# Report on the work and outcome related to the International Expert Committee on the Future of GANIL

Michel Spiro with the precious help of
Fanny Farget and Nicolas Alamanos

GANIL 17th October 2022

# International Expert Committee on The Future of GANIL (Dec 2019)

- Maria Jose Garcia Borge (CSIC, Spain)
- Paolo Giubellino (GSI, Germany)
- Ulli Koester (ILL, France)
- Hiroyoshi Sakurai (Riken, Japan)
- Boris Sharkov (JINR, Russia)
- Brad Sherill (MSU, USA)
- Michel Spiro (Chair)
- Johanna Stachel (University of Heidelberg)

# Terms of Reference (1)

Cher collègue,

Comme vous le savez, le paysage européen, pour ce qui concerne la physique nucléaire et les applications associées est en forte évolution avec en particulier la mise en service prochaine de la phase 1 de SPIRAL 2 au GANIL, l'évolution de la construction de FAIR en Allemagne, les développements de ISOLDE au CERN et les importants investissements engagés à JINR en Russie. Sur le plan international également, d'importantes infrastructures de ces domaines de recherche sont en construction ou en projet en Corée du sud et en Chine ainsi qu'aux États-Unis.

Dans ce contexte en forte évolution et compte-tenu de la position et du rôle de notre pays dans le développement des sciences et techniques nucléaires, il nous apparait essentiel d'actualiser notre vision de la place et du rôle futur de notre installation nationale le GANIL. Nous souhaitons démarrer cet exercice en ayant en main une analyse experte et indépendante du positionnement scientifique et technologique du GANIL débouchant sur des voies possibles d'évolution du laboratoire dans son contexte local et régional.

Nous avons souhaité vous confier cette mission et proposons pour cela que vous vous entouriez d'un petit comité composé d'experts de renommée mondiale. Sans que ce soit limitatif, les personnes dont le nom suit

# Terms of Reference (2)

Nous souhaitons que les points suivants soient abordés :

- Le GANIL dans son environnement local et régional : positionnement disciplinaire (physique fondamentale et applications), lien thématiques et structurels avec les laboratoires voisins, liens avec le milieu industriel régional et national,
- Quel rôle futur pour le GANIL dans la recherche en physique nucléaire fondamentale, dans le contexte européen et à l'international ? Quels partenariats privilégier ?
- Quel rôle futur pour le GANIL dans les applications associées, en France et dans le contexte européen en particulier ?
- Quelles évolutions possibles du positionnement disciplinaire ?

- December 2019: message adressed by the chair to the committee

Dear colleagues,

Thank you very much for having accepted to be part of the international expert committee on the long term future of GANIL. Your expertise and vision will certainly mark the history of GANIL. I am very honoured to chair this very high level group of expert personalities. I have asked Fanny Farget (CNRS) and Nicolas Alamanos (CEA) to help me in this task.

The process, if you agree will be the following:

1) A call, for about 2 pages maximum contributions from the national and international community, will be open end of January till end of April 2020

2) Meanwhile, Fanny, Nicolas and myself will interview selected French personalities who have a responsibility connected to GANIL.

3) In April and May, Fanny, Nicolas and myself will produce a digest of all the inputs we collected in a no more than 10 pages document.

4) All this will be given access to you to start the work of your committee.

5) We may need to meet (remotely at least) in June to set up working groups on most attractive options and meet again in Fall to try to converge.

**Note added afterwards for info**: In 2021, with the final reports of the working groups we could converge to writing our report which was finalized at the end of 2021 (we met virtually twice in 2020 and twice in 2021 and exchanged a lot by email)

# Spring 2020 : CALL for contributions

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

Call directed to international mailing lists and newsletters of GANIL members

Received contributions from :

- Nuclear Physics Community
- GANIL users
- CS members
- And beyond…

# Contributions received

- 12 for Nuclear Physics
- 9 for applications and interdisciplinary fields
- 5 support letters
- 2 directly to us, not on the site

- About 200 people replied (1/3 of the user community, seniors mostly → almost 100% of all seniors)
- → Converging views for the future
- All inputs were not retained at the end. Examples: storage ring, interdisciplinary hall..

