6–8 sept. 2023 GANIL

Iulian STEFAN
IJCLab –Orsay
Laboratoire de Physique des 2 Infinis
Irène Joliot-Curie

Reaching for the infinities :
Nuclear Physics - MNT with NEWGAIN injector

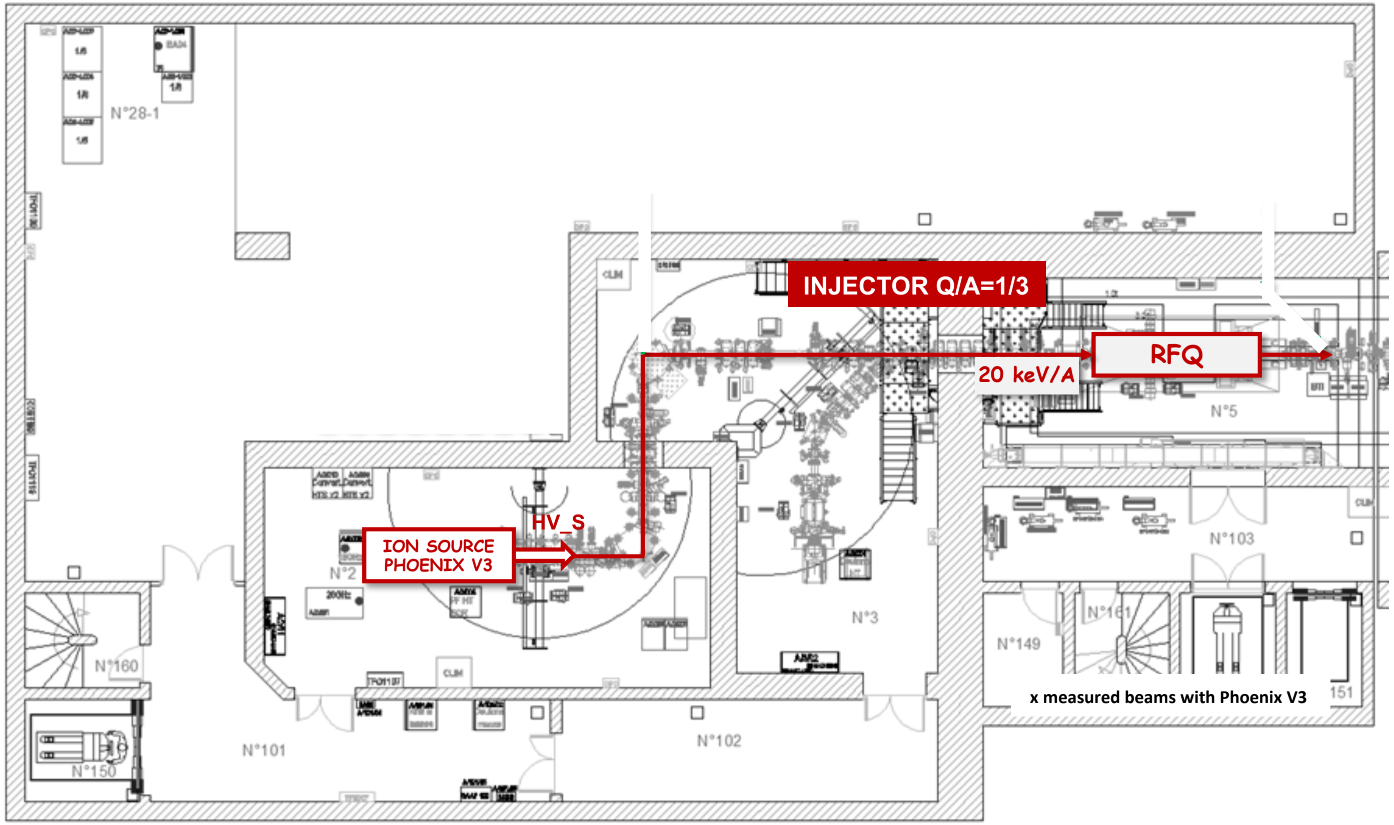
1. **NEWGAIN** project
   - Implantation
   - Existing program
   - Opportunities (MNT)
2. MNT reactions
   - S3 and MNT
   - Gas target for MNT
   - Nier-Bernas Ion Source for MNT

1. NEWGAIN project

NEWGAIN NEW GANIL INJECTOR · FRANCE 2030 · anr agence nationale de la recherche · cea · cnrs · GANIL laboratoire commun CEA/DRF CNRS/IN2P3 · Irfu · lpc caen · LPSC Grenoble · IPHC Institut Pluridisciplinaire Hubert Curien Strasbourg · LP2i Bordeaux · IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

NEWGAIN project: Relevant Beams & Intensities

Estimated in 2021



Existing

Ions	Intensity (pμA) Phoenix V3 RFQ A/Q≤3
^{18}O	80
^{19}F	>15
^{36}Ar	16
^{40}Ar	3.6
^{36}S	2.3
^{40}Ca	2.9
^{48}Ca	1.2
^{58}Ni	1.1
^{84}Kr	0.1
^{139}Xe	0.001
^{238}U	<<0.001

