Melting the Vacuum

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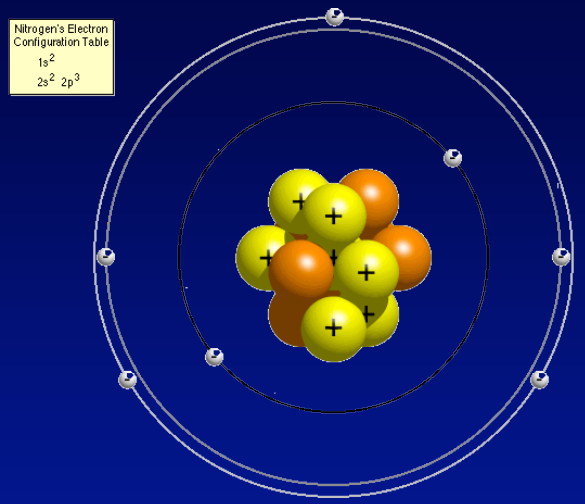
Is the vacuum empty?

I. "Bare" vacuum (Casimir effect)

II. Higg's condensate

III. Quark-antiquark condensate
RHIC program

I. "Bare" Vacuum

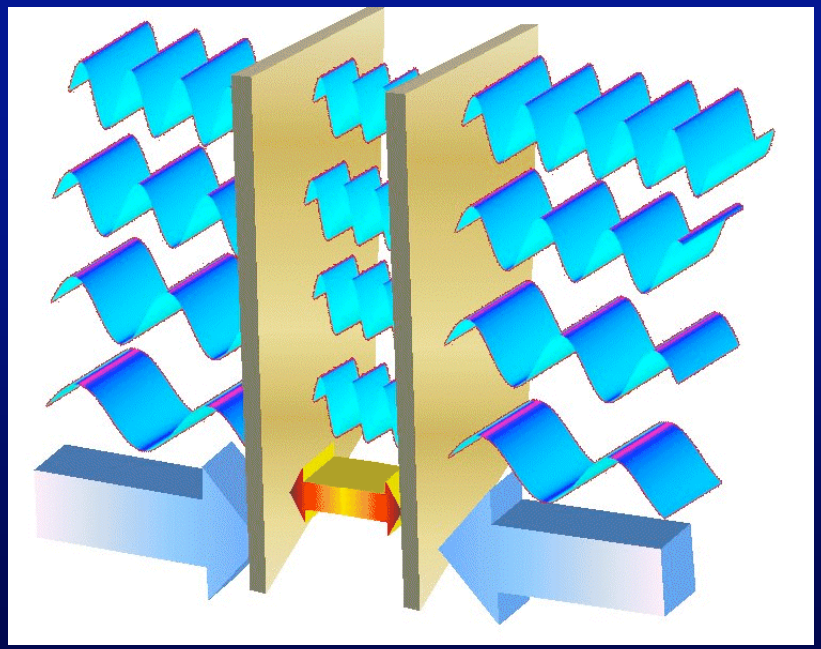


1. Quantum mechanics:
   Electrons have levels

2. Same is true for EM fields

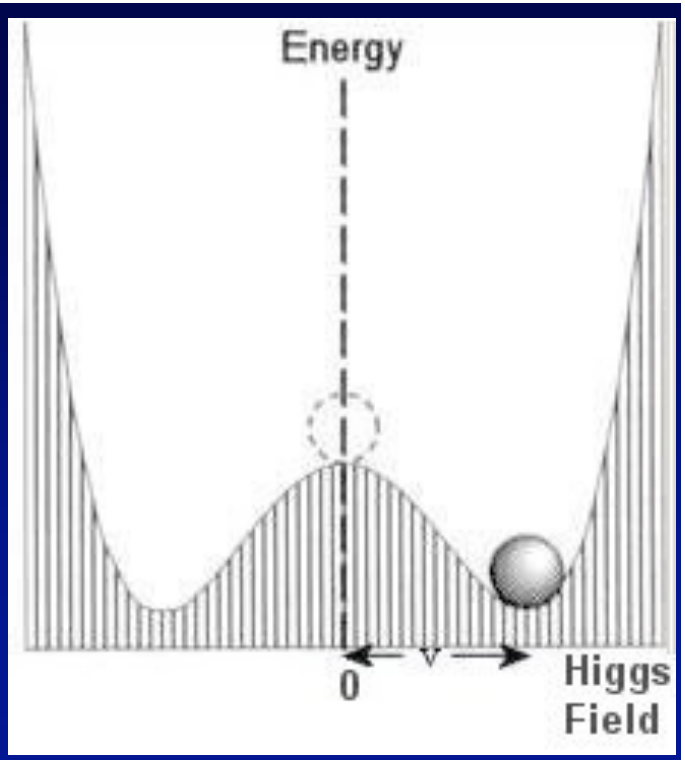
3. Quantum-Field Theory:
   Vacuum levels have 1/2 "photon"

