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BriX

ISOL@MYRRHA : an Application of the MYRRHA Accelerator for Nuclear Physics

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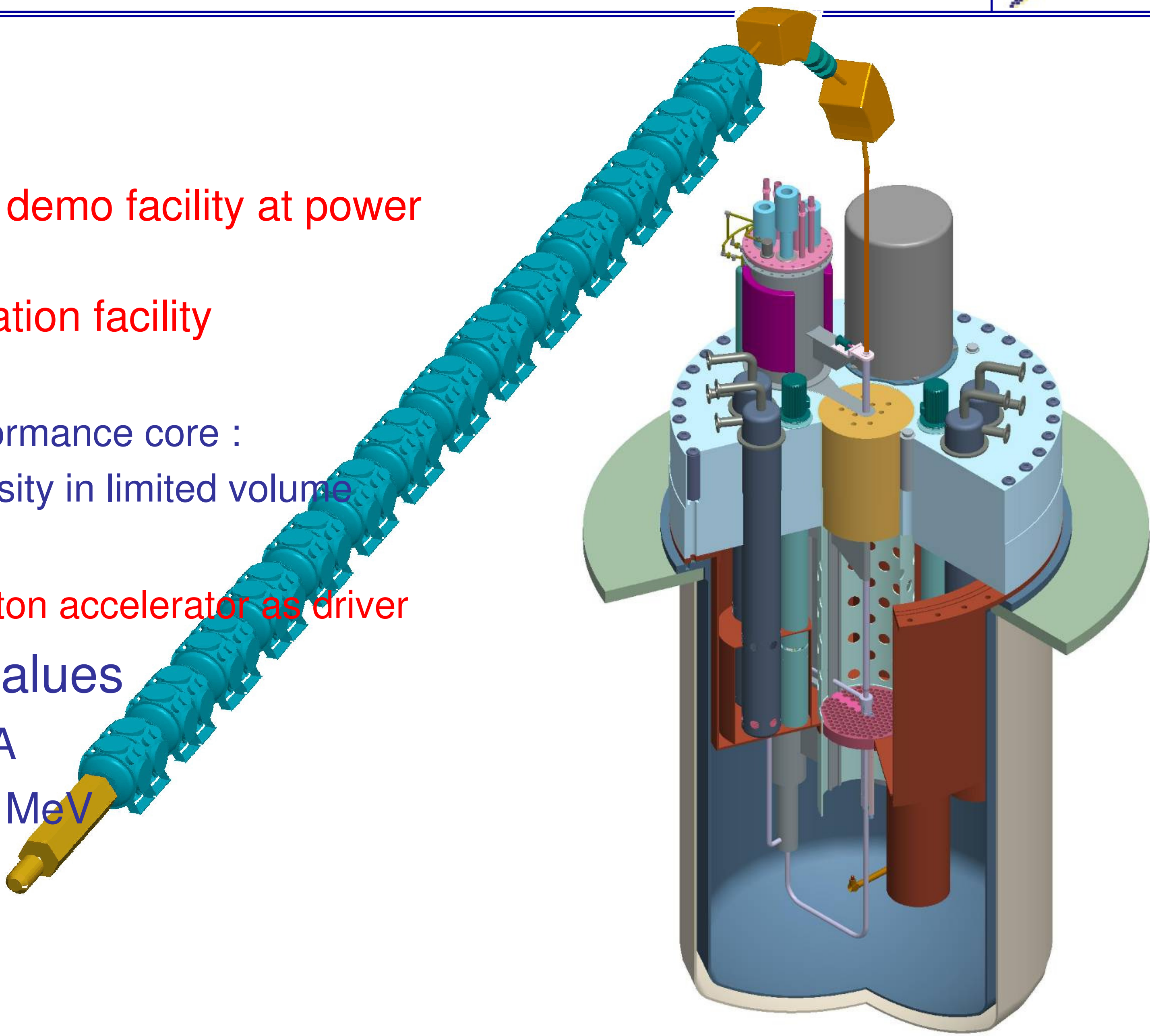
MYRRHA



- ADS first step demo facility at power (50-100 MW)
- Flexible irradiation facility

Need for high performance core :

high power density in limited volume

- High power proton accelerator as driver
  - Design values
    - I= 4mA
    - E=600 MeV

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ISOL@MYRRHA

•Idea :

Use part of the MYRRHA proton beam for nuclear physics applications

- 600 MeV, 100-200 μA, D.C. proton beam
  - 2.5-3 mA required for MYRRHA spallation target

    DC beam needed (how to split off 100 to 200 μA: RF kicker)
- Different target materials including uranium
  - e.g. Nb, TiC/C, La, Ta, UC: workhorse targets at present)
- Ruggedized target-ion source systems that deliver RIB @ ~50 keV:
  - ECR 1^+: gaseous elements (noble gases, C, N, O,..))
  - surface ion source (hot cavity):
    - for beam of alkaline and earth alkaline elements
  - lasers

