ISOLDE (Isotope Separator OnLine DEvice)

>50 years at CERN
First such facility worldwide

- ~0.1% of CERN budget
- ~ 8 % of CERN users scientists
- >50 % of CERN protons

Operates ~ 8 months/year, 24/7
~ 100 ongoing experiments

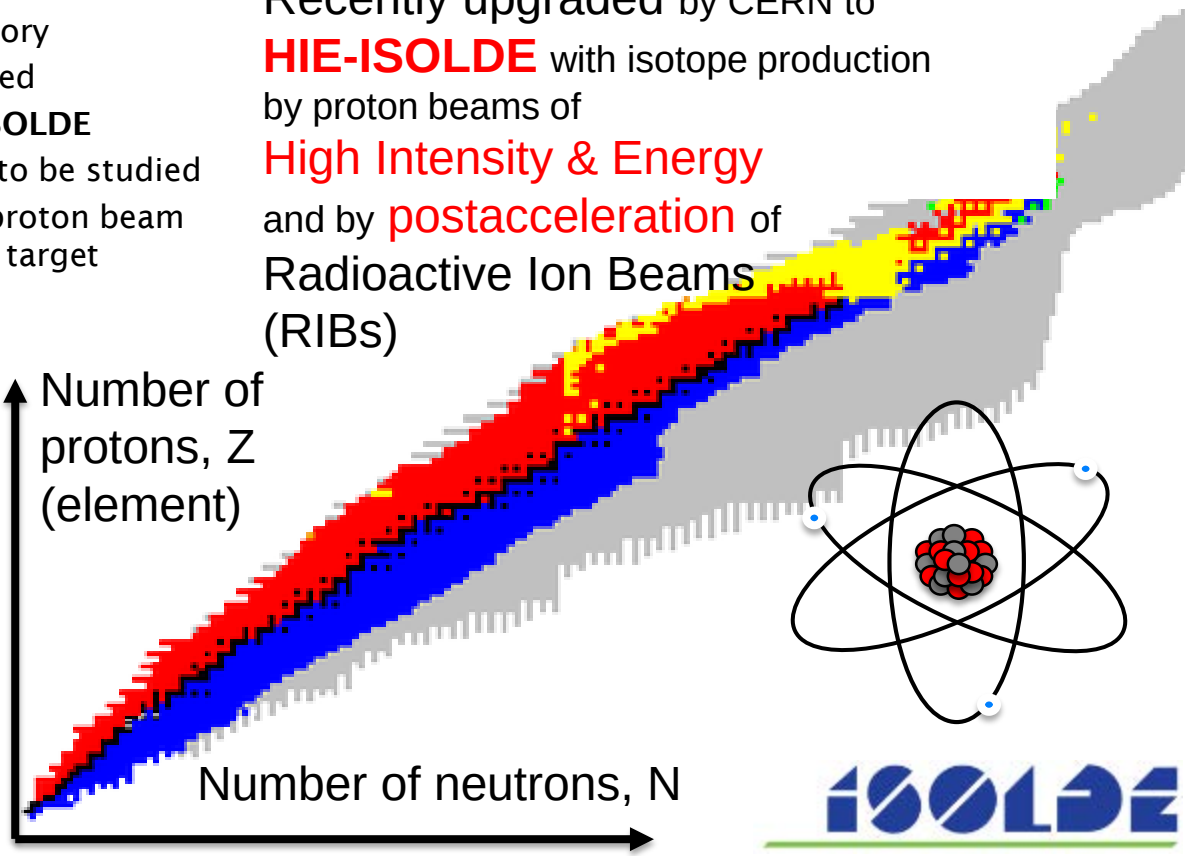
~ 500 active users for physics
~ 50 staff/students/fellows

- ~6000 isotopes predicted by theory
- ~3000 isotopes already discovered
- **~1000 isotopes produced by ISOLDE**
- **75 different elements** … ready to be studied
- Method of production: 1.4 GeV proton beam from proton booster sent onto a target

More than 50% of all protons accelerated at CERN are delivered to ISOLDE !

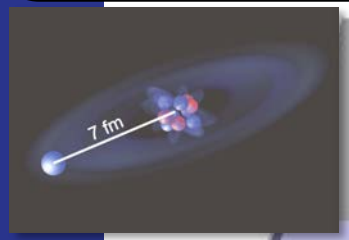
- Challenge: select one (exotic) isotope out of hundreds others produced, most of them with several orders of magnitude higher abundance!

Recently upgraded by CERN to **HIE-ISOLDE** with isotope production by proton beams of High Intensity & Energy and by postacceleration of Radioactive Ion Beams (RIBs)

