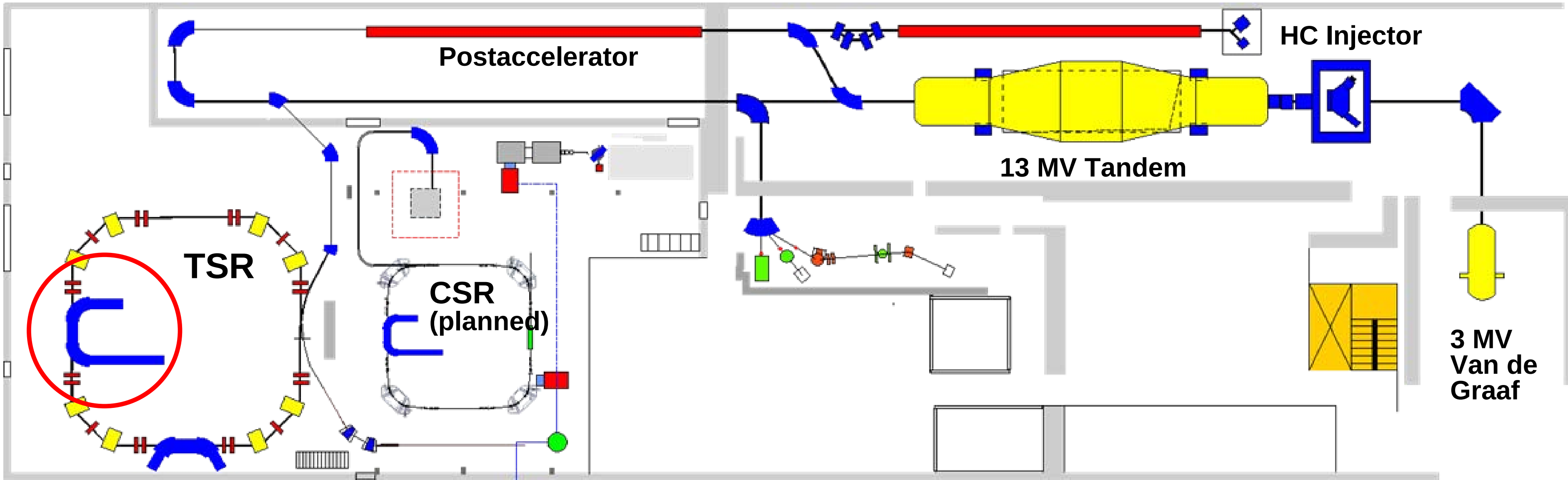
Intensity and Profile Measurements for Low Intensity Ion Beams in an Electrostatic **C**ryogenic **S**torage **R**ing (CSR)

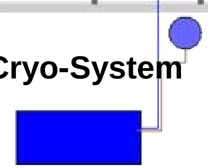
Outline

- Layout of the Cryogenic Storage Ring CSR
- Beam Diagnostics in Electrostatic Storage Rings
- Beam Intensity Measurement
- Ionisation Profile Monitor IPM
- Project Status + Outlook

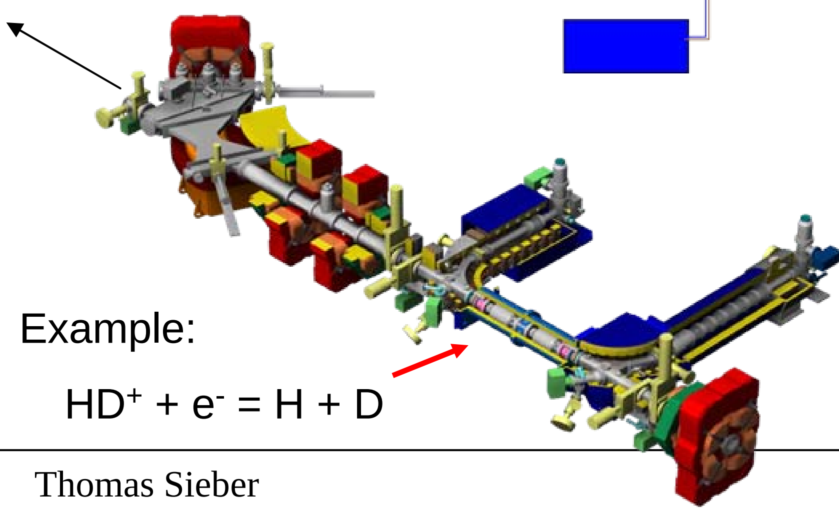
The CSR Project at MPI-K



CSR Cryo-System



H D neutral



Example:

$HD^+ + e^- = H + D$

<u>Molecules must be in rotational ground state</u>

→ **Long storage times (1000s), p < 10^{-13} mbar**

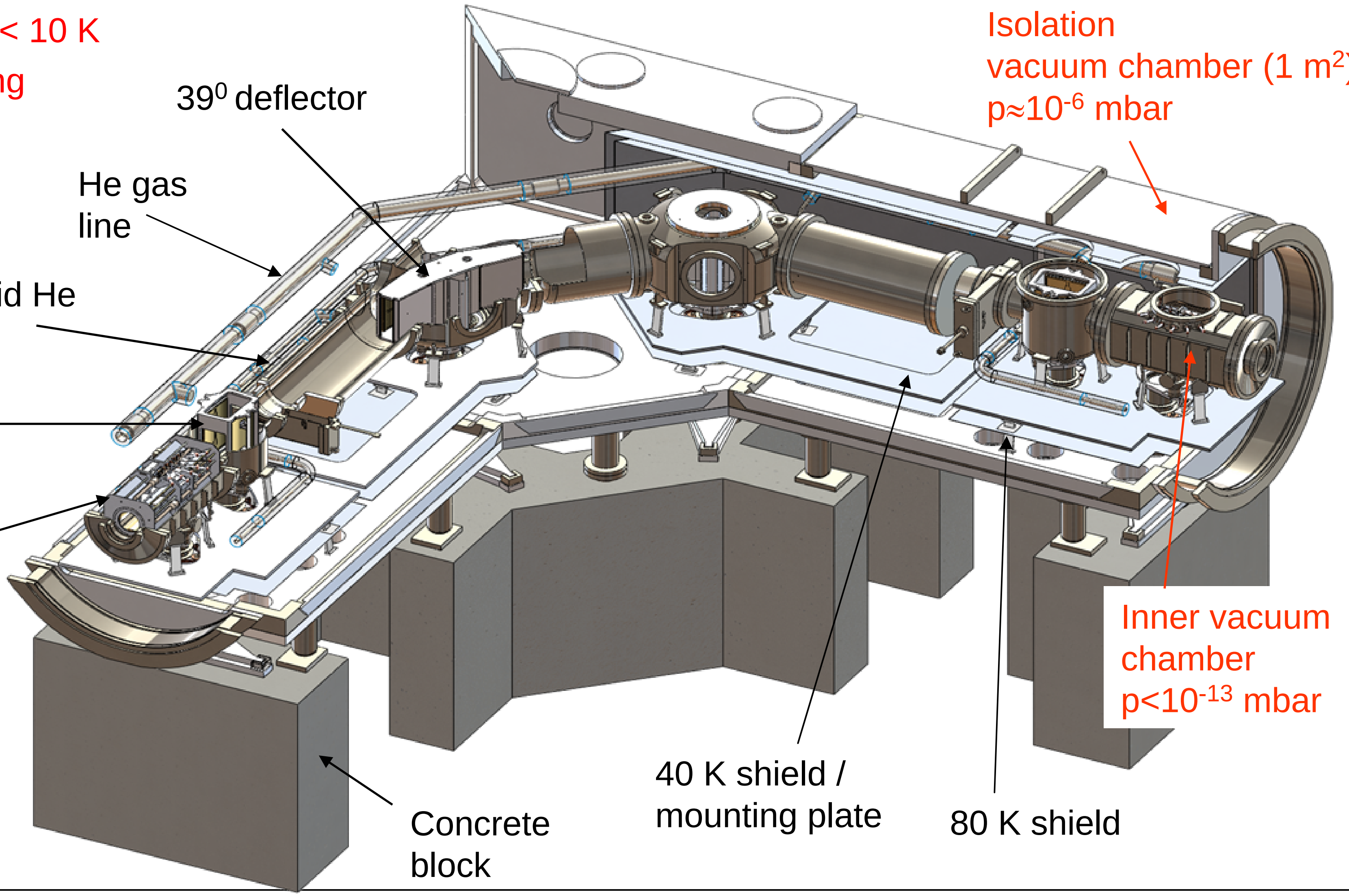
→ **No thermal radiation from chamber, T < 10 K**

<u>Mass independent ion storage</u>

→ **Electrostatic ring**

→ **Cryogenic Storage Ring**

CSR Mechanical Layout



Electrostatic Storage Rings: BD Systems

year	ring	Faraday Cup	Scintil. Screen	Scraper	Beam Trafo	Ionisation Profile M.	Position PU	Schottky PU	Neutral Detector
1999	ELISA	x	x	x			x	x	o
2002	KEK		x	x			x		o
2004	Tokyo MU		x	x			x		o
under constr.	DESIREE	x	o	x			x	x	o
under constr.	FLSR	x	x					x	o
under constr.	CSR	o	x/o	x	x	x	x	x	o

(yellow) = destructive (light green) = non-destructive x = inside ring o = outside ring

Beam Intensity Measurement

CSR Parameters

Type	**electrostatic**
Circumference	**35.2 m**
Corner deflectors	**2x39°, 2x6°**
Acceptance	**100 mm mrad**
Mass range	**1 – 100 amu**
Energy range (1^+ ions)	**20 – 300 keV**
→ **Intensity range**	**1 nA – 1 μA**
Revolution Frequency	**5 - 220 kHz**
Operation temperature	**2 - 300 K**
Bakeout temperature	**< 320°C**
Vacuum pressure	**1×10^{-13} mbar**
Mat. cold chamber	**316 L**
Mat. isolation chamber	**Al**

Requirements

- Lifetime measurements
- Determination of reaction rates / cross sections
- Pickup calibration
- Injection efficiency

⇒ Non-destructive, absolute current measurement

⇒ Beam transformer based on a Cryogenic Current Comparator (CCC) with SQUID sensor

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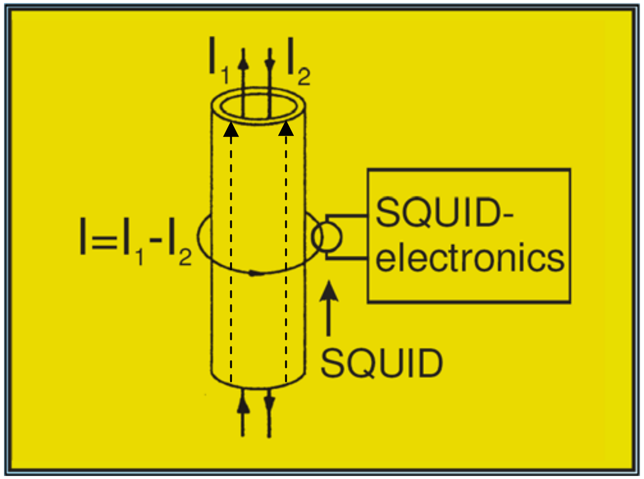
Boundary conditions in CSR

