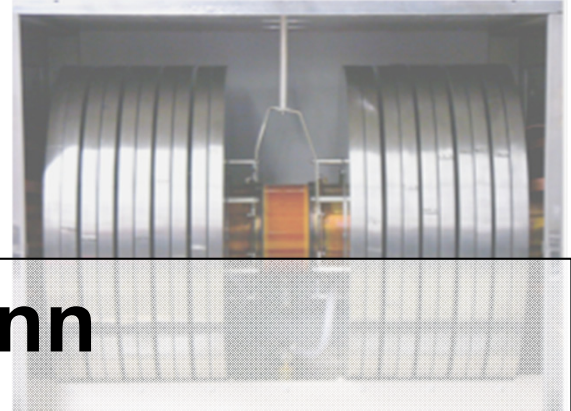
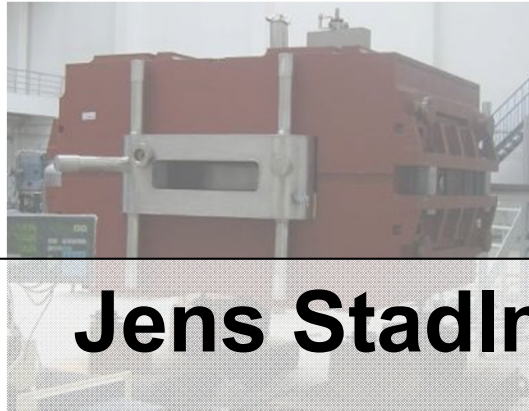
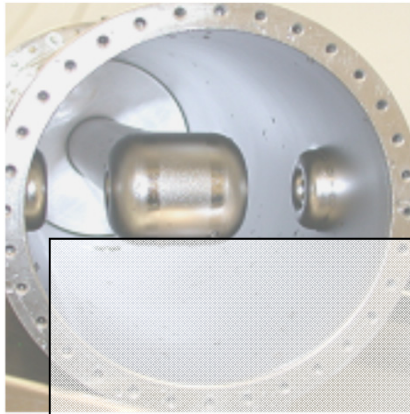


Future accelerators for Secondary particle production



Jens Stadlmann

GSI Helmholtzzentrum für Schwerionenforschung



Outline

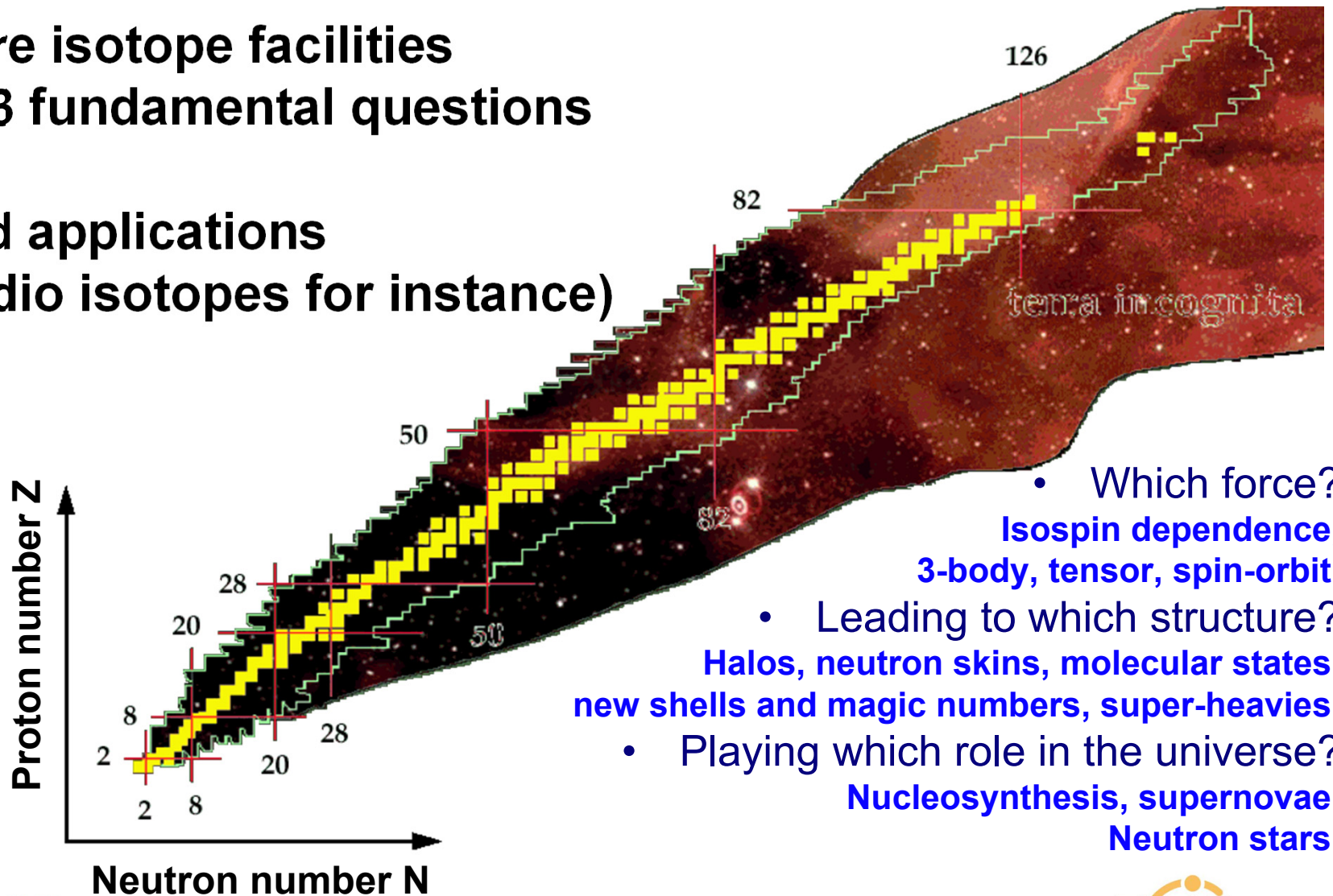
- **Motivation: “Rare isotope production”**
- **Advances and technical developments for rare isotope accelerators**
 - **Application of Superconductivity**
 - **Radiation resistant materials and targets**
 - **Vacuum technology, rf-systems**
- **Technologies and the link to industry**

Motivation: Physics with rare isotopes

Rare isotope facilities

→ 3 fundamental questions

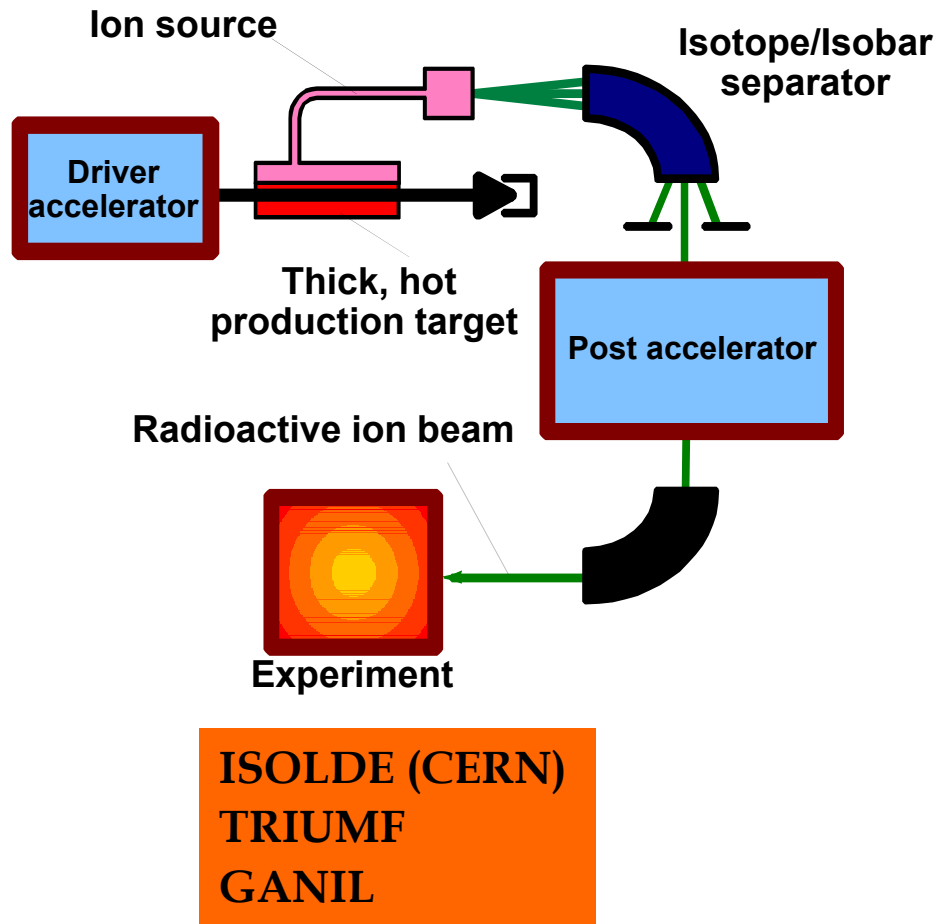
and applications
(radio isotopes for instance)



