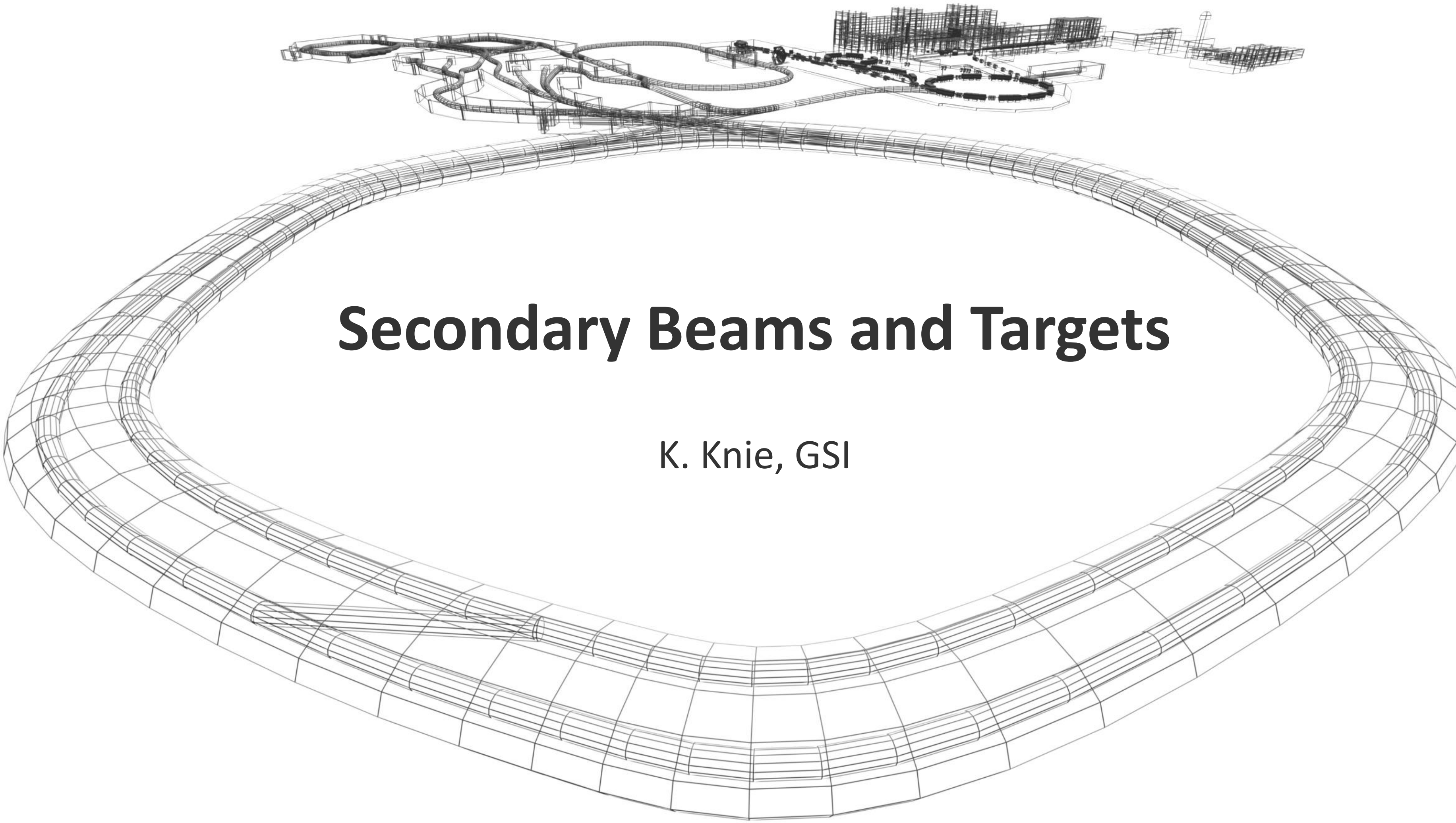


Secondary Beams and Targets

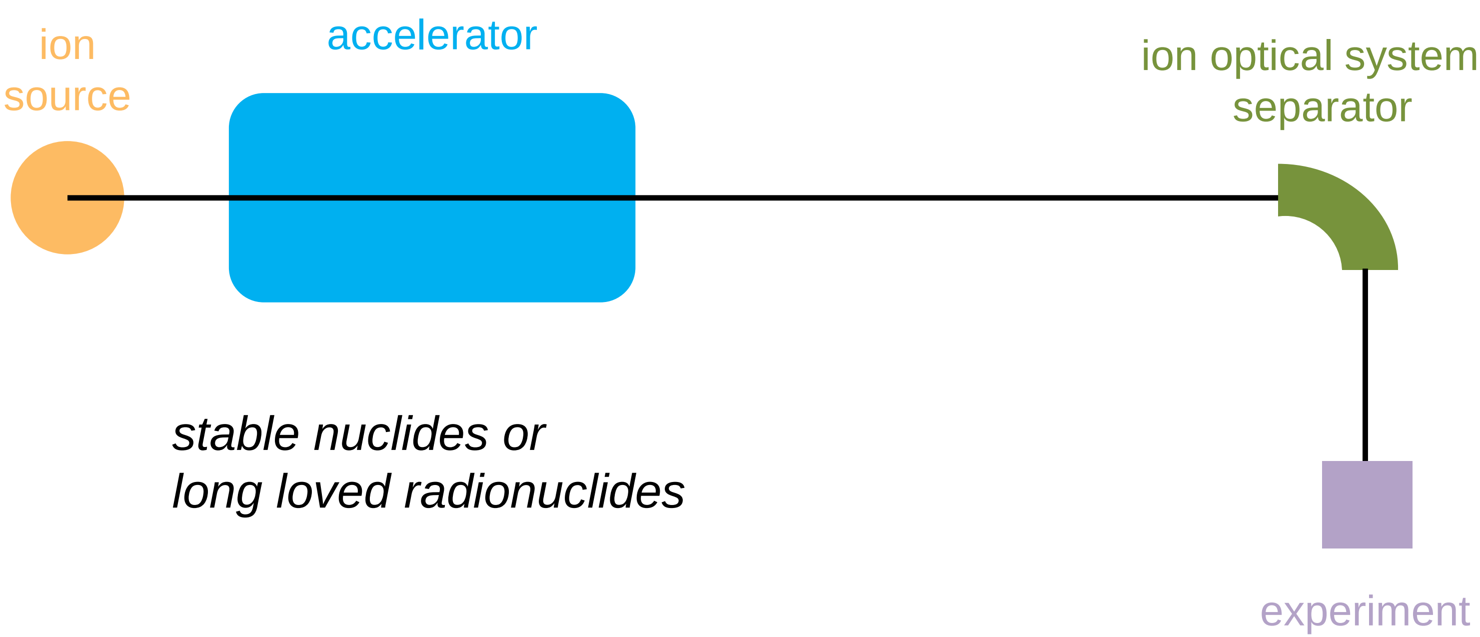
K. Knie, GSI

- **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

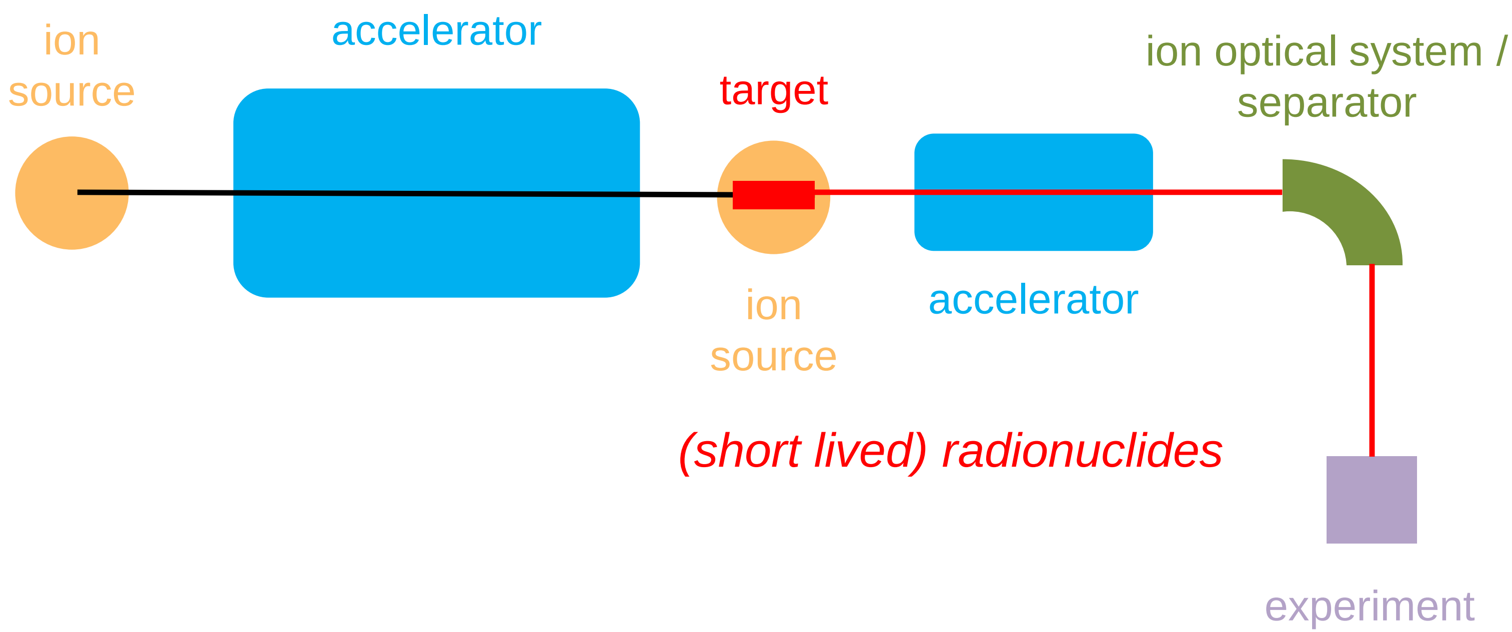
- **“Ternary” Beams:**
  Muon Beams
  Neutrino Beams (CNGS, NuMi...)

Primary / Secondary Beams

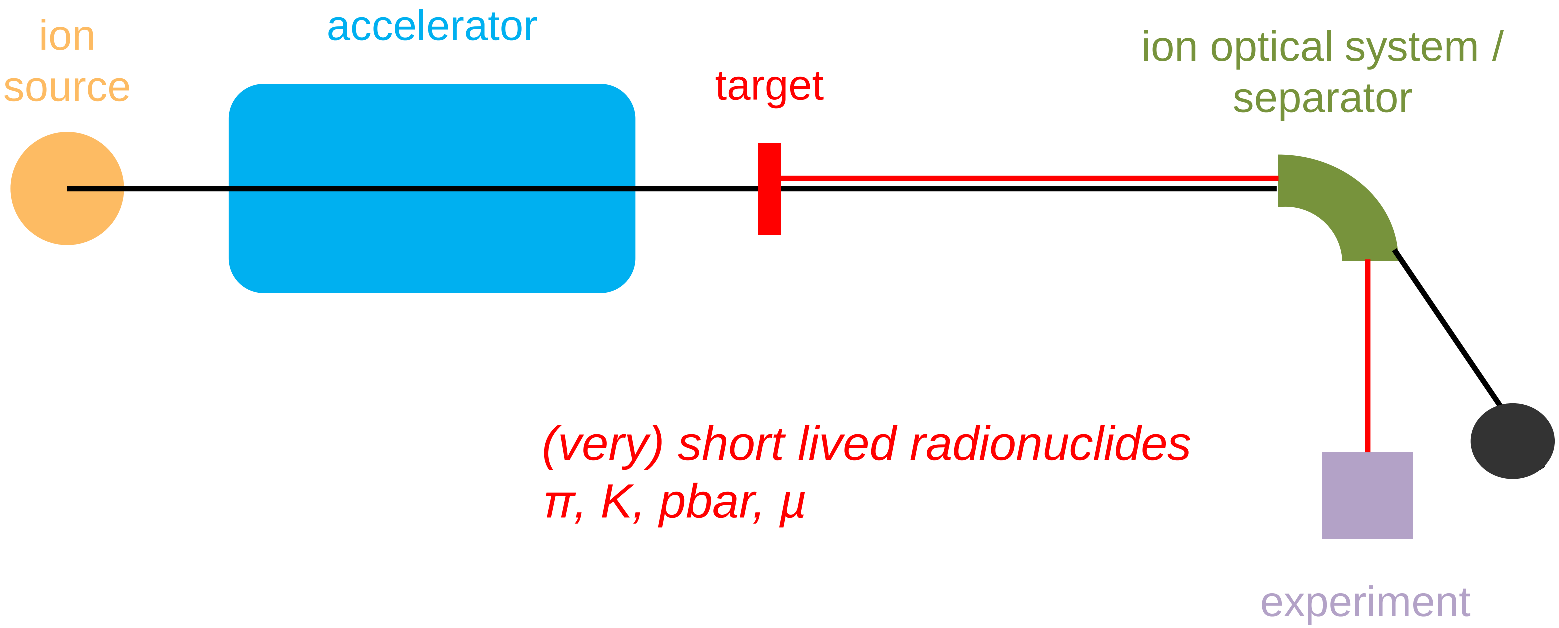


stable nuclides or
long loved radionuclides

Primary / Secondary Beams (ISOL)

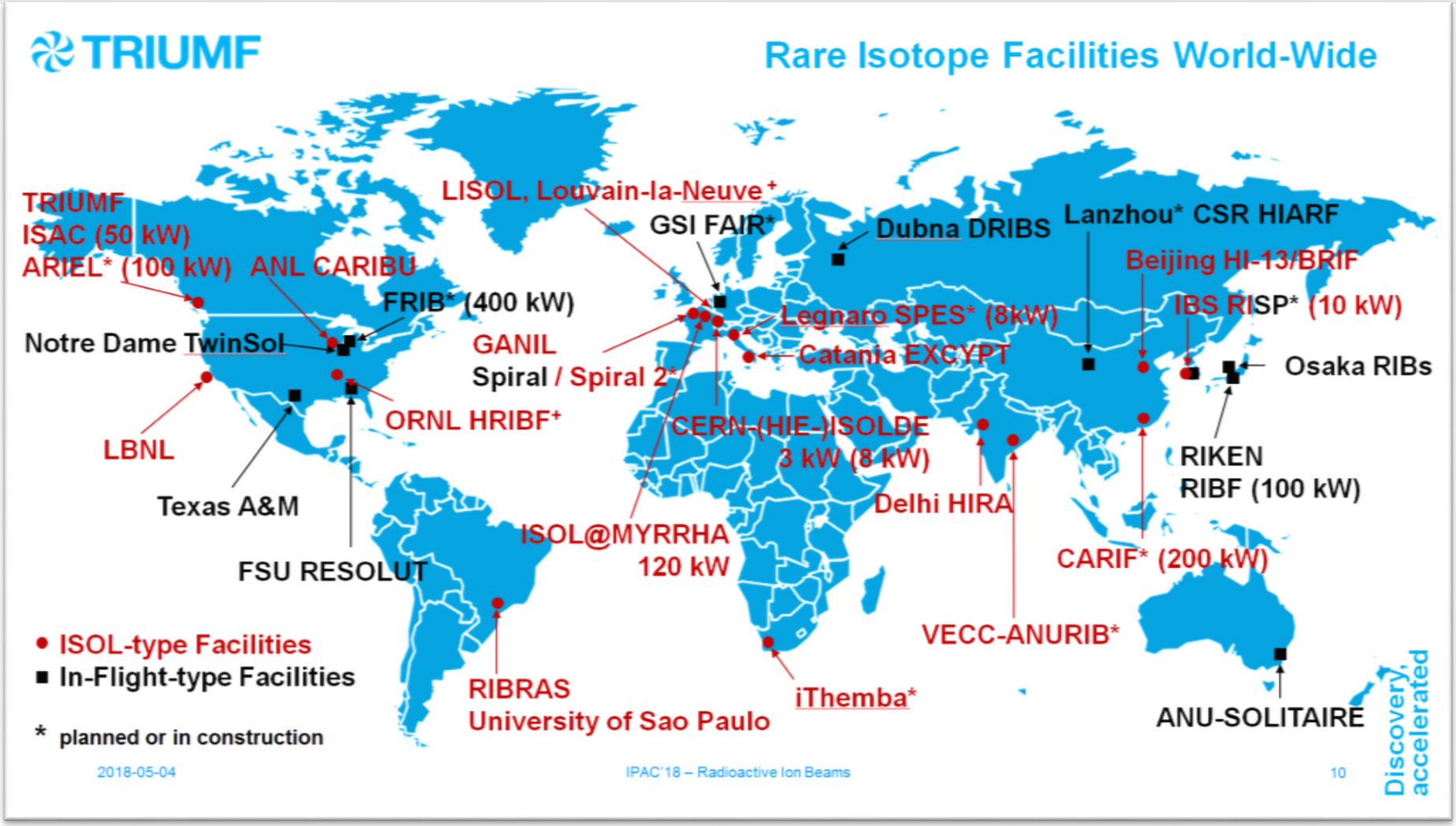


Primary / Secondary Beams: In-Flight



(very) short lived radionuclides
π, K, pbar, μ

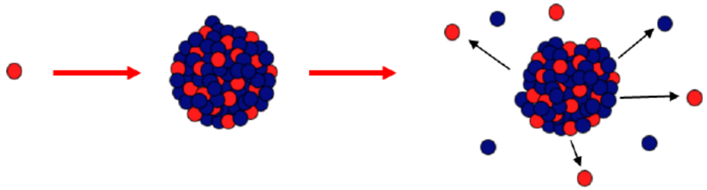
In-Flight / ISOL Facilities



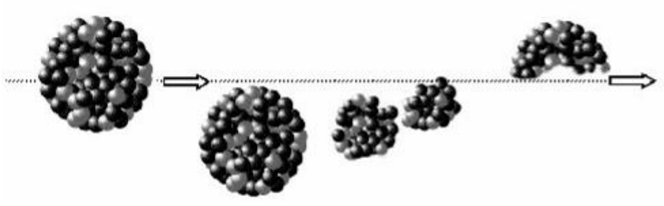
Alexander Gottberg, IPAC 2018

Production Mechanism

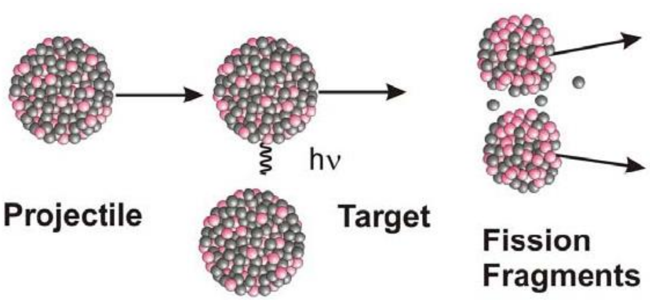
Spallation (ISOL only):
few nucleons lighter than target

