Physics motivation for the EPIC upgrade proposal of ISOLDE

Razvan Lica

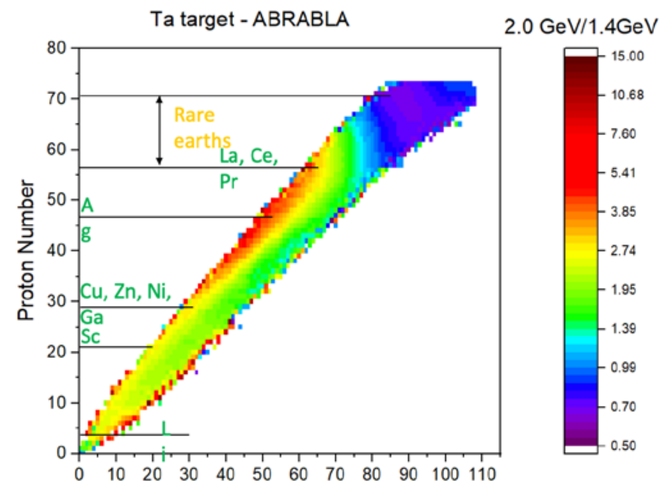
on behalf of the EPIC working groups

Special thanks for slides and info: S. J. Freeman, G. Neyens, K. Flanagan, S. Gilardoni, K. Johnston, M. Kowalska, A. Mengoni, M. Doser, D. Atanasov, L. Gaffney, M. Mougeot, R. F. Garcia-Ruiz, R. De Groote, D. Doherty, I. Martel

ISOLDE Workshop and Users meeting 2021
14-16 Dec

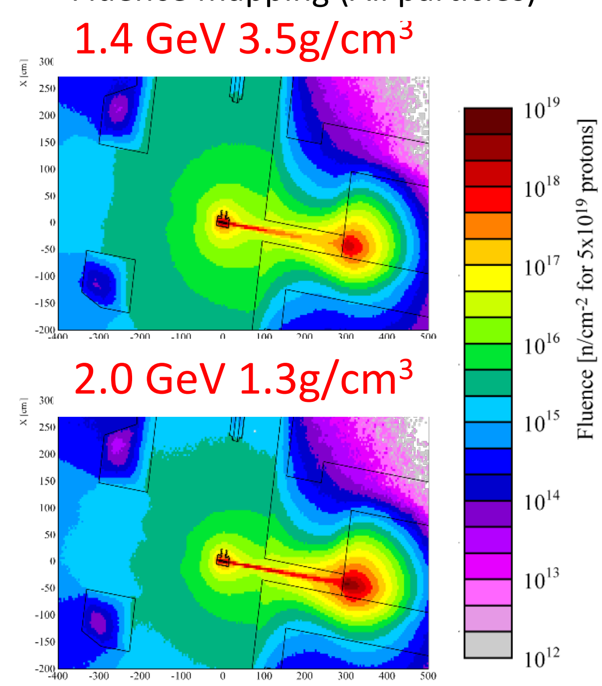
Challenge 1: LHC Injectors Upgrade (LIU)
PSB energy and intensity upgrade

- Potential increase of PS-BOOSTER proton energy (1.4 - 2 GeV)



- <u>Exotic n-deficient isotopes (largest increase)</u>:
  - **$Z_{isotope} = Z_{target}$ – (10 to 30)**
  - Factors of 2 to 40 have been predicted by FLUKA/ABRABLA
- <u>Low Z isotopes (fragmentation)</u>:
  - Increase in factors of 2 to 4

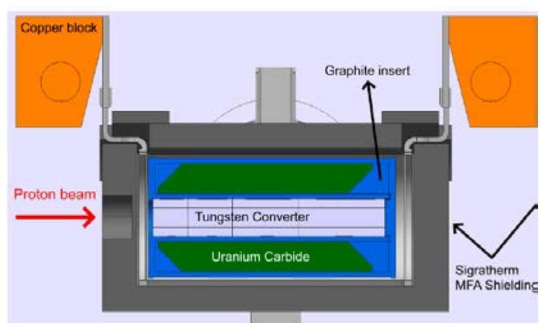
Fluence mapping (All particles)



- Potential increase of proton intensity

- "Theoretical" value of **2x** protons-per-pulse compared to present limits, difficult to estimate final proton current.
- This will also increase the target dose and frontend dose
- Peak power and shocks may impact on target lifetime.

The user community was clear we should keep as an option the 1.4 GeV energy



Challenge 2: growing ISOLDE community
(doubled from 500 to nearly 1000 in the last 2 decades)

No space in the present experimental hall for:
- New permanent setups for low-energy experiments (already approved /endorsed)
- Expansion of existing low-energy and HIE-ISOLDE setups

Bigger demand for beamtime:
- HIE-ISOLDE has brought more users (nuclear reactions, astrophysics)
- New user groups for low-energy beam (precision studies, antiproton-nuclei interaction, material science, life sciences)
- Very limited possibilities for parallel use of radioactive beams

Different requirements for different types of research:
- Pure and more intense beams of the most exotic nuclei for nuclear structure
- Ultra-stable environment and regular beamtimes for New Physics searches (to eliminate systematic errors)
- Multiple short beamtimes for material science and life sciences

Our response: EPIC proposal

The EPIC proposal @ ISOLDE

Exploiting the Potential of ISOLDE at CERN

1. **Fully exploit the LHC Injectors Upgrade (LIU): proton BOOSTER energy and intensity increase**

2. **Improve beam purification capabilities and install additional target station(s):**
   → in addition to the currently planned target developments
   → a 30 keV MR-TOF for fast high-resolution mass separation

3. **Install a 'Storage Ring' for short-lived (1-10 MeV/u) isotopes – unique worldwide**
   → new opportunities in atomic, nuclear and fundamental (new) physics

4. **Upgrade REX-ISOLDE**
   → HIE-ISOLDE physics at full 10 MeV/u energy

5. **A new experimental hall** (new experiments coming – mostly low-energy for searching new symmetries/interactions)
   - **MIRACLS** (ultrapure beams)
   - **PUMA** (interactions between exotic matter/anti-matter)
   - **Set-up/Trap for RaF molecules** (eEDM and other symmetry violations)
   - **Large superconducting magnet** for materials studies
   - **Applications, others …**

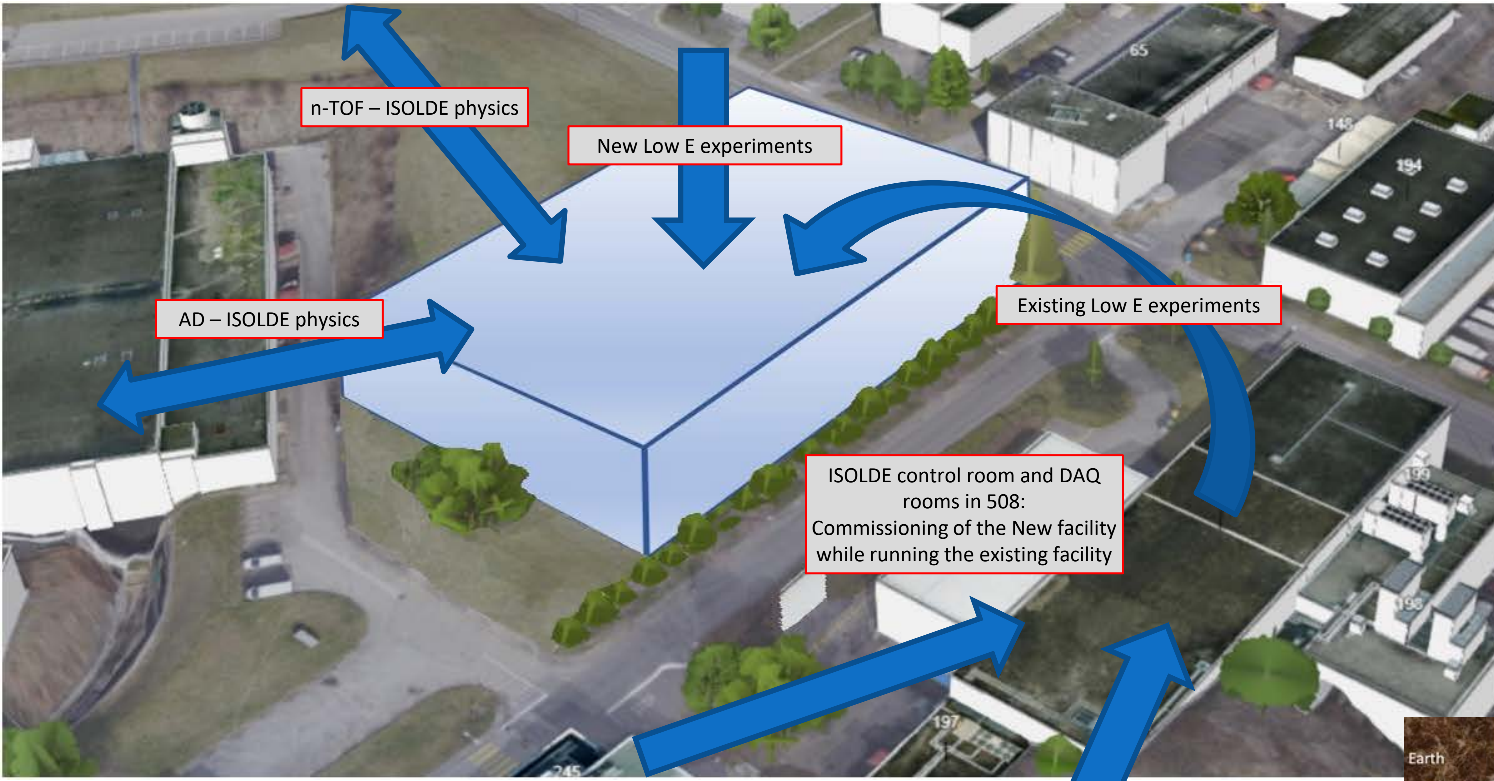
   → space for new HIE-ISOLDE experiments (in existing hall)

How ?

