Петербургский институт ядерной физики им. Б. П. Константинова
Национального исследовательского центра «Курчатовский институт»

# Эксперименты на установке ISOLDE (CERN)

**Д.В. Федоров**

**А.Е. Барзах, П.Л. Молканов, М.Д. Селиверстов, В.Н. Пантелеев**

50 ЛЕТ НА ПИКЕ НАУКИ

# ISOLDE Physics

## Sizes and shapes

Exotic nuclei come in a variety of sizes and shapes, from spherical to deformed shapes, which can be “prolate” (cigar-shaped) or “oblate” (like a discus). Experiments at ISOLDE can investigate the transitions between extremes, for example, the development of a neutron-halo structure in lithium-11, which makes this nucleus as big as a lead nucleus with 208 nucleons.

## Excitation and Decay

Radioactive decays and nuclear collisions can leave nuclei in excited states that decay to the ground state by emitting gamma rays. These can be detected by advanced germanium detectors. The properties of the gamma-rays (energy and angle) provide information on the excited states, which can be used to test theories.

## Nuclear astrophysics

One of the most fundamental and challenging questions of the 21st century is how the elements from iron to uranium were created. Nuclear reactions occurring in explosive stellar environments, such as novae, supernovae are believed to play an important role in the synthesis of these heavier elements. The pathways of the reactions leading to them involve short-lived radioactive exotic nuclei, which can be studied at ISOLDE.

## Fundamental symmetries

The nuclei produced at ISOLDE, with proton-to-neutron numbers varying over a wide range, provide an interesting microscopic laboratory for low-energy tests of the Standard Model of elementary particle physics. The high quality of the beams allows high-precision measurements of beta decay, particle correlations and atomic masses.

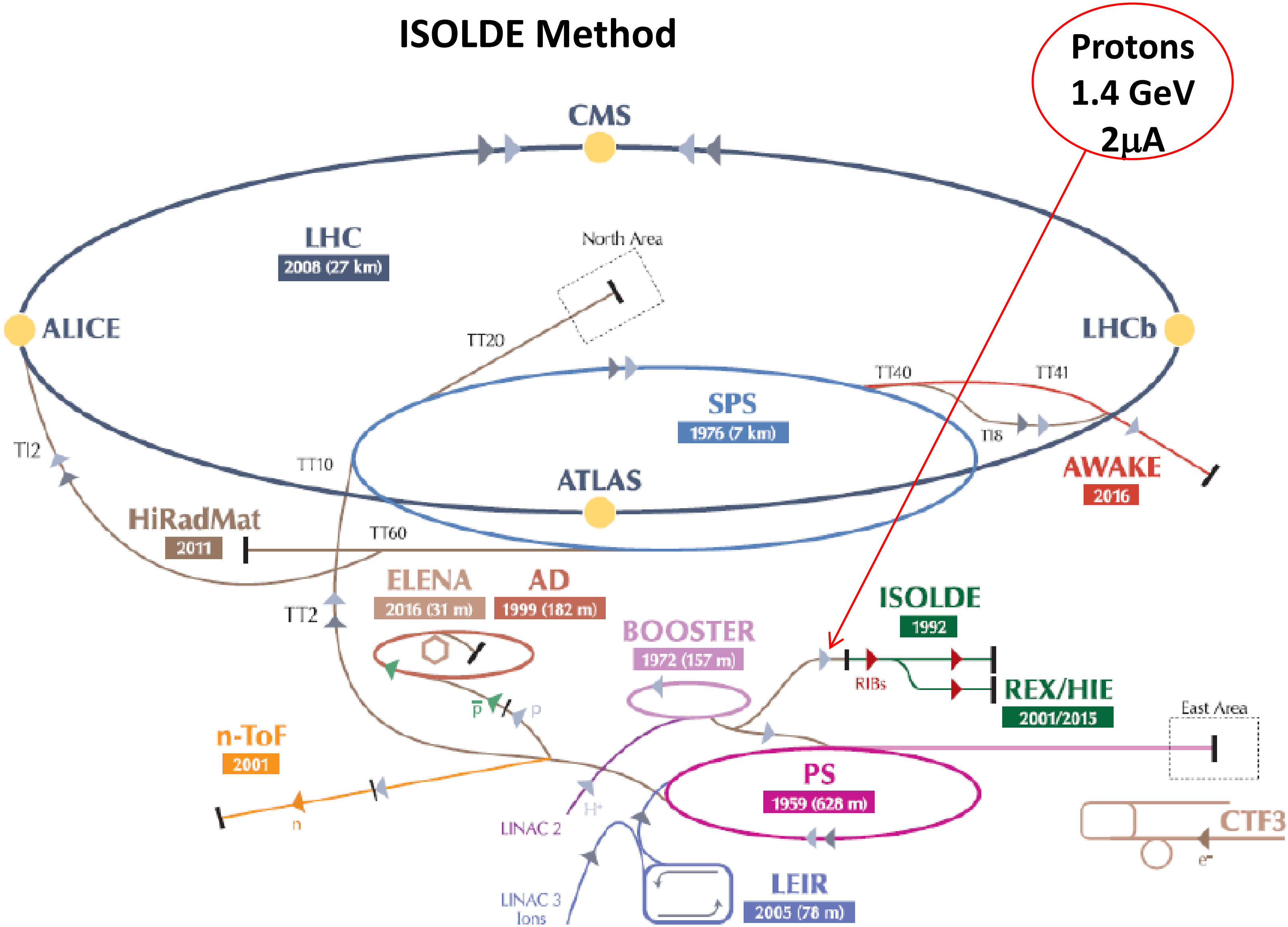
## Bio- and Medical physics

The applications in Biophysics aim at the study of the structure, bonding and transport mechanisms in a variety of biological molecules such as proteins and amino-acids. Other studies investigate which isotopes are most suitable for Medical diagnostics and cancer therapy.

## Condensed matter

The beams at ISOLDE can also be used to study structural, electrical, optical, magnetic and transport properties in a variety of technologically and fundamentally relevant materials, including semiconductors, metals, high-temperature superconductors and ceramic oxides.

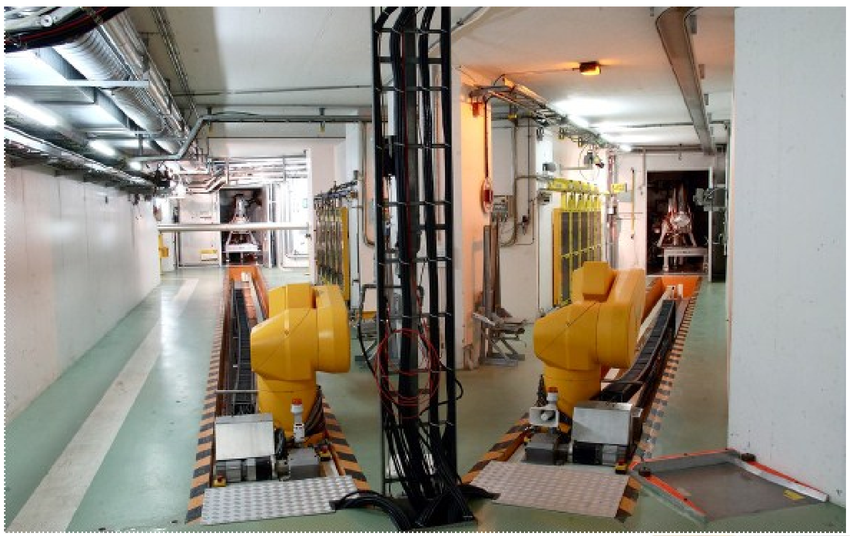
# ISOLDE Method

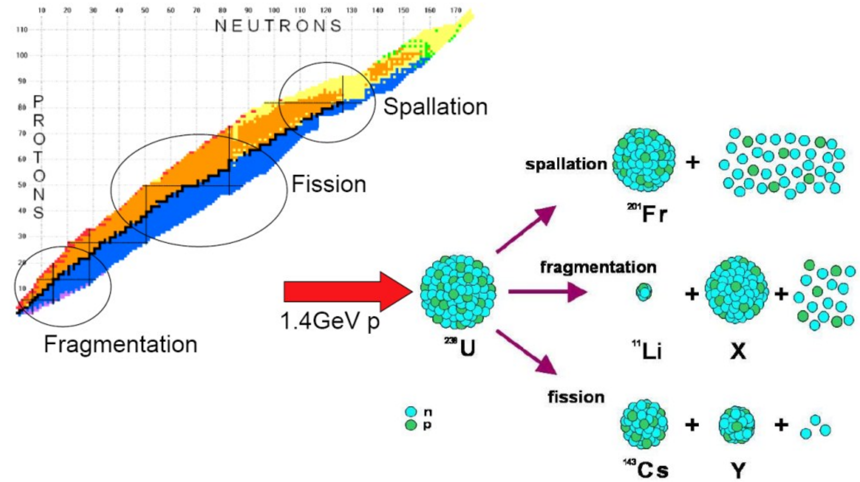


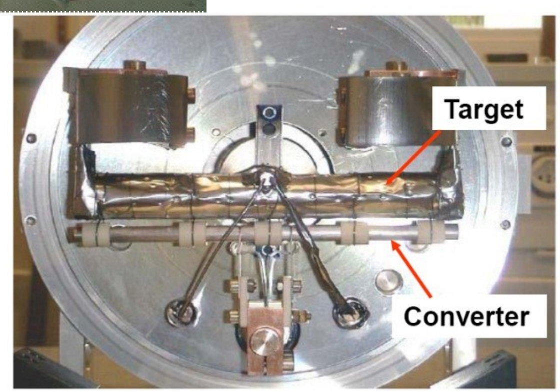
# ISOLDE Method

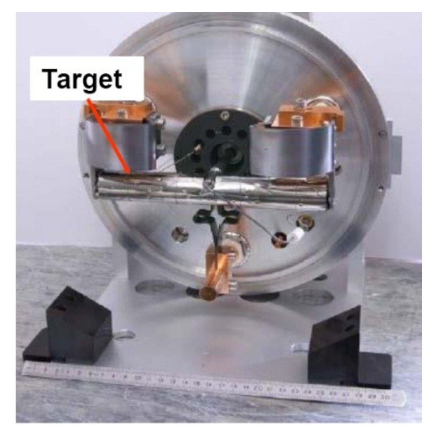
## Production

ISOLDE produces exotic nuclei in reactions between protons of 1.4 GeV energy and stable nuclei in a range of special targets. Multiple reactions take place, generating a vast range of nuclei. The targets are heated so that the exotic radioactive species diffuse out quickly before they decay.





