Exotics from heavy ion collisions

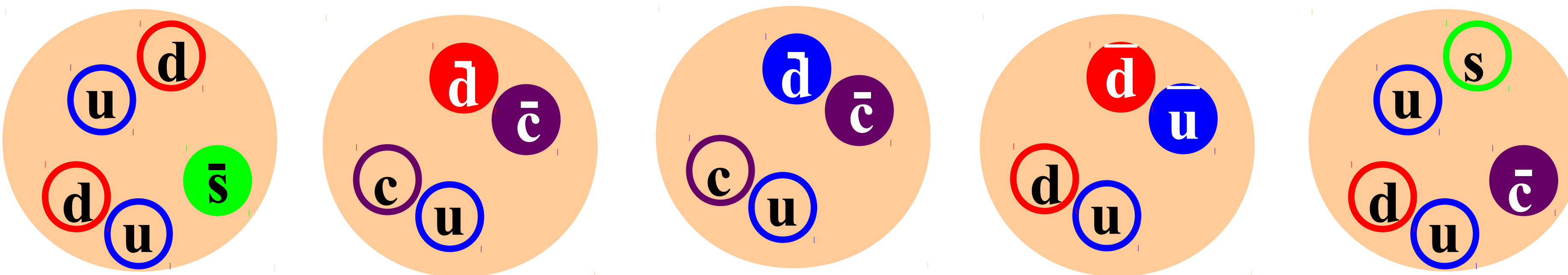
Akira Ohnishi (Nuclear Theory Group)

S. Cho,[1] T. Furumoto,[2, 3] T. Hyodo,[4] D. Jido,[2] C.-M. Ko,[5] S. H. Lee,[2, 1]
M. Nielsen,[6] A. Ohnishi,[2] T. Sekihara,[2, 7] S. Yasui,[8] and K. Yazaki[2, 9]
(ExHIC Collaboration), arXiv:1011.0852

1 Yonsei, 2 YITP, 3 RIKEN Nishina Center, 4 TITech,
5 Texas A&M, 6 Sao Paulo, 7 Kyoto, 8 KEK, 9 RIKEN

Exotic Hadrons

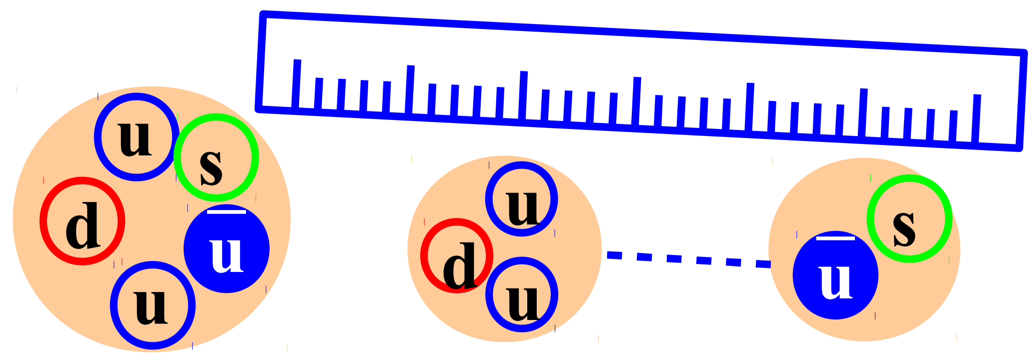
- Exotic hadrons
  → Θ^+, Z, X, Y, ... Discovered/Proposed at LEPS, Belle, BaBar,...



Θ^+ Z(4430) X(3872) f_0 Θ^+_{cs}

- Various pictures
  - Di-quark, Hadronic molecule, Tetraquark ($QQ^{bar}qq^{bar}$)

Key quantity = Size
→ Do we have any Ruler
to measure hadron size ?



