Low Energy Beam Transport for Ion Beams created by an ECRIS

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Low Energy Beam Transport for Ion Beams created by an ECRIS

- what is coming in?

  ➭

  extracted ions, represented by a certain distribution of the 6D phase space volume.

Low Energy Beam Transport for Ion Beams created by an ECRIS

- what is coming out?

  The same sized 6D phase space, may be distorted by non linear forces, but the projections might behave differently.

  A beam line might incorporate coupling between the different planes: space charge, magnetic lenses --- even quadrupoles when they are skewed will do so.

Low Energy Beam Transport for Ion Beams created by an ECRIS

- what is coming in?

Let's have a closer look to the beam line input

model for extraction

- Magnetic flux density is high: several T.
- Ion energy is low: fraction of eV.

    - Larmor radius of ions is sub-mm.
    - ion-ion collissions have minor effect on the path of the ion.

- Inside the plasma $|E| \sim 0$

    - Equation of motion is given by |B| and its direction only.

Consequences

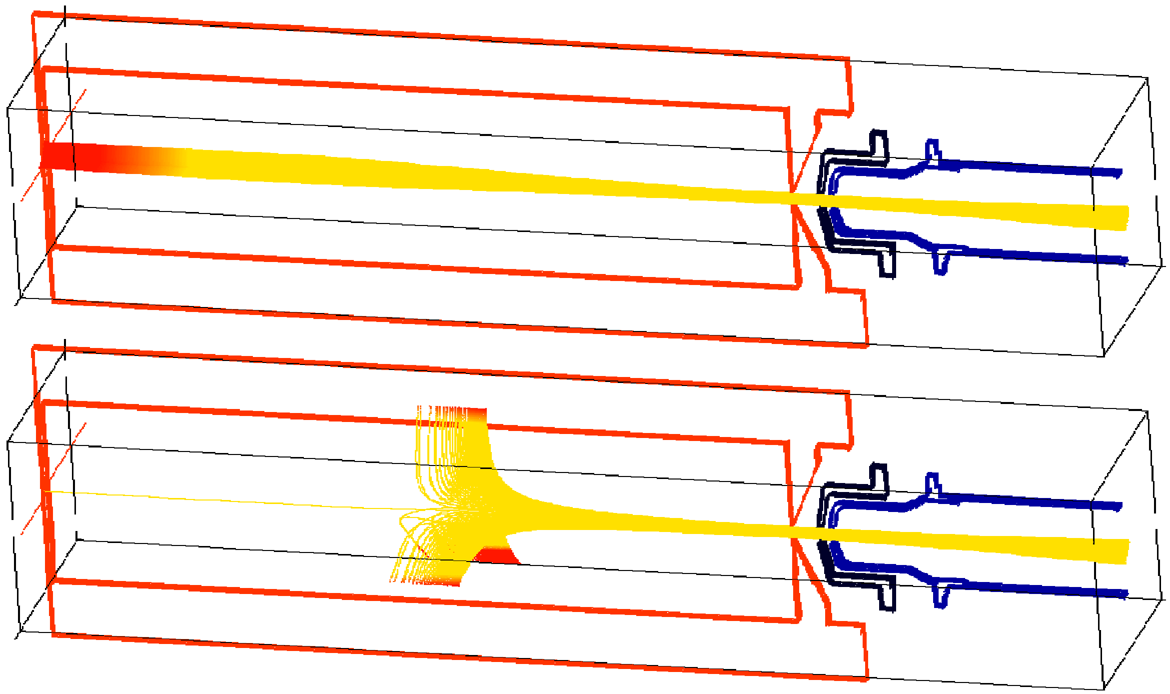
- Each magnetic field lines going through the extraction aperture is an allowed path for the ion to be extracted.
- If the magnetic flux density is increasing along the path of the field line, the particle will transfer longitudinal momentum (direction of field line) into rotational momentum (perpendicular to the field line).
- For an ion without momentum in field direction, extraction is possible only if the magnetic flux density at its origin is at least as high as in the extraction aperture.

Consequences

- It should be mentioned, that this simulation does not cover the plasma generator, we only check whether it is possible to extract.

!!!

- Space charge and space charge compensation, charge state distribution, temperatures are important and to be included, but this has not been done for all cases here.



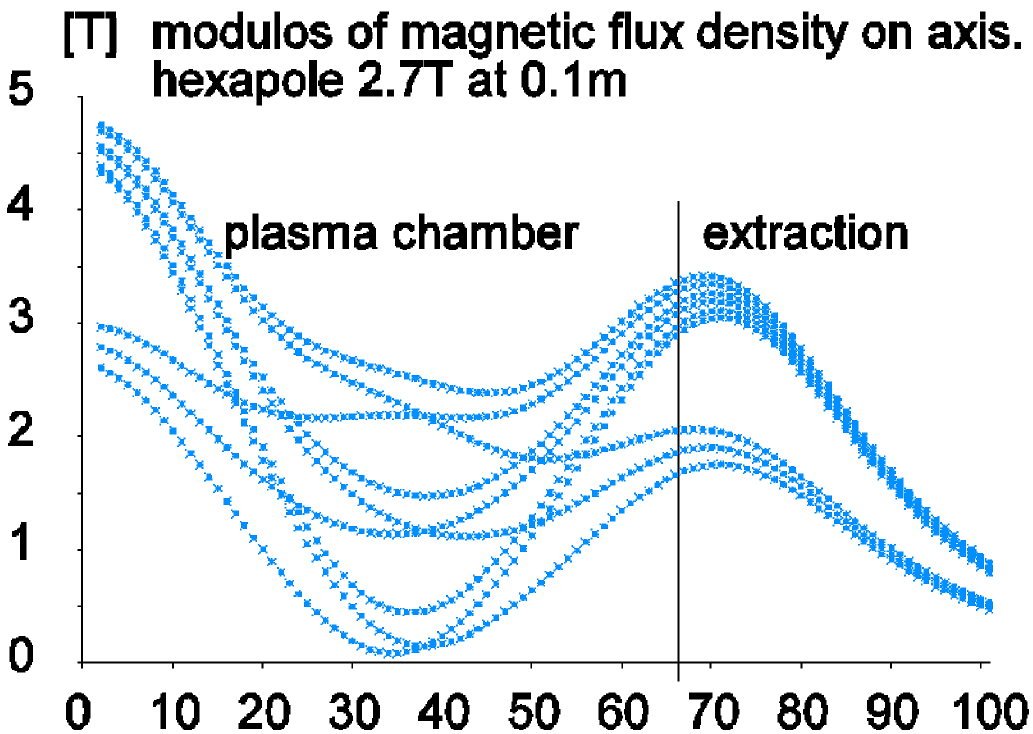
Different operating conditions as example for MSECRIS:

- top: all coils with their design value; mid solenoid switched off, extraction is made from the back side of the plasma chamber.

- bottom: all coils with their design value; injection coil to 60%, extraction is made from the cusp loss lines.

Different origin of ions which can be extracted. When the color of the field line becomes red, the flux density is above the flux density of the extraction aperture.

Consequences



magnetic flux density on axis for different coil settings:

injection side: 100%, 60%

mid coil: -100%, 0, 100%

extraction side: 100%, 60%

Simulation has to be made for the full range of possible magnetic flux density distributions.

For a system with three solenoidal coils nine simulations are minimum required for each hexapolar setting.

Not mentioning the influence of charge state distribution, space charge, temperature of electrons and ions, ...

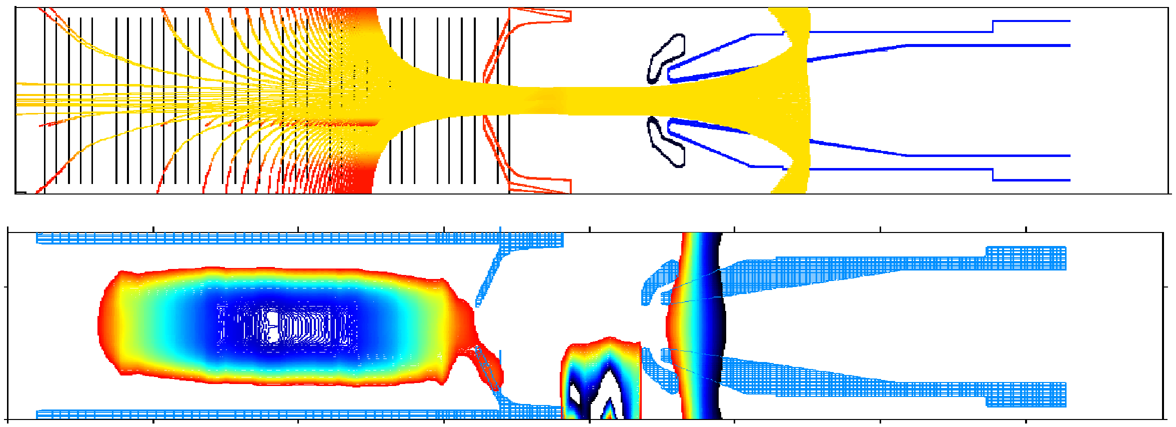
what is common for all ECRIS?

we did compare different existing ECRIS as well as future ECRIS:

- CAPRICE, 14.5GHz, two solenoids, hexapole by permanent magnets
- SUPERNANOGAN, 14GHz, Mirror / hexapole by permanet magnets
- APHOENIX, 18GHz, 2 (3) solenoids, hexapole by permanent magnets
- SECRAL,18GHz, 24GHz, fully sc
- MSECRIS, 28GHz, fully sc
- RIKEN, 28GHz, fully sc
- ARCECRIS, different magnetic design

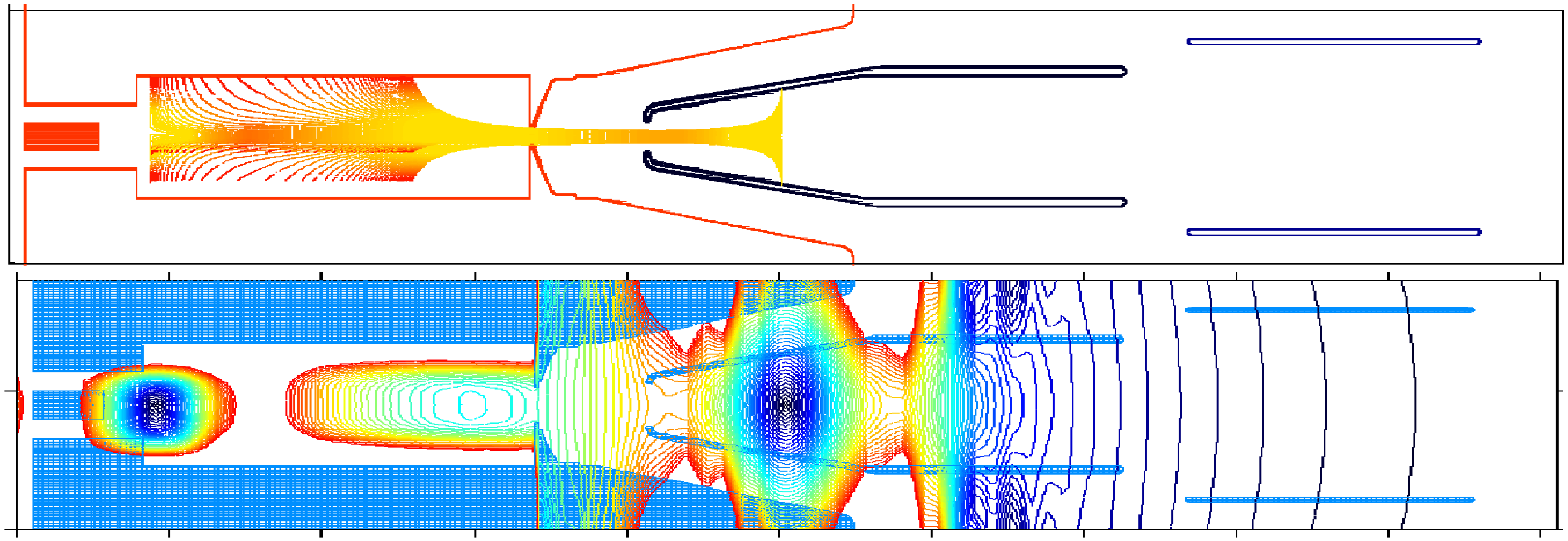
Note: most data are taken from literature. Reliable?

CAPRICE

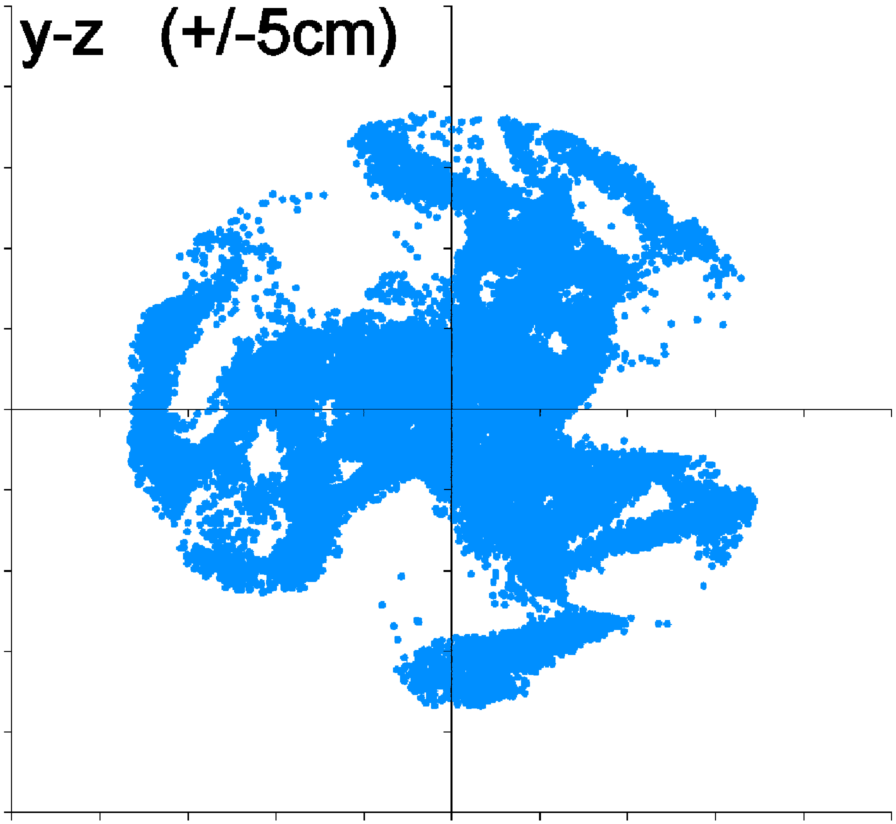


extracted ions will be shown later.

SUPERNANOGAN

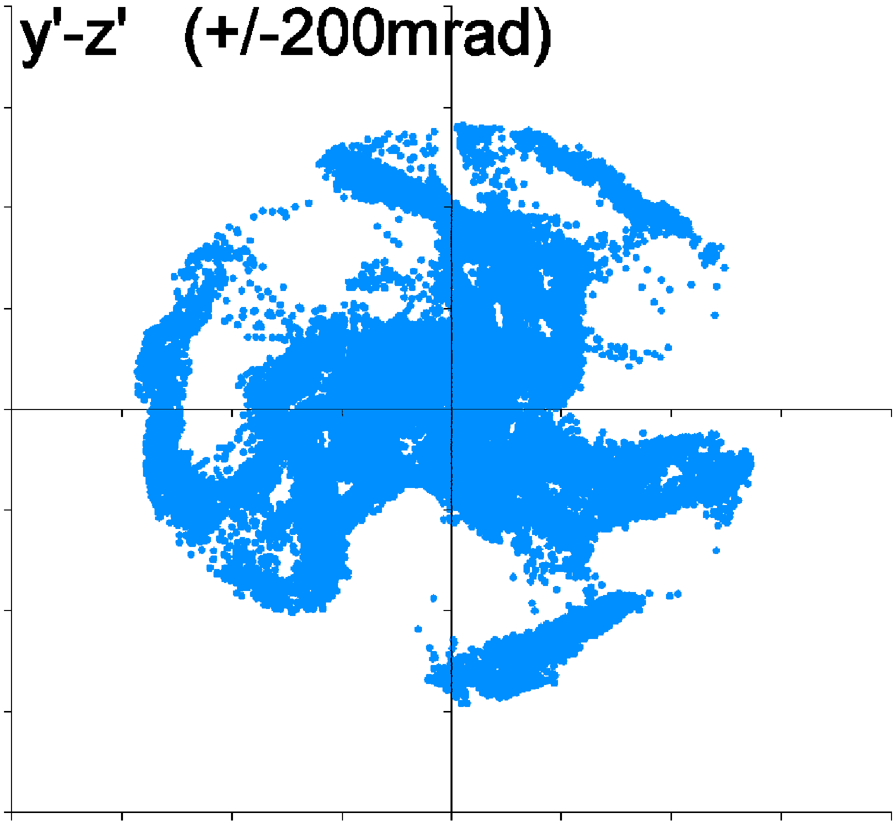


SUPERNANOGAN



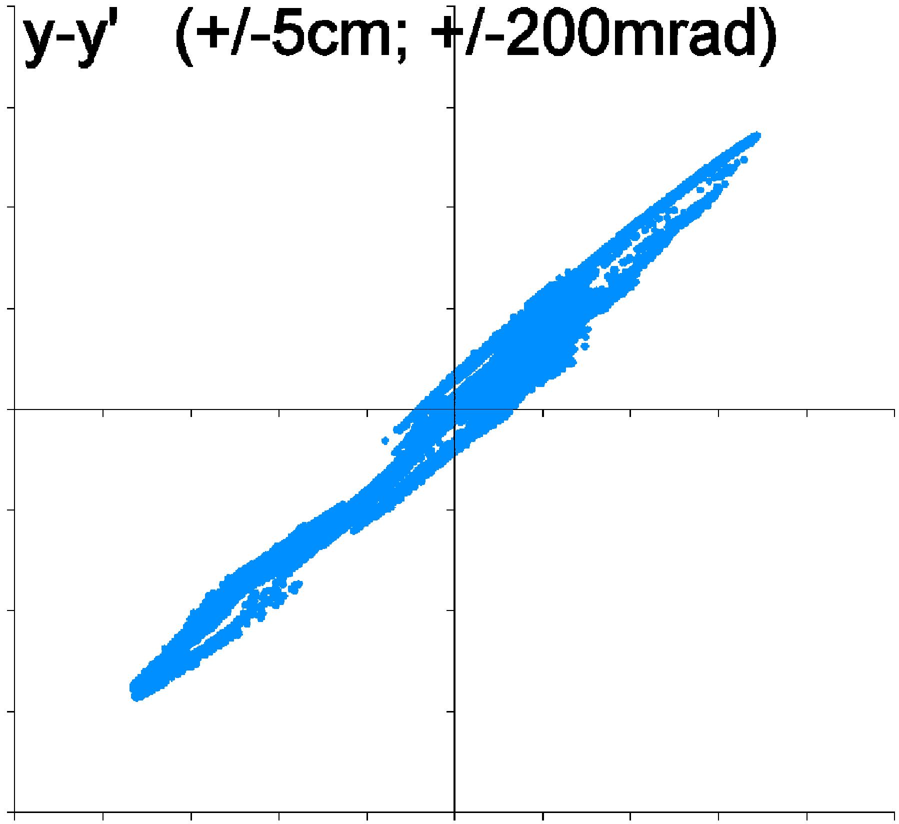
beam properties after extraction: real space

SUPERNANOGAN



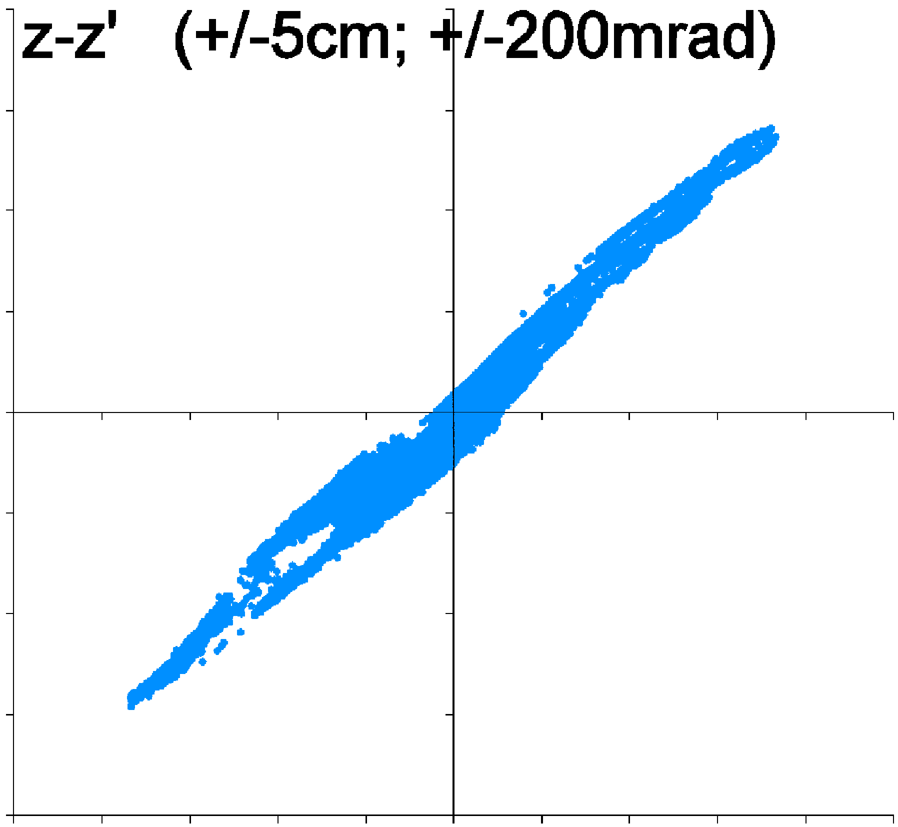
beam properties after extraction: momentum space.