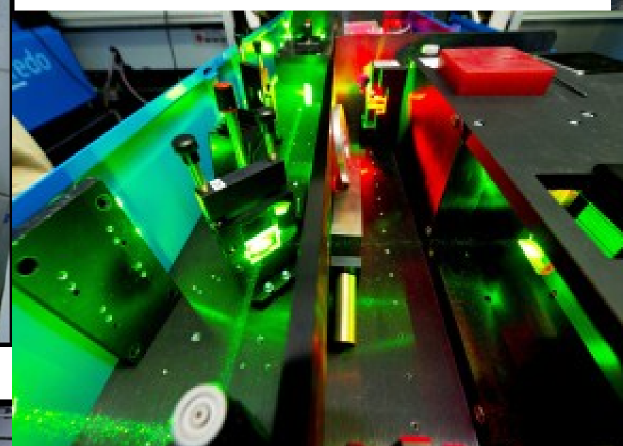
# ISOLDE Method

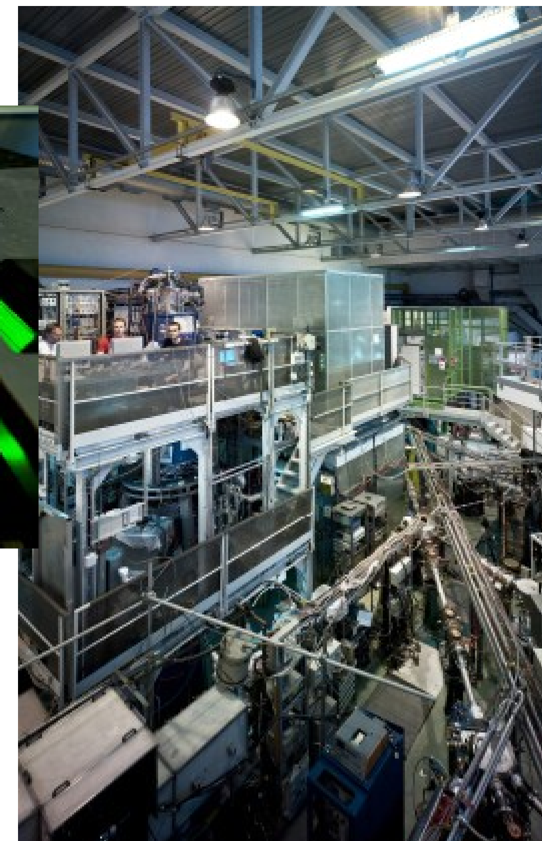
## Selection

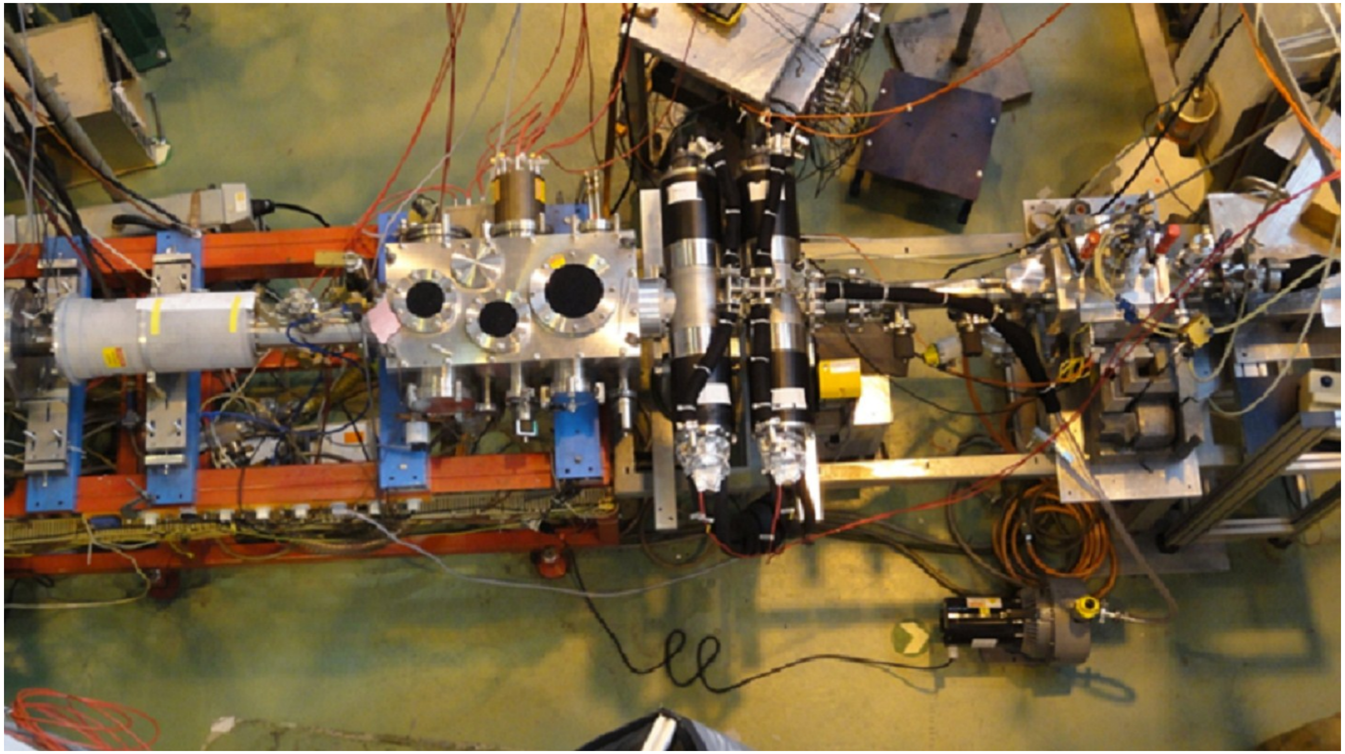
To produce a beam of a chosen exotic nucleus requires methods to extract the nuclei as ions and to separate them electromagnetically from other species. ISOLDE has a very selective ionization technique that uses several wavelengths of laser light simultaneously to pick out specific elements.

GPS: M/ΔM=2400


HRS: M/ΔM=5000

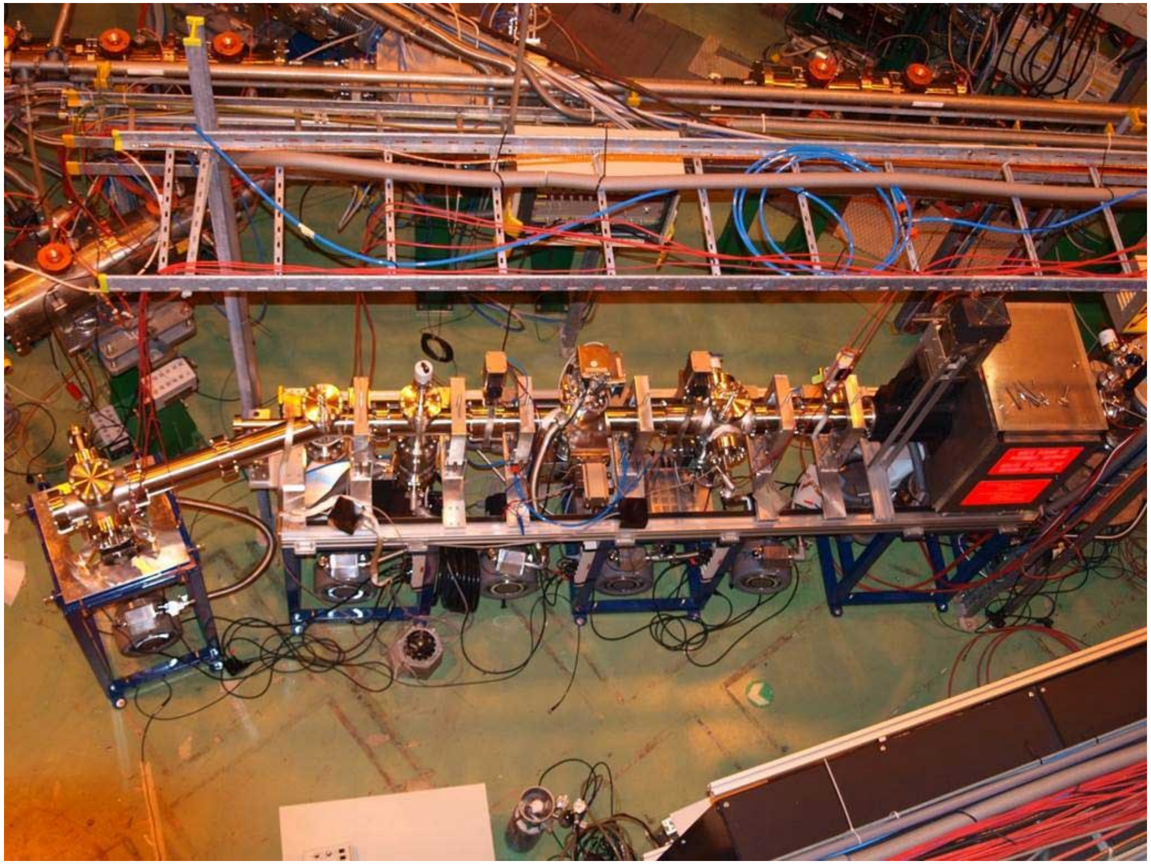





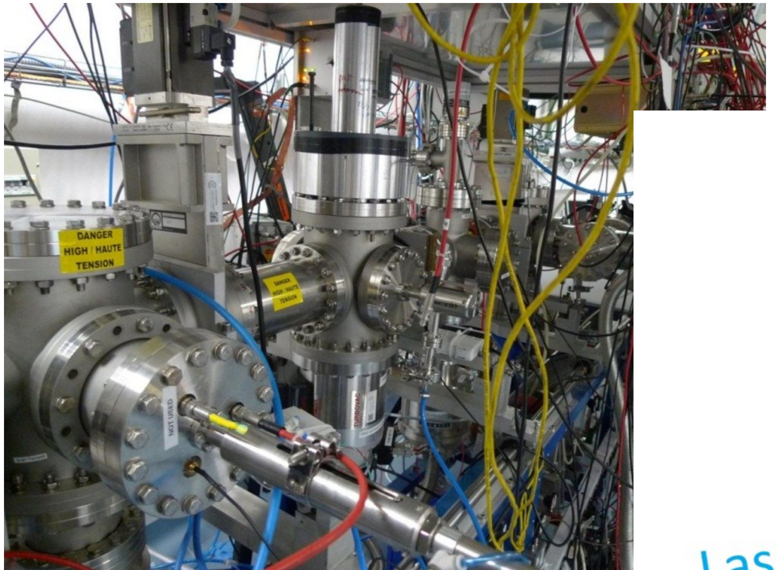


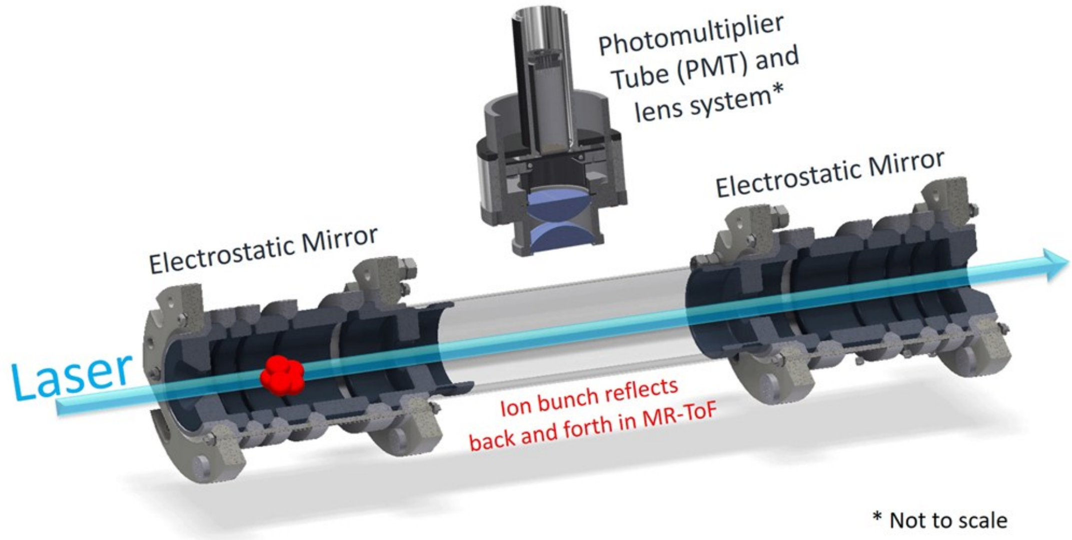
**COLLAPS (COLlinear LAser SPectroscopy)**

Its aim is the investigation of ground state properties of exotic, short lived nuclei, such as spins, electro-magnetic moments and charge radii. All these observables contribute widely to our understanding of the nuclear force – they give valuable information about the coupling between nucleons, about symmetry of the nuclear wave-functions and thus about the symmetry of the nuclear interaction itself.

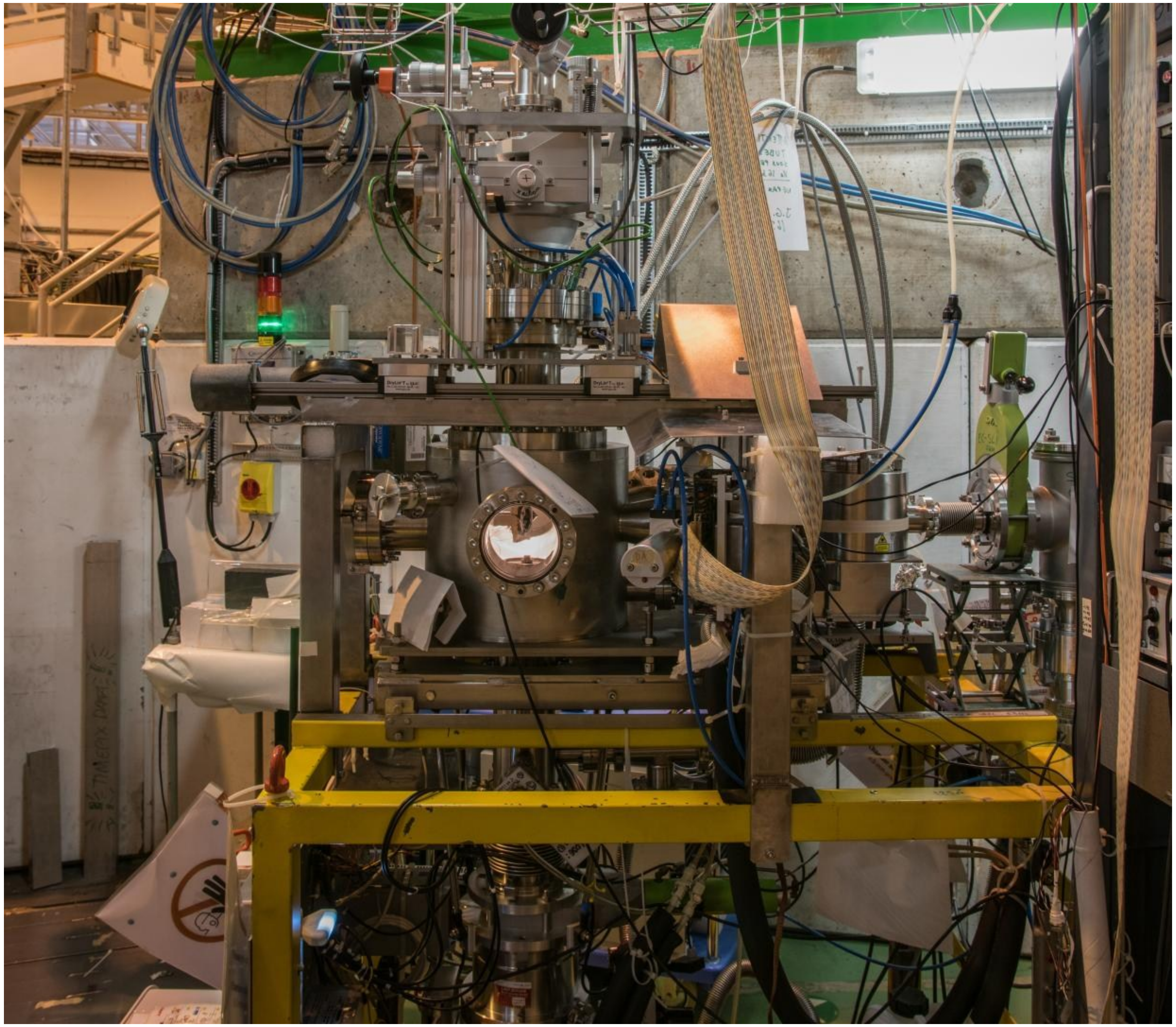


**CRIS (Collinear Resonance Ionization Spectroscopy) -** experiment at CERN ISOLDE is joining together the high resolution of collinear laser spectroscopy with the high efficiency and selectivity of resonant ionization. It is used to study the ground-state properties of exotic nuclei, such as spins, nuclear moments and shapes, and to produce beams of high isomeric purity for dedicated decay studies.

