Detector systems for studying the structure of exotic nuclei at ACCULINNA-2 fragment separator

Anh Mai

ACCULINNA group,
Flerov Laboratory of Nuclear Reactions

Association of Young Scientists and Specialists
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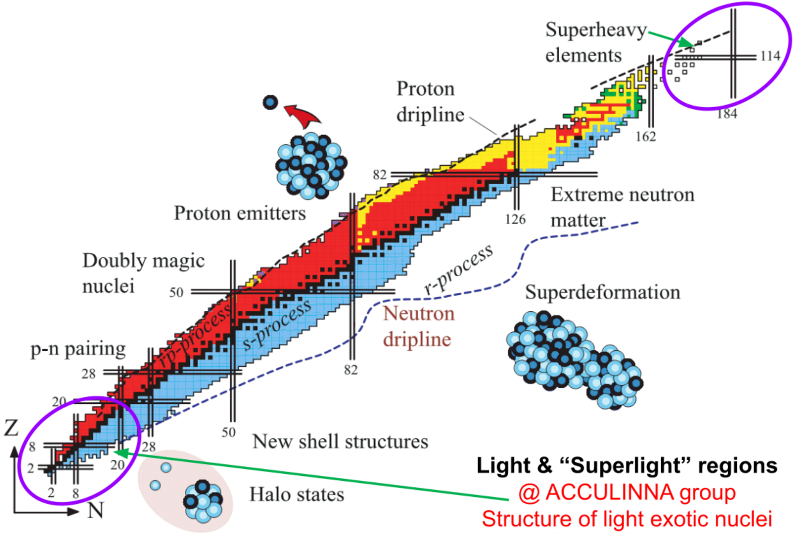
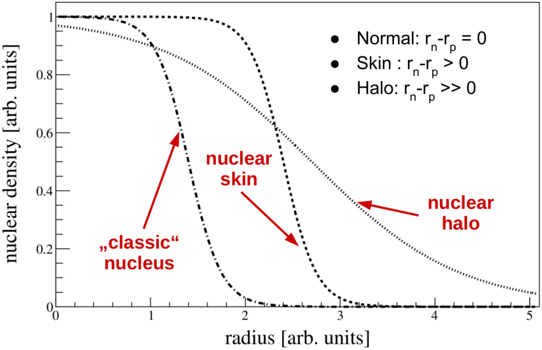
Main areas of interest at FLNR at nuclide chart



Light & "Superlight" regions
@ ACCULINNA group
Structure of light exotic nuclei
^{10}Li, $^{5-7}$H and $^{7-9}$He isotopes

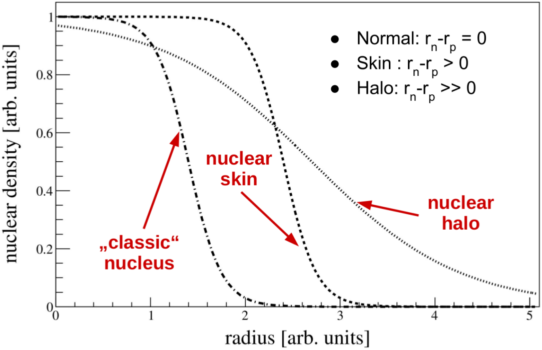
Why exotic nuclei?



Stable nuclei:

- N/Z = 1-1.5
- The average binding energy per nucleon is about 6-8 MeV
- $R \sim 1.2A^{1/3}$

Why exotic nuclei?



Stable nuclei:

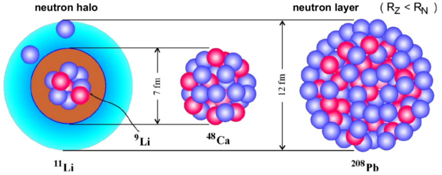
- $\mathrm{N/Z} =$ 1-1.5
- The average binding energy per nucleon is about 6-8 MeV
- $\mathrm{R} \sim 1.2\mathrm{A}^{1/3}$

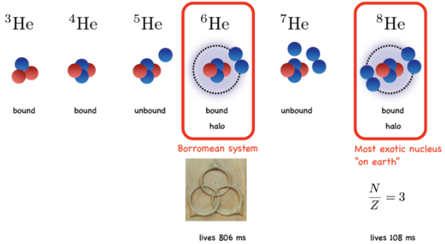
- extended size of nucleus
- tunneling to the forbidden regions

