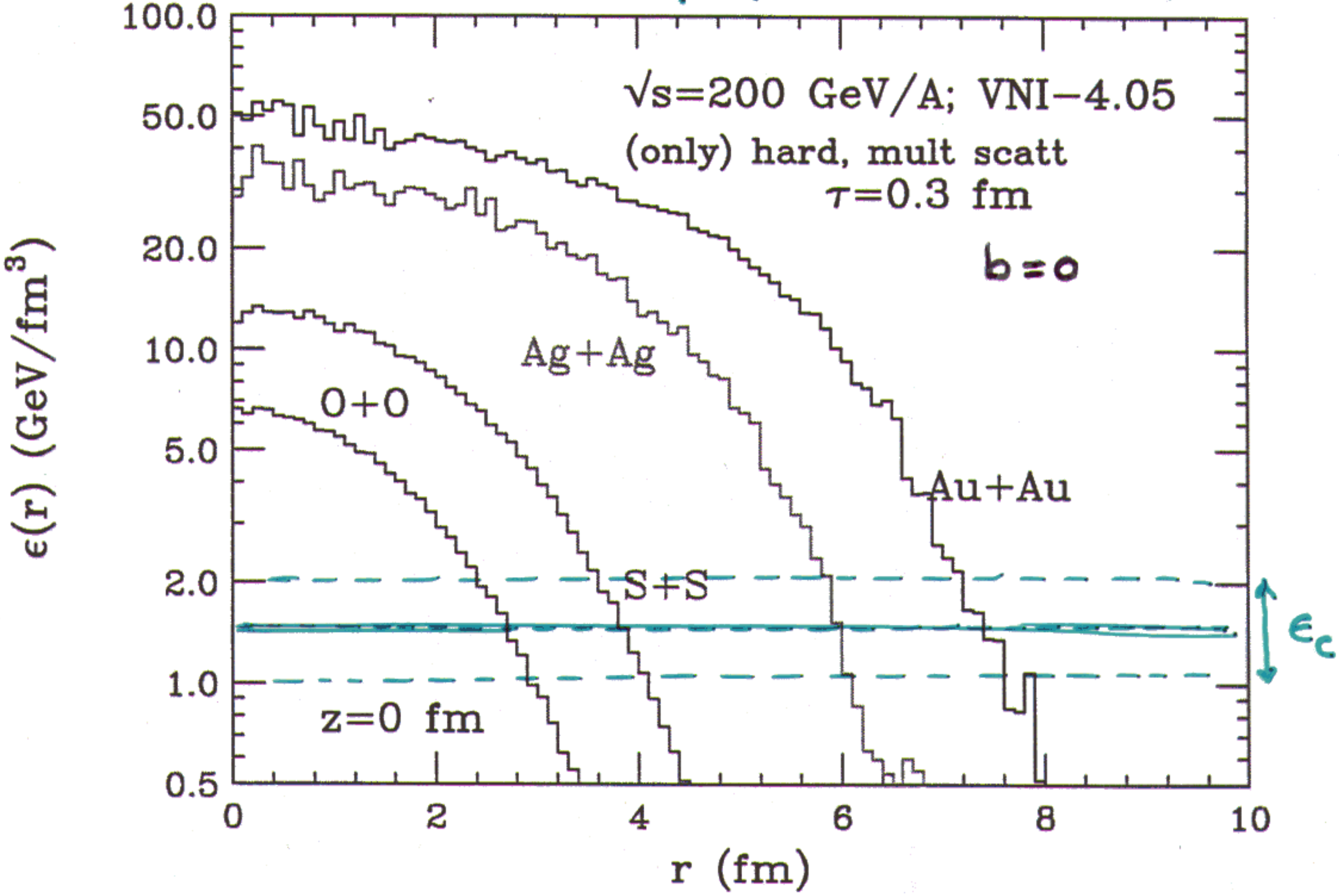
(Recieved 3 June 1997)

PARTON CASCADE MODEL

RHIC ENERGY



GEIGER + SRIVASTAVA

1. ORIGIN OF ENTROPY

∴ Really an artefact of course-graining:
defined by limitations of observation

$$S = \mathrm{Tr}(\rho \ln \rho) \qquad \text{is constant}$$

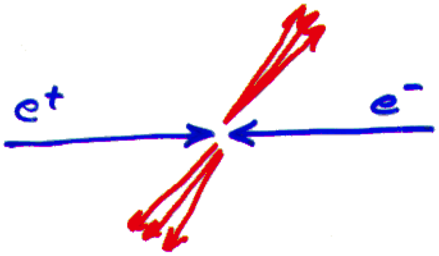
$$\left.\begin{aligned} S_{rel} &= \mathrm{Tr}(\rho_{rel} \ln \rho_{rel}) \\ \text{with} \quad \rho_{rel} &\equiv \mathrm{Tr}_{\{irrel\}}(\rho) \end{aligned}\right\} \text{grows with } t$$

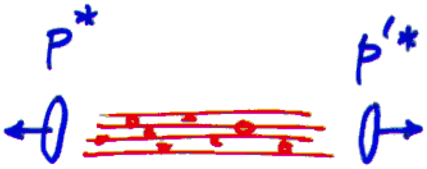
$\{irrel\}$ typically : multi-particle correlations
relative phases in wavefct.

∴ Simple case $\{rel\} = \{\text{single particle distrib.}\}$

Where is S_{rel} produced ?

- Low-energy A+A : nucleon-nucleon collisions
- High-energy p+p: hadronization
  e^+e^-:





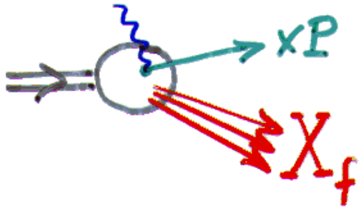
– High-energy A+A : ???

Concept of a <u>QGP</u> says that <u>most</u> S_{rel} is produced at the partonic (pQCD) level.

Q1: Can this concept be established at RHIC ?

- How to "measure" $S_{rel}(t)$, or at least compare S_{rel} before hadronization with $S_{rel}^{(fin)}$?

∴ Parton cascade produces some S_{rel} in partonic interactions, but already has $S_{rel} \neq 0$ in the <u>initial</u> state. Problem of parton model:

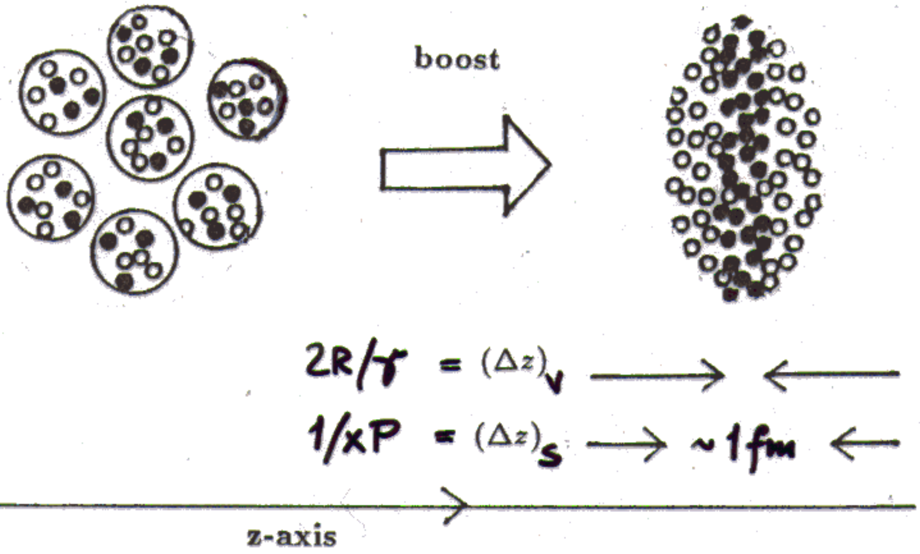
$F(x) = \sum_{X_f} \Big|$  $\Big|^2$

S_{rel} is generated by "trace" over all final states particles except the struck parton.

Classical Glue at small x :

McLerran + Venugopalan
et al.
Kovchegov
+ Rischk
Matinya
BM

Gluon structure of heavy nuclei



Consider $2R\frac{M}{P} \ll \frac{1}{xP}$ i.e. $x \ll \frac{1}{2RM} \sim 10^{-2}$

Sea quarks and gluons see valence quarks as sheet-like, random color source.

Area density

$$\mu^2 = \frac{3A}{\pi R^2} \longrightarrow \mu \sim A^{1/6}$$

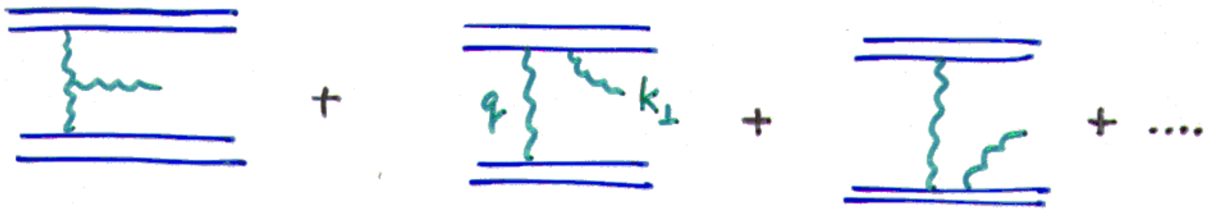
Hence $\alpha_s(\mu^2) \ll 1$ for large A.

Weak-coupling problem of QCD in a random 2-dim. color source.

Random Light-Cone Source Model (RLSM)

RLSM can be justified in color-dipole model for nucleons. (Korchegov)

Detailed semiclassical calculation of gluon production at central rapidity: (Korchegov + Rischke)



at order $\alpha_s^3 A_1 A_2$: (Matinyan, Rischke, BM)

$$\frac{d\bar{N}_g}{dy\, d^2k_\perp d^2b} = \frac{4\alpha_s^3}{\pi^2} \frac{N_c^2-1}{N_c} \langle T_{A_1A_2}(b)\rangle \frac{1}{k_\perp^2} \int d^2q \frac{F(qa)F(|k-q|a)}{q^2\,(k-q)^2}$$

where $F(qa)$ is the color dipole form factor of the nucleon.