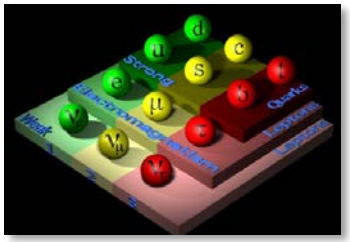


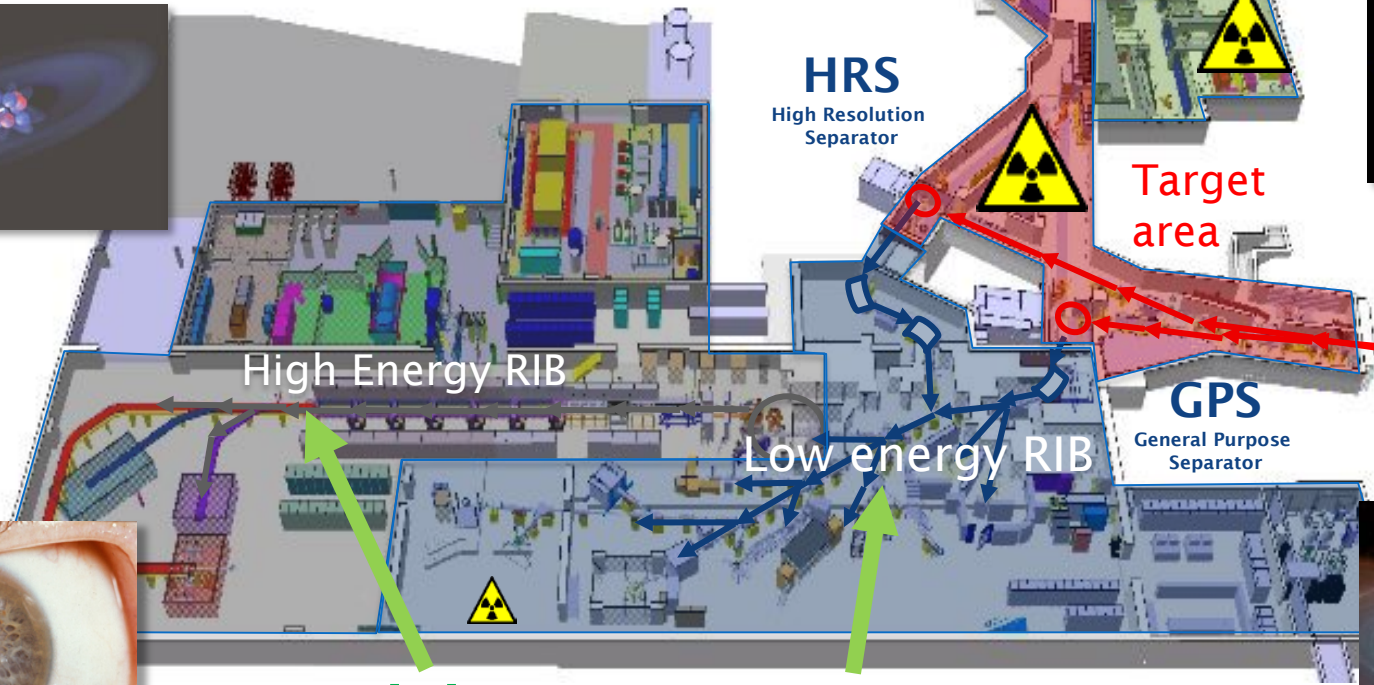
What is studied at ISOLDE? And how?

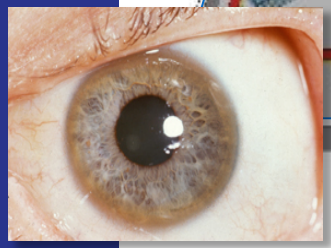
Nuclear physics and **atomic physics**

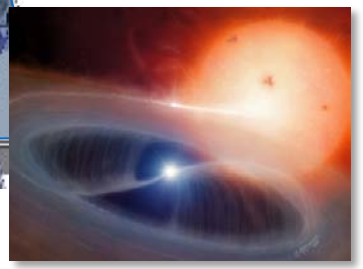


Fundamental symmetries









High Energy (up to 10 MeV/u)

Low Energy (up to 60 keV)

branches of Radioactive Ion Beams (RIBs)

Material science and **life sciences**

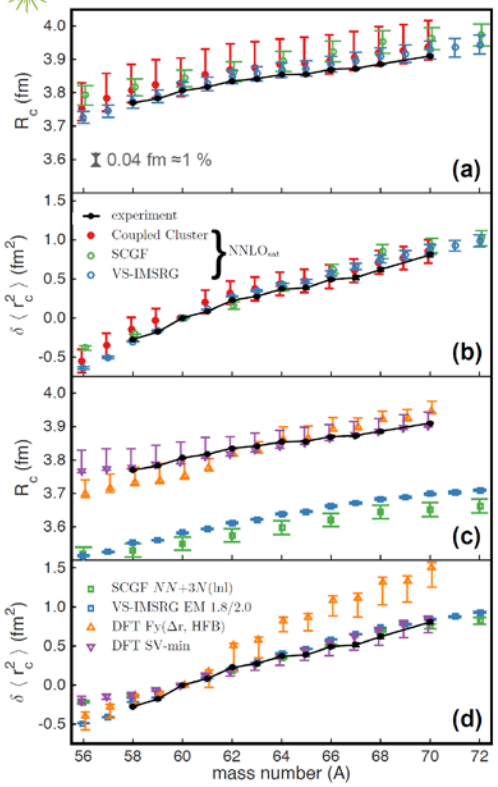
Astrophysics and nucleosynthesis

Research with Low-Energy RIBs

Laser spectroscopy

German university groups: - TU Darmstadt (Nörtershäuser, Schwenk)
(with present BMBF projects) - Univ. Mainz (Wendt)

COLLAPS

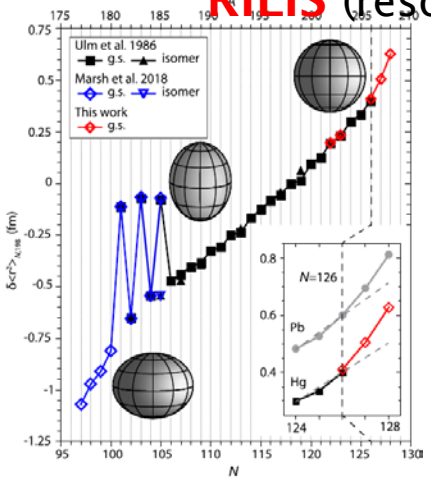


Charge Radii of nickel from ^{58}Ni up to ^{70}Ni across the N=40 subshell closure measured by **collinear laser spectroscopy**. Agreement with ab initio and density functional calculations on the 1% level.
Malbrunot-Ettenauer *et al.*, Phys. Rev. Lett. in print (2021) arXiv:2112.03382v1

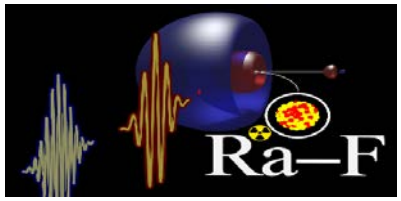
Upcoming: MIRACLS

Multi-Ion-Reflection Apparatus for Collinear Laser Spectroscopy

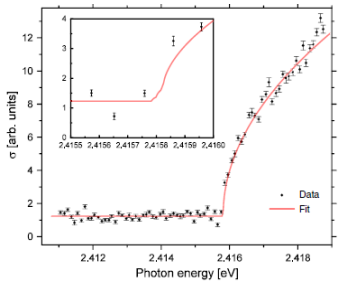
RILIS (resonance ionization laser ion source)