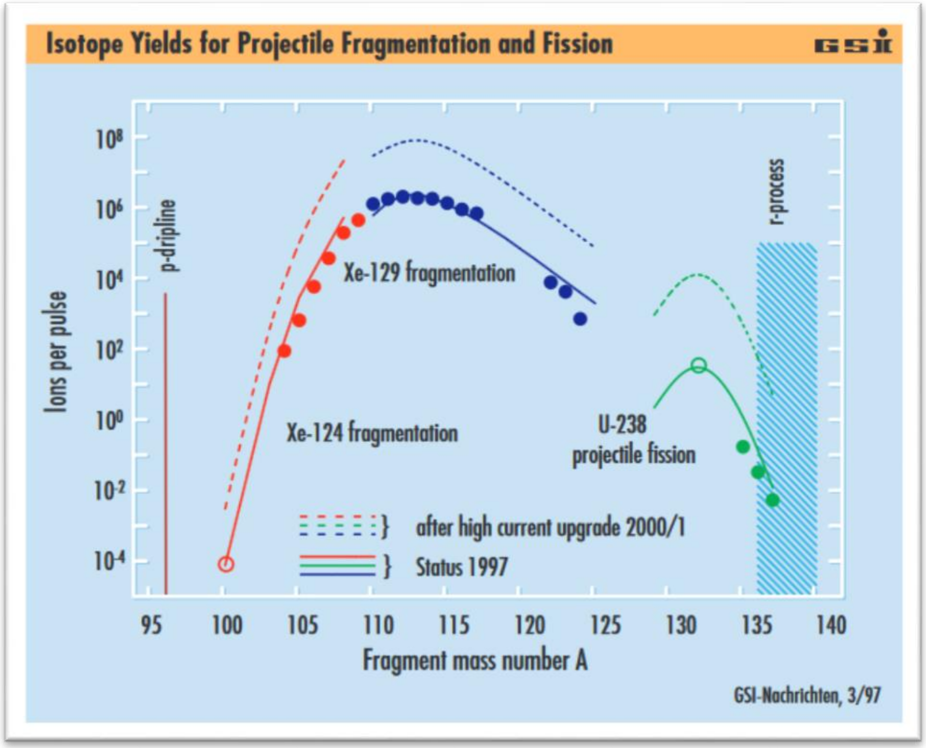


Projectile fragmentation:
neutron deficient (evaporation of neutrons after collision)

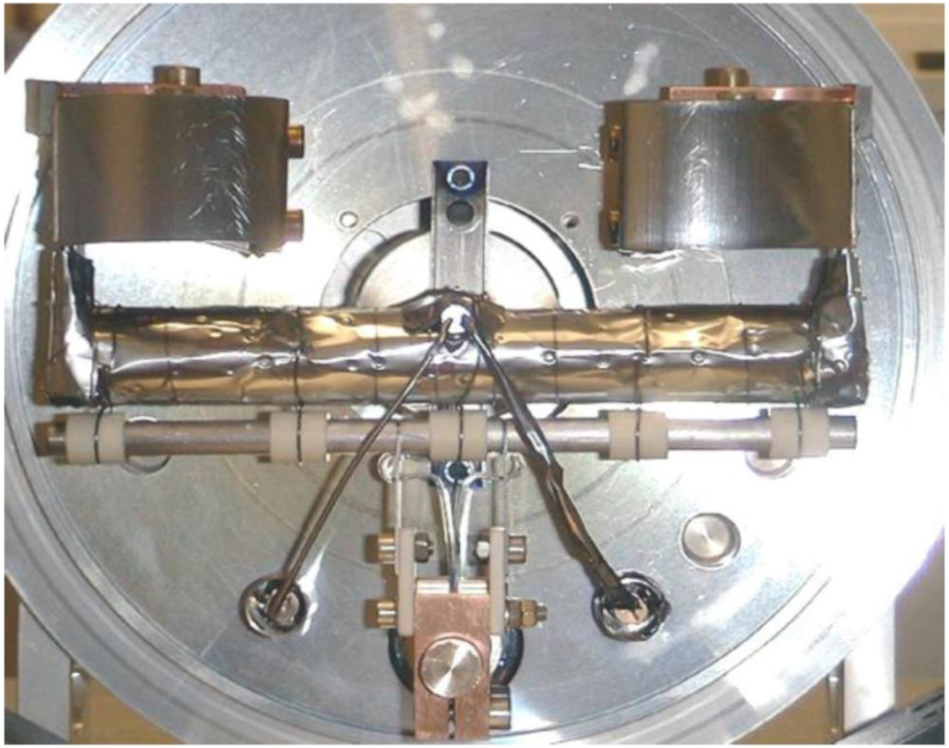


Projectile fission:
neutron rich (*N/Z* similar heavy projectile)



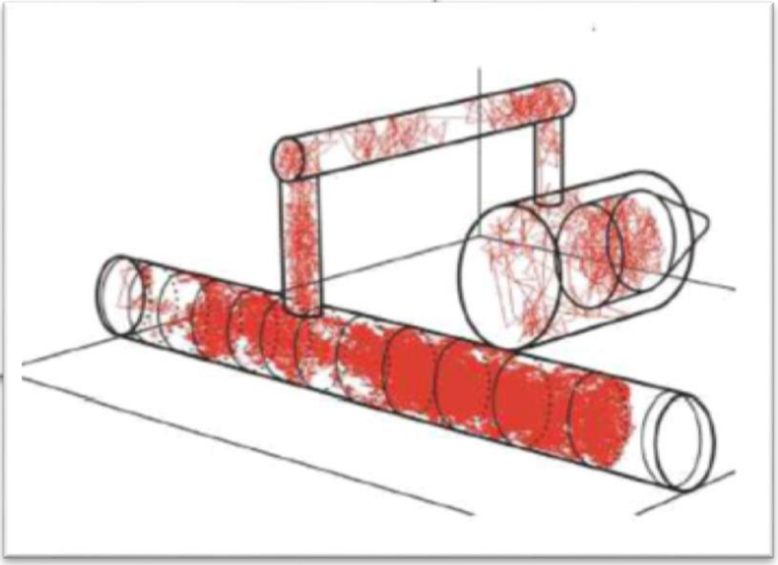


ISOLDE (CERN)



T. Stora, FAIR-CERN meeting, 2007

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



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

TRIUMF

RIB Intensity

$$I_{\text{RIB}} = \varepsilon \cdot I_{\text{prod}} = \varepsilon \cdot \int_{\text{target}} \sigma(E)\, N_{\text{target}}(l)\, I_{\text{primary}}(l)\, dl$$

- I_{RIB} - rare ion beam intensity $[s^{-2}]$
- ε - overall efficiency
- I_{prod} - pruduction rate of a reaction product$[s^{-2}]$
- σ - reaction cross−section $[\text{barn} = 10^{-24}\text{cm}^2]$
- N_{target} - target atoms per exposed area $[\text{cm}^{-2}]$
- $I_{primary}$ - primary beam intensity

typically 10^{-3} to 10^{-8} !!! ($\varepsilon_{\text{release}} \cdot \varepsilon_{\text{ionization}}$)

typically 5% to 90% ($\varepsilon_{\text{transport}} \cdot \varepsilon_{\text{cool-bunch}} \cdot \varepsilon_{\text{breeding}} \cdot \varepsilon_{\text{post-accel}}$)

$$\varepsilon = \varepsilon_{\text{release}} \cdot \varepsilon_{\text{ionization}} \cdot \varepsilon_{\text{transport}} \cdot \varepsilon_{\text{cool-bunch}} \cdot \varepsilon_{\text{breeding}} \cdot \varepsilon_{\text{post-accel}}$$

- $\varepsilon_{\text{release}}$ - probability of not-decaying during the time of extraction from the target/ion source unit
- $\varepsilon_{\text{ionization}}$ - probability of ionization of desired species by chosen ionization mechanism
- $\varepsilon_{\text{transport}}$ - efficiency of mass selection and transport to experimental setup
- $\varepsilon_{\text{cool-bunch}}$ - cooling and bunching efficiency (when applicable)
- $\varepsilon_{\text{breeding}}$ - charge state breeding efficiency
- $\varepsilon_{\text{post-accel}}$ - post acceleration efficiency

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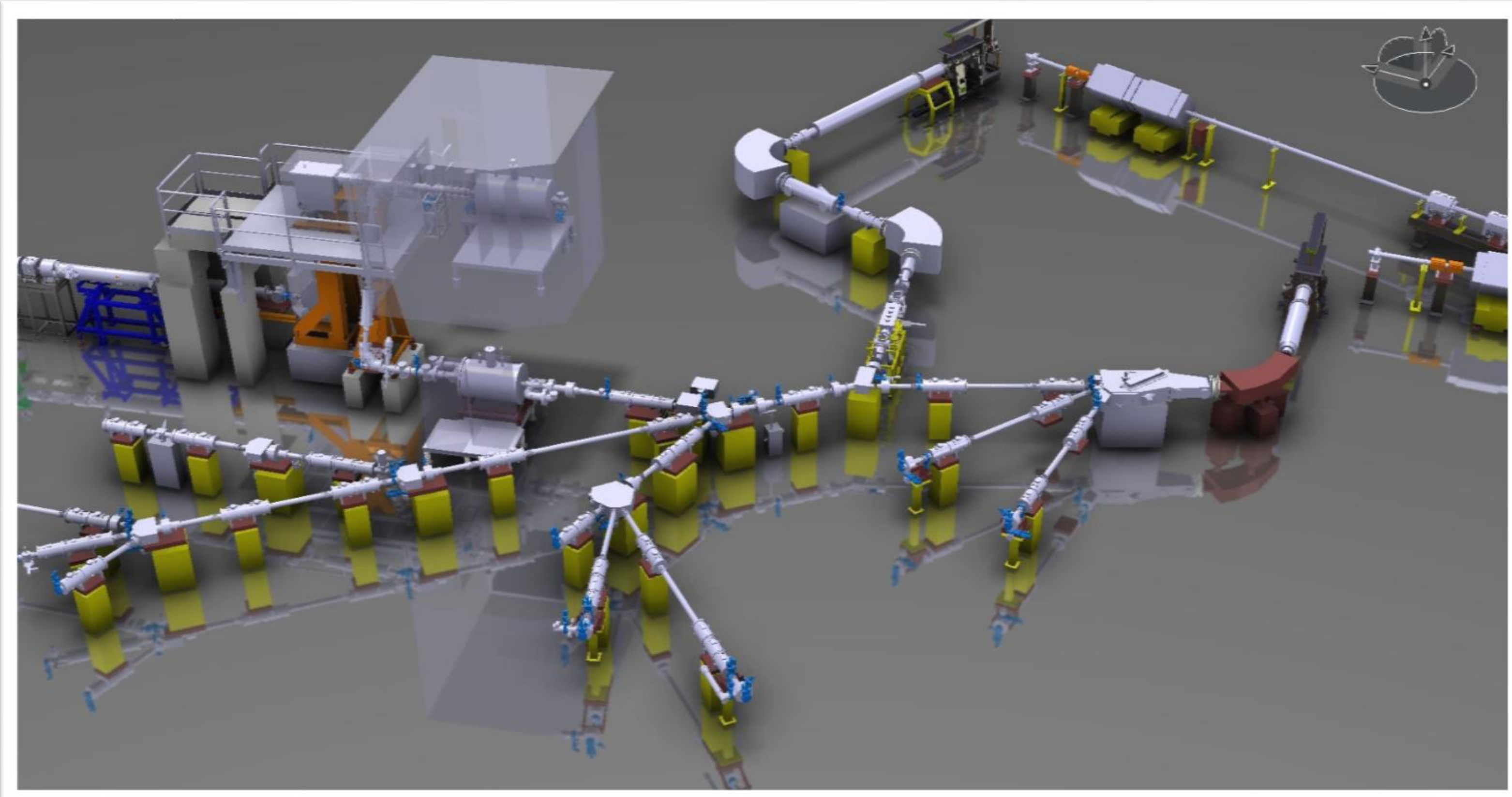
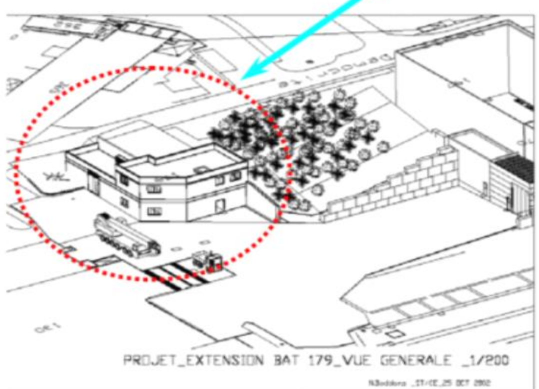
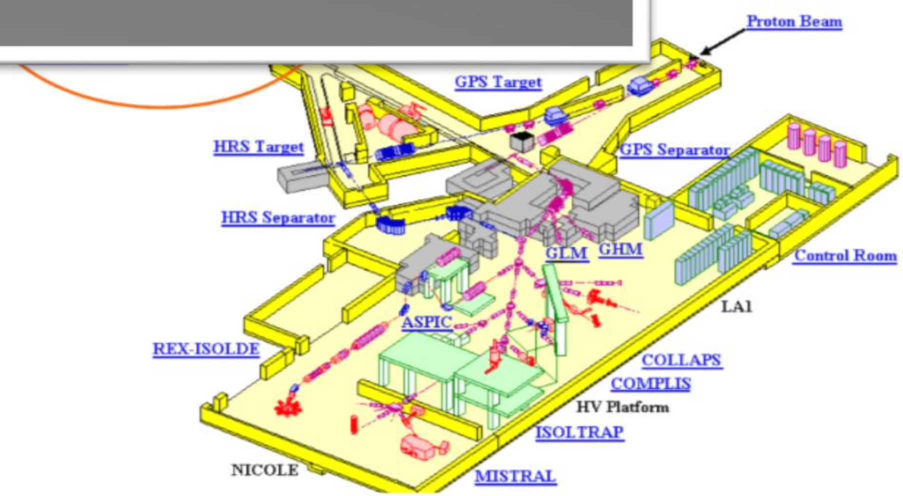
Discovery, accelerated

Alexander Gottberg, IPAC 2018

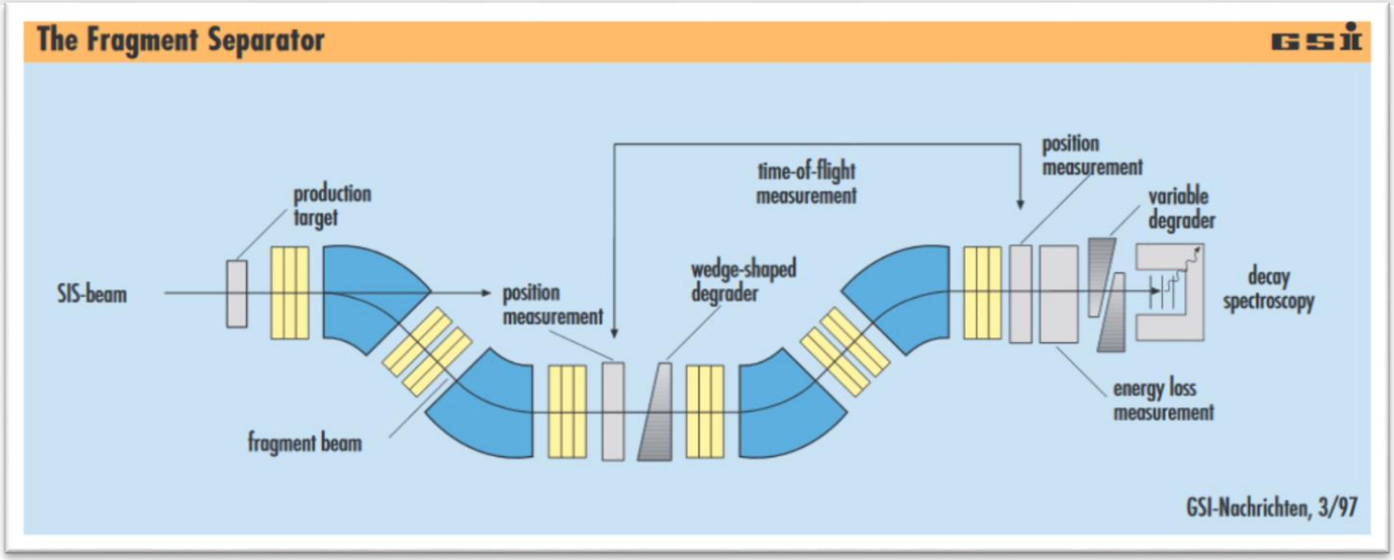






T. Stora, FAIR-GSI meeting 2007

Fragment Separators (in-Flight)



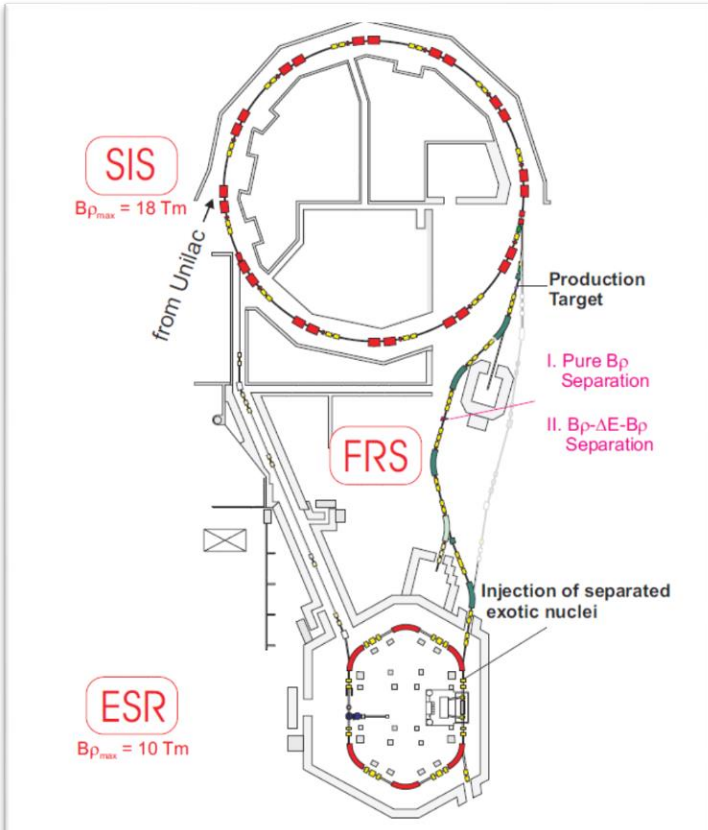
$B{\cdot}\rho = p/(q{\cdot}\mathrm{e}) \approx (2\mathbf{E}{\cdot}\mathbf{m})^{1/2}/(\mathbf{q}{\cdot}\mathbf{e})$

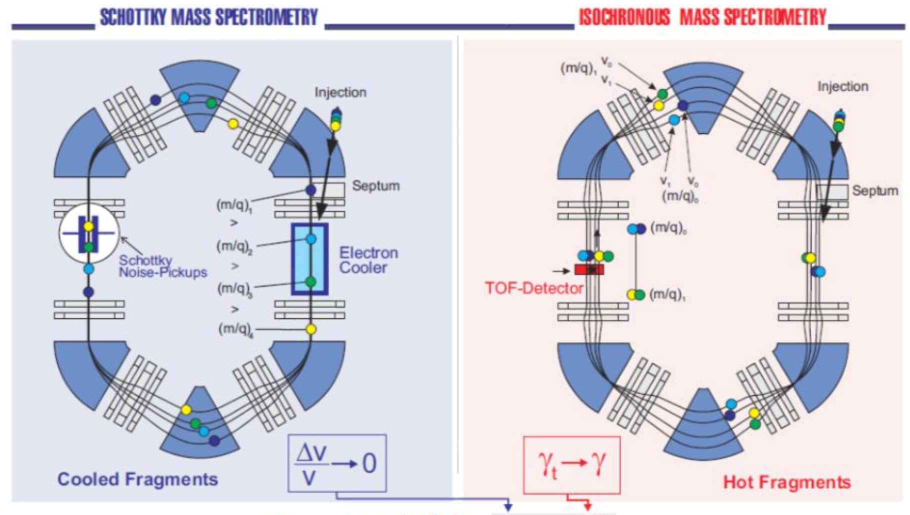
1st part: ***m/q*** or ***A/q*** selection, charge states ≠ *q* lost
no isobaric selection (***E*** similar for isobars)!

