The DESIR Physics Programme

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CEN Bordeaux-Gradignan

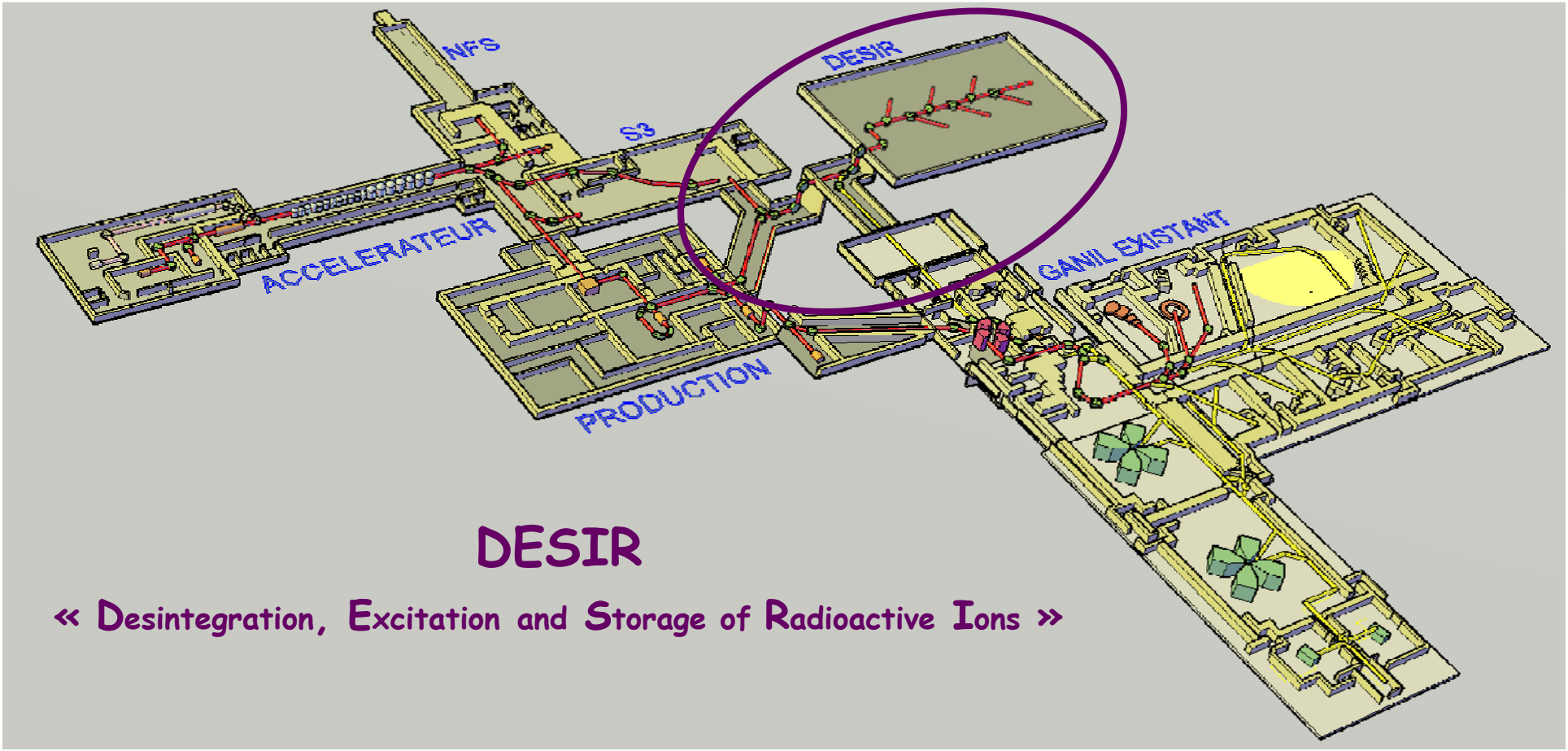
GANIL/SPIRAL2 week, October 6-9, 2014

The DESIR facility at GANIL/SPIRAL2

DESIR Collaboration Spokesperson: *B. Blank, CENBG*
DESIR Facility coordinator: *J.-C. Thomas, GANIL*
DESIR technical coordinator: L. Serani, CENBG/GANIL

http://www.cenbg.in2p3.fr/desir

-> A low-energy RIB facility dedicated to the study of the fundamental properties of the nucleus in its ground and isomeric states, applications



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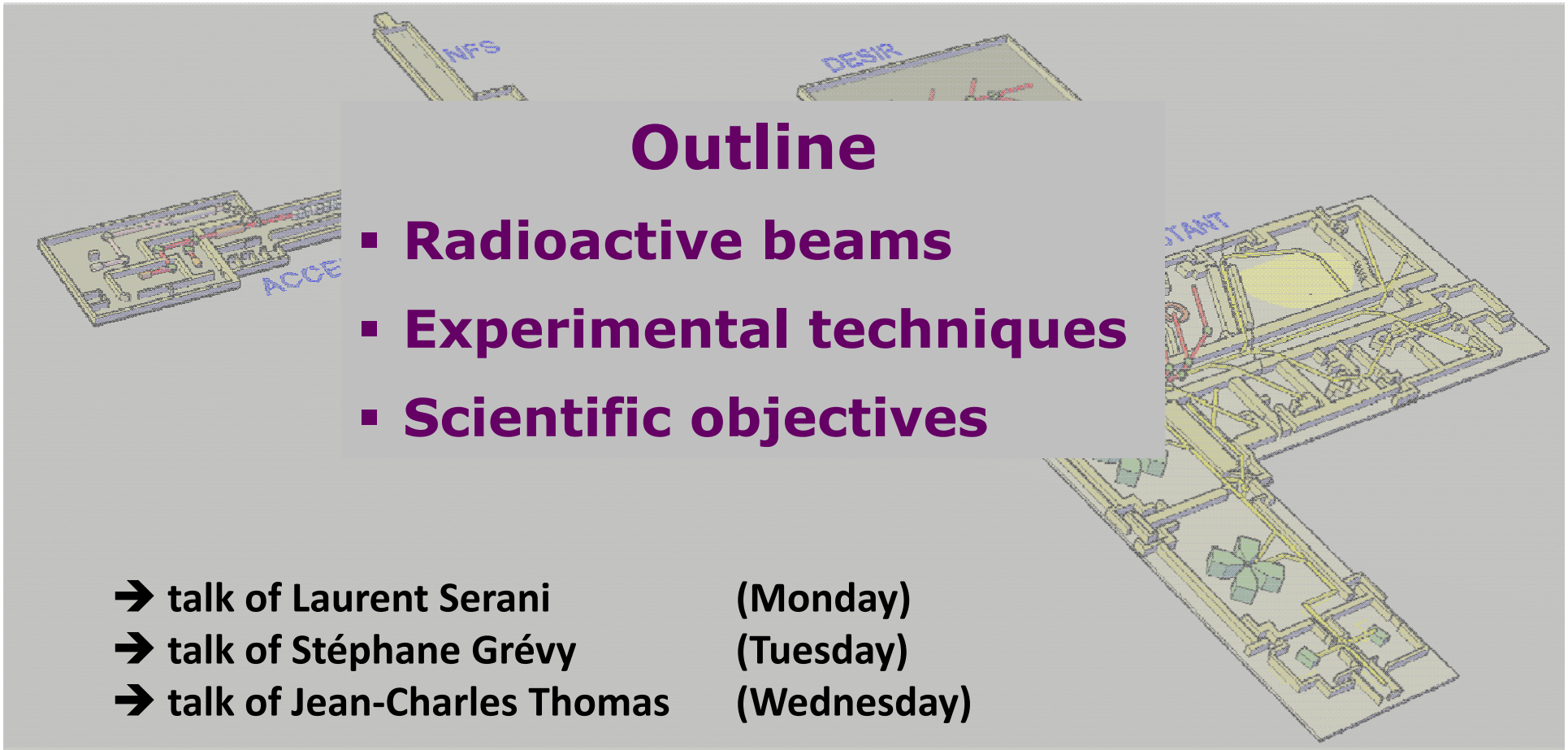
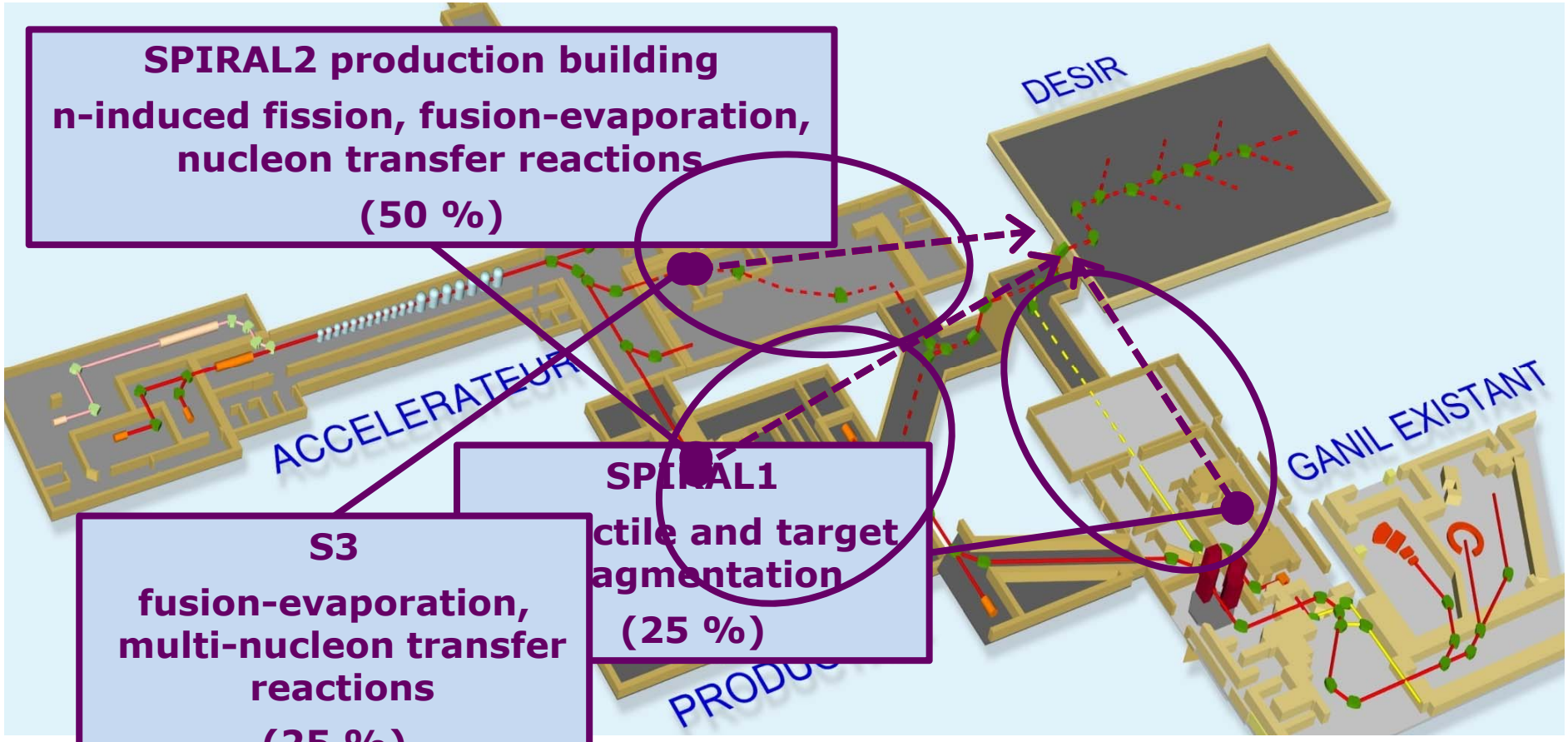


Outline

- **Radioactive beams**
- **Experimental techniques**
- **Scientific objectives**

➔ talk of Laurent Serani (Monday)
➔ talk of Stéphane Grévy (Tuesday)
➔ talk of Jean-Charles Thomas (Wednesday)

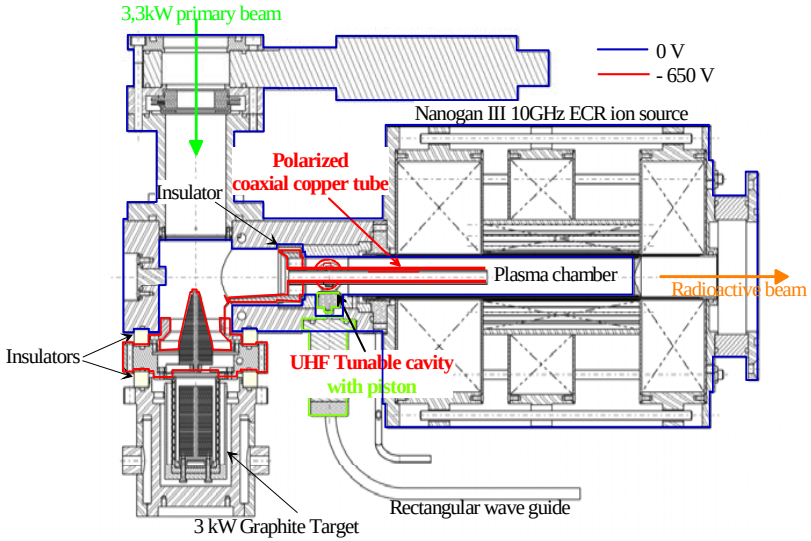
RIB production: reaction mechanisms <-> production sites

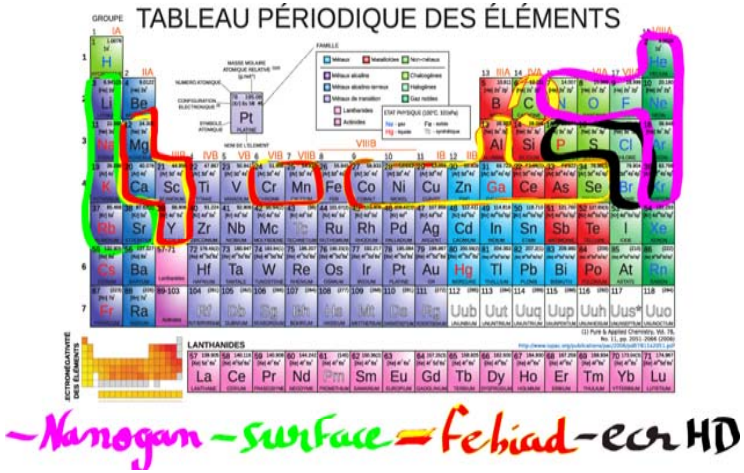


-> a large variety of radioactive beams allowing to access most of the regions of interest in the nuclide chart