=> nuclear charge radii
=> shape staggering & coexistence in **Hg isotopes** Marsh *et al.* Nature Phys. (2018)
n-rich magic number N=126 in Day Goodacre *et al.*, Phys. Rev. Lett. (2021)



RaF molecules for tests of fundamental symmetries
Nature 581, 396 (2020)



Electron affinity of astatine
Nature Comm. 11, 3824 (2020)

ISOLDE

Research with Low-Energy RIBs

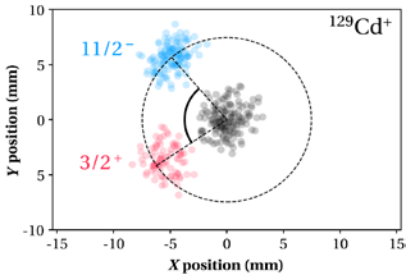
Mass spectrometry

Antiproton Interaction

German university groups: - TU Darmstadt (Obertelli)
(with BMBF proposals) - Univ. Greifswald (Schweikhard)

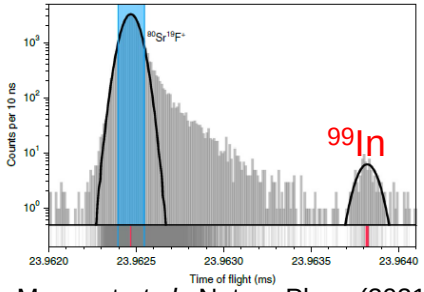
ISOLTRAP as mass spectrometer

=> nucl. binding energies => nucl. structure



Penning trap
Isomeric resoving power at half-lives of 150ms

Manea *et al.*, Phys. Rev. Lett. (2020)

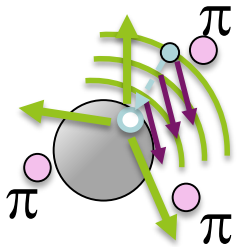


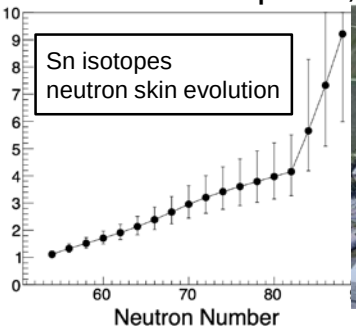
Multi-Reflection Time-of-Flight Mass Spectrometer
(MR-ToF MS with half-lives down to 10ms)

Mougeot *et al.*, Nature Phys. (2021) including ^{101}In with resolved isomers & ^{100}In (β-decay connected to ^{100}Sn)

PUMA (antiProton Unstable Matter Annihilation)

=> probing the skin of nuclei by
$\bar{p} + p \rightarrow \ldots$ vs. $\bar{p} + n \rightarrow \ldots$ different pion (charge) distrib.
=> targeting neutron (possibly proton) halos, neutron skins towards the drip line, …



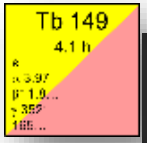


Antiprotons will be „shipped“ from ELENA to ISOLDE

isotope separation for medical research

example

^{149}Tb is α and e^+ emitter
=> therapy and diagnostics



PET Image of mouse

In addition, **IDS** (ISOLDE Decay Station)

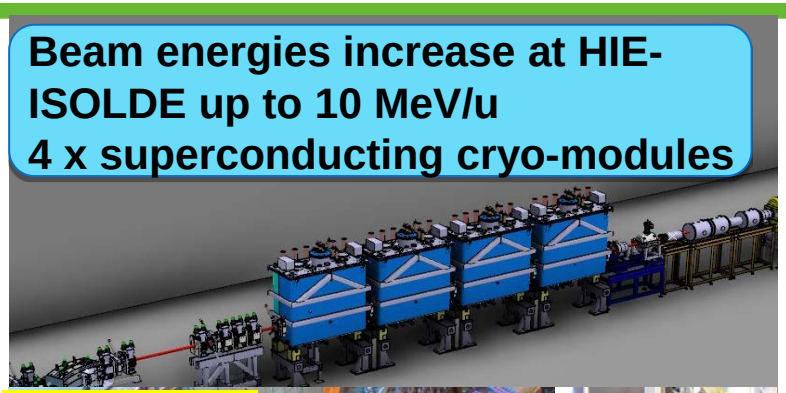
Several German univ. groups, but not part of the present ISOLDE.de grant proposals

ISOLTRAP as mass separator

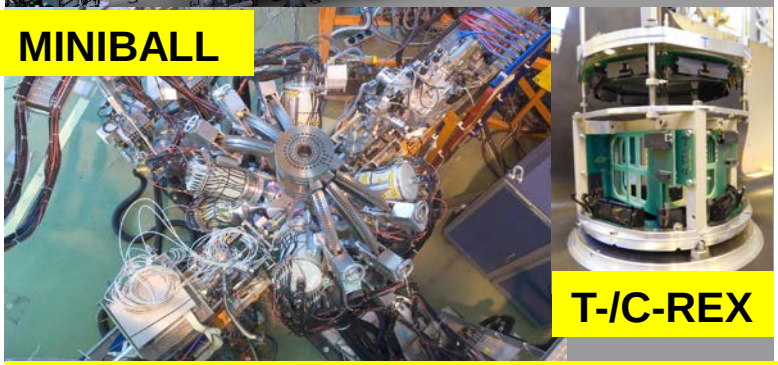
=> Highly selective & sensitive ion detector
=> Essential tuning/optimization/background-free detection for many other experiments => ISOLDE develops its own MR-ToF MS

Research with High-Energy RIBs

Beam energies increase at HIE-ISOLDE up to 10 MeV/u
4 x superconducting cryo-modules

