J-PARC-HI へのコメント

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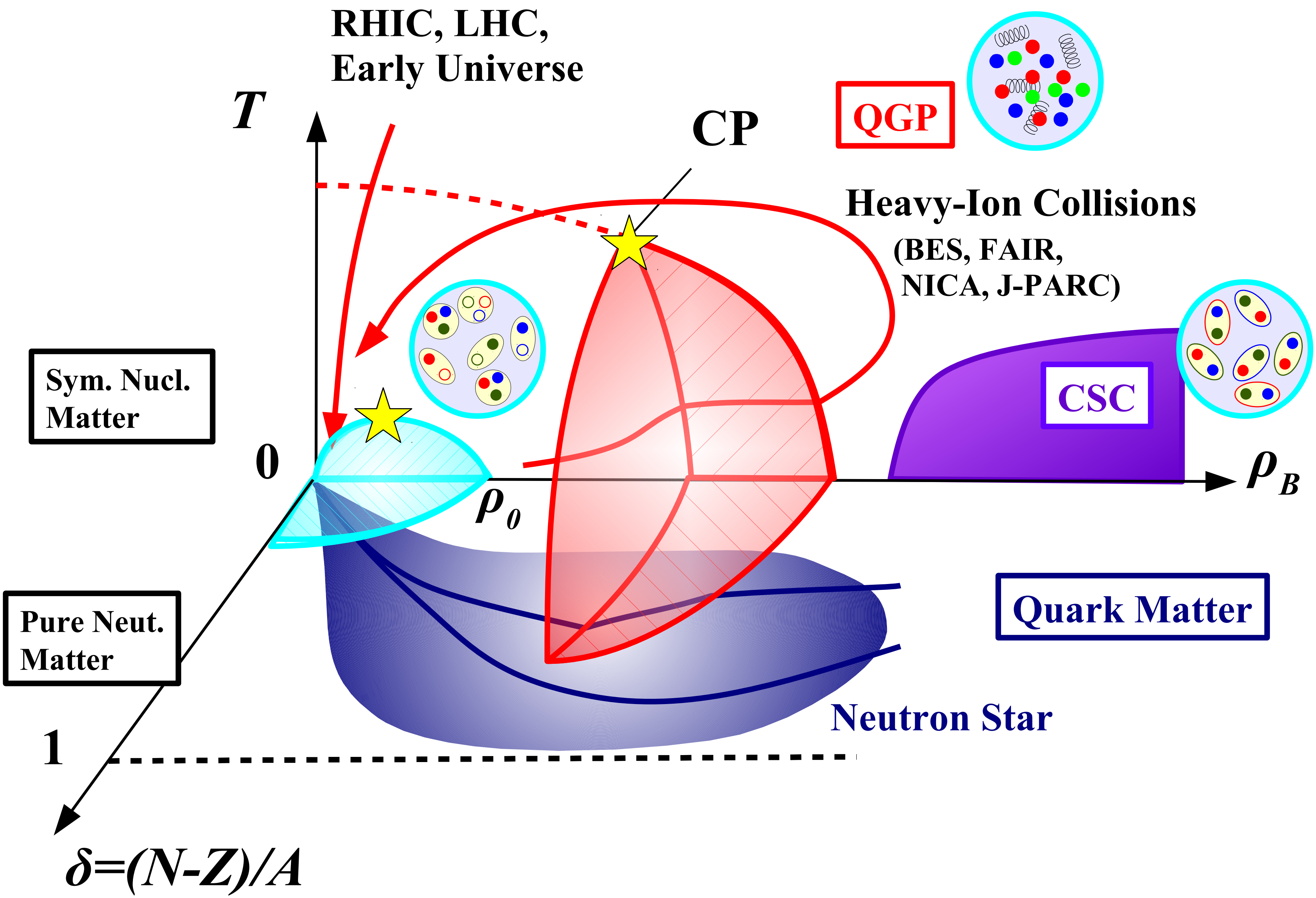
J-PARC-HI インフォーマルミーティング
Aug.10, 2016, J-PARC, Japan

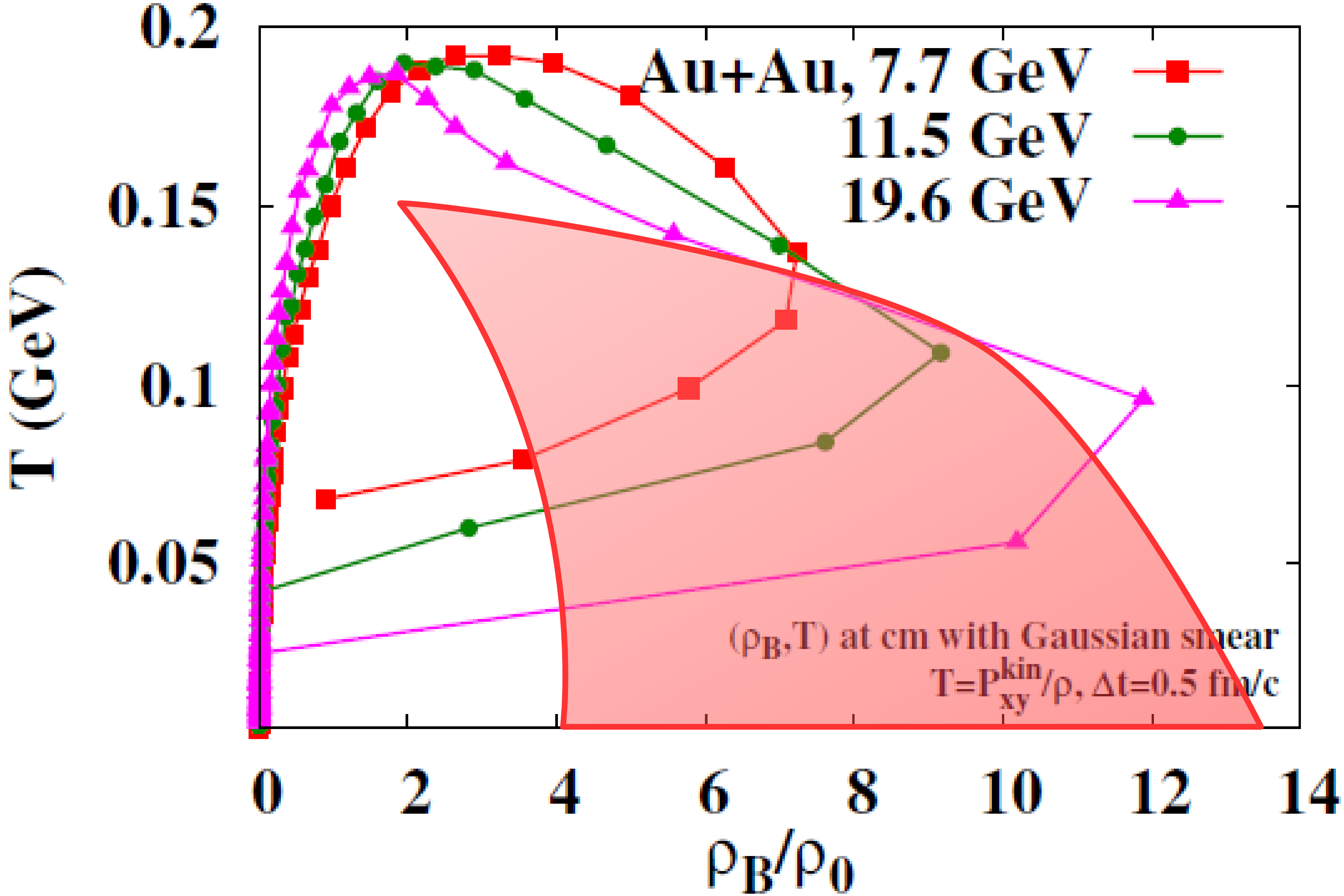
Physics at J-PARC-HI program

- **Goals of J-PARC-HI program**
  - **QCD phase diagram (1st or 2ndnd order phase transition)**
  - **Chiral restoration (probed by dileptons and others)**
  - **Collective dynamics of hadrons (EOS & Thermalization)**
  - **Strange matter search (nuclei with exotic constituents and their interactions)**
  - **...**
- **Already explored energies at AGS ! But ...**
  - **There are many unobserved quantities at AGS**
    Dilepton spectrum, Spectral function of resonances,
    Cumulants of conserved charges, Higher order flow harmonics, …
  - **Intensity is much stronger at J-PARC-HI**
    Much more accurate data of standard observables,
    Event selected flow (e.g. strangeness number tagged, T. Sakaguchi),
    K^* and K_1 spectral functions (H. Ohnishi),

