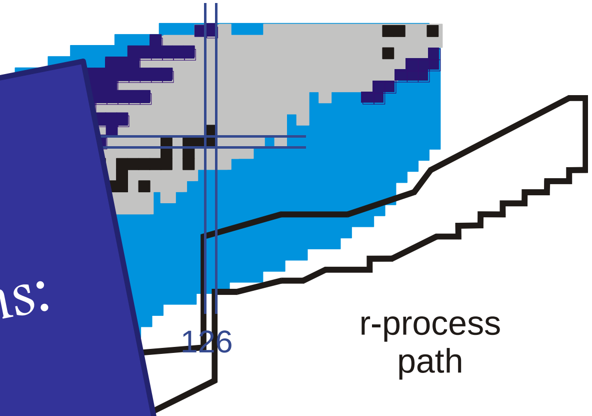
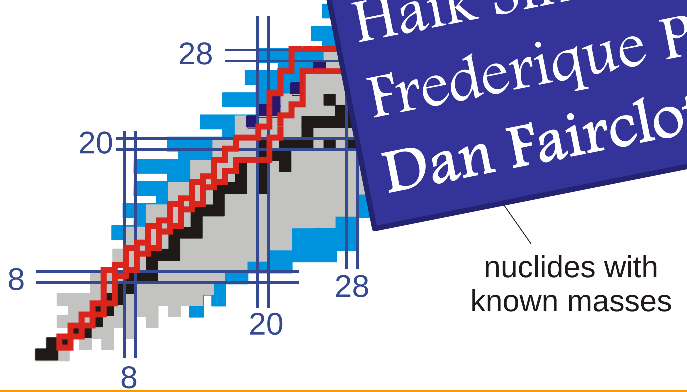
Secondary Beams

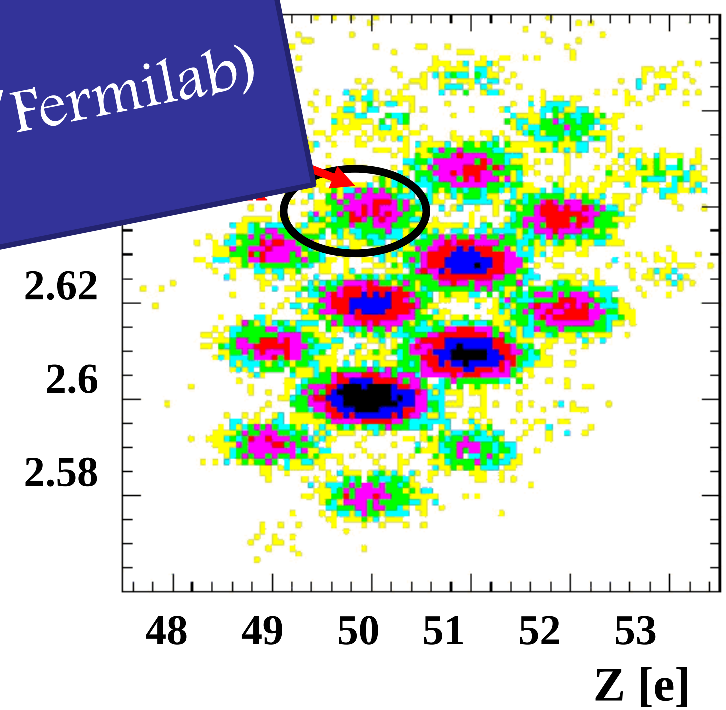
K. Knie / GSI



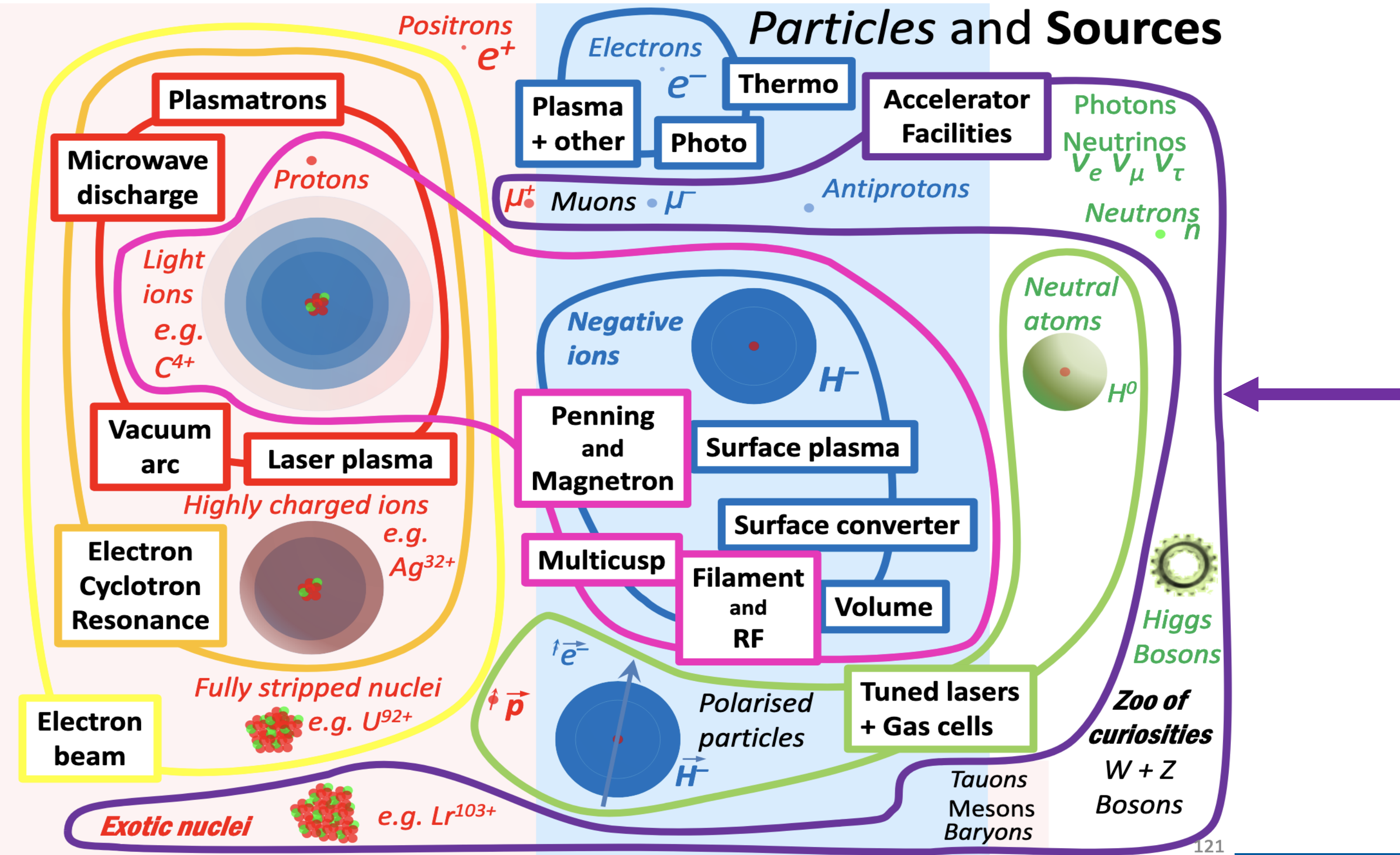
Thank you very much
for providing me lots of information
and letting me steal your illustrations:

Alexander Gottberg (TRIUMF)
Haik Simon (GSI)
Frederique Pellemoine (MSU/Fermilab)
Dan Faircloth (RAL)





Introduction



Introduction

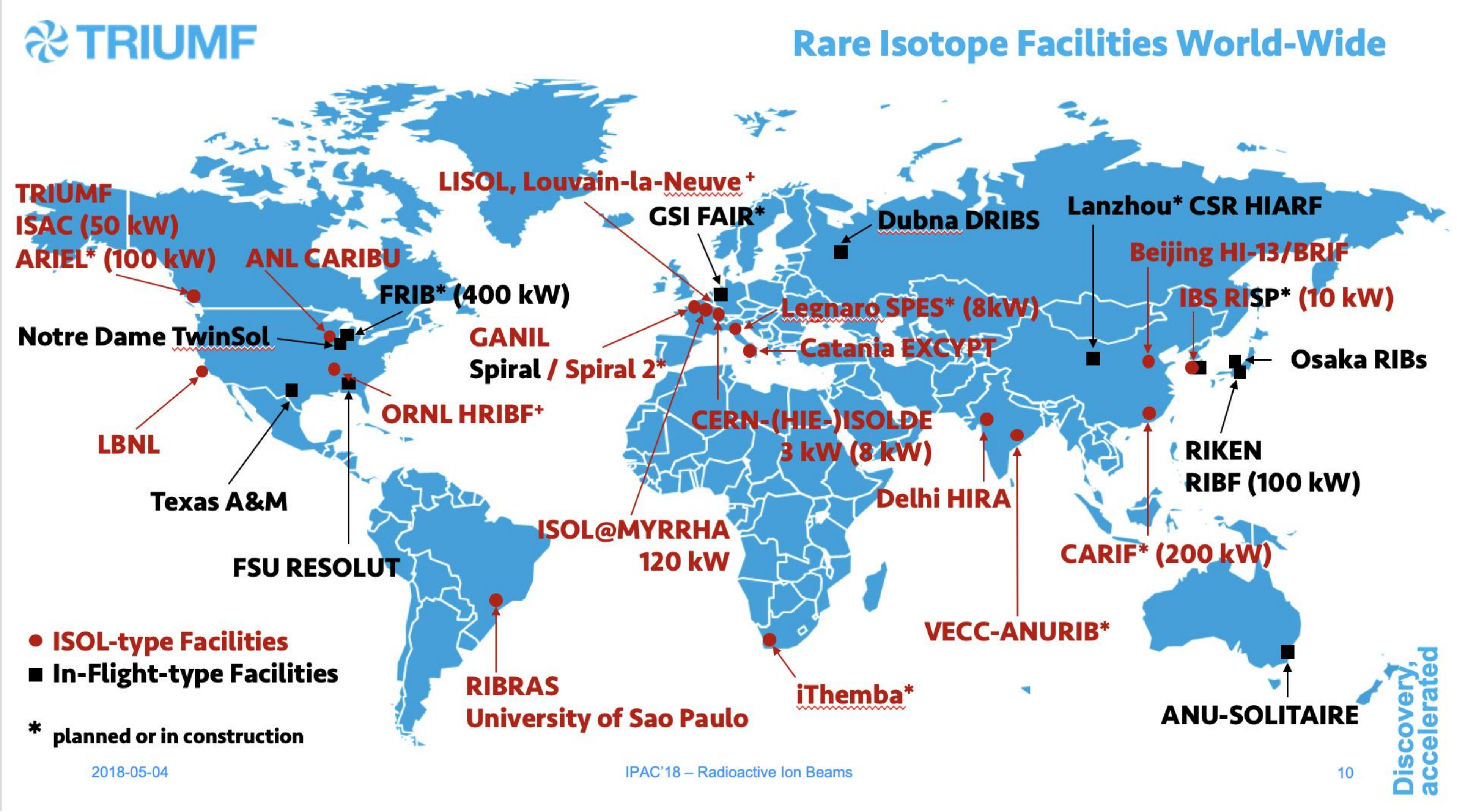
Put the desired beam particles into the source and extract them

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

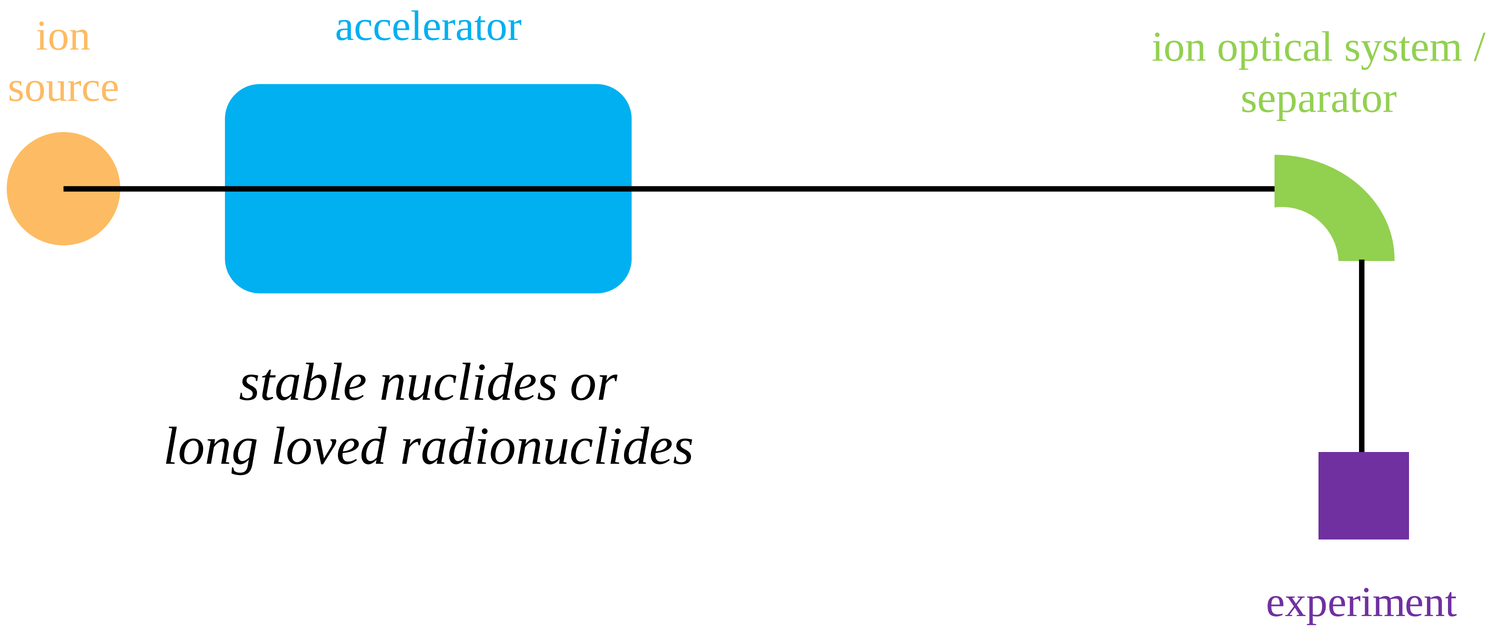
Secondary Beams at FAIR:

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

“Tertiary” Beams:

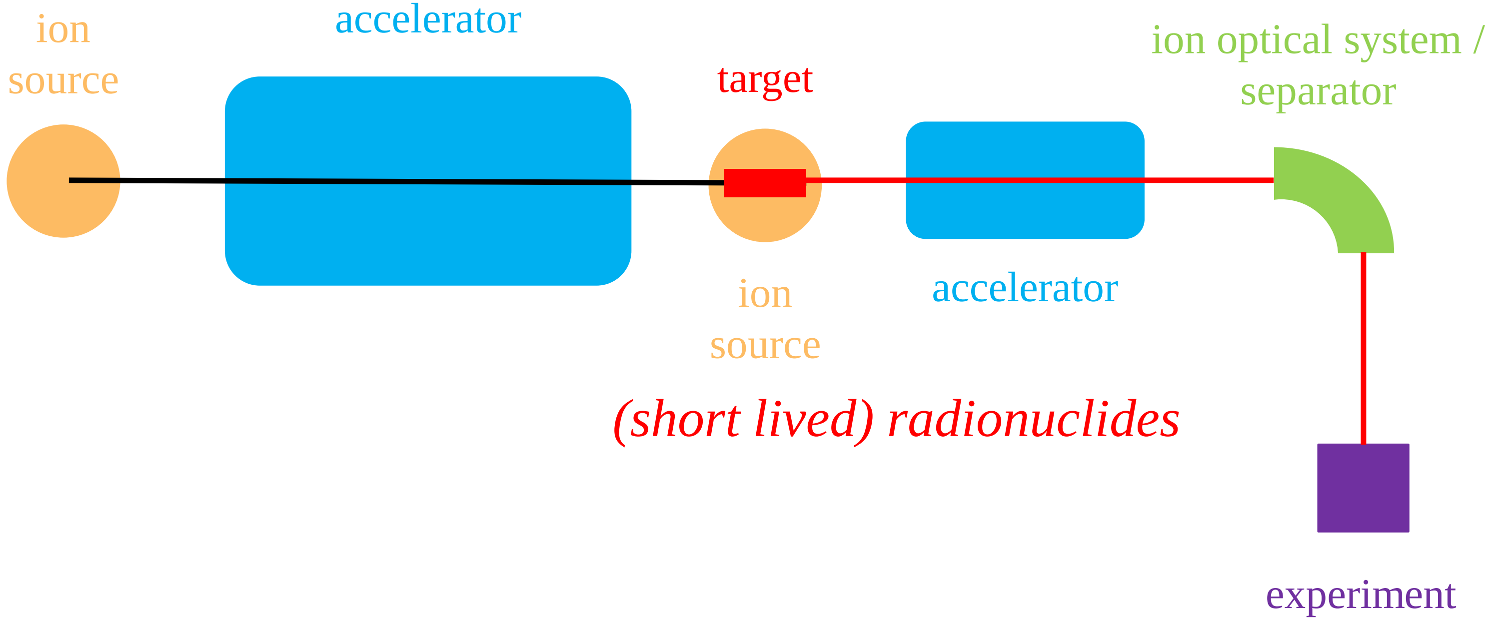
Muon Beams
Neutrino Beams (CNGS, NuMi...)

Primary / Secondary Beams



stable nuclides or
long loved radionuclides

Primary / Secondary Beams (ISOL)



ISOL Method

N_{target}

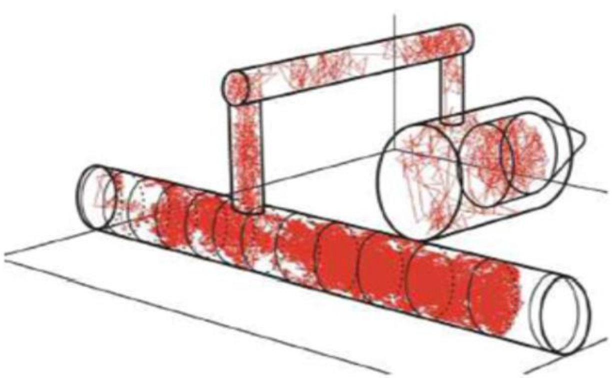
Projectile → Target → Source → Spectrometer → Post Accelerator

Production	Diffusion	Effusion	Ionisation	Selection	Acceleration
I_{beam}, σ_{prod}	$\varepsilon_{diff+eff}$		ε_{ion}	ε_{sep}	ε_{acc}

3.6 10^{12} pps $^{36}Ar^{18+}$ → 590 pps $^{32}Ar^{7+}$ → 176 pps $^{32}Ar^{7+}$

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

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



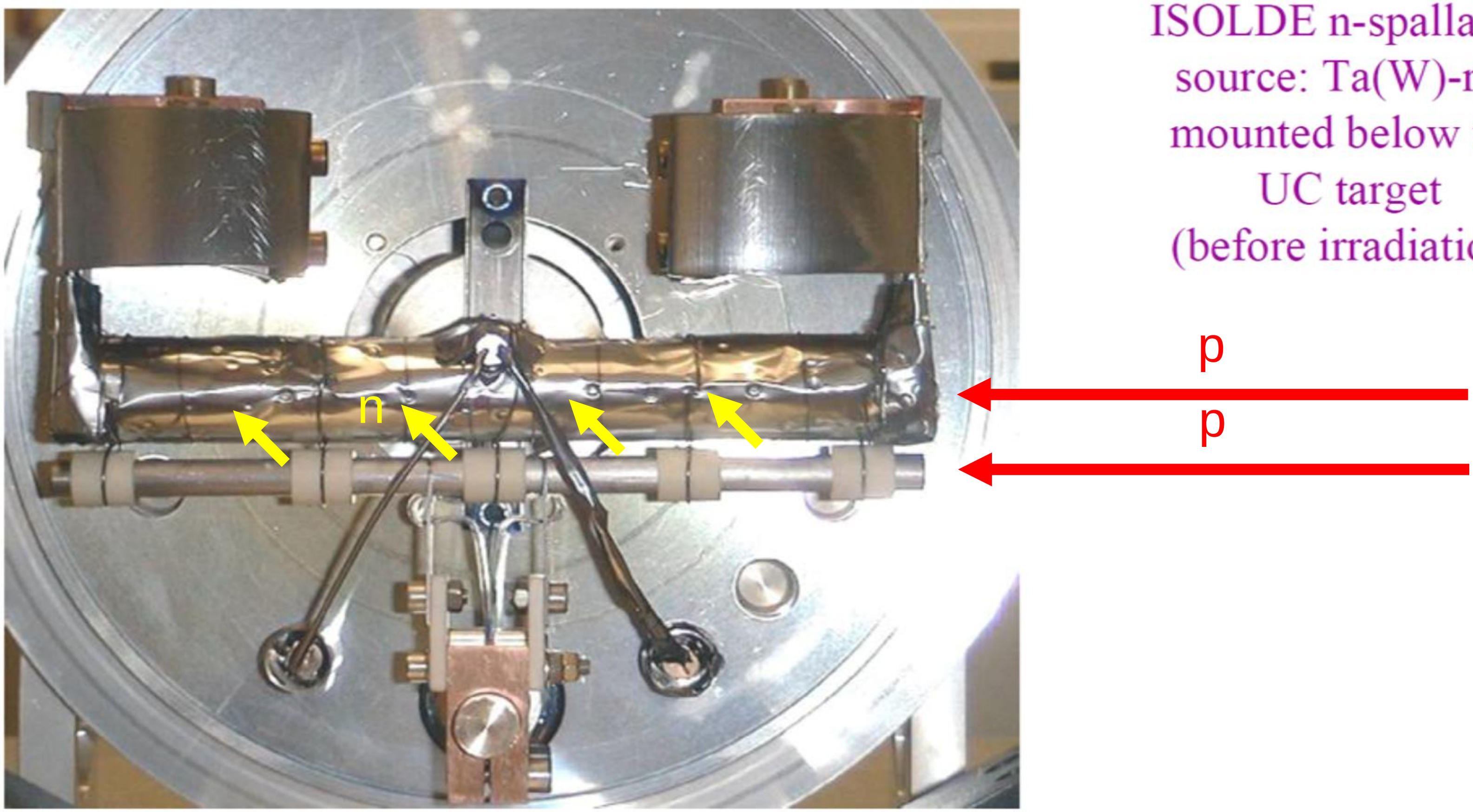
Path of an atom travelling out of a foil target to the ion source (RIBO code, (Santana-Leitner, 2005))

