Title: Undergraduate Talk

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URL: http://pirsa.org/10080024

Abstract:

Hydrodynamics and holography - modelling RHIC collisions

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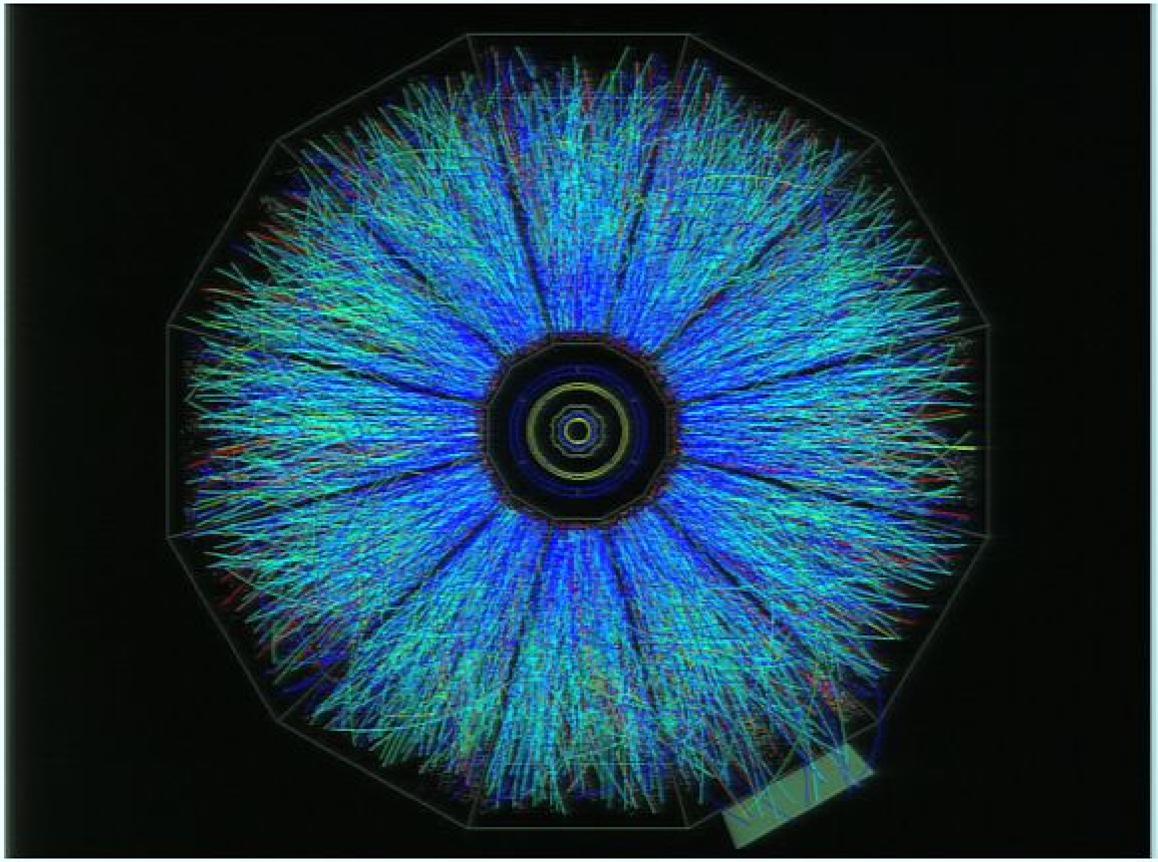
Summer Undergraduate Research Project
Perimeter Institute for Theoretical Physics

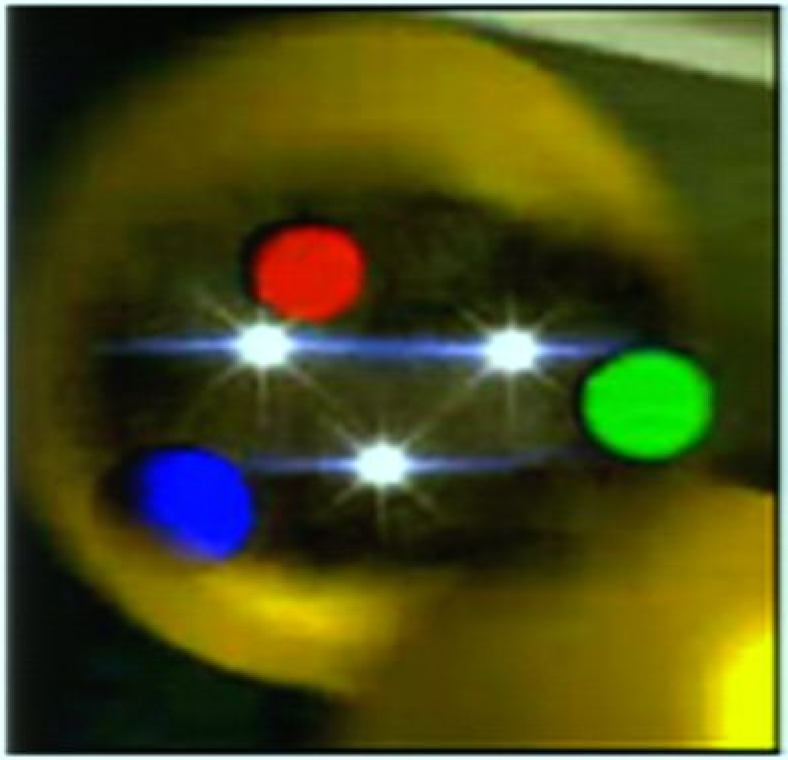
August 2010

Relativistic Heavy Ion Collider

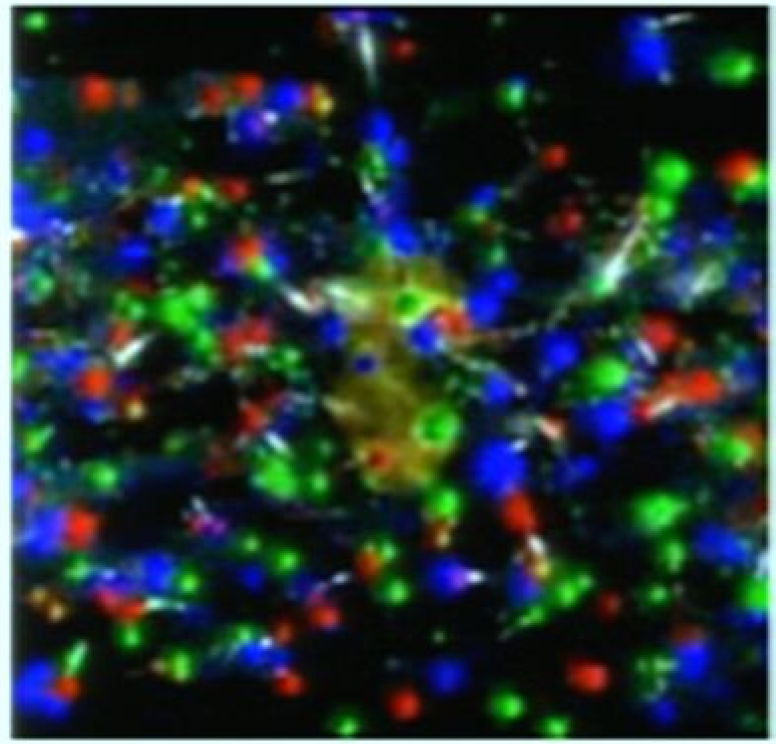
- Colliding two beams of heavy gold ions
- Center-of-mass energy per nucleon: ~100GeV
- 99.995% speed of light



Collision as pictured in STAR detector



Quarks and gluons confined



Quarks and gluons deconfined

Quantum Chromodynamics

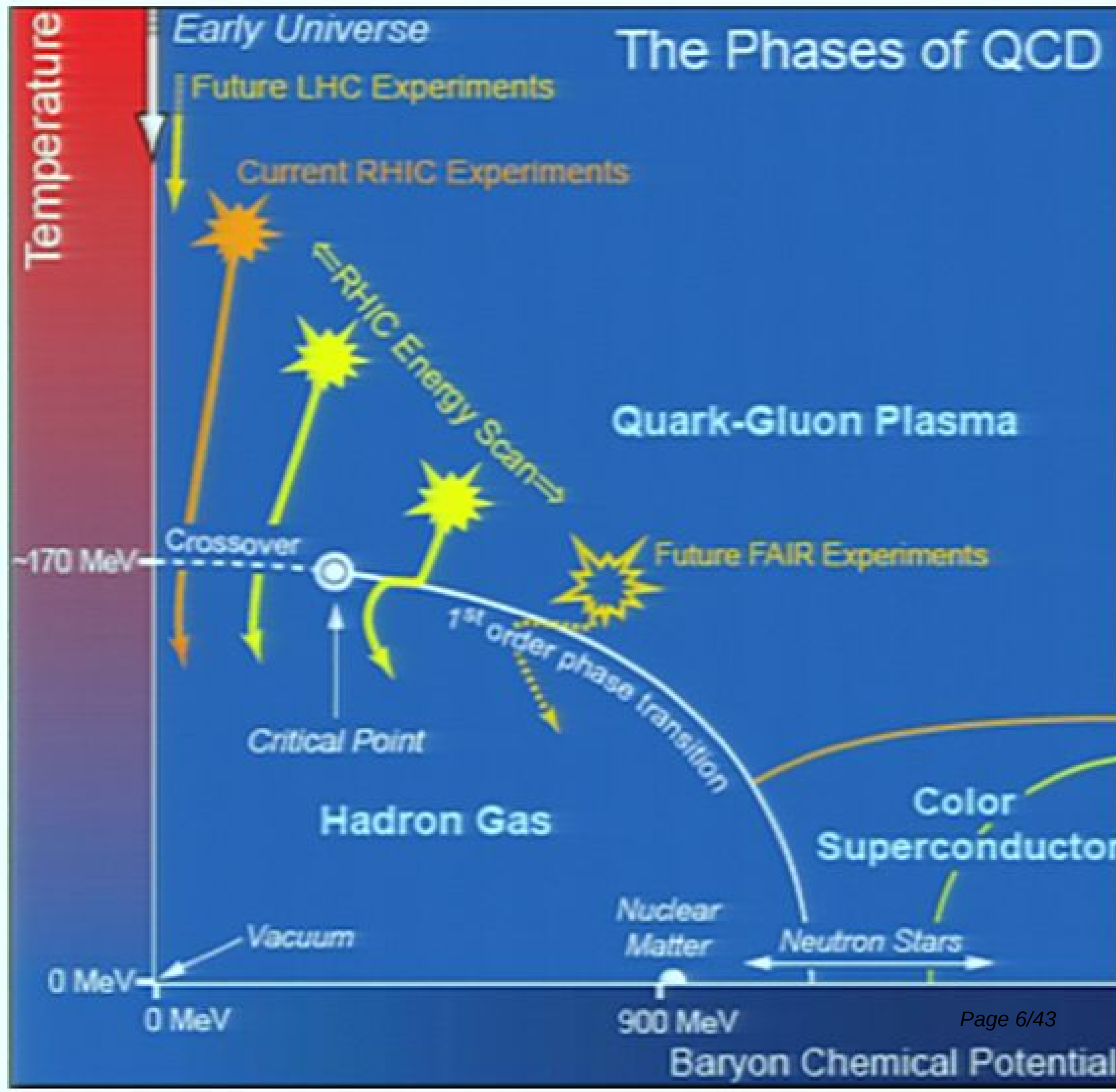
- Lagrangian for QCD: gluon and quark fields
- Free parameters : coupling constant g and quark masses

$$V(r) = -\frac{A(r)}{r} + Kr$$

- Potential for quark-antiquark separation

QCD phase transitions

- Asymptotic freedom (weak coupling for high-energy gluons)

