QM2014
Theoretical summary of
Collective dynamics
&Correlations and fluctuations

@HIP・HIC合同, Nagoya, 2014-06-06

Koichi Murase

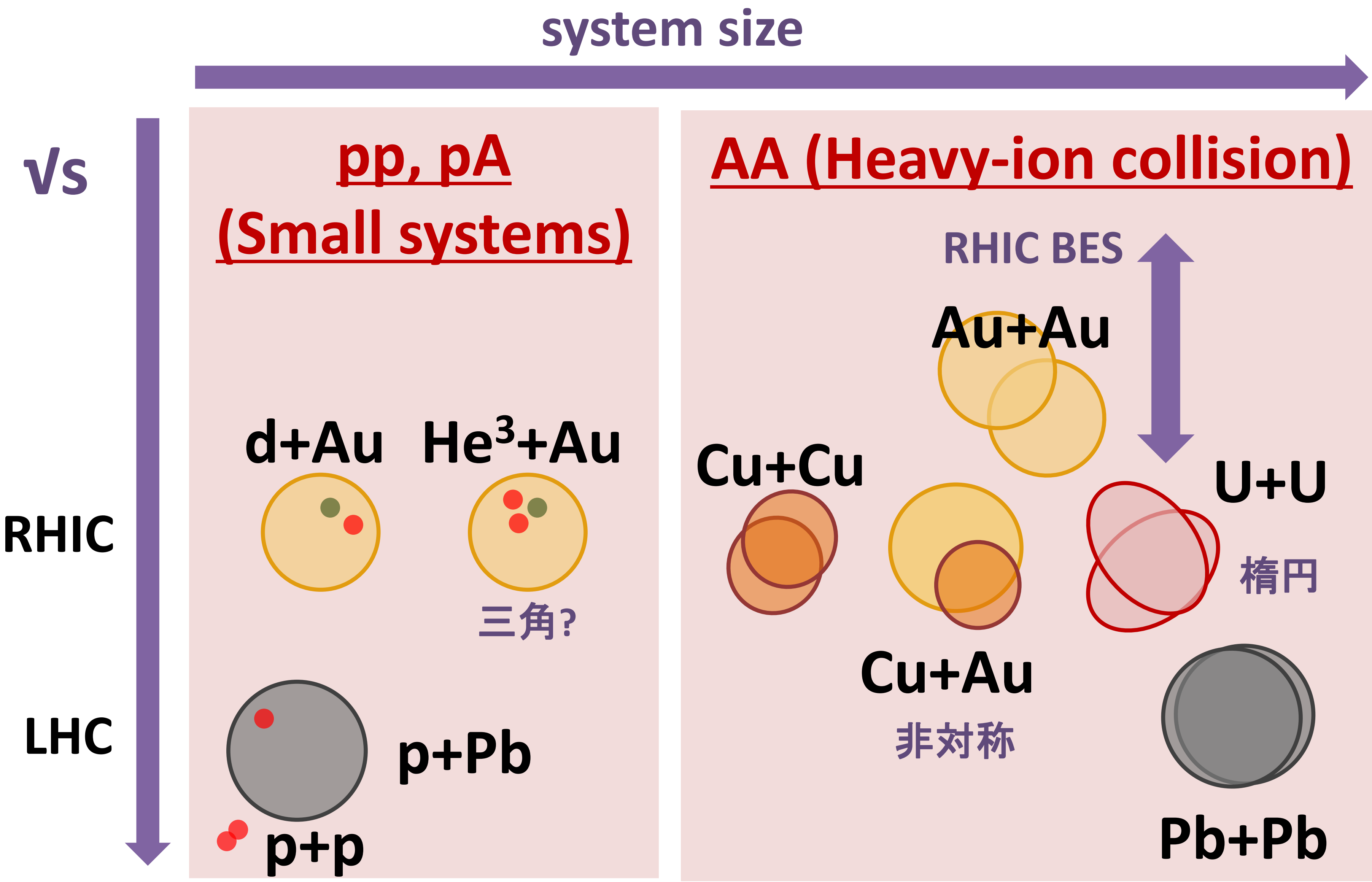
Univesrity of Tokyo,

RIKEN Nishina Center,

Sophia University

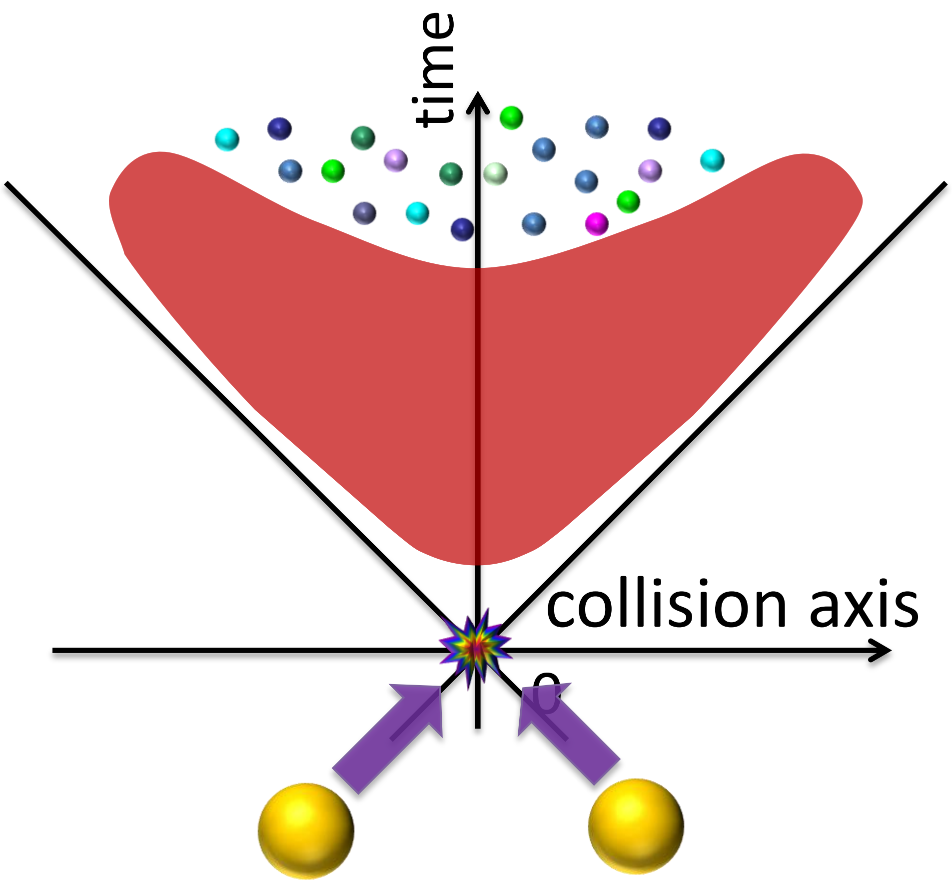
INTRO

色々な衝突


system size
√s
RHIC
LHC
pp, pA
(Small systems)
d+Au
He3+Au
三角?
p+Pb
p+p
AA (Heavy-ion collision)
RHIC BES
Au+Au
Cu+Cu
U+U
楕円
Cu+Au
非対称
Pb+Pb

現在のモデル

重イオン衝突反応の過程



測定量･統計量

p_T, v_n, Ψ_n, r_n, …

ハドロンカスケード

運動論、freeze-out

散逸流体

η/s, ζ/s, 熱揺らぎ

初期状態

模型: Glauber, CGC, IP-Glasma

Talks 俯瞰

① Small system: pA, dA …
集団的な振る舞い? どう解釈するか Basar, …
   – 流体? Bozek, Schenke, Romatschke, …
   – CGC/Glasma? Venugopalan, Dusling, Shuryak, Gyulassy, …

