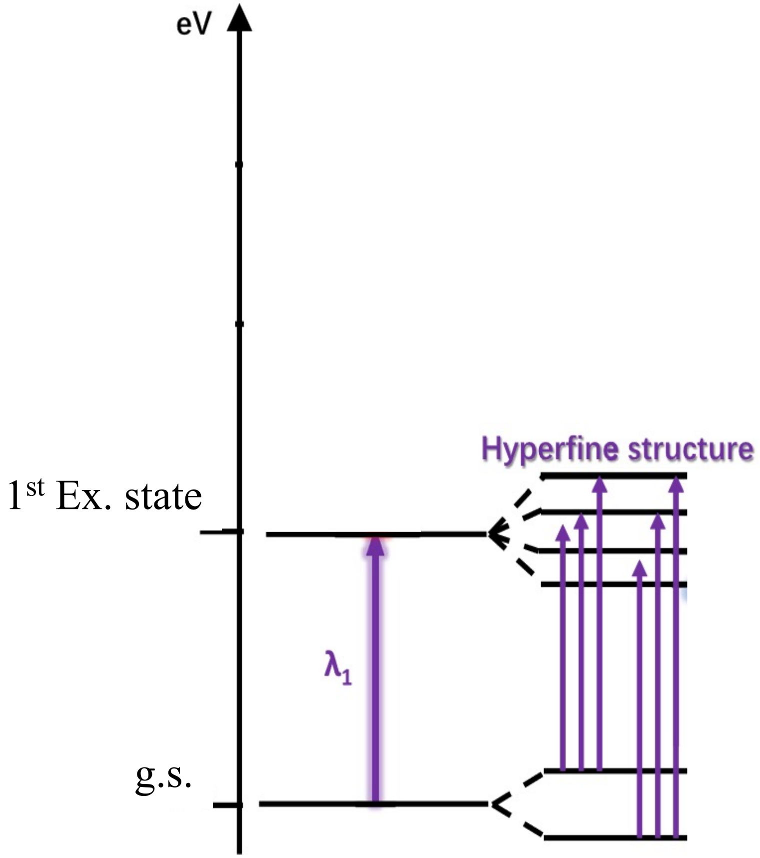
LASAGN : a new laser spectroscopy setup at DESIR

Louis Lalanne IPHC / CNRS

ISOL-France workshop – 04/04/2025

Institut Pluridisciplinaire Hubert Curien STRASBOURG

DESIR



Hyperfine splitting:

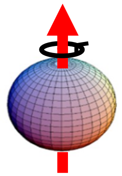
$$E(F) = kA + k'B \qquad A = \frac{\mu\, Be(0)}{I.J} \qquad B = e\, Qs\, V(0)$$

Isotope shift : HFS shift between an isotope A and A'

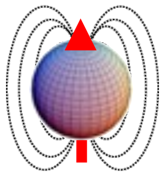
$$\delta\nu_i^{A,A'} = \frac{A - A'}{AA'} M_i + F_i \delta\langle r^2 \rangle^{A,A'}$$

Measuring the HFS allows access to:

- Nuclear spin I



- Dipole magnetic moment μ
  - → Single particle configuration



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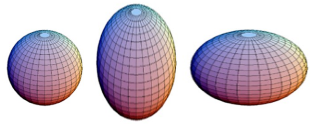
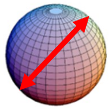
  - → Nuclear shapes

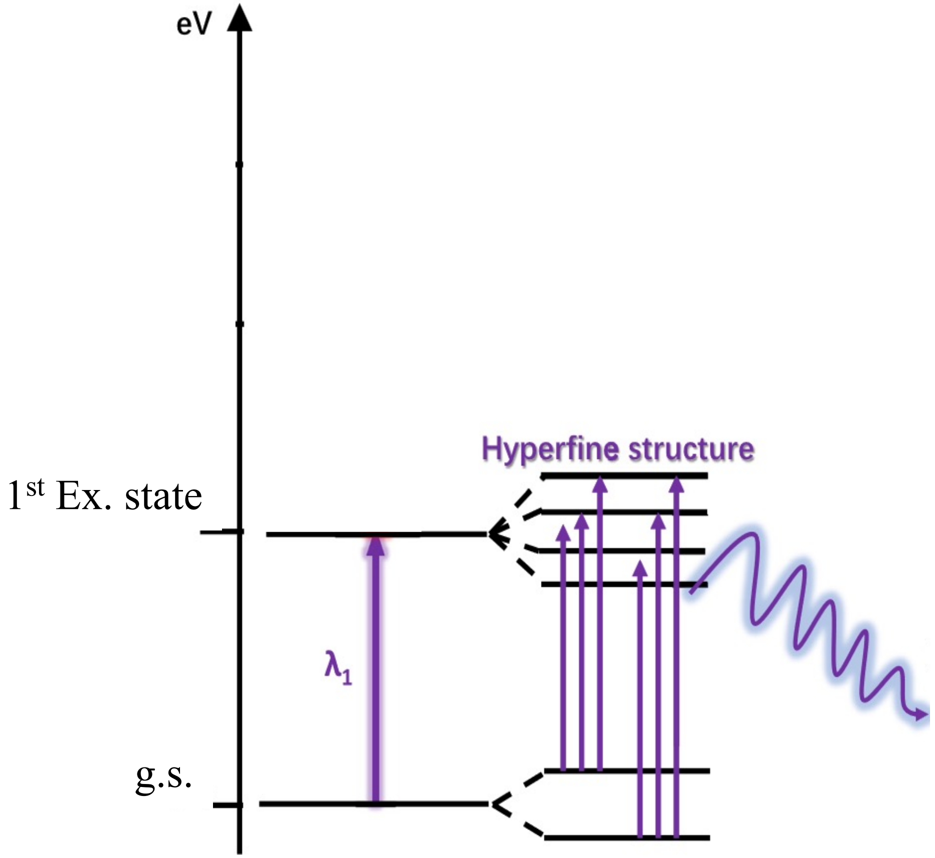


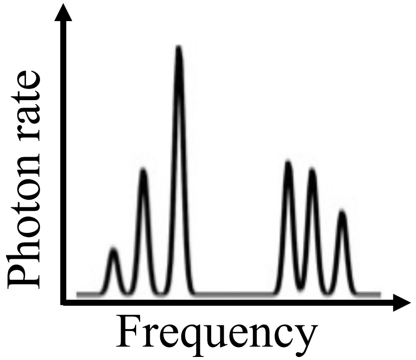
- Mean-squared charge radii
  - → Magicity, collectivity, correlations



X.F. Yang et al., PPNP 129 105005 (2023)

Collinear Laser Spectroscopy





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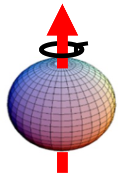
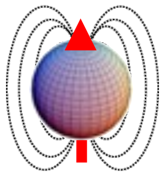
- Nuclear spin I 
- Dipole magnetic moment μ 
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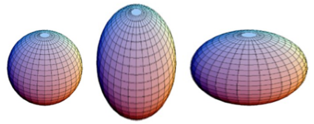
  - → Nuclear shapes 
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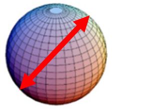
  - → Magicity, collectivity, correlations 

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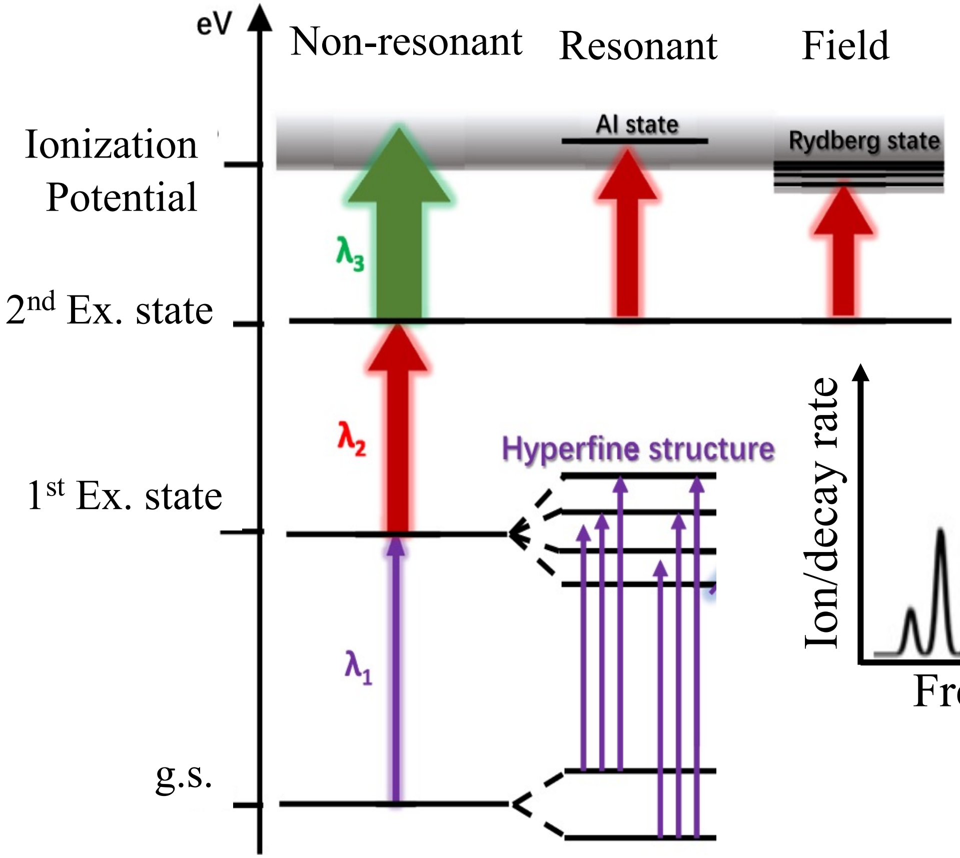
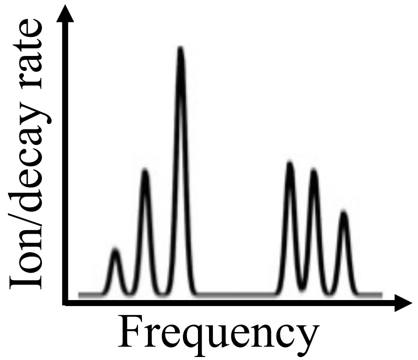
X.F. Yang et al., PPNP 129 105005 (2023)

Resonance Ionization Spectroscopy





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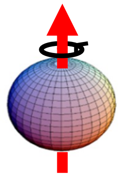

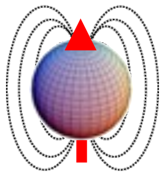

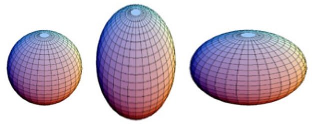

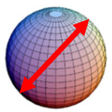

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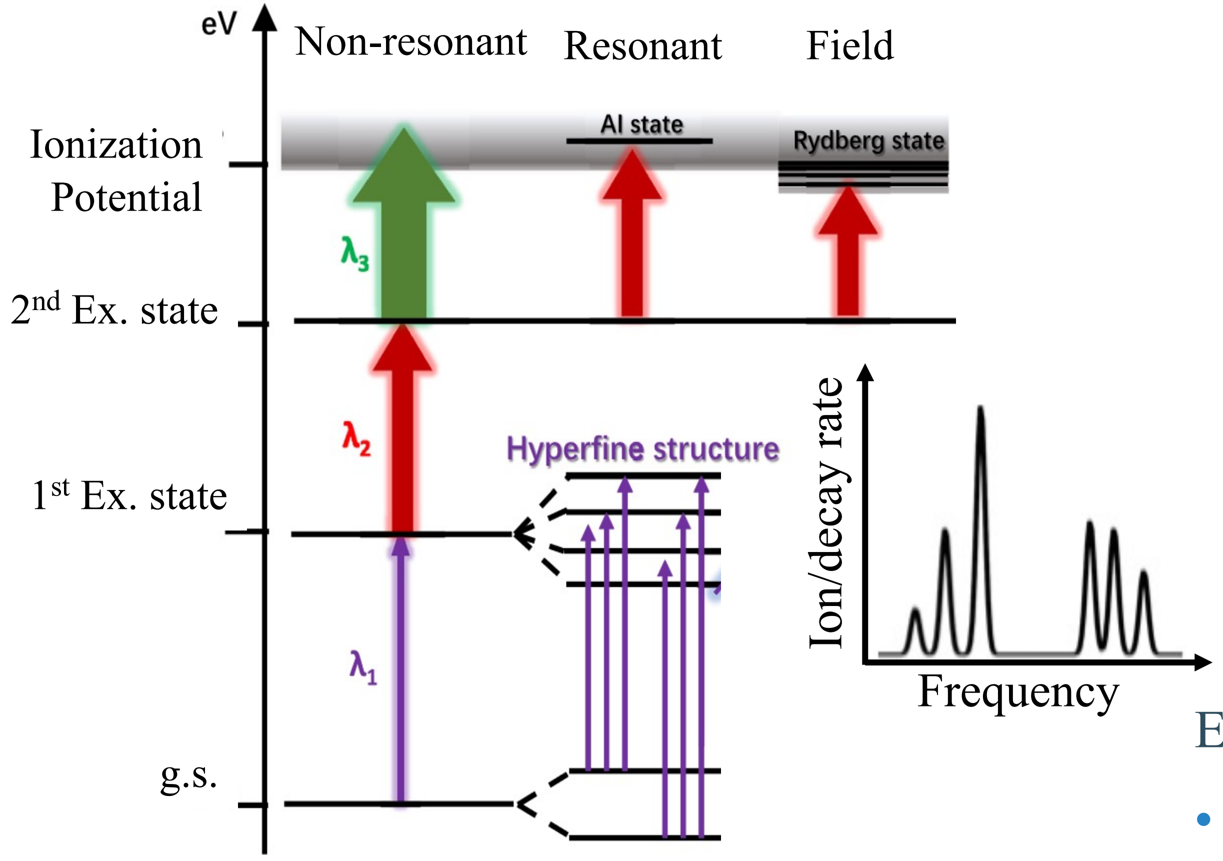