Classical radiation matches "smoothly" onto pQCD minijet production at higher $k_\perp$. (Gyulassy + McLerran)

Loop corrections determine an A-dependent (and x-) screening scale (Kovner, McLerran, Weigert ; Eskola, BM, Wang)

→ Screening scales $g\mu$, $g^2\mu$ (Krasnitz + Venugopalan)

$\therefore$ Coherent glue does <u>not</u> solve the entropy problem!

$$\langle O[A] \rangle \propto \int [d\rho]\, e^{-\frac{1}{2\mu^2}\int d^2x_\perp \rho^2} \int \mathcal{D}A\, O(A)\, e^{iS(\rho,A)}$$

$\uparrow$

Incoherent integral over $\rho(x_\perp) \longrightarrow S_{rel} \neq 0$

In a A+A collision : $\int [d\rho_1][d\rho_2] \cdots\cdots$

For given ρ_1, ρ_2, $A(\rho_1, \rho_2)$ is a coherent state and remains coherent even in the presence of nonlinear interactions $\Longrightarrow S_{rel} \equiv 0$

$\int [d\rho_1][d\rho_2]$ generates entropy, but "artificially".

Source of entropy must be nonlinear dynamics of glue (and quark) fields: <u>Chaotic glue</u>.

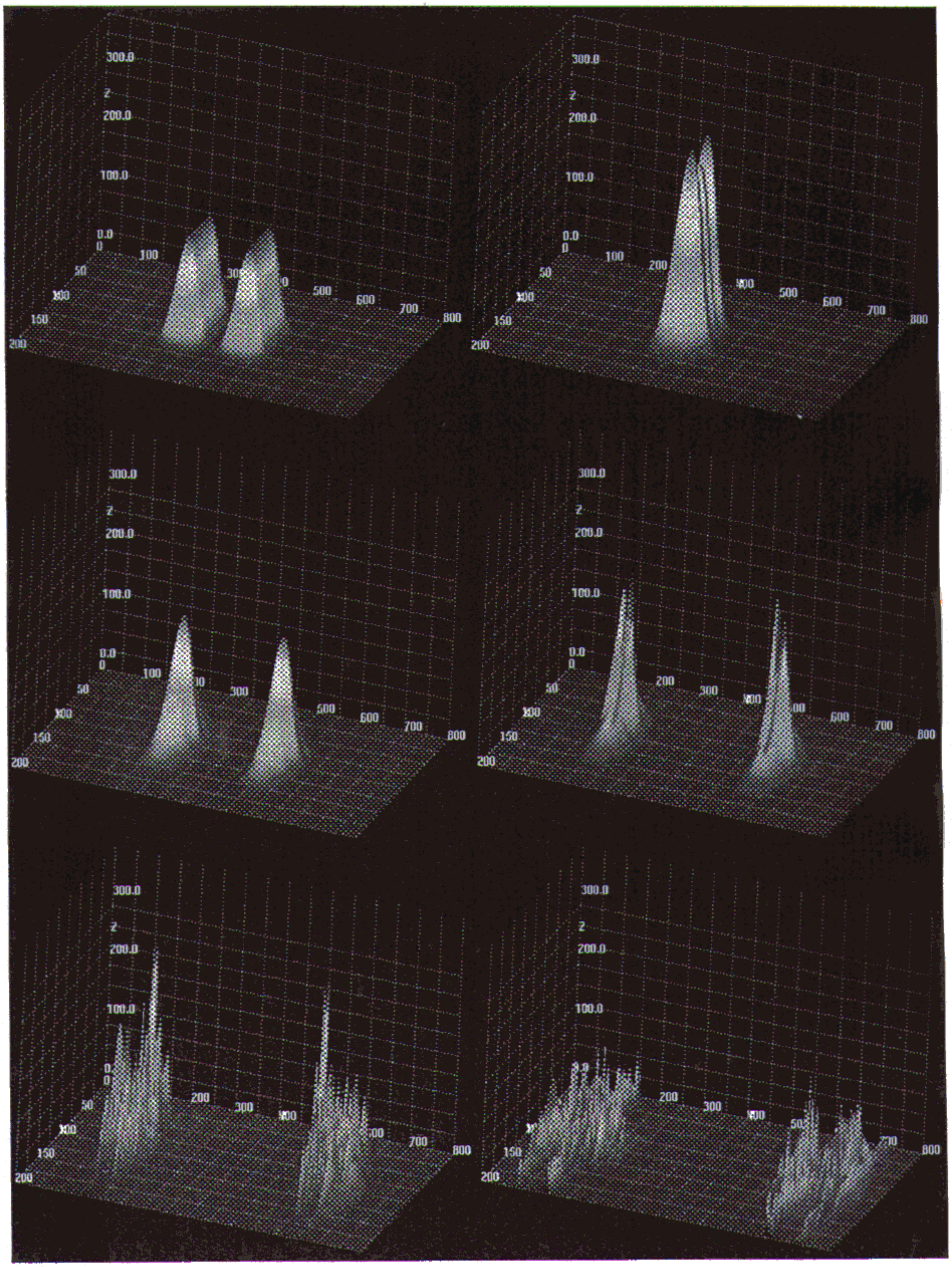
$$\frac{dS_{rel}}{dt} = \sum_{\lambda_i > 0} \lambda_i \qquad \text{(KS entropy)}$$

Established on classical lattice (BM, Trayanov, Gong) but physical connection to RLSM picture unclear.

"soft" glue dynamics only !

W. PÖSCHL

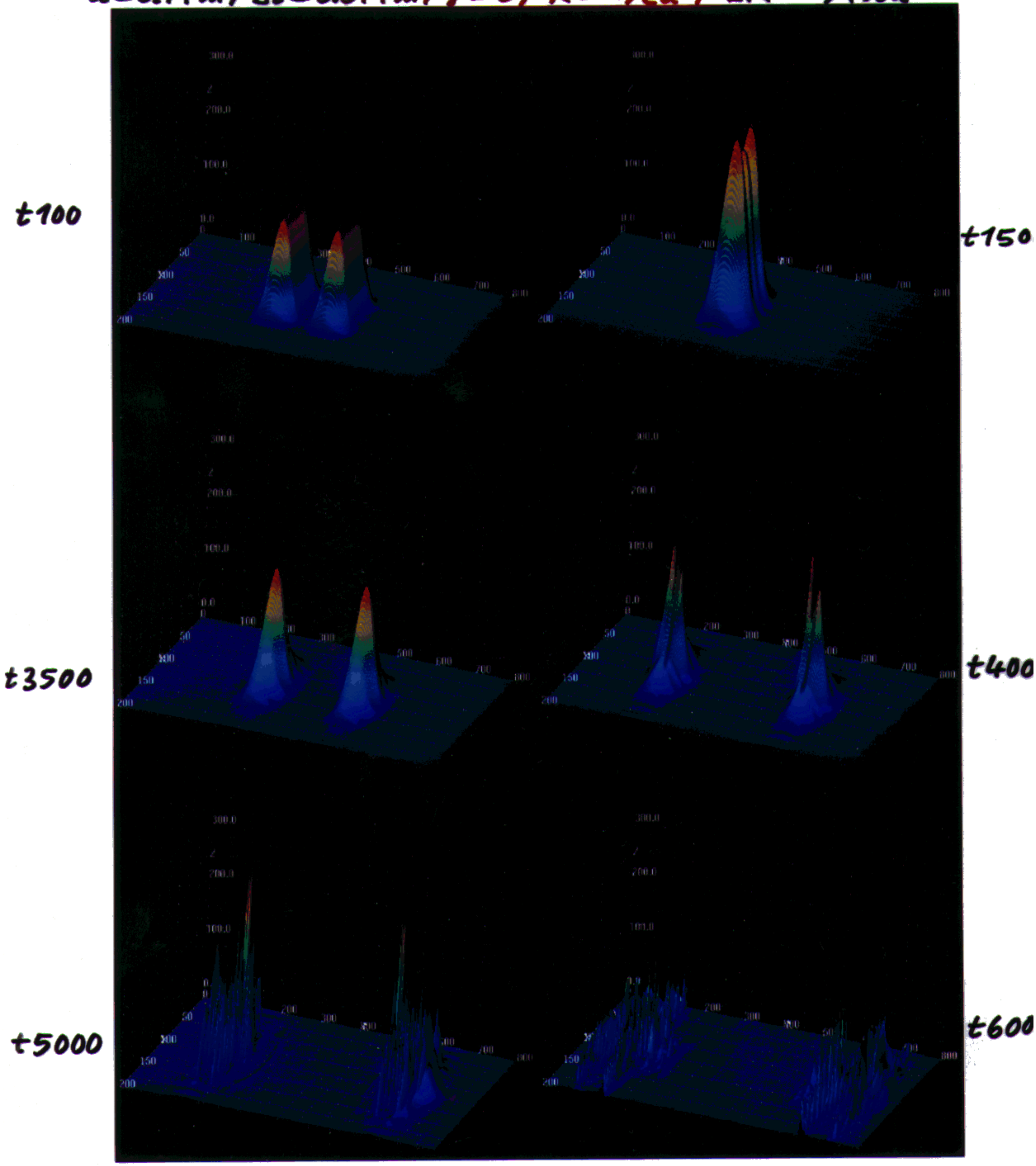
$W_T^{(E)}$



Time scale for disintegration/decoherence

$$\tau_d \sim \frac{1}{g^2\mu}$$

$a=0.1$ fm, $\Delta t=0.01$ fm, $g=6$, $K=\pi/2a$, $\Delta K=\pi/100a$



Lattice Size: $4 \times 200 \times 800$

2. HARD VS. SOFT PROCESSES

Hard processes (jets, $Q\bar{Q}$, ...) occur fast, hence are probes of early phase.