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

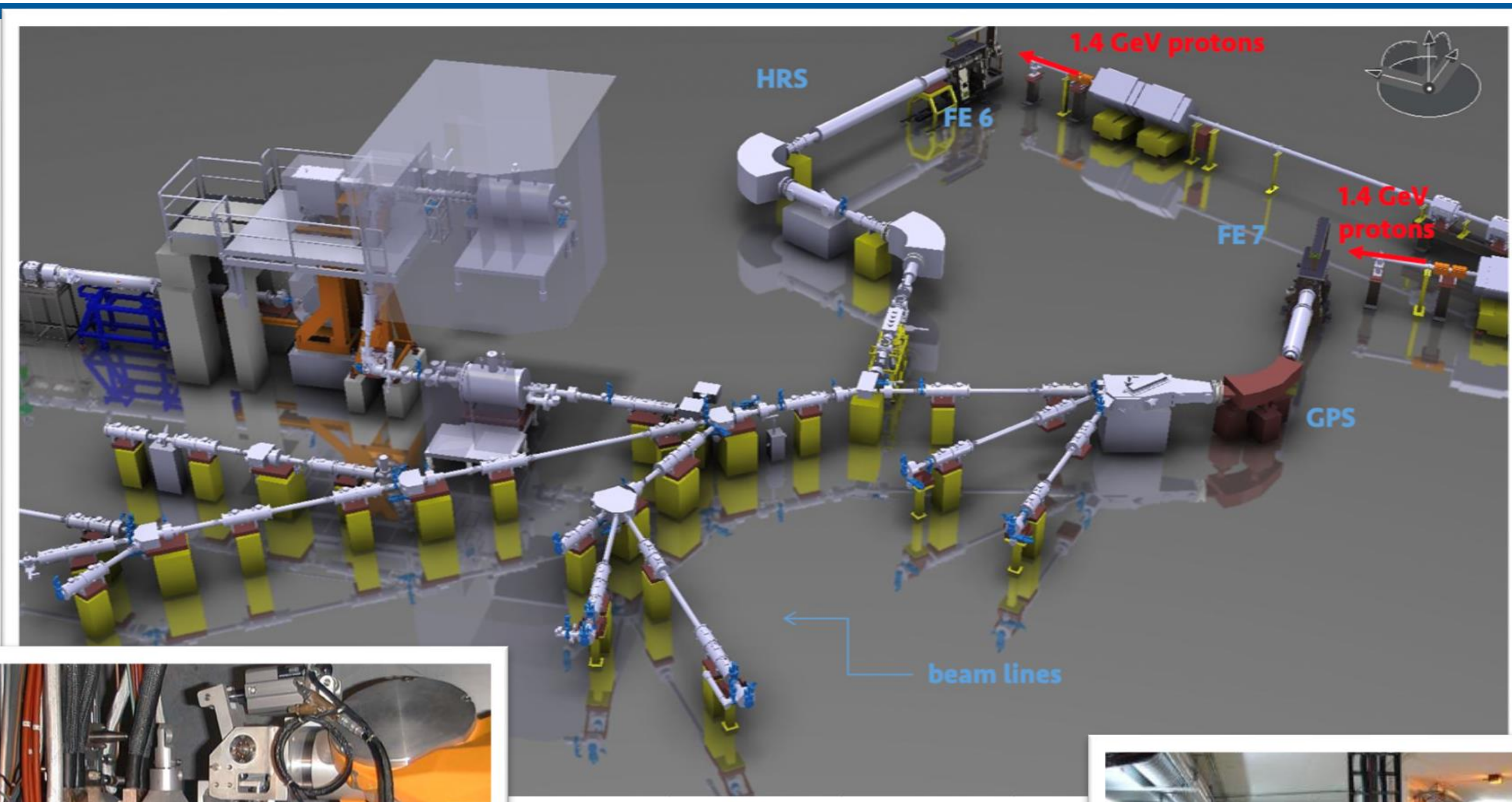
ISOLDE (CERN)

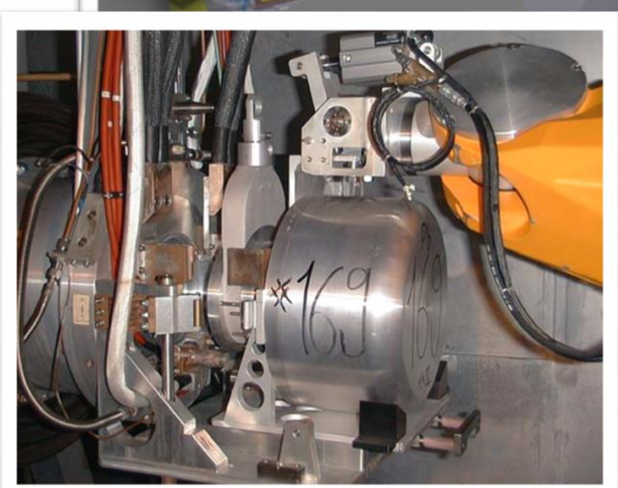


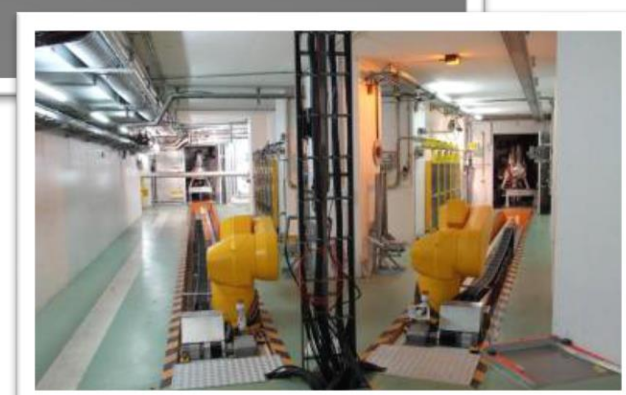
ISOLDE n-spallation source: Ta(W)-rod mounted below the UC target (before irradiation)

T. Stora

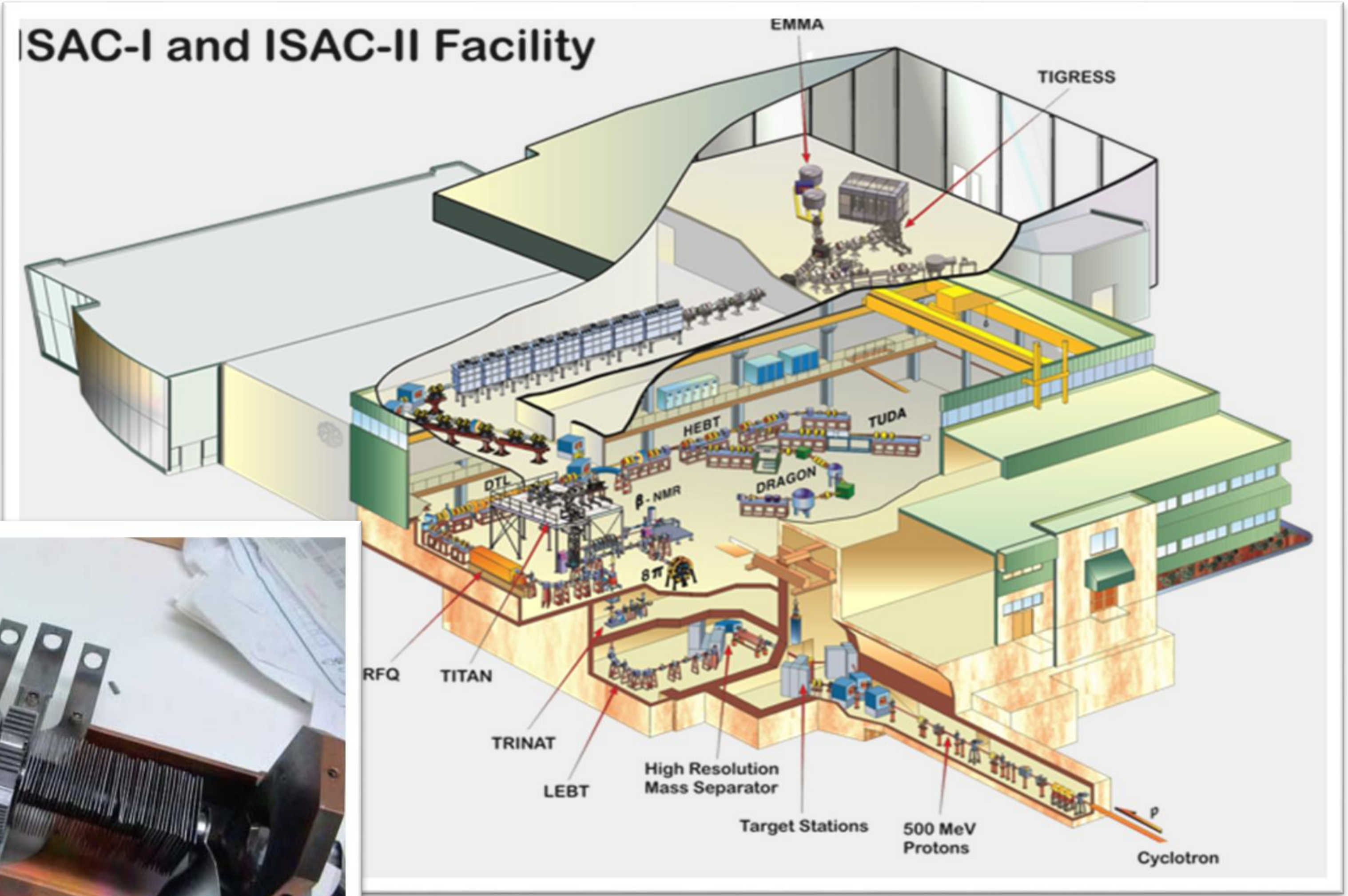
ISOLDE (CERN)





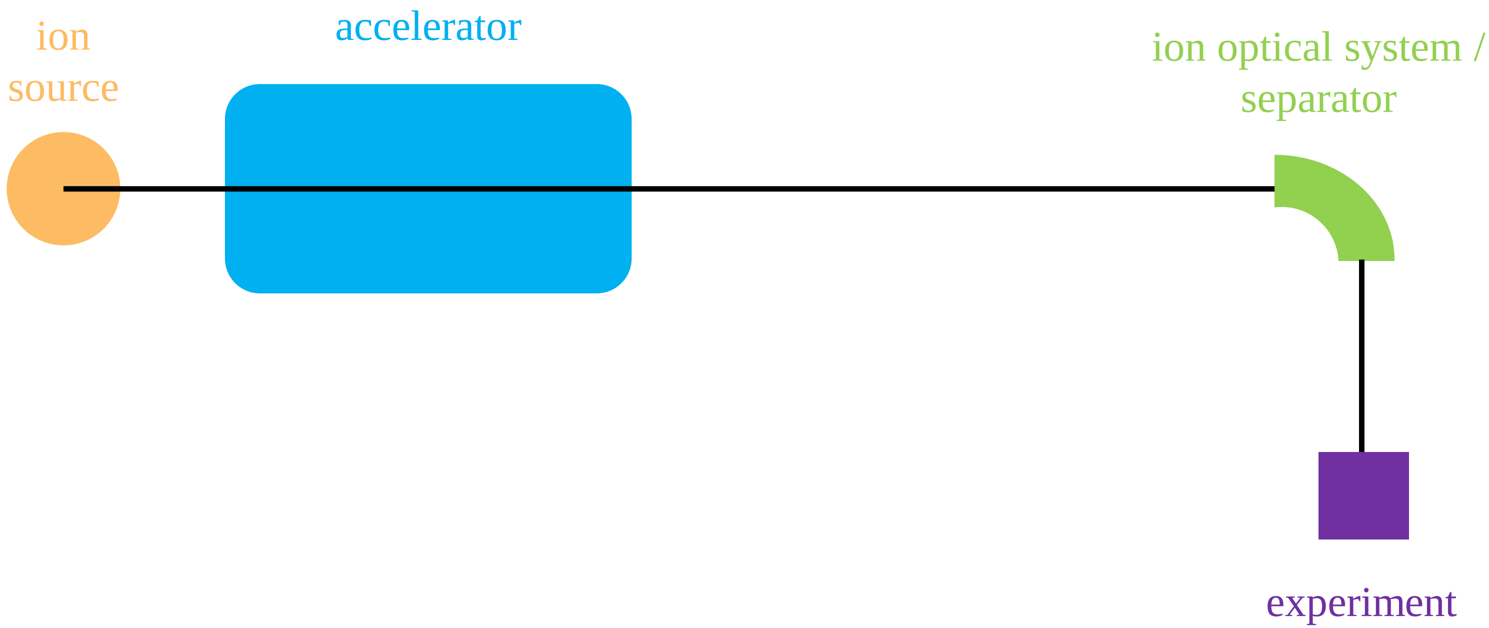


ISAC (TRIUMF)


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
p
Cyclotron

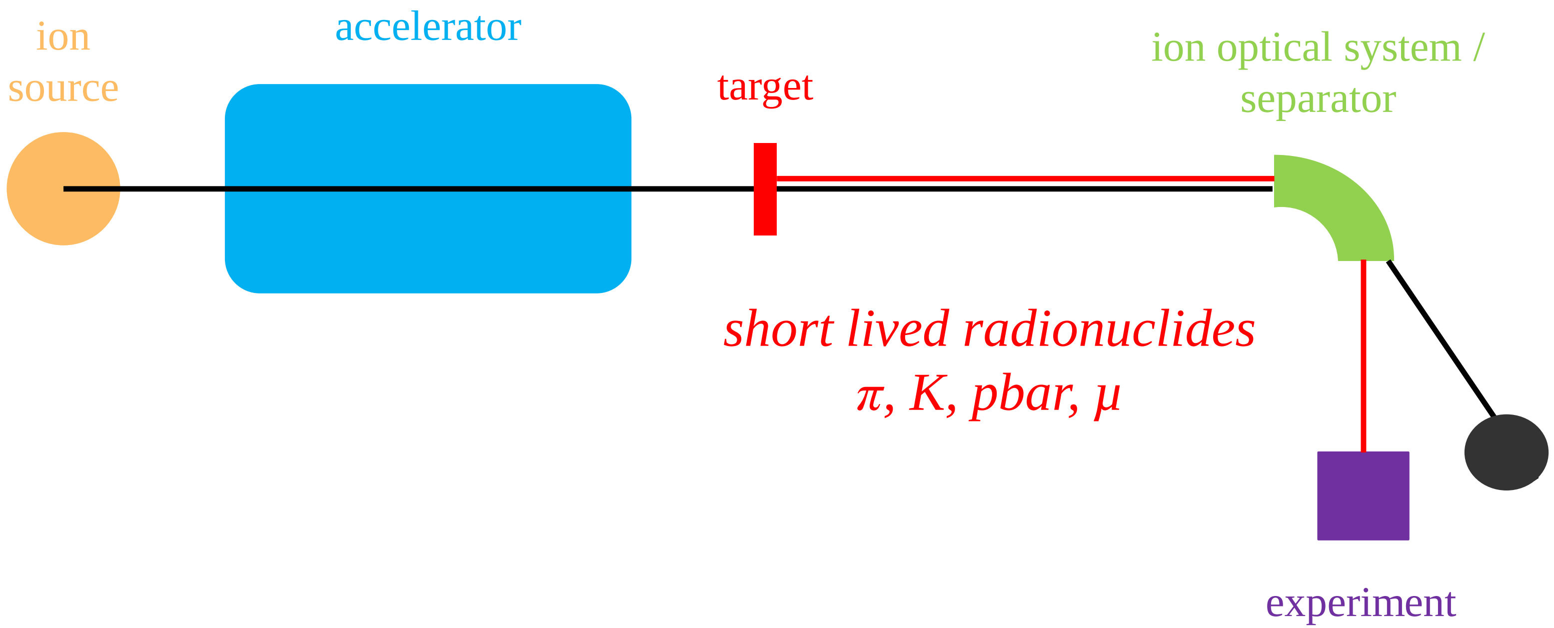

50 kW primary beam power!

Primary / Secondary Beams



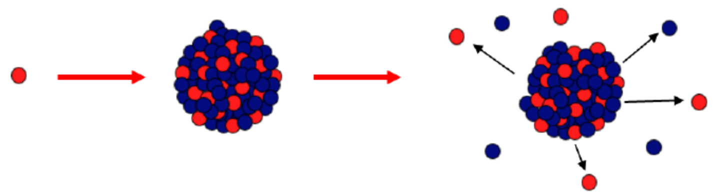
13

Primary / Secondary Beams: In-Flight

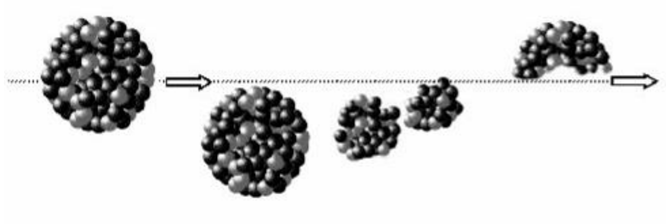


Production Mechanism

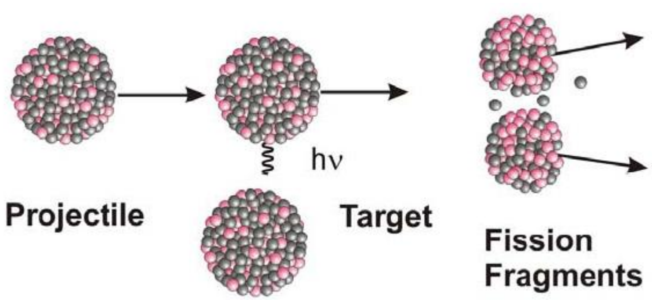
Spallation (ISOL only):
few nucleons lighter than target

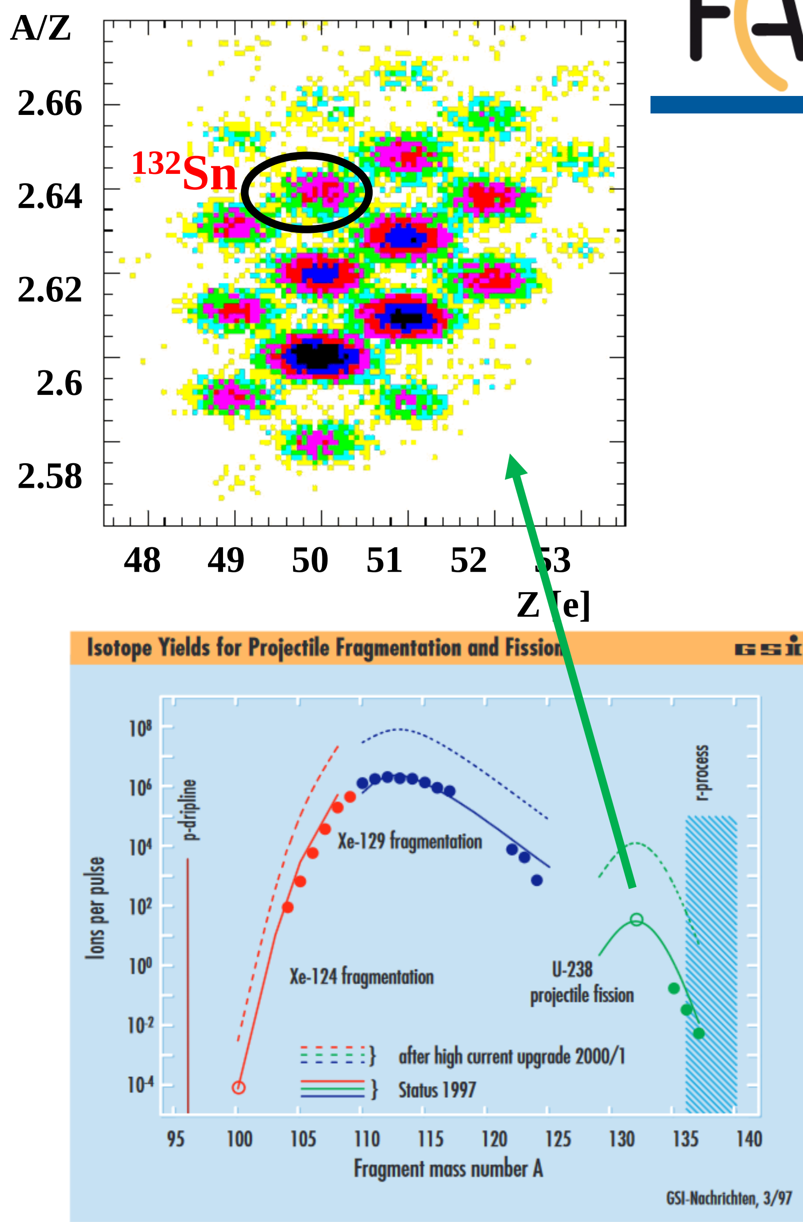


Projectile fragmentation:
neutron deficient (evaporation of neutron after collision)