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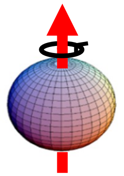

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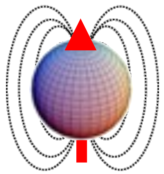

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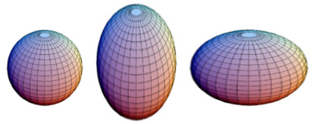

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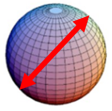
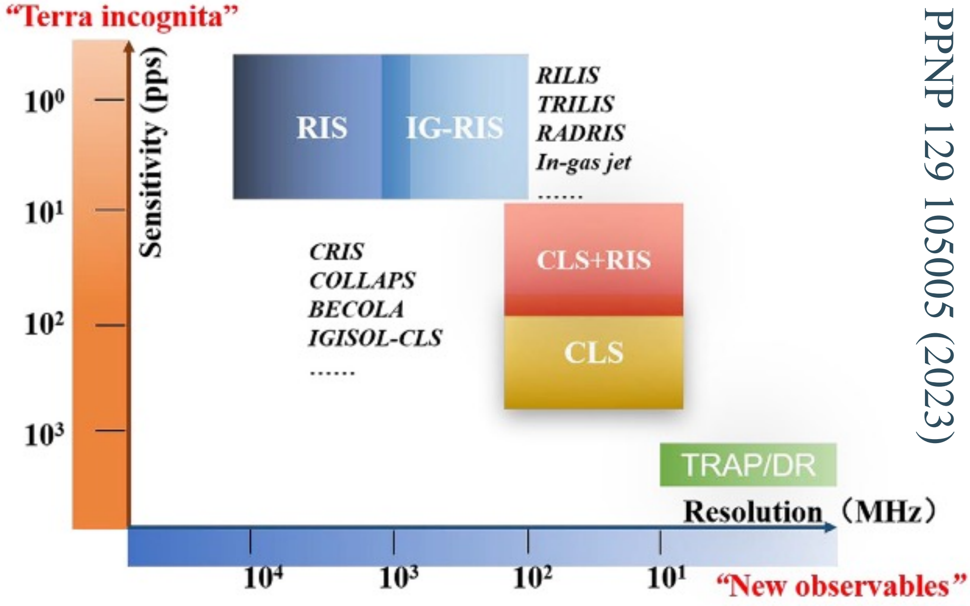


Environments:

- In-source
- In-gas-cell
- In-gas-jet
- In-beam
- In-trap



X.F. Yang et al., PPNP 129 105005 (2023)

The GANIL / SPIRAL2 facility

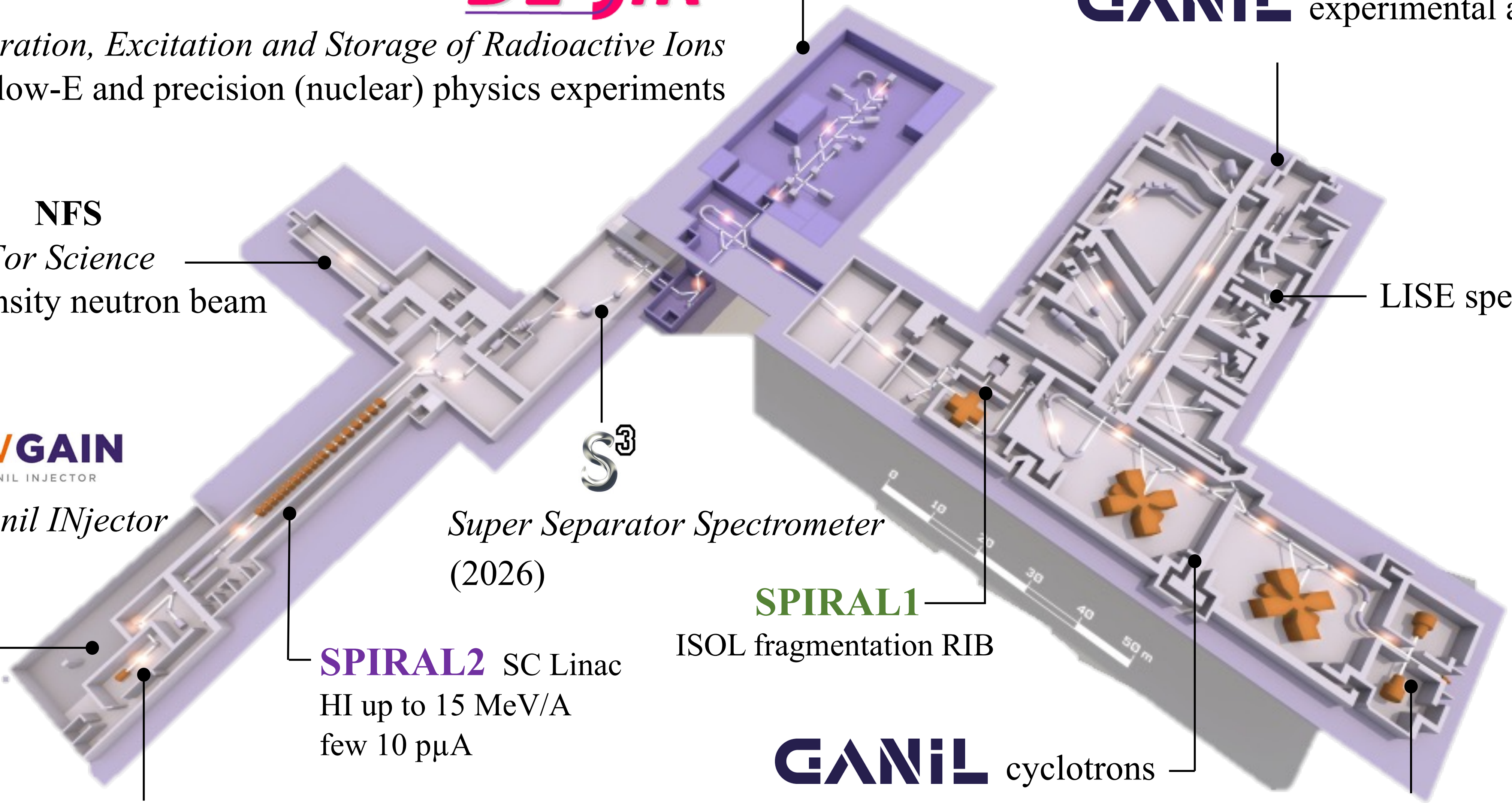
DESIR

Desintegration, Excitation and Storage of Radioactive Ions
Hall for low-E and precision (nuclear) physics experiments
(2027)

GANIL experimental areas

NFS
Neutron For Science
High intensity neutron beam
1-30MeV

LISE spectrometer



NEWGAIN
NEW GANIL INJECTOR

NEW Ganil INjector
(2030)

S3

Super Separator Spectrometer
(2026)

SPIRAL1
ISOL fragmentation RIB

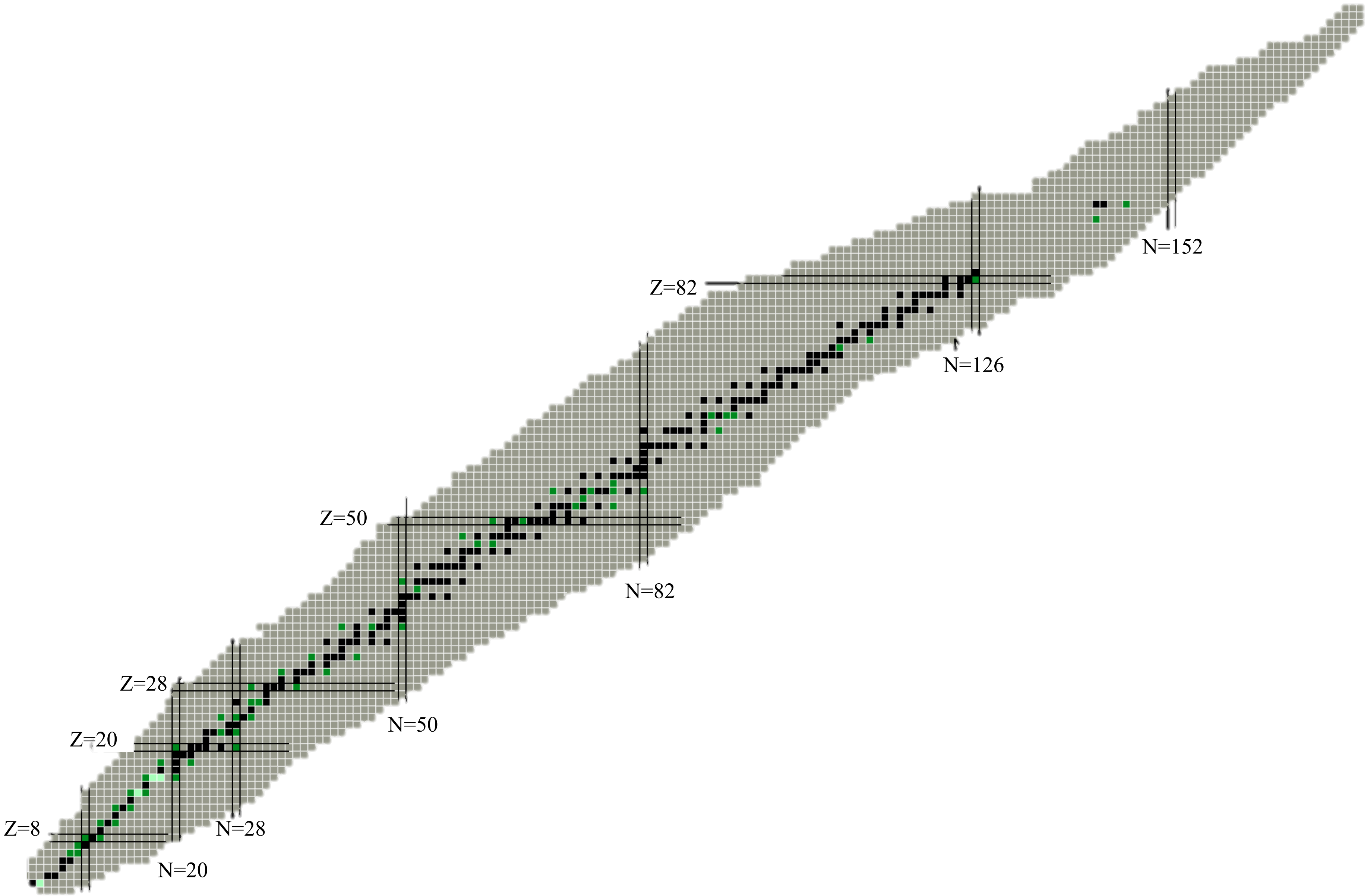
SPIRAL2 SC Linac
HI up to 15 MeV/A
few 10 pμA