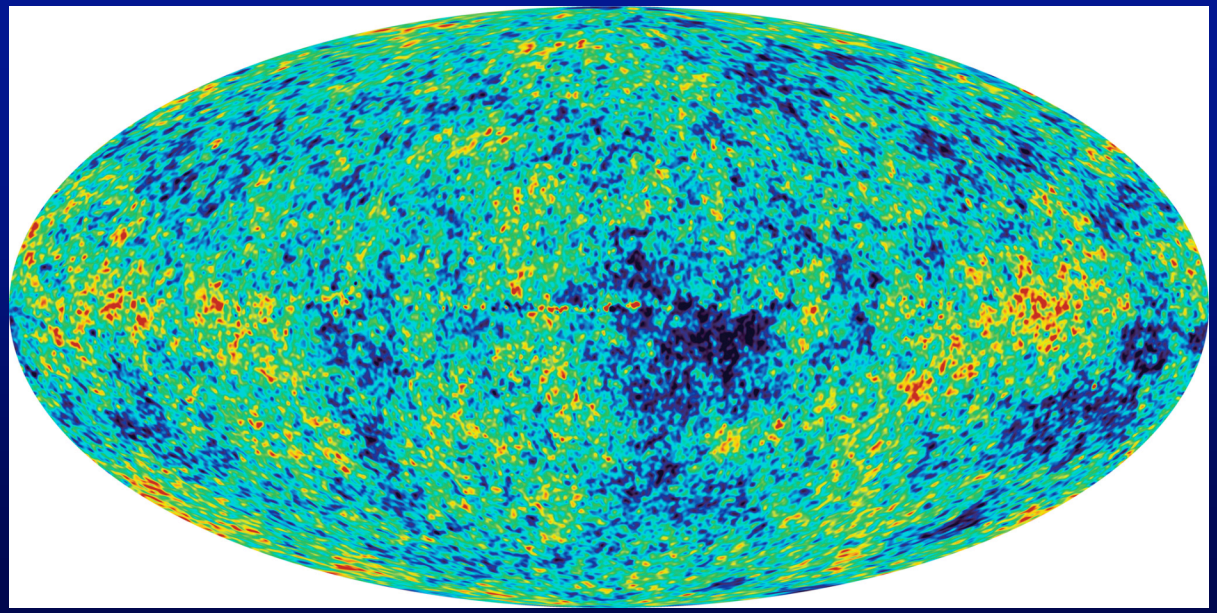
4. Capacitor plates alter modes
   -> repulsion (Casimir effect)



II. Higg's condensate

- vacuum has non-zero Higg's field
- particles "feel" field & acquire mass
- field melts at T ≈ 10^{16} K
  (10^{-11} seconds into big bang)
- evidence in cosmological background