Beam production: SPIRAL1

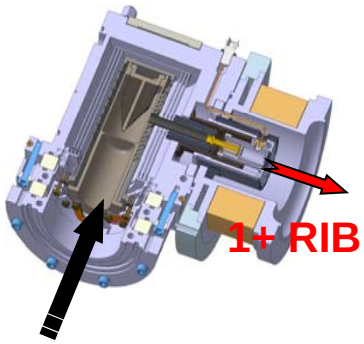
ECR source



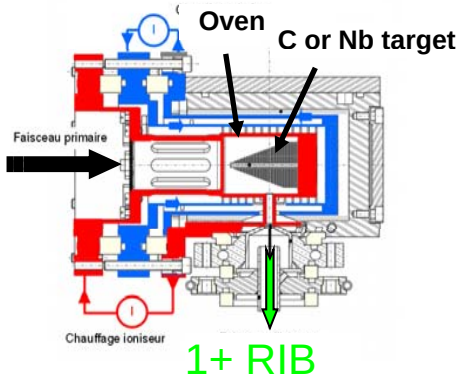


~Nanogan ~surface ~febiad ~ecr HD

FEBIAD



Surface ionization

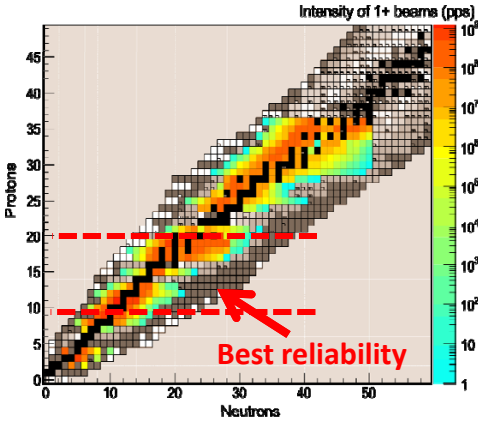


ECR: Ne, Ar, Kr, N, O, F

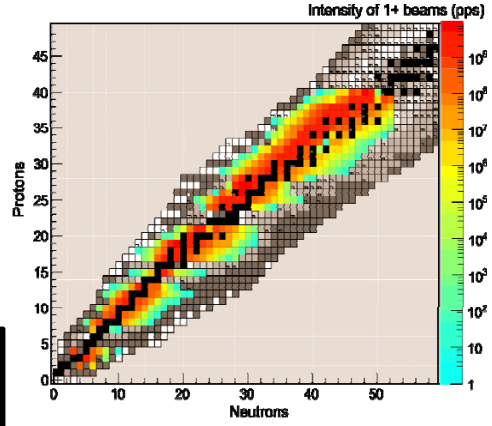
Surface Ionization : Li, Na, K, Rb

FEBIAD: Mg, Al, P, S, Cl, Fe, Cu

Expected yields



SPIRAL: Expected production by projectile fragmentation



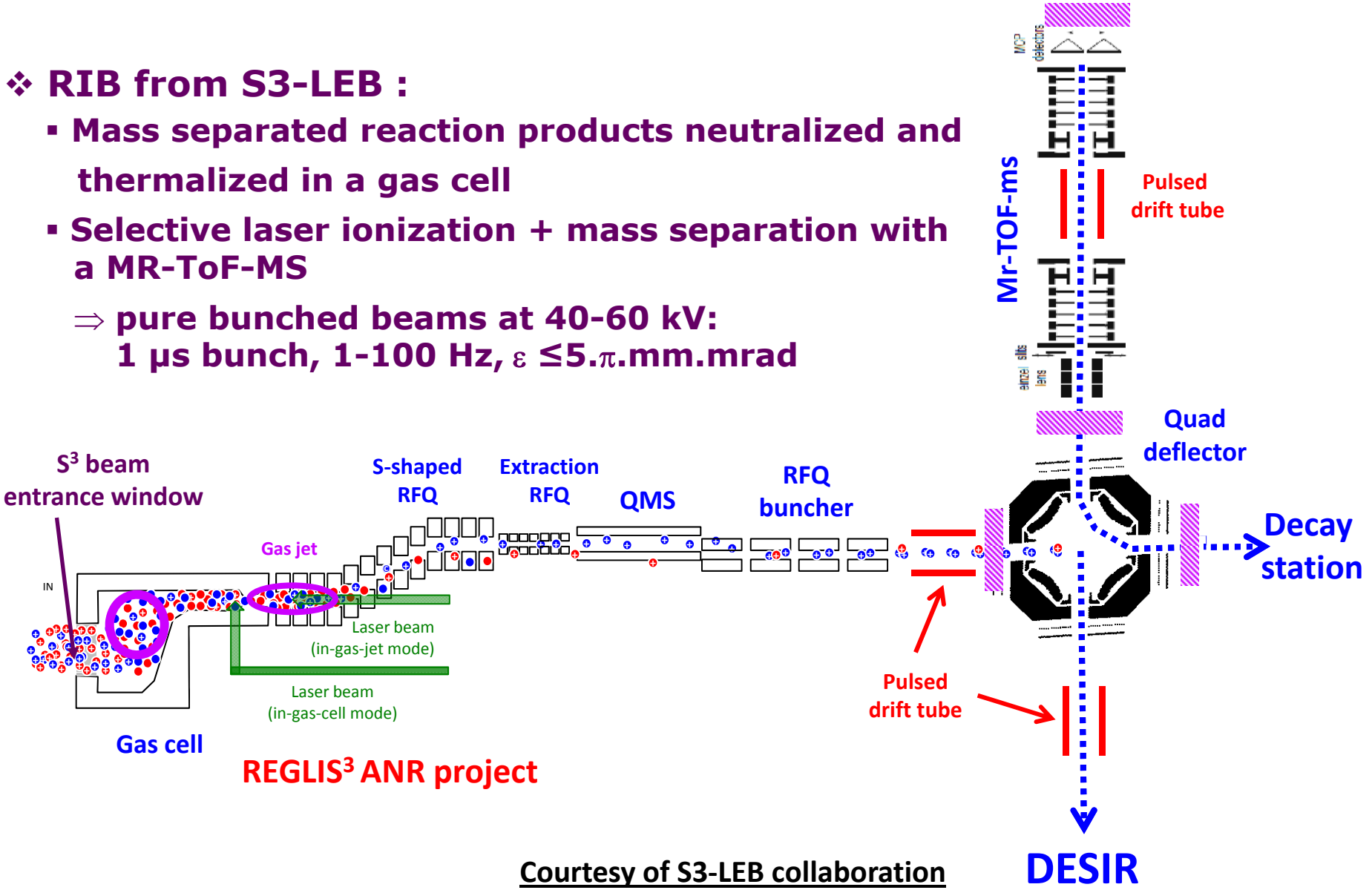
SPIRAL: Expected production by target fragmentation

Courtesy of P. Delahaye

Beam production: S3 - LEB

- **RIB from S3-LEB :**
  - **Mass separated reaction products neutralized and thermalized in a gas cell**
  - **Selective laser ionization + mass separation with a MR-ToF-MS**

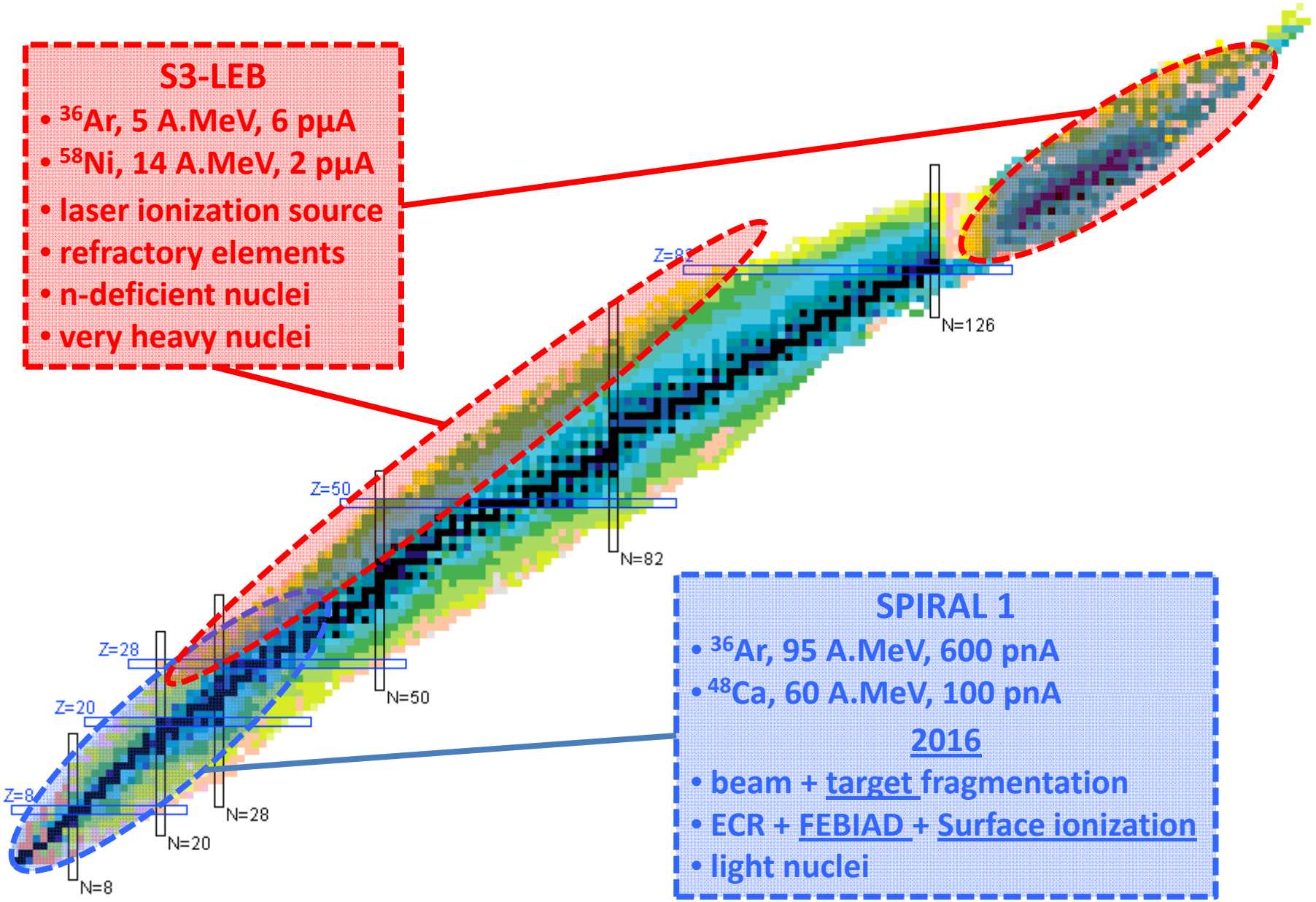
    ⇒ **pure bunched beams at 40-60 kV:**
    1 µs bunch, 1-100 Hz, ε ≤5.π.mm.mrad



Courtesy of S3-LEB collaboration

DESIR RIBs

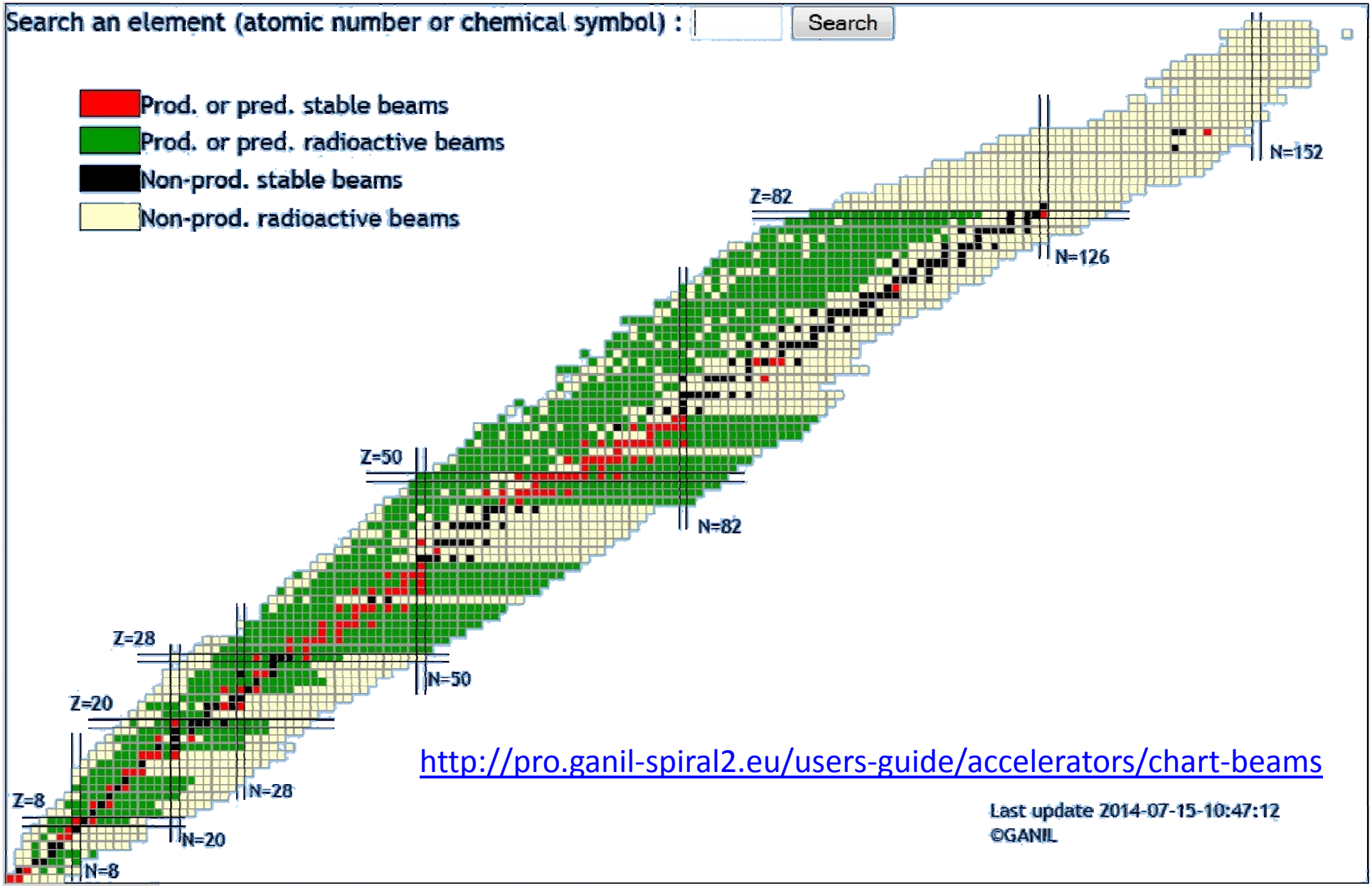
S3-LEB
- ^{36}Ar, 5 A.MeV, 6 pμA
- ^{58}Ni, 14 A.MeV, 2 pμA
- laser ionization source
- refractory elements
- n-deficient nuclei
- very heavy nuclei