Q2: How do we identify hard probes?

$\frac{dN}{dp_\perp}$ for $p_\perp >$? J/ψ, χ_c, ψ' ? $c\bar{c}$?

DY seems to work at SPS, but $c\bar{c}$?

Litmus test: $\sigma \sim A_1 A_2$ (factorization)

(modified by soft initial state physics = shadowing, etc.)

Final state interactions destroying factorization:

∴ Can we separate perturbative from nonperturb.?

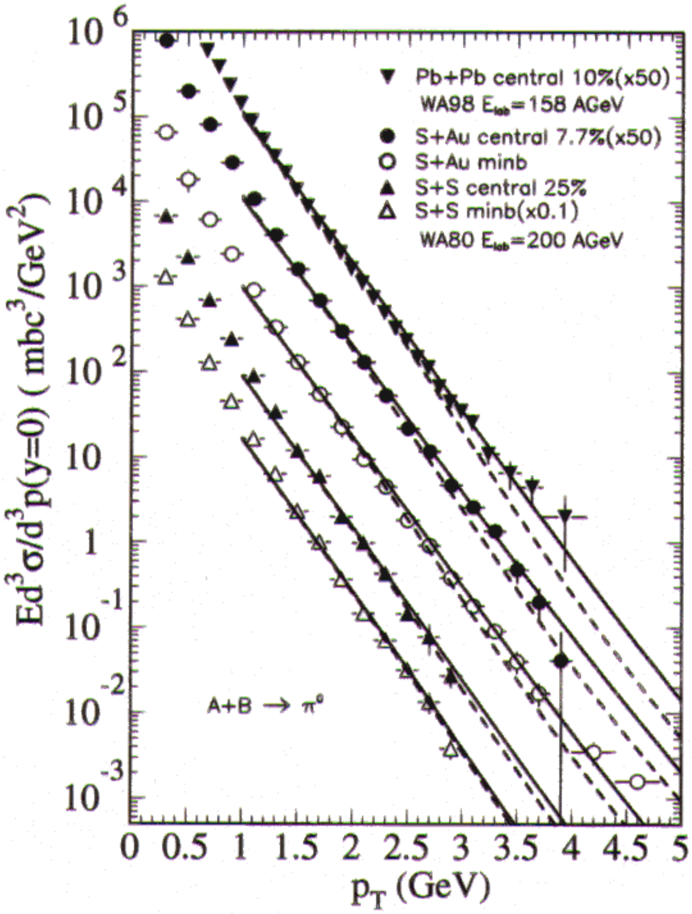
(Color screening from hadronic absorption ...)

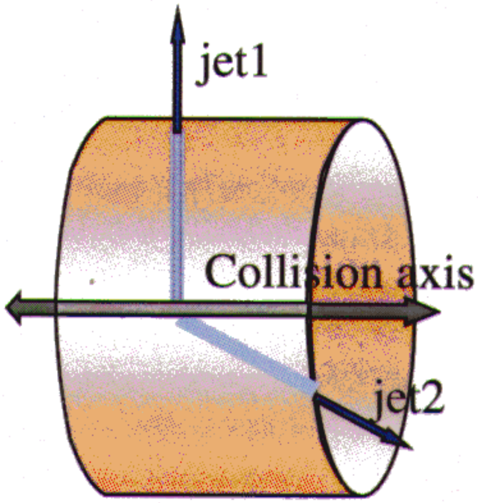
Well defined, theory based strategy required!

E_{beam}-dep. vs. b-dep. vs. A-dep.

Large p_T hadrons in $A+A$ Collisions

$$\frac{d\sigma}{dyd^2p_T}=\sum_{abcd}\int dx_a d^2k_{\perp a}dx_b d^2k_{\perp b}f_{a/A}(x_a,k_{\perp a})f_{b/B}(x_b,k_{\perp b})\times\frac{d\sigma_{ab\to cd}}{dt}\frac{1}{z_c\pi}D_{h/c}(z_c)$$





(X.-N.W, PRL81(98)2655)

- **No evidence of *dE/dx* in *A+A* Collisions**
- **Implications:**
  - Life time of dense matter short ~ 2 fm/c
  - Long formation time τ_f~ 1 p_T/m_π fm/c
  - Weak jet interaction in hadronic matter
  - Constraints on thermalization of the system

A-dependence of energy deposition:

$$x \frac{dN(b)}{dx\,dp_\perp^2} = 2\, T_{AB}(b) \sum_{ik} \int_{\frac{4p_\perp^2}{xs}}^{1} \frac{dx'}{x'}\, x' f_{i/A}(x', p_\perp^2)\, x f_{k/B}(x, p_\perp^2)\, \frac{d\hat{\sigma}_{ik}}{dp_\perp^2}$$

High-$p_\perp$: $\quad f_{i/A}(x, p_\perp^2) \approx A\, f_{i/N}(x, p_\perp^2)$

Saturation effects at "small" $p_\perp$ (Gribov, Levin, Ryskin)

$$\frac{d}{\partial(\ln\frac{1}{x})} \frac{\partial}{\partial(\ln p_\perp^2)}\, xg(x, p_\perp^2) = \underbrace{\frac{3\alpha_s(p_\perp^2)}{\pi}\, xg(x, p_\perp^2)}_{\text{splitting}}$$

$$\underbrace{- \frac{9\pi}{2}\, \alpha_s(p_\perp^2)^2\, \frac{\lambda}{p_\perp^2}\, \frac{(xg(x, p_\perp^2))^2}{\pi R_A^2}}_{\text{recombination}}$$

$xg(x, p_\perp^2) \sim A$, $\quad \pi R_A^2 \sim A^{2/3} \longrightarrow \frac{\text{recomb.}}{\text{split.}} \sim A^{1/3}/p_\perp^2$

$\rightarrow \quad p_{crit}^2 \sim A^{1/3}$ × log. energy dependence

$$\frac{1}{\pi R_A^2} \times \frac{dN(b)}{dx\,dp_\perp^2} \sim \begin{cases} A_1^{1/3} + A_2^{1/3} & \text{for } p_\perp < p_{crit} \\ (A_1 A_2)^{1/3} & \text{for } p_\perp > p_{crit} \end{cases}$$

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$$x\,\frac{dN(b)}{dx\,dp_\perp^2} = 2\,T_{AB}(b)\sum_{ik}\int_{\frac{4p_\perp^2}{xs}}^{1}\frac{dx'}{x'}\,x' f_{i/A}(x',p_\perp^2)\,x f_{k/B}(x,p_\perp^2)\,\frac{d\hat{\sigma}_{ik}}{dp_\perp^2}$$

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$xg(x,p_\perp^2) \sim A\,,\quad \pi R_A^2 \sim A^{2/3} \longrightarrow \dfrac{\text{recomb.}}{\text{split.}} \sim A^{1/3}/p_\perp^2$

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$$\frac{1}{\pi R_A^2}\times\frac{dN(b)}{dx\,dp_\perp^2} \sim \begin{cases} A_1^{1/3}+A_2^{1/3} & \text{for } p_\perp < p_{crit} \\ (A_1 A_2)^{1/3} & \text{for } p_\perp > p_{crit} \end{cases}$$

Also note that

$$\frac{1}{\pi R_A^2}\int dp_\perp^2\,\frac{dN}{dy\,dp_\perp^2} = \frac{1}{\pi R_A^2}\left\{\int_0^{p_{crit}^2} dp_\perp^2\,\frac{dN}{dy\,dp_\perp^2} + \underset{\overset{\nearrow}{A^{1/3}}}{\int_{p_{crit}^2}^{\infty}} dp_\perp^2\,\underset{\overset{\uparrow}{\frac{A^{2/3}}{p_\perp^4}}}{\frac{dN}{dy\,dp_\perp^2}}\right\}$$

$$A^{1/3} \sim \frac{A^{2/3}}{p_{crit}^2} \sim A^{2/3}\int_{p_{crit}^2}^{\infty}\frac{dp_\perp^2}{p_\perp^4}$$

High-$p_\perp$ multiplicity grows $\sim A^{2/3}$, but total multiplicity grows only $\sim A^{1/3}$.

Gluon multiplicity relevant for J/ψ dissociation:

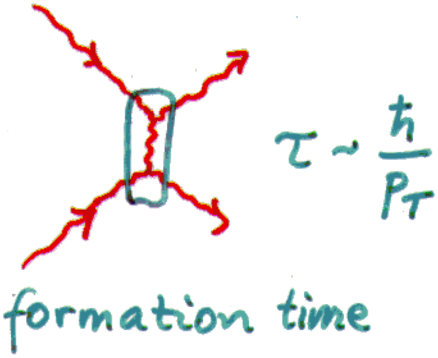
$$\frac{dN^{(J/\psi)}}{dy} = \int_{R_\psi^{-2}} dp_\perp^2\,\frac{d^2N}{dy\,dp_\perp^2} \sim A^{2/3}R_\psi^2$$

as long as $p_{crit} \lesssim R_\psi^{-1}$. Probably so at SPS (?), but no longer at RHIC.

Problem: Separate break in A-dependence at some $p_\perp$ from Cronin effect?