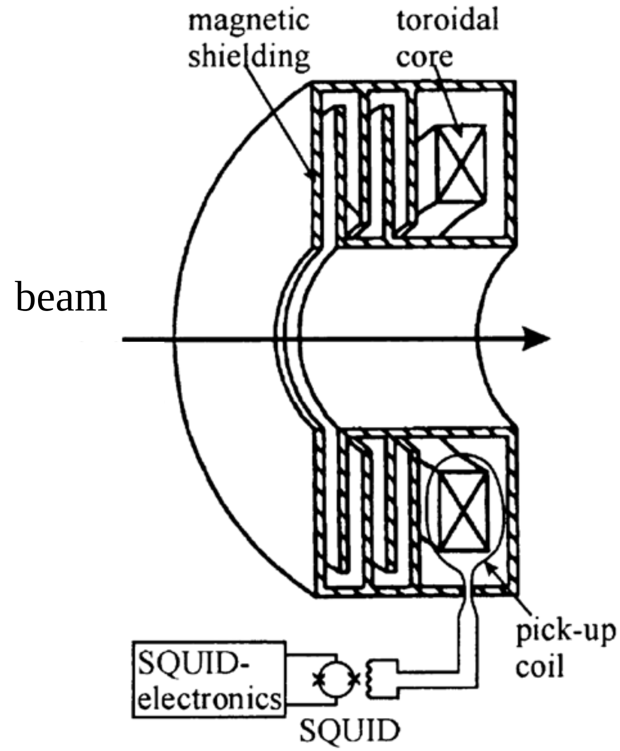
- Electrostatic elements
- Nonmagnetic materials
- Cryostat, LiHe supply
- Low bandwidth required

- Room temperature operation
- High bakeout temperatures

→ Prototype for FAIR

Cryogenic Current Comparator (CCC) Principle





CCC (Harvey 1972):

- Uses Meissner-effect and SQUID for I_1/I_2 measurement
- If $I_1 \neq I_2$ magn. field produces compensation current
- Magnetic flux through SQUID $\rightarrow$ voltage change

For charged particle beams:

$I_{comp} = I_1 - I_2 = I_{beam} - 0$ (position independent)

- SC shielding for non-azimuthal fields
- SC pickup coil with toroidal core ($\mu_r \approx 50000$)
- Low noise, high performance DC SQUID control electronics (FSU Jena)

Optimisation of CCC Performance

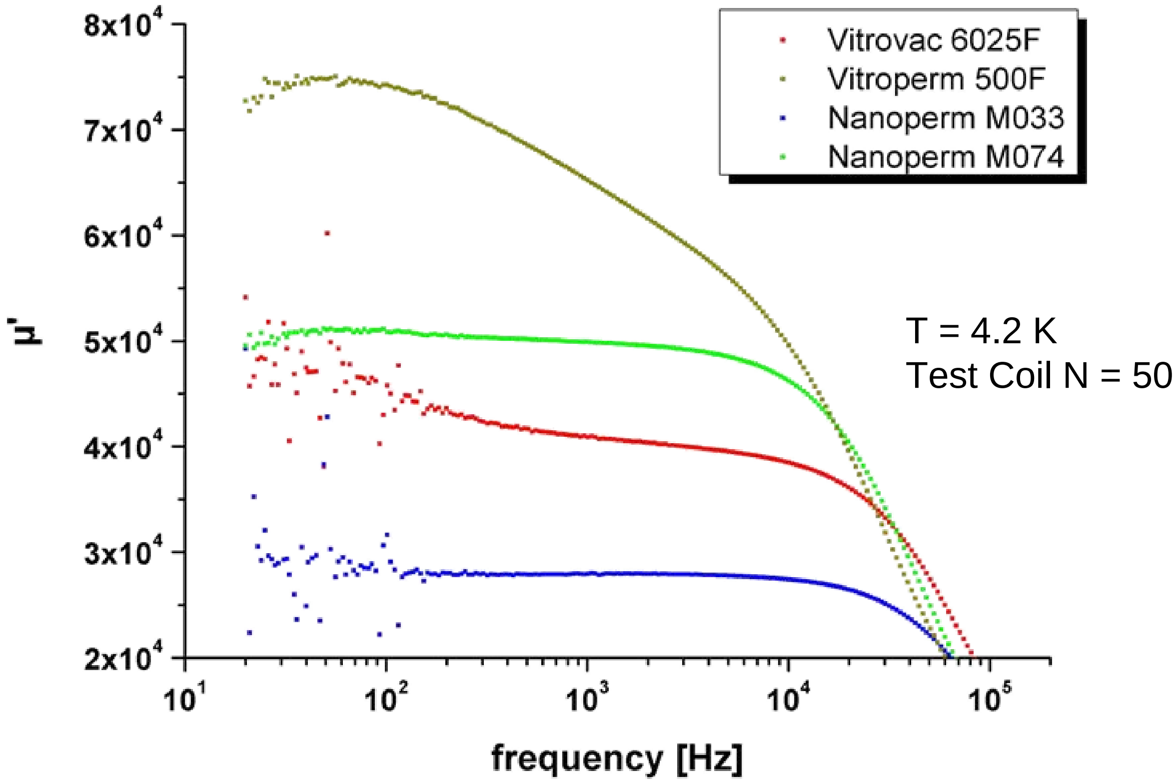
Achievements so far: $250\,pA/\sqrt{Hz}, BW = 0...50kHz$ at GSI (A. Peters et al. 1999) ⇒ TARN II
$40\,pA/\sqrt{Hz}, BW = 0...70kHz$ at test setup for DESY (W. Vodel et al. 2007)

Limitations of the system:

- Mechanical vibrations
- Magnetic shielding
- Noise from toroidal core
- SQUID intrinsic flux noise
- Electronics (amplifier input noise, crosstalk etc.)
- Slew rate / core mat. (BW)

Current detection limit from pickup coil:

$$I_S = \frac{2\pi\sqrt{k_b T L}}{\mu_0 \mu_r f\left(R_a, R_i, b\right)}$$



W. Vodel, R. Geithner (FSU)

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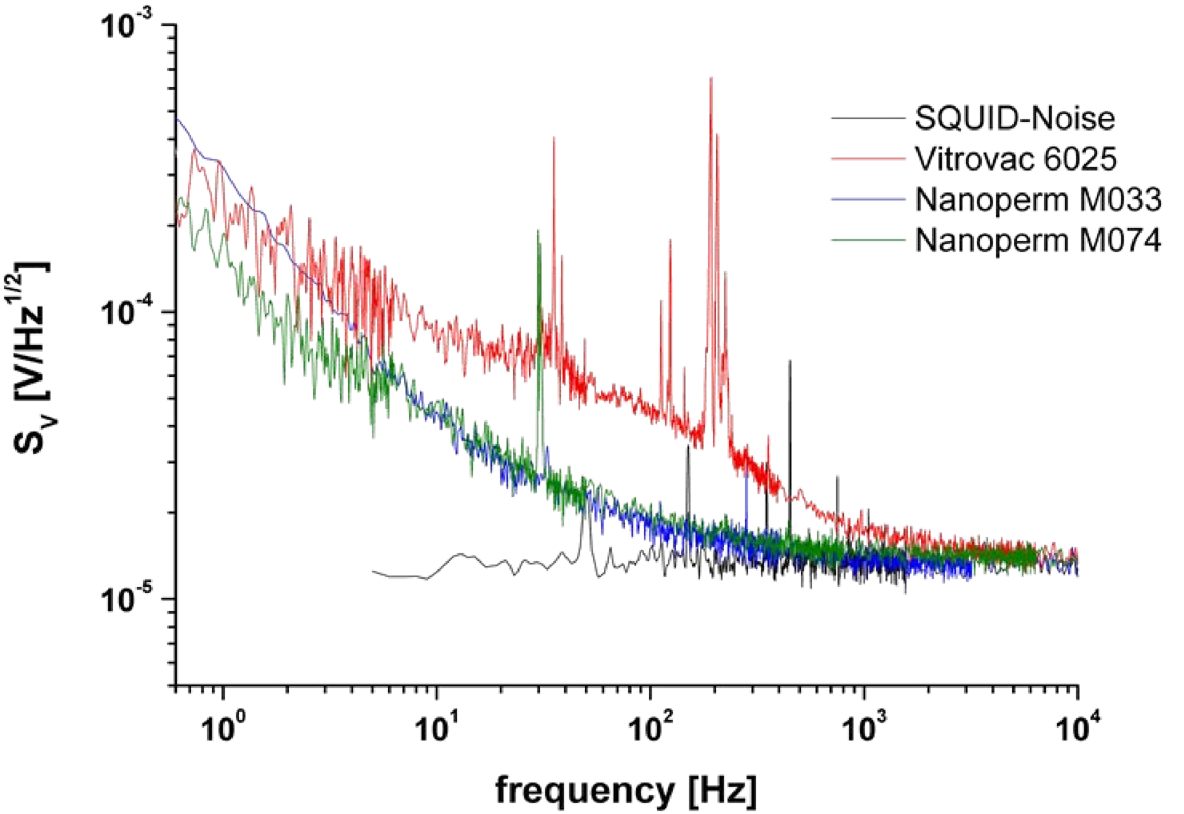

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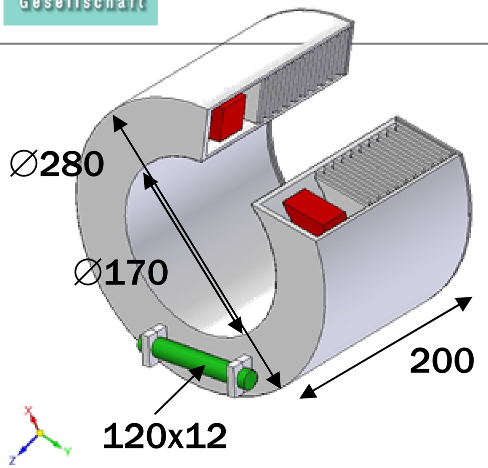
CCC Installation in CSR

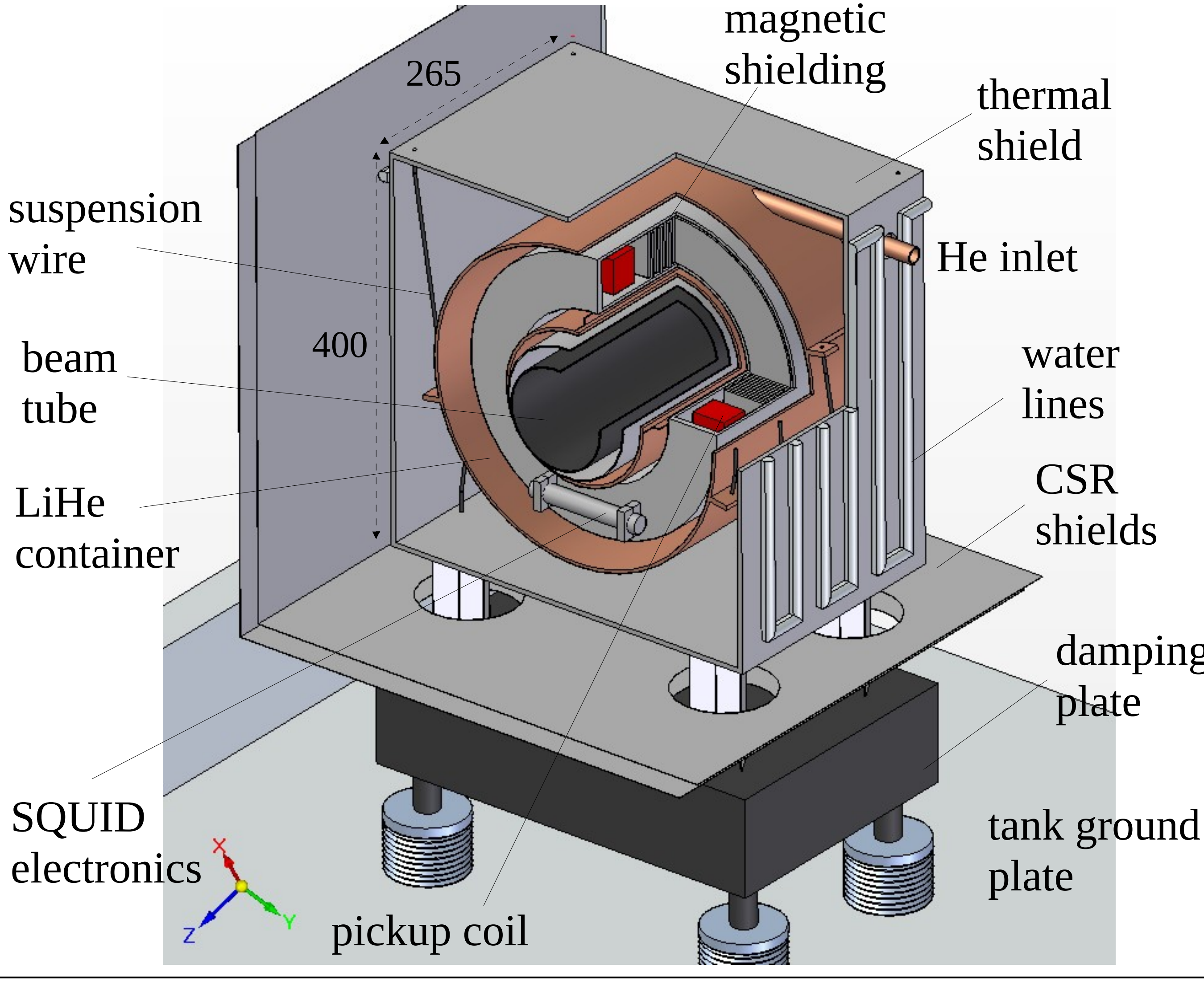


- Shield efficiency from analytical model, coaxial and ring cavities A ~ $(r_i/r_a)^2$