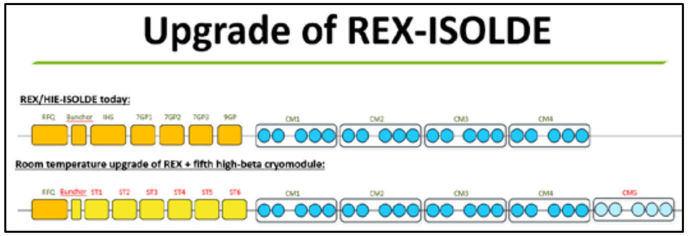
→ First ideas for European Strategy for Particle Physics (Dec 2018)
→ Some Physics goals presented in several presentations at the Open Symposium Granada 2019
→ EPIC workshops at CERN to discuss priorities through discussion between ISOLDE users and technical teams
  * December 2019 (134 participants) https://indico.cern.ch/event/838820/
  * November 2020 (214 participants, Zoom) https://indico.cern.ch/event/928894/
→ **Produce a scientific report: enhanced research capabilities and initial technical solutions (on-going)**

Proposed ISOLDE experimental hall and target stations

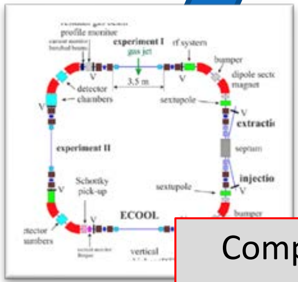
E. Siesling, J.A. Rodriguez - 2020 EPIC Workshop



- A possible option to build a new ISOLDE experimental hall and target stations at the present recuperation site B133 to make use of the existing TT70 tunnel and underground structures.
- Construction and installation work of a new hall and target stations can be carried out in parallel with physics at the existing ISOLDE facility, securing nuclear physics at CERN
- Possibility to connect AD and n-TOF, enabling promising future physics.
- Existing facility dedicated to HIE physics, MEDICIS and a possible future compact storage ring

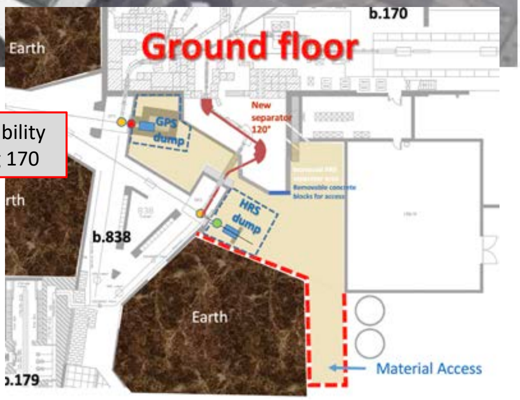


-Ideally 10 MeV/u for all masses
-Upgrading of the EBIS



Compact storage ring

Enhanced capability within building 170

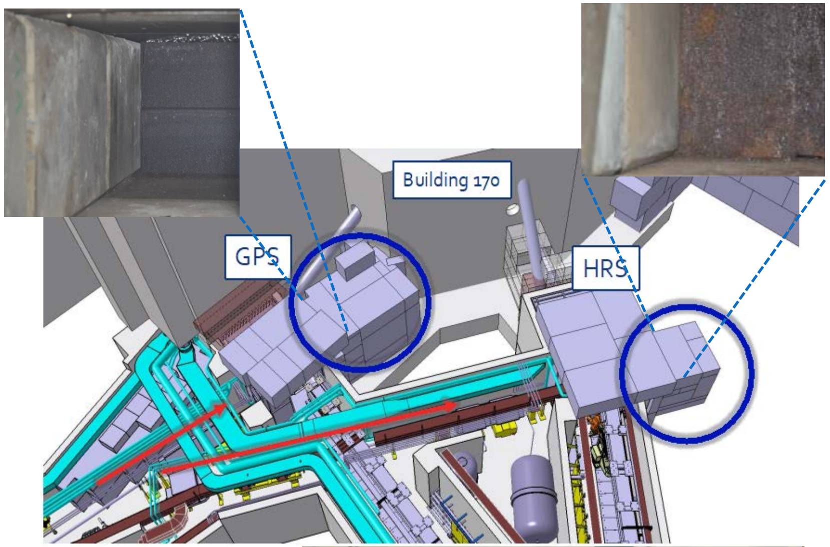


Complementary developments (existing facility)

- **Beam dumps** need to be exchanged.
  - Material not conform standards
  - Unknown condition and signs of corrosion
  - Required for Energy and Intensity upgrade
  - IBDRS project (realization LS3)

    preparatory study started 2020

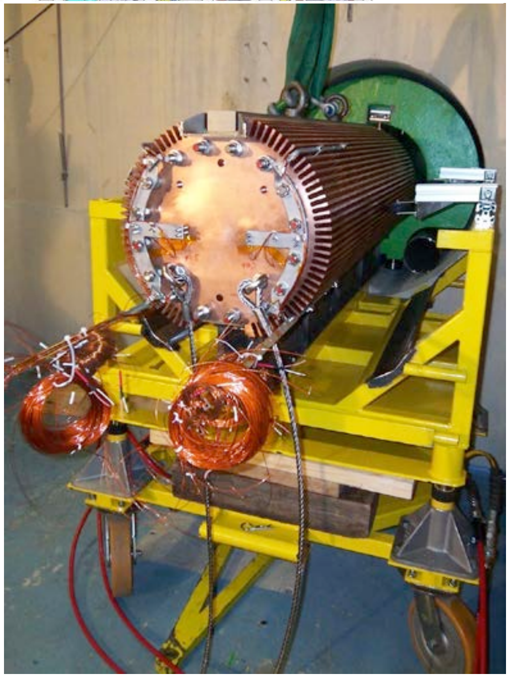
Talk by A. P. Bernandes (14 Dec) – "ISOLDE Beam Dump Replacement Study (IBDRS) update"



- **BTY line** upgrade to transfer 2 GeV protons to ISOLDE
  - It is feasible and there are two potential routes
  - Already suitable to transfer 1.7 GeV protons
  - Needs identifying funding

- Improve target area to cope with higher activation

- **On-going** target developments to enhance target lifetimes (nano-materials, ...) and parallel operation of the GPS and HRS front-ends.



Talk by S. Rothe, S. Stegeman (14 Dec) – "ISOLDE Target and Ion Sources: Production and Development"

EPJ ST
Recognized by European Physical Society
Special Topics

"Present goal: to create a document like the TDR for the Storage Ring at ISOLDE. Opportunity for the community to provide input into the document"

K. Flanagan, EPIC Workshop 2020

The EPIC proposal: Exploiting the Potential of ISOLDE at CERN

The ideas presented in this paper are the result of discussions with the ISOLDE User community at the occasion of two dedicated **EPIC workshops, held in 2019 and 2020**, which were attended by more than 130 and 210 persons, respectively:

- The **motivations** for a significant expansion of the ISOLDE facility at CERN, such that the ISOLDE scientific community can fully exploit the potential that CERN offers to maintain ISOLDE as a world class ISOL facility in the coming decades.
- **Upgrades and consolidation plans of the existing facility**, along with a proposal for a new ISOLDE experimental hall, that will receive protons through a new proton transfer line and new target stations, in parallel to the existing facility.
- The proposed developments will lead to an **increased capacity and capability** for producing more intense, higher-quality, radioactive ion beams for precision studies on very exotic isotopes from He (Z=2) up to actinium (Z=89), using low-energy and post-accelerated beams.
- By also exploiting **synergies with other CERN facilities** (e.g. AD, n_{TOF}, …) as well as other scientific communities (e.g. quantum technologies, quantum chemistry, particle physics, …), the range of science done at ISOLDE and its scientific output will be further enhanced.

G. Neyens, S.J. Freeman, K. Flanagan, R. Lică, D. Atanasov, M. Grieser, E. Siesling, F. Wenander, L. P. Gaffney, D. K. Sharp, D. T. Doherty, G. Lotay, J. Henderson, M.J.G. Borge , J.P. Ramos, X.F. Yang, Zs. Podolyák, J. Pakarinen, J. Schell, R. Berger, P. D. Stevenson, B. Olaizola, Y. Fujita, Tor Bjørnstad, A. Kankainen, D. Lunney, A. St.J. Murphy, R. Wolf, J. Jolie, S. Lechner, K. Wimmer, P. Van Duppen, S. Malbrunot-EttenauerCern, M. Lewitowicz, T. Davinson, F. P. Gustafsson, S. Franchoo, M. Vilén, Amlan Ray, Y. Ayyad, B. Blank, C. R. Hoffman, A. Gottberg, M.Scheck, L. Popescu, E. Leistenschneider, M. Athanasakis-Kaklamanakis, M. Siciliano, L. Schweikhard, M. Pfützner, F. de Oliveira Santos, N. Pietralla, G. Rainovski, L. Nies, P. A. Butler, P. Jones, S.G. Wilkins, A.R. Vernon, R.F. Garcia Ruiz, J. Karthein, S. Geldhof, L.M. Fraile, J. Vollaire, V. Manea, A. Nannini, F.M. Maier, S. Stegemann, M. Calviani, V.N. Fedosseev, AP.Bernardes, T. Stora, B. Jonson, G. Benzoni, A. Bracco, S. Leoni, P. Plattner, E. Nacher, S.E.A. Orrigo, K. Hadynska-Klek, S. Sels, Th. Kröll, W. N. Catford, J. G. Cubiss, B. Rubio, A. Algora, W. Nörtershäuser, S. Rothe ...

- More contributors are welcome to join
- The draft should be finalized soon and circulated

The EPIC proposal: Exploiting the Potential of ISOLDE at CERN

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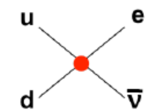
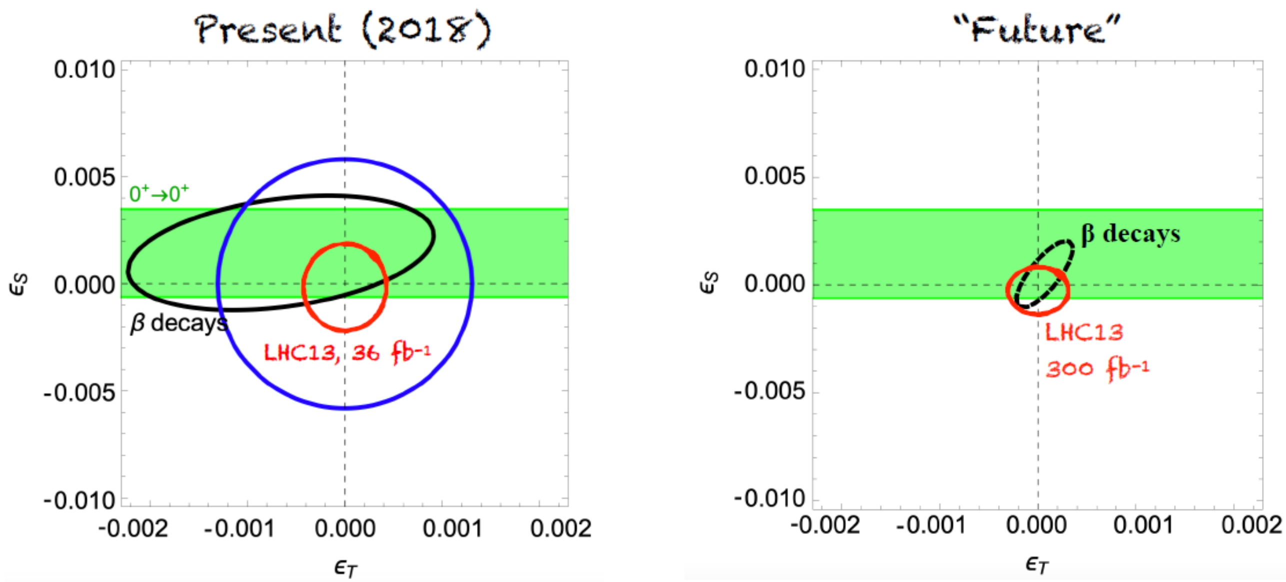
Probing New Physics with Radioactive Isotopes