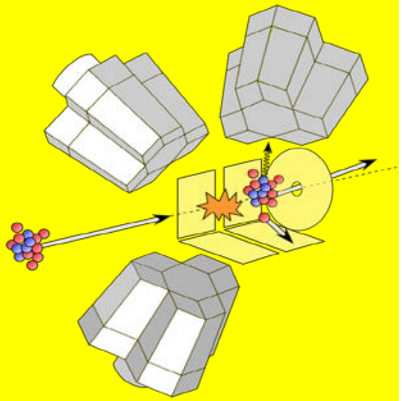


MINIBALL

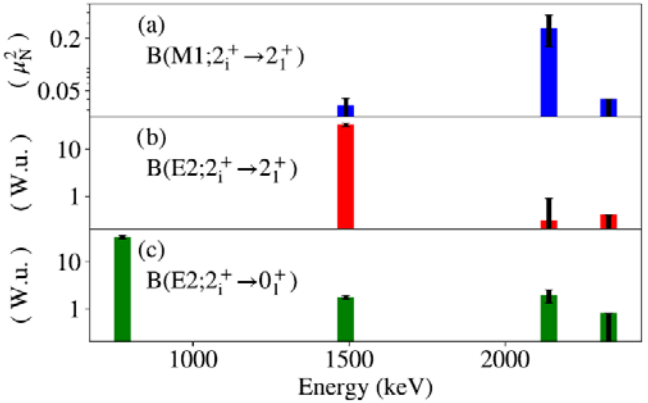


T-/C-REX

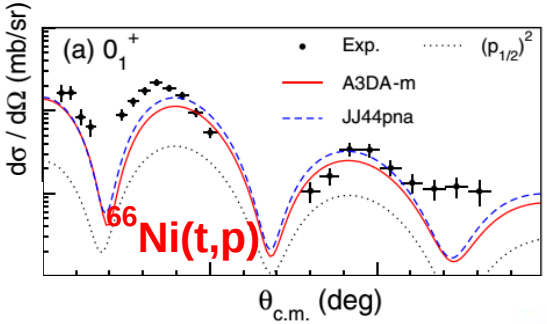
MINIBALL is the most requested instrumentation for experiments with beams from HIE-ISOLDE:
- **Coulomb excitation**
- **nucleon transfer reactions**

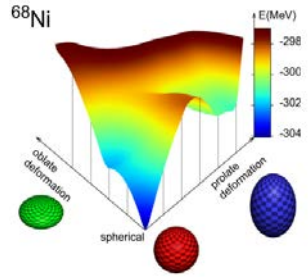


Coulomb excitation
→ **Valence-shell stabilization in ^{140}Nd**
PRC, Rapid Communication (2020)
Groups: Jolie, Kröll, Pietralla, Reiter



Nucleon transfer reactions
→ **shape-coexistence of 0$^+$ states in doubly-magic ^{68}Ni**
Phys. Rev. C (2019)

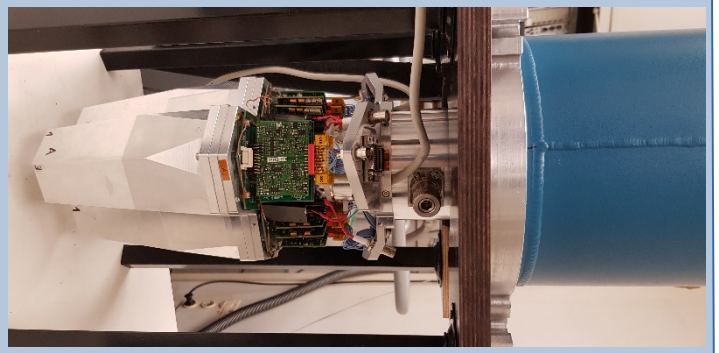




Upgrade projects

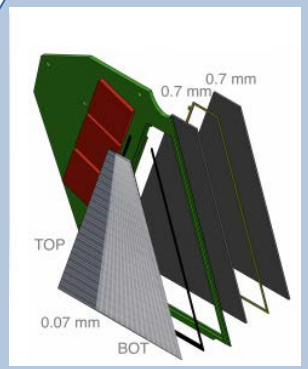
After more than 20 years of operation at ISOLDE, MINIBALL requires upgrades to allow for a successful continuation …

Topics carried out by the German groups:
- **completion of exchange of cryostats**
- **replacement of capsules by advanced reuseable versions**

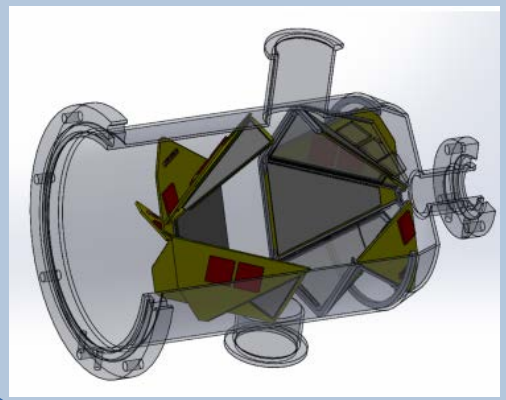


Prototype of new MINIBALL Triple cluster

MINIBALL cryostats



New HI-TREX NIM A (2021)



German university groups:
- **TU Darmstadt (Kröll/Pietralla)**
- **Univ. zu Köln (Jolie/Reiter/Warr)**
- **TU/LMU München (Bishop/Gernhäuser/Thirolf)**

Spokesperson of MINIBALL collaboration: Th. Kröll

Possible future ISOLDE developments

are investigated by the **EPIC "project"** **Exploiting the potential of ISOLDE at CERN**

- **EPIC workshop, Dec. 2019**
  https://indico.cern.ch/event/838820/
- **EPIC workshop, Nov. 2020**
  https://indico.cern.ch/event/928894/
- => **EPIC procedings** in preparation as single paper in Eur. Phys. J. Special Topics

  Outline of the proposed upgrades for ISOLDE in the mid- and long-term future
  - The **mid-term** upgrades include

