

Study of neutron pairing in the (core+4n) ^{18}C and ^{20}O nuclei

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Knockout of deeply-bound nucleons to promote neutron pairs to the continuum (GSI/R3B)

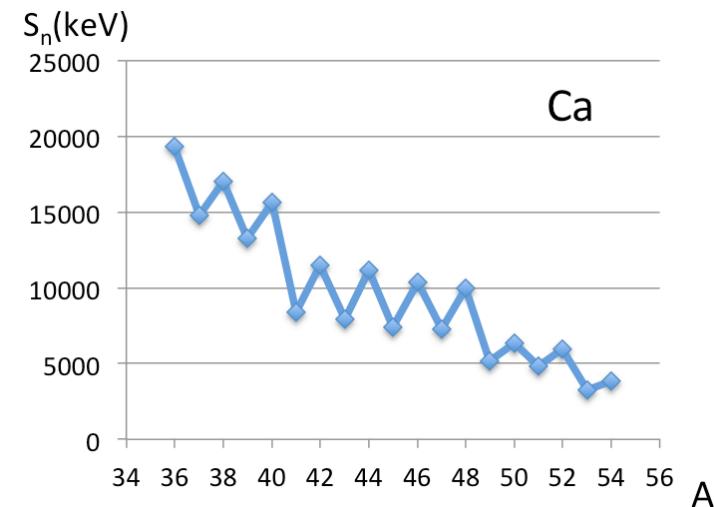
Derive n-n correlations from their decay pattern (LAND)

Determine the role of the reaction mechanism (neutron or proton knockout)

Signs of superfluidity, evolution towards the drip line

Pairing correlations play essential role in atomic nuclei and in neutron stars (NS)

- oscillations in S_n values
- g.s. spin 0^+ of even-even nuclei
- Moment of inertia \ll rigid value
- Enhanced pair transfer
- cooling of NS, glitches



Pairing scheme towards drip-line, from BCS to BEC ? (e.g. Hagino et al. PRL99 (2007))

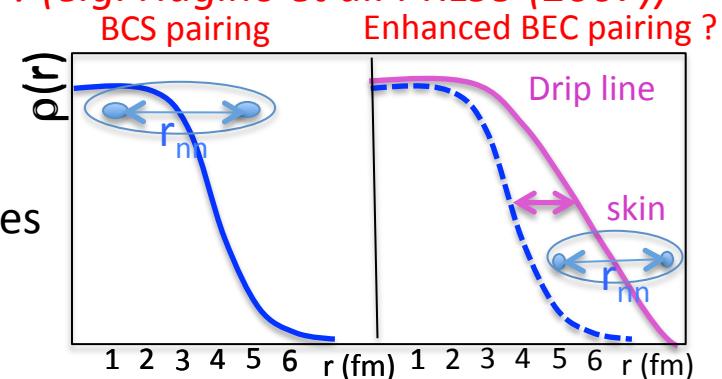
-> Study n-n correlations in various systems:

(core+xn, haloes, drip line nuclei...)

-> Decay mode & spectroscopy of intermediate states

-> Correlation function of the pairs

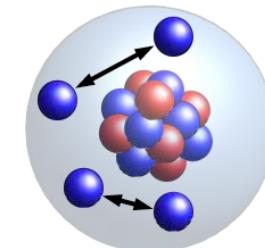
-> Average distance r_{nn} between neutrons



Possible existence of a narrow $4n$ resonance (e.g. Marquès, Shimura)

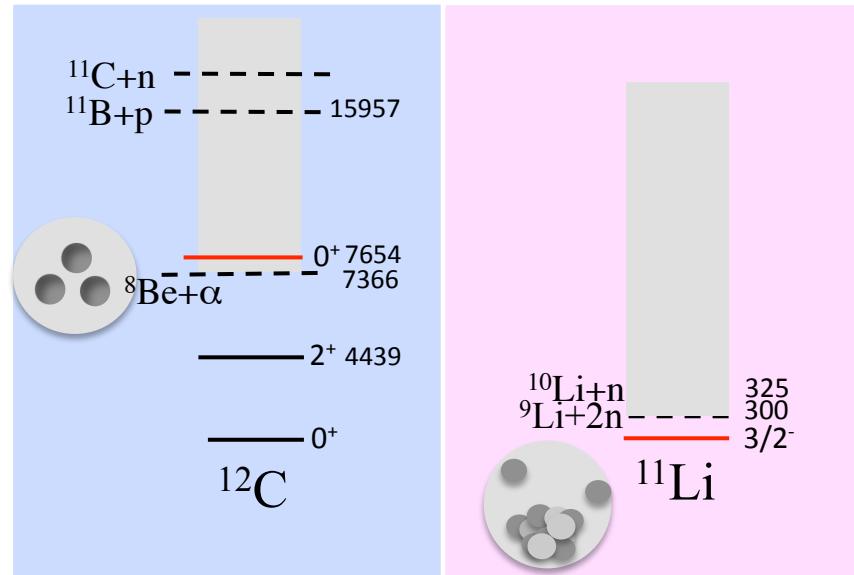
-> Role of tetra neutron correlations on nuclear superfluidity ?

-> Not yet revealed or studied in atomic nuclei



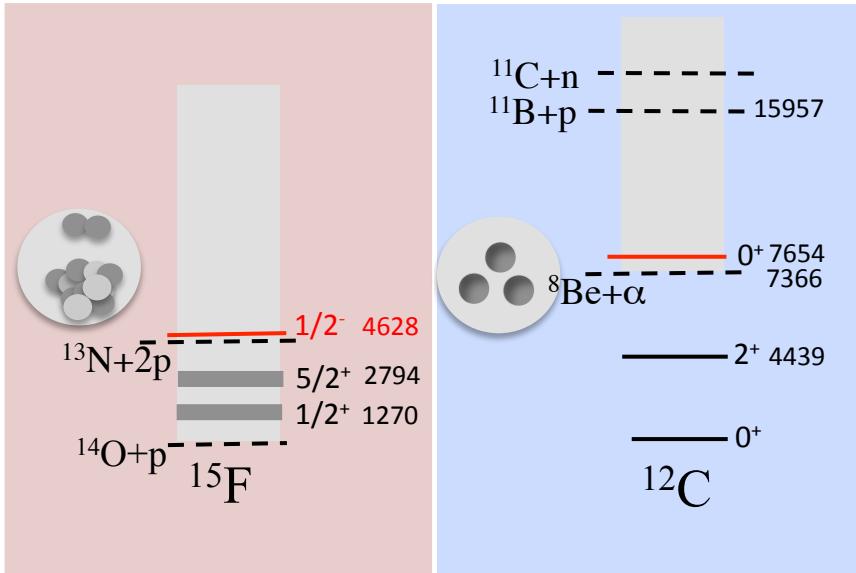
Ikeda's conjecture applied to di-neutron configurations

$\alpha, 2p, 2n$ clustering (*adapted from J. Okolowicz, et al. Prog. Th. Phys. Supp. 196 (2012)*)



