From FRS to Super-FRS

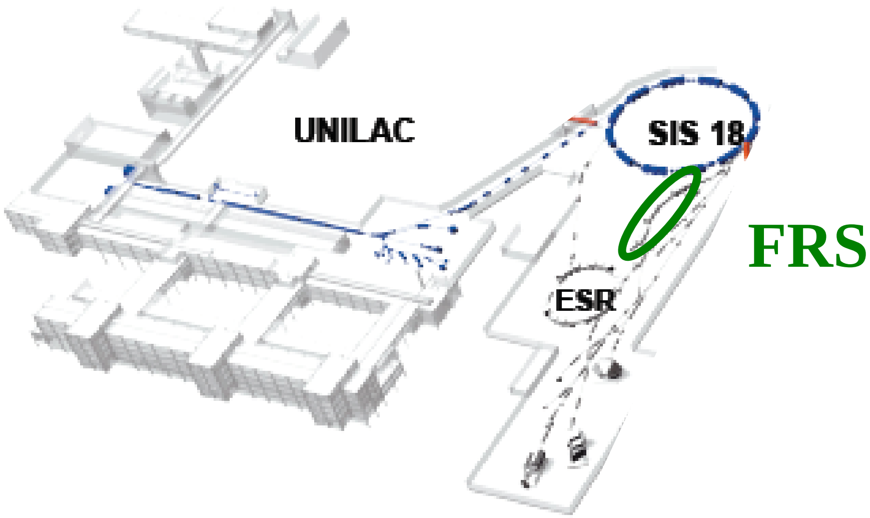
Martin Winkler

Artic FIDIPRO-EFES Workshop, April 20-24, 2009, Saariselkä, Finland

- **From GSI to FAIR (Facility of Antiproton and Ion Research)**
- **The FRagment Separator FRS @ GSI**
- **The Super-FRS (Layout, Features, Challenges) @ FAIR**
- **The Experimental Branches of the Super-FRS**
- **Summary**

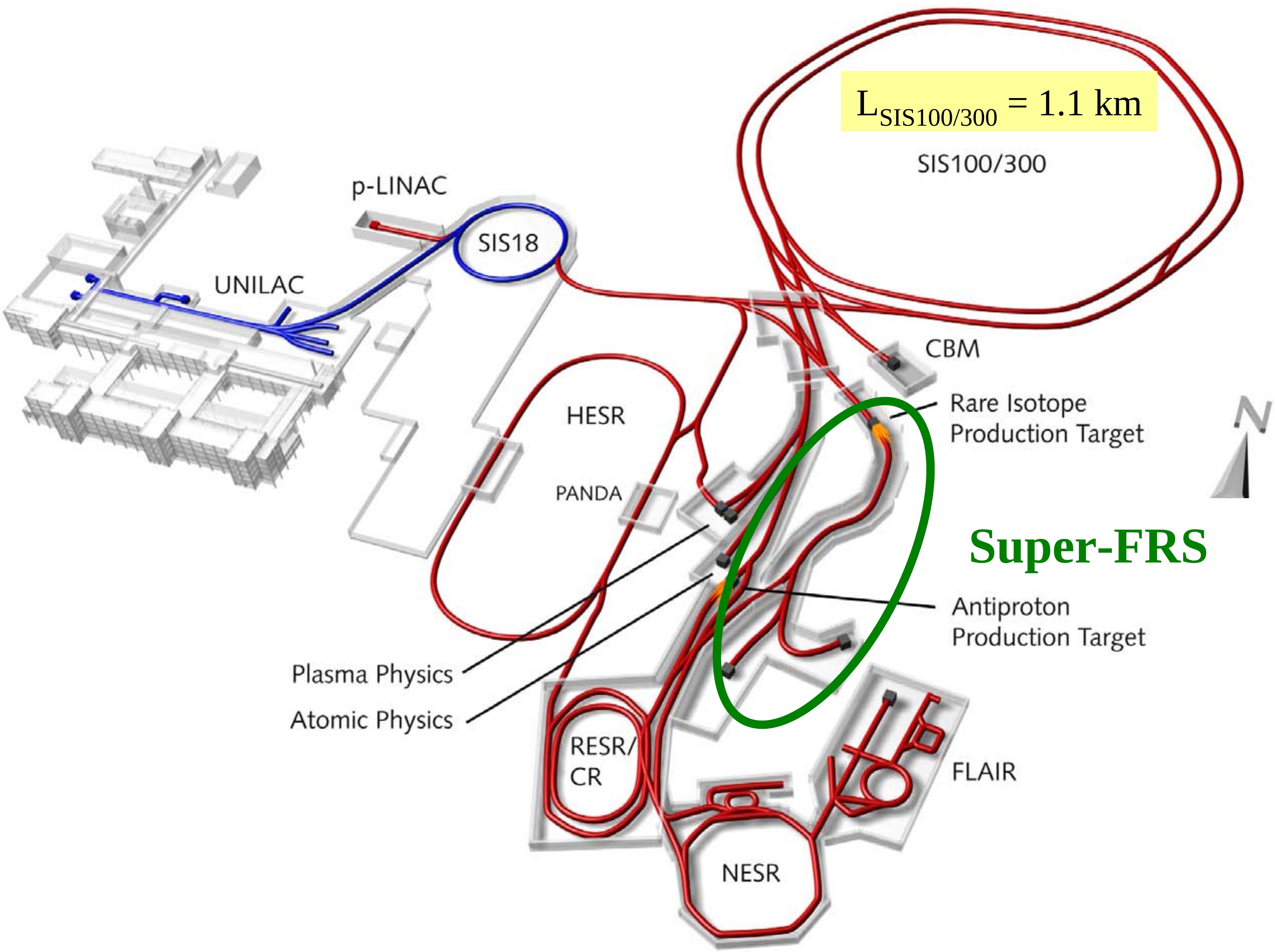
GSI and FAIR

GSI today



GSI and FAIR

FAIR in the future



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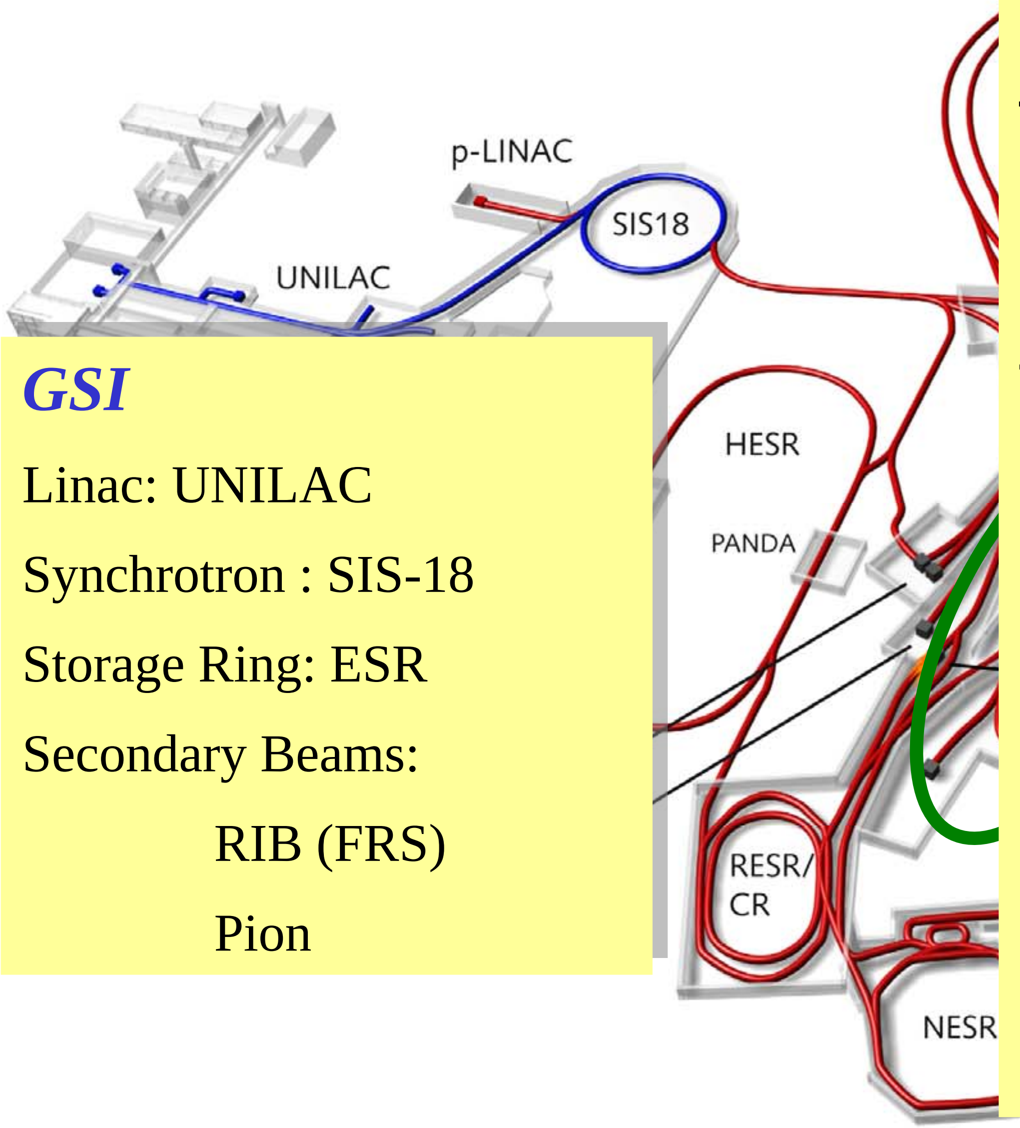
GSI and FAIR



GSI

Linac: UNILAC

Synchrotron : SIS-18

Storage Ring: ESR

Secondary Beams:

- RIB (FRS)
- Pion

FAIR

2 Linac's

- Proton
- Electron

8 Rings

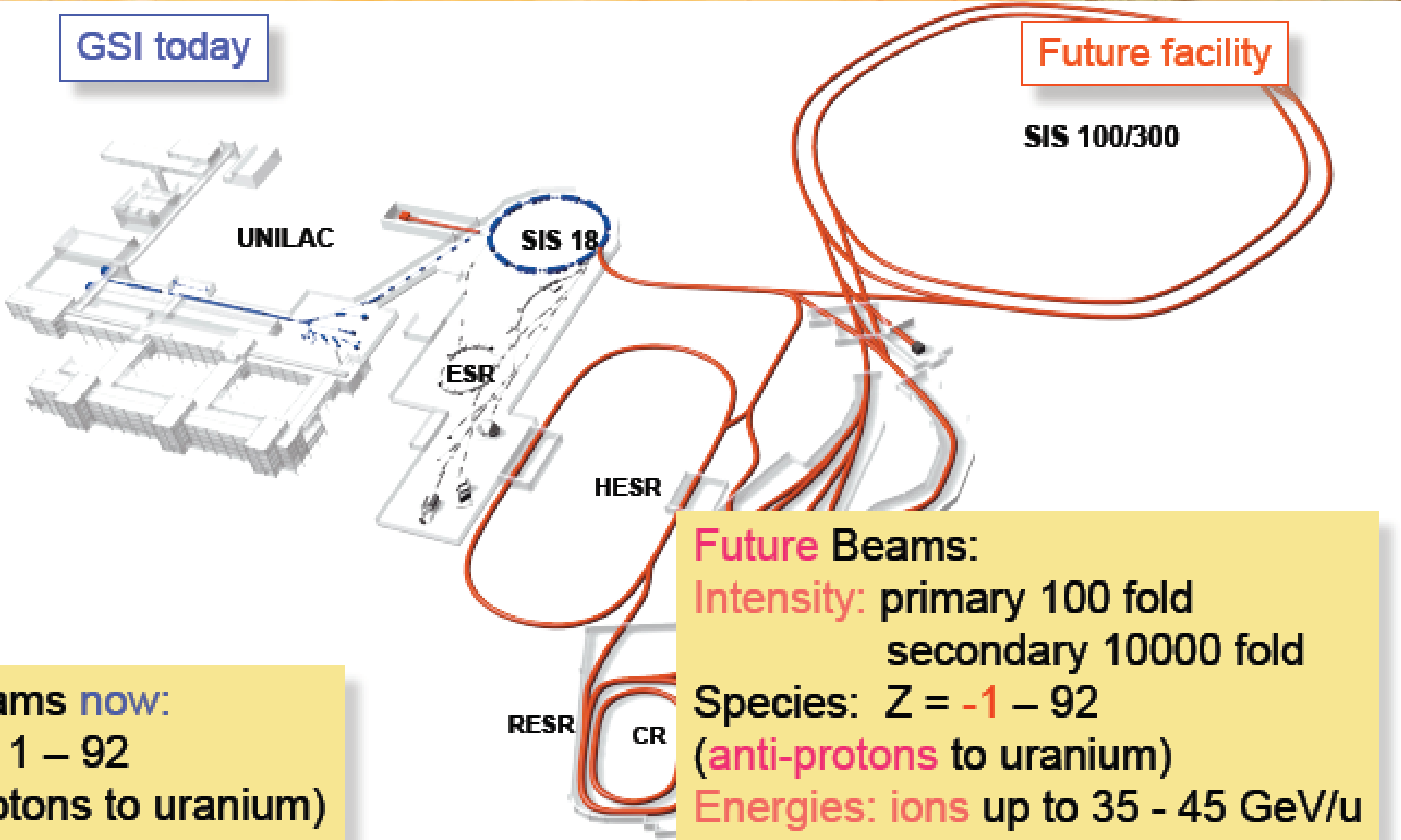
(Synchrotron, Storage/Cooling)

- SIS-100, SIS -300
- CR, RESR,NESR
- e^- ($\bar{p}$) - Ring (collider)
- HESR ($\bar{p}$)
- FLAIR

Secondary Beams:

- RIB (Super-FRS)
- Anti-Proton ($\bar{p}$)

Beams at GSI and FAIR

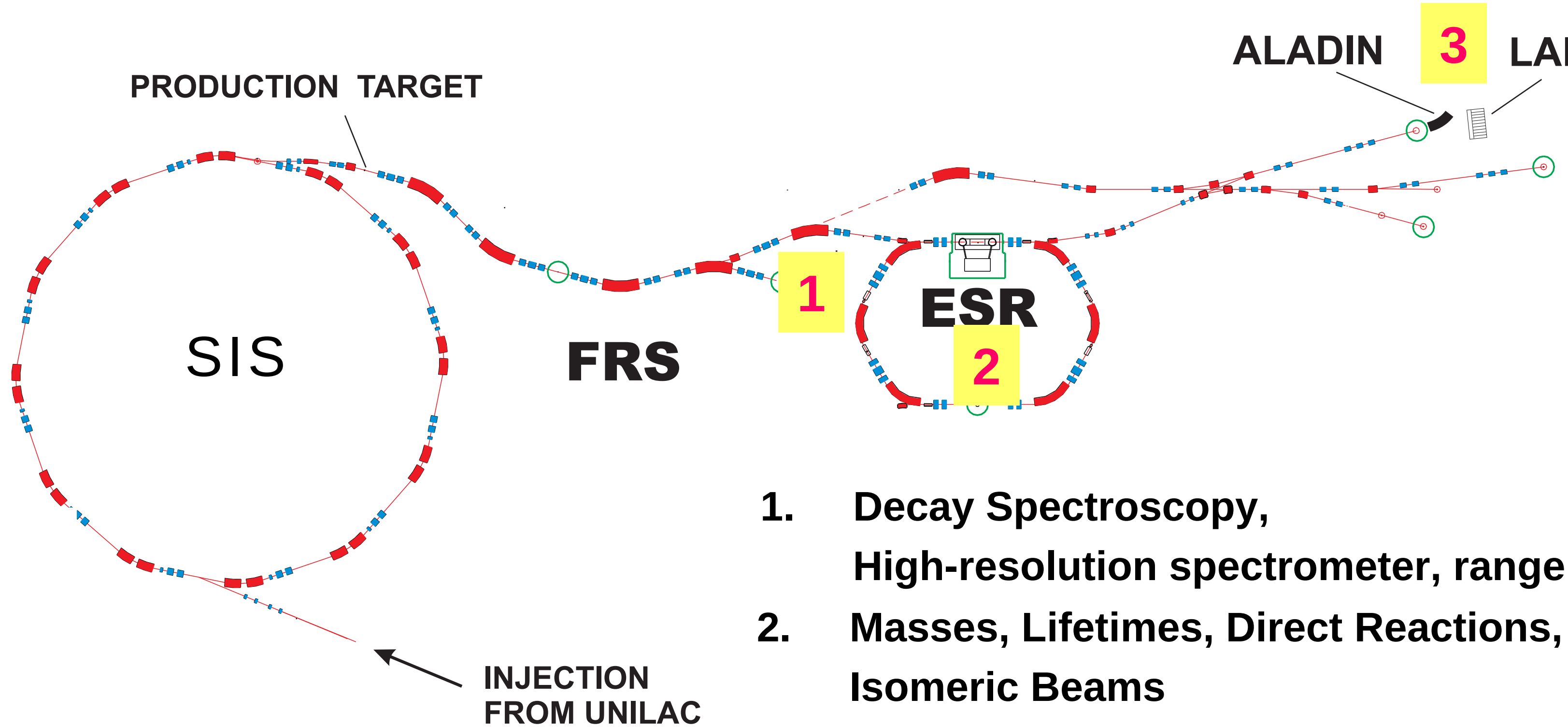


Beams now:
Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon
Some beam cooling

Future Beams:
Intensity: primary 100 fold
secondary 10000 fold
Species: Z = -1 – 92
(anti-protons to uranium)
Energies: ions up to 35 - 45 GeV/u
antiprotons 0 -15 GeV/c
Precision: full beam cooling

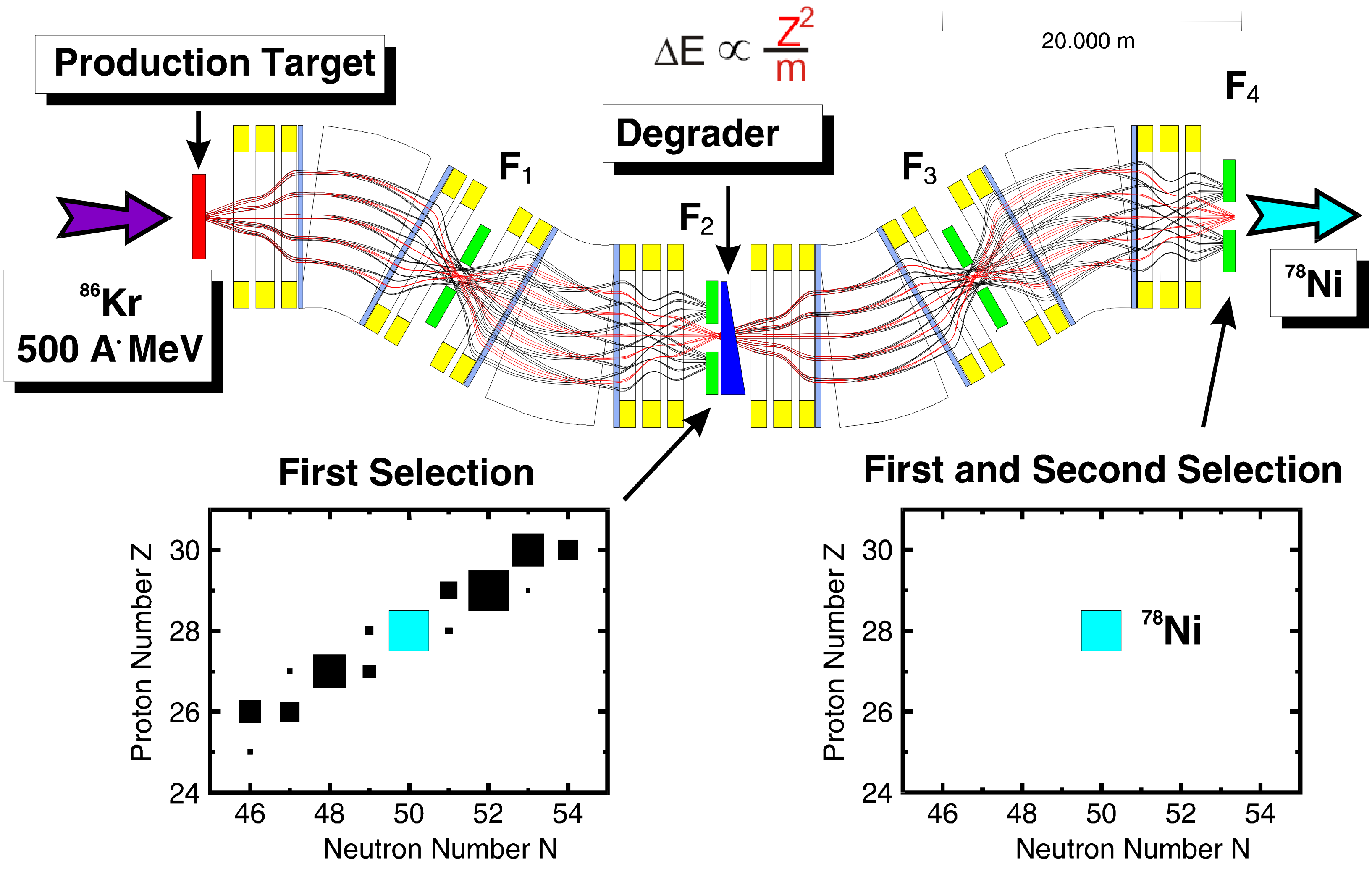
Secondary Nuclear Beam Facility at GSI

FRS: In-flight Separator & High-Resolution Spectrometer



1. Decay Spectroscopy,
   High-resolution spectrometer, range bunching
2. Masses, Lifetimes, Direct Reactions,
   Isomeric Beams
3. Reactions Studies (Complete Kinematics)

Bρ - ΔE - Bρ Separation Method



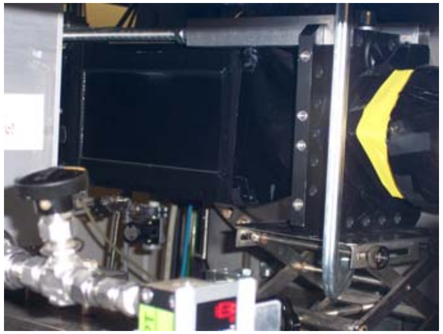
M. Winkler, Artic FIDIPRO-EFES Workshop, April 20-24, 2009, Saariselkä, Finland

