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# New extraction design for the JYFL 14 GHz ECRIS

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# Introduction and motivation

- Rather poor ”ion source-to-target” performance at JYFL
  - Beam quality issues
  - Originate from the ion source and LEBT
- Plan to upgrade the LEBT between JYFL 14 GHz ECRIS and K-130 cyclotron
- First step: ECRIS extraction upgrade
  - More tuning flexibility
  - Better ion beam starting conditions for future LEBT modifications
  - Better beam quality and ECRIS performance

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# Simulations – the code issues

- ECRIS extraction challenging for simulation codes
  - Complicated plasma conditions
  - Many approaches to model the extraction exist
- IBSimu by Taneli Kalvas (JYFL)
  - Extraction of multiple ion species
  - Magnetic field in the extraction region
  - Space charge effects
- However – positive plasma model does not exactly match ECRIS conditions

  ➡ Verification needed

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# Simulations – verification of code

- The old extraction was modeled with IBSimu
  - Accel-decel system
  - 0.5 - 3 mA of argon beam simulated (1 mA case measured)
  - Charge states 1+ ... 16+, fractions from measured spectra
  - Plasma potential of 20 V (measured)
  - Electrode voltages from normal operation
  - Solenoid fringe field included
  - Cylindrically symmetric simulation
  - Full space charge

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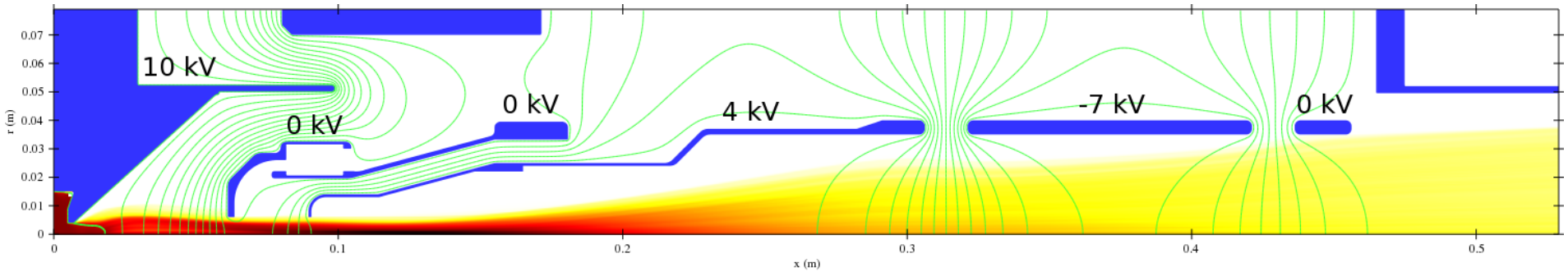
# Simulations – old extraction




- Extraction is barely able to handle the beam
- Beam leaving the extraction region:
  - Max half-axis divergence 60 mrad
  - Beam diameter 75 mm (FWHM 65 mm)

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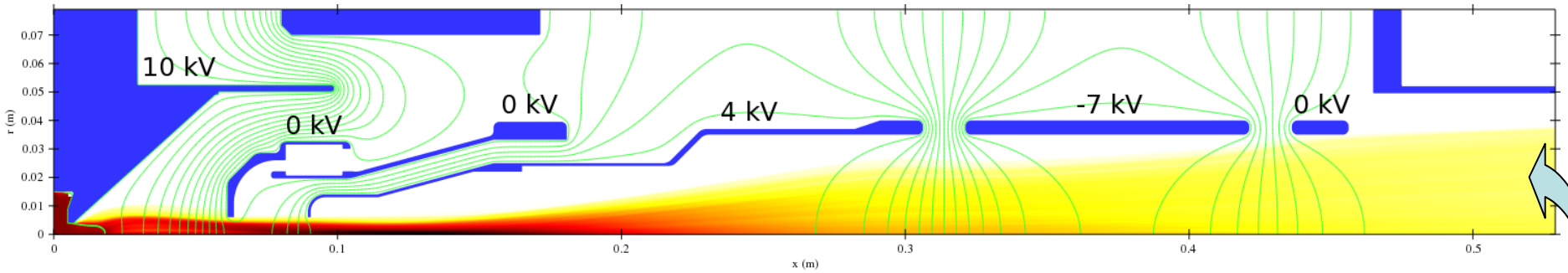
# Simulations – comparison to measurements




