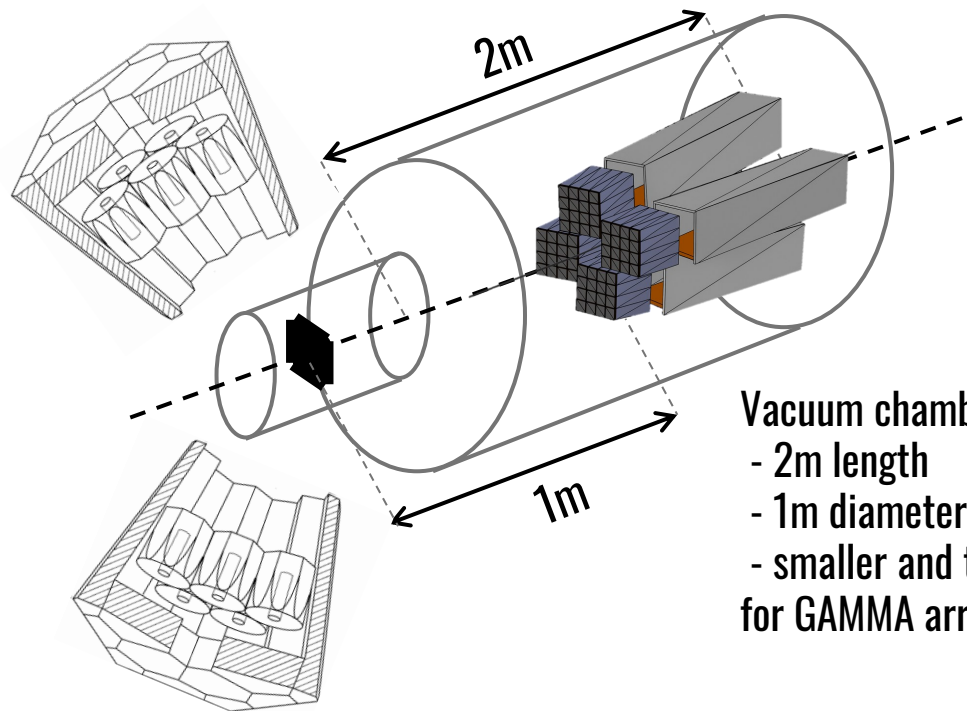
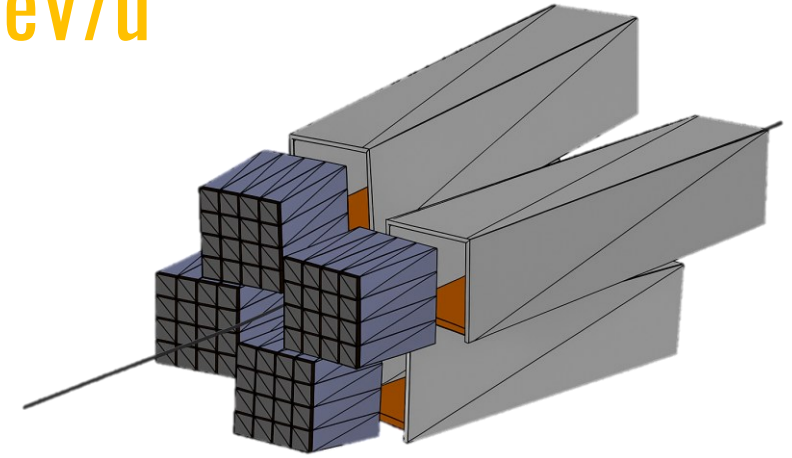


FAZIAEXPLORER: a possible research line at 30-80 MeV/u

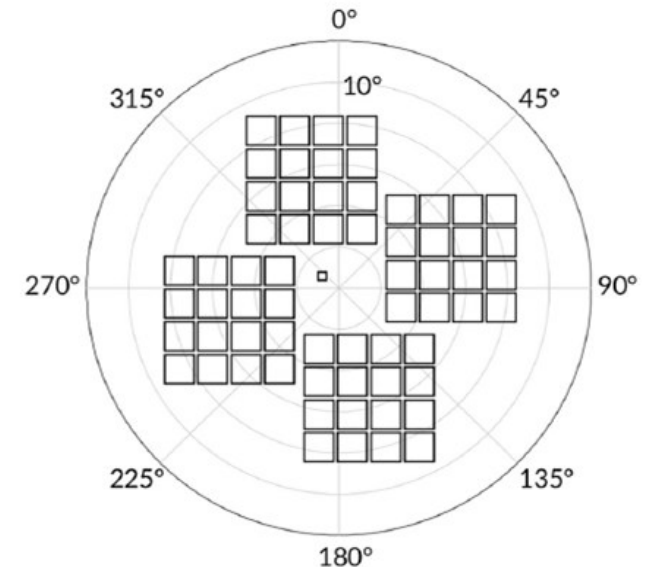
- Beam range: 30-80 MeV/u by degrading the primary fragmentation beams
- 4 +1 FAZIA blocks in stand-alone mode mounted in a wall configuration at forward angles, 1m distance from target. The +1 is for Zero Degree detections à la FAZIAZERO
- Polar range: about 2 to 9 degrees with a geometric efficiency in this range about 70%
- Additional Gamma Detector may be placed around the target. Is such configuration suitable for GRETA/GRETINA?



Vacuum chamber requirements:

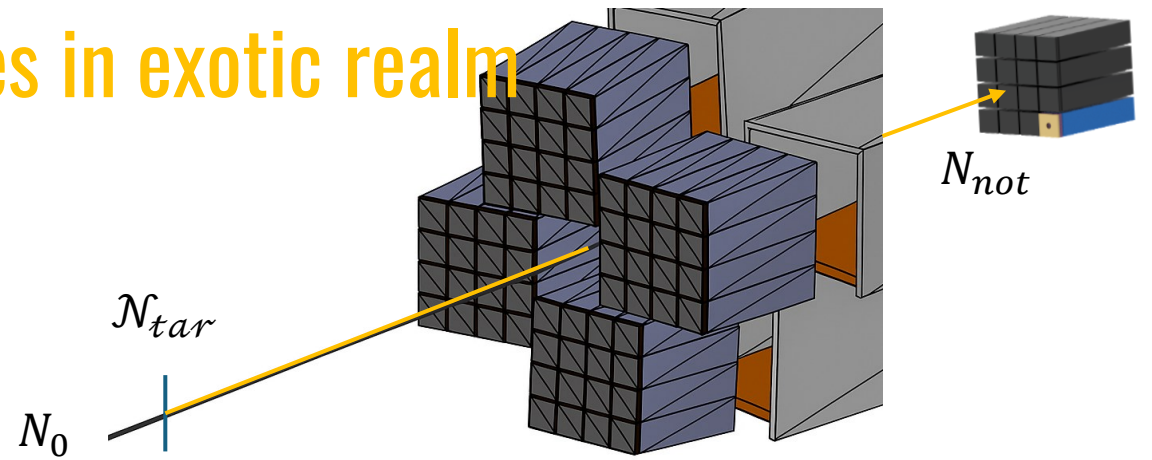
- 2m length
- 1m diameter
- smaller and thinner volume around the target for GAMMA array coupling

4 FAZIA Block polar plot at 1m



FAZIAEXPLORER: nuclear structure studies in exotic realm

- Not reacted beam:** ZeroDegree configuration
 For ions available only with very low currents some cross sections (interaction, charge exchange) could be measured with the transmission method



Reaction cross section: from not reacting particles

$$\sigma_{RCS} = \frac{1}{N_{tar}} \ln\left(\frac{N_{not}(Zb, Ab)}{N_0}\right)$$

Identification in charge and mass of not reacting beam
 Current measurement with 0.1% precision to infer on nuclear radii
 (from FAZIA ZERO proposal)

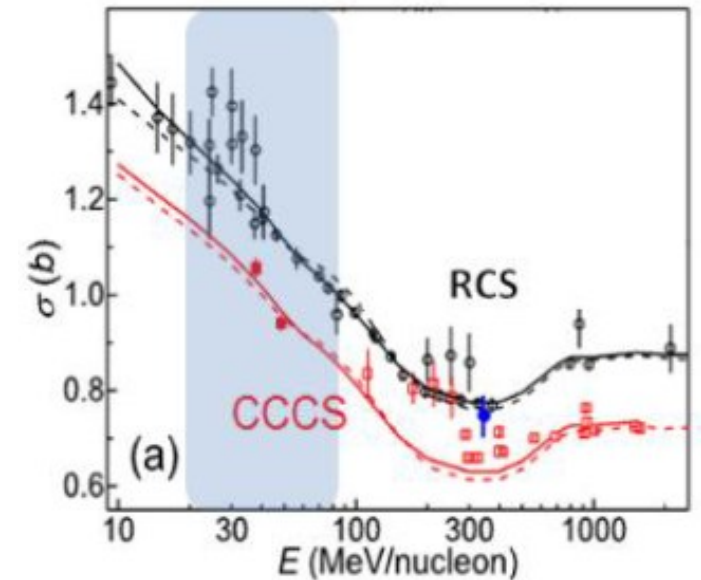
Charge change cross section: channel leading a charge change of the projectile

