# Progress towards High Intensity Heavy Ion Beams at the AGOR Facility

Sytze Brandenburg

KVI



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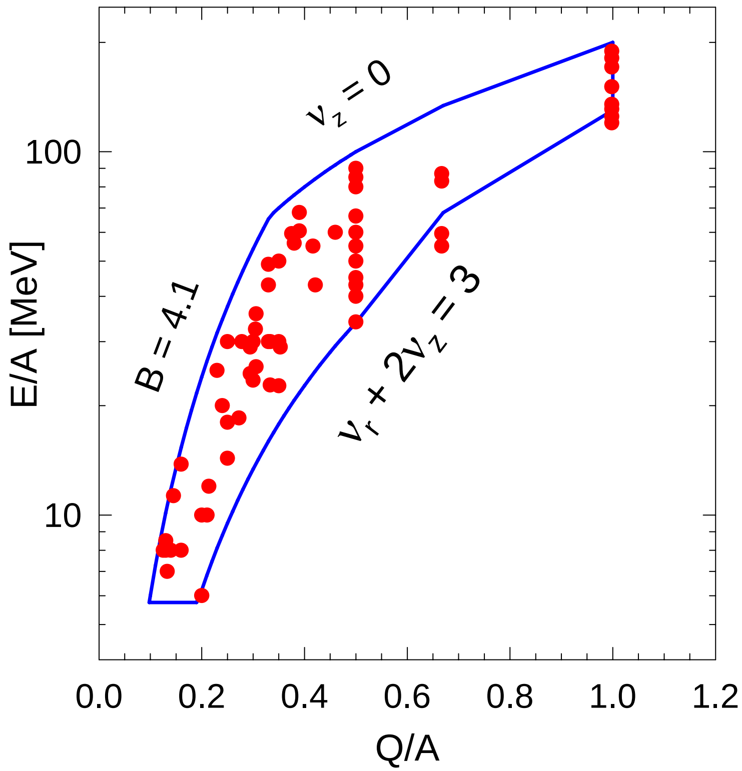
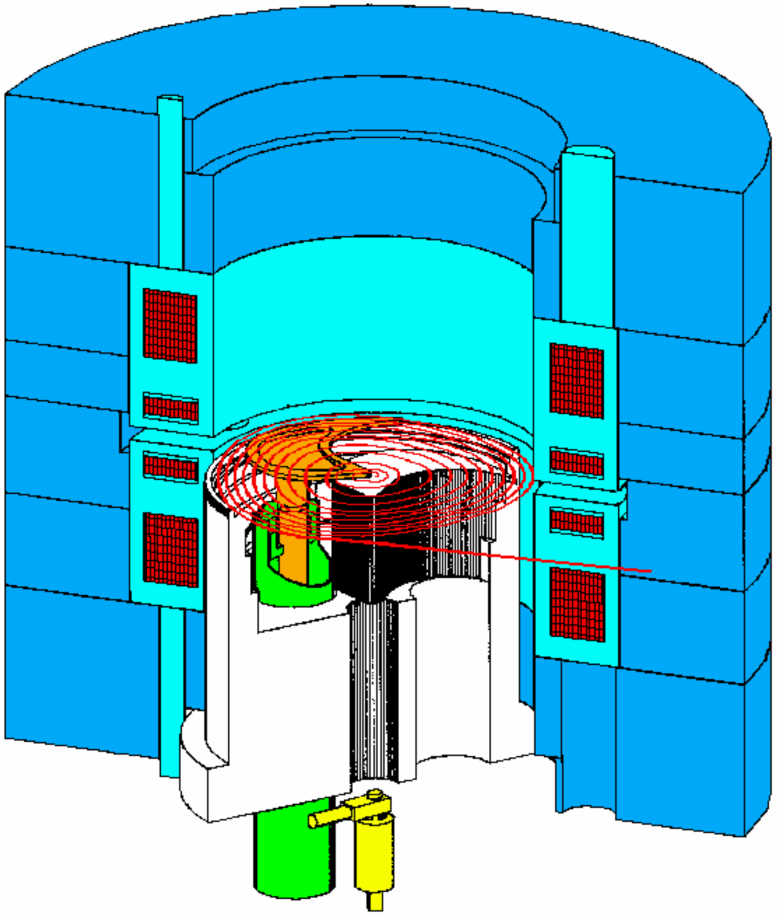
# outline

- physics motivation, objectives
- current status
  - ECR ion source
  - LEBT
  - cyclotron
  - operational safety
- conclusions

# AGOR cyclotron

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



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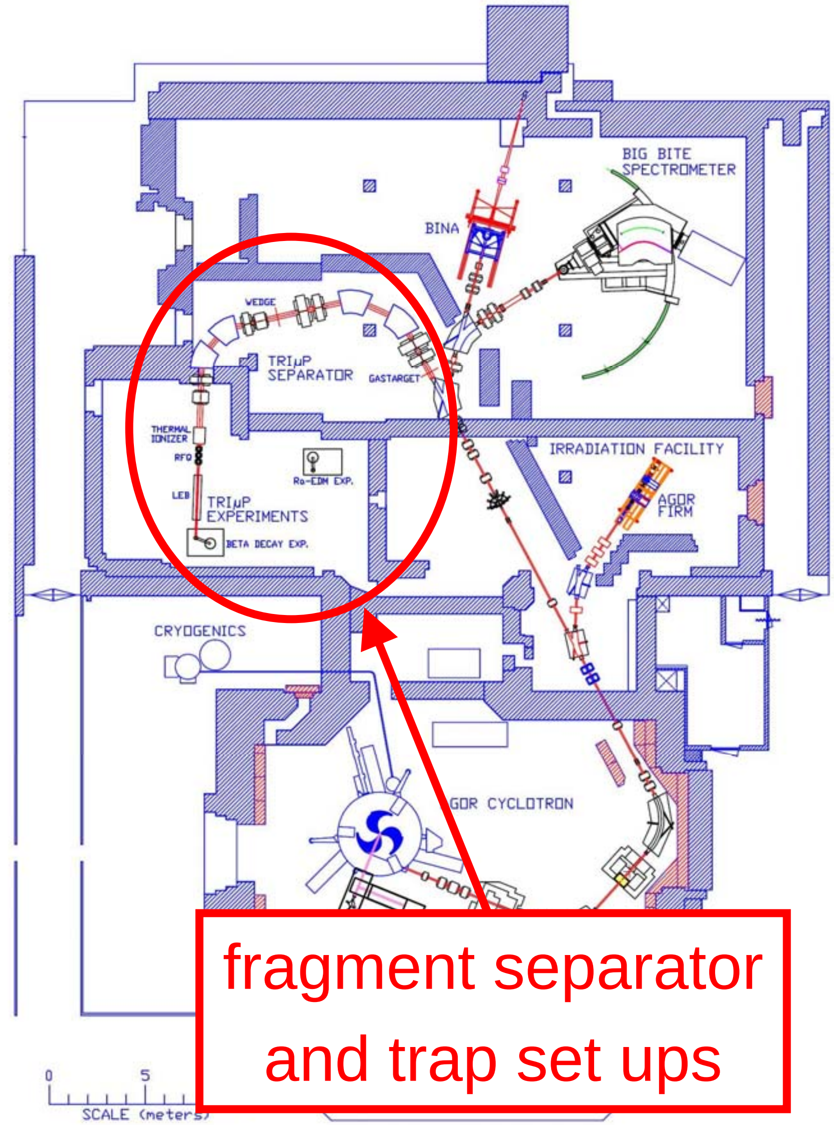




