

Studying baryons at high temperature using supercomputers

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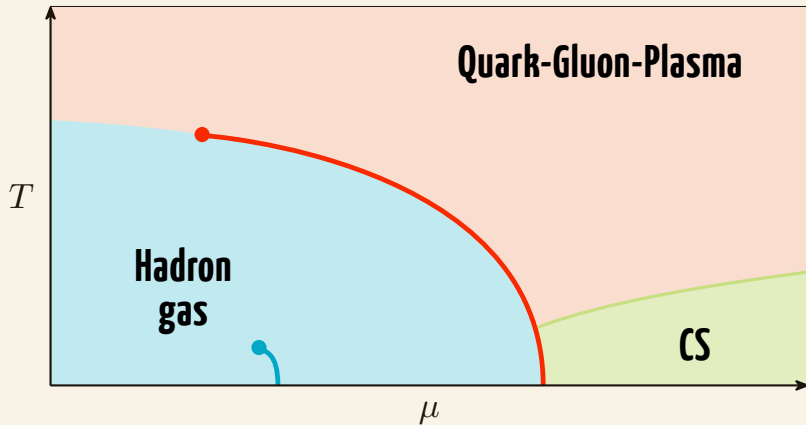
June 6th 2018

Quantum Chromo Dynamics

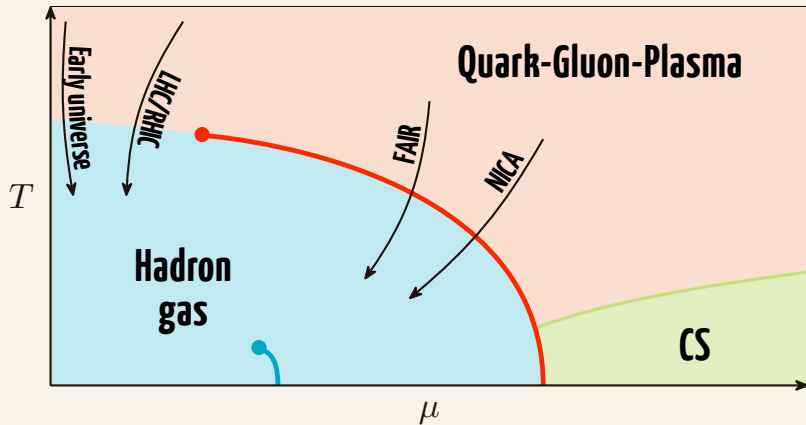
Theoretical description of the **strong nuclear force**