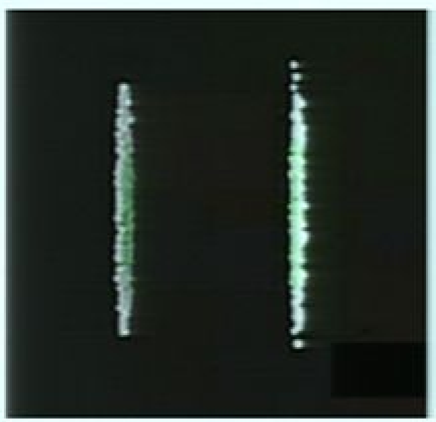


Quark-gluon plasma

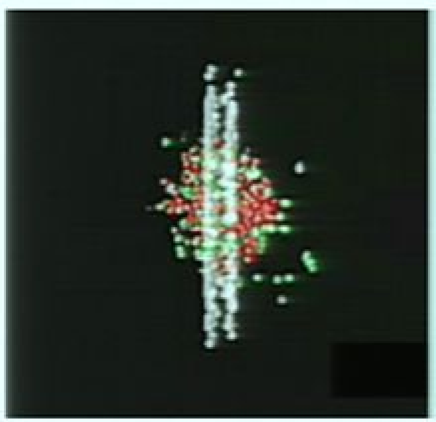
Quark and gluons no longer confined in hadrons

Reproducing conditions for first 10μs after Big Bang

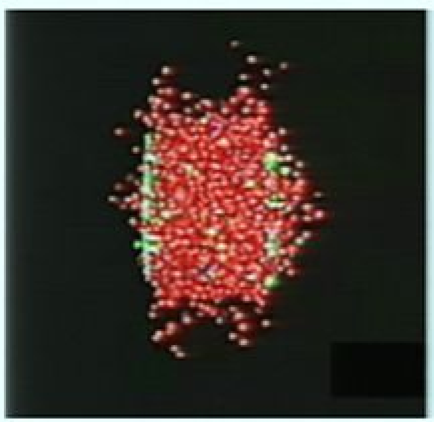
Hadronization after 10^{-18}μs



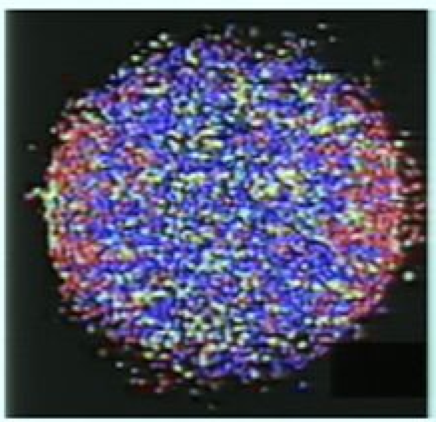
1. Ions about to collide*



2. Ion collision



3. Quarks, gluons freed



4. Plasma created

Gas vs. fluid

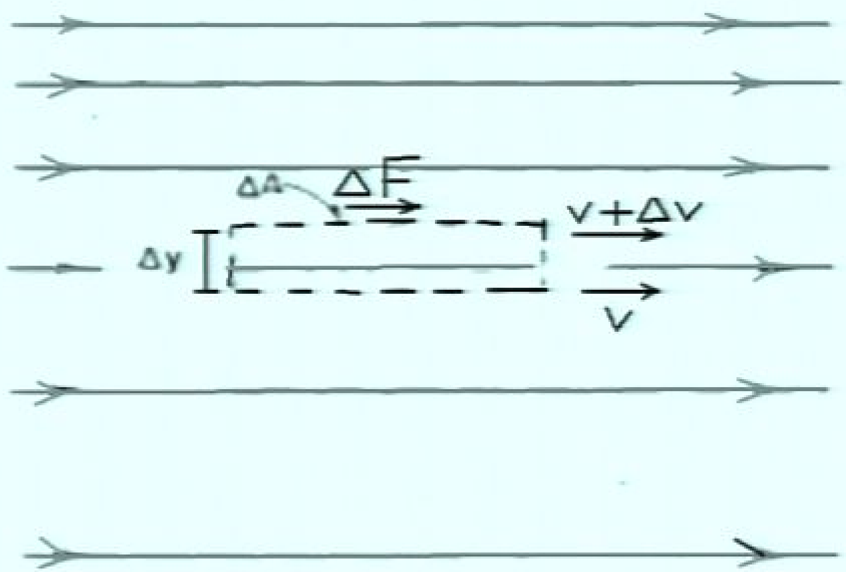
- Expectations: expanding ideal gas of non-interacting quark and gluons (approximation of weak coupling at high energies)
- Observed: collective motion, elliptical flow with distribution:

$$dn/d\phi \propto 1 + 2v_2(p_{\mathrm{T}}) \cos 2\phi$$

- Conclusion: QGP behaves like a fluid

Not only a fluid but a perfect fluid

- Ideal fluid: entropy conserved, no viscosity
- Real life fluids: always some viscosity
- Quark gluon plasma – very low shear viscosity



$$\frac{F}{A} = \eta \nabla_y v_x$$

Shear stress appears with a velocity gradient

Not only a liquid but a superliquid

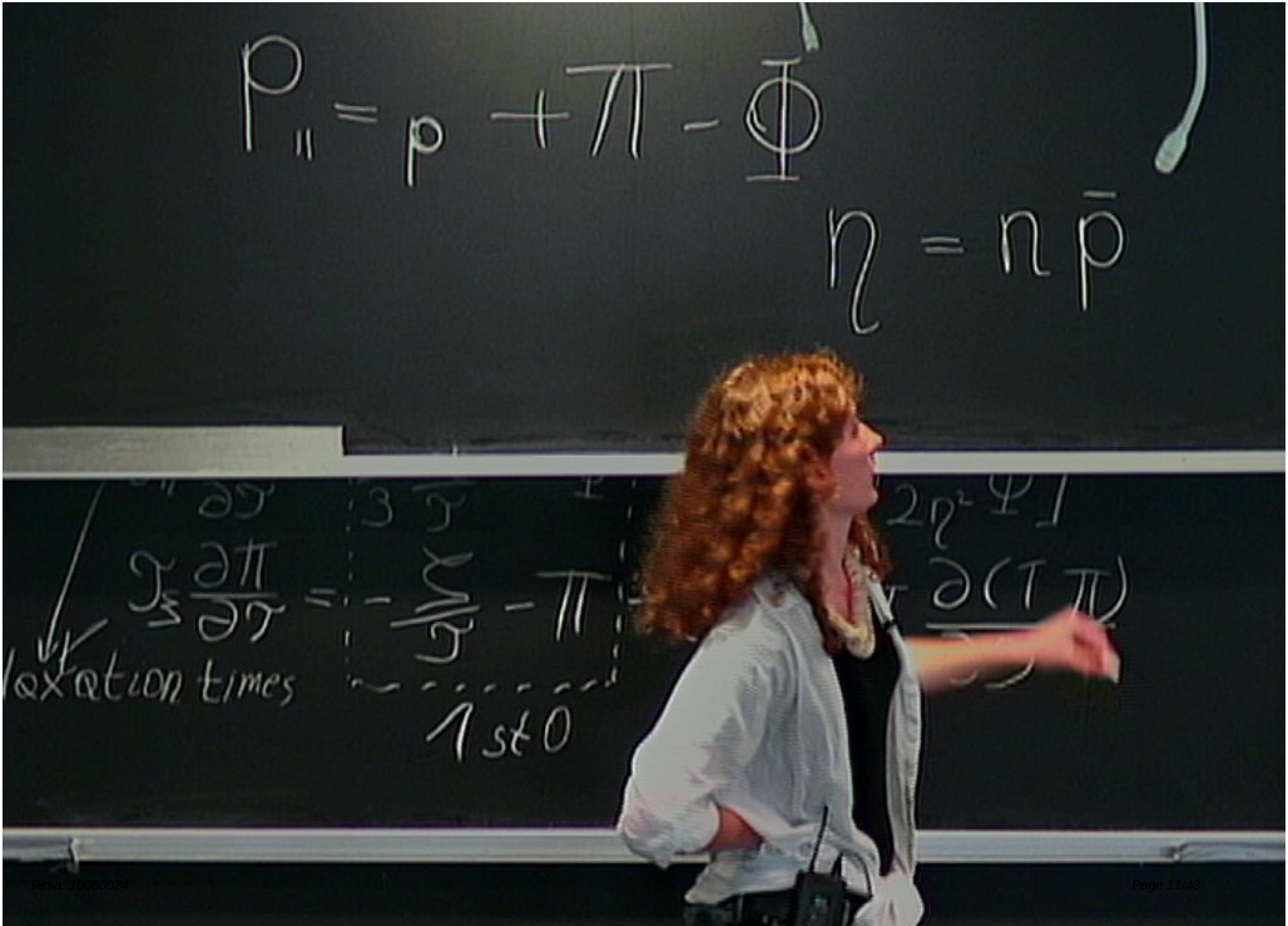
- Theoretical lower bounds on shear viscosity
- Estimation – transport theory and uncertainty principle:

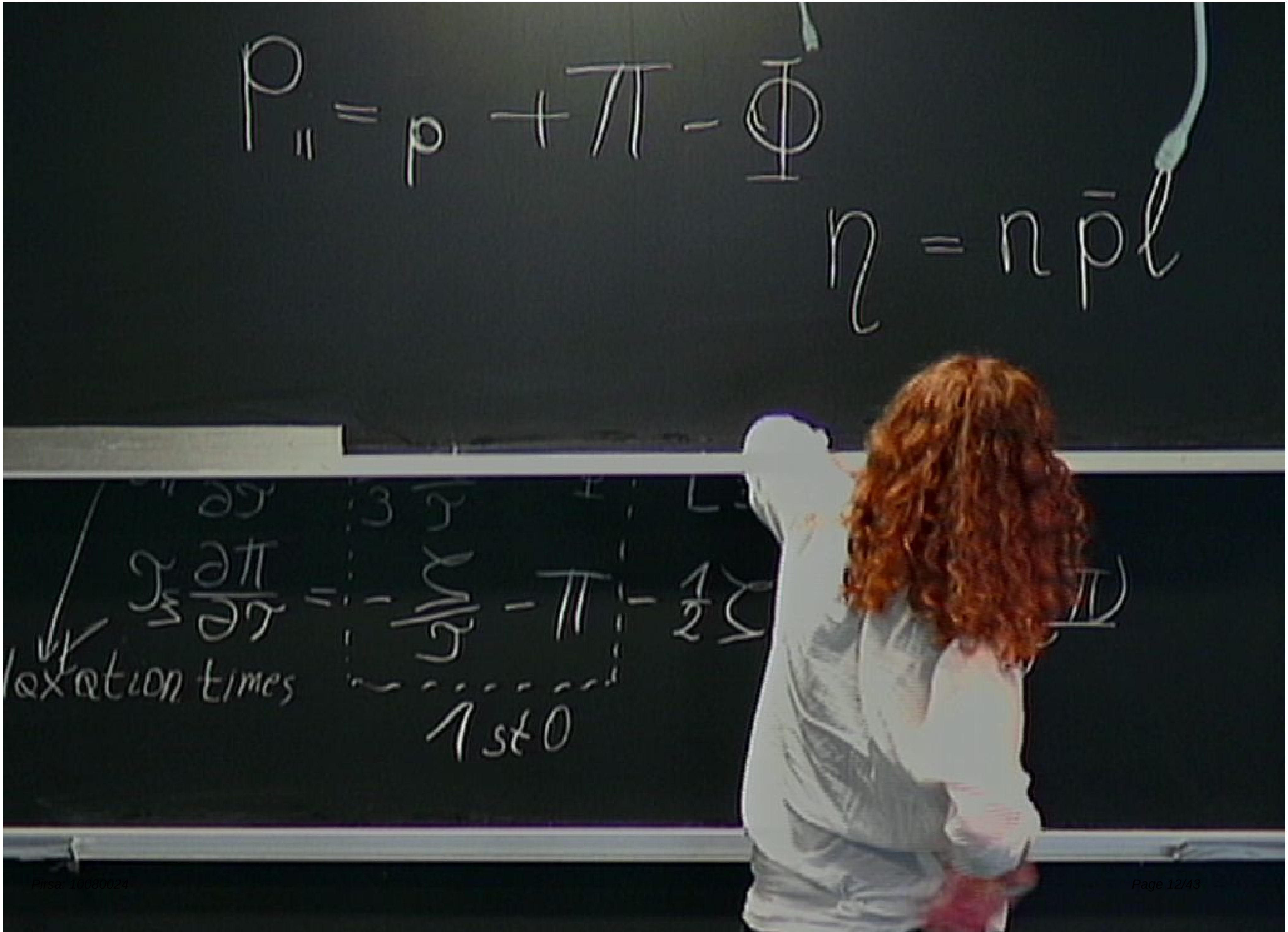
$$\eta / s \sim \hbar / k_B$$

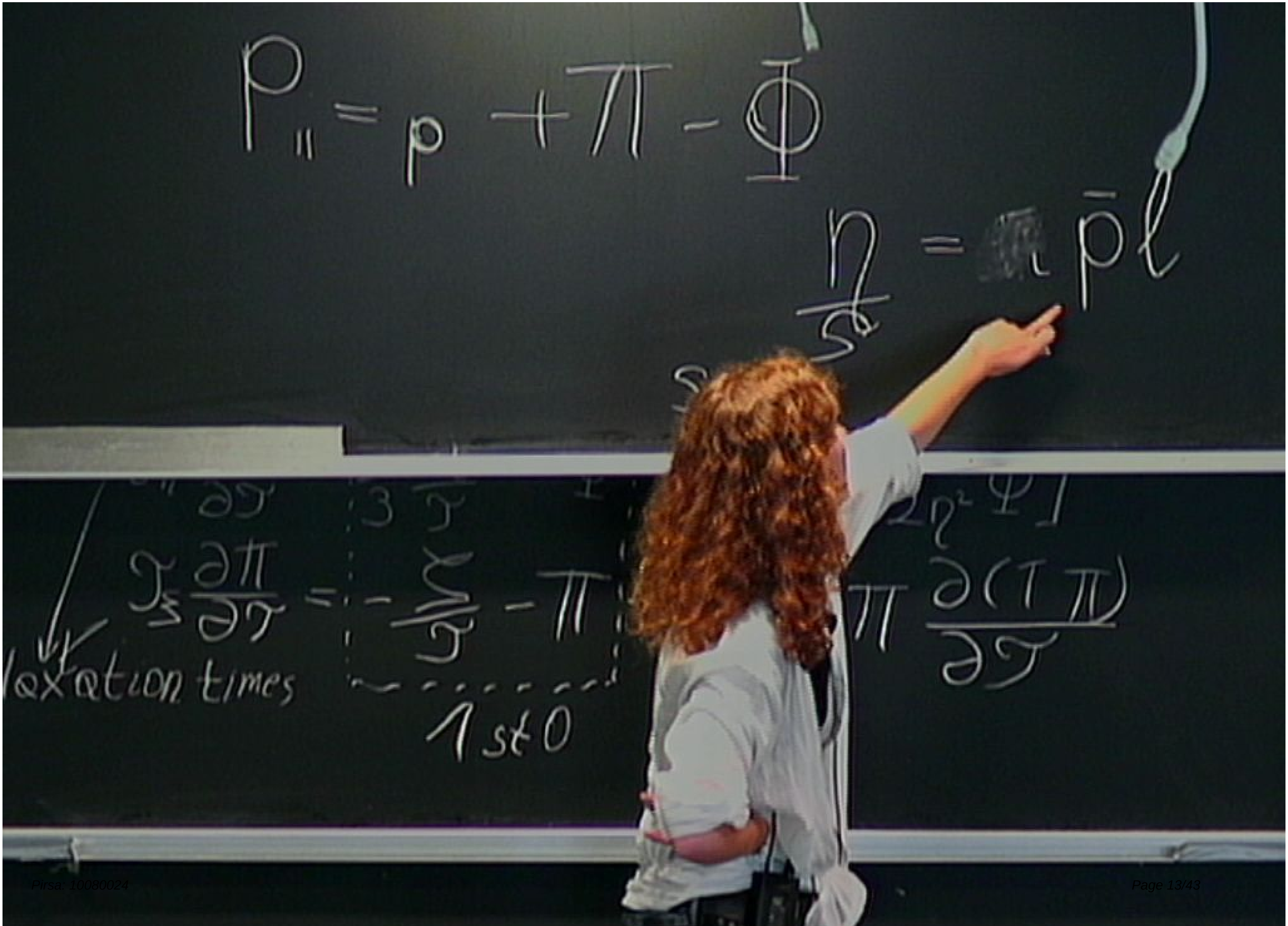
- AdS/CFT correspondence (x<1?):

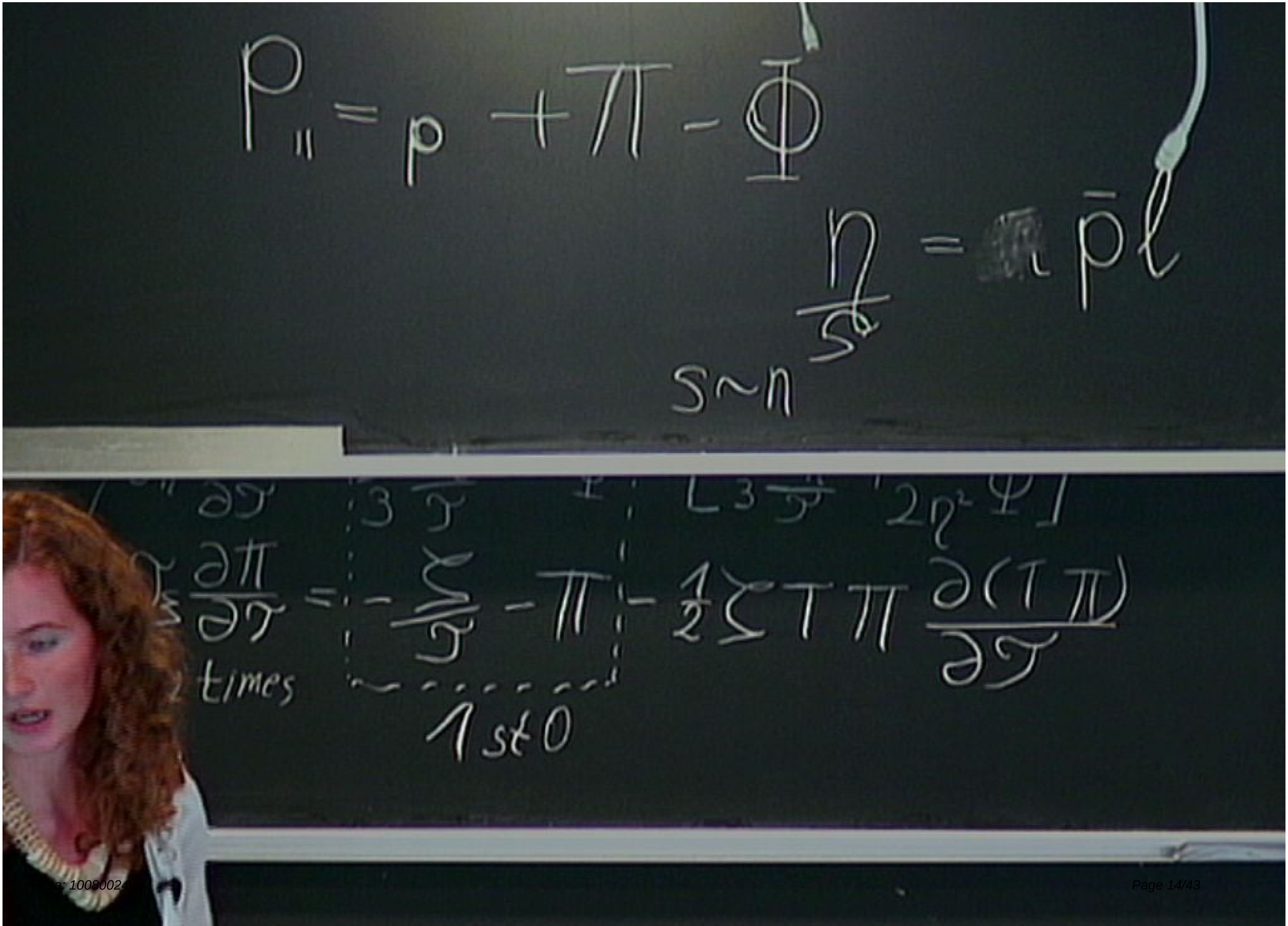
$$\eta / s \geq x \hbar / (4\pi k_B)$$

- Viscosity @ RHIC: same order of magnitude!


$P_{\parallel} = p + \Pi - \Phi$
$\eta = n\bar{p}$
laxation times
1st O


P∥ = p + Π − Φ
η = n p̄ ℓ
laxation times
1st O


$P_{11} = p + \Pi - \Phi$
laxation times
1st O


$P_{\parallel} = p + \Pi - \Phi$
$\eta = \bar{p}\ell$
$s \sim n$
$\frac{\partial \pi}{\partial \tau} = -\frac{\xi}{\tau} - \pi - \frac{1}{2}\xi \tau \pi \frac{\partial(\tau\pi)}{\partial \tau}$
times
1st O

Not only a liquid but a superliquid

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Relativistic hydrodynamics

- Energy momentum tensor:

$$T^{\mu\nu} = \varepsilon\, u^\mu\, u^\nu \, - p\, \Delta^{\mu\nu} + \Pi^{\mu\nu}$$

- Conservation of energy momentum tensor:

$$D_\mu T^{\mu\nu} = 0$$

- Viscous tensor (shear and bulk viscosity):

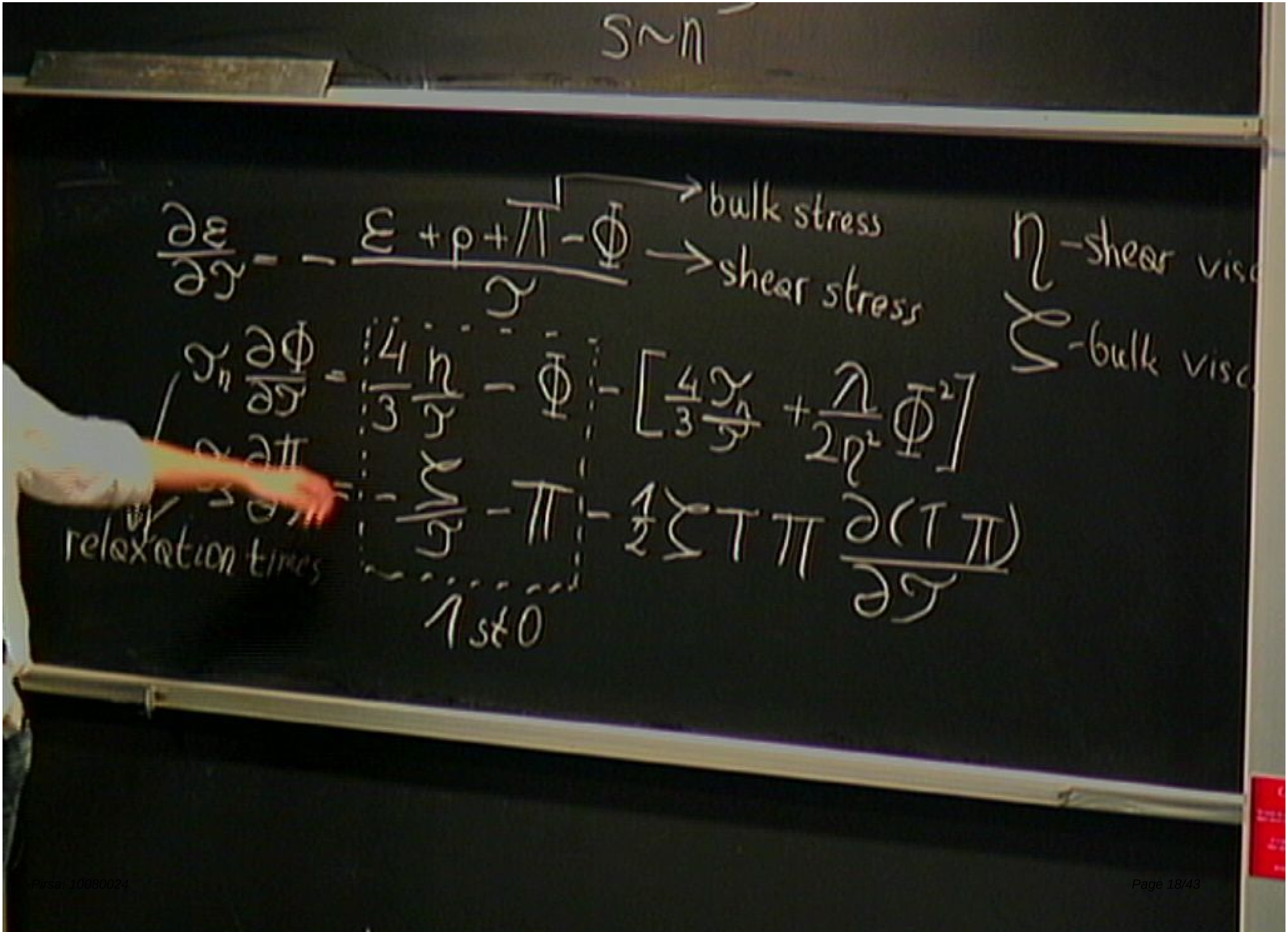
$$\pi^{\mu\nu} = \eta\sigma^{\mu\nu} - \tau_\pi^\eta \left(\langle D\pi^{\mu\nu} \rangle + \frac{4}{3}\pi^{\mu\nu}\nabla_\alpha u^\alpha \right) - \frac{\lambda_1}{2\eta^2}\pi_\alpha^{<\mu}\pi^{\nu>\alpha}$$