Standard FRS equipments

Target

TPC- **x,y position** @ S2,S4

Plastic scintillator **(TOF)**
@ TA, S1, S2, S3, S4, S8



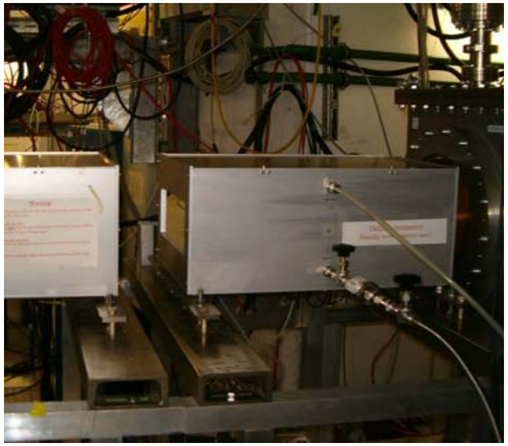
Beam profile
@TA,S1,S2
S3,S5,S6

Full isotope identification

$$B\rho = \frac{mv}{q}; \quad q = Z$$

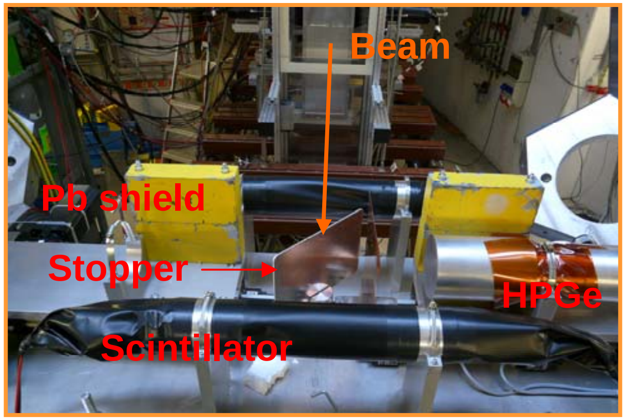
$$\left.\begin{cases} ToF \rightarrow v \\ \Delta E \rightarrow Z \\ B\rho \end{cases}\right\} \Rightarrow {}^{A}_{Z}El$$

MUSIC (**ΔE**) @ S2,S4

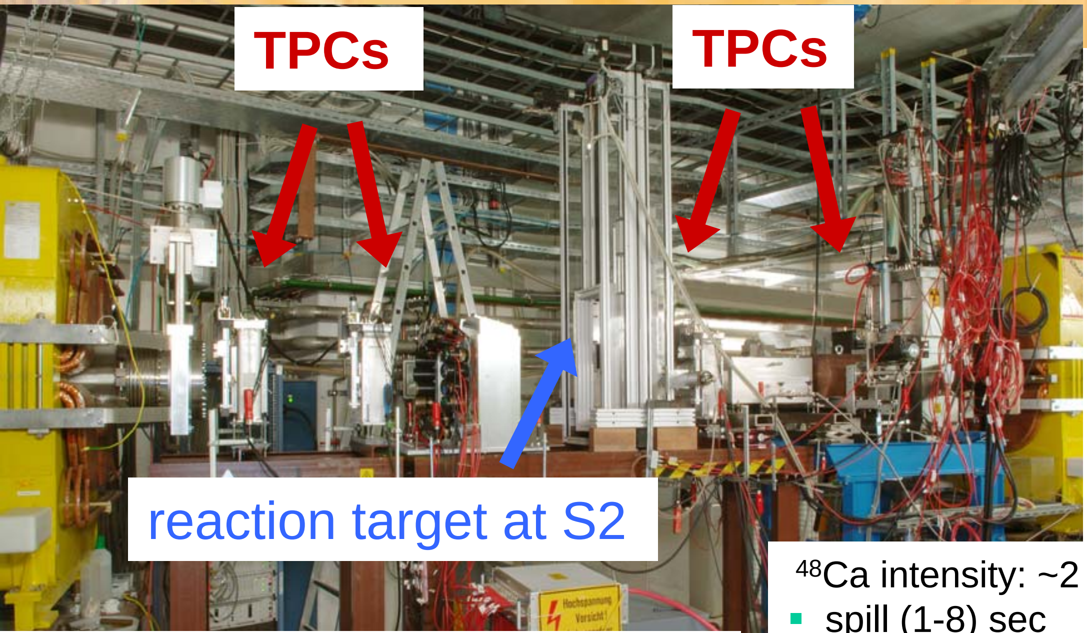


SEETRAM Intensity monitor
(primary beams) @TA
Schottky probes, Degrader, etc.

NEW: Isomer tagger @ S4

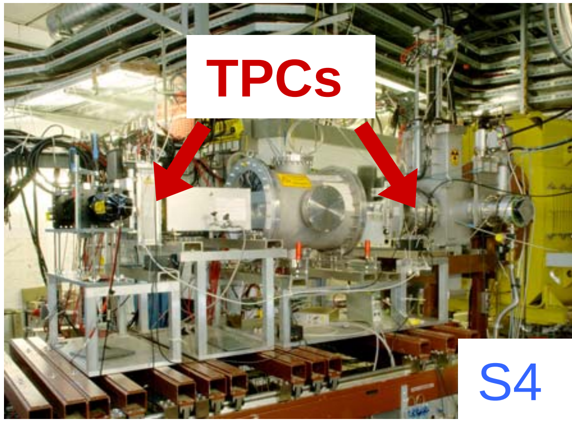


Tracking detectors at the FRS



High-resolution momentum measurements (~1.5 ·10^{-4}) in knockout reactions

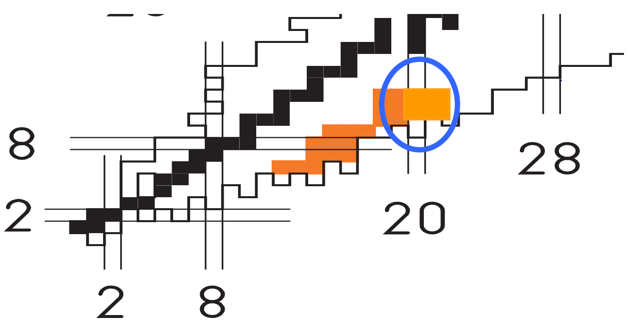
$$^{33}Mg + C \longrightarrow {}^{32}Mg + (\gamma)$$

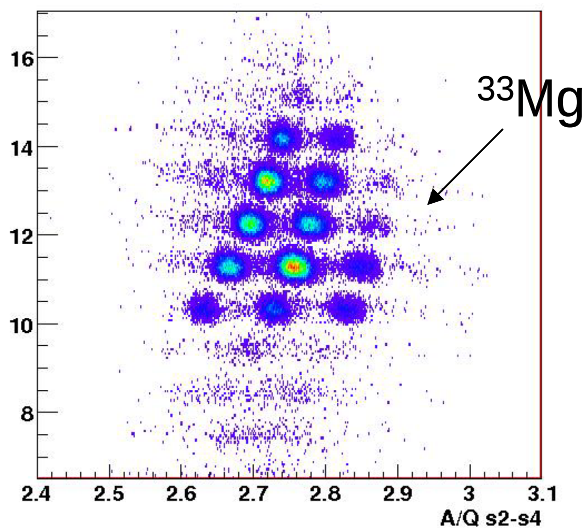


^{48}Ca intensity: ~2 10^{9}/spill

- spill (1-8) sec
- multi-injection mode (SIS18)

Interaction cross-section measurements in the *Island of Inversion* @ 1GeV/u



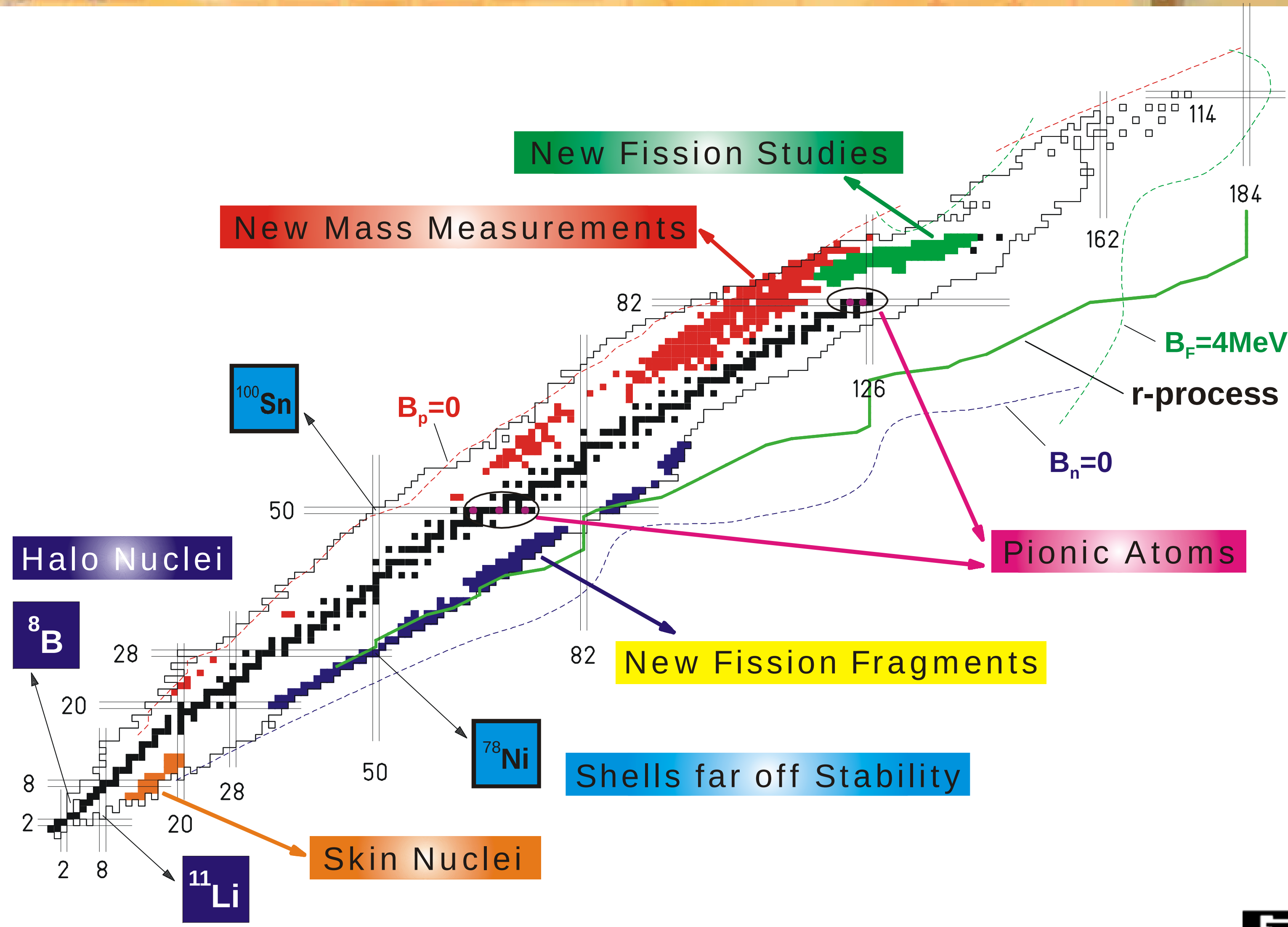


- S1 total rate : 4·10^{4}/s
- ^{33}Mg rate at S2 : ~40 /s
- max. trigger rate : 10^{3}/s (low Z rejection)

