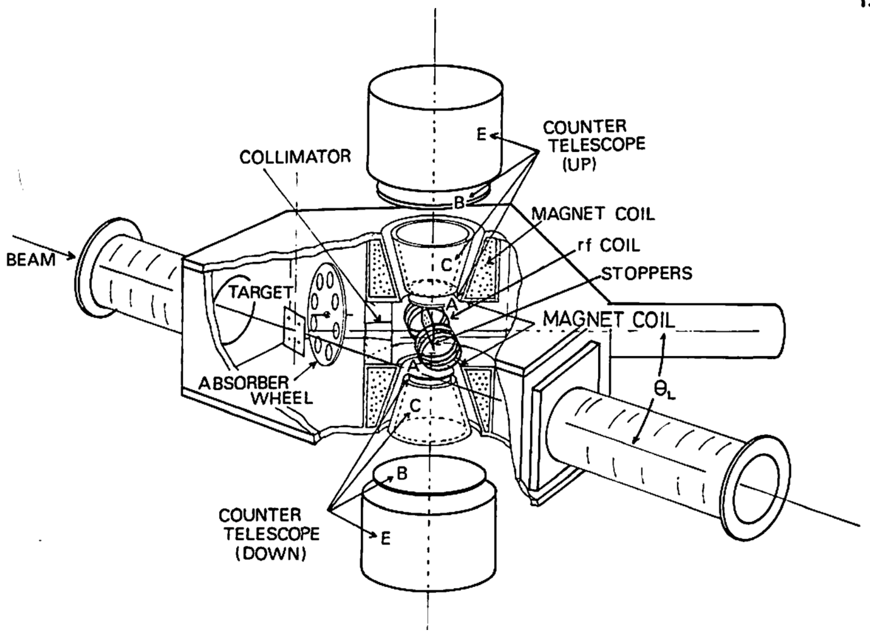
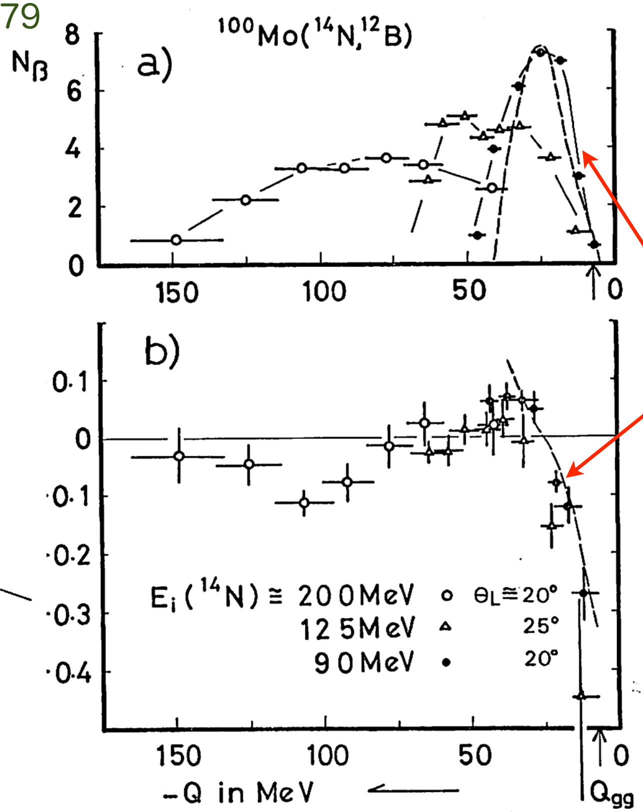
My first experiment and Tamura & Udagawa

Y. Miake, Thesis for Master degree, Osaka Univ.,1979





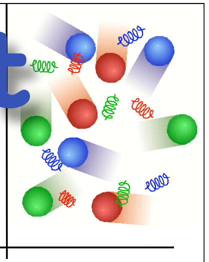
2 step DWBA by Udagawa & Tamura

✓Measurement of ^{12}B polarization

- $^{100}Mo(^{14}N,^{12}B)$, E_{Beam}= 130 GeV, 200 GeV

✓Working with N. Takahashi, Osaka Univ.

My name appeared as a first time in PRL of their paper



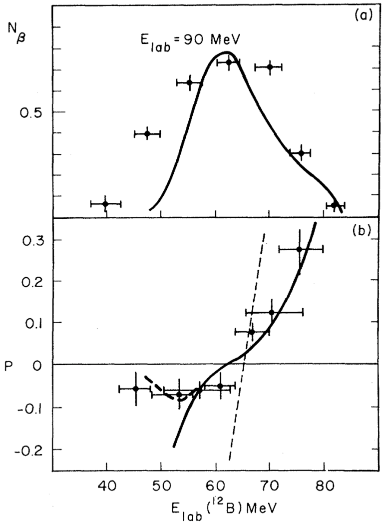
Phys. Rev. Lett. 41(1978)1770

Description of the Polarization of ^{12}B Produced in the Reaction $^{100}Mo(^{14}N,^{12}B)^{102}Ru$

T. Udagawa and T. Tamura
Department of Physics, The University of Texas, Austin, Texas 78712
(Received 2 August 1978)

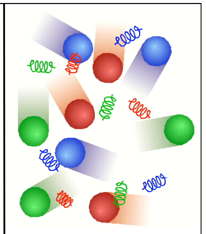
The polarization of ^{12}B produced in the reaction $^{100}Mo(^{14}N,^{12}B)^{102}Ru$ is explained in a fully quantum mechanical way. It is found that recoil plays a decisive role.

Recently we applied successfully a multistep direct reaction (MSDR) theory to explain continuous spectra of reactions induced by both light[5] and heavy[6] ions. The most important ingredient in making such calculations possible was to recognize that, in calculating continuous cross sec-



contribution is that $\psi \leq 0$. Very recently, Takahashi *et al.*[12] repeated the experiment of Ref. 1, but with $E_{lab}(^{14}N) = 200$ MeV, and found that P became positive again for $-Q \geq 100$ MeV. It may be that ψ has indeed become negative, and thus

But, spell of my name was wrong



VOLUME 41, NUMBER 26 PHYSICAL REVIEW LETTERS 25 DECEMBER 1978

P_1 is contributing positively. Work to test such a conjecture is also under way.

We are very much indebted to the authors of Refs. 1 and 12, in particular to Professor K. Sugimoto, Professor H. Kamitsubo, and Dr. M. Ishihar… We als… lating … read t… suppor… ergy.

Y. Miake → Y. Miyake

[14]N. Takahashi, Y. Miyake, Y. Nojiri, T. Minamisono, A. Mizobuchi, M. Ishihara, and K. Sugimoto, to be published.

[1]K. Sugimoto, N. Takahashi, A. Mitzobuchi, Y. Nojiri, T. Minamisono, M. Ishihara, K. Tanaka, and H. Kamisubo, Phys. Rev. Lett. 39, 323 (1977).

[2]*Proceedings of the Third International Symposium on Polarization Phenomena in Nuclear Reactions, Madison, Wisconsin, 1970*, edited by H. H. Barschall and W. Haeberli (Univ. of Wisconsin Press, Madison, Wis., 1971), p. 3.

[3]M. Ishihara, K. Tanaka, K. Kammuri, K. Matsuoka, and M. Sano, Phys. Lett. 73B, 281 (1978).

[4]D. M. Brink, Phys. Lett. 40B, 37 (1972).

[5]T. Tamura, T. Udagawa, D. H. Feng, and K. K. Kan, Phys. Lett. 66B, 109 (1977); T. Tamura and T. Udagawa, Phys … , 273 (1977).

[6]T … , B. T. Kim, and T. Tamura, in Proceed… …IPCR (Institute of Physical and Chemical …rch) Symposium, Hakone, Japan, September …977, edited by H. Kamitsubo and M. Ishihara (unpublished), p. 3.

…78 …ana, …99

[10]S. Cohen and D. Kurath, Nucl. Phys. A101, 1 (1967).

…W. F. Frahn, Nucl. Phys. A272, 413 (1976).

[12]…ecisely speaking Γ_b, Γ_d, and ψ all depend on the Q val… This dependence is rather weak, however, and this …s neglected in the present calculations for simplicity.

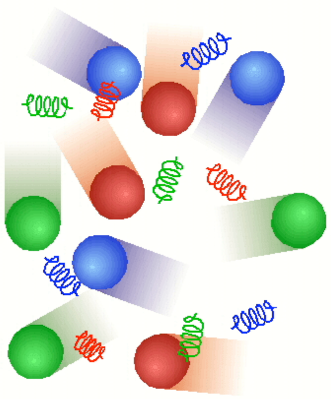
[13]In princip… N_0 may differ greatly for normal and non-normal l's, pa…ticularly if the energy of the incident particle is low. …ith energy of the present reaction the dependence of N …on l, whether normal or non-normal, turned out to be …ery weak and we used a common value for all of them.

[14]N. Takahashi, Y. Miyake, Y. Nojiri, T. Minamisono, A. Mizobuchi, M. Ishihara, and K. Sugimoto, to be published.

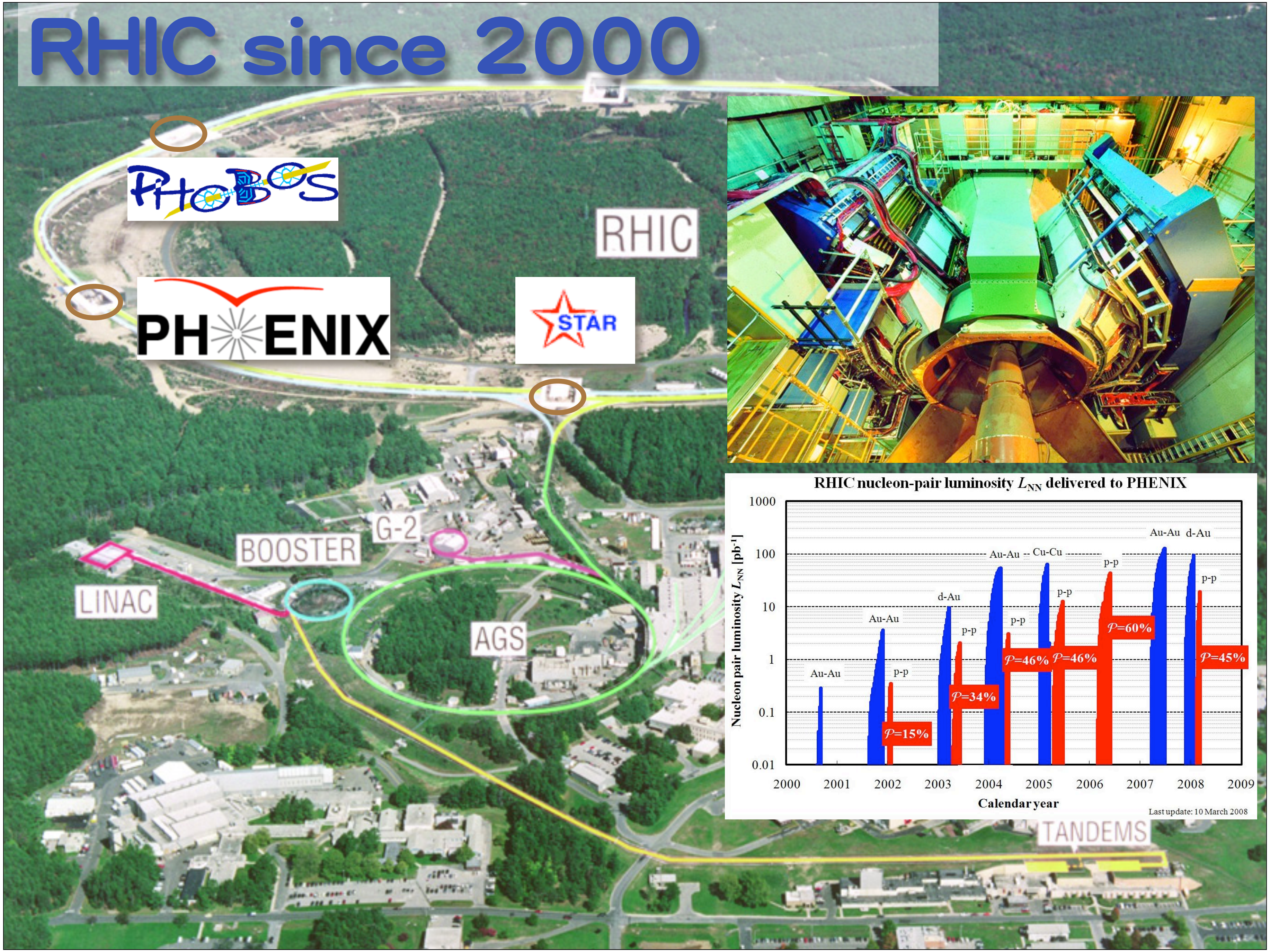
Flow measurements in heavy ion coll.