Glauber model (with modern refinements)
 and related theory to extract R_p

$$\sigma_{CCCS} = \frac{1}{N_{tar}} \ln\left(\frac{N_{not}(Zb)}{N_0}\right)$$

Determination of the nuclear and charge radius via Glauber Model (below 100 A MeV?)
 even if Charge Particle Evaporation Process should be taken into account

(not clear the CPEP effect)



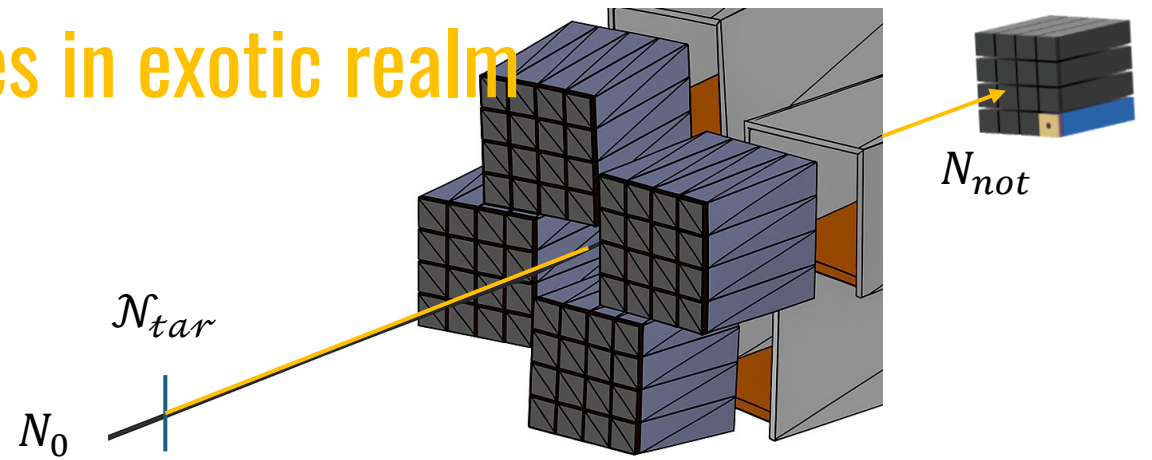
12C+12C from FAZIAZero Proposal

M. Tanaka et al PRC 106 (2022) 014617.

J.W. Zhao et al., Phys. Lett. B 847 (2023) 138269.

FAZIAEXPLORER: nuclear structure studies in exotic realm

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H. H. Li et al, PHYSICAL REVIEW C 109, L061304 (2024)

Halo nuclei:

- 6He, 11Li, 14Be, 17B, 22C, and 29F (2n-halo)
- 11Be, 15,19C, 31Ne, and 37Mg (1n-halo)

Charge change cross section: channel leading a charge change of the projectile

Glauber model (with modern refinements)
 and related theory to extract R_p

$$\sigma_{CCCS} = \frac{1}{N_{tar}} \ln\left(\frac{N_{not}(Zb)}{N_0}\right)$$

Signature halo vs n-skin
 (necessary but not sufficient)

Halo -> sudden σ_{RCS} increases while constant σ_{CC} along an isotopic chain

Determination of the nuclear and charge radius via Glauber Model (below 100 AMeV?)
 even if Charge Particle Evaporation Process should be taken into account

n-skin -> gradual σ_{RCS} divergence respect to σ_{CC} along an isotopic line

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FAZIAEXPLORER: nuclear structure studies in exotic realm

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Reaction cross section: from not reacting particles

$$\sigma_{RCS} = \frac{N_0 - N_{not}(Z_{beam}, A_{beam})}{\mathcal{N}_{tar}}$$

Identification in charge and mass of not reacting beam
Current measurement with 0.1% precision to infer on nuclear radii
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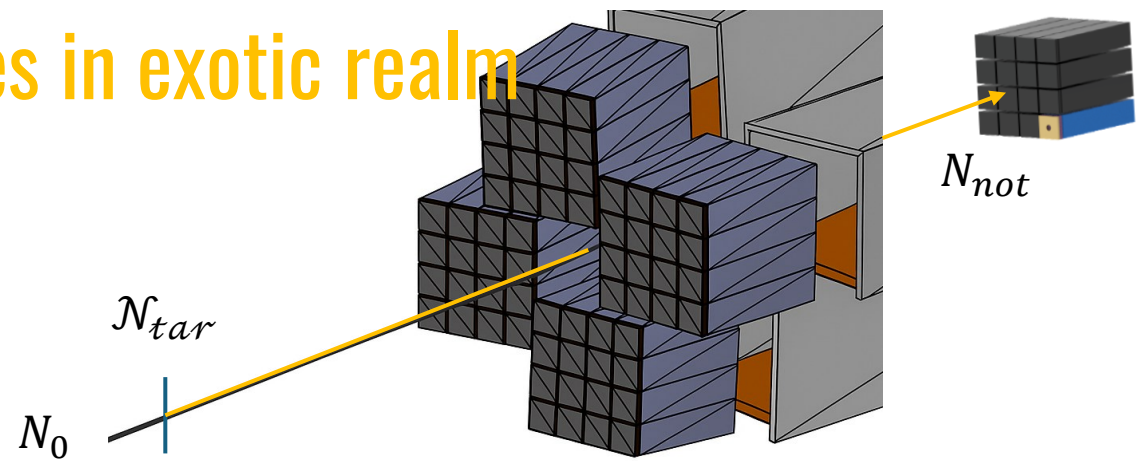
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H. H. Li et al, PHYSICAL REVIEW C 109, L061304 (2024)

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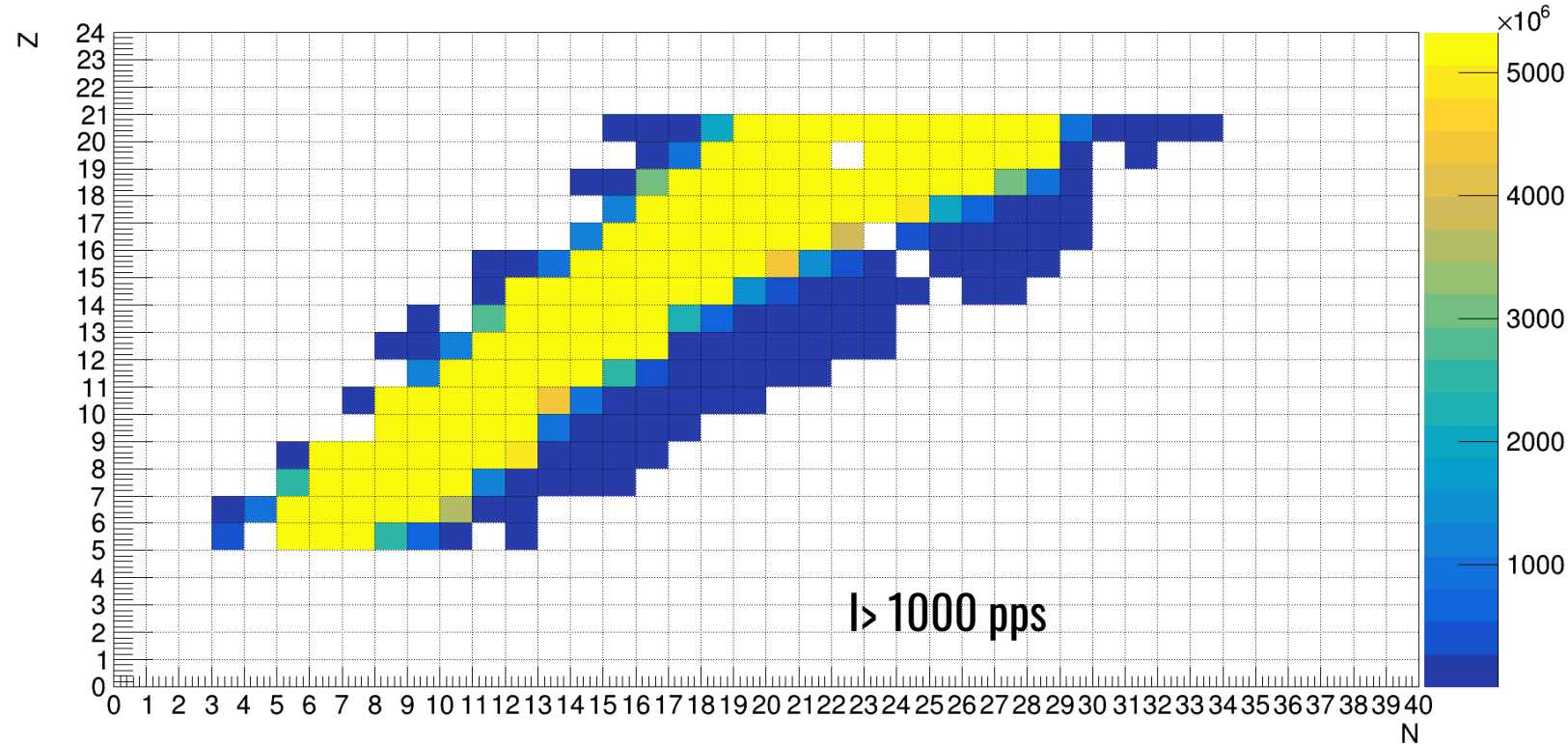
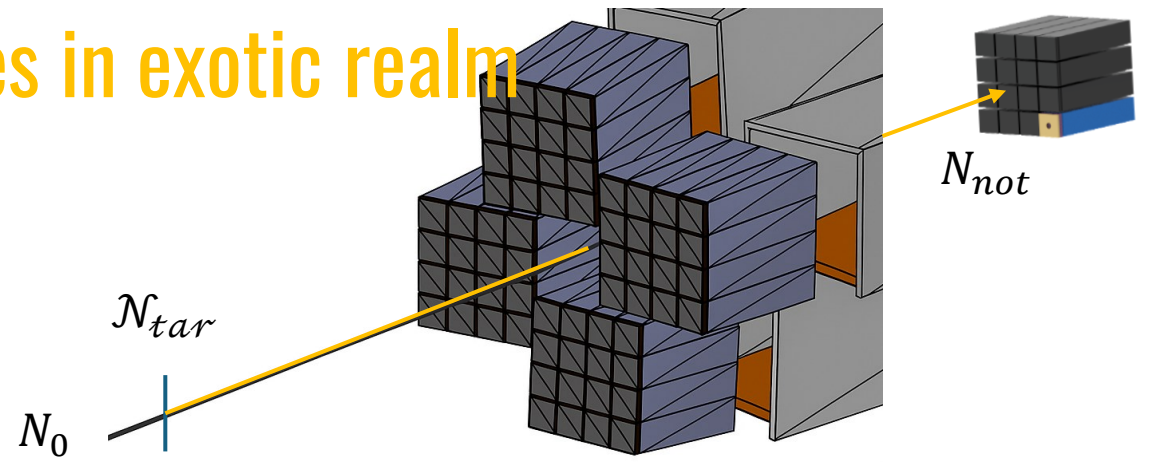
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(necessary but not sufficient)