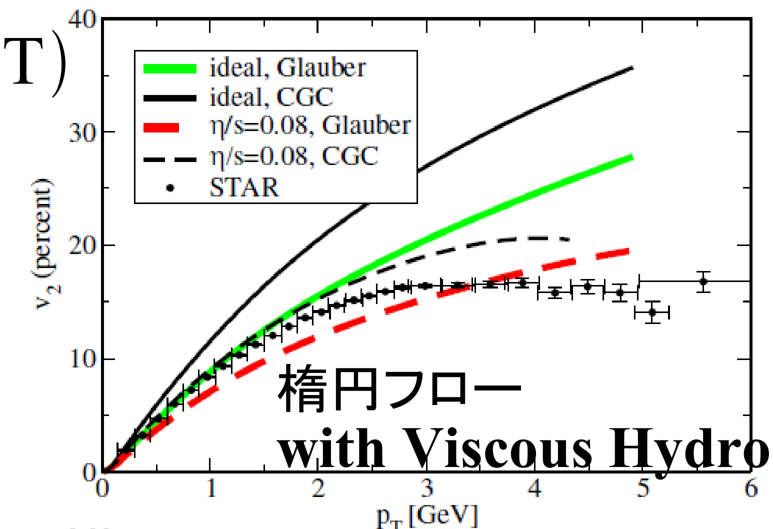
uudsū p K^-

Λ (1405)

What does RHIC tell us ?

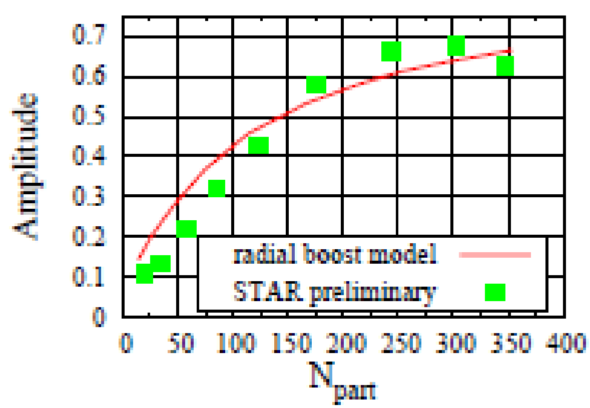
- **Large energy loss of partons → Color is deconfined.**
- **Success of ideal hydrodynamics → Perfect fluid (sQGP)**

$$\frac{\eta}{s} \leq 0.1 \sim \frac{1}{4\pi} \quad \text{(KSS bound from AdS/CFT)}$$

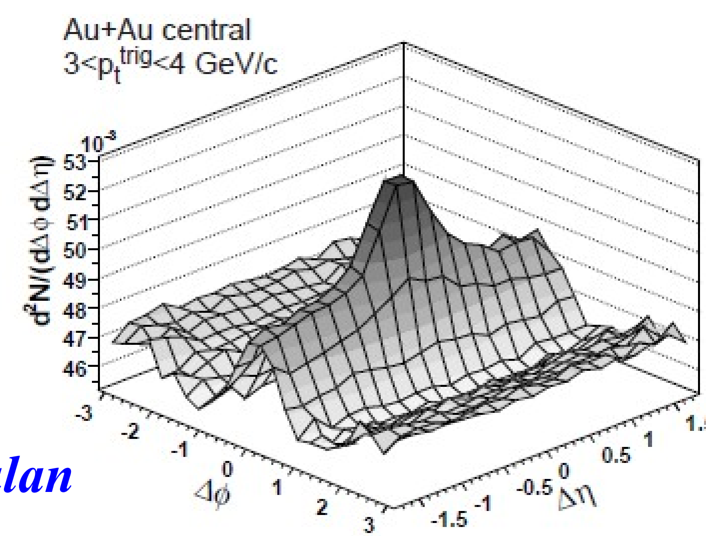


横運動量 *Luzum, Romatschke*

- **Ridge structure**
  → Color Glass Condensate
  (Observed also in pp collisions at LHC)
- **Mach cone → Slow sound velocity (?)**
- **Success of statistical model**
  → formation of
  thermalized
  hot matter
- **and more ?**



Dumitru, Gelis, McLerran, Venugopalan



What does RHIC tell us ?

