Summary Talk

Takashi Nakamura
Tokyo Institute of Technology

The 11th International Conference on Direct Reactions with Exotic Beams (DREB2022)
@ Santiago de Compostela, Spain, 26 June-1 July, 2022

Remarks

- ✓ I would like to congratulate all the speakers and poster presenters in DREB2022
- ✓ Please allow me to select some of the talks among all the great talks in all the sessions in DREB2022
- ✓ This selection is biased, and somewhat affected by my preferences
- ✓ I tend to pick up more experimental talks
- ✓ I also tend not to pick up the very preliminary results
- ✓ I may not be politically correct
- ✓ Note: My nickname is “Bogen” (I tend to say something which is uncomfortable to you, unknowingly)

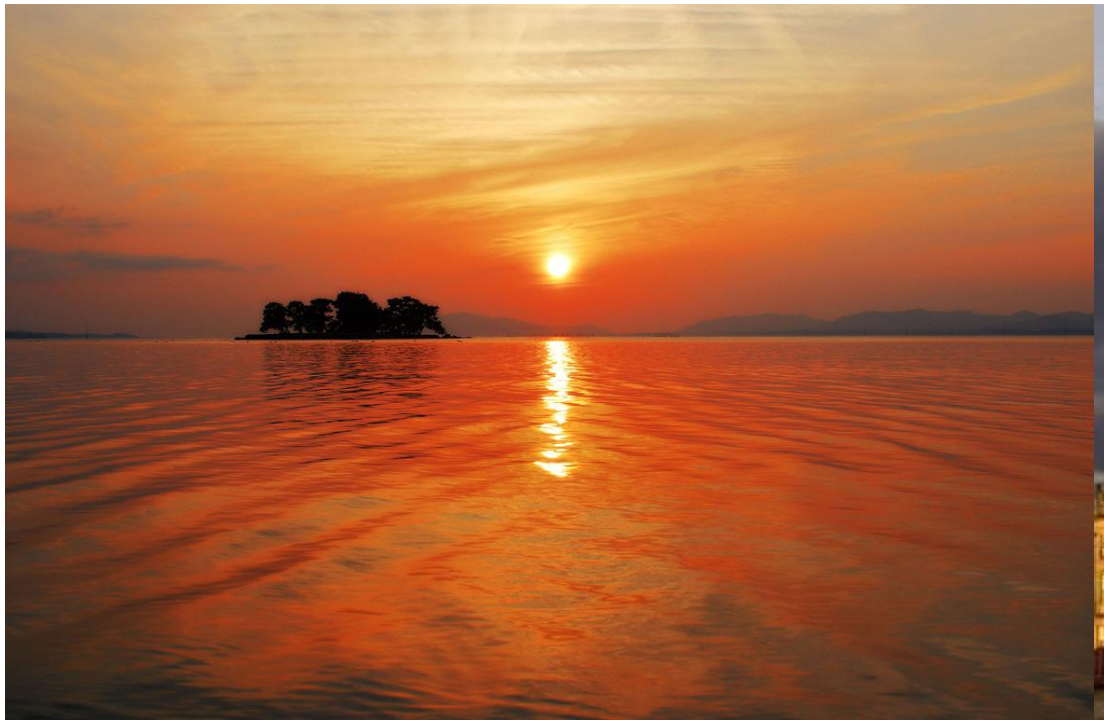
From Matsue to Santiago de Compostela

DREB2018: June, 2018, Matsue, Japan

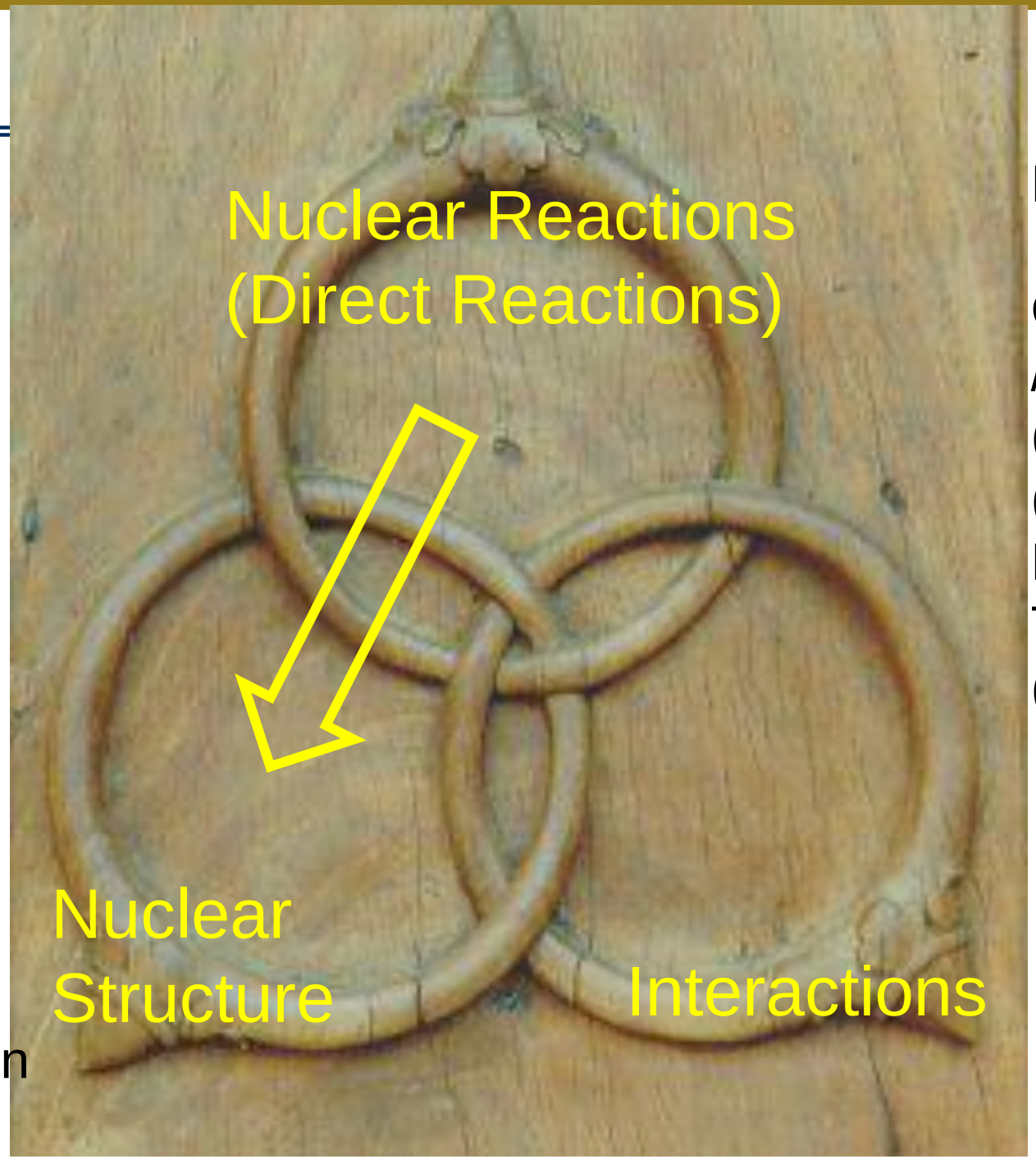
Felomena-san,
Please correct it!

→DREB2022: June-July, 2022, Santiago de Compostela

"Looking back, Looking forward"



Trinity

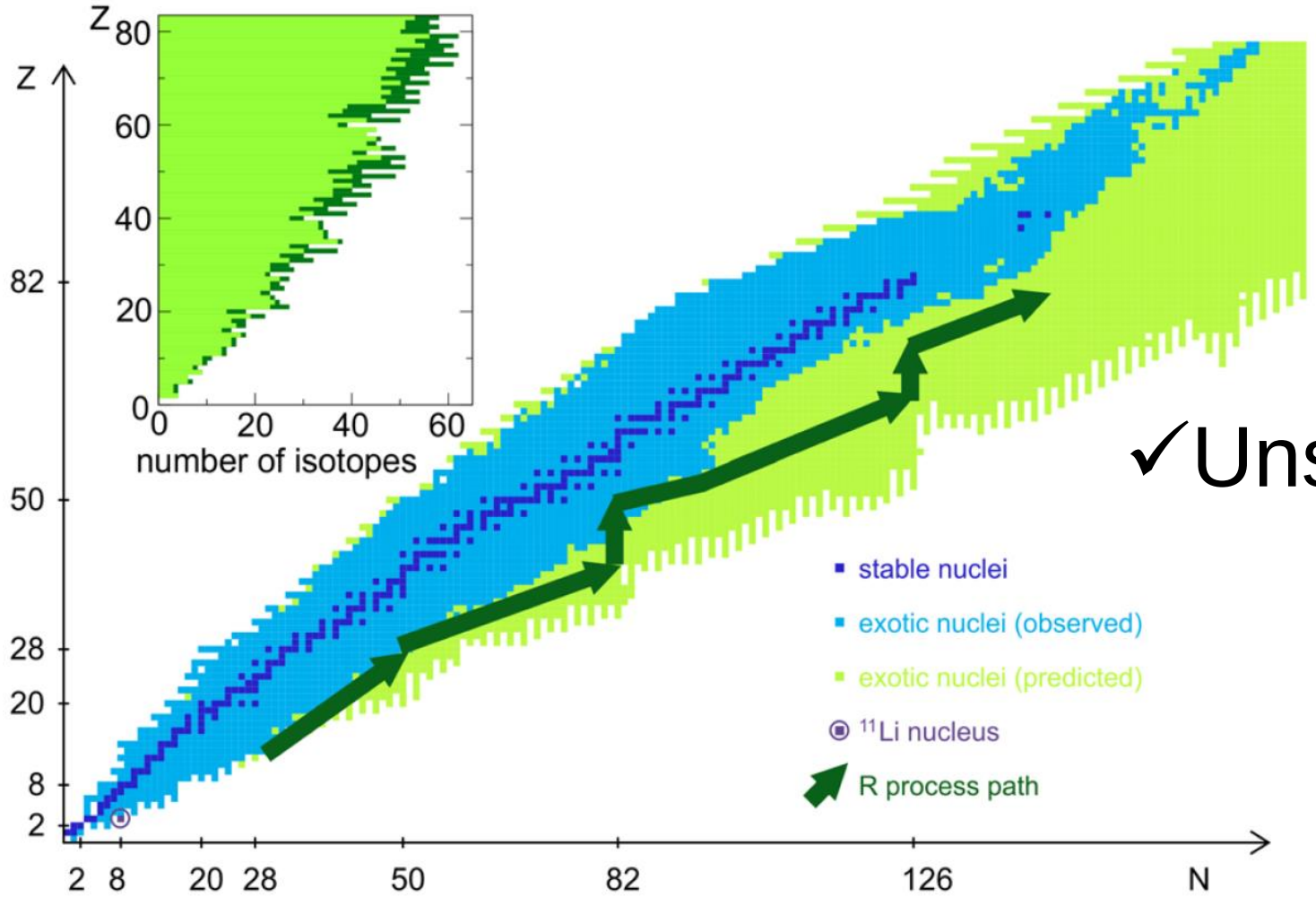


Shell Structure
(Shell Evolutions,
Magic numbers)
Cluster
Halo
Resonance
^{2}n,^{4}n,^{6}n…
Driplines
Continuum
Short Range Correlation

Elastic scattering
Inelastic scattering
Quasi free scattering
/Knockout reaction
(p,pa), (p,pp), (p,pn),
(p,3p),
Breakup Reactions
Transfer reactions
(d,p),(t,p),(p,t),(p,^{3}He)

QCD, Chiral EFT
NN, NNN, NNNN
Effective interactions
(Optical Potential)

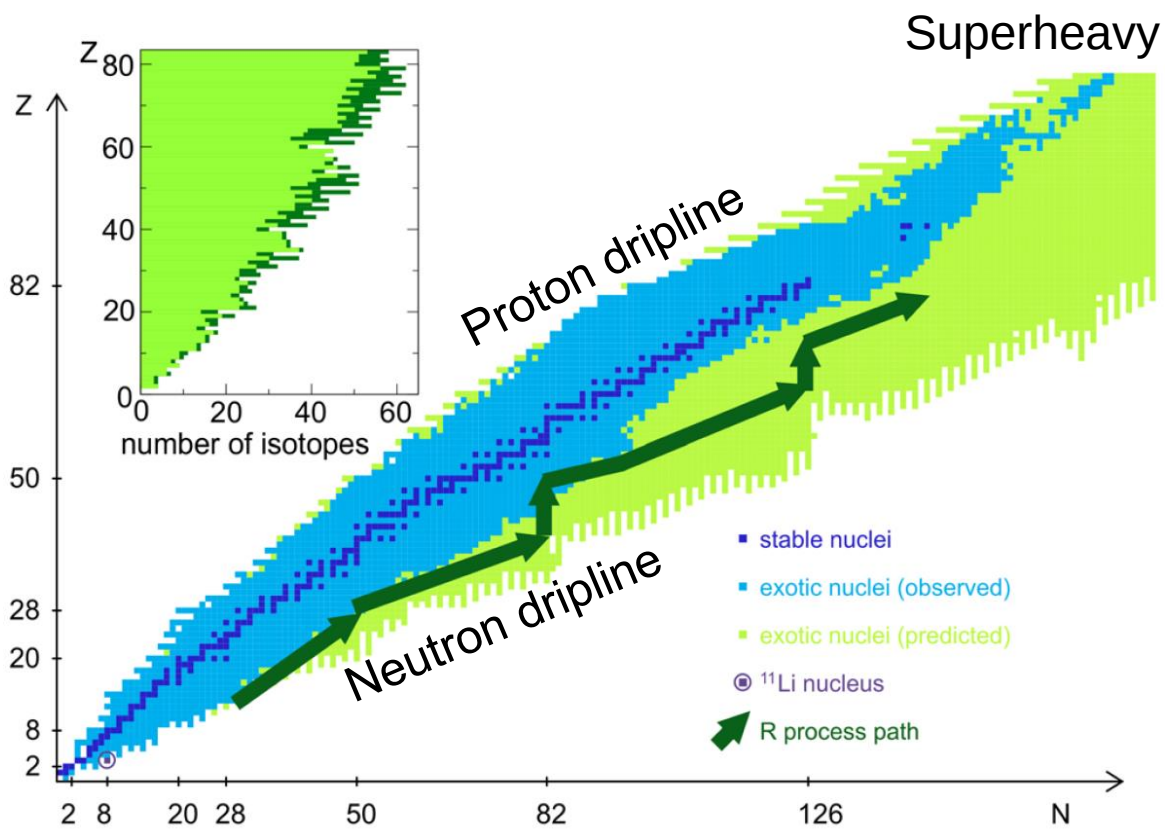
Exoticness



✓Unstable Nuclei (RI)

T.Otsuka et al., Rev. Mod. Phys. 92, 015002 (2020).

Exoticness → Edges



T.Otsuka et al., Rev. Mod. Phys. 92, 015002 (2020).

Exoticness

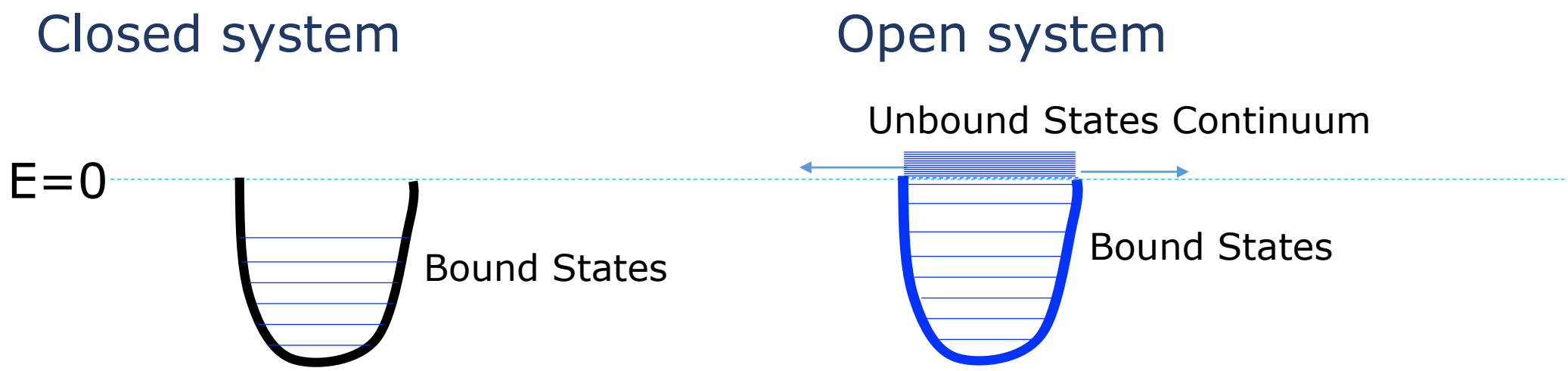
Ordinary	Exotic
Stable Nuclei	Unstable Nuclei
Valley of Stability	Driplines
Deeply bound nuclei	Weakly bound nuclei/Unbound nuclei
Nucleus made of nucleons	Nucleus made of quarks Nucleus made of alphas, dineutrons
Independent Particle Model	Short range correlations/ Correlations
Nuclei below ^{238}U	Superheavy
Magic numbers 2,8,20,28,50,82,126	Magic numbers 6,14,16,32,34,…

Edges/Boundaries

Edges: Closed or Open?

