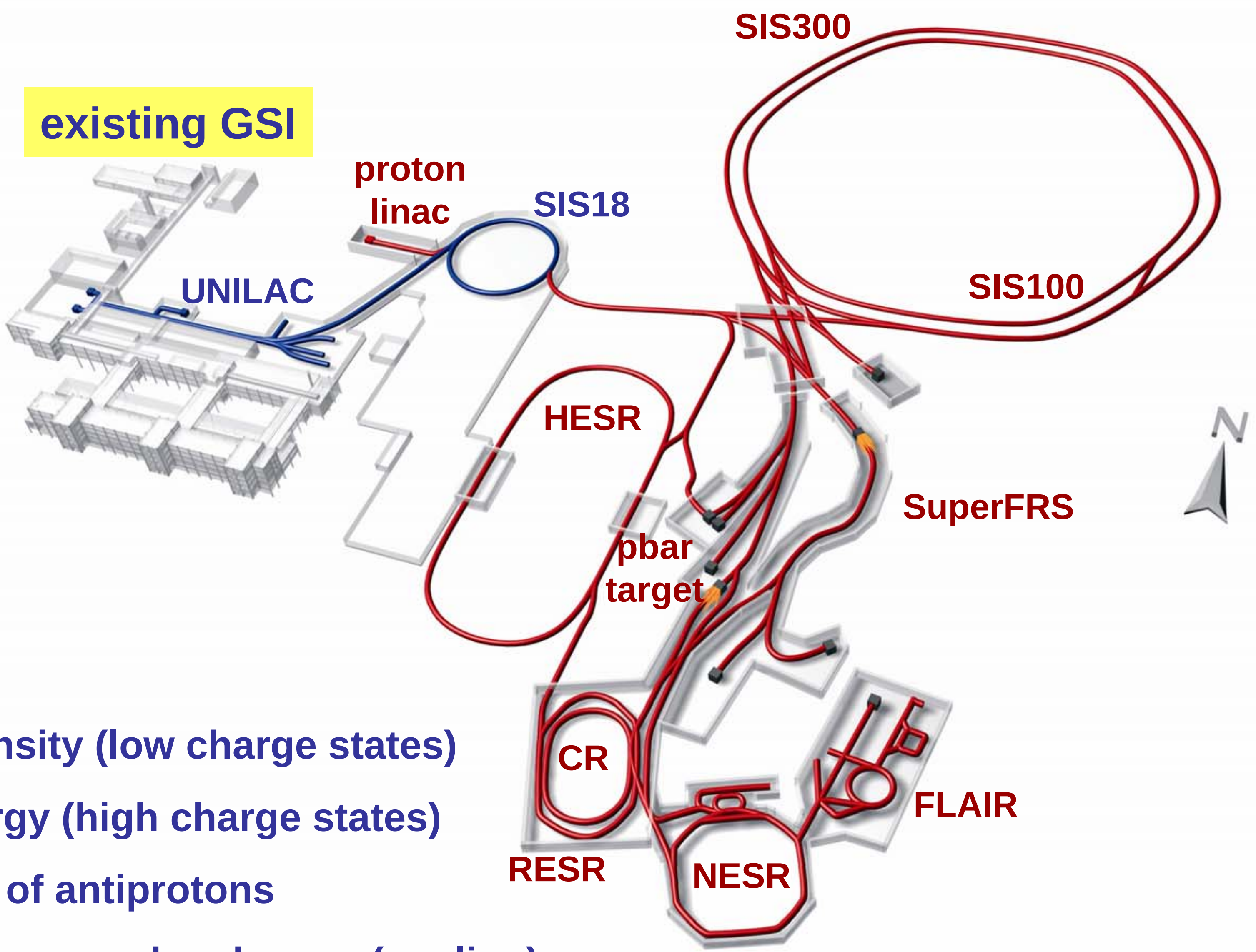
# The FAIR Accelerator Facility




goals:

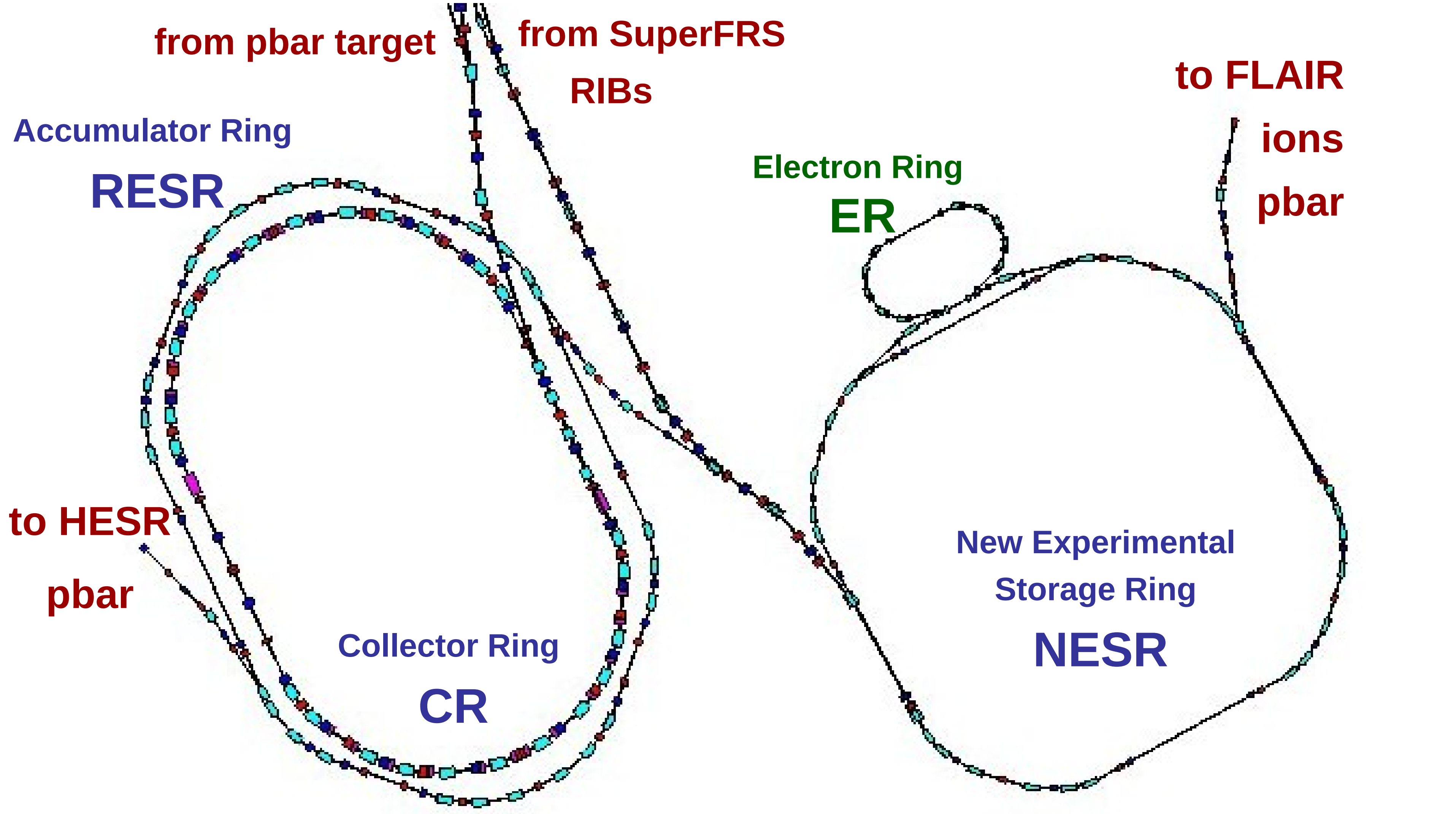
higher intensity (low charge states)

higher energy (high charge states)

production of antiprotons

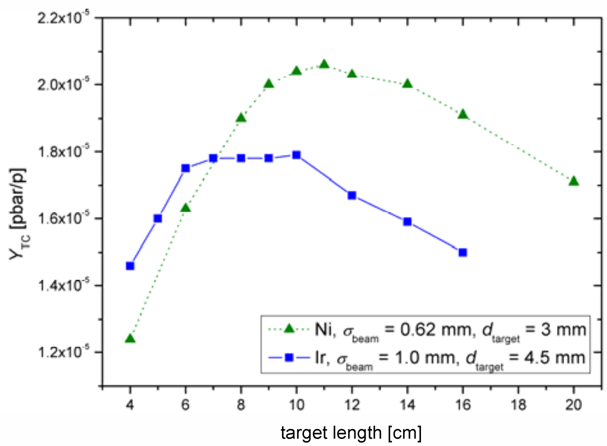
high quality secondary beams (cooling)

