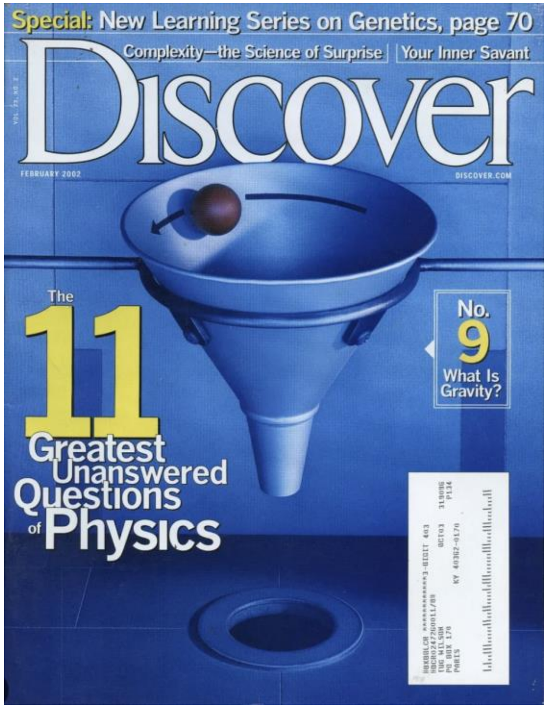
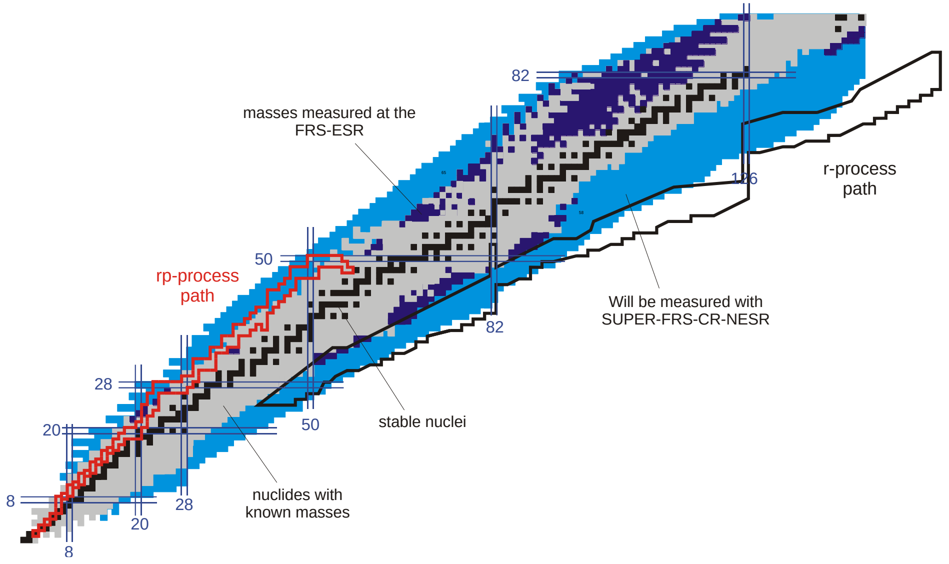
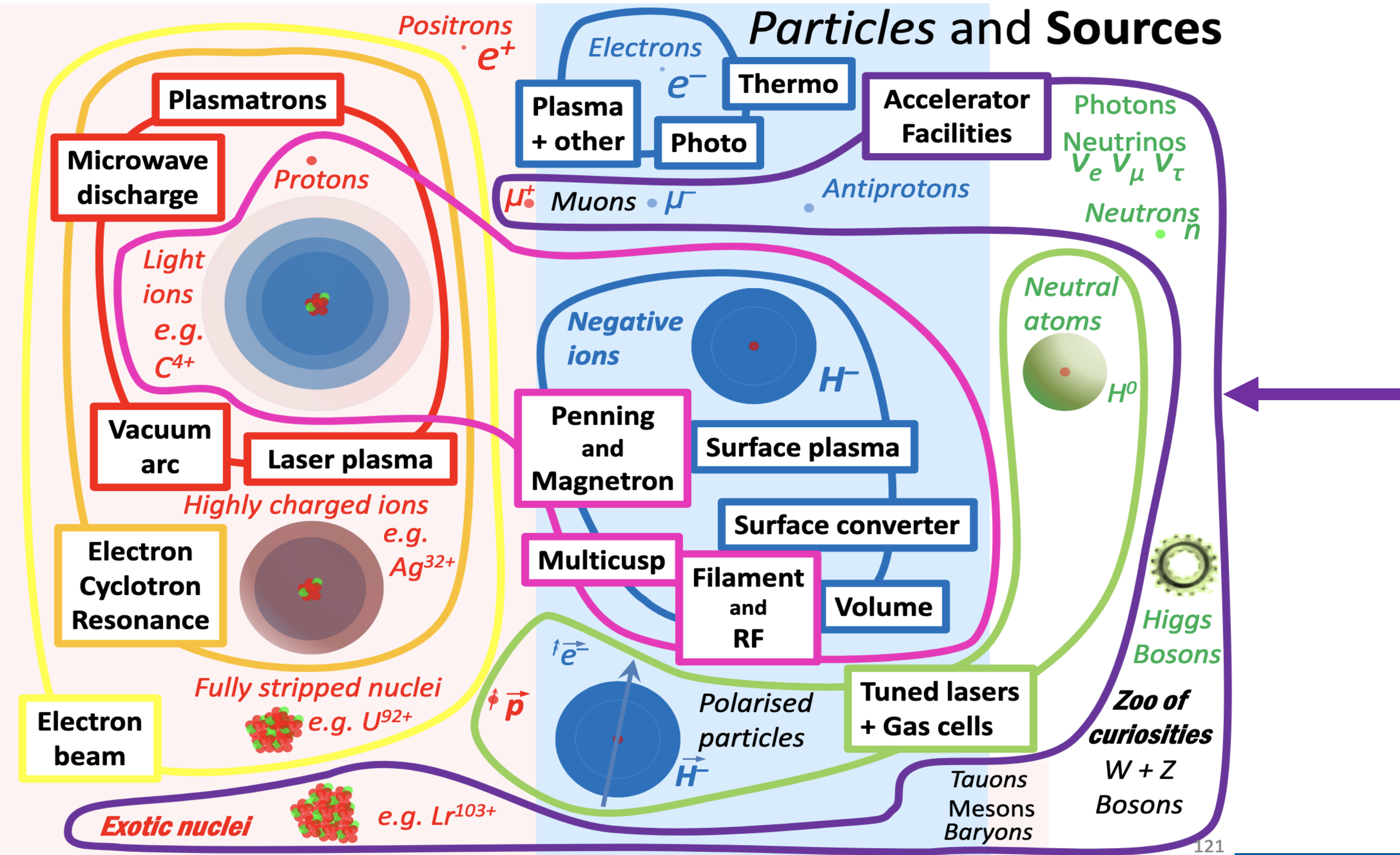
Secondary Beams
K. Knie / GSI





No. 3: How were the heavy elements from iron to uranium made?

Introduction



Introduction

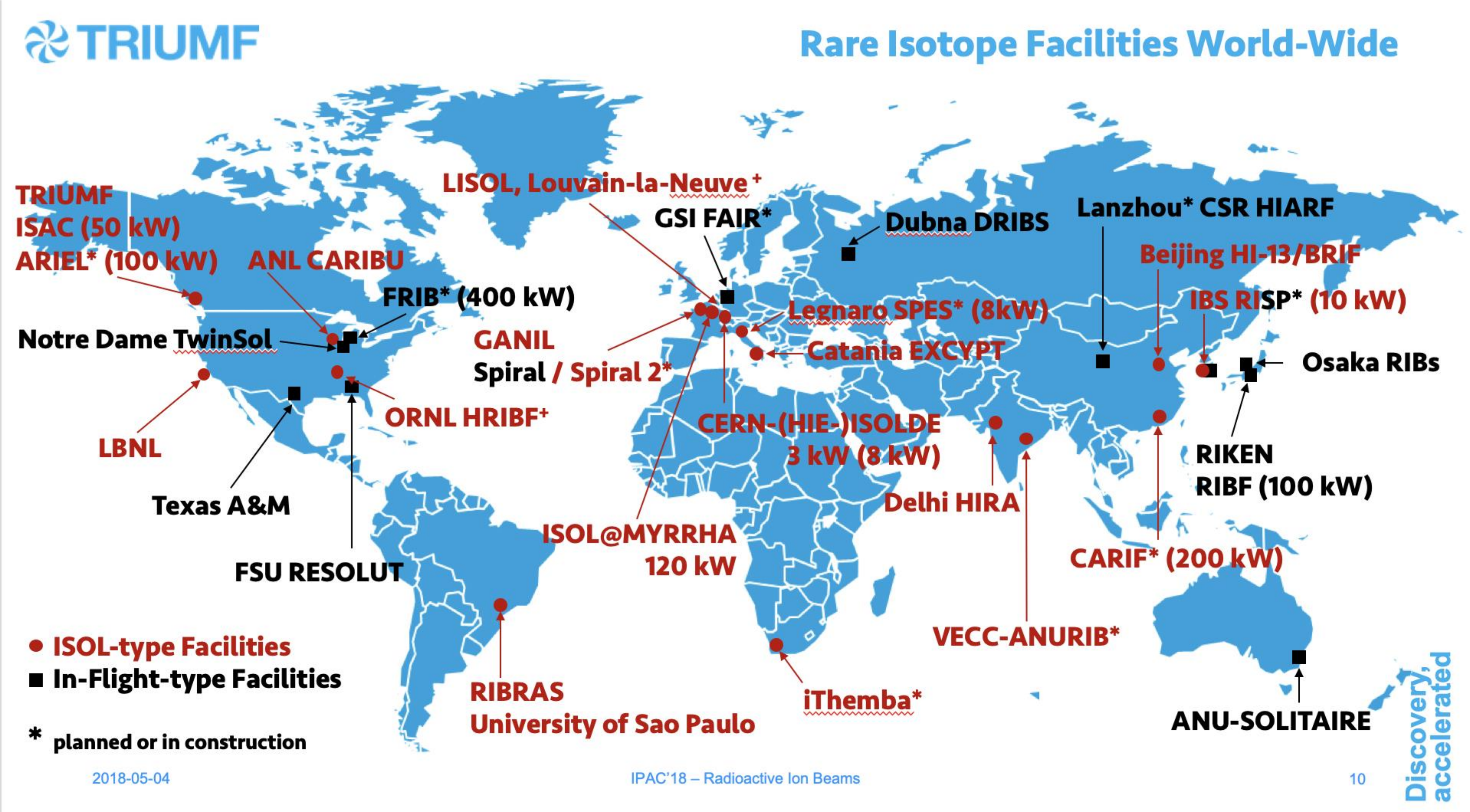
Put the desired beam particles into the source and extract them

Convert the particles in the source to the desired beam particles right before extraction

Convert the actual beam particles into the desired beam particles

Convert the actual beam particles into particles which will decay to the desired ones

Introduction



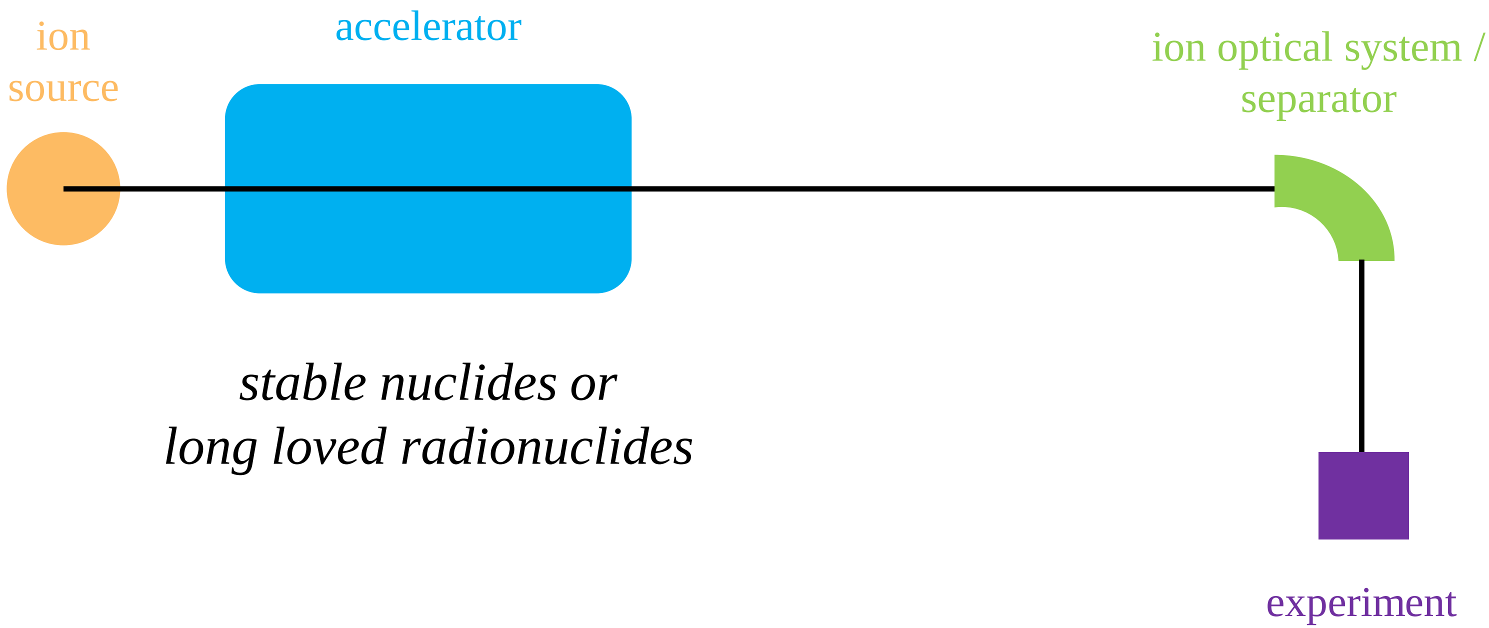
Overview

Introduction:
primary / secondary beam
ISOL method
In-Flight fragment separators

Secondary Beams at FAIR:
Radioactive Isotope Beams: SuperFRS
Antiprotons: Target, Magnetic Horn and pbar Separator
Target handling, Radiation Protection

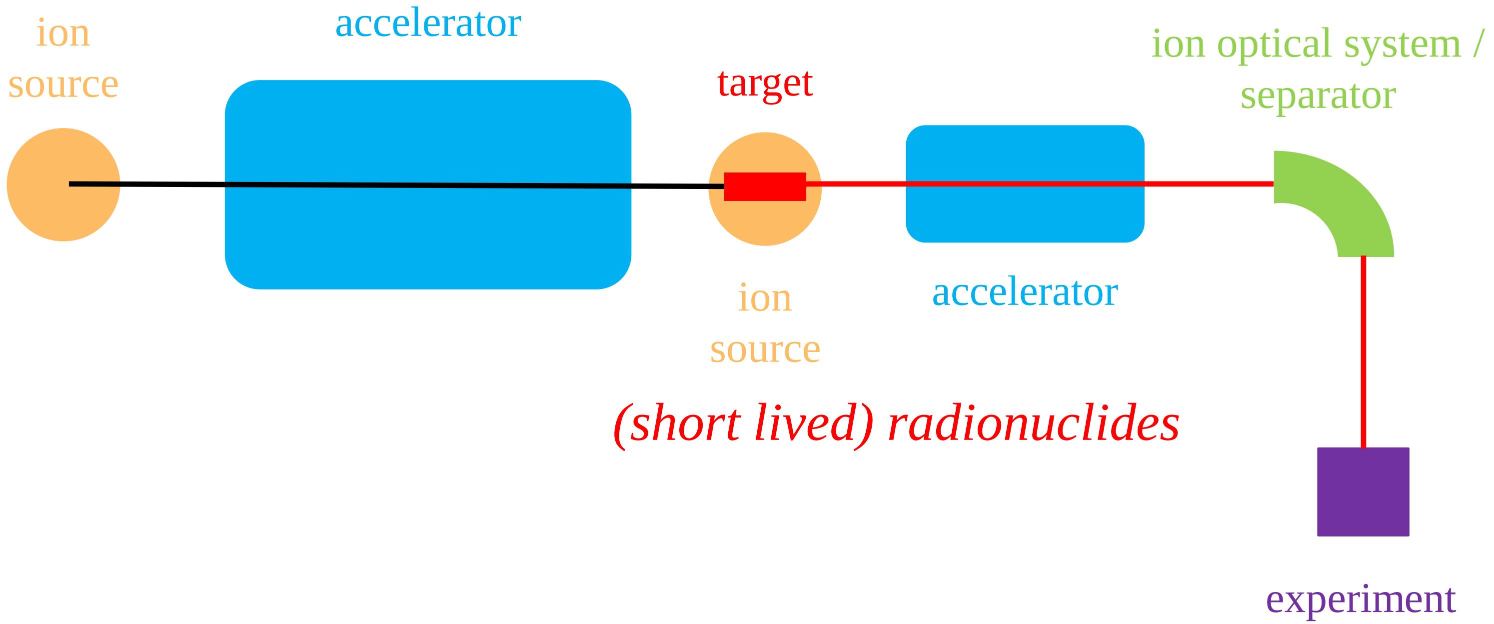
"Tertiary" Beams:
Muon Beams
Neutrino Beams (CNGS, NuMi...)

Primary / Secondary Beams

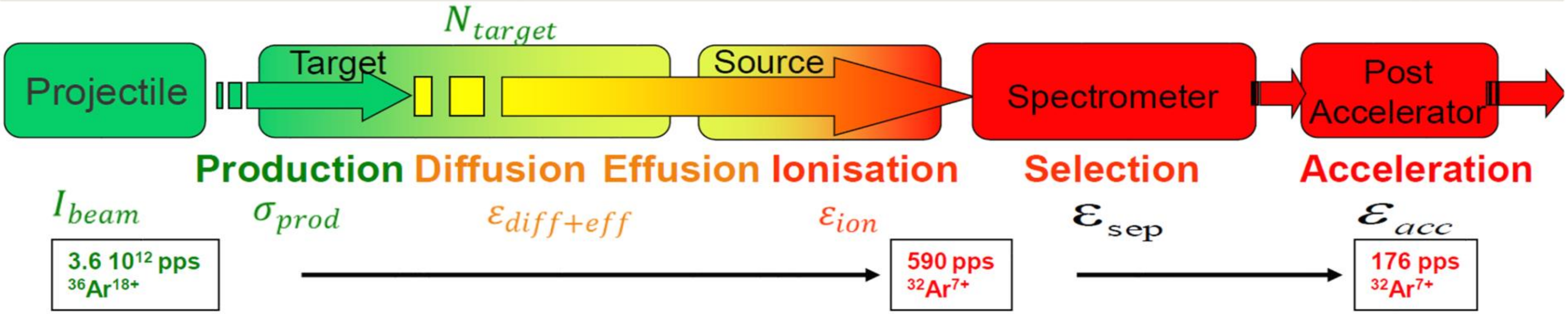


stable nuclides or
long loved radionuclides

Primary / Secondary Beams (ISOL)

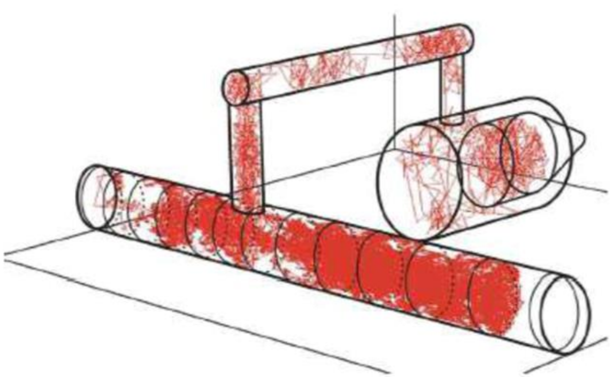


ISOL Method



$$I_{RIB} = \left(\sigma_{prod} \cdot N_{target} \cdot I_{beam}\right) \cdot \varepsilon_{diff+eff} \cdot \varepsilon_{ion} \cdot \varepsilon_{sep} \cdot \varepsilon_{acc}$$

$$\varepsilon_{diff+eff} \cdot \varepsilon_{ion} \; as \quad low \quad as \quad 10^{-6}$$