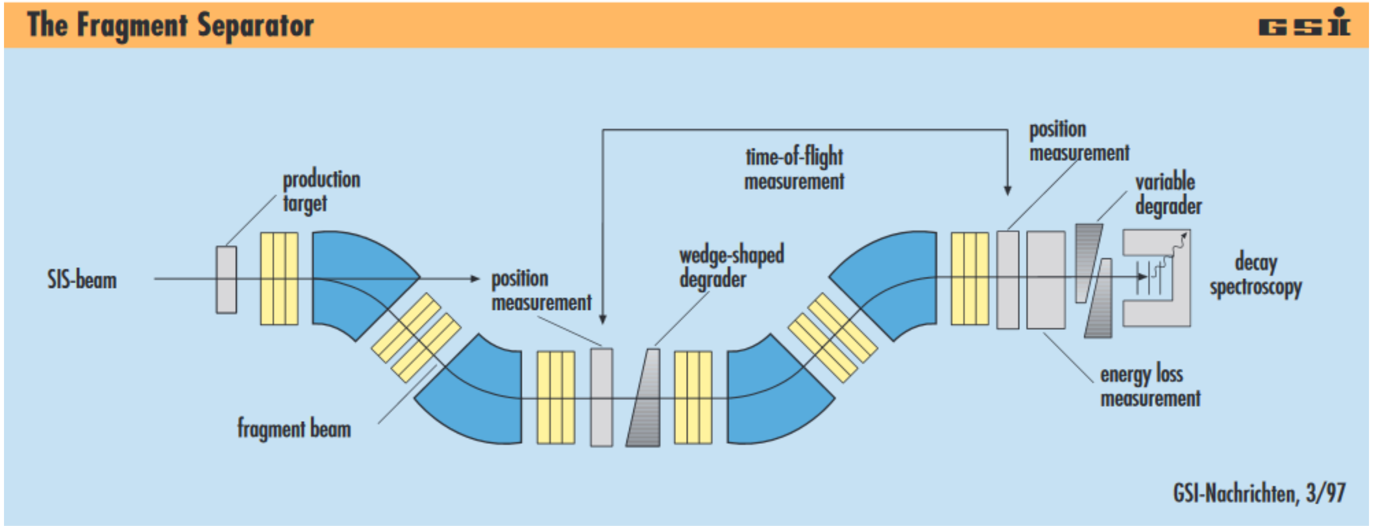


Projectile fission:
neutron rich (N/Z similar heavy projectile)





Fragment Separators (in-Flight)

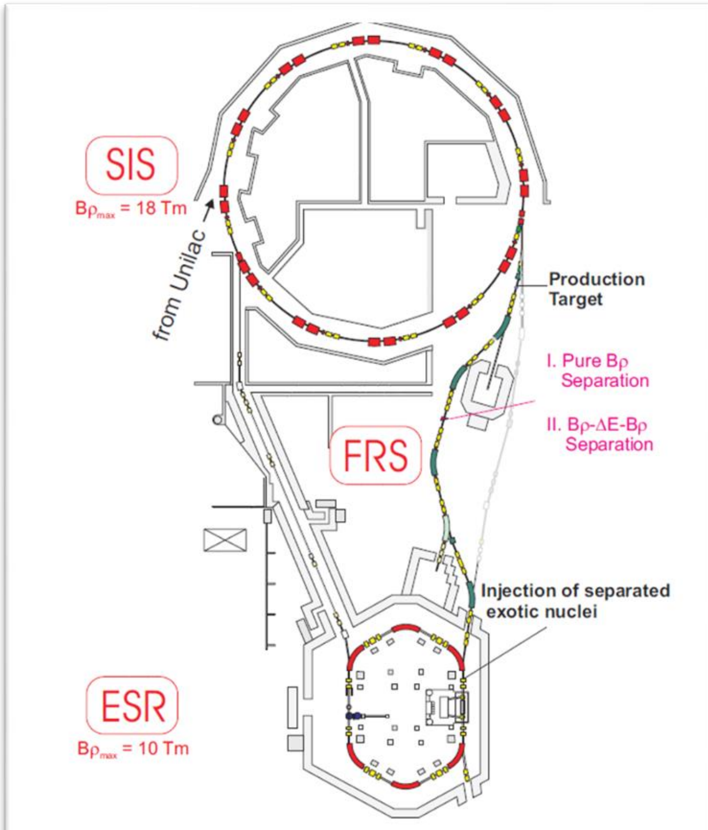


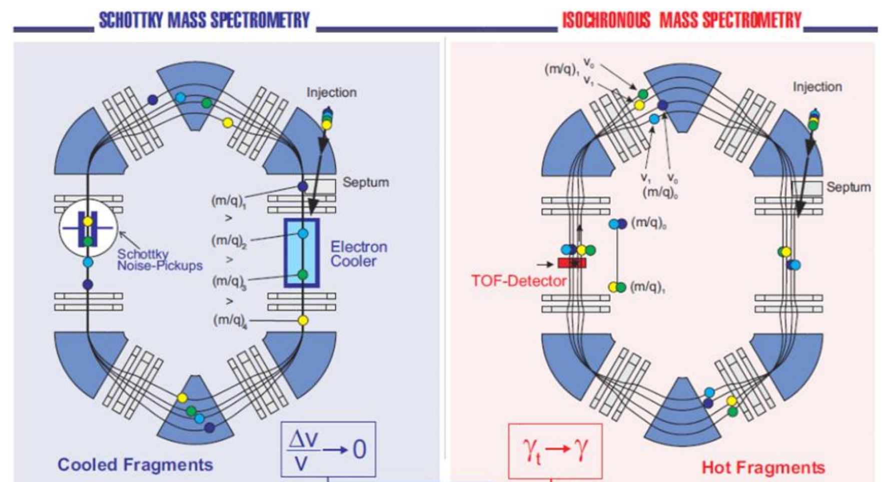
$B \cdot \rho = p/(q \cdot e) \approx (2\mathbf{E} \cdot \mathbf{m})^{1/2}/(\mathbf{q} \cdot \mathbf{e})$

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

Degrader: dE/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)

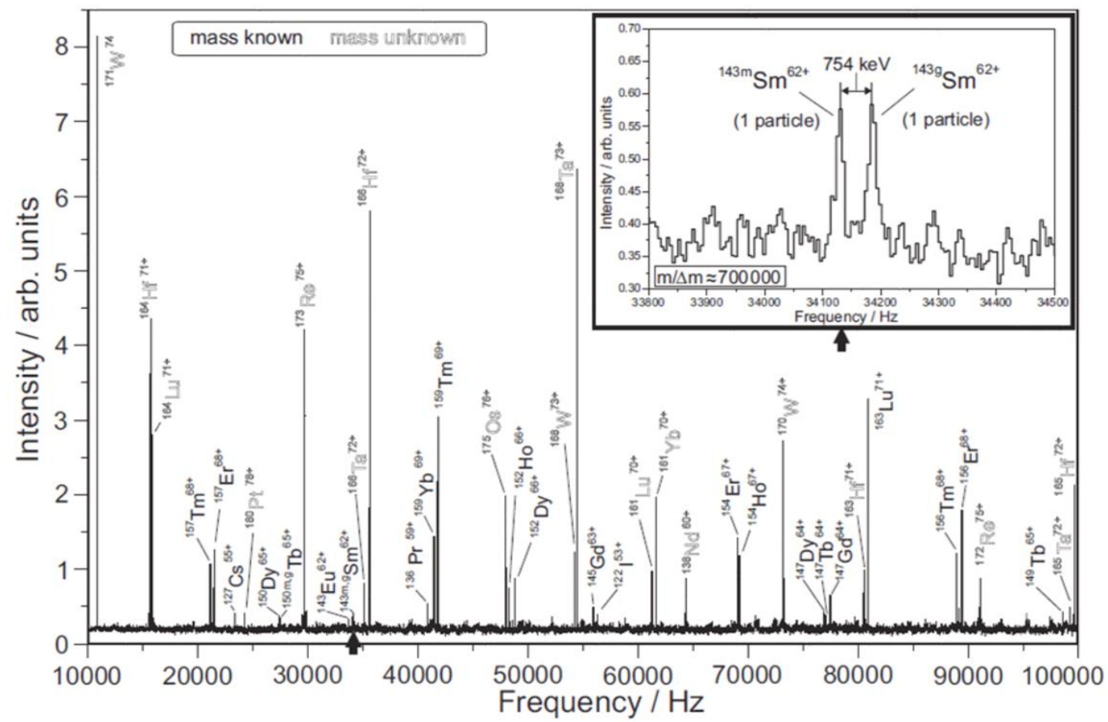
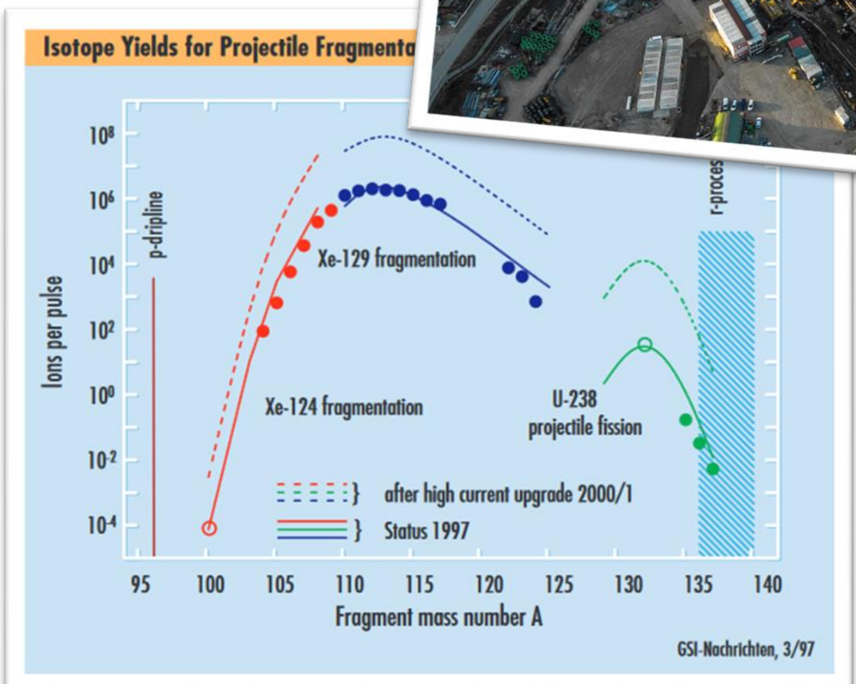


Fig. 9. Schottky spectrum of fragments from a primary ^{209}Bi beam, stored and electron-cooled in the ESR. The main spectrum shows the difference between the 30th harmonic of the revolution frequencies of the many stored ion species and of a local oscillator operating at about 60 MHz. It covers roughly 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)

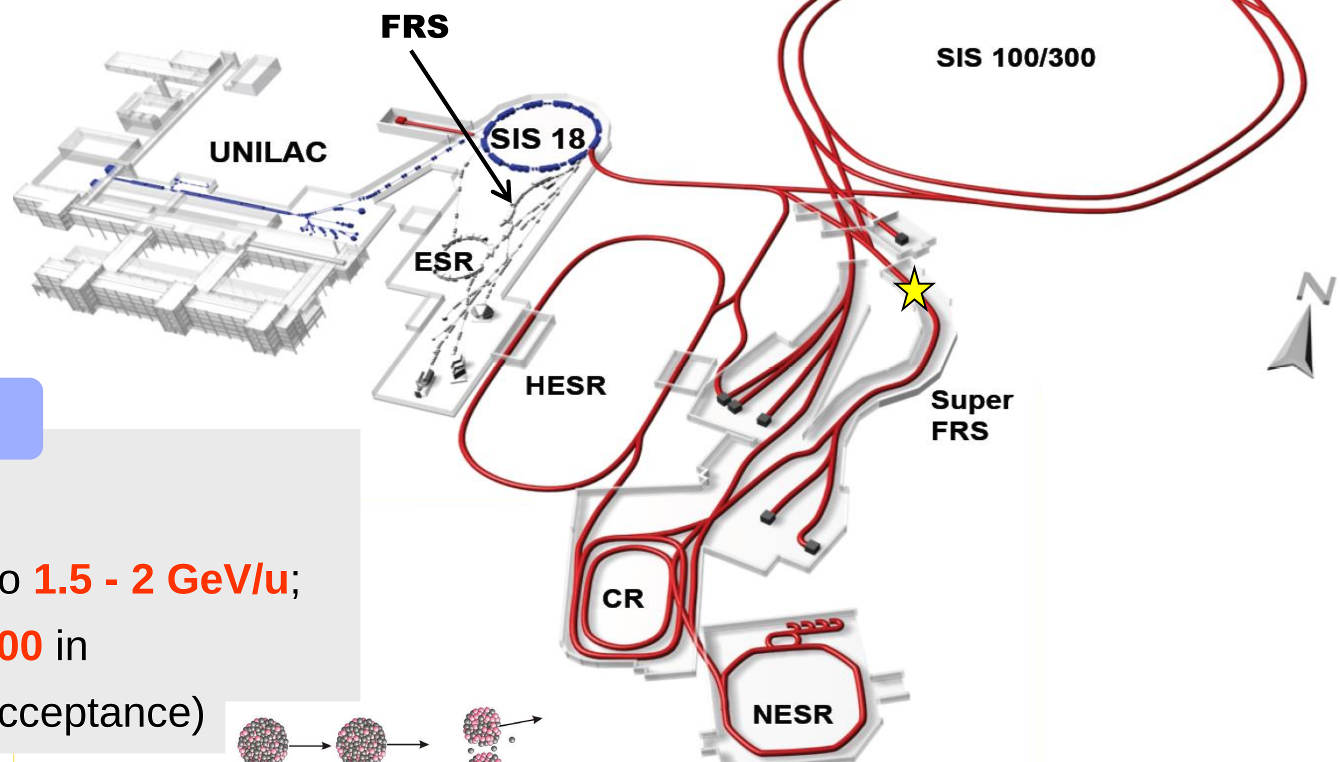
The Super Fra



SuperFRS @ FAIR

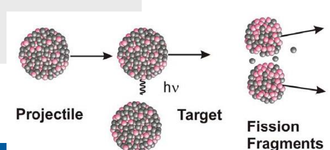
Primary Beams

- 3 x10^{11}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- **Factor > 100**
  over present in intensity (space charge!)

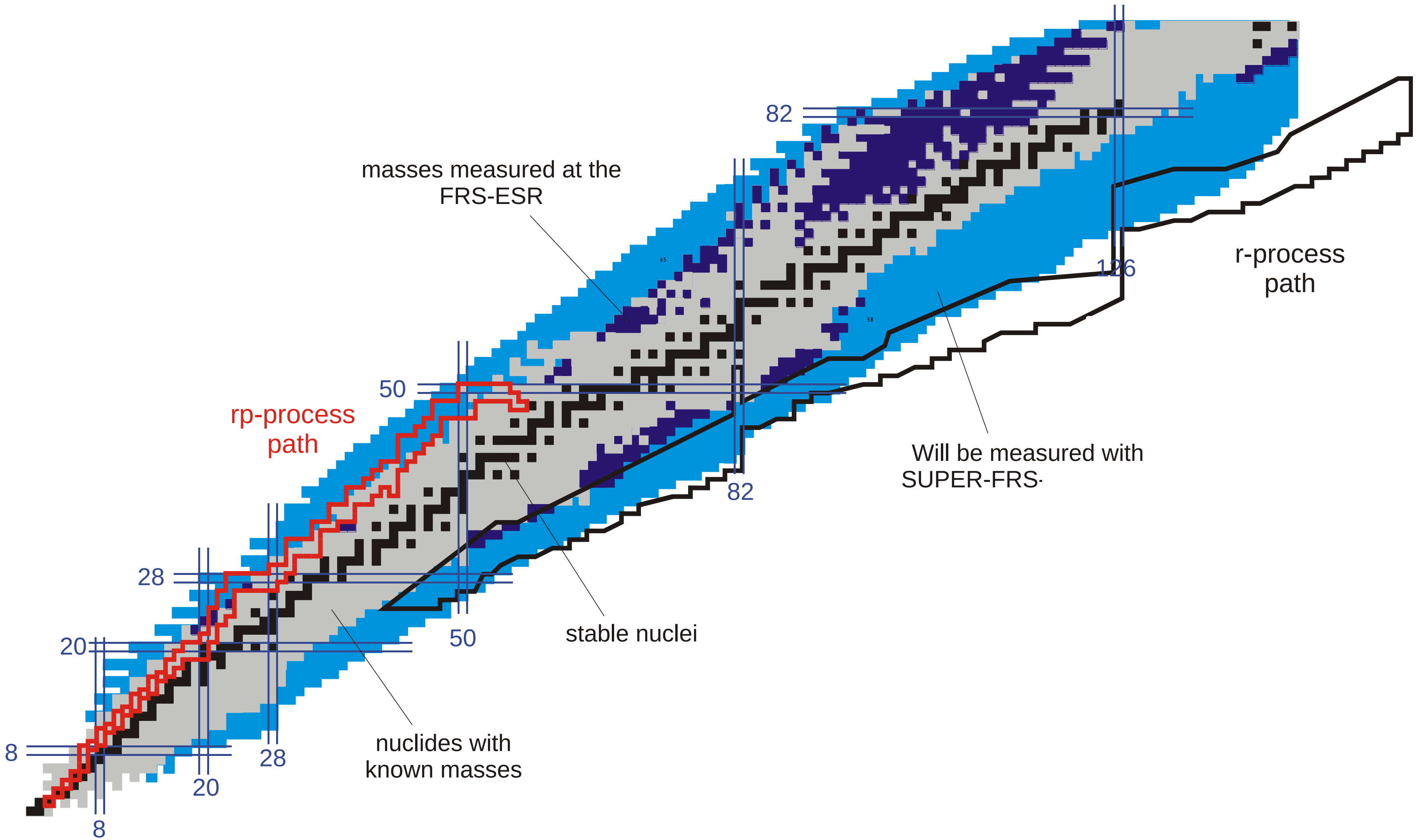


Rare Isotope Beams

- Broad range of
  radioactive beams up to **1.5 - 2 GeV/u**;
  up to factor **1 000 - 10 000** in
  intensity over present (acceptance)

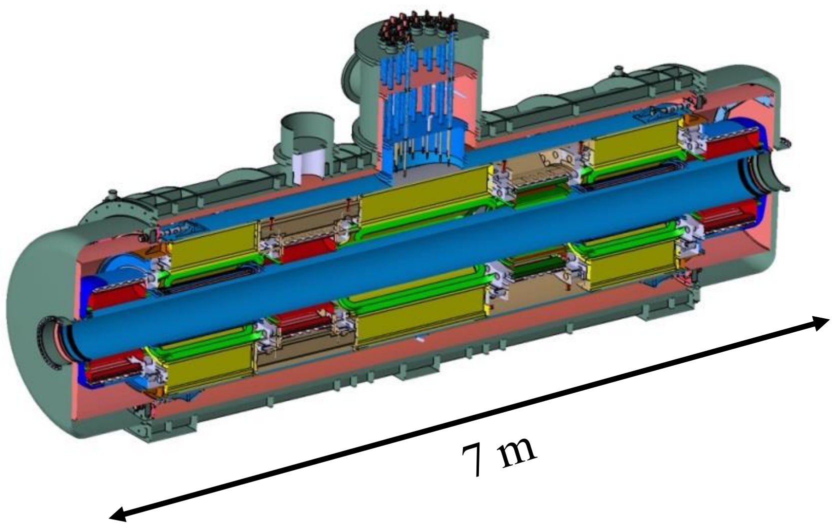


Phase 1 Physics with SuperFRS and rings:
Potential for new masses, lifetimes & isomers with ILIMA