EXAMPLE: new interactions – future limits for beta-decay and LHC

Scalar & tensor interactions





WISArD (^{32}Ar)
\+ TRIUMF
\+ TA&M

Benchmark numbers
(from ongoing / planned experiments):

$\delta\tau_n = 0.1\,s$

$\tilde{A}_n,\ a_n,\ \tilde{a}_F,\ a_{GT}$ at 0.1%

$b_{GT} = 0.001$

Talk by B. Blank (15 Dec) – "Beta-decay studies to explore physics beyond the weak-interaction standard model"

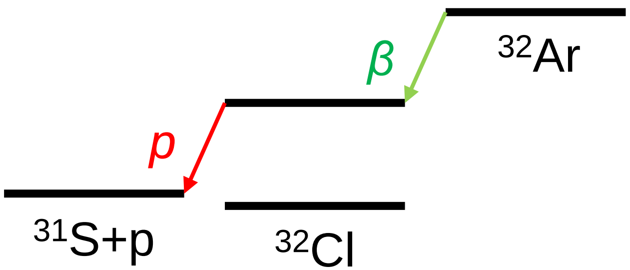
[M. Gonzalez-Alonso, O. Naviliat Cuncic, N. Severijns, Prog. Part. Nucl. Phys. 104 (2019) 165;
Gupta et al. Phys.Rev. D98 (2018) 034503]

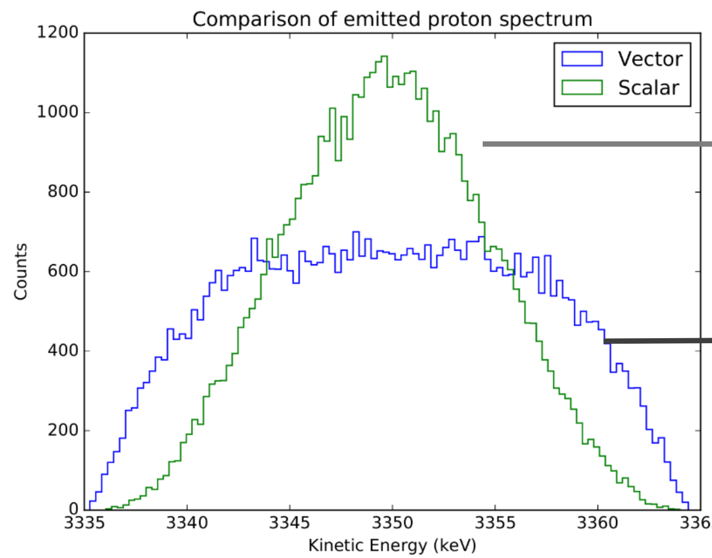
Courtesy M. Gonzalez-Alonso, N. Severijns, B. Blank

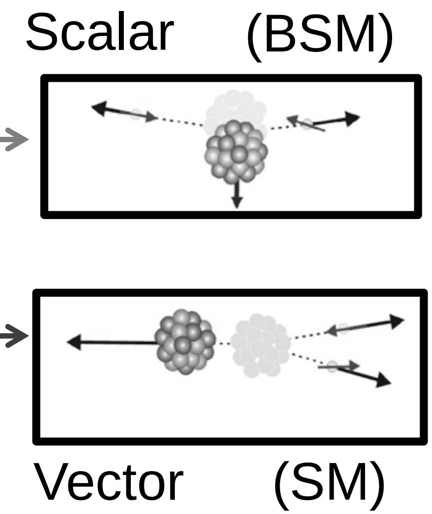
Weak interaction: search for exotic currents

- **Present limits on scalar current from βν correlation a_F = 0.65%**
  - **β-delayed proton peak broadening in 0+ → 0+ ^{32}Ar decay**

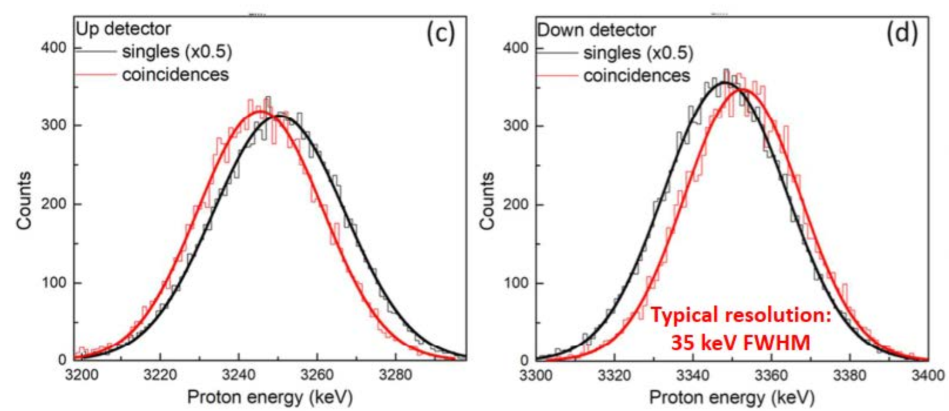
^{32}Ar: Adelberger et al., PRL 83 (1999) 1299







- **higher sensitivity by using kinematic shift of proton peak in beta-proton coincidences**

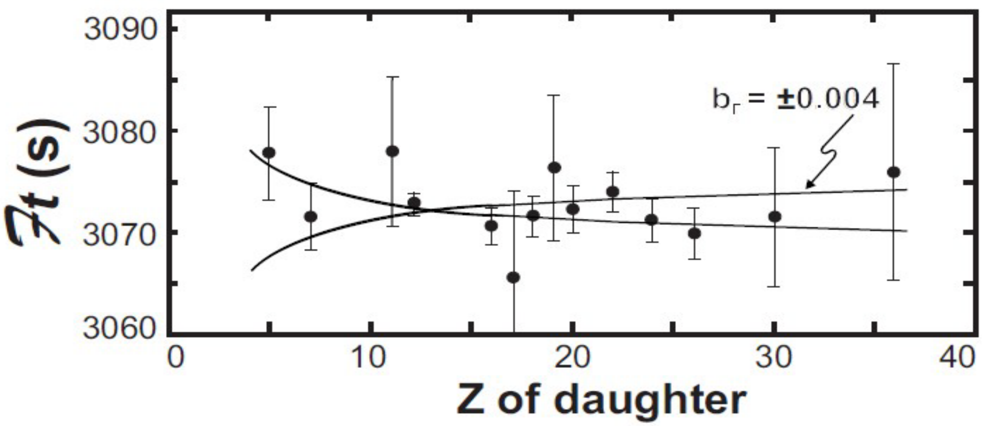


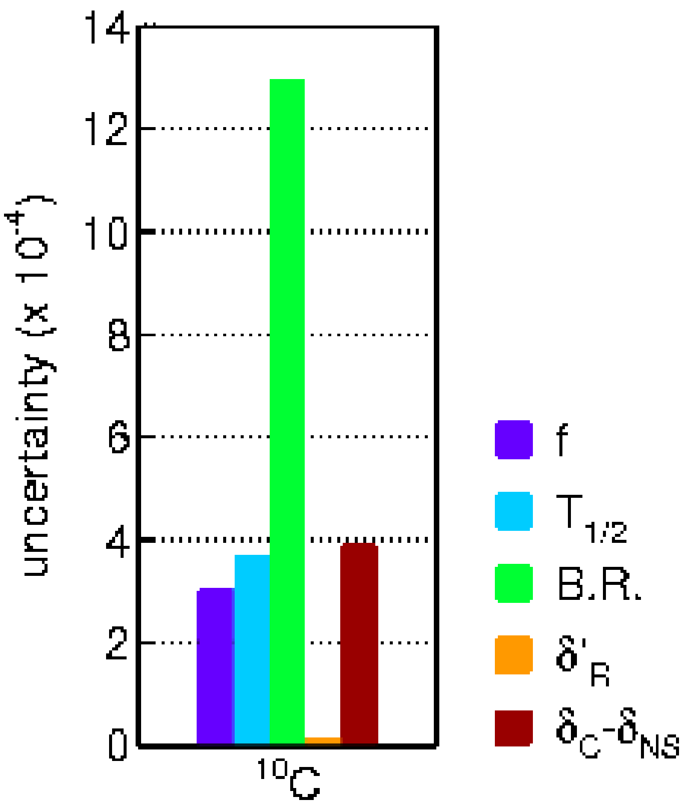
Talk by F. V. Cresto (15 Dec) – “Weak interaction studies with 32Ar decay”

Courtesy of D. Atanasov

Weak interaction: search for scalar currents

- standard model assumption: only vector current for Fermi transitions
  - limit on scalar current from term in Fermi function: $(1+b_f * g_1 / <E>)$
- from 0+ → 0+ β decay: $b_f = -0.0028 \pm 0.0026$





- highest sensitivity for low Q-value (= light nuclei) transitions

  ➔ improve on low-Z nuclei

  ➔ improve BR for ^{10}C

Courtesy of D. Atanasov

Gain from EPIC

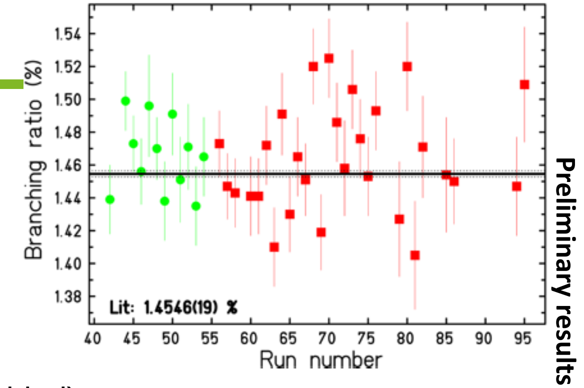
^{32}Ar

- **Proof-of-principle results:**

$$\tilde{a}_F = 1.01(3)_{stat}(2)_{syst}$$
$$\tilde{a}_{GT} = -0.22(9)_{stat}(2)_{syst}$$

- **Statistical error at the 1% level (3rd most precise measurement of a_F)**
- **Improve Statistics:**
  - ➢ **Higher beam intensity or longer beam times (facility upgrades)**
  - ➢ **Higher detection sensitivity (experiment upgrades)**
  - ➢ **Larger solid angle (experiment upgrades)**
- **No significant gain in production rate from 2 GeV**
- **<u>Gain from multi-production site facility: longer beam times – access to other lower yield nuclides e.g. ^{20}Mg</u>**

