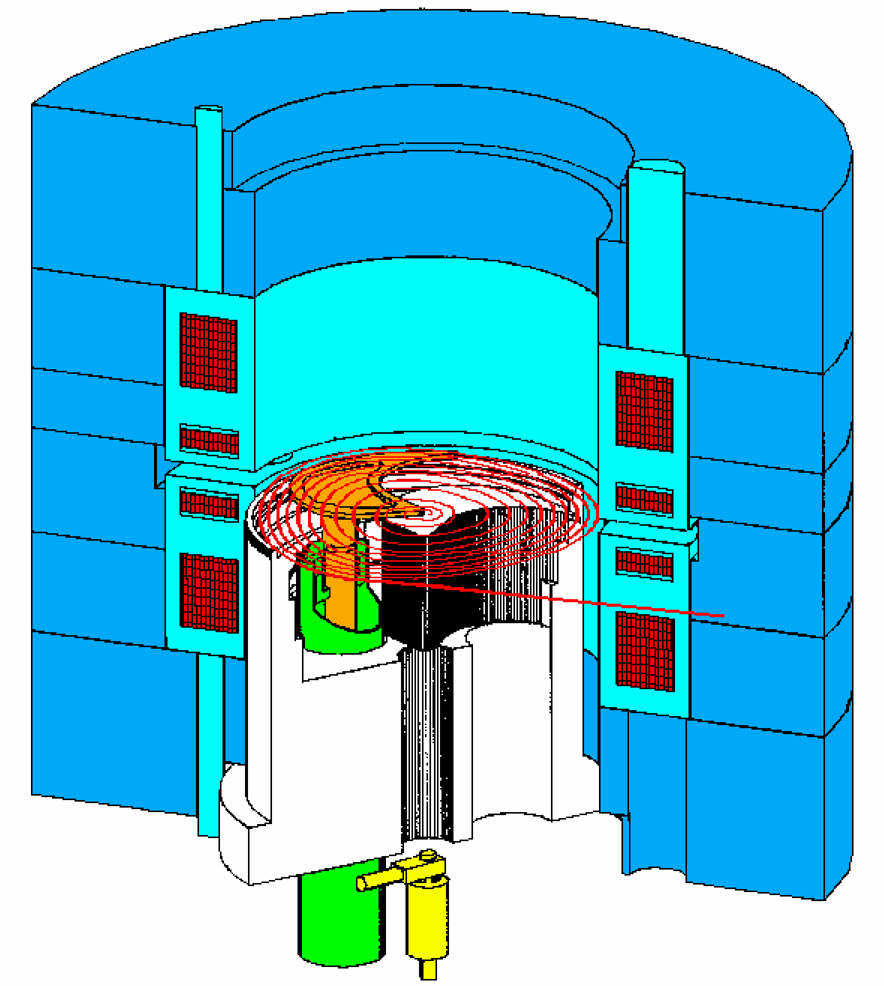
high intensity operation of the AGOR cyclotron for RIB-production



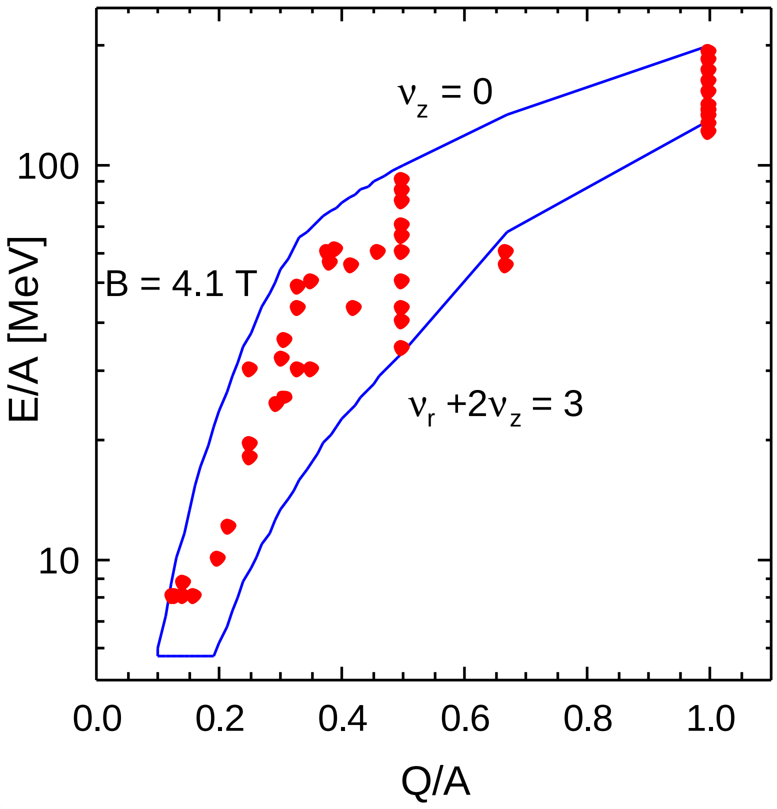
Sytze Brandenburg

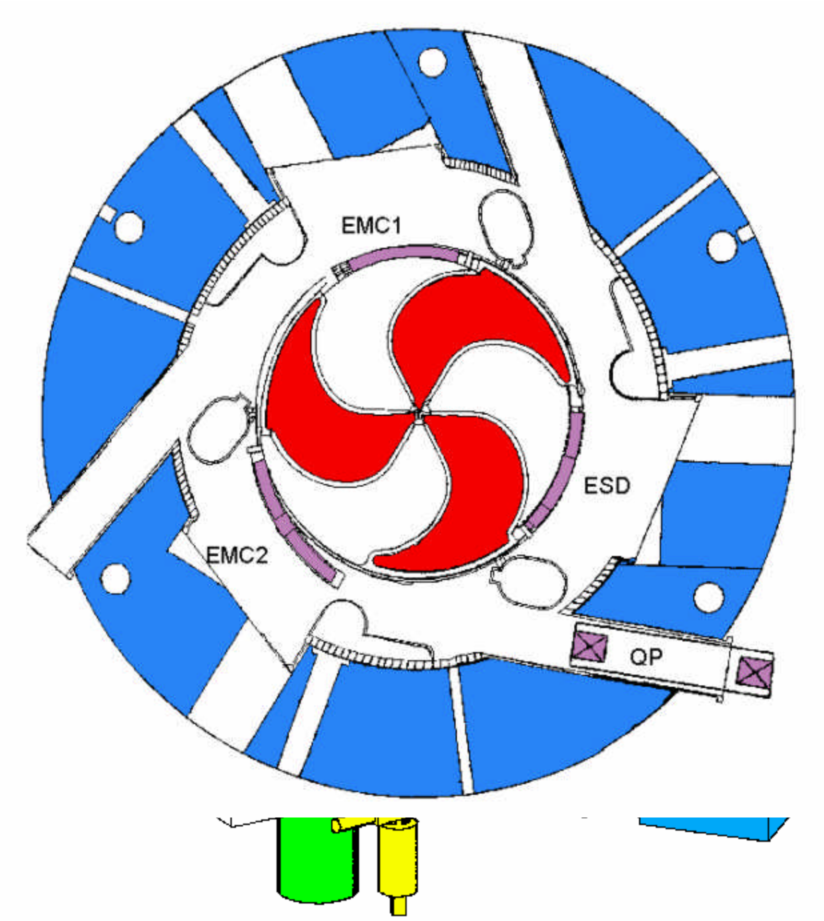
outline

- physics motivation; objectives
- R & D program
- conclusions

AGOR cyclotron

- K600 superconducting cyclotron
  - proton < 190 MeV
  - heavy ions down to 5.5 MeV/A
- produced beams from proton to Pb