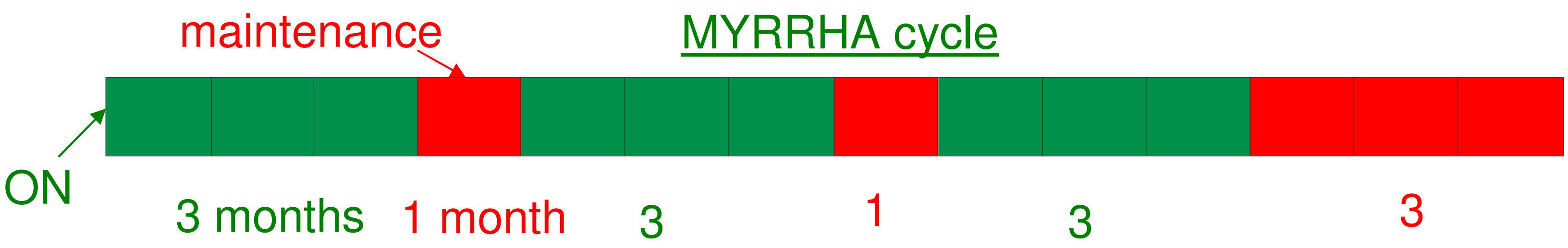
!! degradation of the target performance to be taken into account !!

ISOL@MYRRHA

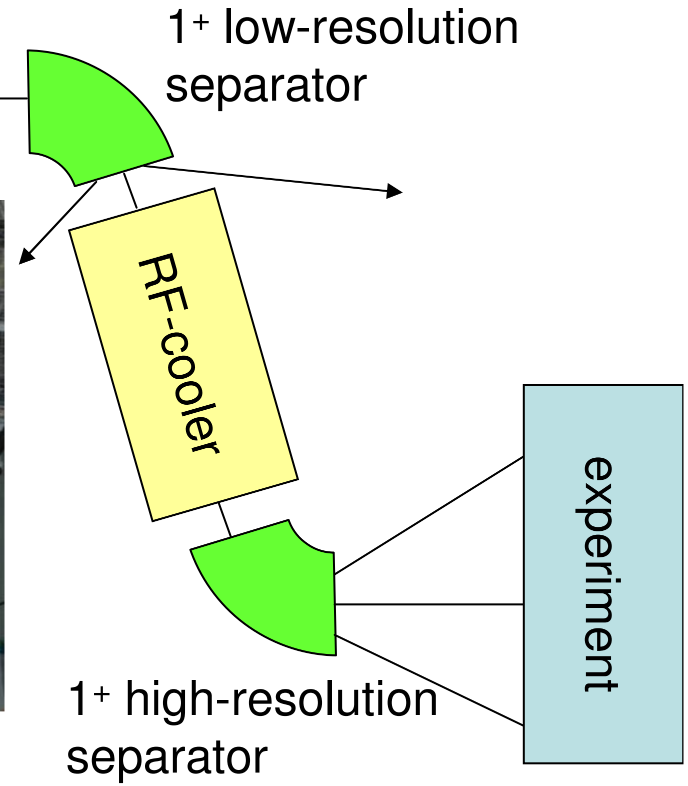
- Operational approach

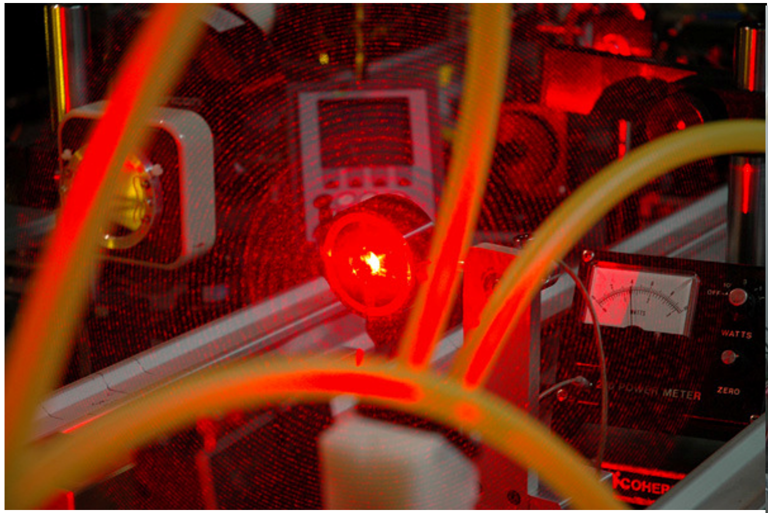
  - Long beam times (e.g. 12 weeks) for experiments that:
    - ➢ need very high statistics
    - ➢ involve many time consuming systematic measurements
    - ➢ hunt for very weak signals
    - ➢ have an inherent low-detection efficiency