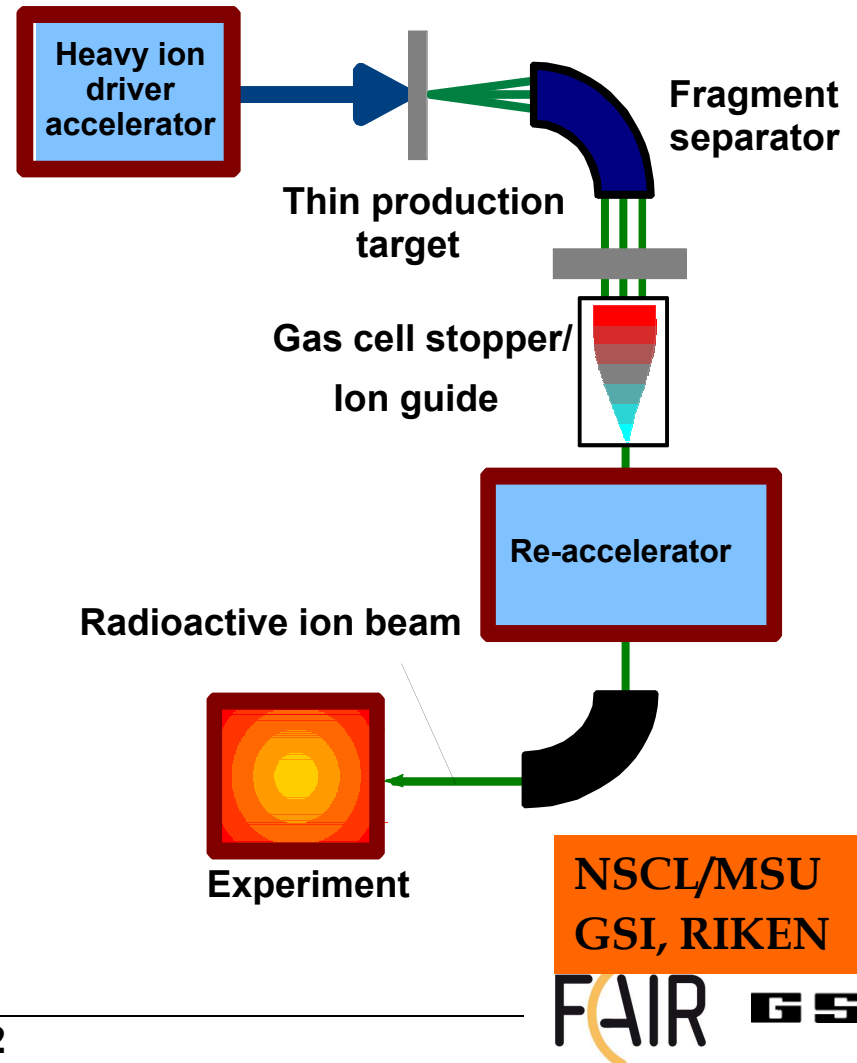
- Which force?
Isospin dependence,
3-body, tensor, spin-orbit.
- Leading to which structure?
Halos, neutron skins, molecular states,
new shells and magic numbers, super-heavies.
- Playing which role in the universe?
Nucleosynthesis, supernovae,
Neutron stars.

Production of rare isotopes:

ISOL

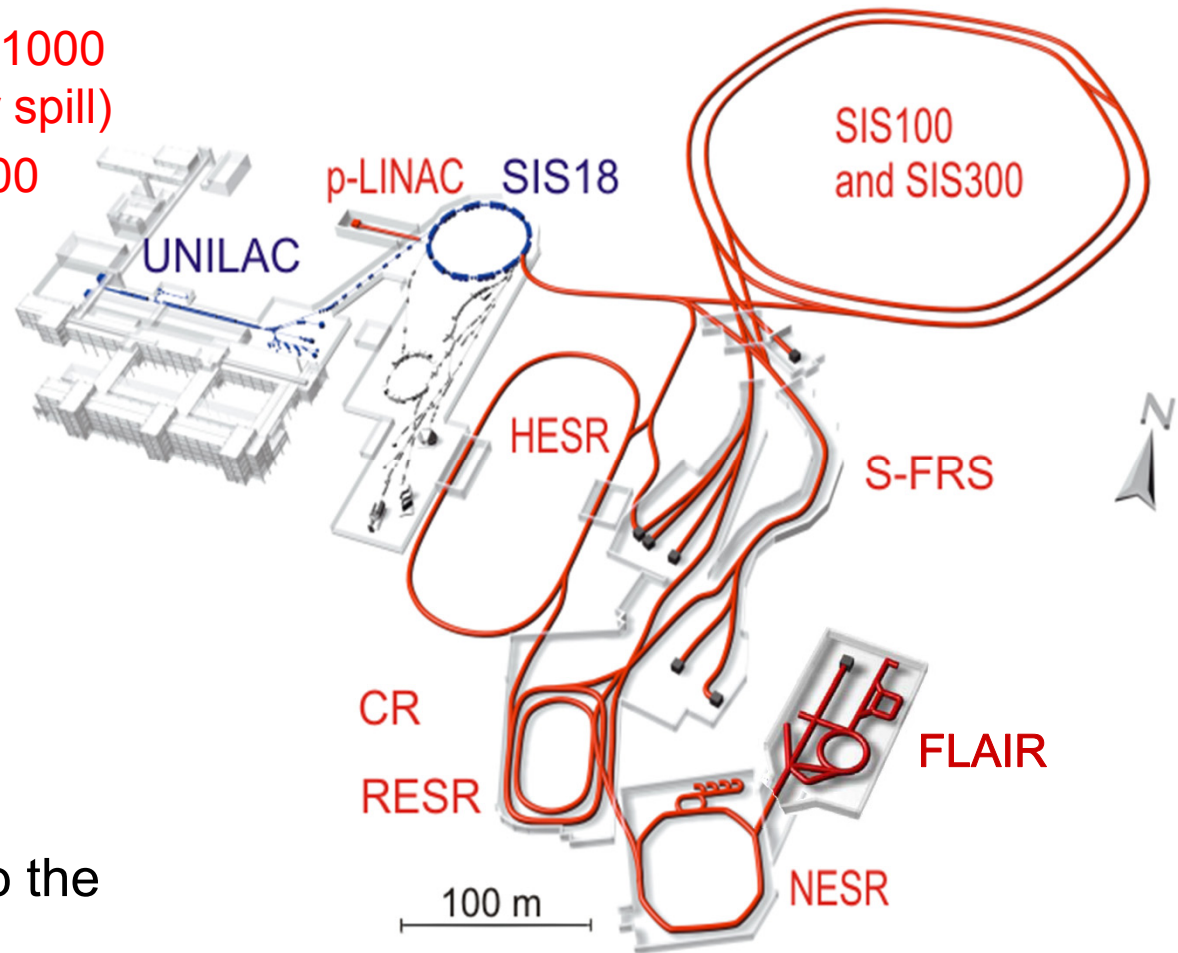


Projectile Fragmentation (PF) and stopped beams



The Facility for Antiproton and Ion Research (FAIR)

- Beam intensity increase:
 - Primary beams: $\times 100 - \times 1000$ ($7.5 \cdot 10^{11}$ uranium ions per spill)
 - Secondary beams: $\times 10.000$
- Beams:
 - Anti protons
 - Protons to uranium, RIBs
- Beam quality:
 - Cooled anti proton beams
 - Cooled, intense RIBs
- Beam pulse structure:
 - extreme short pulses to quasi continuous
- 1.5 GeV/u ^{238}U beams to the S-FRS for instance



