ARD Accelerator Initiative

Introduction and Strategic R&D for Future Hadron Synchrotrons

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Strategic R&D for Future Hadron-Accelerators

- The R&D program does not cover the whole field of developments for future Hadron accelerators.
- The selected R&D topics covers developments which are of major interest for potential future programs and projects of the involved HGF centers (FZJ, GSI).

- Substructure of the Hadron Program Topic

1. R&D for future Hadron-Linacs (GSI)
2. R&D for future Hadron-Synchrotrons (circular accelerators) (GSI)
3. R&D for future Hadron-Storagerings (FZJ,GSI)

Strategic R&D for Future Hadron-Synchrotrons

- Major interest of Helmholtz center GSI: Acceleration of Intense Heavy Ion Beams
- However, many of the selected technical developments are of importance
  for future Proton synchrotrons as well.
- Heavy Ion and Hadron Synchrotrons are drivers for
  Fixed Target Experiments or for the Production of Secondary Beams
- Synchrotrons suffer in comparison with Linacs from low average intensity >
  Higher pulse intensity and higher repetition rates partyl compensates
- Heavy ion synchrotrons show lower number of ions than Proton synchrotrons
  Proton synchrotrons reach the range of 10^{14} /cycle
  Heavy ion synchrotrons reach the range of $10^{9} – 10^{10}$ /cycle

Thus increasing the intensity per cycle and the intensity in average is a major goal.

Generation of Ultimate Heavy Ion Beam Intensities

- So far, to save acceleration and bending power typical heavy ion synchrotrons were designed for the highest possible charge state.
- Now, with the need to increase intensities, charge states are lowered.

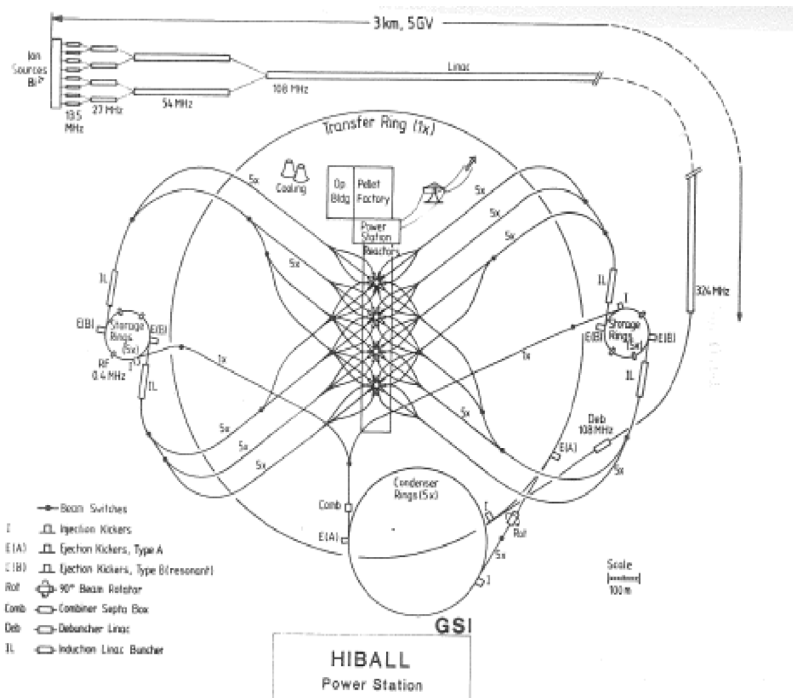
Heavy ion accelerators and projects based on intermediate charge state heavy ions:

AGS Booster	BNL	Au32+
LEIR	CERN	Pb54+
NICA Booster	JINR	Au32+
SIS18	GSI	U28+
SIS100	FAIR	U28+