- $\mathrm{R} \neq 1.2\mathrm{A}^{1/3}$
- $\mathrm{p_n/p_p} \neq \mathrm{N/Z}$

B. Jonson P.G. Hansen, Europhys. Lett., 4(4):409–414, 1987.

Example of exotic nuclei



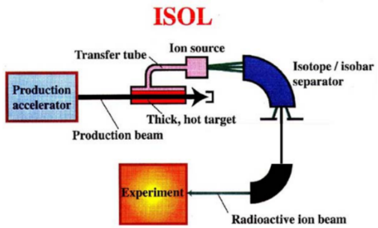


^{11}Li = ^{9}Li + n + n
^{11}Li-n ➡ ^{10}Li does not exist

^{6}He = ^{4}He + n + n
^{6}He-n ➡ ^{5}He does not exist

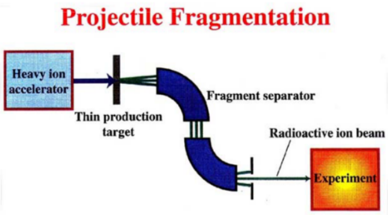
Production of Radioactive Ion Beams

The Isotope Separation-On-Line (ISOL) method



- thick production target, slow release
- reaction products to be extracted, ionized and re-accelerated
- high-quality secondary beam, $I < 10^8$ pps

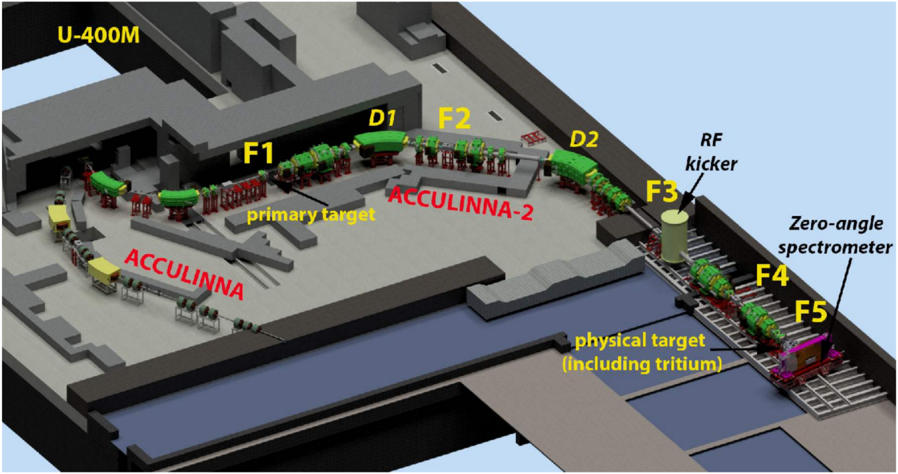
The in-flight method



- thin production target
- fast and does not depend on chemistry
- ions available at high energy
- secondary beam, $I < 10^6$ pps

Riccardo Raabe - KU Leuven, 30 years of RIB Physics, 2015.

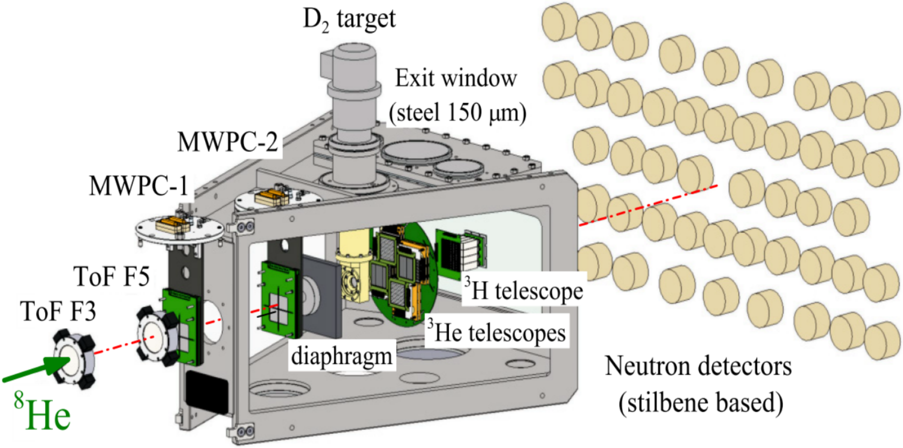
Beam production @ ACCULINNA-2



$^{11}B^{5+}$ @ 32 AMeV + 1 mm ^{9}Be → ACCULINNA-2 →∼ 90% and 10^5 pps ^{8}He @ 26 AMeV