Quantum Chromo Dynamics

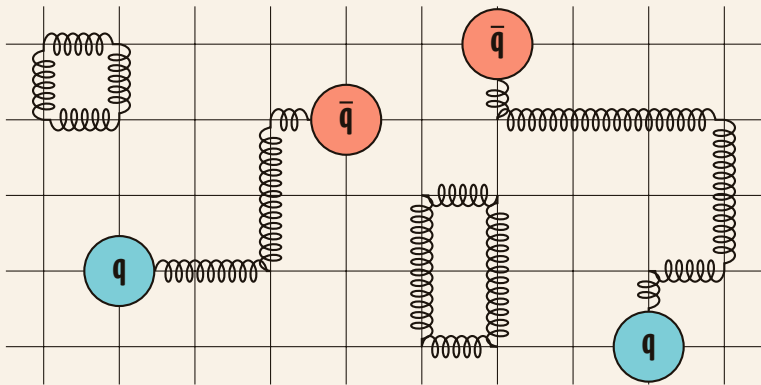


Quantum Chromo Dynamics



Lattice QCD

Basically we just put on a **(HUGE)** lattice



$$\begin{array}{c}
\text{\textit{VOL}} \times N_d \times N_c \\
\updownarrow
\end{array}
\begin{pmatrix}
D(0|0) & D(0|\hat{0}) & 0 & 0 & 0 & \dots \\
D(\hat{0}|0) & D(\hat{0}|\hat{0}) & D(\hat{0}|2\hat{0}) & 0 & 0 & \dots \\
0 & D(2\hat{0}|\hat{0}) & D(2\hat{0}|2\hat{0}) & D(2\hat{0}|3\hat{0}) & 0 & \dots \\
0 & 0 & D(3\hat{0}|2\hat{0}) & D(3\hat{0}|3\hat{0}) & D(3\hat{0}|\hat{4}\hat{0}) & \dots \\
0 & 0 & 0 & D(4\hat{0}|3\hat{0}) & D(4\hat{0}|\hat{4}\hat{0}) & \dots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
D(\hat{1}|0) & D(\hat{1}|\hat{0}) & 0 & 0 & 0 & \dots \\
D(\hat{1}|0) & D(\hat{0}\hat{1}|\hat{0}) & D(\hat{0}\hat{1}|2\hat{0}) & 0 & 0 & \dots \\
0 & D(2\hat{0}\hat{1}|\hat{0}) & D(2\hat{0}\hat{1}|2\hat{0}) & D(2\hat{0}\hat{1}|3\hat{0}) & 0 & \dots \\
0 & 0 & D(3\hat{0}\hat{1}|2\hat{0}) & D(3\hat{0}\hat{1}|3\hat{0}) & D(3\hat{0}\hat{1}|\hat{4}\hat{0}) & \dots \\
0 & 0 & 0 & D(4\hat{0}\hat{1}|3\hat{0}) & D(4\hat{0}\hat{1}|\hat{4}\hat{0}) & \dots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
D(2\hat{1}|0) & D(2\hat{1}|\hat{0}) & 0 & 0 & 0 & \dots \\
D(2\hat{1}|0) & D(\hat{0}2\hat{1}|\hat{0}) & D(\hat{0}2\hat{1}|2\hat{0}) & 0 & 0 & \dots \\
0 & D(2\hat{0}2\hat{1}|\hat{0}) & D(2\hat{0}2\hat{1}|2\hat{0}) & D(2\hat{0}2\hat{1}|3\hat{0}) & 0 & \dots \\
0 & 0 & D(3\hat{0}2\hat{1}|2\hat{0}) & D(3\hat{0}2\hat{1}|3\hat{0}) & D(3\hat{0}2\hat{1}|\hat{4}\hat{0}) & \dots \\