SUPERNANOGAN



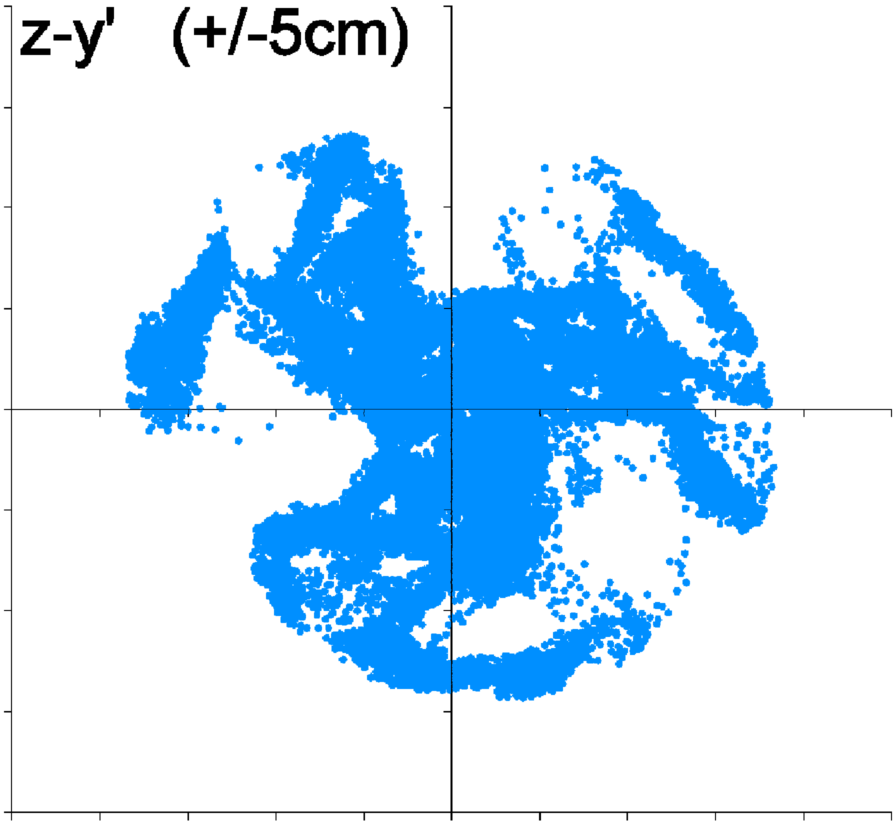
beam properties after extraction: vertical emittance.

SUPERNANOGAN



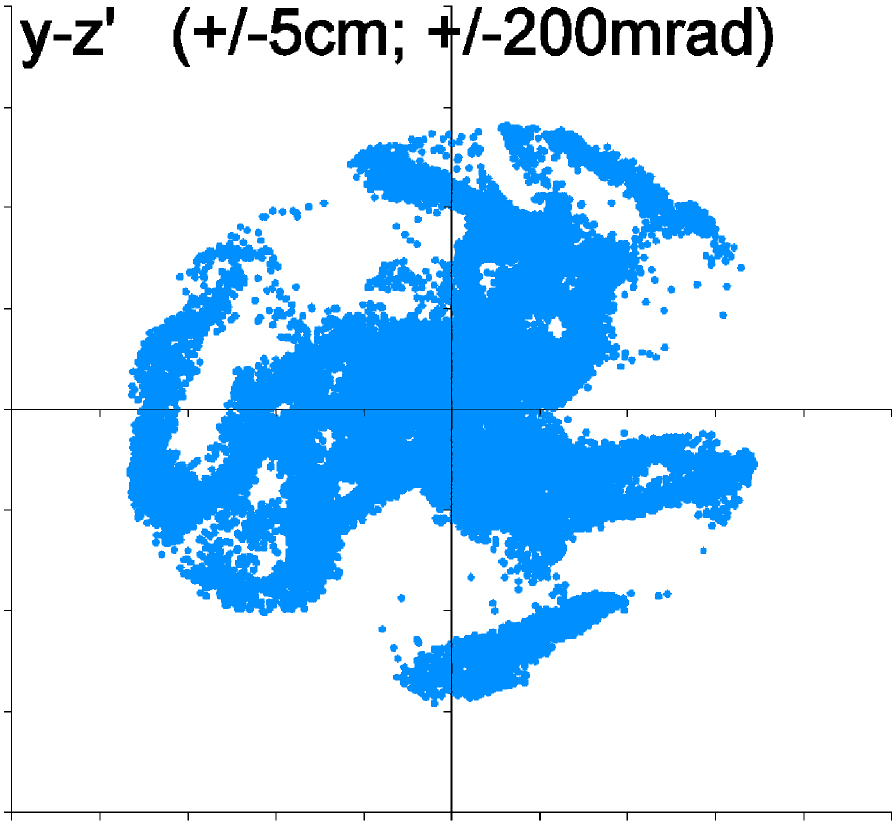
beam properties after extraction: horizontal emittance.

SUPERNANOGAN



beam properties after extraction: different projection.

SUPERNANOGAN

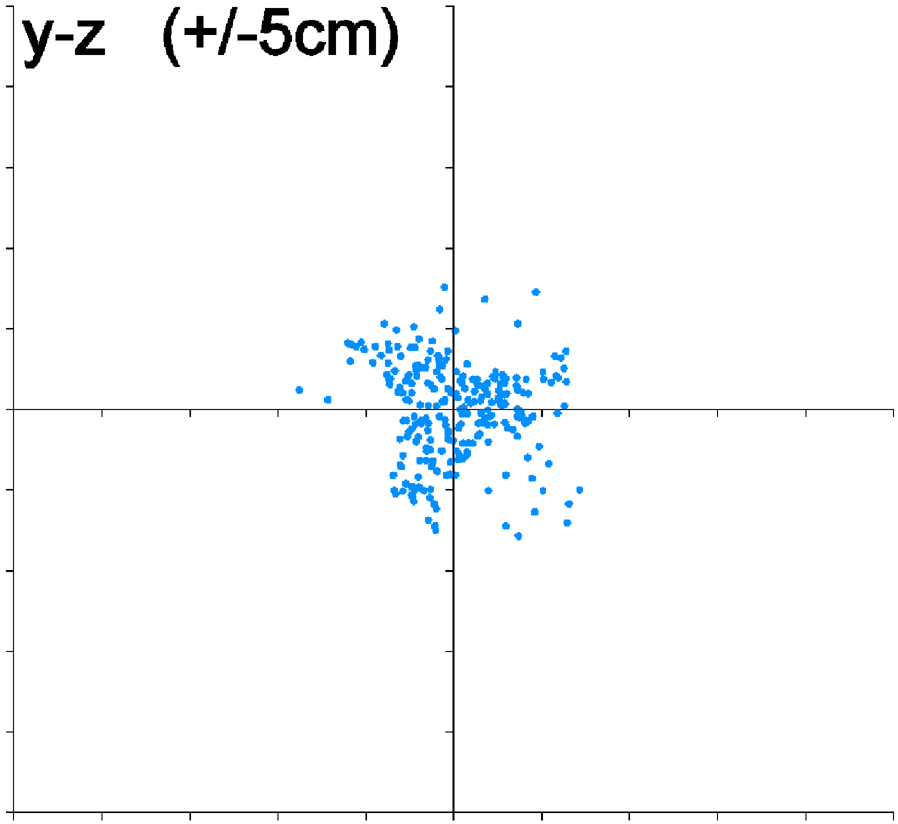


beam properties after extraction: different projection.

MSECRIS

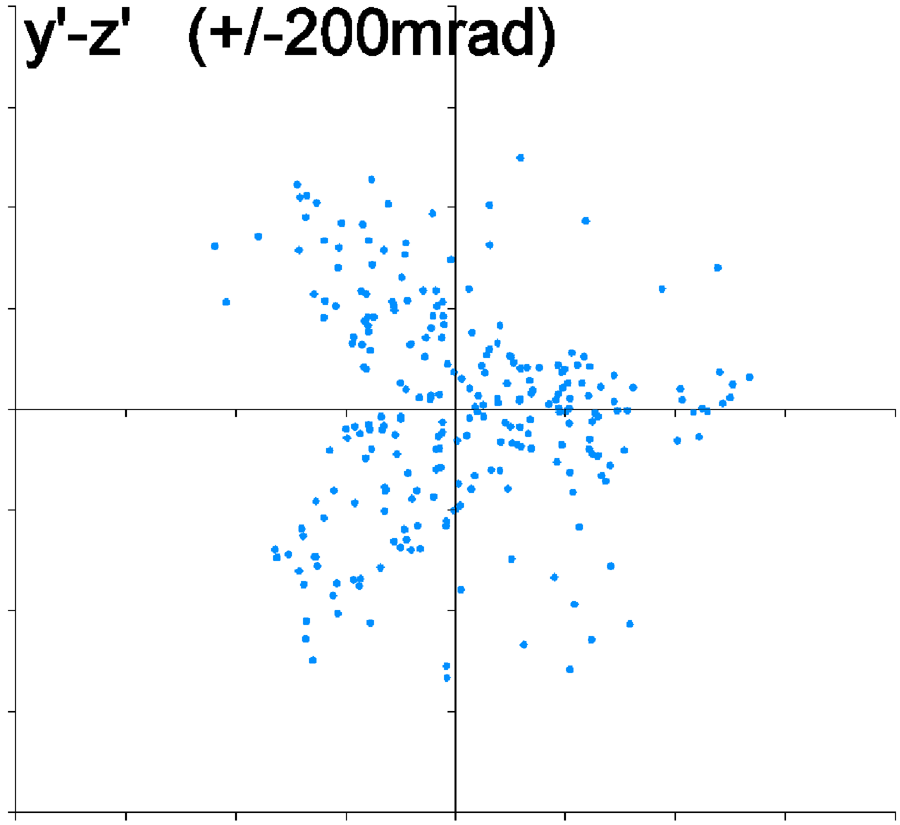
magnetic field settings: all coils design value: extraction is made from the back side of the plasma chamber, the triangular shape is defined there.

MSECRIS design values



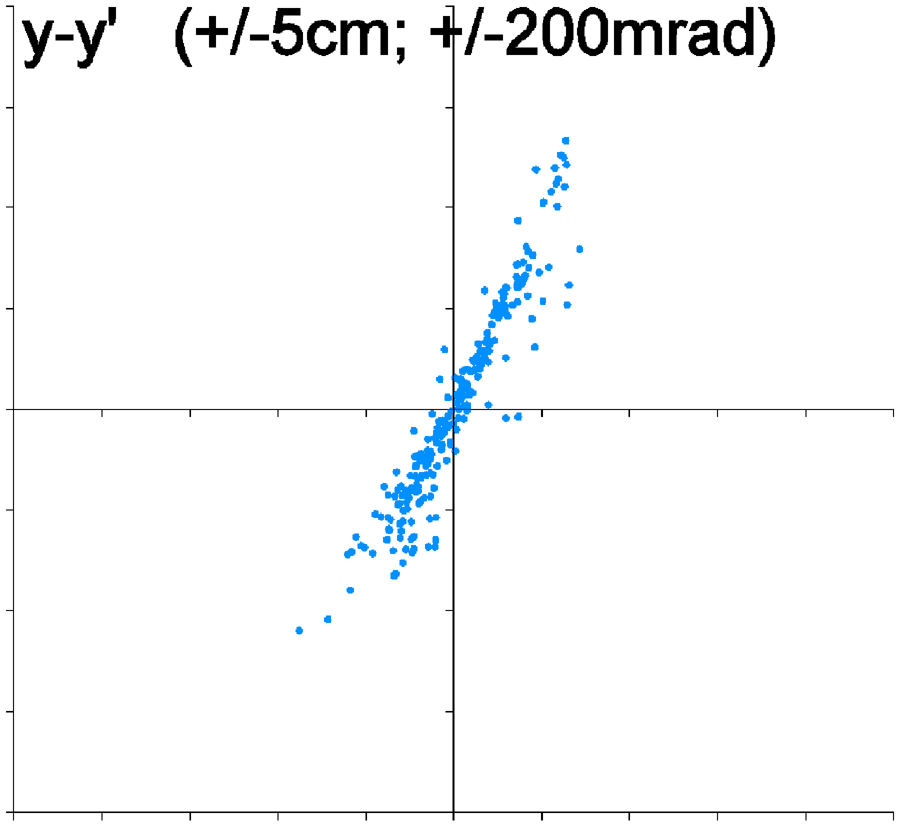
Different transverse projections of the 6D phase space

MSECRIS design values



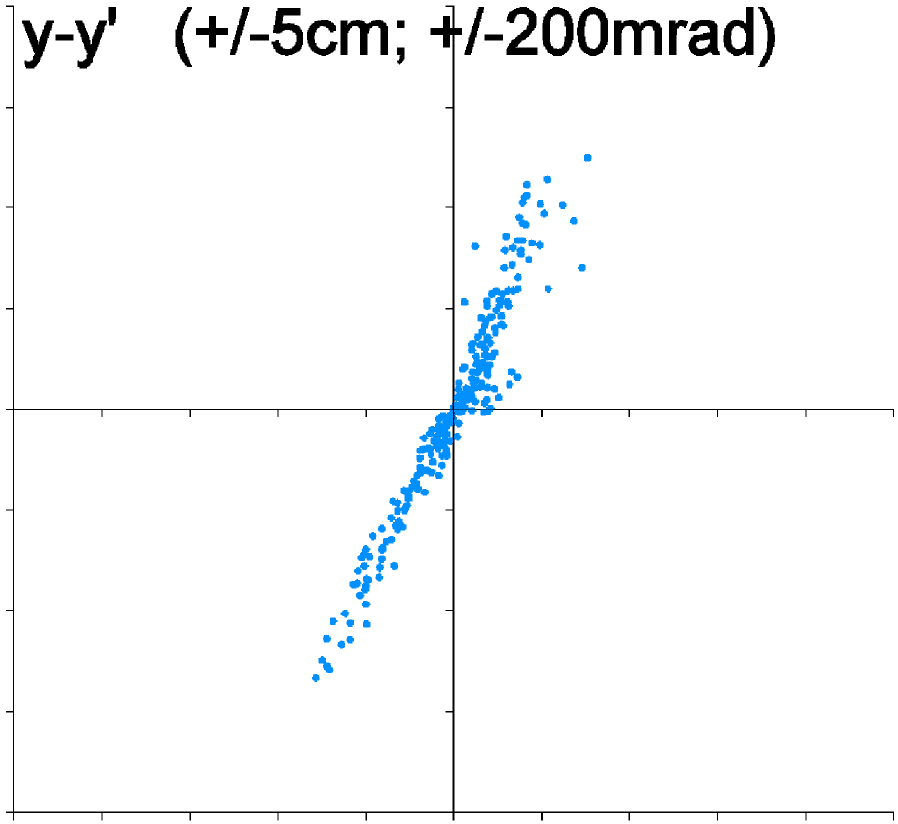
Different transverse projections of the 6D phase space

MSECRIS design values



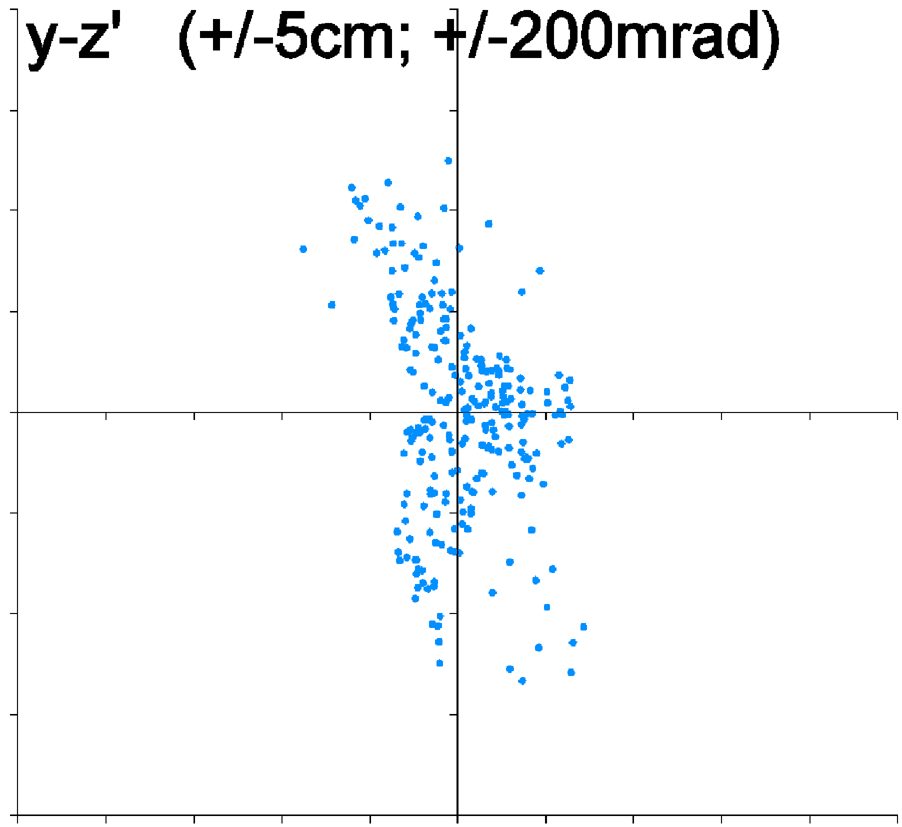
Different transverse projections of the 6D phase space

