CERN

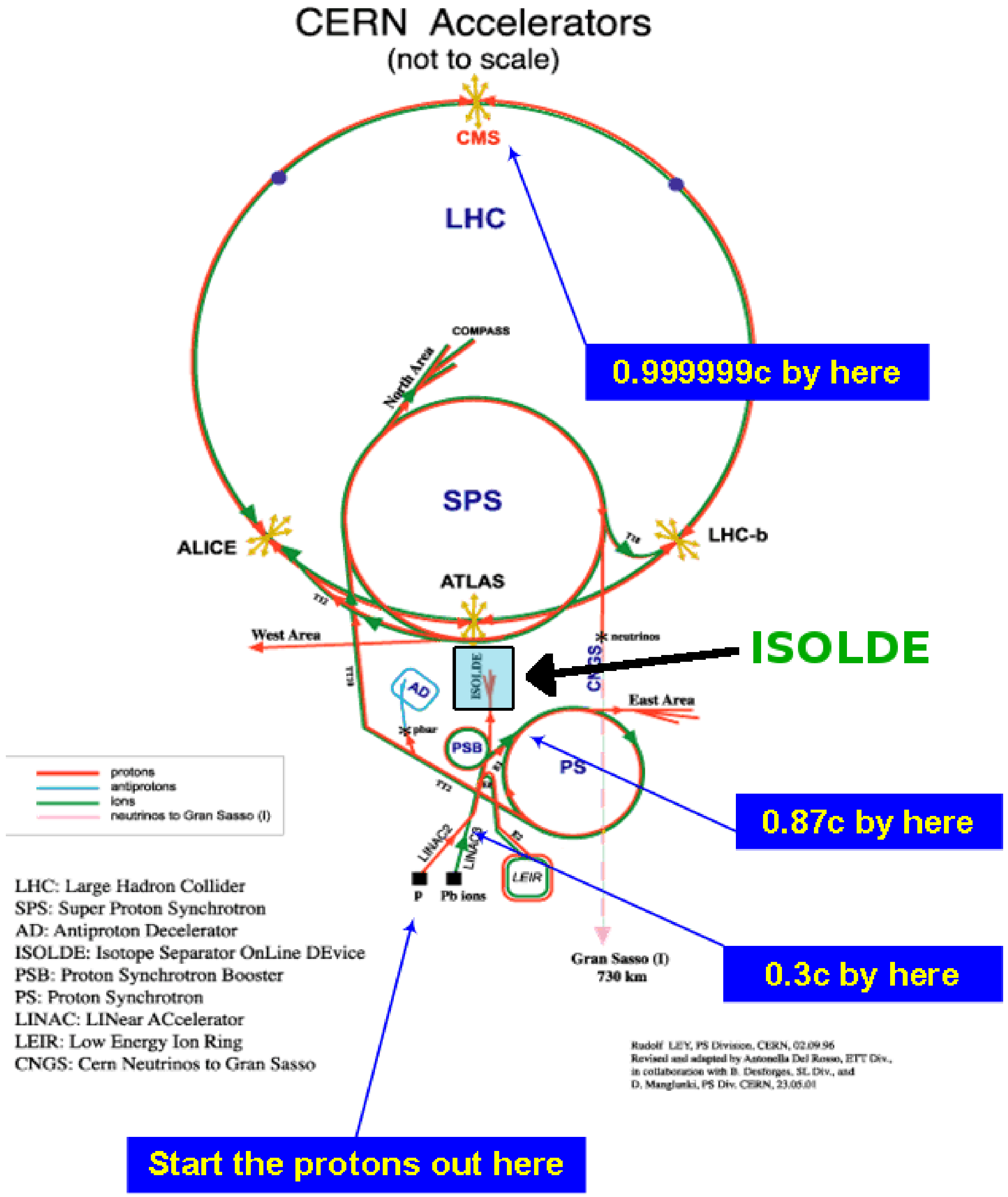
#askCERN

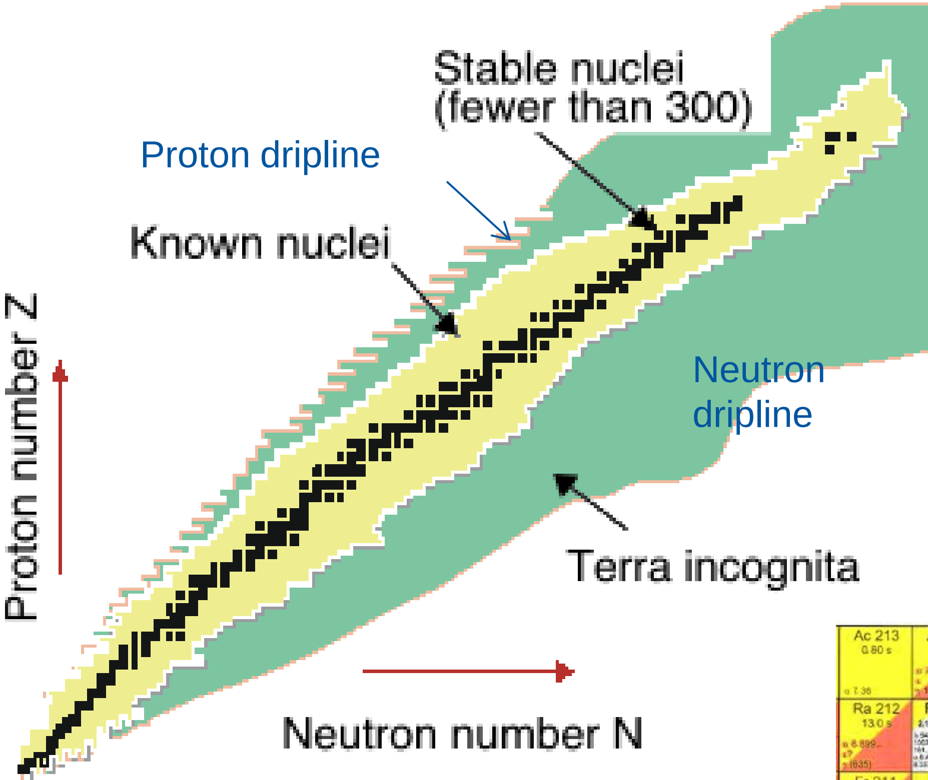
# Hangout with CERN: Going pear-shaped

**23 May 2013**

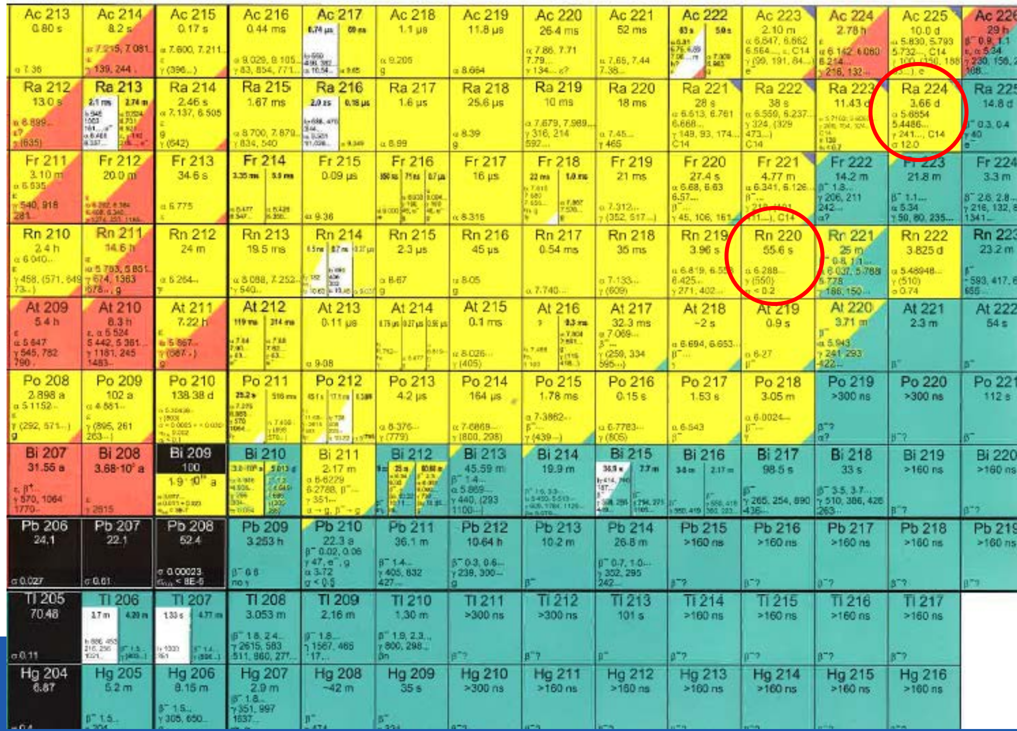
# Today’s trivia question

- Back in January 2013, the mass spectrometer ISOLTRAP at ISOLDE made ions travel how many kilometres during a test?

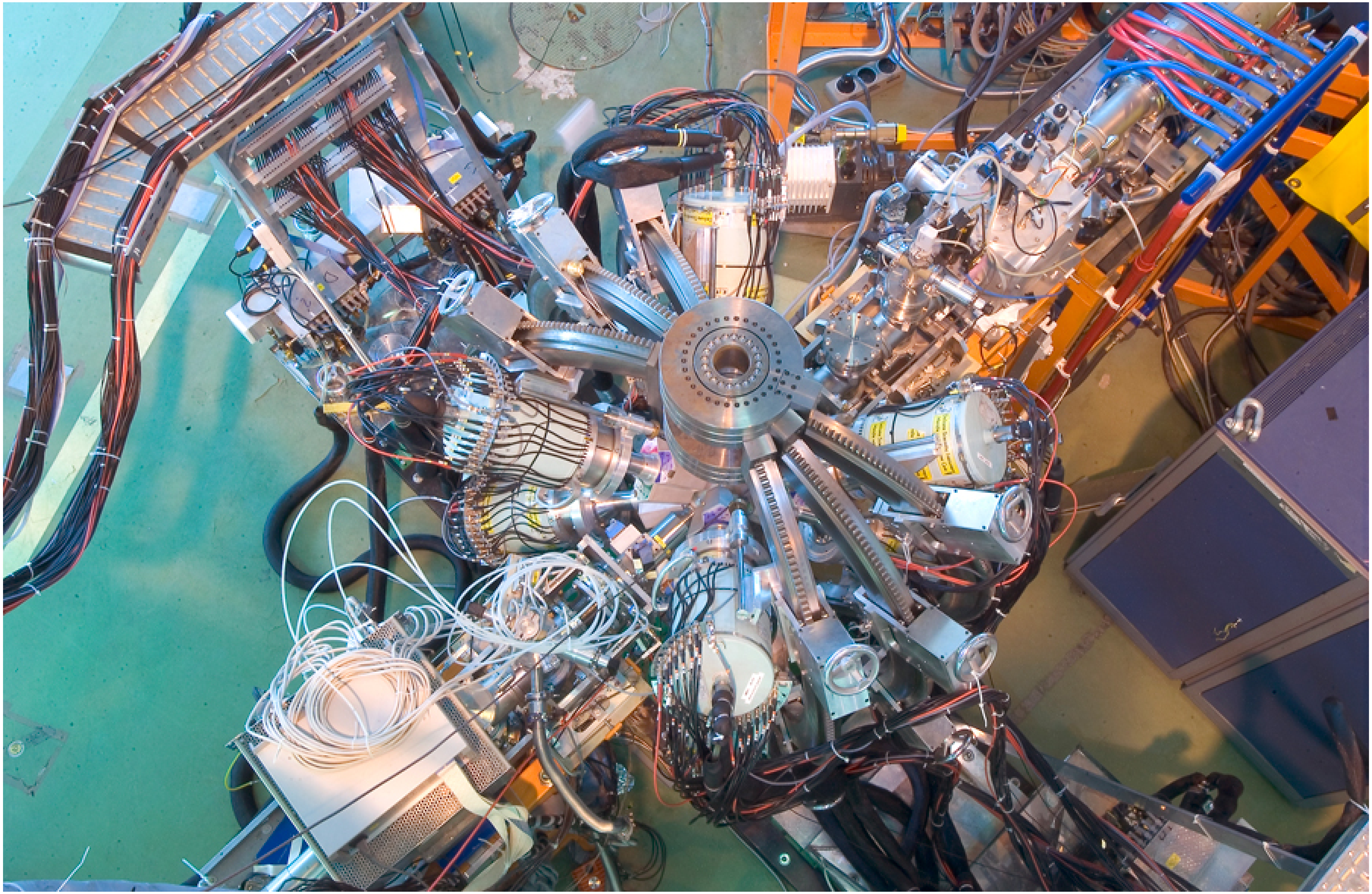

CERN Accelerators
(not to scale)
CMS
LHC
COMPASS
North Area
0.999999c by here
SPS
ALICE
LHC-b
ATLAS
West Area
neutrinos
ISOLDE
CNGS
AD
East Area
pbar
PSB
PS
0.87c by here
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
LINAC2
LINAC3
LEIR
P
Pb ions
0.3c by here
Gran Sasso (I)
730 km
LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01
Start the protons out here

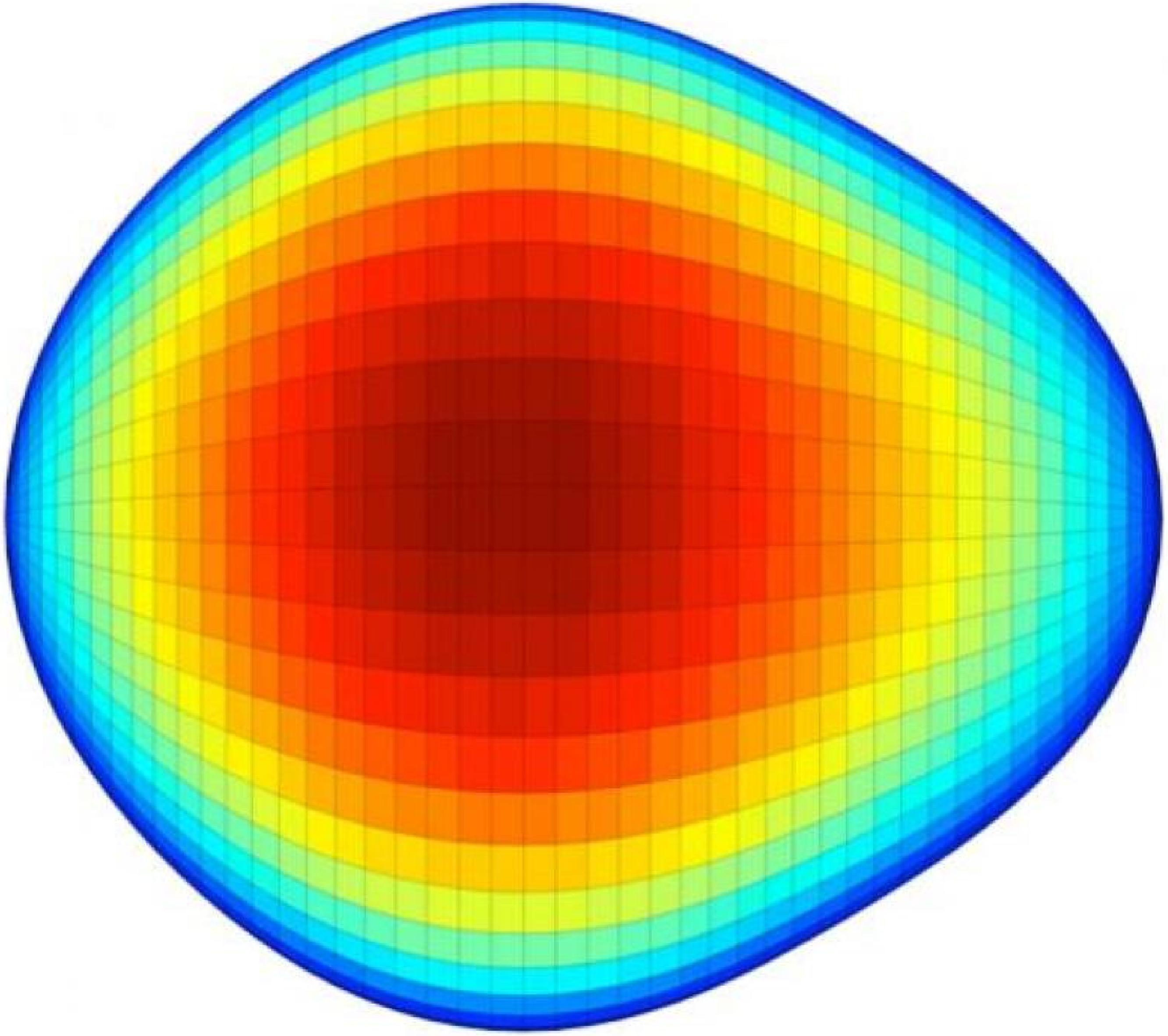


Stable nuclei
(fewer than 300)
Proton dripline
Known nuclei
Proton number Z
Neutron
dripline
Terra incognita
Neutron number N

Ac 213 Ac 214 Ac 215 Ac 216 Ac 217 Ac 218 Ac 219 Ac 220 Ac 221 Ac 222 Ac 223 Ac 224 Ac 225 Ac 226
Ra 212 Ra 213 Ra 214 Ra 215 Ra 216 Ra 217 Ra 218 Ra 219 Ra 220 Ra 221 Ra 222 Ra 223 Ra 224 Ra 225
Fr 211 Fr 212 Fr 213 Fr 214 Fr 215 Fr 216 Fr 217 Fr 218 Fr 219 Fr 220 Fr 221 Fr 222 Fr 223 Fr 224
Rn 210 Rn 211 Rn 212 Rn 213 Rn 214 Rn 215 Rn 216 Rn 217 Rn 218 Rn 219 Rn 220 Rn 221 Rn 222 Rn 223
At 209 At 210 At 211 At 212 At 213 At 214 At 215 At 216 At 217 At 218 At 219 At 220 At 221 At 222
Po 208 Po 209 Po 210 Po 211 Po 212 Po 213 Po 214 Po 215 Po 216 Po 217 Po 218 Po 219 Po 220 Po 221
Bi 207 Bi 208 Bi 209 Bi 210 Bi 211 Bi 212 Bi 213 Bi 214 Bi 215 Bi 216 Bi 217 Bi 218 Bi 219 Bi 220
Pb 206 Pb 207 Pb 208 Pb 209 Pb 210 Pb 211 Pb 212 Pb 213 Pb 214 Pb 215 Pb 216 Pb 217 Pb 218 Pb 219
Tl 205 Tl 206 Tl 207 Tl 208 Tl 209 Tl 210 Tl 211 Tl 212 Tl 213 Tl 214 Tl 215 Tl 216 Tl 217
Hg 204 Hg 205 Hg 206 Hg 207 Hg 208 Hg 209 Hg 210 Hg 211 Hg 212 Hg 213 Hg 214 Hg 215 Hg 216