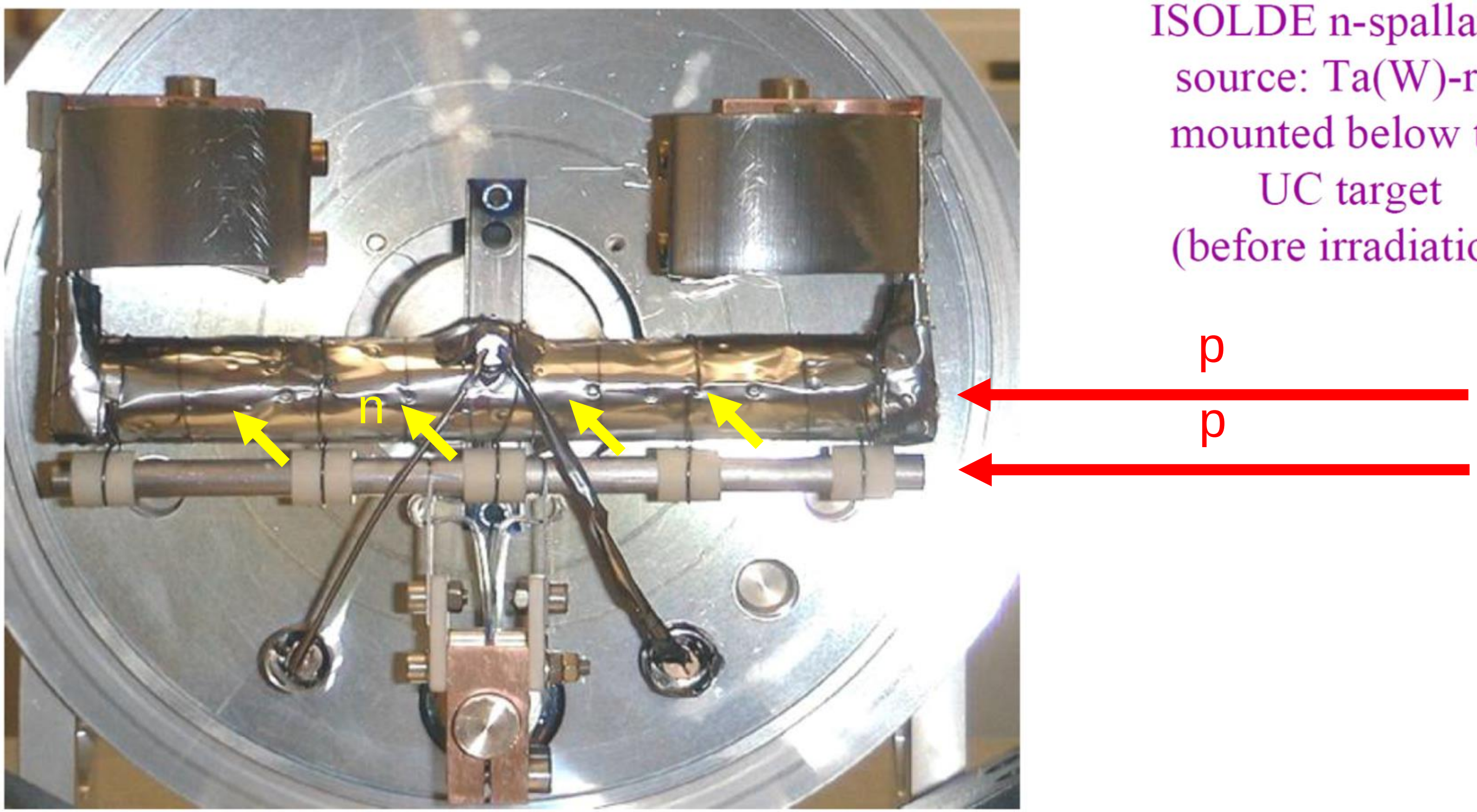
Path of an atom travelling out of a foil target to the ion source (RIBO code, (Santana-Leitner, 2005))

FRIB
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

F. Pellemoine, HPTW April 2016 - Oxford, Slide 11

https://eventbooking.stfc.ac.uk/uploads/6th_high_power_targetry_workshop/pellemoine-rib-production-target.pdf

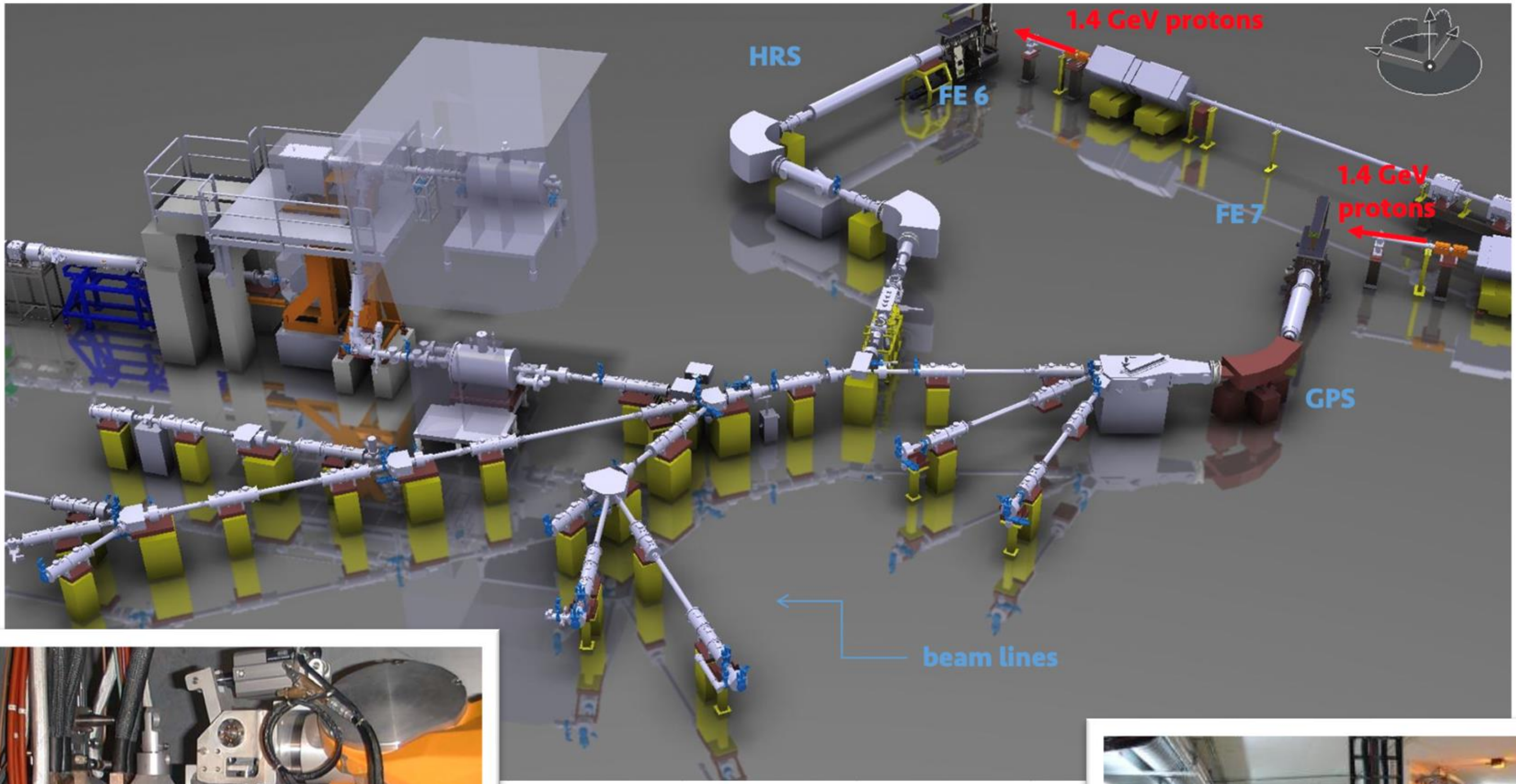
ISOLDE (CERN)

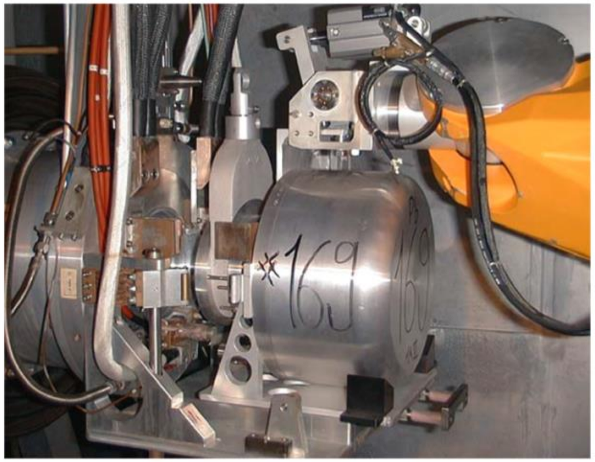


ISOLDE n-spallation source: Ta(W)-rod mounted below the UC target (before irradiation)

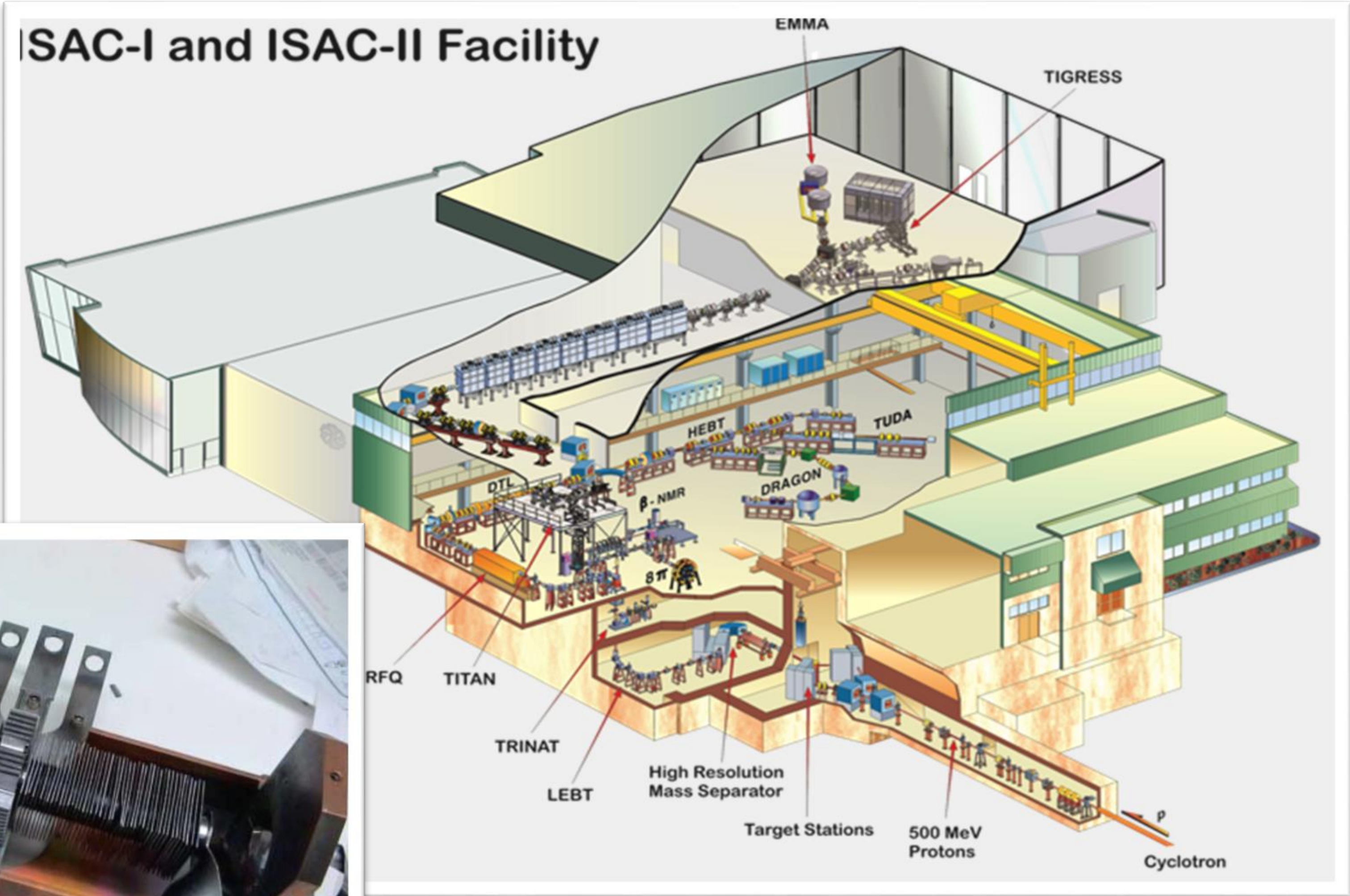
T. Stora

ISOLDE (CERN)



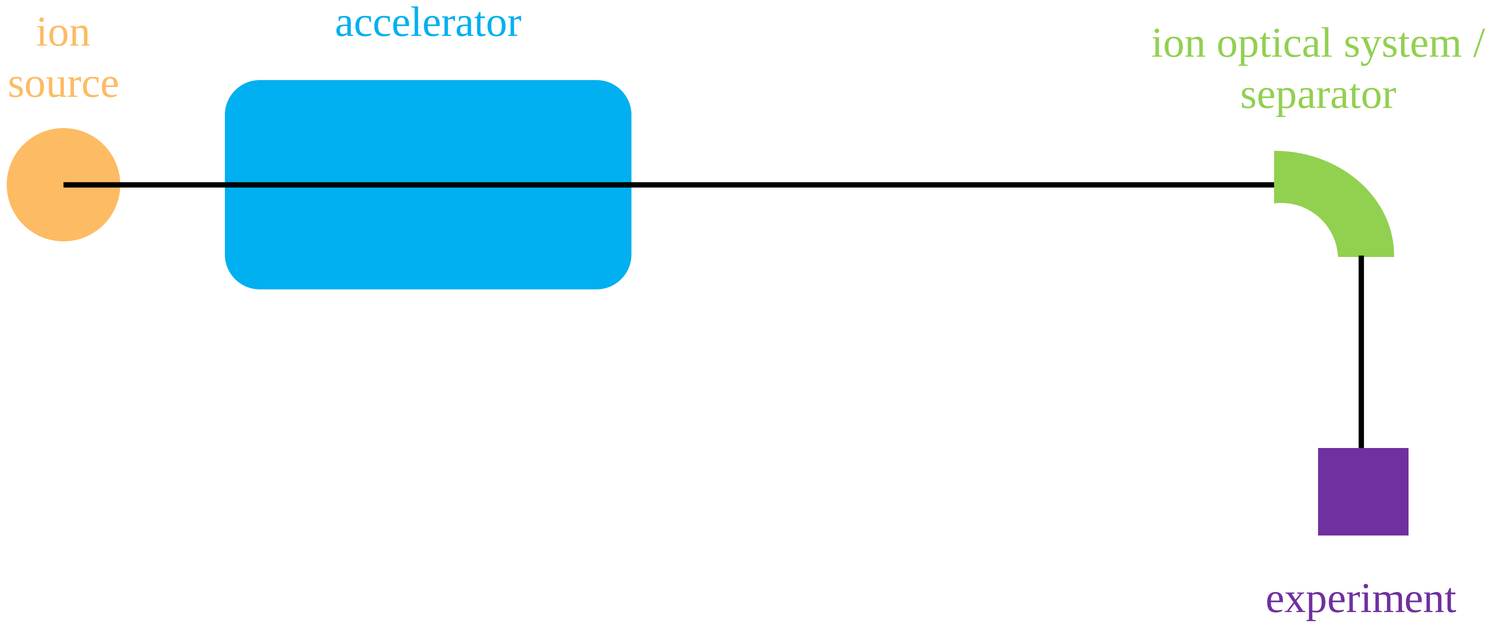


ISAC (TRIUMF)

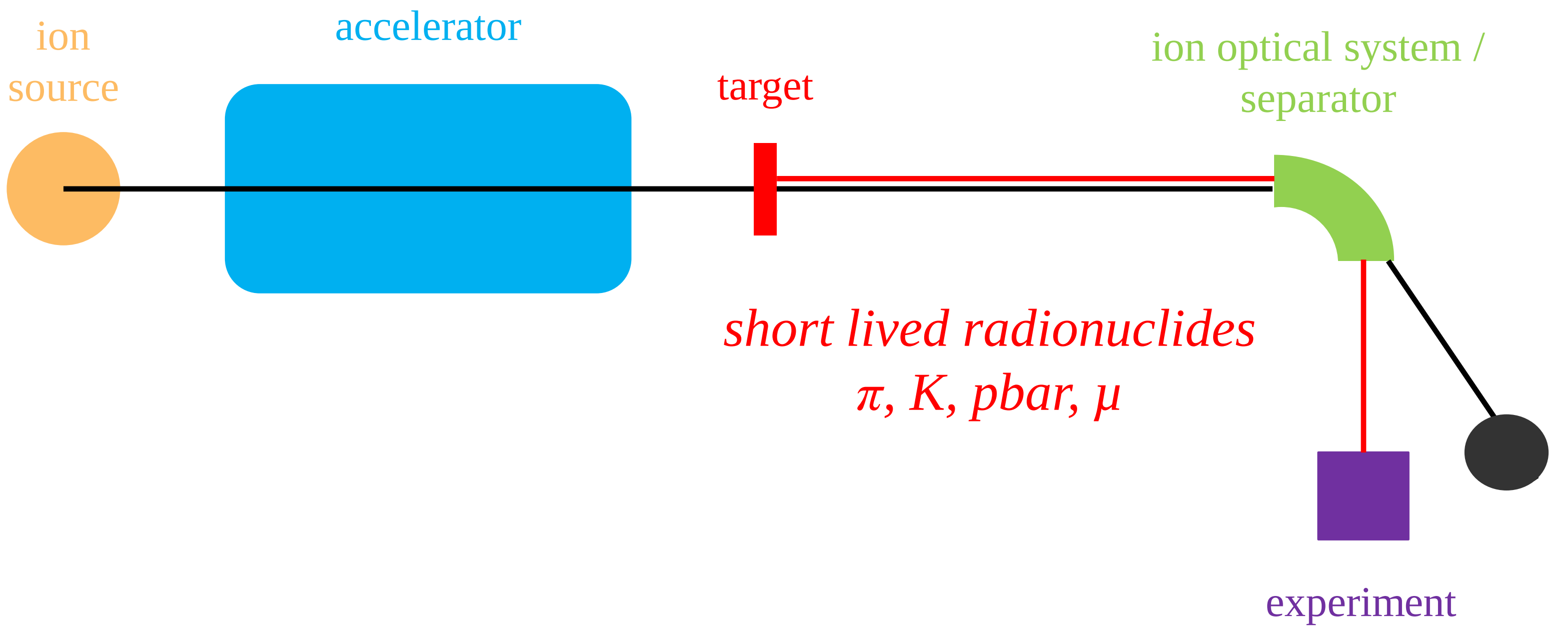

ISAC-I and ISAC-II Facility
EMMA
TIGRESS
HEBT
TUDA
DTL
β - NMR
DRAGON
8π
RFQ
TITAN
TRINAT
LEBT
High Resolution
Mass Separator
Target Stations
500 MeV
Protons
Cyclotron

50 kW primary beam power!

Primary / Secondary Beams

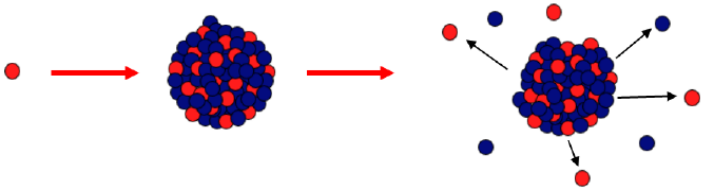


Primary / Secondary Beams: In-Flight

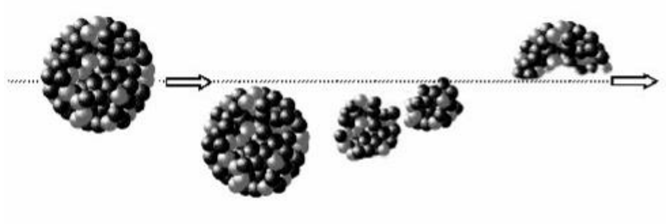


Production Mechanism

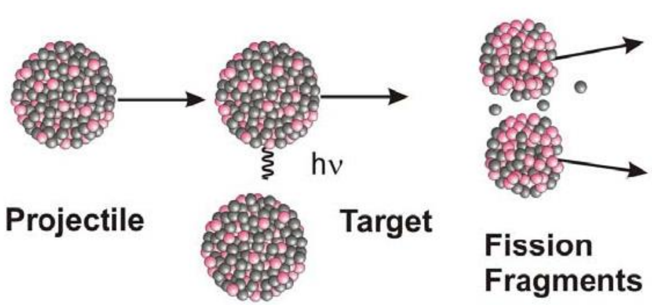
Spallation (ISOL only):
few nucleons lighter than target

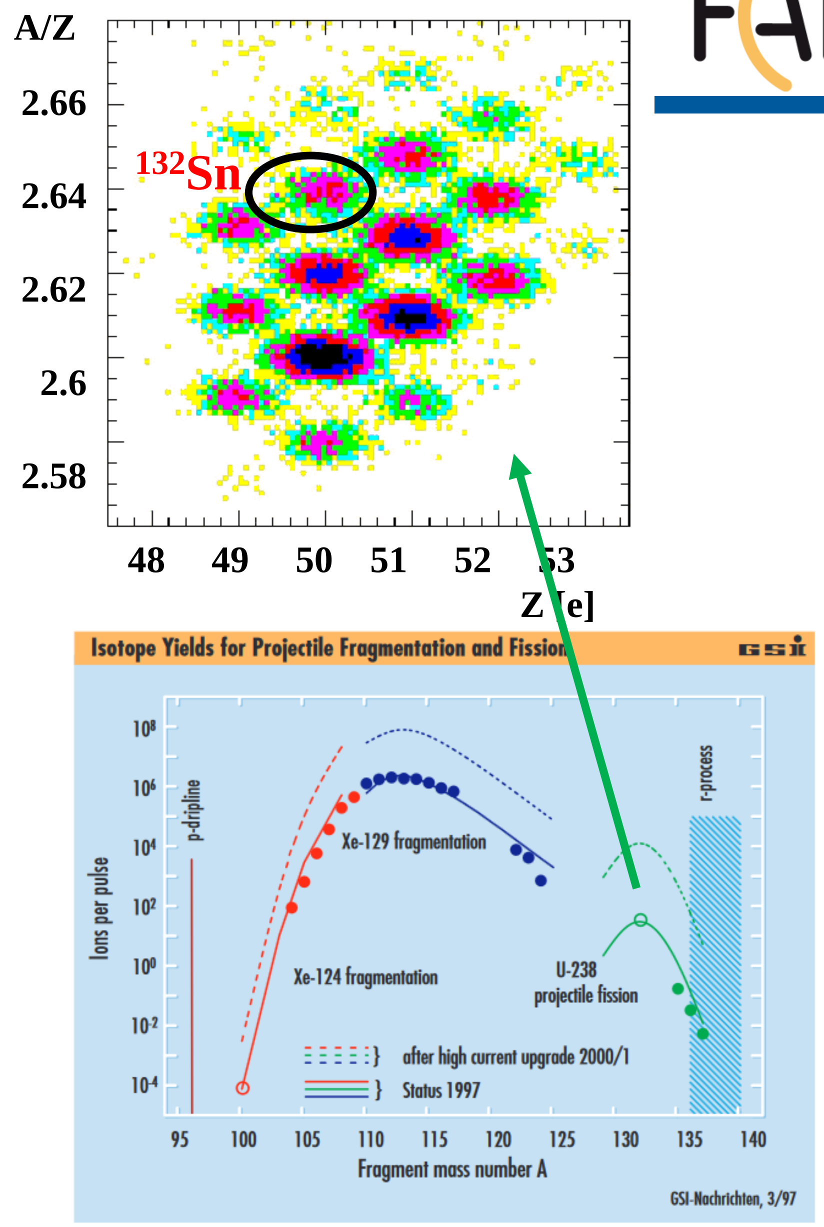


Projectile fragmentation:
neutron deficient (evaporation of neutron after collision)