Self-screened parton cascade

X.N. Wang



Consider scattering of initial state partons as complete after $\tau(p_T) \sim \frac{1}{p_T}$:

Let hard-scattered partons screen the softer scattering processes:

$$\mu_D^2(p_T) = + \frac{3}{\pi^2} \alpha_s(p_T^2) \int_{p_T}^{\infty} d^3k \, | \nabla_k n(k) |$$

Density of scattered partons:

$$n(k) = T_{AA}(0) \left. \frac{d\hat{\sigma}}{dk_T^2 \, dy} \right|_{y=0}$$

$$\frac{d\hat{\sigma}}{dk_T^2} \longrightarrow \frac{\alpha_s^2(k_T^2)}{(k_T^2 + \mu_D^2(k_T))^2} \cdot |M(\hat{s},\hat{t})|^2$$

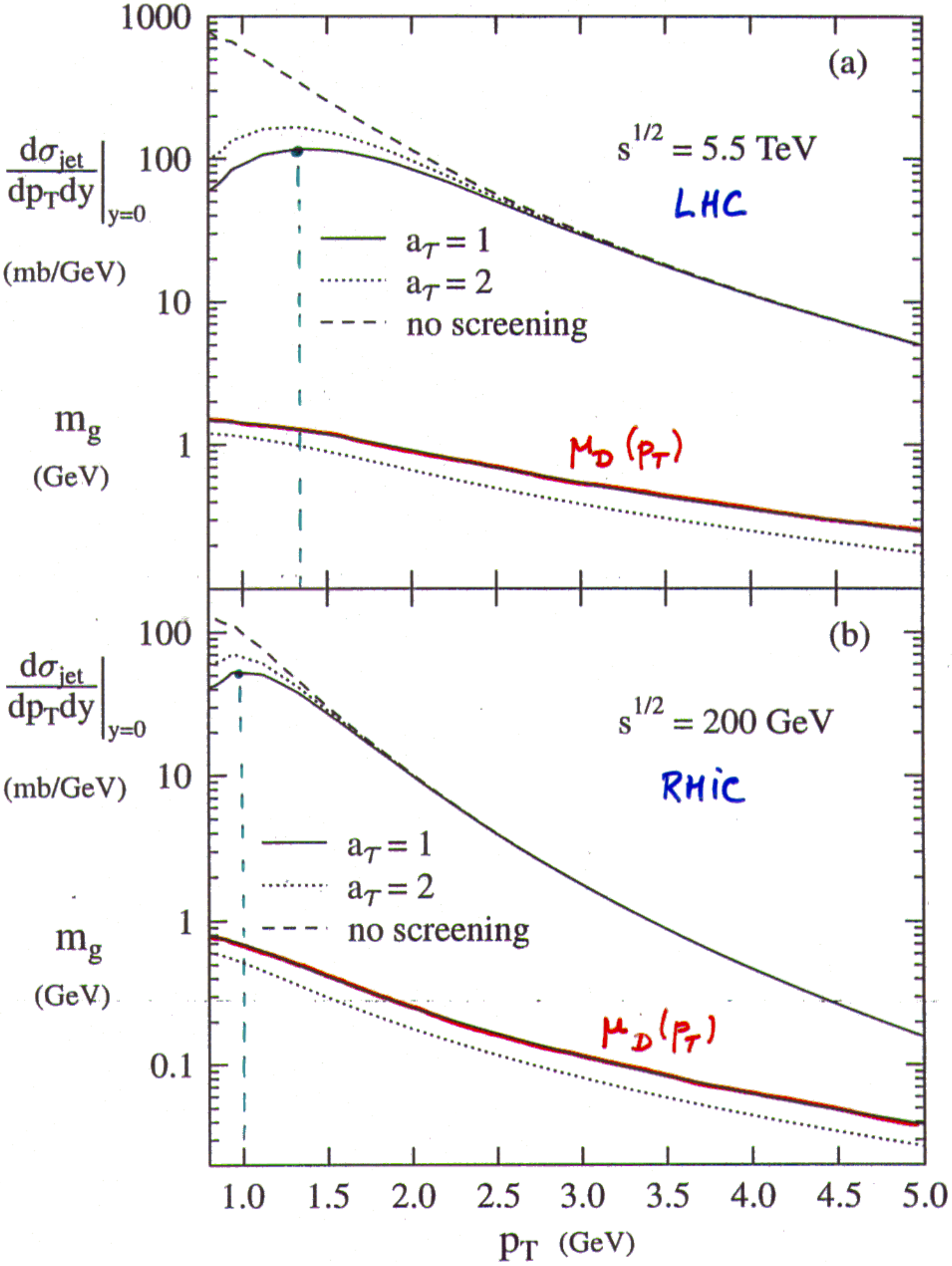
Can be integrated down to $p_T = 0$, if μ_D becomes large enough, so that $d\hat{\sigma}/dk_T^2$ remains perturbative.

$$f(k) \sim (A_1 A_2)^{1/3} \ln^2 \sqrt{s}$$

Requires $A_1, A_2 \gg 1$ and high energy!

Screening of soft interactions.

BM
WANG


(a)
1000
100
10
1
$\frac{d\sigma_{jet}}{dp_T dy}\Big|_{y=0}$
(mb/GeV)
m_g
(GeV)
$s^{1/2} = 5.5$ TeV
LHC
$a_T = 1$
$a_T = 2$
no screening
$\mu_D(p_T)$
(b)
100
10
1
0.1
$\frac{d\sigma_{jet}}{dp_T dy}\Big|_{y=0}$
(mb/GeV)
m_g
(GeV)
$s^{1/2} = 200$ GeV
RHIC
$a_T = 1$
$a_T = 2$
no screening
$\mu_D(p_T)$
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
p_T (GeV)

Makhlin + Surdutovich (hep-ph/9803364):

QCD transport + evolution equations must be defined in terms of physical final states.

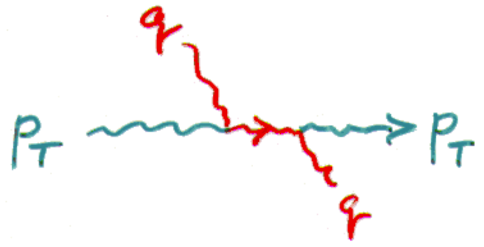
In e+e-, pp collisions IR singularities are cured by non-pert. hadronic physics.

In A+A (RHIC?) cure may come from (perturbative) color screening!

Difficult (impossible?) to implement in light-cone coordinate (null-plane dynamics)

Screening (plasmon) mass:

$$m_p^2(p_T, y) = 4\,\frac{g^2 N_c}{\pi R^2}\int_{p_T^2}^{\infty}\frac{dq^2}{\tau q}\;\frac{dN_g(q^2, y)}{dq^2}$$



"Mass shell" for gluons at (p_T, y) in phase space is given by m_p^2.

3. HADRONIC FREEZE-OUT

Most final state particles are <u>hadrons</u>.

Final state almost thermal → no memory !?

(Except T, $\langle\beta_\perp\rangle$, $\langle\beta_\parallel\rangle$)

SPS data indicate differentiation : Ξ, Ω.

Freeze-out condition : $\lambda_f = \frac{1}{\sigma\rho} > L$.

(thermal: σ_{tr} ; chemical: σ_{react} ; HBT: σ_{tot})

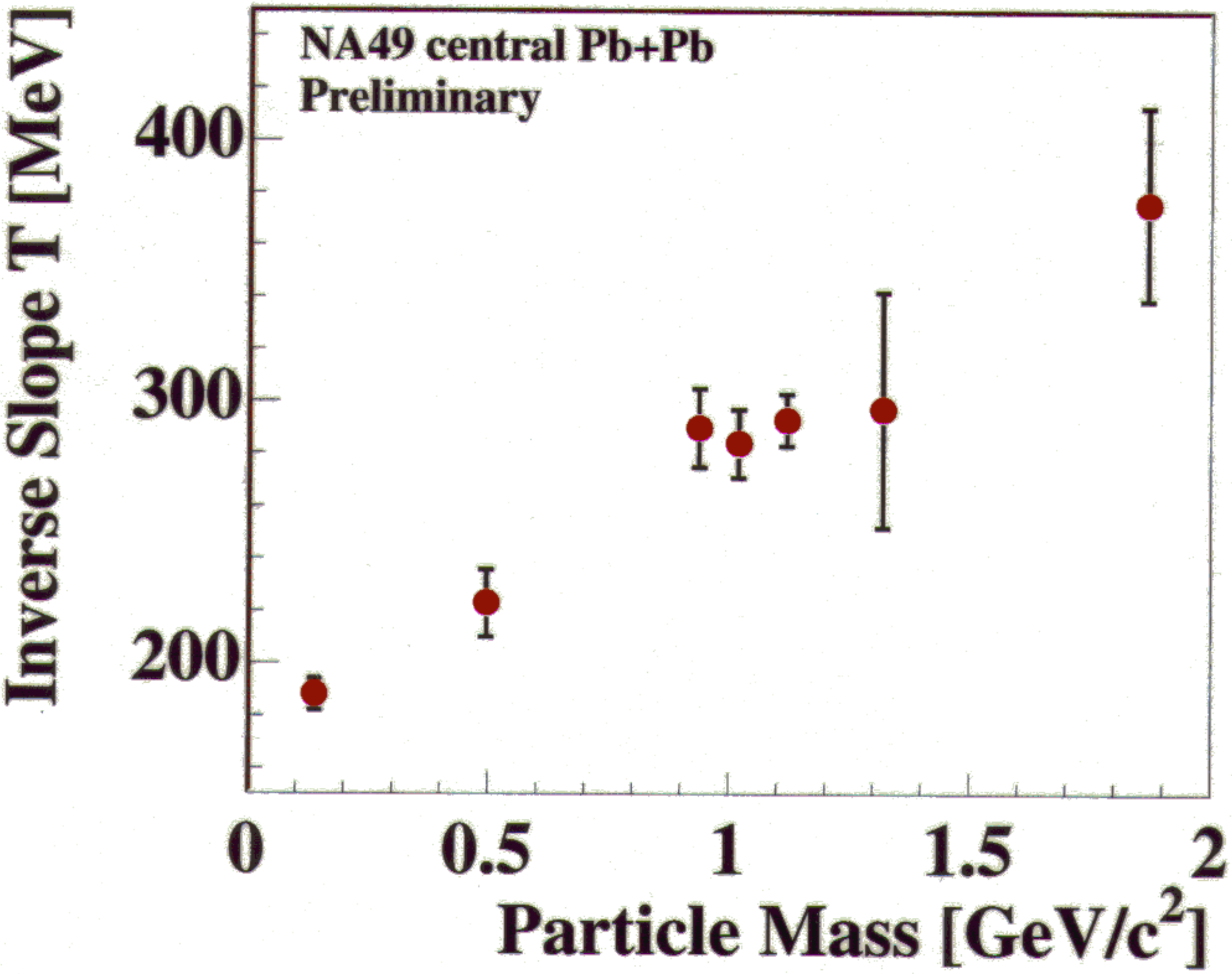
Limited study – Prakash^2, Venugopalan, Welke (93/94)

Complete study with hadronic cascade models would be very useful.

