Lambda-Lambda correlation in high-energy heavy-ion collisions

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- **Introduction: Where is "H" ?**
- **ΛΛ correlation in heavy-ion collisions**
- **Coupling effects to ΞN**
- **Summary**

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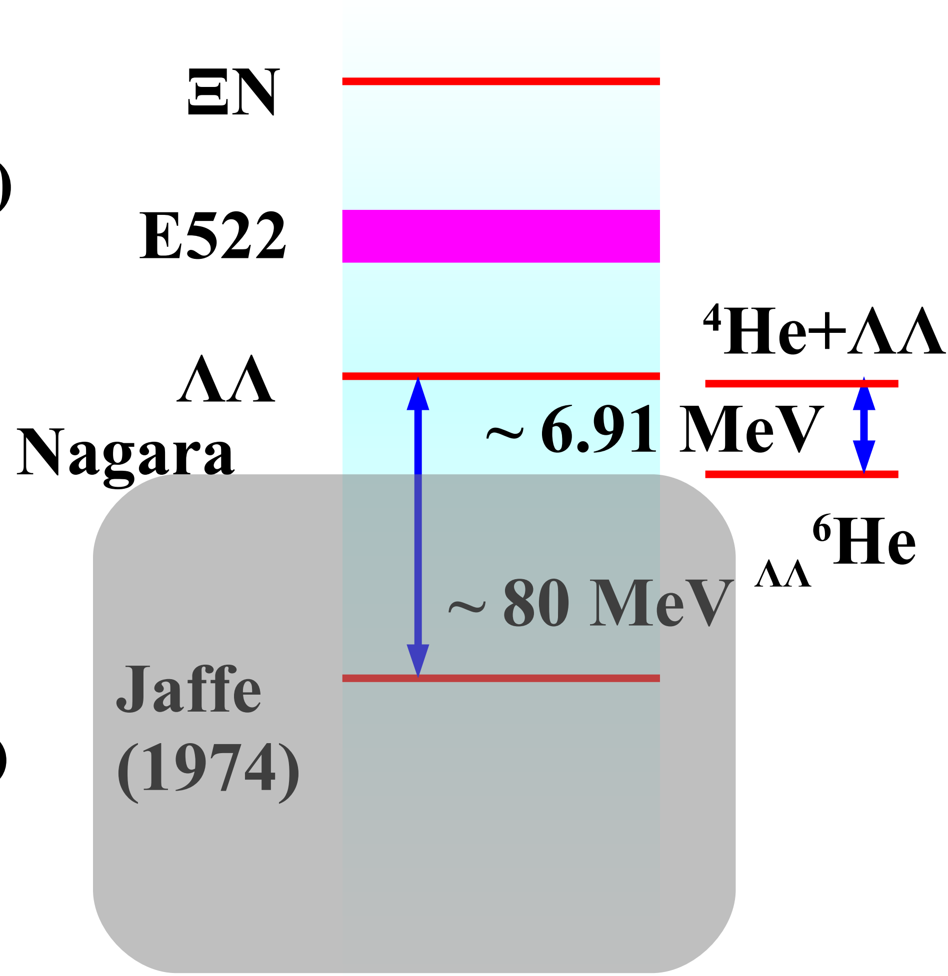
Furumoto, AO, in prep.

Where is the S=-2 dibaryon (uuddss) "H" ?

- **Jaffe's prediction (1977)**
  → 80 MeV below ΛΛ
  (strong attraction from color mag. int.)
- **Double hypernuclei $_{\Lambda\Lambda}{}^{6}$He (Nagara)**
  → No deeply bound "H"
- **Resonance or Bound "H" ?**
  - **KEK-E522 (Yoon et al., ('07))**
    → "bump" at $E_{\Lambda\Lambda}$ ~ 15 MeV
  - **Lattice QCD (HAL QCD & NPLQCD)**
    → bound H at large ud quark mass
- **How about HIC ?**
  - **RHIC & LHC = Hadron Factory including Exotics**
  - **"H" would be formed as frequently as stat. model predicts.**
    Cho,Furumoto,Hyodo,Jido, Ko, Lee,Nielsen,AO,Sekihara,Yasui,Yazaki (ExHIC Collab.), PRL('11)212001; arXiv:t:1107.1302



Nagara event

- ${}_{\Lambda\Lambda}{}^{6}$He hypernuclei

  Takahashi et al., PRL87('01)212502

  (KEK-E373 experiment)

Lambpha

$$m({}^{6}_{\Lambda\Lambda}\mathrm{He}) = 5951.82 \pm 0.54\,\mathrm{MeV}$$

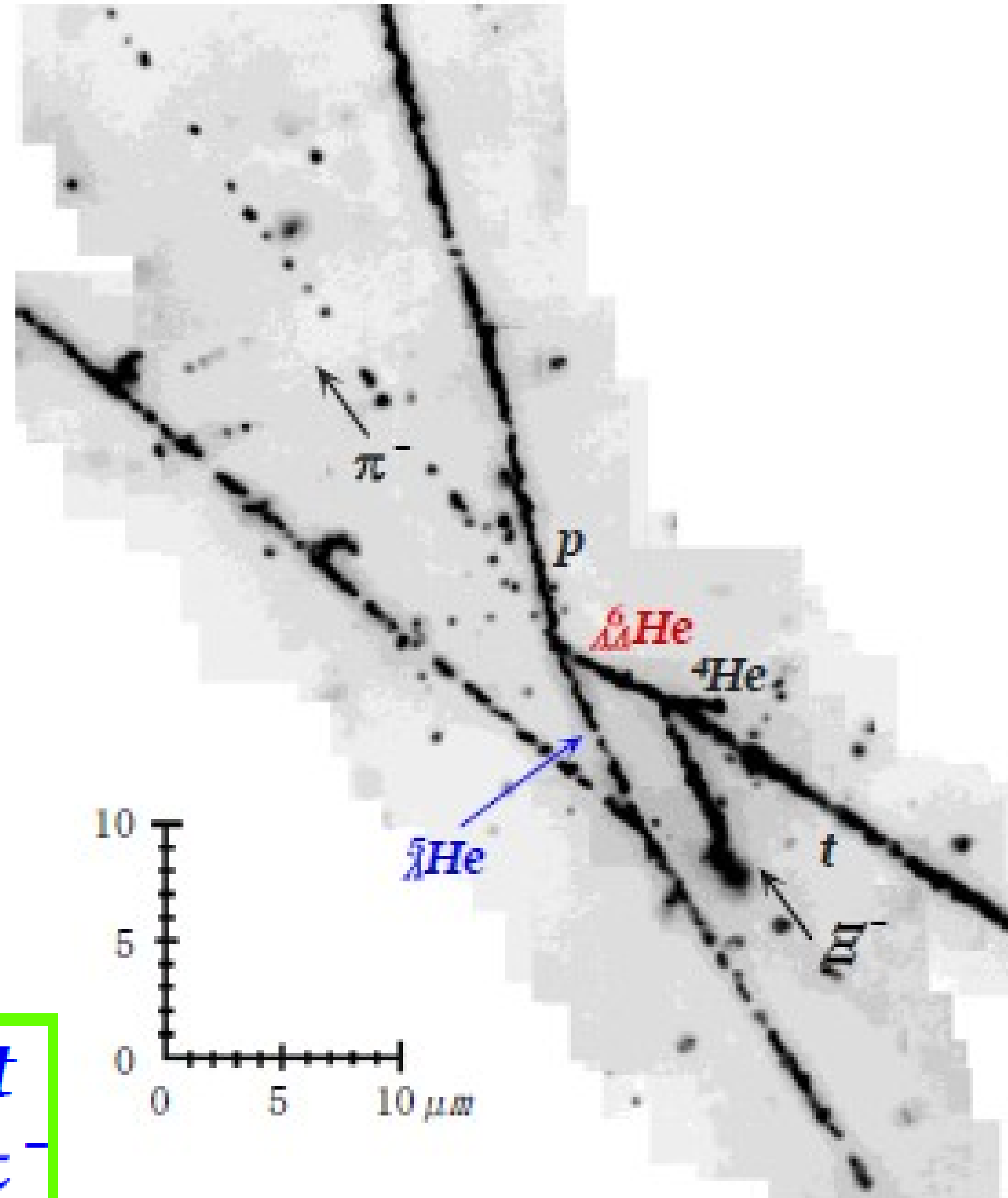
$$B_{\Lambda\Lambda} = 7.25 \pm 0.19^{+0.18}_{-0.11}\,\mathrm{MeV}$$