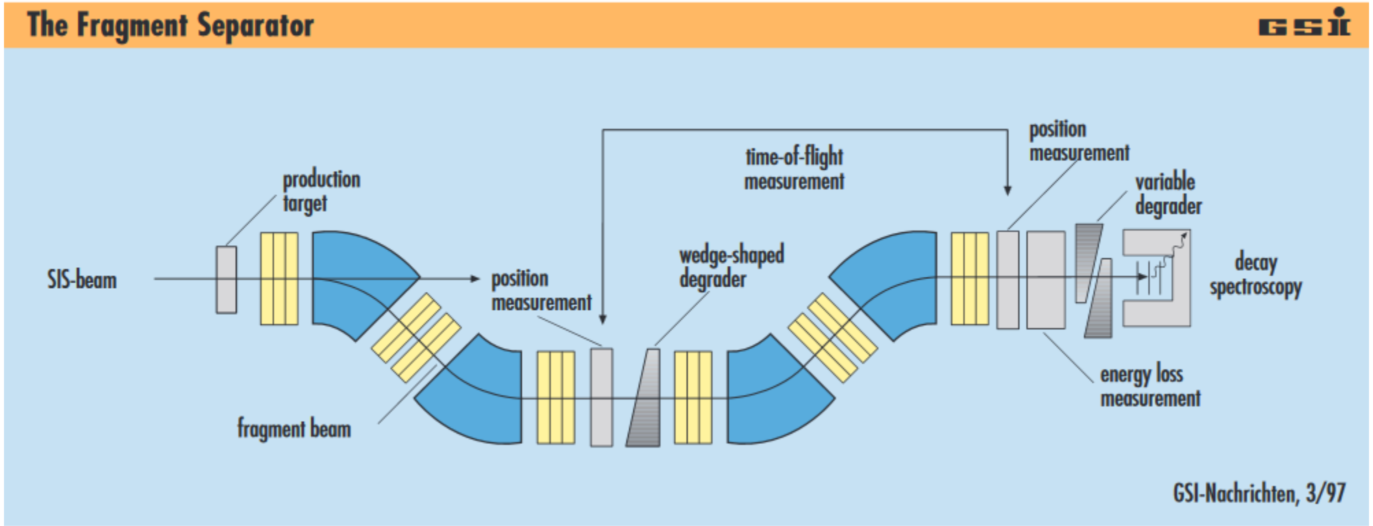


Projectile fission:
neutron rich (*N/Z* similar heavy projectile)





Fragment Separators (in-Flight)

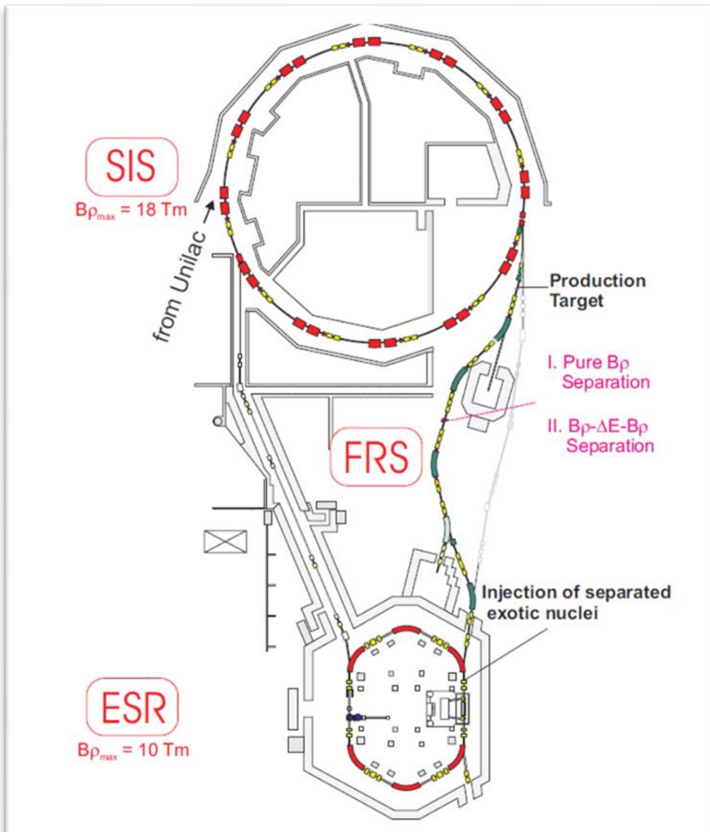


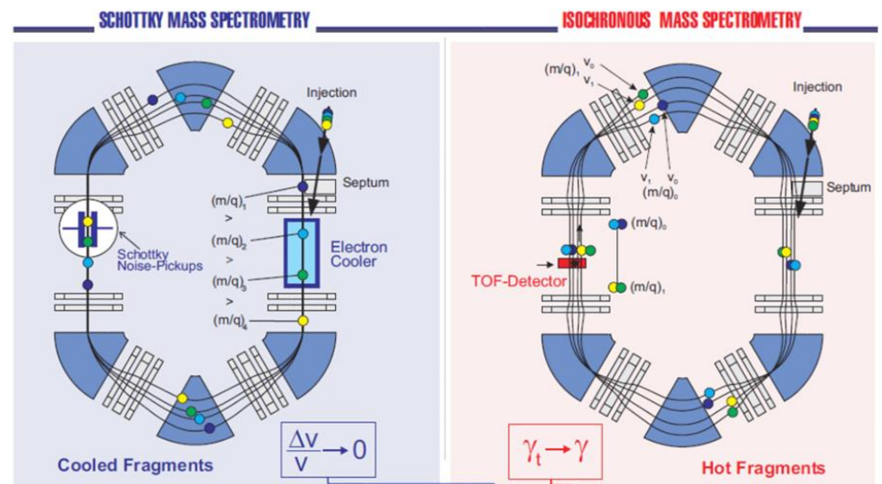
$B \cdot \rho = p/(q \cdot e) \approx (2\mathbf{E} \cdot \mathbf{m})^{1/2}/(\mathbf{q} \cdot \mathbf{e})$

1st part: ***m/q*** or ***A/q*** selection, charge states $\neq q$ lost
no isobaric selection (***E*** similar for isobars)!

Degrader: $d\mathbf{E}/dx$ depends on projectile's ***Z***.

2nd part: ***E*** selection, i.e. ***Z*** selection. (*A/q'* is the same for isobars)
charge states $\neq q'$ lost





$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

Fig. 8. The two kinds of mass spectrometry applied at the ESR by measuring the revolution frequencies of stored exotic ions. Left hand side: Schottky mass-spectrometry. Here the ions are electron-cooled, therefore their velocity spread Δv gets negligibly small. Their revolution frequencies are measured by pick up plates mounted in the ring aperture. This technique has been successfully applied at longer-lived exotic nuclei. Right hand side: Isochronous mass-spectrometry. Uncooled ions circulate at the transition energy γ_t. Their revolution times are measured by a time-of-flight technique. This method is in particular suited for short-lived nuclei with half-lives in the millisecond- or even microsecond range.

F. Bosch, Measurement of Mass and Beta-Lifetime of Stored Exotic Nuclei, Lect. Notes Phys. **651**, 137–168 (2004)

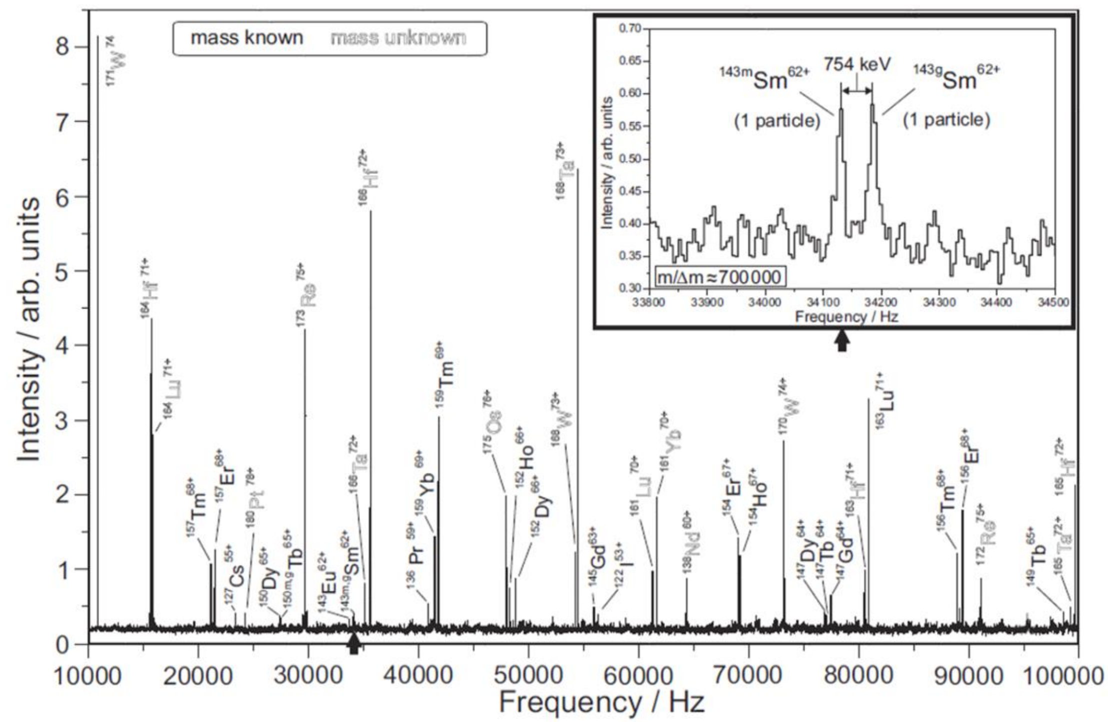
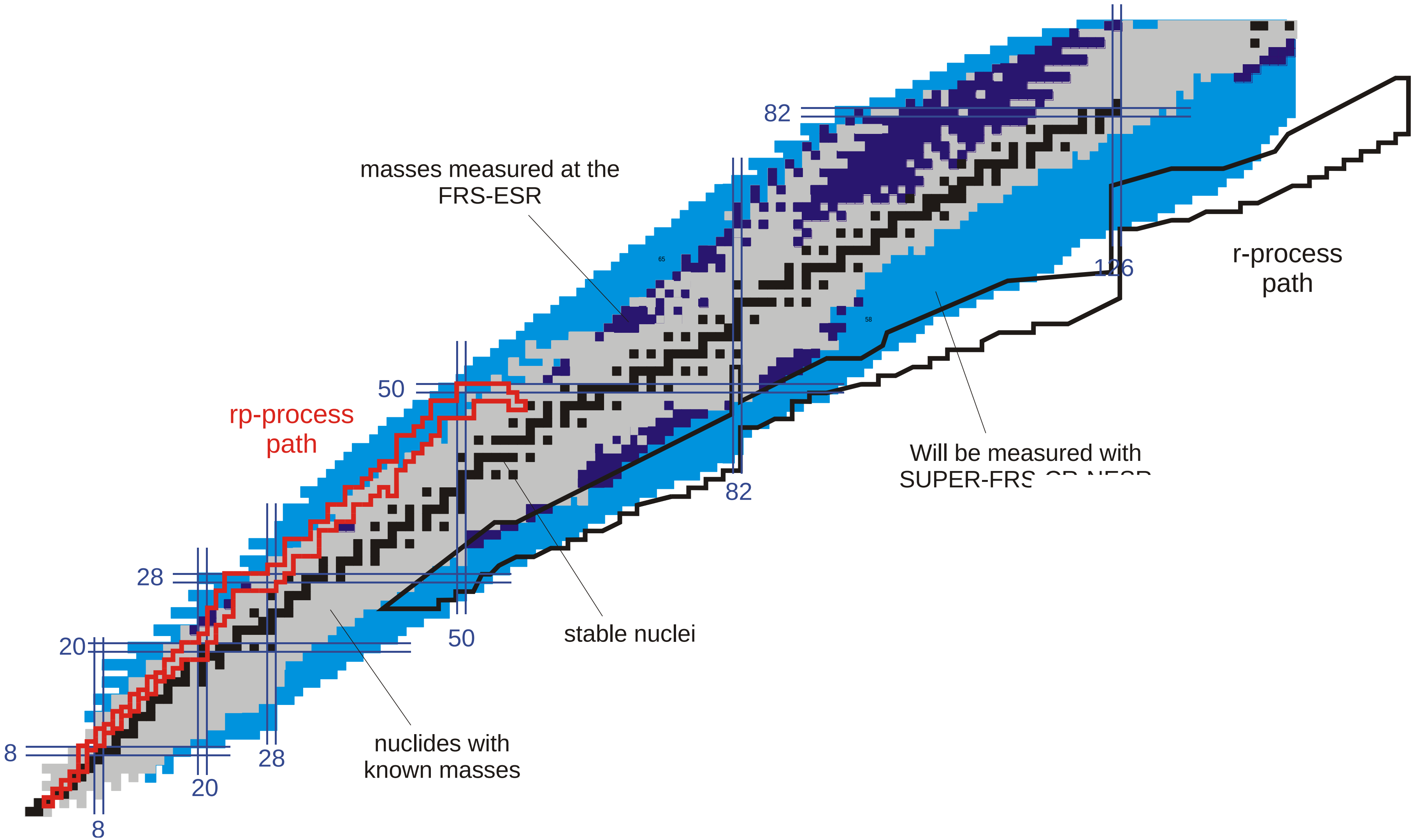
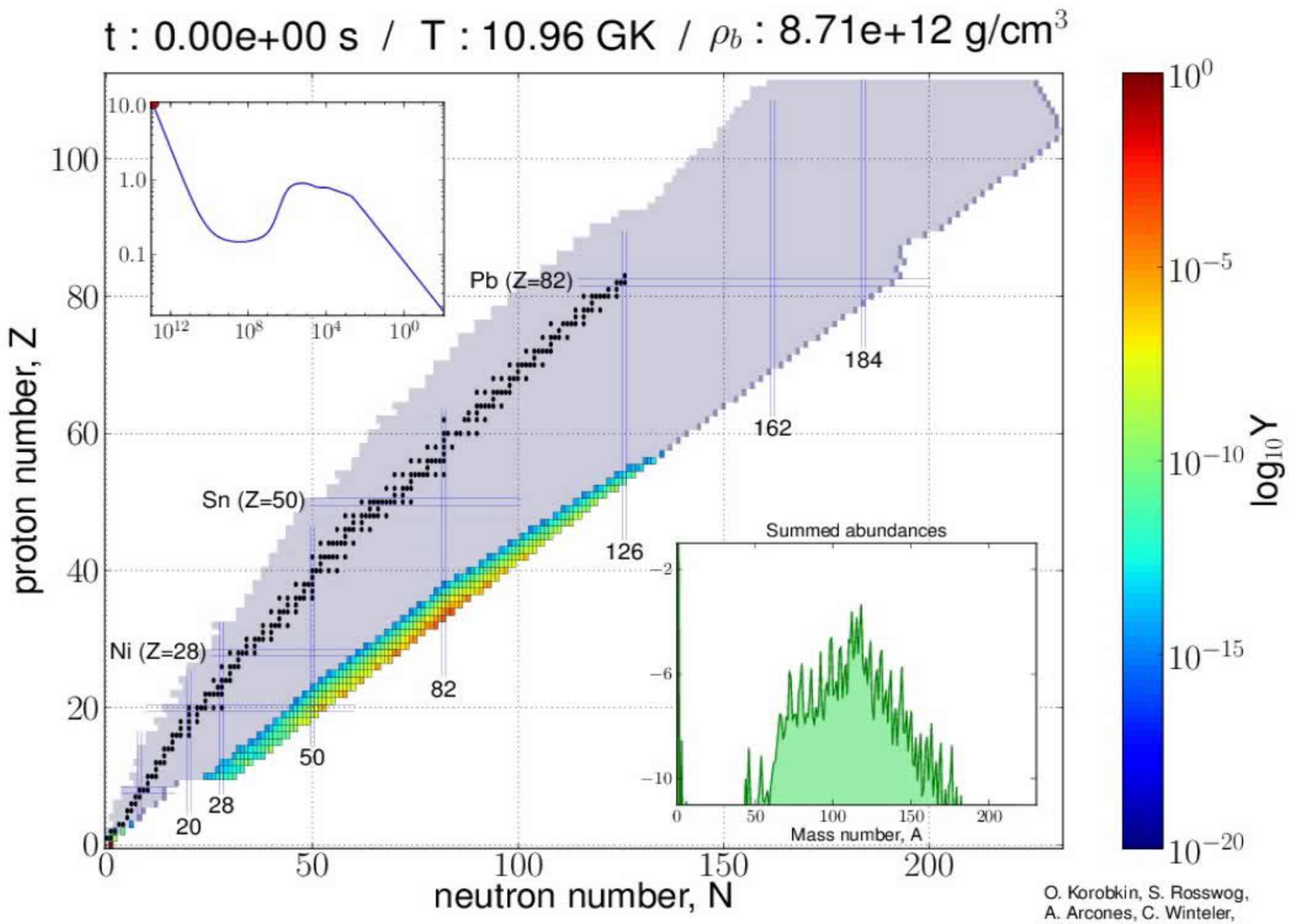


Fig. 9. Schottky spectrum of fragments from a primary ^{209}Bi beam, stored and electron-cooled in the ESR. The main spectrum shows the difference between the 30th harmonic of the revolution frequencies of the many stored ion species and of a local oscillator operating at about 60 MHz. It covers roughly the full acceptance of the ESR. The inset shows a zoom into the spectrum with the well-resolved ground and isomeric state of bare ^{143}Sm^{62+}, each of them populated by one single ion. Parts of this figure were originally published in [27,28].