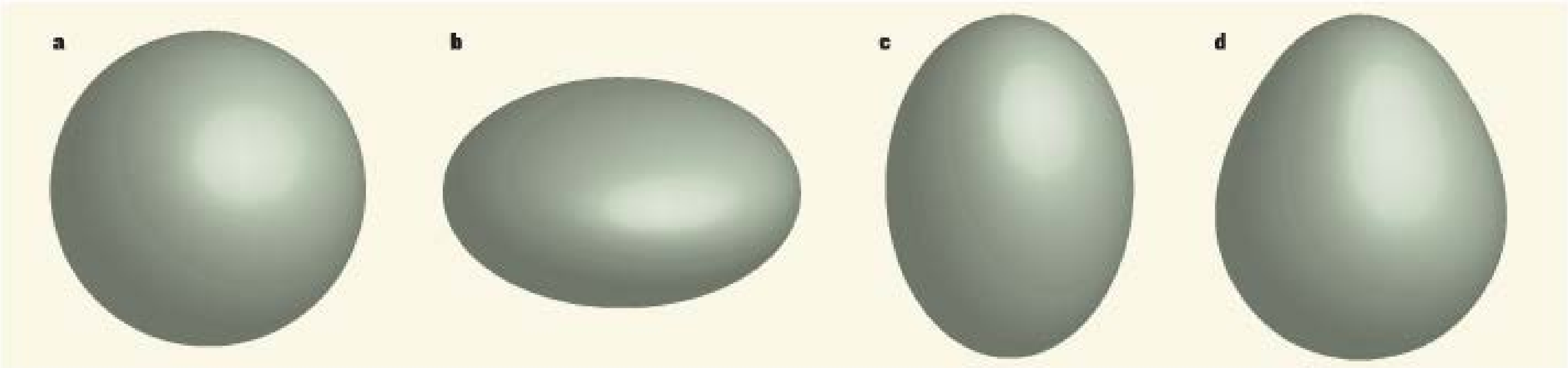
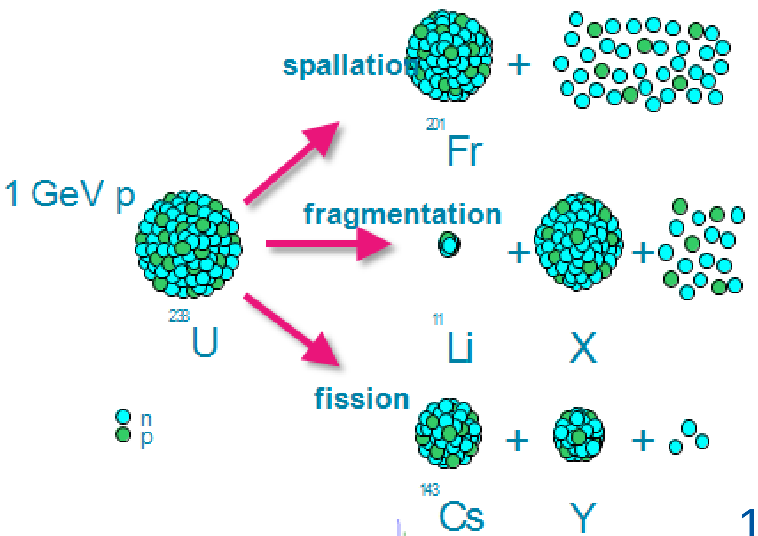
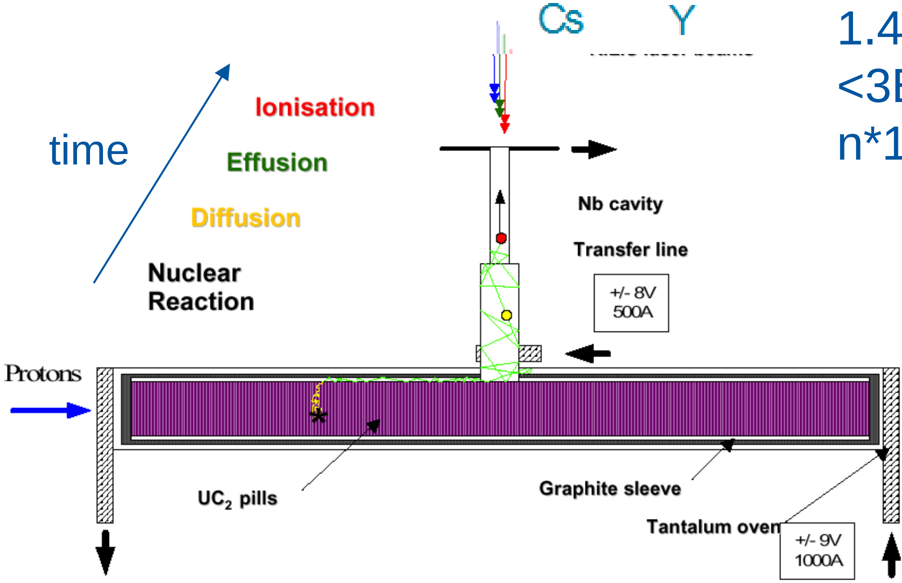
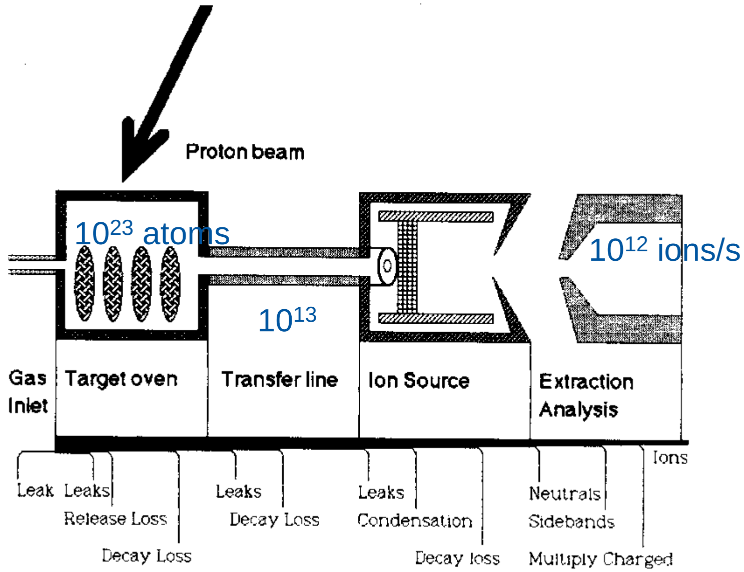



**Figure 1 | Nuclear shapes.** Nuclei can take several shapes, including a sphere (**a**), an oblate spheroid (**b**) and a prolate spheroid (**c**). Gaffney *et al.*[1] have observed the more exotic pear shape (**d**).

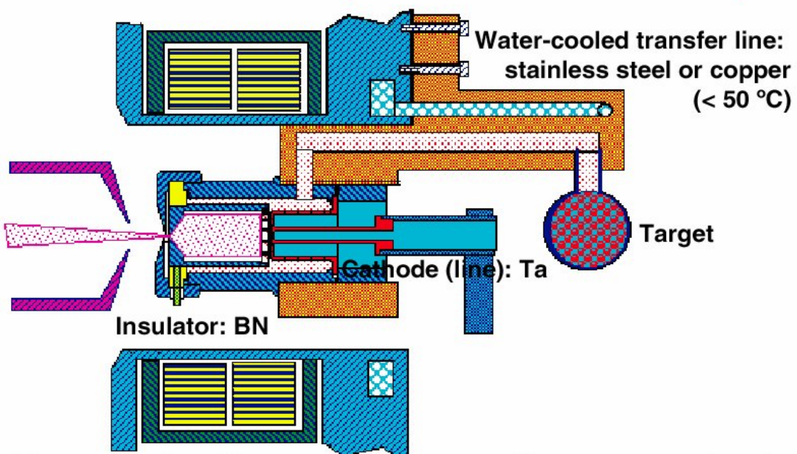


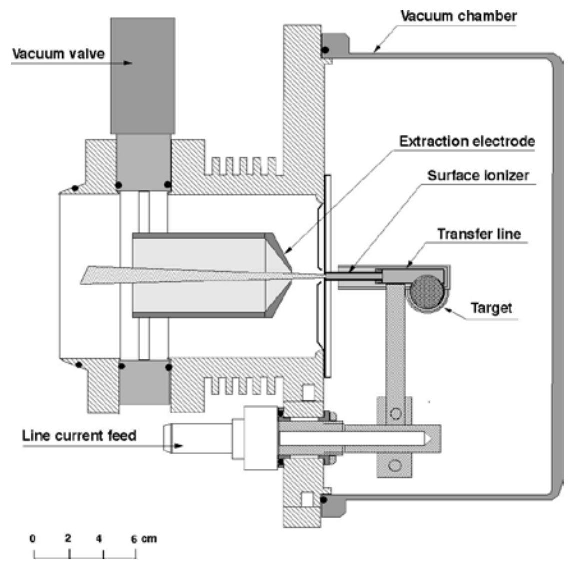

1.4 GeV protons
<3E13 ppp
n*1.2 s



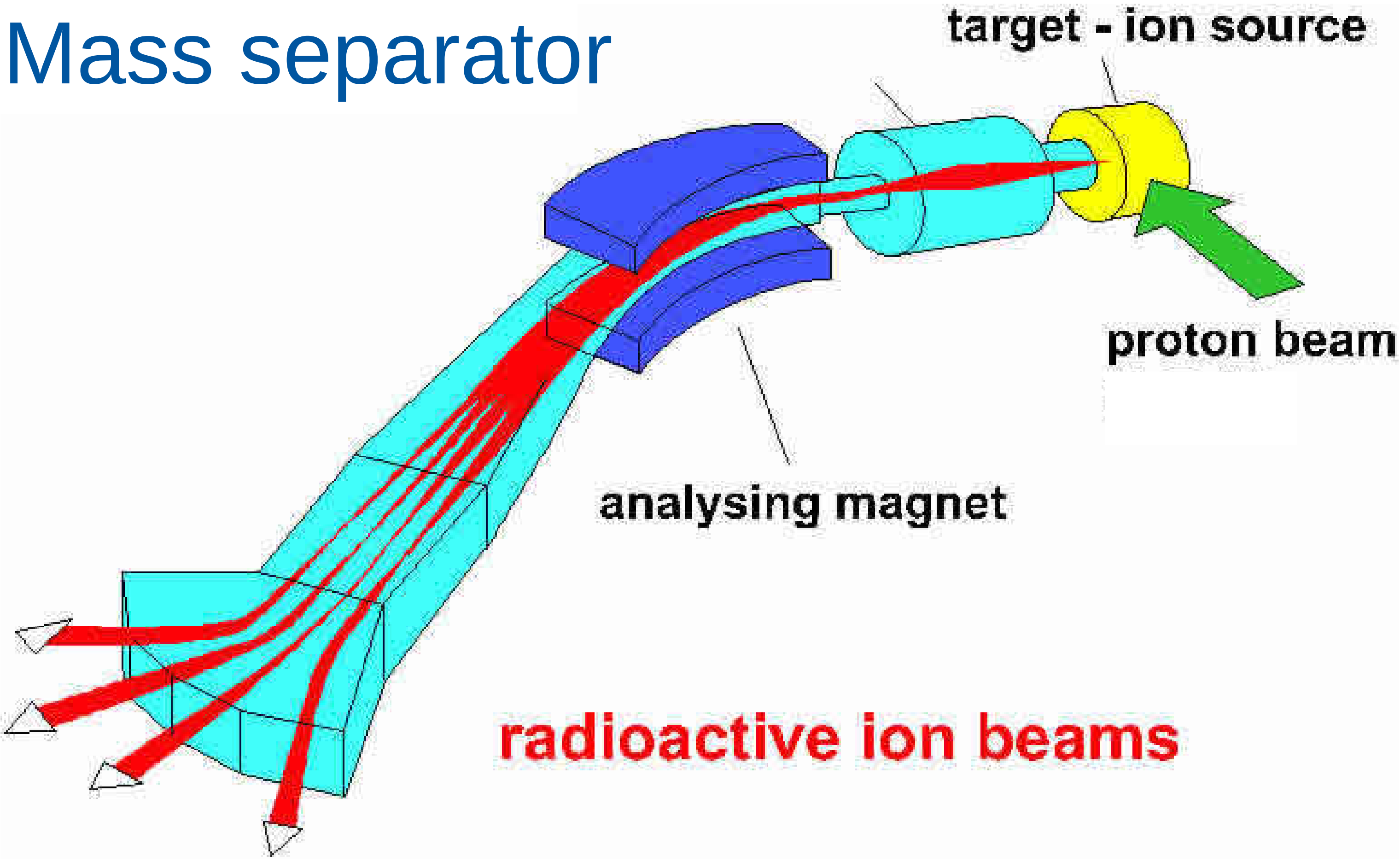

## ISOLDE FEBIAD MK7 (water-cooled transfer line)

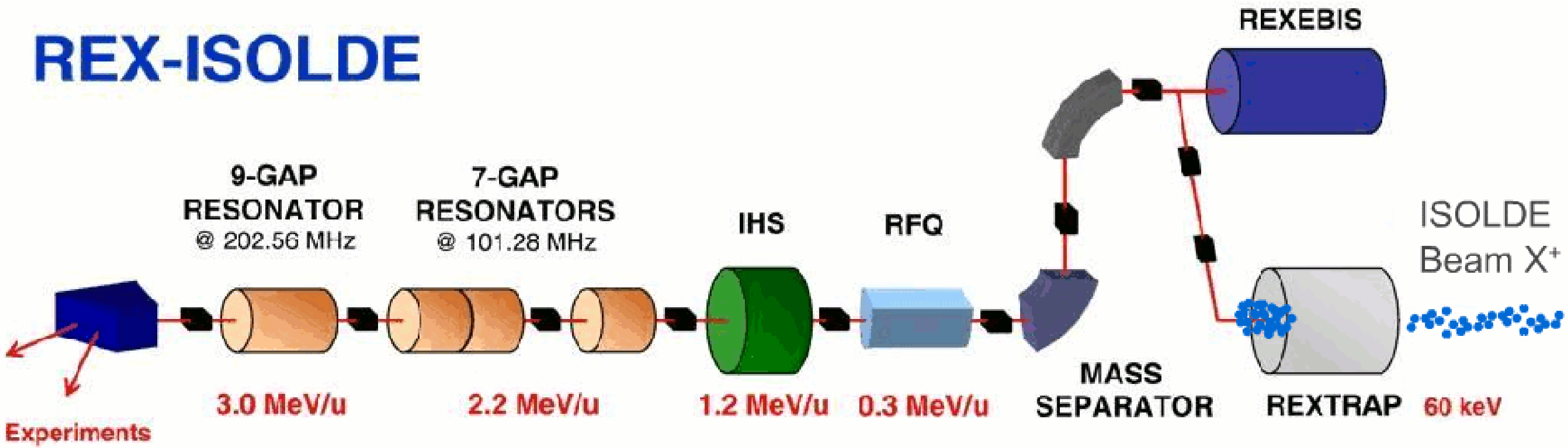


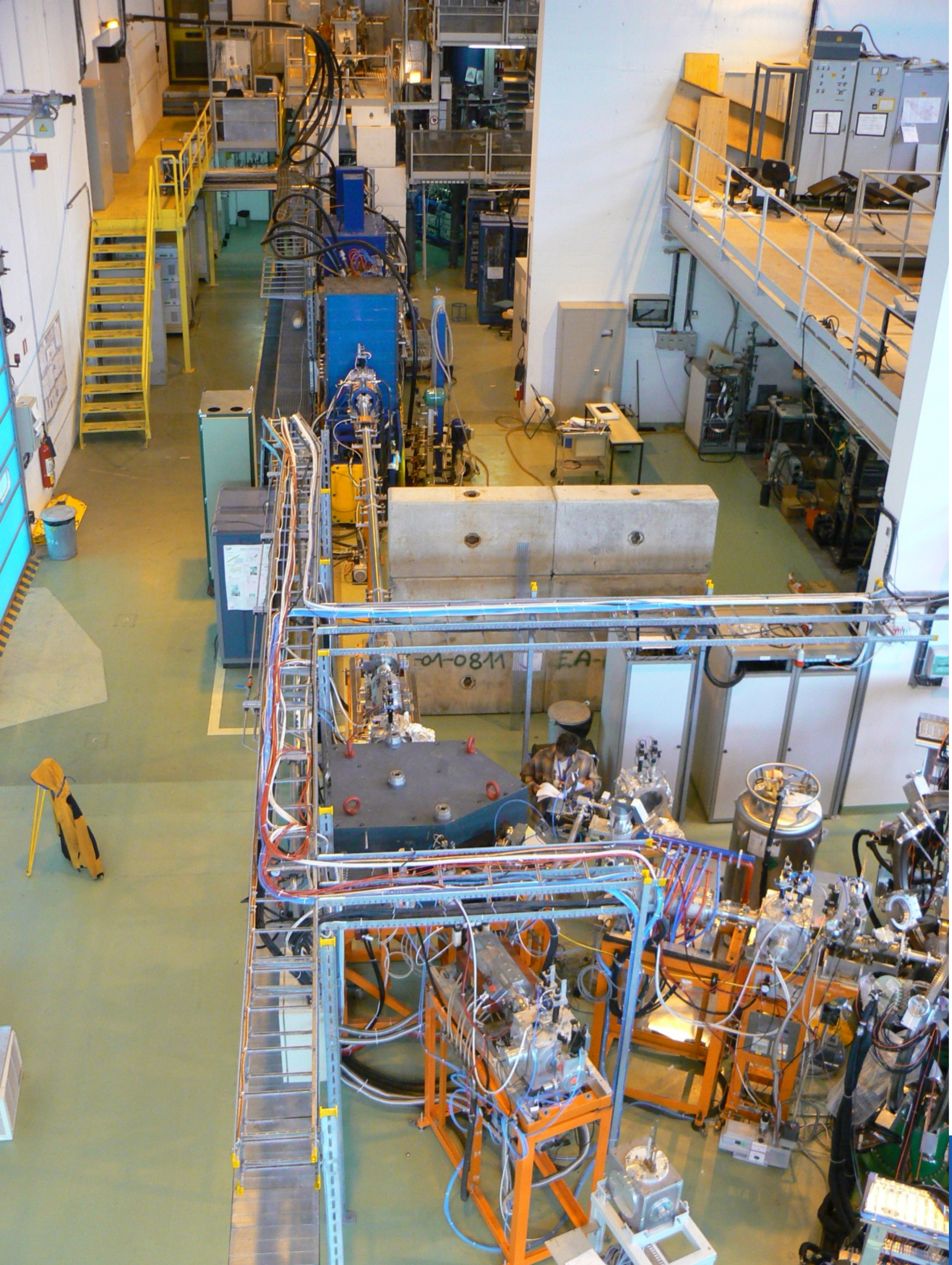

Plasma chamber: Mo or graphite, 12.5 mm diameter, 22 mm length
Source body: stainless steel