^{10}C



ISOLDE 2015

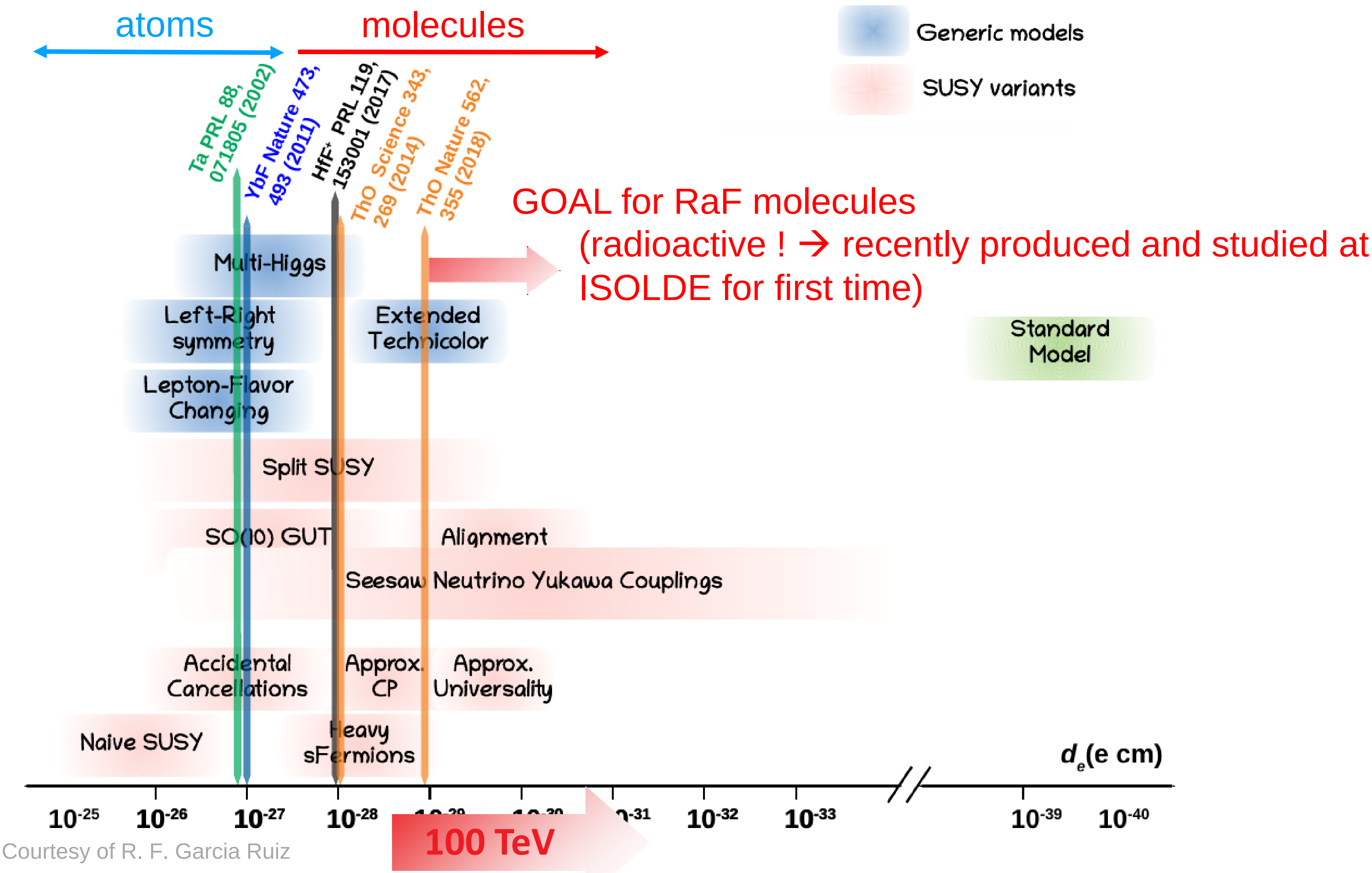
- **Preliminary result:**
  BR = 1.4517(26) %
  (systematic errors to be added)
- **Statistical error: ~ 2 ‰**
- **No significant gain in production rate from 2 GeV**
- **<u>Gain from multi-production site facility: longer beam times</u>**
- **Today typical beam times in β-decay experiments: 7 days**
- **Production of ^{10}C-^{16}O (mass=26)**
- **Main contaminants: ^{13}N-^{13}N and ^{14}O-^{12}C**

<u>➔ need of high resolution separation to reduce contaminants</u>
<u>➔ avoid general limitation due to overall counting rate</u>

Courtesy of D. Atanasov

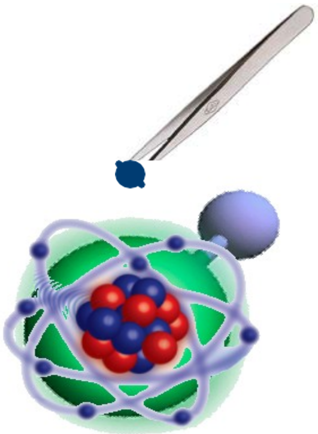
Probing New Physics with Exotic Atoms and Molecules

EXAMPLE: The best limit on the electron EDM comes from molecules



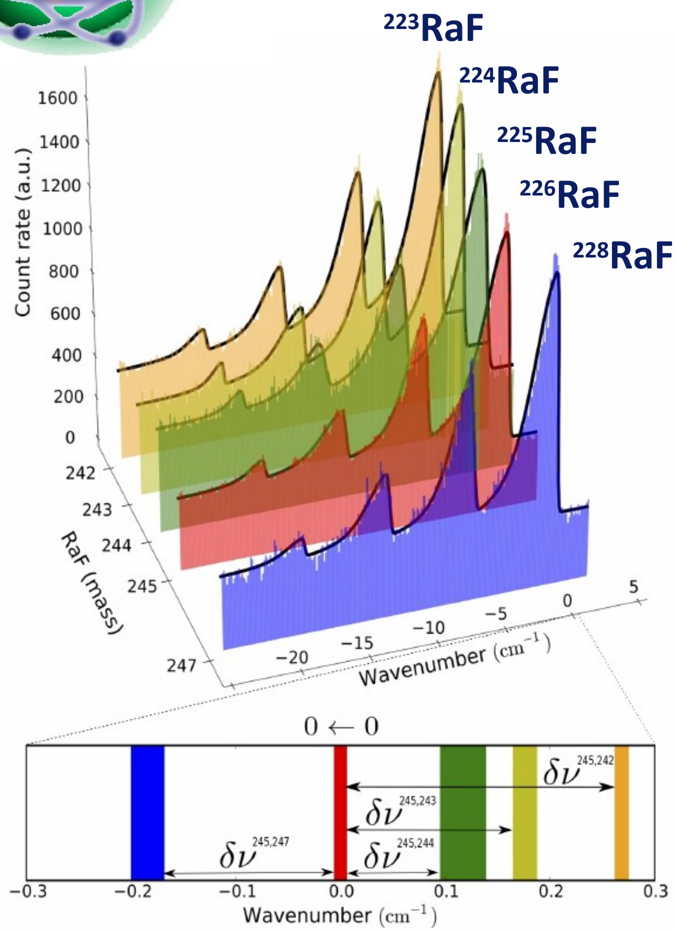
Courtesy of R. F. Garcia Ruiz

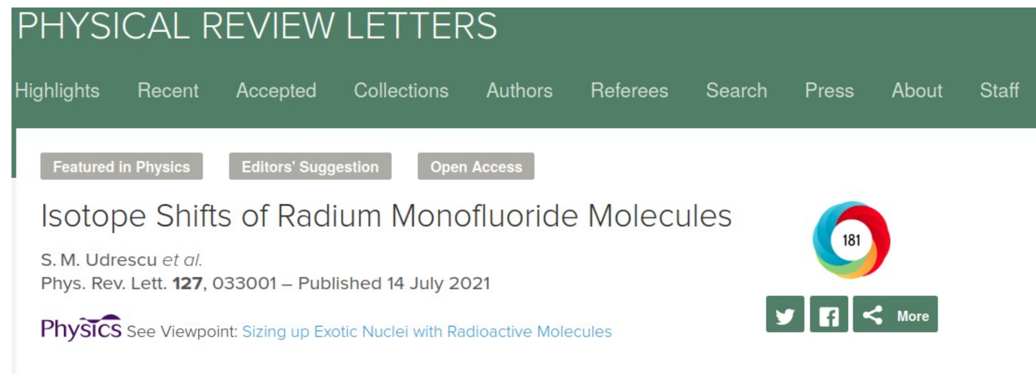
Recent Results (RaF)



New opportunities for nuclear structure studies of the heaviest elements (e.g. ThO, PaO,…)

[Udrescu et al. Phys. Rev. Lett. 127, 033001 (2021)]

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Isotope Shifts of Radium Monofluoride Molecules

S. M. Udrescu *et al.*

Phys. Rev. Lett. **127**, 033001 – Published 14 July 2021

Physics See Viewpoint: Sizing up Exotic Nuclei with Radioactive Molecules

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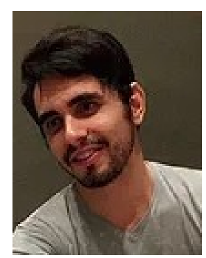
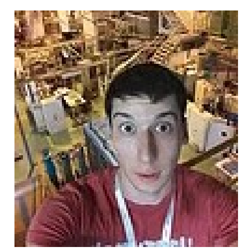
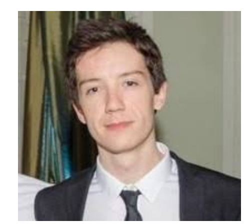
More



S. Udrescu



A. Brinson



S. Wilkins

Talk by S. Udrescu (14 Dec) – “Precision spectroscopy of RaF molecules for fundamental physics”

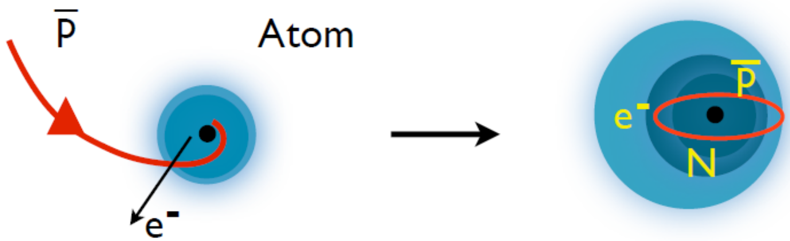
Courtesy of R. F. Garcia Ruiz

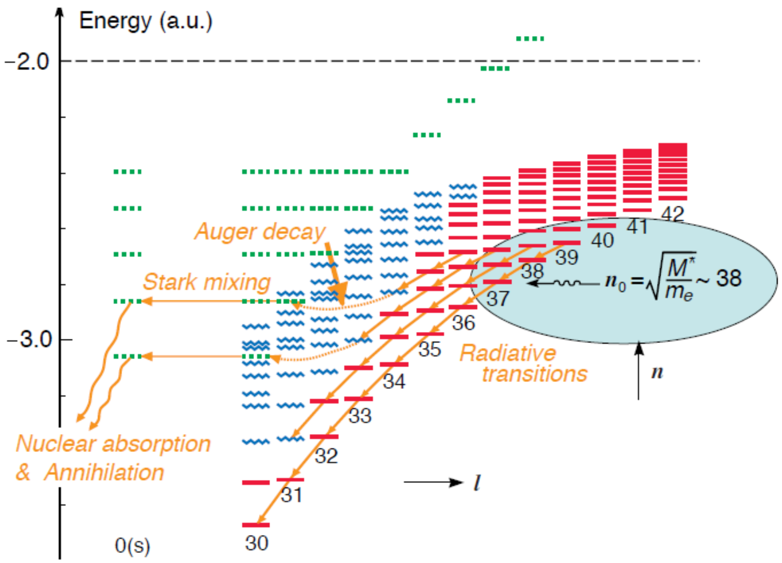
antiprotonic (Rydberg) atoms:

atomic physics processes (Rydberg states, fluorescence cascades, binding energies, lifetimes) → ASACUSA

nuclear physics processes: the deeply bound states' energy levels and lifetimes are affected by strong-interaction effects, which in turn provide the opportunity to study nuclear forces at large distances ("nuclear stratosphere") as well as isotope-related nuclear deformations → PS209, PUMA

