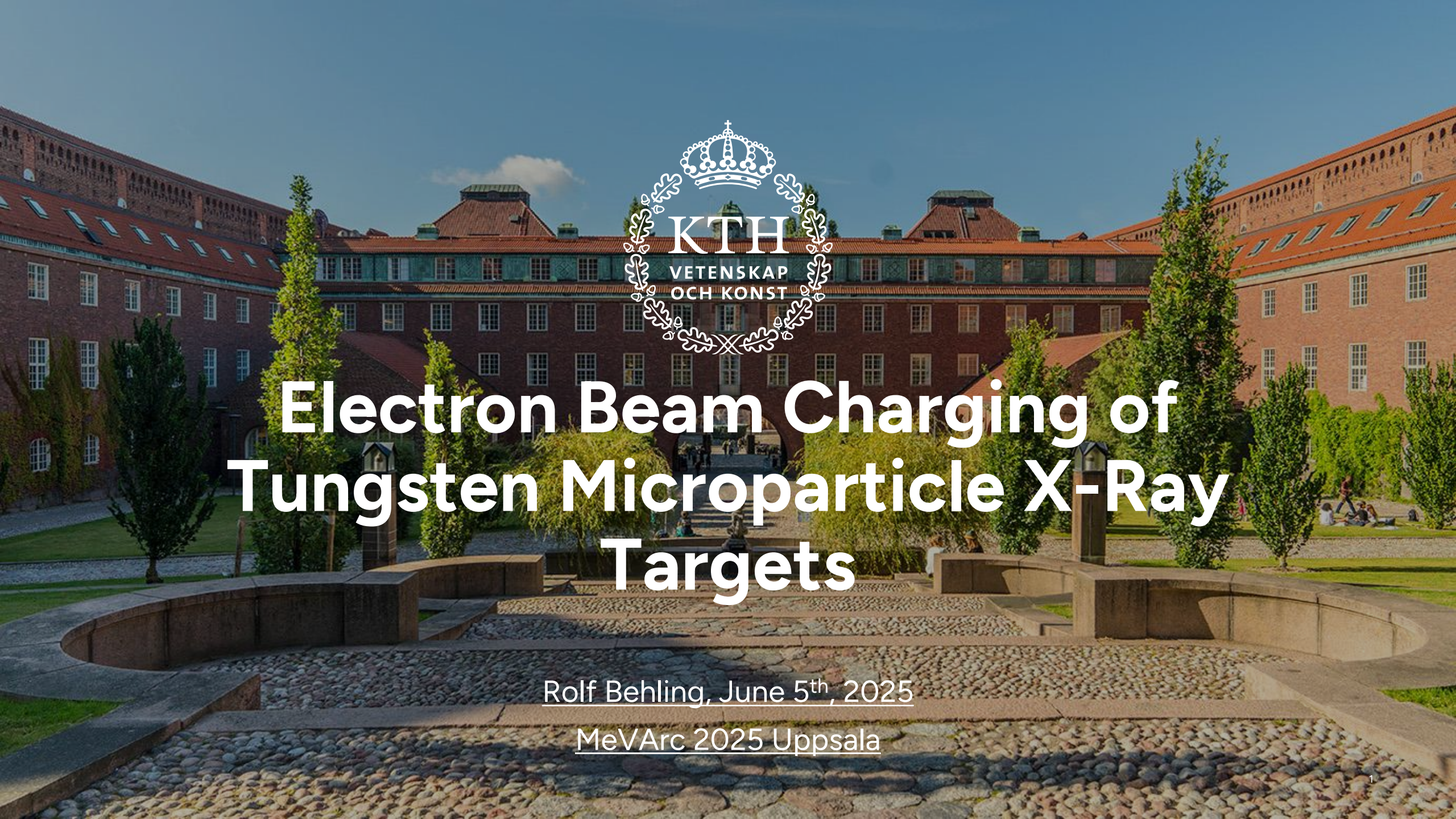


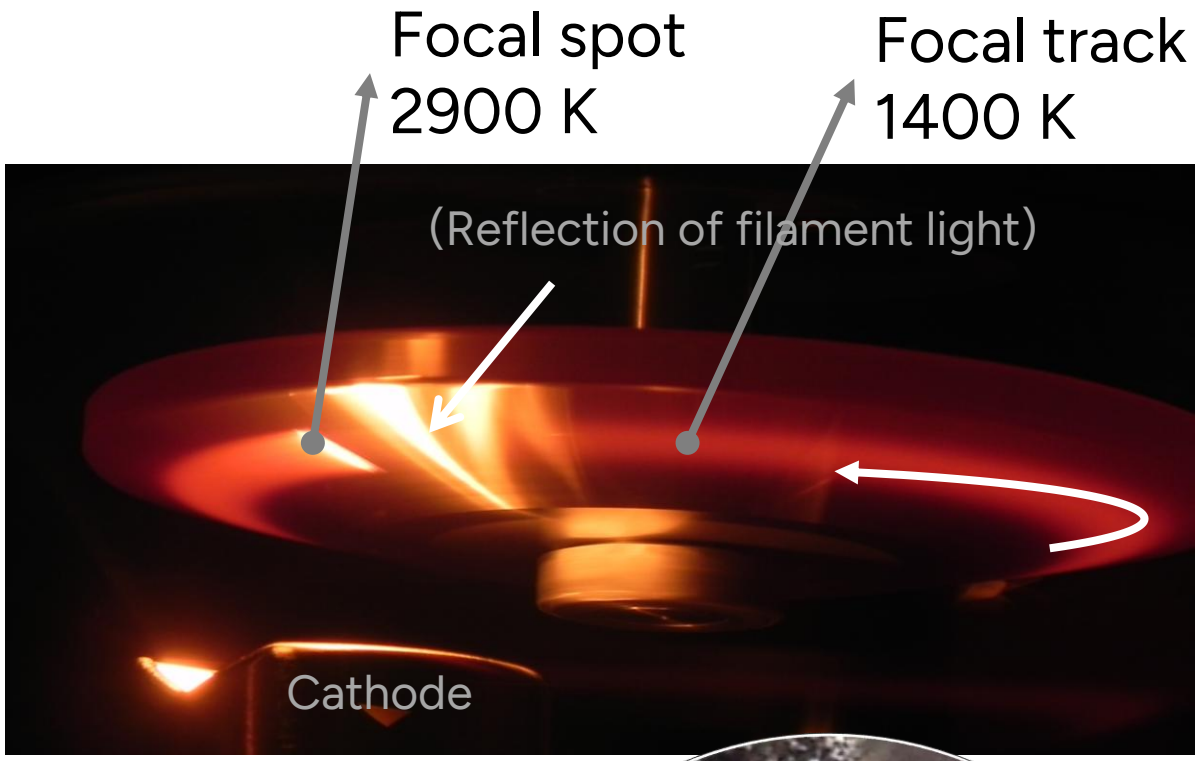
Electron Beam Charging of Tungsten Microparticle X-Ray Targets

Rolf Behling, June 5th, 2025

MeVArc 2025 Uppsala

In Search for Replacing Classic Rotating X-Ray Anodes

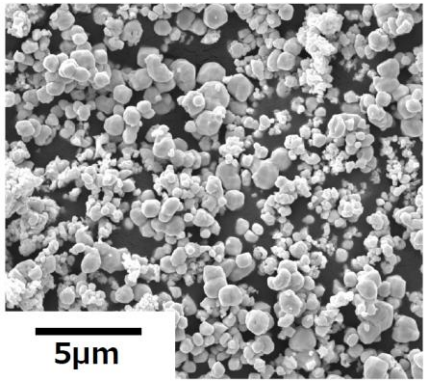
- 10^8 thermal cycles (typical CT tube)
- Erosion begins after the first few cycles
- Severe damage after few percent overload

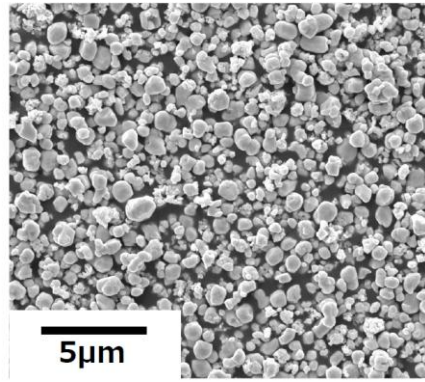


Rotating anode in operation

Focal track erosion and melting

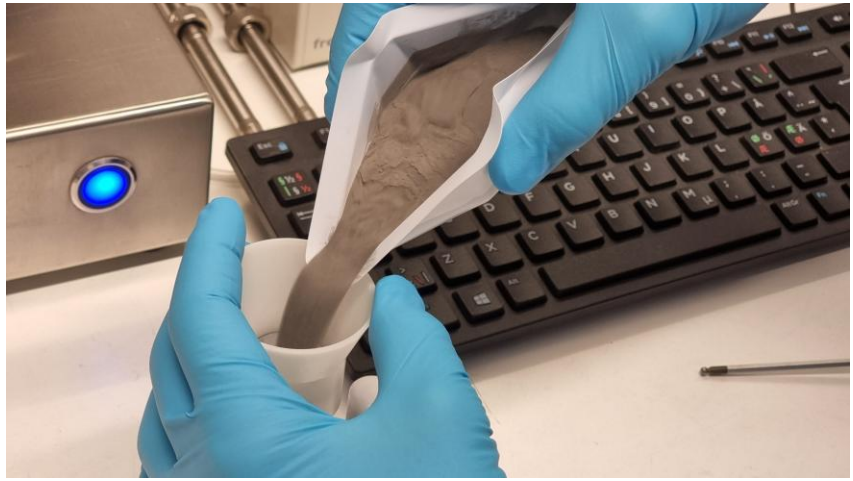
New Paradigm:
Tungsten Microparticle Target