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





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

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)

Lifetime and Mass Measurements of stored exotic nuclei @ FRS

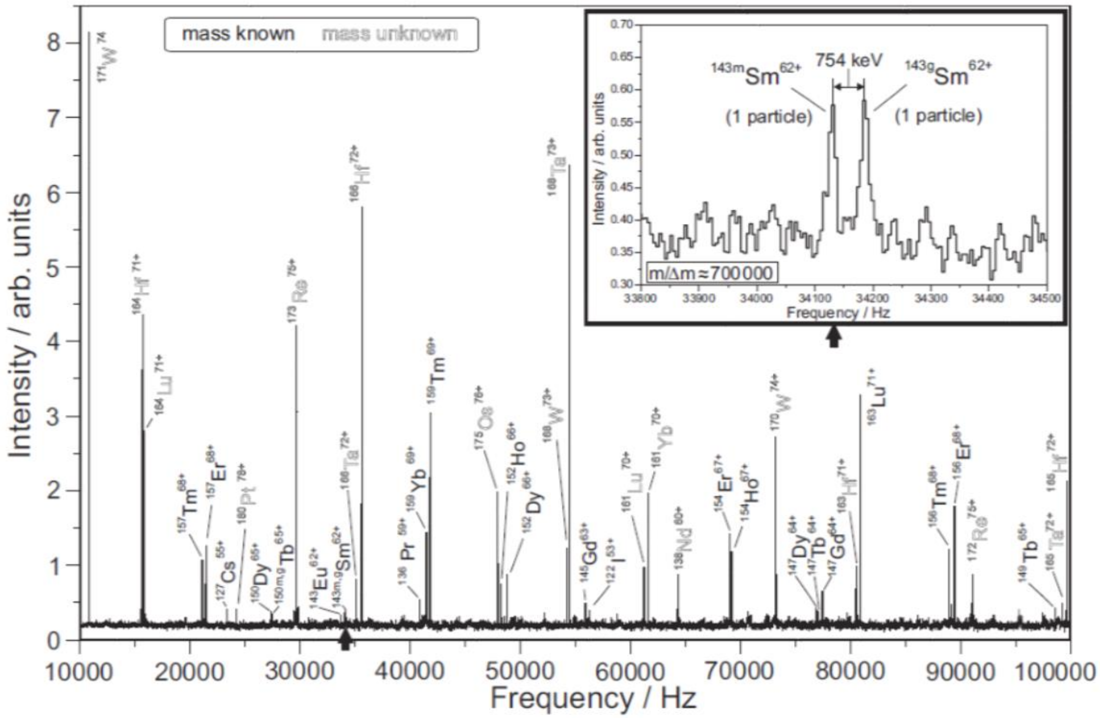
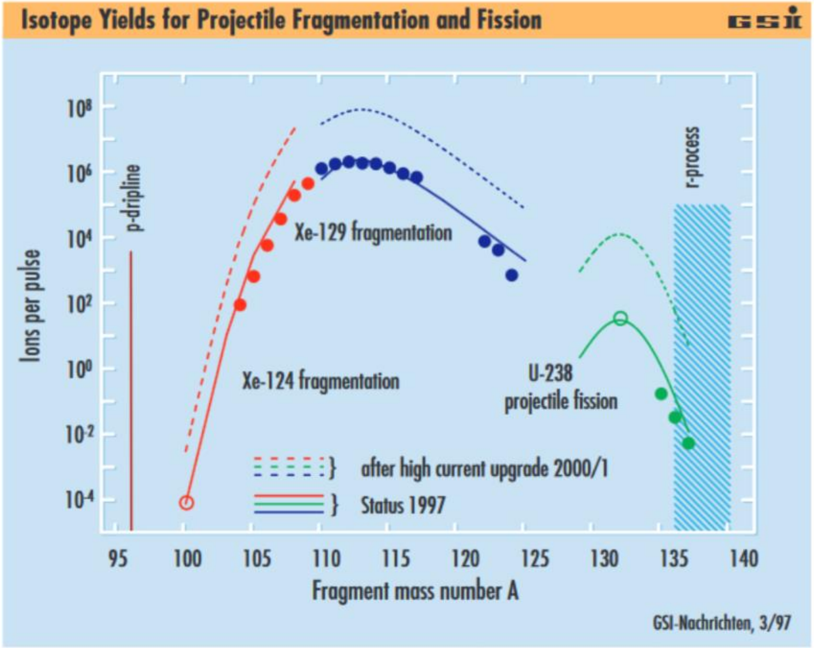
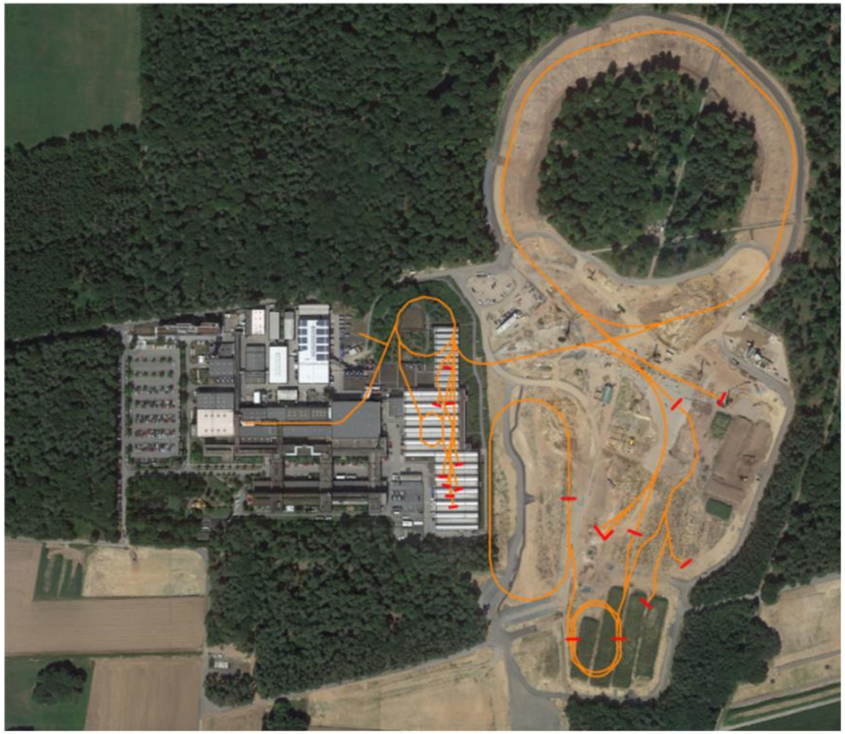


Fig. 9. Schottky spectrum of fragments from a primary ^{209}Bi beam, stored and electron-cooled in the ESR. The main spectrum shows the difference between the 30th harmonic of the revolution frequencies of the many stored ion species and of a local oscillator operating at about 60 MHz. It covers roughly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

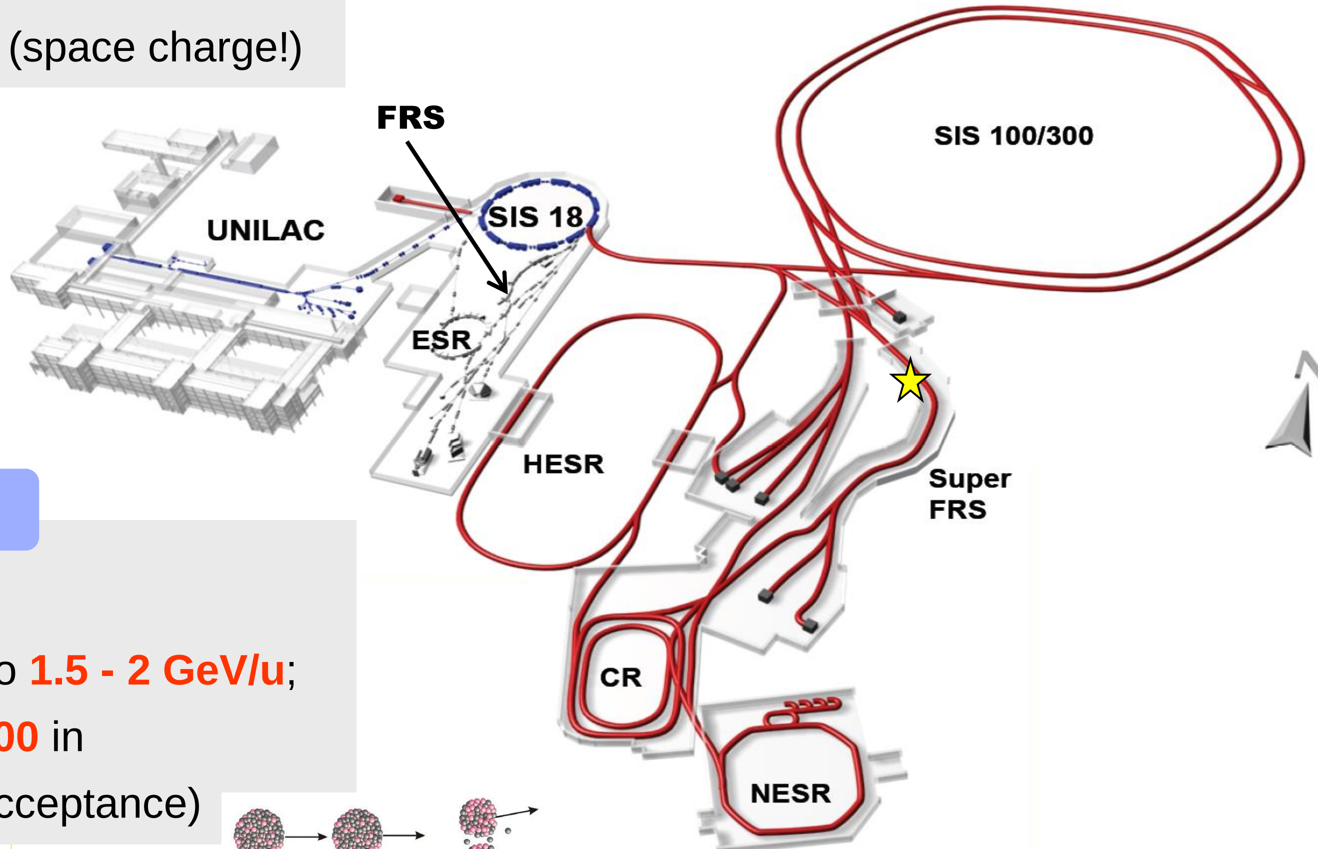




SuperFRS @ FAIR

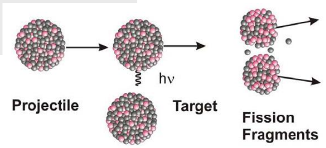
Primary Beams

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

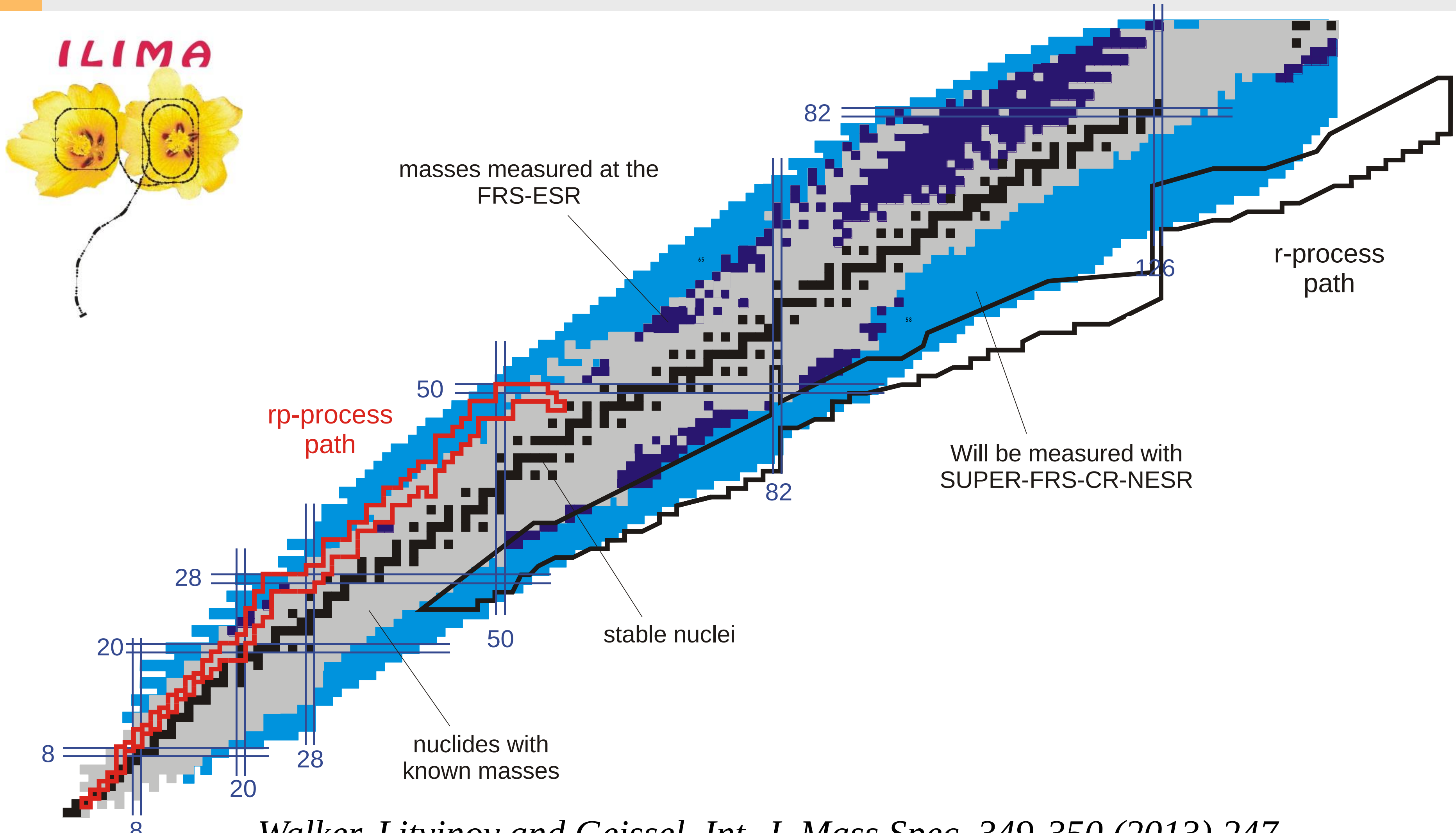


Rare Isotope Beams

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



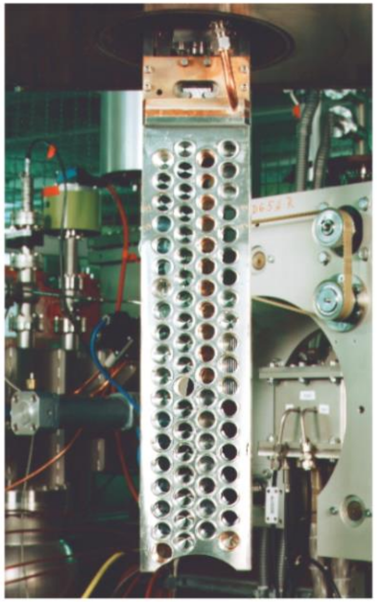
Phase 1 Physics with Super-FRS and rings:
Potential for new masses, lifetimes & isomers with ILIMA



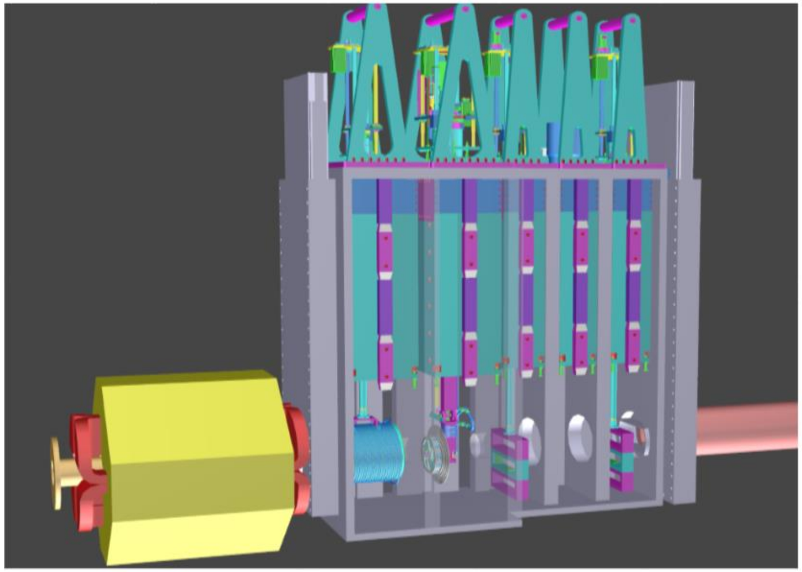
Walker, Litvinov and Geissel, Int. J. Mass Spec. 349-350 (2013) 247