Presence of narrow cluster states at the corresponding emission thresholds

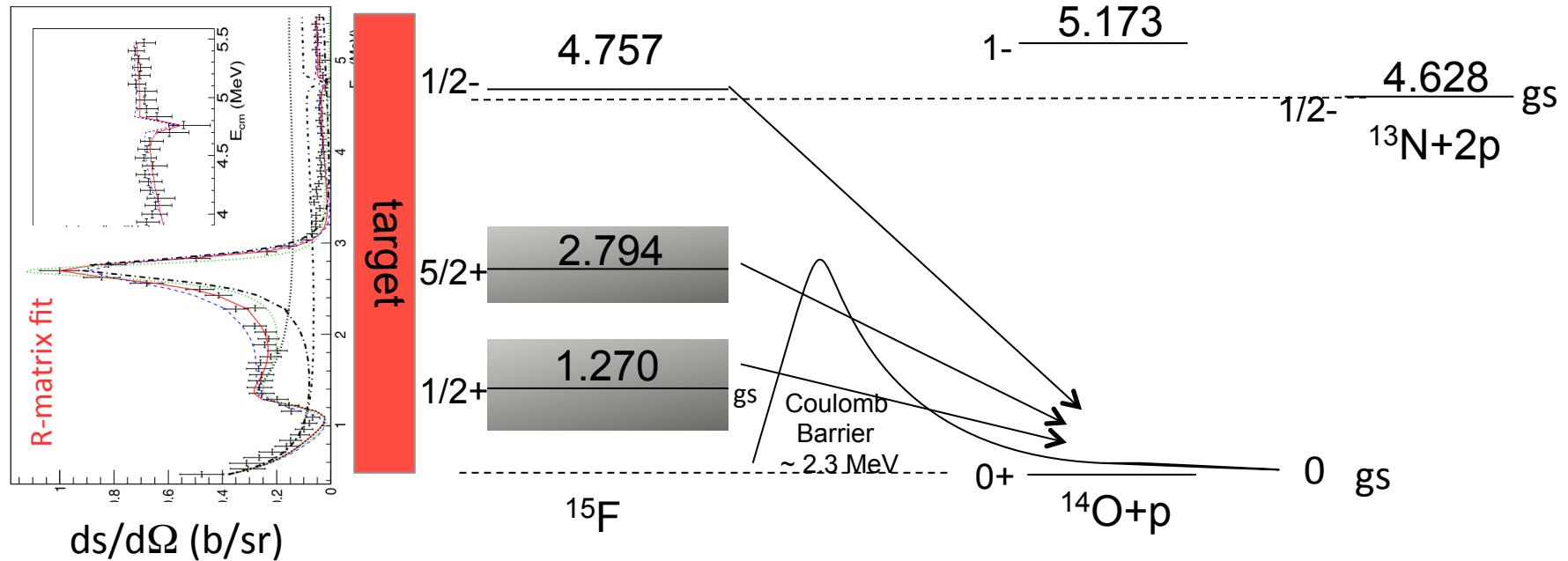
Narrow resonance in ^{15}F above $S_{2\text{p}}$ threshold



- Narrow $1/2^-$ resonance
- 2p structure energetically unfavorable

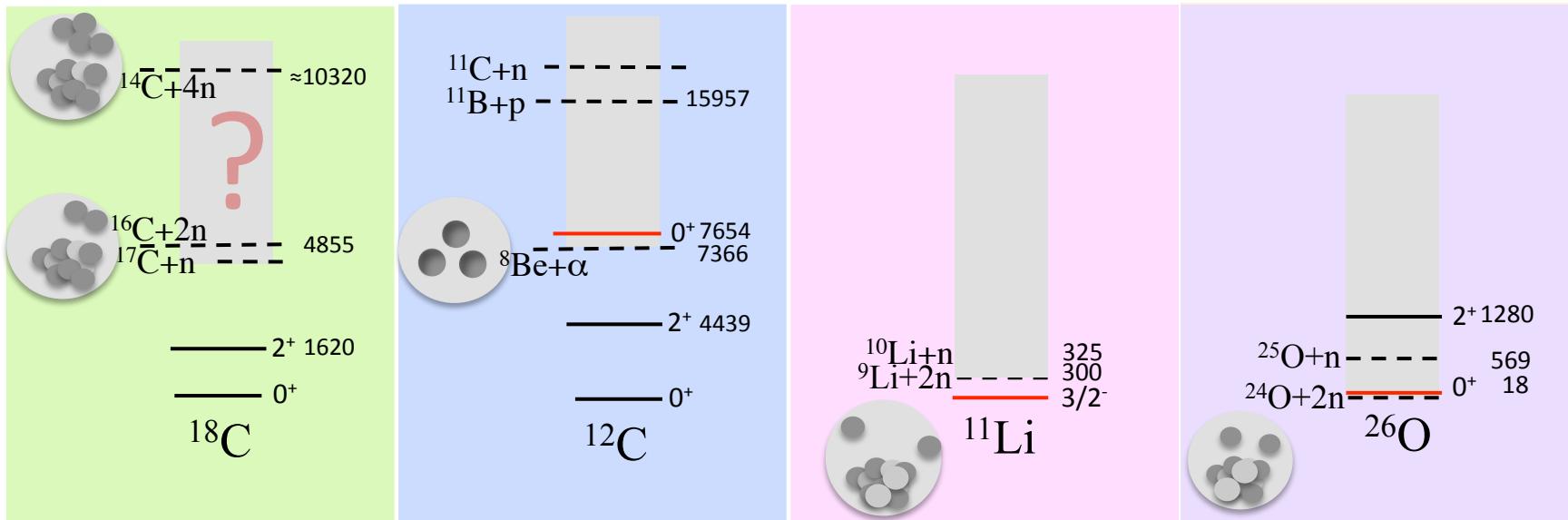
$^{14}\text{O}(\text{p},\text{p})^{14}\text{O}$ @ SPIRAL1

F. De Grancey, I. Stefan, F de Oliveira et al. PLB (2016)

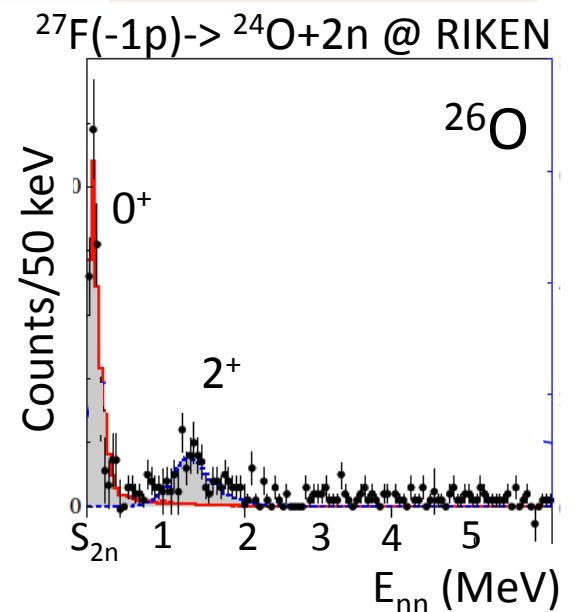


Ikeda's conjecture applied to di-neutron configurations

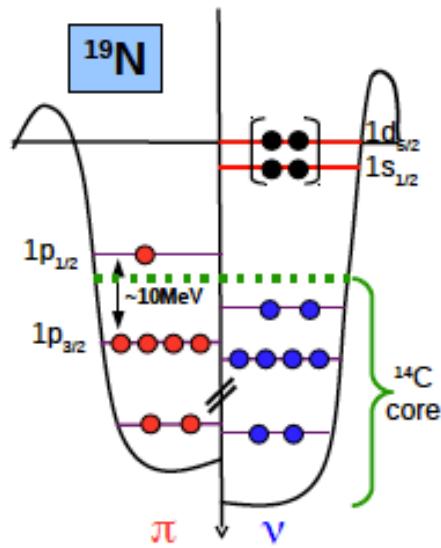
$\alpha, 2p, 2n$ clustering (*adapted from J. Okolowicz, et al. Prog. Th. Phys. Supp. 196 (2012)*)



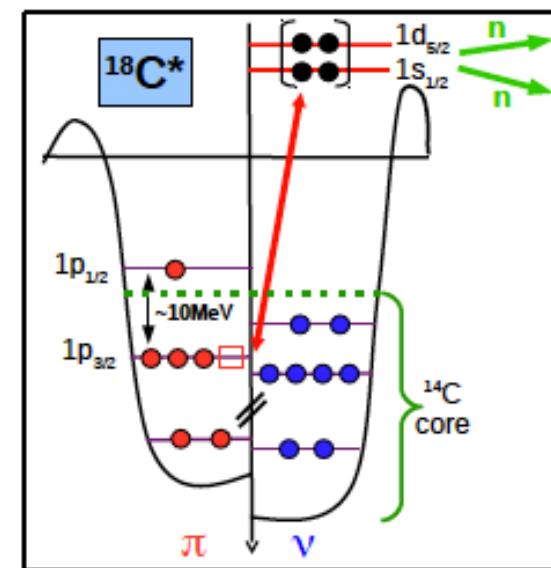
Any narrow resonance close to the 2n threshold in ^{18}C ?