- **Interdisciplinary Hall Working Group**

G. deFrance, GANIL,
Alain Pautrat, CRISMAT
Antoine Drouart, IRFU
Maud Baylac, LPSC-IN2P3
Charles Simon, Institut Neel
Romuald Duperrier, IRFU
Frédéric Ott, LLB
Ferid Haddad, ARRONAX
Xavier Hulin, GANIL
Emmanuelle Lacaze, INP
Jean-Michel Lagniel, GANIL
Xavier Ledoux, GANIL
Loic Thulliez, LPSC-IN2P3
Marie Plazanet,
Isabelle Monnet, CIMAP
Nicolas Arbor, IPHC
Jimmy Rangama, CIMAP
Serge Bouffard, CIMAP
Sylvie Leray, IRFU
Virginie Simonet, Fédération Française de Diffusion Neutronique
Daniel Santos, LPSC-IN2P3
Marco Di Giacomo, GANIL
Robin Ferdinand, GANIL

- **Reacceleration working group**

**Coordination:**
S. Galès, IJCLAB
Y. Blumenfeld, IJCLAB
F. Chautard, IJCLAB
**Physics Subgroups**
D. Beaumel, IJCLab
A.-F. Fantina, GANIL
J. Frankland, GANIL
W. Korten, CEA/DRF/IRFU
A. Lemasson, GANIL
N. Le Neindre, LPCC
I. Stefan, IJCLab
C. Theisen, CEA/DRF/IRFU
M. Vandebrouk, CEA/DRF/IRFU
**Post-Accelerator Subgroup**
B. Jacquot, GANIL
R. Ferdinand, GANIL
L. Maunoury, GANIL
**Invited**
P. Delahaye (GANIL)
D. Verney (IJCLab)

- **Electron Probe Working Group**

A. Chancé, IRFU, P. Delahaye,GANIL, F. Flavigny, LPCC, V. Lapoux, IRFU, A. Matta, LPCC, V. Soma, IRFU

**Radioactive ion beam RIB production**

-multi-nucleon transfer, fusion-evaporation :

I. Stefan, IJCLab, C. Theisen, IRFU

-fission; photofission: M. Fadil, IJCLab, P. Delahaye, GANIL

**Radioprotection issues, production building:**

H. Franberg, GANIL, X. Hulin, GANIL

**Radioactive ion beam production and interdisciplinary activities (working group):**

A. Drouart, IRFU G. de France, GANIL

Physics cases and ERL: A. Obertelli, Univ. Mainz, D. Verney, IJCLab, V. Lapoux, IRFU, A. Matta, LPCC, F. Flavigny, LPCC, V. Soma, IRFU

Discussions about ERL design and beam optics: W. Kaabi, IJCLab, A. Chancé, IRFU

- **Injector Cyclotrons for Interdisciplinary use Working Group**

Nathalie Moncoffre , IP2IL, EMIR&A

Amine Cassimi, CIMAP

- Marika Schleberger, University of Duisburg-Essen, Germany, representative of the GANIL interdisciplinary research user in the GANIL Users Executive Committee (GUEC)