# The FAIR 13 Tm Storage Rings

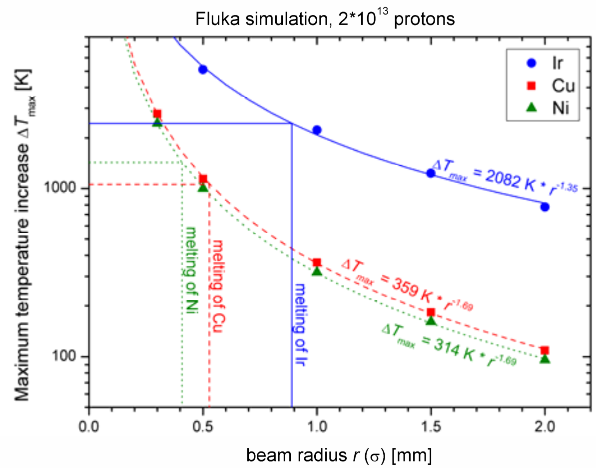


# Antiproton Target and Separator

## production rate of antiprotons

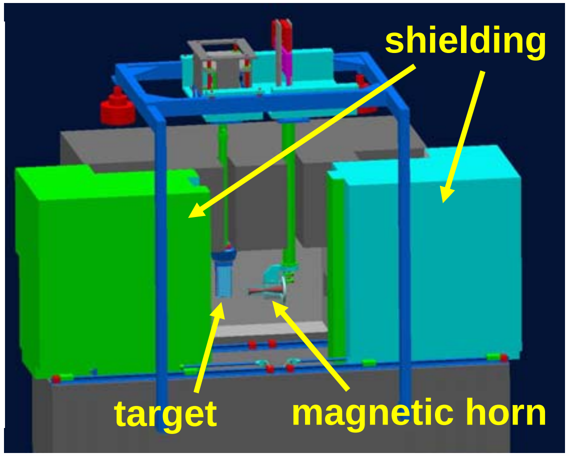



## temperature of target

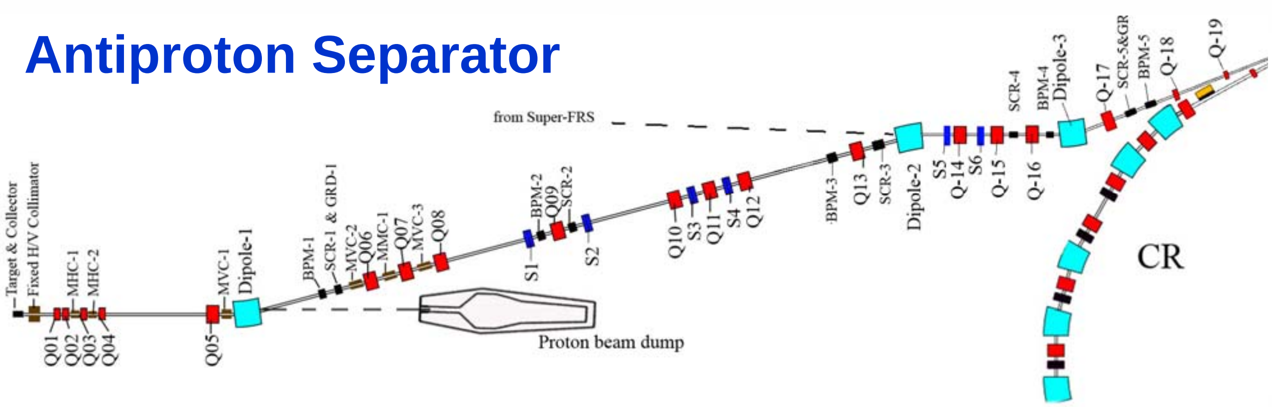


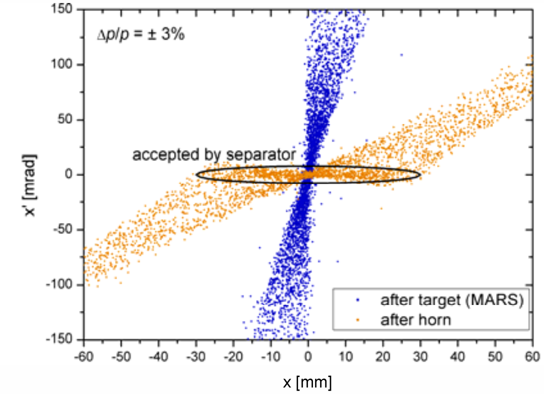

## target station

shielding and handling




## Antiproton Separator

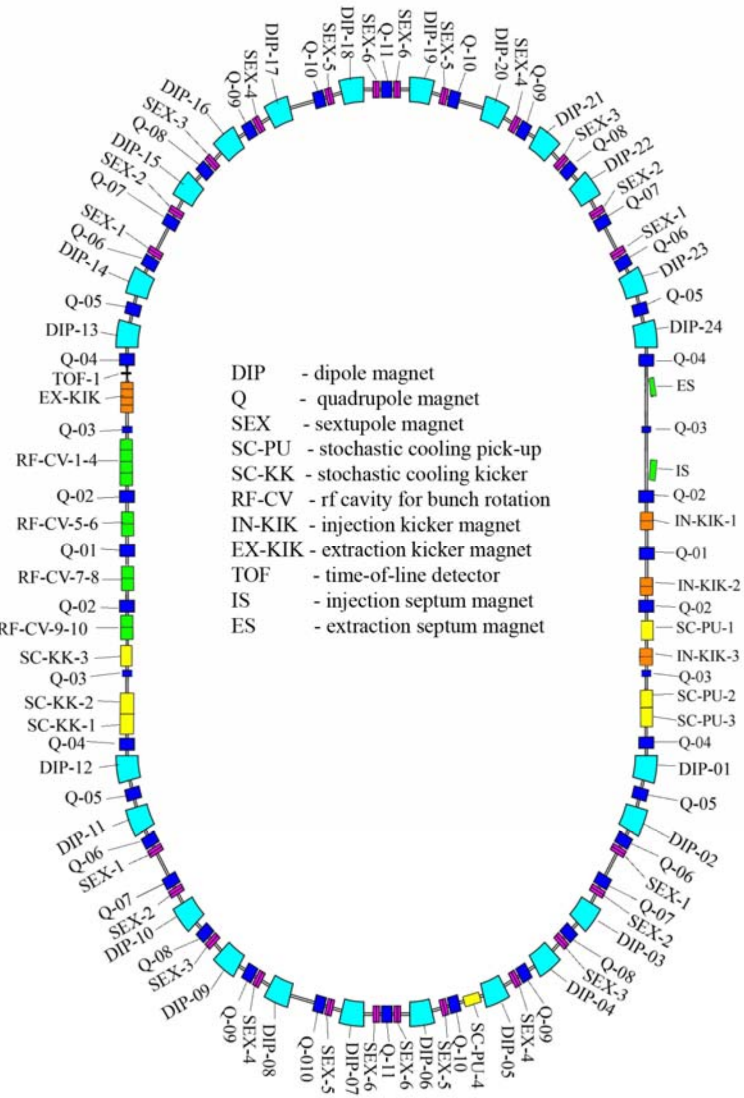



according to tracking calculations about 70 % of the produced antiprotons will be stored in the CR

*M. Steck, EPAC08, Genua, 23 – 27 June 2008.*

# The Collector Ring CR




| | |
|---|---|
| **circumference** | **216 m** |
| **magnetic bending power** | **13 Tm** |
| **large acceptance** | $\varepsilon_{x,y}$ **= 240 (200) mm mrad** |
| | $\Delta p/p = \pm 3.0\ (1.5)$ **%** |

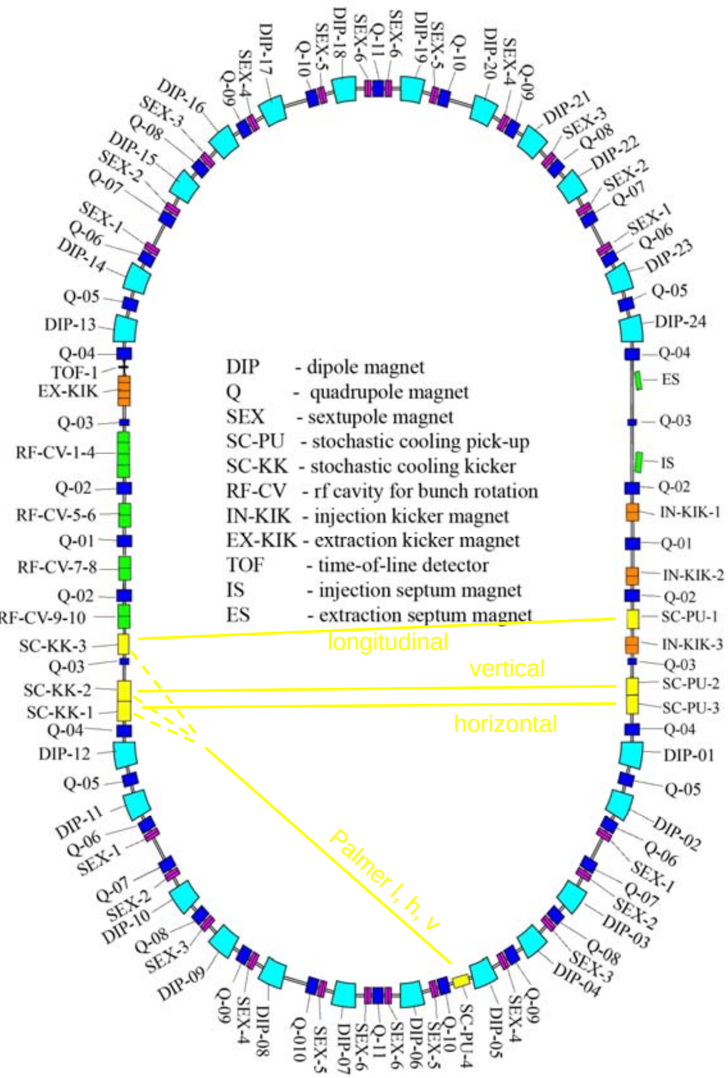
**fast stochastic cooling (1-2 GHz)**
**of antiprotons (10 s) and**
**rare isotope beams (1.5 s)**

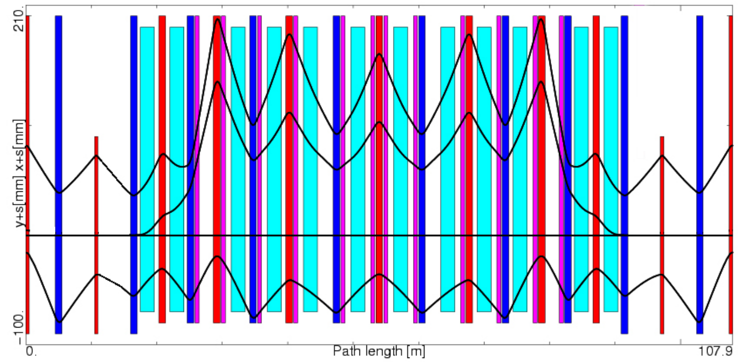
*fast bunch rotation at h=1*
*with rf voltage 200 kV*
*adiabatic debunching*

*optimized ring lattice (slip factor)*
*for proper mixing*
*large acceptance magnet system*

