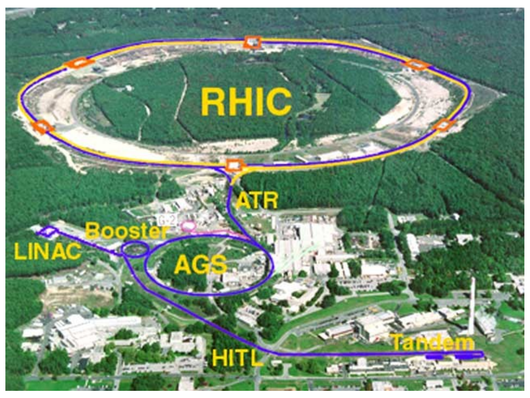

Measurement of Azimuthal Anisotropy of hadron in Au+Au collision at $\sqrt{s_{NN}}$=200, 62 and 39 GeV in PHENIX experiment at RHIC

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PHENIX

RIKEN

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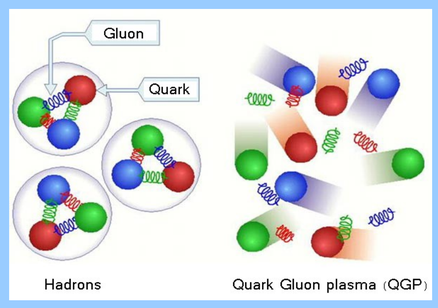
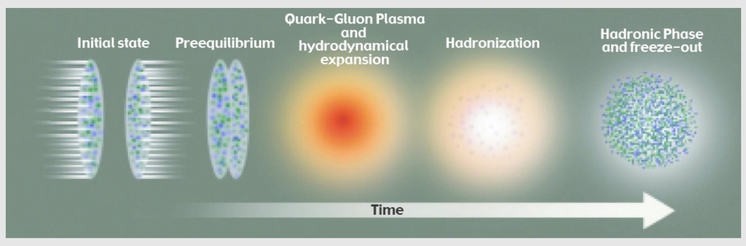
What is Quark Gluon Plasma?



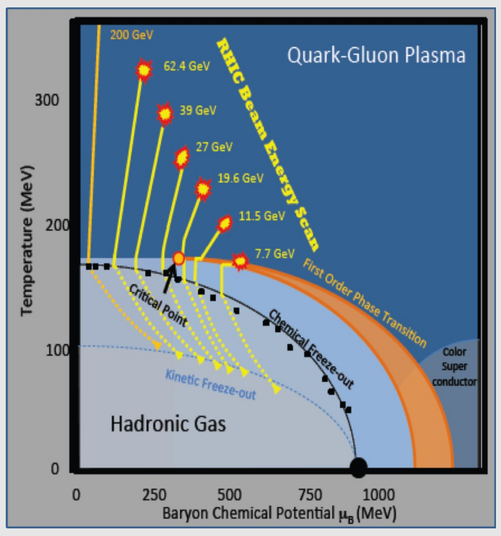
Quark and gluon are confined in hadron at low energy scale.
It is called Quark Gluon Plasma (QGP) if the **quark and gluon are de-confined** in high temperature (early universe of big ban theory) or high density (core of neutron star).

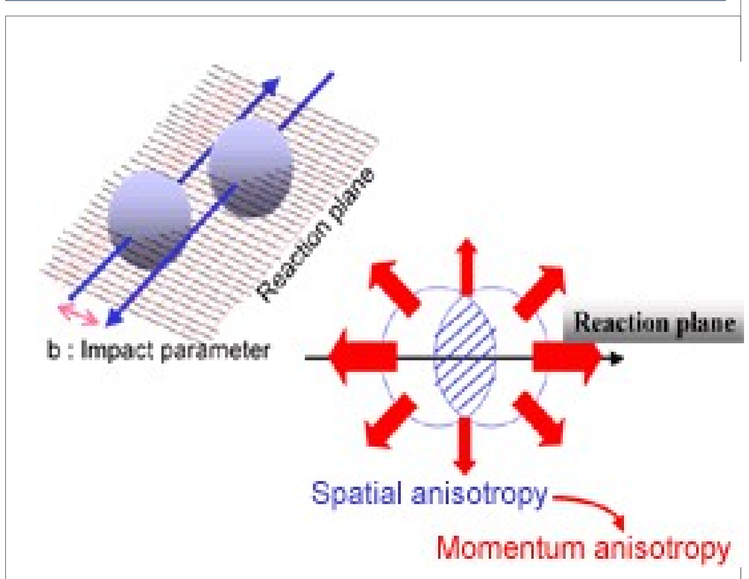
Experiment with Relativistic Heavy Ion Collider (RHIC)



The relativistic Ions pass through each other, and hot dense matter is generated just after that. QGP may be created if the energy is enough. The **QGP** will be changed to **hadron gas** when the matter expands and cools down.

