RHIC Winter Workshop '99

Studying ISIPP with SCOPE

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Outline

* Intro
* philasophy of the time evolution model of the parton phase SCOPE
* impact on t-evolution of the parton plasma
* unique property of PP
* non-equilibrium effect

Introduction

Importance of models & simulations

* a way to test what we know
* translate them into #
  cf experiment
* full equilibration @ RHIC
  is unlikely so
  memory of the collision gets
  propagated down the collision
  time line
* Need to follow the collision
  history

Problems with Modelling

More reliable models tend to be PQCD based + transport equation

Watch Out!!

* Knowledge of PQCD got from interactions in a vacuum which is not the environment created @ RHIC ⟹ medium effects

* The evolution in time is foreign to PQCD, no important role not so @ RHIC

* Tend to be quite superior numerically but not so transparent physically, highly numerical

We want a model

* just a touch more qualitative
* still bases on PQCD
* incorporate medium effects
* abeys Murphy's law (ML) of the parton plasma which states

"Anything that can change with time will!!"

Self
COnsistent
Partonic
Equalibration
model

Partonic Equilibration Model

Not another cascade code ! Promise !!

But more in line with the

"Parton chemical equilibration model"

T.S. Biró et al PRC 48 (1993) 1275.

* Have to assume thermal equilibrium to start off with (a problem!)
* Time evolution ≡ chemical equilibration only !

We want a full equilibration model !!

Model in the flesh

* Relaxation time / collision time Model

$$\left(\frac{\partial}{\partial t} + \underline{v}_p \cdot \frac{\partial}{\partial \underline{r}}\right) f(p,t) = -\frac{f - f_{eq}}{\Theta(\tau)}$$

← collision time

A toy model of sort on its own

No QCD !!

* Inelastic interactions (minimal)

$gg \longleftrightarrow ggg$ ⟸ with LPM suppression borrowed from Biró et al

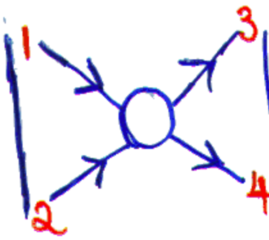
$gg \longleftrightarrow q\bar{q}$

* Elastic interactions (minimal)

$gg \leftrightarrow gg$ $qg \leftrightarrow qg$ $\bar{q}g \leftrightarrow \bar{q}g$

$qq \leftrightarrow qq$ $q\bar{q} \leftrightarrow q\bar{q}$ $\bar{q}\bar{q} \leftrightarrow \bar{q}\bar{q}$

* typical collision term

$\sim \int d(\text{momenta})$ $\left| \right.$  $\left. \right|^2$ $\left\{ \begin{array}{l} f_1 f_2 (1 \pm f_3)(1 \pm f_4) \\ - f_3 f_4 (1 \pm f_1)(1 \pm f_2) \end{array} \right\}$

Self consistencies

a) Screening

QCD $|\mathcal{M}|^2$ full of holes $\Longleftarrow$ IR div.

PQCD cutoff with p_{T0} ~ arbitrary

medium masses $\Longrightarrow$ natural cutoff

Interactions at any moment screened by existing partons at the same time $\Longrightarrow$ $m^2_{scr}(\tau) \sim \int \frac{d^3k}{k} f(k,\tau)$

b) Coupling

Models use average α_s !

Popular value $\alpha_s(\langle Q \rangle) \sim 0.3$

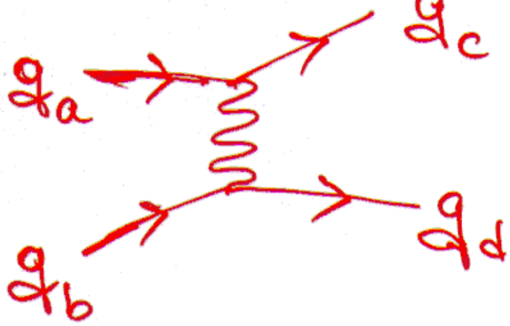
for $\langle Q \rangle \sim 2\,\text{GeV}$

All usually taken to be fixed !

But Murphy's law of the parton plasma says NO !!!