**additional feature:**
**isochronous mass measurements**
**of rare isotope beams**

# Ion Optical Modes of the CR



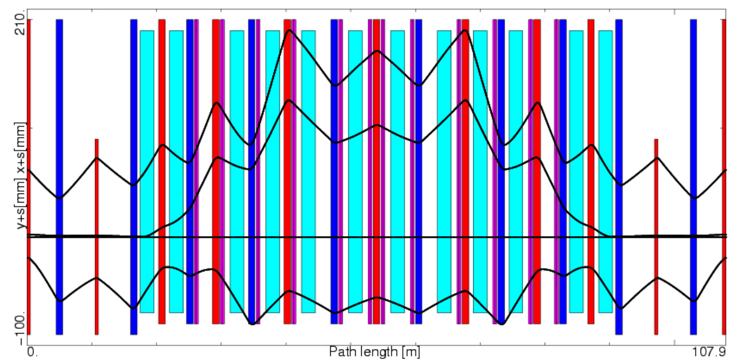




## antiprotons

$Q_x = 4.26$, $Q_y = 4.84$

$\gamma_t = 3.7$

$\eta = -0.016$

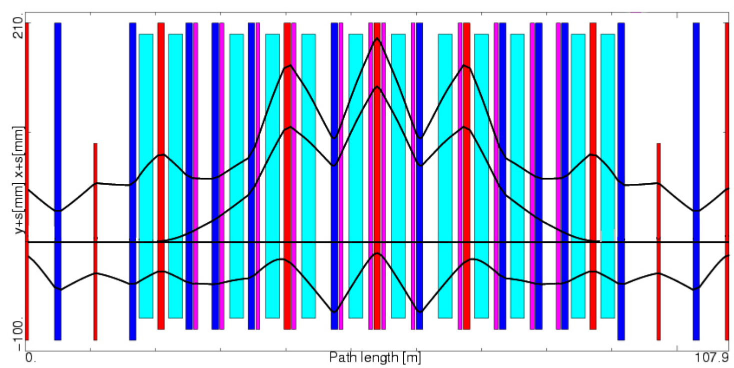



## RIBs

$Q_x = 3.21$, $Q_y = 3.71$

$\gamma_t = 2.8$

$\eta = +0.185$




## isochronous

$Q_x = 2.33$, $Q_y = 4.64$

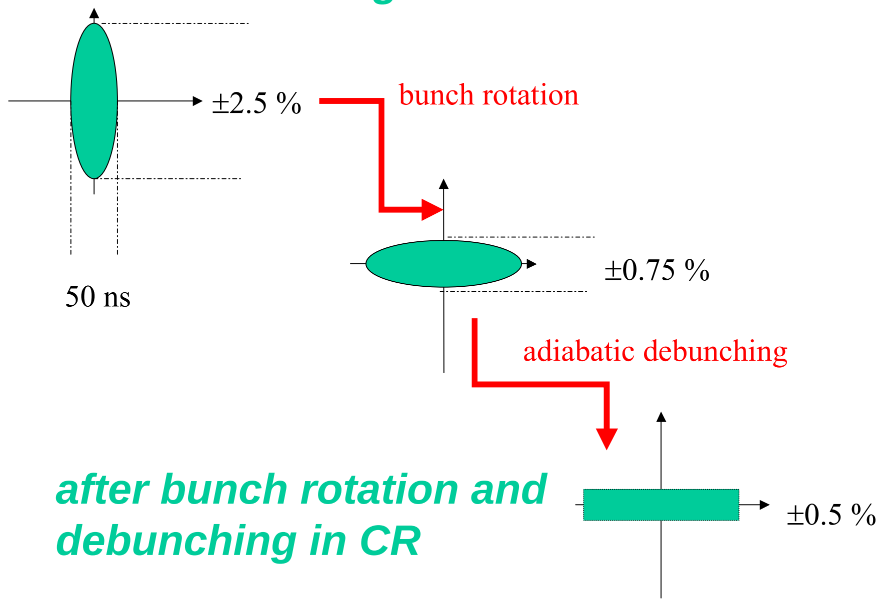
$\gamma_t = 1.67\text{-}1.84$

$\eta = 0$

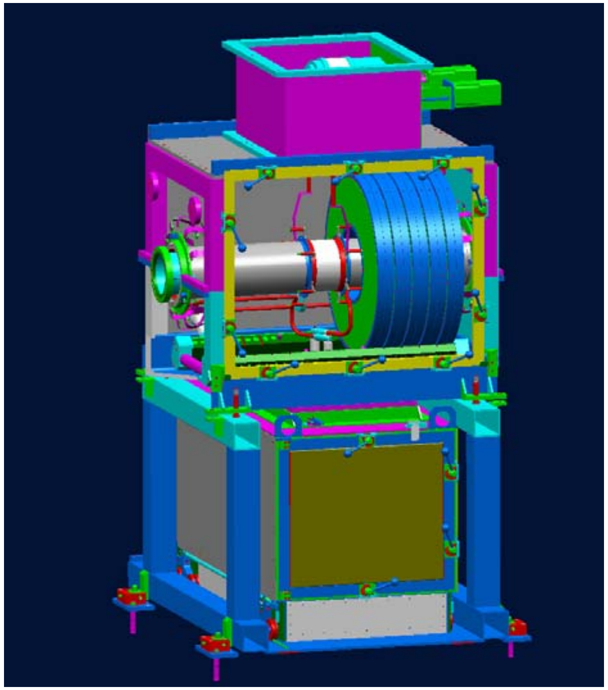
# Fast Bunch Rotation in CR

**Fast bunch rotation of SIS100 bunch**
**to provide optimum initial parameters**
**for stochastic cooling**
**total rf voltage 200 kV at h=1 reduces**
**the momentum spread (2.5→ 0.5 %)**
**after passage of production target**

***SIS100 bunch after target***




***after bunch rotation and debunching in CR***

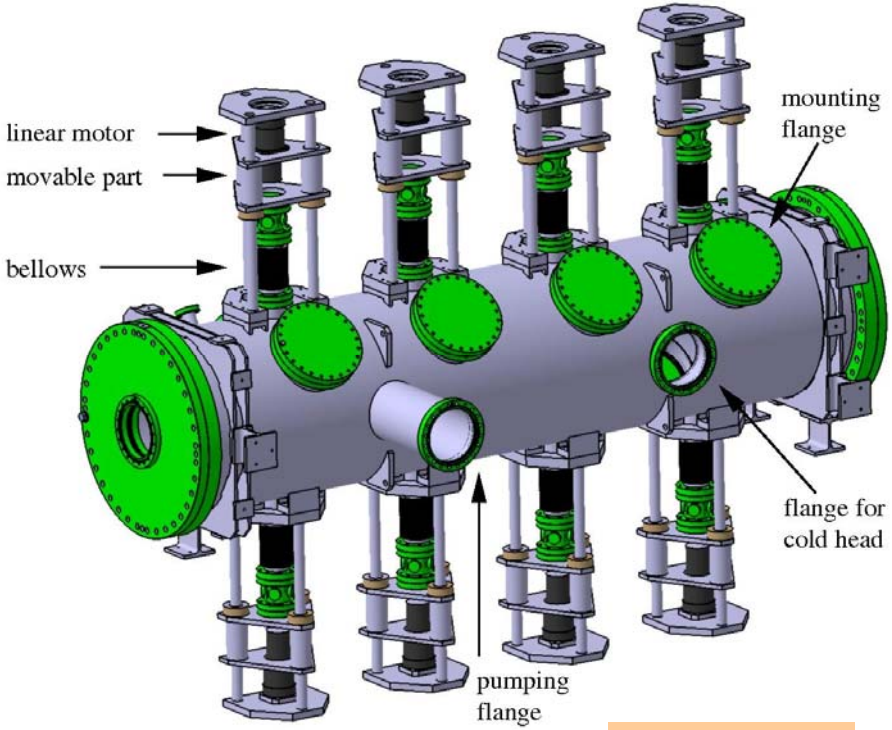


**bunch rotation cavity**
**(*SIS18 bunch compressor*)**

**voltage 40 kV**
**length 1 m**
**frequency range 1.18 – 1.38 MHz**
**rotation time ~ 100 μs**

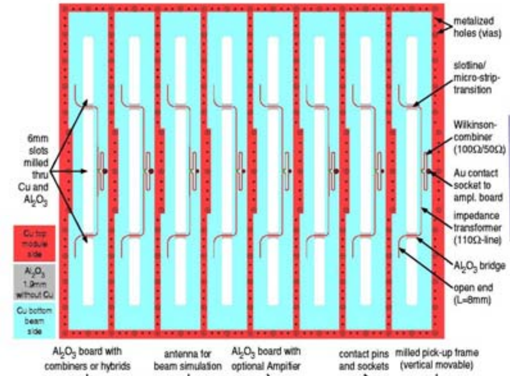
# Stochastic Cooling Developments

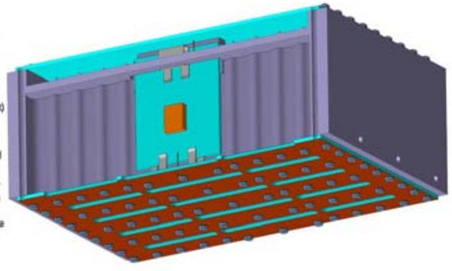
**vacuum tank**
**with actuators for electrode movement including cold heads (20 K) and cooled pre-amplifiers**

