静止 Ξ- 反応からのハイパー核破片生成

Hyperfragment fomation from Ξ^- absorption at rest on nuclei

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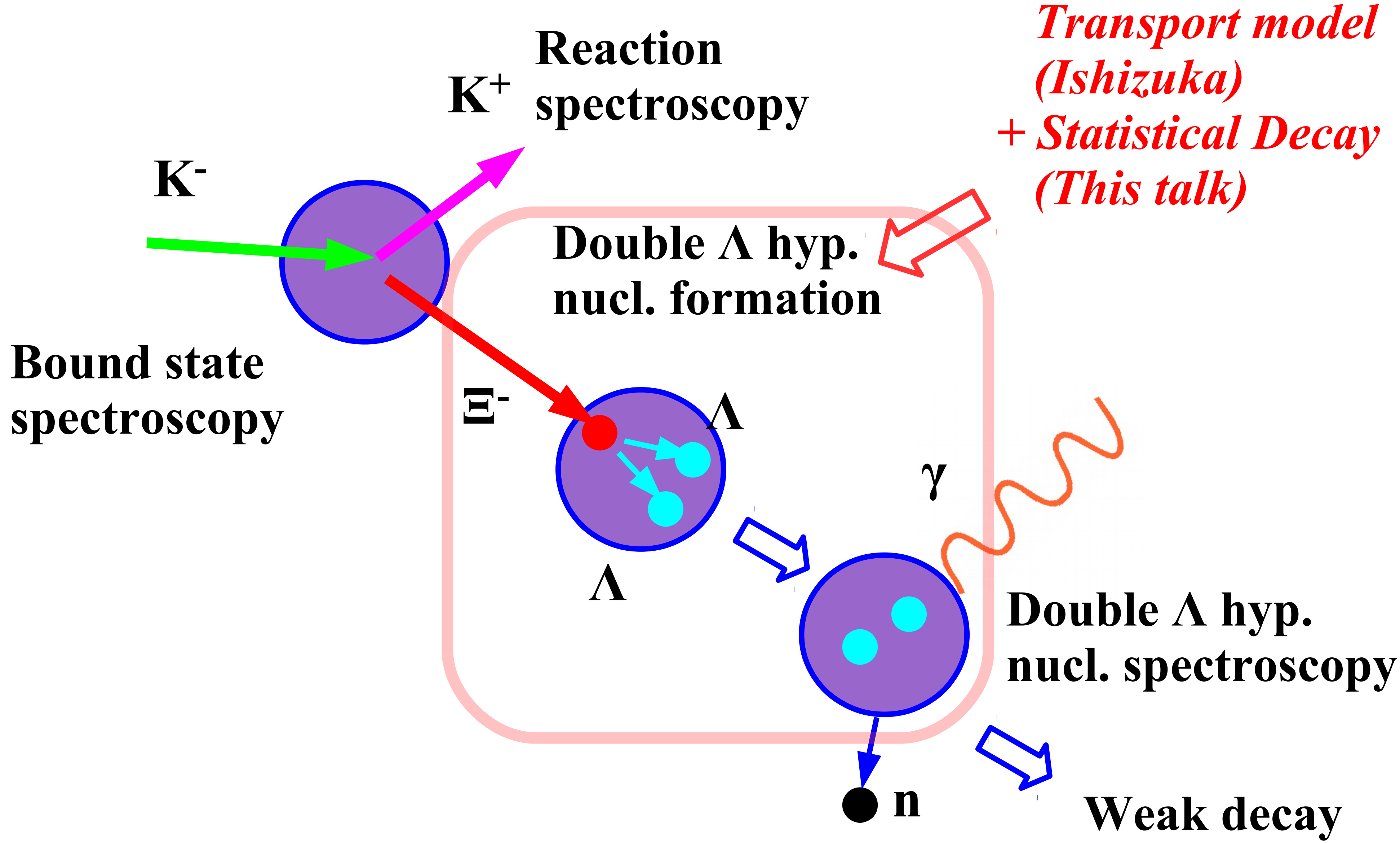
「物質階層を横断する会」第４回

～ハドロン・原子核・原子・分子合同ミーティング～

May 10, 2019

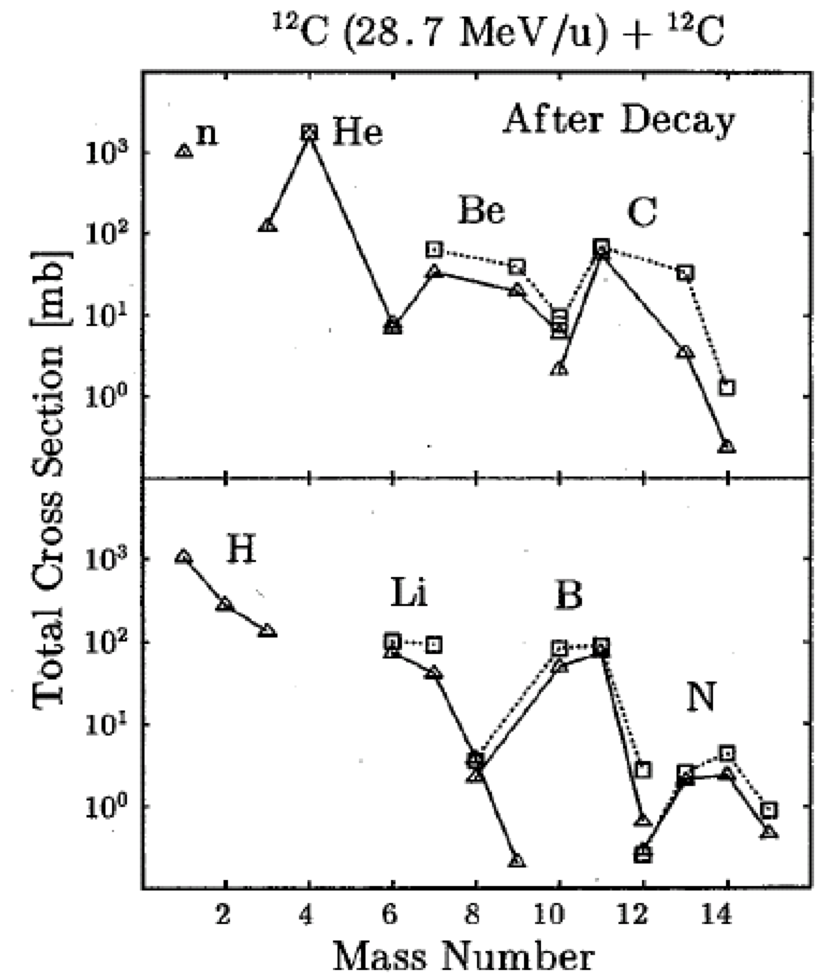
S=-2 Hypernuclear Physics

- Ξ hypernuclei = Doorway to Multi Strangeness Systems



Transport + Statistical Decay Model (1)

- **Multistep evap. of nucleons and α from Excited Nuclei (Statistical Cascade Decay Process)**
  - **Established decay process**
  - **Combined with transport model, Cascade gives reliable results !**
  - **AMD + Cascade (Δ)**
    → Describes frag. form. data (□) within a factor of two !



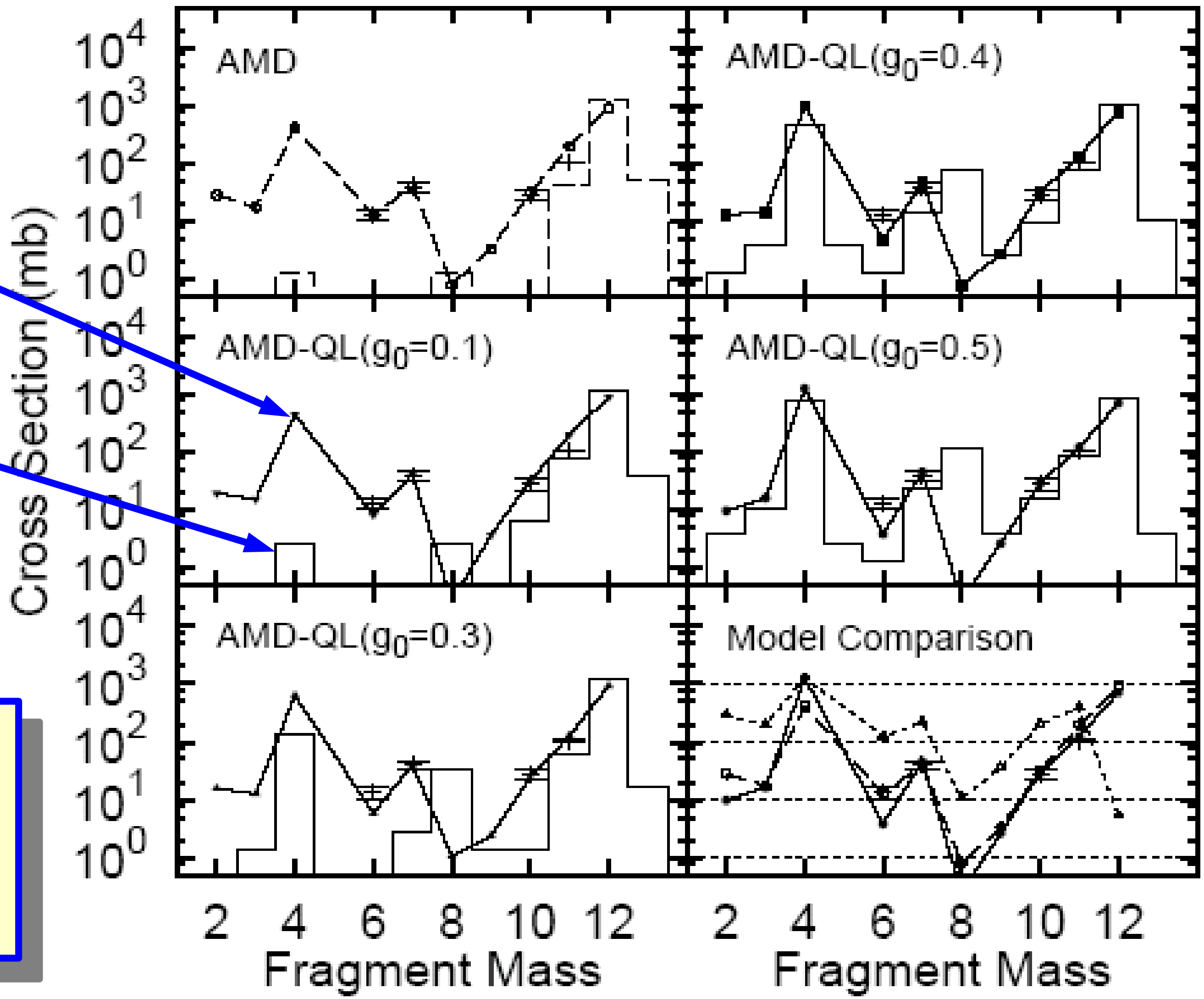
Ono, Horiuchi, Maruyama, AO, PRL and PTP, 1992.

Transport + Statistical Decay Model (2)

- **AMD-QL (AMD with Quantum Statistical Fluctuation) + Cascade decay**

AMD-QL + Stat. Dec.

AMD-QL



Incl. quantum fluc. simulats stat. decay dynamically.

p(45 MeV)+^{12}C

Hirata, Nara, AO, Harada, Randrup, 1999

Transport + Statistical Decay Model (3)

- **Anti-symmetrized (version of) Molecular Dynamics with Quantum Langevin force**
  A. Ono, H. Horiuchi, T. Maruyama, AO ('92); AO, Randrup ('95-'99); Hirata et al. ('99)
  - **AMD: 反対称化したガウス波束を時間依存変分原理 (~ 正準方程式) と 2 体衝突 (~ Boltzmann eq.) で時間発展**

$$|\Psi\rangle = \det\phi_{\boldsymbol{z}_i}(\boldsymbol{r}_j) \quad \phi_{\boldsymbol{z}}(\boldsymbol{r}) \propto \exp[-\nu(\boldsymbol{r}-\boldsymbol{z}/\sqrt{\nu})^2]$$

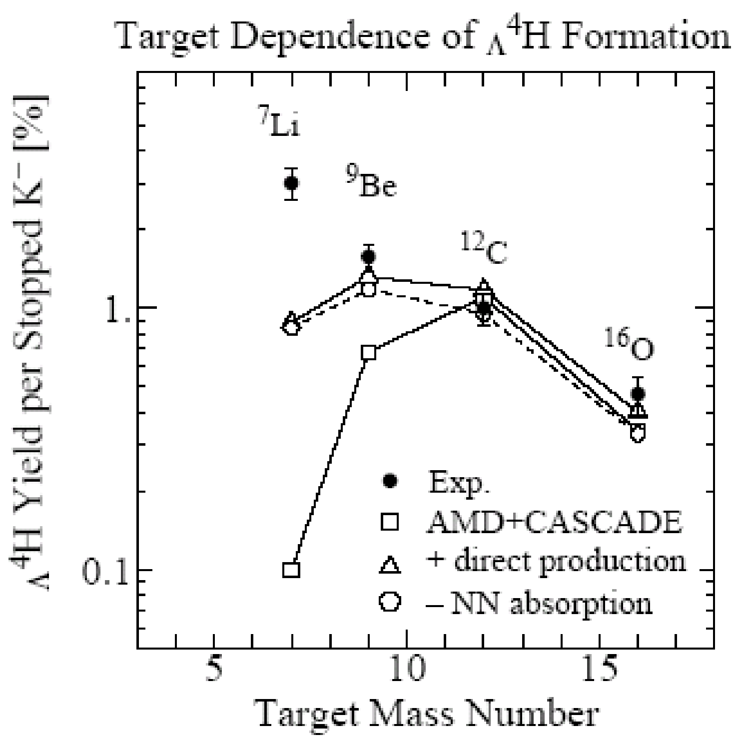
$$\boldsymbol{z} = \sqrt{\nu}\boldsymbol{r} + i\boldsymbol{p}/2\hbar\sqrt{\nu}$$

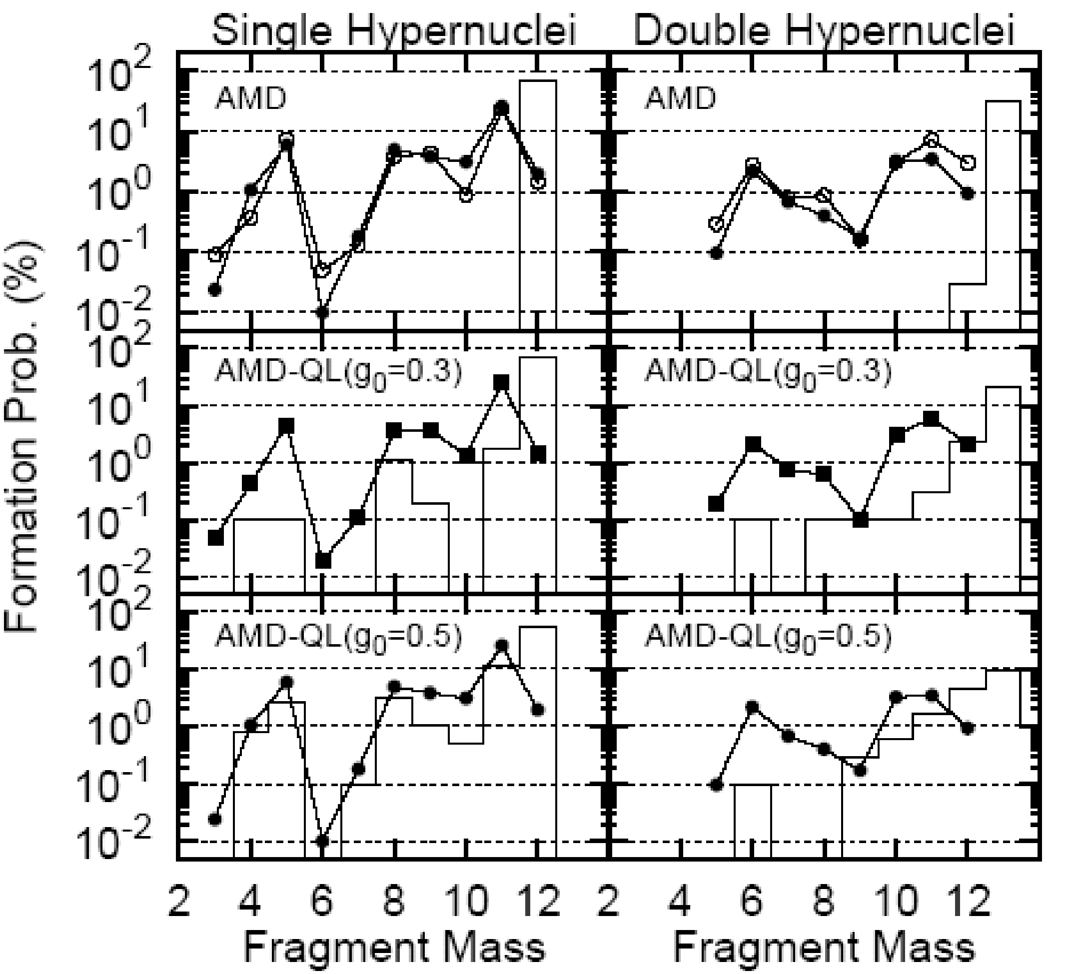
$$\dot{z}_i = \frac{i}{\hbar}\boldsymbol{F}_i + \Delta z_i^{(coll)} \quad (\sim \dot{\boldsymbol{x}} = \boldsymbol{p}/m, \dot{\boldsymbol{p}} = -\partial V/\partial \boldsymbol{x} \;\; \text{2-body collisions})$$

  - **Quantum Langevin force: 熱平衡状態で量子統計性が担保されるように量子揺らぎを導入**
- **統計崩壊模型 (後述)**
  - **多段階 2 体統計崩壊 (cascade)**
  - **多重破砕模型 (canonical multi-frag. model)**

Hyperfragment Formation (1)