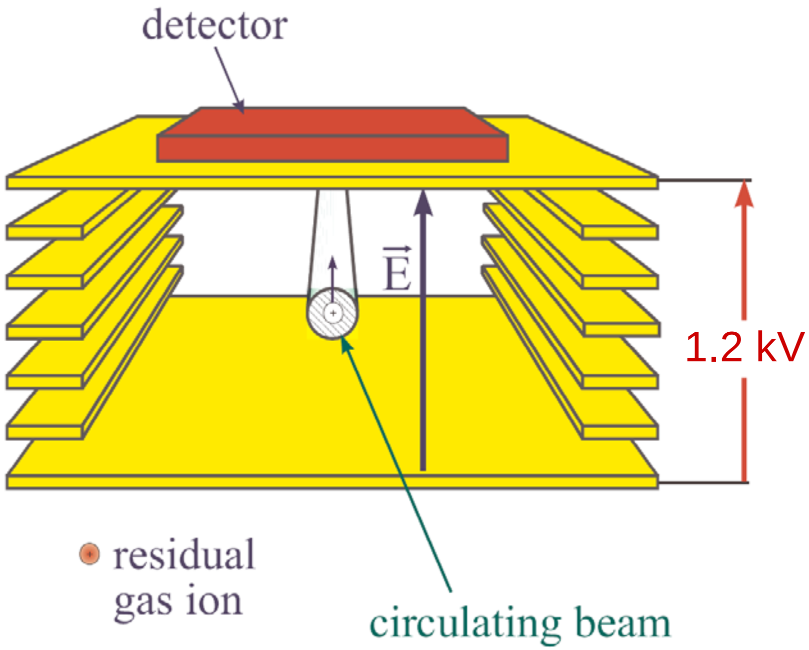
- Diameters fixed by CSR dimensions. Maximum length: 200 mm → A ≈ $5 \cdot 10^{-10}$

- Toroidal core mech. properties?

- Temperature stability from Δp: ΔT < 50 mK



The Ionisation Profile Monitor



$R = \sigma n v \eta N, \eta = L_{eff} / C_0$

⇒ For I = 1μA, E = 300 keV
p = 10^{-13} mbar: R = 10 Hz

⇒ Locally higher pressure required
(~10^{-11} mbar)

Local increase of gas density:

- Gas inlet
- Gas curtain ← USR **M. Putignano** TUPB08
- Heating filament
- Heated chamber ← CSR
- Laser heating

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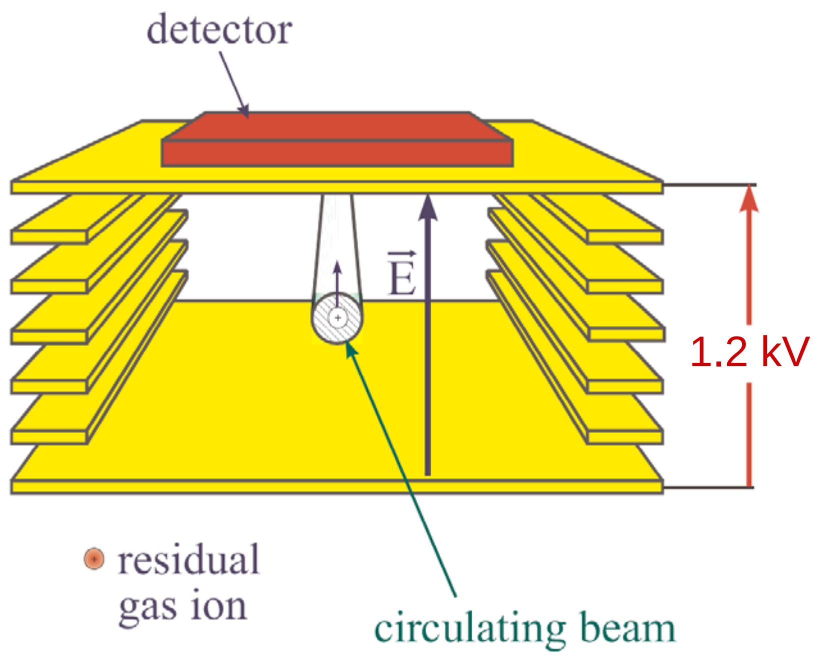

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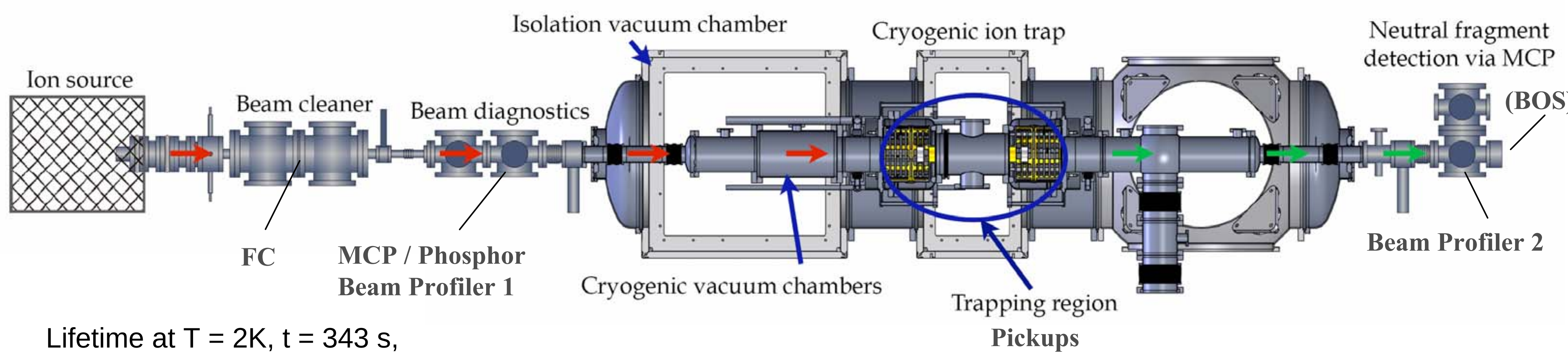
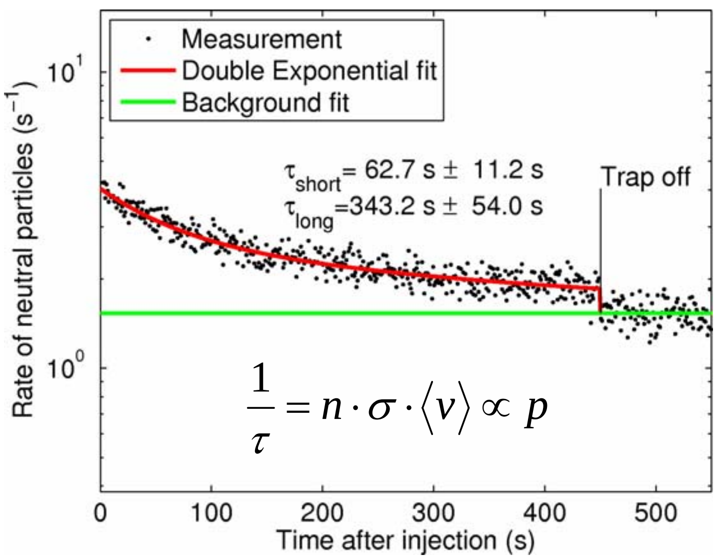
IPM design criteria for CSR:

- MCP operation at 10 K (MSL, MPI)
- Electrode voltages small (E_{th})
- Kick compensation required (20 keV)
- MCP voltage screening
- Large beam dimensions
- Backup system
- Charge exchange dominant at 20 keV

Local Gas Density Increase

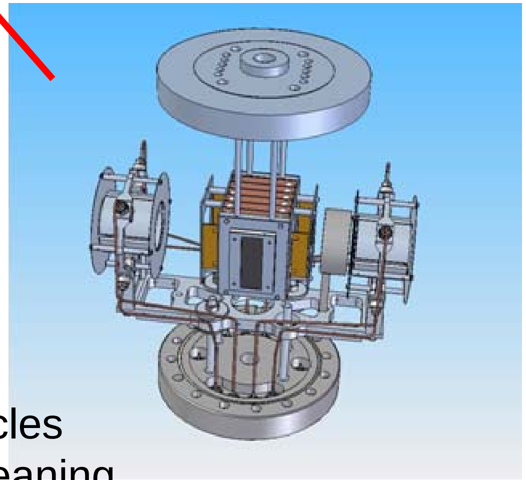


Lifetime at T = 2K, t = 343 s,
→ p = $4 \cdot 10^{-13}$ mbar



$$\frac{1}{\tau} = n \cdot \sigma \cdot \langle v \rangle \propto p$$

Heating with 800 mW to release 10% of monolayer hydrogen
⇒ p = $1 \cdot 10^{-13} \rightarrow 1 \cdot 10^{-11}$ mbar
for 30 days!
Cycling with neighbouring chambers



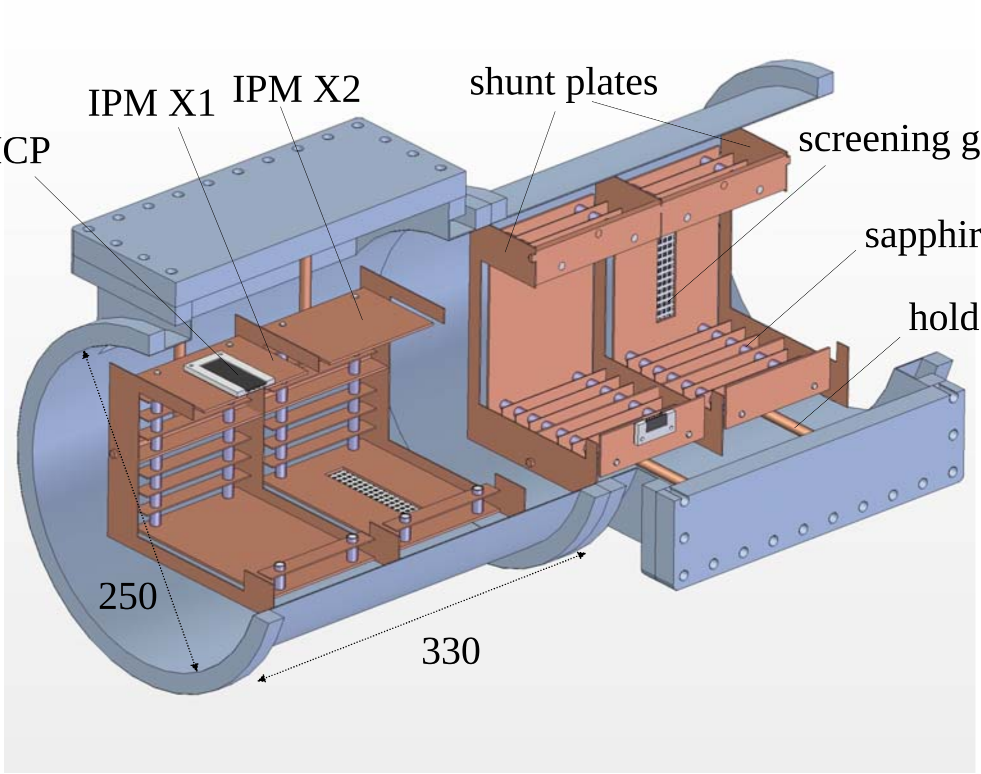
Next steps:

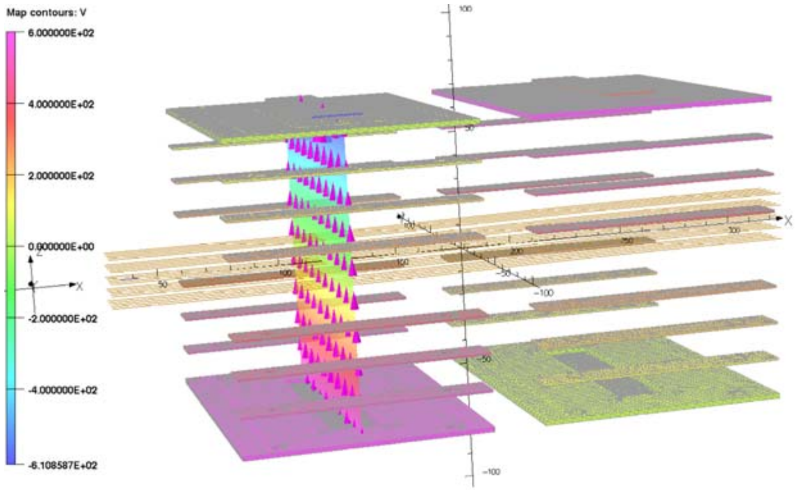
- more heating cycles to investigate cleaning
- install test IPM in pickup chamber

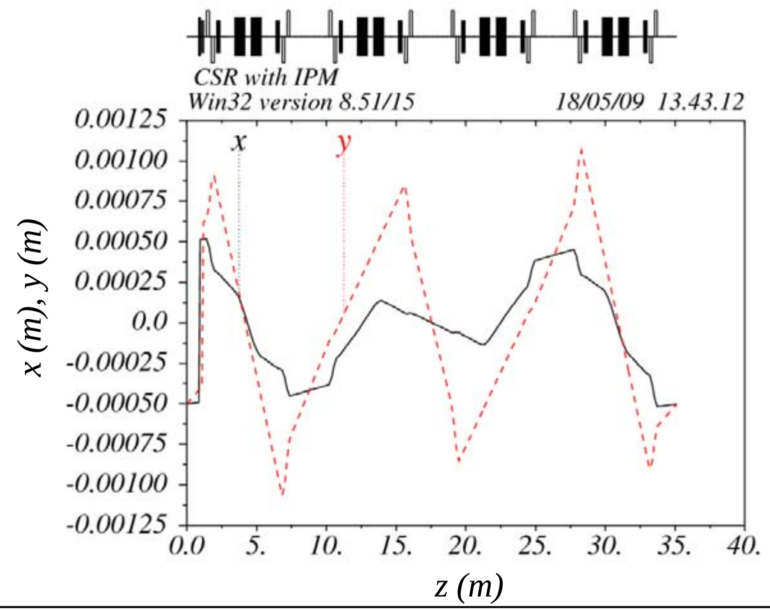
IPM Design Calculations (TOSCA, MAD)

- "Self compensating" with backup system
- Field homogeneity E_y / E_x (70 x 100 mm): < 2 %
- Maximum deviation at U = ± 600 V: Δx_{th} = 50 μm
- Parallel displacement for 20 keV (p): Δy = 1 mm, α = 0.5°

→ Closed orbit distortion: ±x = 0.5 mm, ±y = 1.1 mm



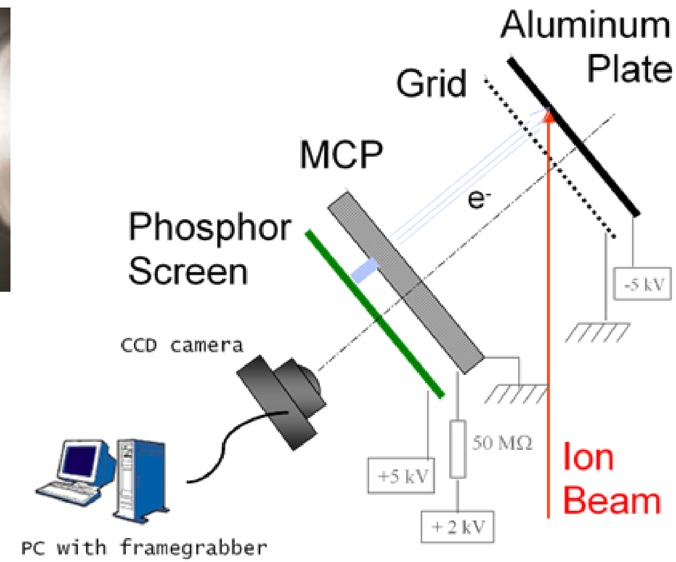


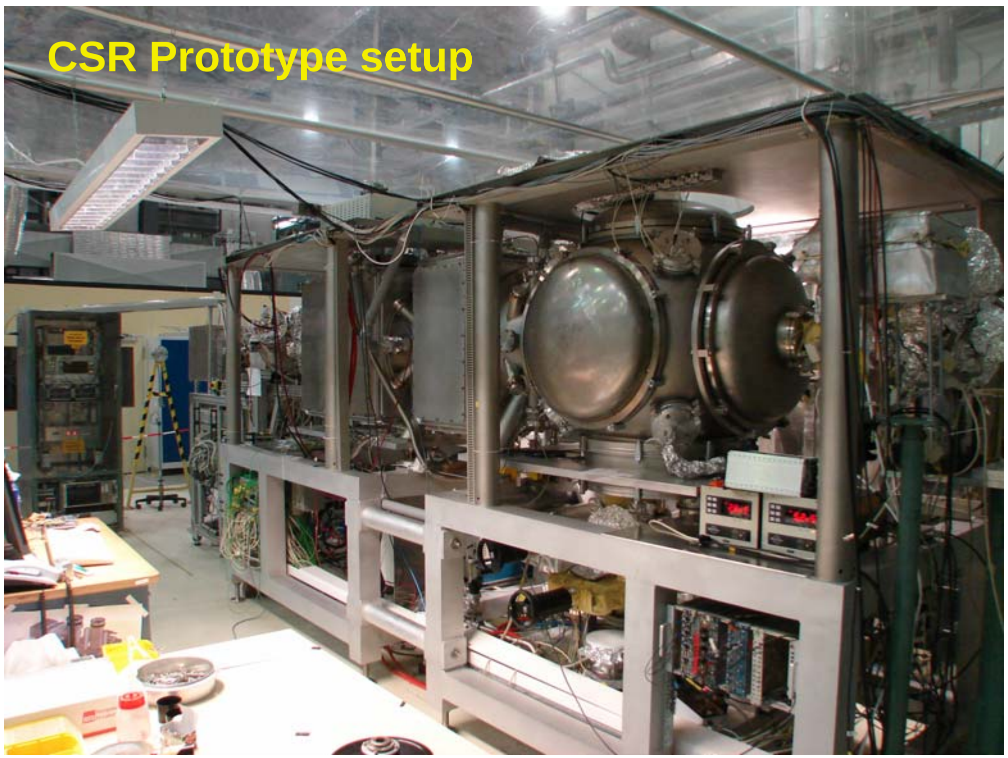


Interceptive Profile Measurement in CSR

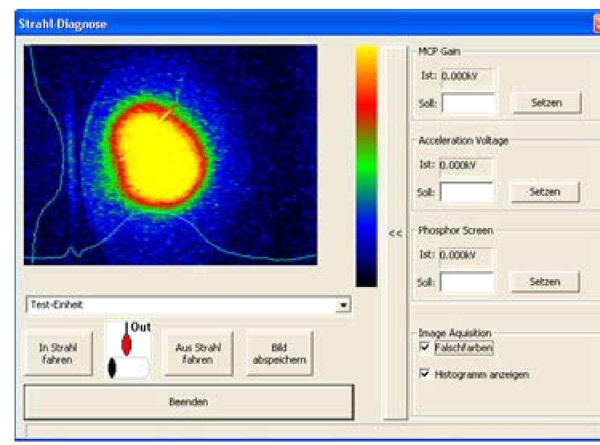
Scintillators not sensitive enough for 20 keV, nA beams

⇒ “Beam Profiler” developed for REX ISOLDE: 10^2 pps – μA



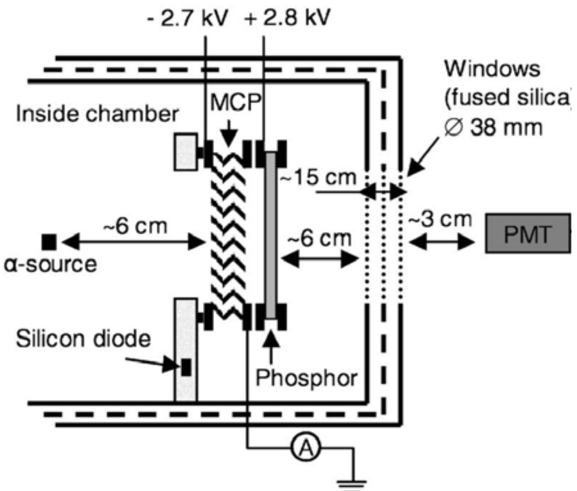


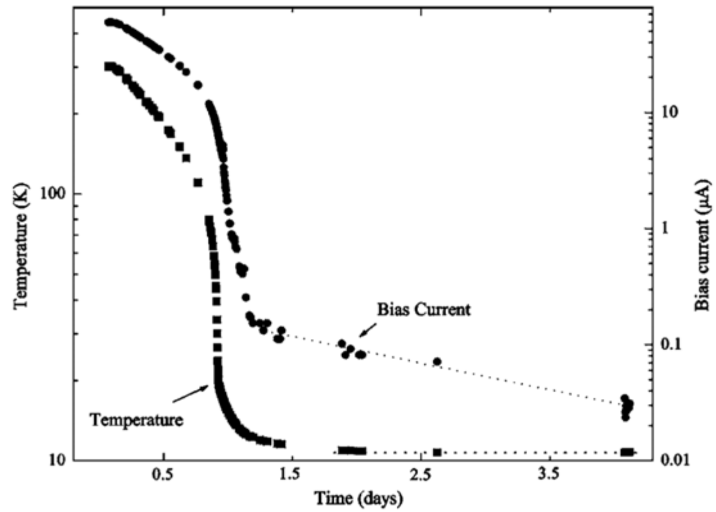
<u>Example</u>
10 pA He^+
10 keV,
∅ 15 mm