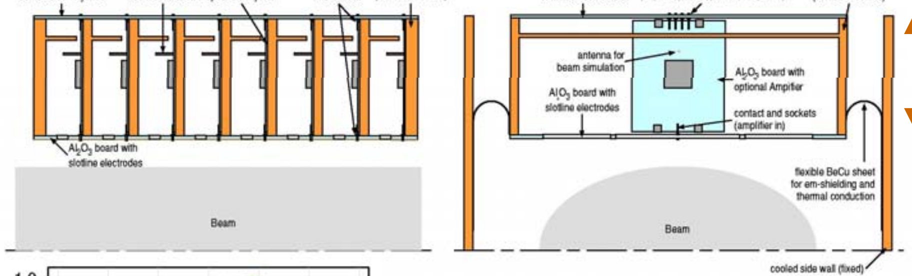


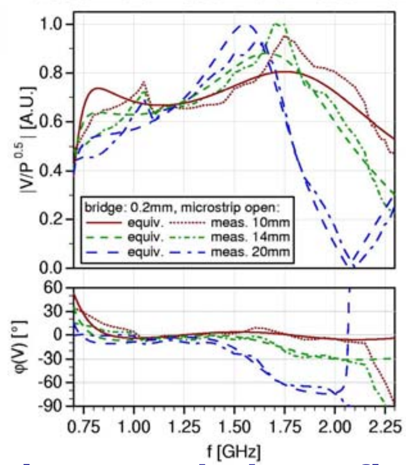

for details: **THPP051**

**electrode +amplifiers**

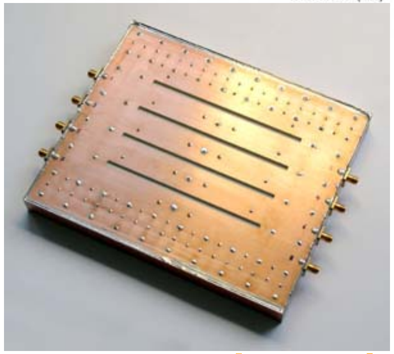




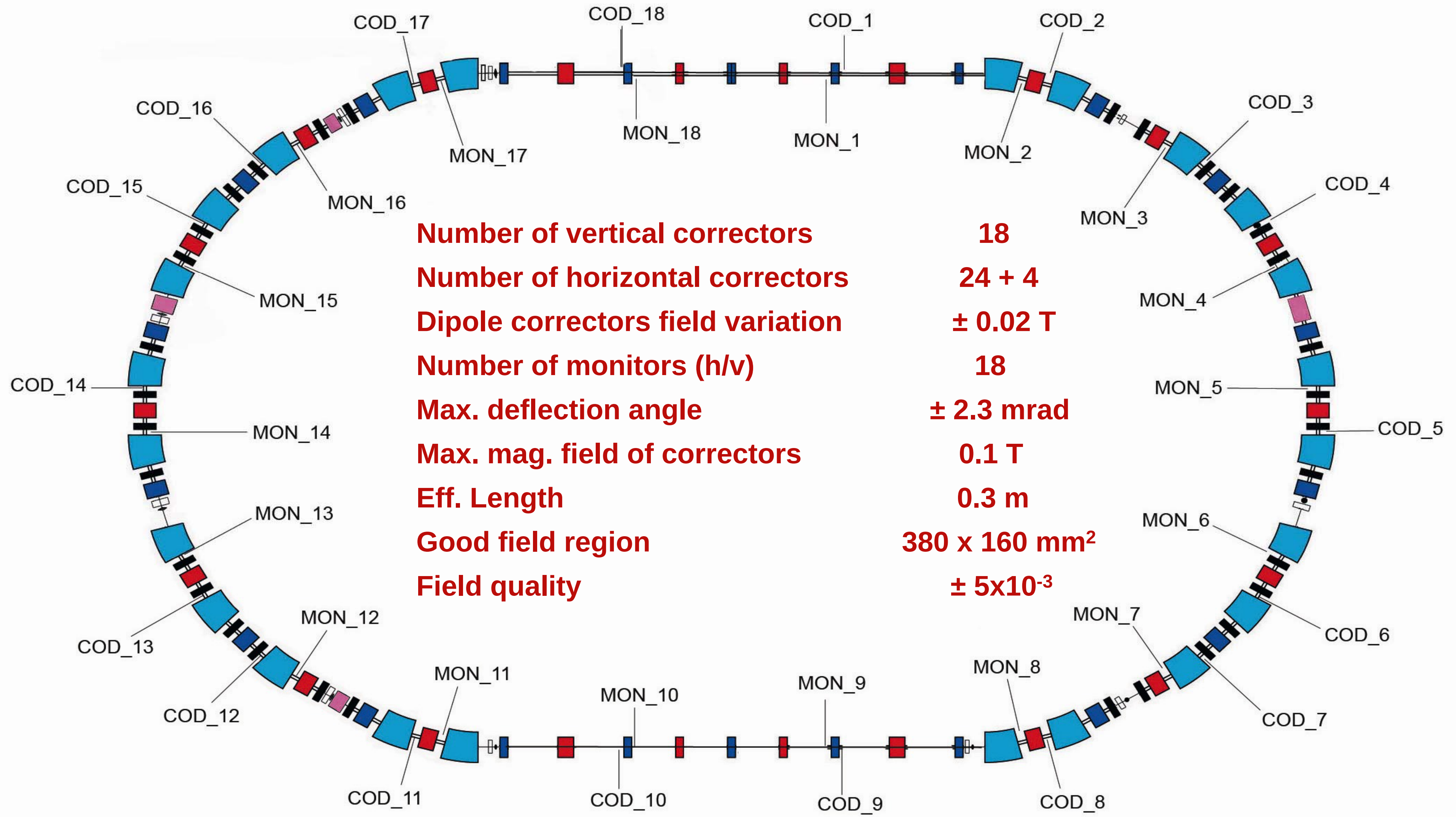




**voltage and phase flatness**



**prototype electrode (ß = 0.83-0.97)**

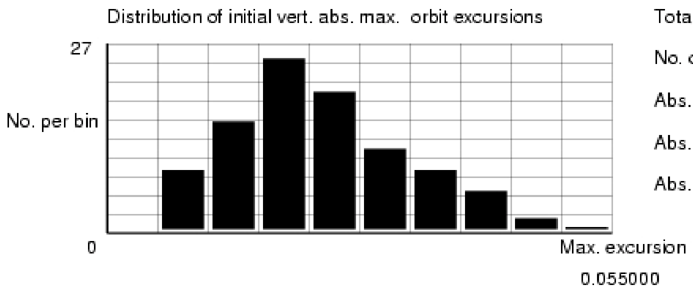
# CR Closed orbit correction




| | |
|---|---|
| **Number of vertical correctors** | **18** |
| **Number of horizontal correctors** | **24 + 4** |
| **Dipole correctors field variation** | **± 0.02 T** |
| **Number of monitors (h/v)** | **18** |
| **Max. deflection angle** | **± 2.3 mrad** |
| **Max. mag. field of correctors** | **0.1 T** |
| **Eff. Length** | **0.3 m** |
| **Good field region** | **380 x 160 $mm^2$** |
| **Field quality** | **± $5x10^{-3}$** |

# CR Closed orbit correction

## MAD and WINAGILE simulations



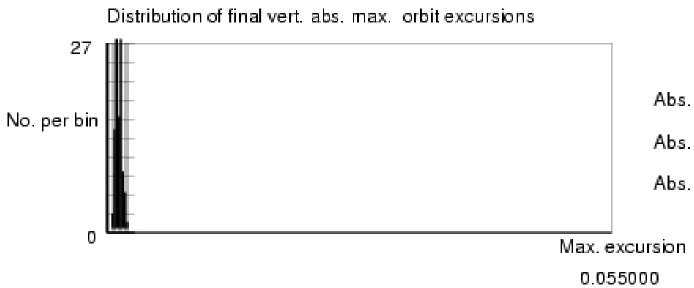

Total no. of orbits in sample 100

No. of correction failures 0

Abs. max. initial excursion [m] 0.051265

Abs. av. initial excursion [m] 0.023751

Abs. RMS initial excursion [m] 0.009816




Abs. max. final excursion [m] 0.002722

Abs. av. final excursion [m] 0.001632

Abs. RMS final excursion [m] 0.000432

**Alignment rms errors used in tracking studies**

| Element | Δx [mm] | Δy [mm] | Δz [mm] | Roll [mrad] |
|---|---|---|---|---|
| Dipole | 0.2 | 0.2 | 0.5 | 0.5 |
| Quadrupole | 0.2 | 0.2 | 0.3 | 0.5 |
| Sextupole | 0.2 | 0.2 | 0.3 | 0.5 |

**Closed orbit excursions before correction**

| | PBAR | | RIB | | ISO | |
|---|---|---|---|---|---|---|
| | hor | ver | Hor | ver | hor | ver |
| $\Delta X_{max}$ [mm] | 17.22 | 20.93 | 42.17 | 51.06 | 17.07 | 15.19 |
| $\Delta X_{average}$ [mm] | 9.76 | 11.57 | 14.71 | 23.75 | 10.71 | 8.64 |

**Closed orbit excursions after correction**

| | PBAR | | RIB | | ISO | |
|---|---|---|---|---|---|---|
| | hor | ver | hor | ver | hor | ver |
| $\Delta X_{max}$[mm] | 3.07 | 2.52 | 1.40 | 2.64 | 0.45 | 0.92 |
| $\Delta X_{average}$ [mm] | 1.10 | 1.20 | 0.81 | 1.34 | 0.25 | 0.46 |

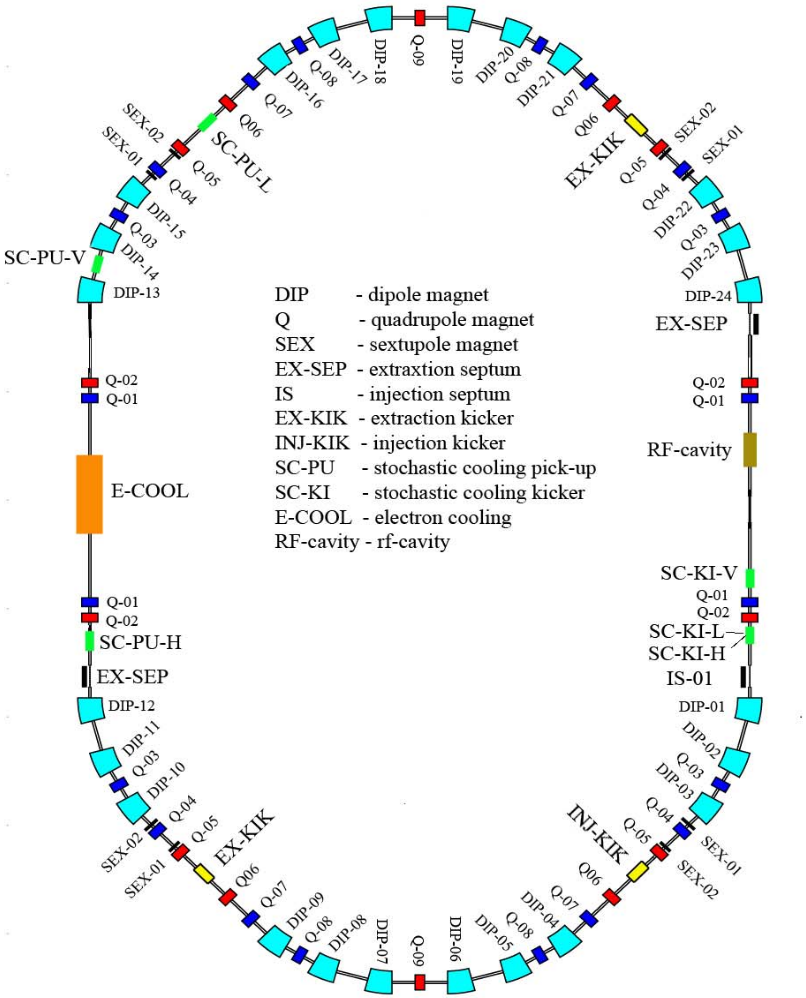
Before correction
The most probable COD ≈ 20 mm

After correction
The most probable COD ≈ 1 mm

Orbit corrections are important for optimum stochastic cooling

# RESR

## The Antiproton Accumulator Ring




| | |
|---|---|
| **circumference** | **240 m** |
| **magnetic bending power** | **13 Tm** |
| **tunes $Q_x/Q_y$** | **3.12/4.11** |
| **momentum acceptance** | **±1.0 %** |
| **transverse accept. h/v** | **$25\times10^{-6}$ m** |
| **transition energy** | **3.3-6.4** |

**accumulation of antiprotons by a combination of rf stochastic cooling**

*max. accumulation rate 3.5 (7)×$10^{10}$/h*

*max. stack intensity ~ 1 × $10^{11}$*

***additional mode:***
***fast deceleration of RIBs to a minimum energy of 100 MeV/u for injection into NESR (collider mode)***