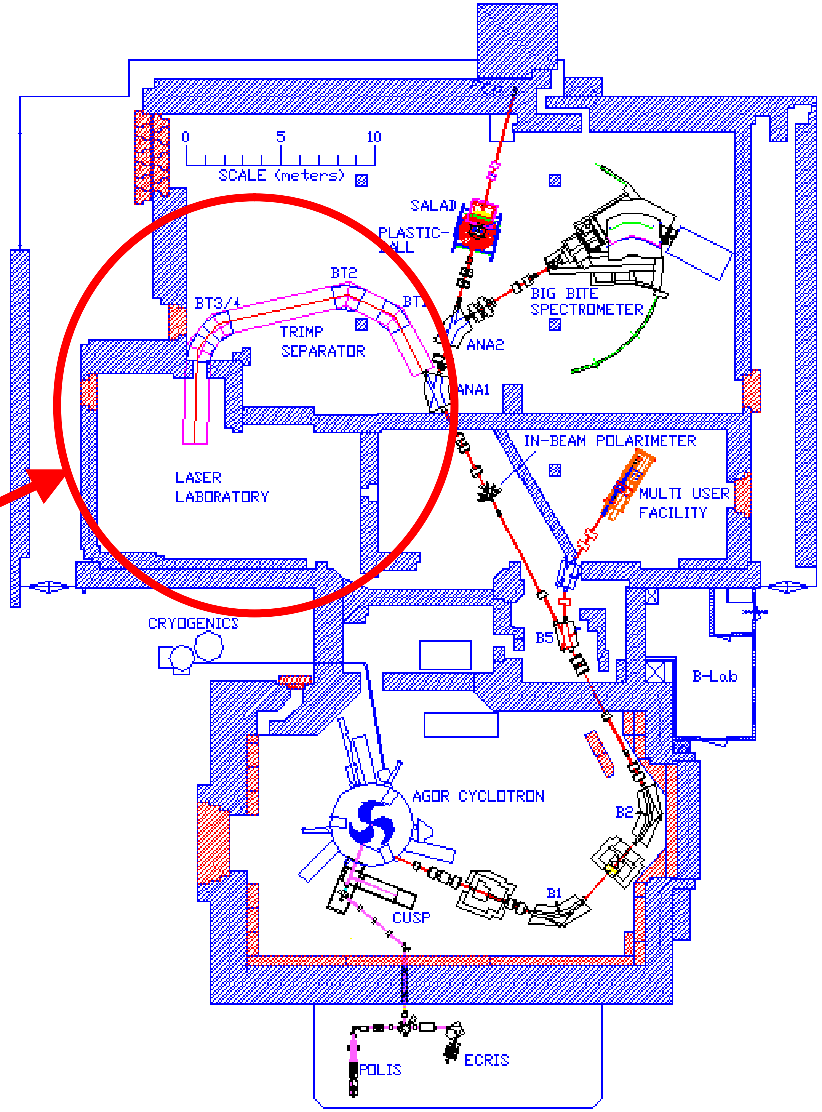




physics motivation

- Trapped Radioactive Ions: μlaboratories for fundamental Physics
- low energy experiments on violation fundamental symmetries
- focus on breaking of time reversal symmetry
  - β - ν correlation in nuclear β-decay (Na isotopes)
    - measure β - recoil correlation; recoil energy < 200 eV
      - atom trap: selection and cooling to μK
  - permanent electric dipole moments (Ra isotopes)
- production: heavy ion reactions in inverse kinematics
  - light elements: fragmentation, direct reactions; beam energy 20 – 40 MeV per nucleon
  - heavy elements: fusion; energy 8 – 12 MeV per nucleon