Otsuka, Mittig, Volya

Tokyo Tech



- Normal Nuclei: Bound and Isolated system→ Closed quantum system
- Exotic nuclei at driplines, Highly excited states → Open quantum system

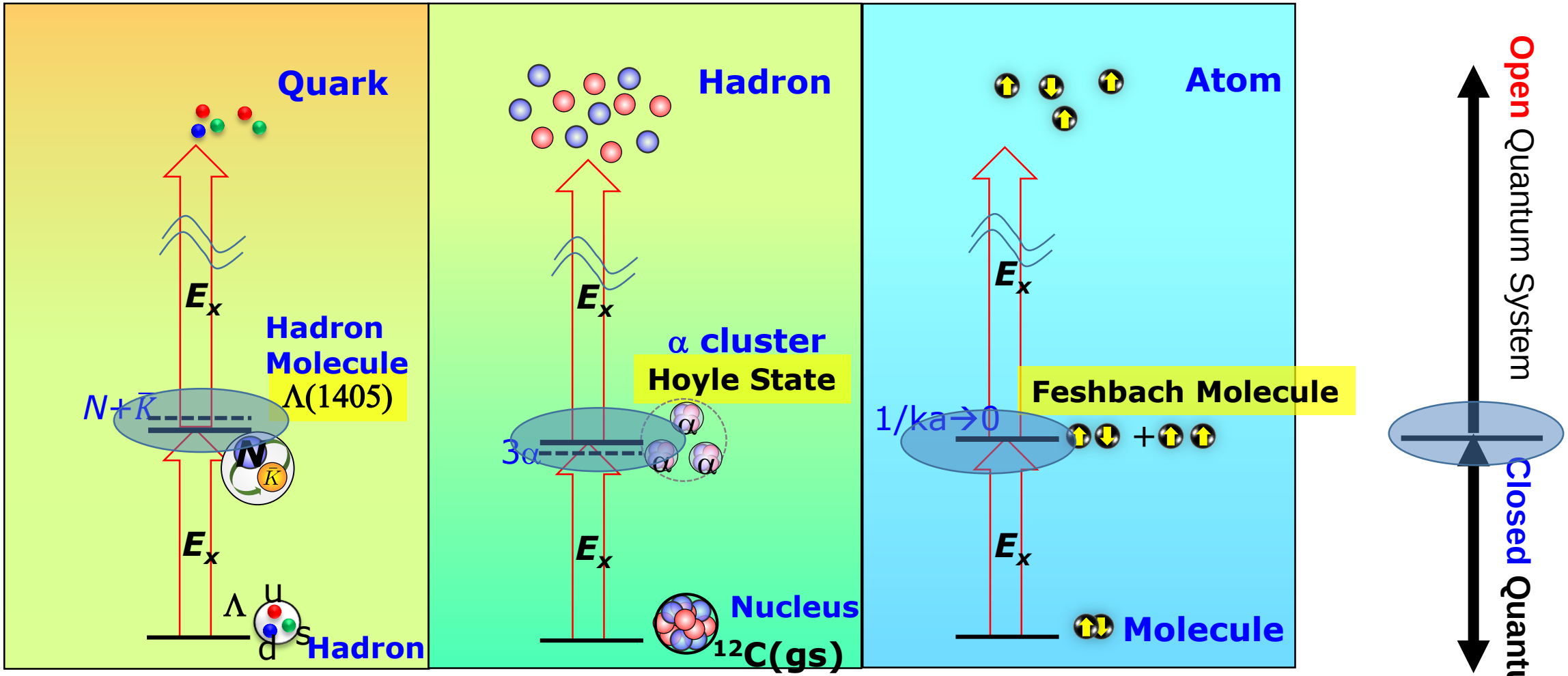
"Nuclear Reaction (open)"& "Exotic Nuclear Structure (closed-open)"

Boundary between "open" and "closed"

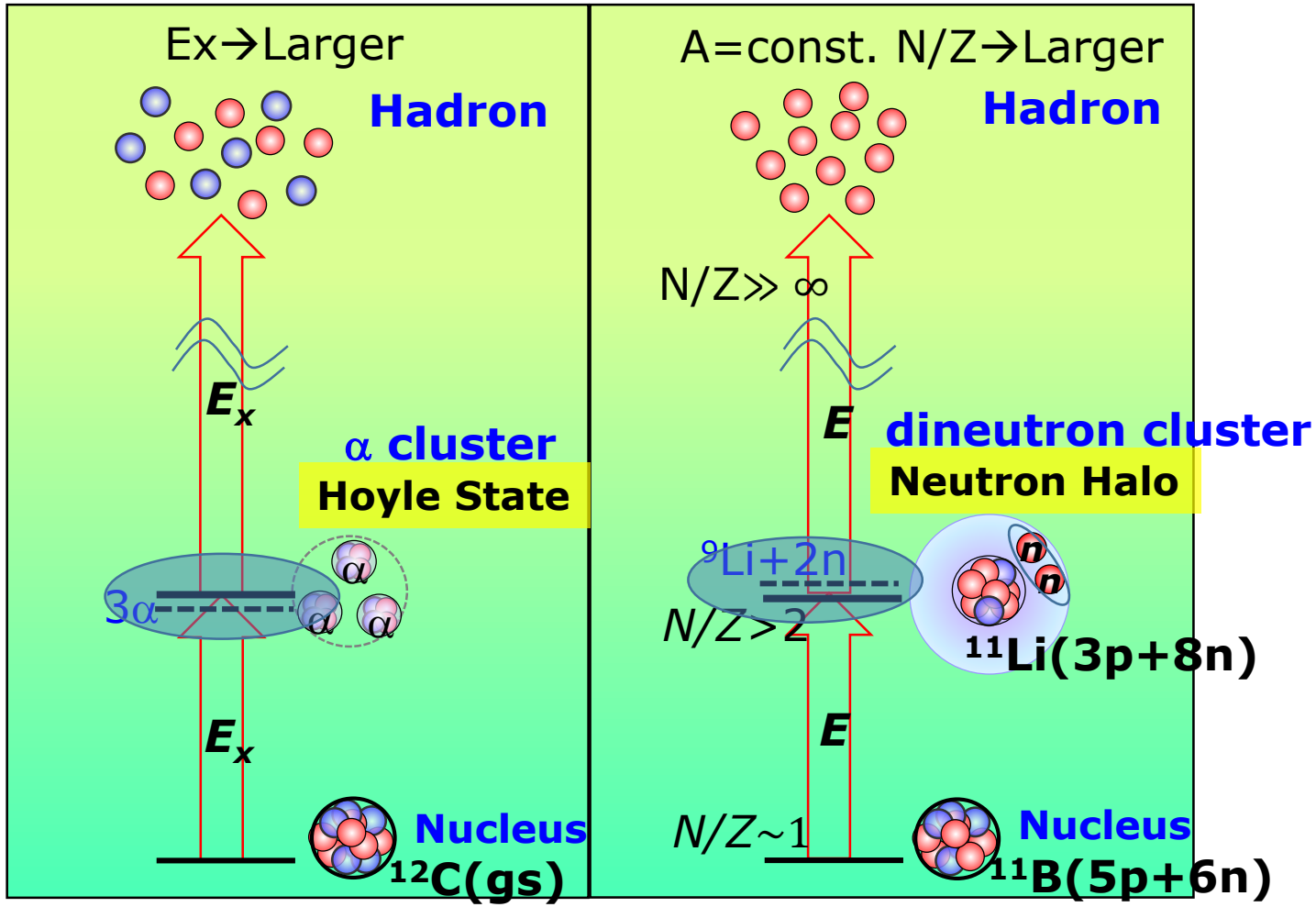
→ Novel phenomena and features in Nuclear Structures and Reactions

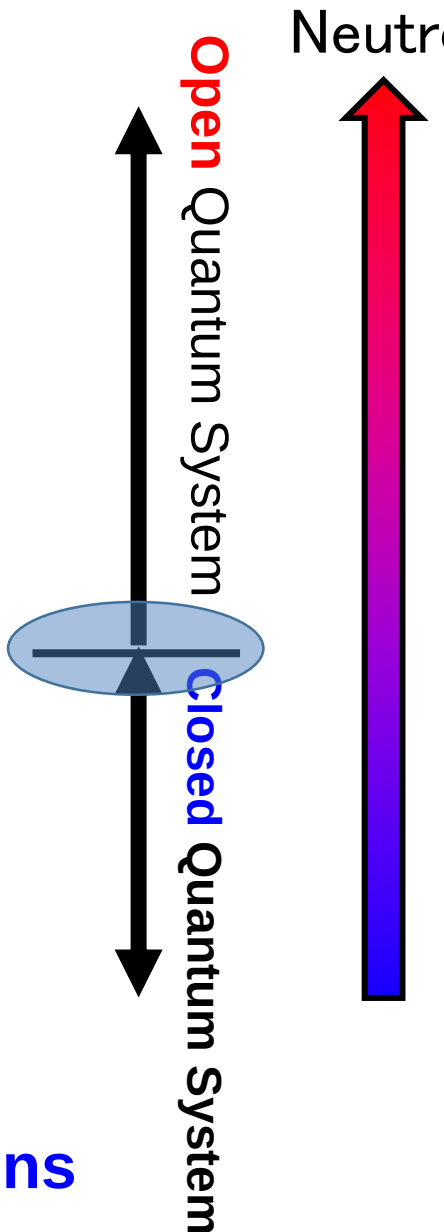
"Reaction" and "Structure" on equal footing?

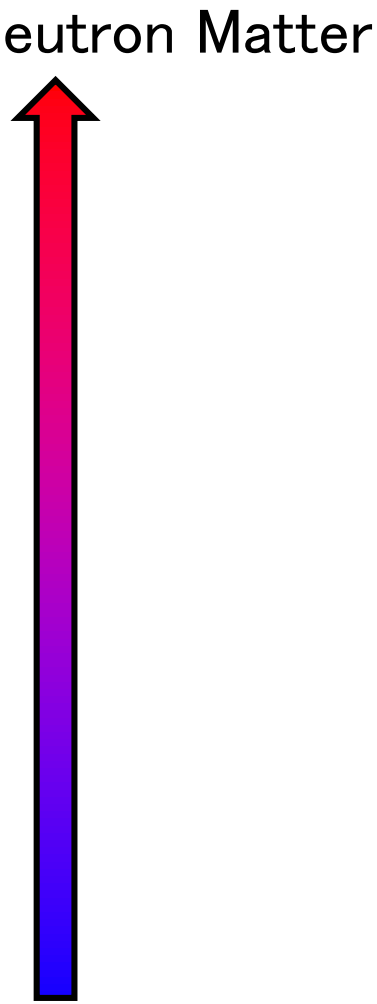
Edges: Boundary of open/closed quantum systems



Edges: Boundary of open/closed quantum systems







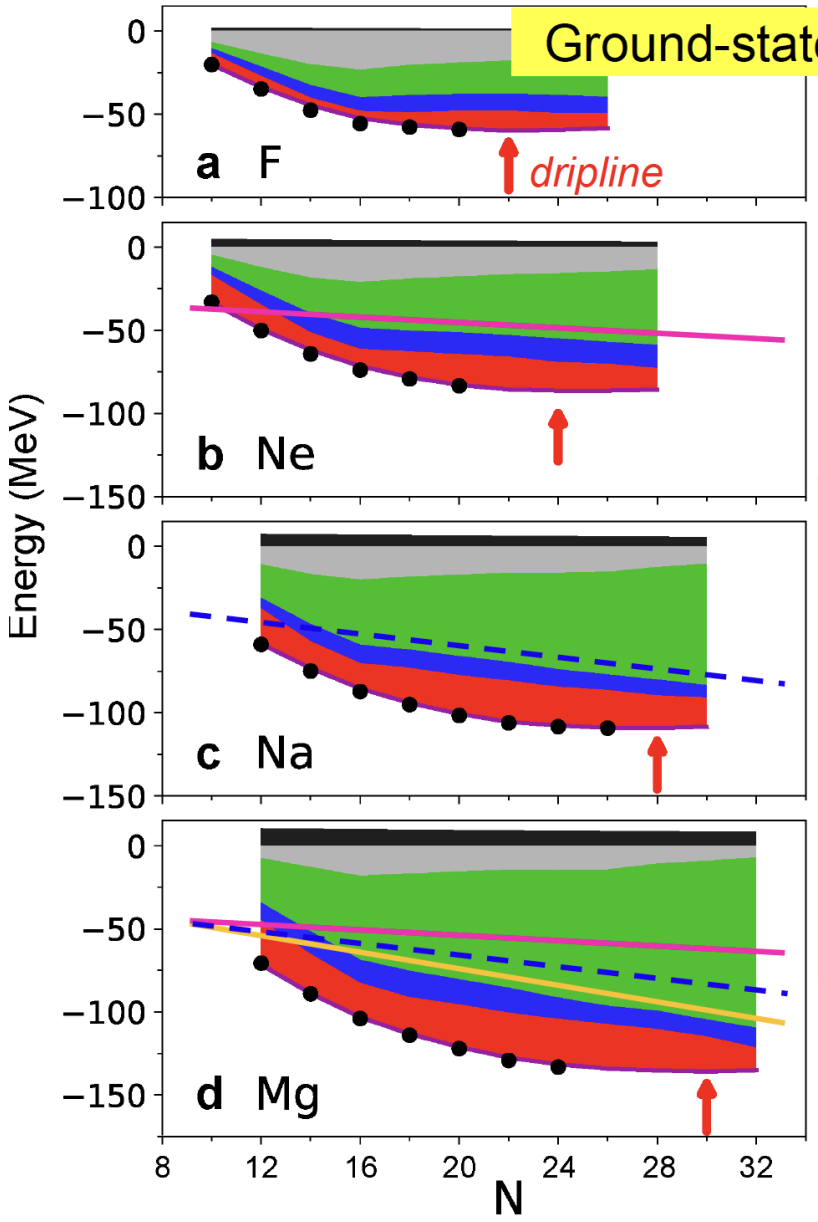
Edges (near threshold): Relevant to Stellar Nuclear Reactions

Edges of open/closed systems:

Driplines:

- ✓ Beyond neutron dripline
- ✓ Halo Nuclei
- ✓ Neutron clusters (dineutron/tetraneutron)

What locates neutron driplines? Taka Otsuka



Ground-state energy is decomposed (EEdf1 int.)

EXP.
total
Coulomb
bare SPE
monopole
pairing
rest (quadrupole *etc*)
monopole-type

The monopole effect (lower edge of green part) lowers the energy as a function of *N*, and its slope becomes steeper as *Z* because of the p-n monopole int., as shown by three lines fitted to different slopes.

The rest (~quadrupole deformation) effect (red part) varies locally.

Neutron dripline:
Monopole←→Deformation

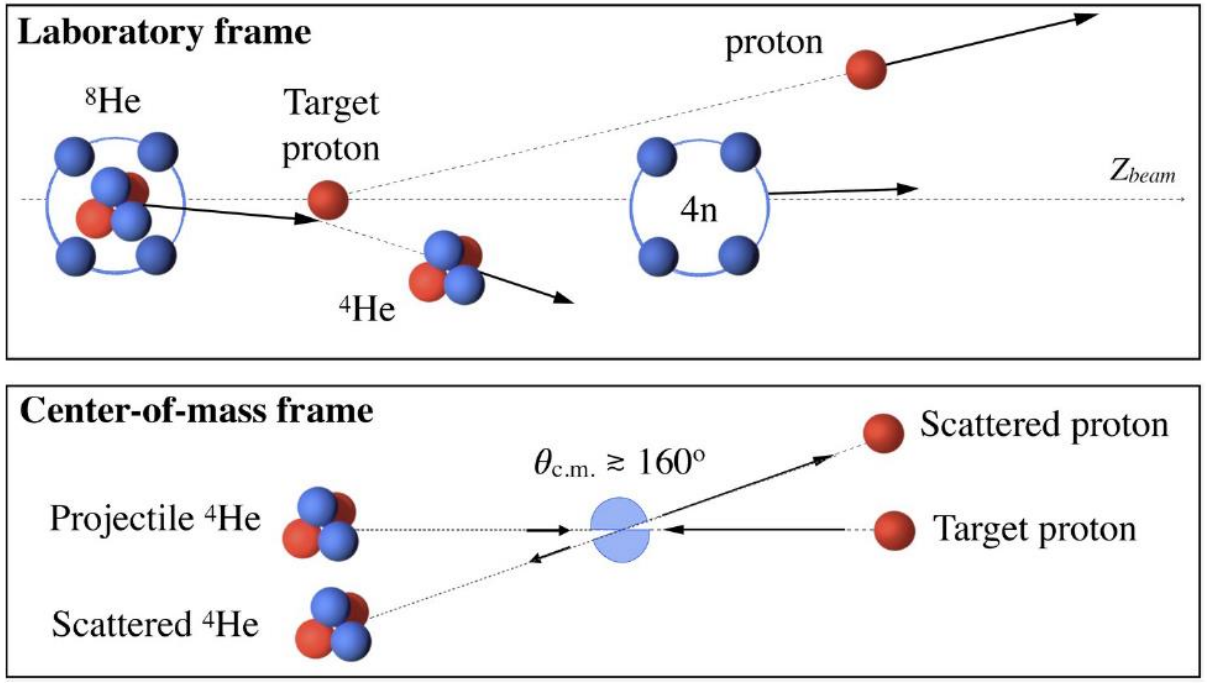
Balance

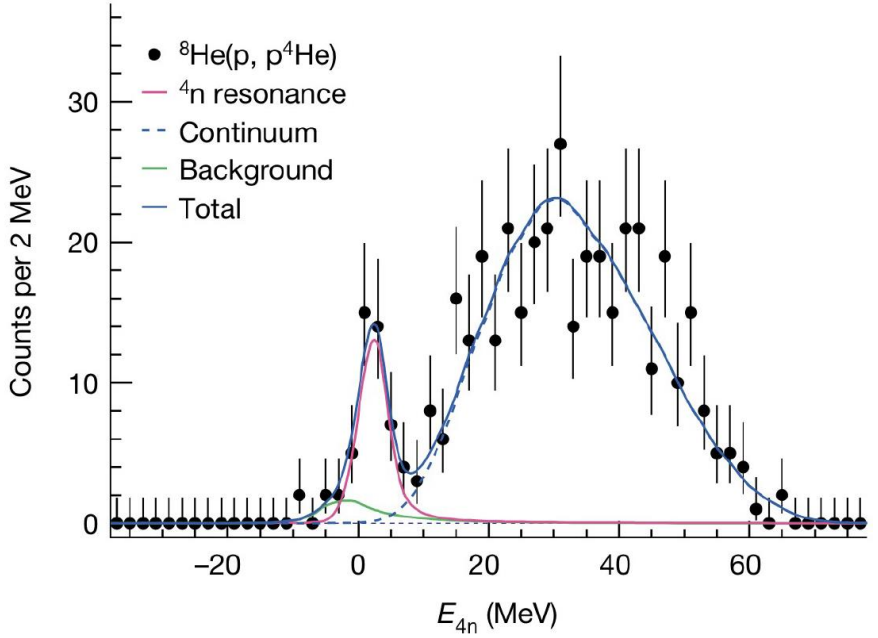
Tetra Neutron

Maytal Duer @SAMURAI-RIBF

- (p,pα) at backward kinematics (@156MeV/u)

^{8}He(p,p^{4}He) quasi-elastic knockout





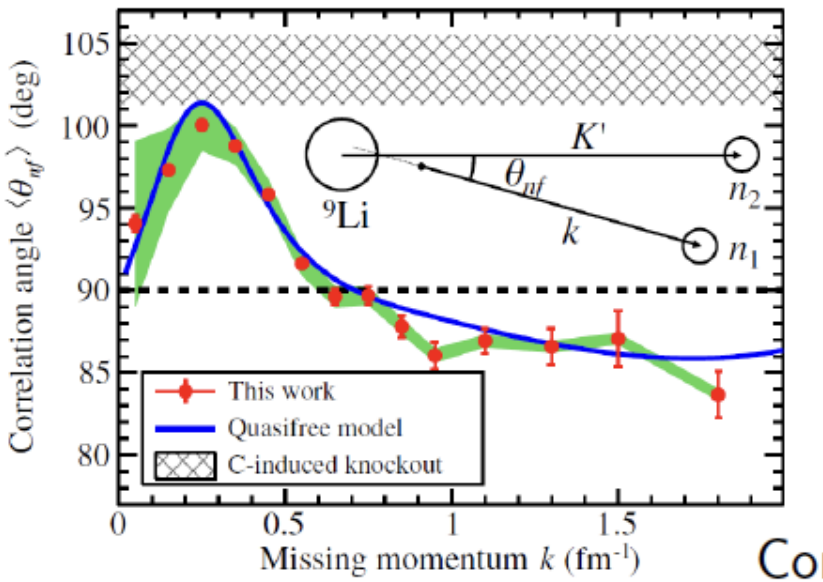
E_r = 2.37±0.38(stat.)±0.44(sys.) MeV

Γ = 1.75±0.22(stat.)±0.30(sys.) MeV

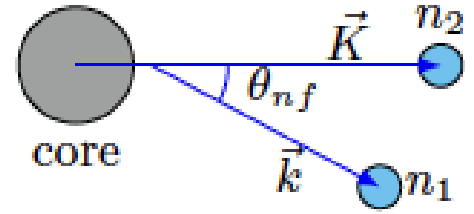
M. Duer et al., Nature 606, 678 (2022).