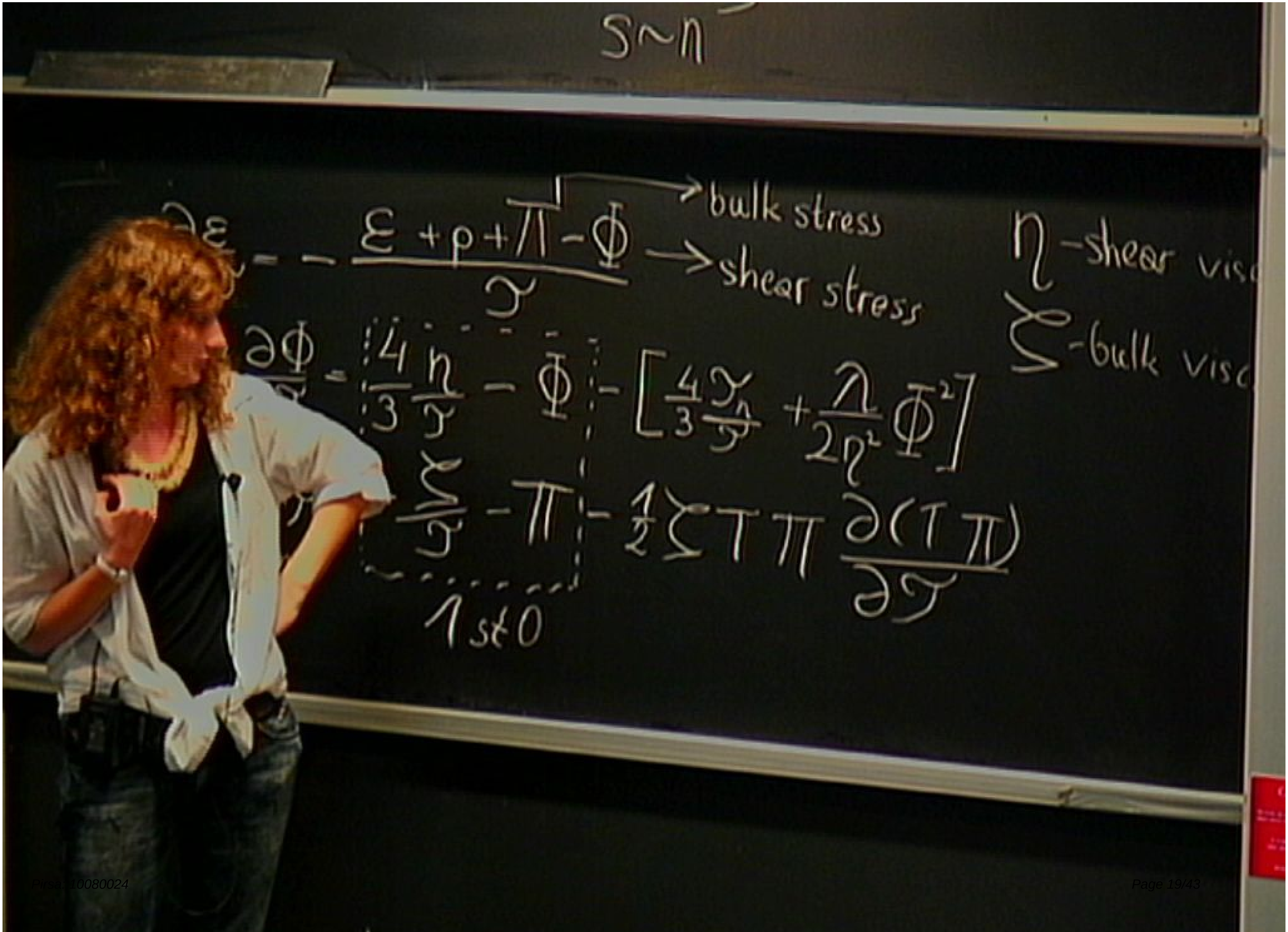
$$\tau_\Pi \dot{\Pi} + \Pi = -\zeta \bigtriangledown_\mu u^\mu - \frac{1}{2}\zeta T \Pi \partial_\mu \left(\frac{\tau_\Pi u^\mu}{\zeta T} \right)$$

What do we need?

- Equation of state – P[T], E[T]
- Transport coefficients – shear & bulk viscosity, further order terms:

  - Shear viscosity
  - Bulk viscosity
  - Relaxation times


s~η
bulk stress
shear stress
η - shear visc
ζ - bulk visc
$\frac{\partial \varepsilon}{\partial \tau} = -\frac{\varepsilon + p + \Pi - \Phi}{\tau}$
relaxation times
1st O


s~η
bulk stress
shear stress
η -shear visc
ζ -bulk visc
1st O

$s \sim \eta$

$$\frac{\partial \varepsilon}{\partial \tau} = -\frac{\varepsilon + p + \Pi - \Phi}{\tau}$$

Π → bulk stress

Φ → shear stress

η - shear visc

ζ - bulk visc

$$\tau_\eta \frac{\partial \Phi}{\partial \tau} = \frac{4}{3}\frac{\eta}{\tau} - \Phi - \left[\frac{4}{3}\frac{\tau_\eta}{\tau} + \frac{\lambda}{2\eta^2}\Phi^2\right]$$

$$\tau_\zeta \frac{\partial \Pi}{\partial \tau} = -\frac{\zeta}{\tau} - \Pi - \frac{1}{2}\zeta T \Pi \frac{\partial (T\Pi)}{\partial \tau}$$

relaxation times

1st O

How can we get it?

- Lattice QCD calculations
- Phenomenological guesses
- Holographic principle (string theory): quantum gravity theories dual to QCD cousins:

○ N=4 Yang-Mills theory

○ N=2* Yang-Mills theory

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Cavitation

How can we get it?

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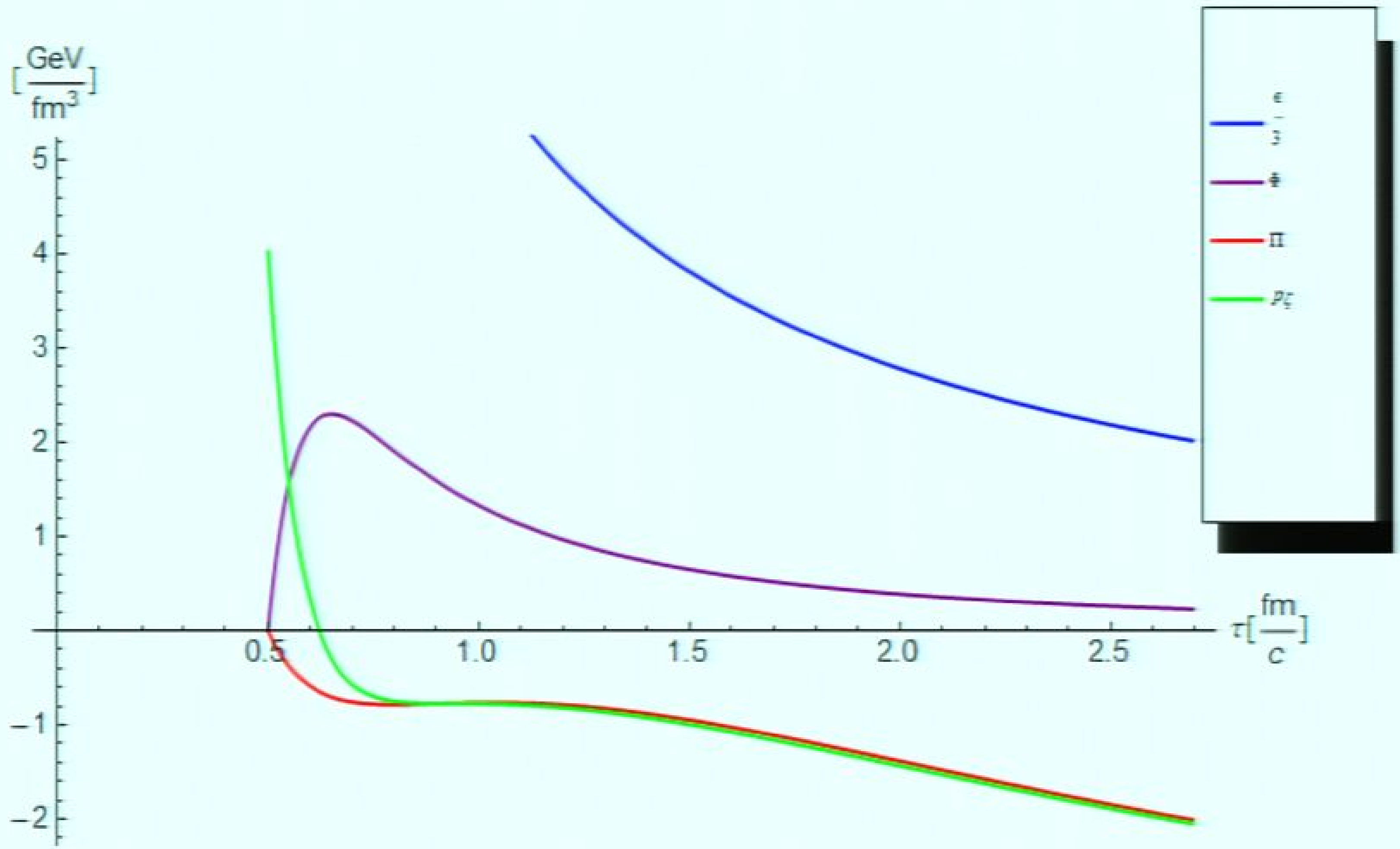
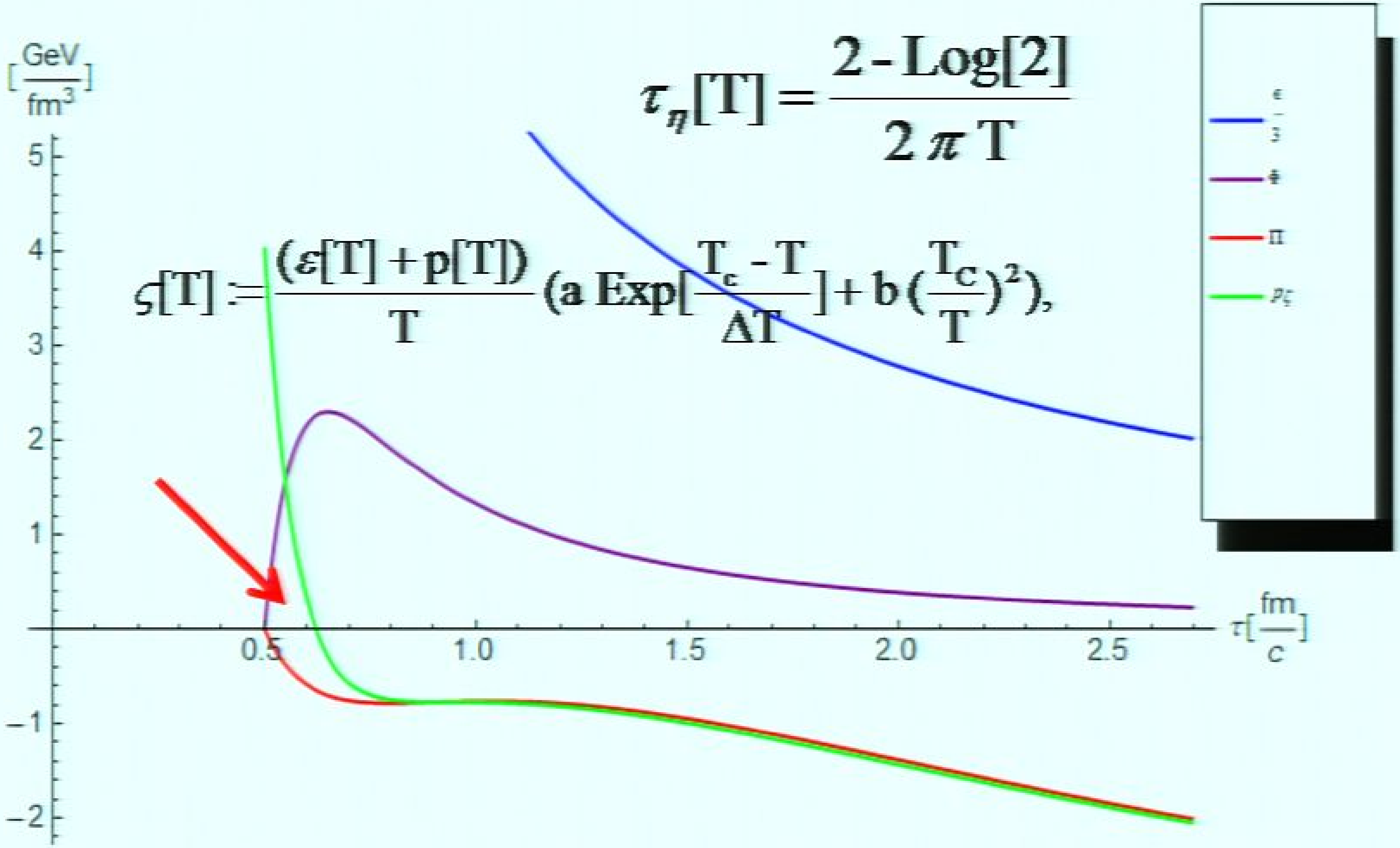
Cavitation