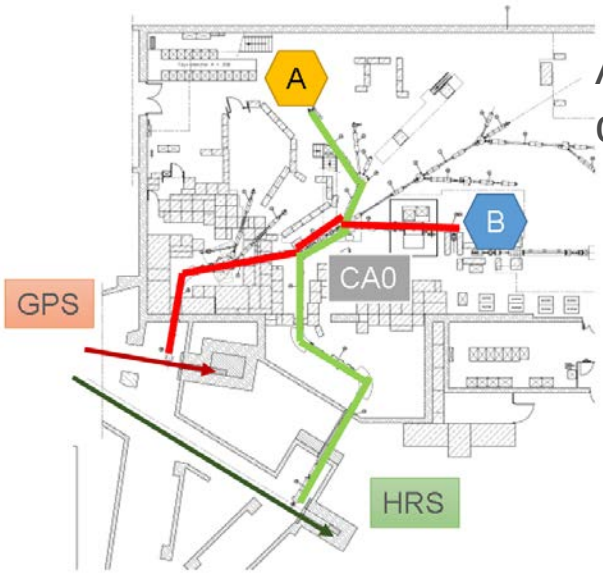
    - **new beam dumps** (compatible with higher proton beam energy (2 GeV) and intensity (x 2 to 50)
    - more **parallel operation** options
    - improved **beam purity**
  - **long-term** future ideas include

    - construction of a new ISOLDE **experimental hall** with
    - new **target stations** and dedicated space for new experiments and
    - improved beam purification systems **feeding several** experiments.
    - => space in the existing hall for a new **compact storage ring** and
    - a new **recoil separator** to be coupled to HIE-ISOLDE.

Ideas for ISOLDE Upgrades and Expansion

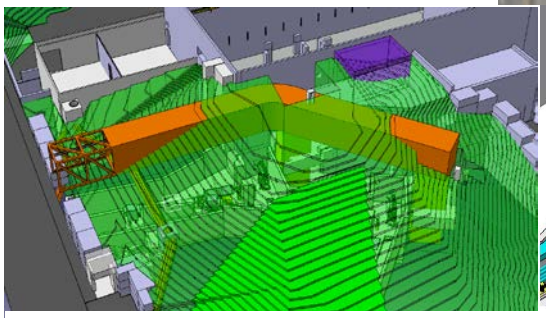
Mid-term goals (2025-2026, see CERN accelerator operation plan)

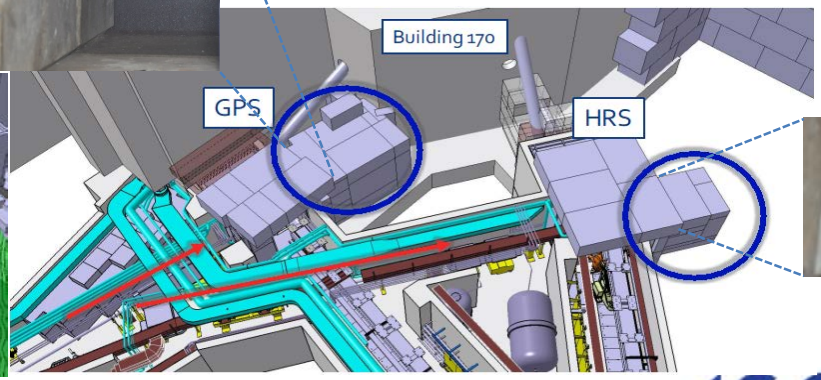
- Parallel RIB operation
- New beam dumps for both target stations (=> higher energy proton beam at double intensity)
- Upgrade of transfer line from PS Booster to ISOLDE to allow sending 2 GeV (presently 1.4 GeV) beams. => **Increase RIB beam intensity by up to factor 50** (isotope dependent**)**



Alternating mode operation

Beam dump consolidation



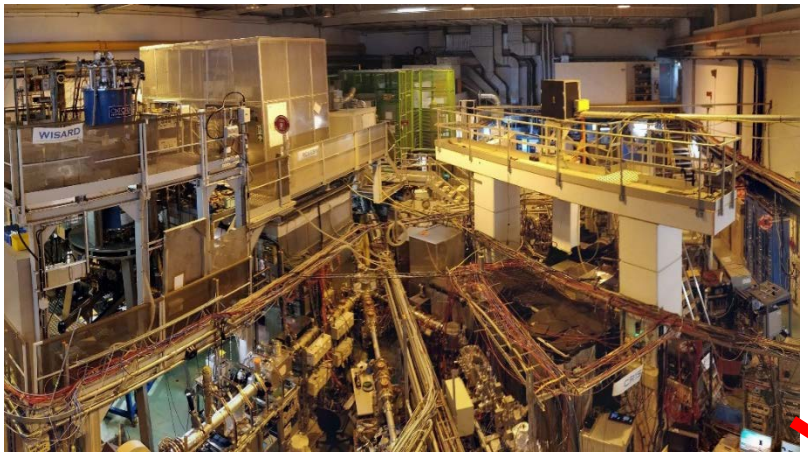


Option with permanent access to dump

Ideas for ISOLDE Upgrades and Expansion

Long-term goals (> 2026 see CERN accelerator operation plan)

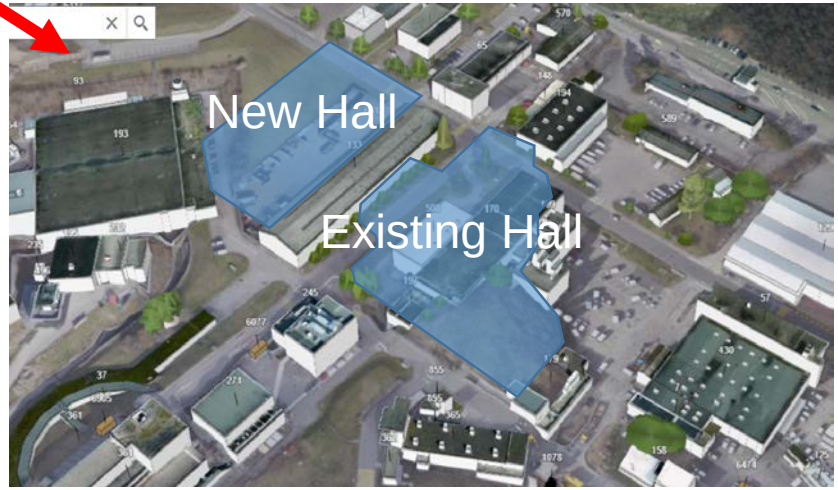
Existing Hall (quite crowded):