  - Interplay with MYRRHA maintenance schedule

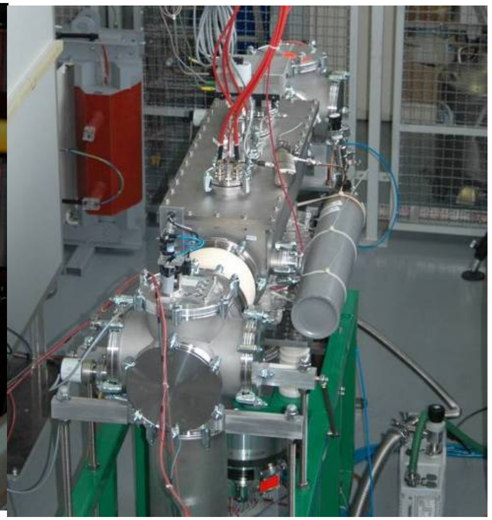


- “Green field” facility at a nuclear site (SCK•CEN):
  - optimal lay-out of the facility: pre-separator – RF-cooler – post-separator (high mass resolution: M/ΔM > 10000)
  - multiple – ion beams simultaneaously : limited mass range for same element
  - specific experimental hall requirements (e.g. neutron detection hall)





Laser ion source



RF cooler

- ISOL@MYRRHA can deliver:
  - pure RIB: selective ionization, chemistry, M/ΔM > 10.000
  - intense RIB x100 compared to the present ISOLDE
    - ➢ limited number of isotopes at start-up,
    - ➢ important to leave options open
  - RIB of good ion optical quality
  - very long beam times
  - optimal experimental conditions/lay-out/support

- ISOL@MYRRHA is based on proven technology

!! effort to make the beams/effort for the experiments !! long-beam times = long idle times

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ISOL@MYRRHA

- Complementary to ISOL and In-Flight facilities:
  - HIE-ISOLDE, CERN (Switzerland)
  - SPIRAL2, GANIL (France)
  - TRIUMF (Canada)
  - ORNL (U.S.A.)
  - EURISOL (somewhere in Europe)
  - FAIR, GSI (Germany)
  - RIB factory, RIKEN (Japan)
  - FRIB (U.S.A.)

- Neutron for Science (cfr. SPIRAL2) versus ISOL@MYRRHA

- Possible physics experiments:
  - Many examples given in field of fundamental nuclear physics, fundamental interactions, atomic physics, materials science, nuclear medicine

Nuclei of interest

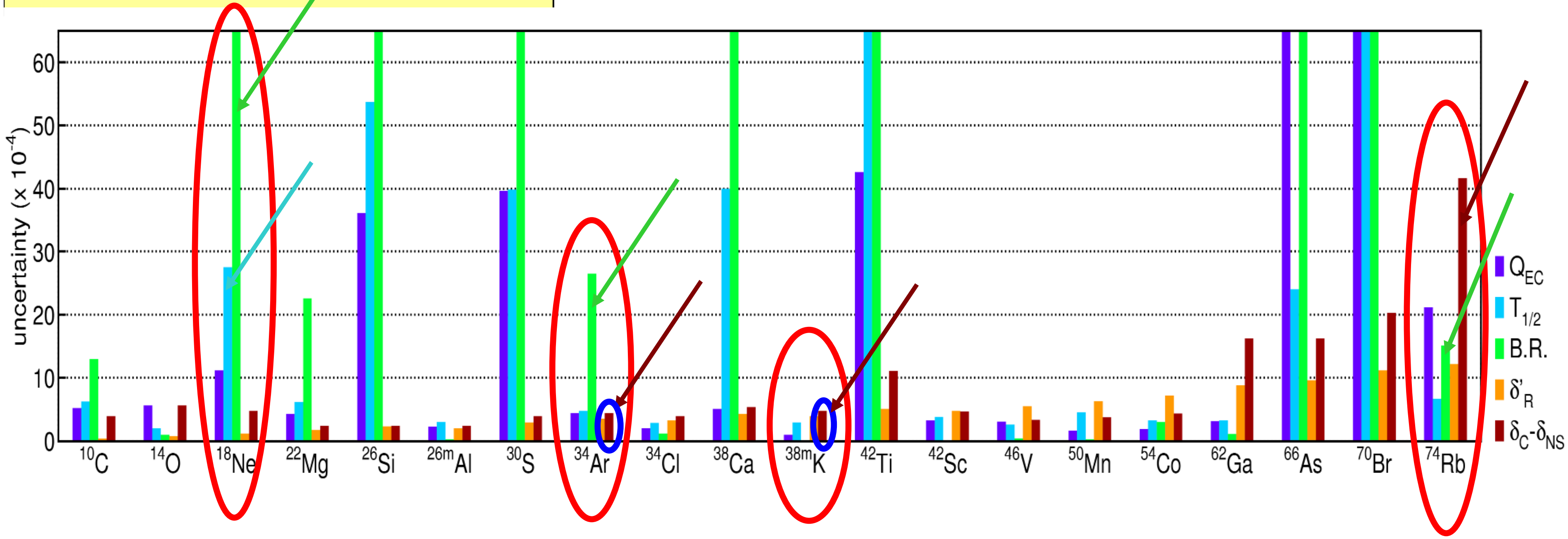
- nuclei at or close to the **N = Z line**
  - nuclei with **$0^+ \rightarrow 0^+$ transitions**
  - **T = 1/2 mirror nuclei** (N = Z-1 → N = Z+1; e.g. $^{21}Na \rightarrow ^{21}Ne$)
- nuclei with **fast** (small log*ft*) and pure **Gamow-Teller transitions**