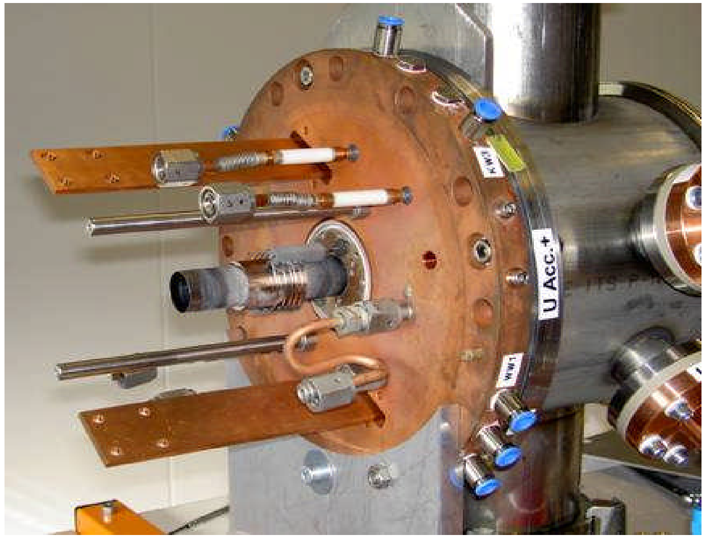
fragment separator

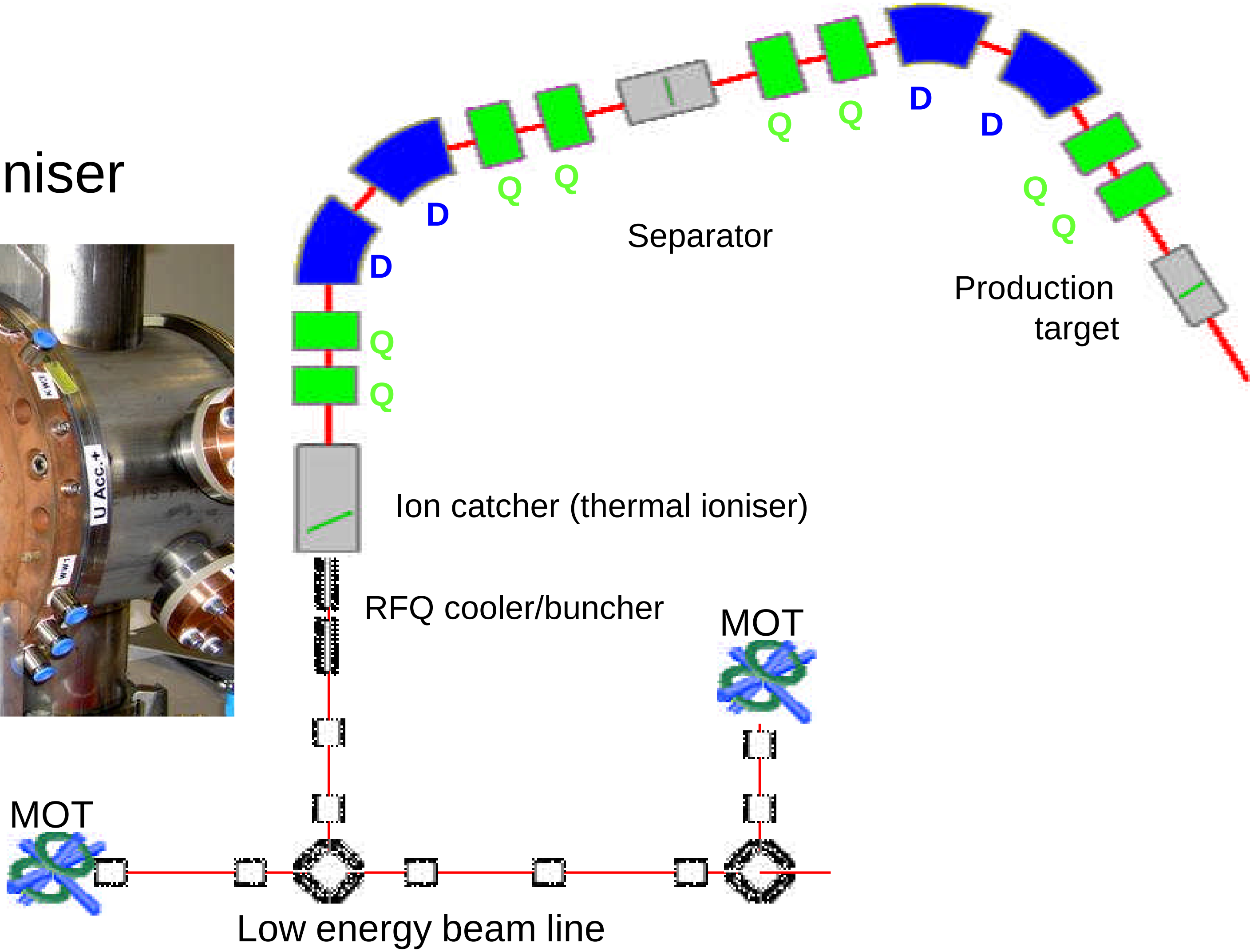


fragment separator
and trap set ups

experimental setup

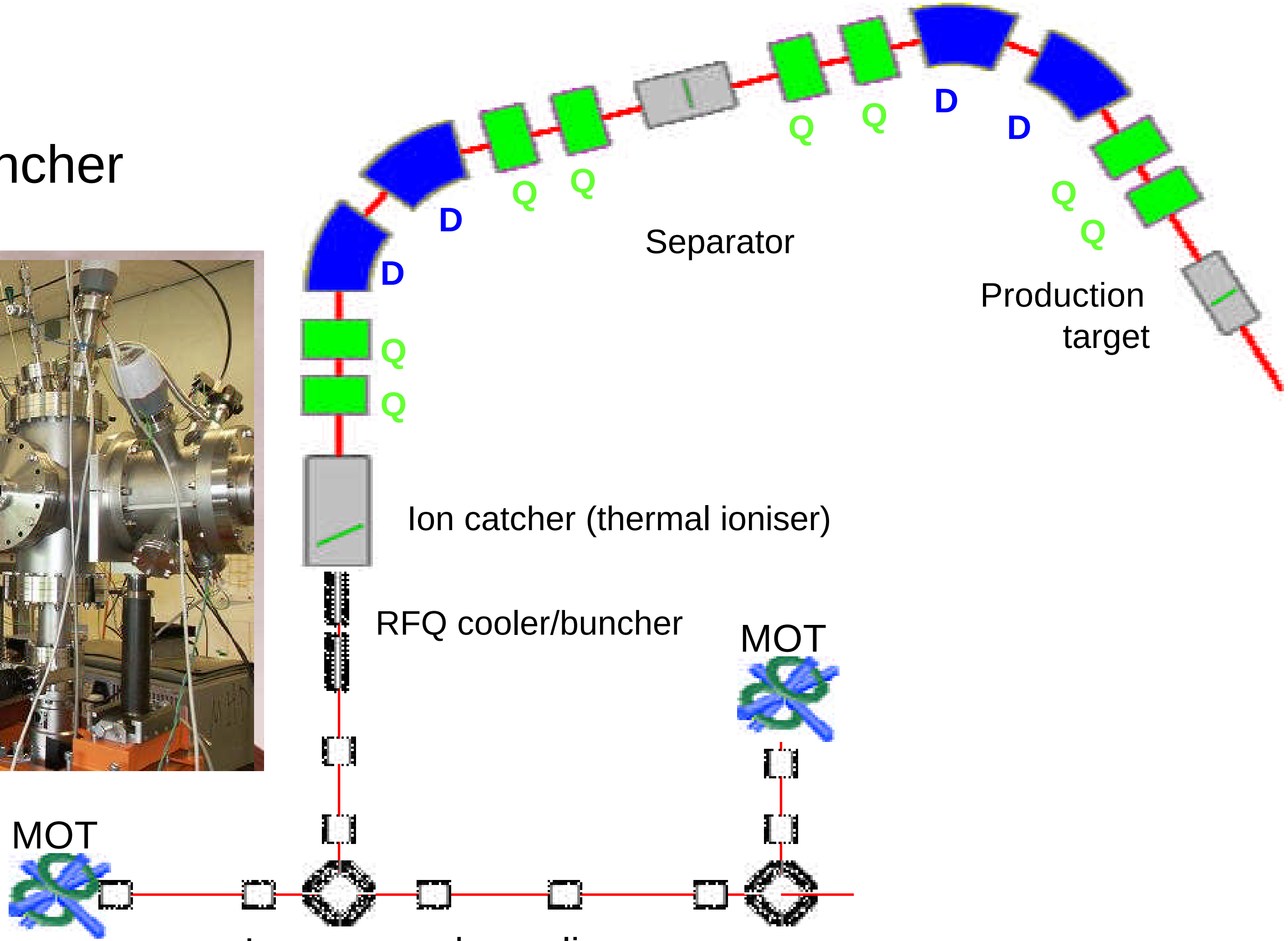
thermal ioniser





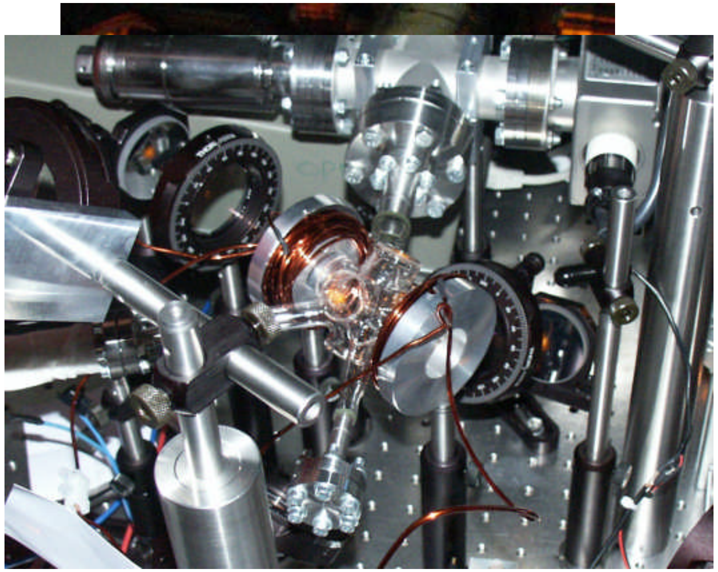
experimental setup

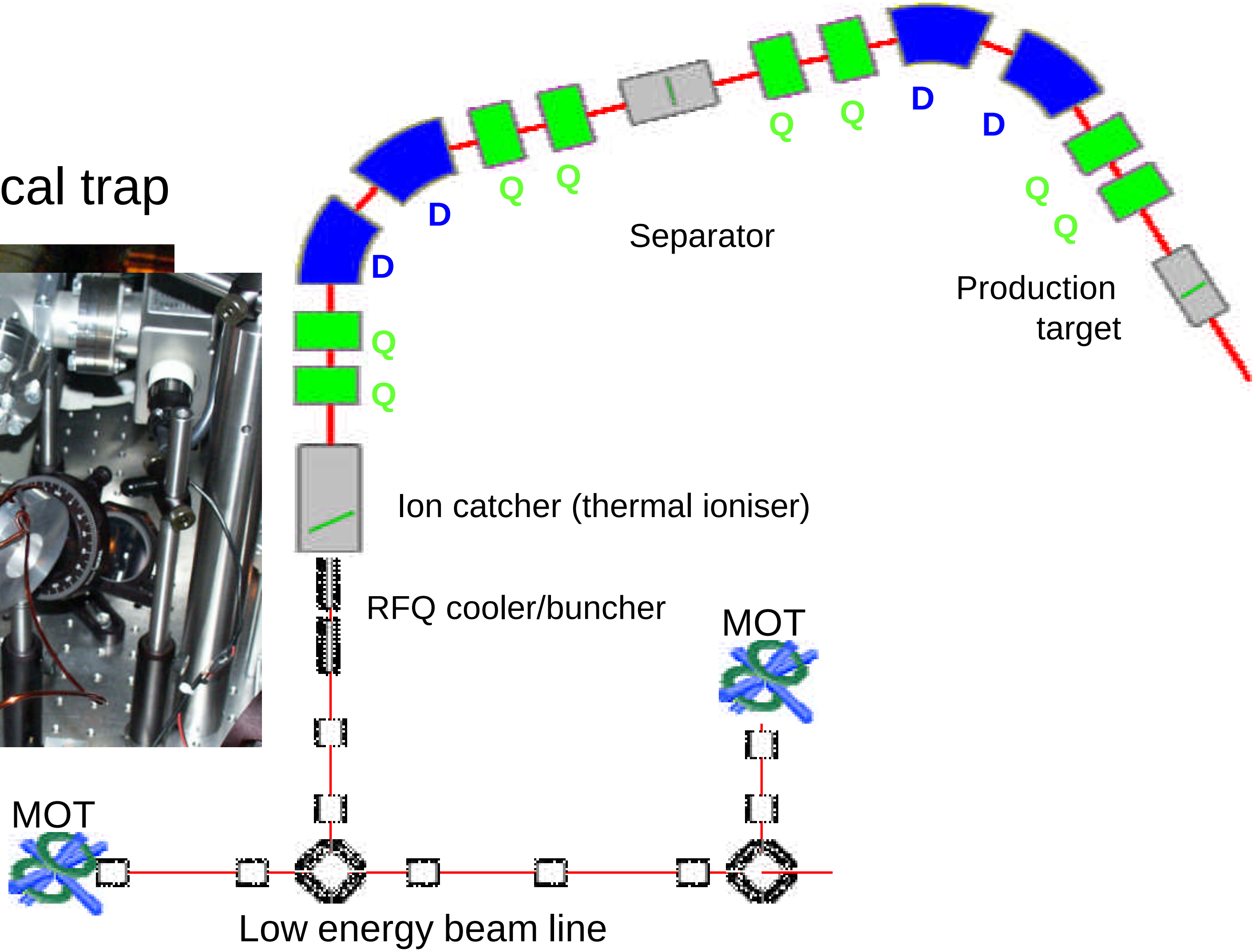
RFQ cooler buncher



experimental setup

magneto optical trap





objectives beam intensity

- typical production rate 10^{-6} per particle

- efficiencies
  - thermo-ionizer 5×10^{-1}
  - RF cooler/buncher 6×10^{-1}
  - MOT system 2×10^{-3} estimated
  - detection 1×10^{-2} estimated
  - OVERALL 6×10^{-6}

  è countrate ~80 s^{-1}pμA^{-1}

improvement needed

è high intensity primary beam (>1 pμA) needed

- beampower ~ 1 kW
- beams for first experiments: ^{20}Ne, ^{208}Pb

KVI

FOM

rijksuniversiteit groningen

outline

- physics motivation; objectives
- R & D program
  - intensity limitations
    - space charge
    - beam $\leftrightarrow$ vacuum
  - cyclotron upgrade
    - ECR ion source & LEBT
    - extraction
    - beam loss monitoring and control
- conclusions

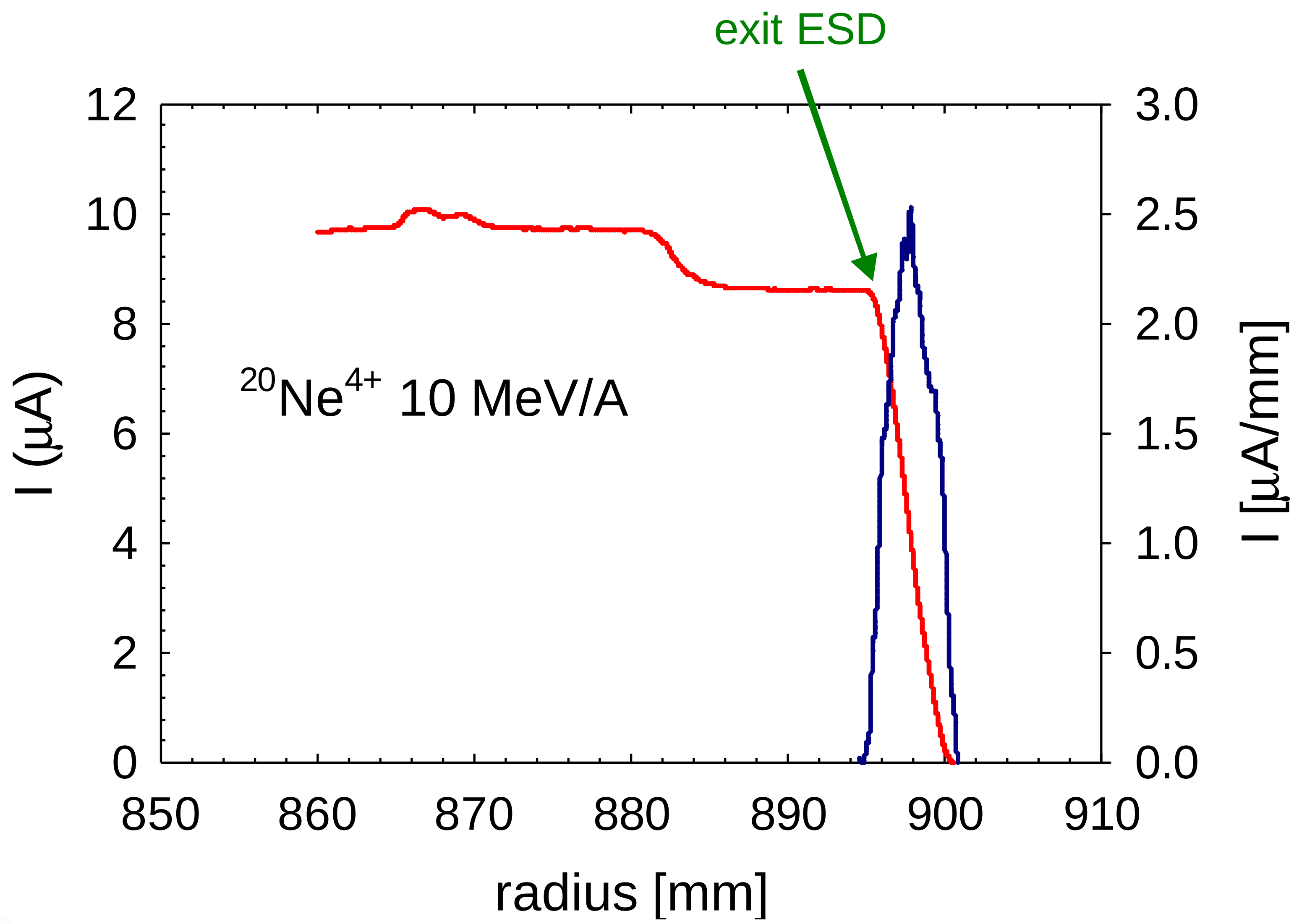
space charge

- dimensioning case corresponds to 20 … @ 10 MeV/A
- tests performed with up to 10 μA 2… eV/A
- injection: reduction axial focu…
    - acceptance depende…
    - loss axial stability … energy heavy ions
    - no effect obs…
- extraction: … paration
    - mul… only minor effect expected
    - no … und
        - 9… D; 85 % machine exit