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 (at present hall)
- More space for new re-accelerated RIB experiments
- could include a compact storage ring



Schedule has to fit into the

future CERN accelerator operation plan

Draft version:

Mid-term plans should fit into long shutdown (LS) 3

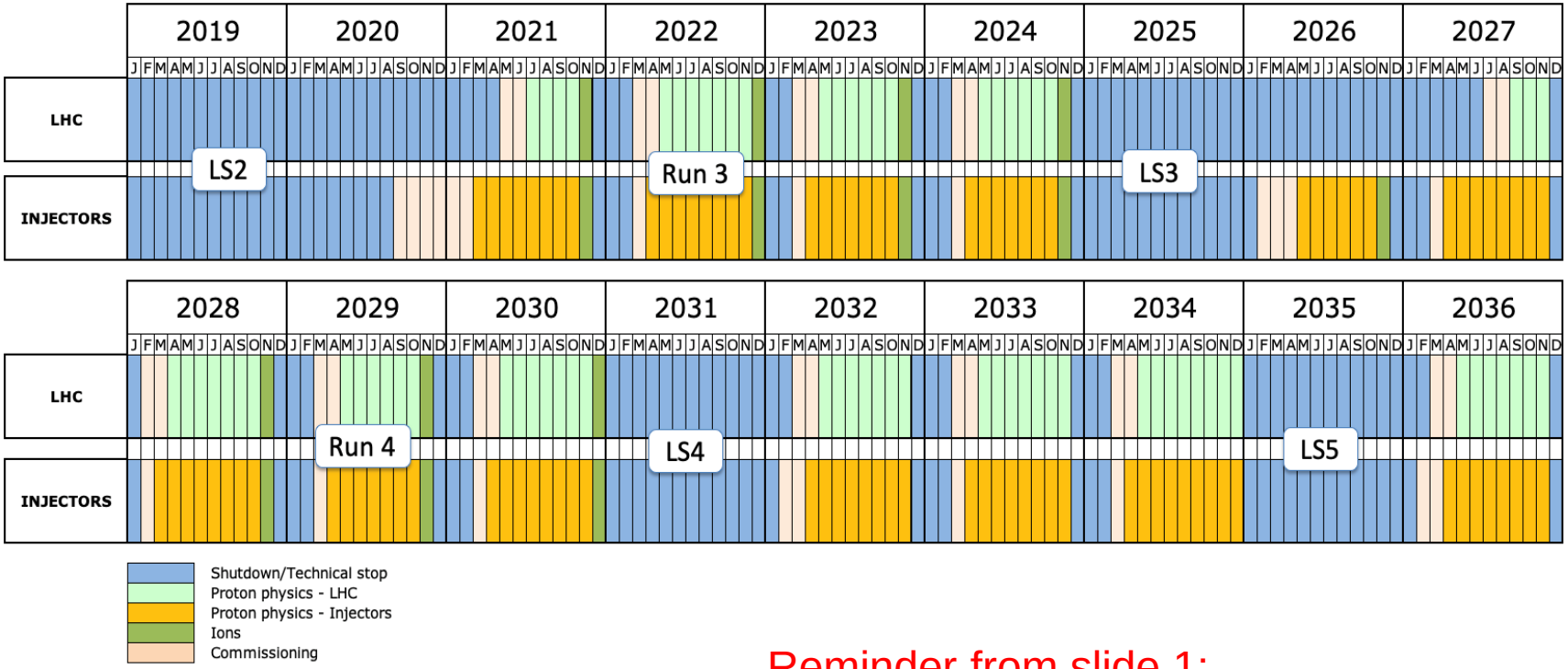
Note: Exploring financing issues and in particular support from CERN management has only just begun !

Schedule has to fit into the

future CERN accelerator operation plan

Draft version:

Mid-term plans should fit into long shutdown (LS) 3



Note: Exploring financing issues and in particular support from CERN management has only just begun !

Reminder from slide 1:

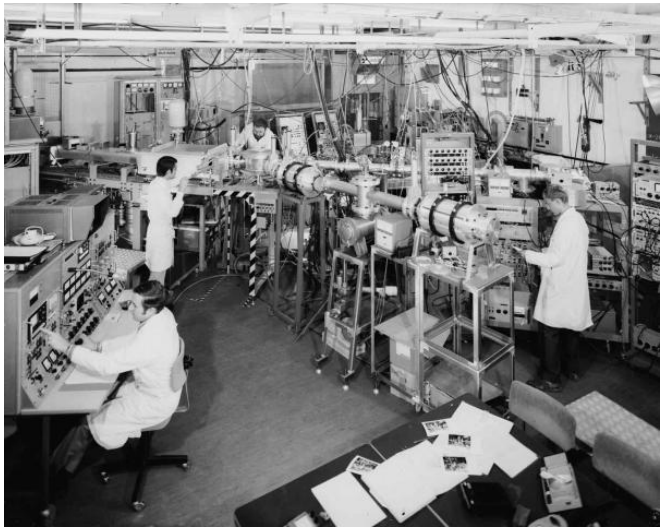
More than 50% of all protons accelerated at CERN are delivered to ISOLDE