GANIL cyclotrons
^{12}C to ^{238}U, up to 95 MeV/A
< 1 pμA

GANIL ion sources

SPIRAL2 ion source

RIB production for DESIR



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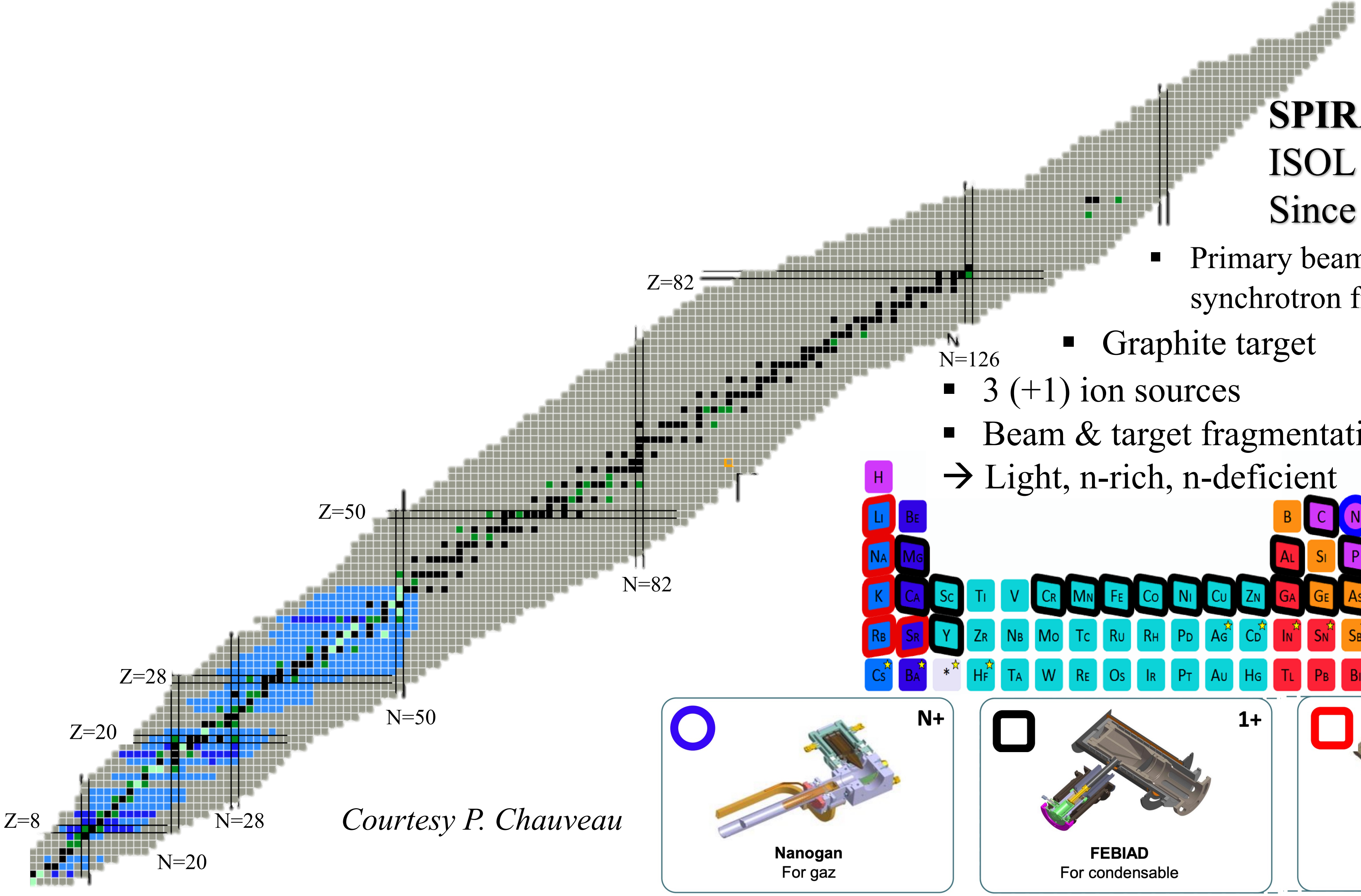


Courtesy P. Chauveau

SPIRAL 1
ISOL fragmentation
Since 2001

- Primary beam from GANIL synchrotron from C to U
- Graphite target
- 3 (+1) ion sources
- Beam & target fragmentation

→ Light, n-rich, n-deficient

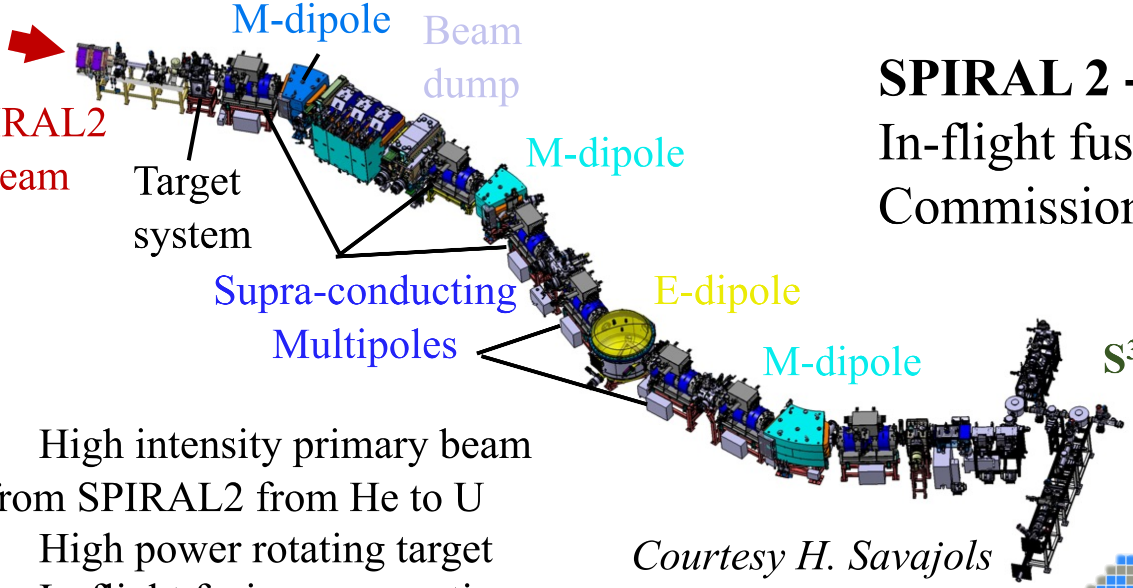
N+
Nanogan
For gaz

1+
FEBIAD
For condensable

1+

MonoNaKe
For alkaline

RIB production for DESIR



Courtesy H. Savajols

SPIRAL 2 - S^3:
In-flight fusion-evaporation
Commissioning 2026

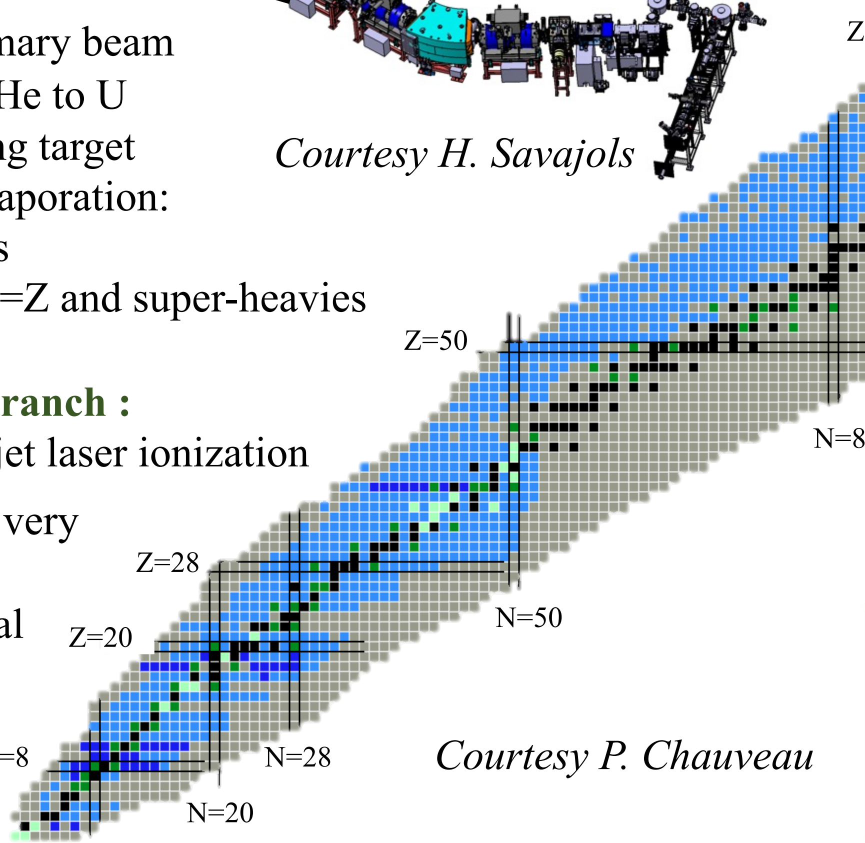
- High intensity primary beam from SPIRAL2 from He to U
- High power rotating target
- In-flight fusion-evaporation:

→ refractory elements
→ proton drip-line, N=Z and super-heavies

- **S^3-Low Energy Branch :**

Gas stopper + in-gas-jet laser ionization

- Medium-res. and very high sensitivity
- Located at S^3 focal plane



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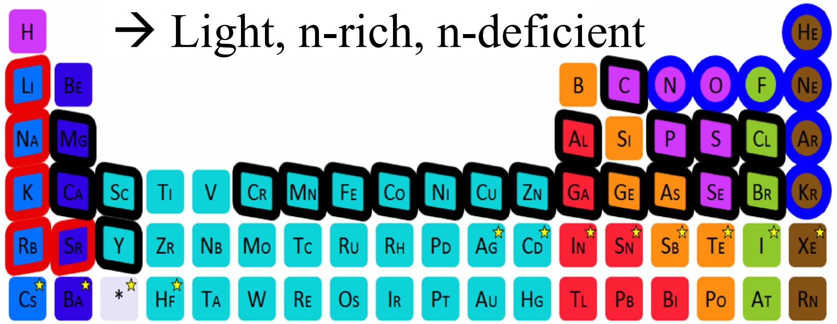
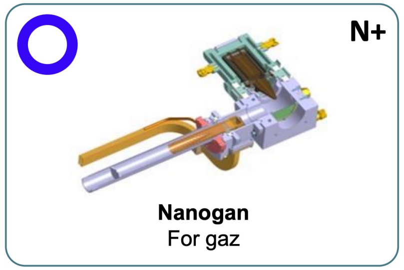


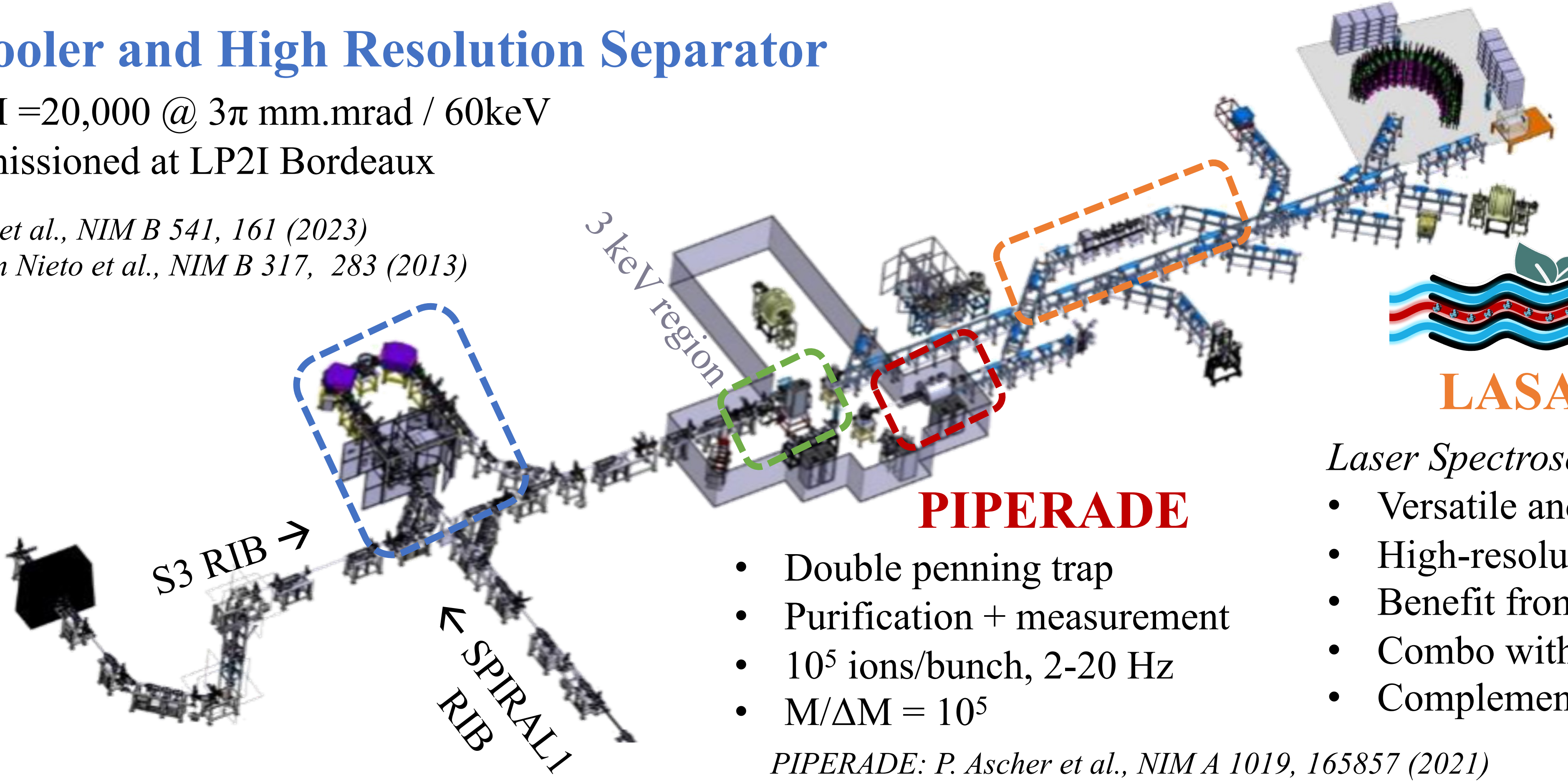


DESIR RIB preparation and purification

RFQ cooler and High Resolution Separator

- M/ΔM =20,000 @ 3π mm.mrad / 60keV
- Commissioned at LP2I Bordeaux

J. Michaud et al., NIM B 541, 161 (2023)
T. Kurtukian Nieto et al., NIM B 317, 283 (2013)



LASAGN

Laser Spectroscopy At GaNil

- Versatile and sensitive
- High-resolution and precision
- Benefit from purification
- Combo with trap and decay
- Complementary to S^3-LEB