Scaling properties of v_2 re-visited with Blast Wave Model

Yasuo MIAKE
Univ. of Tsukuba



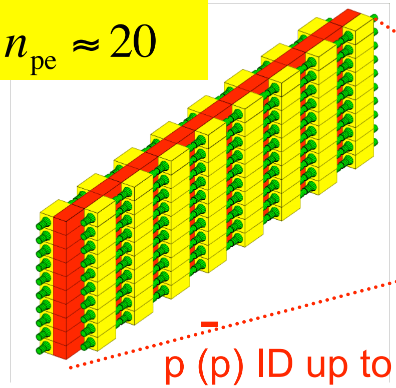
RHIC since 2000

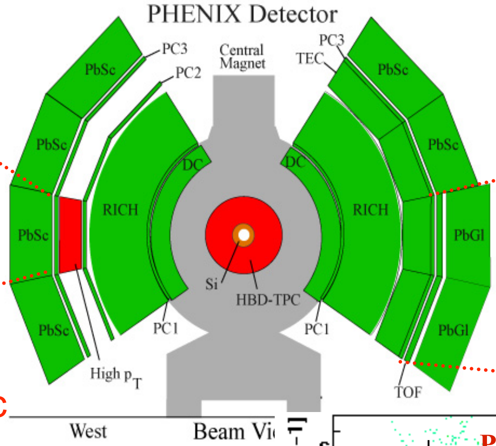


Tsukuba Contribution
1) PID with TOF & Aerogel

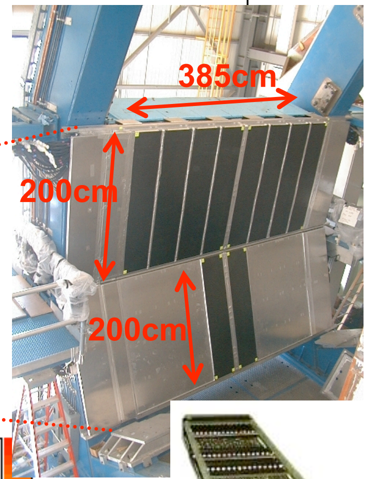
$n_{\text{index}} = 1.012$

$n_{pe} \approx 20$

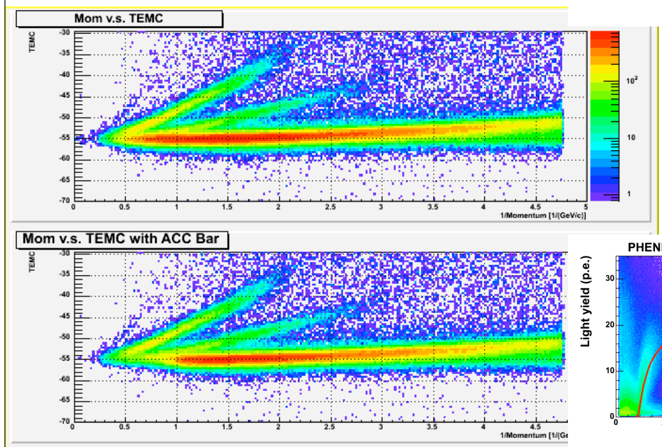


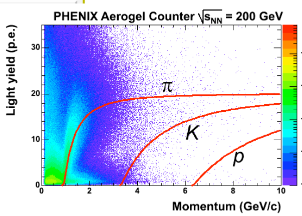


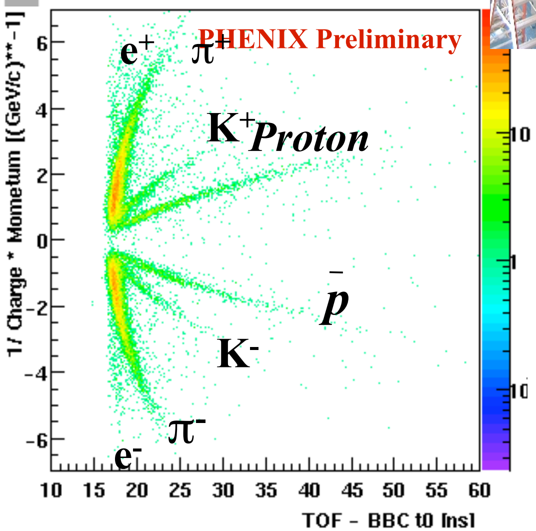
$\sigma_{TOF} \leq 100\text{ps}$

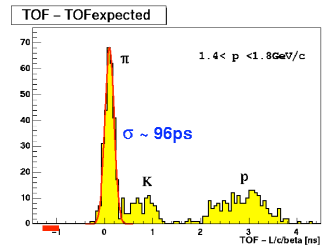


p ($\bar{p}$) ID up to 8 GeV/c









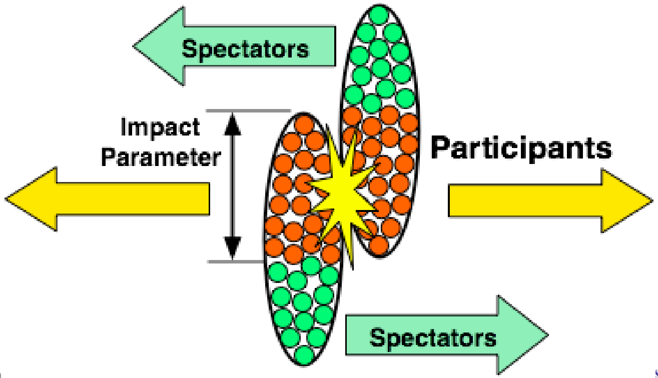
p ($\bar{p}$) ID up to 4 GeV/c

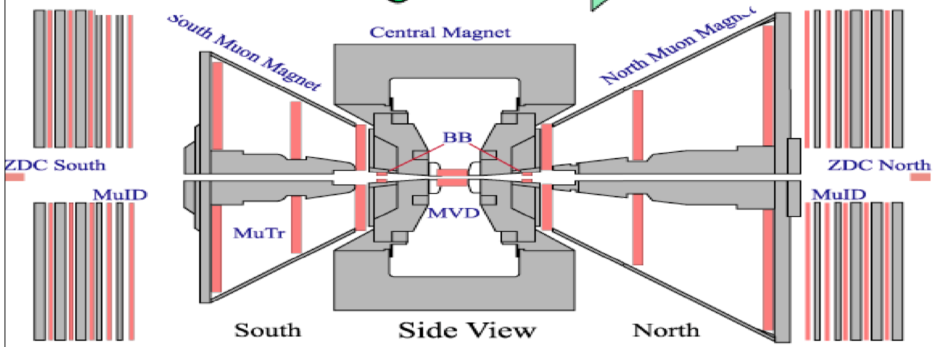
√ High resolution TOF and low index of 1.01 Aerogel Cherenkov

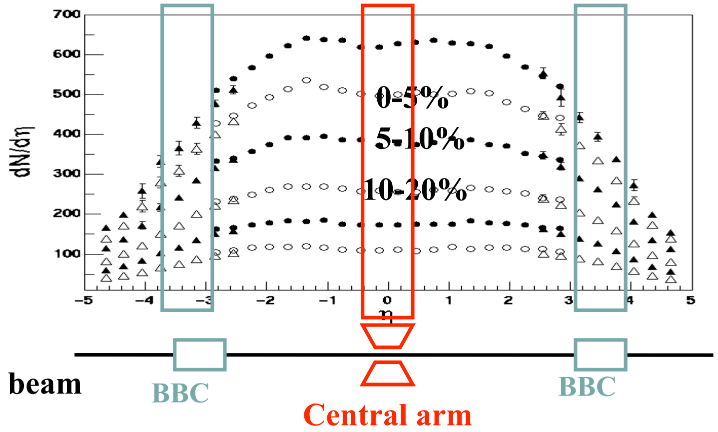
- Both Tsukuba contribution

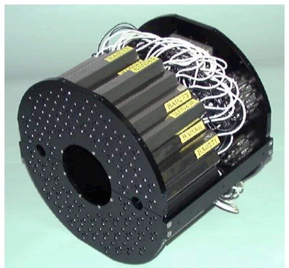
Tsukuba Contribution
2) R.P. determination

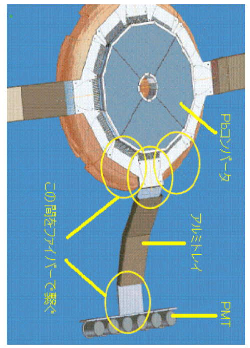
S. Esumi, Tsukuba

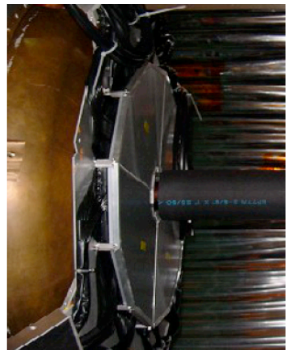












√Wide rapidity gap from central detector

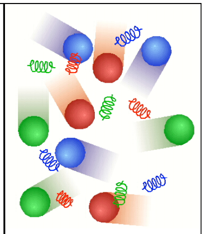
- Free from other source of corr such as HBT, decays, jets & auto-corr.

√Corr. between SMD(spect) and BBC(part) also confirmed

➡R.P. determination from whole event wide

√Detector for Reaction Plane determination

Key ; Statistical Nature



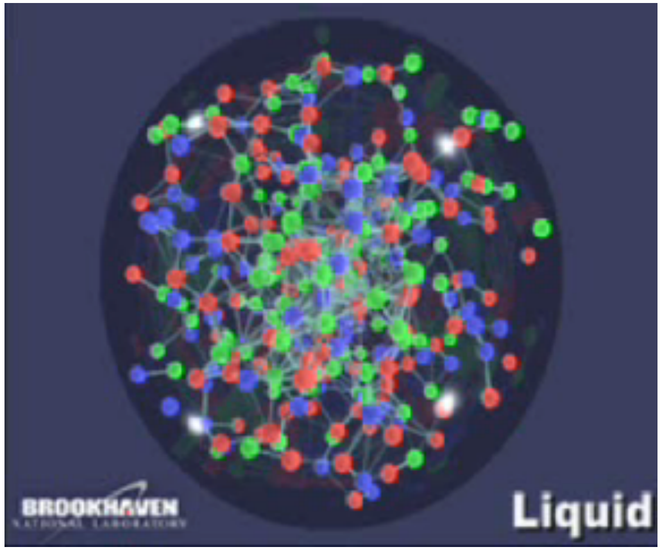
$$\epsilon_{\mathrm{QGP}} \sim 2\ [\mathrm{GeV/fm^3}]$$ ← **Ex. Lattice QCD**

$$< n_{q,\bar{q}} > \sim \frac{\epsilon_{\mathrm{QGP}}}{< m_T >} \sim \frac{2\mathrm{GeV}}{0.4\mathrm{GeV}} \sim 5$$

$$\lambda_q = \frac{1}{n\sigma_{qq}} \sim \frac{1}{5 \times 0.4} = 0.5\ [\mathrm{fm}]$$

$$\lambda_q \ll R_{\mathrm{system}}$$

$$\because \sigma_{qq} \sim \frac{\sigma_{NN}}{3 \times 3} \sim \frac{4[\mathrm{fm}^2]}{9} \sim 0.4$$

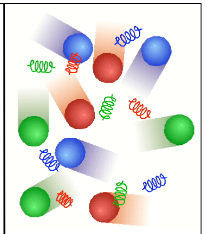


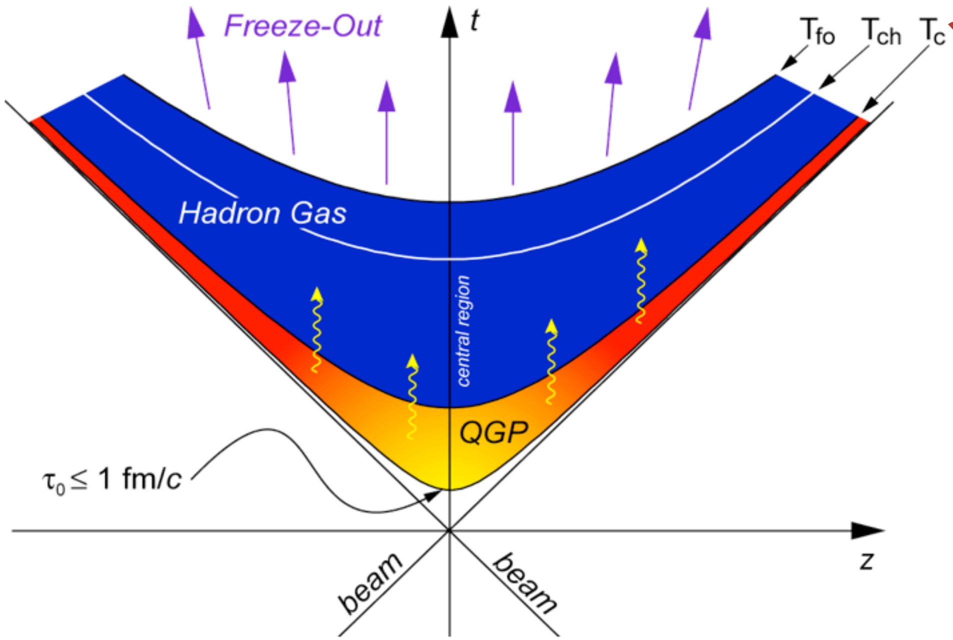
Animation by Jeffery Mitchell (Brookhaven National Laboratory). Simulation by the UrQMD Collaboration

✓ What we can expect:

- **Statistical physics at quark level**
- **Hydrodynamical behavior at quark level**

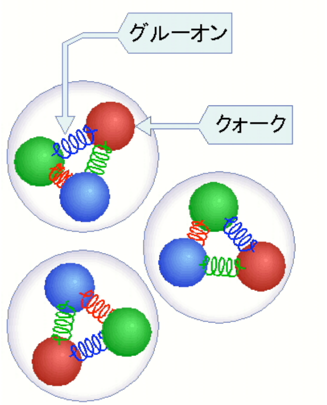
Key; Time Evolution



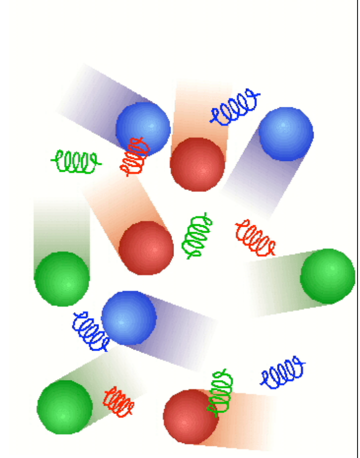


- ✓ It is like Big Bang.
- ✓ Time evolution in statistical nature
  - Parton cascade followed by partonic thermalization (QGP)
  - Hadron production
  - Freezeout of v_2 ?
  - Chemical freeze-out
  - Kinematical freeze-out

Need consistent understanding of these epocs, in particular, aspects of statistical nature.

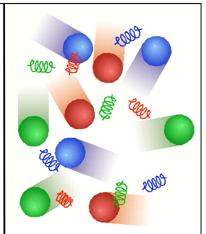


Thermal Eq. and Collective Flow

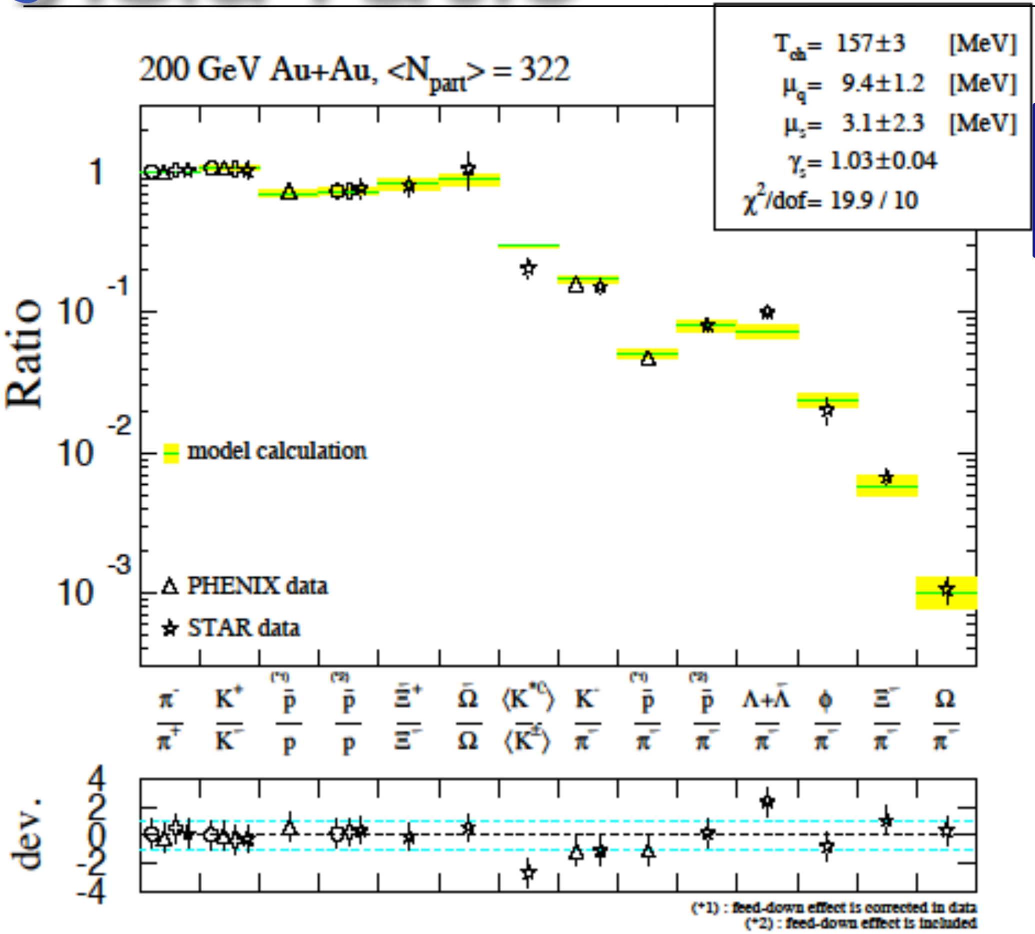


- ★ Chemical Eq. from particle yield ratio
- ★ Kinematical Eq. from transverse mom. distr.
- ★ Blast Wave