What <u>exactly</u> are deviations from hadronic equilibrium ($T_{kin} \neq T_{ch}$, etc.) telling us?

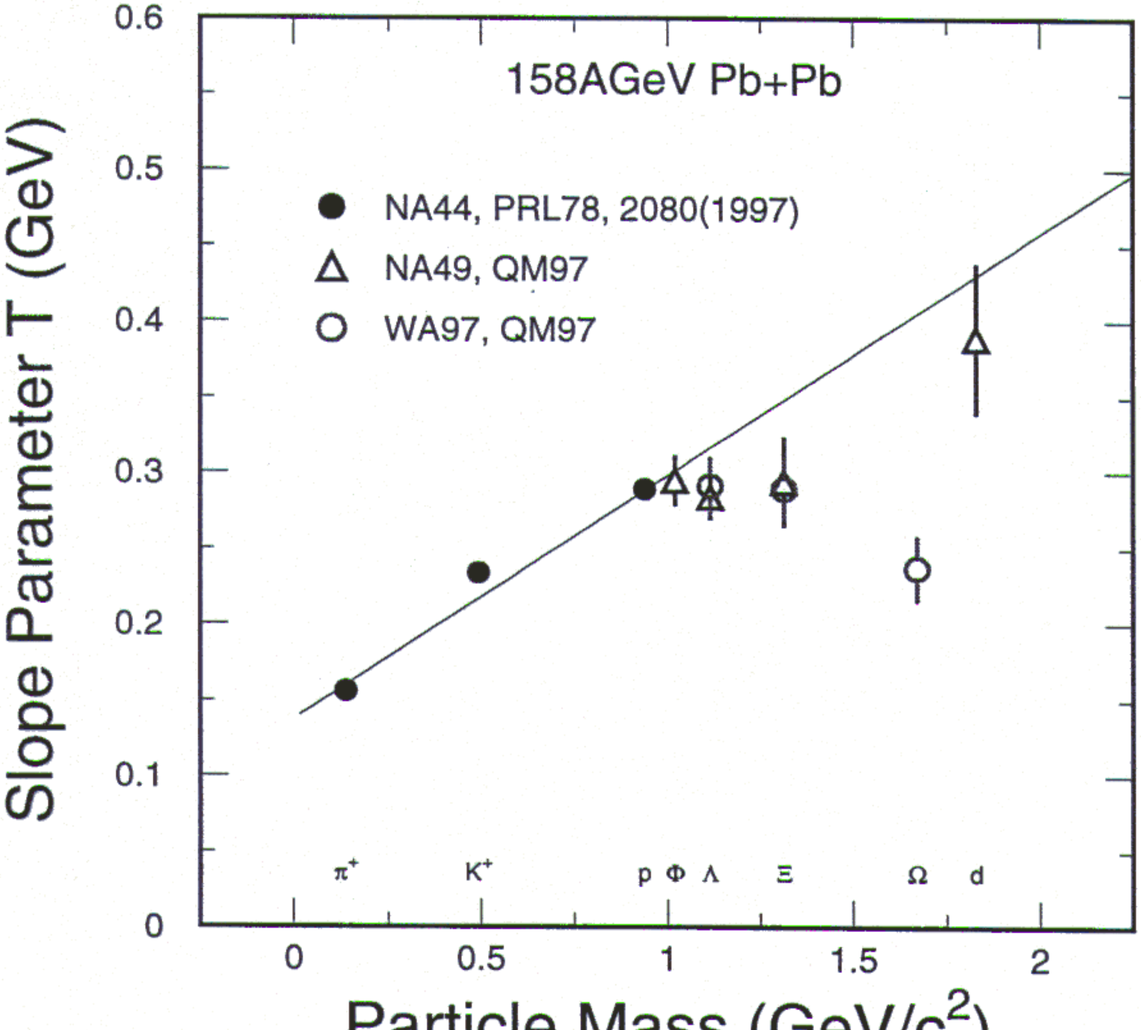
Bialas' argument : HG vs. QGP (hep-ph/9808434)

Inverse Slope vs Particle Mass



Transverse Velocity Effect → $T = T(\text{mass},\beta_T,T_f)$

(Lee, Heinz, Schnedermann, Z. Phys. C48 (1990) 525)


158AGeV Pb+Pb
● NA44, PRL78, 2080(1997)
△ NA49, QM97
○ WA97, QM97
Slope Parameter T (GeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
Particle Mass (GeV/c^2)
0
0.5
1
1.5
2
π^+
K^+
p
Φ
Λ
Ξ
Ω
d

Hadron formation by quark coalescence

(Biró + Zimanyi, Koch, BM, Rafelski, ..., Bialas)

$$\frac{\bar{p}}{p} = \frac{\bar{q}^3}{q^3} \qquad \frac{\bar{\Lambda}+\bar{\Sigma}}{\Lambda+\Sigma} = \frac{\bar{p}}{p} D \qquad \frac{\bar{\Xi}}{\Xi} = \frac{\bar{p}}{p} D^2 \qquad \frac{\bar{\Omega}}{\Omega} = \frac{\bar{p}}{p} D^3$$

with $D = q\bar{s}/\bar{q}s$

	Pb+Pb	S+S	p+Pb
$\bar{p}/p$	0.07 ± 0.01	0.12 ± 0.01	0.31 ± 0.03
$(\bar{\Lambda}+\bar{\Sigma})/(\Lambda+\Sigma)$	0.133 ± 0.007	0.22 ± 0.01	0.20 ± 0.03
$\bar{\Xi}/\Xi$	0.249 ± 0.019	0.55 ± 0.07	0.33 ± 0.03
$\bar{\Omega}/\Omega$	0.383 ± 0.081		
D_Λ	1.9 ± 0.3	1.83 ± 0.17	0.65 ± 0.11
D_Ξ	1.89 ± 0.15	2.14 ± 0.16	1.03 ± 0.07
D_Ω	1.76 ± 0.15		
$D_K = \frac{\bar{K}}{K}$	1.8 ± ?	1.91 ± 0.37	

Partonic vs. hadronic degrees of freedom

- the full description of RHIC physics needs both, partonic **and** hadronic degrees of freedom

VNI

- initial conditions:

→ nucleon structure functions

→ elastic form factors

- partonic interactions:

→ pQCD cross sections

- hadronization:

→ phase space coalescence with color neutrality constraint

UrQMD

- hadronic interactions:

→ 55 baryon- and 32 meson species

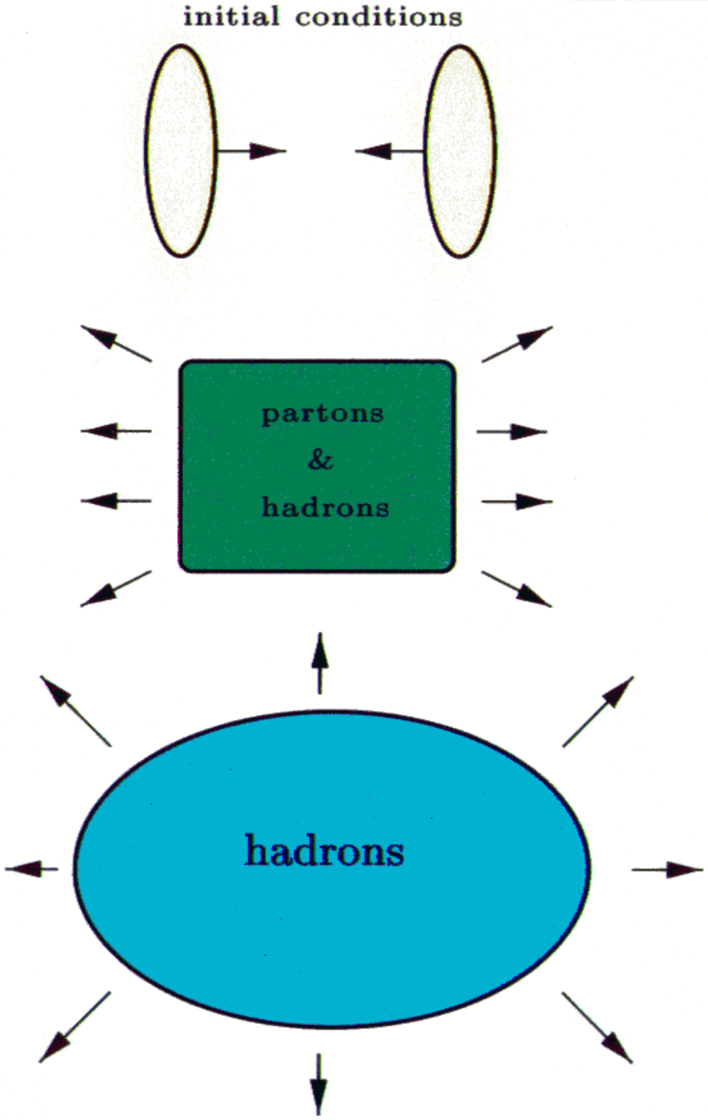
→ param./tabulated cross sections for elast. and inel. scattering