- **Stopped K- + (Li, Be, C, O) → $^4_\Lambda$H**
  Tamura et al. ('89); Nara, AO, Harada ('95)
- **Stopped Ξ^- + ^{12}C → Double, Twin, Single hypernuclei**
  KEK-E176/E373; J-PARC E07; Hirata et al. ('99)





Transport + Stat. Dec. works for target >= ^{12}C

Hyperfragment Formation (2)

- **KEK E176**
  - **Stopped Ξ events on light nucl.**
    31.1 ± 4.8 (77.6 ± 5.1 (all))

	Hyperfragment	(A)	(B)	(C)
$S=-2$	Double	1	} +1	} +8
	Twin	2		
$S=-1$	Single	8		

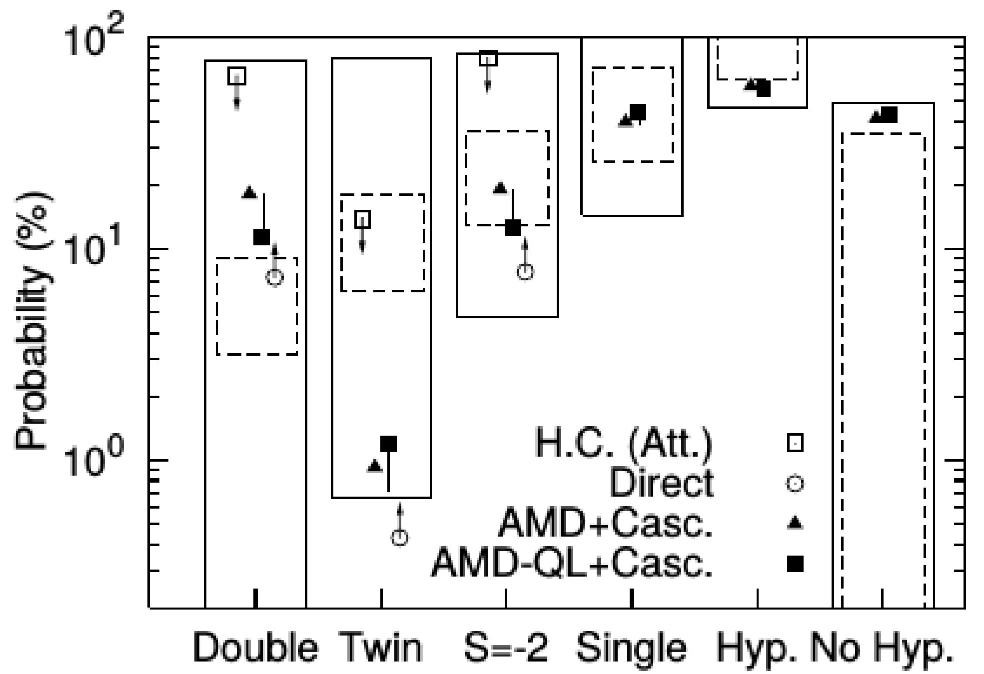
  - **1+ Double Λ hypernuclei ($^{13}{}_{\Lambda\Lambda}$B) (< 77.9 %, Rough est. (3-9) %)**
  - **2+ Twin Λ hypernuclear events (0.66-81.5 %, Rough est. (6-18)%)**

- **KEK E373**
  - **~ 1000 Stopped Ξ events (at least 650 events)**
  - **4+ Double Λ hypernuclei**

    Nagara($^{6}_{\Lambda\Lambda}$He), Mikage,

    Demachiyanagi($^{10}_{\Lambda\Lambda}$Be*),

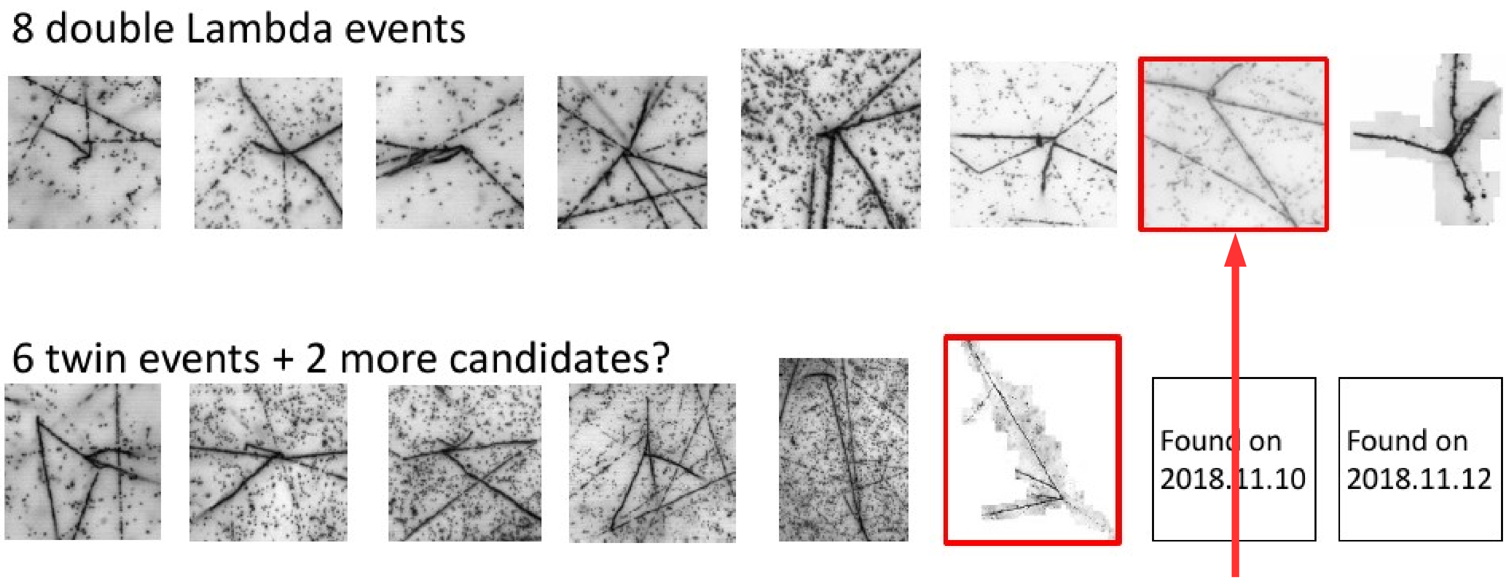
    Hida($_{\Lambda\Lambda}$Be),
  - **2+ Twin Λ hypernuclear events**



Y. Hirata, Y. Nara, AO, T. Harada, J. Randrup, PTP102 ('99) 89

Hyperfragment Formation (3)

- **J-PARC E07**
  - **~ 920 Stopped Ξ events** *@ QNP2018 (by J. Yoshida)* **→ 2400 events**
  - **8 Double & 6(+2) Twin Λ hypernuclear events**



- **Mino event (Double Λ hypernuclear formation)**
  Ekawa et al. (J-PARC E07 Collab.), PTEP 2019, 021D02

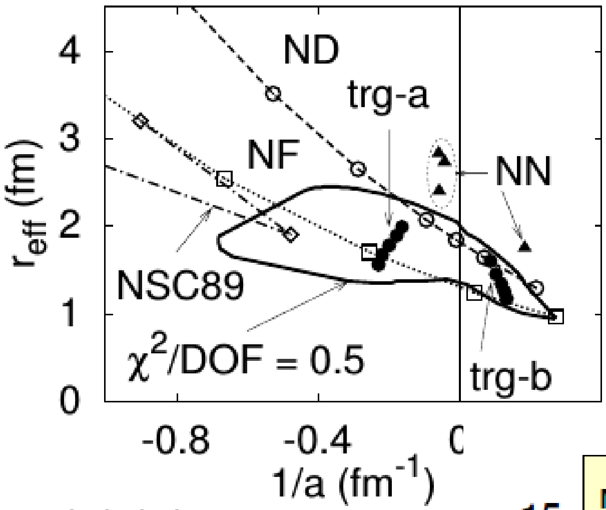
$$^{16}\mathrm{O} + \Xi^-(3D) \to {}^{10}_{\Lambda\Lambda}\mathrm{Be} + {}^4\mathrm{He} + t \quad (\Delta B_{\Lambda\Lambda} = 1.63 \pm 0.14 \text{ MeV})$$

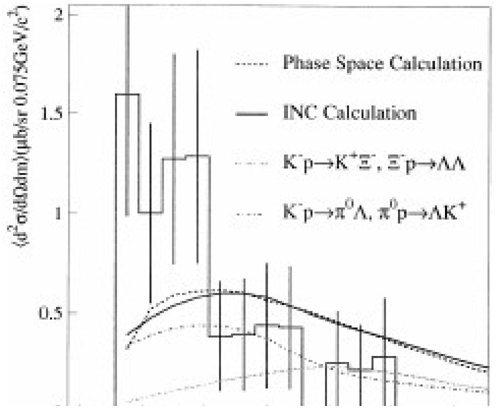
$$^{16}\mathrm{O} + \Xi^-(3D) \to {}^{11}_{\Lambda\Lambda}\mathrm{Be} + {}^4\mathrm{He} + d \quad (\Delta B_{\Lambda\Lambda} = 1.87 \pm 0.37 \text{ MeV})$$

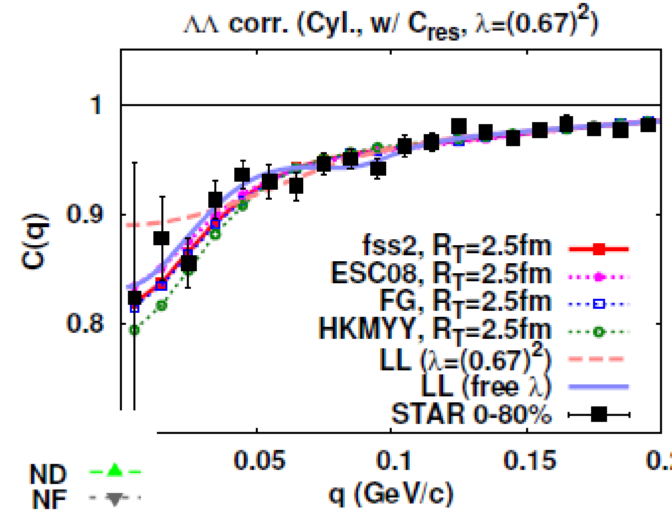
most probable

$$^{16}\mathrm{O} + \Xi^-(3D) \to {}^{12}_{\Lambda\Lambda}\mathrm{Be}^* + {}^4\mathrm{He} + p \quad (\Delta B_{\Lambda\Lambda} = -2.7 \pm 1.0 \text{ MeV})$$

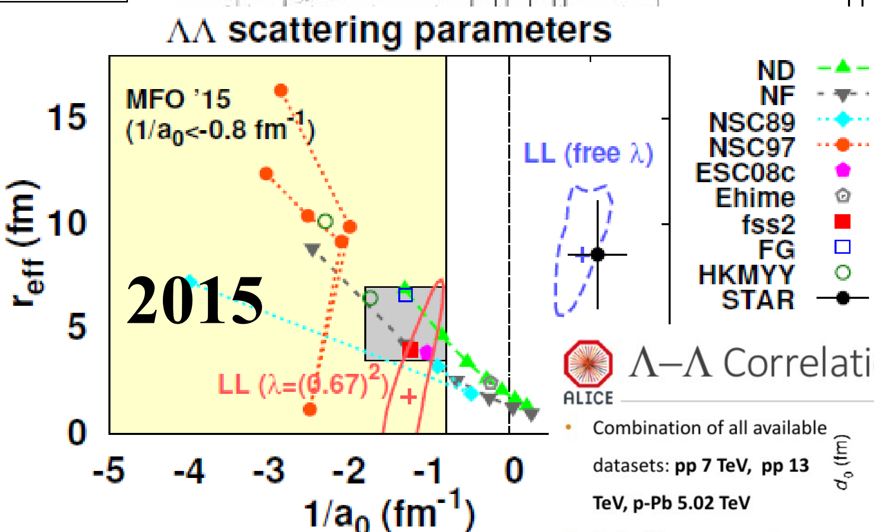
Time dependence of ΛΛ interaction from ΛΛ correlation







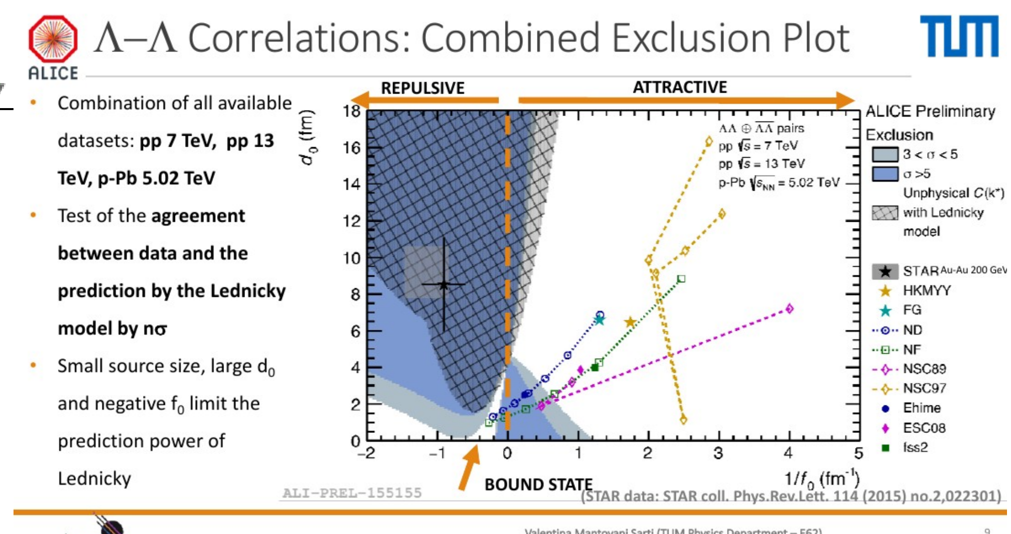
2000



2015

2018

Nagara (2001)



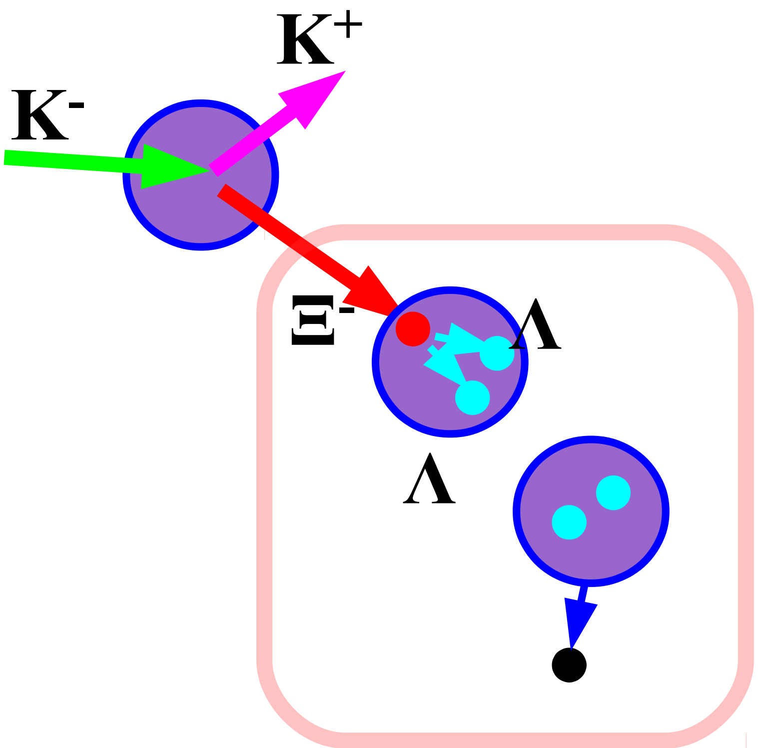
Double & Twin Hypernculear Formation from Stopped Ξ

- **Now it becomes (barely) possible to discuss statistics of double & twin hypernuclear formation probability from stopped Ξ reaction on nuclei.**
- **Questions !**
  - **What are the effects of $\Delta B_{\Lambda\Lambda}$ on S= – 2 hypernuclear formation ?**
    Hirata+('99, before Nagara) used $\Delta B_{\Lambda\Lambda}$ =4.9 MeV rather than $\Delta B_{\Lambda\Lambda}$ = 0.67 MeV
  - **Is the observed double hypernuclear events probable from Ξ absorption on nuclei ?**
    Double Λ hypernuclear formation Prob.
    = (Double Λ Compound Nucleus (DΛC) formation prob. w/o quantum fluc. → Ishizuka)
    × (Double Λ hypernucleus (DΛHN) survival prob. → This talk)
  - **What is the fragmentation mechanism of S= – 2 hyper compound nuclei ?**

Outline

- Introduction
  - S=-2 Hypernuclear Physics
  - Transport + Statistical Decay Model
  - Hyperfragment Formation
- Statistical decay model study of S=-2 hyperfragment formation
  - Statistical decay model(s)
  - Binding energies of single and double Λ hypernuclei
  - Ξ – absorption at rest on ^{12}C, ^{14}N and ^{16}O
- Summary

Statistical decay model study of Ξ hypernuclei



Work in progress.
Results are preliminary.

Double Hypernuclear Formation from Stopped Ξ^-

- **Theoretical Models**
  - **Statistical Decay**
    - **Canonical dist. model** (*Yamamoto, Sano, Wakai ('94)*)
    - **Micro-canonical** (*Lorente, Botvina, Pochodzalla ('11)*)
  - **Direct Reaction** (*Yamada, Ikeda ('97)*)
    Two-Cluster Res. dominance in Twin hypernuclear form.
  - **AMD/AMD-QL + Cascade** (*Hirata et al.('99)*)

→ Double Λ hypernuclear formation Prob.
= (Double Λ Compound Nucleus (DΛC) formation prob. w/o quantum fluc.)
× (Double Λ hypernucleus (DΛHN) survival prob.)

Let's evaluate DΛHN survival prob. in Cascade Decay Model in Stopped Ξ^- on ^{12}C, ^{14}N and ^{16}O.