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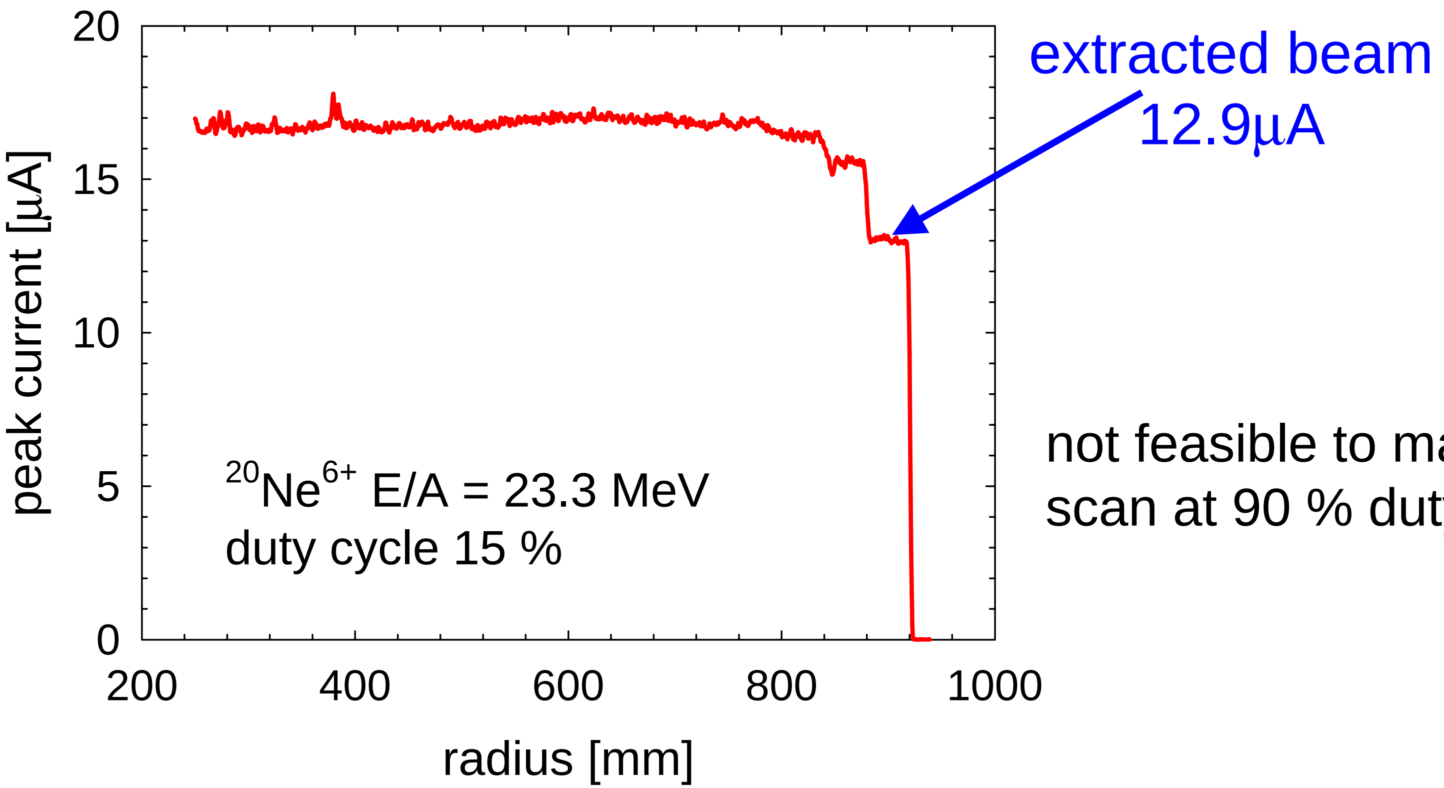
# physics motivation, objectives

- low energy experiments on violation fundamental symmetries
- focus on breaking of time reversal symmetry
  - $\beta$ - $\nu$ correlation in nuclear $\beta$-decay (Na isotopes)
  - permanent electric dipole moments (Ra isotopes)
  - measurements on trapped atoms and ions
- production: heavy ion reactions in inverse kinematics
  - Na-isotopes: Ne-beam @ 20 – 25 MeV per nucleon
  - Ra-isotopes: Pb-beam @ 7 – 10 MeV per nucleon
- overall trapping rate: 1 event per $10^{11}$ - $10^{12}$ beam particles

  ➡ beam intensity $10^{12}$ - $10^{13}$ pps needed for production phase

# current status

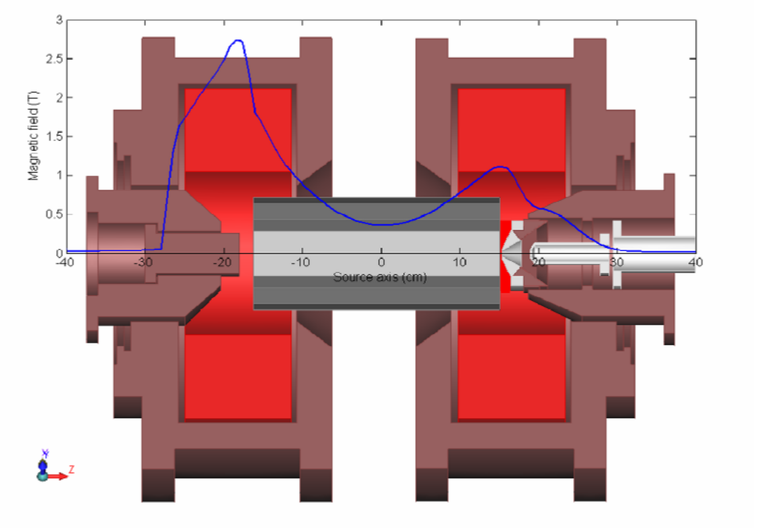
- beam intensities achieved
  - $^{20}Ne^{6+}$ @23.3 MeV/nucleon 1.3 x $10^{13}$ pps P = 1 kW
  - $^{206}Pb^{27+}$ @ 7 - 10 MeV/nucleon 3 × $10^{11}$ pps P = 100 W



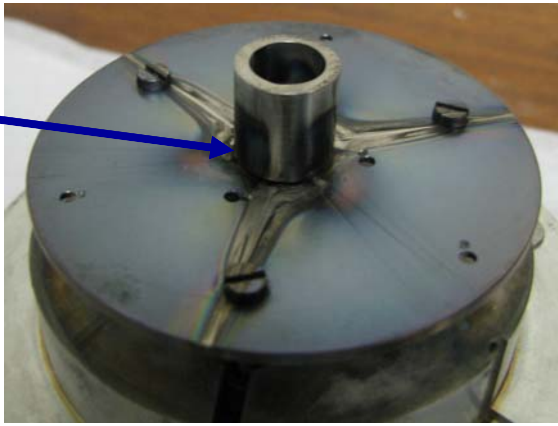

not feasible to make scan at 90 % duty cycle

# ECRIS

- 14 GHz AECR-type source
  cf. LBNL, JYFL
  - aluminium plasma chamber
  - open hexapole structure




- dual frequency heating
  - 14 GHz up to 2 kW
  - 11 – 12.5 GHz (variable frequency) up to 400 W,
- modifications plasma chamber
  - stainless steel plasma electrode + **collar**
  - stainless steel biased disk