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

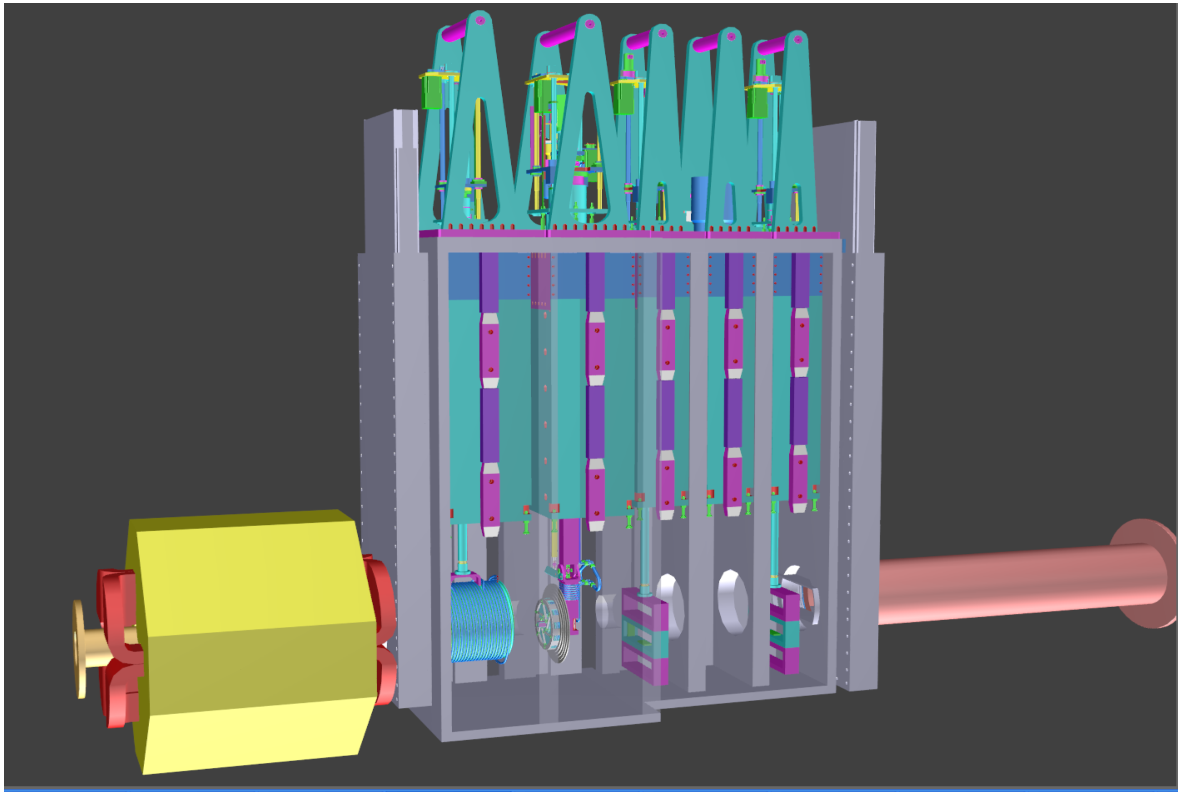
Superconducting Multiplets



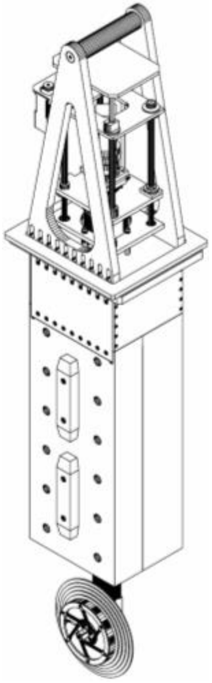
- 25 long multiplets (mainly MS)
- 8 short multiplets (PS)
- Quadrupol triplet / QS configuration
- up to 3 sextupoles and 1 steerer
- Octupole coils in short quadrupoles

- 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

SuperFRS at FAIR



Targetchamber



Target with shielding

Prototype

SuperFRS at FAIR

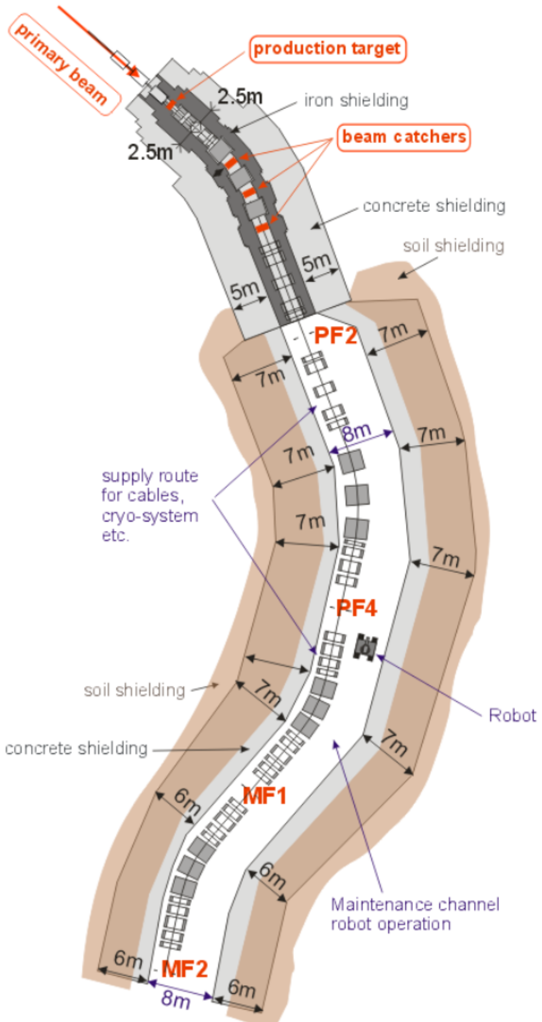


Figure 2.4-166: Schematic layout of the Super-FRS with beam line and shielding measures. The area from the target up to the intermediate focal plane PF2 of the Pre-Separator is shielded with iron in order to provide a compact radiation protection in the target building. The concrete in the Main-Separator can be partially replaced by soil taking into account an about 20% smaller absorption of the soil.

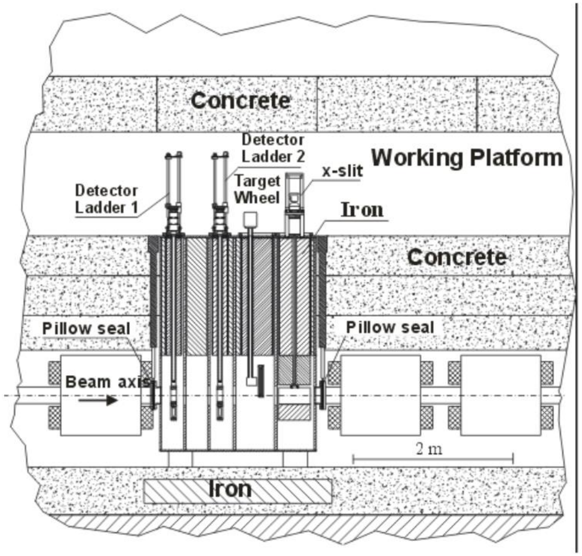


Figure 2.4-126: Schematic layout of the target area of the Super-FRS. A vertical plug system has been adapted which has proven to guarantee a safe and reliable operation at PSI in a very high radiation field. Routine maintenance at PSI is done about once per year.

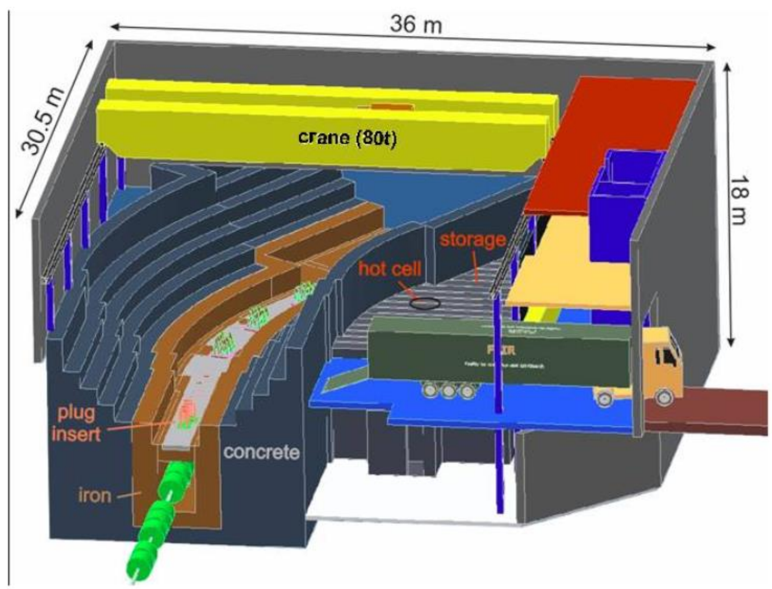
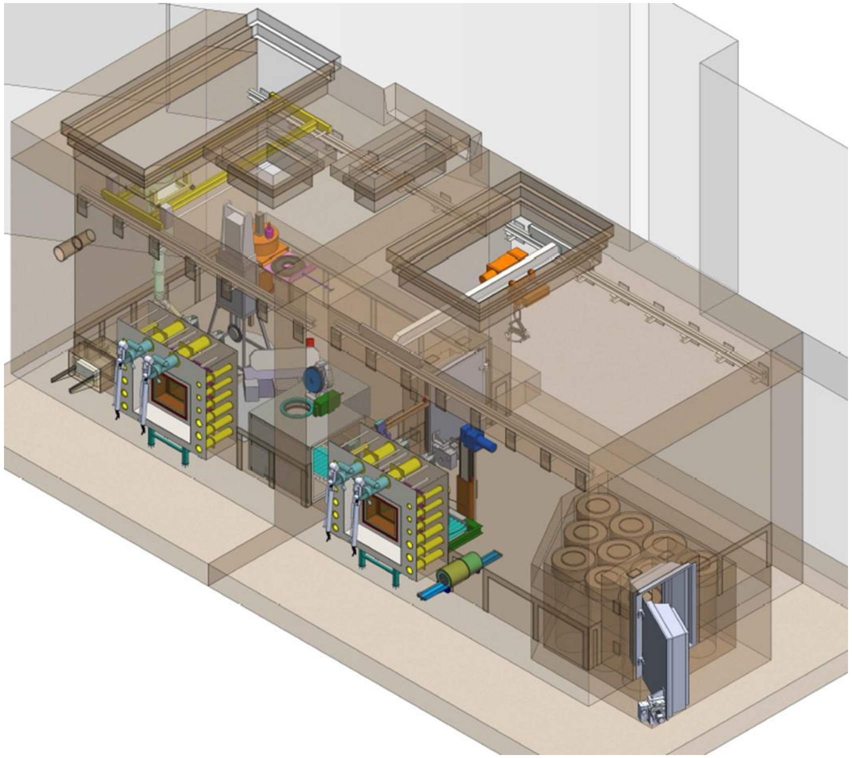


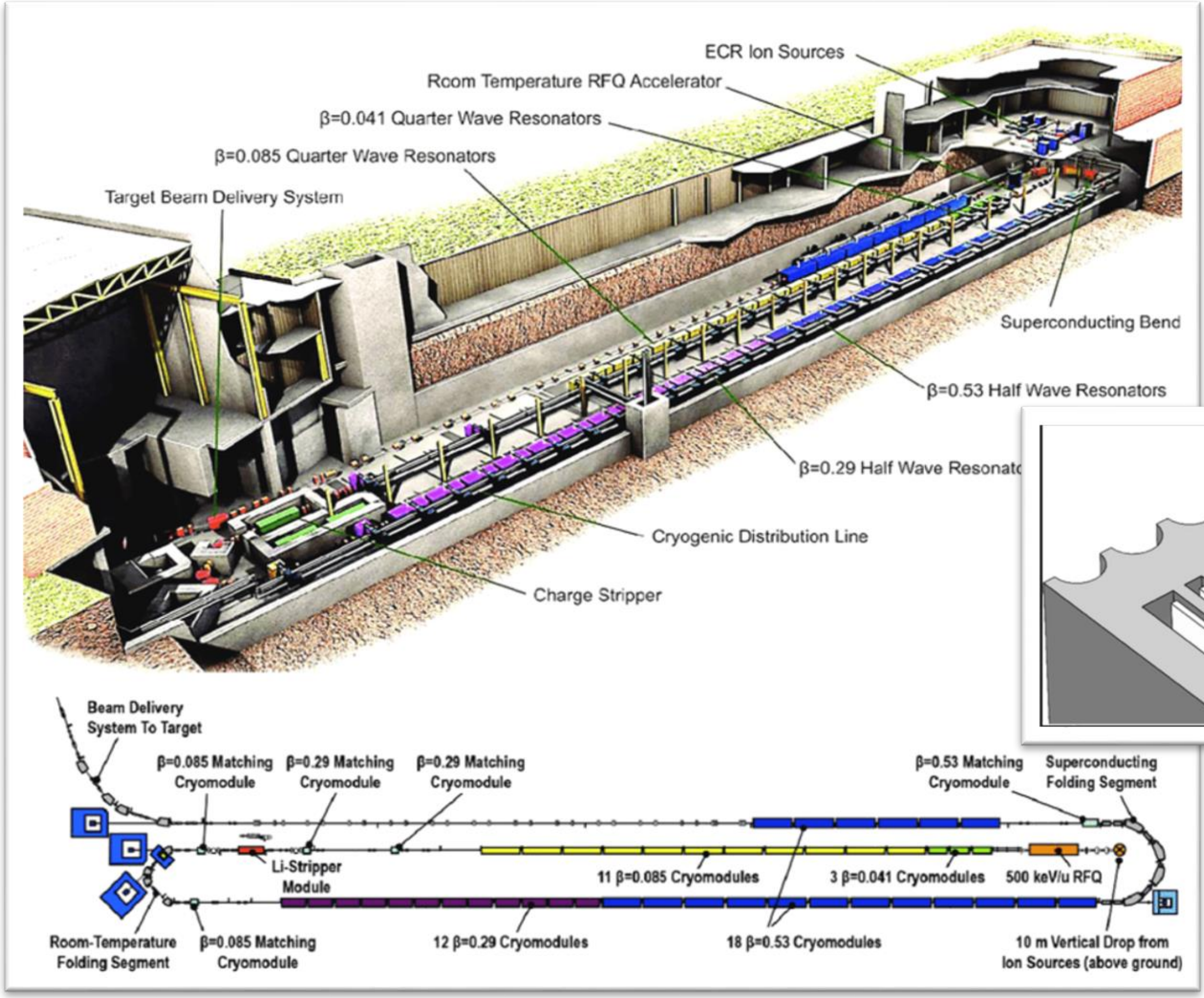
Figure 2.4-175: Layout of the Super-FRS target building. The top part of the concrete shielding can be removed to access the working platform. Heavy devices can be transported by crane to the nearby hot cell, storage places or directly onto a truck which can drive into the hall.

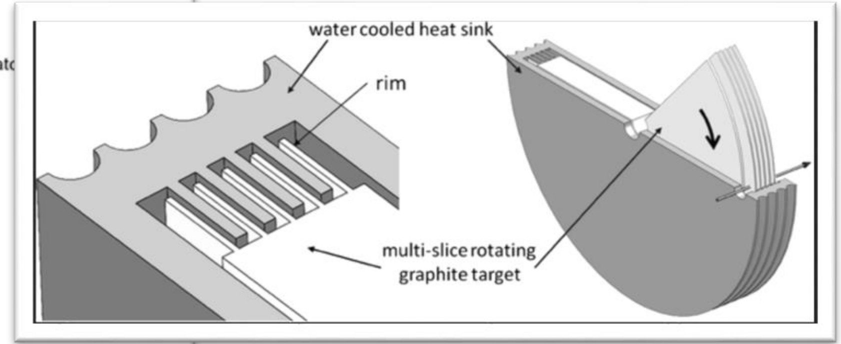
SuperFRS at FAIR

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.

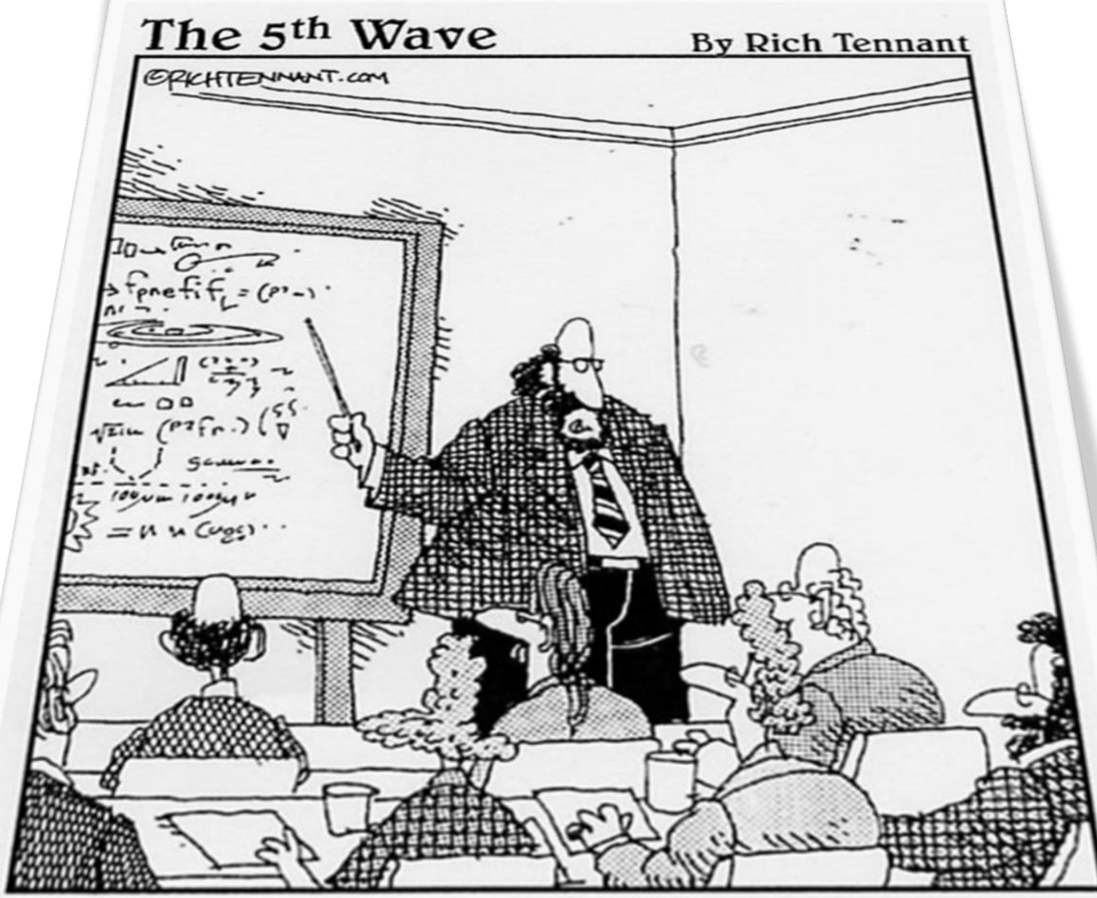


FRIB (MSU)


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
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)

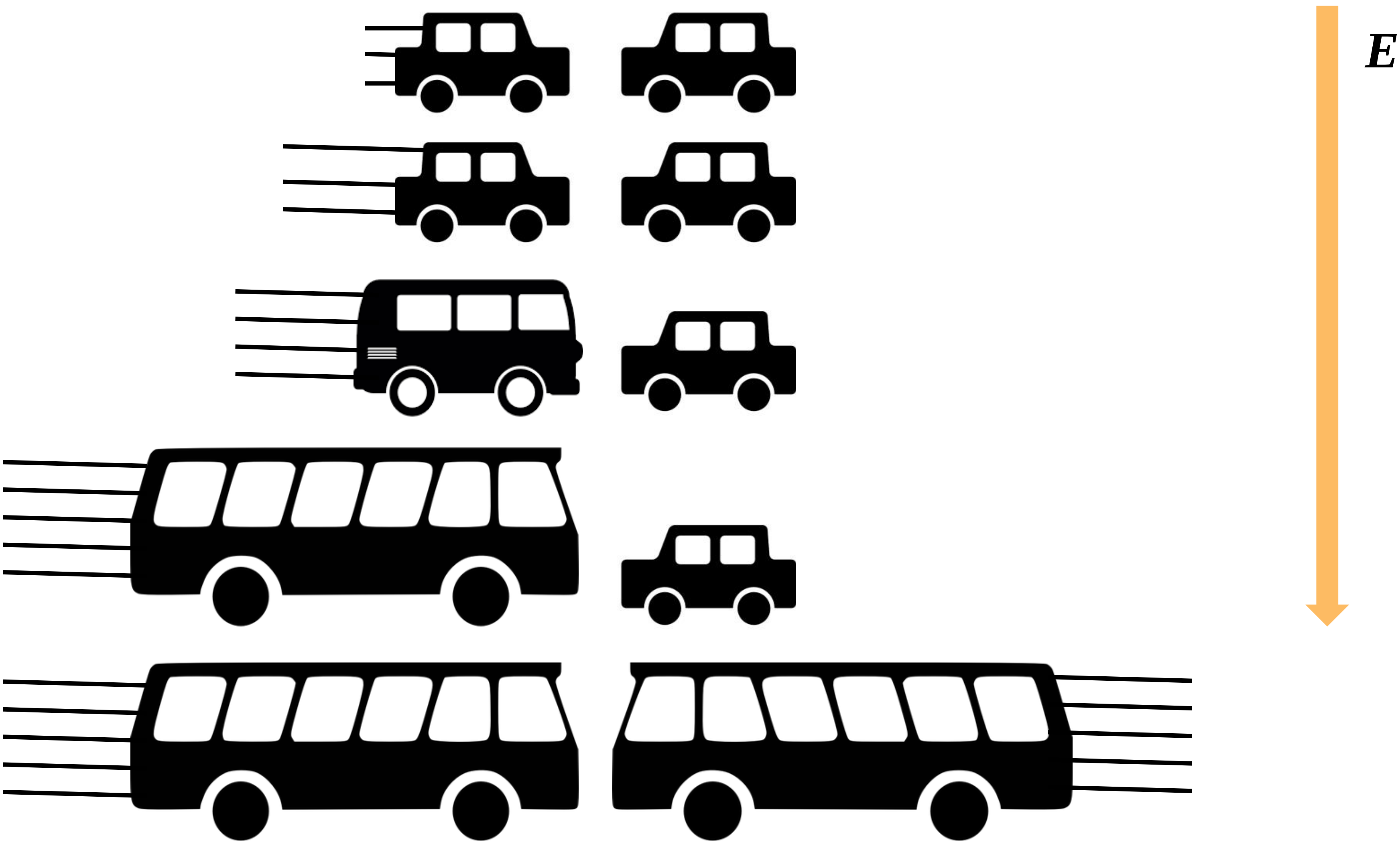

water cooled heat sink
rim
multi-slice rotating graphite target

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).