$$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}\,\mathrm{MeV}$$

(assumed $B_{\Xi^-} = 0.13$ MeV)

→ $B_{\Lambda\Lambda} = 6.91$ MeV

(PDG modified(updated) Ξ^- mass)

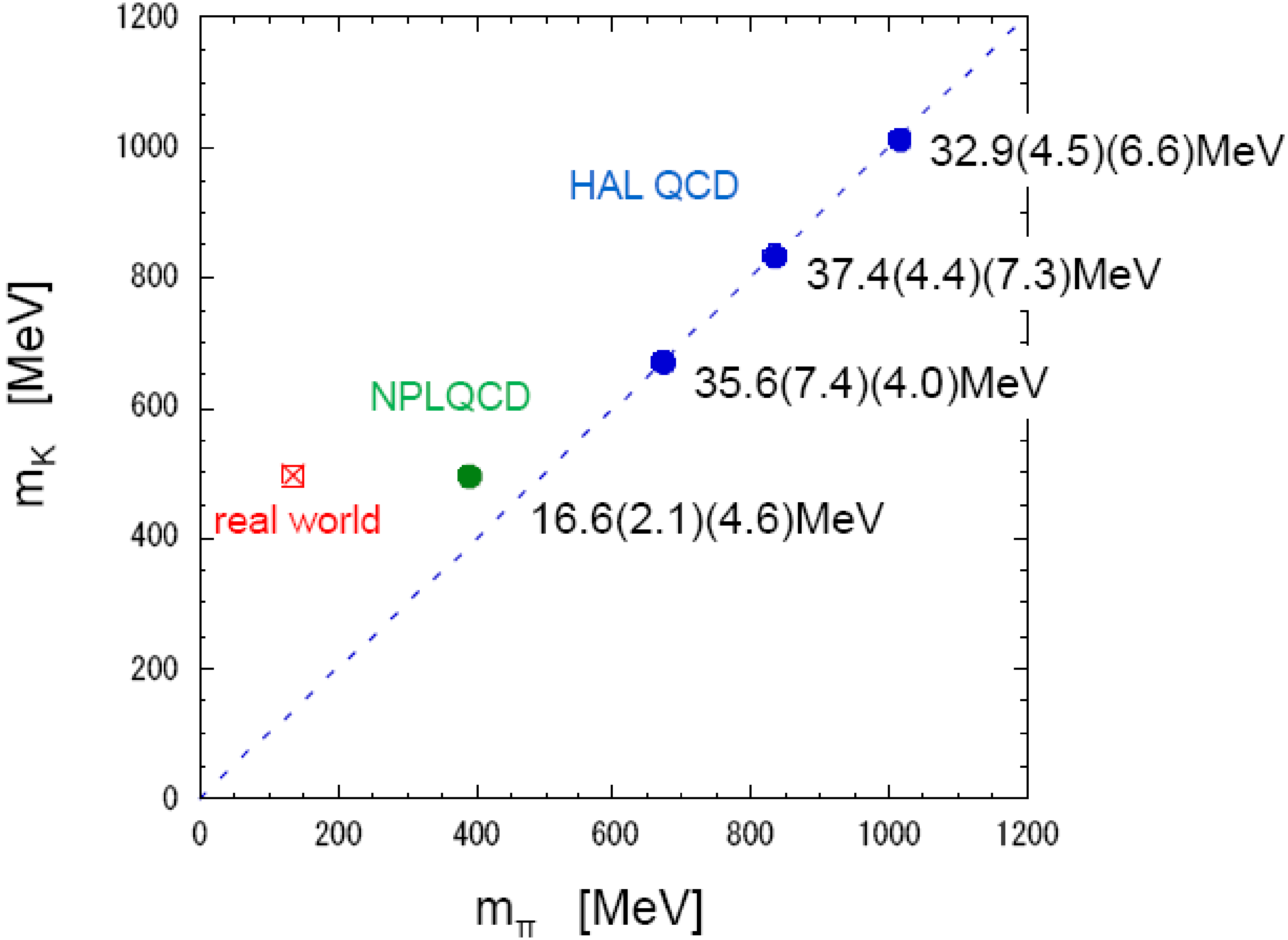


$$\Xi^- + {}^{12}\mathrm{C} \longrightarrow {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + t$$

$${}^{6}_{\Lambda\Lambda}\mathrm{He} \longrightarrow {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$$

Lattice QCD predicts bound "H"