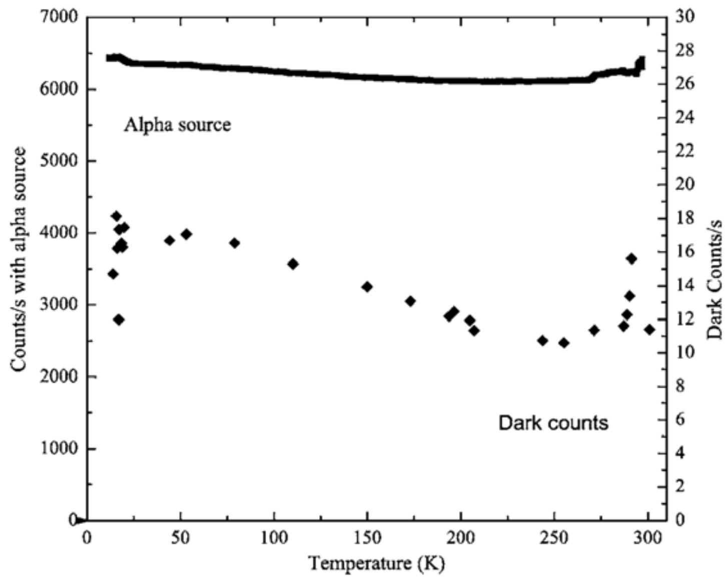


MCP Operation at Low Temperatures

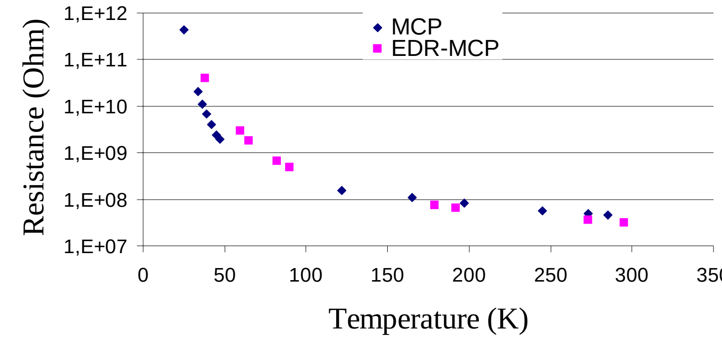
Experimental Setup

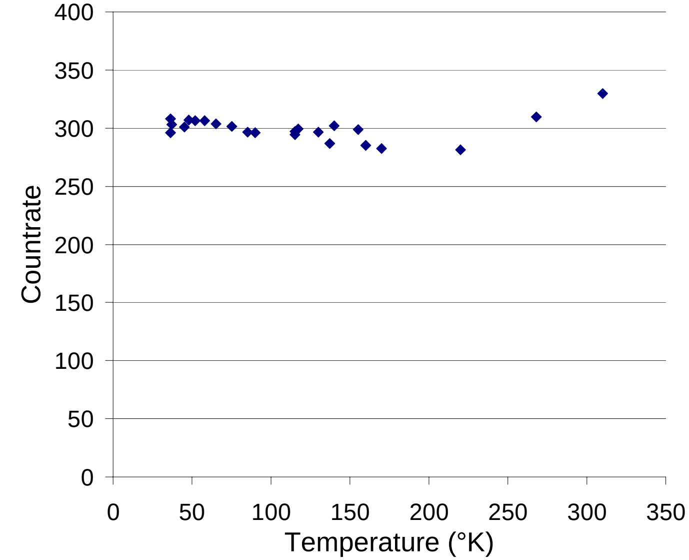






K. U. Kühnel (MPI)





S. Rosén (Univ. Stockholm)

Measurements:
- Bias current /
  MCP resistance
- MCP count rate
- (Pulse shape)

Material:
MCP: Burle APD 9040PS
40 mm, EDR 180:1 / 120:1
Phosphor: P24

Summary

- Beam transformer will use existing CCC technology + electronics from FSU Jena. Mechanical and cryogenic design for CSR exists ($\rightarrow$ FAIR) Toroidal core from NANOPERM©. SC shield performance under investigation

- IPM could be twin version combined with heating of cold chamber. 20 keV lower limit for reasonable operation (charge exchange, CO dist.).

  Vacuum measurements performed with the prototype ion trap, More heating tests when experimental runs are over $\rightarrow$ test IPM

- Beam Profiler: MCP / phosphor screen system tested in CSR prototype beamline

- First corner of CSR will be built up in the fall of 2009

Thanks to ...

MPI-K Heidelberg
R. Bastert
K. Blaum
F. Fellenberger
M. Froese
M. Grieser
K.U. Kühnel
M. Lange
F. Laux
S. Menk
D. Orlov
R. Repnow
A. Shornikov
R. von Hahn
A. Wolf

FSU Jena
R. Geithner
R. Nawroth
R. Neubert
W. Vodel

Cockroft Institute, Daresbury
J. Harasimovicz
M. Putignano
C. Welsch

Univ. of Stockholm
A. Källberg
S. Rosén

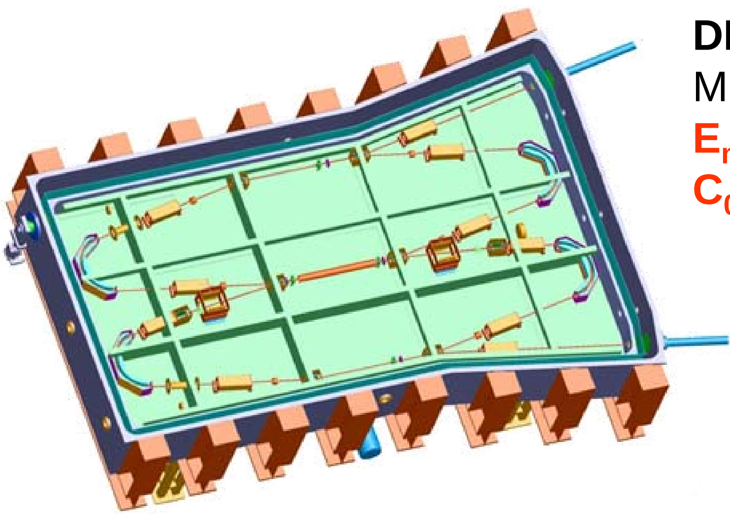
GSI, Darmstadt
P. Kowina
H. Reeg
M. Schwickert
M. Witthaus

A. Peters (HIT)

Weizmann Institute, Rehovot
O. Heber
M. Rappaport
J. Toker
D. Zajfman

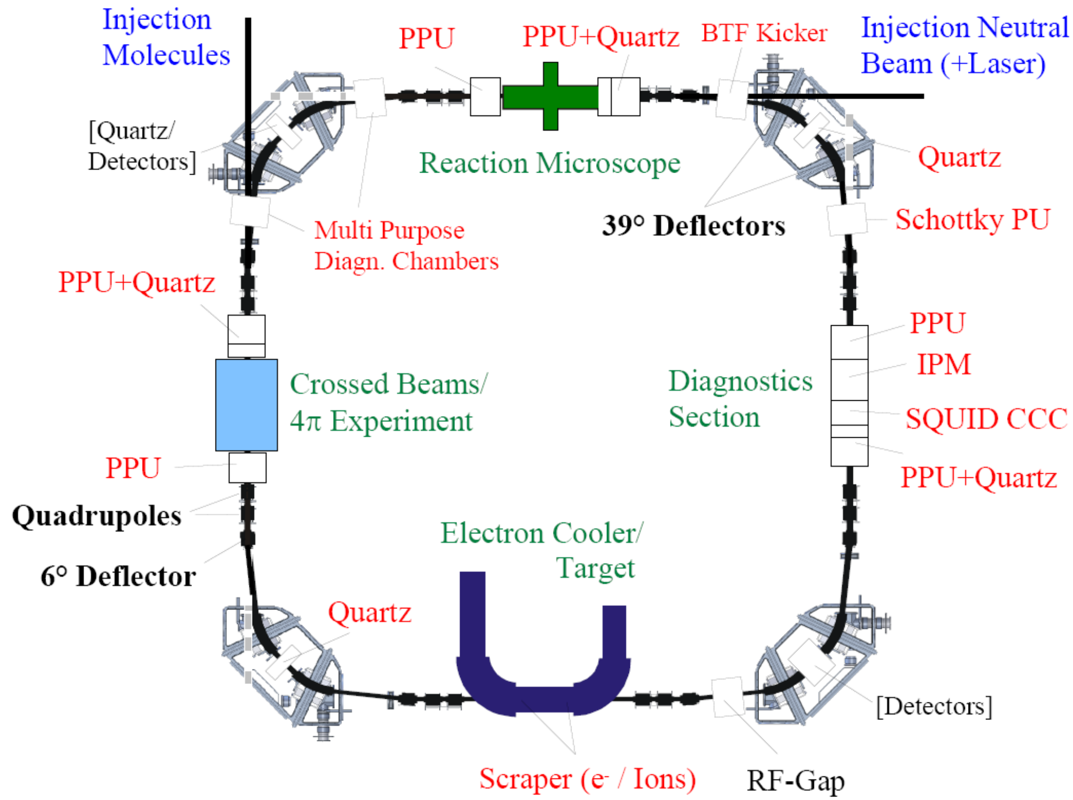
Thank you for your attention !

Electrostatic Storage Rings: Current Projects

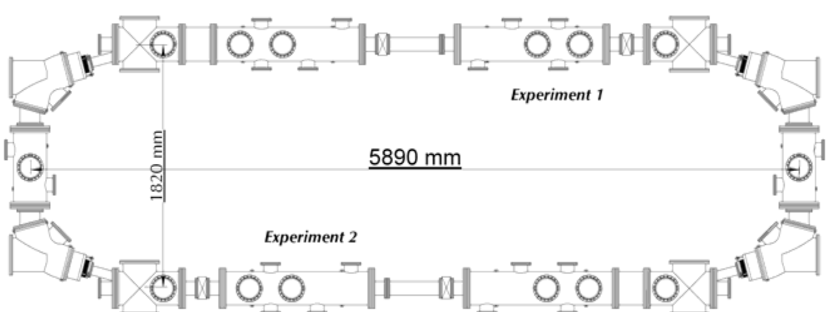


DESIREE,
MSL Stockholm
E_{max}/Q = 25 / 100 keV
C_0 = 2 x 9 m

CSR
MPI Heidelberg
E_{max}/Q = 300 keV
C_0 = 35 m



FLSR,
IAP Frankfurt
E_{max}/Q = 50 keV
C_0 = 15 m



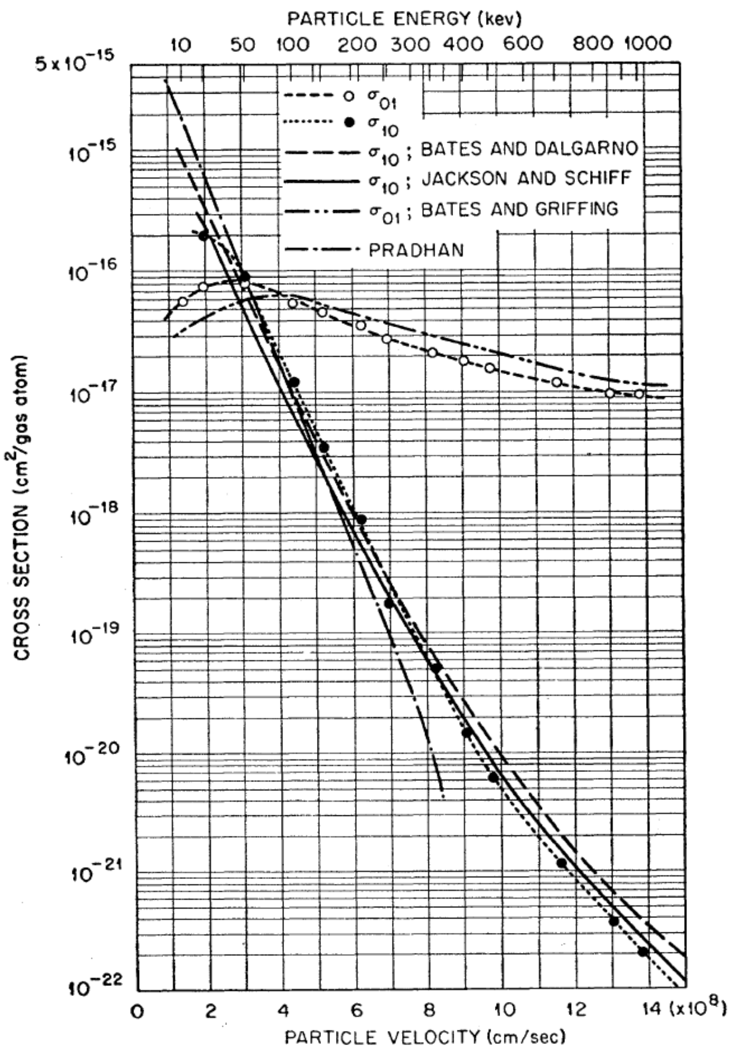


FIG. 3. The charge transfer cross section per atom of gas traversed as a function of particle velocity and energy. Hydrogen atoms and ions in hydrogen gas.

