QM02
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Physics of LHC (theory)

QCD plasma for sure exists

- equilibrium predictable all T, $\mu=0$
- some dynamics — " — $T \gg T_c$

Can these be measured at

SPS → RHIC → LHC ?

$\sqrt{s} = 20 \ll 200 \ll 5500$

$A = 200 = 200 = 200 \gg 1$

Why is LHC a BIG step forward?

We know the theory (theories!)

$$\int \mathcal{D}A_\mu^a \, \mathcal{D}\bar{\psi}_{if} \, \mathcal{D}\psi_{if} \, e^{\frac{i}{\hbar}\int d^4x \left[-\frac{1}{4}(F_{\mu\nu}^a)^2 + \bar{\psi}(i\partial\!\!\!/ + gA\!\!\!/ - m)\psi + J\cdot A + \bar{\eta}\cdot\psi + \varphi\bar{\psi}\psi + \tilde{\varphi}\psi\psi\psi + \cdots \right]}$$

Ext currents

specify the problem; structure, parameters

N A A+A RHIC/LHC

but do not know how to solve it.

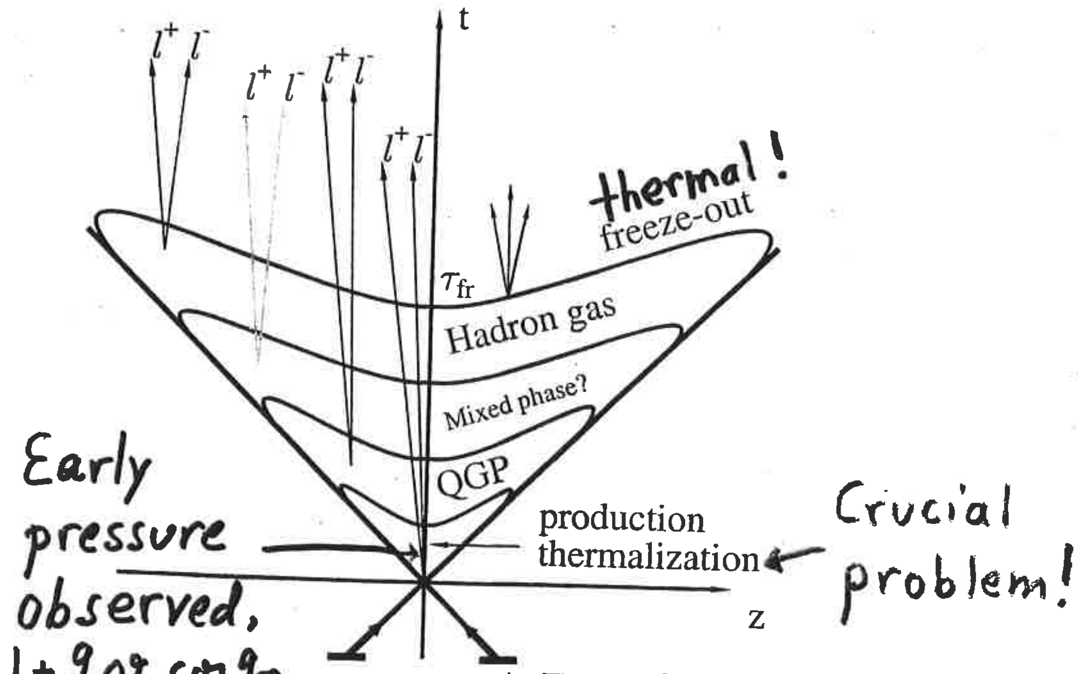
If we did, ⇒ no need to build ALICE/LHC

- particle physics progresses by discovering new theories: fields, interactions

- physics of A+A, branch of QCD, progresses within the framework of the "A+A expansion paradigm" (finite Δt, Δx !)