must be $\alpha_s = \alpha_s(\tau)$

Typical partons — Typical collision in the plasma



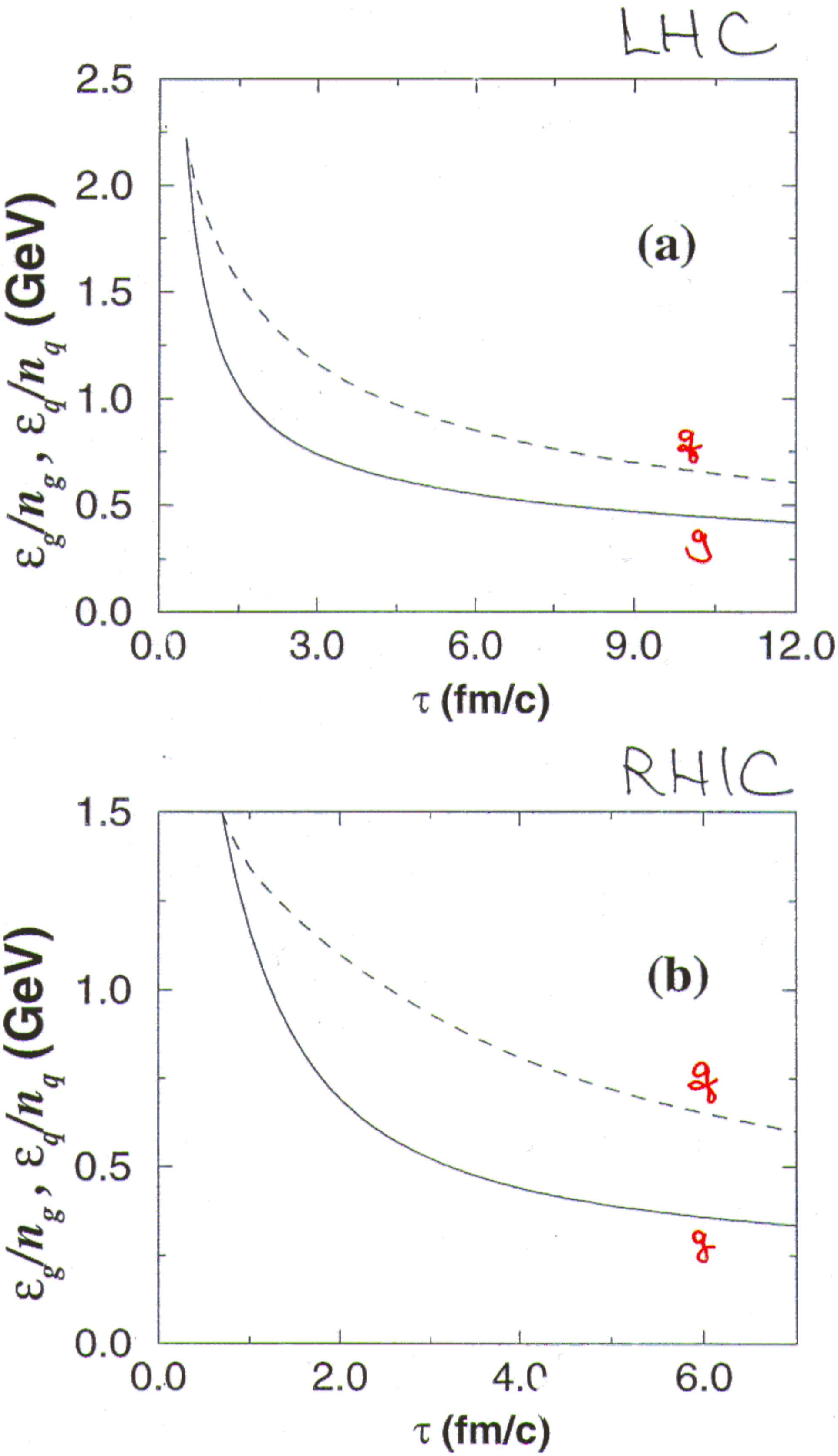
$E_a \sim E_b \sim E_c \sim E_d \sim \langle E \rangle$ = average parton energy

Momentum transfer

$$0 < -t < 4\langle E \rangle^2 \quad !!$$

$\Uparrow$ bounded by the value of $\langle E \rangle$!!

S.M.H.W. PRC 54 (1996) 2588.
PRC 56 (1997) 1075.



changes in the average parton energies > 1 GeV during the time evolution.

So $\langle Q \rangle \sim 2$ GeV &
$\therefore$ $\alpha_s = 0.3$ throughout is unlikely!

Use a simple recipe

- $\langle Q \rangle \sim \langle \varepsilon \rangle / \langle n \rangle$

  ($\langle \varepsilon \rangle$: average parton energy)

- 1-loop α_s

$$\alpha_s(\langle Q \rangle) = \frac{4\pi}{\beta_0 \ln \frac{\langle Q \rangle^2}{\Lambda_{QCD}^2}}$$

System decides its own interaction strength!

Expansion + Particle creation

$\Longrightarrow$ $\langle E \rangle \downarrow$ $\therefore$ $\langle Q \rangle \downarrow$