SuperFRS at FAIR

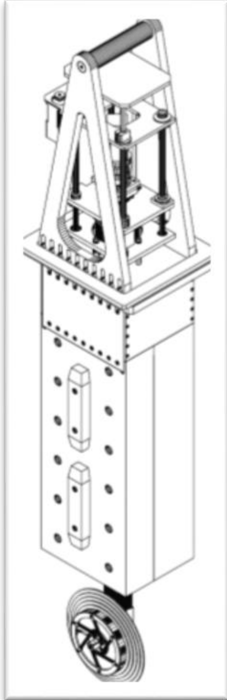
A total of 75 targets of different elements with differing thicknesses can be installed at the target station at the entrance of the fragment separator. Each of the cylindrical targets, which have a diameter of two centimeters, can be moved into the path of the ion beam with millimeter precision using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



Target chamber



Target with shielding



Prototype

SuperFRS at FAIR

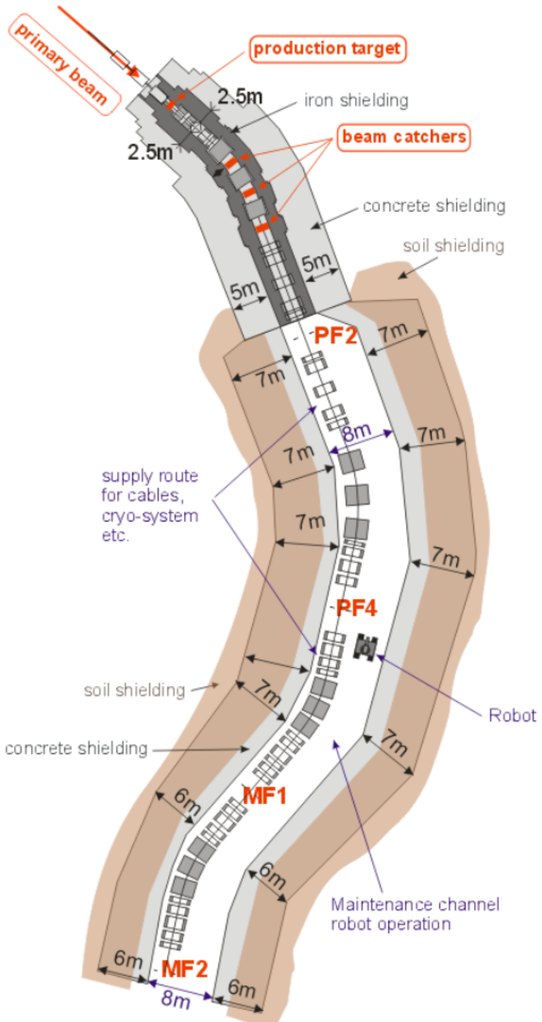


Figure 2.4-166: Schematic layout of the Super-FRS with beam line and shielding measures. The area from the target up to the intermediate focal plane PF2 of the Pre-Separator is shielded with iron in order to provide a compact radiation protection in the target building. The concrete in the Main-Separator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

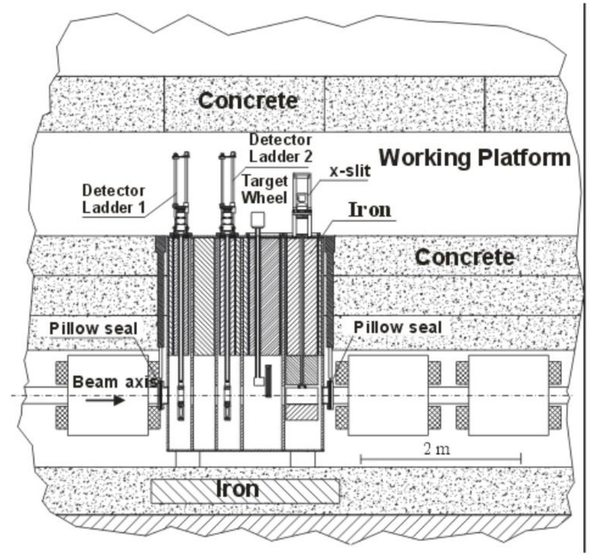


Figure 2.4-126: Schematic layout of the target area of the Super-FRS. A vertical plug system has been adapted which has proven to guarantee a safe and reliable operation at PSI in a very high radiation field. Routine maintenance at PSI is done about once per year.

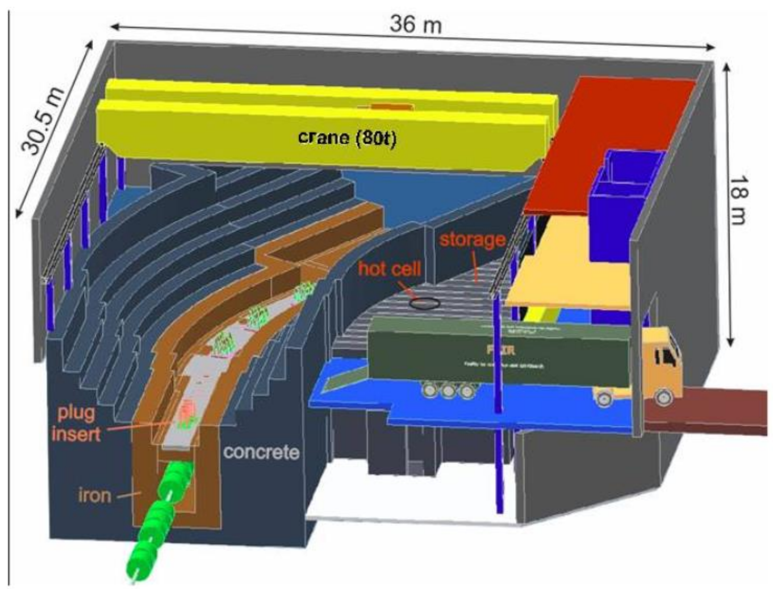
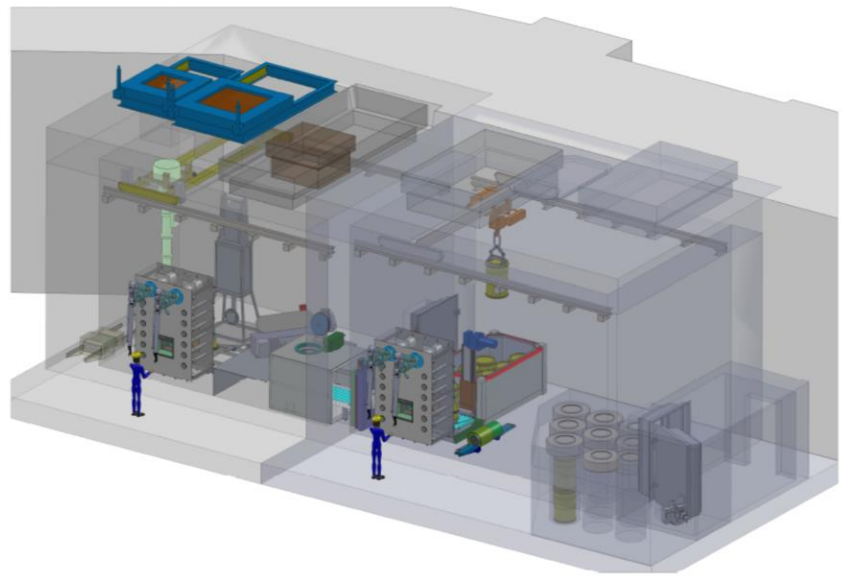


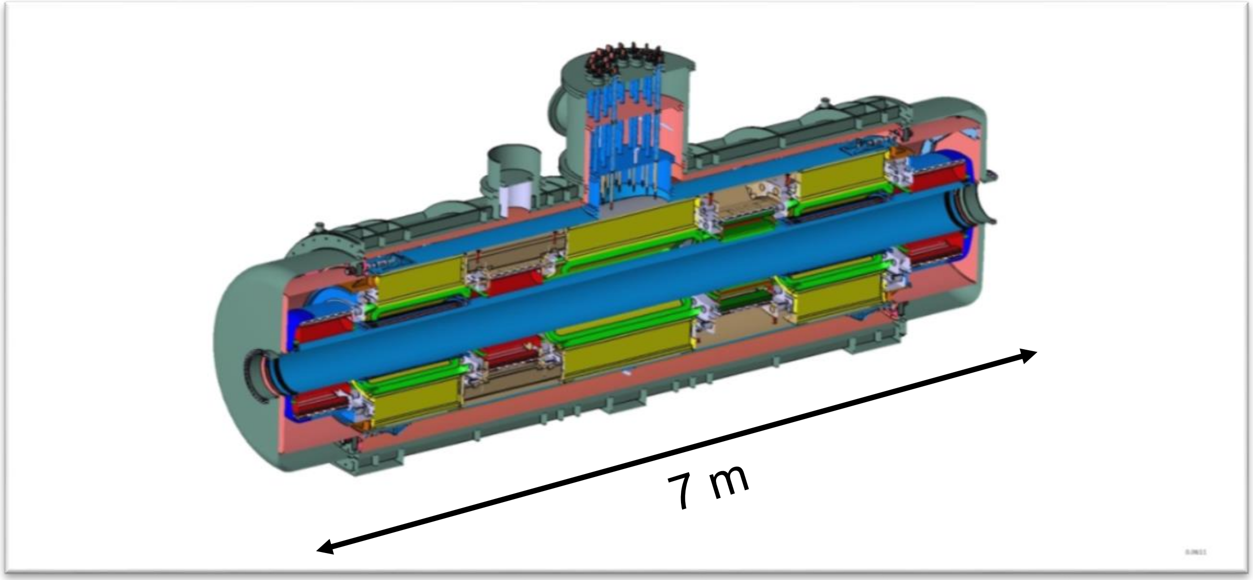
Figure 2.4-175: Layout of the Super-FRS target building. The top part of the concrete shielding can be removed to access the working platform. Heavy devices can be transported by crane to the nearby hot cell, storage places or directly onto a truck which can drive into the hall.

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.



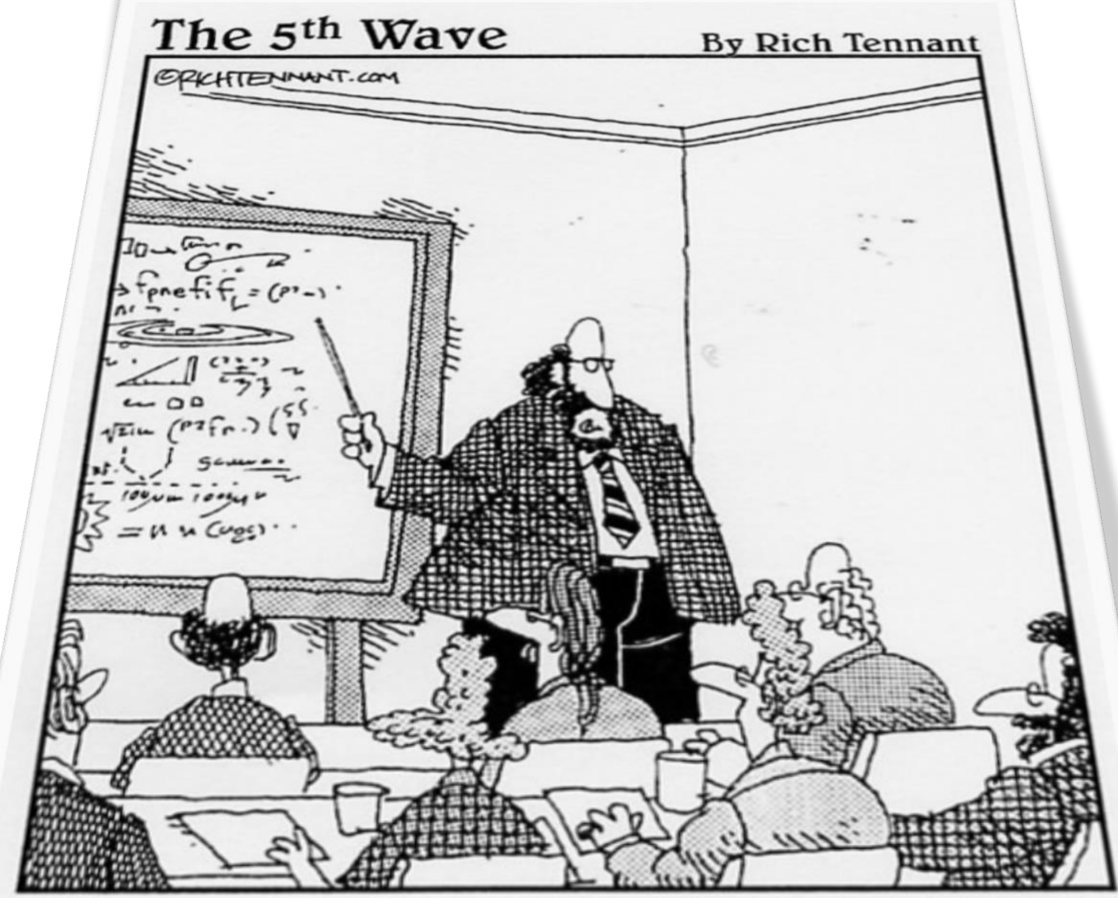
Superconducting Multiplets



- 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

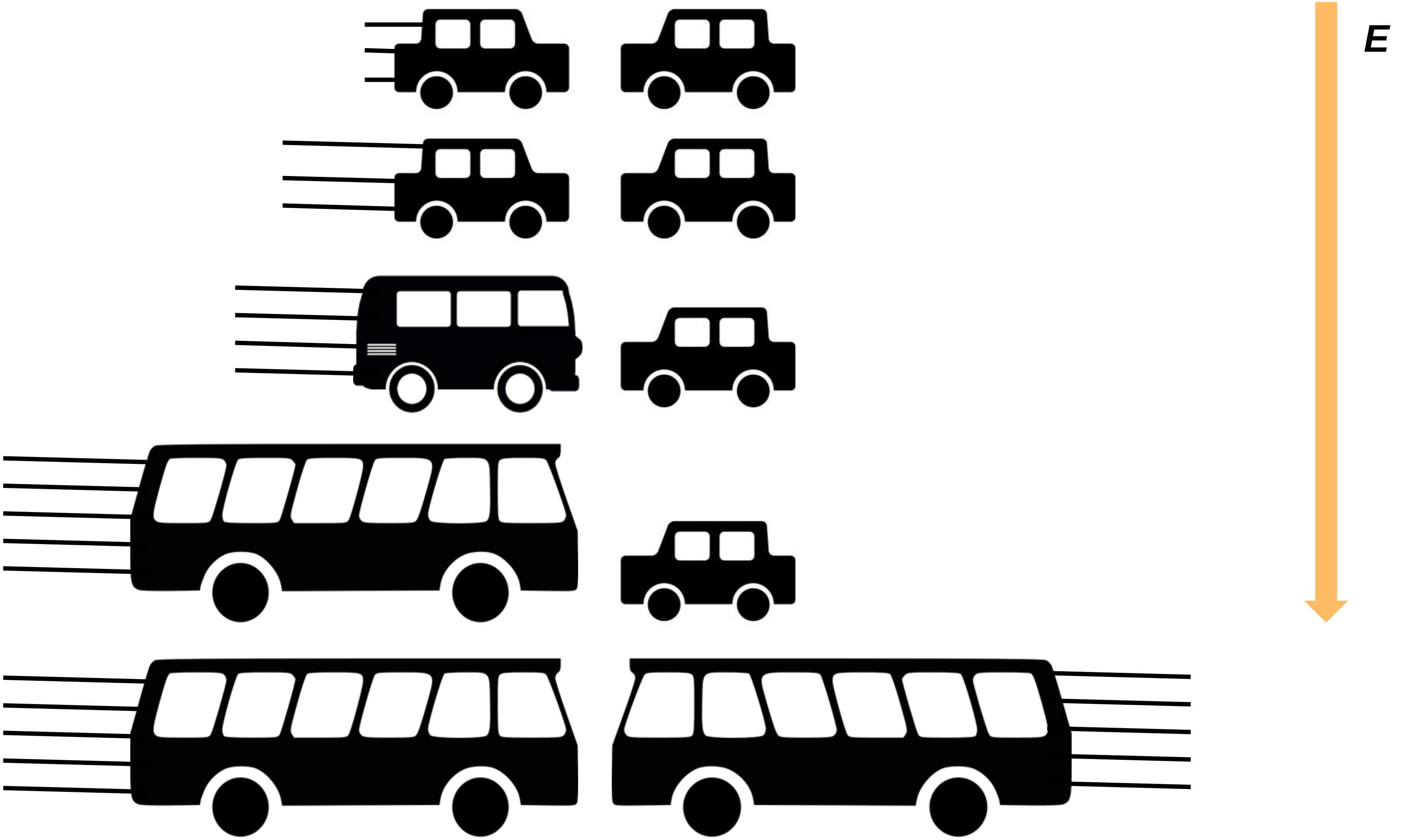
- iron dominated, cold iron (≈40 tons)
- common helium bath, LHe ≈ 1.300 l
- warm beam pipe (38 cm inner diameter)
- per magnet 1 pair of current leads
- max. current <300A for all magnets

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).

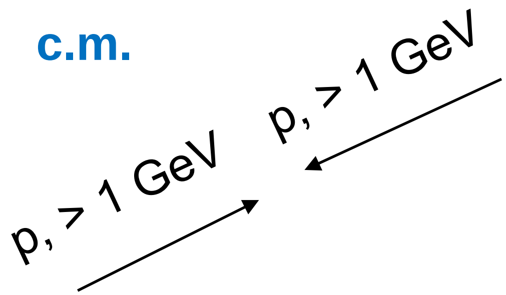
Detection of the top quark at Fermilab (1995)
Nobel Prize 2008 to Makoto Kobayashi (left) and Toshihide Maskawa (right) for its prediction.

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

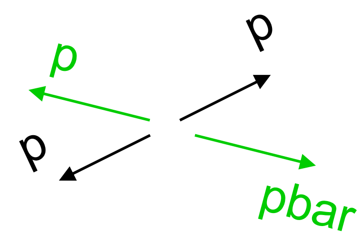
Creation of Antiprotons

c.m.