MSECRIS design values



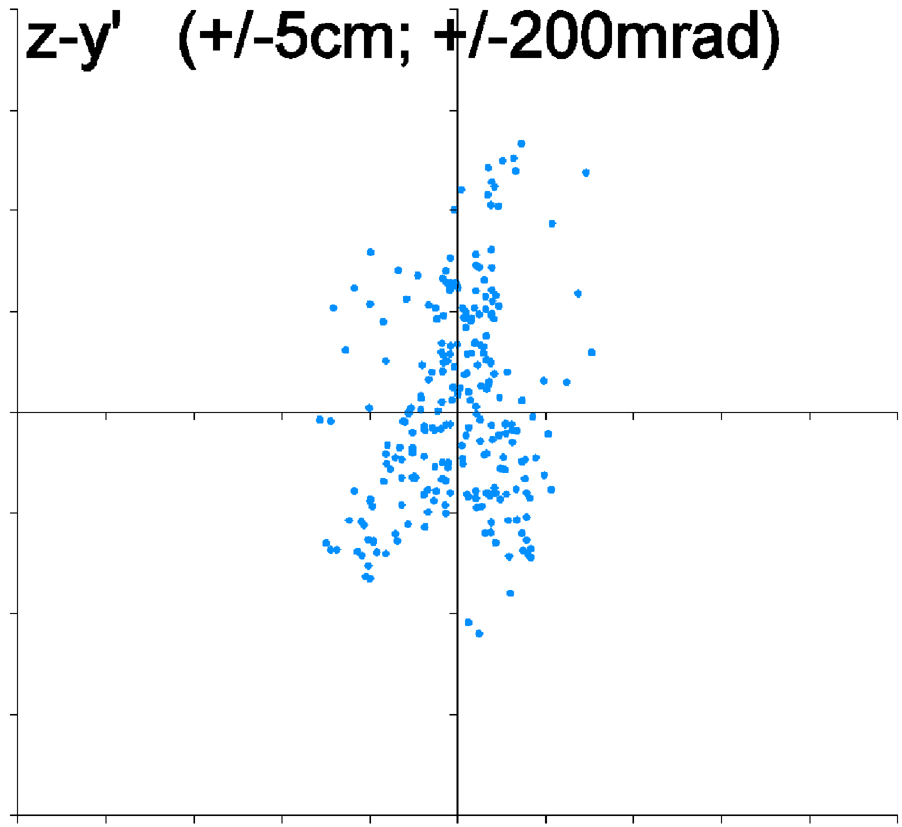
Different transverse projections of the 6D phase space

MSECRIS design values



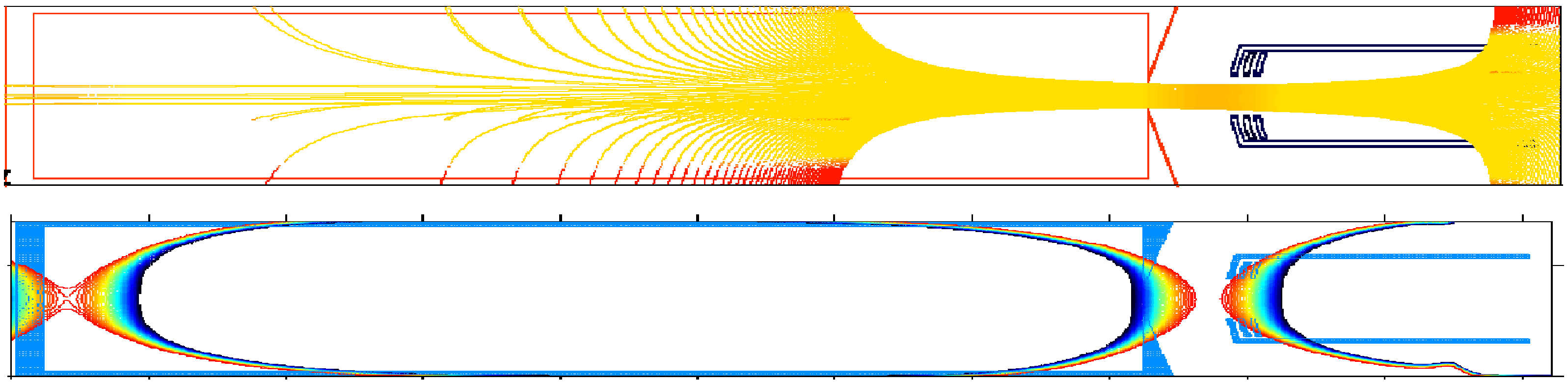
Different transverse projections of the 6D phase space

MSECRIS design values



Different transverse projections of the 6D phase space

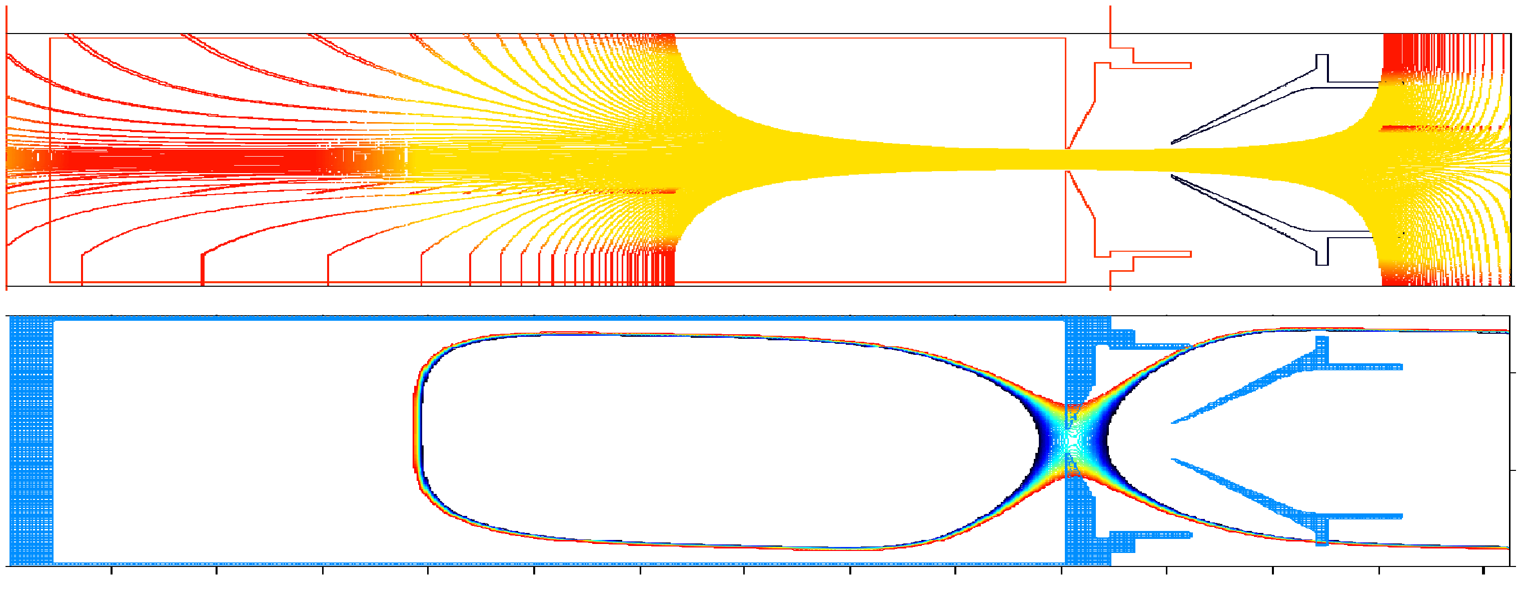
A-PHOENIX



The extraction electrode is far away from the maximum.

If it would be there, the plasma chamber seems to be too small for an effective extraction.

SECRAL



Very good extraction properties.

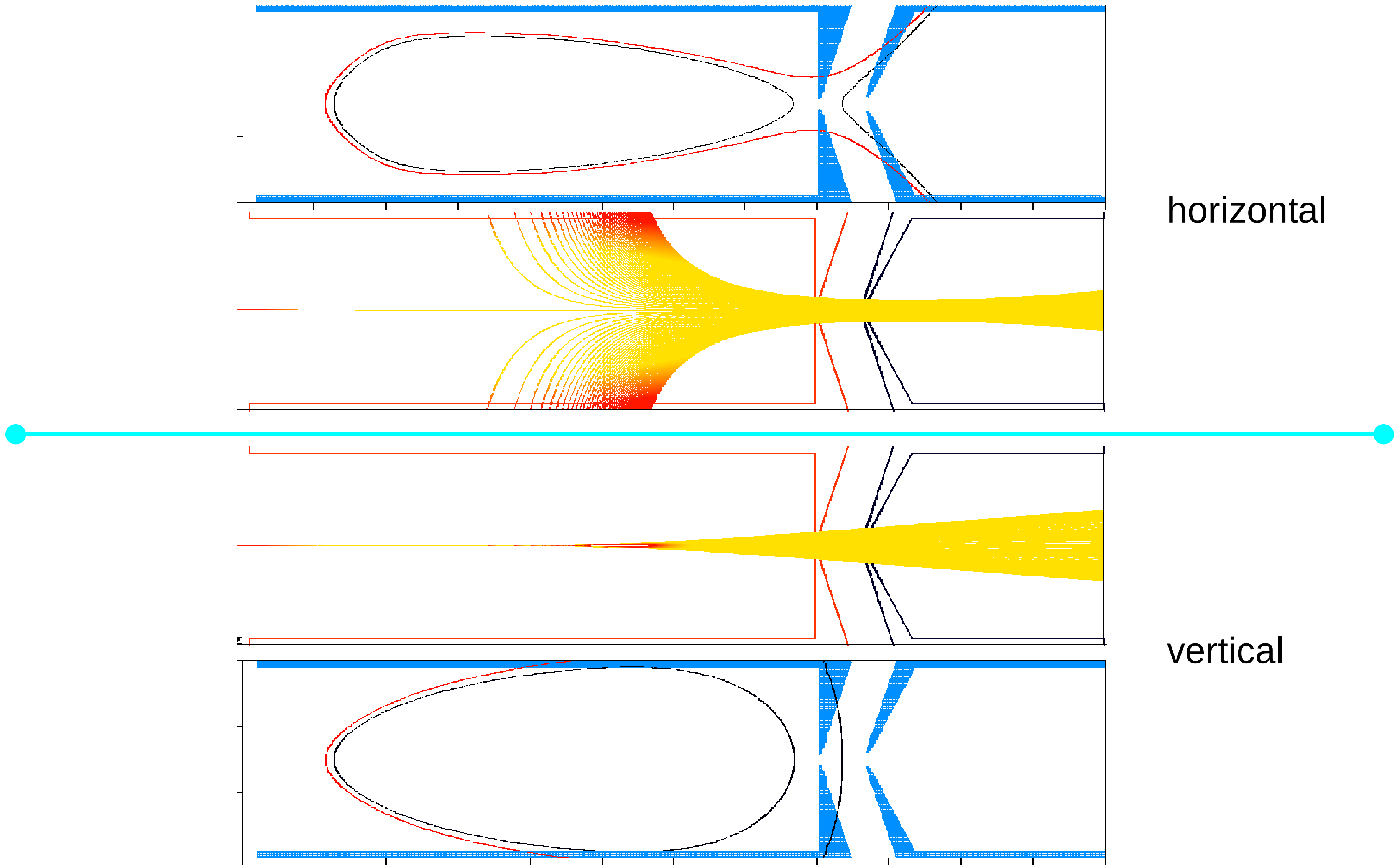
ARC-ECRIS

This source is different. No hexapole. A special curvature of the coil generates a stable plasma confinement with quadrupole like loss lines.

Field lines going through the round extraction aperture are bent into one plane.

The properties of the plasma generator are still to be proven, but from the standpoint of extraction it seems to be an interesting alternative.