Generation of Ultimate Heavy Ion Beam Intensities

GSI – FAIR - HIBALL

Today	FAIR	HIBALL
U73+	U28+	U1+
10^9	$\sim 10^{12}$	10^{15}



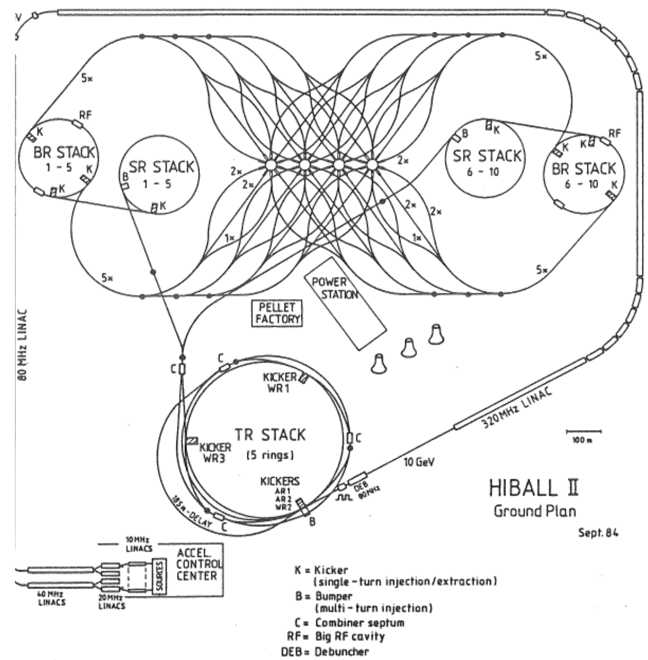


Fig. 1.2-1. HIBALL-II ground plan.

Goal: Energy Production 8 GW - 4.8 MJ Bi^{1+} / Bi^{2+}-ions

Strategic R&D for Future Hadron-Synchrotrons

- Increasing the Heavy Ion Beam Intensity requires Operation with Low Charge States (space charge limit, stripping loss, sources..)

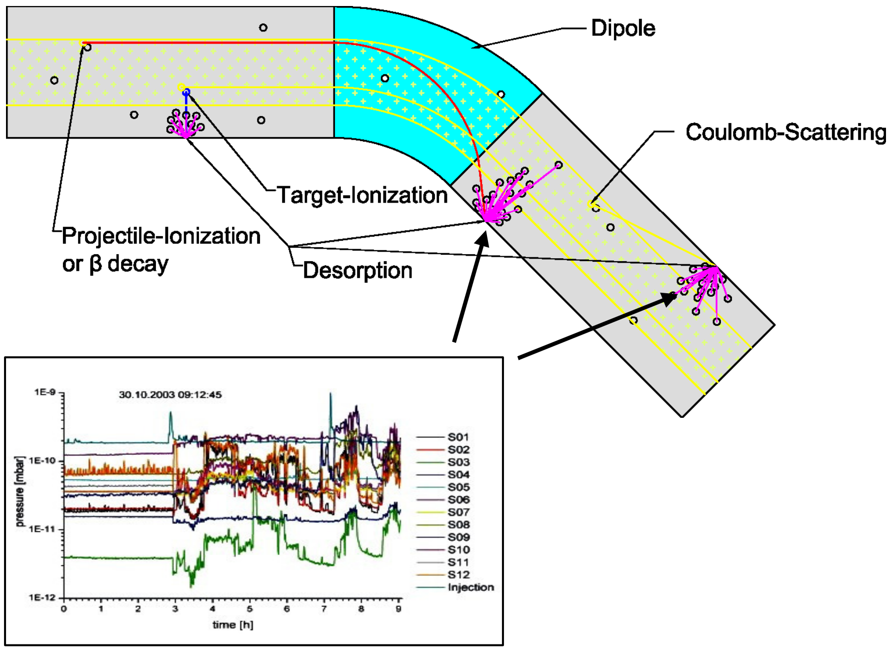
- Low Charge State Heavy Ions show significantly higher Cross Sections for Ionization and consequently Higher Beam Loss at collisions with the rediual gas.

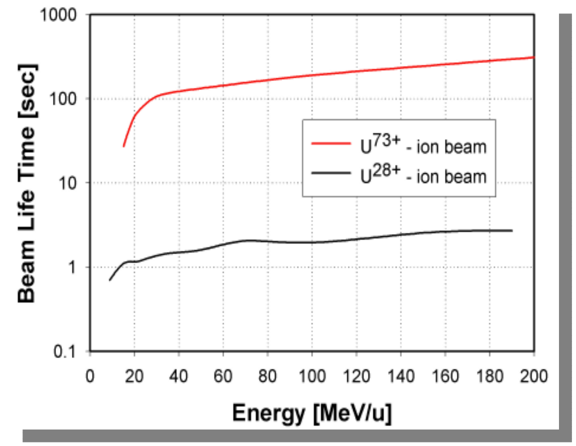
- Ionization Beam Loss drives Pressure Bumps by means of Ion Induced Gas Desorption (> self amplification)