0 & 0 & 0 & D(4\hat{0}2\hat{1}|3\hat{0}) & D(4\hat{0}2\hat{1}|\hat{4}\hat{0}) & \dots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
D(3\hat{1}|0) & D(3\hat{1}|\hat{0}) & 0 & 0 & 0 & \dots \\
D(3\hat{1}|0) & D(\hat{0}3\hat{1}|\hat{0}) & D(\hat{0}3\hat{1}|2\hat{0}) & 0 & 0 & \dots \\
0 & D(2\hat{0}3\hat{1}|\hat{0}) & D(2\hat{0}3\hat{1}|2\hat{0}) & D(2\hat{0}3\hat{1}|3\hat{0}) & 0 & \dots \\
0 & 0 & D(3\hat{0}3\hat{1}|2\hat{0}) & D(3\hat{0}3\hat{1}|3\hat{0}) & D(3\hat{0}3\hat{1}|\hat{4}\hat{0}) & \dots \\
0 & 0 & 0 & D(4\hat{0}3\hat{1}|3\hat{0}) & D(4\hat{0}3\hat{1}|\hat{4}\hat{0}) & \dots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix}
=
\begin{pmatrix}
\psi(0) \\
\psi(\hat{0}) \\
\psi(2\hat{0}) \\
\psi(3\hat{0}) \\
\psi(4\hat{0}) \\
\vdots \\
\psi(\hat{1}) \\
\psi(\hat{0}\hat{1}) \\
\psi(2\hat{0}\hat{1}) \\
\psi(3\hat{0}\hat{1}) \\
\psi(4\hat{0}\hat{1}) \\
\vdots \\
\psi(2\hat{1}) \\
\psi(\hat{0}2\hat{1}) \\
\psi(2\hat{0}2\hat{1}) \\
\psi(3\hat{0}2\hat{1}) \\
\psi(4\hat{0}2\hat{1}) \\
\vdots \\
\psi(3\hat{1}) \\
\psi(\hat{0}3\hat{1}) \\
\psi(2\hat{0}3\hat{1}) \\
\psi(3\hat{0}3\hat{1}) \\
\psi(4\hat{0}3\hat{1}) \\
\vdots
\end{pmatrix}
=
\begin{pmatrix}
\xi(0) \\
\xi(\hat{0}) \\
\xi(2\hat{0}) \\
\xi(3\hat{0}) \\
\xi(4\hat{0}) \\
\vdots \\
\xi(\hat{1}) \\
\xi(\hat{0}\hat{1}) \\
\xi(2\hat{0}\hat{1}) \\
\xi(3\hat{0}\hat{1}) \\
\xi(4\hat{0}\hat{1}) \\
\vdots \\
\xi(2\hat{1}) \\
\xi(\hat{0}2\hat{1}) \\
\xi(2\hat{0}2\hat{1}) \\
\xi(3\hat{0}2\hat{1}) \\
\xi(4\hat{0}2\hat{1}) \\
\vdots \\
\xi(3\hat{1}) \\
\xi(\hat{0}3\hat{1}) \\
\xi(2\hat{0}3\hat{1}) \\
\xi(3\hat{0}3\hat{1}) \\
\xi(4\hat{0}3\hat{1}) \\
\vdots
\end{pmatrix}$$