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FAZIAEXPLORER: nuclear structure studies in exotic realm

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H. H. Li et al, PHYSICAL REVIEW C 109, L061304 (2024)

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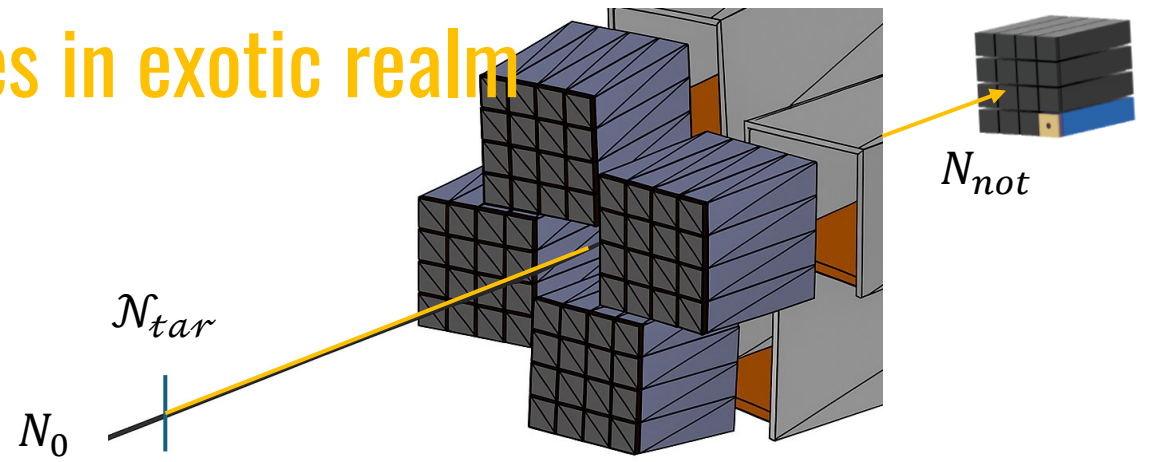
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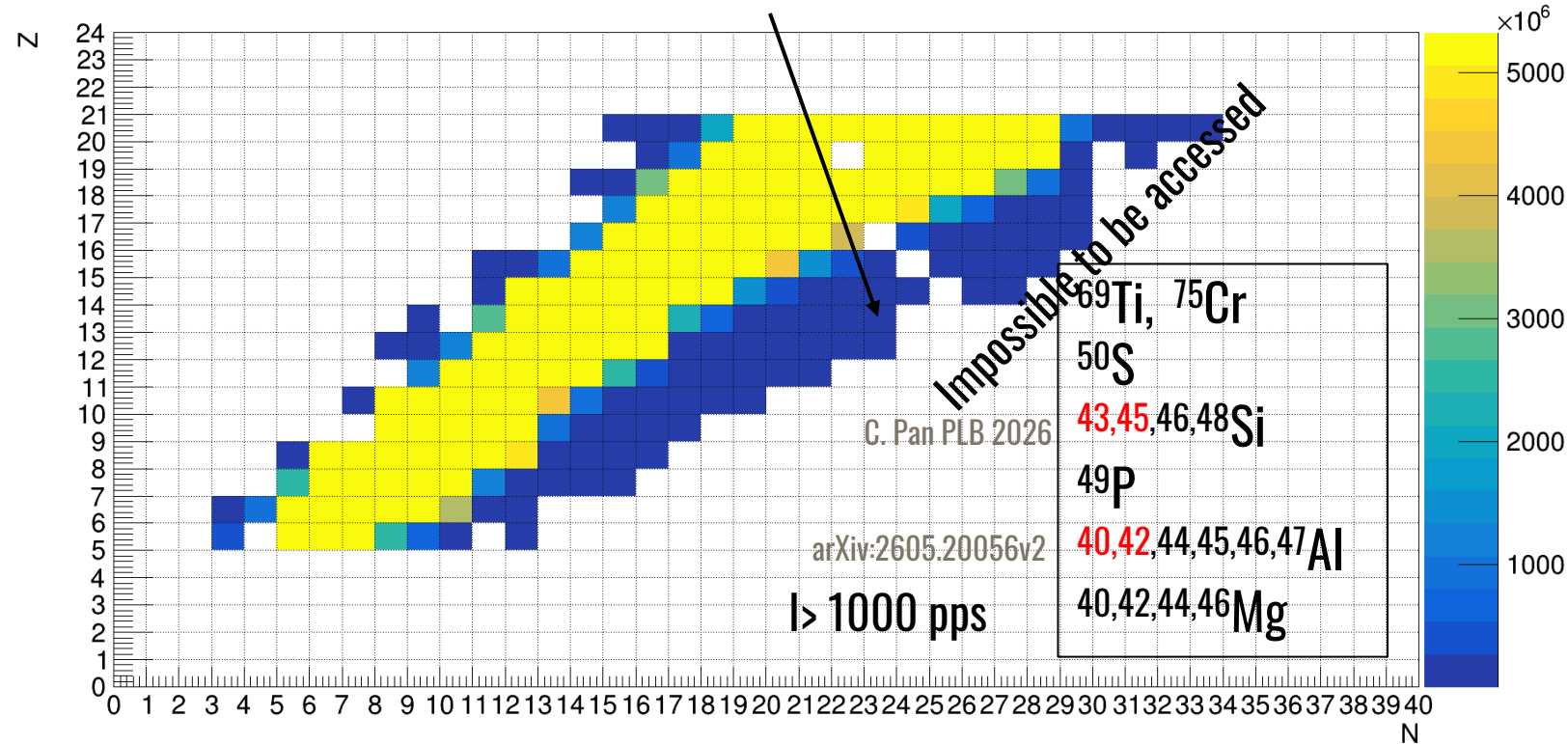
- Halo \rightarrow sudden σ_{RCS} increases while constant σ_{CC} along an isotopic chain
- n-skin \rightarrow gradual σ_{RCS} divergence respect to σ_{CC} along an isotopic line

FAZIAEXPLORER: nuclear structure studies in exotic realm

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^{36}Al



H. H. Li et al, PHYSICAL REVIEW C 109, L061304 (2024)

Halo nuclei:

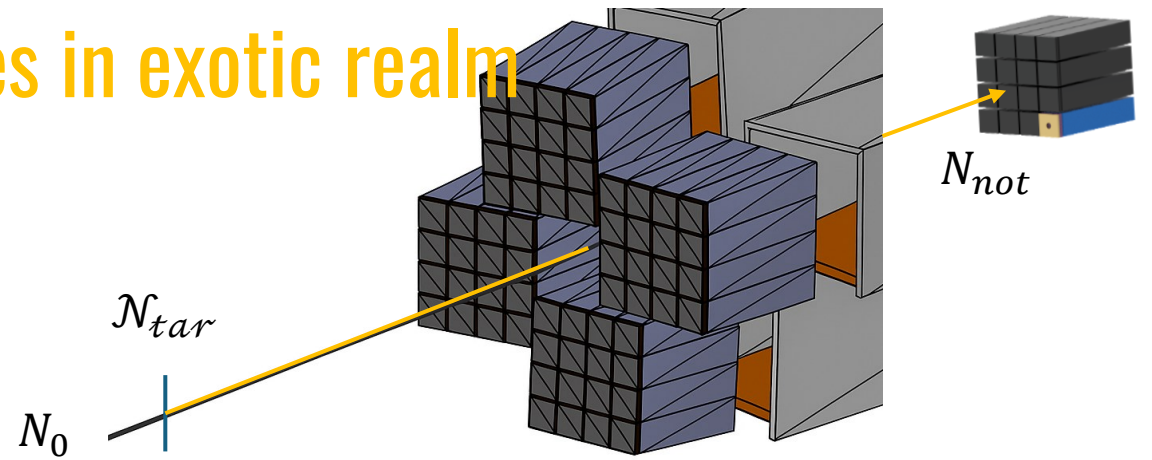
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- ^{11}Be , $^{15,19}\text{C}$, ^{31}Ne , and ^{37}Mg (1n-halo)