Locating dineutron in 2n halo by (p,pn)

Jésus Casal



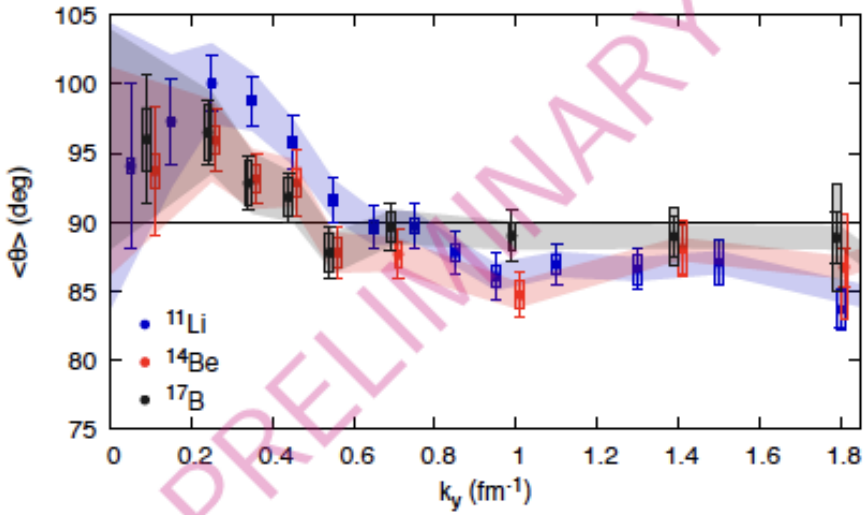
^{11}Li(p,pn)^{10}Li



maximum at $k \sim 0.3$ fm^{-1}
(theory $\Rightarrow r \sim 3.6$ fm)

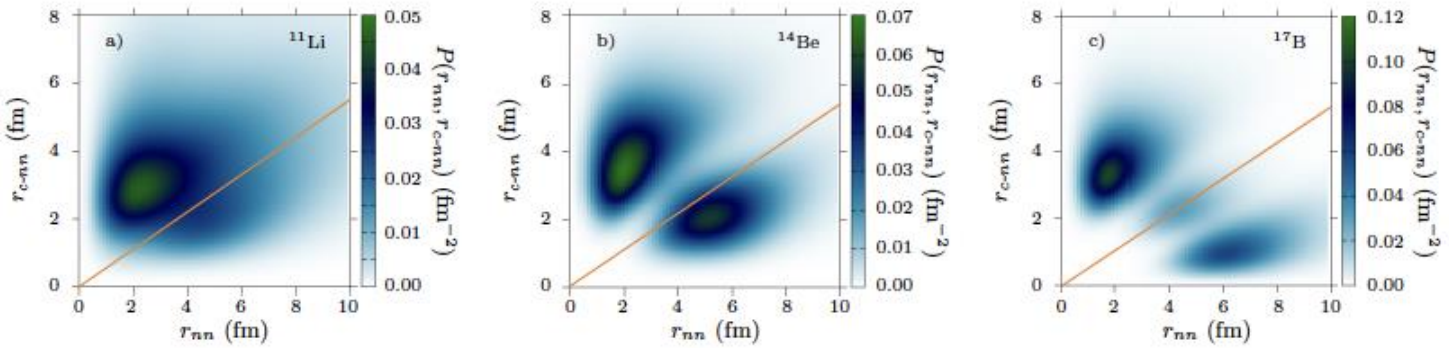
Y.Kubota et al.,PRL125, 252501 (2020).

Comparison ^{11}Li, ^{14}Be, ^{17}B. RIKEN ~250 MeV/nucleon (SAMURAI18)



A.Corsi et al., submitted

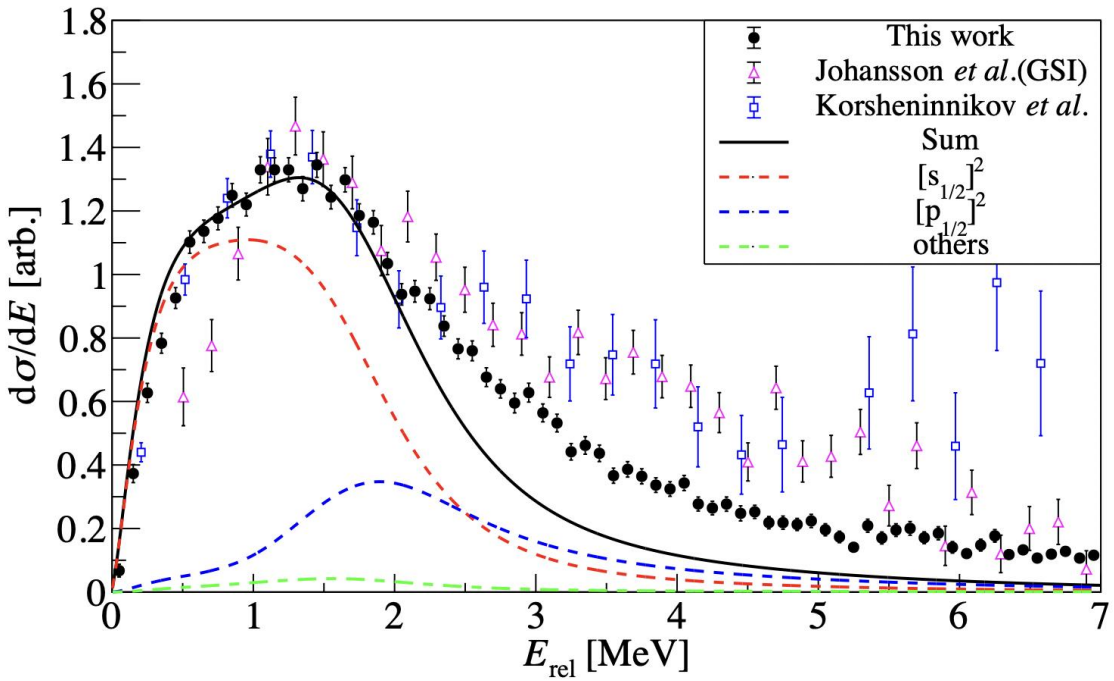
Eikonal Sudden Approximation+ three-body model



Dineutron in a limited region of surface
→Common feature?

^{10}He from ^{11}Li(p,2p) Yelei Sun

253 MeV/u SAMURAI@RIBF



Two components:
E~1 MeV, ~2 MeV

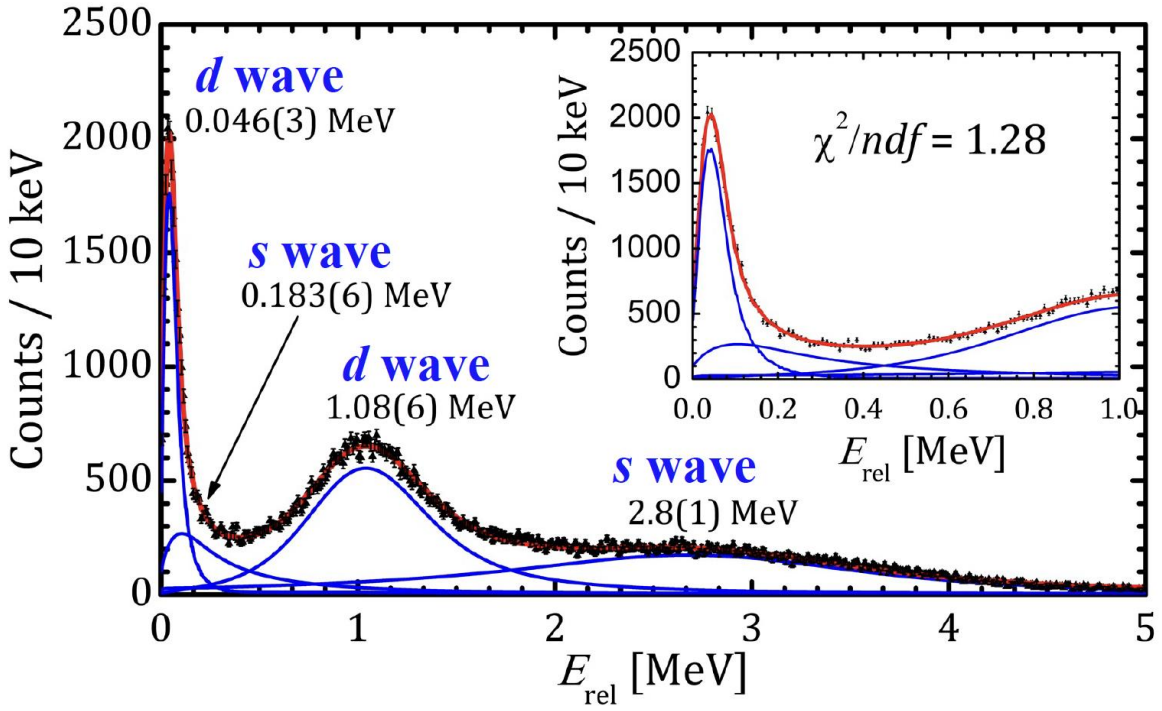
- ^{8}He-n interaction based on current ^{10}He spectrum
  - *s*-wave scattering length -3.45 fm (close to recent ^{9}He results)

Three-body Virtual States?
Dineutrons at E_x>2 MeV?

More dripline nuclei with (p,2p) @SAMURAI-RIBF

Tokyo Tech

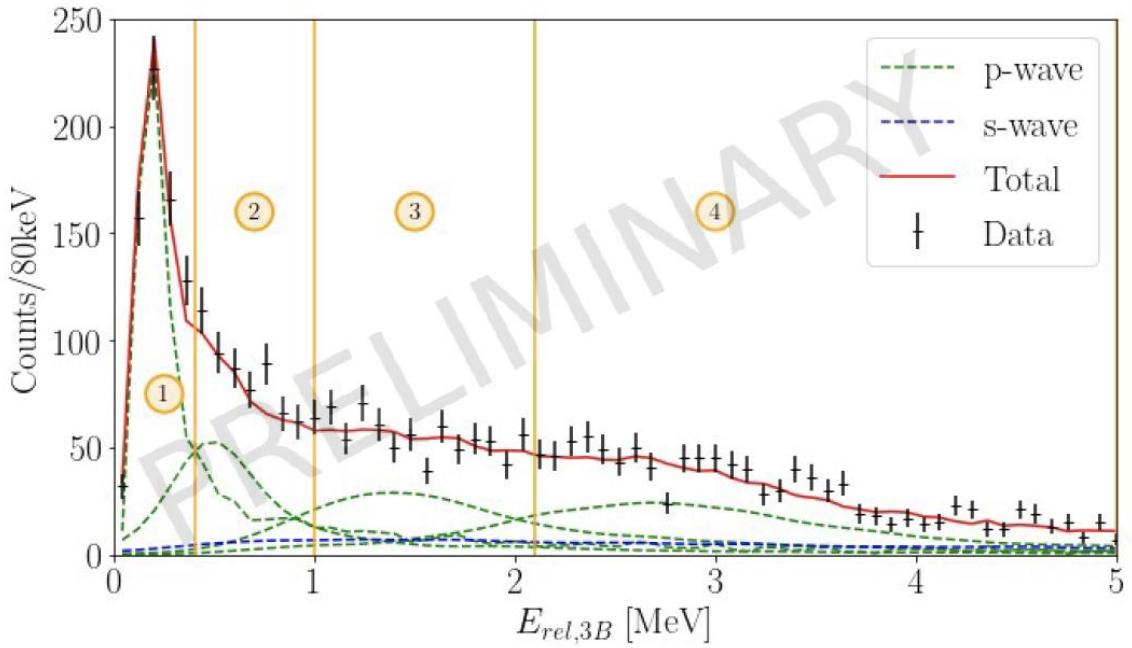
^{17}B(p,2p)^{16}**B** Zaihong Yang



^{17}B: valence neutrons: *d*-dominant

Z.Yang et al., PRL**126**, 082501 (2021).

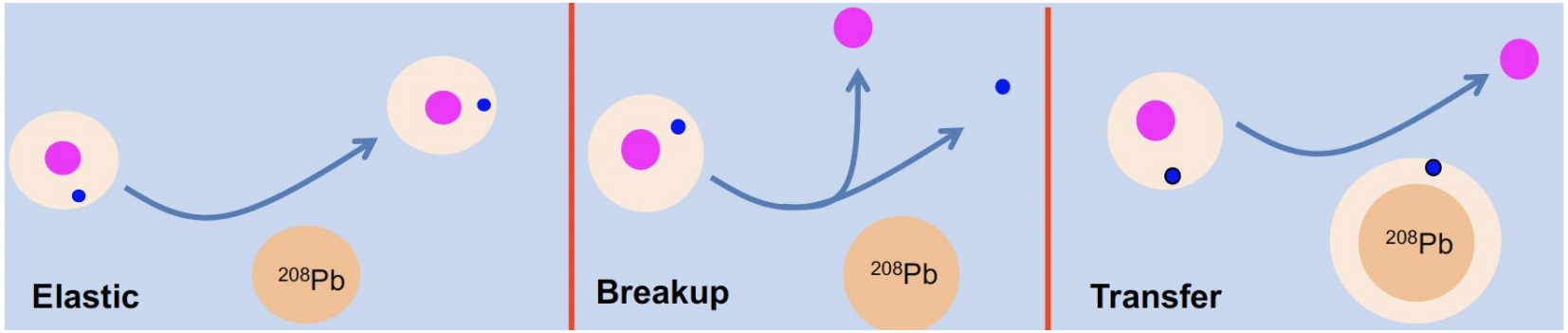
^{14}Be(p,2p)^{13}**Li** Paul André

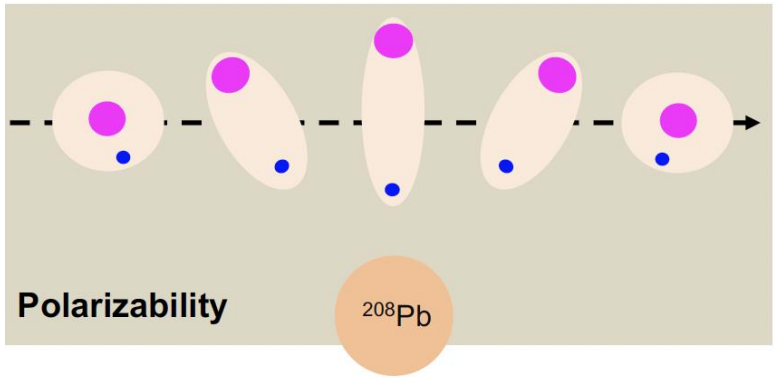


^{7}H, ^{7}He Siwei Huang

Reactions of halo nuclei near Coulomb Barrier

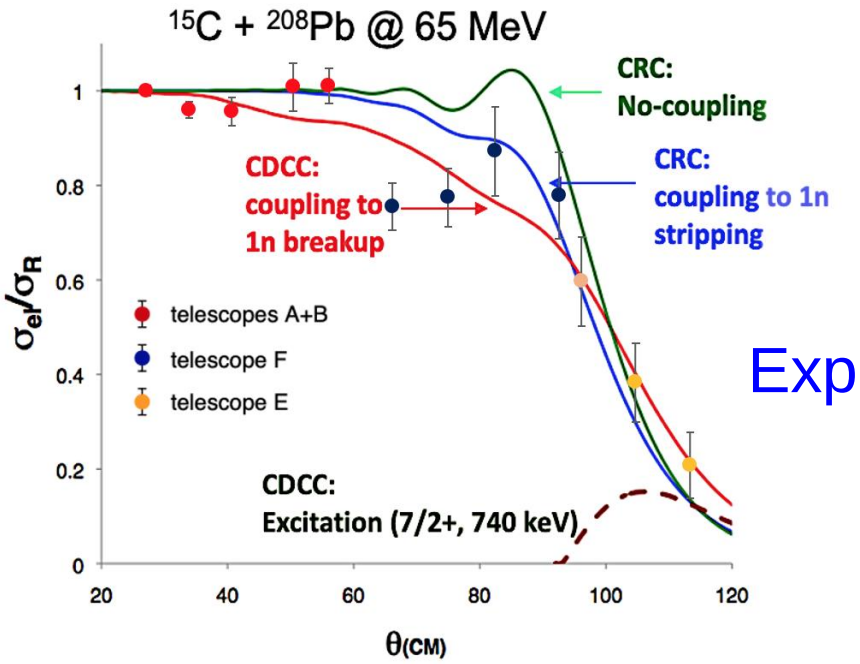
María José García Borge





@HIE ISOLDE CERN

Elastic Scattering of ^{15}C
Near Coulomb Barrier



Theory: Keenly PRC2007
CDCC, CRC

Experiment-Theory-Collaboration

Edges of open/closed systems:

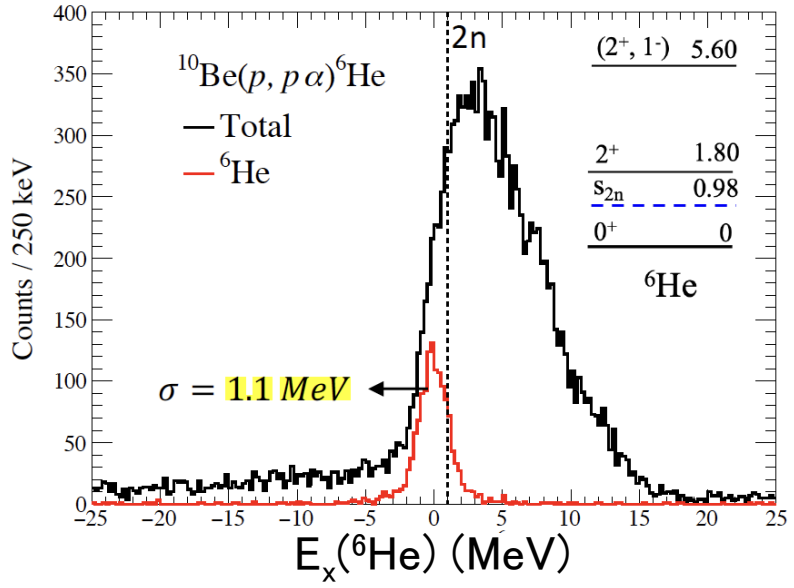
α, d, t Clusters

(p,pα) for alpha clustering

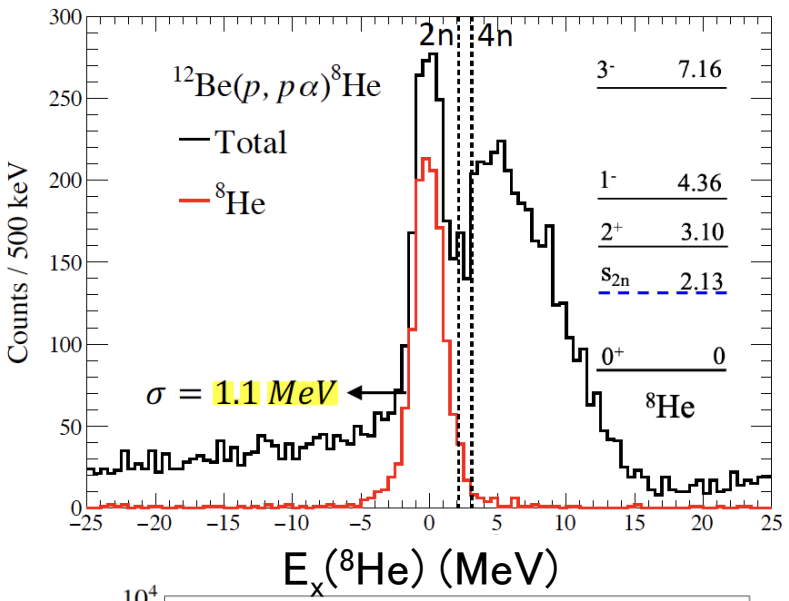
Pengijn Lee

Tokyo Tech

^{10}Be(p,pα)^{6}He 150MeV/u



^{12}Be(p,pα)^{8}He 150MeV/u

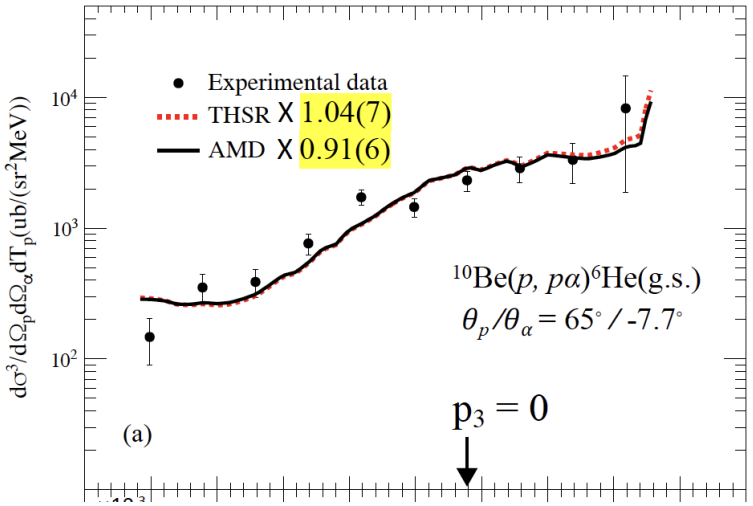


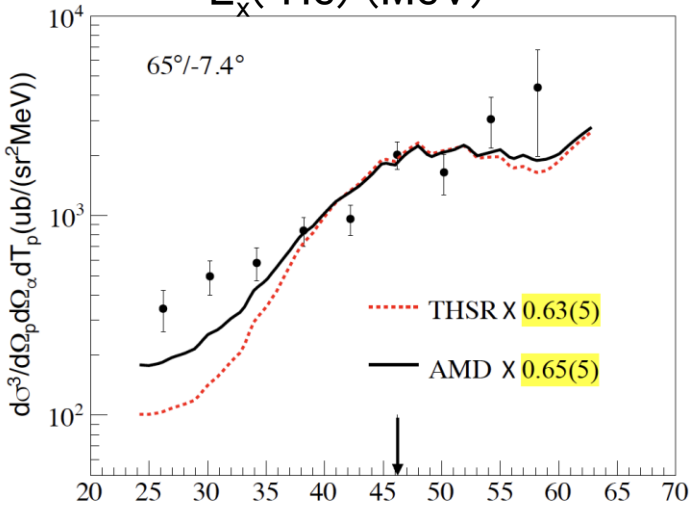
@SAMURAI-RIBF

(p,pα)
Excellent probe for alpha cluster

^{10}Be: alpha cluster ~1
^{12}Be: alpha cluster ~0.6

Triple Differential Crosssection

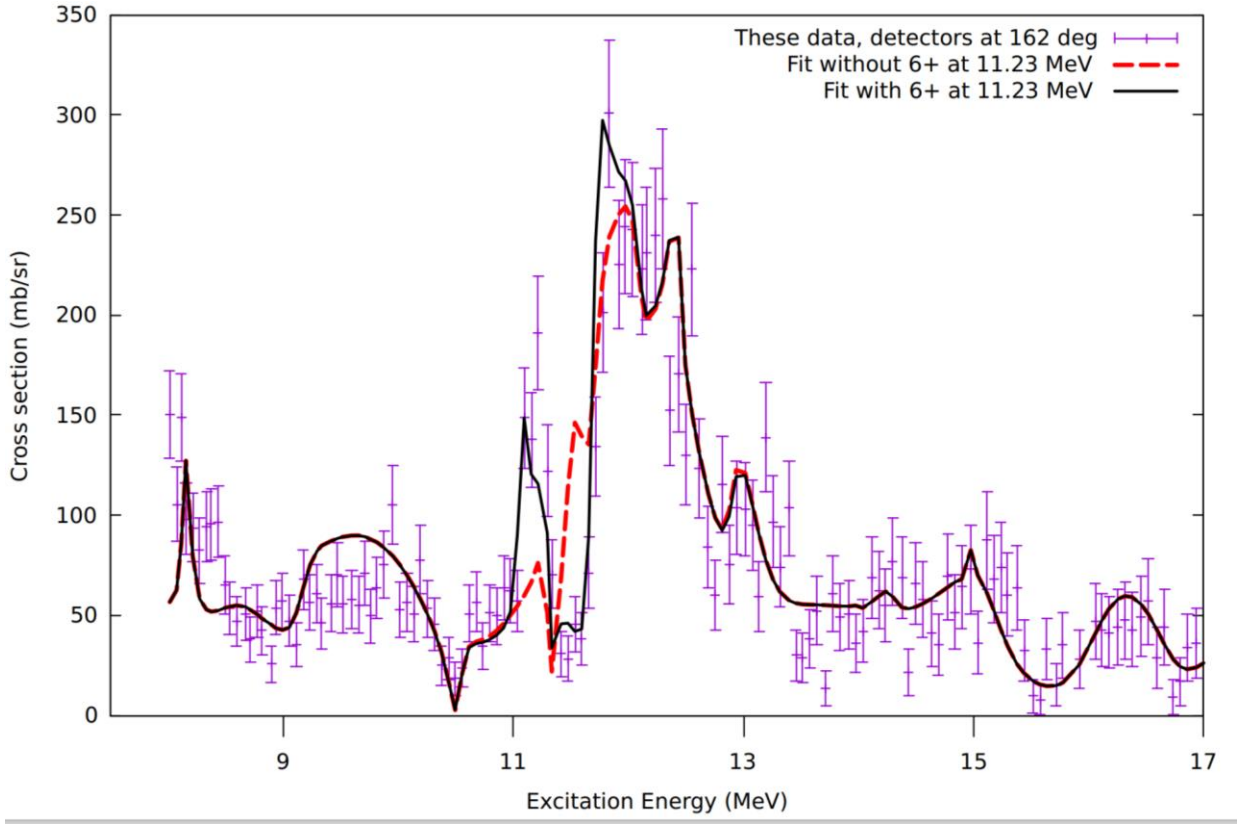




α-cluster states using a variety of reactions

Marina Barbui

Active target at **Texas A&M**: **^{18}Ne**: ^{14}O+α



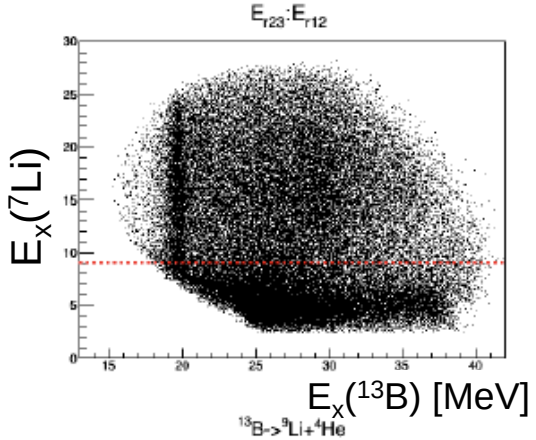
Nikola Vukman

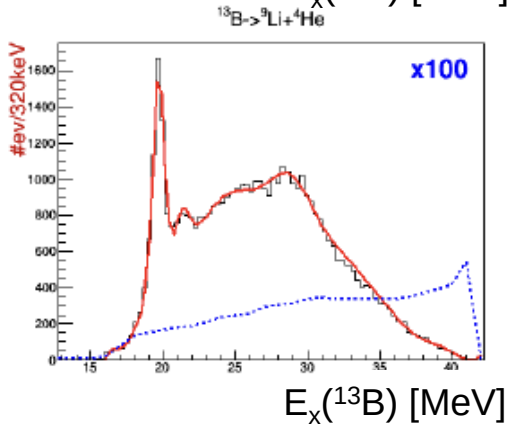
TRIUMF **^{13}B,^{12,11}Be**: (^{6}He,α clusters)

^{9}Li(75 MeV) +^{7}Li →**^{13}B,^{12,10}Be**

^{4}He, triton transfer etc.

^{13}B
→^{9}Li+^{4}He





Knockout Reaction for clusters

Tomo Uesaka

(*p*,*pX*) @ E/A = 200—300 MeV
***X*: *d*, *t*, ^{3}He, α**

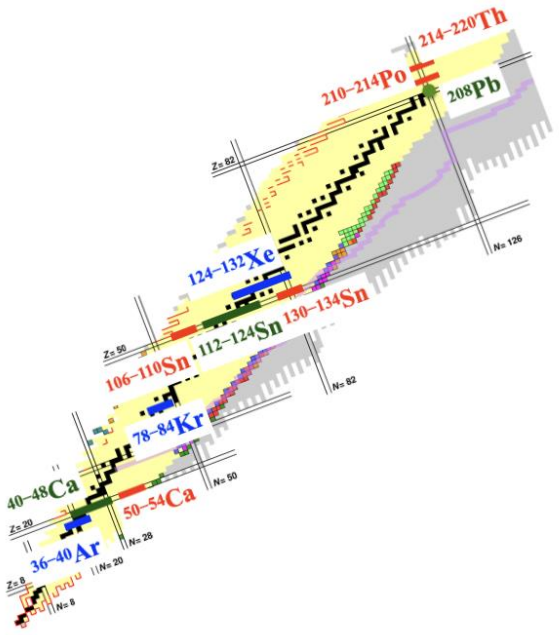
Wide mass region
A=40−220

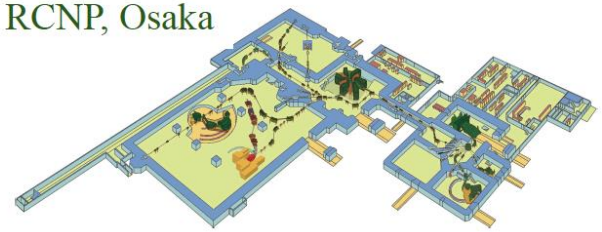
×

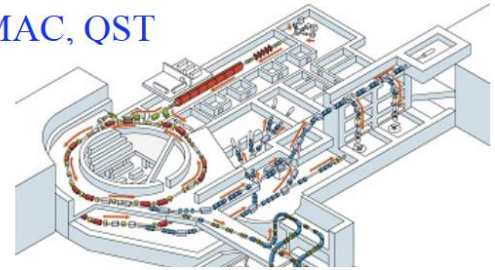
Stable and unstable nuclei

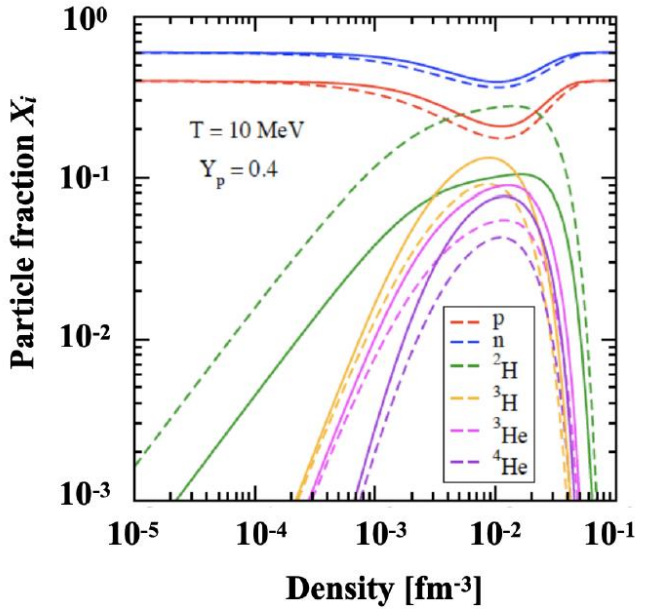
×

All the light clusters
d, t, ^{3}He, α …









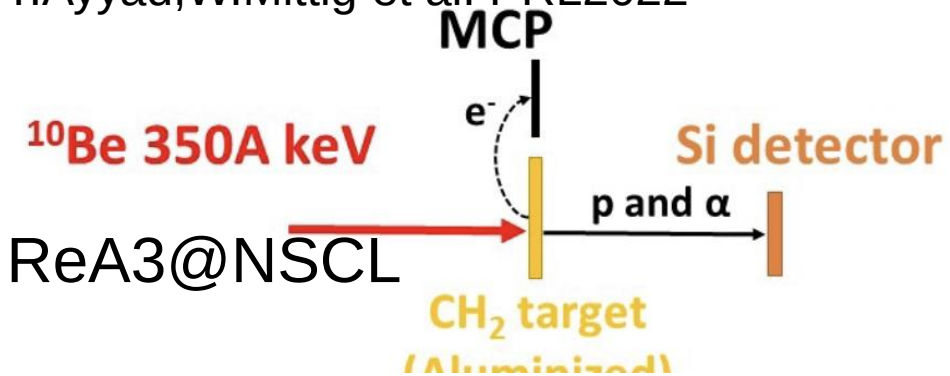
Edges of open/closed systems:

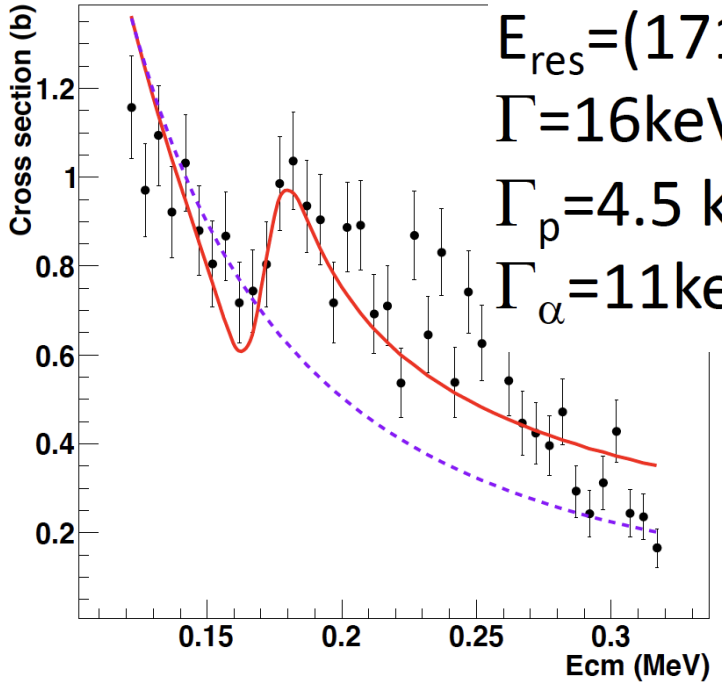
Excited states near thresholds

Enhanced Resonance near threshold

Wolfgang Mittig

Y.Ayyad,W.Mittig et al. PRL2022





E_{res}=(171 +-20)keV

Γ=16keV

Γ_p=4.5 keV

Γ_α=11keV

11.45 MeV ½+

^{10}Be+p

^{11}B

S-wave resonance

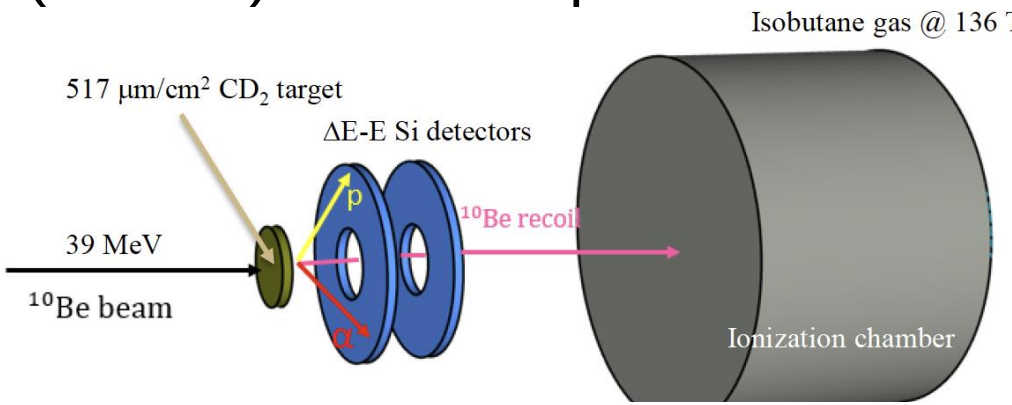
Enhanced at the threshold?