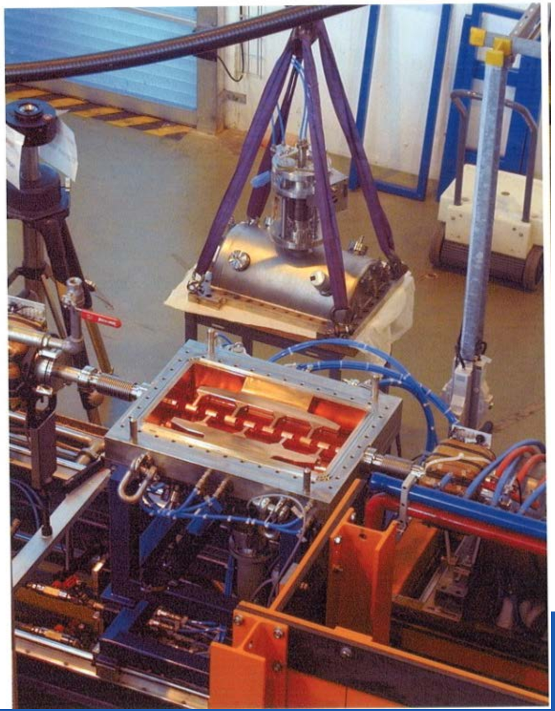
# Mass separator

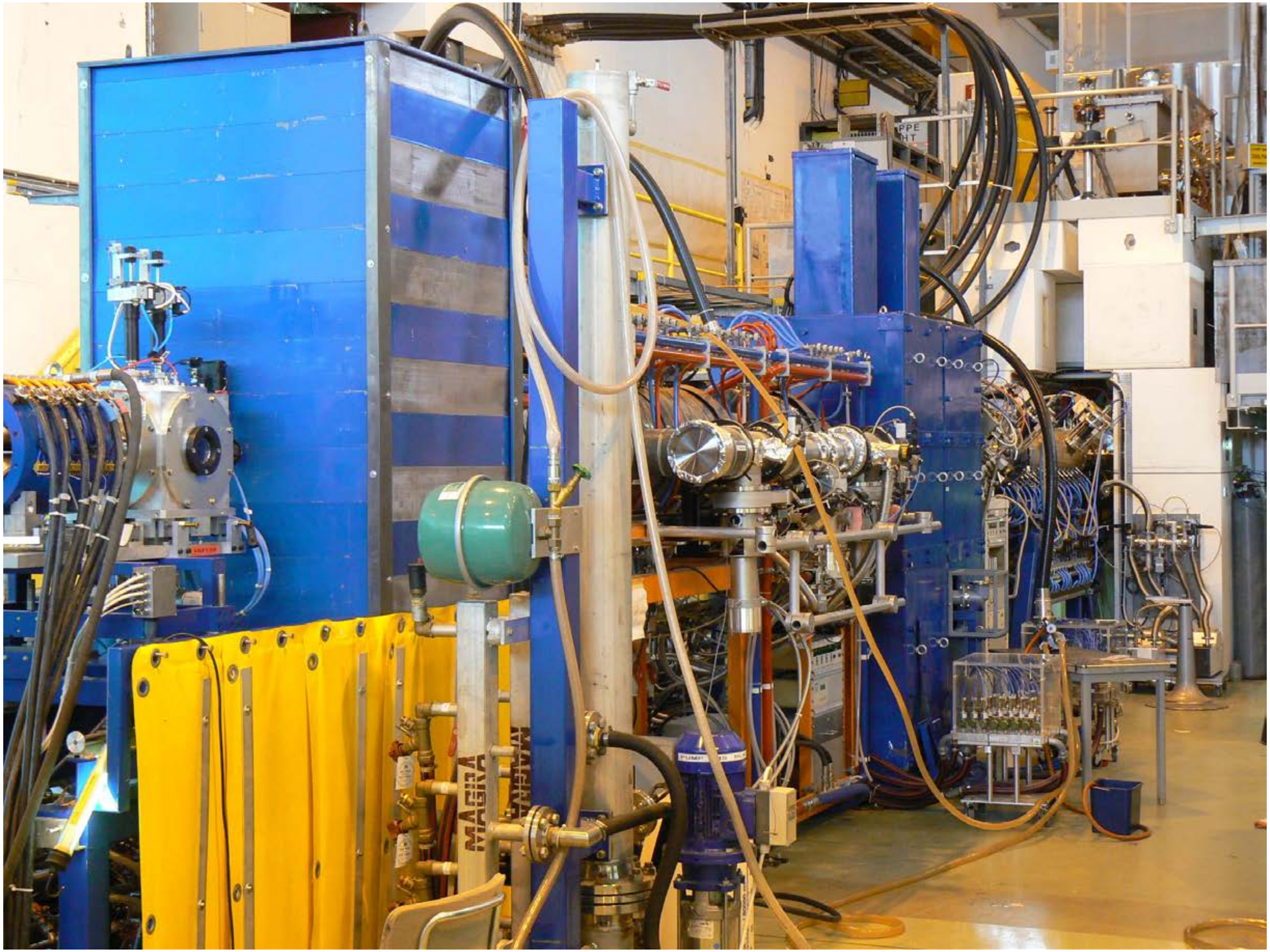


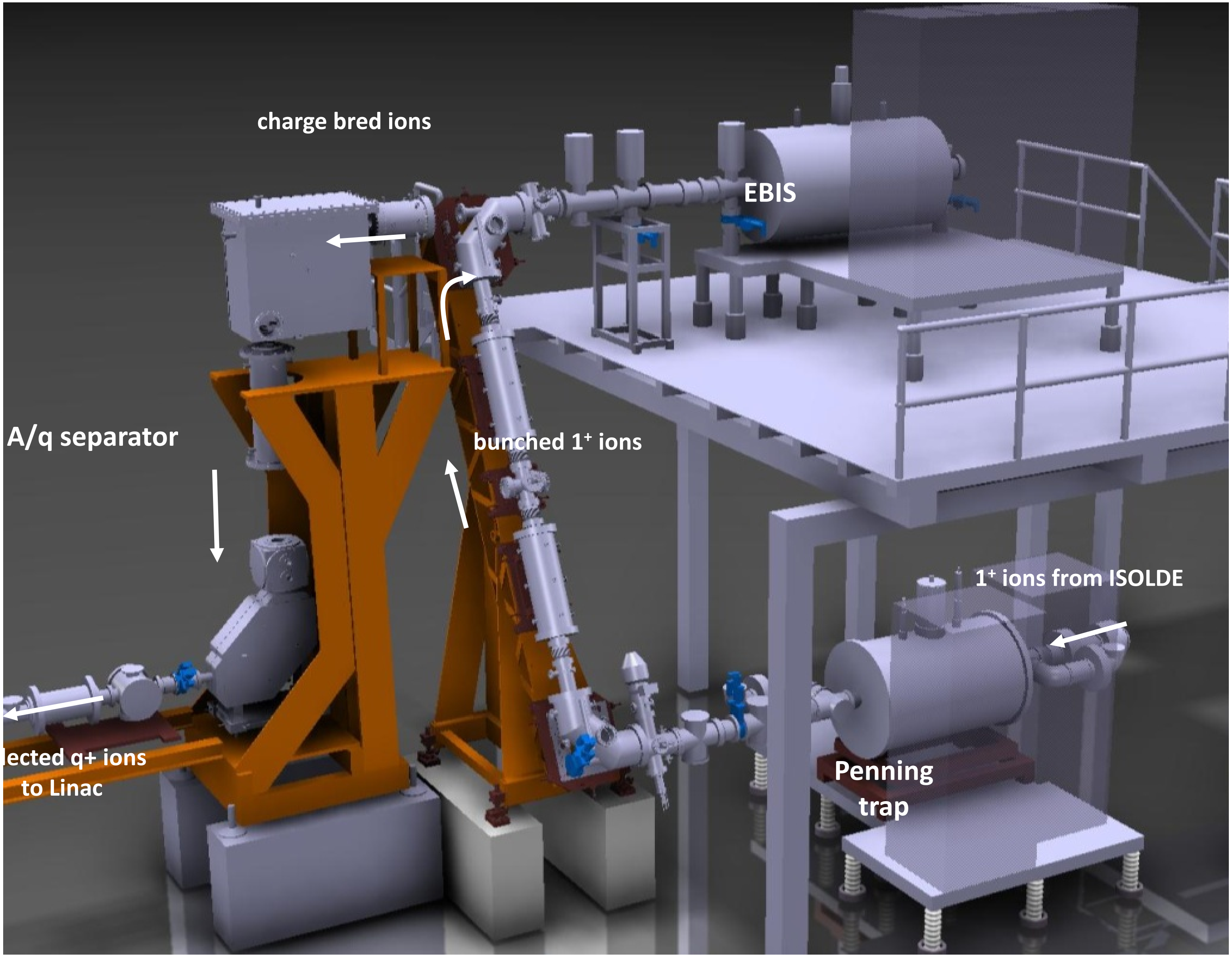

REX-ISOLDE
REXEBIS
9-GAP
RESONATOR
@ 202.56 MHz
7-GAP
RESONATORS
@ 101.28 MHz
IHS
RFQ
ISOLDE
Beam X+
Experiments
3.0 MeV/u
2.2 MeV/u
1.2 MeV/u
0.3 MeV/u
MASS
SEPARATOR
REXTRAP
60 keV


-01-0811
E.A-


X-Ray

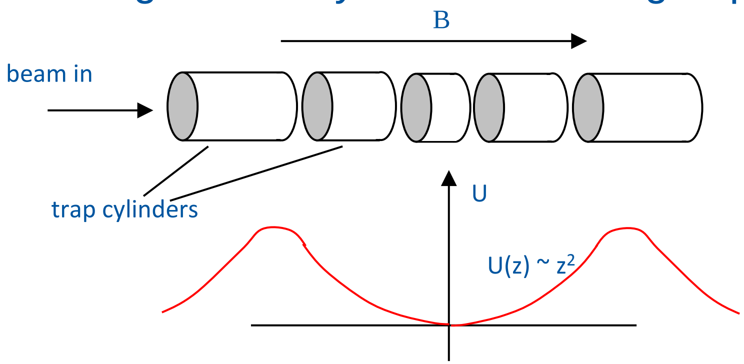



MAGRA

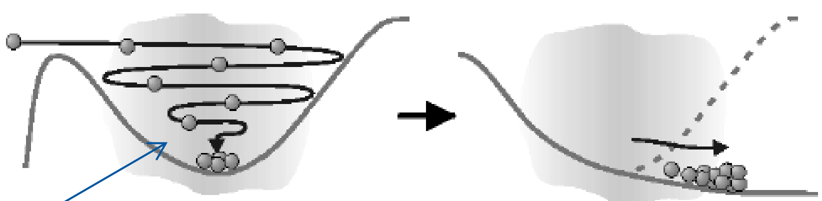

charge bred ions
EBIS
A/q separator
bunched 1+ ions
1+ ions from ISOLDE
lected q+ ions
to Linac
Penning
trap

# Preparatory beam cooling

## gas filled cylindrical Penning trap



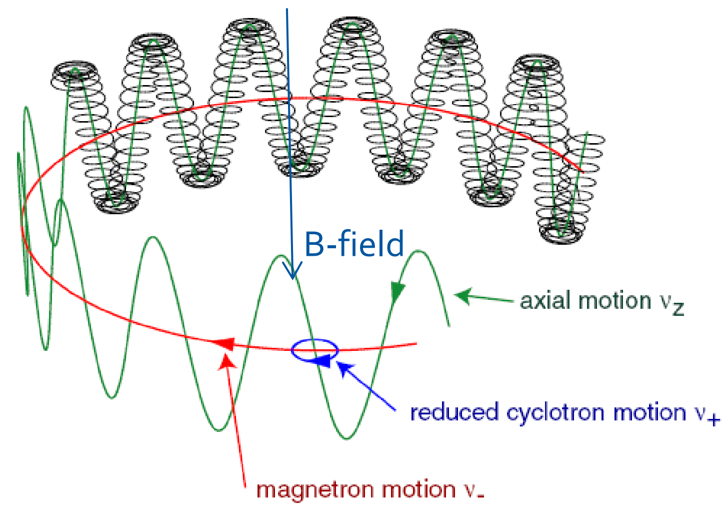

Axially - electrostatic field
Radially – magnetic field




Energy loss due to buffer gas collisions: F=-δmv

Introduce a *Penning trap* in ISOL-line to:

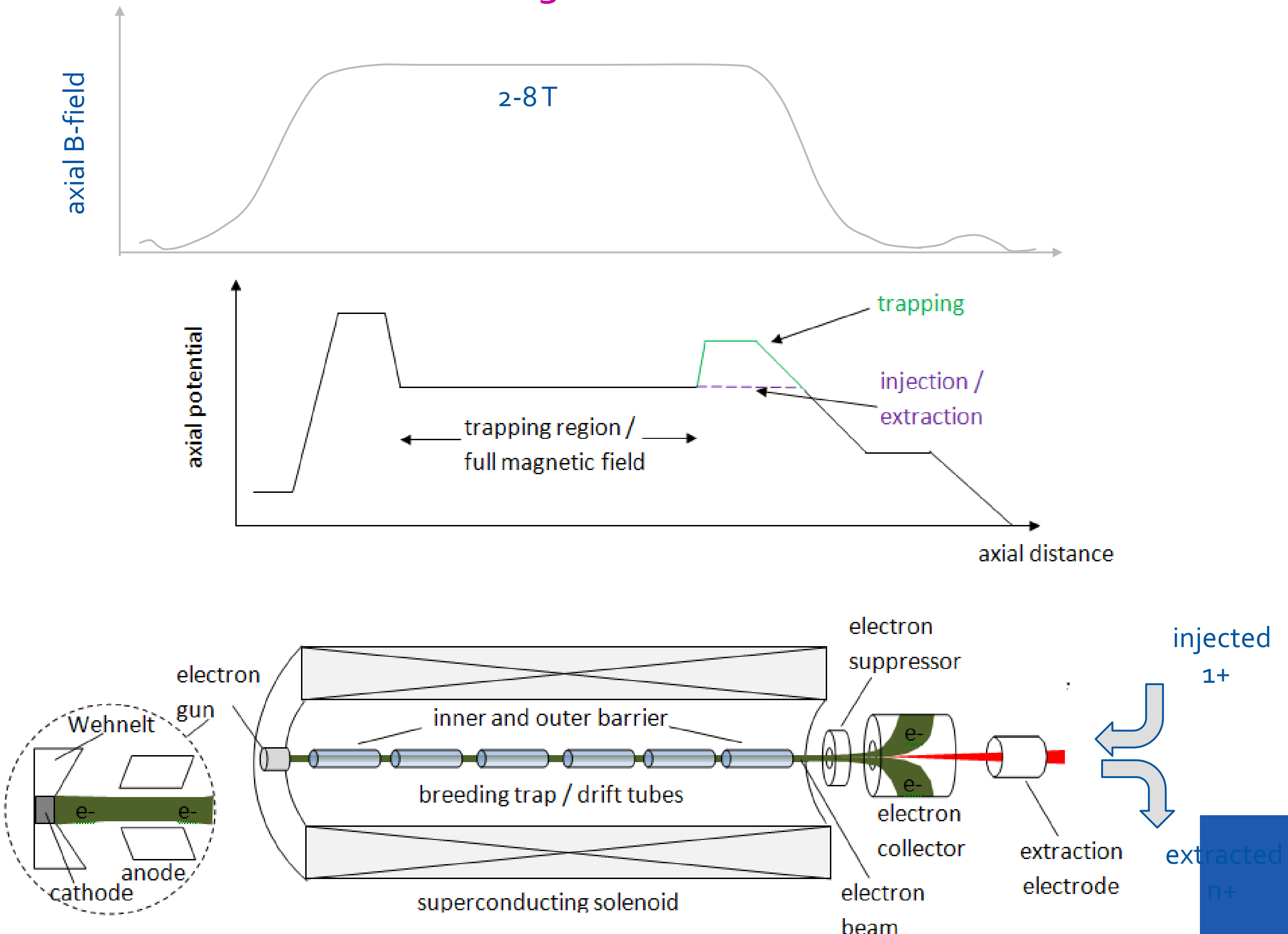
accumulate
phase space cool
bunch the beam



