Progress towards High Intensity Heavy Ion Beams at the AGOR Facility

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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
AGOR cyclotron

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fragment separator and trap set ups
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
  - $^{20}\text{Ne}^6+$ @23.3 MeV/nucleon $1.3 \times 10^{13}$ pps $P = 1$ kW
  - $^{206}\text{Pb}^{27+}$ @ 7 - 10 MeV/nucleon $3 \times 10^{11}$ pps $P = 100$ W

![Graph showing extracted beam]

- $^{20}\text{Ne}^6+$ $E/A = 23.3$ MeV
duty cycle 15%

- 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

poster MOPCP53
ECRIS

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

- routinely obtained output
  - $^{16}\text{O}^{6+}$ 500 $\mu$A
  - $^{20}\text{Ne}^{6+}$ 500 $\mu$A
  - $^{206}\text{Pb}^{27+}$ 50 $\mu$A

**best result:** $^{16}\text{O}^{6+}$ 750 $\mu$A
ECRIS

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

⇒ more output.....

loan from HZB
LEBT ion optics

- ECRIS analysing magnet
  - acceptance too small $\Rightarrow$ 30% beam loss
  - large higher order aberrations $\Rightarrow$ 50% beam loss transfer line
- simulation $\leftrightarrow$ experiment: semi-quantitative agreement
LEBT ion optics

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- 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 \( \sim 2 \times 10^{-8} \) mbar
  - transmission 90 % for \(^{206}\text{Pb}^{27+}\)

- vertical injection beam line
  - turbomolecular pump at bottom
  - little conductance in cyclotron center
  - length 5 m, average pressure \( \sim 5 \times 10^{-7} \) mbar
  - transmission \( \sim 50 \% \) for \(^{206}\text{Pb}^{27+}\)

\[\Rightarrow\] work to be done
  - high magnetic field \[\Rightarrow\] no pumps with moving parts
  - NEG-pumps under investigation

- for lighter ions (Ne, Ar) overall transmission \( \sim 90 \% \)
cyclotron vacuum

- basics transmission understood
cyclotron vacuum

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

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

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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

\[ \text{beam intensity at } r = 0 \times [10^{12} \text{ pps}] \]

\[ \text{output intensity } [\text{pps}] \]

\[ P_0 = 10^{-9} \text{ mbar} \quad Q = 10^5 \]
\[ P_0 = 10^{-7} \text{ mbar} \quad P_c = 2 \times 10^{-6} \text{ mbar} \]
\[ P_0 = 10^{-6} \text{ mbar} \]

\[ P_0 = 10^{-8} \text{ mbar} \quad P_0 = 10^{-7} \text{ mbar} \quad P_0 = 10^{-6} \text{ mbar} \]
\[ Q = 10^4 \]
\[ Q = 10^5 \]
\[ Q = 10^6 \]

\[ P_0 = 10^{-7} \text{ mbar} \quad P_c = 2 \times 10^{-6} \text{ mbar} \]
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

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  - cooling septum and cathode
  - pre-septum
  - assembly stage
beam loss control

- power density in material up to 1 kW/mm³
  - damage at 10 ms scale
  - beam loss control system essential
- modular system to measure beam losses
- variable duty cycle chopper to control intensity

*poster MOPCP87*
conclusions

- $^{20}\text{Ne} \: @ \: 23.4 \: \text{MeV/nucleon} \: 10^{13} \: \text{pps}, \: 1 \: \text{kW beam demonstrated}$
  - technical improvements for routine operation nearly completed
- $^{206}\text{Pb} \: @ \: 7 - 10 \: \text{MeV/nucleon} \: 3 \times 10^{11} \: \text{pps}, \: 100 \: \text{W demonstrated}$
  - factor $\geq 3$ increase needed
  - several on-going improvements
    - ion optics LEBT
    - vacuum LEBT
    - desorption cyclotron
  - feasible
thank you for your attention