Sergio Almaraz-Calderon

E. Lopez-Saavedra et al., PRL2022

^{10}Be(39MeV)+d→^{10}Be+p

Florida State U.



E_{ex} = 11.44 ± 0.04 MeV

E_{res} = 211(40) keV

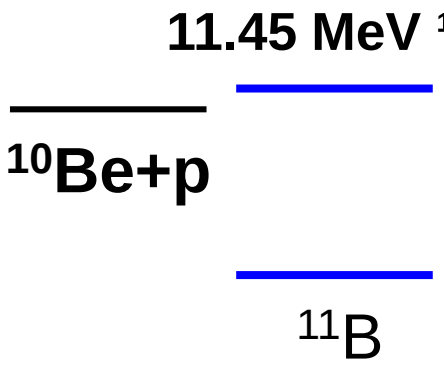
$J^\pi = (½+)$

$C^2S \approx 0.27(6)$

$\Gamma_p \sim 5$ keV

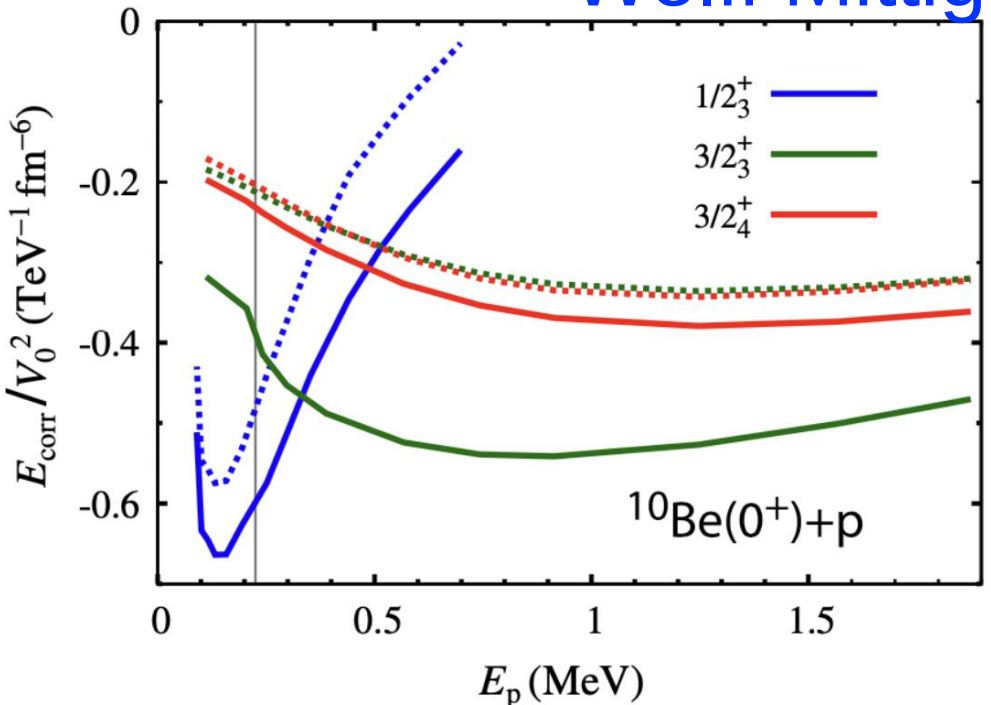
} Assuming 100% proton decay

Enhanced Resonance near threshold



S-wave proton resonance
Enhanced at the threshold due to coupling to the continuum?

Wolfi Mittig



Alexandre Volya

Is this universal?
Superradiant?
Relevance to alpha clusters?

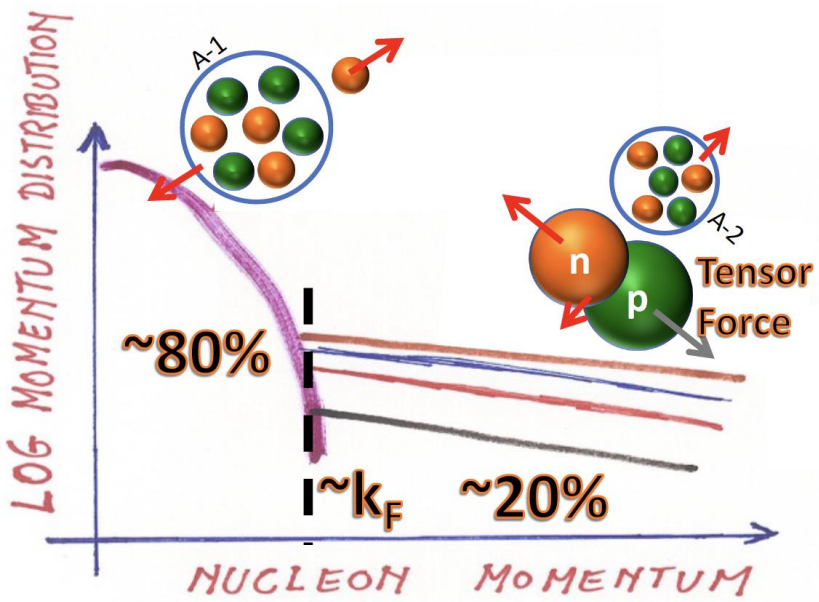
Minch-Loc Bui
Petr Navratil

Beyond the mean field

Short Range Correlations

Short Range Correlation

Marina Petri



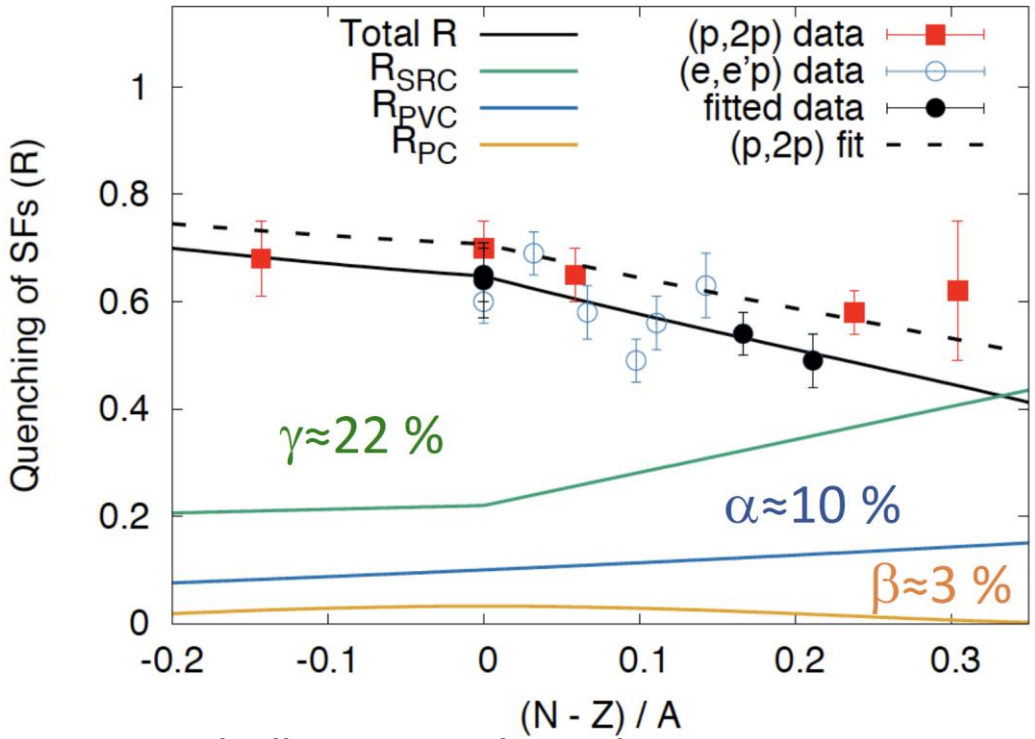
J-Lab Experiments by
Hen, Korover, Duer, Cohen…

Short Range Correlation
Isospin Dependence?

single-particle configuration
Particle-vibration coupling
Pairing correlations
Short-range correlations

$$|qp\rangle = K_{SP}|SP\rangle + K_{PVC}|PVC\rangle + K_{PC}|PC\rangle + K_{SRC}|SRC\rangle$$

LRC



S. Paschalis, M. Petri, et al., PLB800, 135110, (2020).

Reduction-factor issue continues

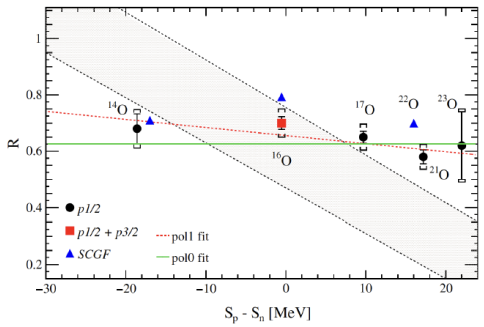
Experimentally, the depletion of single-particle states is quantified as quenching of spectroscopic factors (SFs) with respect to the IPM limit.

PHYSICAL REVIEW LETTERS 120, 052501 (2018)

Quasifree $(p, 2p)$ Reactions on Oxygen Isotopes: Observation of Isospin Independence of the Reduced Single-Particle Strength

L. Atar,[1,2*] S. Paschalis,[3,1] C. Barbieri,[4] C. A. Bertulani,[5] P. Díaz Fernández,[6] M. Holl,[1] M. A. Najafi,[7] V. Panin,[1,8] H. Alvarez-Pol,[6] T. Aumann,[1,2,1] V. Avdeichikov,[9] S. Beceiro-Novo,[6] D. Bemmerer,[10] J. Benlliure,[6] J. M. Boillos,[6,2]

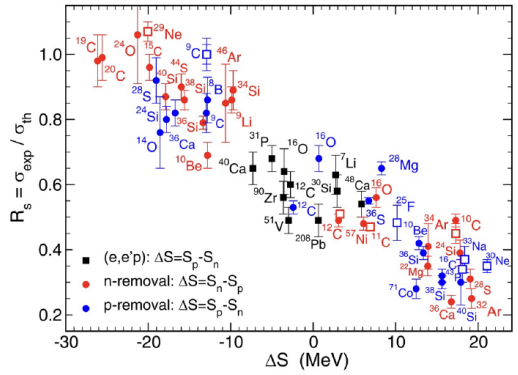
.....



PHYSICAL REVIEW C 103, 054610 (2021)

Updated systematics of intermediate-energy single-nucleon removal cross sections

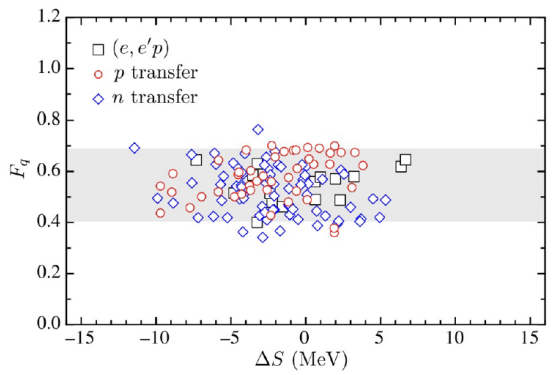
J. A. Tostevin[1] and A. Gade[2,3]



PRL 111, 042502 (2013) PHYSICAL REVIEW LETTERS week ending 26 JULY 2013

Quenching of Cross Sections in Nucleon Transfer Reactions

B. P. Kay,[1,2,*] J. P. Schiffer,[1] and S. J. Freeman[3]



←Slides by Marina Petri

A number of speakers discussed this in this conference

→

SRC?

Reaction Mechanism?

Other effects?

Also see T.Aumann et al., PPNP**118**, 103847 (2021)

Shell Evolution near ^{78}Ni

Intruder state ?

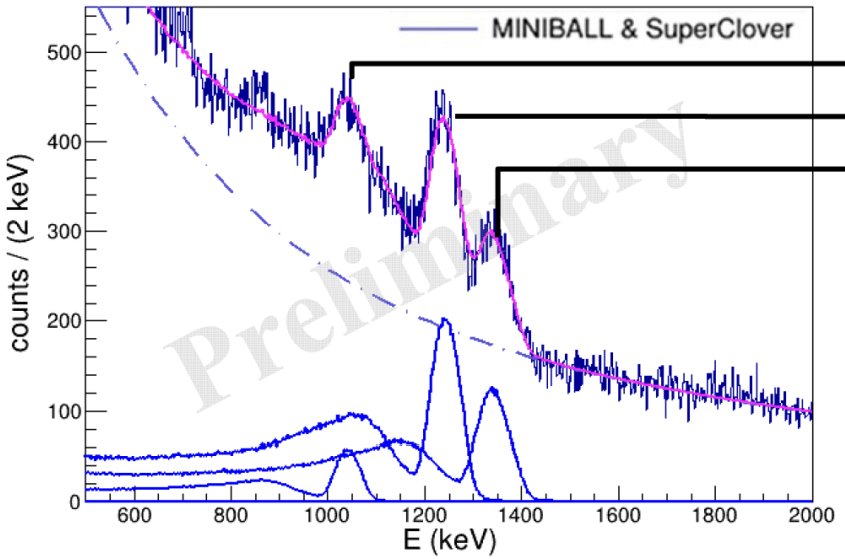
Léo Plagnol

Tokyo Tech

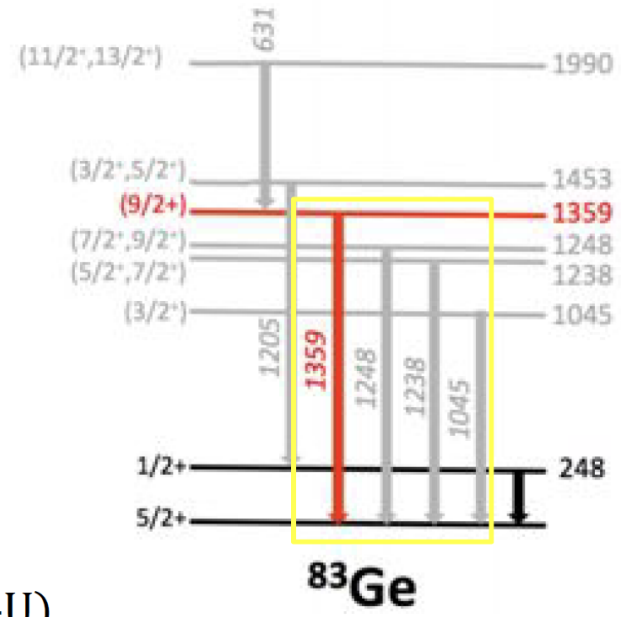
Preliminary fit of channel of interest : ^{84}Ge(^{9}Be, X)^{83}Ge

1n Reomval from N=50 ^{84}Ge

@HiCARI-RIBF



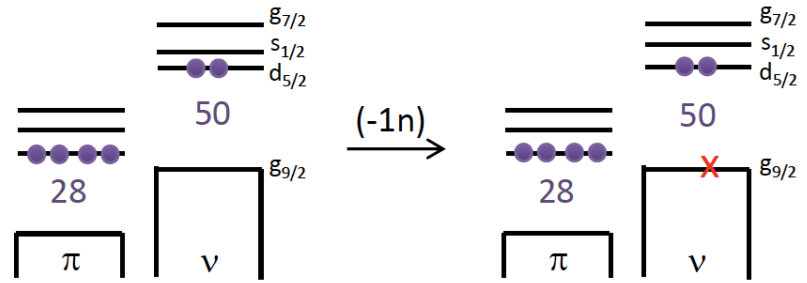
- First tests with three transitions only :
  - 1045 keV
  - 1248 keV
  - 1359 keV ($9/2^+$ single particle intruder candidate)



(Z=32,N=51)

- Preliminary scan for a lifetime on this transition shows $T_{1/2} \approx 9$ ps
  - Experiment :
    $11\ \text{ps} \leq T_{1/2} \leq 74\ \text{ps}$
  - SM predictions :
    $E = 1336\ \text{keV}, T_{1/2} = 15\ \text{ps}$ (CP)
    $E = 1004\ \text{keV}, T_{1/2} = 25\ \text{ps}$ (PFSDG-U)

Neutron knockout : ^{84}Ge(-1n)

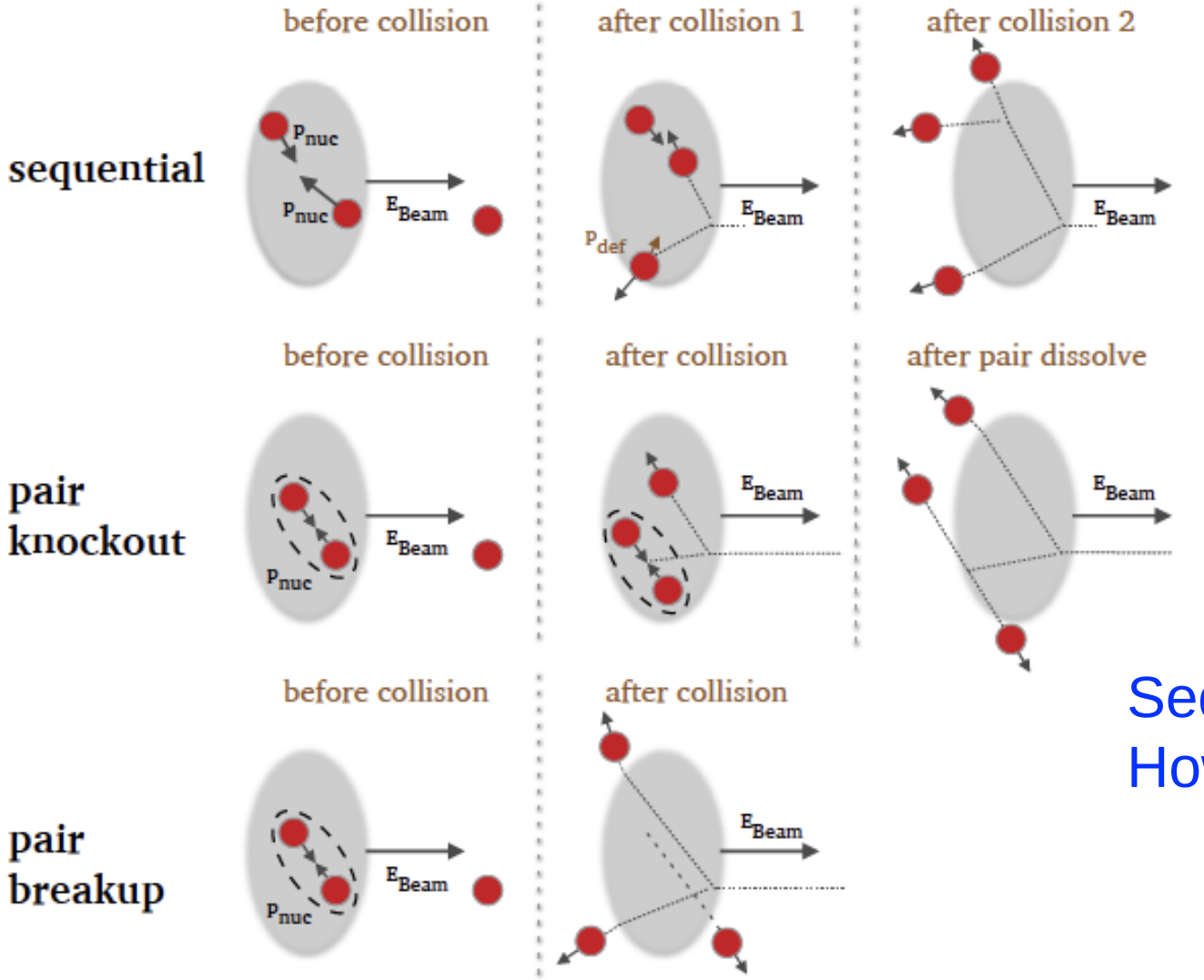


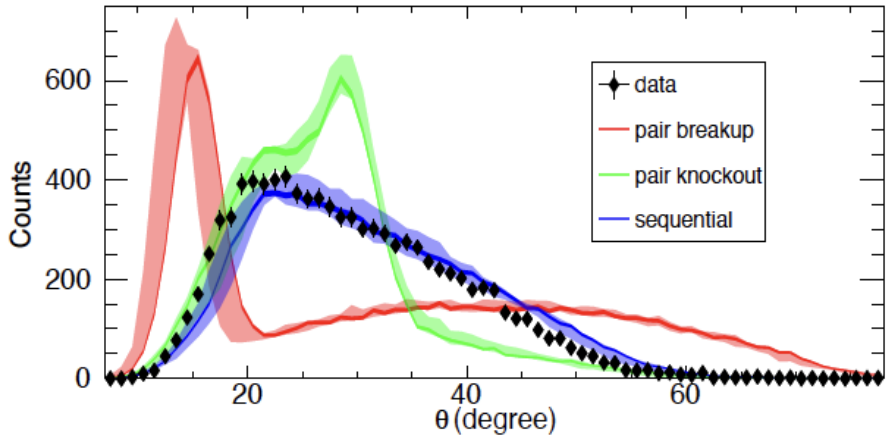
Exotic reactions

Exotic Reactions-(p,3p)

Axel Frotscher

@ZDS-RIBF





^{81}Ga(p, 3p). θ-distribution and different models.