Talk by F. Wienholtz (14 Dec) – "Status for the PUMA (antiProton Unstable Matter Annihilation) experiment at CERN"





example: antiprotonic helium

formation process: inject antiprotons into solid/gaseous target material

As the capture and subsequent de-excitation process occurs on time-scales of ps ~ ns, muons, pions, kaons, antiprotons, but also shorter-lived baryons, such as Σ^-, or even potentially Ξ^- and Ω^-, can form exotic relatively long-lived atoms

Courtesy of M. Doser

Antiprotonic atoms can have an impact on:

(building on existing technologies)

- **a novel formation mechanism for radioisotopes** (complementary to radioactive decay, spalation) and isomers inside traps *and that most likely remain trapped*

- a pathway towards **formation of trapped HCI** (highly charged ions) of a wide range of radioisotopes, with the possibility of attaching either an electron or an antiproton in Rydberg levels

- **studies of the intranuclear cascade after peripheral annihilation**, including the population of isomeric states on timescales of ms (with the possibility of observing transitions)

- formation of **low energy (400 keV) antineutrons** and potential for measuring low energy antineutron-nucleus cross sections.

Courtesy of M. Doser

The NEAR Station

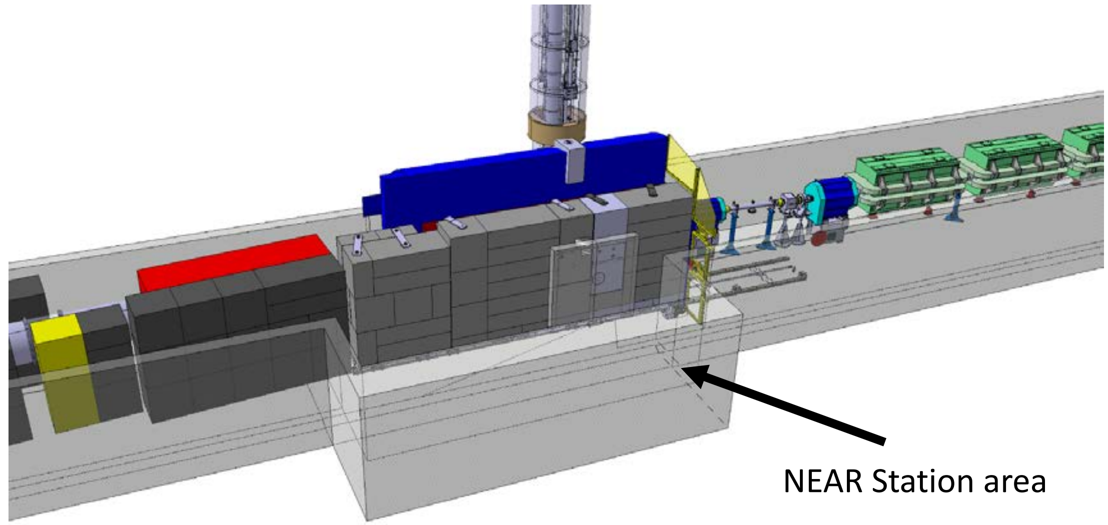
During the design studies of the new shielding around the target station the opportunity for a new near-target experimental area appeared (NEAR station)

1. Measurements of MACS (Maxwellian averaged cross section) by activation for nuclear astrophysics

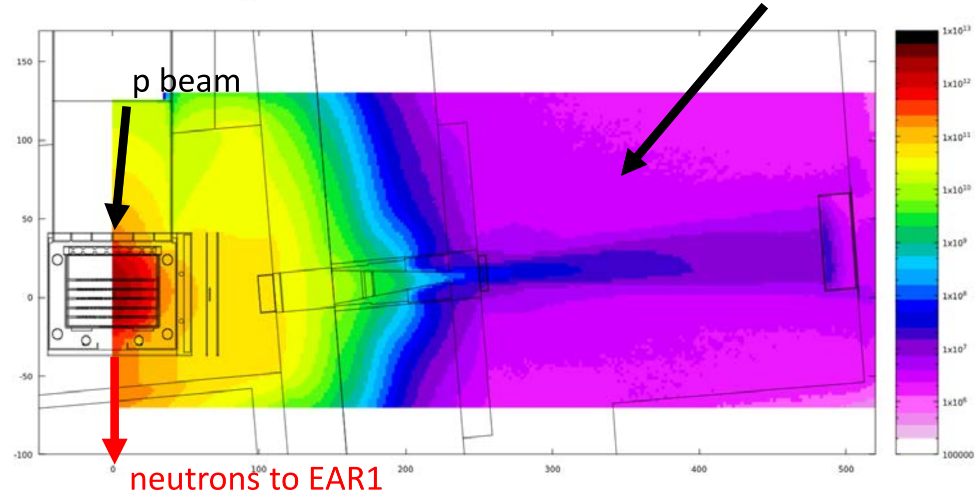
2. Fusion-related measurements (cross sections, not irradiation)

3. Measurements of decay rates of long-lived isotopes

4. Irradiation of non-metallic materials + SEE



NEAR Station area



simulations by M Barbagallo

Radioisotopes measured at n_TOF

Isotope	half-life [yr]	mass [g]	N	Activity [Bq]	reaction	note
Be-7	0.15	7.94E-08	6.83E+15	1.03E+09	(n,p)	
Be-7	0.15	2.78E-06	2.39E+17	3.60E+10	(n,a)	
Al-26	7.17E+05	1.11E-05	2.58E+17	7.91E+03	(n,p); (n,a)	
Mn-53	3.74E+06	8.80E-07	1.00E+16	5.88E+01	(n,g)	failed
Ni-59	7.60E+04	1.75E-04	1.78E+18	5.16E+05	(n,a)	
Ni-63	101.2	7.72E-02	7.38E+20	1.60E+11	(n,g)	
Zr-93	1.61E+06	1.04E+00	6.76E+21	9.23E+07	(n,g)	partial results obtained
Pm-147	2.62	8.50E-05	3.48E+17	2.92E+09	(n,g)	
Sm-151	90	8.90E-02	3.55E+20	8.67E+10	(n,g)	
Tm-171	1.92	3.13E-03	1.10E+19	1.26E+11	(n,g)	
Tl-204	3.78	9.00E-03	2.66E+19	1.54E+11	(n,g)	

n_TOF pushed feasibility of neutron capture cross section measurements to limits of half-life of a few years on sample materials with ~ 10^{17} – 10^{19} atoms

With the availability of the NEAR Station, these limits could be pushed to shorter half-lives and smaller sample masses (at least for activation measurements)

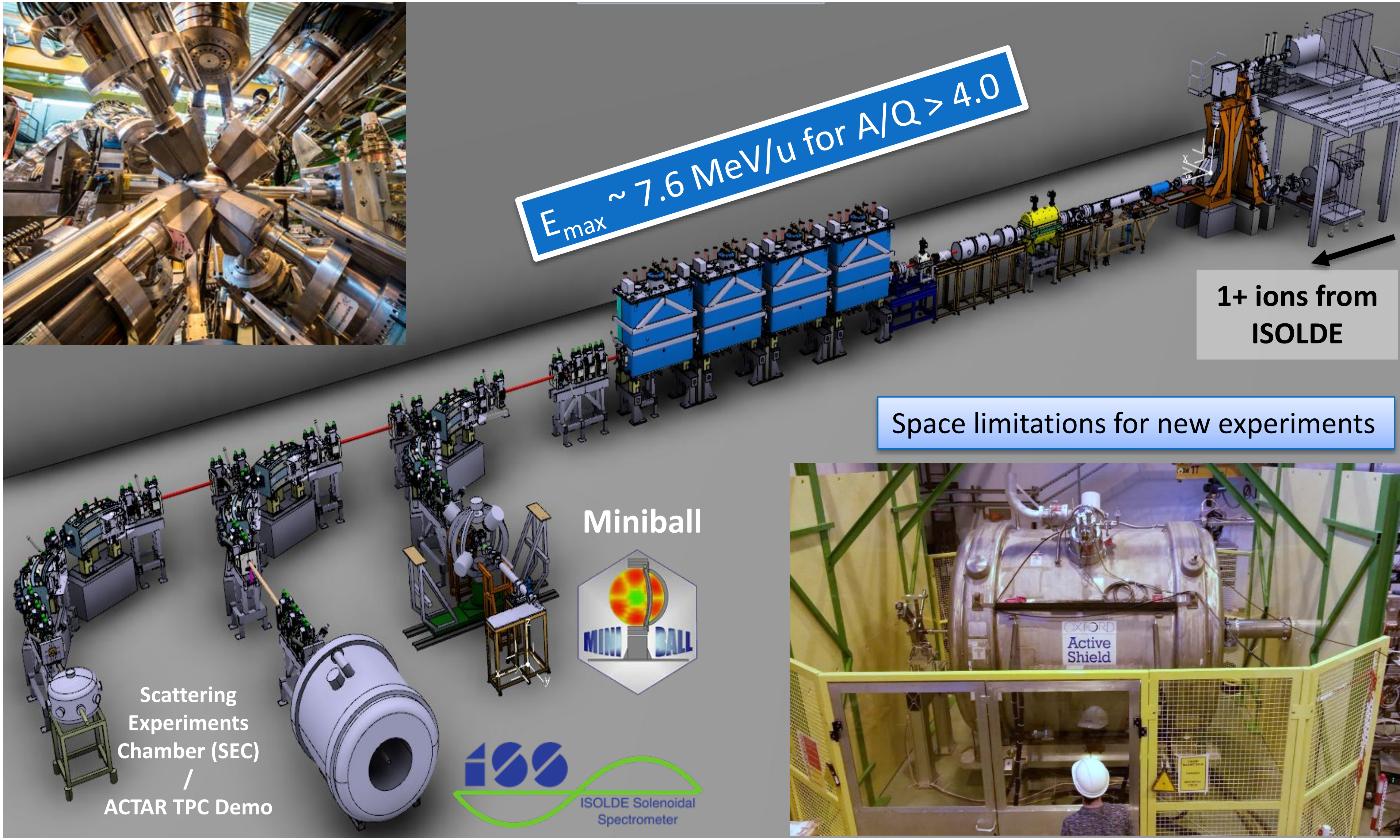
<u>ISOLDE can provide</u>

- mass separation & implantation on material provided from outside source
- direct production of separated ions with a variety of species & yields