- Christina Trautmann, GSI Darmstadt, Germany

- Muriel Ferry, CEA/DES Saclay, France

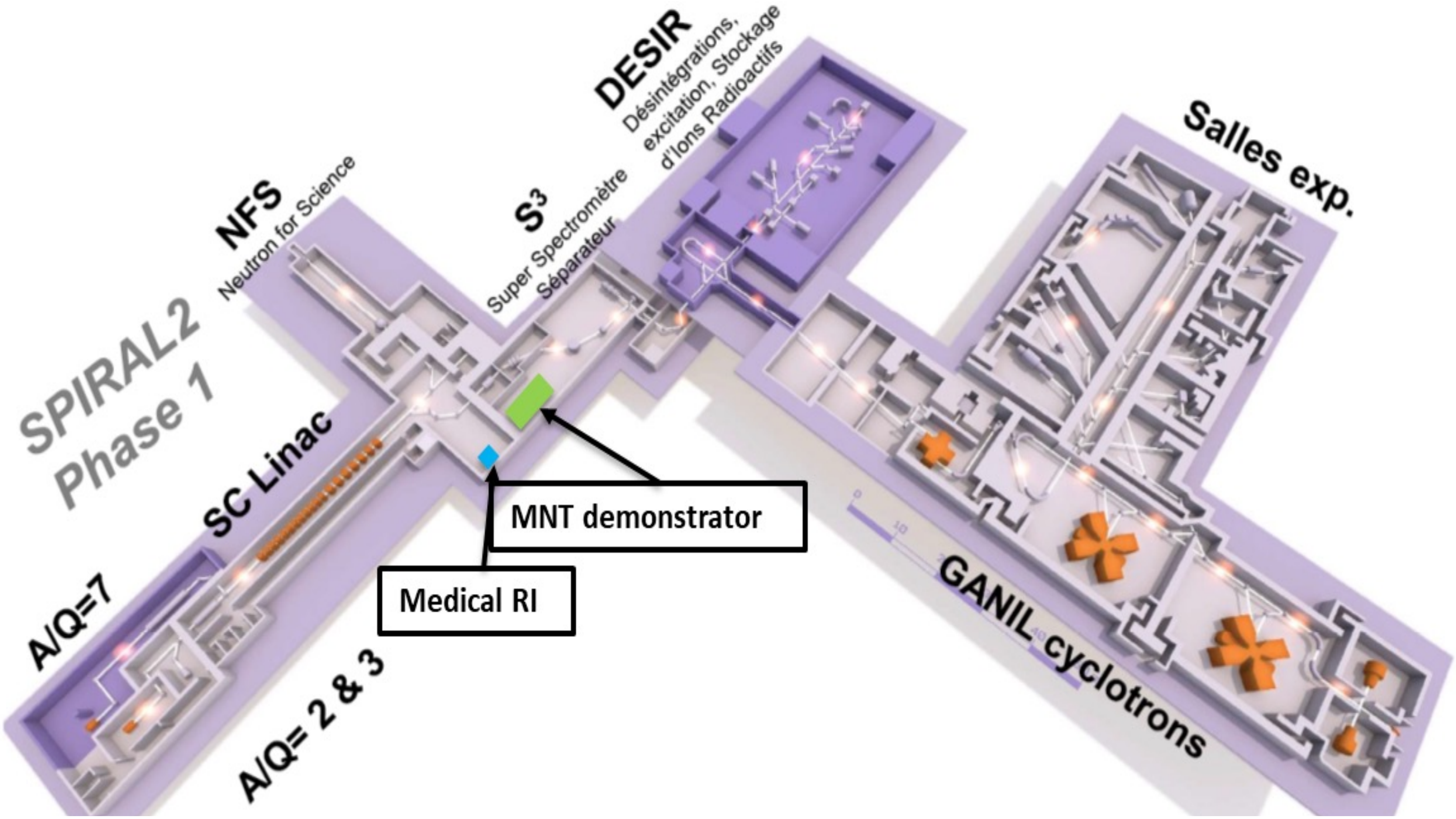
- Claire Rodriguez-Lafrasse, CNRS/IN2P3/IP2I Lyon, PUPH Université Lyon I, France