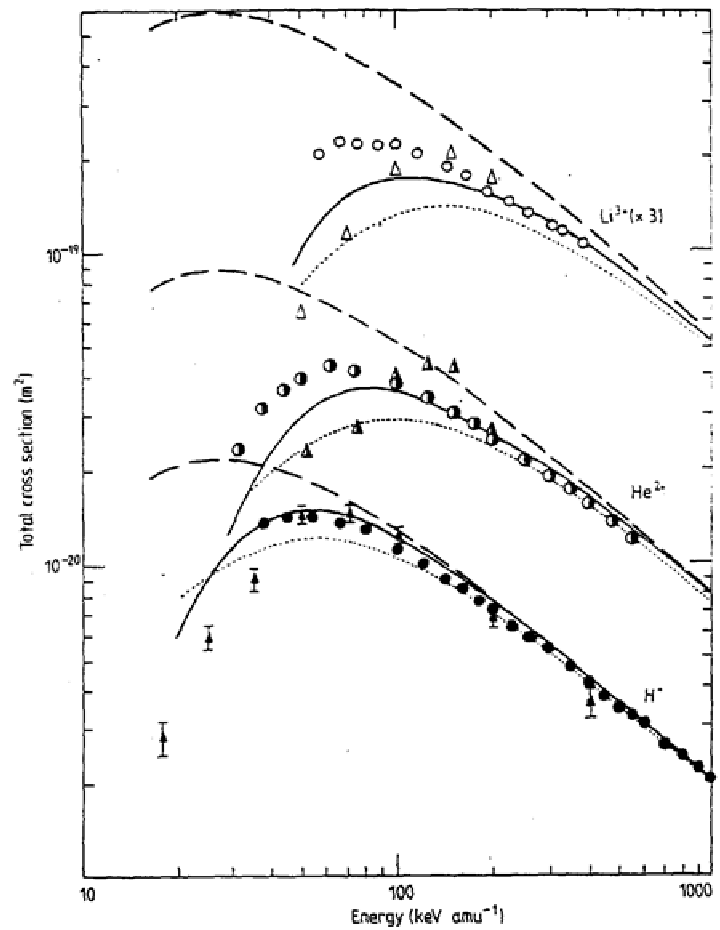


Figure 3. Total ionisation cross sections for a hydrogen-atom target in collision with fully stripped ions. Theory: -----, B1 (Bates and Griffing 1953); ·····, Glauber approximation (McGuire 1982); ——, CDW-EIS (this work); Δ, ▲, CTMC (Olson and Salop 1977); ▲, CTMC (Banks *et al* 1976). Experiment: ○, ◑, ●, Shah and Gilbody (1981a, 1982).

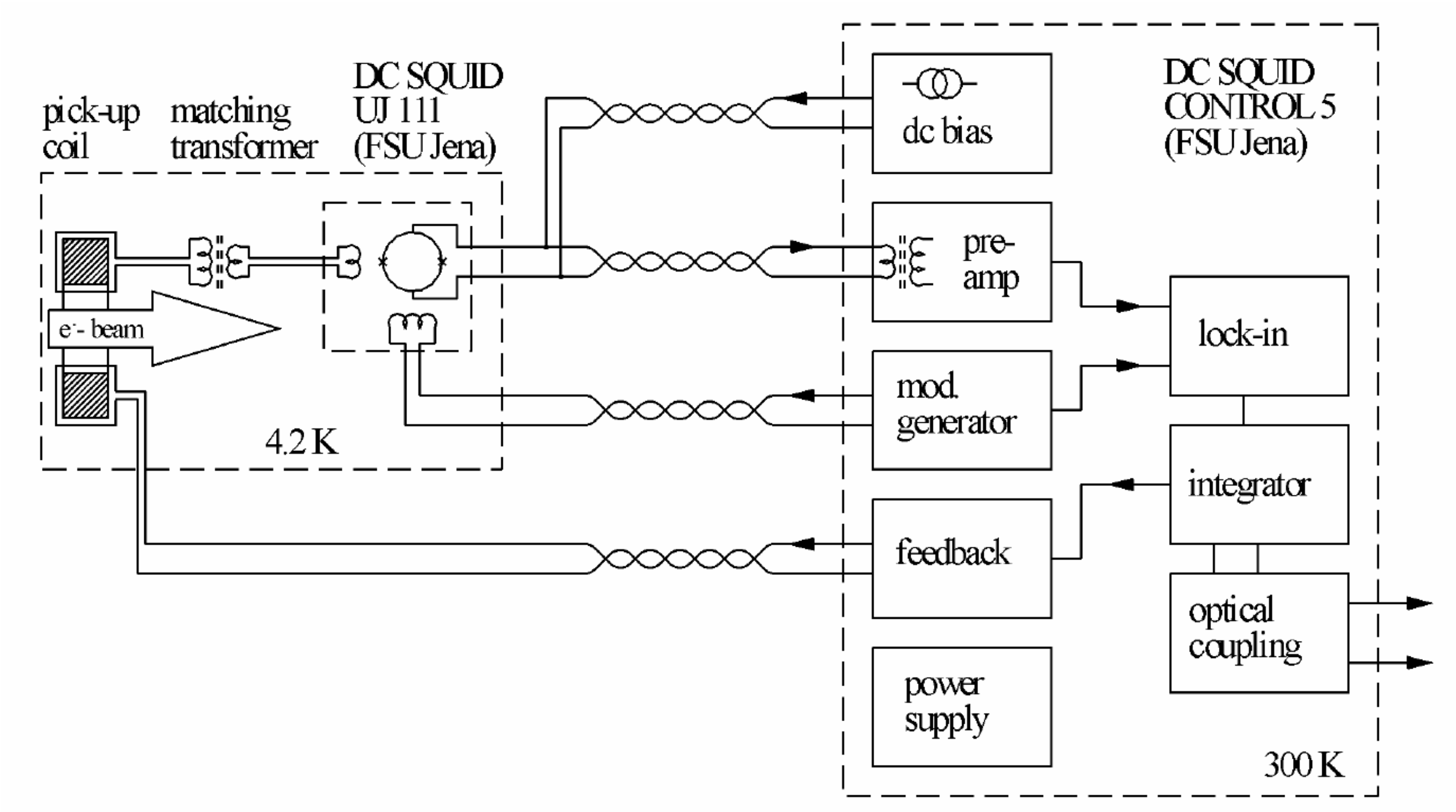
Measured performance of the CCC

- System bandwidth:	dc...70 kHz
- System sensitivity:	167 nA / Φ_0
- Flux noise (in the white noise region):	$8 \times 10^{-5}\ \Phi_0 / \sqrt{\text{Hz}}$
- Corresponding current noise:	13 pA / $\sqrt{\text{Hz}}$

But:
The current resolution of the final system will decrease by about one order of magnitude due to the additional noise contribution of the VITROVAC core of the pickup coil.

W. Vodel, FSU Jena

SQUID Control Electronics



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$40\,pA/\sqrt{Hz}, BW = 0...70kHz$ at test setup for DESY (W. Vodel et al. 2007)

CSR Vacuum Concept

- separate vacuum systems for UHV and insulation vacuum, He-lines outside the cold chamber (←cryo leaks)

- differential pumping and baffles in the corners

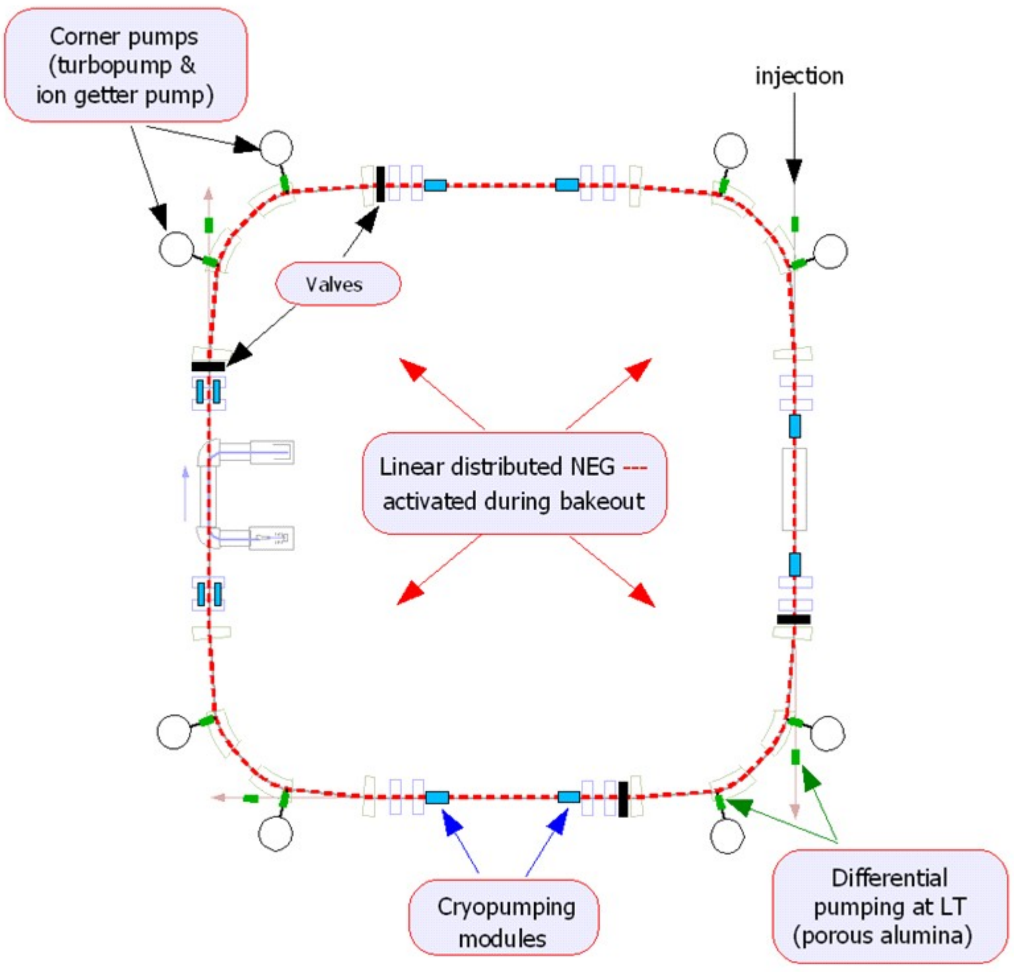
- bakeout to high temperatures (>300°C, NEG activation) pumping by turbo and ion pumps