Sequential Dominant

How (p,3p) can be used for spectroscopy?

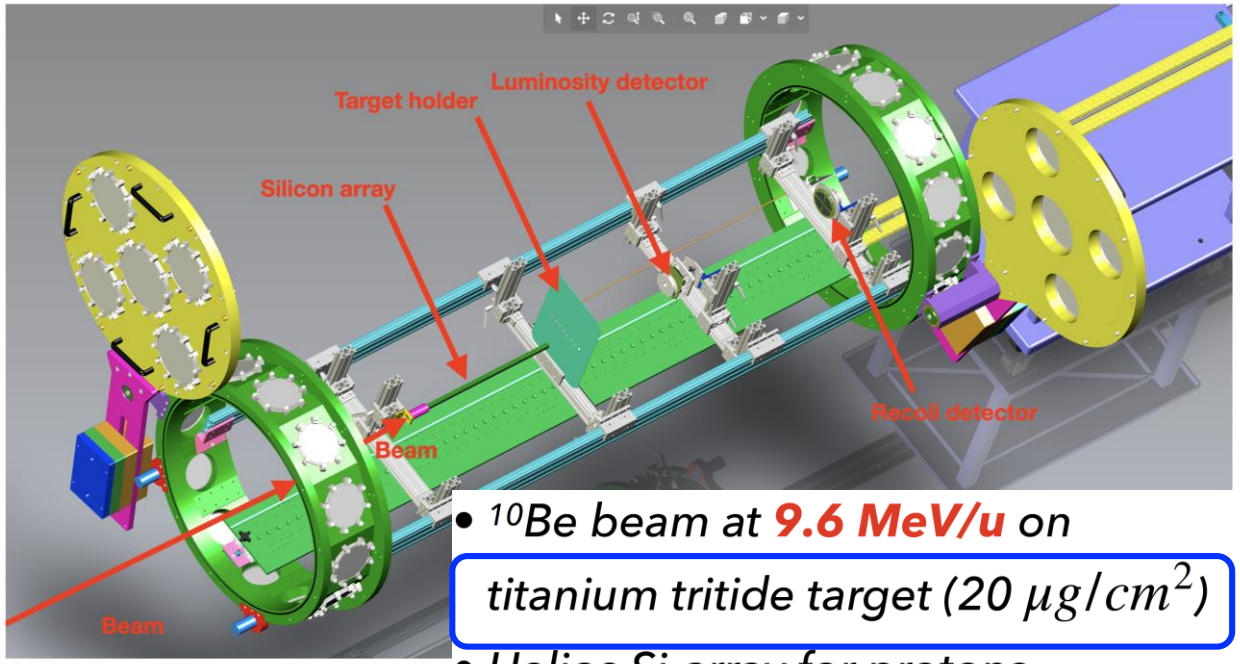
Hongna Liu (future exp.)

Exotic Reactions-(t,p) reaction

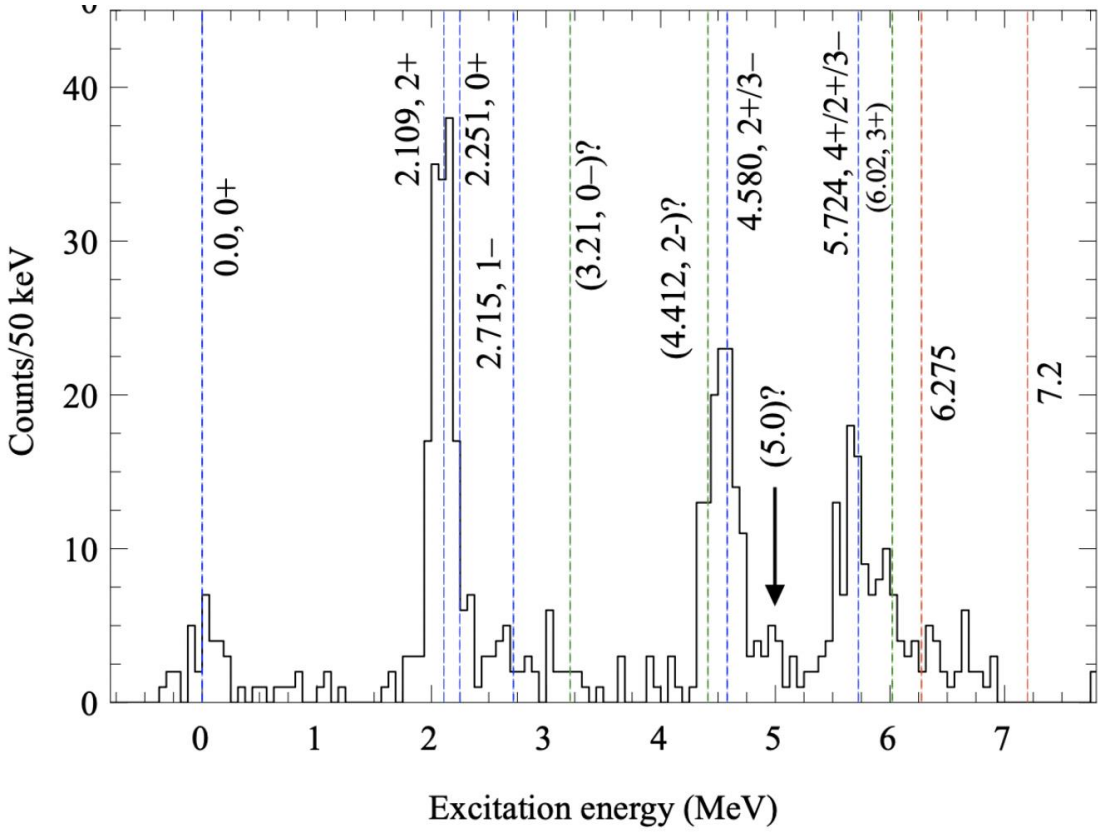
Alicia Muñoz-Ramos

NSCL-ReA3-**SOLARIS**

^{10}Be(t,p)^{12}Be*



- *^{10}Be beam at **9.6 MeV/u** on titanium tritide target (20 $\mu g/cm^2$)*
- *Helios Si-array for protons*
- *Recoil detection: annular Si detectors*
- *B field of 3T*
- *Q-value resolution ~150 keV FWHM*



Assign spin-parity of the observed states by the angular distribution

2N transfer reactions --Theories

Stefano Burrello $^{9}Li(p,t)^{11}Li$

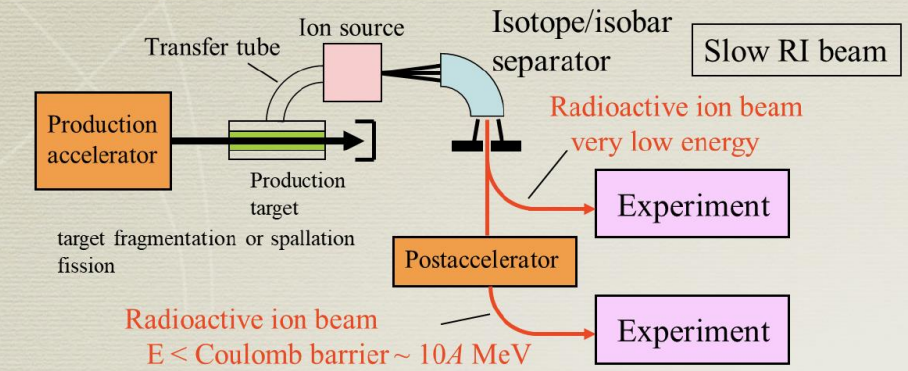
José Antonio Lay $^{A-2}Sm(t,p)^{A}Sm$
Quantum Phase Transition

Enrico Vigezzi $^{12}C(^{18}O,^{16}O)^{14}C$
Giant Paring Vibration?

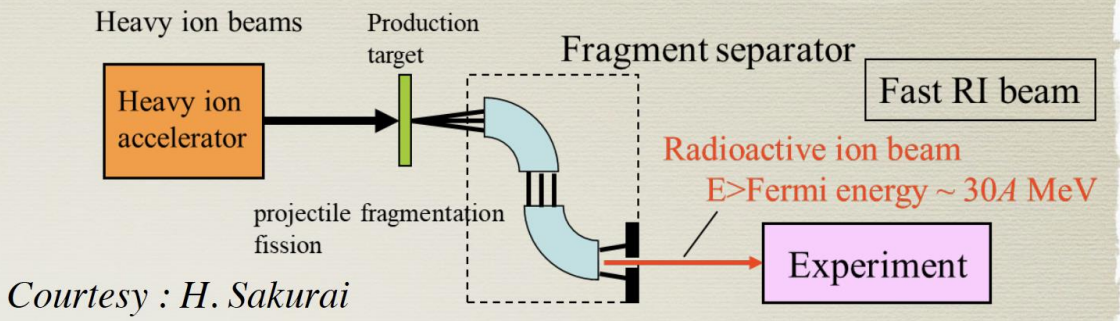
Seems sensitive to "pairing correlation"
How experimentalists can make better use of it?

Experimental Developments

Isotope Separator Online (ISOL)

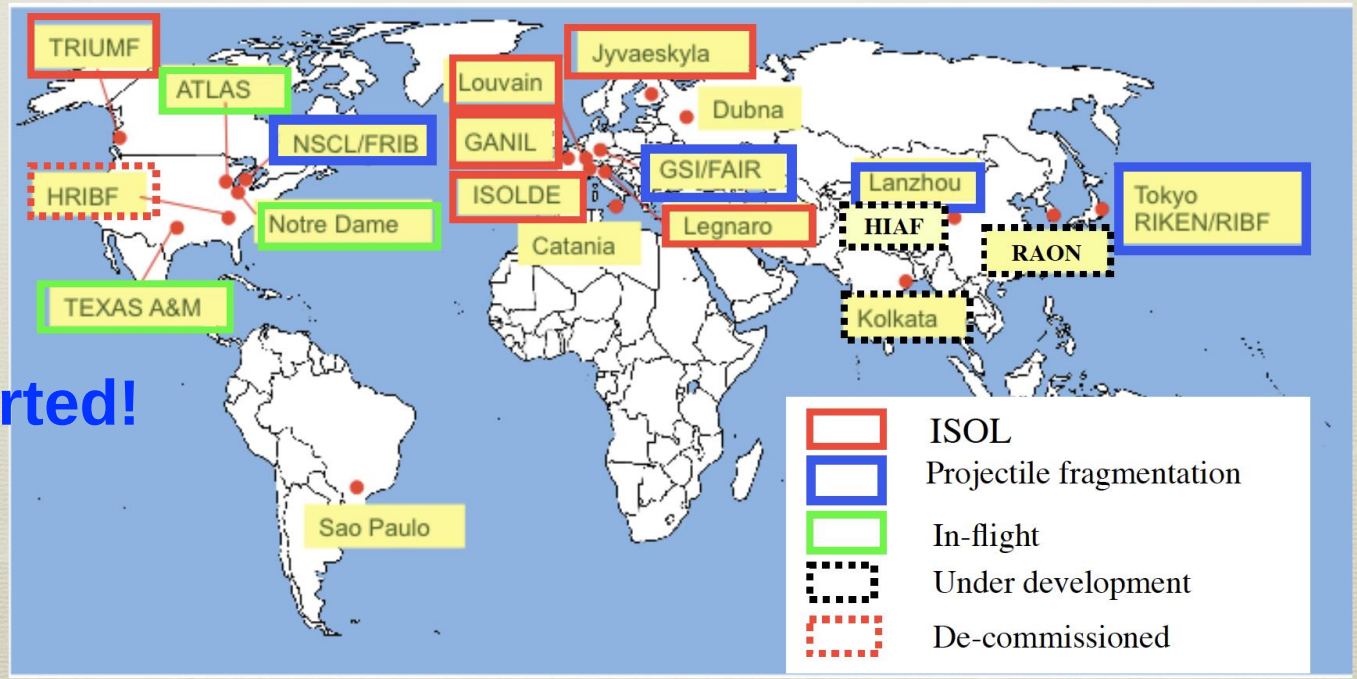


In-flight - Projectile Fragmentation



Courtesy : H. Sakurai

E/A	5 - 30 MeV	200 - 1000 MeV
	Transfer Reactions, Inelastic & Elastic Scattering, Resonant scattering	Fragmentation, Nucleon removal, Coulomb dissociation, Reaction and charge changing cross sections, Quasi-free knockout, Charge exchange reactions, Elastic Scattering

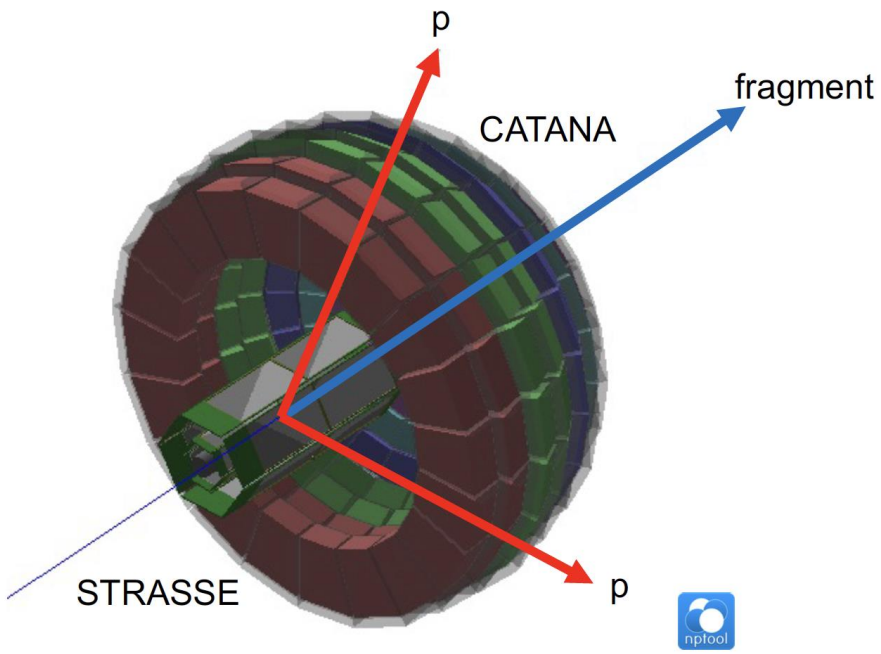


FRIB has started!