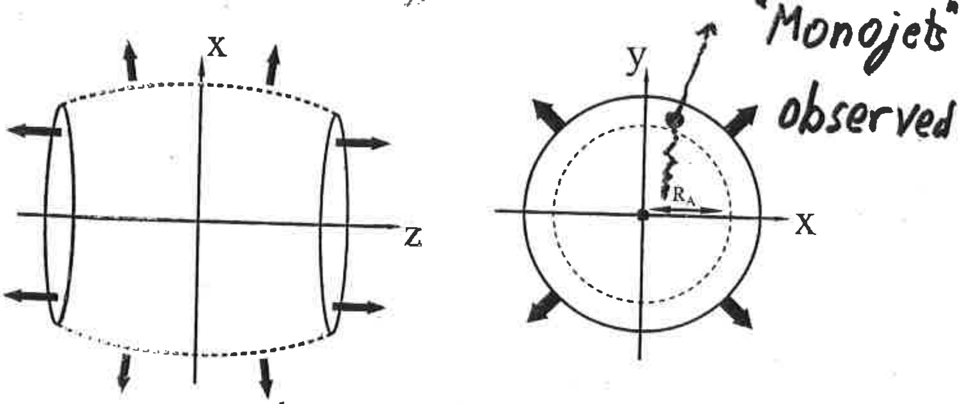
communication problems!

A+A paradigm ~1980



A, E_b, b the only experimentally controllable parameters!

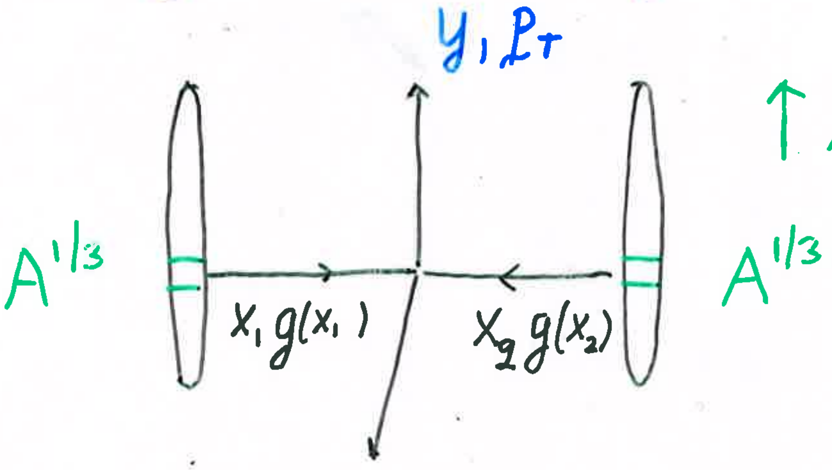
$b \neq 0$ Other projections at $t = \tau_{fr}$.