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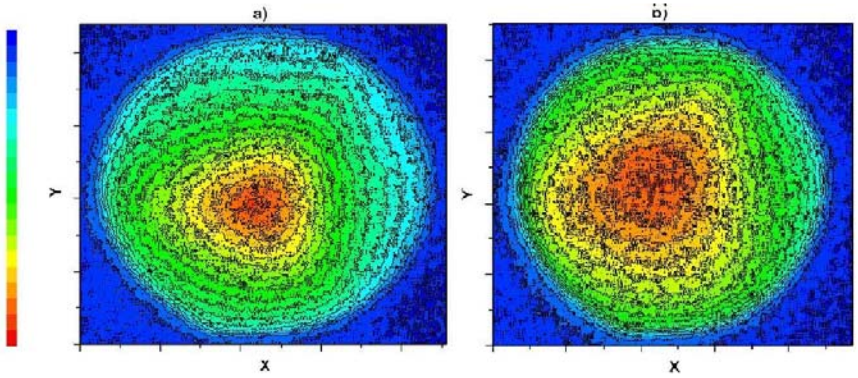
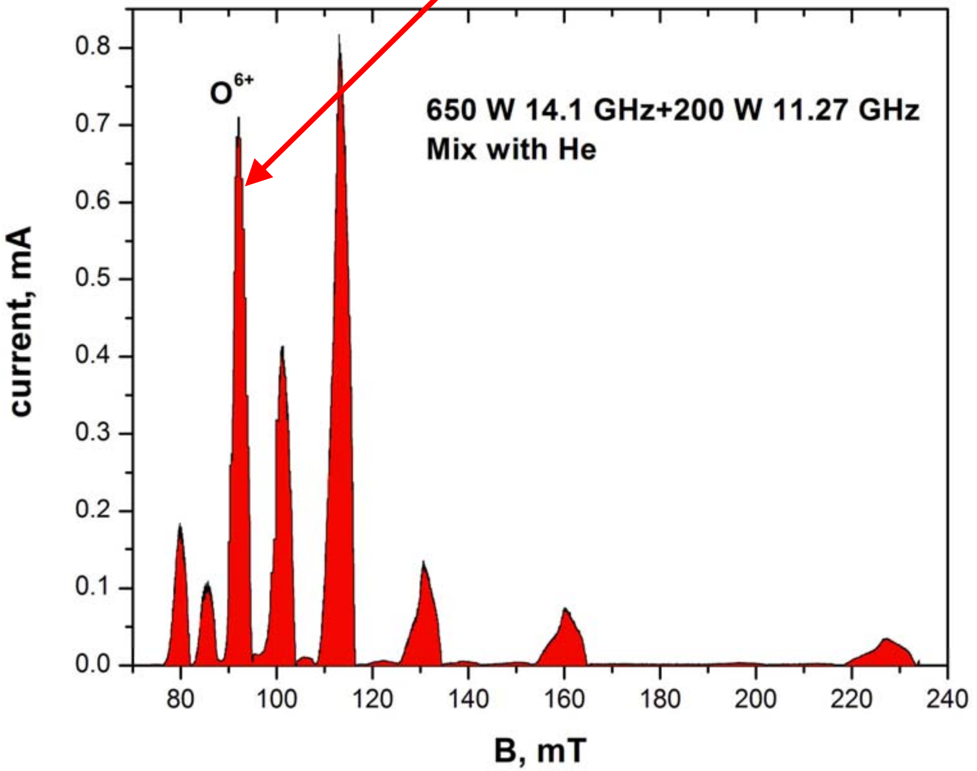
# ECRIS

- optical diagnostics
  - CCD camera viewing plasma
  - low depth of field optics
    ➡ scan over depth
  - very useful for tuning (stability)




best result: $O^{6+}$ 750 µA




- routinely obtained output
  - $^{16}O^{6+}$ 500 µA
  - $^{20}Ne^{6+}$ 500 µA
  - $^{206}Pb^{27+}$ 50 µA

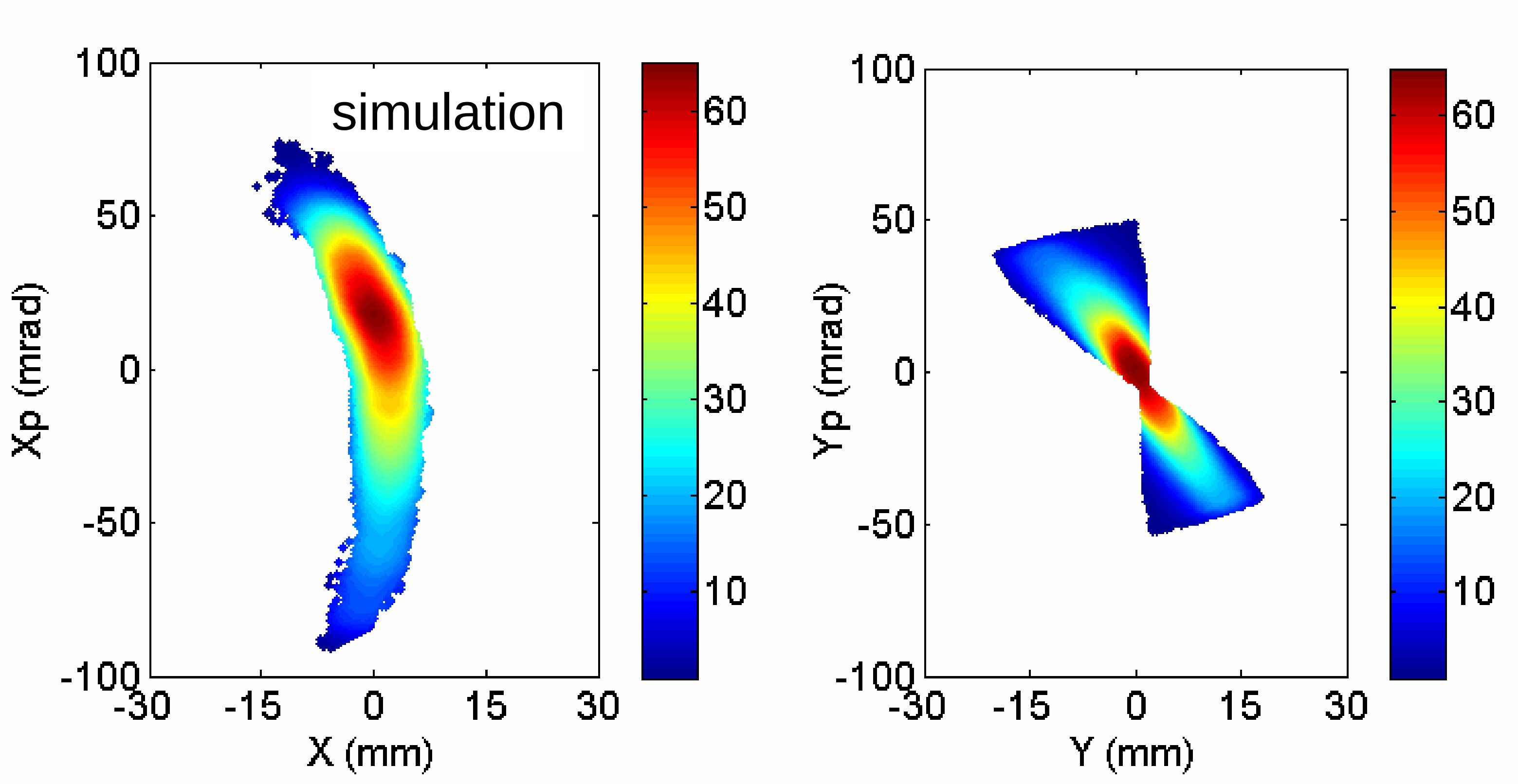
# ECRIS

- installed SUPERNANOGAN at location polarized source
  - AECR dedicated for metal beams

➡ more output…..