QCD Phase Diagram

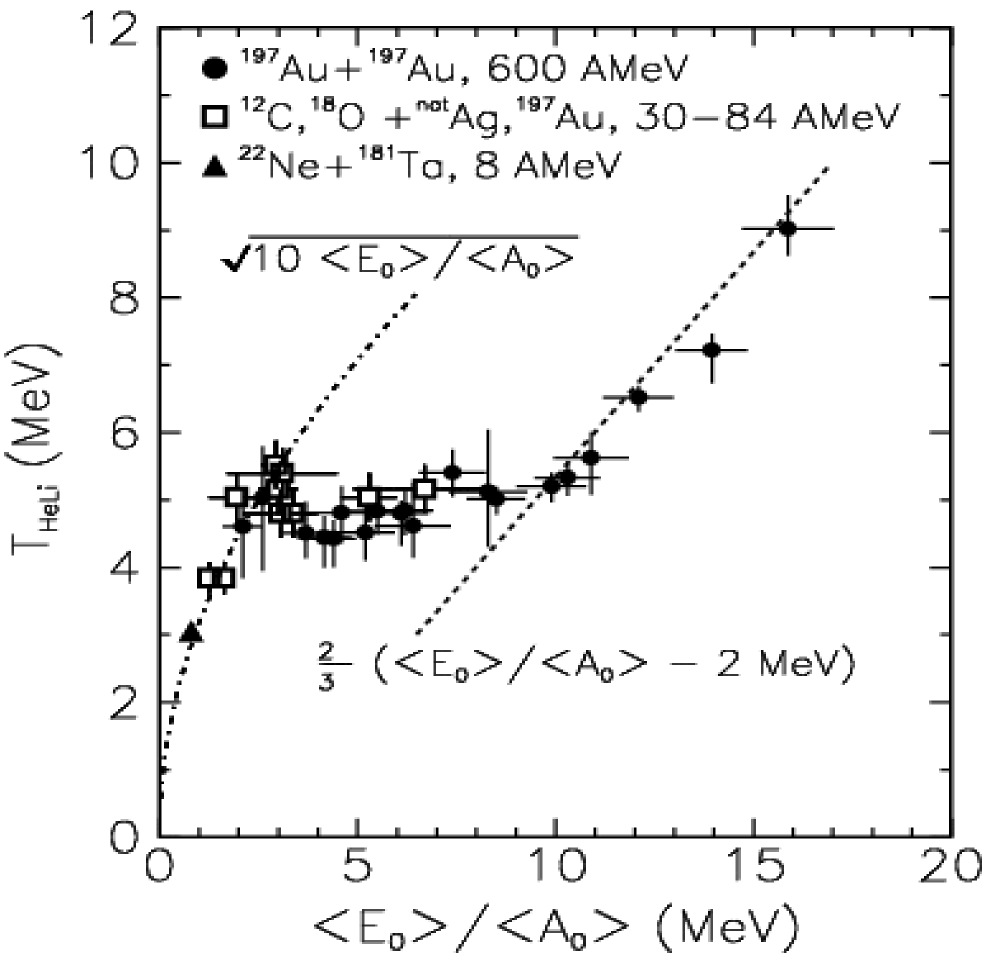


Two ways to probe QCD phase transition

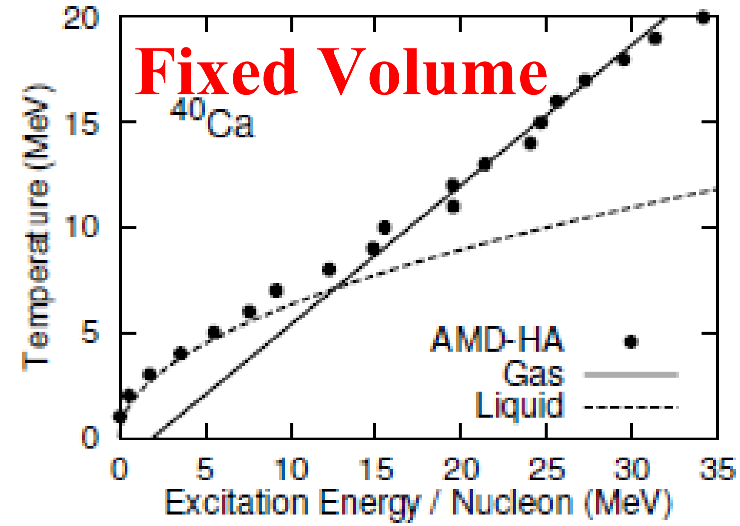


Nuclear Liquid-Gas Phase Transition

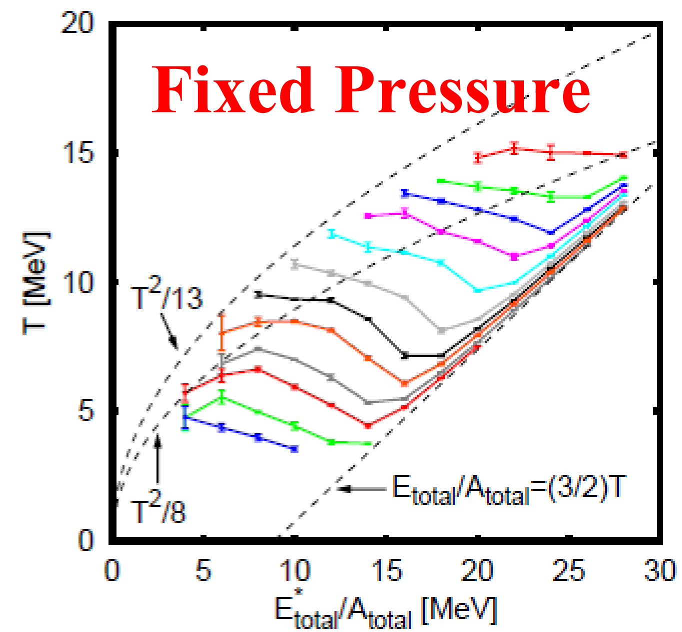
- **Caloric curve → LG phase transition (Smoking gun)**



J. Pochadzalla et al. (GSI-ALLADIN collab.), PRL 75 (1995) 1040.



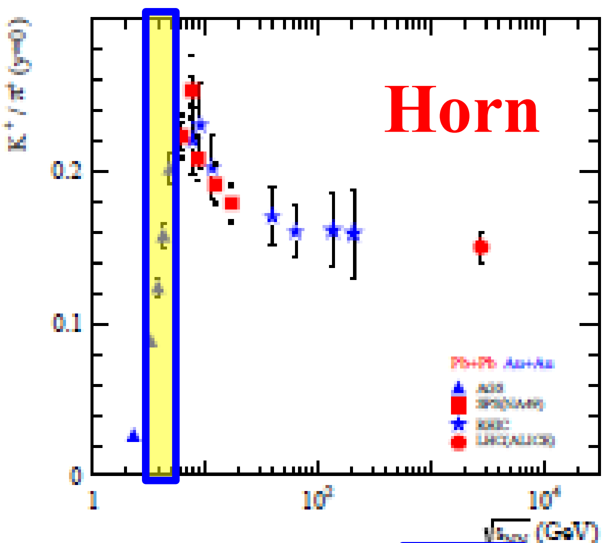
AO, Randrup ('98)

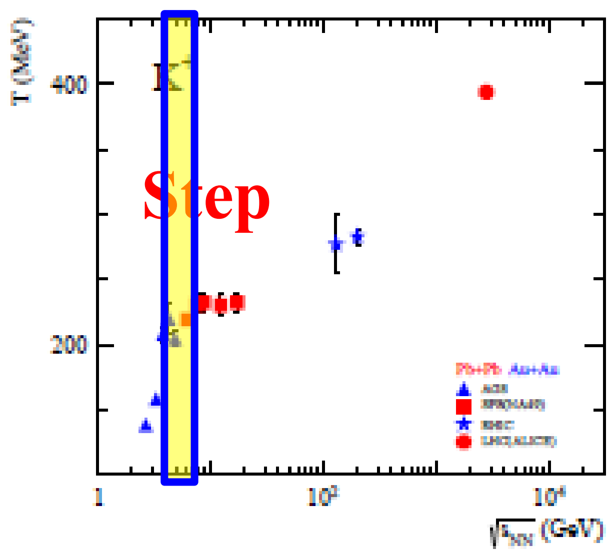


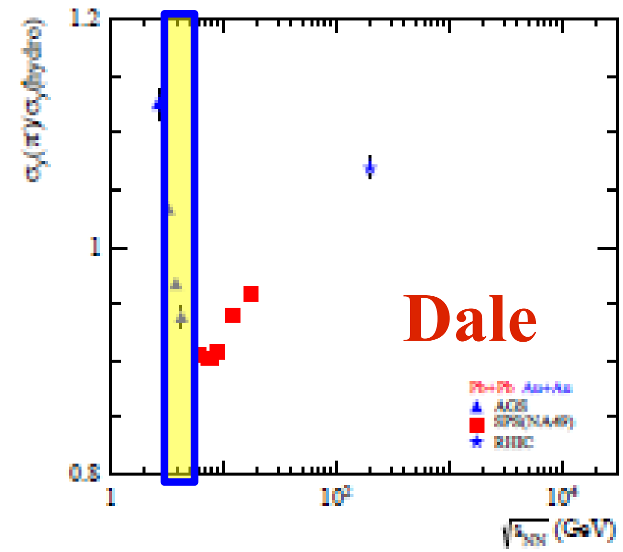
T. Furuta, A.Ono ('09)