Candidates:

The neutron-rich Mg, Al, Si, P, and S isotopes provide excellent conditions for the study of halo structures and isotopic identification of nuclei of such size should be achieved with FAZIA in the Fermi domain

FAZIAEXPLORER: nuclear structure studies in exotic realm

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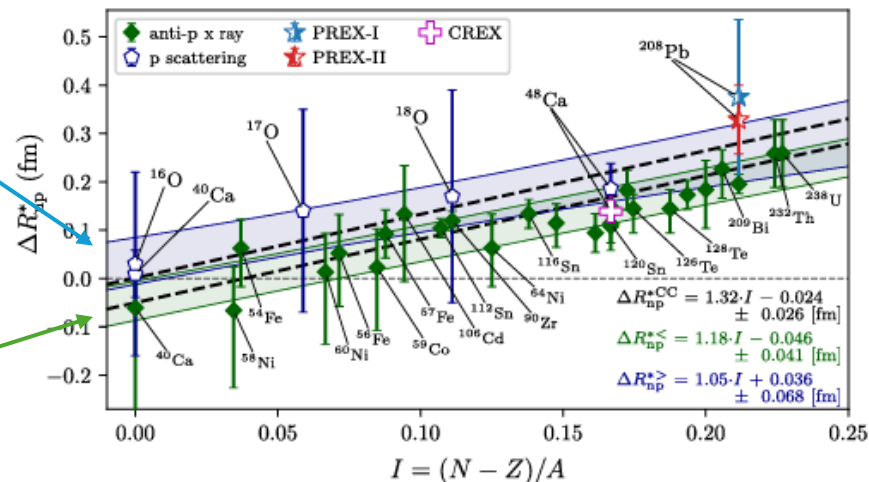
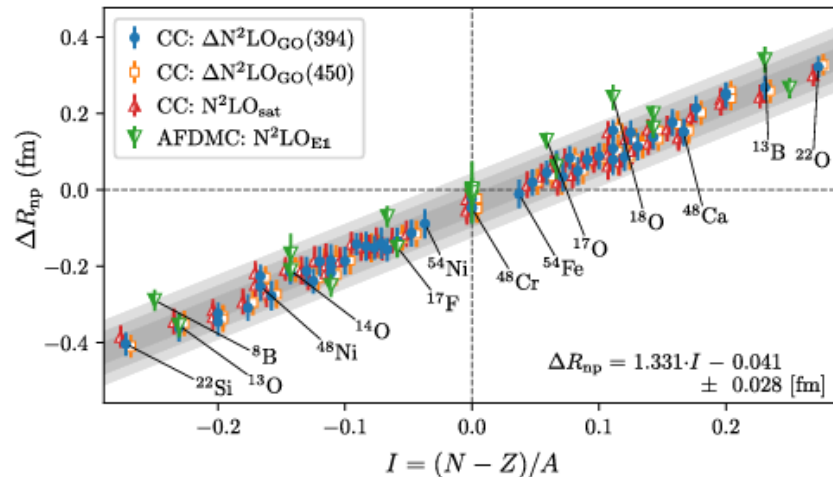
Novario et al PRL 130, 032501 (2023)

Ab initio Coupled Cluster

- $$\Delta R_{np} \sim k \frac{N-Z}{A}$$

and once Coulomb is taken into account

- $$\Delta R_{np}^{Coul} \approx -ZA^{-1/3} \times 0.0033 fm$$

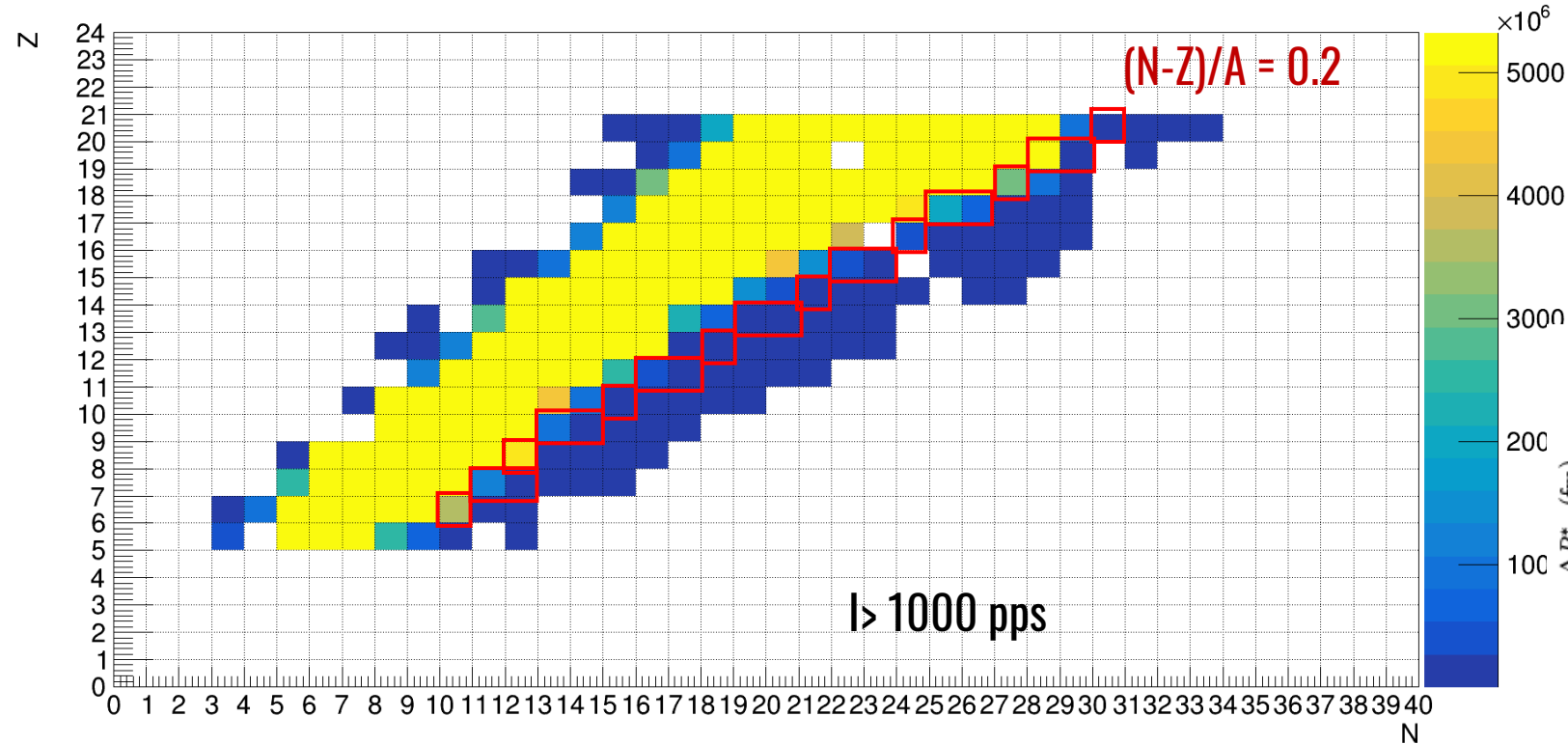
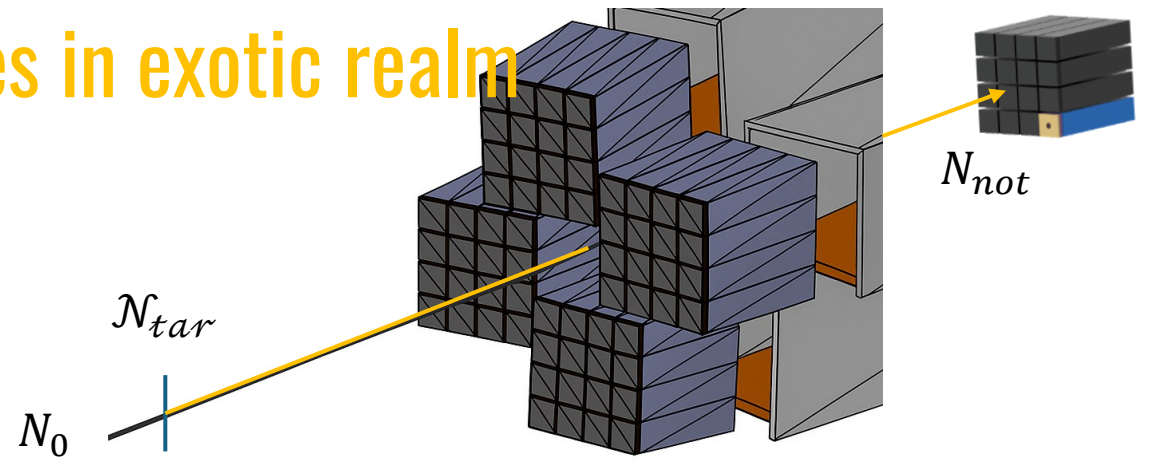


O(p,p)
Ca(p,p)

