Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

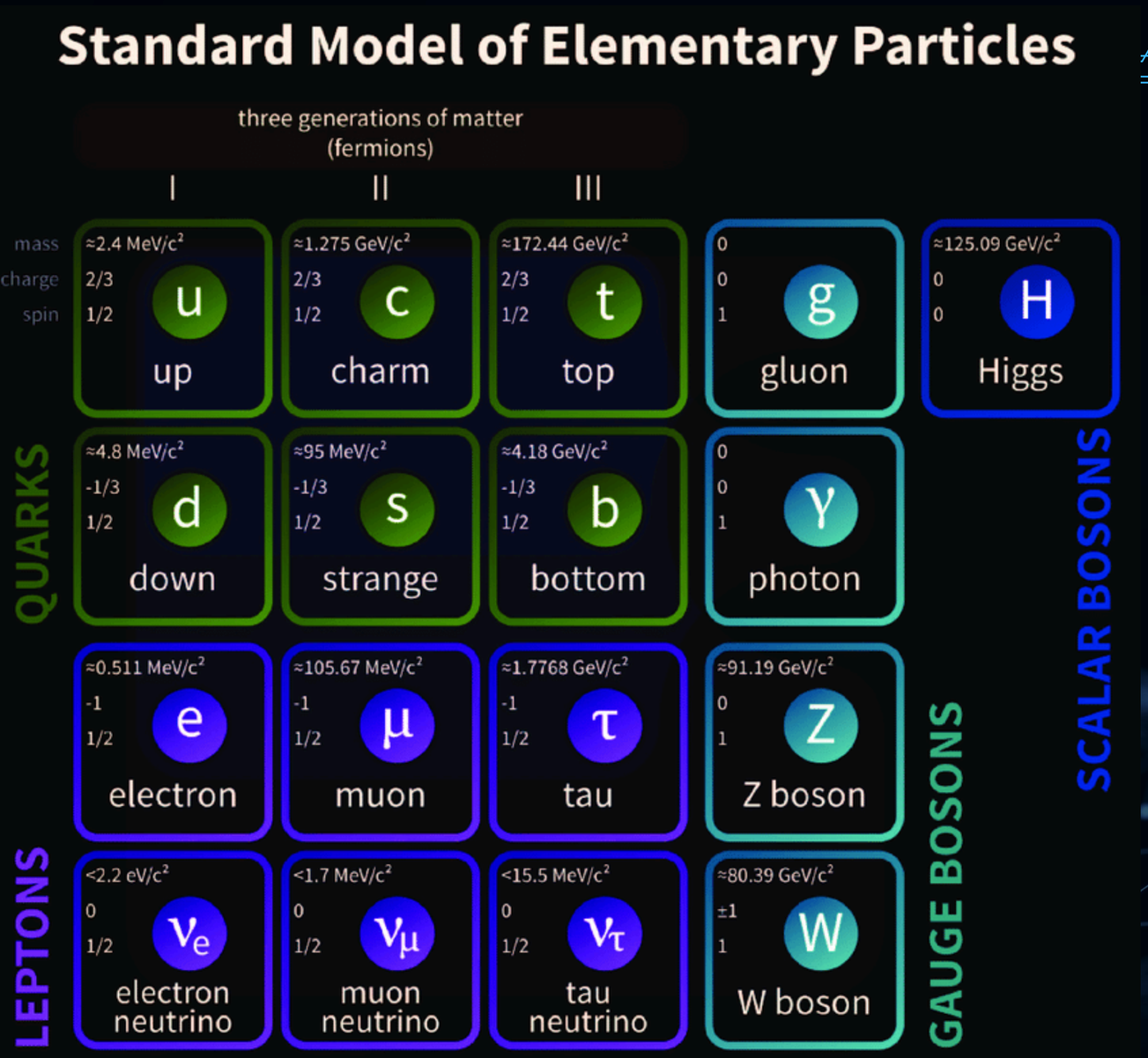
NuSTEAM
Nuclear Science in Texas to Enhance and Advance Minorities

UTEP

PARTICLE ACCELERATORS

NUSTEAM PROGRAM - 2025

VIANNEY DIAZ
UNIVERSITY OF TEXAS AT EL PASO



HIGH ENERGY PHYSICS

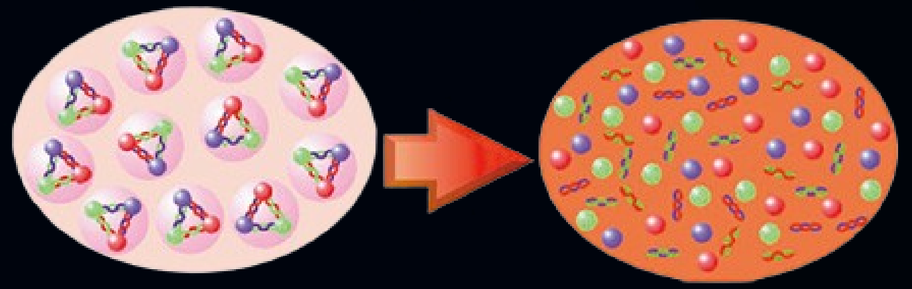
Study of fundamental particles of nature and the forces through which they interact.

It explores the smallest known building blocks of matter and their behavior under high-energy conditions.

