7th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX7)

LATEST RESULTS ON THE FraISe FACILITY AND POSSIBLE PHYSICS CASES AT INFN-LNS

N.S. Martorana

nunzia.martorana@ct.infn.it
INFN-Sezione di Catania
CHIRONE collaboration

INFN CATANIA
Istituto Nazionale di Fisica Nucleare
Sezione di Catania

Outline

- Status of the FraISe facility at Laboratori Nazionali del Sud of INFN (INFN-LNS)
- Diagnostics and tagging devices based on SiC technology
- Preliminary tests and simulations studies
- Possible physics cases
- Conclusions
- Perspectives

N.S. Martorana - nunzia.martorana@ct.infn.it

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PON RICERCA E INNOVAZIONE 2014 - 2020

The **POTLNS project (https://potlns.lns.infn.it/it/)** aims at the production of high intensity ion beams and it consists in an upgrade of existing and operating devices at INFN-LNS designed for the basic research in Nuclear Physics

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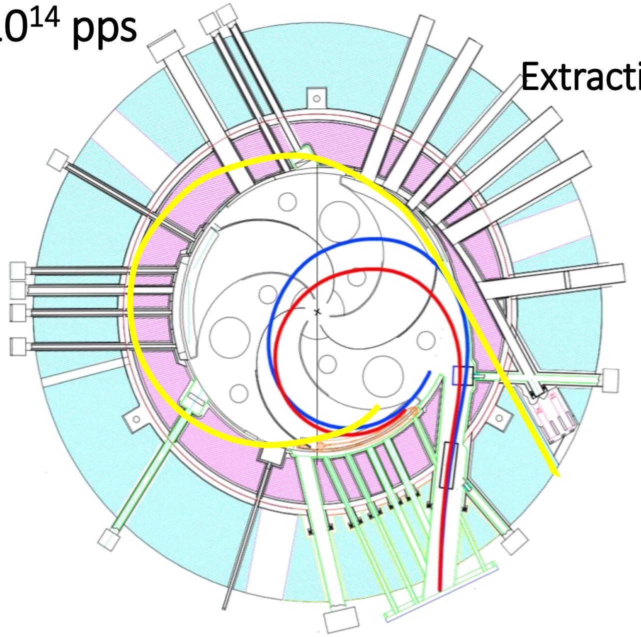
The upgrade of the Superconductive Cyclotron will provide stable ion beams with a power up to **10 kW** → beams from carbon to argon at intermediate energies with intensity up to **10^{13} – 10^{14} pps**

Extraction for stripping



D. Rifuggiato HIB@LNS 2015

Ion	Energy	Isource	Iextr	Iextr	Pextr
	MeV/u	eμA	eμA	pps	watt
^{12}C q=5+	30	200	45 (6+)	4.7•10^{13}	2700
^{12}C q=4+	45	400	90 (6+)	9.4•10^{13}	8100
^{12}C q=4+	60	400	90 (6+)	9.4•10^{13}	10800
^{18}O q=6+	20	400	80 (8+)	6.2•10^{13}	3600
^{18}O q=6+	29	400	80 (8+)	6.2•10^{13}	5220
^{18}O q=6+	45	400	80 (8+)	6.2•10^{13}	8100
^{18}O q=6+	60	400	80 (8+)	6.2•10^{13}	10800
^{18}O q=7+	70	200	34.3 (8+)	2.7•10^{13}	5400
^{20}Ne q=7+	28	400	85.7 (10+)	5.3•10^{13}	4800
^{20}Ne q=7+	70	400	85.7 (10+)	5.3•10^{13}	10280
^{40}Ar q=14+	60	400	77.1 (18+)	2.7•10^{13}	10280

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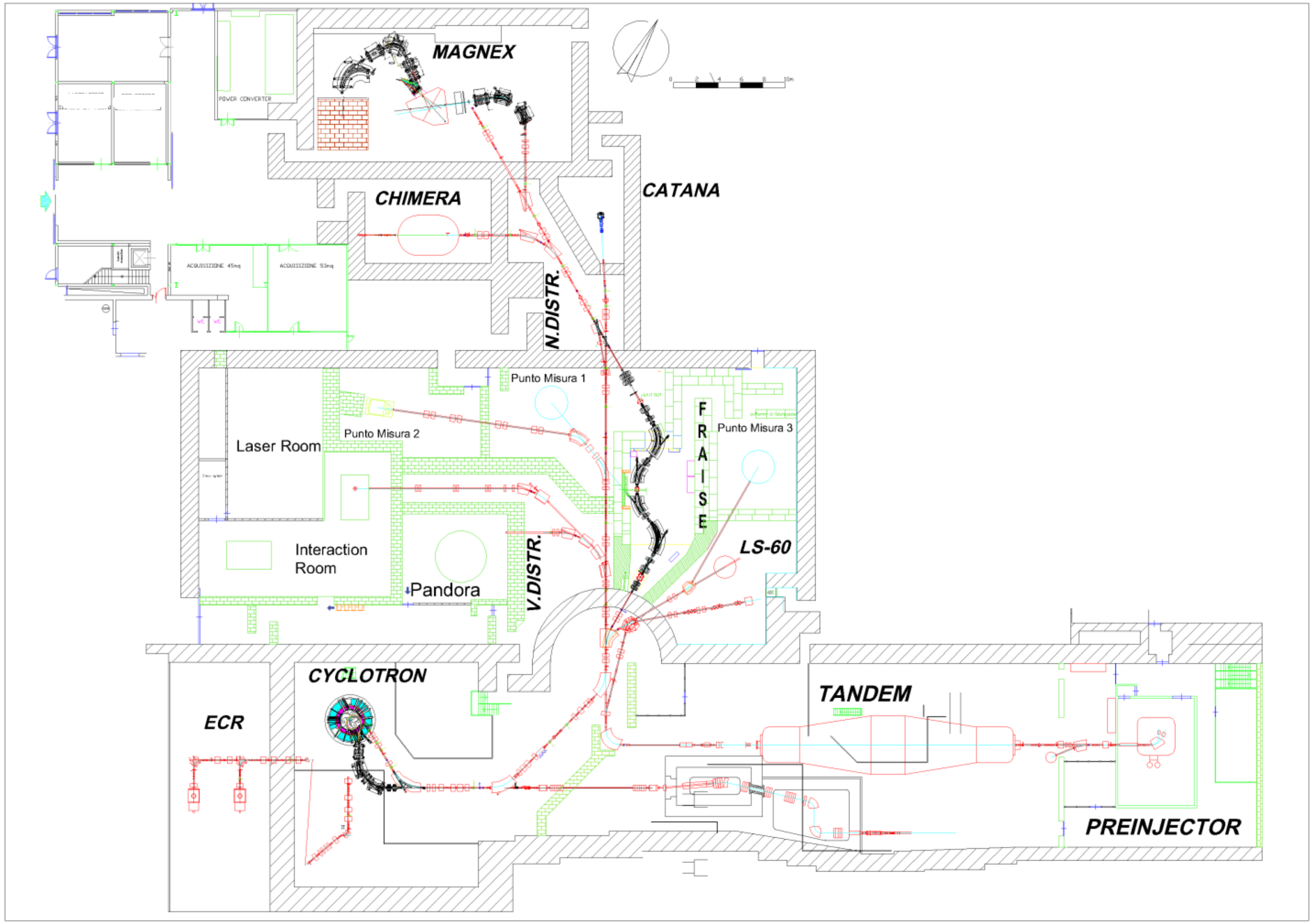
The building of a new fragment separator **FraISe (Fragment In- Flight Separator)** is on its final construction phase to deliver high intensity **Radioactive Ion Beams (RIBs)**



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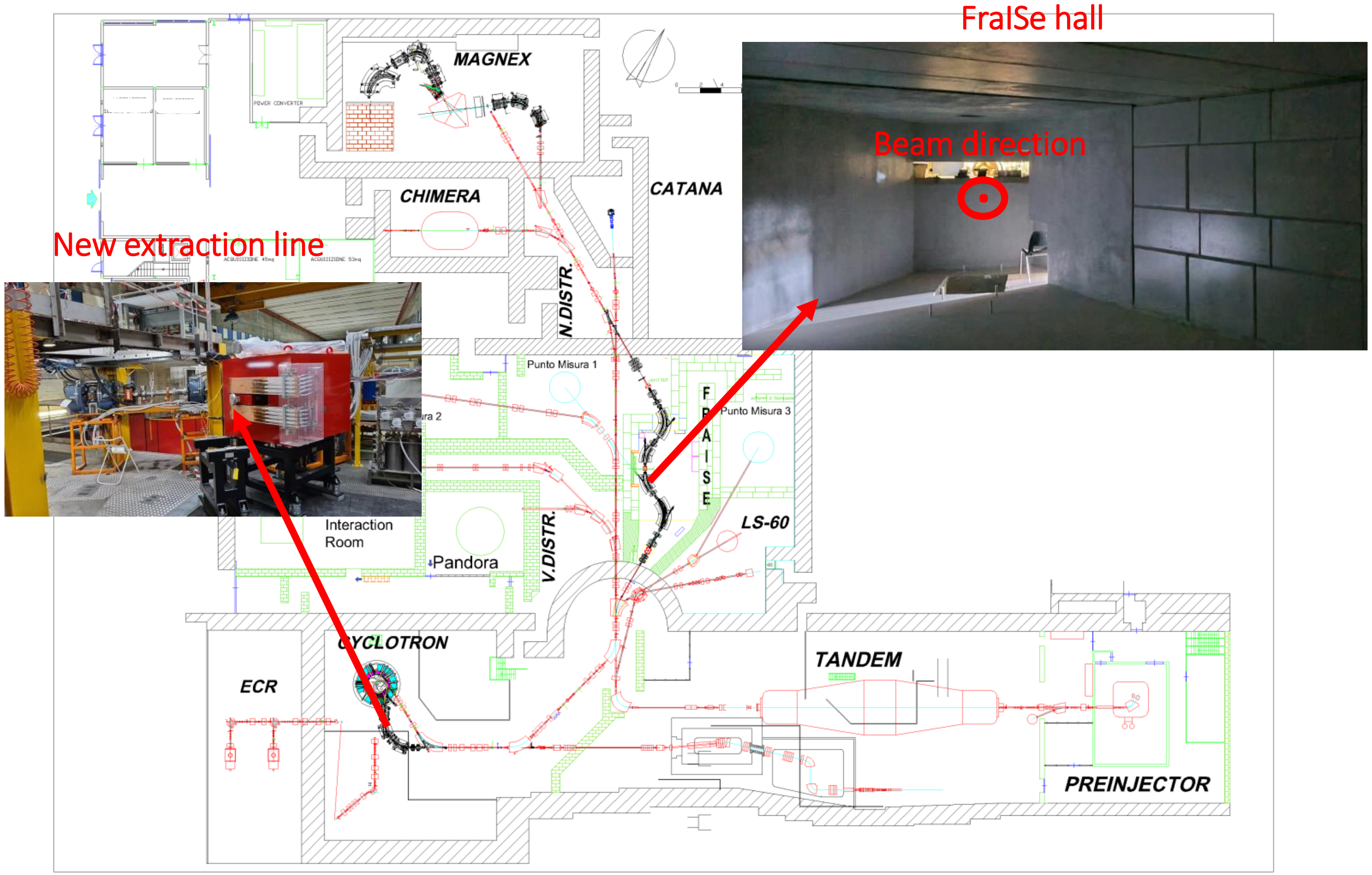
- In-flight method (fragmentation of primary CS beam on Be/C targets) using a maximum beam power of 2-3 KW
- FraISe will produce RIBs with intensity in the range of 10^3 –10^7 pps in the Fermi energy regime



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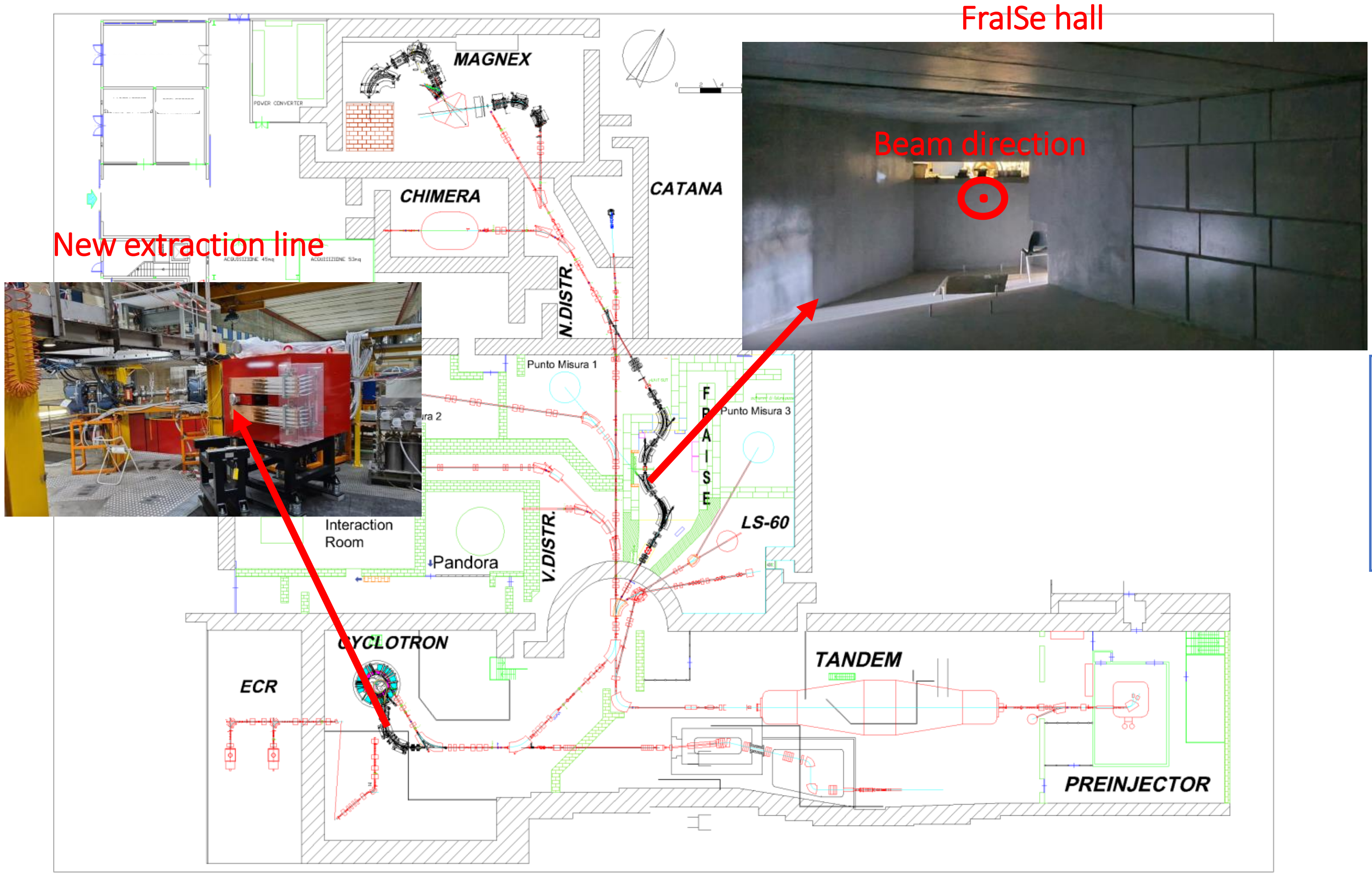