Anti-p
x-ray

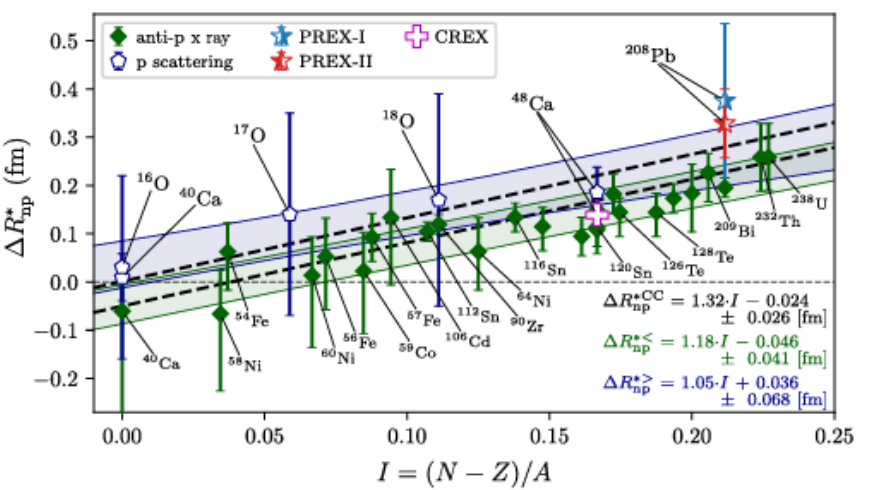
FAZIAEXPLORER: nuclear structure studies in exotic realm

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Novario et al PRL 130, 032501 (2023)

N-skin nuclei:
 All these nuclei are good candidates for transmission method



FAZIAEXPLORER: nuclear structure studies in exotic realm

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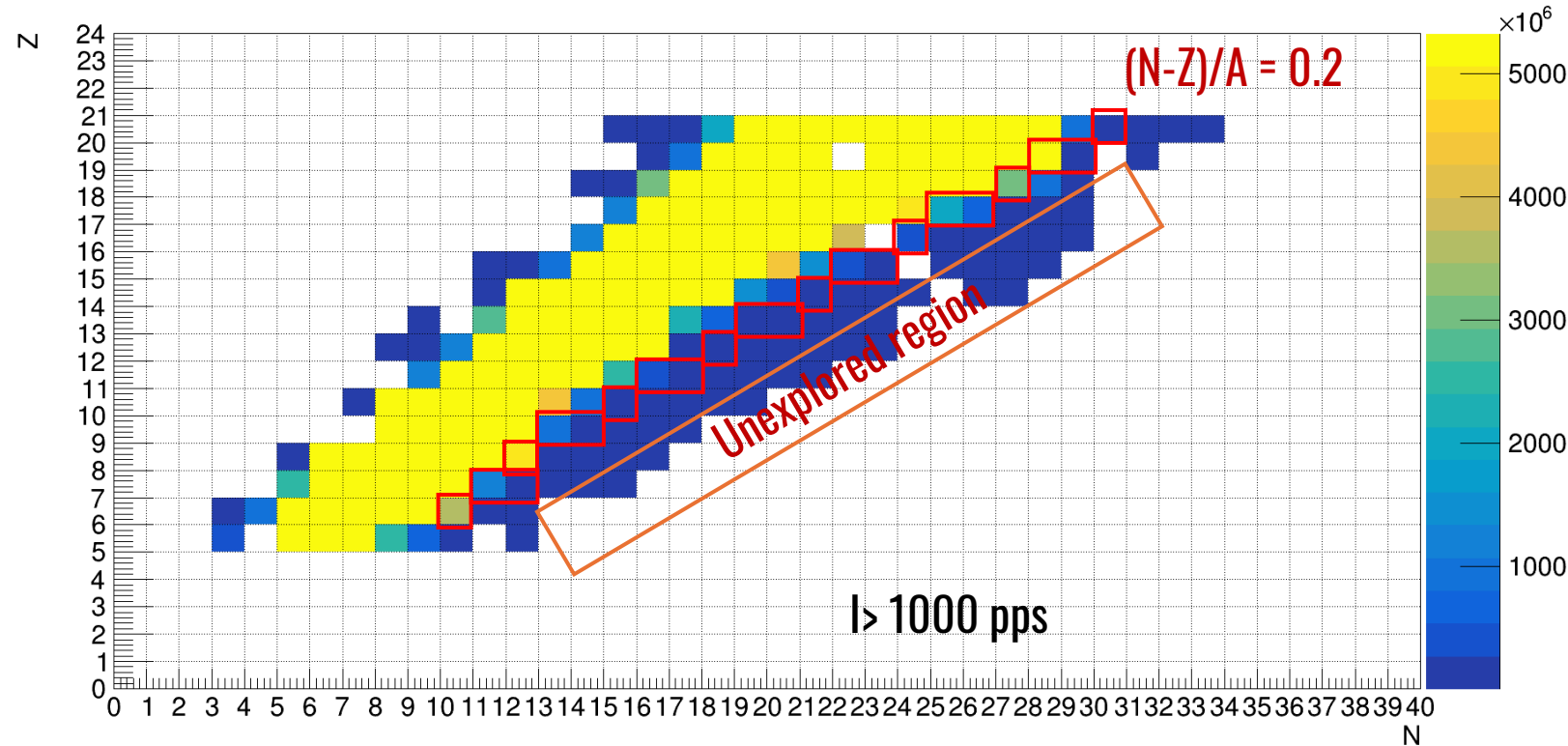
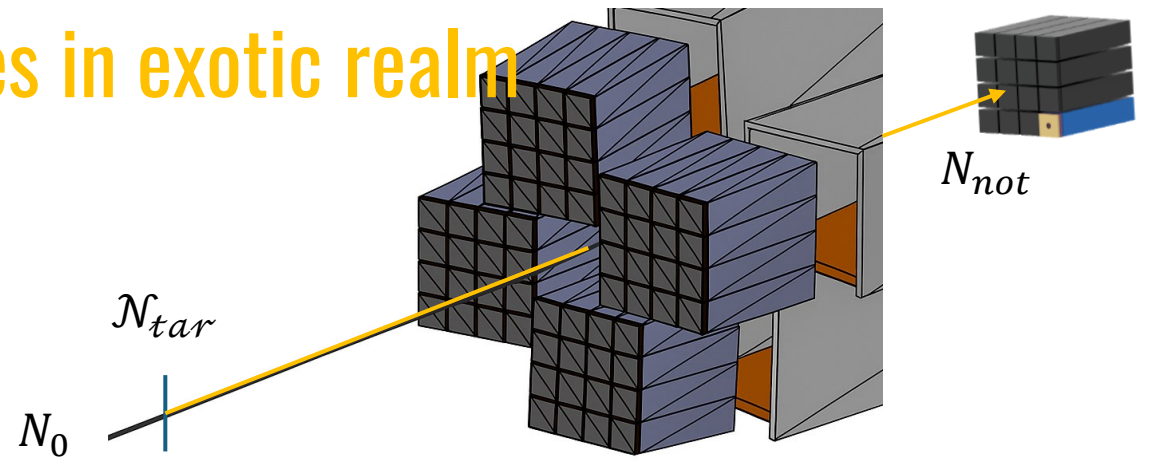


Table 1
 R_{ch} and R_p of $^{11-16}\text{C}$, $^{13-17}\text{N}$ and $^{15-18}\text{O}$ extracted from their experimental CCCSs, which include the ones measured in the present work (i.e., CCCSs of $^{12-16}\text{C}$, $^{14-17}\text{N}$ and ^{16}O), published in our previous paper [24] and Ref. [20].

	Energy (MeV/u)	CCCS (mb)	R_p (fm)	R_{ch} (fm)	
^{11}C	319 (38)	716 (20) ^a	2.18 (12)	2.32 (11)	
	228 (9)	723 (23)	2.41 (24)	2.54 (22)	
	294 (5)	731 (52) ^a	2.40 (26)	2.53 (25)	
^{13}C	231 (8)	720 (25)	2.28 (21)	2.41 (20)	
	322 (30)	729 (22) ^a	2.30 (13)	2.42 (13)	
	234 (7)	707 (13)	2.33 (21)	2.45 (20)	
^{14}C	339 (12)	732 (22) ^a	2.38 (13)	2.50 (13)	
	287	731 (5) ^b	2.36 (10)	2.48 (9)	
	236 (7)	749 (19)	2.44 (21)	2.56 (20)	
^{15}C	327 (16)	758 (56) ^a	2.44 (28)	2.56 (27)	
	285	743 (6) ^b	2.36 (9)	2.47 (8)	
	237 (6)	738 (17)	2.46 (22)	2.57 (21)	
^{16}C	284	726 (6) ^b	2.33 (10)	2.44 (10)	
	^{13}N	310 (29)	752 (35) ^a	2.23 (17)	2.37 (16)
		223 (7)	843 (32)	2.47 (19)	2.59 (18)
289 (4)		878 (77) ^a	2.62 (31)	2.74 (30)	
^{15}N	226 (6)	808 (15)	2.46 (17)	2.58 (16)	
	315 (21)	815 (11) ^a	2.47 (9)	2.59 (9)	
	227 (3)	860 (21)	2.56 (16)	2.67 (15)	
^{16}N	322 (18)	813 (9) ^a	2.38 (7)	2.50 (7)	
	236 (3)	809 (17)	2.46 (17)	2.57 (16)	
	328 (13)	790 (11) ^a	2.35 (9)	2.47 (9)	
^{17}N	301 (24)	880 (18) ^a	2.57 (10)	2.69 (9)	
	219 (5)	862 (17)	2.61 (20)	2.73 (19)	
	288	852 (17) ^b	2.54 (11)	2.66 (10)	
^{17}O	308 (12)	866 (11) ^a	2.51 (8)	2.62 (8)	
	294	896 (9) ^b	2.61 (8)	2.72 (7)	
	368 (2)	887 (39) ^a	2.66 (17)	2.76 (17)	
^{18}O	299	891 (10) ^b	2.67 (9)	2.78 (9)	

To be competitive
 We need CCCS
 measurement with
 1-4% precision

E.g.
 W. Zhao, B.A. Sun et al
 Phys. Lett. B 858 (2024) 139082

^a Data measured with the same setup, already published in Ref. [24].
^b Data from Ref. [20].