with time

so

$\alpha_s(Q) \uparrow$ with time

Result :-

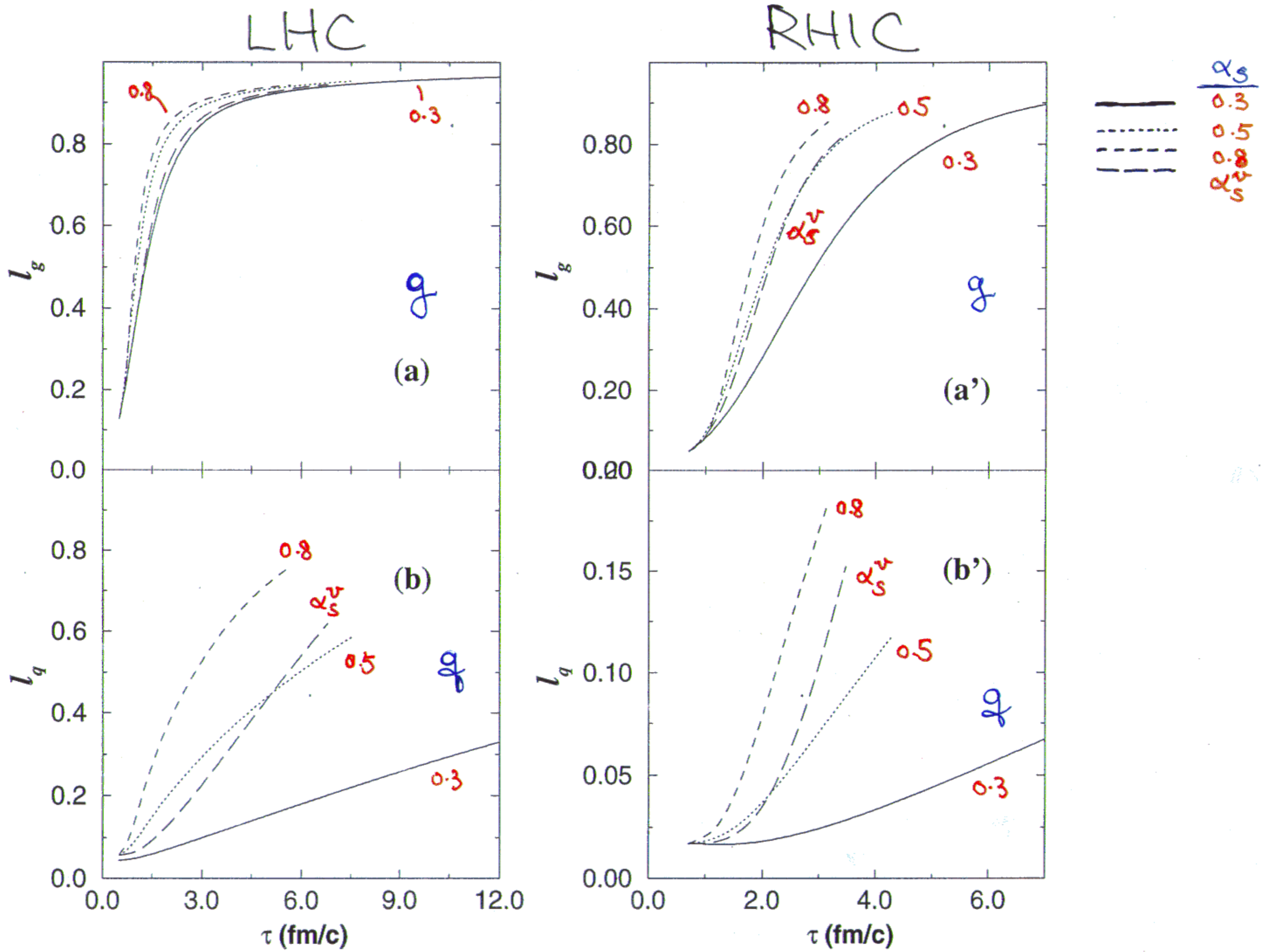
Increasingly

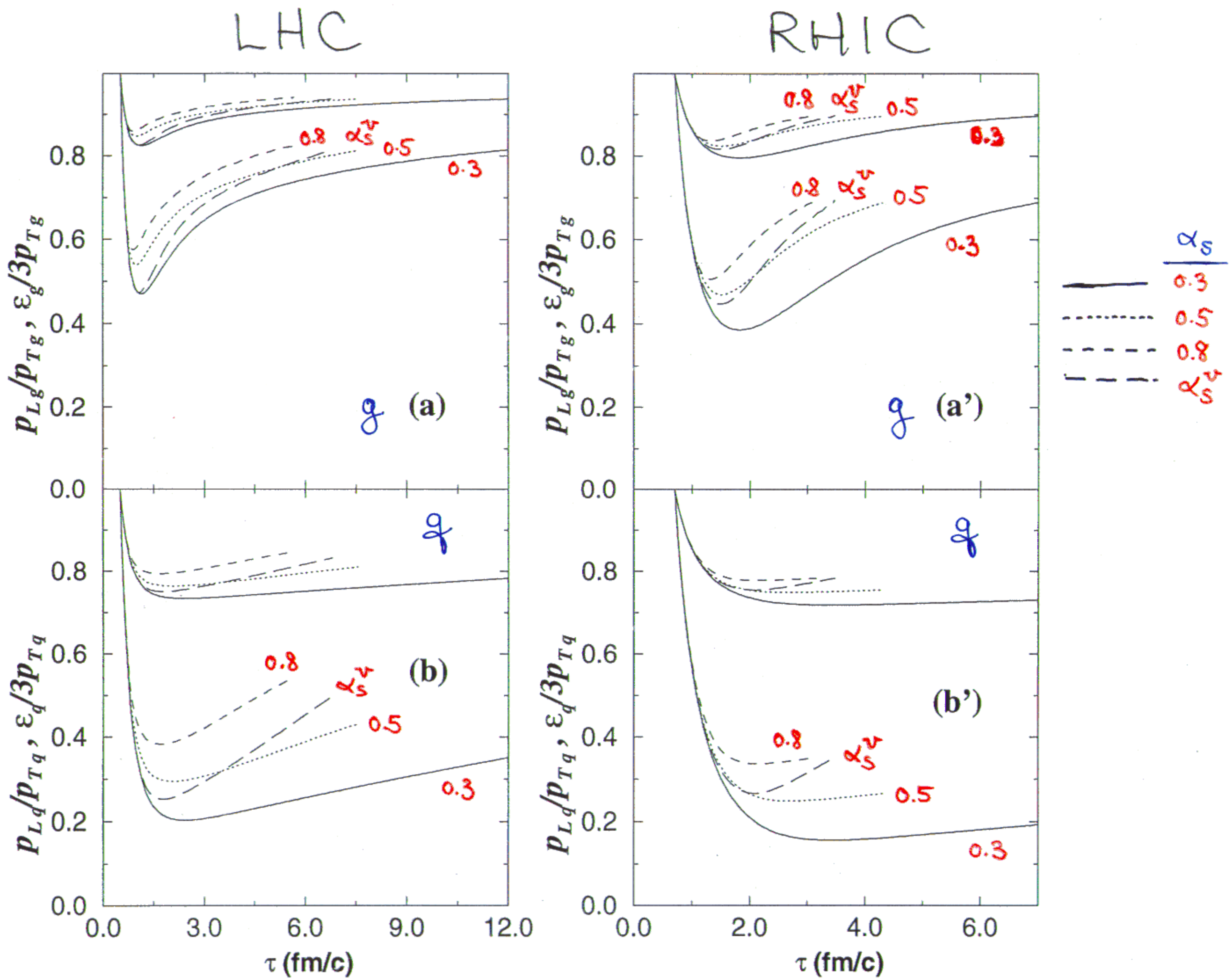
Strongly

Interacting

Parton

Plasma


LHC
RHIC
(a)
(b)
(a')
(b')
l_g
l_q
τ (fm/c)
τ (fm/c)
α_s
0.3
0.5
0.8
α_s^v


LHC
RHIC
(a)
(a')
(b)
(b')
g
0.3
0.5
0.8
α_s^v
α_s