Statistical Decay Models

- **Sequential decay of compound nucleus (Cascade)**
  - **Established decay model at low excitation**

$$\Gamma_{1\to 23} dE_2 dE_3 = \frac{\rho_2(E_2, J_2)\rho_3(E_3, J_3)}{2\pi\rho_1(E_1, J_1)} \sum_{L, J_{23}} T_L dE_2 dE_3$$

$\rho(E, J)$: Level density in back-shifted Fermi-Gas model

$T_L = \Theta(L_c - L)$ (Transmission coef. of $23 \to 1$)

- **Simultaneous Multi-fragmentation Models**
  Yamamoto+('94), Lorente+ ('11), Fai, Randrup ('82), AO, Randrup ('95,,'97,'97)
  - **Allow multi-fragmentation via (micro-)canonical partition fn.**

$$\mathcal{Z} = \sum_{\text{parition}} e^{-V_C/T} \prod_i \left[\int \frac{V d^3 p_i}{(2\pi)^3} \int^{E_{\text{thr}}+\Delta E} dE_i^* \rho_i(E_i^*) e^{-(p_i^2/2m_i + E_i^* - B_i)/T} \right]$$

Coulomb **Level density** **Boltzmann**

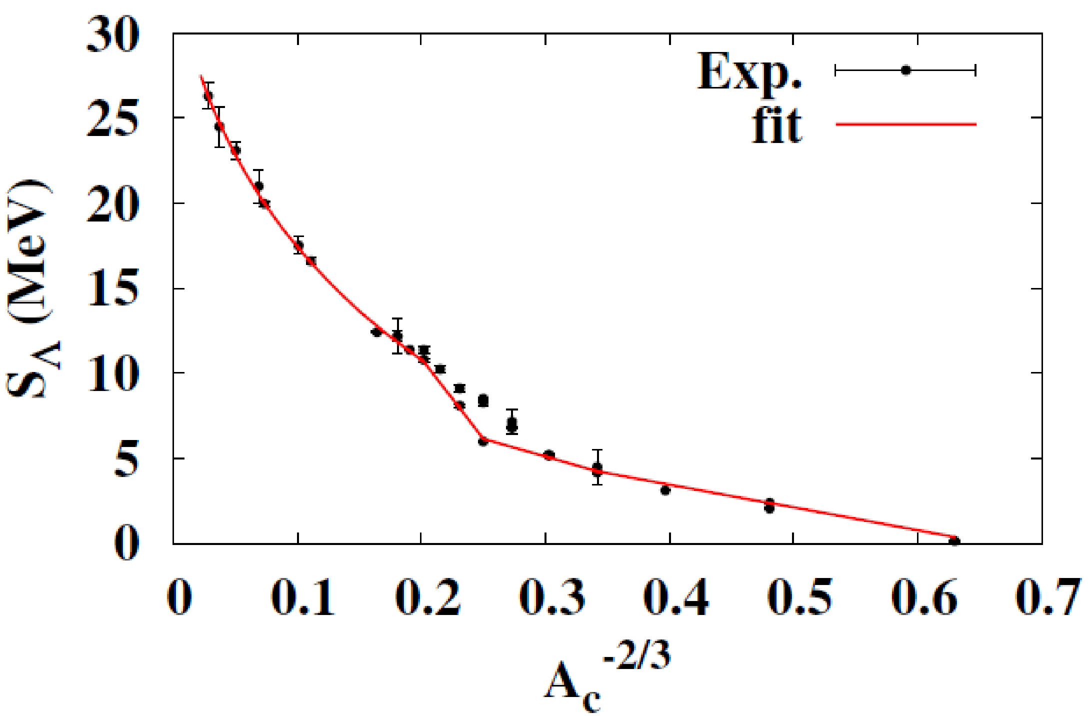
parameter (V, ΔE)

Statistical Decay of Double Λ Compound Nuclei

- **Binding energy (or Λ separation energy): Crucial**
- **Single hypernuclei**
  Data (observed hypnucl.) + Fit (unobserved hypernucl.)
- **Double hypernuclei**
  - **Before Nagara** $\Delta B_{\Lambda\Lambda}$ **=4.9 MeV**
    → After Nagara $\Delta B_{\Lambda\Lambda}$ **= 0.67 MeV**
  - **A dependence of** $\Delta B_{\Lambda\Lambda}$ **(w/ and w/o Nagara & Mino event)**
    - **Model A:** $\Delta B_{\Lambda\Lambda}$ **=4.9 MeV (A-indep.)**
    - **Model B:** $\Delta B_{\Lambda\Lambda}$ **=0.67 MeV (A-indep.)**
    - **Model C:** $\Delta B_{\Lambda\Lambda}$**(A=6)=0.67 MeV,** $\Delta B_{\Lambda\Lambda}$**(A=11)=1.87 MeV (linear fn. of A)**

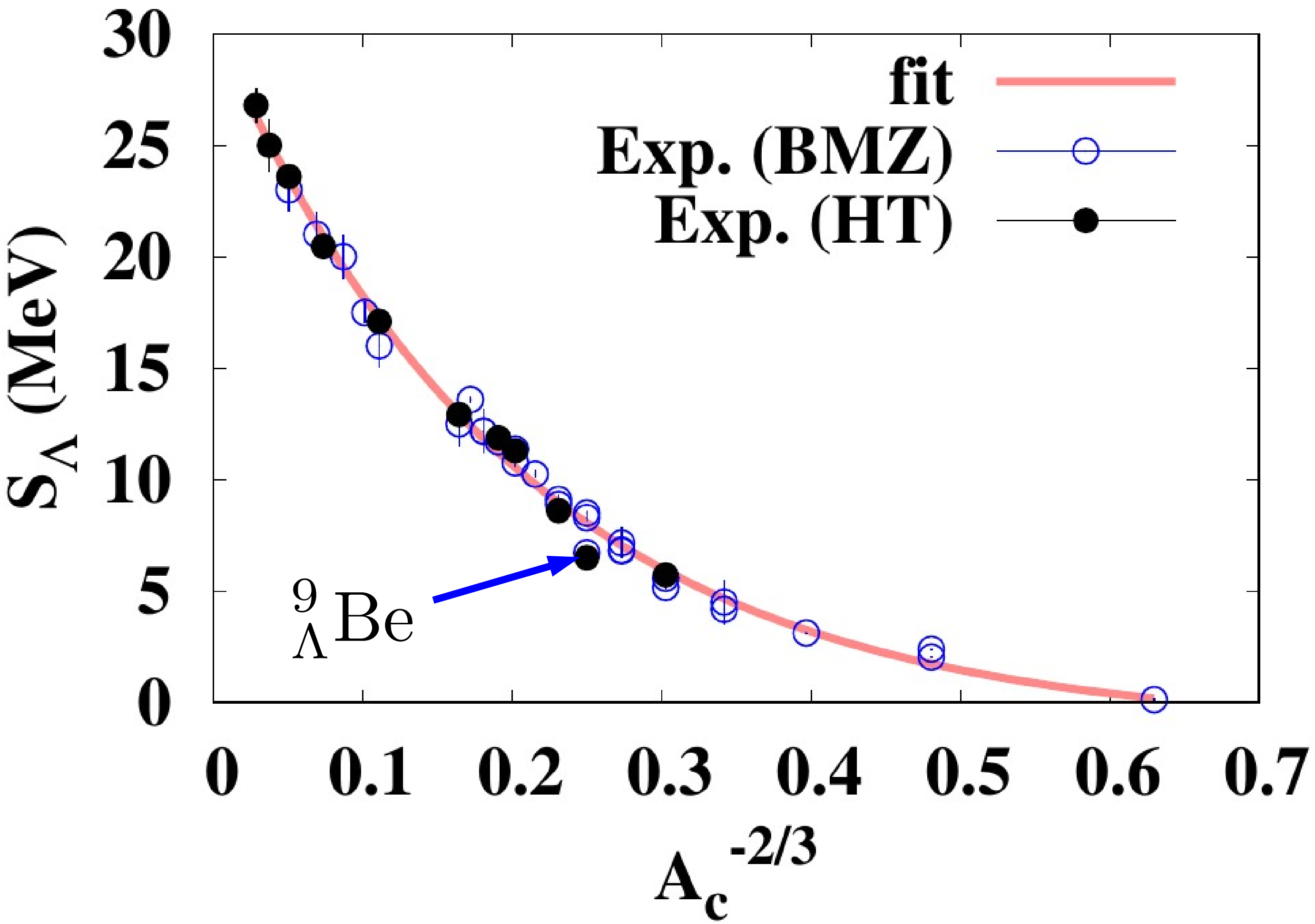
Binding Energies of Hypernuclei

- Stat. Dec. calculation needs hypernuclear mass table.
  - All existing normal nuclei + Λ (and ΛΛ) are assumed to form single and double hypernuclei.
  - Un-observed hypernuclear binding energies are given by the fit function of S_Λ.
    (We put more emphasis on KEK data using (π^+, K^+) reactions.)
  - Double hypernuclear BE are evaluated by using $\Delta B_{\Lambda\Lambda}(A)$, which is assumed to be a linear fn. of A.
    Input=$\Delta B_{\Lambda\Lambda}(A=6)$ and $\Delta B_{\Lambda\Lambda}(A=11)$



Binding Energies of Hypernuclei

- 実は理研での会合で、SKS での分離エネルギーは 500 keV 小さかったと知りました。(原点がずれていたらしい。)
  そうすると9ΛBe 以外はほぼ滑らかな線に乗るので、質量数領域を分けずに fit した結果も後ほど示します。



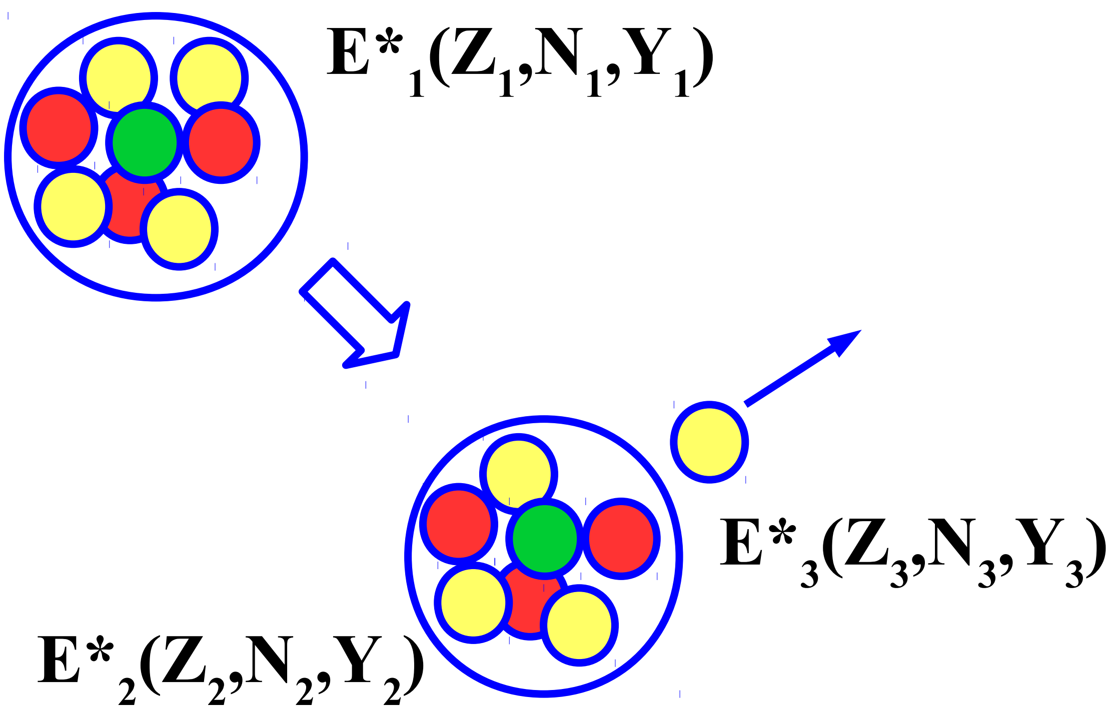
Sequential statistical binary decay model (cascade)

- **Decay of an excited nuclei ~ Inverse process of absorption (fusion)**

$$\Gamma_{1\to 23} dE_2 dE_3 = \frac{\rho_2(E_2, J_2)\rho_3(E_3, J_3)}{2\pi\rho_1(E_1, J_1)} \sum_{L, J_{23}} T_L dE_2 dE_3$$

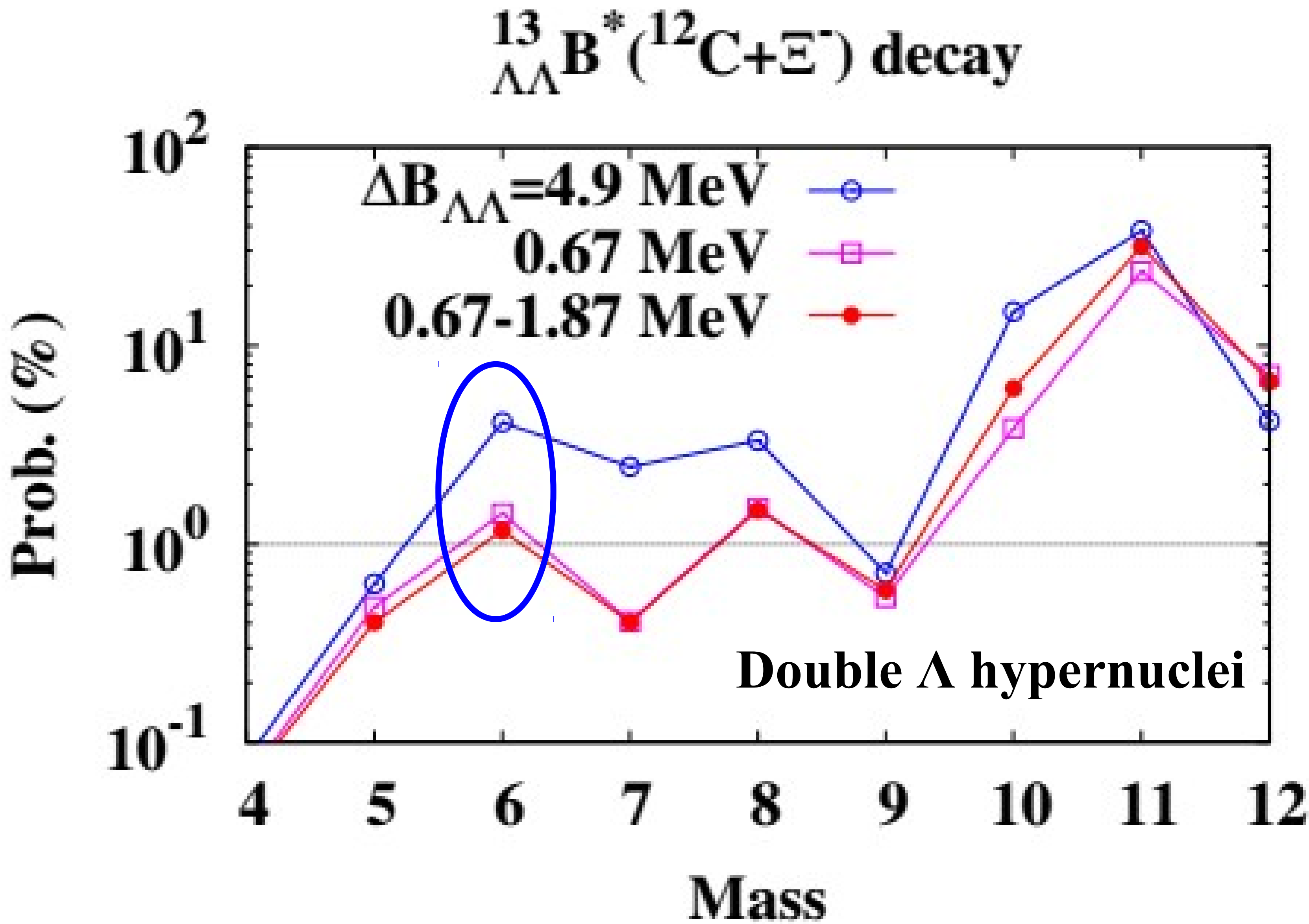
$\rho(E, J)$: Level density in back-shifted Fermi-Gas model

$T_L = \Theta(L_c - L)$ (Transmission coef. of $23 \to 1$)



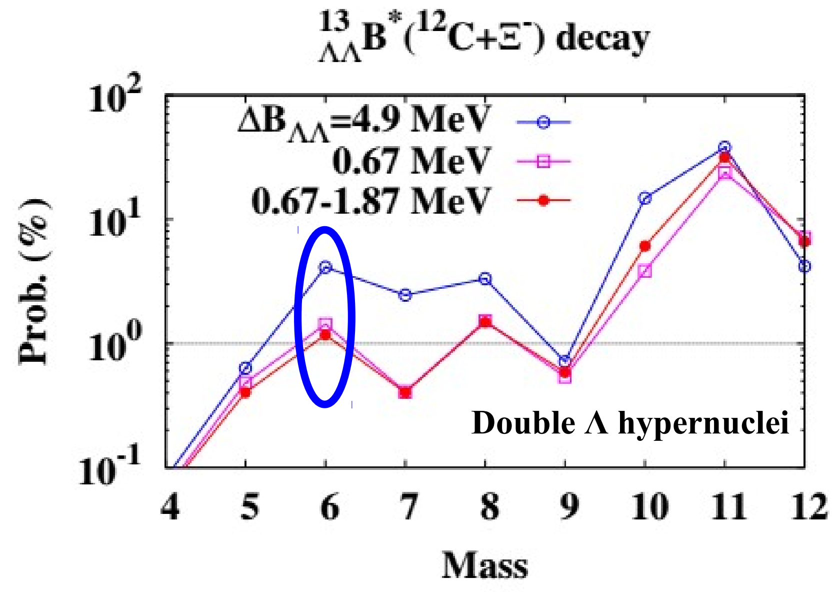
Ξ^- absorption at rest on ^{12}C

- **Nagara event (KEK E373)** $^{12}\mathrm{C} + \Xi^- \to {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + t$