Horn, Step and Dale

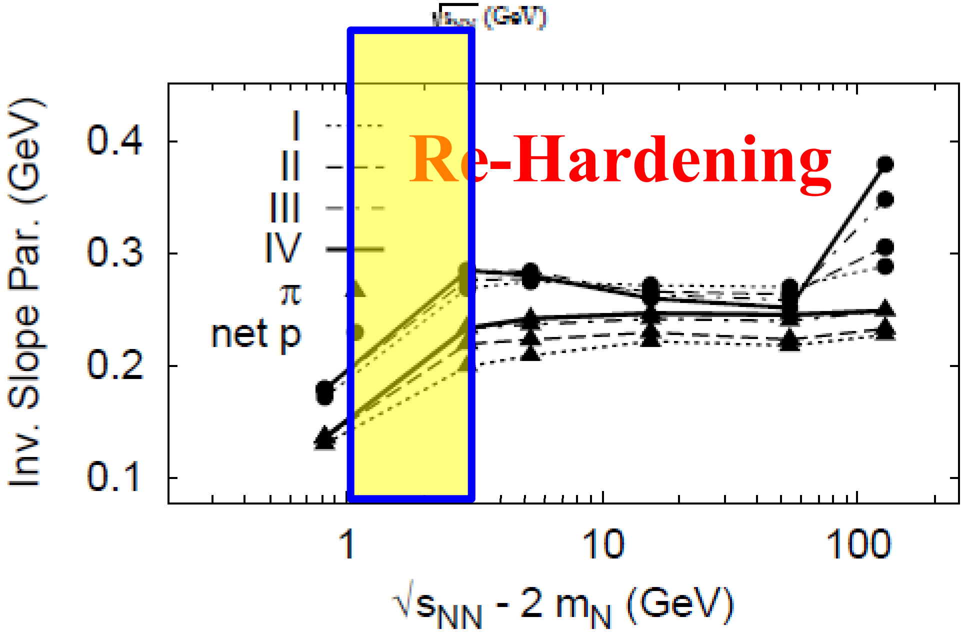
- **Non-monotonic behavior in K^+/π^+ ratio (Horn), m_T slope par. (Step or re-hardening), rapidity dist. width of π**





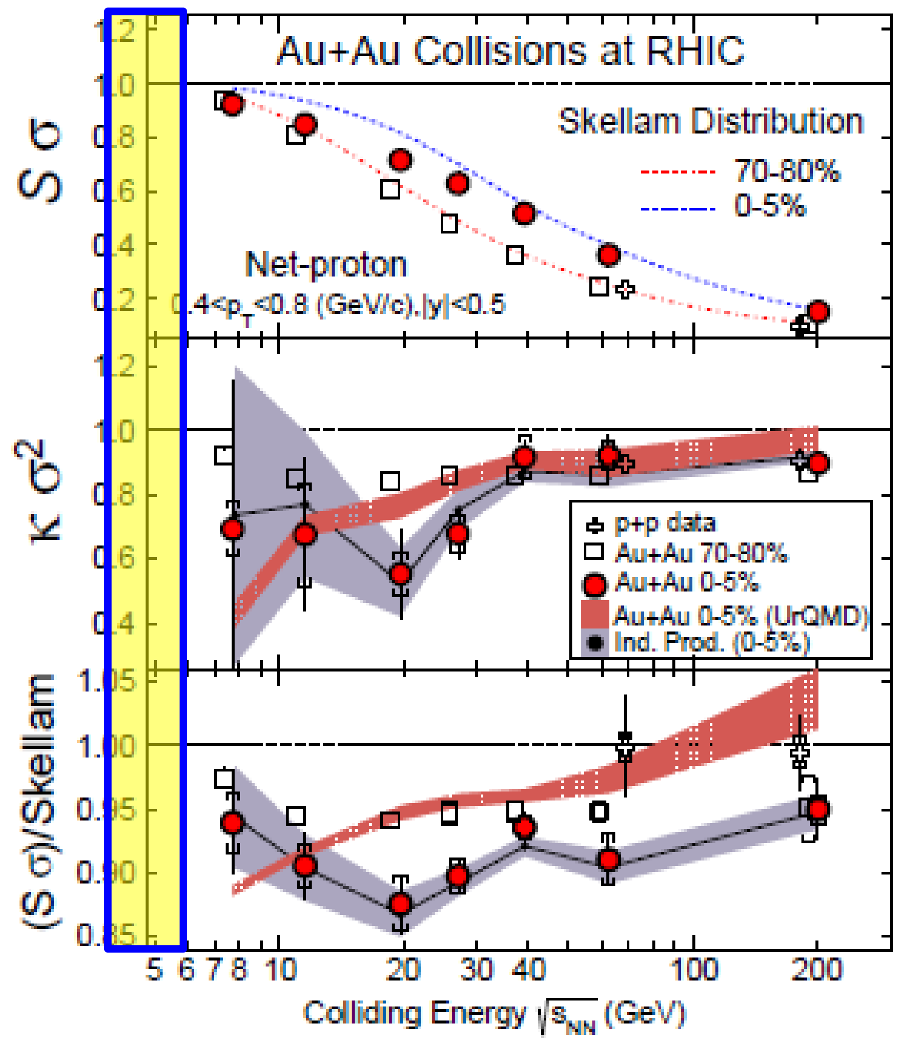


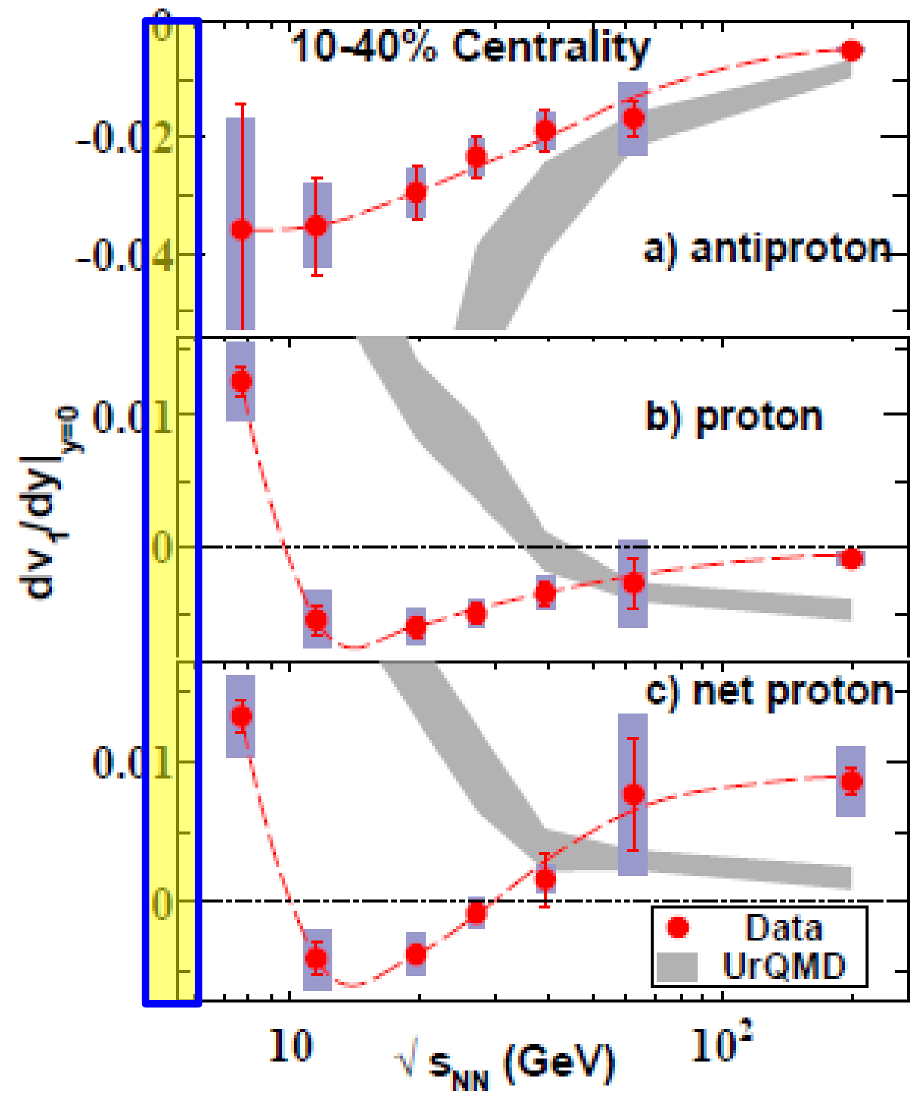
E.g. A. Rustamov (2012)