SPIRAL 1
- ^{36}Ar, 95 A.MeV, 600 pnA
- ^{48}Ca, 60 A.MeV, 100 pnA

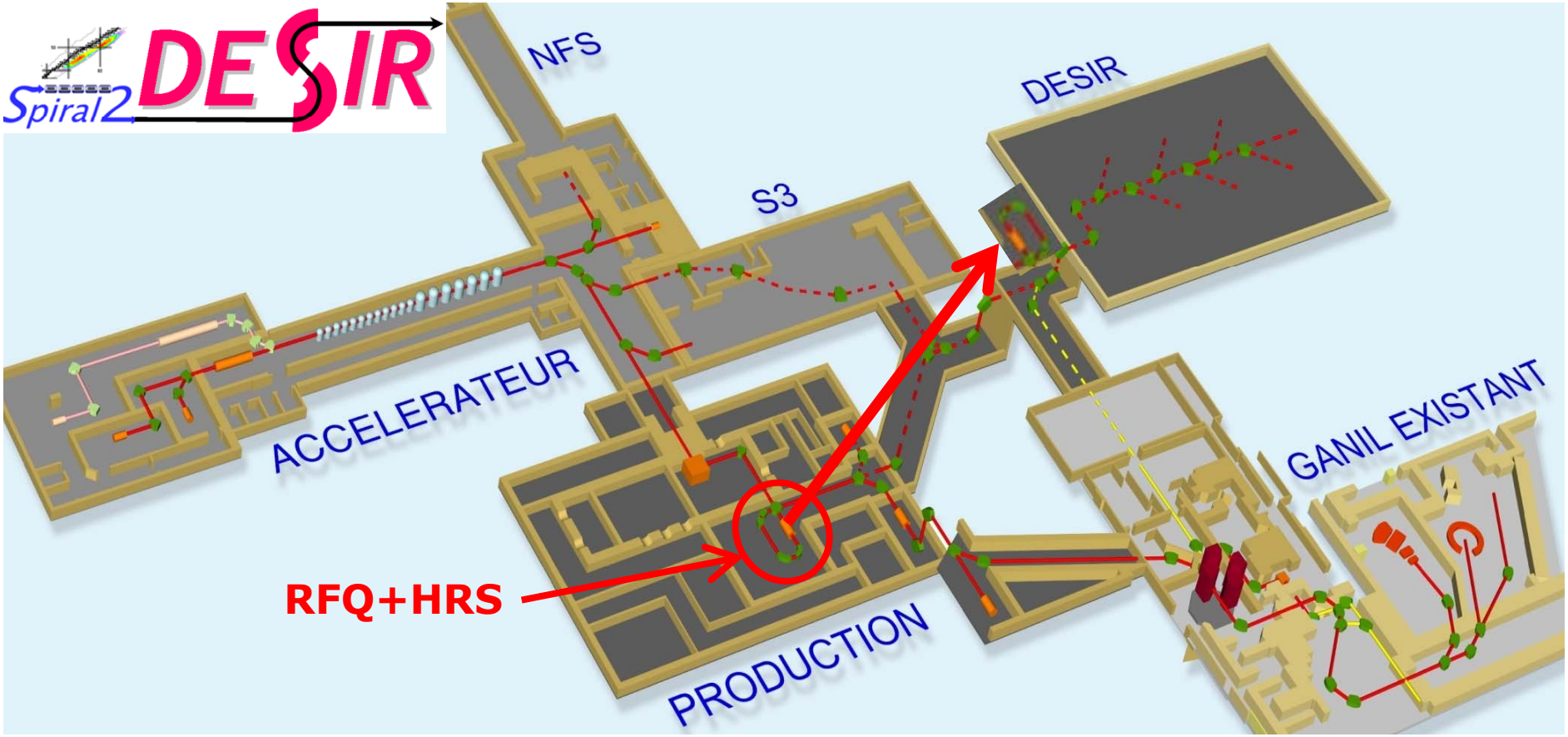
2016
- beam + target fragmentation
- ECR + FEBIAD + Surface ionization
- light nuclei

Beam production: SPIRAL1 – S3 - LEB

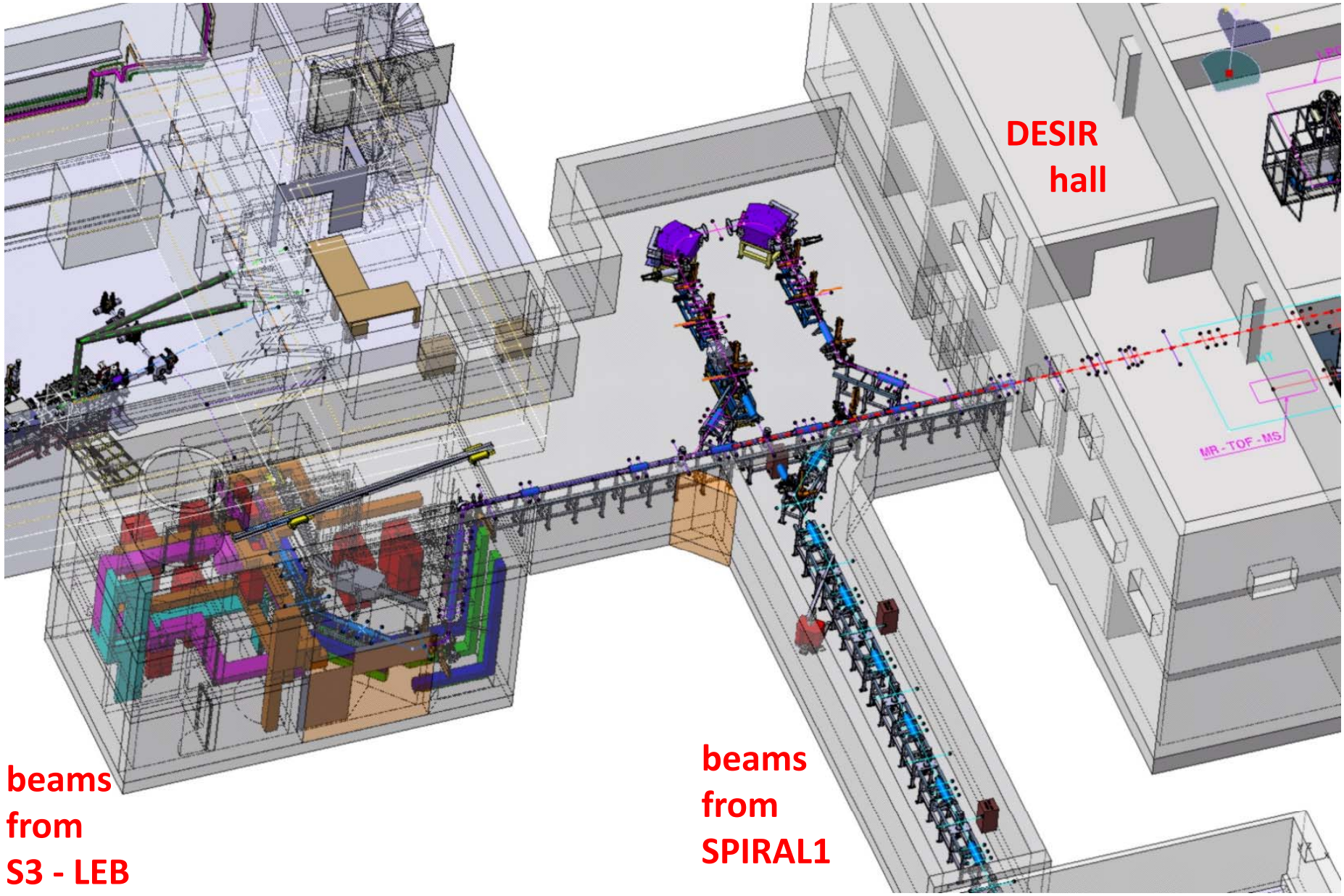


Beam preparation

RFQ cooler and a HRS to achieve a high isobaric selection with M/ΔM ~20000-30000



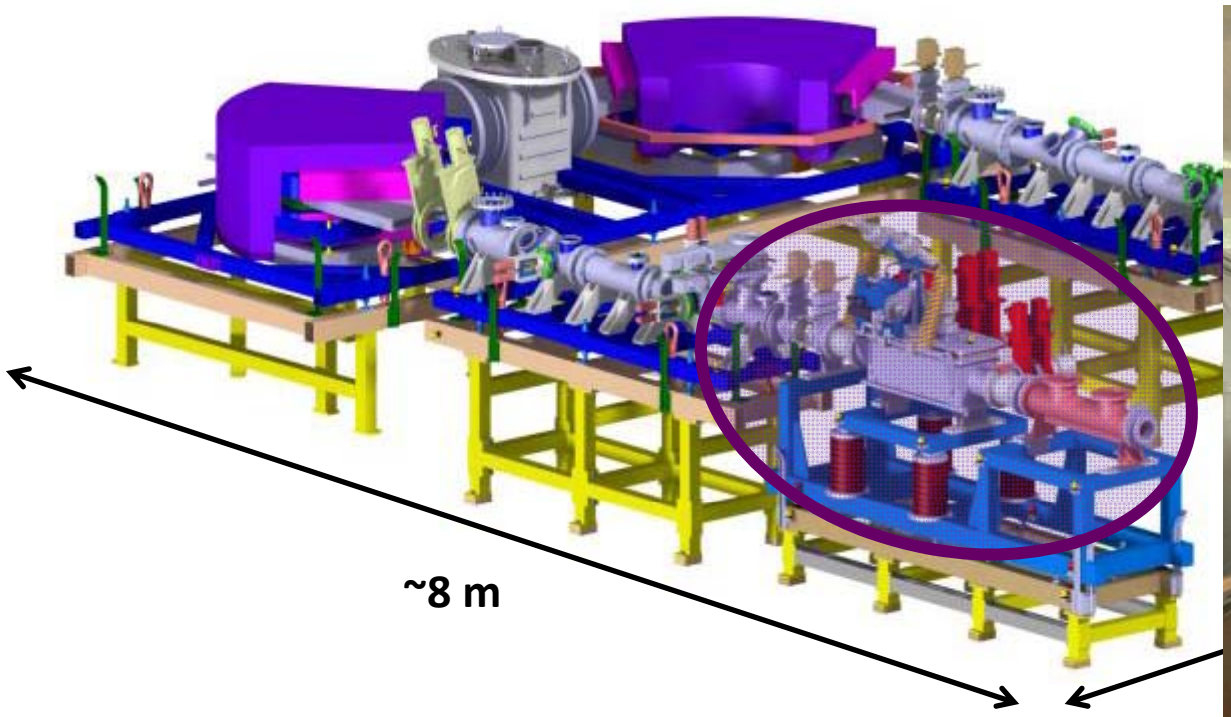
New location of RFQ SHIRaC - HRS



Beam preparation

RFQ Cooler "SHIRaC" built at LPC Caen (coll. CSNSM, GANIL)

- **Objectives:** $\varepsilon \leq 3.\pi.$mm.mrad, $\Delta E/E \leq 1$ eV, 70 % transmission
- **Achievements:** $\varepsilon = 2.\pi.$mm.mrad , $\Delta E/E \sim 1$ eV, 50-70 % transmission for $40 \leq A \leq 130$



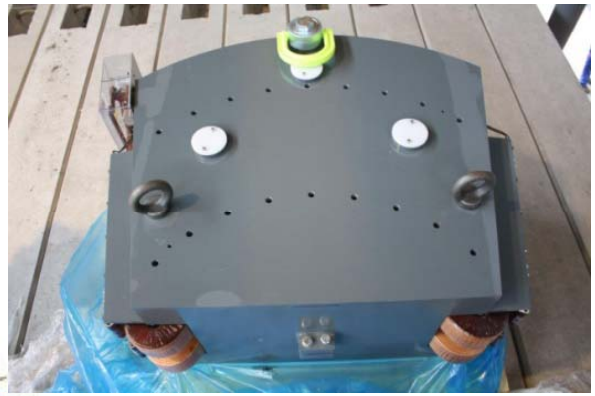
-> include ALARA principle

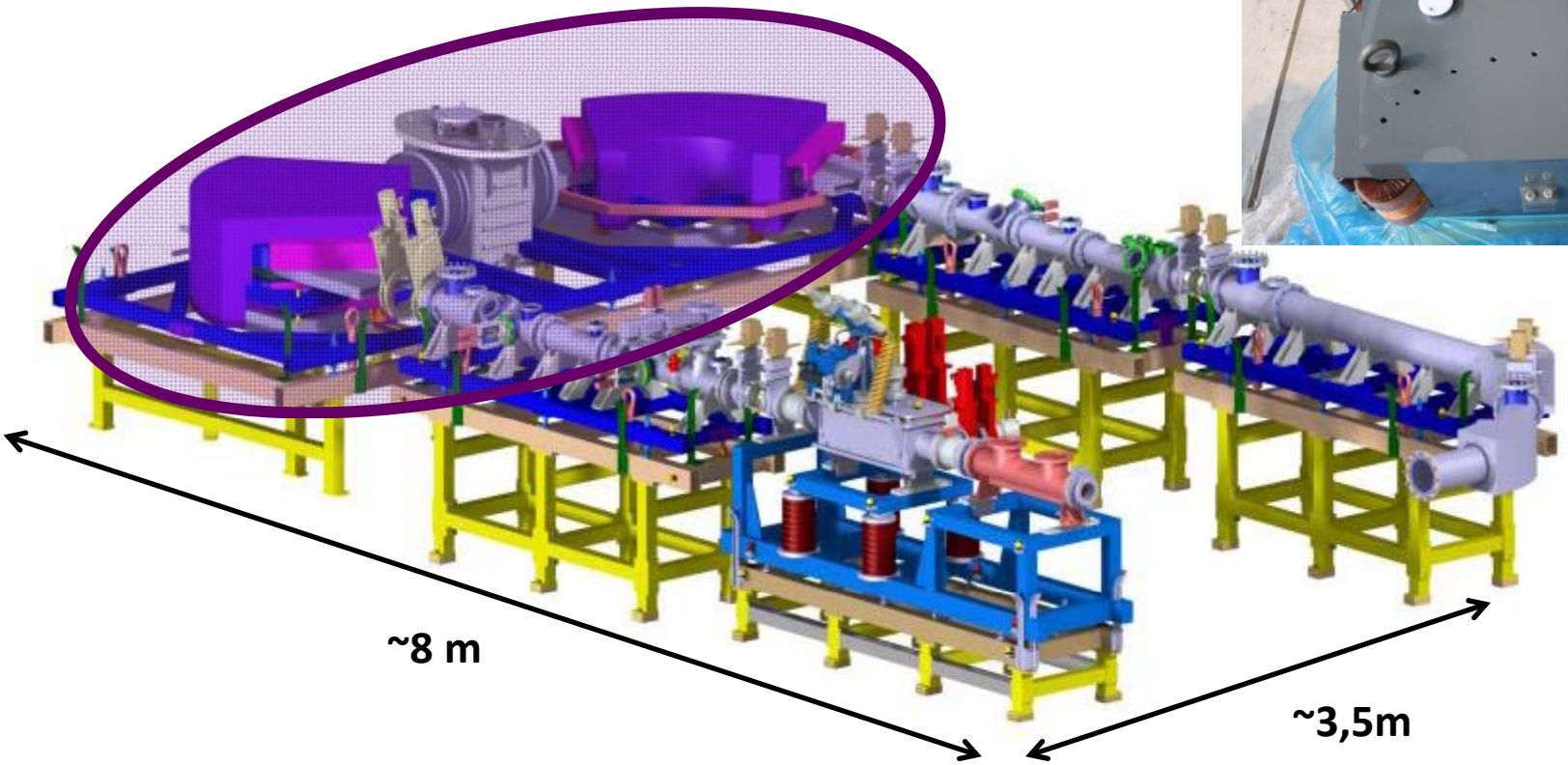
-> continue performance tests

Beam preparation

HRS built at CENBG (coll. GANIL) - ***T. Kurtukian-Nieto et al., NIMB 2013***

- **Optical design completed and detailed simulations performed (5th order) -> M/ΔM > 20000 expected at 60 keV for ε ≤3.π.mm.mrad**
- **Mechanical design well advanced**
- **Dipoles delivered to GANIL in July 2014**