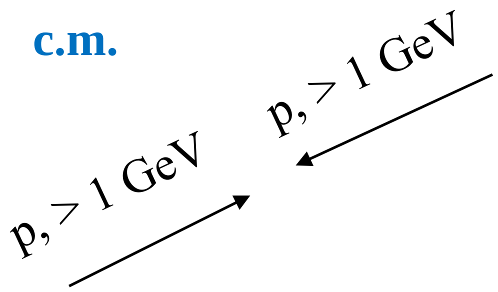
Detection of the top quark at Fermilab (1995)
Nobel Prize 2008 to Makoto Kobayashi (left) and Toshihide Maskawa (right) for its prediction.

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

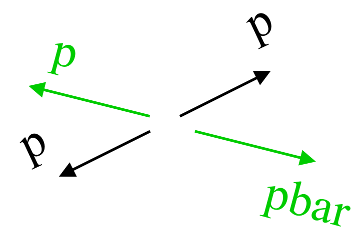
Creation of Antiprotons

c.m.

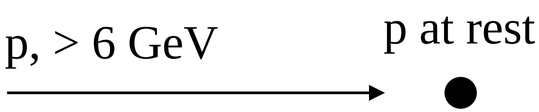


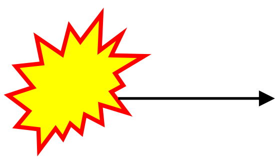
$m = E / c^2$

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



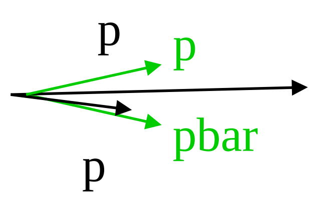
lab



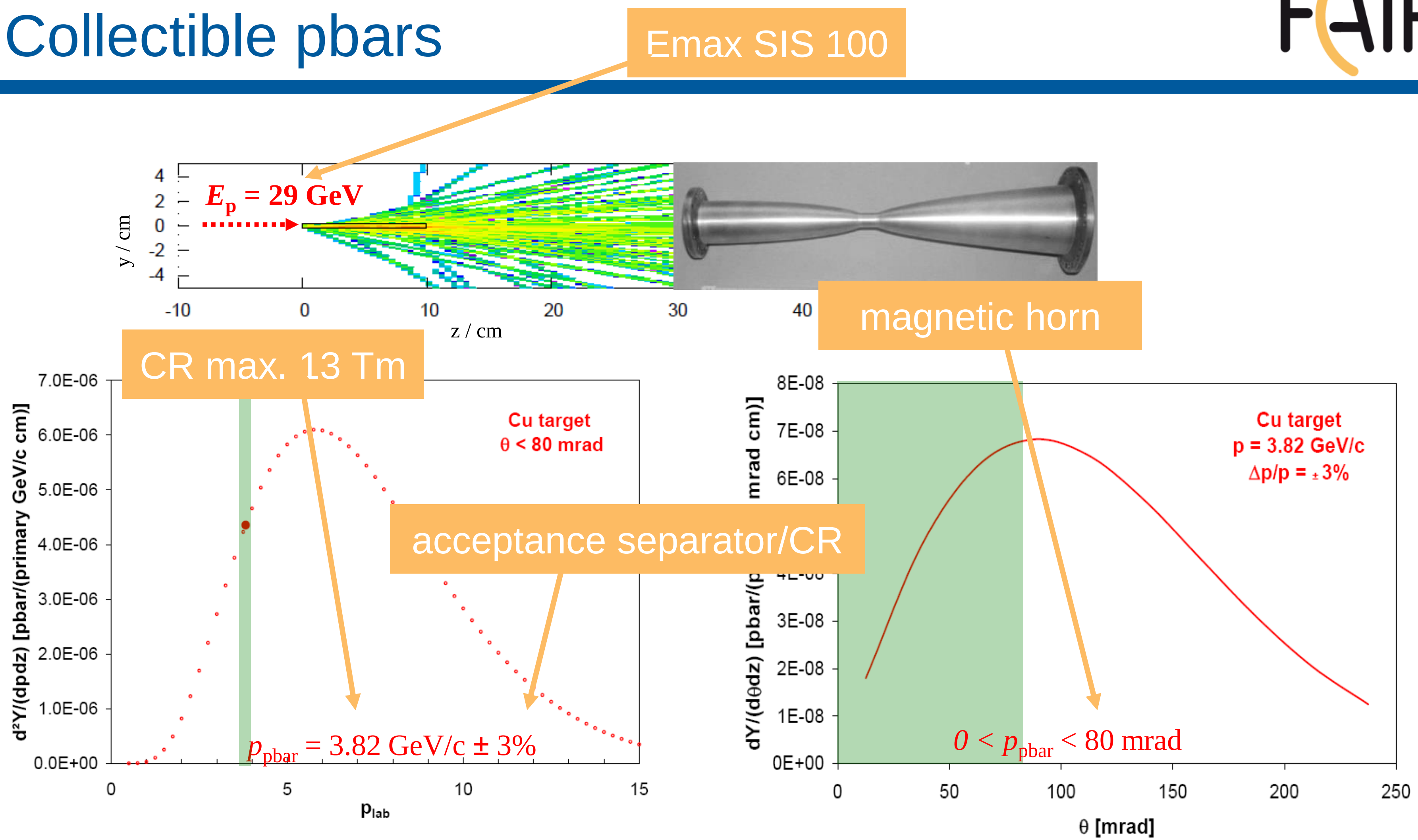


$m = E / c^2$

$T_{pbar} > 6$ GeV

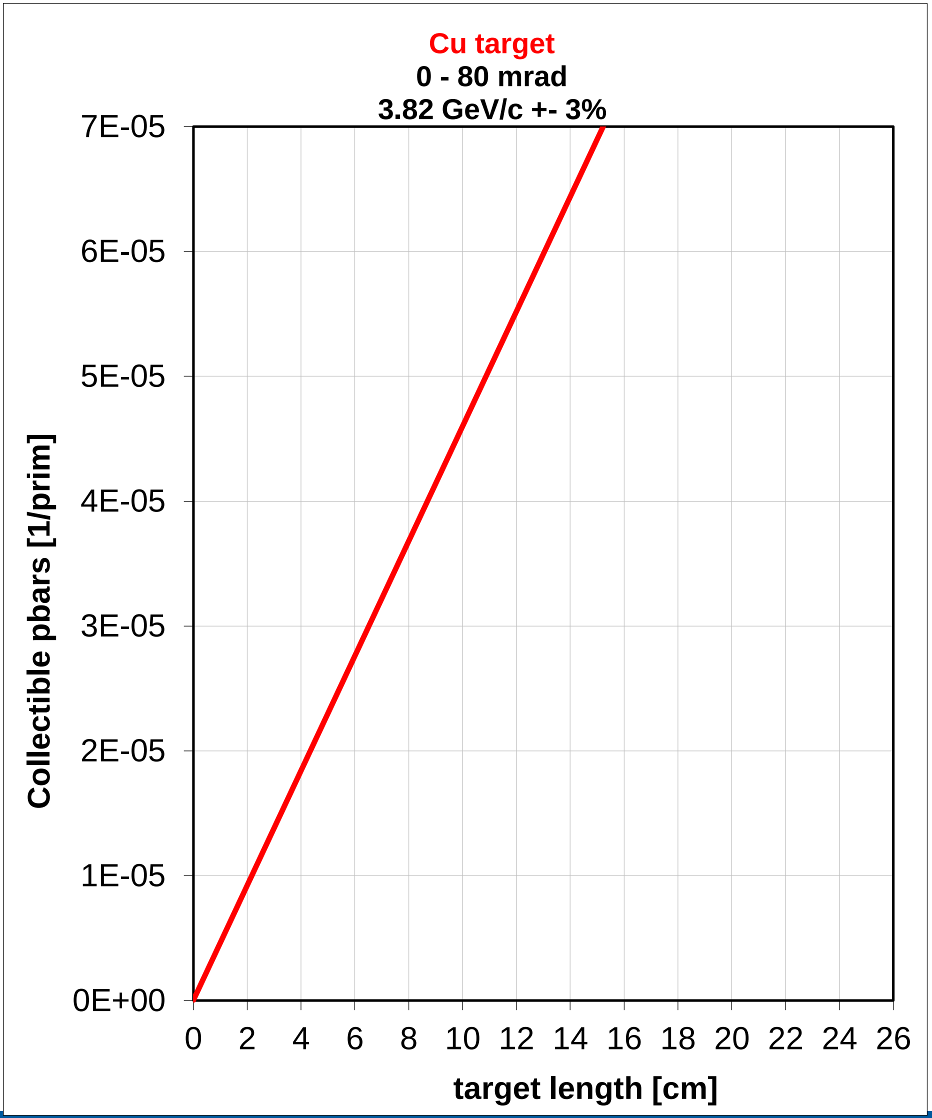


Collectible pbars

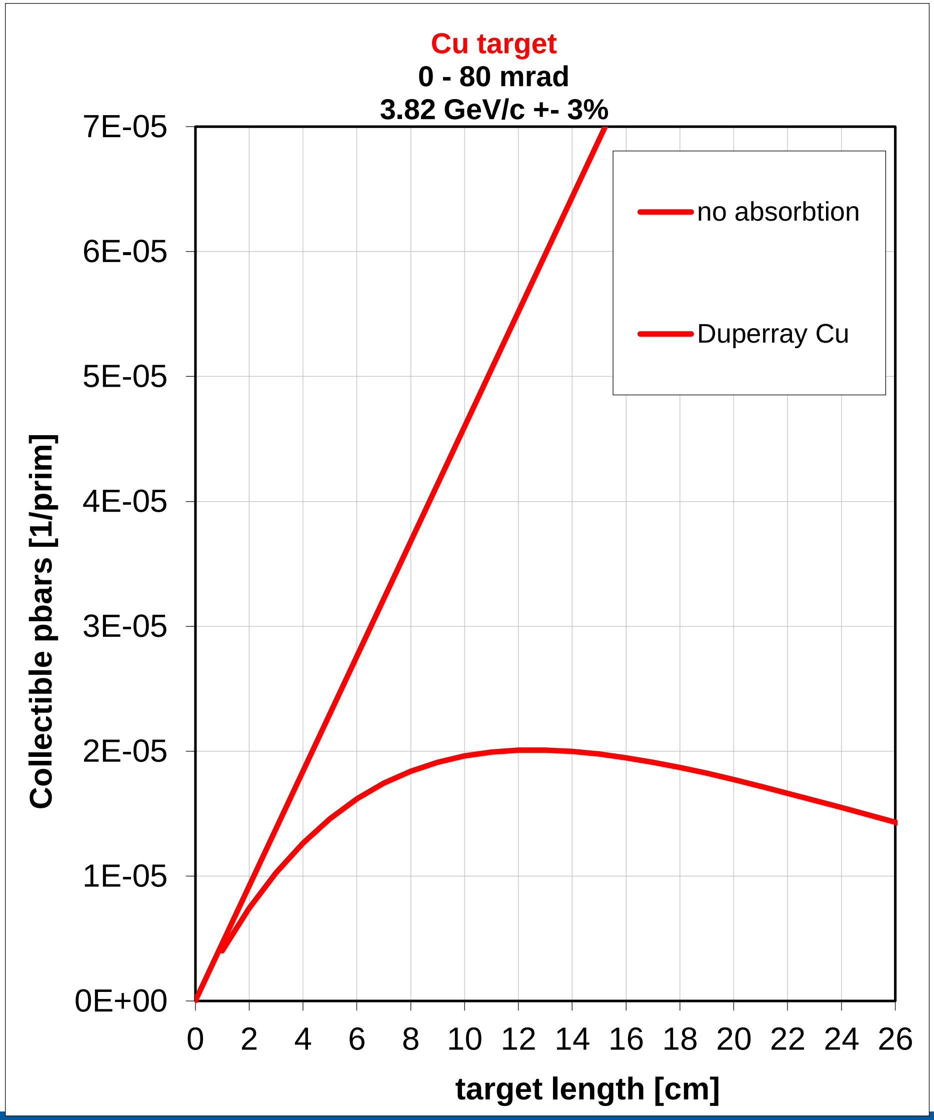


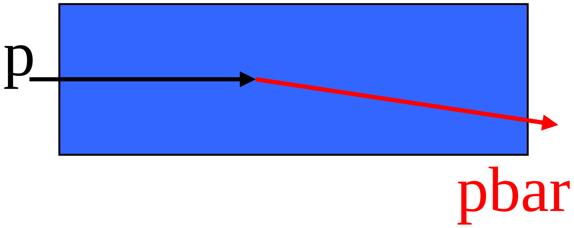
From ~ 2.5 × 10^{-4} pbar / (p cm target) ~ 5 × 10^{-6} (or 2 %) are "collectible"