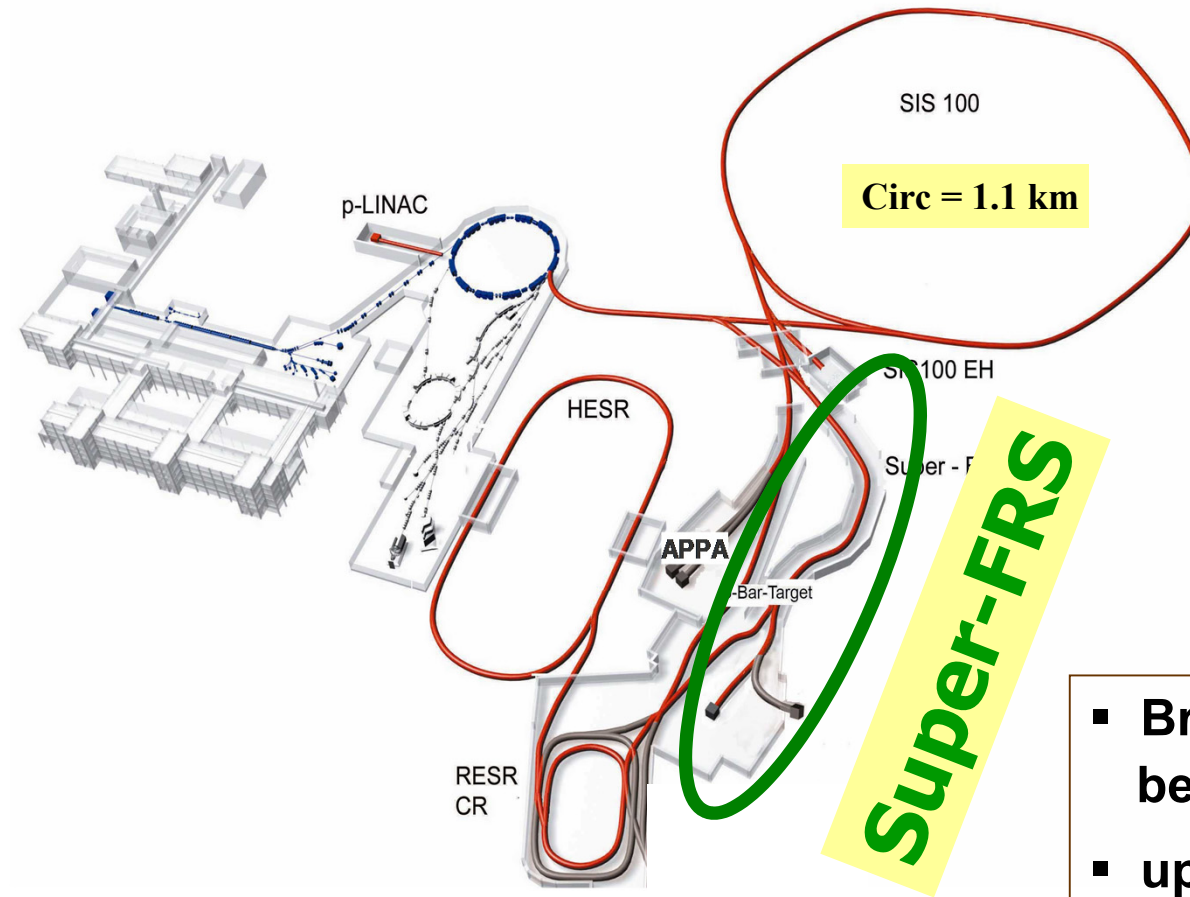
Super-FRS at FAIR

Primary Beams

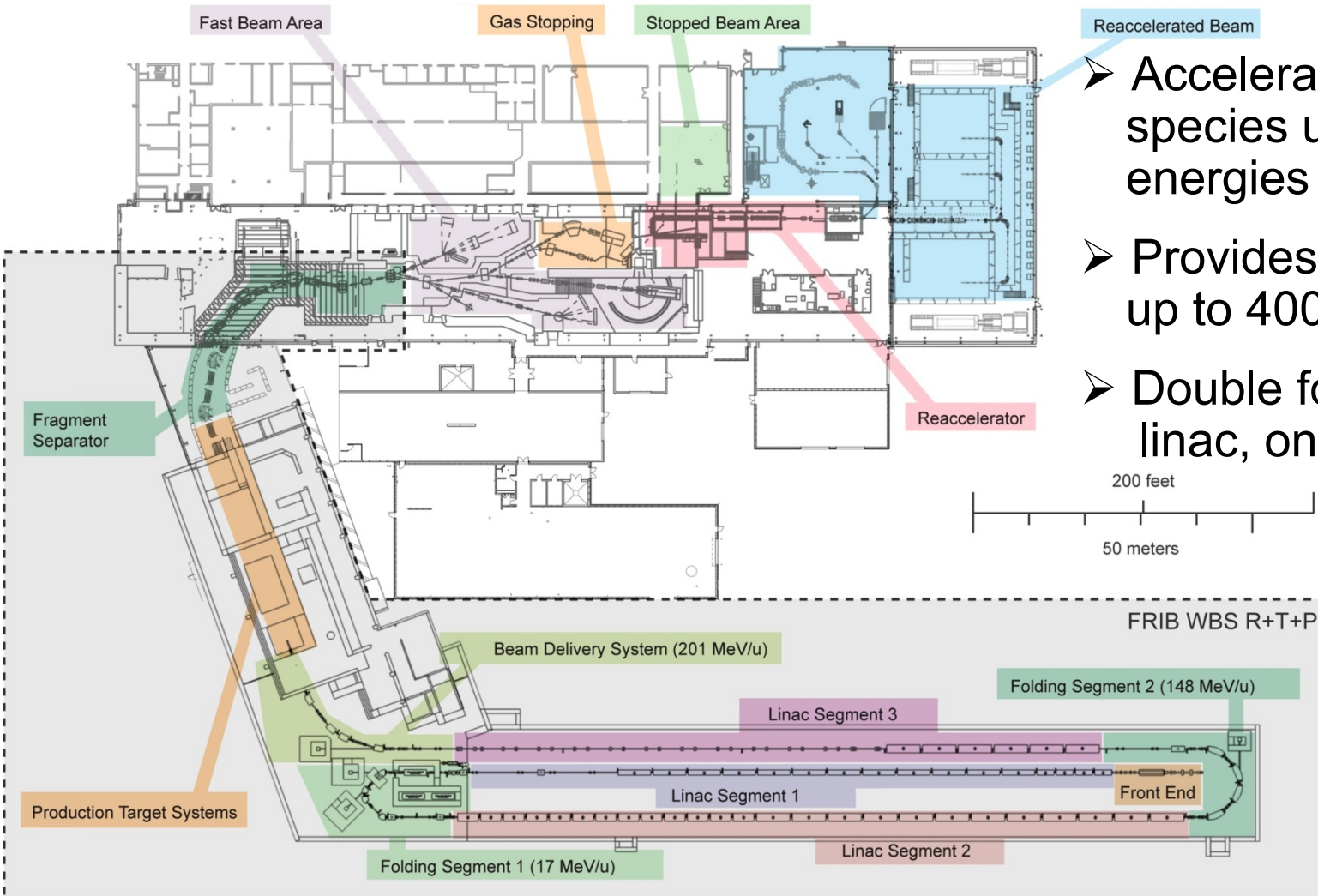
- $3 \cdot 10^{11} \text{ }^{238}\text{U}^{28+}/\text{s}$ (Slow extr.)
@ 1.5 GeV/u
- $4 \cdot 10^{11} \text{ }^{238}\text{U}^{28+}$ (pulsed)
@ 1 GeV/u
- factor 100 in intensity
over present

Secondary Beams

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

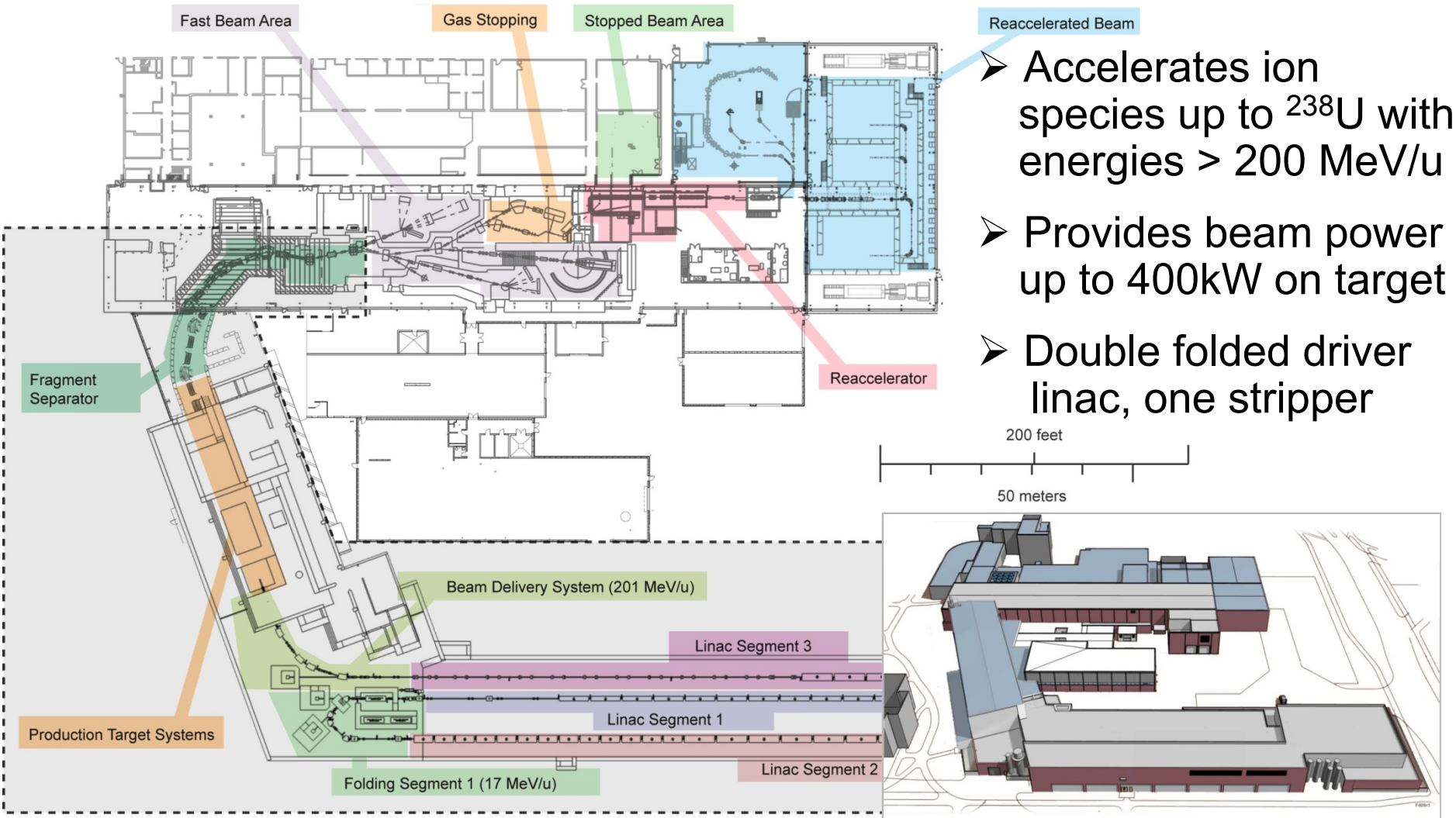


Facility for rare ion beams (FRIB) at MSU

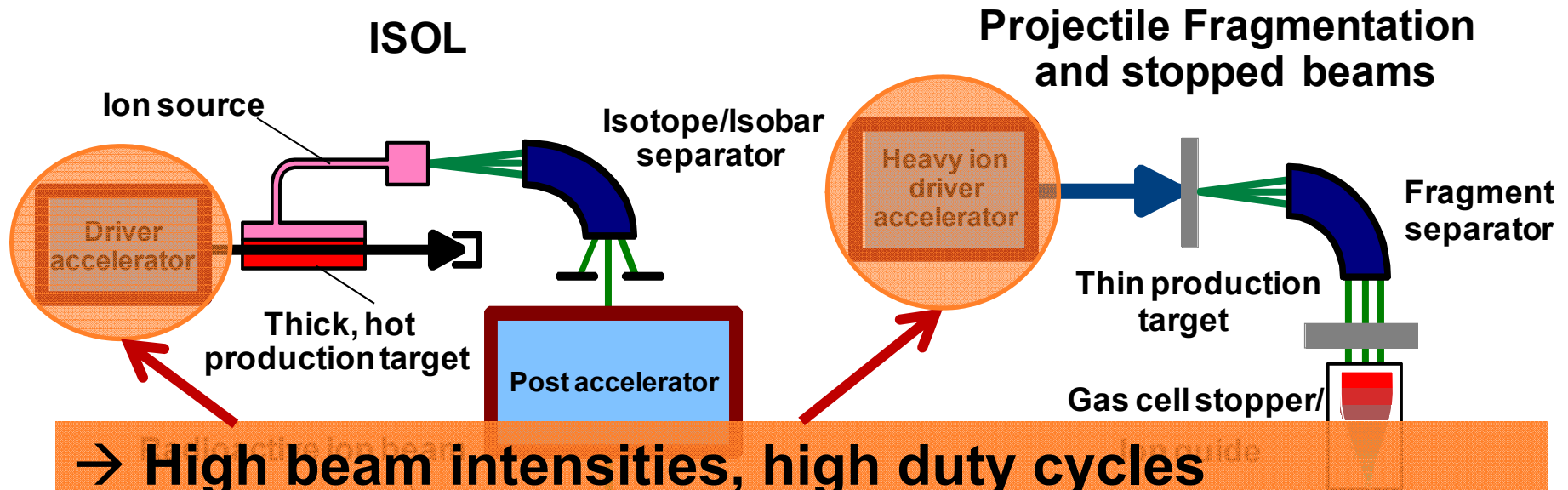


- Accelerates ion species up to ^{238}U with energies $> 200 \text{ MeV/u}$
- Provides beam power up to 400kW on target
- Double folded driver linac, one stripper