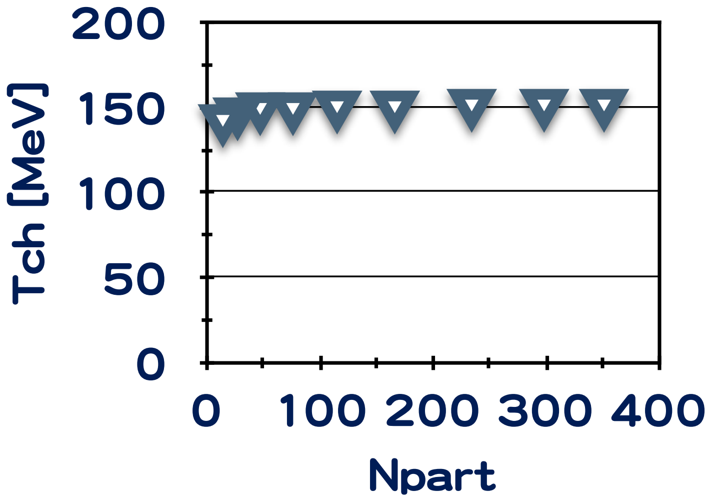
Chemical Eq. from particle yield ratio



M.Kaneta, N.Xu, nucl-th/0405068

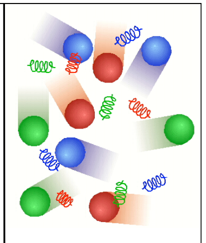


$$n_i = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{(E_i-\mu_i)/T} \pm 1}$$



- √Only few parameters fit every ratio very well !
- √T_{ch} stays constant from peripheral to central collisions

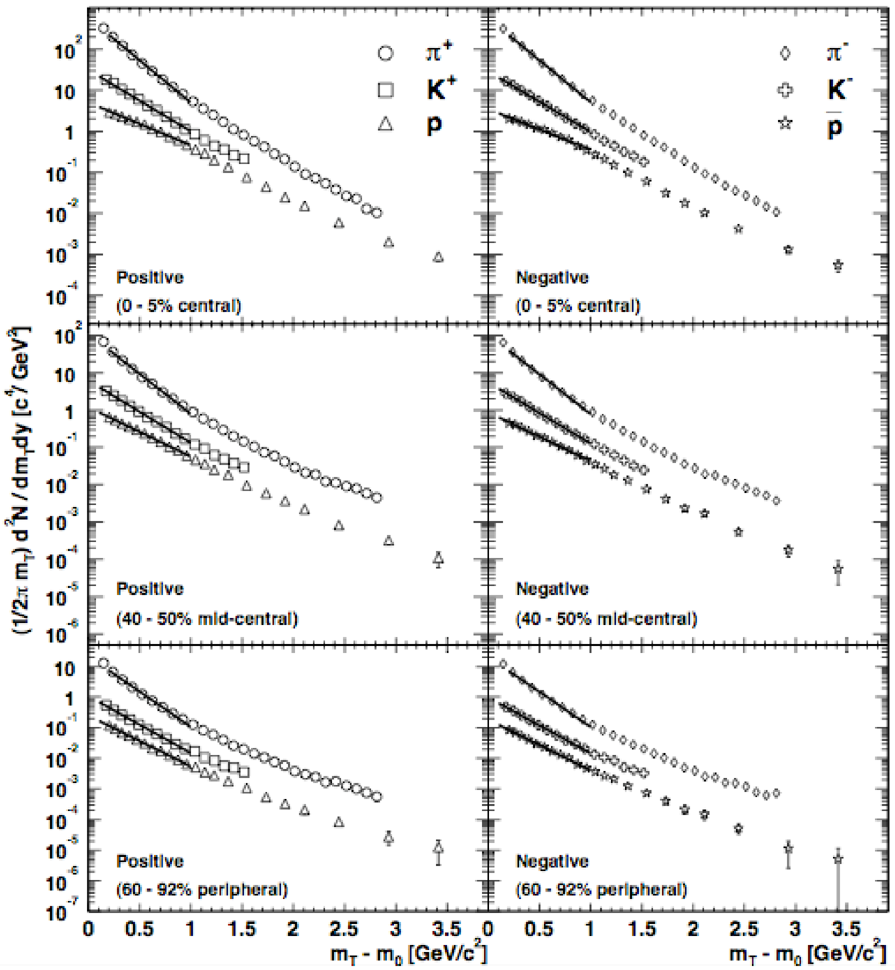
Kinematical Distr.: Transverse mass distr.

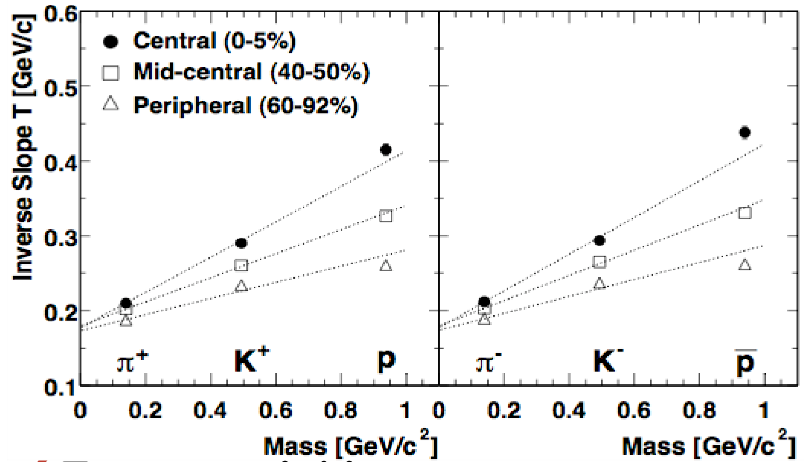


$$m_t = \sqrt{p_t^2 + m^2}$$

$$\frac{d^2N}{2\pi m_T dm_T dy} = \frac{1}{2\pi T(T+m_0)} A \exp\left(-\frac{m_T - m_0}{T}\right)$$

PHENIX, PRC69,034909(2004)

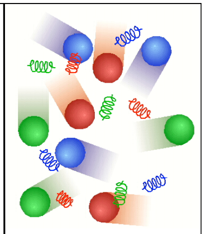




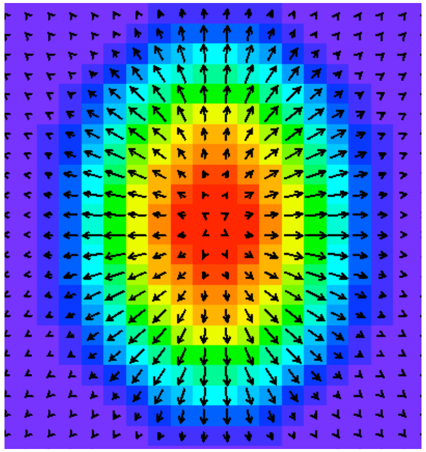
- ✓ Exponential in m_t
  - Known as m_t scaling
  - Thermal distr.
- ✓ Flatter m_t distr for heavier particle mass
  - Mass Ordering of Slope param.
  - Effect of Collective Flow

$$T \approx T_0 + \frac{1}{2} m \langle v_r \rangle^2$$

Collective Flow



Blast Wave Model



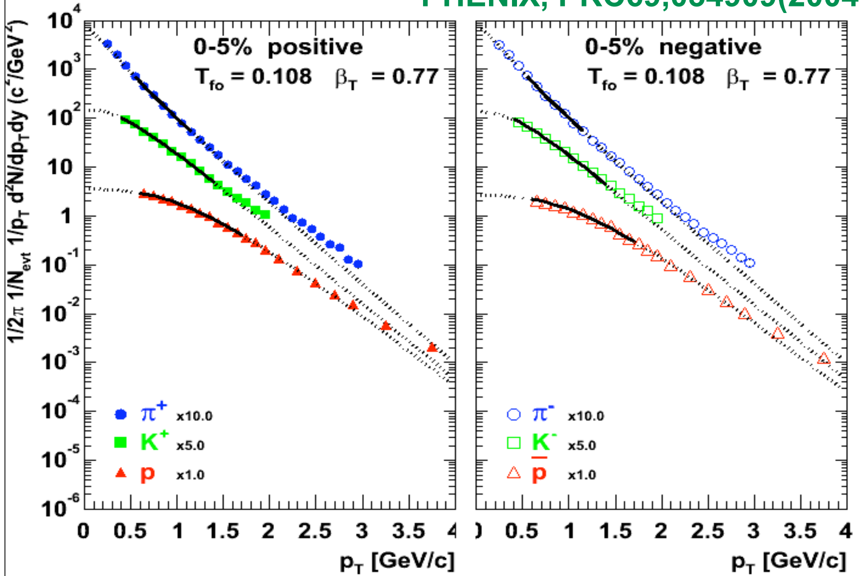
$$\frac{1}{m_T}\frac{dN}{dm_T} = A\int_0^R f(r)\,r\,dr\,m_T\,\mathrm{I}_0\left(\frac{p_T\sinh\rho}{T_{fo}}\right)\mathrm{K}_1\left(\frac{m_T\cosh\rho}{T_{fo}}\right)$$

PRC48(1993)2462.

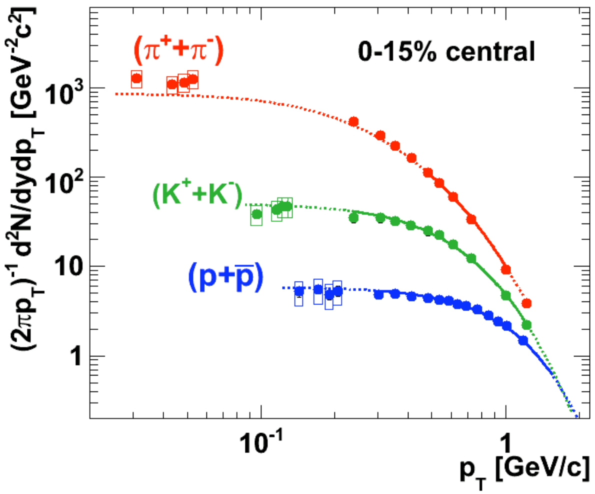
$$\rho(r) = \tanh^{-1}(\beta_T)\cdot r/R$$

$\mathbf{I_0}$, $\mathbf{K_1}$: modified Bessel function

PHENIX, PRC69,034909(2004)

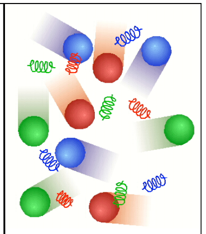


Phobos, J.Phys.G34,S1103-7(2007)



- ✓ Good tool to separate thermal and collective
- ✓ Well describe < 2 GeV/c

Original Blast Wave Model

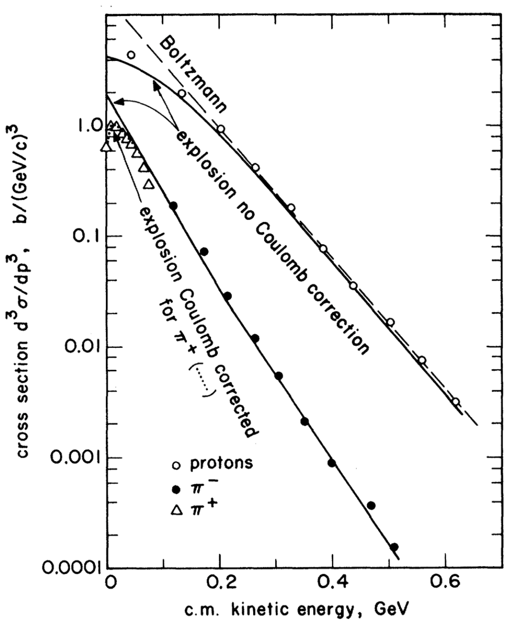


VOLUME 42, NUMBER 14 PHYSICAL REVIEW LETTERS 2 APRIL 1979

Evidence for a Blast Wave from Compressed Nuclear Matter

Philip J. Siemens[(a)] and John O. Rasmussen
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 27 November 1978)

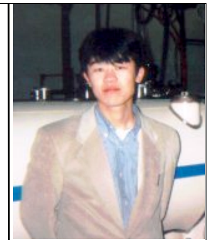
Central collisions of heavy nuclei at c.m. kinetic energies of a few hundred MeV per nucleon produce fireballs of hot, dense nuclear matter. Each fireball explodes, producing a blast wave of nucleons and pions. Several features of the observed cross sections for pions and protons from Ne on Na F at 0.8 GeV/nucleon (lab) are explained by the blast wave, but contradict earlier, purely thermal models. The available energy is equally divided between translational energy of the blast, and thermal motion of the paritlces in the exploding matter.