Such intensities will increase the yield by a factor ≈ 20 with respect to the FRIBs facility (INFN-LNS 2001-2019)

The improvement in intensity opens the way to more precise studies on nuclei close to the stability and allows to extend investigations to nuclei far from the stability

Martorana N.S. et al., Frontiers in Physics, 10 (2022)
Martorana N.S. et al., Il Nuovo Cimento 45 C (2022) 63
Martorana N.S., Il Nuovo Cimento 44 (2021) 1
Russo A et al., NIM B 463 (2020) 359 418 – 420
Russotto P. et al., J. Physics: Conf. Ser., 1014 (2018) 012016

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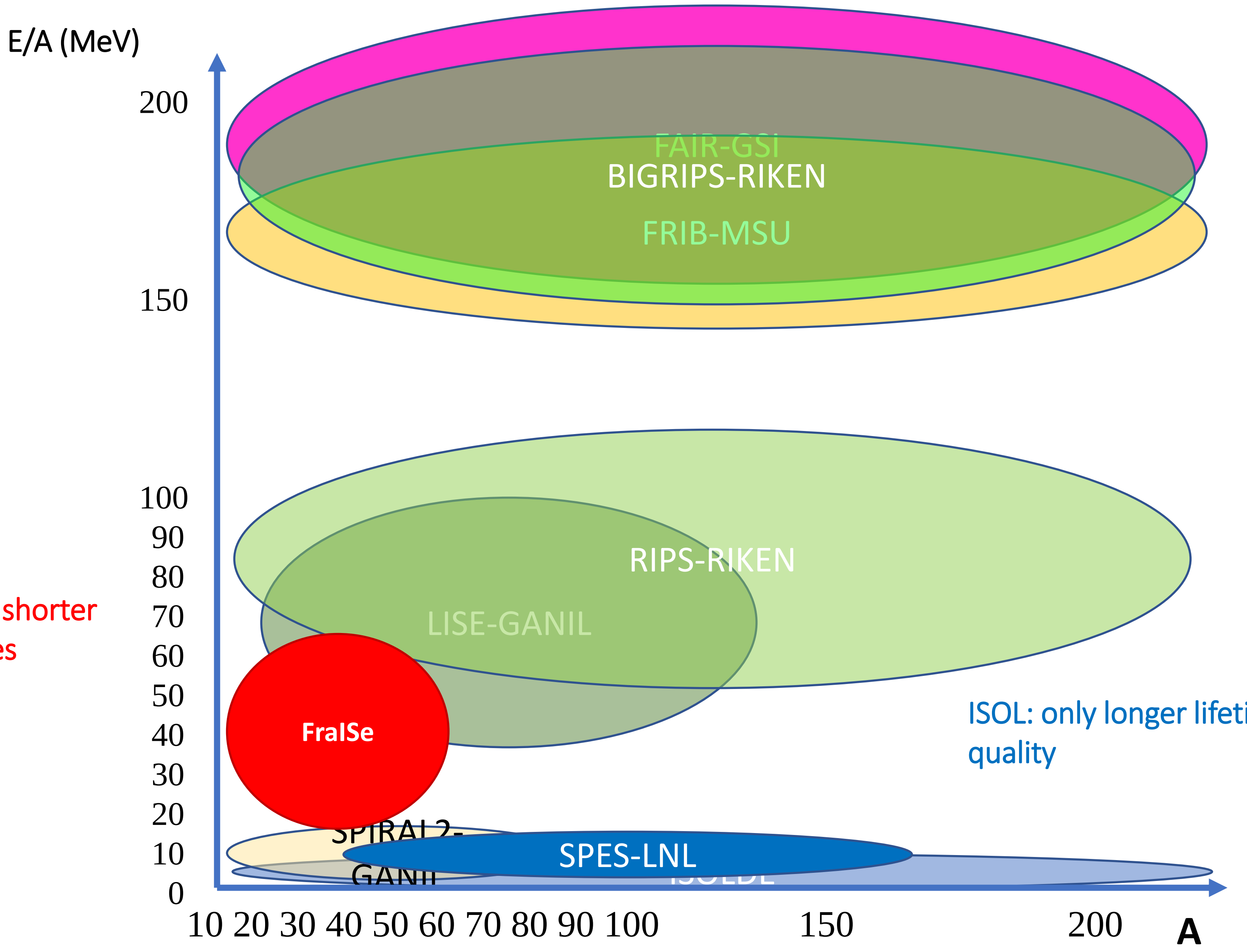
Our future: FraISe



Complementarity!

In-flight: also shorter lifetimes

ISOL: only longer lifetimes, better beam quality

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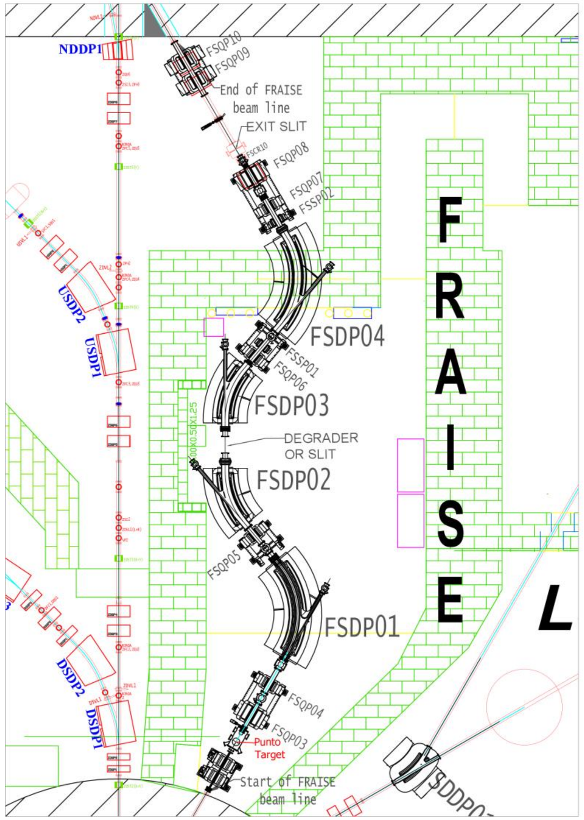
- Main selection: **fragment separator made of 4 dipoles and 6 quadrupoles in a symmetrical configuration and 2 sextupoles to adjust the aberration effect**



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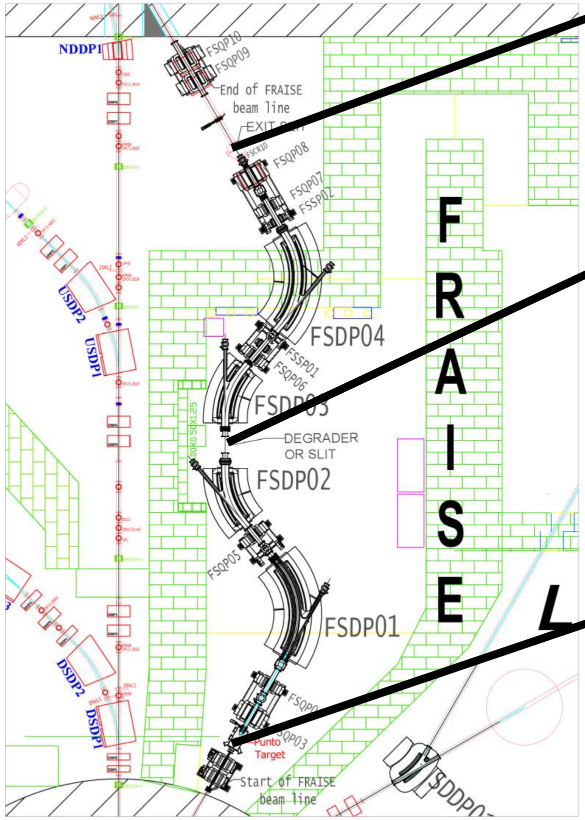
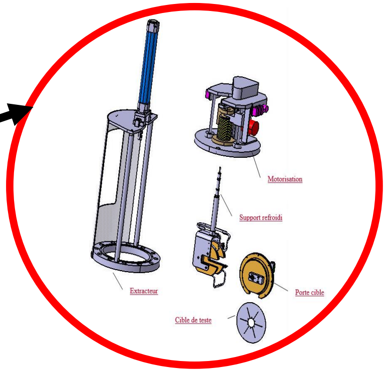


Exit Slit

Wedge and/or Slit

Rotating Target CLIM



- maximum magnetic rigidity 3.2 Tm
- 2 slits: in the dispersive plane and at the exit of fragment separator
- possibility of almost pure secondary beams through the use of a wedge/degrader
- a rotating target CLIM

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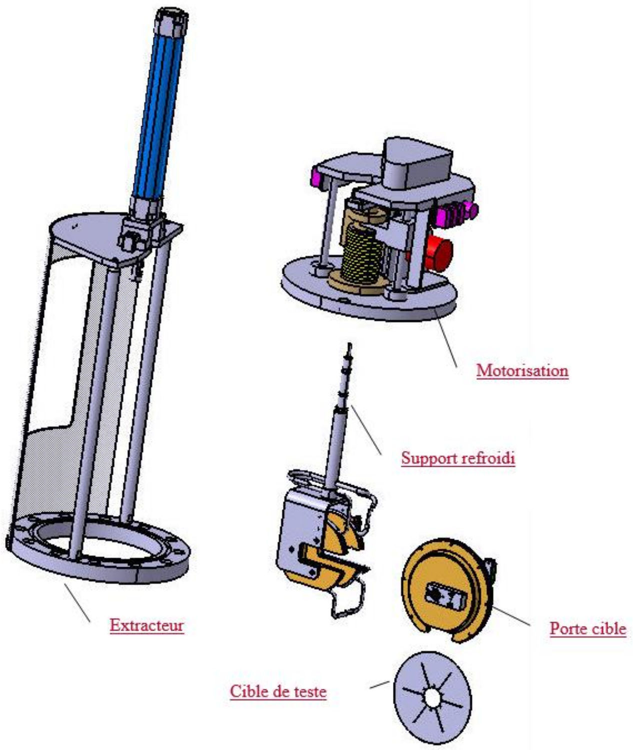
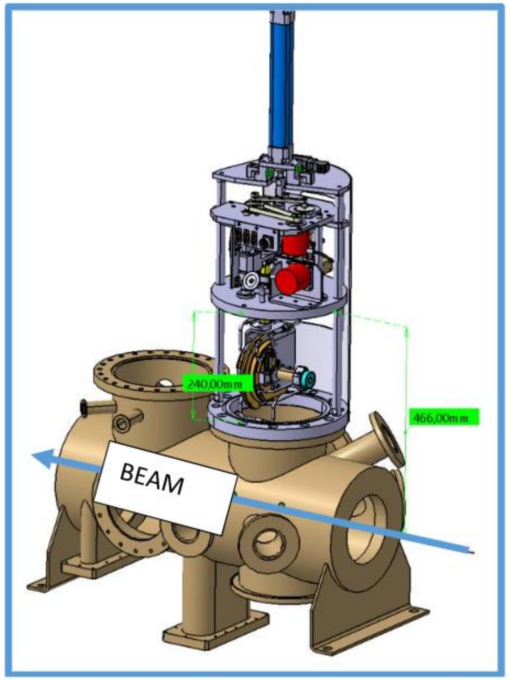
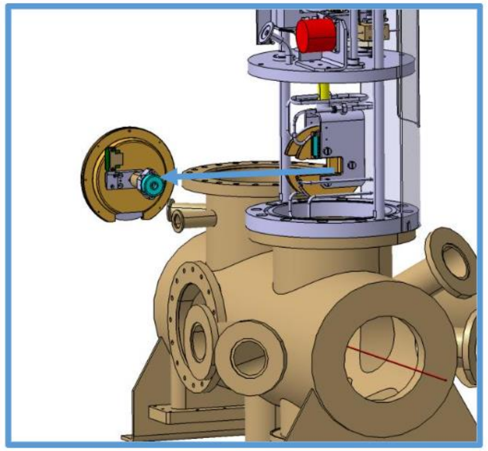
A new production target CLIM will be used (S. Grévy and R. Hue, INTDS2008, (Caen, France), Sep 2008)

- Material target Beryllium or Carbon
- Thickness 100 to 1500 μm
- Max beam power 3 kW
- Max beam power deposited in the target 500 W
- Beam spot size in the target σ=0.5 mm
- Target rotation speed: 2000 revs/min







The target will be significantly activated → a dedicate system for automatic change and remote handling has been designed

The tagging system is going to be tested this week!

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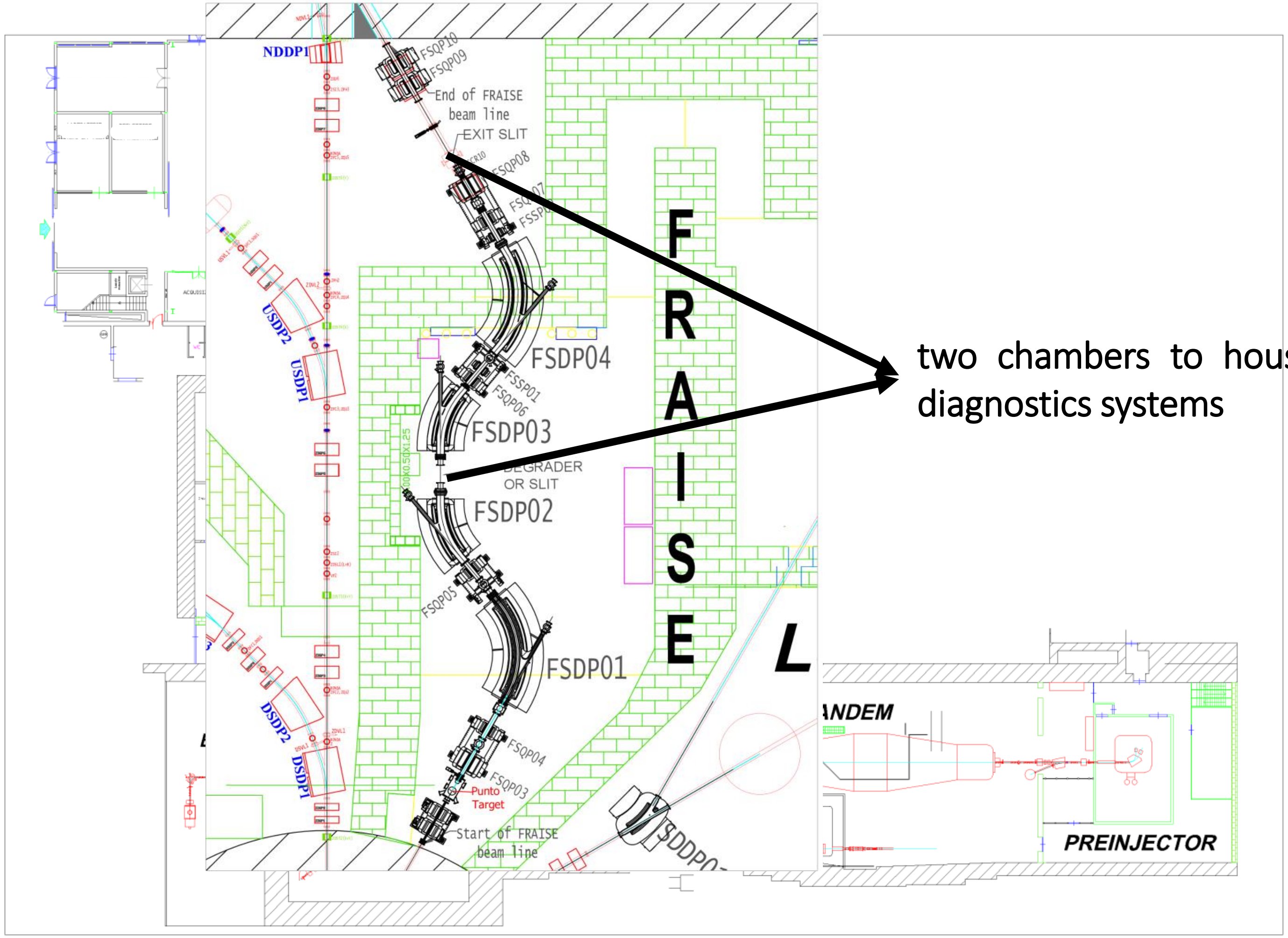
Critical aspects for high-quality beams are the tuning and the transport, representing time-consuming processes and requiring dedicated **diagnostics and tagging devices** measuring different RIBs features



two chambers to house diagnostics systems

- within a Fragment Separator:
  - point-to-point measurement of the cocktail intensity, relative composition, 2D profile, angular distribution
  - start time for event-by-event ToF/energy measurement