N. Otuka, P.K.Sahu, M. Isse, Y. Nara, AO, nucl-th/010205

Net-Proton Number Cumulants & Directed Flow





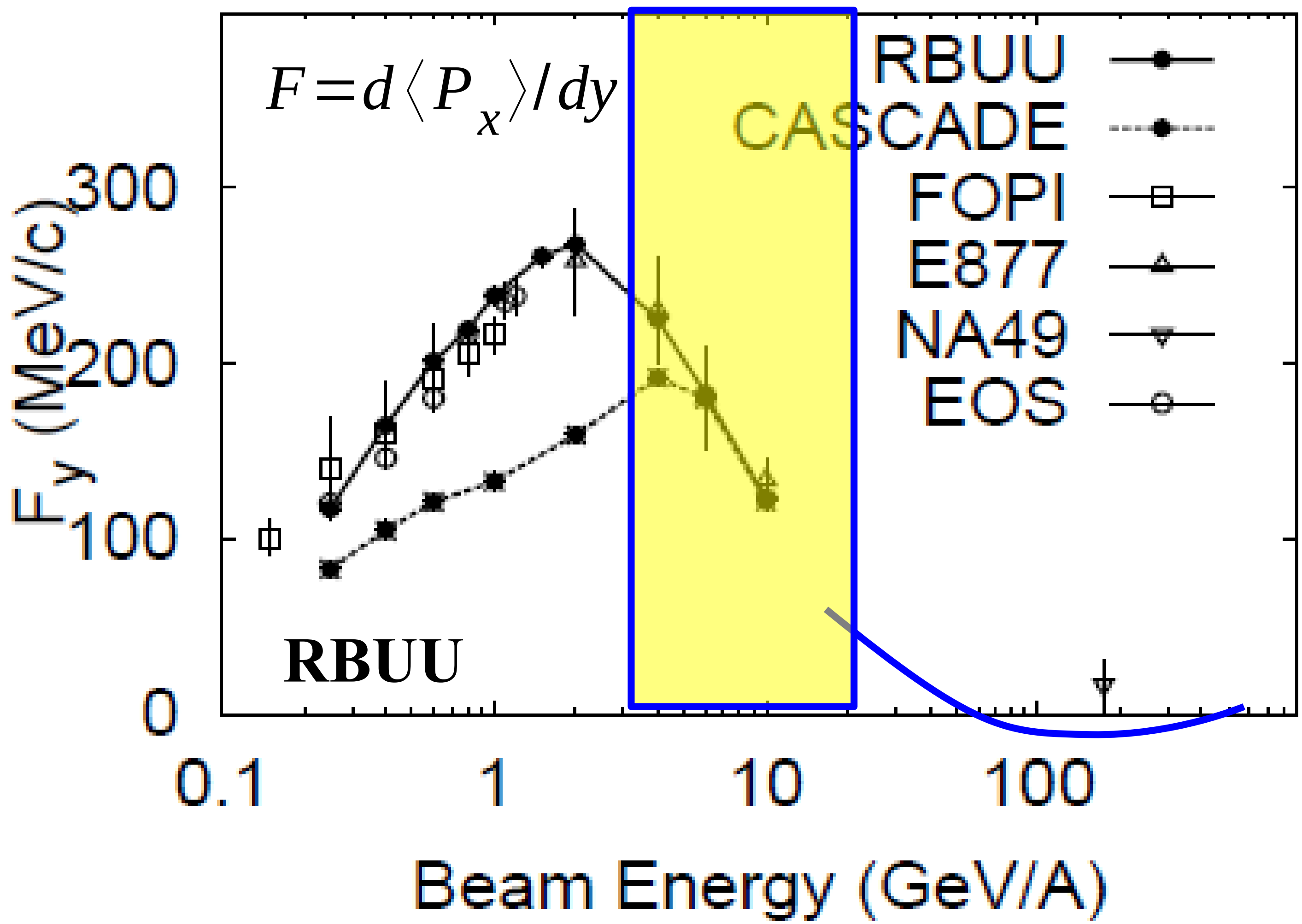
STAR Collab. PRL 112('14)032302

STAR Collab., PRL 112('14)162301.

Need statistics. J-PARC-HI may provide conclusive data.

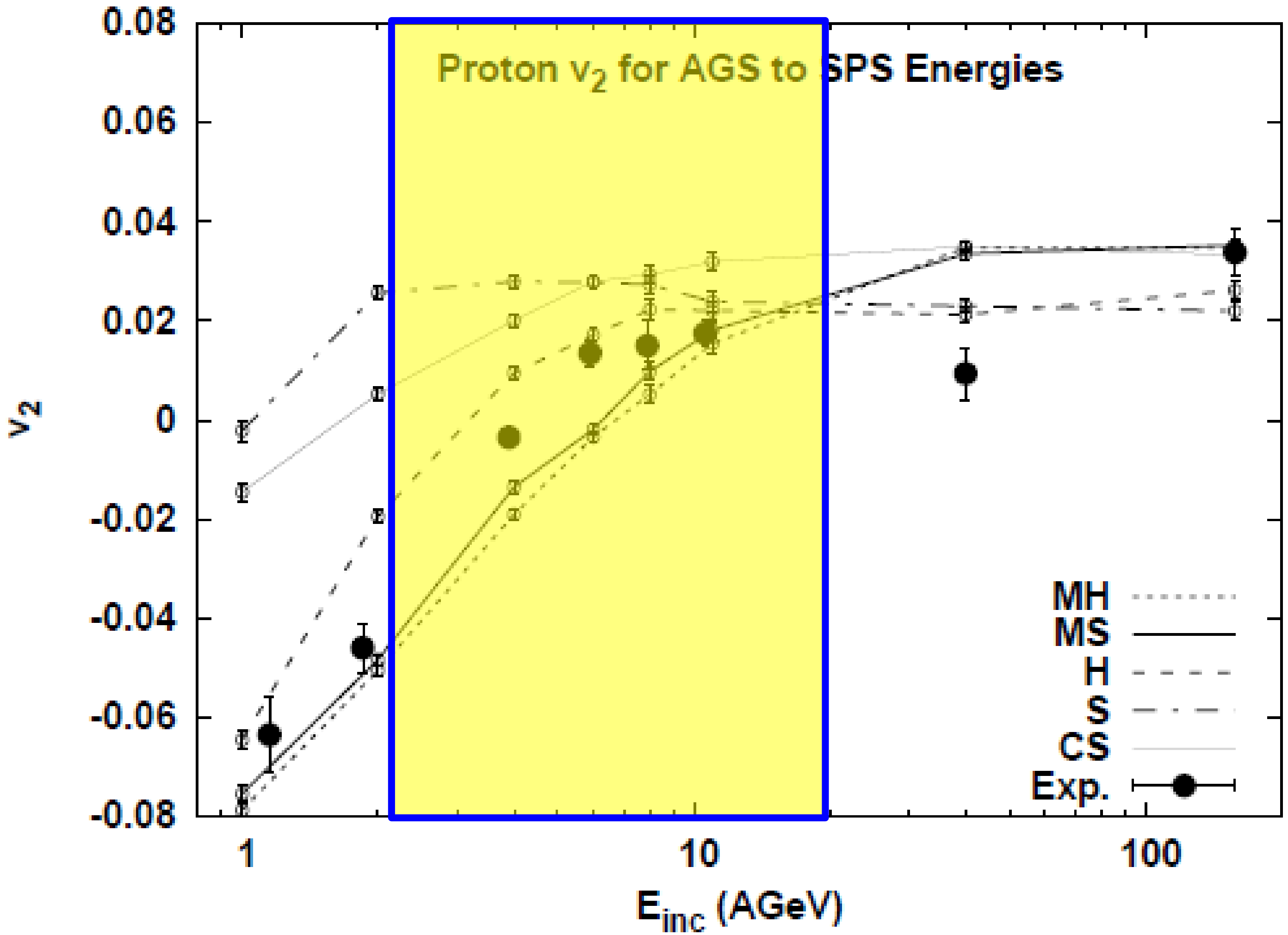
J-PARC-HI will not be competitive.

Directed Flow



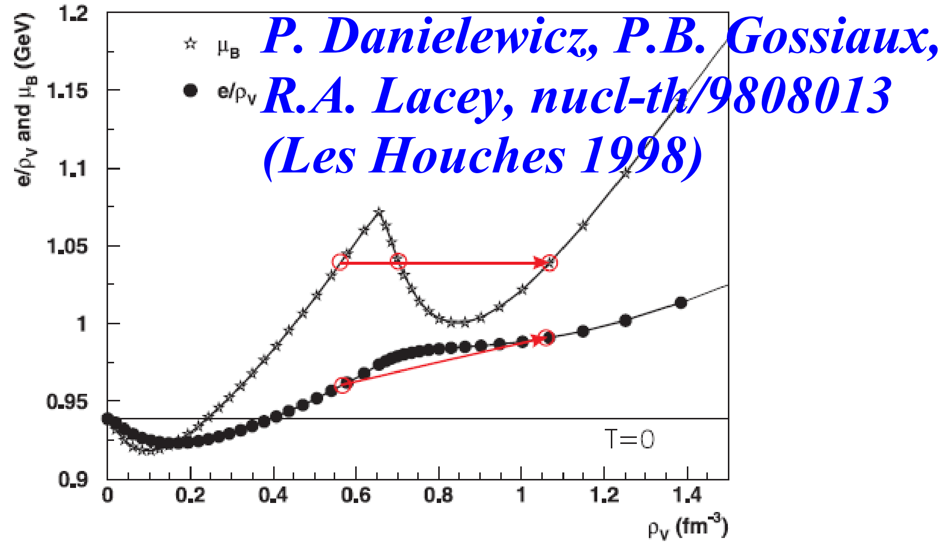
P. K. Sahu, W. Cassing, U. Mosel, AO, Nucl. Phys. A 672 (2000),376