Collectible pbars



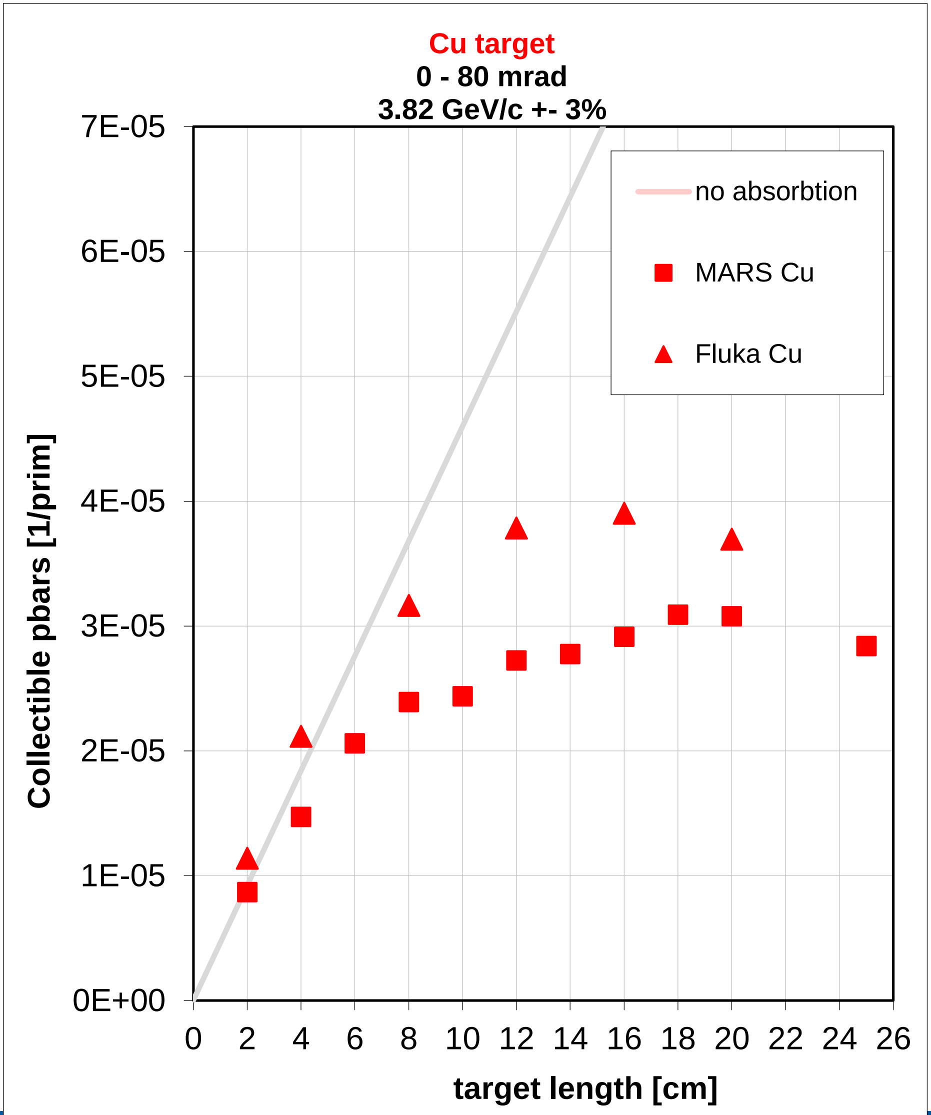
Collectible pbars: Self Absorption

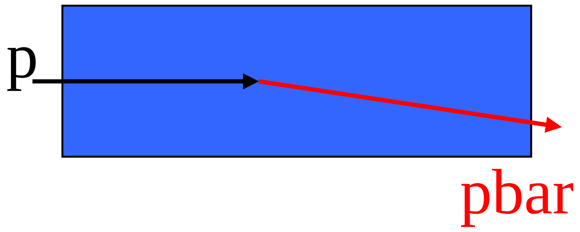




Cu: σ_{pbar} = 8.8 b

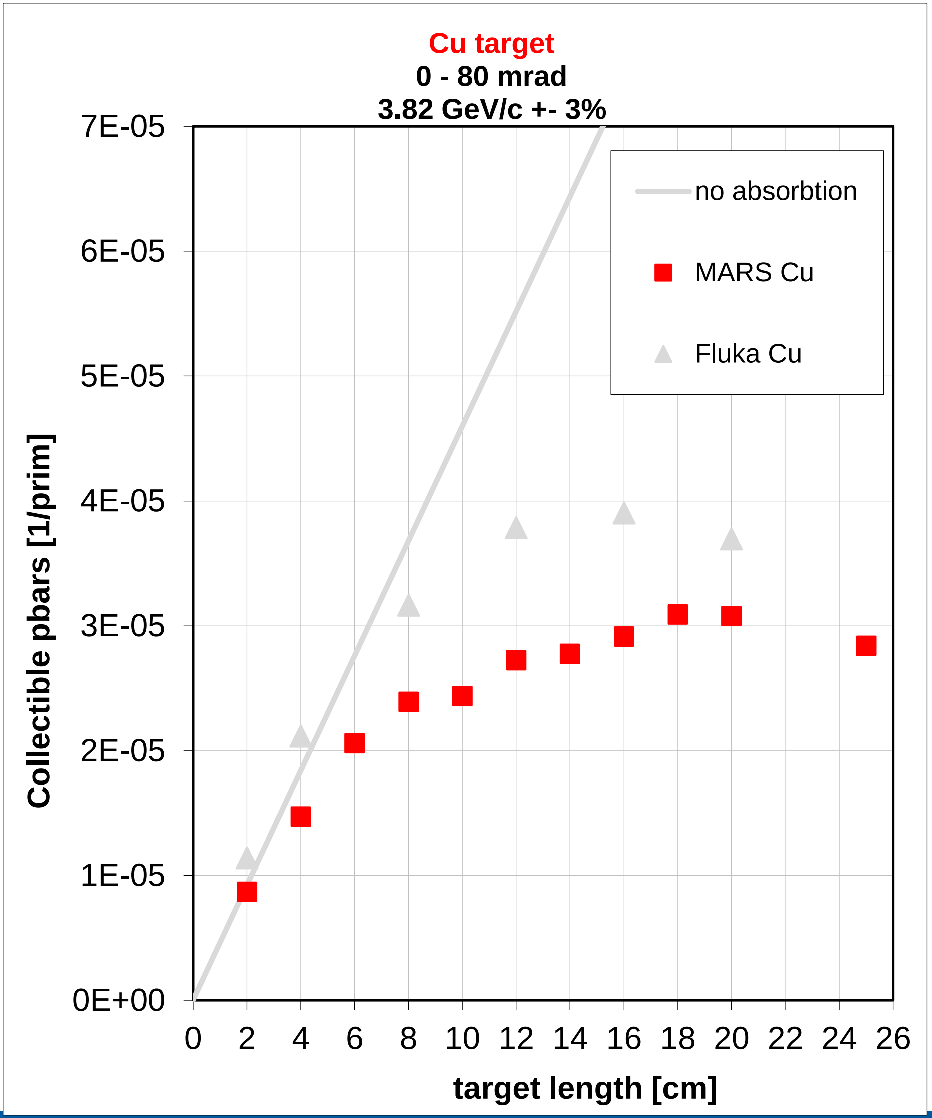
Collectible pbars: MARS/FLUKA

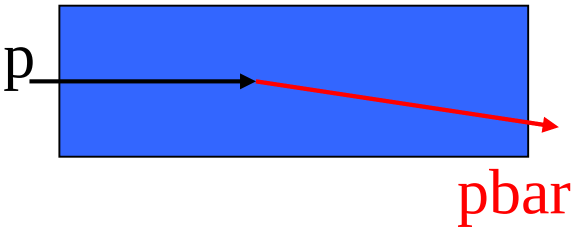




Cu: σ_{pbar} = 8.8 b

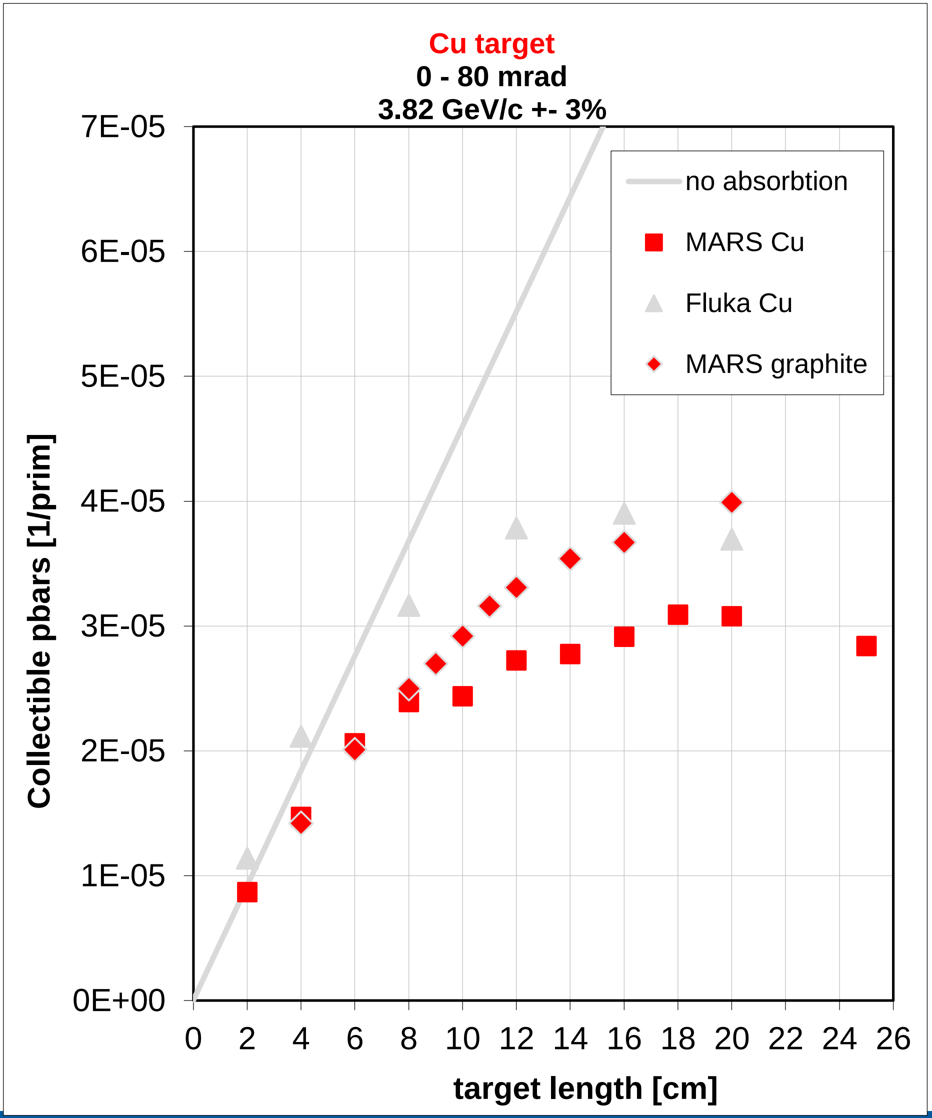
Collectible pbars: MARS

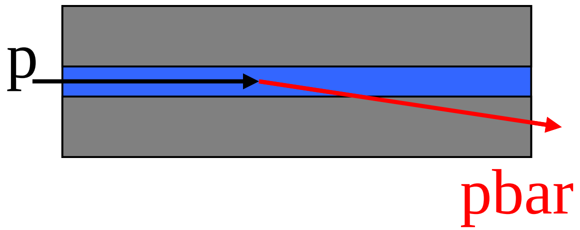




Cu: $\sigma_{pbar} = 8.8$ b

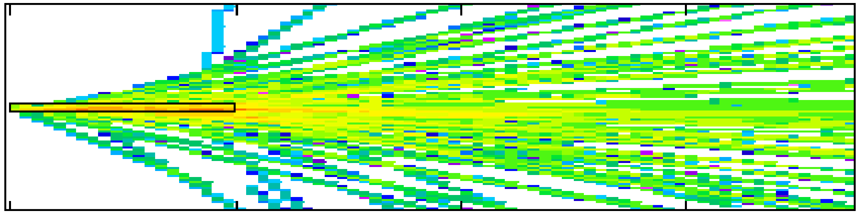
Collectible pbars: Graphite Surrounding



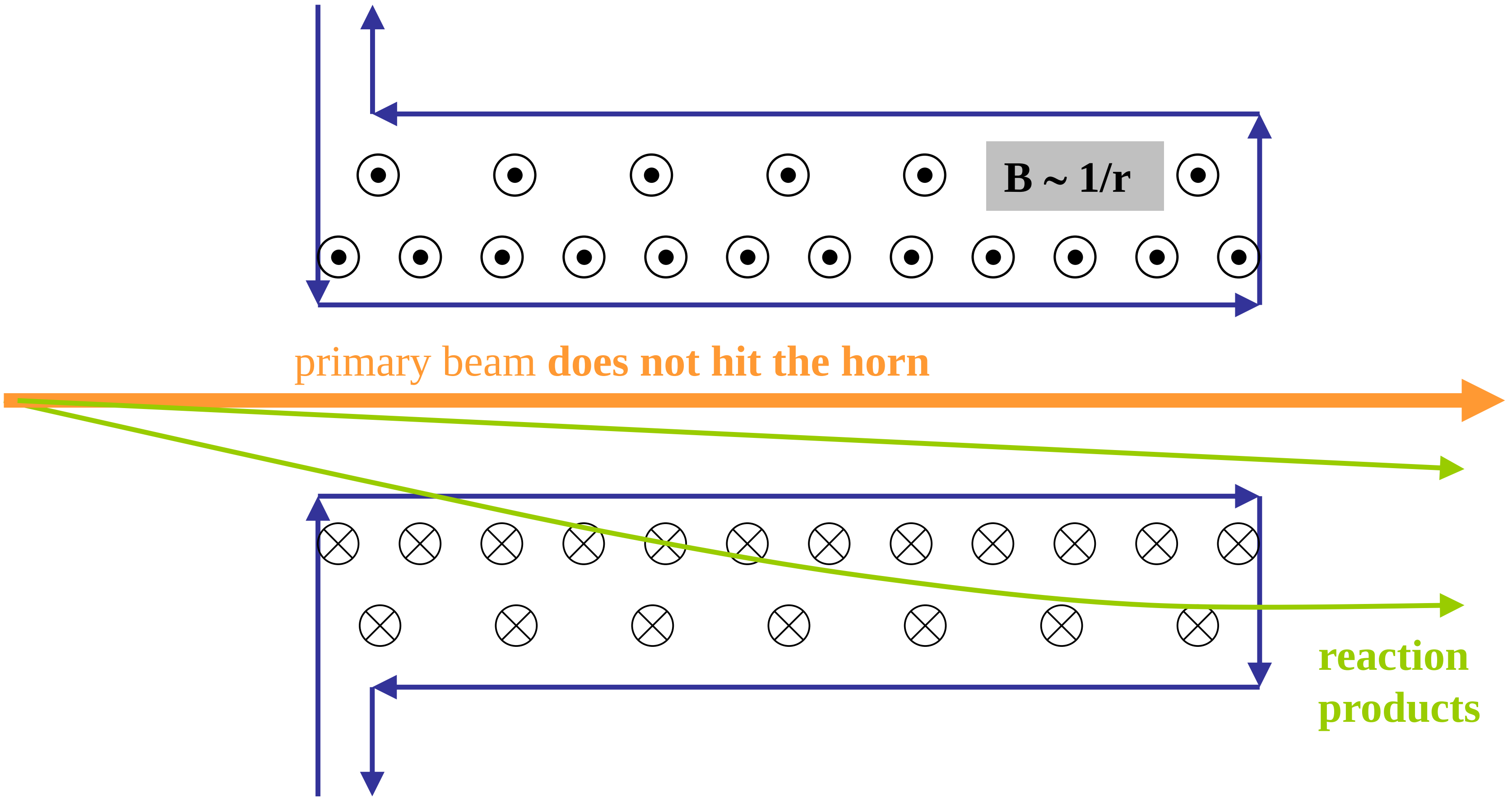


Cu: σ_{pbar} = 8.8 b

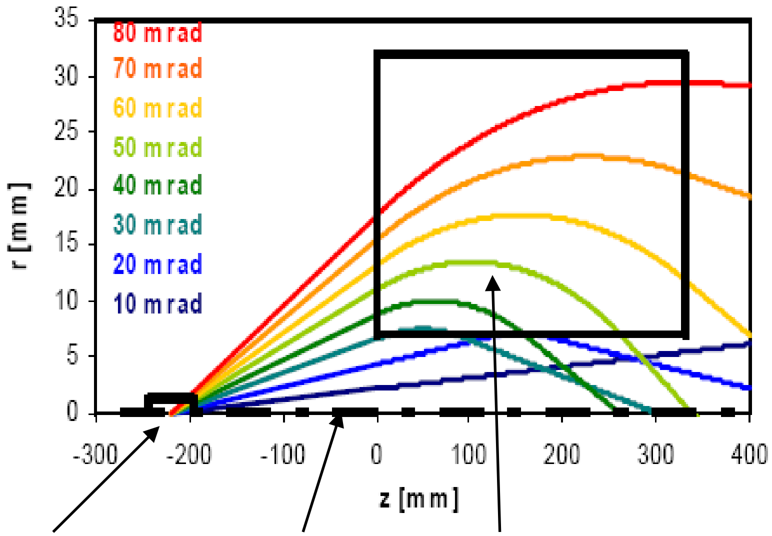
C: σ_{pbar} = 0.42 b

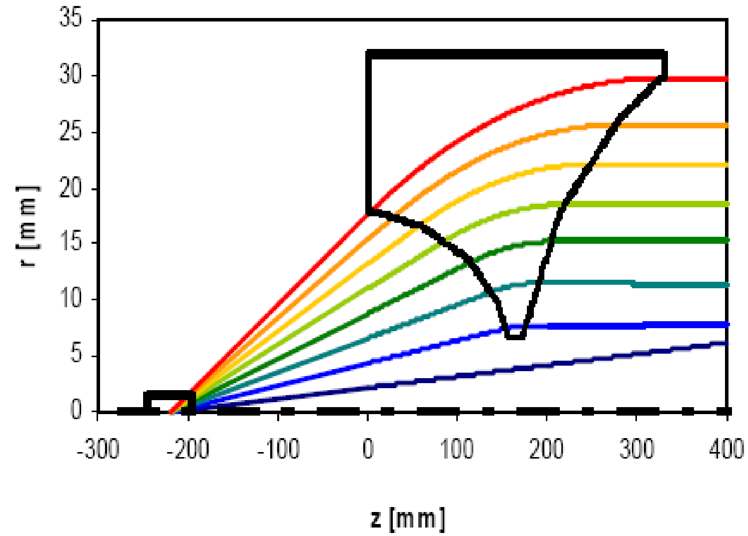


Collecting pbars: Magnetic Horn

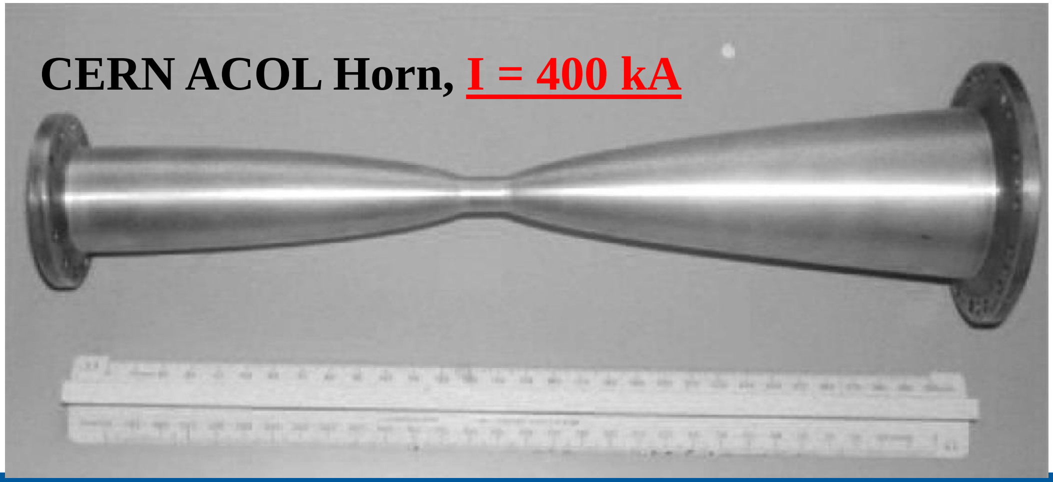


Collecting pbars: Magnetic Horn

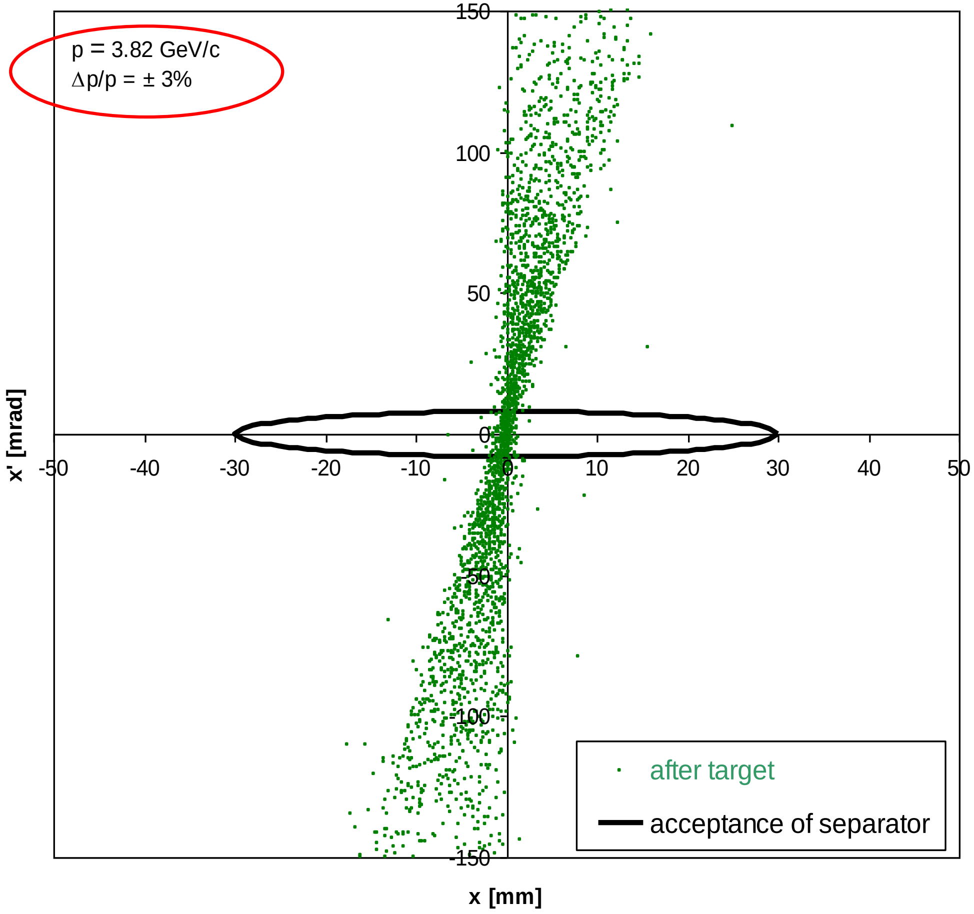




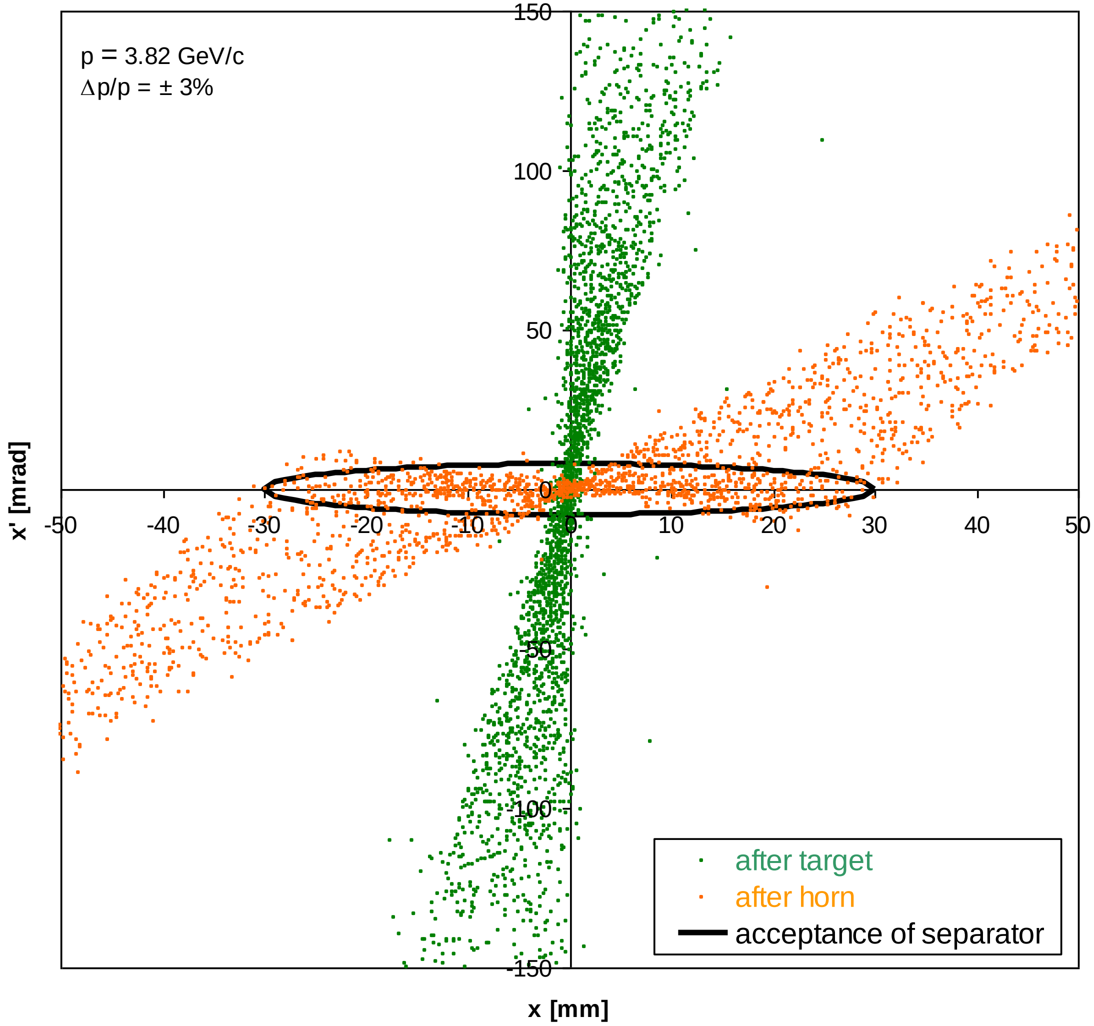