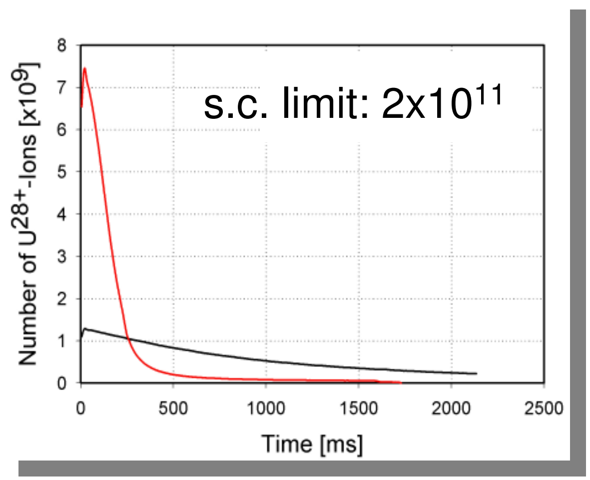
Concepts to minimize or stabilize initial pressure bumps

Generation of Ultimate Heavy Ion Beam Intensities

Ionization Beam Loss and Dynamic Vacuum





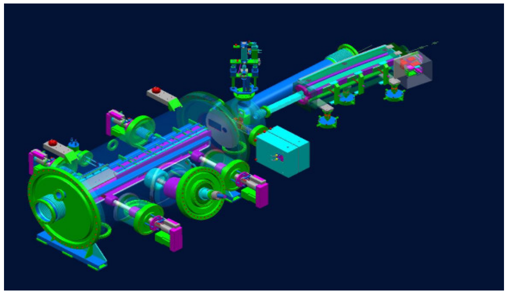


Main Issue of the Booster Operation:

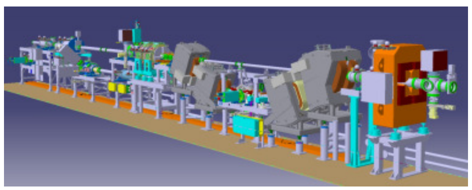
- Life time of low-q ions is significantly lower than of high-q ions.
- Life time of low-q ions depends strongly on the residual gas pressure
- Ion induced gas desorption (η≈ 10 000) increases the local pressure
- Beam loss increases with intensity (dynamic vacuum)

Generation of Ultimate Heavy Ion Beam Intensities

SIS18 Upgrade Program

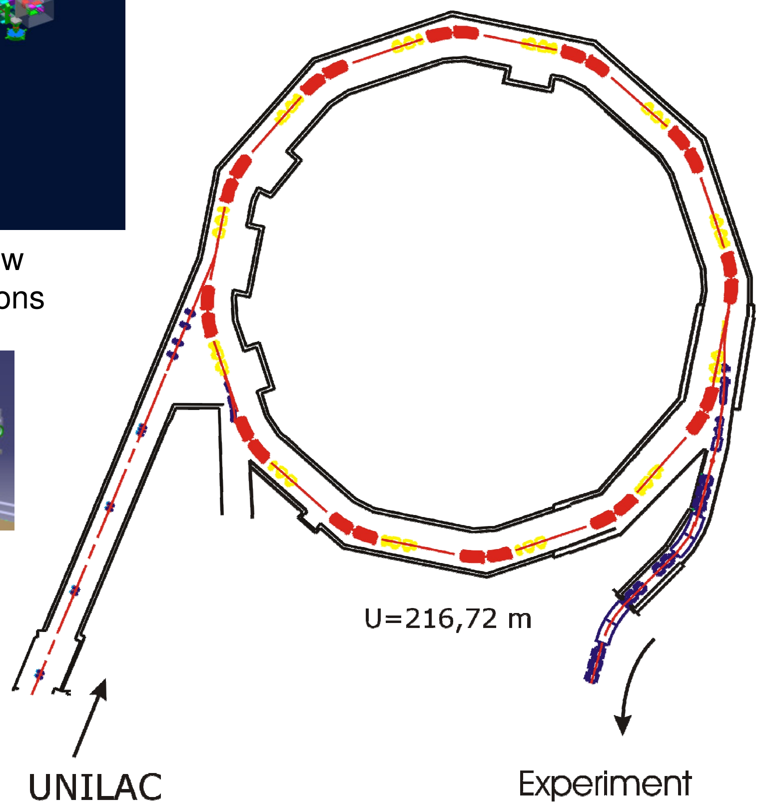


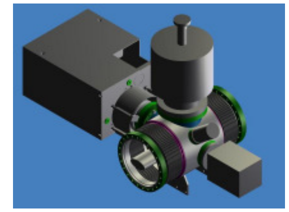
Injection system for low charged state heavy ions