Example of cavitation in
Rajagopal&Tripuraneni's model

$$\frac{\eta}{s} = \frac{1}{4\pi}$$

$$\tau 1 = \tau 2 = \frac{2 - \mathrm{Log}2}{2\pi T}$$



$$\tau_\eta[T] = \frac{2 - \mathrm{Log}[2]}{2\pi T}$$

$$\varsigma[T] := \frac{(\varepsilon[T] + p[T])}{T}\left(a\,\mathrm{Exp}\left[\frac{T_c - T}{\Delta T}\right] + b\left(\frac{T_c}{T}\right)^2\right),$$

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$$\frac{\eta}{s} = \frac{1}{4\pi}$$

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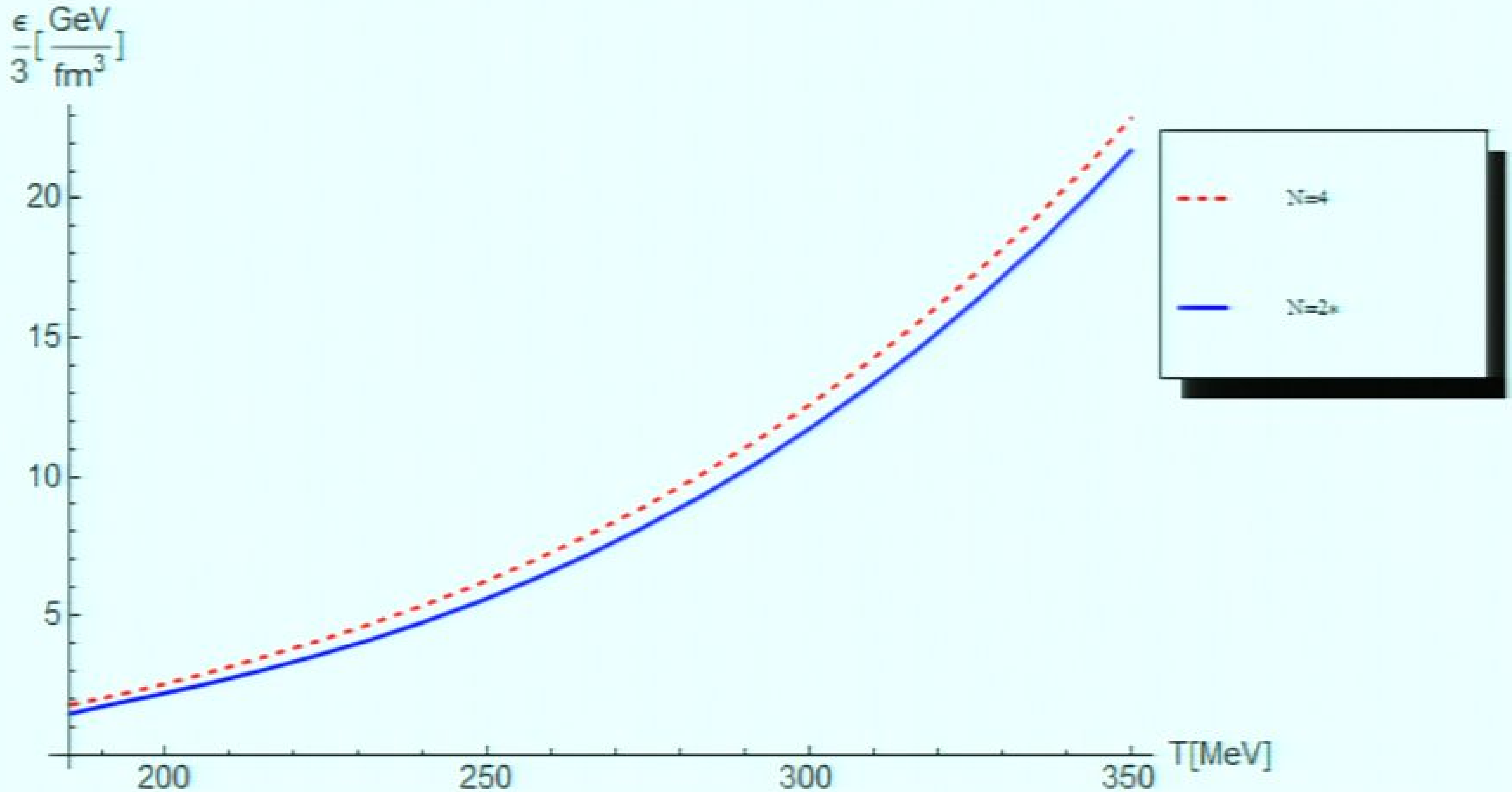
What do we dislike about the model?

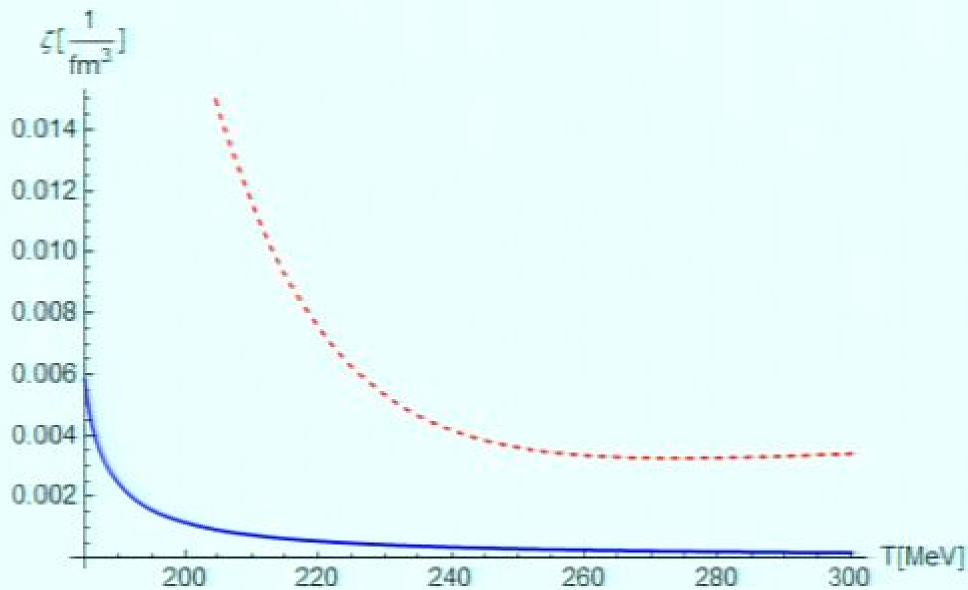
- N=4 Yang-Mills theory is conformal
- Introducing non-conformal bulk viscosity
- Guesses on bulk viscosity and relaxation time, from conformal model

Energy density

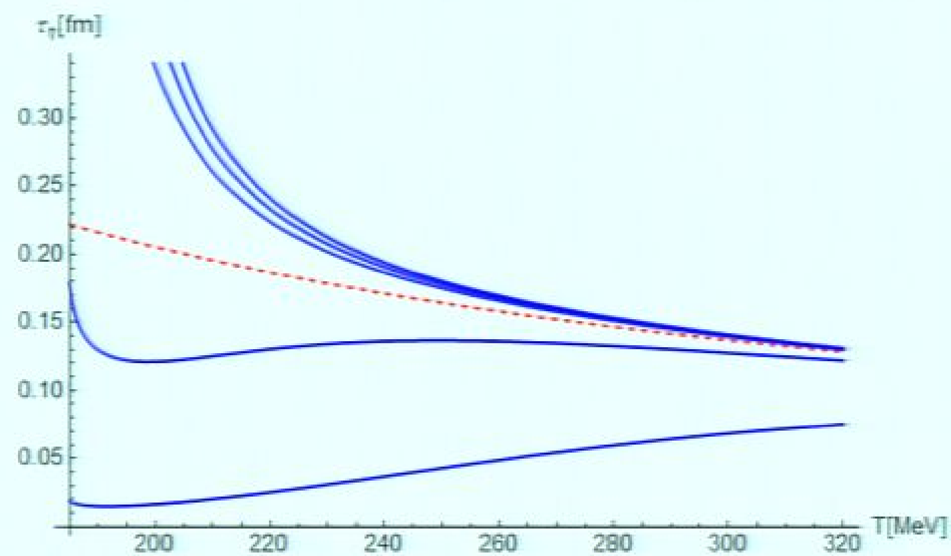


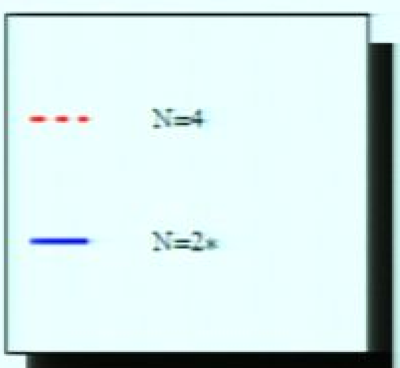
New model: N=2* (Buchel)