Measured	Estimated

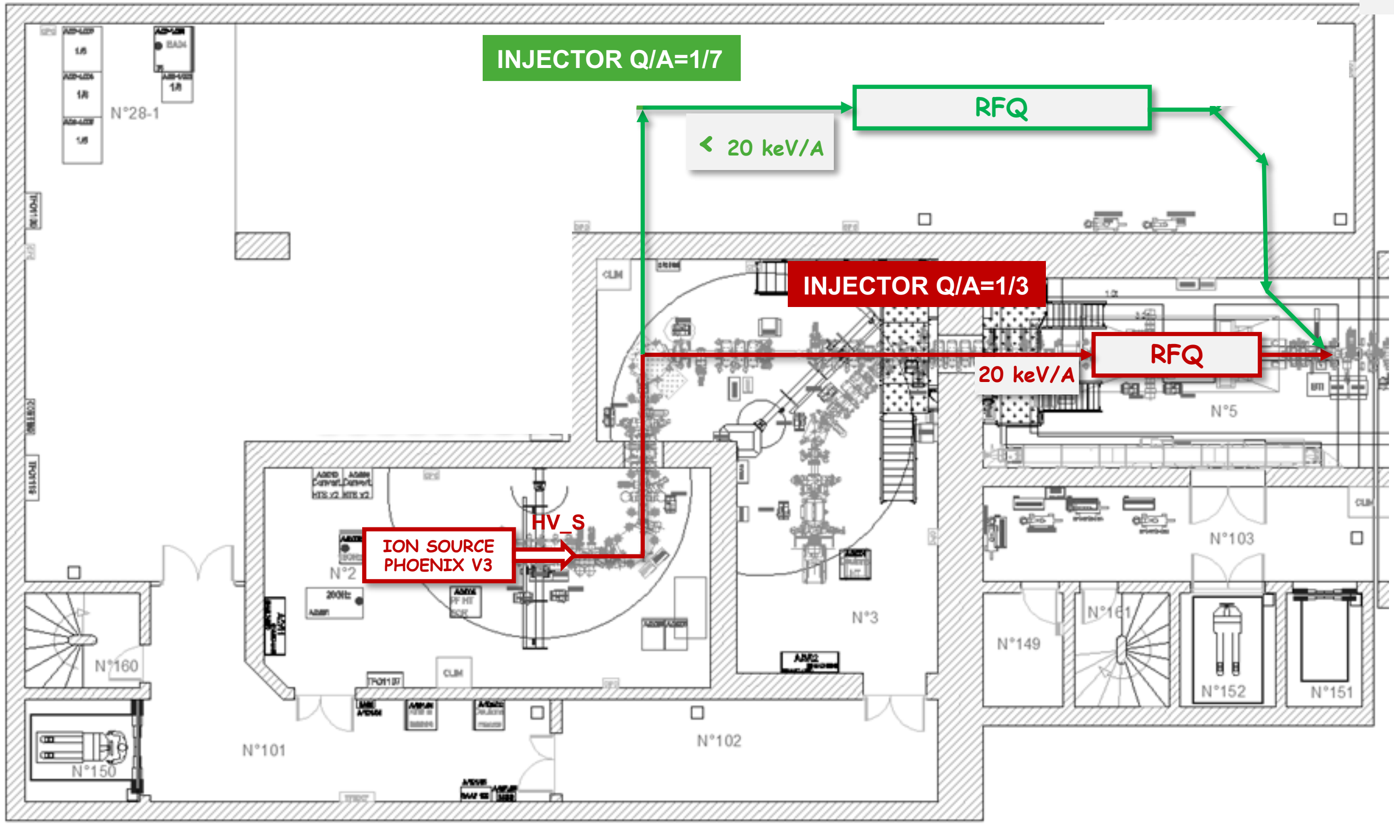
* -> no estimation

A/Q=3 (existant): E<=14.5 MeV/A
A/Q=7 : E<=7 MeV/A

NEWGAIN project: Relevant Beams & Intensities

Estimated in 2021

Important: RFQ dimensioned for 15 puA ^{48}Ca and 10 puA for ^{238}U



Ions	Intensity (pμA) Phoenix V3 RFQ A/Q≤3	Intensity (pμA) Phoenix V3 RFQ A/Q≤7
^{18}O	80	*
^{19}F	>15	>40
^{36}Ar	16	70
^{40}Ar	3.6	70
^{36}S	2.3	*
^{40}Ca	2.9	10
^{48}Ca	1.2	10
^{58}Ni	1.1	4
^{84}Kr	0.1	10
^{139}Xe	0.001	7
^{238}U	<<0.001	0.1

Measured | Estimated

* -> no estimation

Existing

NEWGAIN

A/Q=3 (existant): E<=14.5 MeV/A
A/Q=7 : E<=7 MeV/A

NEWGAIN project: Relevant Beams & Intensities

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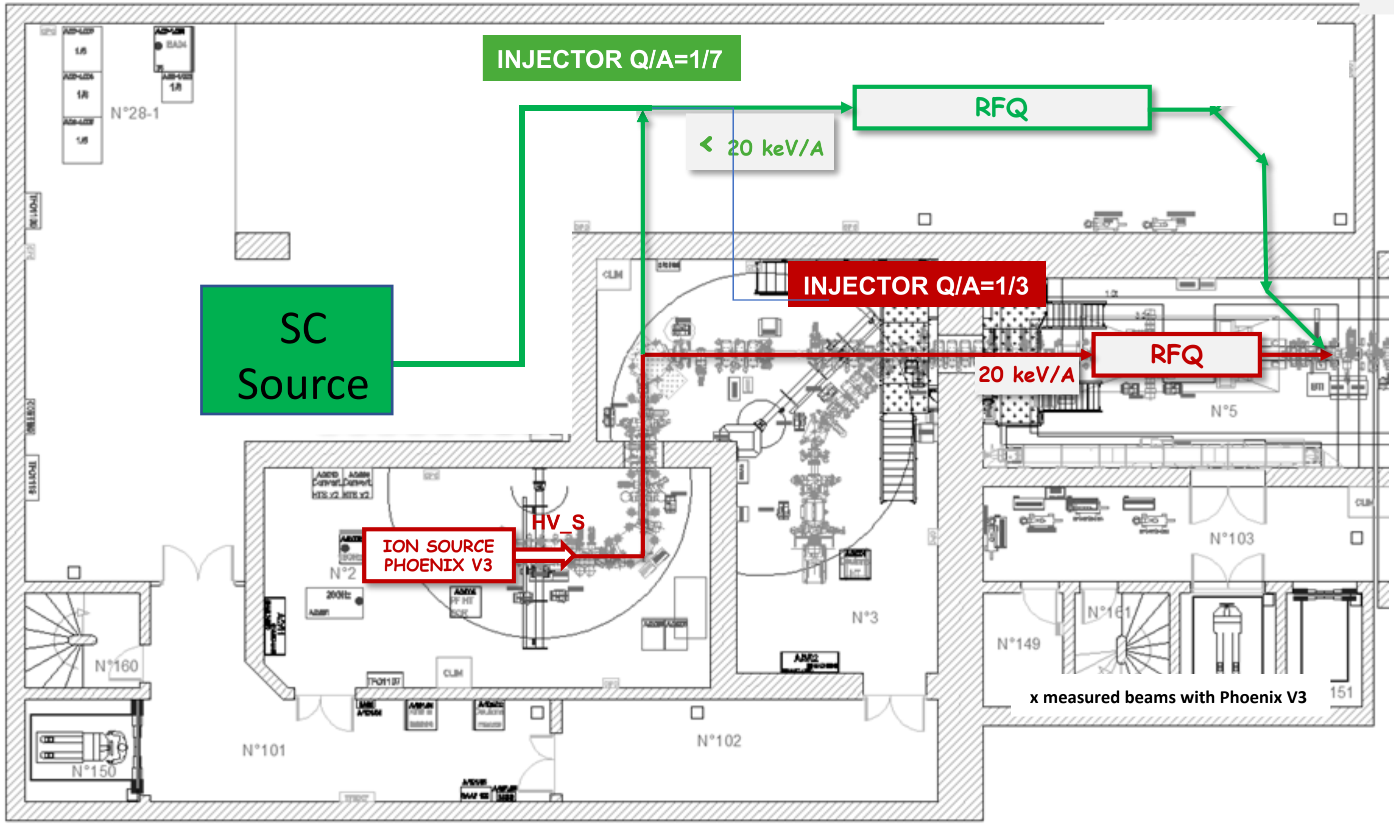