→ mass dependent decay widths

→ detailed balance for 2 ↔ 2 as well as 1 ↔ 2

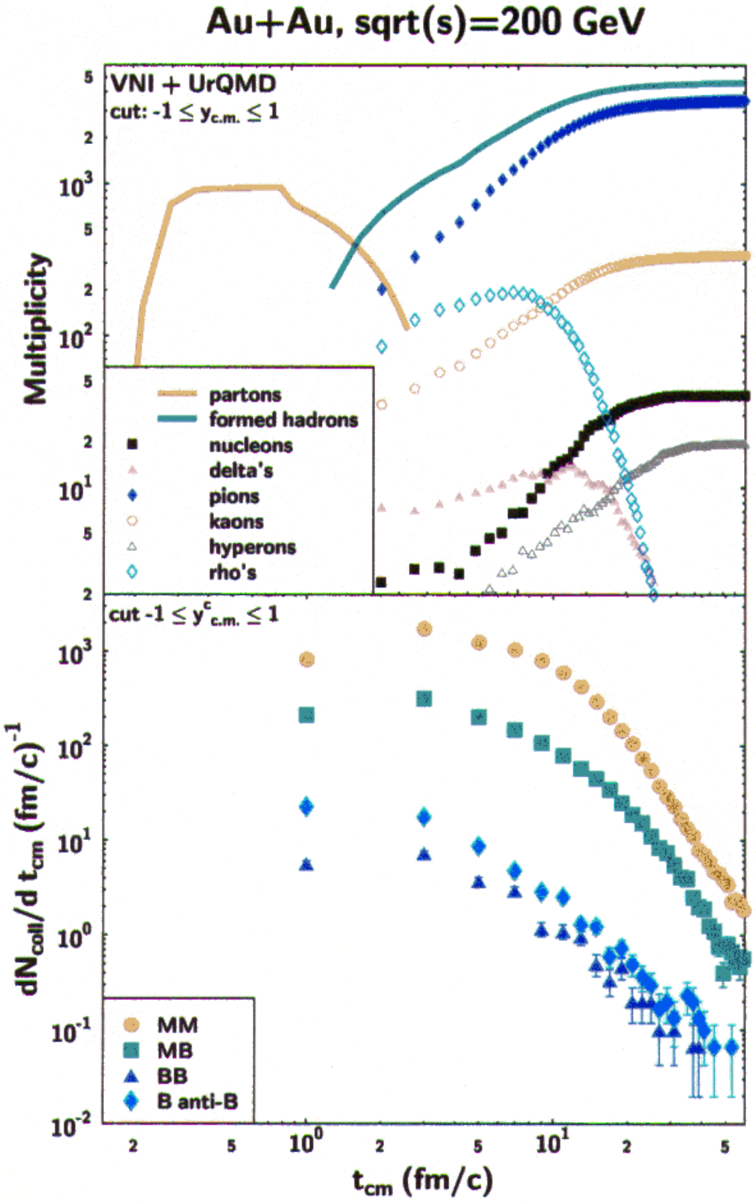
→ well tested at SIS, AGS, SPS

Interplay of partons and hadrons



- parton-parton and hadron-hadron interactions may occur within the same space-time volume
- no parton-hadron interactions
- hadronization occurs dynamically, depending on local conditions for individual parton-cluster/hadron
- after hadronization, hadrons do not interact within formation-time
- hadronization is unidirectional: no hadron to parton conversion

Time evolution of multiplicities and hadronic collision rates

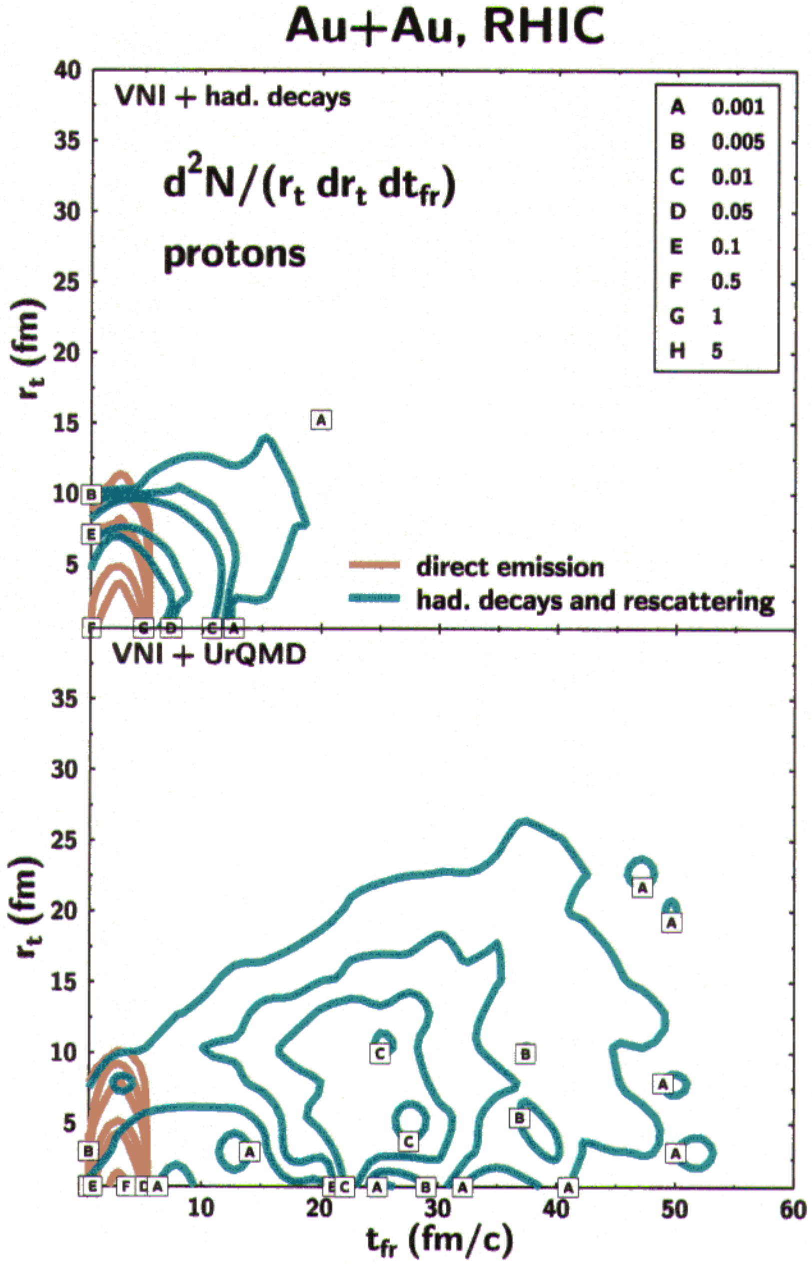


- overlap between partonic and hadronic phase
- had. rescattering dominated by MM and MB interaction

→ mixed phase: 1 fm/c $\leq \Delta\tau_m \leq$ 4 fm/c

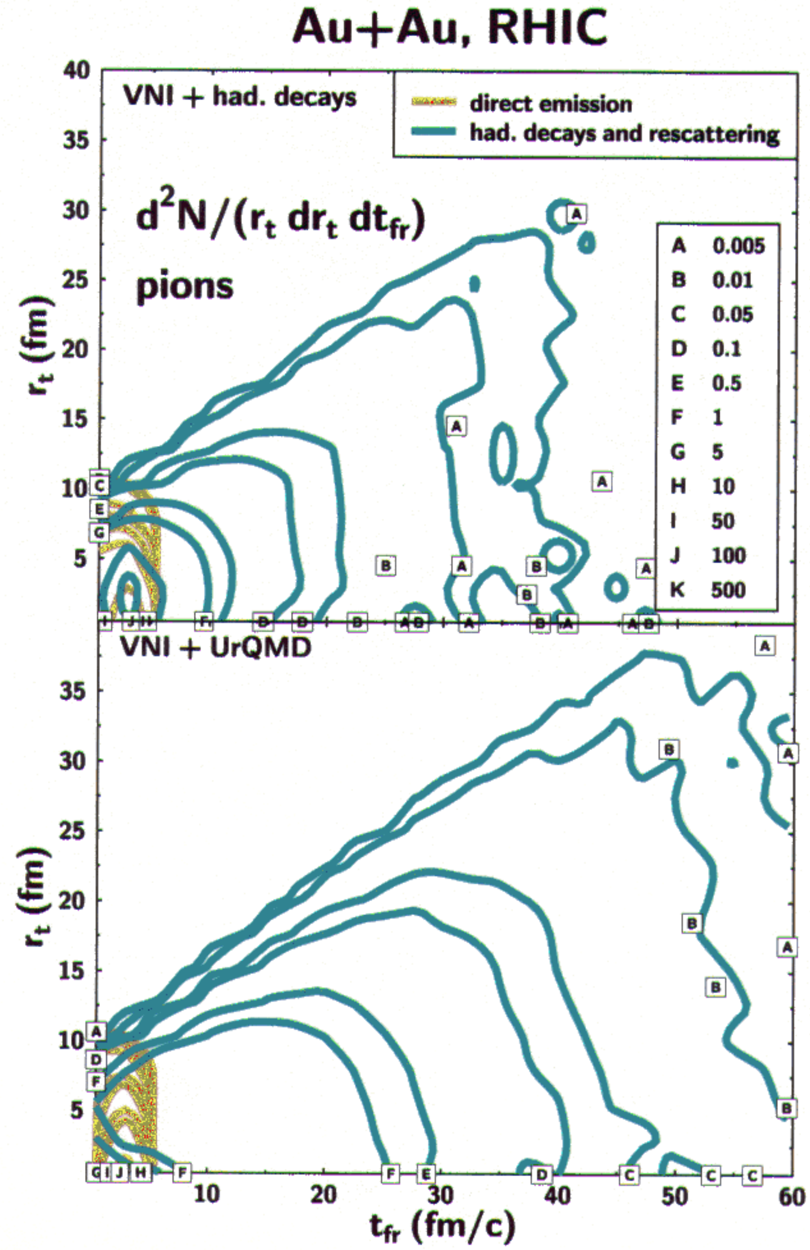
→ hadronic phase: 4 fm/c $\leq \Delta\tau_h \leq$ 20 fm/c

Proton freeze-out hypersurface


Au+Au, RHIC

- strong rescattering effects
- two sources: direct emission vs. rescattered emission