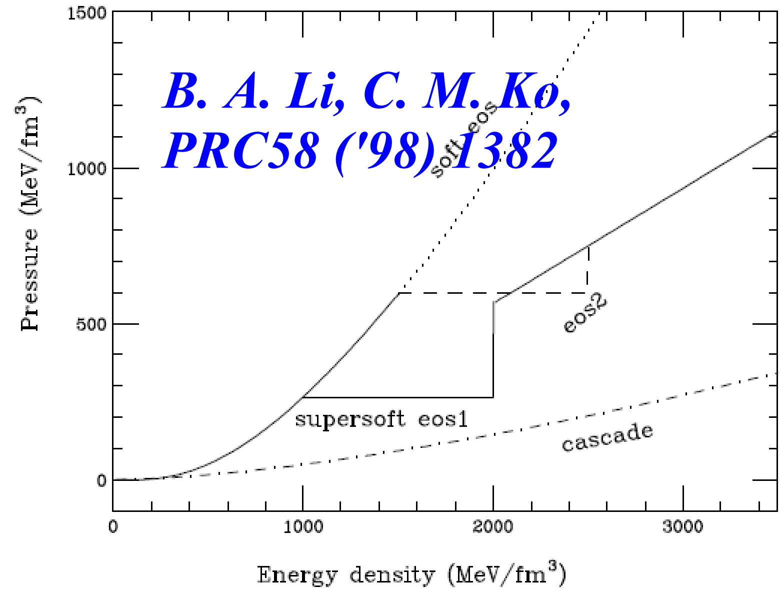
Elliptic Flow

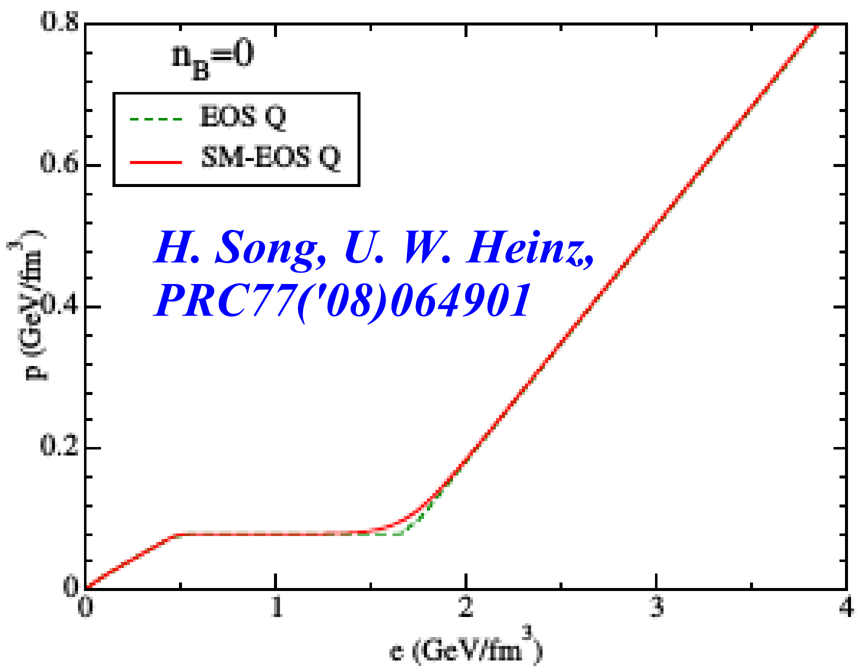


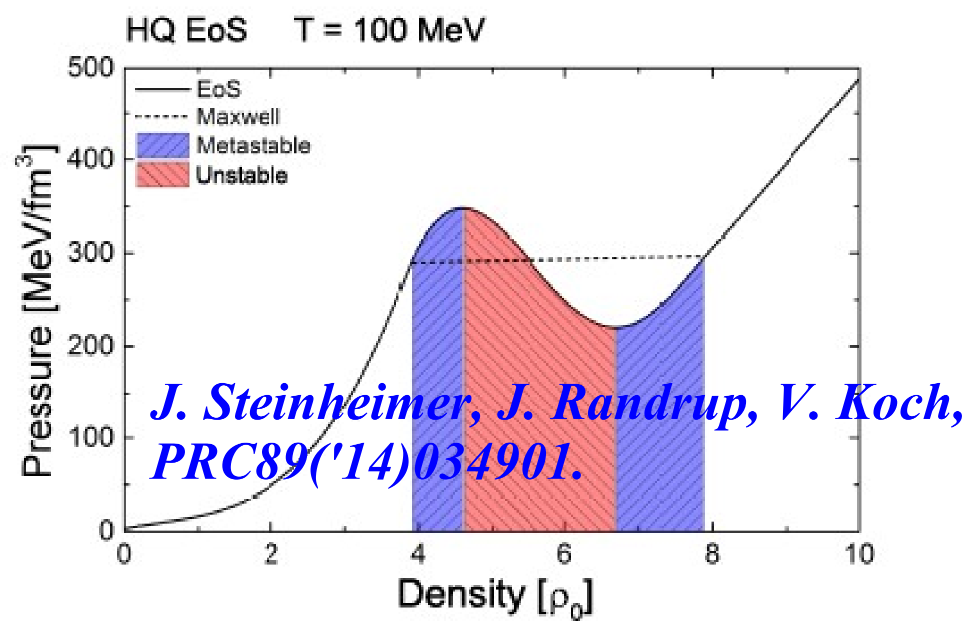
M. Isse, A. Ohnishi, N. Otuka, P. K. Sahu, Y. Nara, PRC72('05)064908

Where do we find FOPT ?