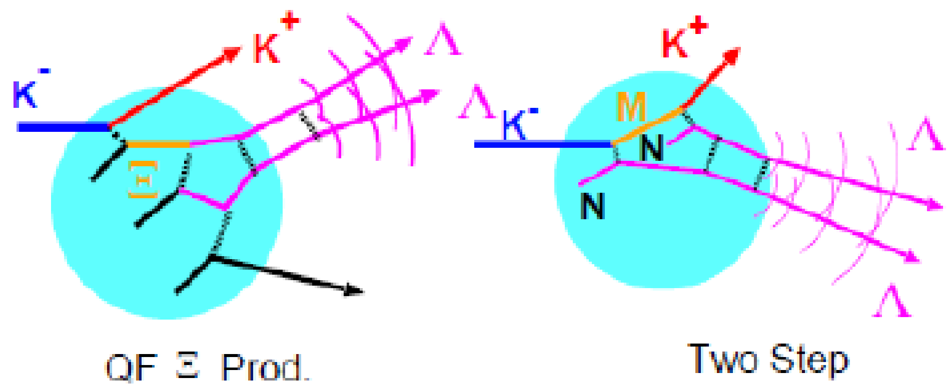
- "H" bounds with heavy π (M_π > 400 MeV)

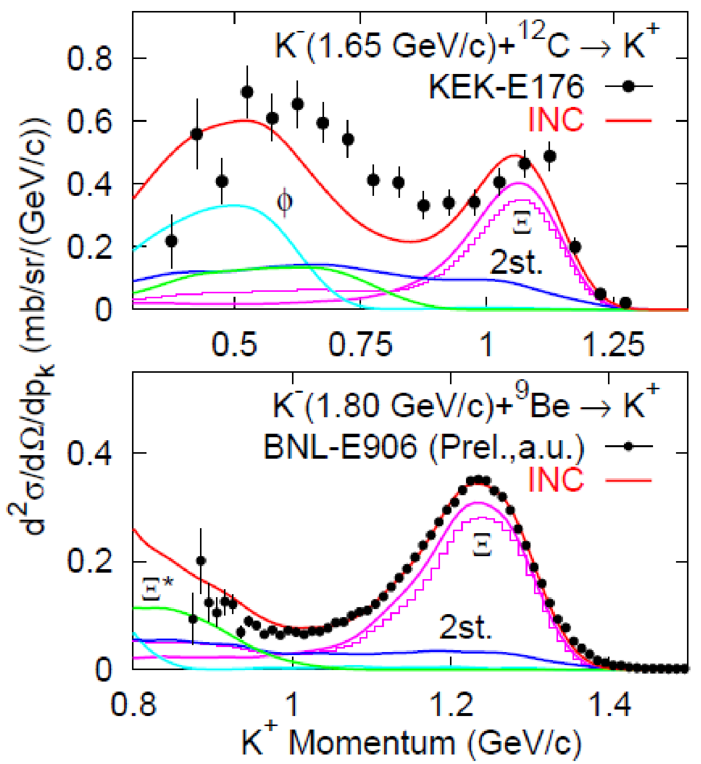


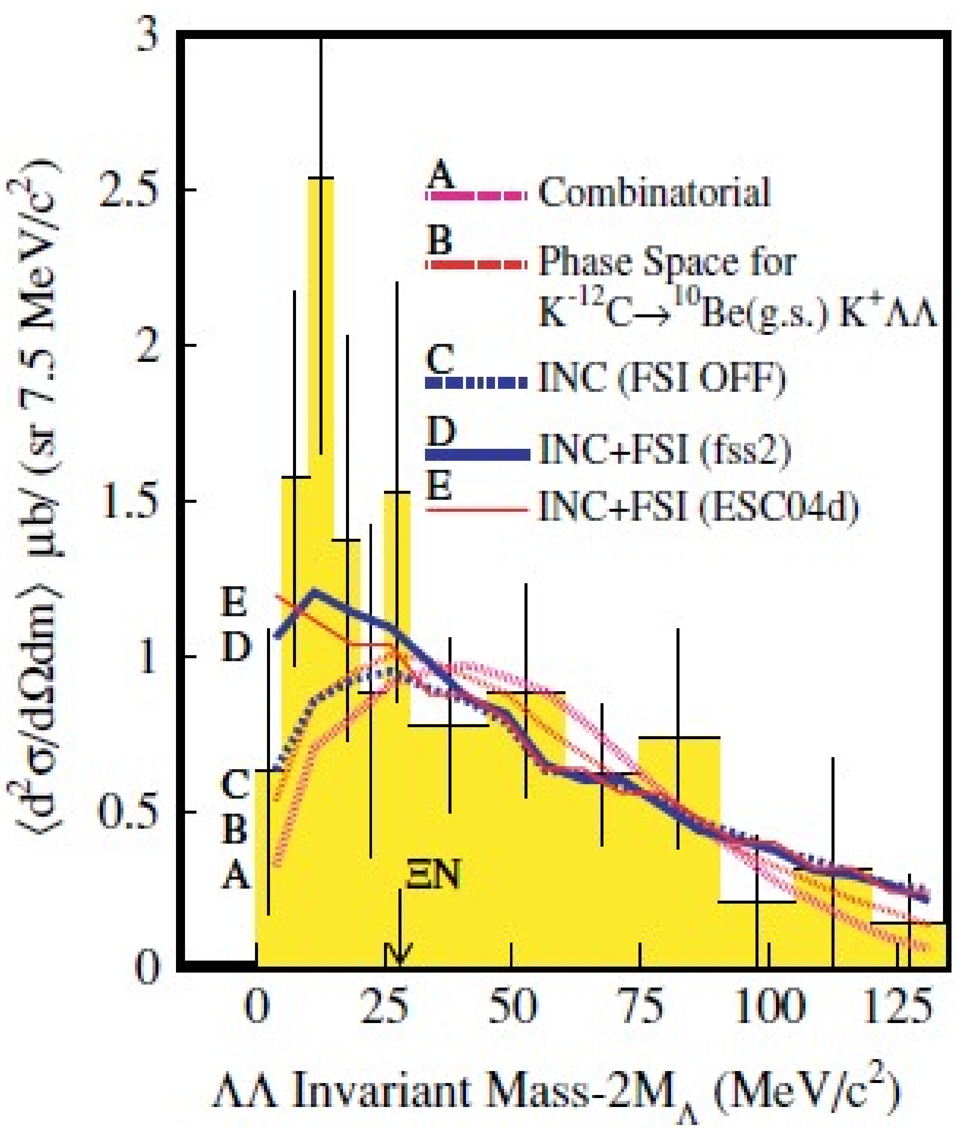
NPLQCD Collab., PRL 106 (2011) 162001; HAL QCD Collab.,PRL 106 (2011) 162002