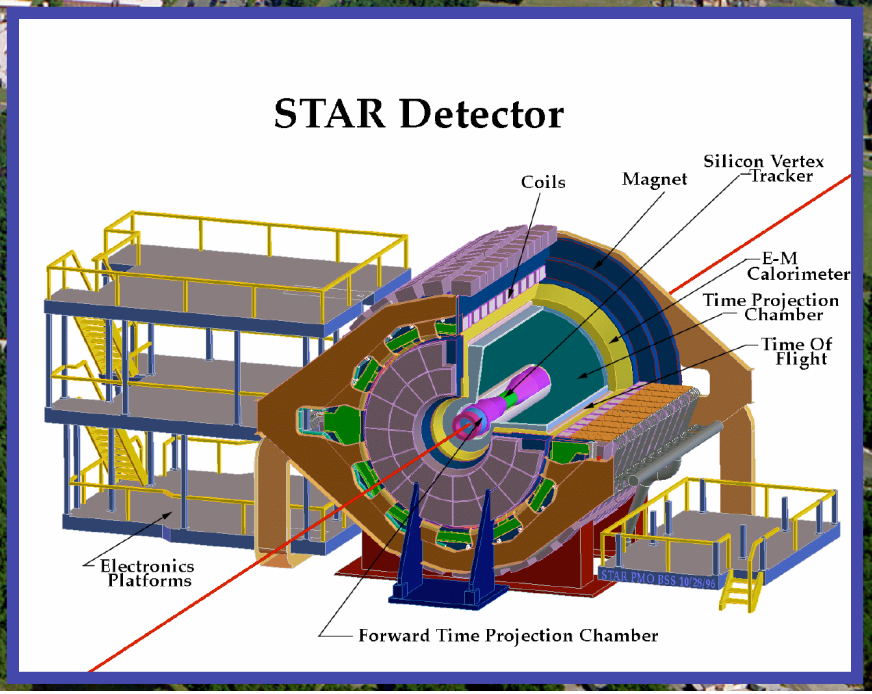


III. Quark-antiquark condensate

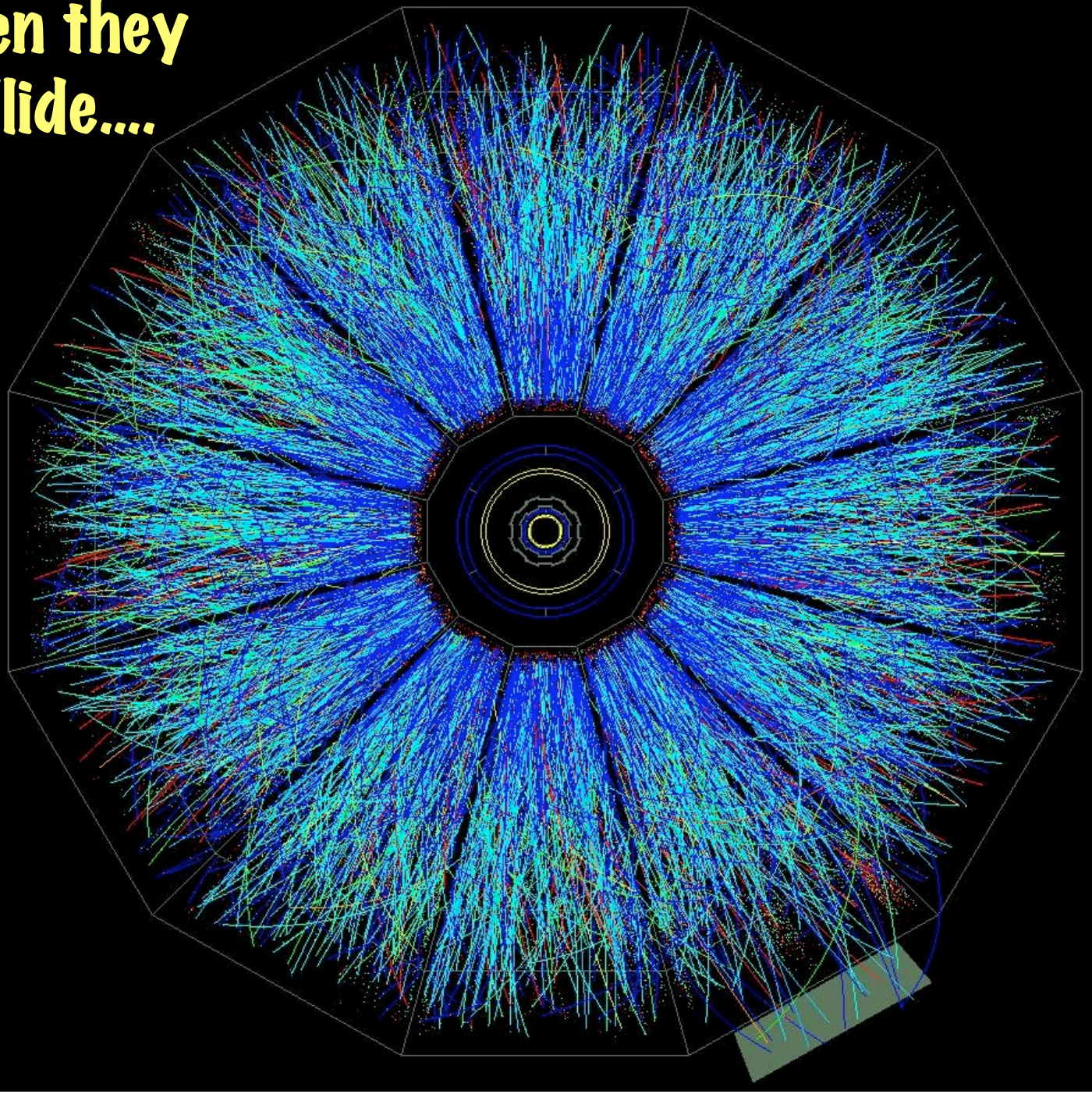
- Vacuum fills with quark pairs
- Condensate couples to protons & neutrons & gives mass
- Melts at $T \approx 10^{13}$ K (10^{-6} seconds into big bang)
- At same T, protons and neutrons melt into quarks
- Temperatures reached in relativistic heavy ion collisions