Facility for rare ion beams (FRIB) at MSU



Driver accelerator challenges

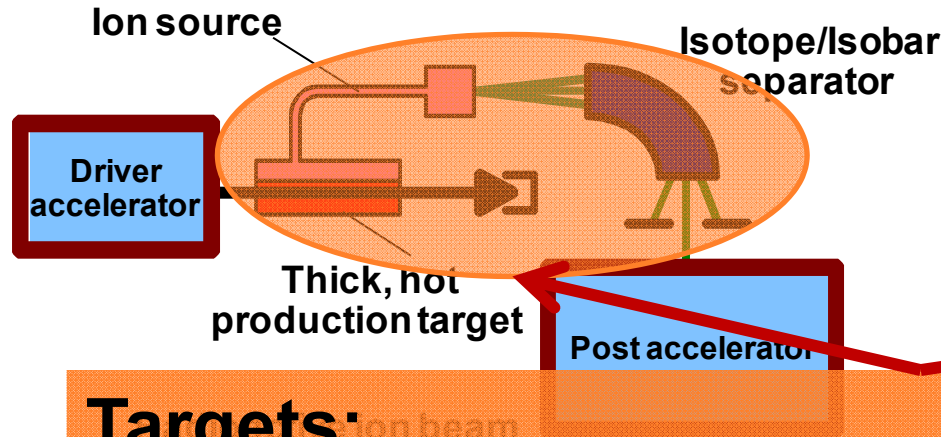


→ High beam intensities, high duty cycles

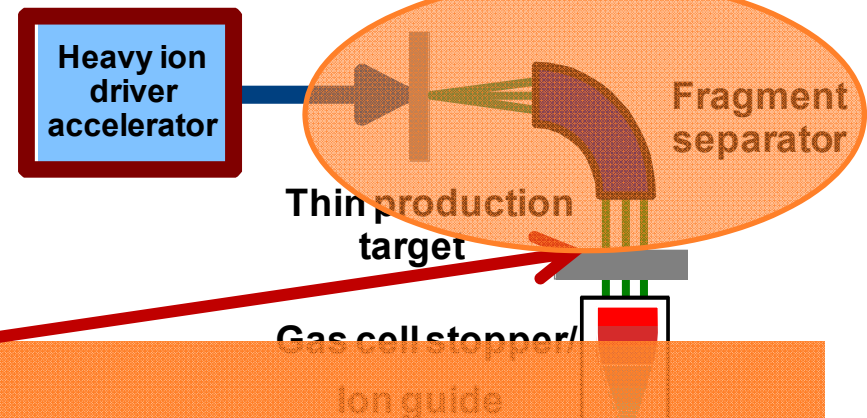
- Ion sources, Low energy beam transport (LEBT),
- Cavities (high duty cycle) → superconducting RF
- Charge state stripper
- Quality of magnets in ring machines
- Highest intensities in ring machines (resonances)
- beam diagnostics and machine protection
- Beam losses and activation

Target and separator challenges

ISOL



Projectile Fragmentation and stopped beams



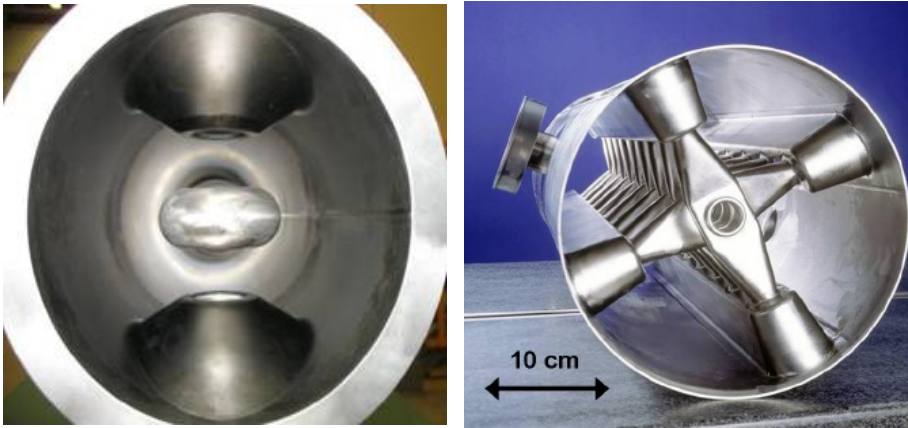
Targets:

- Beam power deposition in the targets and lifetime of the targets (similar to charge state stripper)
- Activation and target handling

Separators

- Phase space acceptance, resolution → Magnet size
- Activation of components, Suppression of background contamination

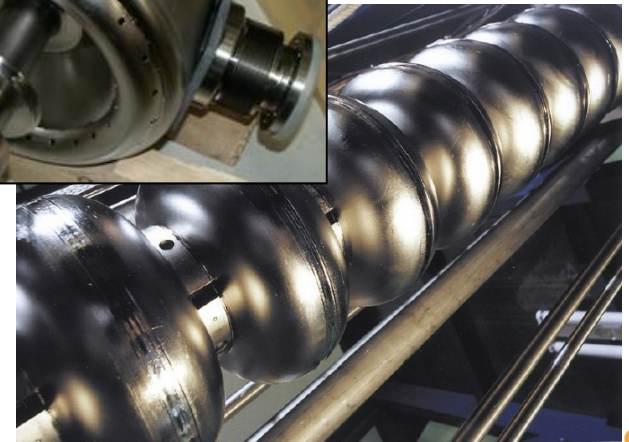
Superconducting rf-cavities (SRF)



- E-Beam welding, Nb
- Sufficient LHe cooling
- High gradients → surface preparation and processing
BCE, HPR, EP, degassing (high T)

Typical for driver and post accelerators
(TRIUMF, MSU, CERN, GANIL...)

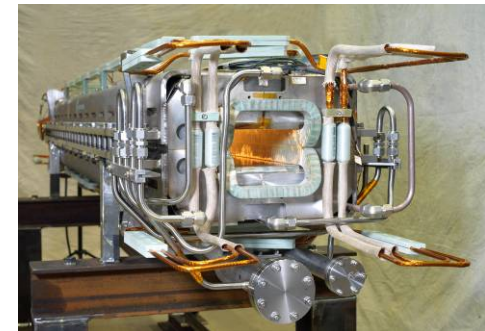
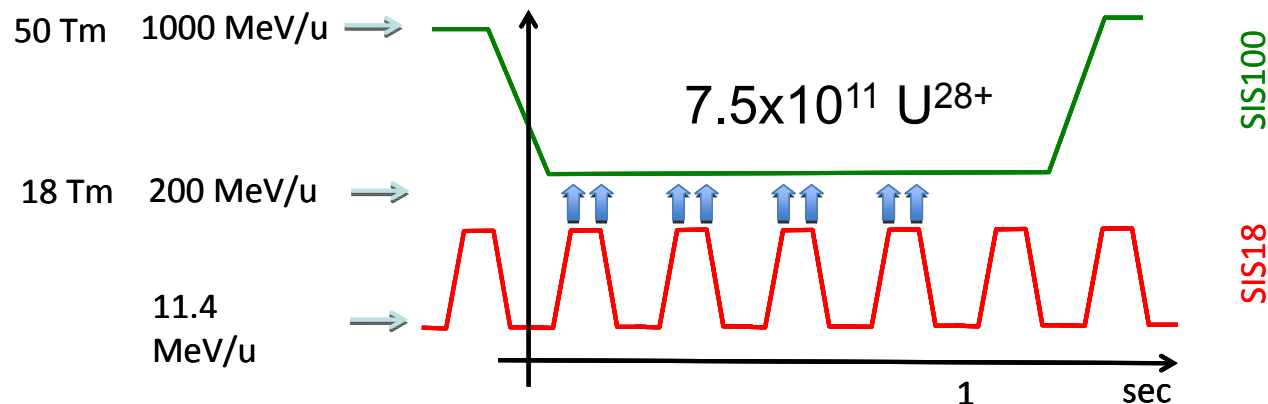
- Quarter and half wave resonators (QWR/HWR)
- single and multi spokes cavities
- Cross bar (CH) structure
- Elliptical cavities



Challenges of the SC-magnets development for SIS100

Fast ramped magnets (synchrotrons)

- Dynamic load and AC heat losses (Synchrotron magnets)
 $B_p = 100 \text{ Tm}$ - $B_{\text{max}} = 1.9 \text{ T}$ - $dB/dt = 4 \text{ T/s}$
- High field quality, low multipole strength