Examples: ^{134,137}Cs, ^{85}Kr, ^{154}Eu, …

Courtesy of A. Mengoni

HIE-ISOLDE Status (2021)

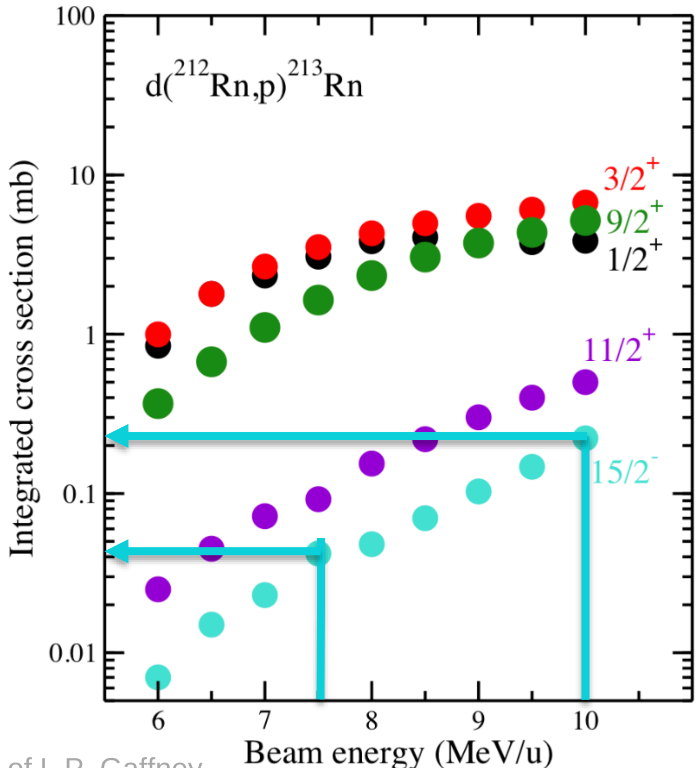


Courtesy of L.P. Gaffney

What are EPIC enhancements for HIE?

- We want to achieve the full **HIE** enhancements:
  - **H**igh **I**ntensity and **E**nergy ISOLDE…

- Most HIE-ISOLDE experiments are statistics limited → *Luminosity* x *cross section*:
  - Improvements to **I**ntensity proportionally reduces beam time requests.
  - Higher **E**nergy range gives access to optimal reaction cross-sections; new physics.



Courtesy of L.P. Gaffney

Energy

- In direct reactions of heavy nuclei, going from 7.5 → 10 MeV/*u* gains almost an *order of magnitude*!

- Pronounced angular distributions:
  - Determine angular momentum

- Excitation of high-energy resonances:
  - Pygmy dipole mode

Physics Opportunities with a Compact Heavy-ion Storage Ring

Would enable a rich and varied programme of measurements, taking advantage of **cooled** and **stored** RIBs

→ Energies (**up to 10 MeV/u**) and **range** of beams at ISOLDE offer unique and hitherto unexploited opportunities for **nuclear astrophysics** in particular

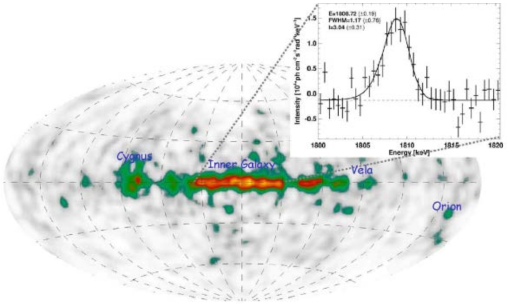
→ **Uniqueness**: injection at the required energy (fast – shorter lifetimes accessible, complementary FAIR)

→ Can be used multiple times in an in-ring detector (luminosity increase!)

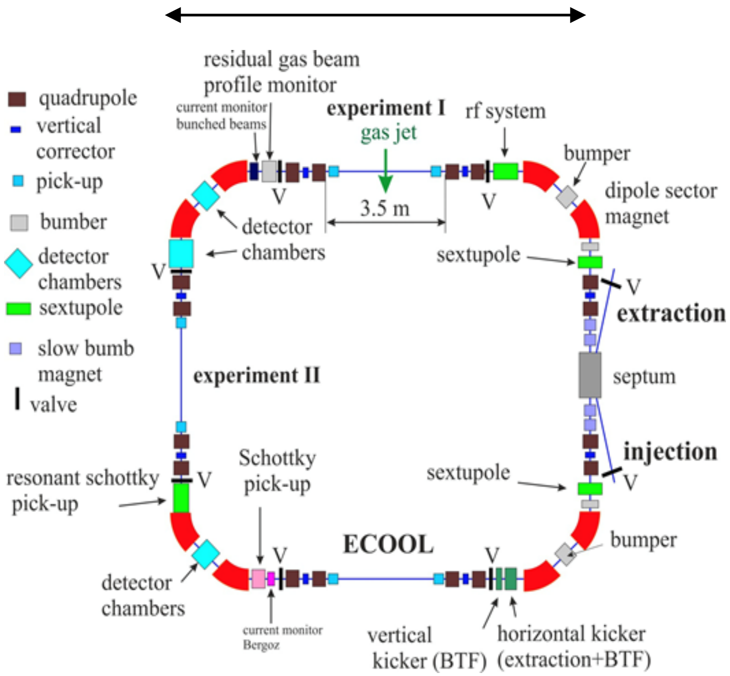
→ Can be cooled to deliver excellent quality beams to external experiments for high-precision studies

Gas-jet target will enable (^{3}He,d) reactions to be performed

- Direct surrogate for (p,γ) radiative capture
- Requires a bespoke UHV detector system
- Exciting possibility would be ^{26g}Al(^{3}He,d) for the understanding cosmic γ rays



COMPTEL/ INTEGRAL



The **p Process** is thought to take place in Core Collapse Supernovae (T ~ 2 – 3 GK => $E_{c.m.}$ ~ 2 – 3 MeV/u)

- Recent work at TRIUMF (Lotay et al., PRL **127** (2021) has indicated that statistical model approaches are inappropriate.
- Direct measurements with gas-jet target required. Injection at the **appropriate energy**

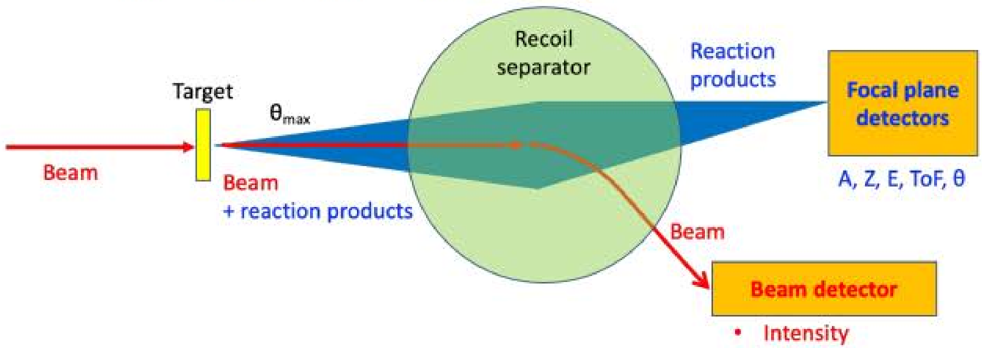
CCSN

Courtesy of D. Doherty

The ISOLDE Superconducting Recoil Separator (ISRS)

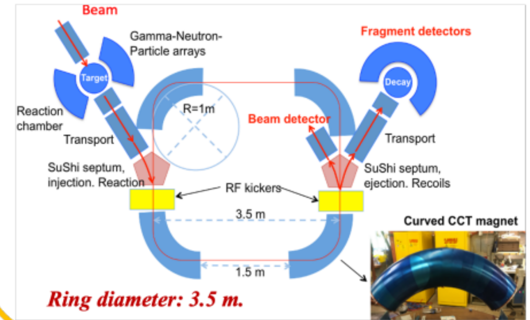
(1) Mini-Storage ring < 5 m diameter – Cyclotron frequency
(2) Fixed Field Alternating Gradient – large Δ(p, Ek, m, Z)
(2) Curved Canted-Cosine Theta-Multifunction SC solenoid
- Iron free magnets
- Cryocooling
- Magnetic shield

- Use to detect forward focussed reaction products (recoils): A, Z, E, ToF, θ
- Separate them from the primary beam.



Conceptual layout of the separator

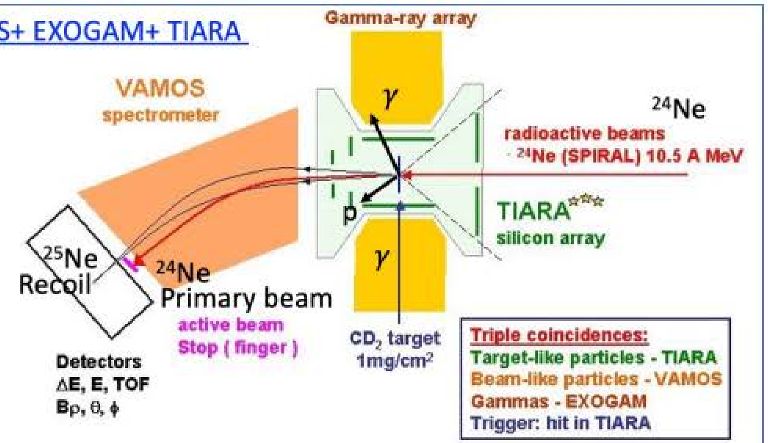
The ring consists of curved CCT magnets, straight sections, injection/extraction systems and beam diagnostics.



A prototype of an assembled curved CCT magnet (NIM A (2020) 163414)

A Recoil Separator can bring new and exciting possibilities to the HIE- ISOLDE physics program.