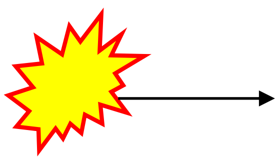


$m = E / c^2$

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

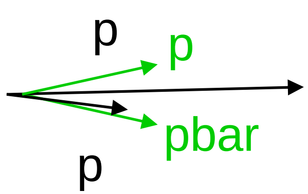


lab

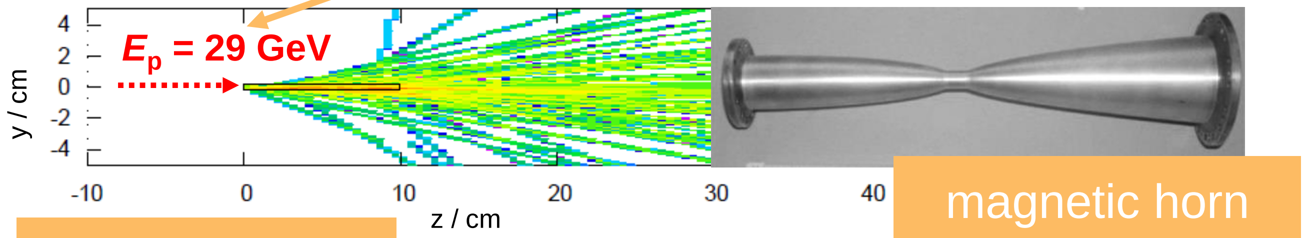


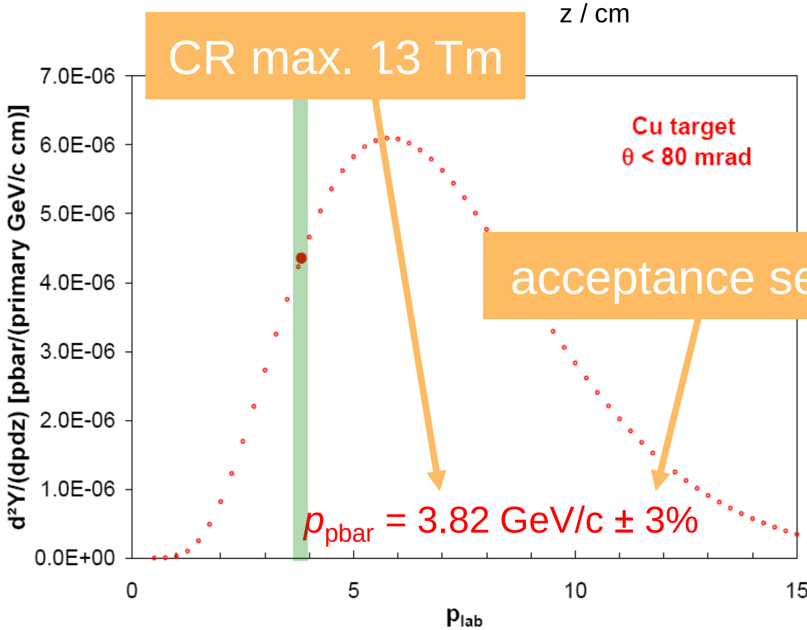
$m = E / c^2$

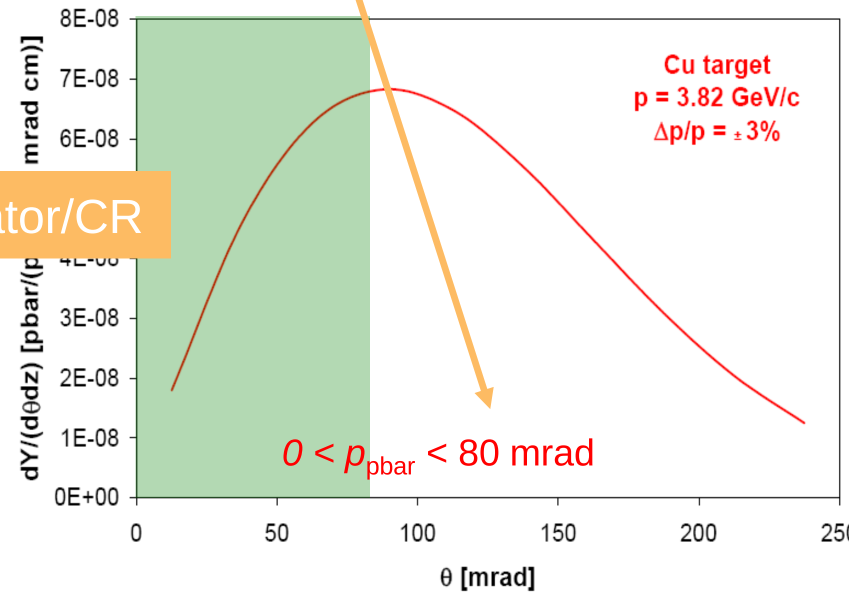
$T_{pbar} > 6 \text{ GeV}$



Collectible pbars

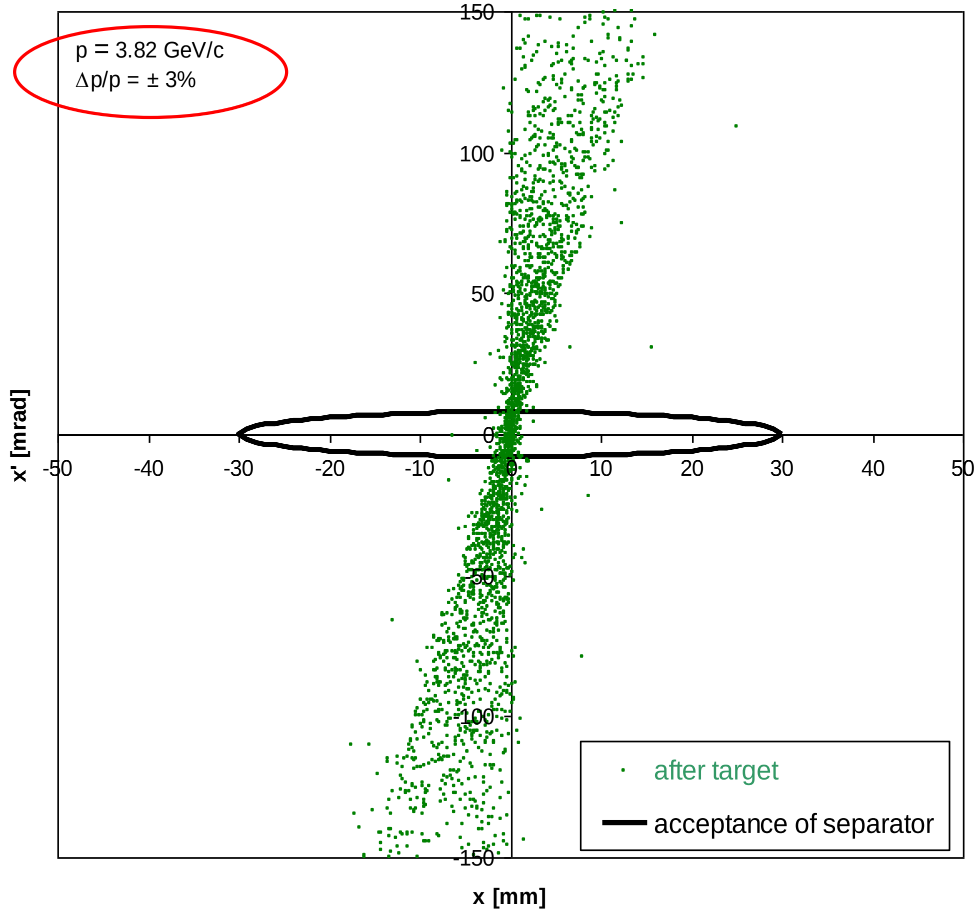




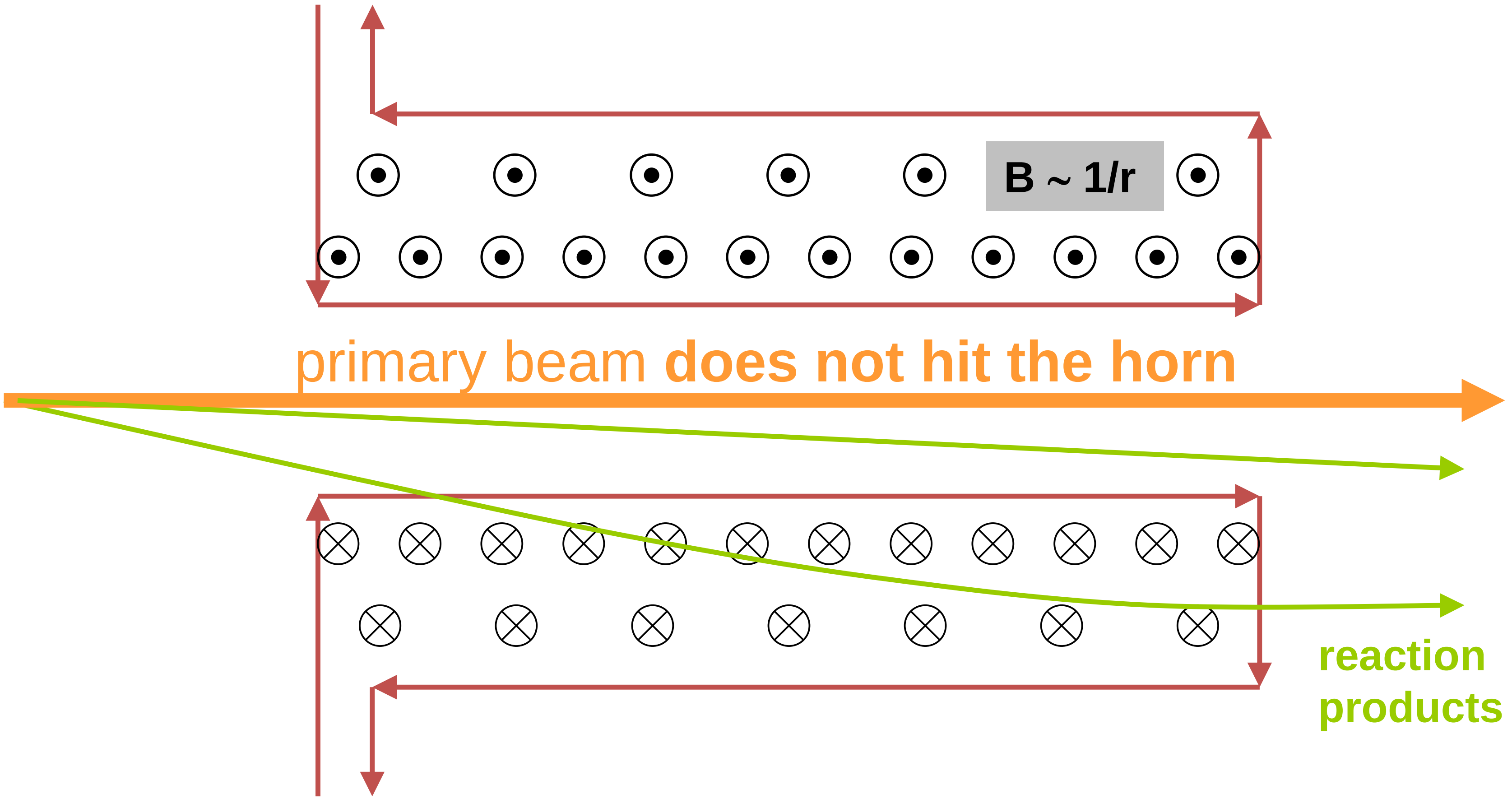


From ~ 2.5×10^{-4} pbar / (p cm target) ~ 5×10^{-6} (or 2 %) are "collectible"