Possible subjects

1. ***Ft*** $^{0^+ \rightarrow 0^+}$
   - **Conserved vector current hypothesis**
   - **unitarity of Cabbibo Kobayashi Maskawa quark mixing matrix**
   - **right-handed currents**
   - **scalar currents**
2. **searches for exotic weak currents**
   - **scalar currents**
   - **tensor currents**
3. **symmetry tests**
   - **parity**
   - **time reversal**

Error budget, required precision, and opportunities for ISOL@MYRRHA (arrows)

- **overall precision: Ft = (3074.4 ± 1.2) s**
  ⇒ 4 * 10^{-4}
  ⇒ single measurements of $T_{1/2}$ and BR : < 10^{-3}
- **theoretical corrections: $\delta_{Coulomb}$, $\delta'_{Radiative}$ ~ 1% → < 10%**



Options: - improve quantities indicated by green & blue arrows
- if CVC accepted → Ft-measurements test δ_c - δ_{NS} from theoretical models
- go for factor ~10 higher precision in Ft than available now for the 4 isotopes indicated

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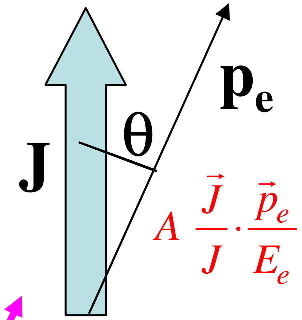
Exotic weak currents and symmetry tests via precision correlation experiments between spin en momentum vectors



decay rate for beta decay of (un)polarized nuclei :

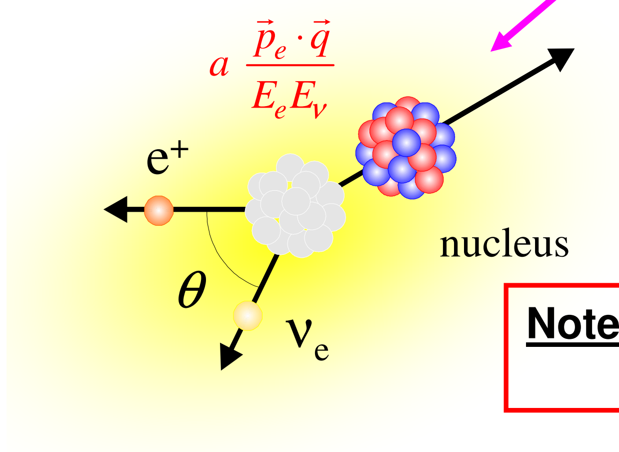
$$\omega(E,\,\Omega,\,\ldots)\;\propto\;\xi\left\{1\;+\;a\,\frac{\vec{p}_e\cdot\vec{q}}{E_eE_\nu}\;+\;b\,\frac{\gamma m_e}{E_e}\;+\;A\,\frac{\vec{J}}{J}\cdot\frac{\vec{p}_e}{E_e}\;+\;R\,\vec{\sigma}\cdot\frac{\vec{J}}{J}\times\frac{\vec{p}_e}{E_e}\;+\ldots\right\}$$

β-ν correlation

Fierz interference term (b ≡ 0 in standard model)

β-asymmetry

R-correlation



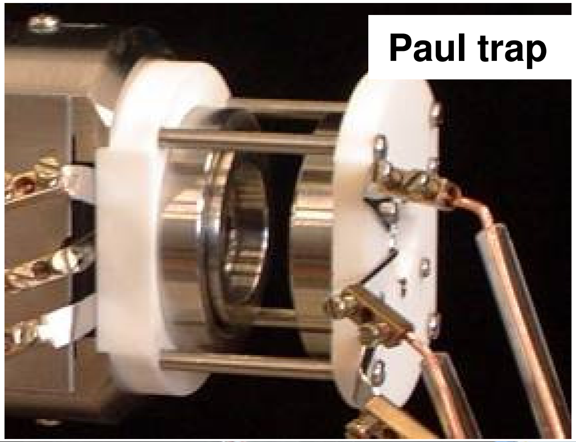
$$\tilde{X}=\frac{X}{1\;+\;b\,\dfrac{\gamma m_e}{E_e}}\qquad (X\;=\;a,\;A,\;\ldots)$$