FAZIAEXPLORER: nuclear structure studies in exotic realm

- **Mirror nuclei method:** Brown PRL 119 122502 (2017)

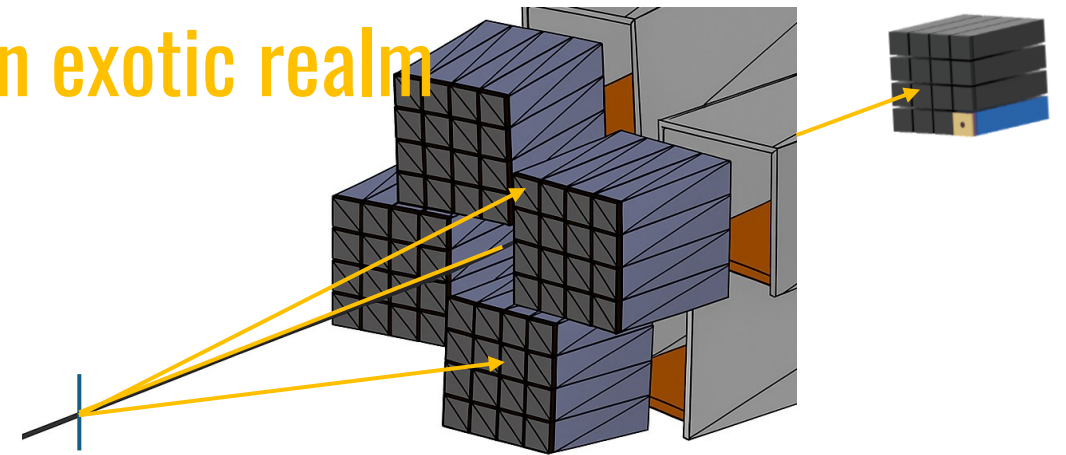
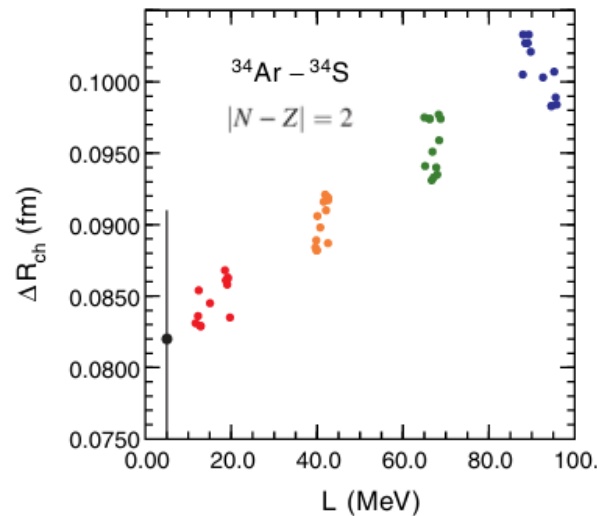
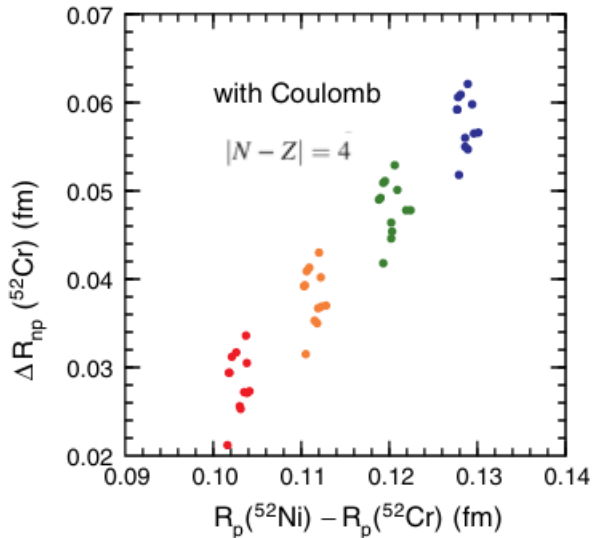
The n-skin nuclei can be measured by exploiting mirror nuclei

$$R_{skin} = R_n - R_p$$

but for mirror nuclei $R_p(Z, N) = R_n(N, Z)$ once Coulomb is taken into account. So ..

$$R_{skin}(Z, N) = R_p(N, Z) - R_p(Z, N)$$

and R_p can be extracted from CCCS and Glauber model.



Mirror-nuclei radii are sensitive to the stiffness of EoS. The larger the N-Z gap of the nuclei, the larger the sensitivity

${}^{34}_{18}\text{Ar}_{16}$	3×10^9 pps	N-Z = 2
${}^{34}_{16}\text{S}$	5×10^{10} pps	
${}^{26}_{15}\text{P}_{11}$	1×10^6 pps	N-Z = 4
${}^{26}_{11}\text{Na}_{15}$	2×10^9 pps	

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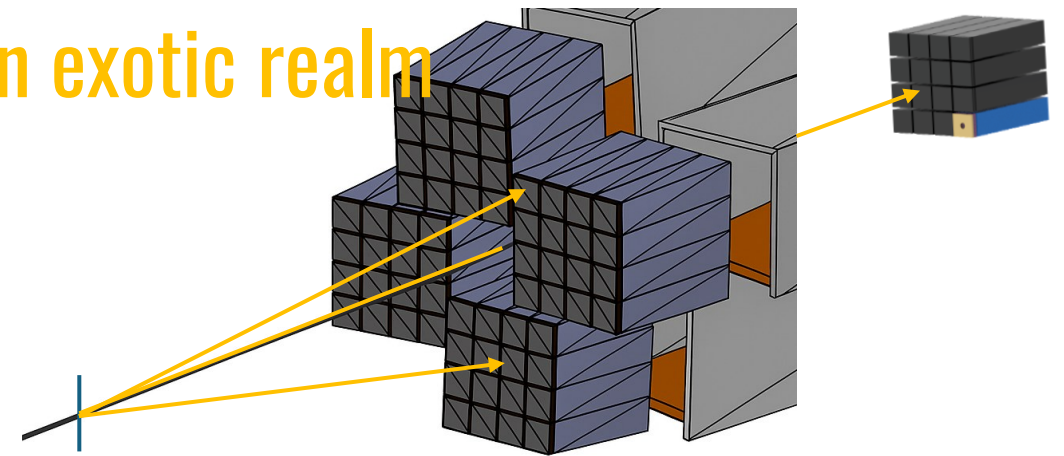
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Methodology:

- Transmission Mode
- Differential cross sections:
 - Z identification mandatory, A very useful
 - Extrapolation with model like DWBA or QMD below 2-8°
 - Theory more challenges to extract R_p from CCCS



Mirror-nuclei radii

are sensitive to the stiffness of EoS.

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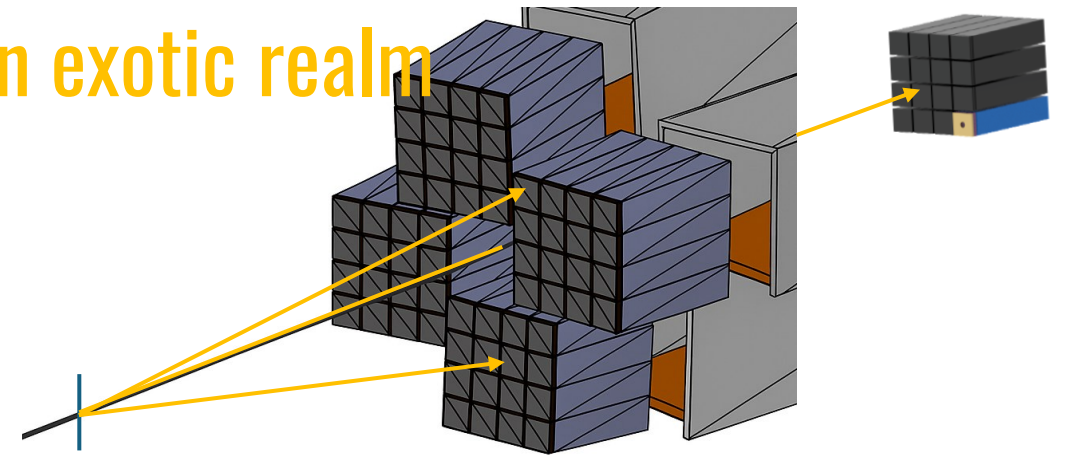
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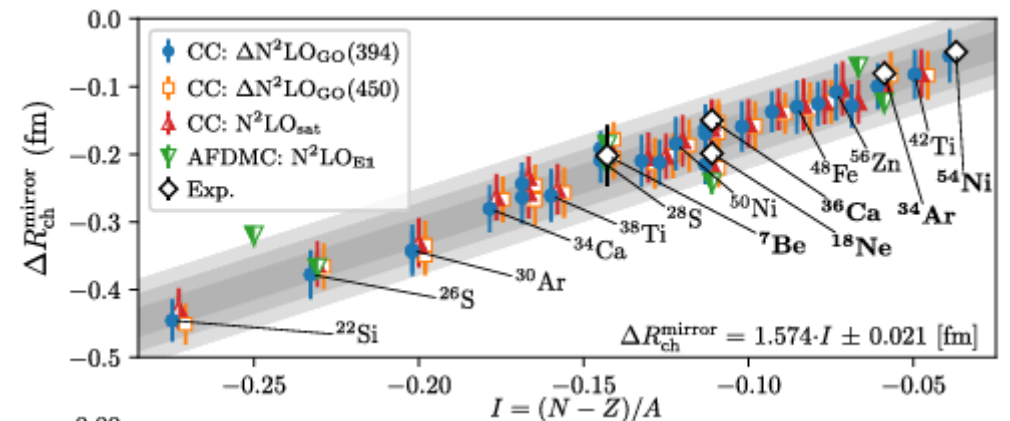
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Novario et al PRL 130, 032501 (2023)

