The Collector Ring Debuncher Overview and Project Status

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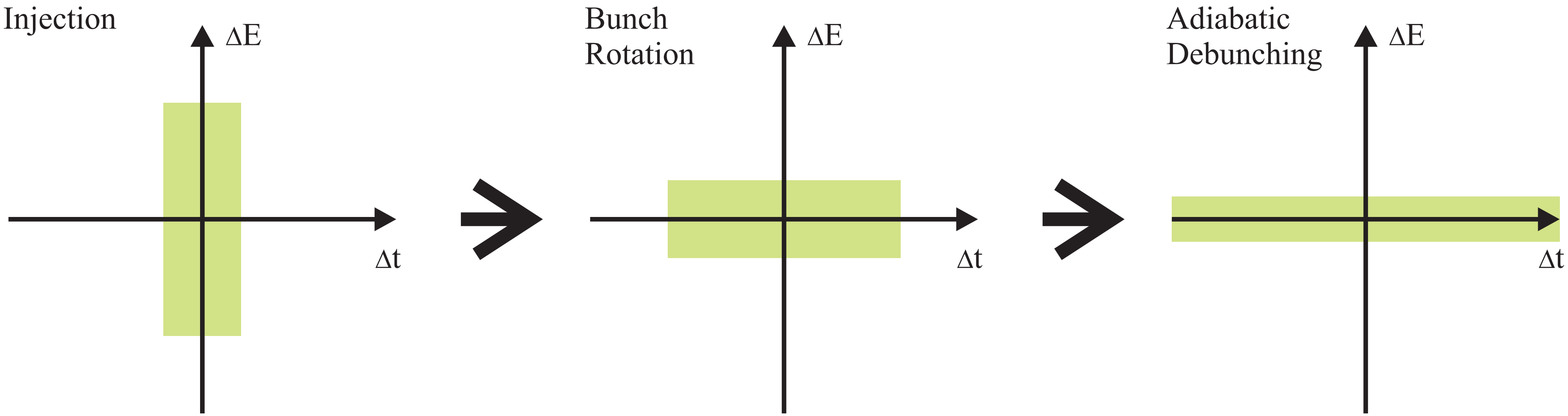
- Introduction
- Requirements
- System Overview
- Conceptual Design
- External Interfaces
- Project Status

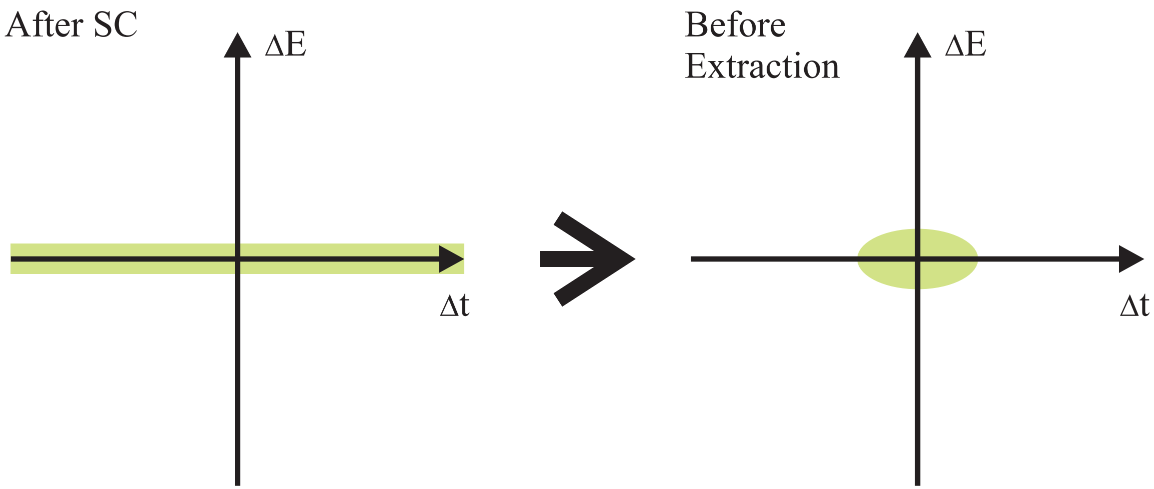
GSI

Collector Ring
Principle Tasks of the RF System

1. Fast debunching of the beam directly after injection:



2. Rebunching prior to extraction



Longitudinal Beam Dynamics Parameters

Ring Parameters:

Circumference	216.25 m
Harmonic number	1
Reference beams	$\bar{p}$; $^{238}U^{88+}$
Gamma transition	$\bar{p}$ 3.85; RIBs 2.67

Beam Parameters:

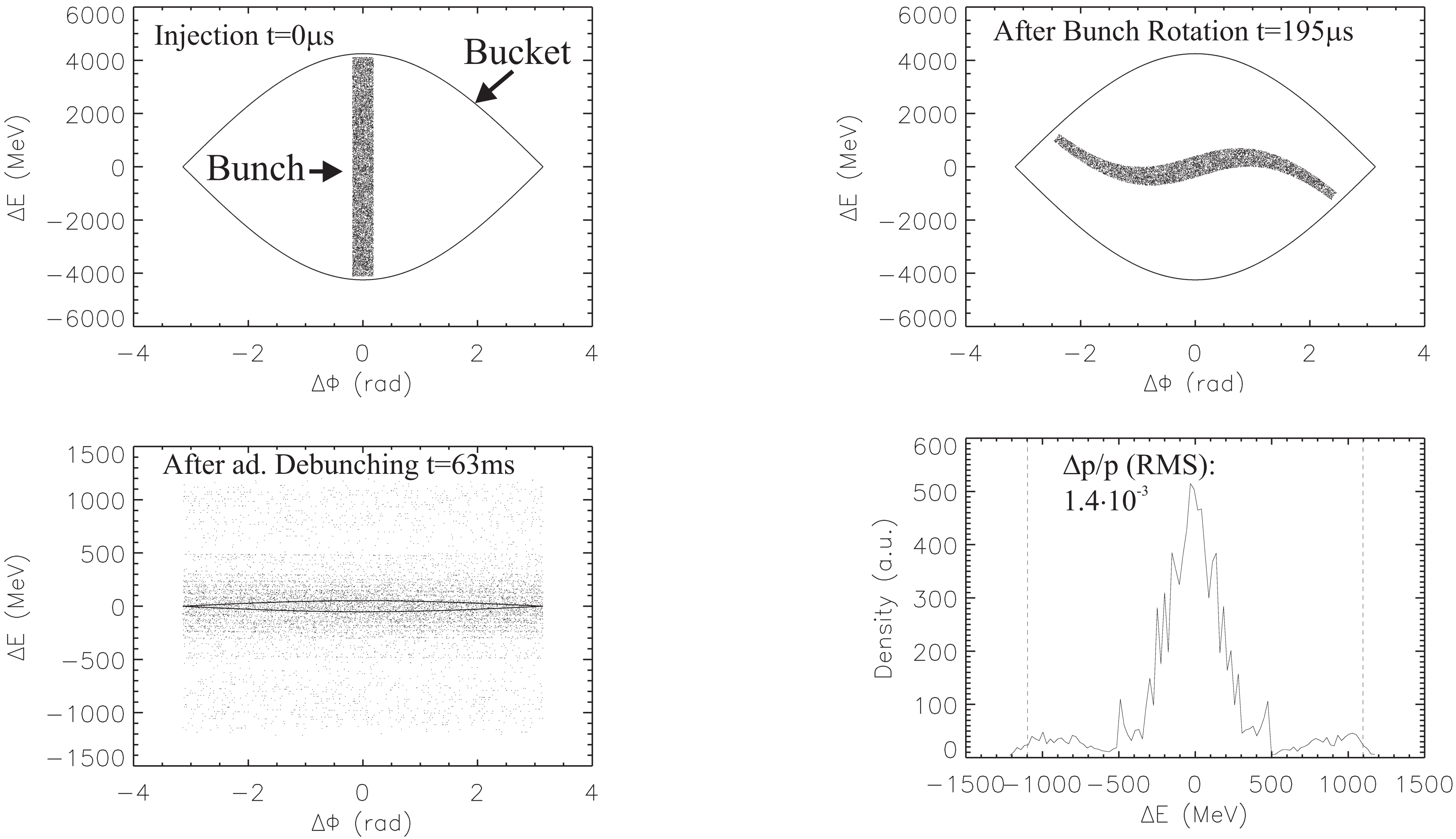
	$\bar{p}$	RIBs
Kinetic energy	3GeV	740MeV/u
Bunch length at injection[+]	±25 ns	±25 ns
Maximum relative momentum width at injection[+]	±3%	±1.5%
Target relative momentum width after debunching	±0.7%	±0.4%
Relative momentum spread after SC[++]	±0.1%	±0.05%