p_{Lg}/p_{Tg}, $\varepsilon_g/3p_{Tg}$
p_{Lq}/p_{Tq}, $\varepsilon_q/3p_{Tq}$
τ (fm/c)
0.0
0.2
0.4
0.6
0.8
3.0
6.0
9.0
12.0
2.0
4.0

Unique Property of the Parton Plasma

* Collision terms $= -\frac{f - f_{eq}}{\theta(\tau)}$

* Interpretation of $\theta(\tau)$

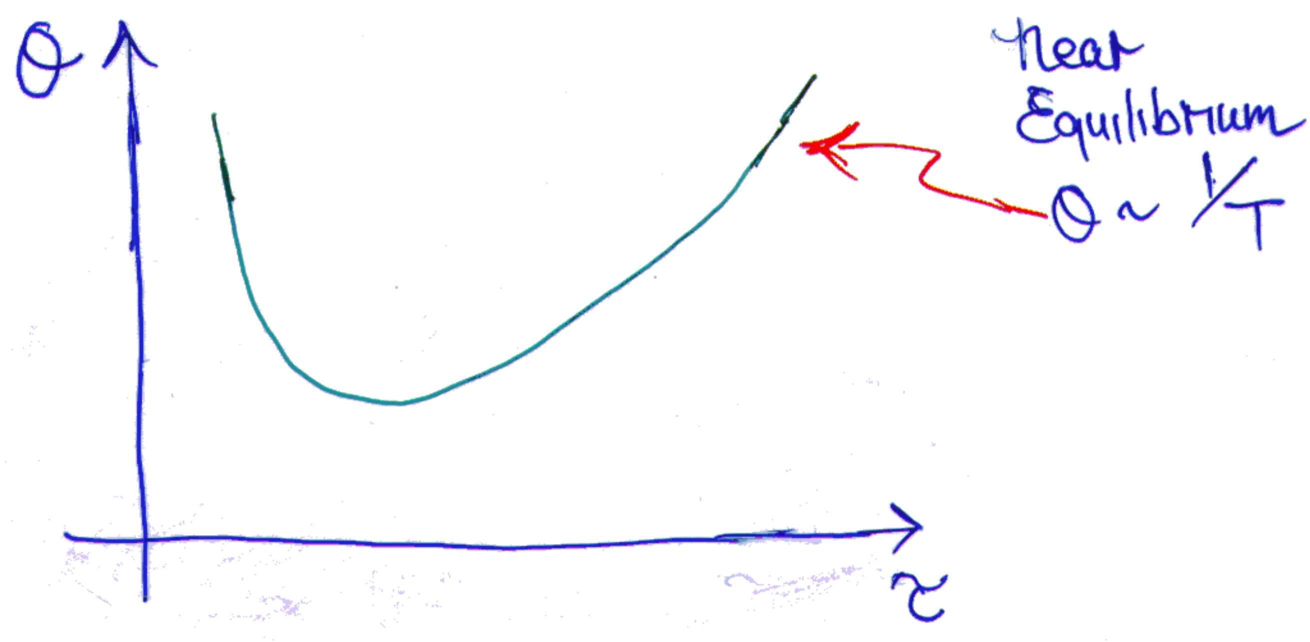
$1/\theta(\tau) \approx$ Net collision/equilibration rate