② Ultracentral v2, v3 Denicol

③ Beam Energy Scan, CuAu, UU Auvinen, Tribedy, …

④ 熱揺らぎ・電荷揺らぎ Kapusta, Hirano, Kitazawa, …

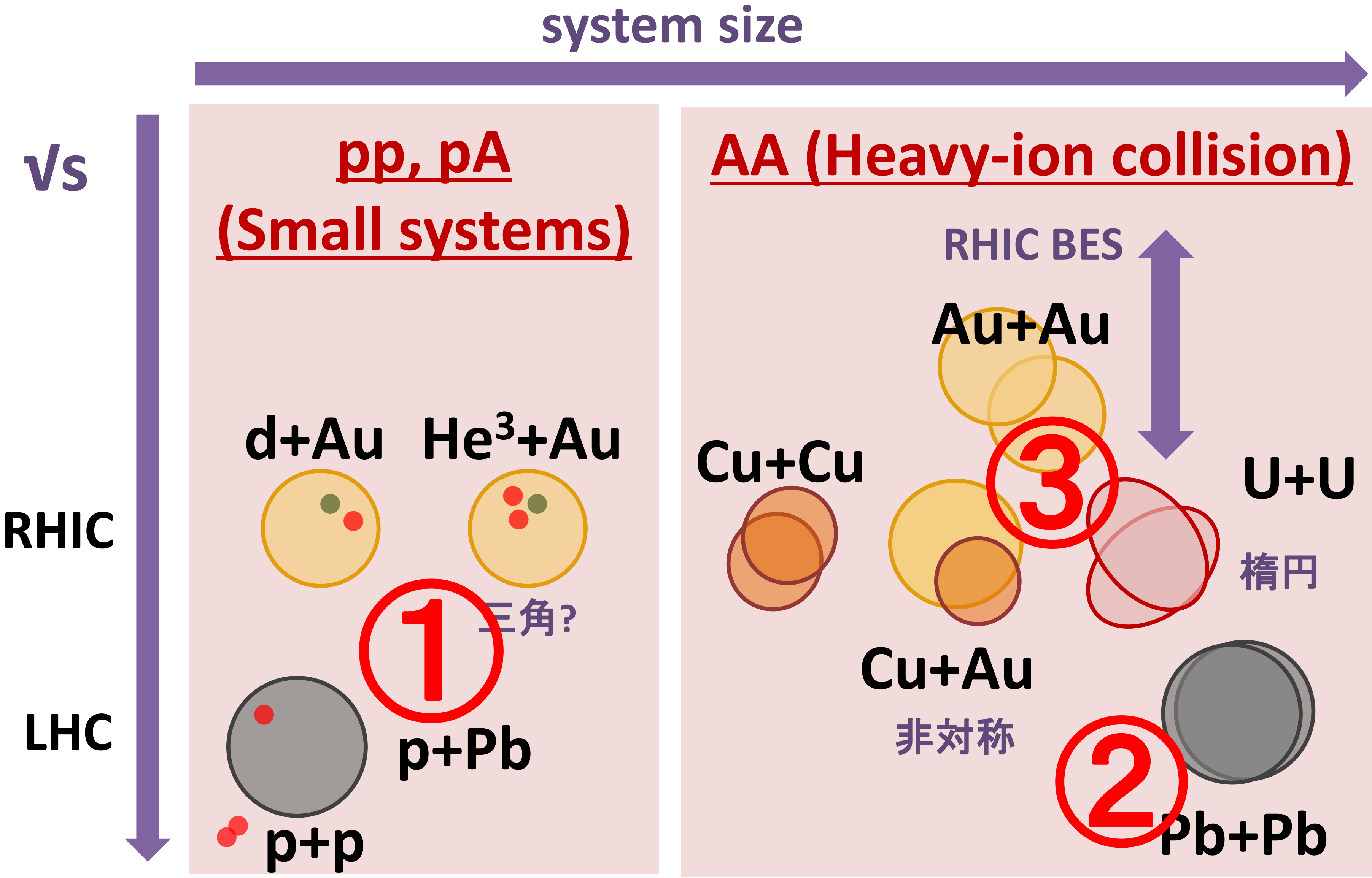
⑤ HBT 相関 (物質の大きさ) Sinyukov, Csernai, ...

⑥ 粘性流体、運動論 Rolando, Nonaka, Greiner, Bratkovskaya

⑦ フロー・相関 L. Yan, Florchinger, Kozlov, …

⑧ 他 Heinz, Gursoy

色々な衝突



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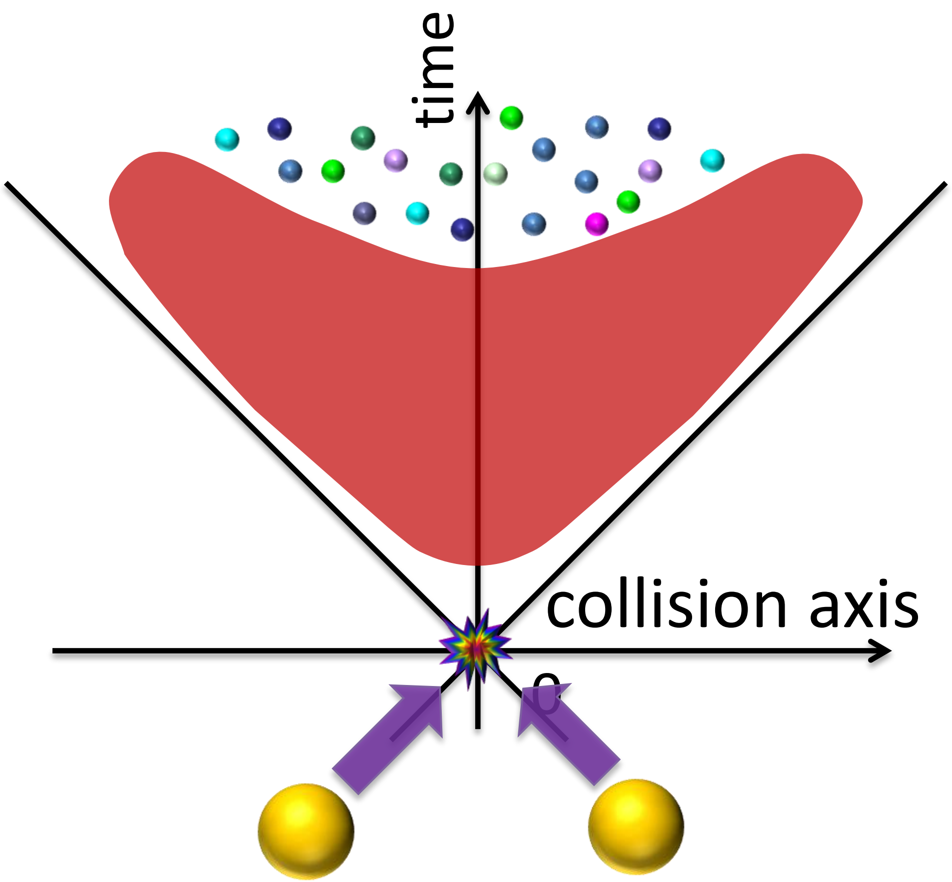