# LEBT ion optics

- ECRIS analysing magnet
  - acceptance too small ➡ 30 % beam loss
  - large higher order aberrations ➡ 50 % beam loss transfer line
  - simulation ↔ experiment: semi-quantitative agreement



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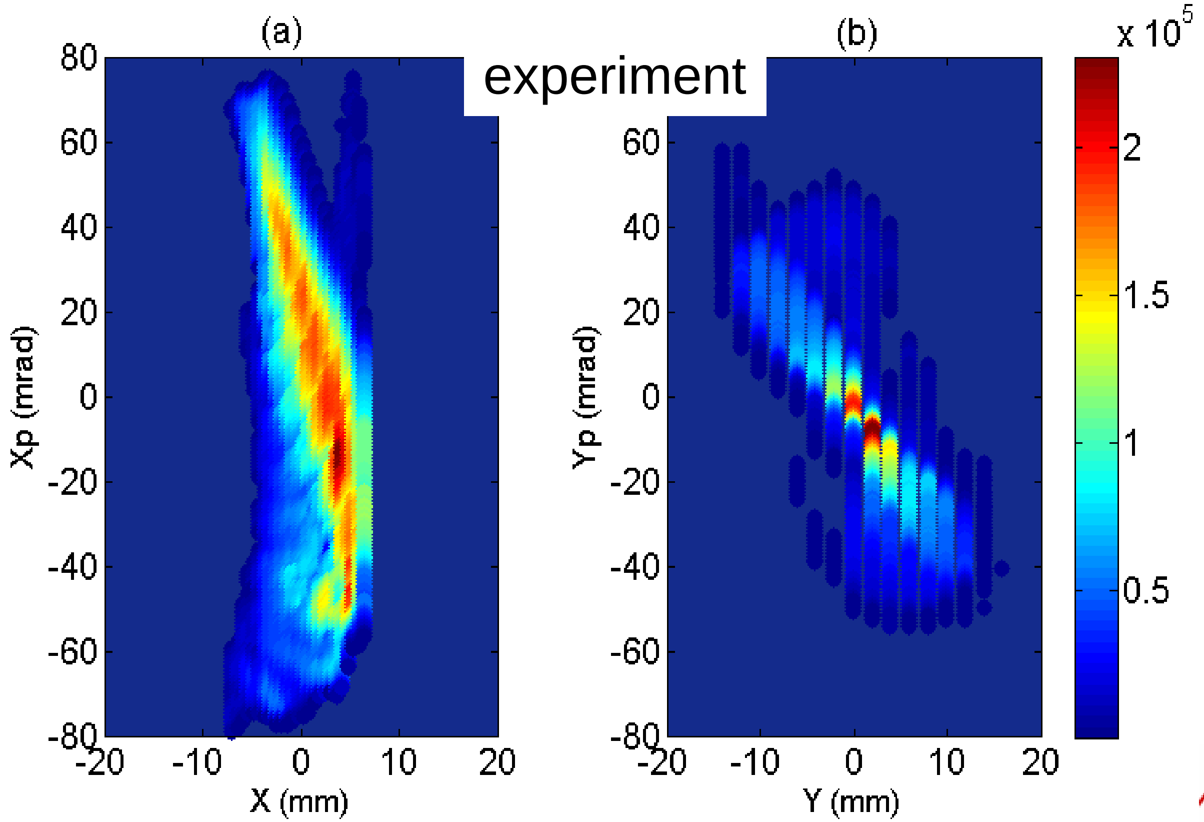
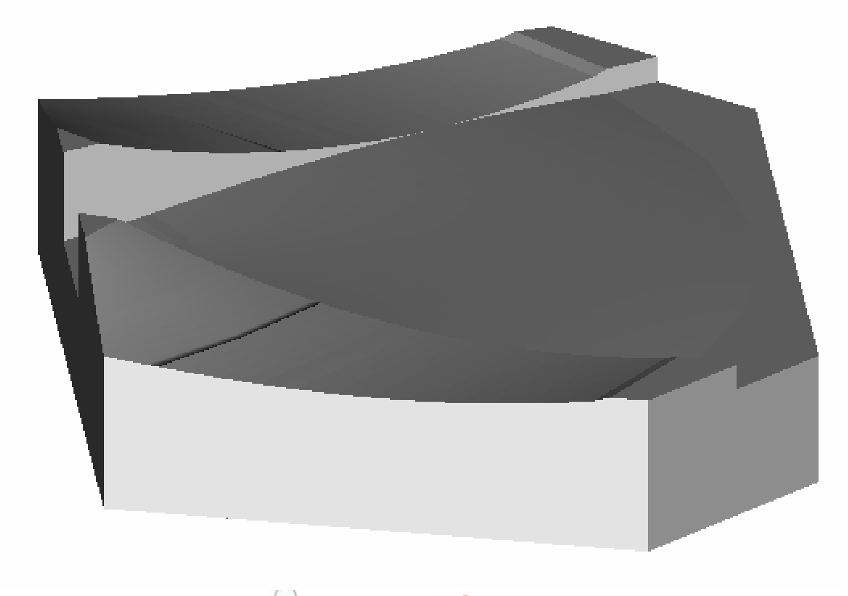


# LEBT ion optics

- ECRIS analysing magnet
  - acceptance too small ➡ 30 % beam loss
  - large higher order aberrations ➡ 50 % beam loss transfer line
  - simulation ↔ experiment: semi-quantitative agreement
  - no space for separate hexapoles
  
  ➡ magnet redesign
    - increased acceptance
    - reduced aberrations
    - similar LBNL



# LEBT vacuum

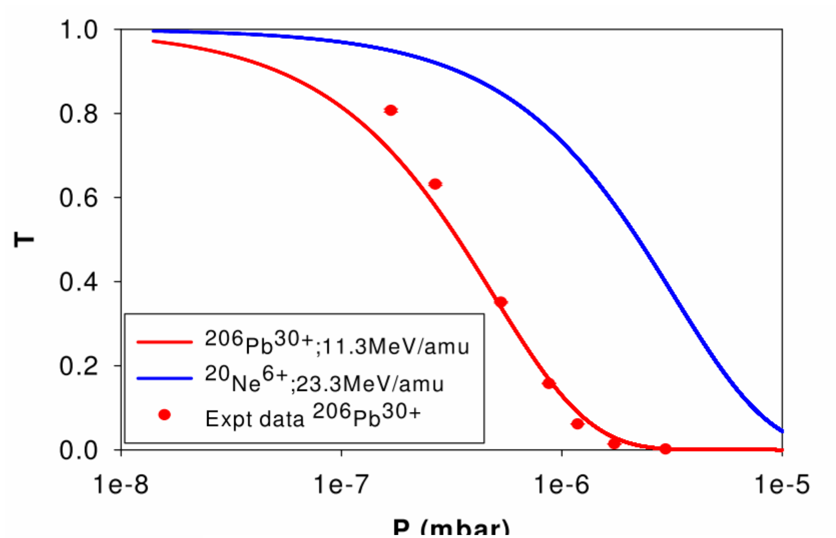
- beam line ECR – cyclotron
  - turbomolecular + ion getter pumps
  - length 20 m, average pressure ~2 × $10^{-8}$ mbar
  - transmission 90 % for $^{206}Pb^{27+}$
- vertical injection beam line
  - turbomolecular pump at bottom
  - little conductance in cyclotron center
  - length 5 m, average pressure ~5 × $10^{-7}$ mbar
  - transmission ~ 50 % for $^{206}Pb^{27+}$