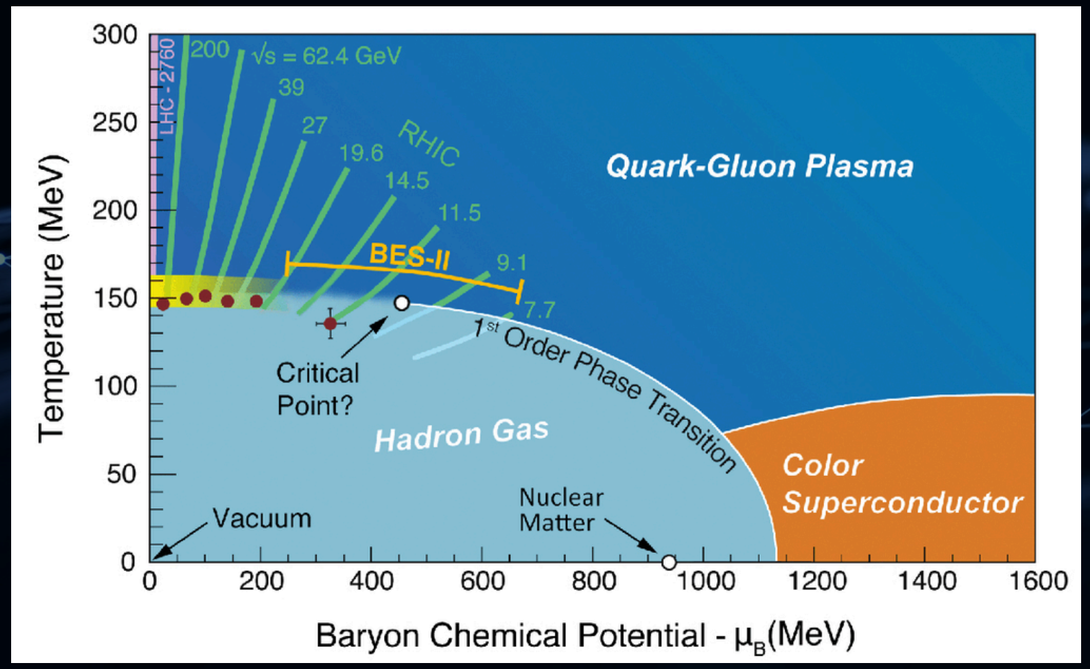
Probing the structure of matter at tiny scales requires big energies, like in particle accelerators.

QUARK-GLUON PLASMA

- State of matter in which quarks and gluons are **deconfined.**
- It forms at extremely **high temperatures** (around 2 trillion °K), approximately 250,000 times hotter than the Sun's core.
- The QGP behaves like a nearly **perfect liquid**, with almost **no viscosity**, and only lasts about **10^{-23} seconds**.