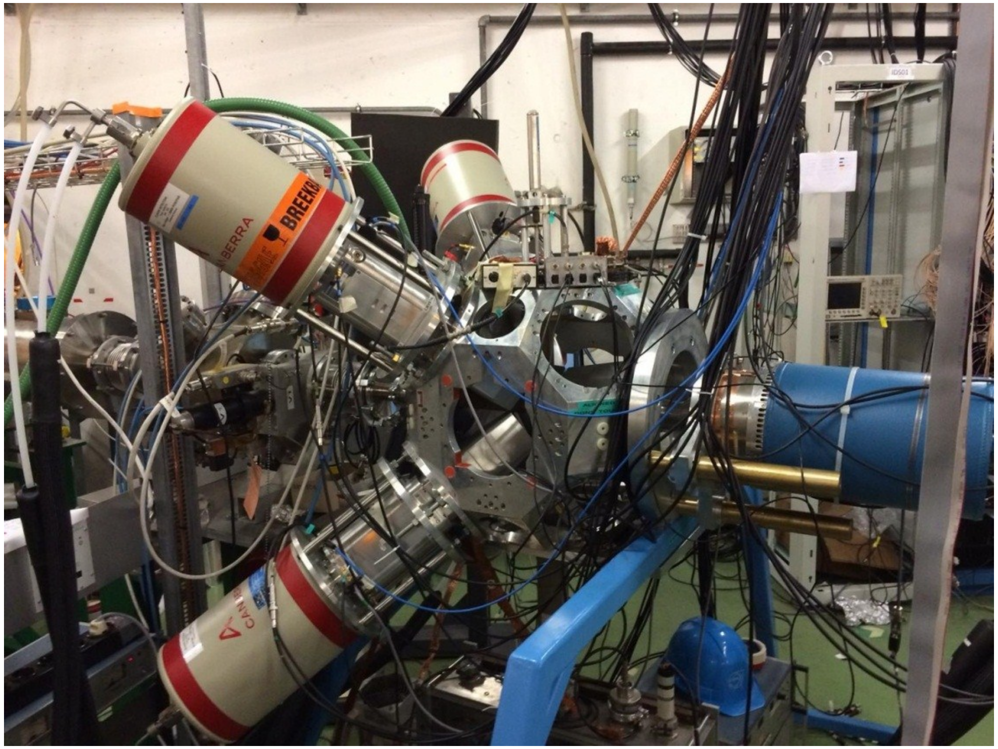



**MIRACLS** (Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy) at ISOLDE aims to measure nuclear ground-state properties such as the size, shape and electromagnetic moments of rare radioactive isotopes. These properties are extracted from the measurements of the isotopes' hyperfine structure using laser spectroscopy. MIRACLS' goal is to increase the sensitivity of conventional, fluorescence-based collinear laser spectroscopy by confining the investigated ions in an ion trap. This novel scheme allows for the ions to be probed up to several thousands of times.



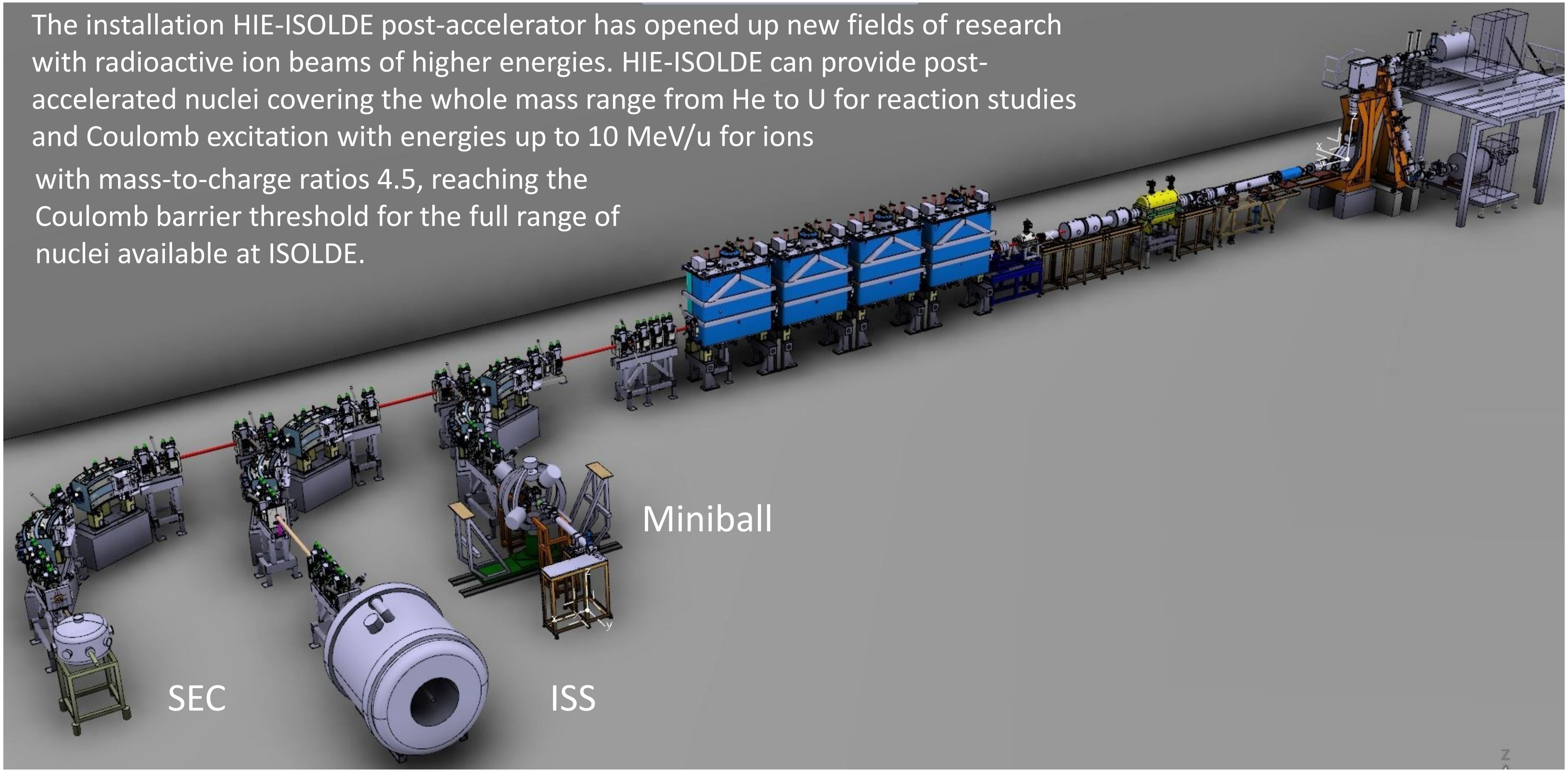
**EC-SLI (Emission Channeling with Short-Lived Isotopes)** is dedicated to studying the lattice location of dopants and impurities in single crystals and epitaxial thin films. The main fields of work currently include semiconductor doping for applications in electronics and colour centers in diamond and related materials for quantum technologies, among others. While EC-SLI is the on-line setup for short-lived isotopes located at the GHM beam line, it is complemented by three off-line ones, also at ISOLDE, which are suitable for longer-lived isotopes with half-lives above a few hours.

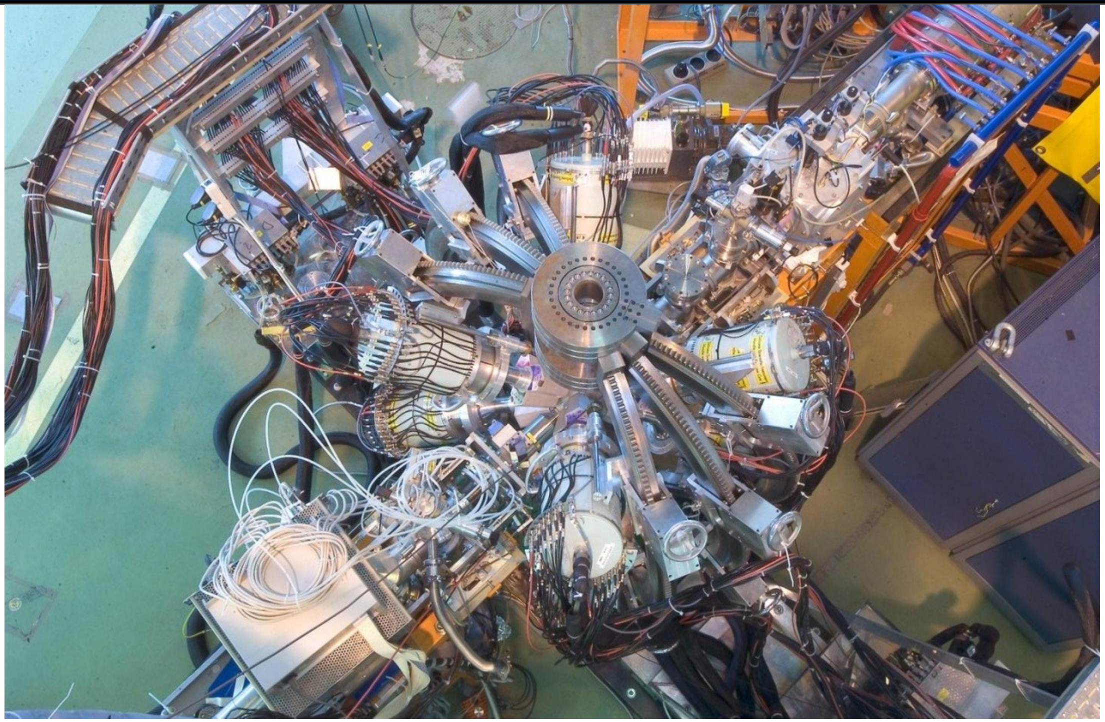


**IDS (ISOLDE Decay Station)** is a permanent experiment at the ISOLDE facility dedicated to measure the decay properties of radioactive species of importance for nuclear structure, nuclear engineering and astrophysics. Gamma-ray detection is provided by four HPGe clovers and one MiniBall HPGe cluster. A variety of experimental systems can be coupled to the station for specialized decay measurement, such as fast timing measurement of excited states lifetimes, proton and alpha particle emission, and neutron time of flight detectors for neutron energy spectroscopy. This makes the IDS an ideal tool to study the nuclear properties of species across the nuclear chart, from the lightest species that fragment in charged particles to the beta-delayed fission of the heaviest nuclei.