⑦
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p_T, v_n, Ψ_n, r_n, …

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η/s, ζ/s, 熱揺らぎ
④
⑧

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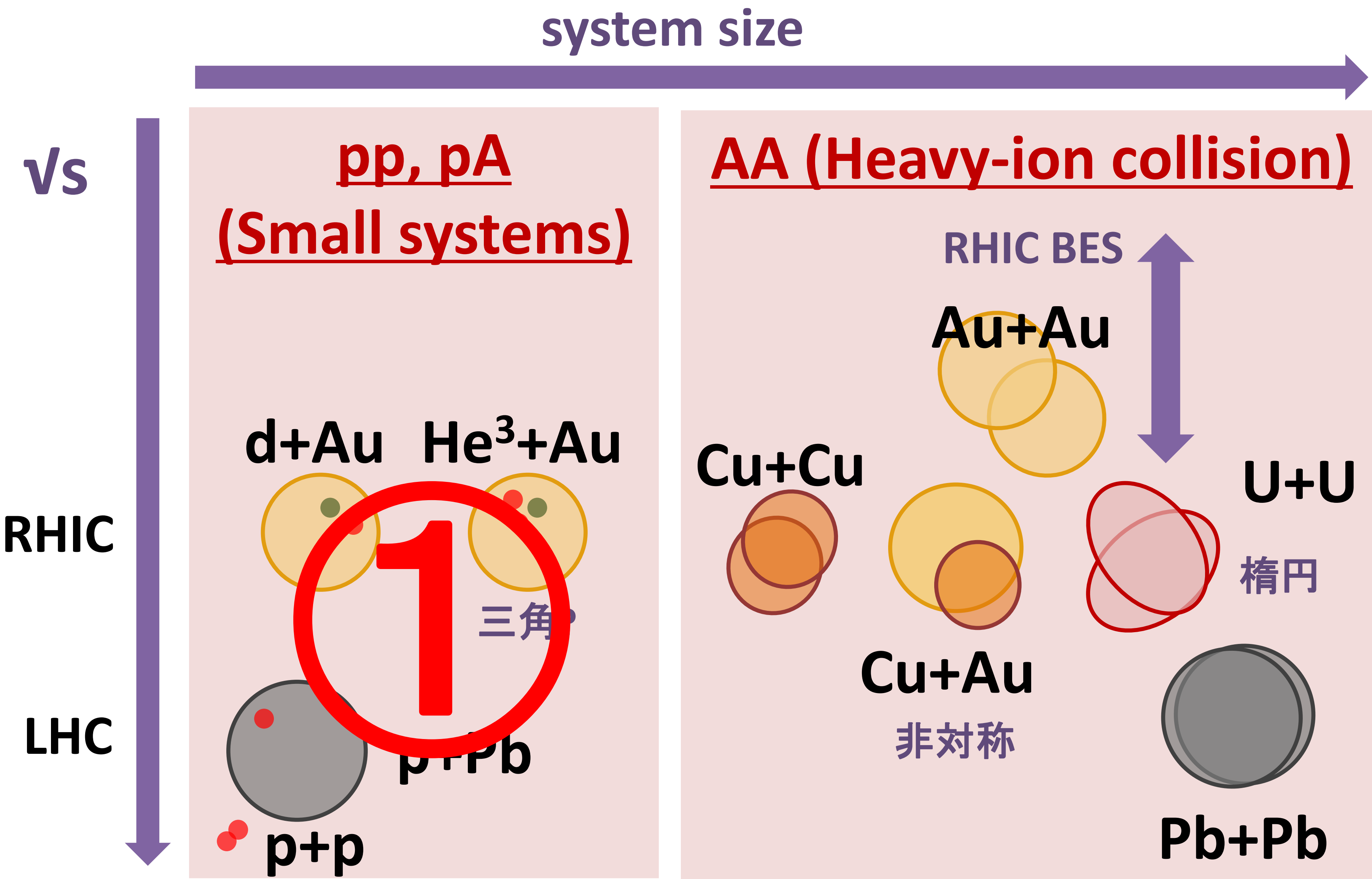
いくつか紹介

色々な衝突



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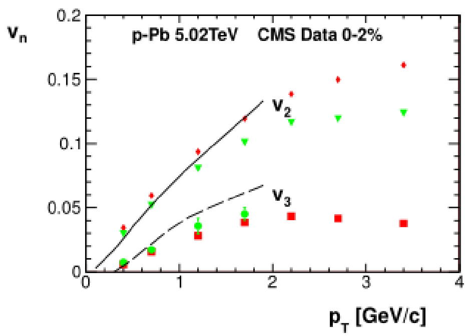
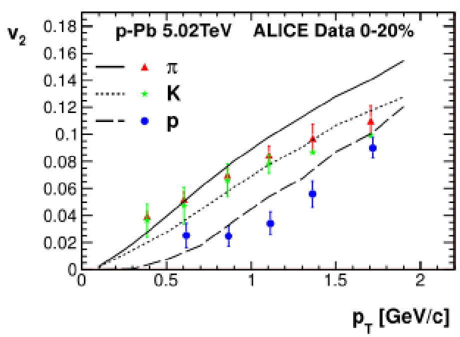
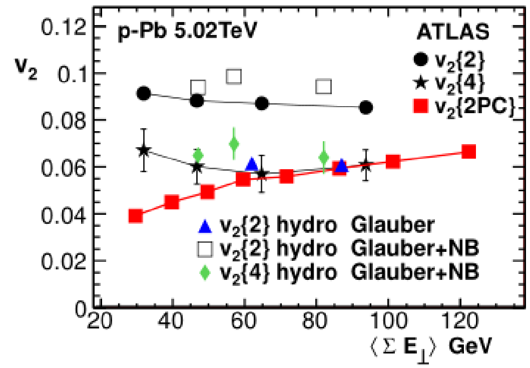
Collective flow in small systems

Elliptic and triangular flow





PB, Broniowski, Torrieri arXiv:1306.5442



PB, Broniowski, arXiv:1304.3044

- elliptic and triangular flow
- mass hierarchy of v_2

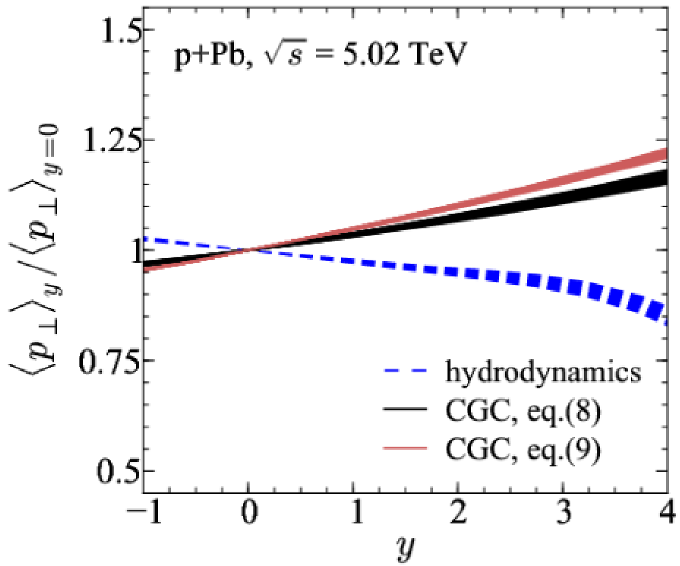
v2, v3 大きさ @pPb : 流体で大体合う

※初期条件を Glauber + NBD (量子揺らぎ) にしないと小さい

P. Bozek

Collective flow in small systems

$< p_\perp >$ **rapidity dependence**



different prediction of CGC and hydro

PB, Bzdak, Skokov, 1309.7358

⟨p_T⟩ラピディティ依存性
流体とCGCで逆の振る舞い

G. Basar

A scaling relation between proton-nucleus and nucleus-nucleus collisions

- Eccentricity in AA: $\langle \epsilon_2^2 \rangle_{AA} = \underbrace{\epsilon_s^2}_{\text{average}} + \underbrace{\langle \delta\epsilon_2^2 \rangle}_{\text{fluctuations}}$
- Eccentricity in pA: $\langle \epsilon_2^2 \rangle_{pA} = \underbrace{\langle \delta\epsilon_2^2 \rangle}_{\text{fluctuations}}$