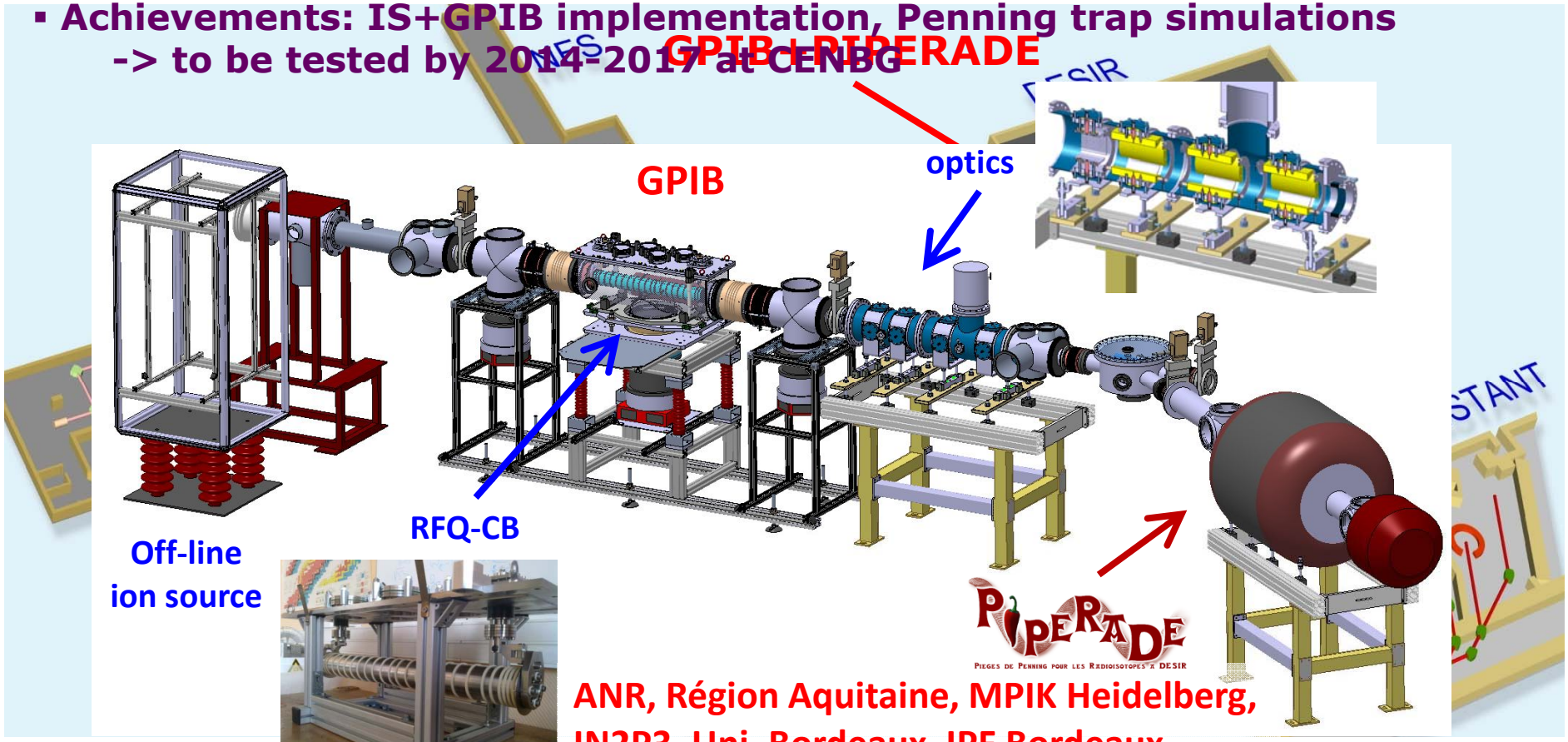


Assembling and test of the ensemble scheduled at CENBG in 2015-2016

Beam preparation

RIBs inside the DESIR experimental hall

- Beam preparation by means of a General Purpose Ion Buncher (GPIB)
- Collaboration: CENBG, MPIK Heidelberg, LPCC, GANIL, CSNSM, IRNO
- Objectives: fast (50-500 ms) cleaning ($\Delta M/M \sim 10^{-5}$) of large samples (10^5 ions/bunch)
- Purification with a double Penning trap system (PIPERADE)
- Achievements: IS+GPIB implementation, Penning trap simulations
  -> to be tested by 2014-2017 at CENBG

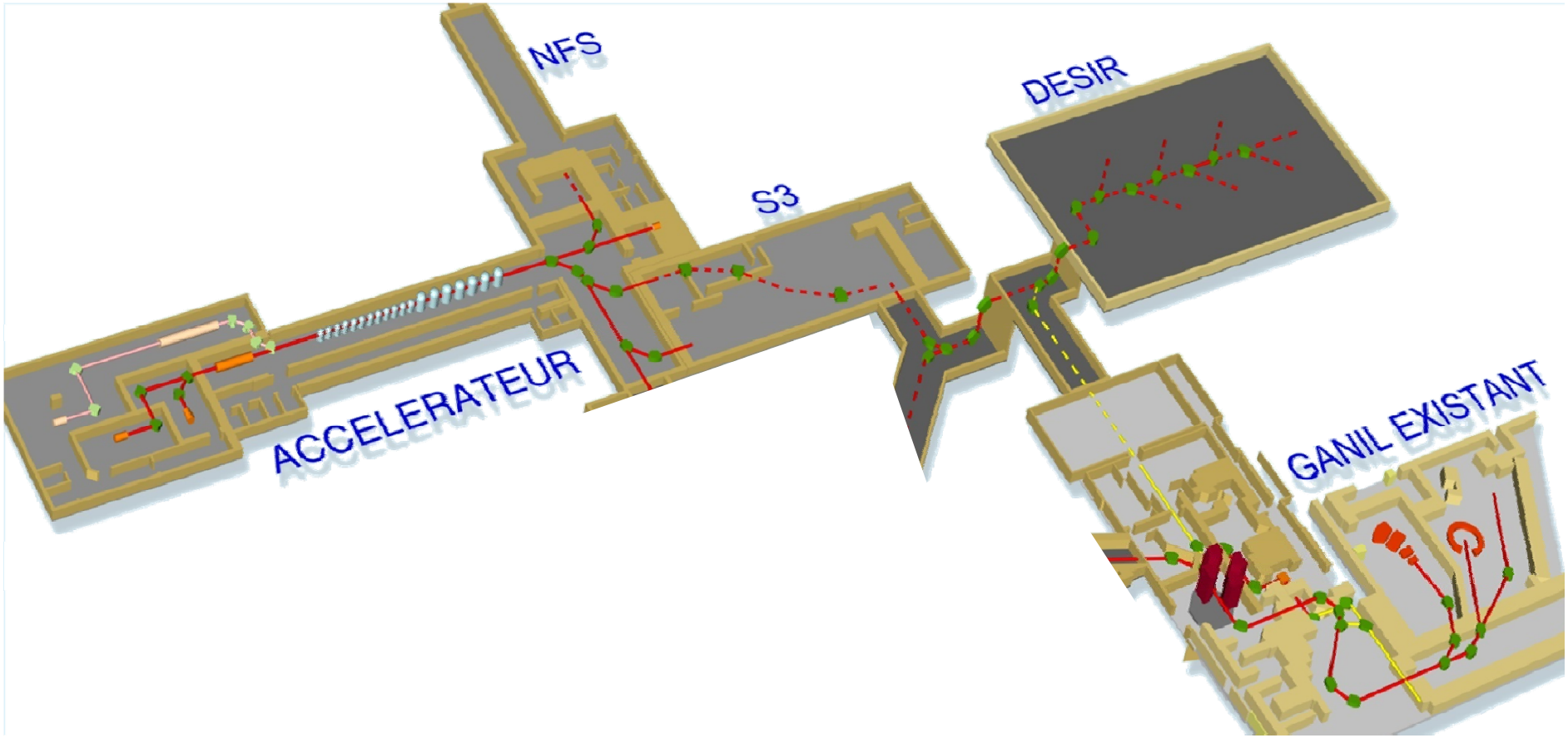


ANR, Région Aquitaine, MPIK Heidelberg,
IN2P3, Uni. Bordeaux, IPF Bordeaux

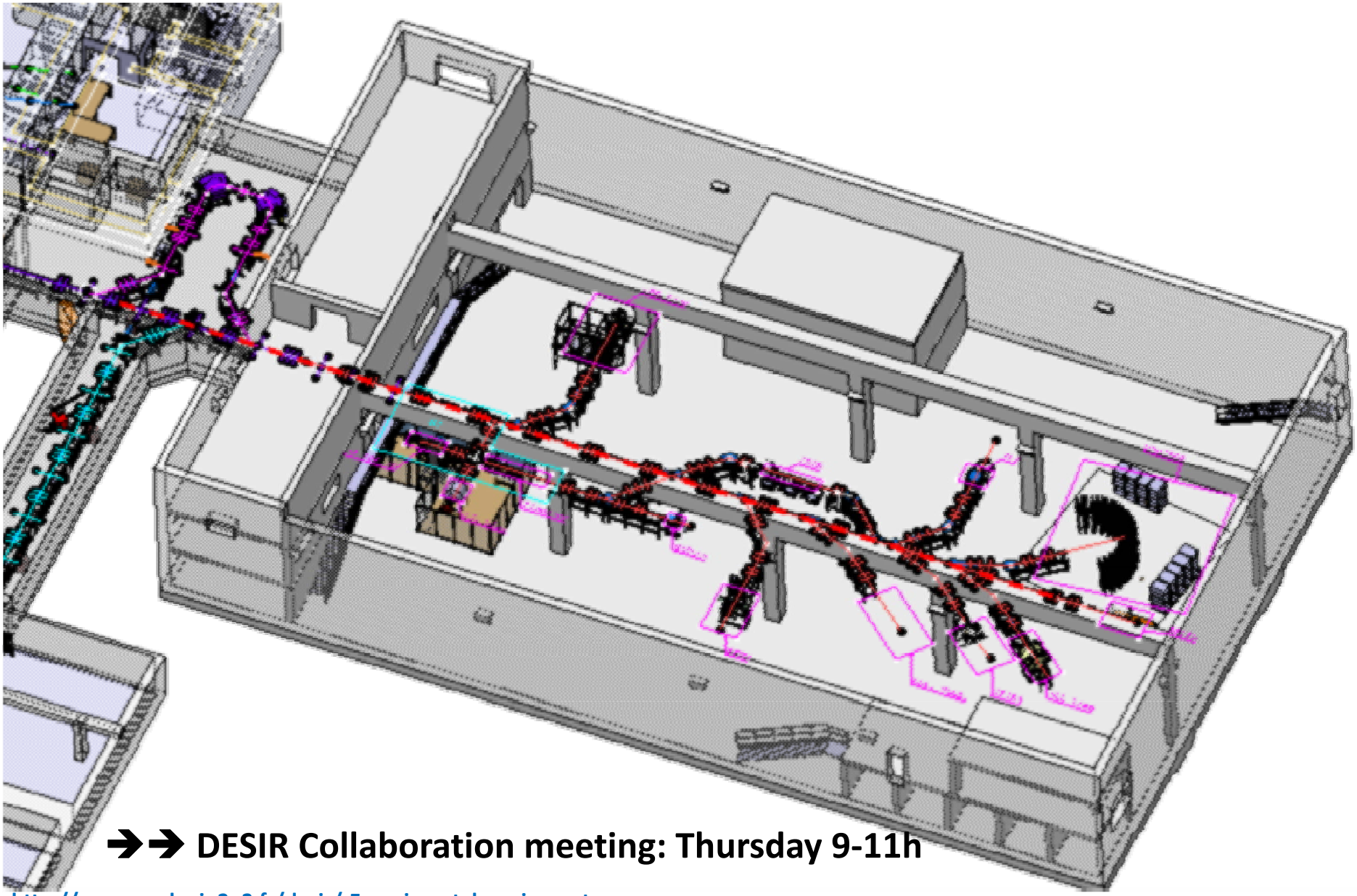
Experimental equipment

DESIR instrumentation: http://www.cenbg.in2p3.fr/desir/-Experimental-equipment-

- **DETRAP: mass measurement, trap assisted spectroscopy, weak interaction studies**
- **BESTIOL: β-decay studies (β-n,γ,xp) and full absorption spectroscopy**
- **LUMIERE: collinear laser spectroscopy + β-NMR studies**



Experimental equipment



➔➔ **DESIR Collaboration meeting: Thursday 9-11h**

http://www.cenbg.in2p3.fr/desir/-Experimental-equipment-

DESIR Scientific Program

- **Nuclear structure**
  - basic properties (mass, nuclear moments, J^{π})
  - from single-particle to collective behaviors
  - clustering
  - rare decay modes (β-xp)
  - isospin symmetry breaking
- **Weak interaction**
  - search for exotic currents (S,T)
  - test of standard model prescriptions (CVC, CKM unitarity)
- **Astrophysics**
  - input parameters for nucleosynthesis scenarios
- **Interdisciplinary researches**
  - atomic and solid-state physics
  - nuclear data
  - medicine

-> requires a large variety of radioactive beams

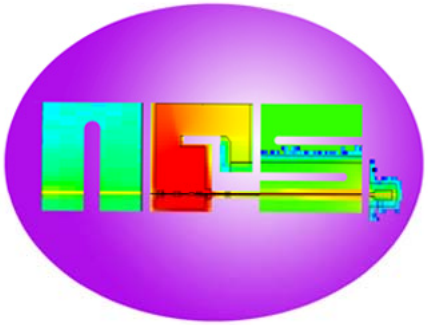
-> can benefit from high quality beams (purity & optics)

-> calls for complementary investigation techniques

WORKSHOPS 2014

24 March - 1 April, in Caen, France

DESIR S3



DESIR – S3-LEB: March 24-26, 2014 at GANIL

- update DESIR Physics case after SPIRAL2 Production Building was postponed, S3-LEB experiments
- 75 participants
- 13 technical presentations: production, purification, set-ups…
- 18 scientific presentations: mass measurements, laser spectroscopy, decay studies

DESIR Physics program (2010)