halfway final objectives

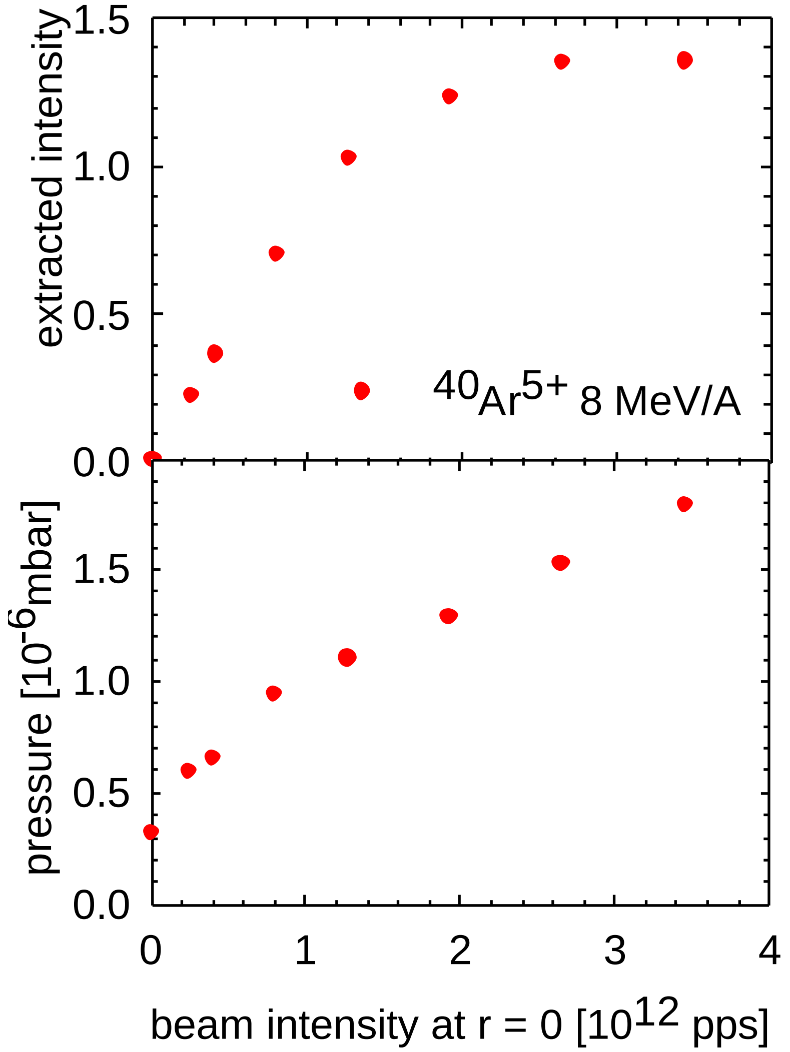
no serious problems expected

extraction


exit ESD
$^{20}Ne^{4+}$ 10 MeV/A
I (μA)
I [μA/mm]
radius [mm]
12
10
8
6
4
2
0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
850
860
870
880
890
900
910

beam ↔ residual gas

- pressure intensity dependent
- transmission pressure dependent
- mechanism: desorption from walls
  - by ionised rest gas (~10 %)
  - by beam losses (~90 %)
- extract from data
  - charge exchange cross section
  - desorption yield
  - è intensity limit
- show stopper for certain beams ?
- strong beam dependence
  - è systematic study needed
- relevant for other machines



beam ↔ residual gas

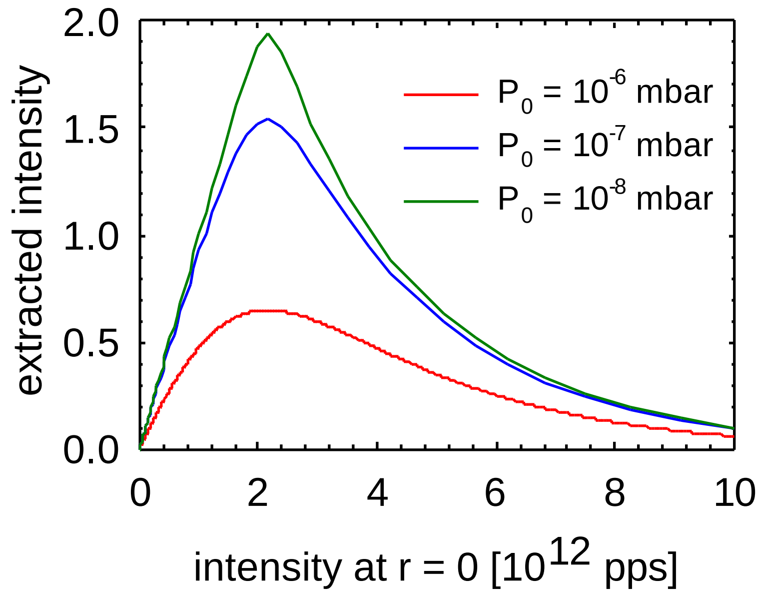
- neglect energy dependences

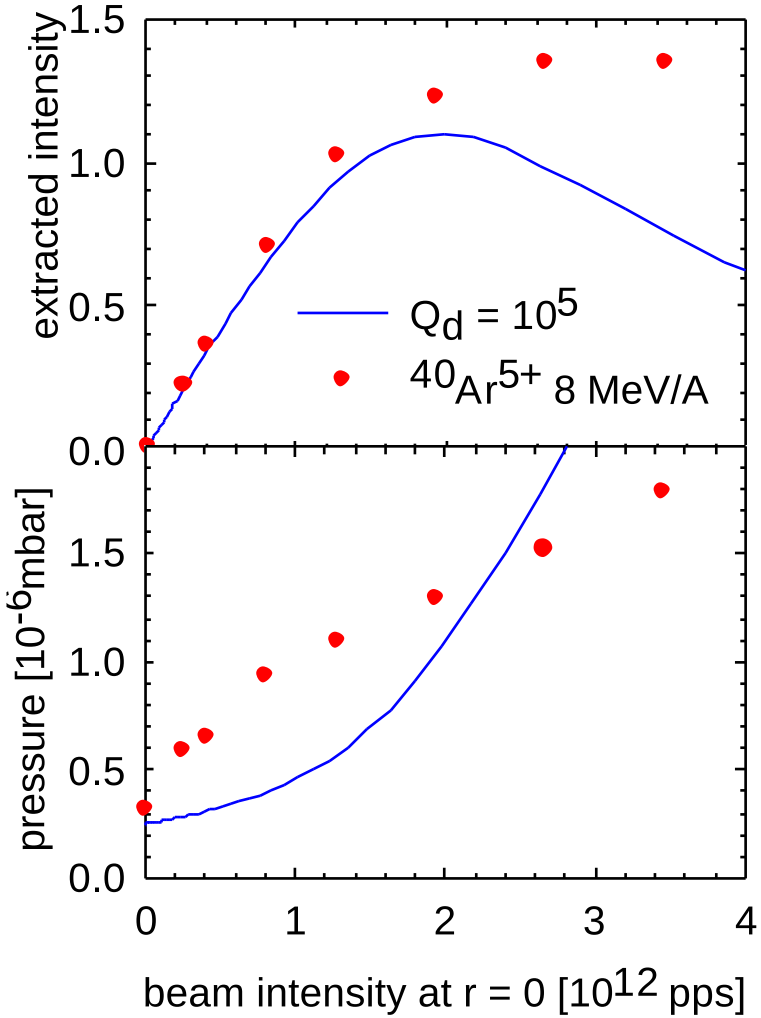
  $I_{out} = I_{in} \exp(-P/P_c)$

  $P = P_0 + Q_d (I_{in} - I_{out})/S_p$

è $Q_d \approx 10^5$; $P_c \approx 2 \times 10^{-6}$ mbar

- P_0 has minor influence
  - machine has to be clean ...





