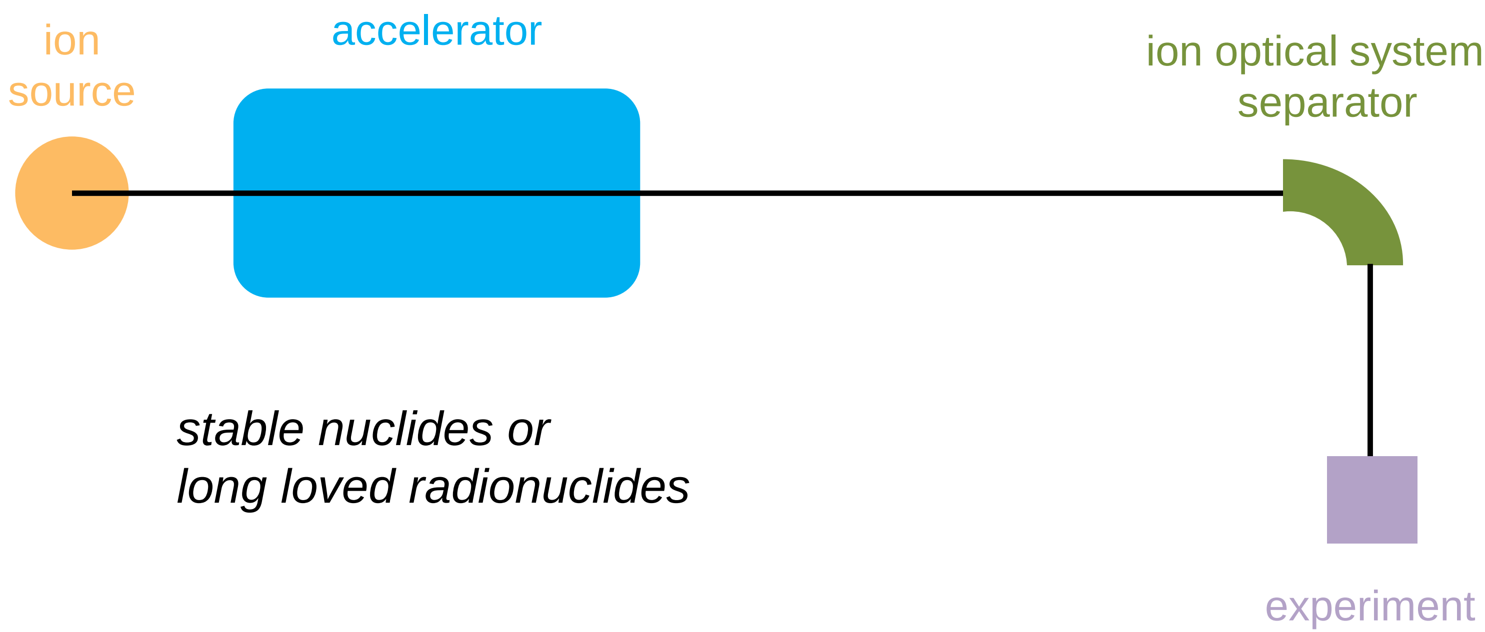
Secondary Beams and Targets

- Introduction:
  primary / secondary beam
  ISOL method,
  in-Flight (fragment) separators

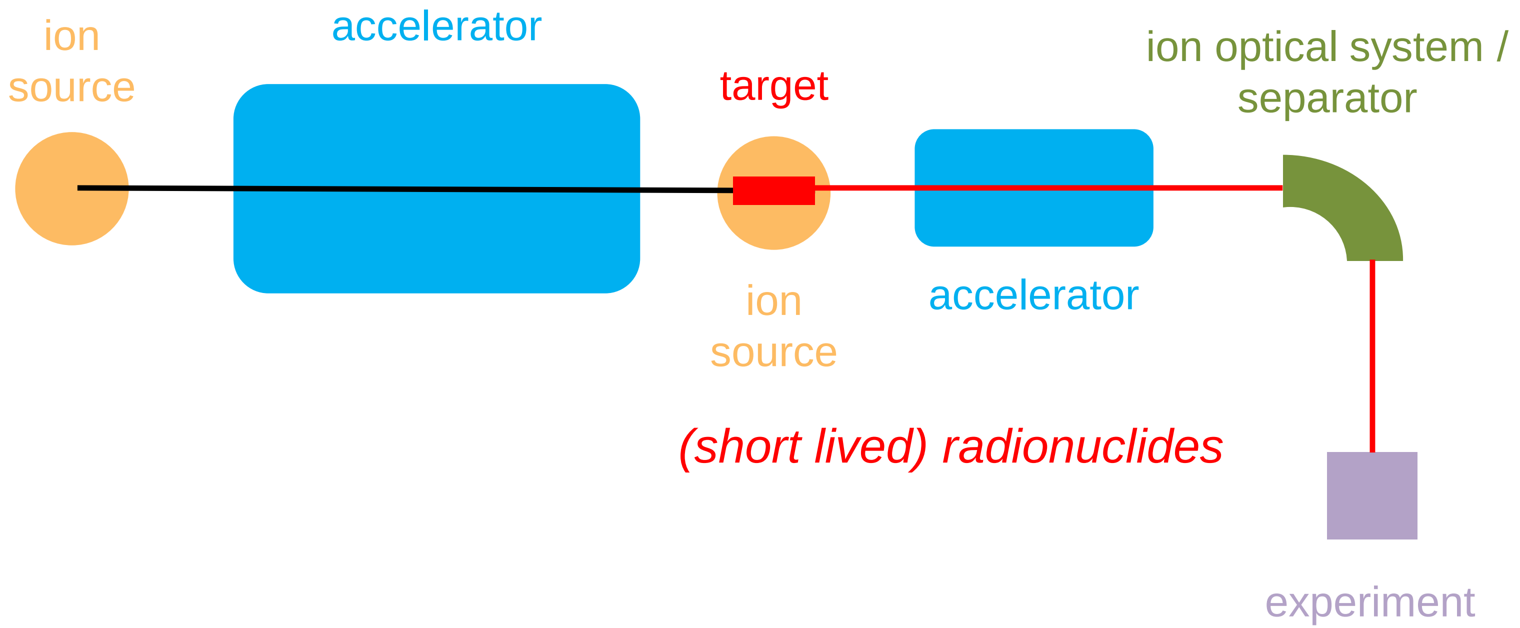
- Secondary beams at FAIR:
  Radioactive Isotope Beams: SuperFRS
  Antiprotons: Target, Magnetic Horn and pbar Separator
  Target handling, Radiation Protection

- “Ternary” Beams:
  Muon Beams
  Neutrino Beams (CNGS, NuMi...)

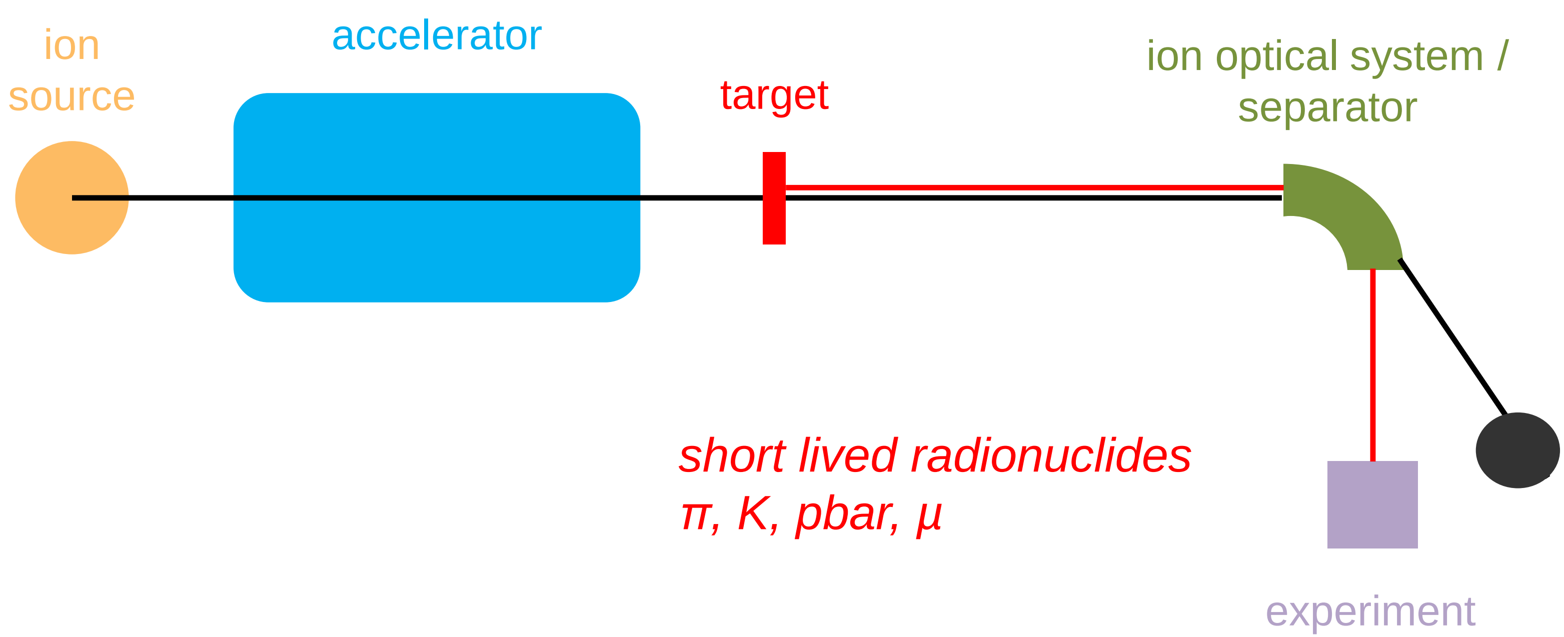
Primary / Secondary Beams



Primary / Secondary Beams (ISOL)

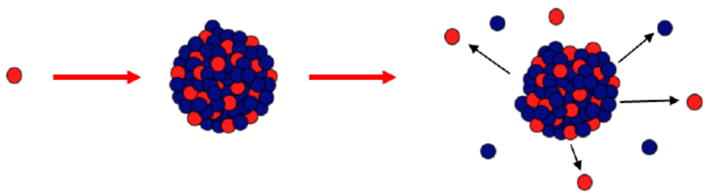


Primary / Secondary Beams: In-Flight

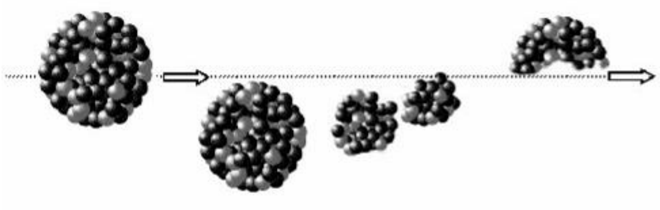


Production Mechanism

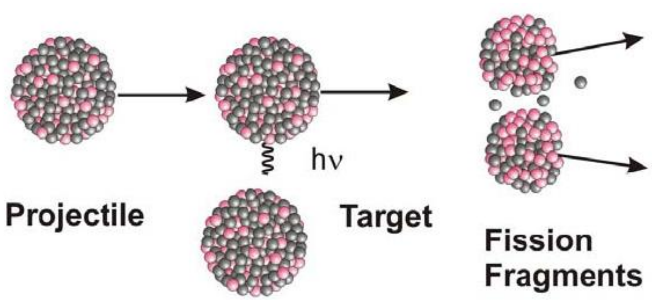
Spallation (ISOL only):
few nucleons lighter than target

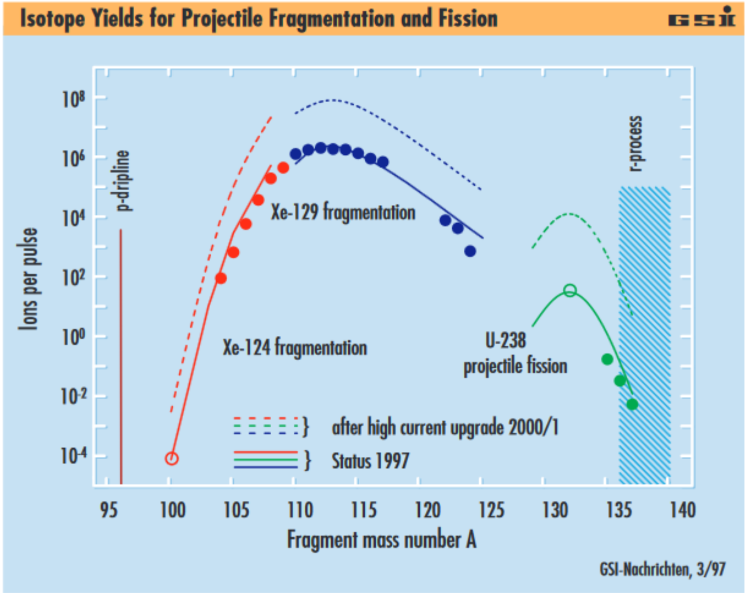


Projectile fragmentation:
neutron deficient (evaporation of neutrons after collision)

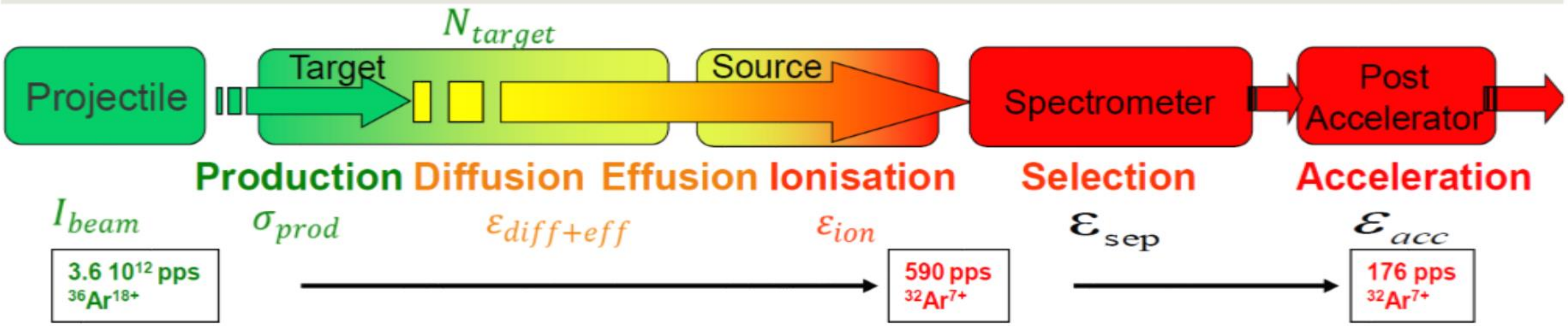


Projectile fission:
neutron rich (*N/Z* similar heavy projectile)



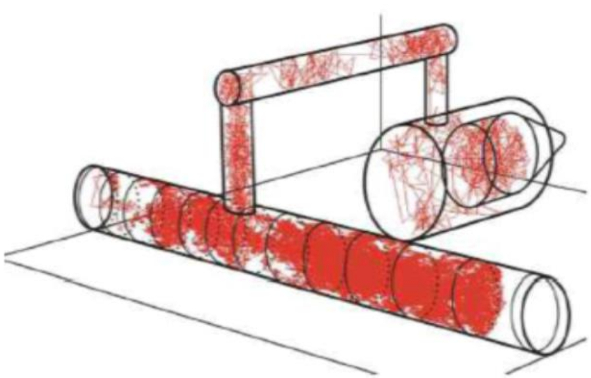


ISOL Method



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

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



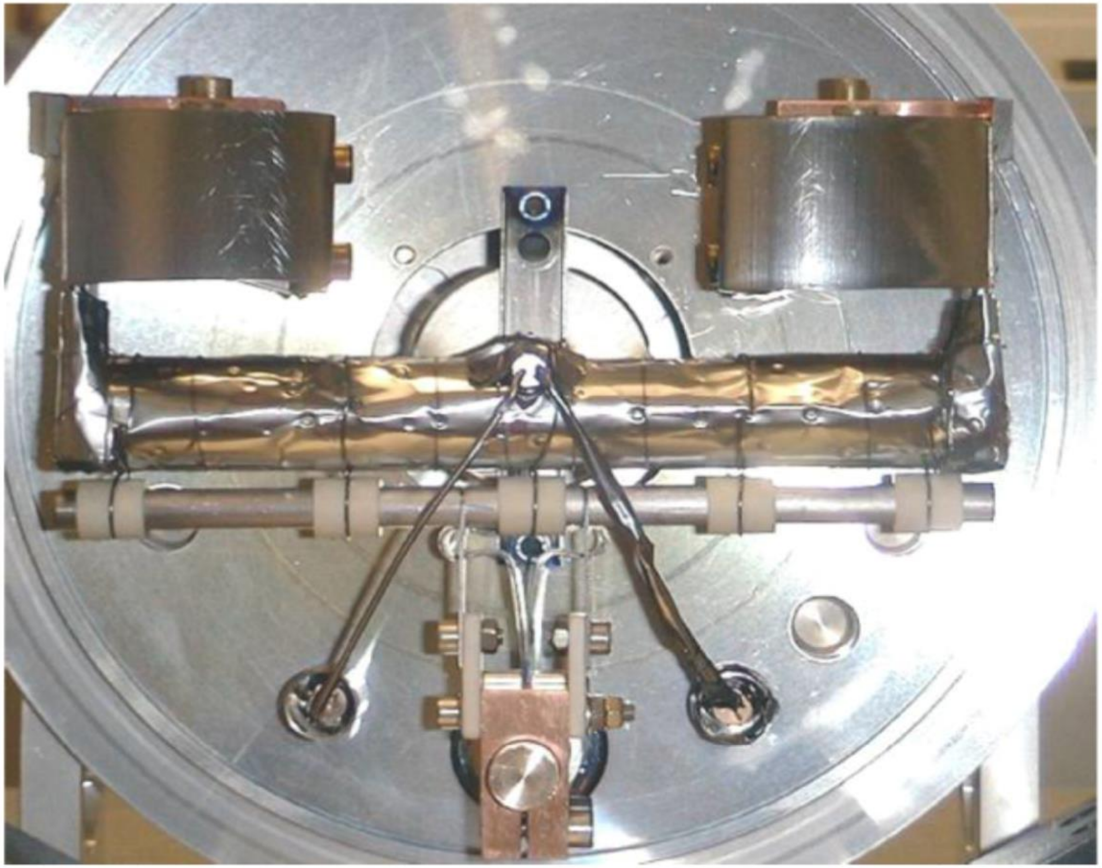
Path of an atom travelling out of a foil target to the ion source (RIBO code, (Santana-Leitner, 2005))

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

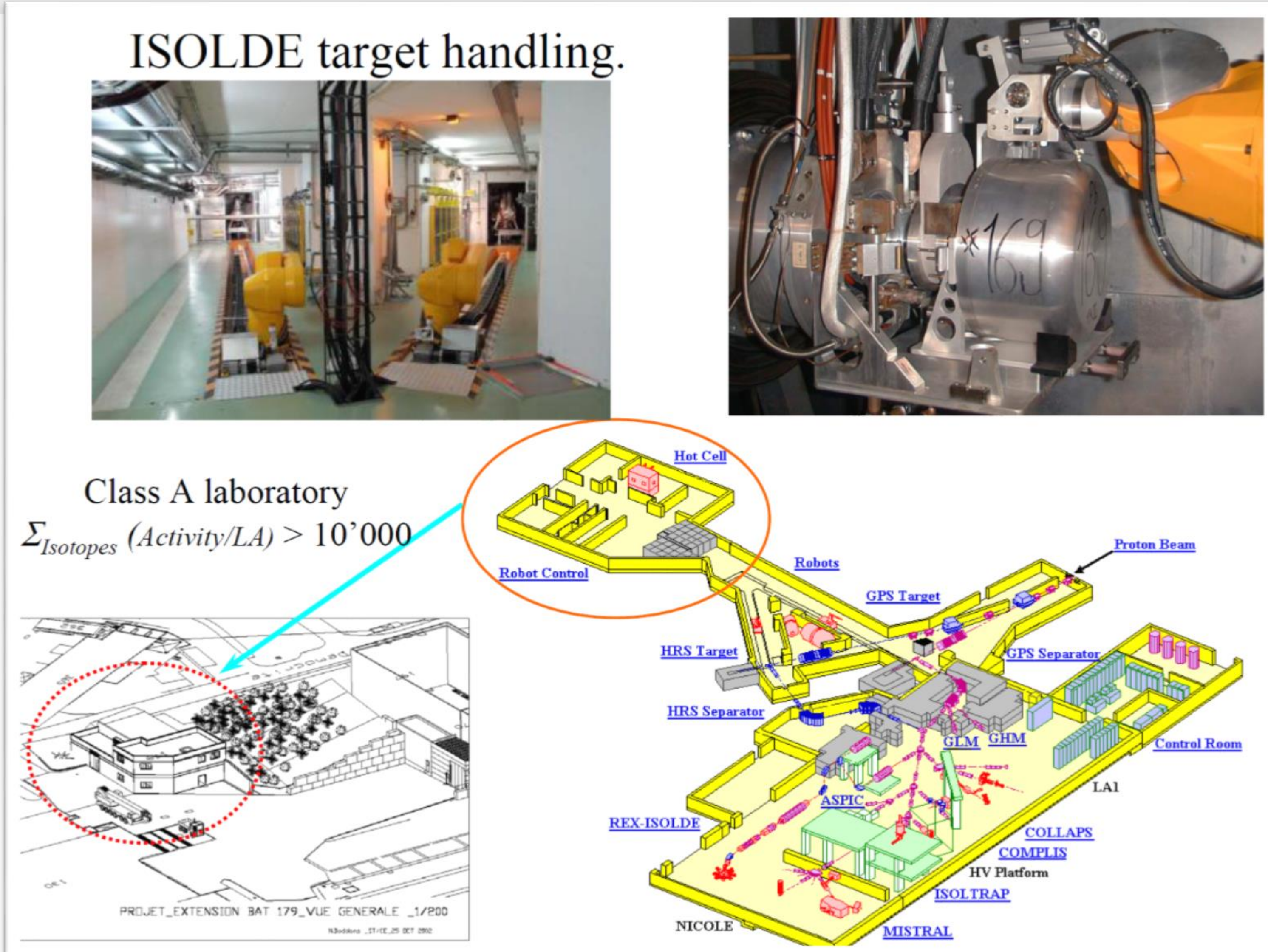
ISOLDE (CERN)



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

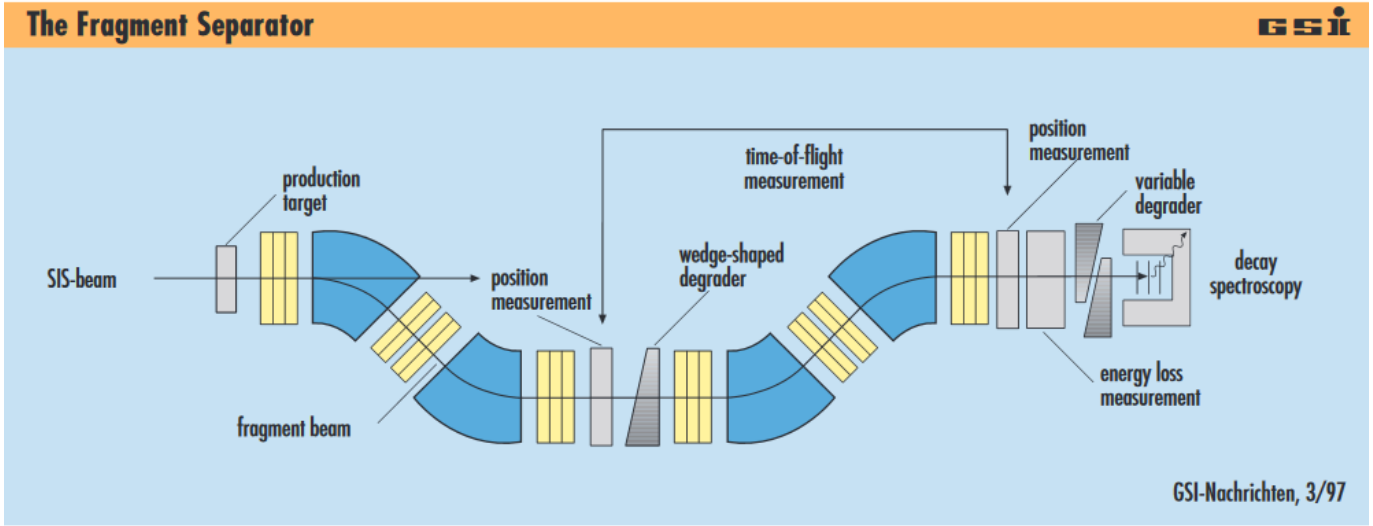
T. Stora

ISOLDE (CERN)



T. Stora

Fragment Separators (in-Flight)