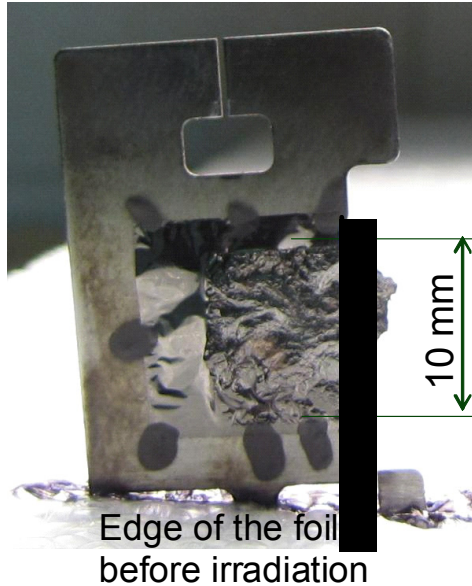
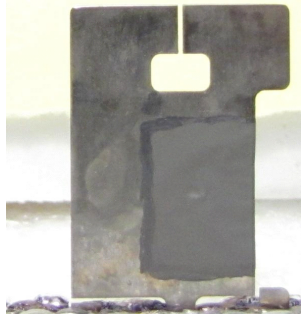
R&D Goals

- Reduction of eddy / persistent current effects
- Guarantee of long term mechanical stability ($\geq 2 \times 10^8$ cycles)

(mechanical stress $\rightarrow$ coil restraint)

Charge state stripper for intense heavy ion beams

8
Unused foil



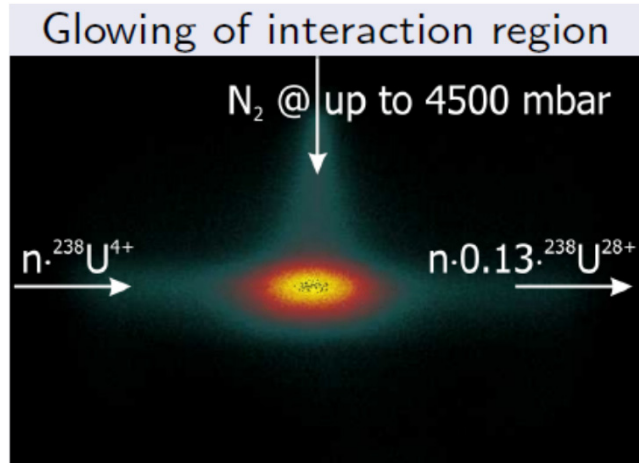
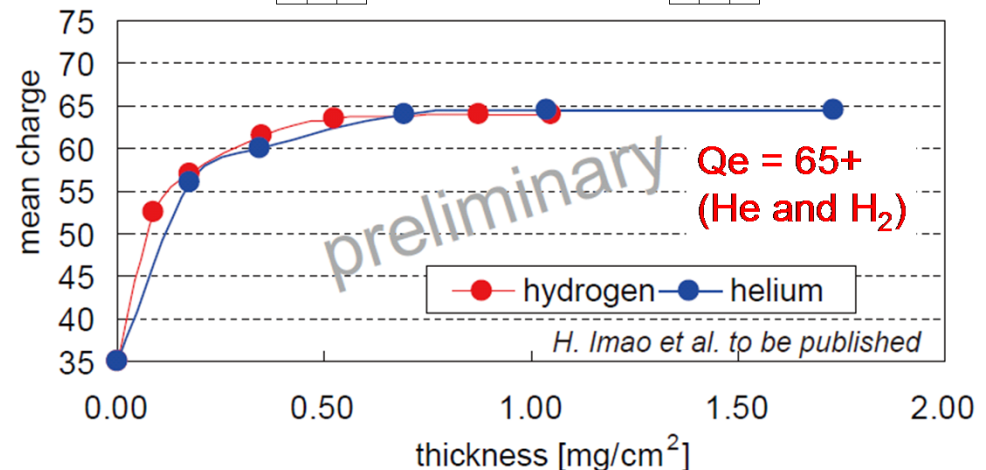
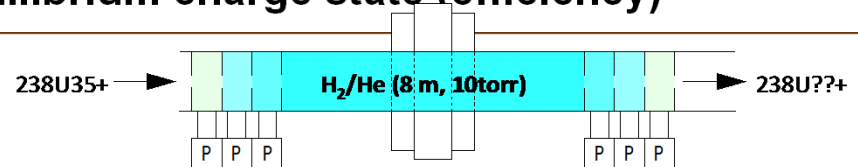
Edge of the foil
before irradiation

C-foil stripper

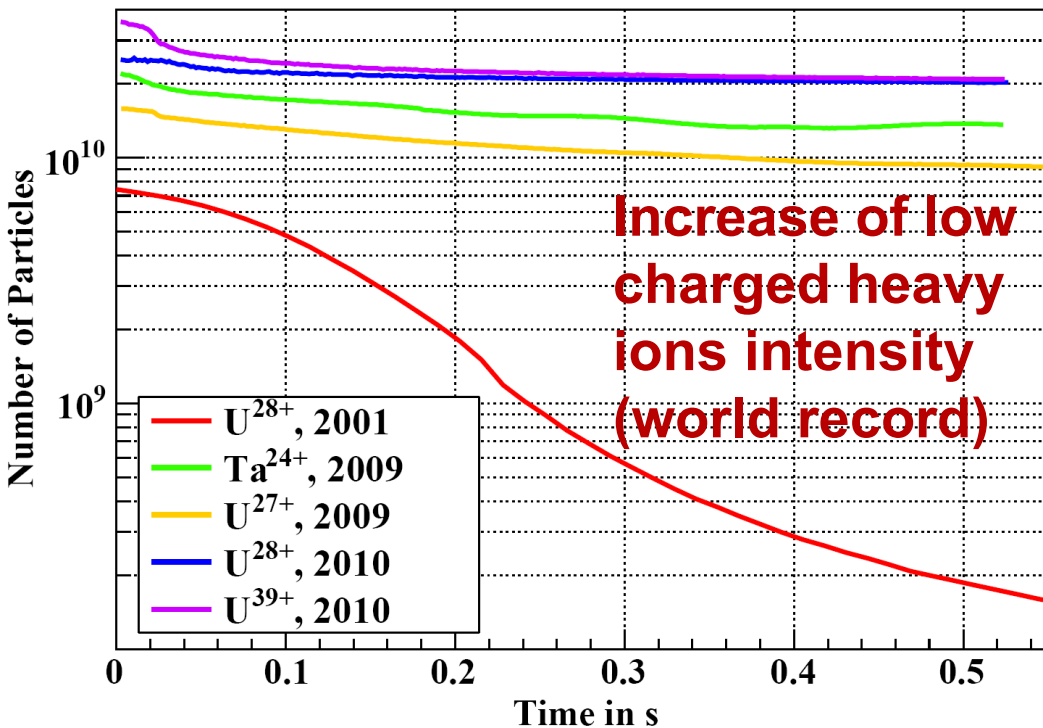
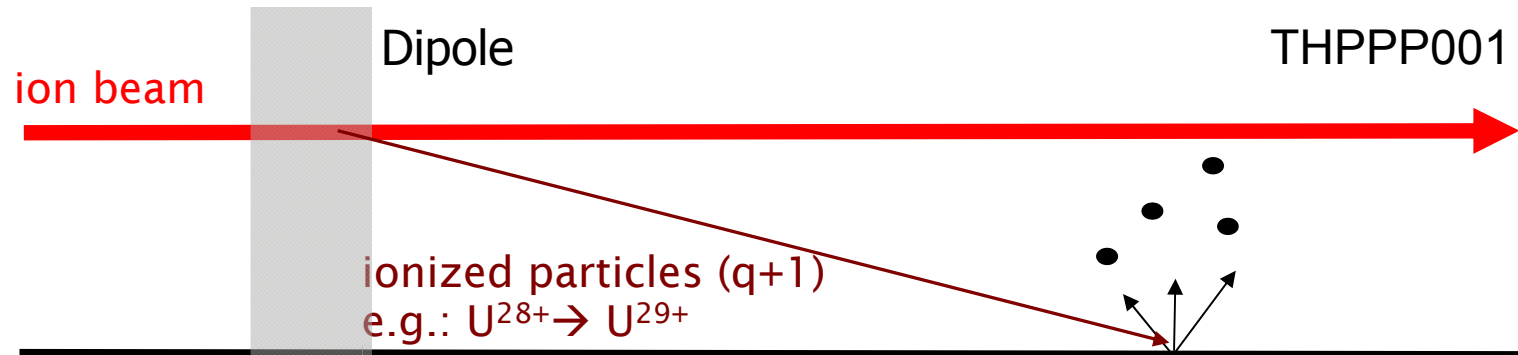
- short lifetime at highest intensities, but highest charge states

gas stripper

- High intensity capabilities, but lower charge states
- Equilibrium charge state (efficiency)