VAMOS+ EXOGAM+ TIARA

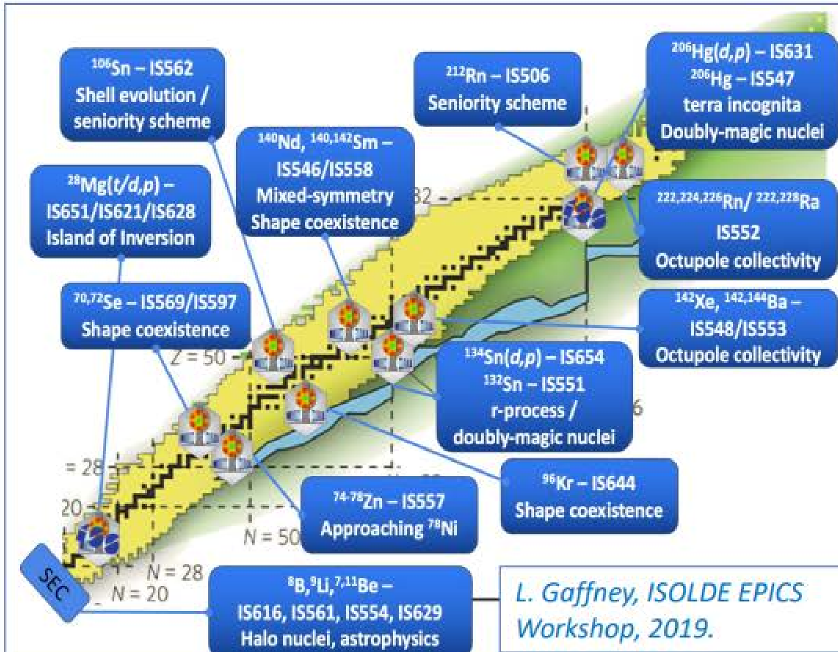


Triple coincidences:
Target-like particles - TIARA
Beam-like particles - VAMOS
Gammas - EXOGAM
Trigger: hit in TIARA

- **Particle - γ – n** coincidences
- Selection of reaction channel, background removal, etc

Courtesy of I. Martel

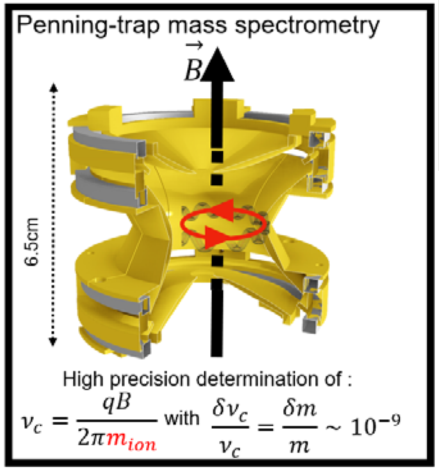
Selected physics cases investigated at HIE-ISOLDE



L. Gaffney, ISOLDE EPICS Workshop, 2019.

Poster by I. Martel (14 Dec) – "Recent developments in the design of the HIE-ISOLDE Superconducting Recoil Separator (ISRS)"

EPIC mass measurements:



- **Energy/Intensity upgrade impact on physics:**
  - Evolution of the *N*=50 shell gap —> $^{80\text{-}81}$Cu
  - Evolution of the *N*=82 shell gap —> n-rich Ag and Pd
  - Mid-shell deformation —> Second IoI around *N*=40
  - Development of n-rich Au and Pt to study *N*=126, also important for *r*-process
  - Neutron deficient side between ^{56}Ni and ^{100}Sn, nuclear structure effects and rp-process (Type-I X-ray bursts, Wigner effect, *N*=*Z*=50 shell closure study, IMME, proton decay)
  - Investigating fission from isomeric yield ratio measurements.
- **Technical aspects:**
  - Increase in yields —> need a new improved ISOLTRAP RFQ-CB to match it
  - RFQ-CB also matched to MRToF-MS requirements —> higher resolving power, faster purification
  - Explore synergies between ion traps and laser spectroscopy, decay spectroscopy (PI-ICR)
    —> **ISOLTRAP as a mid-beam line setup injecting into CRIS, COLLAPS, IDS ?**
  - PI-ICR improvements—> larger bore size for a larger image radius, lower preparation trap temperature —> requires a new trap system to be built (horizontally this time)

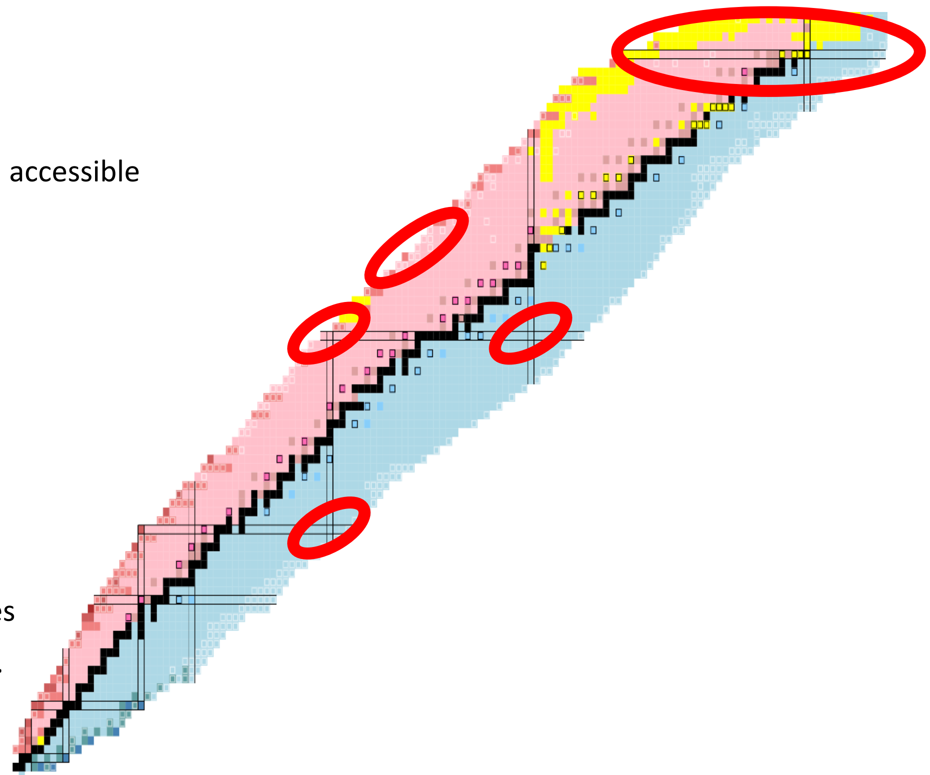
Courtesy of M. Mougeot

LASER Spectroscopy and EPIC

Opportunities with higher proton energy and intensity

Examples of key isotopes far from stability

1. Near exotic shell closures
   - Isotopes near ^{78}Ni, ^{100}Sn, ^{132}Sn produced via fission become accessible due to higher neutron converter yields
   - Sensitive probes of magicity of underlying core
2. Lanthanide proton emitters (Z=57-71)
   - Higher spallation cross sections boost proton-rich yields
   - Proton-emitters have never been studied using laser spectroscopy
3. Nuclear shape and size in the lead region
   - Higher intensity + energy will boost yields near the drip lines
   - Octupole shapes, shell crossing effects, shape staggering, …



- **Study of nuclear shell evolution and magicity**
- **Shape, size and configuration of proton-emitting isomers**
- **Anchor points for new theory development**

Courtesy of R. De Groote

New experimental stations for the next generation of techniques in a new hall

1. New high-precision techniques
   - Atom and ion traps for nuclear physics and BSM research
   - Study of both atomic species and radioactive molecules
2. MIRACLS
   - Spectroscopy in MR-TOF to boost sensitivity
   - Study weakly produced isotopes
3. He-like boron, carbon, nitrogen
   - Addition of an EBIT before collinear laser spectroscopy to strip ions
   - Study of these light isotopes, currently inaccessible
4. Negative ion spectrometers
   - Electron affinities of radioactive elements
   - Specific mass shift in negative ions to test atomic calculations
5. Laser spectroscopy in storage rings
   - Development of polarization using lasers or electron capture
   - Delivery of polarized beams for spin-spin dependent reactions, PV effects, …
6. …

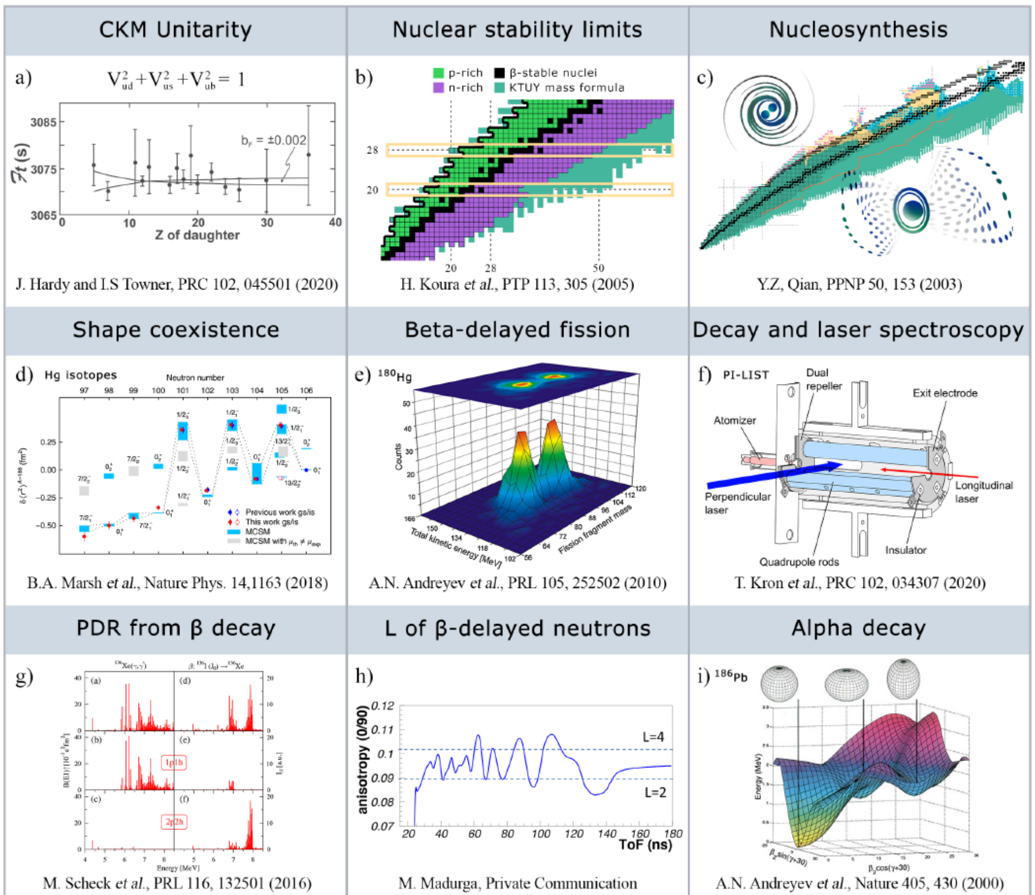
Strong synergies between these concepts and other EPIC ideas!