ARC-ECRIS



horizontal

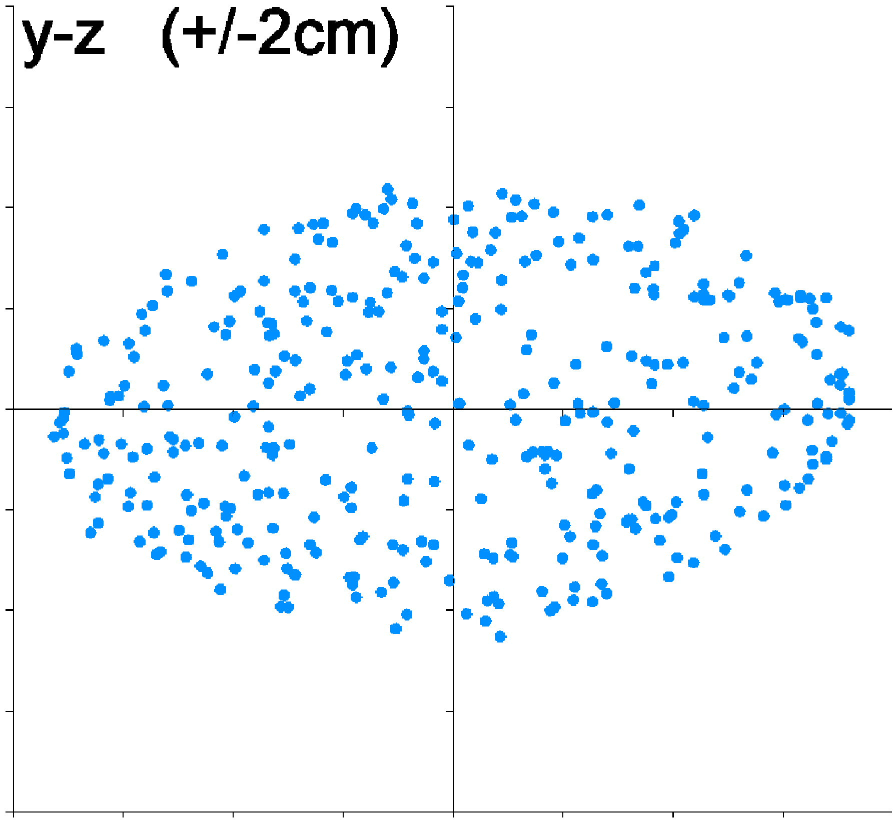
vertical

ARC-ECRIS

This simulation is made still without space charge effects

ARC-ECRIS

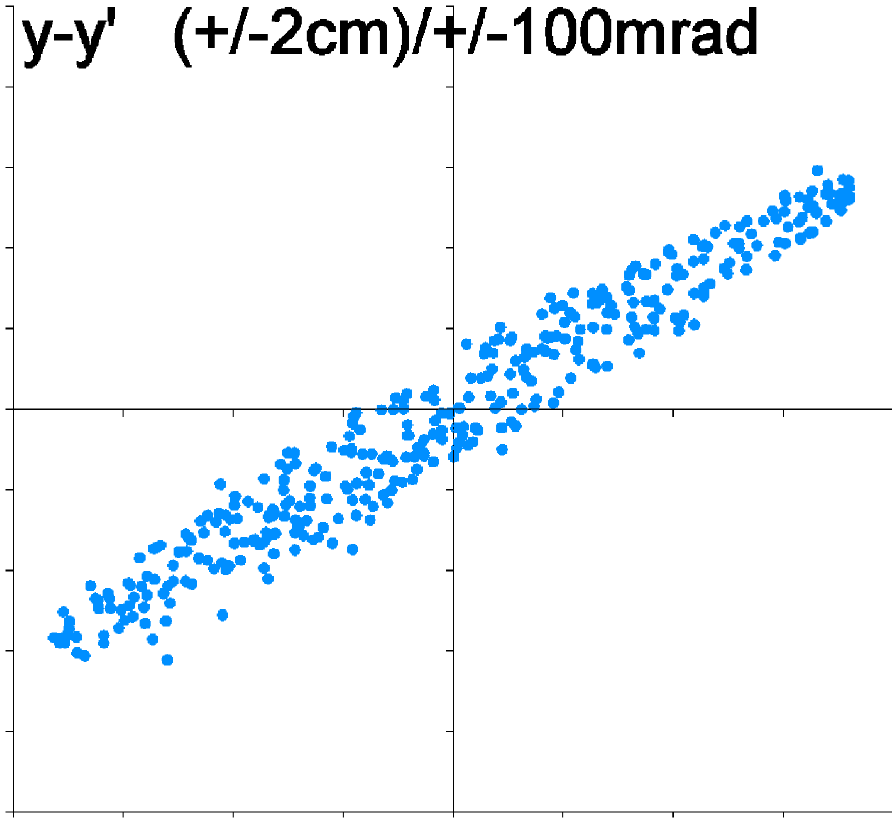
real space



Different transverse projections of the 6D phase space

ARC-ECRIS

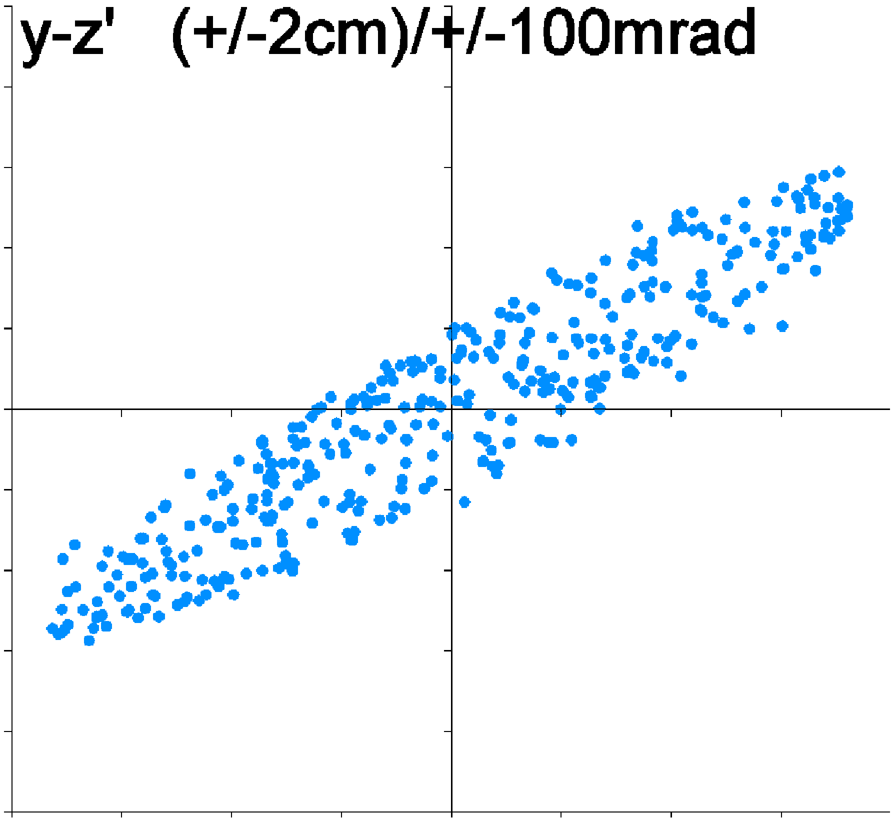
horizontal emittance



Different transverse projections of the 6D phase space

ARC-ECRIS

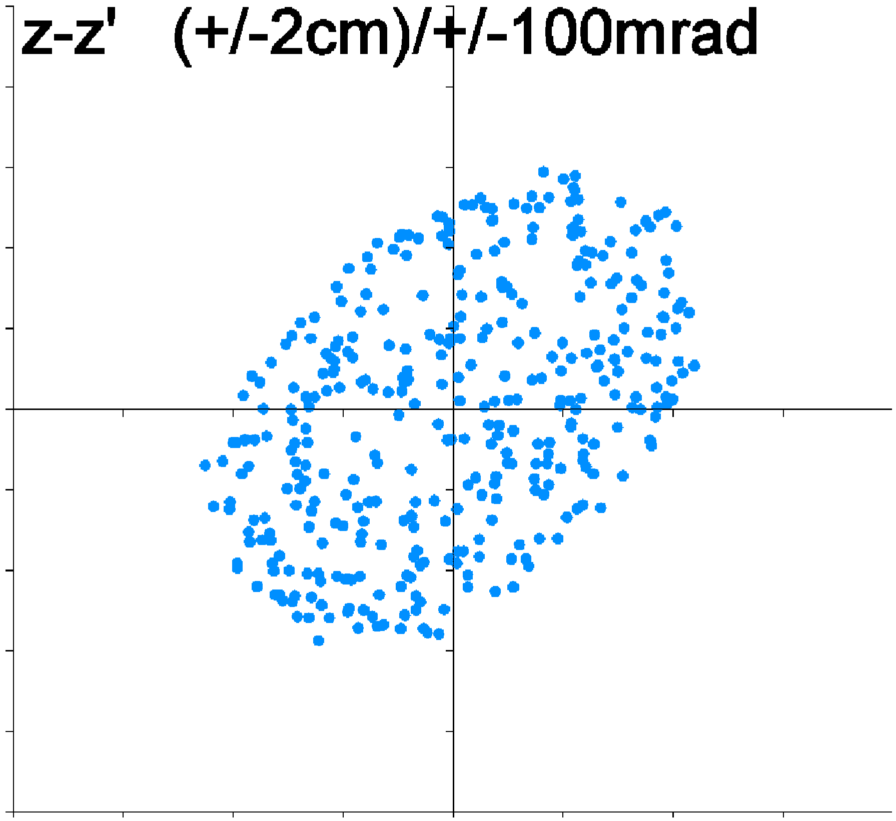
mixed phase space



Different transverse projections of the 6D phase space

ARC-ECRIS

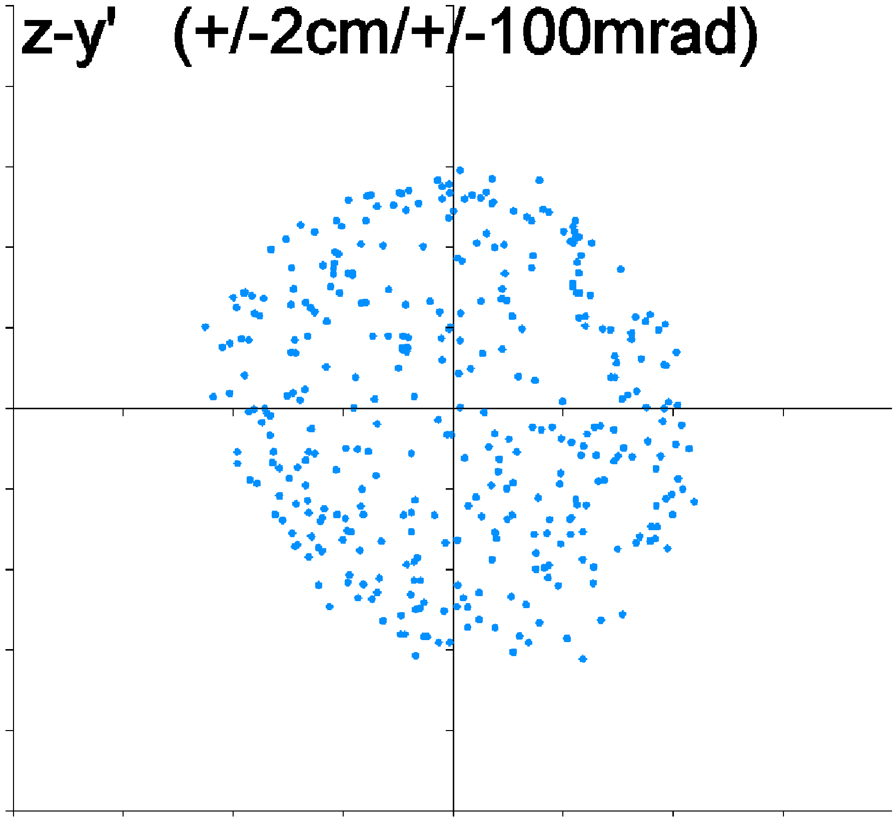
vertical emittance



Different transverse projections of the 6D phase space

ARC-ECRIS

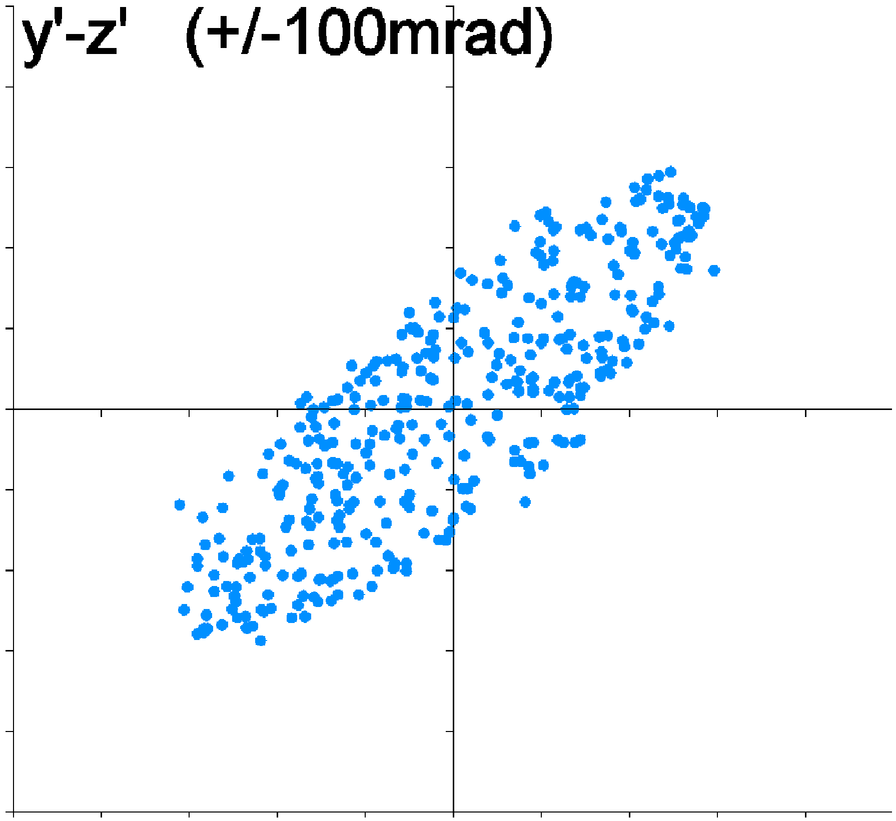
mixed phase space



Different transverse projections of the 6D phase space

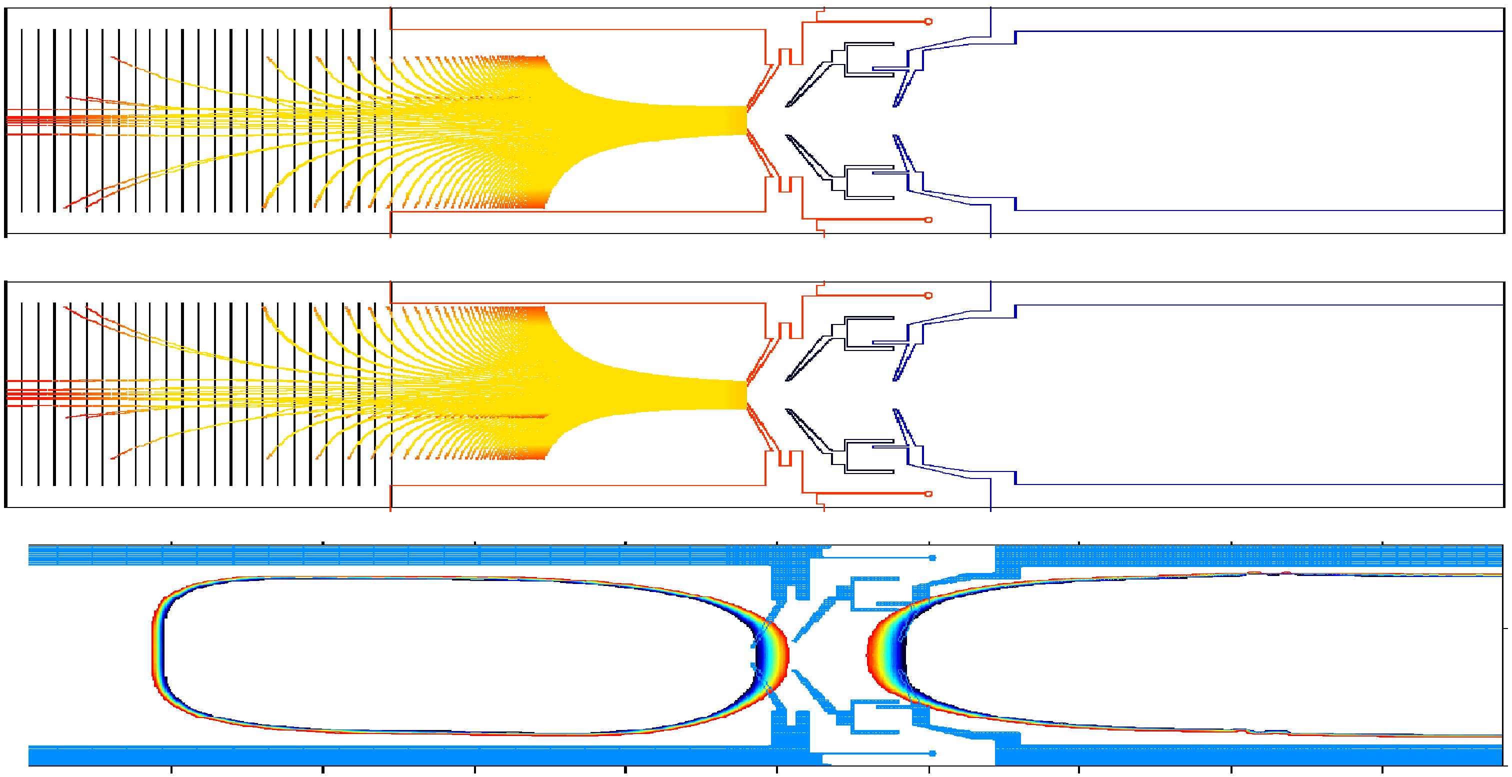
ARC-ECRIS

momentum space



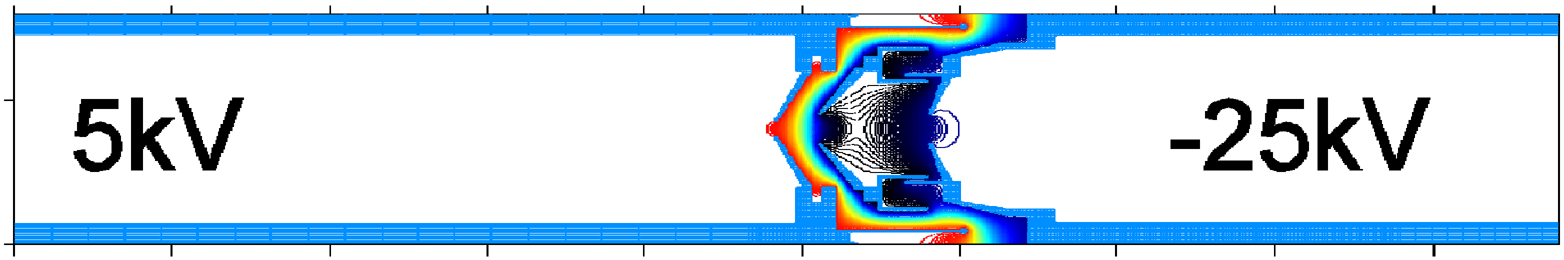
Different transverse projections of the 6D phase space

RIKEN 28GHz



Here the maximum of field is also not at the position of extraction electrode.

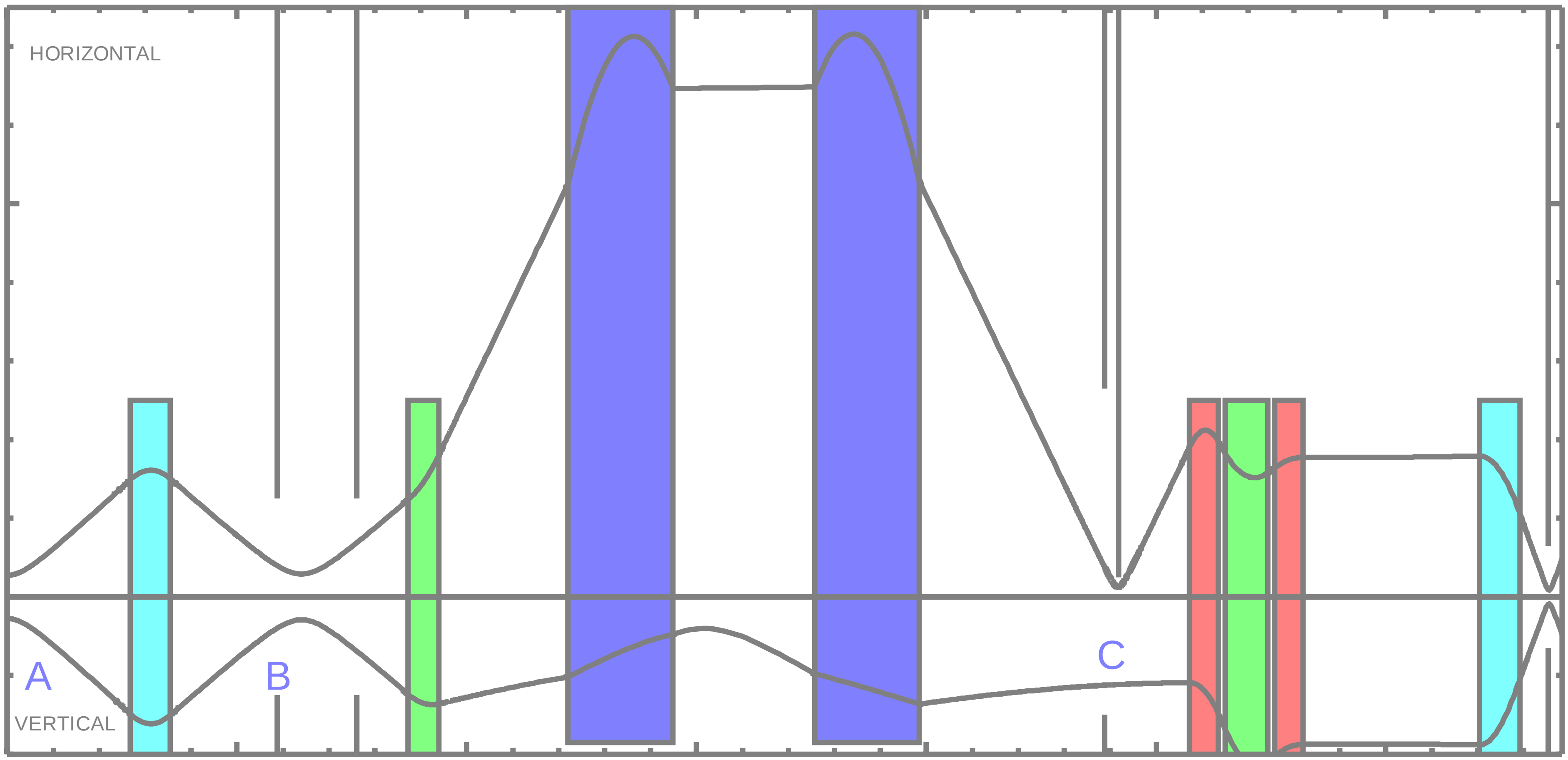
RIKEN 28GHz



The Riken version of a 28GHz ECRIS includes the possibility to bias the beam line, giving the opportunity to increase beam energy without having the source on extensive high potential. The advantage is the smaller emittance for the beam transport with higher energy, according to Liouville. The space charge compensation is not affected. When connecting the beam line again to ground, decelerating the beam, the emittance will increase again. Screening just before decelerating is required, otherwise the space charge compensation would be lost due to extracting electrons from the beam.

beam line simulation

- We did most beam line simulation with MIRKO: 6D linear particle optics code.
- Correct 6x6 transfer matrices are essential.
- Starting coordinates (all 6 phase space coordinates) were taken from extraction simulation done with KOBRA3.
- Space charge was assumed to be 0; full space charge compensation.



beamline EIS: solenoid, quadrupole singlet, split dipole, quadrupole triplet, solenoid.

location A: starting point

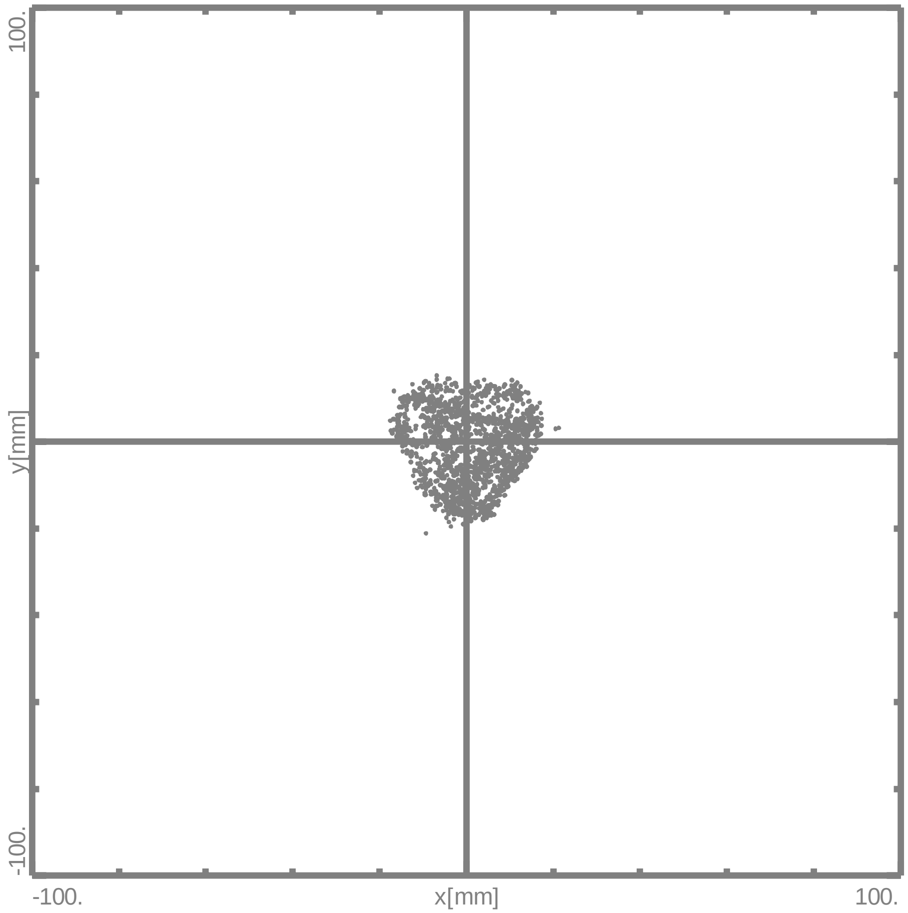
location B: behind solenoid

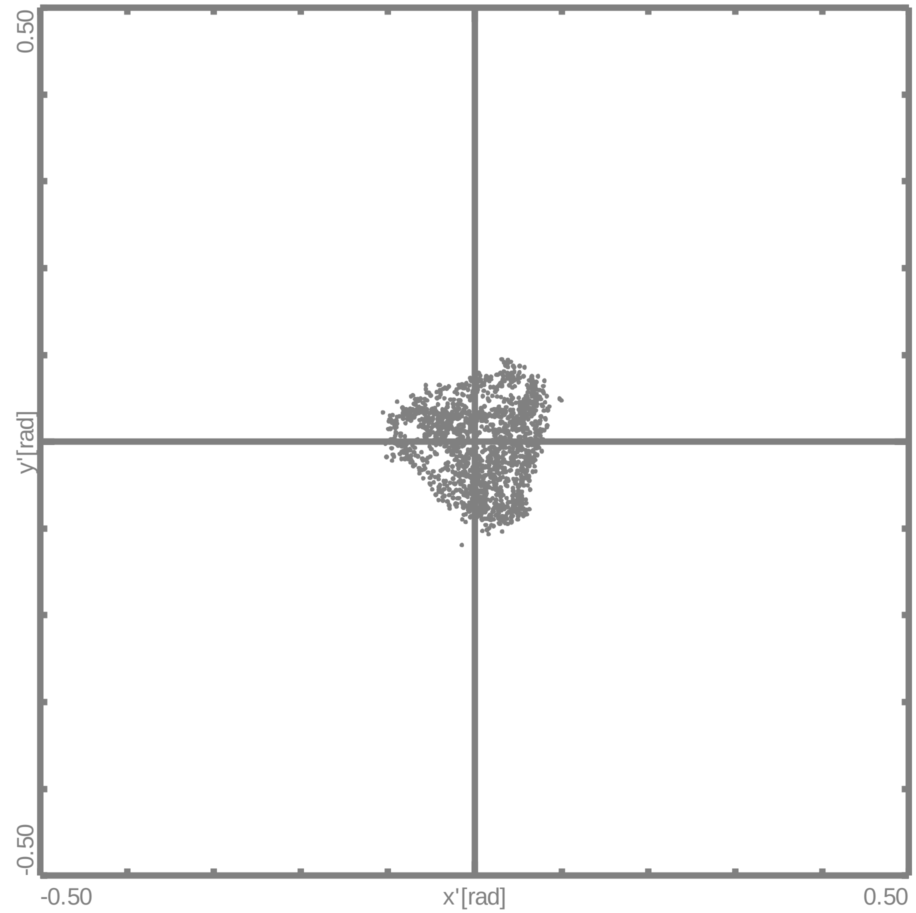
location C: behind dipole in the plane of resolving slits