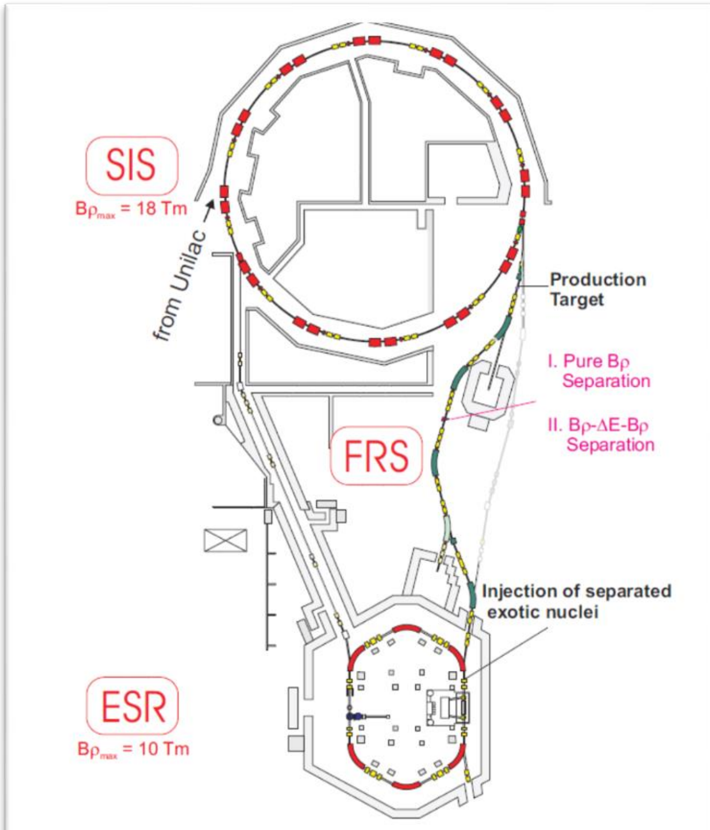
$B{\cdot}\rho = p/(q{\cdot}e) \approx (2\mathbf{E}{\cdot}\mathbf{m})^{1/2}/(\mathbf{q}{\cdot}\mathbf{e})$

1st part: ***m/q*** or ***A/q*** selection, charge states ≠ *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 ≠ *q'* lost

Lifetime and Mass Measurements of stored exotic nuclei @ FRS



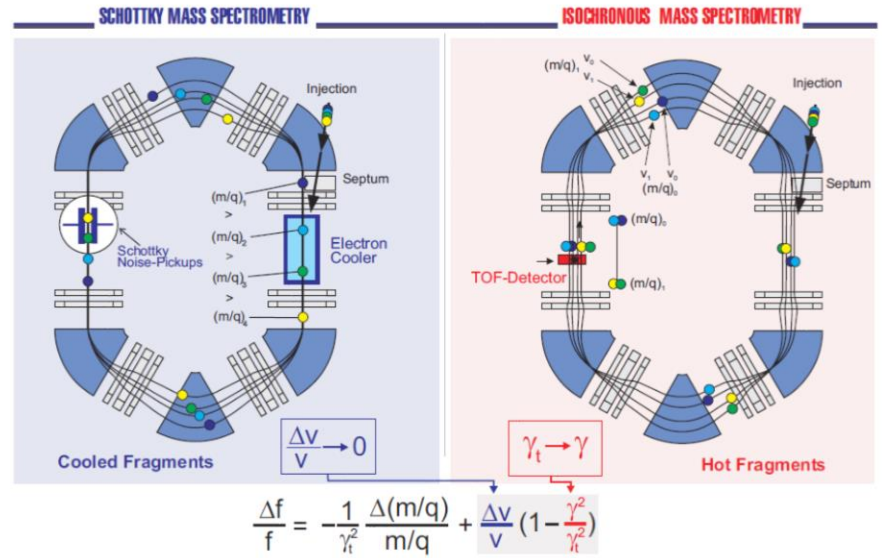


Fig. 8. The two kinds of mass spectrometry applied at the ESR by measuring the revolution frequencies of stored exotic ions. Left hand side: Schottky mass-spectrometry. Here the ions are electron-cooled, therefore their velocity spread Δv gets negligibly small. Their revolution frequencies are measured 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)

Lifetime and Mass Measurements of stored exotic nuclei @ FRS

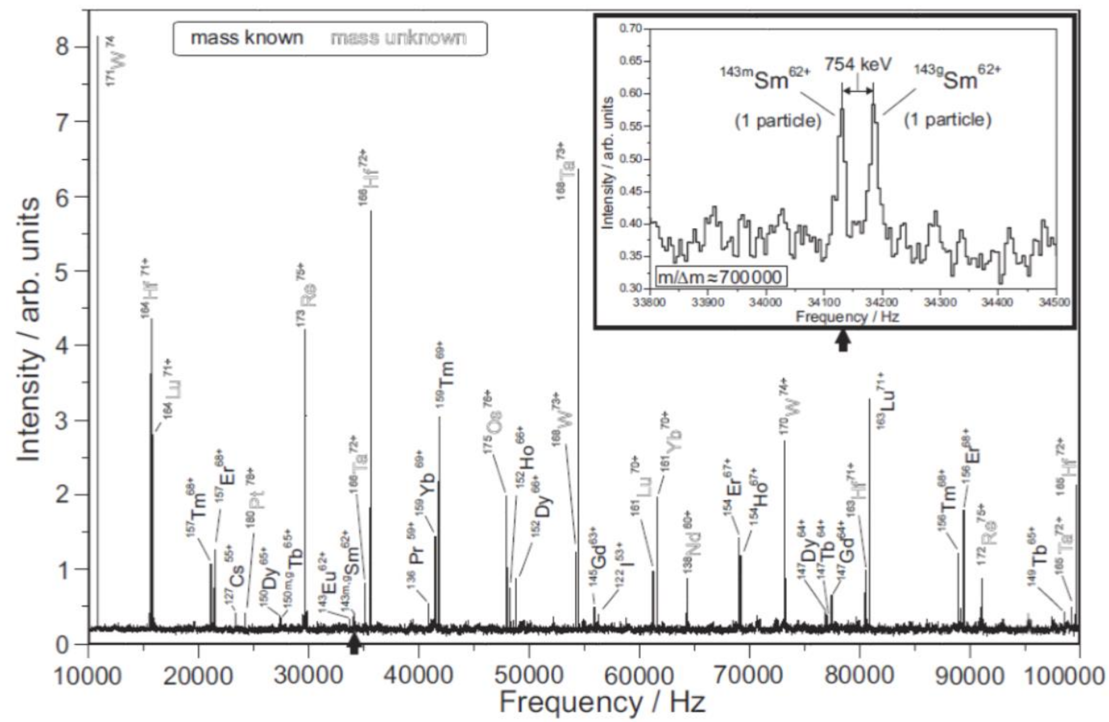
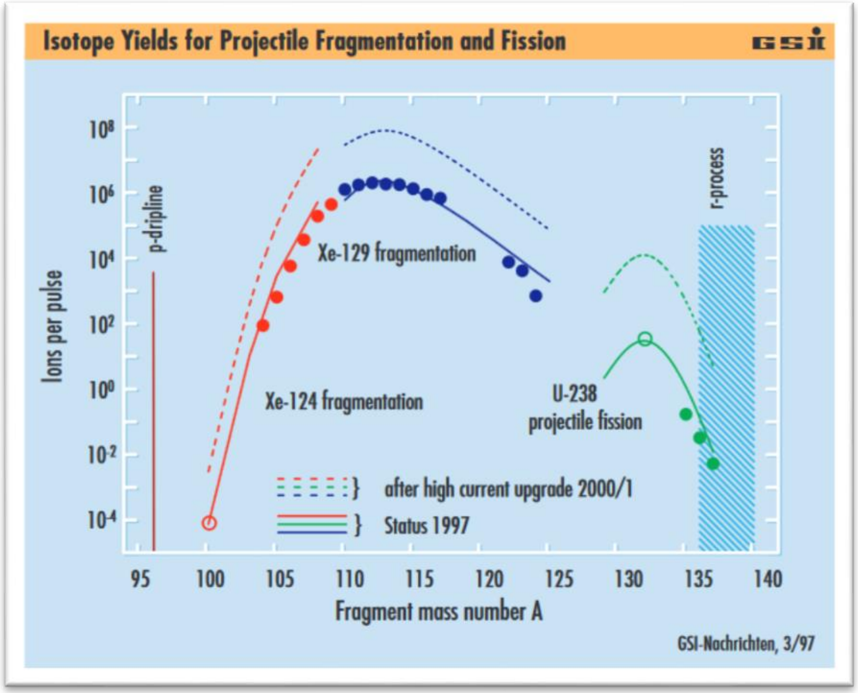
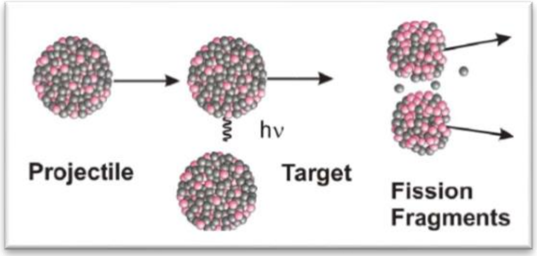


Fig. 9. Schottky spectrum of fragments from a primary ^{209}Bi beam, stored and electron-cooled in the ESR. The main spectrum shows the difference between the 30th harmonic of the revolution frequencies of the many stored ion species and of a local oscillator operating at about 60 MHz. It covers roughly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

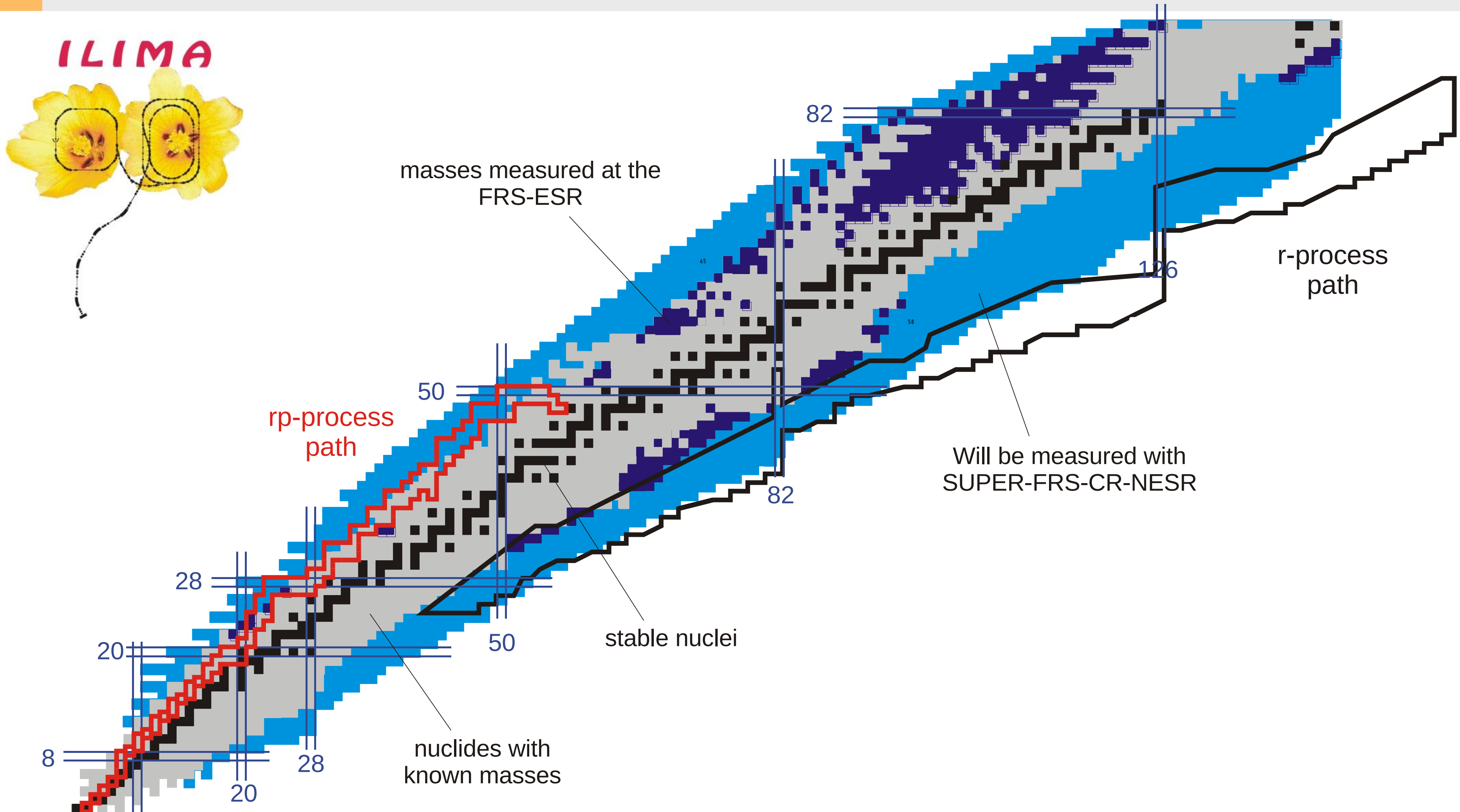
F. Bosch, Measurement of Mass and Beta-Lifetime of Stored Exotic Nuclei, Lect. Notes Phys. **651**, 137–168 (2004)

The Super Fragment Separator





Phase 1 Physics with Super-FRS and Rings:
Potential for new masses, lifetimes & isomers with ILIMA



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

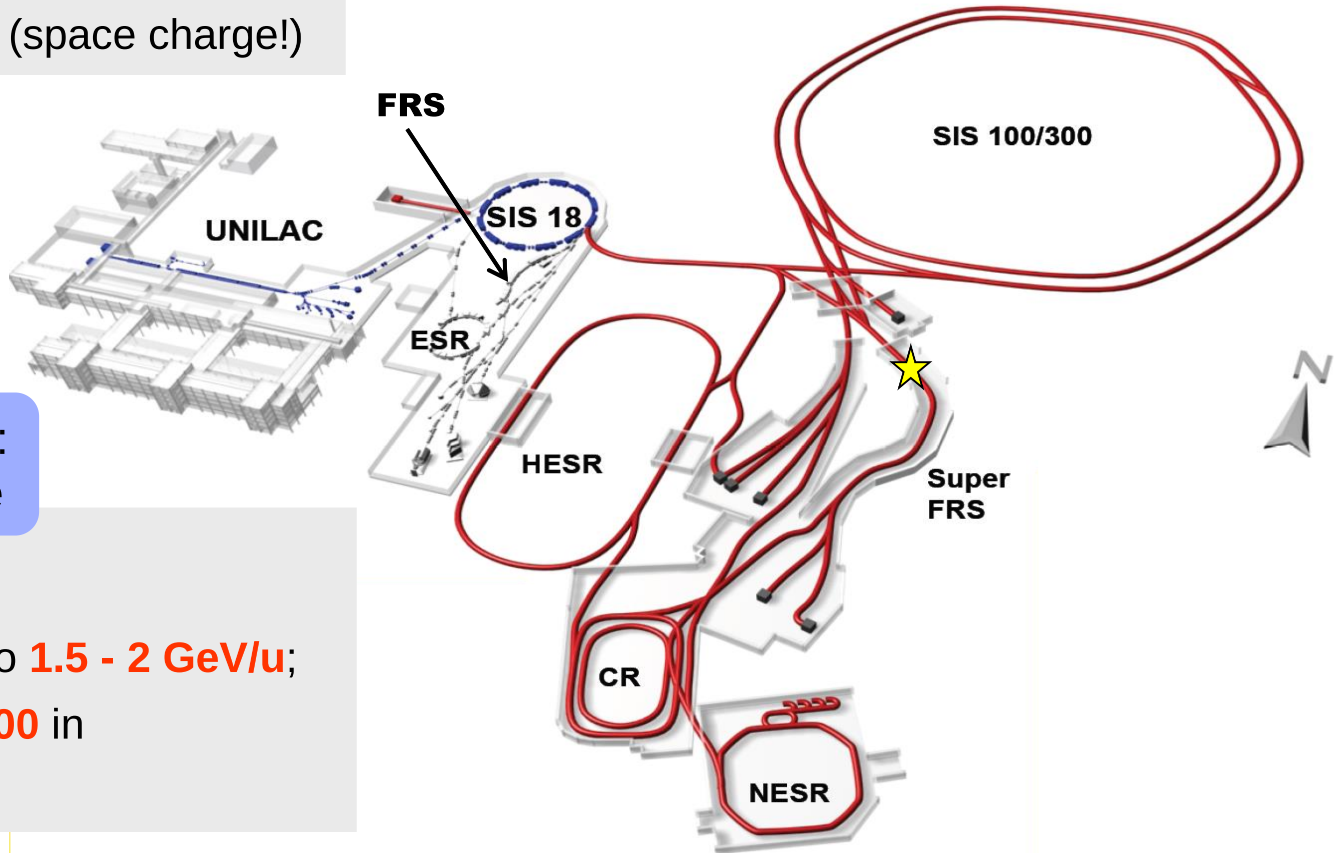
SuperFRS @ FAIR

Primary Beams: Increase intensity

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

Rare Isotope Beams: Increase Acceptance

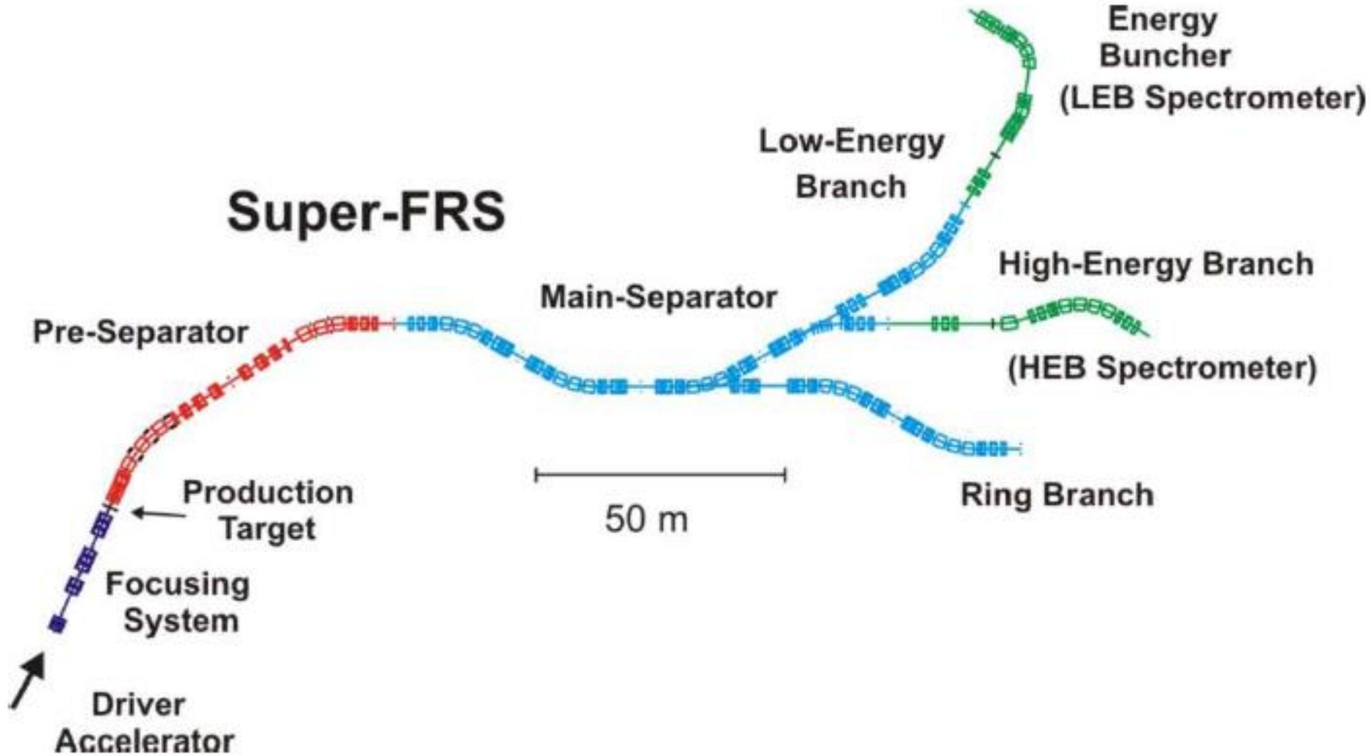
- Broad range of **radioactive beams** up to **1.5 - 2 GeV/u**; up to factor **1 000 - 10 000** in intensity over present



SuperFRS @ FAIR

SuperFRS at FAIR

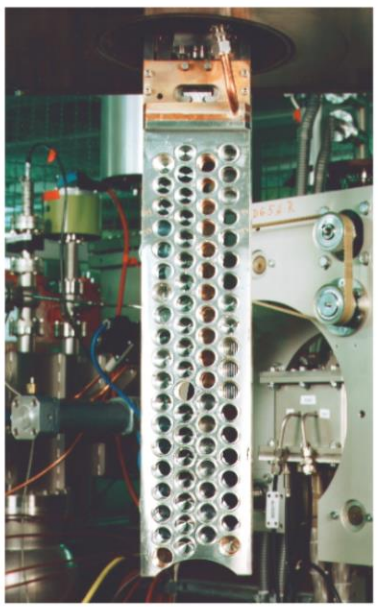
Facility	Max. Magnetic Rigidity $B\rho_{max}$ / [Tm]	Momentum Acceptance $\Delta p/p$	Angular Acceptance ϕ_x / [mrad]	ϕ_y / [mrad]	Momentum Resolution
FRS	18	±1 %	±7.5	±7.5	1500 (ε=20π mm mrad)
Super-FRS	20	±2.5 %	±40	±20	1500 (ε=40π mm mrad)



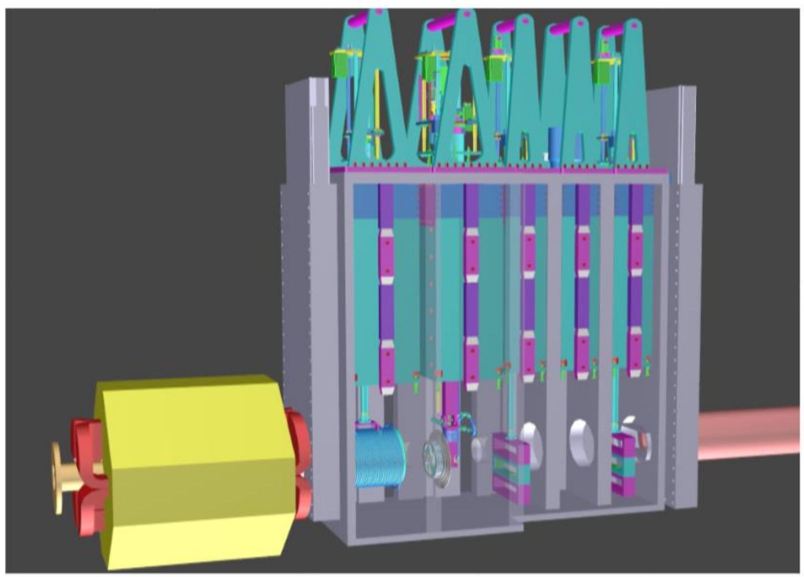
SuperFRS at FAIR

A total of 75 targets of different elements with differing thicknesses can be installed at the target station at the entrance of the fragment separator. Each of the cylindrical targets, which have a diameter of two centimeters, can be moved into the path of the ion beam with millimeter precision using step motor control. If required, the target holder can also be exchanged by remote control.

