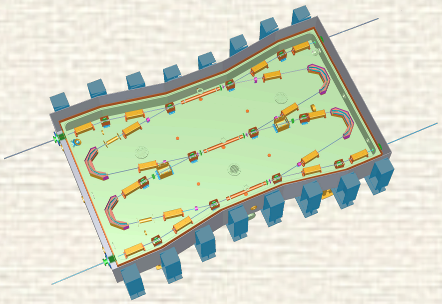
DESIREE

A Double ElectroStatic Ion Ring ExpEriment



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COOL05

Galena, Illinois, 21 September 2005

Why Electrostatic Rings?

Using electrostatic optics, rather than magnets, in a low-energy storage ring has some advantages, and also some disadvantages

The main issue, at least in our case, is cost: A pair of deflection plates is much cheaper than a magnet. They also take less space and are lighter, allowing a more compact overall design.

Heavy singly charaged ions in a small ring are slow, and for slow particles the magnetic force, which is proportional to v, is small. This is, however, not as strong an argument as it may seem, since the only consequence is that heavy particles are slower in a magnetic ring than in an electrostatic ring.

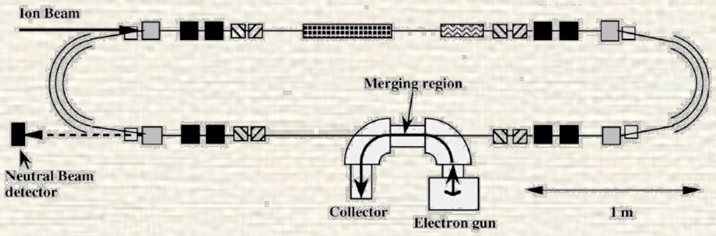
Voltages are independent of mass (for an ion source on a given potential), which makes injection of rare ion species simple

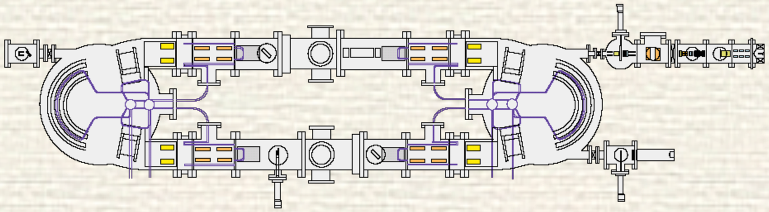
There are fewer design tools for electrostatic rings and less experience in building them. Also, electrostatic elements tend to have larger aberrations than magnetic ones.

Other Electrostatic Rings

The first electrostatic ring for atomic and molecular physics, ELISA, was built in Århus almost 10 years ago (S.P. Møller, NIM A 394 (1997) 281).

Similar rings have later been built at KEK and Tokyo Metropolitan University

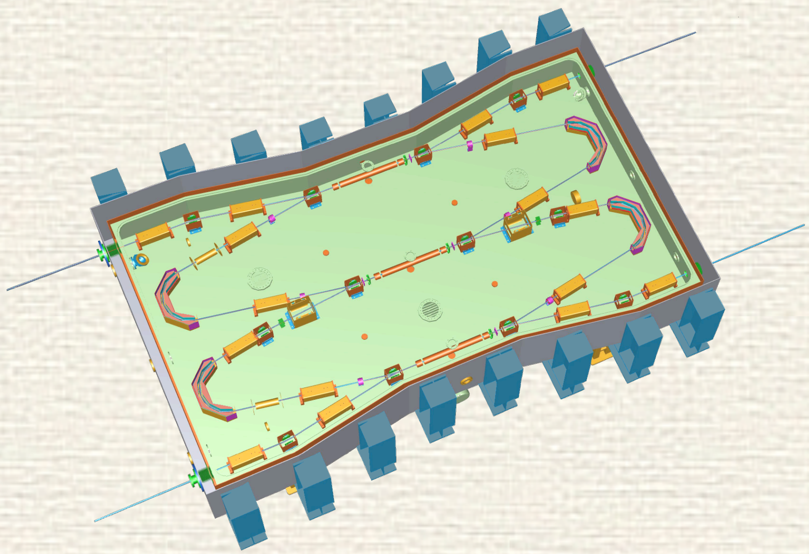




Still other electrostatic rings are being designed or built in Frankfurt and Heidelberg, and one is considered for deceleration of antiprotons at FAIR.