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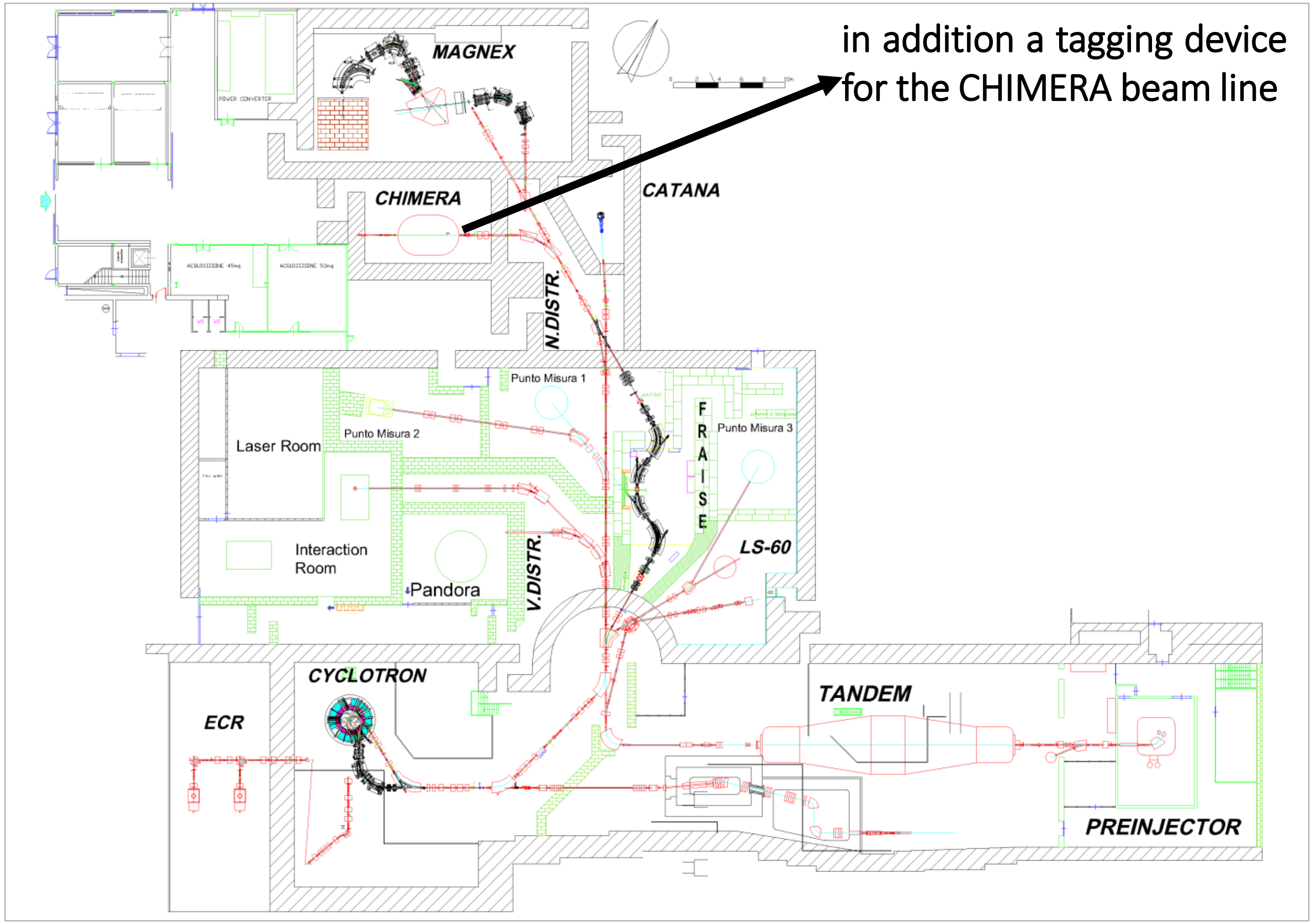

- **within a Fragment Separator:**
  - point-to-point measurement of the cocktail intensity, relative composition, 2D profile, angular distribution
  - start time for event-by-event ToF/energy measurement
- **in the final set-up point (measurement chamber)**:
  - event-by-event tagging of cocktail beam and trajectory info

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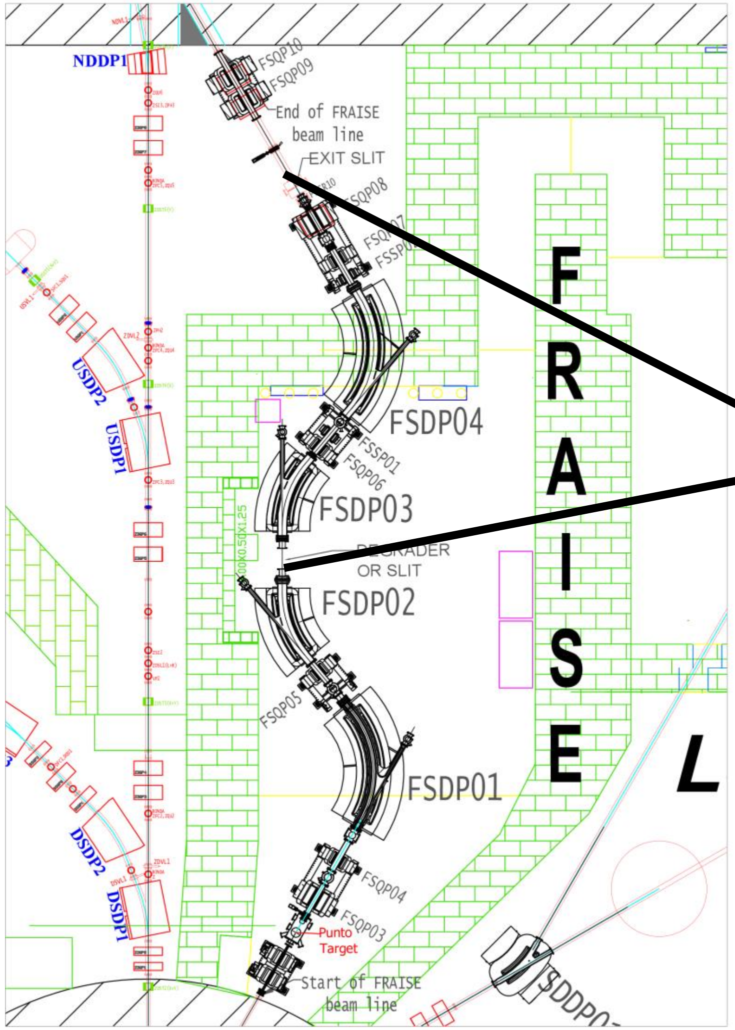
Critical aspects for high-quality beams are the tuning and the transport, representing time-consuming processes and requiring dedicated **diagnostics and tagging devices** measuring different RIBs features



two chambers to house diagnostics systems and in addition a tagging device for the CHIMERA beam line

- **within a Fragment Separator:**
  - point-to-point measurement of the cocktail intensity, relative composition, 2D profile, angular distribution
  - start time for event-by-event ToF/energy measurement
- **in the final set-up point (measurement chamber)**:
  - event-by-event tagging of cocktail beam and trajectory info

Array of radiation hard detectors equipped with optimized fast frontend electronics

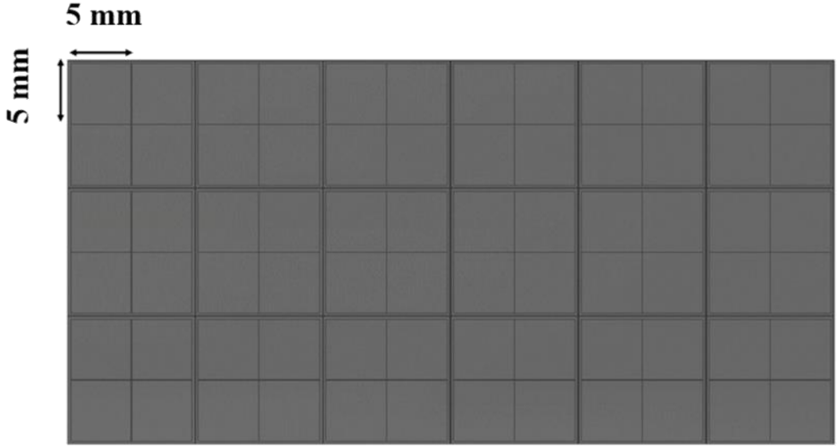
- versatile and useful for FraISe and other facilities
- sustain several experiments per year
- relevant timing features for the determination of the RIBs composition by the ΔE-TOF and energy

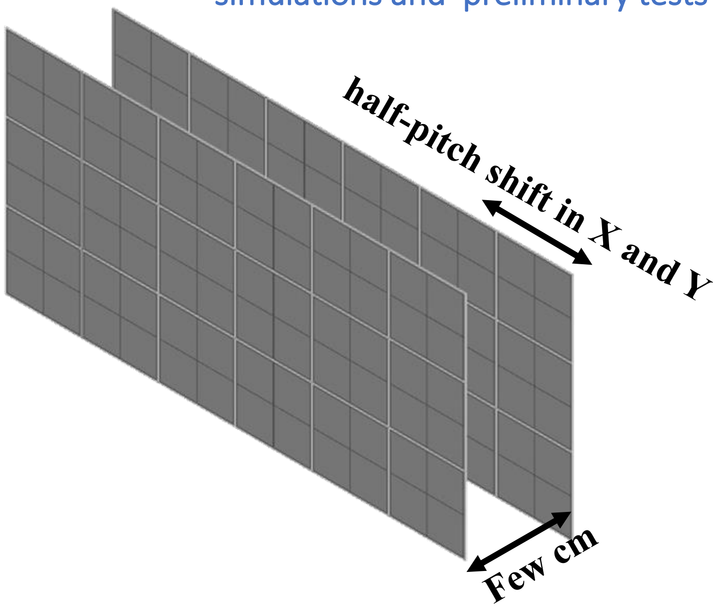
N.S. Martorana - nunzia.martorana@ct.infn.it

Due to its robustness and radiation hardness→ Silicon Carbide (SiC) technology has been chosen

- The system will consist of two arrays, each one made of single detection pads with an active area of 5 mm × 5 mm and a thickness of 100 µm
- By arranging an array of several pads in rows and columns will be covered an area of the order of ≈ 60×30 mm^2
- Such a segmentation sustains a maximum value of ≈ 10^7 pps
- A sandwich configuration of two detection arrays readout in coincidence will improve the position resolution and partially recover for the dead region around each sensor die (efficiencies larger than 90%)
- The energy resolution has to be 0.5% →ToF resolution of ~ 250 ps is requested

We performed important feasibility studies through simulations and preliminary tests





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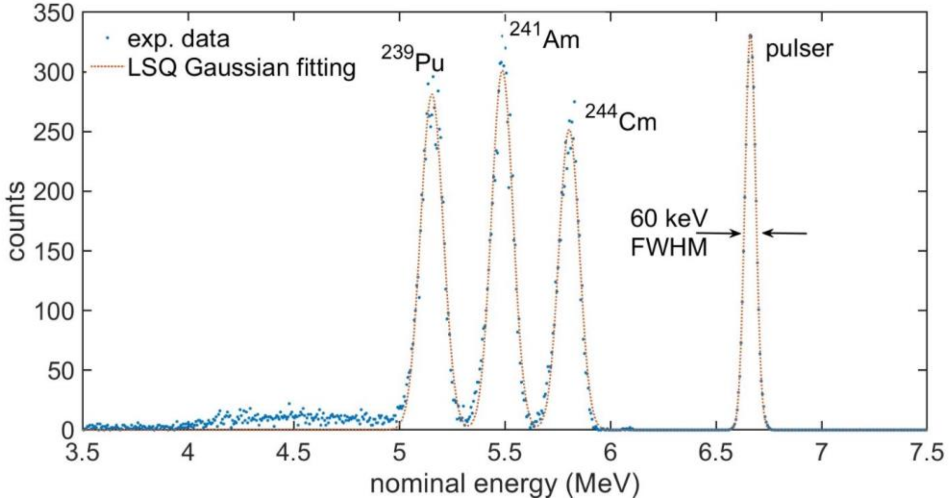
- Preliminary qualification of first 5 mm × 5 mm detector prototypes→ measurements show a 21 pF detector capacitance at about 400 V depletion voltage

- First design of a dedicated frontend in charge preamplifier configuration to readout the full detection system (Altana C et al., IEEE Nuclear Science Symposium and Medical Imaging Conference 390 (NSS/MIC) (2021), 1–4. doi:10.1109/NSS/MIC44867.2021.9875842)



α energy spectrum in air

Courtesy of C. Guazzoni

Photograph of the first mini-carrier developed for a 1 cm^2 active area detector prototype →the reduced thickness area is evident as transparent to light

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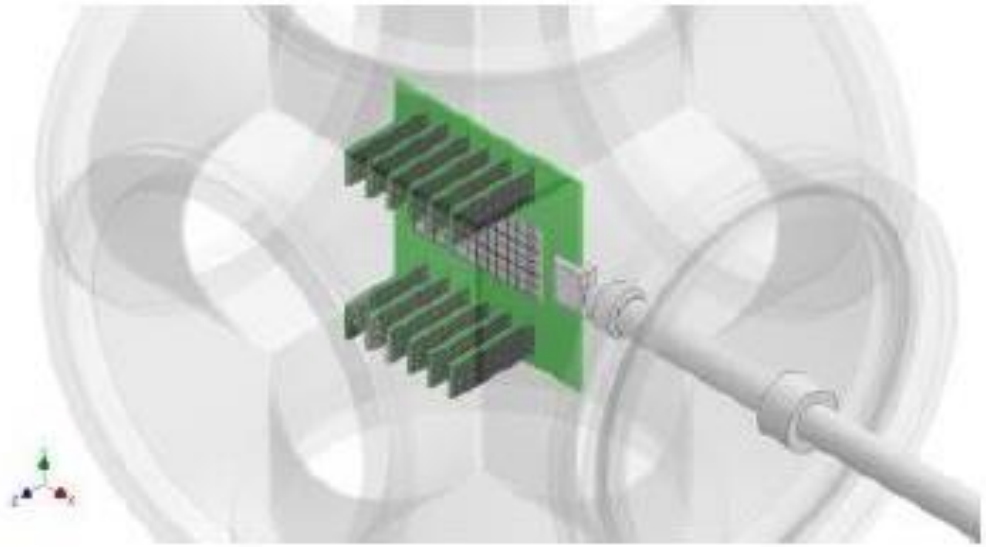