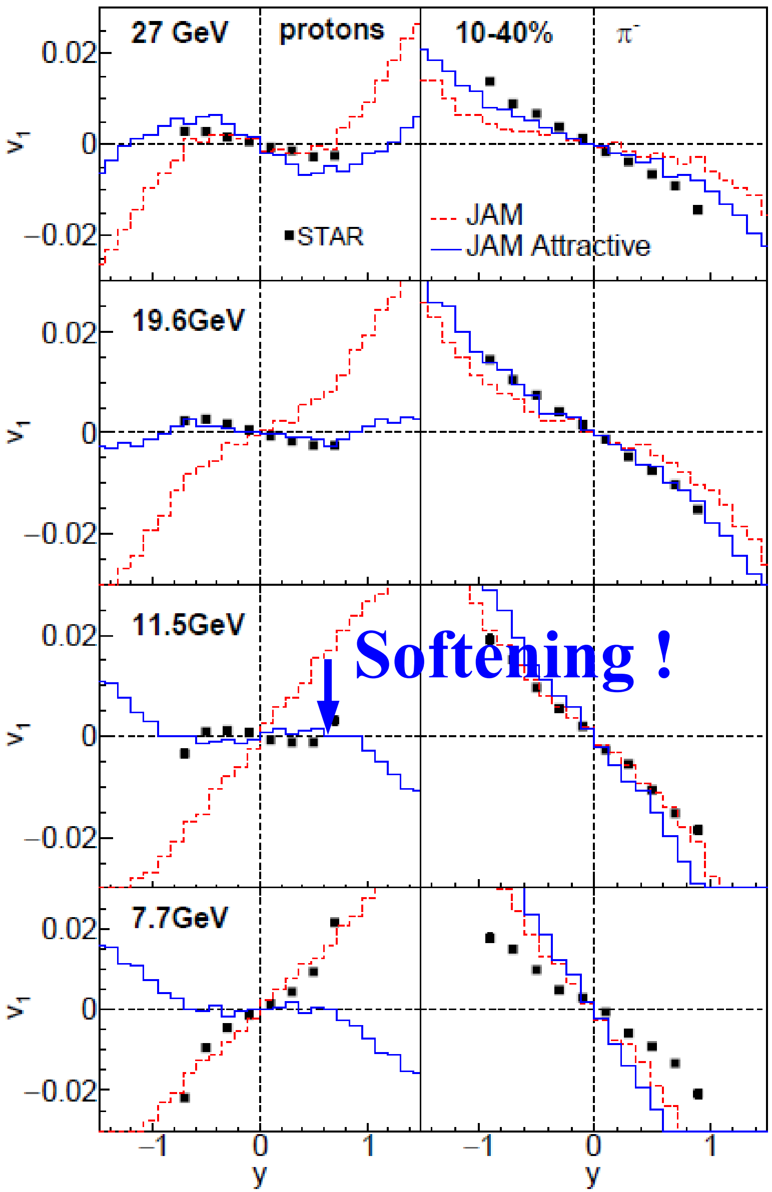




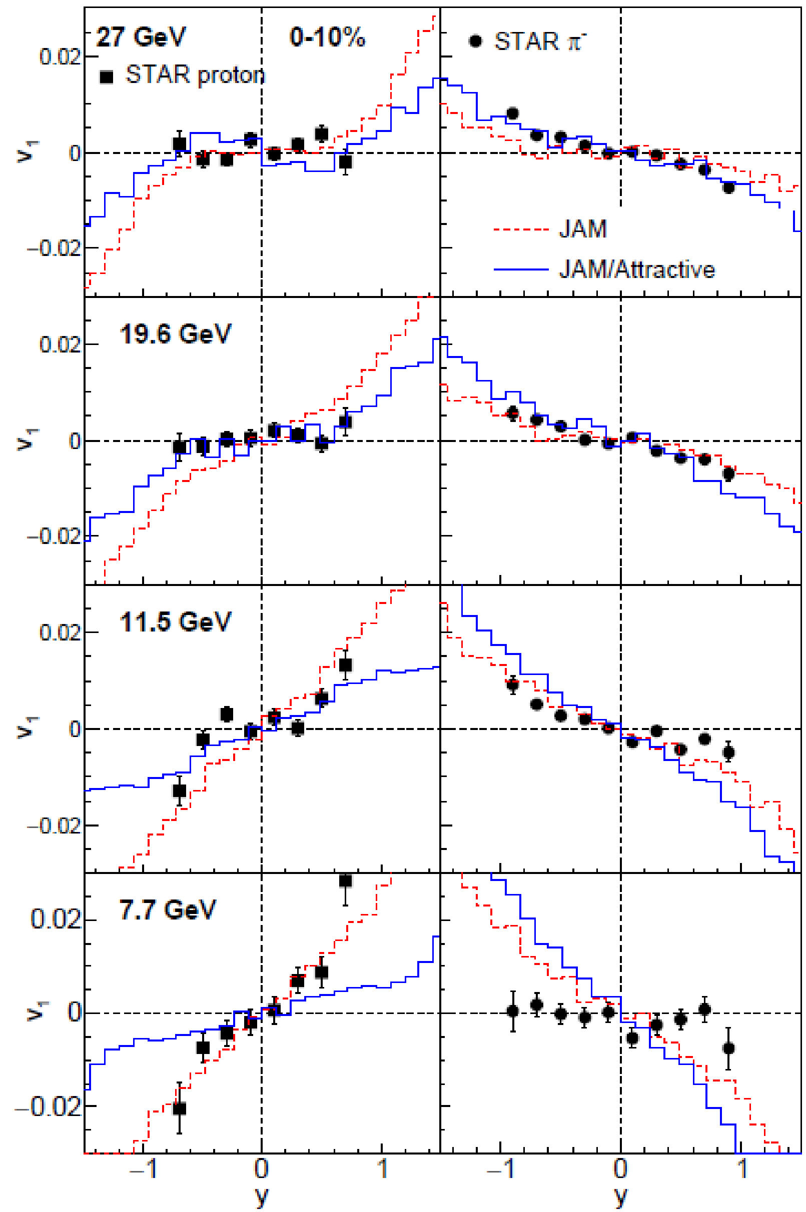
1st order phase transition: ρ_B=(3-10) ρ_0, P=(80-700) MeV/fm^3

Directed Flow with Attractive Orbits

Nara, Niemi, AO, Stöcker ('16)



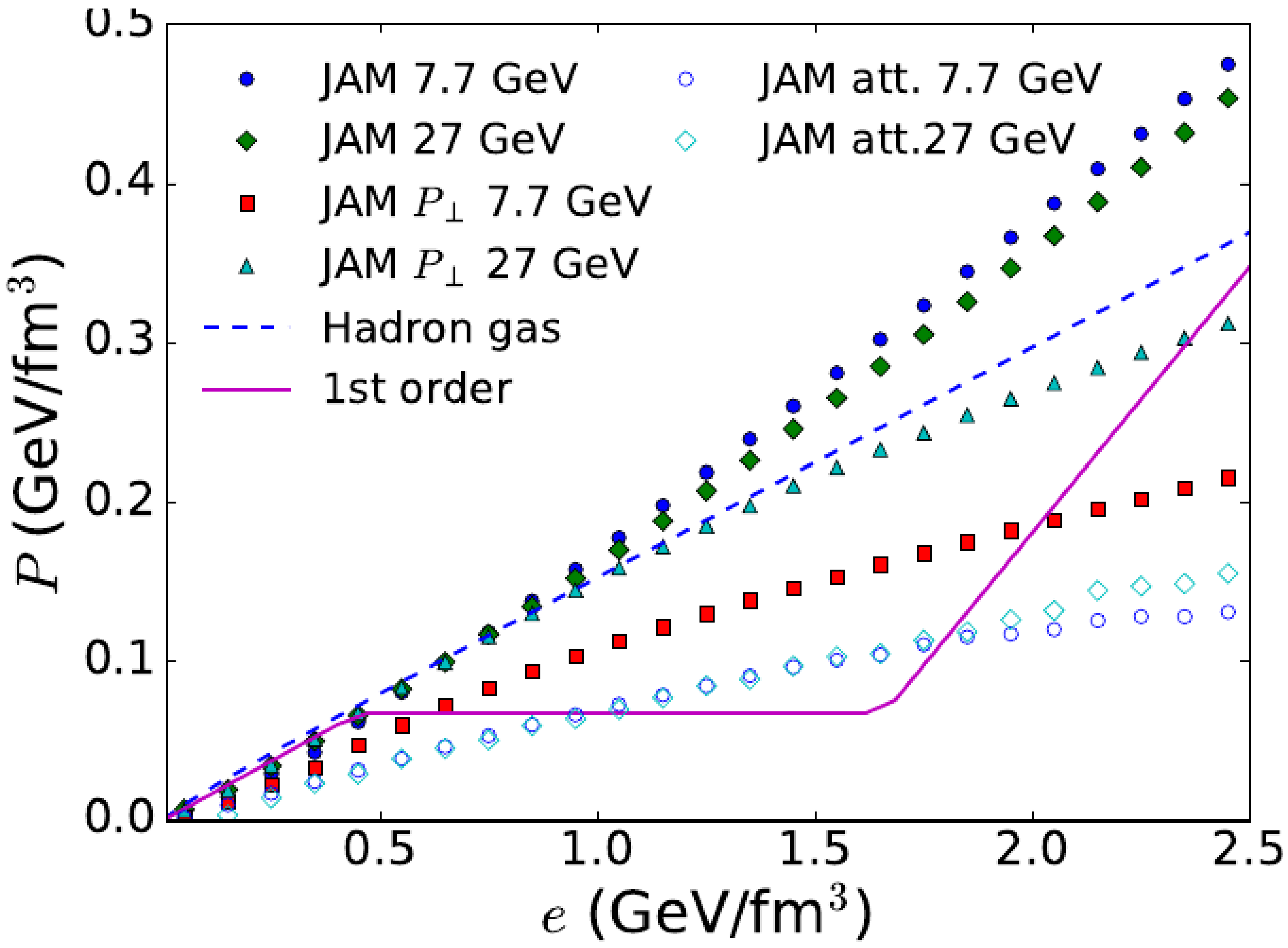
mid-central (10-40 %)



central (0-10 %)

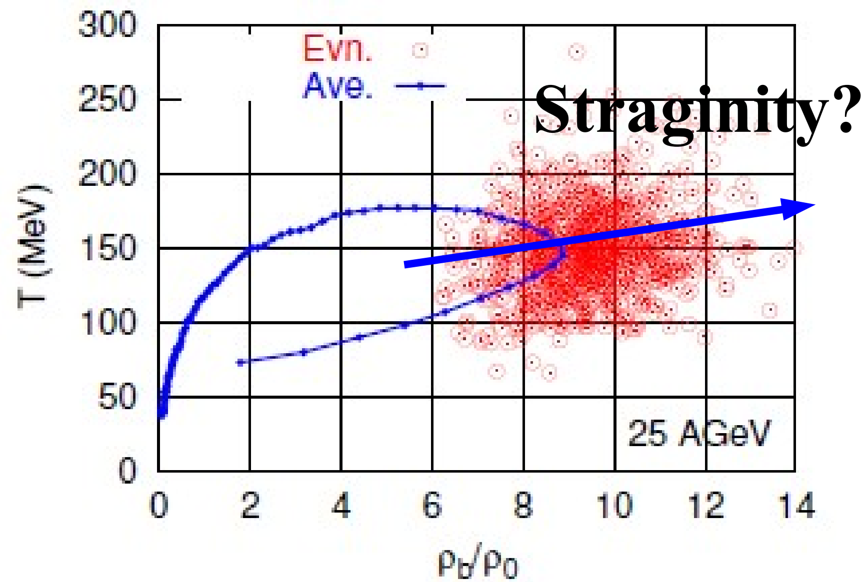
Softening of EOS by Attractive Orbits

$$\Delta P = -\frac{\rho}{3(\delta\tau_i + \delta\tau_j)}(p'_i - p_i)^\mu (q_i - q_j)_\mu.$$