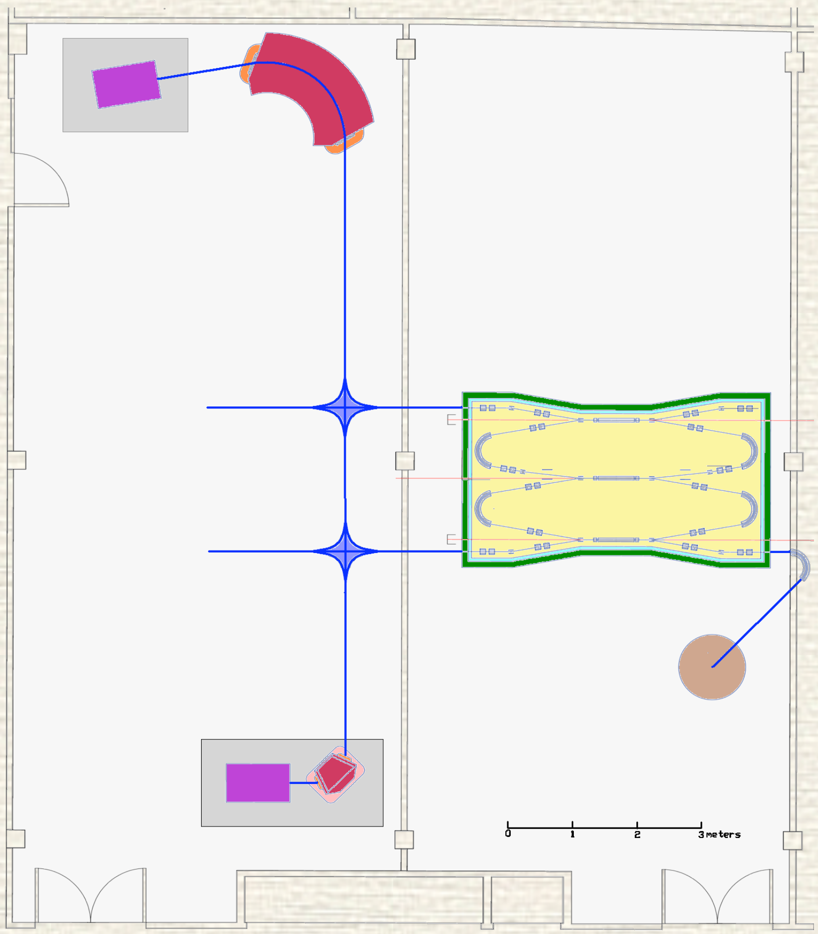
Features of DESIREE

The rings of DESIREE are similar to ELISA in that they have an oval shape with 160º cylindrical bends and 10º parallel-plate deflectors which are also used for injection (and possibly extraction). Four quadru-pole doublets per ring provide focusing.



DESIREE is different from other rings built so far in that it consists of two rings with a common straight section for merged-beam experiments, and that it is housed in a single vacuum vessel/cryostat that can be cooled to cryogenic temperatures.

Overall Layout



It will have at least two external ion sources and will be used together with other equipment such as femtosecond lasers.

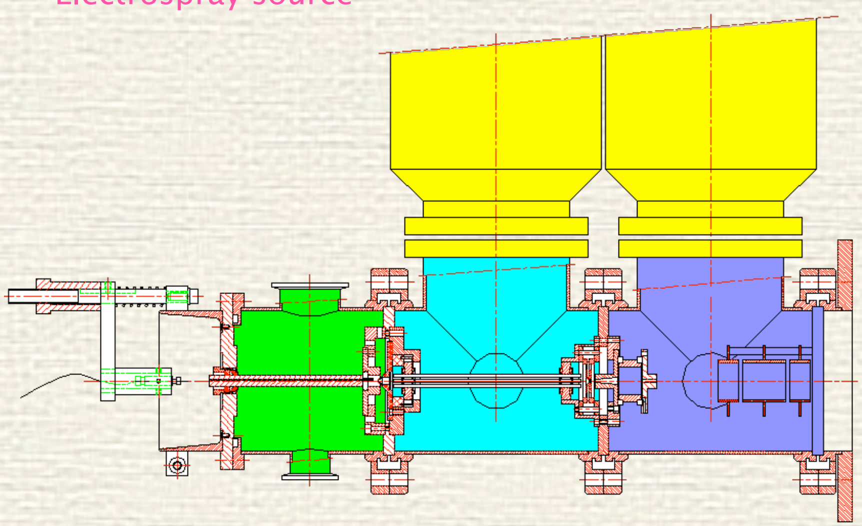
DESIREE was originally foreseen to be located at MSL, but it is now planned to put it at the Department of Physics at Stockholm University.

Ion Sources

Injection will be made from two ion-source platforms, at 100 kV and 25 kV maximum voltage, with analyzing magnets.

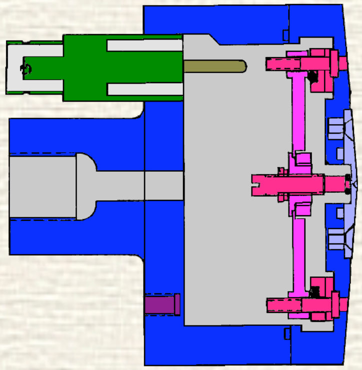
Ion sources include: “Nielsen” source, sputter source, electrospray, expansion source and a small ECR.