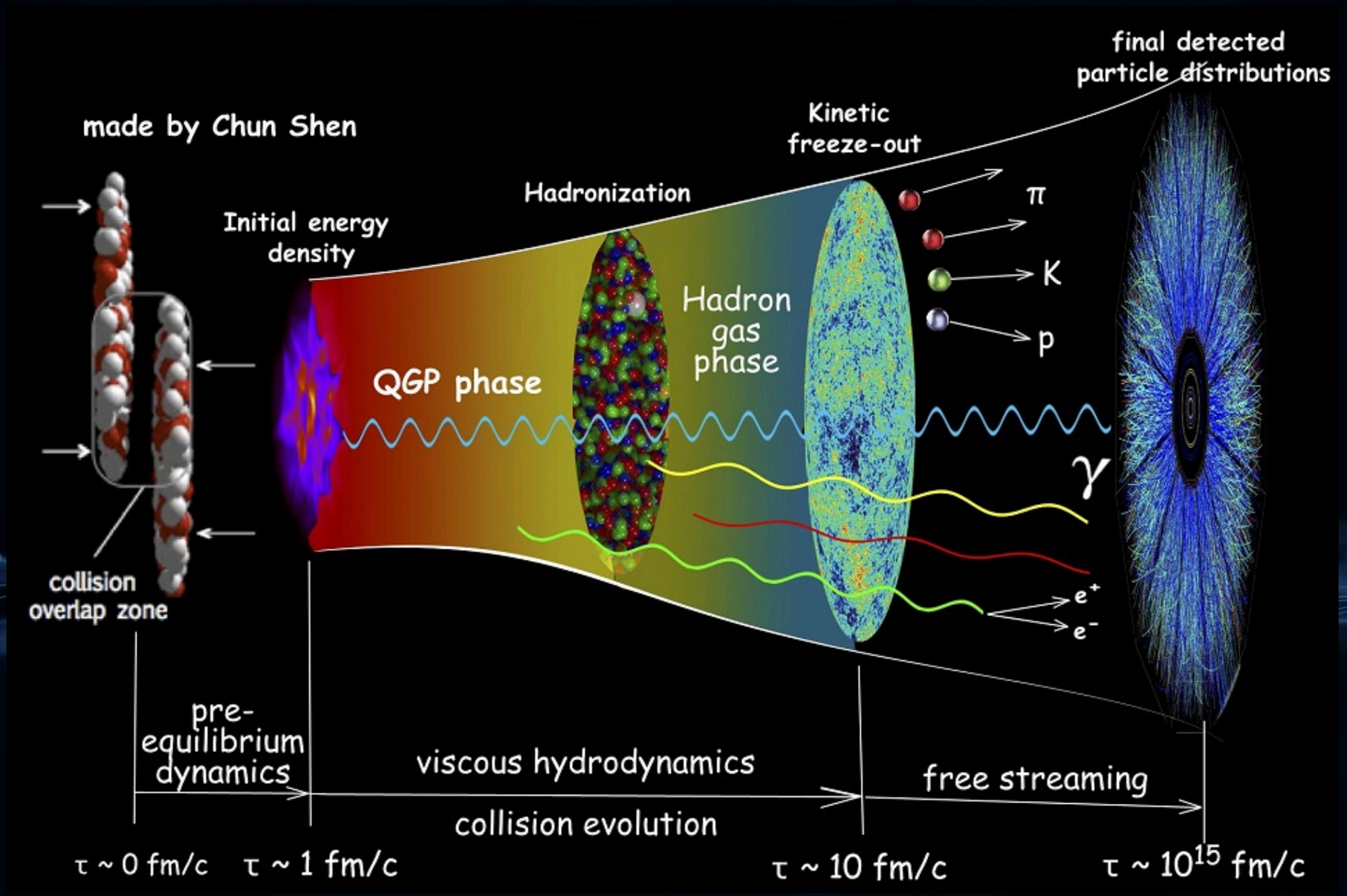
Extreme Heat or density = QGP



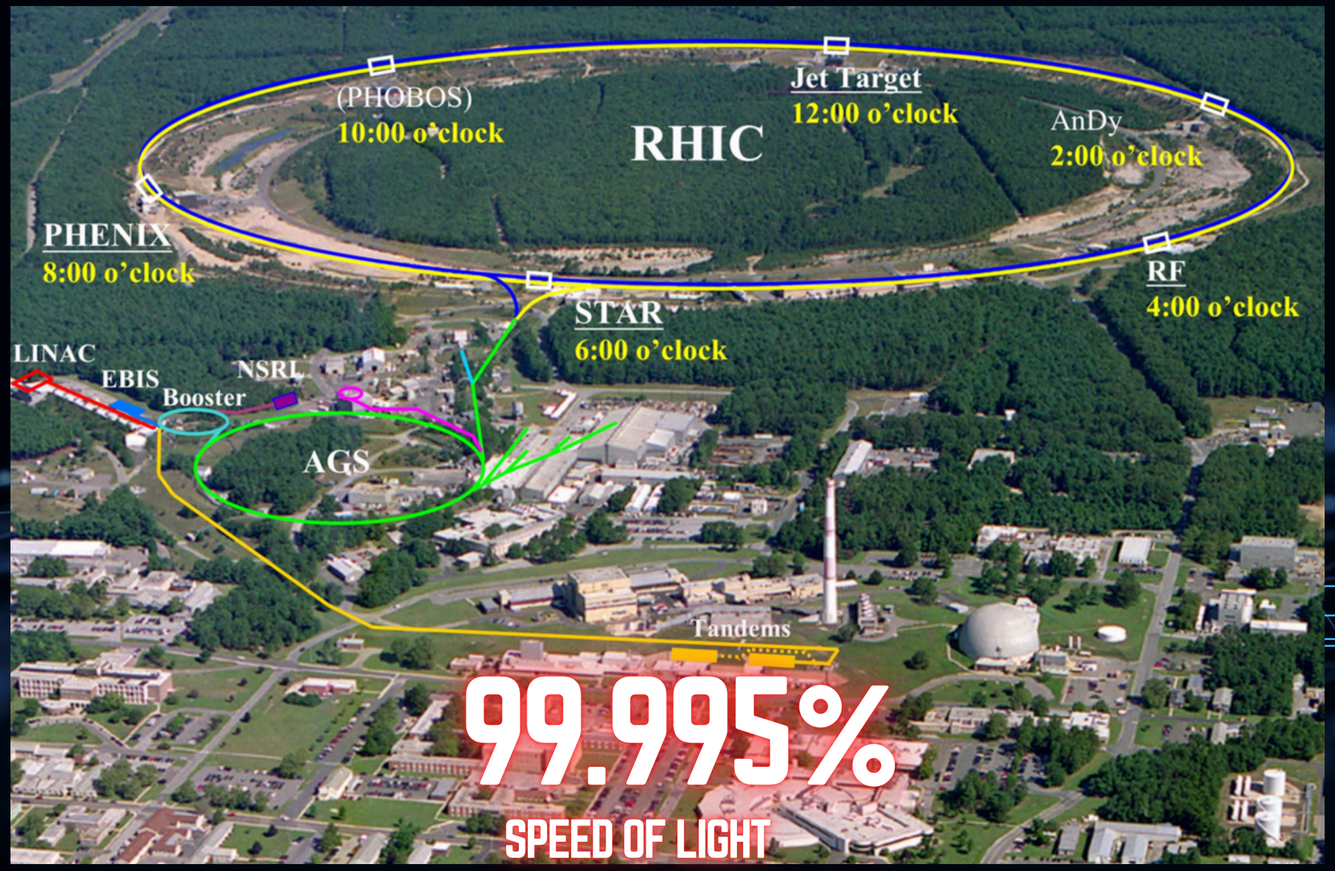
First strong experimental evidence came from the RHIC!!

In 2005, RHIC scientists from four major collaborations (STAR, PHENIX, BRAHMS, PHOBOS) jointly announced that they had created a strongly coupled quark-gluon plasma in gold-gold (Au+Au) collisions.

RELATIVISTIC HEAVY-ION COLLISION



RELATIVISTIC HEAVY-ION COLLIDER



Devices that speed up **charged** particles that make up all matter in the universe and **collide** them together or into a target.
This allows scientists to study those particles and the forces that shape them.

The Relativistic Heavy-Ion Collider (RHIC) collides all ion beam species from protons to Uranium at energies up to **100 GeV** per nucleon and two concentric accelerator rings **2.4 miles** in circumference.

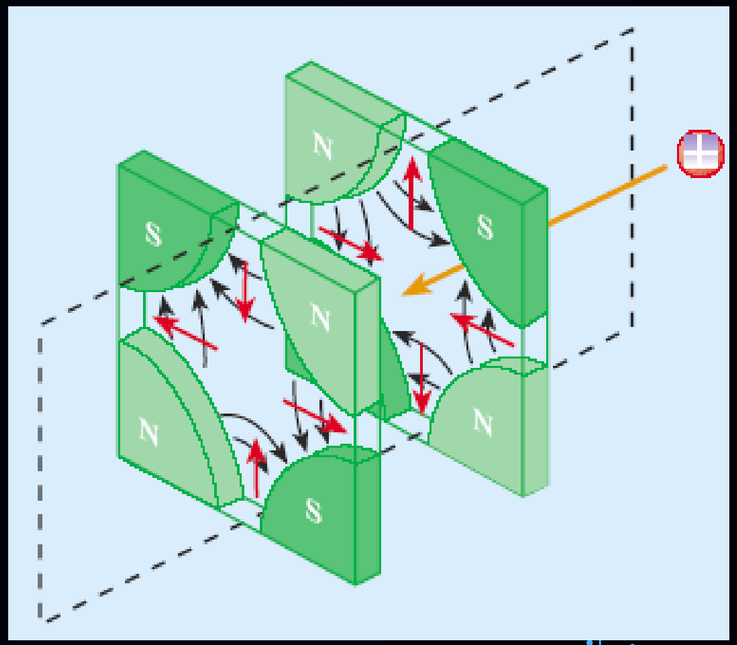
Contains a total of **1,700 superconducting magnets** afford RHIC the capability to independently accelerate and collide different beam species and for protons, different spin polarizations.