Ξ^- absorption at rest on ^{12}C

- **Nagara event (KEK E373)** $^{12}\mathrm{C} + \Xi^- \to {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^4\mathrm{He} + t$
- **Statistical decay model**
  - **Model A ($\Delta B_{\Lambda\Lambda}$ =4.9 MeV)** **2.4 %** **($^{6}_{\Lambda\Lambda}$He total 4.1 %)**
  - **Model B ($\Delta B_{\Lambda\Lambda}$ =0.67 MeV)** **0.87 %** **($^{6}_{\Lambda\Lambda}$He total 1.4 %)**
  - **Model C ($\Delta B_{\Lambda\Lambda}$ =(0.67, 1.87) MeV)** **0.72 %** **($^{6}_{\Lambda\Lambda}$He total 1.2 %)**
- **Event No. estimate**
  - **E373 Stopped Ξ^- events ~ 1000**
  - **^{12}C absorption ~ 160 (?)**
  - **DΛC formation prob. ~ 30 % (AMD)**
    → (0.35-1.2) events in the channel
    ($^{6}_{\Lambda\Lambda}$He total (0.58-2.0) events)

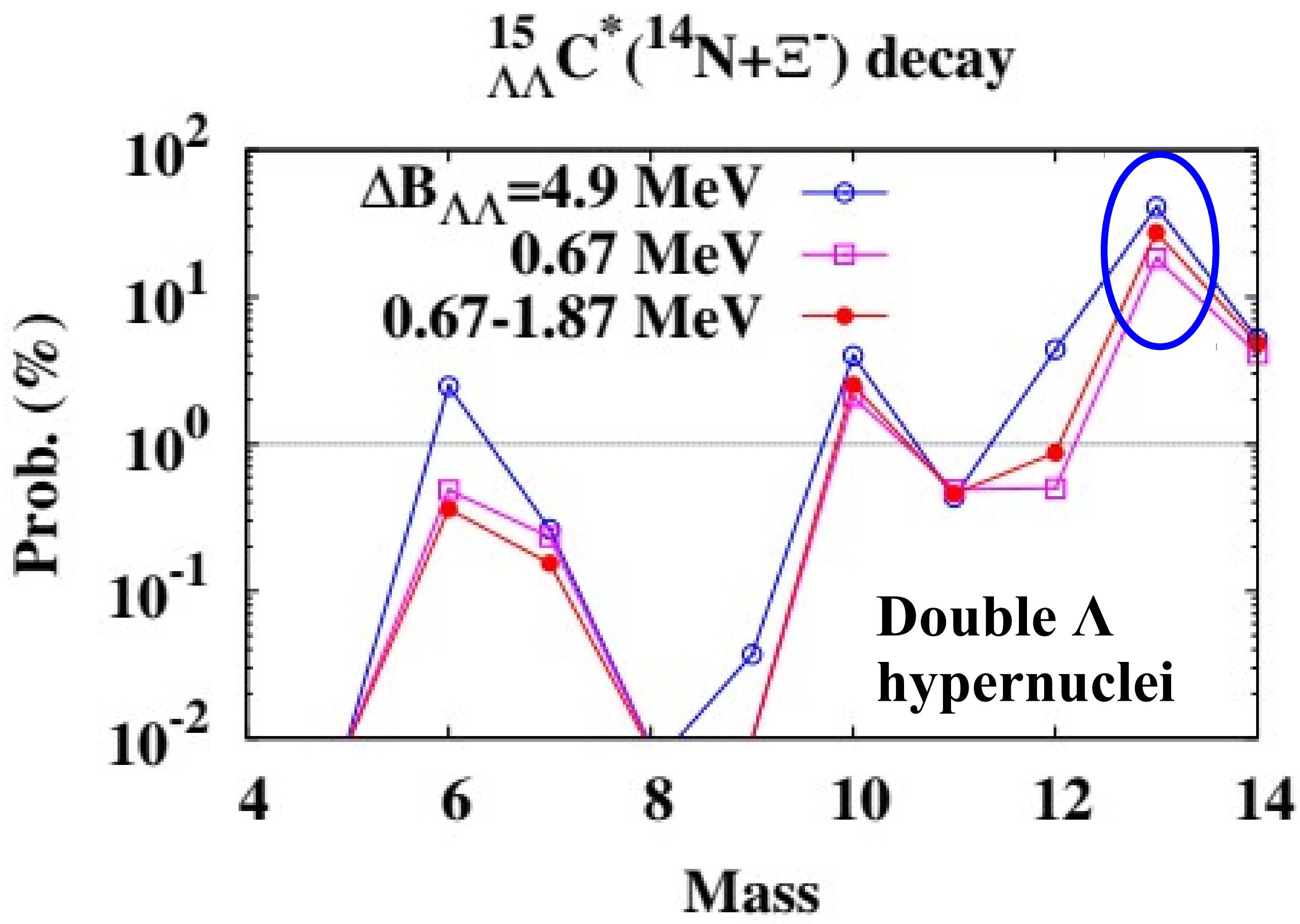


E373 was reasonably lucky !

Ξ^- absorption at rest on ^{14}N

- **KEK E176 double Λ hypernucleus event (most probable)**

$$^{14}\mathrm{N} + \Xi^- \to {}^{13}_{\Lambda\Lambda}\mathrm{B} + p + n$$

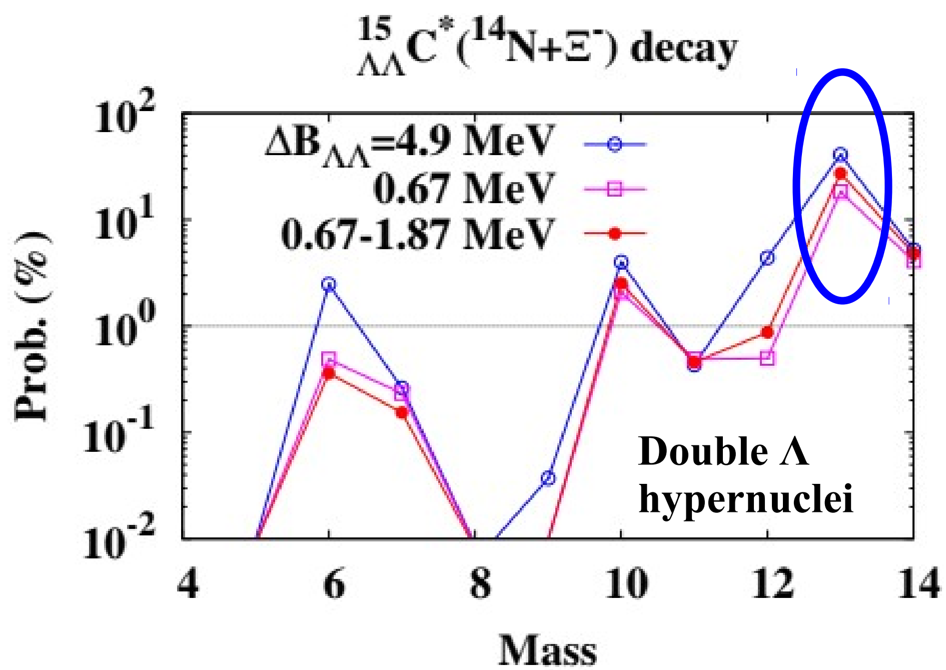


Ξ^- absorption at rest on ^{14}N

- **KEK E176 double Λ hypernucleus event (most probable)**

$$^{14}\mathrm{N} + \Xi^- \to {}^{13}_{\Lambda\Lambda}\mathrm{B} + p + n$$

- **Statistical decay model**
  - **Model A ($\Delta B_{\Lambda\Lambda}$ =4.9 MeV) 28 % ($^{13}{}_{\Lambda\Lambda}$B total 31 %)**
  - **Model B ($\Delta B_{\Lambda\Lambda}$ =0.67 MeV) 11 % ($^{13}{}_{\Lambda\Lambda}$B total 15 %)**
  - **Model C (0.67, 1.87) 18 % ($^{13}{}_{\Lambda\Lambda}$B total 21 %)**
- **Event No. estimate**
  - **E176 Stopped Ξ^- events ~ 80**
  - **^{14}N absorption ~ 13 (?)**
  - **DΛC formation prob.~30 % (?)**
    → (0.43-1.1) events
    ($^{13}{}_{\Lambda\Lambda}$B total (0.82-1.2) events)

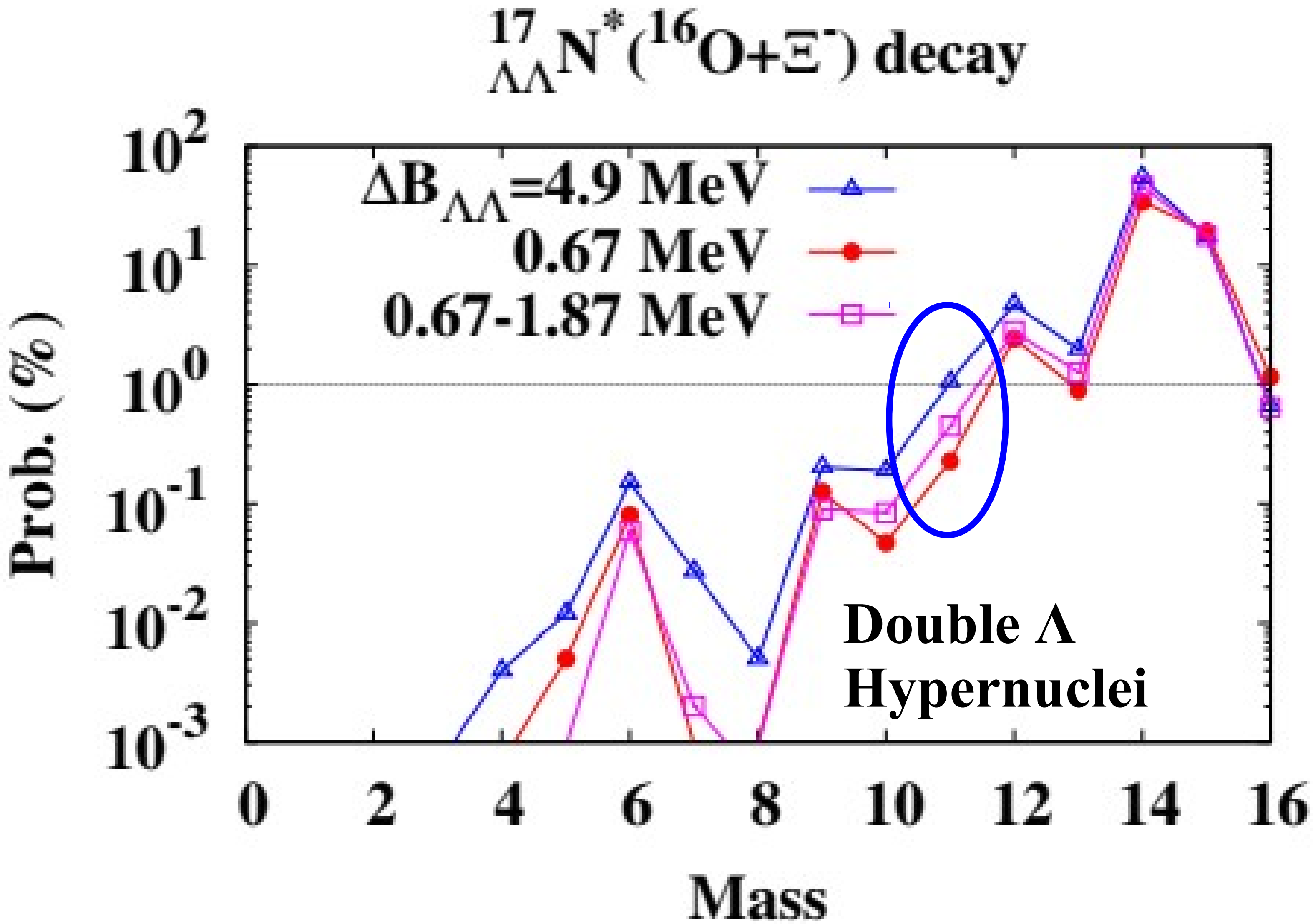


E176 was also reasonably lucky !

Ξ^- absorption at rest on ^{16}O

- **J-PARC E07 double Λ hypernucleus event (most probable)**

$$^{16}\mathrm{O} + \Xi^- \to {}^{11}_{\Lambda\Lambda}\mathrm{Be} + {}^{4}\mathrm{He} + d$$



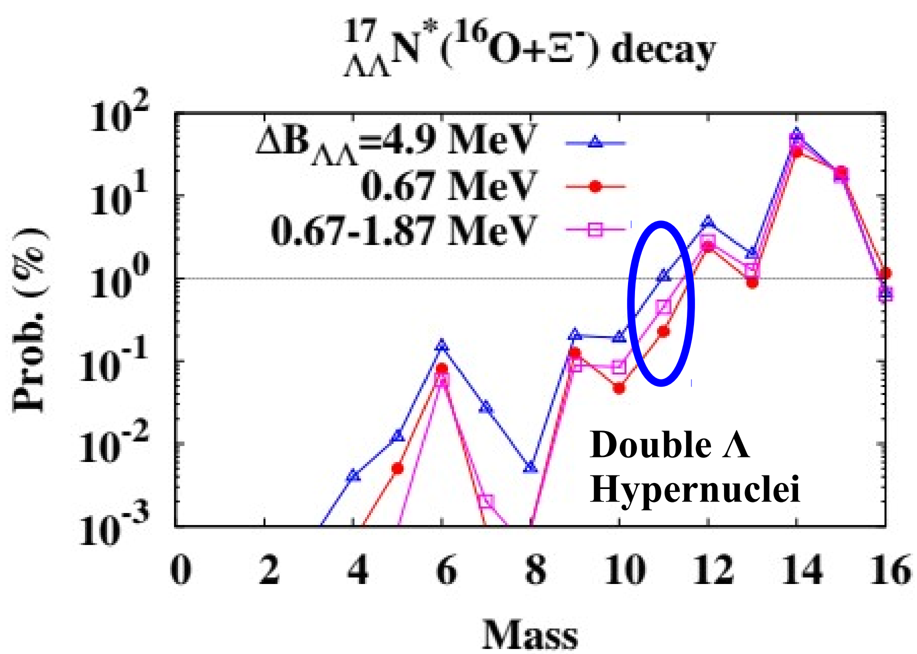
Ξ^- absorption at rest on ^{16}O

- **J-PARC E07 double Λ hypernucleus event (most probable)**

$$^{16}\mathrm{O} + \Xi^- \to {}^{11}_{\Lambda\Lambda}\mathrm{Be} + {}^4\mathrm{He} + d$$

- **Statistical decay model**
  - **Model A ($\Delta B_{\Lambda\Lambda}$ =4.9 MeV)** **0.33 %** **($^{11}_{\Lambda\Lambda}$Be total 1.0 %)**
  - **Model B ($\Delta B_{\Lambda\Lambda}$ =0.67 MeV)** **0.13 %** **($^{13}_{\Lambda\Lambda}$B total 0.23 %)**
  - **Model C (0.67, 1.87)** **0.17 %** **($^{13}_{\Lambda\Lambda}$B total 0.44 %)**

- **Event No. estimate**
  - **E07 Stopped Ξ^- events ~ 900**
  - **^{14}N absorption ~ 150 (?)**
  - **DΛC formation prob.~30 % (?)**
    → (0.06-0.14) events
    ($^{13}_{\Lambda\Lambda}$B total (0.10-0.45) events)



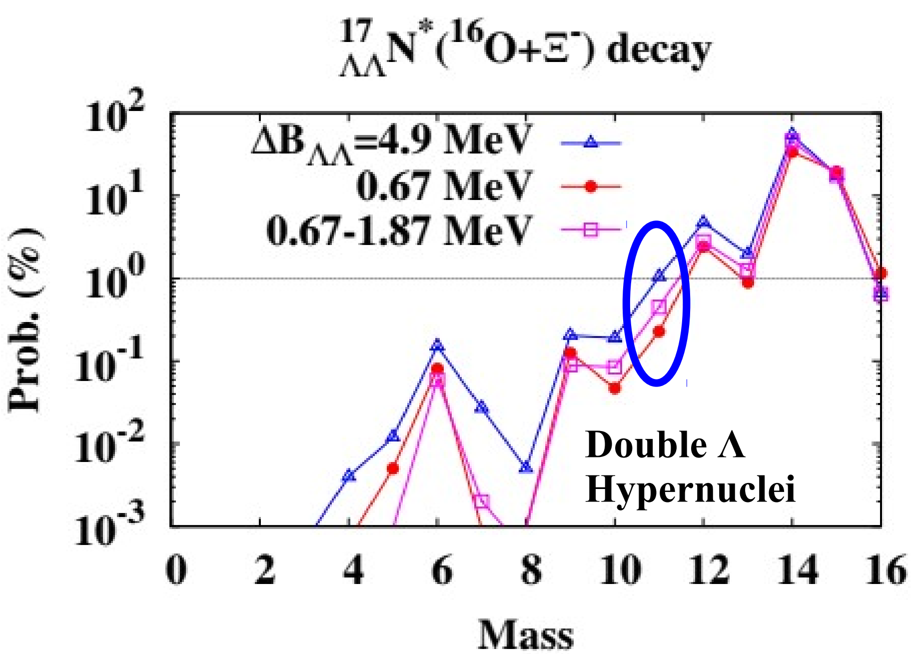
Was E07 very lucky ?

Ξ^- absorption at rest on ^{16}O

- Other channel ?

Channel	Model A	Model B	Model C
$^{10}_{\Lambda\Lambda}$Be+α+t	0.15 (0.18)	0.014 (0.05)	0.039 (0.084)
$^{11}_{\Lambda\Lambda}$Be+α+d	0.33 (1.0)	0.13 (0.23)	0.17 (0.44)
$^{12}_{\Lambda\Lambda}$Be$^{(*)}$+α+p	0.75 (0.75)	0.41 (0.41)	0.49 (0.49)

- Other channels also have small probability, but $^{12}_{\Lambda\Lambda}$Be formation is more probable.
- Formation mechanism of $_{\Lambda\Lambda}$Be may not be the statistical decay. Pre-equilibrium dynamics should be responsible.