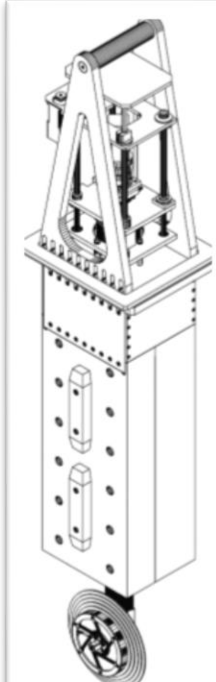
FRS



Targetchamber



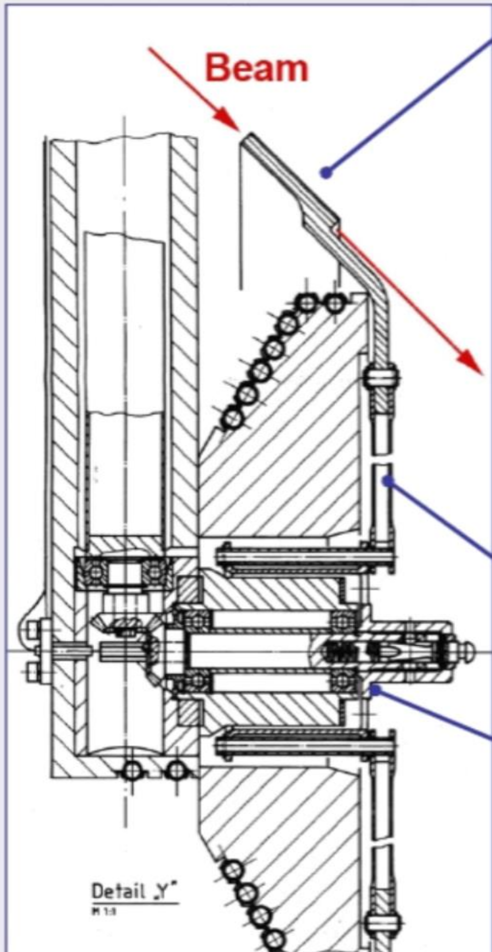
Target with shielding



Prototype

μ Production Target (Target E) at PSI

PSI — High Power Meson Production Target



TARGET CONE

3.0mA o.k., limit: sublimation

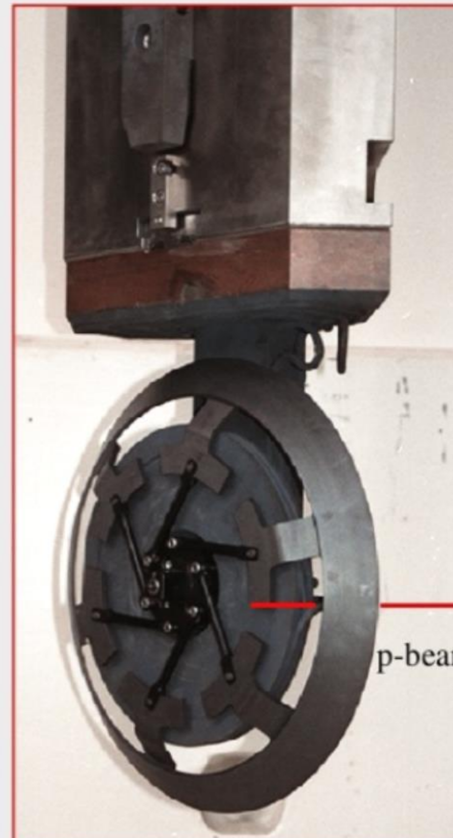
Mean diameter: **450 mm**
Graphite density: 1.8 g/cm^3
Operating Temp.: **1700 K**
Irrad. damage rate: 0.1 dpa/Ah
Rotation Speed: **1 Turn/s**
Target thickness: **60 / 40 mm**
10 / 7 g/cm^2
Beam loss: 18 / 12 %
Power deposit.: 30 / 20 kW/mA

SPOKES

To enable the thermal expansion of the target cone

BALL BEARINGS *)

Silicon nitride balls
Rings and cage silver coated
Lifetime 2 y
*) GMN, Nürnberg, Germany



G.Heidenreich et. al.

M.Seidel, ESS Bilbao Initiative Workshop, March 16-18 (2009)

SuperFRS at FAIR

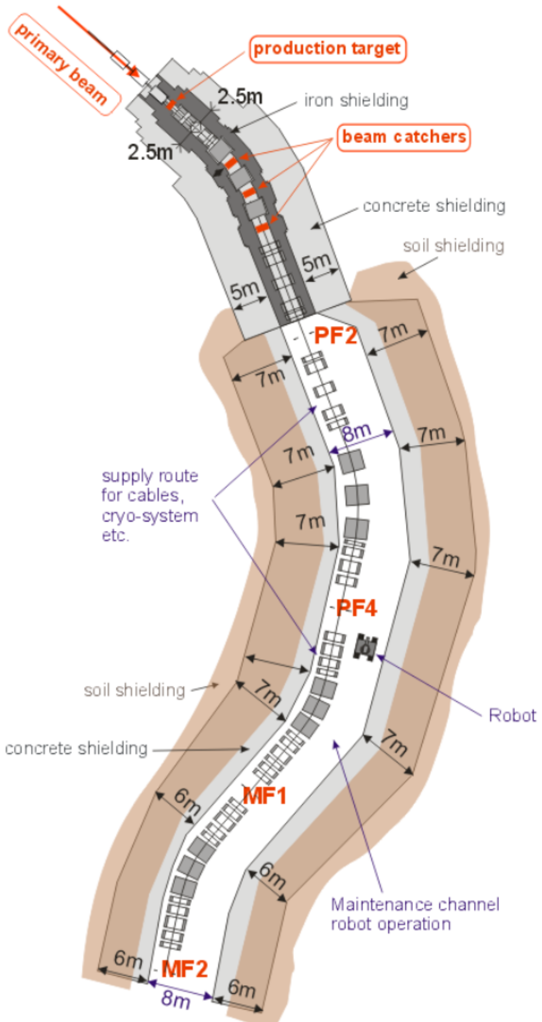


Figure 2.4-166: Schematic layout of the Super-FRS with beam line and shielding measures. The area from the target up to the intermediate focal plane PF2 of the Pre-Separator is shielded with iron in order to provide a compact radiation protection in the target building. The concrete in the Main-Separator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

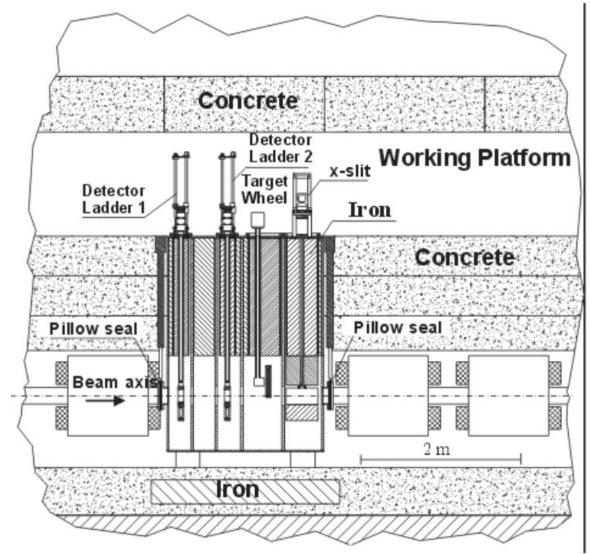


Figure 2.4-126: Schematic layout of the target area of the Super-FRS. A vertical plug system has been adapted which has proven to guarantee a safe and reliable operation at PSI in a very high radiation field. Routine maintenance at PSI is done about once per year.

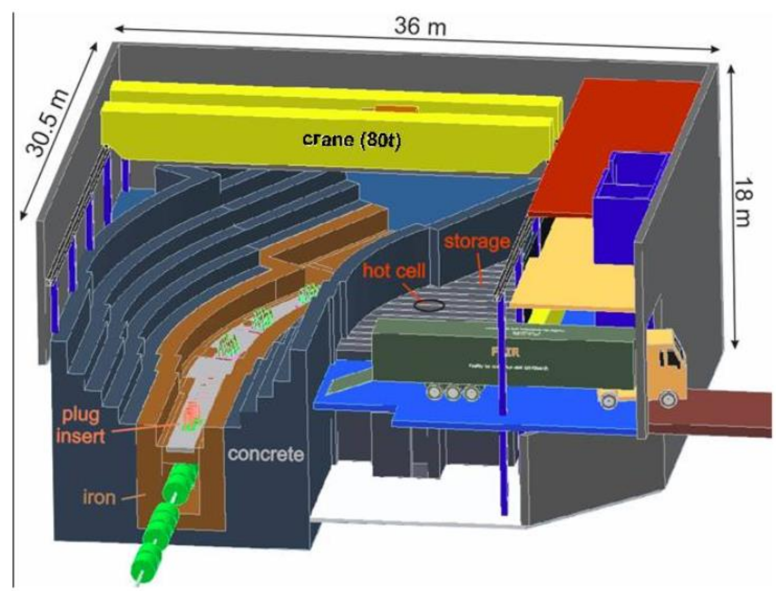
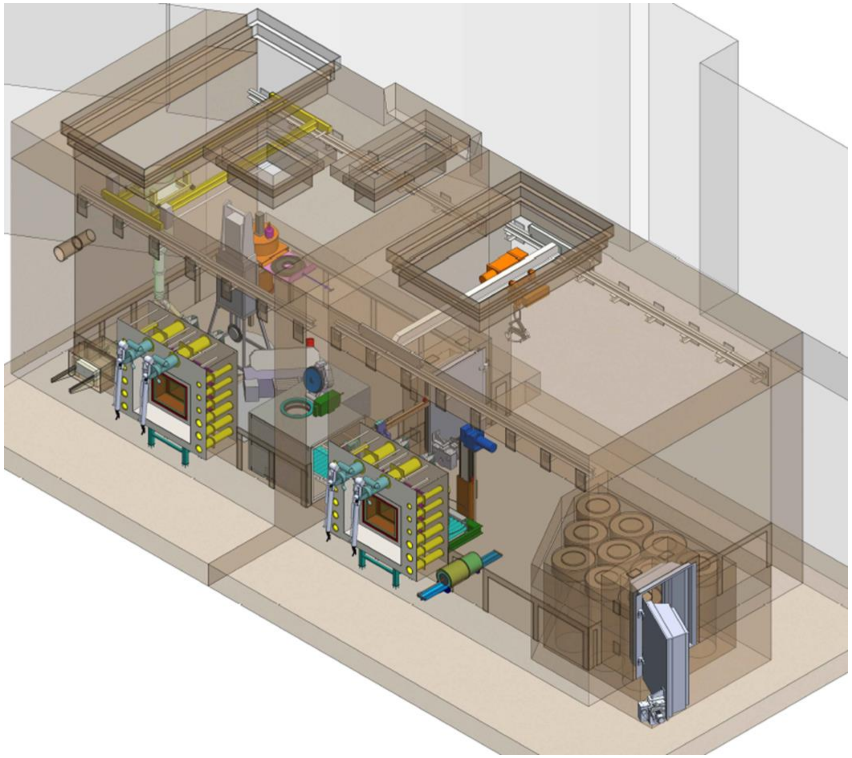


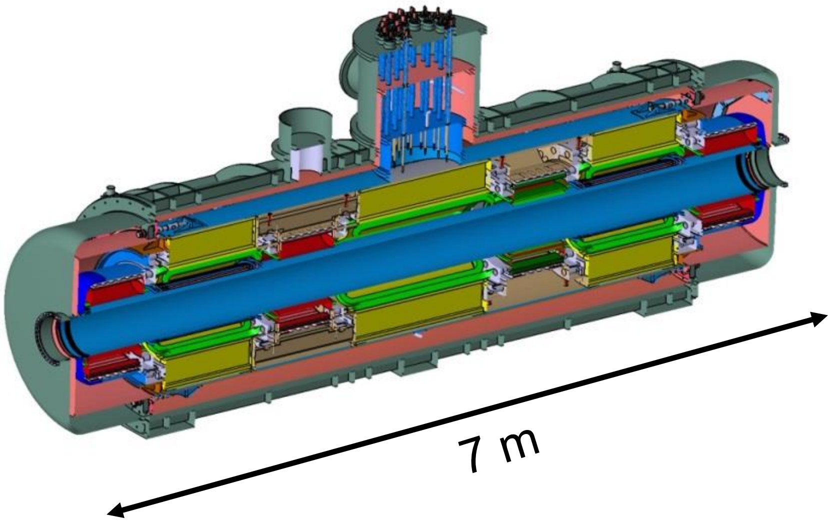
Figure 2.4-175: Layout of the Super-FRS target building. The top part of the concrete shielding can be removed to access the working platform. Heavy devices can be transported by crane to the nearby hot cell, storage places or directly onto a truck which can drive into the hall.

Target Handling

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.



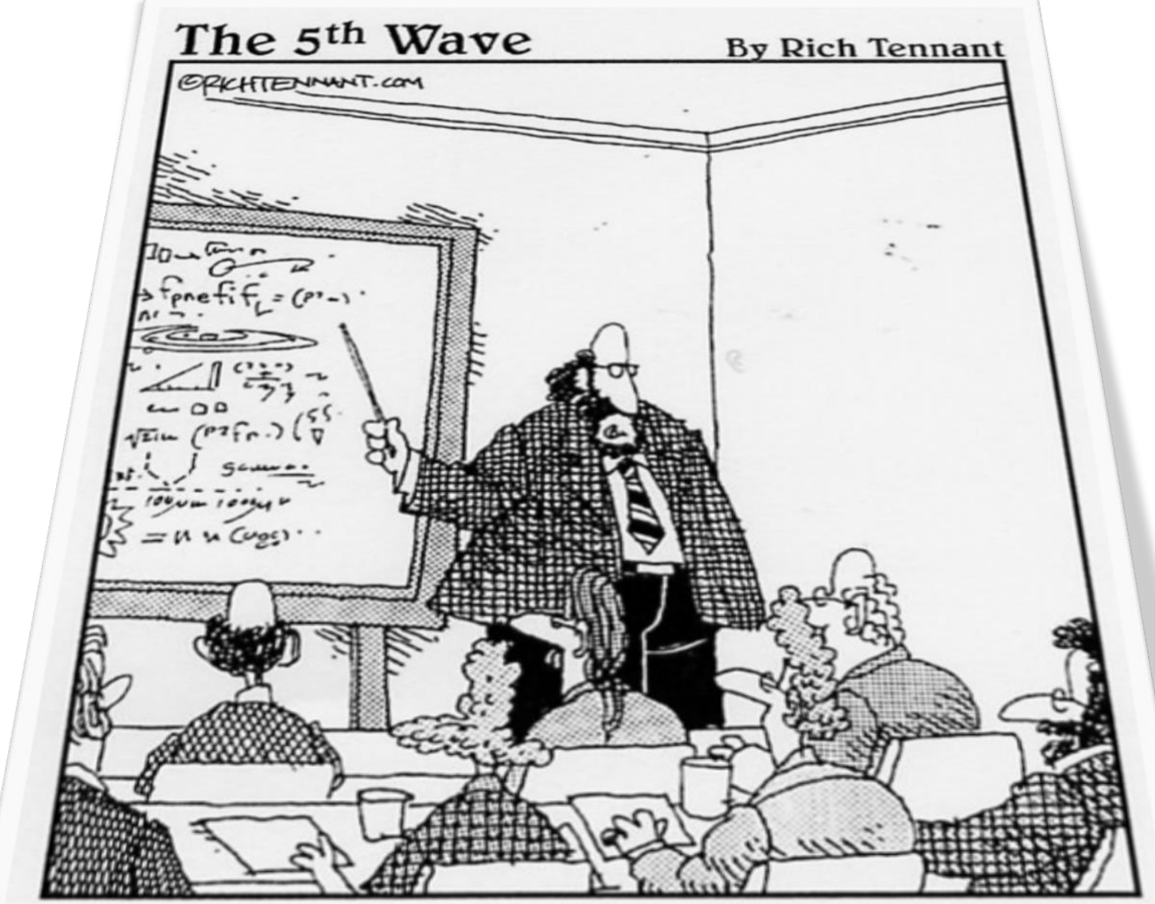
Superconducting Multiplets



- 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

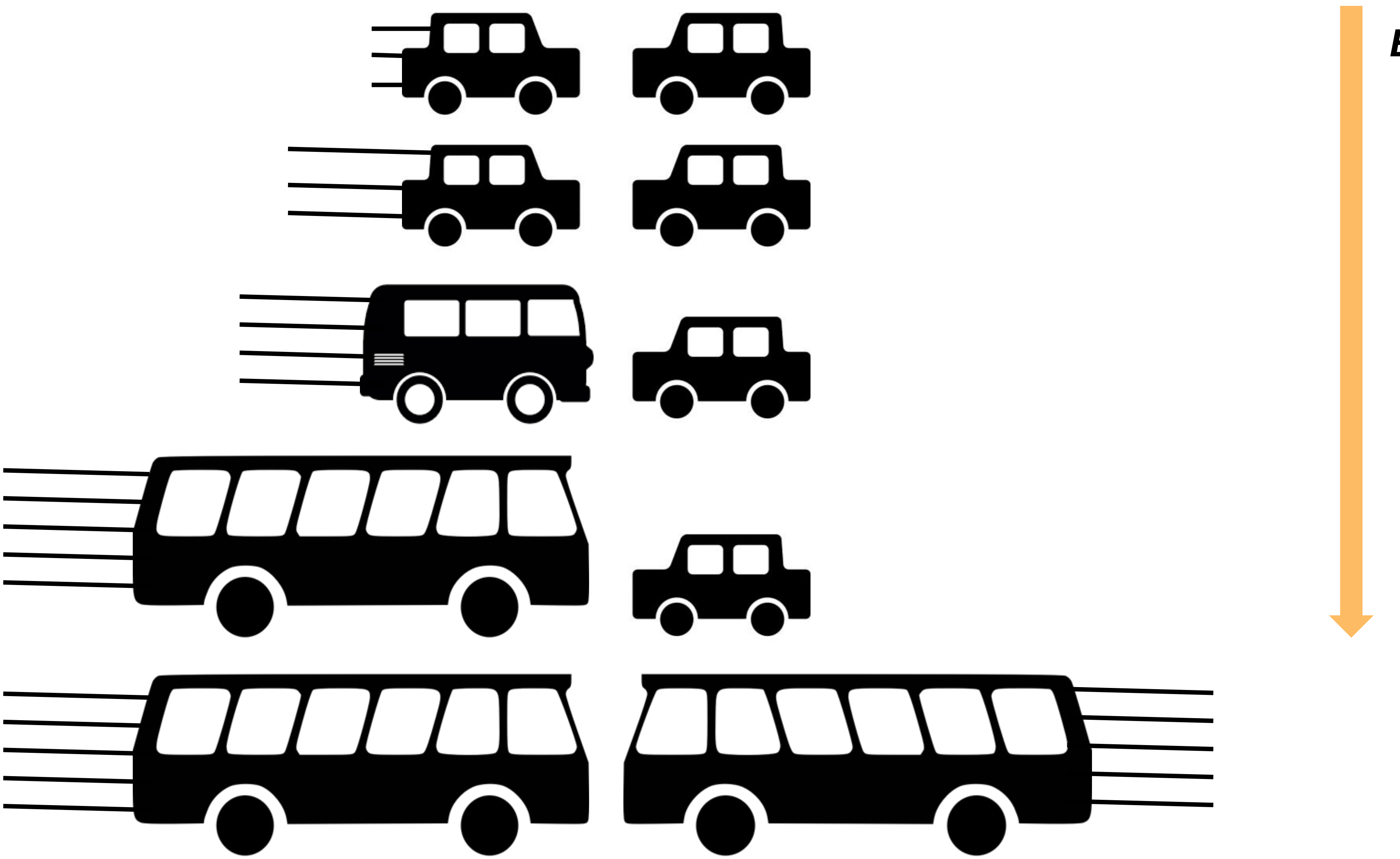
- iron dominated, cold iron (≈40 tons)
- common helium bath, LHe ≈ 1.300 l
- warm beam pipe (38 cm inner diameter)
- per magnet 1 pair of current leads
- max. current <300A for all magnets

Antiprotons at FAIR



"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.

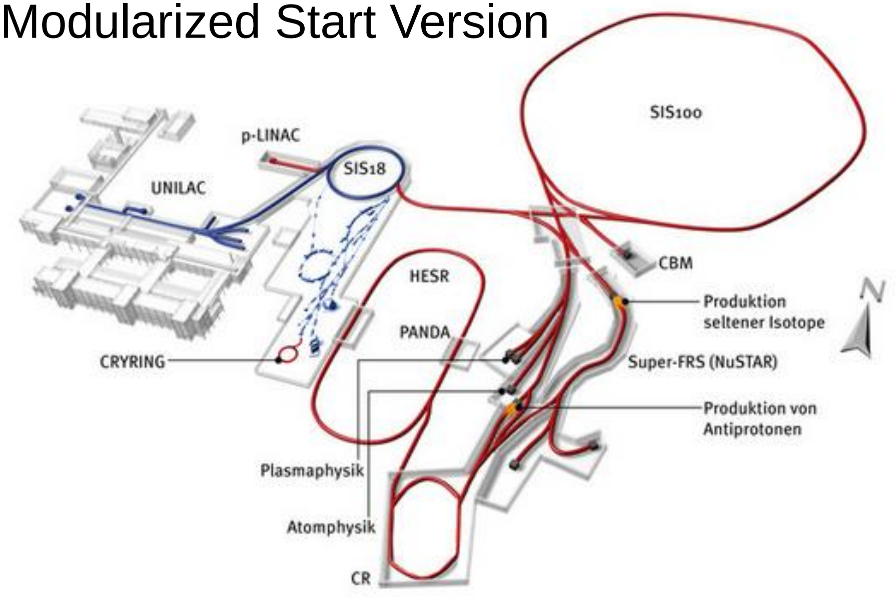
FAIR / CERN / FNAL pbar Sources

	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

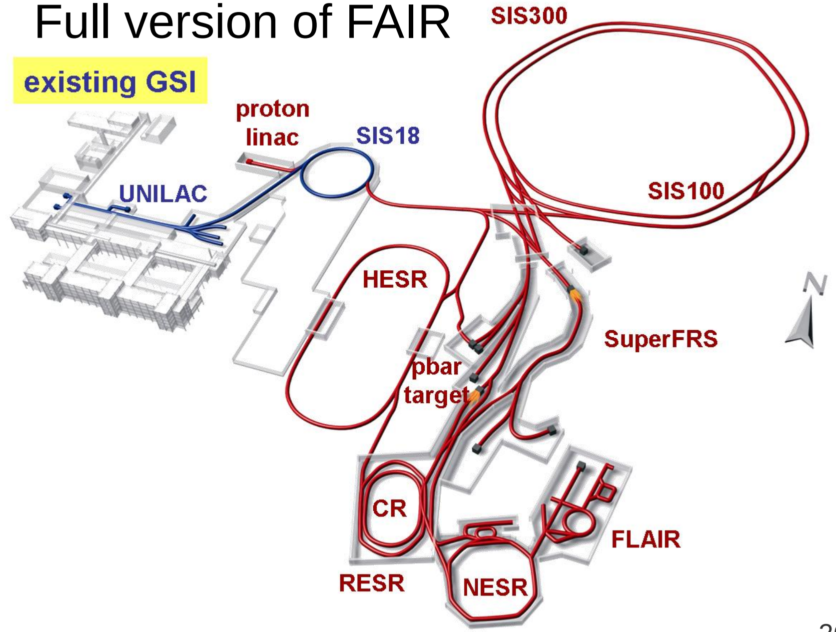
The Antiproton Chain

- 70 MeV / 70 mA dedicated pLinac
- SIS18 (4 GeV p)
- SIS100 (29 GeV p)
- Target / Separator: ≈10^{13} ppp → ≈10^{8} pbar (0.1 Hz)
- Stochastic cooling of hot pbars in collector ring
- accumulation of pbars in accumulator ring (1 h)
  ≈10^{8} pbar → ≈10^{10} - 10^{11} pbar
- transfer to experimental ring → measurement
- continue accumulation during measurement
- Alternatively, accumulation and measurement can be done in one ring.

Modularized Start Version

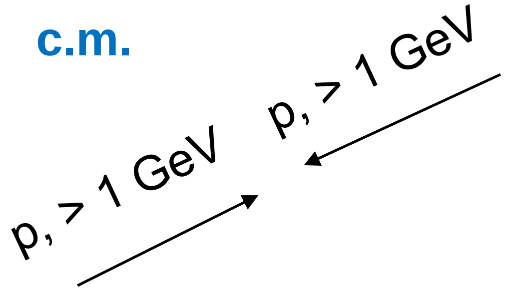


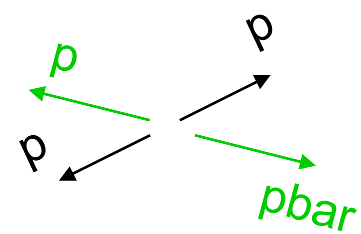
Full version of FAIR



Creation of Antiprotons

c.m.