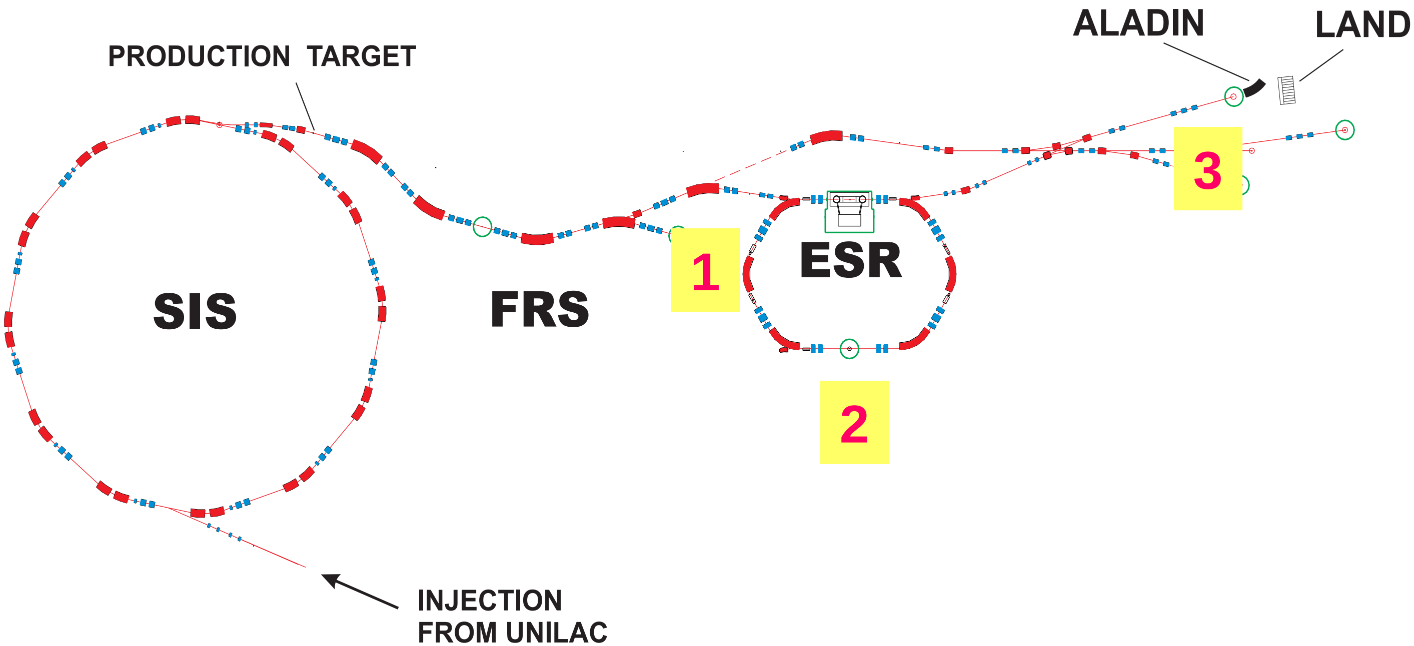
Rate limitation due to pile-up in the Music at S2

(pile-up rejection by trigger selection)

Landmarks from FRS Experiments



The Present Rare Isotope Facility at GSI
Limitations



- 'Low' primary beam intensity (e.g. 10^9 ^{238}U /s)
- 'Low' transmission for projectile fission fragments (4-10% at the FRS)
- 'Low' transmission for fragments into the storage ring and to the exp. area # 3 (beam-line magnets are not designed for fragment beams
- Limited space at focal planes and the experimental areas

Layout and Design parameters for the Super-FRS

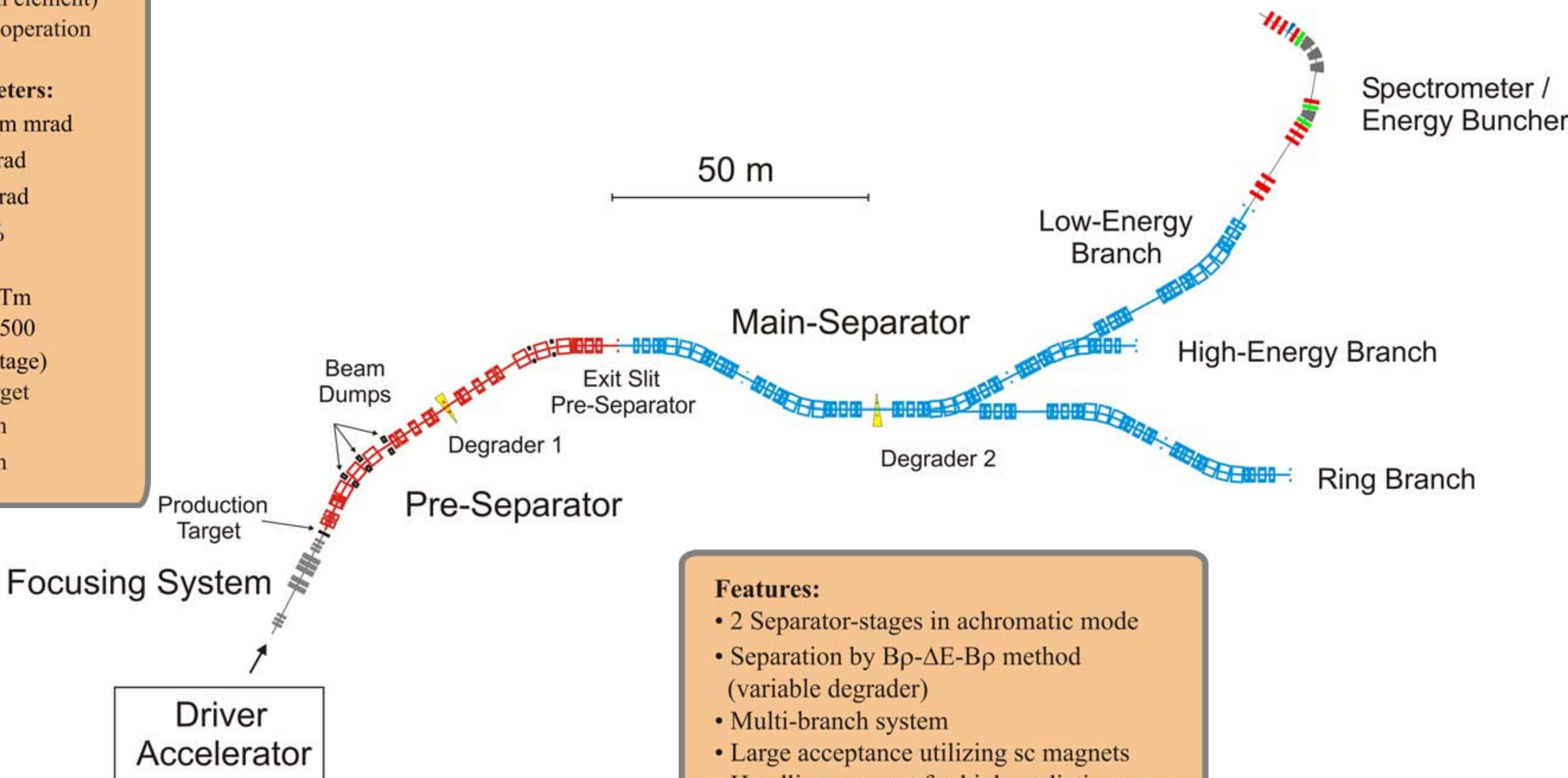
Projectile:
- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity up to 10^{12} /s (depending on element)
- DC or pulsed operation

Design Parameters:

$\varepsilon_x = \varepsilon_y =$ 40 π mm mrad
$\Phi_x =$ ± 40 mrad
$\Phi_y =$ ± 20 mrad
$\Delta P/P =$ ± 2.5 %

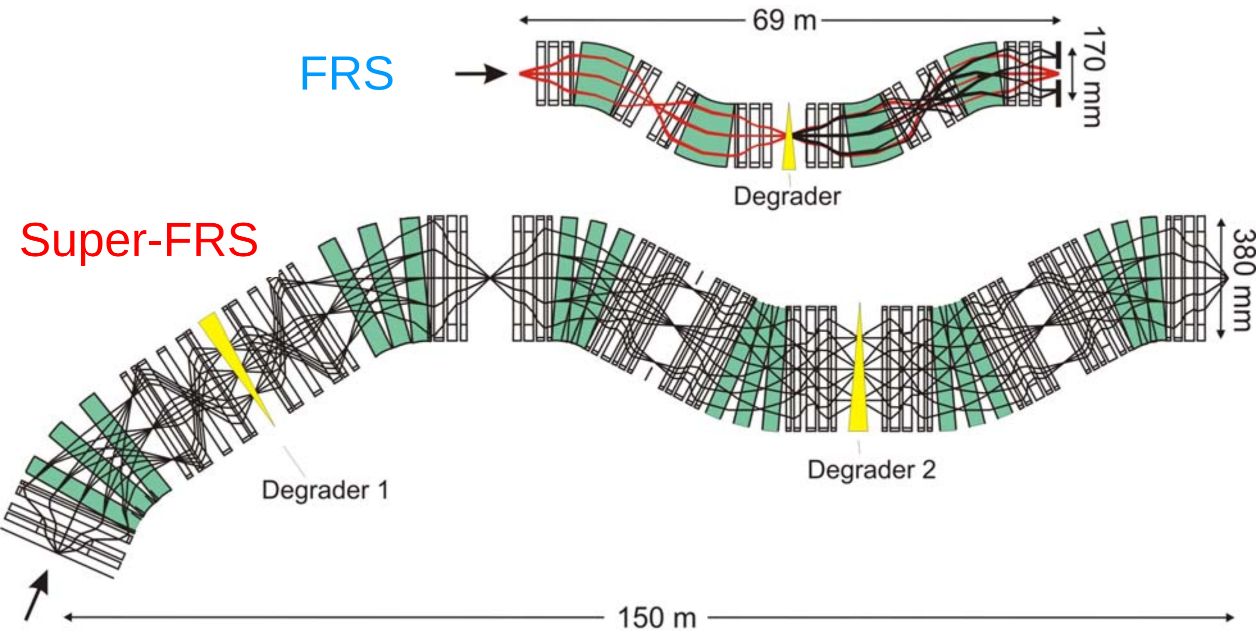
$B\rho$ = 2 - 20 Tm
R_{ion} = 750 / 1500
(first / second stage)
Spot size on target
σ_x = 1.0 mm
σ_y = 2.0 mm