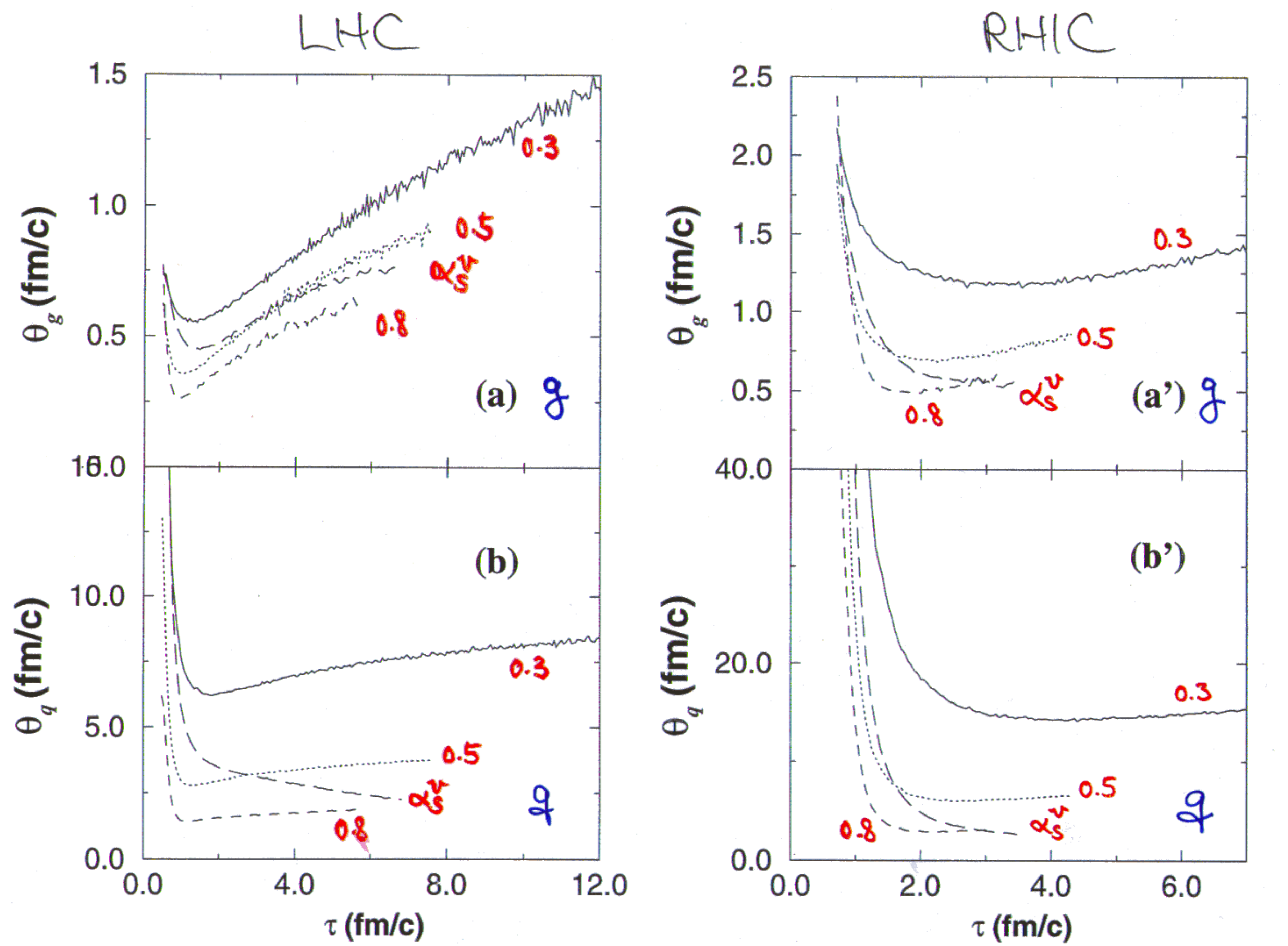
$\approx$ (forward − backward) reaction rate

∴ $\theta(\tau)$ reflects the state of equilibrium of the parton plasma

large θ — near equilibrium

small θ — far out of equilibrium





LHC
RHIC
(a)
(b)
(a')
(b')
g
q
0.3
0.5
0.8
α_s^v
θ_g (fm/c)
θ_q (fm/c)
τ (fm/c)