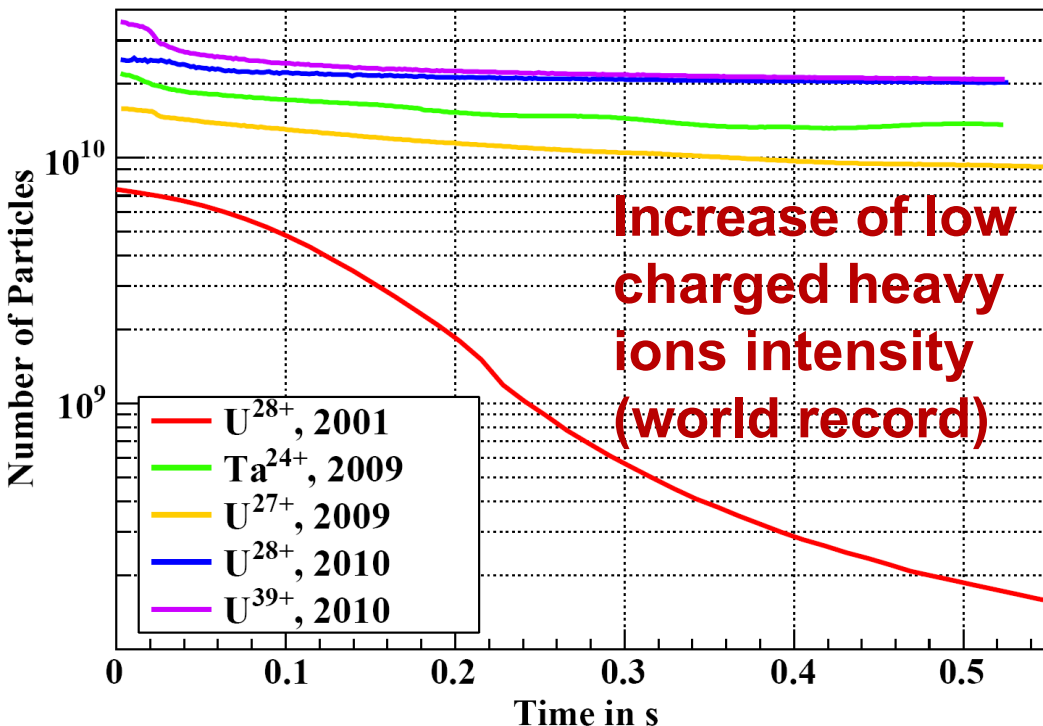
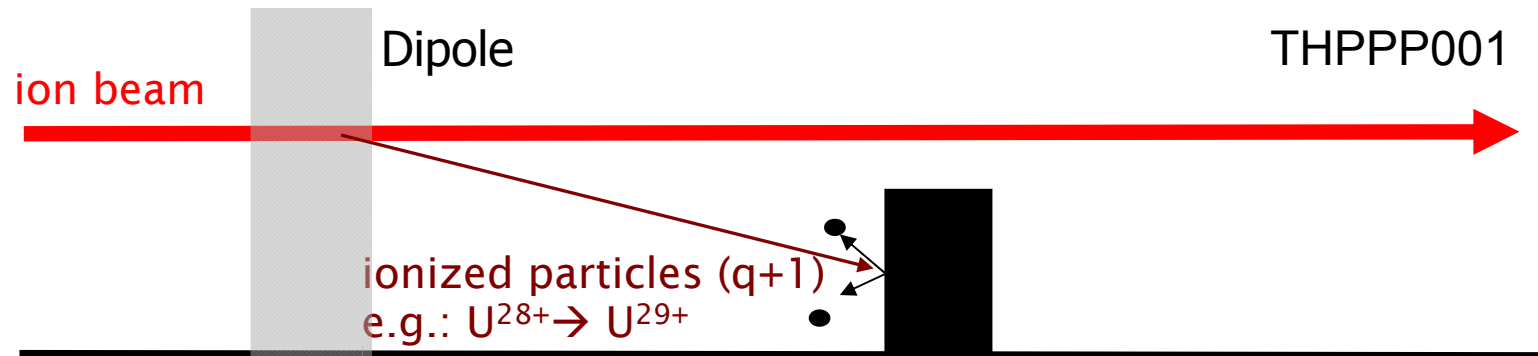


Lifetime of Heavy ions in a synchrotron



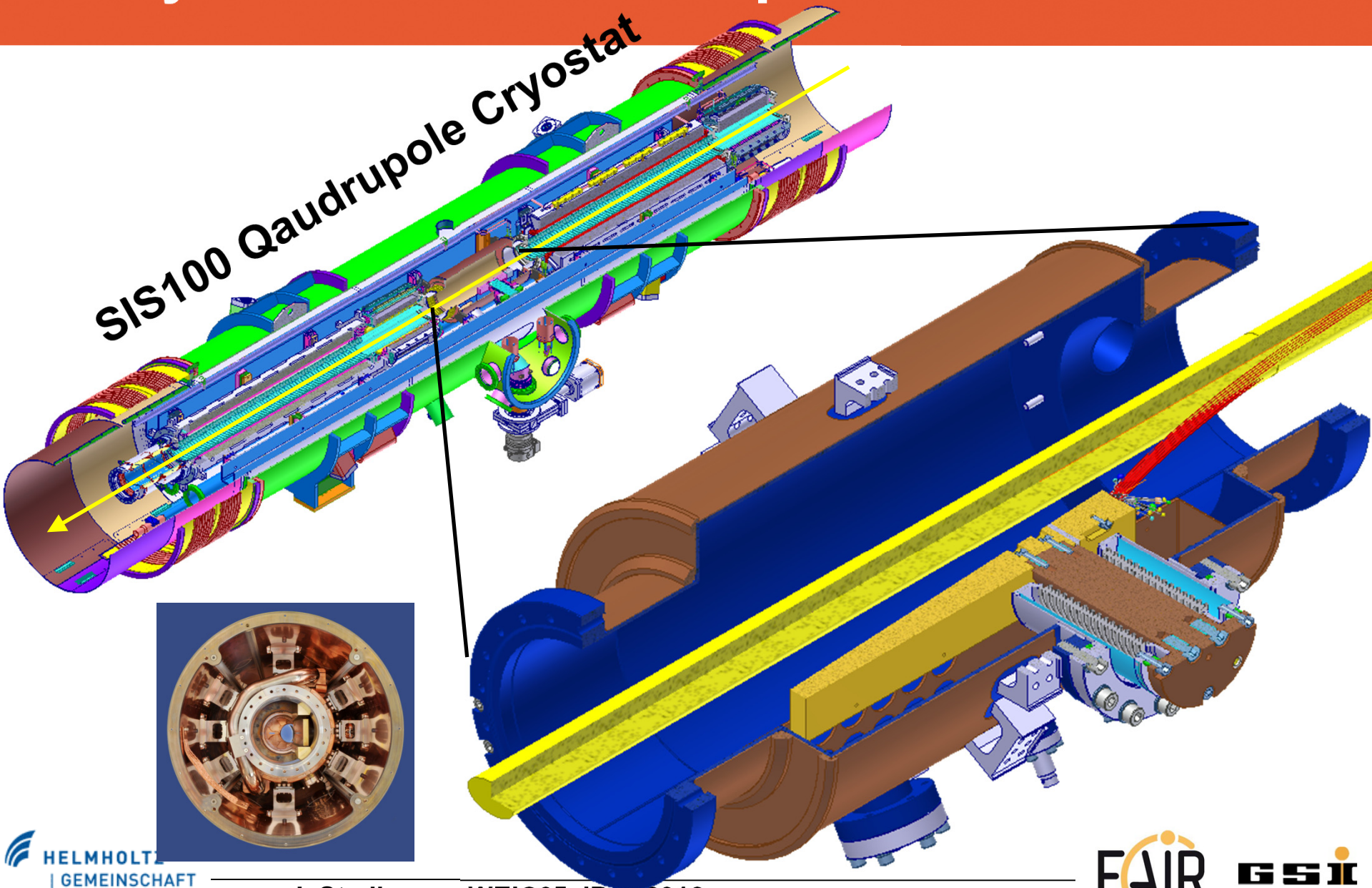
- Charge changing reactions due to rest gas atoms
- Losses induce pressure bumps
- Define location for losses with high pumping capacity
- Low desorbing material

Lifetime of Heavy ions in a synchrotron



- Charge changing reactions due to rest gas atoms
- Losses induce pressure bumps
- Define location for losses with high pumping capacity
- Low desorbing material

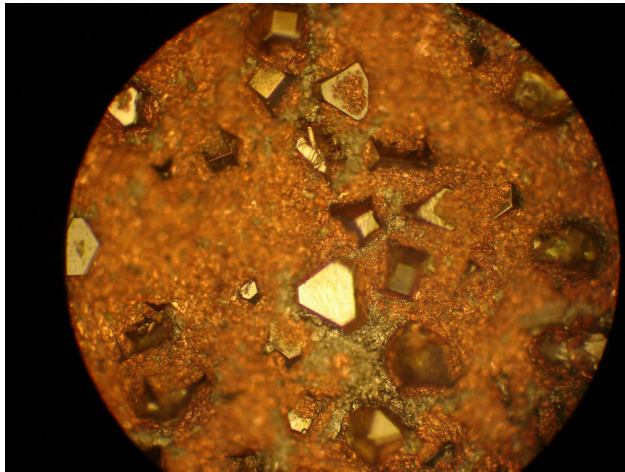
Cryocatcher in Quadrupole Module



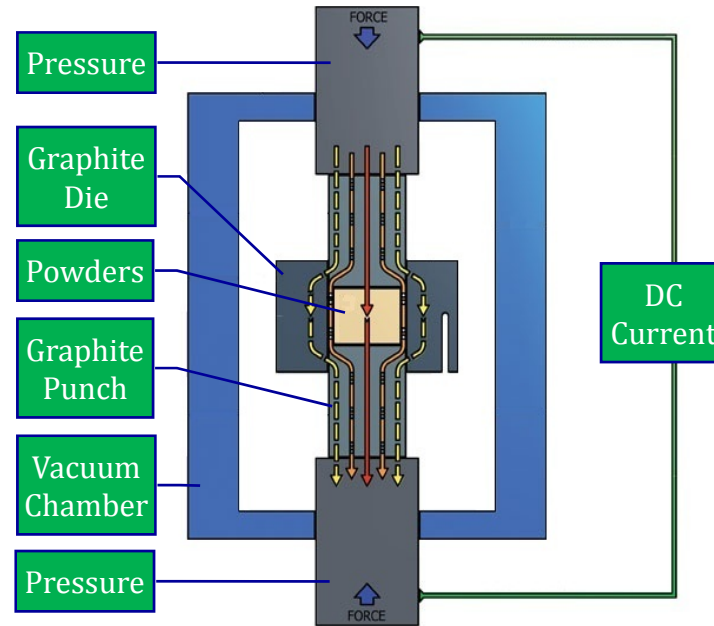
Exotic Materials for Accelerators

Metal-diamond composites:

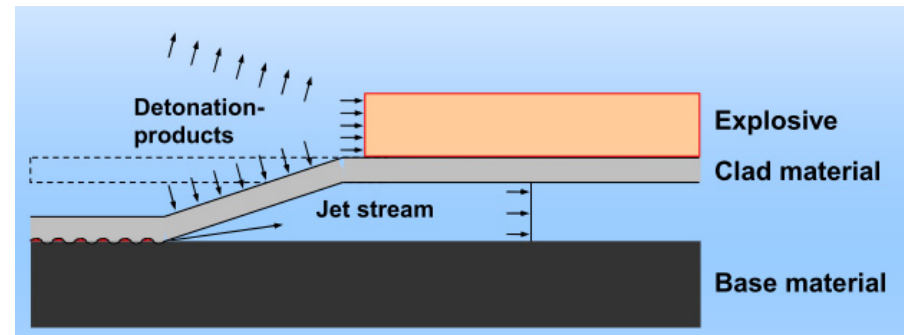
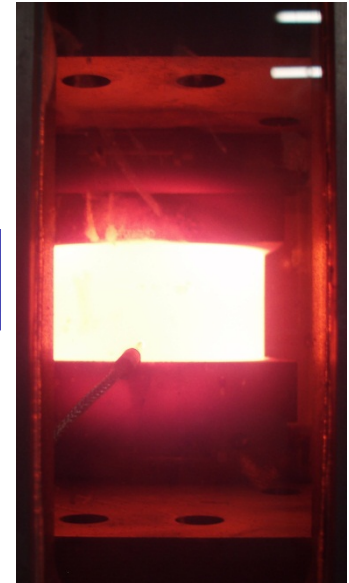
- High thermal and electrical conductivity
- Mechanical and thermal robustness



Explosive plating:
Copper onto stainless steel
For FAIR cryocatcher



(WEPPD028)



(THEPPB004)

Summary

- **The nuclear frontier is determined by the availability of intense rare isotope beams**
- **There are key development towards the new facilities FRIB, ARIEL, FAIR, SPIRAL2, HIE-ISOLDE and EURISOL**
- **The high experimental challenge requires newest state of the art technologies.**
- **Industry benefits by delivering high technology into RIB projects and thus acquiring expertise for new products.**

Additional slides

Expected reach for ^{132}Sn

heaviest
stable

115

116

109

110

103

104

In 125	In 126	In 127	In 128	In 129	In 130	In 131	In 132	In 133
12.2 s 2.3 s β^- 4.1; 4.3... γ 1335; γ 188 m	1.64 s 1.60 s β^- 4.5... γ 1141; 909; 112...	1.04 s 3.67 s 1.09 s β^- 4.8; 6.8... γ 1095; 716... g	0.72 s 0.84 s β^- 5.3; 6.8... γ 1867; 1974... m; g	0.67 s 1.23 s 0.61 s β^- 5.4; 7.6... γ 1136; 570... m	0.53 s 0.53 s 0.33 s β^- 5.7; 7.0... γ 2118; 1865... β n; g; m	0.32 s 0.35 s 0.28 s β^- 6.6; β^- 9.2 β^- 6.8 γ 4273 γ 332 γ 2434 ...; m ...; g; m	0.20 s β^- 6.4; 8.9... γ 375; 4041; 299... β n 0.23; 0.33	180 ms β^- β n γ 802; 1561...
Cd 124	Cd 125	Cd 126	Cd 127	Cd 128	Cd 129	Cd 130	Cd 131	Cd 132
1.29 s β^- 3.9... γ 180; 63; 143... g	0.57 s 0.65 s β^- 4.5; 6.1... γ 1028; 1173... g	0.51 s β^- 4.8; 5.2... γ 260; 428... g	0.43 s β^- 5.5... γ 1235; 376; 524; 1067... g; m	0.30 s β^- 5.9 γ 248; 857... g	0.27 s β^- γ 281	162 ms β^- 6.2; 8.3... γ 1669; 451; 1171; 950... β n	68 ms β^- β n	97 ms β^- β n
Ag 123	Ag 124	Ag 125	Ag 126	Ag 127	Ag 128	Ag 129	Ag 130	
0.30 s β^- γ 264; 410; 591...; g; m β n	? 172 ms β^- 613; 772; 461... β n	166 ms β^- β n	95 ms β^- 652; 815; 402... β n	109 ms β^- β n	58 ms β^- γ 645; 784... β n ?	~160 ms 44 ms β^- ? β n ?	~50 ms β^- γ 957 β n ?	2.879 3.724
Pd 122	Pd 123	Pd 124	Pd 125					
>300 ns β^- ?	>300 ns β^- ?	>300 ns β^- ?	0.02604 New Pd 125	0.05941 0.3136	0.1202 0.4616	0.3306 0.8325	0.7061 1.407	1.779 2.794
Rh 121	Rh 122			80		82		84
>300 ns β^- ?	>300 ns β^- ?	0.01506 0.08901	0.03162 0.1283					
Ru 120								
>300 ns	0.0126 0.05509	0.01803 0.06972						

r-process
& drip-line

Karlsruher Nulidkarte 2006

heaviest
stable

r-process & drip-line

heaviest
stable

	In 125	In 126	In 127	In 128	In 129	In 130	In 131	In 132	In 133
115	12.2 s 2.3 s β^- 4.1; 4.3... γ 1335; 1032... m	1.64 s 1.60 s β^- 4.5... γ 1141; 909; 112...	1.04 s 3.67 s 1.09 s β^- 4.8; 6.8... γ 1095; 716... g	0.72 s 0.84 s β^- 5.3; 6.8... γ 1867; 1974... m; g	0.67 s 1.23 s 0.61 s β^- 5.4; 7.6... γ 1136; 315... β n	0.53 s 0.53 s 0.33 s β^- 5.3; 7.0... γ 2259; 774... m; g	0.37 s 0.35 s 0.28 s β^- 6.1; 9.2... γ 4273; 332... m; g	0.20 s β^- 6.4; 8.9... γ 375; 4041; 299... β n 0.23; 0.33	180 ms β^- β n γ 802; 1561...
116	Cd 124 1.29 s β^- 3.9... γ 180; 63; 143... g	Cd 125 0.57 s 0.65 s β^- 4.5; 6.1... γ 1028; 1173... g	Cd 126 0.51 s β^- 4.8; 5.2... γ 260; 428... g	Cd 127 0.43 s β^- 5.5... γ 1235; 376; 524; 1067... g; m	Cd 128 0.30 s β^- 5.9 γ 248; 857... g	Cd 129 0.27 s β^- γ 281	Cd 130 162 ms β^- 6.2; 8.3... γ 1669; 451; 1171; 950... β n	Cd 131 68 ms β^- β n	Cd 132 97 ms β^- β n
109	Ag 123 0.30 s β^- γ 264; 410; 591...; g; m β n	Ag 124 ? 172 ms β^- γ 613; 772; 461... β n	Ag 125 166 ms β^- β n	Ag 126 95 ms β^- γ 652; 815; 402... β n	Ag 127 109 ms β^- β n	Ag 128 58 ms β^- γ 645; 784... β n ?	Ag 129 10-5 ms β^- ? β n ?	Ag 130 ~50 ms β^- γ 957 β n ?	2.879 3.724
110	Pd 122 >300 ns β^- ?	Pd 123 >300 ns β^- ?	Pd 124 >300 ns β^- ?	New Pd 125 0.02604 0.01124 80	0.05941 0.3136	0.1202 0.4616	0.3306 0.8325 82 10-7	0.7061 1.407	1.779 2.794 84
103	Rh 121 >300 ns β^- ?	Rh 122 >300 ns β^- ?	0.01506 0.08901	0.03162 0.1283			10-9		
104	Ru 120 >300 ns	0.0126 0.05509	0.01803 0.06972				10-11 COFRA		

r-process
& drip-line

Karlsruher Nulidkarte 2006

r-process & drip-line

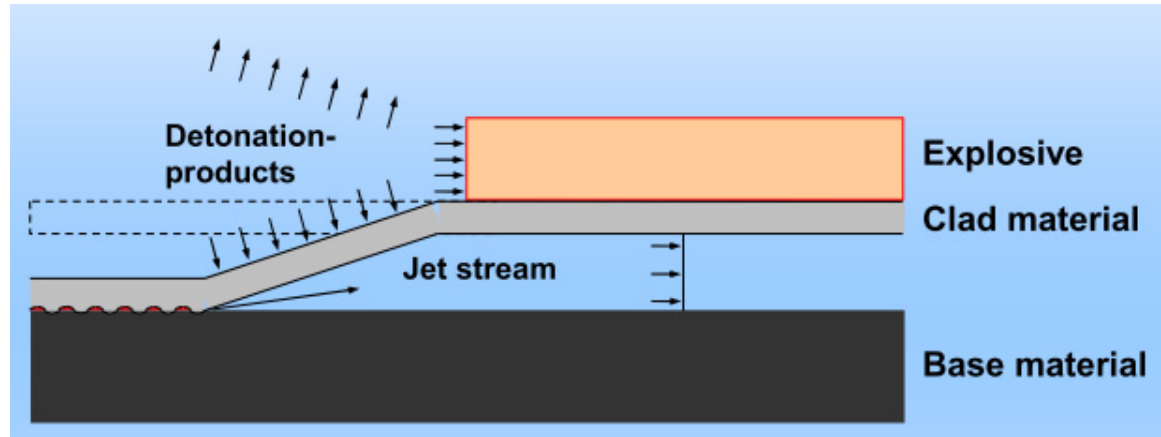
Karlsruher Nulidkarte 2006

COFRA

Challenges

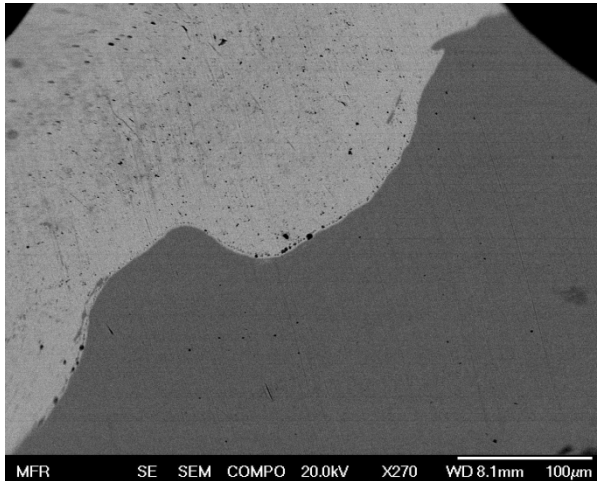
- **Driver accelerators:**
Ion sources, LEBT, cavities (SRF), magnets,
beam diagnostics, machine protection
highest intensities in ring machines
- **Targets, stripper and separators:**
Beam power deposition, lifetime, acceptance,
resolution, activation, beam dumps
- **Post acceleration:**
Beam stopping (PF), charge breeding,
beam diagnostics, cavities