target beam axis magnetic field area



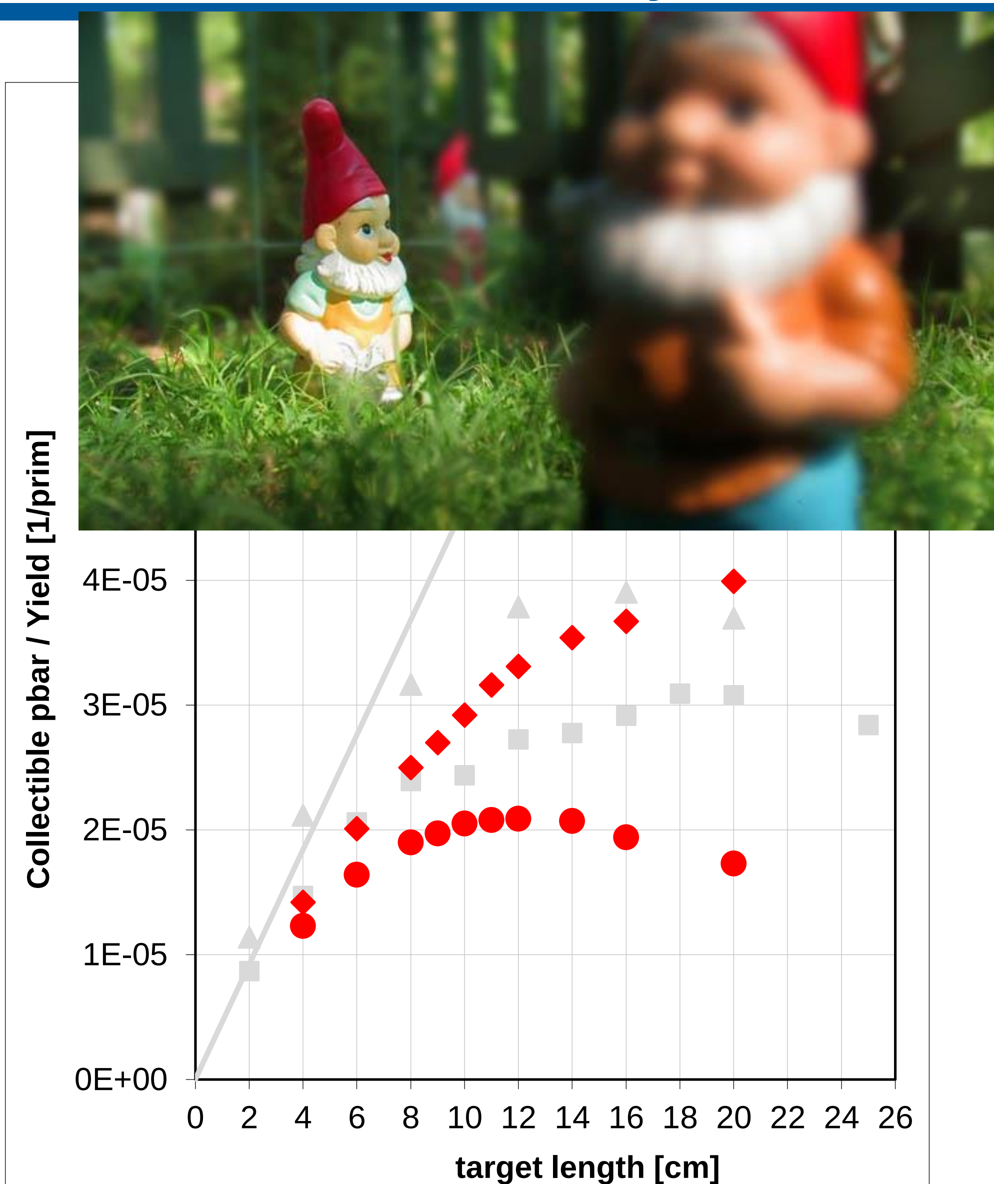
MARS Simulation of the pbar Yields



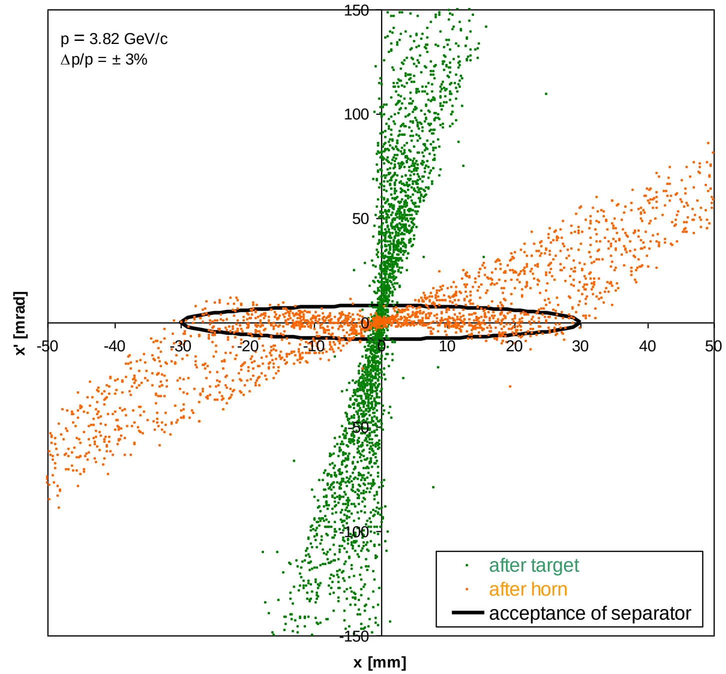
MARS Simulation of the pbar Yields



pbar Yield:
Collection efficiency of the magnetic horn



$$\text{yield} = \frac{\text{pbars in the ellipse}}{\text{primary protons}} = 2 \times 10^{-5}$$



pbar Yield: Comparison to CERN Data

To injection orbit of collector ring:

pbar/p = $2\times10^{-5} \times 0.8 \times 0.7 =$ **1.1×10^{-5}**

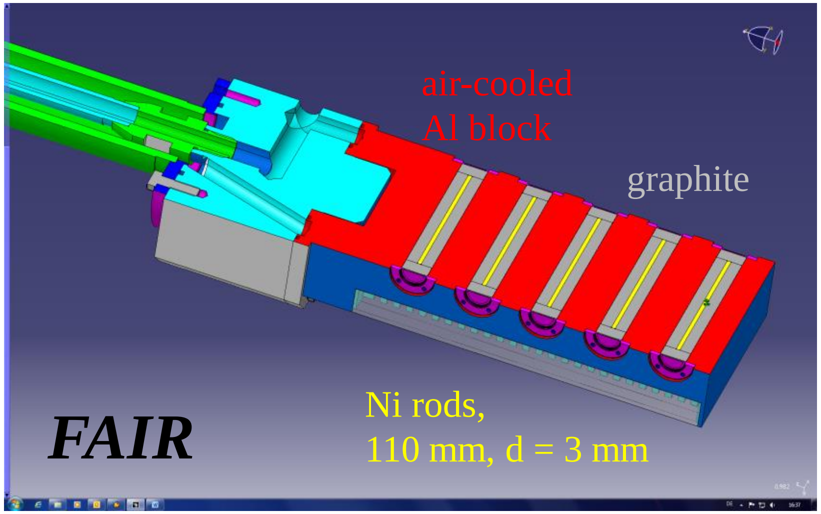
scattering losses/annihilation in air/aluminum *losses in separator / during injection*

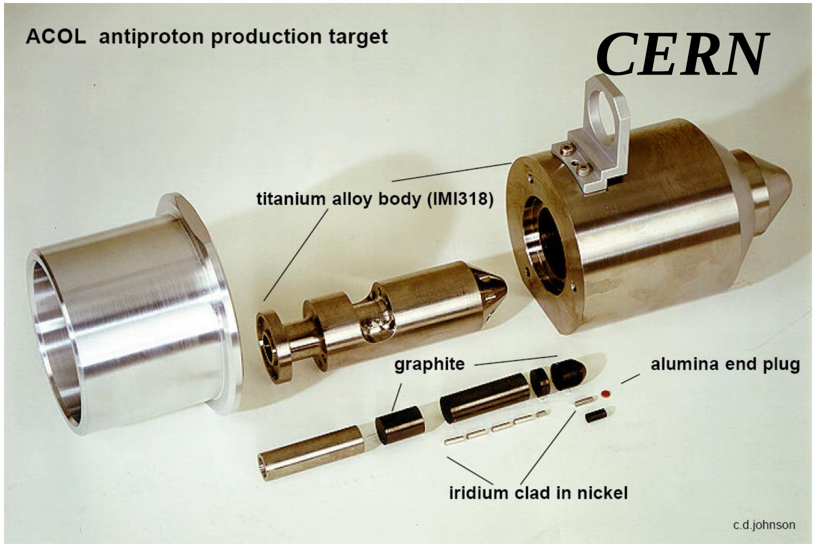
Exp. data from CERN (Baird 1998) to injection orbit:

pbar/p = $0.45\times10^{-5} \times 1.5 =$ **0.7×10^{-5}**

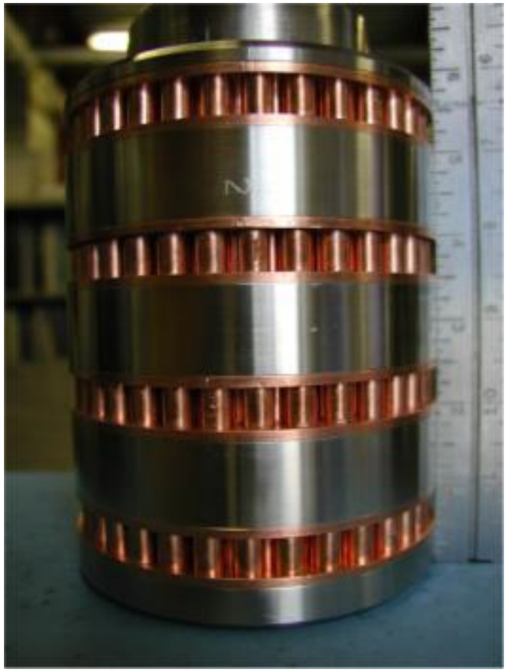
correction for different energies and emmitances