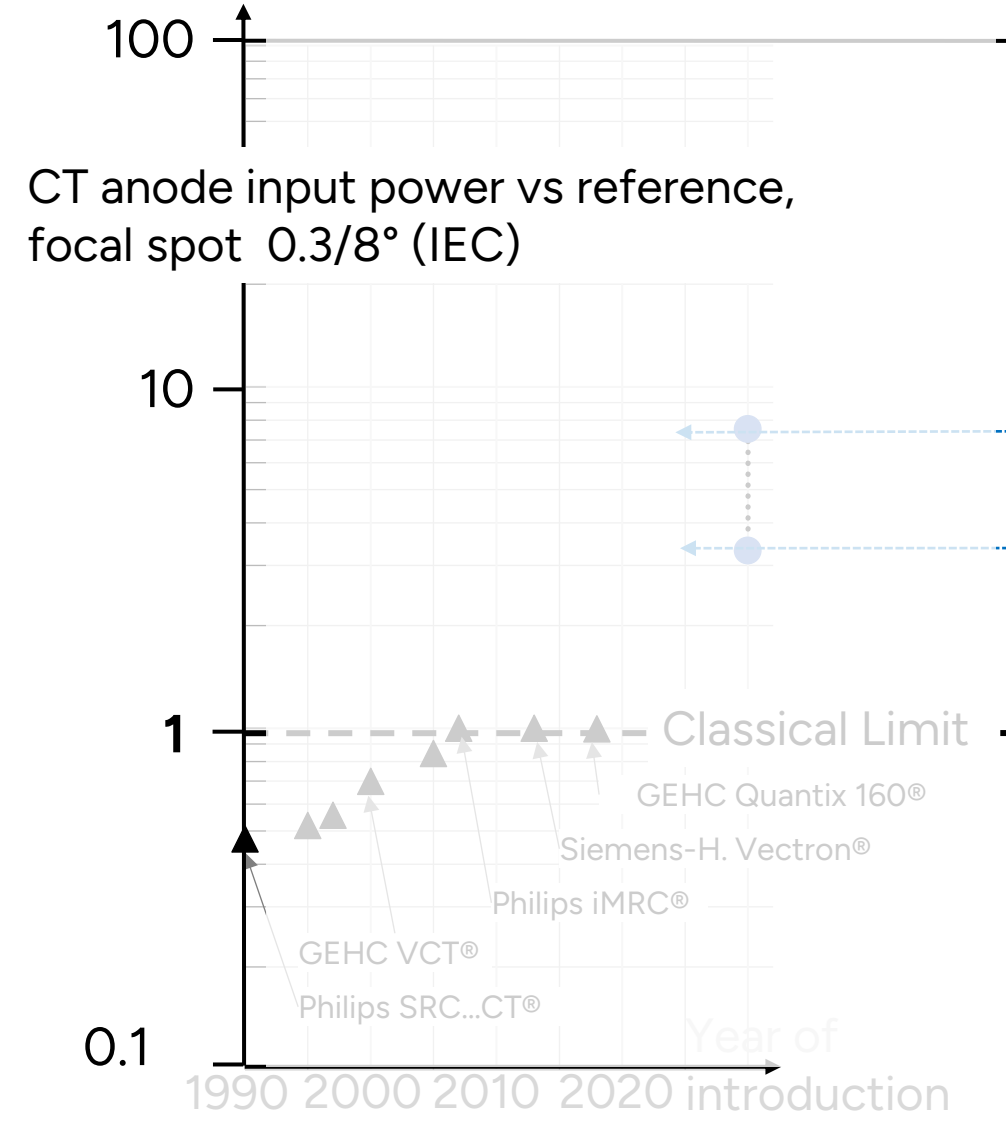


Benefits

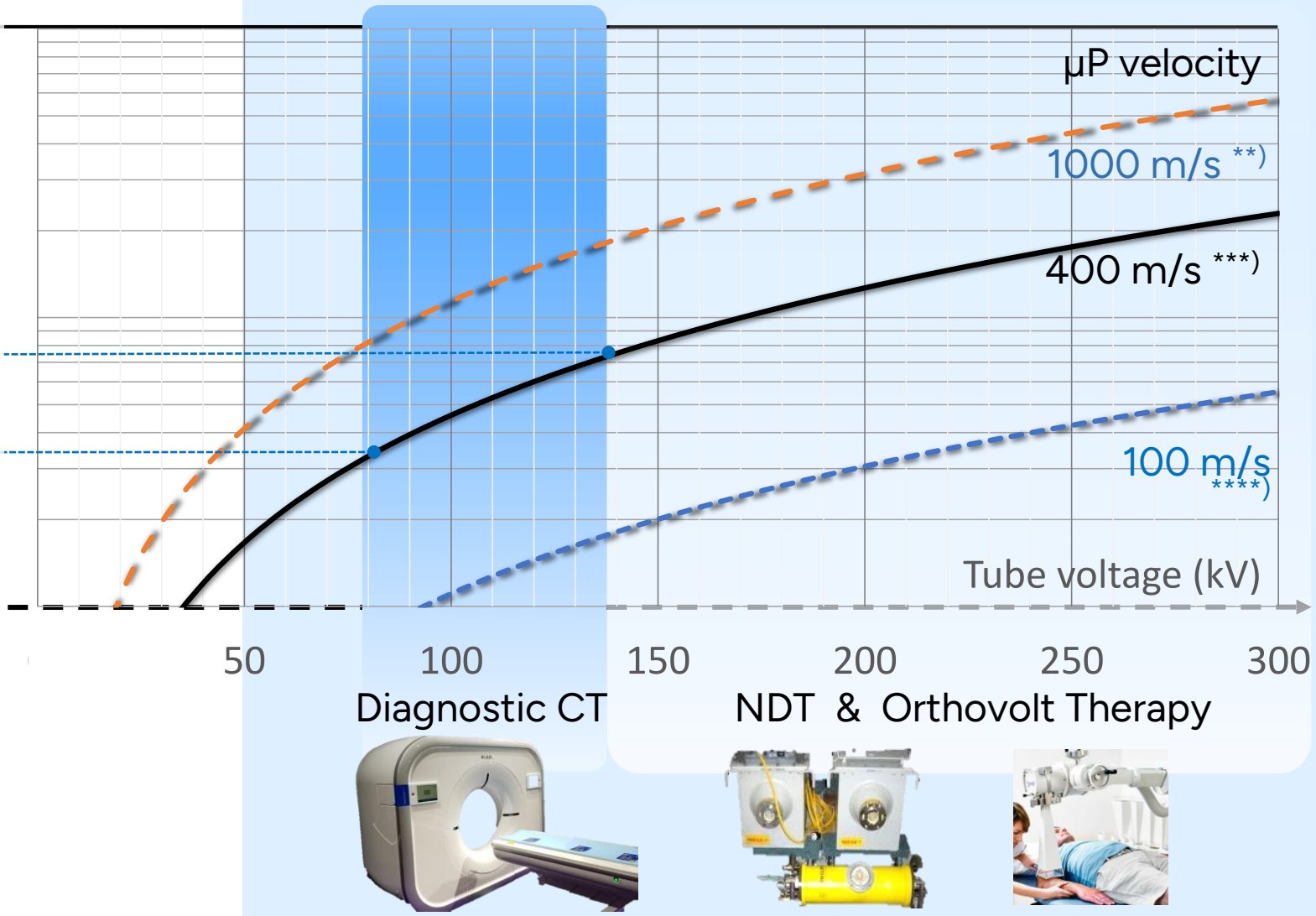
- No erosion
- 4x target velocity
- 3x heat capacity
- →8x gain of power density (CT)
- Remote cooling
- High brilliance (spectrum, intensity) where required



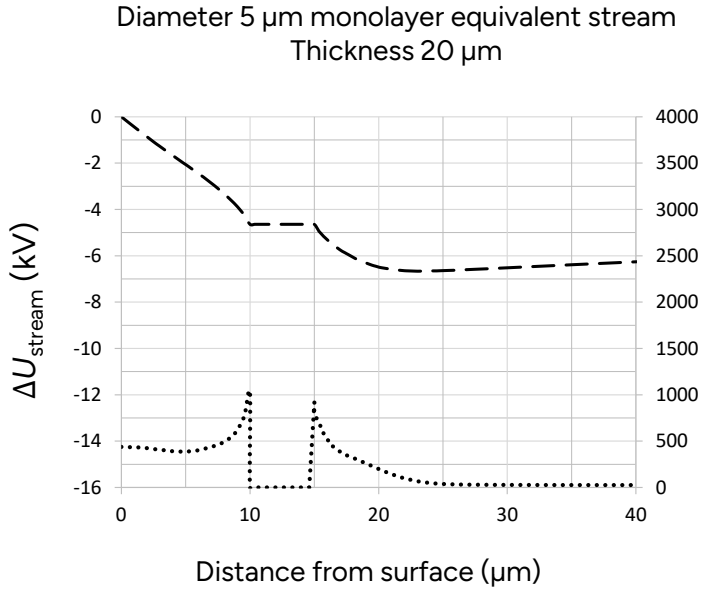
Rotating anode



Microparticle targets



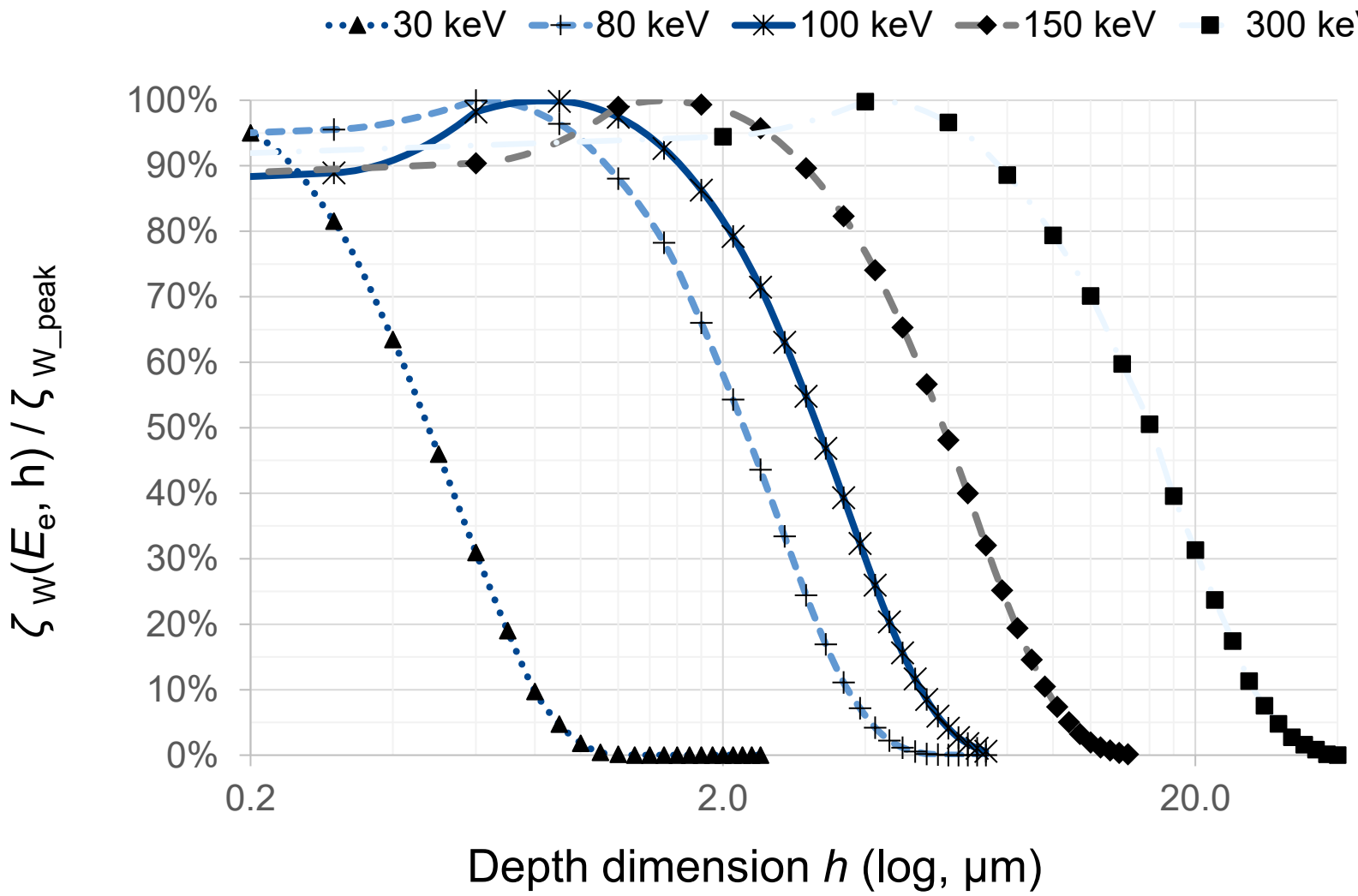
The Challenges



Potential issues

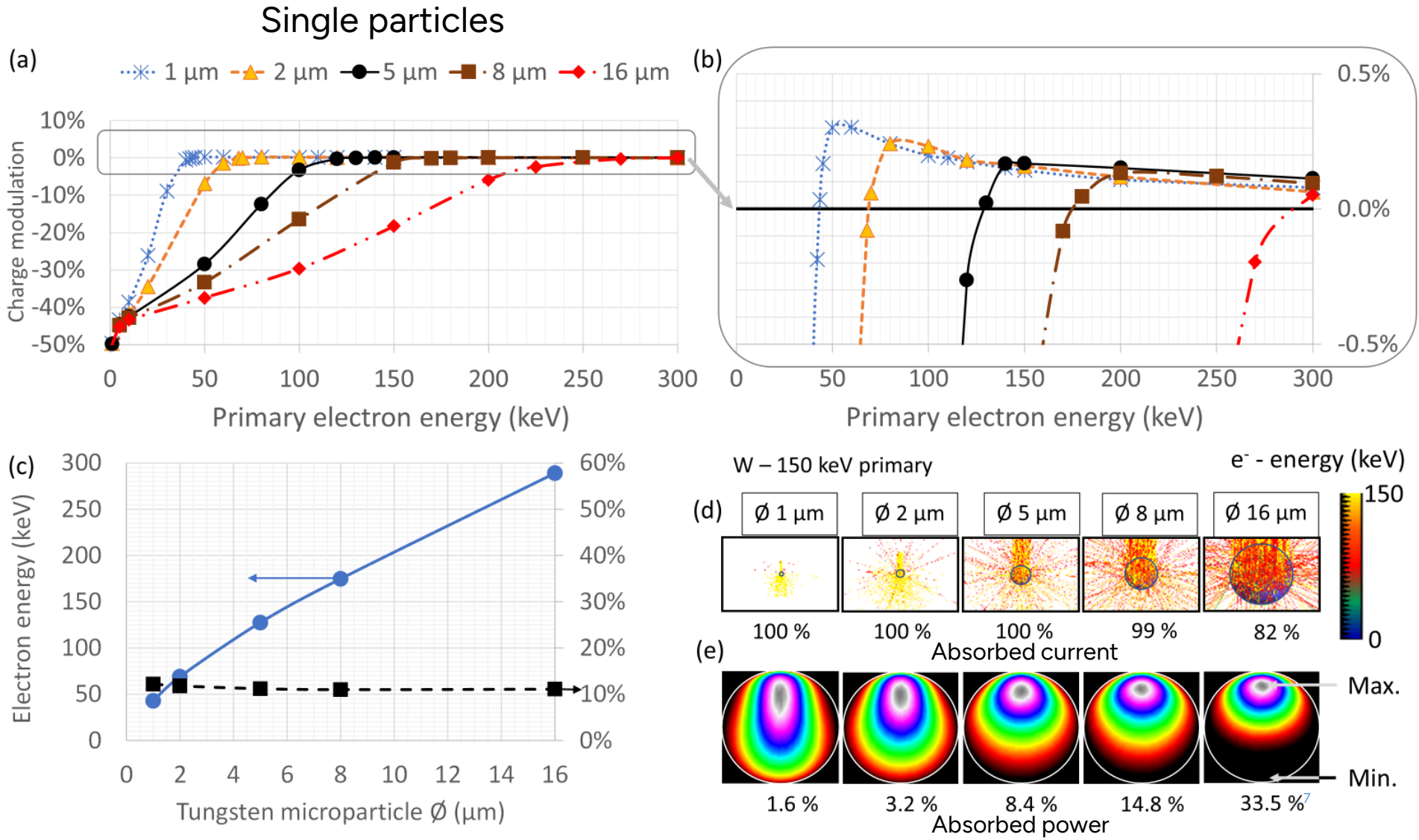
- Charging of thick µP streams
  - false tube voltage
  - Smoking (uncontrolled µP motion)
- Erosion during µP acceleration / braking
  - µP accretion

Integrated Electron Power Deposition in W (max normed, normal impact)