- large ratio of pumping surfaces / outgassing surfaces

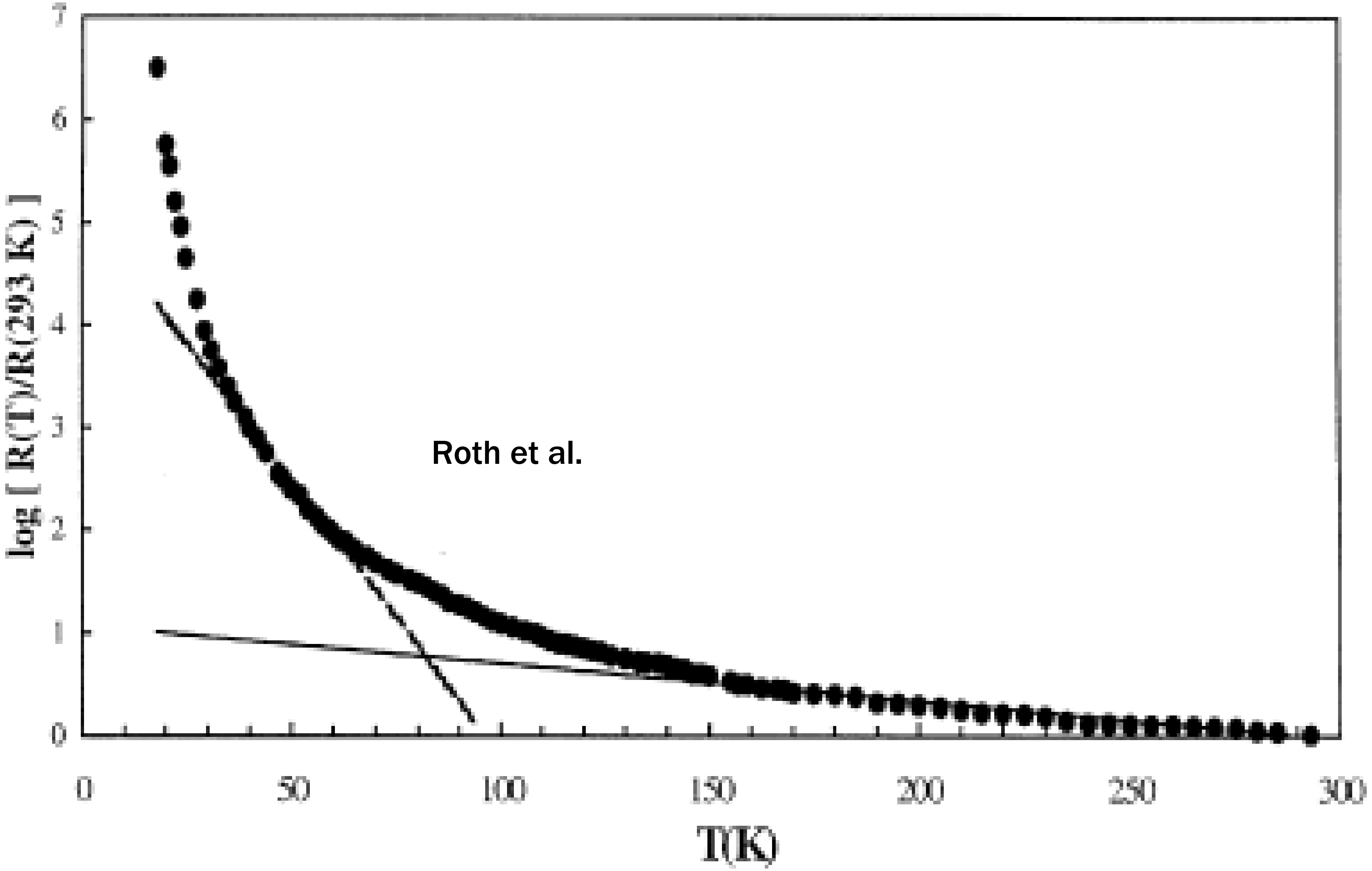
- bakeable cryo-pumps for most gasses ($H_2 \rightarrow$NEG)

- T<30K H_2 cryo absorption up to two monolayers, reduced outgassing rate

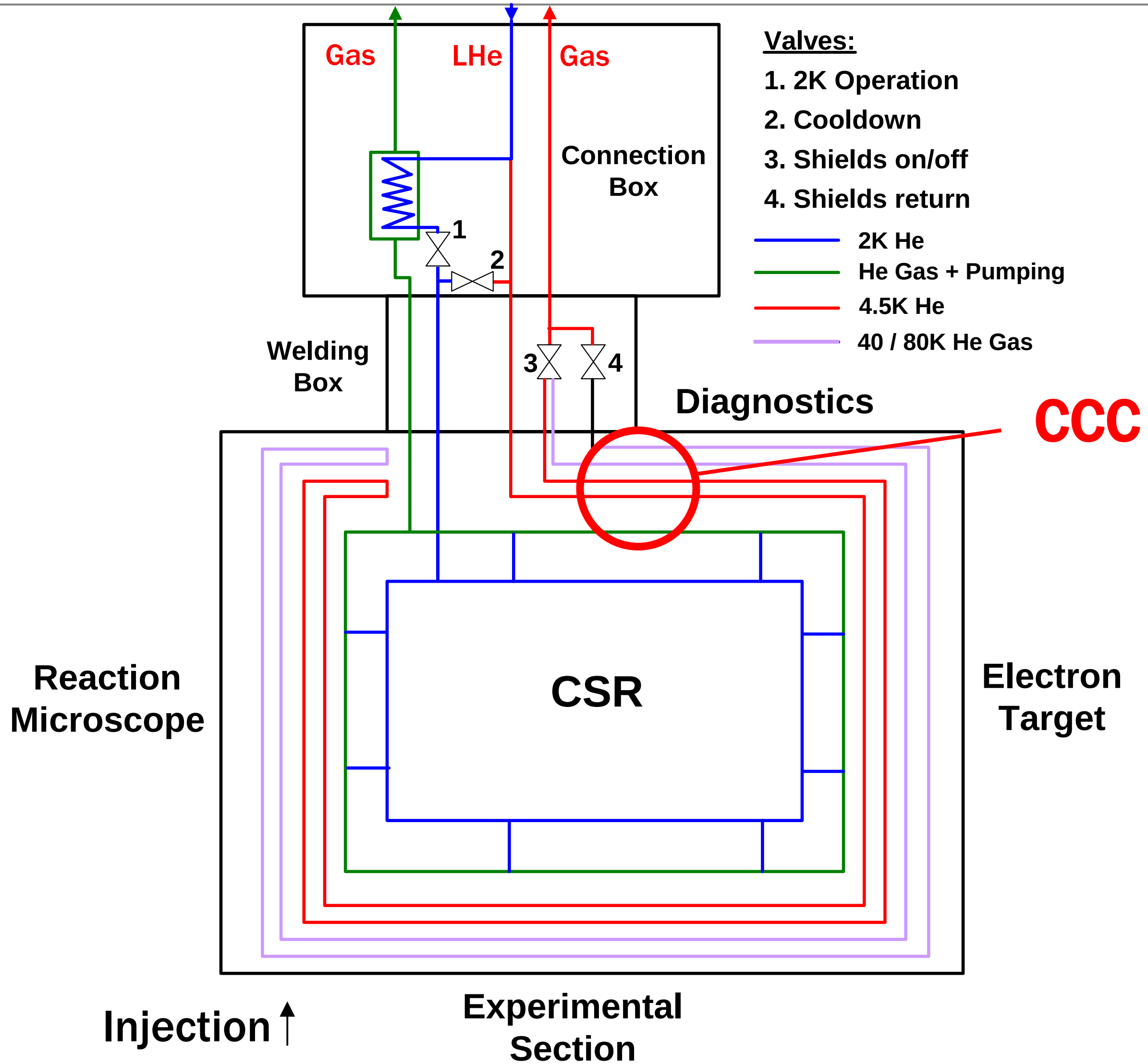
- at T < 2K, $P_D(H_2) < 10^{-16}$ mbar, cryo - condensation of the Hydrogen



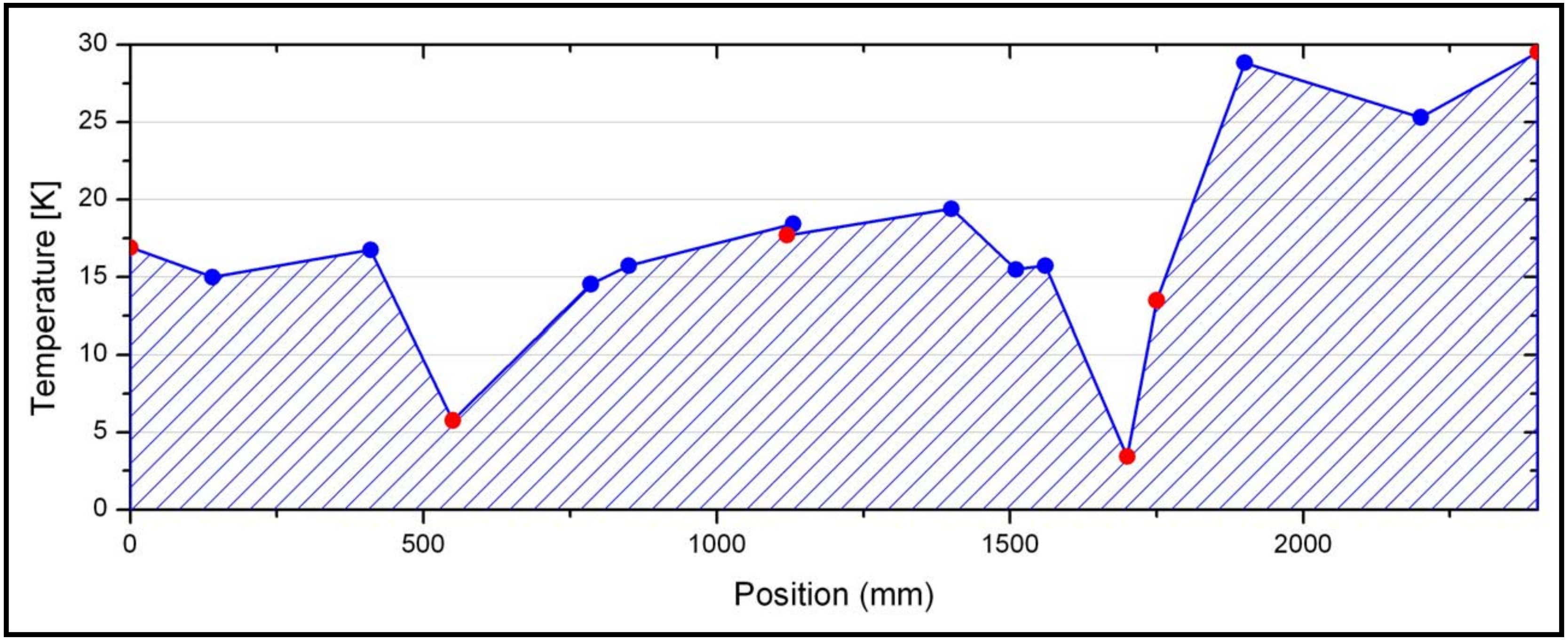
MCP



CSR Cryo System

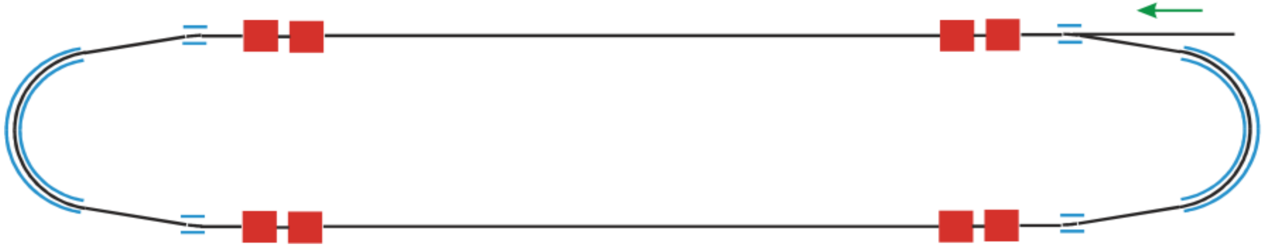


Prototype Temperature Distribution



Electrostatic storage ring

Lattice of the three existing electrostatic storage rings:



deflector

ρ=0.25 m

g=3cm

E_{max}=20·Q keV

Electrical field E_ρ in the deflector on the central orbit

$$E_\rho = \frac{2 \cdot E / Q}{\rho}$$

E - Energy of the ions

Q- Charge of the ions

ρ - radius of the central orbit in the deflector

cylindrical deflector

electrode voltage U_e

$$U_e = \frac{2 \cdot E}{Q} \ln \frac{\rho \pm g/2}{\rho}$$

for $\rho >> g$ $U_e \approx \frac{E}{Q}\frac{g}{\rho}$

independent of the ion mass and charge !!!