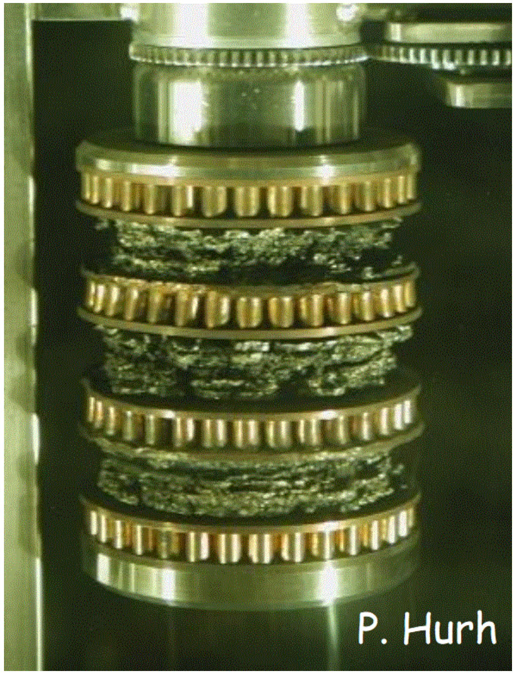
pbar Targets



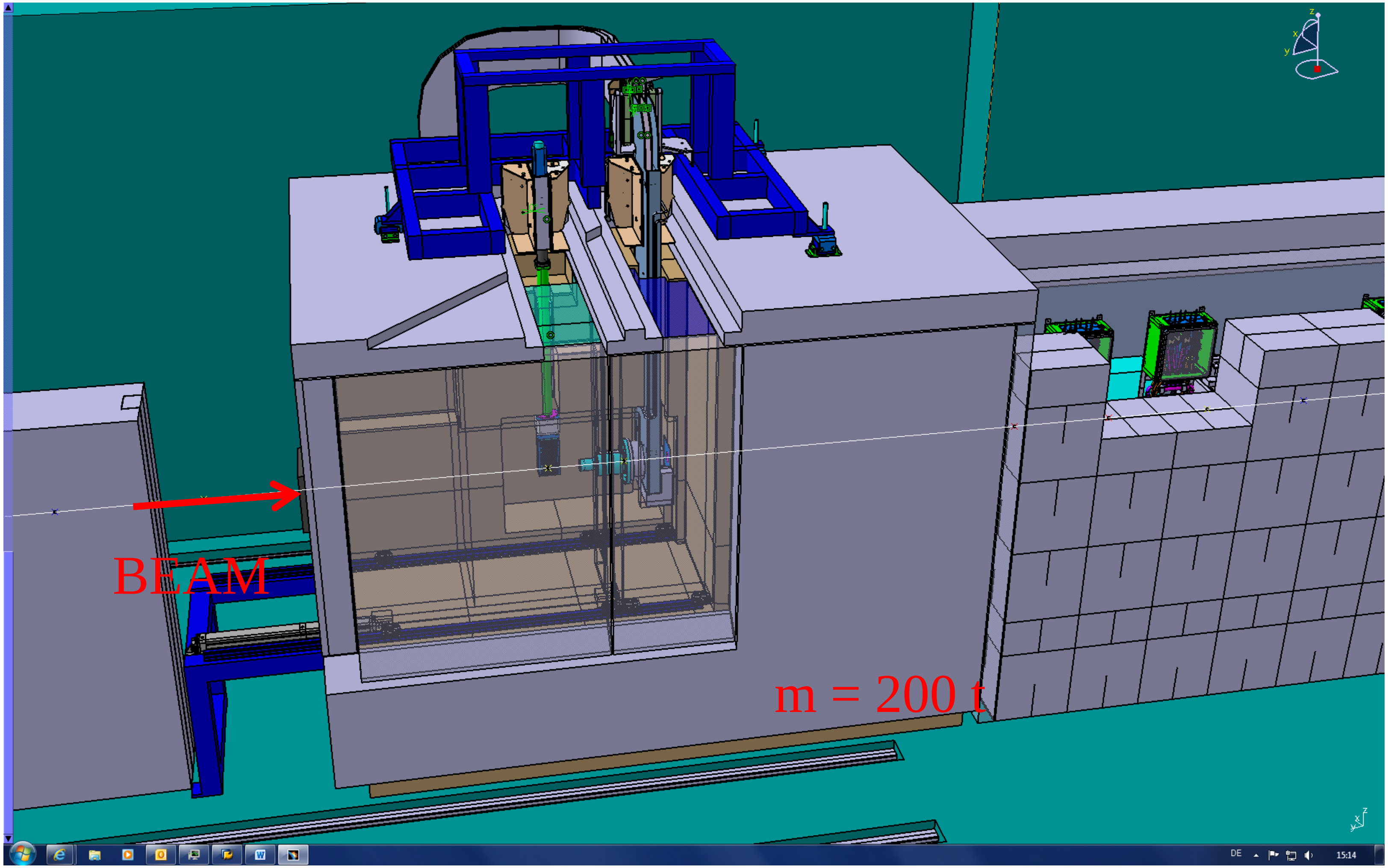


Fermilab

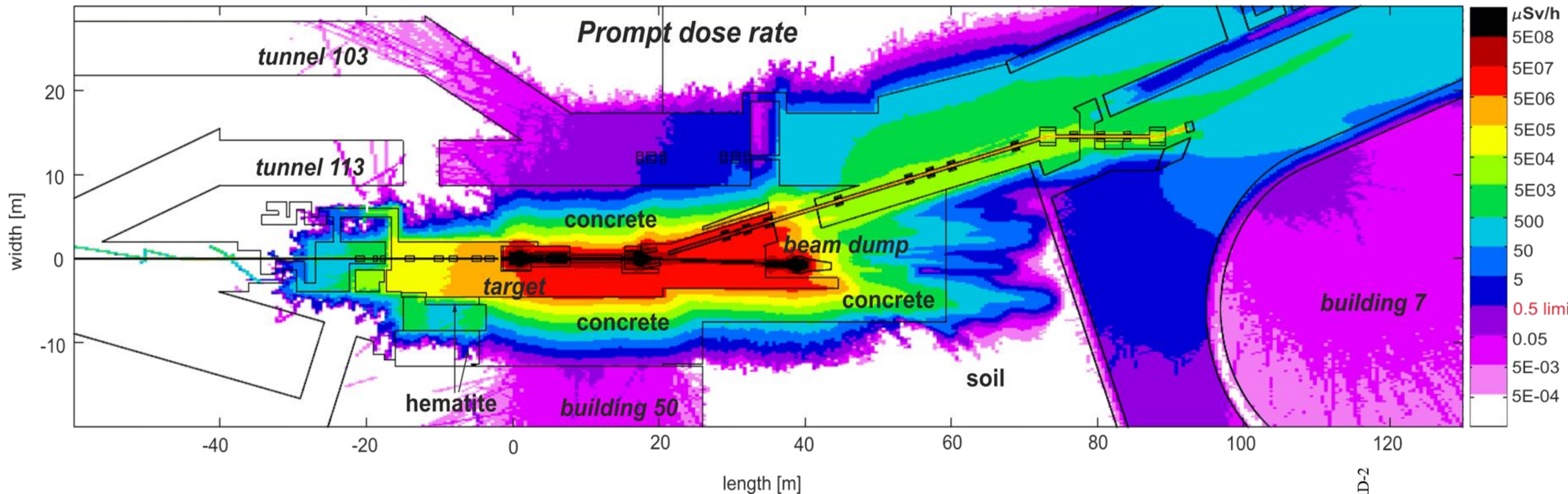


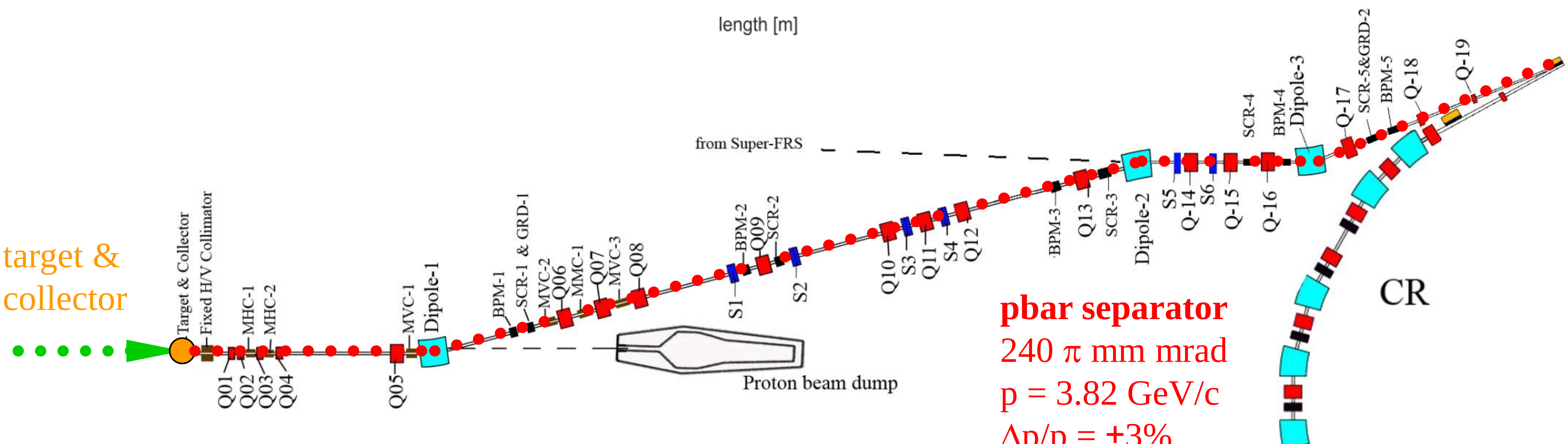


pbar Target station



The pbar separator



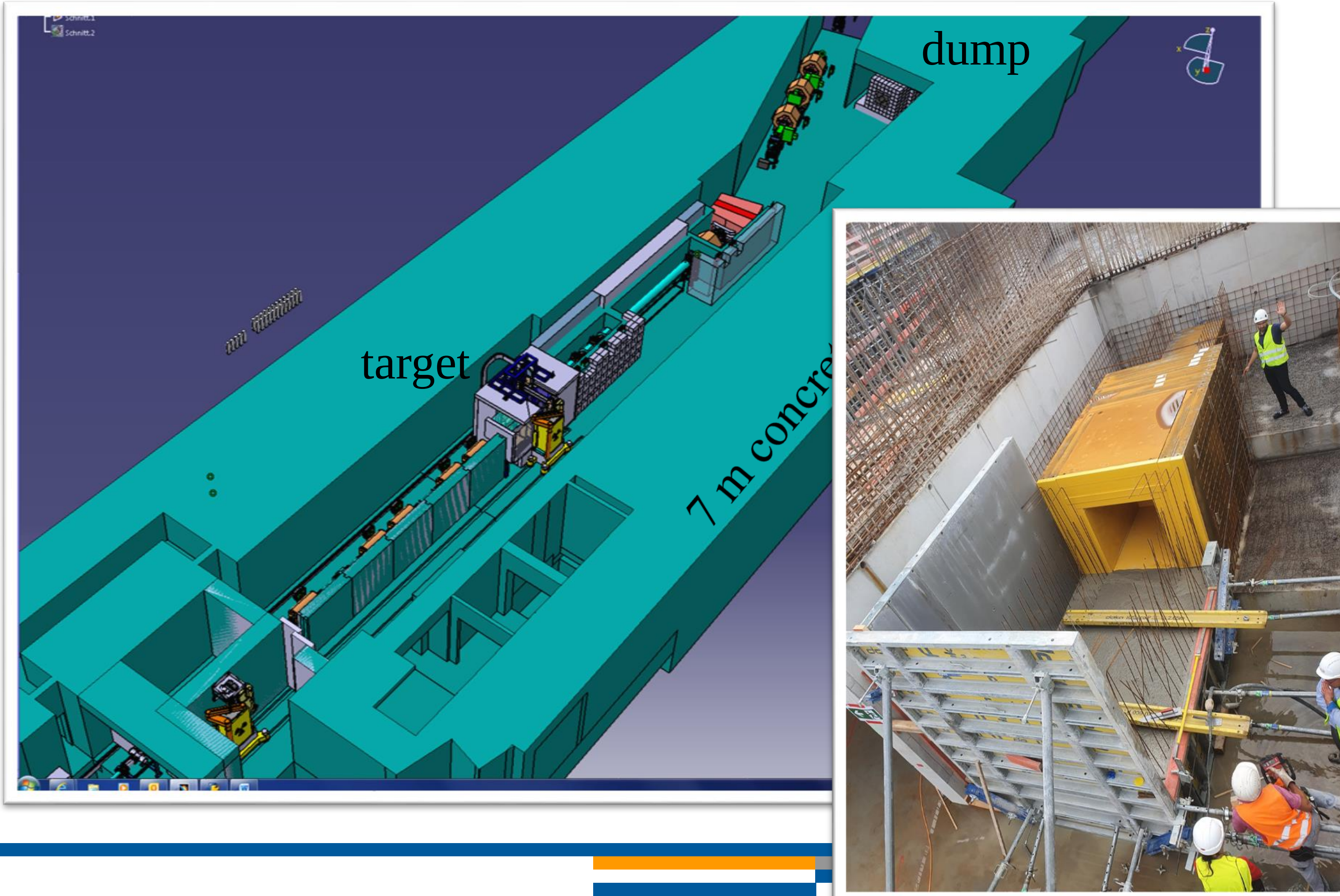


target &
collector

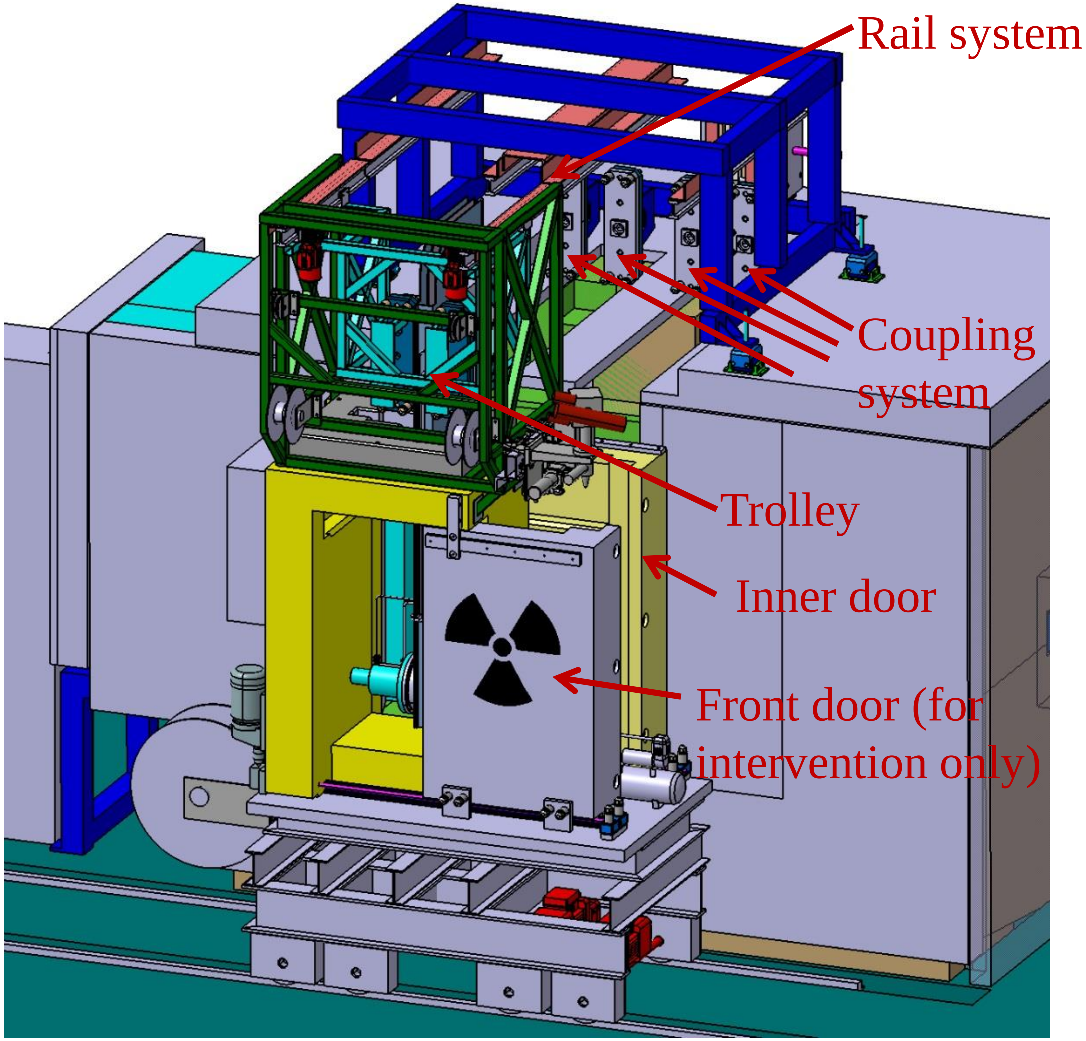
29 GeV p from SIS 100

pbar separator
240 π mm mrad
p = 3.82 GeV/c
Δp/p = ±3%

The pbar tunnel

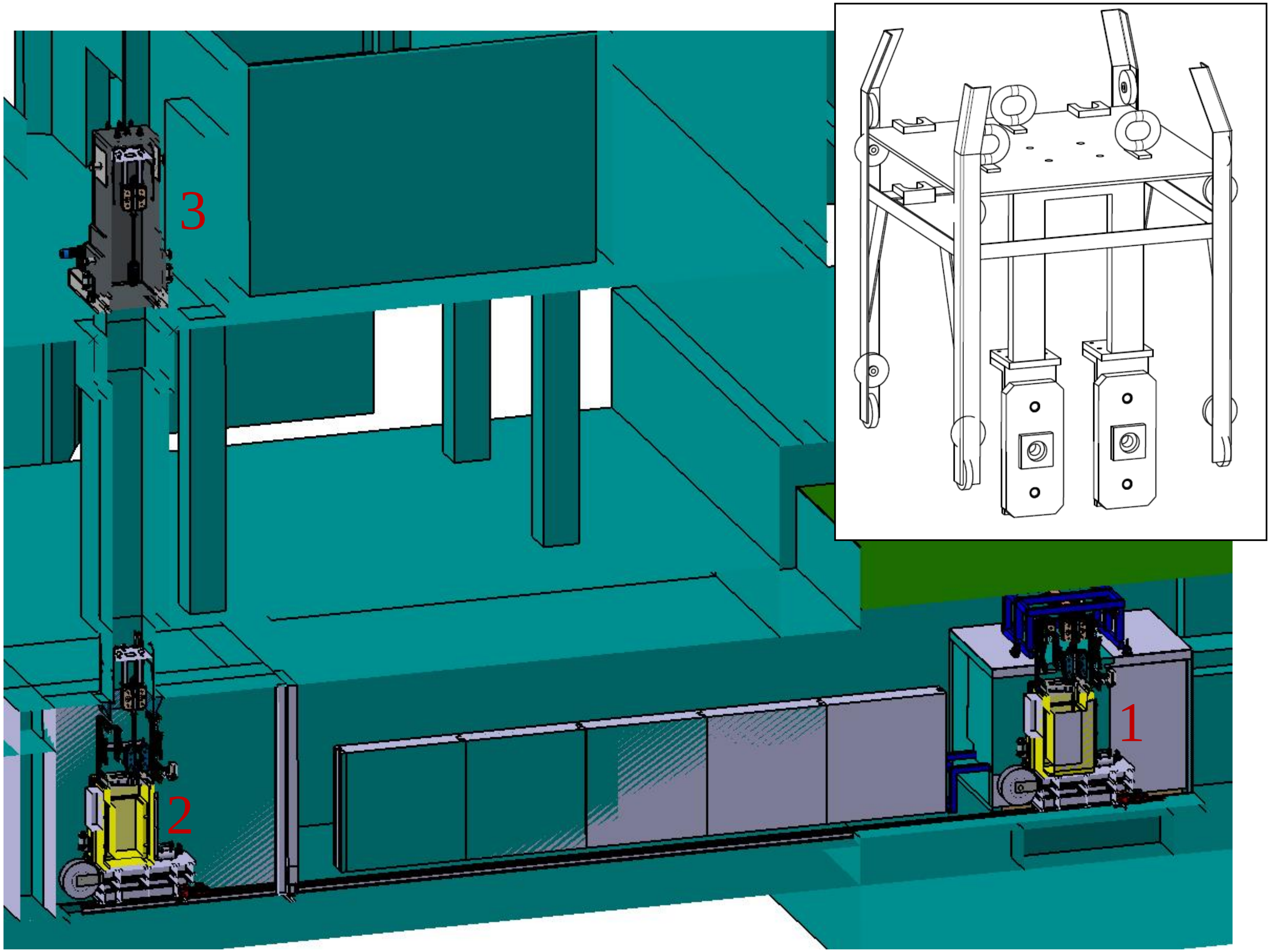


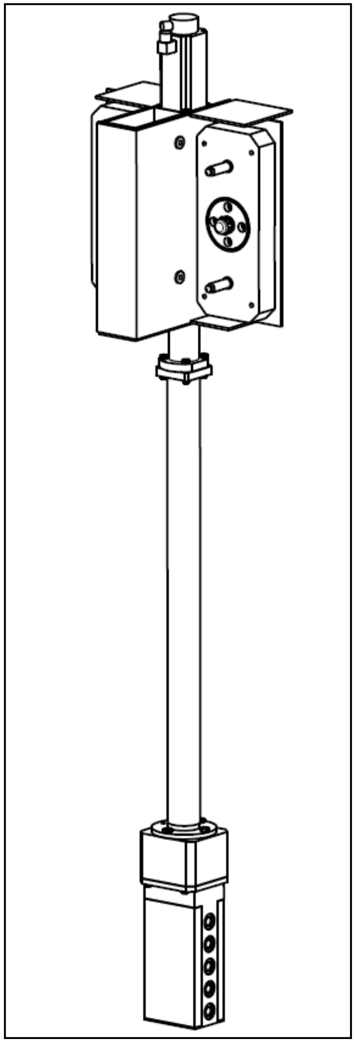
Target station and transport container



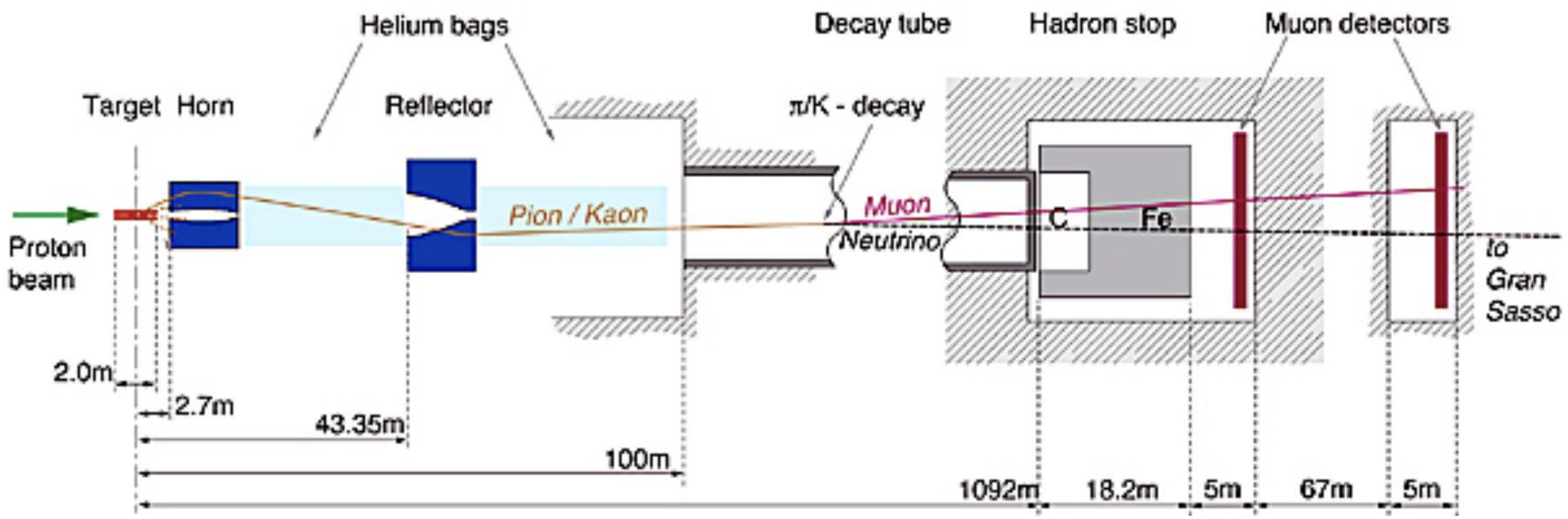
- Transport container is placed in front of target station.
- Door of target station and transport container are opened.
- Component is gripped by a quick coupling system.
- Trolley moves the component via rail system into the transport container.
- Doors are closed.

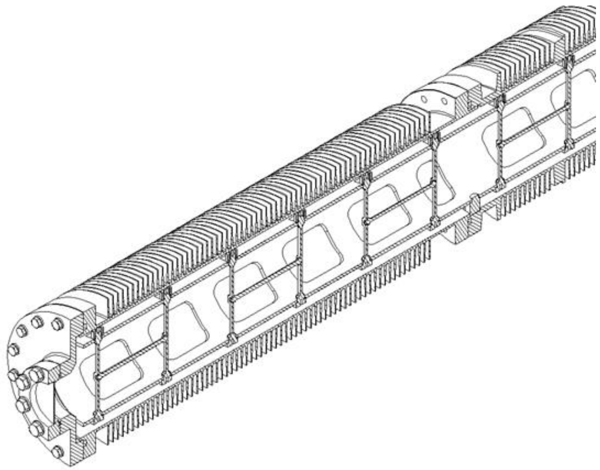
Overview of transport



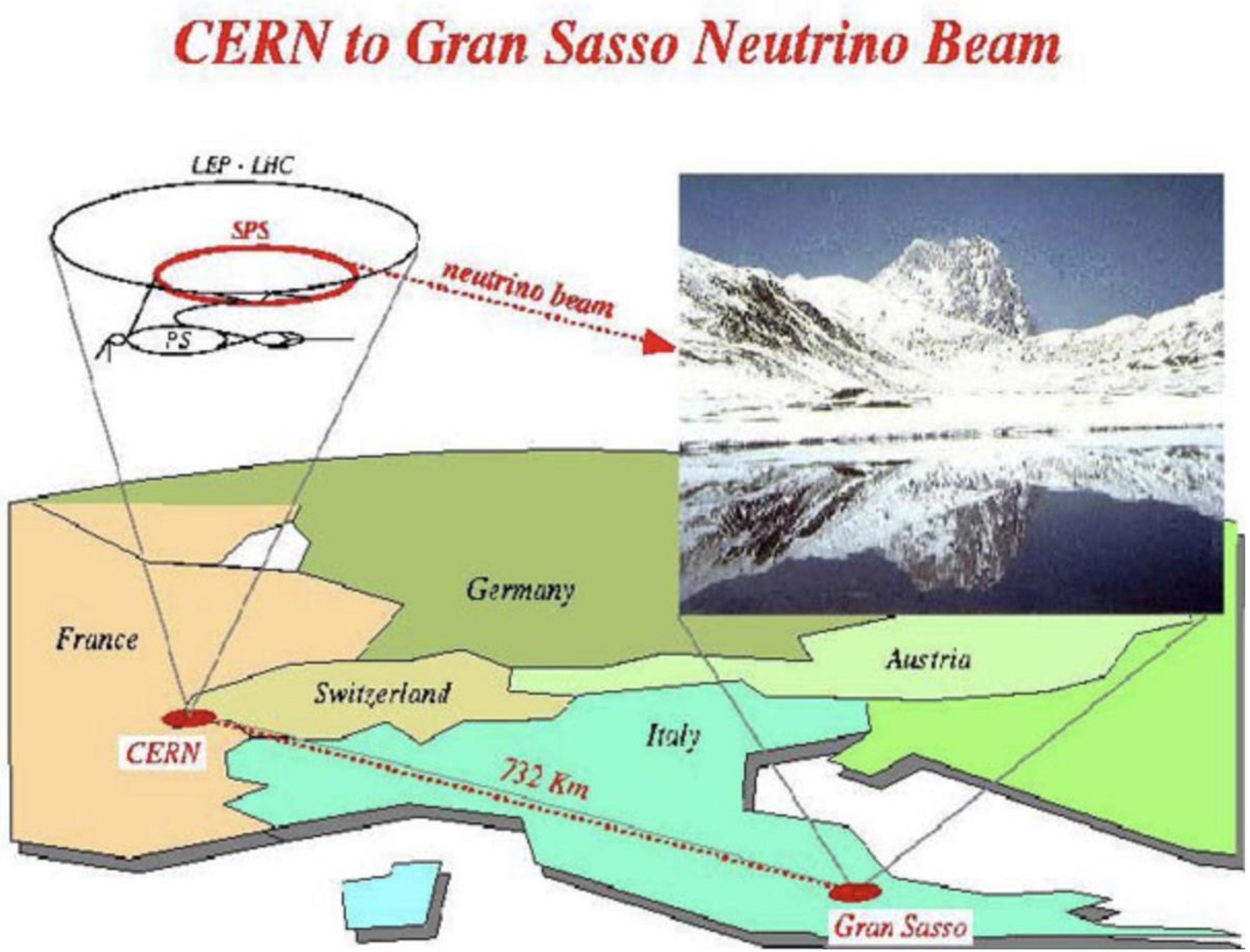


„Tertiary“ Beams: CNGS





„Tertiary“ Beams: CNGS



„Tertiary Beams: CNGS

symmetry
dimensions of particle physics

topics

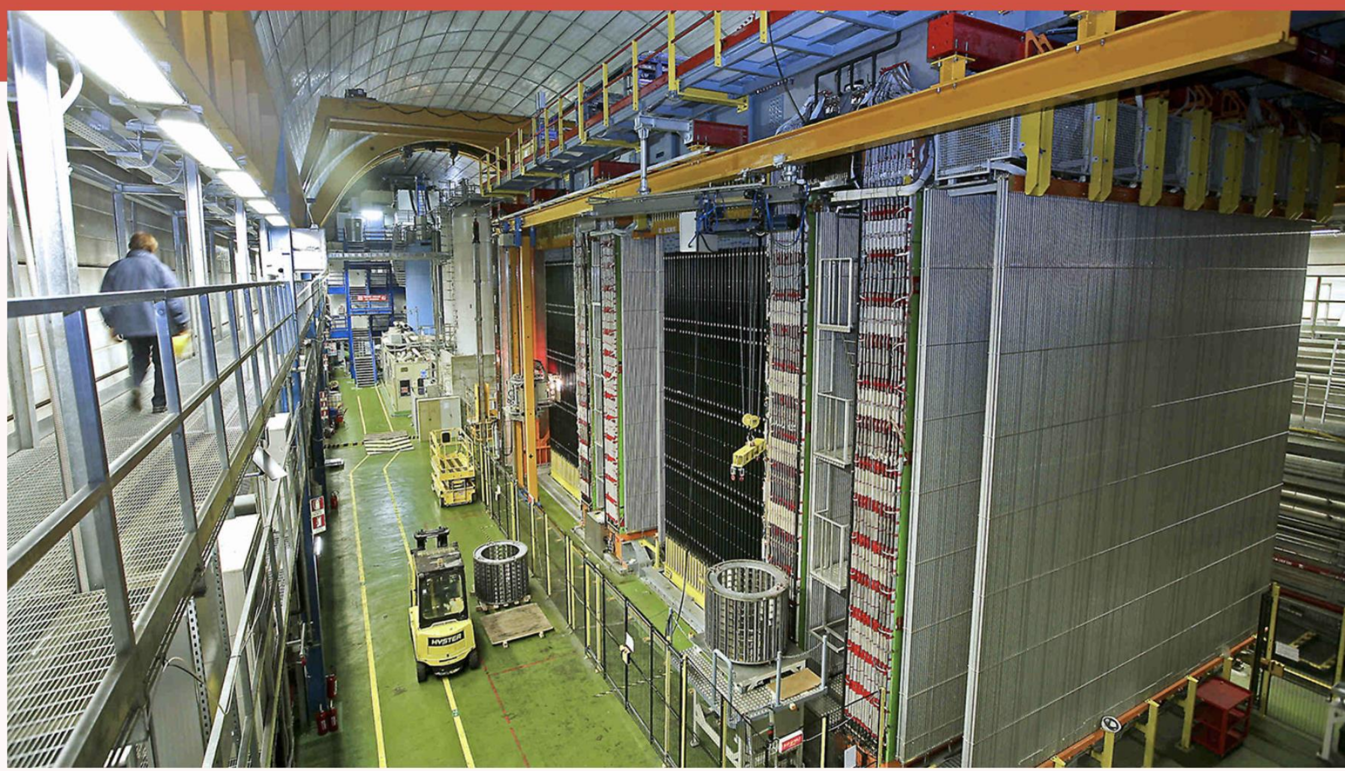
follow +

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