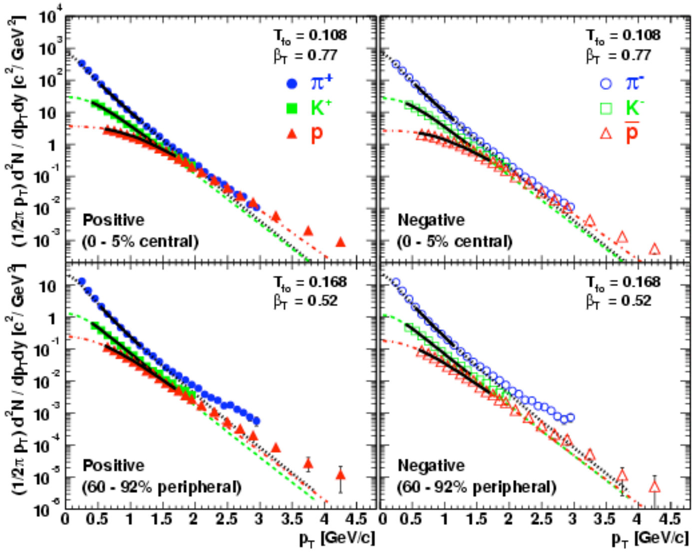
✓ Collective Flow

✓ Adiabatic expansion

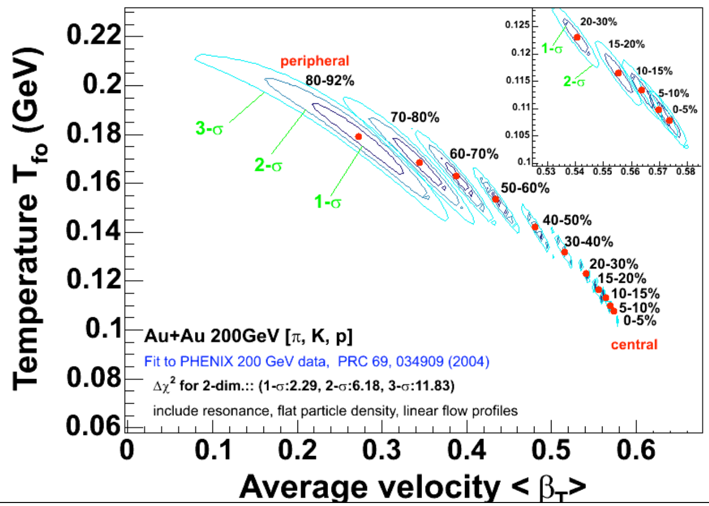
Tested Robustness of Blast Wave results

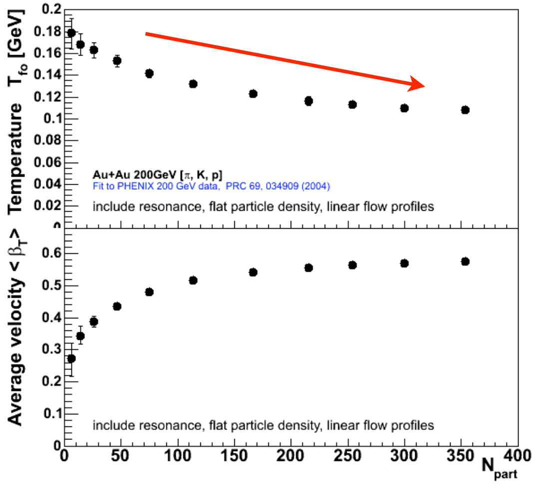


A Kiyomichi, Tsukuba



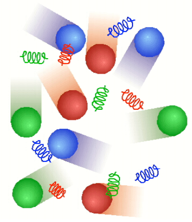
- ✓ Result of Blast Wave analysis depends very much on the pt range for the fitting.
  - ➡ Significant amount of decayed particles at low pt region
- ✓ Substract decay products first, then fit the spectra with Blast Wave Model.
  - Thesis of Akio Kiyomichi

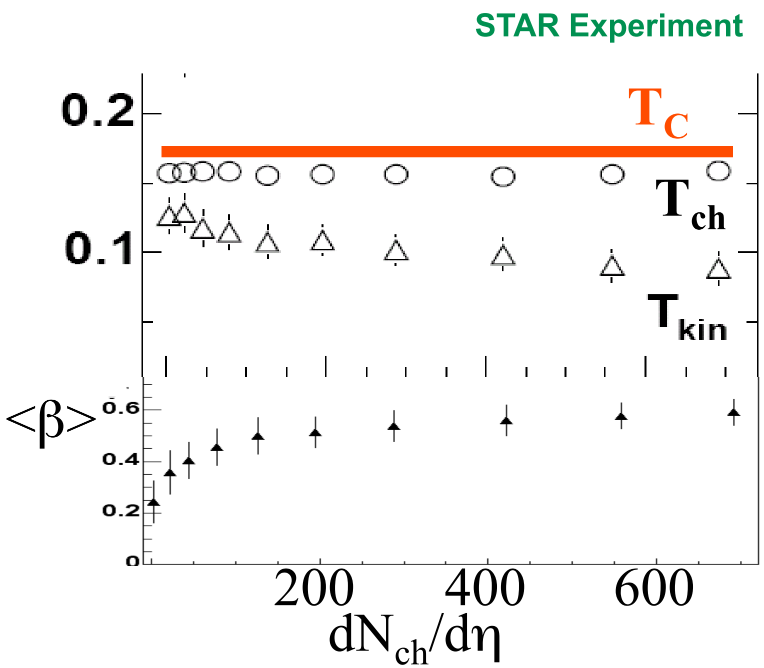




Lower T_{kin} in central collisions

Distinct feature of freeze-out conditions



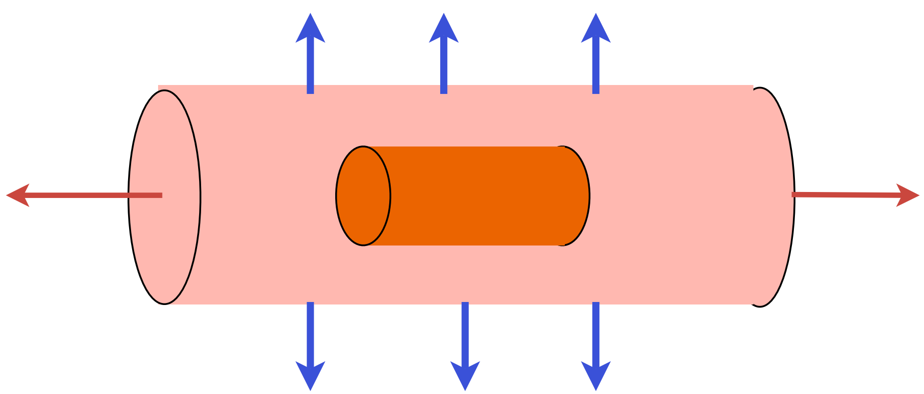


√Difference of T_{ch} and T_{kin} corresponds to time evolution of the system.

√Kinematical & Chemical freeze-out show difference in centrality dependence!

➡Might be difference in Nature of Freeze-out

Adiabatic Expansion Model



$$V(t) = ct\pi R(t)^2 = ct\pi(R_0 + \beta_T t)^2$$

$$\frac{V(t_{fo})}{k n_{part}\sigma} \sim R(t_{fo})$$

$$t_{fo} = \frac{\sqrt{R_0^2 + 4\frac{k\sigma}{c\pi}\beta_T n_{part}} - R_0}{2\beta_T}$$

$$T(t_{fo}) = T_0\left(\frac{V_0}{t_{fo}(R_0 + \beta_T t_{fo})^2}\right)^{1/3}$$

✓Intuitive Model

✓Assuming,

- Cylindrical expansion
- Freeze-out condition

$$\lambda = \frac{1}{n\sigma} \sim R$$

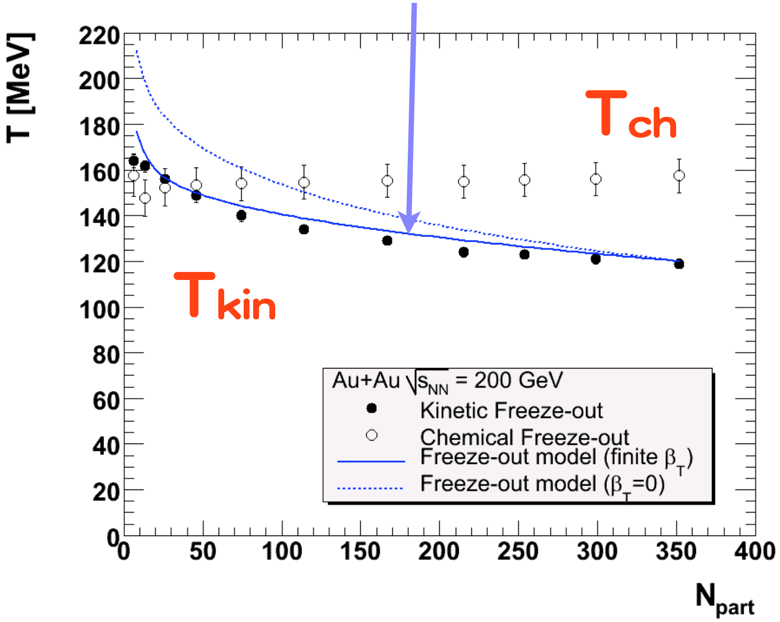
- Adiabatic expansion

$$T^3(t)V(t) = \text{Const.}$$

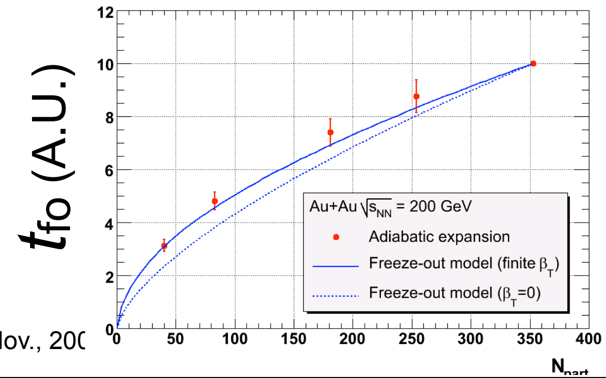
$$(\because s \propto T^3)$$

✓Larger fireball freeze out later

Kinematical Freeze-out w. Adiabatic Expansion



Central collisions freeze-out late.

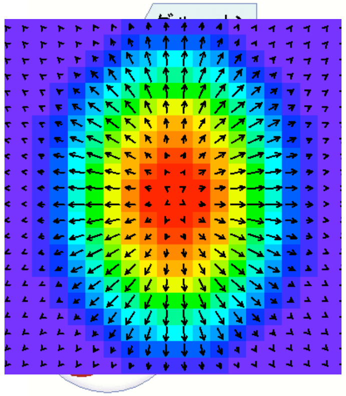


✓ Adiabatic Expansion Model explains centrality dependence very well.

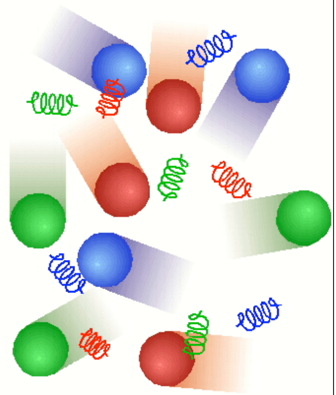
- Freeze-out conditions ; λ ~R

✓ In central collsions, the F.B. is so large that F.O. occurs later than peripheral.

➡ Kinematical freeze-out is collisional, while chemical is not.

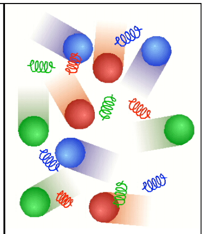


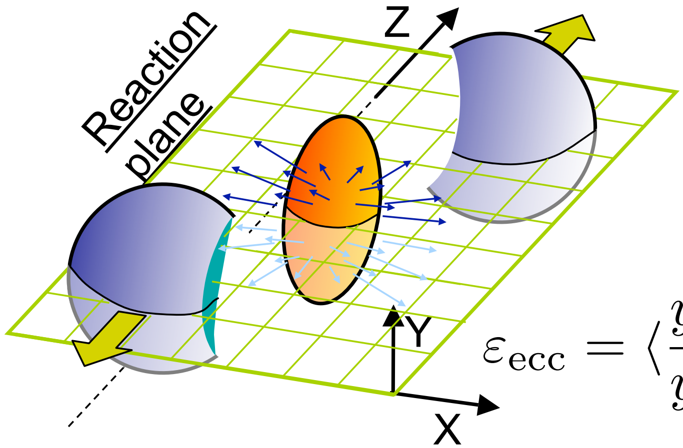
Further Study of Collective Flow



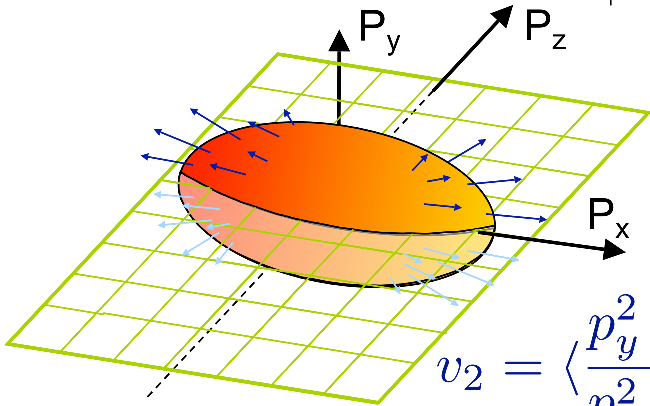
Azimuthal Anisotropy
of
Collective Flow,
Elliptic Flow

Elliptic Flow, v_2 (Azimuthal Anisotropy)





$$\varepsilon_{ecc} = \langle \frac{y^2 - x^2}{y^2 + x^2} \rangle$$



$$v_2 = \langle \frac{p_y^2 - p_x^2}{p_y^2 + p_x^2} \rangle$$

✓ In non-central collisions, participant region has almond shape.

➡azimuthal anisotropy in coordinate space

✓ If $\lambda \ll R$, azimuthal anisotropy of the coordinate space is converted to that of the momentum space.

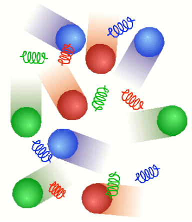
➡v_2 ; second Fourier harmonics of azimuthal distribution

✓ Goodies :

