QCD Jet Quenching

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plan

Plan:

- Why Nuclei?
- LPM suppression
- Quenching

Piercing the Wall

QCD wall of our ignorance is still stone solid.

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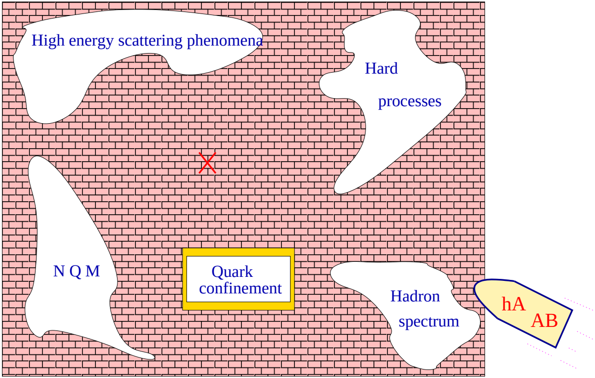

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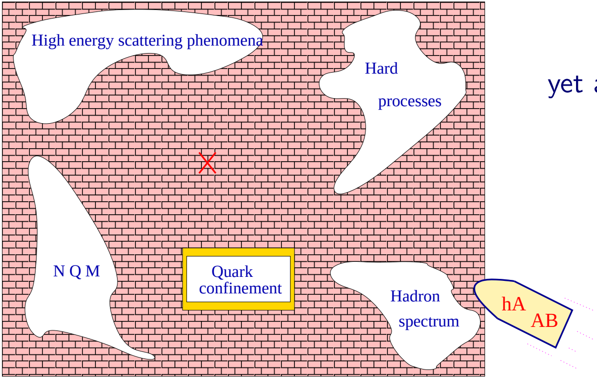

yet another brick in the wall

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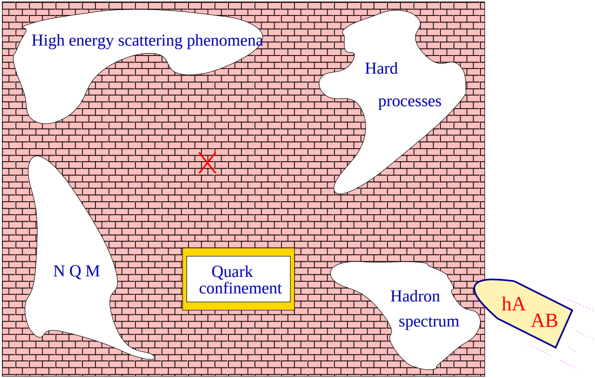

The Hope:

Clarity out of Mess

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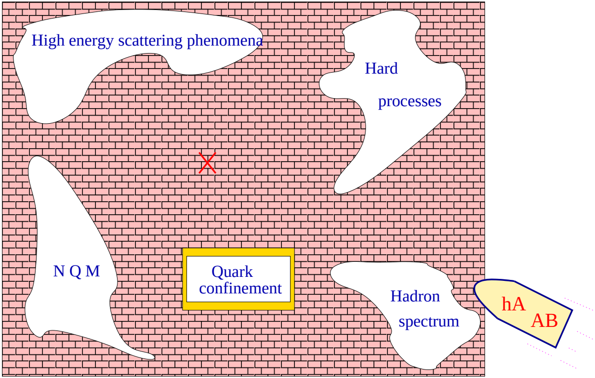

The Hope:

Clarity out of Mess

again . . .

Heavy Ions, Small distances and Jets

QCD speaks incoherently: it mutters and stutters.

Those looking for Confinement hide behind *bars* (e.g. $48 \times (24)^3$)

(Asymptotic) Freedom lovers wander around, wondering . . .

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A new hope: **experimental**

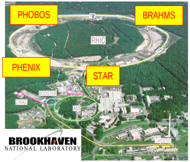
Relativistic Heavy-Ion Collider (RHIC) @ BNL

Specifications:

- 3.83 km circumference
- 2 independent rings:
  - 120 bunches/ring
  - 106 ns crossing time
- **A + A collisions @ $\sqrt{s}$ = 200 GeV**
- Luminosity: $2\cdot10^{26}$ cm^{-2} s^{-1} (~1.4 kHz)
- **p+p collisions @ 500 GeV**
- **p+A collisions @ 200 GeV**