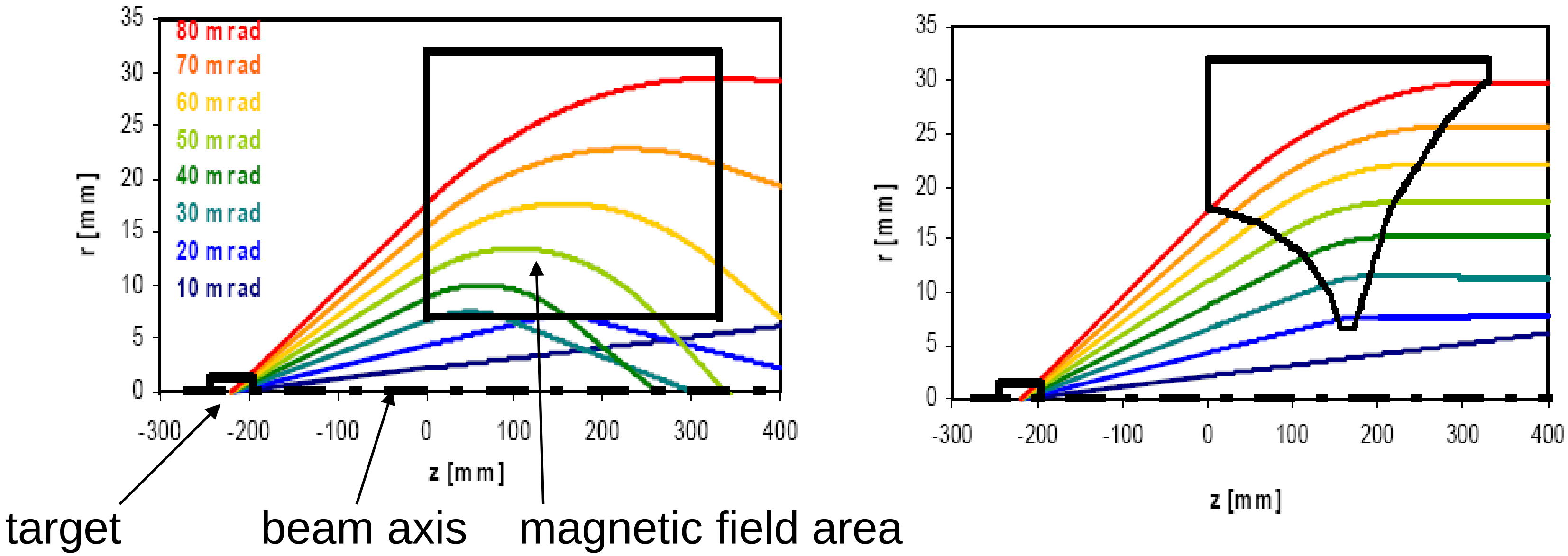
MARS Simulation of the pbar Yields

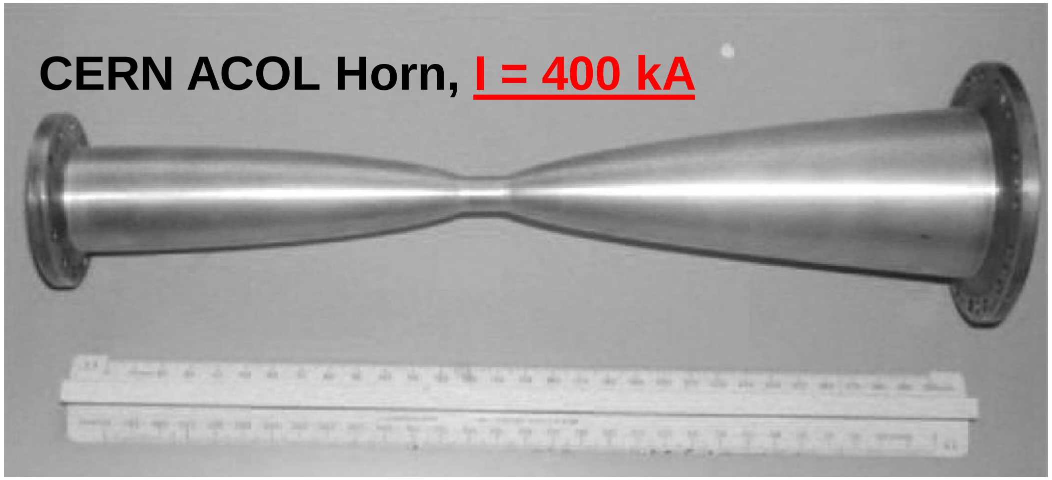


Collecting pbars: Magnetic Horn

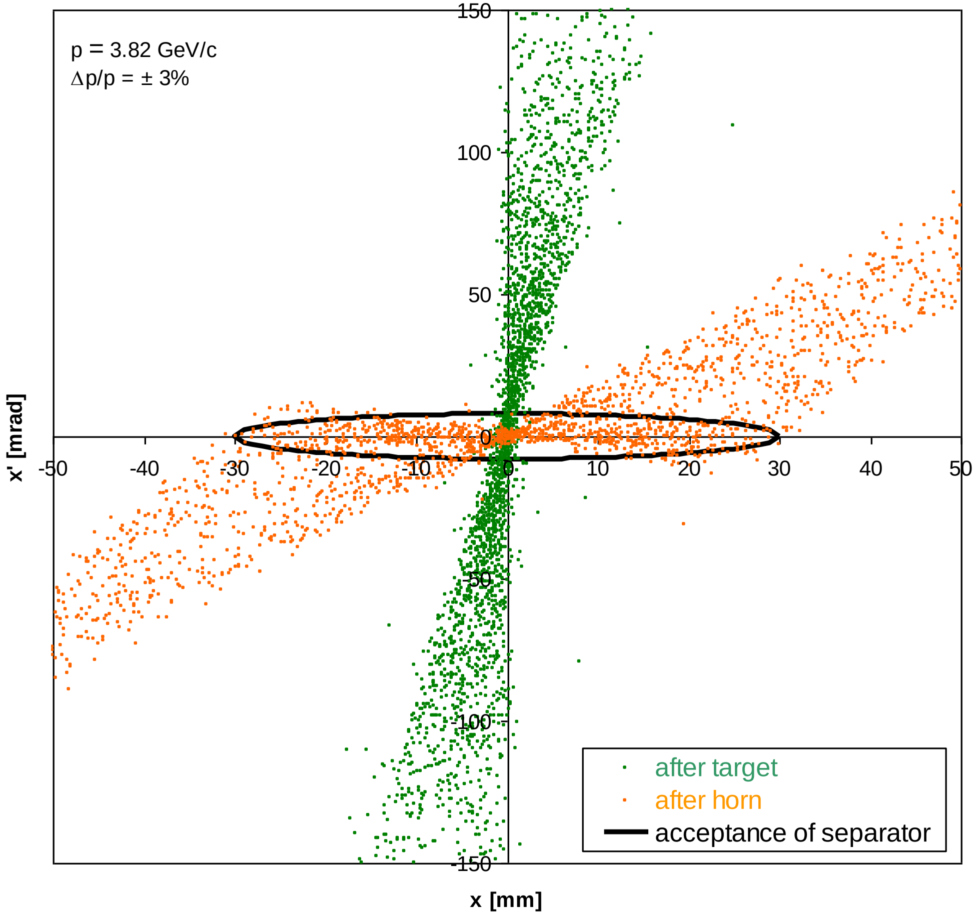


Collecting pbars: Magnetic Horn





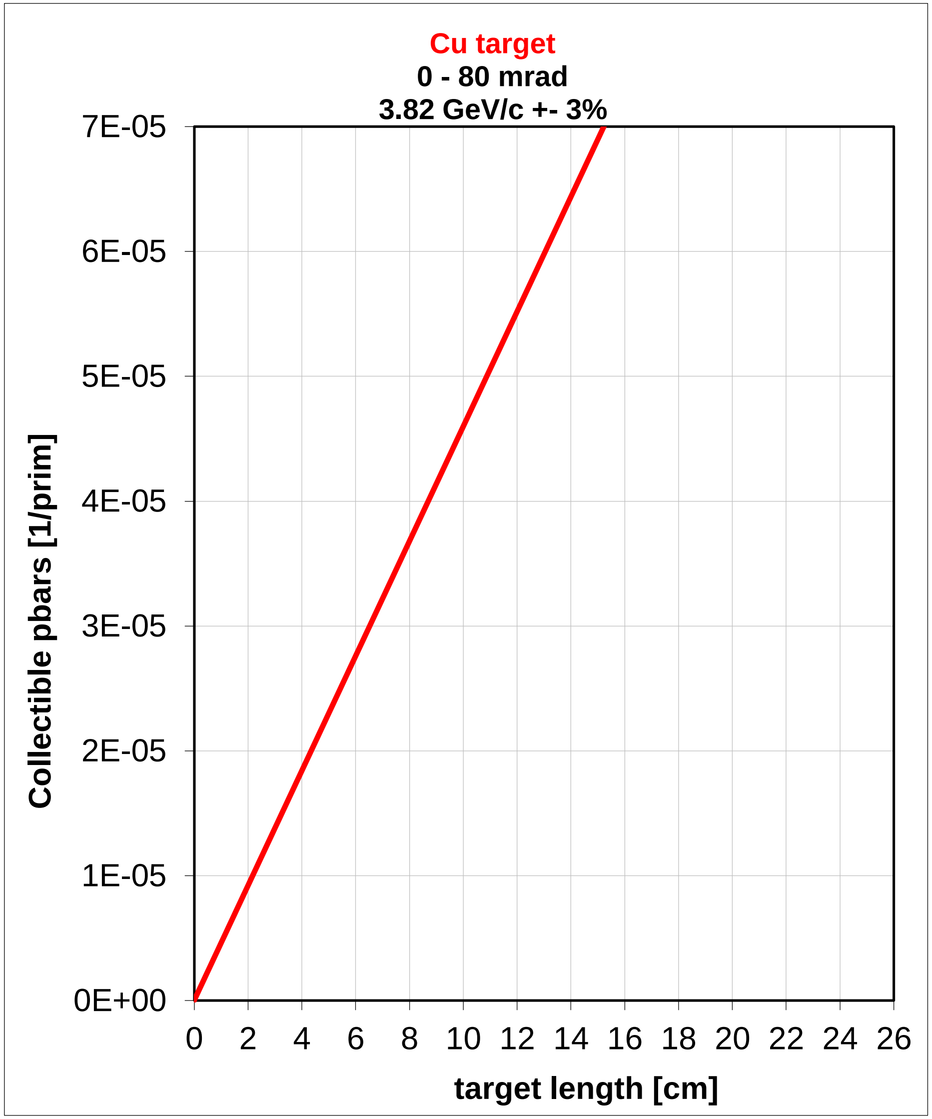
MARS Simulation of the pbar Yields



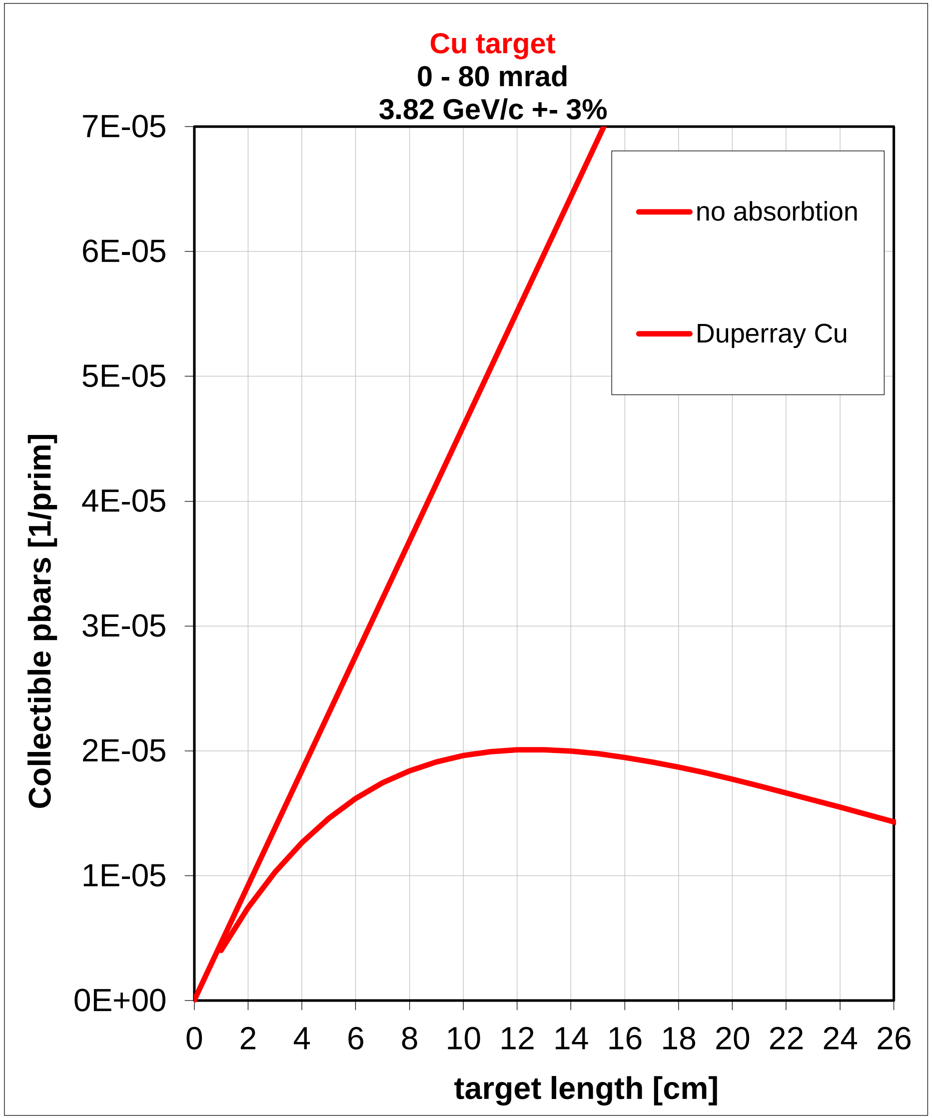
$$\text{yield} = \frac{\text{pbars in the ellipse}}{\text{primary protons}}$$