- **Success of statistical model → formation of hot matter under equil.**

$$N_h^{\mathrm{stat}} = V_H \frac{g_h}{2\pi^2} \int_0^\infty \frac{p^2\,dp}{\gamma_h^{-1} \exp(E_h/T_H) \pm 1}$$

  - **γ_h: particle fugacity**

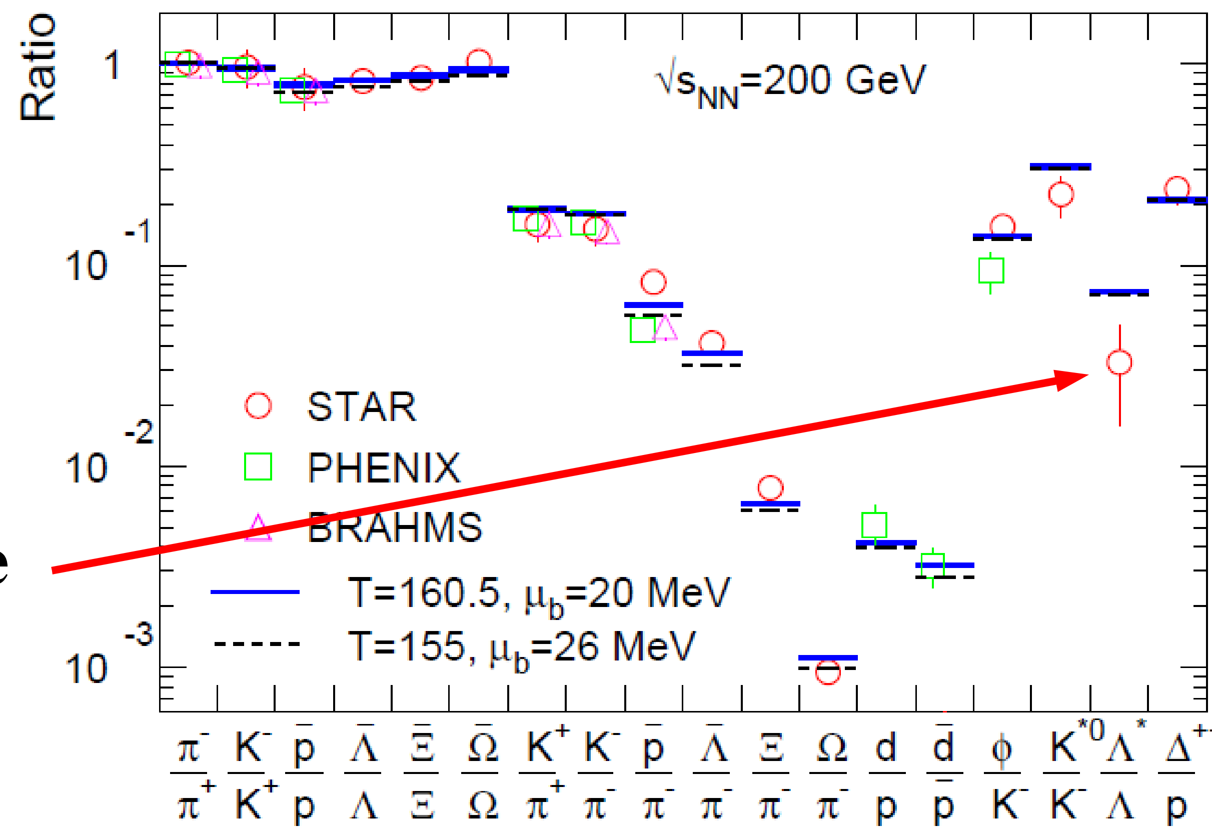
    $$\gamma_h = \exp(\mu/T_H)$$

    for hadrons made of u,d,s quarks

  - **T, V, μ → Yield N_h**

- **Stat. model overestimate finite L hadrons. → Coalescence picture**

  Kanada-En'yo, Muller (2006)



