

# Studying baryons at high temperature using supercomputers

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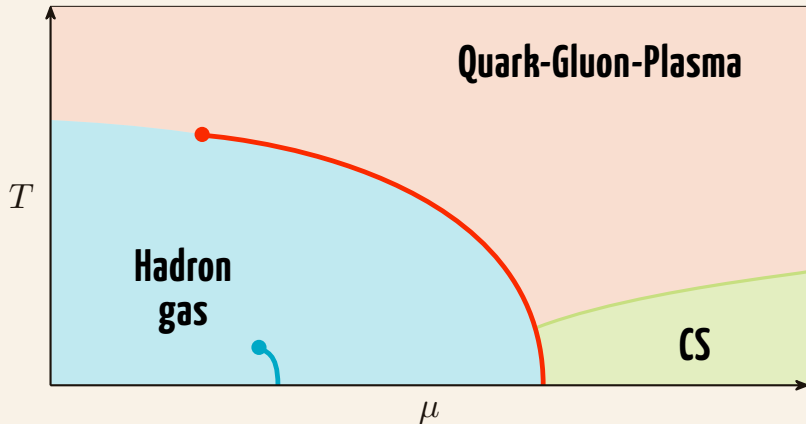
**June 6th 2018**

# Quantum Chromo Dynamics

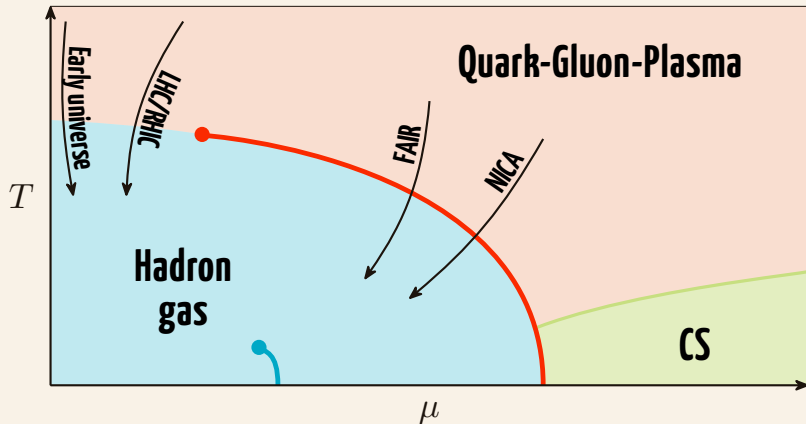
Theoretical description of the **strong nuclear force**



# Quantum Chromo Dynamics

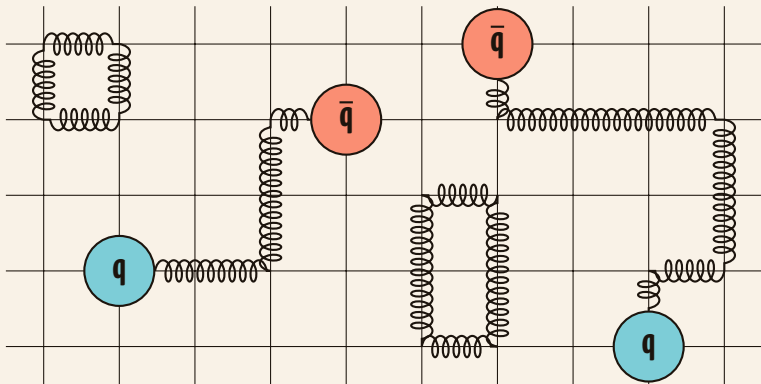


# Quantum Chromo Dynamics



# 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}|\hat{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}|\hat{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}|\hat{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}$$

$$\begin{array}{c}
\text{\textit{VOL}} \times N_d \times N_c \\
\leftarrow \hspace{1.5cm} \rightarrow
\end{array}$$

$VOL \times N_d \times$

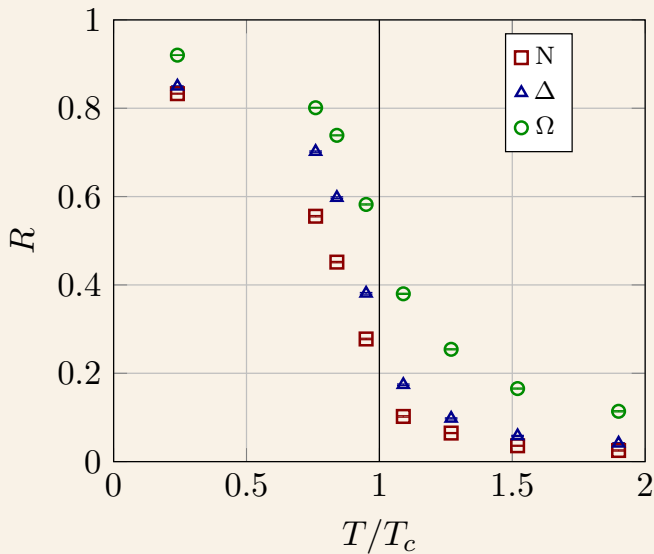
**We need to solve this matrix equation  
many many many times**

**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!**