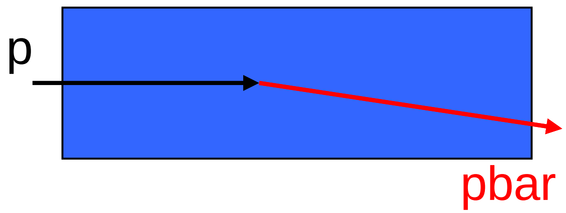
$$= 2 \times 10^{-5}$$

Collectible pbars



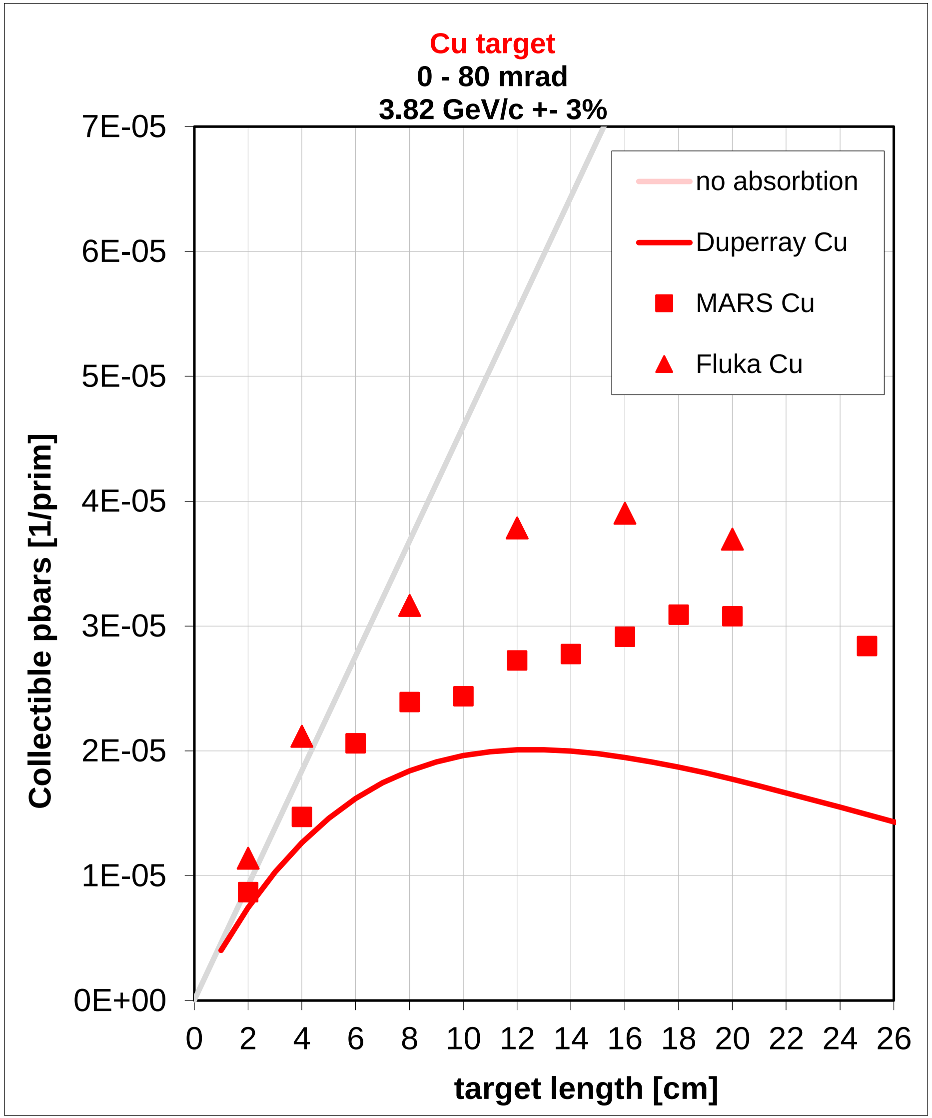
Collectible pbars: Self Absorption

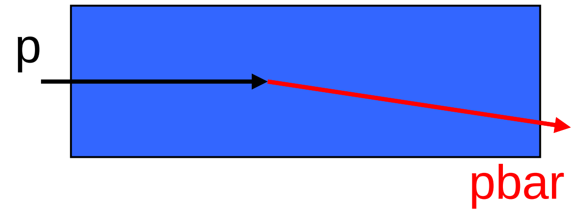




Cu: σ_{pbar} = 0.8 b

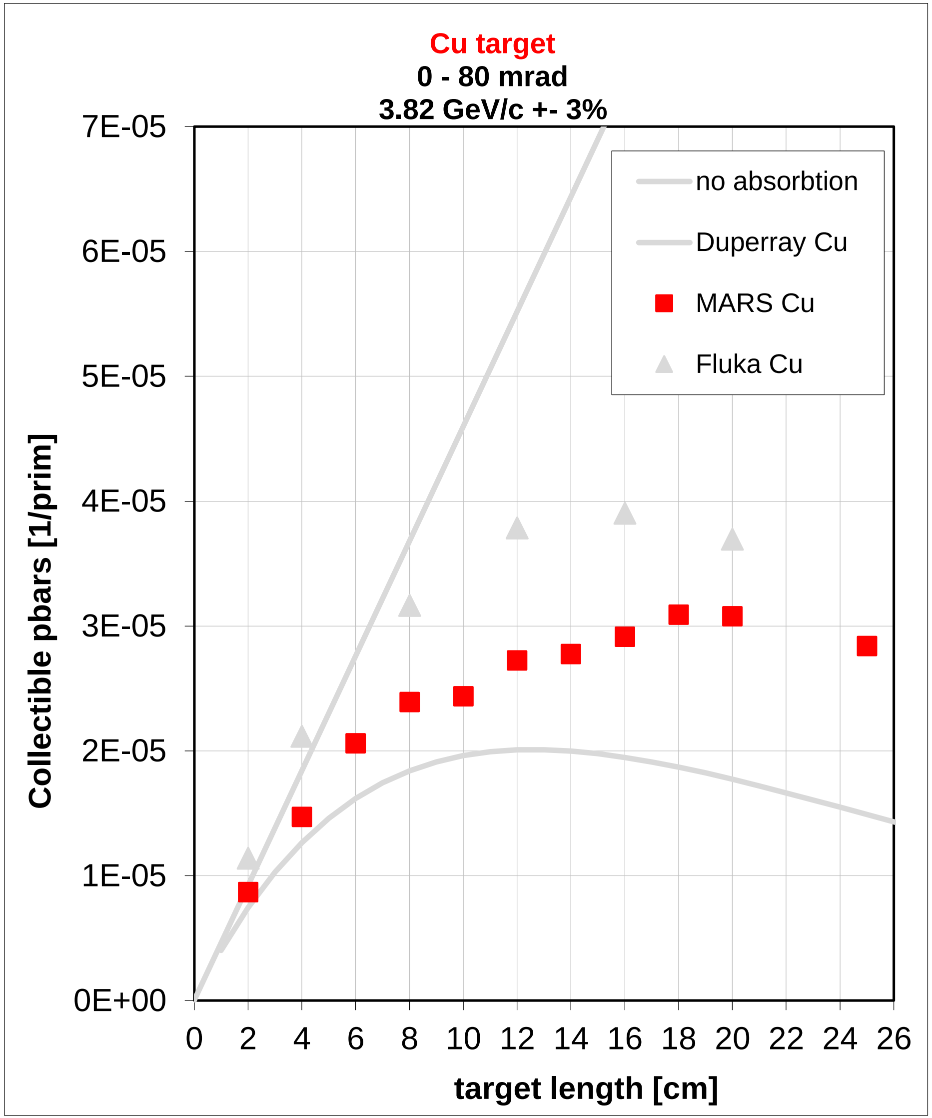
Collectible pbars: MARS/FLUKA

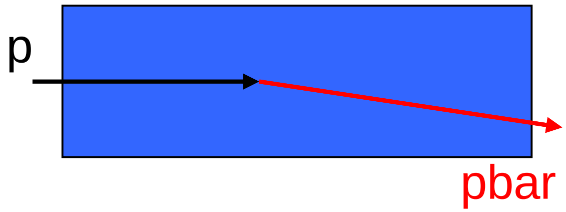




Cu: σ_{pbar} = 0.8 b

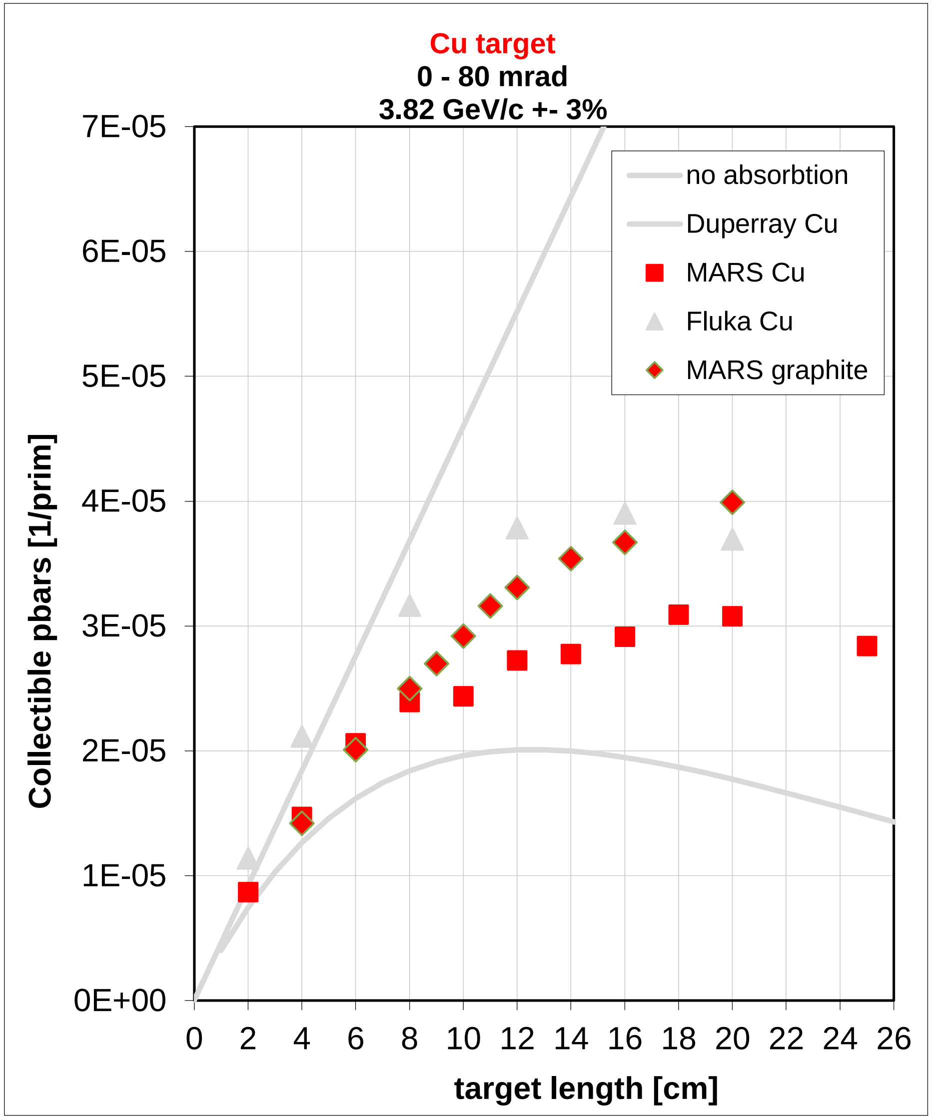
Collectible pbars: MARS

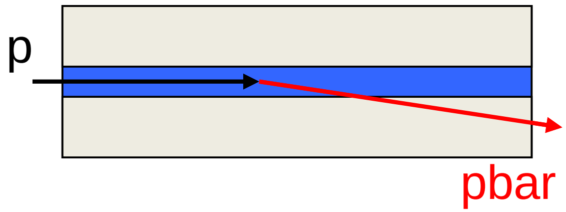




Cu: σ_{pbar} = 0.8 b

Collectible pbars: Graphite Surrounding

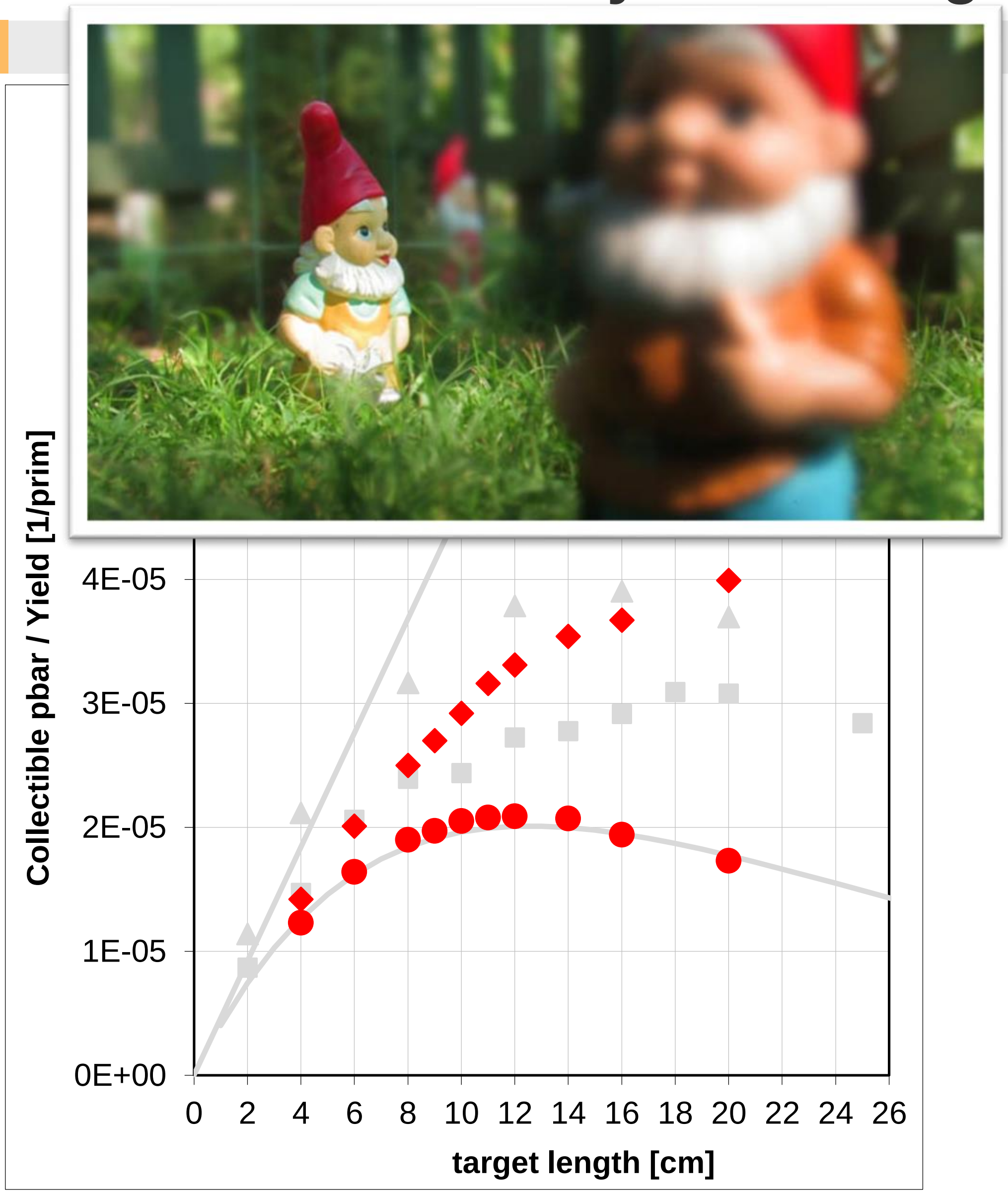


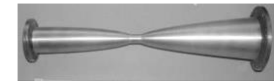


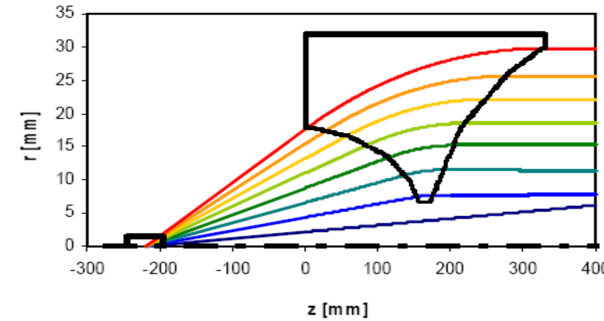
Cu: σ_{pbar} = 8.8 b

C: σ_{pbar} = 0.42 b

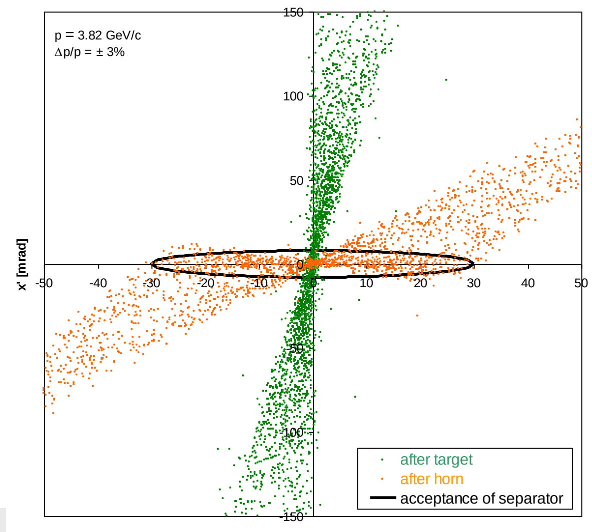
pbar Yield:
Collection efficiency of the magnetic horn







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



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}**

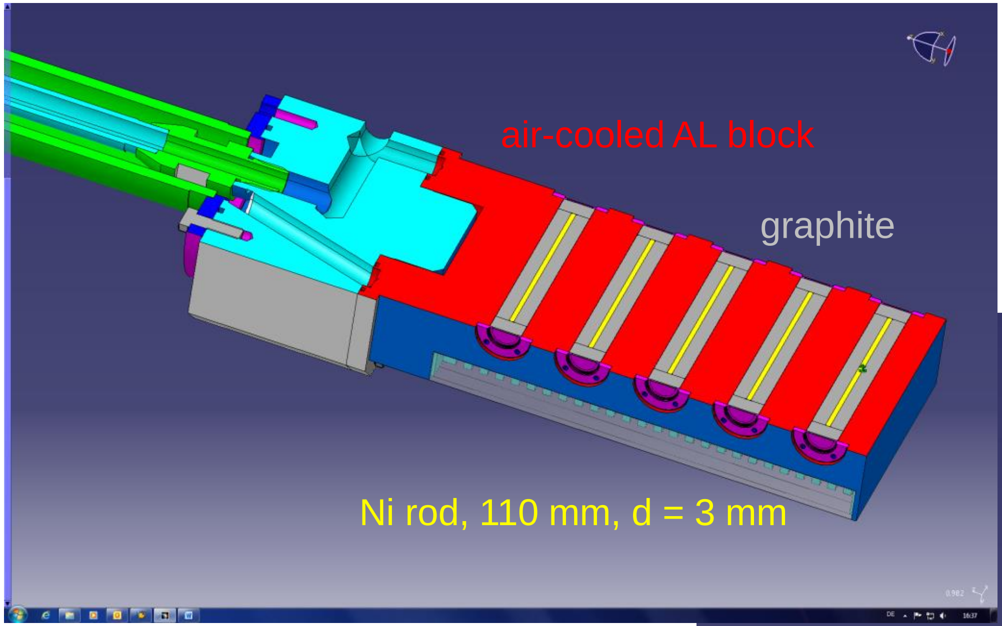
scattering losses/annihilation in air/aluminum *losses in separator / during injection*

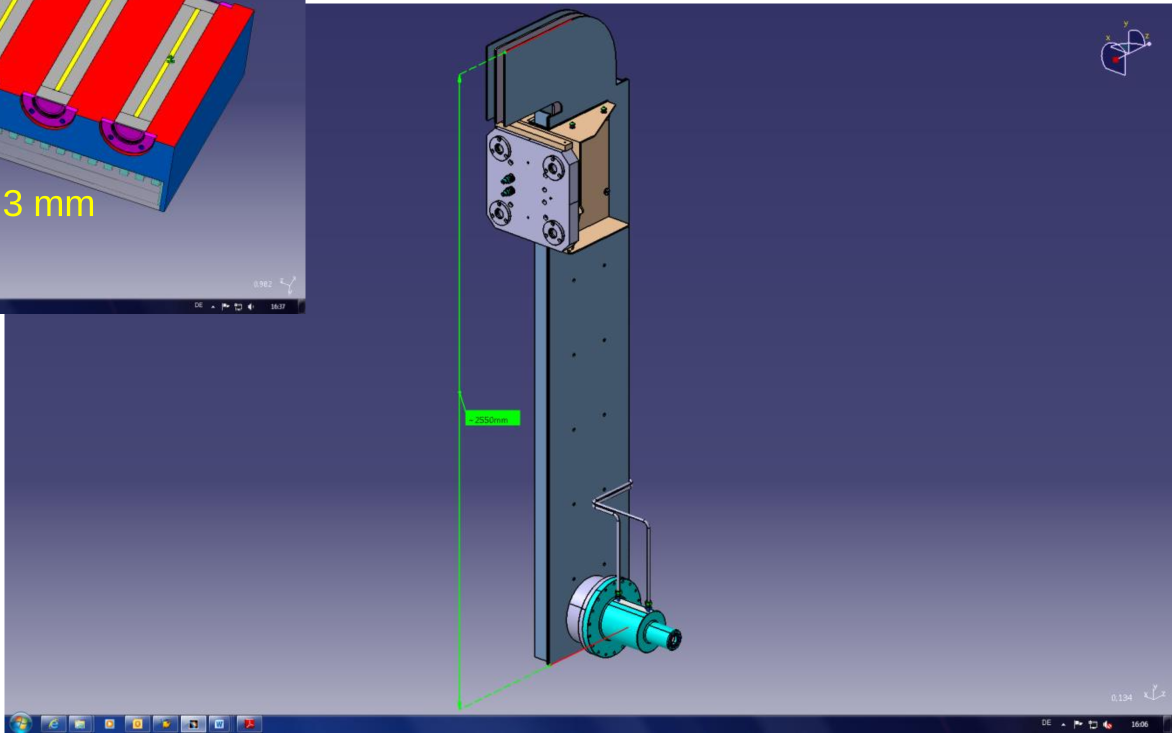
Exp. data from CERN (Baird 1998) to injection orbit:

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

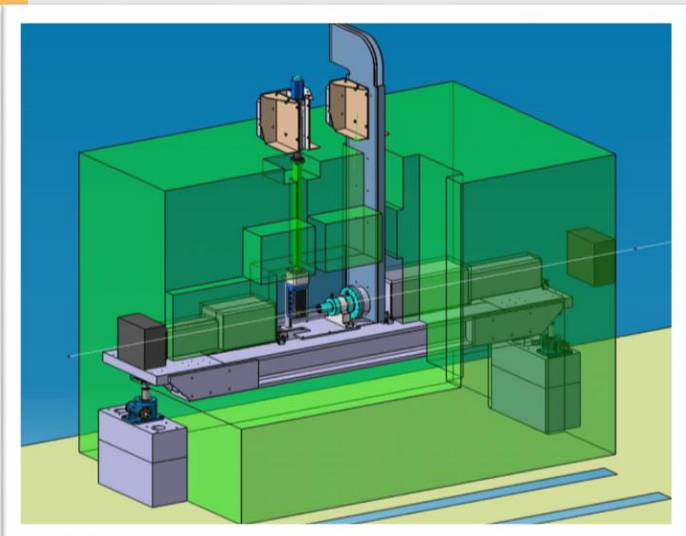
correction for different energies and emmitances

pbar Target and Magnetic Horn



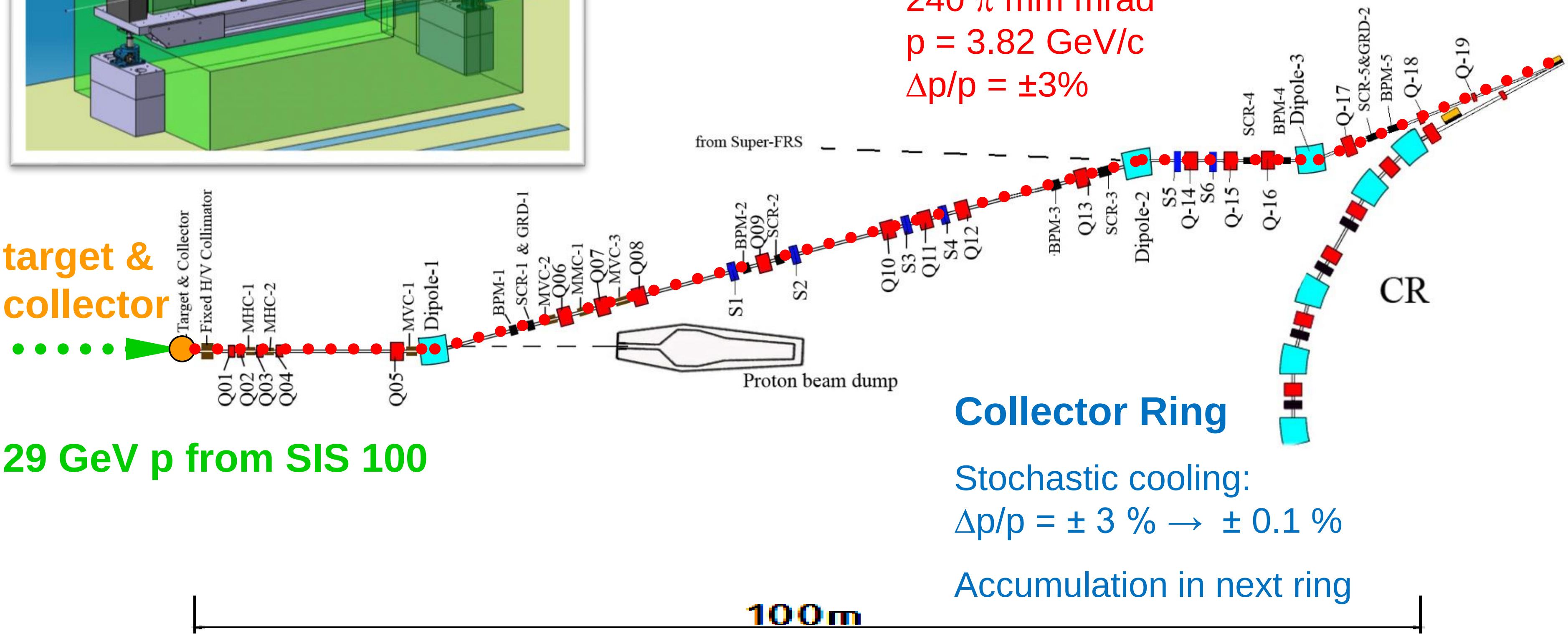


The pbar separator



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

target & collector



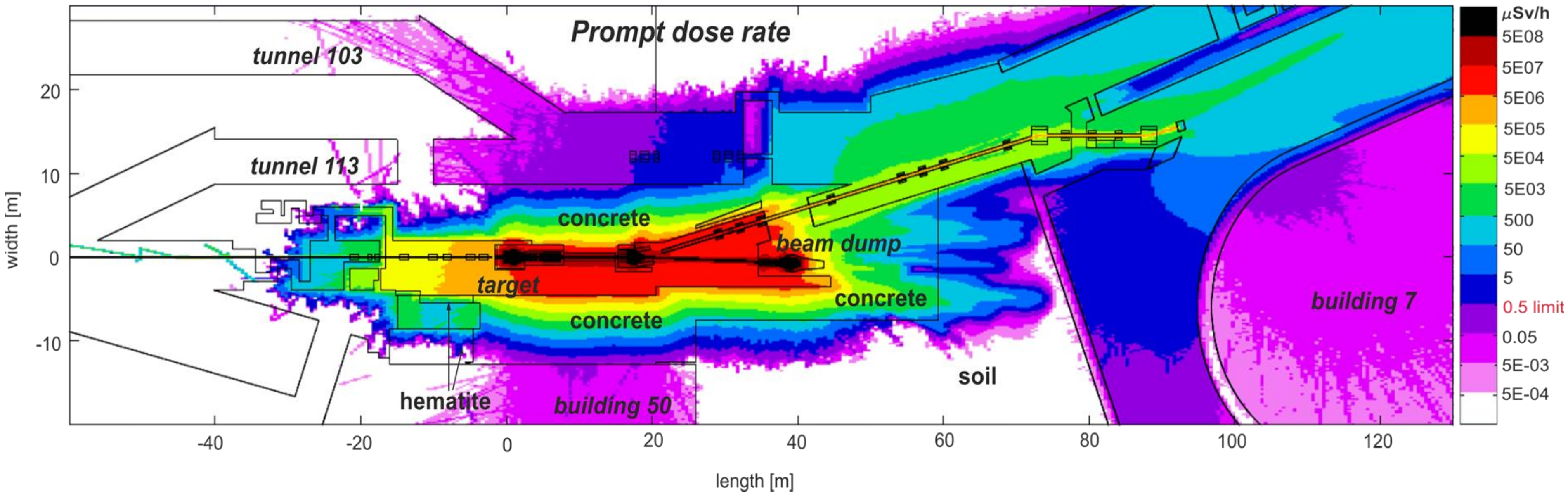
29 GeV p from SIS 100

Collector Ring

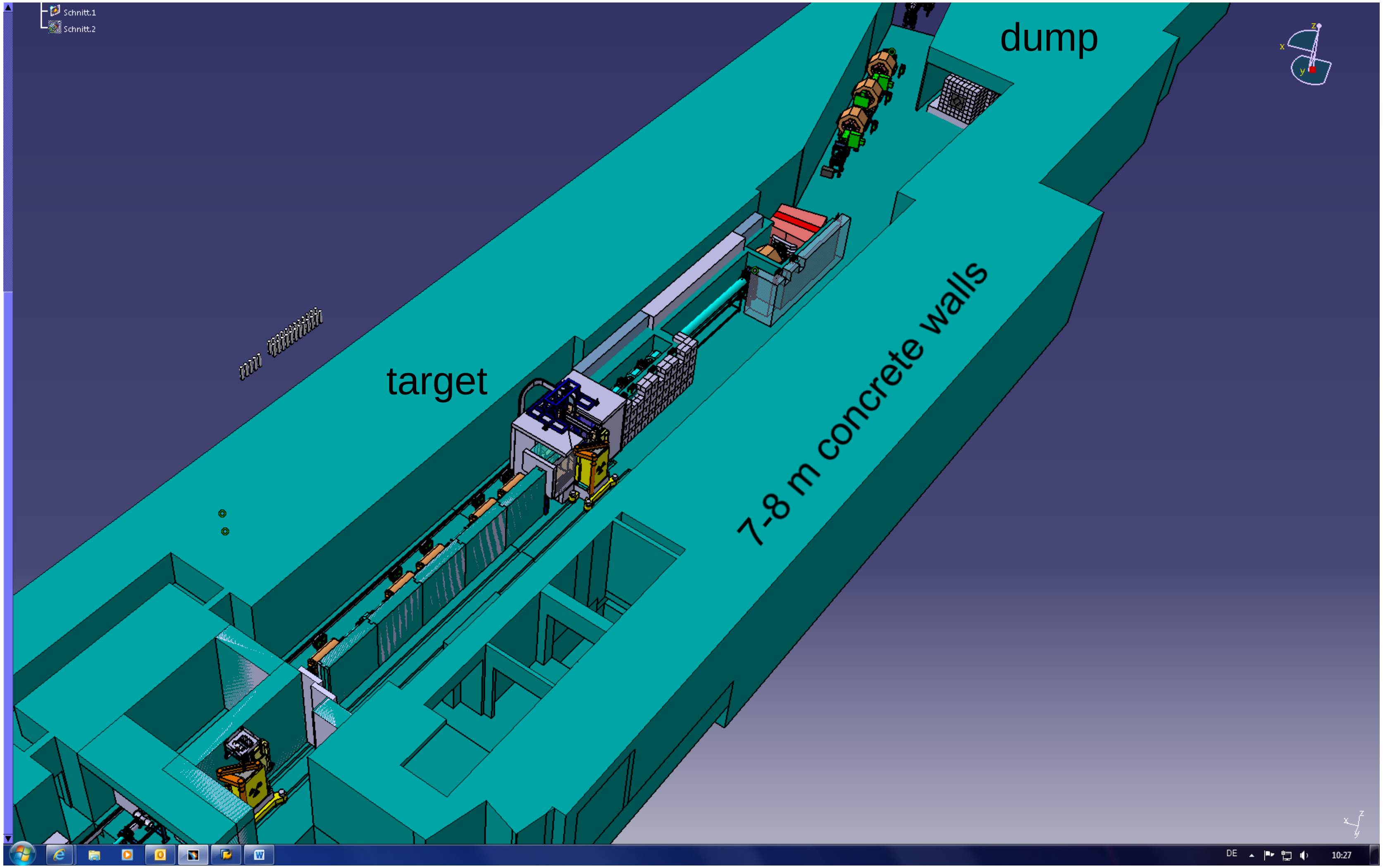
Stochastic cooling:
Δp/p = ± 3 % → ± 0.1 %