PIPERADE

- Double penning trap
- Purification + measurement
- 10^5 ions/bunch, 2-20 Hz
- M/ΔM = 10^5

PIPERADE: P. Ascher et al., NIM A 1019, 165857 (2021)

General Purpose Ion Buncher (GPIB)

- Transmission : 100 % @ 10^6 ions/bunch
- time dispersion down to ≈ 250 ns (FWHM)
- 2-50 Hz

GPIB: M. Gerbaux et al., NIM A 1046, 167631 (2023)

Transport lines

- 1+ ions, 3, 30-60 keV, 3-80 π.mm.mrad
- Fully electrostatic

The LASAGN project

- **Jan 2024 – First visit of LINO @ ALTO** : discussion for potential physics program at ALTO.
- ➢ Decision not to start any physcis program with LINO @ ALTO.

- **Fev/Mar 2024 - DESIR WS** : Presentation/discussion of different laser spec technics
- ➢ Strong interest for the CRIS technic à DESIR
- ➢ Formation of a proto-collaboration : IPHC, KU Leuven, IJCLab, LPC, Manchester

- **May 2024 - ISOL-France WS** : Detailed discussion about LUMIERE and LINO
- ➢ First priority: Install and commission LINO à DESIR
- ➢ No strong support for and nuclear orientation program
- ➢ Decision to upgrade LINO toward a CRIS-like beam line : projet LASAGN

- **Jully 2024 - LUMIERE WS** : Presentation of the LASAGN project to the international comunity
- ➢ Final decision to go for LASAGN at DESIR
- ➢ Potential financial contribution from the UK et IKS/Leuven

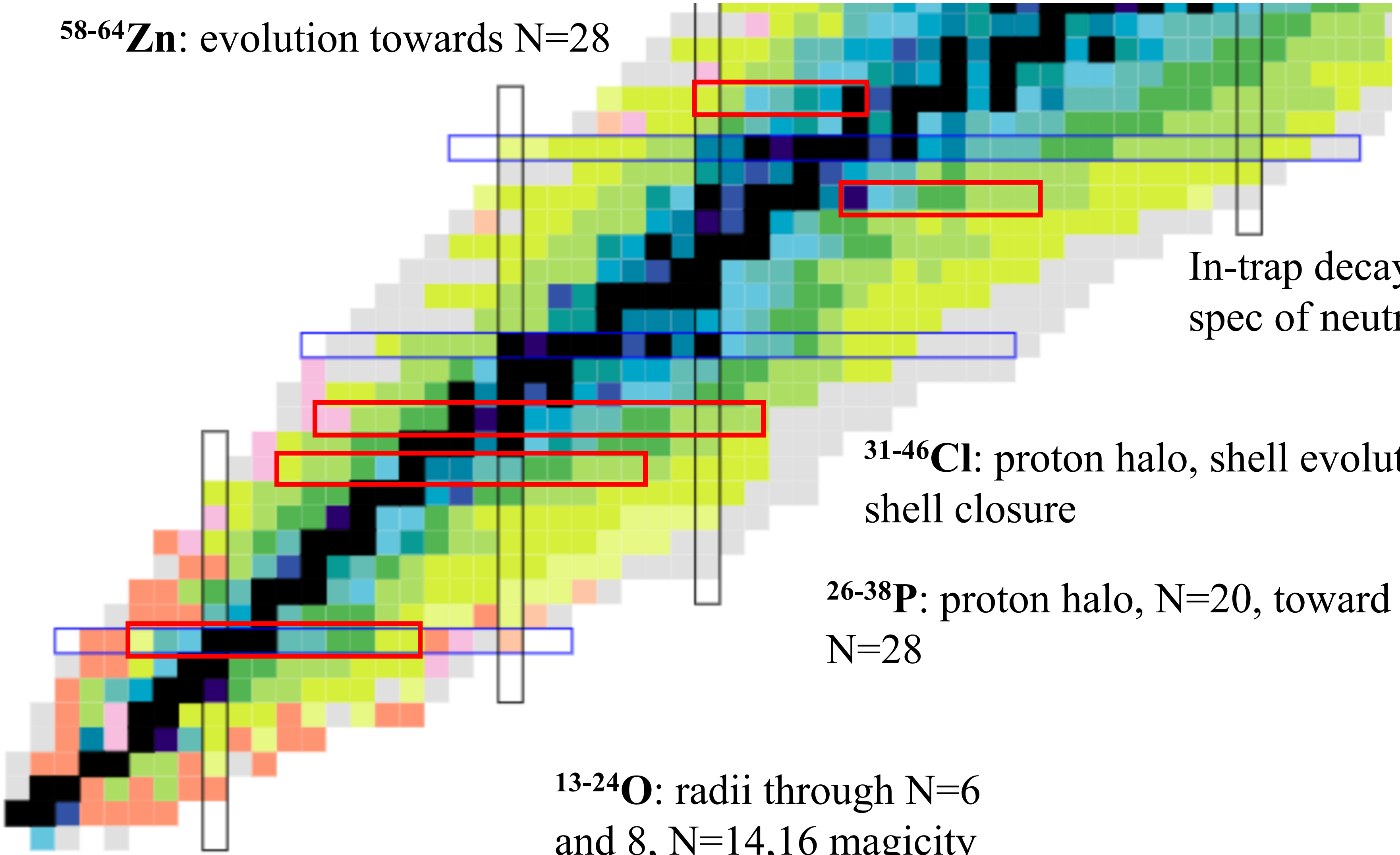
- **Sept 2024 : Visits at ALTO and GANIL** : Inventory, DESIR laser lab, Integration of LINO at DESIR…

- **Oct 2024 : Ganil Community Meeting** : presentation of the project to the GANIL community

- **Feb 2025 : beam request for SPIRAL1 RIB**

LASAGN first physics cases

$^{58-64}$**Zn**: evolution towards N=28



In-trap decay of Mn for laser spec of neutron rich Ti

$^{31-46}$**Cl**: proton halo, shell evolution, N=28 shell closure

$^{26-38}$**P**: proton halo, N=20, toward N=28

$^{13-24}$**O**: radii through N=6 and 8, N=14,16 magicity

How to make a lasagn?

How to make a lasagn?

1 paquet
de lasagnes

3
oignons jaunes

125 g
de beurre

100 g
de farine

poivre

sel

70 g
de fromage râpé

3 pincées
de muscade râpée

thym

2
feuilles de laurier

20 cl
de vin rouge

800 g
de purée de tomate

1
carotte

basilic

15 cl
d' eau

125 g
de Parmesan

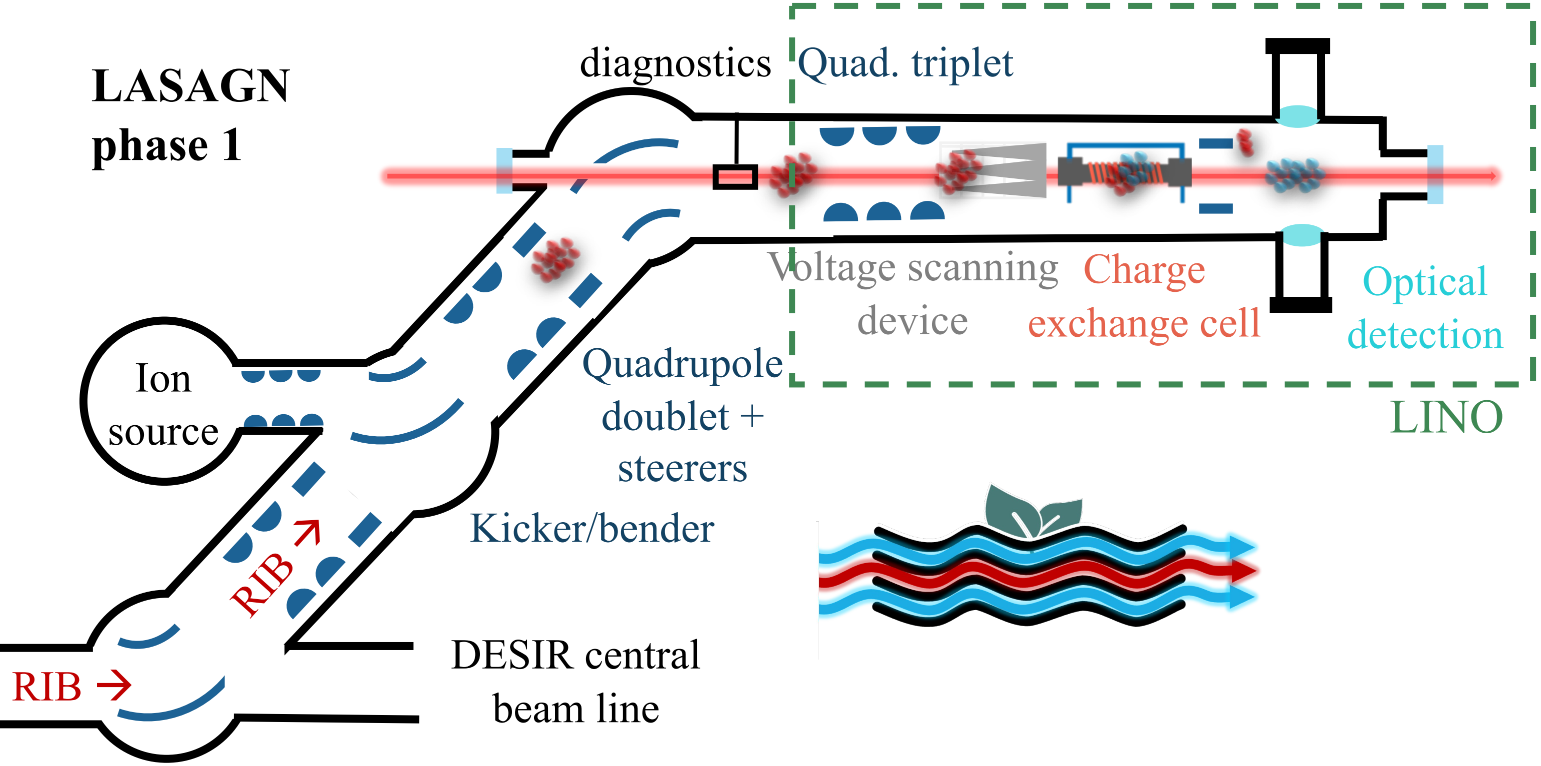
600 g
de boeuf haché

1 branche
de céleri

2 gousses
d' ail

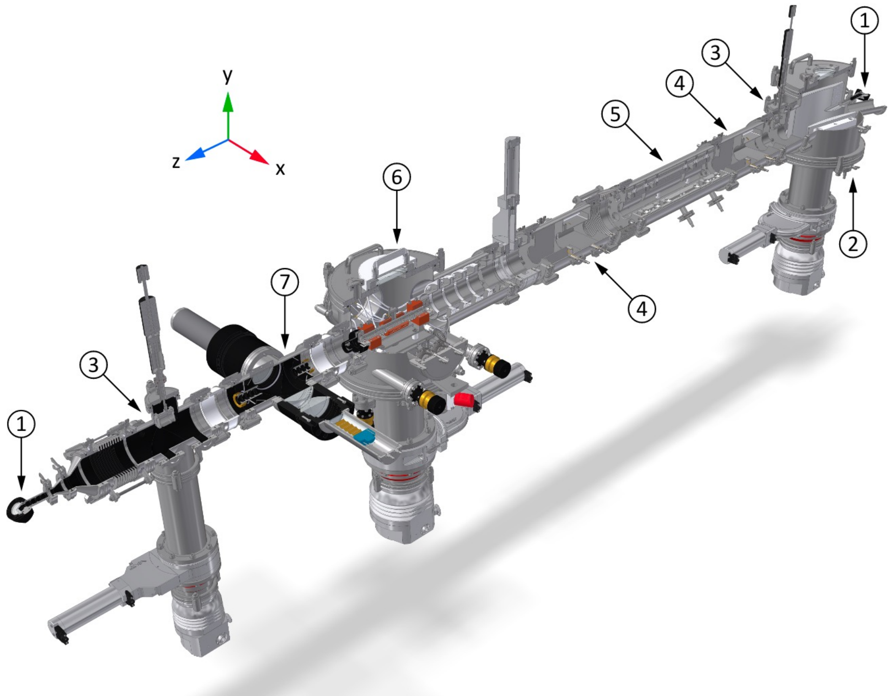
1 l
de lait

LAser Spectroscopy At GaNil : Phase 1



Timeline :
- Installation, comissioning : 2026 - 2027
- Day 1 experiment : 2027

✓ CLS with fluorescence detection
✓ High res : < 50MHz
X Sensitivity limit: > 10^4pps