Slide by Ritu Kanungo

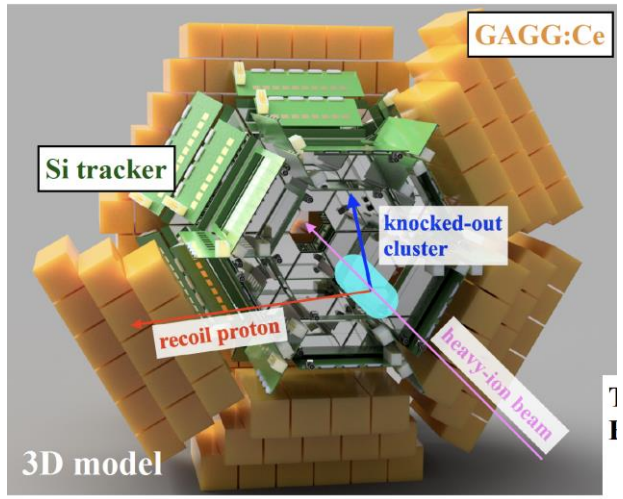
Devices for missing mass spectroscopy

(p,2p),(p,2pγ),(p,3p),(p,pd),(p,pα) @200– GeV/u



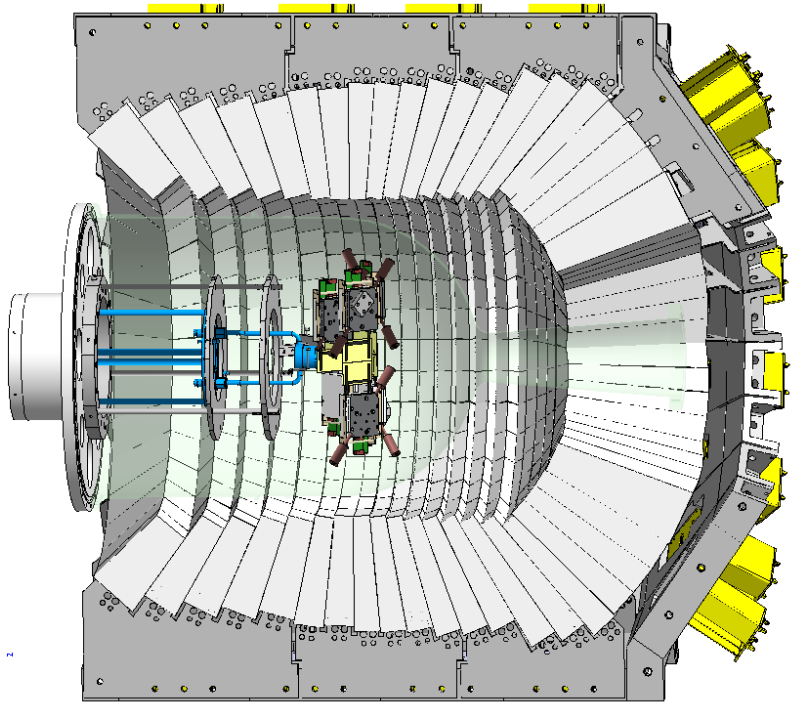
STRASSE/CATANA@RIBF

V. Alcindor



TOGAXSI@RIBF

T. Uesaka



T. Jenegger
A.Graña Gonzalez

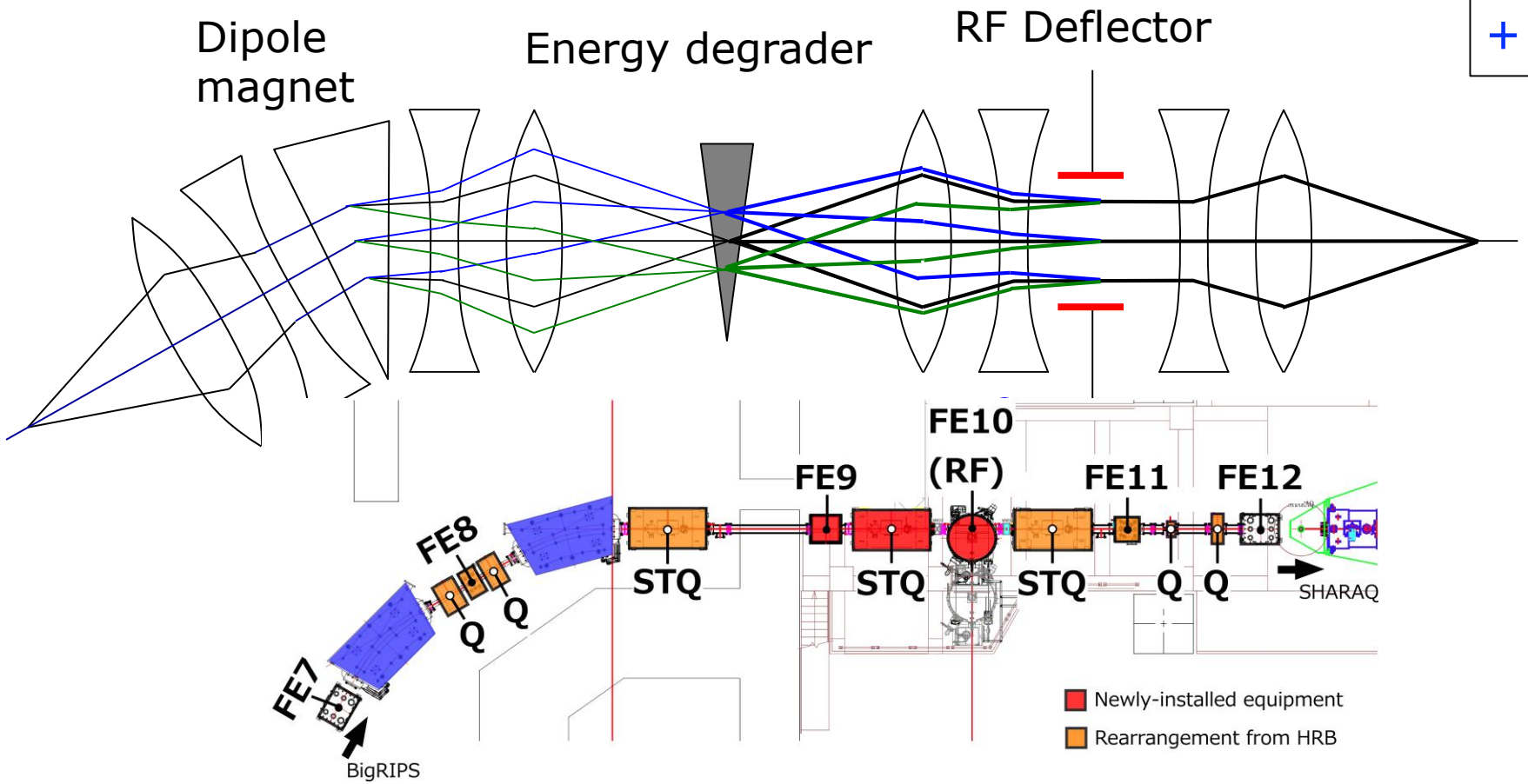
CALIFA/Si Tracker
R^{3}B@GSI/FAIR

Slowing down for transfer reactions

OEDO@RIBF

Susumu Shimoura

Transfer Reactions : 10-50 MeV/nucleon
(Higher for ISOL, Lower for Fragment Separators)



Mono-energetic degrader
+ RF Deflector

⇨ 10-50 MeV/u
90% Transmission
Fast Collection!

(d,p)(t,p)…

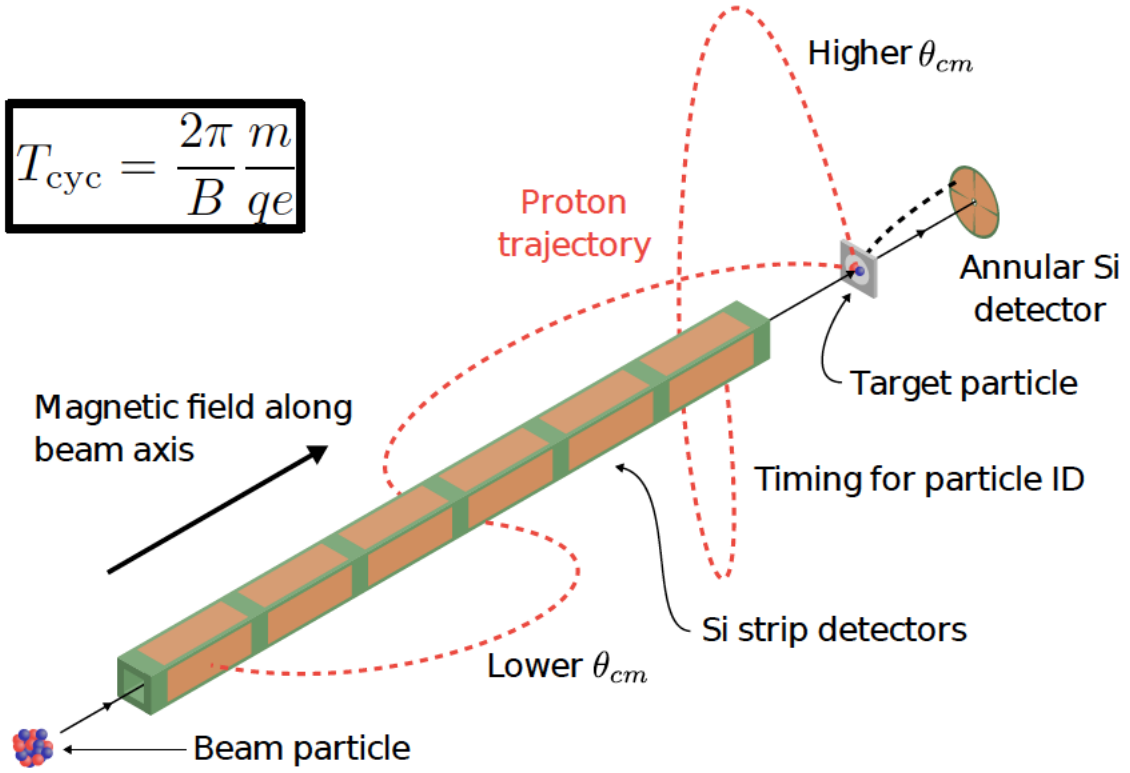
Direct Reactions with a Solenoid

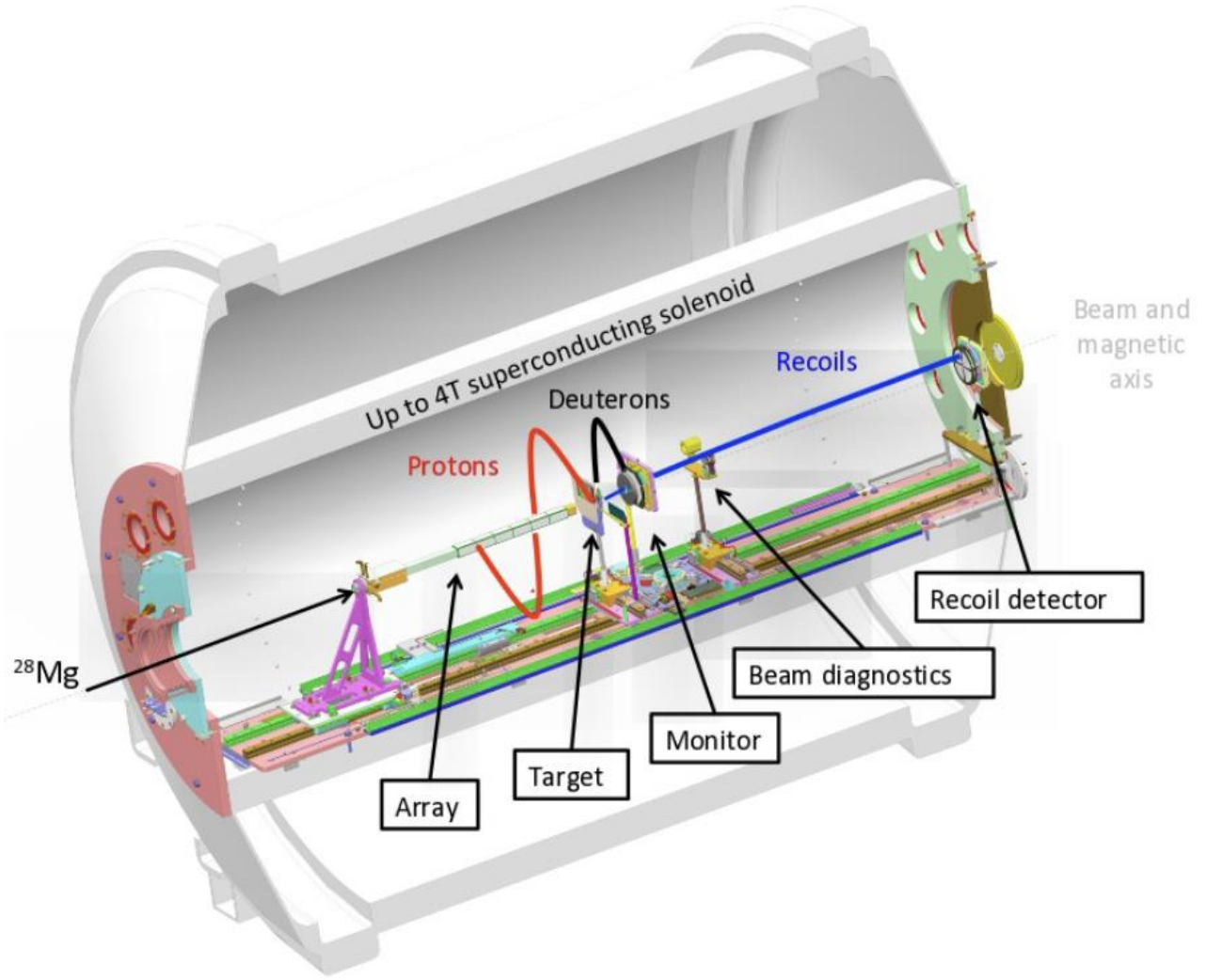
David K. Sharp

Tokyo Tech

ISS at HI-ISOLDE

$$T_{\mathrm{cyc}} = \frac{2\pi}{B}\frac{m}{qe}$$



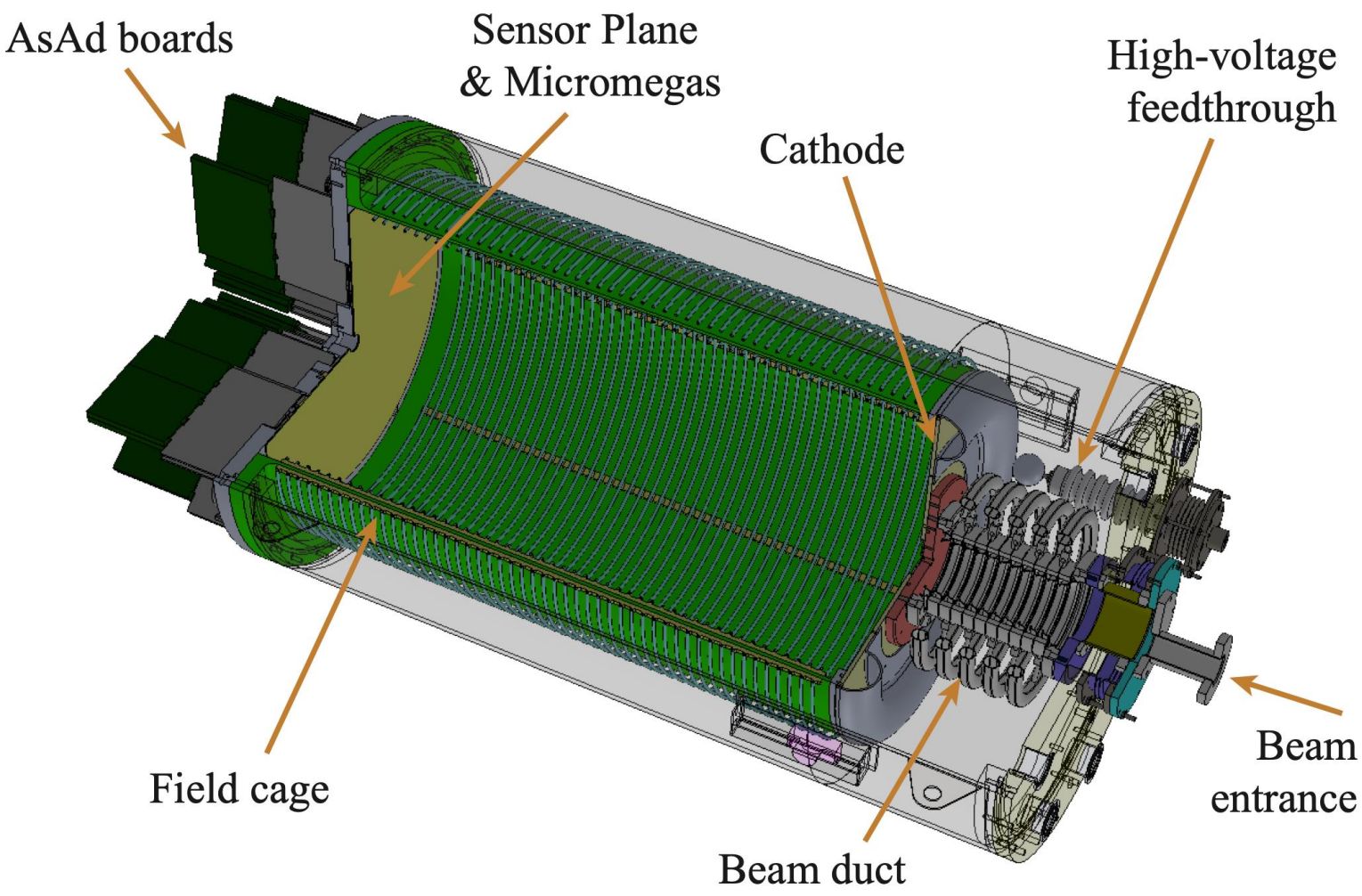


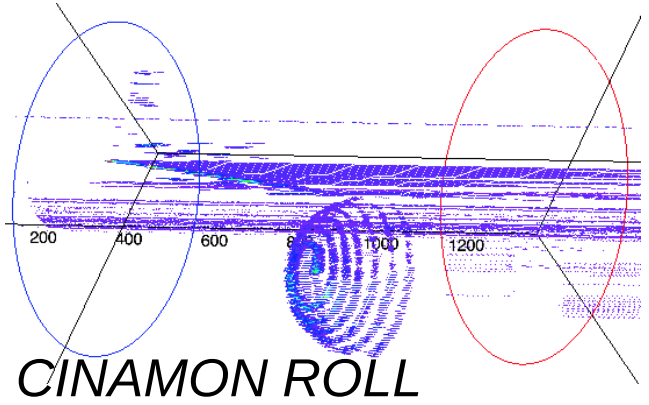
Direct Reactions with Solenoid & Active Target

Daniel Bazin

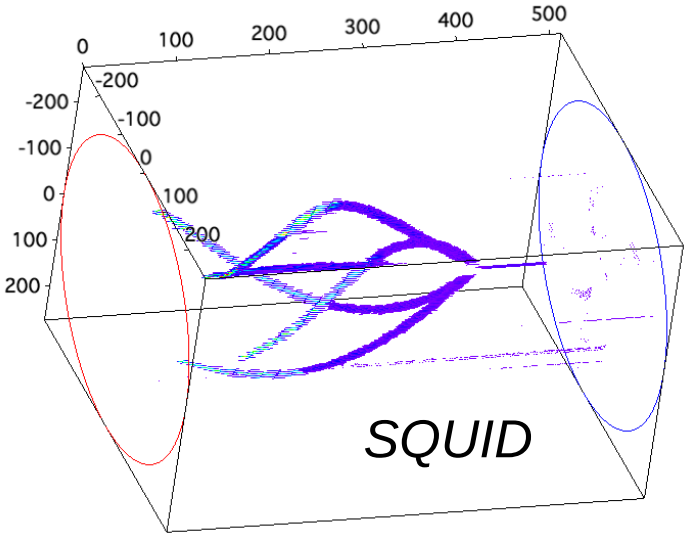
SOLARIS+ATTPC at FRIB(NSCL)

(t,p) (d,p) (d^2He)