- Conformal
- Values for bulk viscosity ->



...and relaxation time ->





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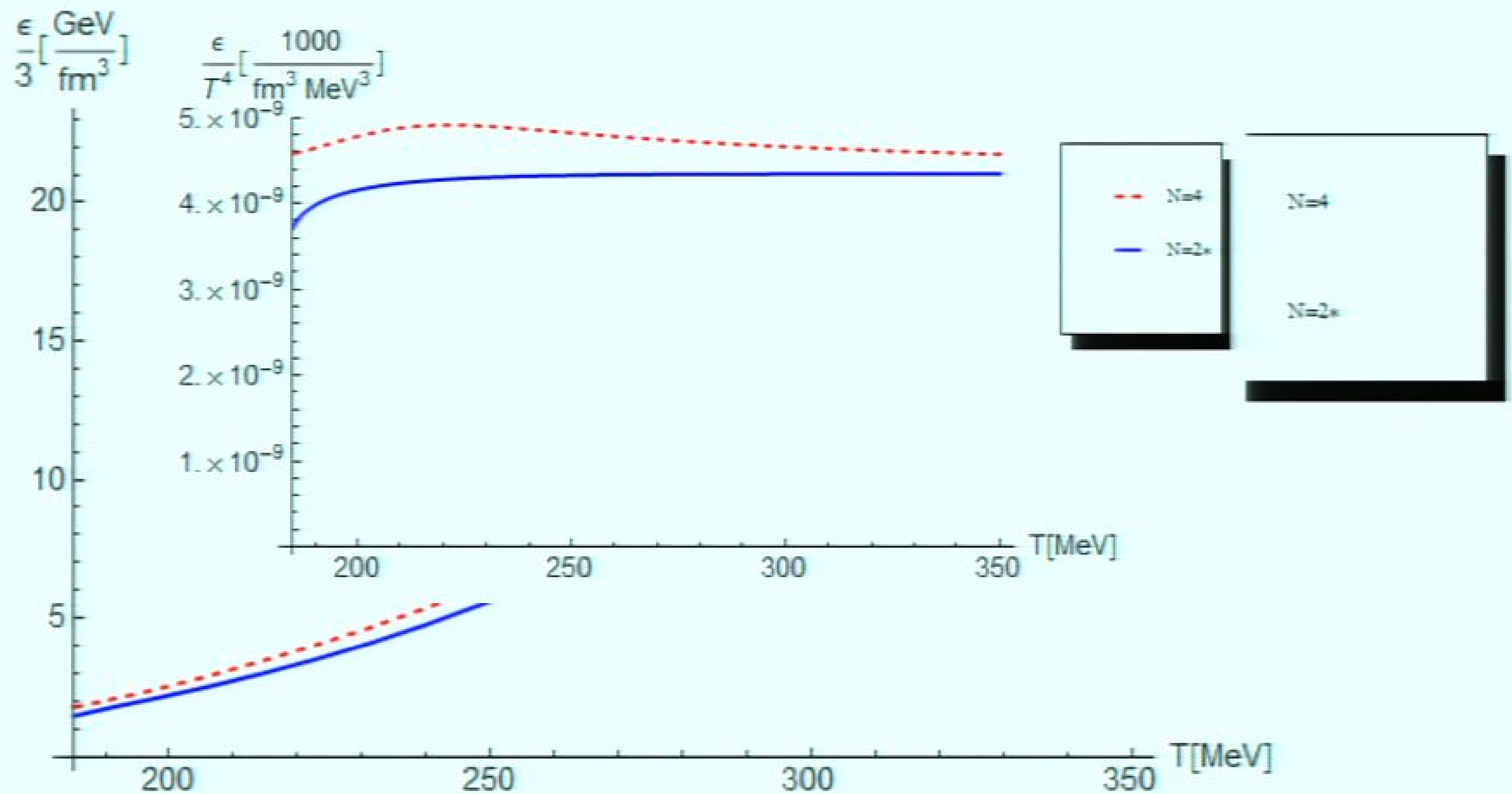
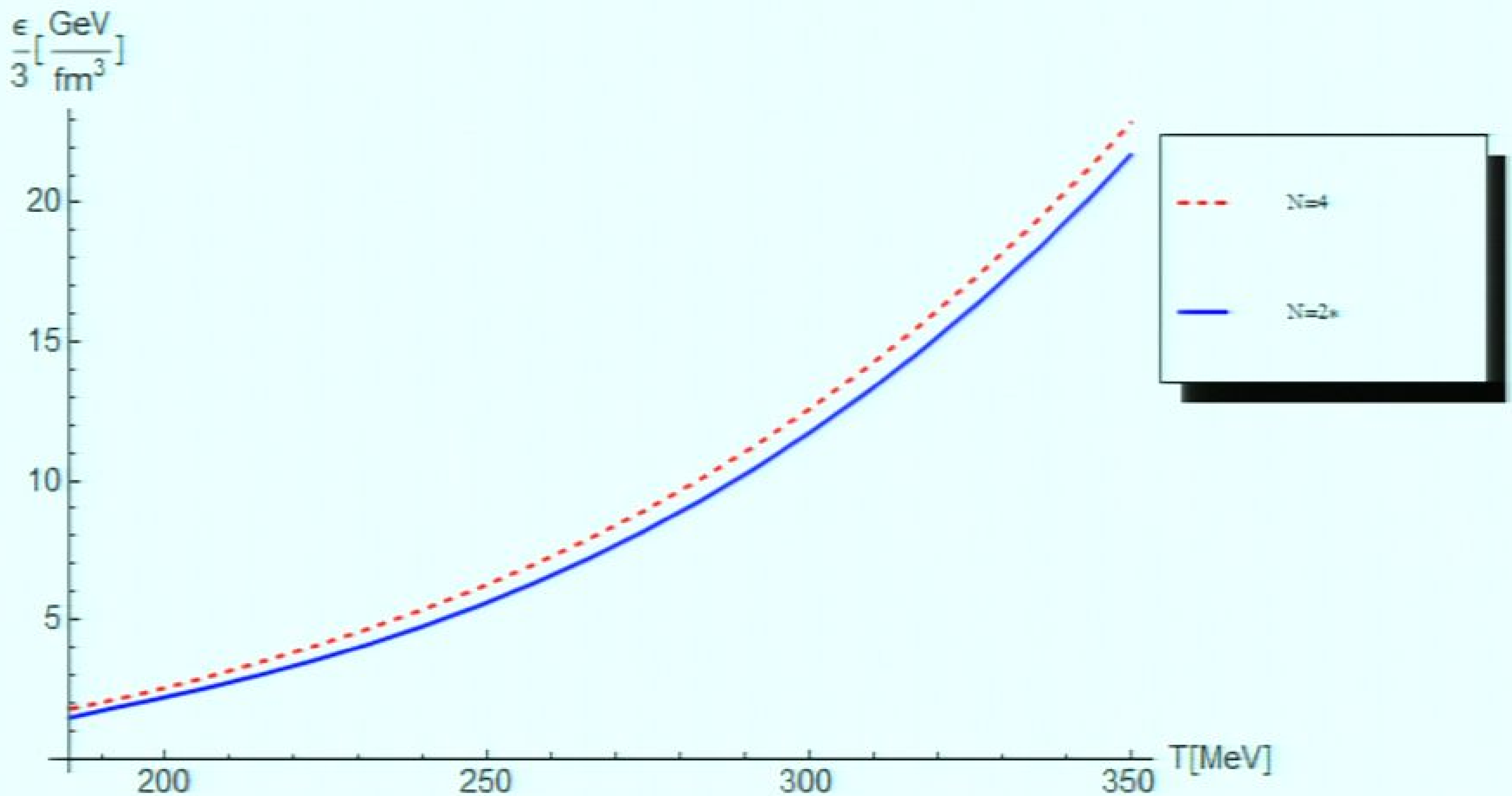


Energy density



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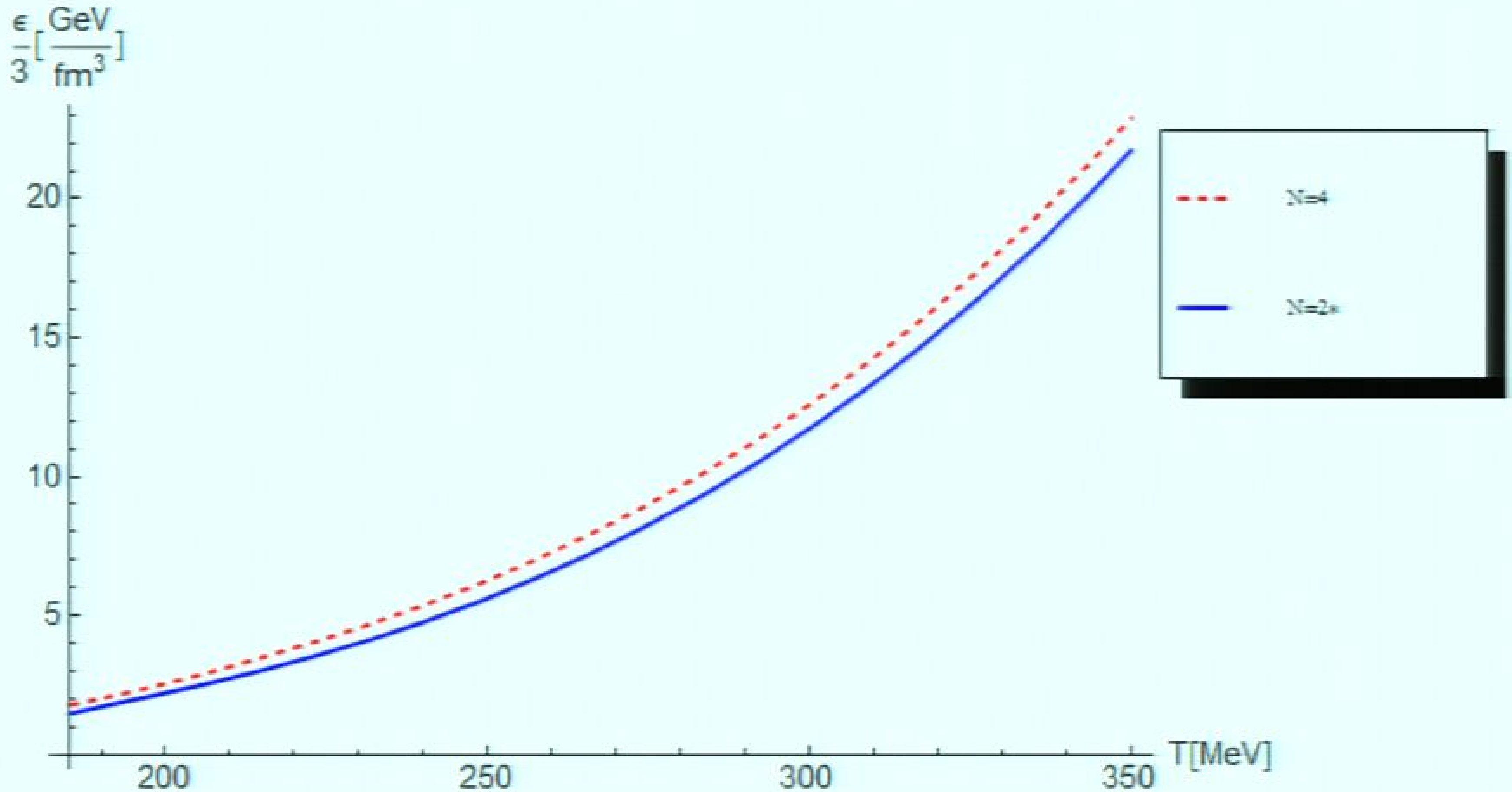