- **Collinear laser spectroscopy**
- **β-delayed γ spectroscopy (laser)**

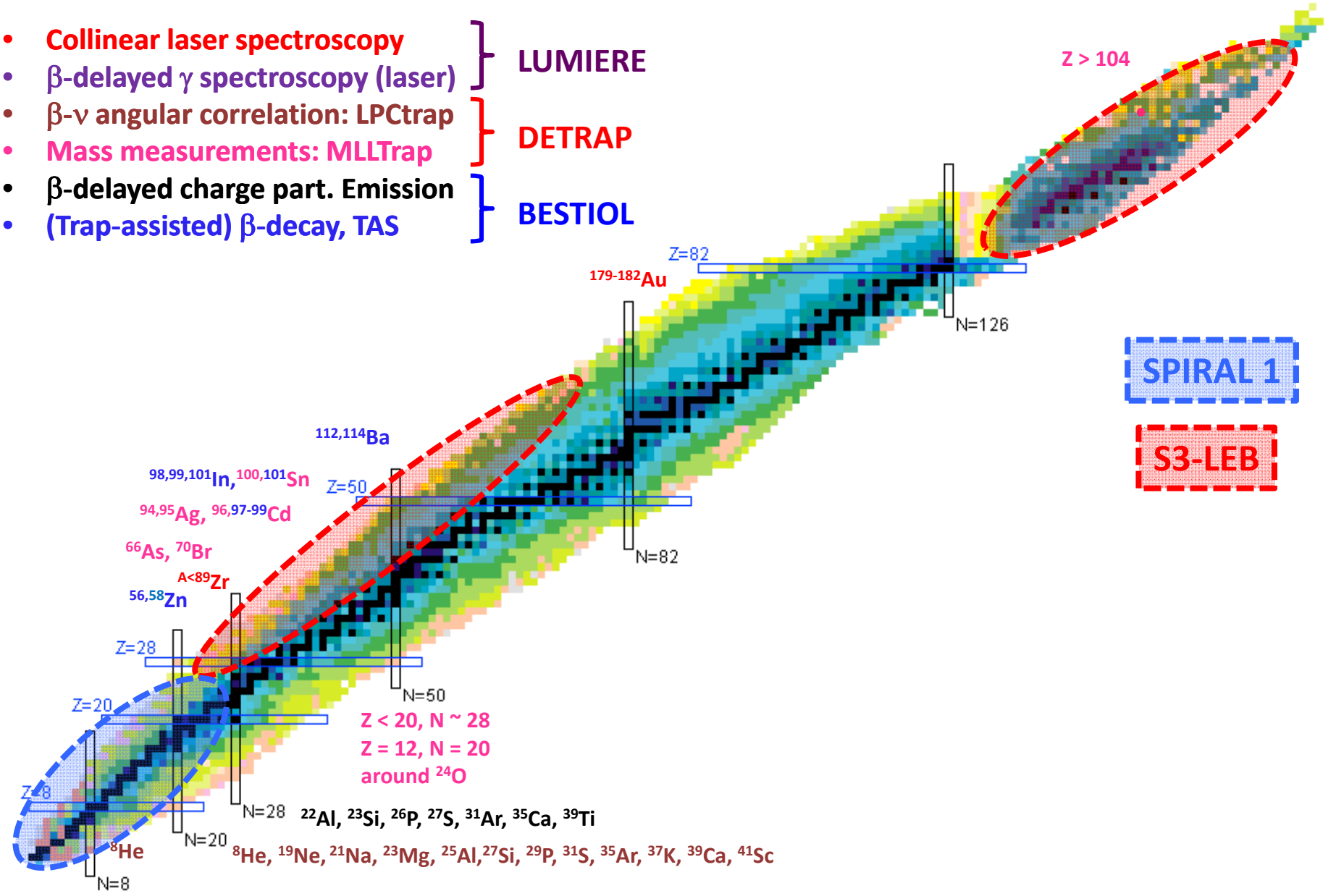
} **LUMIERE**

- **β-ν angular correlation: LPCtrap**
- **Mass measurements: MLLTrap**

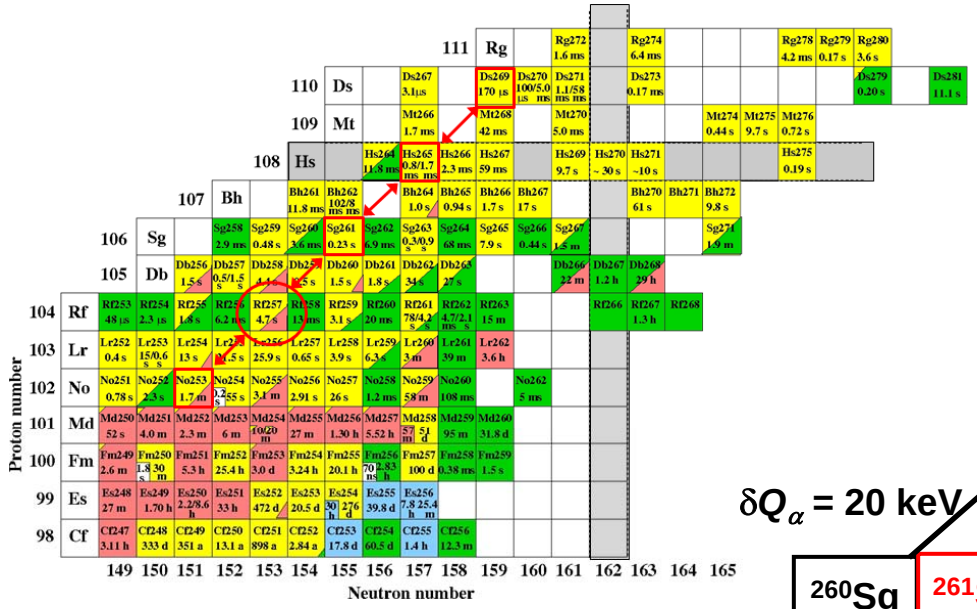
} **DETRAP**

- **β-delayed charge part. Emission**
- **(Trap-assisted) β-decay, TAS**

} **BESTIOL**



Mass measurements of VHE and SHE: MLLTrap



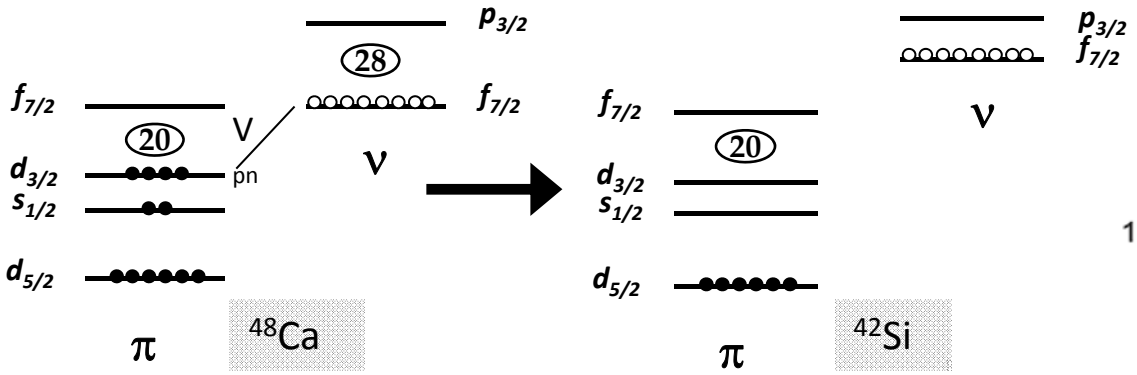
→ day 1 for commissioning (with ^{48}Ca, ~ 2.5μA)

→ Z >= 104

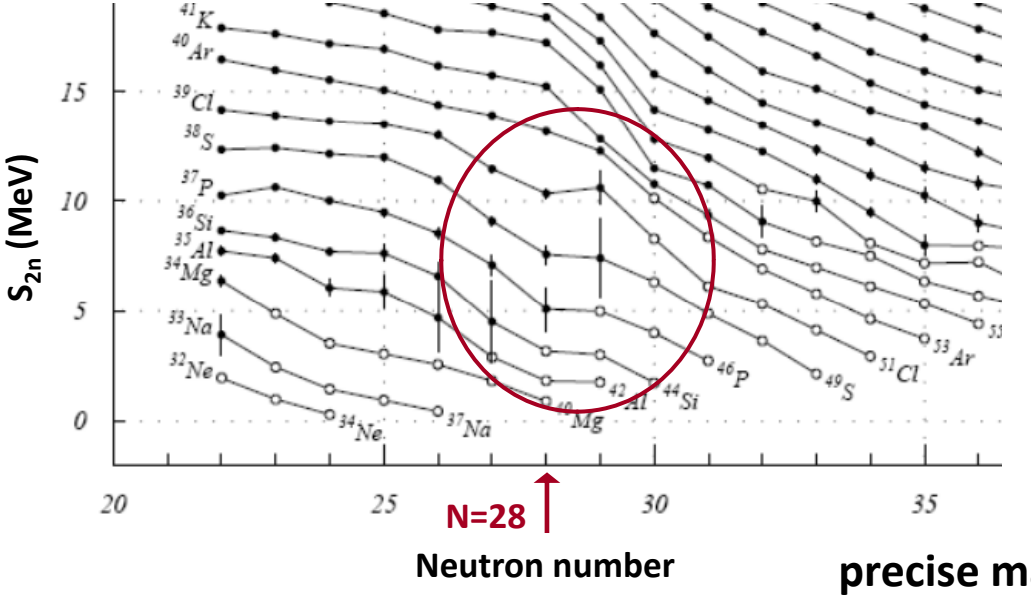
Ch. Weber et al.

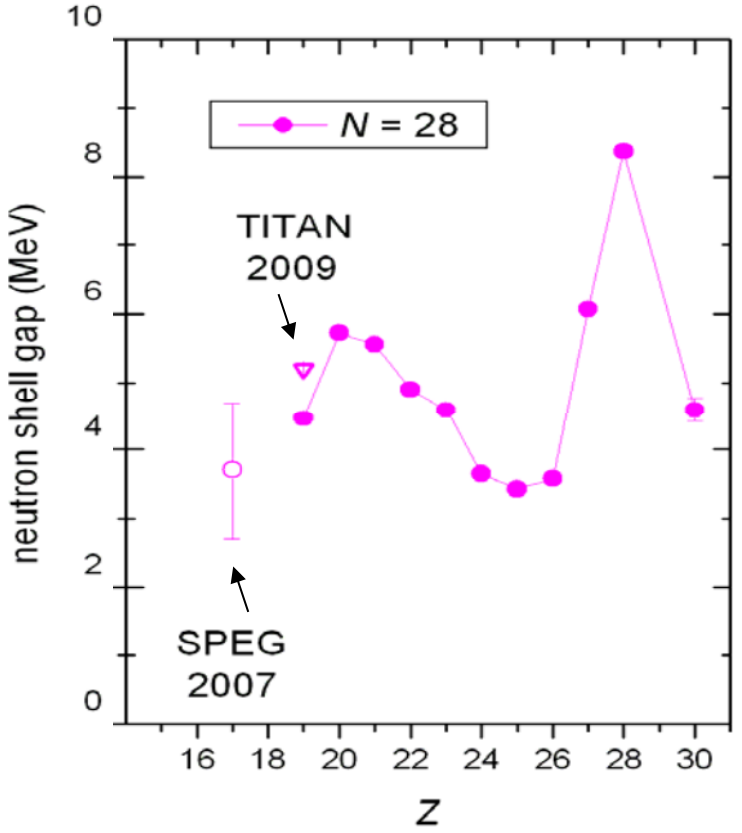
Disappearance of the N=28 shell: MLLTrap

Role of the $V_{pn}(\pi d_{3/2} - \nu f_{7/2})$ interaction



… but mass data are missing aroung N=28

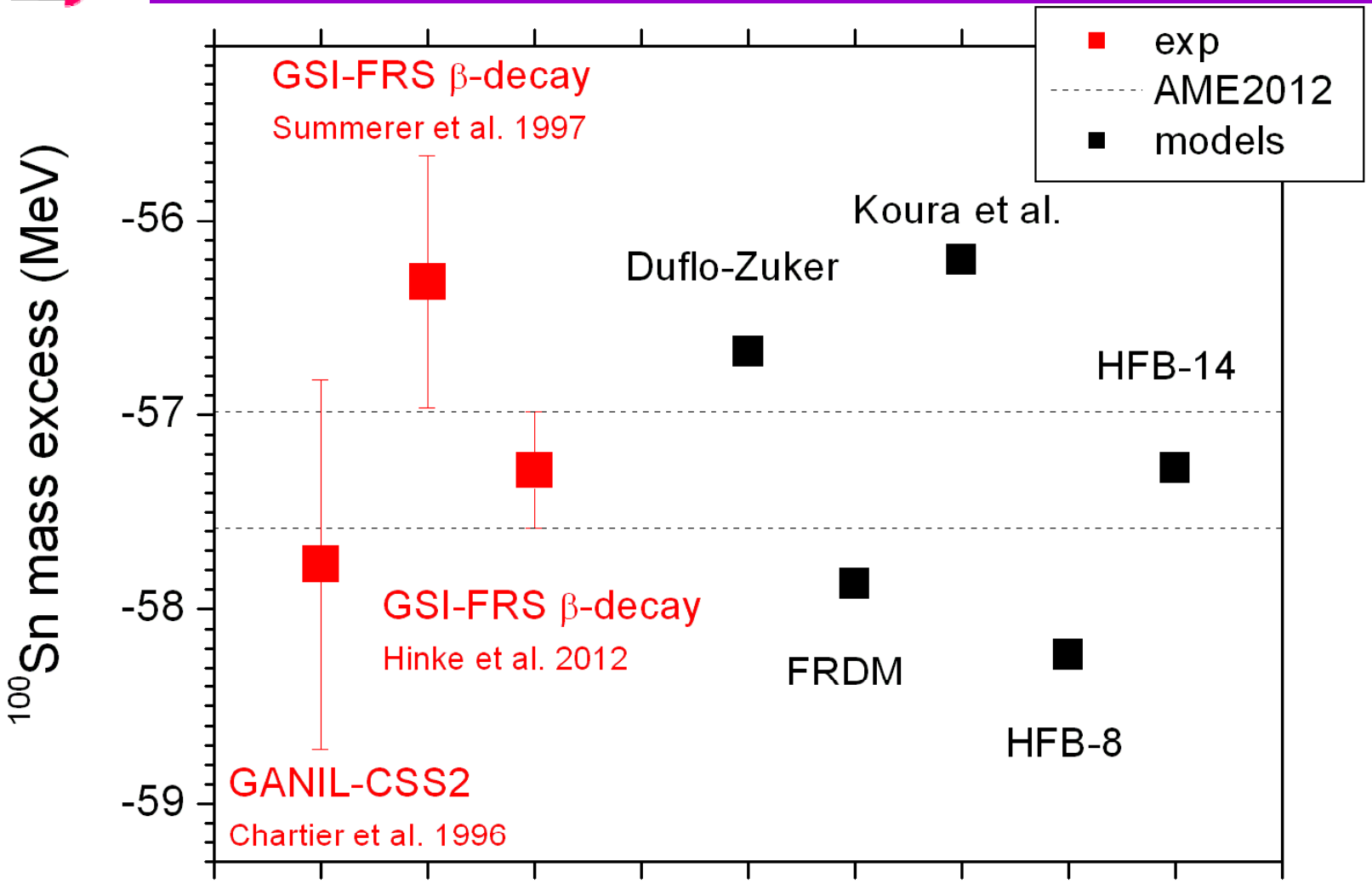




precise masses are needed for the isotones Z < 20

P. Ascher et al.

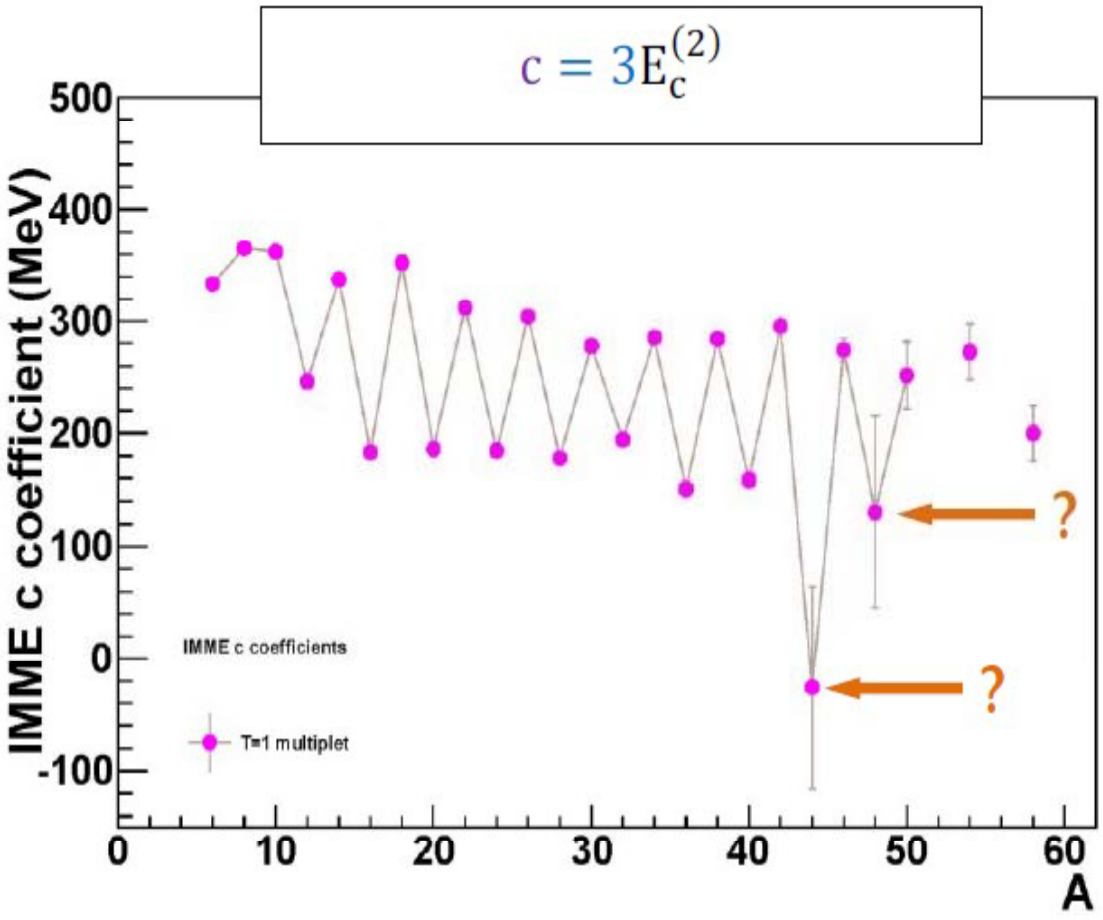
Mass of ^{100}Sn: MLLTrap



^{100}Sn mass accuracy:	**300 keV**
MR-ToF mass accuracy:	**100 keV**
Penning-trap accuracy:	**1-10 kev**