Sketch of the proposed detection system with also the moveable arm housed in a DN160 spherical cross element along the beam path

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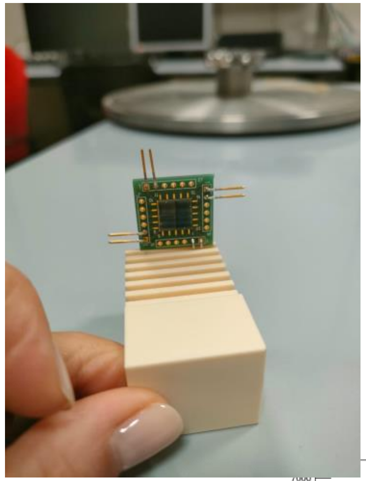
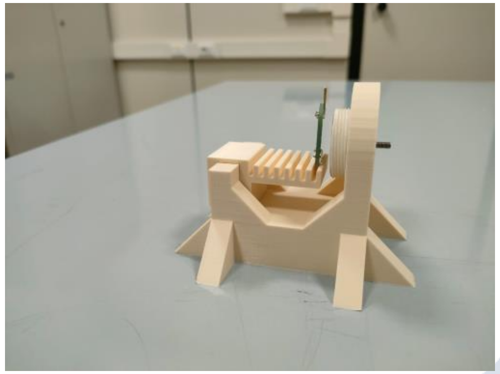
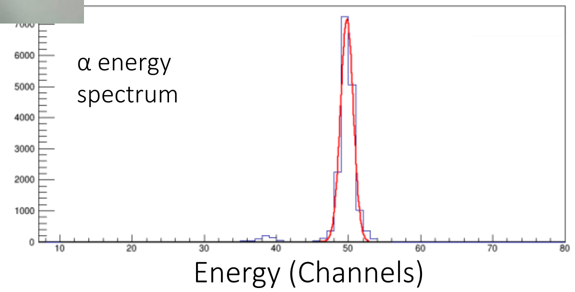




Study of the inter pad effect with first tests on 2x2 SiC prototype



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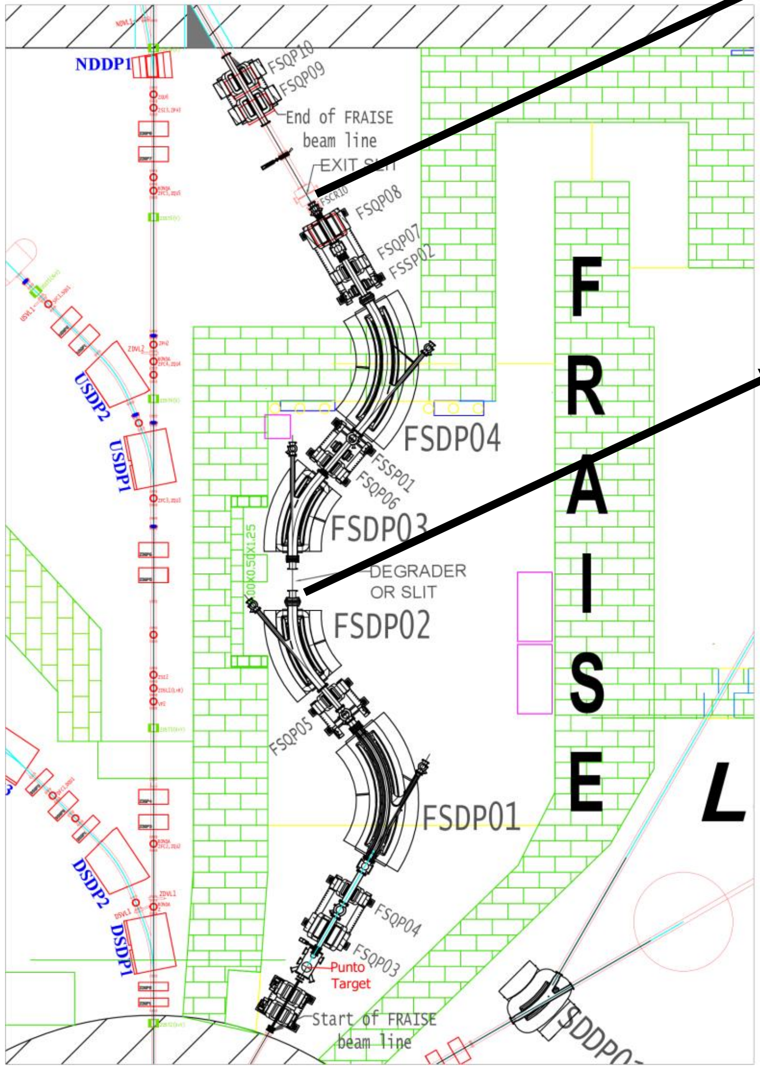
Simulations using LISE++ tool unveiled the FraISe possibilities for the production of RIBs



100 µm SiC tagging detector

Al 100 µm homogenous Al wedge

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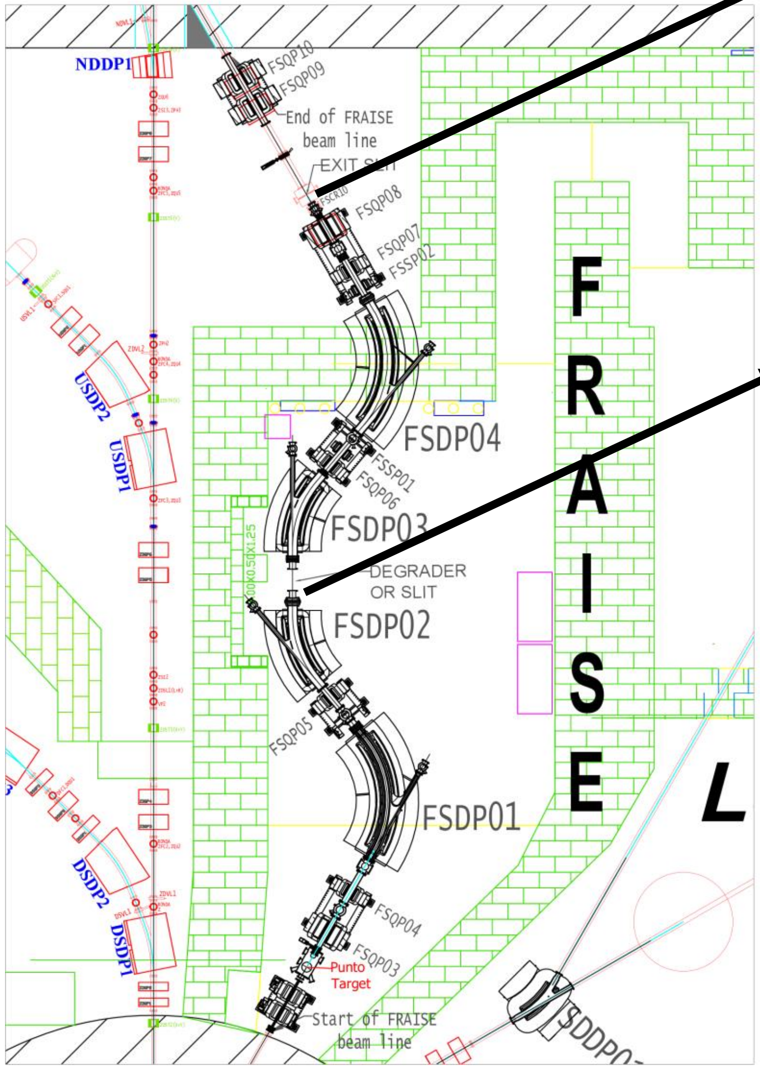

First results have been obtained using primary beams whose extraction by stripping in the upgraded CS has been studied in details

Ion	Energy	P
	MeV/u	kW
^{12}C q=6+	60	2
^{18}O q=8+	70	2
^{20}Ne q=10+	70	2
^{40}Ar q=18+	60	2

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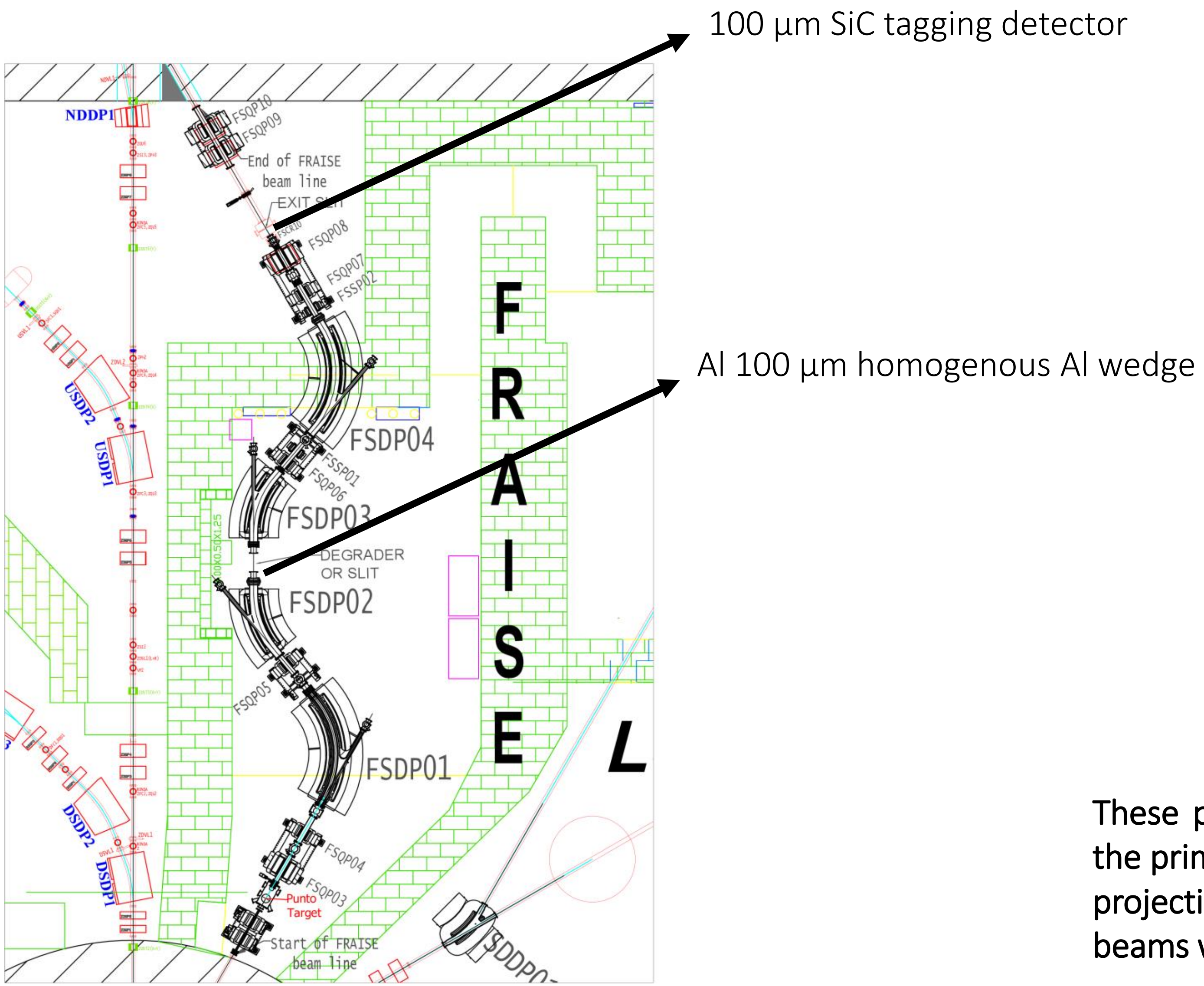

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^{20}Ne q=10+	70	2
^{40}Ar q=18+	60	2

These primary beams can be accelerated also at lower energies→ the primary beam energy has to be ≥ 20 AMeV in order to make the projectile fragmentation reaction possible→ lower energy primary beams will cause a decrease of expected intensities

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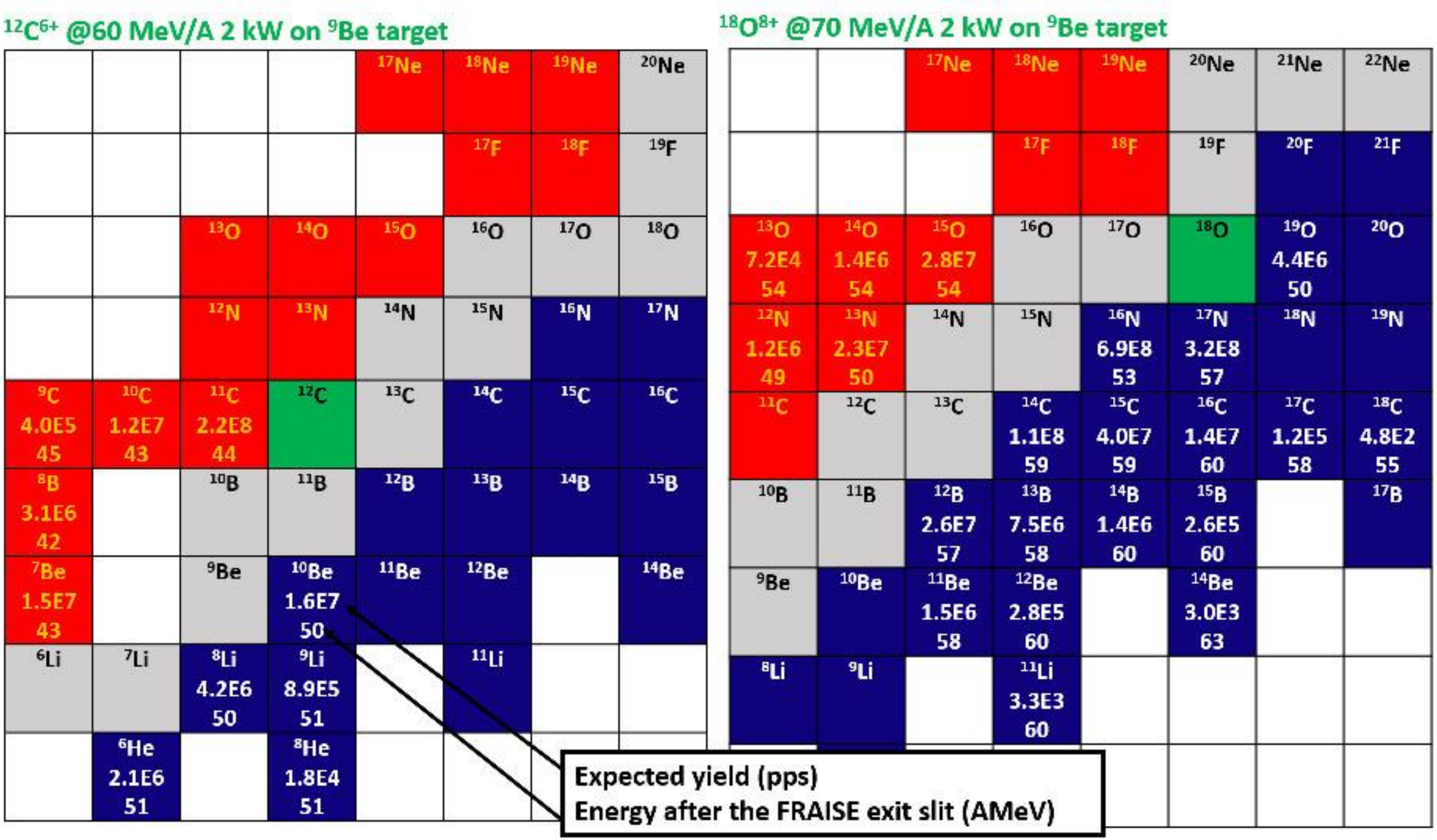