A. Andronic, P. Braun-Munzinger, J. Stachel, NPA772('06)167.

Coalescence model

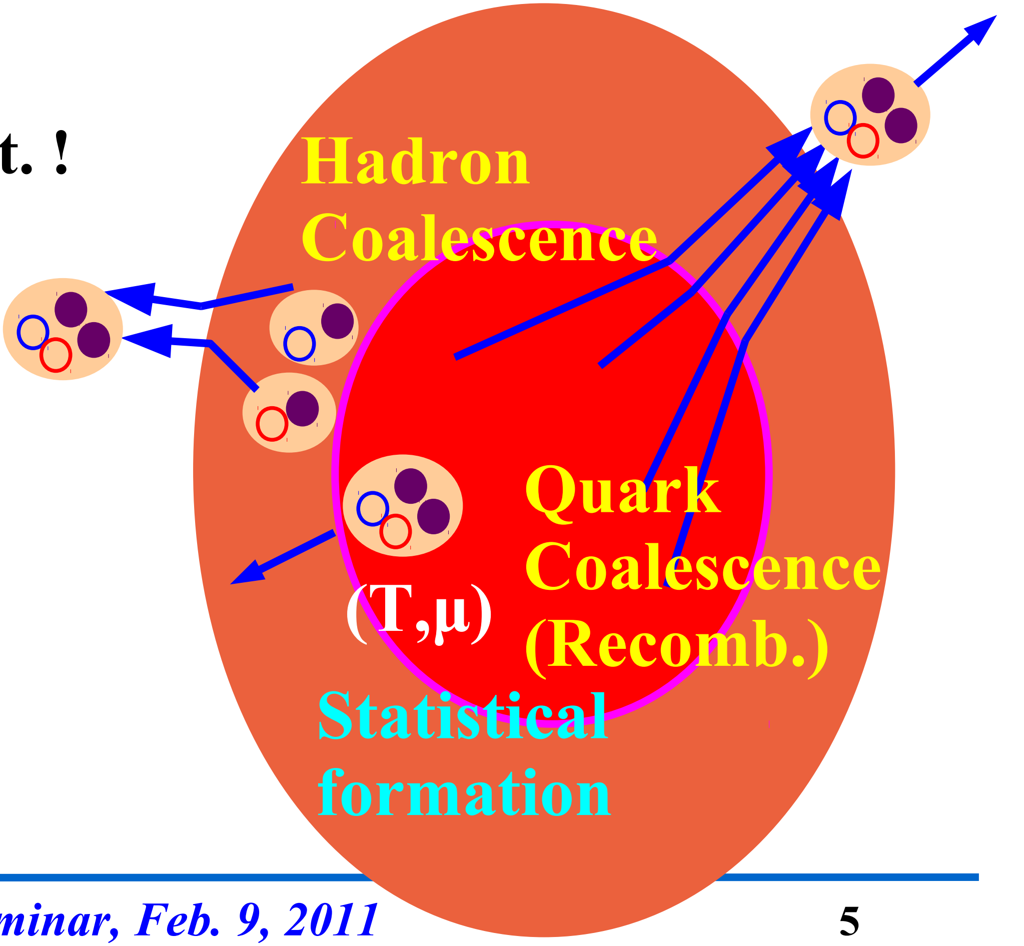
- Yield = Overlap of Dist. & Intrinsic Wigner func. (~ wave fn.)

$$N_h^{\mathrm{coal}} \simeq g_h \int \left[\prod_{i=1}^{n} \frac{d^3x\,d^3p}{(2\pi)^3} f(x_i, p_i) \right] \times f^W(x_1, x_2, \dots x_n; p_1, p_2, \dots p_n)$$

Dist. of constituents — Intrinsic Wigner func.