Electrospray source



Courtesy of Aarhus University

Expansion source



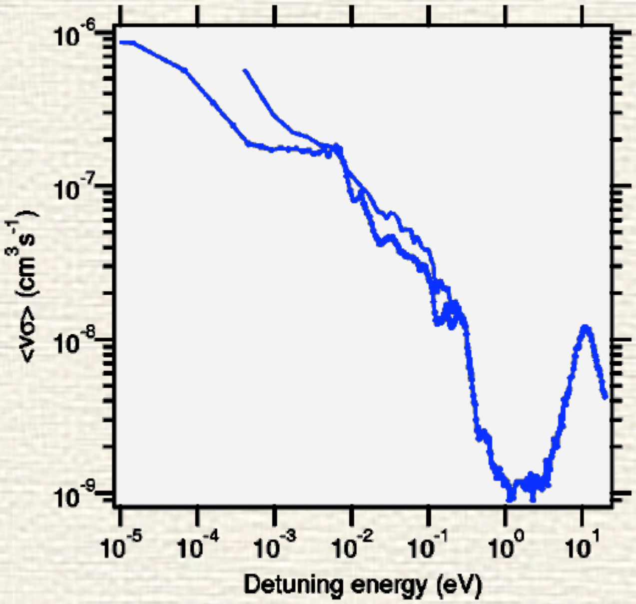
Adopted from R.E. Continetti, UCSD

Low Temperatures

The rings will be cooled with cryogenerators to 5-10 K.

This will allow internal degrees of freedom of (infrared-active) molecular ions to cool radiatively, and ions produced in a cold ion source will stay cold. Also, the vapour pressure of all gases except H_2 and He is below 1×10^{-13} mbar at T < 18 K.

Development in atomic and molecular physics since 1990: Cooled ions -> cold electrons (≥20 K) -> low quantum states. Figure shows rate for $H_3^+ + e^- \rightarrow H_2 + H$ with ions from hot plasma source/cold expansion source.

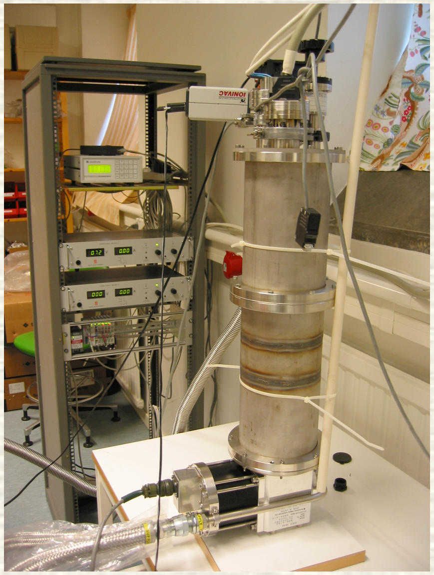


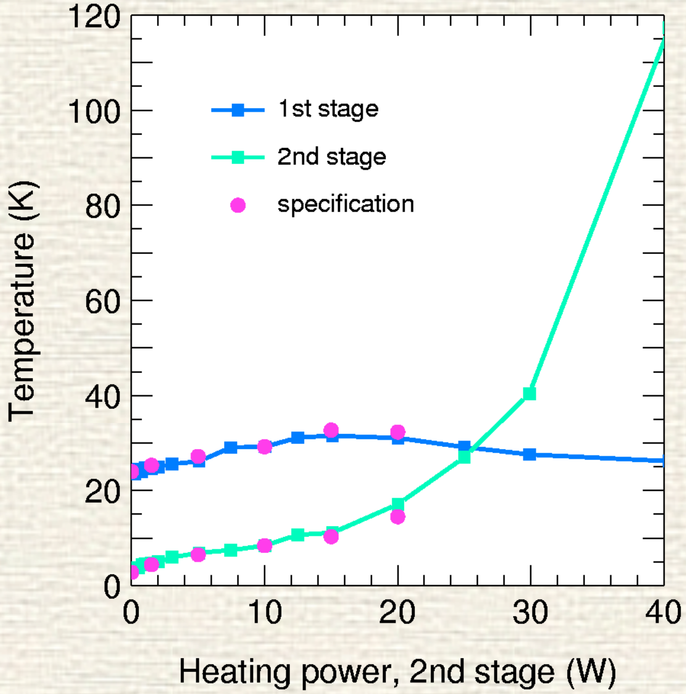
McCall et al., PRA 70, 052716 (2004)

DESIREE will allow measurements as a function of temperature by controlling the cryostat temperature from room temperature and down.

Cryogenerator Tests

Tests have been performed on a Sumitomo CSW71/RDK-415D compressor/cryogenerator to verify its specified cooling power and to measure cooling power at temperatures where it is not specified.





Numerical Data

Outer dimensions: 5 m × 3 m × 1 m

Outer vacuum vessel: Soft steel, thickness 5 mm

Multilayer insulation between room temperature and 60 K: 30 layers

Screen at 60 K (cryogenerator 1st stage): Copper, thickness 3 mm

Multilayer insulation between between 60 K and “4 K”: none

Inner vacuum vessel at “4 K” (cryogenerator 2nd stage): Aluminium, 5 mm thick

Bottom of vacuum vessel: Aluminium, 12 mm thick

Weight: total 7 ton, lid 1.5 ton

Seals: Viton (outer vessel), Helicoflex (inner vessel)