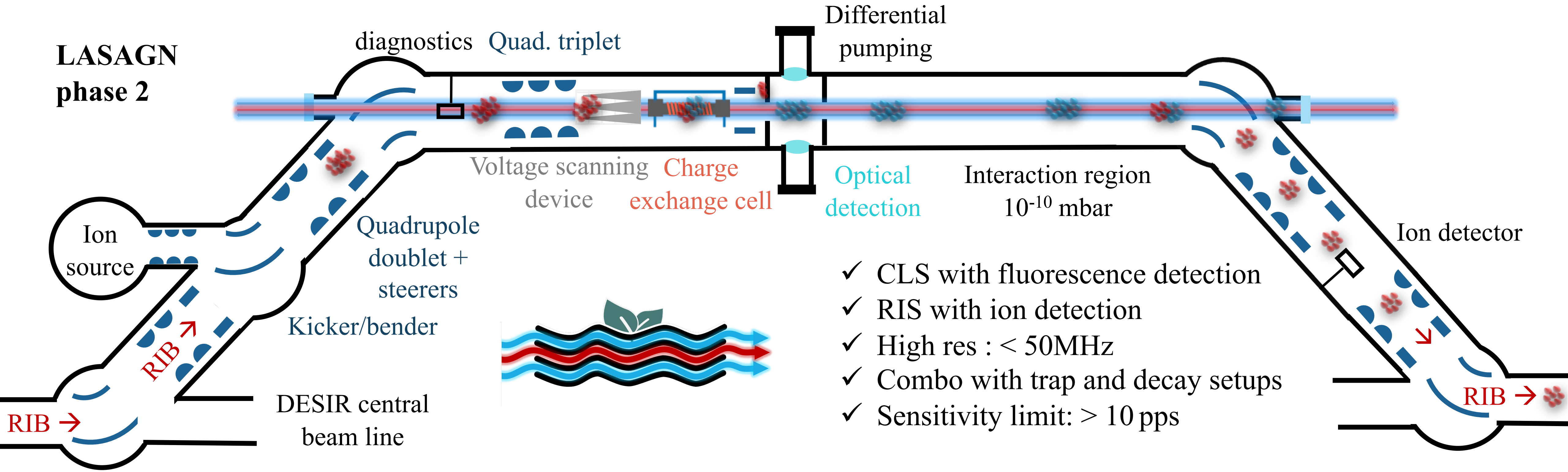
D.T. Yordanov *et al* 2020 *JINST* **15** P06004

The LINO beam line (Laser Induced Nuclear Orientation)

- Collinear Laser Spectroscopy with fluorecence detection
- Commissioned at ALTO facility in IJCLab

➢ **Install and commission LINO at DESIR**
➢ Day 0 experiment with standard CLS and radioactive Spiral1 beam

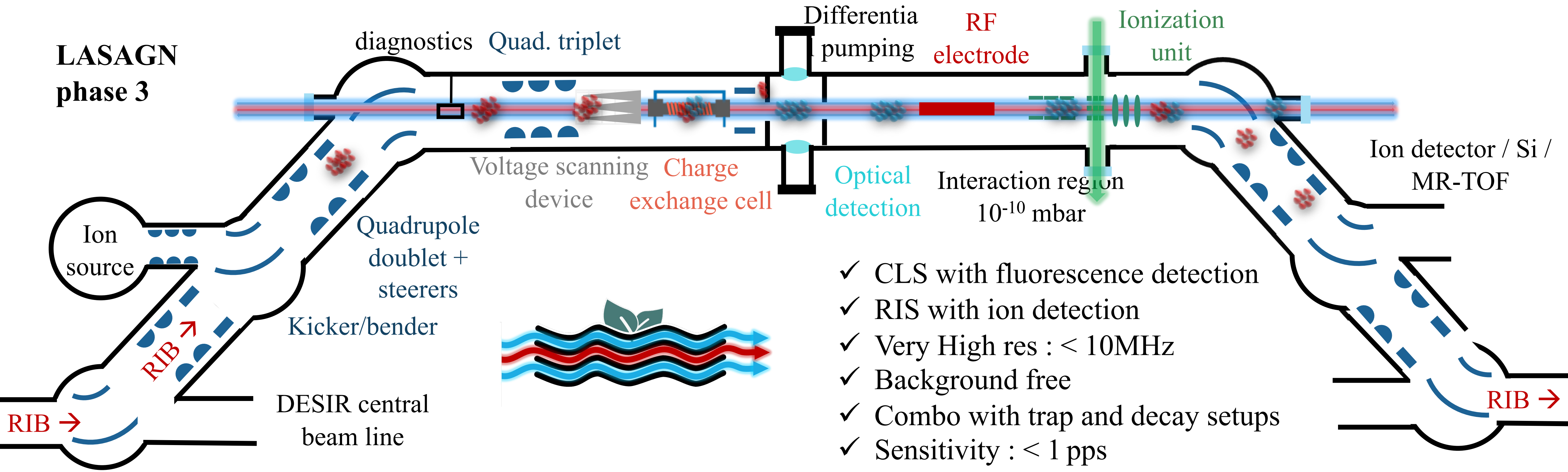
LAser Spectroscopy At GaNil : Phase 2



- ✓ CLS with fluorescence detection
- ✓ RIS with ion detection
- ✓ High res : < 50MHz
- ✓ Combo with trap and decay setups
- ✓ Sensitivity limit: > 10 pps

- ➢ **Upgrade to CRIS-like :** Collinear resonance laser ionization spectroscopy with ion detection and pulsed lasers
- ➢ Day 1 experiment with exotic Spiral 1 beam + first experiment with S3 beams

LAser Spectroscopy At GaNil : Phase 3

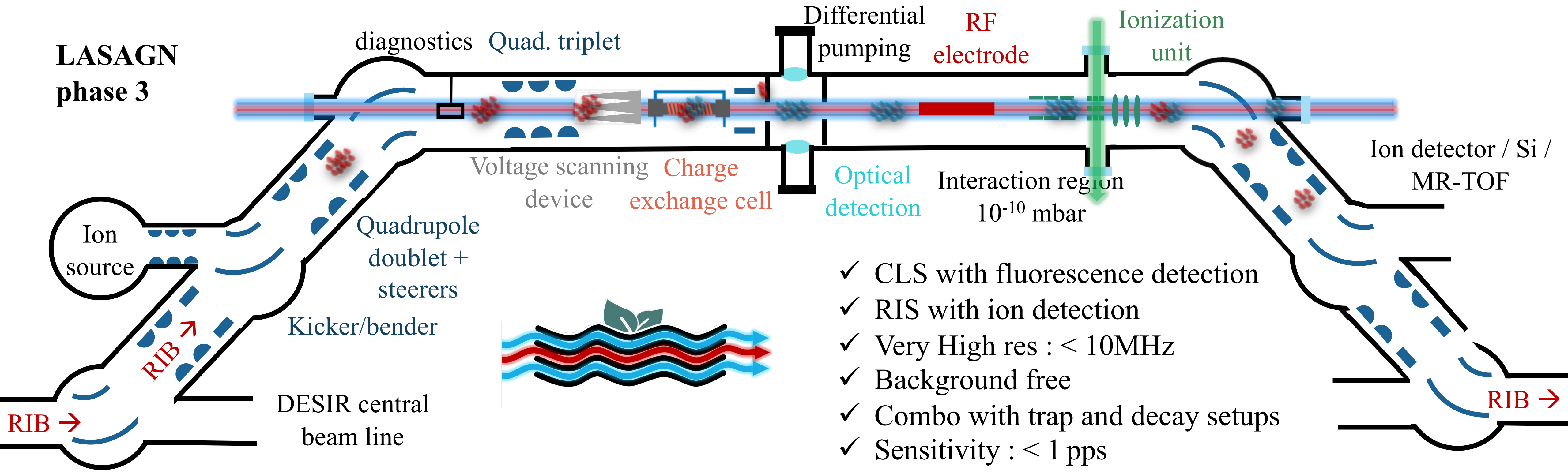


- ✓ CLS with fluorescence detection
- ✓ RIS with ion detection
- ✓ Very High res : < 10MHz
- ✓ Background free
- ✓ Combo with trap and decay setups
- ✓ Sensitivity : < 1 pps

New development to enhance the capacity of the setup :

- Collinear-Anticolinear fluorescence and RIS → <1MHz precision on IS
- Perpendicular illumination using ultra narrow bunches → background free spec.
- In-flight double laser-RF spectroscopy → resolution < 10 MHz

LAser Spectroscopy At GaNil : Phase 3



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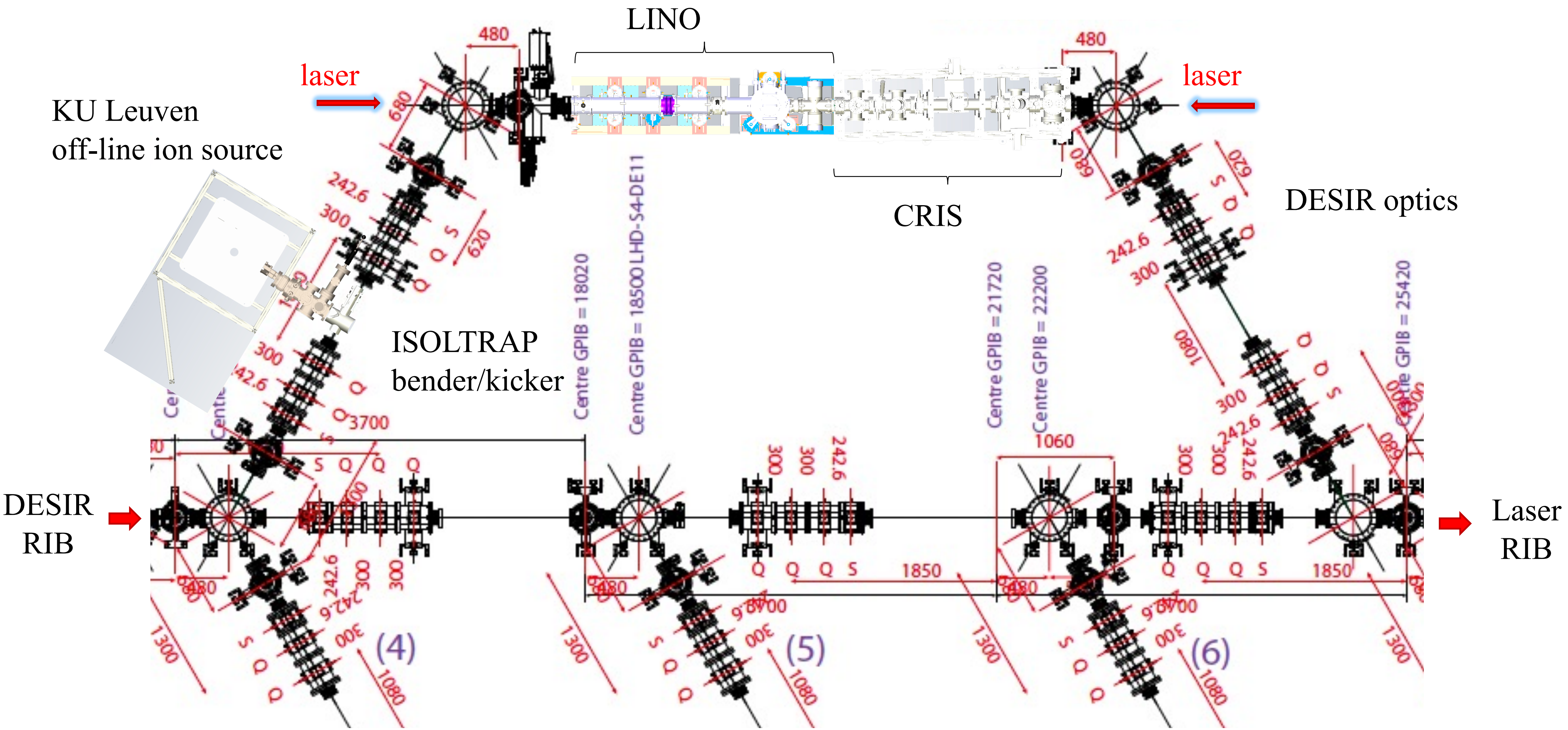
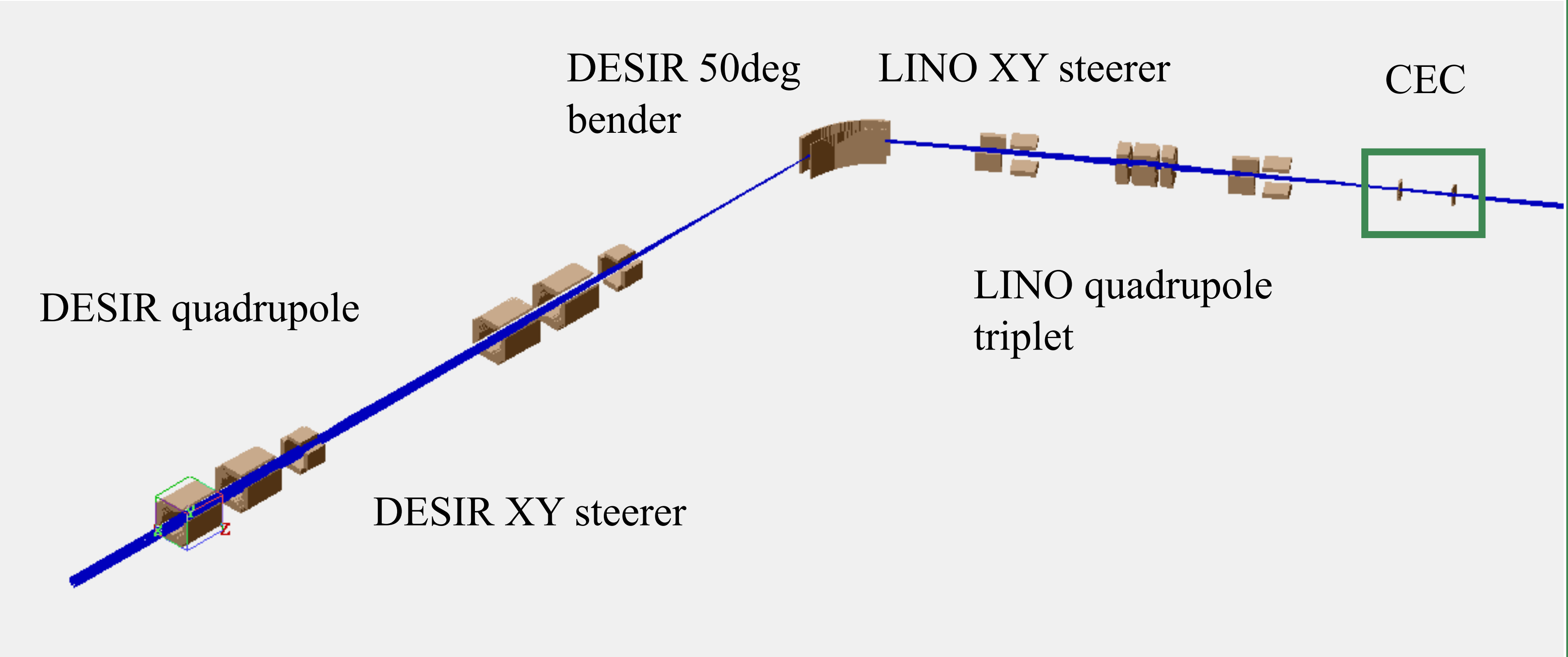
LASAGN : Versatile high-resolution, high-precision and high-sensibilty laser spec. setup