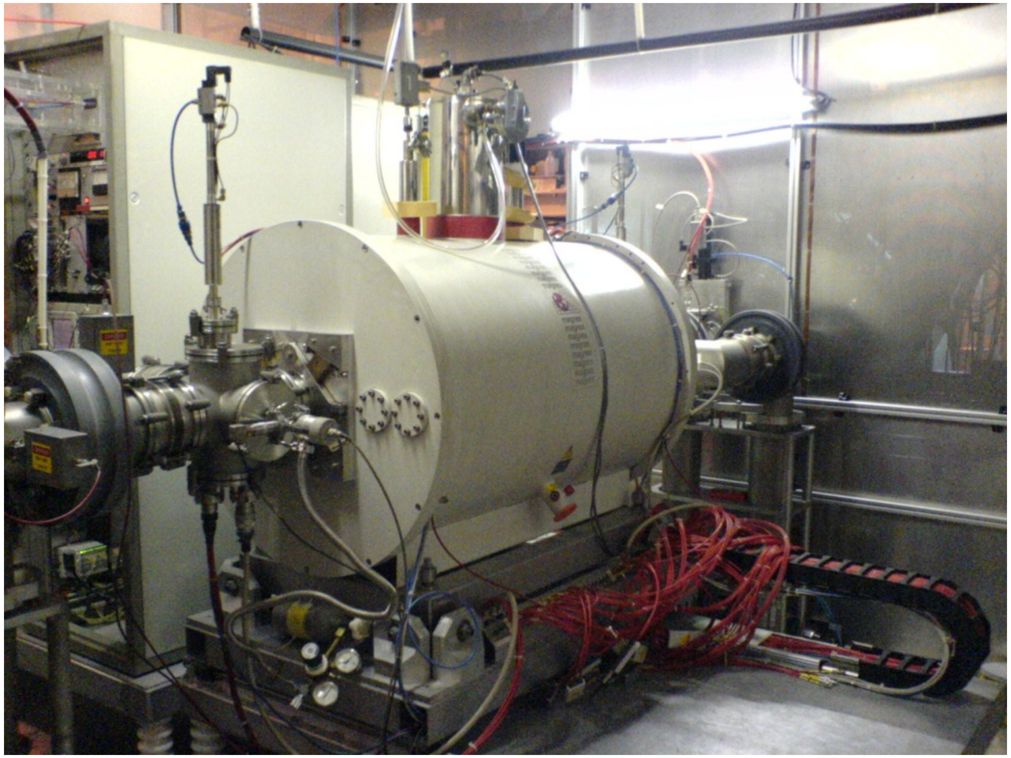

With buffer gas and RF coupling between $\nu_+$ and $\nu_-$
all three motions cooled => amplitudes reduced

# Electron Beam Ion Source

- Produces highly charged ions
- $e^-$ beam compressed by solenoid B-field
- Ions are trapped in a magneto-electrostatic trap
- Ionisation by $e^-$ bombardment from a fast, dense mono-energetic $e^-$ beam

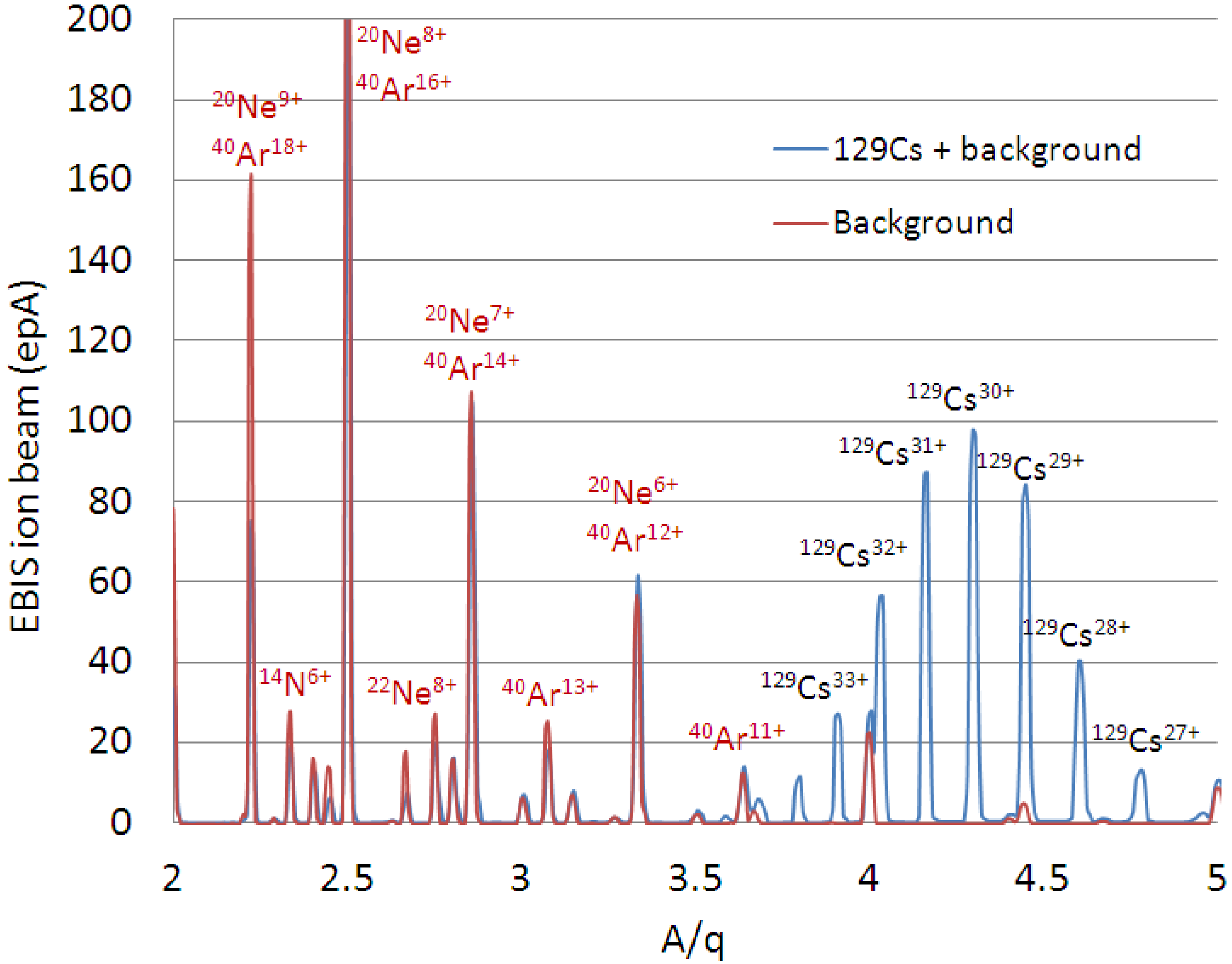


REXTRAP



REXEBIS

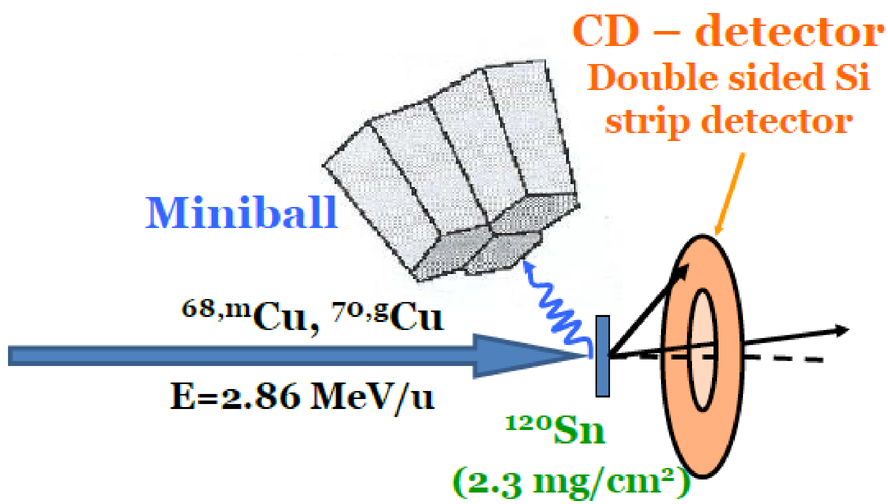
# Constant worry - clean beams?

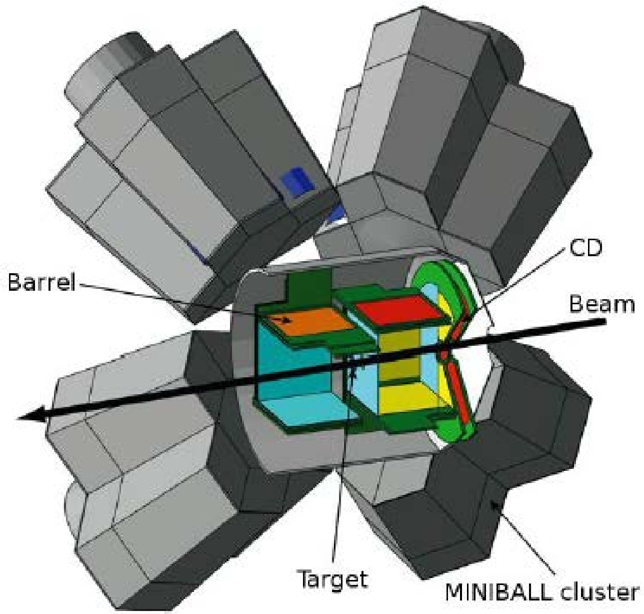



*Extracted beams from REXEBIS as function of A/q showing residual gas peaks and charge bred $^{129}Cs$. The blue trace is with and the red trace without $^{129}Cs$ being injected.*

# Miniball – the experimental workhorse

- High efficiency, low multiplicity spectrometer
- Coulomb excitation and transfer experiments
- 300 keV/u – 3 MeV/u beam energy
- 24 HPGe detectors, 6-fold segmented with Si barrel for Doppler correction



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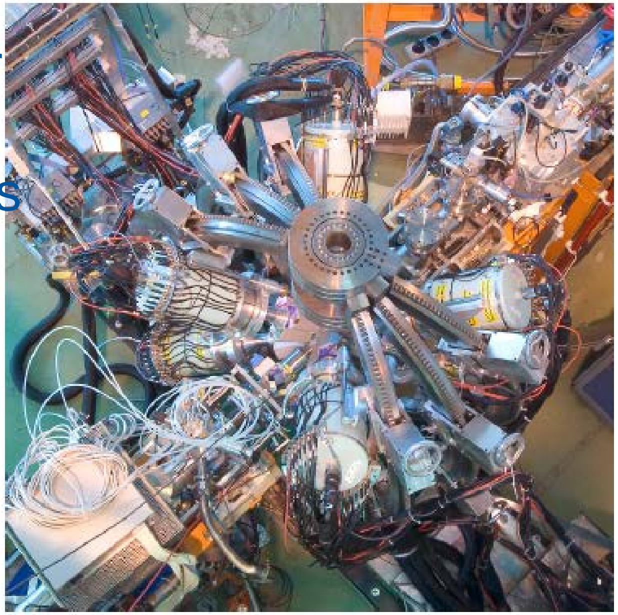
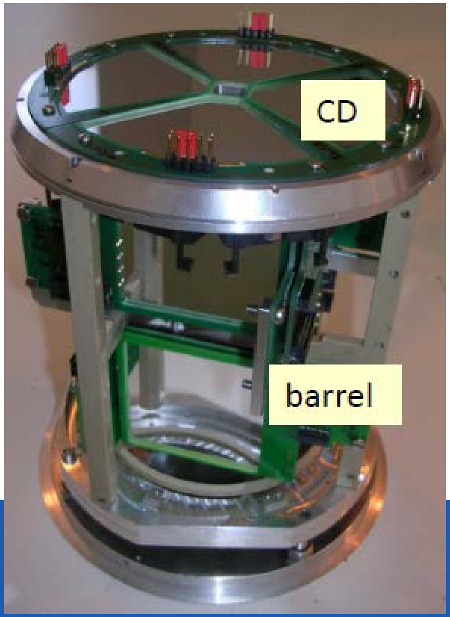
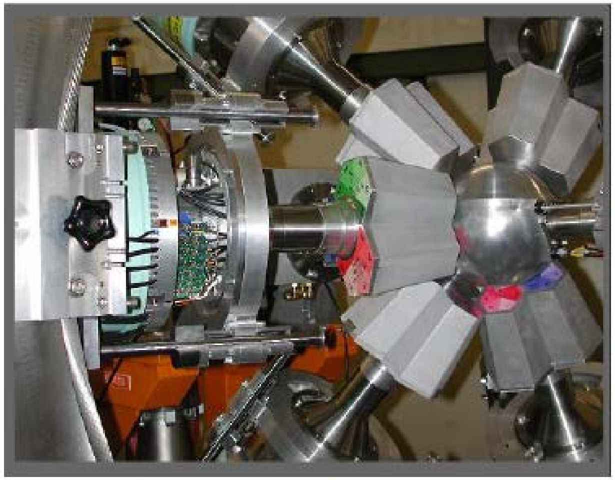
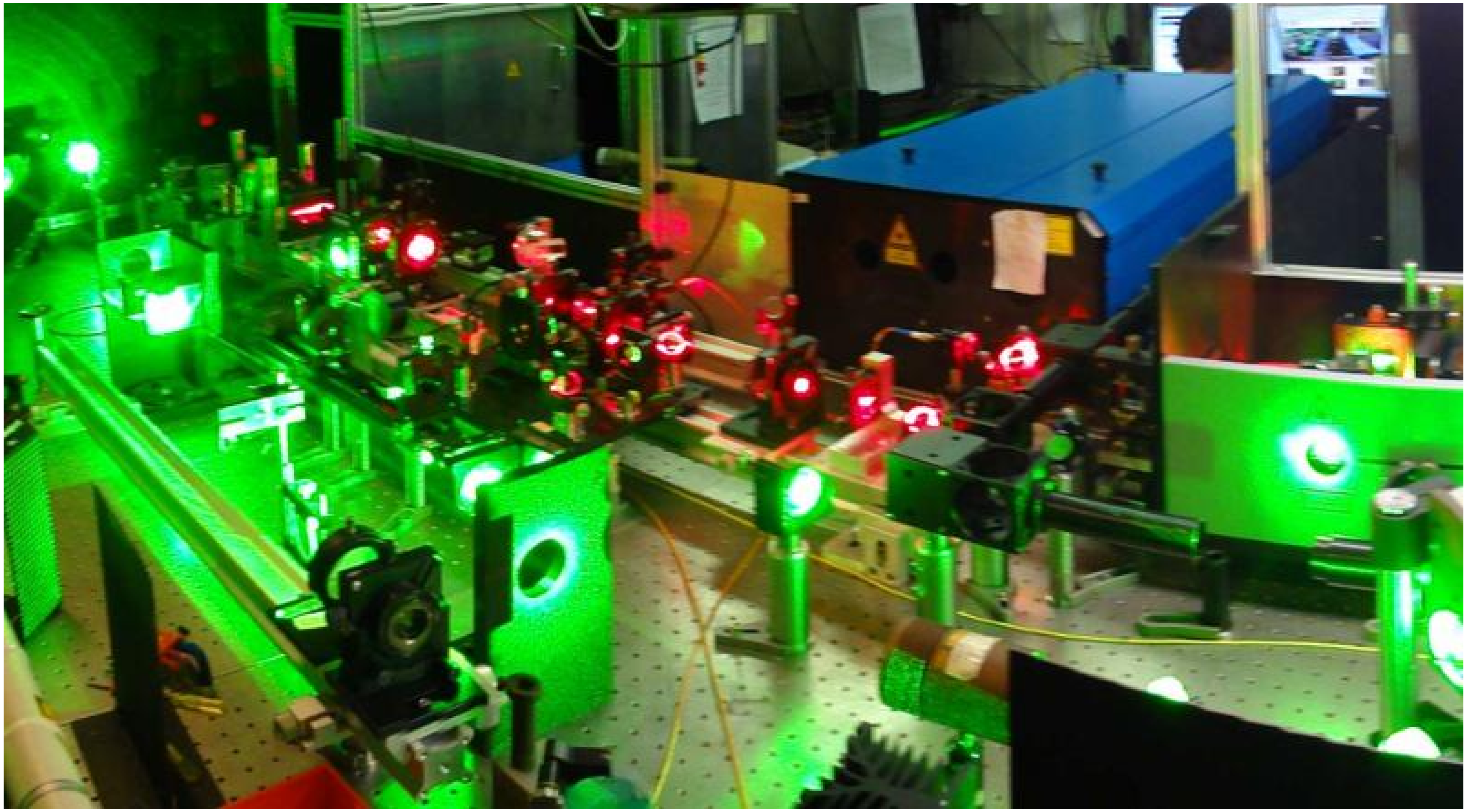