Experimental method to study nn correlations in ^{18}C ($^{14}\text{C}+4\text{n}$)

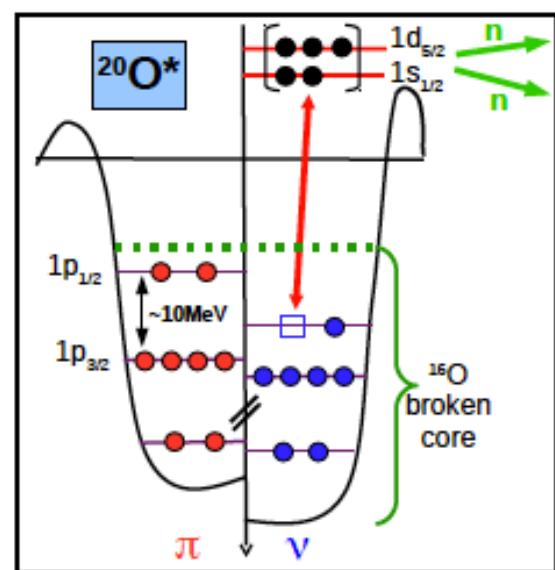
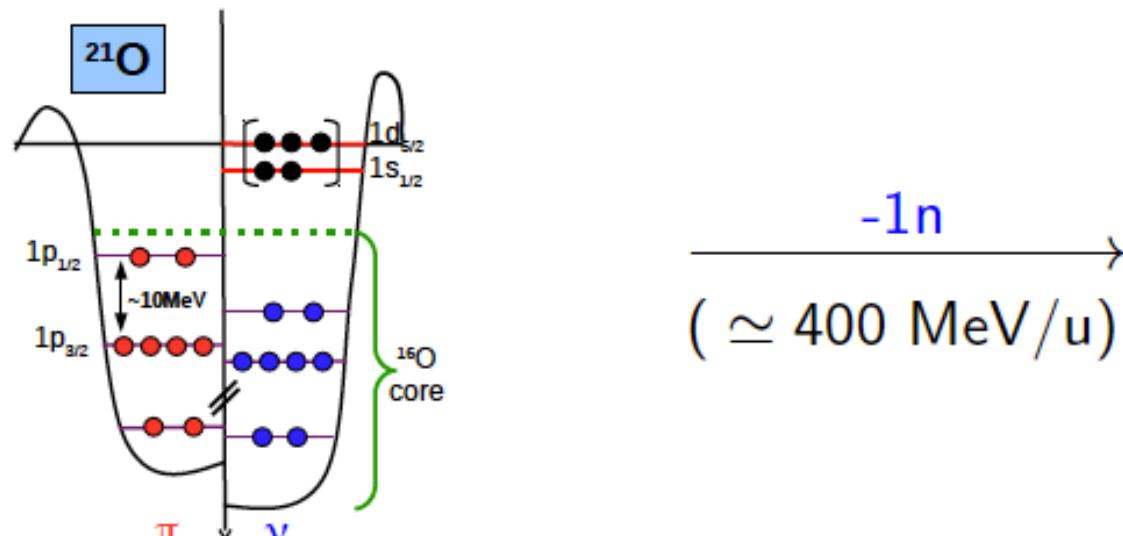


$-1p$
 $(\simeq 400 \text{ MeV/u})$



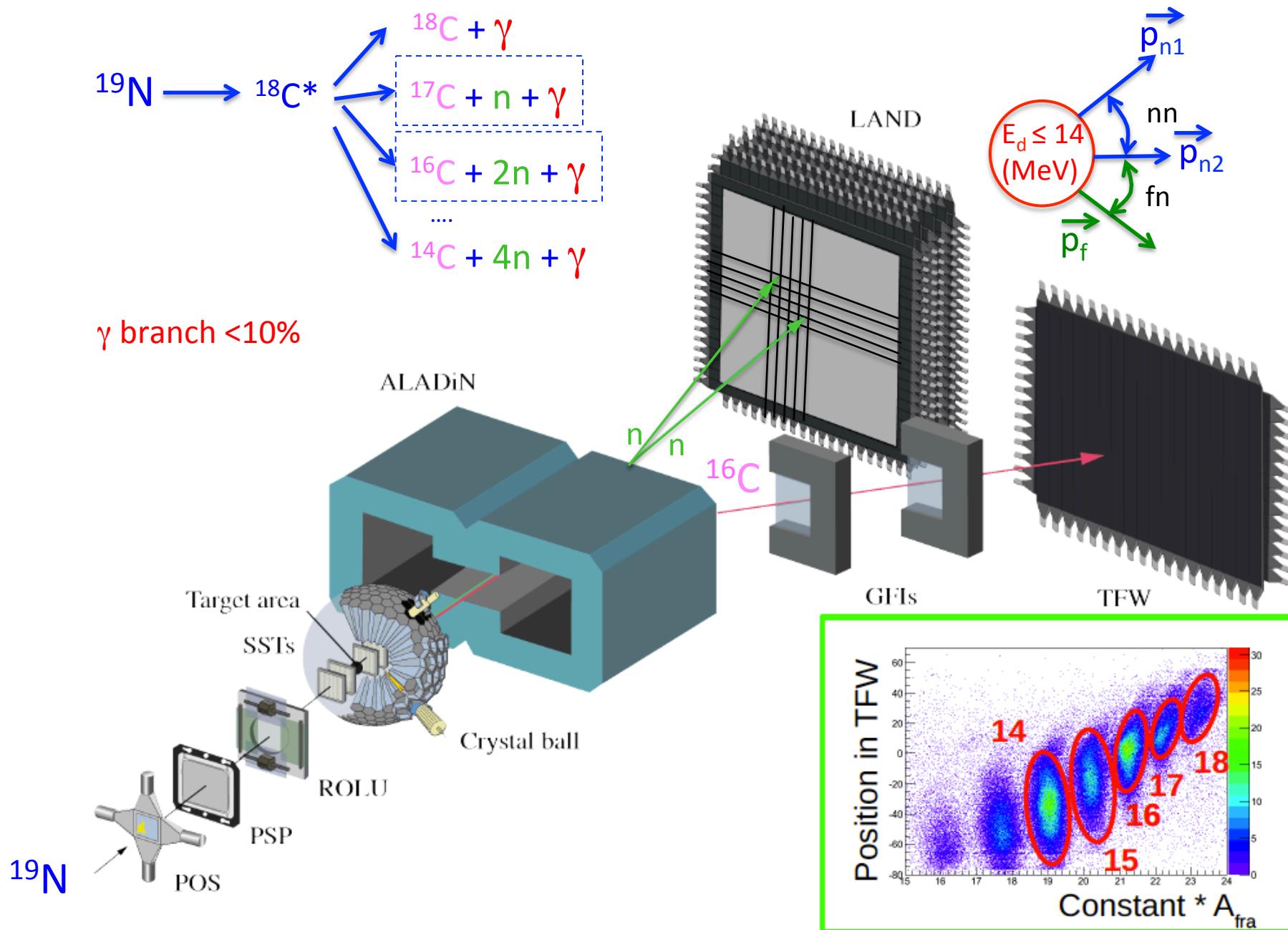
- High energy **proton** knock-out ($p, 2p$)
→ Quasi-free reaction at GSI
- Deeply bound **proton**
→ Promote neutrons into the continuum
- Neutron correlations unaffected by **proton** knock-out
- Deduce correlations from subsequent decay patterns

Experimental method to study nn correlations in ^{20}O ($^{16}\text{O}+4\text{n}$)