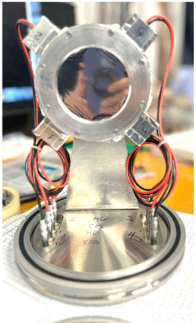
Reaction chamber @ final focal plane F5

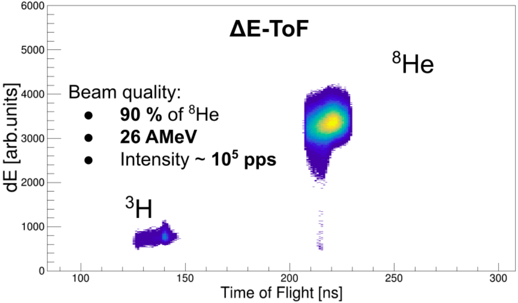
$^{8}\mathrm{He} + \mathrm{d} \rightarrow {}^{3}\mathrm{He} + {}^{7}\mathrm{H} \rightarrow {}^{3}\mathrm{H} + 4\mathrm{n}$

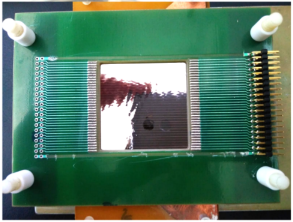


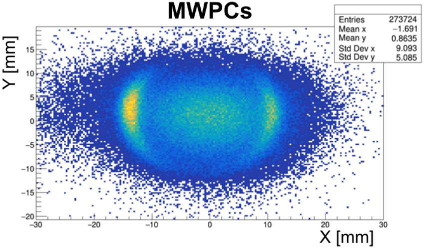
Reaction chamber in the experiment

Beam diagnostics

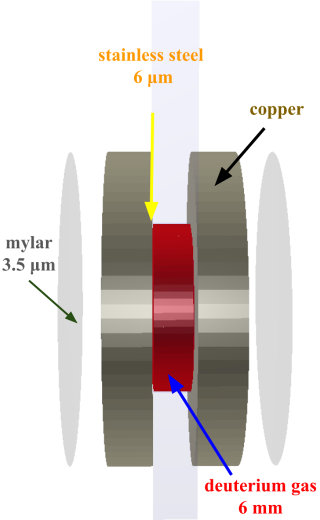


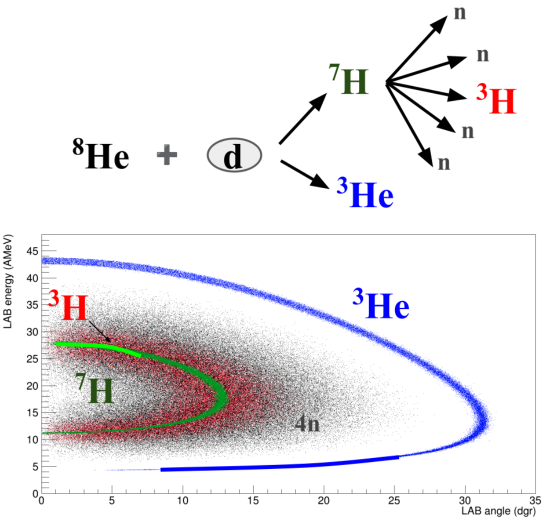






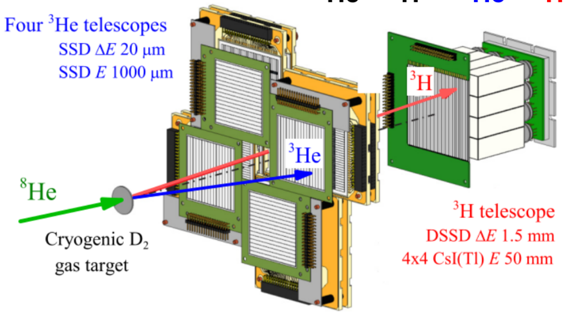
Monte Carlo simulation

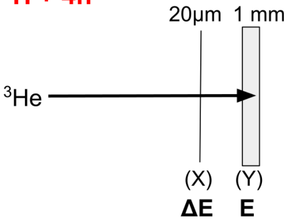


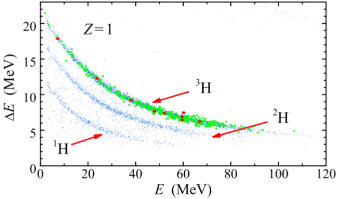


Charged-particle detectors

$^{8}He + {}^{2}H \rightarrow {}^{3}He + {}^{7}H \rightarrow {}^{3}H + 4n$

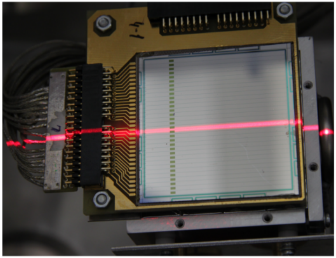




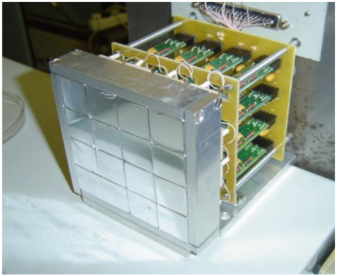


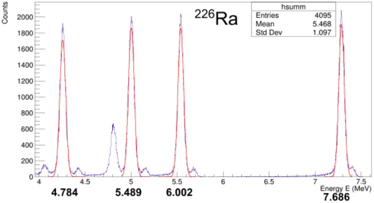
Charged-particle detectors (cont.)

Silicon Strip Detectors

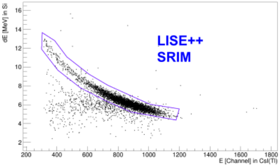