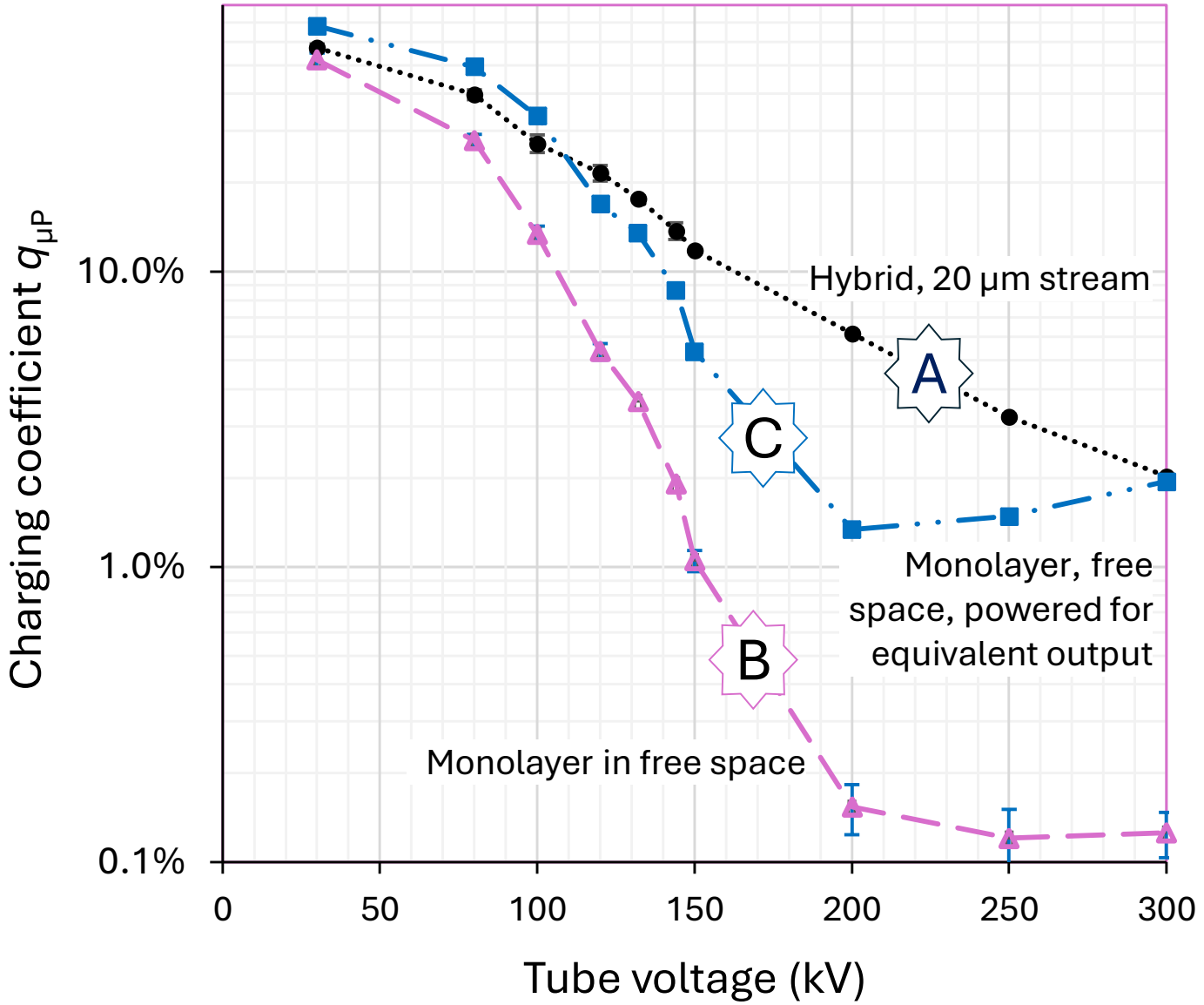


Electron Charging & Power Deposition (Single W Microsphere)

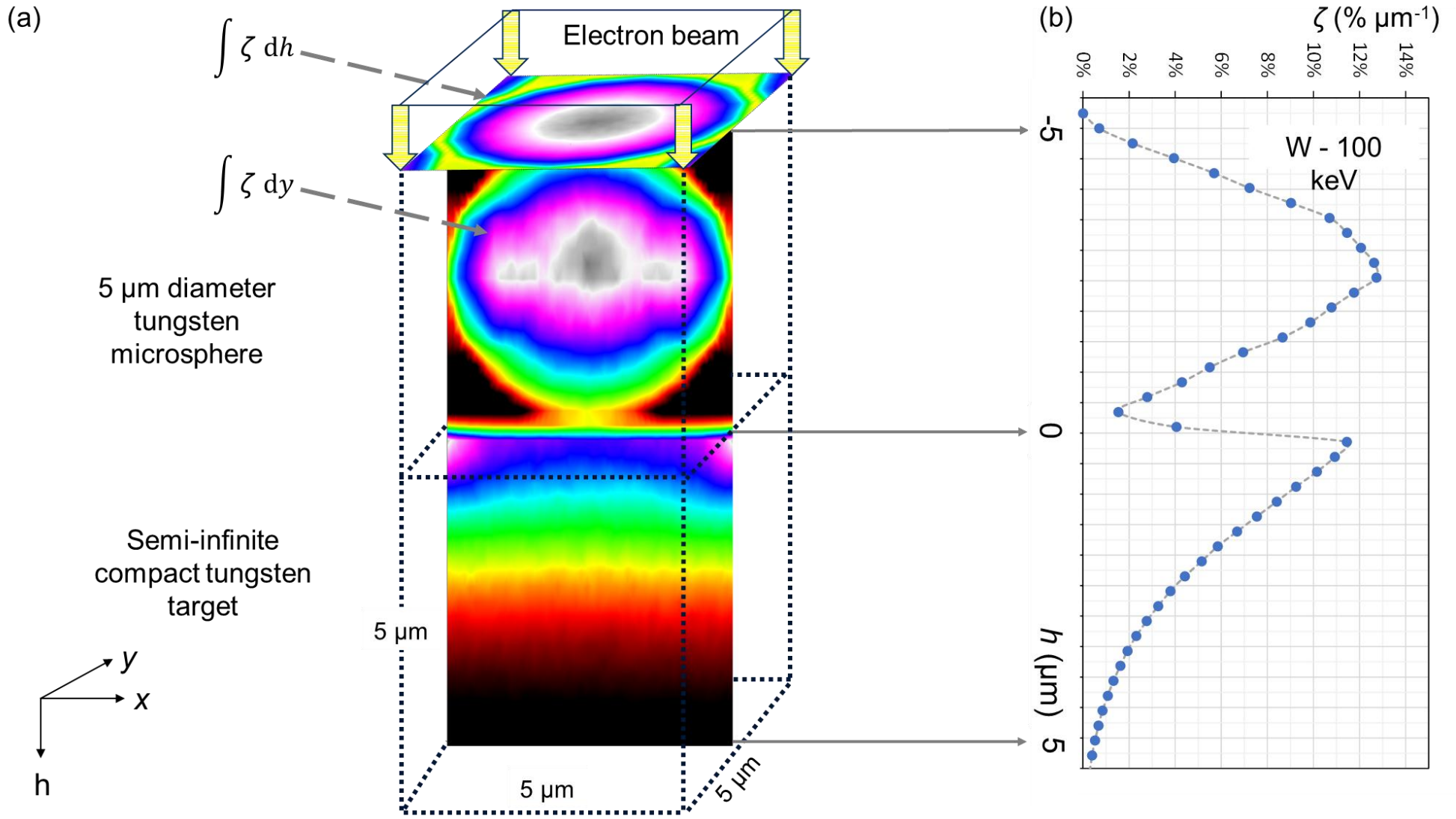
- Discharge by
  - Backscatter (graphs)
- In addition (expected, not shown):
  - Secondary electron emission
  - Thermionic Schottky emission
  - Field emission



W Ø5 µm Monolayer, on Top of W and in Free Space



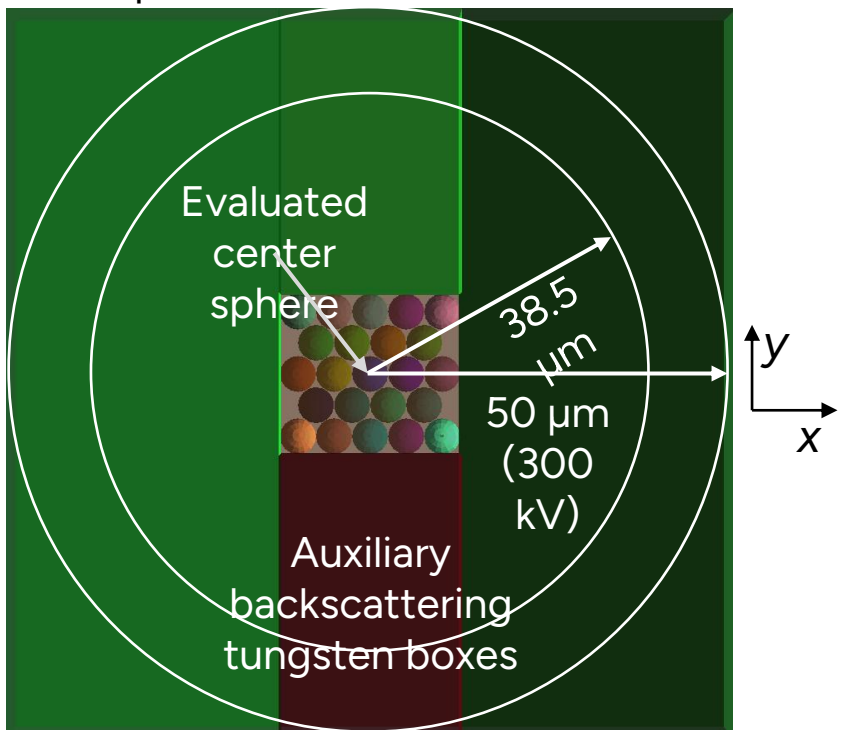
Power Deposition
(W ∅5 µm Monolayer, on Top of W Substrate)



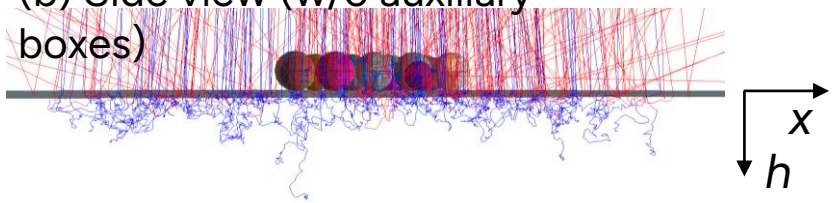
MC Model for Hybrid Rotatry Anode/ µP Target

- Electron scattering (all directons, in and out of the µP)
- Center sphere evaluated

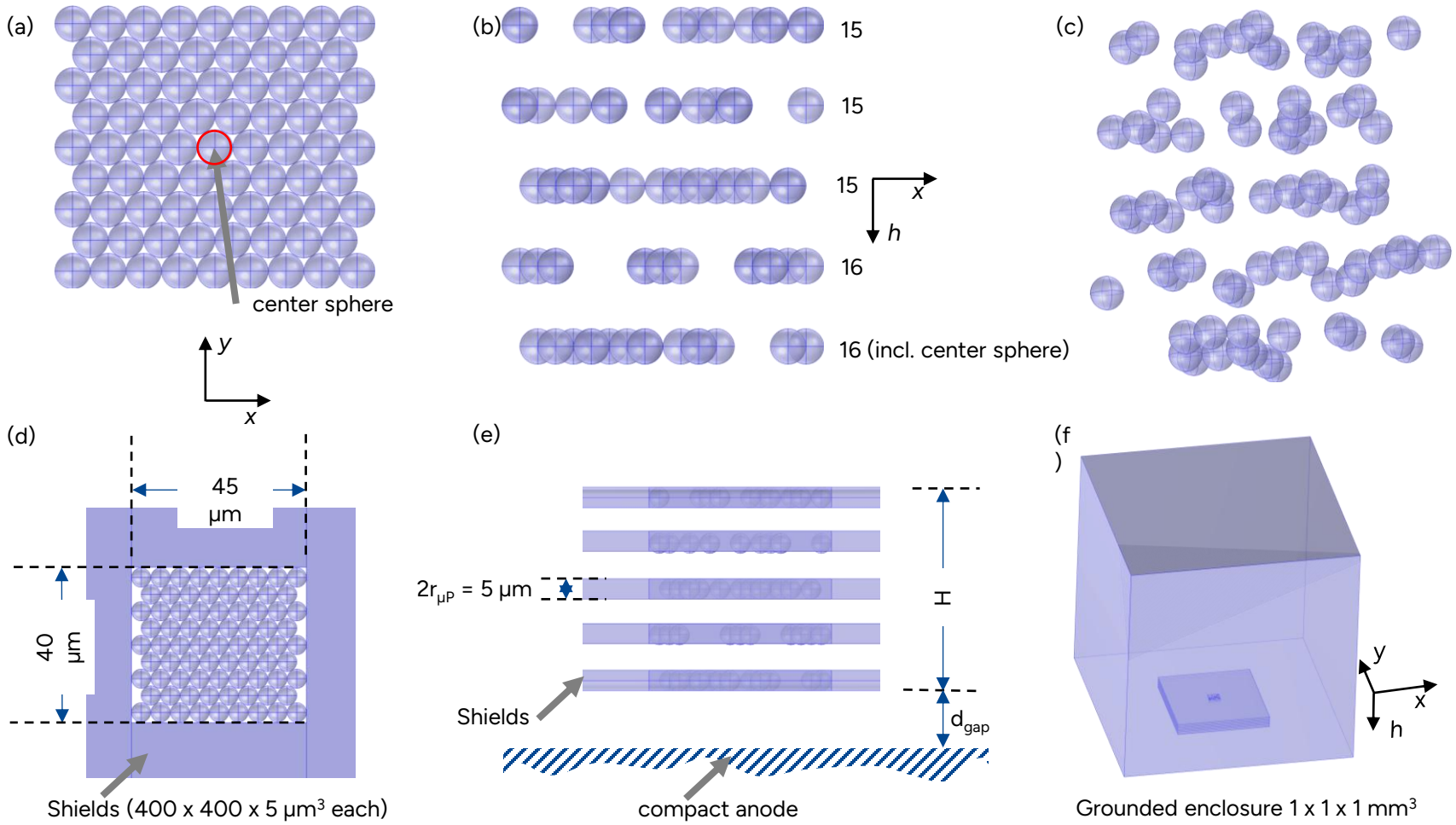
(a) Top view



(b) Side view (w/o auxiliary boxes)