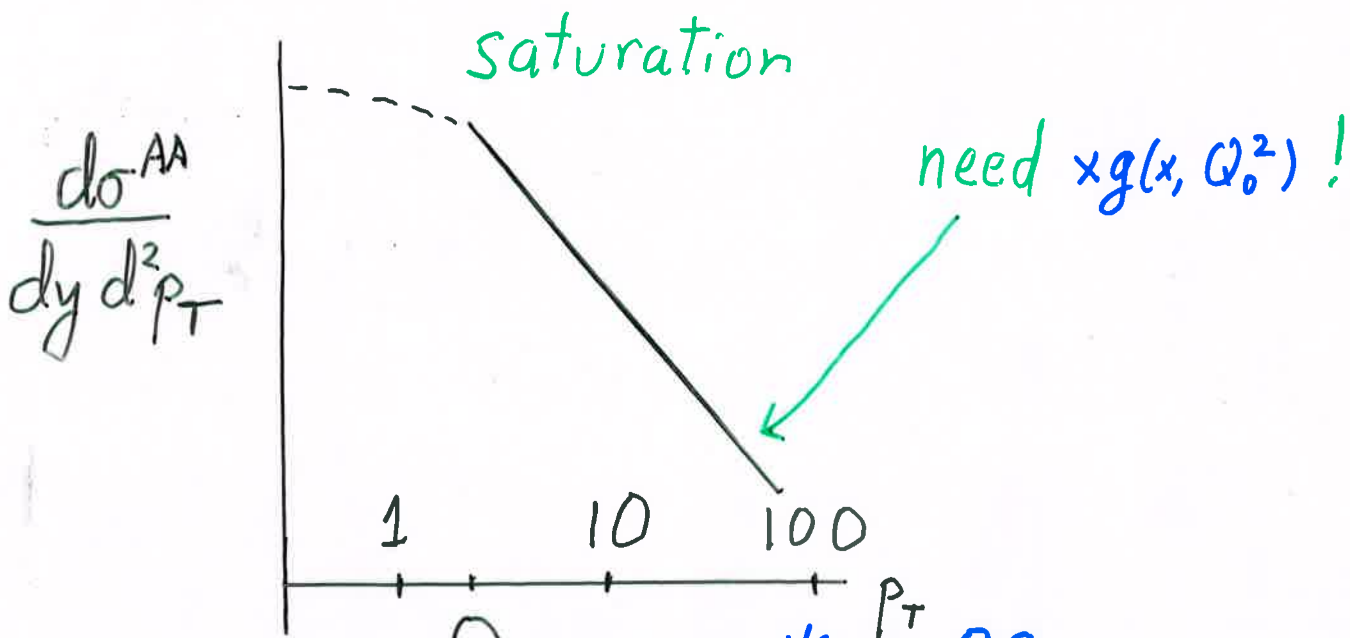
longitudinal & transverse expansion

Fig by KJEskola

Creating little bang:



$\uparrow A^{\frac{2}{3}}$ Transverse decoherence!



$$Q_s \sim 0.2\, A^{1/6} (\sqrt{s})^{0.2}$$

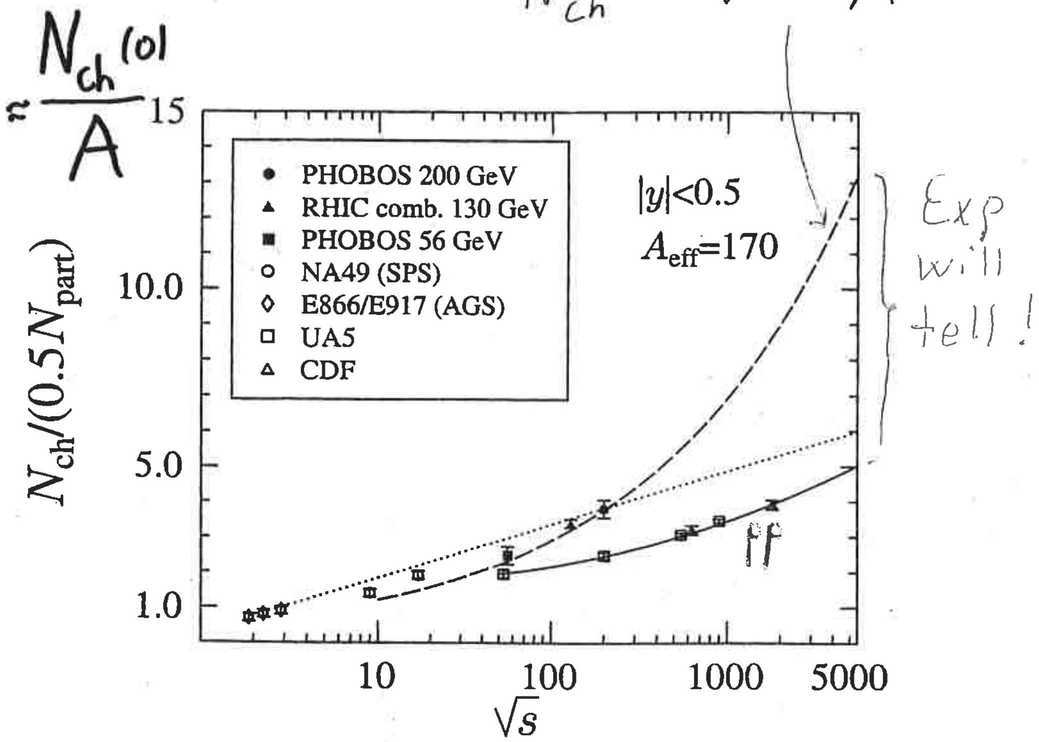
$$x_{eff} = \frac{2Q_s}{\sqrt{s}} = \begin{cases} 0.01 & \text{RHIC} \\ 0.0007 & \text{LHC} \end{cases}$$

|| LHC profits from the HERA small-x enhancement $xg \sim x^{-\lambda}$

$N_{ch}(y=0)$ & LHC vs RHIC

Saturation models:

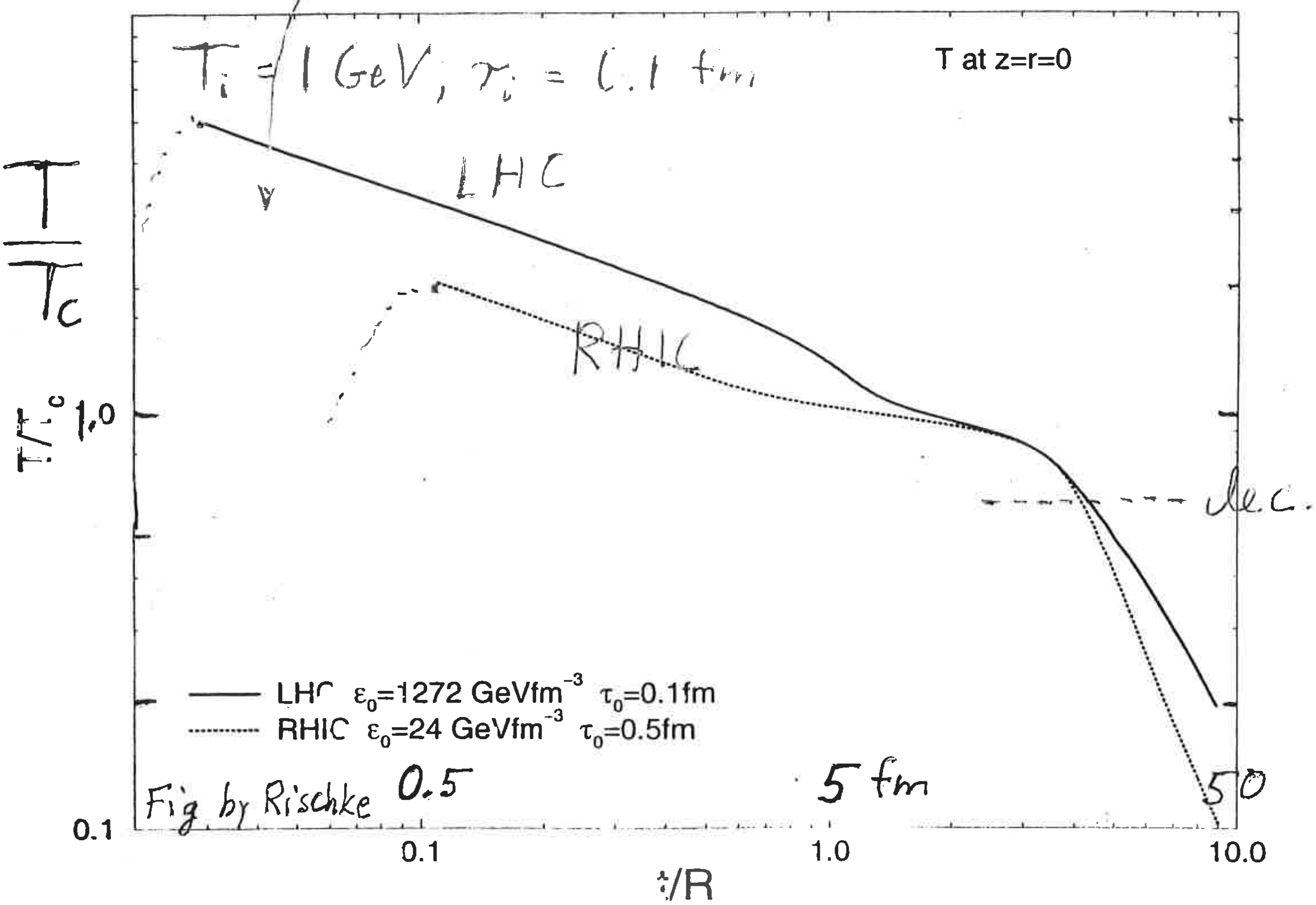
$N_{ch} \sim \sqrt{s}^{\,b} \cdot A$



A wide range of predictions!