- Very limited space for measurements
- Simple setup with two parallel plates
  - Plate with apertures
  - Water cooled solid screen plate
- Diameter 64±1 mm, max divergence 60±10 mrad

➡ Good agreement with simulations

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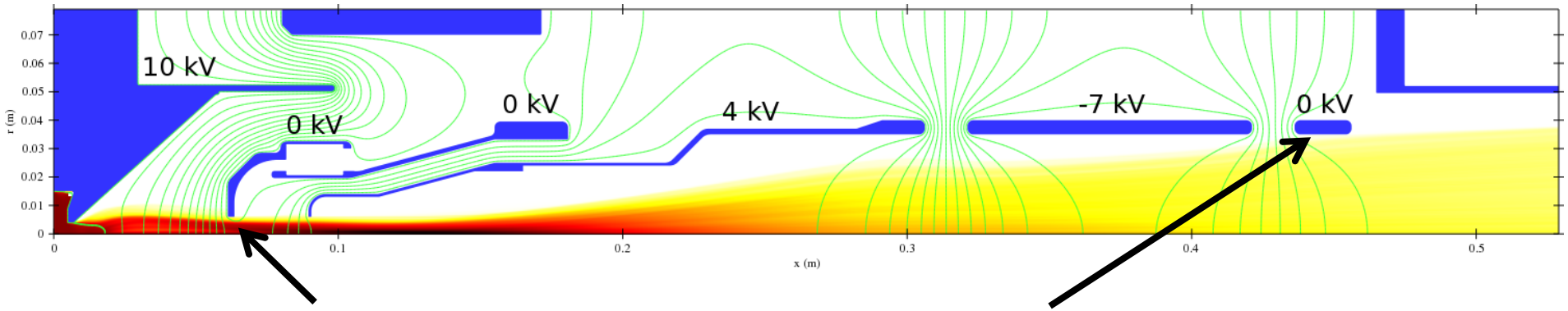
# Simulations – guidelines for new design




Collimation of beam inside extraction

- Becomes worse with increasing current
  - ➡ transmission drops
  - ➡ constant ~1 mA leaves the extraction
  - ➡ beam quality degrades
- Signs of this seen experimentally

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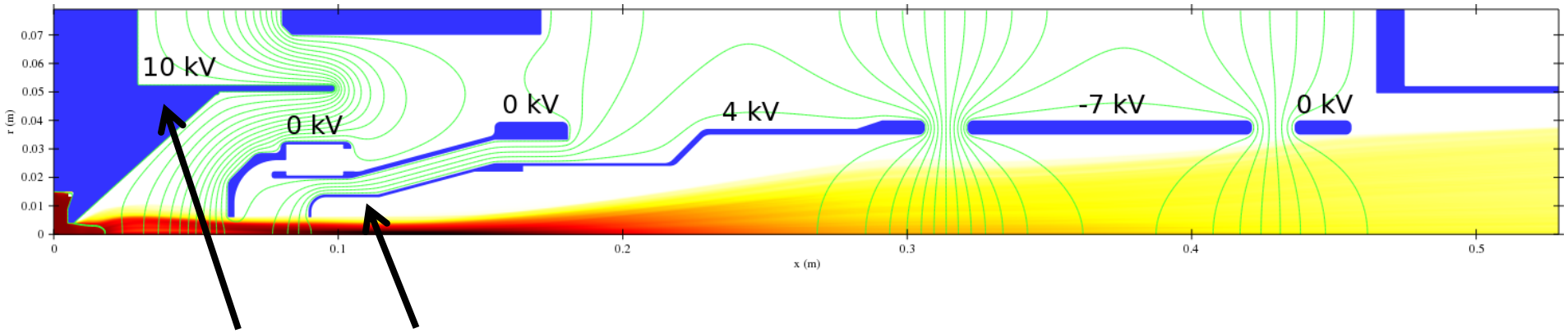
# Simulations – guidelines for new design




Low acceleration voltages (~10 kV) due to cyclotron limitations
Further slowing down of beam with decelerating electrode