FEM (Comsol 6.2) Model for Hybrid Target

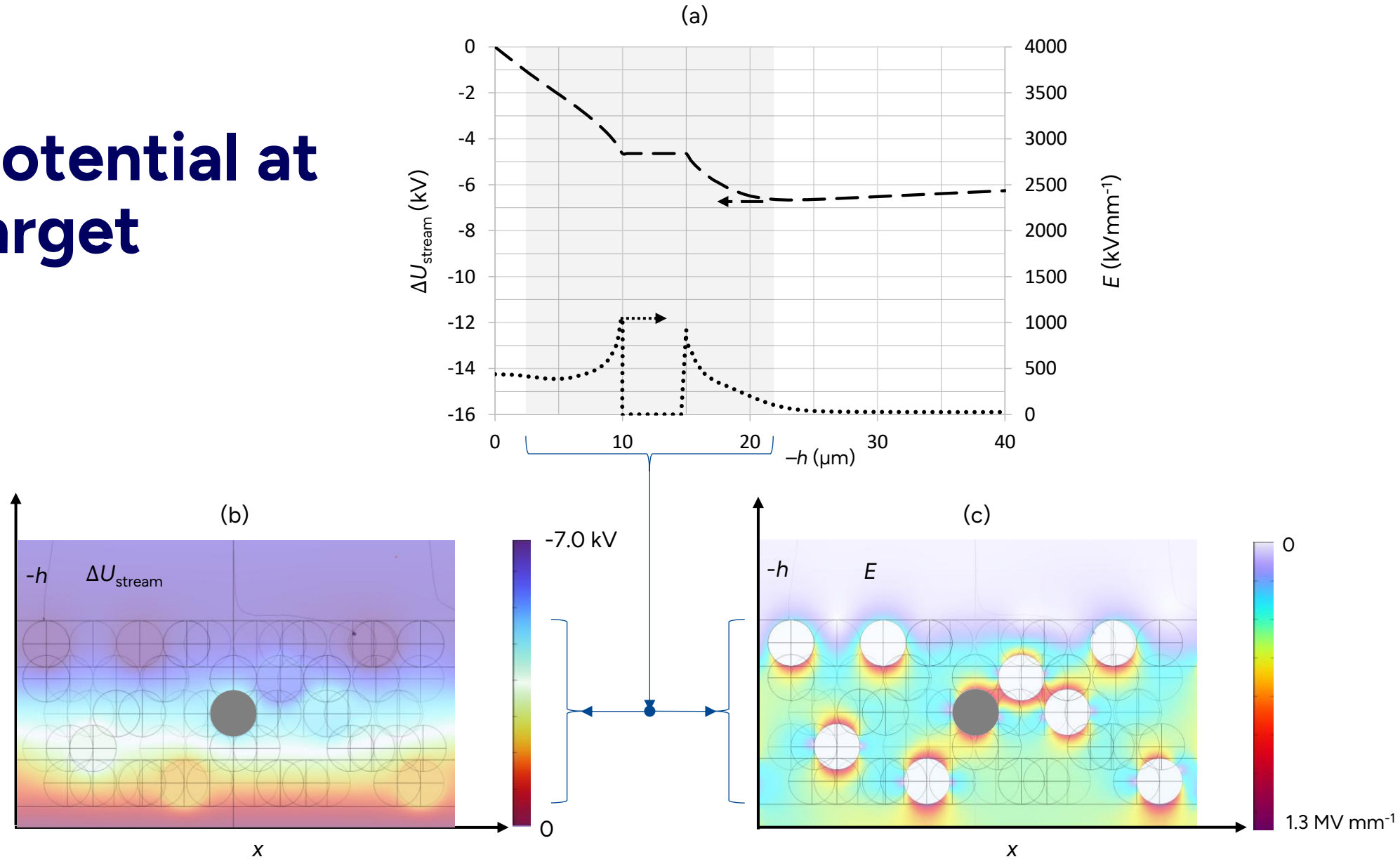


Electric Potential at Hybrid Target

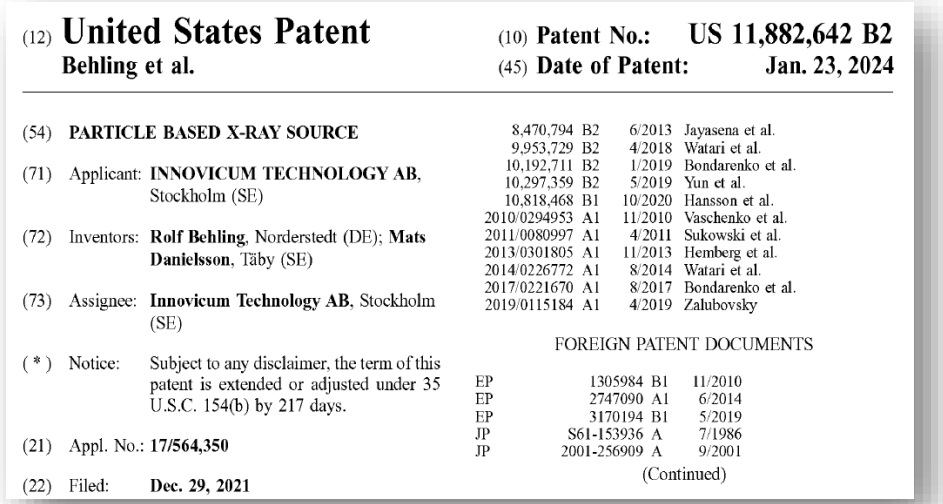
(a) Potential $\Delta U_{stream}(h)$ and electric field strength $E(h)$ @ FS exit of a 20 µm thick μP stream 2.5 µm from a rotating anode ; field emission discharged & maximally loaded (144 kV)

(b) $\Delta U_{stream}(h)$

(c) $E(h)$ (color-coded), in a cross section comprising the normal through the center-sphere probe placed in the middle layer. The electric-field strengths at the surfaces of all the µPs were adjusted to about 1 MV mm^{-1}



Publications



(12) **United States Patent**
Behling et al.

(10) **Patent No.: US 11,882,642 B2**
(45) **Date of Patent: Jan. 23, 2024**

(54) **PARTICLE BASED X-RAY SOURCE**

(71) Applicant: **INNOVICUM TECHNOLOGY AB**, Stockholm (SE)

(72) Inventors: **Rolf Behling**, Norderstedt (DE); **Mats Danielsson**, Täby (SE)

(73) Assignee: **Innovicum Technology AB**, Stockholm (SE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 217 days.

(21) Appl. No.: **17/564,350**

(22) Filed: **Dec. 29, 2021**

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The impact of tube voltage on the erosion of rotating x-ray anodes

Rolf Behling, Christopher Hulme, Panagiotis Tolias, Mats Danielsson

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A compact X-ray source via fast microparticle streams

Rolf Behling, Christopher Hulme, Gavin Poludniowski, Panagiotis Tolias & Mats Danielsson

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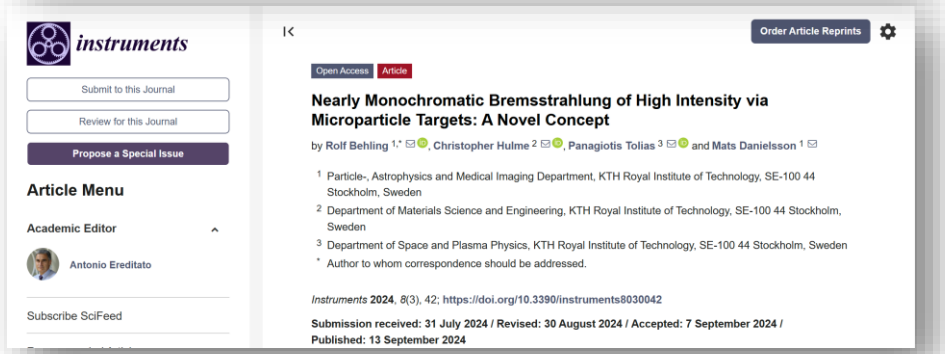

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Nearly Monochromatic Bremsstrahlung of High Intensity via Microparticle Targets: A Novel Concept

by Rolf Behling [1,*], Christopher Hulme [2], Panagiotis Tolias [3] and Mats Danielsson [1]

[1] Particle-, Astrophysics and Medical Imaging Department, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
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Microparticle Hybrid Target Simulation for keV X-ray Sources

by Rolf Behling [1,*], Christopher Hulme [2], Panagiotis Tolias [3], Gavin Poludniowski [4] and Mats Danielsson [1]

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* Author to whom correspondence should be addressed.

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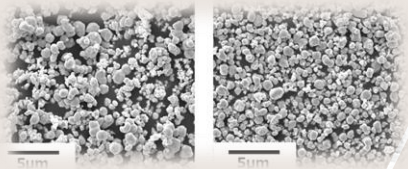
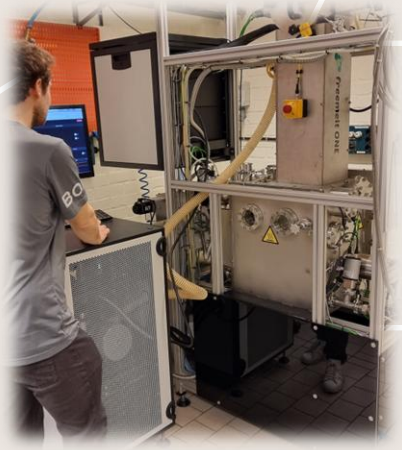
Conclusions

- Tungsten microspheres will not charge if electron impact energy is beyond threshold (ca. 30 keV for 1 µm particle diameter)
- Particle motion between electrodes will depend on electron energy during interaction
- Lower z metals typically exhibit lower backscatter yield and higher charging