Further evolution *if* ideal expansion:

- more "hard probes" at LHC
  "non-equil. signals"



- if late thermalisation, one has to hit the same curve

- RHIC & LHC may be very similar at decoupling at $z=0$, but **different earlier!**

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to BNL 6/04

An immense amount of interesting A+A data can be collected,

but the real goal is

Identify a "new phase of matter", quark-gluon plasma (thermalised - nearly, at least) and measure its properties:

- EOS $p(T, \mu ; T_c)$
- dynamic response; spectrum

Calculable from 1st principles:

EOS

$$e^{P(T)\frac{V}{T}} = \int \mathcal{D}A_\mu^a \, \mathcal{D}\bar{\psi} \, \mathcal{D}\psi \; e^{-\frac{1}{\hbar}\int_0^{1/T} d\tau \, d^3x \, \mathcal{L}_E(A,\psi)}$$

No external currents, parameters

$$p(T, \mu=0, T_c) \qquad T_c \approx \# \cdot \Lambda_{QCD}$$

Euclidian $\Rightarrow$ Lattice MC

Genuine prediction!

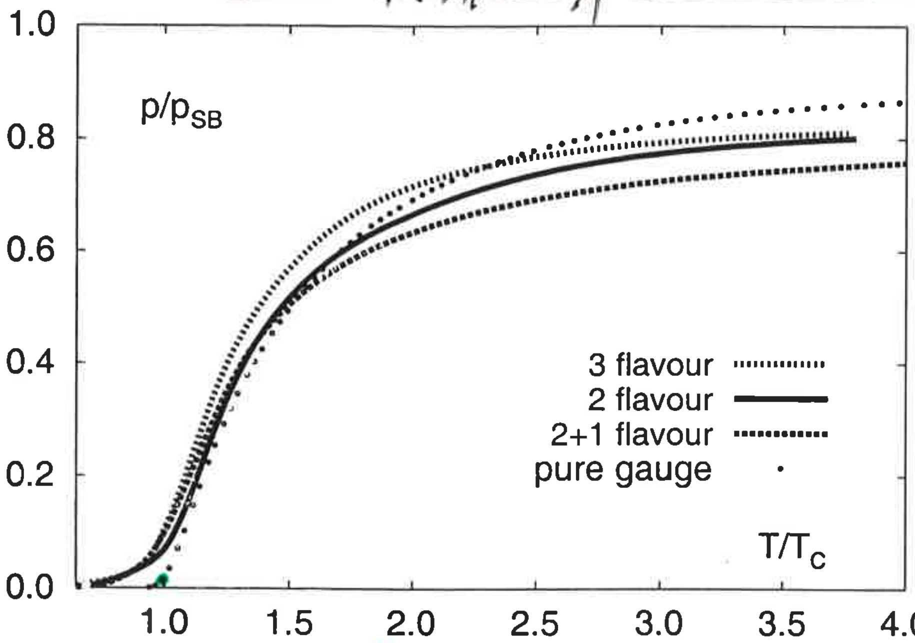
Need nothing but $\mathcal{L}_{QCD}$!

EOS: $p(T, \Lambda_{QCD}) = T^4 f\left(\frac{T}{T_c}\right)$

dofs = interacting q, g

dofs = ?

RHIC → LHC?



α_s: 0.43, 0.30, 0.26, 0.23 ← $\alpha_s = \dfrac{4\pi}{18 \ln 5 \frac{T}{T_c}}$

g → 2.3, 1.9, 1.8, 1.7

↑ Discontinuity in $p'(T_c)$? N_f-dependence!

crucial!

- Our field is mature only after we see exp error bars in this fig!
- Theory precedes exp by $\gtrsim \frac{1}{4}$ century!

Thermalisation

- RHIC data tells that there is early pressure $\quad 16 + \frac{21}{2} N_f$

- Weak coupling computations:

$$\lambda_{free} \sim \frac{1}{n\sigma} \sim \frac{1}{\alpha_s^2} \frac{1}{T} \quad \text{BIG}$$

$\Rightarrow$ free streaming, no pressure

$\Rightarrow$ weak coupling does not apply (not surprising!) $\quad g_W = \frac{2}{3} \lll g_s = 2$

[[But what instead?]] $\quad e^{-1/2\beta_0 g^2}$

$\Lambda \sim 10^8 m \quad 10^{-15} m$

Related (physical, measurable) example:

viscosity η

Eff. theory of t-dep phenomena:
kinetic theory.