Now we can compare the results of Au+Au collision at $\sqrt{s_{NN}}$=200, 62 and 39 GeV which were taken in 2007 and 2010 at RHIC.
One of purpose of the RHIC energy scan program is to elucidate the **threshold of collision energy with QGP phase transition**.





Elliptical azimuthal anisotropy (v_2)

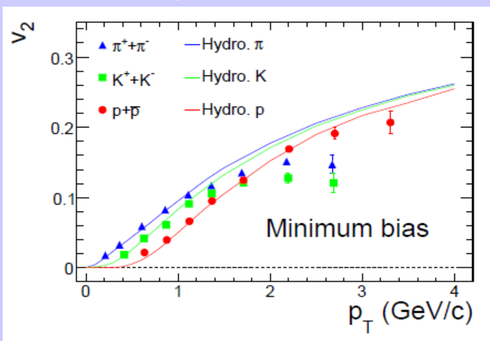
Participant which consists of colliding nucleons and spectators which consist of non-colliding nucleus are well separated because the relativistic speed is much faster than Fermi motion of nucleons in nucleus.
The system geometry of first stage of non-central collision of relativistic heavy ion is elliptical.
The particle emission from the hot matter depends on the initial geometry.
The elliptical anisotropy is measured as second class (v_2) of Fourier function.

$$\frac{dN}{d\phi} \propto 1 + 2 v_2 \cos 2(\phi - \Psi)$$

Ψ: reaction plane

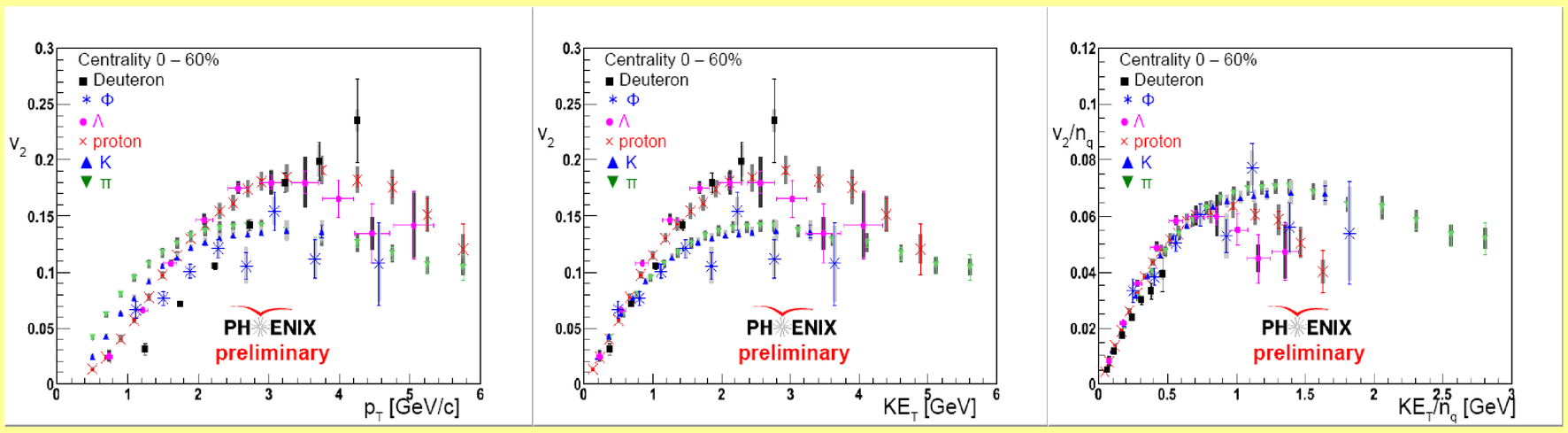
Hydro-dynamical model

Hydro-dynamic model is proposed to explain the large v_2 that is observed in relativistic heavy ion collision with radial collective expansion.
Thermalization at initial stage of collision and **low viscosity** of the medium are assumed, and elliptic flow is generated with anisotropy of pressure gradient in this model.



Points show the results of experiment at RHIC. lines show the results of theoretical calculation of hydro-dynamic model. They are consistent.