- Eric Quirico, IPAG-Université Grenoble-Alpes, France

# The report warning)

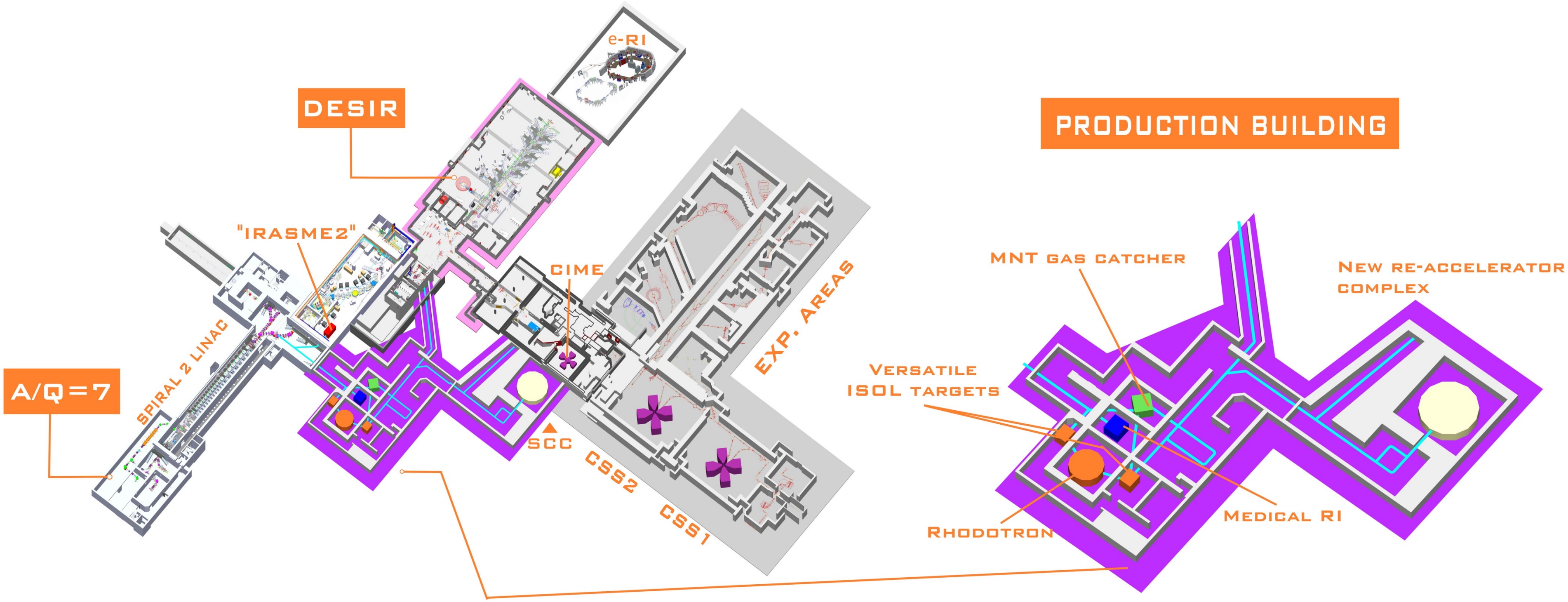
- *The present document reflects the thoughts and the views of the committee following consideration of the material received.*
- *The vision is composed of a series of modular components, with options that would keep GANIL at the leading edge of nuclear science globally for the decades to come. The vision, as presented in this document, includes discussion of a possible timetable, prioritization for realization of the modules, and the links between the components.*
- *This report was drafted by a committee of international scientific experts with different profile and the scenarios that emerge reflect their thoughts on the scientific and technological aspects only, without constituting an action plan at this stage.*

# STEP 1 : Deployment of on-going Phase 1



- In addition, **the committee considers it very important to operate optimally the existing cyclotrons and the LINAG** and **to maintain the capabilities of the existing cyclotron chain**. This is necessary to meet the ion beam requirements both for Nuclear Physics and Interdisciplinarity.

# Layout Vision for the Future



# Step 2

- **Refurbishment/replacement of CIME with a new re-accelerator complex**, to reaccelerate exotic nuclei with high beam quality (intensity, emittance and purity) from the energy domain starting from the Coulomb barrier up to the Fermi energy and beyond. This unexplored energy domain coupled with the wide array of reaccelerated beams of nuclei far from stability will provide a deeper insight into the many facets of the nuclear system.
- **Construction of the production building** for production of neutron-rich exotic nuclei: a revised Phase 2 version that would include different production mechanisms,

  i) from fission of a uranium carbide target, induced by LINAG beams

  ii) from photo-fission by an electron driver

  iii) from multi-nucleon transfer reactions using a gas-cell catcher
- The same production building should also house the target stations for production **of medical radioisotopes or slow neutron beams** respectively. The space freed in the $S^3$ experimental hall after the movement of the Multi Nucleon Transfer demonstrator moves to the production building, could accommodate an **"IRASME2" beamline thus providing LINAG beams also to the materials science community**

# Radioactive Ion Beams Re-acceleration

A great variety of beams (fusion evaporation, multi nucleon transfer, fission products) could be re accelerated at unique energies
Structure and Equation of state of nuclear matter can be addressed in a significant way

**Conclusions**

The full spectrum of ISOL post-accelerated RIB in the energy domain above Coulomb energy (~7MeV/A) up to Fermi energy and beyond (<100 MeV/n) is not covered by any of the running or projected RIB facilities in the world (see section II, Table 1).

Investigation of long chain of neutron rich and proton rich nuclei produced by ISOL from light species (C, O, Ne) to medium (Kr, Sn) and up heavy Trans-Actinides with intensities $10^{2-7}$ pps in the energy range 10-60 MeV/n (Flagship beam $^{132}$Sn 10-60 MeV/A, $10^{7}$pps on target) with high purity and beam optics comparable to the best stable beams will be possible and open the way to a rich nuclear structure and reaction research program.