CAPRICE at EIS

Three hexapoles made by different magnetic materials with different flux densities have been used in simulation and in experiment:

–0.8T	always measured
–1.0T	at the inner diameter
–1.2T	of the plasma chamber



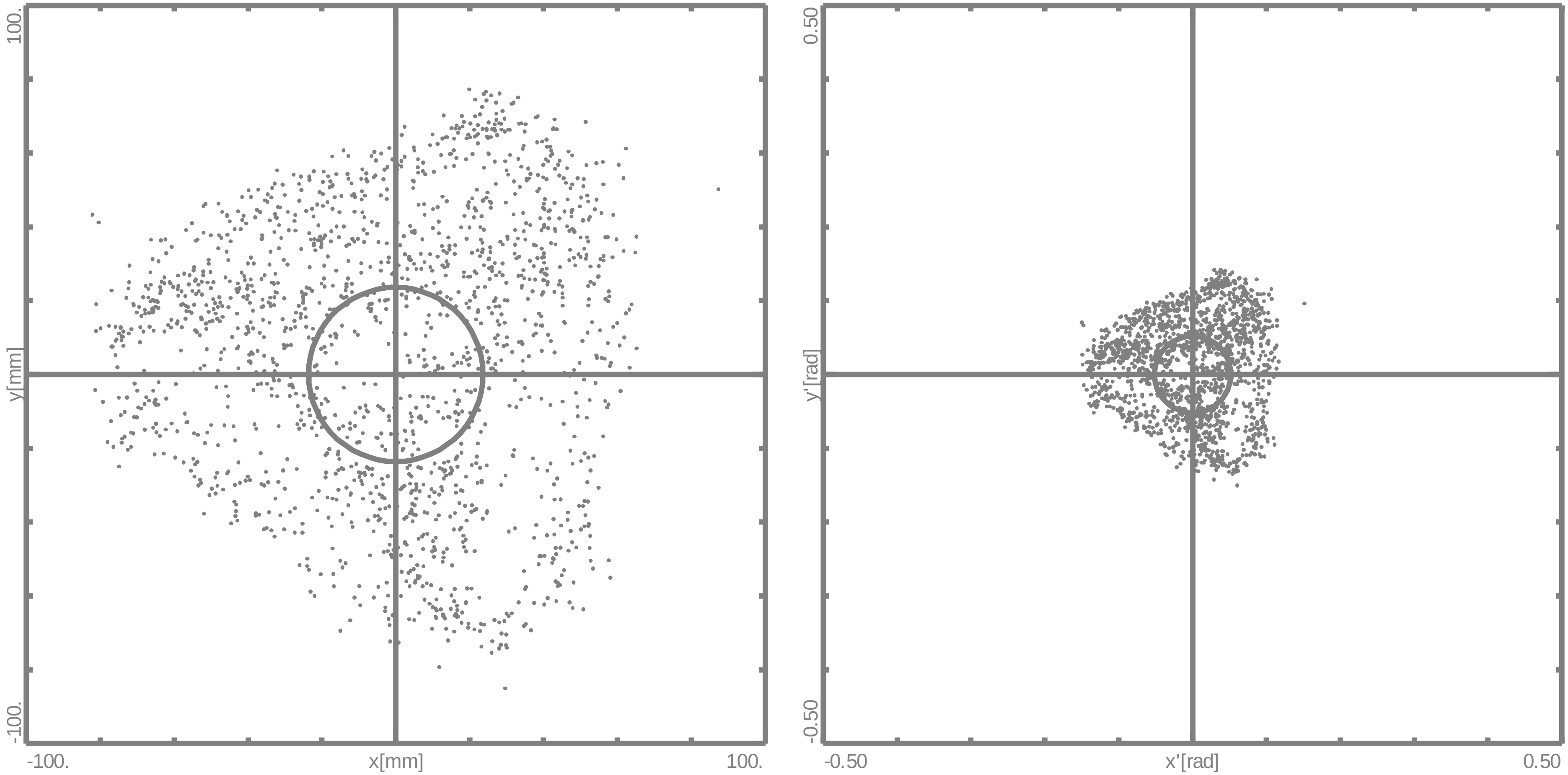


real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 0.8T hexapole,
Beam transport in EIS.

location A

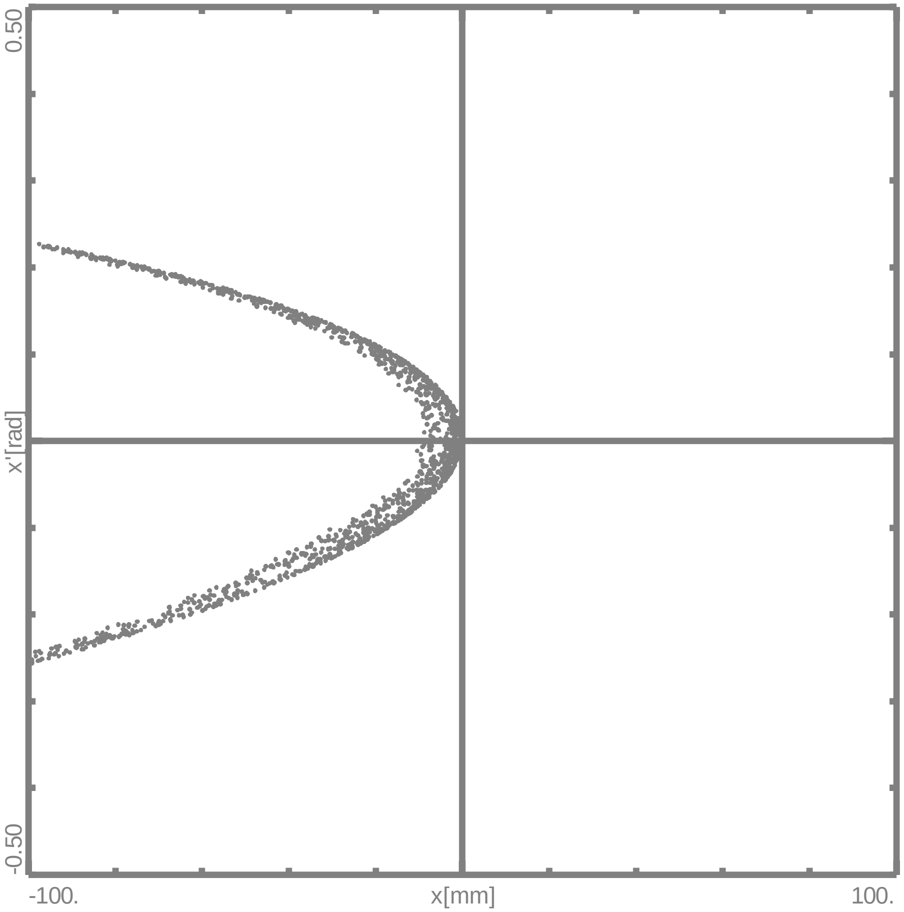


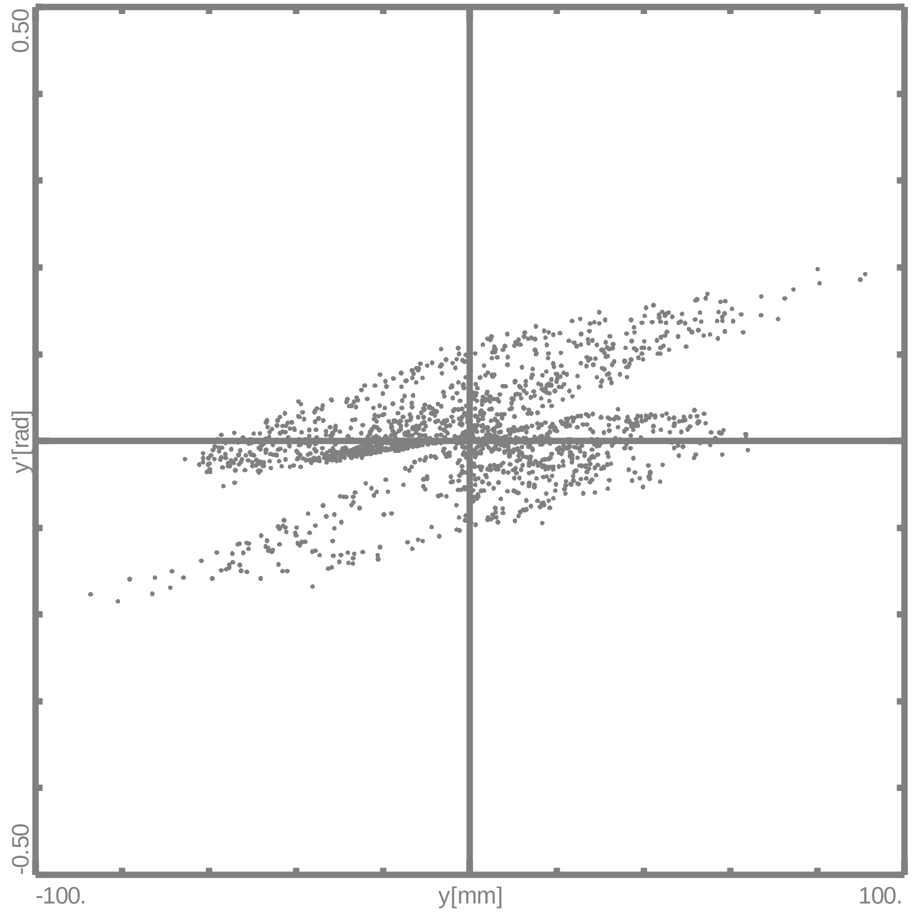
real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 0.8T hexapole,
Beam transport in EIS.

location B



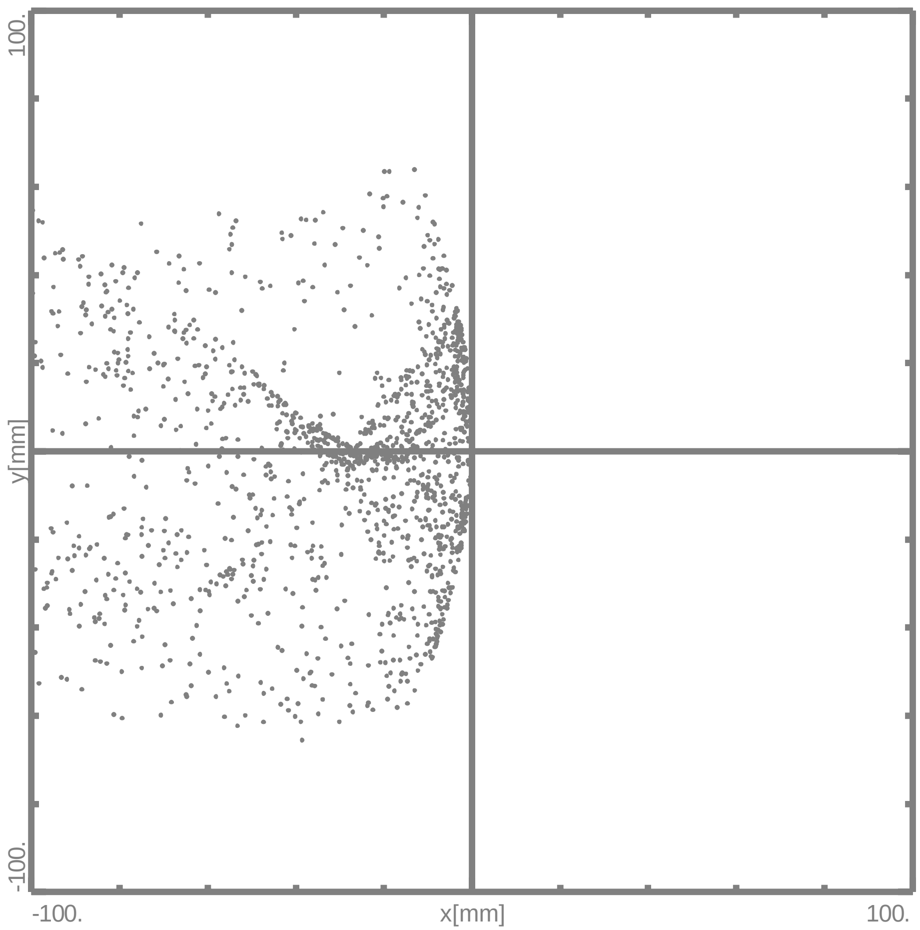


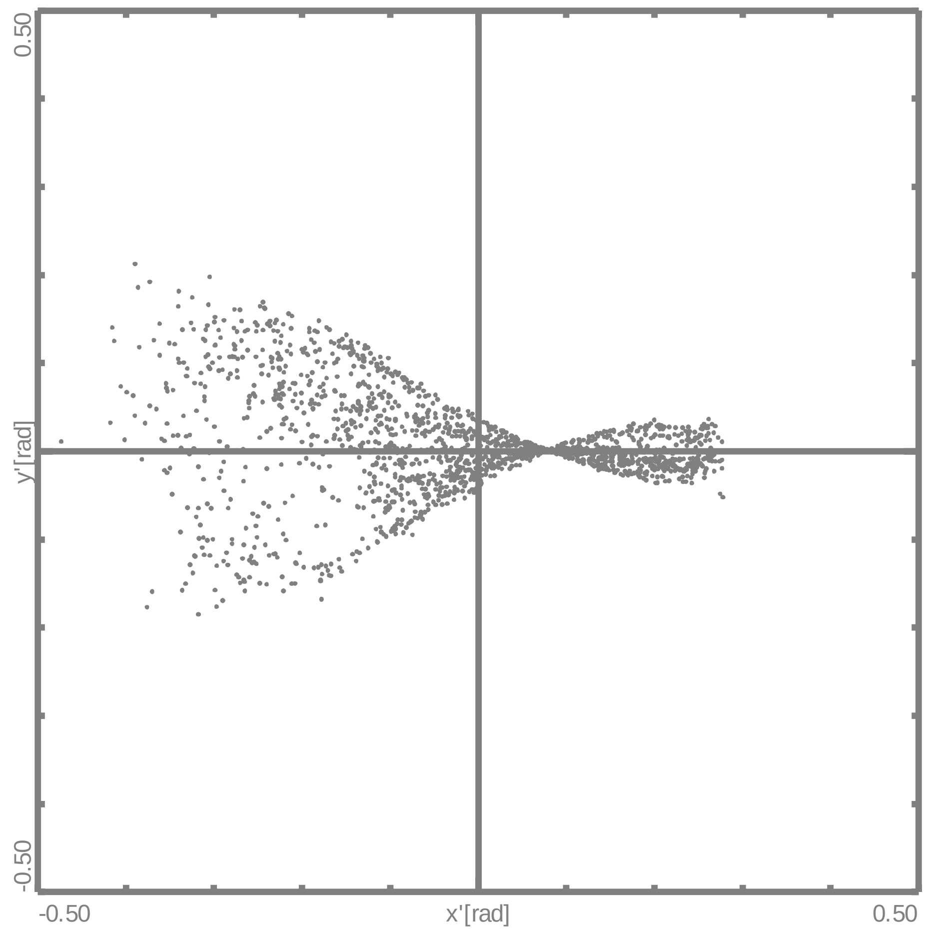
horizontal emittance
+/-100 mm; +/- 500 mrad

vertical emittance
+/- 100 mm +/-500 mrad

Beam extracted from CAPRICE with 0.8T hexapole,
Beam transport in EIS.