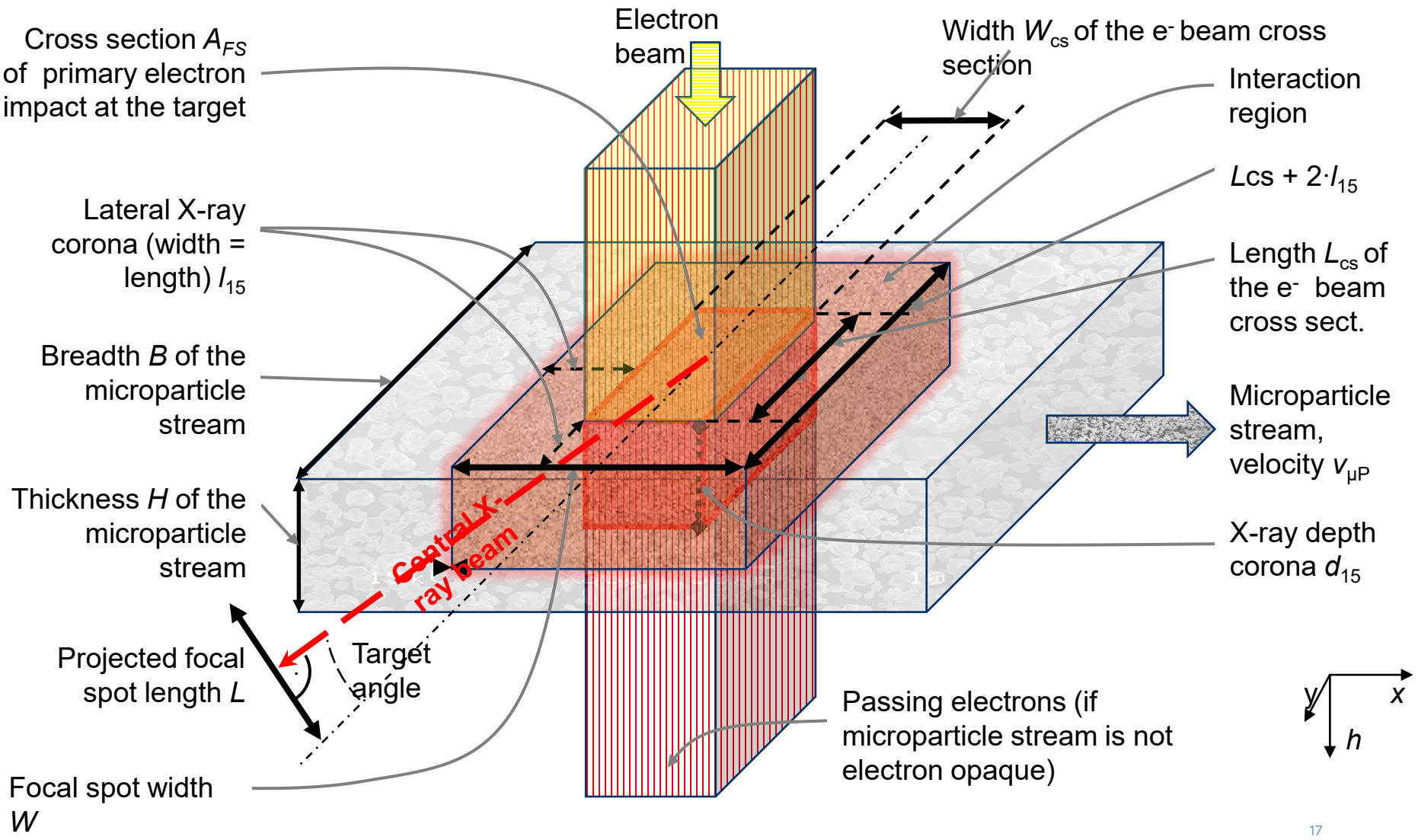


Thank you

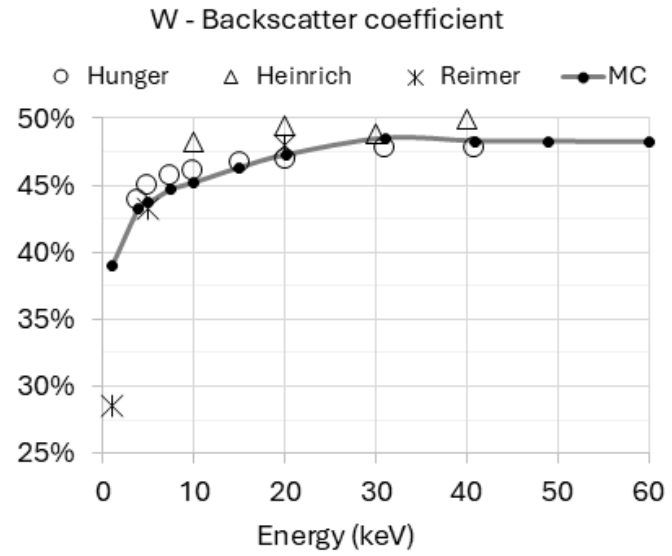
Rolf Behling, Christpher Hulme, Gavin Poludniowski, Panagiotis Tolias, Mats Danielsson

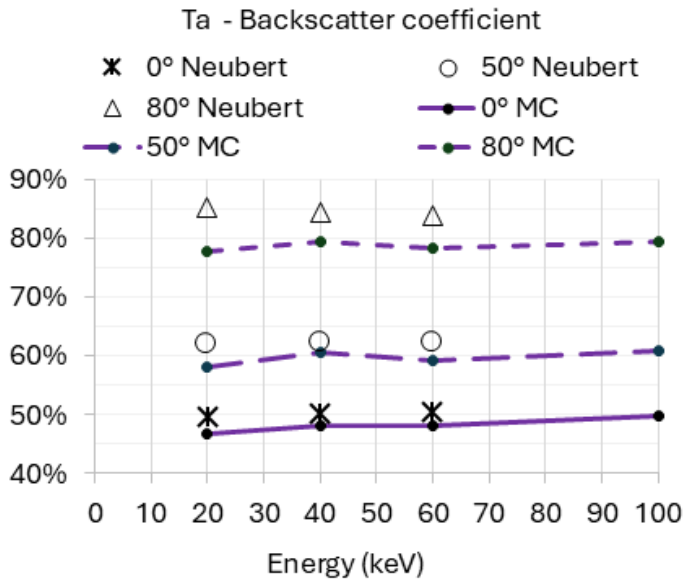
More Details

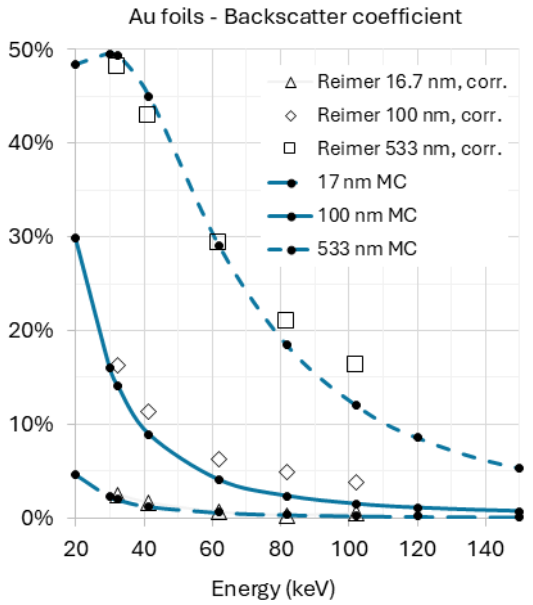
Interaction Region

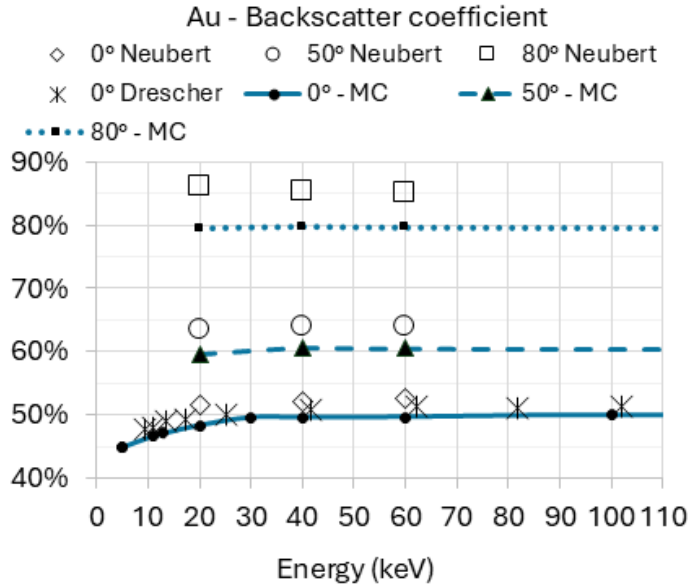


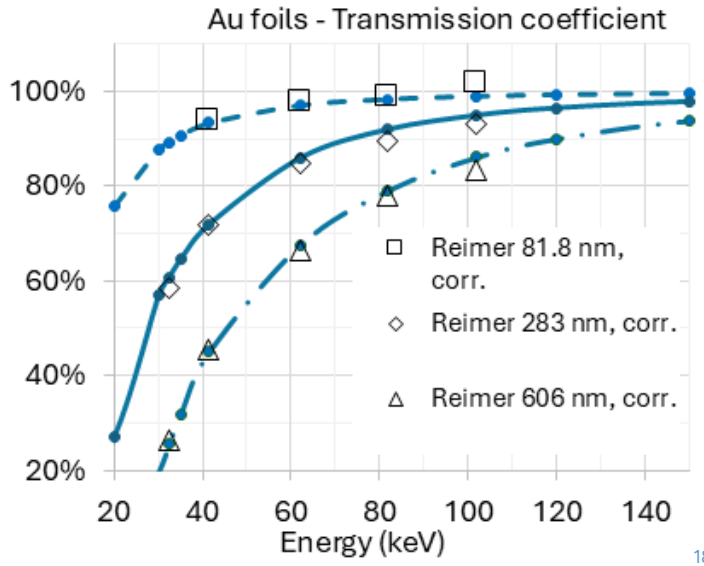
Validation of the MC Simulation with Casino v3





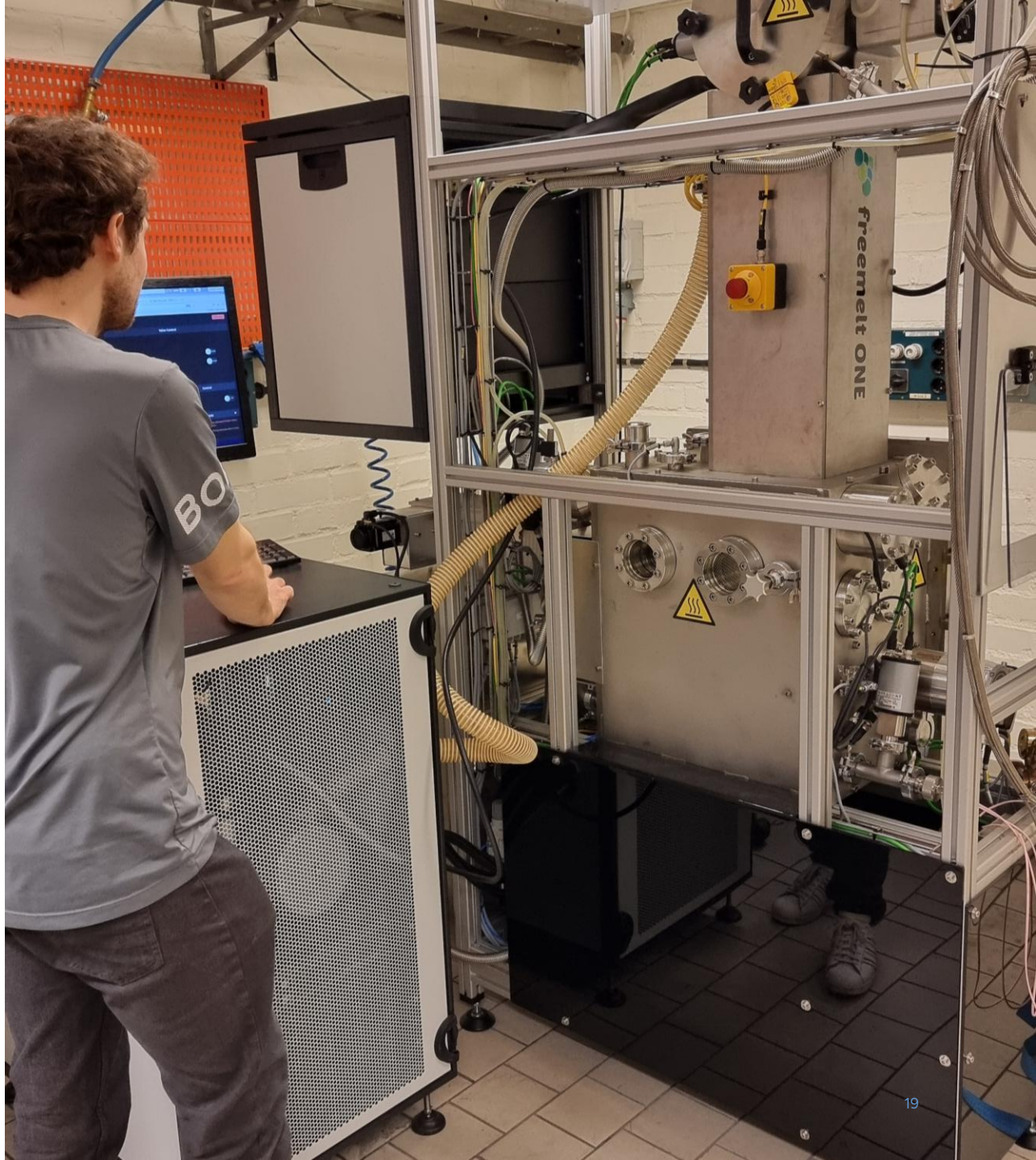






Ongoing Work

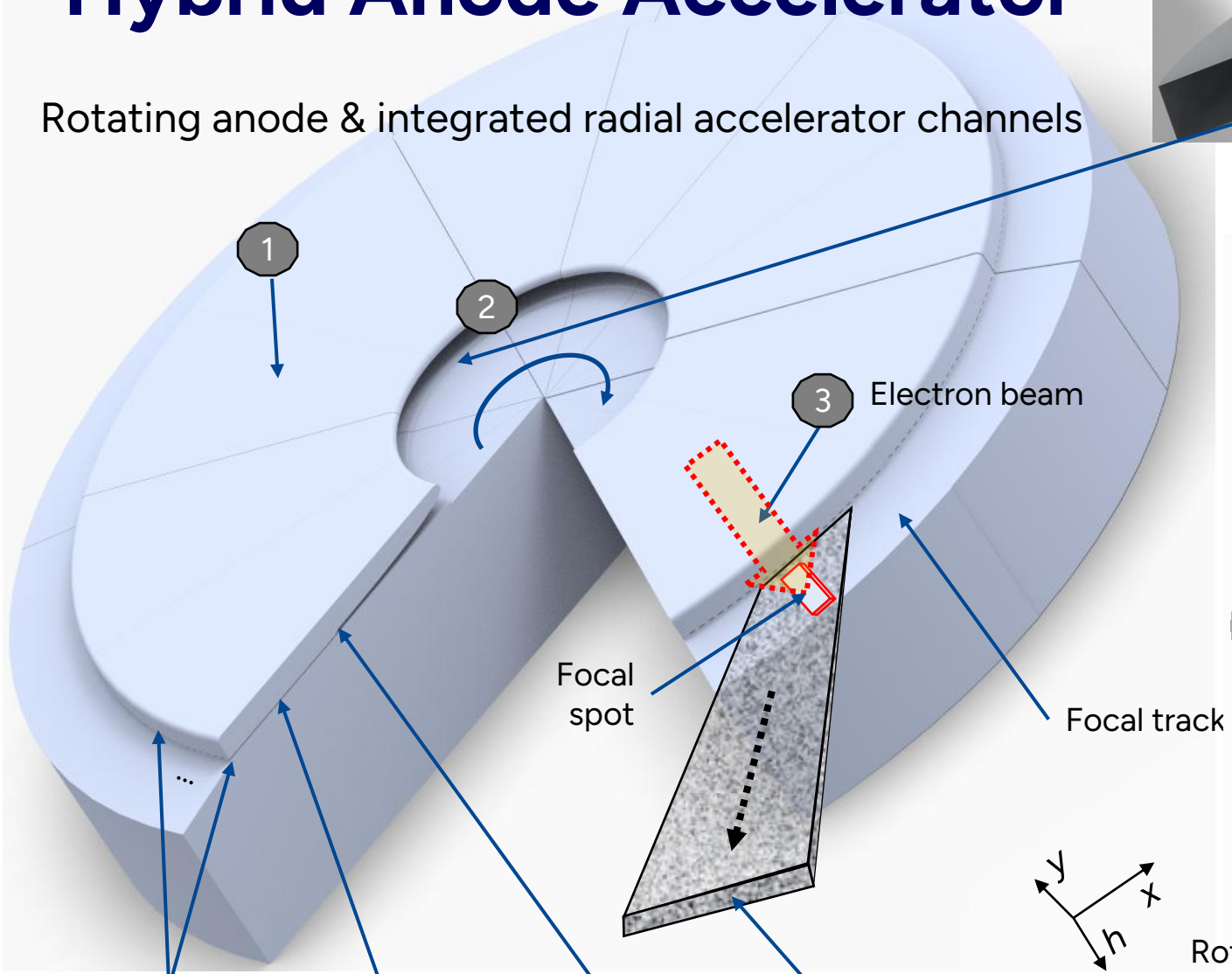
- Preparing for public funding
- Rheologic tests
- Supplier contacts
- Validation of MC simulations
- Publishing