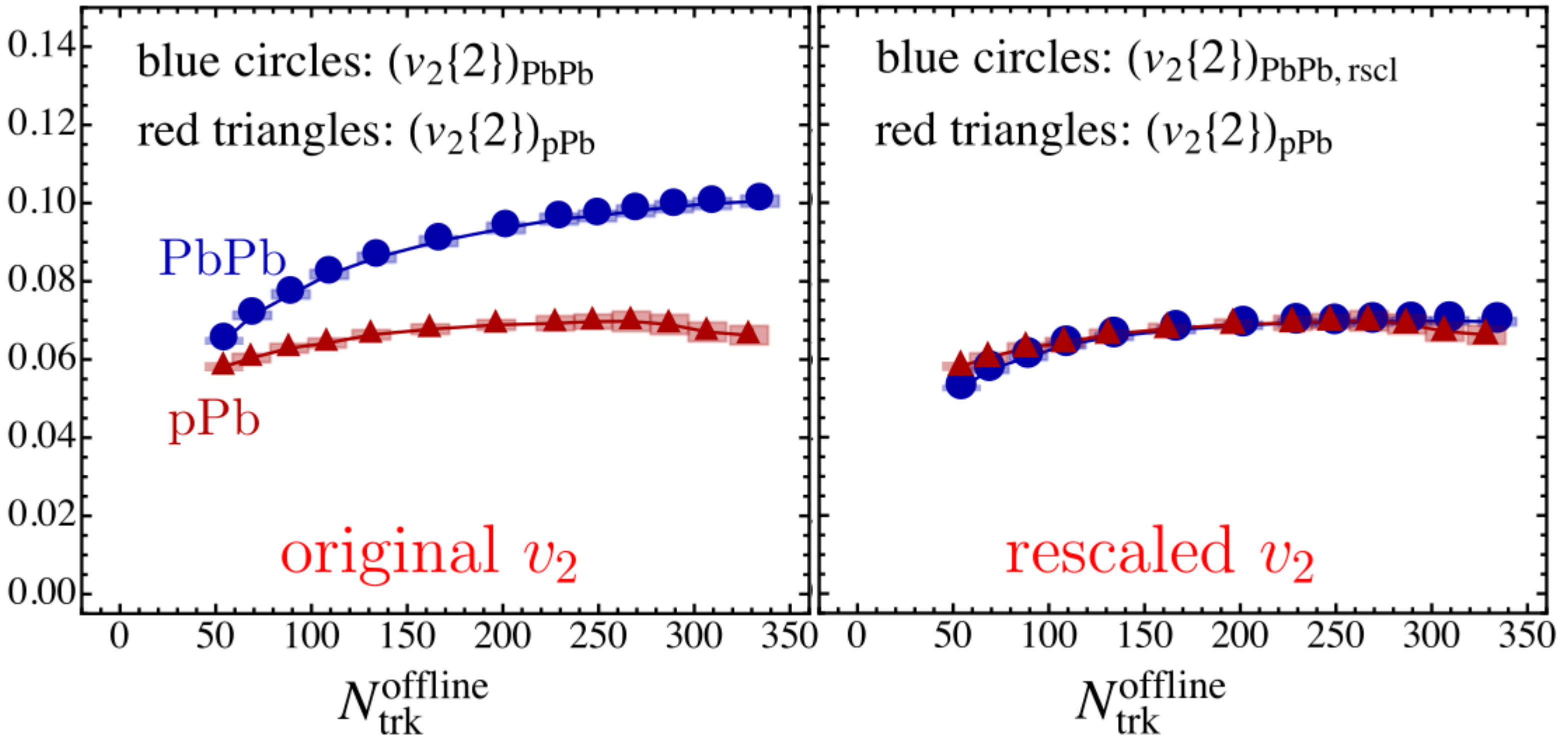
$\Rightarrow$ To compare the v_2s, scale out the average geometry from AA:

$$(v_2\{2\})_{\mathrm{PbPb,rscl}} \equiv \sqrt{1 - \frac{\epsilon_s^2}{\langle \epsilon_2^2 \rangle_{PbPb}}}(v_2\{2\})_{\mathrm{PbPb}}$$

v ∝ ε と仮定 → 平均的成分を消す様に v を rescale
綺麗に一致する

G. Basar

A scaling relation between proton-nucleus and nucleus-nucleus collisions



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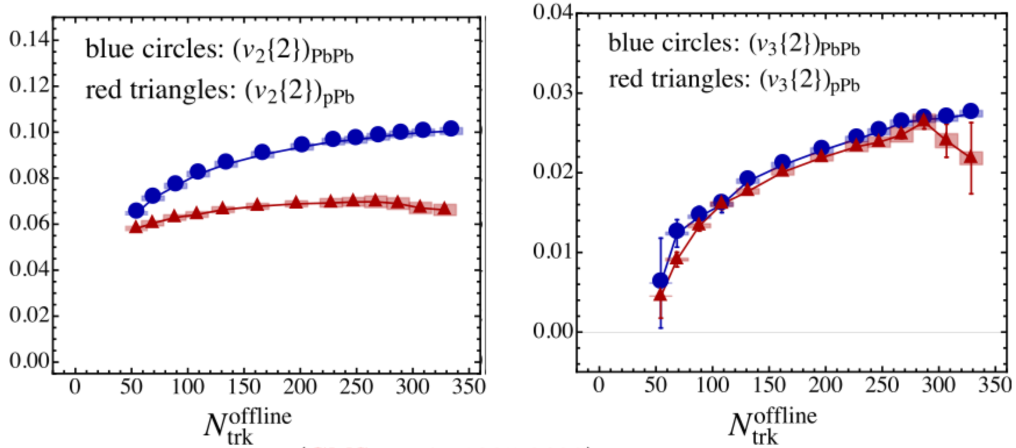
Motivation and introduction

The two particle correlations show a striking similarity between high multiplicity pA and AA collisions at fixed multiplicity.