➡ Strong space charge, degradation of beam quality

➡ Remove the decelerating electrode

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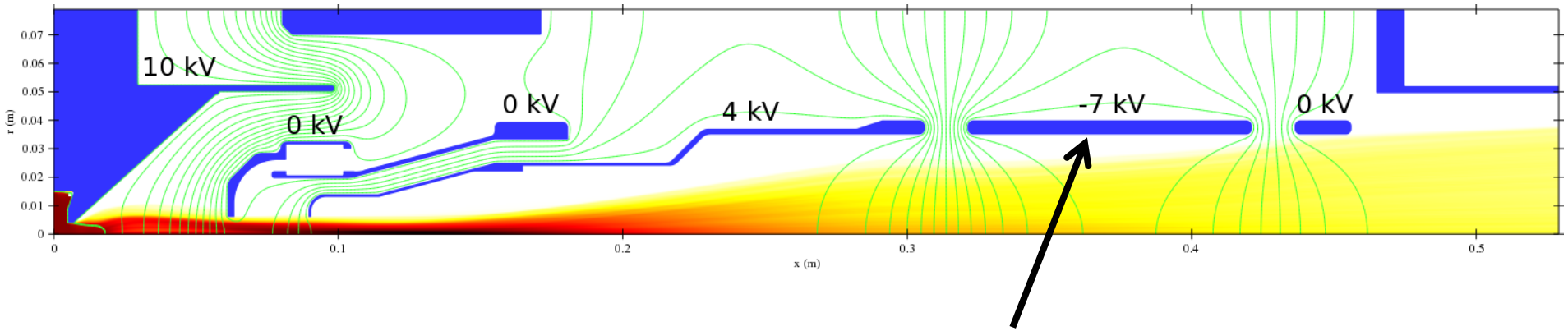
# Simulations – guidelines for new design




Weak accelerating Einzel lens

- Incapable to provide sufficient focusing
- Not possible to increase the voltage due to structure limitations (sparking)

➡ More focusing power needed

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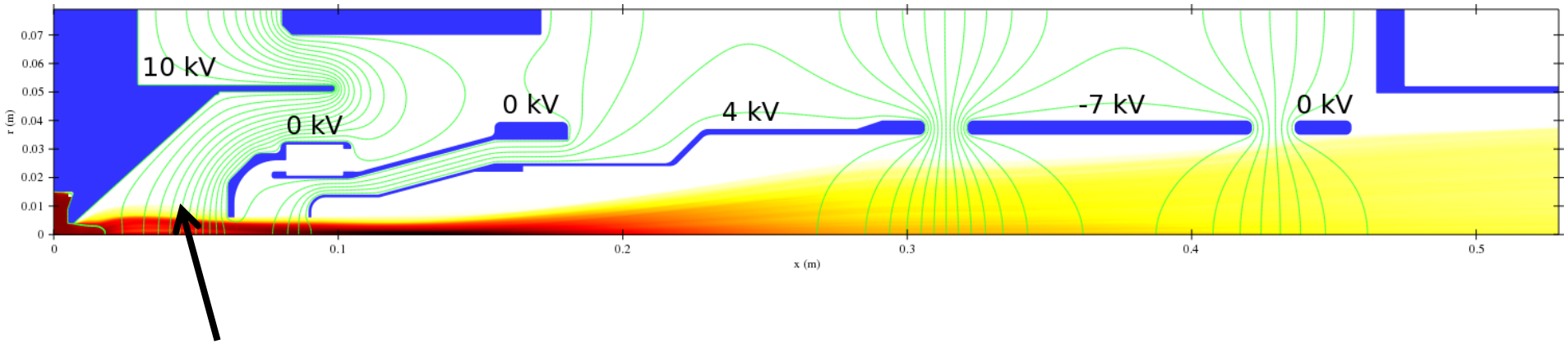
# Simulations – guidelines for new design