ΛΛ correlation from (K^-,K^+ΛΛ) reaction

- **Enhancement at ~ 2 M(Λ)+ 10 MeV, CL=2σ**

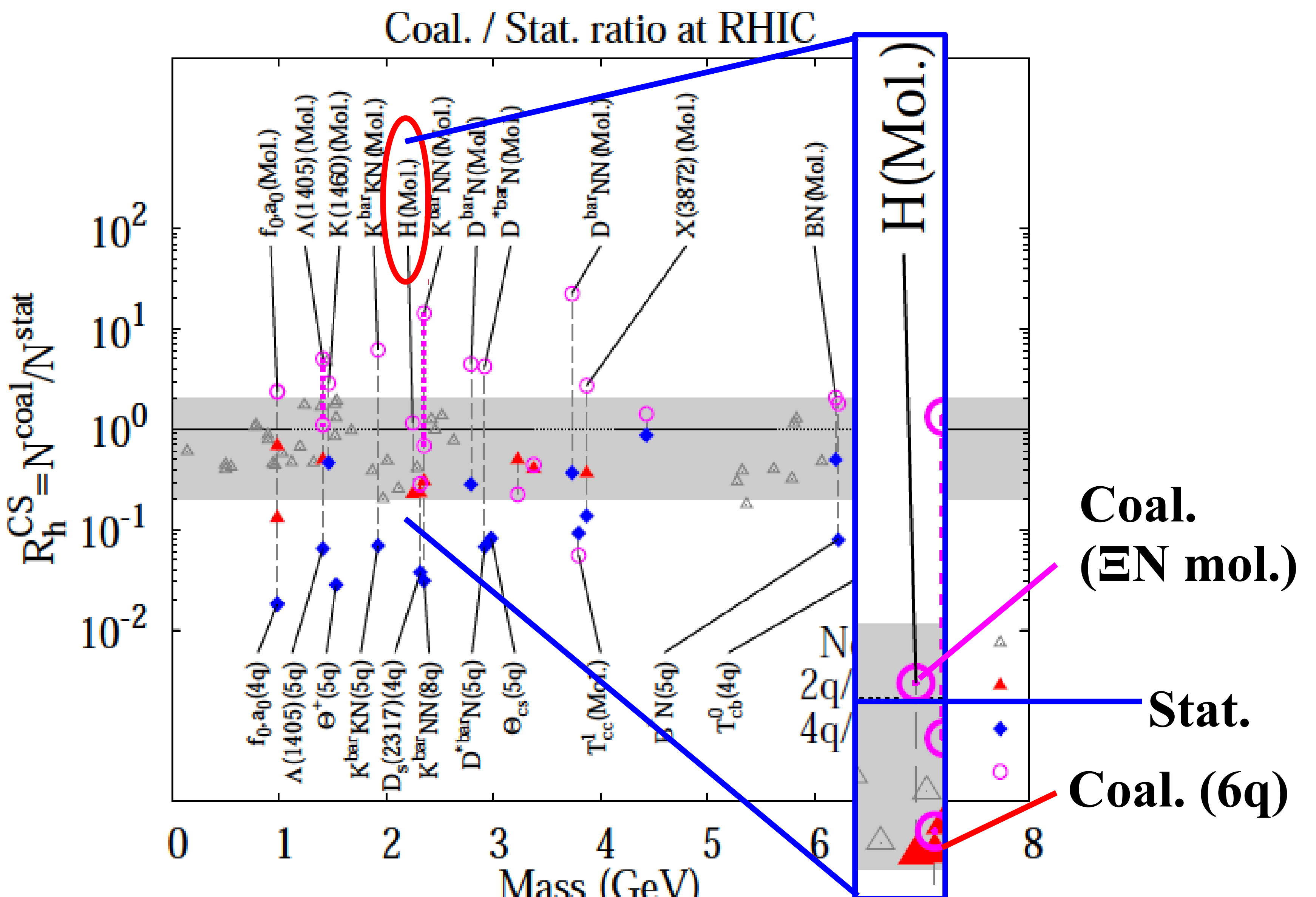






C.J.Yoon, …, (KEK-E522),AO, PRC75 (2007) 022201(R)