Feedthroughs: Ion beam, laser, detectors, electrical

Operational temperature: “4 K” to room temperature

Cooling power: 30 W @ 15 K (2 W @ 4 K), 100 W @ 60 K, with two cryogenerators

Pumps: Turbopumps (outer), turbo+sublimation (inner), plus cryopumping when cold

Bakeout temperature: 150 ºC

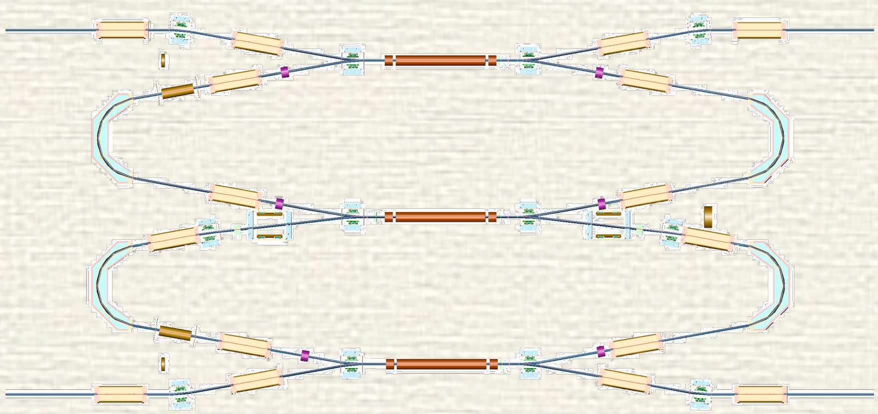
Vacuum: 1e−5 mbar (outer), 1e−11 mbar (inner) when warm

All numbers are approximate

Ring Layout

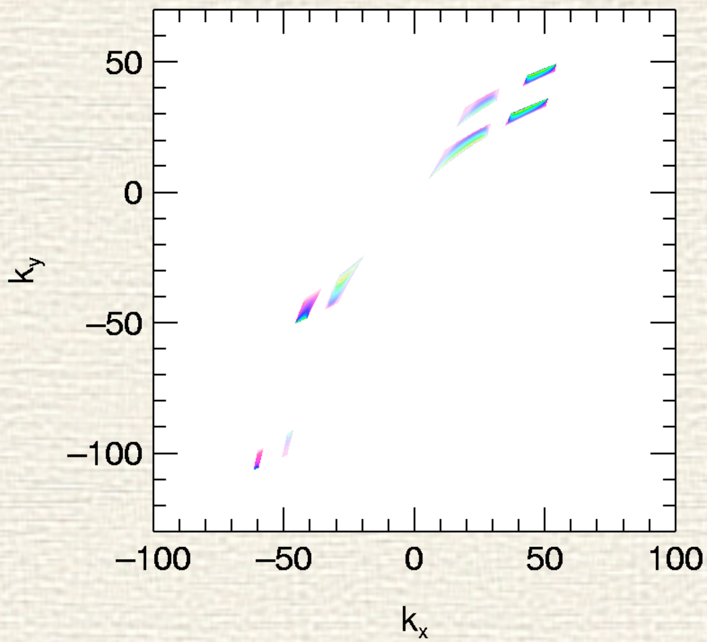
	Ring 1	Ring 2
160º cylindrical bends	2	2
Quadrupole doublets	4	4
10º deflections	4	2
Variable deflections	–	6
Symmetries	2	1

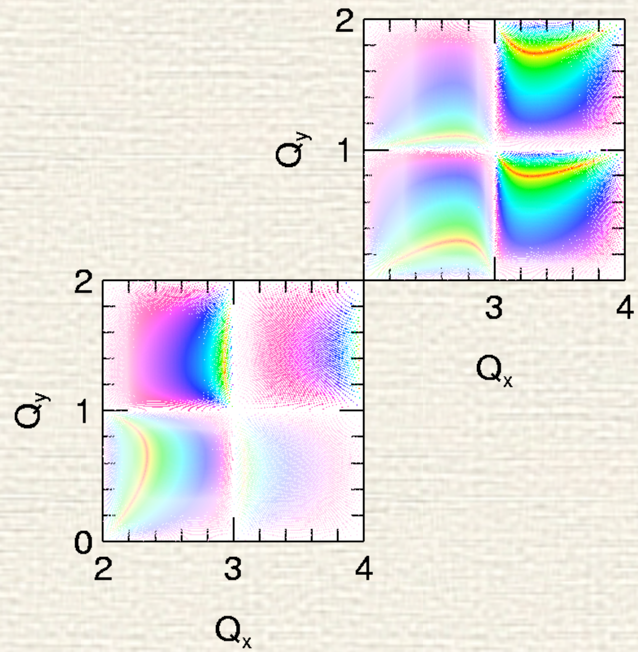
Platform voltage:	< 25/100 kV
Electrode voltage:	< 16 kV
Beam energy:	5–100 q keV
Ion mass ratio:	1–20 (q = ±1)



Working Diagram, Ring 1

Stable motion in ring 1 from linear transfer matrices





Red/pink is round/oval beams in common straight section
Saturated/unsaturated is small/large beams in common straight section