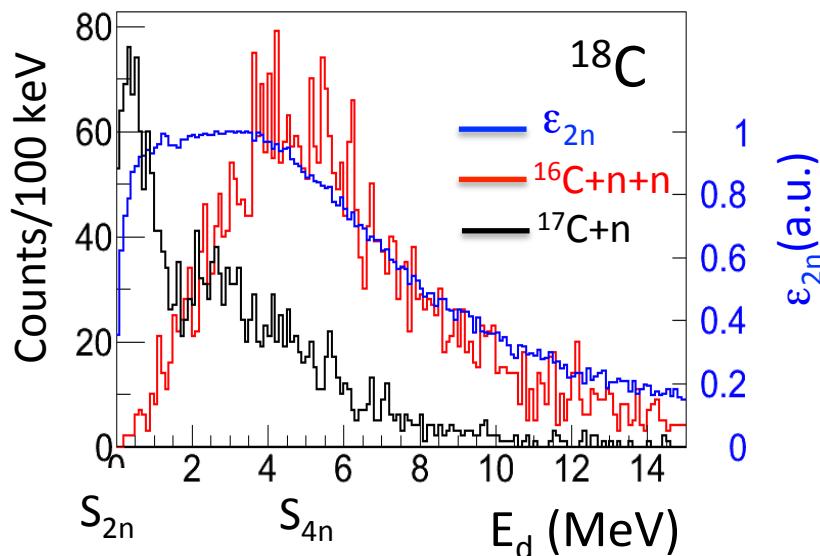
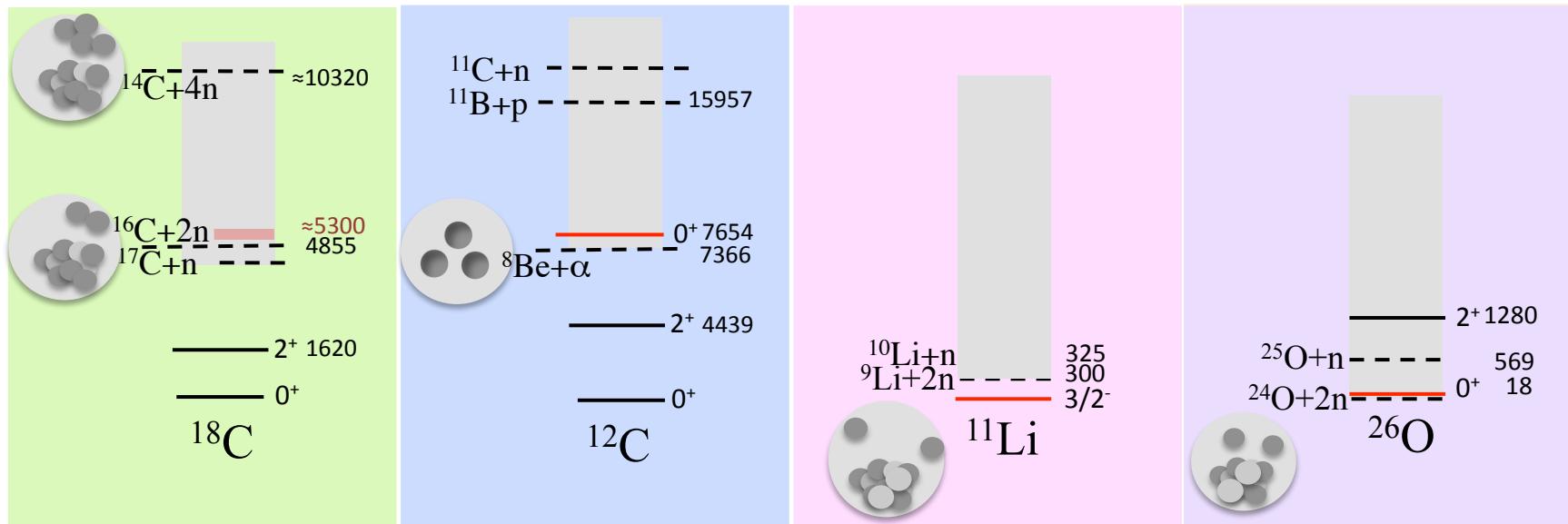
- High energy **neutron** knock-out (p, pn)
→ Quasi-free reaction
- Deeply bound **neutron**
→ Promote neutrons into the continuum
- Neutron correlations likely affected by **neutron** knock-out
- Qualitative/quantitative differences between ^{20}O and ^{18}C isotones?

Fully inclusive study of fragment-n-n correlations at R³B / GSI

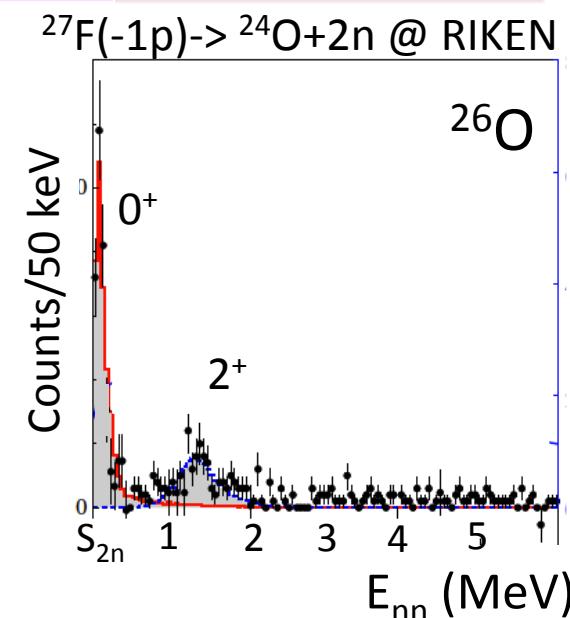


ikeda's conjecture applied to di-neutron configurations

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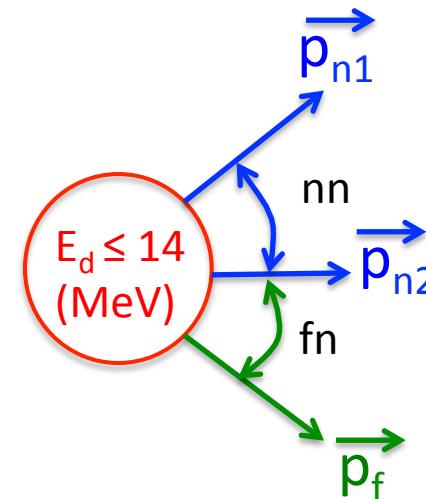
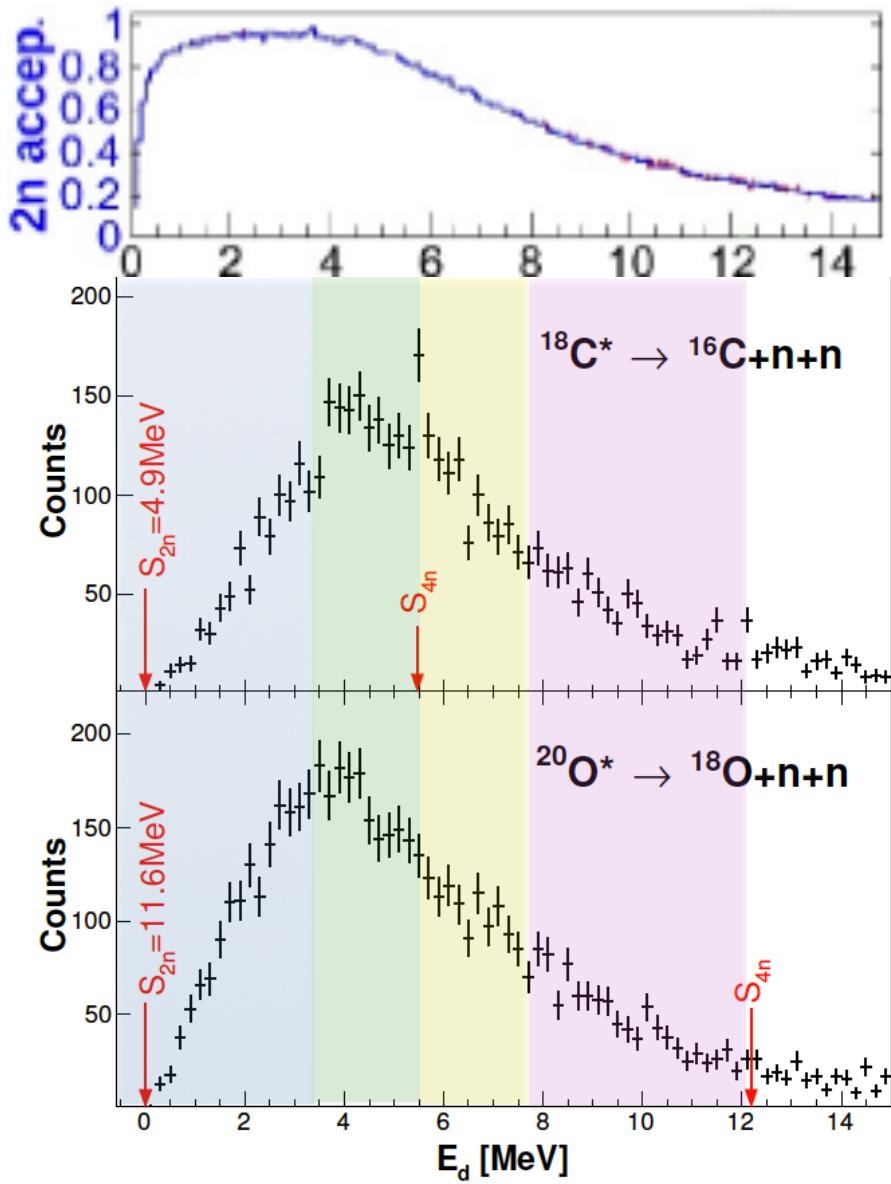