Out of equilibrium effect on photon production

2 contributions from partons

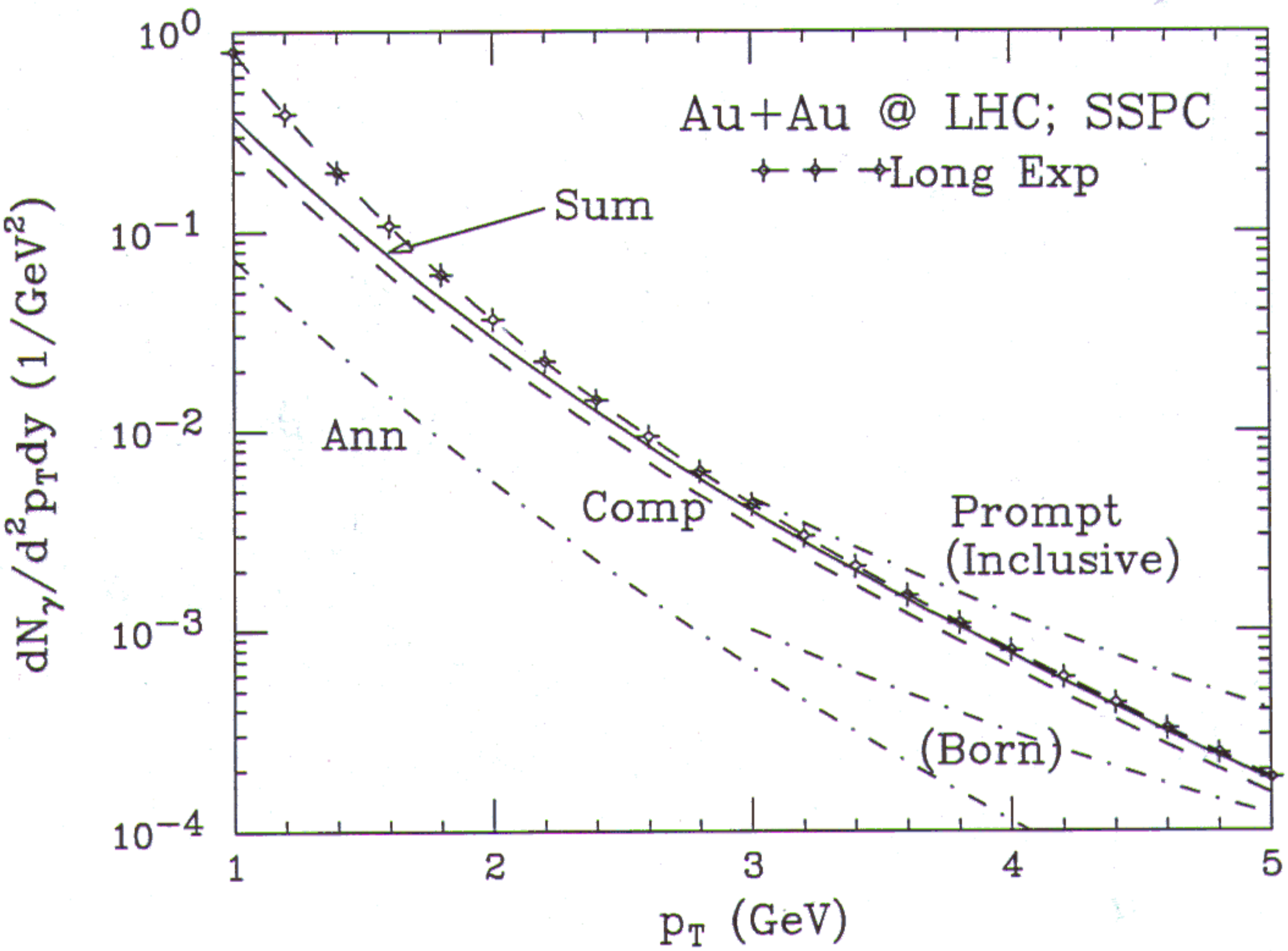
$$R \sim \int \frac{d^3k_1}{(2\pi)^3 2\omega_1} \frac{d^3k_2}{(2\pi)^3 2\omega_2} \frac{d^3k_3}{(2\pi)^3 2\omega_3}$$

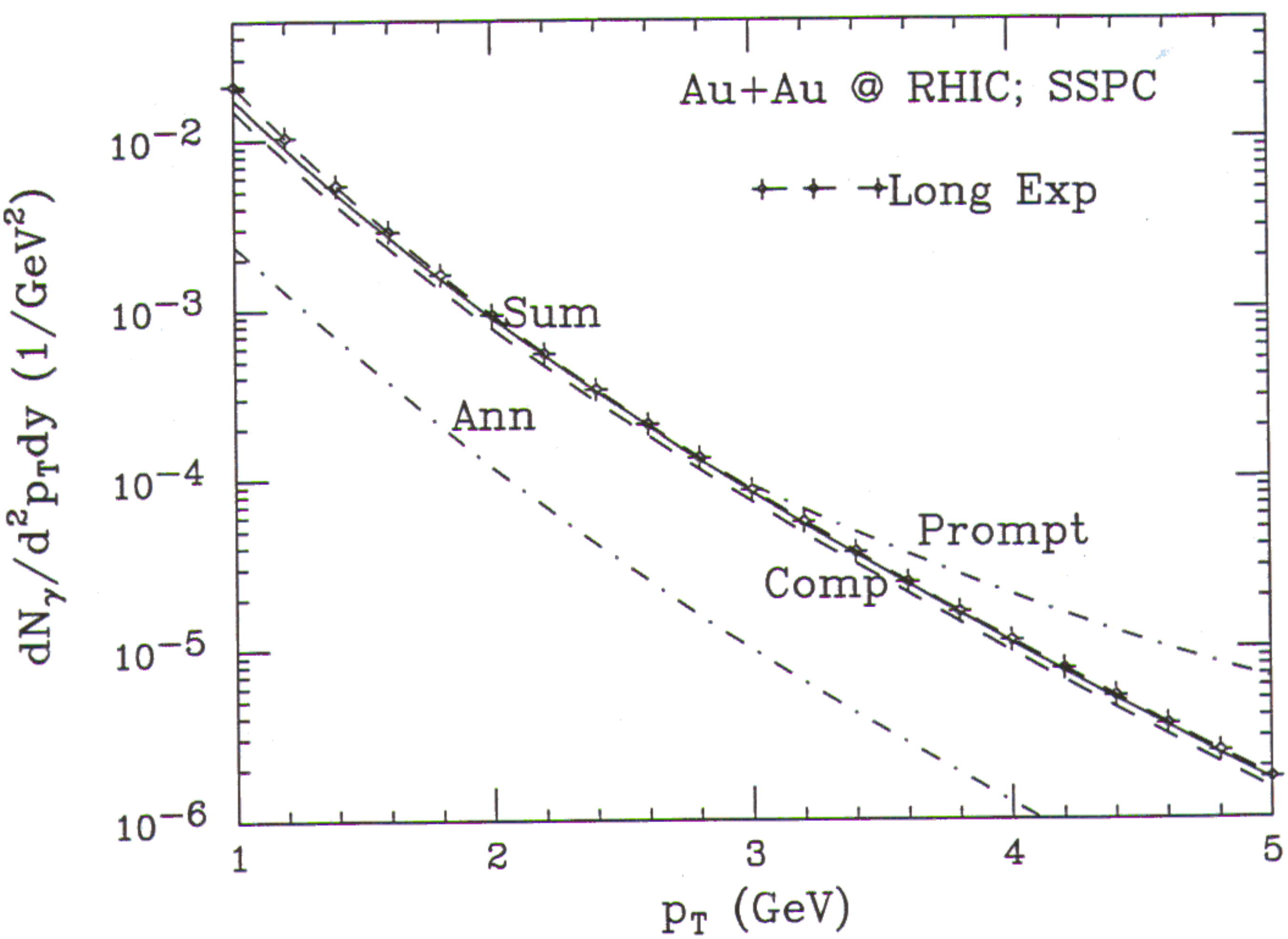
$$(2\pi)^4 \delta^{(4)}(k_1 + k_2 - k_3 - P) \quad \leftarrow \gamma$$