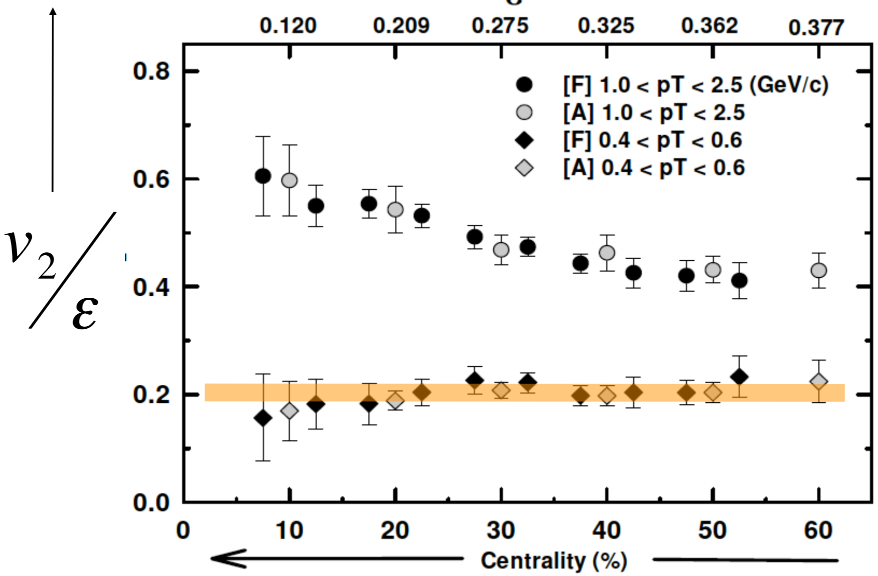
- Clear origin of the signal
- Collision geometry can be determined experimentally

$$N(\phi) = N_0\{1 + 2v_1\cos(\phi - \Psi_0) + 2v_2\cos(2(\phi - \Psi_0))\}$$

Early study of v_2 vs. ε_{ecc}



Phenix; PRL 89(2002)212301



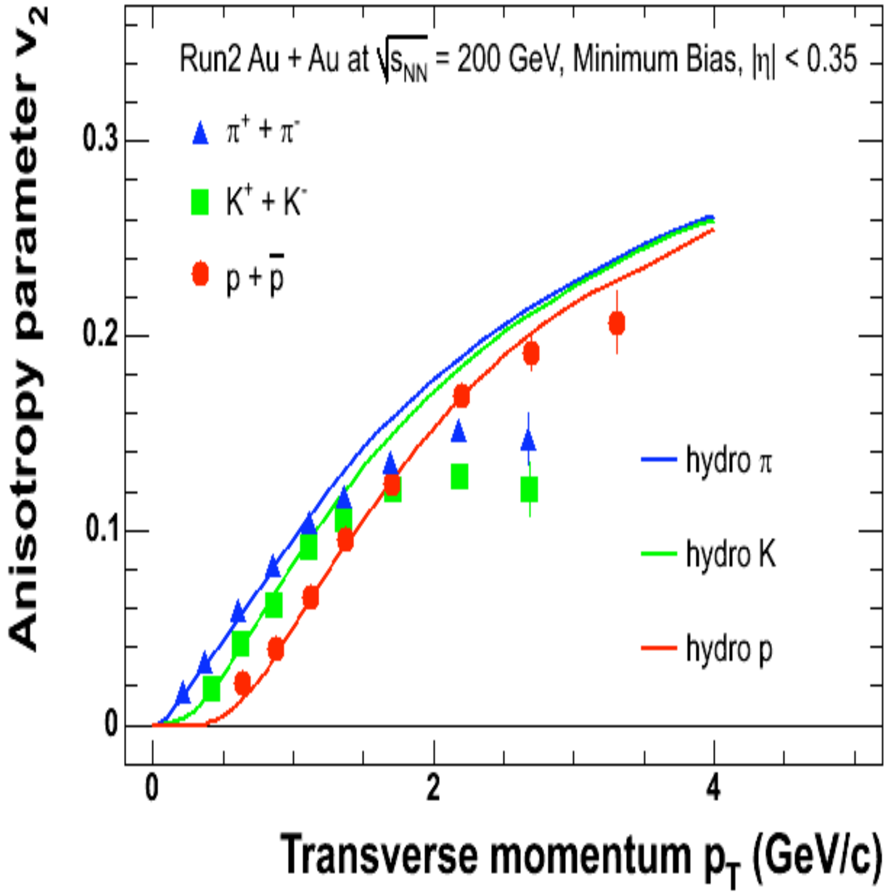
$\because \langle v_2 \rangle \propto \varepsilon$

- ✓ Eccentricity is evaluated from centrality of collisions
- ✓ Ratio stays ~constant
  - Eccentricity scaling observed in comparison of Au+Au, Cu+Cu
    - →Scaling with eccentricity shows v_2 builds up at early stage

v_2 of identified particle

S. Esumi, Tsukuba

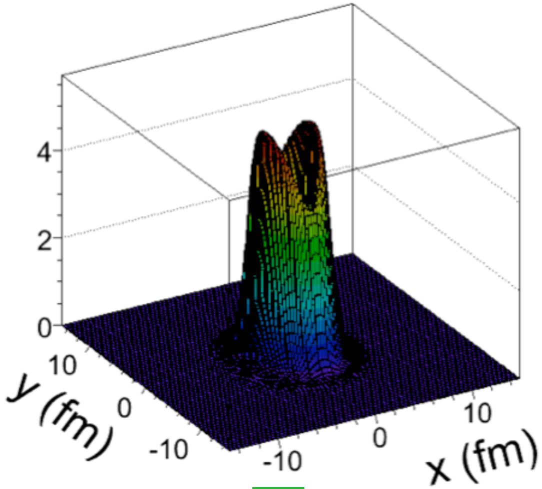
PHENIX : P.R.L. 91, 182301 (2003)



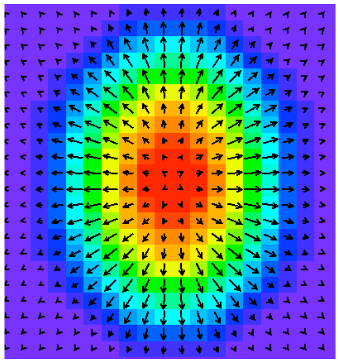
- ✓ Mass Ordering of v_2 at low p_t region:
  - ➡Existence of collective flow
- Good agreement with hydrodynamics of perfect fluid
  - ➡Early thermalization (~0.6 fm/c)
  - ➡High energy density (~20 GeV/fm³)
  - ➡Very low viscosity
- ✓ Departure at high pt region (> 1.5 GeV/c);
  - ➡Other mechanism?

Extended Blast Wave Fit 1

Initial Density Profile



Final Velocity Profile



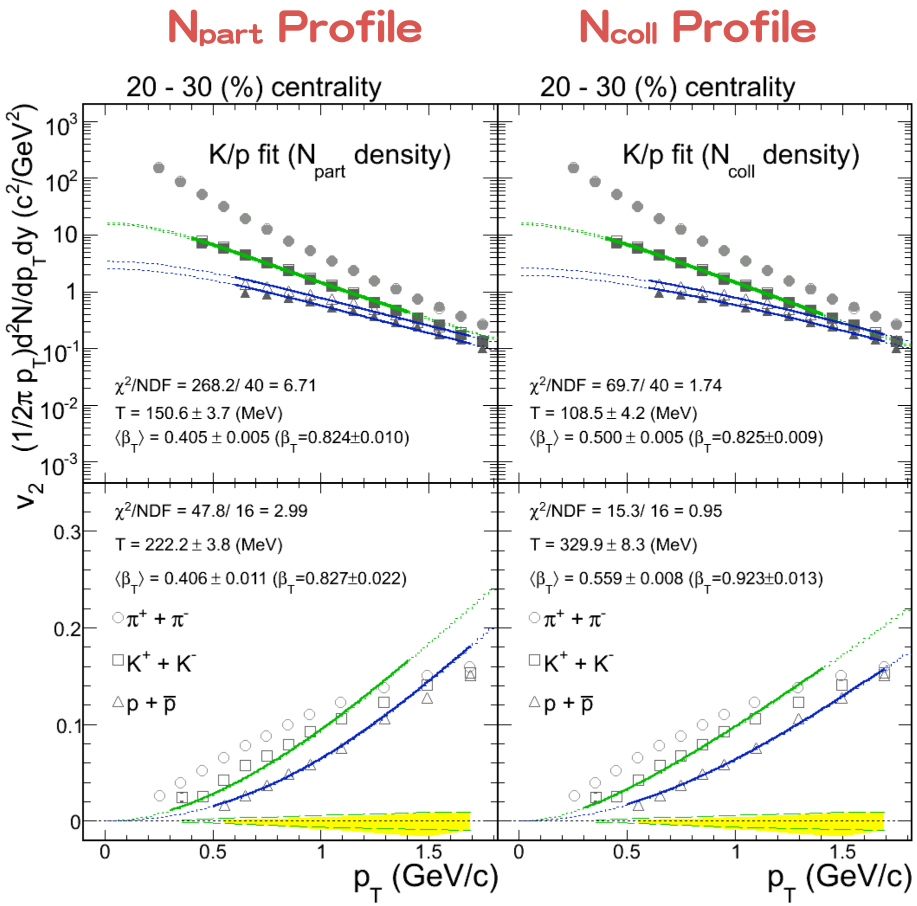
Extended Blast Wave Fitting (H. Masui, Y.M. 2007)

- √ With hydrodynamics, ∇p generates collective flow.
- √ Assuming p∝ρ, velocity profile is obtained from initial density profile ρ.
  - ➡Freeze-out time for v_2 =0
  - ➡Yes, very/too naive, but see what happens. Fun!
- √ Choice of density profile
  - Glauber Model ; N_{part}
  - Glauber Model ; N_{coll}

Extended Blast Wave Fit 2

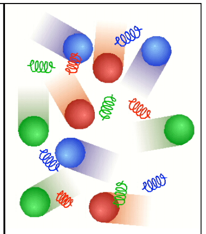
H. Masui, Tsukuba

D.Thesis, H. Masui, Univ. of Tsukuba (2008)



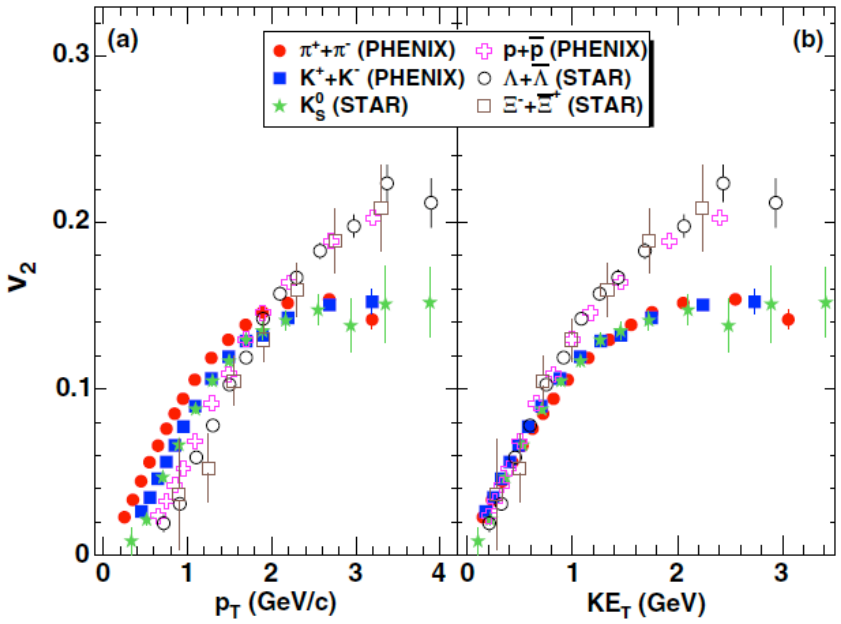
- ✓ It was fun to see;
  - N_{coll} distr. seems to give better fitting
  - T from v_2 is much higher than T from spectra, while β is very similar.
- ✓ But, fitting does not work at all,
  - for pions,
  - for centrality dep.
  - High T from v_2 may imply finite freeze-out time.

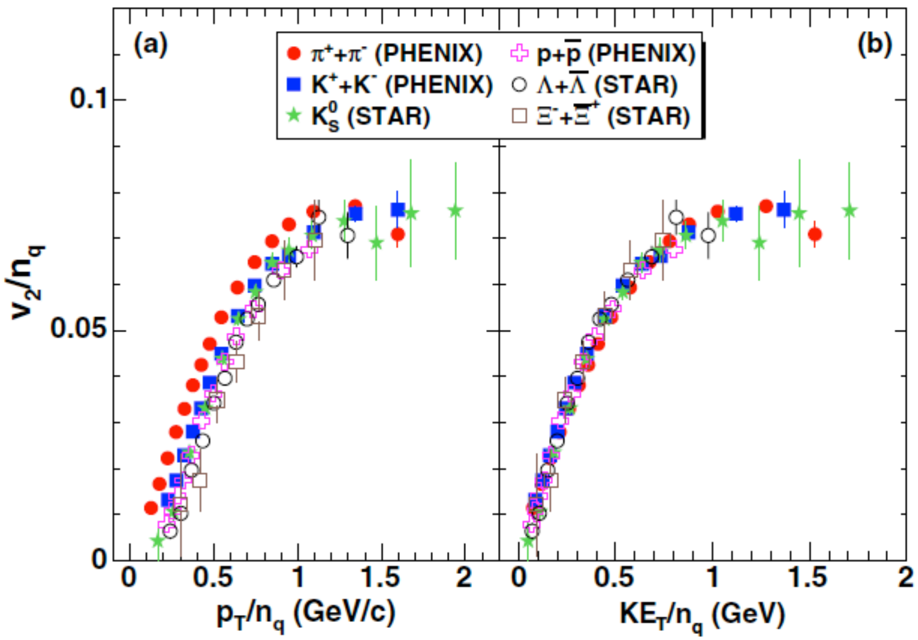
Beautiful scalings of v_2



PHENIX PRL 98(2007)162301

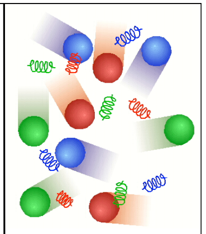
Au+Au 200 GeV

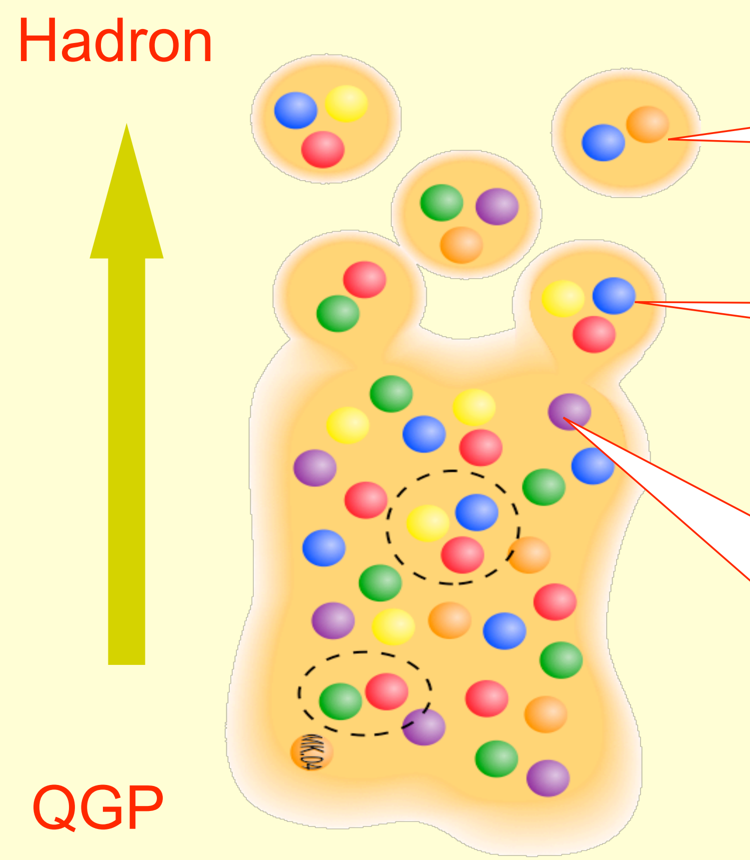




✓ m_t scaling & quark number scaling

Hadronization via Quark Coalescence





Because of the steep distr. of *w(pt), RECO* wins at high pt even w. small *Cx*.