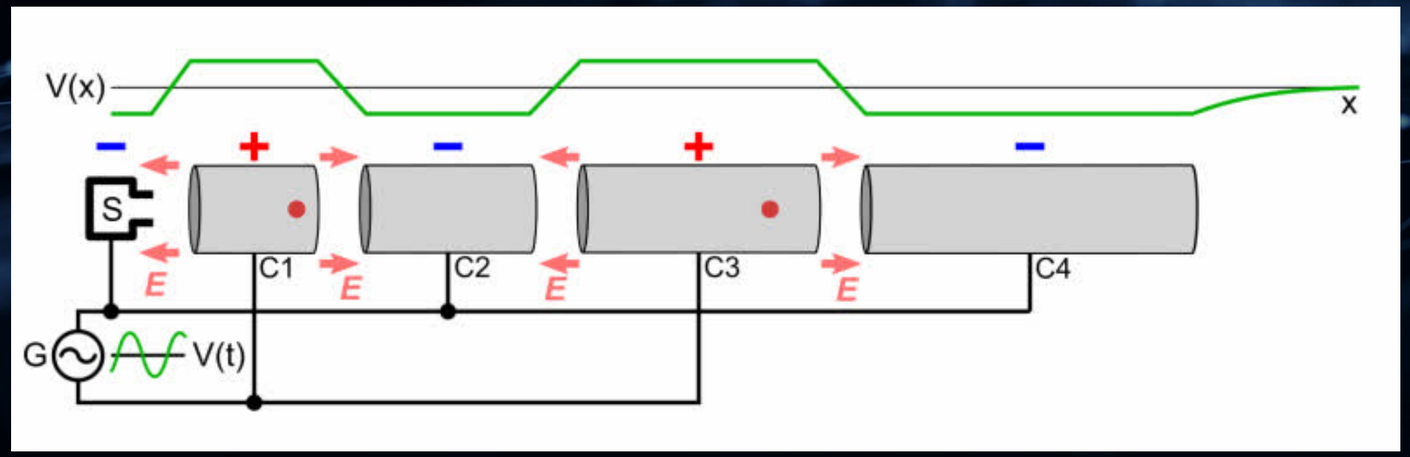
LINEAR

A linear accelerator accelerates charged particles along a straight beamline by applying a series of oscillating electric potentials.

Particles are injected at one end and gain energy each time they cross a gap between drift tubes energized by a radiofrequency (RF) source.

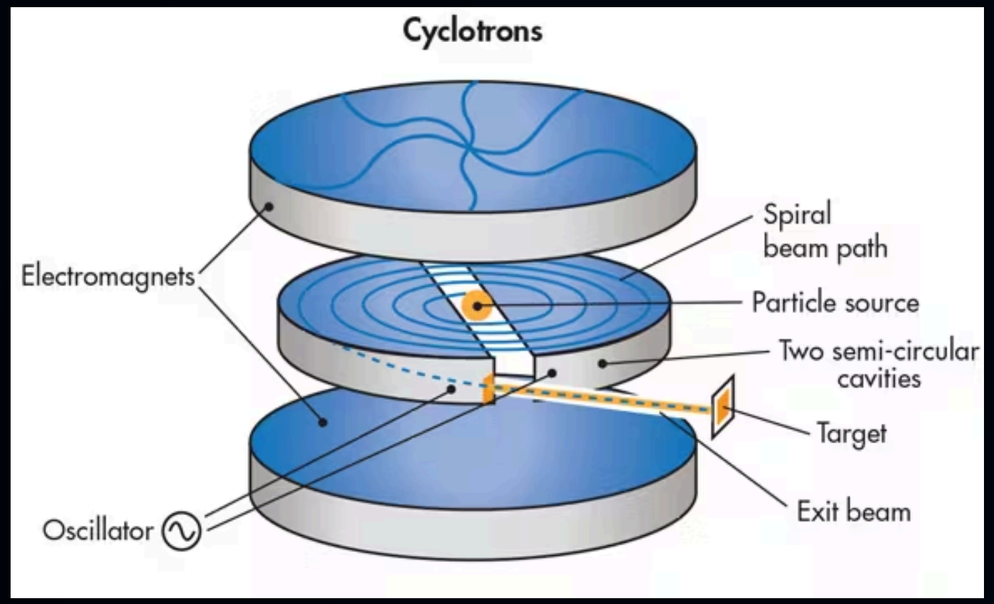
The basic components of the Linac include ion sources, a radiofrequency quadropole, and nine accelerator radiofrequency cavities spanning the length of a 459 foot tunnel (right).

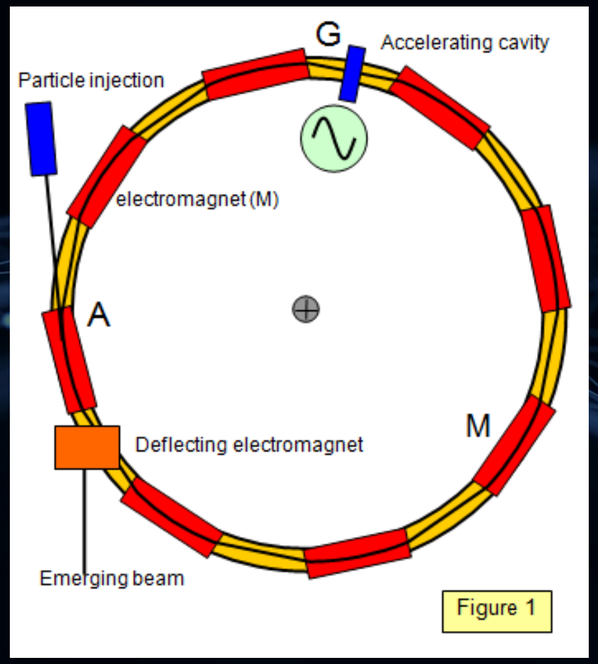




The Brookhaven Linear Accelerator (Linac) operation started in 1971. Its purpose is to provide accelerated protons to the AGS for use in RHIC .