A. Revel, to be published



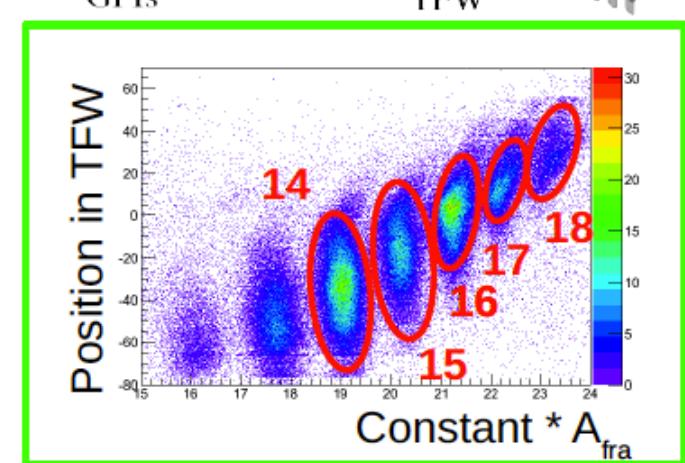
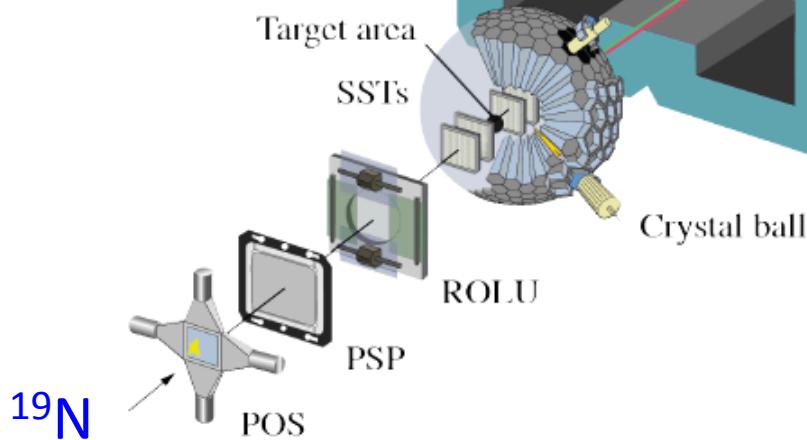
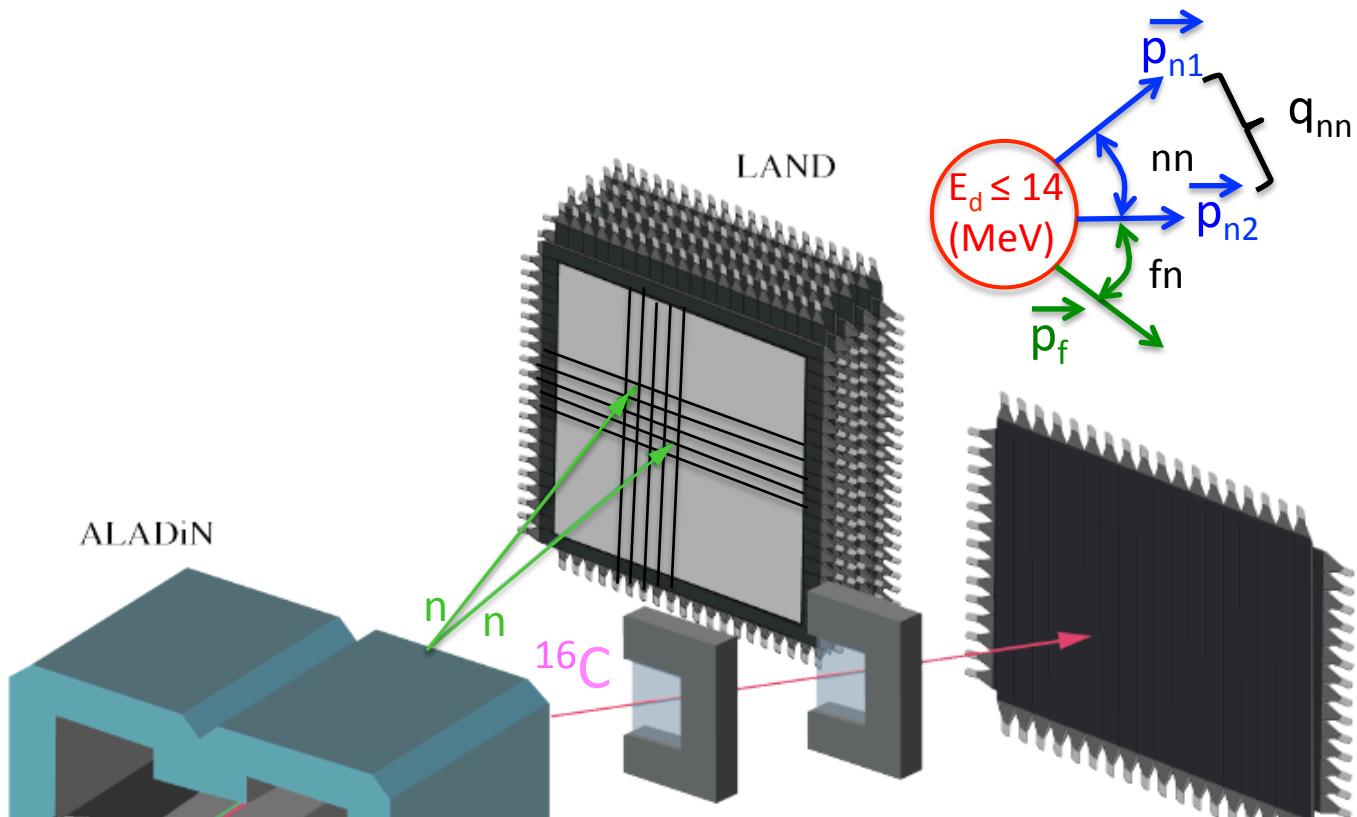
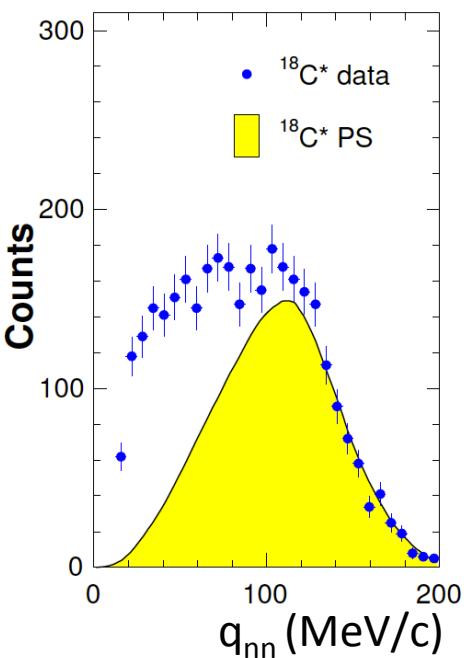
Y. Kondo et al. PRL 116 (2016)