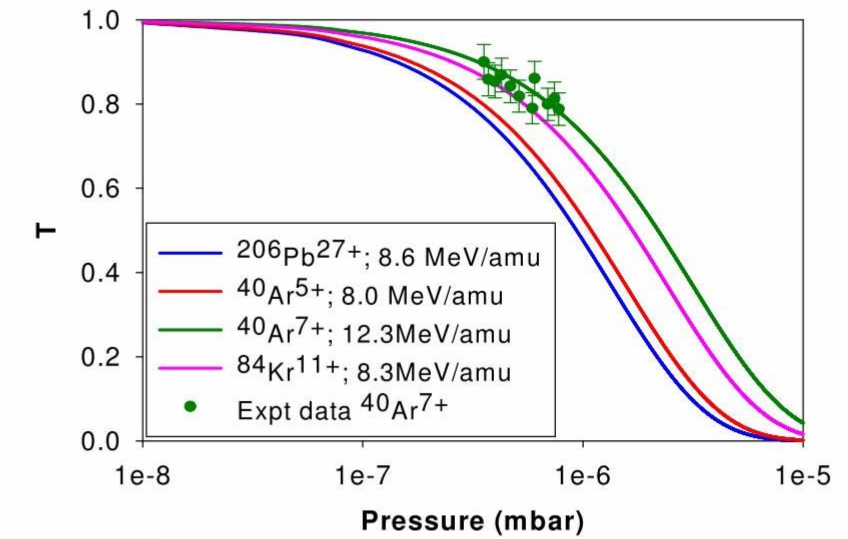
➡ work to be done

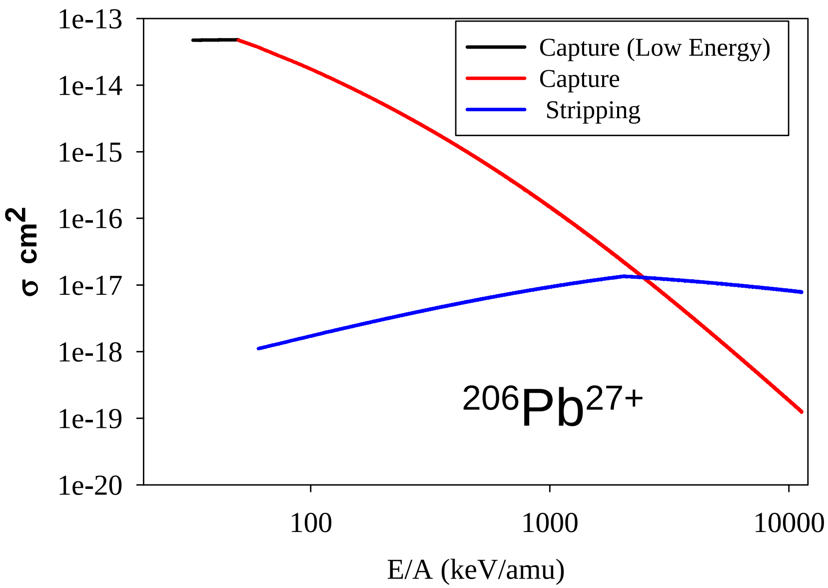
  - high magnetic field ➡ no pumps with moving parts
  - NEG-pumps under investigation
- for lighter ions (Ne, Ar) overall transmission ~90 %

# cyclotron vacuum

- basics transmission understood

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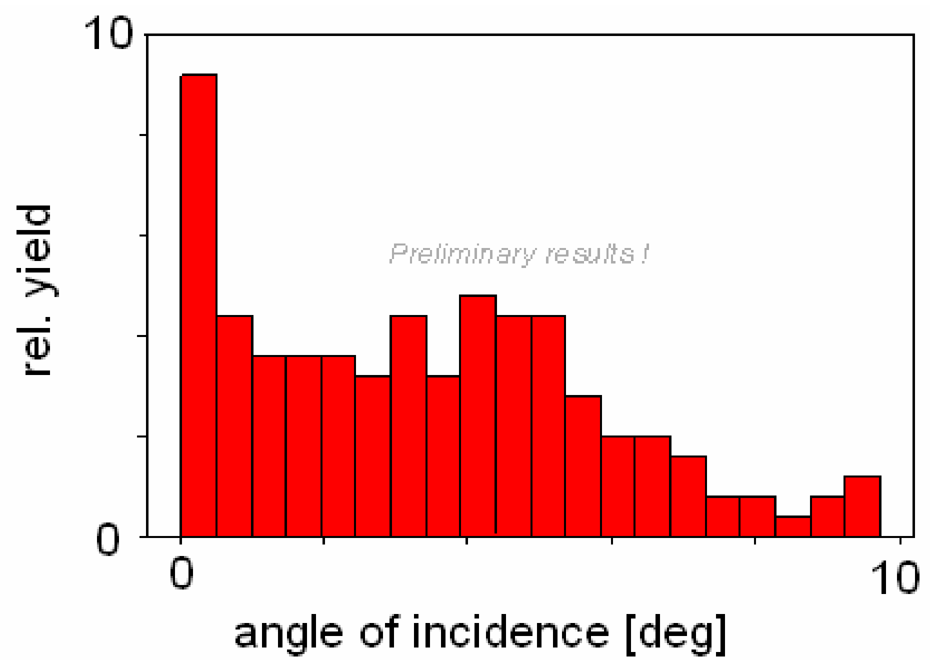
# cyclotron vacuum

- high intensity: beam loss induced desorption
  - ➡ degradation vacuum and transmssion
  - ➡ different pressure distribution in cyclotron
  - limiting factor for increase intensity Pb-beams

- modelling + experiment
  - particle tracking after charge exchange
    - ➡ spatial distribution + angle of incidence



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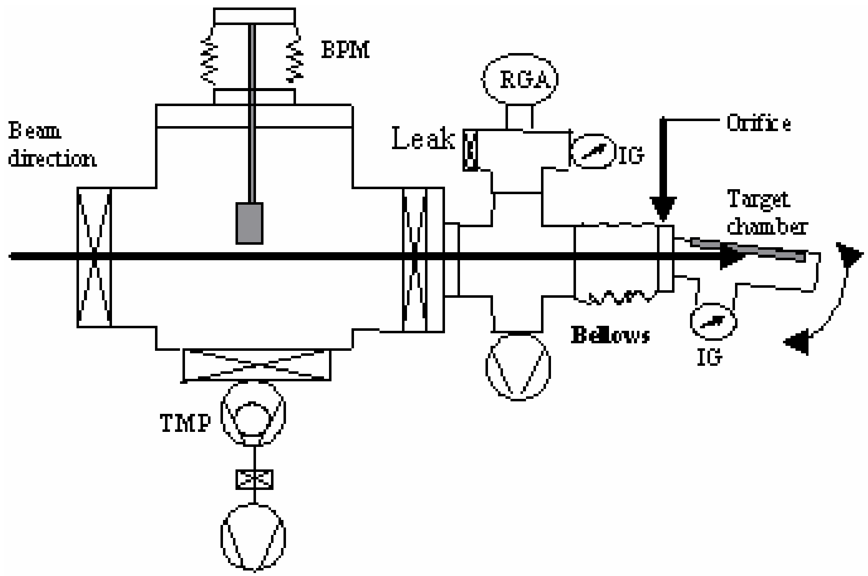
  - desorption yield vs. angle of incidence