molecules with masses up to several thousand AMU can be stored

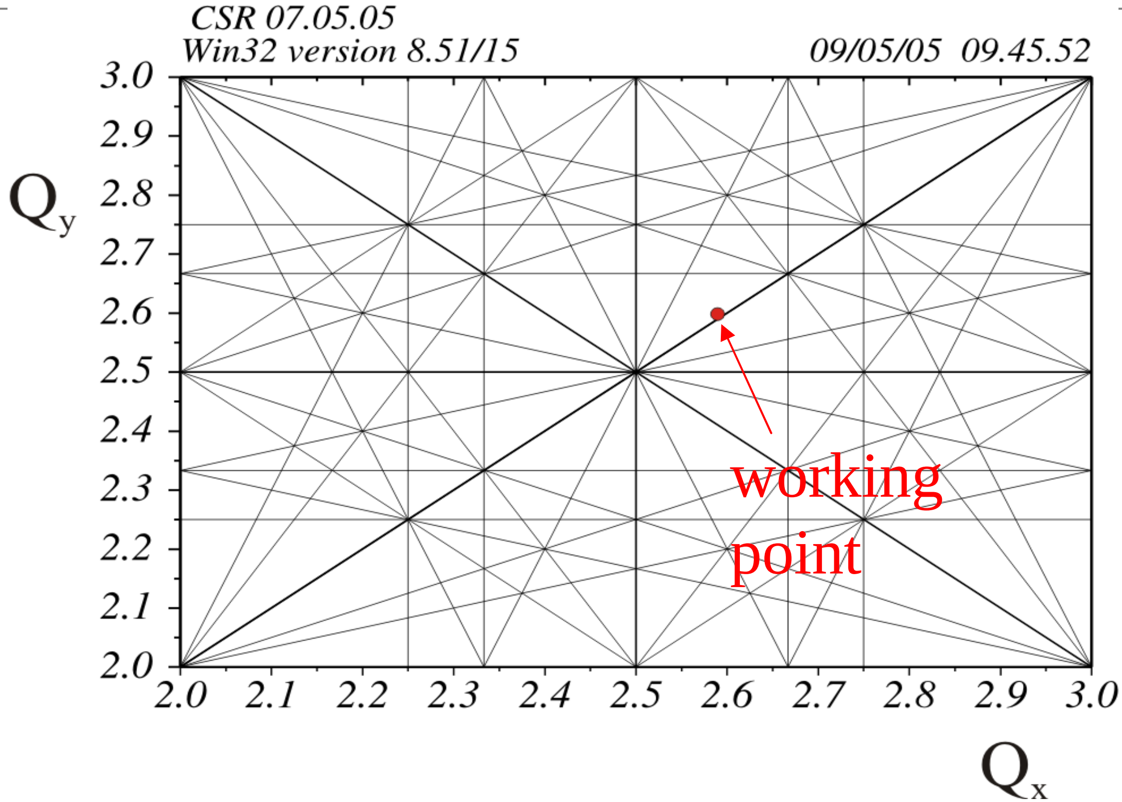
CSR design

E_{max}= 300 ·Q keV

and $U_{e,max}$ < 20 kV g = 6 cm

$\Rightarrow$ ρ=1m

Lattice parameter standard mode



quadrupole settings:

Q_1: k= 5.58 1/m^2

⇔ 4.19 kV (E/Q=300 kV)

Q_2: k=-7.04 1/m^2

⇔ -5.28 kV (E/Q=300 kV)

$Q_x = 2.59$ $Q_y = 2.60$

$ß_{x,max} = 12.44$ m $ß_{y,max} = 6.12$ m

$D_{x,max} = 2.08$ m

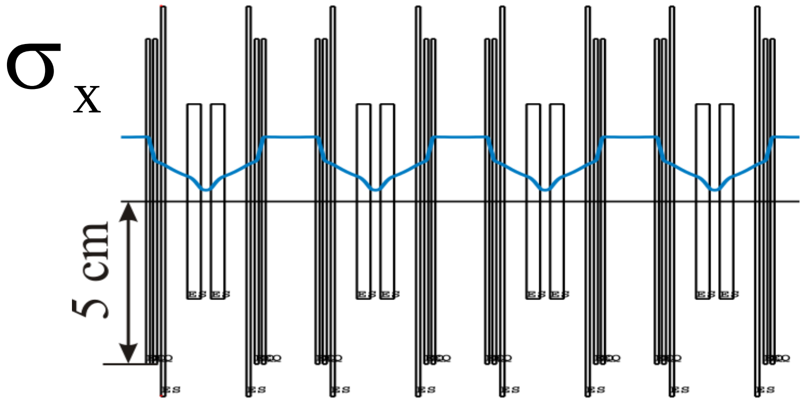
α –parameter: $\alpha = \frac{\Delta C / C}{\Delta p / p}$ α=0.32373 C-length of the closed orbit

η-parameter: $\eta = \frac{\Delta f / f}{\Delta p / p} = \frac{1}{\gamma^2} - \alpha$ η=0.6734 (γ=1)

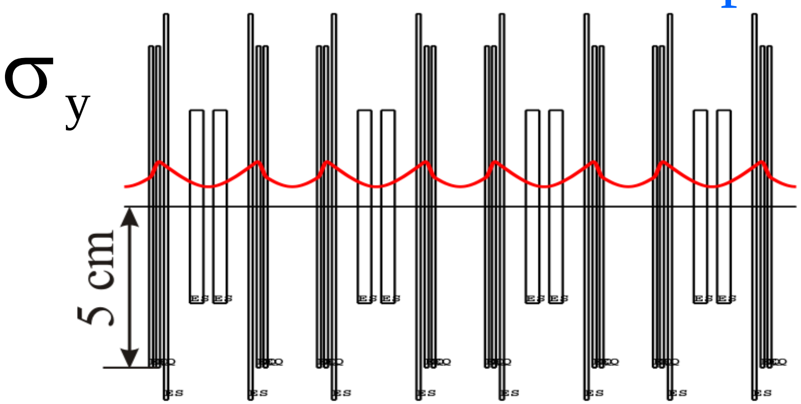
ß function and envelopes

COSY infinity calculation

horizontal beam envelope

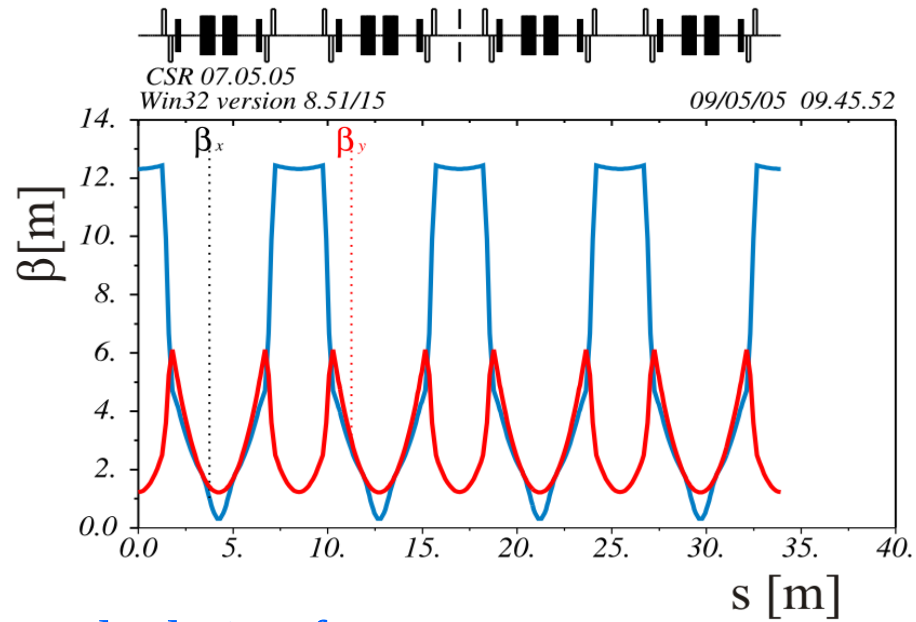


vertical beam envelope



MAD calculation

Horizontal and vertical ß function



calculation for

ε_x=100 mm·mrad ε_y=100 mm·mrad

$$\varepsilon_x = \frac{(2\cdot\sigma_x)^2}{\beta_x} \qquad \varepsilon_y = \frac{(2\cdot\sigma_y)^2}{\beta_y}$$

quadrupole settings:

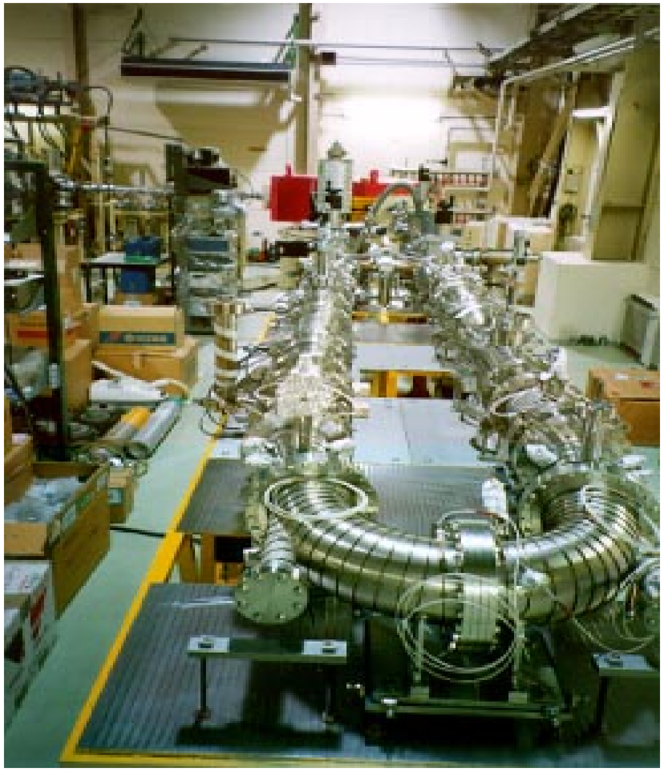
Q_1: k= 5.58 1/m² ⇔ 4.19 kV (E/Q=300 kV)

Q_2: k=-7.04 1/m² ⇔ -5.28 kV (E/Q=300 kV)

Electrostatic Storage Rings: 1st Generation

ELISA
Aarhus

Tokyo Metropolitan University



KEK Tsukuba

E_{max}/Q= 20 kV, $C_0 \approx$ 8 m