The working group has identified the main research areas where the ISOL proton and neutron rich post-accelerated RIB in the energy range between 10 to 60 MeV/A and beyond in some options, with masses ranging from the lightest (A<40) to the heaviest (A>230), will open rather exciting and unique opportunities.

Regarding the production of a wide range of RI, we have assumed that the Radioactive Ion Beams (RIB's) are produced in q=1+ charge state in a production hall, close to Spiral2/Desir buildings.

| | SCC upgrade with LINAC injector | Superconducting Compact Cyclotron | Superconducting LINAC |
|---|---|---|---|
| Cost of accelerator | 23 M€ | 70-80 M€ (based IBA) | 102 M€ |
| Cost Accelerator building | 5 M€ | 5-10 M€ | 22 M€ |
| Cost Experimental building | 0 | 0 | 20 M€ |
| Manpower resources | Medium | Very restricted if industrial | Large |
| Max. Output energy:<br>For $132Sn^{26+}$<br>For $90Kr^{20+}$<br>For Z/A=0.4-0.5 | <br>33 MeV/A<br>49 MeV/A<br>80 MeV/A | <br>64 MeV/A<br>79 MeV/A<br>>100 MeV/A | <br>60 MeV/A<br>75 MeV/A<br>100 MeV/A |
| Energy range (MeV/A) | (discrete energies) [3.5-15] and [24-33-49-80] | [10-100] MeV/A | [5-100] MeV/A |
| Stripping | Required for high energy (SSC2) | Not Required | Required for a minimal selectivity and cost. |
| Selectivity | Good/very good | Good | Low (constraint on source/ stripping) |
| Expected Transmission | 15% to 50% (with /without stripping) | 10-20% (no stripping) | 20 % (with stripping) |
| Main advantage | lower cost | compact | Upgrade possible flexibility |
| Main problem | - CSS ageing<br>-33MeV/A max for $^{132}Sn$ | New Design effort | Manpower cost |

# Step 3

- **Construction of an electron accelerator (for example an Energy Recovery Linac (ERL or latest generation synchrotron) to offer a new probe of exotic nuclei: electron-scattering on radioactive ions (e-RI).**
- This program will complement the studies made by direct reactions using the new re-acceleration complex. It would give a rich and unique flagship programme beyond the middle of this century.

# e-RI

*« Ion-electron colliders represent a crucial innovative perspective in nuclear physics to be pushed forward in the coming decade. They would require the development of intense electron machines to be installed at facilities where a large variety of radioactive ions can be produced ».*

| **Observables**<br>**deduced quantities** | **Reactions**<br>*(q: momentum transfer)* | **Type of nucleus** | **Intensity I or**<br>**Luminosity L** |
|---|---|---|---|
| r.m.s. matter radii | **(p,p)** *elastic at small q* | Light to heavy | I : $10^4$ $10^6$ $s^{-1}$ |
| r.m.s. charge radii | **(e,e)** *elastic at small q* | Light | L: $10^{24}$ $cm^{-2}s^{-1}$ |
| Charge density distribution with 2 parameters $\rho_{ch}$ | **(e,e)** *First min. in elastic form factor* | Light Medium<br>Heavy | L: $10^{28}$ $10^{26}$ $cm^{-2}s^{-1}$<br>$10^{24}$ |
| Charge density distribution with 3 parameters $\rho_{ch}$ | **(e,e)** *$2^{nd}$ min. in elastic form factor* | Medium<br>Heavy | L: $10^{29}$ $cm^{-2}s^{-1}$<br>$10^{26}$ |
| Energy spectra, width, strength, decays | **(e,e')** | Medium-Heavy | L: $10^{28-29}$ $cm^{-2}s^{-1}$ |
| **Neutron-skin density**<br>from $\rho_m$ and $\rho_{ch}$ | **(p,p) and (e,e)**<br>Combined (p,p') and (e,e') | | (p,p) I: $10^6$ $s^{-1}$; **(e,e) L : $10^{29-30}$**<br>(p,p') I:$10^{6-8}$ $s^{-1}$ ; **(e,e') L ~$10^{30}$** |
| Spectral functions, correlations<br>Magnetic form factor → Proton and neutron transition densities<br>*Direct access to neutron-skin* | **(e,e'p)** | | $10^{30-31}$<br>**(e,e'p) L ~$10^{30-31}$** $cm^{-2}s^{-1}$ |

