Collisions of Uranium at RHIC

- Discoveries with collisions of gold at RHIC
- Why are uranium beams useful for RHIC science?
- EBIS: the brand new beam source for RHIC
RHIC – a High Luminosity (Polarized) Hadron Collider

Proton beam in AGS: July 1960 (50 years)
Ion beam in AGS: 1987
AGS Booster: 1991
RHIC Construction: 1993 – 1999
Gold-gold collisions: June 2000 (10 years)
Polarized proton collisions: 2003

Many RHIC operating modes:
Gold-gold, deuteron-gold, copper-copper, uranium-uranium (planned), polarized proton collisions
From us to the proton: the last picture is $100,000,000,000,000 \times$ magnified.
The Strong Force

- The strong force holds 3 quarks together to form the proton (and also the neutron)
- It acts like a string (called gluon): either loose or tight
- When string is loose quarks move at 99.99% of speed of light
- High energy of quarks and gluons inside the proton comes from Big Bang. It gives us our mass ($E = mc^2$)
- During collisions at RHIC the quarks are liberated from the proton – the strings break.
- A new state of matter is formed: the Quark-Gluon-Plasma. It last existed micro-seconds after the Big Bang.
- Discovery at RHIC: the Quark-Gluon Plasma (and the early universe) behaves like a perfect liquid
Explore the very small and very hot and travel back to the beginning of time

The Big Bang

Protons form from quarks and gluons \(\sim 10 \mu s\) after Big Bang. Recreated by RHIC.

- Protons form from quarks and gluons ~10 \(\mu s\) after Big Bang.
- Recreated by RHIC.
Mini-Bang at RHIC: Matter at Extreme Temperature and Density

Colliding gold at 100 + 100 GeV/nucleon:
- Produce and explore a new state of matter
  - Formation phase: scattering of quarks/gluons in gold
  - Hot and dense phase: new state of matter
  - Freeze-out phase: emission of particles into detector
- Discovered a new state of matter (“quark-gluon plasma”)
- Last existed microseconds after Big Bang
- Extremely dense and strongly interacting
  - Matter with strong, self-interacting force
- Hottest matter in the universe:
  - 250,000 times hotter than the center of the sun
- Behaves like a perfect liquid (not like a gas)
- Produced exotic anti-matter
  - for a very brief moment
- Possibly produced bubbles of matter
  - with broken mirror symmetry
Hard Scattering at RHIC

\[ p+p \rightarrow \text{jet+jet} \]  (STAR 200 GeV)

\[ \text{Au+Au} \rightarrow \text{single jet} \]  (STAR 200 GeV/n-n)
Why are Uranium Beams Useful for RHIC Science?

- Uranium is the most highly deformed heavy nucleus available for use in beams:
  - the naturally occurring isotope U-238 is football-shaped, with a length ~ 30% larger than its diameter, and is quite distinct from the nearly spherical nucleus of gold

- The deformation can be exploited to produce quark-gluon plasma under even more extreme conditions than studied with gold-gold collisions:
  - “tip-tip” collisions produce much higher energy density of matter than the most energetic gold-gold collisions yet studied at RHIC
  - Is the matter still a perfect liquid or will it start to behave like a gas?
  - Important test of our understanding of this new state of matter
non-head-on collisions of gold produce an ultra-strong magnetic field, stronger than any known in the present universe!

With this extreme magnetic field, bubbles of broken mirror symmetry can form inside the quark-gluon plasma, observed in RHIC as charge asymmetry.

Analogous to the formation of bubbles of broken matter-antimatter symmetry created in the very early universe that could explain the lack of antimatter today so important to our existence!

head-on “body-body” collisions of uranium produce a strongly deformed quark-gluon plasma without a magnetic field, and should NOT produce bubbles of broken mirror symmetry.
Uranium Beams

- Gold ion collisions at RHIC have used less gold than is found in a single wedding ring over RHIC’s ten years of operations,

- Amount of uranium used will be extremely small and not pose any radiation or any other risk to either Brookhaven Lab staff or the public.

- A handful of soil typically has more naturally occurring uranium than we’ll be using in a year at RHIC.

- RHIC will use the dominant naturally occurring form of uranium, U-238 (uranium with 238 protons and neutrons), which cannot “split” and sustain a nuclear chain reaction like U-235, the fuel used in nuclear reactors.
Electron Beam Ion Source (EBIS)

- New high brightness, high charge-state pulsed ion source, ideal as source for RHIC
- Produces beams of all ion species including noble gas ions (NSRL), uranium (RHIC) and polarized He\(^3\) (eRHIC)
EBIS - A Very Compact New Accelerator
Summary

- The structure of our world today was formed during the first moments of the live of our universe.
- After the discovery of the quark-gluon plasma, present only at the birth of the universe, RHIC is now exploring the novel and exotic properties of this matter in great detail and with new probes.