Progress in Magnetic Fusion Energy Research at the University of Saskatchewan

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NSERC CRSNG

UNIVERSITY OF SASKATCHEWAN

Mitacs

Outline

1. Challenges towards MCF
   - Fuelling and burning efficiency
   - Plasma wall interactions
   - Dust in reactors
2. How USask STOR-M program can address some of those challenges
   - Fuelling studies (compact torus)
   - Plasma-surface interactions (CT, DPF)
   - Dust behaviour studies (Dust dropper)

Outline (cont.)

3. Devices used for those studies
    - STOR-M tokamak
    - Compact Torus Injector
    - Dense plasma focus device
    - Dust dispenser
4. Selected results and plan
    - Fuelling
    - Plasma-target interaction
    - Dust dropper characterization

Outline

1. Challenges towards MFE
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Challenges

- Confinement physics and scaling laws
  - Large devices: ITER→Demo
  - High magnetic field: SPARC, CF (USA), Tokamak Energy (UK)

    Compact, economical, but high power load on the first wall
- Power load → Material, Plasma-Wall interaction
- Steady State Burning plasma → self-heating, fuel self-sufficiency
  - Improve Fuelling/burning efficiency
  - Tritium, tritium, tritium

    Where do they come from (breeding)?

    Where do they go? Dust formation, tritium retention

    Tritium containing dust is explosive when mixed with water

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Acknowledgements

- Plasma-surface interactions
  - CT and W-coated SS target interaction

  -- Akbar Rohollahi (Ph.D.)

  -- General Fusion (target samples)

  Rad. Effects and Defects in Solids, **172**, 119-126 (2017), http://dx.doi.org/10.1080/10420150.2017.1287185

  - DPF ion beam and W and nano-W target Interaction

  -- Priya Sharma (M.Sc., Mitacs intern),

  -- Prof. Rajdeep Singh Rawat (Nanyang Technological University, Singapore)

  Appl. Surf. Sci. Adv., **6,** 100172 (2021); https://doi.org/10.1016/j.apsadv.2021.100172

Acknowledgements (cont.)

- Dust dynamics studies in STOR-M

  -- N. Nelson (M.Sc., Ph.D.)

  -- L. Coudel (professor, USask),

  Radiation Effects and Defects in Solids Incorporating Plasma Science and Plasma Technology, **177**, 181-197 (2022),

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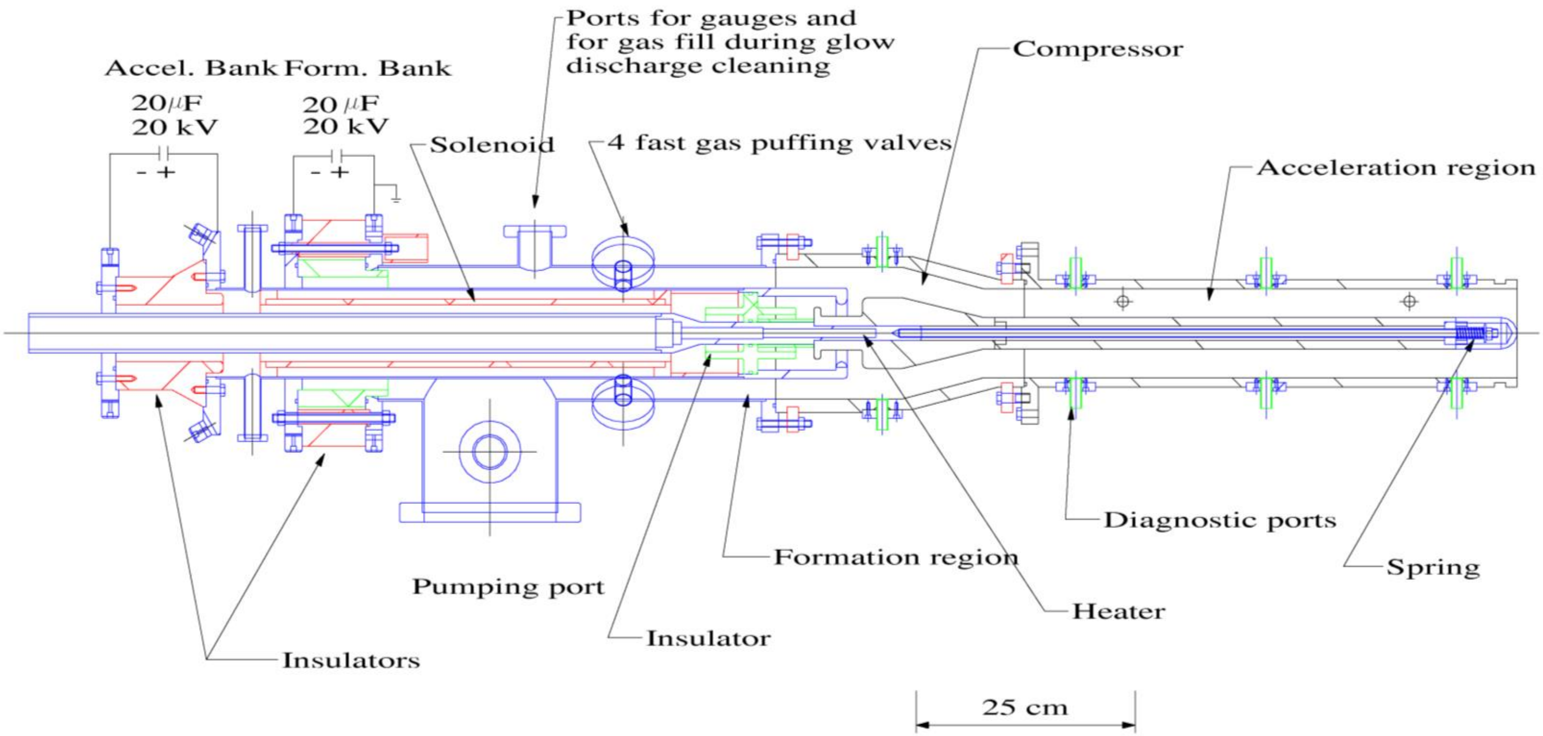
STOR-M tokamak