# e-RI

1. To overcome the limitations for the luminosity, we plan to organize an important R&D work on the optimization of the trapping techniques. We have identified several paths of R&D:
- increasing the number of trapped ions, by optimizing the injection and extraction of ions thanks to an RF trap structure guiding the ions to and from the interaction region;
- working on the overlap efficiency between ions and electrons, by optimizing the spatial distribution of the ion cloud and by controlling the charge state distribution (multiplication) thanks to a regular recirculation of the trapped cloud in a buffer gas in a separate trapping area;
- working on the trapping instabilities using cooling down techniques to reduce ion-ion collisions, ion heating processes.

2.

| | |
|---|---|
| Energy | 500 MeV |
| Total length | 107.372 m |
| Beam current | 200 mA |
| $Q_x/Q_y$ | 16.715/8.705 - |
| $\alpha_c$ | 2.59 $10^{-3}$ |
| Energy loss/turn | 3.32 keV |
| $\beta_{xy,\mathrm{IP}}$ | 4.08/4.15 m |
| $\beta_{xy,\mathrm{max}}$ | 6.3/20.5 m |
| $D_{x,\mathrm{max}}$ | 0.14 m |
| RF energy acceptance | 2.0 % |
| RF Voltage | 107 kV |
| Coupling factor | 50 % |
| Eq. emittance (No IBS) | 0.67 nm |
| Energy spread (No IBS) | 0.45 $10^{-3}$ |
| Bunch length (No IBS) | 8.03 mm |
| Hor./Vert Emittance (IBS) | 1.80/0.9 nm |
| Energy spread (IBS) | 0.92 $10^{-3}$ |
| Bunch length (IBS) | 12.2 mm |
| Touschek lifetime | 1.36 h |

Higher than 200 mA: IBS effects could be difficult to overcome (equilibrium emittance and energy spread).
Reaching 500 mA has a cost on beam quality (and could enhance the beam instabilities and IBS effects, deteriorating the gain in intensity increase).

Other parameters of the accelerator have to be examined for the operation mode in the detailed project.

The detailed discussion on the choice of parameters and IBS effects is given in ***Appendix C.***

*Table III.5. Electron machine-trap parameters to reach the targeted luminosity at $10^{29}$ : beam parameters with IBS, trap characteristics*