Strongly conical plasma electrode and flat puller electrode

➡ weak electric field at extraction aperture

➡ Flat plasma electrode

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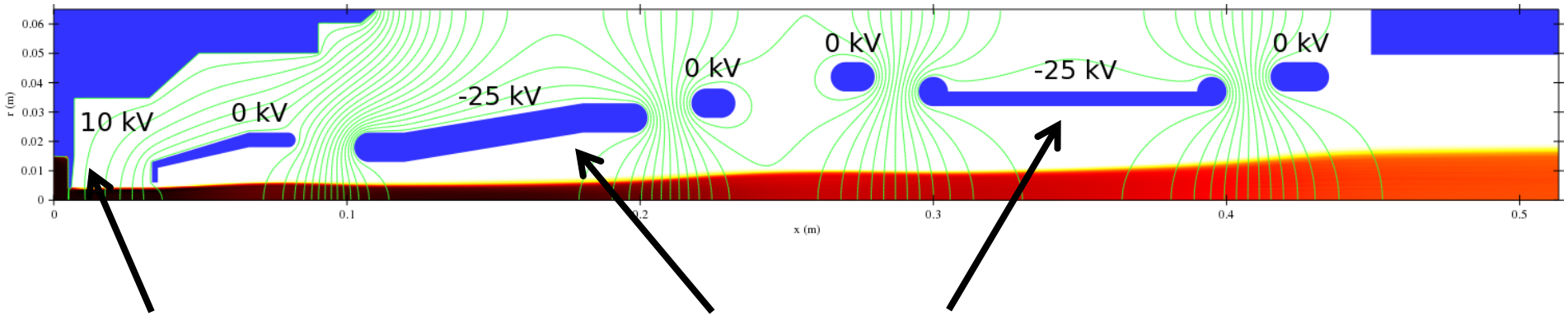
# Simulations – new design




Flat plasma electrode

1.5 mA case

Two accelerating Einzel lenses

- Puller electrode part of the first Einzel
- Both Einzel lenses are movable
- Tuning of acceleration gap for optimum beam extraction
- Flexible operation and beam manipulation

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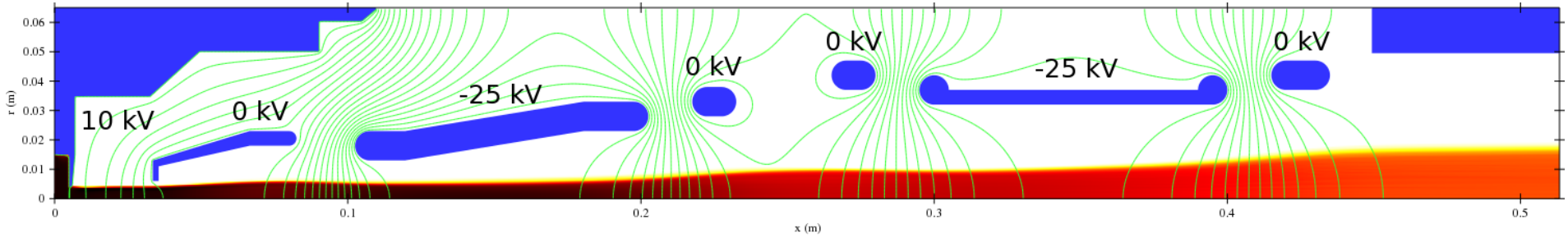
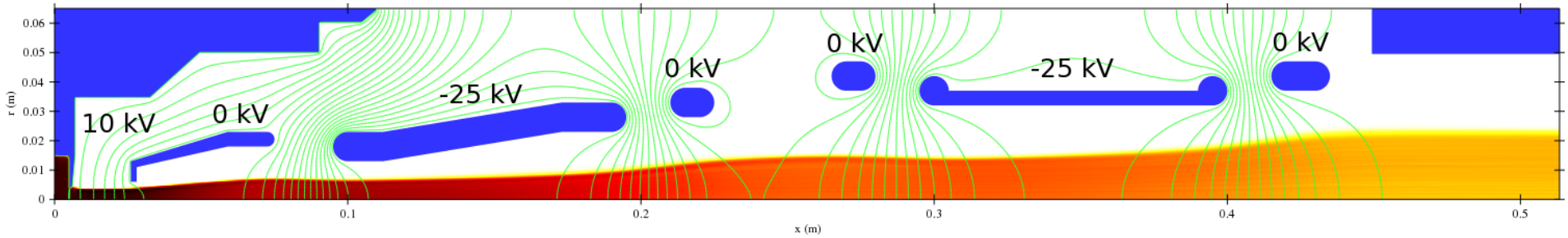
# Simulations – new design