F. Bosch, Measurement of Mass and Beta-Lifetime of Stored Exotic Nuclei, Lect. Notes Phys. **651**, 137–168 (2004)

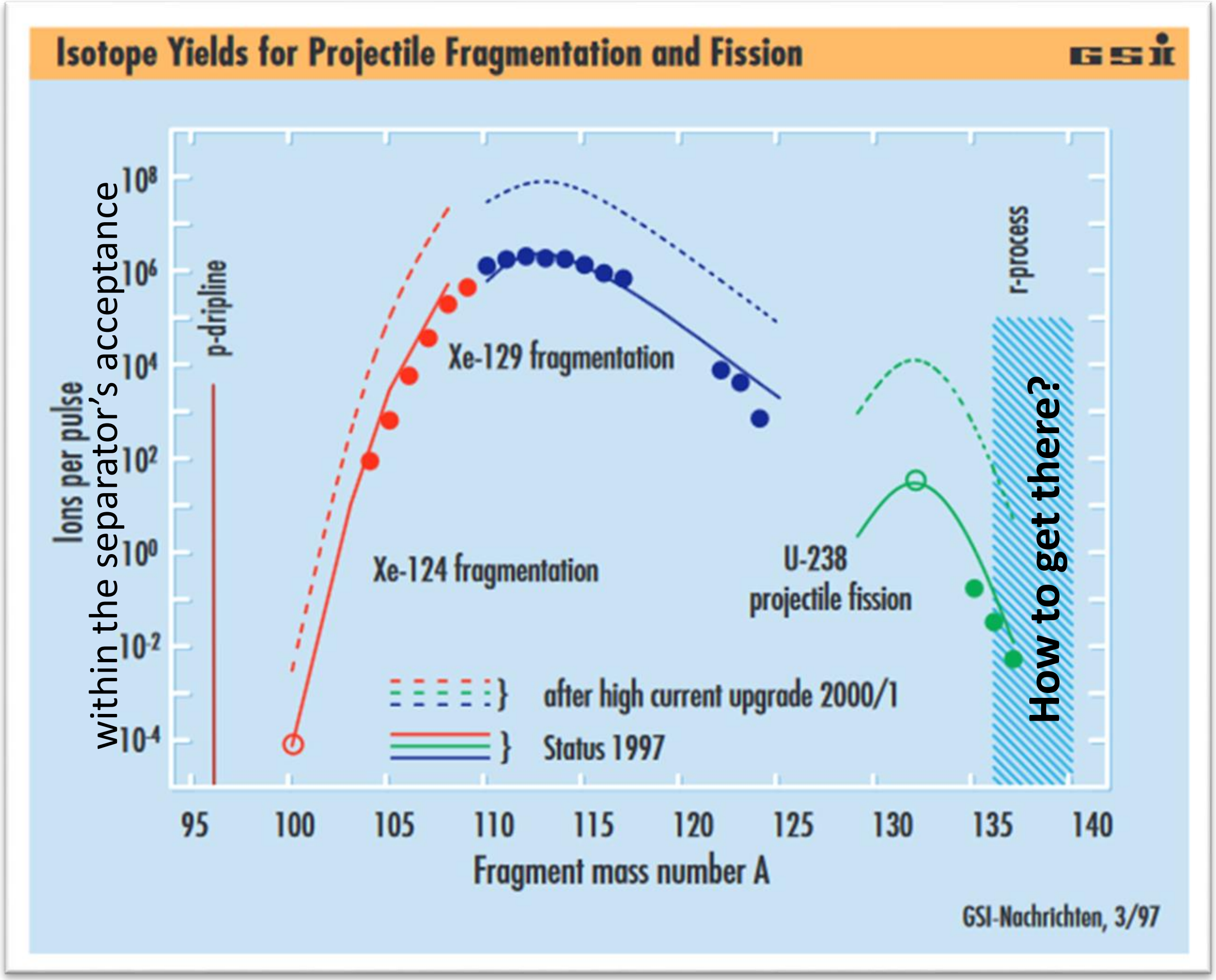


Walker, Litvinov and Geissel, Int. J. Mass Spec. 349-350 (2013) 247



O. Korobkin, S. Rosswog, A. Arcones, C. Winteler, arXiv:1206.2379

The Super Fragment Separator



SuperFRS @ FAIR

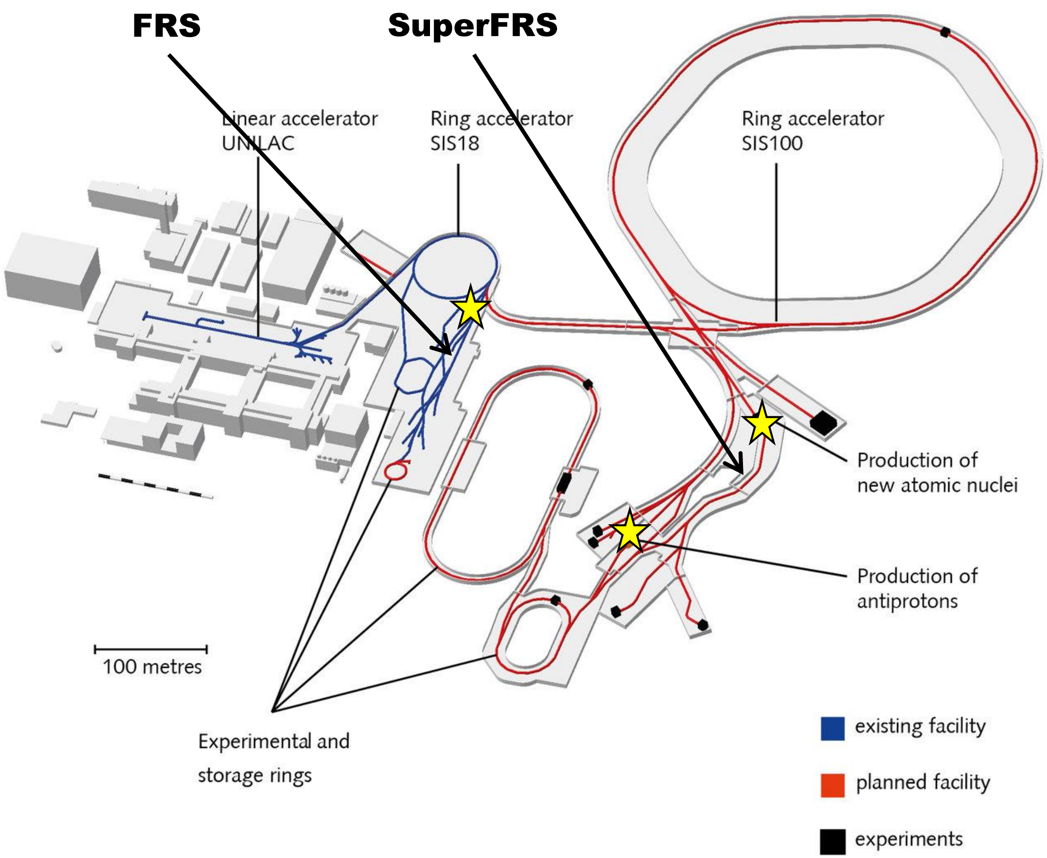
Primary beam intensity:

Larger synchrotron:

- Charge state 28+ instead of 72+
- Highly reduced space charge
- 10 orders of magnitude higher intensity possible
- High requirements on target stability and radiation protection

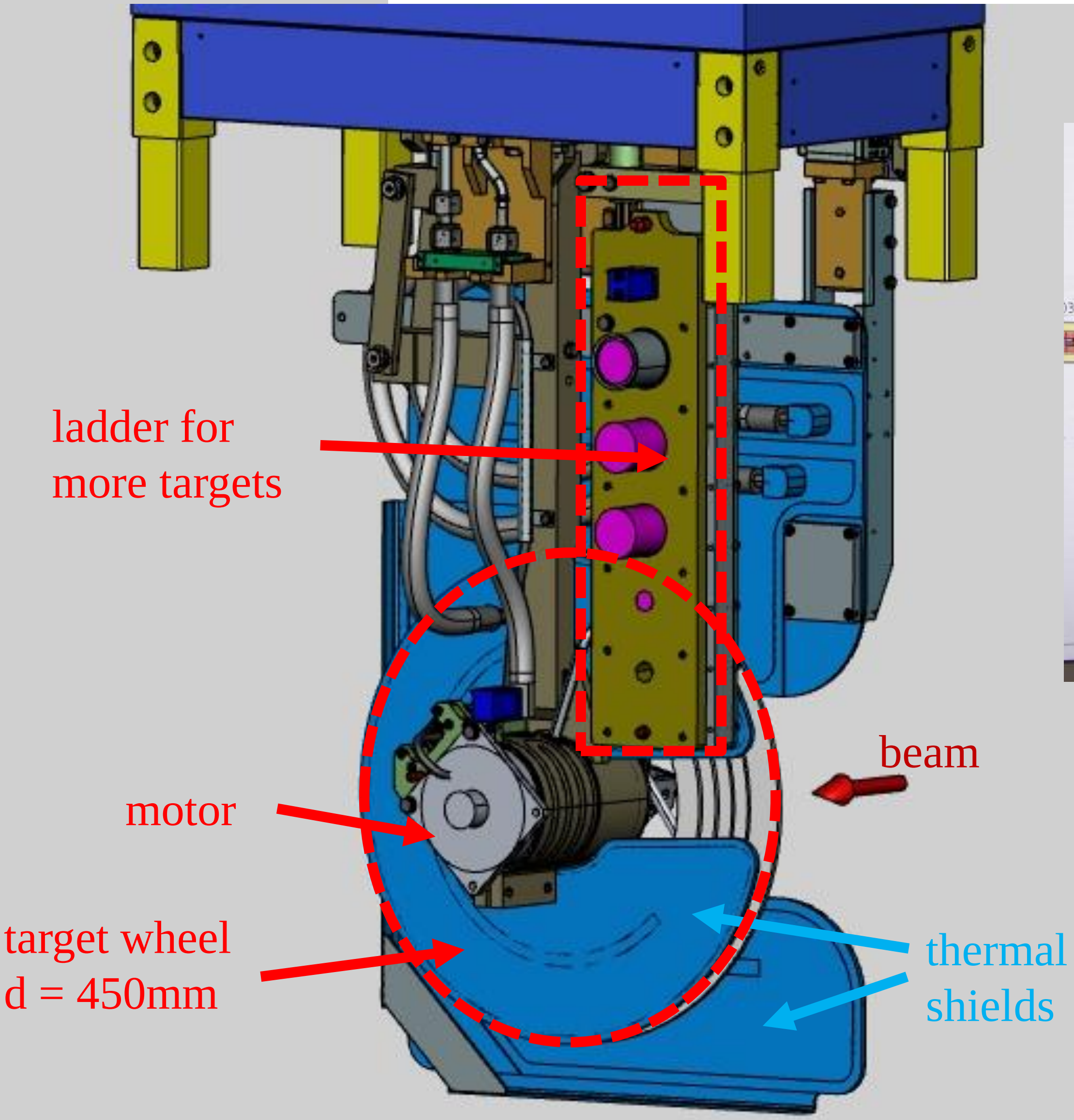
Higher acceptance for secondaries

- Another order of magnitude improvement possible
- Huge apertures (up to 40 cm) require superconducting magnets
- High order correction necessary

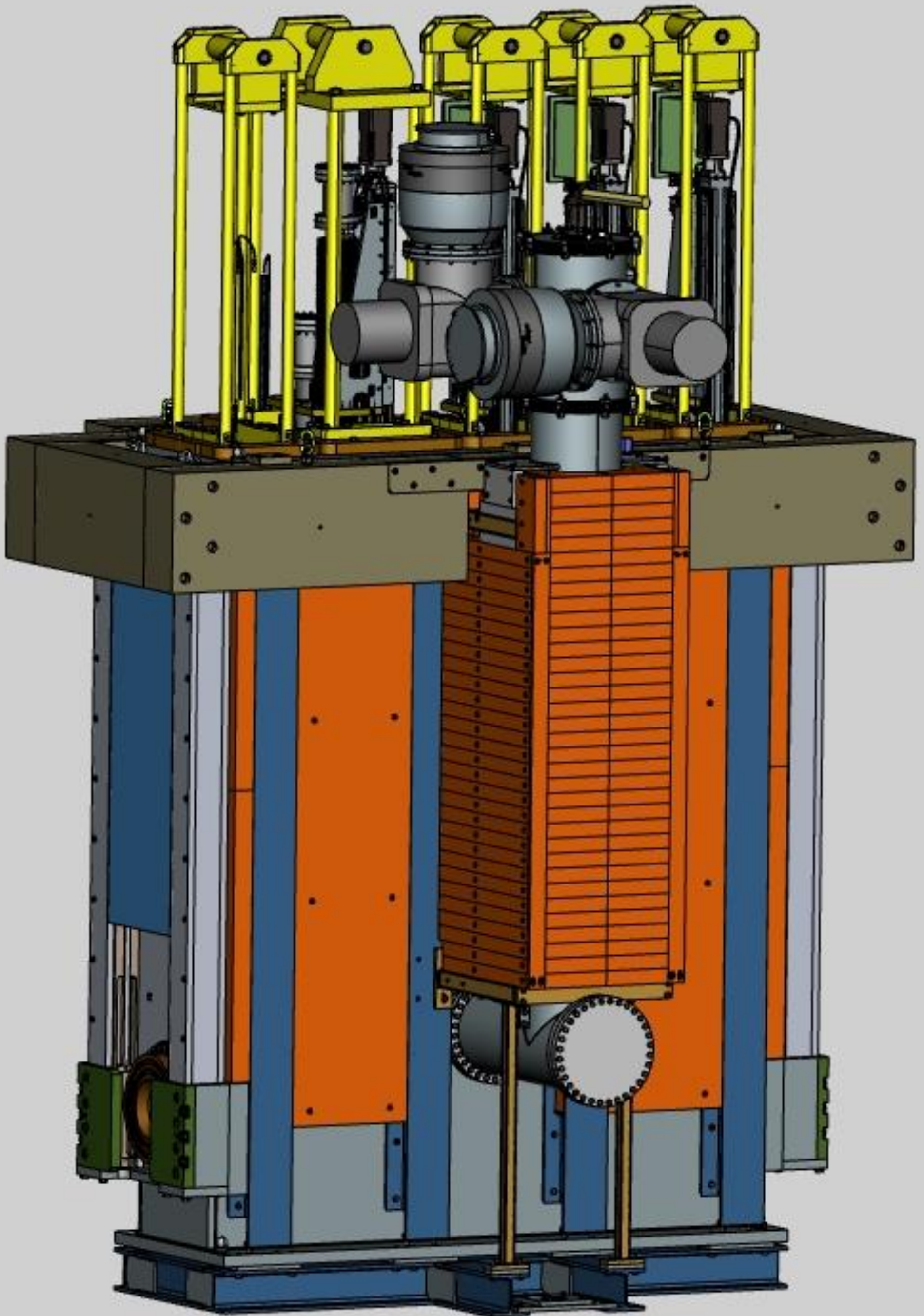


The Super Fragment Separator at FAIR

Target


ladder for
more targets
motor
target wheel
d = 450mm
beam
thermal
shields

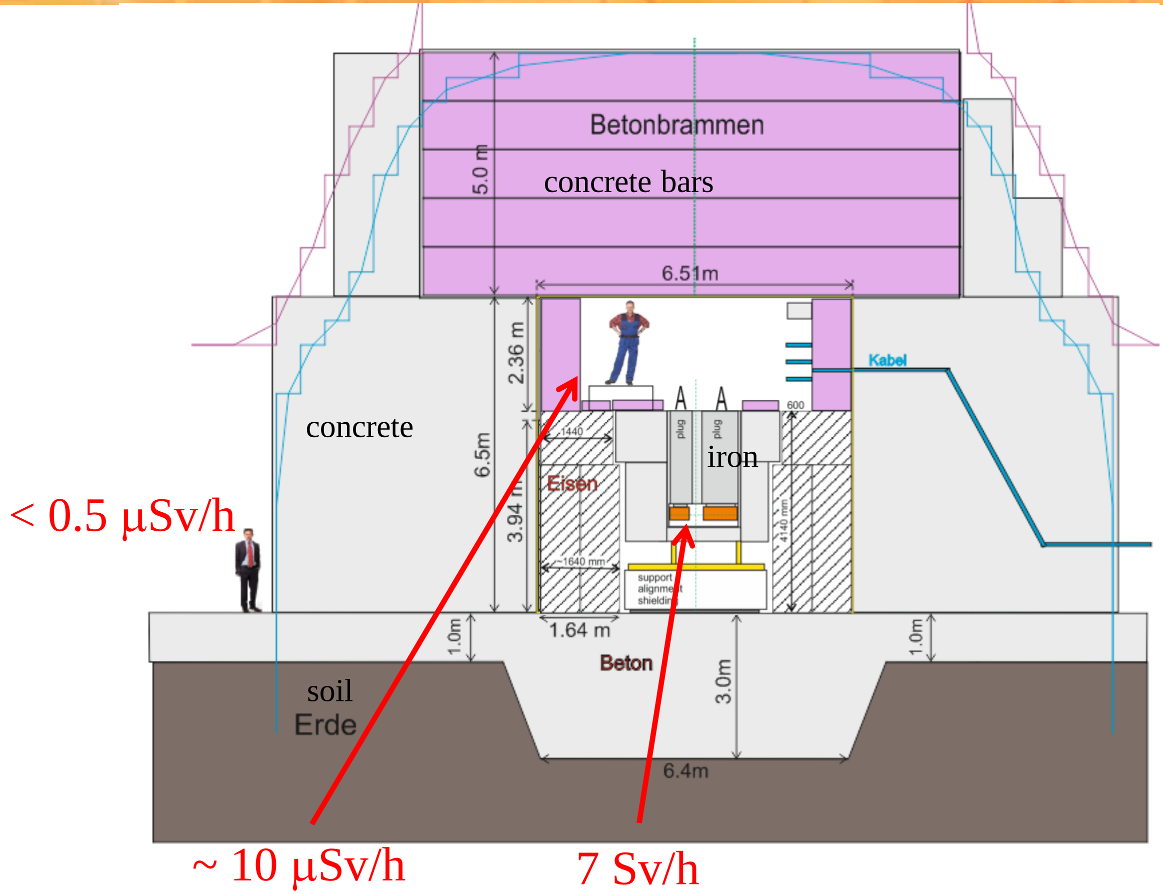
Target Chamber



target plug
+ collimator
+ detectors
+ chamber
+ pumps and
shielding

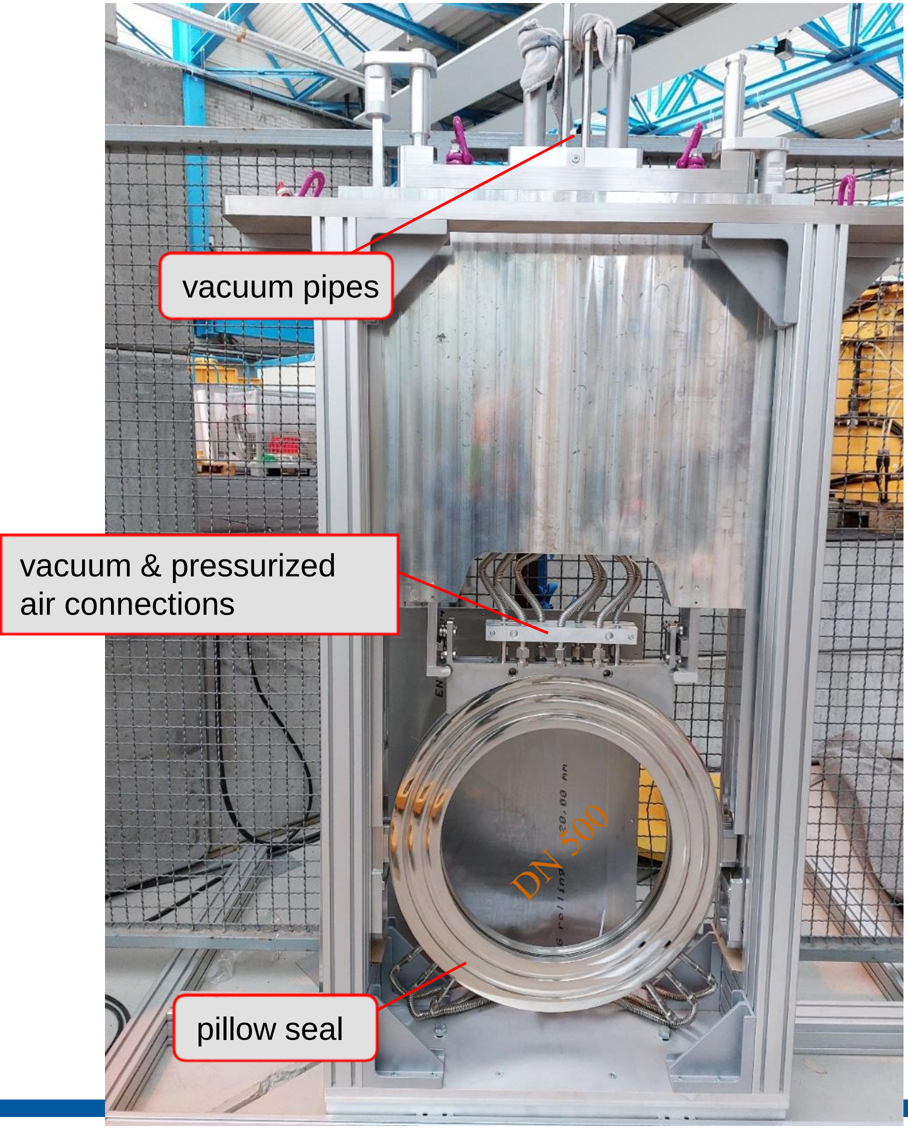
Key Challenges (2)

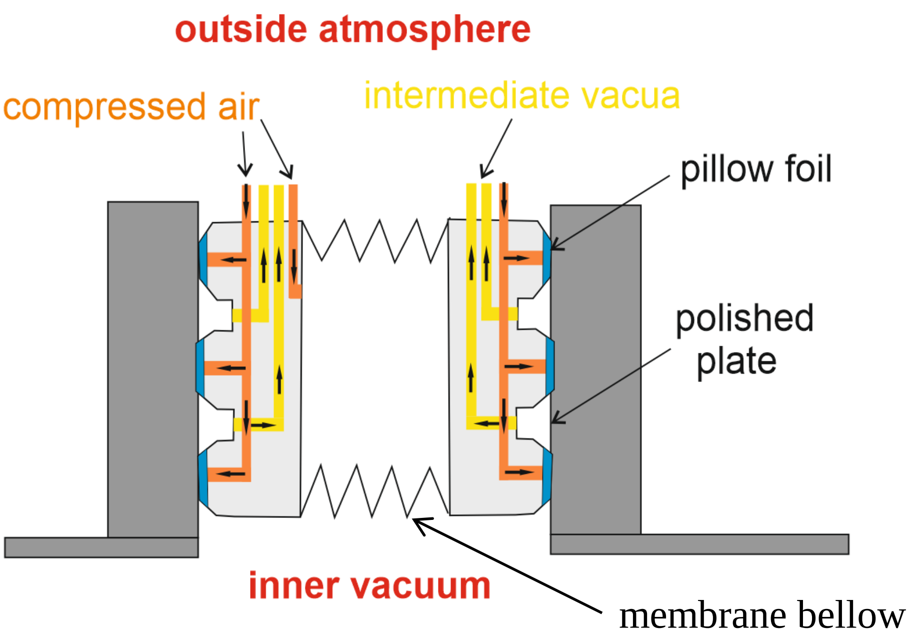
Safe Handling of Activated Parts



Cross section through
beamline and maintenance tunnel,
dose rates in shutdown.