$$\begin{array}{c}
\leftarrow \text{\textit{VOL}} \times N_d \times N_c \rightarrow
\end{array}$$

$VOL \times N_d \times N_c$

$$\begin{pmatrix}
 D(0|0) & D(0|\bar{0}) & 0 & 0 & 0 & \dots \\
 D(\bar{0}|0) & D(\bar{0}|\bar{0}) & D(\bar{0}|2\bar{0}) & 0 & 0 & \dots \\
 0 & D(2\bar{0}|\bar{0}) & D(2\bar{0}|2\bar{0}) & D(2\bar{0}|3\bar{0}) & 0 & \dots \\
 0 & 0 & D(3\bar{0}|2\bar{0}) & D(3\bar{0}|3\bar{0}) & D(3\bar{0}|4\bar{0}) & \dots \\
 0 & 0 & 0 & D(4\bar{0}|3\bar{0}) & D(4\bar{0}|4\bar{0}) & \dots \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
 D(0|2\bar{1}) & D(0|\bar{0}2\bar{1}) & 0 & 0 & 0 & \dots \\
 0 & D(2\bar{1}|0) & D(2\bar{1}|\bar{0}) & 0 & 0 & \dots \\
 0 & 0 & D(2\bar{0}2\bar{1}|\bar{0}) & D(2\bar{0}2\bar{1}|2\bar{0}) & D(2\bar{0}2\bar{1}|3\bar{0}) & \dots \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
 D(2\bar{1}|0) & D(2\bar{1}|\bar{0}) & 0 & 0 & 0 & \dots \\
 D(2\bar{1}|0) & D(\bar{0}2\bar{1}|\bar{0}) & D(\bar{0}2\bar{1}|2\bar{0}) & 0 & 0 & \dots \\
 0 & D(2\bar{0}2\bar{1}|\bar{0}) & D(2\bar{0}2\bar{1}|2\bar{0}) & D(2\bar{0}2\bar{1}|3\bar{0}) & 0 & \dots \\
 0 & 0 & D(3\bar{0}2\bar{1}|2\bar{0}) & D(3\bar{0}2\bar{1}|3\bar{0}) & D(3\bar{0}2\bar{1}|4\bar{0}) & \dots \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \\
 D(3\bar{1}|0) & D(3\bar{1}|\bar{0}) & 0 & 0 & 0 & \dots \\
 D(3\bar{1}|0) & D(\bar{0}3\bar{1}|\bar{0}) & D(\bar{0}3\bar{1}|2\bar{0}) & 0 & 0 & \dots \\
 0 & D(2\bar{0}3\bar{1}|2\bar{0}) & D(2\bar{0}3\bar{1}|3\bar{0}) & D(2\bar{0}3\bar{1}|4\bar{0}) & 0 & \dots \\
 0 & 0 & D(3\bar{0}3\bar{1}|2\bar{0}) & D(3\bar{0}3\bar{1}|3\bar{0}) & D(3\bar{0}3\bar{1}|4\bar{0}) & \dots \\
 0 & 0 & 0 & D(4\bar{0}3\bar{1}|3\bar{0}) & D(4\bar{0}3\bar{1}|4\bar{0}) & \dots \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \ddots
 \end{pmatrix}
 \begin{pmatrix}
 \psi(0) \\
 \psi(\bar{0}) \\
 \psi(2\bar{0}) \\
 \psi(3\bar{0}) \\
 \psi(4\bar{0}) \\
 \vdots \\
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 \psi(\bar{0}2\bar{1}) \\
 \psi(2\bar{0}2\bar{1}) \\
 \psi(3\bar{0}2\bar{1}) \\
 \vdots \\
 \psi(3\bar{1}) \\
 \psi(\bar{0}3\bar{1}) \\
 \psi(2\bar{0}3\bar{1}) \\
 \psi(3\bar{0}3\bar{1}) \\
 \psi(4\bar{0}3\bar{1}) \\
 \vdots
 \end{pmatrix}
 =
 \begin{pmatrix}
 \xi(0) \\
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 \vdots \\
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 \xi(\bar{0}2\bar{1}) \\
 \xi(2\bar{0}2\bar{1}) \\
 \xi(3\bar{0}2\bar{1}) \\
 \vdots \\
 \xi(3\bar{1}) \\
 \xi(\bar{0}3\bar{1}) \\
 \xi(2\bar{0}3\bar{1}) \\
 \xi(3\bar{0}3\bar{1}) \\
 \xi(4\bar{0}3\bar{1}) \\
 \vdots
 \end{pmatrix}$$

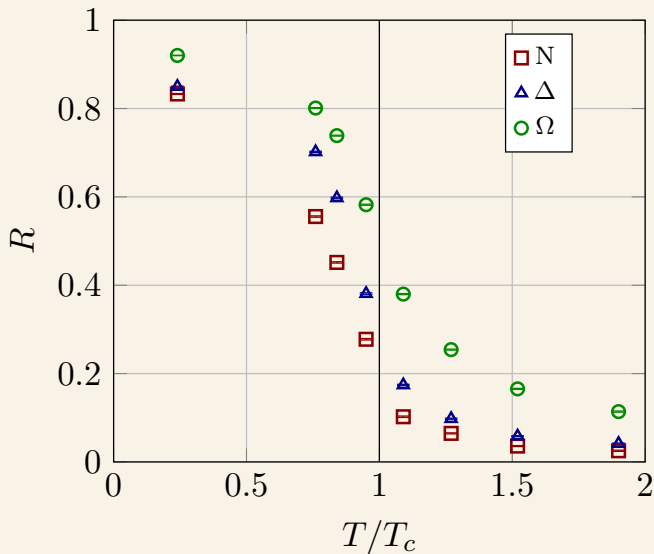
We need to solve this matrix equation many many many times

Our low temperature lattices are:

$$256 \times 32^3 \times 4 \times 3 \sim 10^8$$

$VOL \times N_d \times N_c$

So what do we do with this?



Thanks!