- ✓ Benefits from the many beam preparation and purification devices of DESIR
- ✓ Unique opportunities in the light region with SPIRAL1 RIB
- ✓ Allow to re-inject RIS beams to the central beam line → synergy with trap and decay setups

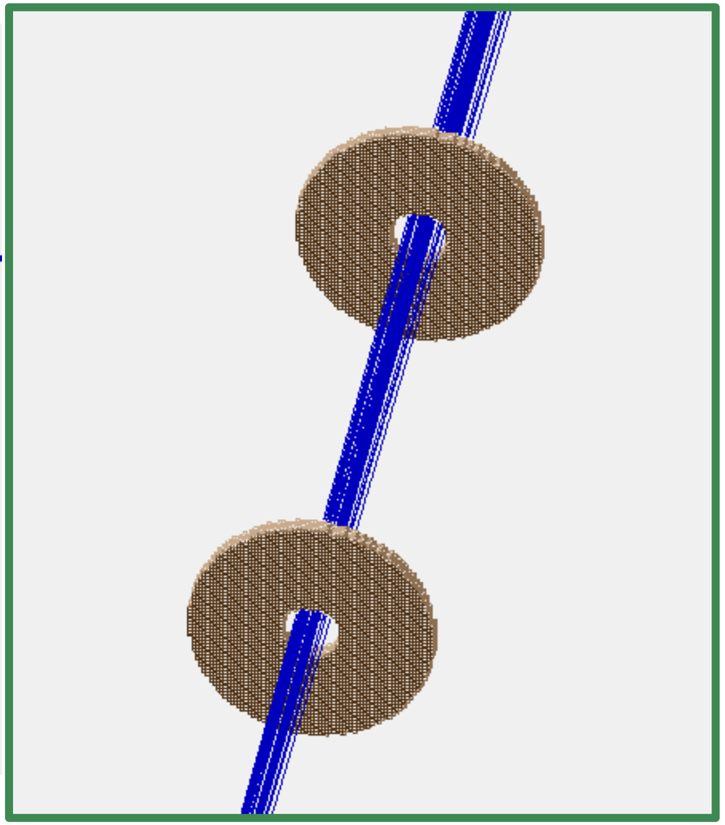
LASAGN technical drawings



LASAGN phase 1: beam transport simulation



Charge Exchange Cell

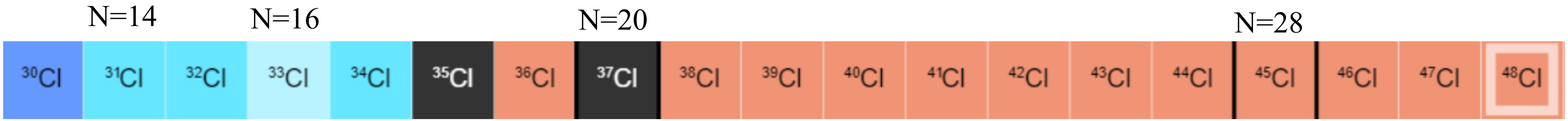


SIMION simulation using proper DESIR and LINO ion optics:

→ 100% transmission through the Charge Exchange Cell (CEC)

→ Work ongoing to implement realistic emitance, ion source and phase 2

Day 1 Exp. : CLS and CRIS of Chlorine



Statues of knowledge:

- g.s. spin A>40 not firmly assign
- Only moments of $^{32\text{-}38,44}$Cl known
- No charge radii measured

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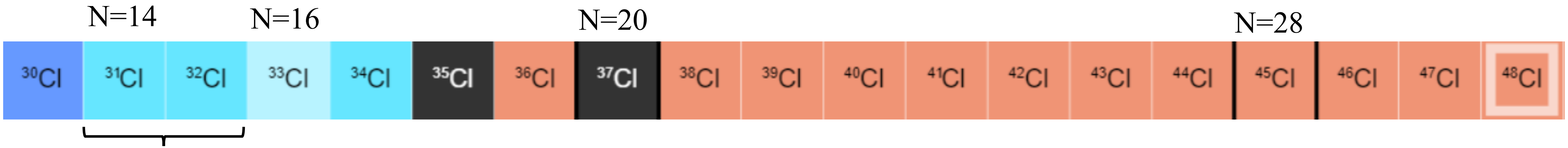
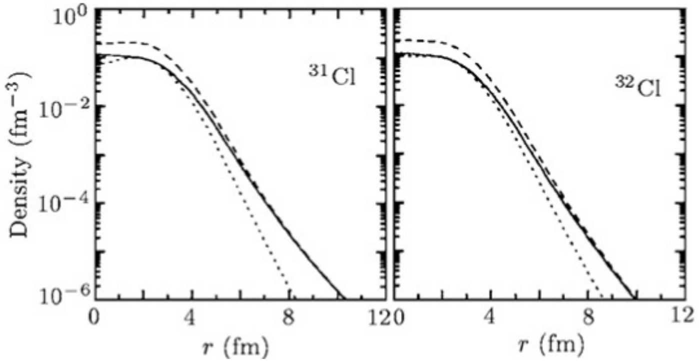


Suggested one-*p* halo in ^{31}Cl and *p* skin in ^{32}Cl from theory
→ Increase in charge radii? Influence of continuum?



C. Xiang-Zhou *et al.*, Chinese Phys. Lett. 19 (2002)
F. Sammarruca, Front. Phys. 6:90 (2018)

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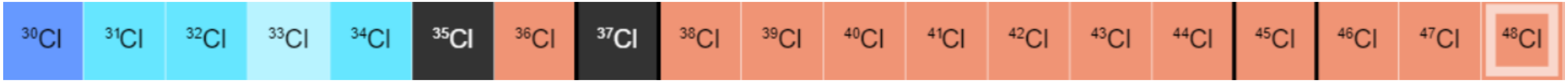
N=14 N=16 N=20 N=28



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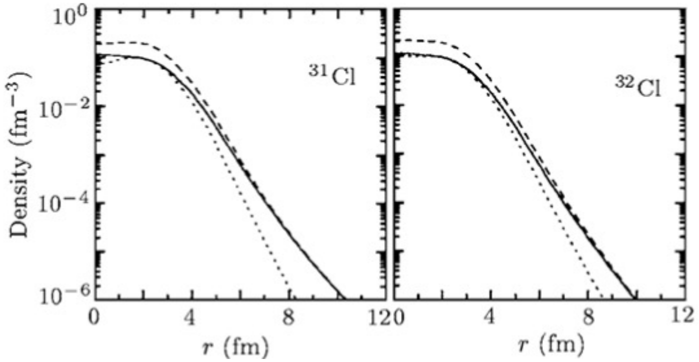

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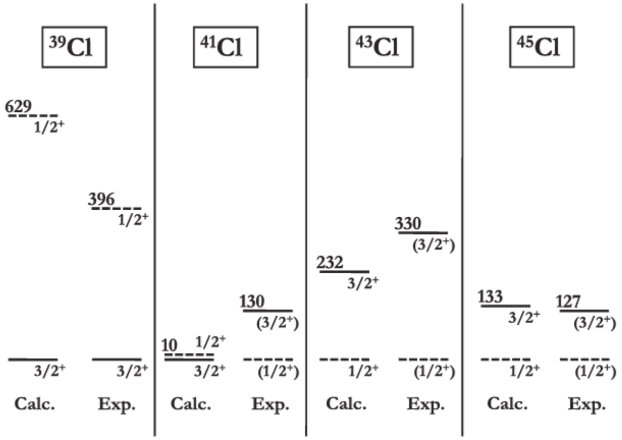

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- Inversion of $3/2^+$ and $1/2^+$ g.s. at A=41?

S. Szilner et al., PRC 87, 054322 (2013)

Statues of knowledge:

- g.s. spin A>40 not firmly assign
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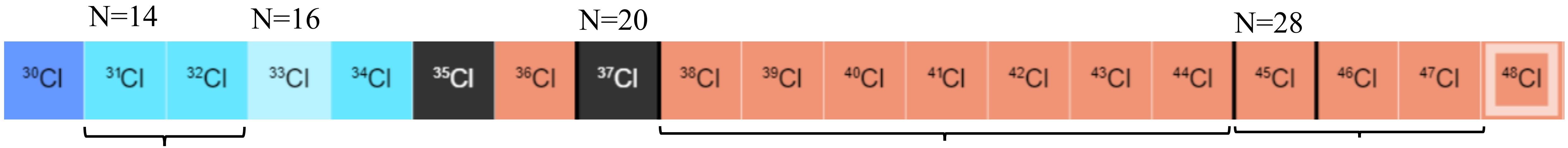
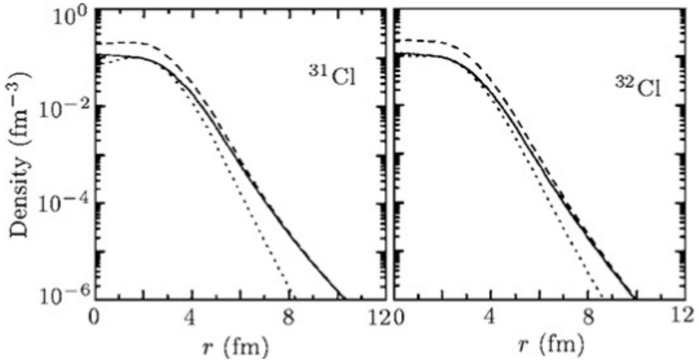
- No charge radii measured

Day 1 Exp. : CLS and CRIS of Chlorine



Suggested one-*p* halo in ^{31}Cl and *p* skin in ^{32}Cl from theory
→ Increase in charge radii? Influence of continuum?