Pillow Seals



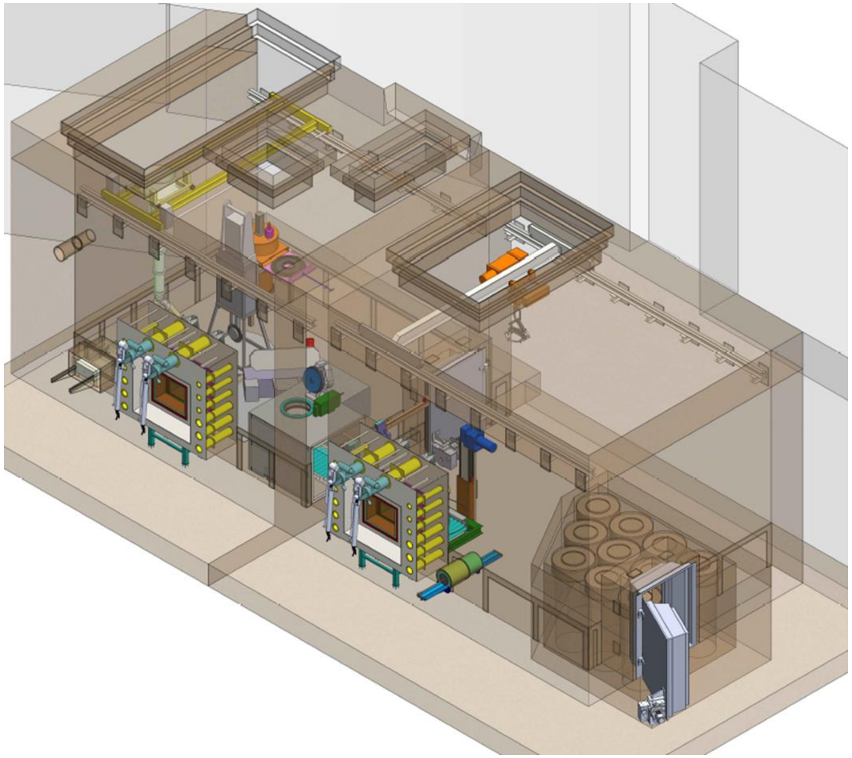


DN500: leak rate < 3e-6 mbar l/s

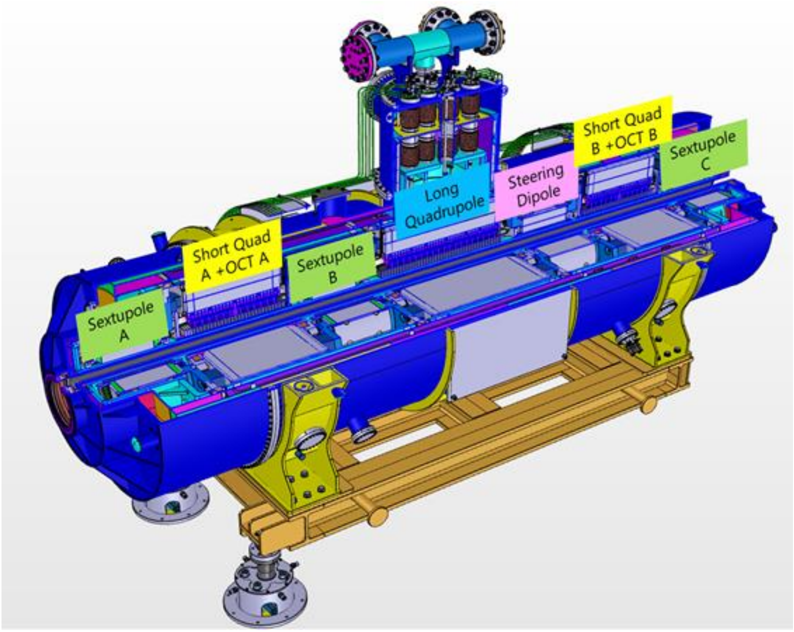
In front of beam catchers
race track shape 1200mm x 140mm

SuperFRS at FAIR

Figure 2.4-176: Radiation shielding bottle at PSI [65] to move activated parts to a hot cell. The whole plug is pulled into the bottle which is then transported with a crane.



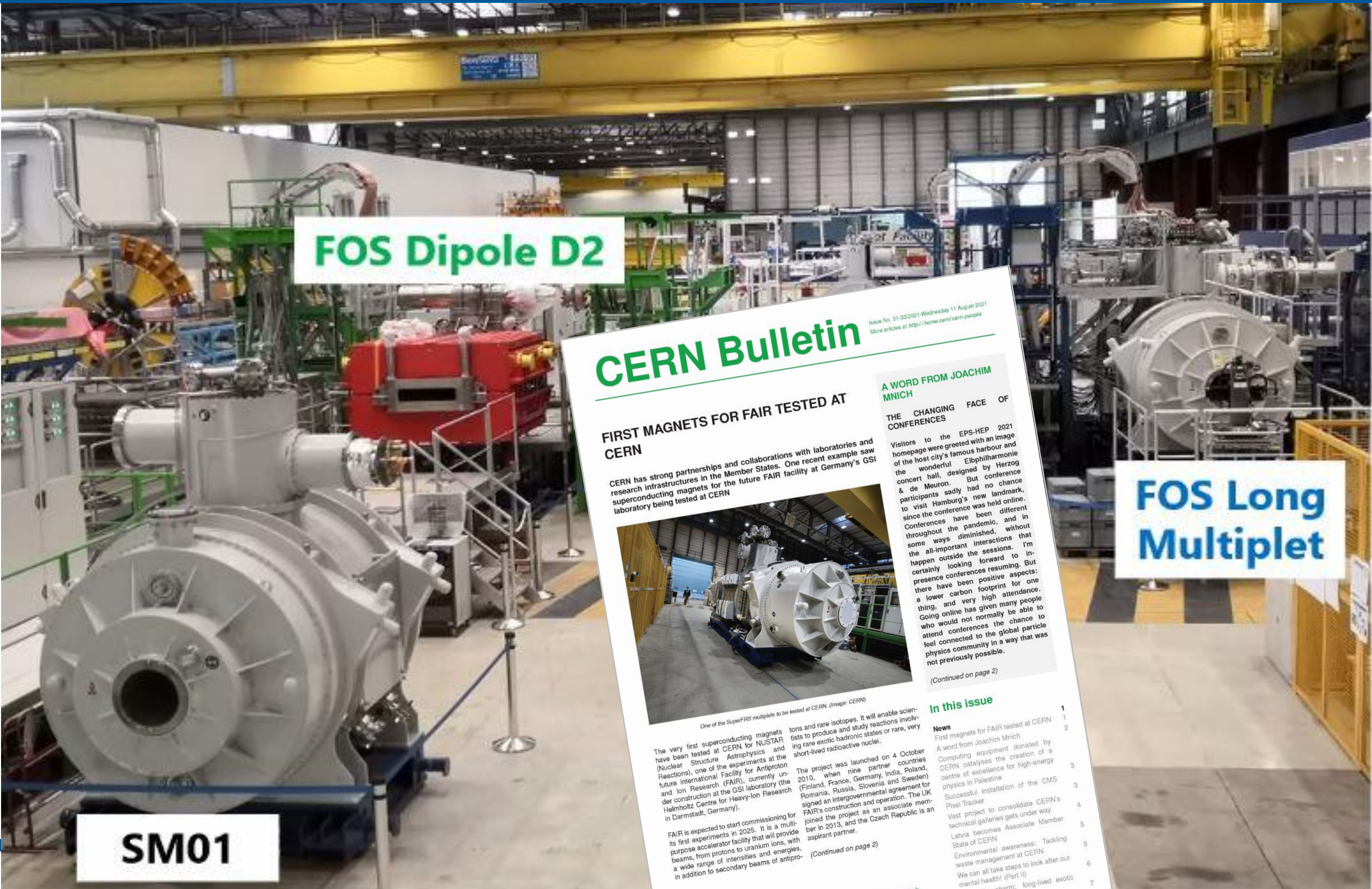
Superconducting Multiplets



- **25** long multiplets (mainly MS)
- **8** short multiplets (PS)
- Quadrupol triplet / QS configuration
- up to 3 sextupoles and 1 steerer
- Octupole coils in short quadrupoles

- iron dominated, cold iron (≈40 tons)
- common helium bath, LHe ≈ 1.300 l
- warm beam pipe (38 cm inner diameter)
- per magnet 1 pair of current leads
- max. current <300A for all magnets

Superconducting Multiplets



CERN Bulletin

Issue No. 31-33/2021-Wednesday 11 August 2021
More articles at http://home.cern/cern-people

FIRST MAGNETS FOR FAIR TESTED AT CERN

CERN has strong partnerships and collaborations with laboratories and research infrastructures in the Member States. One recent example saw superconducting magnets for the future FAIR facility at Germany's GSI laboratory being tested at CERN

One of the SuperFRS multiplets to be tested at CERN. (Image: CERN)

The very first superconducting magnets have been tested at CERN for NUSTAR (Nuclear Structure Astrophysics and Reactions), one of the experiments at the future international Facility for Antiproton and Ion Research (FAIR), currently under construction at the GSI laboratory (the Helmholtz Centre for Heavy-Ion Research in Darmstadt, Germany).

FAIR is expected to start commissioning for its first experiments in 2025. It is a multi-purpose accelerator facility that will provide beams, from protons to uranium ions, with a wide range of intensities and energies, in addition to secondary beams of antiprotons and rare isotopes. It will enable scientists to produce and study reactions involving rare exotic hadronic states or rare, very short-lived radioactive nuclei.

The project was launched on 4 October 2010, when nine partner countries (Finland, France, Germany, India, Poland, Romania, Russia, Slovenia and Sweden) signed an intergovernmental agreement for FAIR's construction and operation. The UK joined the project as an associate member in 2013, and the Czech Republic is an aspirant partner.

(Continued on page 2)

A WORD FROM JOACHIM MNICH

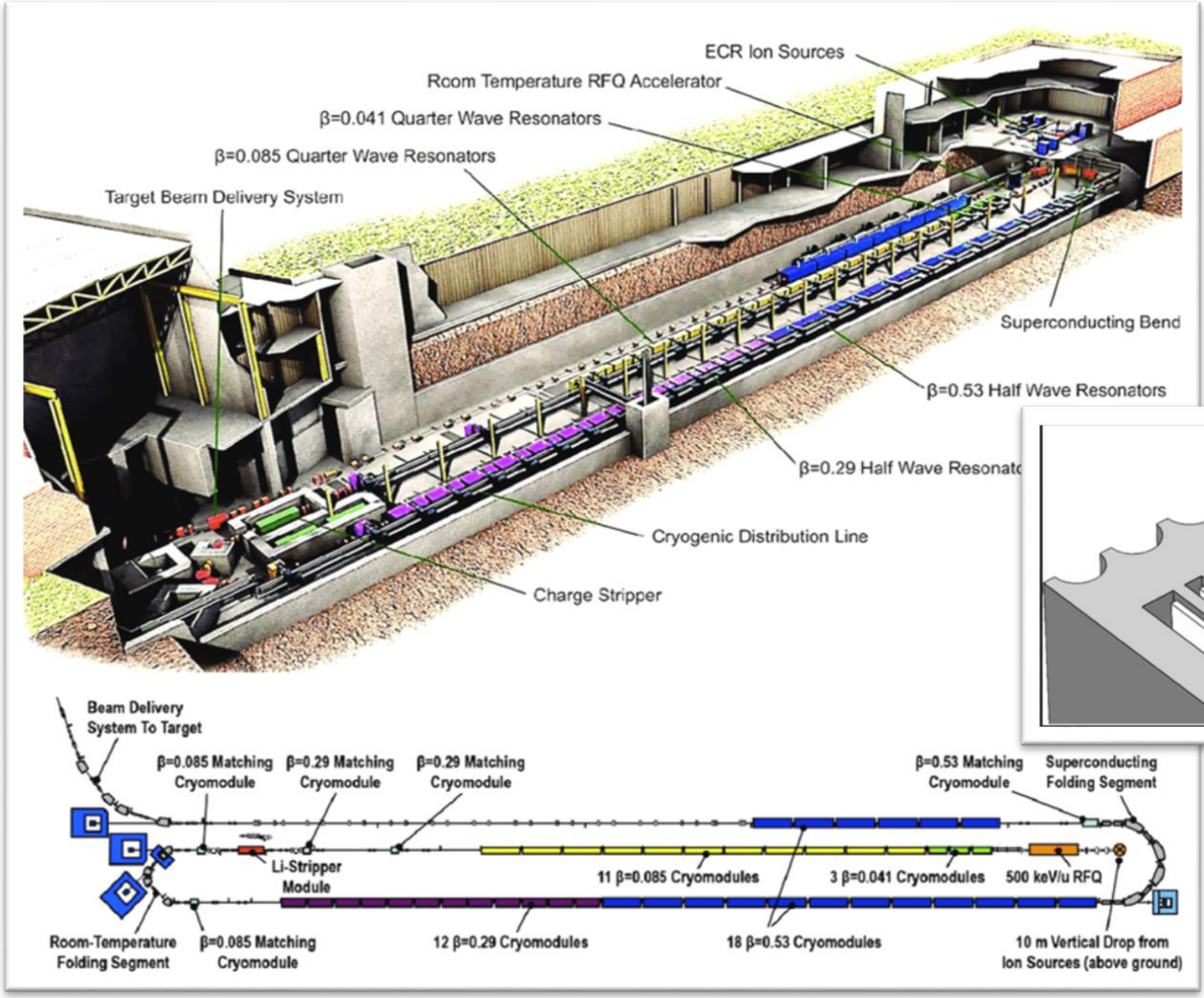
THE CHANGING FACE OF CONFERENCES

Visitors to the EPS-HEP 2021 homepage were greeted with an image of the host city's famous harbour and the wonderful Elbphilharmonie concert hall, designed by Herzog & de Meuron. But conference participants sadly had no chance to visit Hamburg's new landmark, since the conference was held online. Conferences have been different throughout the pandemic, and in some ways diminished, without the all-important interactions that happen outside the sessions. I'm certainly looking forward to in-presence conferences resuming. But there have been positive aspects: a lower carbon footprint for one thing, and very high attendance. Going online has given many people who would not normally be able to attend conferences the chance to feel connected to the global particle physics community in a way that was not previously possible.

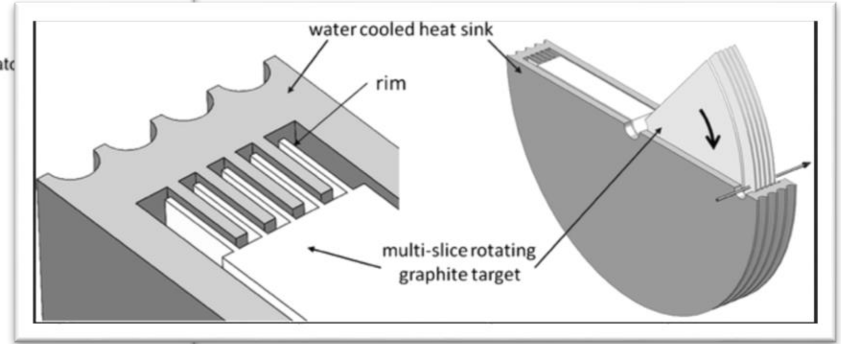
(Continued on page 2)

In this issue

FRIB (MSU)

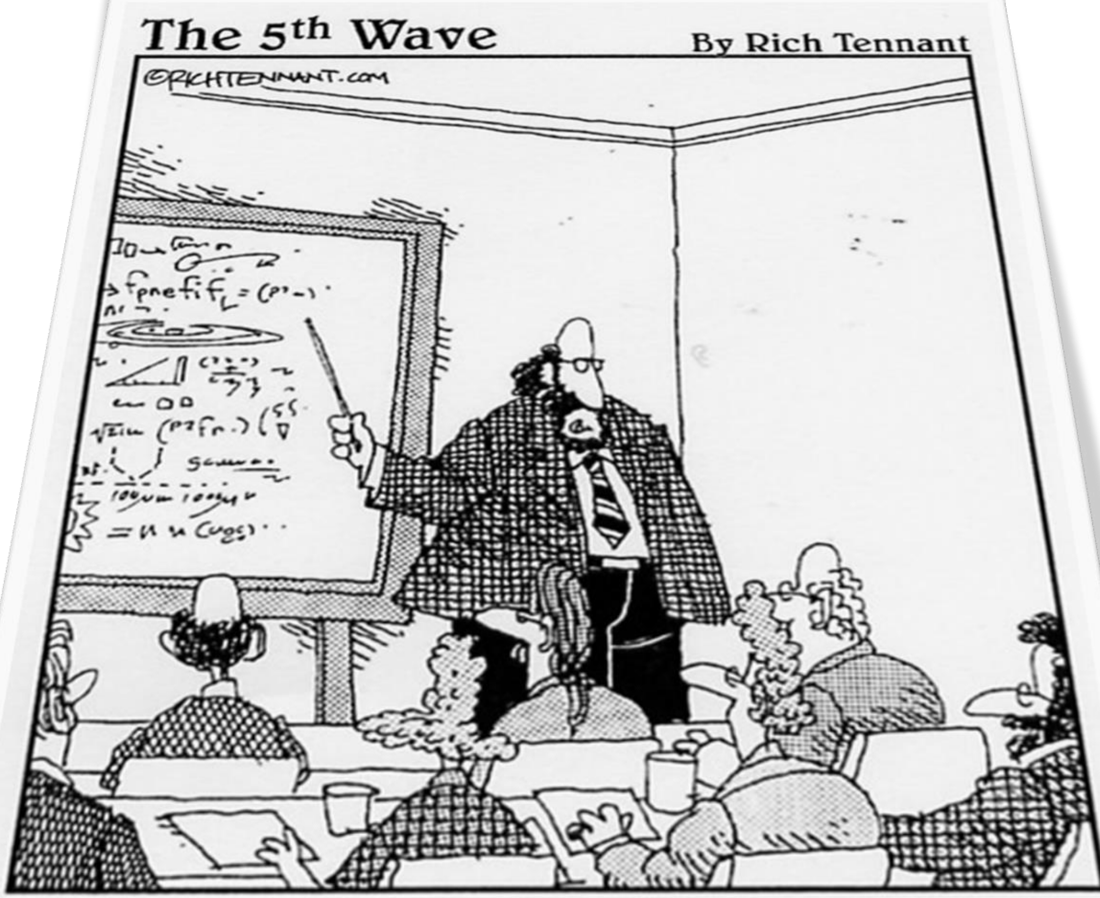


ECR Ion Sources
Room Temperature RFQ Accelerator
β=0.041 Quarter Wave Resonators
β=0.085 Quarter Wave Resonators
Target Beam Delivery System
Superconducting Bend
β=0.53 Half Wave Resonators
β=0.29 Half Wave Resonato
Cryogenic Distribution Line
Charge Stripper
Beam Delivery System To Target
β=0.085 Matching Cryomodule
β=0.29 Matching Cryomodule
β=0.29 Matching Cryomodule
β=0.53 Matching Cryomodule
Superconducting Folding Segment
Li-Stripper Module
11 β=0.085 Cryomodules
3 β=0.041 Cryomodules
500 keV/u RFQ
Room-Temperature Folding Segment
β=0.085 Matching Cryomodule
12 β=0.29 Cryomodules
18 β=0.53 Cryomodules
10 m Vertical Drop from Ion Sources (above ground)



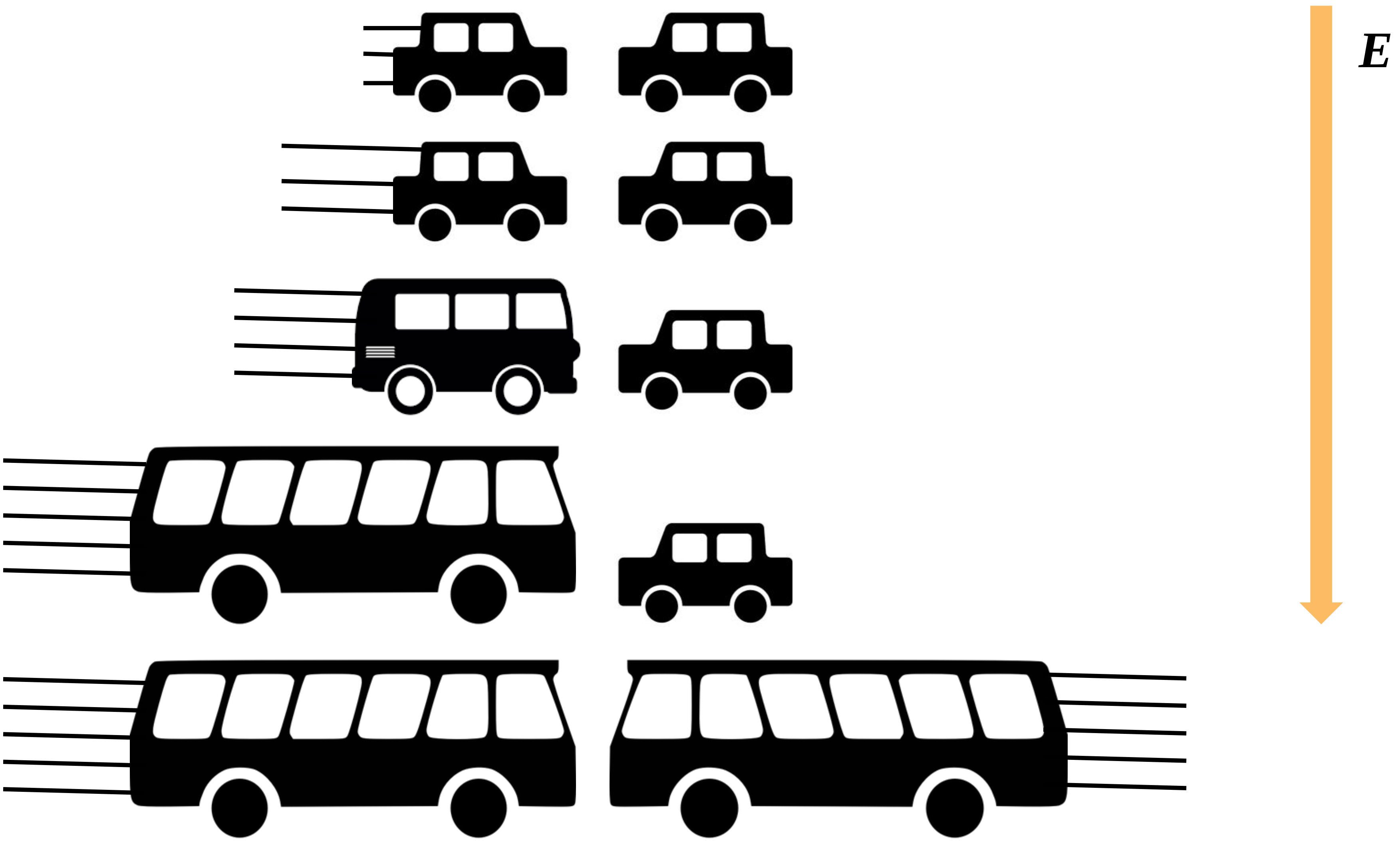
water cooled heat sink
rim
multi-slice rotating graphite target

Antiprotons (pbar)



"After the discovery of 'antimatter' and 'dark matter', we have just confirmed the existence of 'doesn't matter', which does not have any influence on the Universe whatsoever."