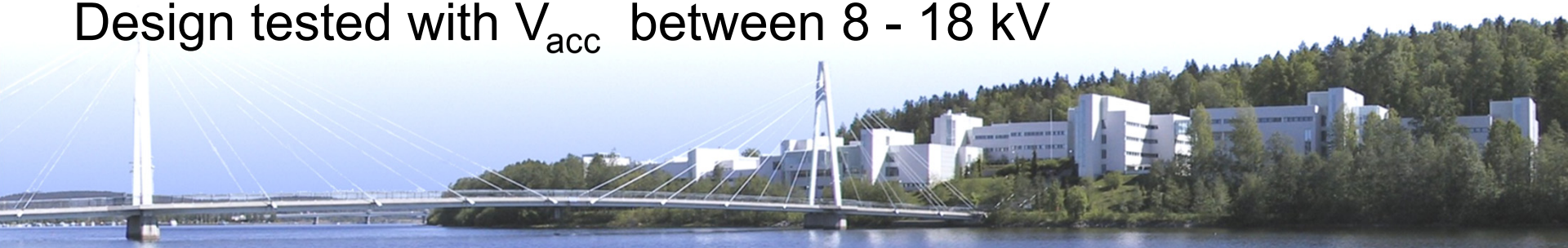
## 1.5 mA




## 3 mA




Design tested with $V_{acc}$ between 8 - 18 kV



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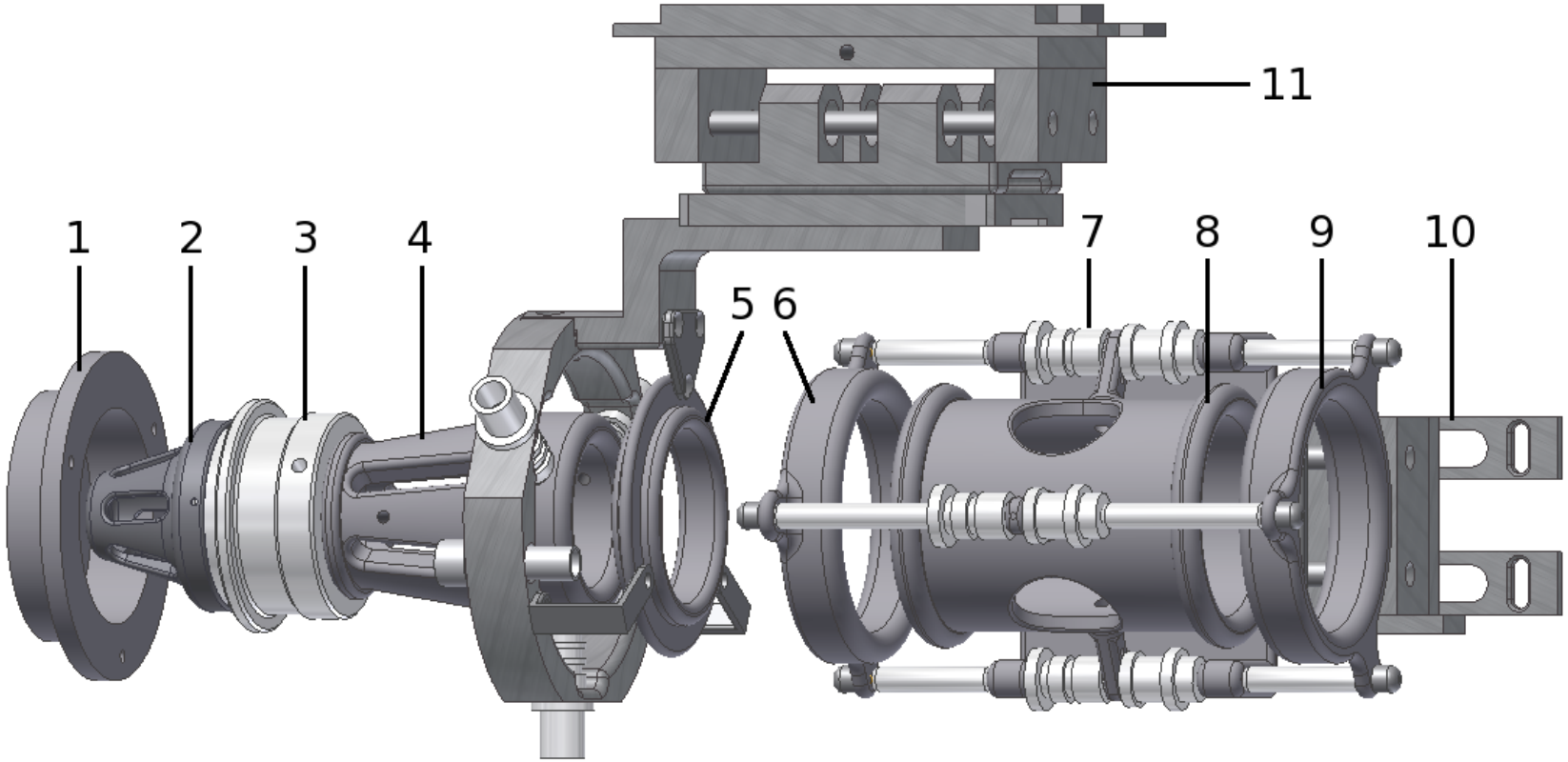
# New extraction – mechanical design