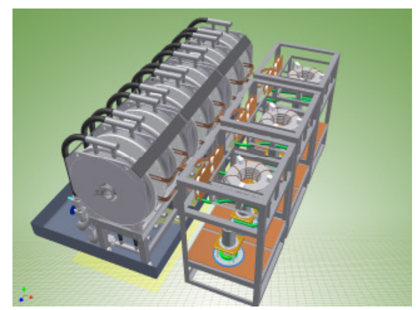
Charge separator for higher intensity and high quality beams

Power grid connection





Scrapers and NEG coating for pressure stabilization

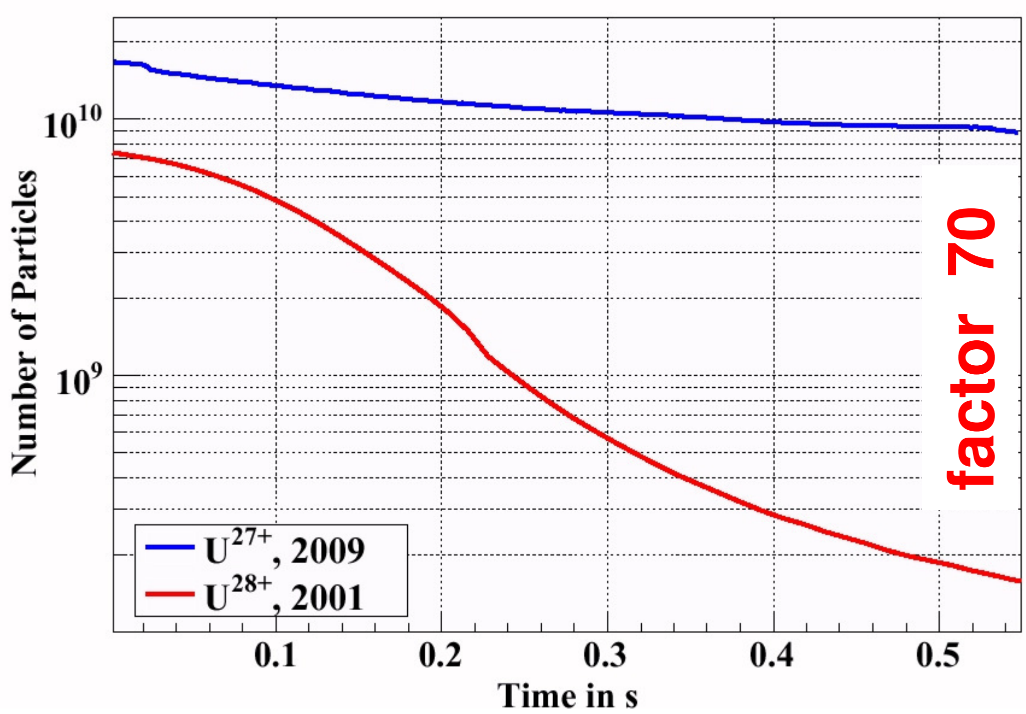


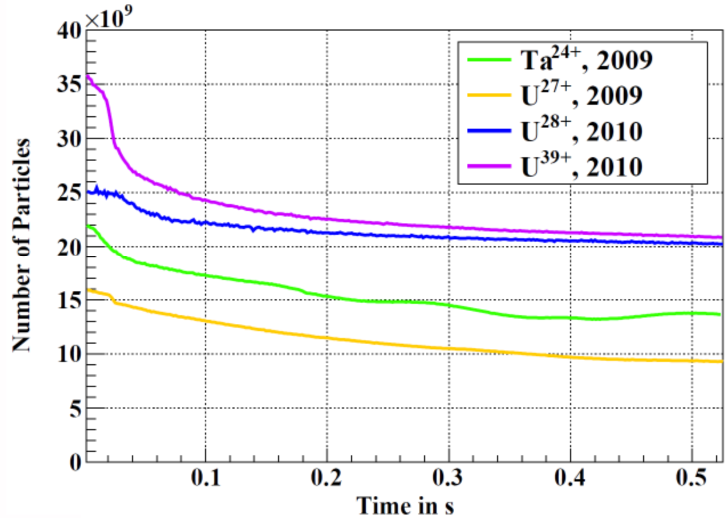
h=2 acceleration cavity for faster ramping

The SIS18upgrade program: Booster operation with intermediate charge state heavy ions

Generation of Ultimate Heavy Ion Beam Intensities

World Record Intensity of Intermediate Charge State Heavy Ions





- **Significantly increased number of accelerated ions (2009 versus 2001)**
- **Interesting option with solid state poststripper > U-beam with 2E10 at 350 MeV/u**

Generation of Ultimate Heavy Ion Beam Intensities

Recipe for the Generation of High Heavy Ion Beam Intensities:

- A dedicated system layout (e.g. charge separator lattice, HE linac for higher injection energy)
- Fast acceleration, short cycle time (to get rid of high cross sections)

Fast acceleration of low charge state heavy ions requires:

a) high Rf voltage

b) fast ramped s.c. magnets (which also provide pumping cryosurfaces)

both research areas are proposed for the ARD program on Hadron Synchrotrons

- High average and local pumping power (to get rid of enhanced, dynamic pressure)
- Low desorption beam catchers and collimation (to get rid of ion induced desorption)

Generation of Ultimate Heavy Ion Beam Intensities

Challenges and Key Issues

- R&D on distributed, strong pumping surfaces

e.g. NEG coated chambers, technologies for cooled, thin wall, cryogenic chambers,

set-up of a s.c. chamber test stand

- R&D on suppression of pressure bumps

e.g. low desorption coatings, low desorption ion catchers (warm and cryogenic)

- R&D on missing parameters and properties for dynamic vacuum simulation

e.g. charge exchange cross sections, sticking coefficients, sojourn time, scrubbing,

desorption yield and scalings, especially for cryogenic and NEG surfaces etc.,

target ionization, low energy desorption etc. (limit for ultimate intensities in circular accelerators)

Generation of Ultimate Heavy Ion Beam Intensities

- R&D on targeted dumping (e.g. halo collimation) – problem large Brho deviation in case of stripping
- R&D on slow extraction of low charge state heavy ions (charge change in the septum wires).

- Investigations are important for the future HE linac design and the choice of optimal accelerator staging of energies and charge states (stripper energy, injection energy, injection charge state etc.)

Magnetic Alloy RF Cavities - Introduction

Properties of MA - Materials

- **High saturation flux density (0.8 T) (higher gap voltage)**
- **Linear permeabiliy μ(B)**
- **Constant power loss product 1/μQf at high flux densities**
- **Low power density at high voltages**
- **High Curie Temperature (570°C)**

Properties of Ferrites

- **Lower saturation flux density (0.3 T) (lower gap voltages)**
- **Decreasing power loss product 1/µQf at high flux densities**
- **Higher power loss density at high voltages**
- **Low Curie Temperaturw (100° - 250°C)**

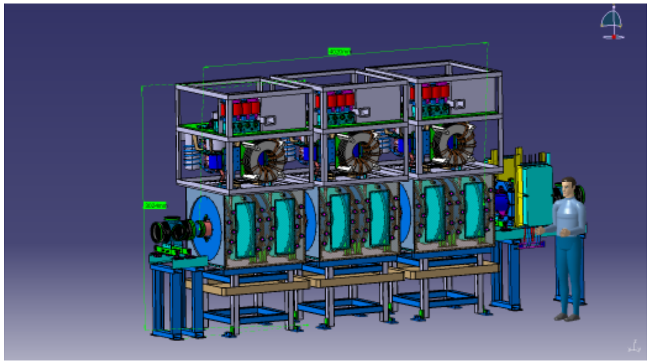
MA - Typen: z.B. Vitrovac (VAC), Vitroperm (VAC), Finemet (HITACHI)

Magnetic Alloy RF Cavities - Introduction

- Higher acceleration gradient compared to ferrite loaded, compact design (e.g. application in small machines e.g. therapy synchrotrons).
- Very low-Q values possible (broad band > pulsed or barrier bucket)
- MA provides unique features for high gradient barrier buckets.
- No pre-magnetization for Rf tuning required.
- Linear behaviour as a function of the Rf amplitude.

- Useful for induction modulators (e.g. HIF Berkely, induction synchrotron (KEK).
- Main developments for MA loaded cavities at KEK/JPARC and GSI

Magnetic Alloy RF Cavities - Introduction



MA loaded cavities can be and are used for several purposes:

- **C.W. operation** as acceleration systems
  provide much higher gradients as conventional ferrite loaded cavities (e.g. HIT, JPARC, future RCS beta beams injector, SIS18)

- **Short pulse operation** as compression or decompression cavities
  provide much higher compression voltage for generation of short, single ion bunches
  (e.g. SIS18, SIS100, CR, MA cores are also used for induction cells)

- **Broadband operation** as barrier bucket, multiple harmonics or longitudinal feedback systems
  (e.g. SIS100 for pre-compression, HESR, ESR for barrier bucket injection)

Magnetic Alloy RF Cavities - Scientific Goals

Development and assembly of a **flexible MA-loaded RF- test system** operating at low frequencies (~MHz) to optimize subcomponents as well as system aspects.