Result1 Measured v_2 in Au+Au $\sqrt{s_{NN}}$=200 GeV collision

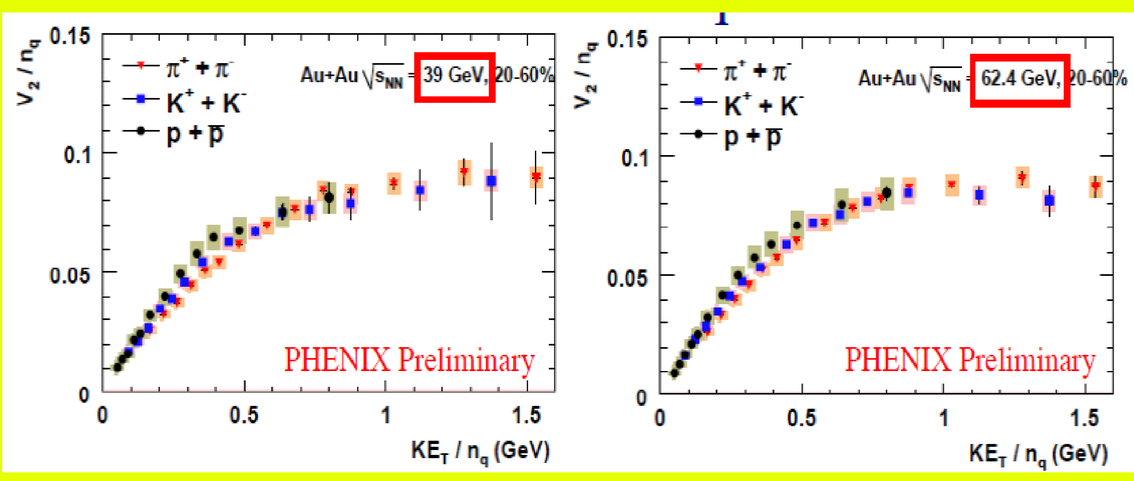


* These are characteristic for each particle species.
* Heavy particle is shifted to high momentum.
(Collective flow)
* Meson, baryon and deuteron are deviated at p_T>2GeV.
(Dependence of number of quark)

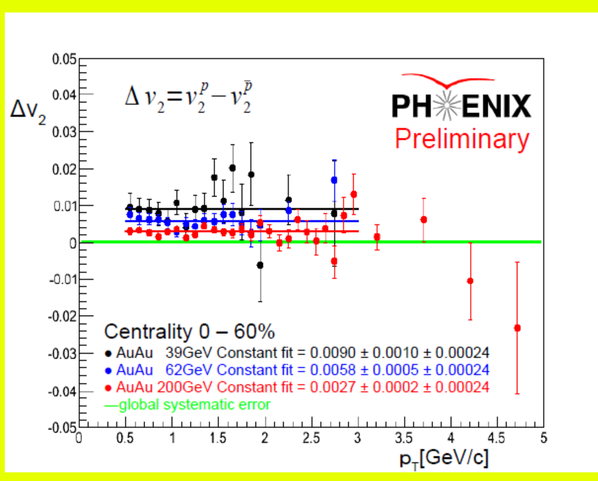
* The momentum shift is described with $KE_T=m_T-m_0$ scaling.
* They are consistent separately for meson, baryon and deuteron.

* All particles are consistent at KE_T/n_q<0.7 GeV.
* Number of constituent quark scaling agree the collective flow of quarks in the hot matter. It is an evidence of QGP phase.

Result2 measured v_2 in Au+Au $\sqrt{s_{NN}}$=62 and 39 GeV collision



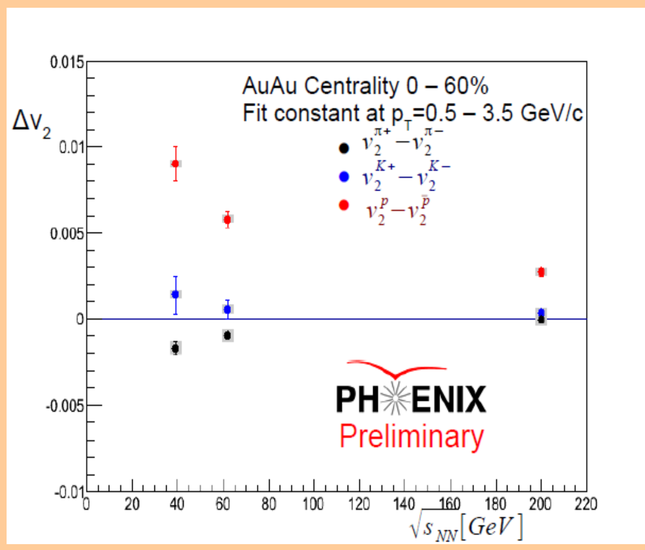
v_2 of pi K and p are almost scaled with number of quark and KE_T in low energy collision, too.
But proton is slightly large.



proton v_2 is larger than anti-proton v_2 in low energy collision which have large net-baryon ratio.

Summary

* Elliptic flow v_2 of particle identified hadron were measured for Au+Au $\sqrt{s_{NN}}$=200, 62 and 39 GeV collisions.
* Succession of Number of Constituent Quark Scaling for v_2 suggests collective flow of quarks in $\sqrt{s_{NN}}$=200 GeV.
* Proton v_2 leaving from anti-proton v_2 although the scaling holds almost in $\sqrt{s_{NN}}$=62 and 39 GeV.



This picture shows the difference v_2 between positive and negative particle as function of collision energy..
Proton v_2 and anti-proton v_2 are deviated at low energy range.