Construction started in 1984
Operational since 1987
Still active as the only tokamak in Canada

Features of STOR-M

- Density 10^{13} cm^{-3} , $R = 0.46$ cm
- Low temperatures $T_e \sim 100$ eV
- No intensive plasma-wall interactions
  - Needs other plasma sources (CT, DPF)
- No significant dust generation
  - Needs dust dispenser

USCTII-Compact Torus Injector



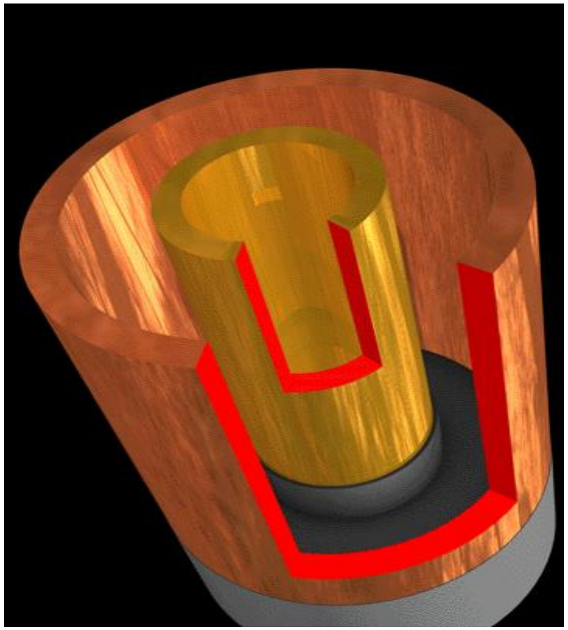
Features of CT

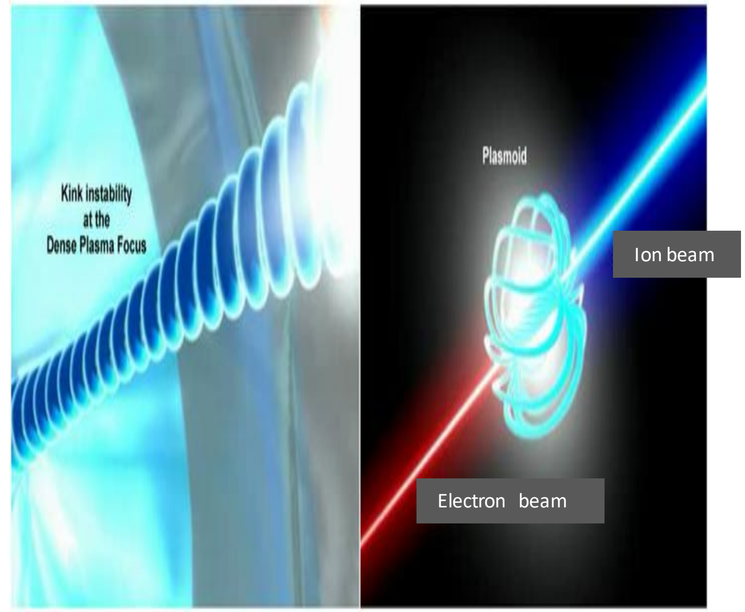
- high density small size (Density 10^{16} cm^{-3} , $R = 0.1$ cm)
- High velocity (100-1000 km/s) → central fuelling, high fuelling efficiency and Tritium Burn-Fraction (TBF)
- Short pulse , 10 μs → high power