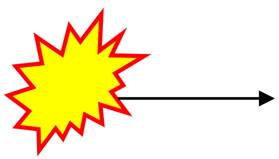


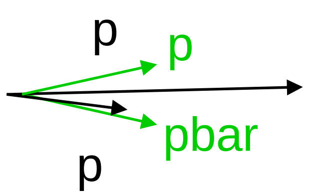


$m = E / c^2$

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

lab

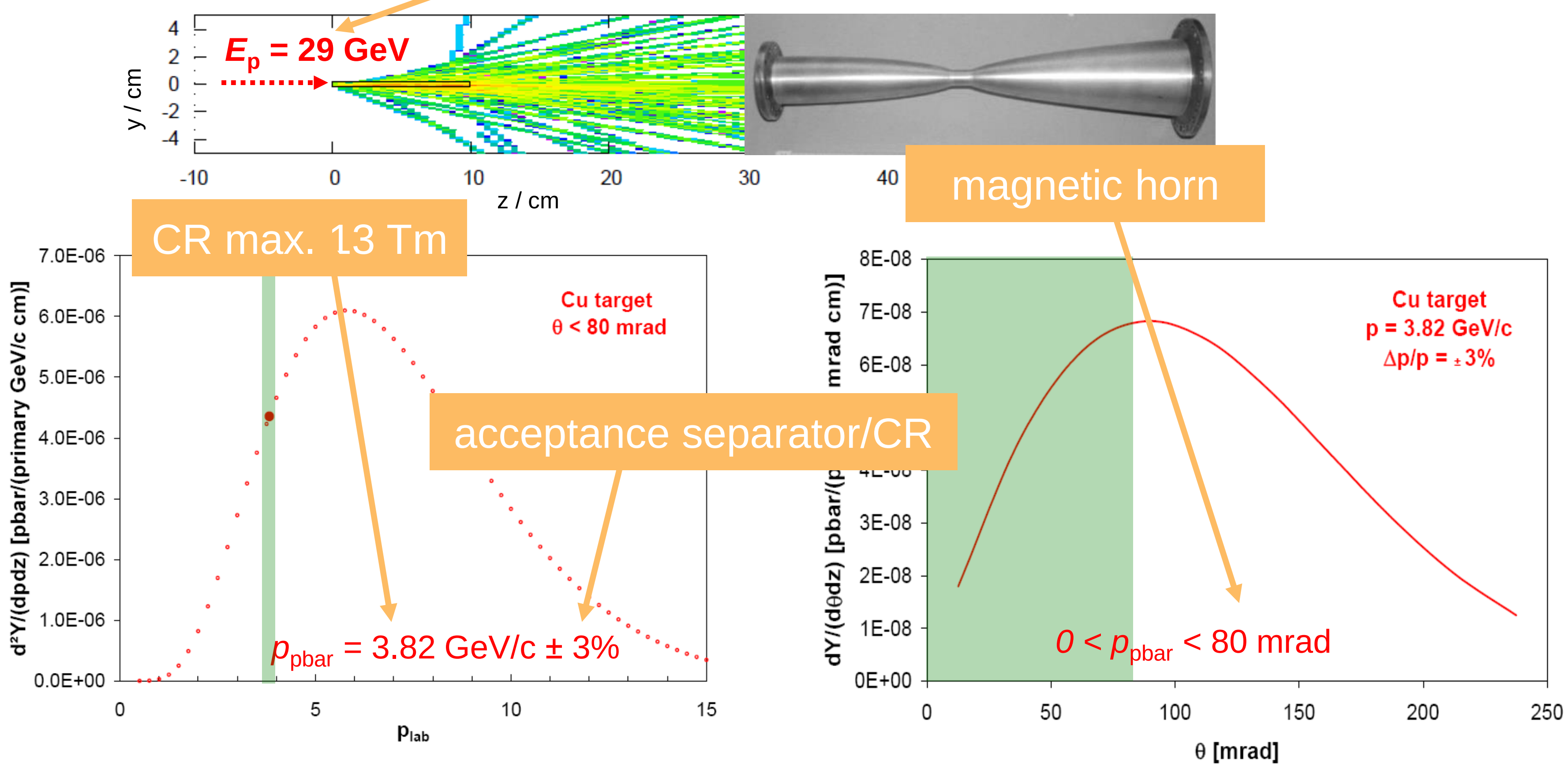




$m = E / c^2$

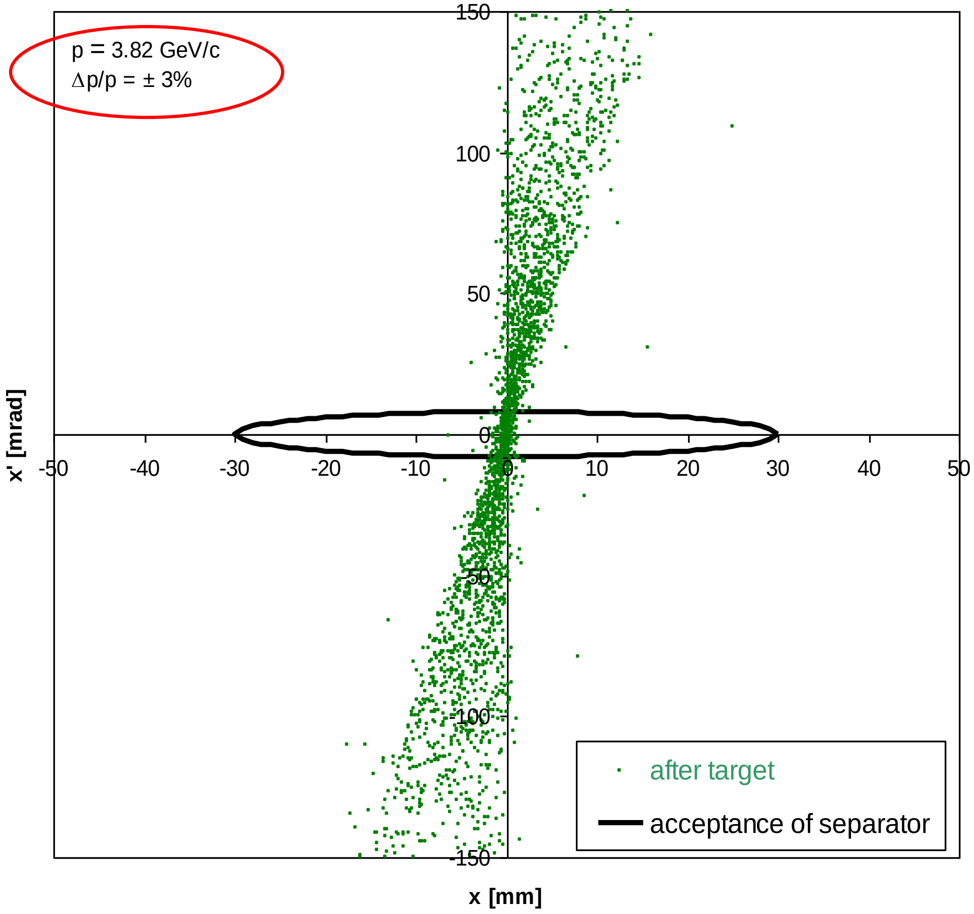
$T_{pbar} > 6$ GeV

Collectible pbars

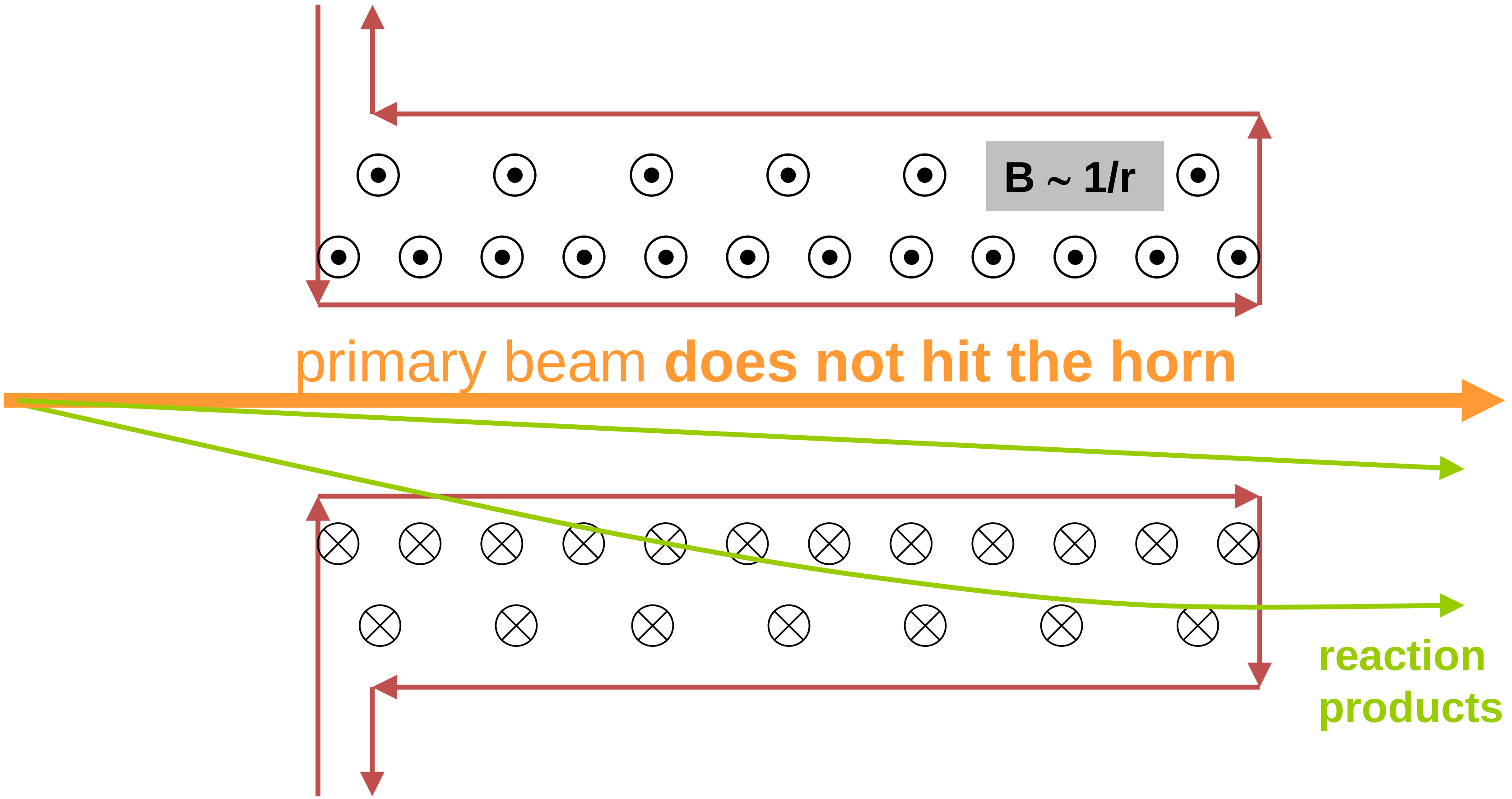


From ~ 2.5 × 10^{-4} pbar / (p cm target) ~ 5 × 10^{-6} (or 2 %) are "collectible"

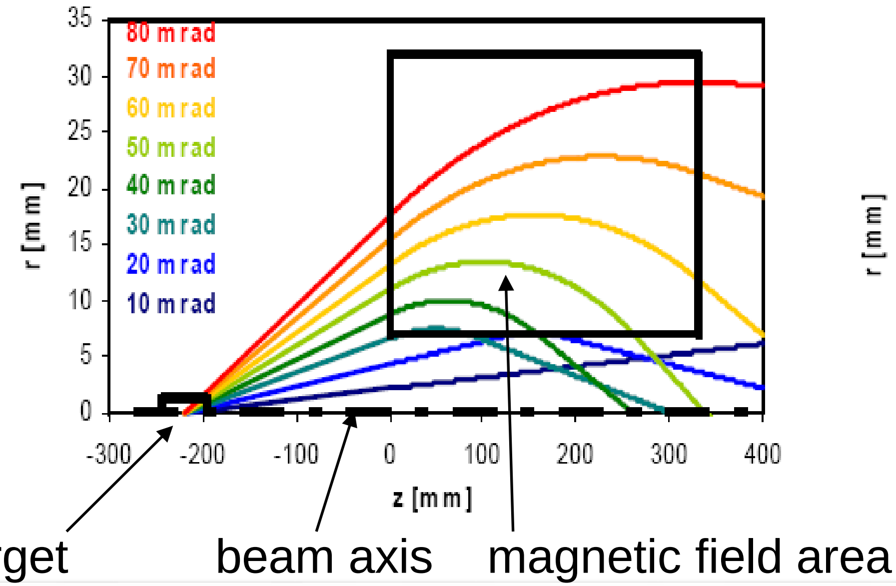
MARS Simulation of the pbar Yields

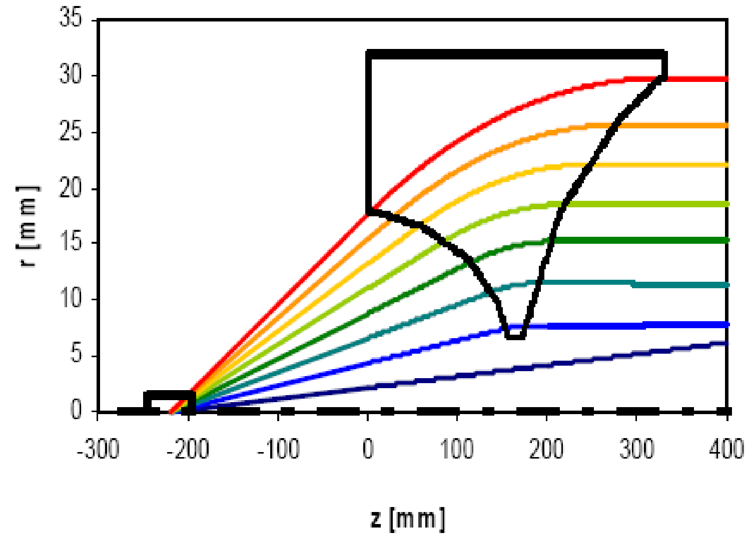


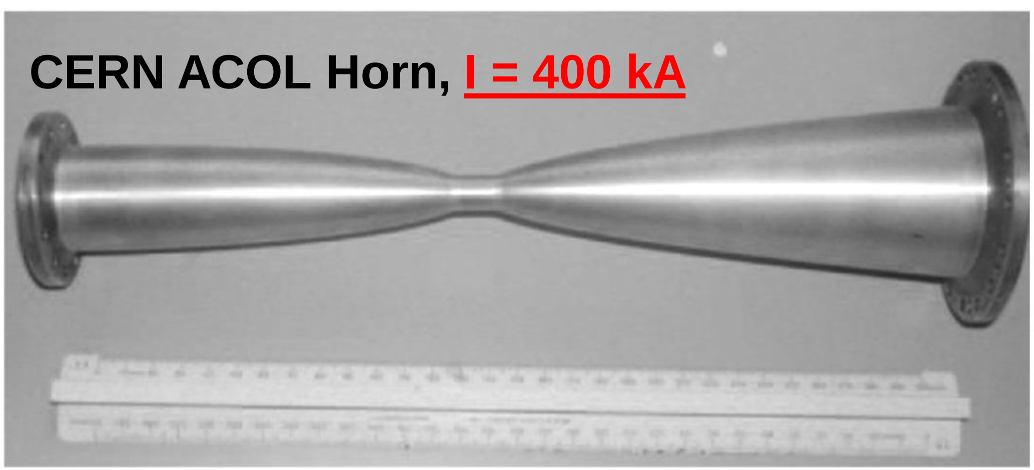
Collecting pbars: Magnetic Horn

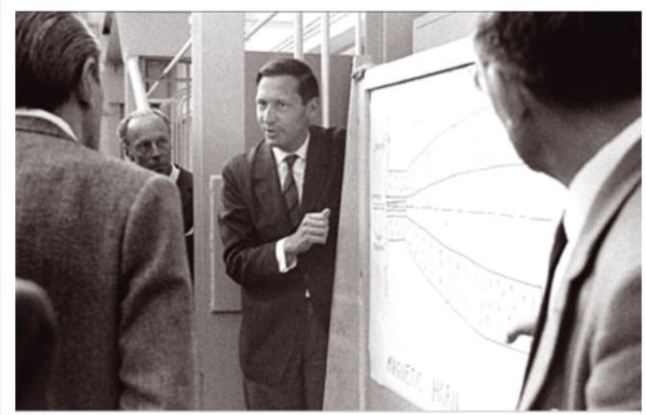


Collecting pbars: Magnetic Horn



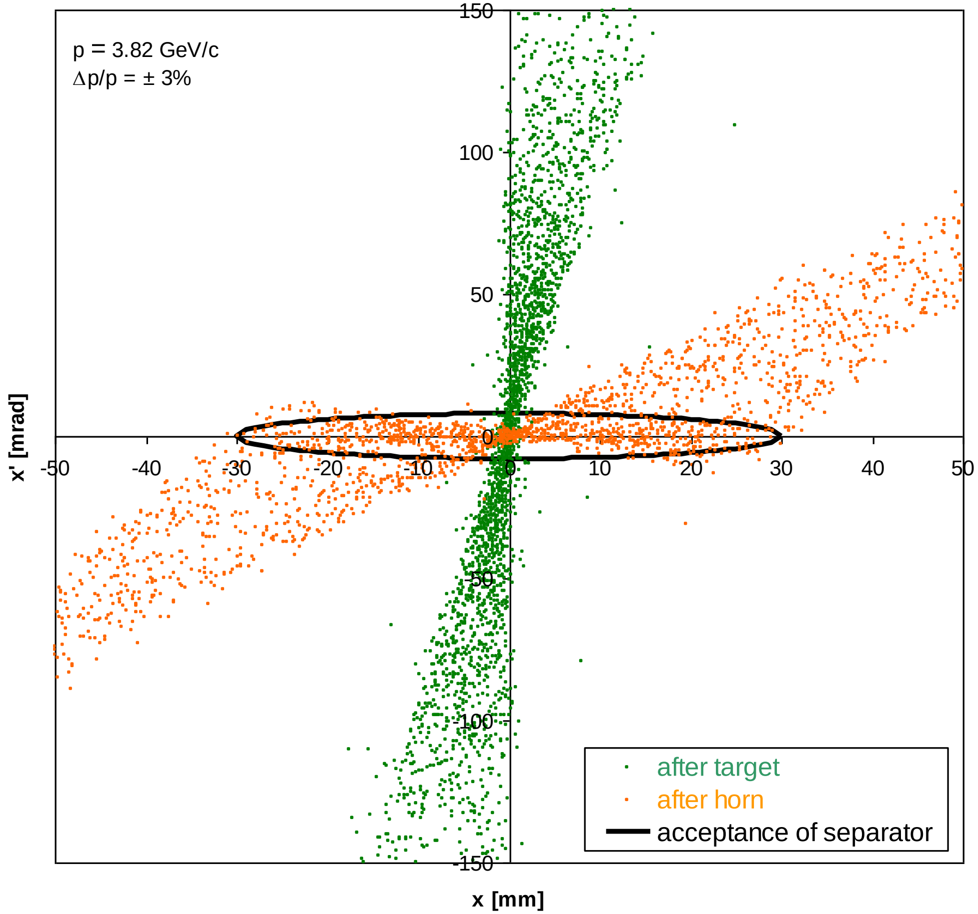






Simon van der Meer explaining the concept of the magnetic horn to visitors in 1962.

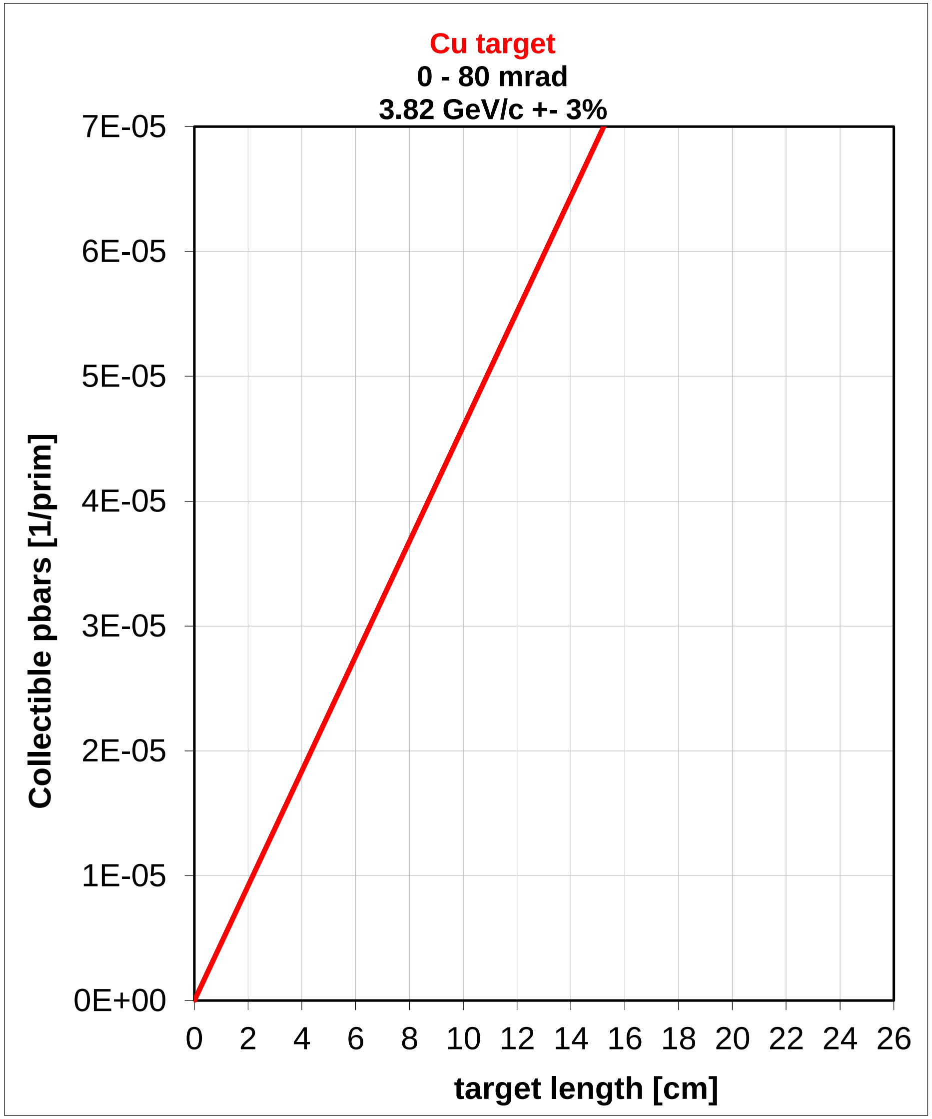
MARS Simulation of the pbar Yields



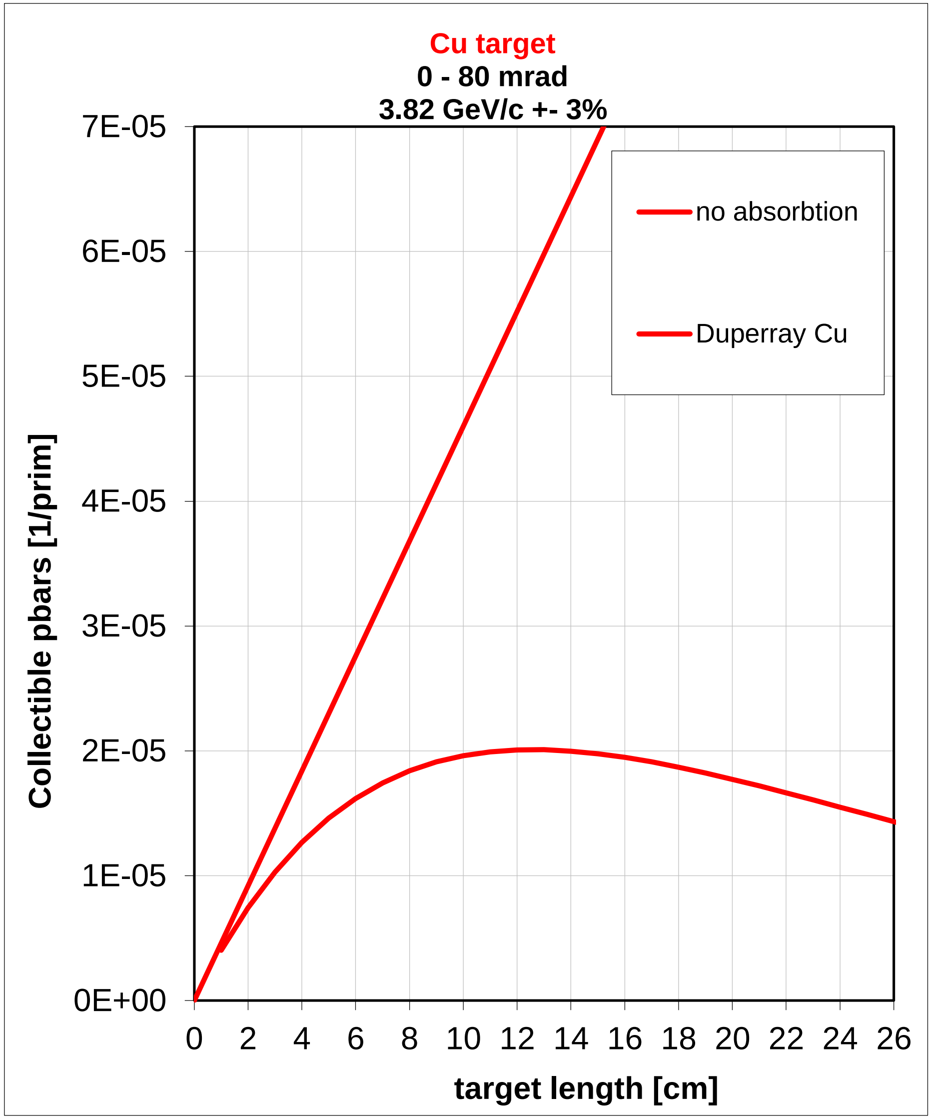
$$\text{yield} = \frac{\text{pbars in the ellipse}}{\text{primary protons}}$$