$$\Delta R_{ch}^{Mirror} \approx 1.754 * I \pm 0.021$$



Linear trend of the mirror-nuclei charge radius with the isospin

FAZIAEXPLORER: nuclear structure studies in exotic realm

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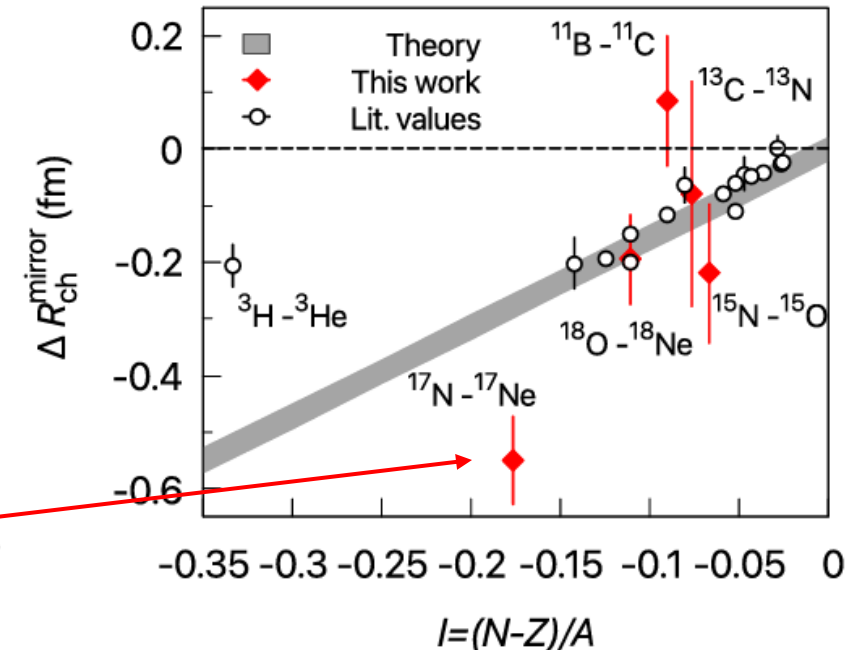
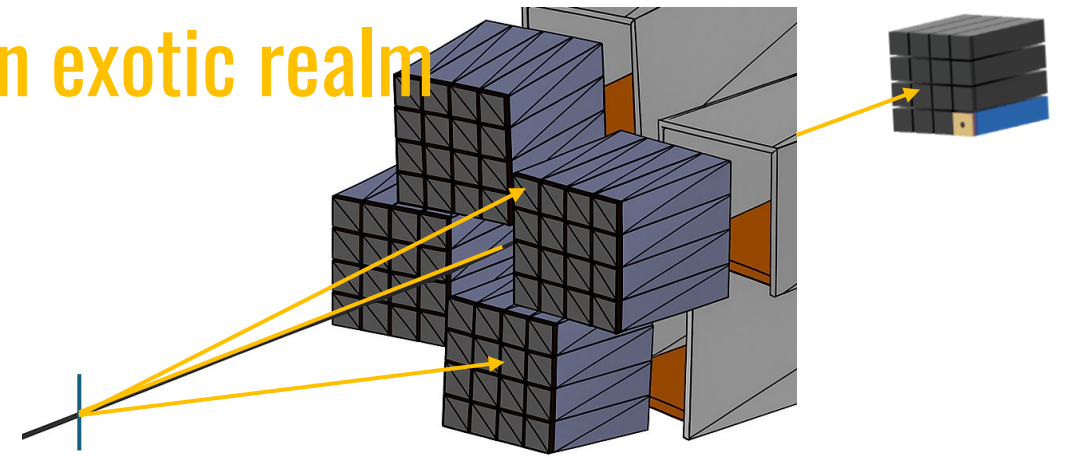
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“A deviation of ΔR_{ch}^{mirror} from Novario et al PRL correlation implies an anomaly in the nuclear structure contributing to the isospin symmetry breaking within the mirror pairs”

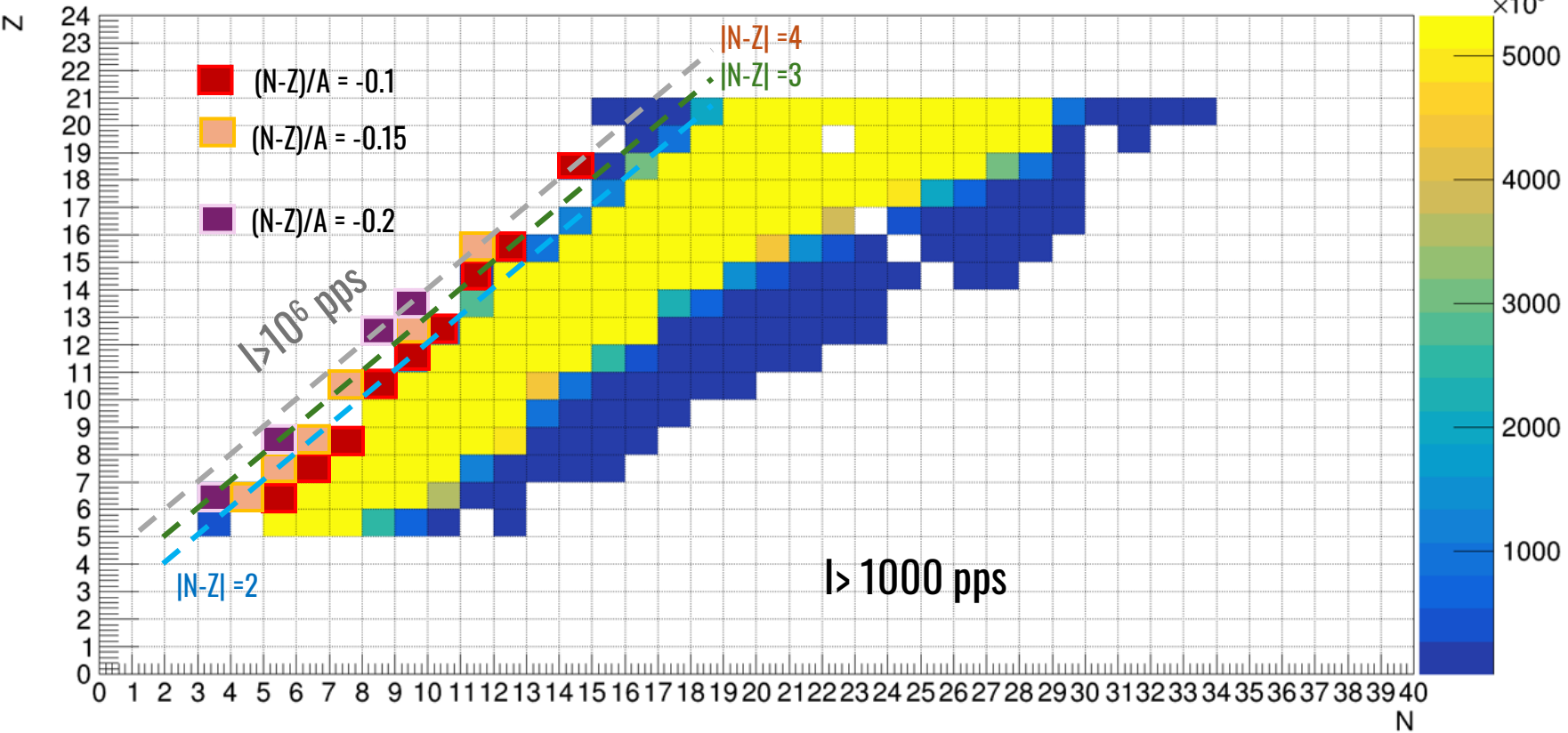
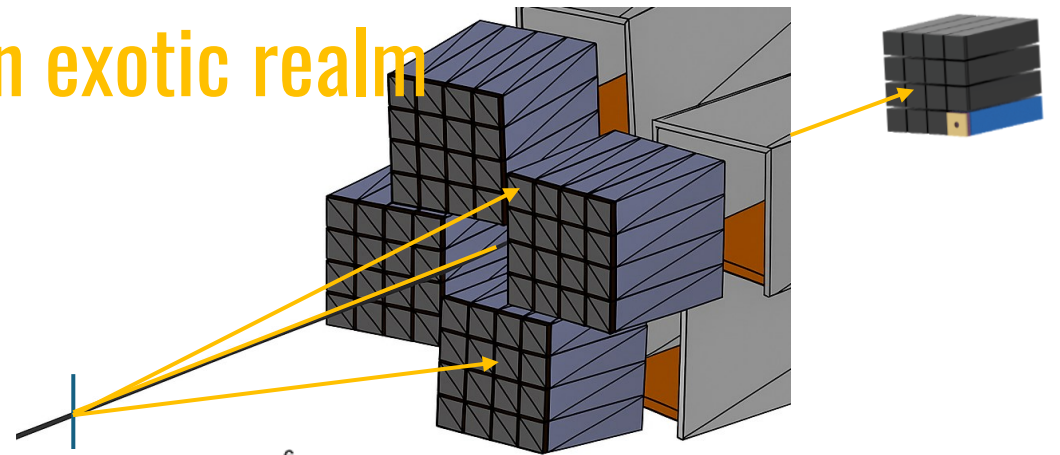
W. Zhao, B.A. Sun et al
Phys. Lett. B 858 (2024) 139082