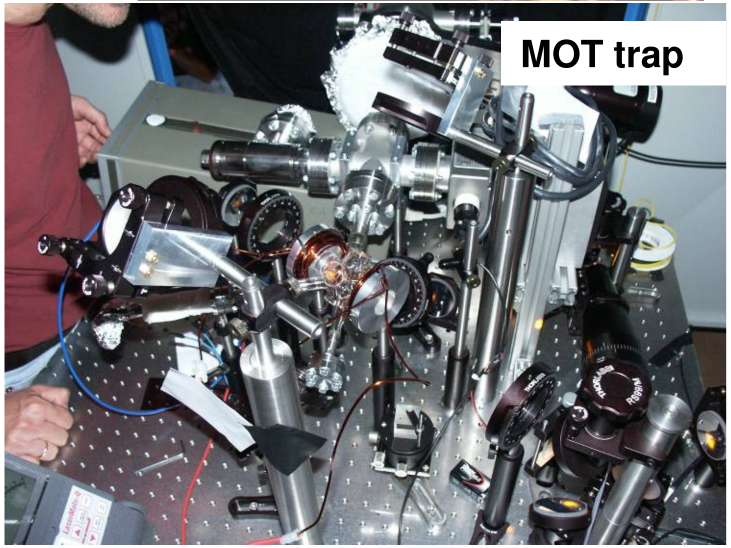
$$\gamma=\sqrt{1-(\alpha Z)^2}$$

Note: *a, b, A, R*, … depend on the coupling strengths for the different possible weak interaction types (i.e A, V, S, T)

J,D, Jackson, S.B. Treiman, H.W. Wyld, Nucl. Phys. 4 (1957) 206

Weak interaction Physics Research





- β-ν **momentum correlation**
  - ➢measure nuclear recoil
  - ➢use ion traps

  - ➢βν-correlation from Doppler-shift of β-delayed γ-rays

    Doppler shift from
    precise measurement of
    γ-ray energy
    with a
    crystal spectrometer
- **β-asymmetry**
  - ➢β emission direction from polarised nuclei
- **R-correlation**
  - ➢combination of β particle spin polarisation and nuclear polarisation

Precision experiments with long beam times

- data taking (statistics)
- instrument calibration (systematic errors)

- Candidate nuclei for spectroscopy experiments
  - Alkali and gaseous elements
    - He, Li, Ne, Na, C , N ?...
  - Decay spectroscopy (beta-decay)
    - implant in catcher foil / detector – trap
    - polarized beams ? Ex. ^{11}Li
    - detectors for β, γ, charged particles, n

- Reactions ??!
  - astrophysics, p capture – n capture ?
  - requires post acceleration