Optimization of subcomponents:

- R&D on MA materials
  - VitroVAC6030 for bunch compression
  - FT-3M for broadband application
  - Co free cores (activation)
  - New annealing technologies

For an optimization of the shunt impedance and inductivity a large variety of nanocristalline (Fe based) and amorphous (Co based) core materials have been investigated for the SIS18 bunch compressor cavity (Vitrovac, Honeywell, Finemet).

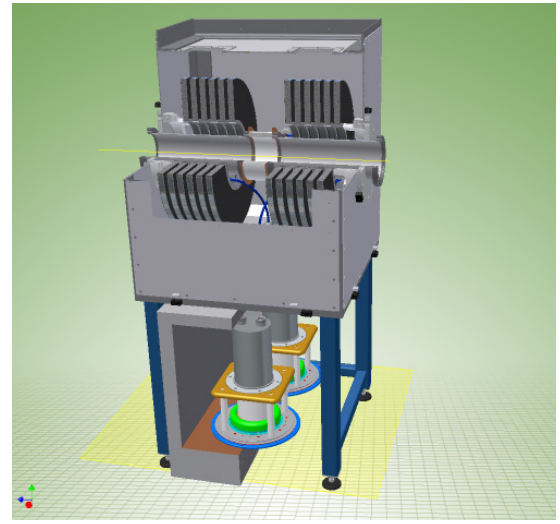
- Refining of cavity cooling concepts (e.g. high power air cooling, pressurized water/oil cooling etc.)
- Characterization of Tetrode parameters (discurpancy between manufacturer datat sheets and actual data..)
- Reliability analysis of subcomponents (e.g. Tetrodes, pre-amplifier, …)

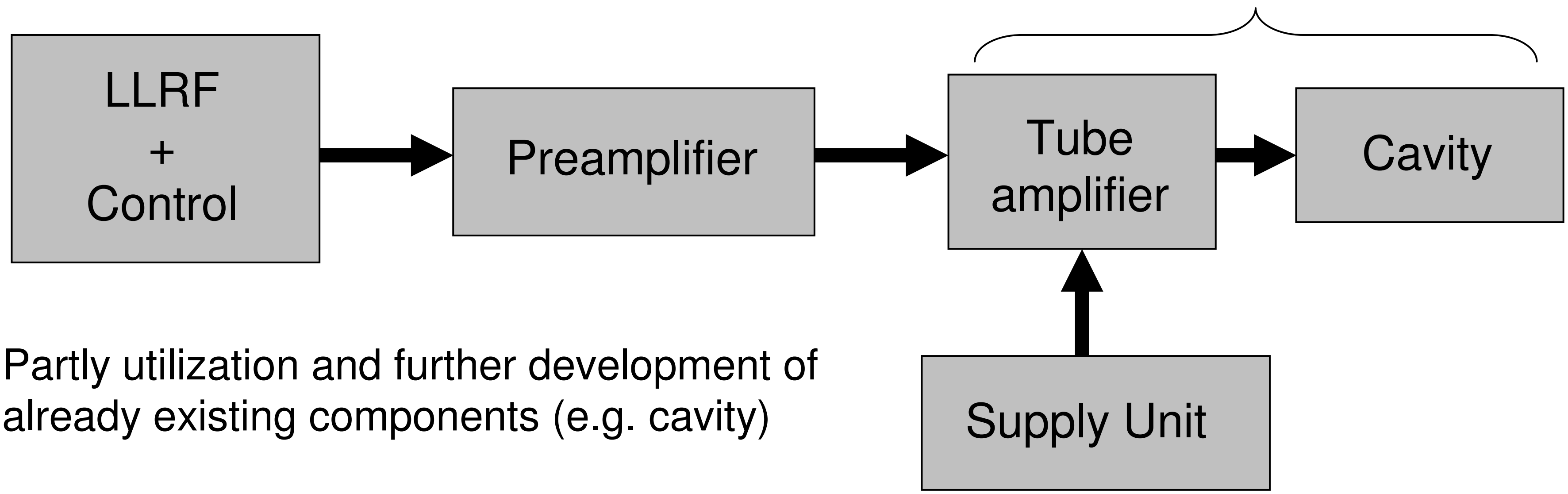
Magnetic Alloy RF Cavities - System Components

Flexibility:

- different MA materials
- vacuum tubes
- amplifier configuration (push-pull, single ended)
- different modes (continuous wave, pulsed operation, single sine)

Setup of RF- test system including all components





Partly utilization and further development of already existing components (e.g. cavity)

Magnetic Alloy RF Cavities - System Components

Cooperations :