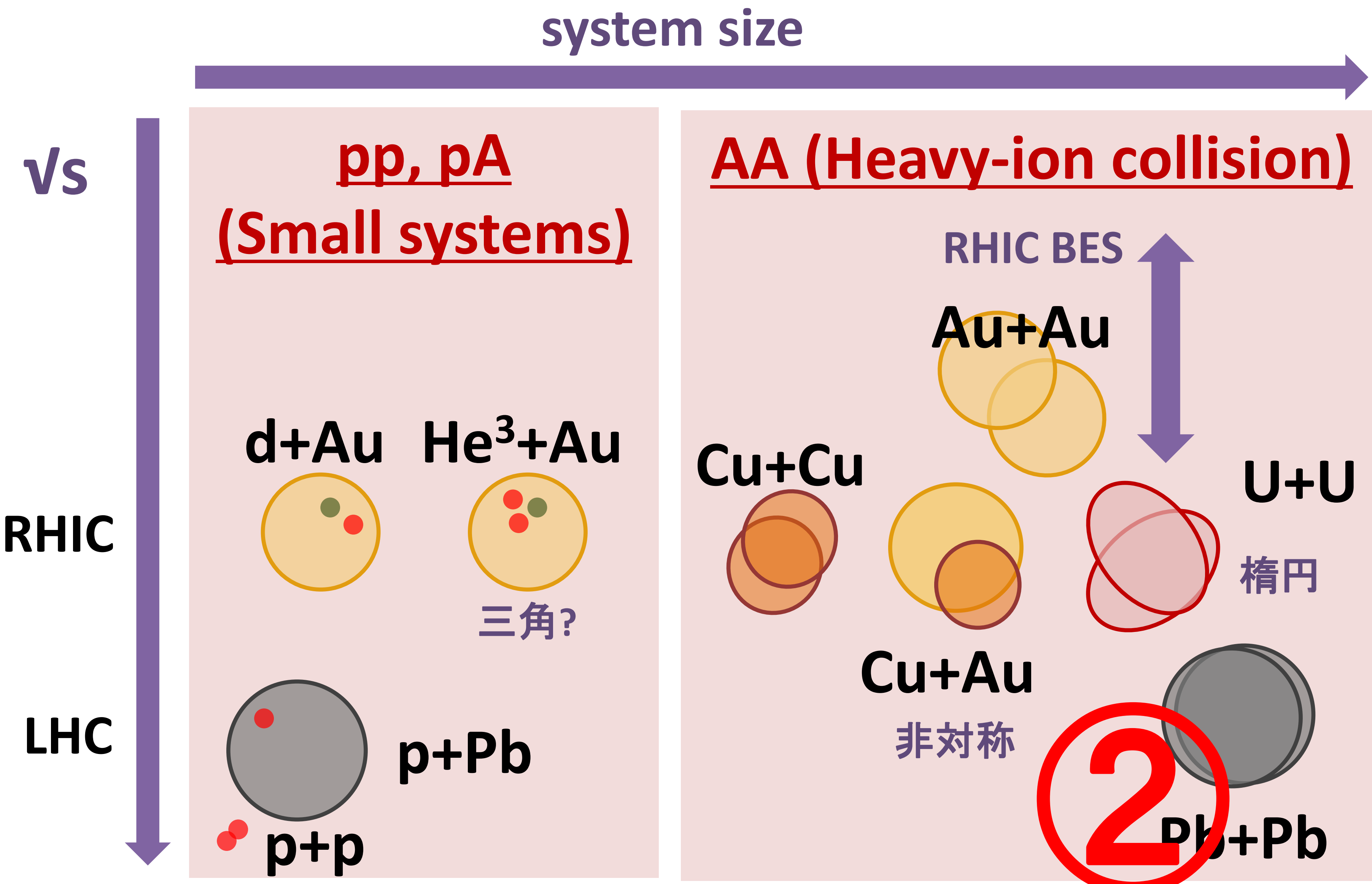
(CMS, arxiv:1305.0609)

Question: Do they originate from the same physics?

Idea: They both emerge from a *collective response* to the geometry dictated by $\frac{l_{mfp}}{L} = f(dN/dy)$.

CMS PbPb/pPb v2, v3: v2 の違いは平均的形の違い

色々な衝突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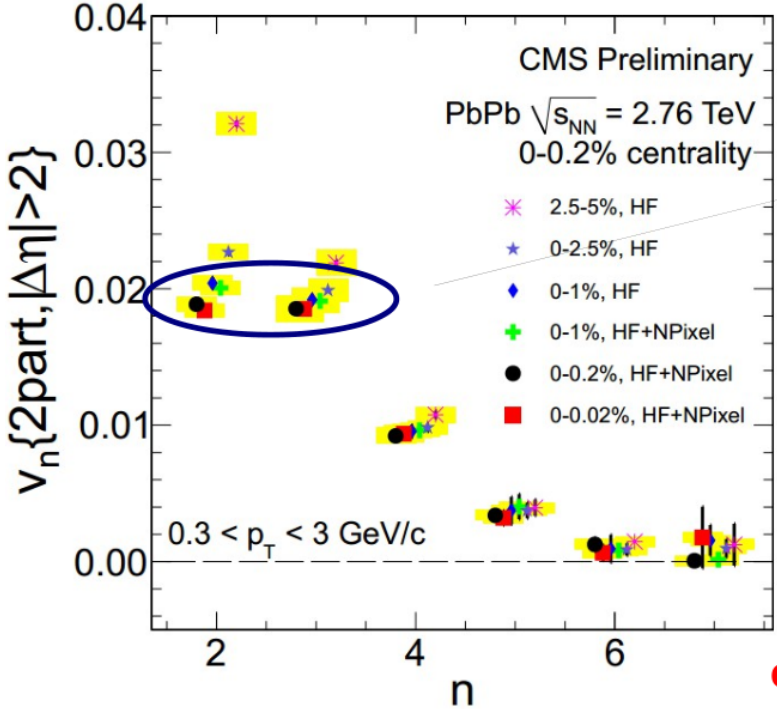
G. Denicol

Extracting the bulk viscosity of the quark-gluon plasma

Issue with ultracentral data

- **Nonhydrodynamic**(?) behaviour in ultracentral PbPb collisions



In ultracentral collisions

$v_2 \sim v_3$

This starts to happen in ~ 0-1% centrality class

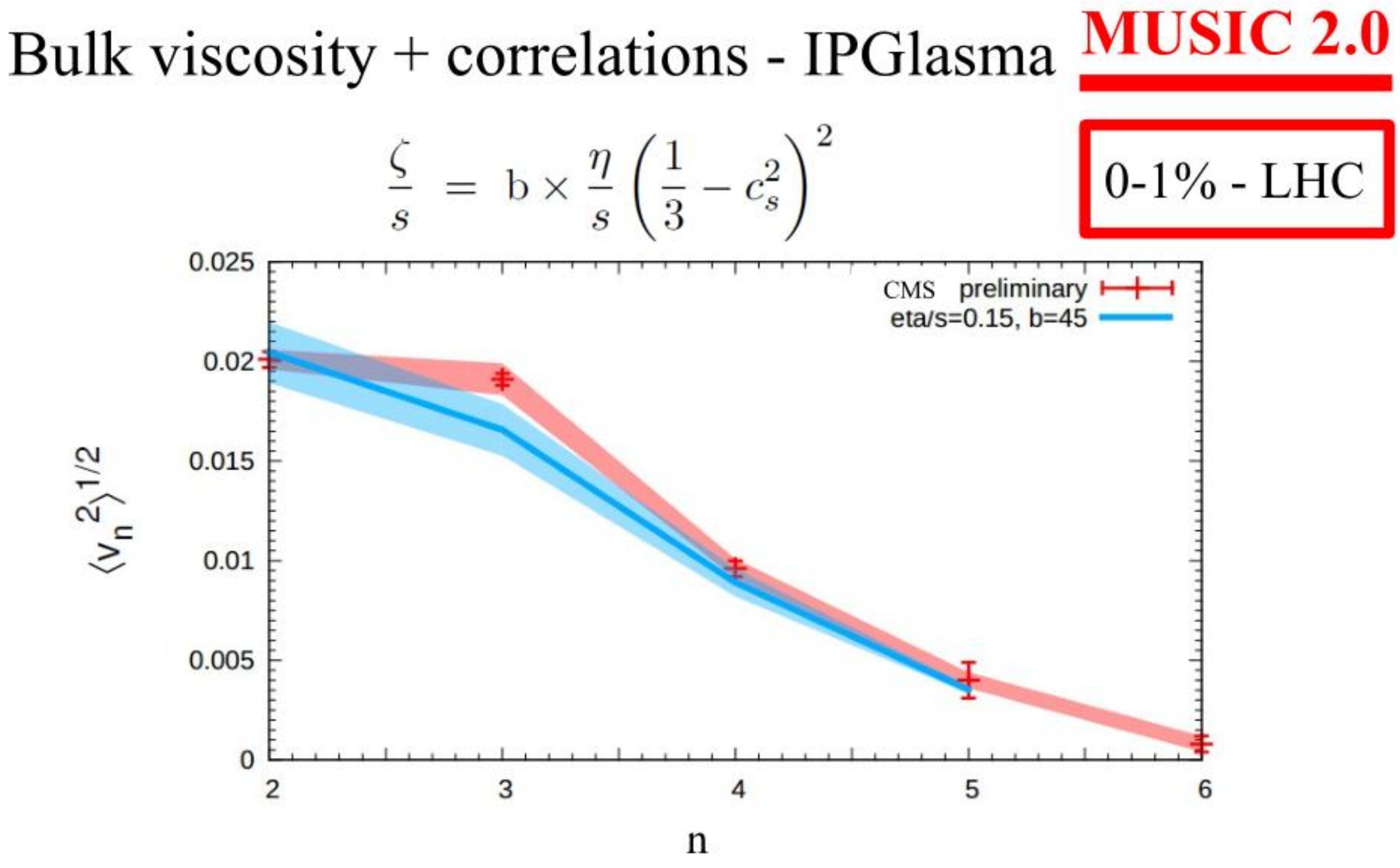
hard to understand with hydrodynamical simulations

but may provide better constraint for bulk viscosity ...