⇒ viscosity 1984-

$$\eta = \# \frac{T^3}{g^4 \log \frac{\#}{g}} \left[1 + \mathcal{O}(g^2) \right]$$

$$\approx 10 T^3 \qquad \alpha_s \approx 0.3$$

big or small ?

$\eta \approx 10^{16} \eta_{air}$ but $\frac{\eta}{s} \approx \frac{\eta}{s}\Big|_{air}$!

need Reynolds!

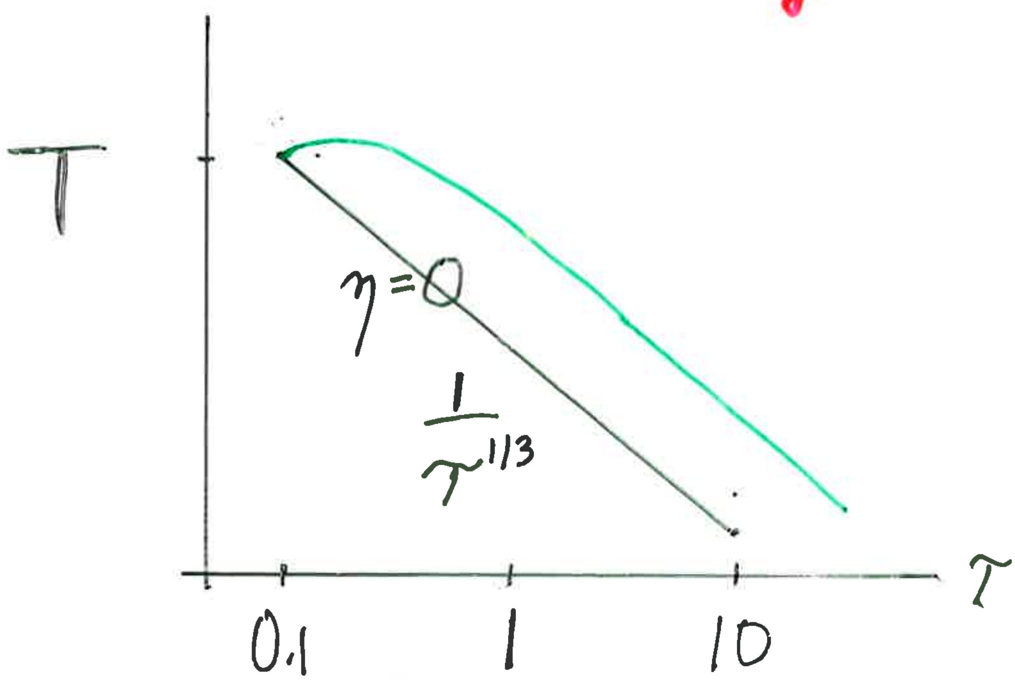
Ideal bj flow + η:

$$\frac{d\varepsilon}{d\tau} + \left(1+\frac{1}{3}\right)\frac{\varepsilon}{\tau} - \frac{\frac{4}{3}\eta}{\tau^2} = 0$$

$$Re = \frac{\varepsilon/T^4}{\eta/T^3} \cdot T\tau \lesssim 1 \quad \text{at } \tau_i$$

$$\approx \frac{4}{10}$$

$\eta_{g^2 \ll 1}$ is "big"



Perturbative computations incompatible with thermalisation, seen explly! (NOT for $q\bar{q}$!)

v_2 jets

After LHC?

- project completed, pack up and do something else

  (entirely respectable)

- invent some other way to explly/ observationally study QCD matter

Conclusions

- LHC will (due to $xg \sim x^{-\lambda}$) be a much more efficient plasma generator than RHIC

SPS:	98% soft	2% hard
RHIC	50% "	50% "
LHC	2% "	98% "

  ⇒ under better {theoretical / experimental} control

- Great open question: thermalisation

- The remarkable flow of data from RHIC should not deviate attention from constructing ALICE/LHC