$$\times \begin{cases} 2 f_g(k_1,\tau) f_q(k_2,\tau)\left(1 - f_q(k_3,\tau)\right) \times \left|\mathcal{M}_{gq\to q\gamma}\right|^2 & \text{Compton} \\ + f_{\bar{q}}(k_2,\tau) f_q(k_1,\tau)\left(1 + f_g(k_3,\tau)\right) \times \left|\mathcal{M}_{q\bar{q}\to g\gamma}\right|^2 & \text{Annihilation} \end{cases}$$

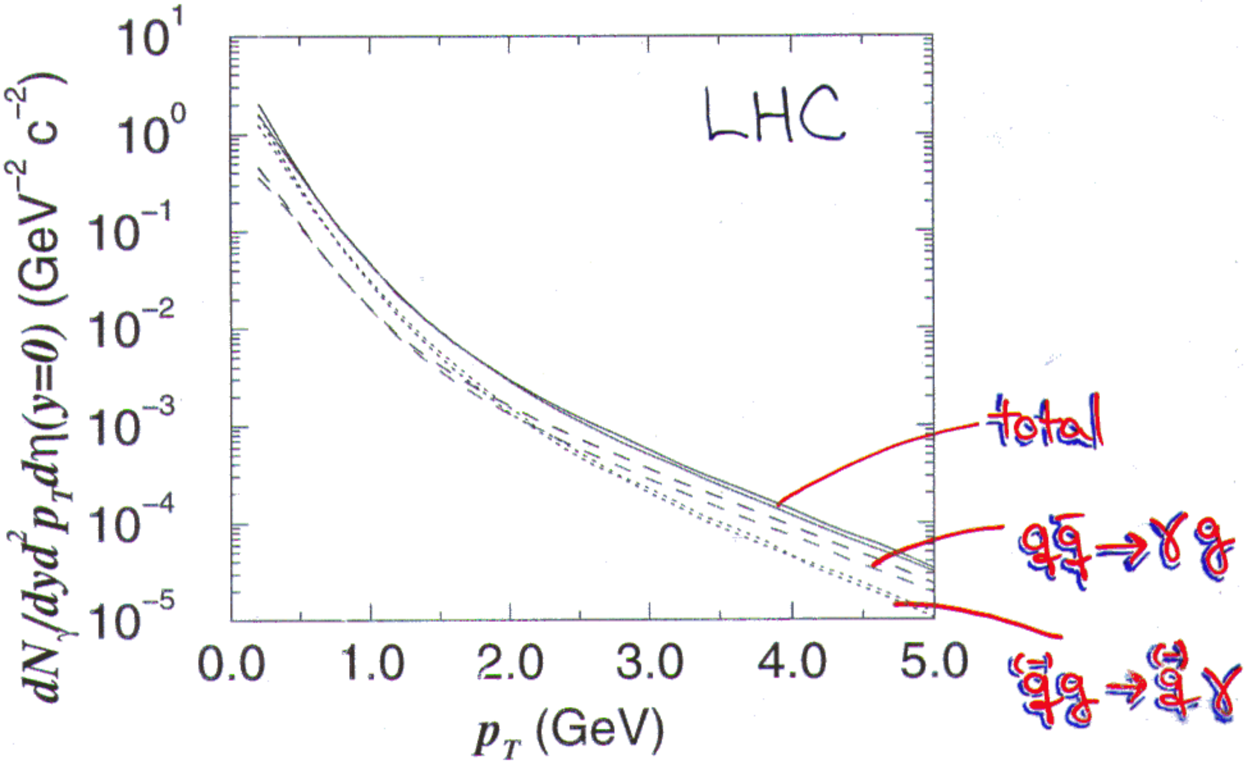
quarks & gluons exist as a mixed fluid with different temperatures (effective), fugacities & particle distribution!