[+] Maximum values of a uniformly distributed rectancular ensemble

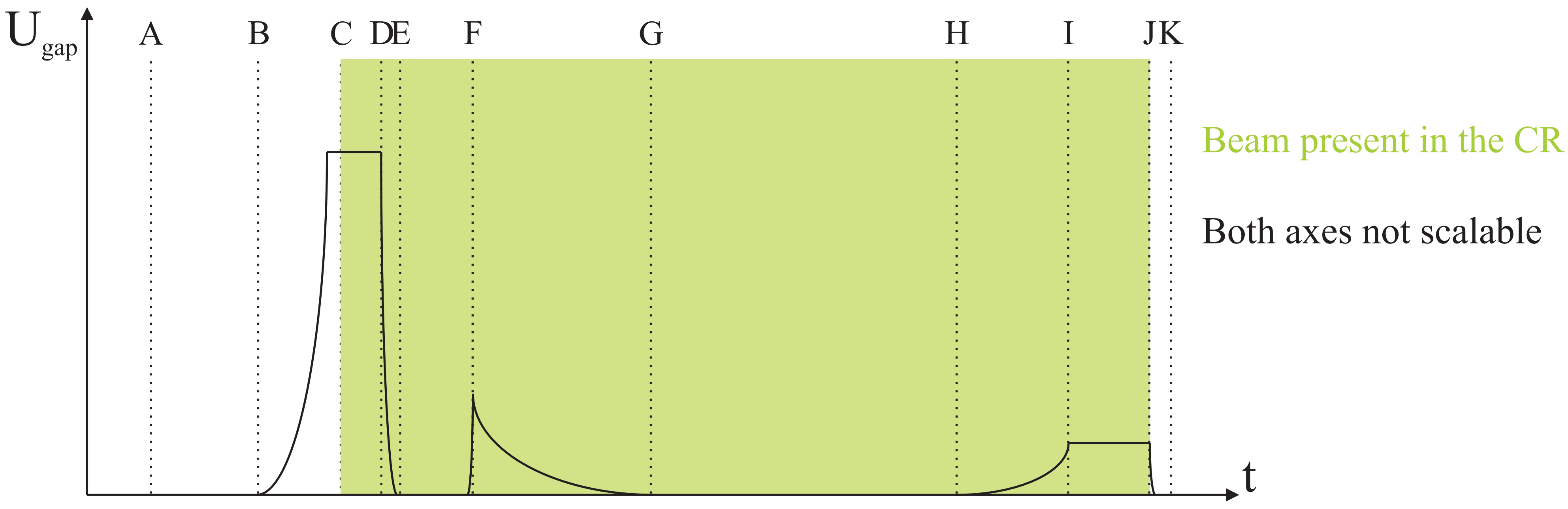
[++] Gaussian distribution, 2σ value

Longitudinal Beam Dynamics Rare Isotopes

740MeV/u $^{238}U^{88+}$, bunchlength 50ns, $\Delta p/p_{max}$=±1.5%, S=216.25m, η=0.17 , 10000 macro particles, 200kV during bunch rotation, 10kV to 30V during ad. debunching



System Requirements
Reference Cycle



A	Start of cycle, working point starts to shift from continuous to pulsed operation
B	Working point for pulsed operation established. Start of voltage rise for pulsed operation
C	Pulsed voltage achieved and settled. Injection into CR. Start of bunch rotation
D	End of bunch rotation
E	Pulsed voltage turned off. Working point starts to shift from pulsed to continuous operation
F	Working point for continuous operation established. Start of adiabatic debunching
G	Adiabatic debunching completed. Start of stochastic cooling
H	Stochastic cooling finished. Start of adiabatic rebunching
I	Adiabatic rebunching completed
J	Extraction from CR
K	Cycle ends

System Requirements Summary

Bunch rotation ⇒ pulsed operation, high voltages
Adiabatic de-/rebunching ⇒ continuous operation, moderate voltages