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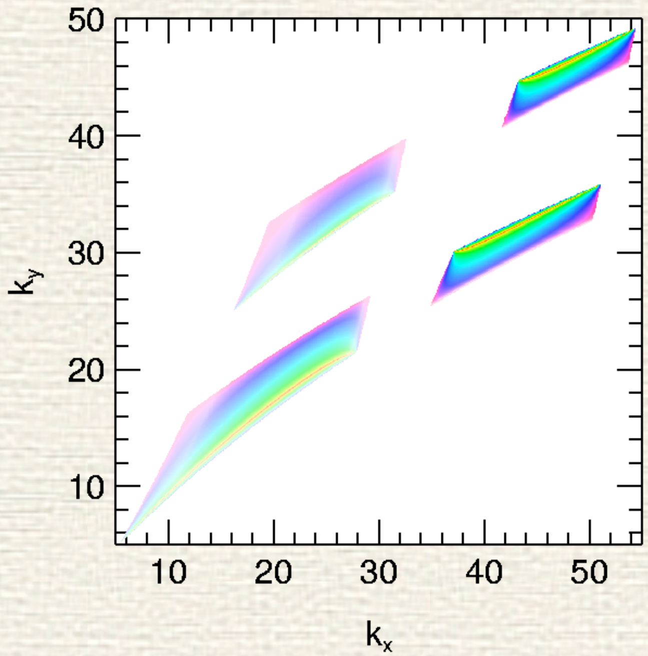

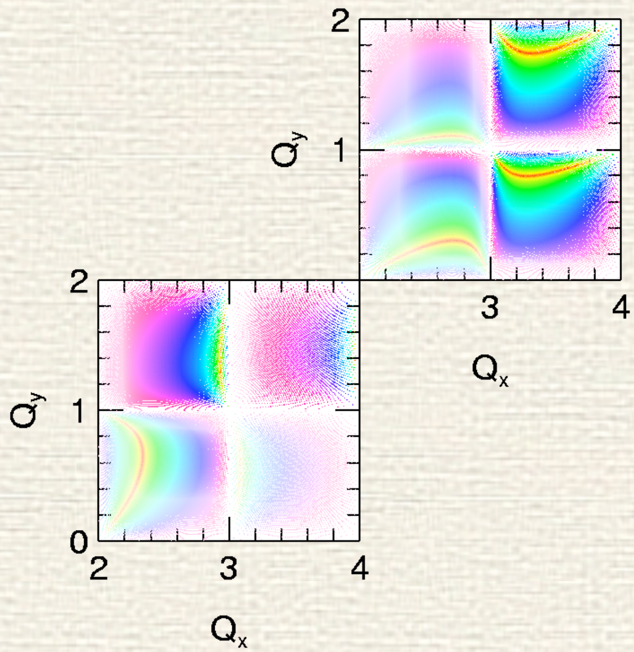

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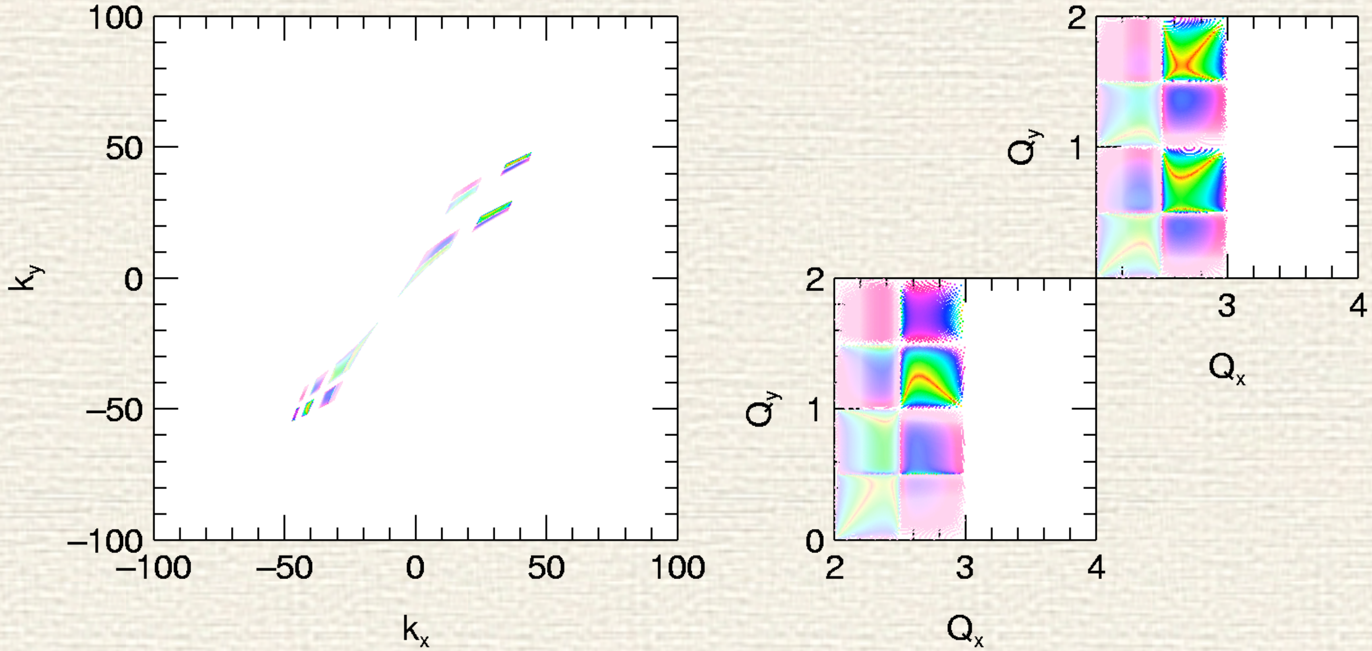
Working Diagram, Ring 2