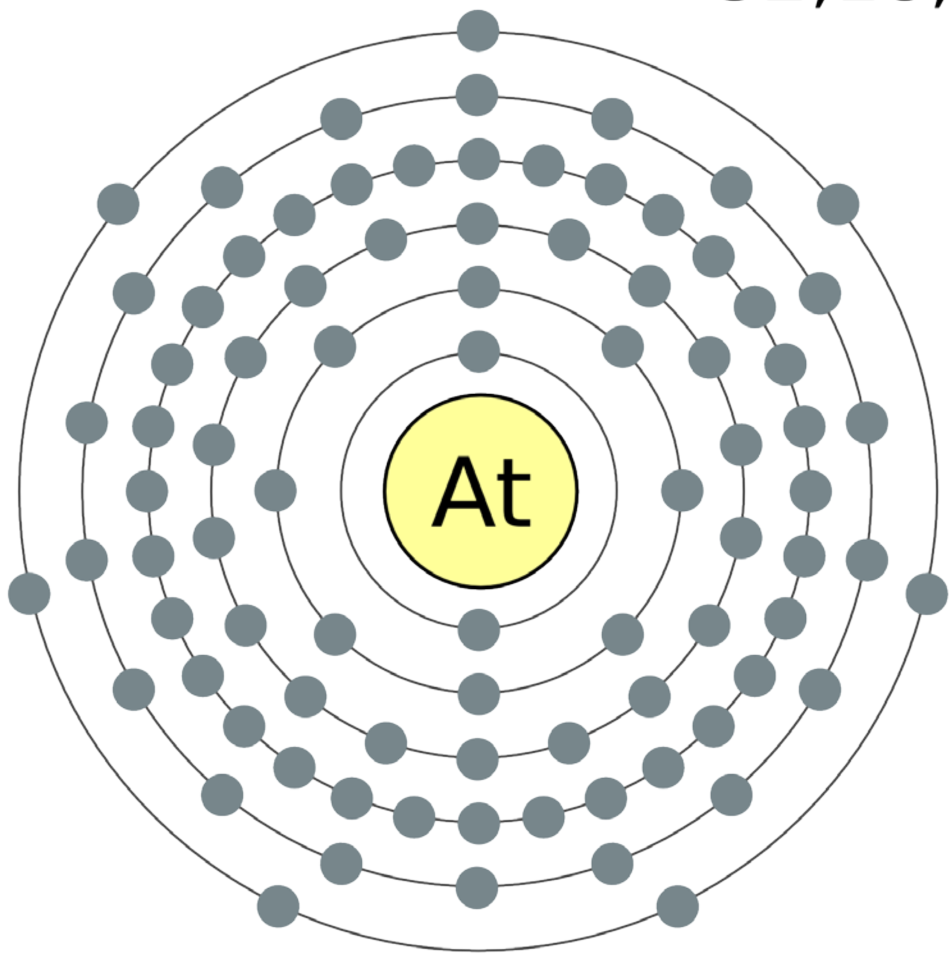




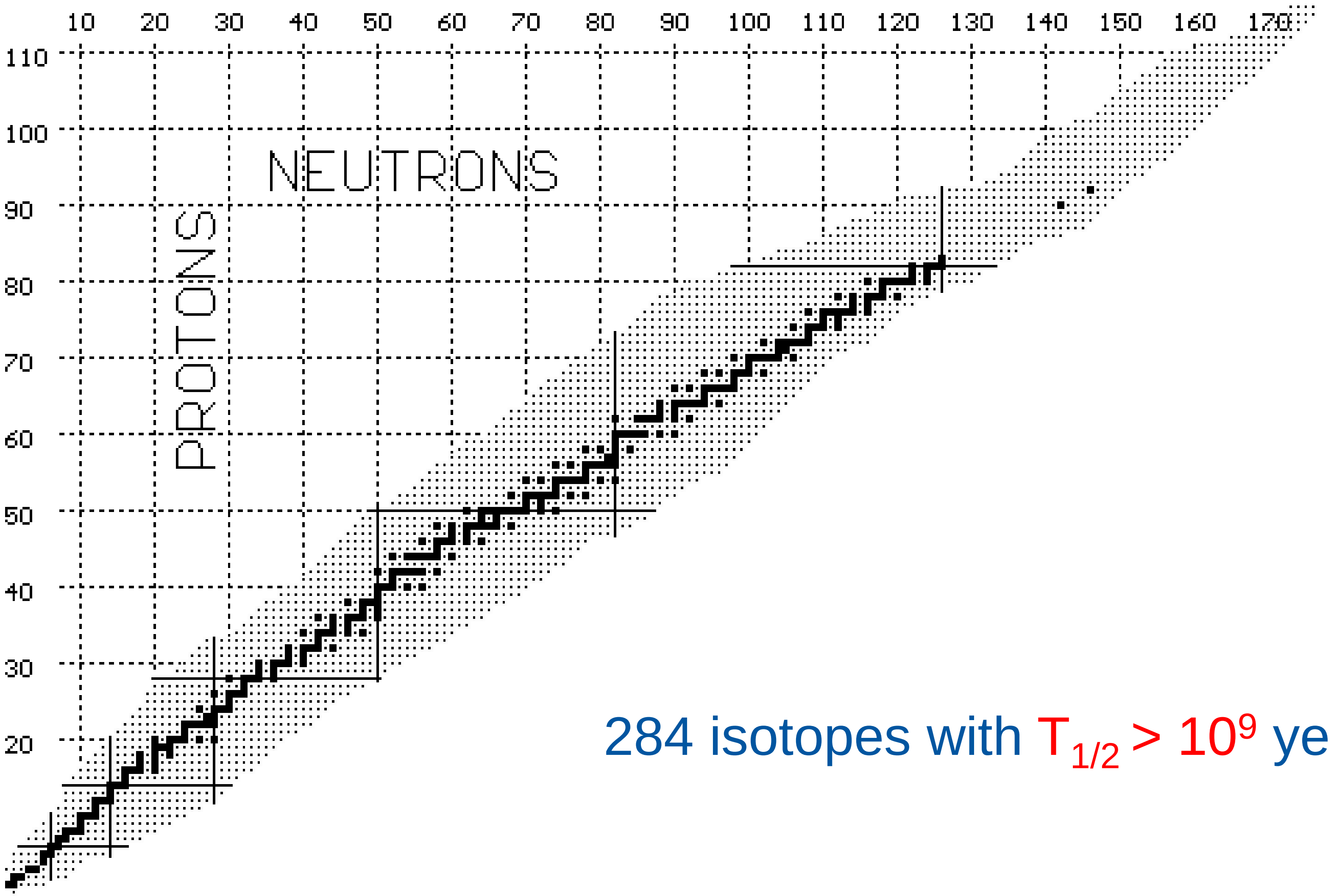
# 85: Astatine

2,8,18,
32,18,7

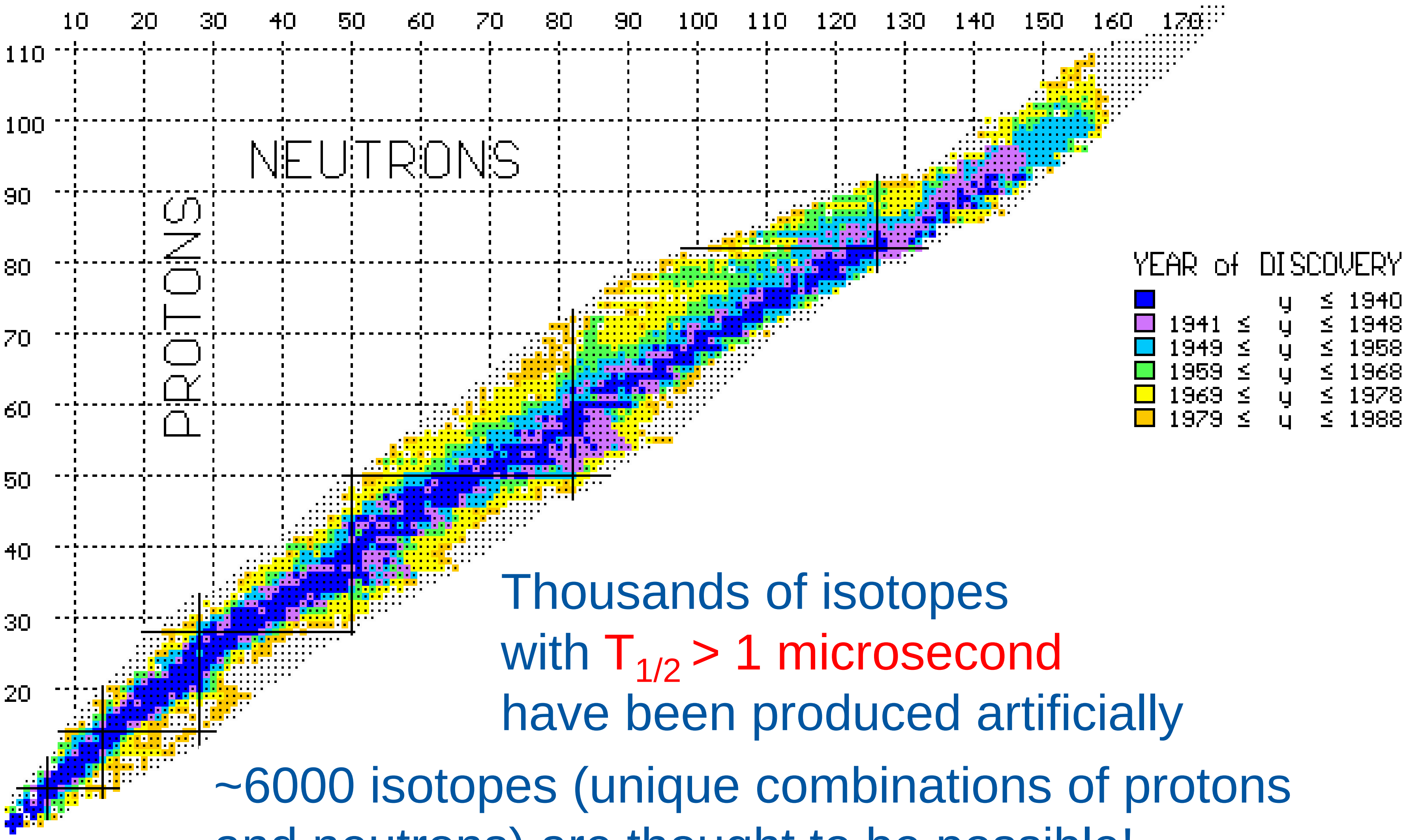


| Group → / ↓ Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H | | | | | | | | | | | | | | | | | 2 He |
| 2 | 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 3 | 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 4 | 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 5 | 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 6 | 55 Cs | 56 Ba | | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 7 | 87 Fr | 88 Ra | | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 Ds | 111 Rg | 112 Cn | 113 Uut | 114 Fl | 115 Uup | 116 Lv | 117 Uus | 118 Uuo |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 La | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| Actinides | 89 Ac | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |



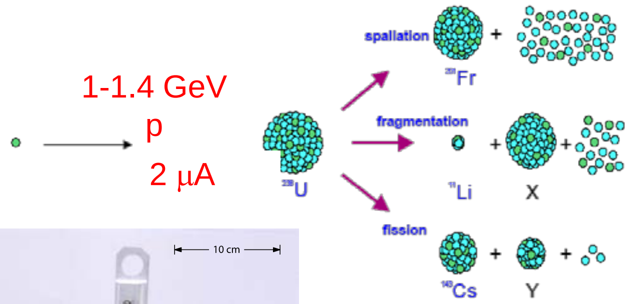

284 isotopes with $T_{1/2} > 10^9$ year

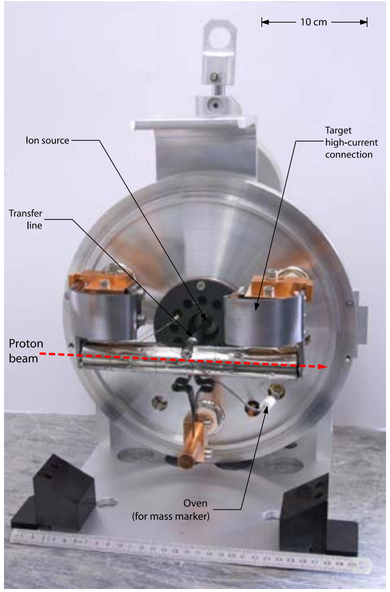



Thousands of isotopes
with $T_{1/2} > 1$ microsecond
have been produced artificially

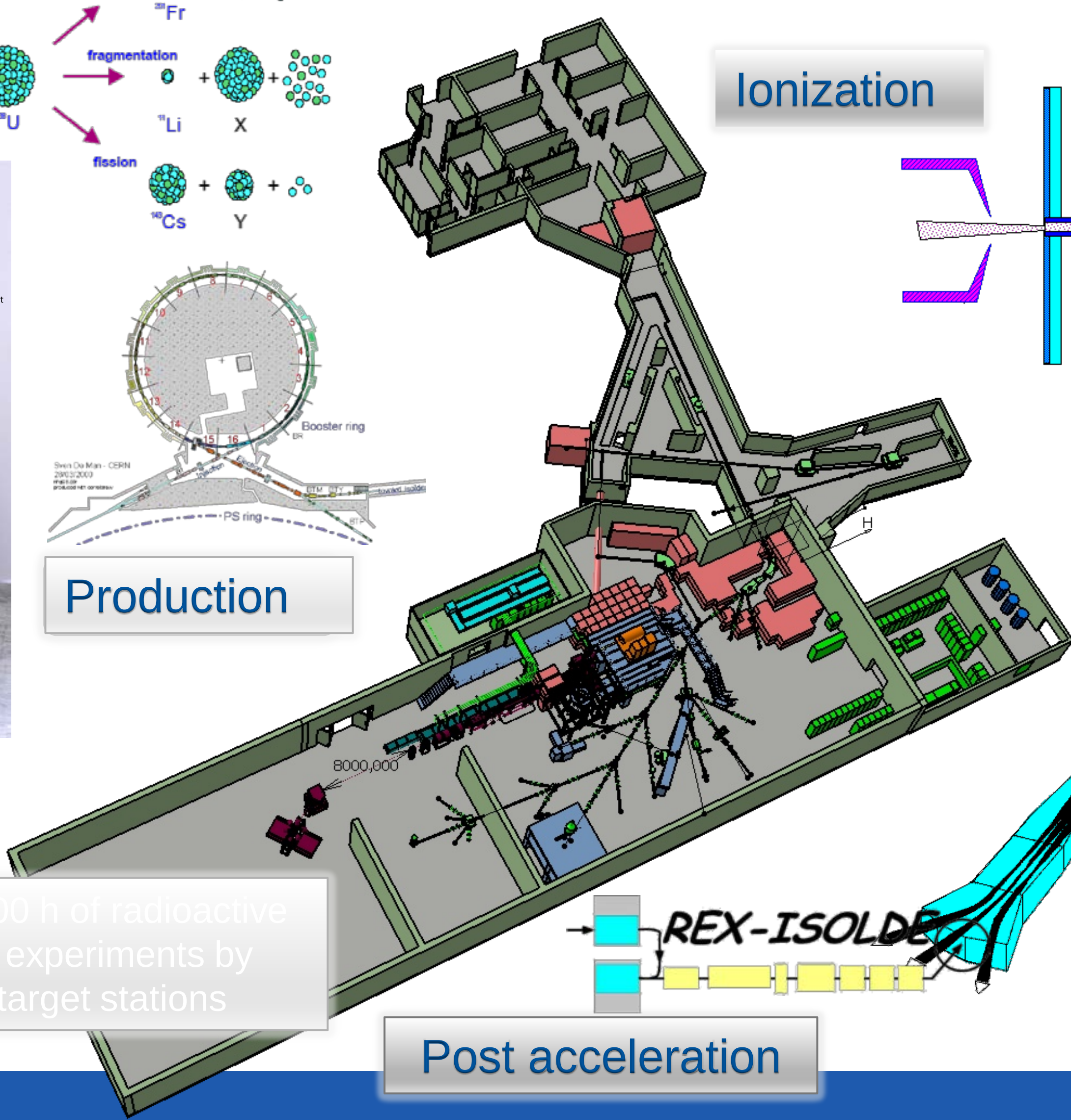
~6000 isotopes (unique combinations of protons and neutrons) are thought to be possible!