Nuclear physics with exotic light nuclei

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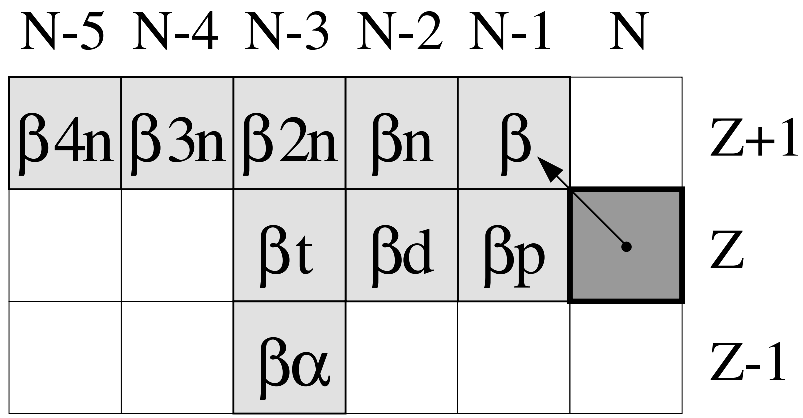
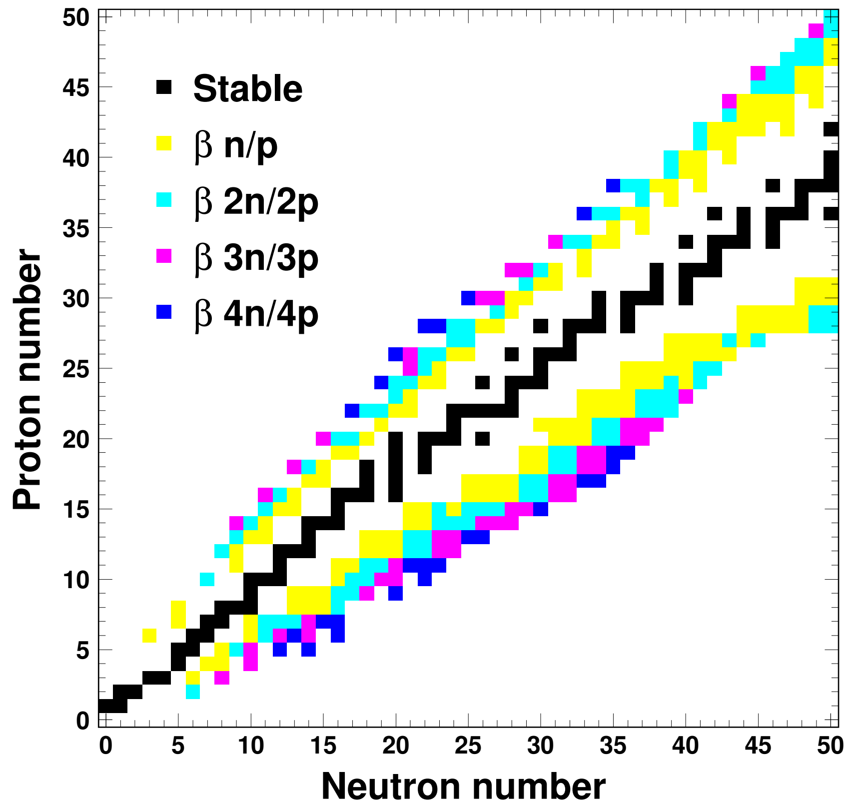
Possible subjects

- β-delayed particle emission
  - β n/p emission
    - study of p/γ competition
  - multiple particle emission
    - β 2p : only data for ^{31}Ar
    - β 2n :emission (very limited information ^{11}Li, ^{19}C, $^{30-34}Na$, ^{52}K
  - β d/t emission (^{6}He (β,d); ^{8}He (β,t))
  - new branches
    - ^{8}He (β,d); ^{11}Li (β,pn)
    - βt $^{29,30,32}Ne$, $^{32,33,34}Na$; βd ^{32}Ne, ^{34}Na



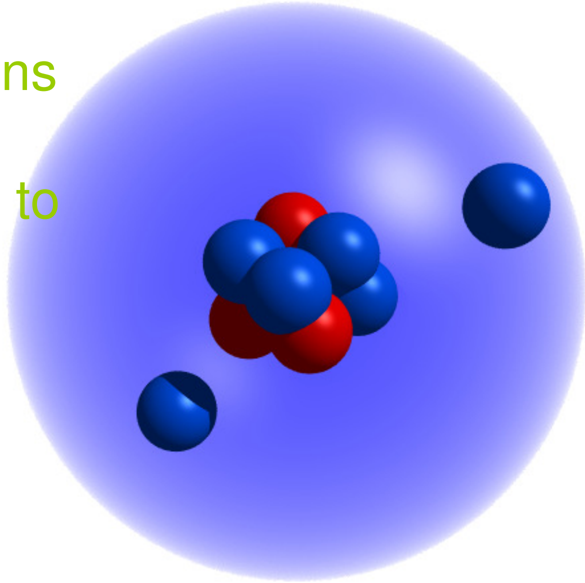


Energetically allowed decays

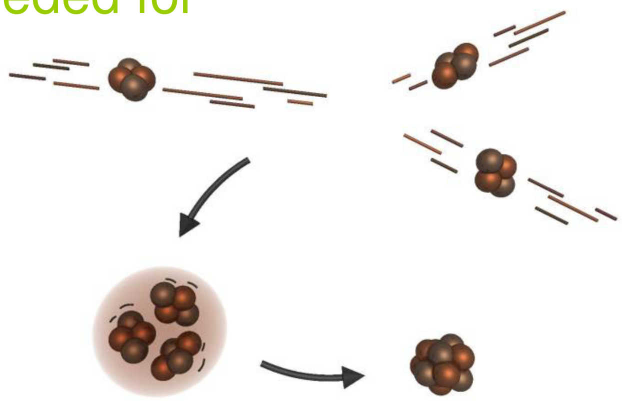
Possible subjects

- decay of 'Halo' nuclei
  - decay into continuum
  - clustering
- Other cluster decays
  - 12C – 3 α's
    - decay of ^{12}N/B
    - ^{13}N/C – add nucleon
    - decay of ^{13}O/B
  - 16O – 4 α's / 12C+α
    - decay of 16N
- Multi-particle states
- Isospin symmetry ?
- All decays with low branching ratios