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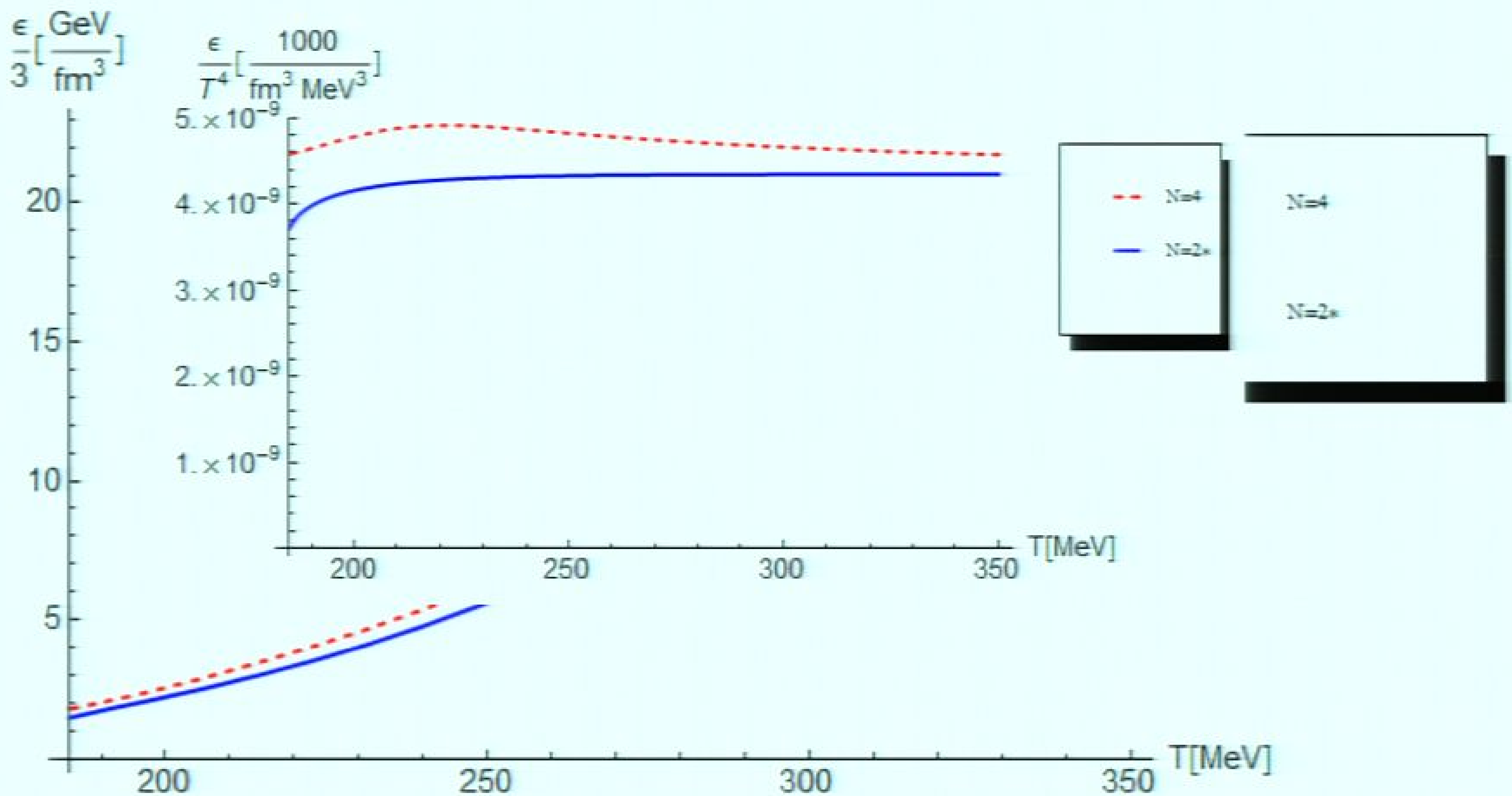
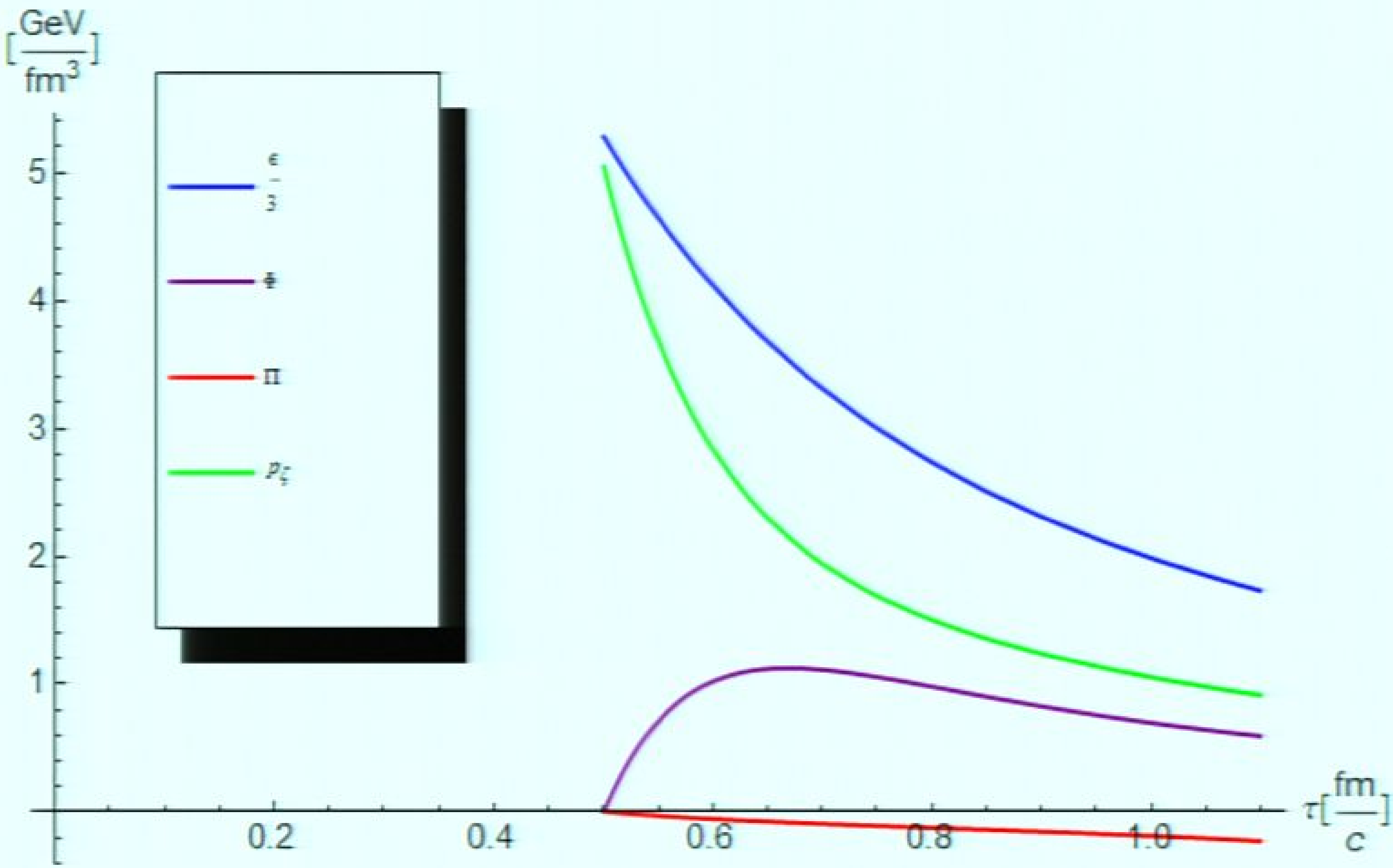




$$\frac{\eta}{s} = \frac{1}{4\pi}$$

$\tau 1 = \tau 2 = \tau\_effective$

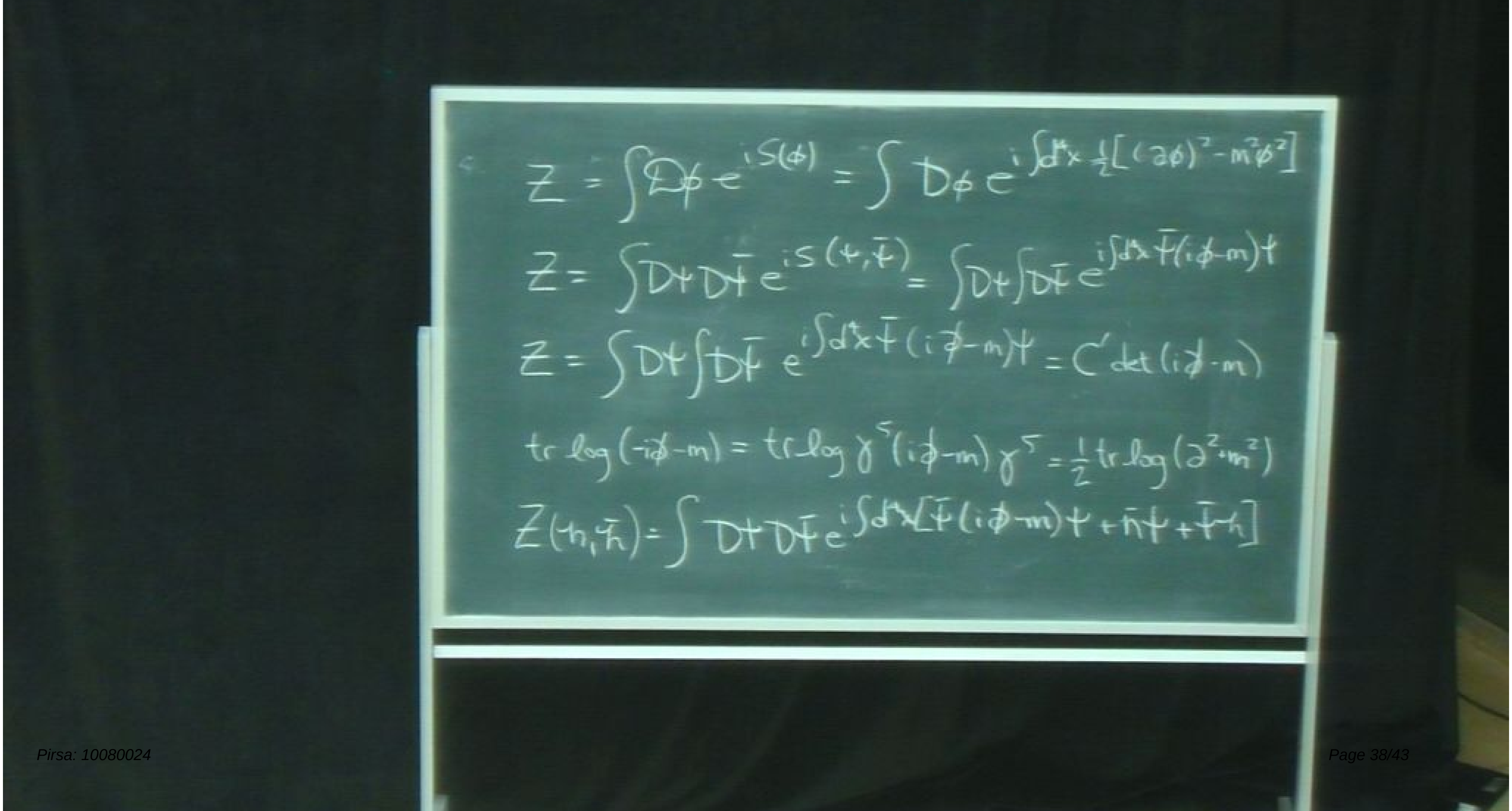
$Nc = 3$

Looking for cavitation with N=2*

Conclusions

- Cavitation – does not occur?
- What if it occurs just at T_c or BEFORE T_c?
- Need for developing the model

Thank you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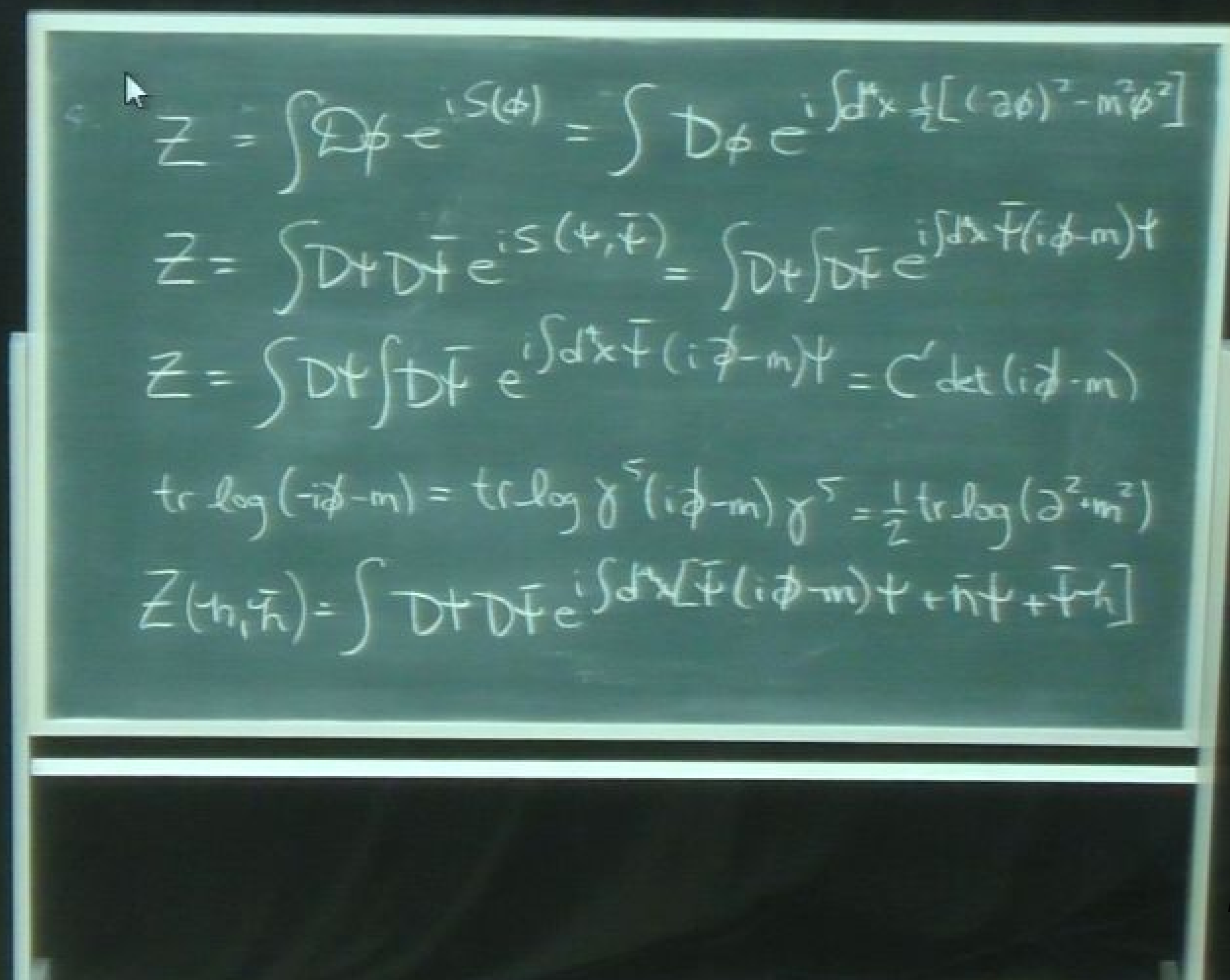
$Z = \int D\psi D\bar{\psi}\, e^{iS(\psi,\bar{\psi})} = \int D\psi \int D\bar{\psi}\, e^{i\int d^4x \bar{\psi}(i\partial\!\!\!/ - m)\psi}$
$Z = \int D\psi \int D\bar{\psi}\, e^{i\int d^4x \bar{\psi}(i\partial\!\!\!/ - m)\psi} = C' \det(i\partial\!\!\!/ - m)$
$\mathrm{tr}\log(-i\partial\!\!\!/ - m) = \mathrm{tr}\log \gamma^5(i\partial\!\!\!/ - m)\gamma^5 = \frac{1}{2}\mathrm{tr}\log(\partial^2 + m^2)$
$Z(\eta, \bar{\eta}) = \int D\psi D\bar{\psi}\, e^{i\int d^4x[\bar{\psi}(i\partial\!\!\!/ - m)\psi + \bar{\eta}\psi + \bar{\psi}\eta]}$