4 experiments:
BRAHMS, PHENIX, PHOBOS, STAR

Run-1 (2000): **Au+Au @ 130 GeV**
Run-2 (2001-2): **Au+Au, p+p @ 200 GeV**
Run-3 (2002-3): **d+Au, p+p @ 200 GeV**



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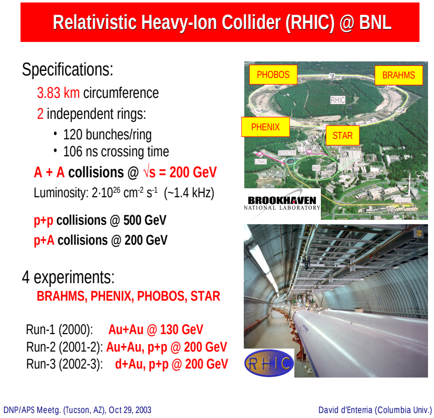

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- CGC $Q^2 \propto A^{1/3}$

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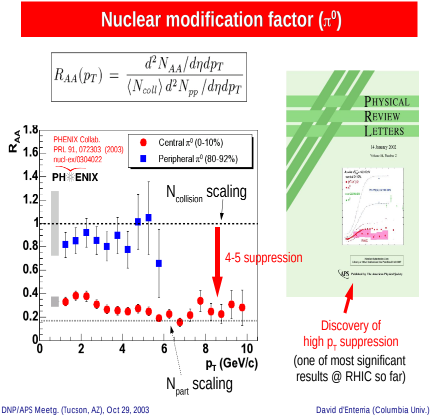

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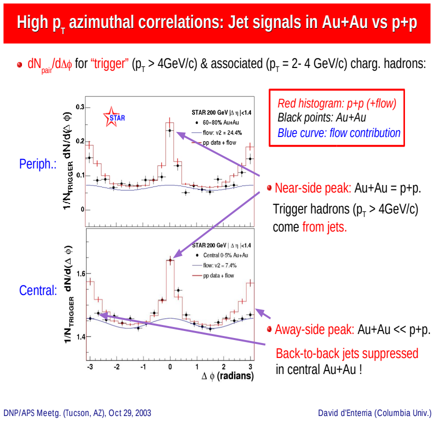

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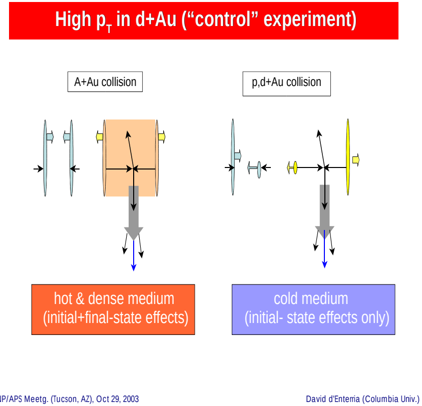

BUT :

in $d + A$ scattering

NOT ANYMORE

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HEP–HEN Interface

Historically, the nucleus has always been a primary source of inspiration for High Energy Particle (HEP) physics.

Gribov's paper "*Interaction of photons and electrons with nuclei at high energies*" laid a cornerstone for the concept of partons.

Diffractive phenomena in hadron-nucleus scattering, and inelastic diffraction in particular, make a nucleus serve as a *probe* of the internal structure of a hadron–projectile.

Rigorous applications of QCD to scattering in media are scarce, in the first place because of the complexity of the problems involved.

The *Landau-Pomeranchuk-Migdal effect* is an example of such an application which addresses the issue of QCD processes in media "*from the first principles*" (if such a notion can be applied to QCD in its state).

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LPM effect

is about radiation induced by multiple scattering of a projectile in a medium. In 1953 Landau and Pomeranchuk noticed that the energy spectrum of photons caused by propagation of a relativistic charge in a medium is essentially different from the Bethe-Heitler radiation pattern. A quantitative analysis of the problem was carried out by Arkady Migdal. Symbolically, the photon radiation intensity per unit length reads

$$\omega \frac{dI}{d\omega\, dz} \propto \frac{\alpha}{\lambda} \cdot \sqrt{\frac{\omega}{E^2} E_{LPM}}\,; \qquad \frac{\omega}{E} < \frac{E}{E_{LPM}}\,. \tag{1}$$

Here E is the energy of the projectile, and E_{LPM} is the energy parameter of the problem, built up of the quantities characterising the medium: the mean free path of the electron λ, and a typical momentum transfer in a single scattering μ :

$$E_{LPM} = \lambda\, \mu^2\,. \tag{2}$$

In QED the parameter $E_{LPM} \sim 10^4$ GeV, which explains why it took *four decades* to experimentally verify the LPM phenomenon (SLAC 1995).