ISOLDE History

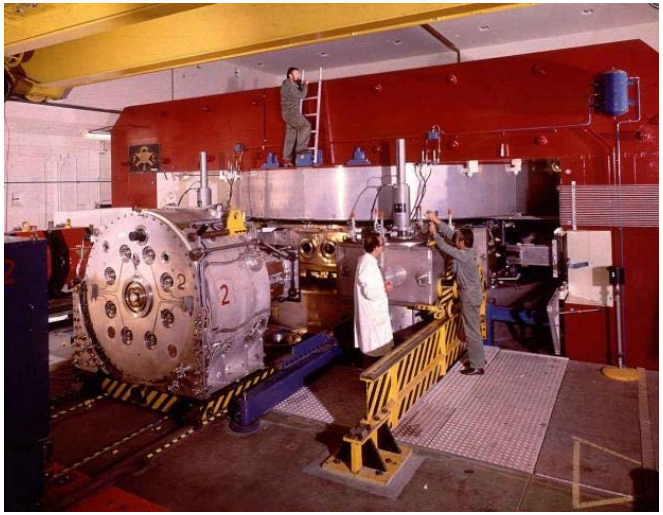
Dec 1964: CERN approves the online separator project

May 1966: SynchroCyclotron shuts down for the construction of ISOLDE

Oct 1967: First proton beams at ISOLDE



1972: SC Improvement doubles the intensity



ISOLDE History

1976: New experiments in ISOLDE II

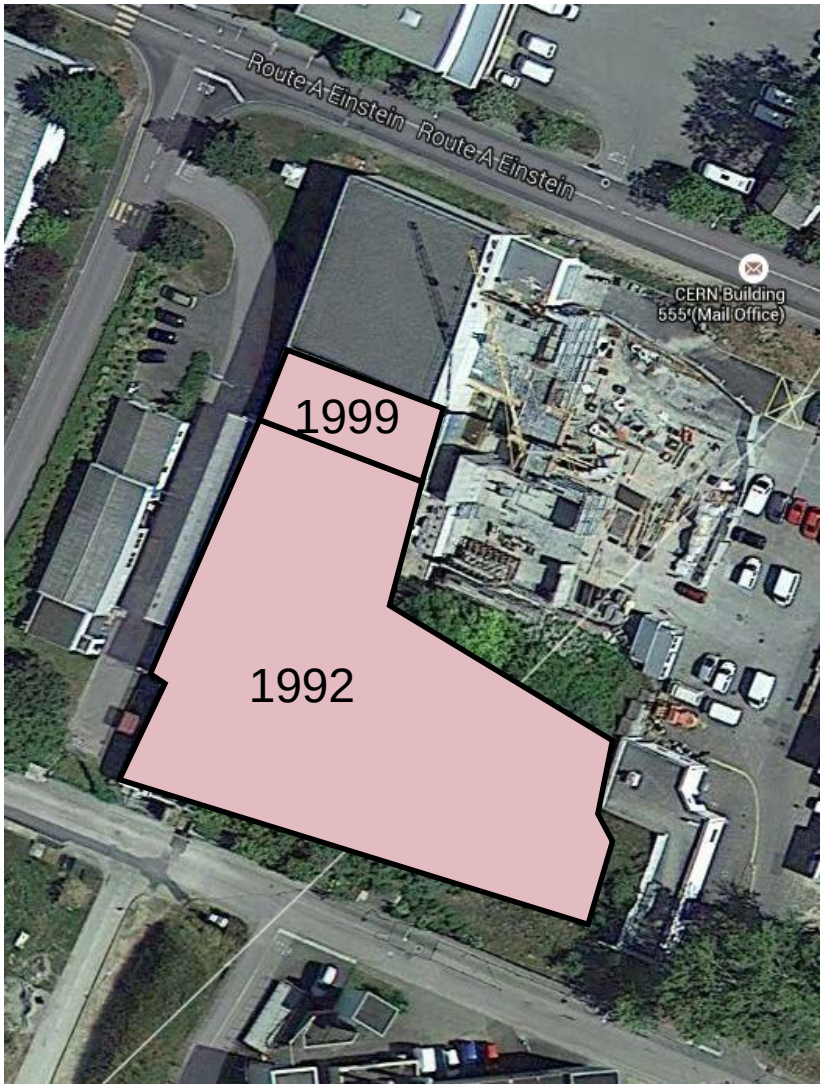
June 1983: ISOLDE III approved – two-stage high resolution separation using two magnets

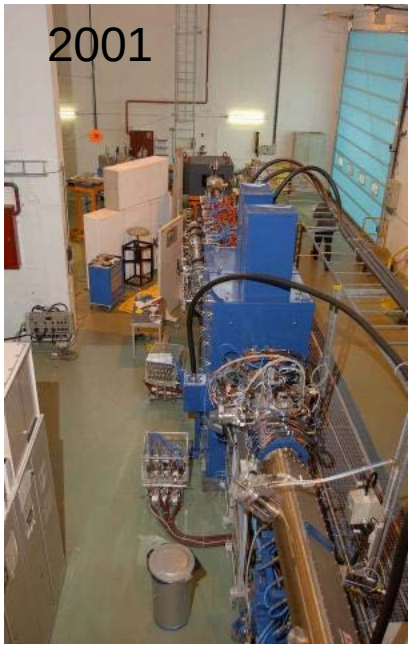
Dec 1990:
The Synchrocyclotron beam ends
However, a new ISOLDE facility was going to be built using protons from the Proton Synchrotron Booster. Online in 1992.