CYCLIC





Feature	Cyclotron	Synchrotron
Magnetic Field	Constant magnetic field	Magnetic field ramped in sync with increasing beam energy
RF Frequency	Fixed-frequency RF	RF frequency (and amplitude) adjusted during acceleration
Particle Orbit	Outward spiral (growing radius)	Fixed-radius circular ring
Energy Range	Tens of MeV (relativistic limit ~30 MeV for protons)	From hundreds of MeV up to TeV scale
Phase Stability	Limited at high energy (relativistic mass shift)	Phase stability maintained throughout via RF phase slippage control
Beam Focusing	Simple weak focusing (edge focusing)	Strong focusing using alternating-gradient quadrupoles
Size & Complexity	Compact, simpler layout	Large, complex ring with hundreds to thousands of magnets

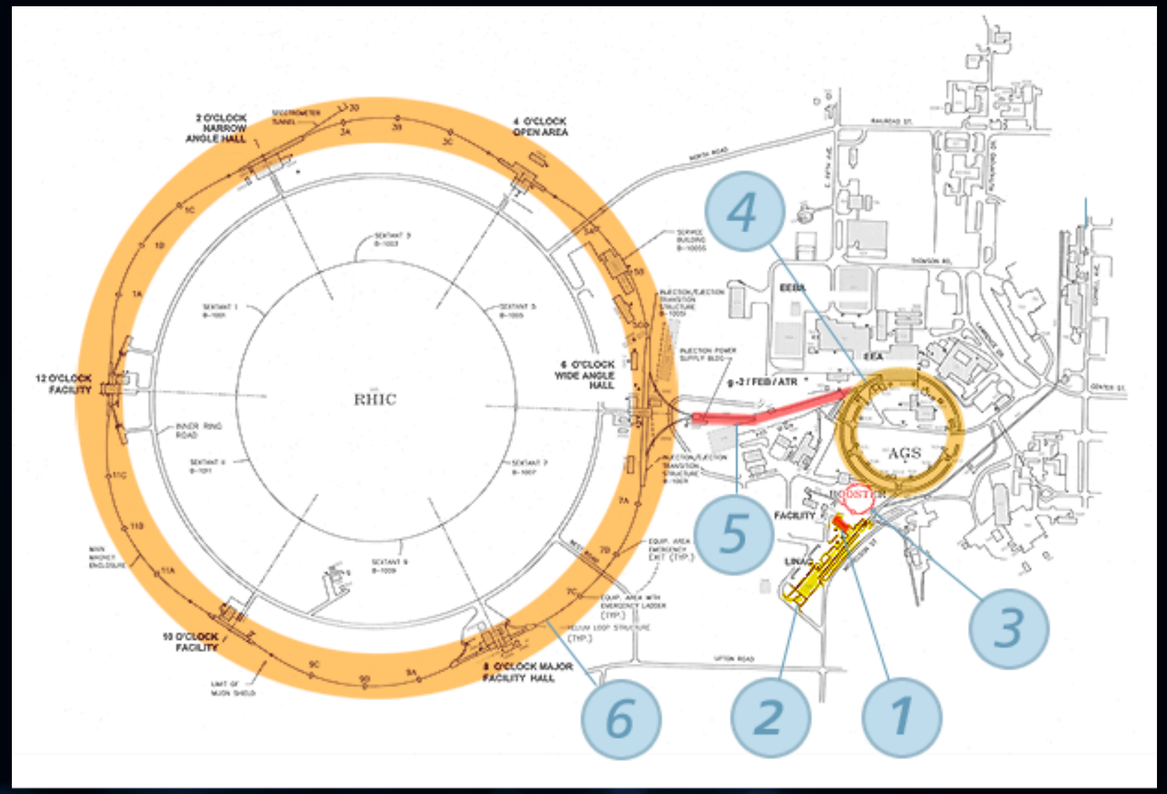
PATH OF PARTICLES AT RHIC

1.- Electron Beam Ion Source (EBIS)

- Produces highly charged heavy-ion beams (from protons up to uranium) in a compact 2 m device.

2.- Linear accelerator

- Bunches and initially accelerates the low-energy H^- beam while providing transverse focusing before Booster entry



3.- Booster Synchrotron

- Provides the ions more energy each turn via phase-stable RF cavities
- The ions are propelled forward at higher speeds, getting 37% closer to the speed of light.

4.- Alternating Gradient Synchrotron (AGS)

- 240 combined-function magnets with alternating inward/outward gradients to focus the beam in both transverse planes
- The ions get even more energy, until they are traveling at 99.7%

5.- AGS to RHIC line

- A dedicated beamline branching into two paths.
- Fast switching magnet directs bunch trains into one of two RHIC rings (“Blue” or “Yellow”)
- Maintains beam emittance and preserves polarization for proton runs