Motivation for the large pbar Sources: p–pbar Collider (SPS, Tevatron)



Motivation for the large pbar Sources: p–pbar Collider (SPS, Tevatron)

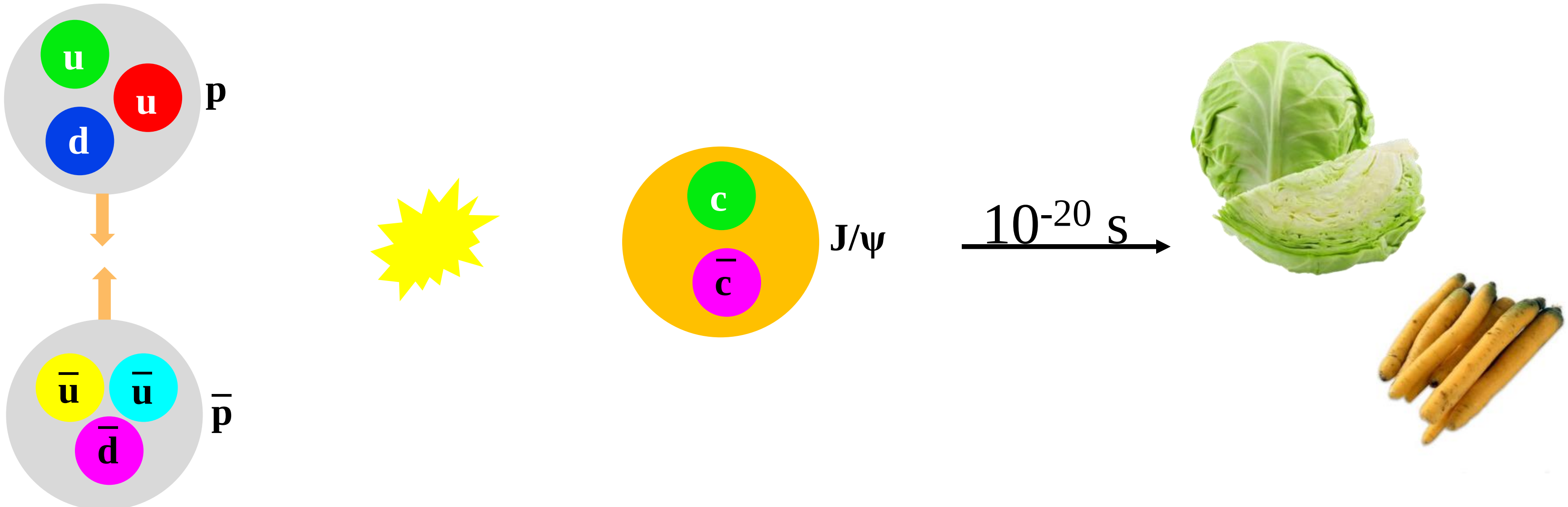
Detection of *W* and *Z* boson at CERN:
Nobel Prize 1984 to Carlo Rubbia (right) and Simon van der Meer (left).

Detection of the top quark at Fermilab (1995)
Nobel Prize 2008 to Makoto Kobayashi (left) and Toshihide Maskawa (right) for its prediction.

Running and planned experiments at the AD & ELENA

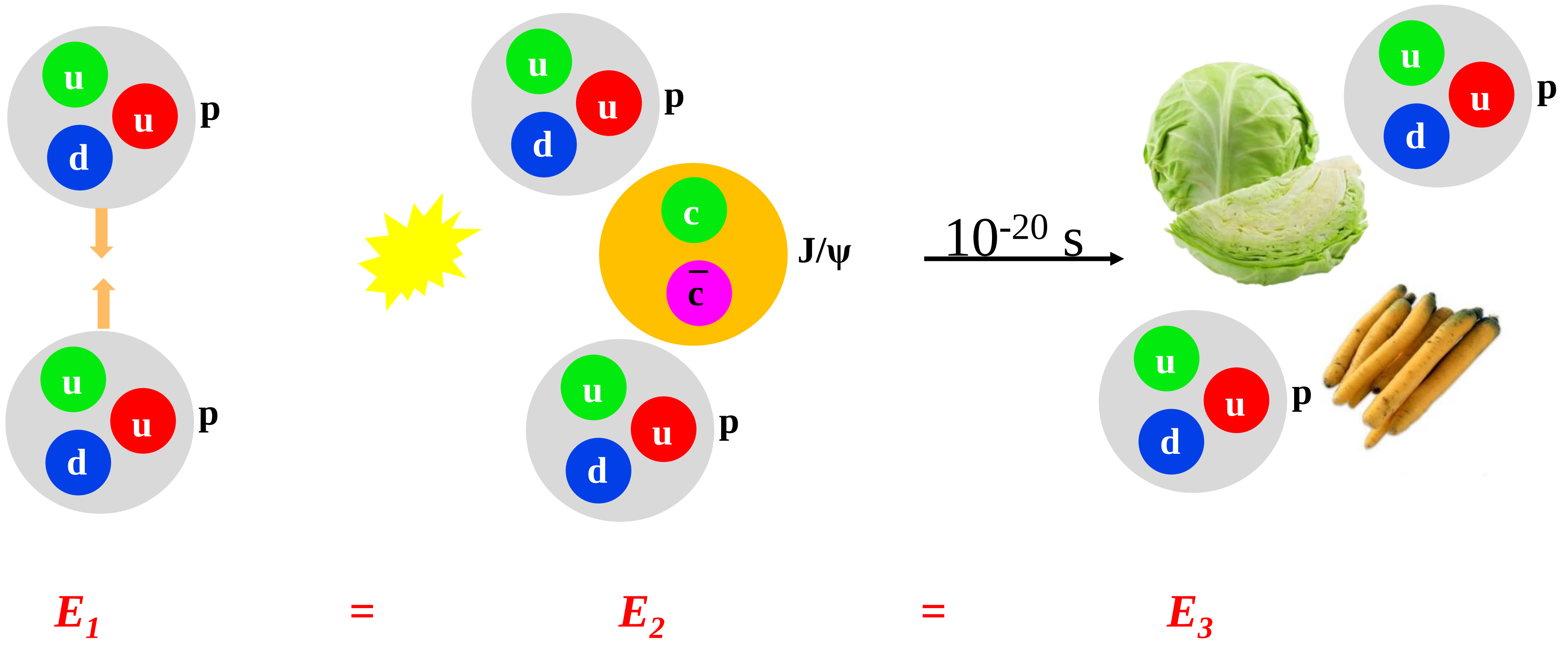
- **ATRAP (Antihydrogen TRAP)**
  $\bar{H}$ laser spectroscopy (to come), $\bar{p}$ magnetic moment & q/m
- **ALPHA (Antihydrogen Laser PHysics Apparatus)**
  $\bar{H}$ laser & mw spectroscopy, gravity (to come)
- **Asacusa (Atomic Spectroscopy And Collisions Using Slow Antiprotons)**
  $\bar{H}$ mw spectroscopy,
  $\bar{p}$-He laser spectroscopy ($m_{\bar{p}}/m_e$),
  antiproton dE/dx, $\sigma_{annihil}$ in matter
- **BASE (Baryon Antibaryon Symmetry Experiment)**
  $\bar{p}$ magnetic moment & q/m
- **AEGIS (Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy)**
  $\bar{H}$ gravity
- **GBAR (Gravitational Behaviour of Antihydrogen at Rest)**
  Future, with ELENA: $\bar{H}$ gravity
- **ACE (Antiproton Cell Experiment)**
  cancer therapy, finished

Charmonium-Production

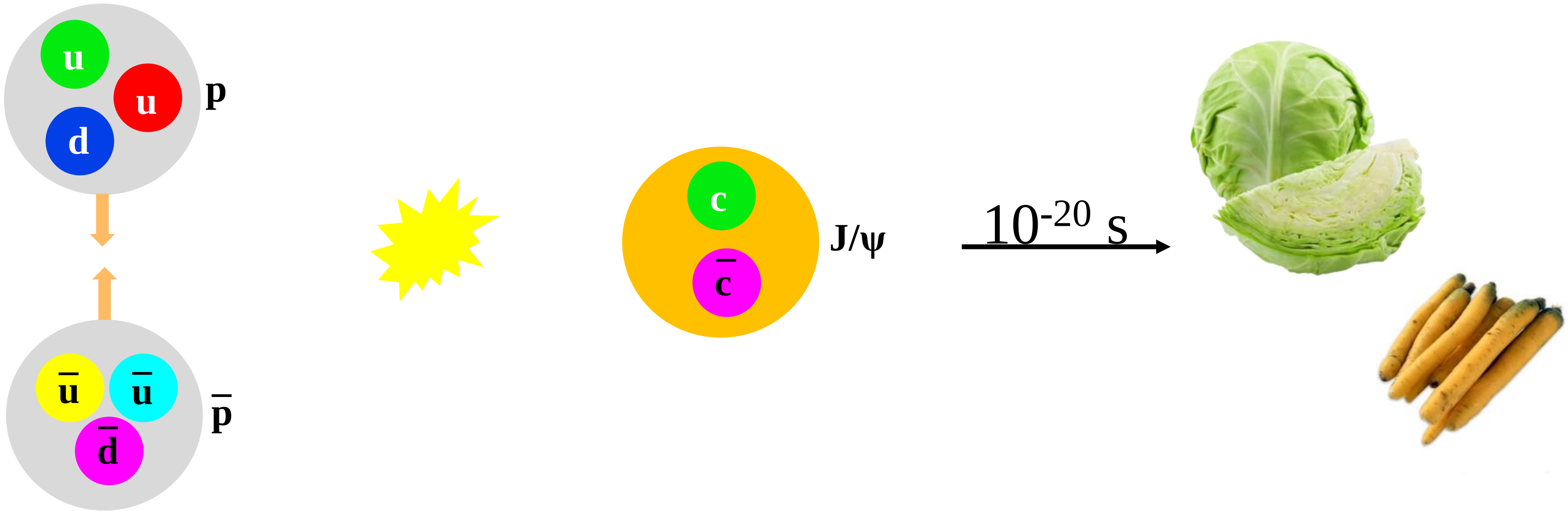


$$E_1 \quad = \quad E_2 \quad = \quad E_3$$

Charmonium-Produktion



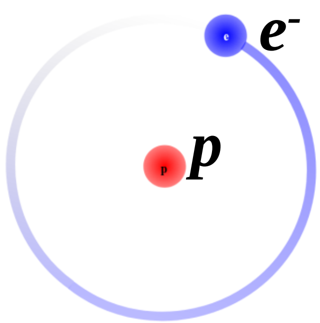
Charmonium-Produktion

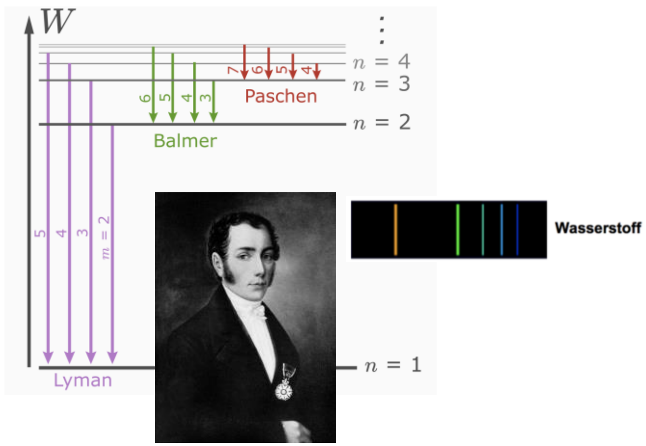


$$E_1 = E_2 = E_3$$

Charmonium-Spectroscopy

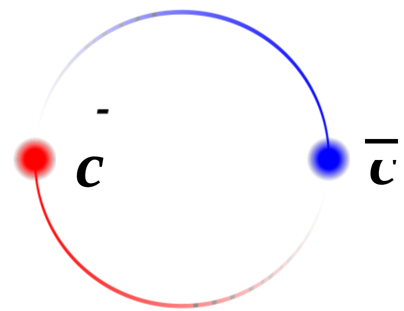
Hydrogen atom

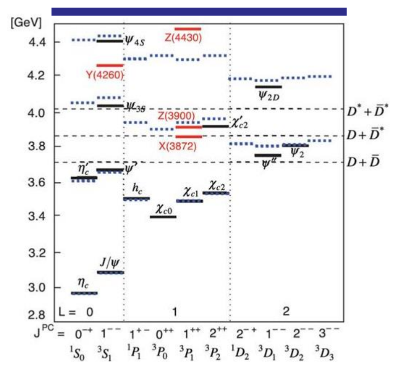




electromagnetic interaction

Charmonium





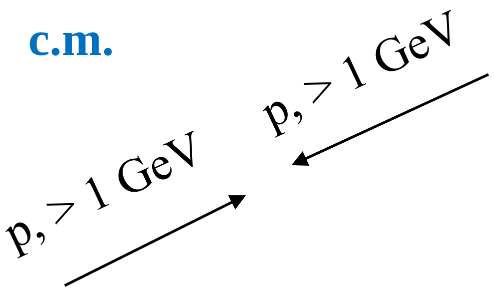
strong interaction

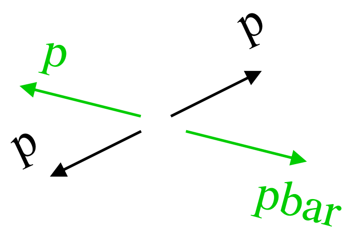
FAIR / CERN / FNAL pbar Sources

	FAIR	CERN (AC+AA)	FNAL
E(p), E(pbar)	29 GeV, 3 GeV	25 GeV, 2.7 GeV	120 GeV, 8 GeV
acceptance	240 π mm mrad	200 π mm mrad	$\approx$ 30 π mm mrad
protons / pulse	2×10^{13}	$1 - 2 \times 10^{13}$	$\geq 5 \times 10^{12}$
pulse length	single bunch (50 ns)	5 bunches in 400 ns	single bunch 1.6 µs
cycle time	10 s	4.8 s	1.5 s

Creation of Antiprotons

c.m.