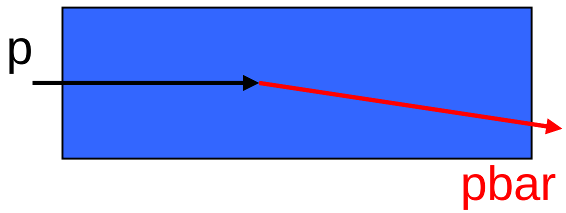
$$= 2 \times 10^{-5}$$

Collectible pbars



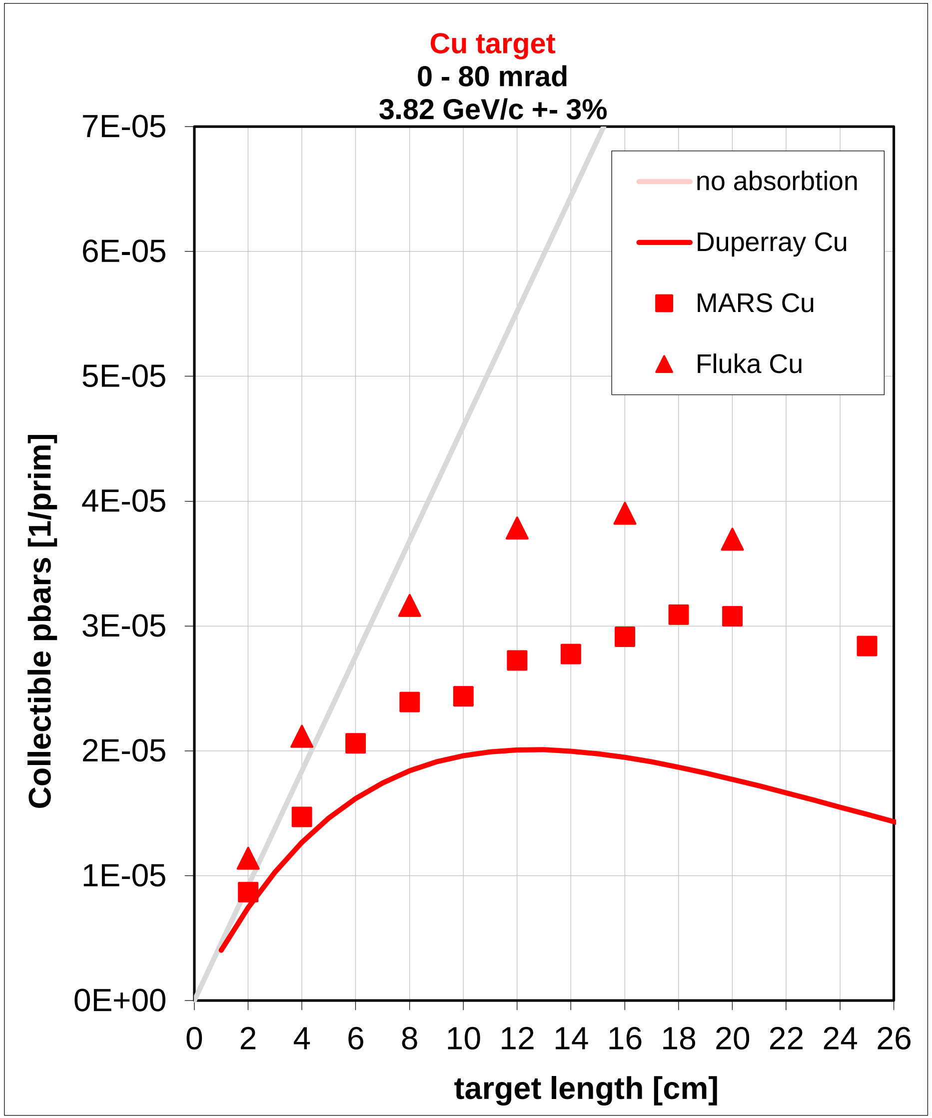
Collectible pbars: Self Absorption

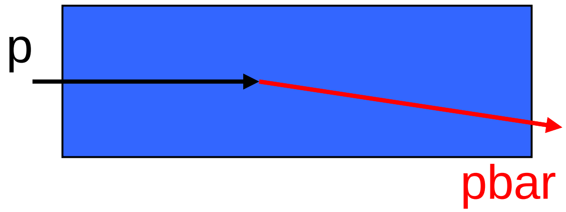




Cu: σ_{pbar} = 0.8 b

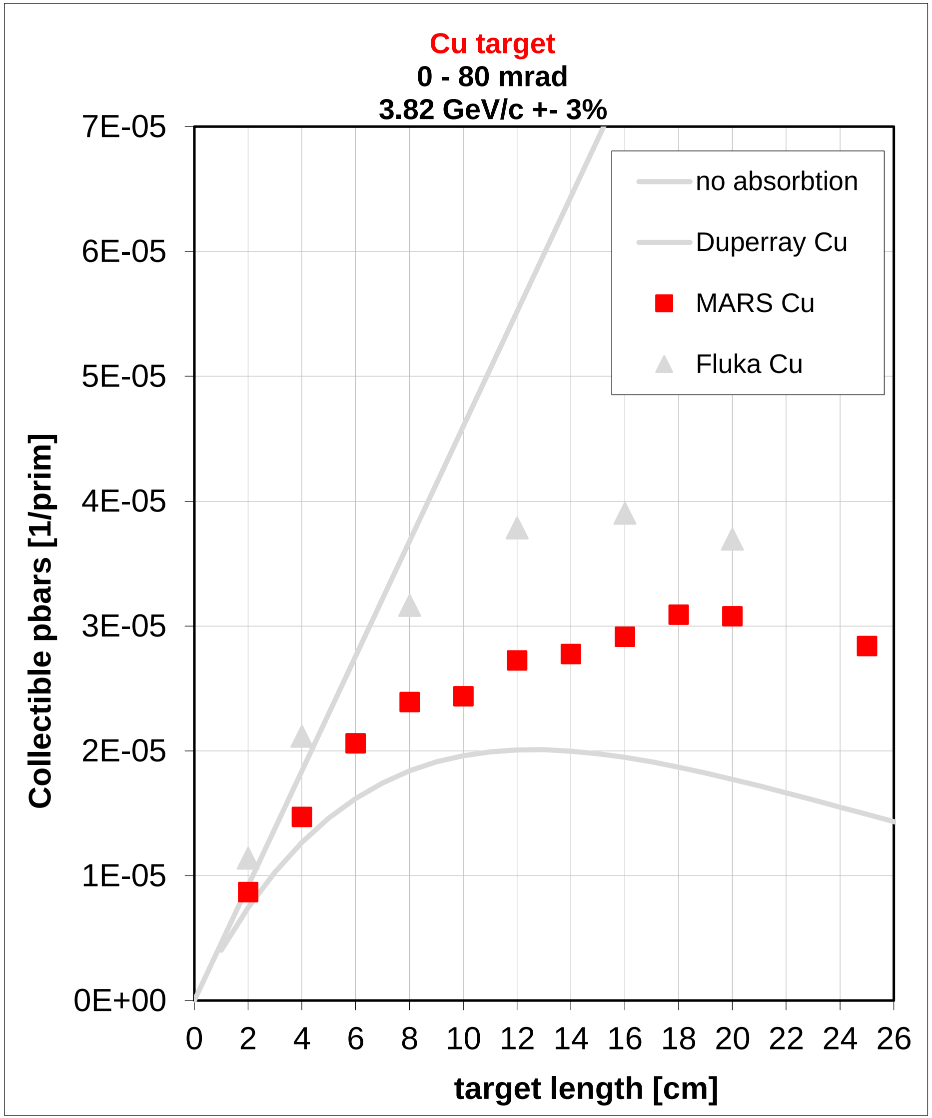
Collectible pbars: MARS/FLUKA

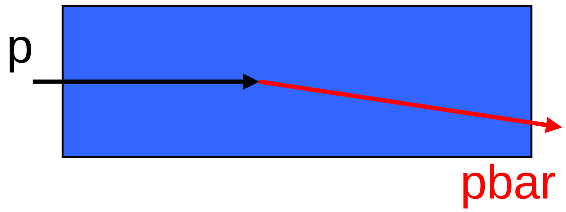




Cu: σ_{pbar} = 0.8 b

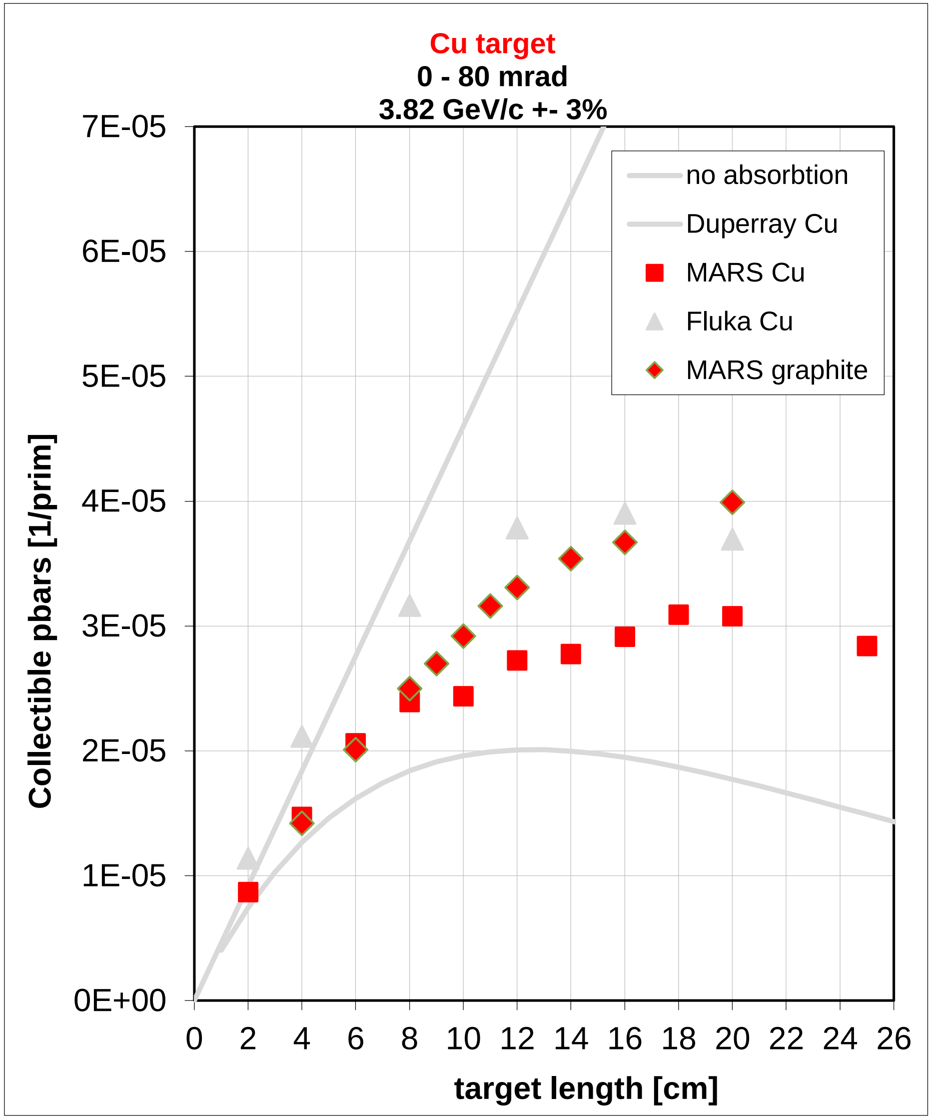
Collectible pbars: MARS

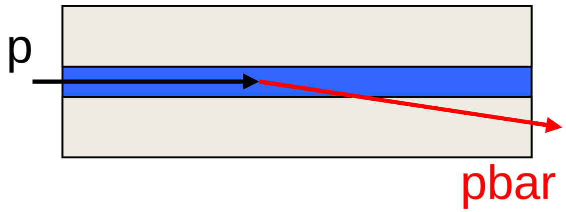




Cu: σ_{pbar} = 0.8 b

Collectible pbars: Graphite Surrounding

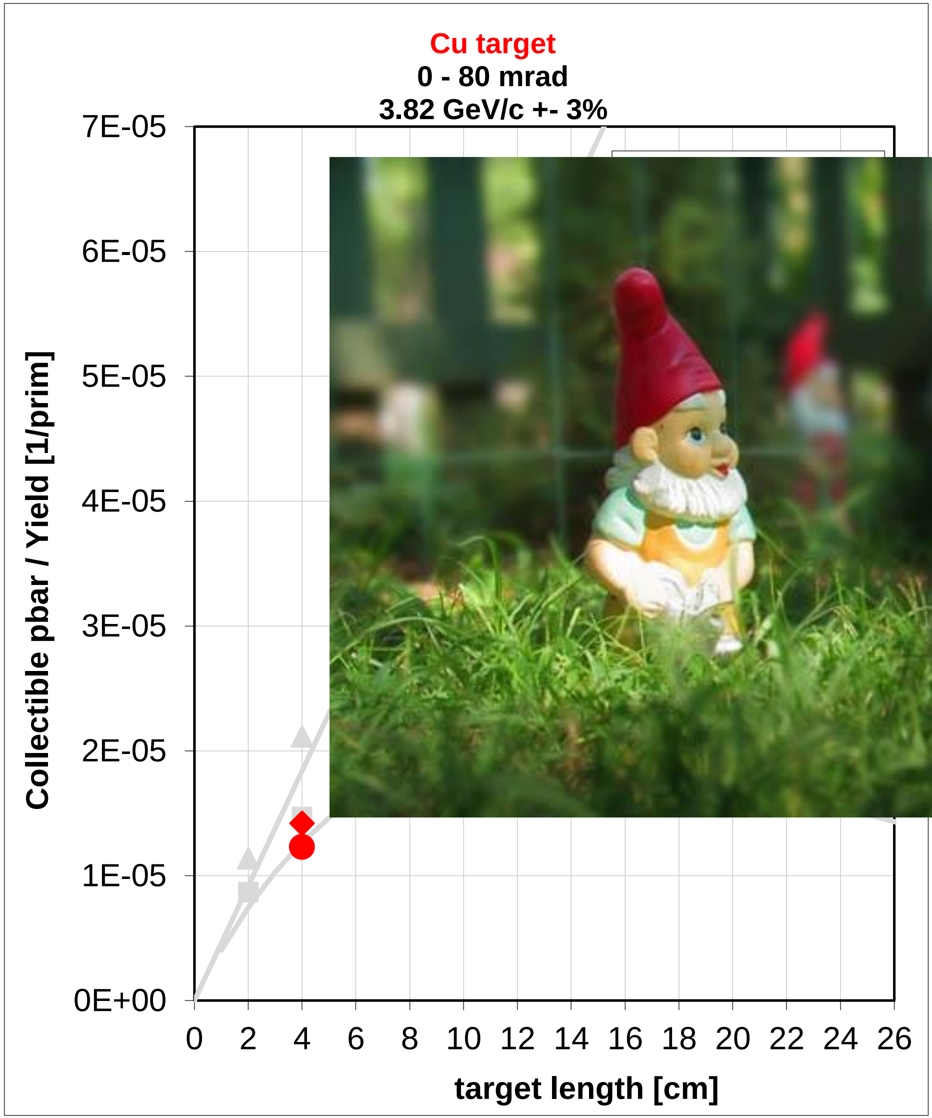


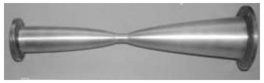


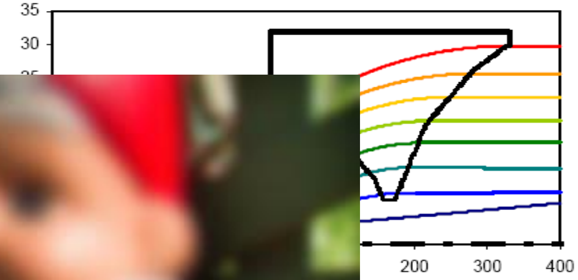
Cu: σ_{pbar} = 8.8 b

C: σ_{pbar} = 0.42 b

pbar Yield:
Collection efficiency of the magnetic horn

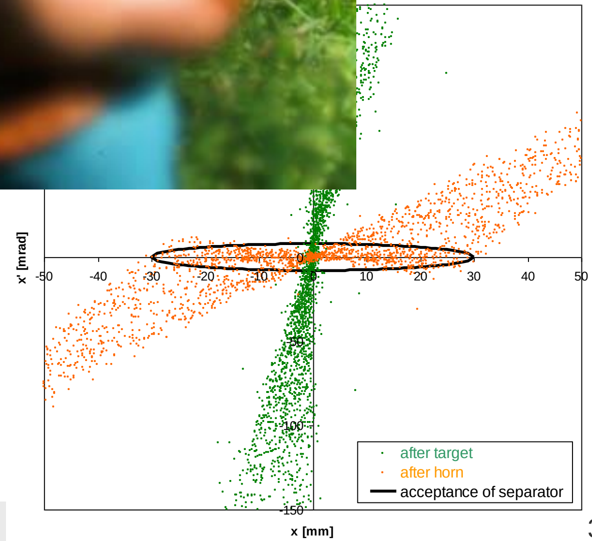




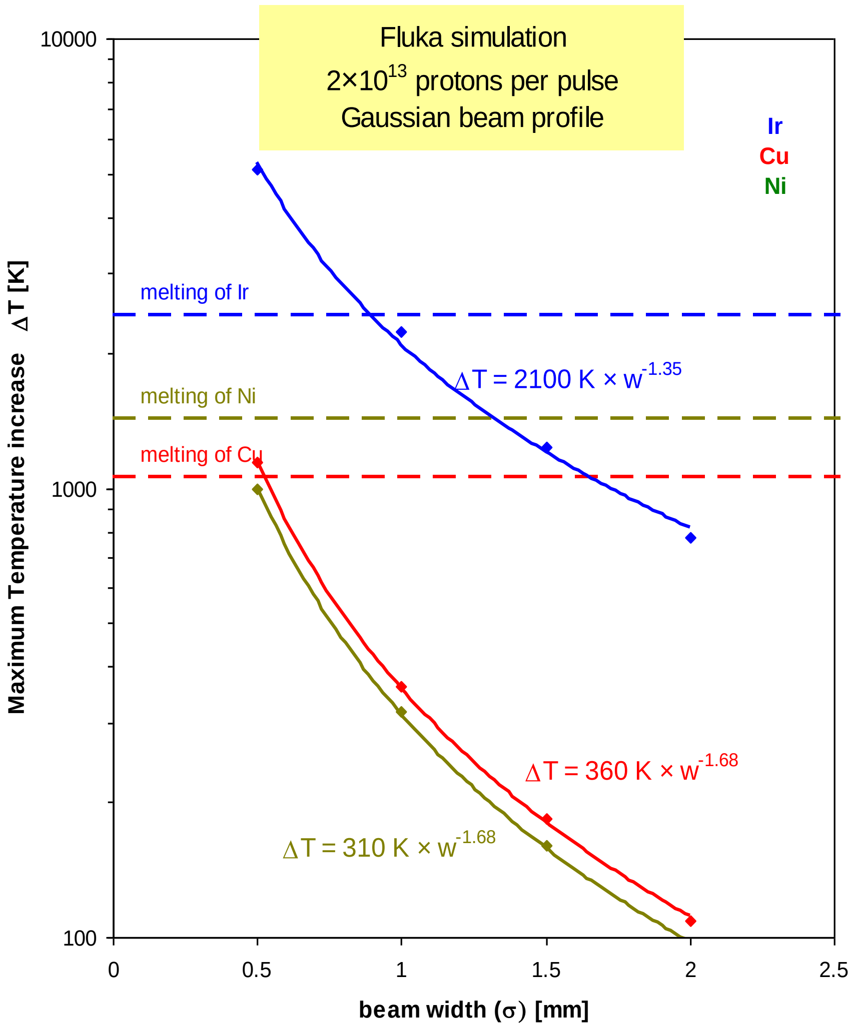


e ellipse

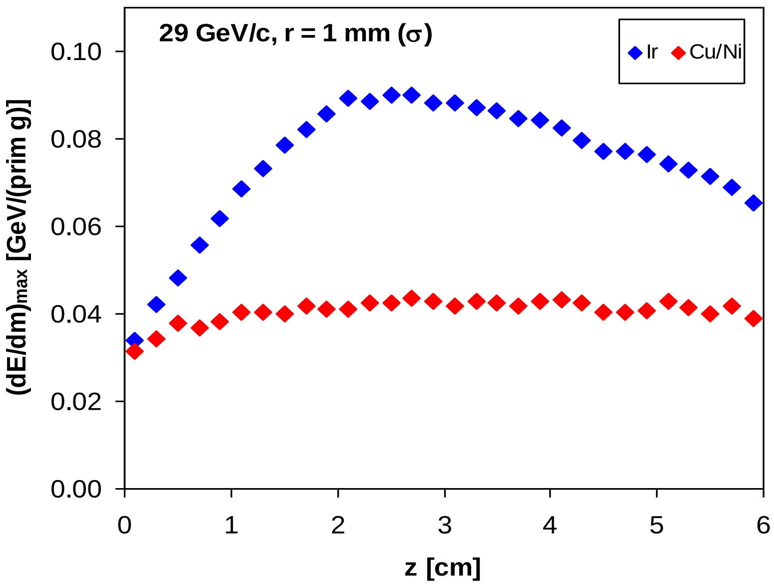
rotons



pbar Yield: High densitiy targets?