Same quadrupole voltage in both halves, $m_1 = m_2$



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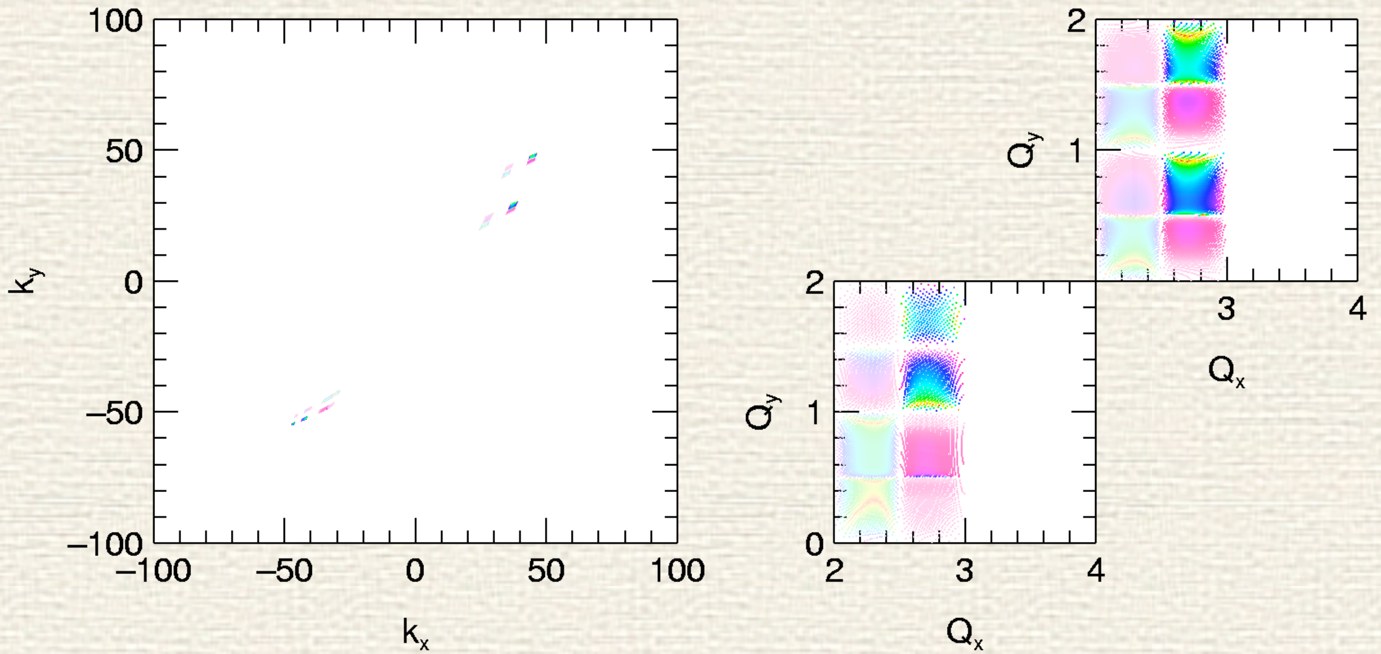
Working Diagram, Ring 2

Same quadrupole voltage in both halves, $m_2 = 20\ m_1$



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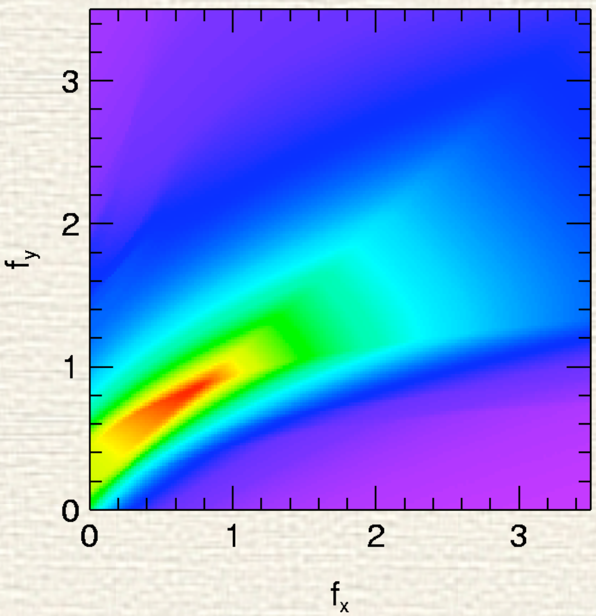
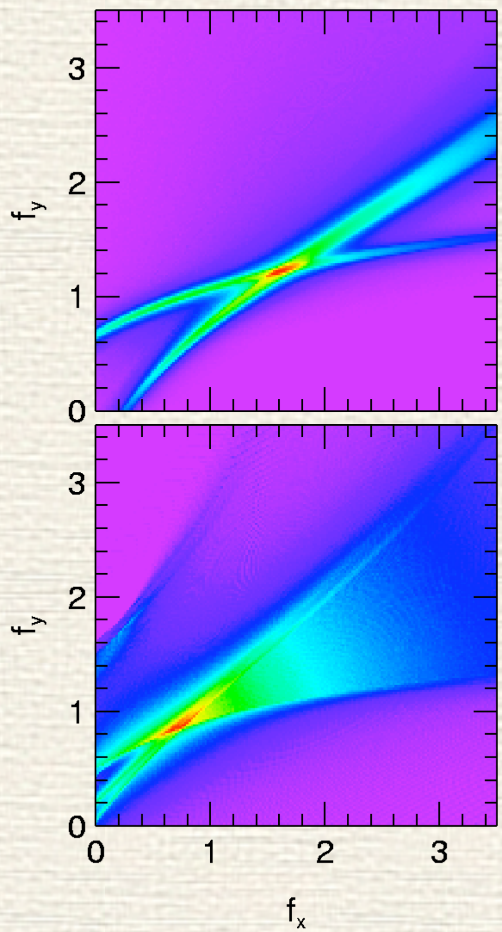
Working Diagram, Ring 2