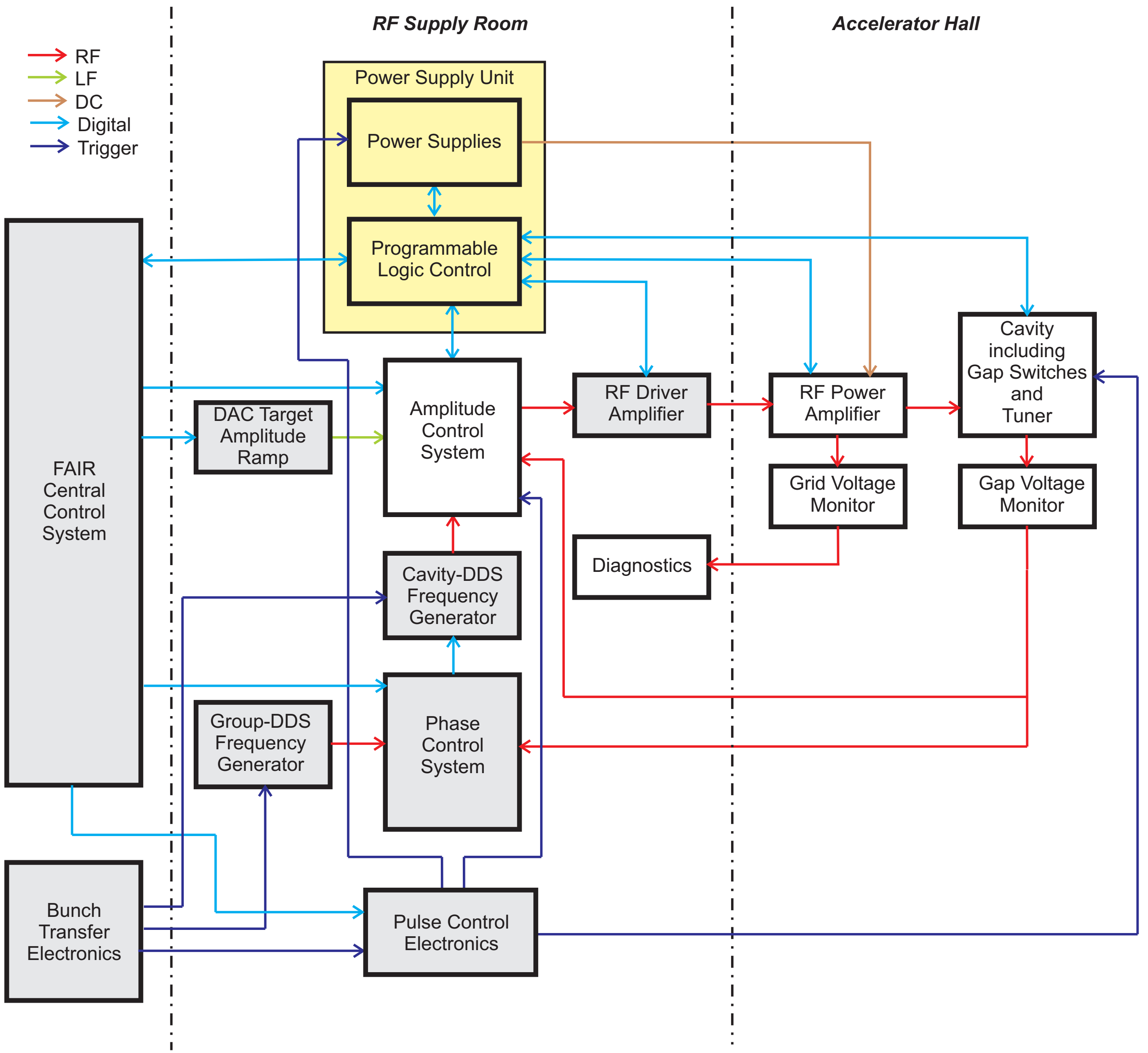
A total of five (ten) RF stations will be installed in the western straight section of the CR.

Requirements imposed on one RF station:

	$\bar{p}$ operation	RIB operation
Frequency (MHz)	1.10< f ≤ 1.50	1.10< f ≤ 1.25
Gap voltage in c.w. operation (kV)	0.03 to 1.35	0.03 to 2
Gap voltage in pulsed operation (kV)	0.5 to 21	0.5 to 40
Maximum duty cycle in pulsed operation	$1.5\cdot10^{-4}$ ($2.6\cdot10^{-4}$)	$2\cdot10^{-4}$ ($6\cdot10^{-4}$)
Maximum pulse duration (μs)	1000 (1300)	200 (600)
Maximum repetition rate (Hz)	0.2	1
Time for transition pulsed ↔ c.w. operation (μs)	<400	<400
Time for full sweep of the operating frequency (s)	<180	
Aperture of the beam pipe, circular diameter (mm)	150 (CF160)	
Available installation length, flange to flange (m)	1.125	
Available installation width (m)	1 (inwards), 0.75 (outwards)	
Available installation height (m)	ground level up to 2.2	
Height of beam axis (m)	1.4	
Pressure of beam pipe (mbar)	$\leq 1\cdot10^{-9}$	

Values in parenthesis denote full RF cycle

Collector Ring Debuncher System Overview

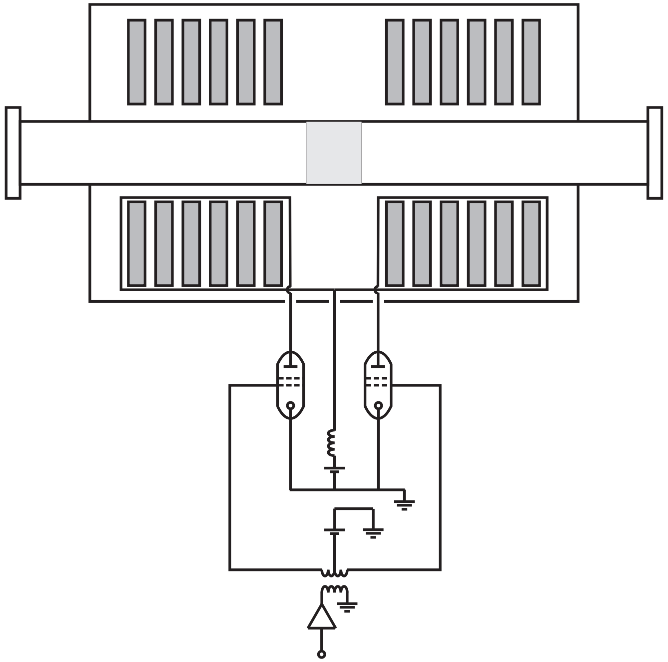


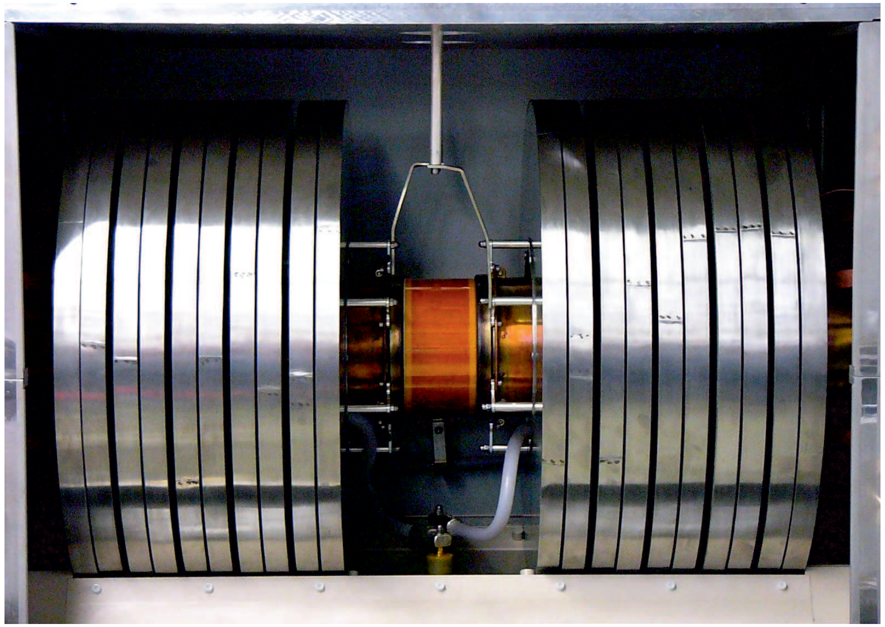
Main system components:

- Cavity including relays, fast switches, gap voltage monitor
- Power amplifier including grid voltage monitor
- Power supply unit (anode, control grid, screen grid, filament) including PLC
- Amplitude control loop including PCE (pulse control electronics)
- Driver amplifier
- Group-DDS, Cavity-DDS, phase control system
- FAIR central control system including interfacing