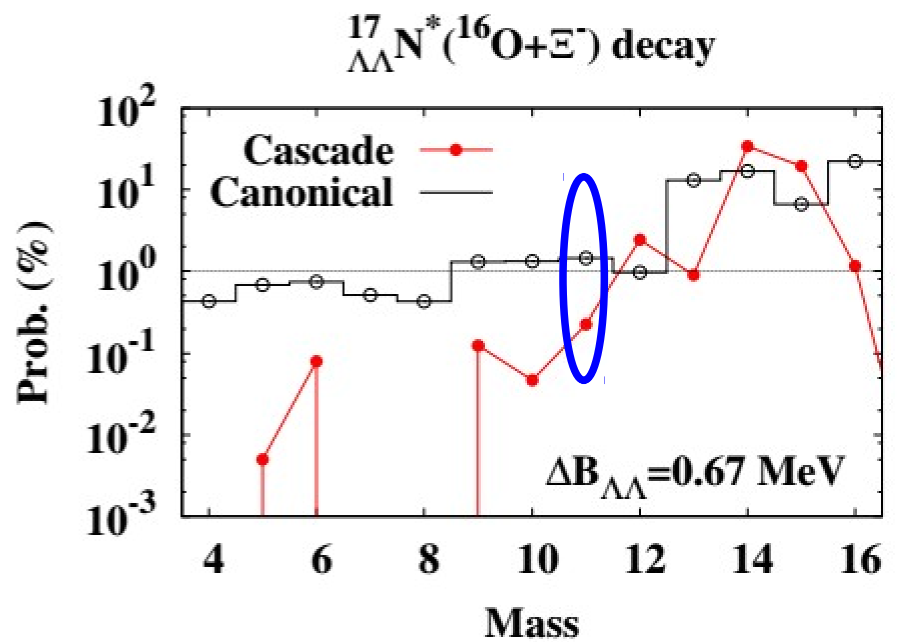


Ξ^- absorption at rest on ^{16}O

- **J-PARC E07 double Λ hypernucleus event (most probable)**

$$^{16}\text{O} + \Xi^- \to {}^{11}_{\Lambda\Lambda}\text{Be} + {}^4\text{He} + d$$

- **Canonical Multi-Fragmentation model**
  - **Model A ($\Delta B_{\Lambda\Lambda}$ =4.9 MeV) 0.29 % ($^{11}{}_{\Lambda\Lambda}$Be total 1.5 %)**
  - **Model B ($\Delta B_{\Lambda\Lambda}$ =0.67 MeV) 0.19 % ($^{11}{}_{\Lambda\Lambda}$Be total 1.1 %)**
  - **Model C (0.67, 1.87) 0.22 % ($^{11}{}_{\Lambda\Lambda}$Be total 1.2 %)**
- **Event No. estimate**
  - **E07 Stopped Ξ^- events ~ 900**
  - **^{14}N absorption ~ 150 (?)**
  - **DΛC formation prob.~30 % (?)**
    → (0.08-0.13) events
    ($^{11}{}_{\Lambda\Lambda}$Be total (0.50-0.68) events)

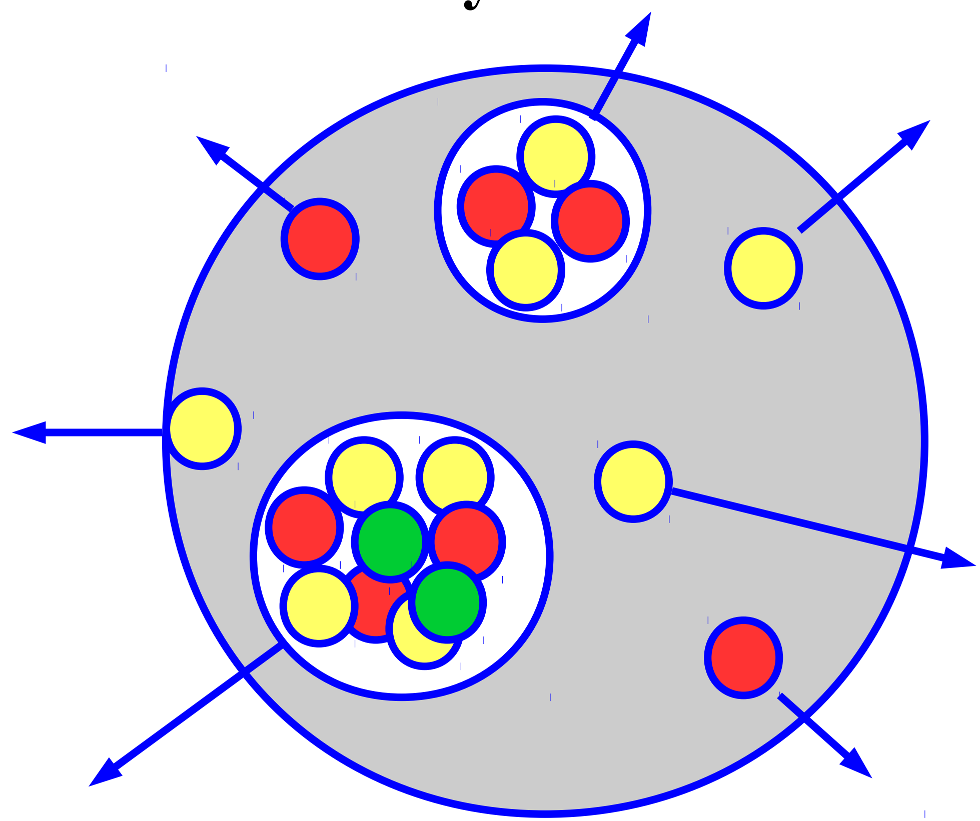


Canonical Multi-Fragmentation model

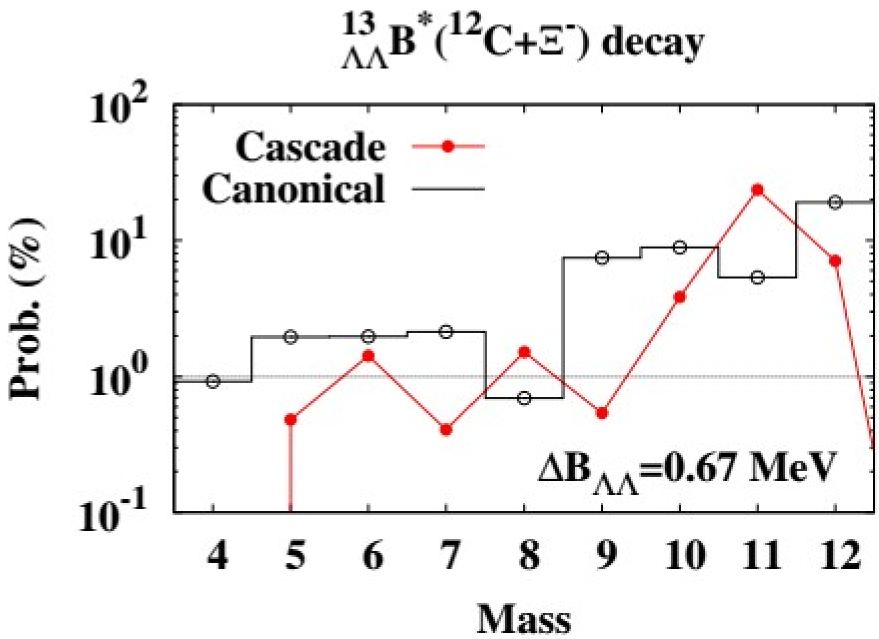
- **Excited state wave function should be described by the asymptotic channel wave functions**
  Yamamoto+('94), Lorente+ ('11), Fai, Randrup ('82), AO, Randrup ('95,,'97,'97)

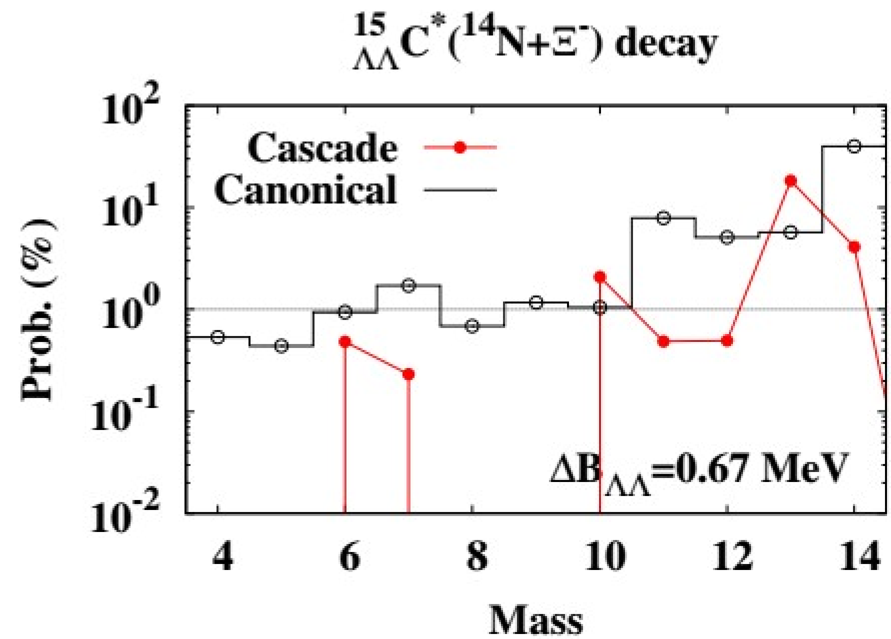
$$\mathcal{Z} = \sum_{\text{parition}} \underline{e^{-V_C/T}} \prod_i \left[\int \frac{V d^3p_i}{(2\pi)^3} \int^{E_{\text{thr}}+\Delta E} \underline{dE_i^* \rho_i(E_i^*)} \underline{e^{-(p_i^2/2m_i+E_i^*-B_i)/T}} \right]$$

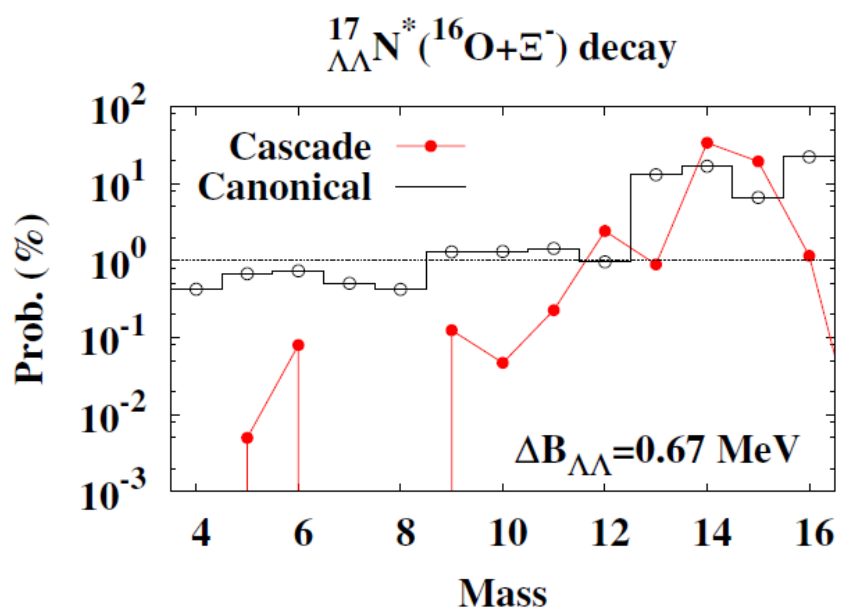
Coulomb **Level density** **Boltzmann**



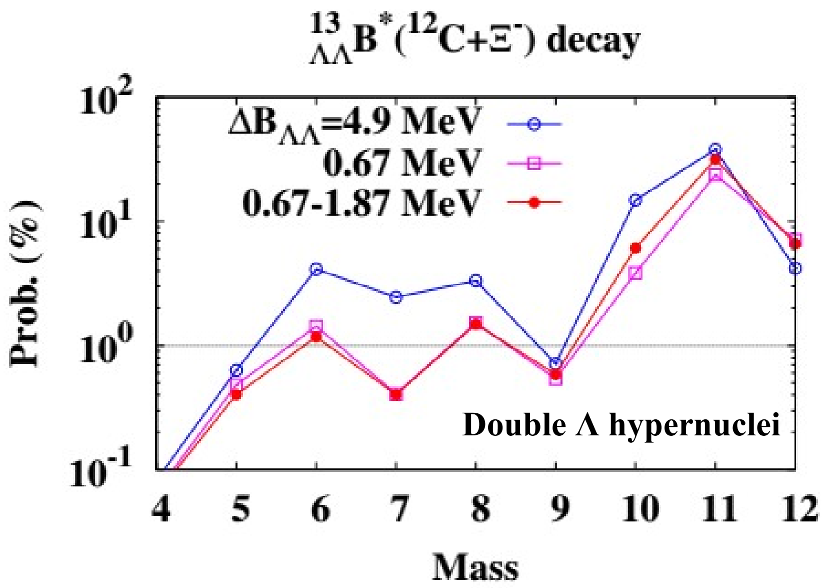
Results with Canonical Multi-Fragmentation Model