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$^{20}Ne^{10+}$ @70 MeV/A 2 kW on ^{9}Be target

^{17}Ne 8.7E5 53	^{18}Ne 3.1E7 51	^{19}Ne 6.0E8 52	^{20}Ne	^{21}Ne	^{22}Ne	^{23}Ne	^{24}Ne
	^{17}F 1.7E8 50	^{18}F	^{19}F	^{20}F 9.5E6 55	^{21}F	^{22}F	^{23}F
^{15}O	^{16}O	^{17}O	^{18}O	^{19}O	^{20}O	^{21}O	^{22}O
^{14}N	^{15}N	^{16}N	^{17}N	^{18}N 3.7E6 57	^{19}N	^{20}N	^{21}N
^{13}C	^{14}C	^{15}C	^{16}C	^{17}C	^{18}C	^{19}C	^{20}C
^{12}B	^{13}B	^{14}B	^{15}B		^{17}B		^{19}B
^{11}Be	^{12}Be		^{14}Be				
	^{11}Li						

$^{40}Ar^{18+}$ @60 MeV/A 2 kW on ^{9}Be target

				^{35}K	^{36}K 6.6E3 48	^{37}K 8.2E4 48	^{38}K 6.3E5 49	^{39}K	^{40}K	^{41}K	^{42}K 1.3E6 41	^{43}K 2.6E3 40
	^{31}Ar	^{32}Ar	^{33}Ar	^{34}Ar	^{35}Ar 8.9E5 45	^{36}Ar	^{37}Ar 9.2E7 42	^{38}Ar	^{39}Ar 1.3E9 43	^{40}Ar	^{41}Ar 1.0E7 47	^{42}Ar 2.2e4 42
		^{31}Cl	^{32}Cl 4.6E4 46	^{33}Cl 1.2E6 46	^{34}Cl 1.5E7 42	^{35}Cl	^{36}Cl	^{37}Cl	^{38}Cl 7.4E8 39	^{39}Cl 3.2E8 44	^{40}Cl 4.9E6 44	^{41}Cl 4.8E3 46
^{28}S	^{29}S	^{30}S 5.7E4 42	^{31}S 3.5E7 45	^{32}S	^{33}S	^{34}S	^{35}S 1.1E8 35	^{36}S	^{37}S 6.1E7 48	^{38}S 1.7E7 48	^{39}S 1.6E5 47	^{40}S 4.1E2 49
^{27}P	^{28}P 5.8E4 42	^{29}P 1.3E6 43	^{30}P 1.1E7 43	^{31}P	^{32}P 9.2E7 44	^{33}P 6.7E7 48	^{34}P 3.9E7 44	^{35}P 1.5E7 48	^{36}P	^{37}P 8.2E5 50	^{38}P 7.9E3 48	^{39}P
^{26}Si	^{27}Si 9.7E5 43	^{28}Si	^{29}Si	^{30}S	^{31}Si 3.5E7 45	^{32}Si 1.3E7 48	^{33}Si 3.5E6 52	^{34}Si 1.0E6 52	^{35}Si 1.9E5 49	^{36}Si 2.5E4 49	^{37}Si	^{38}Si
^{25}Al 9.2E5 44	^{26}Al 5.4E6 44	^{27}Al	^{28}Al 2.0E7 45	^{29}Al 1.2E7 45	^{30}Al 4.4E6 45	^{31}Al 1.0E6 52	^{32}Al 2.1E5 45	^{33}Al 3.1E4 52	^{34}Al 4.3E3 52	^{35}Al 5.0E2 52	^{36}Al 4.9 51	^{37}Al

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The use of other primary beams needs studies concerning the feasibility of extraction through the stripping channel → detailed studies of acceleration trajectories inside the CS, depending also on the maximum injection currents given by the ion sources

Ion	Energy
	MeV/u
^{13}C	55
^{16}O	55
^{22}Ne	50
^{24}Mg	50
^{27}Al	40
^{32}S	50
^{36}Ar	40
^{70}Zn	40

^{13}C → ^{9}Li 1E6 pps, ^{12}B 1.2E8 pps

^{16}O → ^{15}O 2.7E8 pps, ^{14}O 1.3E7 pps, ^{13}O 4.17E5 pps

^{22}Ne → increase neutron rich F, O, N isotopes yield

^{24}Mg – ^{32}S ↔ RIBs in the region of *A* between 20 and 31, where isotopes of S, P, Si, Al, Mg, Na lie

^{36}Ar → better production of neutron poor isotopes with respect ^{40}Ar

^{70}Zn → production of isotopes in the region of $A \geq 40$

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FraISe will be a very competitive facility for the production of light and medium mass unstable nuclei in the Fermi energy regime→ a plethora of studies concerning unstable nuclei close and far from the stability valley will be carried out

- Pygmy Dipole Resonance in ^{20}O, ^{38}S, ^{68}Ni
- Clustering structures (^{10}Be, ^{16}C, ^{13}B)
- Isospin physics in the Fermi energy regime with high isospin asymmetries ($^{46,34}Ar$ and ^{68}Ni)
- Nuclear structures (proton-halo in ^{8}B 3.1×10^{6} pps, nuclear-halo ^{11}Be 1.5×10^{6} pps)
- Reactions for nuclear astrophysics as $^{14}O(\alpha, p)^{17}F$ → reaction that could be the onset of a possible route that breaks out from the HCNO cycles
- Studies of interest for medical physics could be conducted as the study of ^{11}C β^{+} decay →simultaneous use of imaging techniques (using γ emitted by positron annihilation) and energy dissipation techniques

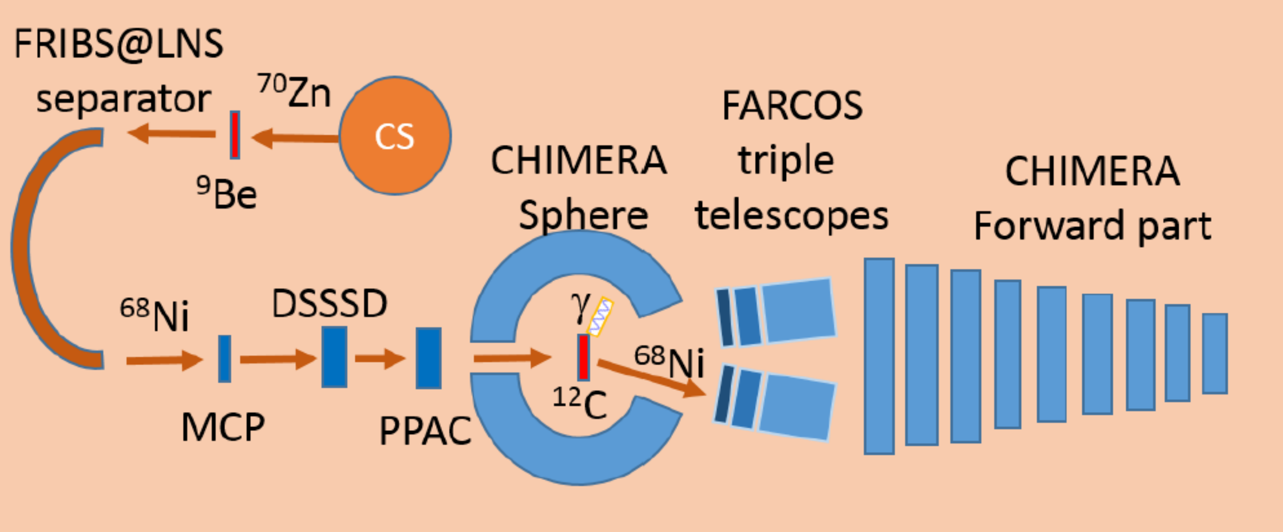
Martorana N.S. et al., Frontiers in Physics, 10 (2022)

N.S. Martorana - nunzia.martorana@ct.infn.it

Pygmy Dipole Resonance

At INFN-LNS we performed the first experiment to excite the PDR in the ^{68}Ni through an isoscalar probe, i.e. a natural carbon target

^{68}Ni + ^{12}C @ 28A MeV (N.S. Martorana et al., Phys. Lett. B, 782, (2018), 112)



Physics Letters B 782 (2018) 112–116

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Physics Letters B

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First measurement of the isoscalar excitation above the neutron emission threshold of the Pygmy Dipole Resonance in ^{68}Ni

N.S. Martorana [a,b,*], G. Cardella [c], E.G. Lanza [c], L. Acosta [d,c], M.V. Andrés [e], L. Auditore [f,c], F. Catara [c], E. De Filippo [c], S. De Luca [f,c], D. Dell' Aquila [g], B. Gnoffo [b,c], G. Lanzalone [h,a], I. Lombardo [c], C. Maiolino [a], S. Norella [f,c], A. Pagano [c], E.V. Pagano [a], M. Papa [c], S. Pirrone [c], G. Politi [b,c], L. Quattrocchi [c], F. Rizzo [a,b], P. Russotto [a], D. Santonocito [a], A. Trifirò [f,c], M. Trimarchi [f,c], M. Vigilante [g], A. Vitturi [i]

[a] INFN-LNS, Catania, Italy
[b] Dipartimento di Fisica e Astronomia, Università degli Studi di Catania, Catania, Italy
[c] INFN-Sezione di Catania, Catania, Italy
[d] Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico
[e] Departamento de FAMN, Universidad de Sevilla, Sevilla, Spain
[f] Dipartimento MIFT, Messina, Italy
[g] INFN-Sezione di Napoli and Dipartimento di Fisica, Università di Napoli Federico II, Napoli, Italy
[h] Facoltà di Ingegneria e Architettura, Università Kore, Enna, Italy
[i] Dipartimento di Fisica e Astronomia, Università G. Galilei and INFN-Sezione di Padova, Padova, Italy

- Exotic beam → FRIBs (in Flight Radioactive Ion Beams) facility (P. Russotto et al., Jour. Phys.: Conf. Ser., 1014, (2018), 012016)
- Standard tagging system → MCP + DSSSD (I. Lombardo et al., Nucl. Phys. B, Proc. Suppl., 215, (2011), 272)
- Trajectory → PPAC (D. Pierroutsakou et al., NIM A, 834, (2016), 46)
- γ rays → CHIMERA CsI(Tl) (A. Pagano et al., Nucl. Phys. A, 734, (2004), 504, G. Cardella et al., NIM A, 799 , (2015), 64)
- ^{68}Ni and other fragments→ FARCOS (E.V. Pagano et al., EPJ Web of Conferences, 117, (2016), 10008)

N.S. Martorana - nunzia.martorana@ct.infn.it

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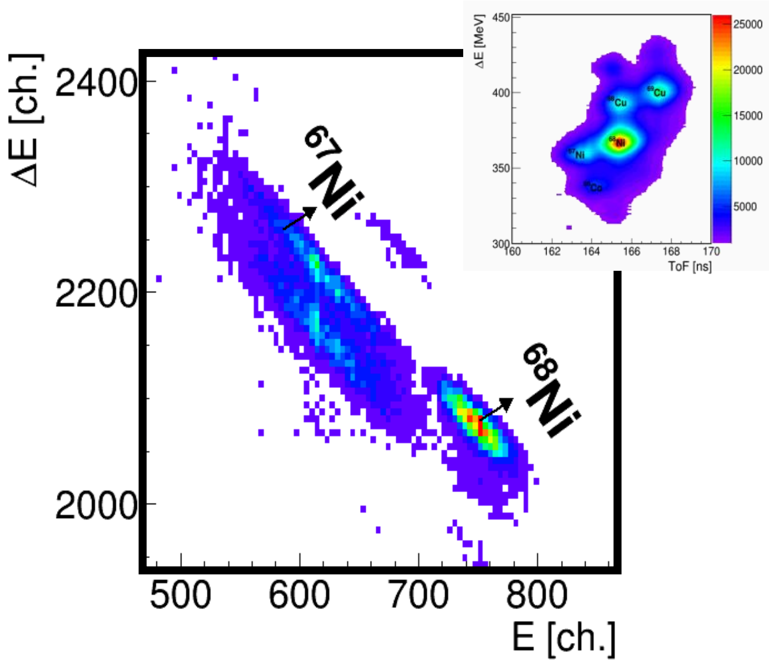
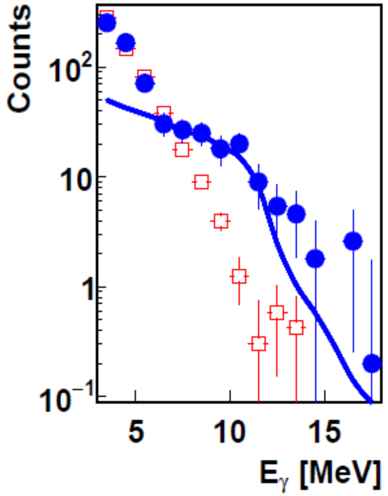
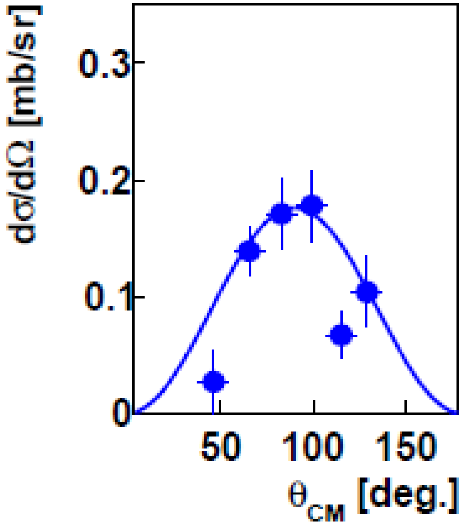
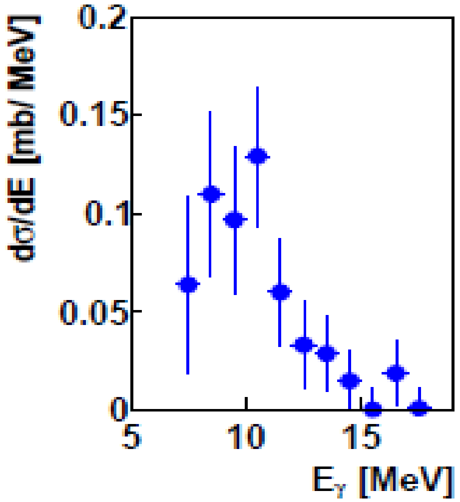
^{68}Ni + ^{12}C @ 28A MeV (N.S. Martorana et al., Phys. Lett. B, 782, (2018), 112)