Standardization

Cavity
Basic Design

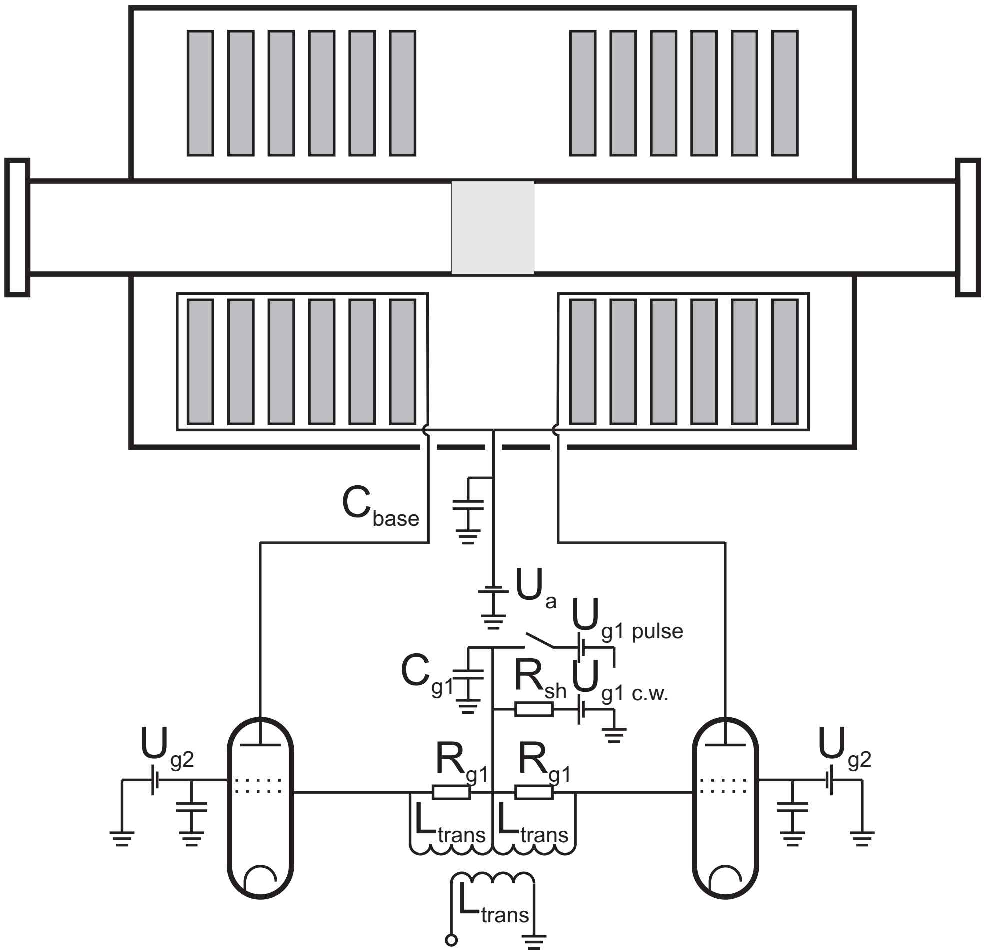




- Two inductively loaded coaxial quarter wave length resonators operating on a common gap
- Amorphous cobalt based magnetic alloy (MA), VitroVac6030F by VACUUMSCHMELZE
- Six ring cores per cavity half (total of 12)
- Forced air cooling of cavity
- Change of res. frequency by means of variable capacitors
- Inductive coupling of amplifier to cavity

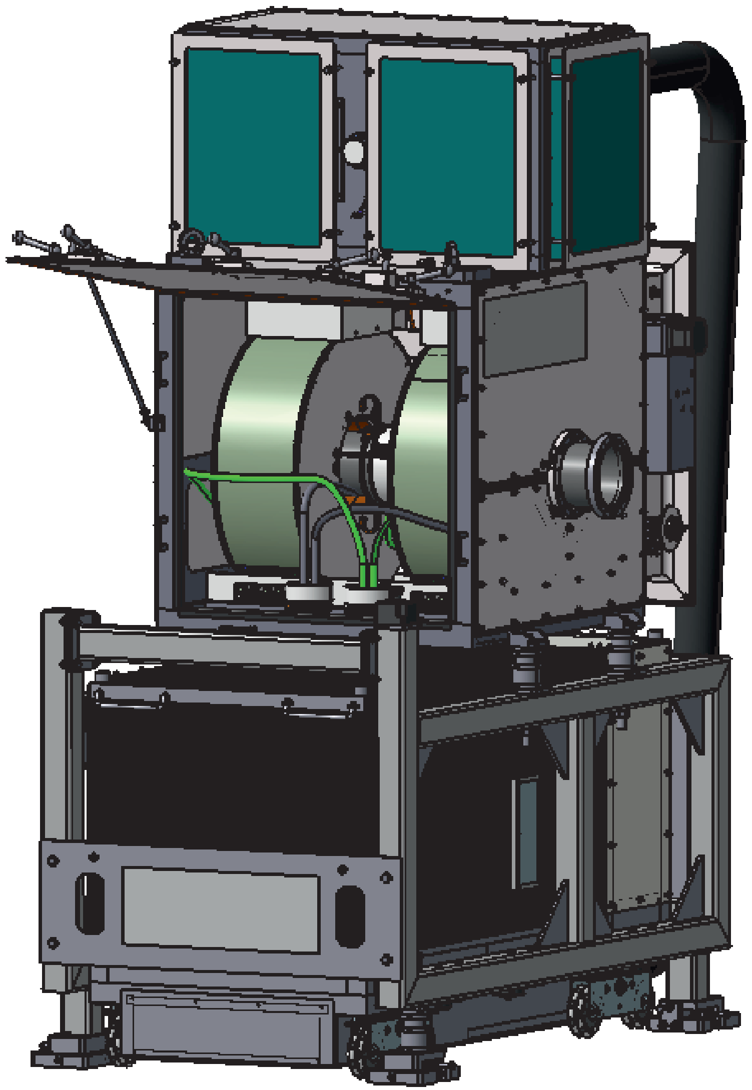
The CR DB will be similar to the existing SIS18 bunch compression cavity.
Design, construction, comissioning done by GSI.