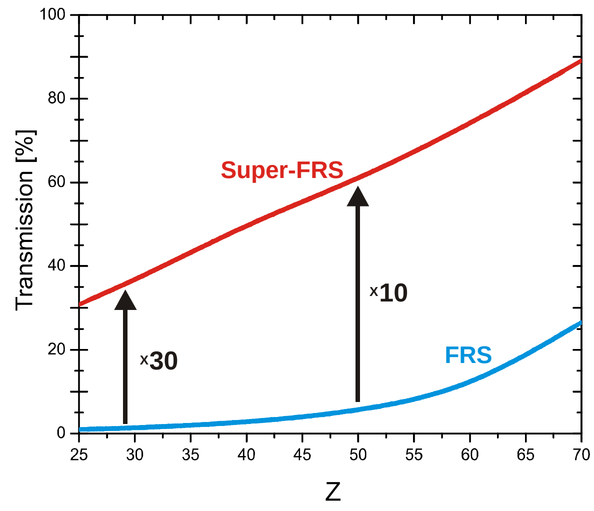
Goal: Larger Acceptance



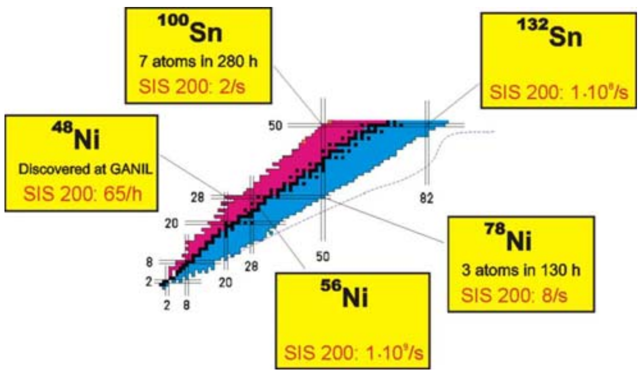
Features:
- 2 Separator-stages in achromatic mode
- Separation by Bρ-ΔE-Bρ method (variable degrader)
- Multi-branch system
- Large acceptance utilizing sc magnets
- Handling concept for high- radiation area

Comparison of FRS with Super-FRS, intensity gain

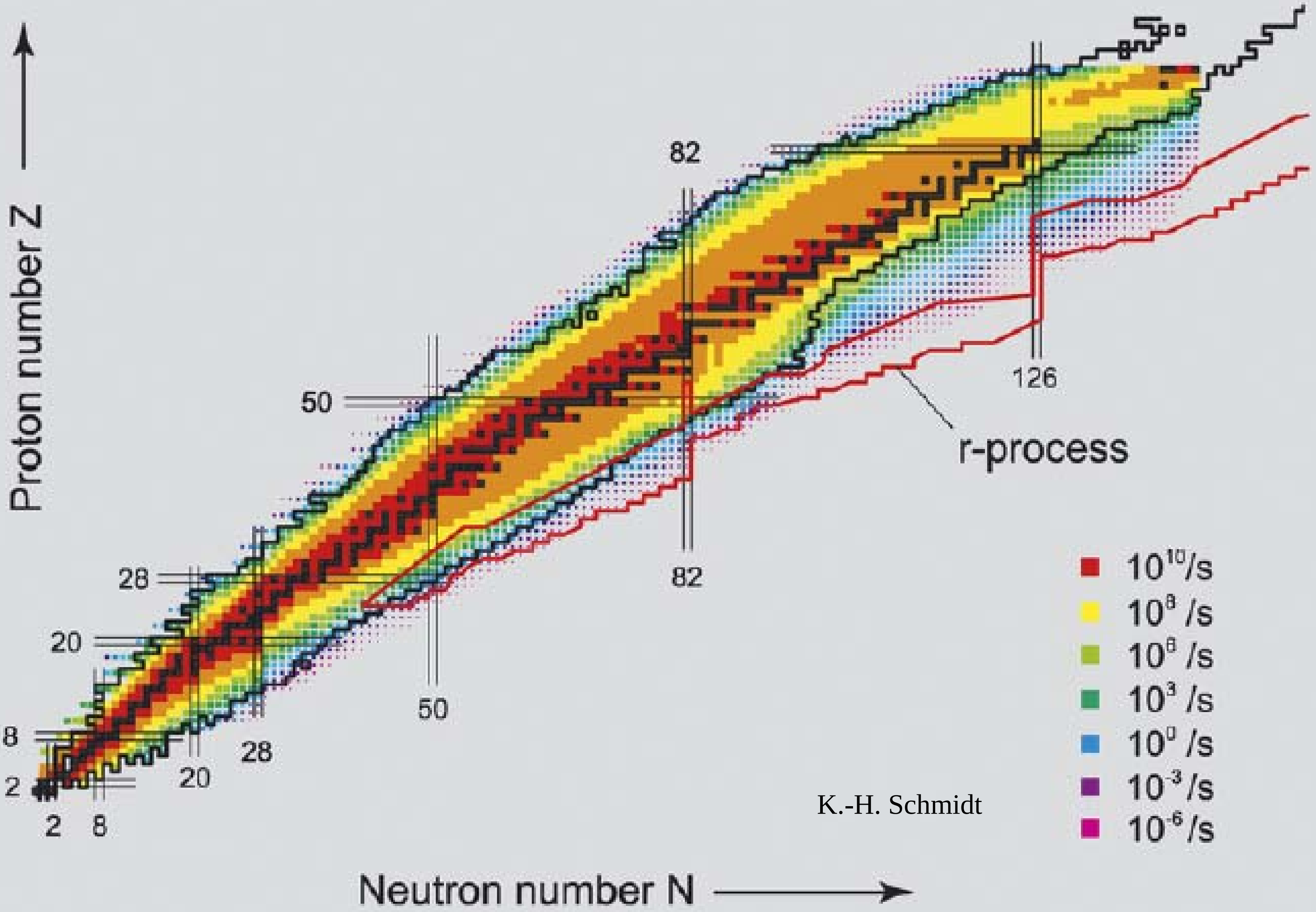




	$B\rho_{max}$	$\Delta p/p$	$\Delta\Phi_x$, $\Delta\Phi_y$	resolving power	gain factor ^{19}C	gain factor ^{132}Sn
FRS	18 Tm	1.0 %	± 13, ±13 mrad	1500	1	1
Super-FRS	20 Tm	2.5 %	±40, ±20 mrad	1500	5	10
				including primary rate	250	20 000



Production Rates for Exotic Nuclei at FAIR



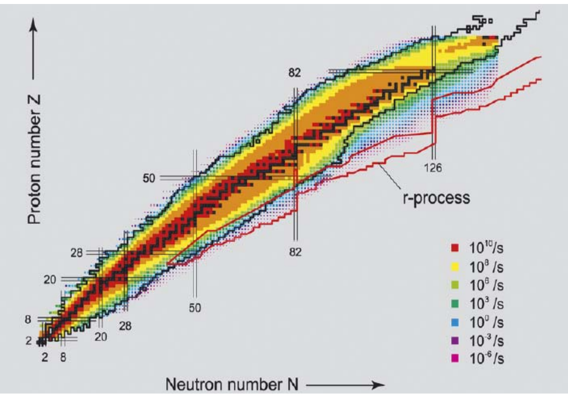
K.-H. Schmidt

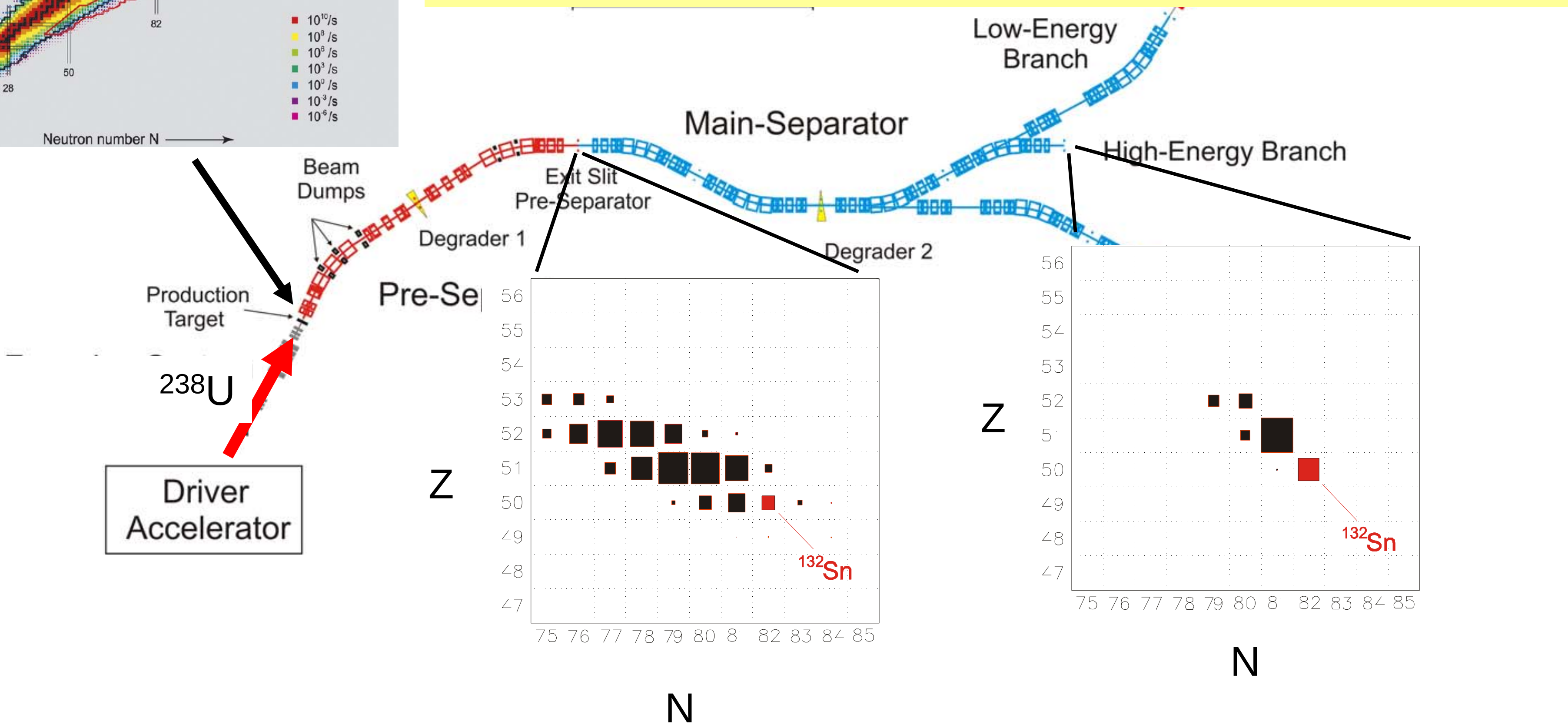
Separation Performance of the Super-FRS

1.1 A GeV ^{238}U on 4 g/cm^2 C target, two Al degraders d/R=0.3, d/R=0.7

Features of two degrader stages

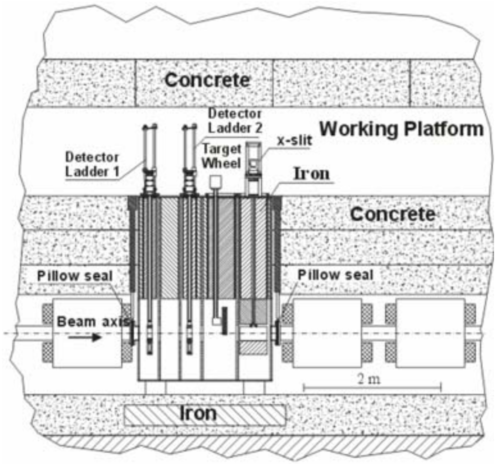
- Introduction of another separation cut in the A-Z plane
- Reduction of contaminants from fragments produced in the degrader
- Optimization of the fragment rate on detectors in the Main-Separator
- Possible usage of Pre- and Main-Separator for secondary reaction studies