Sources

- *Evolution of Hot, Dissipative Quark Matter in Relativistic Nuclear Collisions* – Muronga, Rischke, 0407114 nucl-th
- *Relativistic Viscous Fluid Dynamics and Non-Equilibrium Entropy* – Romatschke, 0906.4787, hep-th
- *Bulk Viscosity and Cavitation in Boost-Invariant Hydrodynamic Expansion* – Rajagopal, Tripuraneni, 0908.1785 hep-ph
- http://www.bnl.gov/rhic/images.asp
- Buchel, Leblond, Sinha – paper?

Thank you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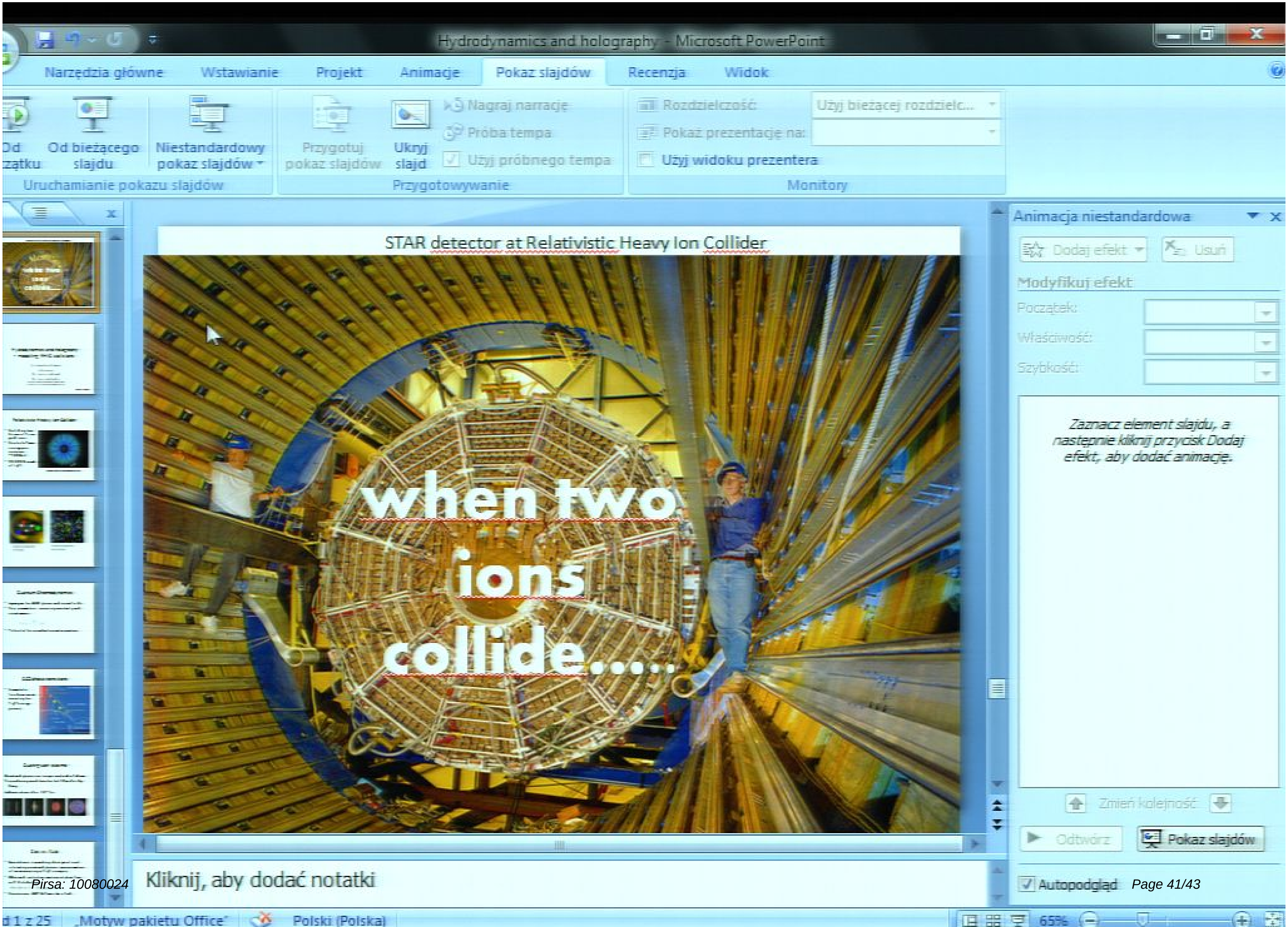
Hydrodynamics and holography - Microsoft PowerPoint
Narzędzia główne
Wstawianie
Projekt
Animacje
Pokaz slajdów
Recenzja
Widok
Od biezącego slajdu
Niestandardowy pokaz slajdów
Przygotuj pokaz slajdów
Ukryj slajd
Nagraj narrację
Próba tempa
Użyj próbnego tempa
Rozdzielczość:
Użyj bieżącej rozdzielc...
Pokaż prezentację na:
Użyj widoku prezentera
Uruchamianie pokazu slajdów
Przygotowywanie
Monitory
STAR detector at Relativistic Heavy Ion Collider
when two ions collide....
Animacja niestandardowa
Dodaj efekt
Usuń
Modyfikuj efekt
Początek:
Właściwość:
Szybkość:
Zaznacz element slajdu, a następnie kliknij przycisk Dodaj efekt, aby dodać animację.
Zmień kolejność
Odtwórz
Pokaz slajdów
Autopodgląd
Kliknij, aby dodać notatki
„Motyw pakietu Office"
Polski (Polska)
65%


WINAMP File Play Options View Help Go Pro
ouis - I Got Plenty O' Nuttin?
Title: I Got Plenty O' Nuttin?
Artist: Ella & Louis
Album: Porgy & Bess
Genre:
Rating:
edia Library Video Visualization Browser
Now Playing
Local Media
Audio
Video
Most Played
Recently Added
Recently Played
Never Played
Top Rated
Podcast Directory
Subscriptions
Portables
Bookmarks
History
Playlists
Online Services
SHOUTcast Radio
Winamp Charts
MetroLyrics
Winamp Add-ons
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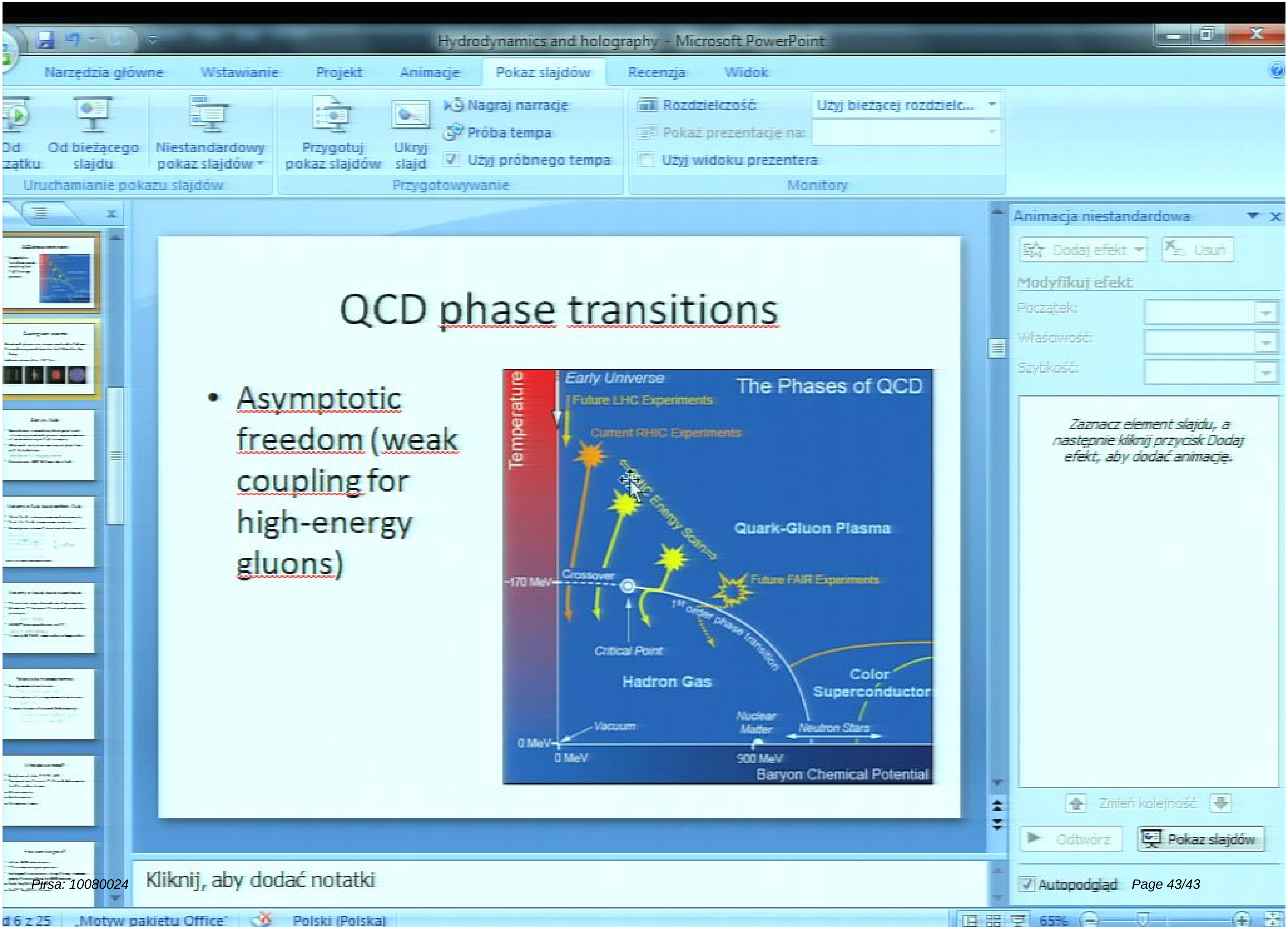
Search: nutt
Clear S
Artist Album Track # Title Length Genre Rating Play Count Played Last Year
Ella & Louis Porgy & Bess I Got Plenty O' Nuttin? 3:52 5 2010-07-21 20:...
Play Enqueue Create Playlist 1 item [3:52] [3.55 MiB] in 0.854 sec.
Ella & Louis
Bio
Bio Unavailable
Videos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Przygotowywanie
Monitory
QCD phase transitions
• Asymptotic freedom (weak coupling for high-energy gluons)
The Phases of QCD
Early Universe
Future LHC Experiments
Current RHIC Experiments
RHIC Energy Scan
Quark-Gluon Plasma
Temperature
~170 MeV
Crossover
Future FAIR Experiments
1st order phase transition
Critical Point
Hadron Gas
Color Superconductor
Vacuum
Nuclear Matter
Neutron Stars
0 MeV
900 MeV
Baryon Chemical Potential
Animacja niestandardowa
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