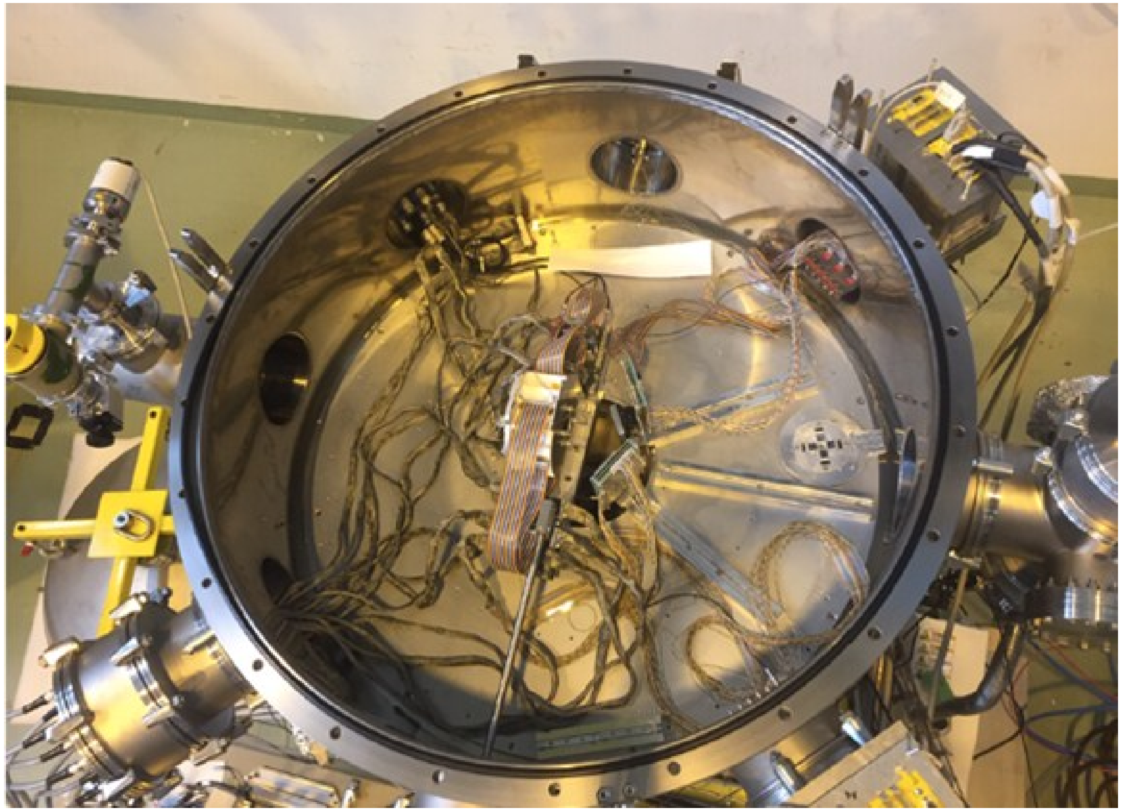
# HIE (High Intensity and Energy)-ISOLDE

The installation HIE-ISOLDE post-accelerator has opened up new fields of research with radioactive ion beams of higher energies. HIE-ISOLDE can provide post-accelerated nuclei covering the whole mass range from He to U for reaction studies and Coulomb excitation with energies up to 10 MeV/u for ions with mass-to-charge ratios 4.5, reaching the Coulomb barrier threshold for the full range of nuclei available at ISOLDE.



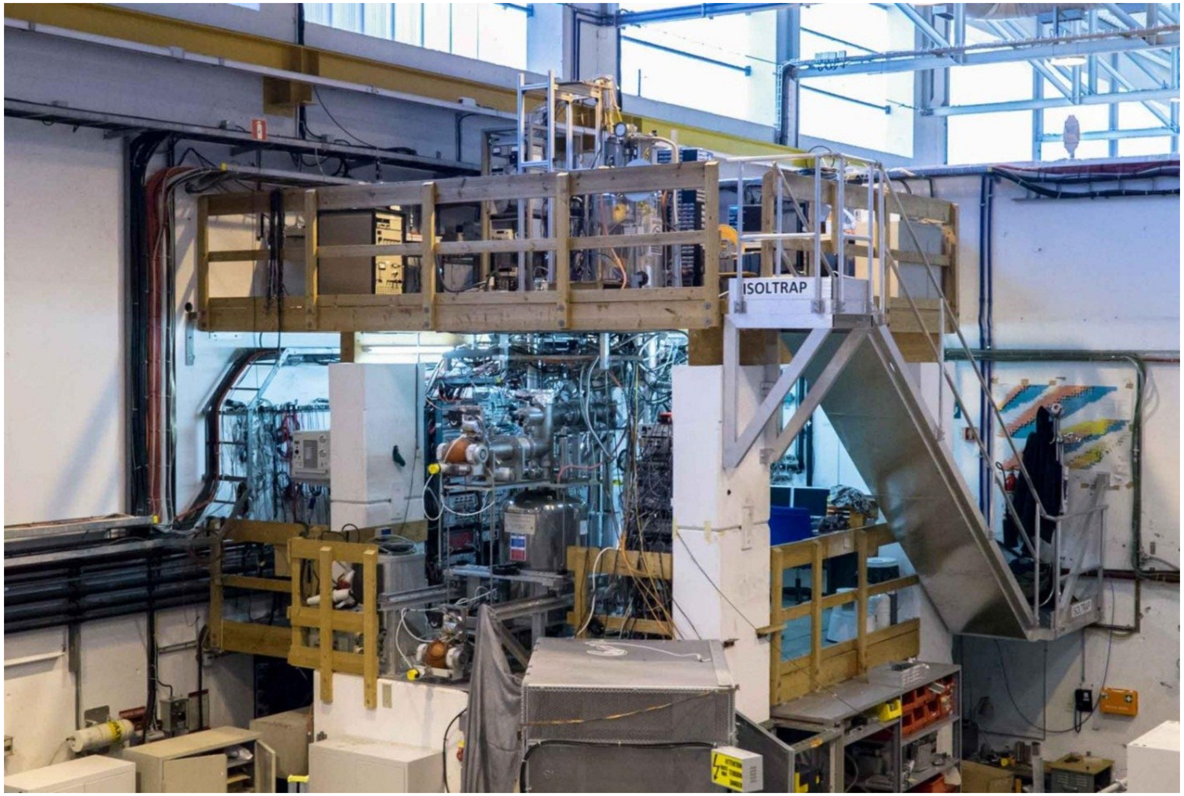


**Miniball** high-resolution germanium detector array has been operational at REX-ISOLDE at CERN for over 10 years. This array consists of 24 six-fold segmented, tapered, encapsulated high-purity germanium crystals and was specially designed for low multiplicity experiments with low-intensity radioactive ion beams (RIB). For work with rare-isotope beams, the multiplicities are low (often only a few states are excited) and the yields of such beams are usually much lower than for conventional experiments, so efficiency is paramount. High granularity and high efficiency were achieved by the segmentation of the charge-collection electrodes of the Ge detectors and the use of pulse-shape analysis to determine the position of the first interaction of the γ ray within the Ge crystal, giving a spatial resolution significantly finer than the dimensions of the crystal. The Miniball array has been used in numerous Coulomb-excitation and transfer-reaction experiments with exotic RIBs, produced at the ISOLDE facility.

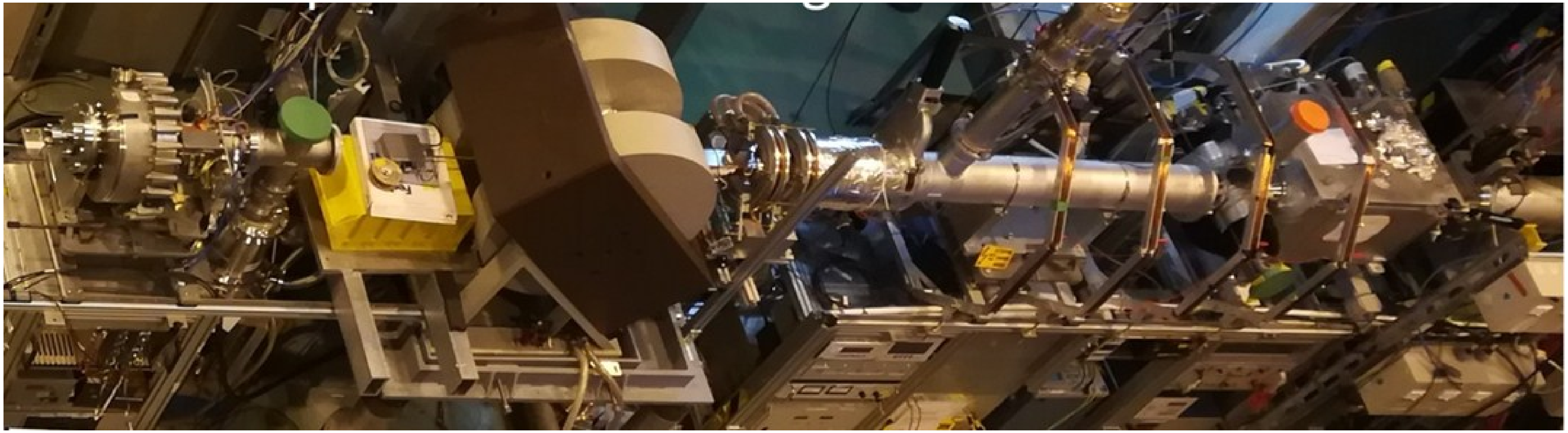


**SEC (Scattering Experiments Chamber)** at beamline of HIE-ISOLDE is an experimental station to facilitate diversified reaction experiments. The chamber is sufficiently big to accumulate a variety of charge particle detectors as well as scintillator detectors for gamma detection. It is equipped with a rotational disc of 50 cm radius radially graduated and supplied with Al-bars for precise support and positioning of detectors. This makes SEC a versatile station for reaction experiments to study low-lying resonances in light nuclei via transfer reactions.


**ISS (ISOLDE Solenoidal Spectrometer )** is being developed for precision studies of inelastic scattering and transfer reactions induced by radioactive ion beams from HIE-ISOLDE. A broad science programme addressing important topics in nuclear structure and nuclear astrophysics is envisaged. The ISS has an advanced design that employs the proven HELIOS concept, whereby light charged particles emitted during the nuclear reactions are transported with high efficiency by the solenoidal magnetic field to an array of position-sensitive silicon detectors mounted on its axis. Measuring the particle energies and interaction positions in the silicon array allows the reaction Q-value to be determined without the problem of kinematic compression encountered in more conventional approaches. The ISS array currently under development comprises 24 double-sided silicon strip detectors with ASIC readout and is designed to allow Q-value resolutions approaching 20 keV to be achieved.




Precision mass measurements are performed at the mass spectrometer **ISOLTRAP** with a relative mass uncertainty routinely reaching to $1*10^{-8}$. The time-of-flight detection technique is employed to determine the frequency of an ion stored in a Penning trap, from which the mass can be extracted. The system has studied nuclides with half-lives below 100ms and production yields of less than 1000 ions per second, supplied by the isotope separator ISOLDE at CERN. The nuclides investigated range from light systems - such as 17Ne - to heavy ones - such as 233Fr, thus, giving insight into numerous physics topics, e.g., to probe nuclear structure and answer questions related to stellar nucleosynthesis or fundamental tests.



**VITO (Versatile Ion polarisation Technique Online)** is a permanent beamline at the ISOLDE facility devoted to versatile studies with laser-polarised radioactive beams. The research at VITO is centered around the details of the weak force, properties of short-lived unstable nuclei and even chemistry and biology. The setup for spin polarisation can be coupled to several end stations. One of them is devoted to Nuclear Magnetic Resonance on unstable nuclei, which is a billion times more sensitive than conventional NMR, and is now used to study the interaction of metal ions with biomolecules. Soon, a new setup will be also added to VITO, devoted to beta, gamma, and neutron emission of polarised nuclei.

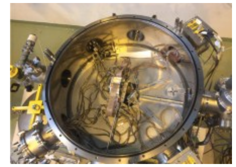
## WISArD (Weak Interaction Searches on Ar Device)

The WISArD experiment has been set up for investigation of the weak interaction focussing on the beta-neutrino angular correlation coefficient of $^{32}$Ar by looking at beta-delayed protons emitted from the daughter nucleus $^{32}$Cl. As the protons are emitted from a moving source, the proton energy distribution is thus subject to kinematical broadening and a kinematical shift. Protons from the isobaric analogue state fed by a Fermi-type beta decay allow searching for small contribution of scalar currents to the dominant vector current, whereas protons from Gamow-Teller-type beta decays allow searching for tensor contributions to the dominant axial-vector current. The experiment aims for a sensitivity limit of 0.1% for these exotic currents.

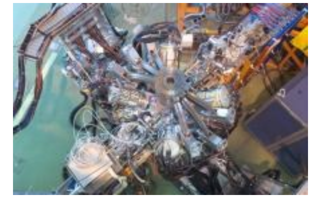
Петербургский институт ядерной физики им. Б. П. Константинова
Национального исследовательского центра «Курчатовский институт»