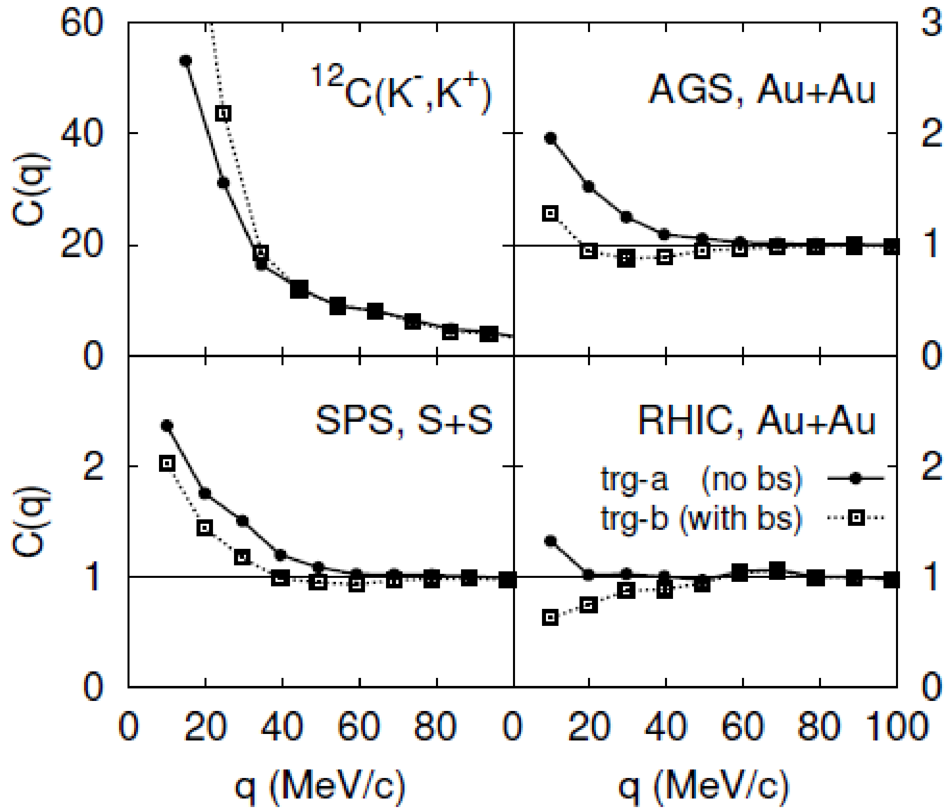
Exotics from Heavy-Ion Collisions

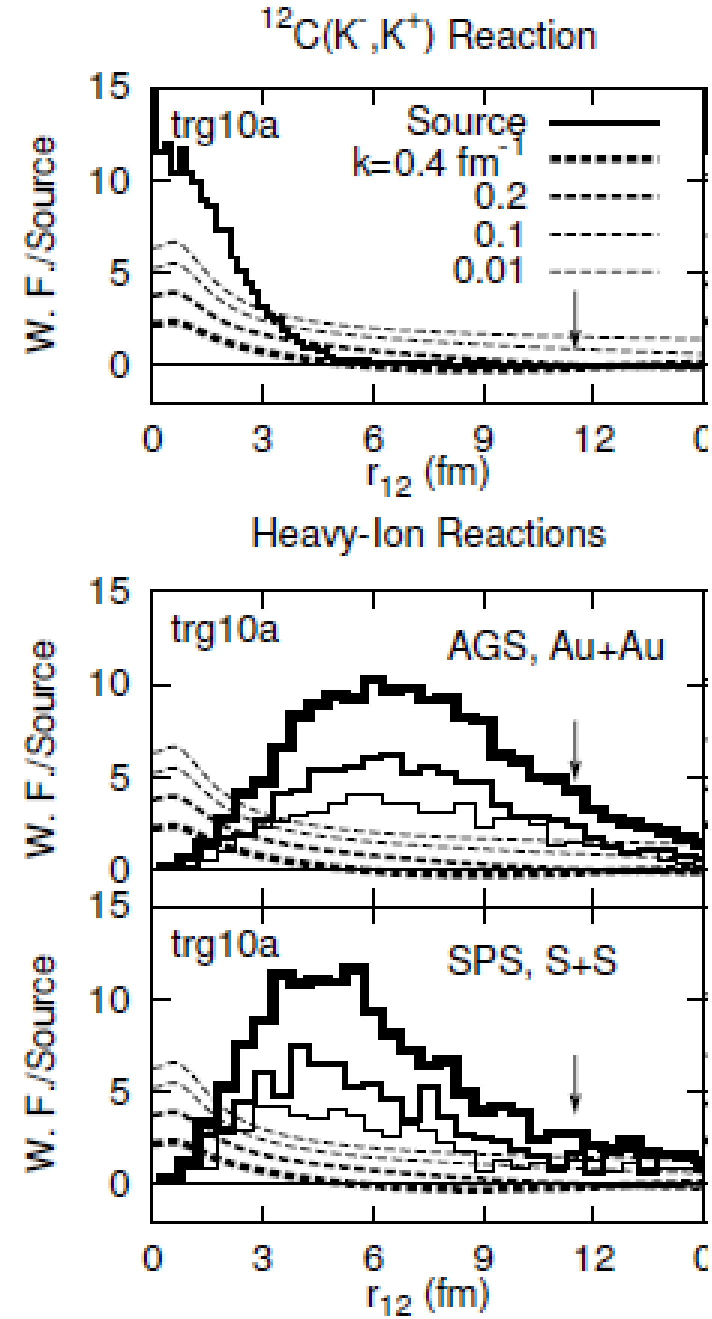


Cho,Furumoto,Hyodo,Jido, Ko, Lee,Nielsen,AO,Sekihara,Yasui,Yazaki (ExHIC Collab.), PRL('11)212001; arXiv:t:1107.1302

Previous Work (before RHIC & Nagara)

- **Hadronic transport (JAM)**
  + Two Range Gaussian $V_{\Lambda\Lambda}$
  - **w/ bound state → w.f. node suppresses C(q)**

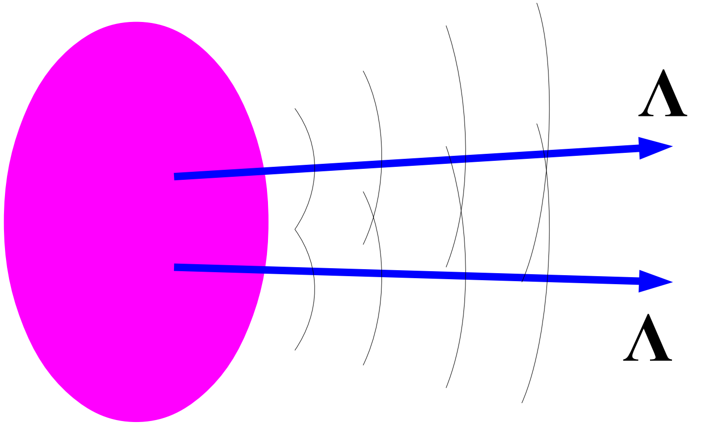




AO, Hirata, Nara, Shinmura, Akaishi, NPA670('00)297c [arXiv:nucl-th/9903021]; SNP2000 proc. p175.
JAM: Nara,Otuka, AO, Niita, Chiba, PRC61 ('00), 024901.

ΛΛ correlation in HIC

- **Merit of HIC to measure ΛΛ correlation**
  - **Source is "simple and clean" !**
    T, μ, flow, size, … are well-analyzed.
    ↔ (x,p) correlated source in (K^-,K^+)
    [c.f. e^+e^- Wes Metzger (Sep.20)]
  - **Source size is BIG and probes w.f. tail.**
  - **Discovery of "H" and/or Constraint on ΛΛ int.**



- **Gaussian Source + s-wave int.**
  c.f. P. Danielewicz' talk; Bauer, Gelbke, Pratt, Annu. Rev. Nucl. Part. Sci. 42('92)77.

$$C_{\Lambda\Lambda}(q)=\frac{\int dx_1\,dx_2\,S(x_1,p+q)\,S(x_2,p-q)\,|\psi^{(-)}(x_{12},q)|^2}{\int dx_1\,dx_2\,S(x_1,p+q)\,S(x_2,p-q)}$$