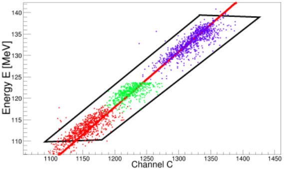
CsI(TI)





dE-E: CsI==8



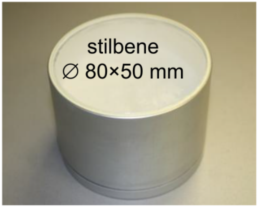


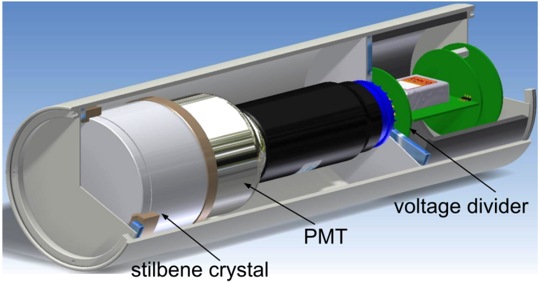
Neutron spectrometer

Stilbene crystals:

- high luminescence efficiency
- fast response time
- crystalline and solid
  $\rightarrow$ high durability,
  non-flammable
- greatly sensitive to neutrons
  $\rightarrow$ well-suited in our range
- excellent $n - \gamma$ discrimination

Neutron spectrometer





Stilbene crystals:

- high luminescence efficiency
- fast response time
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  $\rightarrow$ high durability,
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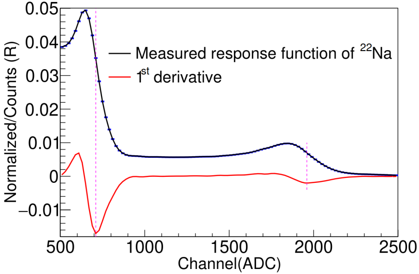
- greatly sensitive to neutrons
  $\rightarrow$ well-suited in our range
- excellent $n - \gamma$ discrimination

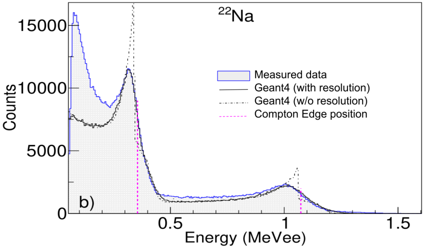
$\rightarrow$ Stilbene fit all qualifications and were implemented into MONES @ ACCULINNA-2.