Phase Transition Signal at J-PARC Energies

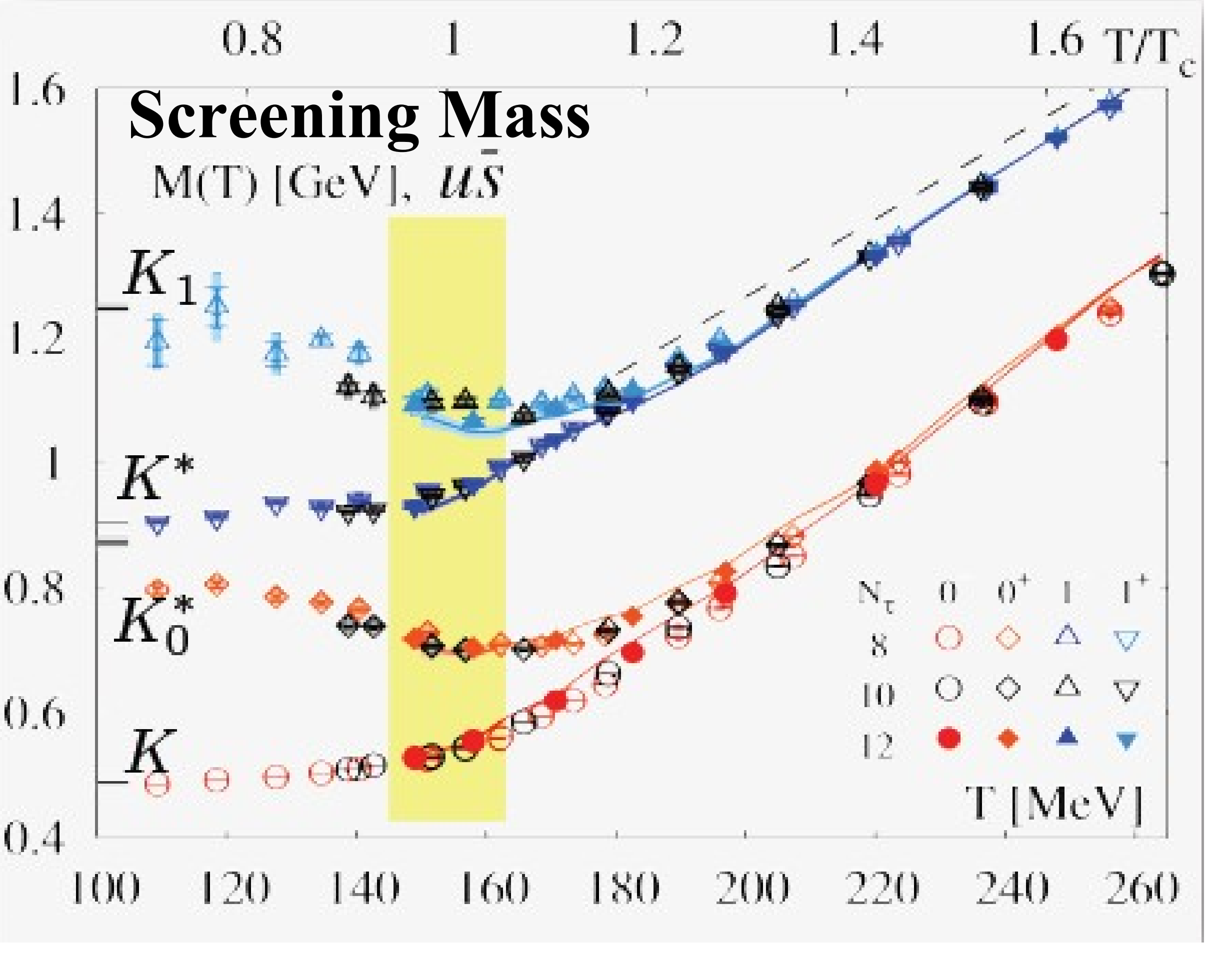
- **J-PARC energy ($\sqrt{s_{NN}}$=3-6 GeV) は色々なシグナルが始まる付近。 High intensity の特徴を生かせば onset of deconfinement を見つけることができるかも知れない。**
- **輸送模型の計算結果は十分に高密度に達しており、小さな体積で短い時間、QGP ができていると思っても自然。**
- **揺らぎにより密度・温度が高くなったイベントを集めると、QGP 生成のシグナルが見えるのでは？**
  例：ストレンジクォーク対生成数でタグしたイベントを集める。
  (坂口さんのアイデア)
  Strangity, Baryonity



AO (JHF workshop, 2002);
J. Phys: Conf. Ser. 668 ('16)012004

Chiral Symmetry Restoration

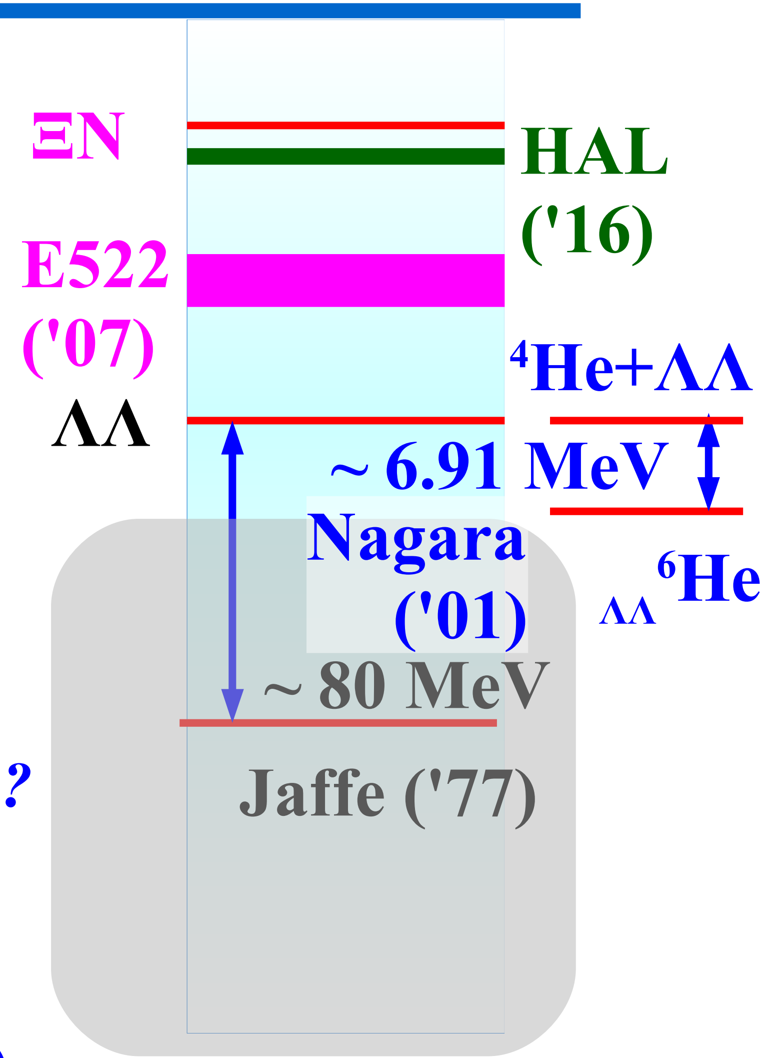
- Vector meson の質量変化 (E16)
- カイラルパートナーの spectral function が一致。
  - ρ(770) and a_1 (1230)
    $\Gamma(a_1)$=250-600 MeV
  - K^* and K_1
    (大西宏明さん)
    K*(892)
    (m,Γ)=(892,47) MeV
    K_1(1270)
    (m,Γ)=(1272,90) MeV
    → K*π (16± 5%)
  - FSI 効果は？
  - pp → pA → AA



Y. Maezawa, ExHIC 2016 workshop.

Relevance of ΛΛ interaction to physics

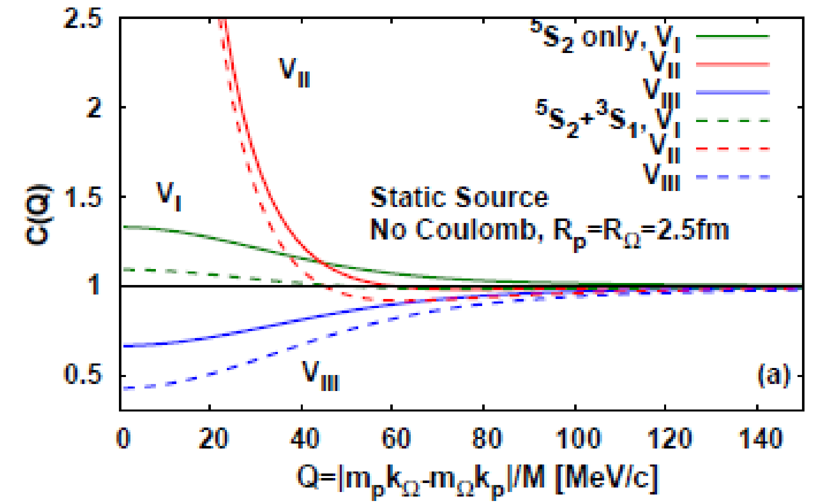
- **H-particle: 6-quark state (uuddss)**
  - **Prediction:** *R.L.Jaffe, PRL38(1977)195*
  - **Ruled-out by double Λ hypernucleus**
    Takahashi et al.,PRL87('01) 212502
  - **Resonance or Bound "H" ?**
    Yoon et al.(KEK-E522) ('07)
  - **Lattice QCD**
    HAL QCD & NPLQCD ('11)
    HAL QCD ('16): H as a loosely bound ΞN ?