Existing

NEWGAIN

Important: RFQ dimensioned for 15 puA ^{48}Ca and 10 puA for ^{238}U

Ions	Intensity (pμA) Phoenix V3 RFQ A/Q≤3	Intensity (pμA) Phoenix V3 RFQ A/Q≤7	Intensity (pμA) Source ASTERICS RFQ A/Q≤7
^{18}O	80	*	375
^{19}F	>15	>40	>40
^{36}Ar	16	70	45
^{40}Ar	3.6	70	45
^{36}S	2.3	*	*
^{40}Ca	2.9	10	20
^{48}Ca	1.2	10	20
^{58}Ni	1.1	4	**8**
^{84}Kr	0.1	10	**20**
^{139}Xe	0.001	7	**>10**
^{238}U	<<0.001	0.1	**6**

Measured | Estimated

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A/Q=3 (existant): E<=14.5 MeV/A
A/Q=7 : E<=7 MeV/A

NEWGAIN project: Relevant Beams & Intensities

Comparison between different installations relevant to SHE studies

Beam intensities puA 100% enriched	SPIRAL2 GANIL, Caen			SHE factory FLNR, Dubna**	RIKEN Nishina Center Wako (Tokyo)		GSI Darmstadt
	LINAG A/q≤3 Phoenix v3	NEWGAIN* A/q≤7 Phoenix v3	NEWGAIN* A/q≤7 SC source	DC-280	RILAC	RRC (RILAC(2) as injector)	UNILAC***
^{18}O	80	>64	300	16	10	-	1
^{40}Ar	16	38	38	10	10	1	8
^{36}S	23	30	30	****	-	-	-
^{40}Ca	2.9	16	16	****	-	-	-
^{48}Ca	1.2	8	16	10	3	0.3	4
^{58}Ni	1.1	3.2	6.4	****	****	****	2.2
^{86}Kr	0.1	8	16	****	10	****	0.2
^{136}Xe	0.001	5.6	>10	16	10	0.3	1
^{238}U	<<0.001	0.06	4.8	0.008	0.2	0.5	0.06^i^

* 80% total transmission assumed
** http://flerovlab.jinr.ru/index.php/2017/03/23/she-factory/
*** for the cw-linac project with the assumption of a 50% total transmission, priv. comm. W. Barth et al., GSI
**** beams not delivered
i VARIS ion source, 80% Alvarez-transmission, mode: 2 Hz/0.1 ms, priv. com. W. Barth et al., GSI
\- intensities not provided

Highest intensity

Estimated in 2021

Estimated in 2021

Important: RFQ dimensioned for 15 puA ^{48}Ca and 10 puA for ^{238}U

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^{238}U	<<0.001	0.1	6

Measured | Estimated   * -> no estimation

A/Q=3 (existant): E<=14.5 MeV/A
A/Q=7 : E<=7 MeV/A

Important:
Existing S3 Target:
S3 - 10 puA ^{70}Zn @ 5 MeV/A. (18 puA for ^{48}Ca and 2.7 puA pour ^{238}U)

NEWGAIN project: Relevant Beams & Intensities

Estimated in 2021

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Measured | Estimated

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NEWGAIN

Consolidation and reinforcement of the S3: SIRIUS, LEB & DESIR physics program.

Relevant beams:

$^{12,13,14}C$, $^{16,17,18}O$, $^{20,21,22}Ne$, ^{23}Na, $^{24,25,26}Mg$, ^{27}Al, $^{28,29,30}Si$, $^{32,34}S$, $^{35,37}Cl$, $^{38,40}Ar$, $^{38,39,40}K$, $^{40,42,43,44,46,48}Ca$, $^{46,47,48,49,50}Ti$, ^{51}V, $^{50,52,53,54}Cr$, ^{55}Mn, $^{54,56,57,58}Fe$, ^{59}Co, $^{58,60,61,62,64}Ni$, $^{63,65}Cu$, $^{64,66,67,68,70}Zn$, $^{74,76}Ge$, $^{78,86}Kr$, $^{84,86}Sr$, ^{90}Zr, ^{92}Mo

Important:

S3 Target crucial for this physics program:

10 puA ^{70}Zn @ 5 MeV/A. (18 puA for ^{48}Ca and 2.7 puA pour ^{238}U)

New opportunities . Not really compatible with existing installation

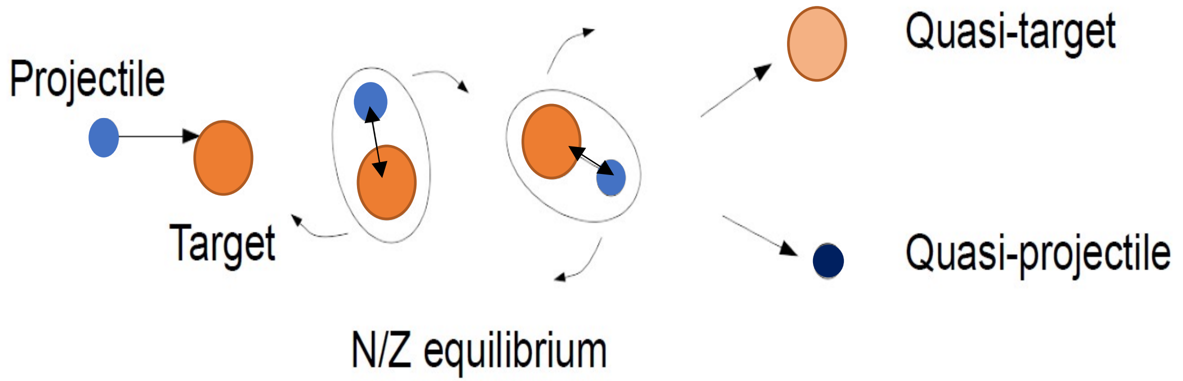
Beams:

Heavy beams: **^{136}Xe to ^{238}U**

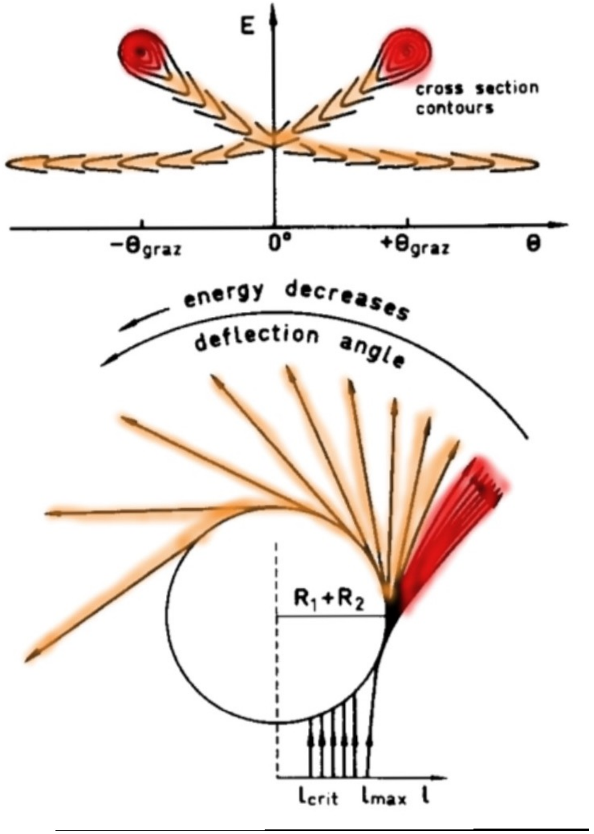
A/Q=3 (existant): E<=14.5 MeV/A
A/Q=7 : E<=7 MeV/A

What is the best way to move forward? How can we use the heavy beams? What equipment, installations?