✓ **Quarks, anti-quarks combine to form mesons and baryons from universal quark distribution, w(pt).**

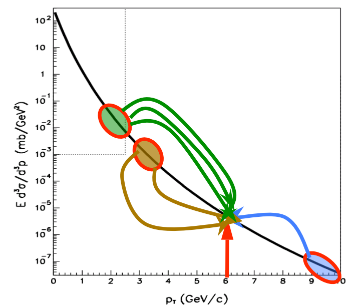
Mom. distr. of meson (2q);

$$W_M(p_t) \approx C_M \cdot w^2(p_t/2)$$

Mom. distr. of baryon (3q);

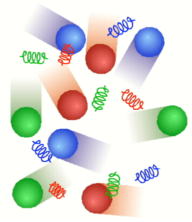
$$W_B(p_t) \approx C_B \cdot w^3(p_t/3)$$

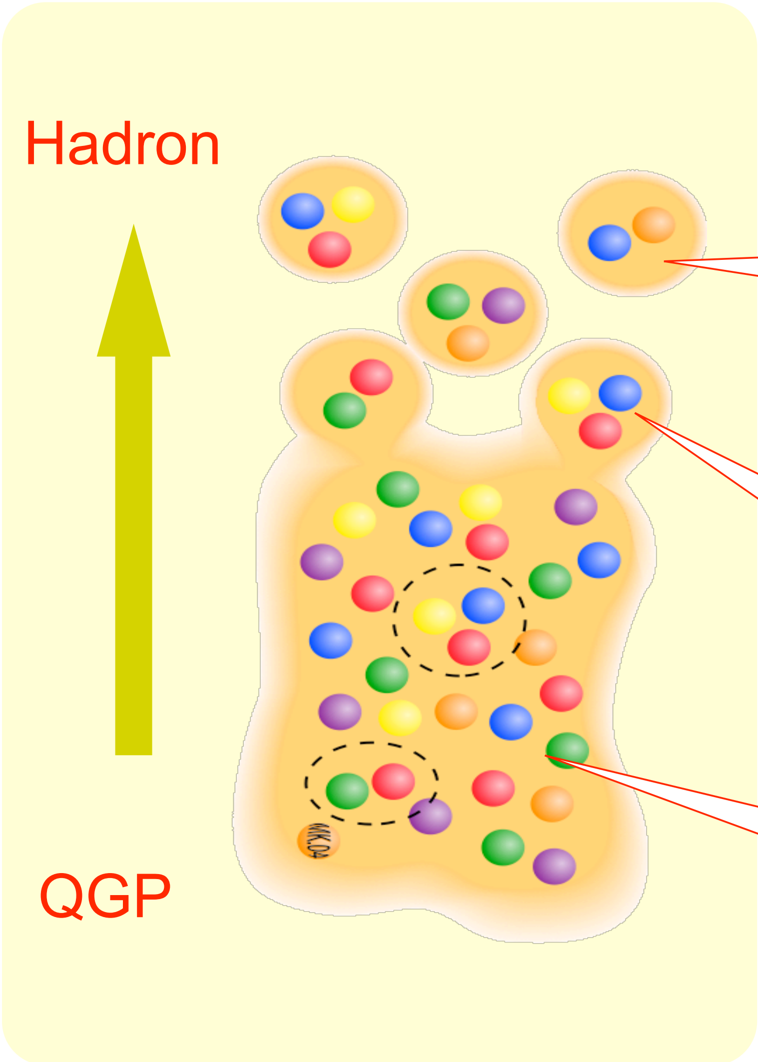
w(pt);
Universal mom. distr. of quarks
{*steep in pt*}



Characteristic scaling features expected.
➔Quark Number Scaling (QNS)

Hadronization via Quark Coalescence (QNS in v2)





✓**Characteristic scaling behavior**

→**Quark Number Scaling**

Azimutal distr. of meson (2q);

$$\frac{dN_M}{d\phi} \propto w^2 = (1 + 2v_{2,q}\cos 2\phi)^2$$

$$\approx (1 + 4v_{2,q}\cos 2\phi)$$

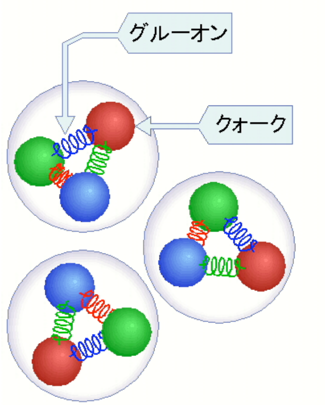
Azimuthal distr. of baryon (3q);

$$\frac{dN_B}{d\phi} \propto w^3 = (1 + 2v_{2,q}\cos 2\phi)^3$$

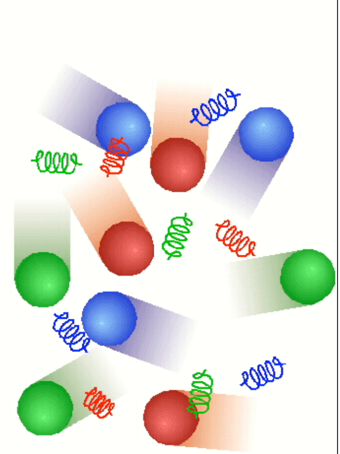
$$\approx (1 + 6v_{2,q}\cos 2\phi)$$

Azimuthal distr of quark; w

$$w \propto (1 + 2v_{2,q}\cos 2\phi)$$



Further Systematics of v_2



Centrality dep.

Energy dep.

→200 vs 64 GeV

System size dep.

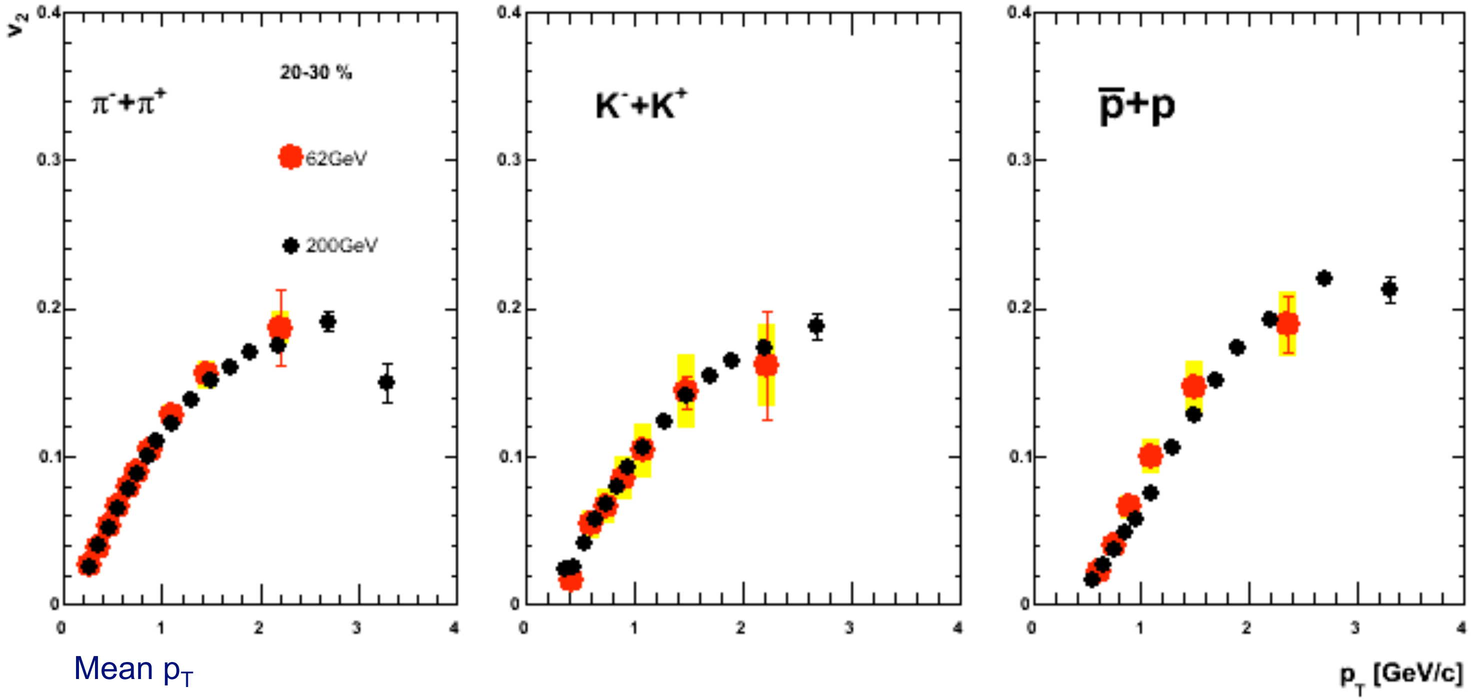
→Au+Au vs Cu+Cu

H. Masui, Tsukuba

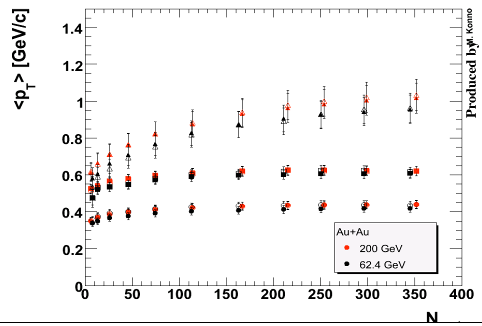
Au+Au 200 vs 64 GeV

D. Thesis soon, M. Shimomura, Univ. of Tsukuba (2008)

PHENIX PRELIMINARY



Mean p_T

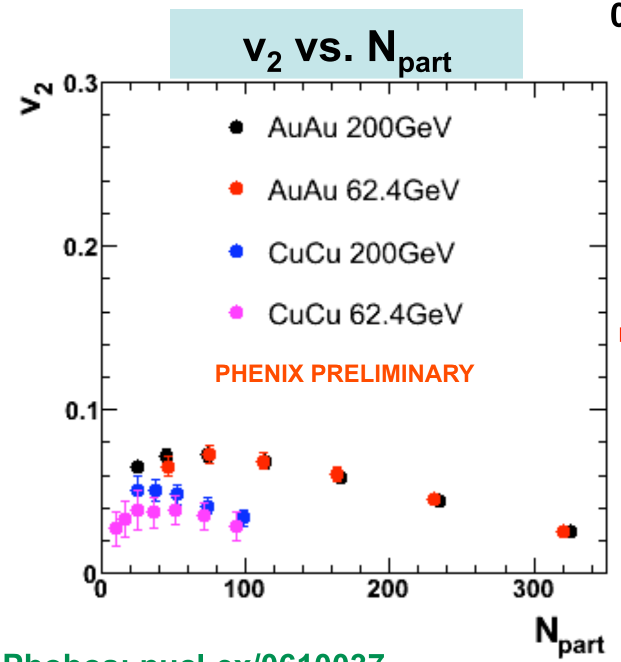


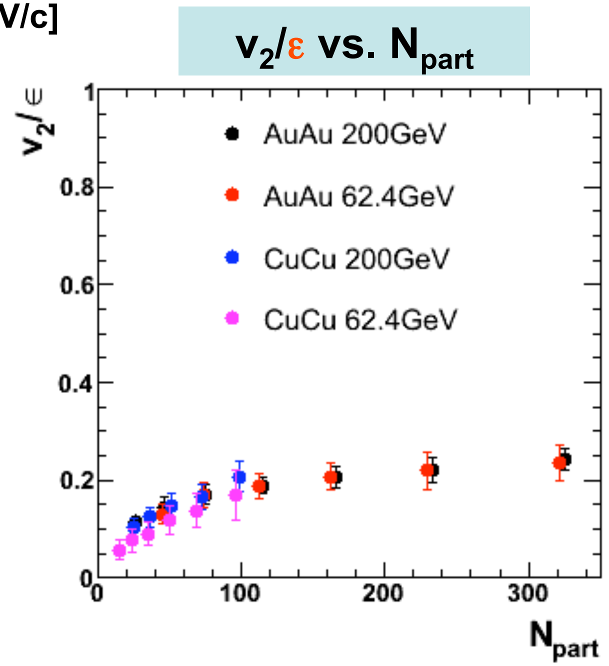
- ✓ No significant change in v2
- ✓ A little larger radial flow seen in <pt> of 200 GeV

Au+Au vs Cu+Cu

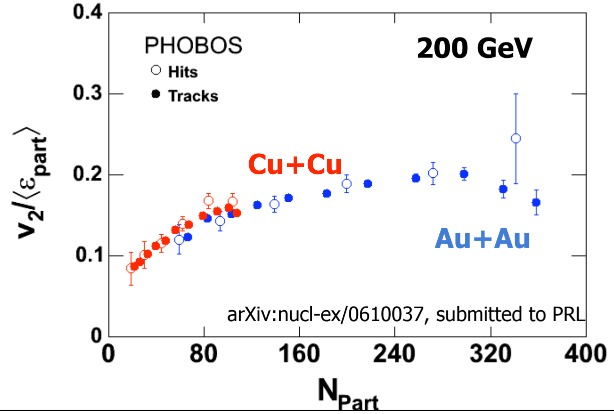
M. Shimomura, Tsukuba

0.2<p_T<1.0 [GeV/c]





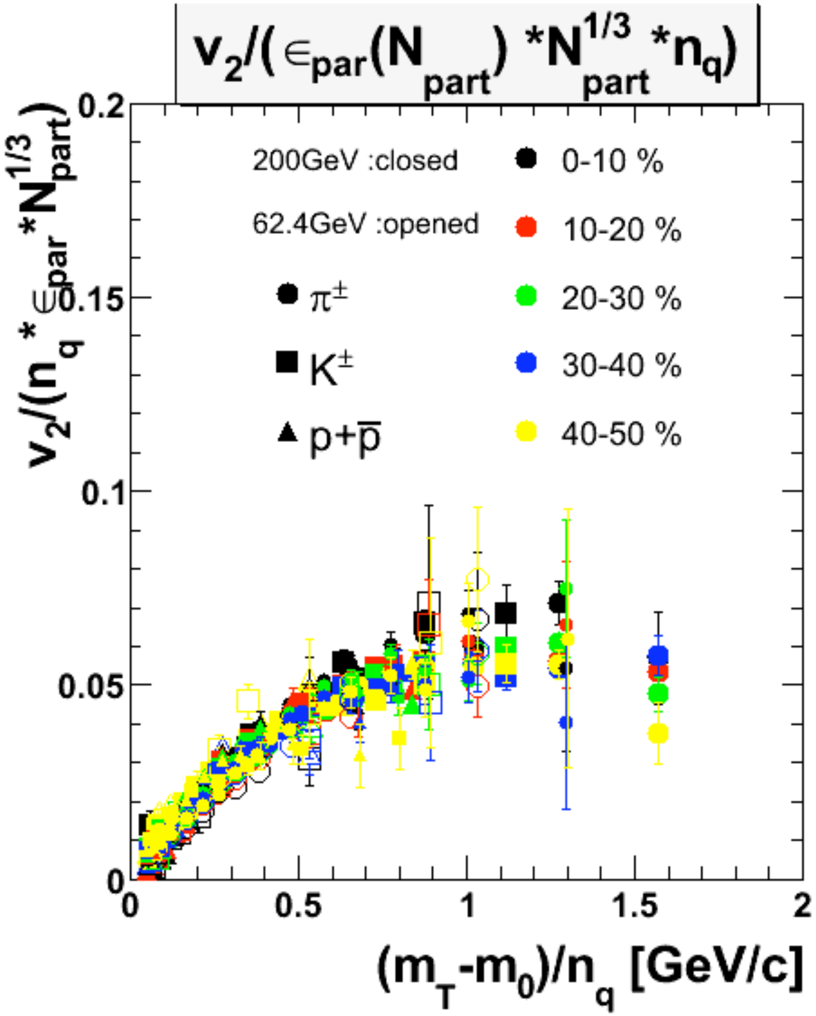
Phobos; nucl-ex/0610037



✓Simlar v_2/ε for Au+Au and Cu+Cu, while there is clear N_{part} dep. !!??????