Amplifier
Basic Design

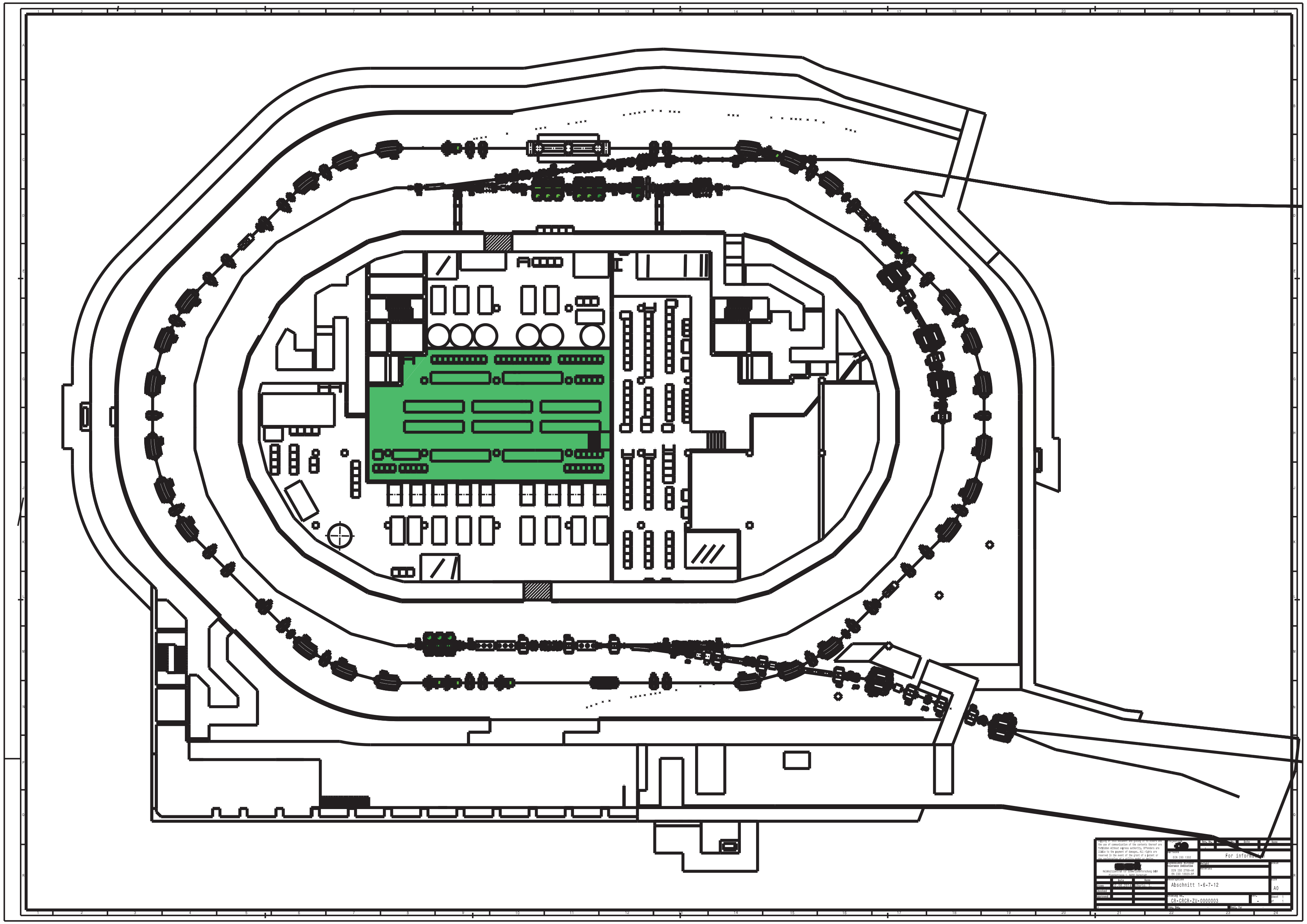


- Push-pull amplifier in class A operation
- Two THALES tetrodes TH555A in grounded cathode scheme
- Four different working points depending on mode of operation (pbar pulsed, pbar c.w., RIB pulsed, RIB c.w.)
  - Change of anode voltage and control grid voltage between pbar and RIB operation
  - Change of control grid voltage between pulsed and c.w. operation
- Common anode supply for both tubes
- Base capacitor to serve as energy storage for pulsed operation and to account for imperfect class A operation.
- Common control grid supply; the fast change in voltage will be realized by two separate power supplies and a DC switch
- Common input transformer for both tubes
- Two separate screen grid supplies, two separate filament supplies for both tubes (to adjust load lines of tubes with slightly different constant current lines)
- Amplifier will be built directly below the cavity
- Supply unit (including PLC), driver, LLRF equipment and diagnostics will be located in a supply room in the center of the CR

Collector Ring Debuncher System Sketch



Collector Ring Debuncher RF Installation Area



Collector Ring Debuncher External Interfaces

- Electrical requirements (voltages, frequency range, duty cycle,...) as listed in parameter list
- Installation space (accelerator hall and supply area)
- Appertur 150mm diameter
- Vacuum, CF160 flanges, beam pipe non bakeable
- Mains power (350kVA mean, 550kVA peak)
- Cooling air (open (28kW+7kW) and closed (18kW+0kW))
- Cooling water (180kW, 100l/min)
- Cables, cable routes
- Control system
- BuTiS

Project Structure

Work package structure:

PSP-Code	Description	EoI
2.5.4.1.1	Cavity, Amplitude Control, Power Amplifier	13b (GSI)
2.5.4.1.2	Driver Amplifier	13b (GSI)
2.5.4.1.3	Supply Unit	13b (GSI)
2.5.4.1.4	Digital Phase Control, Control System Interfacing	13b (GSI)
2.5.4.1.5	Digital Cavity Synchronization	13b (GSI)
2.5.4.1.6	Digital Gap Voltage Monitor, Gap Relays	13b (GSI)

- All CR Debuncher work packages are part of the German EoI
- Realization by GSI

Project Status I

General Contractor: Research Instruments, subcontractor Ampegon PPT

- Tasks:
  - System Design
  - Design and manufacturing of cavity
  - Design and manufacturing of power amplifier
- Contract awarded
- Technical Concept available
- Manufacturing documnets available (minor modifications required)
- Manufacturing of preseries cavity has started
- Next steps:
  - Intergration of preseries cavity and power amplifier at GSI (march/april 2015)
  - Integration of whole preseries RF system (June/July 2015)
  - SAT (July/August 2015)

Project Status II

Power supplies: OCEM

- Tasks:
  Design and manufacturing of power supply unit including PLC hard- and software
- Contract awarded
- Technical Concept available
- Detailing of all interfaces between power supply and he rest of the RF system ongoing
- Next steps:
  Engineering of anode modules
  Manufacturing of preseries power supply
  FAT of preseries power supply (May 2015)
  SAT of preseries power supply (June 2015)

Project Status III

Tubes: Thales
- Declaratiopn of no objection available
- Four tubes (TH555A) and two socktes ordered (delivery december 2014)

Driver amplifier: Barthel
- Preseries driver amplifier delivered (September 2013)

Gap periphery:
- Gap relais in procurment
- Optical voltage transmission for preseries available
- FOT for preseries available

Project Status IV

- Amplitude control loop: Some components available (e.g. detector, modulator, distribution amplifier,...), some components in development (amplitude controller, pulse forming electronics, pulse control electronics,..) Company: KTS GmbH, MEC GmbH, ...
- Phase control loop: Design and development completed, some components in procurement (PDFGEN, mixer); companies unknown
- Synchronization infrastructure: Specifications available, procurement starting soon; company unknown

Available Documents

- U. Laier, Technical Concept CR Debuncher, GSI Darmstadt (2011)
- J. Hottenbacher, CR Debuncher Conceptual Design Report, Reserach Instruments, Bergisch Gladbach (2013)
- U. Laier, Detailed Specification on the CR Debuncher, GSI,Darmstadt (2012)
- G. Blokesch, J. Hottenbacher, U. Laier, Detailed Specification on the CR Debuncher Power Supplies (2013).
- K. Dunkel, G. Blokesch et al, Set of Maufacturing Documents Cavity and Power Amplifier
- H. Klingbeil, Common Specification on FAIR RF Systems, GSI, Darmstadt (2012)
- R. Balss, S. Schaefer, Common Specification on Power Supply Units for RF Systems, GSI, Darmstadt (2012)
- R. Balss, S. Schaefer, Common Specification on PLC-Software for RF Systems, GSI, Darmstadt (2013)
- K.-P. Ningel, Common Specification on Electronic Componets for FAIR RF Systems, GSI, Darmstadt (2012)
- U. Laier, Common Specification on FAIR LLRF Cavity Control Systems for Ring RF-Systems, GSI, Darmstadt (2012)
- H. Klingbeil, Common Specification on LLRF Ring RF Systems, GSI, Darmstadt (2011)
- H.G. Koenig, P. Huelsmann, Common Specification on Gap Periphery for Ring RF Systems, GSI, Darmstadt (2012)
- K.-P. Ningel, Common Specification on Modular Driver Amplifiers for Ring RF Systems, GSI, Darmstadt (2011)

Appendix

Longitudinal Beam Dynamics Simulation Code

Bunch represented by an ensemble of macro particles.