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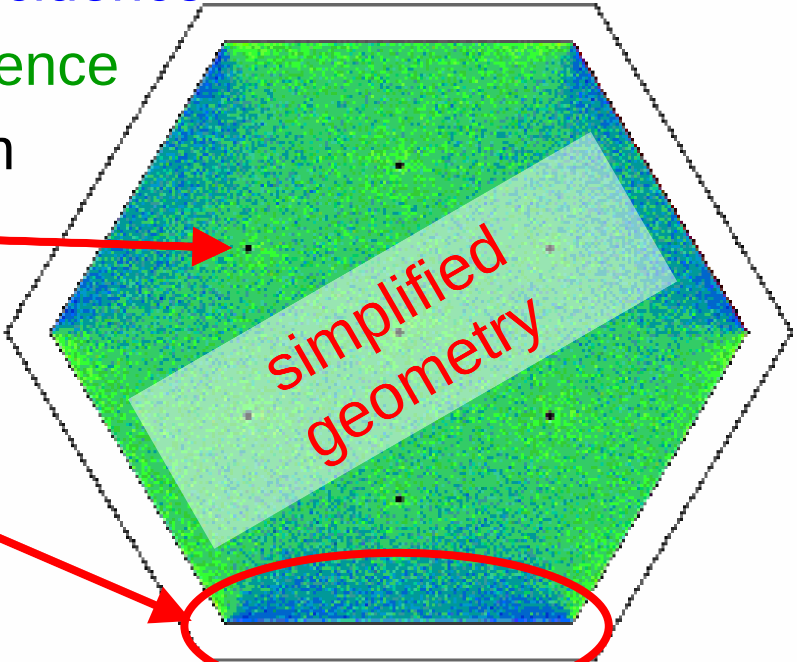
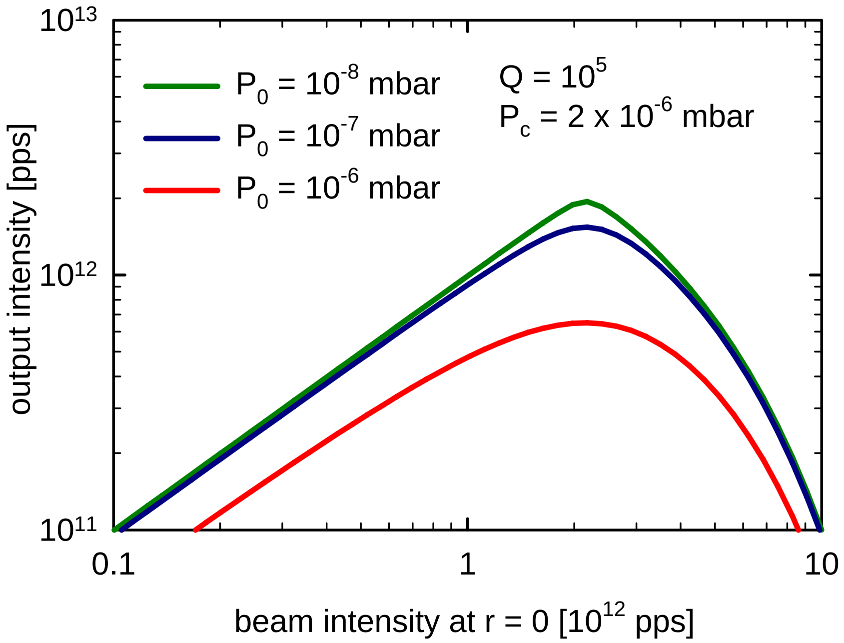
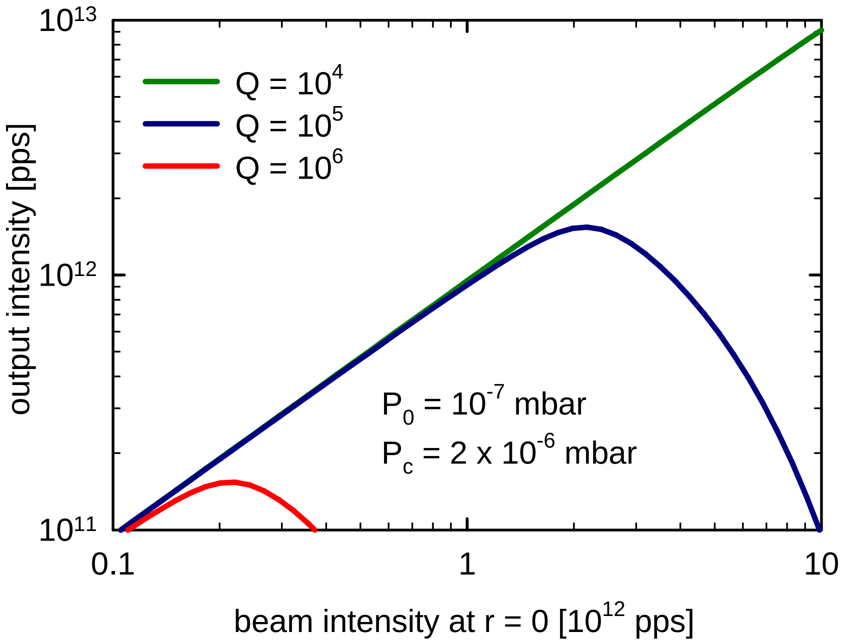
- modelling + experiment
  - particle tracking after charge exchange
    ➡ spatial distribution + angle of incidence
  - desorption yield vs. angle of incidence
  - 3D modelling pressure distribution
    - pumps
    - “normal” outgassing
    - beam induced desorption



# cyclotron vacuum

- possibilities for mitigation
  - pumping in most regions conductance limited
  - reduction outgassing (= base pressure) not very effective
  - reduction beam induced desorption effective



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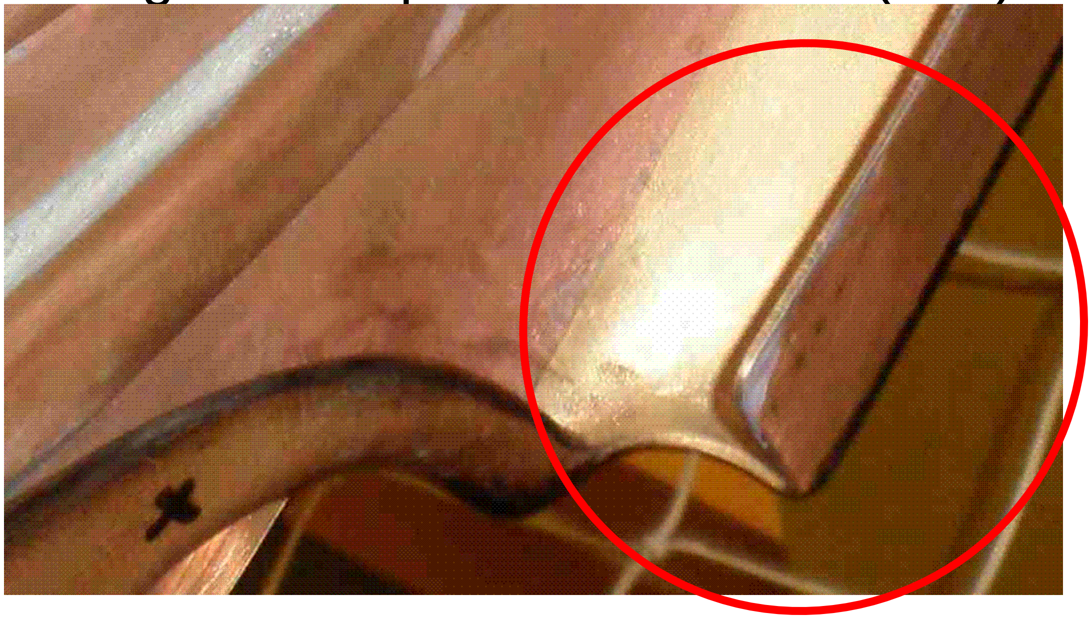
# cyclotron vacuum