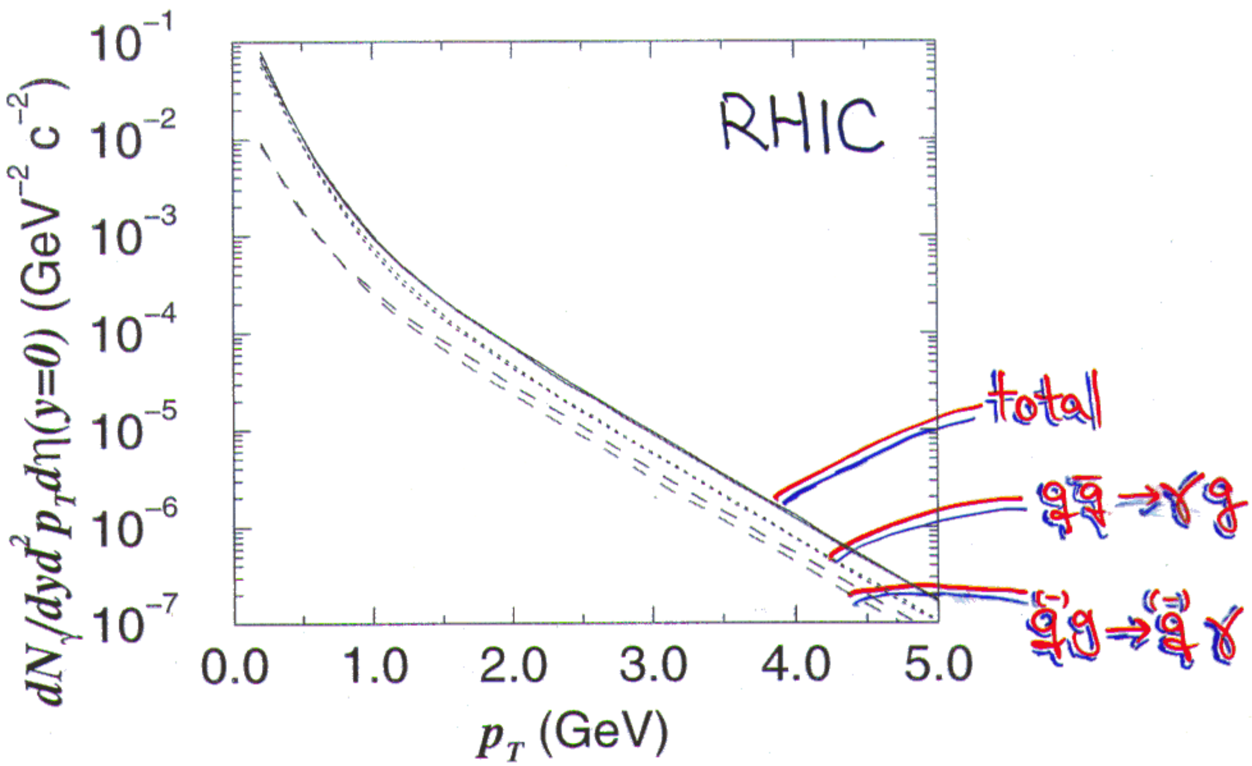
B. Müller et al
PRC 56 (1997) 1064.




Au+Au @ RHIC; SSPC
Long Exp
Sum
Ann
Prompt
Comp
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
dN_γ/d^2p_Tdy (1/GeV^2)
1
2
3
4
5
p_T (GeV)

Photon Production





The effect is most prominent at higher p_T.

Higher p_T γ needs more energetic incoming partons.

Can simplify (use Boltzman)

$$f_g(k_1) \sim \lambda_g \exp\{-k_1^0/T_g\}$$

$$f_{\bar{q}}(k_1) \sim \lambda_{\bar{q}} \exp\{-k_1^0/T_{\bar{q}}\}$$

Annihilation > Compton

form ratio

$$\frac{f_{\bar{q}}(k_1)}{f_g(k_1)} \sim \frac{\lambda_{\bar{q}}}{\lambda_g} \exp\left\{+k_1^0\left(\frac{1}{T_g} - \frac{1}{T_{\bar{q}}}\right)\right\}$$

$$\lambda_{\bar{q}} < \lambda_g$$ always!

So if kinetic equilibrium

then $T_g = T_{\bar{q}}$

Annihilation < Compton

[illegible]

Summary

* Shown a time-evolution model of the parton plasma — SCOPE

  Important feature

  Interaction Strength — determined by the system at any time

  Must be the case for consistency

* Equalibration gets a "boost" from the progressively increasing interaction strength

* More qualitative — special property of the parton plasma

  Parton plasma equalibrates faster & faster

  Normal matter " slower & slower

[Proverb :

Can't find the wood for trees !]

Relying too heavily on PQCD ⟹ Can't see this!

* full equalibration — check for out-of-equilibrium effect on signature

eg. γ – production

At higher p_T, γ from the parton plasma becomes more competitive