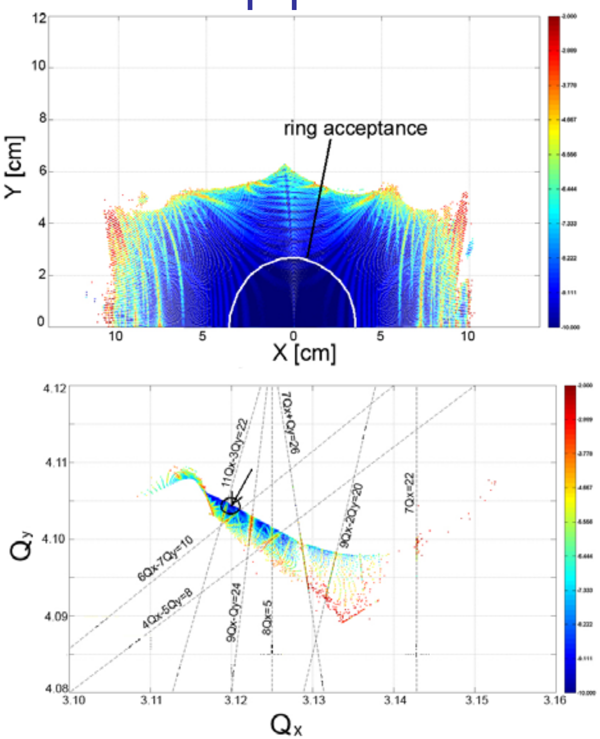
# Dynamic Aperture Calculations

**$Q_x$ = 3.11, $Q_y$ =4.12**

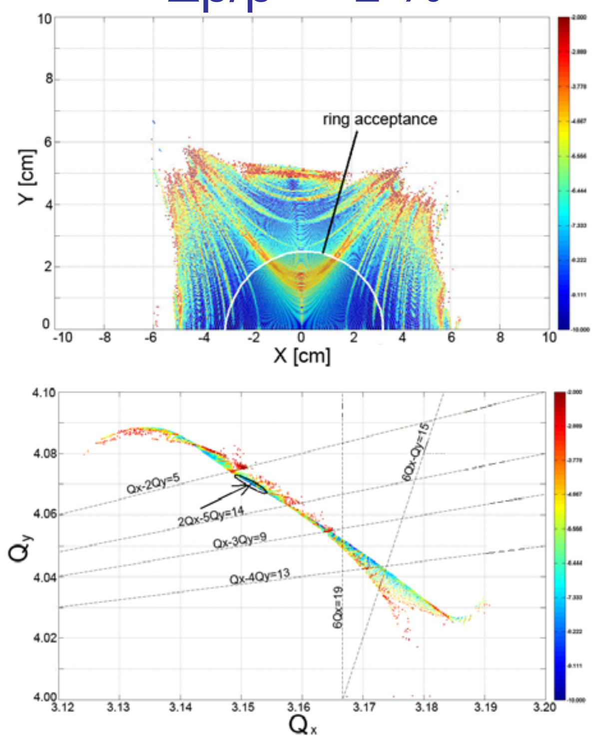
field errors

| Harmonic order | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Dipole | 0 | 0.12 | 0 | -0.016 | 0.0 | 0.017 | 0 | -0.001 | 0 |
| Quadrupole | 0 | 4.0 | 2.8 | 3.0 | 14.0 | 1.8 | 2.5 | 1.0 | 2.0 |
| Sextupole | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.0 | 0 |