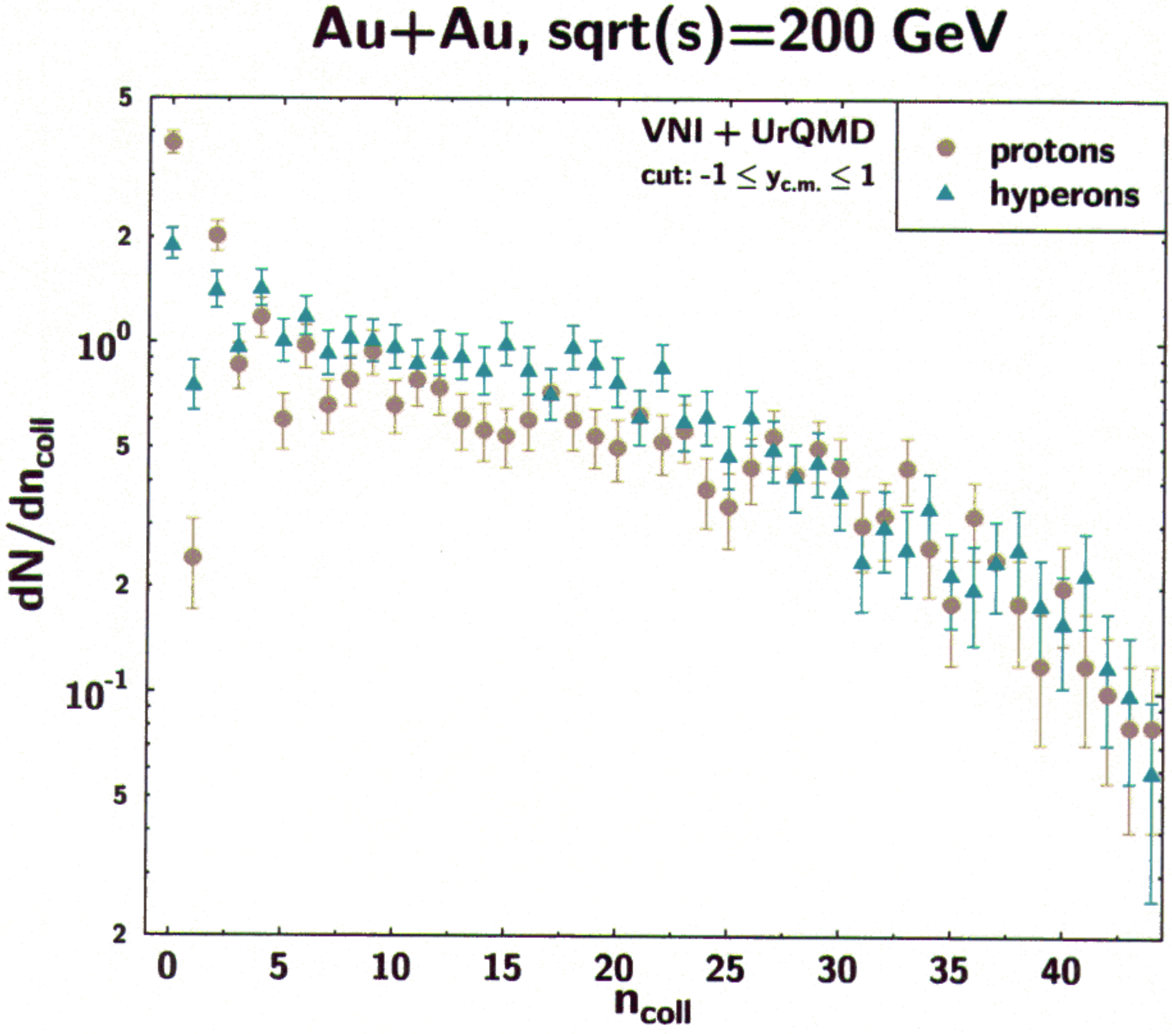
Pion freeze-out hypersurface



- source extended both in temporal and radial direction due to rescattering

→ sensitivity towards HBT analysis

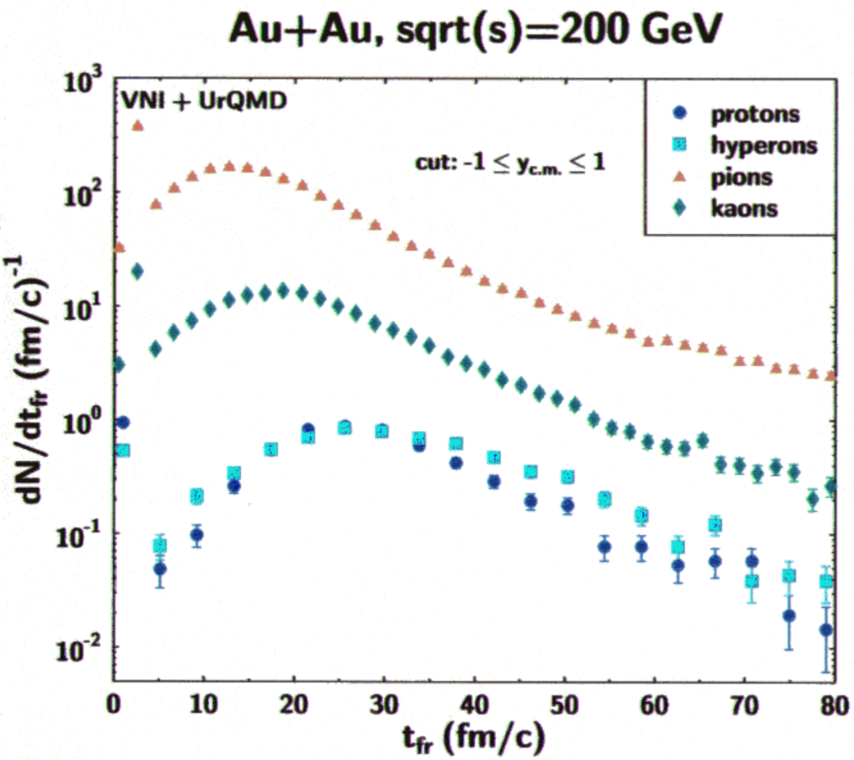
Rescattering of baryons

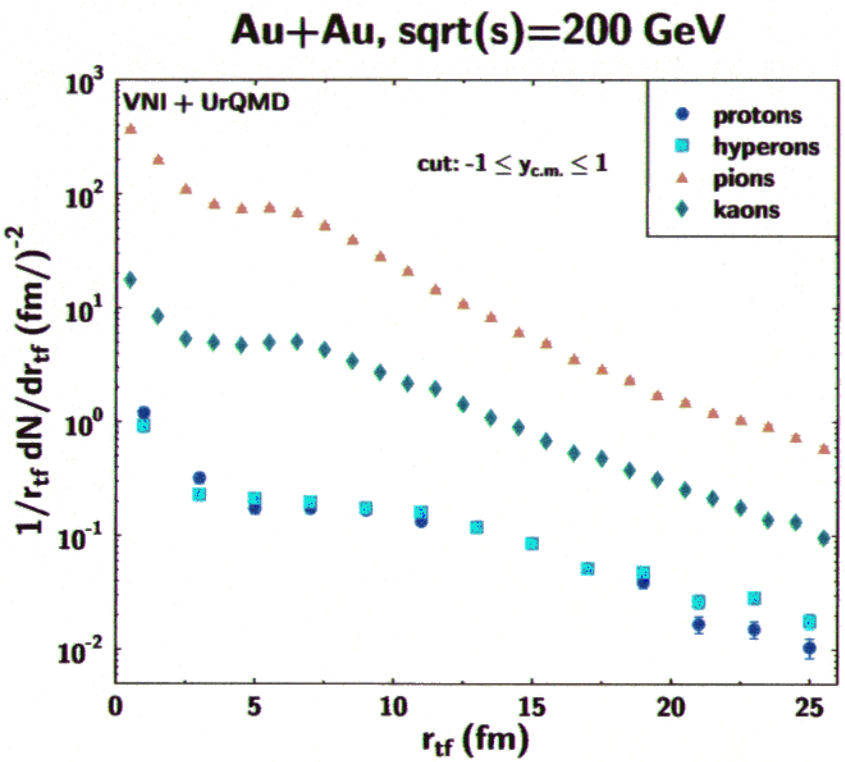


- massive rescattering for protons and hyperons: $\langle n^{p}_{coll} \rangle \approx 14$ and $\langle n^{Y}_{coll} \rangle \approx 15$
- only 15% of protons and 6% of hyperons do not rescatter at all