Energies from coulomb barrier up to 20 MeV/A

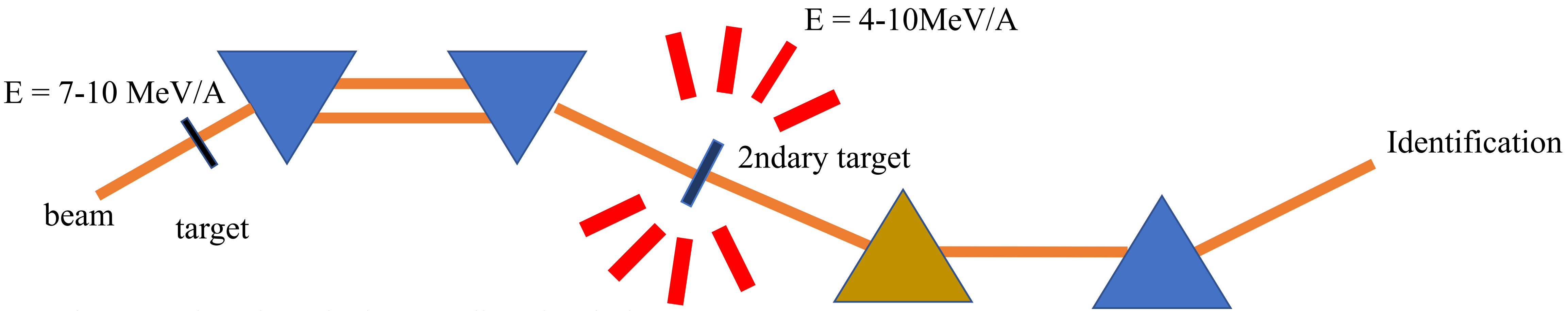


Orbiting phenomenon Evaporation → N/Z equilibration → Evaporation



J. Wilczynski, Phys. Lett. B 47, 484 (1973).

S3 constraints



Secondary reactions into the intermediate focal plane:

Issues:

1. Electric dipole select fragments with E < 2 MeV/A
2. Purity of the secondary beams (<1%)
3. MNT badly know @0° and for heavy fragments (QT)

Strong limitations !

Possible approaches:

1) Degrade the energy of the secondary reaction products bellow 2 MeV/A if QP
2) Look at the heavy fragment (QT). Problem: Charge state distribution …