VITO


SEC

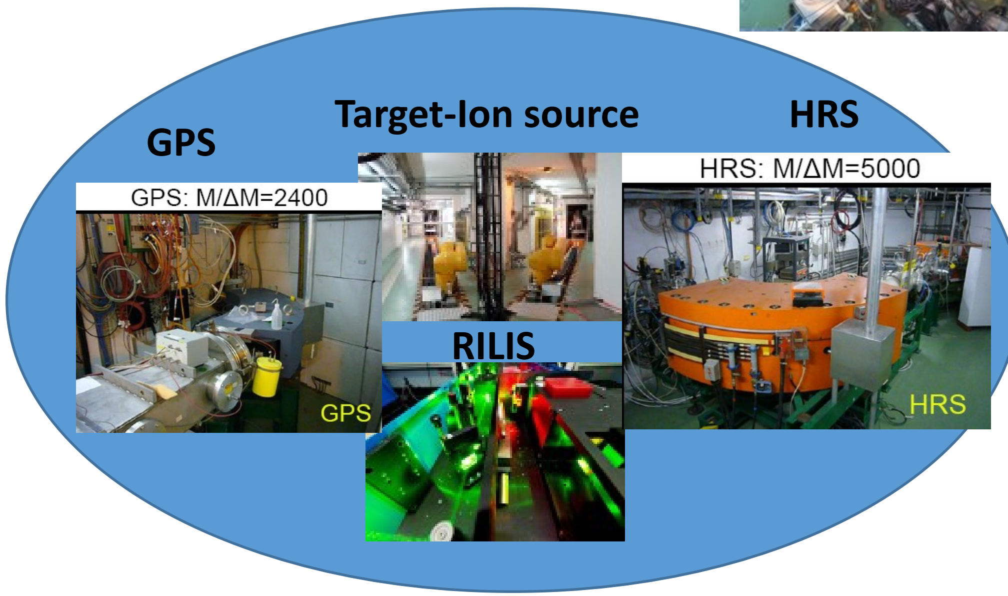


MINIBALL



WISArD

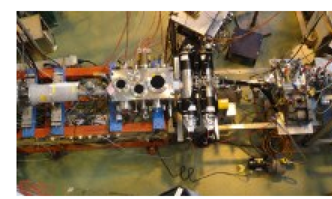
MIRACLS



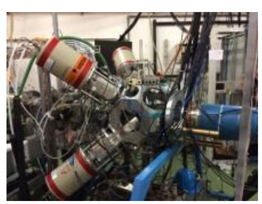

ISS


ISOLTRAP

COLLAPS

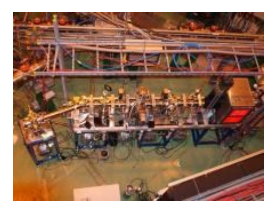


IDS



CEC-SLI

CRIS



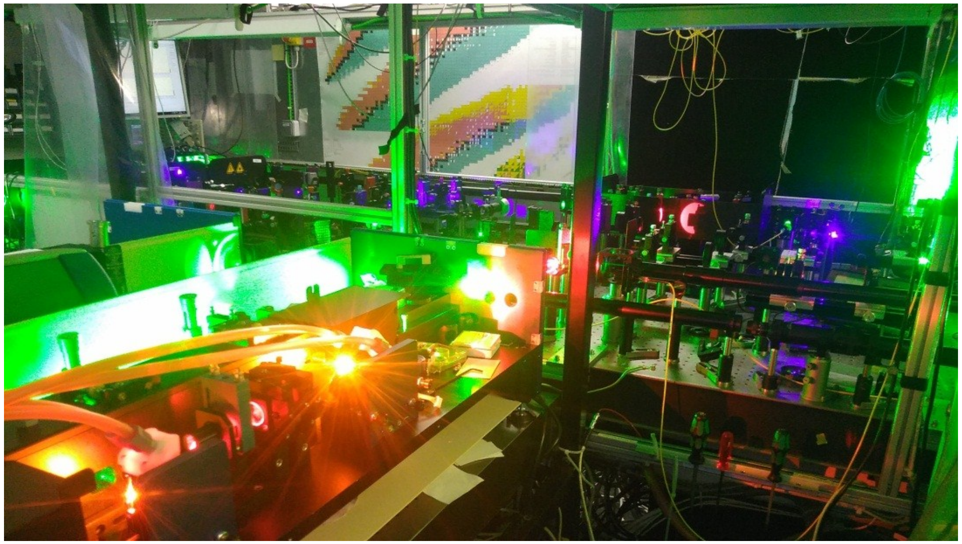
50 ЛЕТ НА ПИКЕ НАУКИ

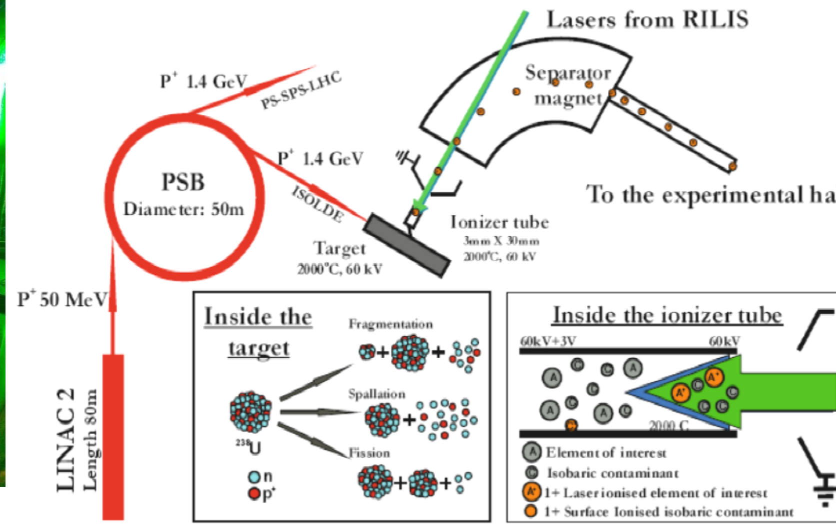
# Эксперименты на лазерном спектрометре RILIS (ISOLDE)

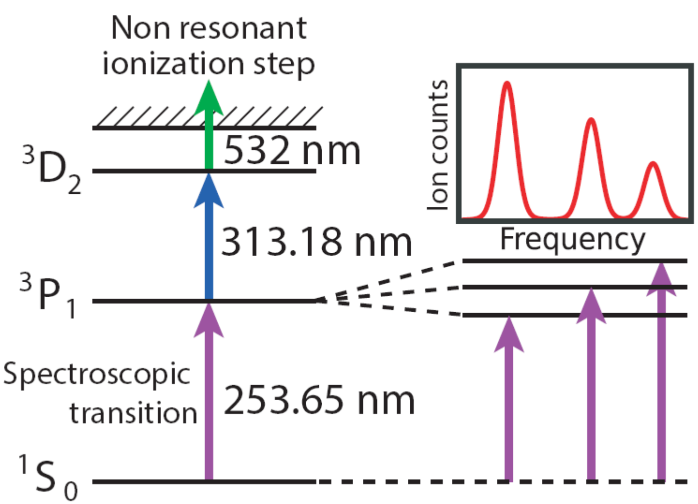
**Лазерная спектроскопия изотопов ртути (IS 598 )**

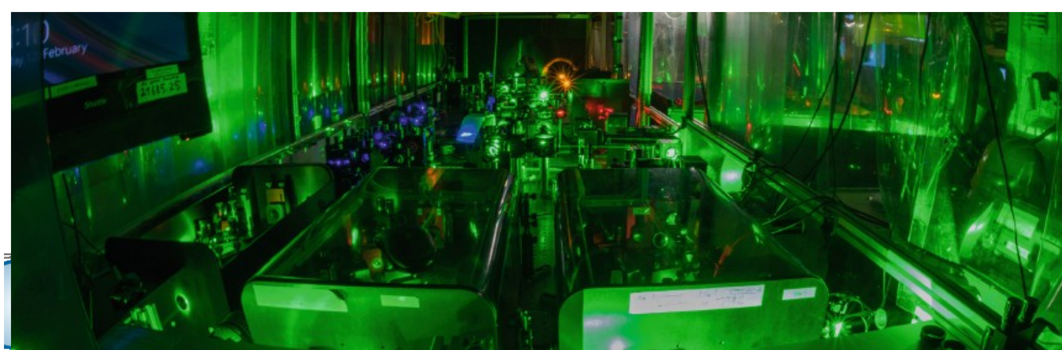
**Исследование сосуществования и эволюции форм ядер висмута методом спектроскопии в лазерном ионном источнике и запаздывающего деления ядра $^{188}$Bi (IS 608)**

# Эксперименты на лазерном спектрометре RILIS (ISOLDE)





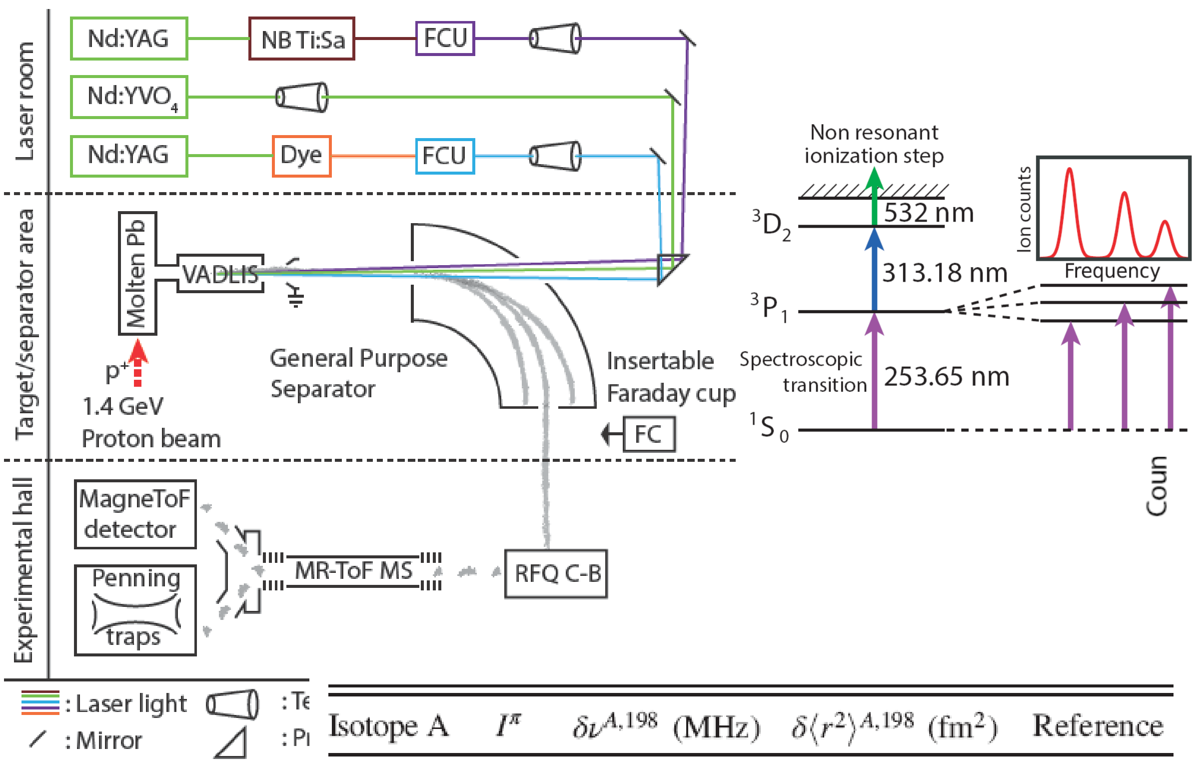
## Эксперименты на лазерном спектрометре RILIS (ISOLDE)

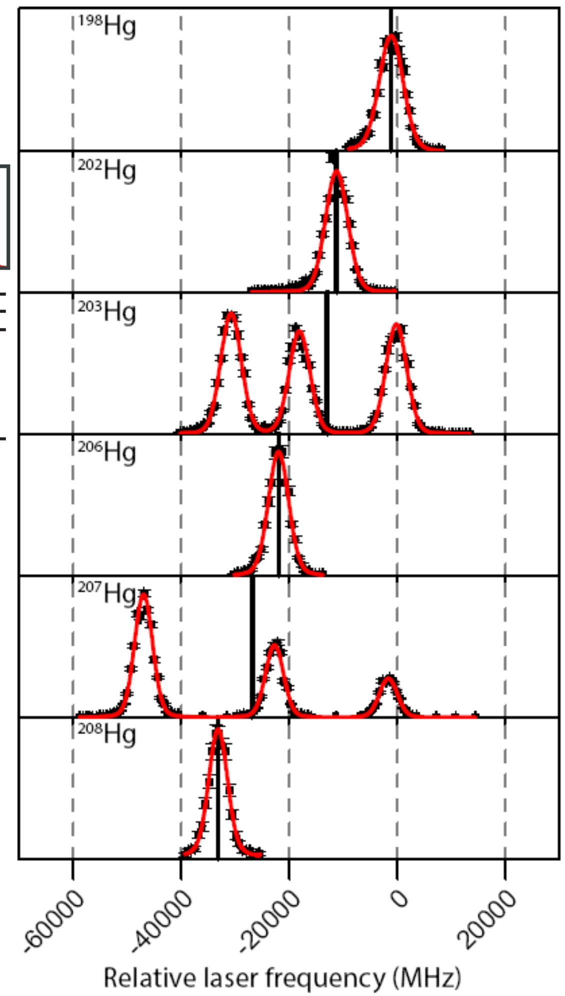
### Ядра ртути в окрестности нейтронной подоболочки N=126

PHYSICAL REVIEW LETTERS **126**, 032502 (2021)

**Laser Spectroscopy of Neutron-Rich $^{207,208}$Hg Isotopes: Illuminating the Kink and Odd-Even Staggering in Charge Radii across the $N = 126$ Shell Closure**