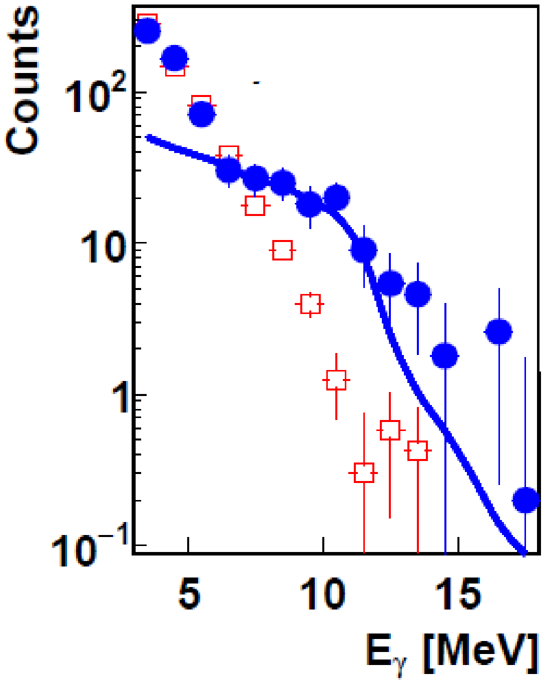
- The γ-rays angular distribution shows the E1 character of the transition
- The measured cross section was 0.32 mb with 18% of statistical error
- The strength of the PDR amount at 9 ± 2 % EWSR

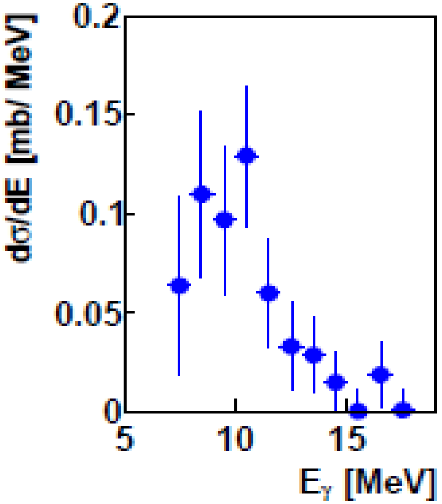
N.S. Martorana - nunzia.martorana@ct.infn.it

Pygmy Dipole Resonance

The comparison with the experiment carried out at the GSI does not show any significant difference in the shape of two distributions → **the isospin splitting is not observed for unstable nuclei above the neutron emission threshold**

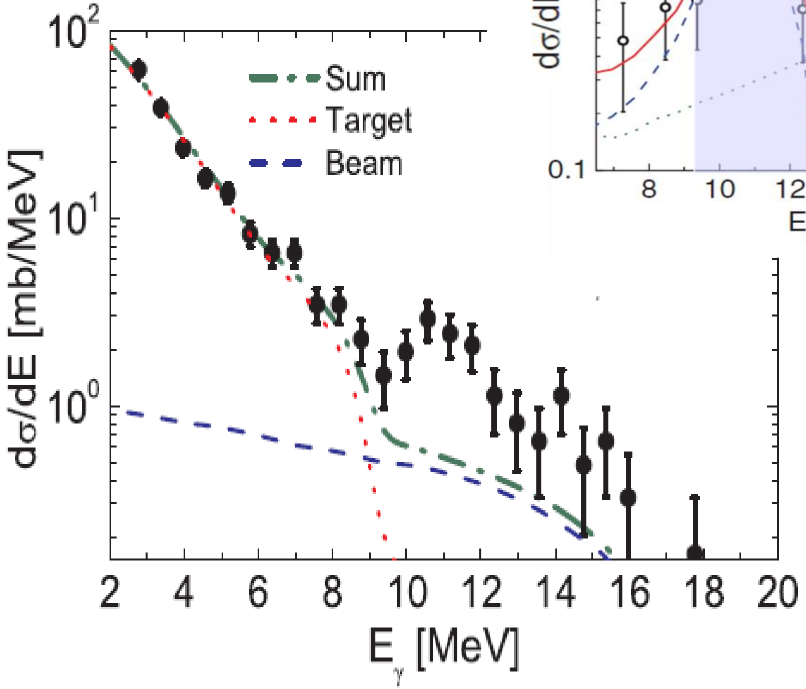
^{68}Ni+C

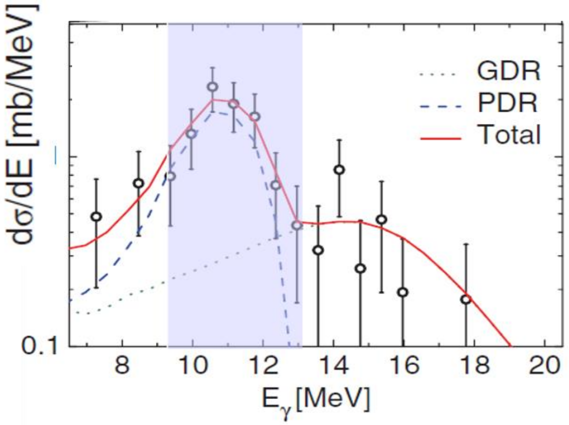




N.S. Martorana et al., Phys. Lett. B, 782, (2018) , 112

^{68}Ni+Au



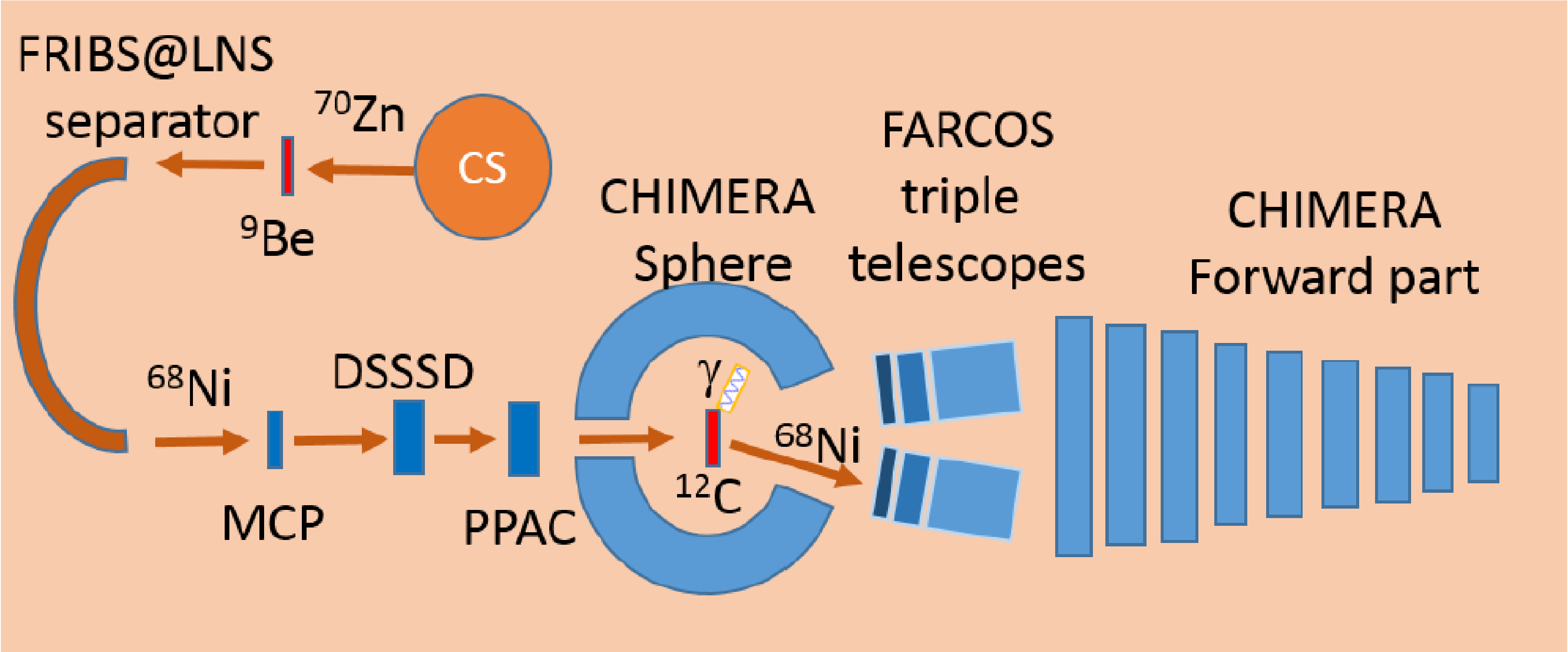


O. Wieland et al., Phys. Rev. Lett., 102, (2009) 092502

N.S. Martorana - nunzia.martorana@ct.infn.it

Pygmy Dipole Resonance

FARCOS covered some of the forward telescopes of CHIMERA→ neutrons can be detected via (n,α) and (n, p) reactions on CsI(Tl) producing α and proton lines (L. Auditore et al., EPJ Web of Conferences, 88, (2015), 01001)



N.S. Martorana - nunzia.martorana@ct.infn.it

Pygmy Dipole Resonance

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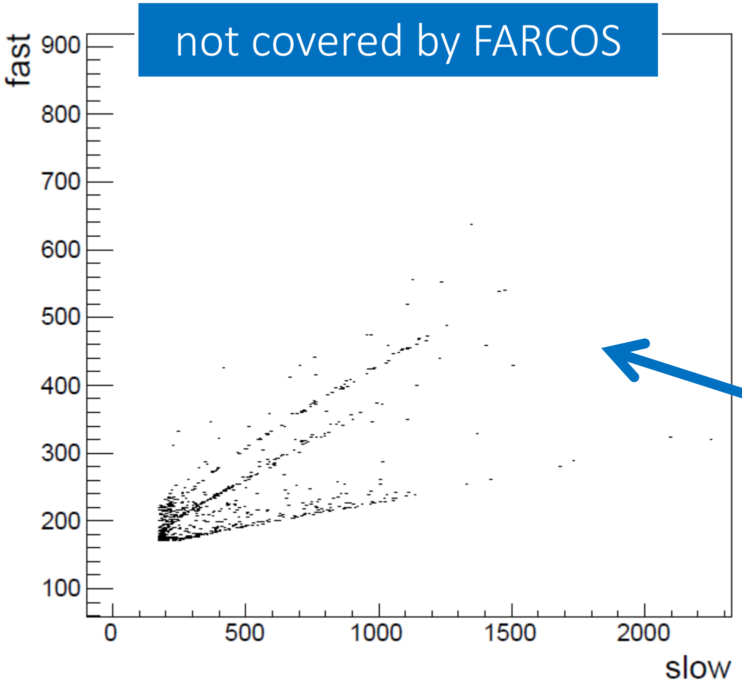
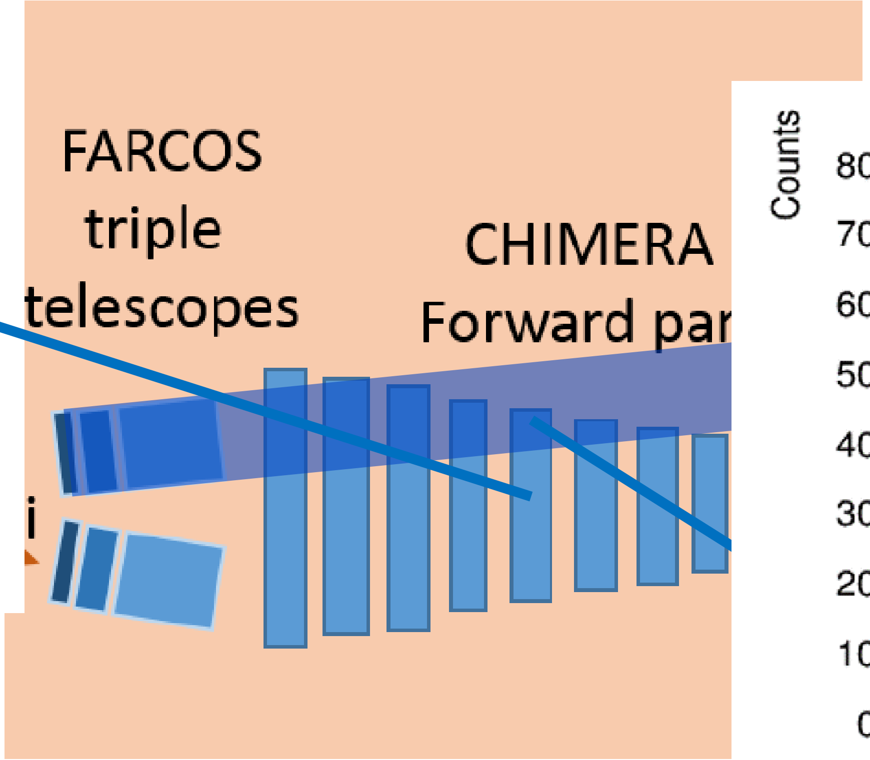
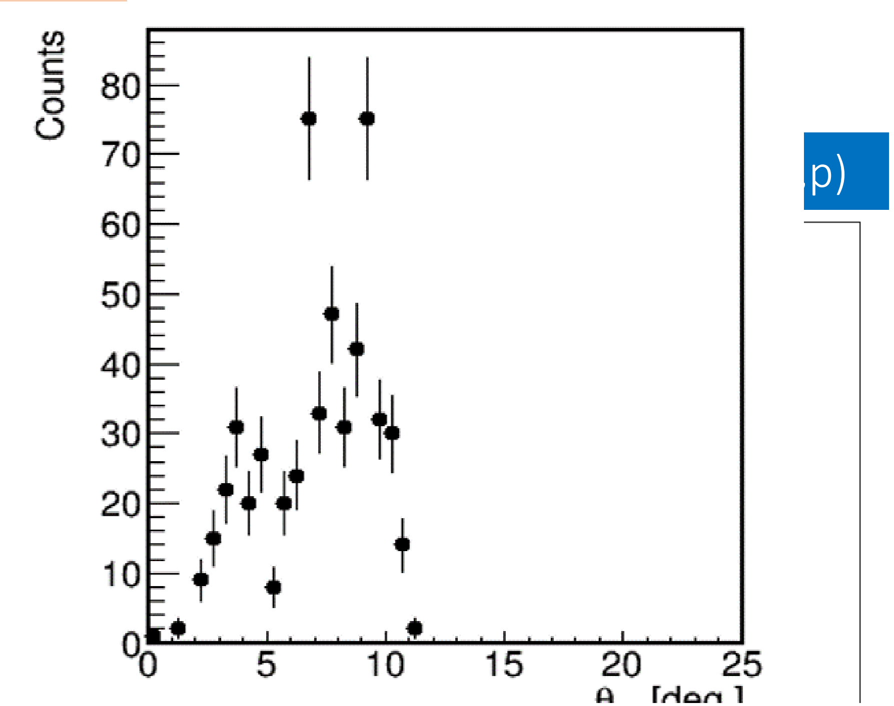