# ISOLDE isotope factory

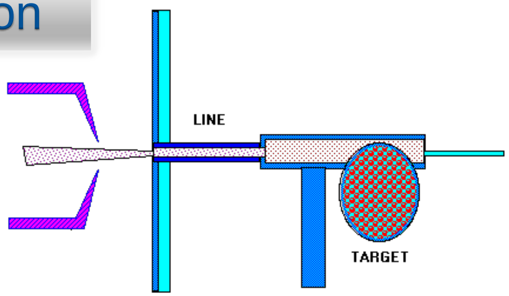



Production




Ionization




Single charge:
- Surface
- Plasma
- RILIS
- ECR

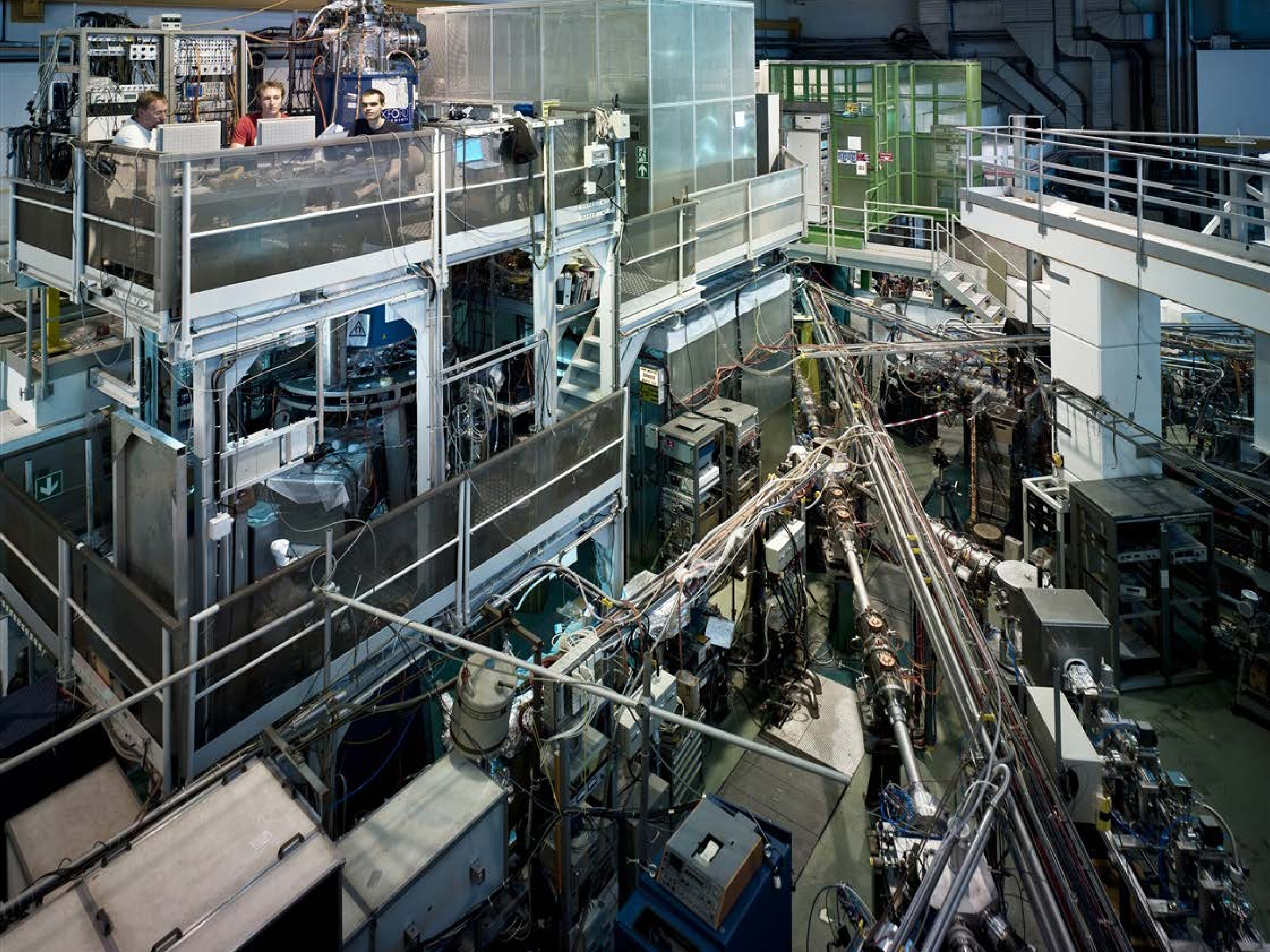
Mass separation

Post acceleration

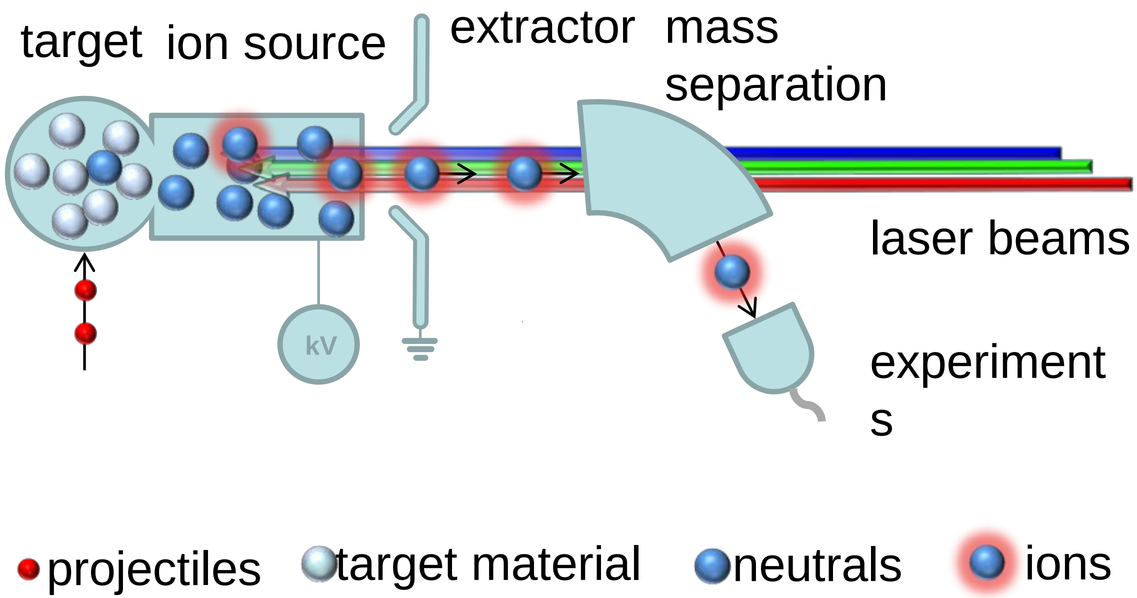
Delivers yearly 3200 h of radioactive ion-beams to 30 experiments by means of two target stations

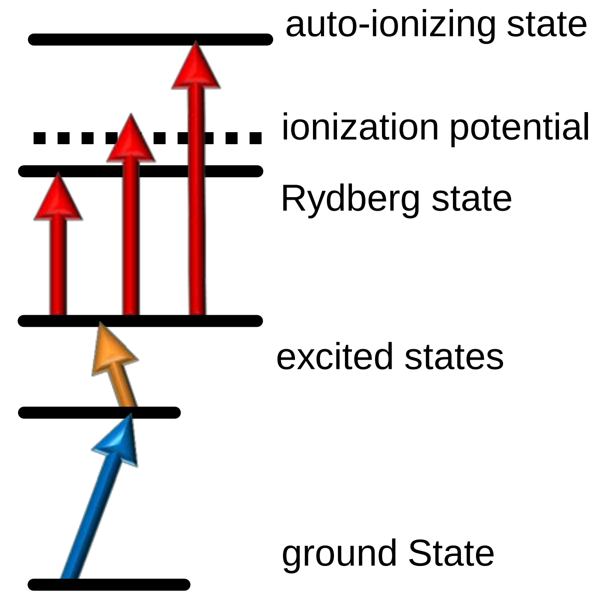
**Jonson, B., & Richter, A. (2000).** *More than three decades of ISOLDE physics. Hyperfine Interactions, 129*, 1–22. doi:10.1023/A:10126891