D. Lunney et al.

Isotensor Coulomb energy: IMME

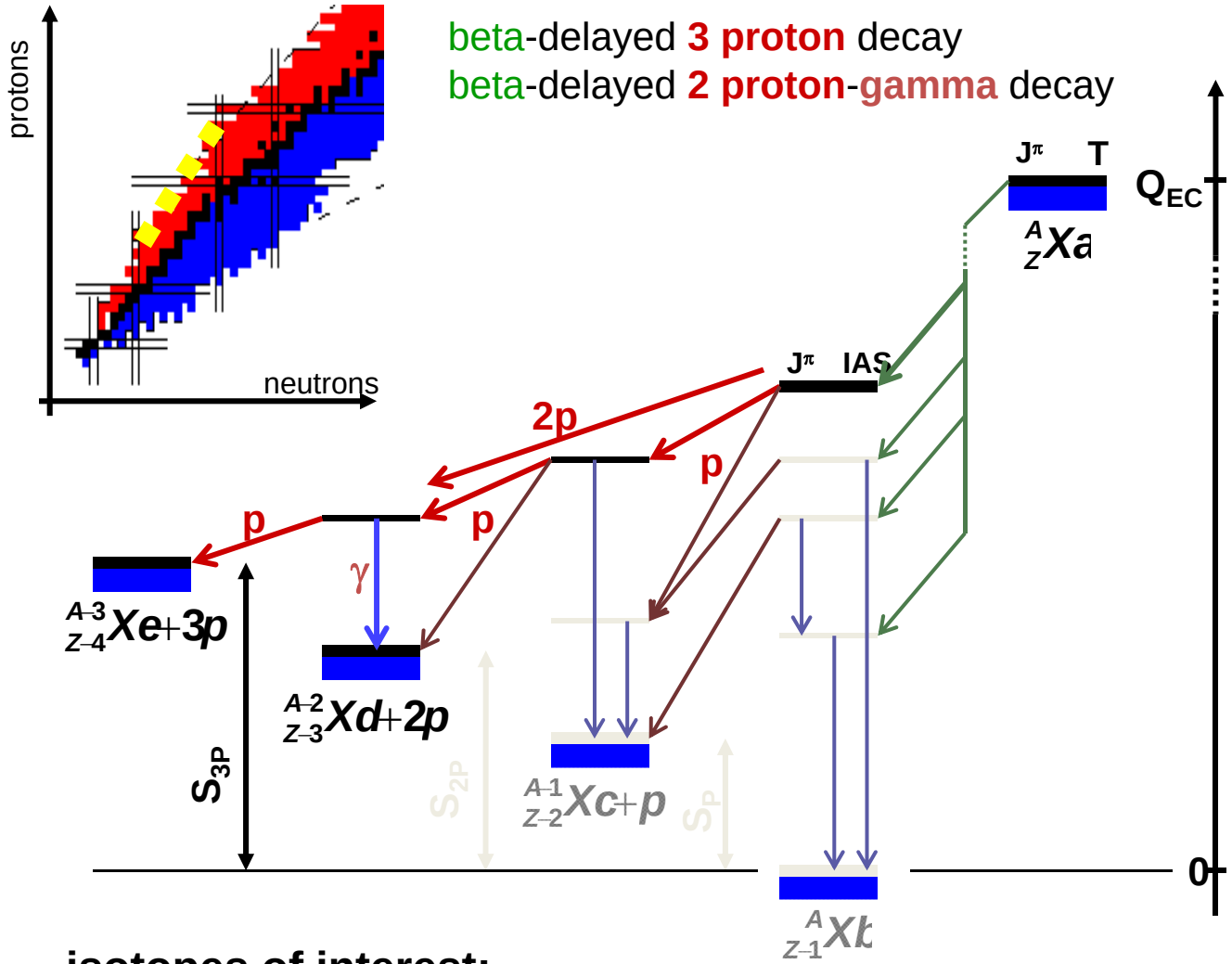


- **determine IMME coefficients**
- **fit isospin-breaking effective interactions**

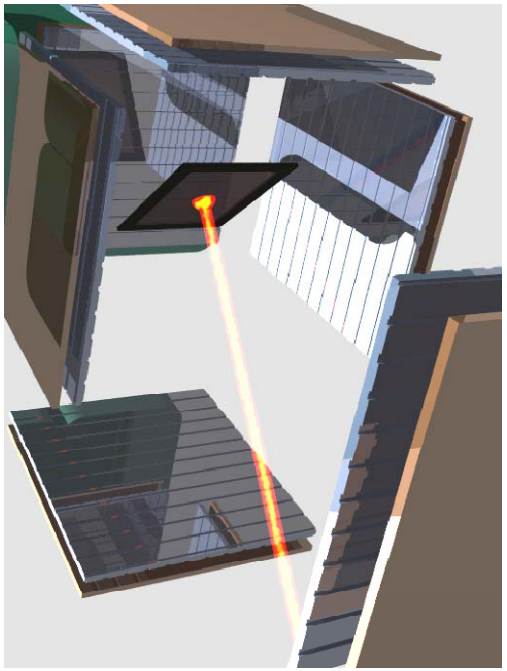
nuclei of interest:
^{44}V, 48Mn, ^{52}Co, ^{56}Cu, ^{60}Ga

M. MacCormick et al.

Decay of proton-rich nuclei



- **pairing**
- **astro physics**



Silicon Cube detector

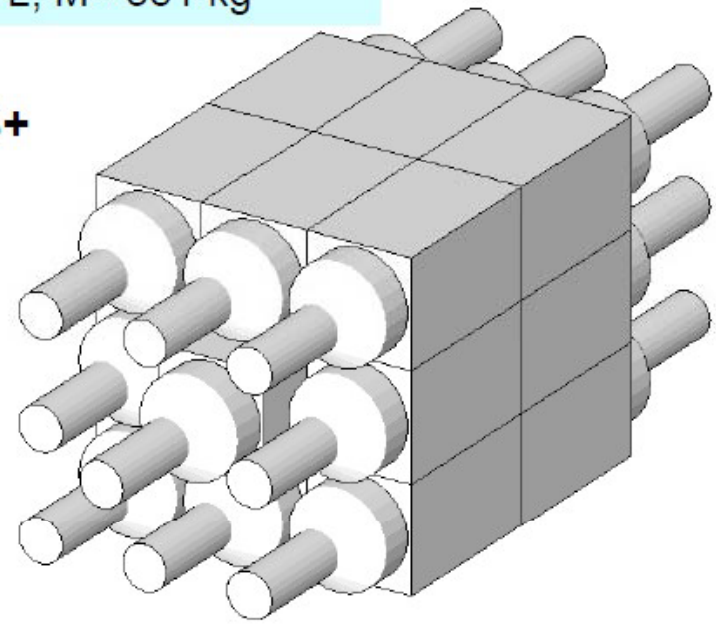
isotopes of interest:

^{22}Al, ^{26}P, ^{31}Ar, ^{35}Ca, ^{39}Ti, ^{43}Cr

Total absorption gamma-ray spectroscopy

16 + (2) modules:
15 x15 x 25 cm^3 **NaI(Tl)**
+ 5" PMT (50% light col.)
V= 95 L, M= 351 kg

TAS+

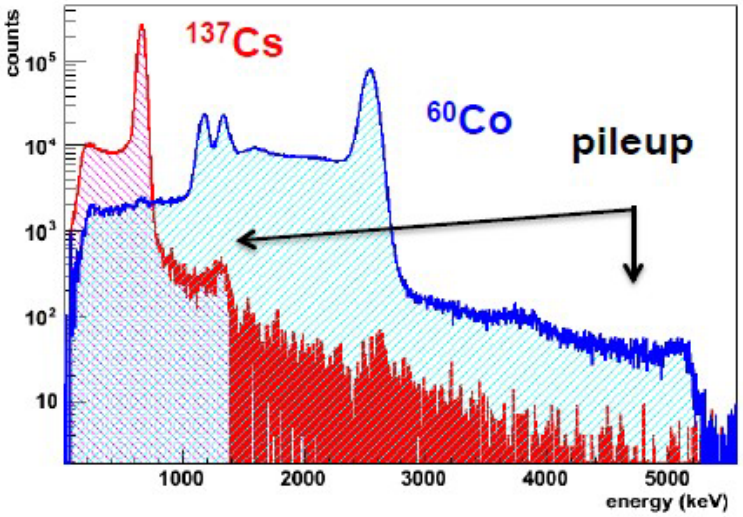


Commissioning at IFIC (01/2014)
First experiments at JYFL (02-03/2014)

measurements in the ^{100}Sn region:

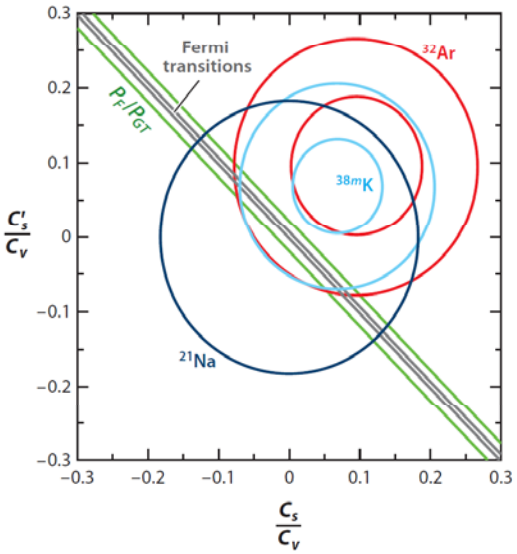
- Study of the GT resonance
- Study of the quenching of the GT strength
- Study of the shell structure around N=Z=50
- Study of the πg9/2 -> νg9/2 and πg9/2 -> νg7/2 transitions

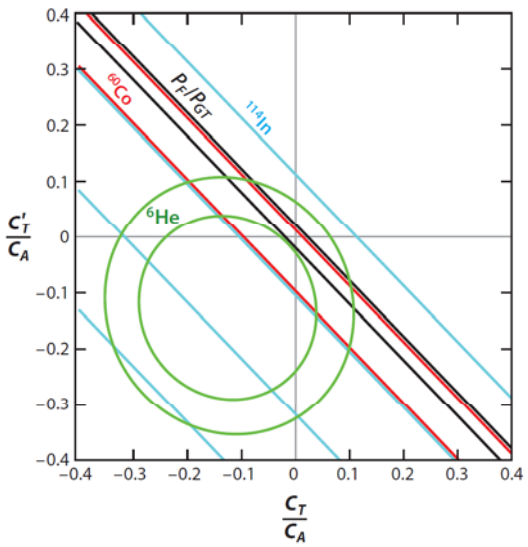
nuclei of interest:
$^{100\text{-}101}$Sn, $^{98\text{-}101}$In, $^{97\text{-}99}$Cd, ^{99}Ag

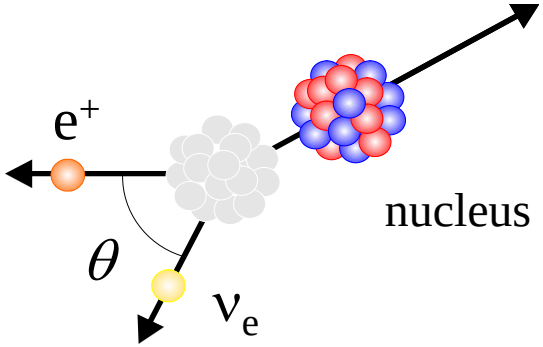


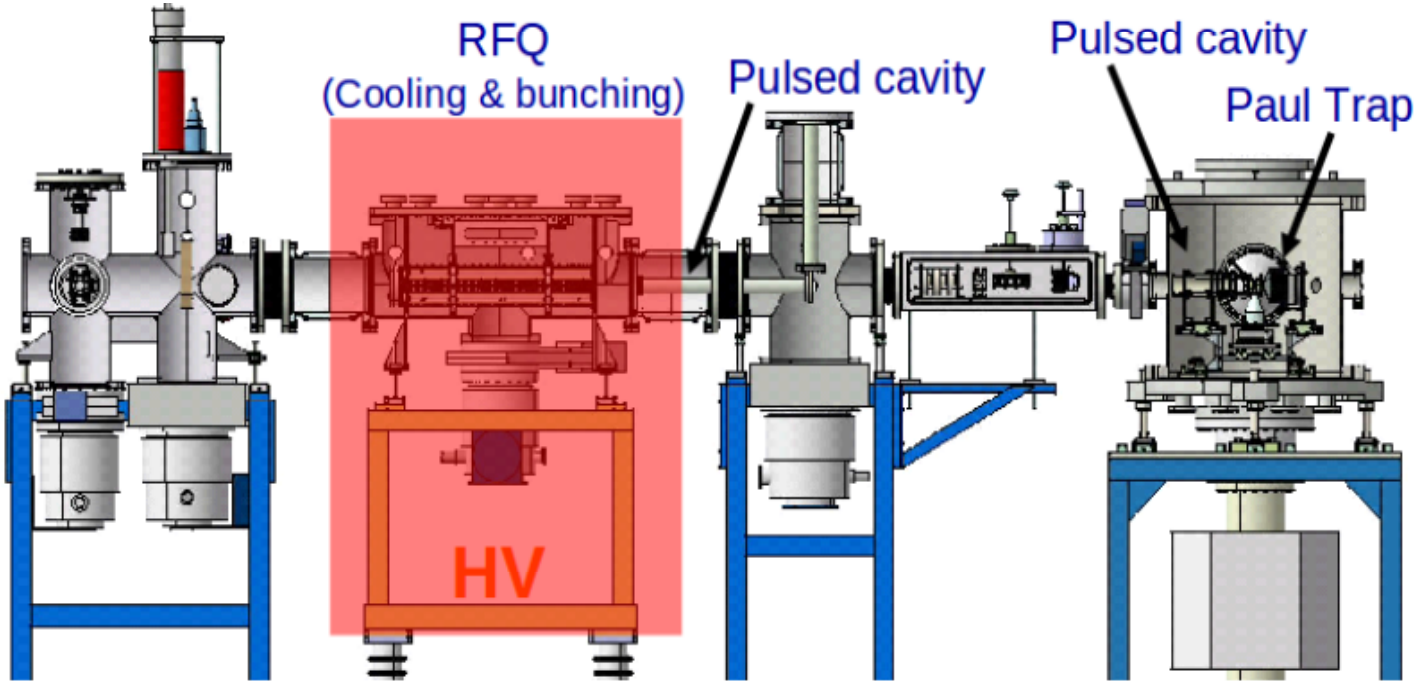
A. Algora et al.