outline

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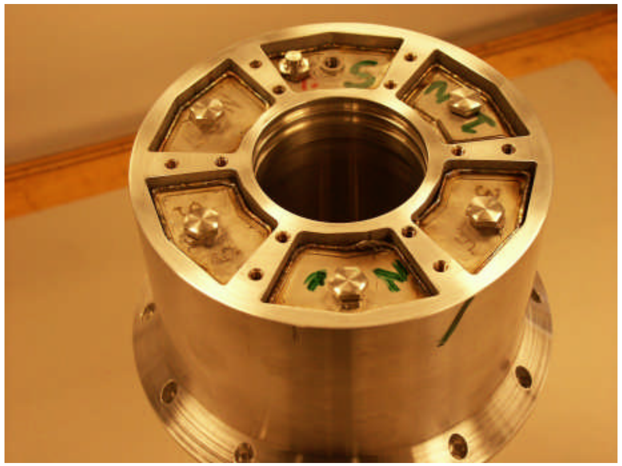
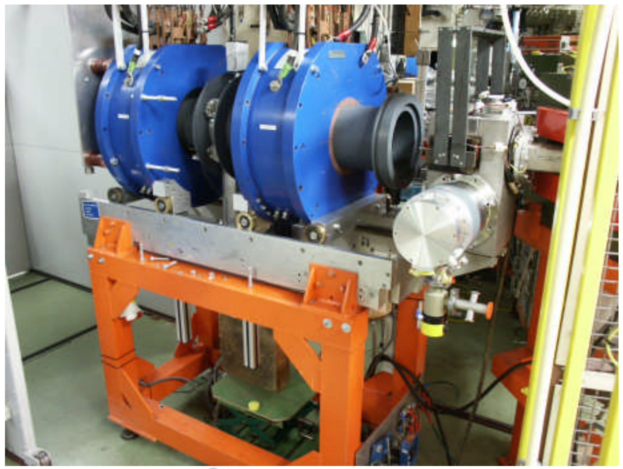
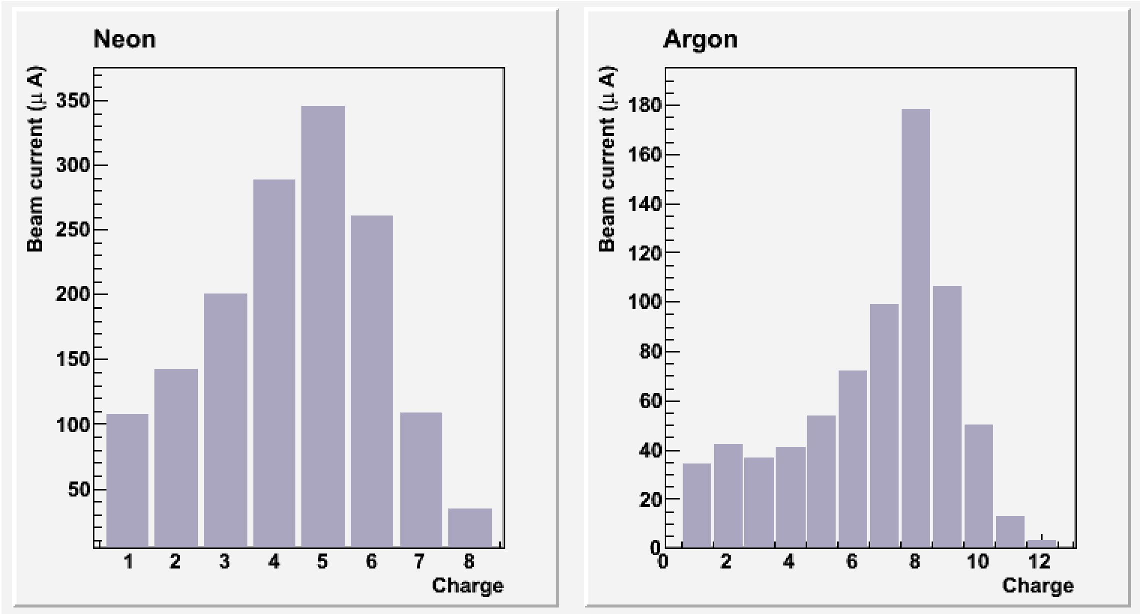
ECR ion source

- existing 14 GHz ECR ion source rebuilt to LBL-AECR type
  - collaboration JYFL, Finland and ANL, USA
  - commissioning completed beginning 2006
  - continuous performance improvement
- ongoing improvements
  - new extraction geometry
  - add 12 GHz heating: charge state boost





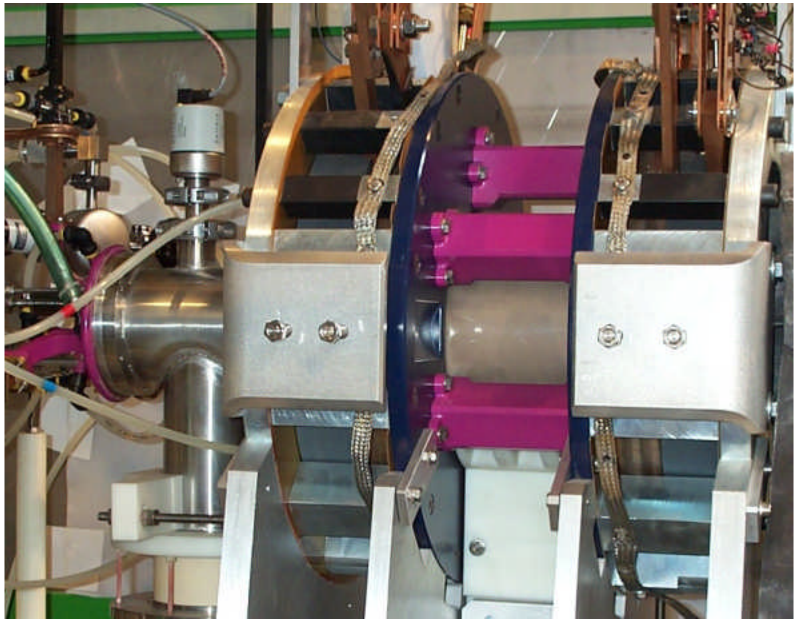
ECR ion source



- intensities exceed requirements for beams up to Ar
  - potential exploited for tests and full experiments
  - $^{20}Ne^{6+}$ 23 MeV per nucleon: 4 μA CW extracted (300 W)
  - $^{20}Ne^{4+}$ 10 MeV per nucleon 10 μA 10 % duty cycle (500 W)
- metal beams: still a lot of work to be done
  - need second source to speed up

future: new ECR ion source

- beam for Ra experiment: 20µA $^{208}Pb^{27+}$ @ E/A = 8 MeV
  - required ECR output >100 µA
  - not feasible with 14 GHz source
  - è new ≥18 GHz source needed
    - installation planned 2010
- options
  - conventional GTS



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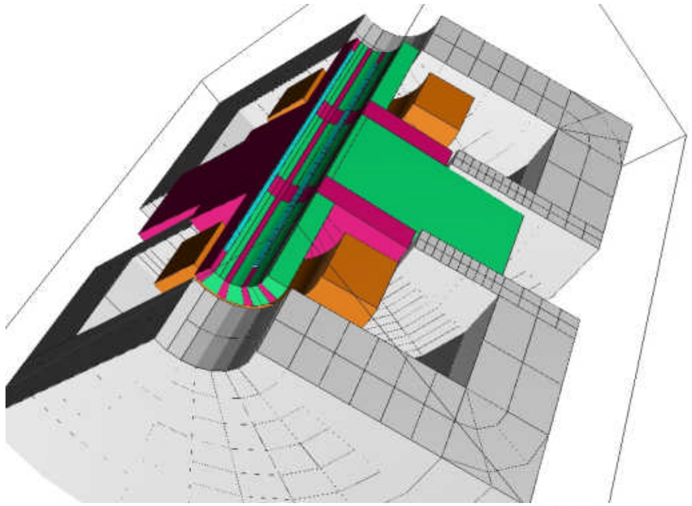
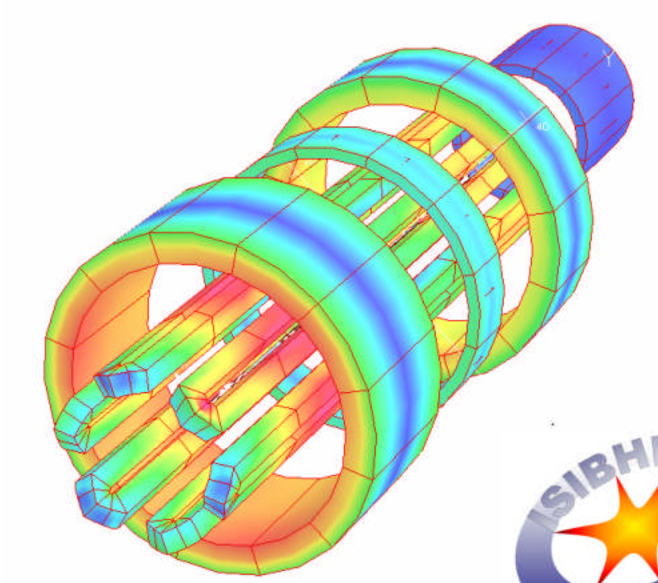
  - hybrid A-PHOENIX; PKDELIS-M



future: new ECR ion source

- beam for Ra experiment: 20μA $^{208}Pb^{27+}$ @ E/A = 7.5 MeV
  - required ECR output >100 μA
  - not feasible with 14 GHz source