- Successful:
  Baryon puzzle & v2 scaling
- *WE KNOW* Quark & hadron dist. !
  (~ Transverse Boltzmann
  + Bjorken)
- *WE ASSUME* Hadron w.f.
  (s-wave and p-wave HO w.f.)

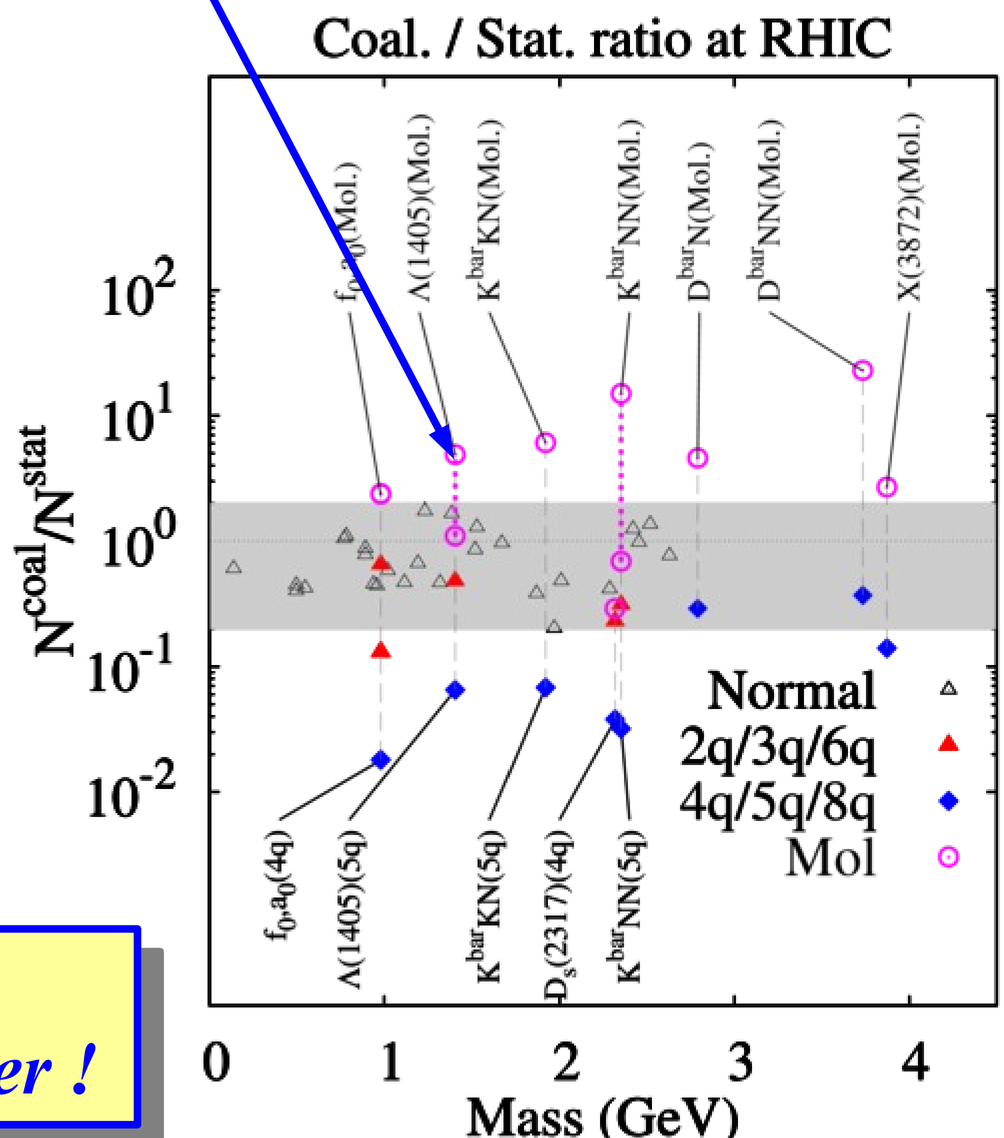
→ *WE CAN OBTAIN* the size
by comparing with data.