Simulation of the evolution of particles in longitudinal phase space, using the recursive algorithm:

$$\Delta E_{n+1} = \Delta E_n + qV\left(\sin\phi_n - \sin\phi^{syn}\right)$$

$$\phi_{n+1} = \phi_n + \frac{2\pi h \eta}{\beta^2 E_{tot}} \Delta E_{n+1}$$

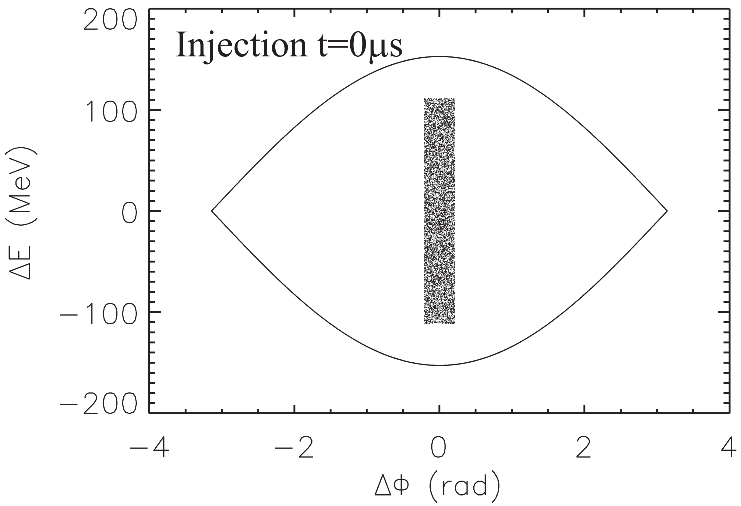
n	Number of turns
ΔE	Energy deviation with respect to the synchronous particle
q	Charge
V	Gap Voltage per turn
ϕ	Phase of the particle in reference to the RF
ϕ^{syn}	Phase of the synchronous particle
h	Harmonic number
η	Frequency slip factor
β	Relativistic β
E_{tot}	Energy of the synchronous particle

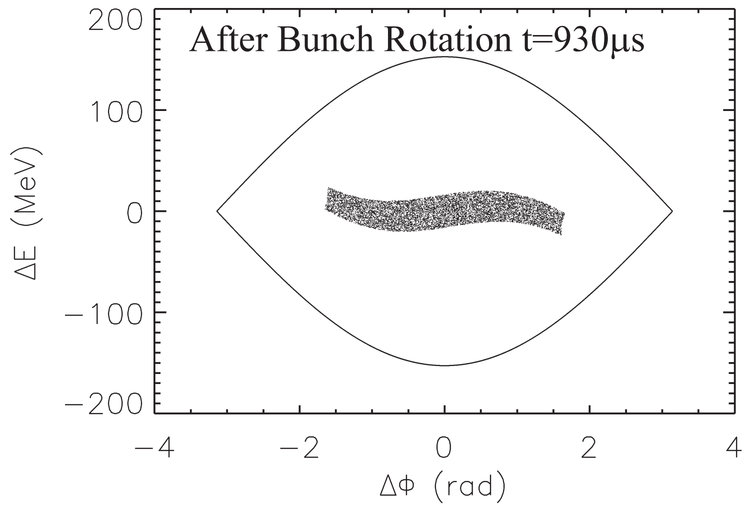
Approximations:

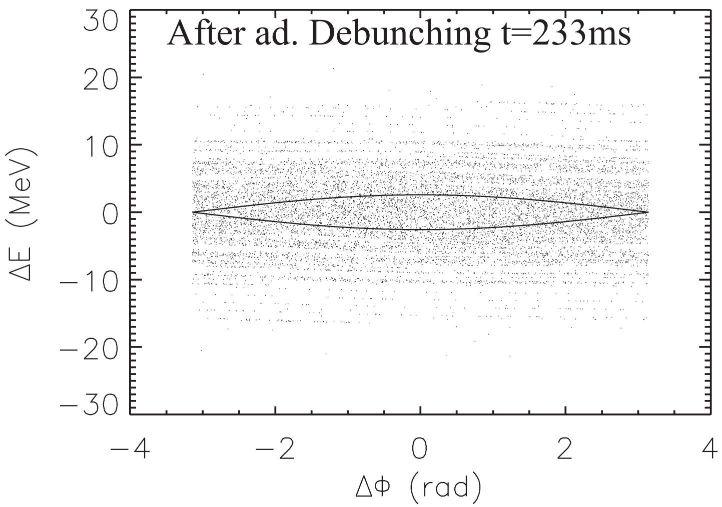
- Voltage per turn concentrated in a single gap ($f^{rev} >> f^{syn}$)
- Particle ↔ particle interactions neglected (low current)
- Particle ↔ surrounding interaction neglected (low current)

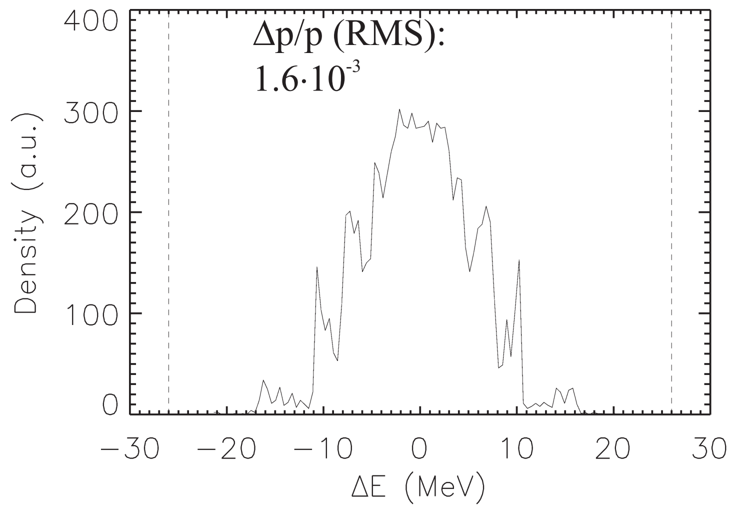
Longitudinal Beam Dynamics Antiprotons

3GeV pbar, bunchlength 50ns, $\Delta p/p_{max}=\pm 3\%$, S=216.25m, η=-0.10, 10000 macro particles, 105kV during bunch rotation, 5.5kV to 30V during ad. debunching