5

ultracentral で v2 と v3 の振る舞いが変

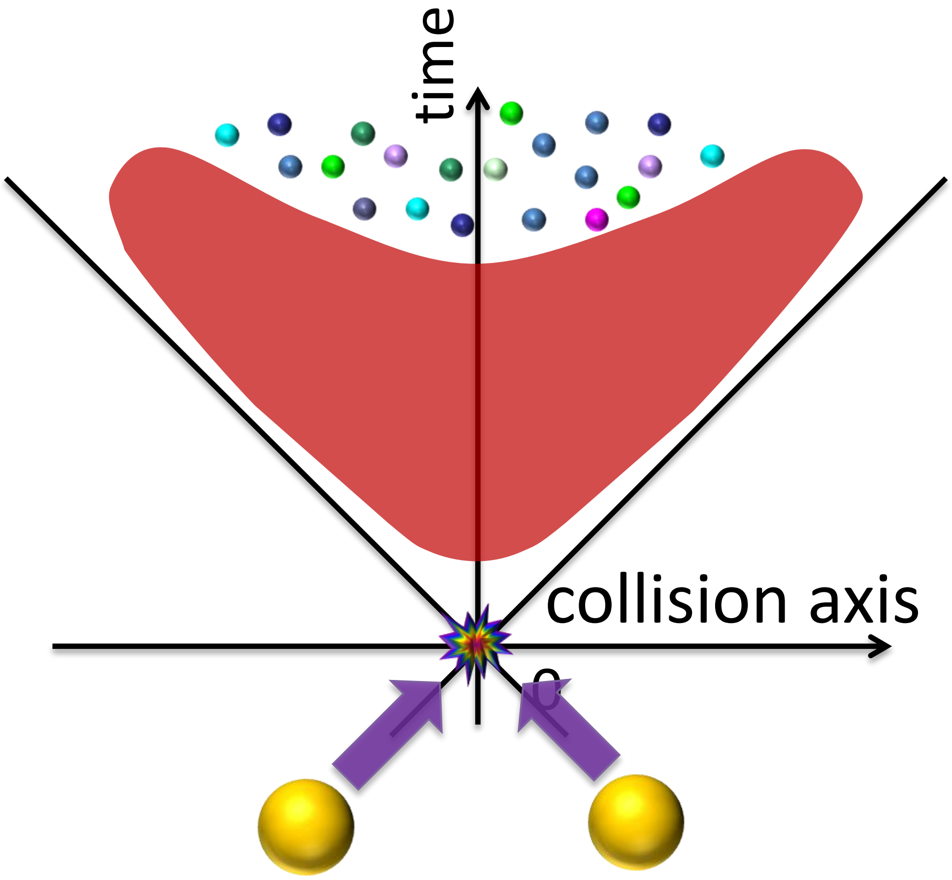
Extracting the bulk viscosity of the quark-gluon plasma



ζ/s と初期条件の核子相関を入れると改善する

現在のモデル

重イオン衝突反応の過程



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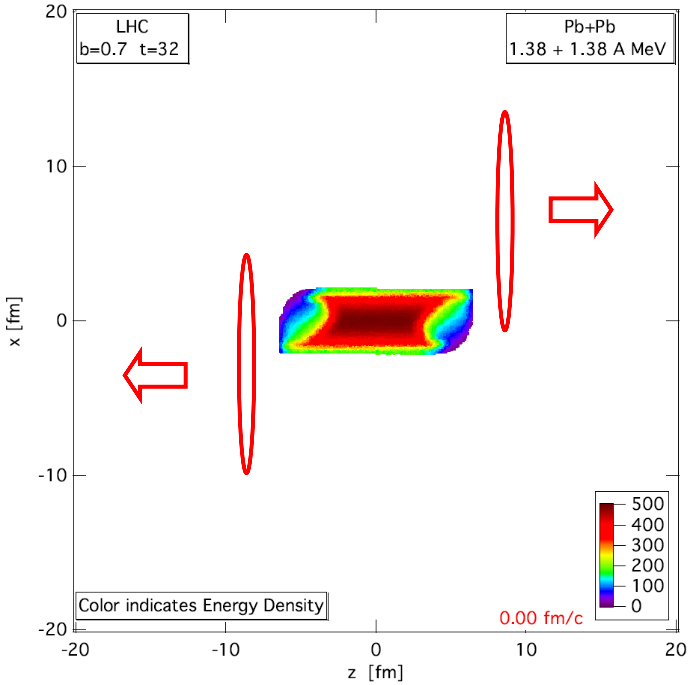
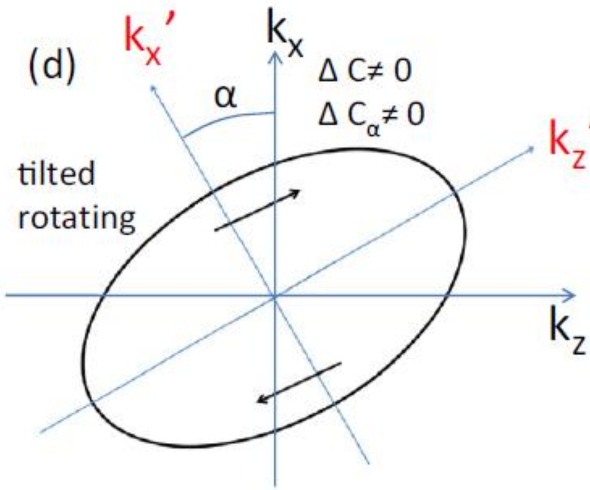
⑤