• Goethe Universität Frankfurt:
  Broad band cavity, core material, barrier bucket cavities

• Synergies see talk on Hadron Storage Rings (FZJ)

Fast Ramped S.C. Magnets

Two main stream R&D programs

a) Developments towards highes magnetic fields

e.g. 15 T for the Super LHC

b) Developments towards highest ramp rates of superferric or cosΘ magnets

e.g. SIS100 (4 T/s), SIS300 (1 T/s), PS2, SPS2, NICA Booster

Fast Ramped S.C. Magnets

Challenges and Key Issues

High ramp rates have several influences on the magnet performance:

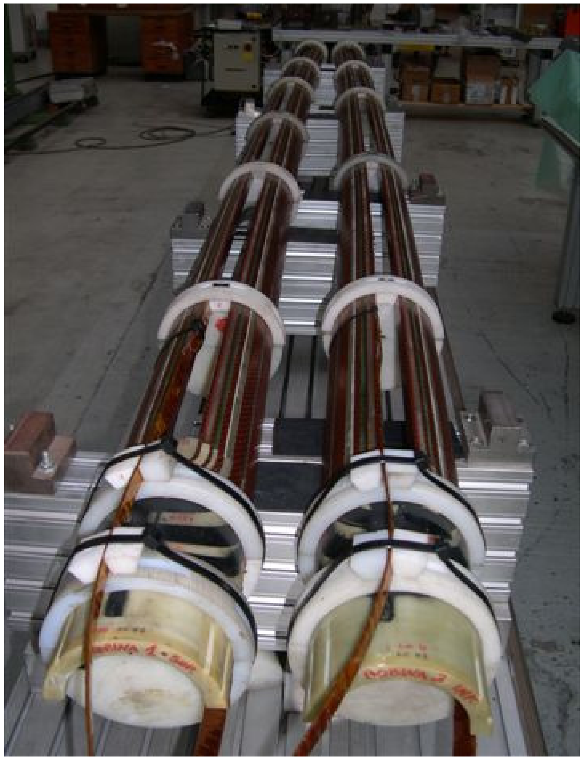
- Field quality is reduced due to superconductor magnetization and coupling currents
- AC heat losses in superconducting cable reduce the margins to quench
- Cycling may lead to mechanical fatigue

and require a new type of superconducting conductor.

Collaborations: e.g. TUD

Strong involvment of industrial partners in Germany and Europe (BNG, Bruker, Ansaldo etc.)

Fast Ramped S.C. Magnets

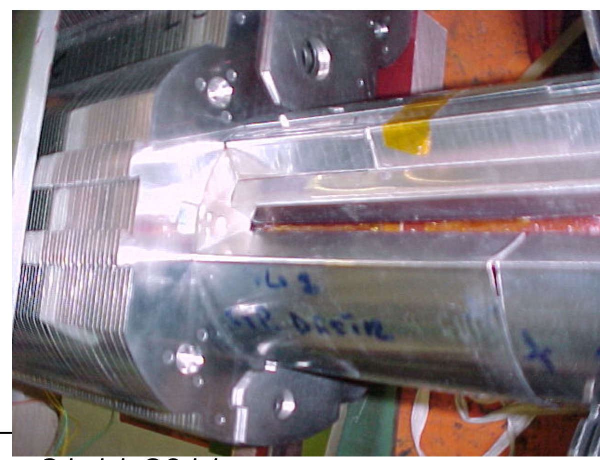


Second Generation of Curved Cos(θ) Dipole with optimised Winding

Continuation and Improvement of an ongoing project with INFN and ASG

The objective is to have the integrated geometrical field harmonics $<10^{-4}$ →

- Re-design of the coil blocks
- Better control of the winding parameters
- Re-shaping of coil end spacers
- Fine calibration of collaring pressure