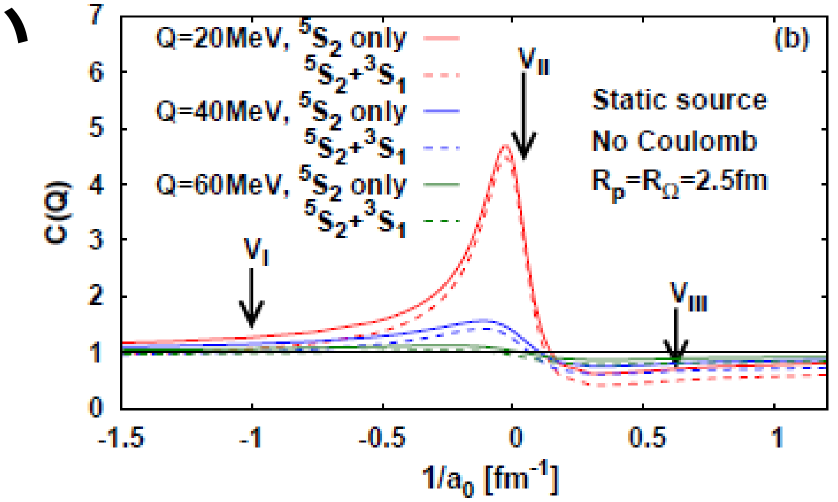


- **Neutron Star Matter EOS**
  - **Hyperon Puzzle**
    Demorest et al. ('10), Antoniadis et al. ('13)
  - **Cooling Puzzle (ΛΛ superfluidity)**
    T. Takatsuka, R. Tamagaki, PTP 112('04)37
- **QGP signal, BB interaction model, ….**

H-particle Hunting

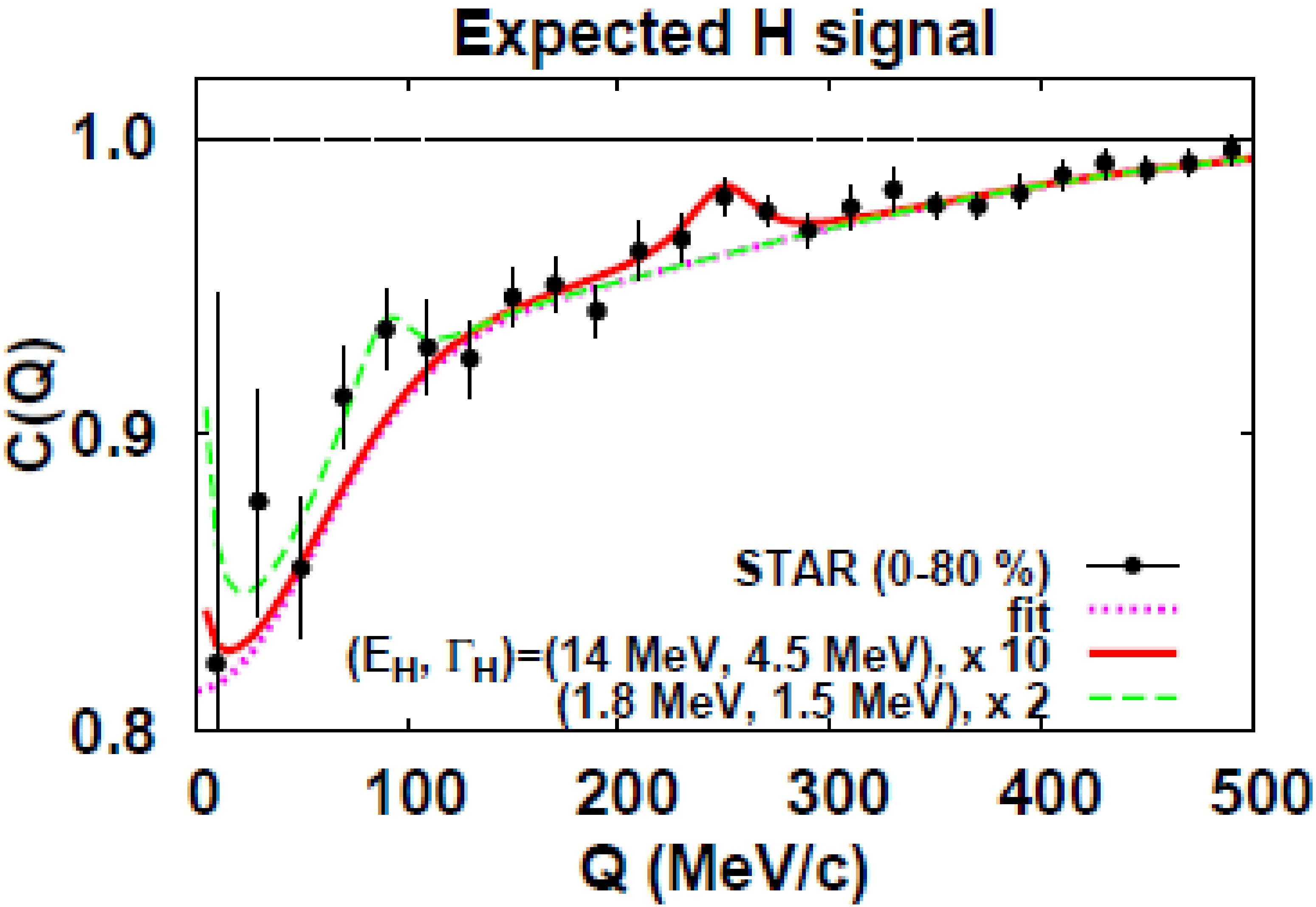
- 最近の HAL の結果「 H は ΞN しきい値のすぐ下にある」 (K. Sasaki et al.)
- とても浅い束縛状態があると Corr. Fn. に大きな増加があるはず。
- ΛΛ の不変質量分布から ΞN 束縛状態のピークを見つけるのは今の RHIC の統計では無理。
- J-PARC エネルギーは Λ/π 比が大きい





K. Morita, AO, F. Etminan, T. Hatsuda, arXiv:1605.06765 [hep-ph]

Detecting H Resonance

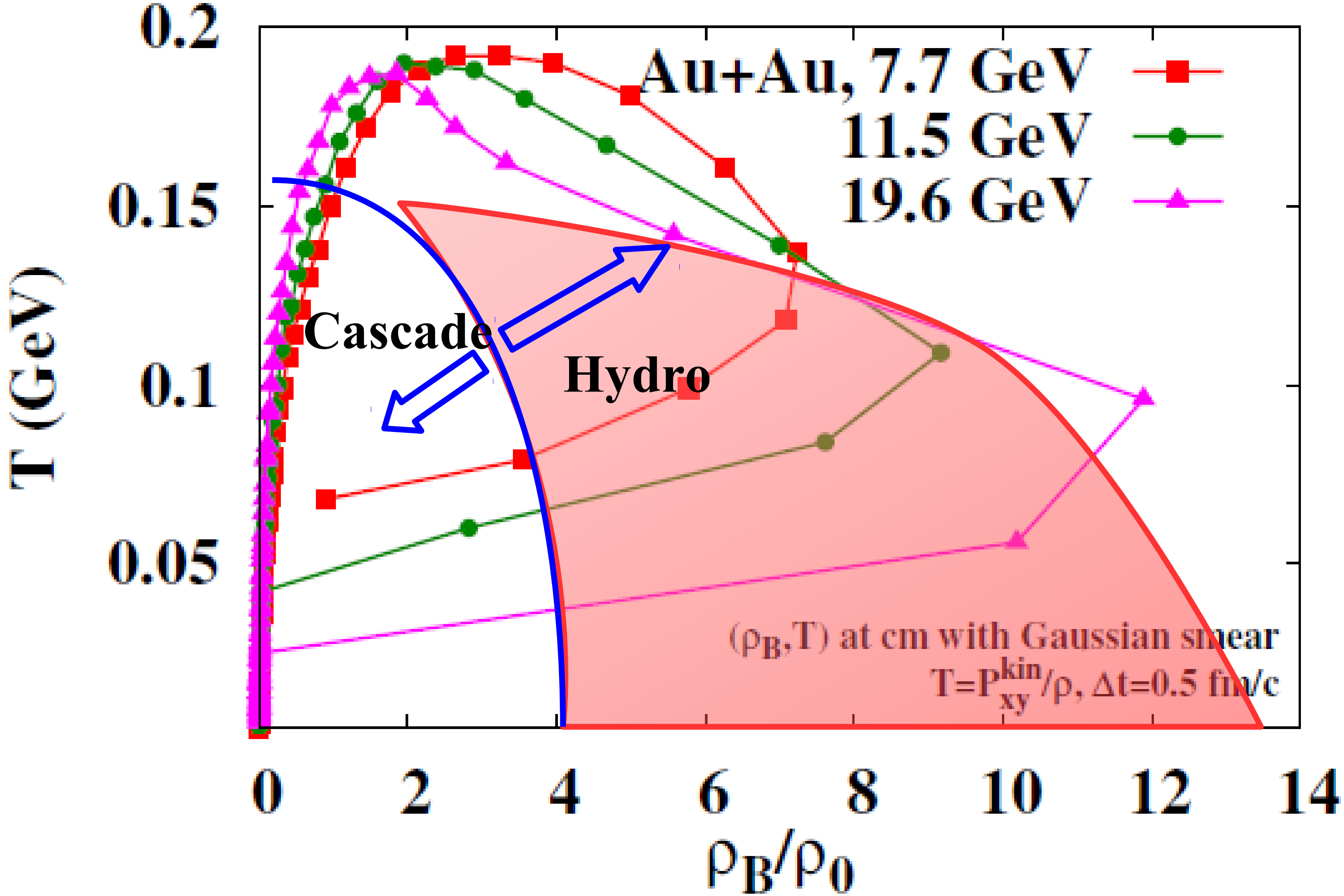


When the resonance energy is much above the threshold, detecting a resonance is not easy because of huge background.

Summary

- J-PARC-HI では
  Onset of deconfinement,
  Chiral restoration,
  Confirmation of H & Other Exotics
  (multi-strangeness, molecule, ...)
  などの可能性がある。
- しかしどれも極めて non-trivial 。特に相転移効果・ハドロン & パートン自由度を含むシミュレーション・プログラム (流体 + カスケード) は是非必要。
- 海外の研究者 (FAIR, NICA の supporting members) を取り込む、責任ある教員の配置、ポスドク枠の確保などを行う必要があろう。

Two ways to probe QCD phase transition



Thank you !