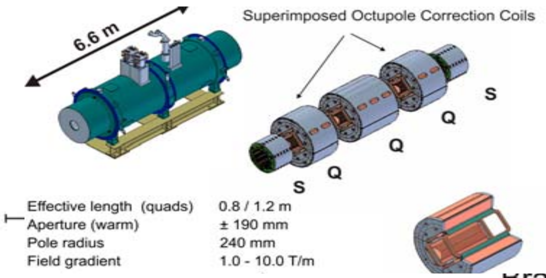
Technical Challenges

Remote Handling

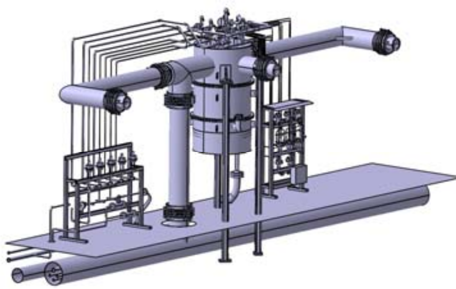


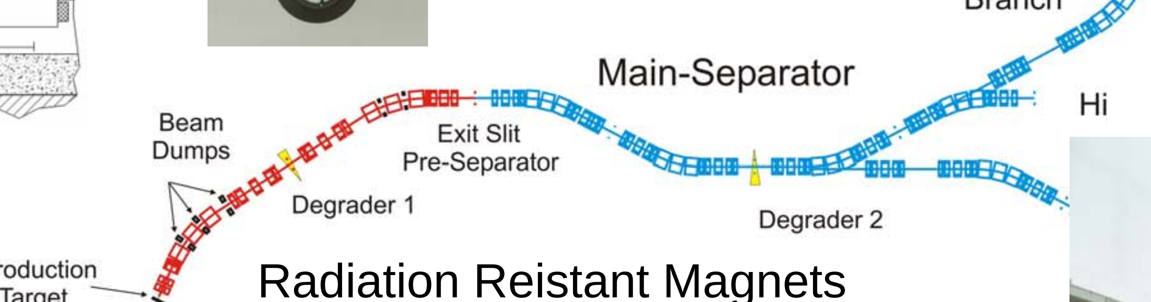
Target & Beam Catcher

SC Multiplets

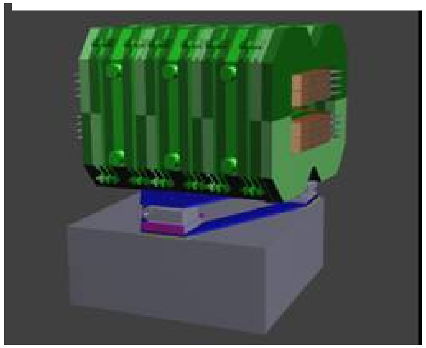


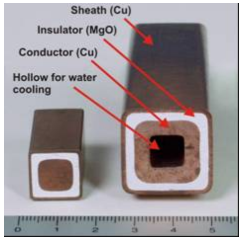
Cryogenics





Radiation Reistant Magnets

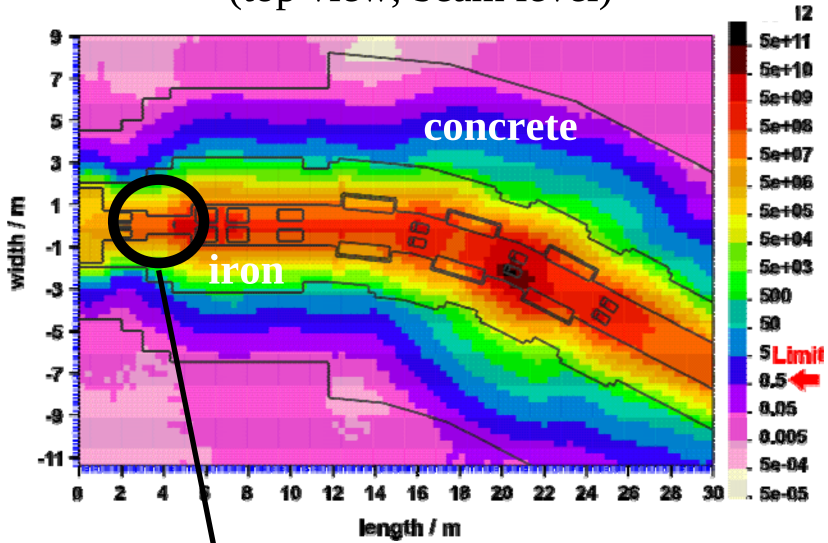




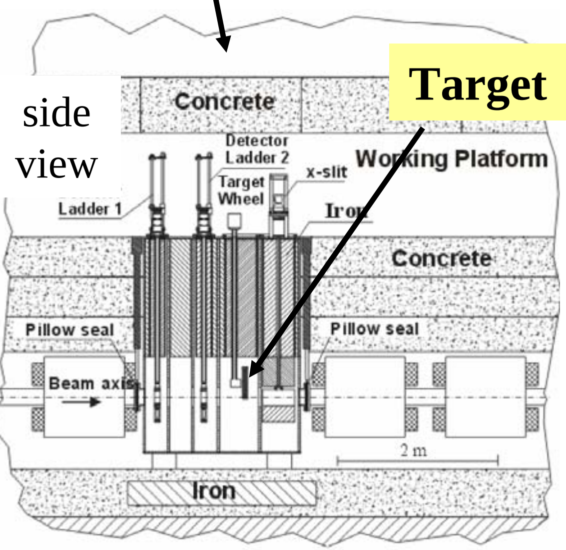
SC Dipoles

Shielding and Handling Concept in the Target Area (vertical plug system)

Promt Dose Rates 1.5 GeV/u 10^{12} /s ^{238}U
(top view, beam level)

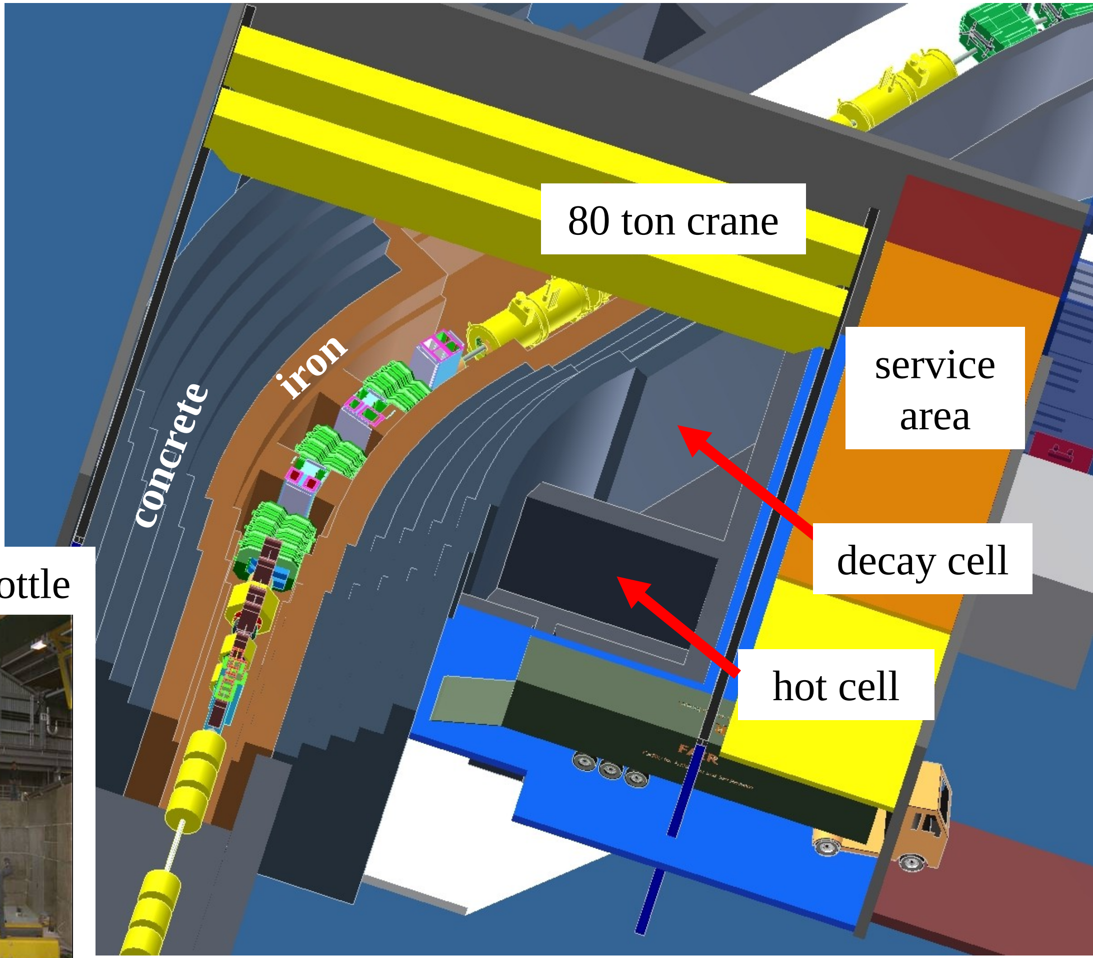


side view

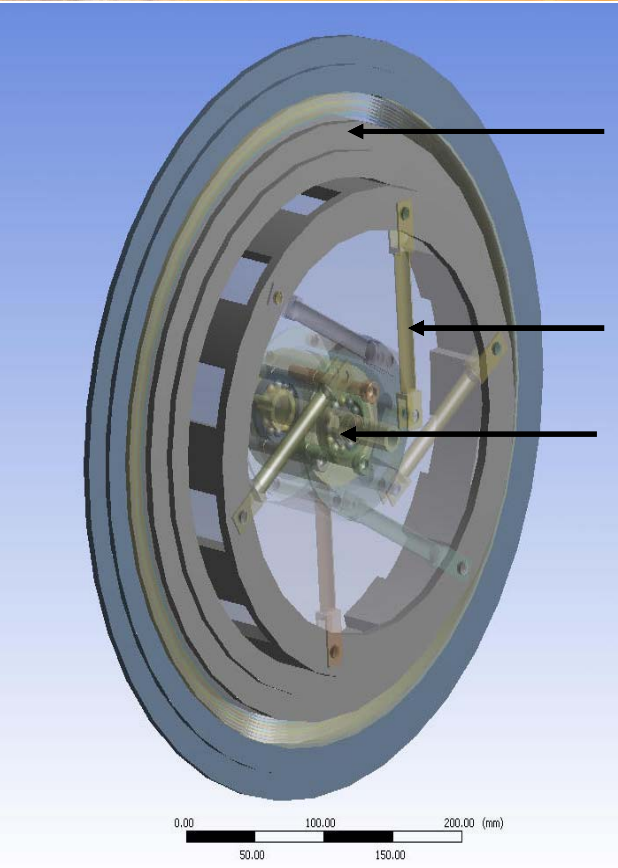


Transport Bottle

Target building (schematic)