Ir (used at CERN), 22.65 g/cm³

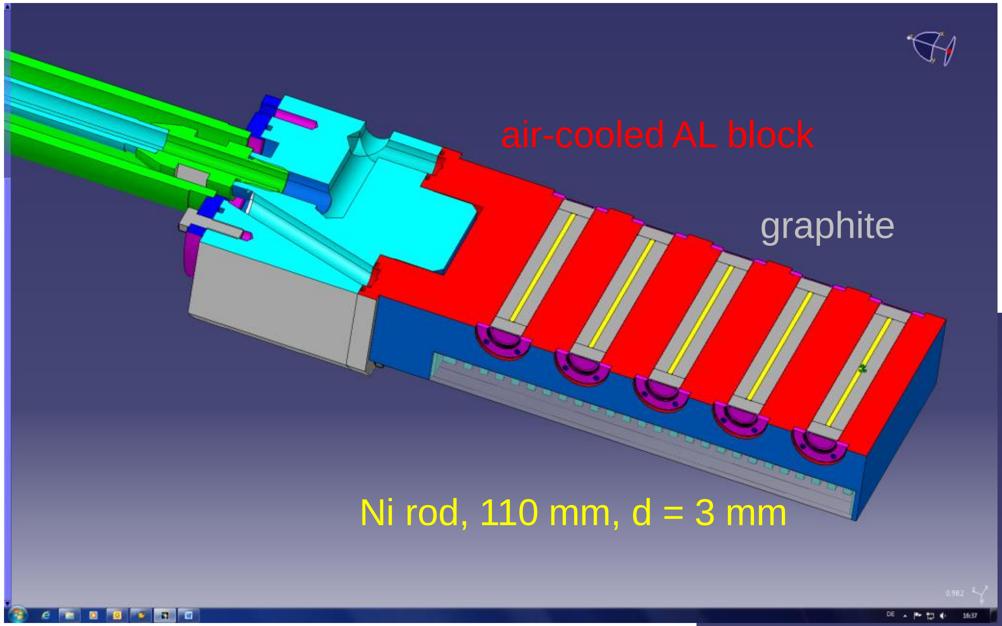


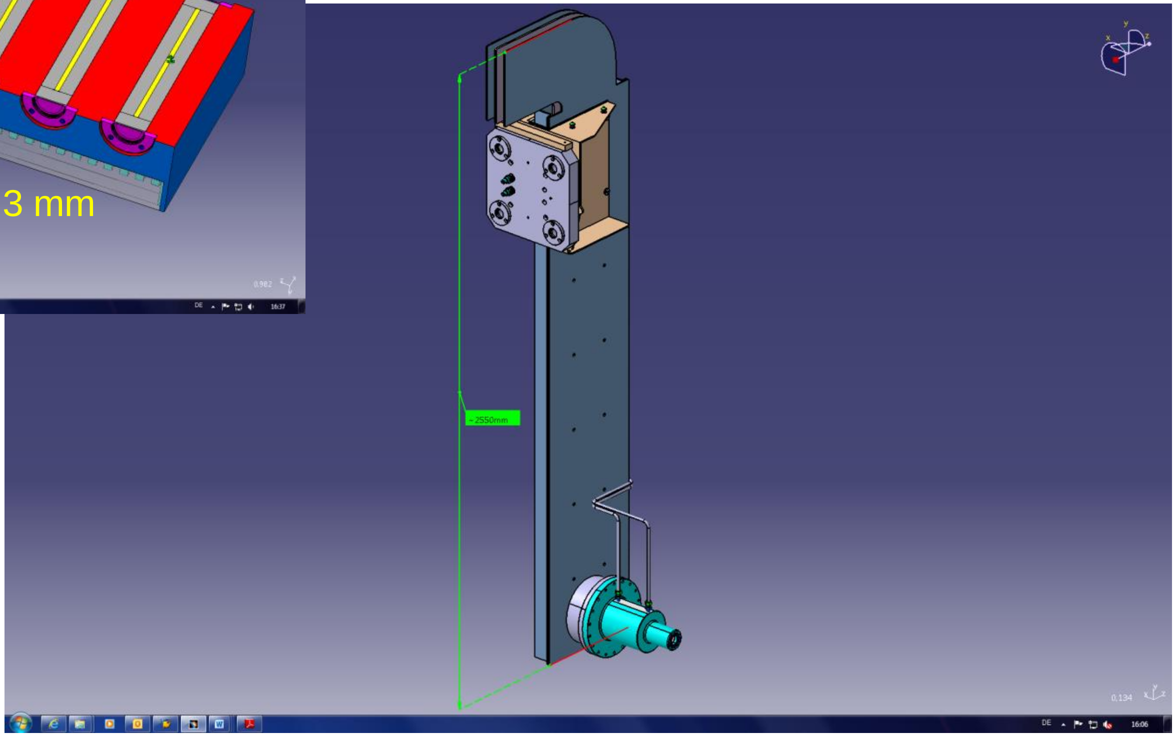
c_{Ir} = 130 J kg^{-1} K^{-1}

c_{Cu} = 385 J kg^{-1} K^{-1}

c_{Ni} = 440 J kg-1 K^{-1}

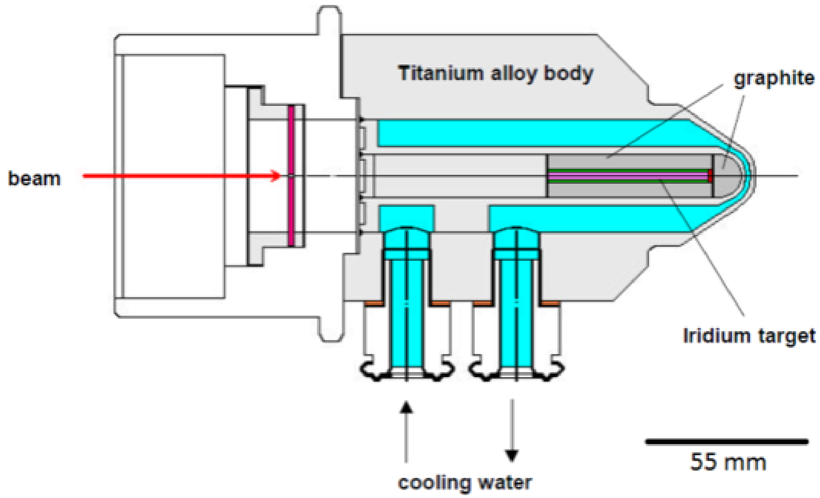
pbar Target and Magnetic Horn



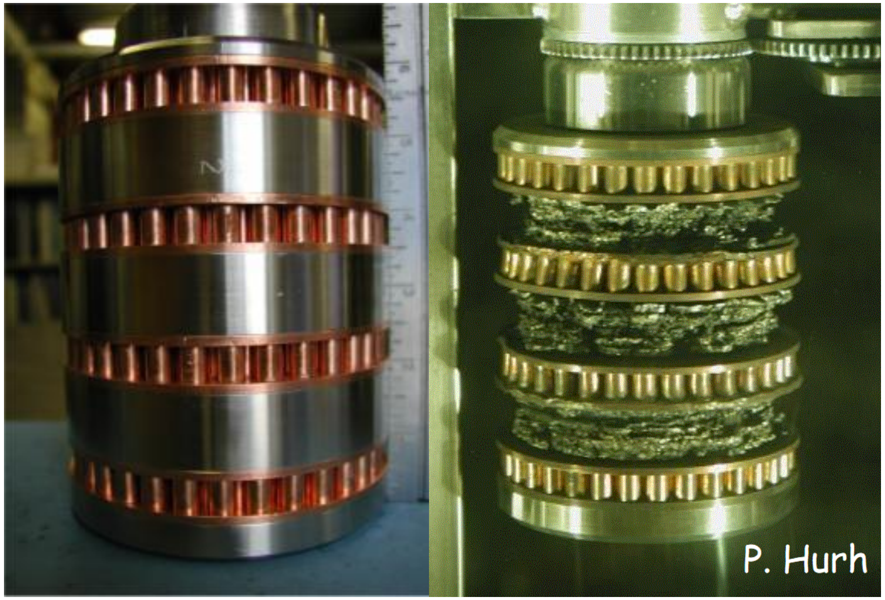


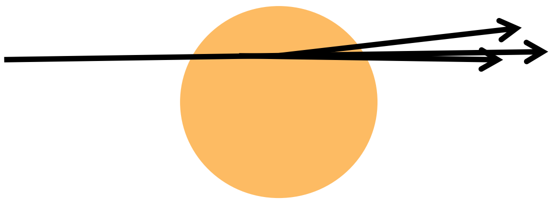
CERN and Fermilab pbar Targets

CERN target (Ir or Cu)

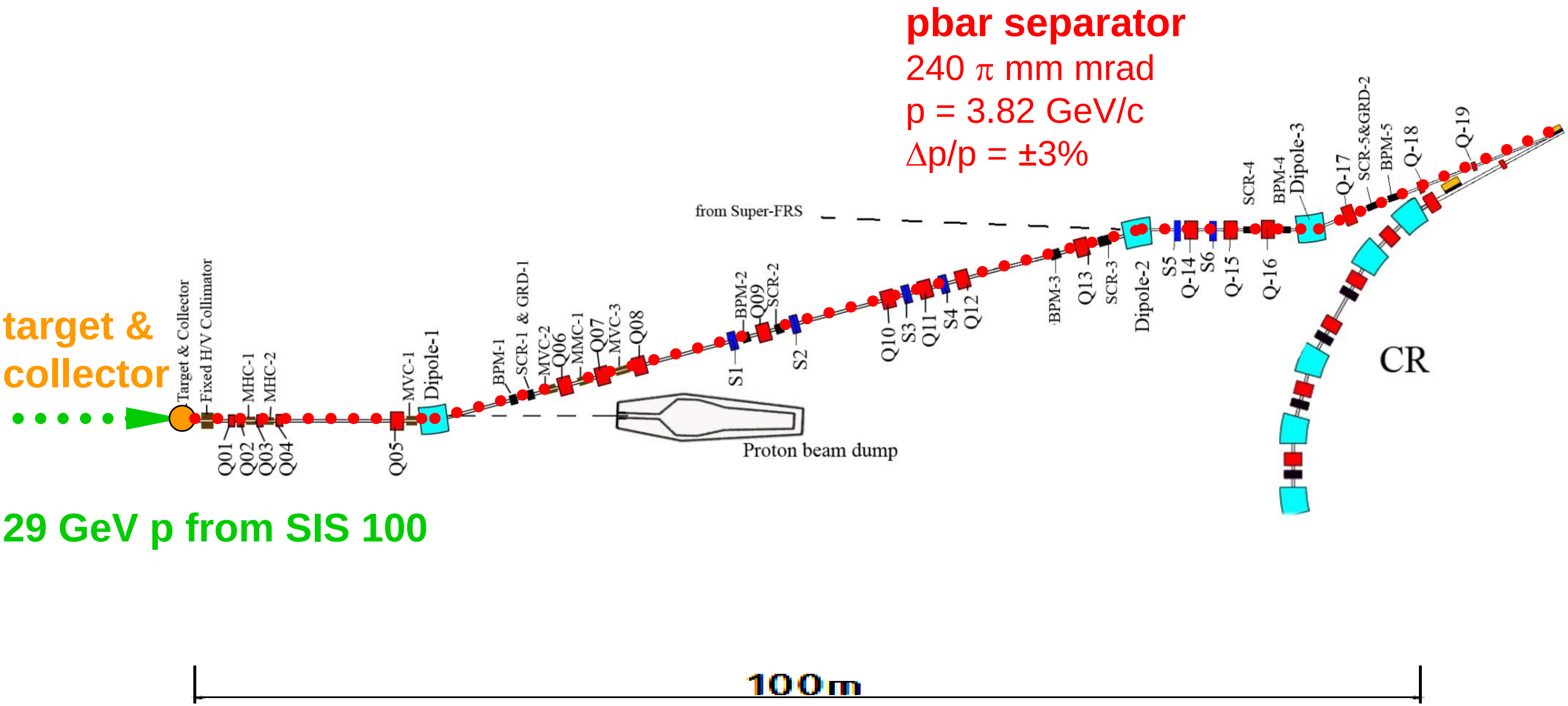


rotating Fermilab target, new and old

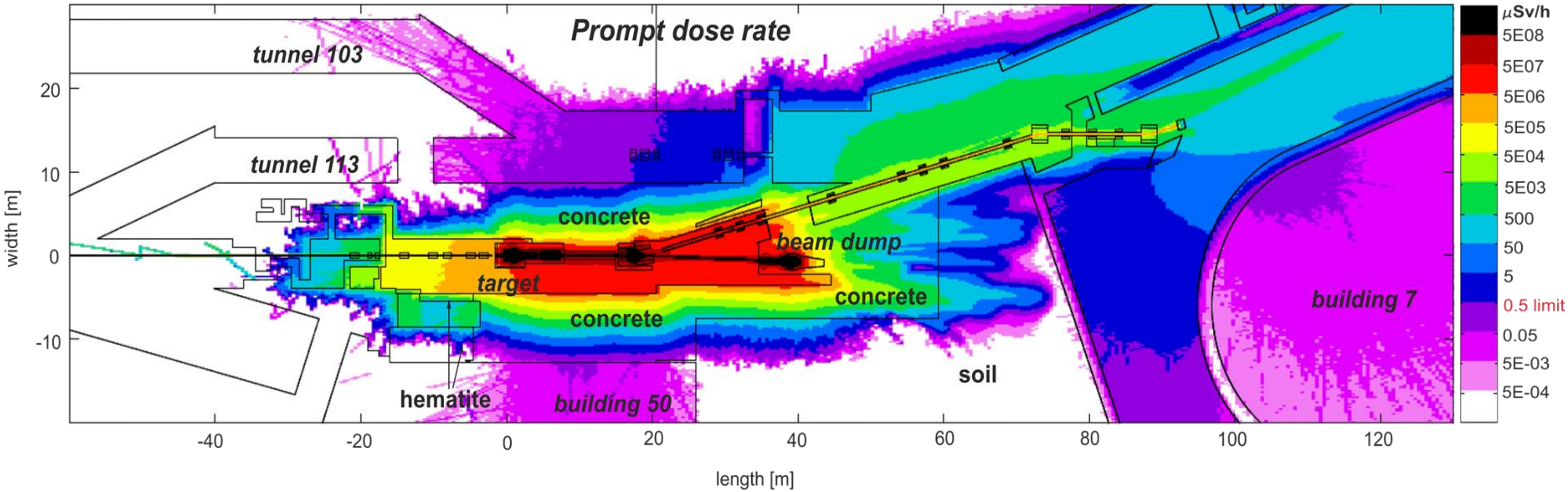




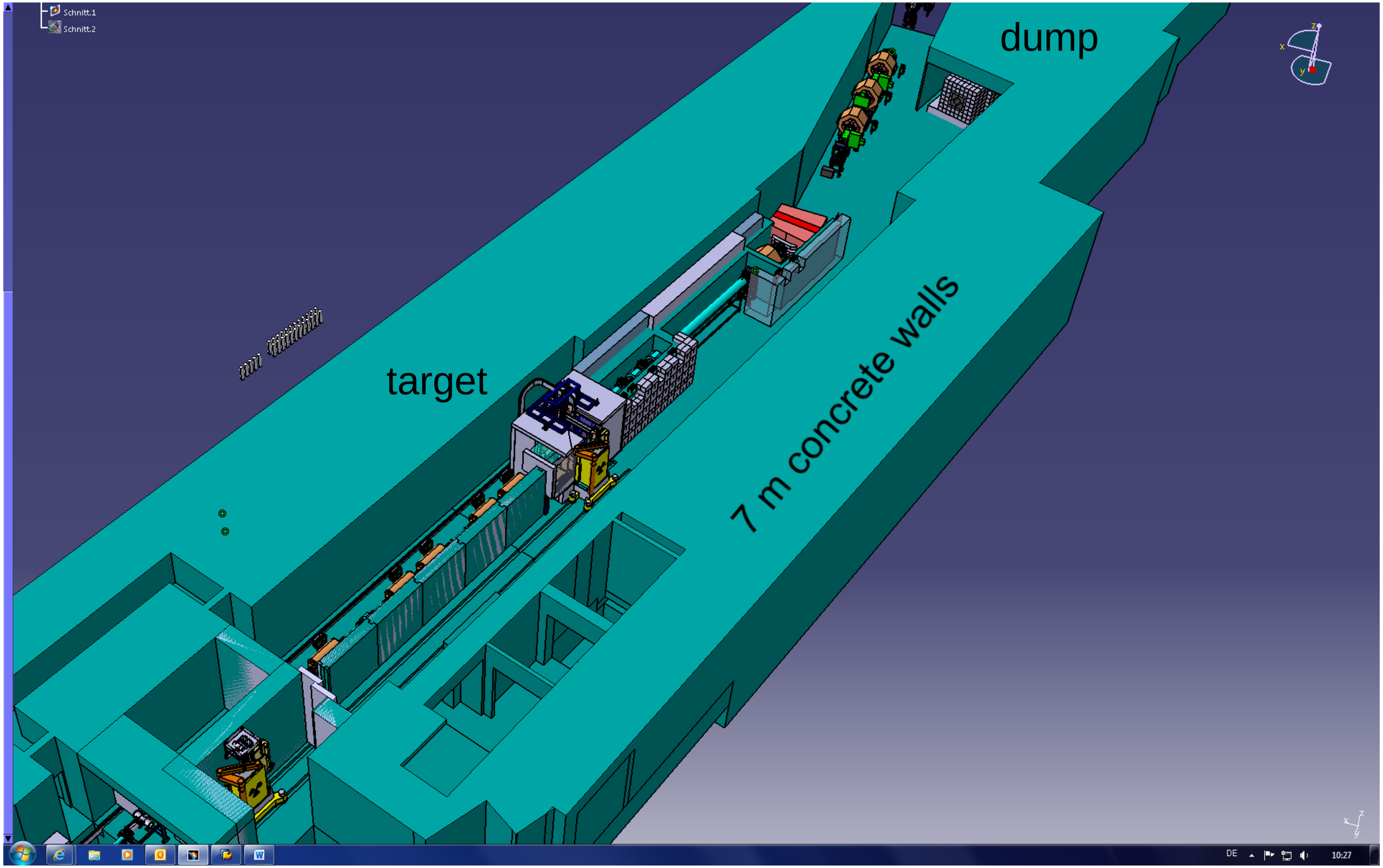
The pbar separator



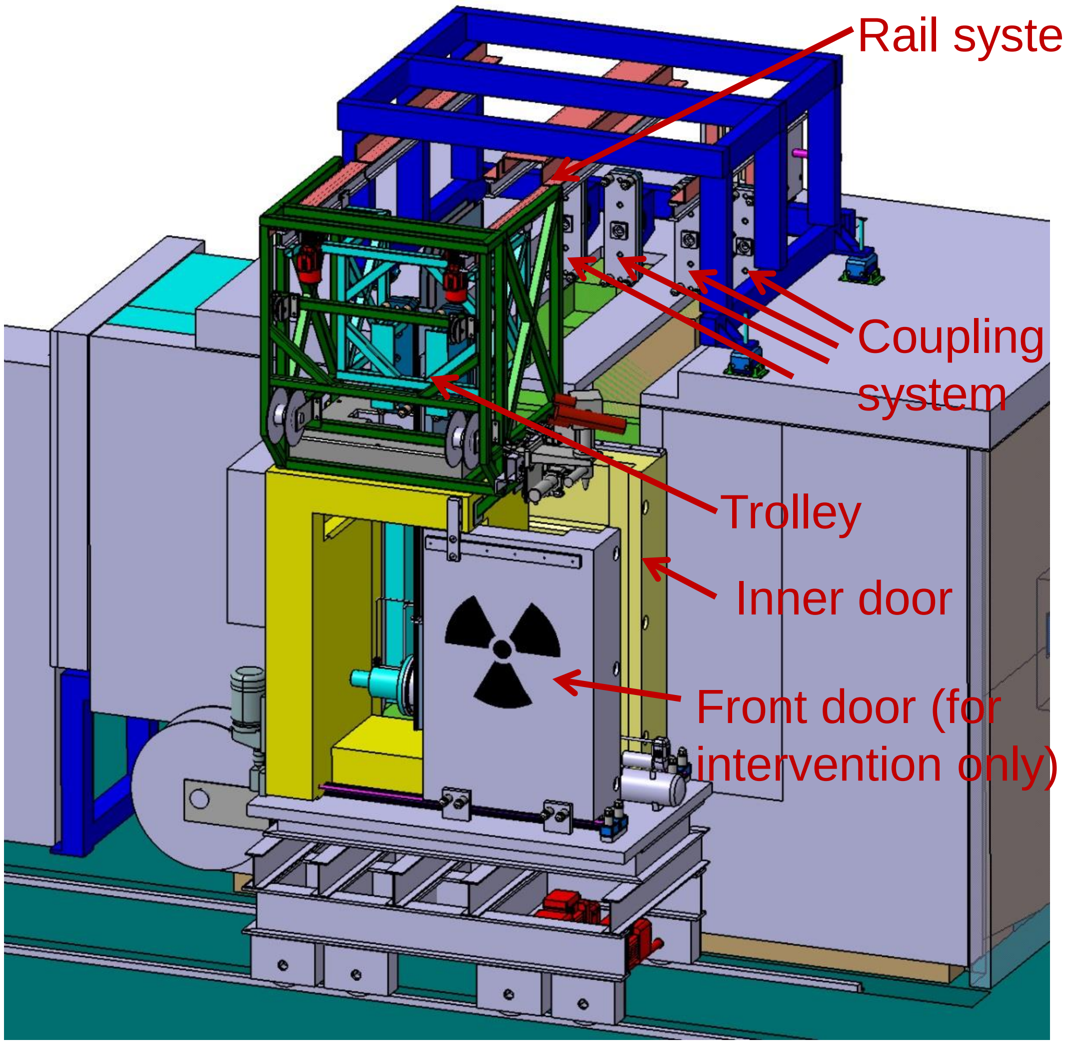
Dose rates during operation



The pbar building

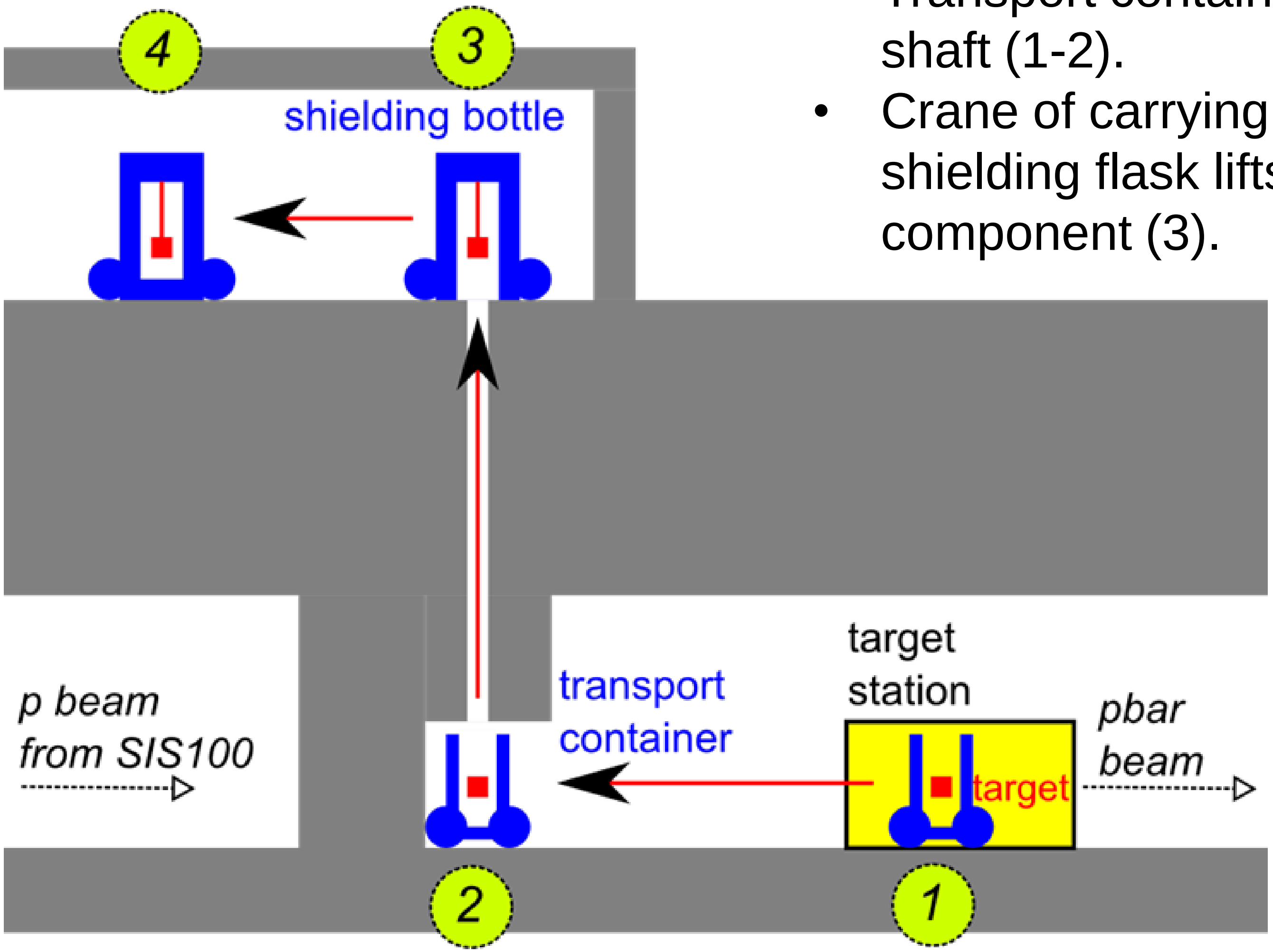


Target station and transport container



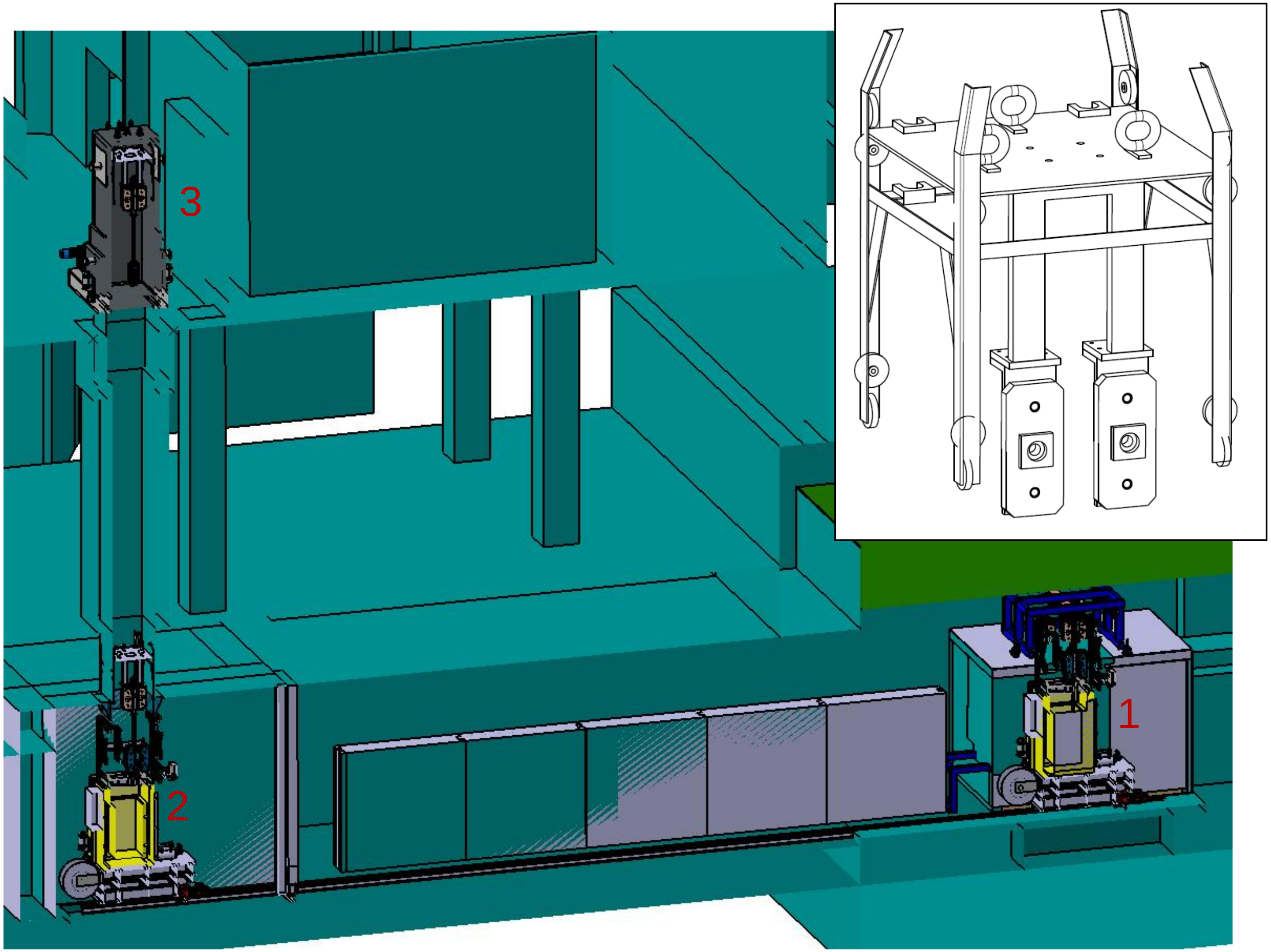
- Transport container is placed in front of target station.
- Door of target station and transport container are opened.
- Component is gripped by a quick coupling system.
- Trolley moves the component via rail system into the transport container.
- Doors are closed.