Decay energy in the 2n decays in ^{18}C and ^{20}O

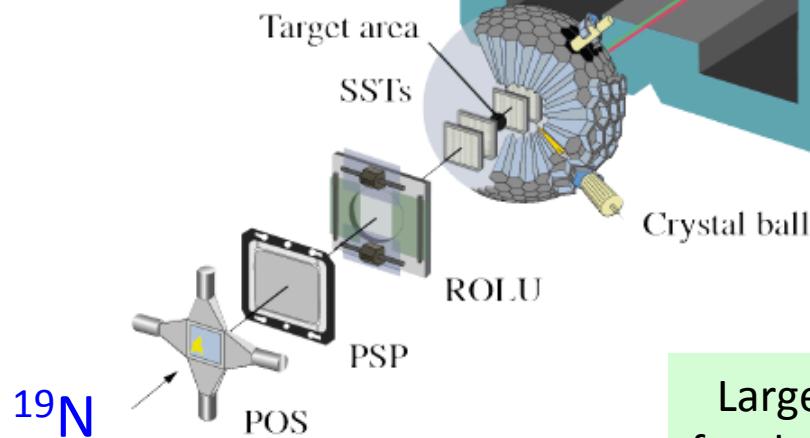
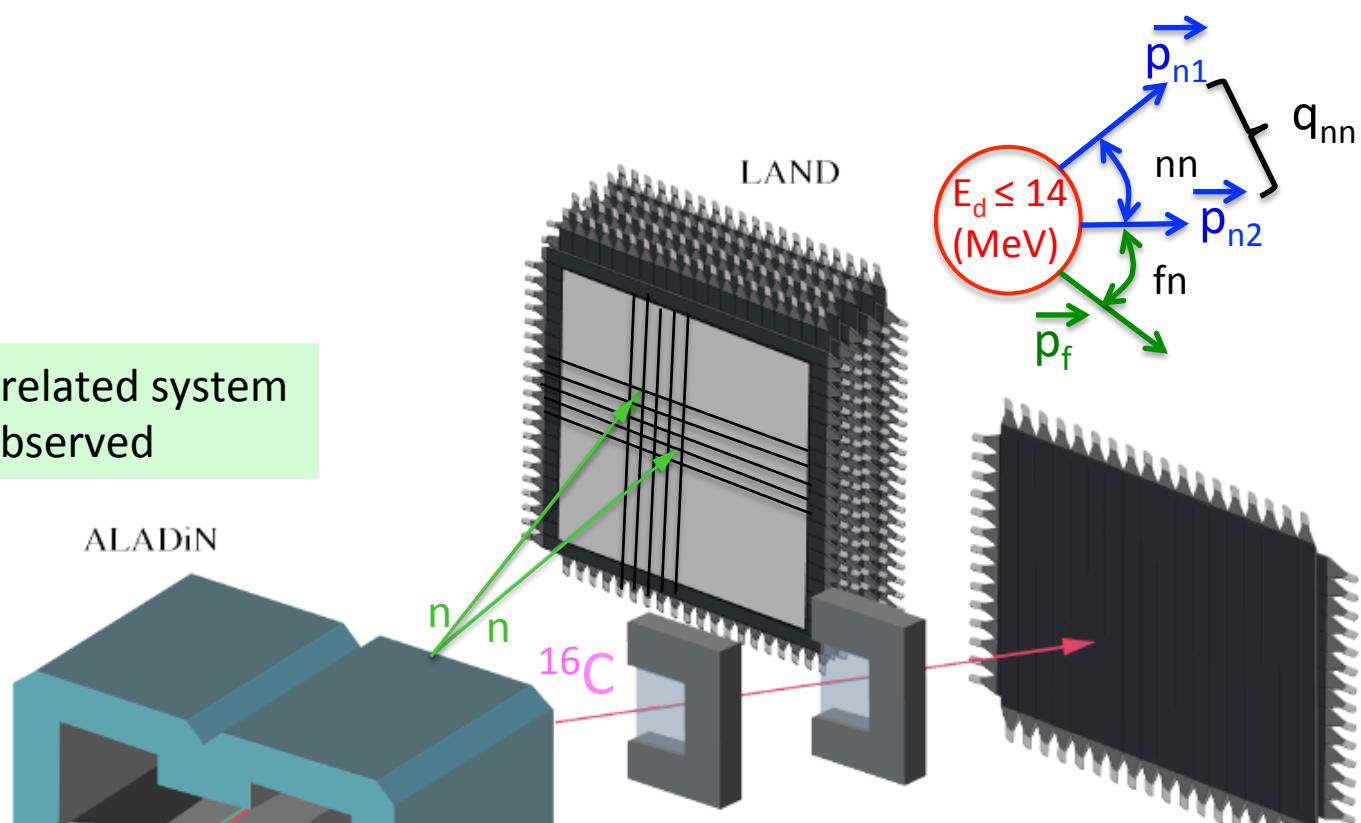
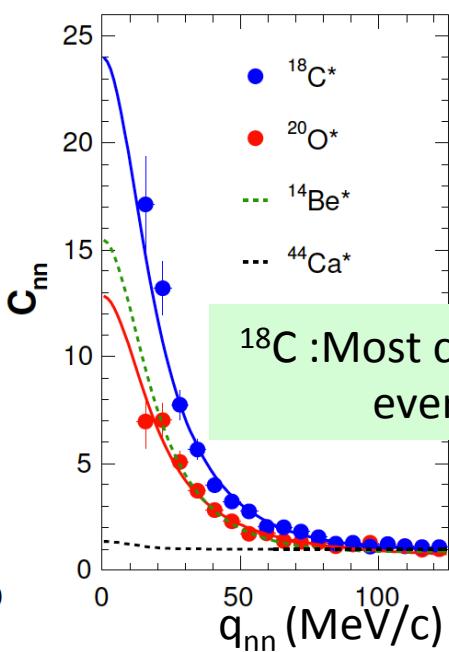


- ❖ Evolution of correlations with $E_d \leq 14 \text{ MeV}$
(Same range of E_d for ^{18}C & ^{20}O)
- ❖ Relatively large efficiency of LAND
- ❖ Role of the reaction mechanism?