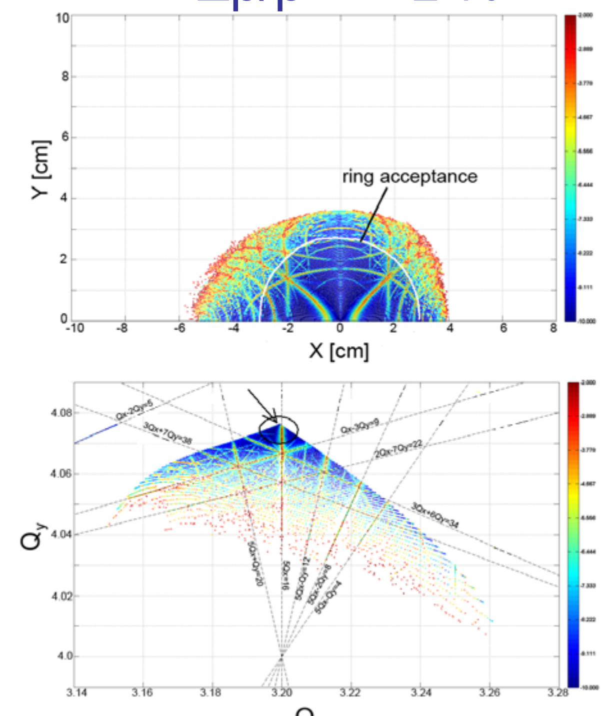
$\Delta p/p = 0$




$\Delta p/p = -1$ %

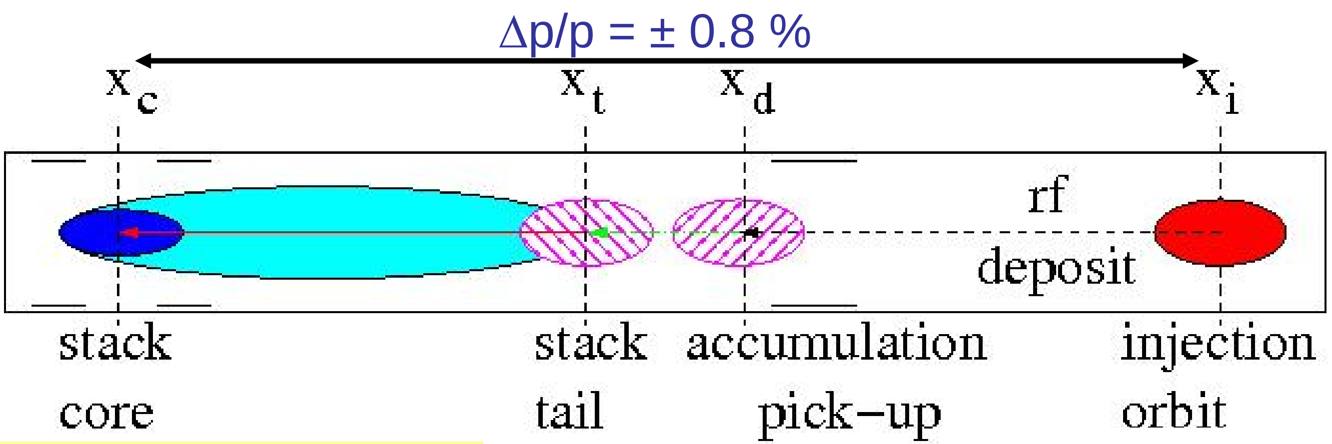



$\Delta p/p = +1$ %




**Frequency Map Analysis** *calculated with PTC code (MAD)* for details: **THPC011** **THPC057**

# Antiproton Accumulation in RESR



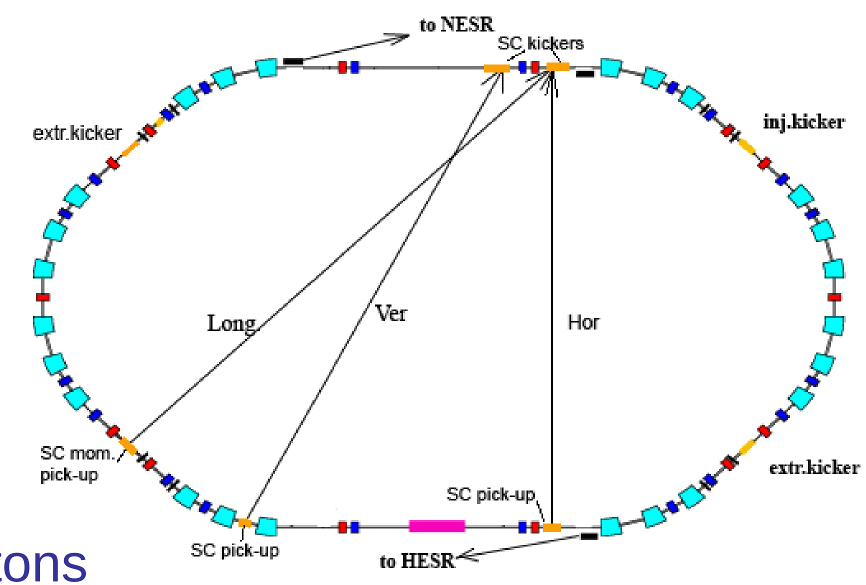

electrodes of Faltin type

core cooling 2-4 GHz

longitudinal
horizontal
vertical

tail cooling 1-2 GHz

longitudinal




injection of $1\times10^8$ antiprotons every 10 s

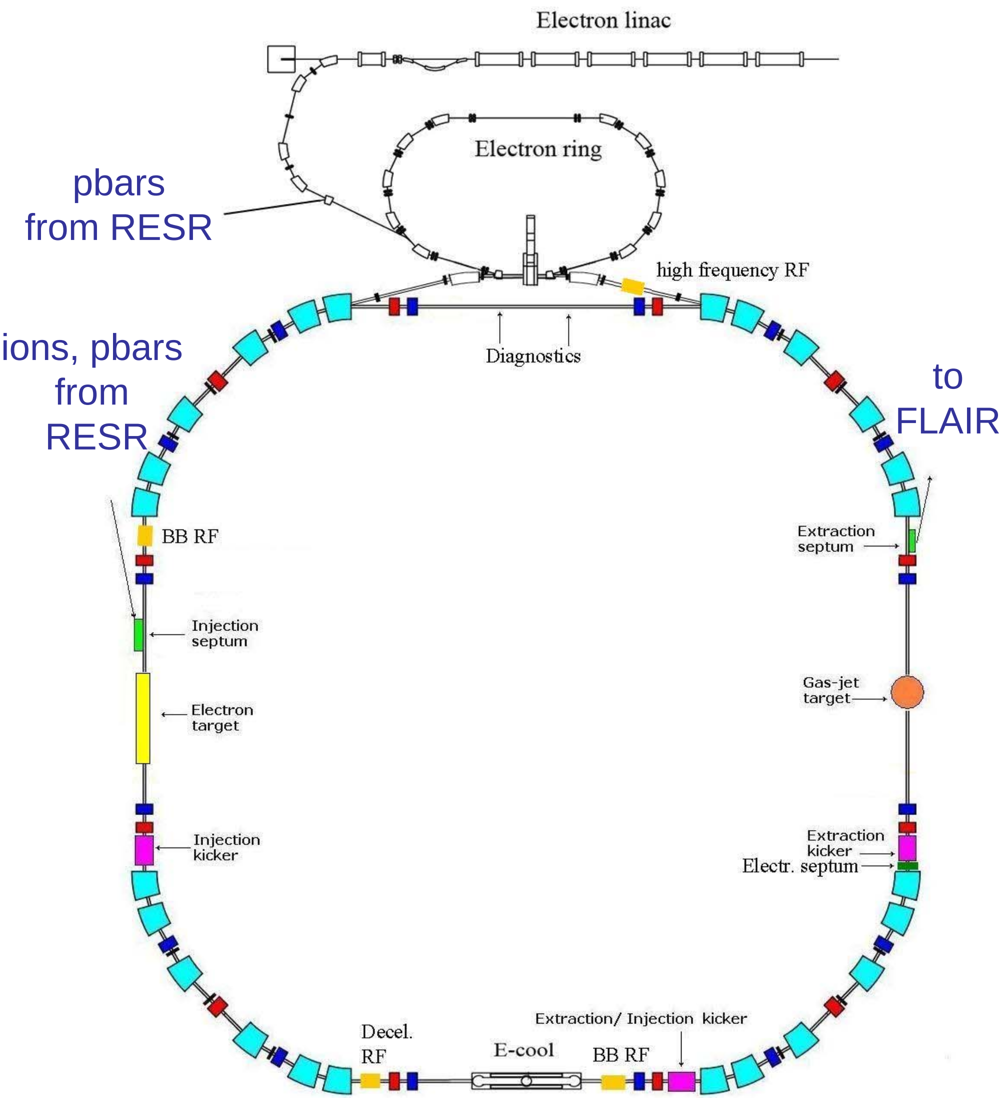
pre-cooling in CR provides

$\delta p/p = 1\times10^{-3}$, $\varepsilon_{x,y} = 5$ mm mrad

maximum stack intensity: $1\times10^{11}$ antiprotons

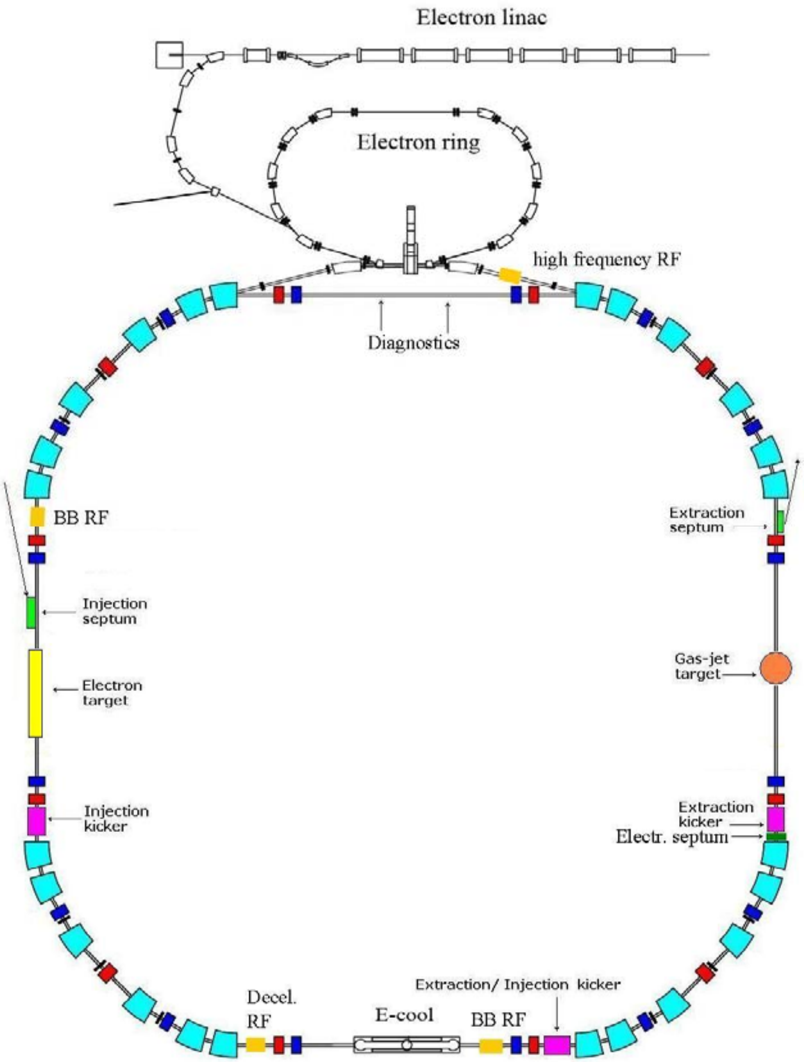
pre-cooling after injection considered as option

# The New Experimental Storage Ring




| | |
|---|---|
| Circumference [m] | 222.8 |
| Straight section length [m] | 18 |
| Horizontal acceptance [mm mrad] | 150 |
| Vertical acceptance [mm mrad] | 40 |
| Momentum acceptance [%] | ±1.5 |
| Max. momentum deviation [%] | ±2.5 |
| Horizontal tune | 4.2 |
| Vertical tune | 1.87 |
| Transition energy | 4.59 |
| Maximum dispersion [m] | 6.8 |
| Horizontal chromaticity | 5.9 |

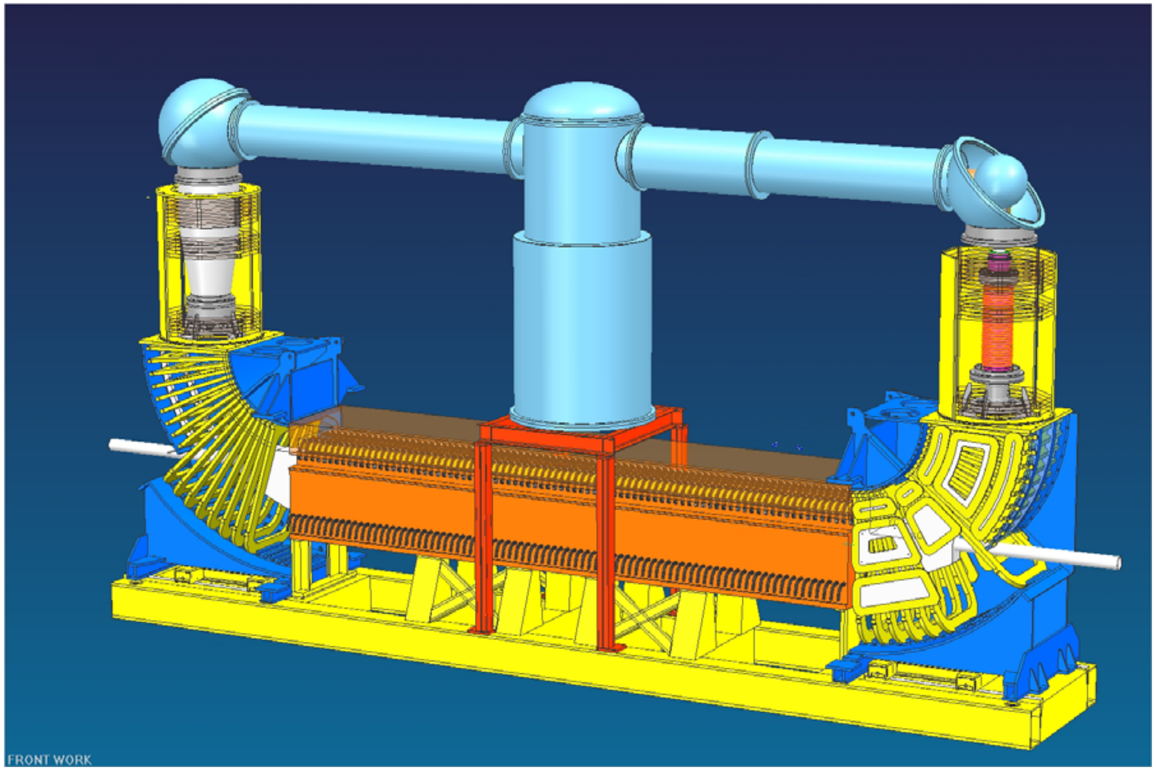
# Accelerator Issues at NESR




- Electron cooling of ions and antiprotons
- Deceleration of ions to 4 MeV/u (in 1.6 s) and antiprotons to 30 MeV
- Fast extraction (1 turn)
- Slow (resonance) extraction
- Ultraslow (charge changing) extraction
- Longitudinal accumulation of RIBs
- Electron-Ion collisions (bypass mode)
- Antiproton-ion collisions
- Internal target
- Electron target
- High precision mass measurements

# NESR Electron Cooler

*design by BINP, Novosibirsk*




**Cooler Parameters**

| | |
|---|---|
| energy | 2 - 450 keV |
| max. current | 2 A |
| beam radius | 2.5-14 mm |
| magnetic field | |
| gun | up to 0.4 T |
| cool. sect. | up to 0.2 T |
| straightness | $2\times10^{-5}$ |
| vacuum | $\leq 10^{-11}$ mbar |

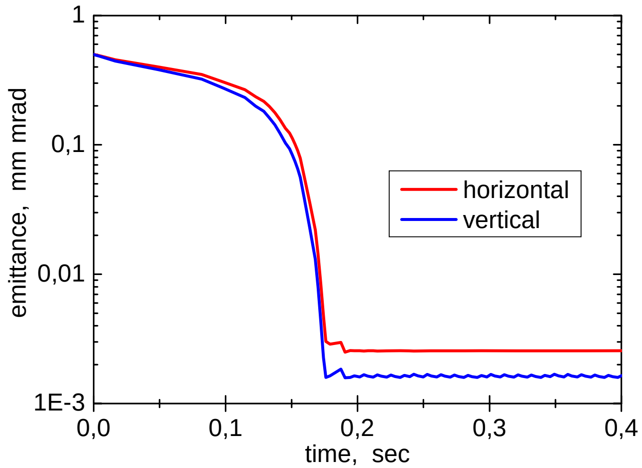
**Issues:**

- high voltage up to 500 kV
- fast ramping, up to 250 kV/s
- magnetic field quality