Accumulation in next ring

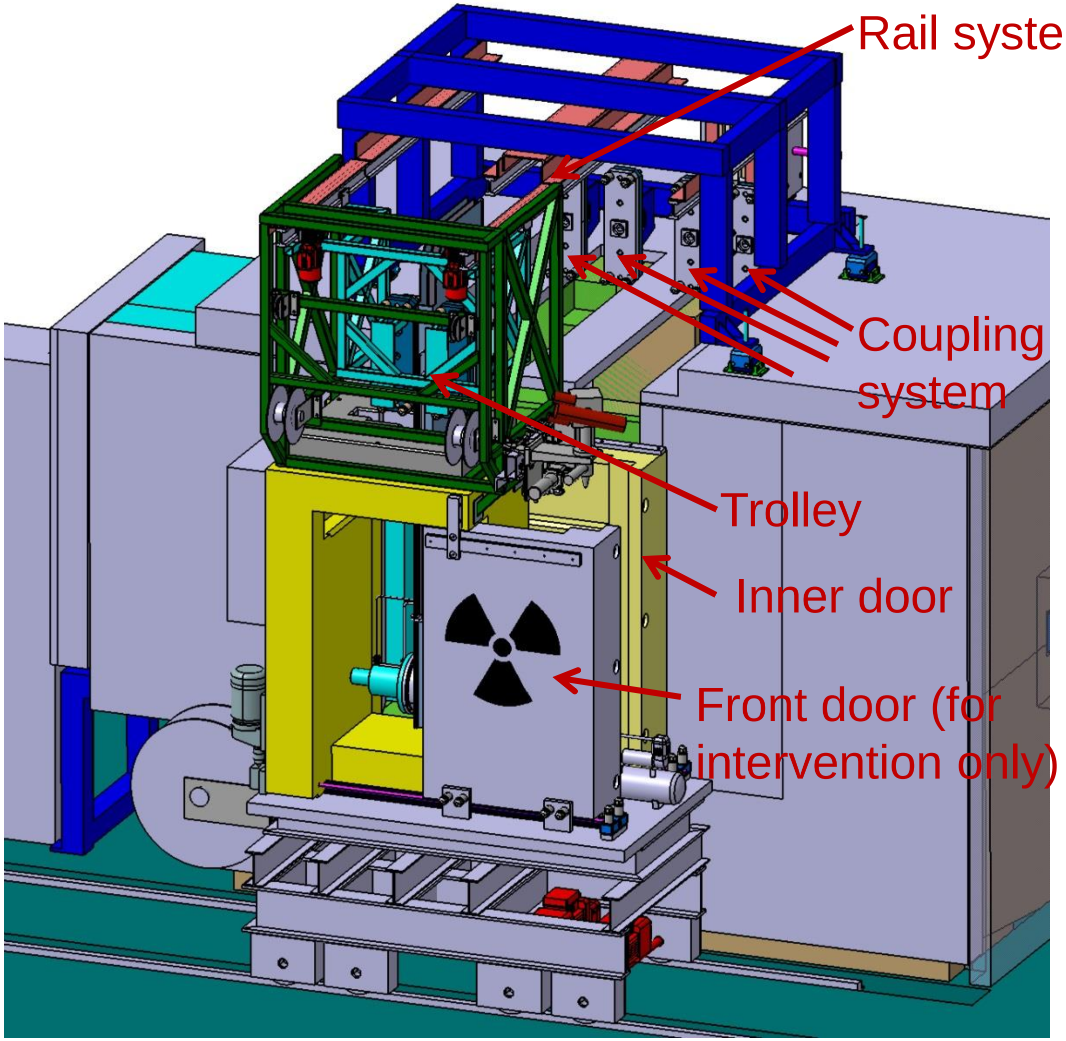
Dose rates during operation



The pbar building

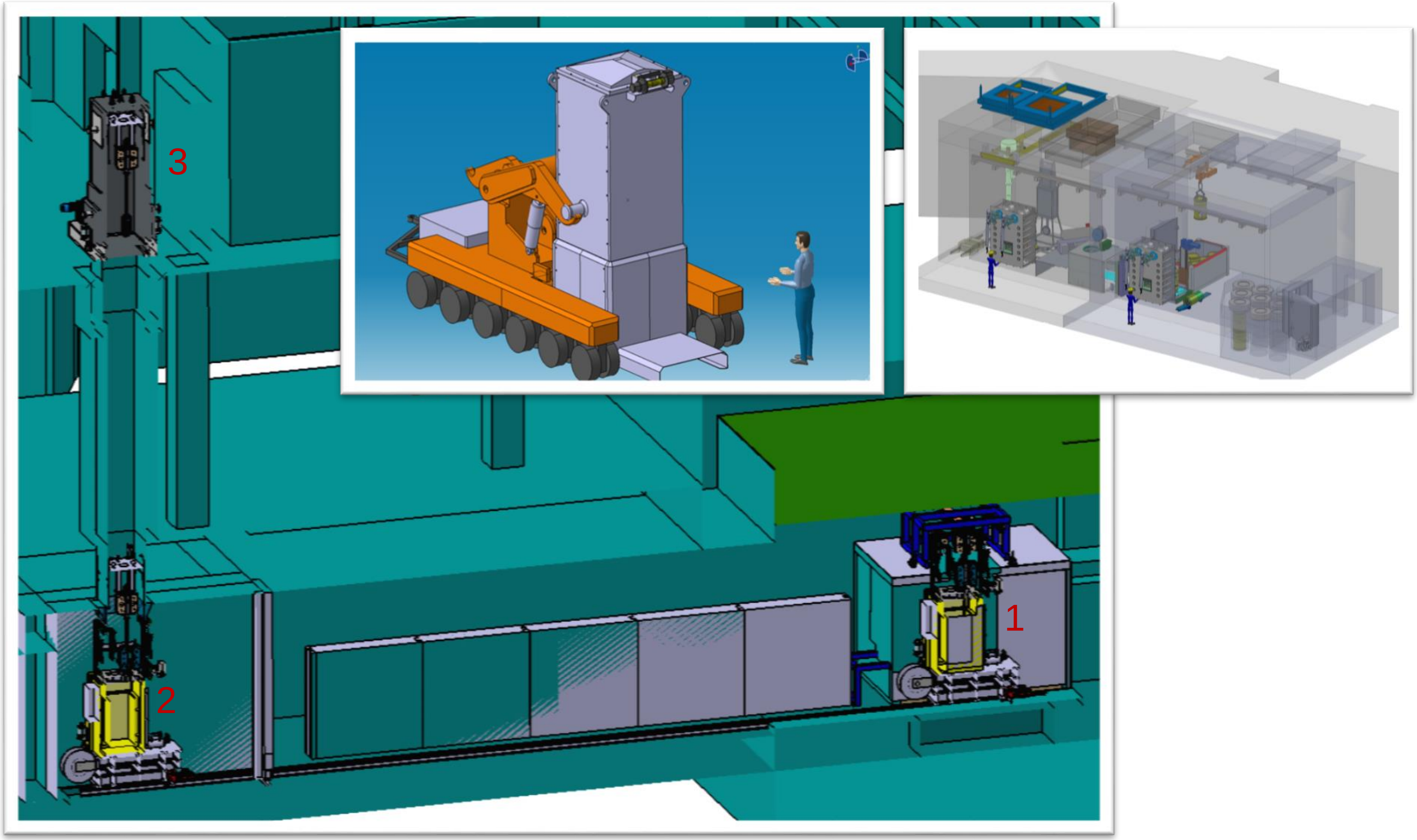


Target station and transport container



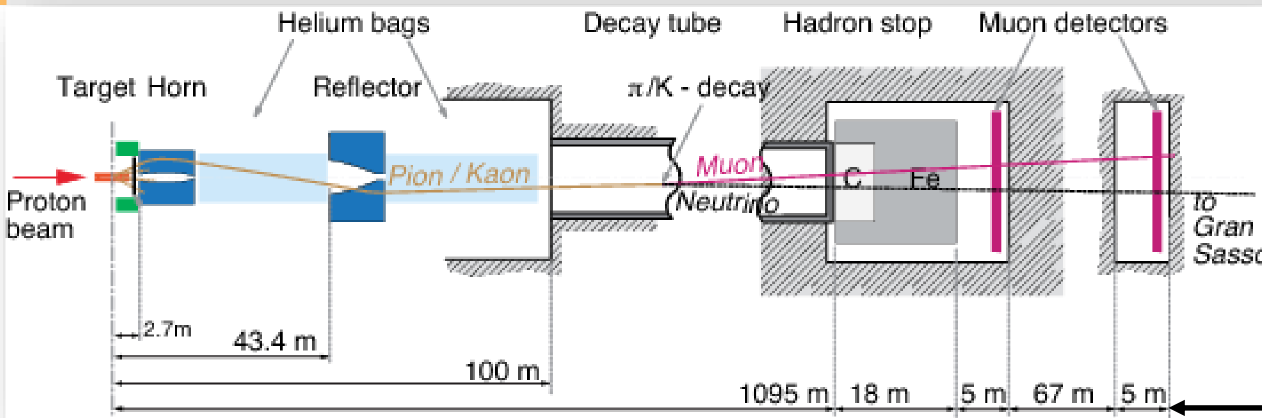
- Transport container is placed in front of target station.
- Door of target station and transport container are opened.
- Component is gripped by a quick coupling system.
- Trolley moves the component via rail system into the transport container.
- Doors are closed.

Overview of transport

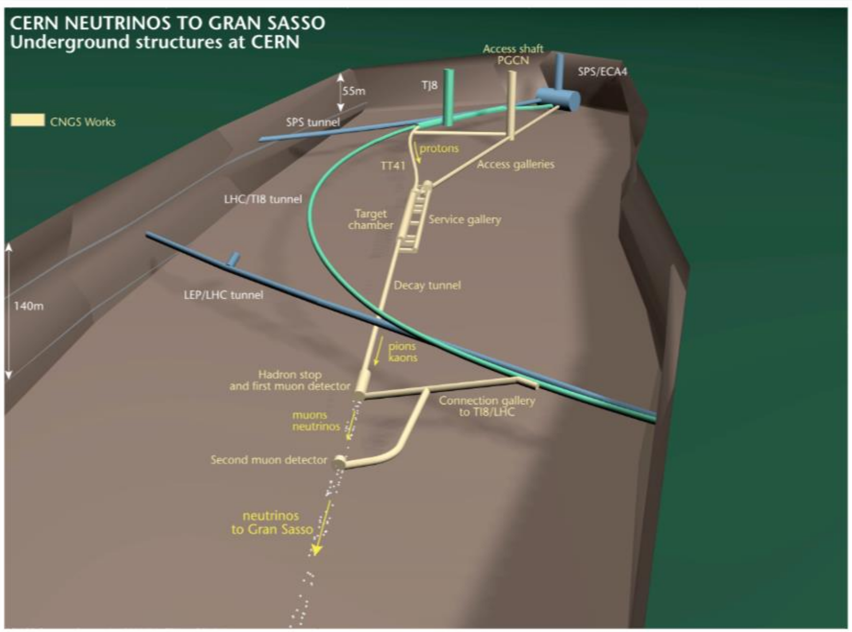


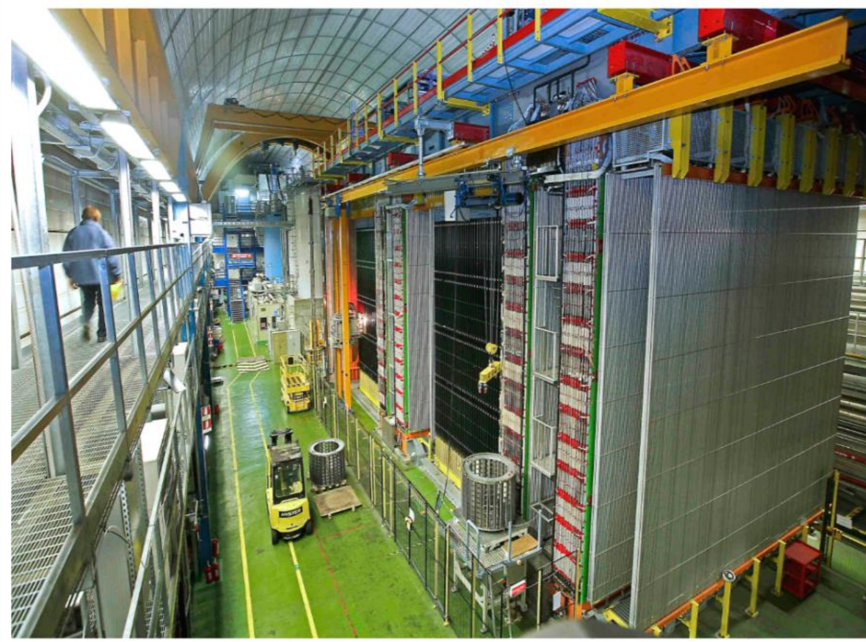
„Ternary“ Beams: e.g. CNGS

CERN neutrinos to Gran Sasso



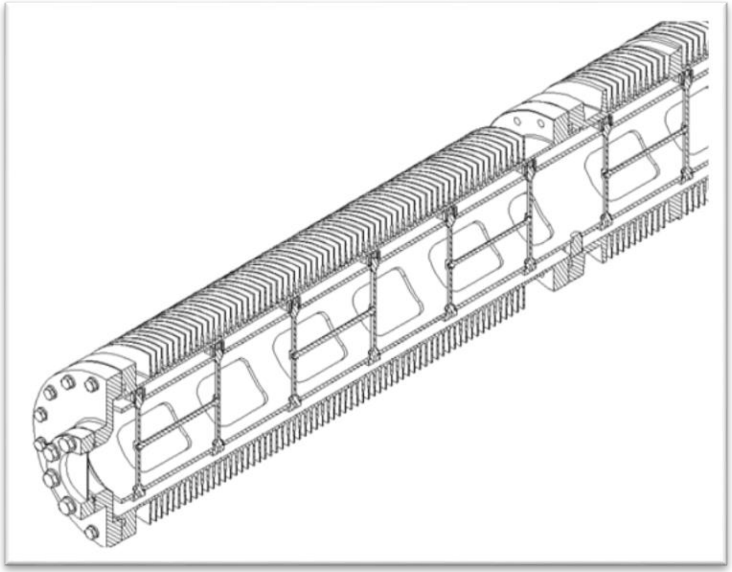
732 km

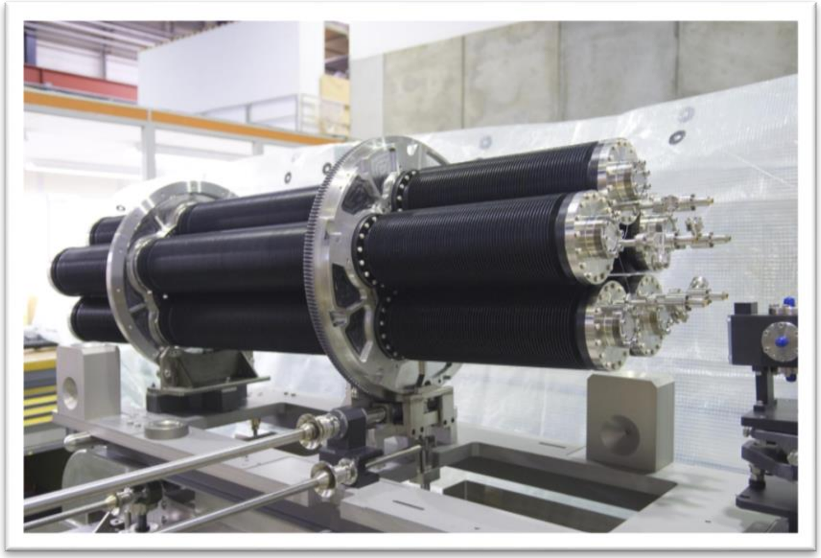


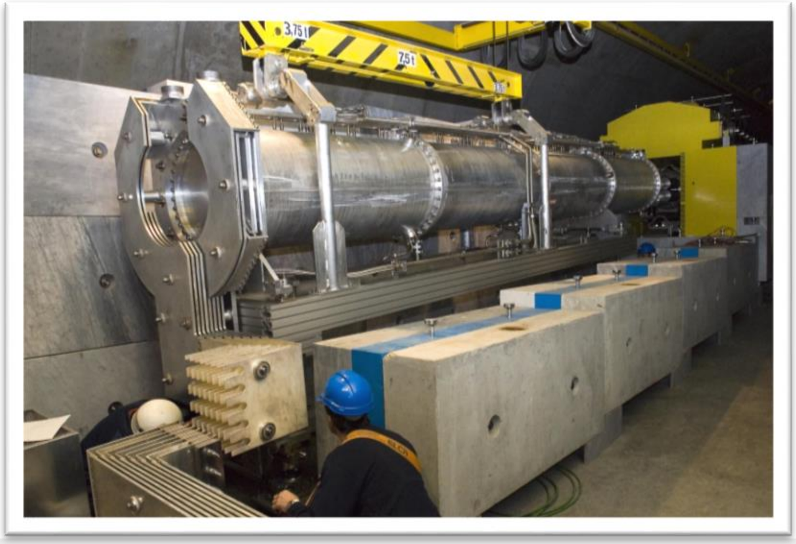


„Ternary“ Beams: e.g. CNGS

CERN neutrinos to Gran Sasso







Thank you for your attention!