# e-RI

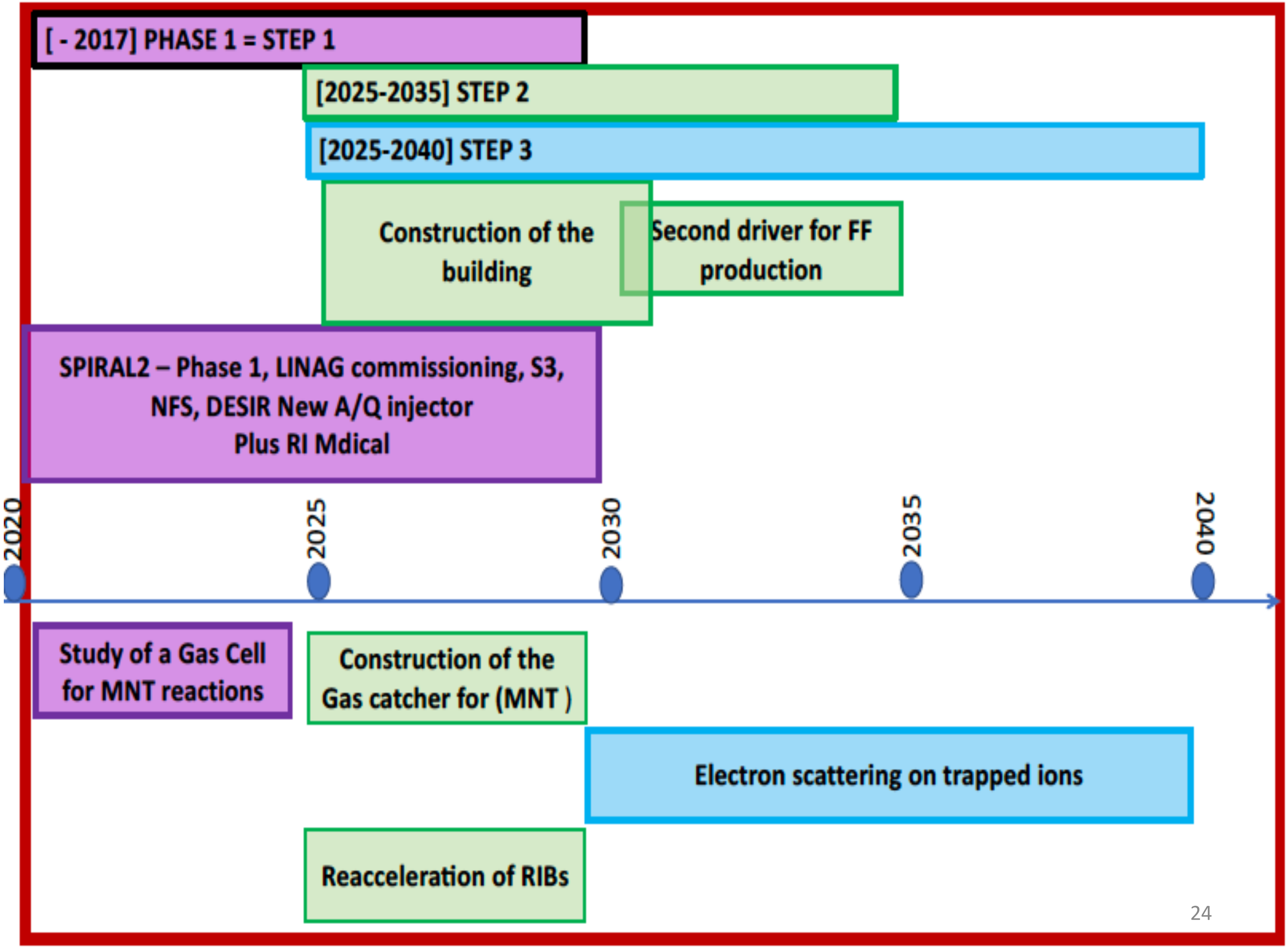
| Ion trap<br>Trap length (mm) | Electron beam<br>Beam size<br>dx*dy (mm$^H$ *mm$^V$) | Ion beam<br>(mm$^H$ *mm$^V$)<br>area overlap (%) | Electron cloud density<br>(mm$^{-3}$) (charge states)<br>→*max number of trap ions (full compensation)* | Luminosity<br>cm$^{-2}$ s$^{-1}$ |
|---|---|---|---|---|
| SCRIT<br>400 mm | $1^H*2^V$ | $3^H*5^V$ 13,3% | 5.08 $10^4$ (1$^+$) →1.7 $10^9$<br>(10$^+$) →1.7 $10^8$ | 2.5 $10^{27}$<br>2.5 $10^{26}$ |
| *e-RIB GANIL tests* | | | | |
| tests I 160 mm | $0.5^H*0.5^V$ | $0.5^H*0.5^V$ 100 % | 1.32 $10^6$ (1$^+$) →6.7 $10^8$<br>(10$^+$) →6.7 $10^7$ | (1$^+$) 2.6 $10^{28}$<br>(10$^+$) 2.6 $10^{27}$ |
| tests II 100 mm | $0.5^H*0.5^V$ | $0.5^H*0.5^V$ 100 % | 1.32 $10^6$ (10$^+$) →4.2 $10^7$ | (10$^+$) 1.6 $10^{27}$ |
| tests III 100 mm | $1.0^{H,V}$ | $1.0^{H,V}$ 100% | 3.3 $10^5$ (10$^+$) →4.2 $10^7$ | (10$^+$) 4.1 $10^{26}$ |
| tests IV 100 mm | $0.5^{H,V}$ | $1.0^{H,V}$ 25 % | 6.6 $10^5$ (10$^+$) →4.2 $10^7$ | (10$^+$) 8.3 $10^{26}$ |
| tests V 160 mm | $0.2^{H,V}$ | $0.2^{H,V}$ 100% | 8.3 $10^6$ (1$^+$) →6.7 $10^8$<br>(10$^+$) →6.7 $10^7$ | (1$^+$) 1.7 $10^{29}$<br>(10$^+$) 1.7 $10^{28}$ |