Low statistics to extract significant information on the neutron channel decay



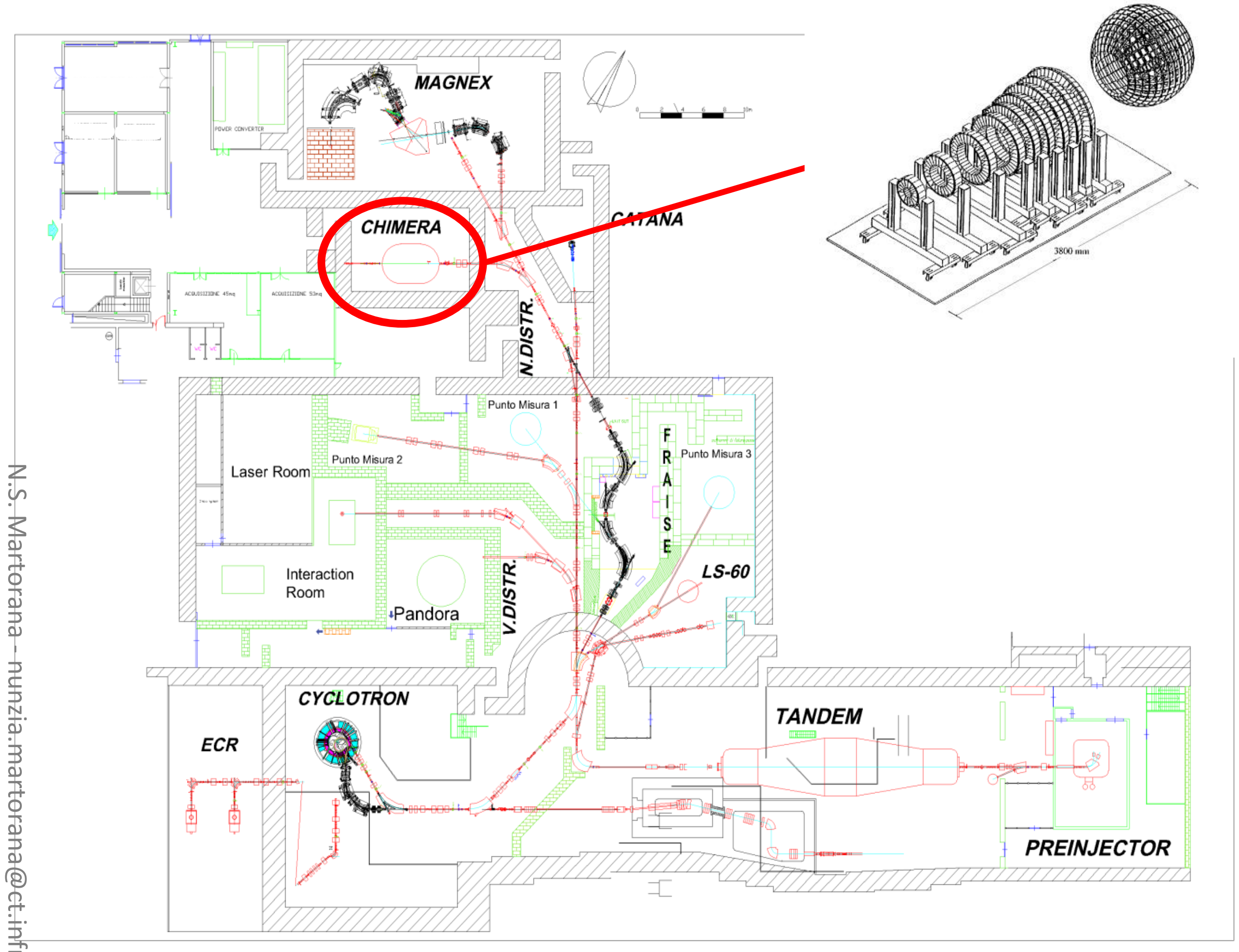
Efficiency for neutrons is of the order of 5% - Taking into account that the PDR decays mainly (>95%) via neutron emission, we

We (spokespersons N.S. Martorana, G. Cardella, E.G. Lanza) proposed an experiment-postponed/deleted due to the COVID pandemic- with the aim to study the ^{68}Ni PDR using both isoscalar and isovector probes

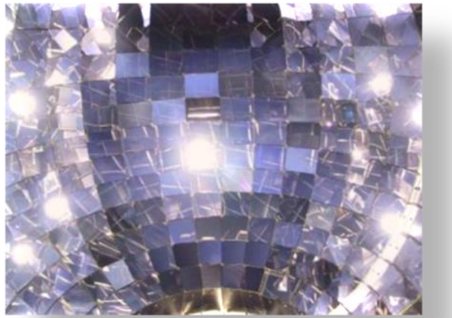
N.S. Martorana - nunzia.martorana@ct.infn.it

What can be done with the new FraISe facility?→**Investigation of the PDR in several nuclei**

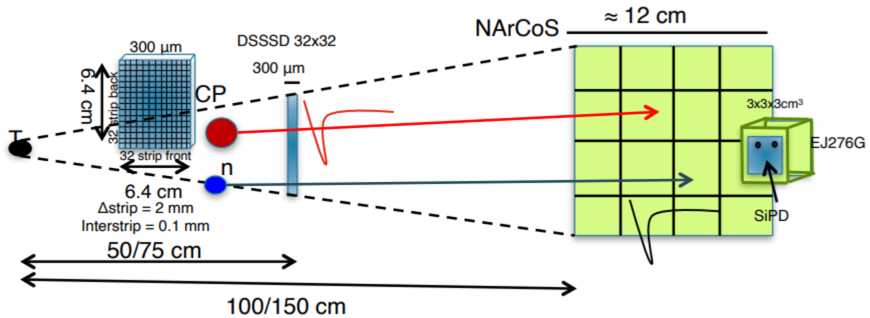
^{68}Ni, ^{38}S, ^{20}O but also in stable medium mass nuclei with isoscalar and isovector probes (carbon and Au/Pb target)



FARCOS in its final configuration to detect reaction products



γ-ray measured with CsI(Tl) - CHIMERA sphere



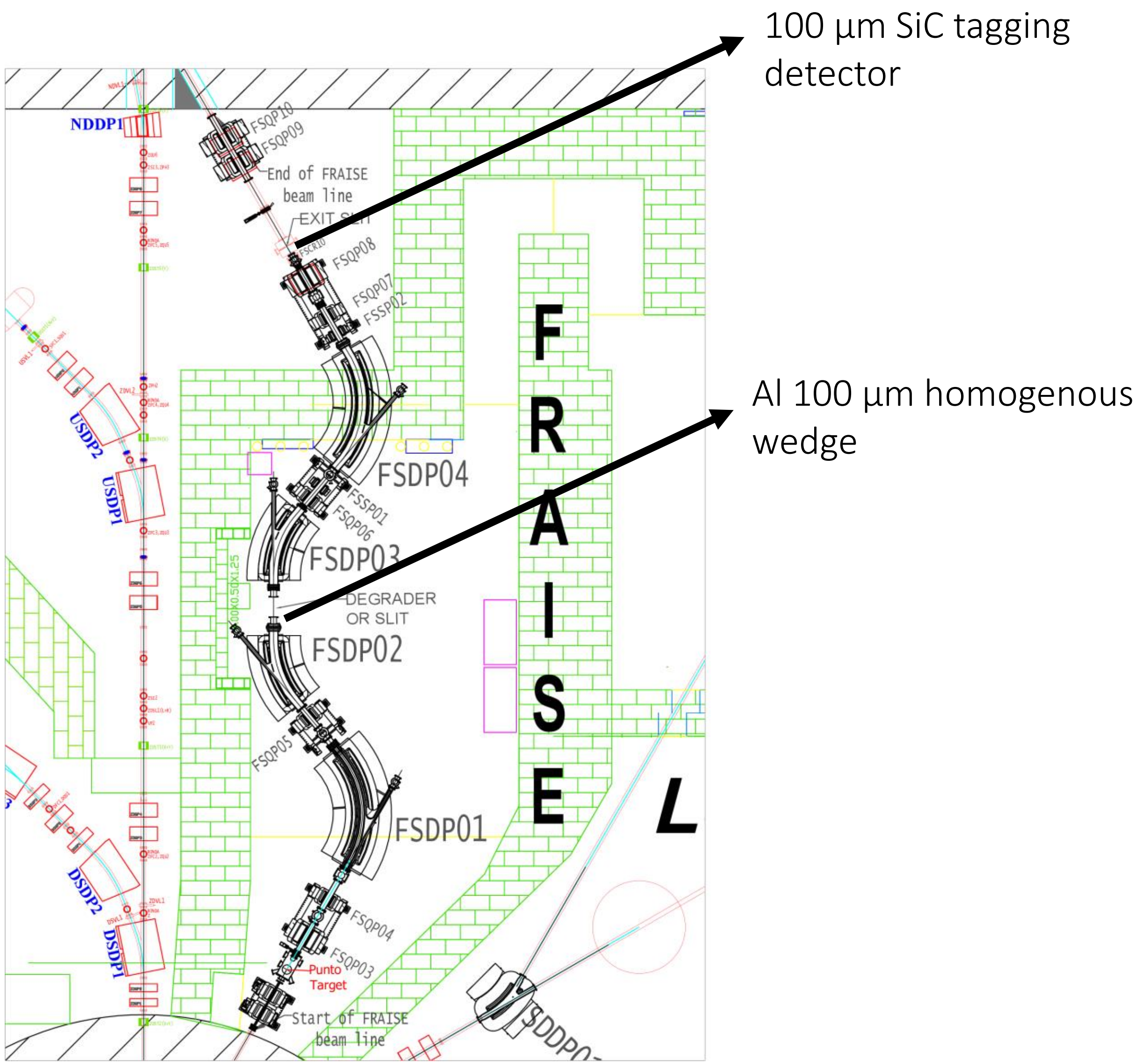
Also neutron detection with a new prototype under construction - PRIN-ANCHISE
https://home.infn.it/it/news-infn/4627-prin-2020-11-progetti-vincitori-con-l-infn-di-cui-3-come-capofila

See the poster of E.V. Pagano

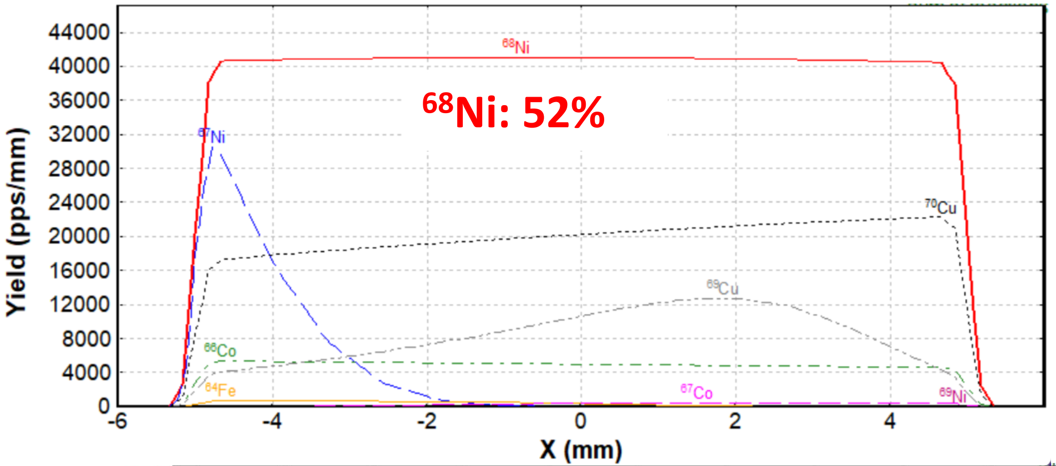
E.V. Pagano et al., NIM A 905 47-52 (2018)
E.V. Pagano et al., NIM A 889 pp. 83-88 (2018)
E.V. Pagano et al., Front. Phys. 10:1051058, (2023)

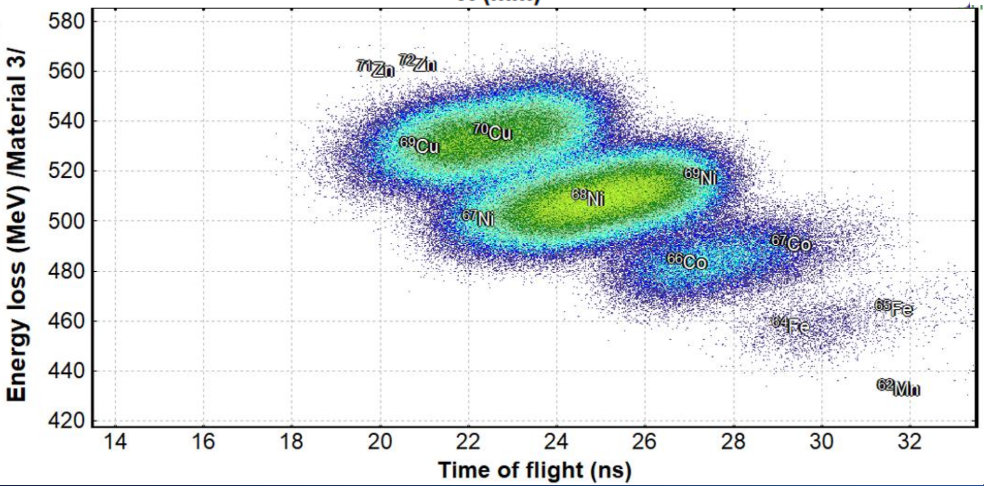
N.S. Martorana - nunzia.martorana@ct.infn.it

^{70}Zn primary beam at 40 MeV/nucleon, 1 kW on a ^{9}Be target → ^{68}Ni 4.1 10^5 pps with the 52% of the whole cocktail beam produced



Simulation of spatial distribution of beam components, using a SiC detector placed after the exit slit

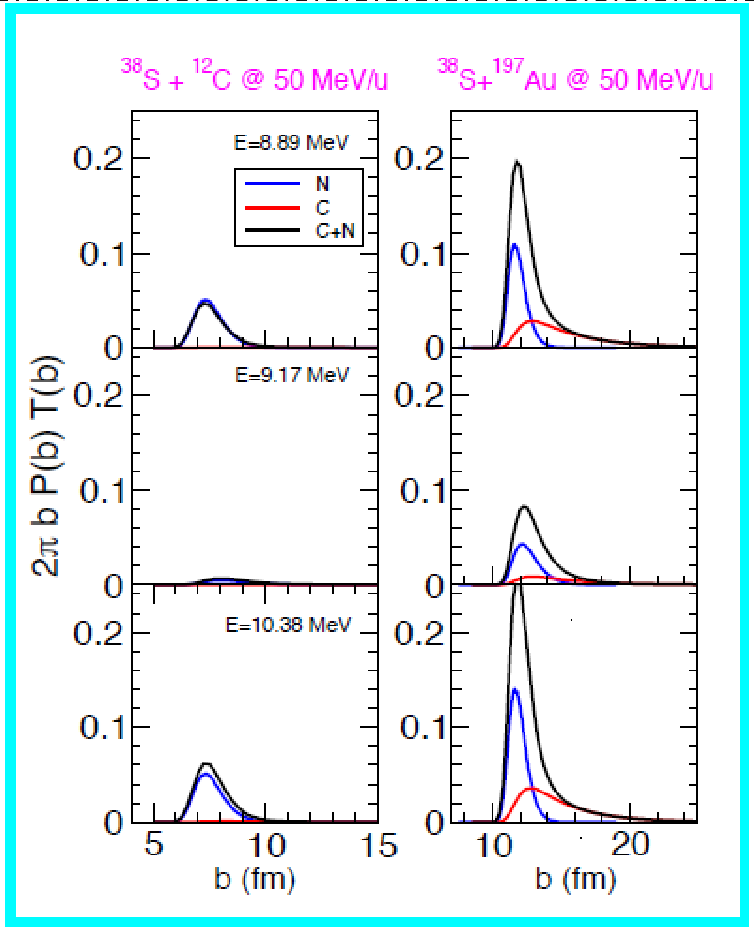




N.S. Martorana - nunzia.martorana@ct.infn.it

Pygmy Dipole Resonance → the case of ^{38}S

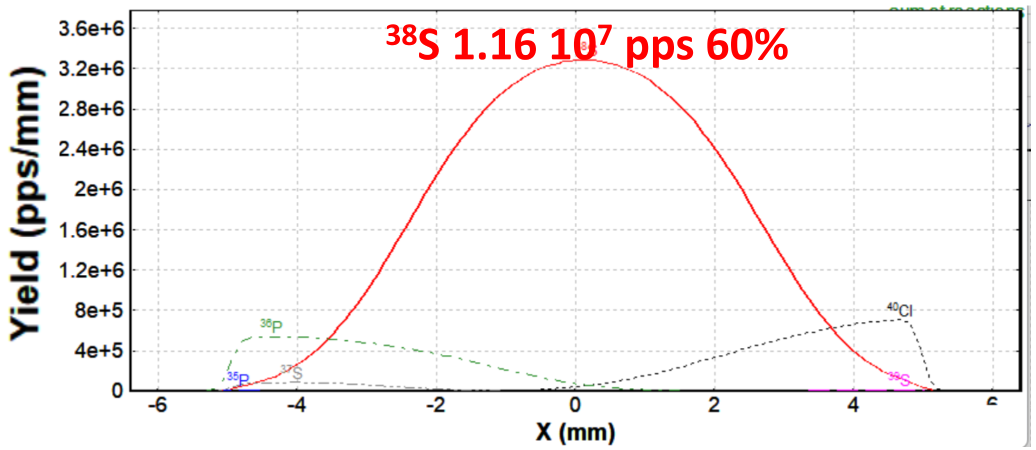
Semiclassical calculations, courtesy of E.G. Lanza