# Эксперимент

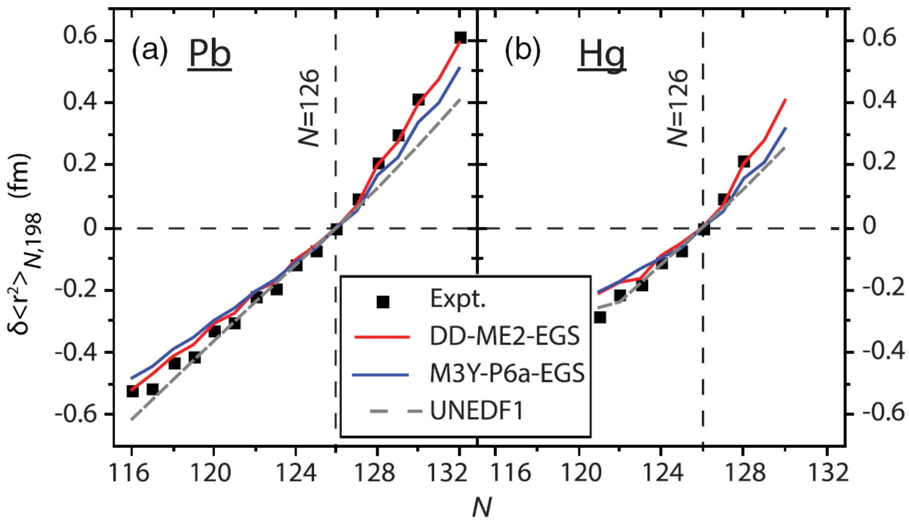


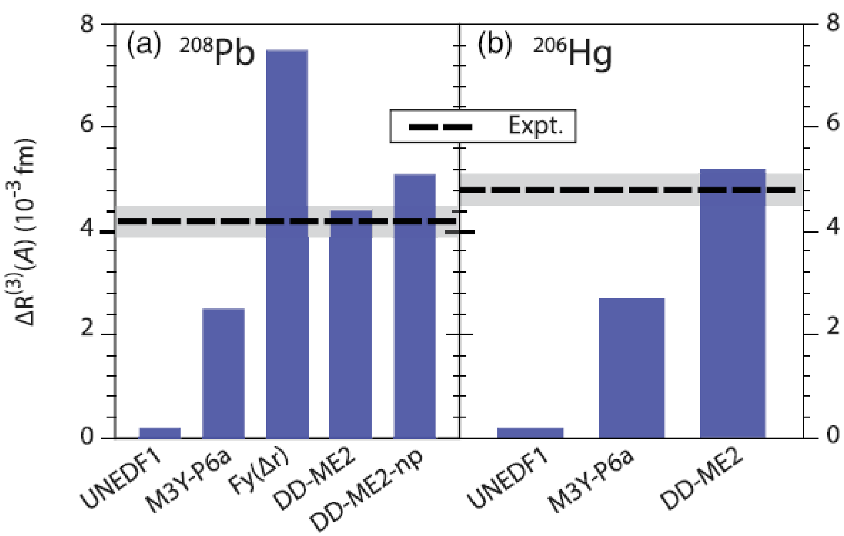




| Isotope A | $I^{\pi}$ | $\delta\nu^{A,198}$ (MHz) | $\delta\langle r^2\rangle^{A,198}$ (fm$^2$) | Reference |
|---|---|---|---|---|
| 202 | 0 | −10 100(180) | 0.197(3){14} | This Letter |
| | | −10 102.4(42) | 0.1973(1){138} | [16] |
| 203 | $5/2^-$ | −11 870(200) | 0.232(4){16} | This Letter |
| | | −11 750(180) | 0.2295(35){161} | [16] |
| 206 | 0 | −20 930(160) | 0.409(3){29} | This Letter |
| | | −20 420(80) | 0.3986(16){280} | [16,39] |
| 207 | $(9/2^-)$ | −25 790(190) | 0.503(4){35} | This Letter |
| 208 | | −32 030(160) | 0.624(3){44} | This Letter |

# «Оболочечный» и «четно-нечетный» эффекты в области N=126

Обнаружен «оболочечный» эффект, т.е. характерный излом в изотопической зависимости зарядовых радиусов ртути при N = 126, а также выраженный четно-нечетный эффект: радиусы нечетно-нейтронных изотопов оказываются меньше среднего арифметического радиусов их четно-нейтронных соседей.




количественная характеристика оболочечного эффекта

$$\Delta R^{(3)}(A) = \frac{1}{2}[R(A-2) + R(A+2) - 2R(A)]$$

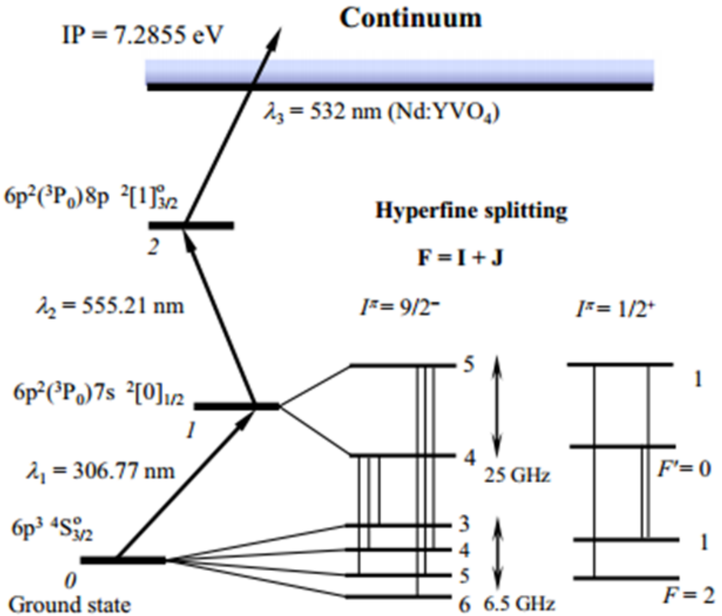
$$\text{where } R(A) = \langle r^2\rangle^{1/2}(A)$$

# Лазерная спектроскопия изотопов висмута

PHYSICAL REVIEW LETTERS **127,** 192501 (2021)

## Large Shape Staggering in Neutron-Deficient Bi Isotopes

# Лазерная спектроскопия изотопов висмута



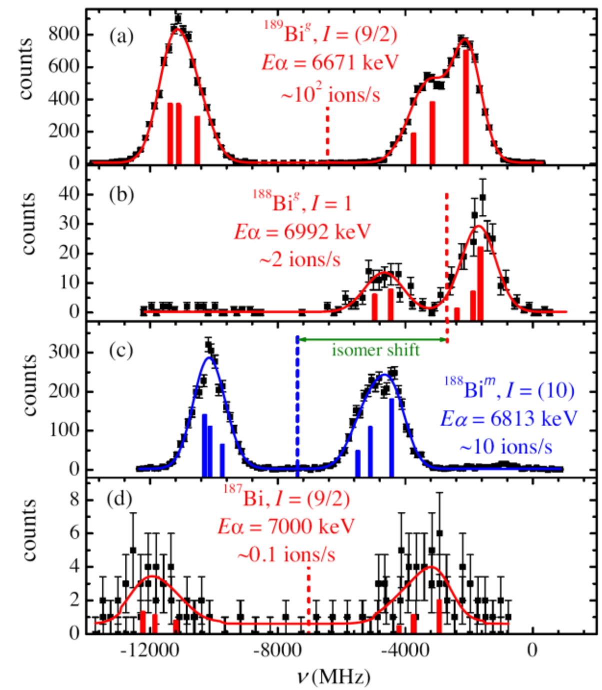
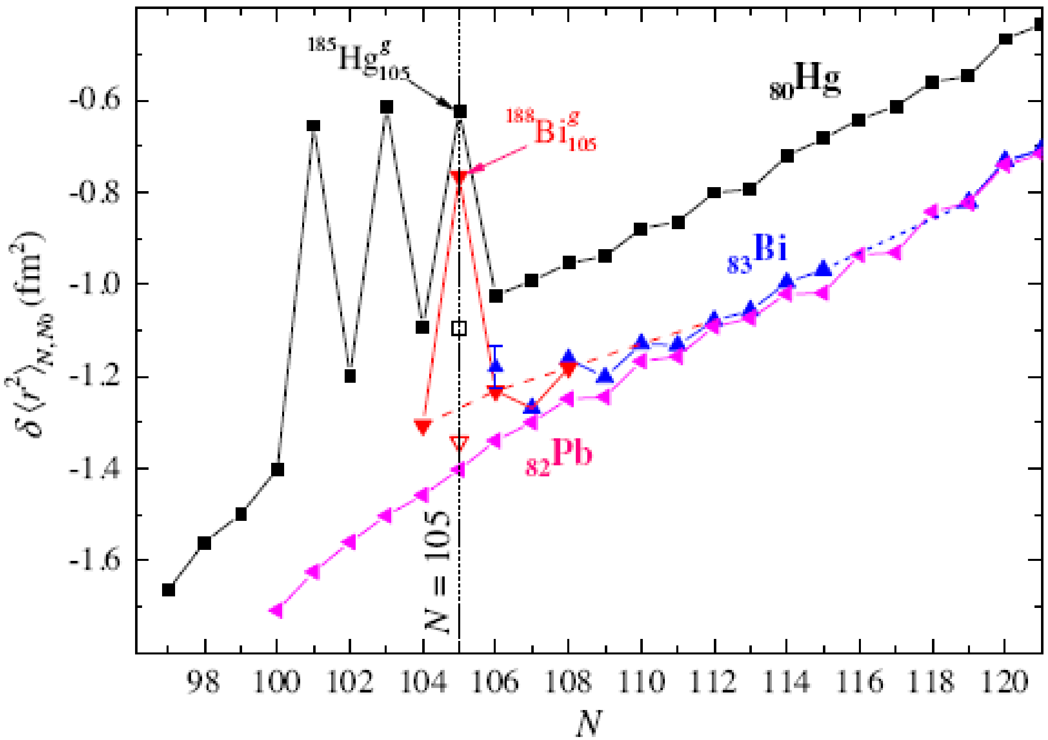




TABLE I. IS ($\delta\nu_{A,209}$), hfs constants ($a_2$, $b_1$), changes in mean-square charge radius ($\delta\langle r^2\rangle_{A,209}$), and magnetic ($\mu$) and quadrupole ($Q_s$) moments for investigated Bi nuclei.

| $A$ | $I^\pi$ | $\delta\nu_{A,209}$ (MHz) | $\delta\langle r^2\rangle_{A,209}$ (fm$^2$)$^a$ | $a_2$ (MHz) | $\mu(\mu_N)^a$ | $b_1$(MHz) | $Q_s(b)$ |
|---|---|---|---|---|---|---|---|
| 187 | (9/2$^-$) | −22990(250) | −0.949(11){47} | 4379(32) | 3.638(27){20} | −910(400) | −1.26(55) |
| 188$g$ | 1$^{(+)}$ | −8370(160) | −0.335(6){17} | 5380(280) | 0.994(51){20} | 620(270) | +0.85(37) |
| 188$m$ | (10$^-$) | −23670(100) | −0.978(4){49} | 1347(8) | 2.464(15){10} | −1220(320) | −1.68(45) |
| 189 | (9/2$^-$) | −20823(50) | −0.859(2){43} | 4413(7) | 3.667(6){20} | −1160(160) | −1.60(23) |
| | | −19900(1100)$^b$ | | 4500(330)$^b$ | | | – |
| 191 | (9/2$^-$) | −19610(50) | −0.810(2){40} | 4482(11) | 3.724(9){20} | −1023(85) | −1.41(13) |
| | | −19370(230)$^b$ | | 4440(60)$^b$ | | | – |

# Лазерная спектроскопия изотопов висмута

Сильный эффект чередования форм для нейтронно-дефицитных изотопов висмута




Величина параметра деформации

$\beta_Q = 0.25(7)$

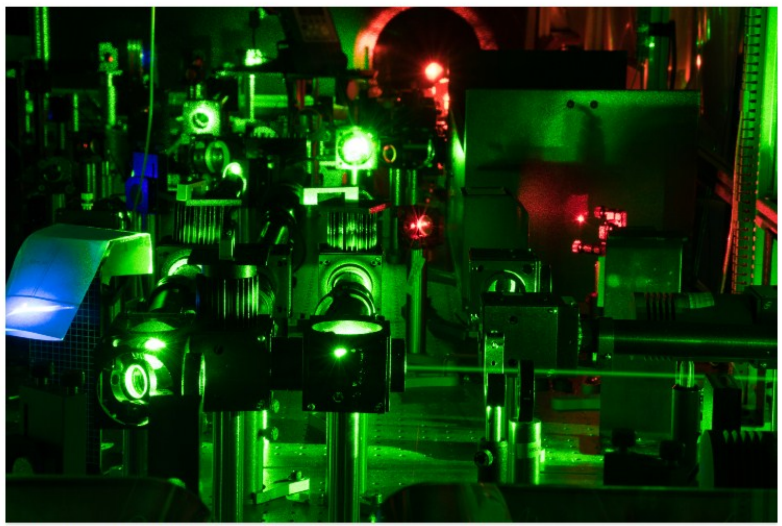
$\beta r = 0.28(2)$

Это лишь второй после ртути случай подобного поведения изотопической зависимости среднеквадратичных зарядовых радиусов, обнаруженный к настоящему времени. Измеренный здесь же квадрупольный электрический момент ядра $^{188}Bi^{g}$ указывает на сильную деформацию данного ядра.

# Bismuth isotopes also alternate from spheres to rugby balls

**The unusual nuclear physics phenomenon, first discovered at CERN's ISOLDE facility 50 years ago, had until now been seen only in mercury isotopes**

18 NOVEMBER, 2021 | By Ana Lopes



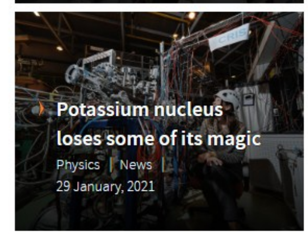
The ultrasensitive set-up used by the ISOLDE team to study bismuth isotopes. (Image: CERN)

Alternating from spheres to rugby balls is no longer the sole preserve of mercury isotopes, an international team at CERN's ISOLDE facility reports in a paper published in *Physical Review Letters*.