*Table III.4. Calculated luminosities for various test cases of the ion-trap parameters and of the beam emittances, for an electron intensity of 200 mA ($N_e$=1.25 $10^{18}$/s).*

***Comparison between the synchrotron and ERL solutions*** **- *Technical constraints***

| ***Assets-difficulties*** | **Synchrotron** | **ERL** |
|---|---|---|
| **Intensity**<br>**200 mA feasible with synchrotron**<br>**Not with the ERL (multi-turn)** | The mean currents are higher since the source and injector are not in a continuous mode and it is possible to accumulate, resulting in less constraints on the injector (the equilibrium emittance is given by the ring, with the synchrotron damping).<br>Asset: **higher average current.** | Assets : **current stability,** there is always a « fresh » electron beam ;<br>Energetic efficiency; better availability of the machine (no cycle to prepare)…<br>*A demonstrator (at 140 MeV) would be needed to ensure that such currents (200 mA) can be reached with the target tolerances.* |
| Beam line design<br>Detection area<br>Stop beam | The average beam power in the dump is low. Indeed, the peak deposited power can seem high (about 100 MW) but it is deposited on a very short time (one revolution time of about 0.36 µs), which corresponds to a beam energy of 36 J. Since the beam is lost with a frequency below 1 Hz, the average deposited power in the beam dump will be below a few watts.<br>Asset: **small average power on the beam dump.** | Assets: a stop block at lower energy (better on the radiological point of view) reduced beam dump activation |
| Operations<br>Stability of the physics parameters | Overlap between the required parameter sets (acceptable one, potential) | For the electron recirculating linac (ERL), the IBS is not anymore a problem, we can work at lower energy. A first layout has been shown at 530 MeV. A special effort must be performed on the electron source quality.<br>With an ERL the beam fluctuations can be better regulated than in the case of a synchrotron, it is easier to maintain the beam emittance parameters.<br>Assets: out-of-equilibrium medium, **beam characteristics (emittance…) determined by the injector, no intra-beam scattering,** possibility to reduce strongly the beam size.<br>**BBU instabilities:** unknown issues |
| Long-term goal machine performances<br>Limitations | **200 mA is reachable.**<br>Higher intensities should be studied. | A few 10 mA in multi–turn. Several electron energies not adequate. Physics requirements: one given energy for 200 mA.<br>Around 100 mA with single-turn<br>How to increase the intensity in single-turn? |
| Costs#<br>Construction / Operation<br>Feasibility | Less risks for this solution: the French community has the **know-how to reach the parameter sets** for the physics.<br>Expert of the domain can work to define the machine design in a few-year detailed project, state-of-the-art machines are known. RF budget is reduced… | Complexity of the machine.<br>Unknowns about the 200 mA intensities.<br>Physics effects (IBS) have to be estimated<br>Less expensive in operation costs? |

*#The cost of the machine, depending on the synchrotron or ERL solutions has to be examined once the parameters of the*


[ - 2017] PHASE 1 = STEP 1
[2025-2035] STEP 2
[2025-2040] STEP 3
Construction of the building
Second driver for FF production
SPIRAL2 – Phase 1, LINAG commissioning, S3, NFS, DESIR New A/Q injector Plus RI Mdical
2020
2025
2030
2035
2040
Study of a Gas Cell for MNT reactions
Construction of the Gas catcher for (MNT )
Electron scattering on trapped ions
Reacceleration of RIBs

# Conclusions

- Full Phase 1 completion plus reshuffling of injector cyclotrons (needed also for interdisciplinary applications)
- Reacceleration of exotic beams
- Production building with a much larger variety of exotic beams, (which could serve also as an Interdisciplinary Hall)
- **Electron probe of trapped exotic nuclei (Flagship program for the middle of this century)**

- The projects presented in this document, which are unique on the international scene, **lay out a vision to keep GANIL at the forefront of nuclear science globally for many decades to come**. The options presented are ambitious, demanding commitment of significant financial and human resources, and can only be realized within the framework of a strong national and international participation of universities and laboratories. **The kick-off should start soon (at the celebration of the 40 years of the first experiment at GANIL?).**
- GANIL will be complementary to FAIR, which will operate at much higher energies. Both installations would be at the forefront of Nuclear Physics in the World
- Thanks to all who have contributed