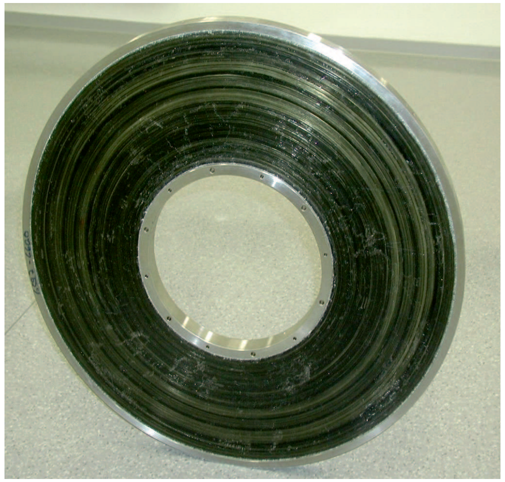




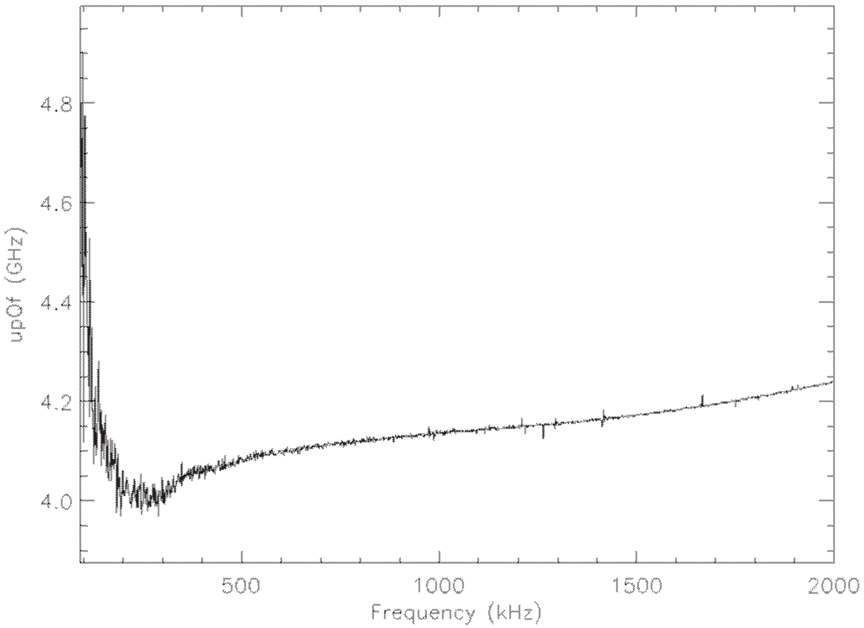




Cavity
MA Core Parameters

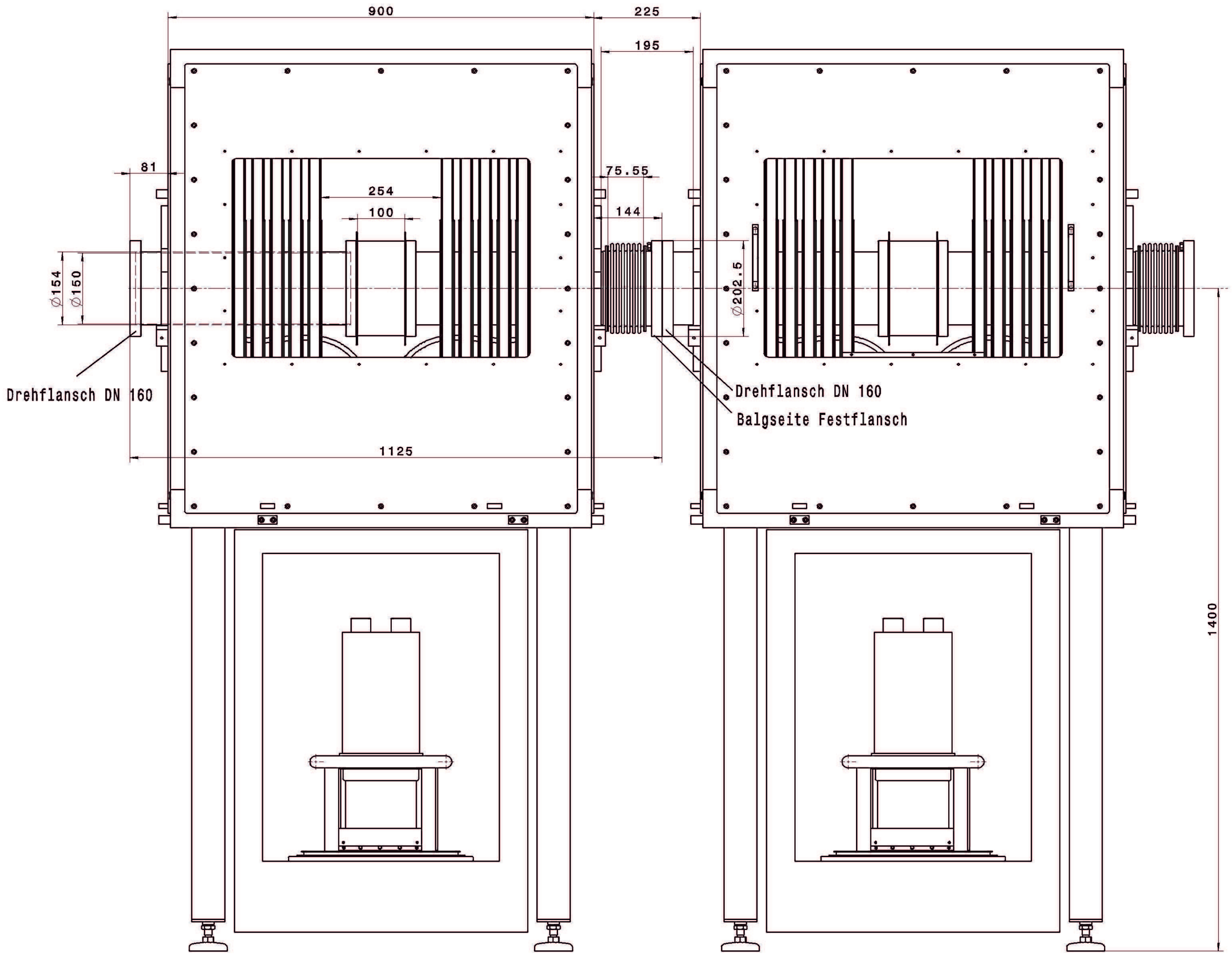


Thin ribbon of cobalt based magnetic alloy (VitroVac6030F) wound to a ring core. Manufactured at VACUUMSCHMELZE
Core stabilized by an inner ring of stainless steel.