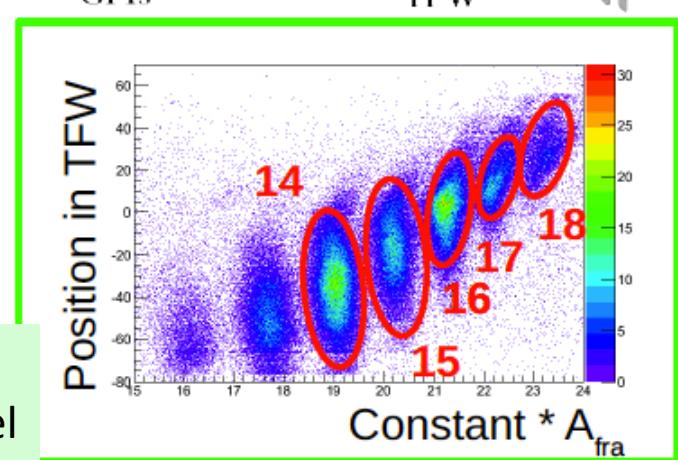
n-n correlation function in ^{18}C



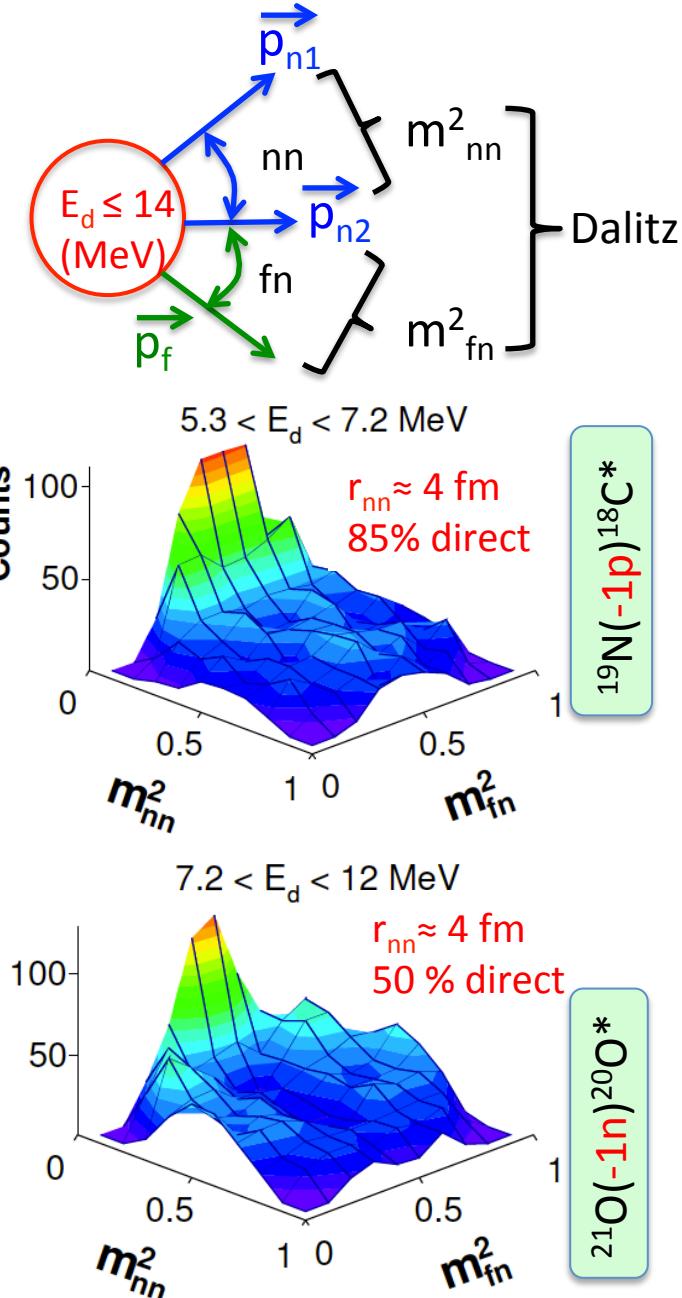
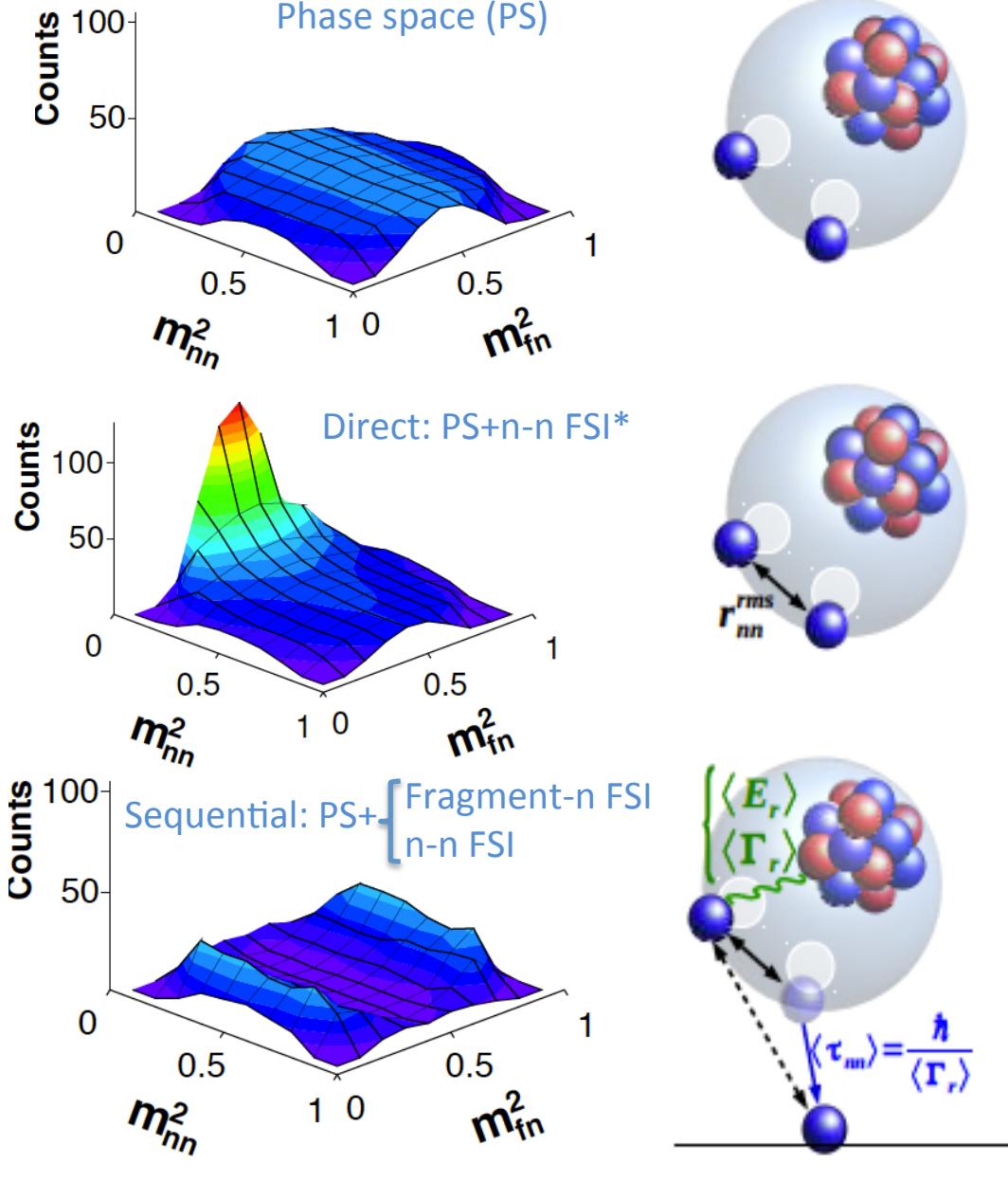
n-n correlation function in ^{18}C and ^{20}O

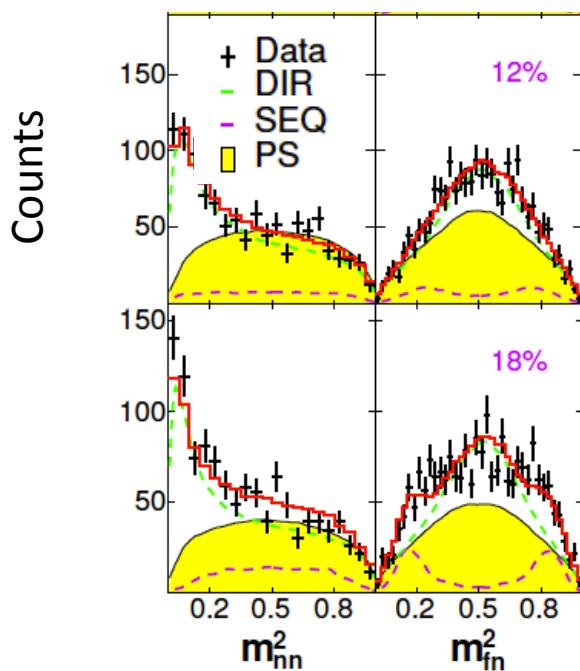
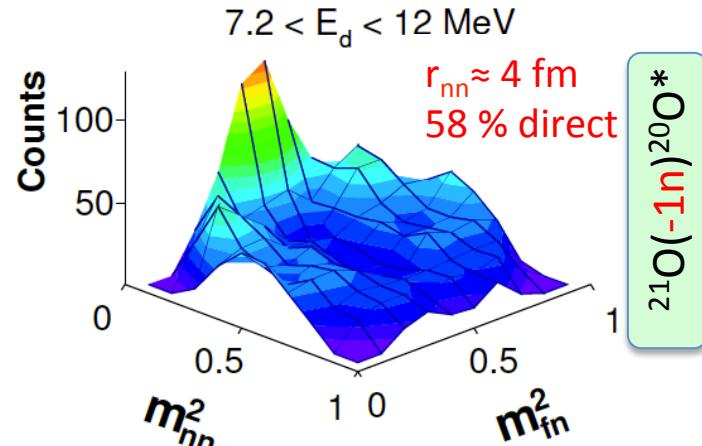
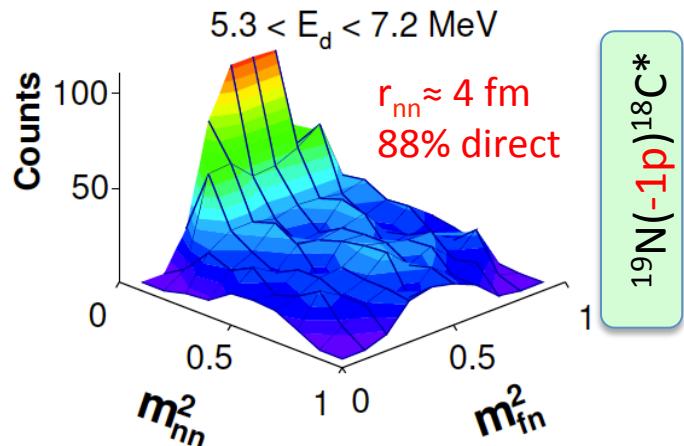