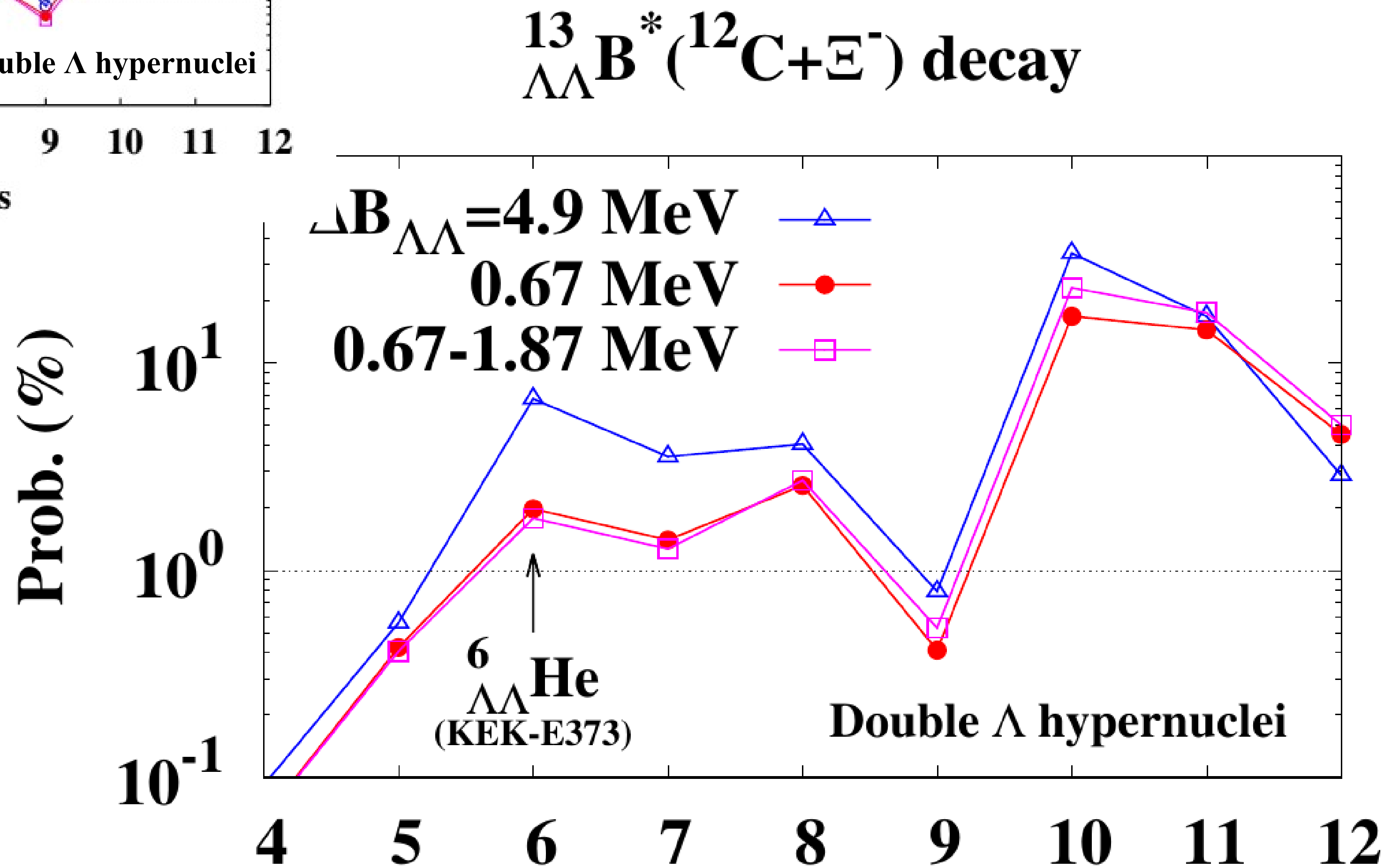




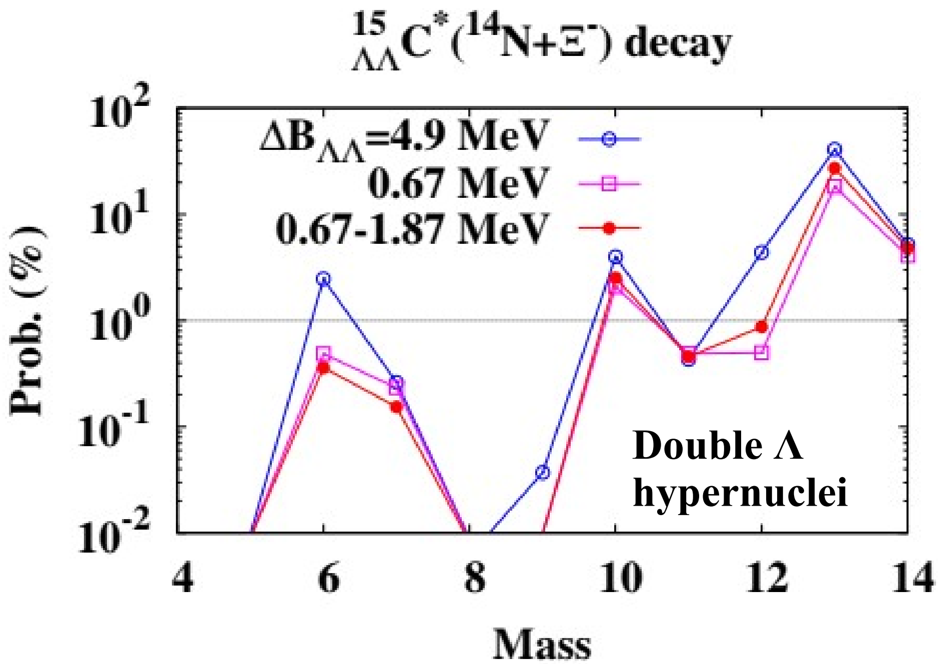


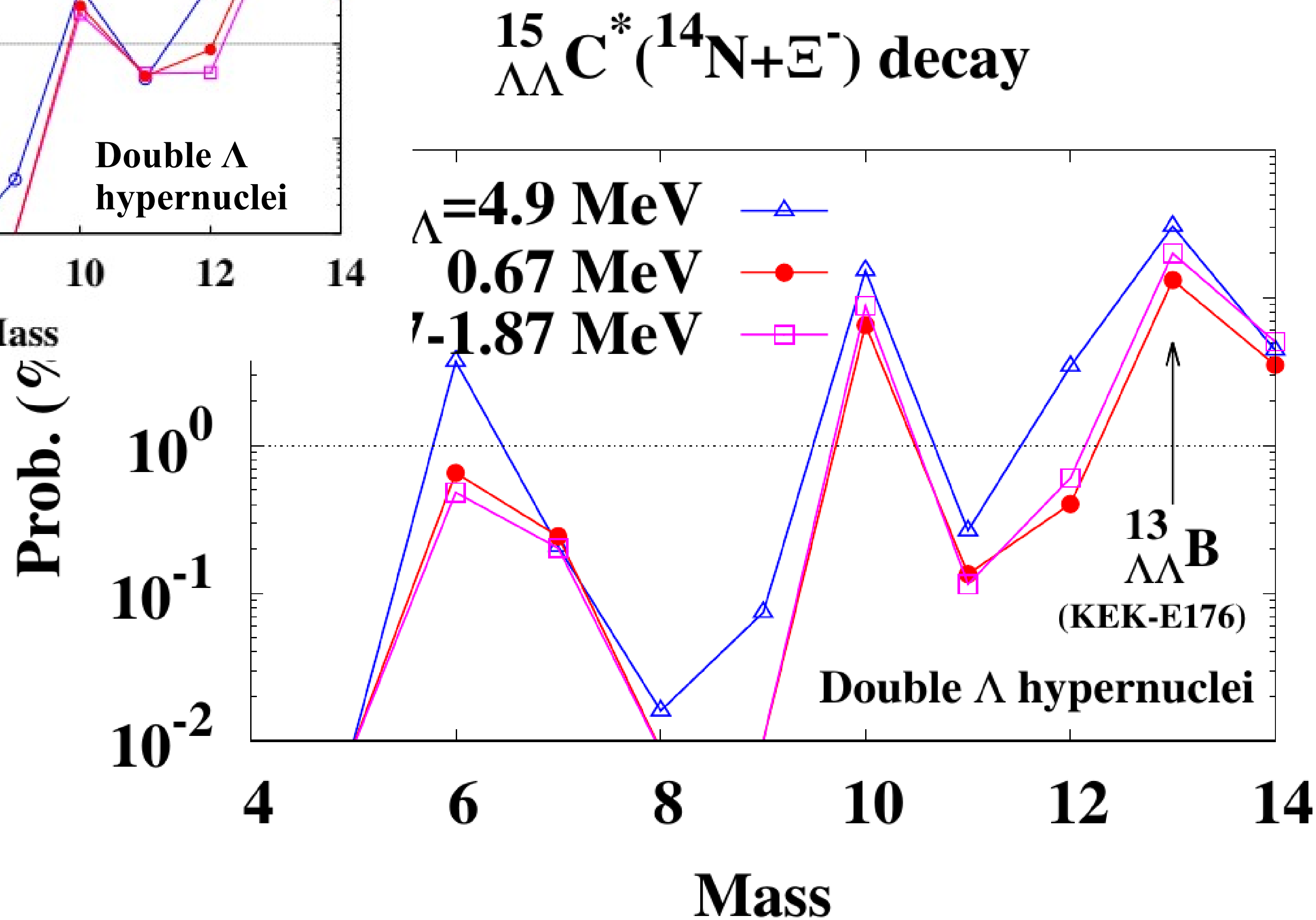
Ξ^- absorption at rest on ^{12}C (w/ modified S_Λ)



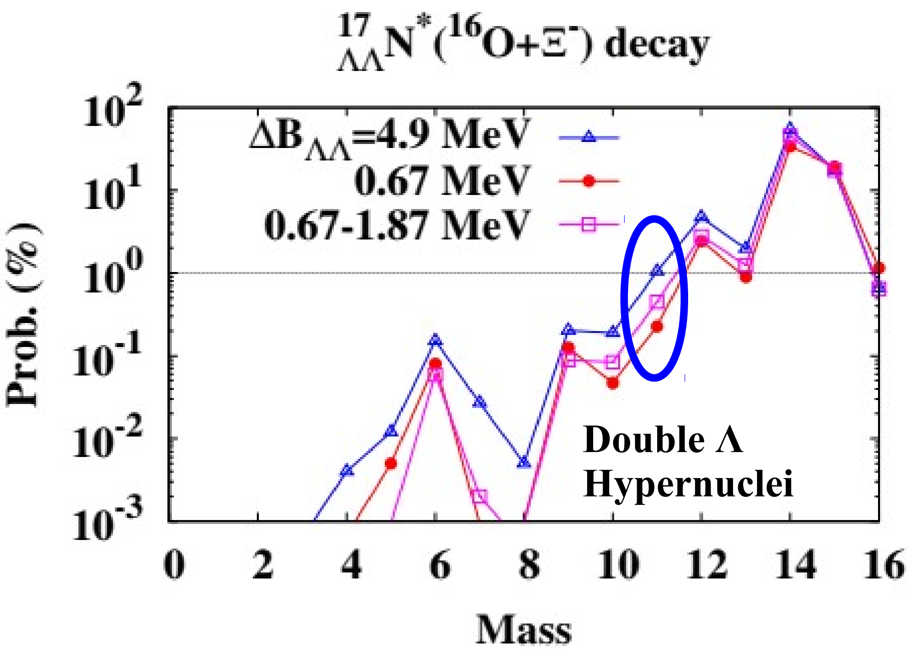


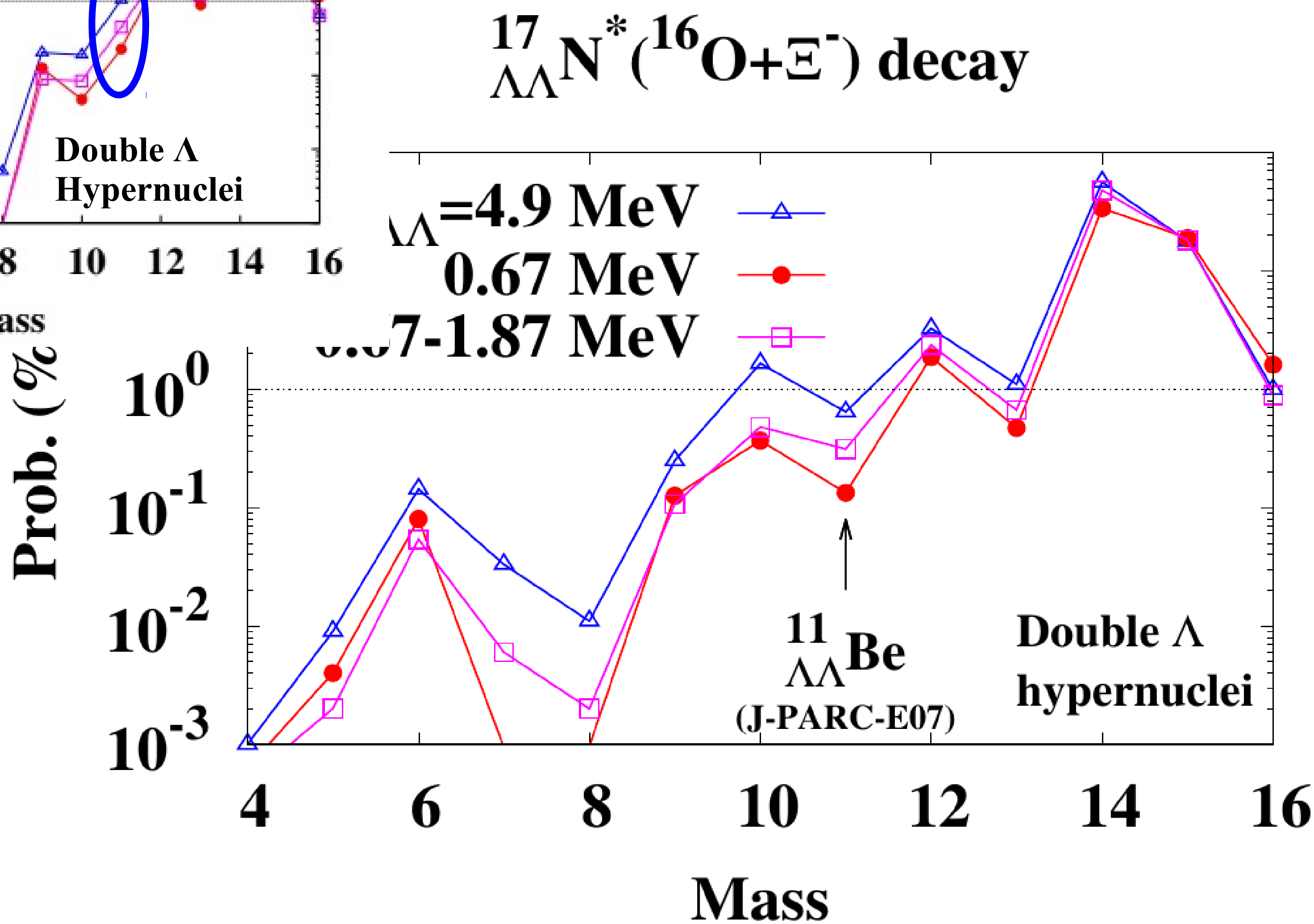
Ξ^- absorption at rest on ^{14}N (w/ modified S_Λ)





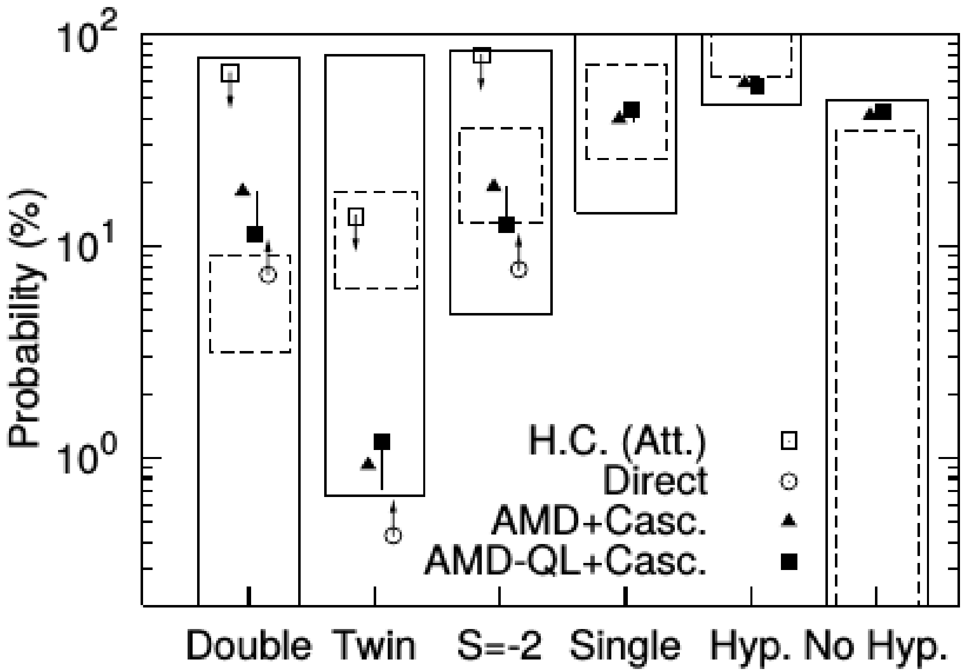
Ξ^- absorption at rest on ^{16}O (w/ modified S_Λ)



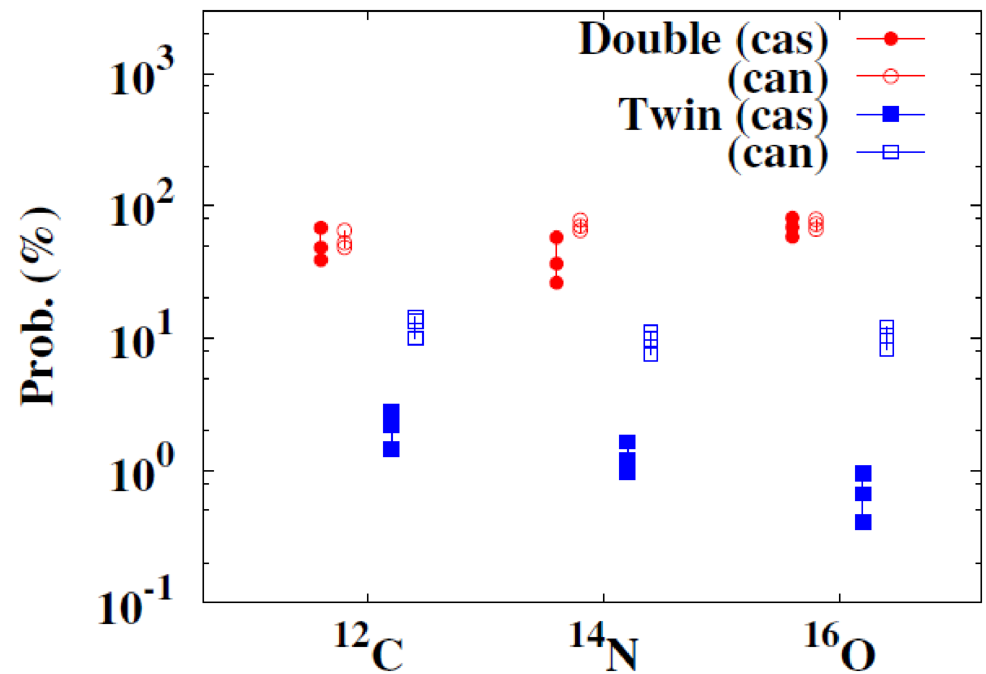


Formation of Twin Single Hypernuclei

- **Twin hyperfragment puzzle**
  - **Emulsion experiments suggest Prob. (Twin) ~ Prob. (Double)**
  - **Theoretical Calculations show Prob. (Twin) < Prob. (Double)**
- **This trend is the same also with small $\Delta B_{\Lambda\Lambda}$.**
- **Multi-fragmentation model gives larger prob. of Twin events.**



Y. Hirata, Y. Nara, AO, T. Harada, J. Randrup, PTP102 ('99) 89

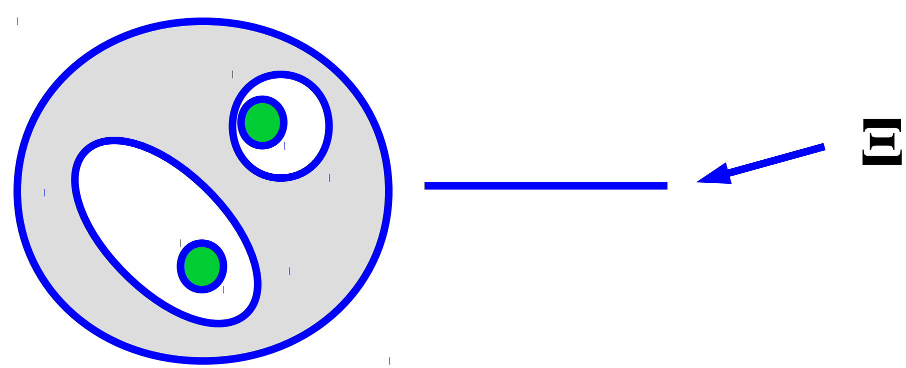


Summary

- **Fragmentation of normal nuclei have been described reasonably well in the combined framework of**
  Transport model (AMD(-QL)) + Statistical Decay.
  This framework was applied to hyperfragment formation from K^- and Ξ^- absorption at rest, and met some successes.
- **We have studied the Ξ^- absorption at rest on ^{12}C, ^{14}N and ^{16}O in statistical decay model(s).**
  - **Smaller $\Delta B_{\Lambda\Lambda}$ suppresses the formation probability of light double Λ hypernuclei such as $6_{\Lambda\Lambda}$He.**
  - **Double hypernucler formation channels in E176 & E373 experiments have reasonably large probabilities.**
  - **E07 channel seems to have small probability. Further works are desired.**
  - **Small twin single hypernuclear formation probability is still a puzzle.**

To do

- **Prequilibrium dynamics is necessary**
  - **Transport model calculation with updated $\Lambda\Lambda$ interaction $\rightarrow$ Ishizuka**
  - **Direct reaction calc. of Λ ($\Lambda\Lambda$) emission from Ξ^- atomic state ?**
- **Ξ^- absorption at rest on ^{6}He.**
  - **^{7}Li (K^- , K^+) $\rightarrow$ Ξ^- + ^{6}He (Fujioka) ~ $^{7}_{\Lambda\Lambda}$H* $\rightarrow$ $^{5}_{\Lambda\Lambda}$H + nn**
    Kumagai-Fuse & Akaishi
  - **One-shot calc.: 34 % in cascade, 4.9 % in canonical**
- **Twin hypernuclear puzzle**
  - **Cannot be solved using transport+stat. decay**
  - **There may be a developed hypernuclear cluster state near the Ξ threshold.**
    e.g. Yamada, Ikeda