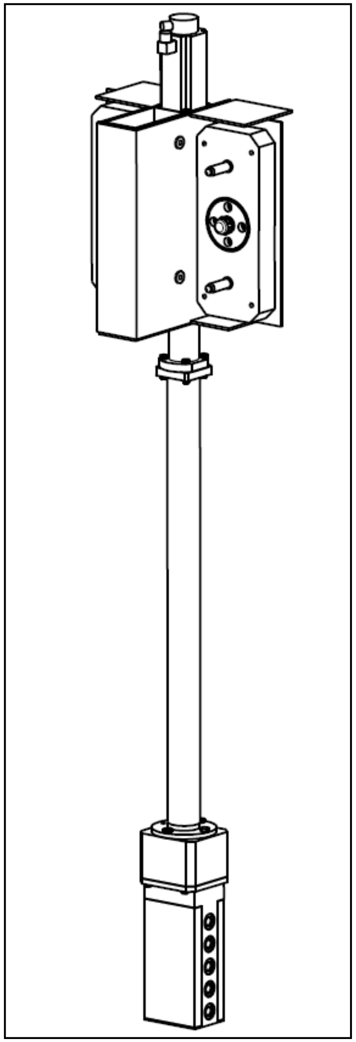
Transport concept



- Transport container moves to the shaft (1-2).
- Crane of carrying frame of the shielding flask lifts up the component (3).

Overview of transport





pbar Yield: Comparison to CERN Data

To injection orbit of collector ring:

$$\text{pbar/p} = 2\times10^{-5} \times 0.8 \times 0.7 = \mathbf{1.1\times10^{-5}}$$

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

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

$$\text{pbar/p} = 0.45\times10^{-5} \times 1.5 = \mathbf{0.7\times10^{-5}}$$

correction for different energies and acceptances

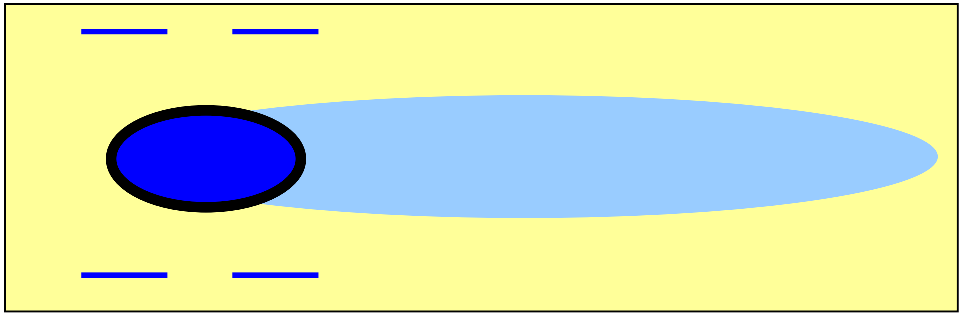
CR: Bunch Rotation and Stochastic Pre-Cooling

bunch rotation | adiabatic debunching | stochastic cooling

$\Delta E/E =$ ± 3 % | ± 0.75 % | ± 0.5 % | ± 0.1 %

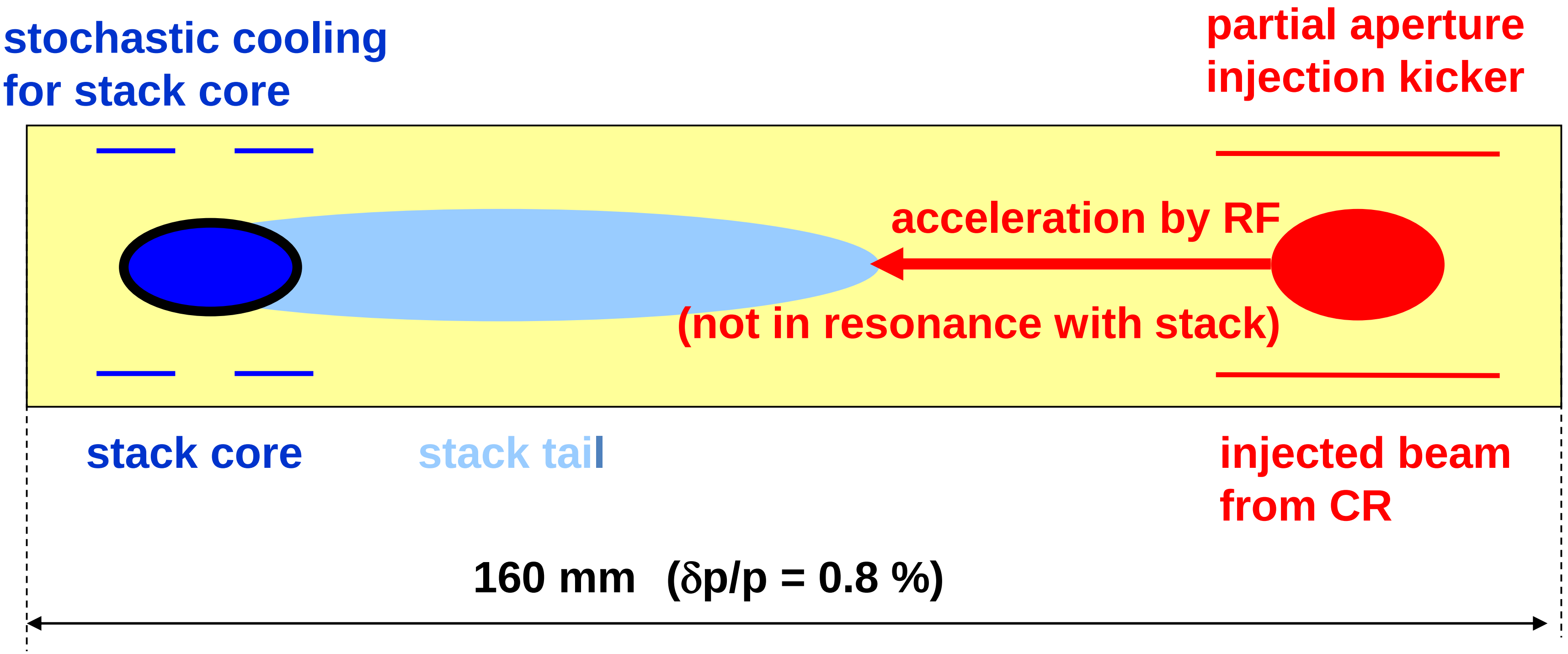
Cross section throught the vacuum chamber at the momentum pick-up