Example : ^{18}O@10 MeV/A → QPs (^{20}O @ 0°)E between 3.5 and 10 MeV/A

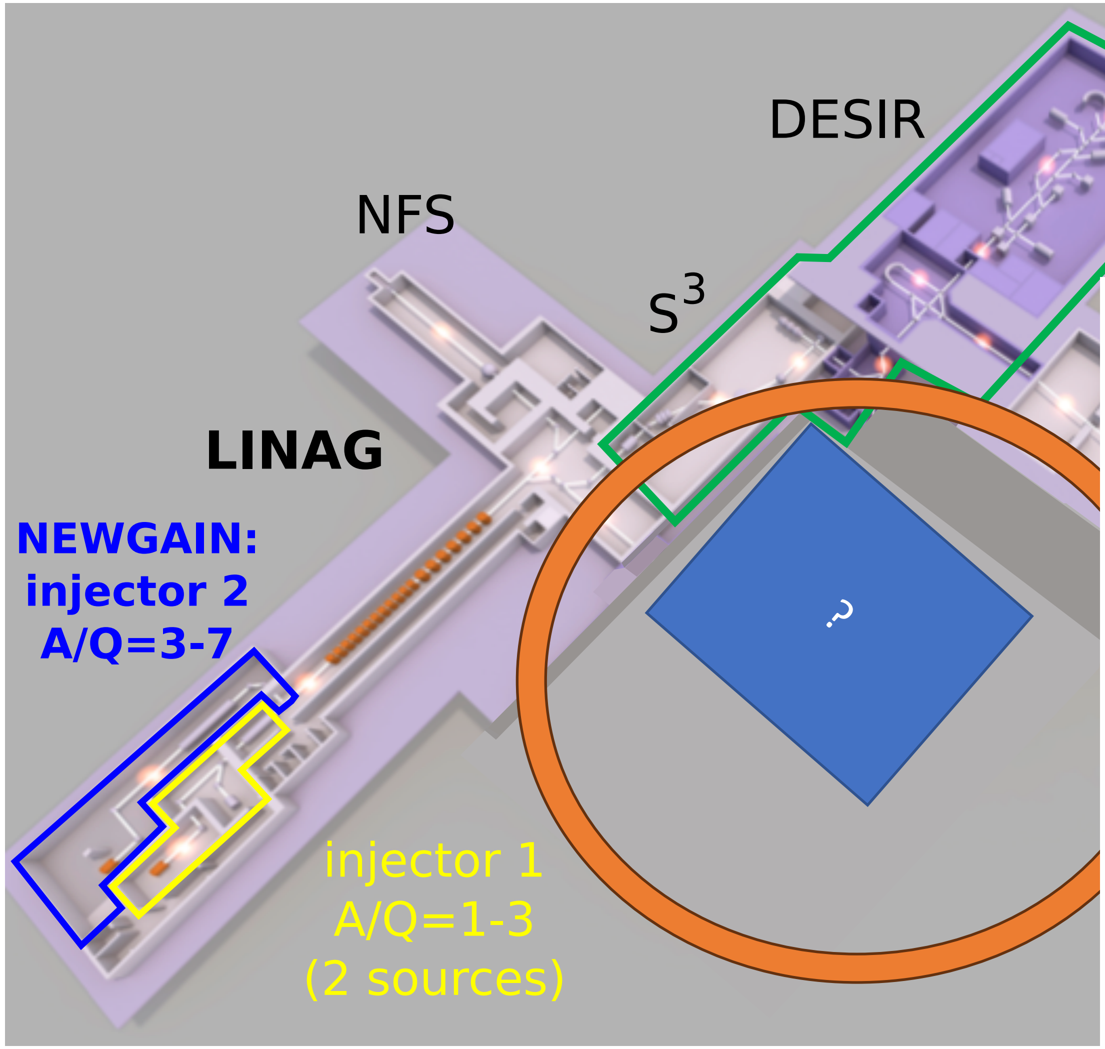
→ Vc~46 MeV for ^{20}O+^{110}Pd

→ QPs (^{22}O @ 0°) between 3.5 and 6.4 MeV/A

→ QTs (^{110}Pd @ 0°) 0.3 MeV/A <E < 0.7 MeV/A

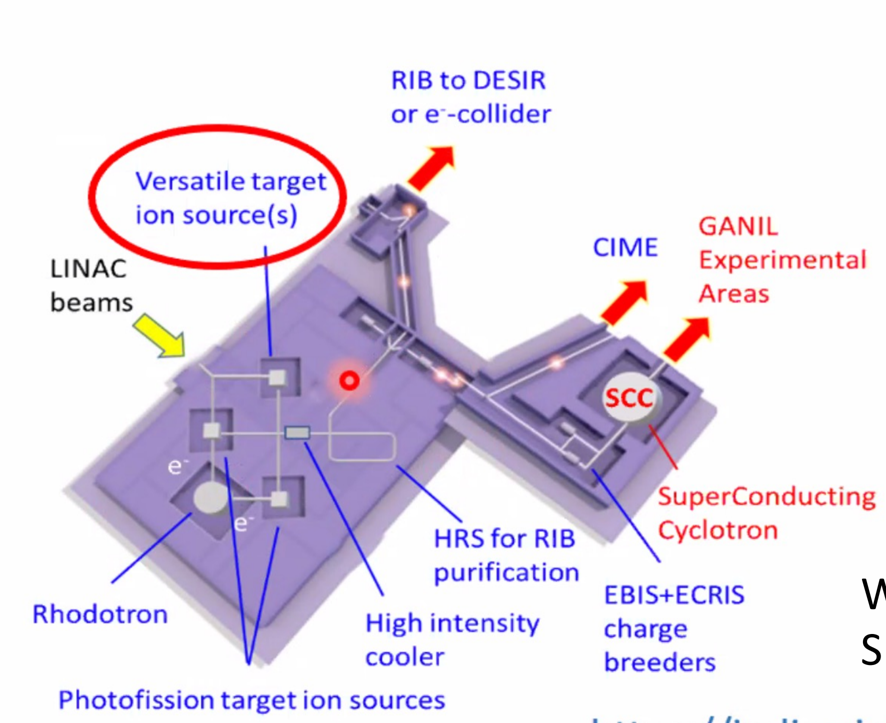
C. Petrone @ December 2022

Other options??



Existing

NEWGAIN project



WG3 proposal for
Spiro committee

https://indico.in2p3.fr/event/20534/

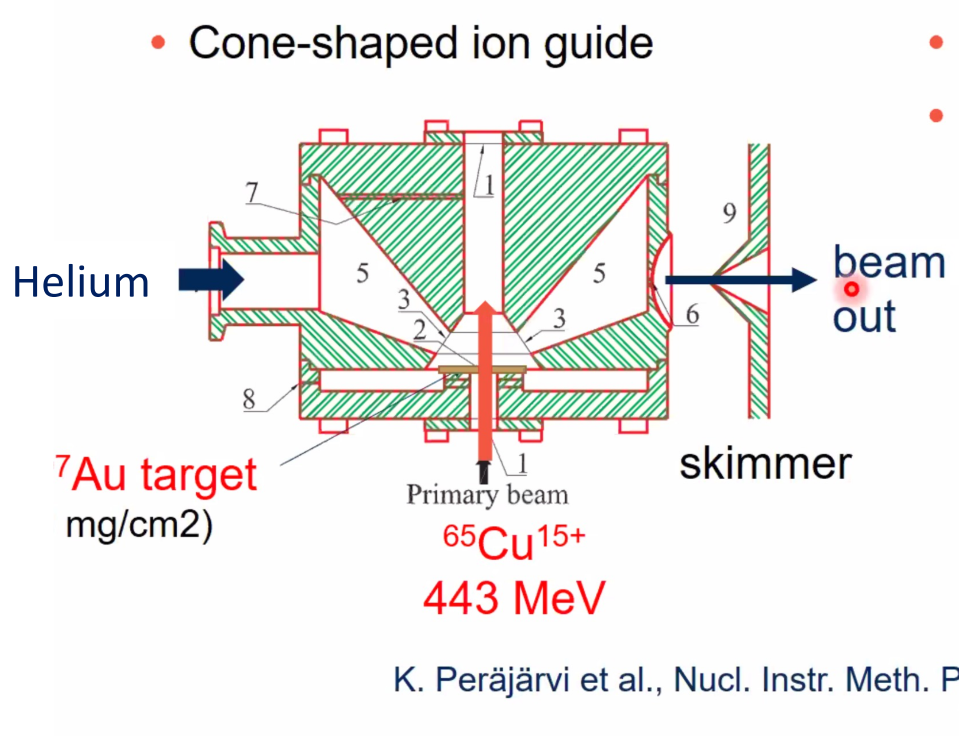
December 2022 “Physics with SPIRAL2 Heavy Ion Beams”
Took a look at the landscape of installation where MNT is used
Call for new ideas

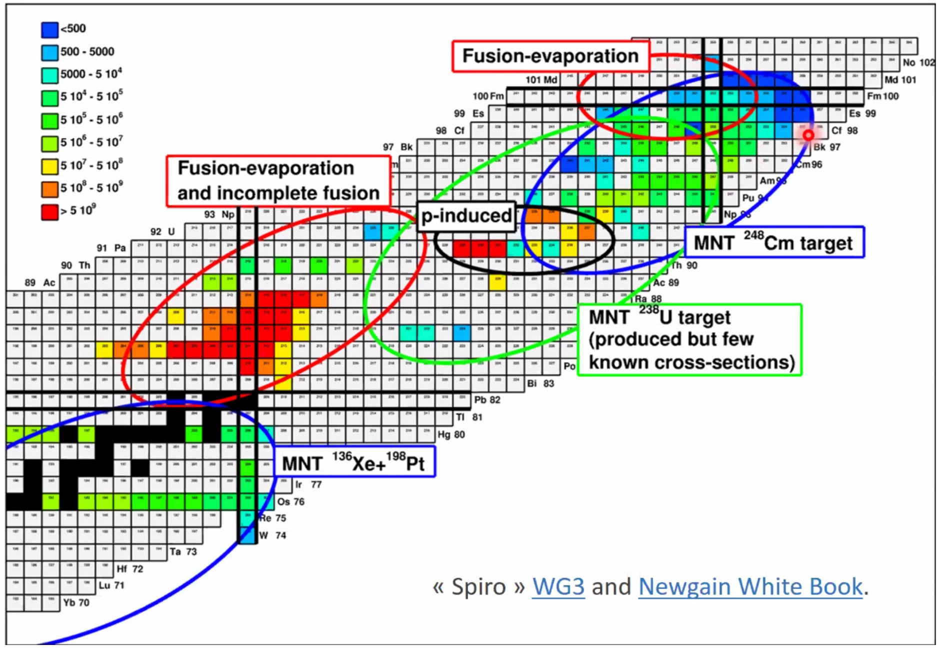
Gas cells presented

Kiss project
GSI gas cell
JYFL gas cell

Limitation: Today < 50pnA beam intensities

105 registered participants (13 countries)