Naive picture: nucleons outside of normal nucleus are sensitive to correlations

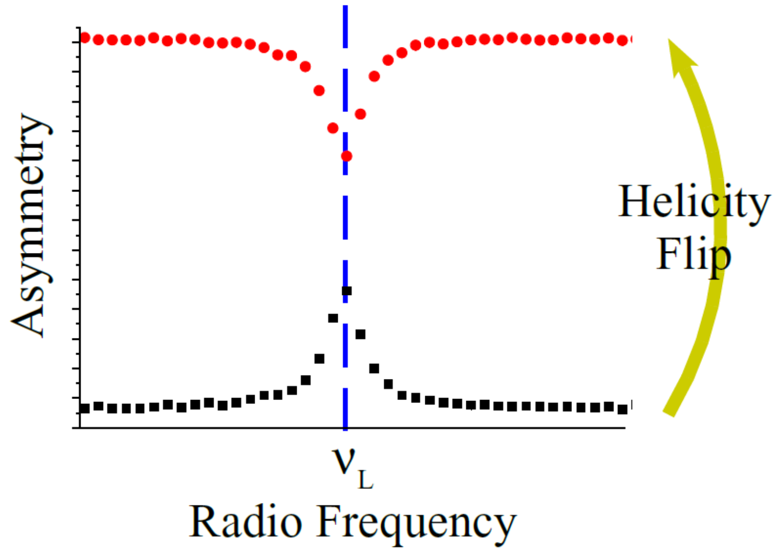


^{12}C continuum needed for triple-α process



Solid state physics with nuclear probes : ^{8}Li β-NMR

- produce polarized ^{8}Li
  - circularly polarized laser light
  - asymmetry in β-decay of ^{8}Li
- Implant ^{8}Li in surface
  - destroy asymmetry by sending in NMR signal
- Frequency and line shape tells about interaction between solid and ^{8}Li



What happens near and interface?

• We go from 3D to 2D system

• Changes in magnetic, electronic and structural properties.

Questions:

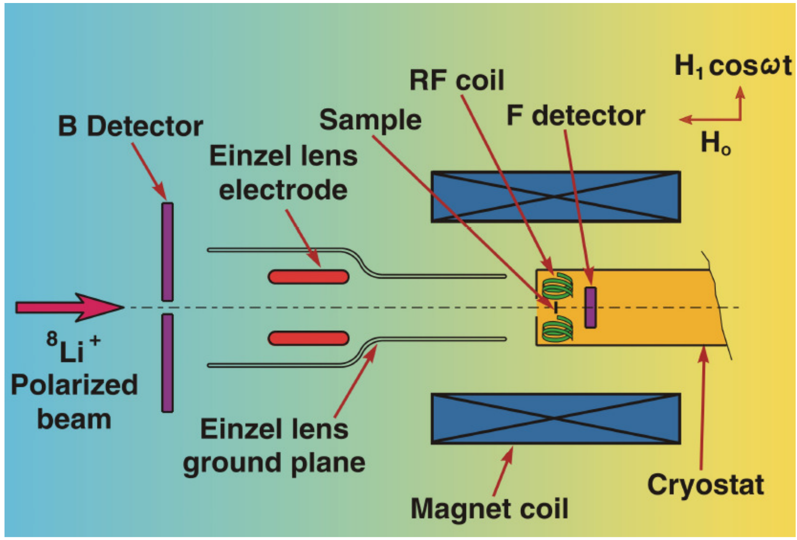
How/why do the properties change?

On what scale ?

Motivation:

Better understanding of *both bulk and interface*

Application in devices.



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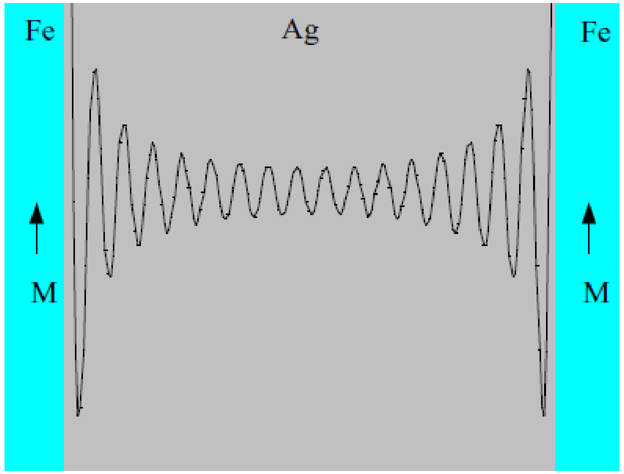
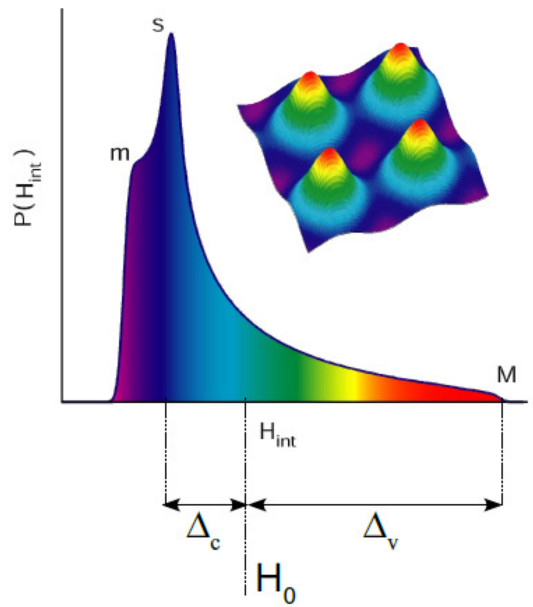
Examples