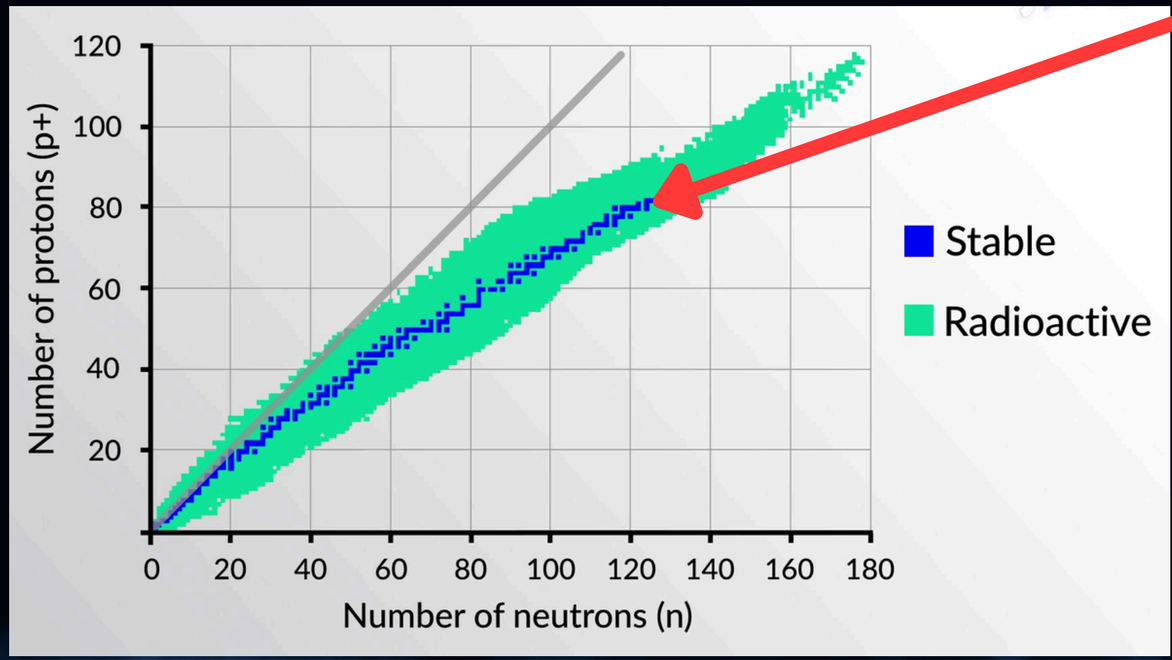
6.- Relativistic Heavy-Ion Collider

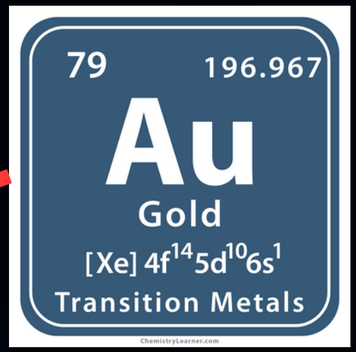
- 1740 superconducting dipoles at 3.45 T to bend beams
- Alternating-gradient quadrupole
- RF systems to phase-stable bunch the beam and control longitudinal emittance

IONIZATION

Gold has one of the largest stable nuclei, so two colliding gold ions create an extremely high density of overlapping nucleons.

Gold is chemically inert, non-radioactive, and readily available in high purity





- Neutral gold atoms are injected into an Electron Beam Ion Source (EBIS).
- A high-current electron beam, confined by a strong solenoidal magnetic field, repeatedly collides with the atoms.
- Successive electron-impact ionizations strip away electrons until the ions reach a charge state of +32.
- Beam enters the Booster synchrotron, a thin-foil stripper at Booster exit removes additional electrons, yielding Au^{77+}.