→ propagation of baryons in dense *mesonic* medium

Freeze-out conditions for different hadron spezies

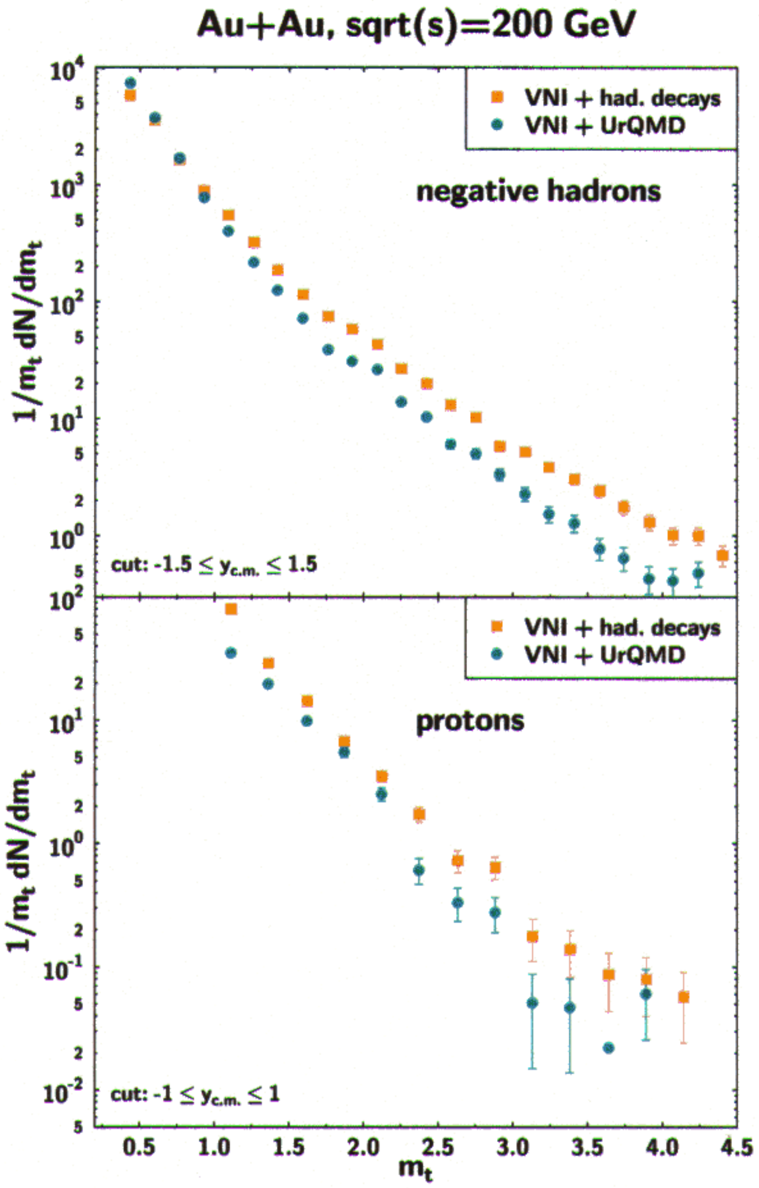




	pions	kaons	protons	hyperons
$\langle t_{fr} \rangle$ (fm/c)	18.6	23.7	27.4	31.7
$\langle r_{t,f} \rangle$ (fm)	9.6	12.2	13.1	14.8

BUT: no sharp freeze-out, broad distributions

Effects of hadronic rescattering: transverse mass spectra

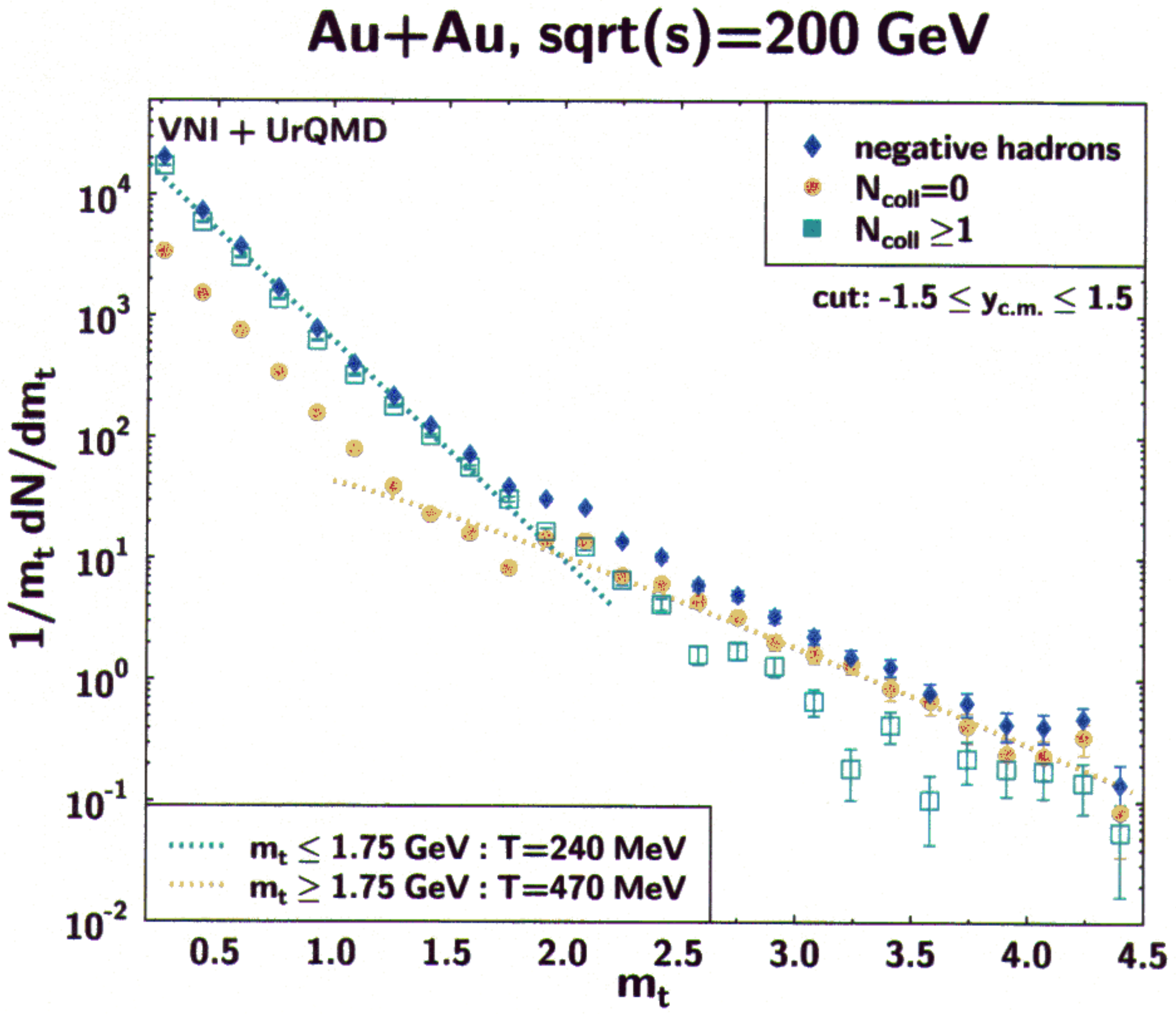


h^-: depletion and slight *cooling* for high m_t

enhancement at low m_t

protons: strong depletion at low m_t ($B\bar{B}$ annihilation)

Decomposition of h^- m_t spectrum: direct emission at high m_t

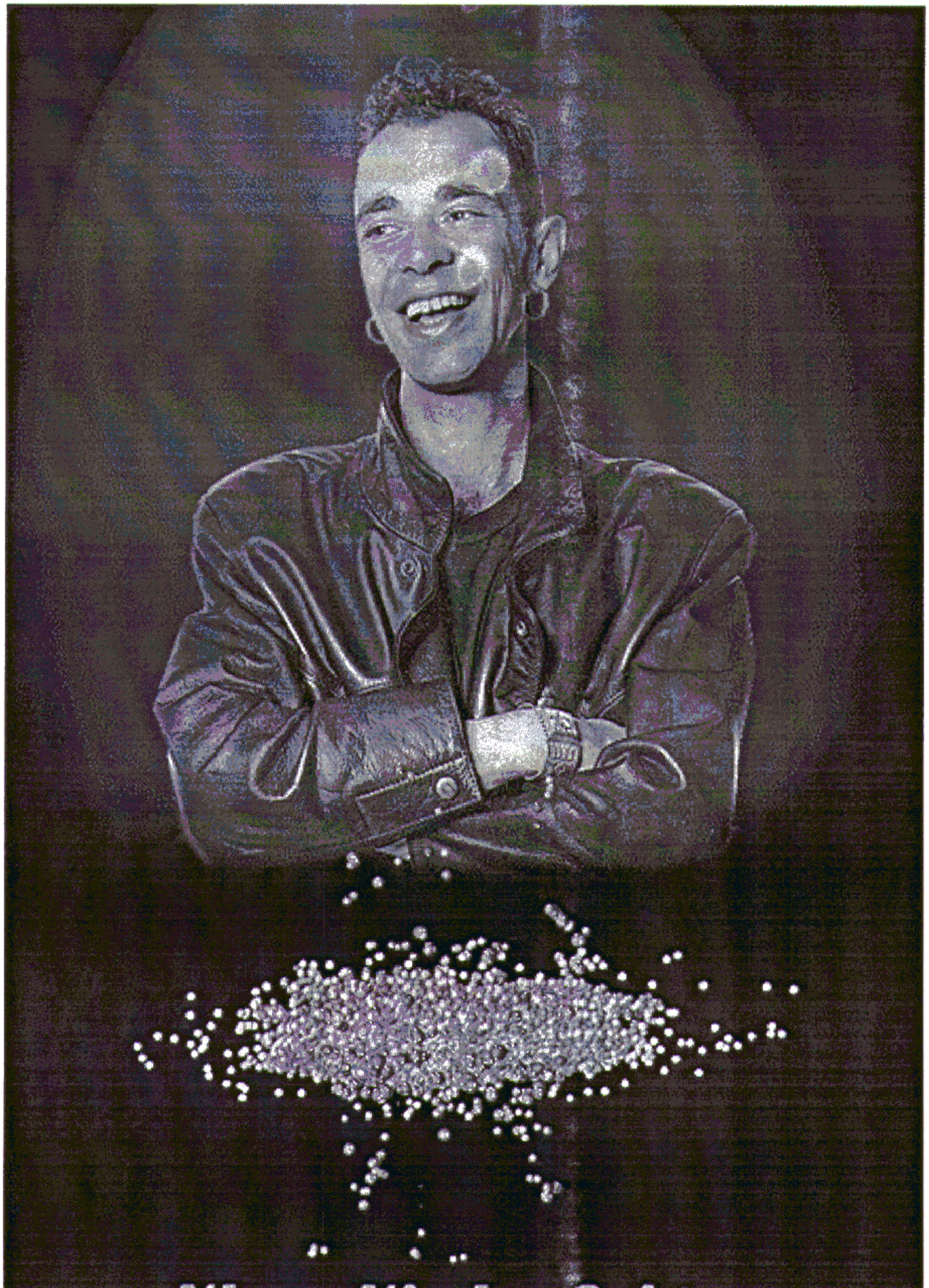


rescattered h^-: dominate for $m_t \leq 1.75$ GeV

81% of total yield

directly emitted h^-: dominate for $m_t \geq 2$ GeV

19% of total yield



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