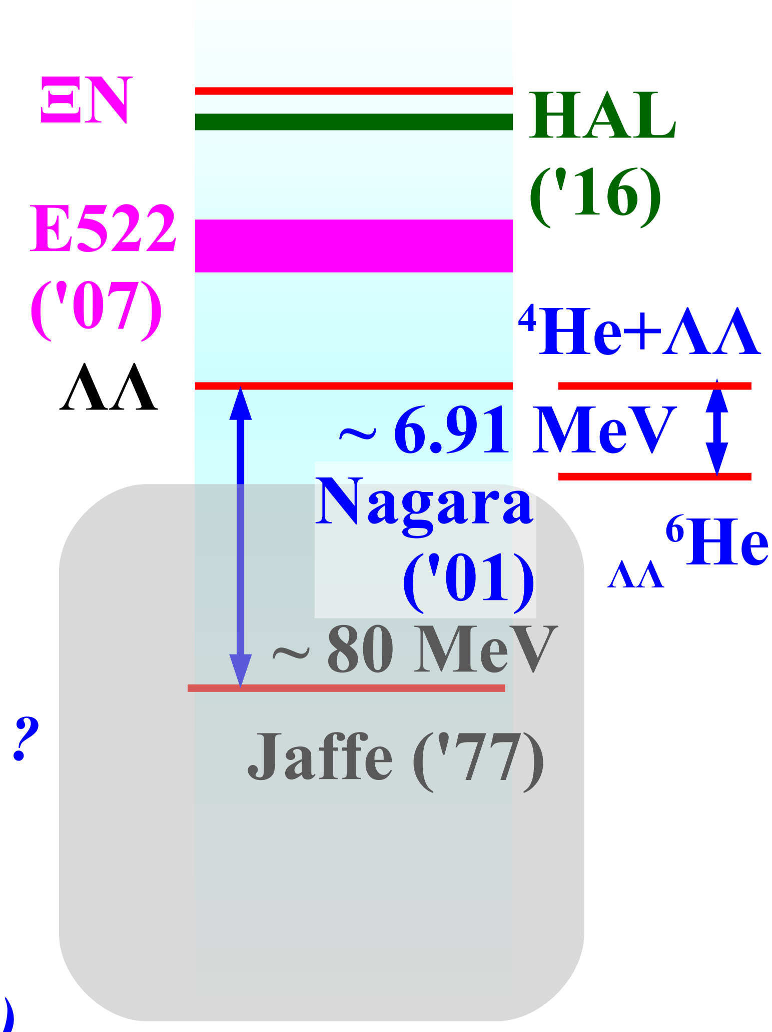


Thank you for your attention !

ΛΛ correlation and ΛΛ interaction

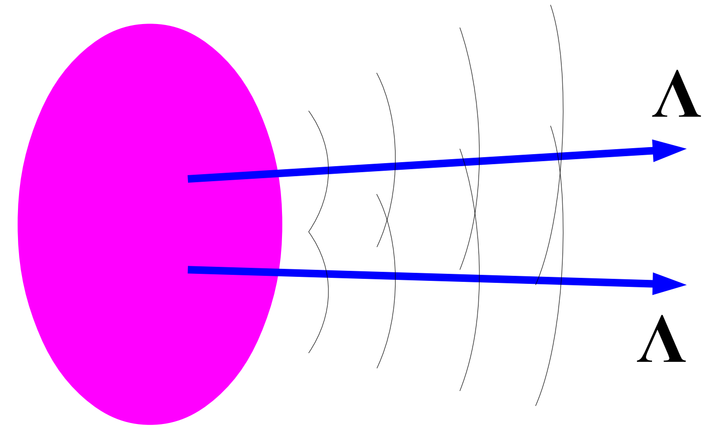
Relevance of ΛΛ interaction to physics

- **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)+AO ('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

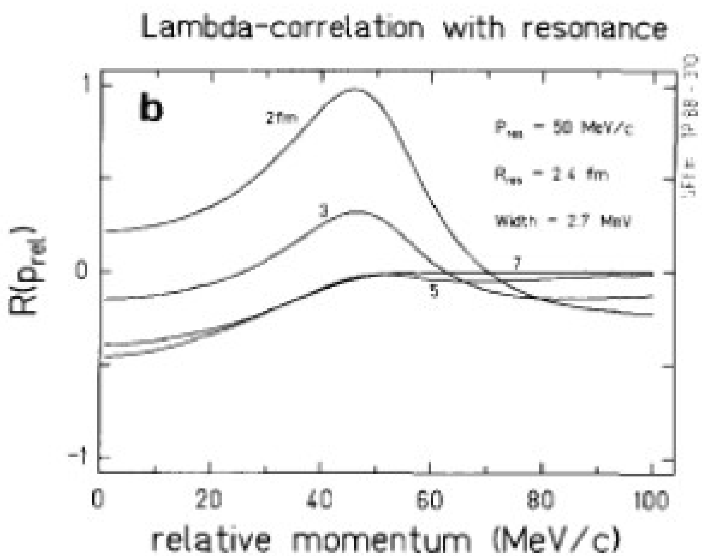


ΛΛ correlation in HIC

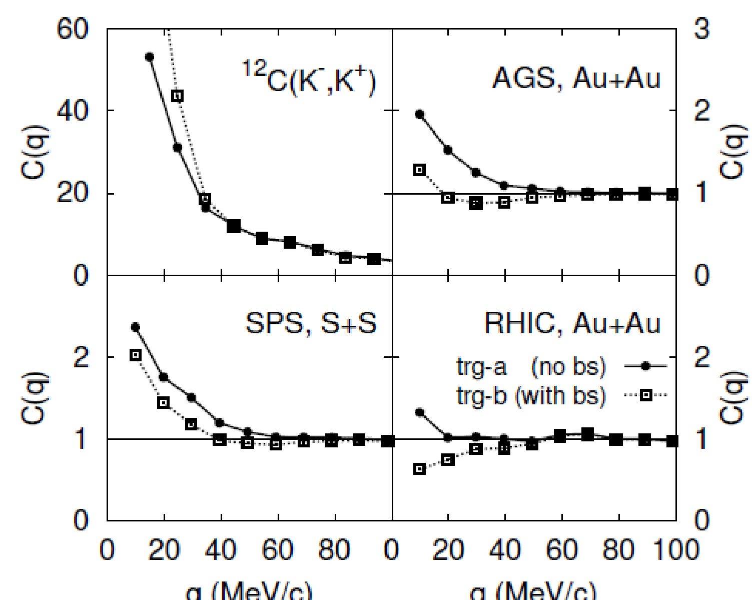
- **Merit of HIC to measure ΛΛ correlation**



  - **Source is "Simple and Clean" !**
    T, μ, flow, size, … are well-analyzed.
  - **Nearly Stat. prod.**
    → Many exotics will be produced.
    Schaffner-Bielich, Mattiello, Sorge ('00), Cho et al.(ExHIC Collab.) ('11)
  - **Discovery of "H" and/or Constraint on ΛΛ int.**
    Bound state exhaust the low q strength → suppressed C(q).



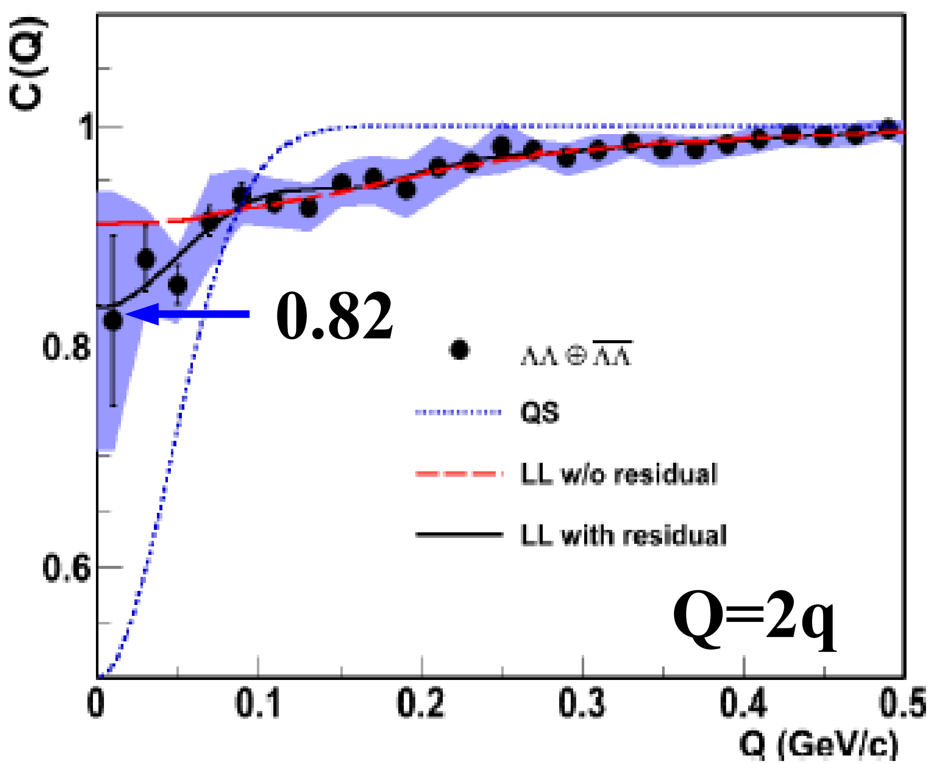
C. Greiner, B. Muller, PLB219('89)199.

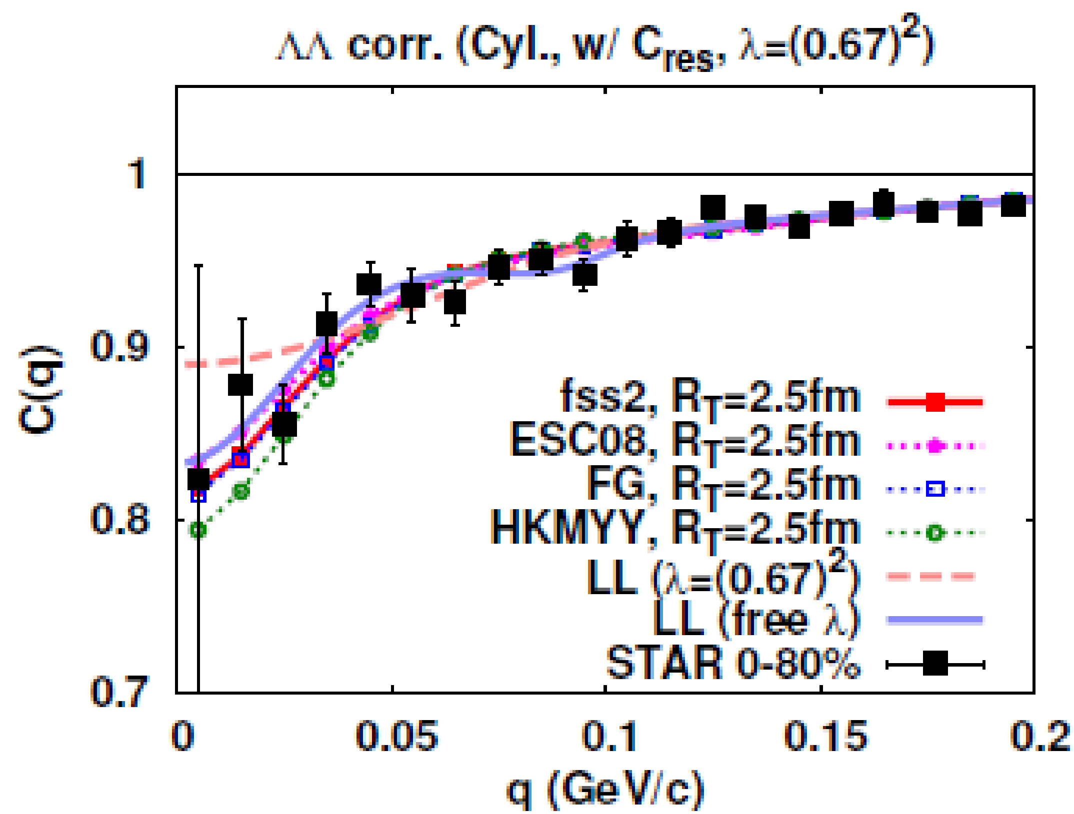


AO, Hirata, Nara, Shinmura, Akaishi, NPA670('00)297c

ΛΛ correlation at RHIC

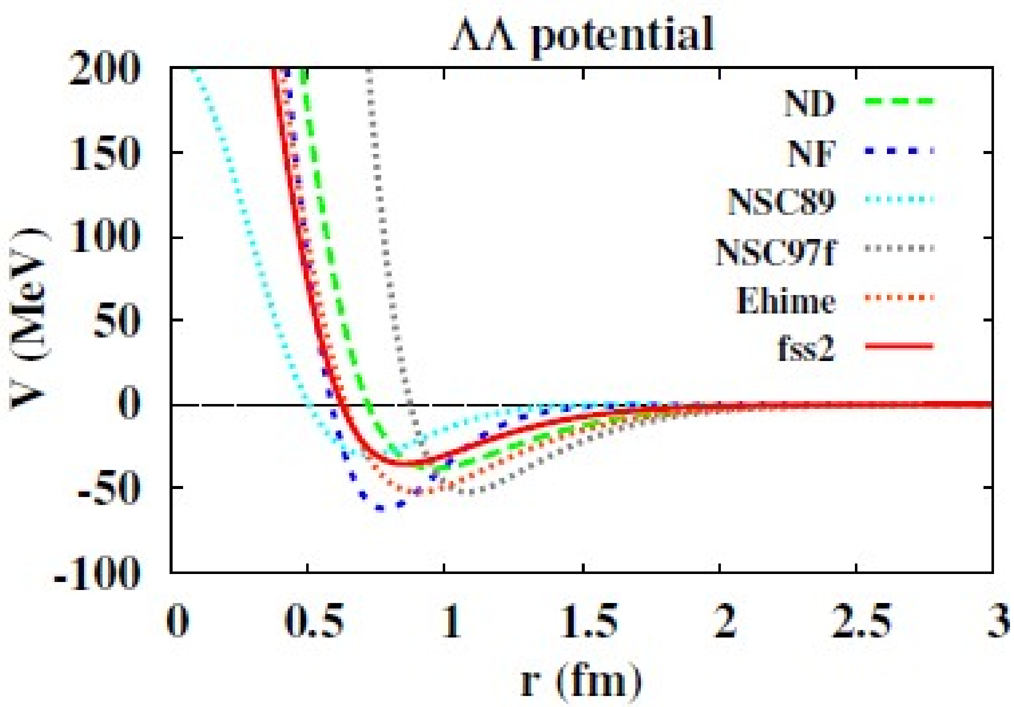
- **STAR collaboration at RHIC measured ΛΛ correlation !**
  Adamczyk et al. (STAR Collaboration), PRL 114 ('15) 022301.
  - **RHIC, Au+Au ($\sqrt{s_{NN}}$=200 GeV), Weak decay vertex analysis.**
- **Theoretical Analysis well explains the data**
  K.Morita et al., T.Furumoto, AO, PRC91('15)024916;
  AO, K.Morita, K.Miyahara, T.Hyodo, NPA954 ('16), 294.