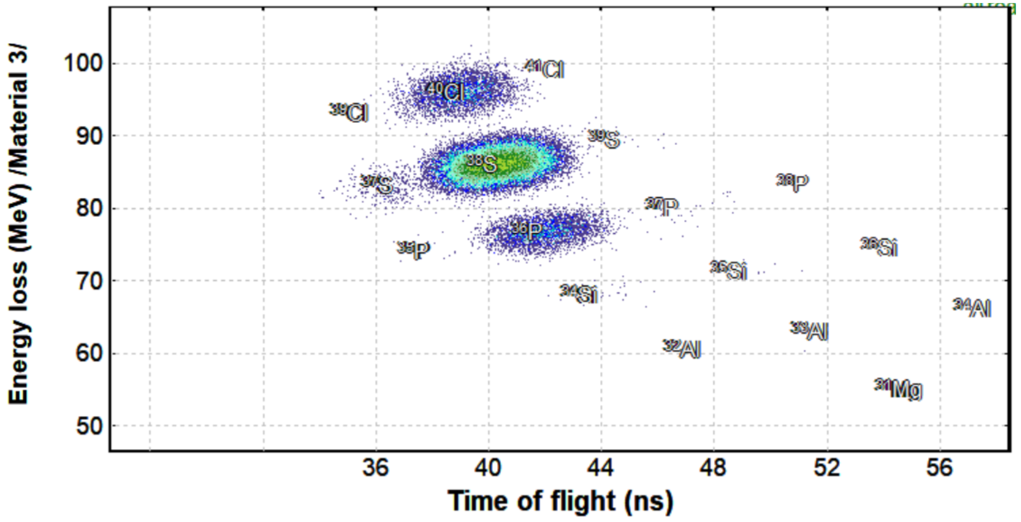


A. Bracco et al., Progress in Particle and Nuclear Physics, 106, (2019)

^{40}Ar at 60 MeVA 2 kW + ^{9}Be target

Simulation of spatial distribution of beam components, using a SiC detector placed after the FraISe exit slit





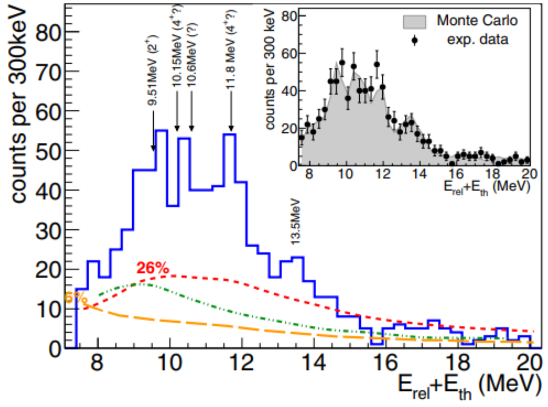
N.S. Martorana - nunzia.martorana@ct.infn.it

Clustering physics

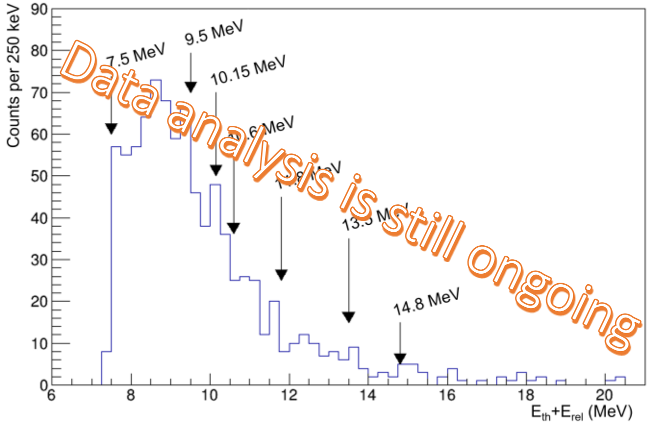
- The clustering structure of α particles in neutron-rich isotopes of Be, B, C, is an interesting topic that could be studied with FraISe

A study on these structures on nuclei as ^{10}Be, ^{16}C has been performed with FRIBS@LNS and the CHIMERA multidetector

D. Dell'Aquila et al., PRC 93(2016)024611



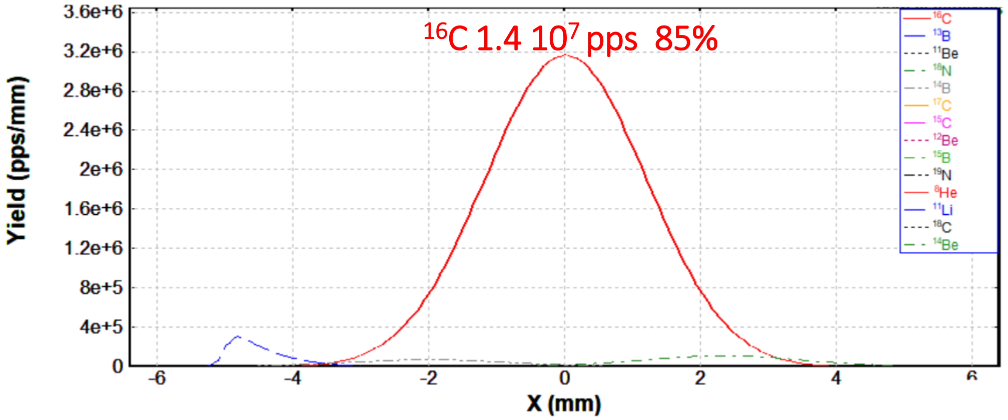
F. Risitano et al. in press on IOP Journal of Physics: Conference Series

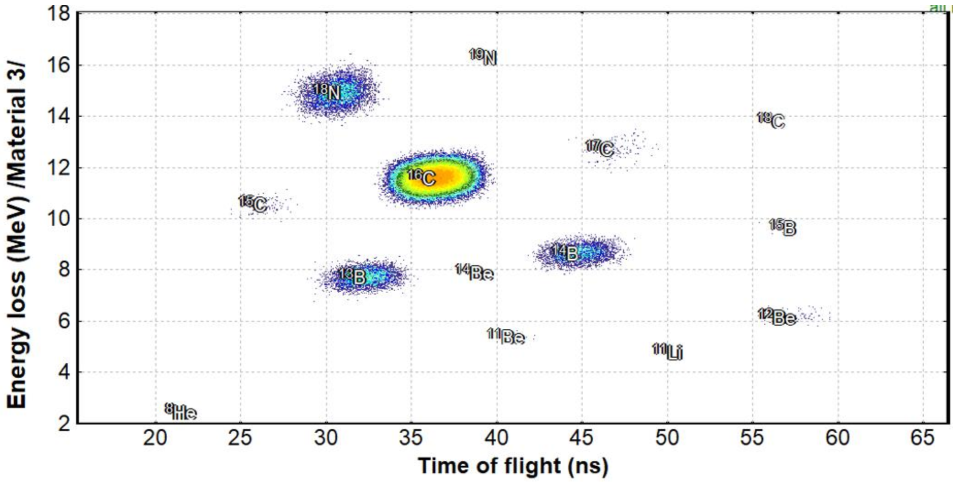


See the talk of F. Risitano Wednesday 14 June

With FraISe and FARCOS+CHIMERA multidetector will be possible to extend these studies to various nuclei

Simulation of spatial distribution of beam components, using a SiC detector placed after the FraISe exit slit





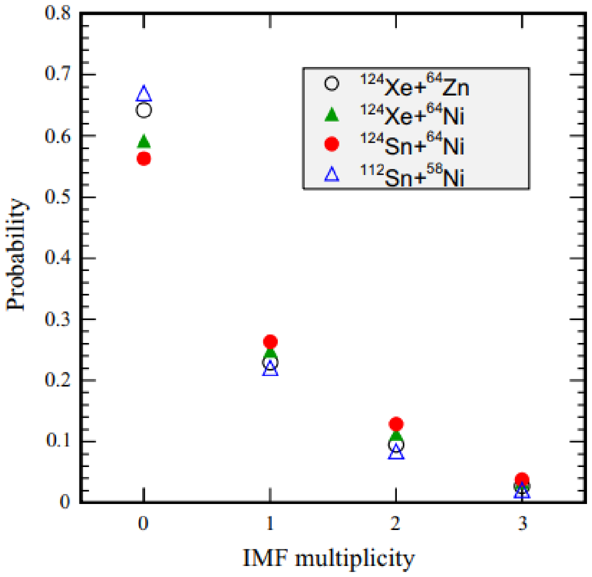
N.S. Martorana - nunzia.martorana@ct.infn.it

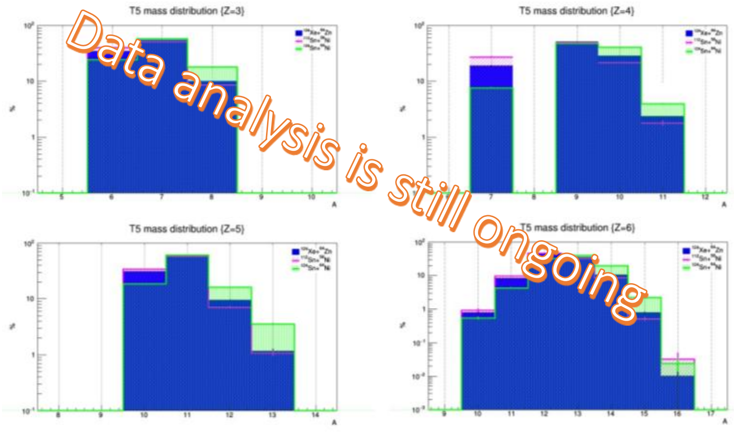
Isospin physics

- The study of Isospin effects in Heavy-Ion reactions at Fermi energies is an important field of research
- Such studies are also important to investigate the density dependence of the symmetry energy at sub-saturation densities

Studies of this phenomenon have been performed with CHIMERA and FARCOS multidetector **on stable nuclei** (E. Geraci et al., IL NUOVO CIMENTO 45 C (2022) 44)

P. Russotto et al., Eur. Phys. J. A (2020) 56:12





See the poster of C. Zagami

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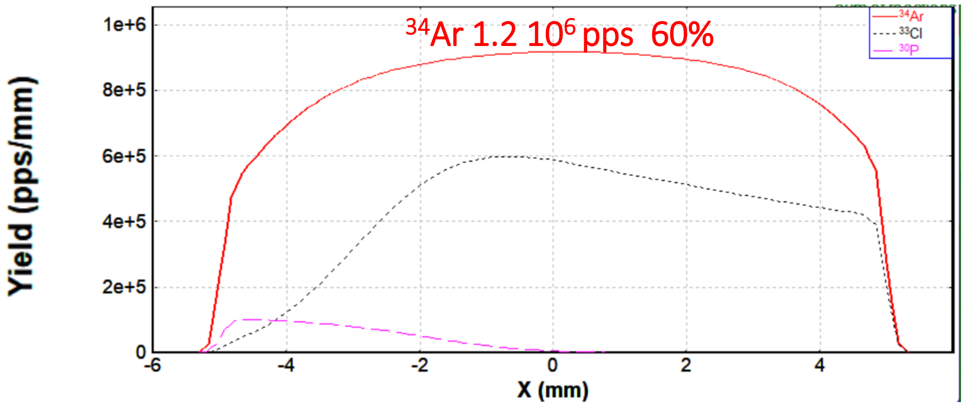

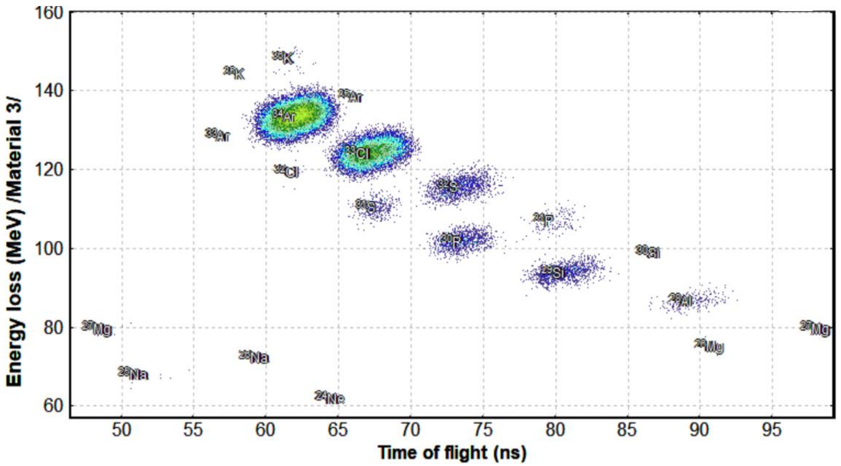

N.S. Martorana - nunzia.martorana@ct.infn.it

Conclusions

- Status of the FraISe@LNS facility and related diagnostics and tagging systems
- FraISe will allow to produce RIBs→2-3 kW primary beam; intensity of 10^3 –10^7 pps
- Investigations performed with both tests and LISE++ simulations
- Reference study fixing the features of diagnostics and tagging systems based on SiC detectors

Perspectives

- Further steps will concern the production of SiC arrays and the validation of whole system
- GEANT4 simulations and experimental tests on the tagging device
- Detailed studies of stripping extraction for further beams

N.S. Martorana - nunzia.martorana@ct.infn.it

Thank you for the attention

N.S. Martorana[1] , L. Acosta[2], C. Altana[3], A. Amato[3] , G. Cardella[1] , A. Caruso[3] , L. Cosentino[3], M. Costa[3], E. De Filippo[1] , G. De Luca[3], S. De Luca[3], E. Geraci[1,4] , B. Gnoffo[1,4], C. Guazzoni[5], C. Maiolino[3] , E.V. Pagano[3], S. Passarello[3], S. Pirrone[1], G. Politi[1,4], S. Pulvirenti[3], F. Risitano[1,6], F. Rizzo[3,4], A.D. Russo[3], P. Russotto[3] , D. Santonocito[3], A. Trifiró[6], M. Trimarchi[1,6], S. Tudisco[3], G. Vecchio[3]

[1]INFN-Sezione di Catania, Italy
[2]Instituto de Física, Universidad Nacional Autónoma de México, Mexico City, México
[3]INFN-LNS, Catania, Italy,
[4]Dipartimento di Fisica e Astronomia Ettore Majorana, Università degli Studi di Catania, Italy,
[5]DEIB Politecnico Milano and INFN Sez. Milano,
[6]Dipartimento MIFT, Universitá di Messina, Italy