Neutron spectrometer (cont.)

An example of Compton edge

from stilbene scintillator using $^{22}\mathrm{Na}$





Neutron spectrometer (cont.)

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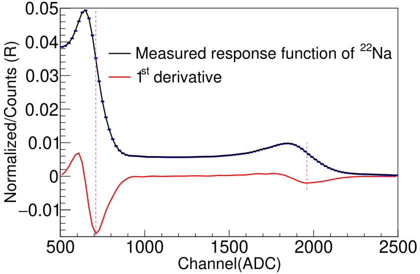
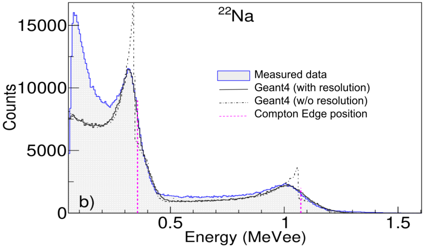
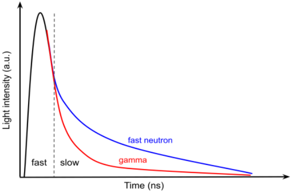




Timing signals for gamma and neutron in the scintillator.



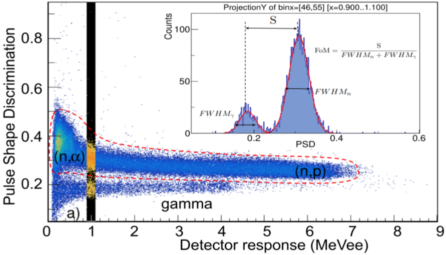


Illustration of neutron-gamma separation by

Pulse Shape Analysis from the 14-MeV neutron generator.

Conclusions

- the detector systems development for registering charged particles and neutrons along with MC simulation to estimate their properties,
- engage in the preparation and conduct of experiments,
- not only to analyze the data but also to **master the physical foundations** of the models underlying the description of nuclear reactions,
- a path way for PhD @ JINR, excel at Nuclear Physics - a **real physicist**.

Much appreciated for your attention.!

Publications

1. G. Kaminski et al. (A. M. Quynh), "Status of the new fragment separator Acculinna-2 and first experiments", Nuclear Instruments and Methods in Physics Research B, 463, 2019.
2. A. A. Bezbakh et al. (A. M. Quynh), "Evidence for the first excited state of $^{7}\mathrm{H}$", Physical Review Letters, 124, 022502, 2020.
3. I. A. Muzalevskii et al. (A. M. Quynh), "Resonant states in $^{7}\mathrm{H}$: Experimental studies of the $^{2}\mathrm{H}(^{8}\mathrm{He},^{3}\mathrm{He})$ reaction", Physical Review C, 103, 044313, 2021.
4. E. Yu. Nikolskii et al. (A. M. Quynh), "$^{6}\mathrm{H}$ states studied in the d($^{8}\mathrm{He},\alpha$) reaction and evidence of an extremely correlated character of the $^{5}\mathrm{H}$ ground state", Physical Review C, 105, 064605, 2022.
5. E. Yu. Nikolskii et al. (A. M. Quynh), "Study of proton and deuteron pickup reactions (d,$^{3}\mathrm{He}$), (d,$^{4}\mathrm{He}$) with $^{8}\mathrm{He}$ and $^{10}\mathrm{Be}$ radioactive beams at ACCULINNA-2 fragment separator", Nuclear Instruments and Methods in Physics Research B, 541, 2023.
6. A. A. Bezbakh et al. (A. M. Quynh), "Properties of the $^{7}\mathrm{He}$ ground state studied by the $^{6}\mathrm{He(d,p)}^{7}\mathrm{He}$ reaction", International Journal of Modern Physics E, 33, 2450002, 2024.
7. M. S. Golovkov et al. (A. M. Quynh), "Observation of a positive-parity wave in the low-energy spectrum of $^{7}\mathrm{He}$", Physical Review C, 109, L061602, 2024.
8. N. Sokolowska et al. (A. M. Quynh), "Decay study of $^{11}\mathrm{Be}$ with an optical time-projection chamber", Physical Review C, 110, 034328, 2024.

My contributions: Participating in the experiments, calibration and data analysis routines.