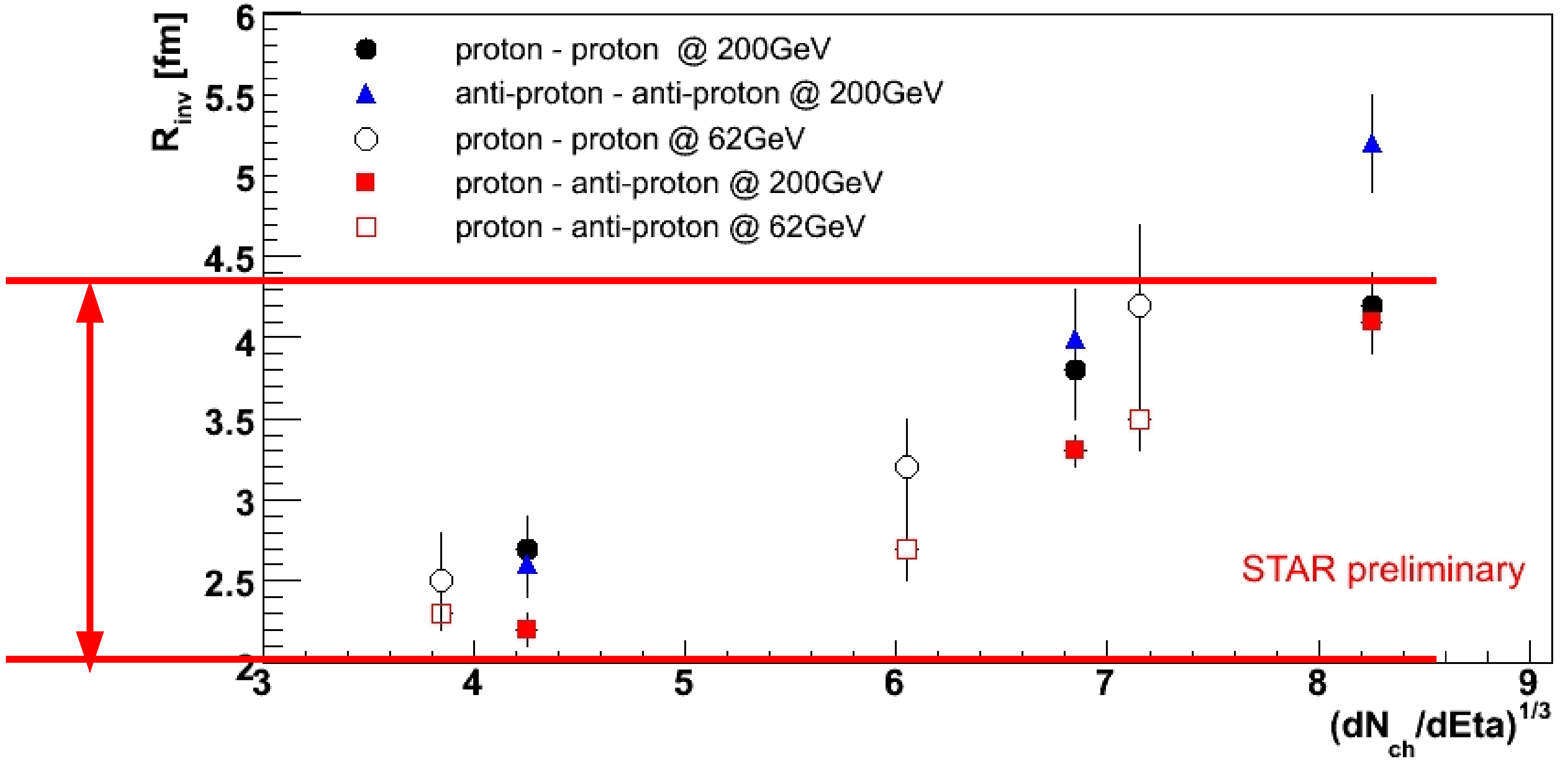
$$\simeq 1-\frac{1}{2}\exp(-q^2R^2)+\frac{1}{2}\int dr\,S_{12}(r)\left(|\chi_0(r)|^2-|j_0(qr)|^2\right)$$

(χ_0 : s-wave wave func., $S_{12}(x)=(R\sqrt{\pi})^{-3}\exp(-r^2/R^2)$)

- **Data from STAR will appear soon (Neha Shah, Huan Z. Huang).**

Toward ΛΛ correlation at RHIC: Source Size

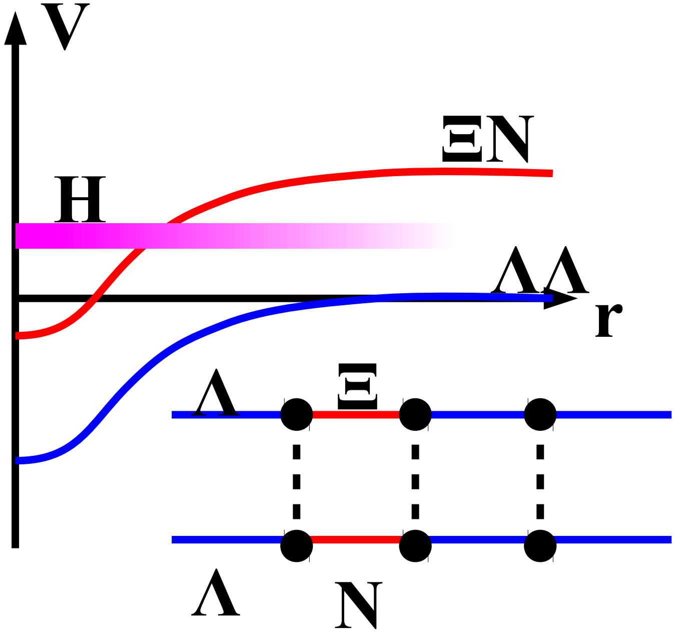
- **Source size : R = (2-4.5) fm**
  - **Smaller than last collision point dist. results in hadron cascade (JAM)**
    → Interaction in the early stage at RHIC
  - **Smaller than π, K homogeneity length**
    → Further smaller for Λ ?