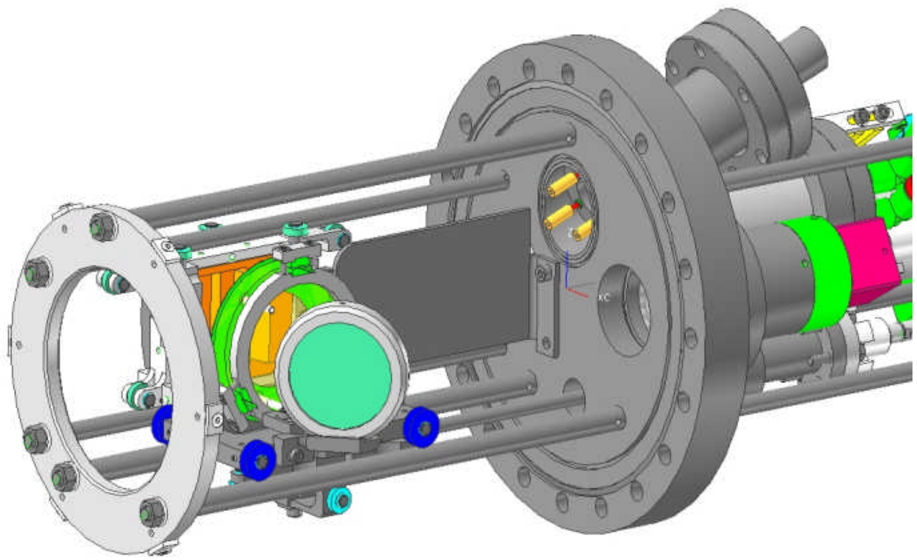
  è new ≥18 GHz source needed
    - installation planned 2010
- options
  - conventional GTS
  - hybrid A-PHOENIX; PKDELIS-M
  - fully SC MS-ECRIS

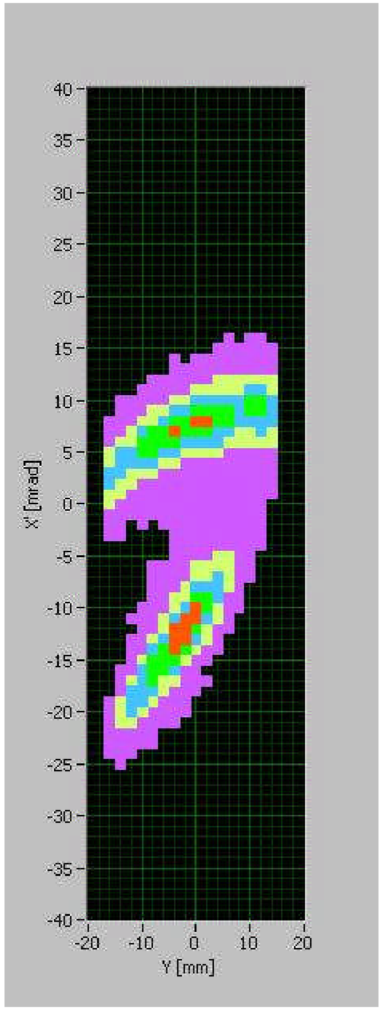


LEBT

- transmission to cyclotron
  - improved 25 % è 50 % but still matching problem
- better understanding of beam formation needed
  - beam contains many components with different Q/A
  - focussing properties depend on Q/A
- tools:
  - 4D-emittance measurements
  - detailed simulations
- work in progress: post-doc + PhD-student

4D-emittance meter

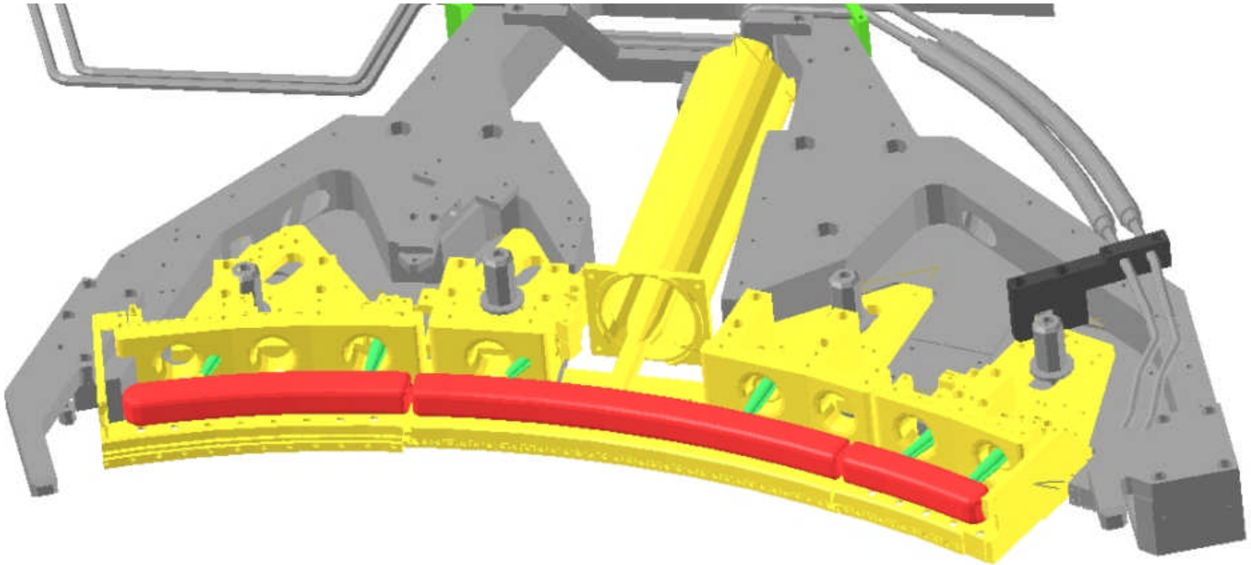




- vertically oriented 20 µm hole pattern
  - match to expected emittance
- horizontal scanning
- MCP + phosphor for imaging onto CCD-camera

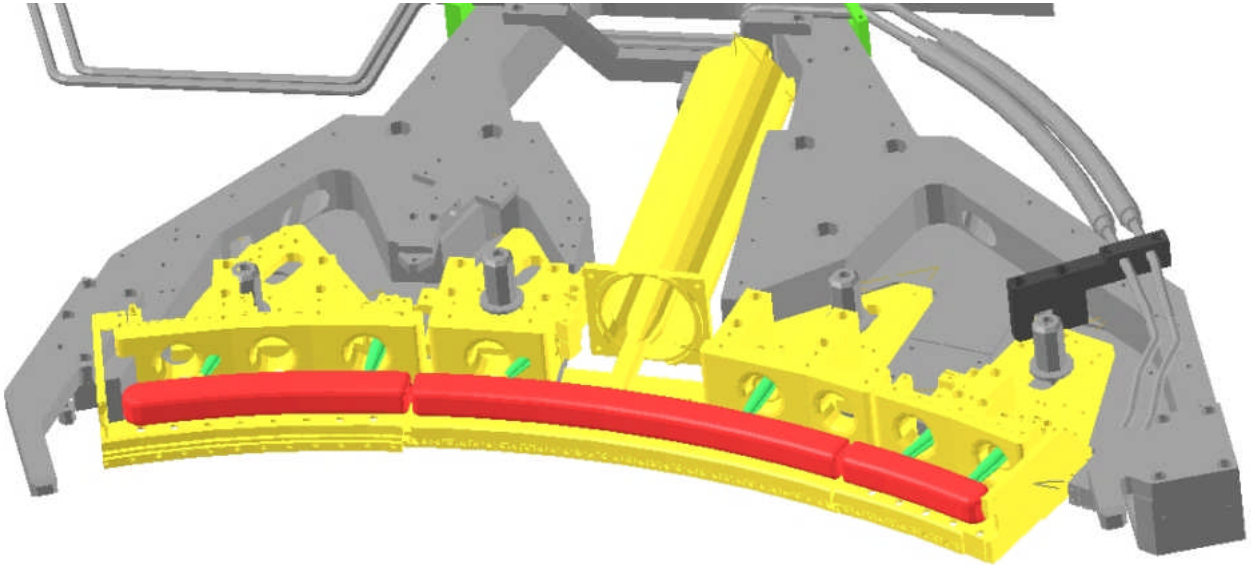
è 4D phase space density ρ(x, y, x', y')

extraction: electrostatic deflector



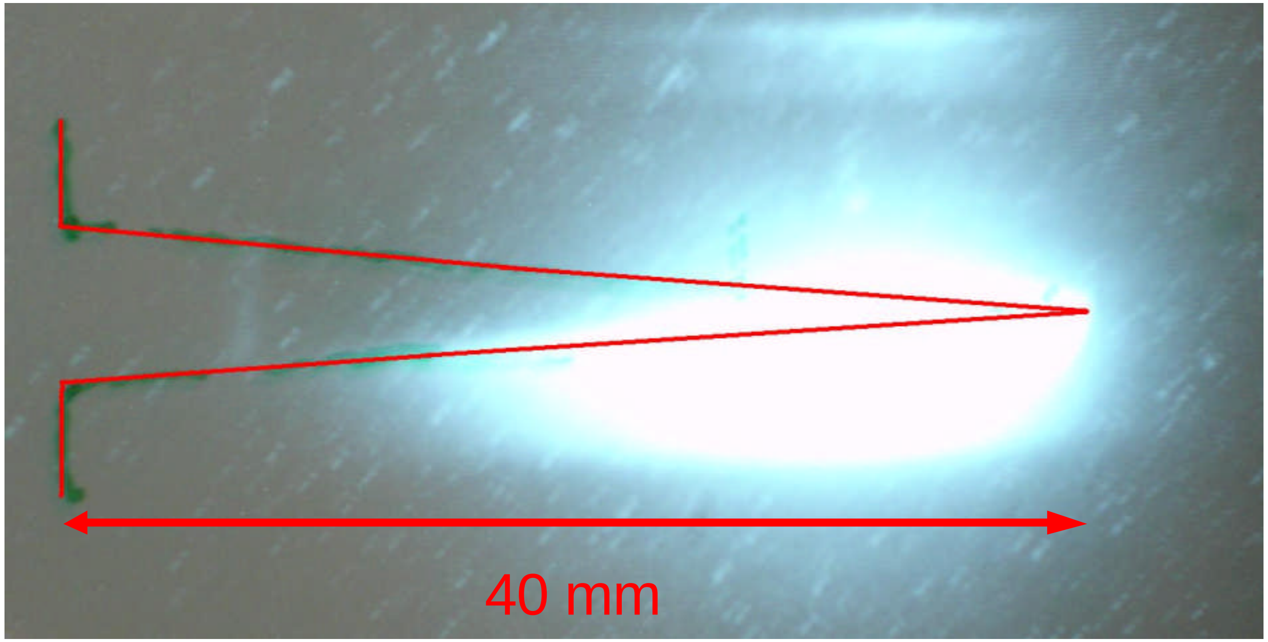
- original deflector
  - no cooling
  - 0.125 mm W septum with straight edge
  - beam power limit ~100 W for ^{20}Ne @ E/A = 23 MeV
    - power density in septum 20 W/mm^3
    - septum temperature ~ 1500 K @ 10 W loss