Material	VitroVac6030F
Thickness of MA ribbon (μm)	17
Thickness of MgO isolation (μm)	2
Inner radius r_{in} (cm)	145
Outer radius r_{out} (cm)	313
Width h (mm)	25
Flux area (m^2)	$4.3 \cdot 10^{-3}$
Filling factor η	0.70
Serial inductivity L_s (μ H)	4.2-4.0
Serial resistance R_s (Ω)	10.5-13.5
Parallel inductivity L_p (μ H)	4.7
Parallel resistance R_p (Ω)	101
Q-value	2.9-2.5
$\mu_p Qf$ value (GHz)	4.1

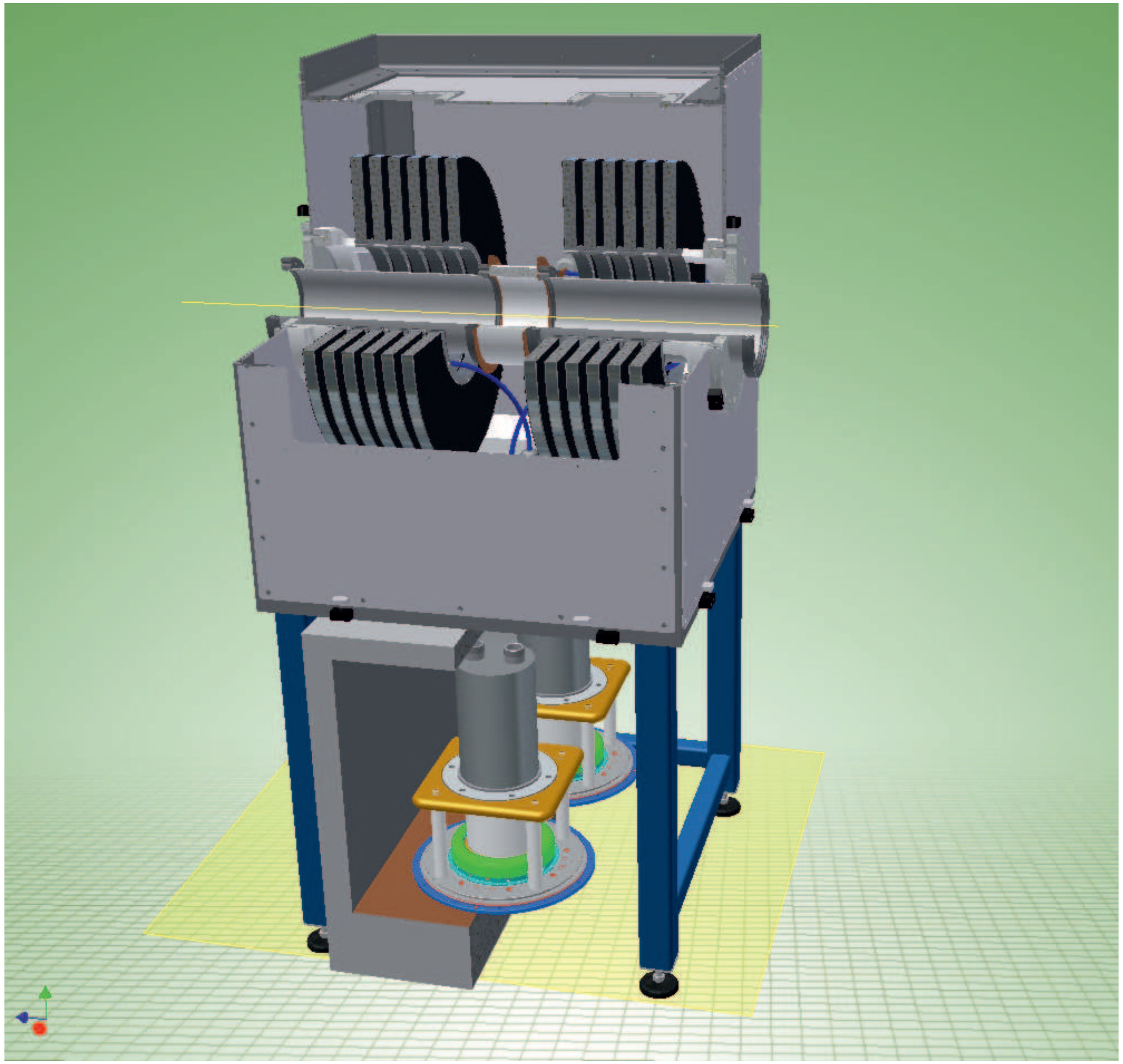
Cavity
First Sketch



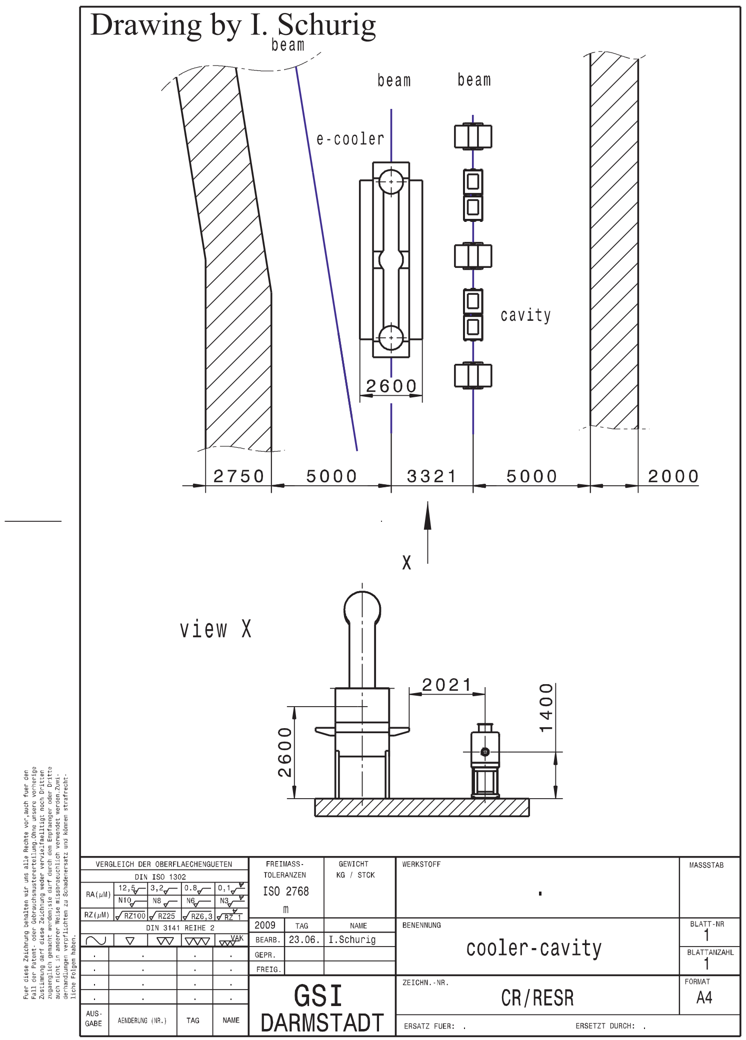
GSI

Collector Ring Debuncher Installation

Preliminary sketch of cavity/amplifier



Installation in CR building (#7)



Organisational Aspects
Project Outlook I

- Detailed time schedule including milestones, budget and resources available on the GSI MS Project Server
- Main contract:
  - Preseries components (Cavity, amplifier) manufactured: Q1/15
  - Preseries system integrated: Q2/15
  - Preseries system optimized, approved: Q3/15
  - Series components manufactured: Q4/16
- Tubes:
  - Preseries tubes, tube sockets delivered: Q4/14
  - Series tubes, tube sockets: Q2/16

Organisational Aspects
Project Outlook II

- Power supply units:
  Preseries power supply FAT/SAT: Q2/15
  Series power supply: Q1/17
- Driver amplifier:
  Series driver: Q3/15