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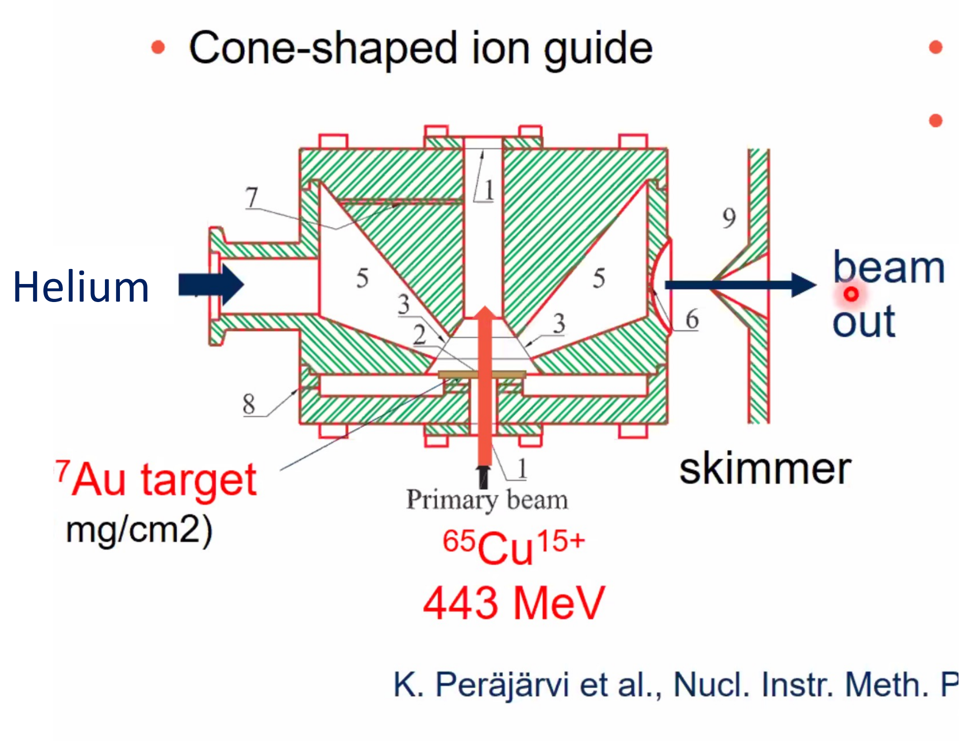
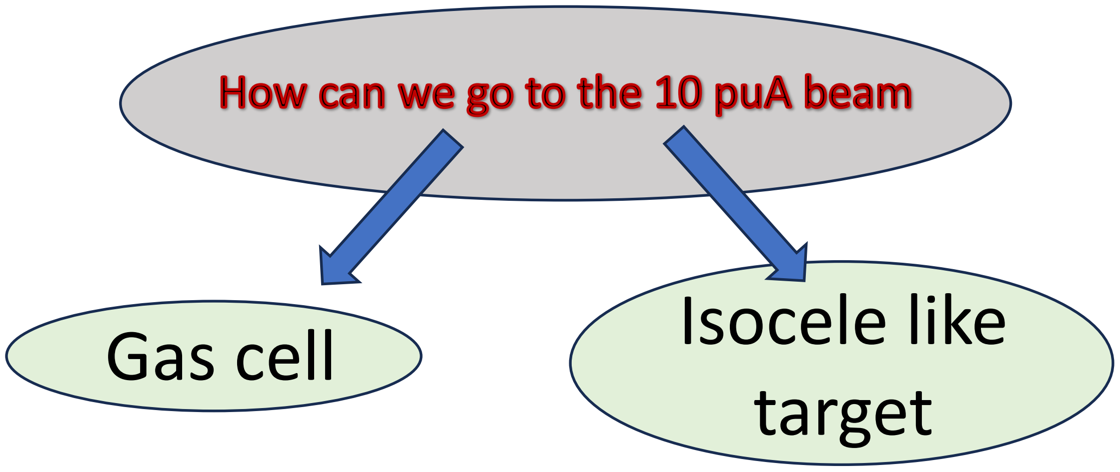