extraction: electrostatic deflector



- present deflector
  - no cooling
  - 0.125 mm W septum with V-shaped notch
  - beam power limit ~300 W for ^{20}Ne @ E/A = 23 MeV
    - power density in septum 20 W/mm^3
    - septum temperature ~ 1500 K @ 30 W loss

extraction: electrostatic deflector



- present deflector
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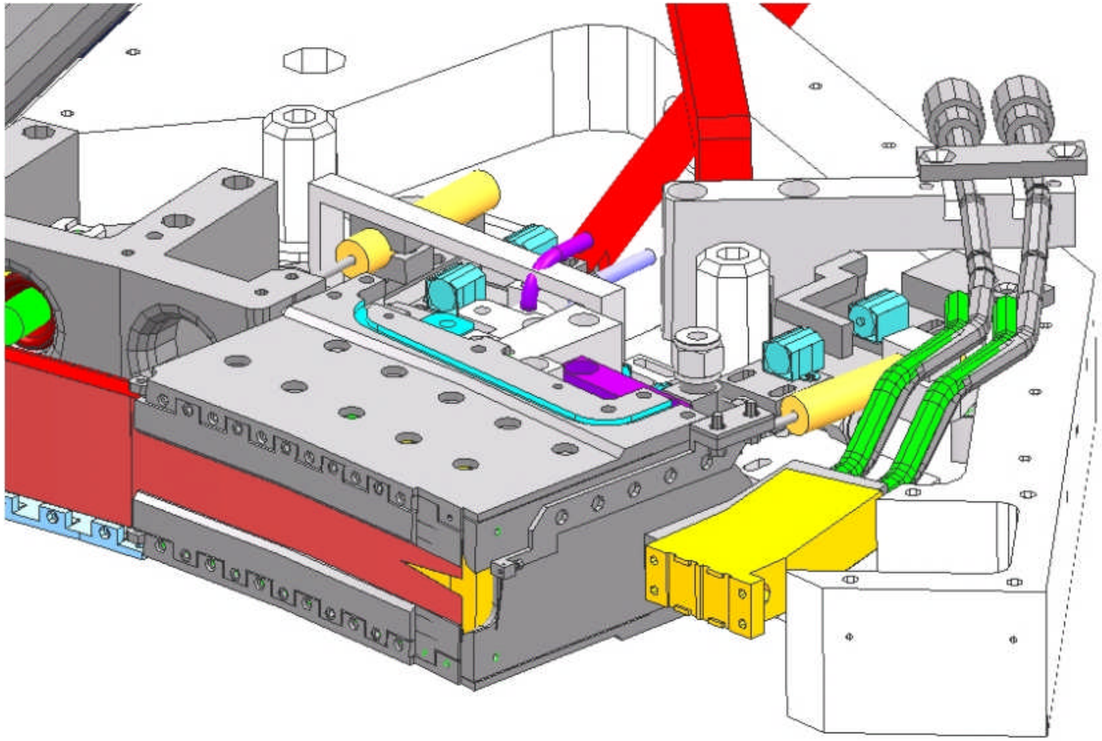
  - 0.125 mm W septum with V-shaped notch
  - beam power limit ~300 W for ^{20}Ne @ E/A = 23 MeV
    - power density in septum 20 W/mm^3
    - septum temperature ~1500 K @ 30 W loss

extraction: electrostatic deflector

- typical examples of requested 1 kW beam (90 % efficiency)
  - 22 µA $^{20}Ne^{6+}$ @ E/A = 23 MeV
    - range: 140 µm è power density 80 W/mm^3
    - expected septum temperature ~2000 K
  - 20 µA $^{208}Pb^{27+}$ @ E/A = 7.5 MeV
    - range: 24 µm è power density 450 W/mm^3
    - expected septum temperature ?????
- feasibility ?
  - test experiments to validate calculations planned

extraction: electrostatic deflector



- new deflector
  - active cooling septum + cathode
  - V-shaped notch in septum
  - increased septum thickness outside median plane
  - commissioning spring 2009

extraction: superconducting channels

- beam channel screen cooled with 4.5 K boil-off gas
  - ΔT screen ~ 1K/W
- radiation load on cold mass 0.3 W for screen @100 K without beam loss heat load 10 W
- normal operation: beam losses < 5 %
  è ΔT < 50 K @ 1 kW

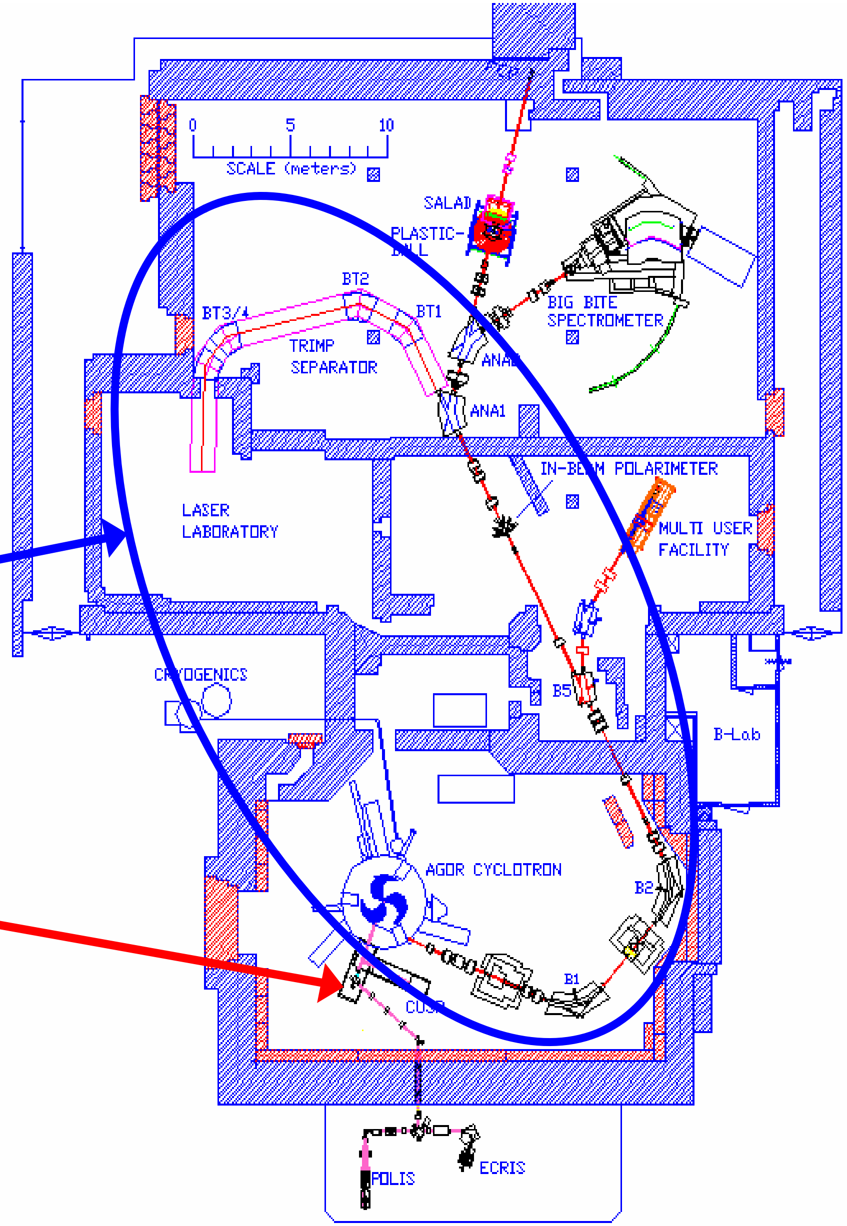
è no problems expected

- loss full beam leads to quench

beam loss monitoring and control

- power density ~1 kW/mm^3
  - è damage om ms timescale
  - è equipment protection essential for cyclotron and HEBT

è beam loss monitoring and control system



beam loss monitoring and control

- low beam energy (down to 7.5 MeV/A for ^{208}Pb)
  - è radiation monitoring not sensitive
  - è measure beam losses directly

- beam loss measurement
  - direct for collimators and slits
  - non-intercepting with inductive pick-ups for beamlines etc.
    - 2 kHz chopper

- beam intensity control
  - continuous: pulse width modulation chopper
  - discrete: pepperpot devices; range 10^9; step 10
    used for tuning and experiment setup using direct beam

- similar to GANIL and GSI-UNILAC systems

outline

- physics motivation; objectives
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conclusions

- beams up to Ar
  - ion source: up to 1 kW feasible
  - extraction: up to 300 W feasible
  - further increase requires
    - new electrostatic deflector
    - beam loss monitoring and control
  - 1 kW might be feasible

conclusions

- Pb beams
  - ion source: up to 50 W feasible
  - extraction: up to 50 W feasible
  - further increase requires
    - new ECR ion source
  - intensity limit to be established
    - feasibility 1 kW questionable