散逸流体
η/s, ζ/s, 熱揺らぎ

初期状態
模型: Glauber, CGC, IP-Glasma

Differential HBT method to analyse rotation in heavy ion collisions





$$\Delta C(k,q) \equiv C(k_+,q_{\rm out}) - C(k_-,q_{\rm out}).$$

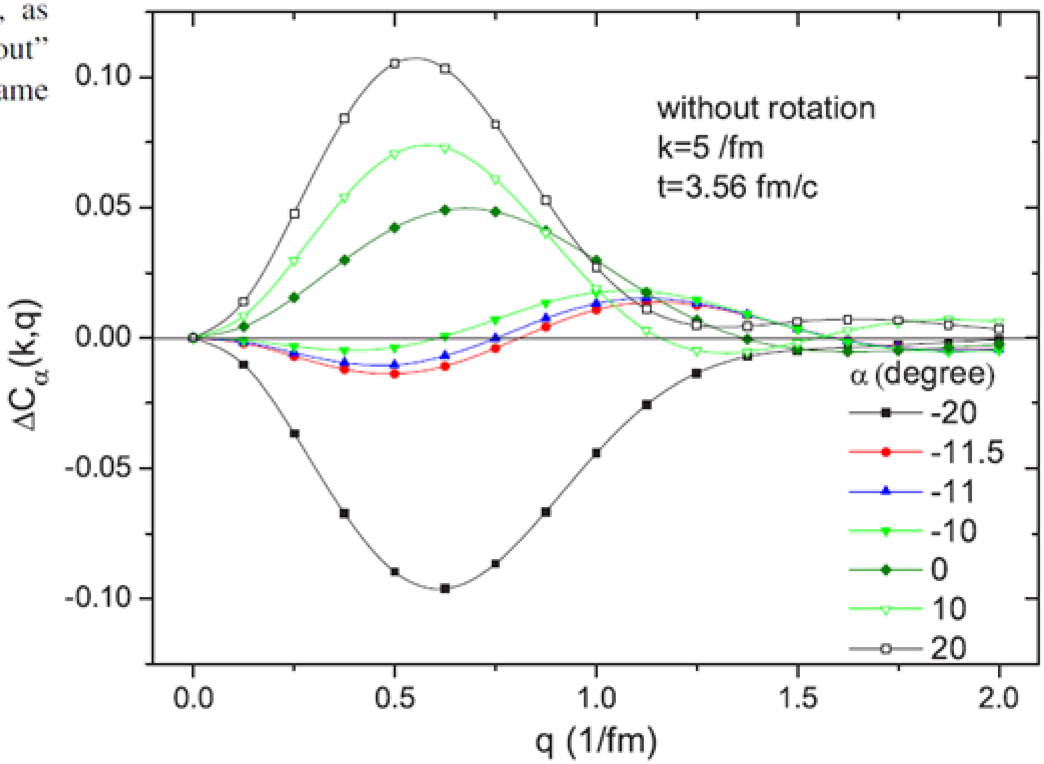
ΔC: k+ k- が対称なら 0

初期の流れにより物質が回転する?
実験的にその兆候を見るには?

L. Csernai

Differential HBT method to analyse rotation in heavy ion collisions

$k = 5/\text{fm}$ and fluid dynamical evolution time $t = 3.56$ fm/c, as a function of the functions of momentum difference in the "out" direction q (in units of 1/fm). The DCF is evaluated in a frame rotated in the reaction plane, in the c.m. system, by angle α.



The DCF shows a minimum for $\alpha = -11^\circ$

For lower, RHIC energy: $\alpha = -8^\circ$

ΔC が 0 に近くなる様に角度を調整する

→ 物質がどれだけ回転したか分かる ～ 8度

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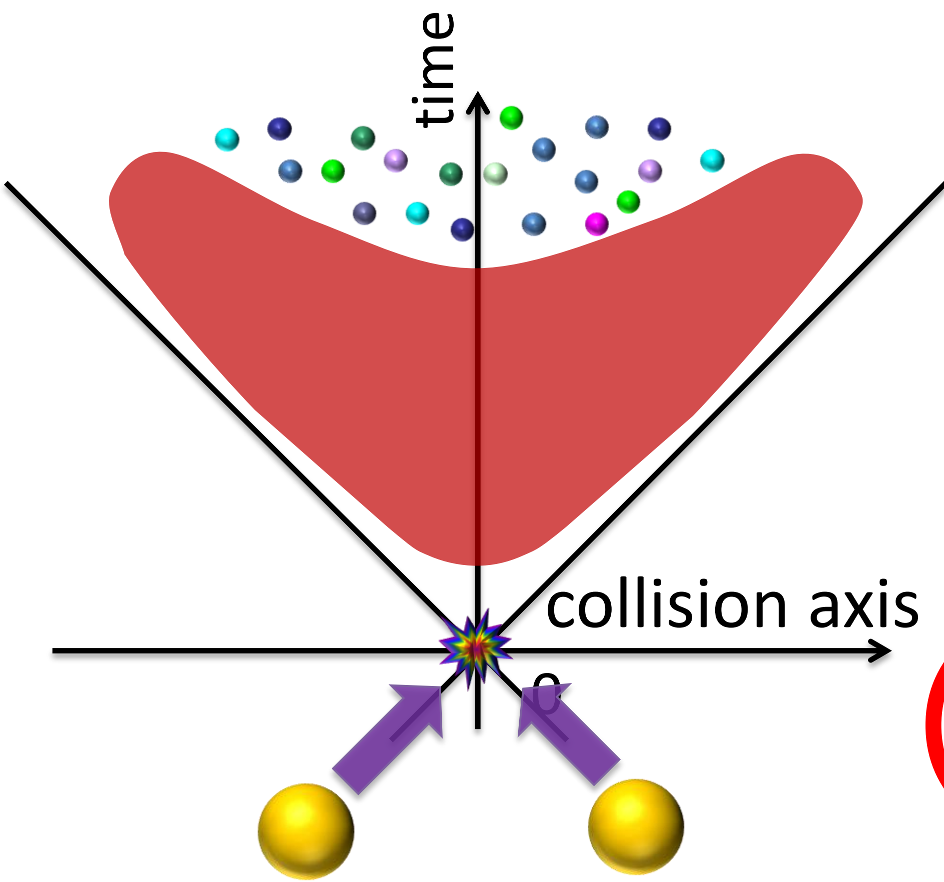

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↑

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Viscous hydrodynamics for systems undergoing strongly anisotropic expansion

Viscous anisotropic hydrodynamics (vaHydro) (I)

$$f(x,p) = f_{\mathrm{RS}}(x,p) + \delta\tilde{f}(x,p) = f_{\mathrm{iso}}\left(\frac{\sqrt{p_\mu \Xi^{\mu\nu}(x) p_\nu} - \tilde{\mu}(x)}{\Lambda(x)}\right) + \delta\tilde{f}(x,p)$$

Boltzmann → 初期の急激な膨張下での流体

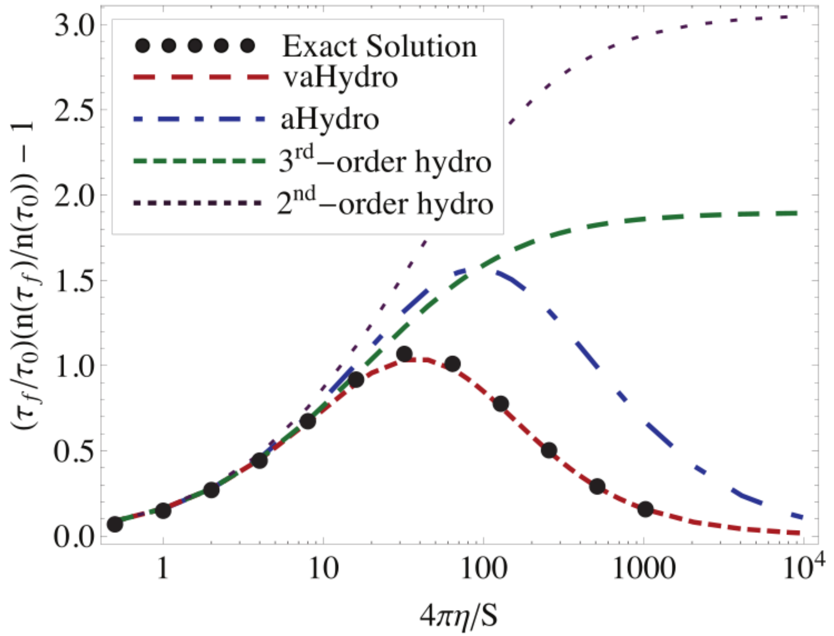
aHydro: 衝突軸方向に歪んだ運動量分布

vaHydro: 更に、2次の粘性の効果を分布関数に取り入れる

U. Heinz

Viscous hydrodynamics for systems undergoing strongly anisotropic expansion

Total entropy (particle) production $\frac{n(\tau_f)\cdot\tau_f}{n(\tau_0)\cdot\tau_0} - 1$