Largest cross section
for the $^{14}\text{C} + 4n$ channel



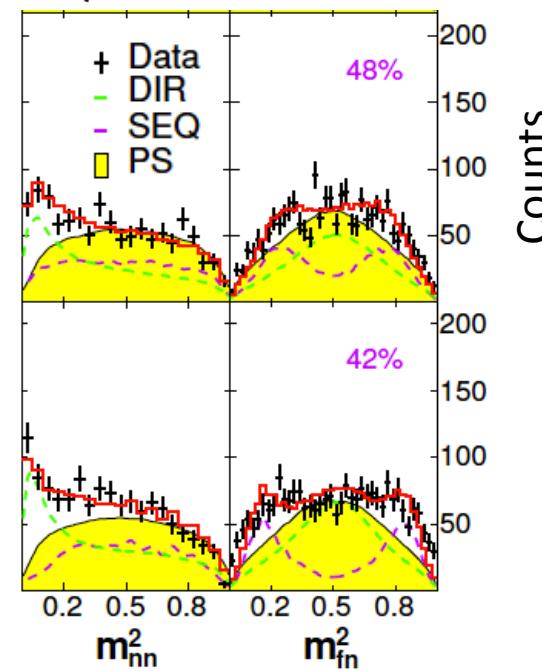
Dalitz plots and n-n correlations in ^{18}C and ^{20}O (core + 4n systems)





5.3 < E_d < 7.2 MeV

7.2 < E_d < 12 MeV

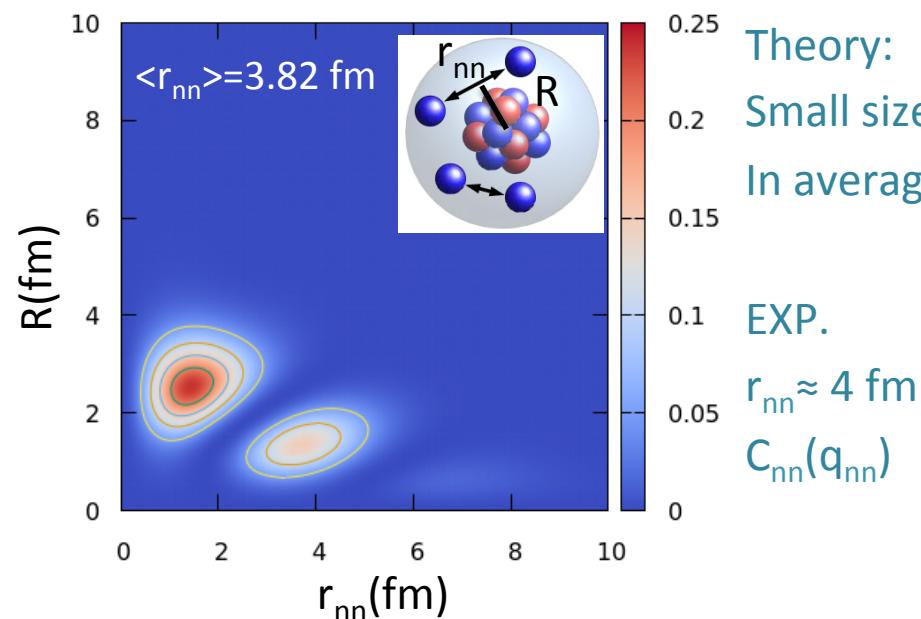
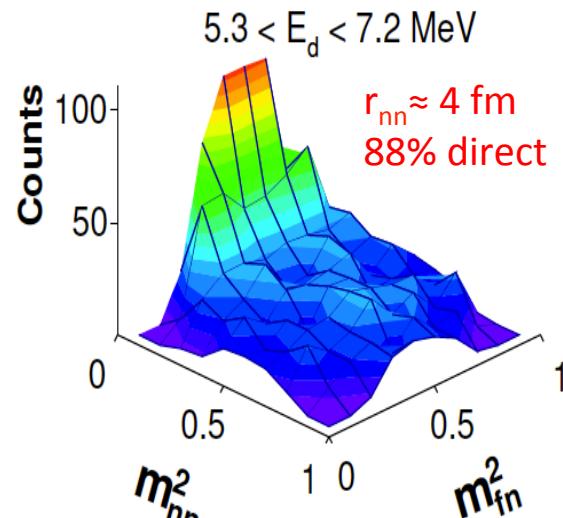
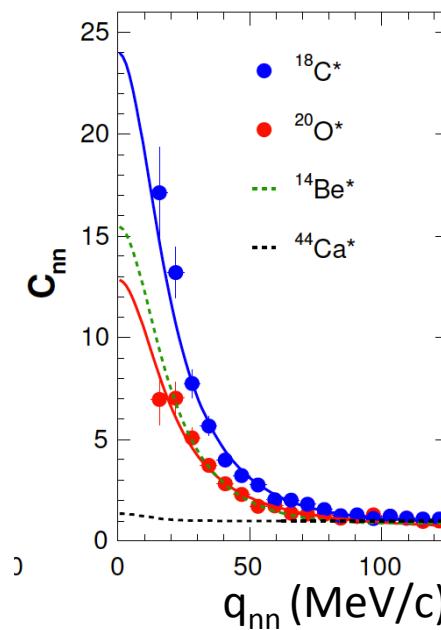


Counts

- Direct decay dominating for $^{18}\text{C}^*$
- More sequential decay in the decay of $^{20}\text{O}^*$
- Neutron source of the size of a $A=18,20$ liquid drop

Conclusions

Perpectives



Theory:

Small size of the pair at the surface, extended otherwise

In average $r_{nn} = 3.82 \text{ fm}$

EXP.

$r_{nn} \approx 4 \text{ fm}$
 $C_{nn}(q_{nn})$



THEORY

$r_{nn} = 3.82 \text{ fm}$
coherence length of a pair

$^{18}\text{C}^*$ strongest correlated system
-> due to (core+4n) configuration ?

Difference between $^{20}\text{O}^*$ and $^{18}\text{C}^*$
-> Influence of reaction mechanism ?

Study 4n correlations with NeuLAND

Evolution of r_{nn} , C_{nn} , m_{nn}^2 at drip line ?

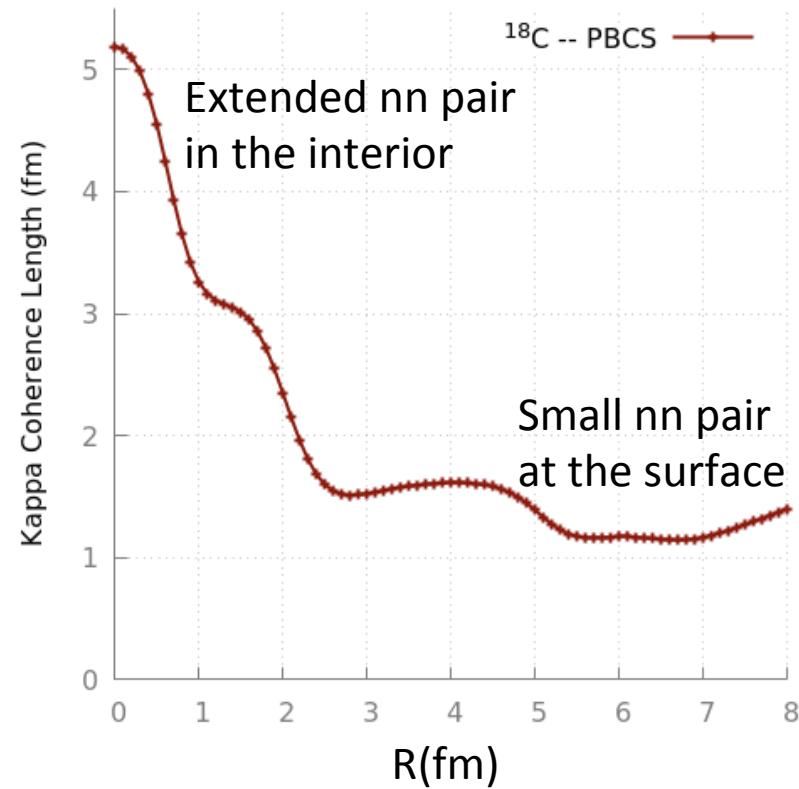
List of collaborators

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(R³B collaboration)



BAKUP SLIDES



Invariant-mass method

$$M_{inv}^2 \cdot c^2 = \left(\sum_i P_i \right)^2 \quad (1)$$

$$M_{inv} = \sqrt{\sum_i m_i^2 + \sum_{i \neq j} E_i E_j - \sum_{i \neq j} \vec{p}_i \cdot \vec{p}_j} \quad (2)$$

$$E_{rel} = \left(\sqrt{\sum_i m_i^2 + \sum_{i \neq j} E_i E_j - \sum_{i \neq j} \vec{p}_i \cdot \vec{p}_j} - \sum_i m_i \right) \cdot c^2 \quad (3)$$

- Need to detect all the products of the reaction