Fast Ramped S.C. Magnets

Low loss conductor

The development of new low AC heat loss wire and cable and of new insulation schemes which provide a better cooling of the cable are indispensable for the further development of high ramped superconducting magnets.
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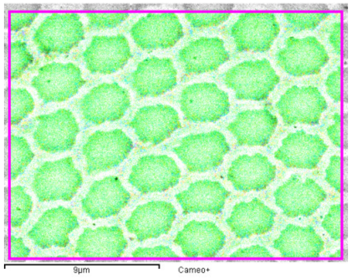
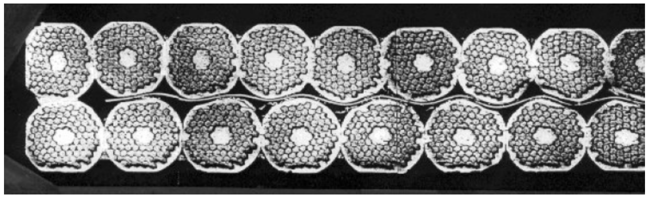
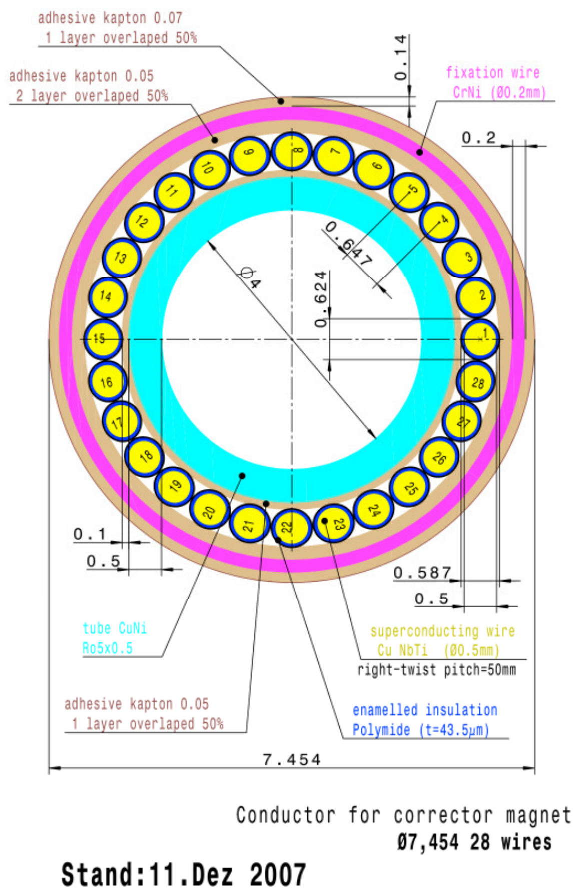


- Fine NbTi filaments (2.5 µm)
- Cu Mn interfilamentary matrix
- Critical current density of 2700 A/mm^2 @B=5 T and T=4.2 K
- Wire twist pitch of 5 mm
- Cored cable
- New insulation scheme



Fast Ramped S.C. Magnets

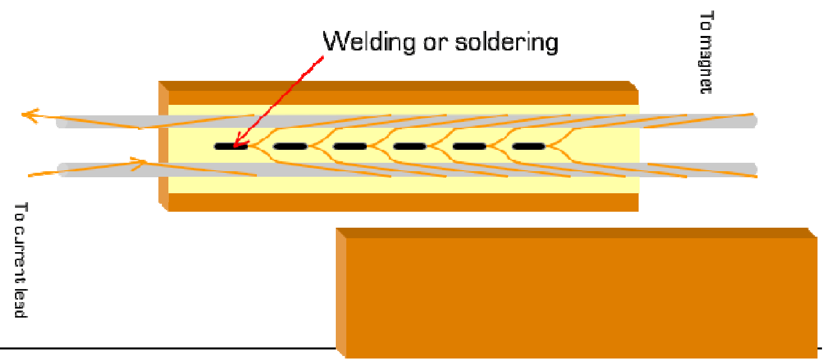
New Nuclotron Type Cable for Fast Ramped Corrector Magnets



Cromaticity Sextupole with 7 T/s

Challenges and Key Issues

- Electrically insulated strands connected in series to allow low current operation
- New insulation scheme with enamel coating of wires and polyimid foils between SC and CuNi tube or NiCr wire not yet tested.
- The heat transfer through the electrical insulation might be critical issue
- Cooling and soldering/welding of joints between strands has to be optimised
- Validation test will be carried out on a sextupol corrector magnet



Mittelverteilung und Jahresplanung GSI

Thema	Koordinator	2011	2012	2013	2014	2015	2016	2017	Summe
	Vorgabe	170	250	525	608	600	250	150	0
Intens. Schwerionenstrahlen niedriger Ladung	Peter Spiller	70	90	120	100	80			460
Neue Akkumulationskonzepte in Speicherringen	Markus Steck	40	40	100	90	20			290
Schwerionen Mittelenergielinac zur Synchrotroninjektion	Winfried Barth	20	40	75	188	175	50	50	598
Niederfrequente Kurzpuls- und Breitbandkavitäten	Ullrich Laier	40	80	190	190	250	150	80	980
Einzelionendetektion	Markus Steck			40	40	75	50	20	185
	Summe	170	250	525	608	600	250	150	**2553**