"Grand Universal" Scaling

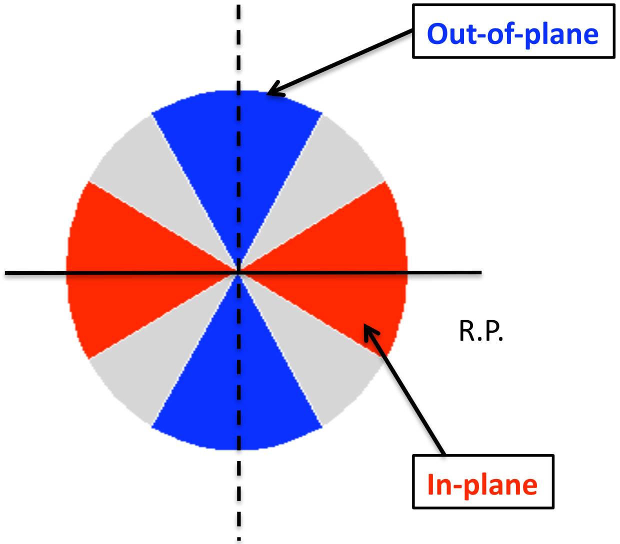
M. Shimomura, Tsukuba

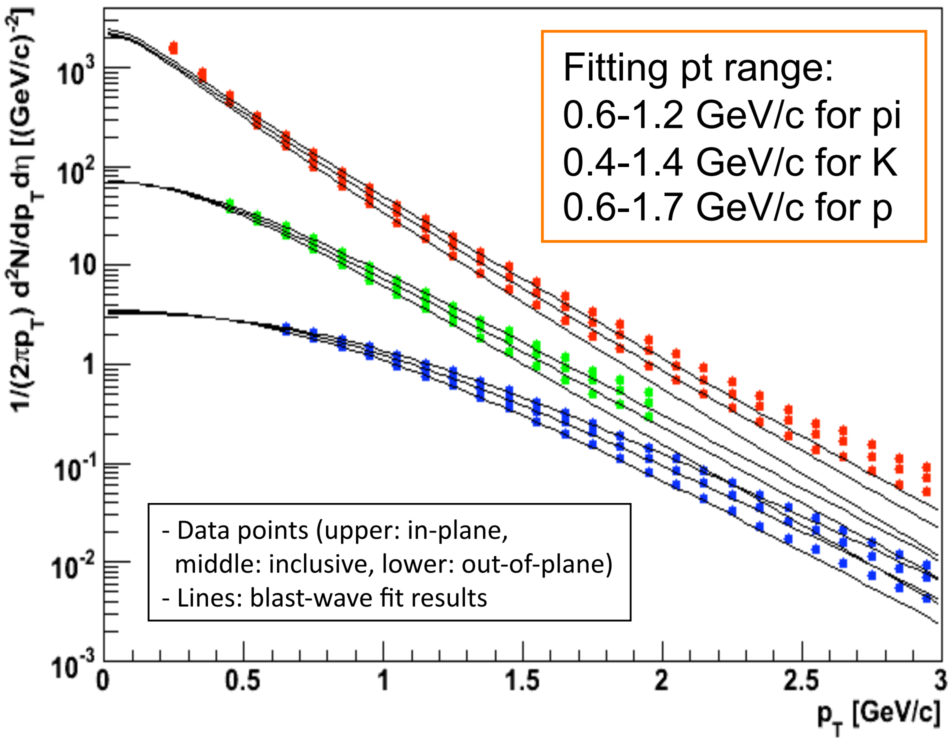


✓Although you cannot distinguish, there are

- Au+Au, Cu+Cu,
- 200 GeV, 64GeV, and
- pion, kaon, proton.

Blast Wave re-visited !

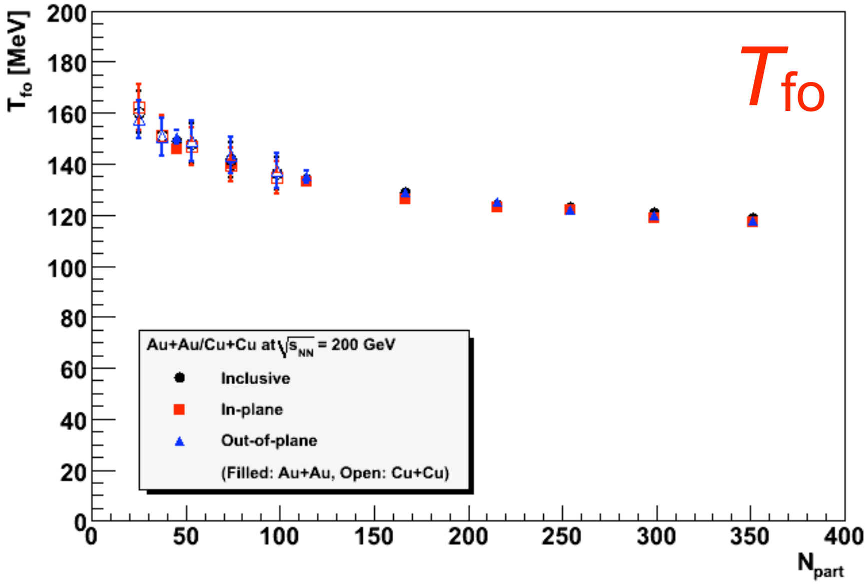


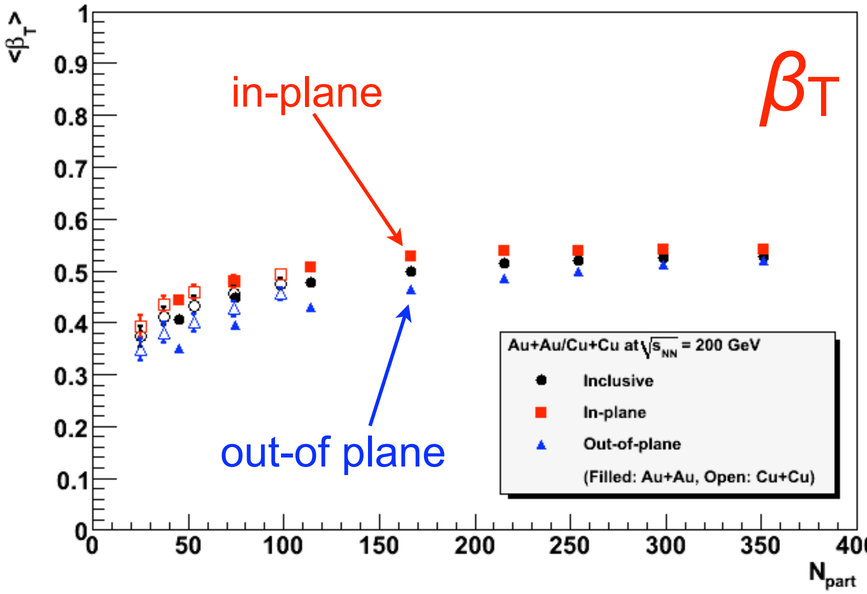


√ pt distributions measured in plane and out-of plane are B.W. fitted independently

B.W. Fitting Results

M. Konno, Tsukuba





By Masahiro Konno

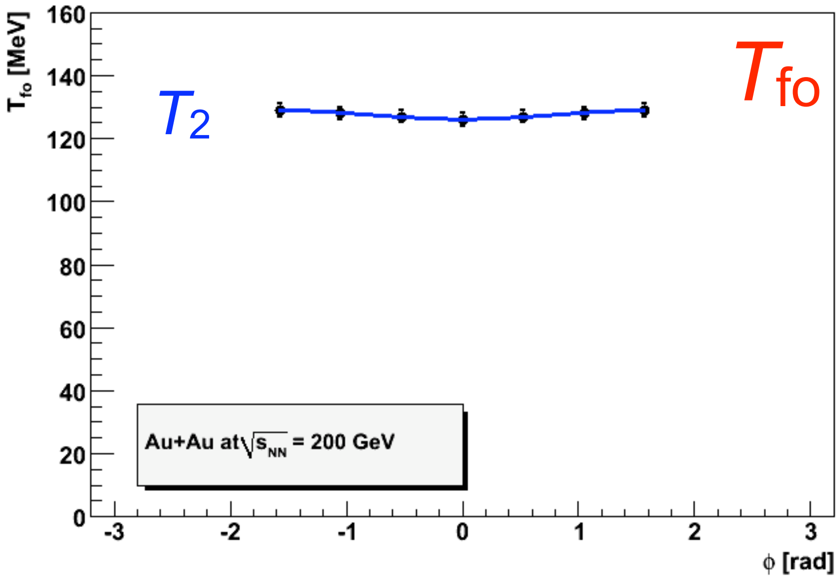
√ *T* **are the same in plane and out-of plane, while**

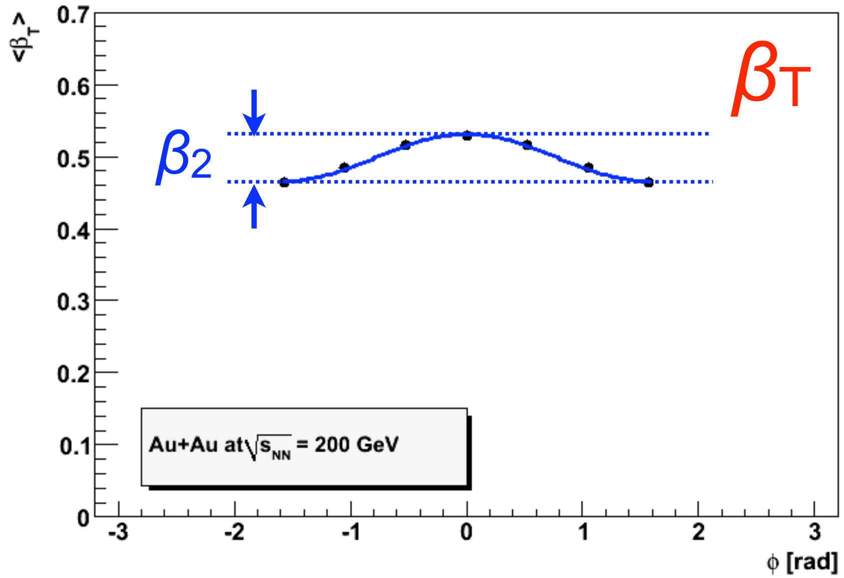
β_T(in-plane) > β_T(out-of plane) !

Modulations wrt the ϕ_{RP}

M. Konno, Tsukuba

Au+Au 200 GeV 20-30 %





By Masahiro Konno

$$T_{\mathrm{fo}}(\phi) = 1 + 2T_2\cos(\phi - \phi_{\mathrm{RP}})$$

$T_2 = (-5.4 \pm 4.0) \times 10^{-3}$

$$\beta_{\mathrm{T}}(\phi) = 1 + 2\beta_2\cos(\phi - \phi_{\mathrm{RP}})$$

$\beta_2 = (3.3 \pm 0.2) \times 10^{-2}$

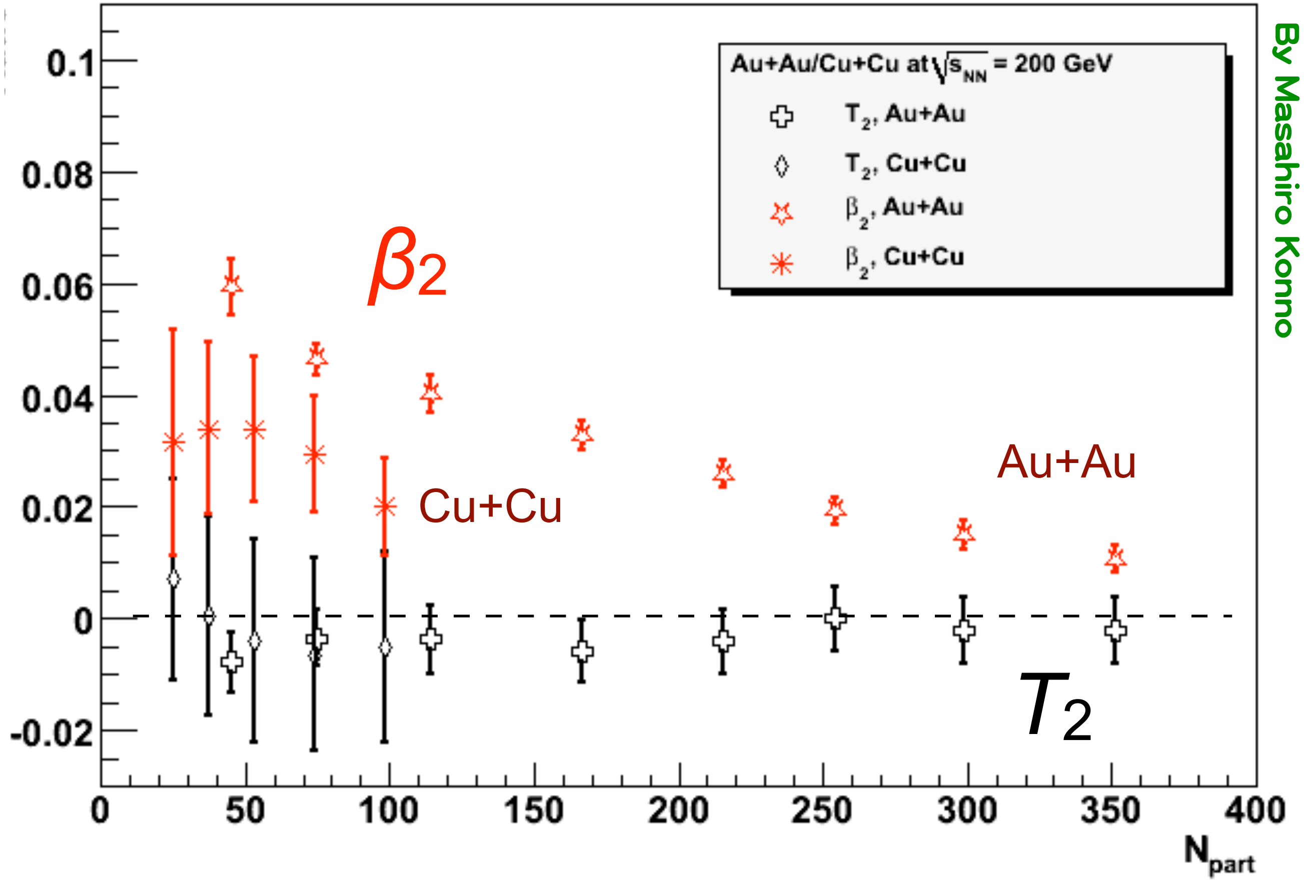
✓ $T_2 \simeq 0$, while clear modulation in β.

✓ Reaction Plane is determined independently.