Size of stable areas as a function of quadrupole assymetry





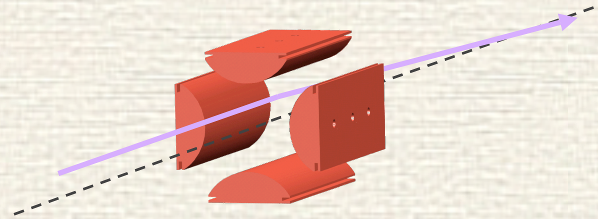
Small, round beams on injection straight section

Small, round beams on common straight section

Aberrations

Electrostatic lenses, such as quadrupoles, in general have larger aberrations than magnetic ones since the particles change energy inside them. The focal length of a thin electrostatic quadrupole is

$$f = \frac{U_{\mathrm{acc}}}{U_{\mathrm{el}}}\frac{r^2}{l} - \frac{x^2}{l}$$



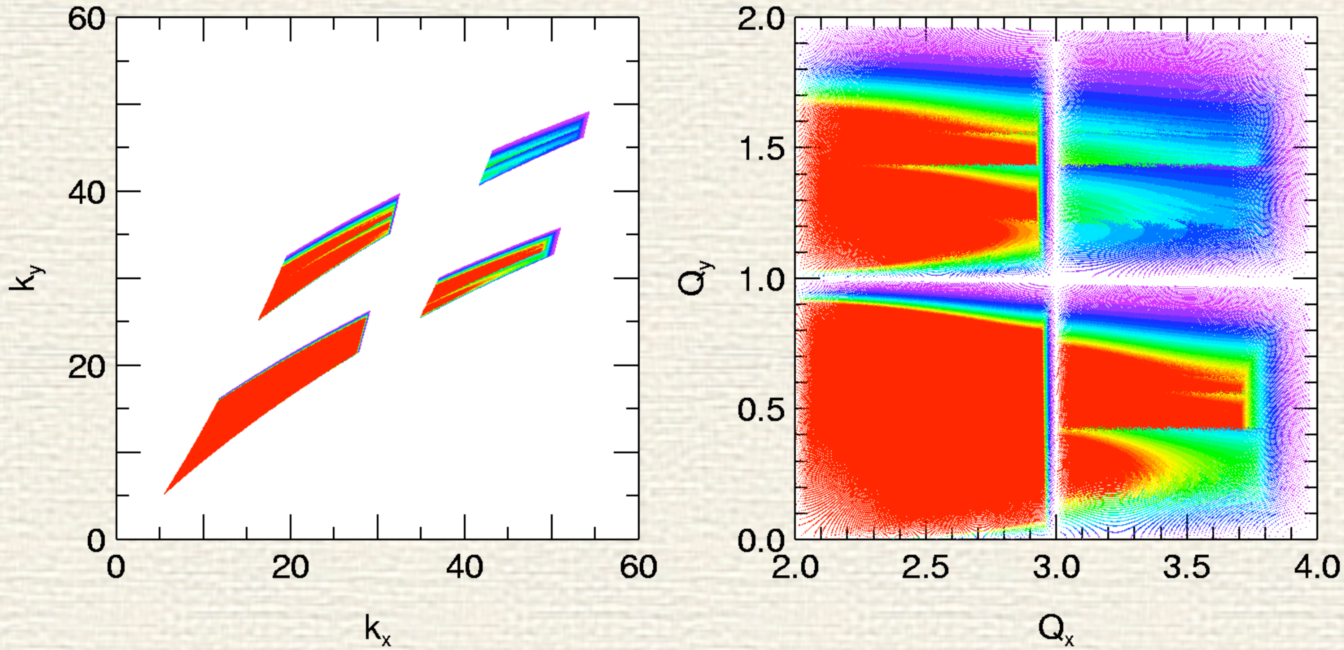
Here, U_{acc} is the acceleration voltage, U_{el} is the electrode voltage, r is the lens's inscribed radius, l is the electrode length and x is the particle's distance from the optical axis.