Isotopes are forms of a chemical element that have the same number of protons in their atomic nuclei but a

## Related Articles






View all news ›

## Лазерно-ядерная спектроскопия. Другие эксперименты

1. Ядерная спектроскопия $^{176,177,179}Au$: схемы распада, времена жизни, факторы задержки альфа распада, схемы уровней дочерних ядер и т. д.
2. α- и β-распад $^{183}Tl^{m}$: деформированные возбужденные состояния в сферическом $^{179}Au$.
3. Запаздывающее деление $^{178}Au$
4. Ядерная спектроскопия $^{214}Bi$: обнаружен новый долгоживущий изомер, существенно расширена схема уровней дочернего $^{214}Po$, проверка продвинутых shell-model расчетов.
5. Атомные расчеты аномалии стс в золоте и градиента электрического поля электронов на ядре висмута (для извлечения квадрупольного момента ядра)
6. Времена жизни возбужденных уровней $^{214}Po$
7. Изомерно-селективная ядерная спектроскопия вблизи дважды магического $^{132}Sn$

# Ближайшие перспективы: новые эксперименты на RILIS

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

## Laser assisted studies of $\beta$-delayed fission in $^{178,176}$Au and of the structure of $^{175}$Au

May 13, 2020

B. Andel[1,2], A. N. Andreyev[3], S. Antalic[2], A. E. Barzakh[4], T. Berry[5], M. J. G. Borge[6], J. A. Briz[6], A. Broniš[2], T. E. Cocolios[1], K. Chrysalidis[7], J. G. Cubiss[3], H. De Witte[1], K. Dockx[1], D. V. Fedorov[4], V. N. Fedosseev[7], L. M. Fraile[8], H. O. U. Fynbo[9], P. T. Greenlees[10], L. J. Harkness-Brennan[11], R. Heinke[1], J. Johnson[1], D. T. Joss[11], D. S. Judson[11], J. Konki[10], J. Kurcewicz[7], I. Lazarus[12], R. Lică[13], M. Madurga[7], N. Marginean[13], B. A. Marsh[7], C. Mihai[13], P. L. Molkanov[4], P. Mosat[2], E. Nacher[14], A. Negret[13], K. Nishio[15], R. D. Page[11], S. Pascu[13], A. Perea[6], V. Pucknell[12], P. Rahkila[10], E. Rapisarda[7], M. D. Seliverstov[4], A. Sott[3], C. Sotty[13], P. Spagnoletti[16], M. Stryjczyk[1], O. Tengblad[6], I. Tsekhanovich[17], P. Van Duppen[1], V. Vedia[8], R. Wadsworth[3], N. Warr[18], and S. G. Wilkins[7]

[1] *KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium*
[2] *Department of Nuclear Physics and Biophysics, Comenius University in Bratislava, 84248 Bratislava, Slovakia*
[3] *Department of Physics, University of York, Heslington, York, YO10 5DD, United Kingdom*
[4] *Petersburg Nuclear Physics Institute, NRC Kurchatov Institute, 188300 Gatchina, Russia*
[5] *Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*
[6] *Instituto de Estructura de la Materia, CSIC, Serrano 113 bis, E-28006 Madrid, Spain*
[7] *CERN, CH-1211 Geneve 23, Switzerland*
[8] *Grupo de Física Nuclear, Universidad Complutense de Madrid, 28040, Madrid, Spain*
[9] *Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark*
[10] *University of Jyväskylä, Department of Physics, P.O. Box 35, FI-40014, Jyväskylä, Finland*
[11] *Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[12] *STFC Daresbury, Daresbury, Warrington WA4 4AD, United Kingdom*
[13] *"Horia Hulubei" National Institute for R & D in Physics and Nuclear Engineering, RO-077125 Bucharest, Romania*
[14] *Instituto de Física Corpuscular, CSIC - Universidad de Valencia, E-46980, Valencia, Spain*
[15] *Advanced Science Research Center, JAEA, Tokai, Ibaraki 319-1195, Japan*
[16] *Simon Fraser University, Burnaby, Canada*
[17] *CENBG, Bordeaux, France*
[18] *Institut für Kernphysik, Universität zu Köln, 50937 Köln, Germany*

CERN-INTC-2020-032 / INTC-P-558
13/05/2020

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

## Investigation of octupole deformation in neutron-rich actinium using high-resolution in-source laser spectroscopy

May 13, 2020

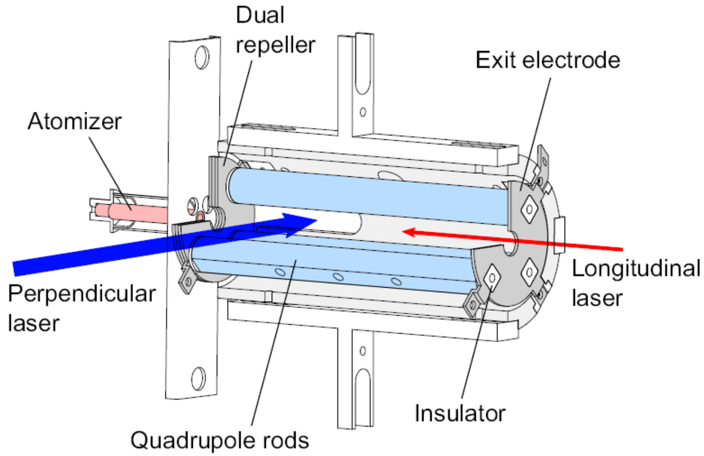
B. Andel[1], A. N. Andreyev[2], M. Au[3], A. E. Barzakh[4], A. J. Brinson[5], K. Chrysalidis[3], T. E. Cocolios[1], B. S. Cooper[6], J. Cubiss[2], H. De Witte[1], K. Dockx[1], D. V. Fedorov[4], V. N. Fedosseev[3], K. T. Flanagan[7], R. F. Garcia Ruiz[5], F. P. Gustafsson[1], R. Heinke[1], J. Johnson[1], M. Kadja[8], V. Leask[1,3], R. Lica[9], B. A. Marsh[3], P. L. Molkanov[4], G. Neyens[1,3], H. A. Perrett[7], S. Raeder[10], B. Reich[3], C. M. Ricketts[7], S. Rothe[3], M. D. Seliverstov[4], S. M. Udrescu[5], P. Van Duppen[1], A. R. Vernon[1], E. Verstraelen[1], K. Wendt[8], J. Wessolek[7], S. G. Wilkins[3], W. Wojtaczka[1], X. F. Yang[6]

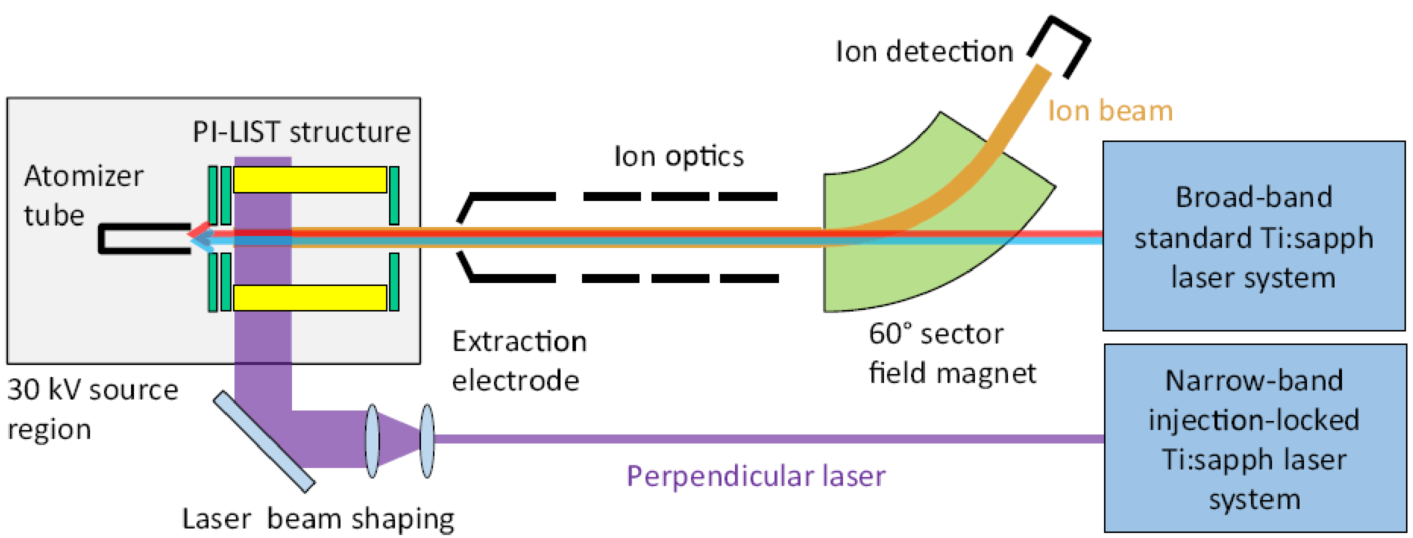
[1] *KU Leuven, Belgium*
[2] *University of York, United Kingdom*
[3] *CERN EN-STI, Switzerland*
[4] *PNPI Gatchina, Russia*
[5] *Massachusetts Institute of Technology, United States*
[6] *Peking University, China*
[7] *The University of Manchester, United Kingdom*
[8] *Johannes Gutenberg University Mainz, Germany*
[9] *Horia Hulubei National Institute of Physics and Nuclear Engineering, Romania*
[10] *GSI Helmholtzzentrum für Schwerionenforschung, Germany*

2020-029 / INTC-P-556

# Ближайшие перспективы: новые эксперименты на RILIS

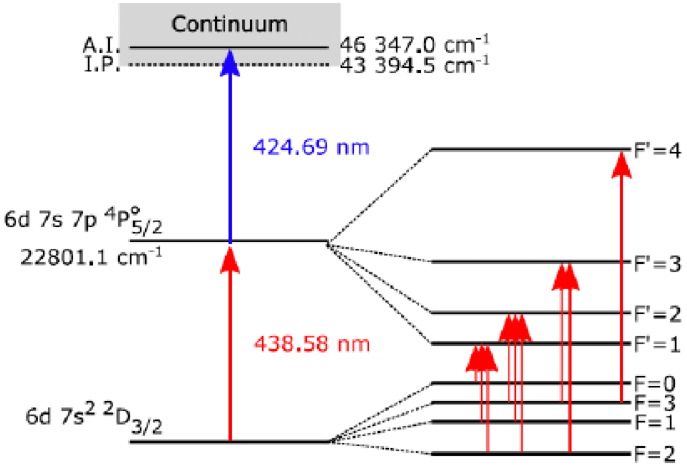
## PI-LIST: Perpendicularly Illuminated Laser Ion Source and Trap

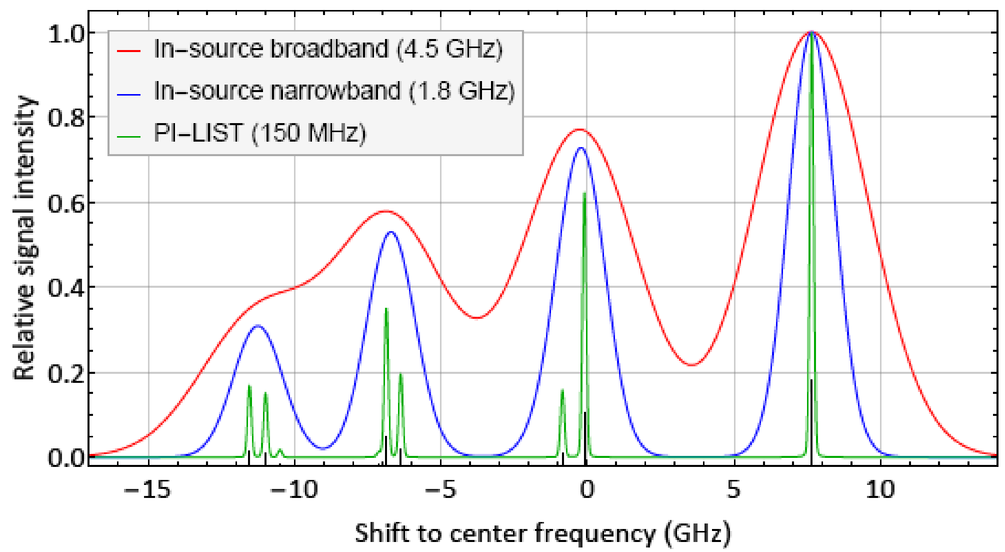


# Ближайшие перспективы: новые эксперименты на RILIS

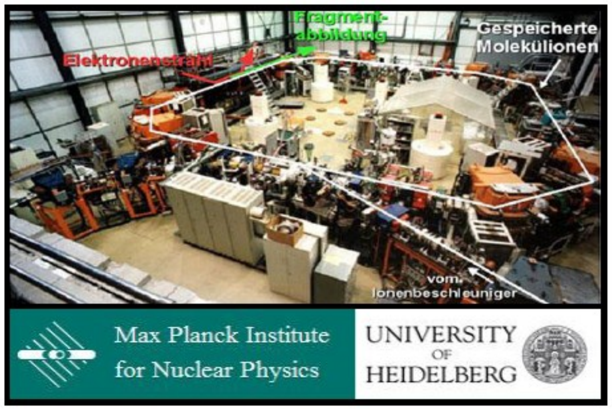
## PI-LIST: Perpendicularly Illuminated Laser Ion Source and Trap