Prediction: Ratio with Statistical model results

- **Coal./Stat. ratio: $R_h = N^{coal}/N^{stat}$**
  - **Normal hadrons**
    → $0.2 < R_h < 2$ (Normal band)
  - **Multi-quark states**
    → Smaller yields in coal.
    $R_h < 0.3$
  - **Hadronic molecules**
    → Larger yields ($R^h > 2$)
    for weakly bound
    or extended sized exotics
    (f_0/a_0, Λ(1405), …)

Sekihara, Hyodo, Jido (large size Λ(1405))



We can use RHIC/LHC
as a (unstable) hadron size ruler !

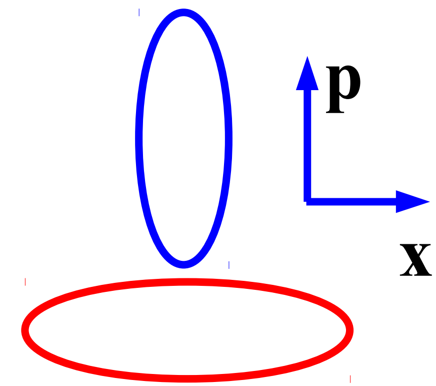
S.Cho et al.(ExHIC Collab.), arXiv:1011.0852

Why ?

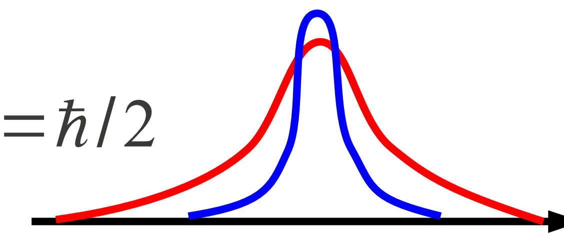
- **Size dep. of Yield**

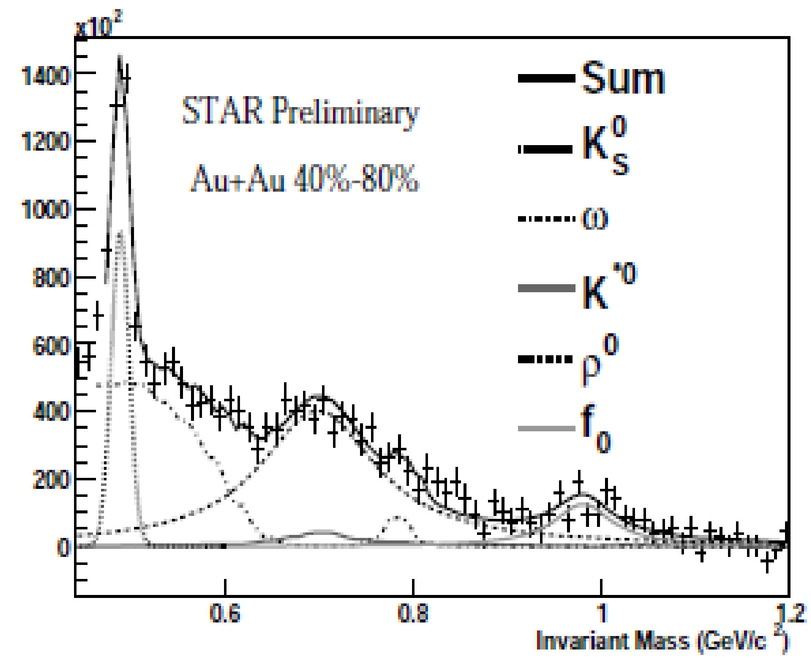
$$N_h^{coal} \simeq g_h \int \left[\prod_{i=1}^{n} \frac{d^3x\, d^3p}{(2\pi)^3} f(x_i, p_i) \right] \times f^W(x_1, x_2, \dots x_n; p_1, p_2, \dots p_n)$$