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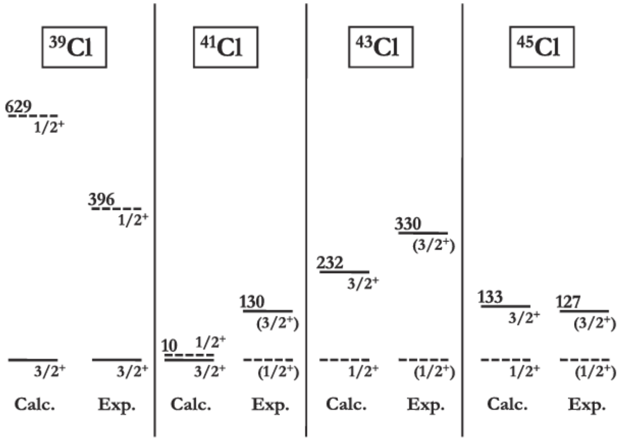

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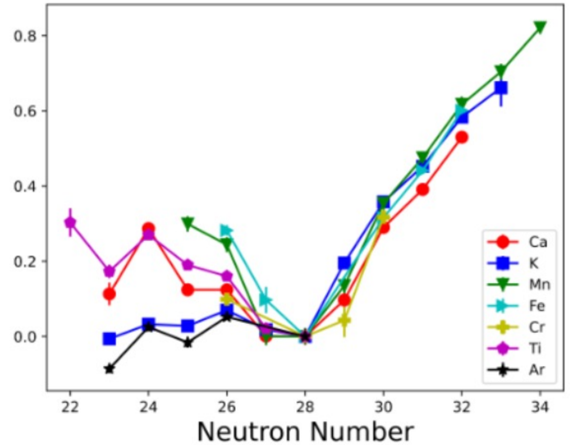
^{45}Cl transition into the N=28 IoI
→ Radii kink at N=28?
→ *s.p.* config and purity from moments



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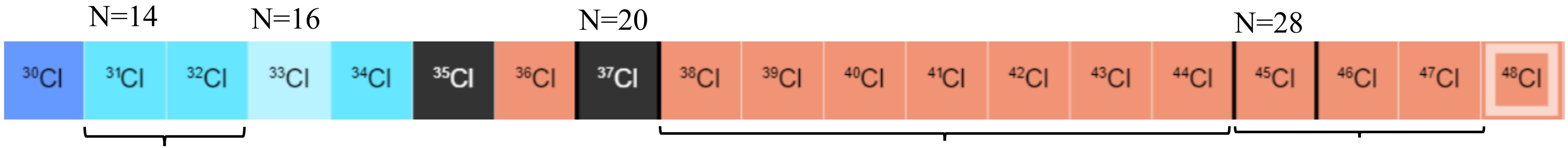

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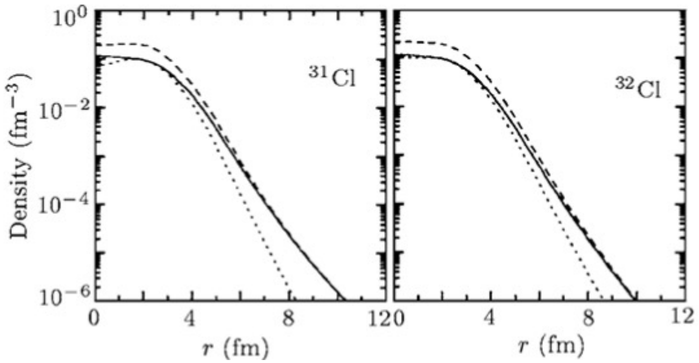

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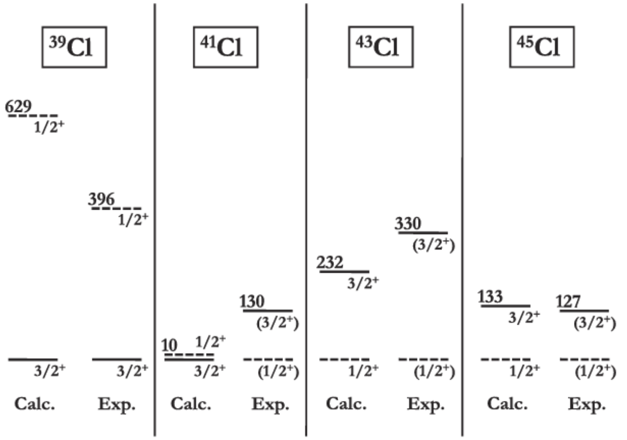

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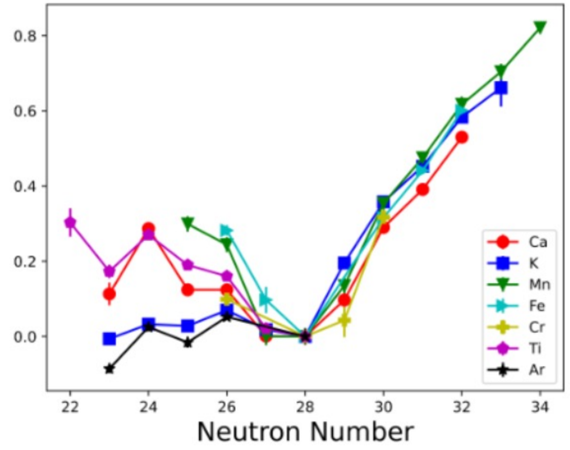
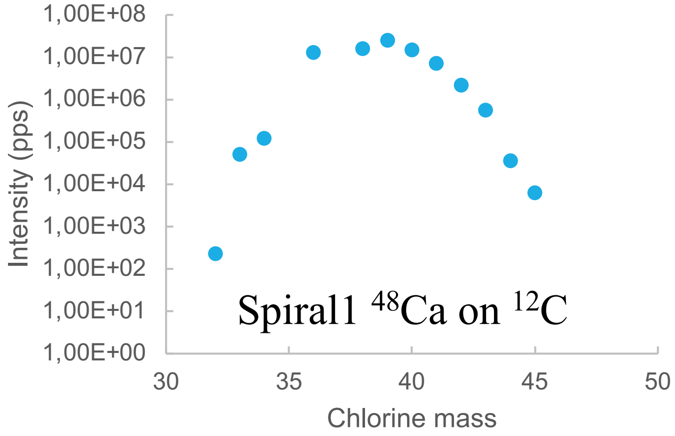




Feasibility:

- Good population of high-lying state in CEC
- Suitable known transitions
- RIS scheme to be devellopped
- Spiral1 yields:
  - $^{33-44}$Cl in reach for CLS
  - $^{31-47}$Cl in reach for CRIS

Statues of knowledge:

- g.s. spin A>40 not firmly assign
- Only moments of $^{32-38,44}$Cl known
- No charge radii measured

Conclusion

- Laser spectroscopy is a very powerful tool to study nuclear structure

  → Access nuclear moments, spin and charge radii in a nuclear-model independent way

- A new low-energy experimental hall DESIR will enter in operation in 2027 at GANIL

  → Unique opportunities with ultra-pure RIB and combinations of exp. technics

- LASAGN : Versatile laser spectroscopy setup of high resolution, precision and sensitivity

  → Unique opportunities for the study of light exotic isotopes, benefiting from existing Spiral1 beams

  → First physics cases envisaged : Cl, P, Zn, O, F…

Timeline : move to DESIR end 2025/ beginning 2026; offline commissioning by 2027. First RIB exp in 2027/28

Grant application end of the year (ANR and ERC)

Spokesperson : L. Lalanne and A. Koszorus (KU Leuven)

Collaboration : IPHC, KU Leuven, IJCLab, LPC, University of Manchester

THANK YOU FOR YOUR ATTENTION

The DESIR Menu

DETRAP *The DEsir TRAPping facility*

MLLTRAP and **PIPERADE**

- Double Penning trap for high precision mass measurements and in-trap decay

→ Nuclear structure & Decay properties

MORA

- RFQ-CB associated with a Paul trap
- D correlation with laser polarized beams

→Fundamental interaction physics (exotic currents, V_{ud}, CP-violation)

LUMIERE

Laser Utilization for Measurement and Ionization of Exotic Radioactive Elements

LASAGN

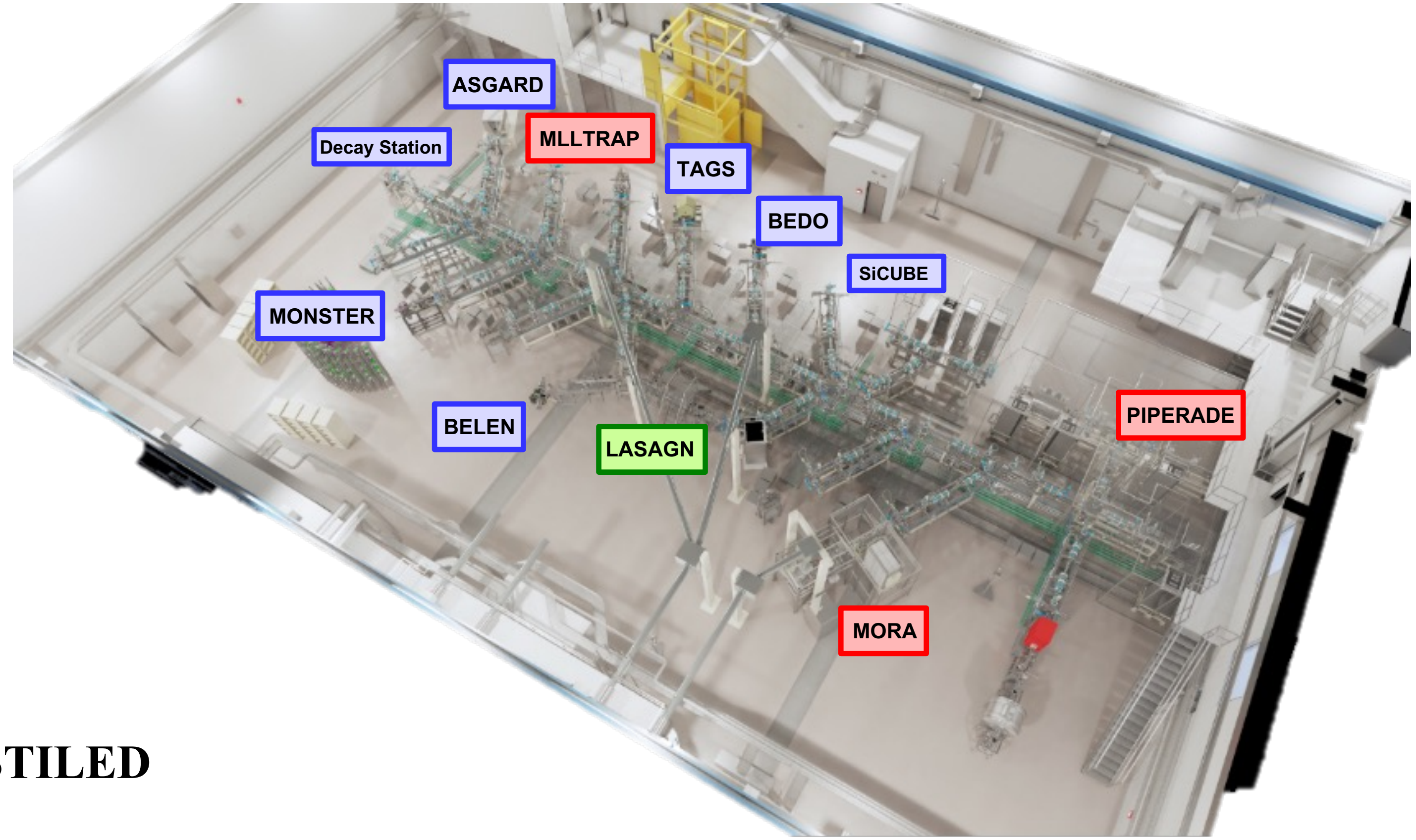
BESTIOL

BEta decay STudies at the SPIRAL2 IsOL facility

High-precision decay measurements with ultra-pure samples (PIPERADE) for fundamental interaction, nuclear structure, nuclear astrophysics…