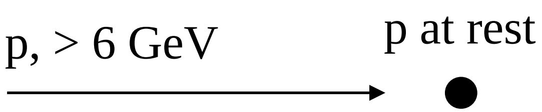


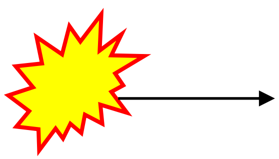


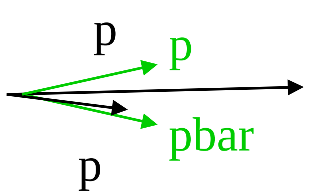
$$\mathbf{m = E / c^2}$$

$$\mathbf{m_p = m_{pbar} \approx 1\ GeV / c^2}$$

lab





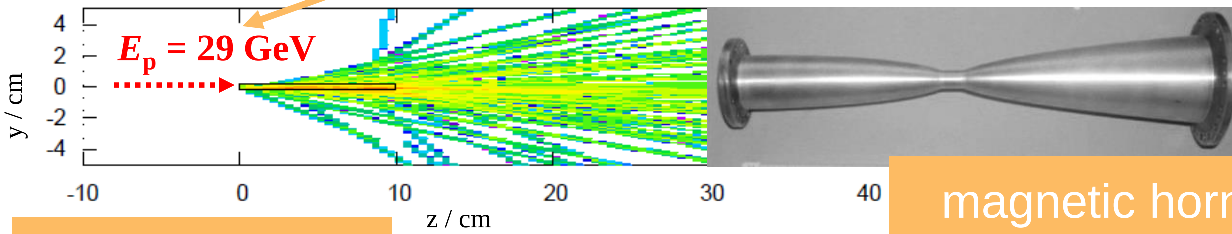


$$\mathbf{m = E / c^2}$$

$$\mathbf{T_{pbar} > 6\ GeV}$$

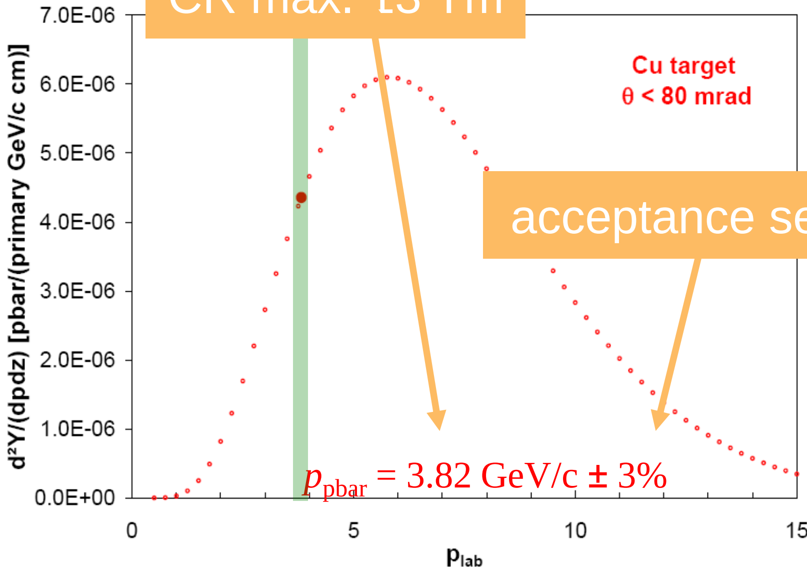
Collectible pbars

Emax SIS 100

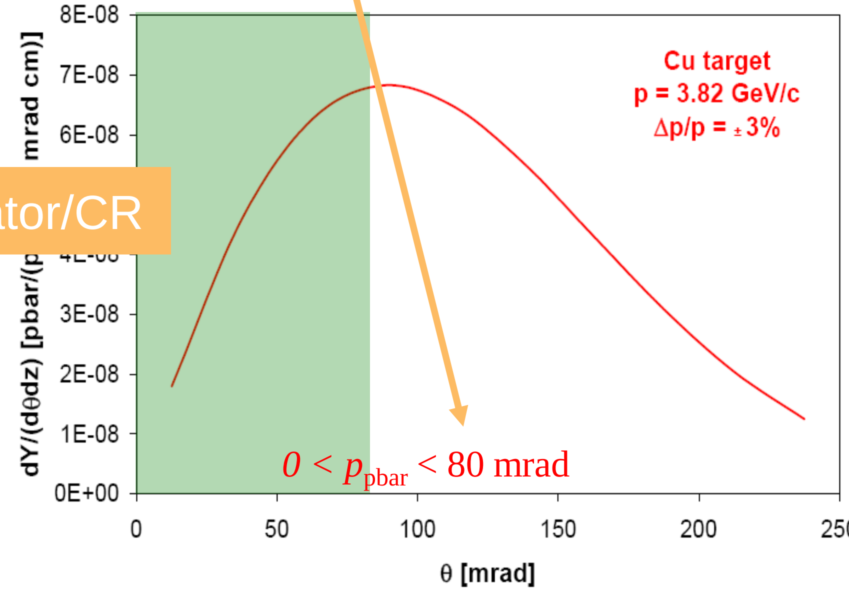


magnetic horn

CR max. 13 Tm

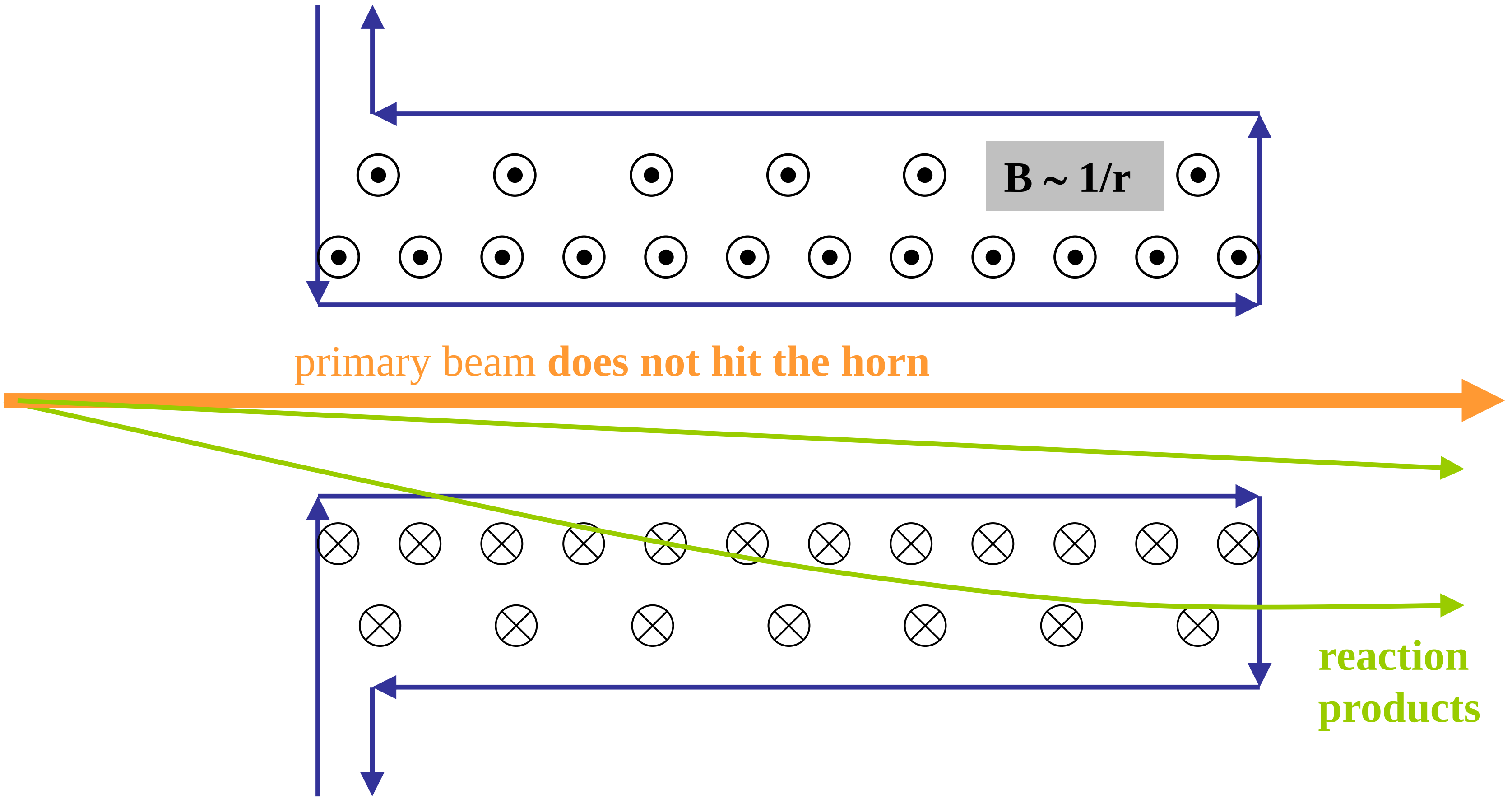


acceptance separator/CR

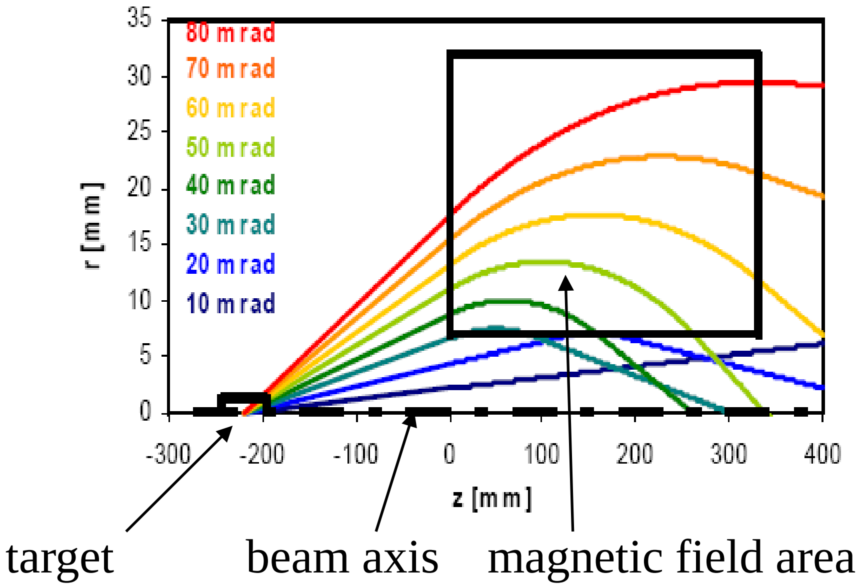


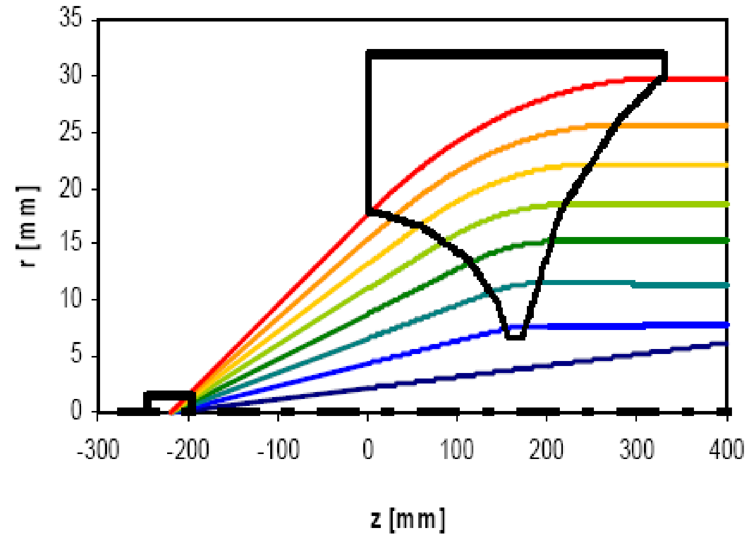
From ~ 2.5 × 10^{-4} pbar / (p cm target) ~ 5 × 10^{-6} (or 2 %) are "collectible"