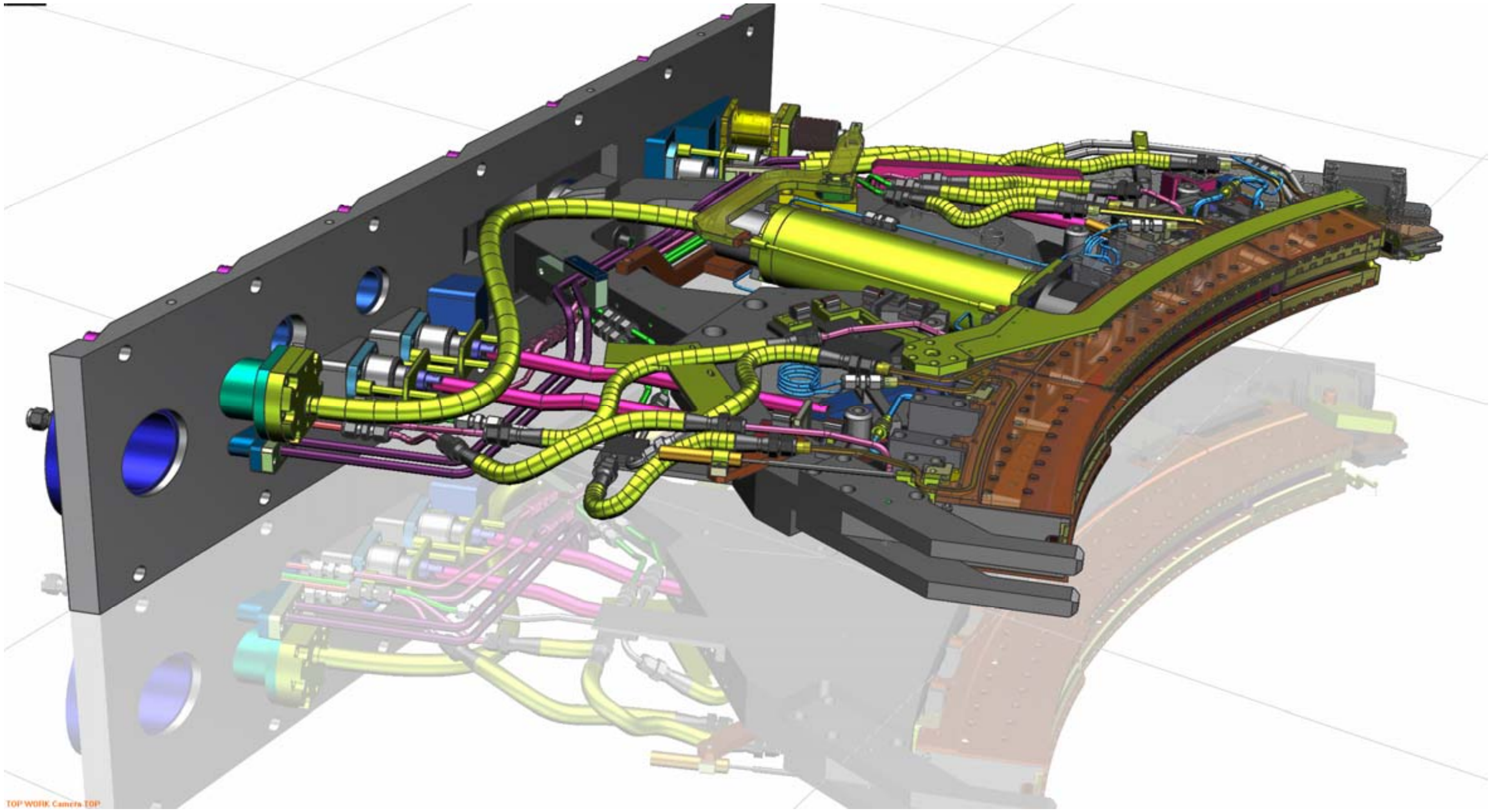
- possibilities for mitigation
  - pumping in most regions conductance limited
  - reduction outgassing (= base pressure) not very effective
  - reduction desorption effective
    - gold coating median plane ➡ factor 10 (GSI)