ISOLDE History

May 1992: Inauguration of the new ISOLDE PSB facility

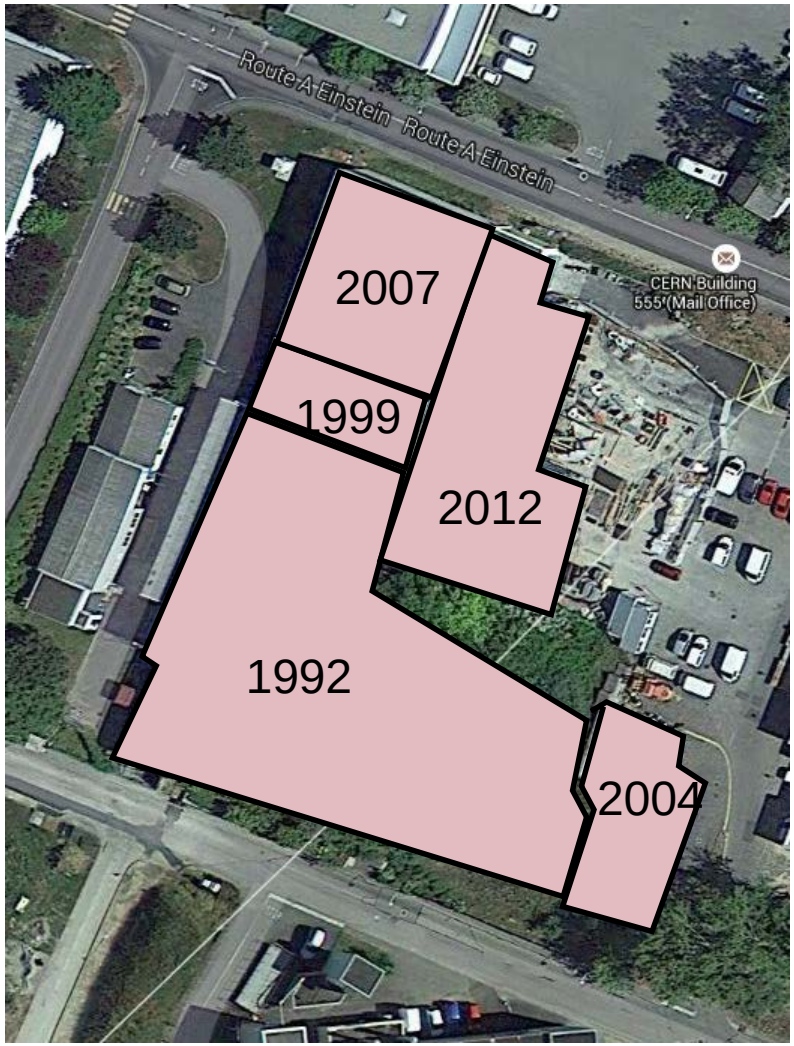
ISOLDE History

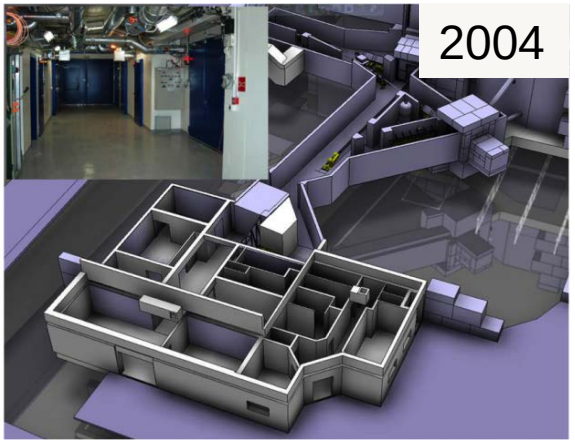




REX-ISOLDE

ISOLDE History

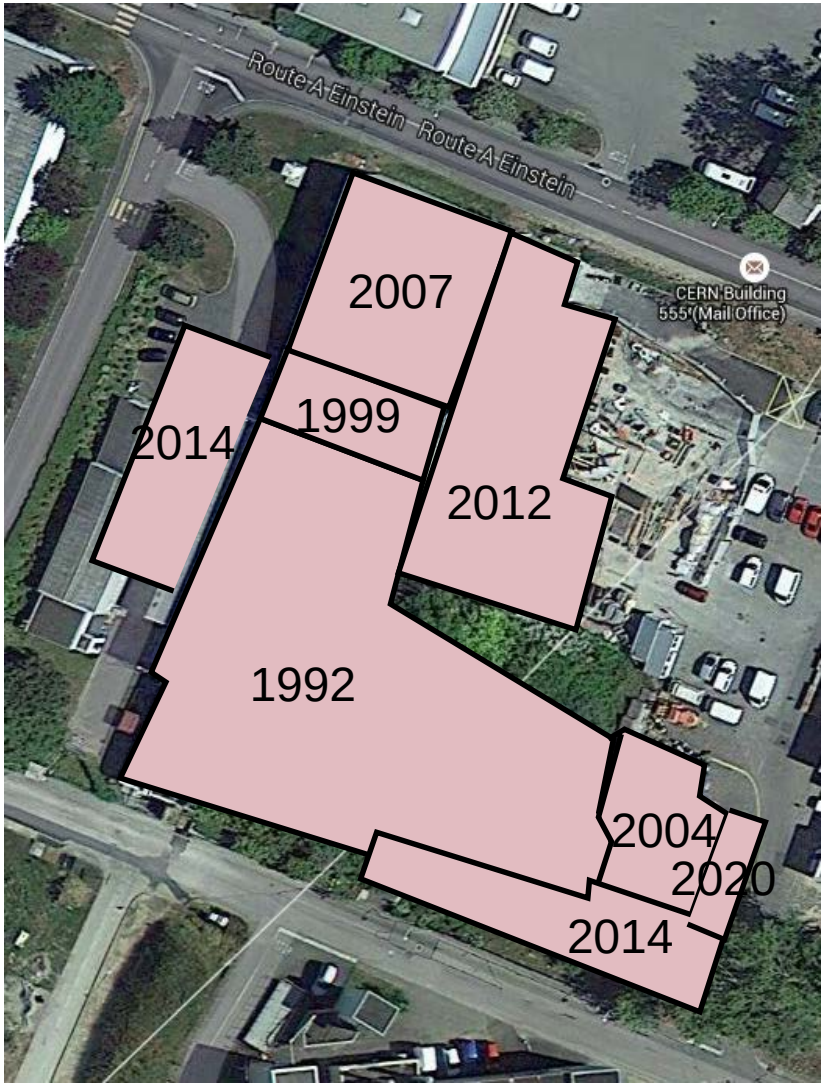




Class A radioactive laboratory

HIE ISOLDE on line 2015

ISOLDE History



User and Operations facility building

Groundbreaking MEDICIS building

NANO-lab building