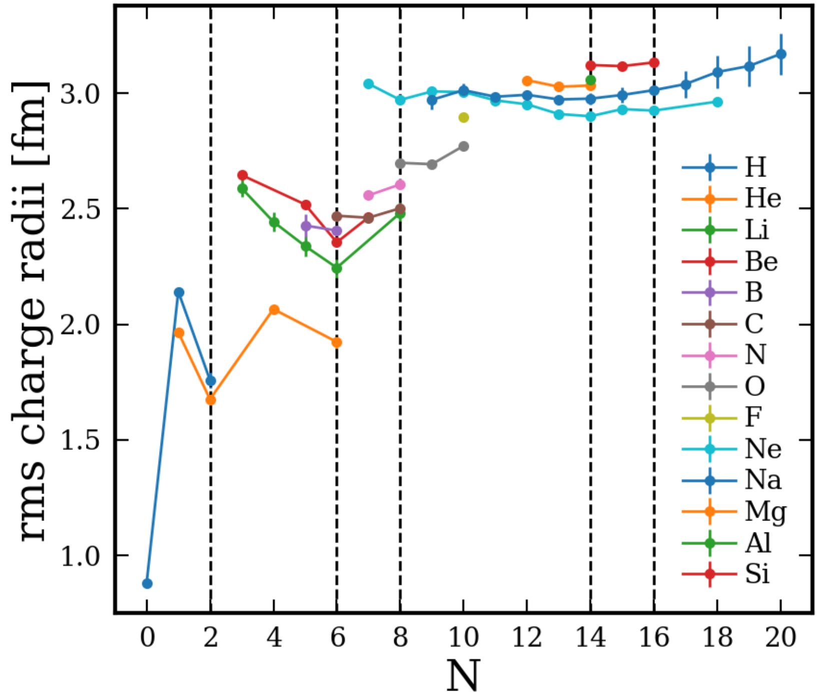
- $\beta - \gamma$ decay stations : **BEDO**, …
- recoil detection **: ASGARD**
- total absorption spectrometers : **DTAS**
- neutron detection arrays : **BELEN**, **MONSTER**, …
- electron and proton detection : **COeCO**, **SiCube**, **b-STILED**

+ open lines for temporary setups



CRIS of Oxygen from the proton to the neutron drip-line

N=6 N=8 N=14 N=16



Study of charge radii kinks at (sub-) shell closures

- Strong kink at N=6
- Small N=8 kink only observed in Ne
- Kink at *N*=14 in Ne and Na

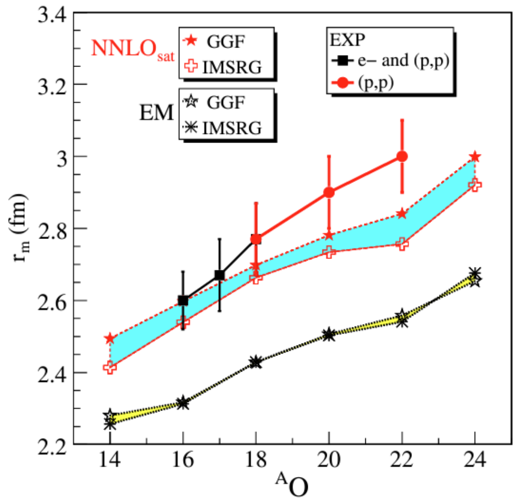
→ Charge radii kink in O at N=6, 8 and 14?

N=14 and 16 magicity

→ Moment of ^{23}O : purity of the g.s. wave function?

→ ^{23}O spin → 5/2 or 1/2 spin?

Charge radii of O → stringent test for NN int. and ab-initio theories



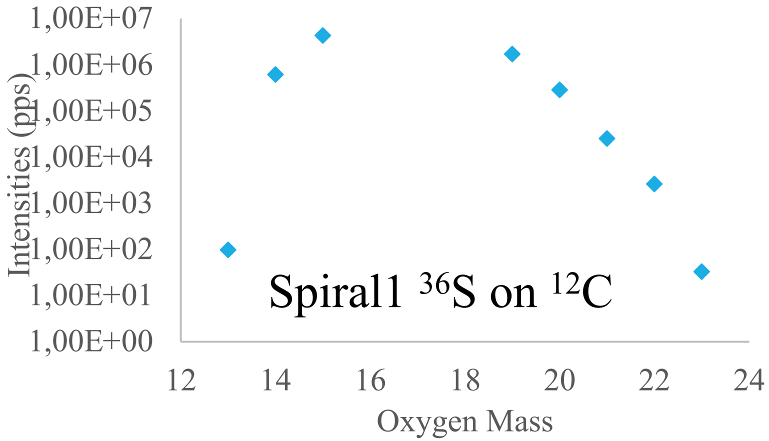
V. Lapoux et al., PRL 117, 052501 (2016)

Status of knowledge:

- $^{13-21}$O Moments known from beta-NMR
- Matter radii of $^{16-18,20,22}$O from e^- and p scat.
- No charge radii known outside stability

Feasibility:

- Suitable known transitions
- Need RIS scheme development
- Yield: $^{13-23(24)}$O in reach with CRIS

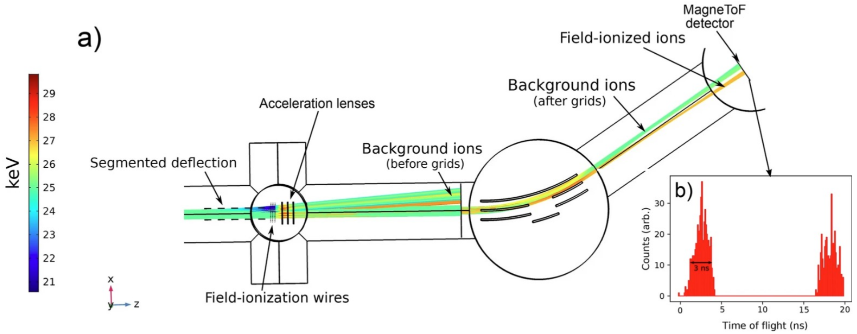


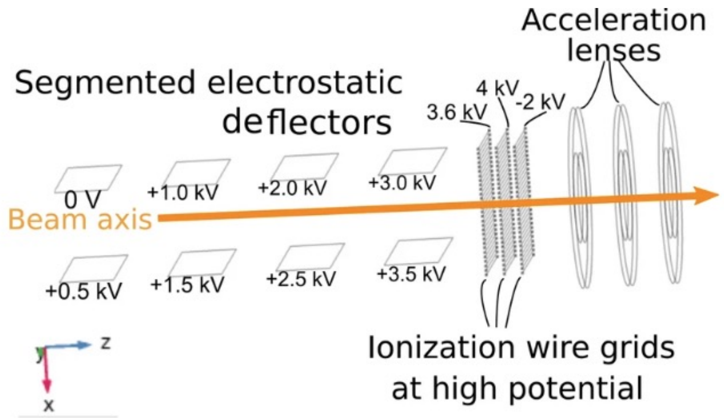
Ongoing developments

How to improve sensitivity?

→ Reduction of ionization volume to reduce collisional rate

→ Field ionization





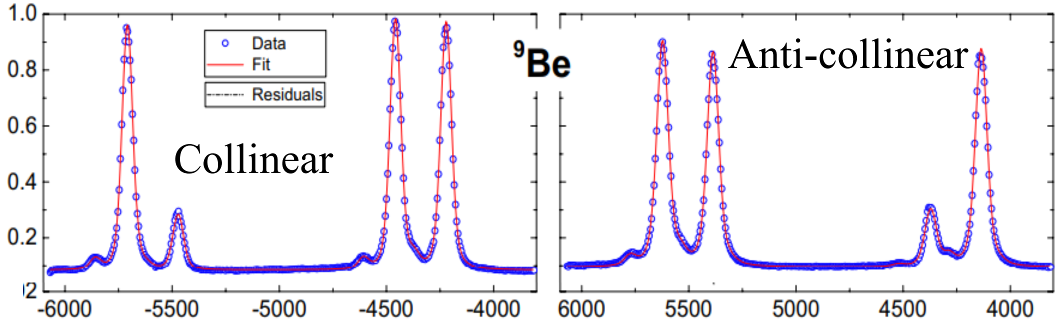
A.R. Vernon *et al.*, Scientific reports 10, 12306 (2020)

→ Ongoing commissioning at CRIS, ISOLDE

How to improve transition frequency measurement precision?

→ Limited by the determination of the ion velocity

→ Collinear / anti-collinear spectroscopy + frequency-comb referenced cw laser system



A. Krieger *et al.*, Appl. Phys. B 123:15 (2017)

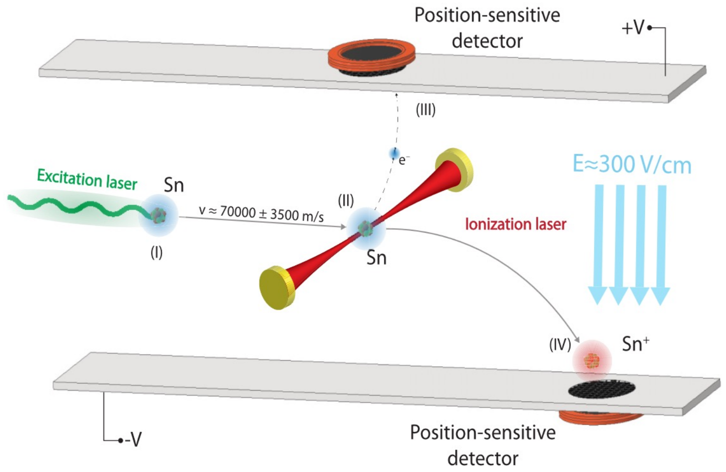
→ <1 MHz precision on transition frequency

→ Collinear / anti-collinear RIS to be implemented

How to do both at the same time?

→ RIS as a two-body reaction

→ Under development at MIT



S.M. Udrescu *et al.*, Phys. Rev. Res. 6, 013128 (2024)

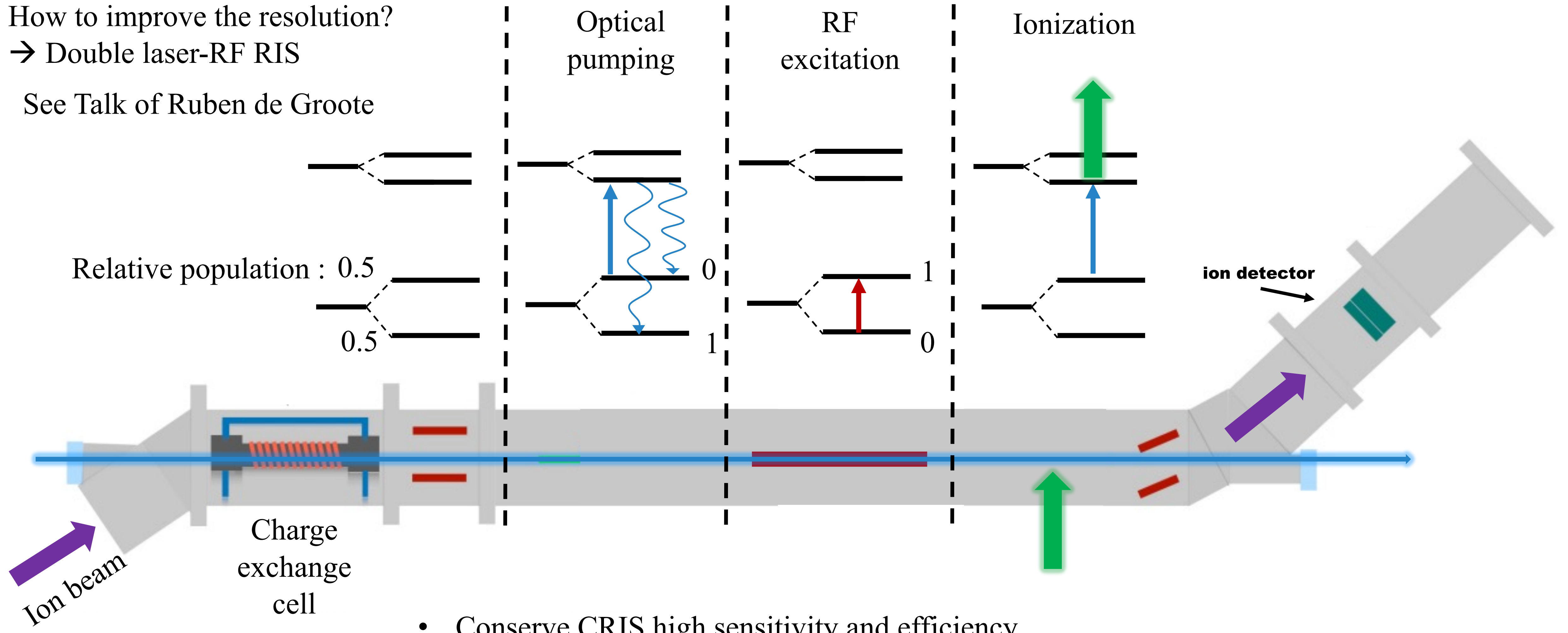
How to improve the resolution?

→ Double laser-RF RIS (see talk of Ruben)

CRIS-RF

How to improve the resolution?
→ Double laser-RF RIS

See Talk of Ruben de Groote



- Conserve CRIS high sensitivity and efficiency
- Improve the precision of hyperfine parameter measurement by several orders of magnitude

→ Measurement of magnetic octupole moment

U. Nielsen et al., PRL 51, 19 (1983)   T.J. Scholl et al., PRA 33, 4 (1986)   R.P de Groote et al., PLB 827, 136930 (2022)