A. Kisiel (H. P. Zbroszczyk) (STAR)

Toward Λ Λ correlation at RHIC: ΛΛ interaction

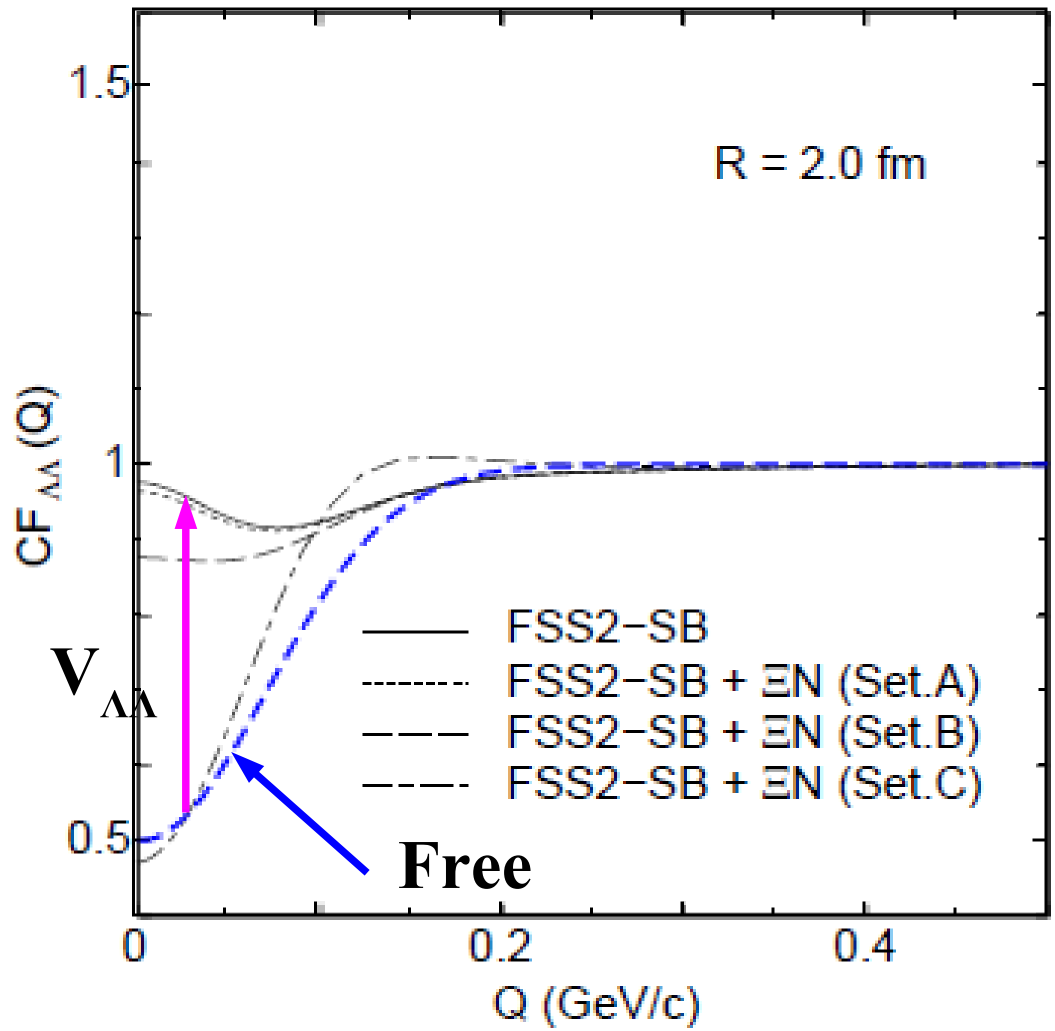
- **ΛΛ interaction**
  After Nagara, "plausible" ΛΛ interaction becomes weaker.
  Bond energy $\Delta B_{\Lambda\Lambda}$=0.7 MeV (old guess=(3-6) MeV)
  - **fss2 (quark model interaction): No bound state**
    Y. Fujiwara, M. Kohno, C. Nakamoto, Y. Suzuki, PRC64('01)054001
    Bond energy $\Delta B_{\Lambda\Lambda}$= (1.2-1.9) MeV (depending on ΛN int.)
  - **Nijmegen model D (boson exch., Rc=0.46 fm): with bound state**
    M.M. Nagels, T.A. Rijken, J.J. de Swart, PRD15('77)2547
    B.E.(H) ~ 1.6 MeV
- **Resonance "H" btw ΛΛ- ΞN threshold**
  → Couple channel calc. is required
  - **Set A, B, C (weak, medium strong coupling)**
    [single range Gauss,
    range=0.5, 1, 2 fm, strength=80,40,20 MeV]
  - **ΞN potential (diagonal) effects on C(q) is almost negligible.**



ΛΛ correlation at RHIC: Results

- **Typical example: fss2 + ΞN coupling, R= 2 fm**
- **Single channel results**
  - **Interaction effects should be clearly seen !**
  - **Dip around Q= 80 MeV/c**

    (suppression from anti-sym. + enh. from ΛΛ int.)
- **Couple channel results**
  - **Suppression of ΛΛ channel w.f. → smaller C(Q)**

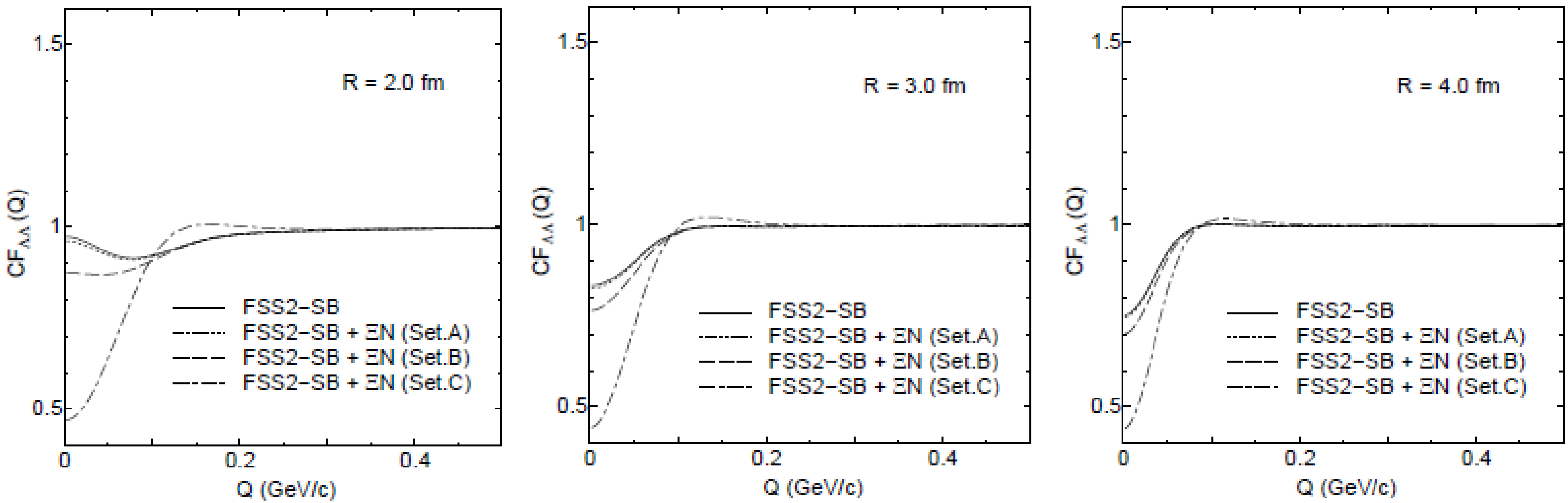


Furumoto, AO, in prep.

Source size dependence

- **Larger size → Smaller Q region**
- **No dip structure for larger size.**
  (Anti-symmetrization effects > Interaction effects)
  → Sensitive only to the scattering length.