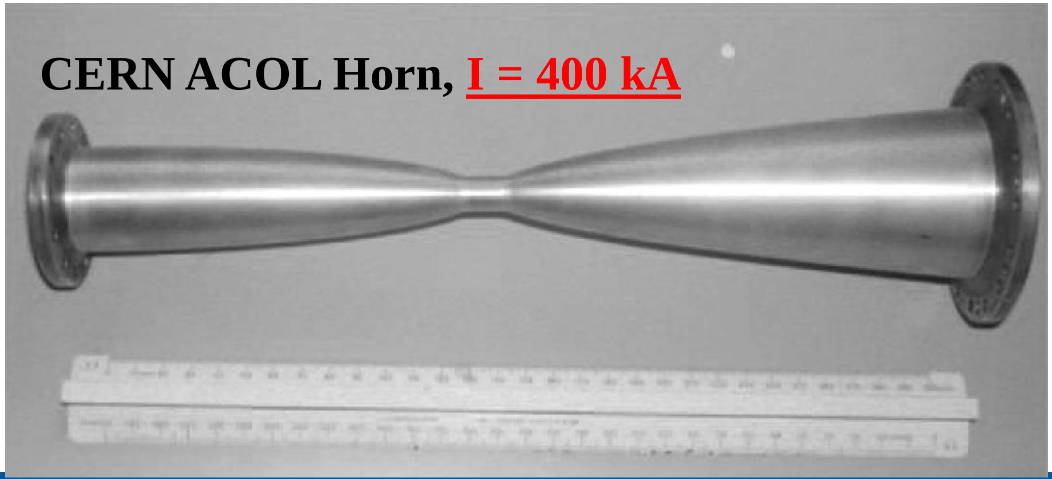
Collecting pbars: Magnetic Horn



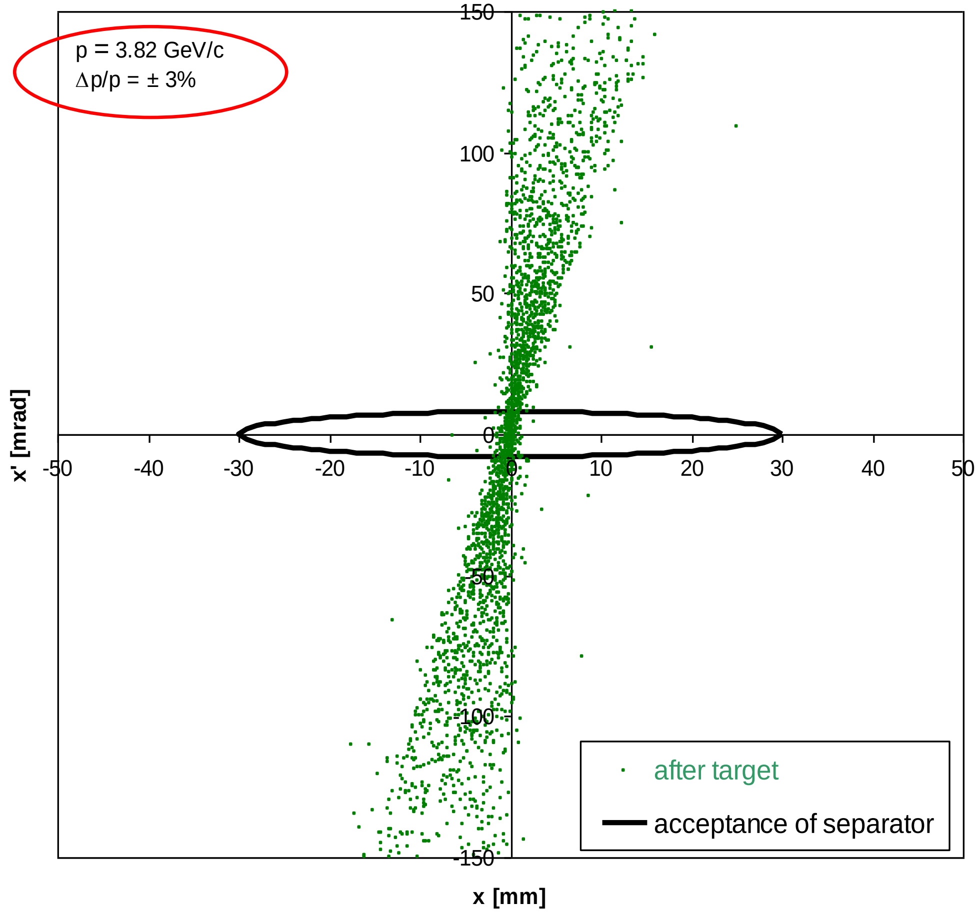
Collecting pbars: Magnetic Horn



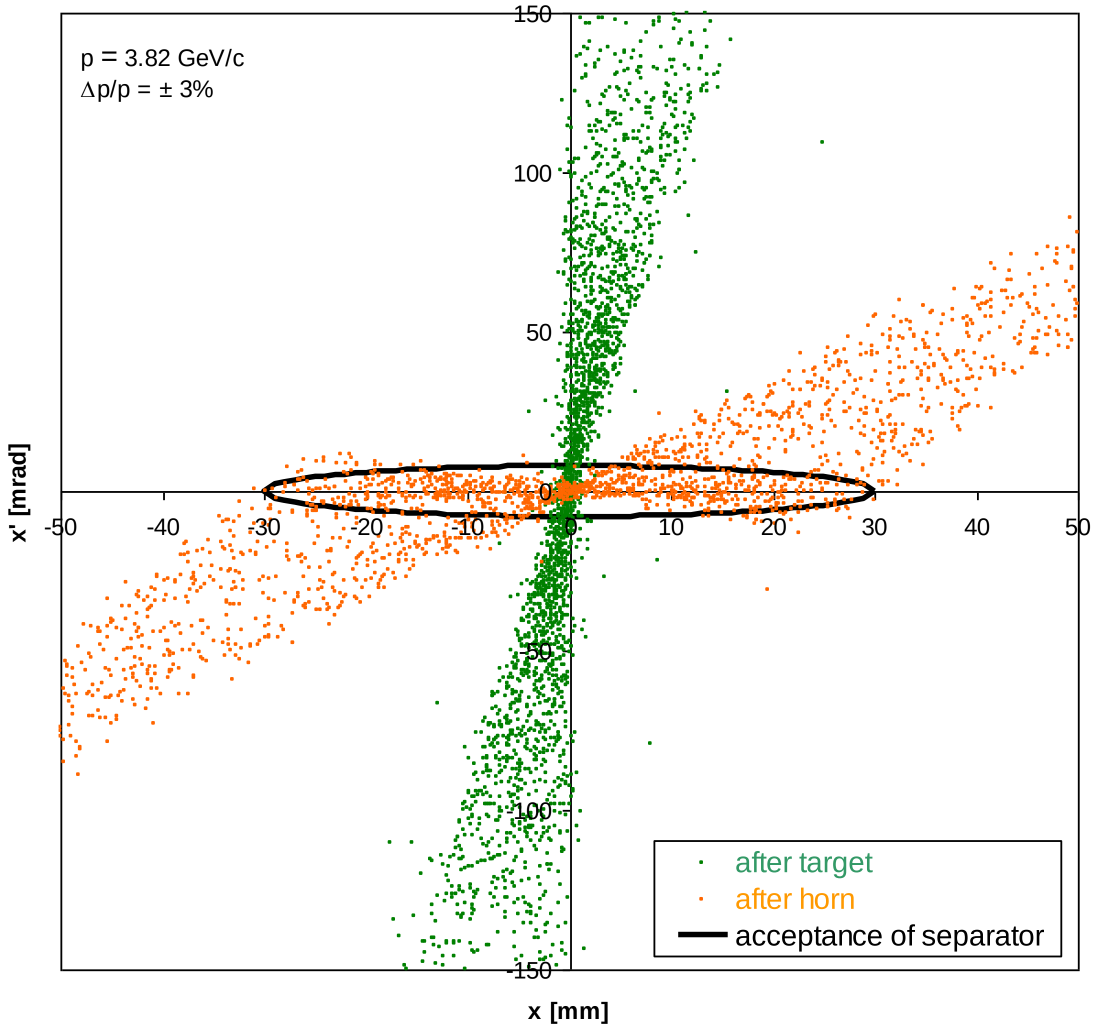




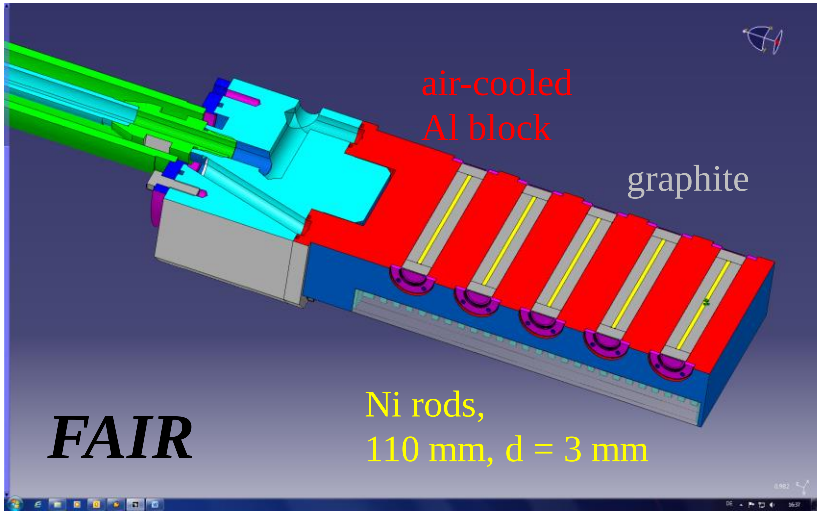
MARS Simulation of the pbar Yields

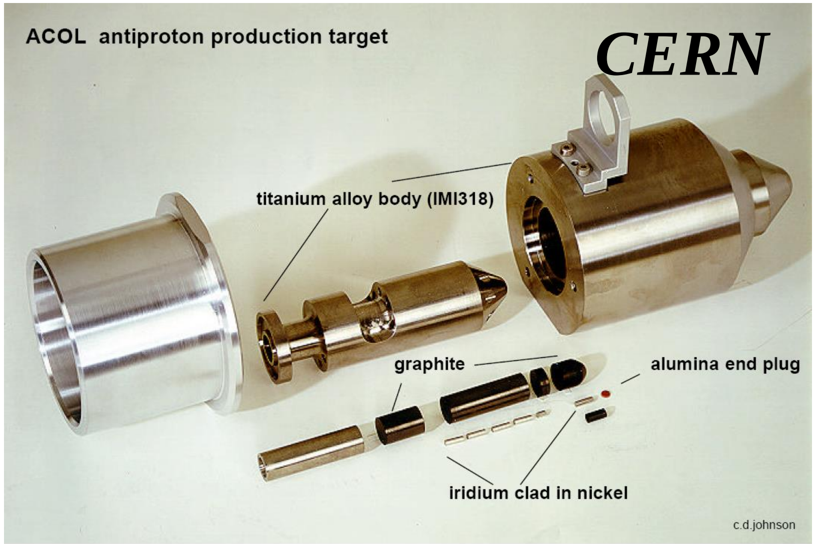


MARS Simulation of the pbar Yields

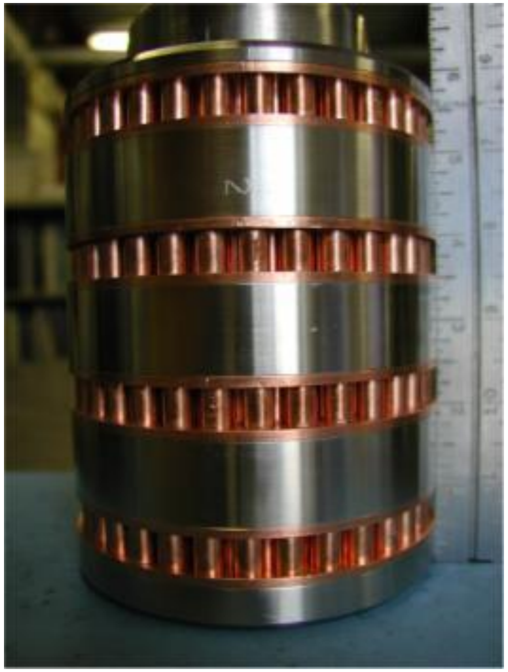


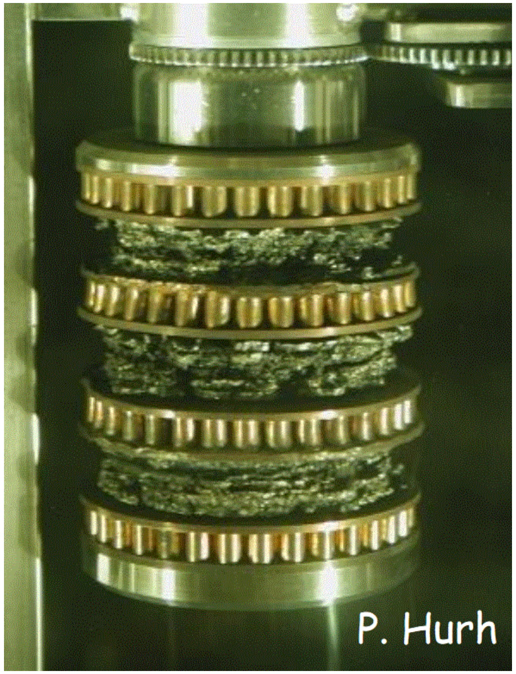
pbar Targets



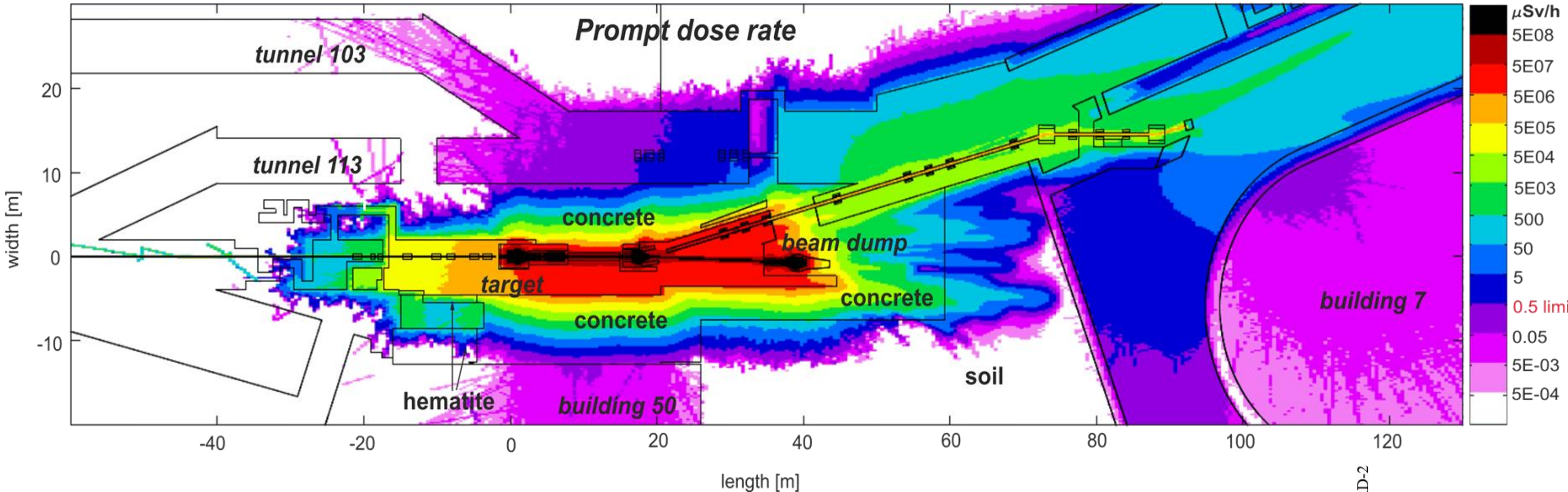


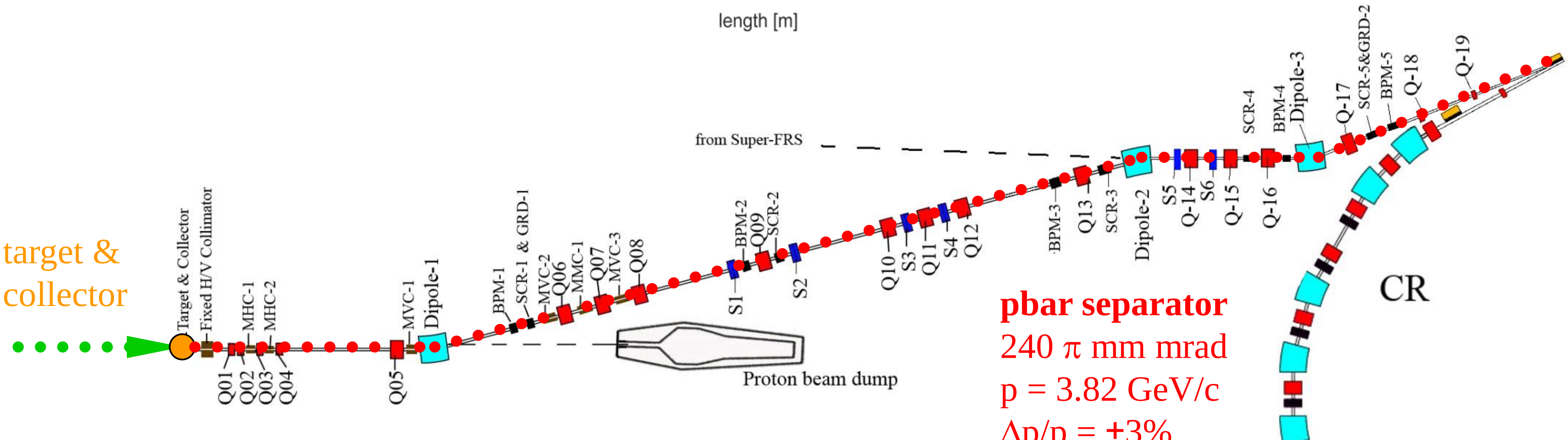
Fermilab





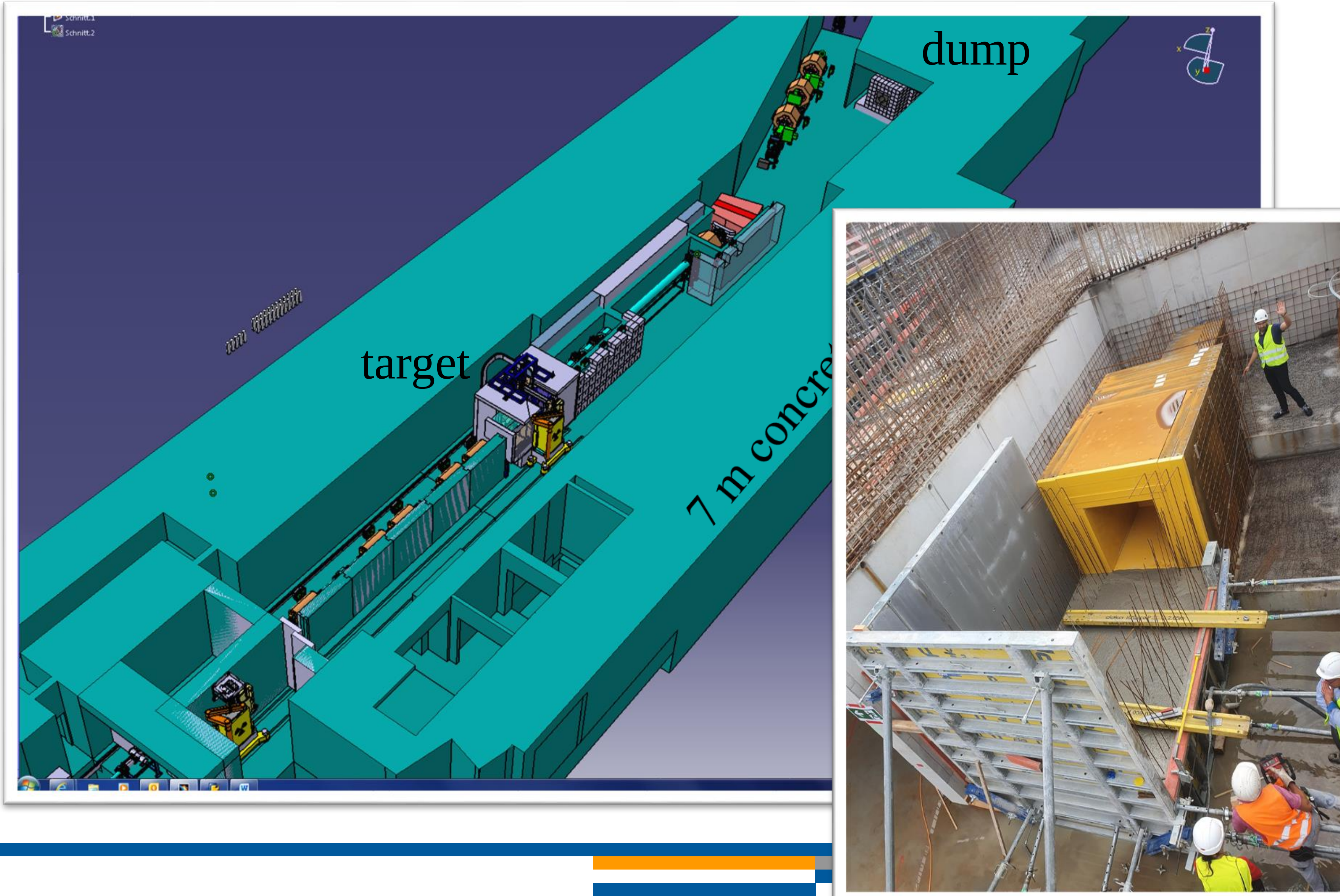
The pbar separator



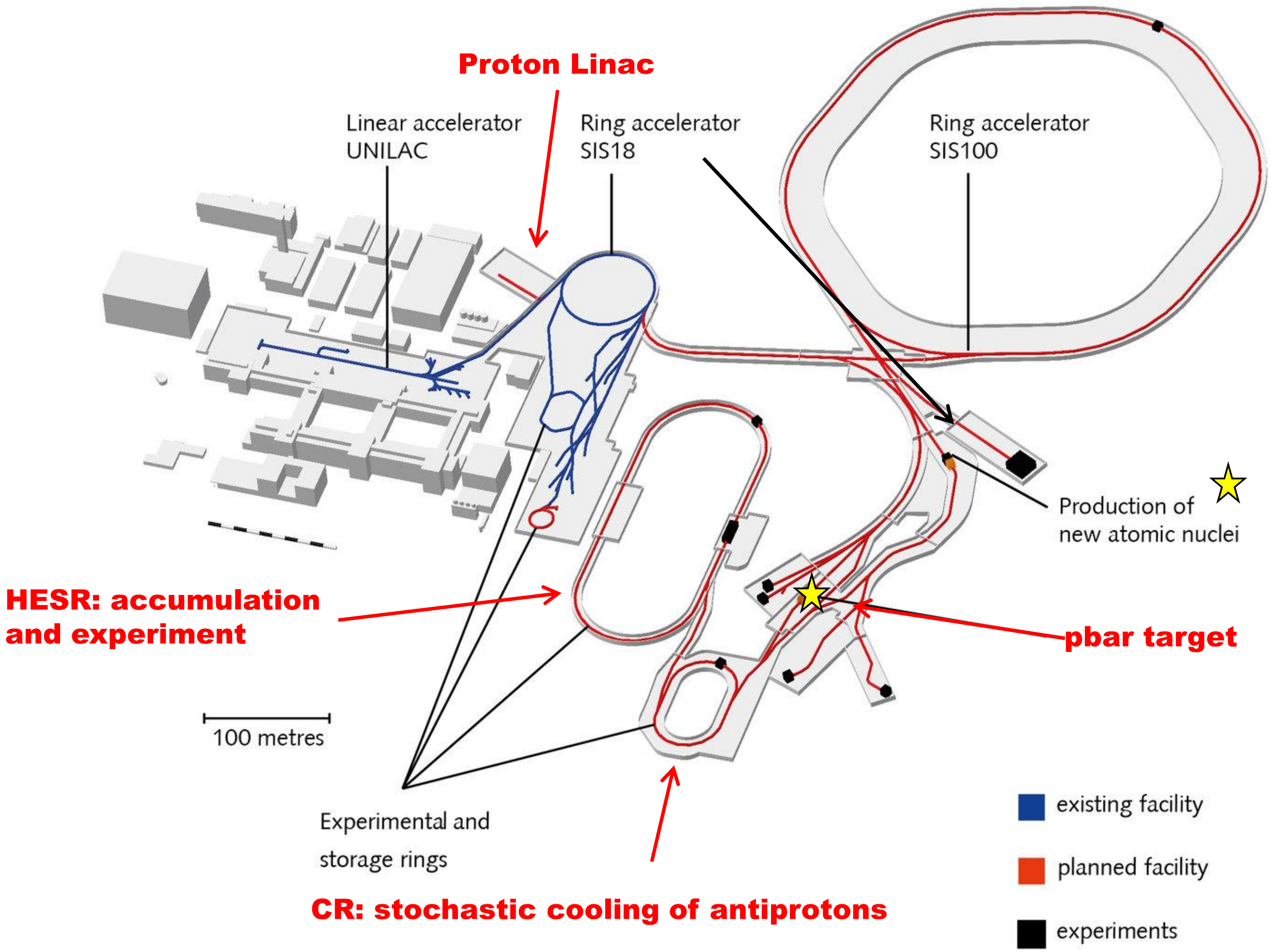


29 GeV p from SIS 100

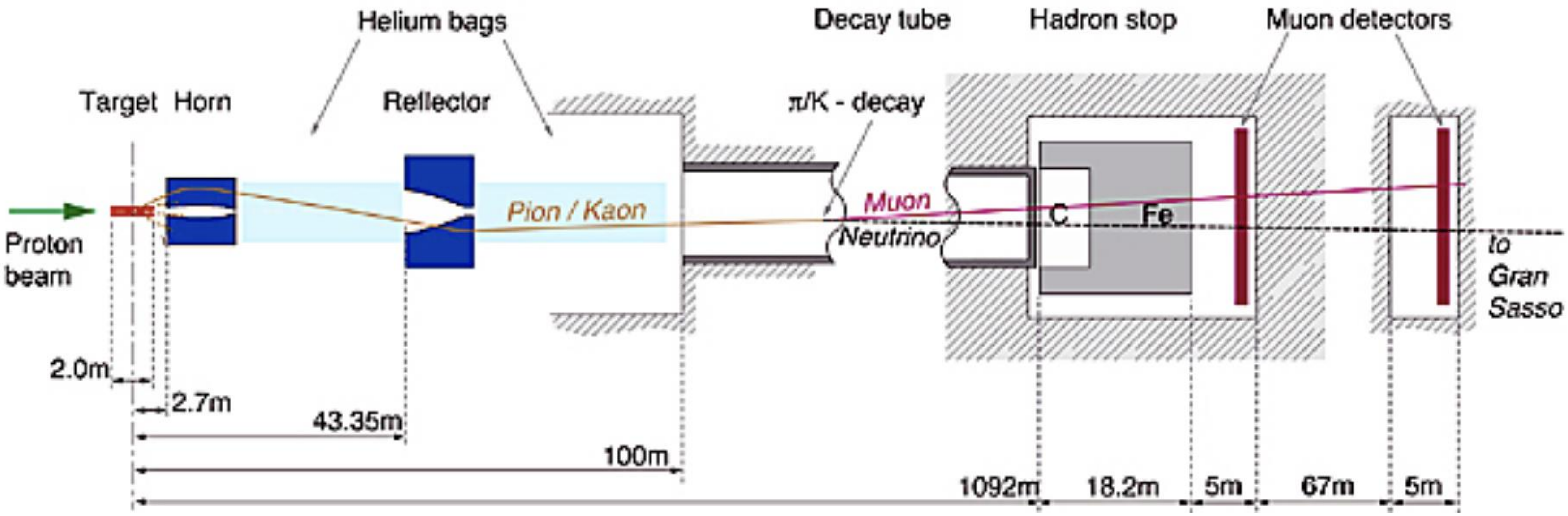
The pbar tunnel

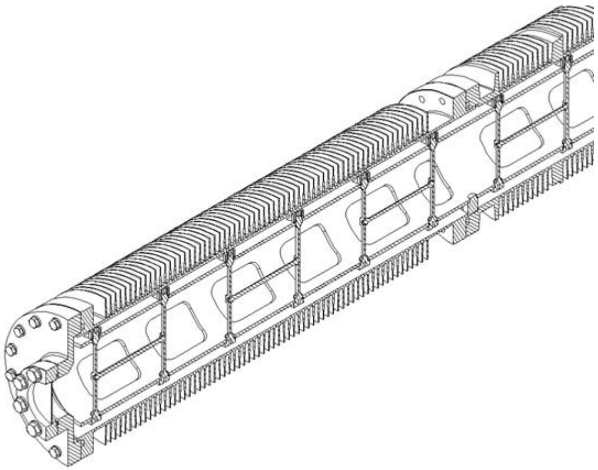


Antiprotons @ FAIR

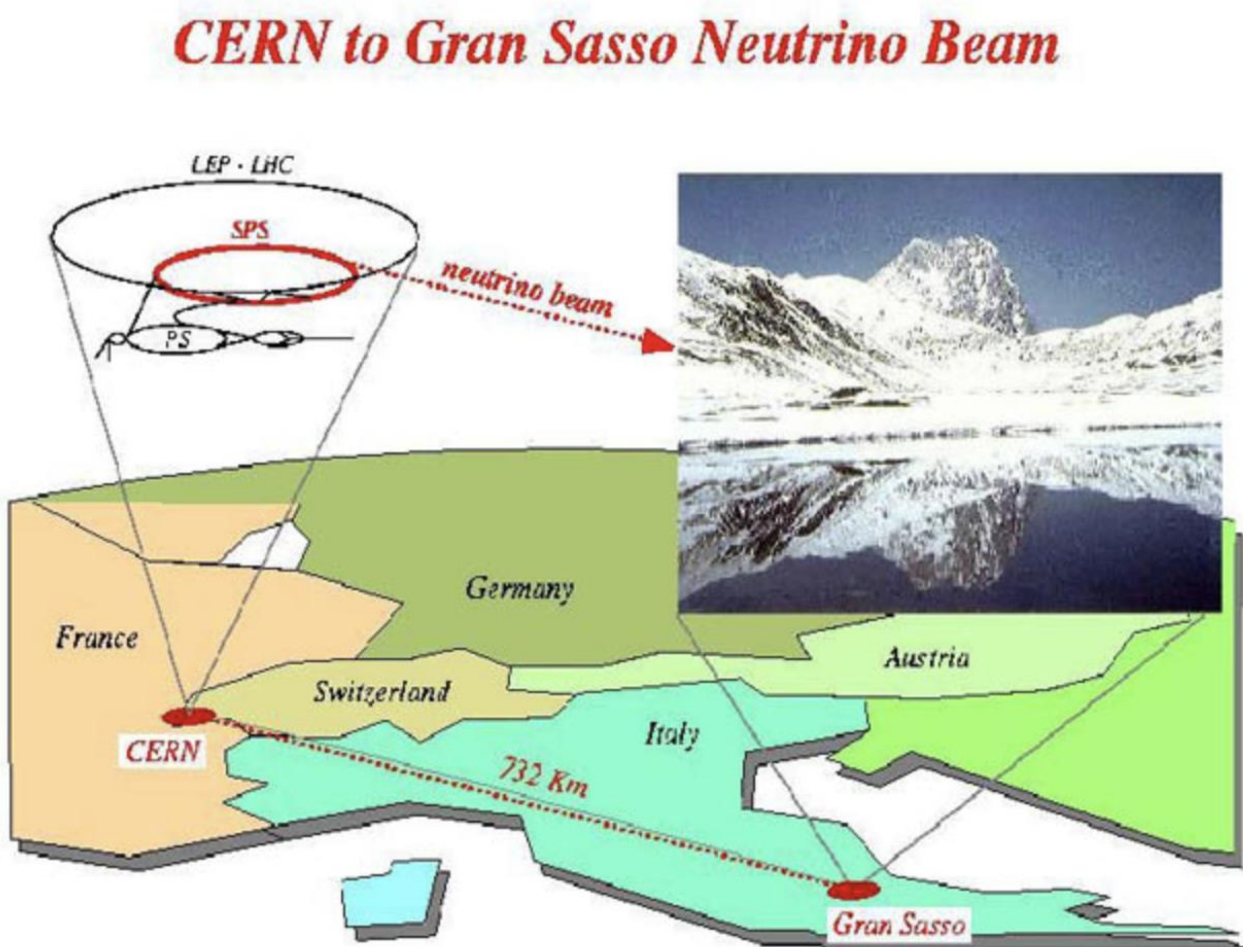


„Tertiary“ Beams: CNGS





„Tertiary“ Beams: CNGS



„Tertiary Beams: CNGS

symmetry
dimensions of particle physics

topics

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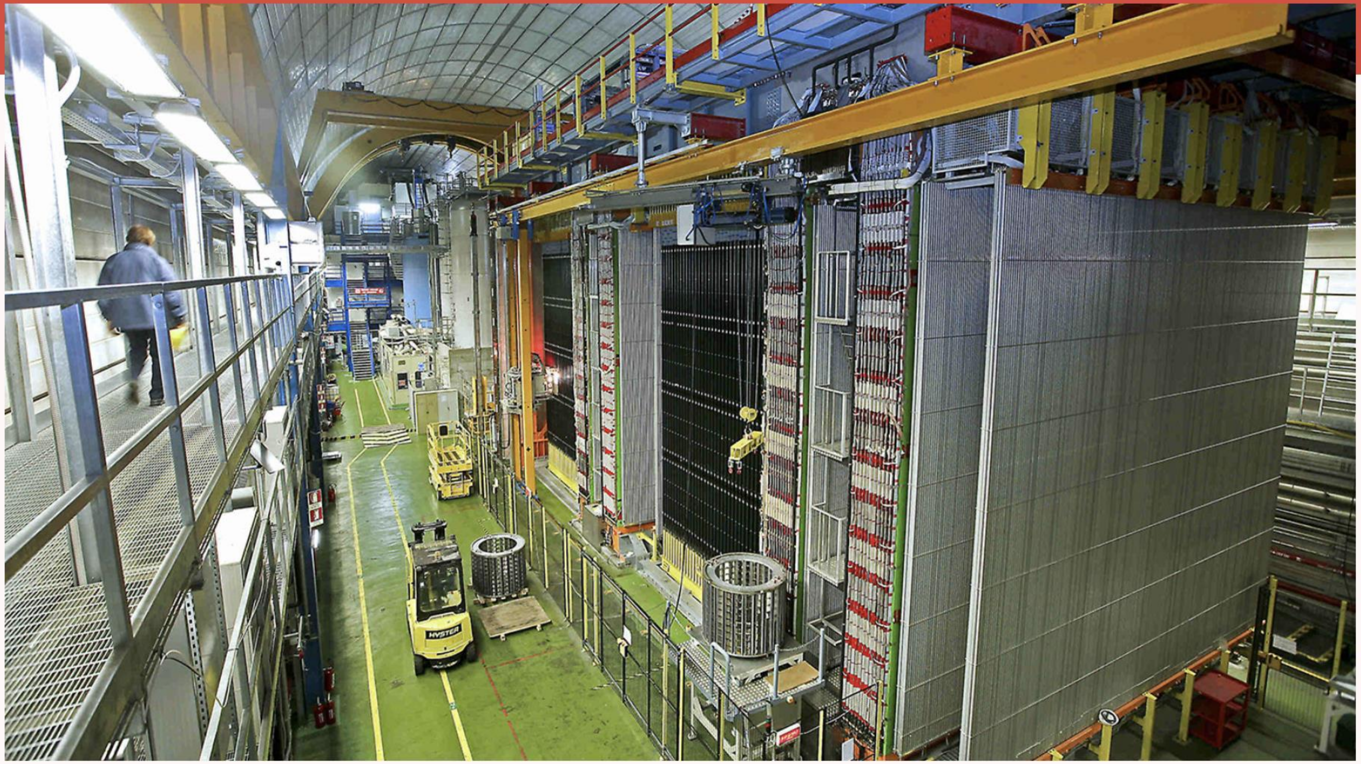
A joint Fermilab/SLAC publication

OPERA catches fifth tau neutrino

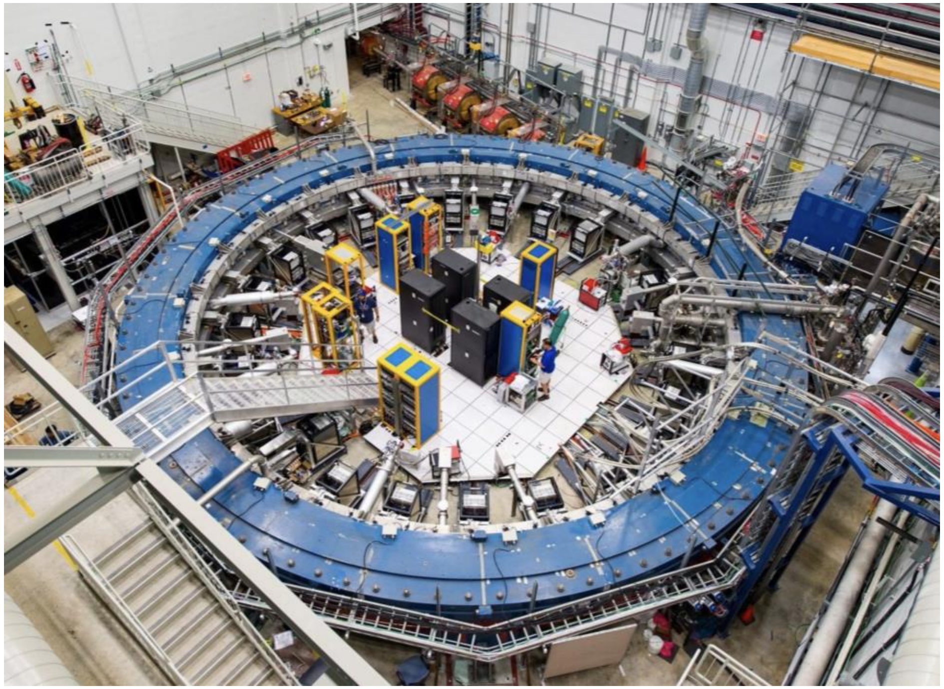
06/16/15 | By Kathryn Jepsen

The OPERA experiment's study of tau neutrino appearance has reached the level of "discovery."



INFN

„Tertiary“ Beams: „g-2“:Magnetic Moment of Muons



g-2 ring at Fermilab