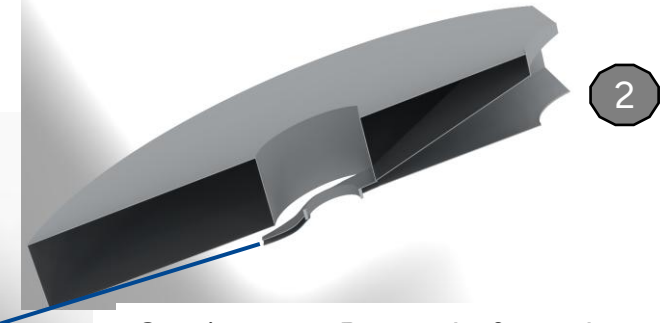


Hybrid Target

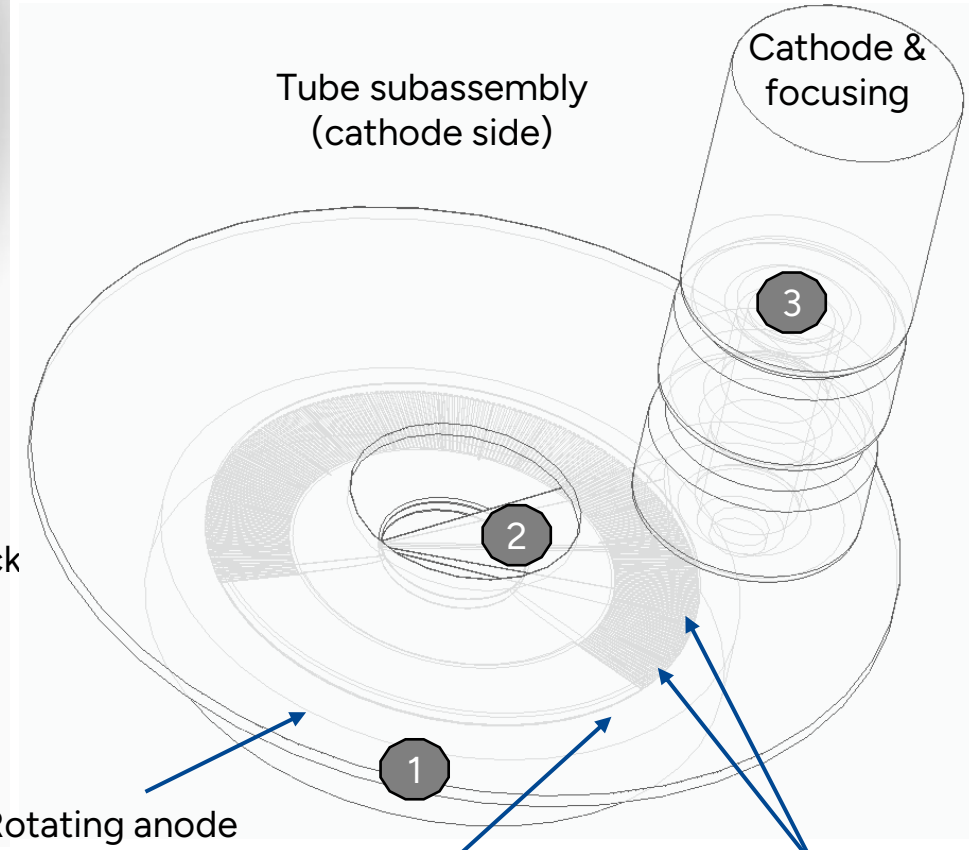
Hybrid Anode Accelerator

Rotating anode & integrated radial accelerator channels

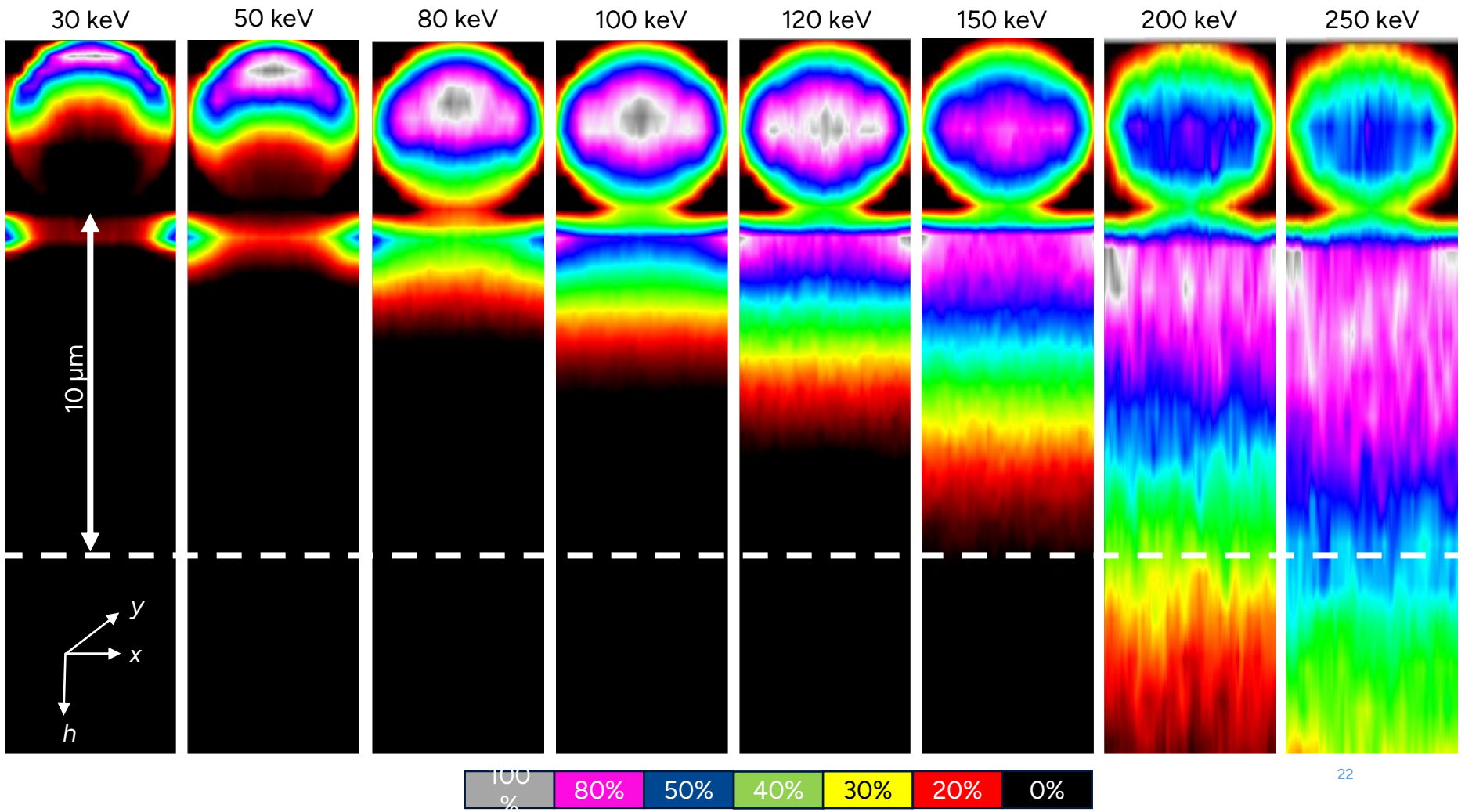




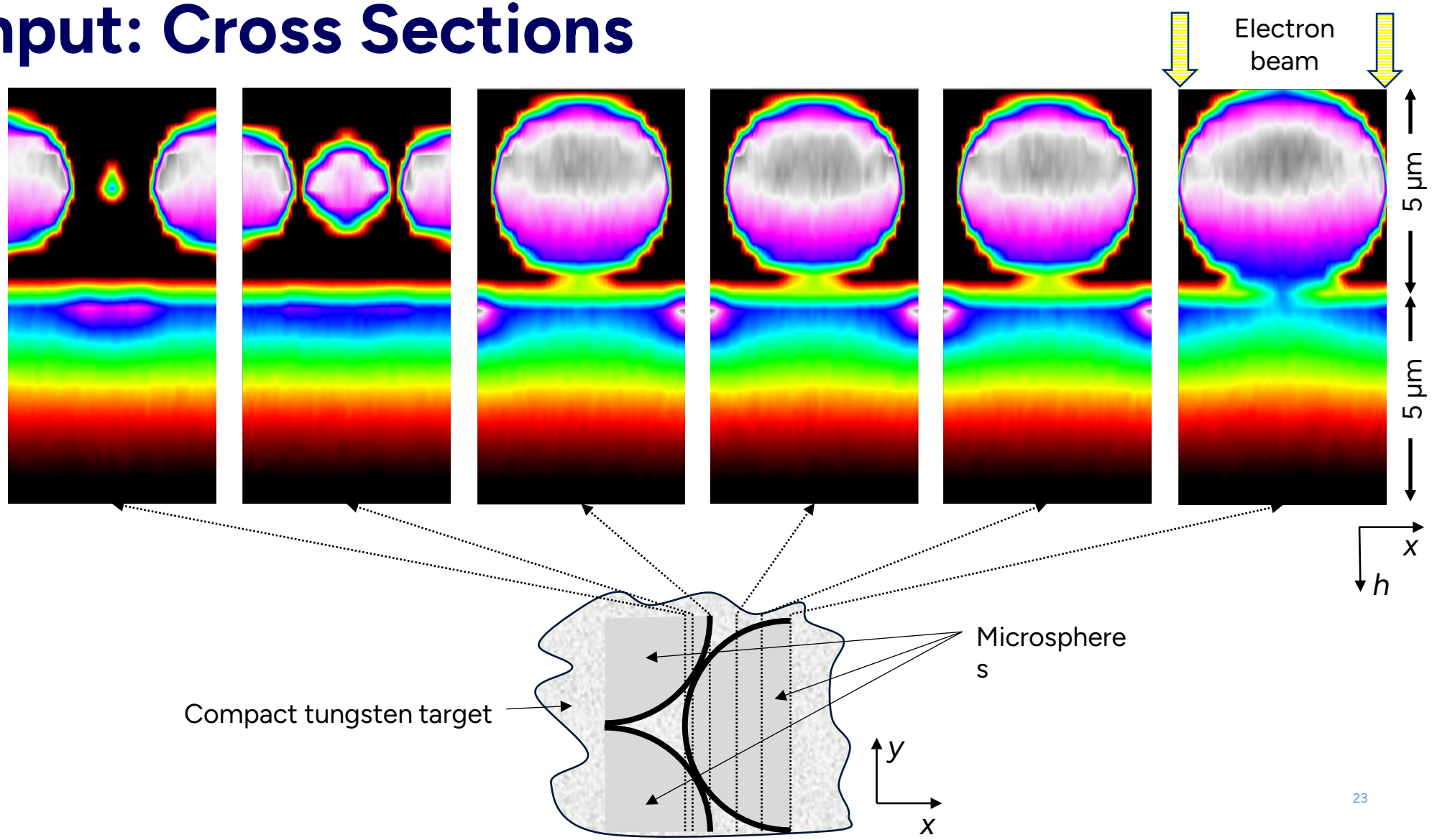
Stationary μP supply funnel replenishing the rotating feed groove