CINAMON ROLL



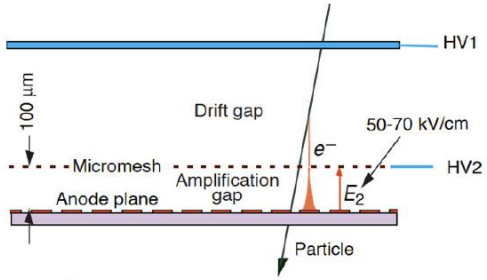
SQUID

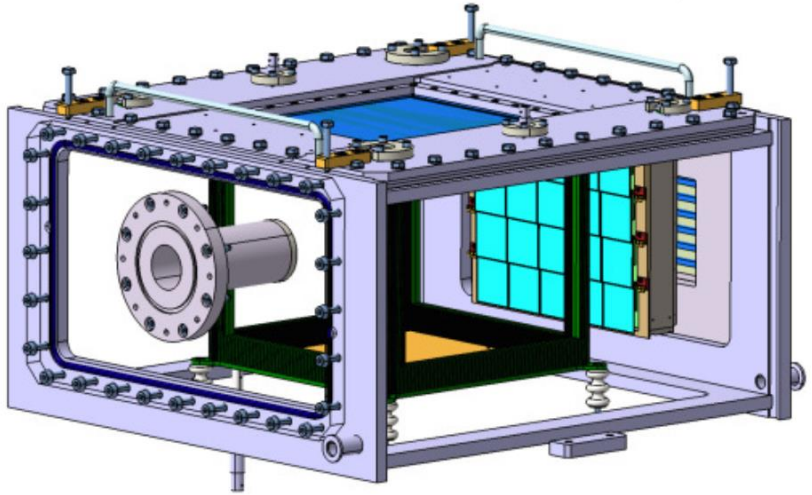
Active Target at GANIL

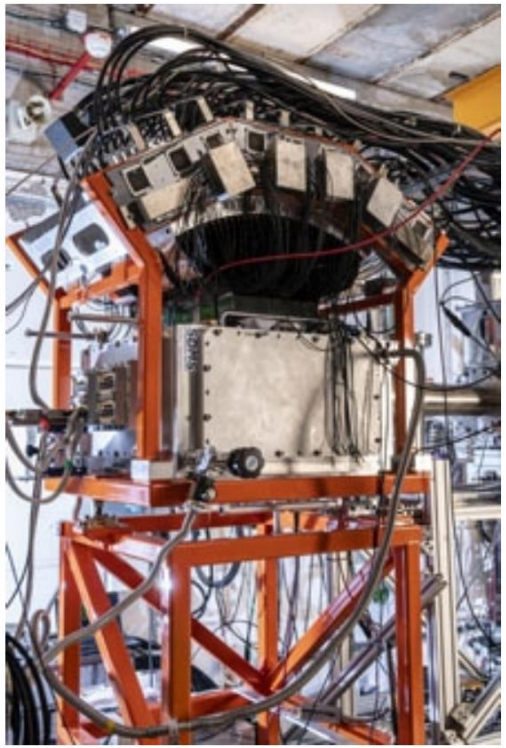
Beatriz Fernández-Domínguez

ACTAR TPC @ GANIL

- **Cubic geometry** field cage: 25.6 cm3
- **Highly segmented pad plane :** 16384 channels: 2x2 mm2.
- **Micromegas technology** (≈128 µm gap).
- **Ancillary detectors**
- **GET electronics**



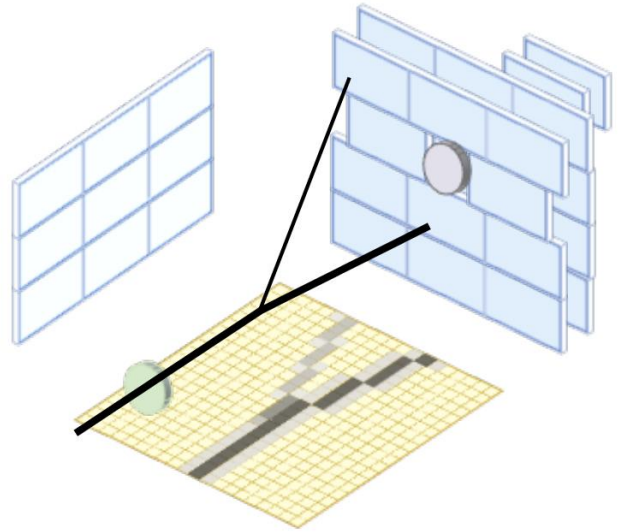


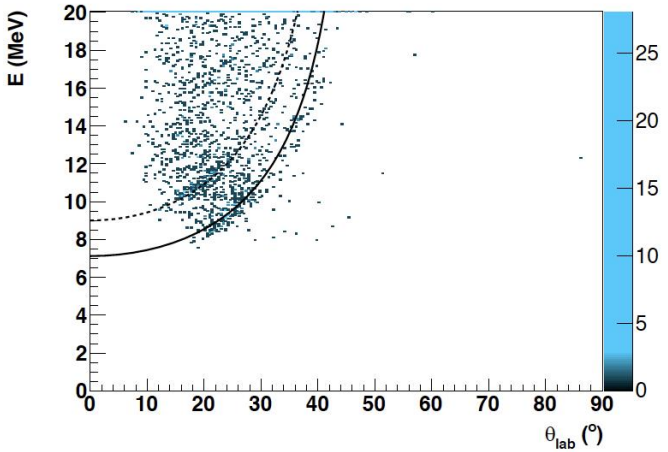


Information:

- Energy (from range or charge)
- Angle, Vertex
- Particle identification

Elastic/Inelastic/Transfer reactions e.g. (d,^{3}He)

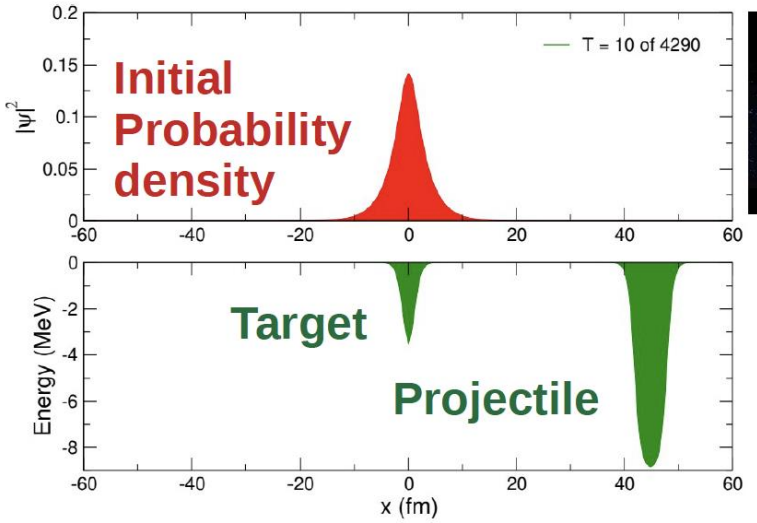


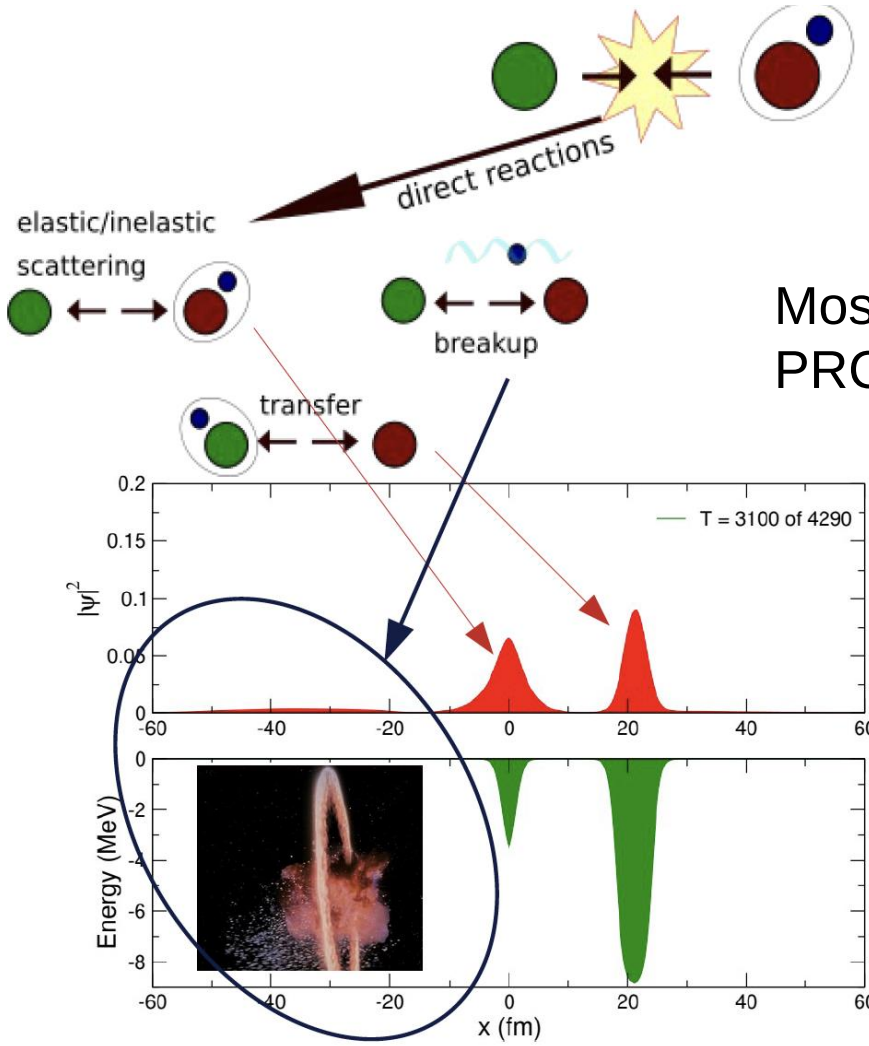


Theoretical Developments

Time-dependent Approach

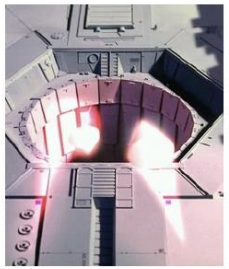
Laura Moschini

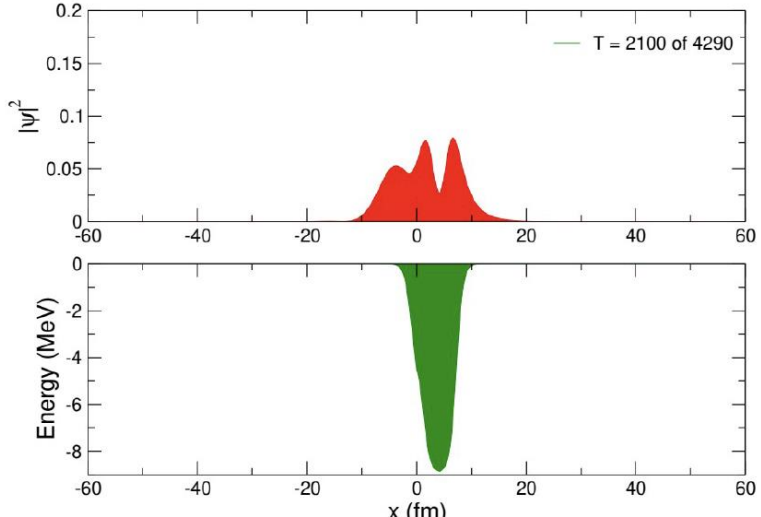




Moschini et al.
PRC103, 014604 (2021)

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \hat{H}\Psi(x,t)$$





Time dependent approach: Very Promising
→3D Treatment Necessary

Theory-Experiment

- Collaborations with theoreticians (both in reaction theory and structure theory) in any experimental papers are getting more and more important and imperative!

Special Thanks to

- Special Thanks to Local Organizing Committee:

M.J.G. Borge

D. Cortina

A.M. Moro

H. Alvarez-Pol

Y. Ayyad

J. Benlliure

O.Tengblad

J.L. Rodriguez

Muchas Gracias

Thanks a lot for making such a nice program

Tokyo Tech

Alessia Di Pietro
Alexandre Obertelli
Alison Laird
Andrea Vituri
Angela Bonaccorso
Augusto Macchiavelli
Benjamin Kay
Carlos Bertulani
David Morrissey
Dan Yang Pang
Ismael Martel
Kazuyuki Ogata
Mahananda Dasgupta
Natasha Timofeyuk
Nigel Orr
Petr Navrátil
Pierre Capel
Pierre Descouvemont
Riccardo Raabe
Rituparna Kanungo
Sean Freeman
Takashi Nakamura
Thomas Nilsson
Tom Aumann
Valdir Guimaraes
Wilton Catford
Yorick Blumenfeld

Muchas Gracias

Special Thanks to

All the Sponsors

Especially EPJA

Muchas Gracias

Thanks a lot for making the conference so enjoyable!

- To All the participants: Speakers, Poster presenters

Muchas Gracias

From Santiago de Compostela to Wiesbaden

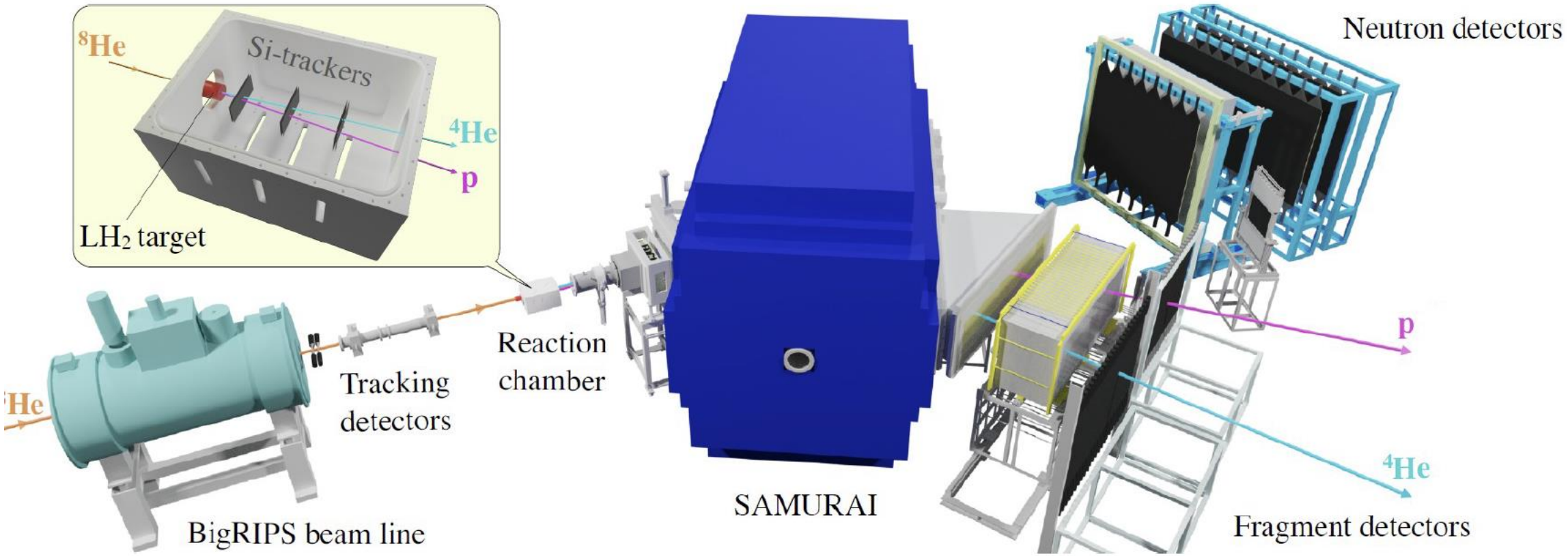
"Looking forward"

Auf Wiedersehen in Wiesbaden in 2024!

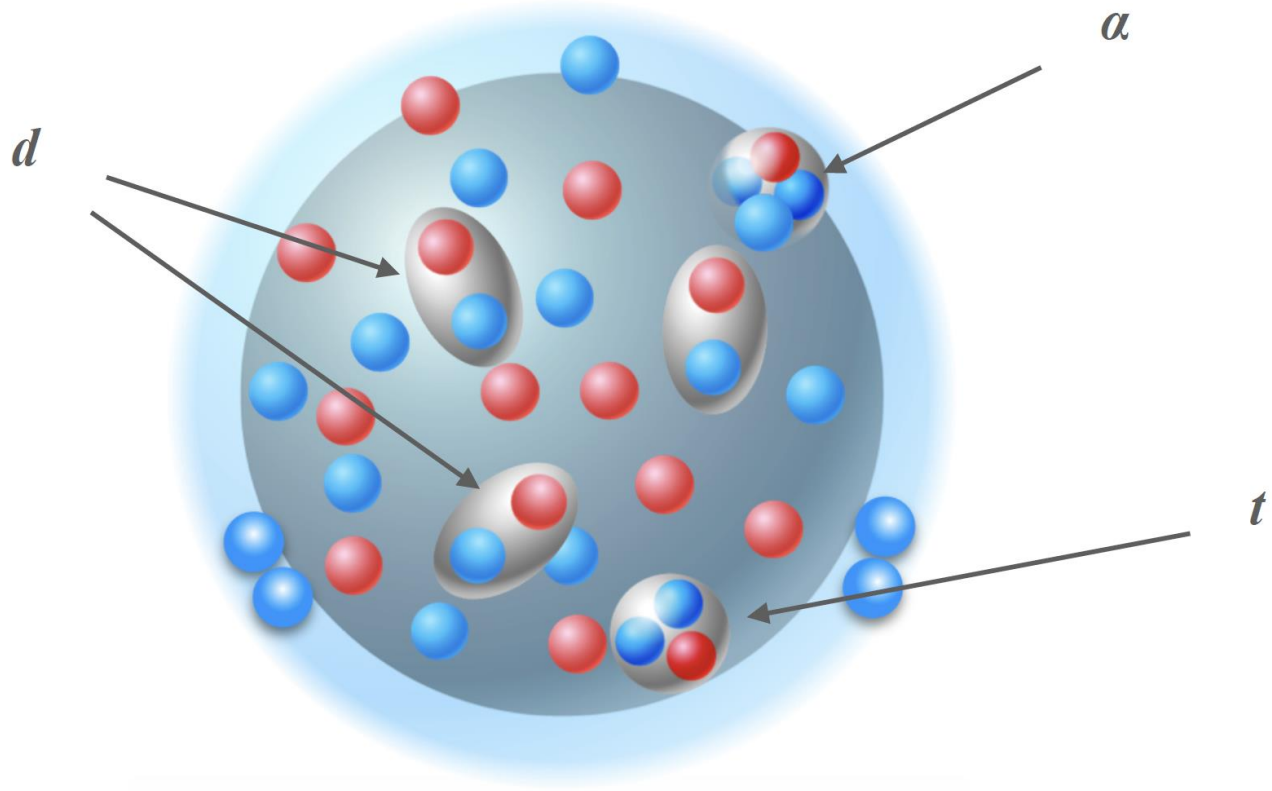
Backup

Tetra neutron at SAMURAI@RIBF

Maytal Duer



Clusters may appear in surface (low-dense region)



T. Uesaka