TANDEM VAN DE GRAAFF

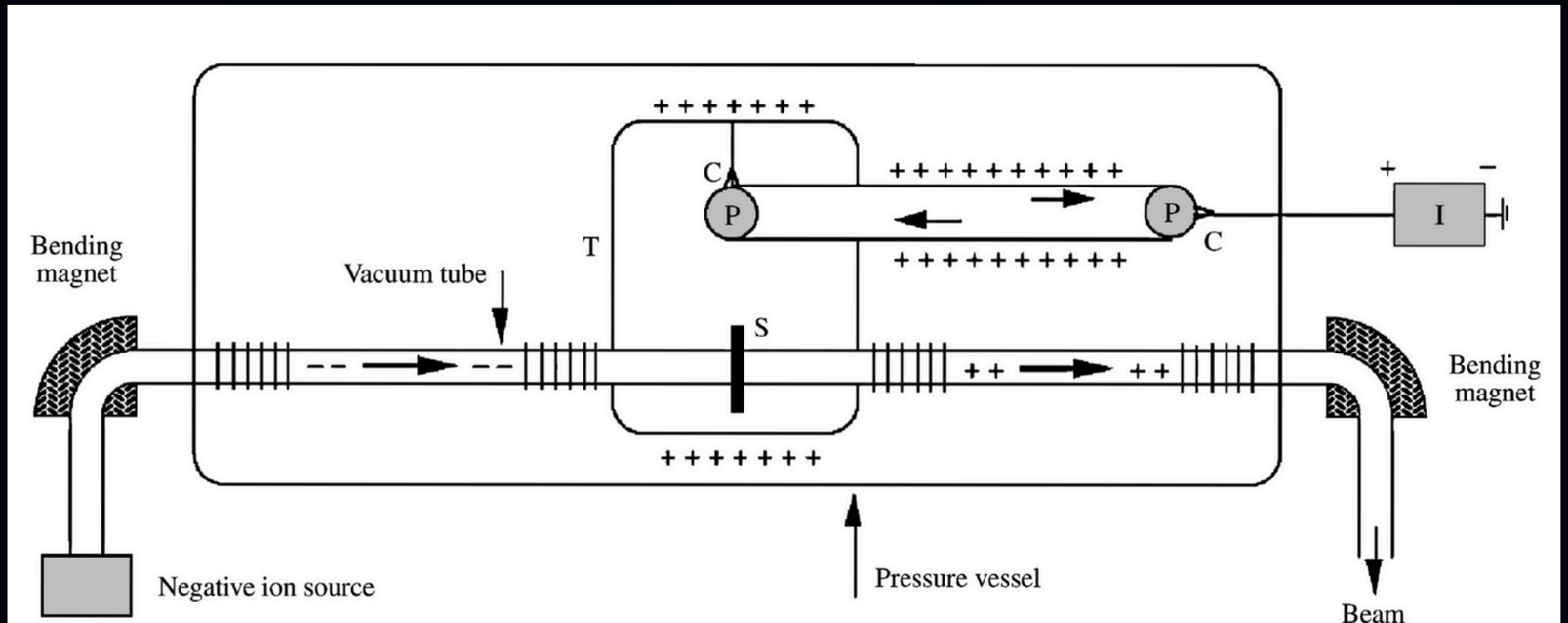
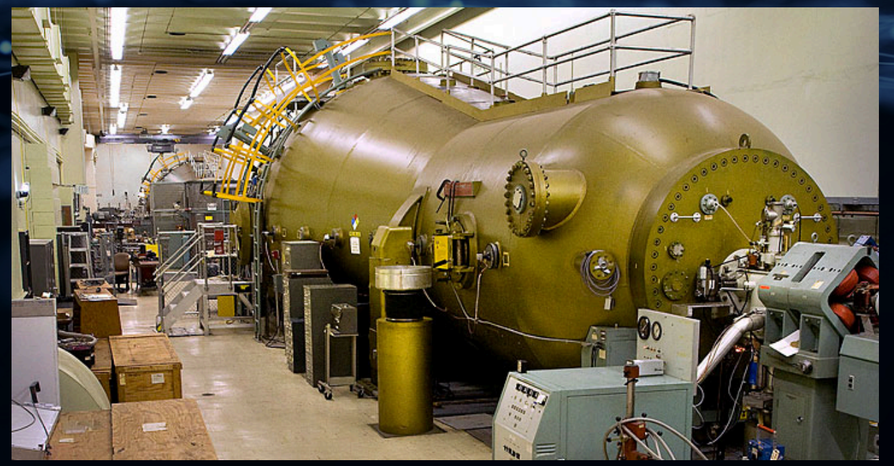
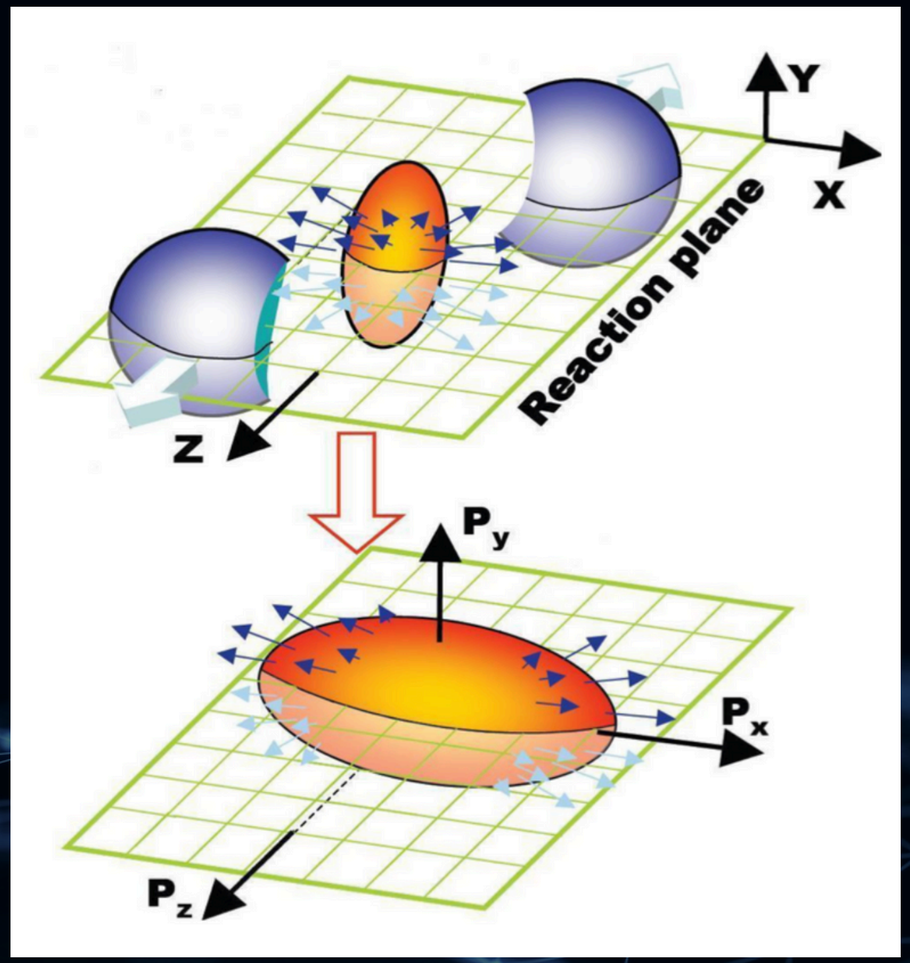
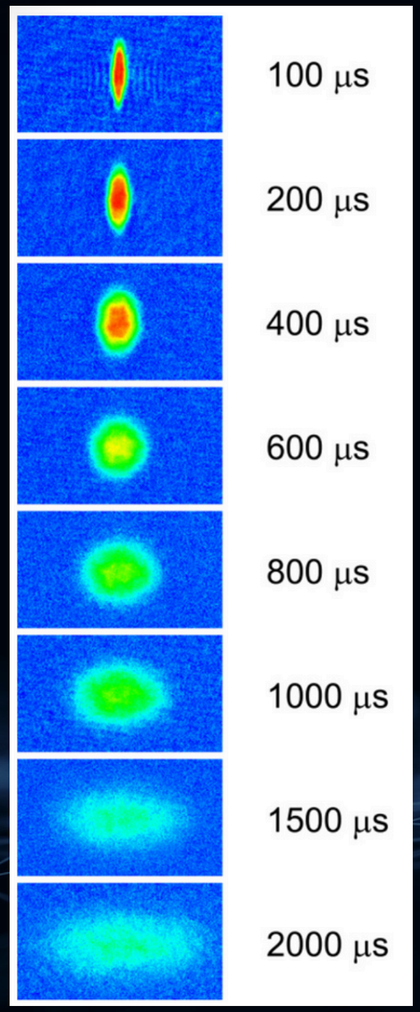