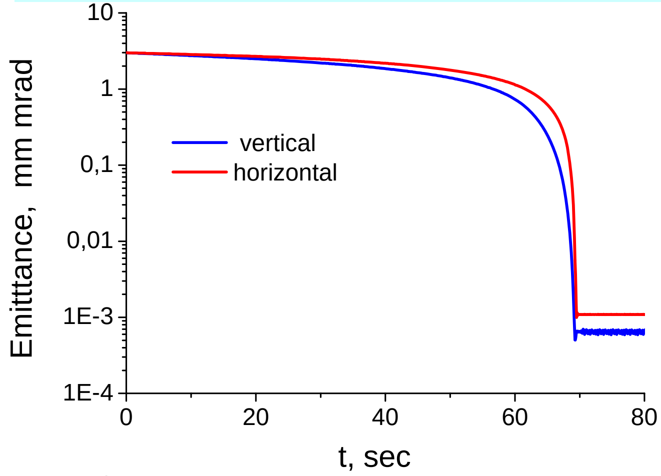
# Electron Cooling in the NESR

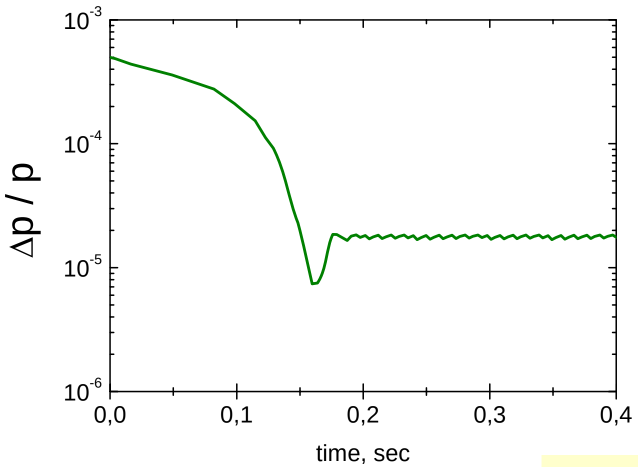
$^{132}Sn^{50+}$ , $N_i = 10^8$ , E = 740 MeV/u,
$I_e$= 1 A, $r_e$= 0.5 cm, B = 0.2 T

Antiprotons, $E_i$ = 800 MeV
$I_e$= 2 A, $r_e$= 1 cm, B = 0.2 T

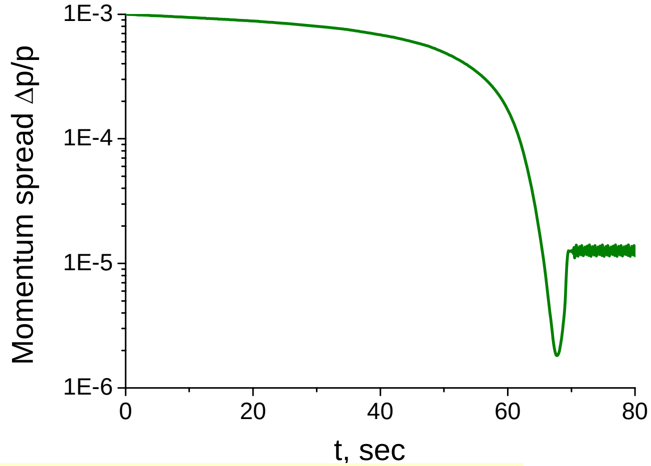



emittance




momentum spread

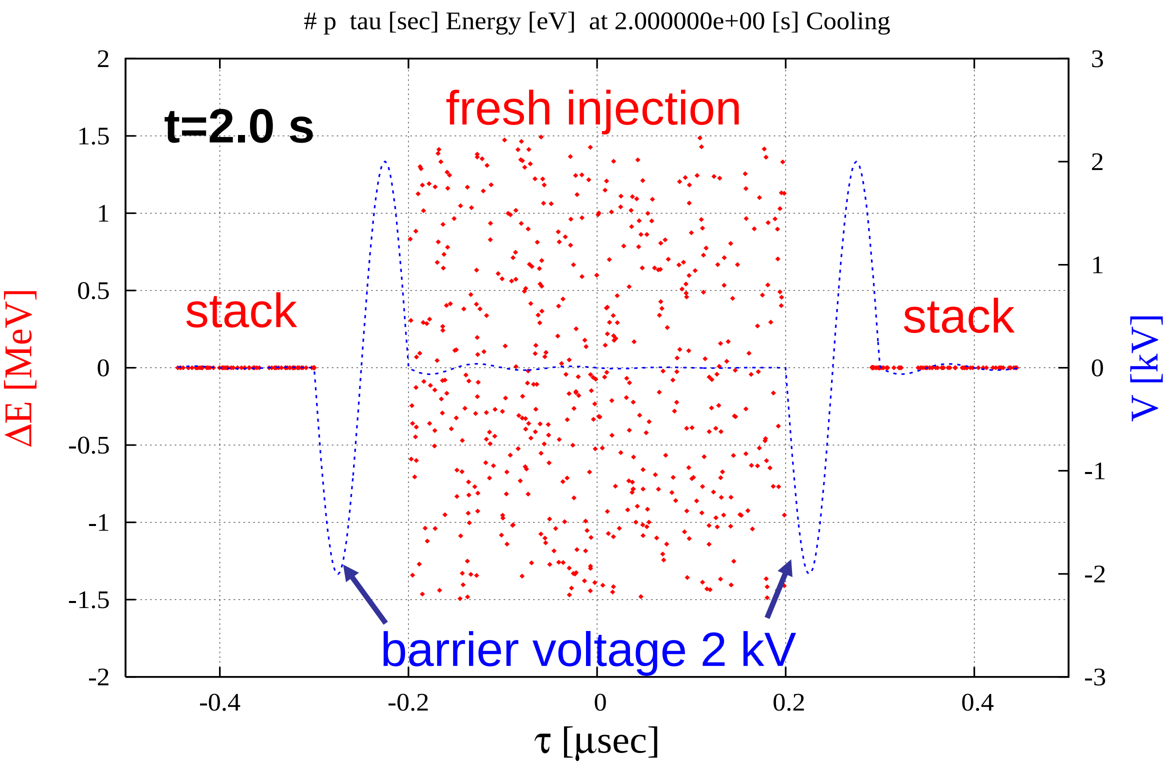



BETACOOL simulations Parkhomchuk model

# Accumulation of RIBs in NESR

**basic idea: confine stored beam to a fraction of the circumference, inject into gap apply strong electron cooling to merge the two beam components**