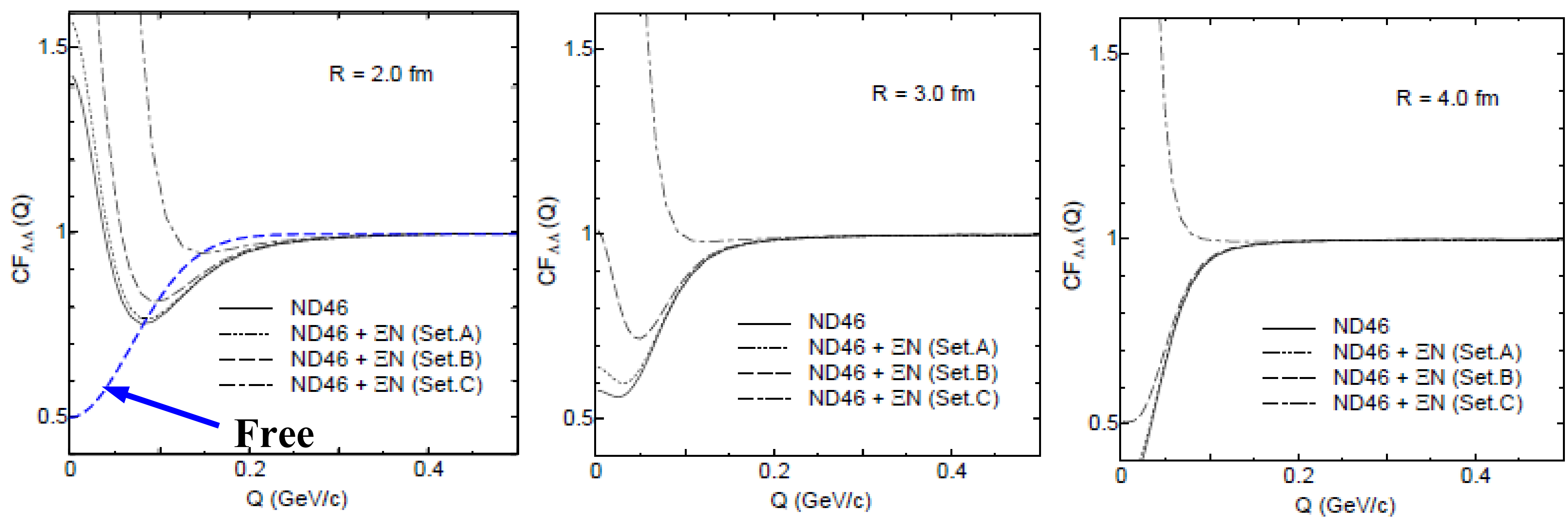
$$C(Q \to 0) \simeq \frac{1}{2} - \frac{2}{\sqrt{\pi}} \frac{a_0}{R} + \left(\frac{a_0}{R}\right)^2 \qquad \textit{(if "Interaction Range" << R)}$$



Furumoto, AO, in prep.

Bound state effects

- **Example with bound "H": ND46 + ΞN coupling**
- **Single channel**
  - **B.E.(H) ~ 1.6 MeV, a_0=4.6 fm**
  - **Stronger suppression than free case for Q > 100 MeV/c or R = 4 fm**
- **Couple channel**
  - **Enhancement of CF(Q)**



Furumoto, AO, in prep.

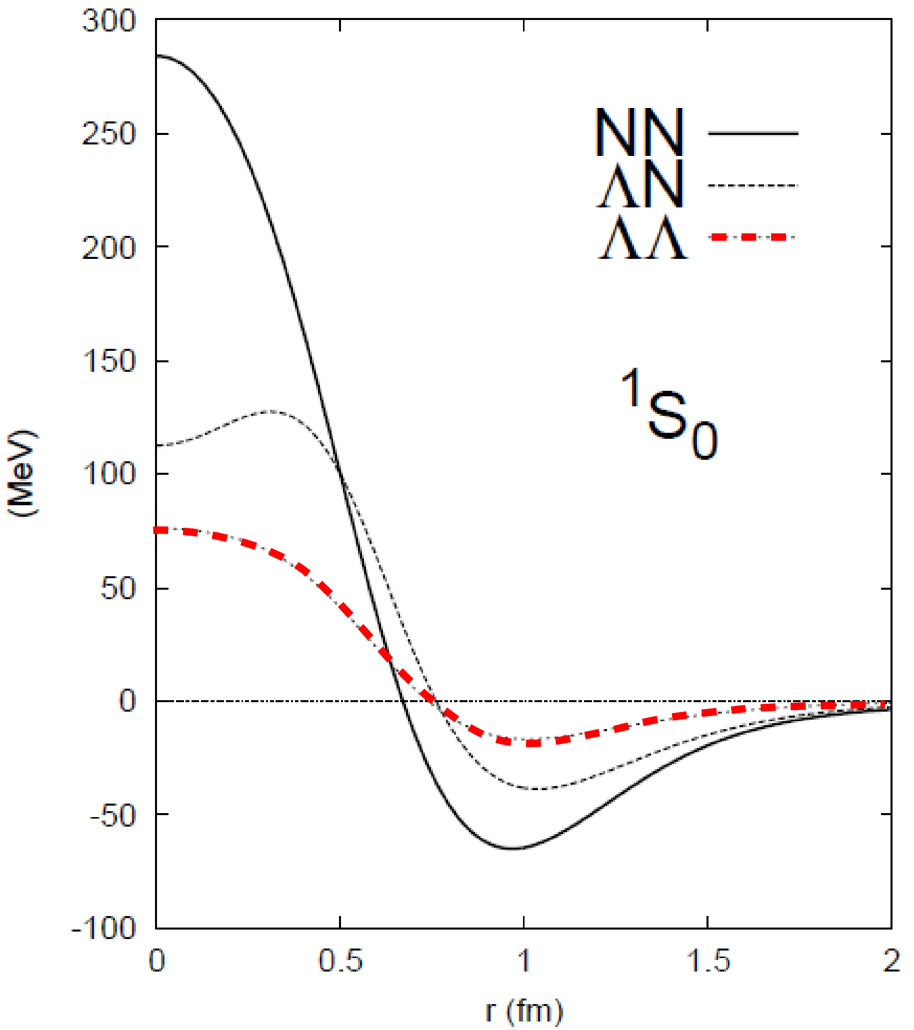
Summary

- ΛΛ interaction and the existence of “H” are still interesting subjects in hadron physics (KEK-E522 data, Lattice QCD calculation).
- Once we know the source function and correlation data, it is possible to obtain information on unknown interaction.
  - ΛΛ in HIC: Simple and clean source, Large source size, No Coulomb.
- ΛΛ Correlation function is sensitive enough to source size, potential (diagonal), and coupling potential. Relation to the pole position should be examined.
- We are working with STAR collaboration to investigate what we can learn from ΛΛ correlation function (Neha Shah and Huan Huang).
  - To be examined/improved
    Statistics, Purity, Interaction in parent channel (ΣΛ, ΣΣ, ΞΛ, ..)
- Stay tuned !

Thank you !

ΛΛ potential

fss2 Phase shift equivalent potential



Y. Fujiwara, Y. Suzuki, C. Nakamoto, Prog.Part.Nucl.Phys. 58 (2007) 439-520

- **fss2**
  - a_0 = - 0.82 fm, r_{eff}=4.1 fm
- **Nagara fit**
  E. Hiyama, M. Kamimura, T. Motoba, T. Yamada, Y. Yamamoto, PRC66('02)024007.
  - a_0= - 0.575 fm, r_{eff}= 6.45 fm