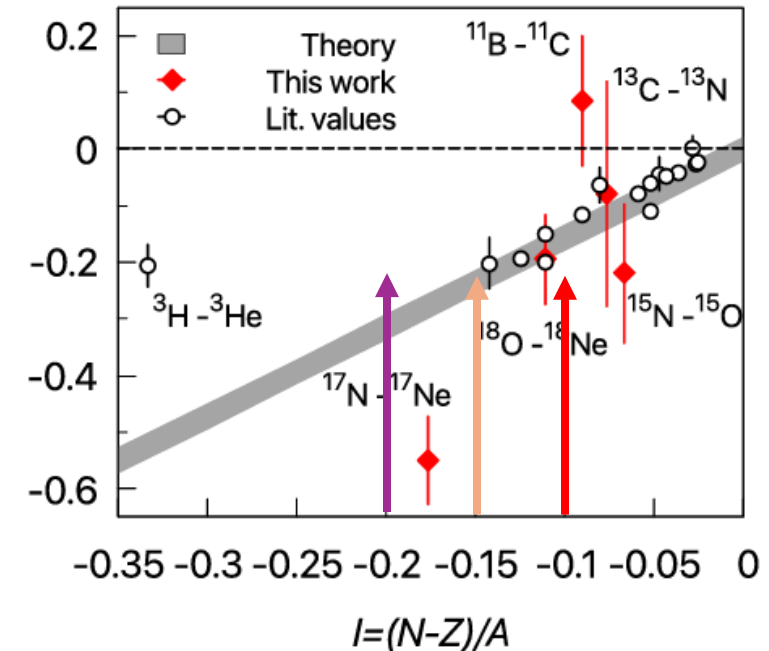
p-halo in ${}^{17}\text{Ne}$?

FAZIAEXPLORER: nuclear structure studies in exotic realm

In conclusion, the n-deficient region ($Z \leq 20$) offers a suitable bench test to access a quite unexplored region in term of charge change cross section and mirror-pairs.

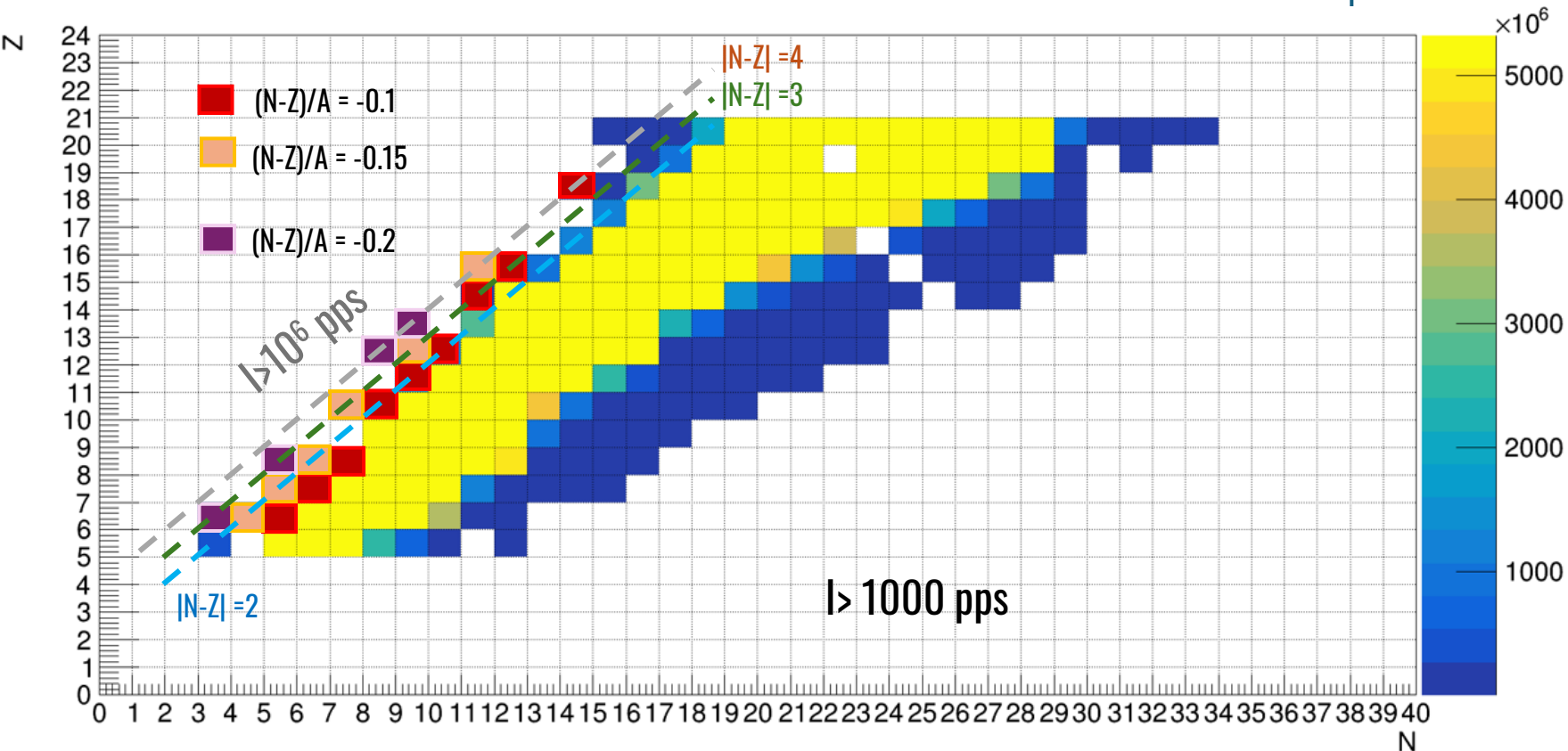
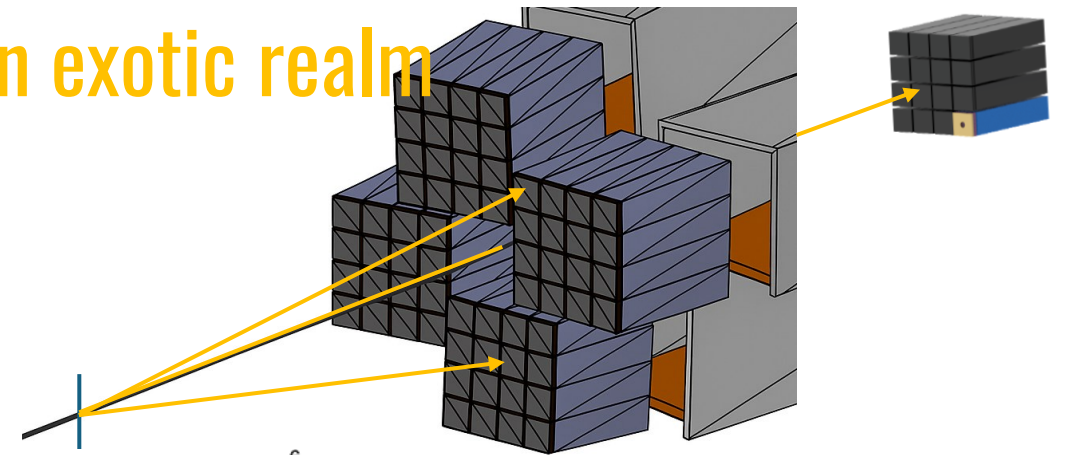


W. Zhao, B.A. Sun et al
 Phys. Lett. B 858 (2024) 139082



FAZIAEXPLORER: nuclear structure studies in exotic realm

In conclusion, the n-deficient region ($Z \leq 20$) offers a suitable bench test to access a quite unexplored region in term of charge change cross section, and mirror-pairs.



Problems and challenges:

- Model and theory: at energies below 100 MeV/u, and in not-transmission mode, how can we link CCCS to charge radius?
- FAZIA: need to go thicker to avoid enhance the energy deposit in Si 650-750 is it enough?
- Beam current measurement:
 - Faraday cup? Si monitor? Plastic?
 - Optical (or not) PPAC?