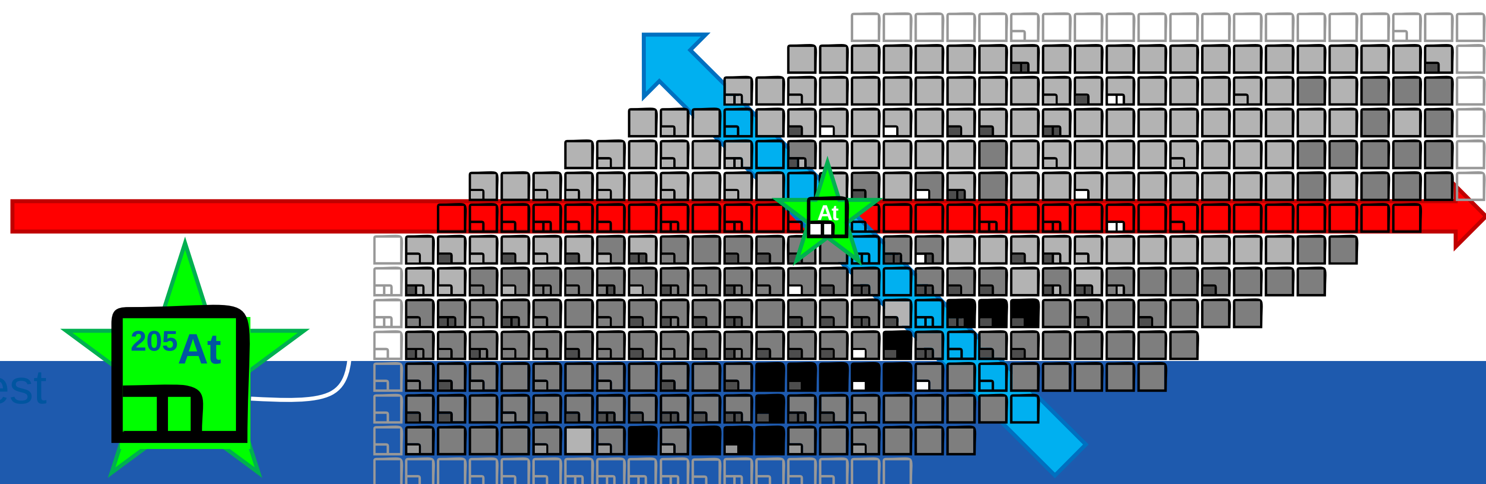
http://isolde.web.cern.ch/ISOLDE/

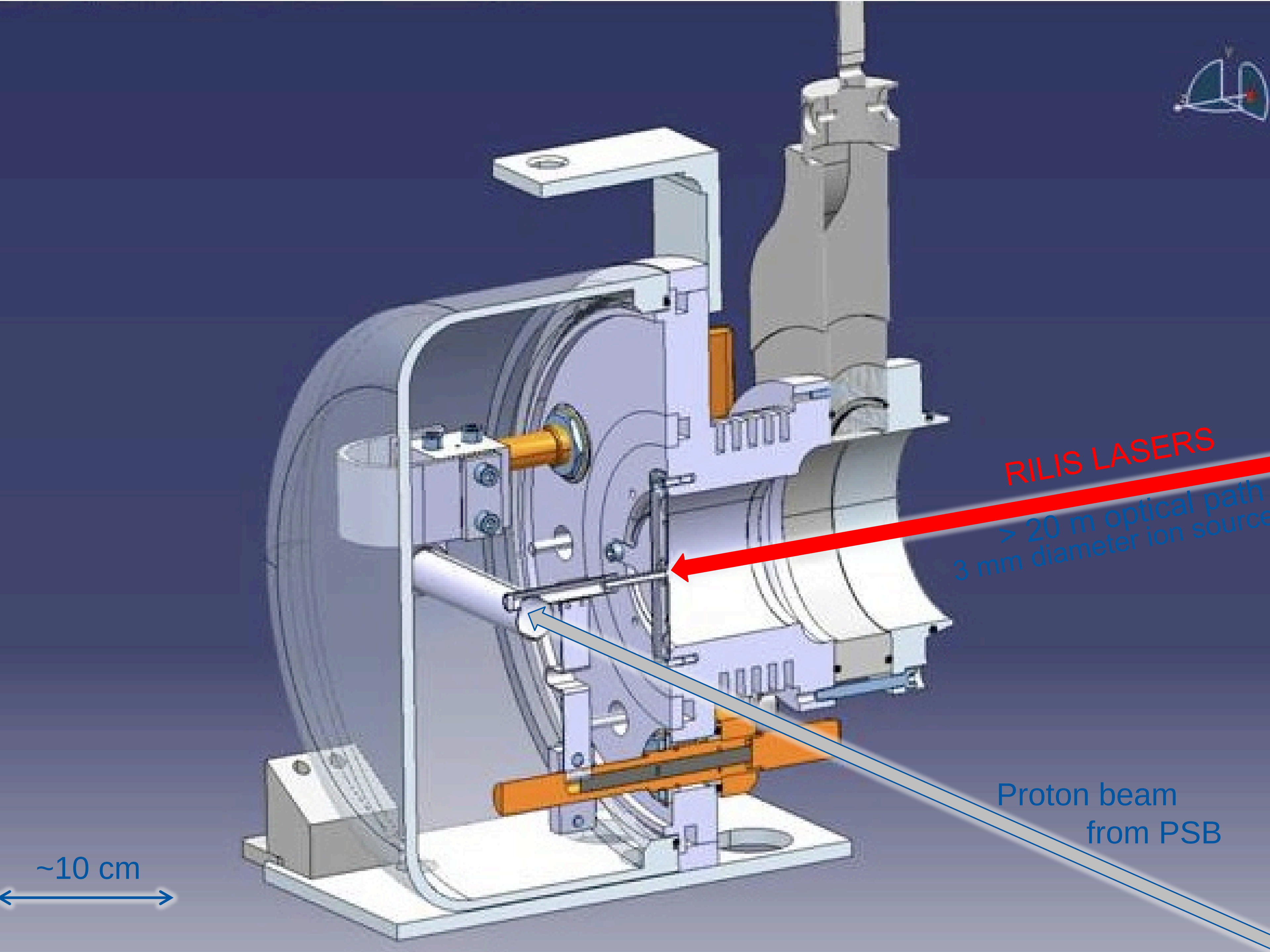


# Resonance laser ionization

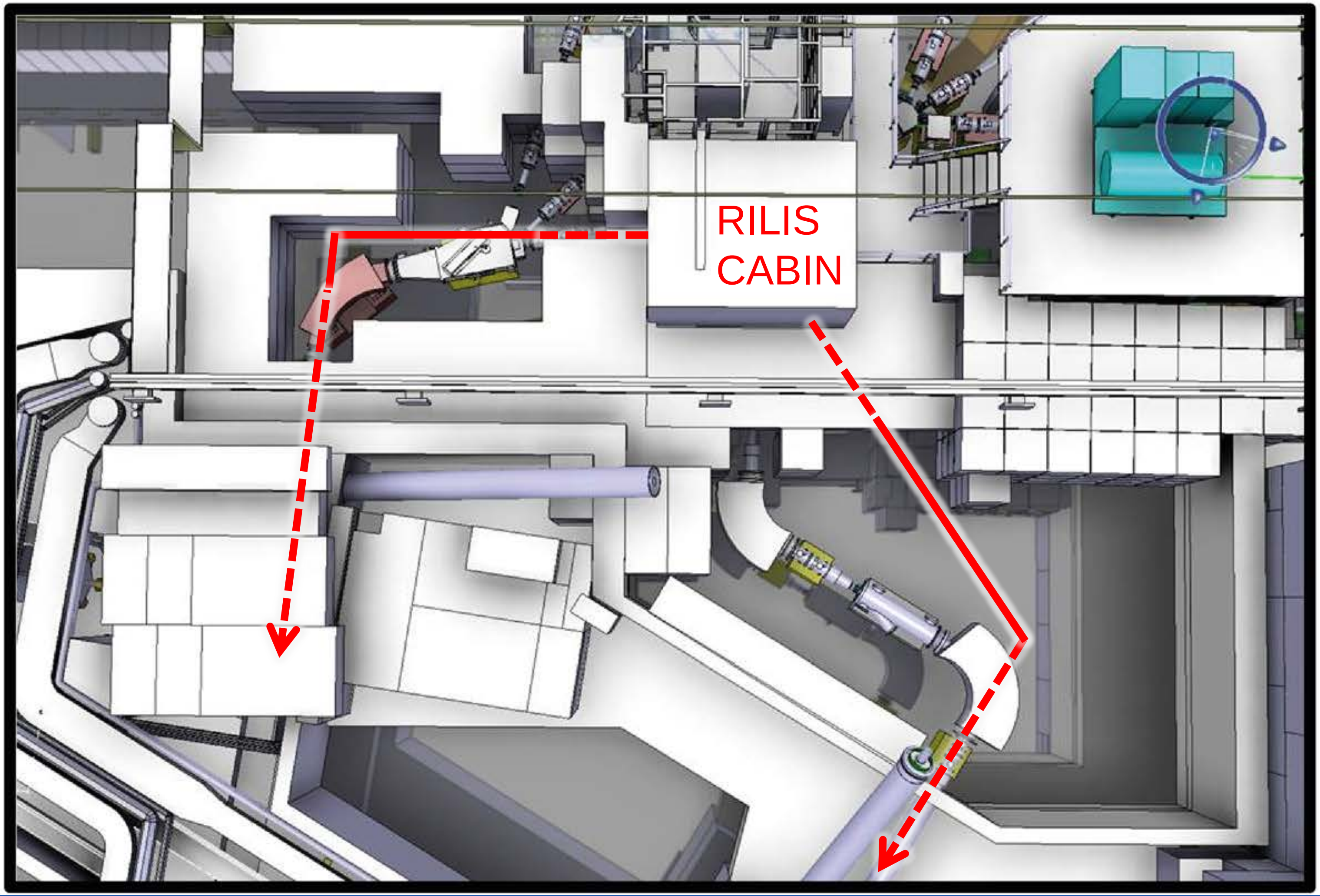


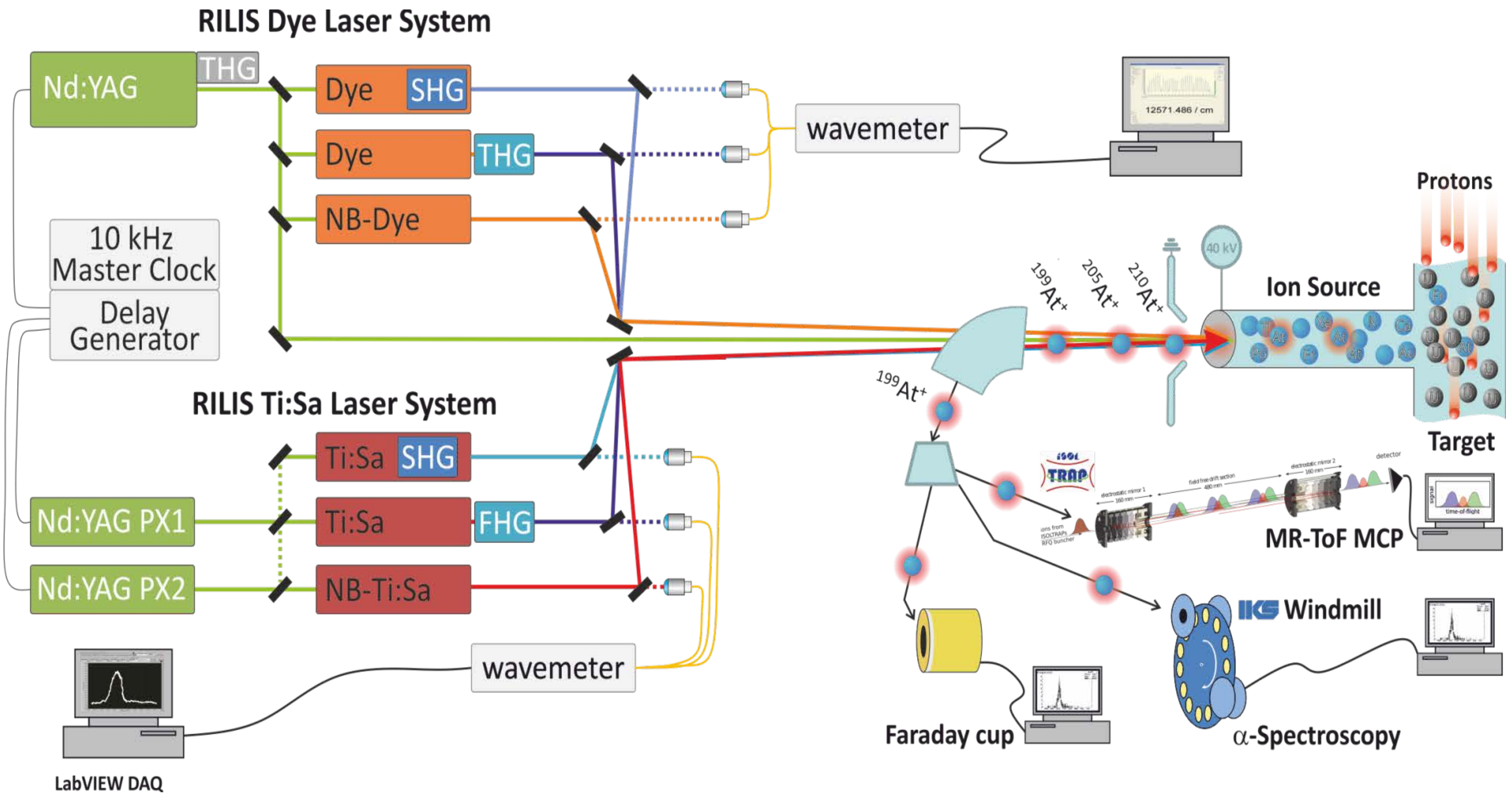




RILIS LASERS
> 20 m optical path
3 mm diameter ion
Proton beam
from PSB
~10 cm

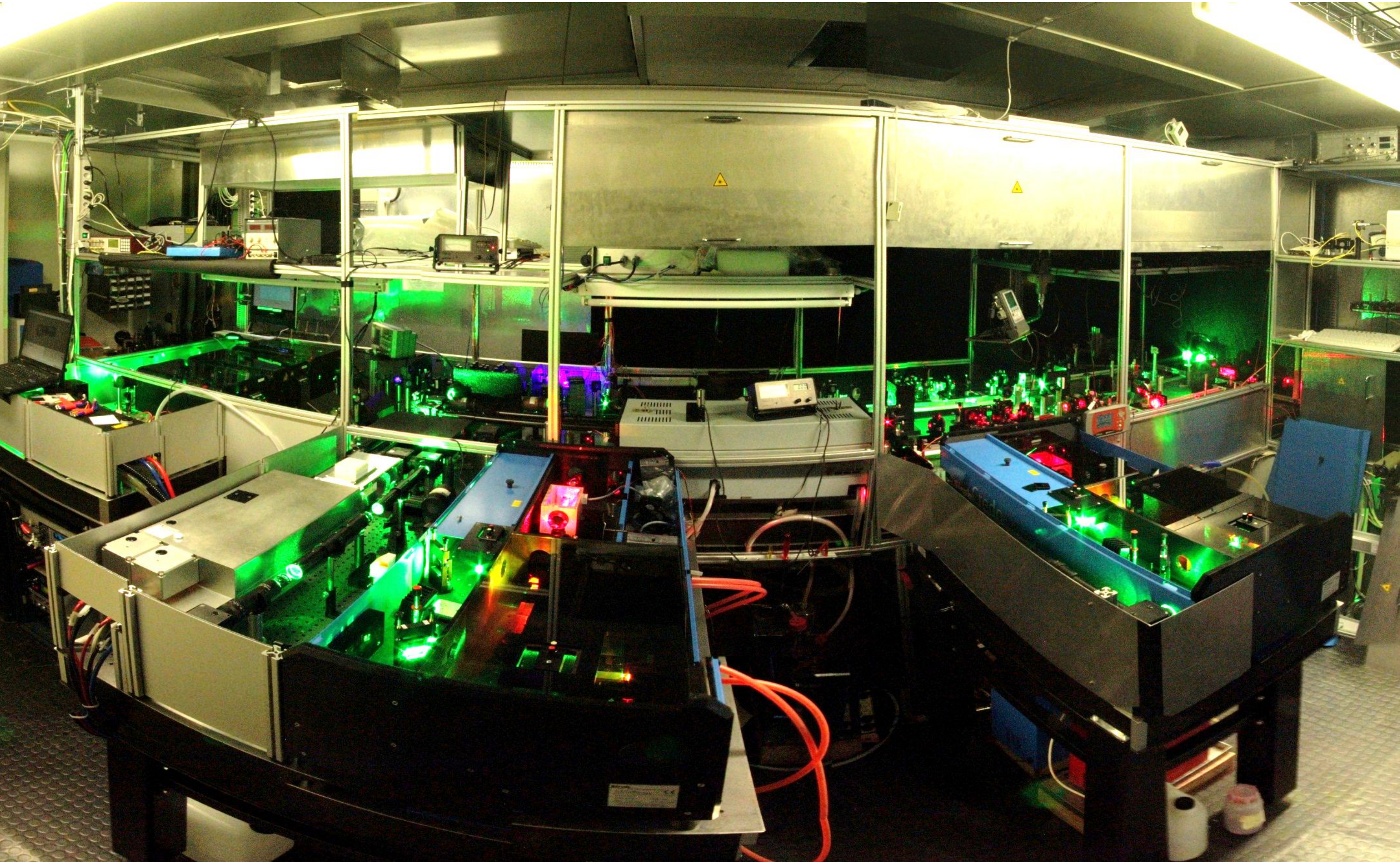
# Laser access to the targets



# RILIS Schematic



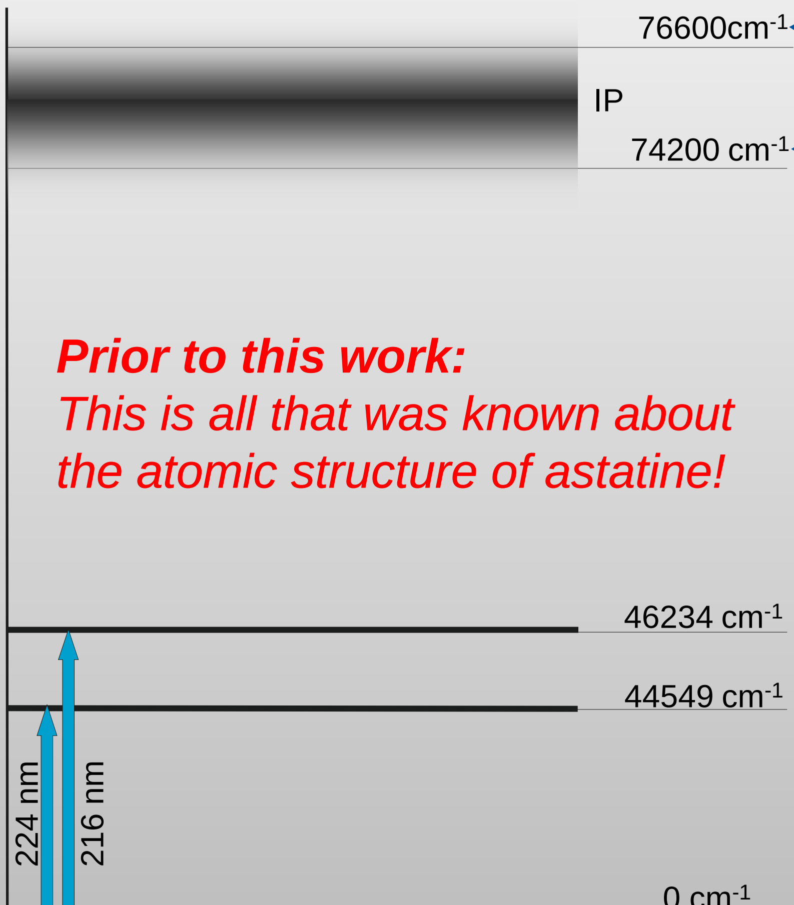
# RILIS in action



# RILIS in action

# Atomic structure of astatine

- Most abundant isotope $^{218}$At, ($t_{1/2}$ = 1.5 s)
- I.Asimov: 1st mile of earth's crust : 70mg (~3.5 atoms/ kg)
- Artificial production: $^{209}$Bi($\alpha$,2n)$^{210}$At, Corson et al. (1940)
- First optical spectroscopy of $^{210}$At, 70 ng sample, (2x10$^{14}$ atoms), McLaughlin (1964)




***Prior to this work:***
*This is all that was known about the atomic structure of astatine!*

## Theoretial predictions of IP(At)

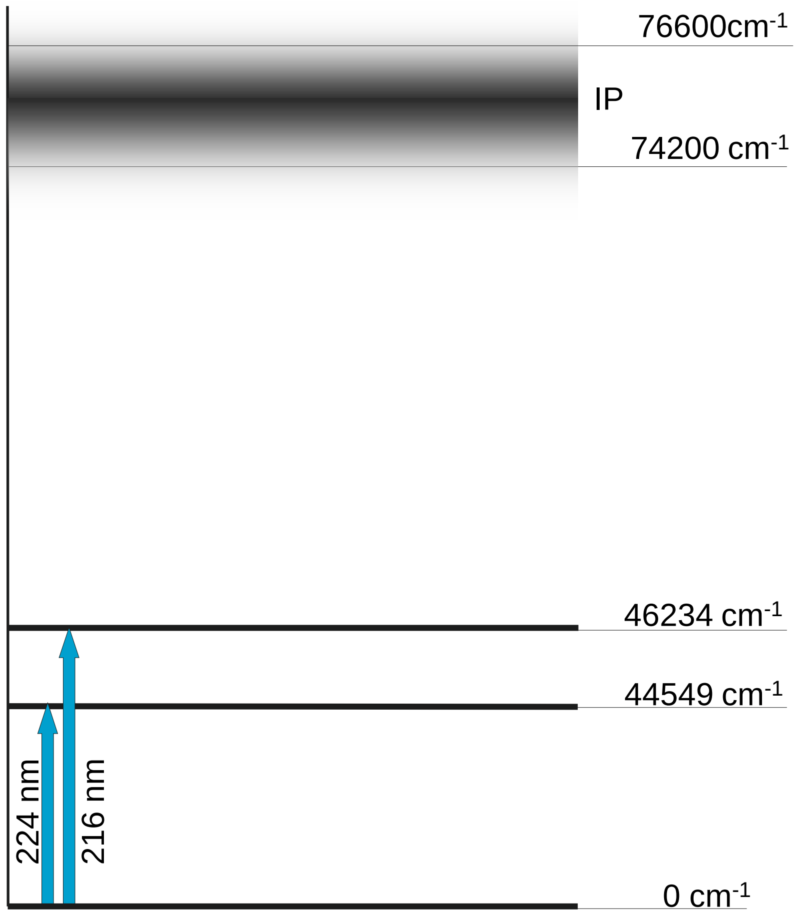
| | | |
|---|---|---|
| Finkelnburg | 1950 | $9.5 \pm 0.2$ eV |
| Varshni | 1953 | 10.4 eV |
| Finkelnburg | 1955 | $9.2 \pm 0.4$ eV |
| Kiser | 1960 | 9.5 eV |
| Dong | 2010 | 9.35 eV ( 75412 $cm^{-1}$) |

## Energy Levels of neutral Astatine (from NIST)

| Configuration | Term | J | Level ($cm^{-1}$) | Ref. |
|---|---|---|---|---|
| $6p^5$ | $^2P°$ | 3/2 | 0.0 | M64a |
| $6p^4(^3P)7s$ | $^4P$ | 5/2 | 44549.3 ? | M64a |
| | | 3/2 | 46233.6 ? | M64a |
| At II ($^3P_2$) | *Limit* | | | |

[M64a] R. McLaughlin, J. Opt. Soc. Am. 54, 965

# Astatine beams




**Step 1**:
Ionization scheme development
→ study of the **atomic structure**

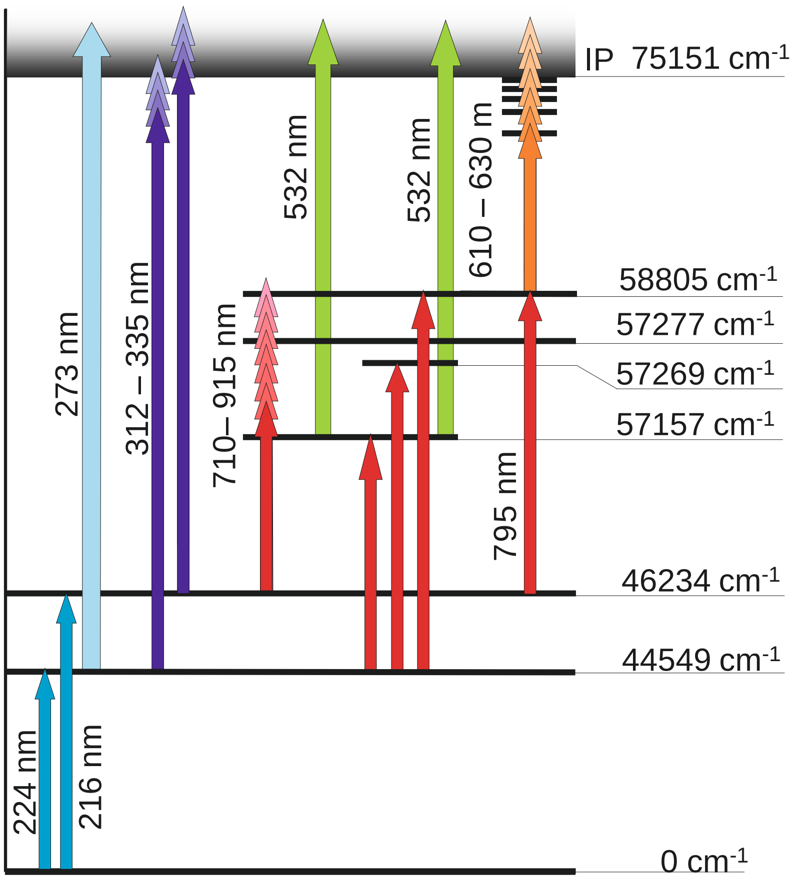
**Step 2**:
Measure the ionization potential

**Step 3**:
Use the best scheme for **nuclear structure** studies by atomic spectroscopy

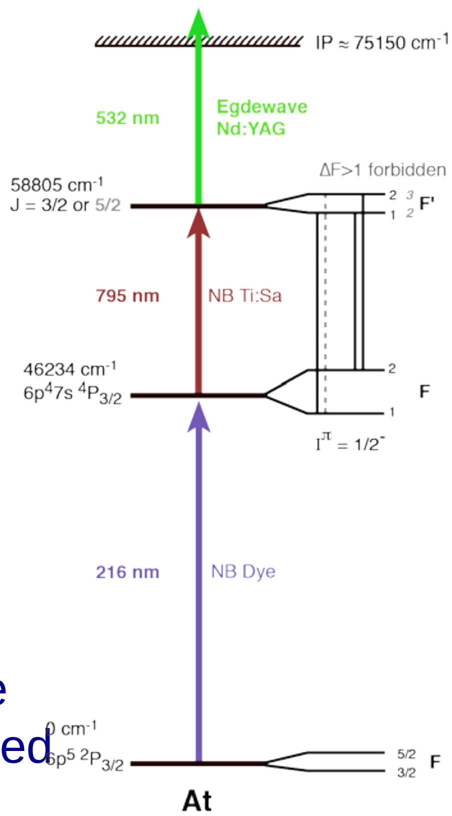
**Step 4**:
The use of RILIS ionized At beams for other experiments at ISOLDE
**Decay studies/Mass measurements**

CERN

# Astatine beams



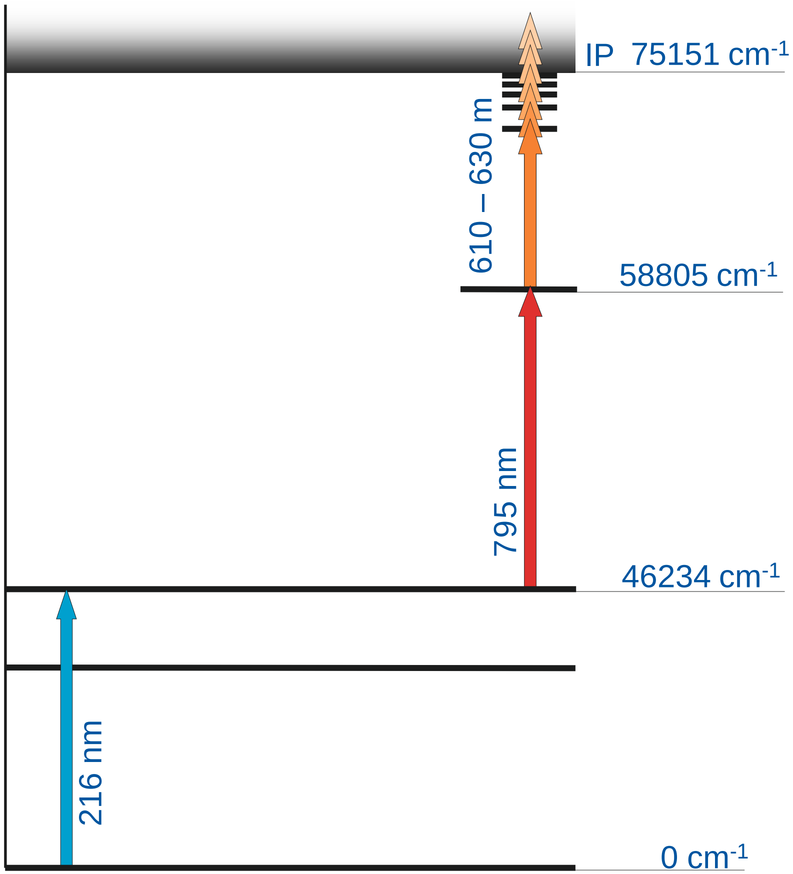

- Many new atomic levels were found
- An efficient three-step ionization scheme was determined
- RILIS ionized At beams are now available and have already been studied at ISOLDE

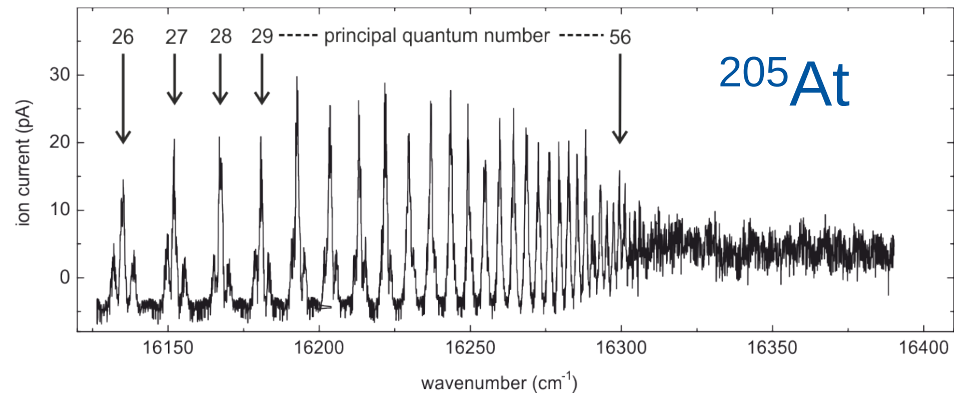


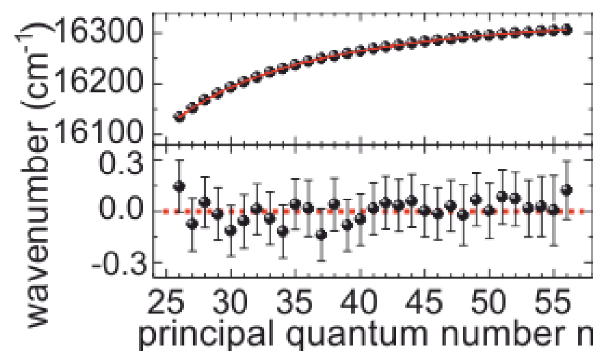
# Astatine ionization potential

Spectroscopy of Rydberg levels by performing a high resolution laser scan across the IP

>30 Rydberg levels found: Precise I.P obtained from Rydberg-Ritz fit to the data.