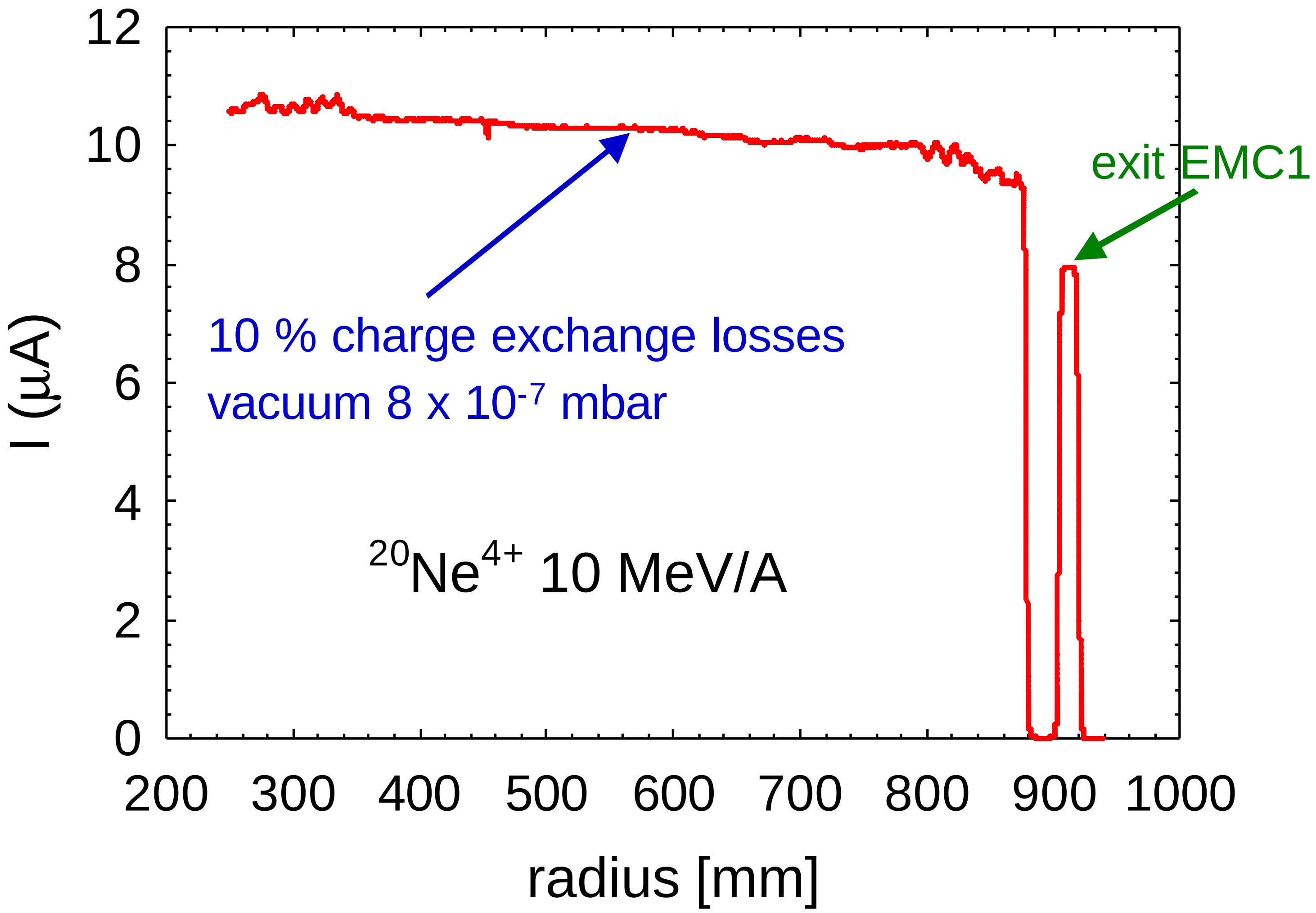
AGOR is made possible by

- the users
- the accelerator group at KVI

investment program

- cost upgrades
  - AGOR 1800 k€
  - TRIμP 1500 k€
- coverage
  - FOM-investment fund 2005 - 2013 ≥2300 k€
  - FOM-investment fund <2005
    ECRIS phase 1 300 k€
    ombuigingen ≤330 k€
  - nog niet gedekt ≥370 k€
  - total 3300 k€

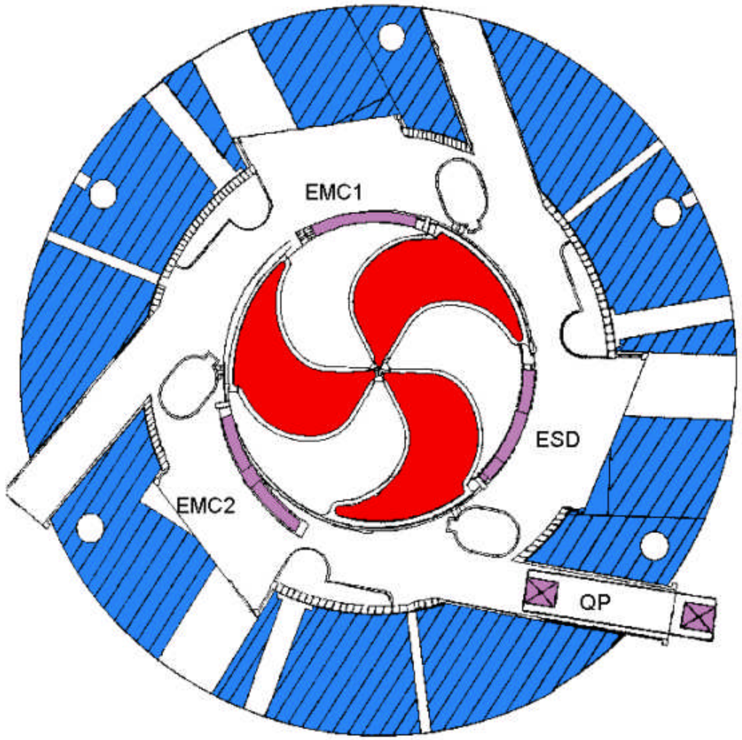
extraction



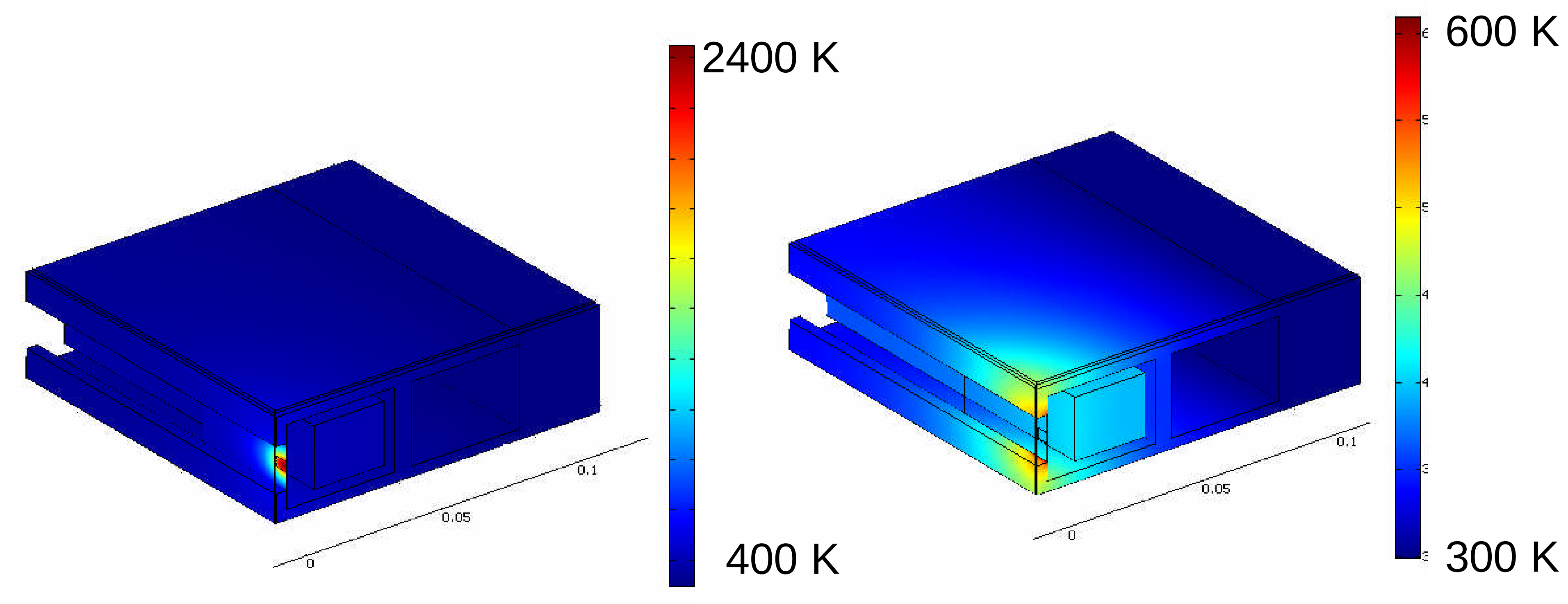
I (µA)
12
10
8
6
4
2
0
200
300
400
500
600
700
800
900
1000
radius [mm]
exit EMC1
10 % charge exchange losses
vacuum 8 x 10-7 mbar
20Ne4+ 10 MeV/A

power dissipation extraction

- ESD — heat load septum and cathode (radiation)
  new design with cooling
  support from NSCL, USA and LNS, Italy
  commissioning begin 2009
- EMC2/QP — heat load on internal screen ?
  need sofar not established



power dissipation electrostatic deflector



- 75 W beam loss on septum
- deposited in ~0.1 mm^3 volume (typical range < 100 µm)