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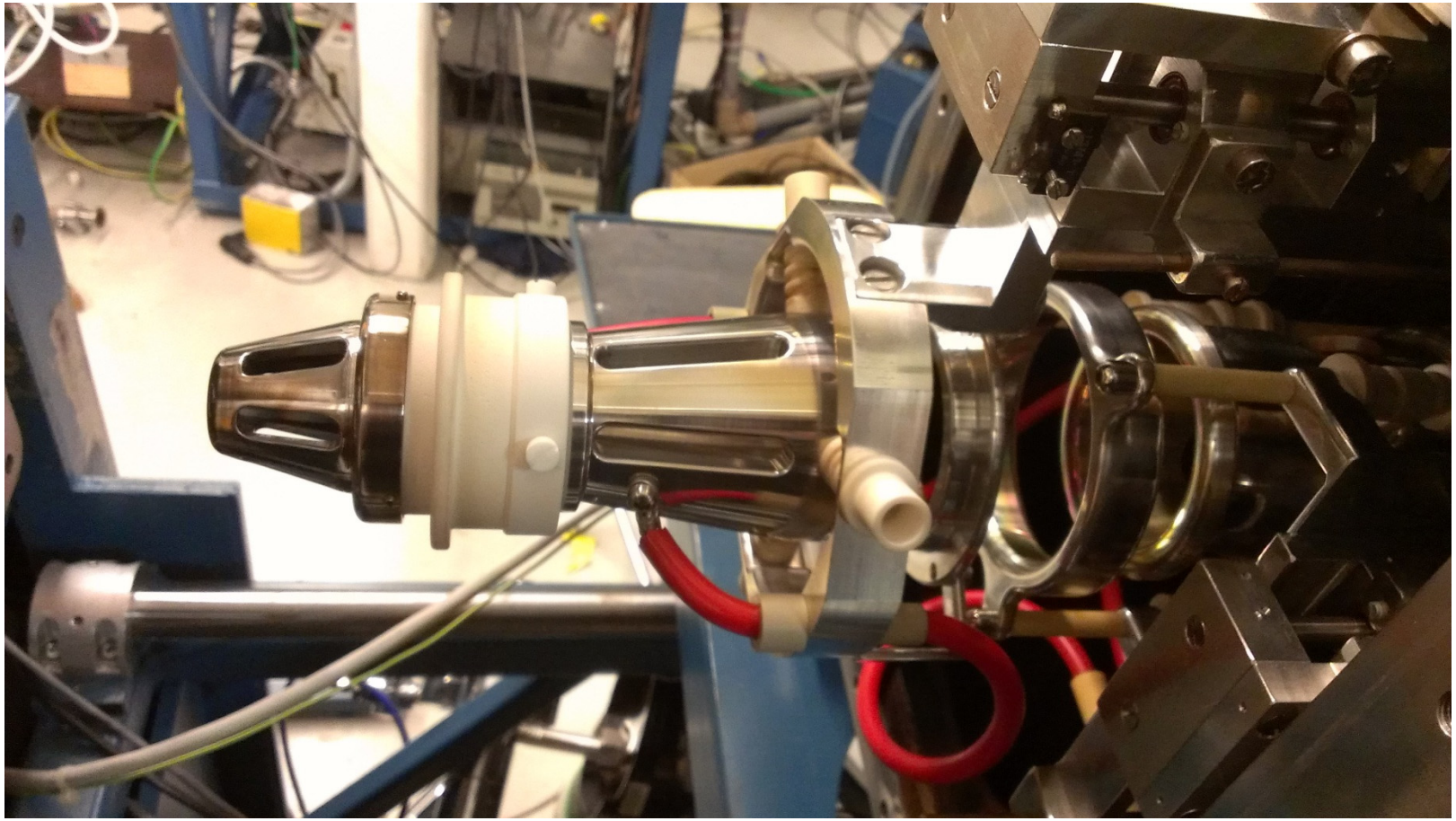