location C



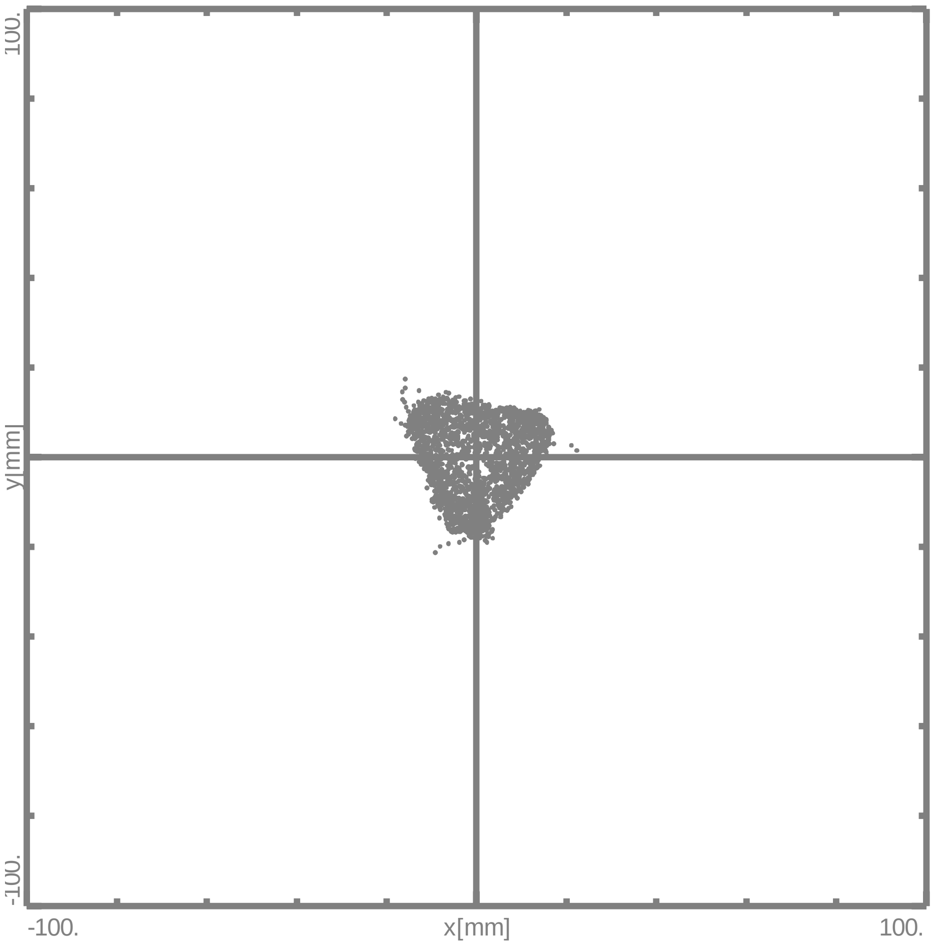


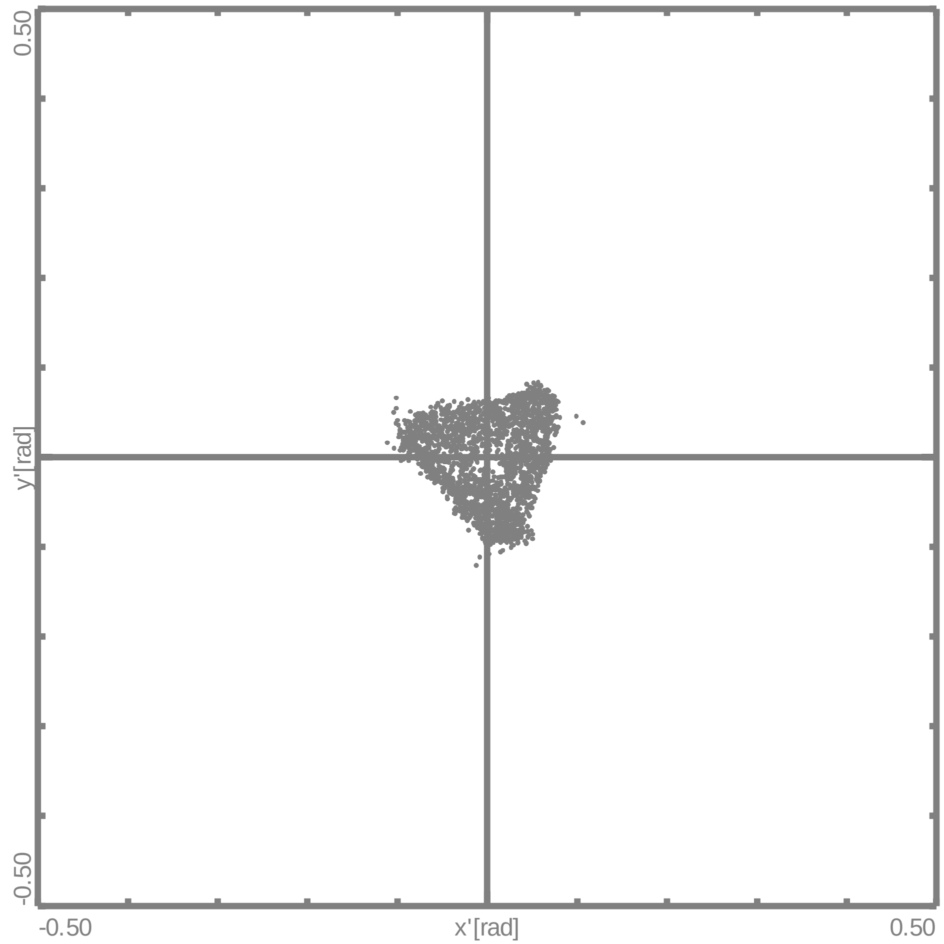
real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 0.8T hexapole,
Beam transport in EIS.

location C



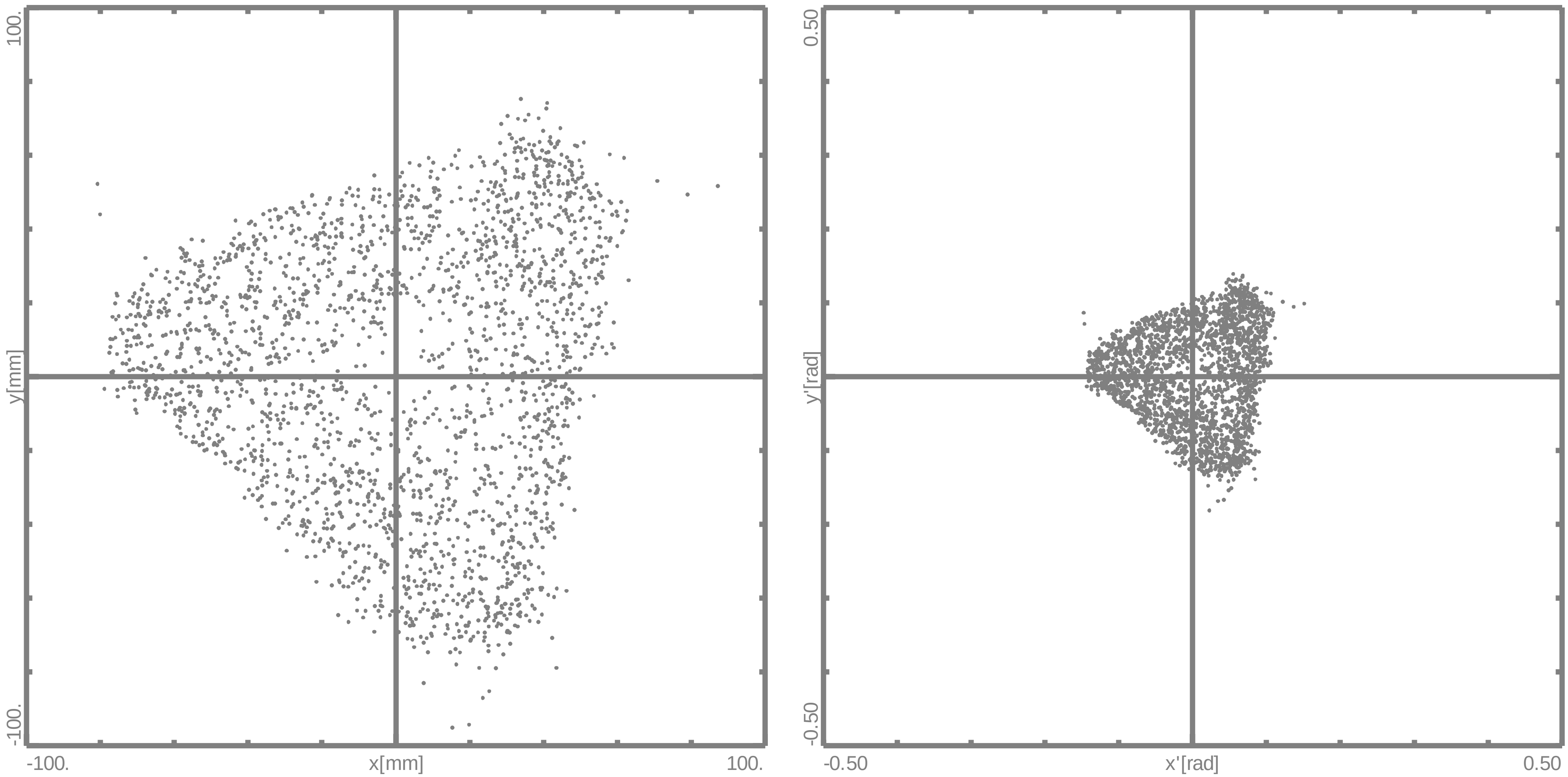


real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 1.0T hexapole,
Beam transport in EIS.

location A

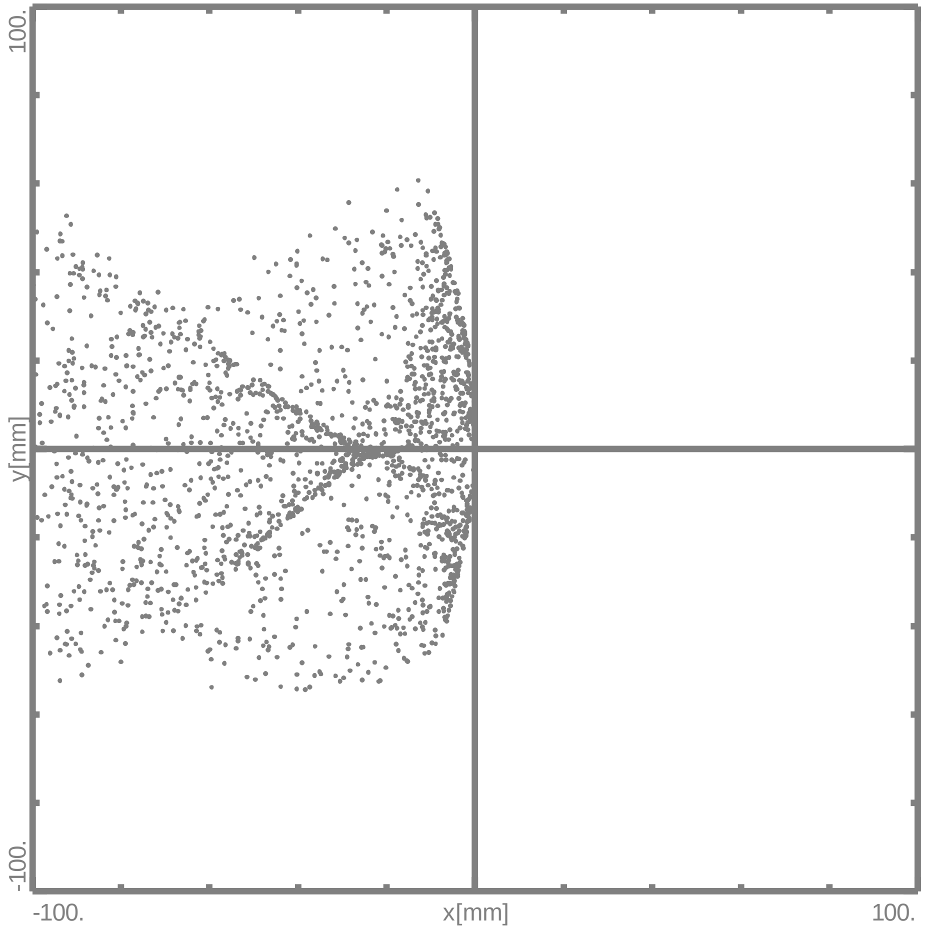


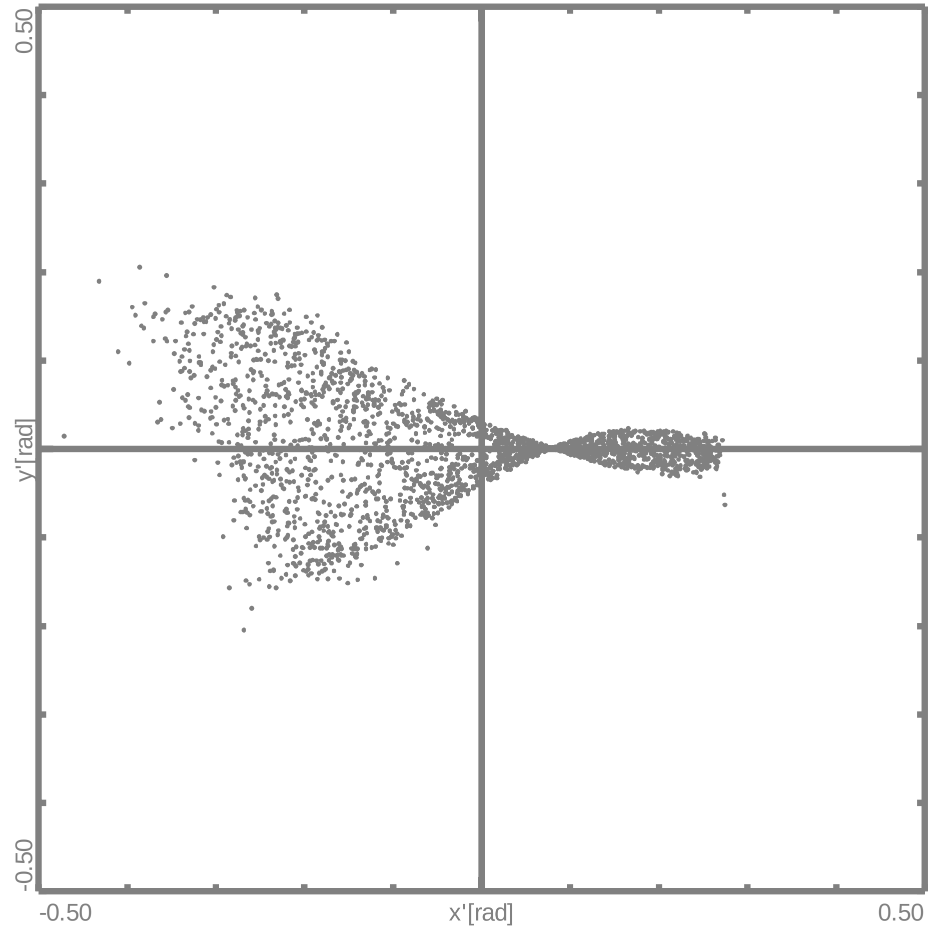
real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 1.0T hexapole,
Beam transport in EIS.

location B



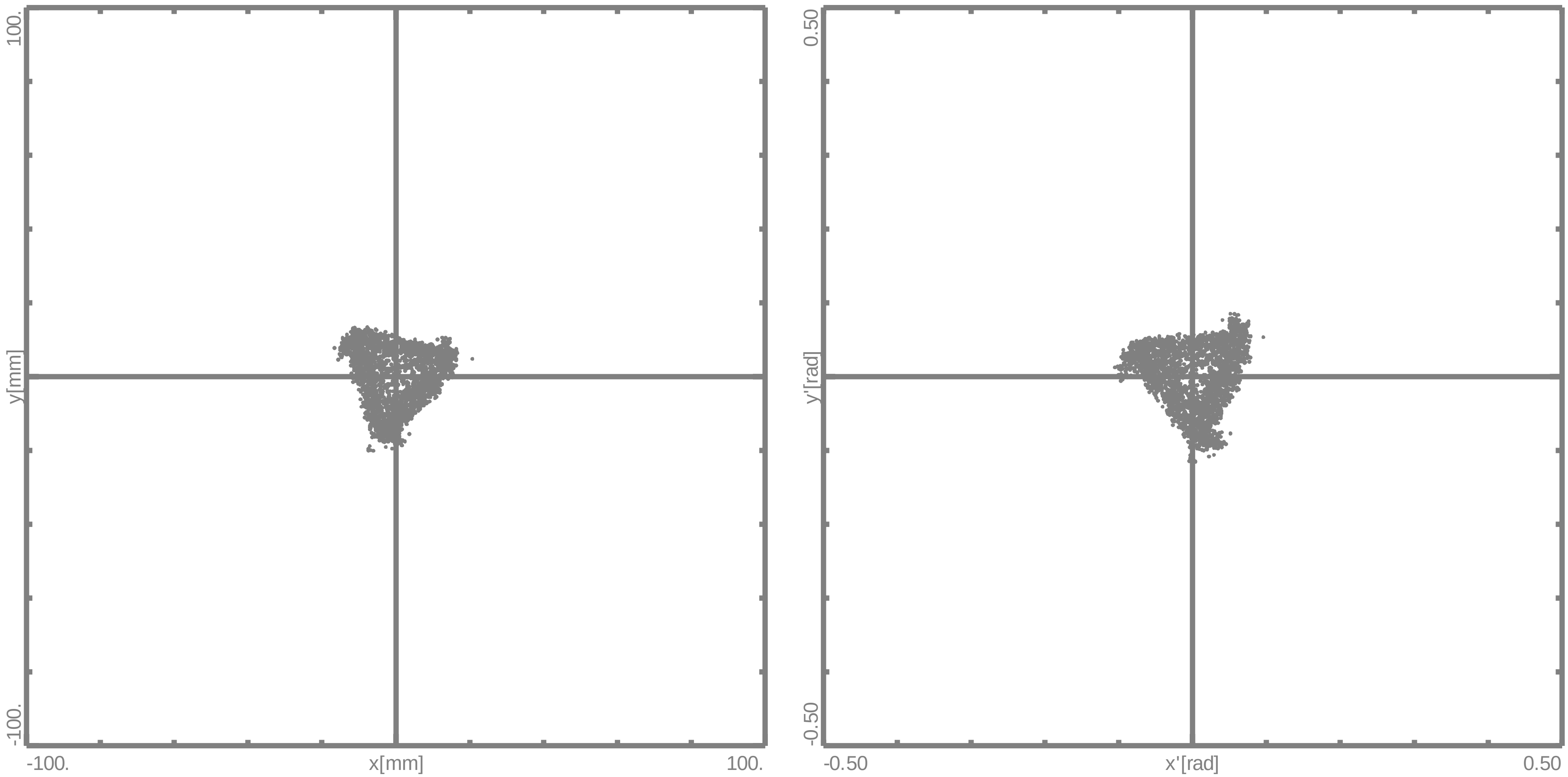


real space +/-100 mm

momentum space +/-500 mrad

Beam extracted from CAPRICE with 1.0T hexapole,
Beam transport in EIS.