Graphite Wheel Target

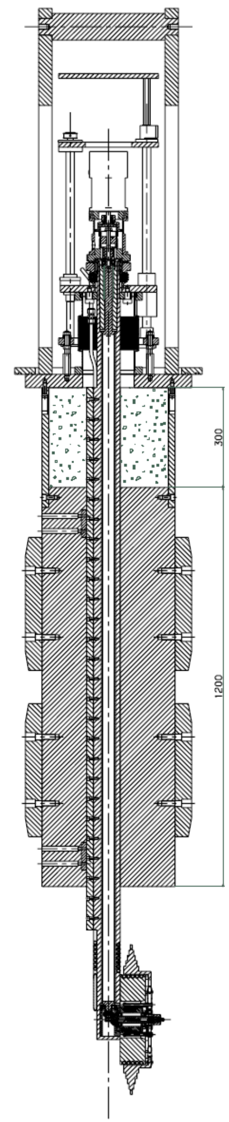


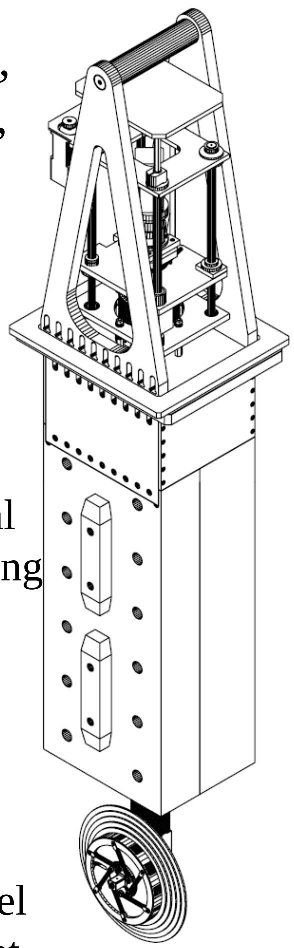
Solid graphite
SGL Carbon R 6400P
5 steps, 1 – 8 g/cm²
each step 16 mm wide

Spokes from INCONEL 600

Si_3N_4 ball bearings
Ag-coated cages
MoS_2 lubrication
T_{limit} = 150ºC

- cooling only by radiation
- R_{out} = 22.5 cm





K. H. Behr,
M. Gleim,
K. Sümmerer et al.

Prototype Target

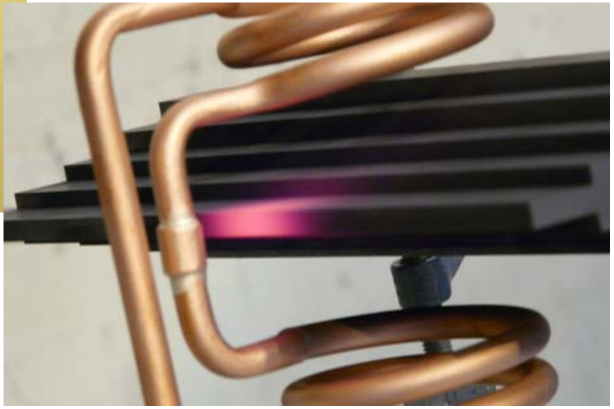
to be used at FRS with SIS18 beams

dummy shielding

drive test at company

Torsion proof Shaft Coupling

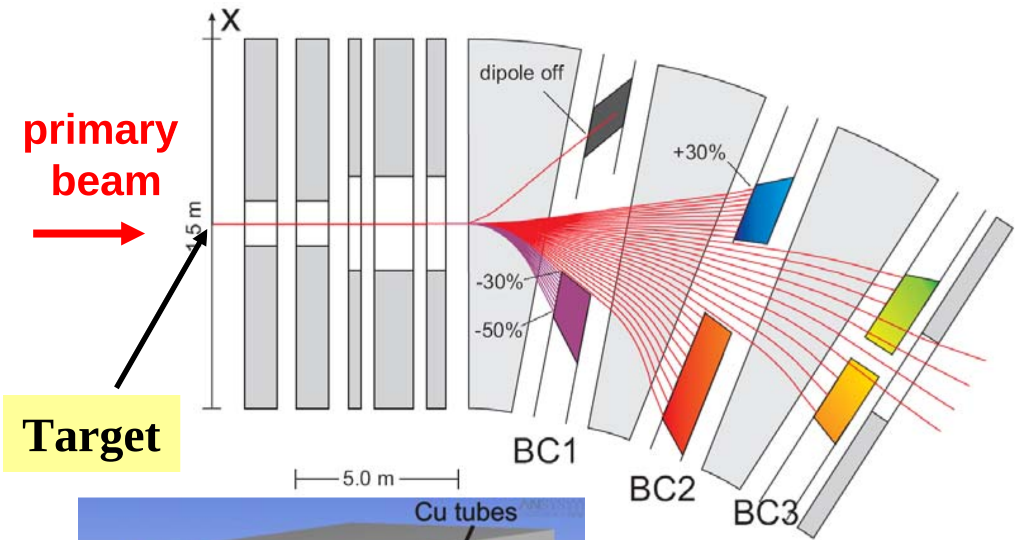
Induction heating

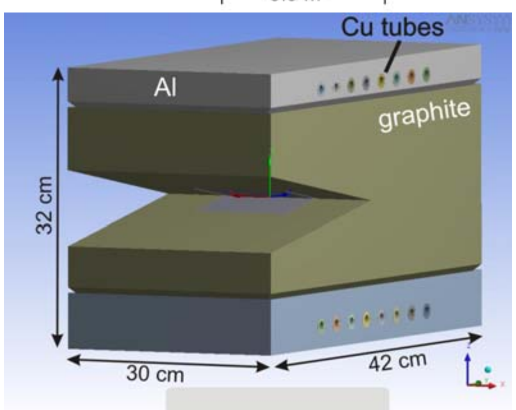


- Prototype target ready
- Off-line tests started
- Preparation of induction heating (20 kW generator)

Beam Catcher
(in Collaboration with VECC Calcutta, India)

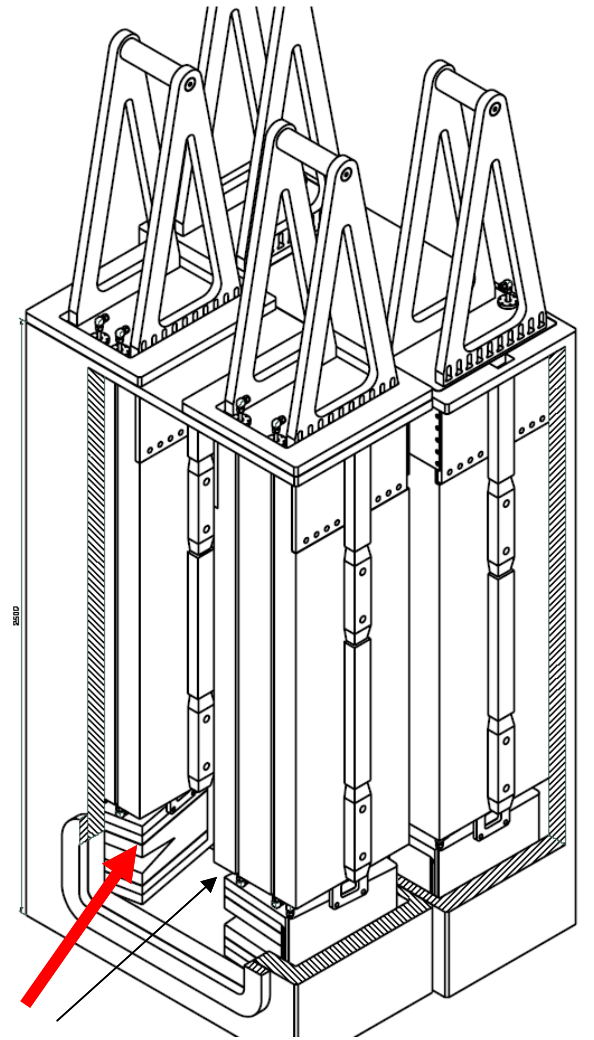
The relative difference in magnetic rigidity (**Bρ**) determines where the beam after passing the target is going to be dumped





We need 3x2 beam catcher:

Remote Handling of Beam Catcher

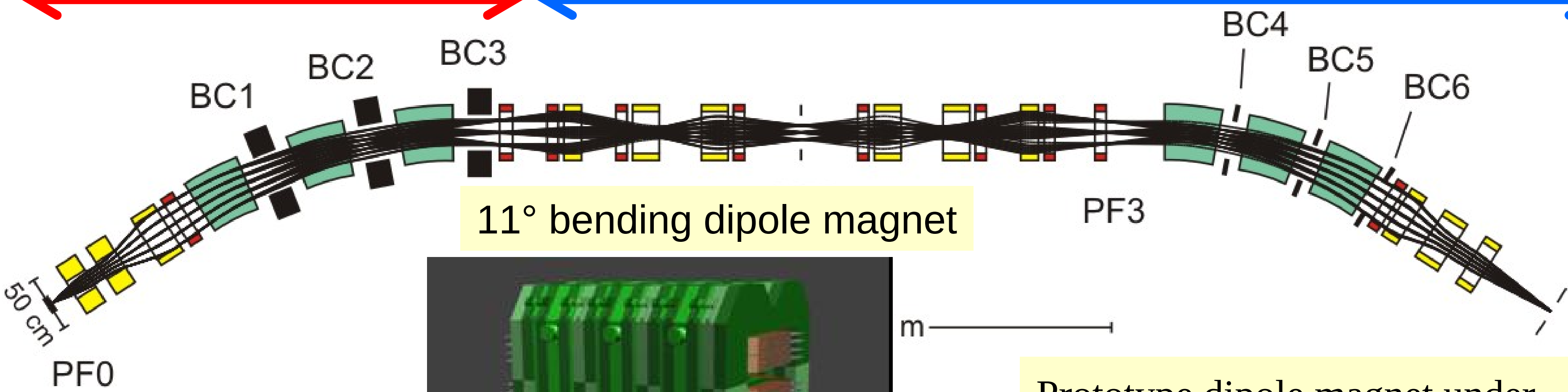


- **Front part**: **graphite** (20cm+), absorb strong pressure waves, water cool
- **Back part: iron** (60cm) to absorb protons and neutrons.