MC Simulation of Power Input for Hybrid Target

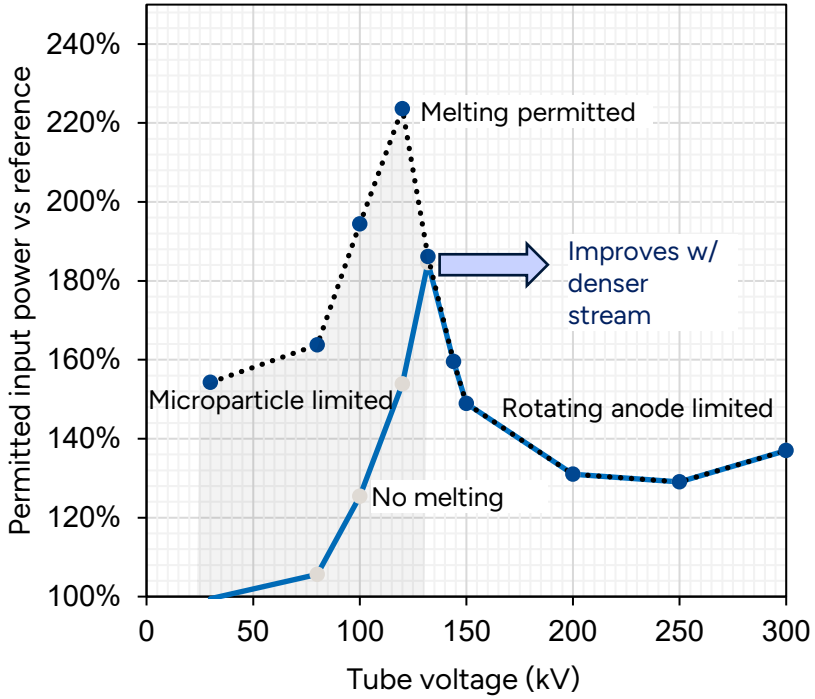


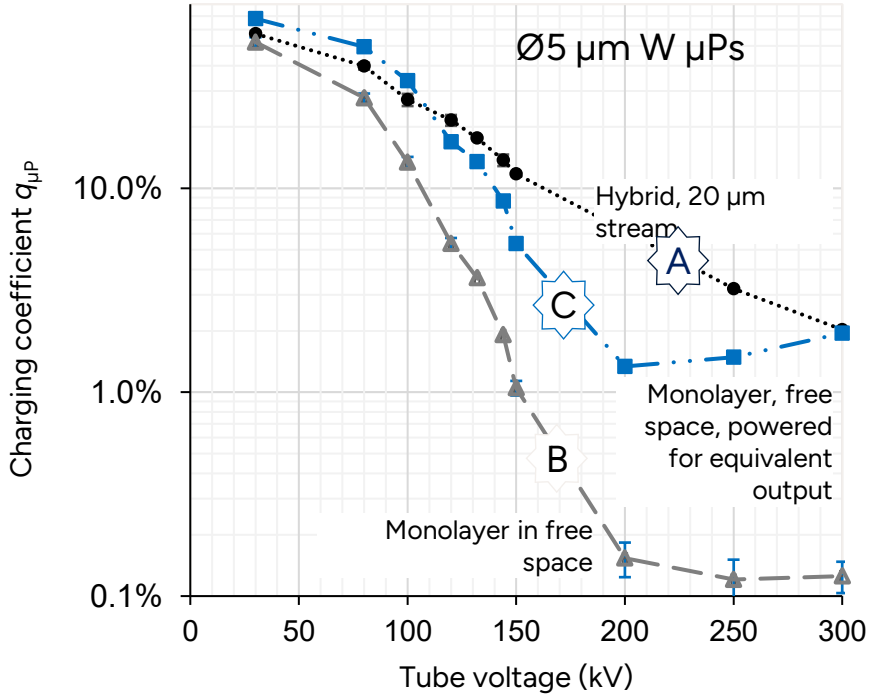
Power Input: Cross Sections



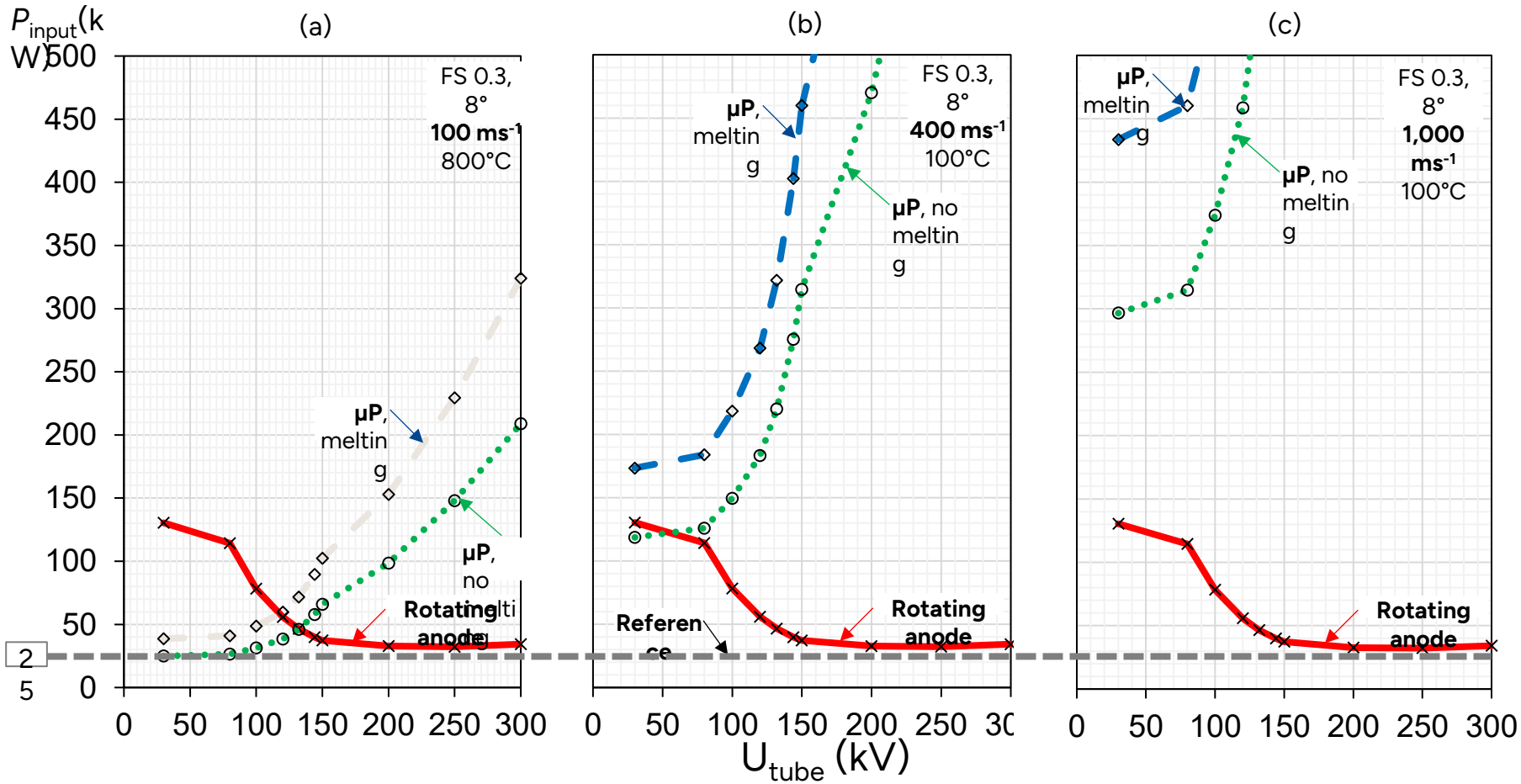
Permitted Input Power / Charging for Hybrid Target

Charging: closely packed monolayer. (A) in front of rotating anode. (B). in free space. (C): in free space, powered to yield hybrid-equivalent output.





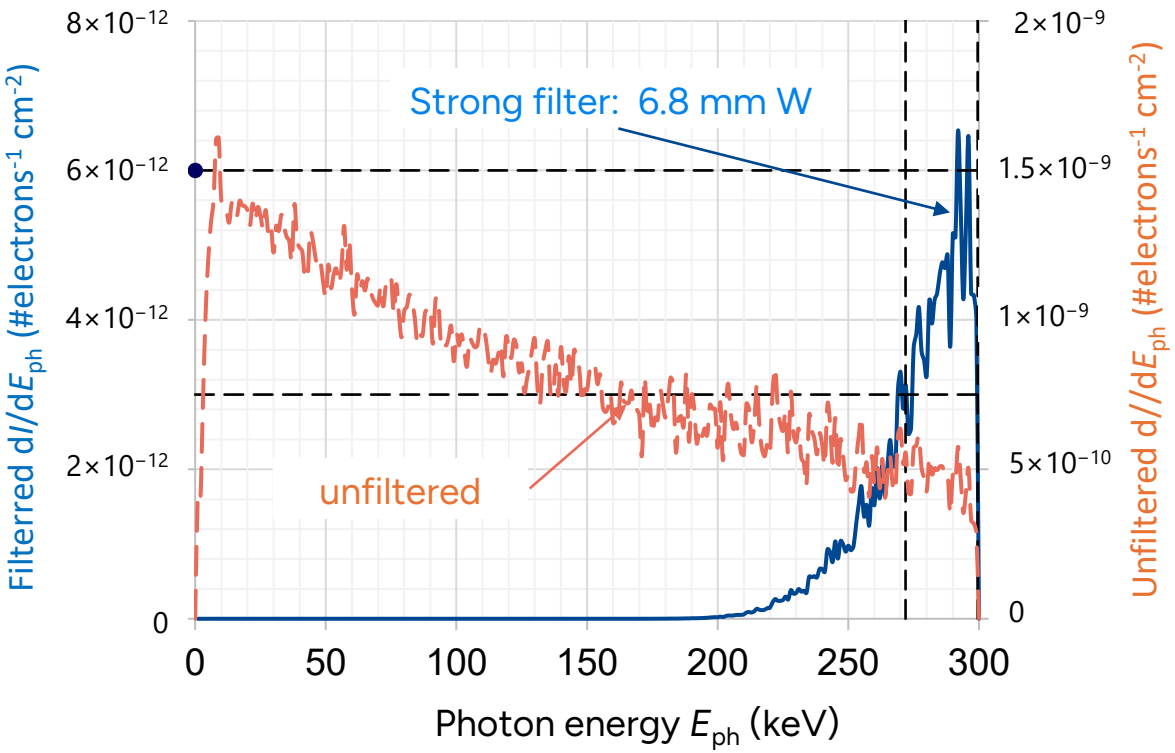
Power Rating Hybrid Anode



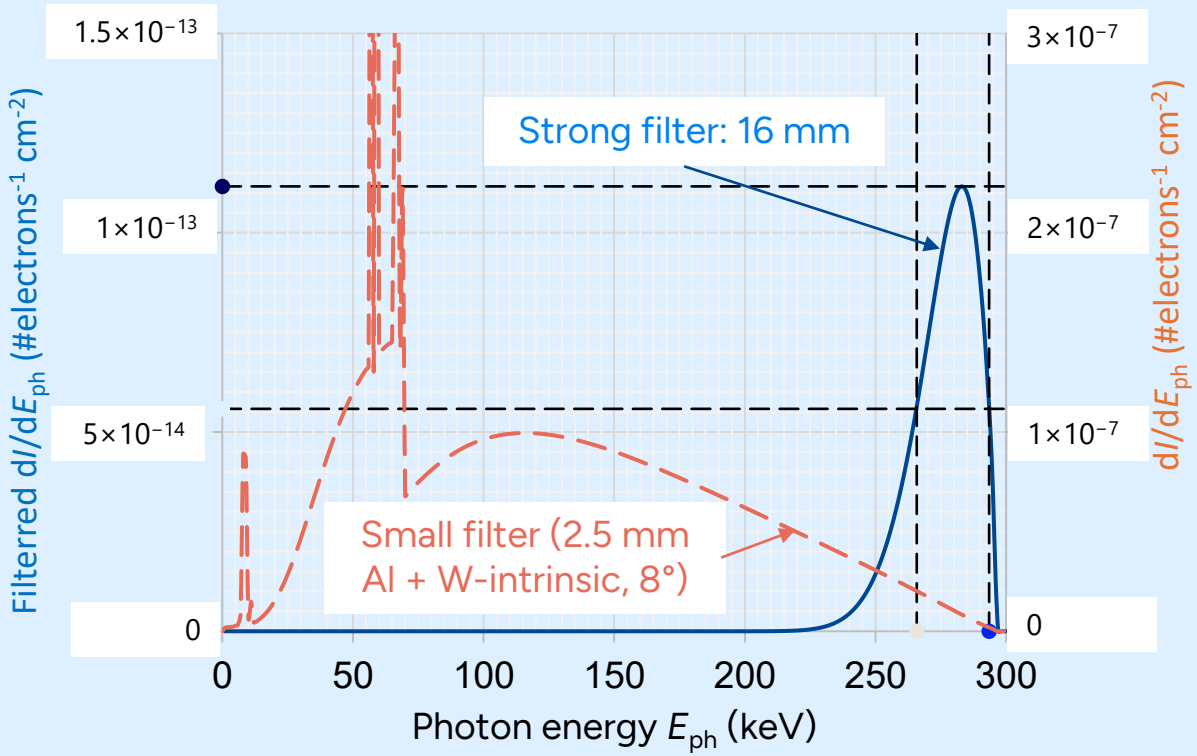
Nearly Monochromatic Filtered Bremsstrahlung