location C

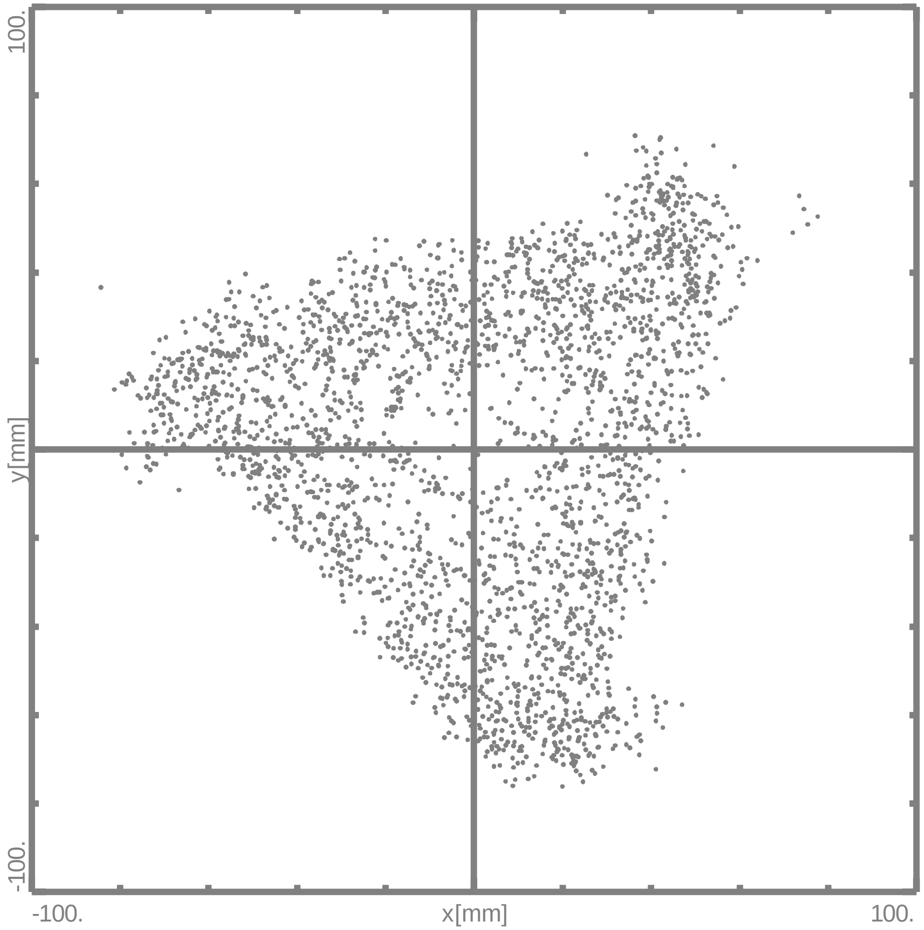


real space +/-100 mm

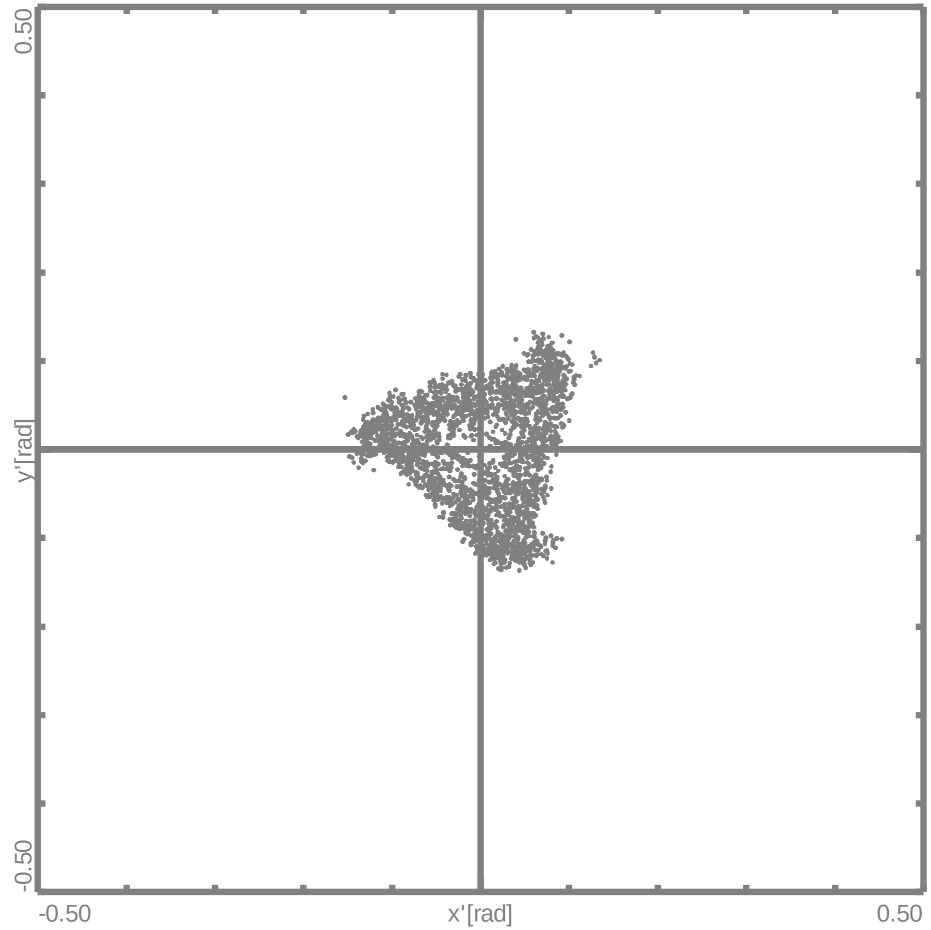
momentum space +/-500 mrad

Beam extracted from CAPRICE with 1.2T hexapole,
Beam transport in EIS.

location A



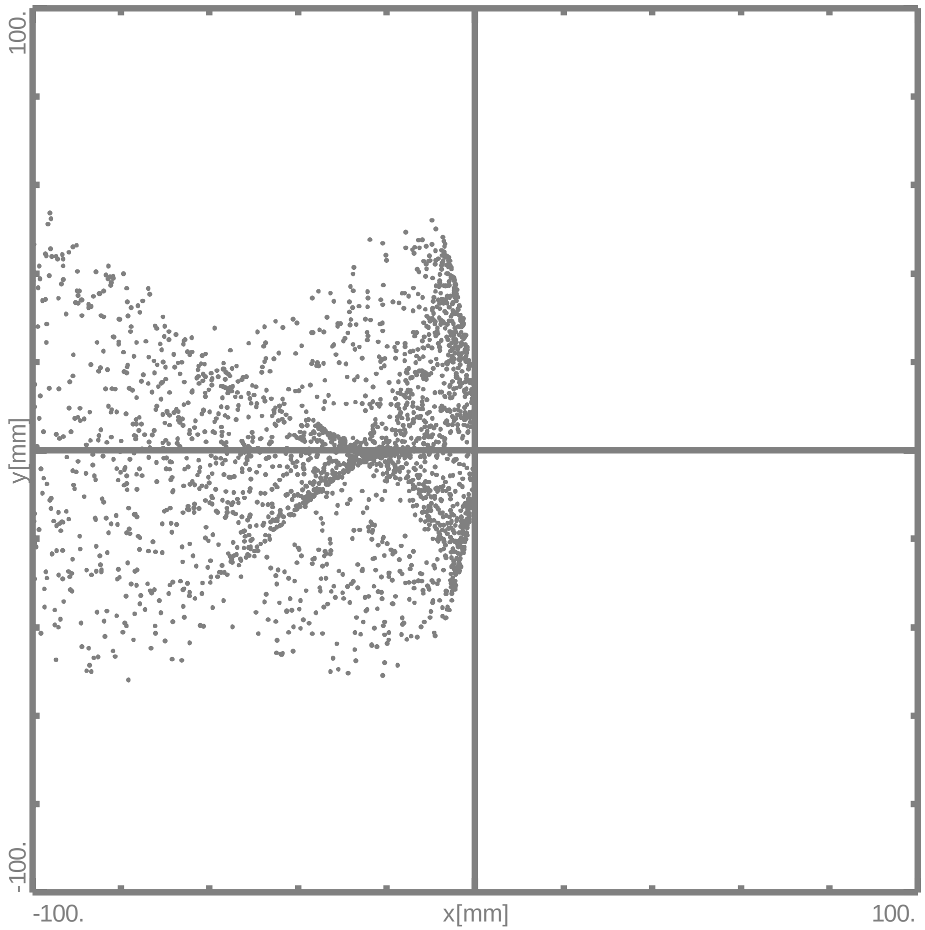
real space +/-100 mm

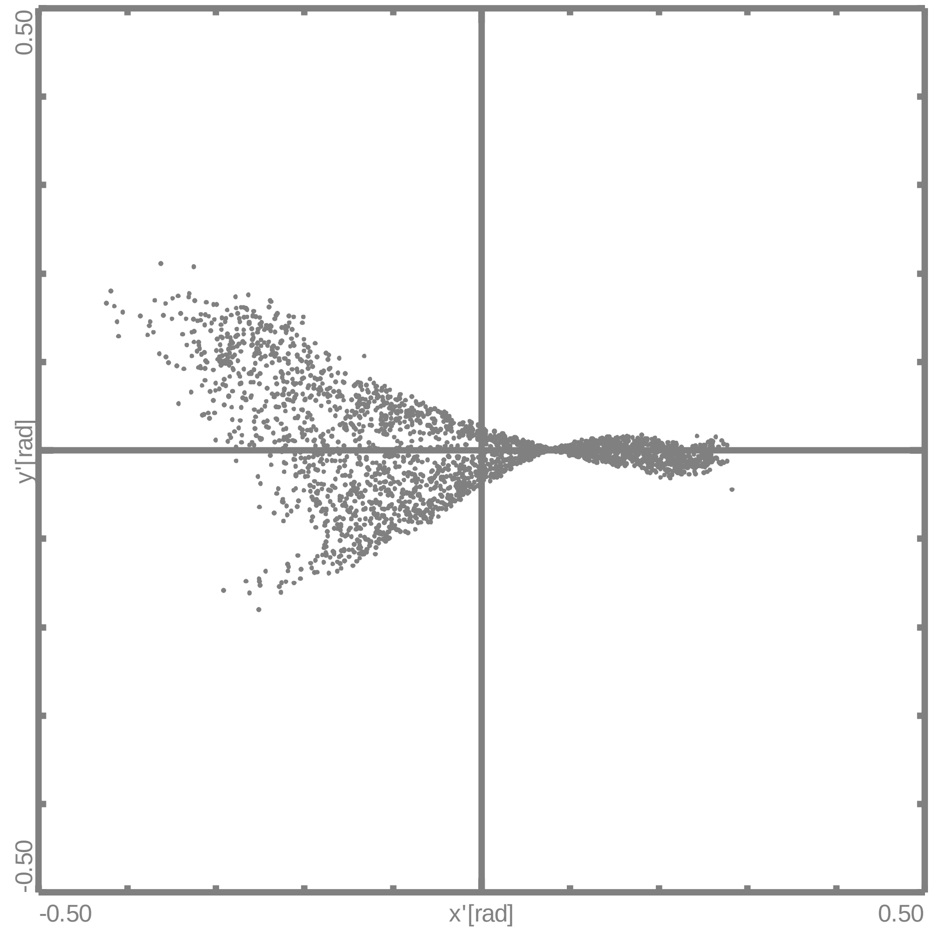


momentum space +/-500 mrad

Beam extracted from CAPRICE with 1.2T hexapole,
Beam transport in EIS.

location B



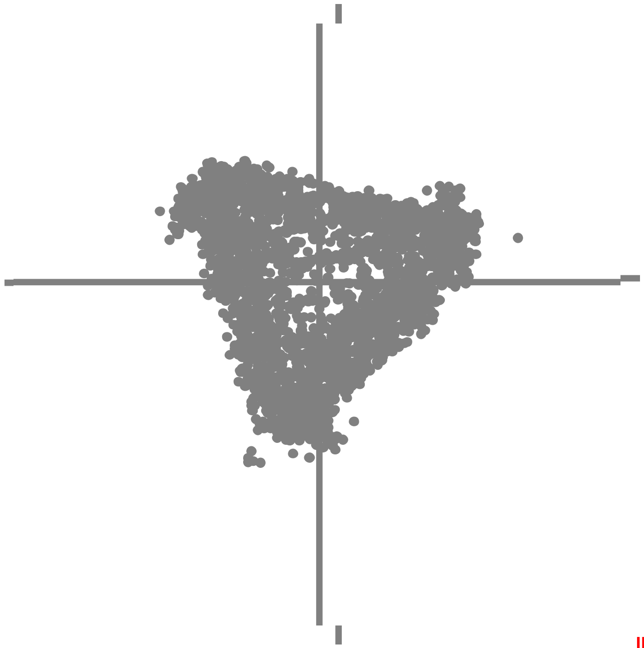


real space +/-100 mm

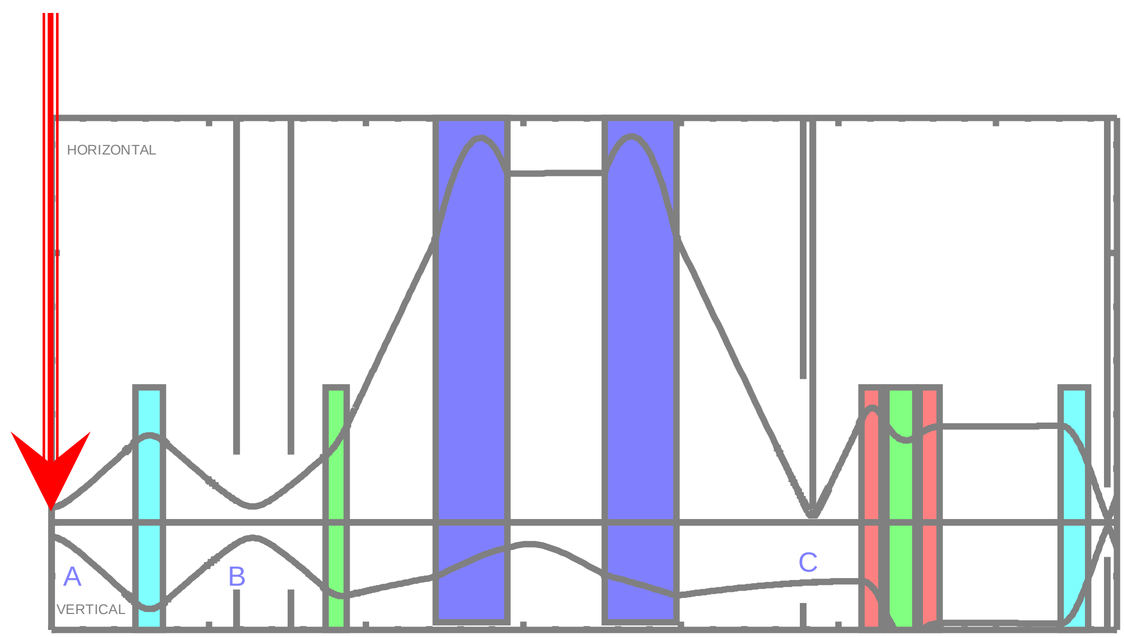
momentum space +/-500 mrad

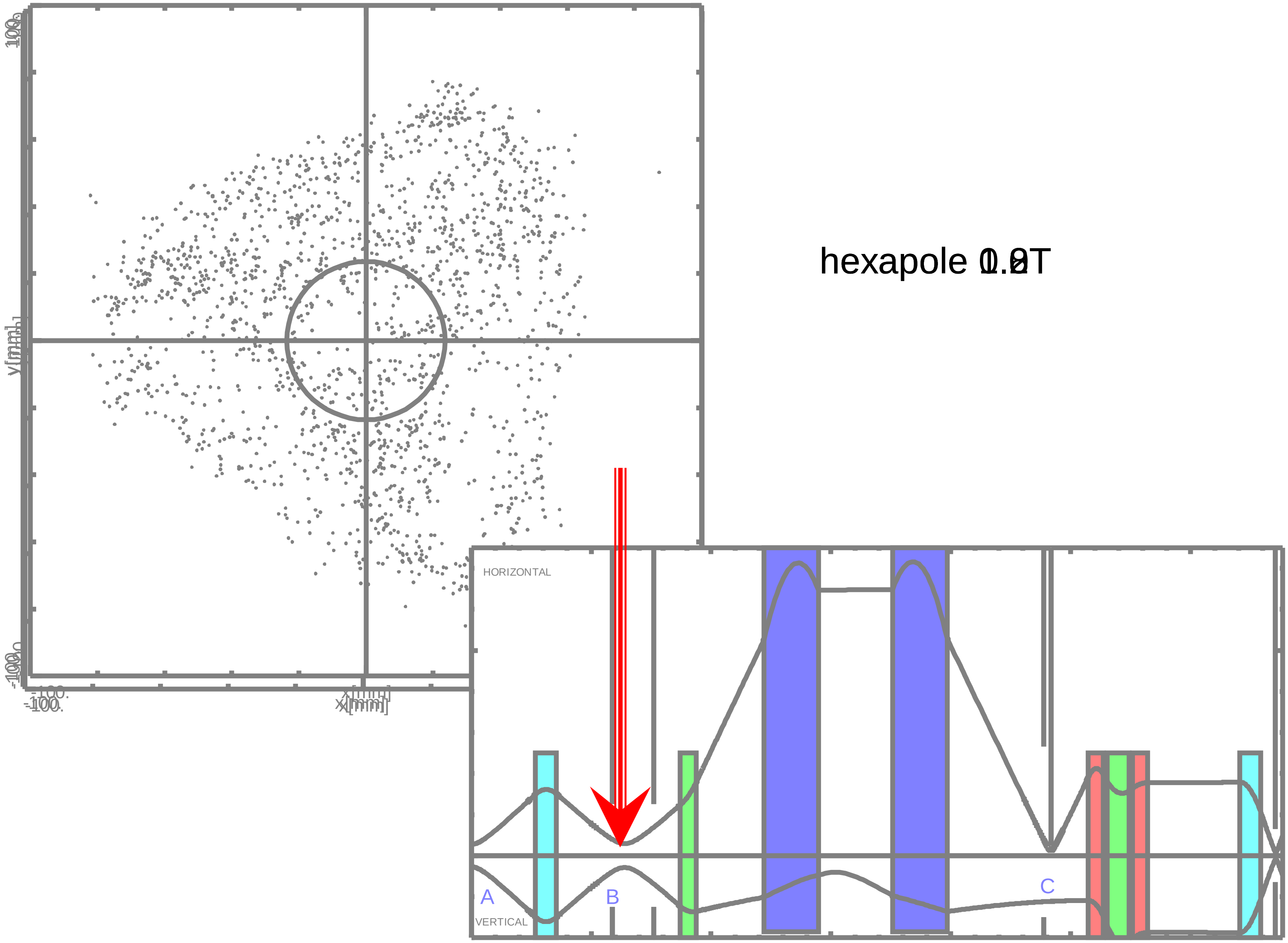
Beam extracted from CAPRICE with 1.2T hexapole,
Beam transport in EIS.