KISS2 project

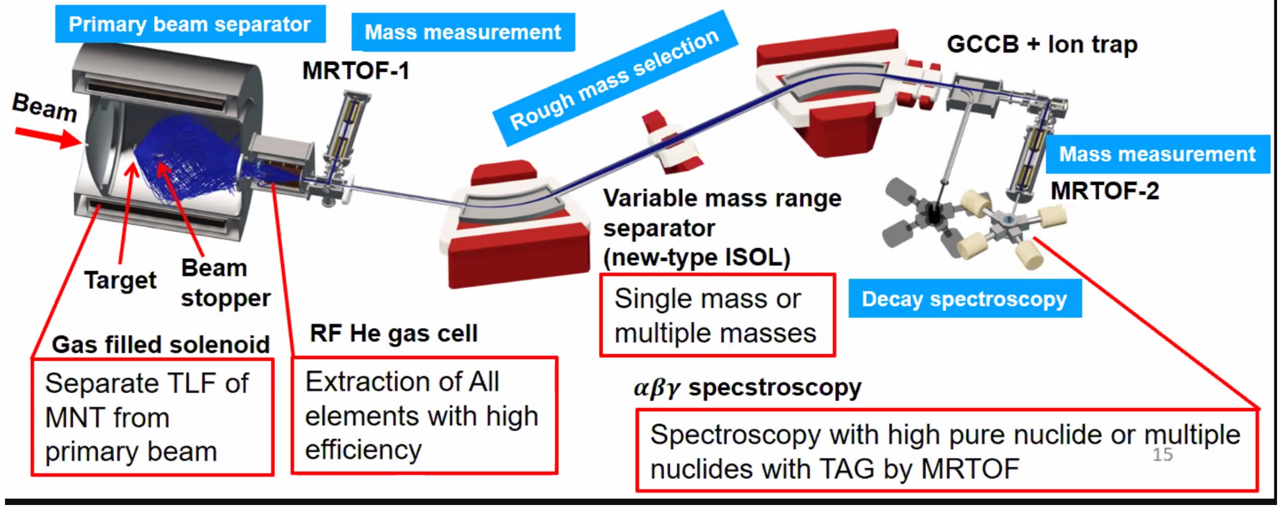
Gas cell inside a Solenoid

Magnetic field reduce beam like elements

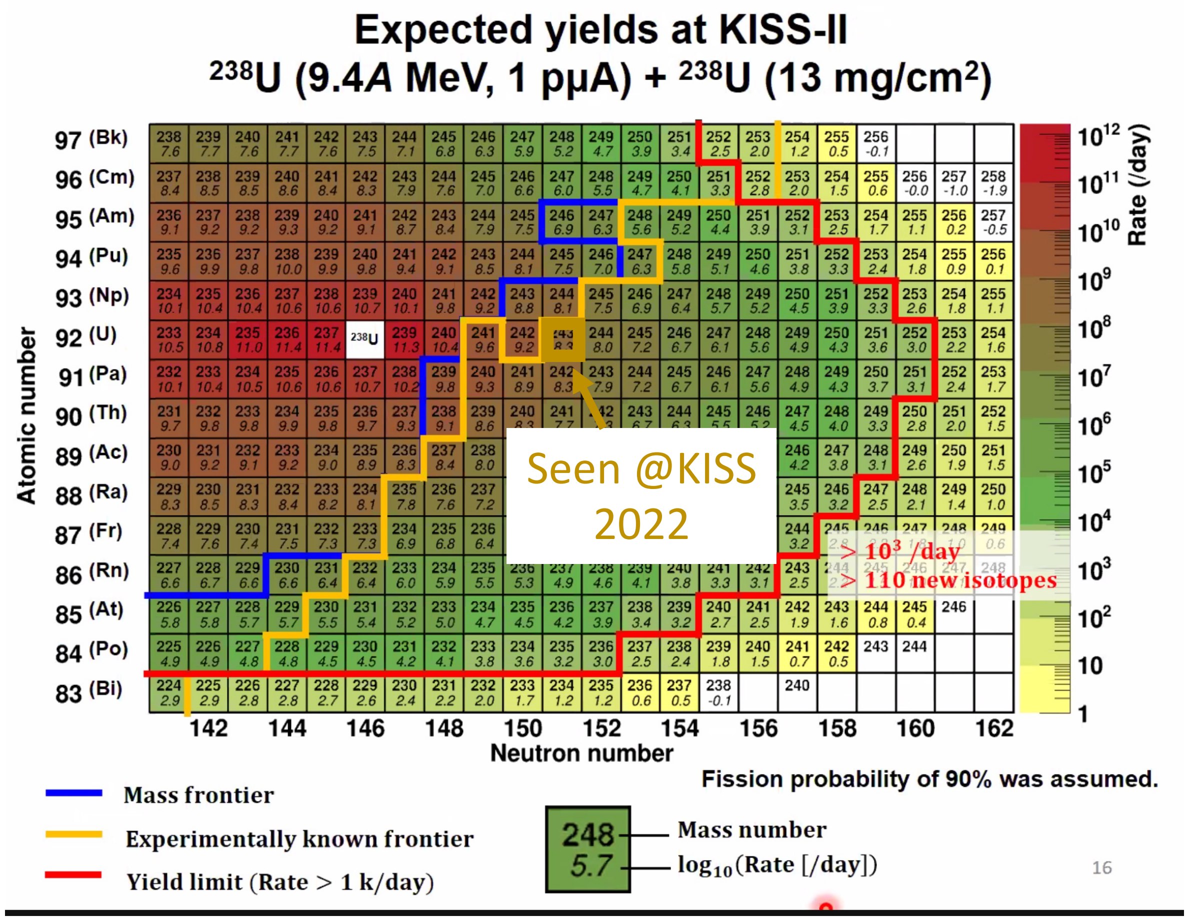
1 500 000 000 Yen for the project

10.223 million euros for a solenoid gas cell

	Primary beam	Total efficiency	#nuclides / unit time	Total gain
KISS	10 pnA	<0.1%	1	1
KISS-II	1 pμA	>1%	> 10	> 10 000
	Primary separator	RF gas catcher	MRTOF	

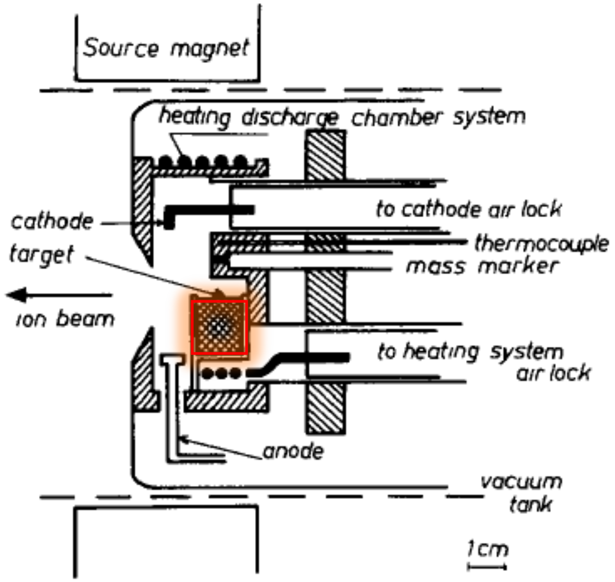


Y. Watanabe December 2022



Nobody is working on Gass cell for Spiral2 today

Nier-Bernas Ion Source for the NEWGAIN project

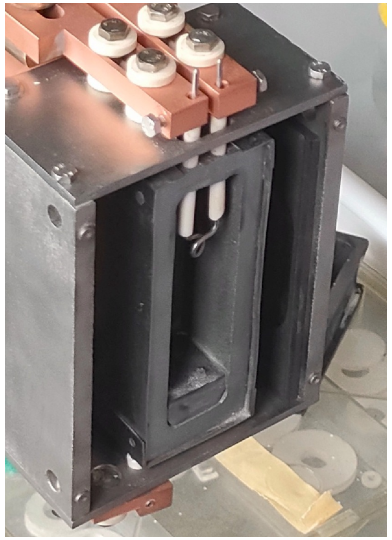


Proposed by D. Verney in December 2022 inspired by a 40 years old ISOSCELE target

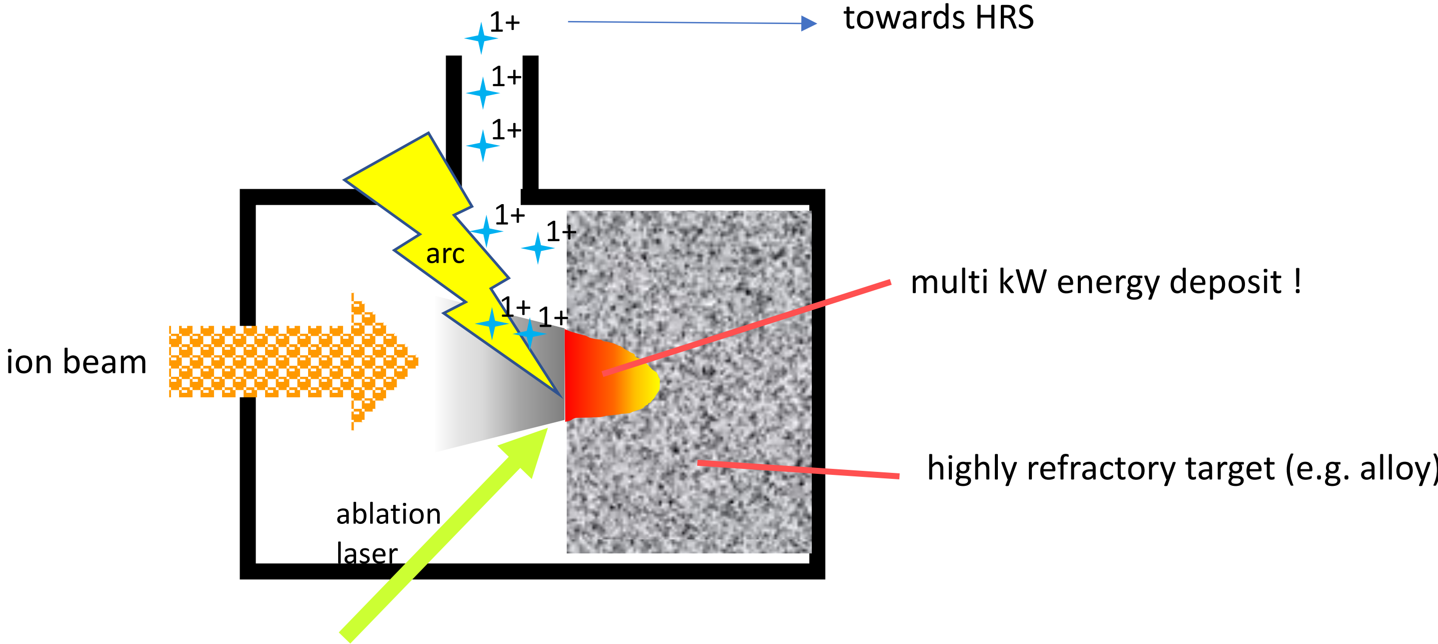
Examples reactions @ Newgain:

^{238}U on ^{238}U @7MeV/A : power in target 16.66 kW (10 pμA)

^{124}Sn on ^{238}U @7MeV/A : power in target 8.68 kW (10 pμA)



Nier-Bernas arc chamber



Maher CHEIKH-MHAMED - IJCLab

Nier-Bernas Ion Source for the NEWGAIN project

Maher CHEIKH-MHAMED - IJCLab

→Technical challenge: How to use the full beam power and dissipate the full beam intensity in the target in order to explore all reaction channels?

→ ISOL technique: using Nier-Bernas ion sources with target hold inside the ionization volume.

→ ISOL branch successfully used at the ISOCELE ISOL facility @ Orsay ~40 years ago and at least 33 target - beams have been tested.

Main technical features:

Target
- 2 target positions (behind / under the arc)
- High temperature volume for the target
- Most of release issues from conventional ISOL targets will be ruled out

Ion source
- Versatile plasma ion source
- High intensity ion source (~mA)
- Low beam emittance

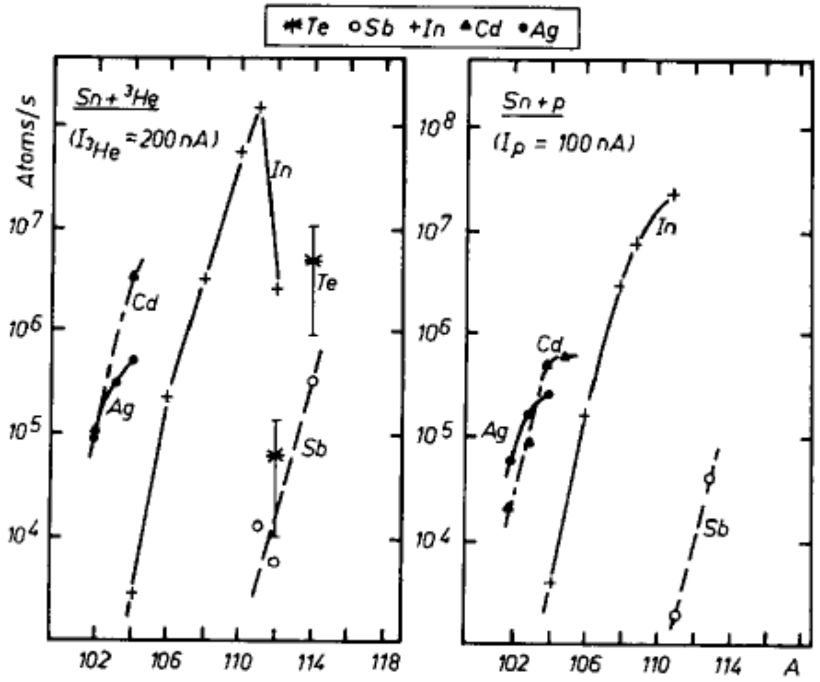


Fig 9 Yields of different elements from a molten Sn target: (a) proton beam, (b) ^{3}He beam

Nier-Bernas Ion Source for the NEWGAIN project

Maher CHEIKH-MHAMED - IJCLab

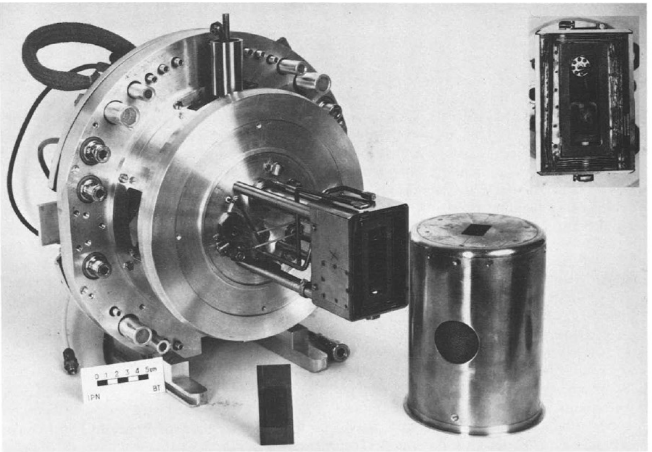


Fig 2 ISOCELE 2 ion-source

R&D items for the project:

- Ion source efficiency and ion intensities (firstly, find the performance of the ISOCELE ion source)
- Target materials
- Desorption processes
- Study the different beam & target combinations

Target goal of the project (timeline) → to be in phase with the first NEWGAIN beams ~2030

Status: pre-project phase and identification of partners already started.

Project cost: scale of ANR projects.

Conclusions

NEWGAIN will deliver a large range of beams in the 10 puA intensity range

Crucial for S3 : SIRIUS, LEB, DESIR

Full advantage of NEWGAIN beams and energies (7 MeV/A and 10 puA)?

MNT is crucial, but also fusion-evaporation in inverse kinematics and fusion-fission

- Development need for a GANIL gas cell (today < 50 pnA @ RIKEN, GSI, JYFL)

  Who? proposed by WG3 for Spiro committee & in NEWGAIN WHITEBOOK *C. Theisen*

- Development started for ISOCELE type target : **Nier-Bernas Ion Source**

  new development, R&D required, pre-project phase

  Maher CHEIKH-MHAMED (phase pre-projet) IJCLab – looking for partners

Important:

S3 Target is crucial for NEWGAIN success!

S3 - 10 puA ^{70}Zn @ 5 MeV/A. (18 puA for ^{48}Ca and 2.7 puA pour ^{238}U)