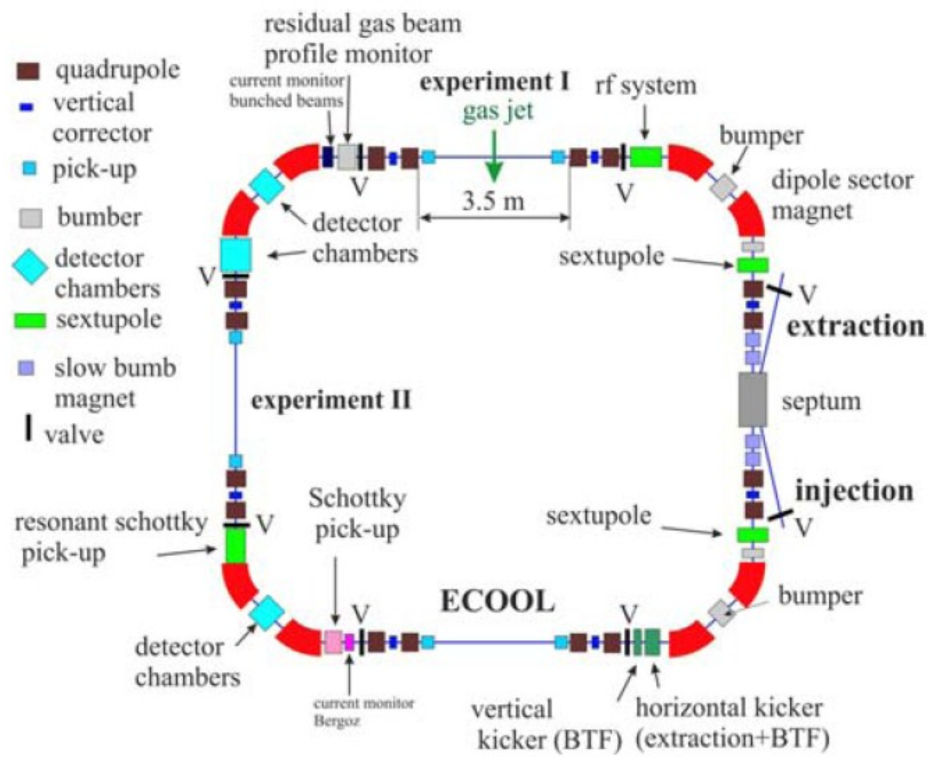


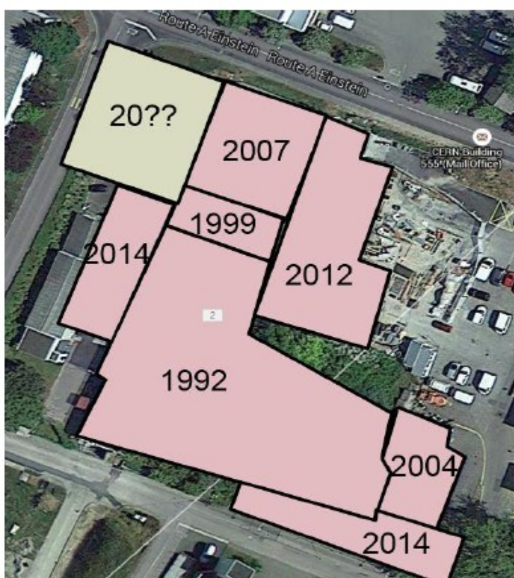



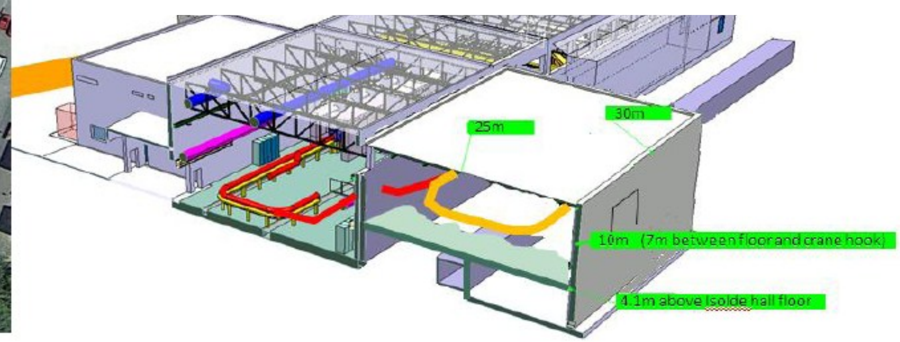
# Перспективы: новые проекты ISOLDE

## ISR - ISOLDE Storage Ring



# Перспективы: новые проекты ISOLDE

## The EPIC project:

## Exploiting the Potential of ISOLDE at CERN

The ISOLDE Collaboration input to the EPPS (European Particle Physics Strategy Update)

Contact persons:

- Gerda Neyens, ISOLDE Collaboration Spokesperson
- Karsten Riisager, Chair of the ISOLDE and N-Tof Committee (INTC)
- Bertram Blank, Chair of the ISOLDE Collaboration
- Richard Catherall, Technical Coordinator of ISOLDE

# EPIC Project

**A. ENHANCING THE PRODUCTION AND CAPABILITY OF ISOLDE** is possible thanks to the increase of the driver beam energy to 2 GeV and an increase in proton intensity through the new LINAC4 driver. The production capacity can be increased in two ways:
**(a)** by **the installation of new beam dumps** to cope with the higher beam powers and the installation **of new bending magnets** between the booster and ISOLDE to allow the 2 GeV beam to be sent to ISOLDE. The increase of the proton energy from 1.4 GeV to 2 GeV results in an increase of the production of short-lived nuclei, in particular those produced in the spallation process, at the limits of nuclear existence.
**(b)** by building **two additional new high-power target stations**. These will be used in such a way as to enable de-coupled parallel operation of the low-energy (30-60 keV) and high-energy (HIE-ISOLDE) facilities, which will double the available beam time, enabling a larger number of more challenging experiments to be performed. That is even more important in case the third component of this project is realized (a storage ring coupled to HIE-ISOLDE), as this will attract a new users community.

**B. UPGRADE OF HIE-ISOLDE ACCELERATOR**, in order to allow re-accelerated beams in the full range of energies between 0.1 and 10 MeV/u by an upgrade of the 20-years old normal-conducting REX-part of the post-accelerator. This is crucial for astrophysical reaction studies relevant for the rp-process in X-ray bursts.

**C. INSTALLATION OF A LOW-ENERGY STORAGE RING**

# Перспективы: EPIC Project

# Перспективы: EPIC Project

| Items | Cost kCHF | FTE | Comments |
|---|---|---|---|
| Beam dumps and 2 GeV | 9,000 | 15 | Includes civil engineering for the existing beam dumps, 4 beam dumps and bending magnets |
| Phase 3 HIE-ISOLDE | 8,000 | | Includes beam chopper, 2 low Beta cryo-modules and refurbishing of cooling plant |
| Target stations and HRS | 67,000 | 400 | 2 new target stations, pre separators , HRS, RFQ Cooler, beam lines, civil engineering, shielding and cooling and ventilation, additional laser laboratory |
| ISR | 17,000 | 46 | Procurement of all ISR equipment and hall extension |
| **Total** | **101,000** | | |

# Перспективы: EPIC Project

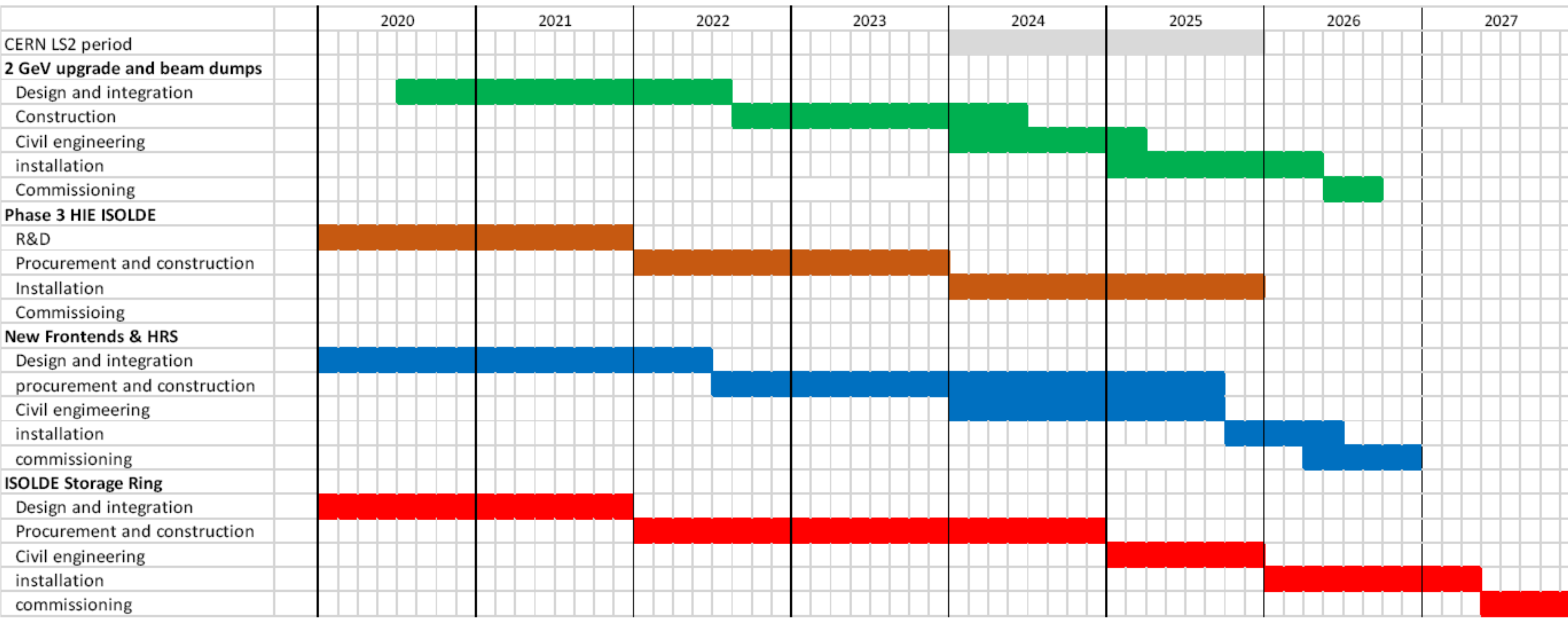
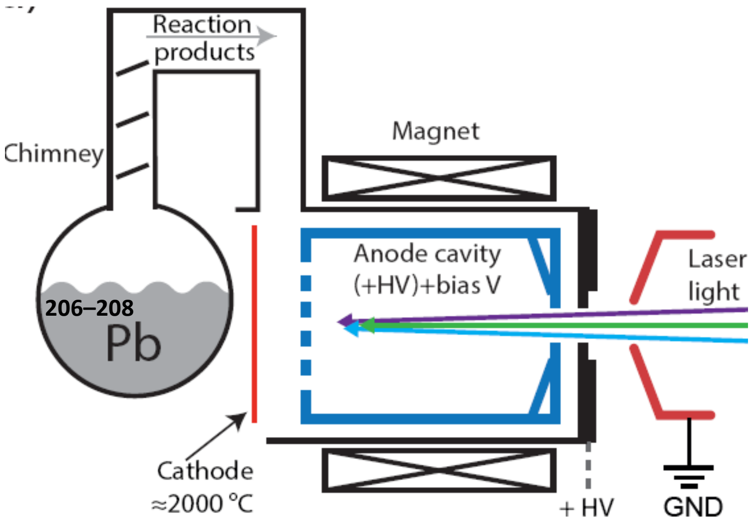



*Figure 2. A proposed schedule for the EPIC project based on the CERN's long shutdown 3.*

# Получение $^{207,208}$Hg




Учитывая, что материал мишени используемый для этого эксперимента - природный свинец ($^{206–208}$Pb),получение изотопов ртути с N<=126 (Hg-206) идет в реакций расщепления, протонами с энергией 1,4 ГэВ. Однако при N>126 это механизм становится невозможным и вступают в дело другие процессы, в частности, вторичные реакции, вызванные легкими продуктами первичной реакции на протонах, движущихся с большими энергиями.

Например, 207Hg получается в реакции **$^{208}$Pb(n, 2p) $^{207}$Hg** и уже был известен на ИЗОЛДЕ

Механизм получения $^{208}$Hg значительно более экзотичен, о чем свидетельствует резкое снижение выходов - в 2400 раз от $^{207}$Hg к $^{208}$Hg. Существует ряд потенциальных каналов производства, включая

$^{208}$Pb(t, 3p) $^{208}$Hg,
$^{208}$Pb(α, 4p) $^{208}$Hg,

или реакции с радиогенными **$^{209}$Pb ($T_{1/2}$ ≈ 3 ч)** или **$^{210}$Pb ($T_{1/2}$ ≈ 22 года)**, которые накапливаются внутри мишени во время эксперимента