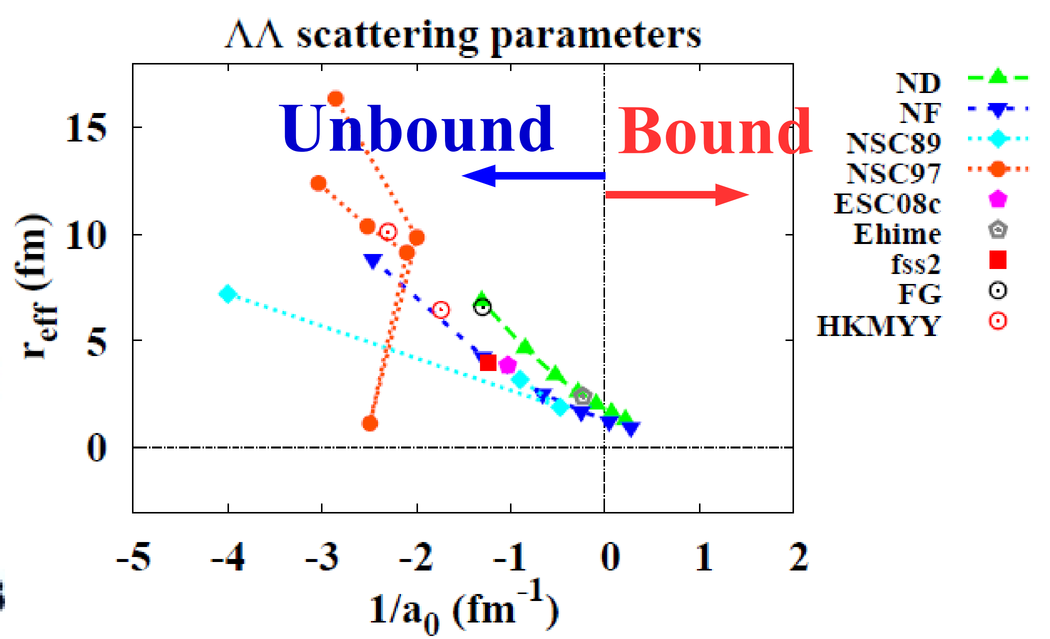




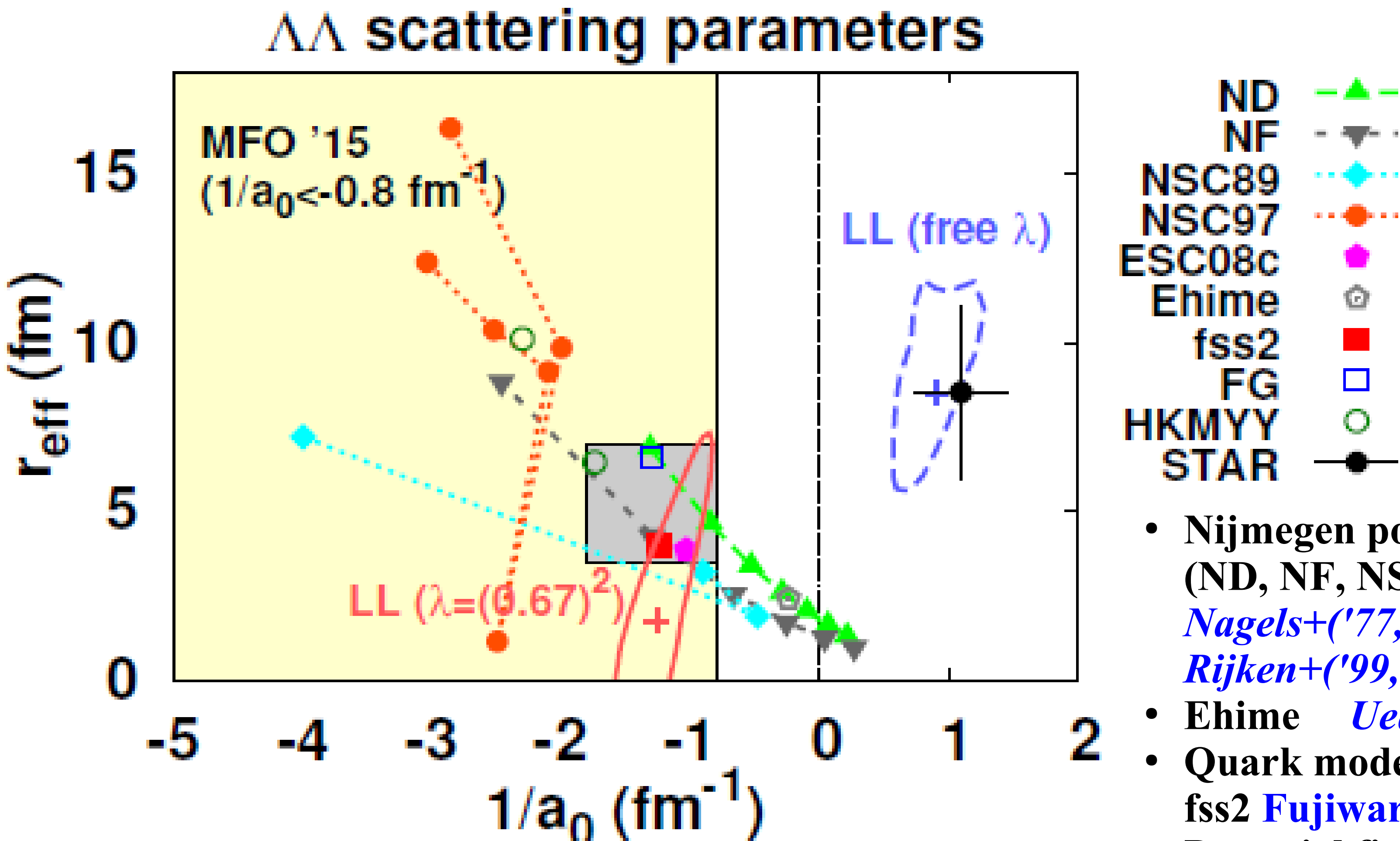
ΛΛ interaction

- **Propsed ΛΛ interactions**
  - **Meson Ex. models: Nijmegen model D, F, Soft Core (89, 97), ESC08**
    Nagels, Rijken, de Swart ('77, '79), Maessen, Rijken, de Swart ('89), Rijken, Stoks, Yamamoto ('99); Rijken, Nagels, Yamamoto ('10).
  - **Quark cluster model interaction: fss2**
    Fujiwara, Fujita, Kohno, Nakamoto, Suzuki ('00)
  - **Phenomenological model: Ehime** T. Ueda et al. ('99).
- **Two (or three) range gaussian fit results are used in the analysis.**





ΛΛ interaction from ΛΛ correlation



- **Nijmegen potentials (ND, NF, NSC89, NSC97, ESC08)** *Nagels+('77, '79), Maessen+('89), Rijken+('99,'10)*
- **Ehime** *Ueda et al. ('98)*
- **Quark model interaction:** **fss2** Fujiwara et al.('07)
- **Potential fitted to Nagara** *Filikhin, Gal ('02) (FG), Hiyama et al. ('02, '10)(HKMYY)*

$$q \cot \delta = -1/a_0 + r_{eff}\, q^2/2 + O(q^4)$$

Positive a_0 (STAR) ⟵⟶ Negative a_0 (MFO'15)

Difference comes from the pair purity

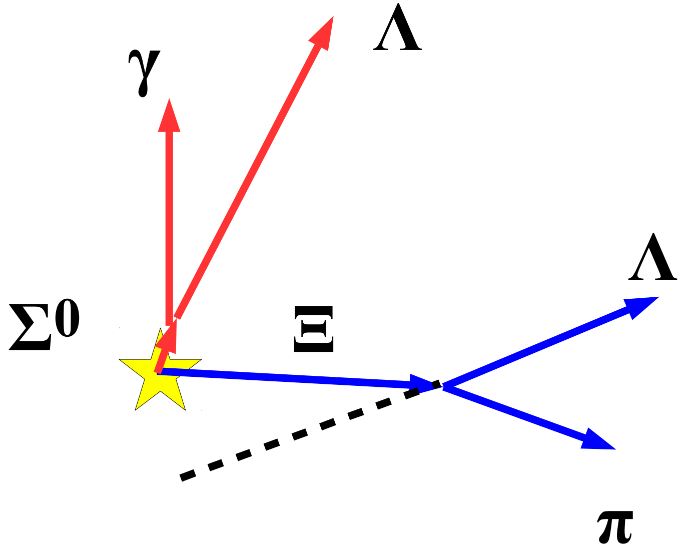
Additional Source

- **Feed down effects**

$$C_{\rm corr}(Q) = 1 + \lambda(C_{\rm bare}(Q) - 1)$$

λ = Purity of ΛΛ pair

  - **Short-lived Y* → mod. of source fn.**
  - **Ξ → Λπ can be excluded (cτ=8.71 cm)**
  - **$\Sigma^0 \to \Lambda\gamma$ is difficult to reject**
  - **Data based purity $\lambda=(0.67)^2$**
    Σ^0/Λ=0.278 (p+Be, 28.5 GeV/c) ***Sullivan et al. ('87)***
    Ξ/Λ = 15 % (RHIC)

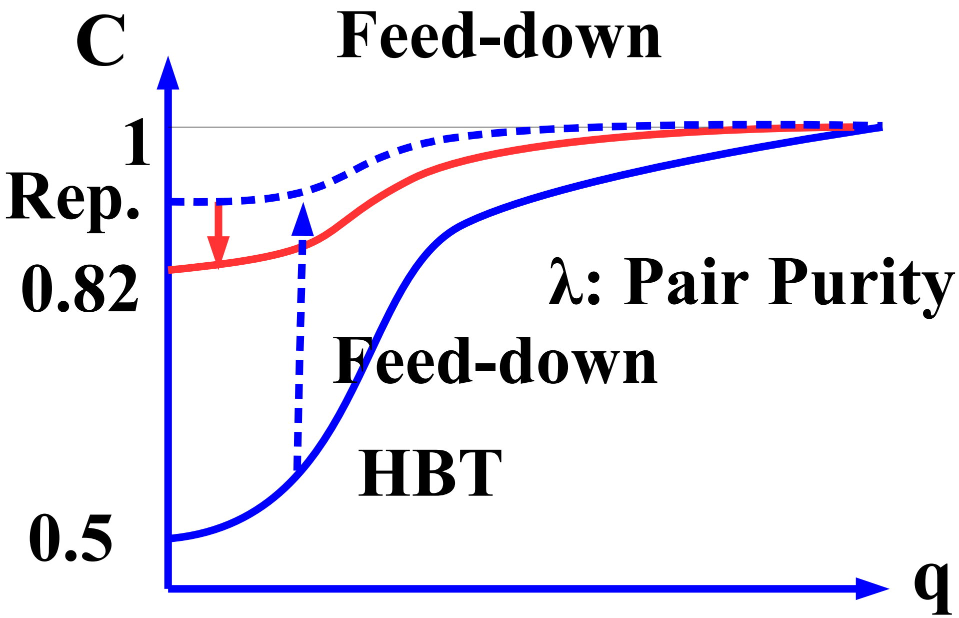


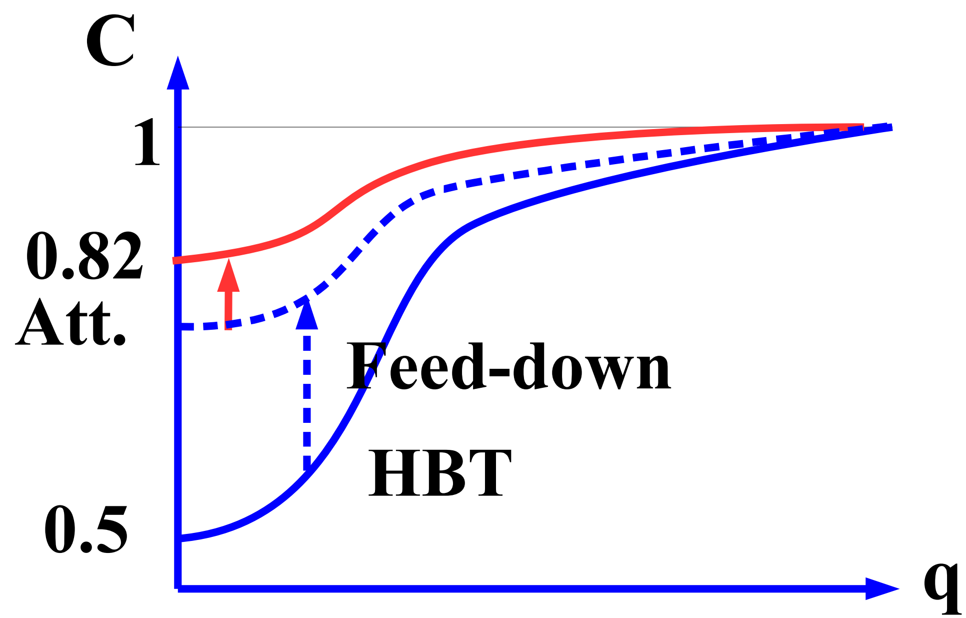
- **"Residual" source**
  - **High-momentum tail → R_{res} ~ 0.5 fm (STAR collab.)**

Feed-Down Effects & Residual Source

- **Correlation Fn. w/ Feed-down & Residual source effects.**

$$C_{\rm corr}(q) = 1 + \lambda(C_{\rm bare}(q) - 1) + a_{\rm res}\exp(-4r_{\rm res}^2 q^2)$$





STAR:
λ ~ 0.18 (free para.)

Morita et al. (MFO15):
λ ~ 0.45

Pair purity (λ) should be determined experimentally !
Puzzle: Residual source

Σ^0/Λ=0.278 (p+Be, 28.5 GeV/c)
Sullivan et al. ('87)
Ξ/Λ = 15 % (RHIC)

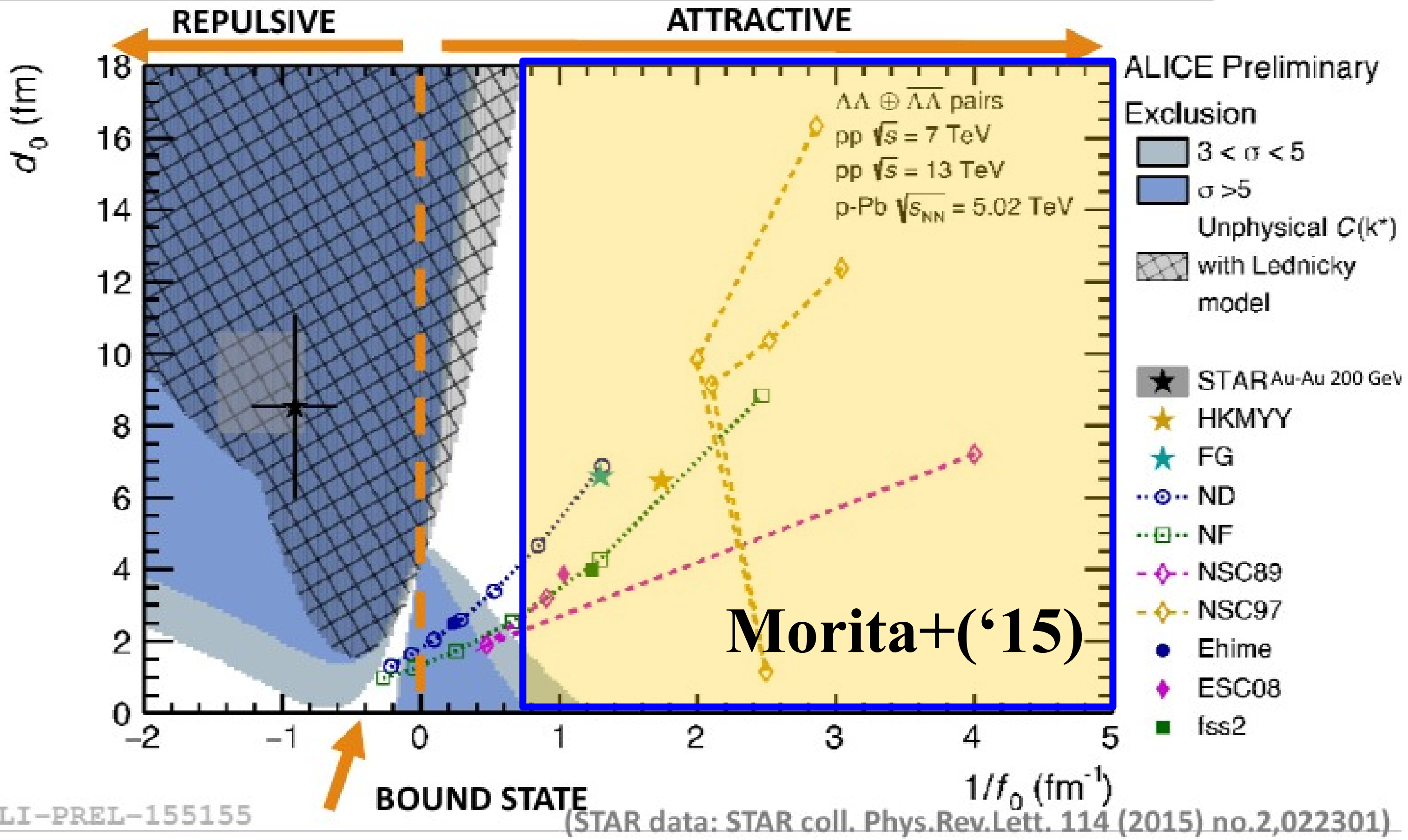
AO, Morita, Mihayara, Hyodo ('16)

New Data from LHC-ALICE

V. Mantovani-Sarti (ALICE Collab.), MESONS 2018

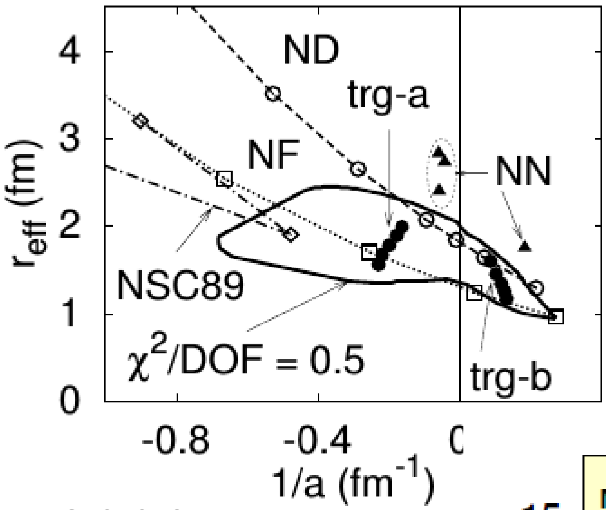
Λ–Λ Correlations: Combined Exclusion Plot

- Combination of all available datasets: **pp 7 TeV, pp 13 TeV, p-Pb 5.02 TeV**
- Test of the **agreement between data and the prediction by the Lednicky model by nσ**
- Small source size, large d_0 and negative f_0 limit the prediction power of Lednicky



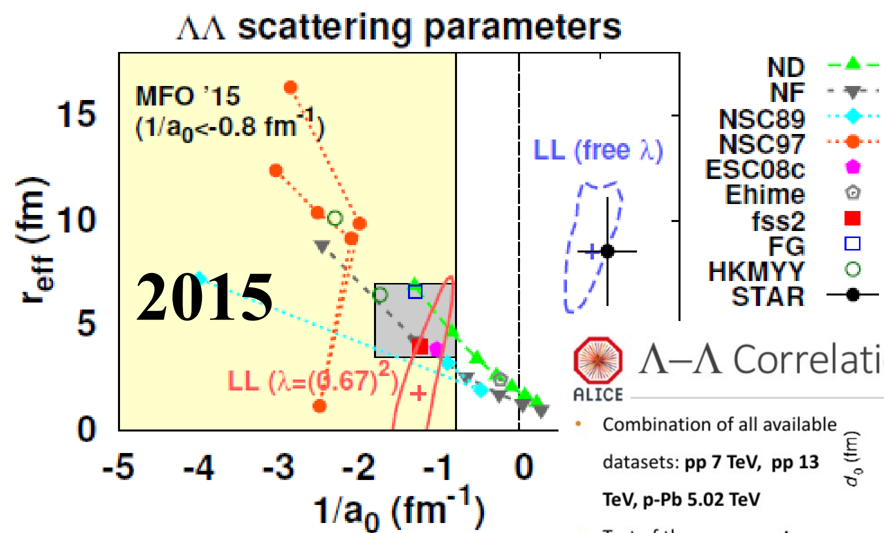
(STAR data: STAR coll. Phys.Rev.Lett. 114 (2015) no.2,022301)

Time dependence of ΛΛ interaction



2000

Nagara (2001)



2015

2018