    - scrapers (increase angle of incidence) ➡ factor 4 (GSI)
      - in preparation

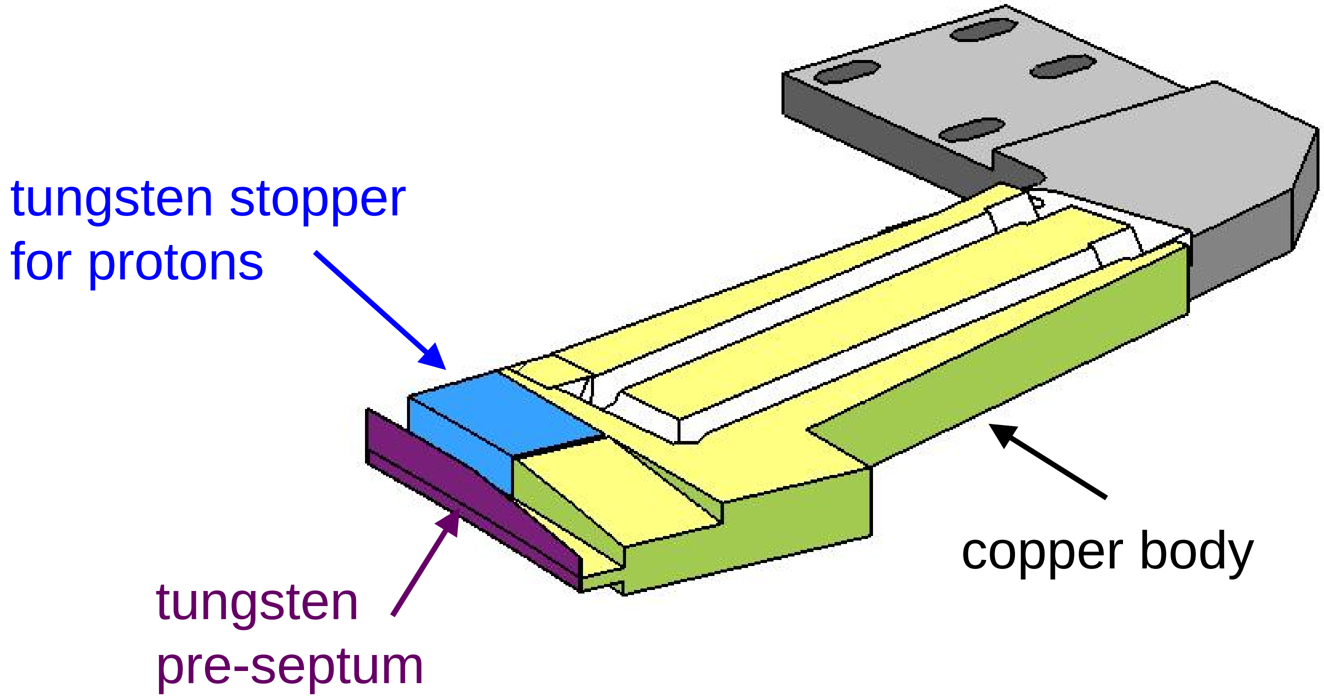
# cyclotron extraction

- new electrostatic deflector
  - cooling septum and cathode



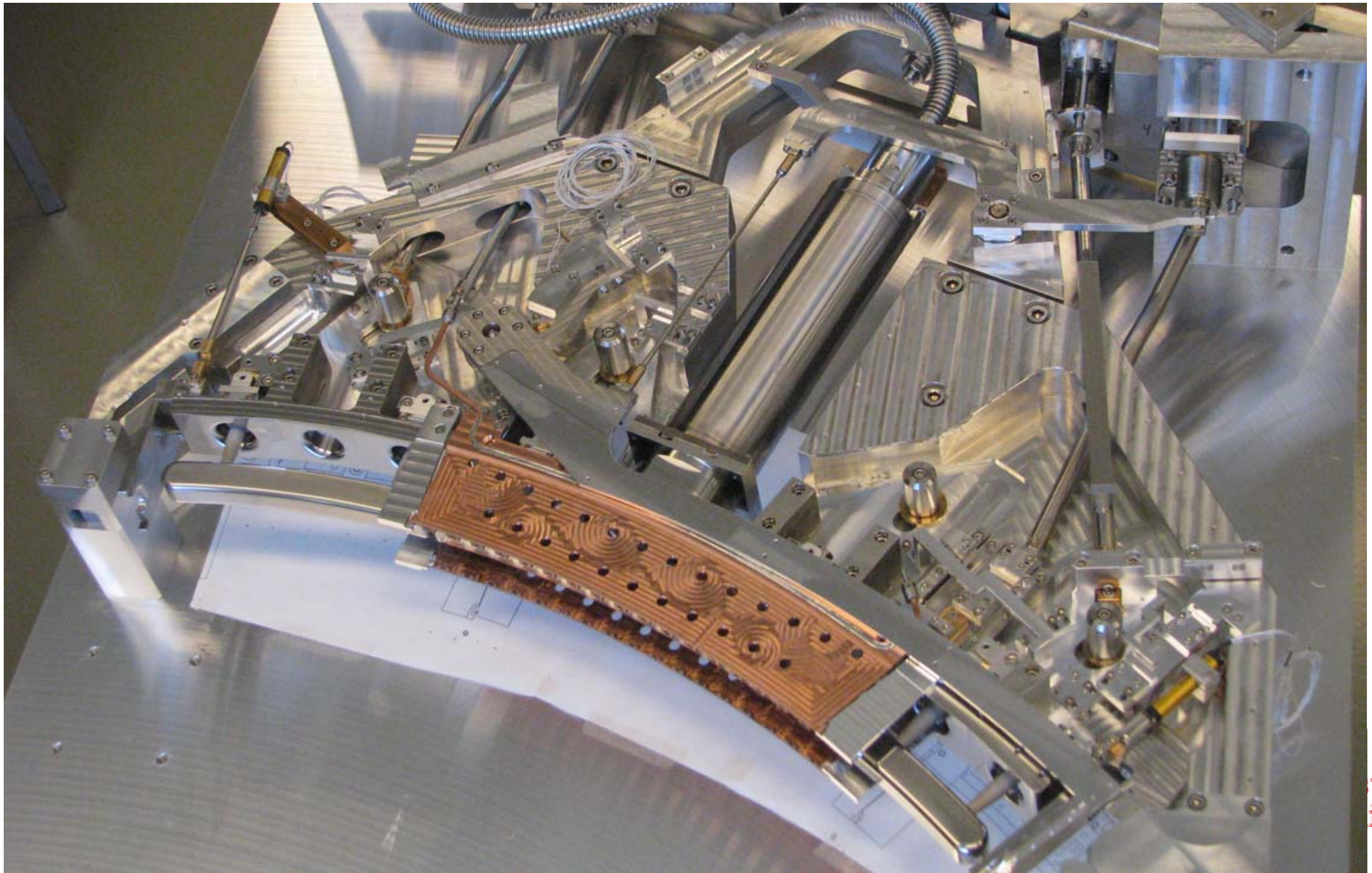
# cyclotron extraction

- new electrostatic deflector
  - cooling septum and cathode
  - pre-septum



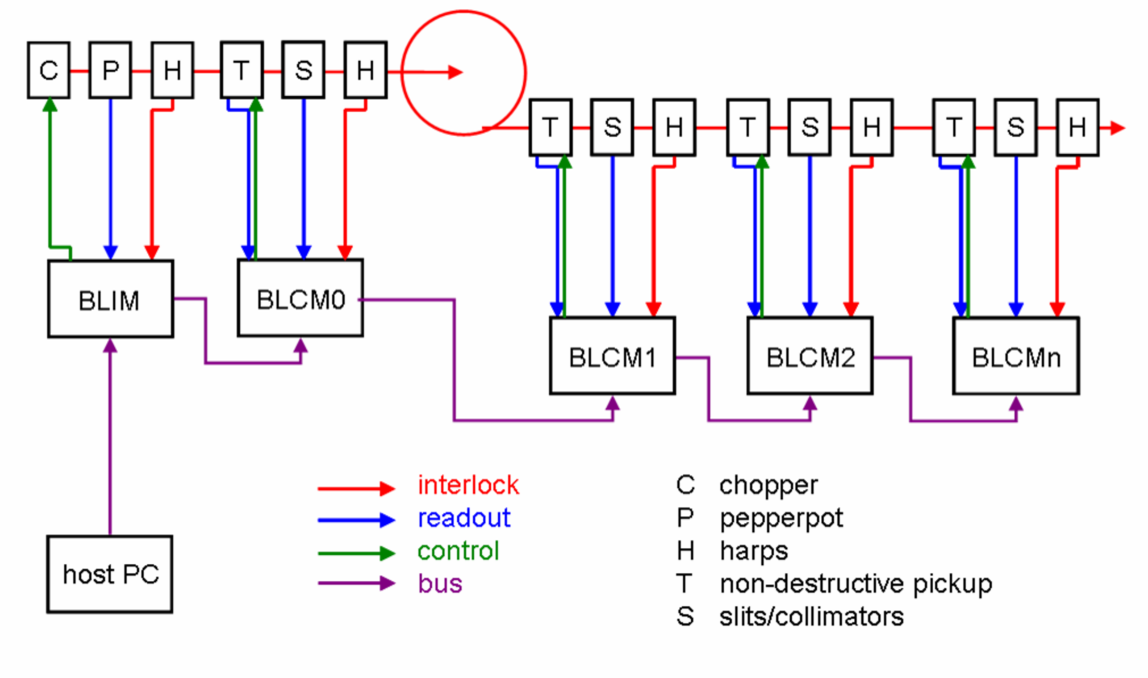
# cyclotron extraction

- new electrostatic deflector
  - cooling septum and cathode
  - pre-septum
  - assembly stage`



# beam loss control

- power density in material up to 1 kW/mm$^3$
  - ➡ damage at 10 ms scale
  - ➡ beam loss control system essential
- modular system to measure beam losses
- variable duty cycle chopper to control intensity

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# conclusions

- $^{20}$Ne @ 23.4 MeV/nucleon $10^{13}$ pps, 1 kW beam demonstrated
  - technical improvements for routine operation nearly completed
- $^{206}$Pb @ 7 – 10 MeV/nucleon 3 x $10^{11}$ pps, 100 W demonstrated
  - factor ≥ 3 increase needed
  - several on-going improvements
    - ion optics LEBT
    - vacuum LEBT
    - desorption cyclotron

  ➡ feasible


thank you for your attention