**⇒ fast increase of intensity (for low intensity RIBs)**




**$^{132}Sn^{50+}$**

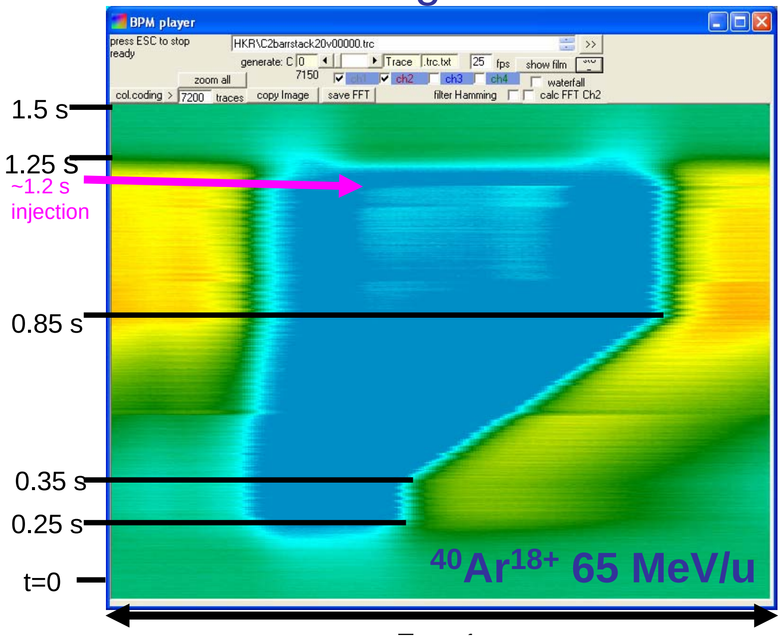
**$E_k$ = 740 MeV/u**

**Longitudinal stacking with Barrier Buckets (simulation by T. Katayama)**

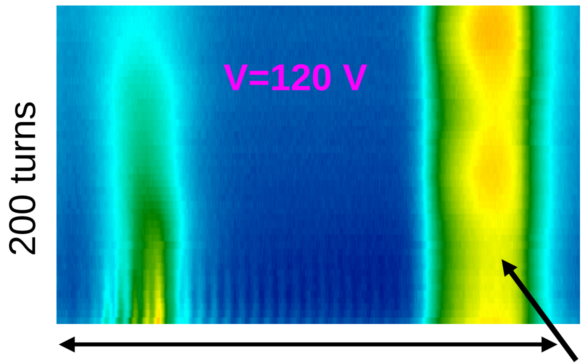
**revolution time 0.9 μs**

# Proof of Principle in the ESR

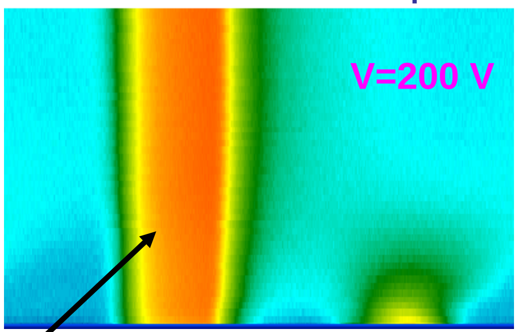
moving barrier




fixed barrier

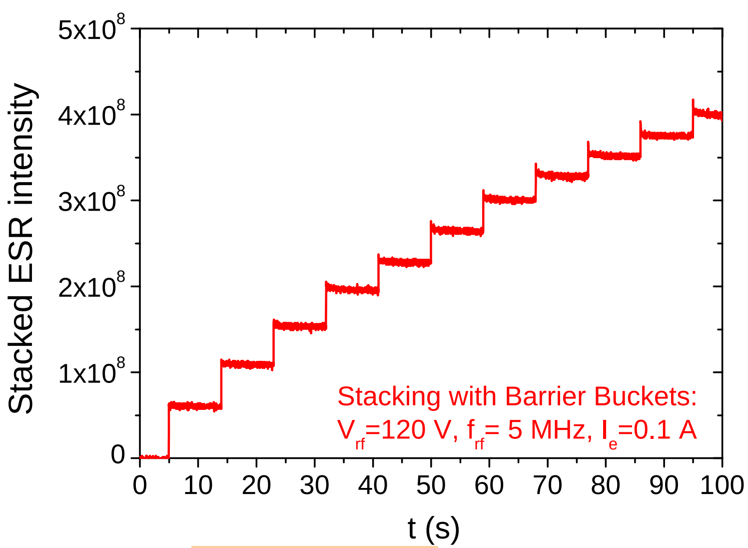



h=1 unstable fixed point




stack

$^{124}Xe^{54+}$ 154 MeV/u




<u>all three schemes worked well:</u>

cooling times close to expectations

eficient accumulation

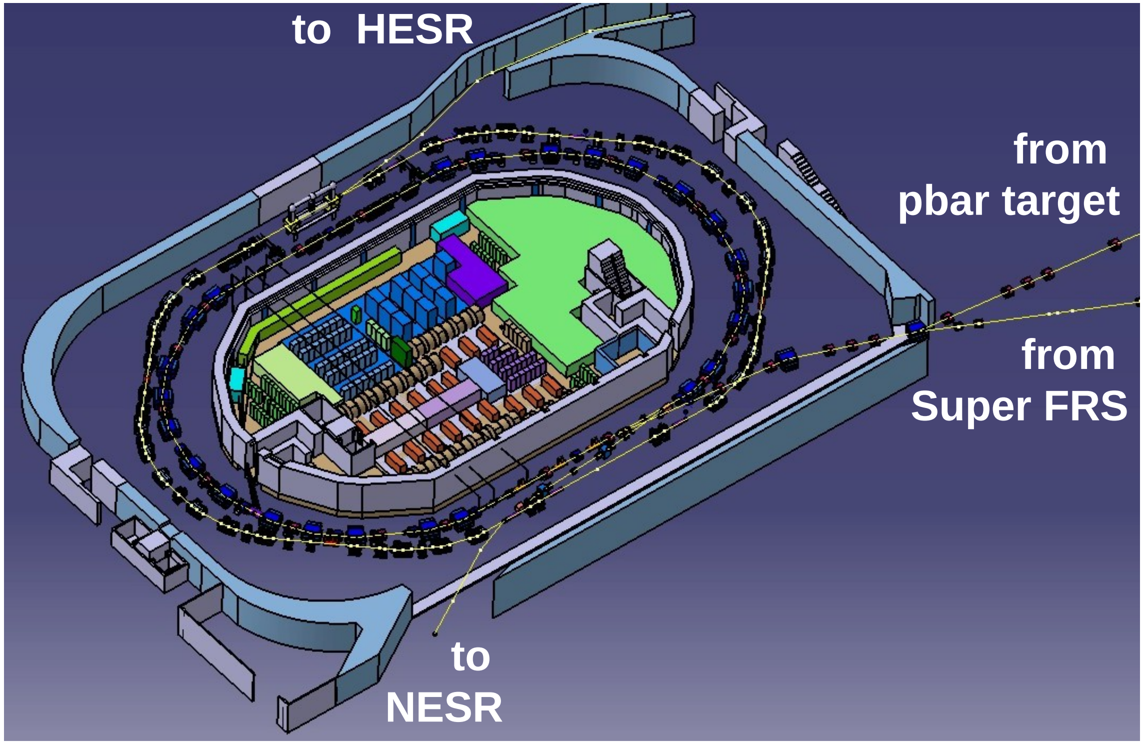
high quality timing and kicker pulses required

Intensity limits: rf voltage and instabilities

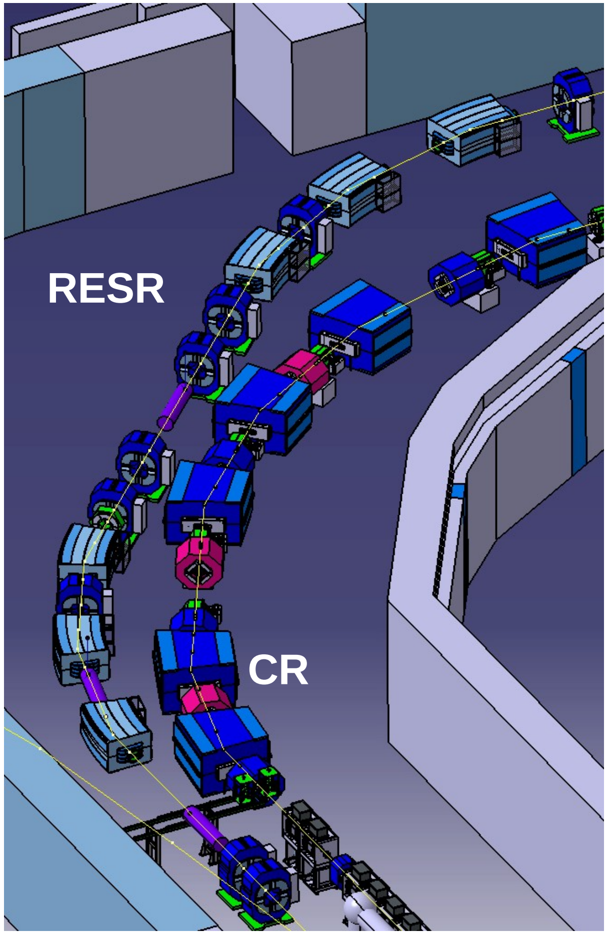
for details: **THPP048**

# Civil Construction of CR/RESR

## Building

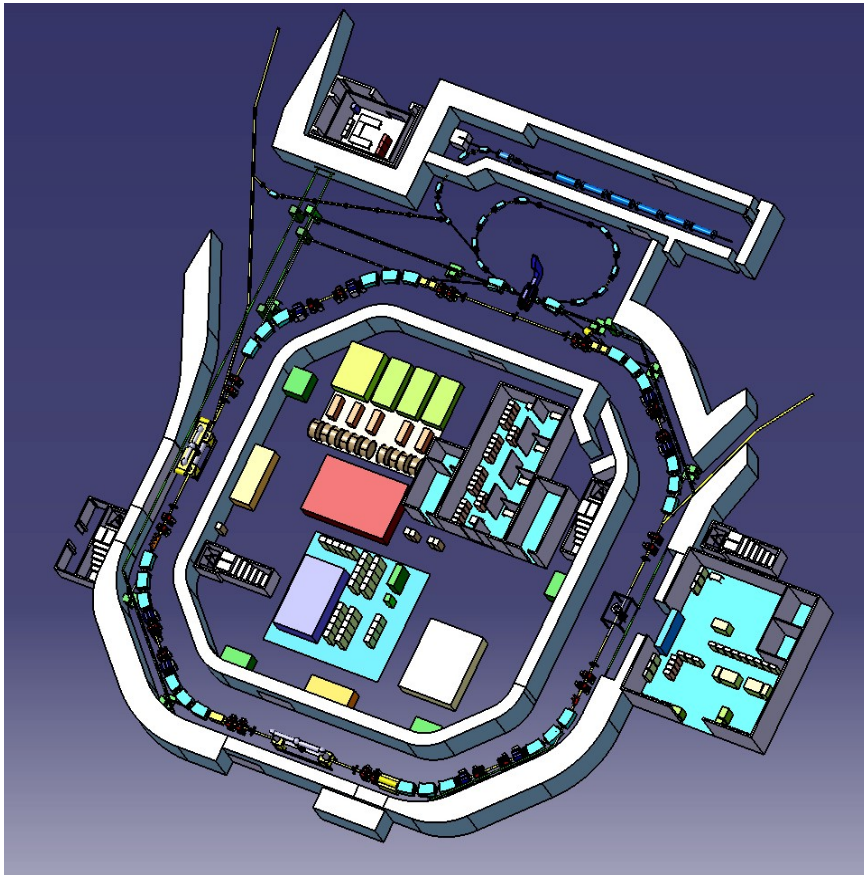



## Ring Tunnel



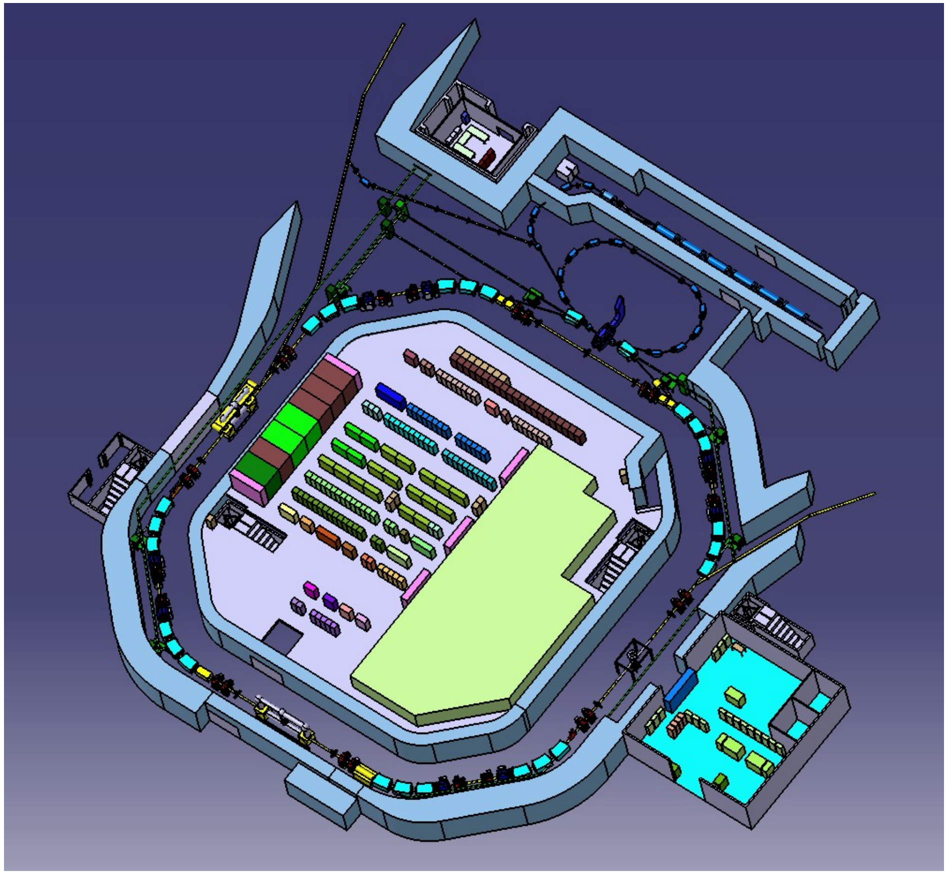
# NESR Civil Construction Planning

**Lower (ring) level**



rf, diagnostics, vacuum, controls

**Upper level**



power converters, common systems

# FAIR Storage Ring Concept

FAIR Technical Division - Storage Ring:

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K. Knie, I. Nesmiyan, F. Nolden, D. Obradors-Campos, C. Peschke

many contributions from technical experts of GSI Accelerator and FAIR Division

advice by B. Franzke, T. Katayama,

D. Möhl, L.Thorndahl (CERN)

contributions by P. Shatunov, D. Shvartz and others from BINP