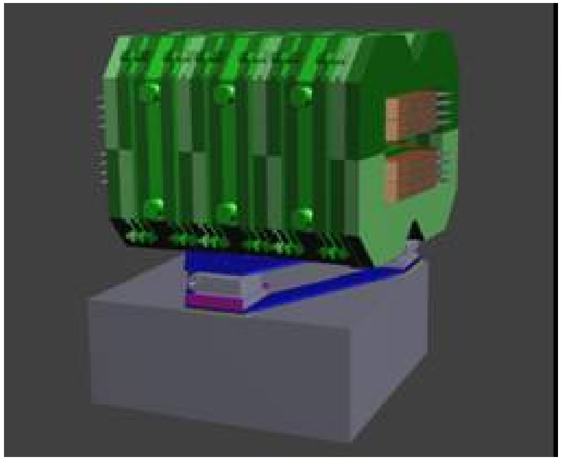
Layout of the Pre-Separator

High-radiation level
→ Normal conducting

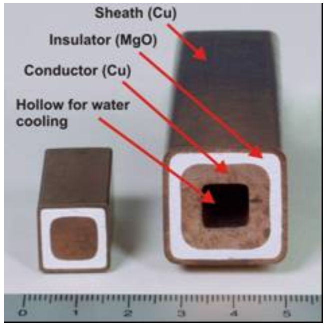
Super conducting



11° bending dipole magnet



Mineral **I**nsulated **C**able (MIC)



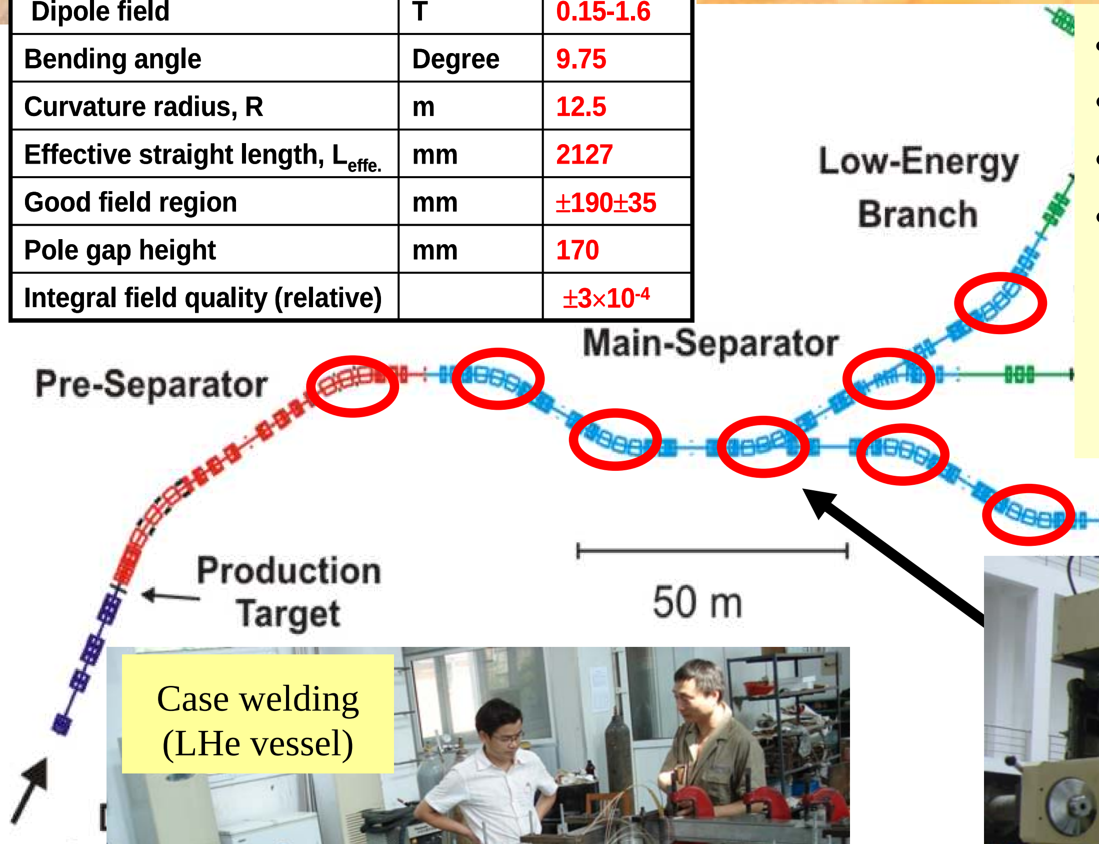
- Pole gap height: 180 mm
- Length / width / hight (m): 3.2 / 3.0 / 2.1
- Total weight: 100 t
- Integrated field quality ±$3 \cdot 10^{-4}$

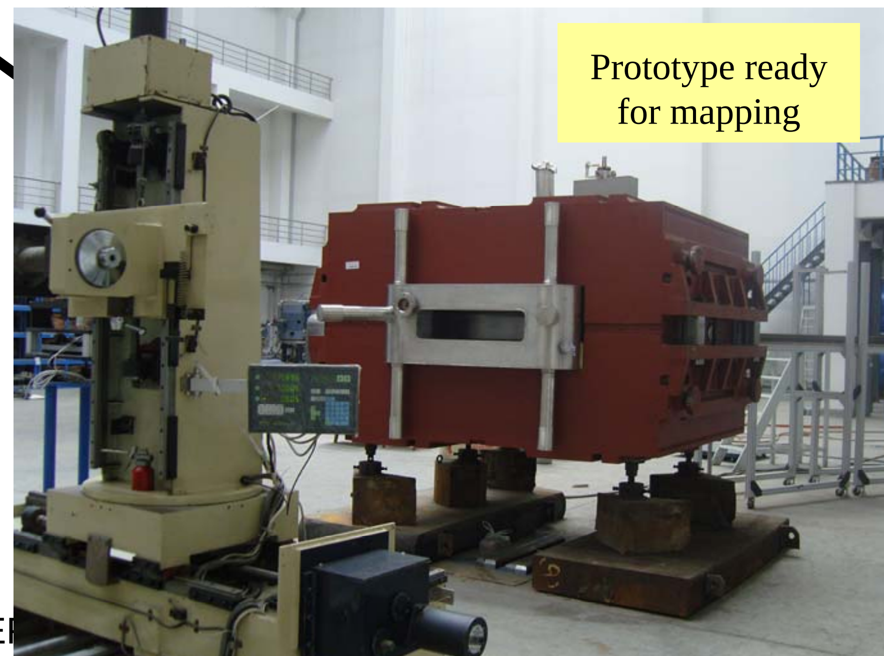
Prototype dipole magnet under construction at **BINP, Russia**

Superferric Dipoles for the Main Separator

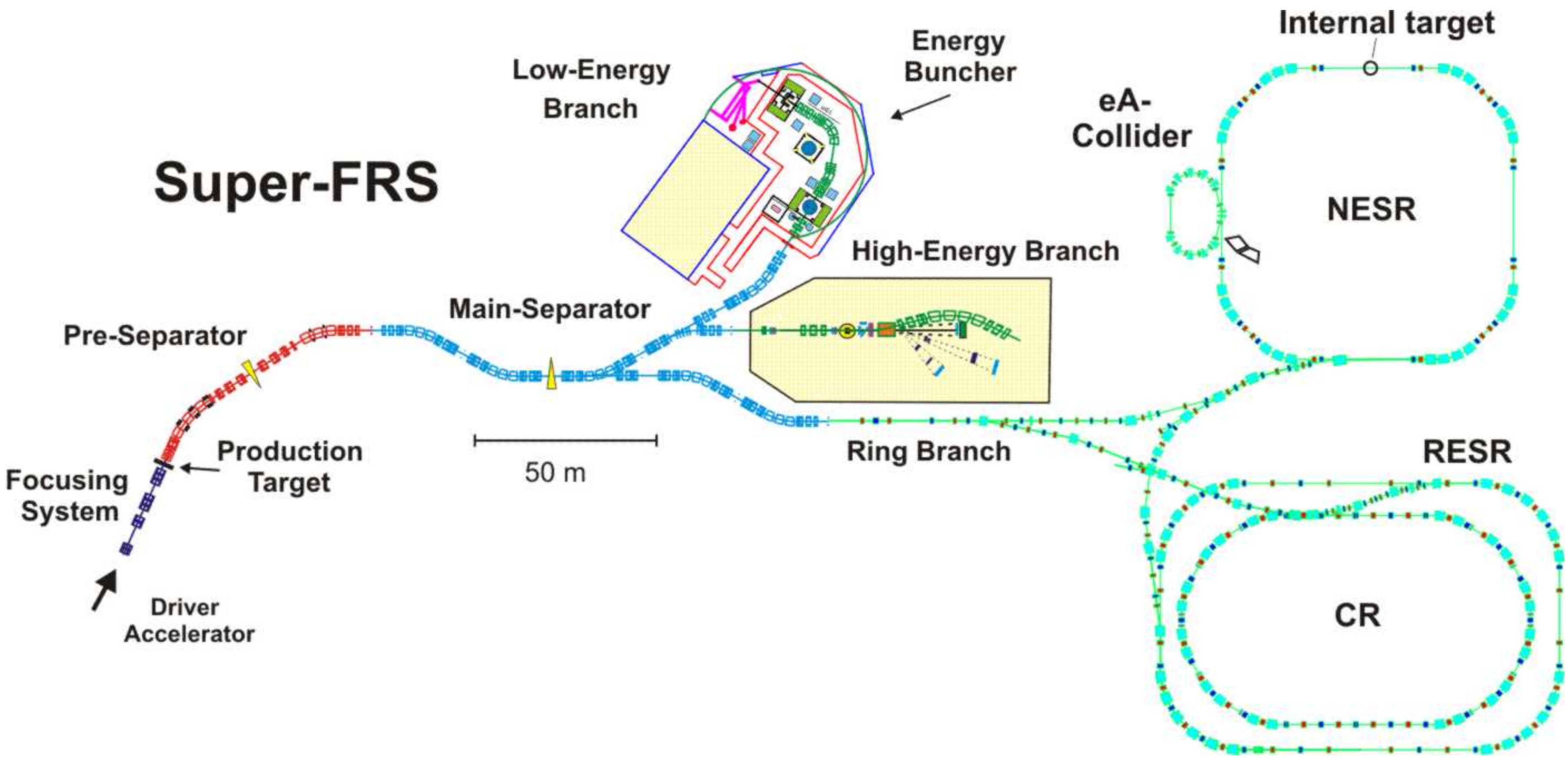
Number of main dipoles		21
Dipole field	T	0.15-1.6
Bending angle	Degree	9.75
Curvature radius, R	m	12.5
Effective straight length, $L_{effe.}$	mm	2127
Good field region	mm	±190±35
Pole gap height	mm	170
Integral field quality (relative)		$\pm3\times10^{-4}$

- H-Type, warm bore, warm iron
- Sector shape
- Total weight: ~50 t
- Prototype fabrication by **China FCG**
  IMP **Lanzhou**,
  Inst. of El. Eng. **Beijing**,
  Inst. of Plasma Phys. **Heifei**





The NUSTAR Facility at FAIR
(The 3 Branches of the Super-FRS)



NUSTAR = **Nu**clear **St**ructure, **A**strophysics and **R**eactions

NUSTAR LOI's (667 authors)

8 approved LOI by NUSTAR-PAC → presented as Technical Proposals in spring 2006

1.) Low Energy Branch (LEB)

High-resolution In-Flight Spectroscopy (HISPEC)/ ✓
Decay Spectroscopy with Implanted Ion Beams (DESPEC) ✓
Precision Measurements of very short-lived Nuclei using an
Advanced Trapping System for highly-charged Ions (MATS) ✓
LASER Spectroscopy for the Study of Nuclear Properties (LASPEC) ✓
Neutron Capture Measurements (NCAP)
Antiprotonic Radioactive Nuclides (Exo+pbar)

2.) High Energy Branch (R3B)

A Universal Setup for Kinematical Complete Measurements of
Reactions with Relativistic Radioactive Beams (R3B) ✓

3.) Ring Branch (STORIB)

Study of Isomeric Beams, Lifetimes and Masses (ILIMA) ✓
Exotic Nuclei Studied in Light-Ion Induced Reactions
at the NESR Storage Ring (EXL) ✓
Electron-Ion Scattering in a Storage Ring (e-A Collider) (ELISe) ✓
Antiproton-Ion Collider: A Tool for the Measurement of Neutron and
Proton rms radii of Stable and Radioactive Nuclei (AIC)

Summary

- Super-FRS based on experiences with FRS
- Large-acceptance device using large-aperture SC magnets
- Two separator stages, multi-branch system
- R&D for major components as well as civil construction under progress
- Super-FRS as part of FAIR

→ Construction together with FAIR member states

Thank You !