Explosive plating – Copper onto stainless steel



Dynaplat, 2010

- Chamber will be coated with copper
- Cryo-tests were performed with test-sample

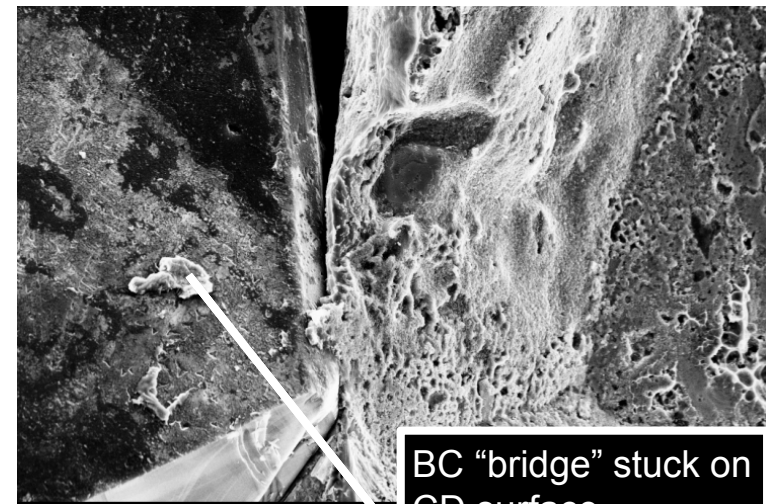
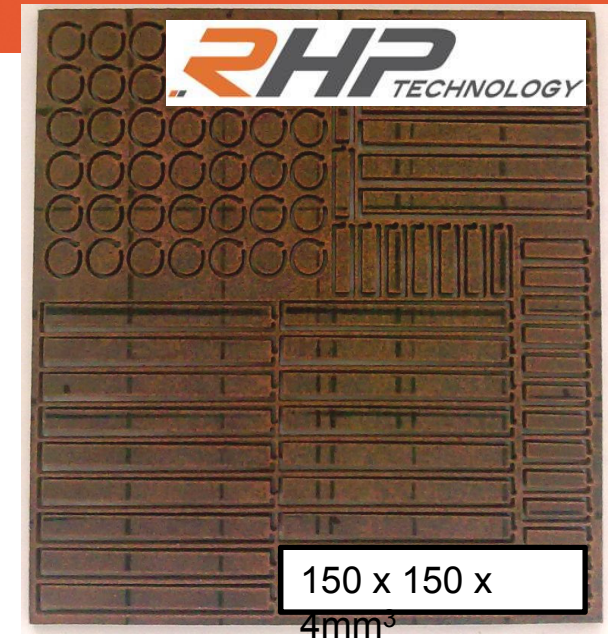


Reuter, 2010

(L.Bozyk, GSI)

Cu-CD Composite

(Alessandro Bertarelli – CERN)



BC "bridge" stuck on CD surface.
No CD graphitization

- Developed by **RHP-Technology** (Austria)
 - Produced by Rapid Hot Pressing (**RHP**).
 - 60% Diamond, 40% Cu
- ↑ No diamond degradation (in reducing atmosphere graphitisation starts at ~ **1300 °C**)
- ↑ Good thermal (~**490 W/mK**) and electrical conductivity (~**12.6 MS/m**).
- ↓ No direct interface between Cu and CD (lack of affinity). Limited bonding surface assured by Boron Carbides hampers mechanical strength (~**120 MPa**).
- ↓ BC brittleness adversely affects material toughness.
- ↓ Cu low melting point (**1083 °C**) limits Cu-CD applications for highly energetic accidents.
- ↓ CTE increases significantly with T due to high Cu content (from ~**6 ppmK⁻¹** at RT up to ~**12ppmK⁻¹** at **900 °C**)

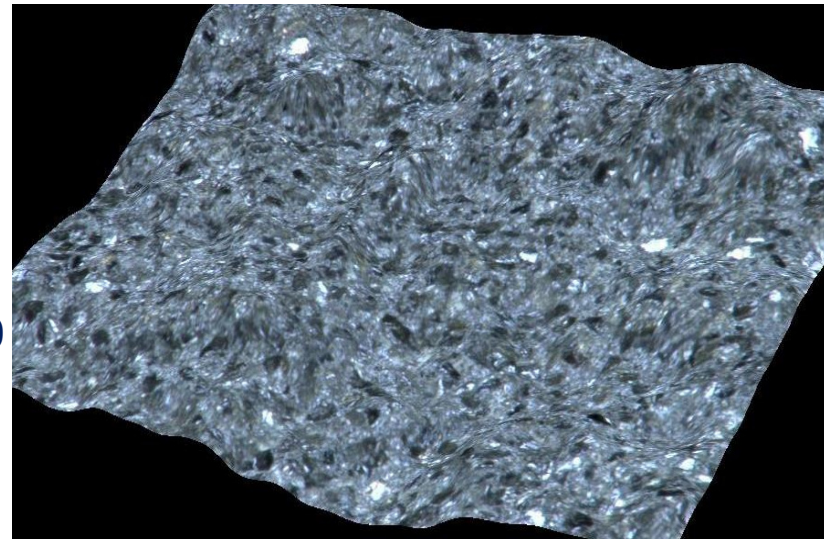
Ag-CD Composite

(Alessandro Bertarelli – CERN)



- Developed by **EPFL**, Switzerland.
- Manufactured by Liquid Infiltration
- ~60% Diamond, ~40% Ag-Si alloy

- ↑ Excellent bonding between Ag and CD assured by SiC formation on diamond.
- ↑ High Flexural Strength (~**500 MPa**) and toughness.
- ↑ High Electrical Conductivity.
- ↓ Max T_{Service} limited by low-melting eutectic phase Ag-Si (**840 °C**).
- ↓ Hard to manufacture large components (>100 mm)
- ↓ Material non homogeneities induced by liquid metal infiltration intrinsic limitations.



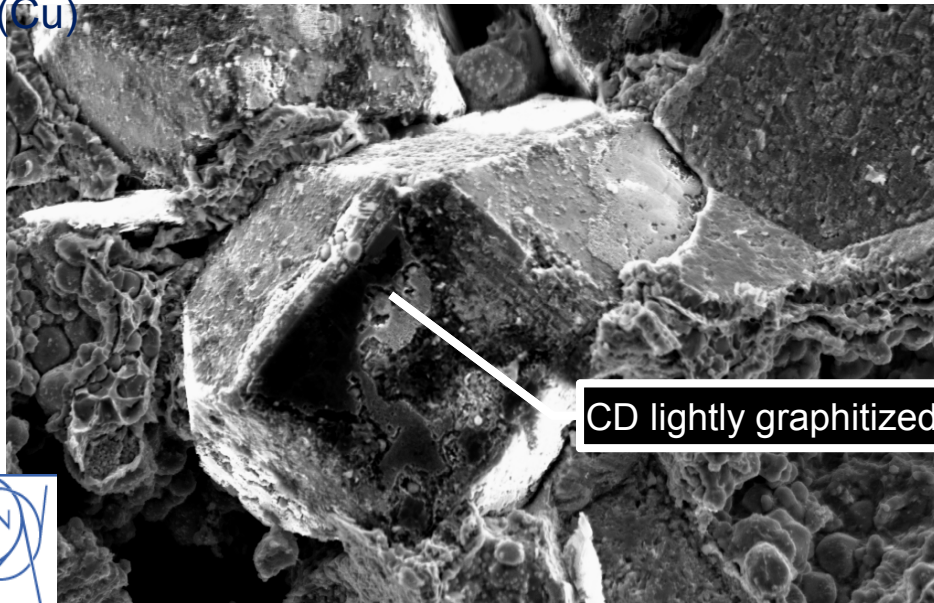
Mo-CD Composites

- Co-developed by **CERN** and a SME, **Brevetti Bizz**, Verona, Italy
- High sintering T of Mo (~1700 °C) leads to diamond graphitisation. 2 alternative processes:

Liquid Phase Sintering (LPS) or **Assisted Solid-state Sintering (ASS)**

LPS

- ↑ Addition of low-melting phase (Cu) to fill in the pores between Mo and CD
- ↑ Good mechanical strength (400+ MPa) and fair Thermal Conductivity (185 W/mK)
- ↓ Max T_{Service} limited by low-melting phase (Cu)



ASS

BREVETTI BIZZ

- ↑ Addition of activating elements (Ni, Pd) enhances Mo sintering at low T (~1300 °C)
- ↑ Absence of low-melting phase increases T_{Service} up to ~2600 °C
- ↓ Large diamond particles interfere with Mo compaction.
- ↓ Diamond graphitization not fully avoided.