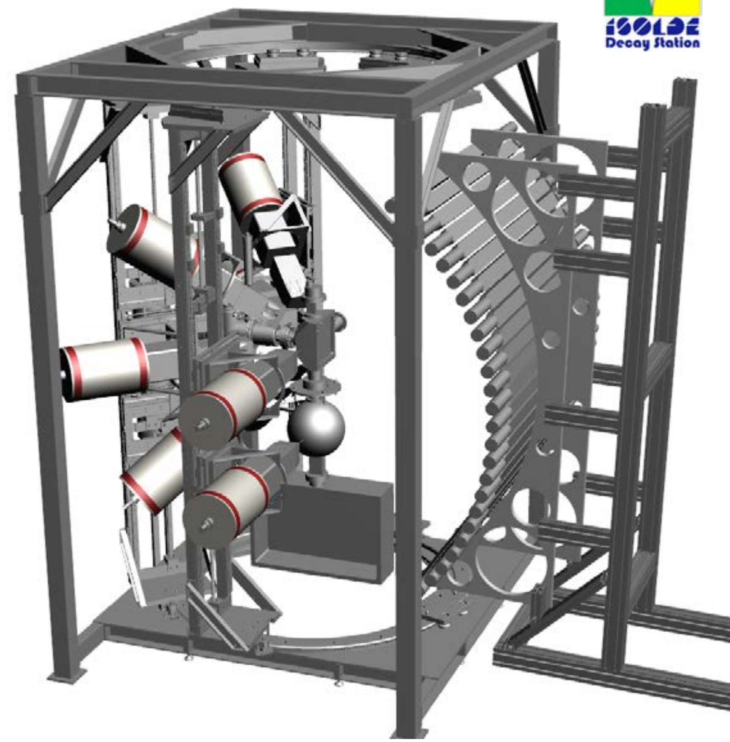
Courtesy of R. De Groote

Next generation Decay Spectroscopy

- Improved yields and beamtimes would allow first time studies for the most exotic isotopes in the world.

- The new beamlines layout could connect IDS with other experimental setups, allowing for tandem operation or beam enhancements (purity, yield, etc) for **next generation decay spectroscopy**.





ISOLDE Decay Station

+

RILIS, PI-LIST (in source laser spectroscopy)

CRIS, COLLAPS (high-res laser spectroscopy)

MR-TOF, PI-ICR (mass separation of contamintants, isomers)

VITO (polarized beams)

⋮

Biological β-NMR at VITO and ISOLDE: present and future

Expertise built in-house:

- *Experiments:*
  - Chemistry and bio-chemistry
  - Conventional NMR
- *Theory:*
  - Molecular Dynamics
  - Density Functional Theory (DFT)

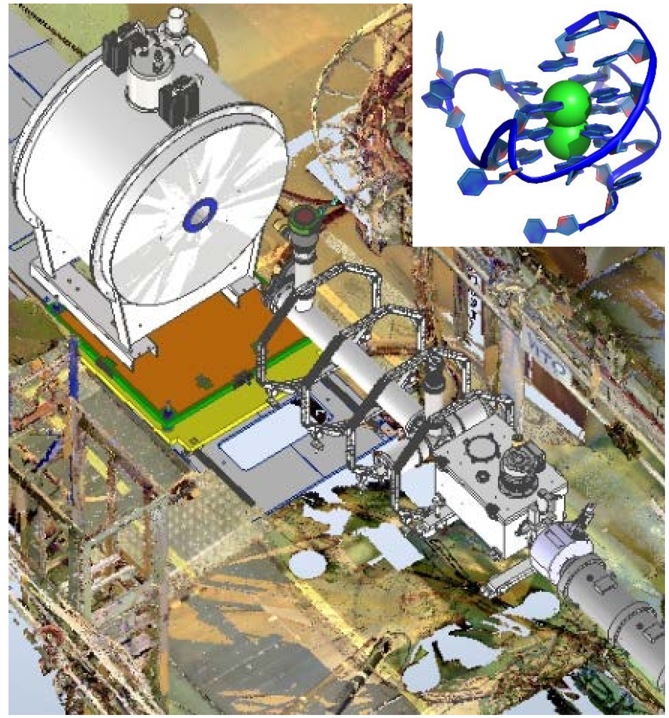
Collaborations with experts in relevant fields:

- *Experiments:*

UNIGE – conventional NMR platform
Ljubljana – NMR of Na/K interaction with DNA
Poznan – NMR, x-ray scattering, pure solvents

- *Theory:*

UNIGE - DFT
Bratislava – coupled cluster theory, DFT



Plans until LS3:

- Priority on studying Na and K interaction with DNA G-quadruplex structures
- Exploring other interesting biological topics relevant to biochemistry collaborators
- Implementing 4.7 T superconducting magnet: better field homogeneity and higher resolution
- More automatisation in liquid sample handling
- Going towards 10 mbar required by aqueous samples

Wish-list:

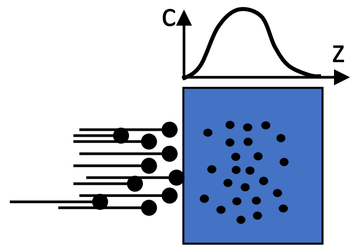
More space → possibility of several permanent end-stations devoted to different projects with different collaborators (biology, material science, nuclear physics, fundamental studies)

Talk by M. Jankowski (15 Dec) – "Recent developments in β-NMR at VITO"

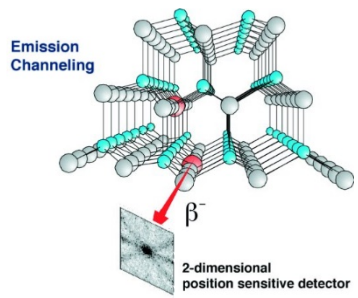
Courtesy of K. Johnston

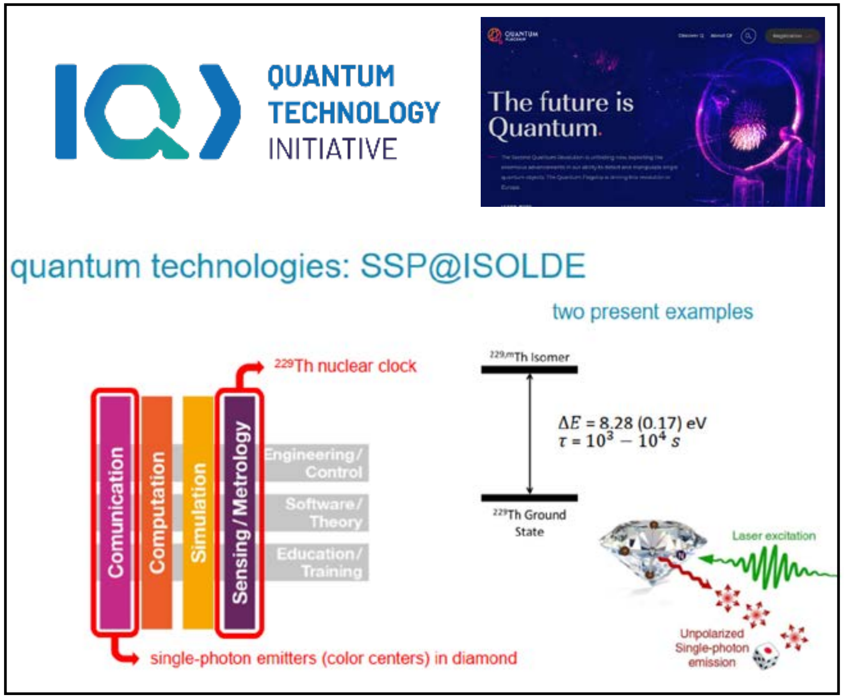
Unique features of radioactive probe atoms for Solid State Physics/biology applications

- **Chemically selective and isotope specific**
- **Extremely good detection limit**
  - among the most sensitive methods, no reaction cross section limitation
    - 10^{15} - 10^{18} probes/cm^3
    - 10^{11} - 10^{12} probe atoms



- **Depth distribution and concentration control**
  - Ion energy and ion fluence control
  - Circumventing solubility and diffusion limits
- **Highly local Information**
  - Nucleus-size sensors for **local** magnetic and electric fields
    Electric Field Gradient ~ r $^{-3}$
    Emission channeling: ~ 0.02 nm position resolution





Where EPIC can help

Increase in capacity i.e. multiple target stations:

- **Greater access to beamtime**
  - Faster response to topical areas of Materials science: 6-9 months can be a long time …
  - Allow more systematic runs so that a complete data set could be collected within one calendar year.
- More «reliable» access would allow groups to invest in training.

Increase in capability

- E.g. purification of beams to allow greater control of isotopes…especially important for precise implantation into e.g. interfaces

Courtesy of K. Johnston

Talk by K.K.F.Van Stiphout (14 Dec) – “The upgraded ASPIC and ASCII setup: expanding experimental capabilities for solid-state physics at ISOLDE”

Talk by S. Kraemer (15 Dec) – “Ultraviolet Spectroscopy of the Actinium-229 beta decay: On the way to the first identification of the 229Th low-energy isomer?”

Morning session 16 Dec

Conclusions

- Many exciting and unique potential experiments, with option to combine radioisotopes with anti-protons (AD) and intense neutron beams (n_TOF).
- Provide time and required laboratory space to study the fundamental properties of quantum materials (link to the CERN quantum initiative).
- A new building could provide space and capability for the next generation of high precision experiments with the required clean areas.
- Creating space in B.170 will enable new experiments with post-accelerated beams (recoil separation, storage ring)
- **Ongoing efforts to produce a scientific report for the EPIC proposal**

  To be circulated soon!

Conclusions: possible timeline

Mid-term goals (2022-LS3)

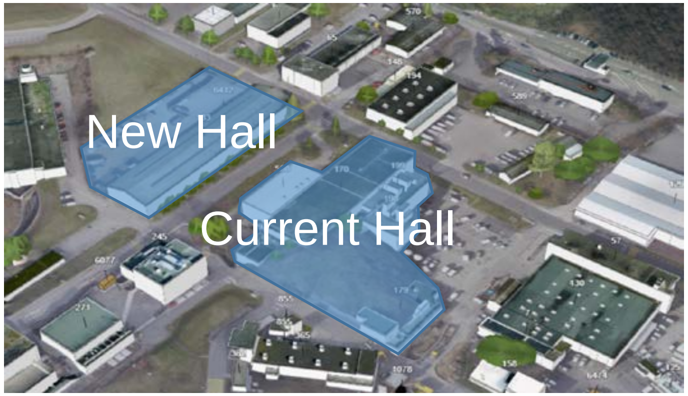
- Nano-material based targets.
- New beam dumps for existing target stations and update to modern radiological standards and to receive higher energy protons at higher intensity.
- Upgrade of BTY transfer line from Booster to ISOLDE to deliver 2-GeV
- Parallel RIB operation.

➔ **Increase RIB beam intensity by factor 1 to 40, with exotic proton-rich nuclides and light fragments benefitting most.**

- **Safety: FIRIA[1] → Upgrade of ventilation and improve fire safety**

Long-term goals (> LS3): EPIC proposal

- A new ISOLDE building + target stations
- Dedicated space and facilities for new (and existing) low-energy experiments
- Improved beam purity (mass resolution) and quality (time structure)
- Parallel operation with exisiting (HIE-ISOLDE) facility
- Extra-Space for new re-accelerated RIB experiments, including a new compact storage ring



Courtesy of S. Gilardoni, S. J. Freeman

Thank you for your attention!