This effect has octupole character and may limit the dynamic aperture of the rings, but could in principle be compensated for.

(The velocity change is what makes deflection plates and electrostatic bends focusing. Non-linearities are of sextupole character or higher.)

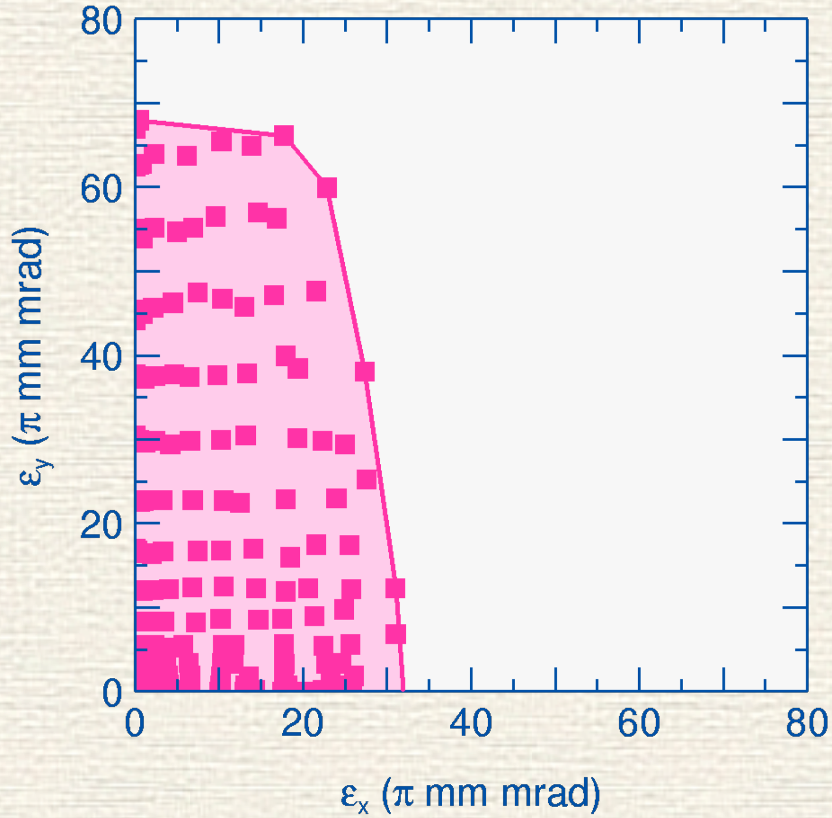
Dynamic Aperture

Stable motion in ring 1, now for emittances varying from 0.1 (pink) to 100 (red) mm mrad. Linear transfer matrices plus octupole component in quadrupoles.



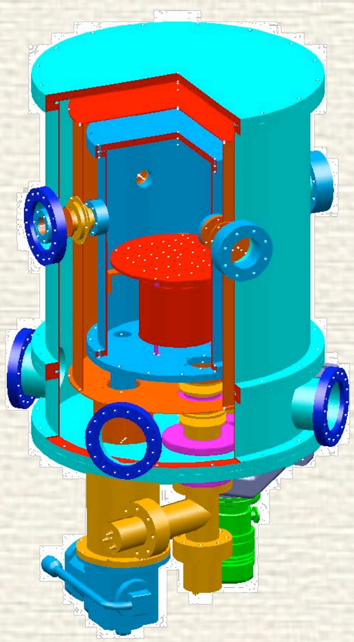
Dynamic Aperture

Stable motion in ring 1, example of result from particle tracking using SIMION. Time-consuming and limited accuracy - good tools missing.



Test Setup

In order to test details of the design, such as mounting of cryogenerators, feedthroughs for detectors and laser light, vaccum and bakeout, a test cryostat is being set up. It will also be used for ion-trap experiments.



Experiments

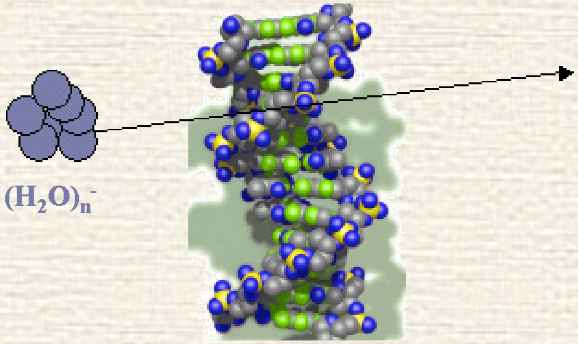
Charged-particle reactions and mutual neutralisation important for chemistry of interstellar clouds and the atmosphere

Destruction of DNA on the atomic level, double-strand break by free radicals

Electron-capture dissociation, fullerene collisions

Lifetime measurements of metastable ions, laser spectroscopy

...etc.



Acknowledgements

Design group: Leif Liljeby, K.-G. Rensfelt, Guillermo Andler, Lars Bagge, Mikael Blom, Håkan Danared, Anders Källberg, Sven Leontein, Patrik Löfgren, Andras Paál, Kjell Schmidt, Ansgar Simonsson

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