- Induced hyperfine fields in magnetic multilayers



- Magnetic properties of a monolayer of single molecule magnets

- Vortices near a surface ($NbSe_2$)



•β-NMR well suited to study berried interfaces and thin films
•Broad range of applications for studying depth dependence of magnetic, electronic and structural properties on a nm length scale.

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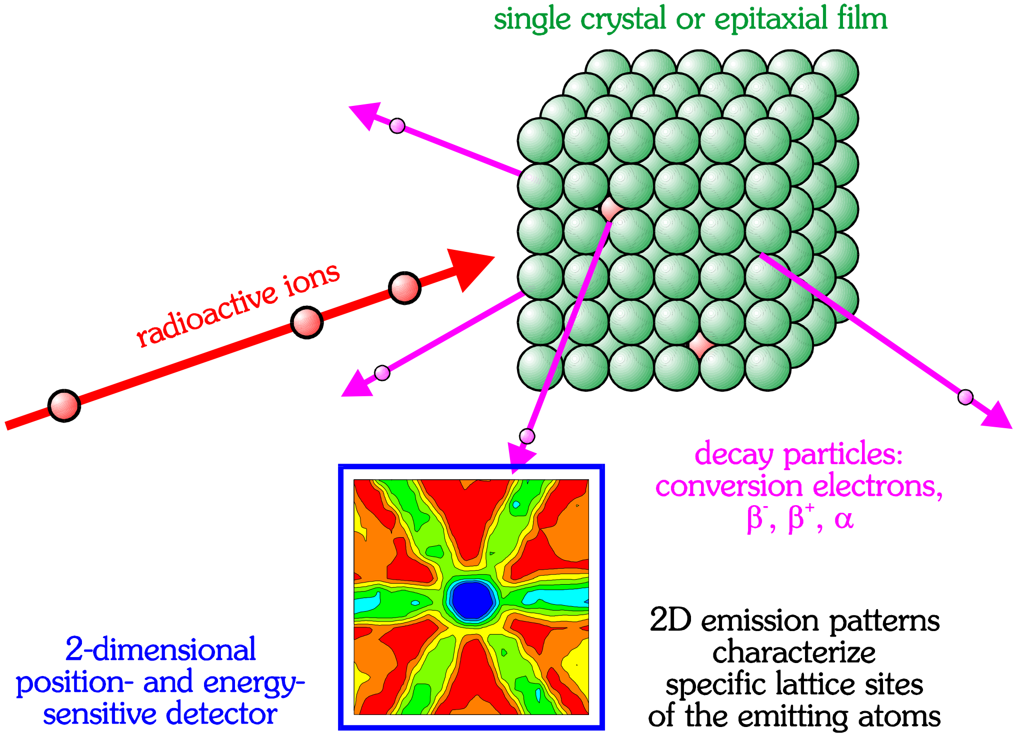
Emission channeling lattice location of radioisotopes

- Determination of lattice location
  - 0.1-0.01 Å precision
  - Single crystals
  - Characteristic emission pattern
  - Comparison with simulations
- Applicable for wide range of radio-impurities
- Application to semiconductors, metals and oxides
- A MYRRHA-based ISOL facility offers opportunities for emission channeling experiments, particularly for ^{8}Li, ^{20}Na, and rare earth a emitters.



(Open) issues & future

•ISOL@MYRRHA is an integral part of the MYRRHA project

•Workplan – roadmap (close contact between possible users and the MYRRHA team):

- ➢ Approval and initial funding of the MYRRHA project
- ➢ Preliminary report
  - • physics cases : look what will (is planned to be) done by 2020.
  - • technical specifications from the users point of view
  - • budgetplan/estimate
- ➢ Establishing a users group (including users outside of nuclear physics)
- ➢ Gathering ISOL expertise at SCK•CEN
- ➢Operational model
- ➢Time line

•Further applications for the full 2.5 mA beam (neutron factory)?