Relativistic Heavy Ion Collider

Brookhaven Natl. Lab.



When they collide....



Inside a Au+Au collision...

- T ≈ 2.7×10^{12} K, 150,000 x greater than inside Sun
- ≈ 5000 particles are emitted
- size of hot region ≈ 10^{-14} m
- explosion lasts ≈ 10^{-22} seconds

But, we only measure outgoing tracks!!!

Unraveling the data...

Temperature --> spectra, yields

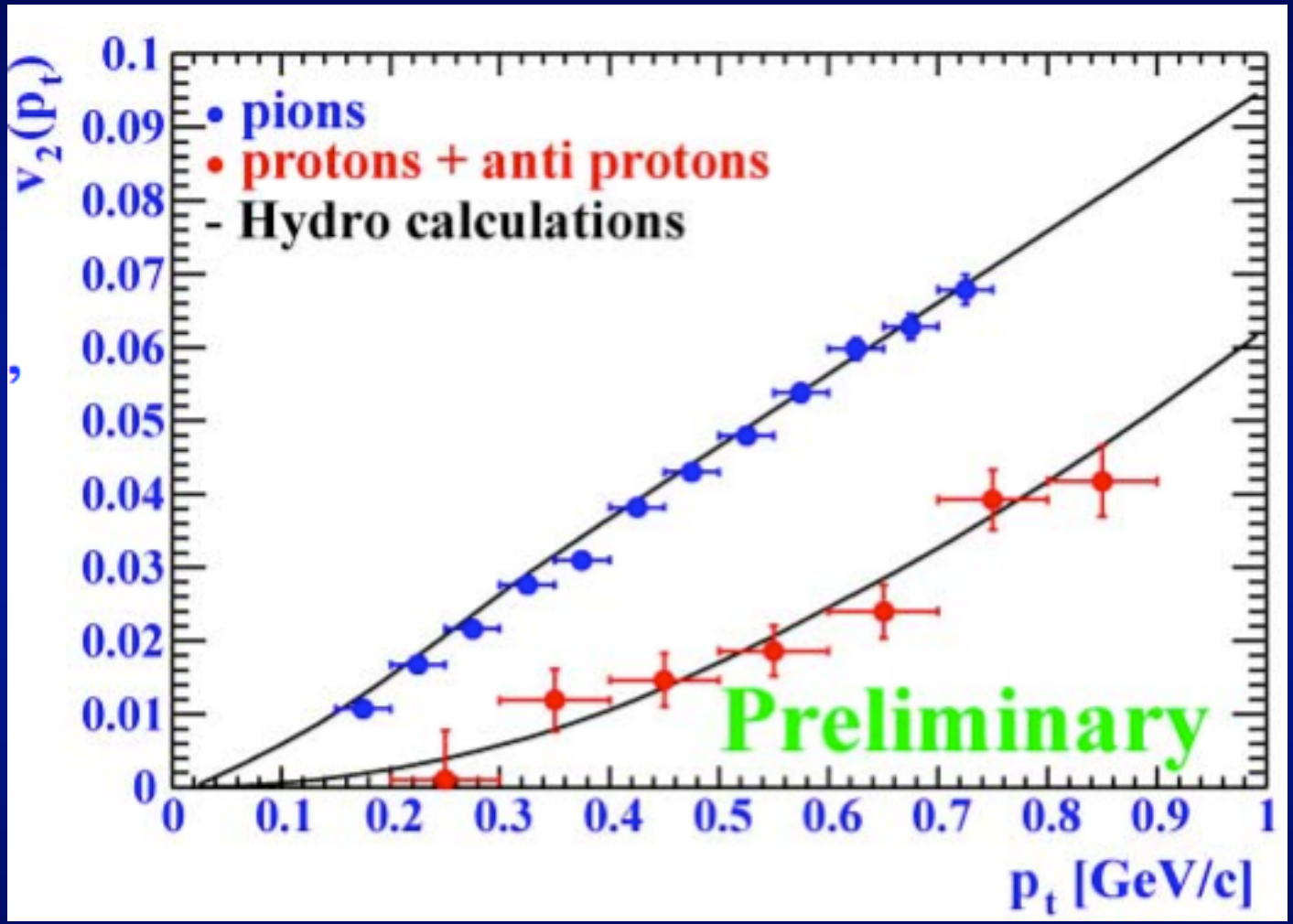
Distance and time --> interferometry

Explosive flow --> light vs. heavy particle spectra

Color composition --> jet suppression

Viscosity --> elliptic flow

Elliptic flow



Hydro calculations assume no viscosity!

What we have learned from RHIC (thus far)