Plotted against N_{part}

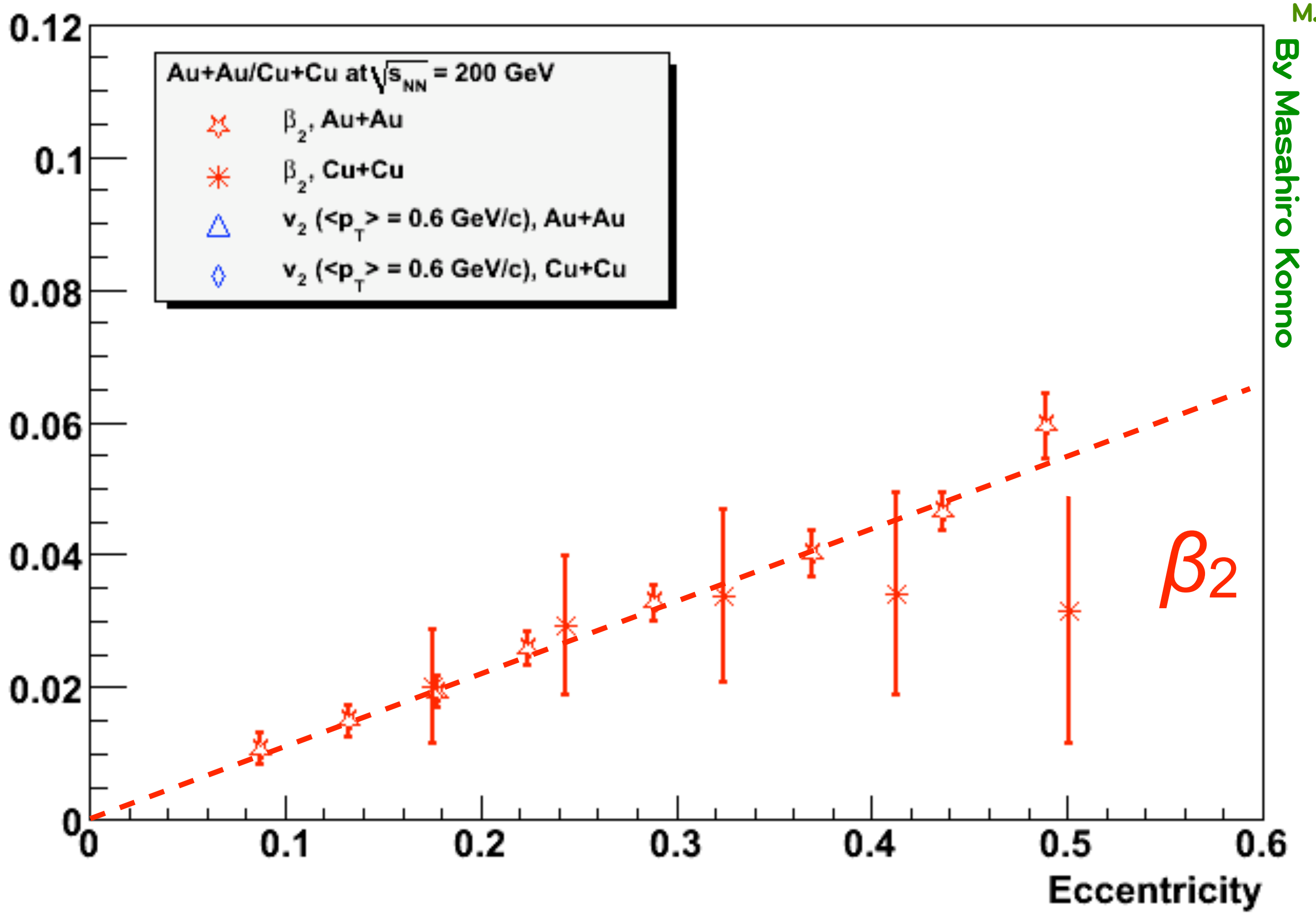
M. Konno, Tsukuba

By Masahiro Konno



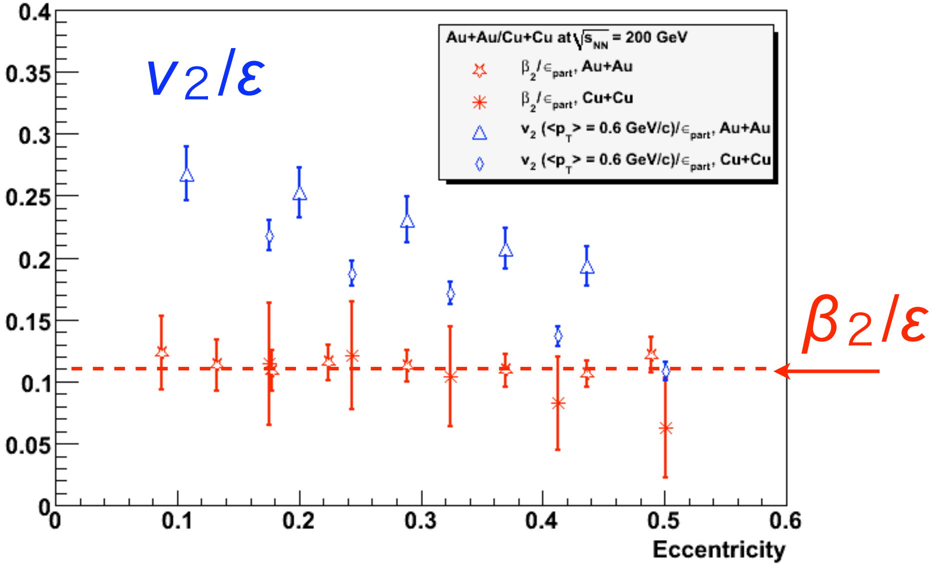
✓ T_2 stays 0, while β_2 shows centrality dep. which is different in Au+Au and Cu+Cu, but,,,

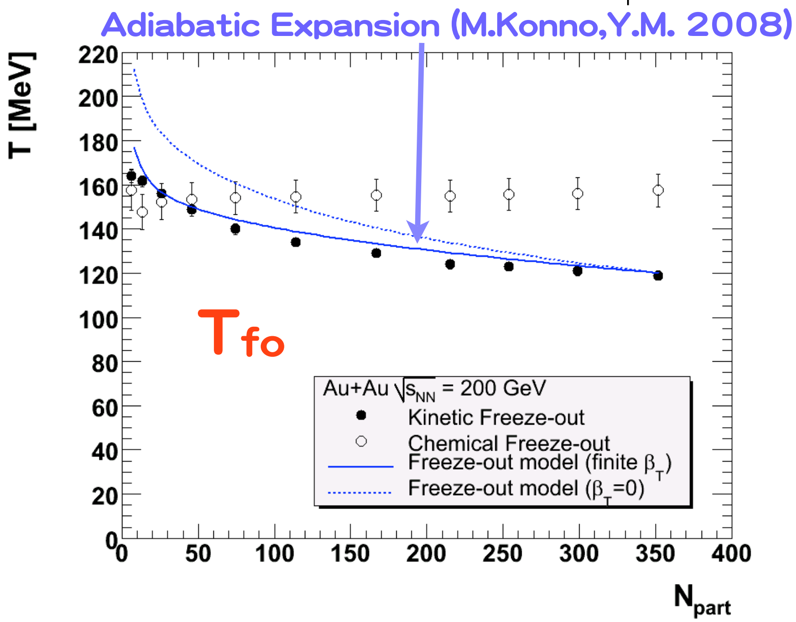
Plotted against ε



✓ β_2 is prop. to eccentricity, while v_2 is not

β_2/ε is the constant !



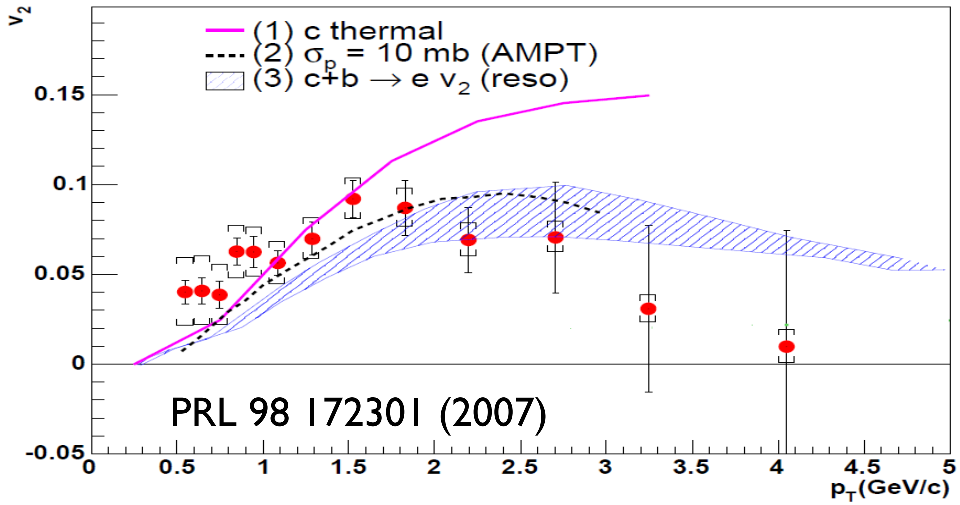


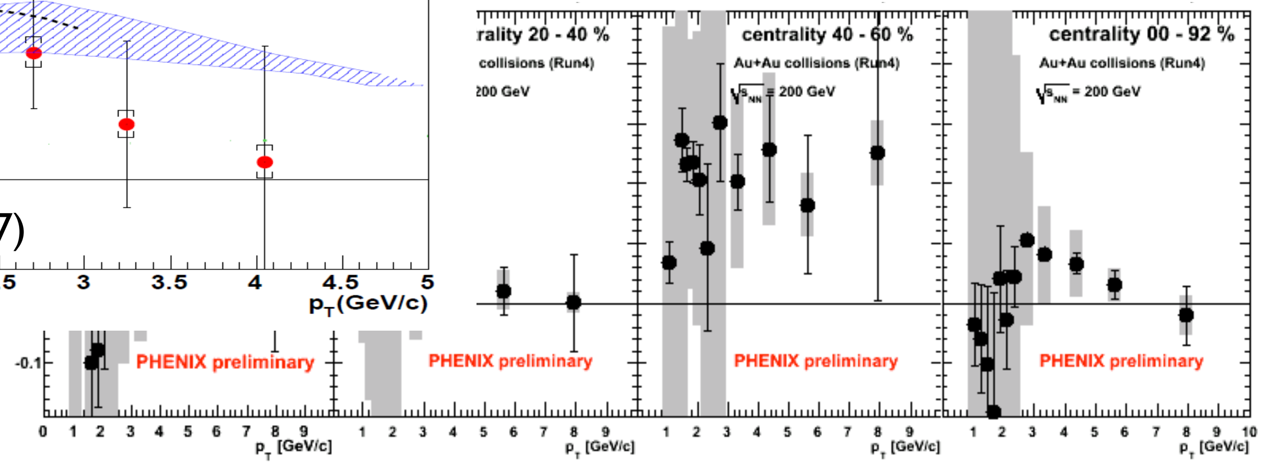
✓ β_2/ε is the constant in Au+Au and Cu+Cu, while v_2/ε shows ~ $N_{part}^{1/3}$.

- ➡Difference comes from the fact that v2 is sensitive to T_{fo} as well. Strength of v2 is diluted if the T_{fo} is high.
- ➡Central collision shows lower T_{fo} because of the late freeze-out.

'Bright' future of v2; heavy flavor and thermal photon

S. Sakai, Tsukuba



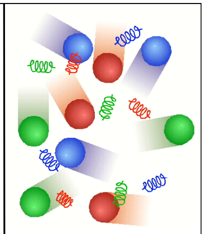


✓S. Sakai founds even charm flows

✓K. Miki is in his PhD defense of his positive results of thermal photon.

➡v2 is interesting business!!

Summary



√Systematic study of v_2 done in Au+Au, Cu+Cu, 200 GeV & 64 GeV.

√Scaling properties of v_2 has been re-visited with Blast Wave picture.

Please note that Blast Wave fits the low pt region of protons, kaons and pions.

- T_2 ~0 ; No ϕ_{RP} dep. of freeze-out temperature.
- β_2/ε stays constant in Au+Au, Cu+Cu, while v_2/ε shows ~$N_{part}^{1/3}$ dependence.

➡ β_2 seems to be the good scaling quantity in the region.

√Even charm flow!? and thermal photons?

Many thanks to my colleagues/students

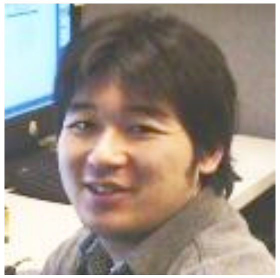
S. Esumi, Tsukuba

T. Chujo, Tsukuba

M. Shimomura, Tsukuba

M. Konno, Tsukuba

H. Masui, Tsukuba

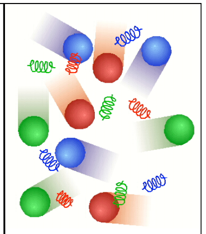


S. Sakai, Tsukuba

A Kiyomichi, Tsukuba

- √ ShinIchi Esumi, Tsukuba
- √ Tatsuya Chujo, Tsukuba
- √ Masahiro Konno,Tsukuba
- √ Akio Kiyomichi, now at KEK
- √ Hiroshi Masui, now at LBL
- √ Shingo Sakai, now at UCLA
- √ Maya Shimomura, Tsukuba
- √ Kentaro Miki, Tsukuba
- √ Yoshimasa Ikeda, Tsukuba
- √ Rei Tanabe, Tsukuba

Now, paperback is available!



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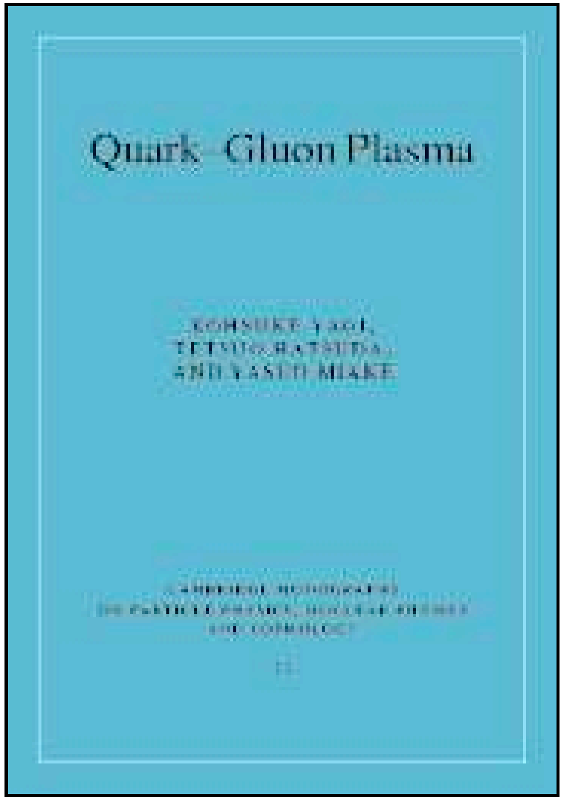

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