Search for exotic couplings: S and T interactions



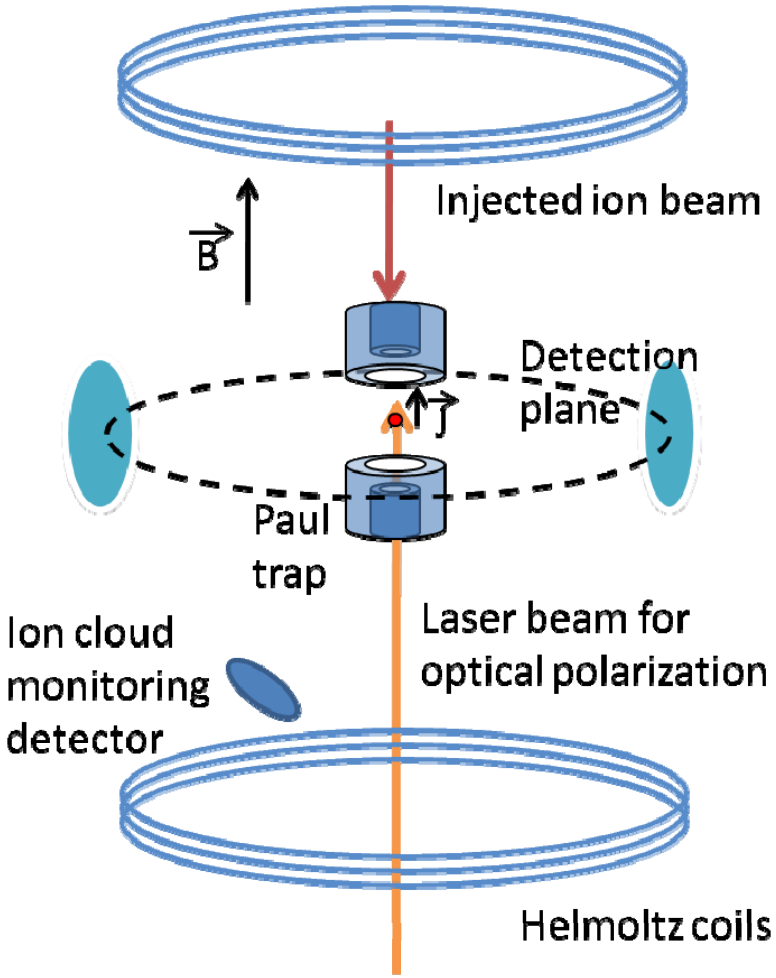


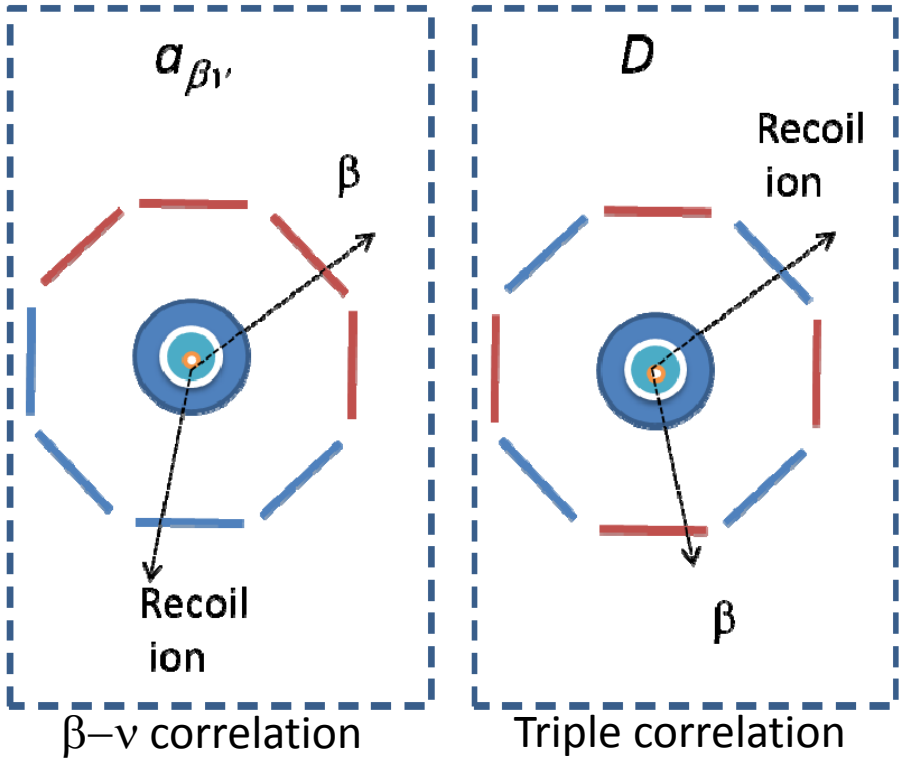




X. Fléchard et al.

Test of time reversal symmetry





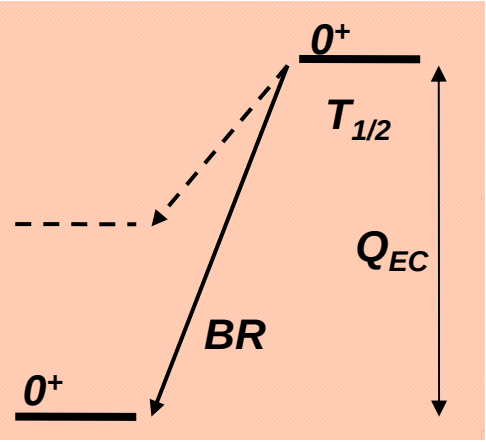
β–ν correlation Triple correlation

$$a_{\beta\nu}\frac{\vec{p}_e}{E_e}\frac{\vec{p}_\nu}{E_\nu} \qquad D\frac{\langle\vec{J}\rangle}{J}\cdot\left(\frac{\vec{p}_e}{E_e}\times\frac{\vec{p}_\nu}{E_\nu}\right)$$

In trap optical polarization of $^{23}Mg^{+}$ and $^{39}Ca^{+}$: upgrade of LPCTRAP?

P. Delahaye et al.

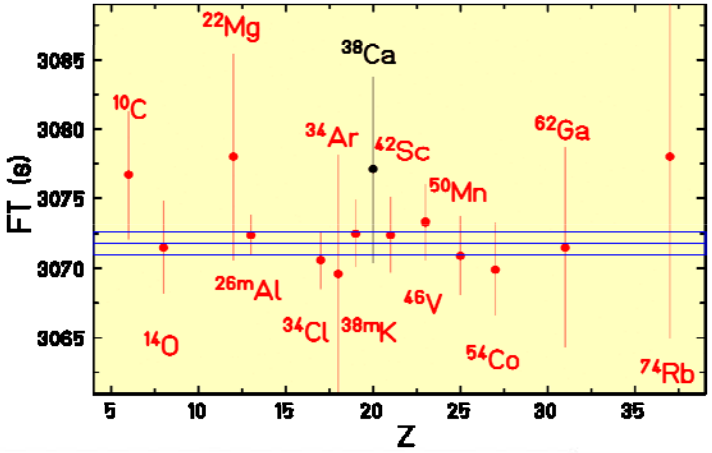
V_{ud} and CVC from 0+ - 0+ beta decays



general: $ft = \dfrac{K}{g_V^2 \langle M_F \rangle^2 + g_A^2 \langle M_{GT} \rangle^2}$

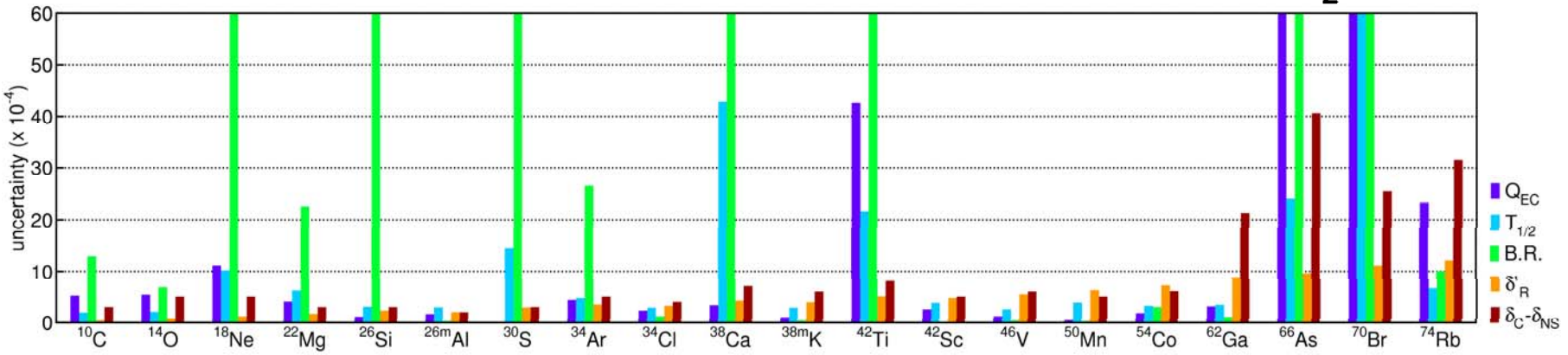
0^+ - 0^+ decays: $ft = \dfrac{K}{g_V^2 \langle M_F \rangle^2} = f(Q_{EC}) * T_{1/2} / BR$

➔ CVC, V_{ud}



Precision measurements required:

- ✓ Q_{EC} → *mass measurements:* $f \sim Q^5$
- ✓ $T_{1/2}$, BR → *β-decay studies:* $t = T_{1/2} / BR$



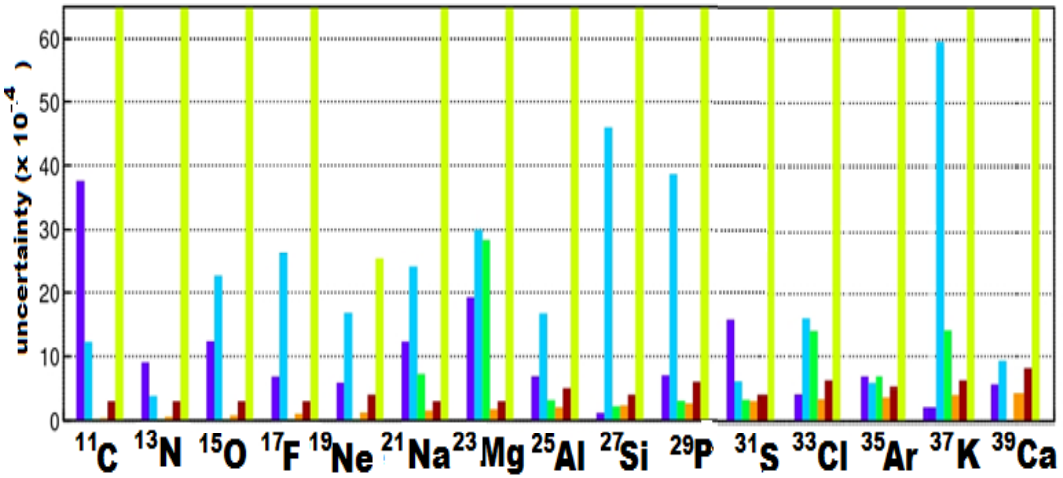
Ch. Weber, H. Guérin et al.

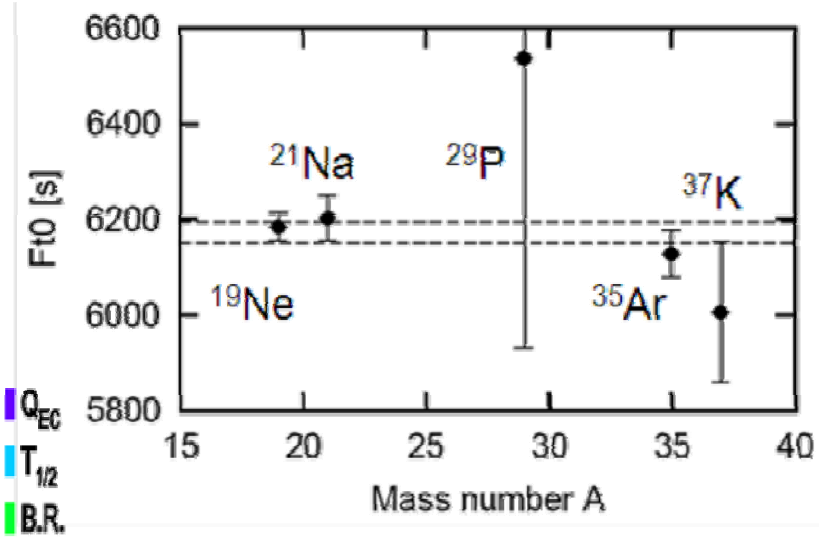
V_{ud} and CVC from mirror beta decays

$$\mathcal{F}t^{\text{mirror}} \equiv f_V t\left(1+\delta'_R\right)\left(1+\delta^V_{\text{NS}}-\delta^V_C\right) = \frac{2\mathcal{F}t^{0^+\to 0^+}}{\left(1+\frac{f_A}{f_V}\rho^2\right)}$$

with $\rho = G_A M_{GT} / G_V M_F$

$$Ft_0 = Ft^{\text{mirror}}\left(1+\frac{f_A}{f_V}\rho^2\right) = 2Ft^{0^+\to 0^+} = \frac{K}{G_F^2 V_{ud}^2 (1+\Delta_R^V)}$$





First consistent test of CVC from a set of nuclear transitions other than super-allowed pure Fermi transitions

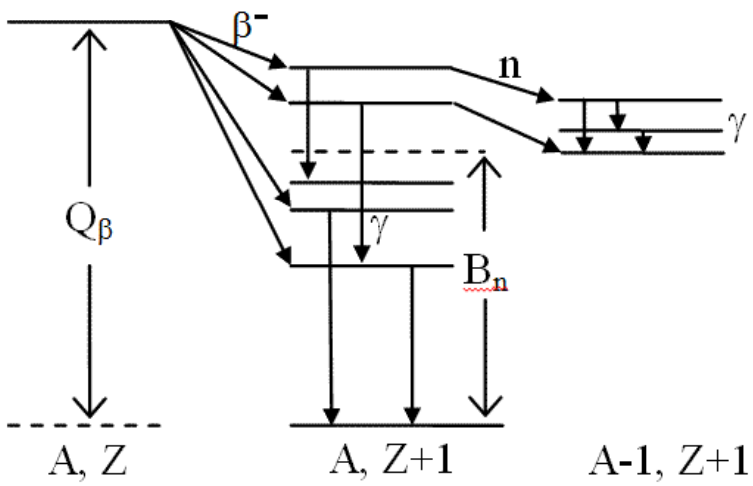
O. Naviliat-Cuncic , N. Severijns PRL 102, 142302 (2009)

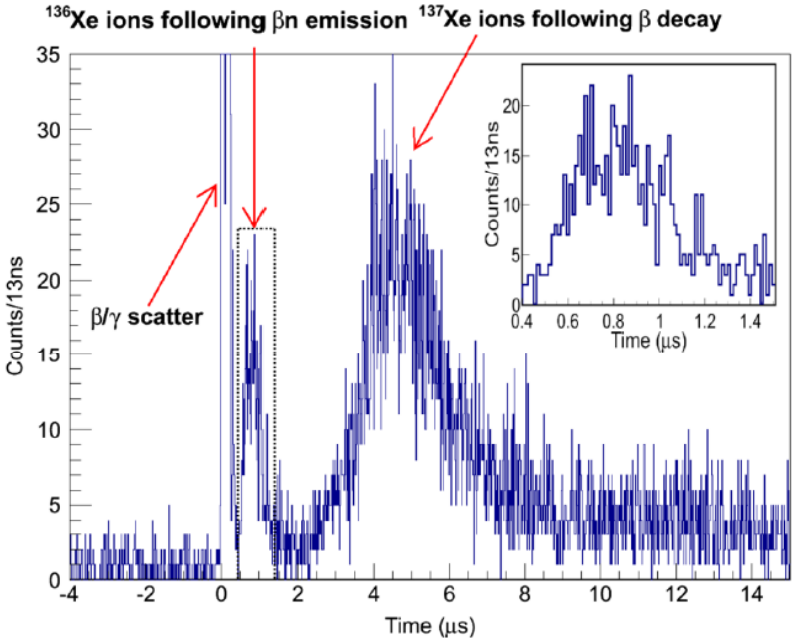
Precision measurements required:

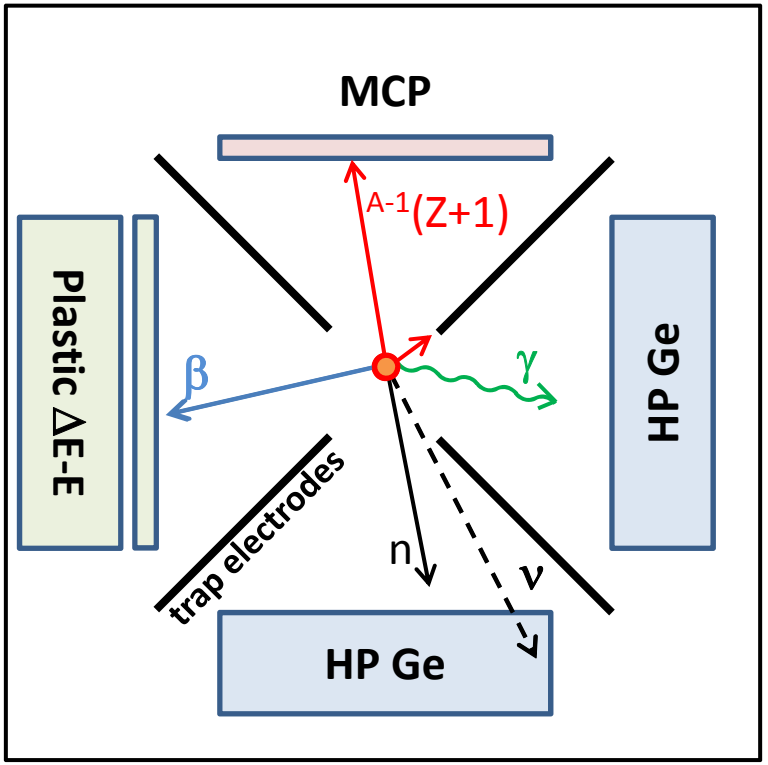
- ✓ Q_{EC} → *mass measurements:* $f \sim Q^5$
- ✓ $T_{1/2}$, BR → *β-decay studies:* $t = T_{1/2} / BR$
- ✓ ***GT / F mixing ratio*** → *trap measurements*

T. Kurtukian Nieto, E. Liénard et al.

Delayed neutron emission in a Paul trap: recoil detection







Spiral1+ Spiral2 → GPIB → *cooling bunching* → HRS/ PIPERADE / MR-TOF-MS → *selection* → Linear Paul Trap → *spectroscopy*

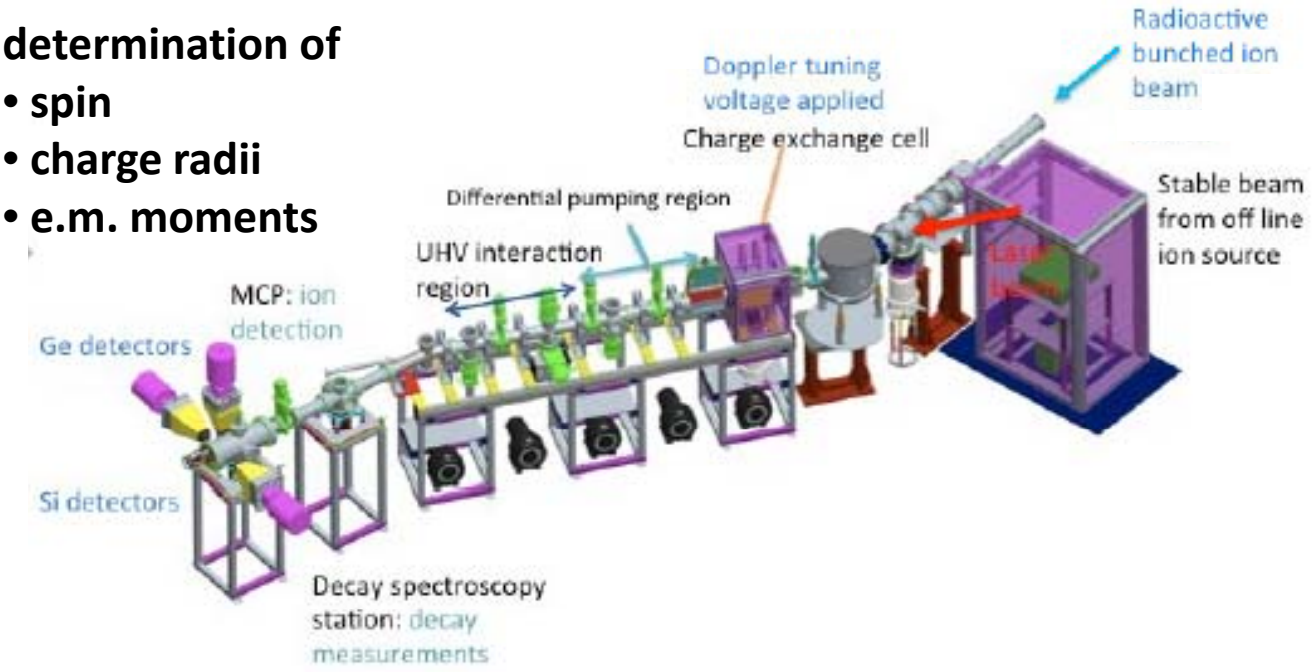
Yee et al., PRL 110(2013) 092501

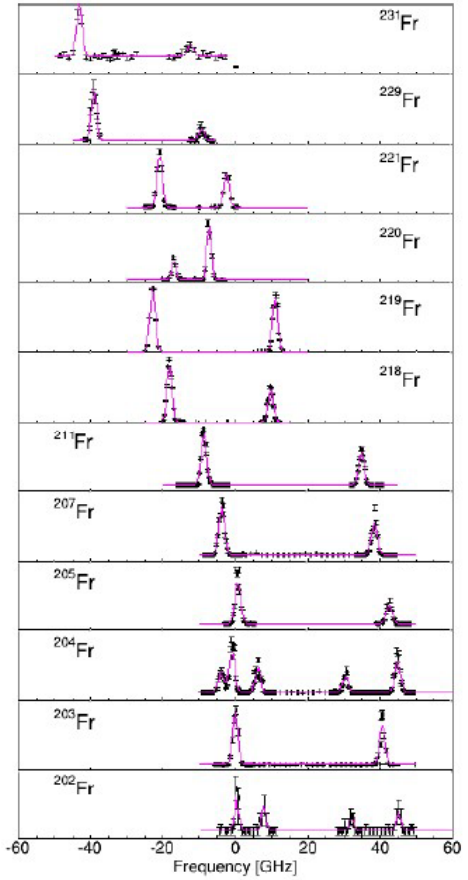
S. Grévy et al.

Laser spectroscopy with neutron-deficient Fe, Co, Ni, Cu

determination of

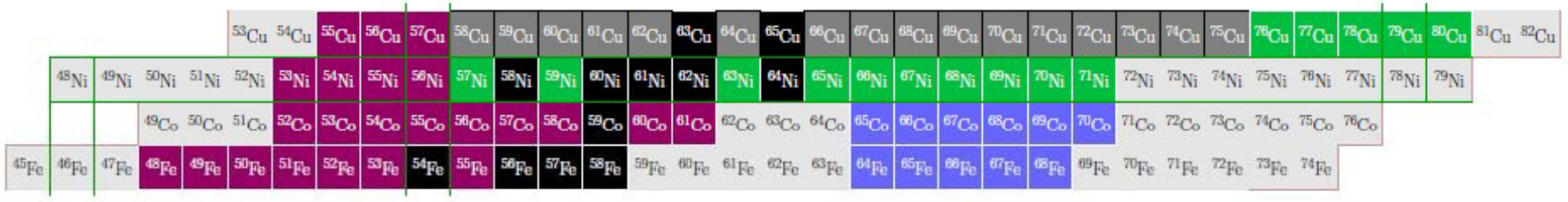
- **spin**
- **charge radii**
- **e.m. moments**





- **Bunches are delivered from GPIB**
- **Ions are neutralised in a charge exchange cell**
- **Non-neutralised ions are deflected away**
- **Lasers are sent through the interaction region**
- **Re-ionised isotopes are detected in an MCP or a decay station.**

K.T. Flanagan, K.M. Lynch et al., PRL 111

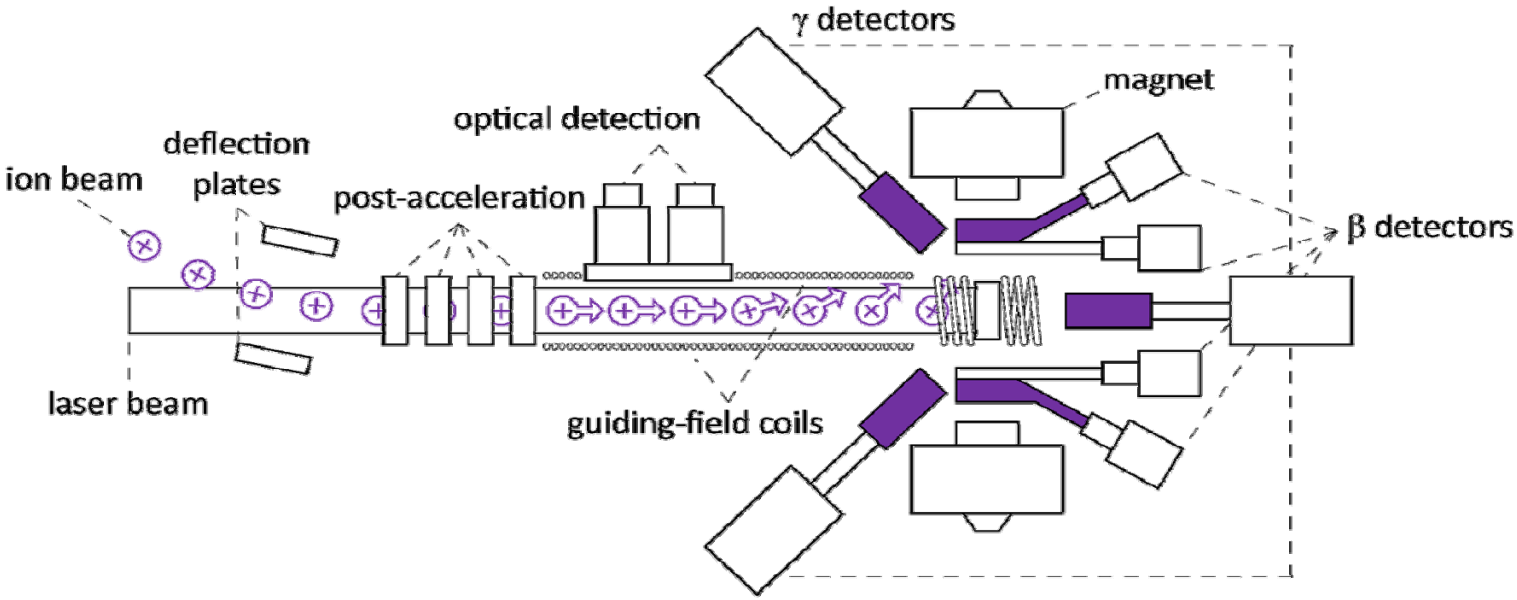


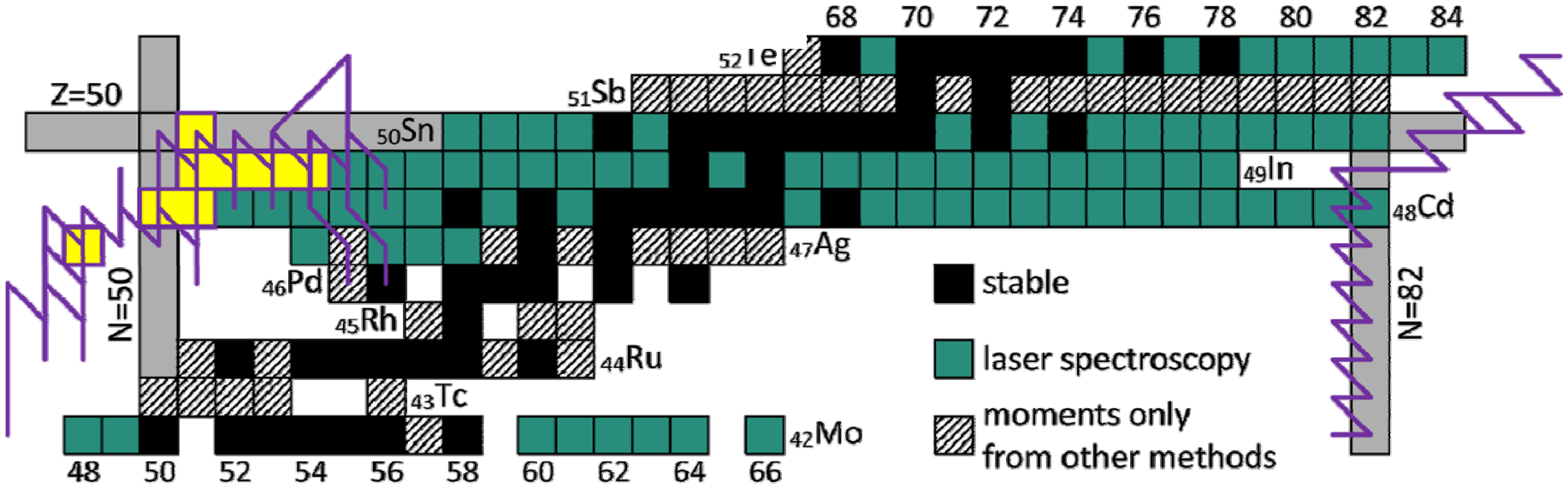
Th. Cocolios et al.

Goal:

β - delayed spectroscopy of laser-polarized beams
(^{95}Ag, ^{101}Sn $^{100-103}$In, $^{98-99}$Cd):

spins and parities of excited nuclear states





To summarize

- **DESIR: a low-energy RIB facility dedicated to the study of the fundamental properties of the nucleus at GANIL/SPIRAL2**

- **Physics program:**
  - **nuclear structure evolution:** *from a single-particle to a collective description of the atomic nucleus*
  - **radioactive decay studies:** *β-delayed xn, γ, charged particle emission*
  - **weak interaction:** *physics beyond the standard model*
  - **astrophysics:** *nucleosynthesis processes*
  - **interdisciplinary research:** *atomic & solid state physics, nuclear data*

- **RIBs :**
  - **a large variety of exotic nuclei:** *produced by fragmentation, fusion-evaporation, transfer and n-induced fission reactions*
  - **of high quality:** *high purity, low emittance*

- **Experimental equipment :**
  - **complementary investigation tools:** *lasers, traps and decay set-ups*

➔ ➔ Operational in 2018-9

http://www.cenbg.in2p3.fr/desir

Thank you for your attention!