location C

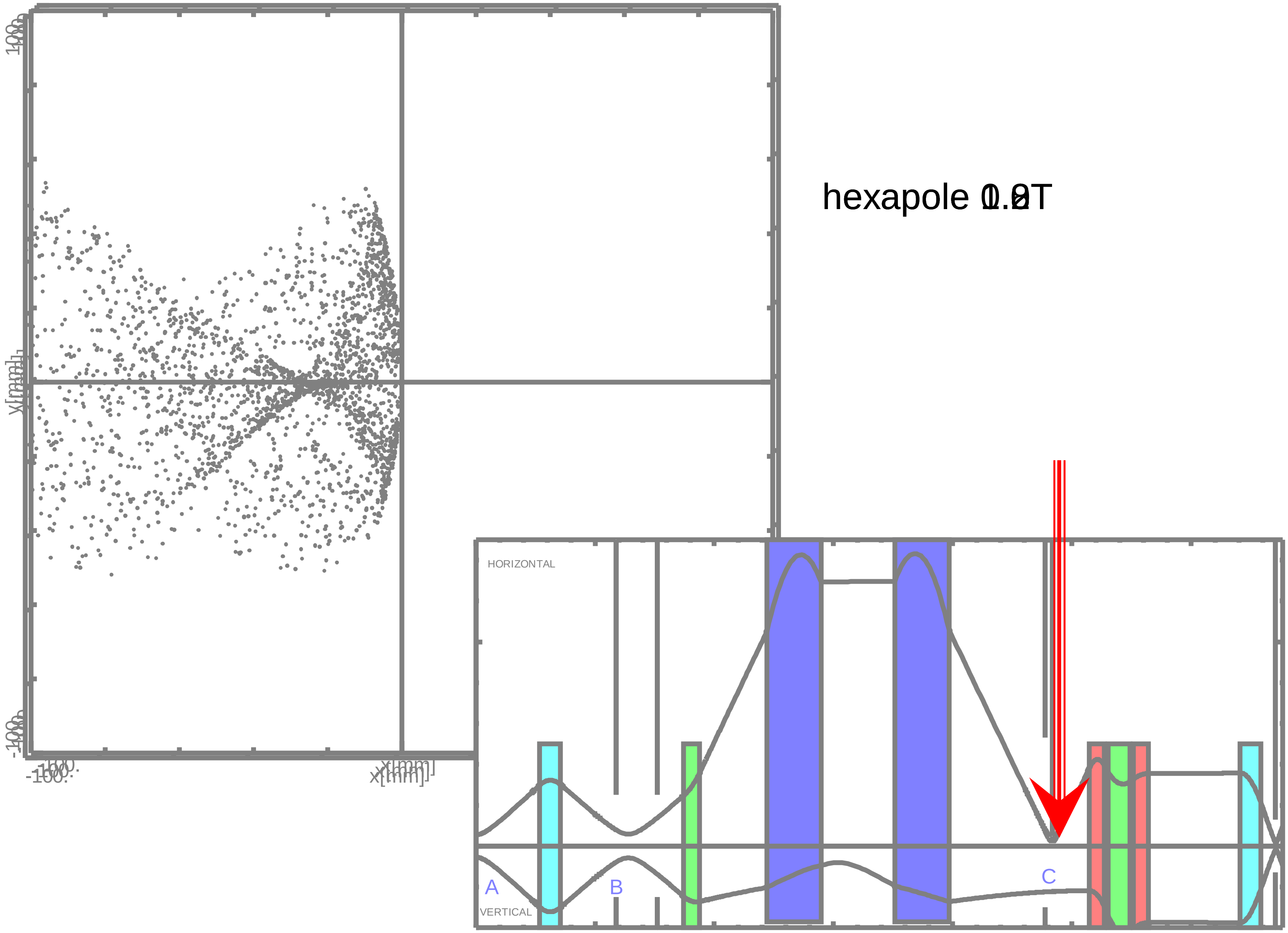


hexapole 0.9T / 1.2T



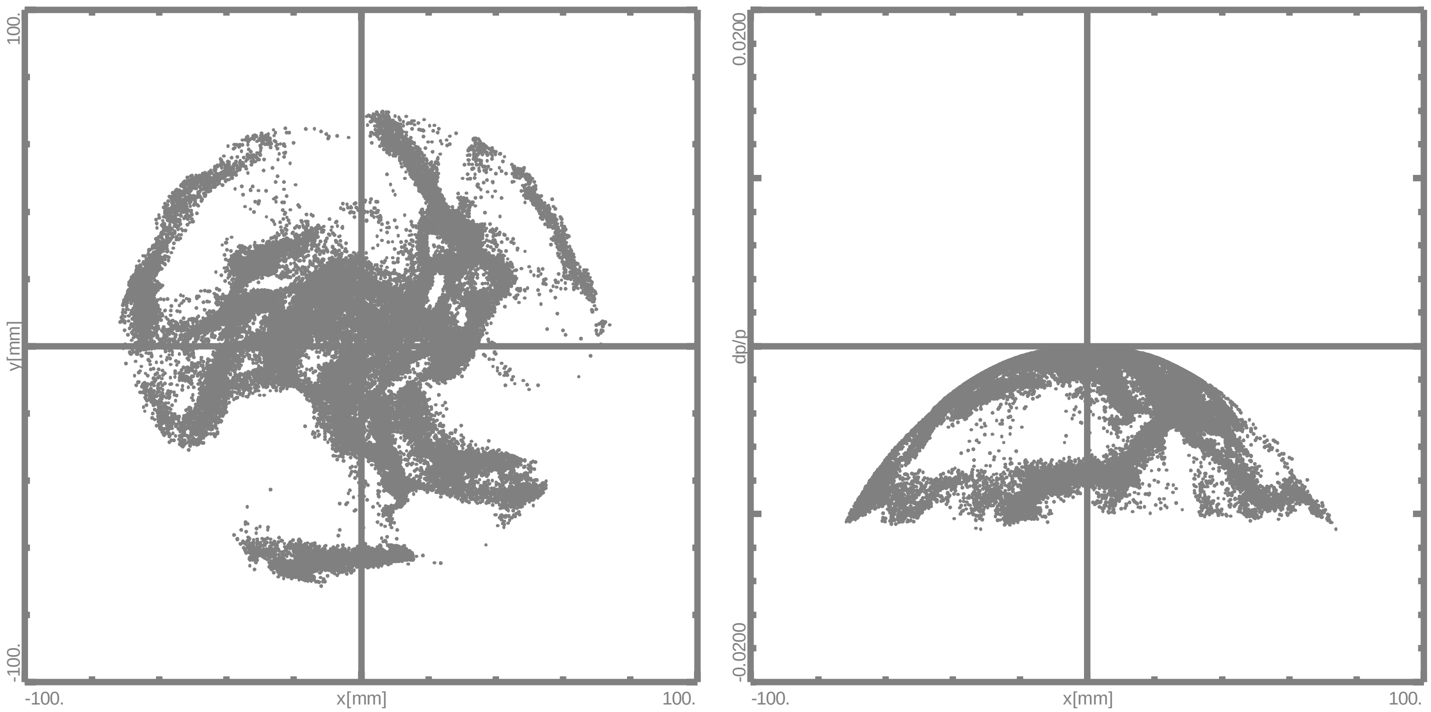


hexapole 0.9T



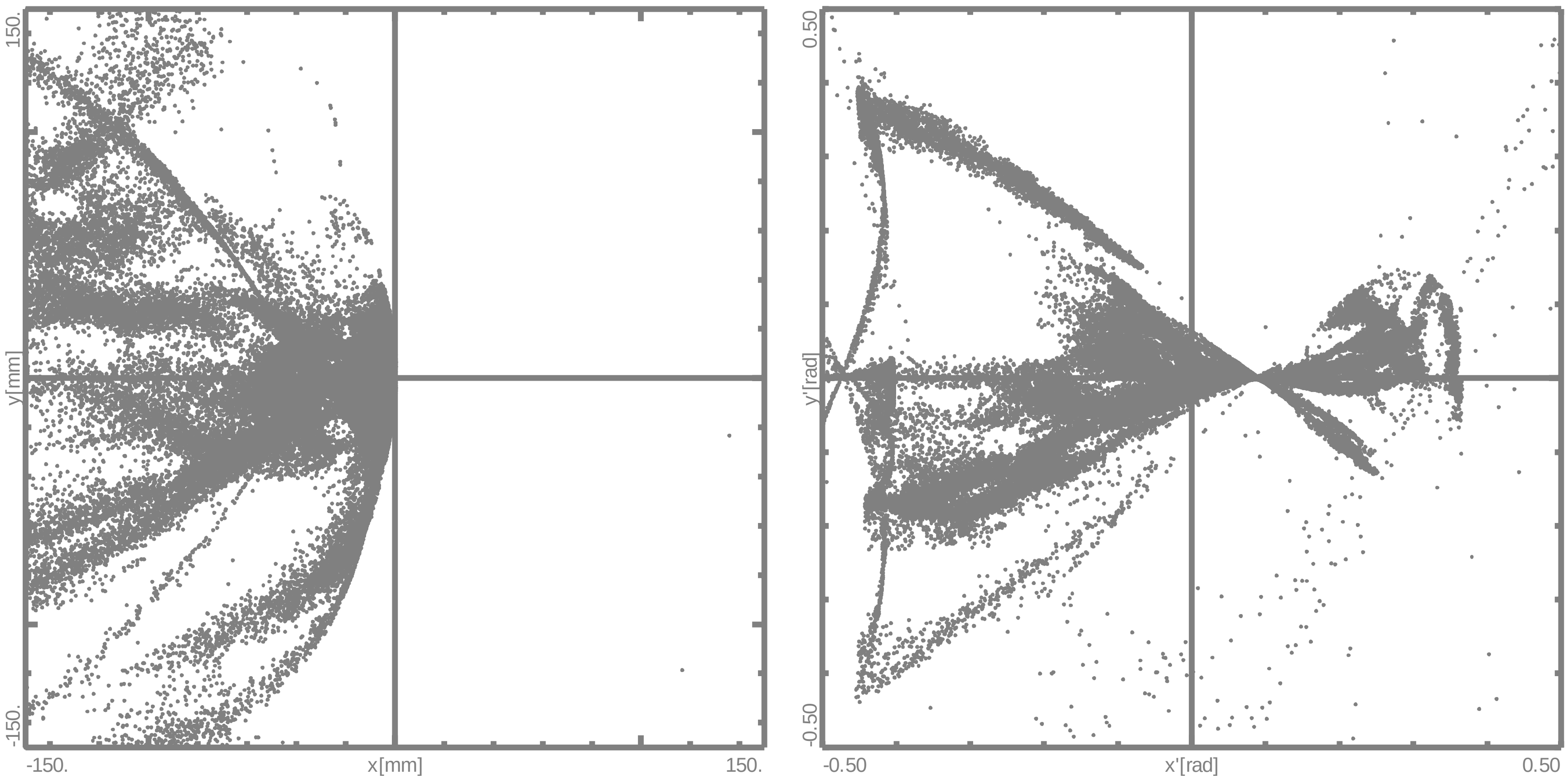
hexapole 0.9T 1.2T

SUPERNANOGAN



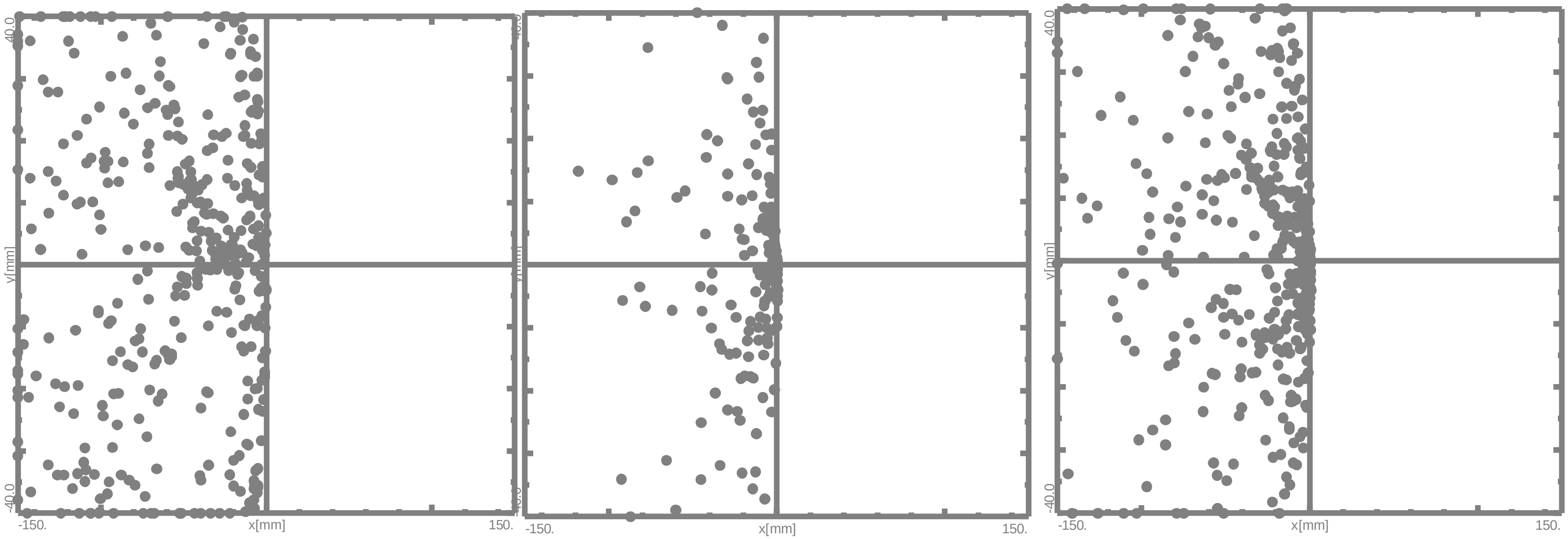
Real space distribution (+/-100mm) and horizontal momentum distribution (+/-100mm, +/-20mrad) behind the beam line solenoid.

SUPERNANOGAN



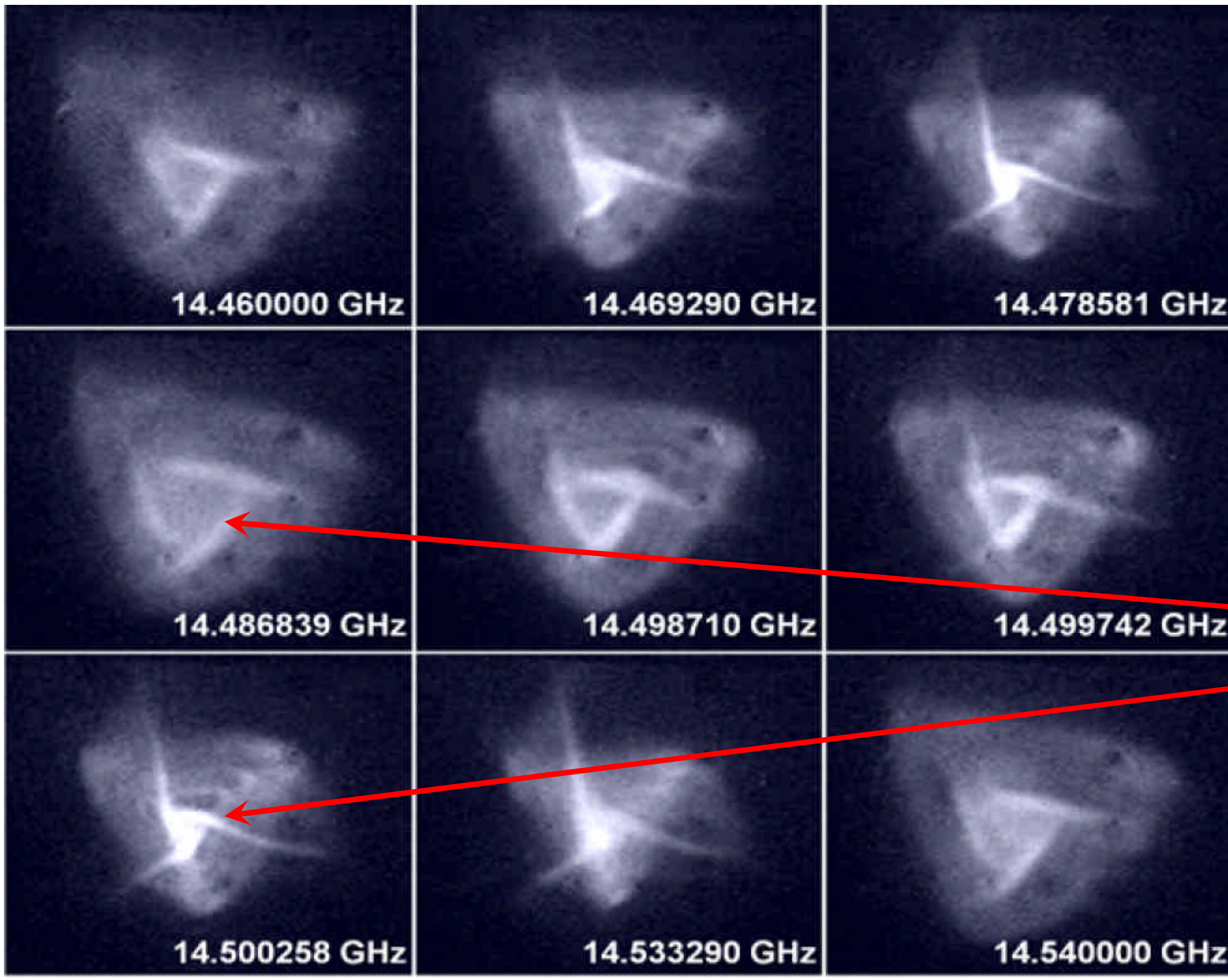
Real space distribution (+/-150mm) and momentum space (+/-500mrad) behind the dipole.

MSECRIS



Real space distribution behind the dipole for different magnetic settings. vertical +/-40mm, horizontal +/-150mm

experimental results



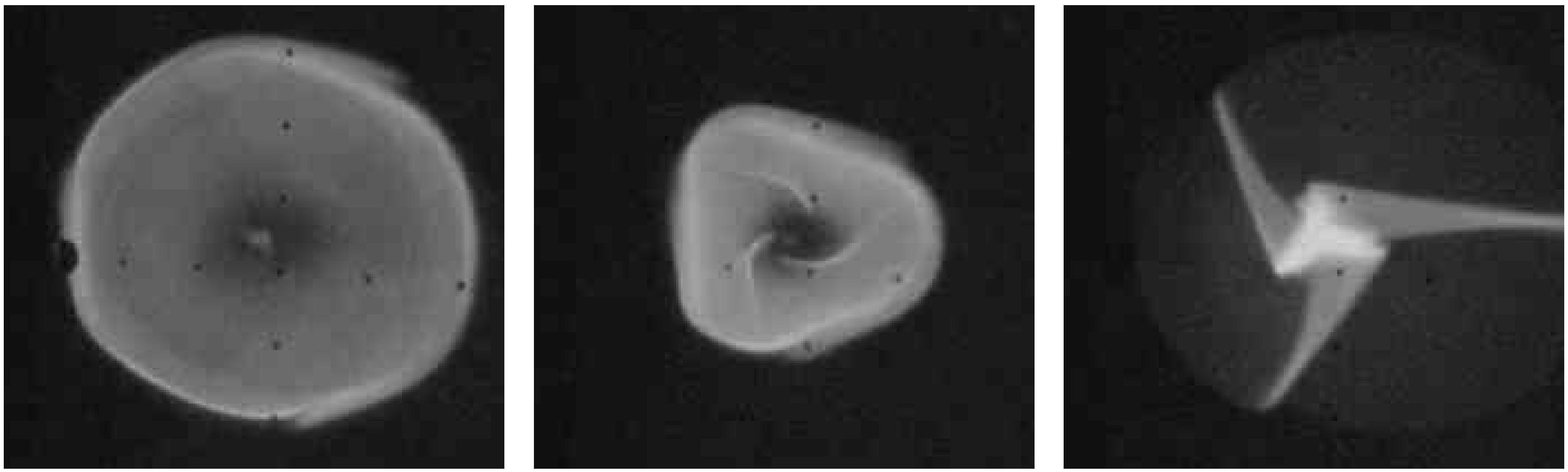
Viewing target directly behind extraction, before the beam line solenoid. Variation of frequency favors different modes. See the talk given by Luigi Celona (INFN Catania).

Different m/q are selectively optimized.

large m/q

low m/q

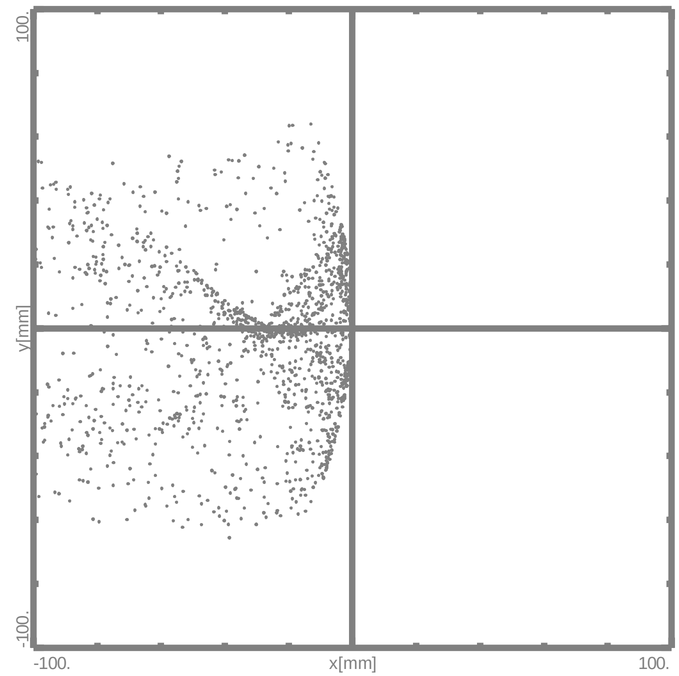
experimental results



Measured beam profiles from CAPRICE at location B with increasing focusing strength of the beam line solenoid. Only one m/q is visible, all other are de- or over focused.

Starting from m/q=1 all different ratios show the same behavior when focused.

experimental results



Measured beam profile (left) and simulated beam profile (right) from CAPRICE at location C.

CONCLUSION

- The distribution of the extracted beam is determined by its starting conditions, which strongly depend on magnetic flux distribution.
- Experimental observations can be explained --- even with linear particle optic, and neglecting space charge effects in the beam line --- by the initial distribution only.