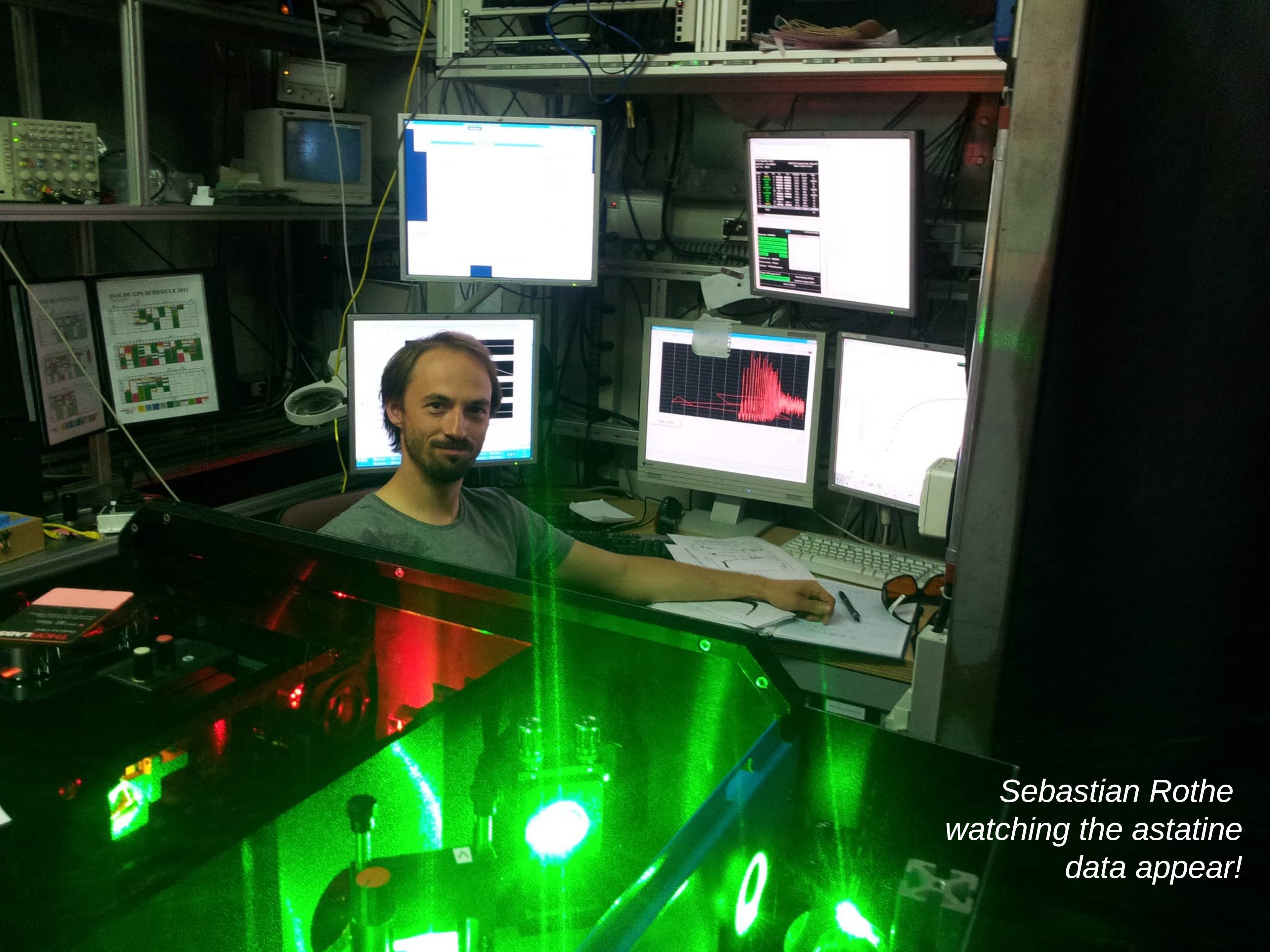




Rydberg-Ritz formula

$$\nu_n = IP - E_2 - \frac{R_M}{(n-\delta)^2}$$

$$IP_{Rydberg}(At) = 75151(1)\ cm^{-1} = 9.317510(84)\ eV$$



*Sebastian Rothe watching the astatine data appear!*

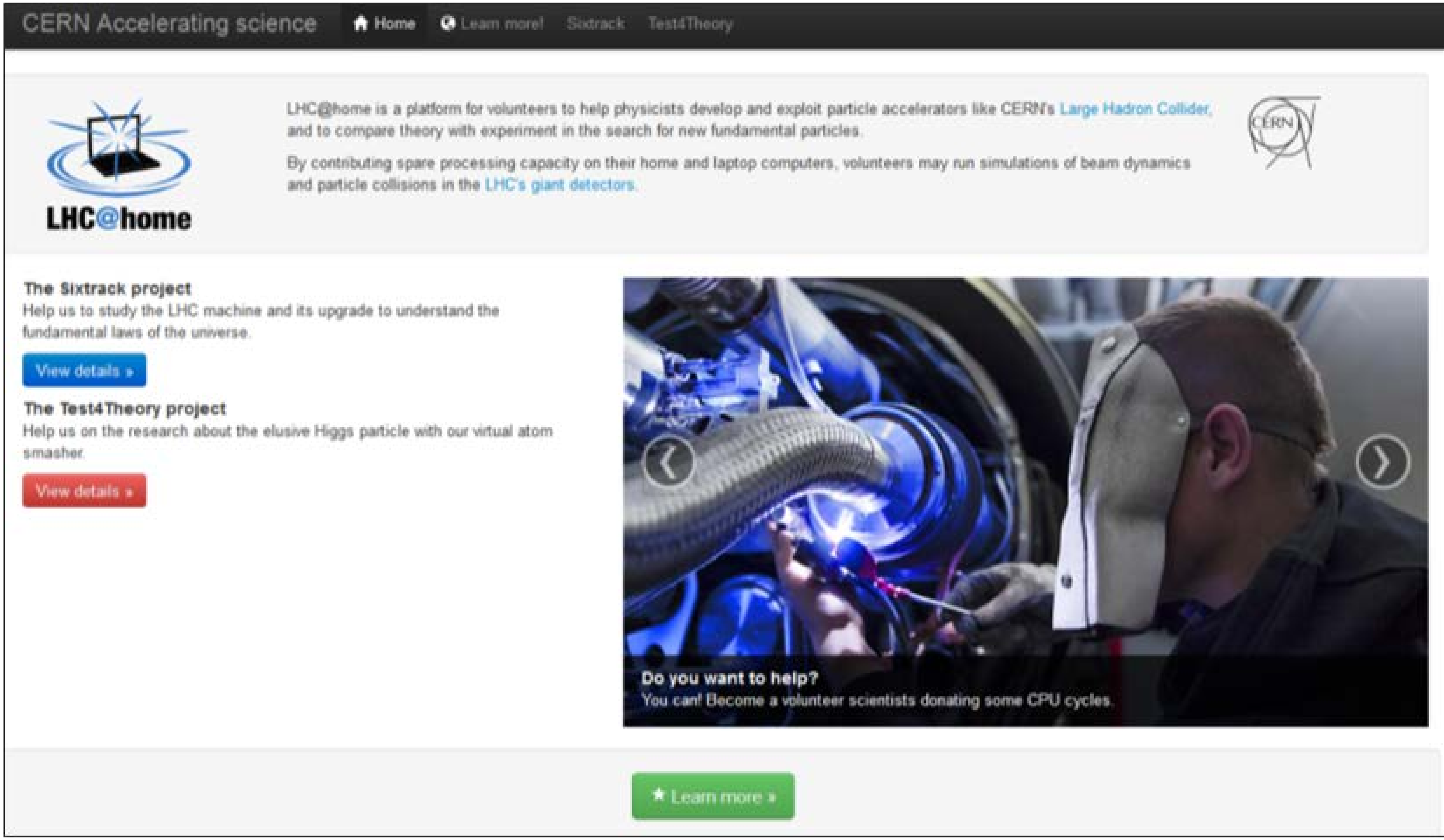
# Today’s trivia answer

Q. Back in January 2013, the mass spectrometer ISOLTRAP at ISOLDE made ions travel how many kilometres during a test?

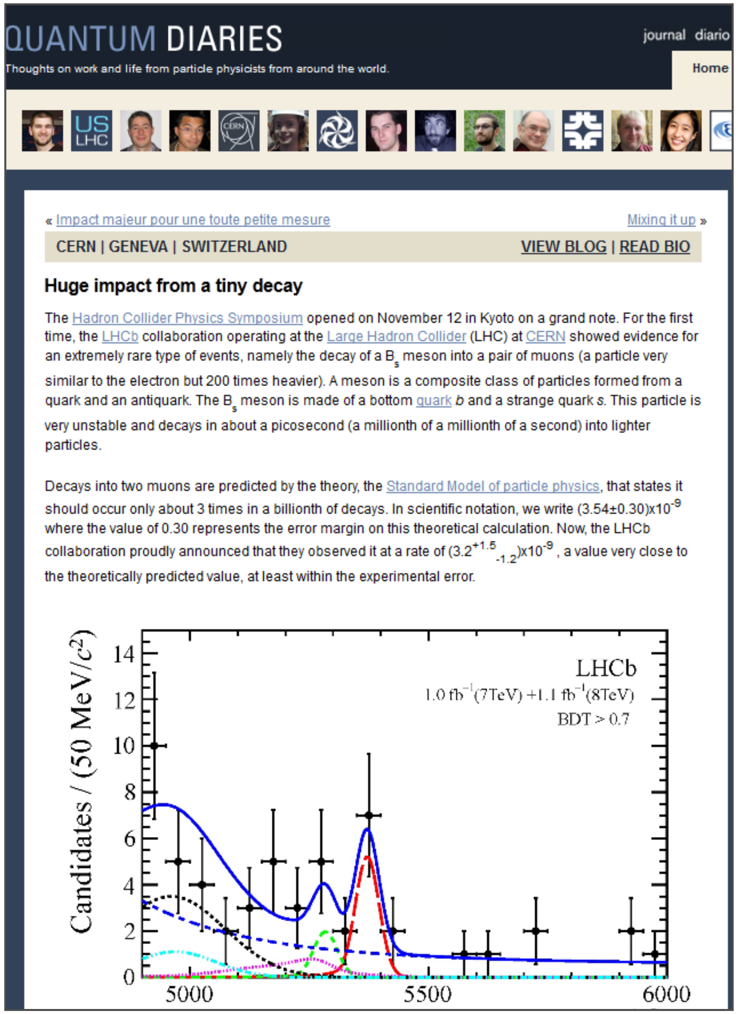
A. 34 kilometres

http://home.web.cern.ch/cern-people/updates/2013/01/new-ion-trap-extends-reach-nuclide-mass-experiment

# cern.ch/LHCathome



# http://www.quantumdiaries.org/author/cern/



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« Impact majeur pour une toute petite mesure | Mixing it up »

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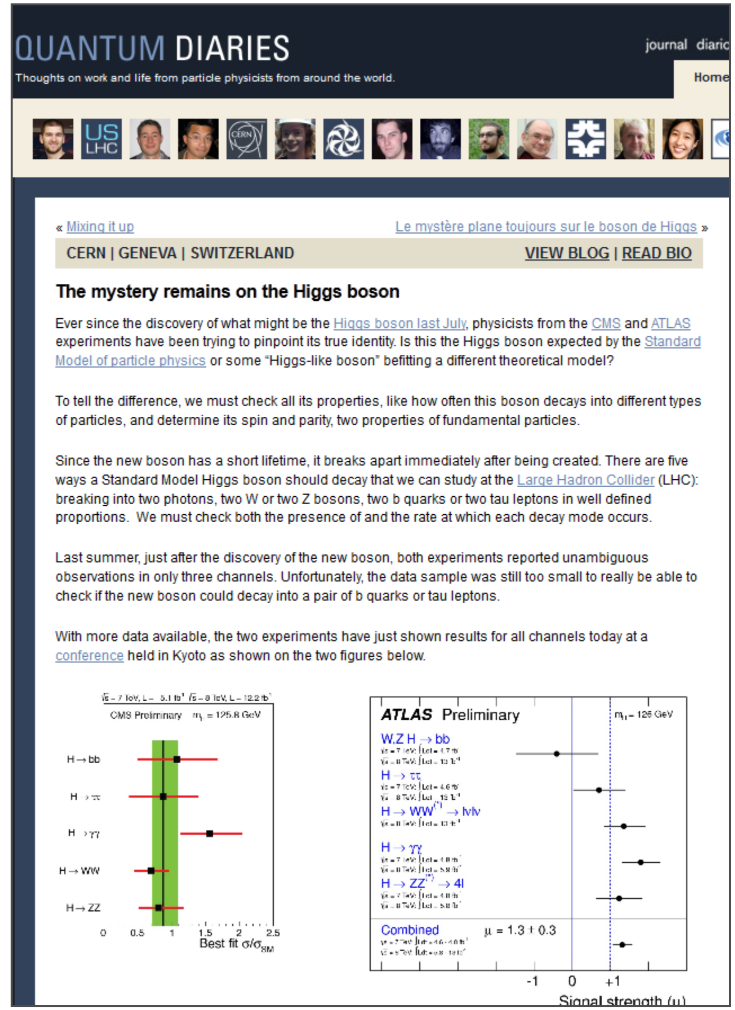
**Huge impact from a tiny decay**

The Hadron Collider Physics Symposium opened on November 12 in Kyoto on a grand note. For the first time, the LHCb collaboration operating at the Large Hadron Collider (LHC) at CERN showed evidence for an extremely rare type of events, namely the decay of a $B_s$ meson into a pair of muons (a particle very similar to the electron but 200 times heavier). A meson is a composite class of particles formed from a quark and an antiquark. The $B_s$ meson is made of a bottom quark *b* and a strange quark *s*. This particle is very unstable and decays in about a picosecond (a millionth of a millionth of a second) into lighter particles.

Decays into two muons are predicted by the theory, the Standard Model of particle physics, that states it should occur only about 3 times in a billionth of decays. In scientific notation, we write $(3.54\pm0.30)\times10^{-9}$ where the value of 0.30 represents the error margin on this theoretical calculation. Now, the LHCb collaboration proudly announced that they observed it at a rate of $(3.2^{+1.5}_{-1.2})\times10^{-9}$, a value very close to the theoretically predicted value, at least within the experimental error.





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« Mixing it up | Le mystère plane toujours sur le boson de Higgs »

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**The mystery remains on the Higgs boson**

Ever since the discovery of what might be the Higgs boson last July, physicists from the CMS and ATLAS experiments have been trying to pinpoint its true identity. Is this the Higgs boson expected by the Standard Model of particle physics or some "Higgs-like boson" befitting a different theoretical model?

To tell the difference, we must check all its properties, like how often this boson decays into different types of particles, and determine its spin and parity, two properties of fundamental particles.

Since the new boson has a short lifetime, it breaks apart immediately after being created. There are five ways a Standard Model Higgs boson should decay that we can study at the Large Hadron Collider (LHC): breaking into two photons, two W or two Z bosons, two b quarks or two tau leptons in well defined proportions. We must check both the presence of and the rate at which each decay mode occurs.

Last summer, just after the discovery of the new boson, both experiments reported unambiguous observations in only three channels. Unfortunately, the data sample was still too small to really be able to check if the new boson could decay into a pair of b quarks or tau leptons.

With more data available, the two experiments have just shown results for all channels today at a conference held in Kyoto as shown on the two figures below.

# Next week’s Hangout with CERN

- Thursday 30 May, same time 17:00 CEST
  - **All eyes on ISOLDE**

# Participants

Mark Huyse, KU Leuven

Liam Gaffney, KU Leuven

Thomas Cocolios, University of Manchester

Fredrik Wenander, CERN

Valentine Fedosseev, CERN

Bruce Marsh, CERN

# Credits

Steven Goldfarb — Host

Achintya Rao — Q&A from Social Media

Kate Kahle and Achintya Rao — Production

Thank you for watching!

www.cern.ch