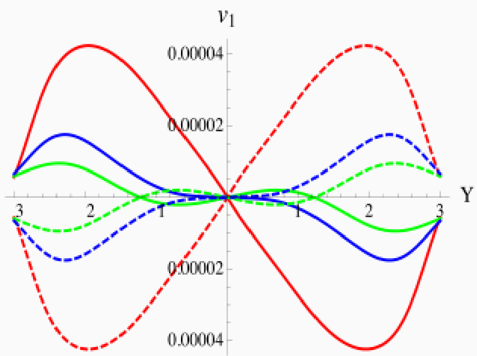
粒子数生成(エントロピー生成) vs η/s:

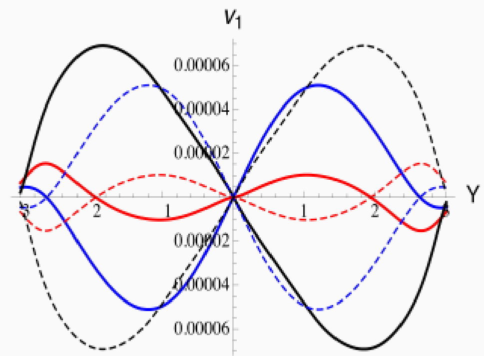
vaHydro で Boltzmann の厳密解と一致

Magnetohydrodynamics, charged currents and directed flow in heavy ion collisions

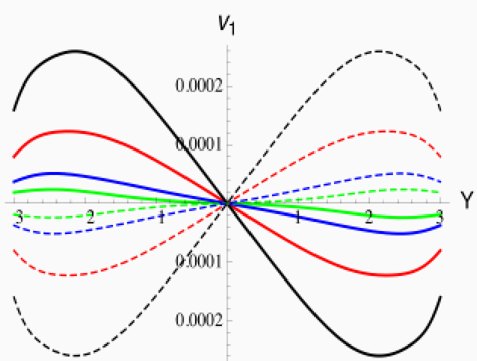
Predictions for charge identified v_1

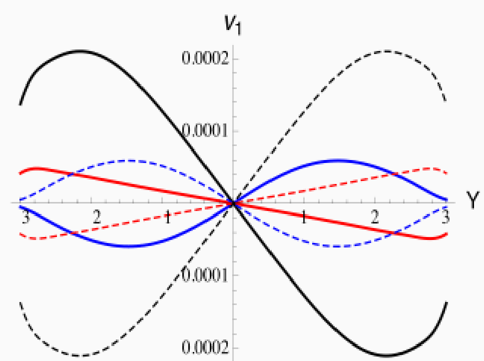
- Pions and protons at LHC





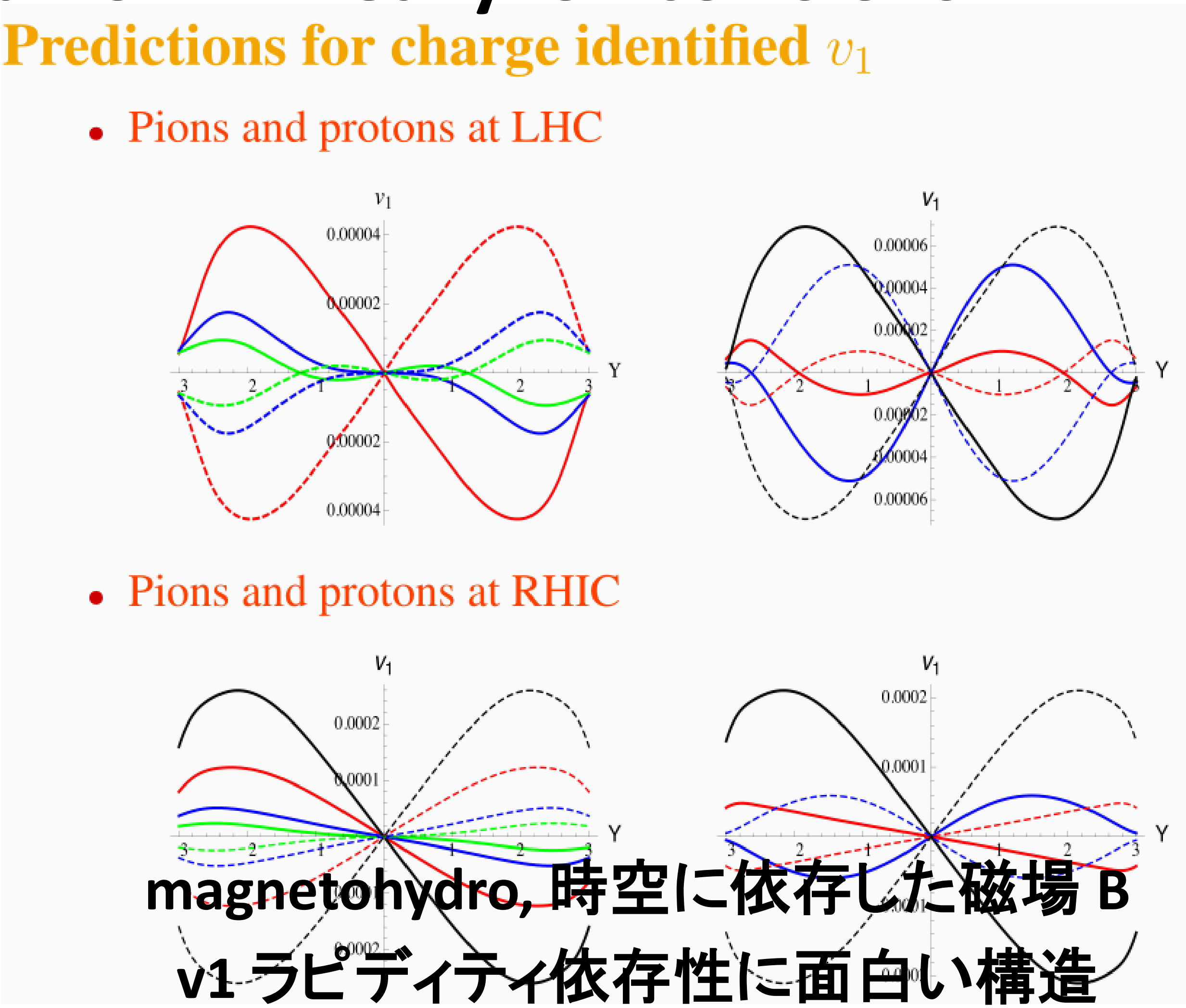
- Pions and protons at RHIC





U. Gursoy

Magnetohydrodynamics, charged currents and directed flow in heavy ion collisions



magnetohydro, 時空に依存した磁場 B

v1 ラピディティ依存性に面白い構造

その他

最近の事がよくまとまっていると思うスライド

- H. Niemi (5月23日プレナリー, 12 番目)
  特に後半部分
- H. Petersen (Student day 5月18日B, 1番目)
  所々にある Summary スライド

これから

重イオン動的模型の今後?

- η/s 温度依存性, ζ/s, κ, τ_R, etc.
- より簡単なモデル・パラメータ制限:
  (各パラメータセット毎の事象毎計算を避ける)
- 初期状態
  - 核子自体の形・揺らぎ → 特に pA
  - 核子の位置相関
  - $\pi^{\mu\nu}$, Π の初期条件
  - IP-Glasma など Classical Yang-Mills dynamics
- 統計量
  - r_n (運動量毎の v_n の相関係数)
  - 様々な揺らぎ起源 → P($\{v_n\}$, $\{\Psi_n\}$) → 様々な相関
  - 衝突軸方向の事象平面の捩れ $\Psi_n^P \neq \Psi_n^N$
- 電磁流体、揺動流体、pA