Fluence per Electron

1 µm diameter W µPs

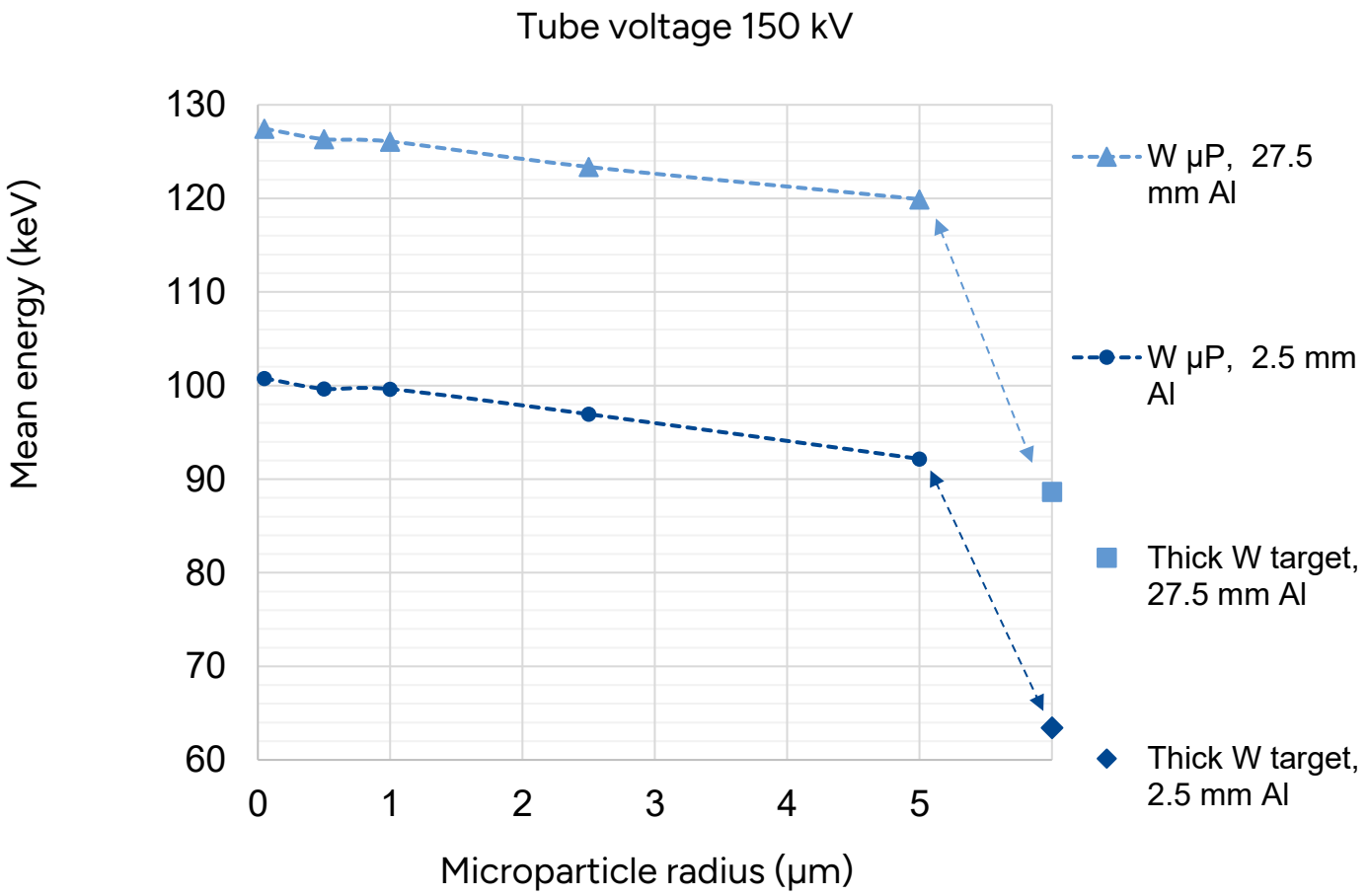


Thick W target



Spectrum vs µP Size

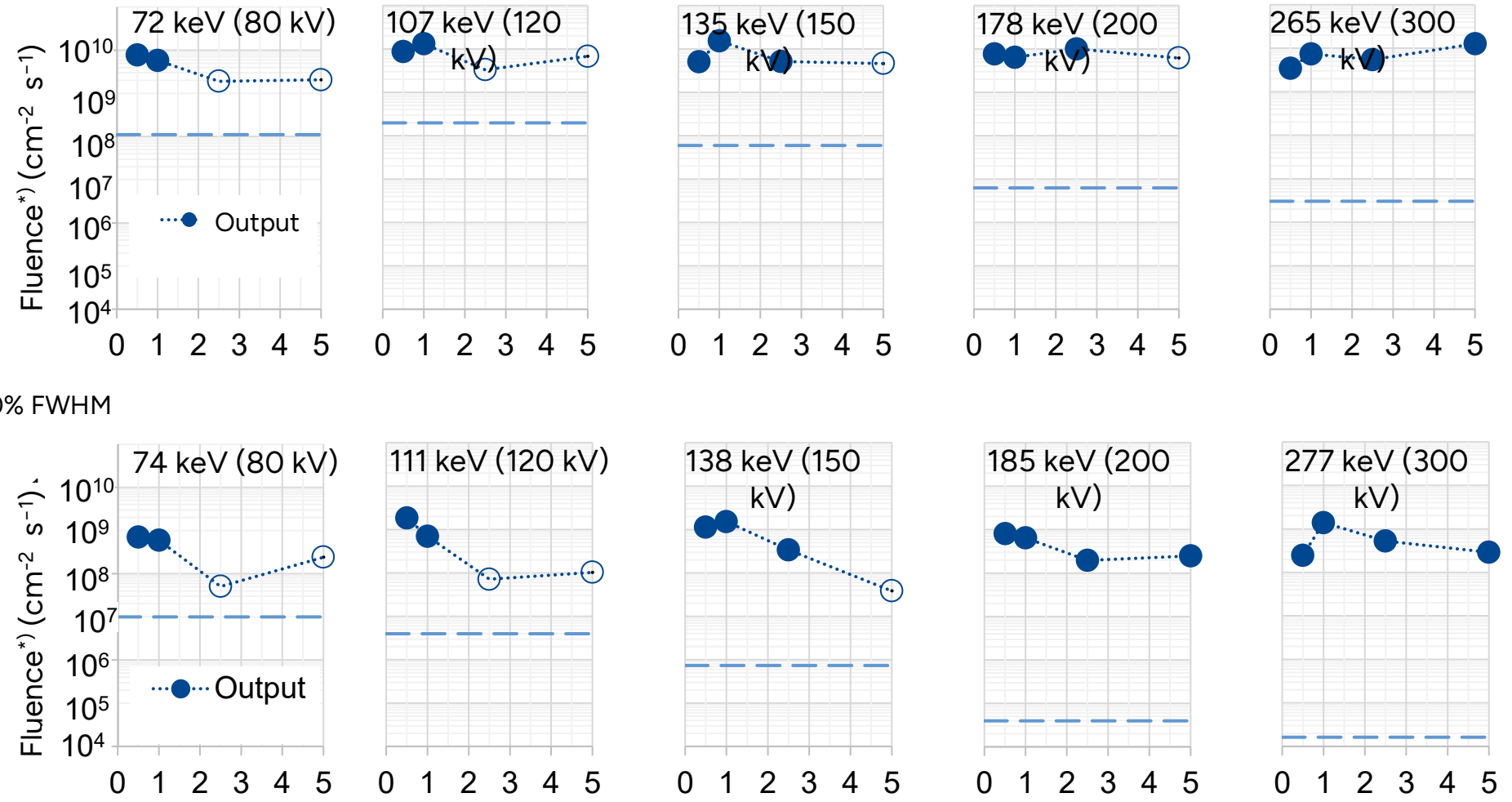
- Output spectrum depends on µP size
- Weak dependency
- Supports spectrum modulation



High Intensity

- Superior fluence

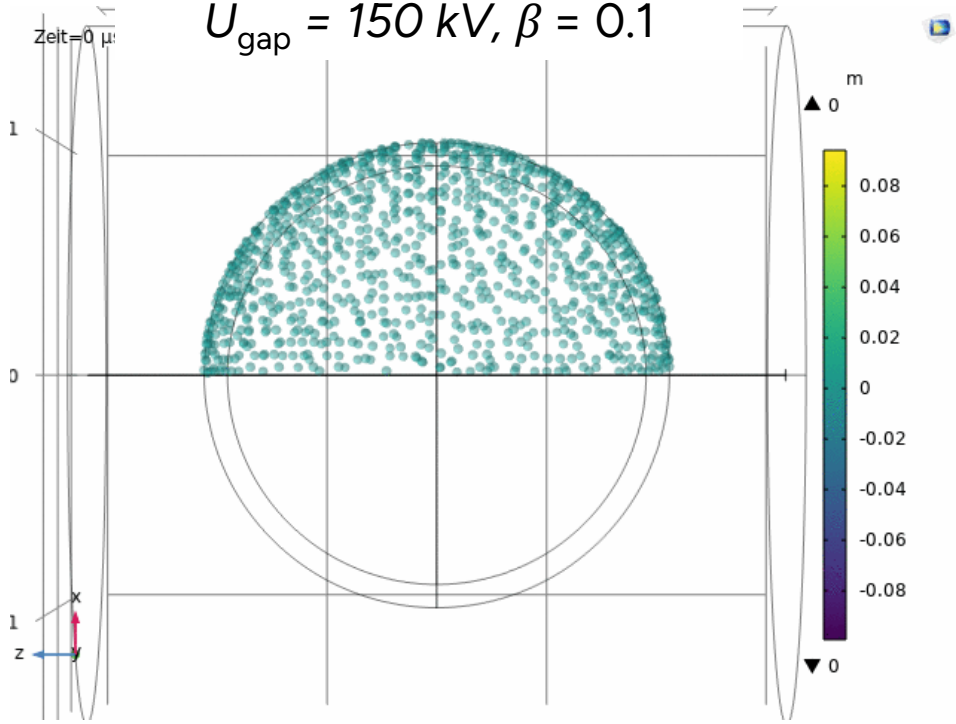
(Ref.: Rotating anodes resp. thin stationary targets for >150 kV)

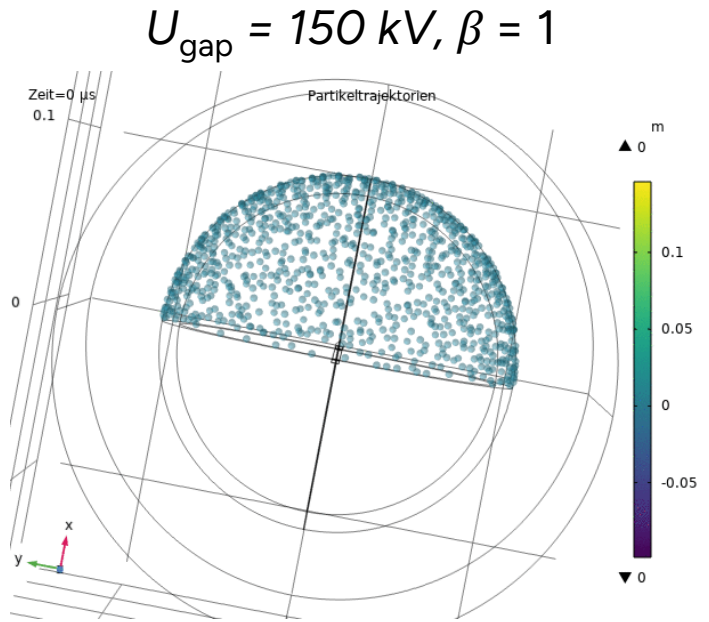


*) 30 cm source detector distance

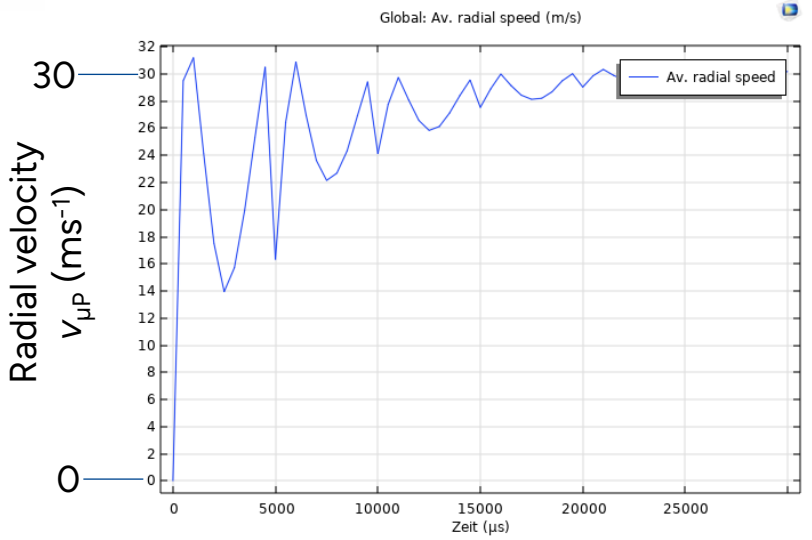
Electric Acceleration

Issue: µP Space Charge Repulsion





Oscillating upon pulse release



Orientating simulations

- Gap 10 mm, voltage 150 kV, (E-field >15 kV mm^{-1} not realistic). Simulated velocity 30 ms^{-1}:
- Space charge repulsion (µP focus too large)
- E-field max. ca. 5 kV mm^{-1}: achievable radial µP velocity << focal track velocity of rotating anodes

End

SPIE MI 2025