Dist. of constituents **Intrinsic Wigner func.**



- **w/o constituent distribution**
  → Wigner fn. is normalized to unity. $\Delta p \times \Delta x = \hbar/2$
- **Boltzmann dist. suppresses Δp-dep.**
  → Integral is larger for larger Δx



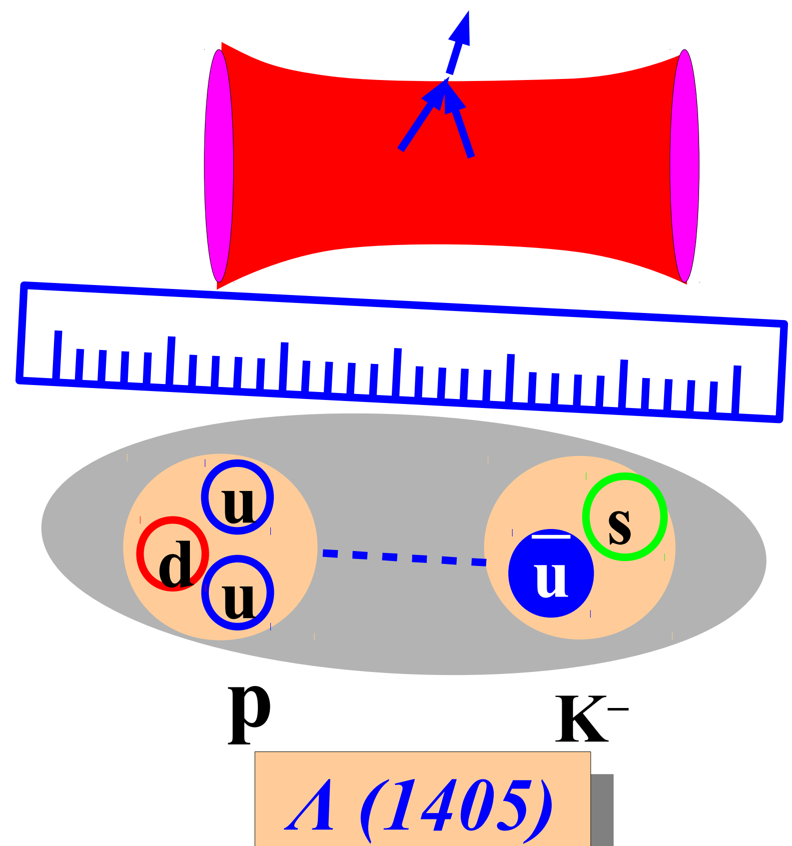


- **Experimental suggestions**
  $f_0(980)$) ~ 8.4 (STAR, 2003)
  Stat: 5.6, 2q:0.76-3.8, 4q:0.1, Mol: 13
  → Tetra-quark picture underestimate the measured yield.

Summary

S.Cho et al. (ExHIC Collab.), arXiv:1011.0852

- **Exotic component is a long-standing problem in hadron physics.**
- **Exotic hadron yields from heavy-ion collisions are studied systematically, and we predict that extended hadronic molecule yields would be enhanced compared with normal hadrons.**
- **RHIC experimentalists (H.Z.Huang, I.-K. Yoo) start identifying D and $\bar{D}$ mesons by using vertex detector.**
  c.f. X(3872)= $c\bar{c}$, $c\bar{c}q\bar{q}$ or $D\bar{D}^*$
- **It is fun to utilize RHIC & LHC to measure (unstable) hadron sizes.**



Thank you !

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Please check the references in our paper,
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