stochastic cooling
for stack core

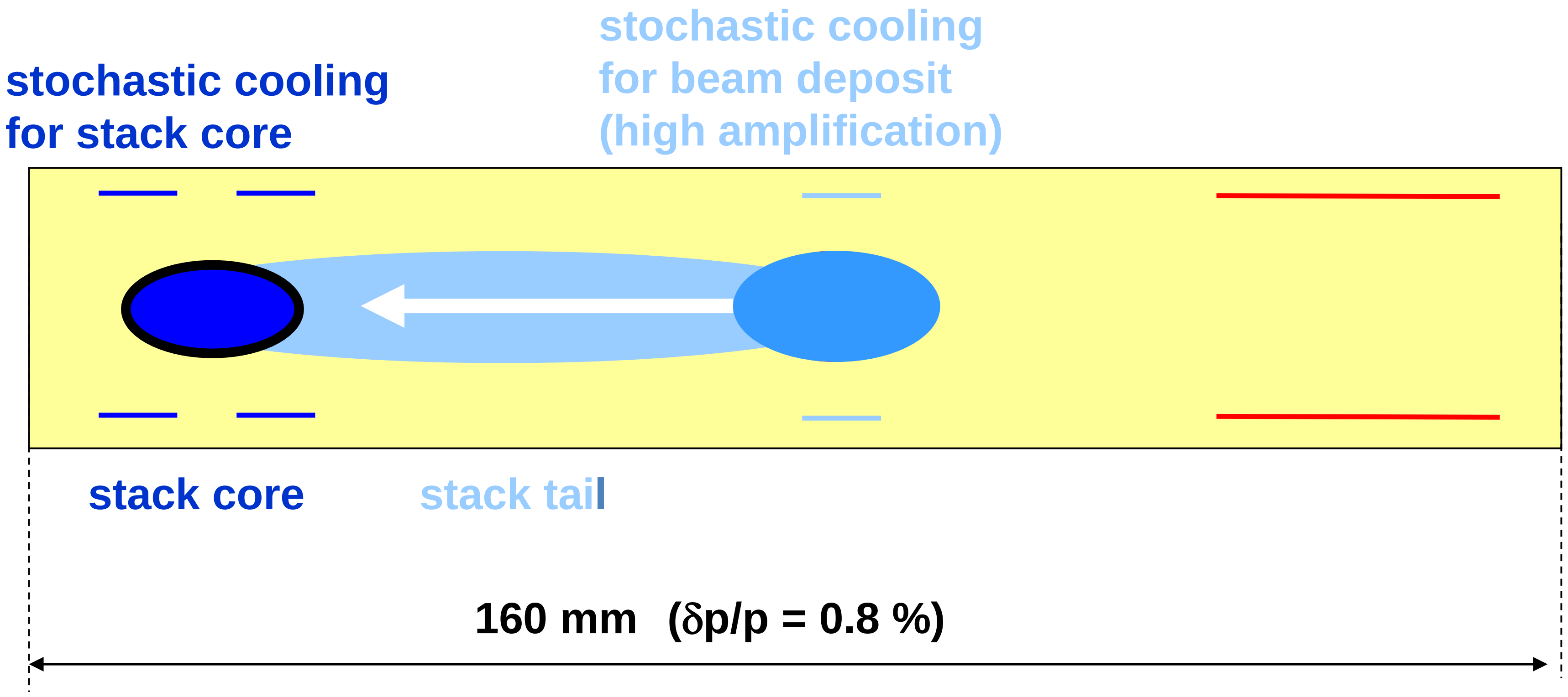


stack core stack tail

RESR (HESR): Antiproton Accumulation

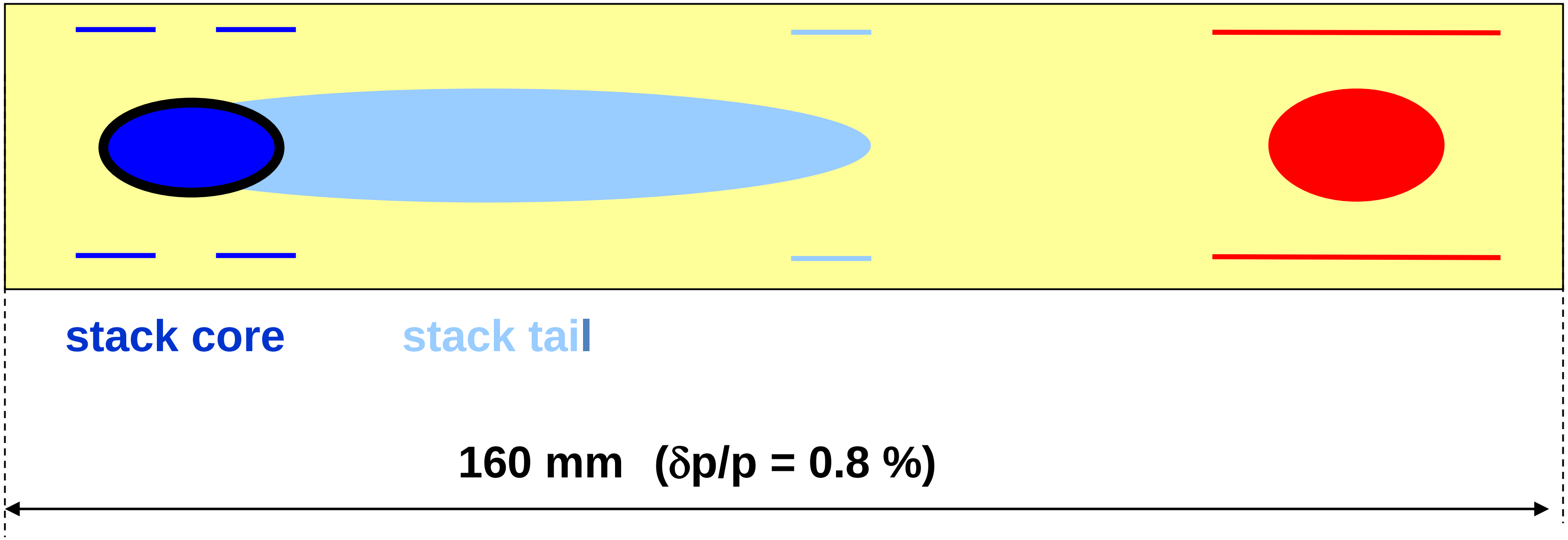


RESR (HESR): Antiproton Accumulation

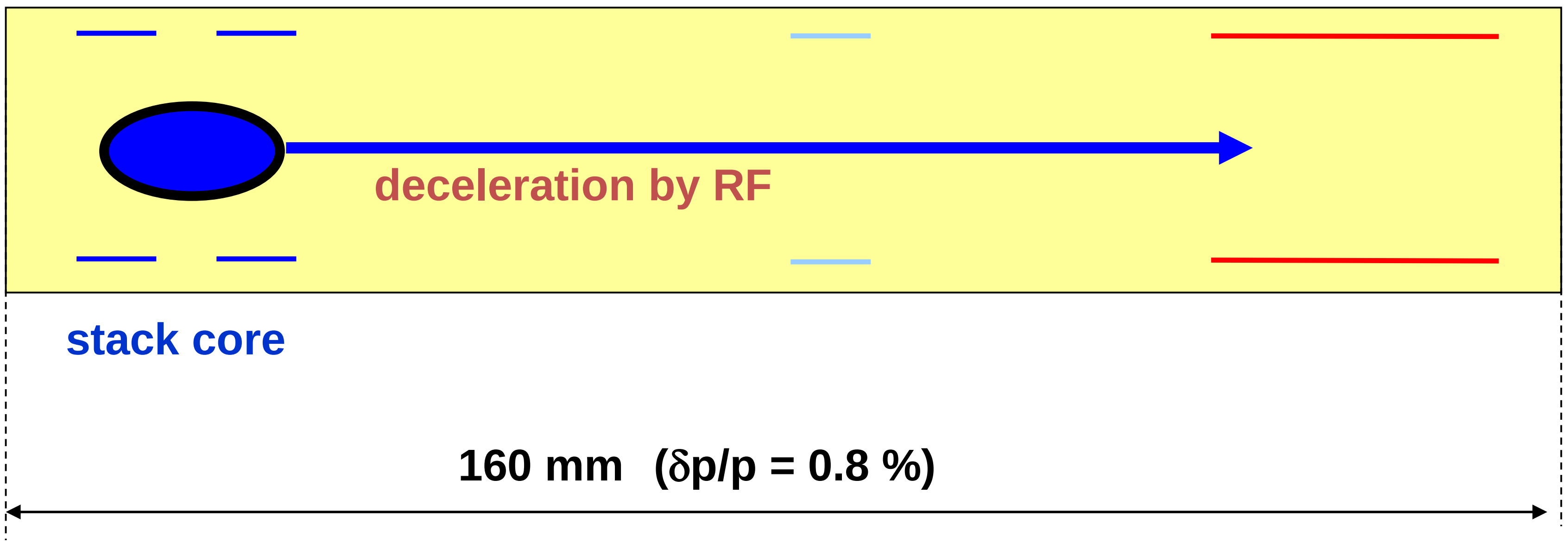


RESR (HESR): Antiproton Accumulation

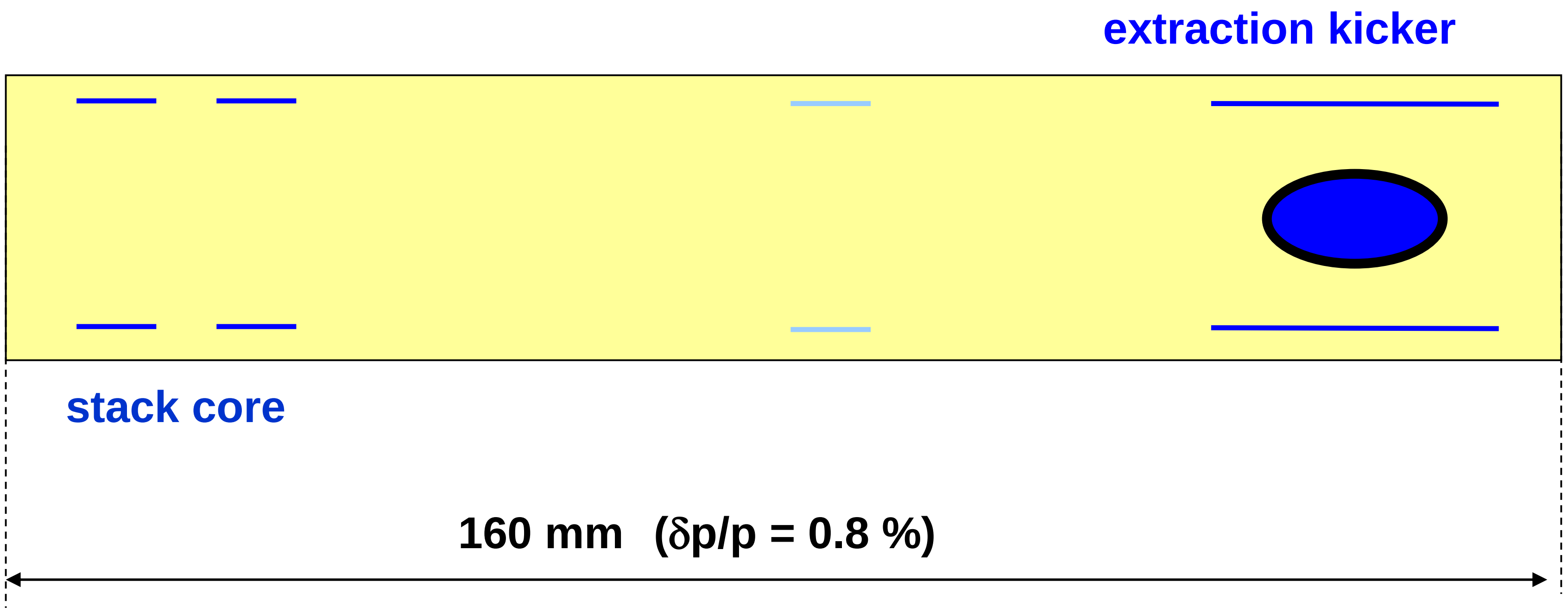
stochastic cooling
for stack core



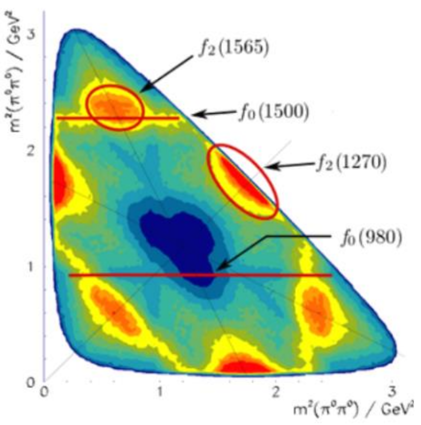
RESR (HESR): Antiproton Accumulation



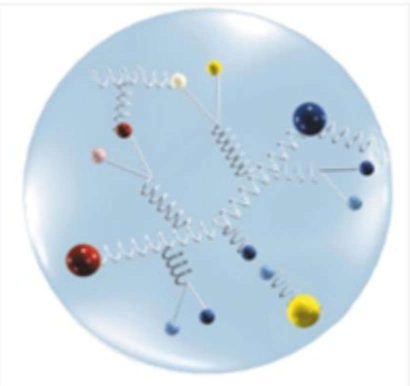
RESR (HESR): Antiproton Accumulation



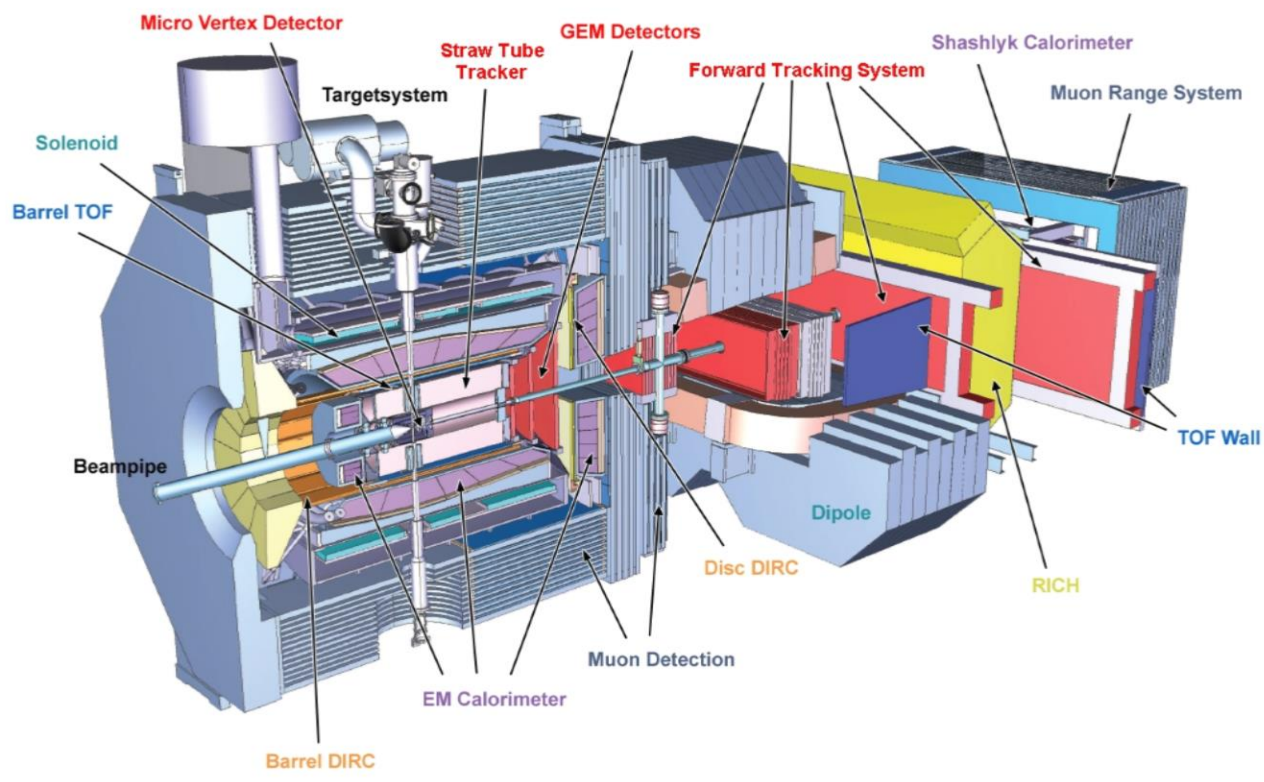
The panda Experiment



Hadron Spectroscopy

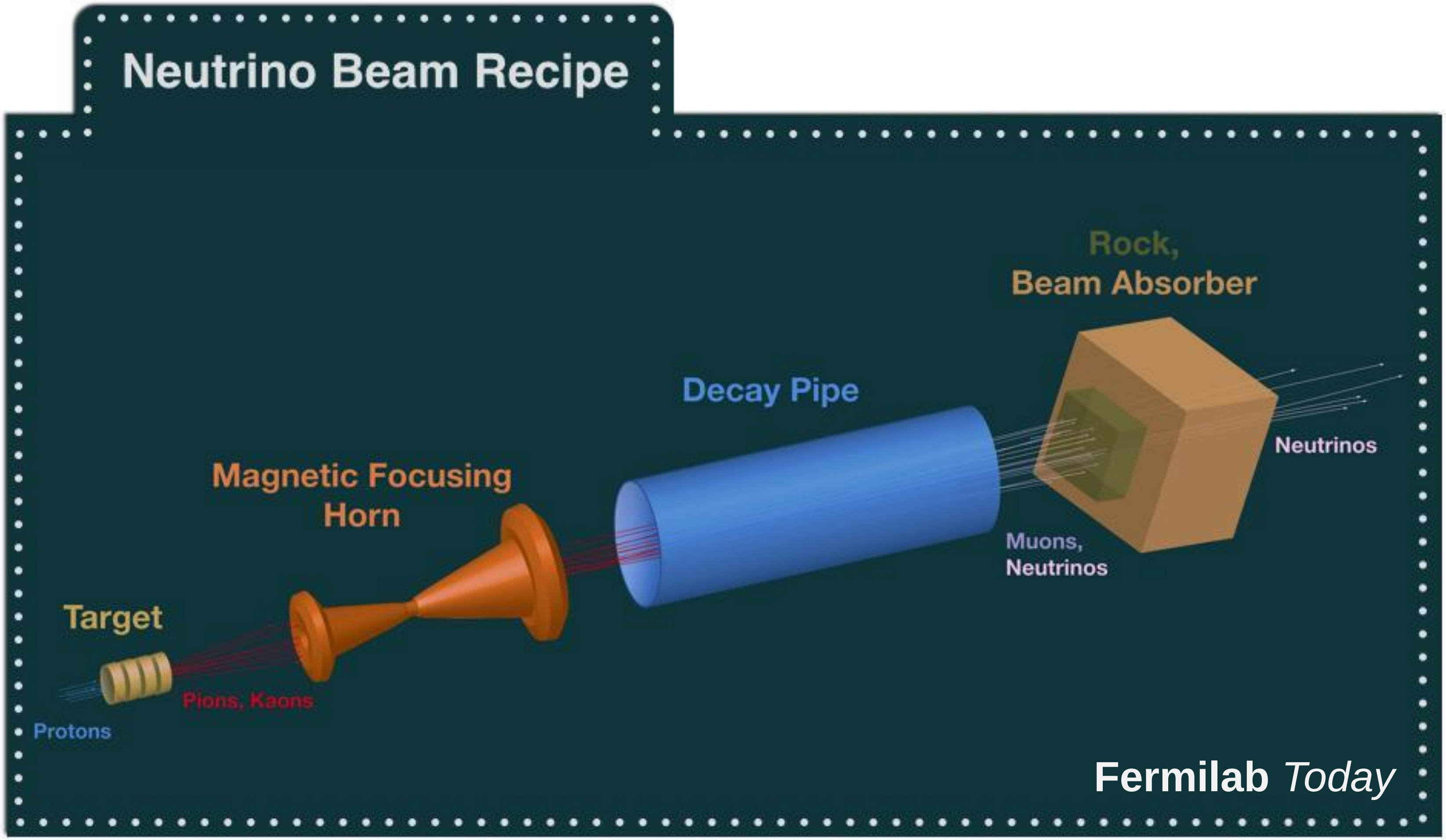


Nucleon Structure

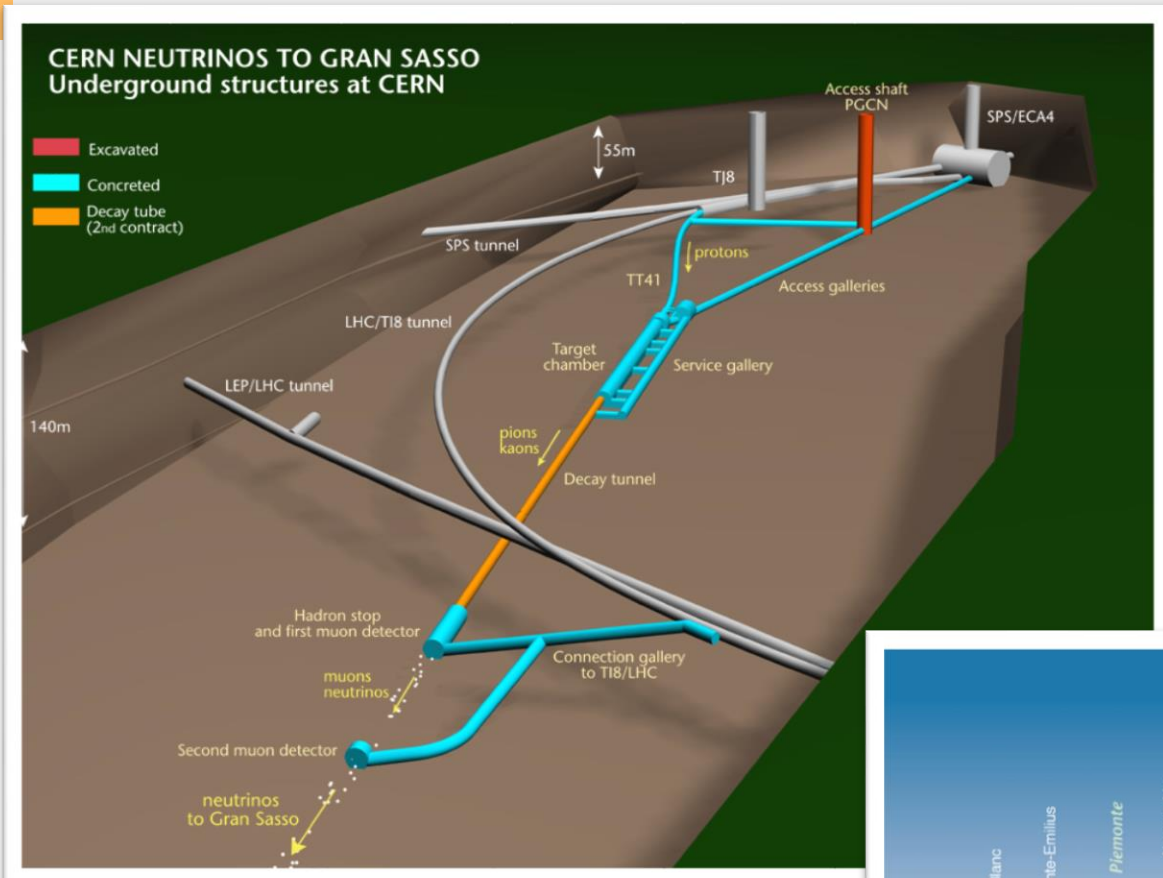


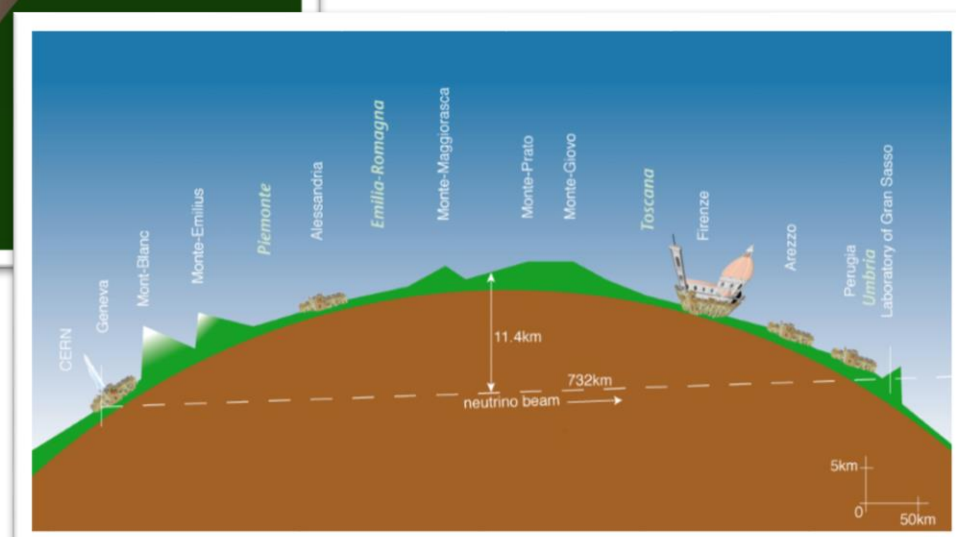
Pellet target: Frozen hydrogen droplets

„Ternary“ Beams, e.g. neutrinos

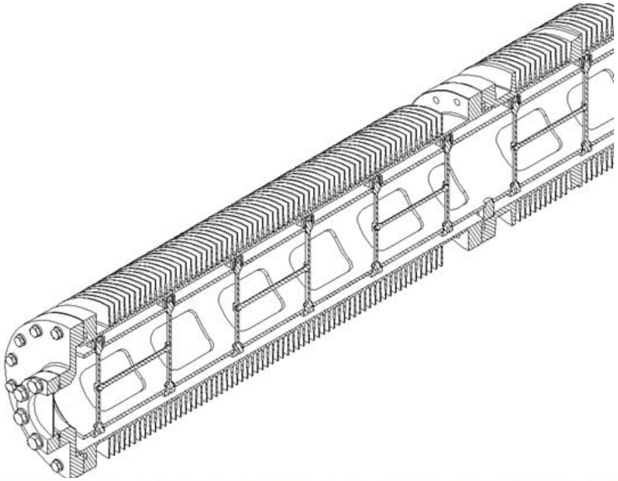


CNGS: CERN Neutrinos to Gran Sasso

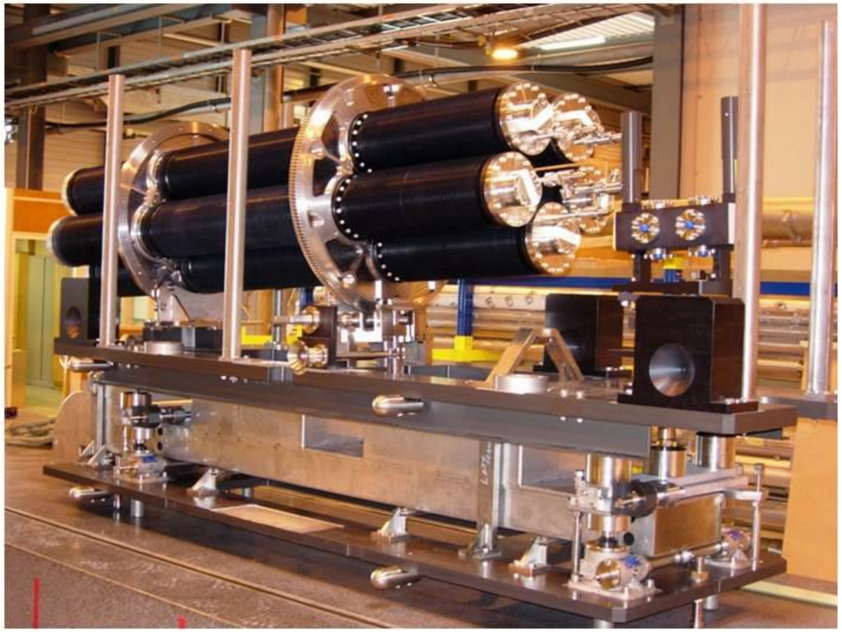




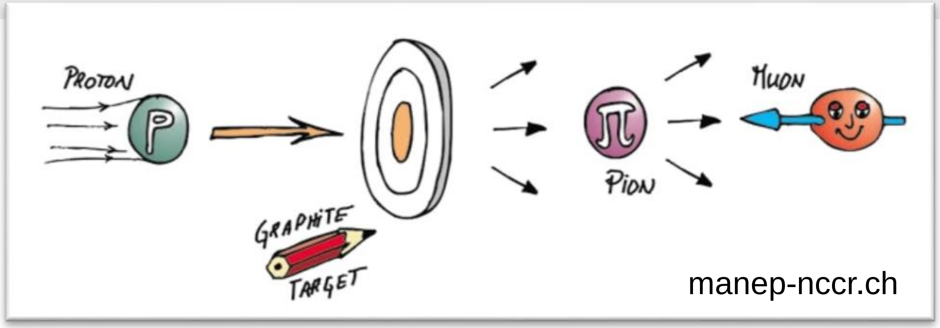
CNGS: CERN Neutrinos to Gran Sasso

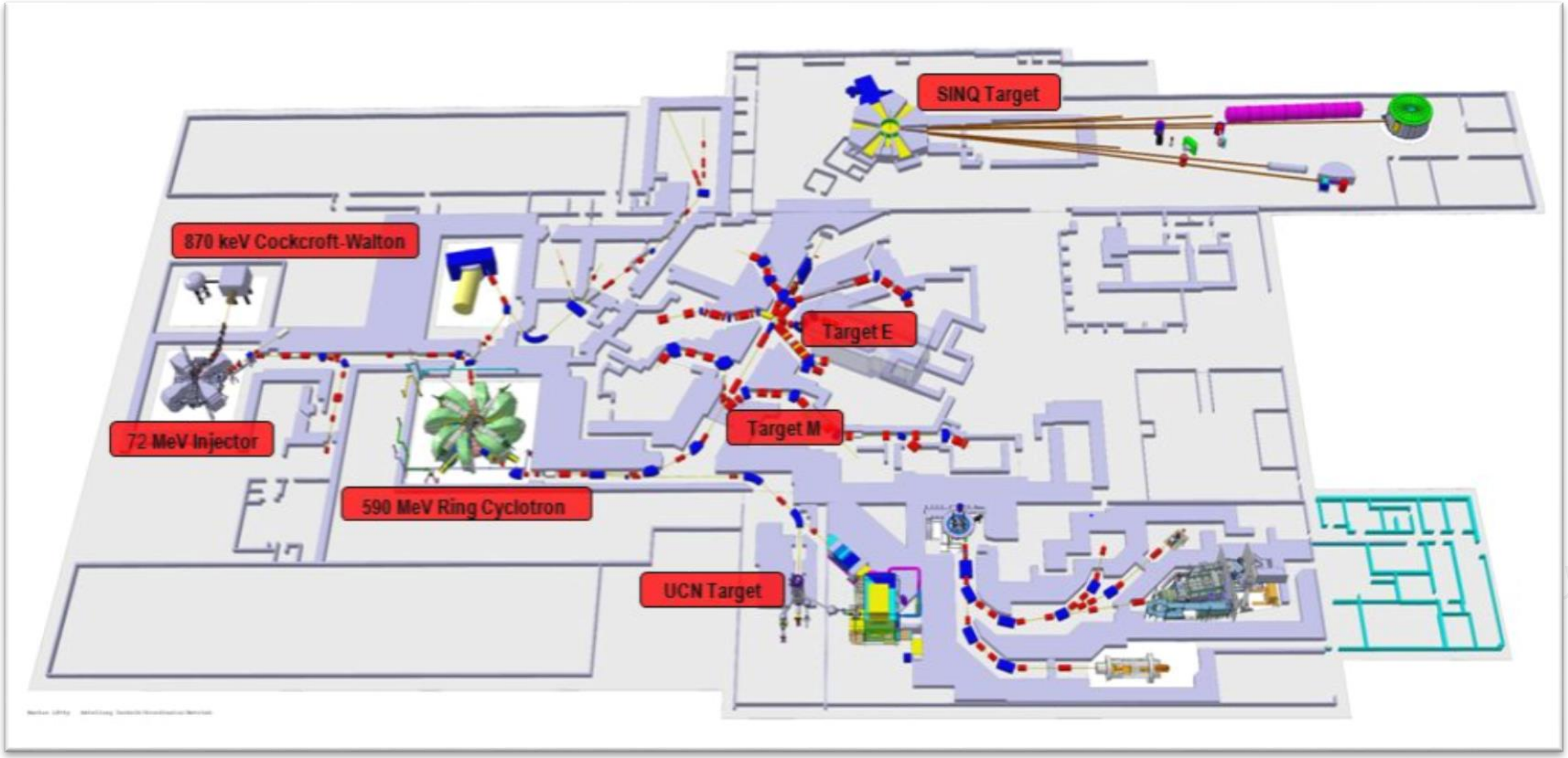


Graphite target, 2 m long
2 large horns
1km decay tunnel



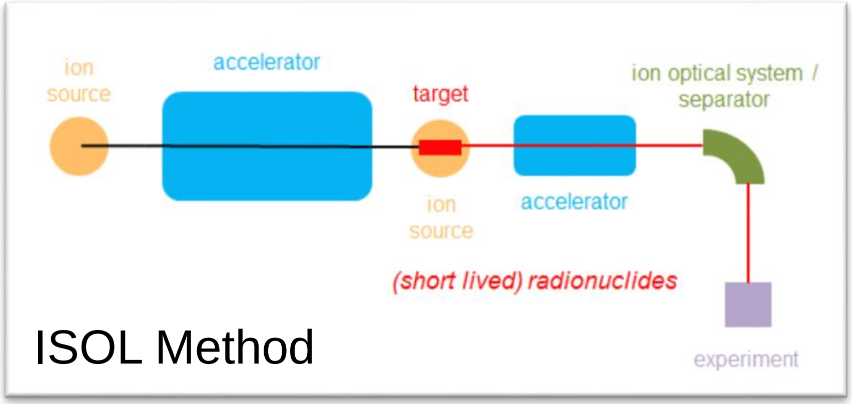
SμS: Swiss Muon Source at PSI



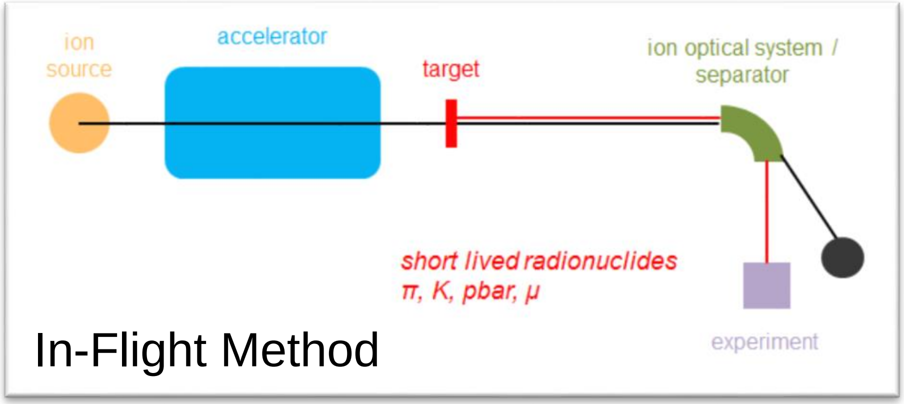


Summary

Two established methods...



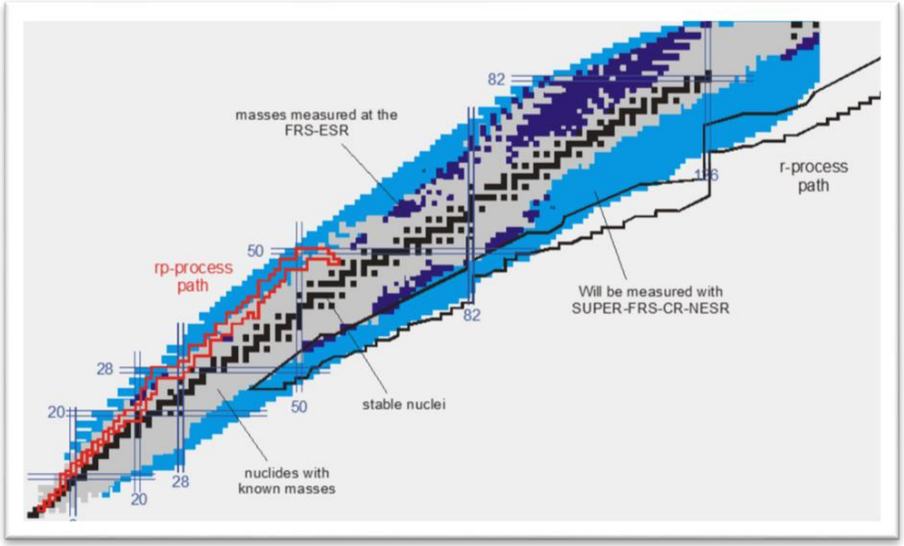
ISOL Method

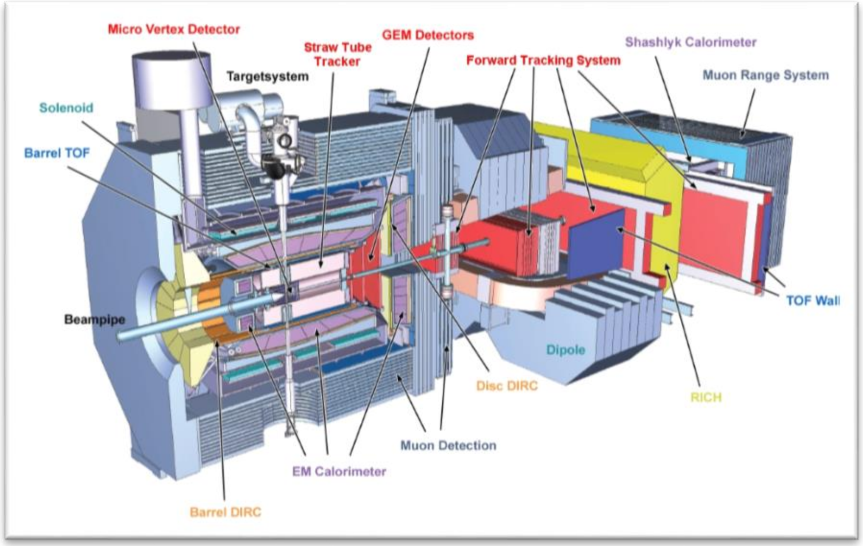


In-Flight Method

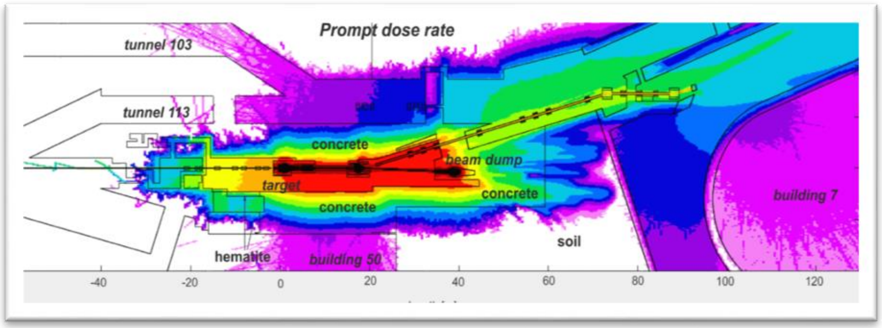
Summary

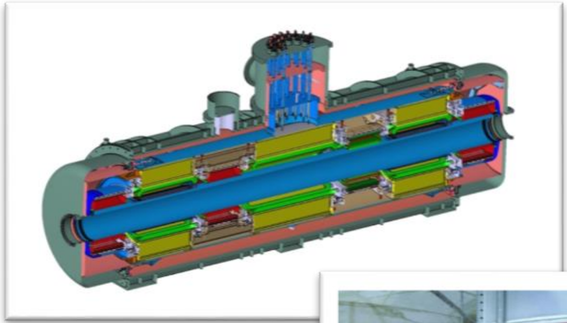
...increasing intensity request from experiments...

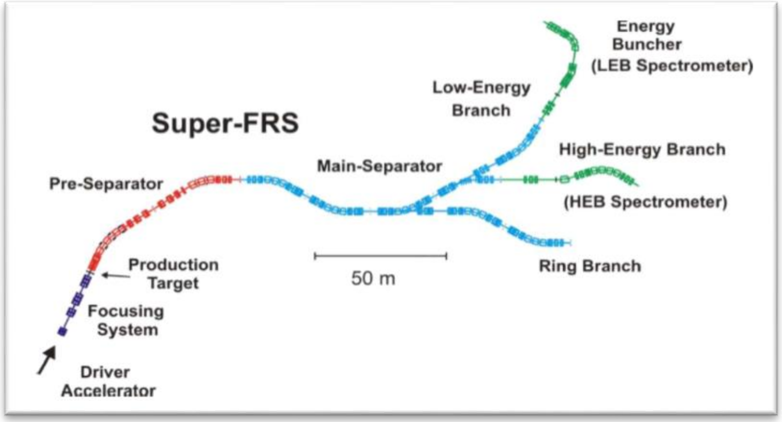




...new challenges: accelerators, targetry, separators, detectors, Rad. prot. ...







Thank you for your attention!