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# First experimental results – Ar transmission

| Beam | Extraction | $I_{ECR}$ | $I_{ACC}$ | T |
|---|---|---|---|---|
| $^{40}Ar^{8+}$ | Old | 90 | 2.3 | 2.6 |
| $^{40}Ar^{8+}$ | Old | 138 | 3.1 | 2.3 |
| $^{40}Ar^{8+}$ | Old | 170 | 3.6 | 2.1 |
| $^{40}Ar^{8+}$ | New | 84 | 3.7 | 4.4 |
| $^{40}Ar^{8+}$ | New | 102 | 4.1 | 4.0 |
| $^{40}Ar^{8+}$ | New | 132 | 6.0 | 4.6 |
| $^{40}Ar^{8+}$ | New | 187 | 7.4 | 4.0 |

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# First experimental results – Kr transmission

| Beam | Extraction | $I_{ECR}$ | $I_{ACC}$ | T |
|---|---|---|---|---|
| $^{84}Kr^{16+}$ | Old | 31 | 1.6 | 5.0 |
| $^{84}Kr^{16+}$ | Old | 60 | 2.6 | 4.3 |
| $^{84}Kr^{16+}$ | Old | 30 | 1.6 | 5.3 |
| $^{84}Kr^{16+}$ | New | 40 | 3.1 | 7.8 |
| $^{84}Kr^{16+}$ | New | 30 | 3.1 | 10.3 |

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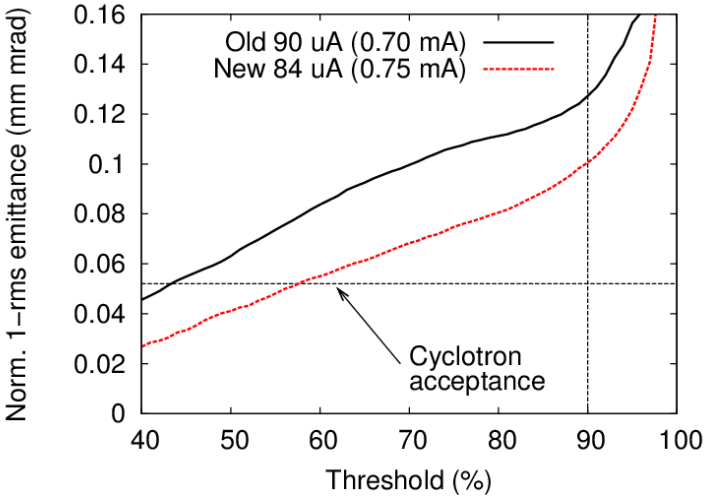
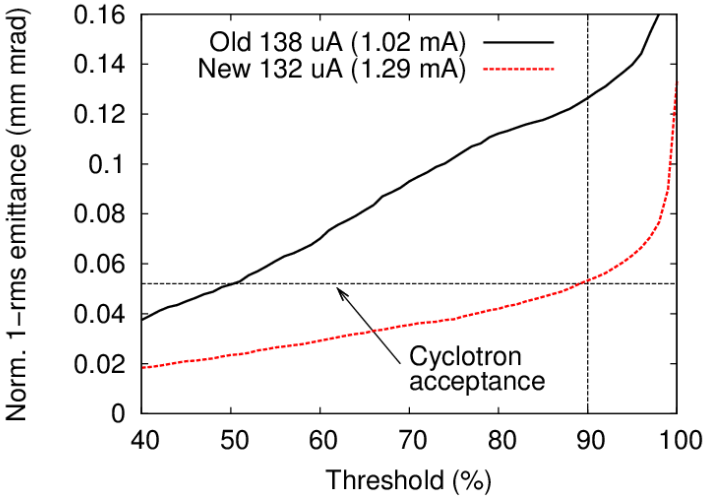
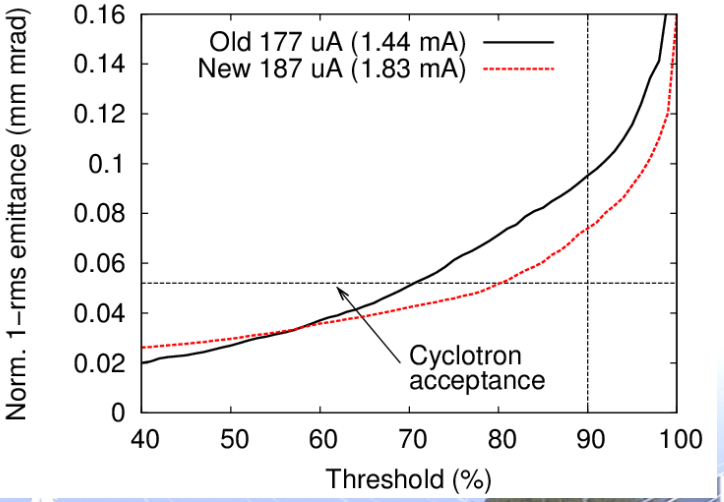
# First experimental results – beam quality