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The LPM spectrum should be compared with the Bethe–Heitler formula

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— independent photon emission at each successive scattering act.
Contrary to BH, the LPM spectrum is free from an "infrared catastrophe": small photon frequencies are relatively suppressed, so that the energy distribution is proportional to $d\omega/\sqrt{\omega}$. Integrating over photon energy ($\omega < E$ in the $E \to \infty$ limit), one deduces the radiative energy loss per unit length to be proportional to $\sqrt{E}$,

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LPM on the back of envelope

"Brownian kicks" of the to-be-radiated gluon:

$$k_\perp^2 \simeq \mu^2 \cdot N_{coh} = \mu^2 \cdot \frac{t}{\lambda};$$

Gluon formation time:

$$t = \frac{\omega}{k_\perp^2}.$$

Equating the two expressions for t,

$$k_\perp^2 \simeq \sqrt{\frac{\omega\,\mu^2}{\lambda}}; \qquad t = \frac{\lambda\,k_\perp^2}{\mu^2}; \qquad N_{coh} = \frac{\omega}{\lambda\,\mu^2}.$$

Thus,

$$\frac{\omega\, dI}{d\omega\, dz} \propto \frac{\alpha_s}{\lambda} \cdot \frac{1}{N_{coh}} = \frac{\alpha_s}{\lambda}\sqrt{\frac{E_{LPM}}{\omega}}$$

Finite Medium

$$c\,t < L \implies \omega < \omega_{\max} = \frac{\mu^2}{\lambda} L^2$$

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Inclusive spectrum of medium-induced gluon radiation:

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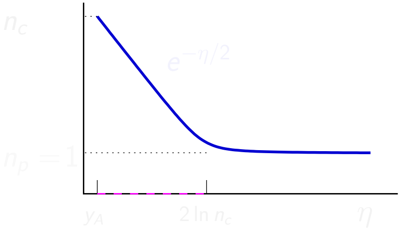

Coherent radiation = "Participant" scaling

Transition region, down to "Collision" scaling;
occupies finite rapidity range (fragmentation of the nucleus)

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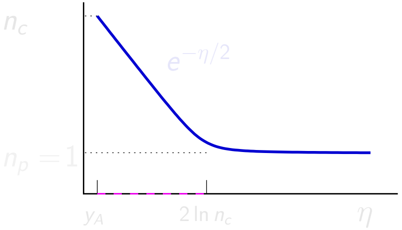
The Bethe-Heitler spectrum (radiation off each scattering centre)



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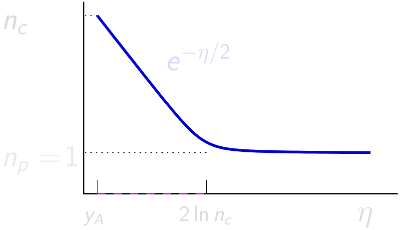

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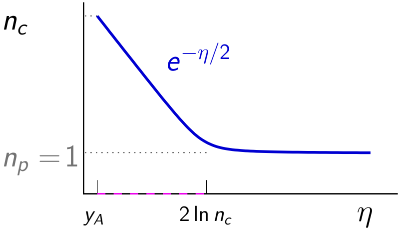

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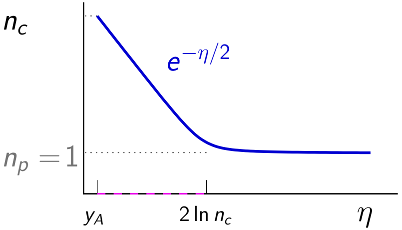

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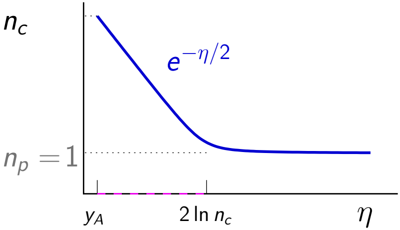

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transport coefficient

The only (non-perturbative) parameter of the problem, characterising the medium — transport coefficient

$$\hat{q} = \frac{\mu^2}{\lambda}$$

Hence, for L large enough stays under perturbative control !

To extract from experiment a *large* $\hat{q}$ — to observe a new "hot" state of quark–gluon matter as compared to a "cold" nucleus.

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Production of a particle / jet with large transverse momentum
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Main message:
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