Figure 4.1 Principle of the tandem van de Graaff accelerator



ANISOTROPIC FLOW

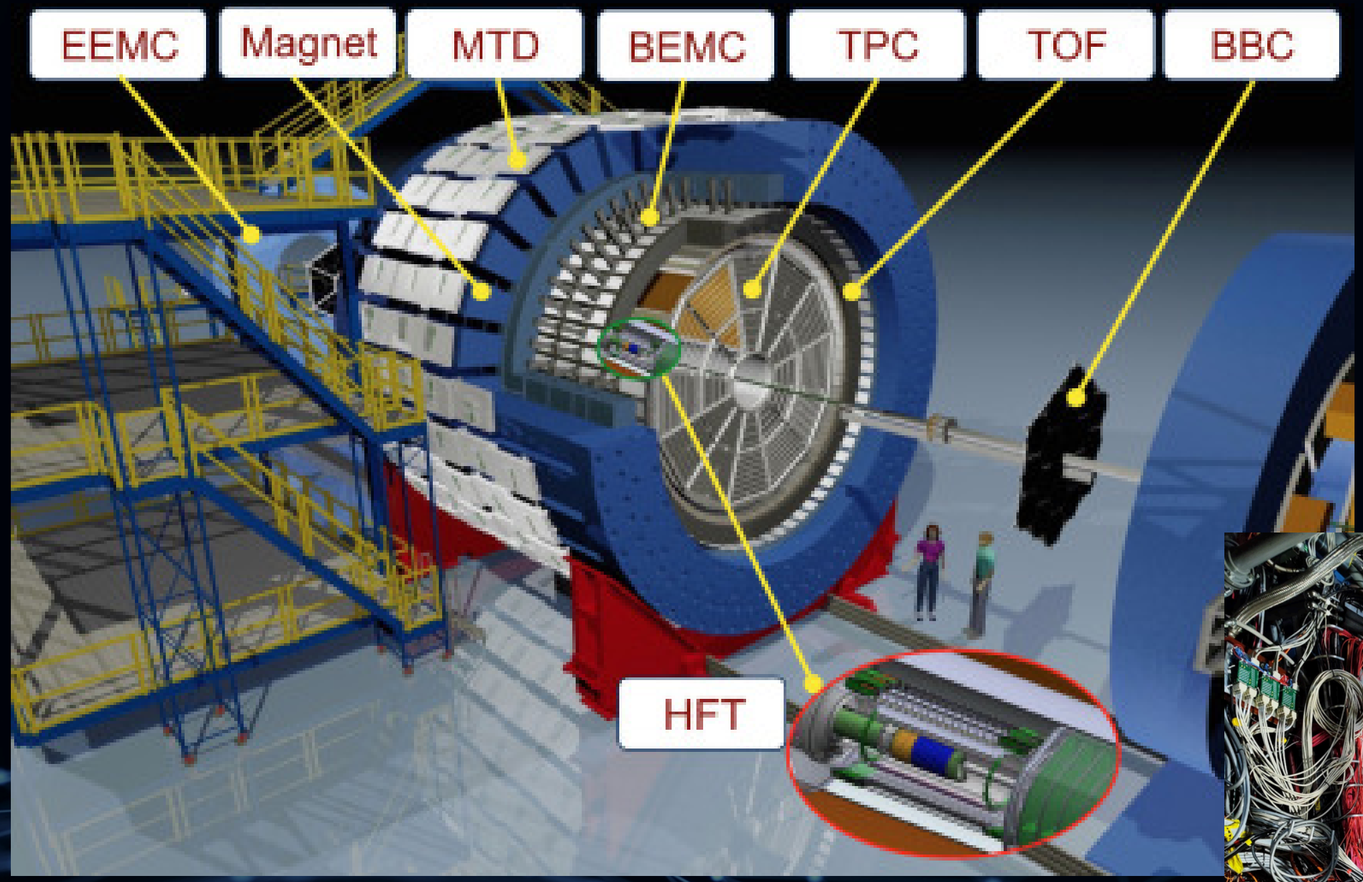


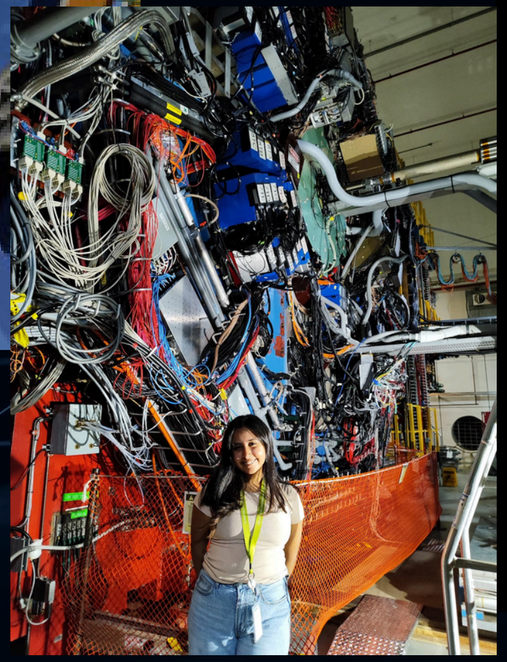


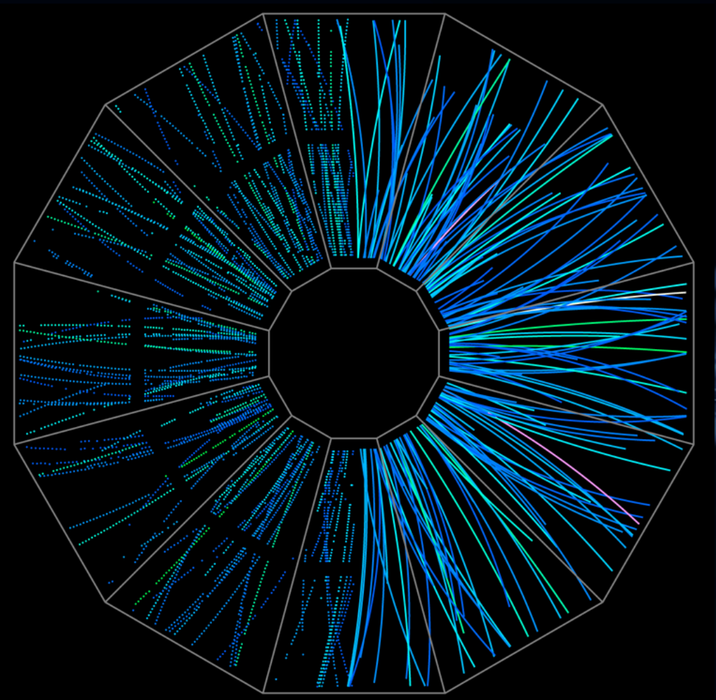
Preferential expansion of the QGP in certain directions due to spatial anisotropies in the initial collision geometry.

Momentum of particles grow quicker in the x-direction.

DETECTION







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THANK YOU