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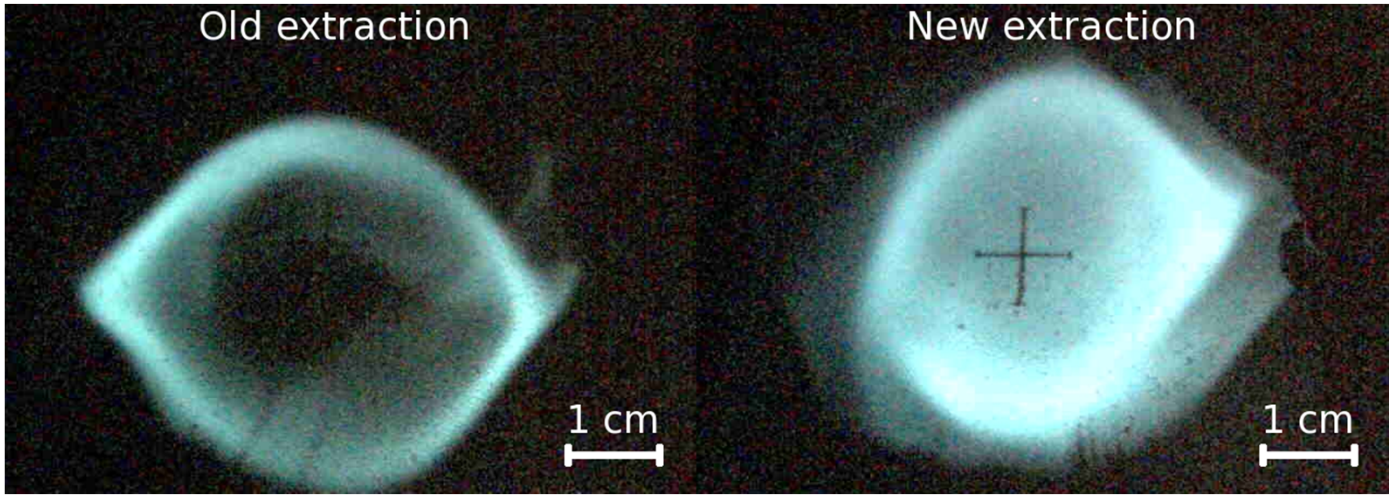
# First experimental results – beam profiles




~130 μA of $^{40}Ar^{8+}$

~1 mA of total extracted current

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# Conclusions

- New extraction system has been successfully designed, constructed and installed
- First tests and delivered beams show improved performance
- Optimum performance obtained with lower lens voltages than simulated (10-15 kV compared to 25 kV)
  - Simulations assume full space charge
  - Matching to following beam line optics
- Better results expected as operation experience increases

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# Thank you!