- Viscosity is small (perfect fluid)
- Matter behaves like quark liquid
- Matter is opaque about $T_c \approx 170$ MeV
- Pressure is high (not too high)

Needed: Global analysis

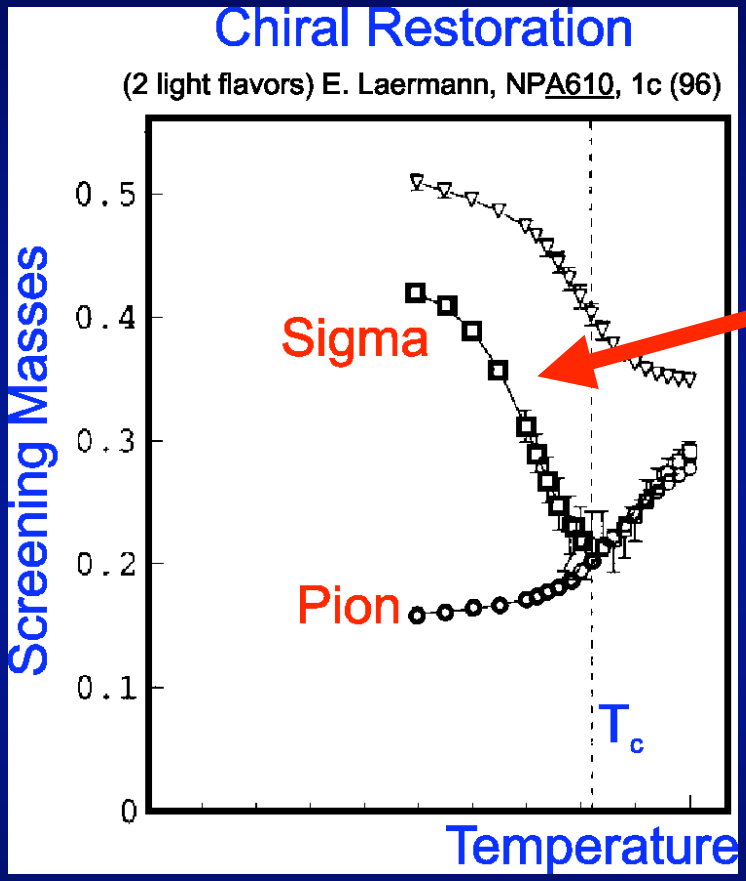
Lattice Gauge Theory

- Pure theory
- Thermodynamic Trace -> 10,000 dimensional integral
- Brute force: > 10^{20} floating point calculations

Figure 3

A 12,288-node QCDOC machine under construction at Brookhaven National Laboratory in October 2004.

Lattice results



Melting condensate

Summary

- RHIC experiments are reproducing conditions to melt quark-antiquark condensate

- Vacuum is far from empty