  7.5 GW/ m^2 comparable with power load on ITER wall during Type I ELMs bursts.

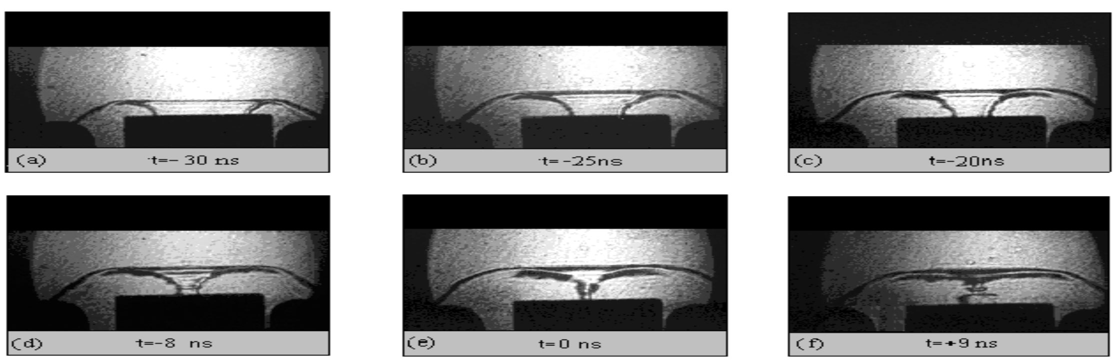
  Good plasma source to study plasma facing component (PFC) wall materials

Dense Plasma Focus





ICTP DPF

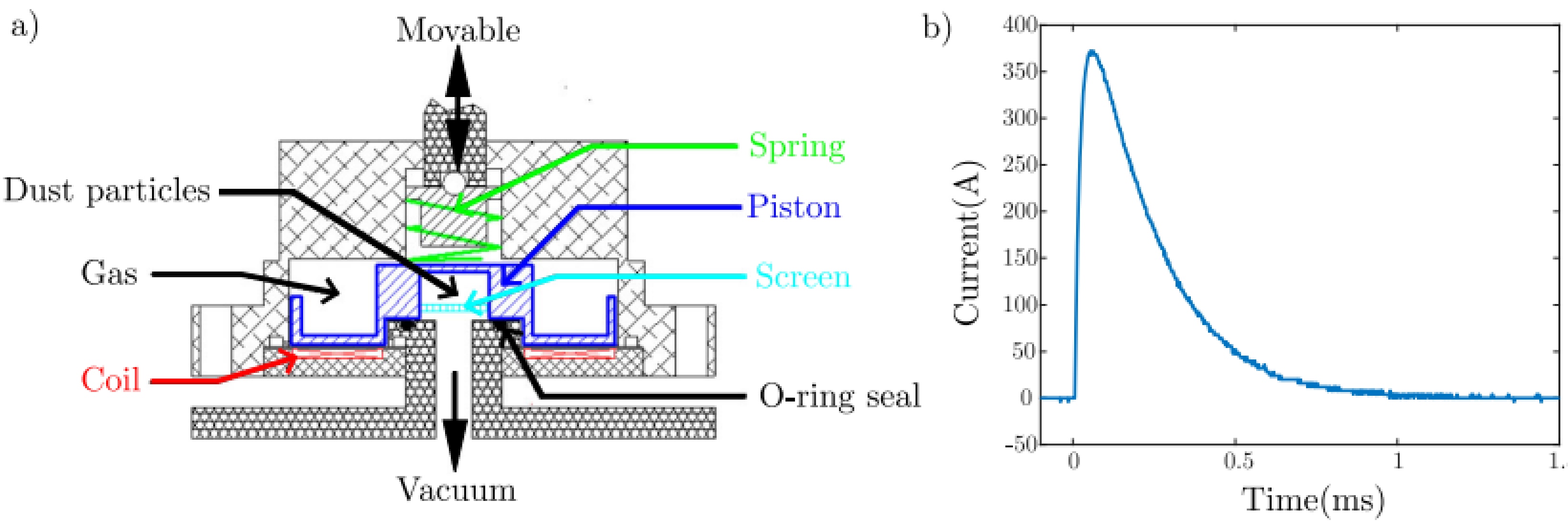


Features of DPF

- Simple device based on high voltage, high current coaxial discharge
- Excellent high energy ion beam source (100s keV)
- Short pulse , 0. 1 μs → high power
  - Damage factor estimated for DPF ion beam is 1.74×10^4 $Wcm^{-2}s^{0.5}$
  - comparable with the estimated 10^4 $Wcm^{-2}s^{0.5}$ energy bursts with a power full Type I ELMs in ITER

DPF is a good plasma source to study plasma facing component (PFC) materials

Dust Dispenser



Pre-fabricated tungsten spheres ~ 20 um

Dust dispenser (pepper-shaker type) controlled by

- Screen size
- Gas pressure
- EM force produced by current through a the coil
- Dust dispenser properties already characterized

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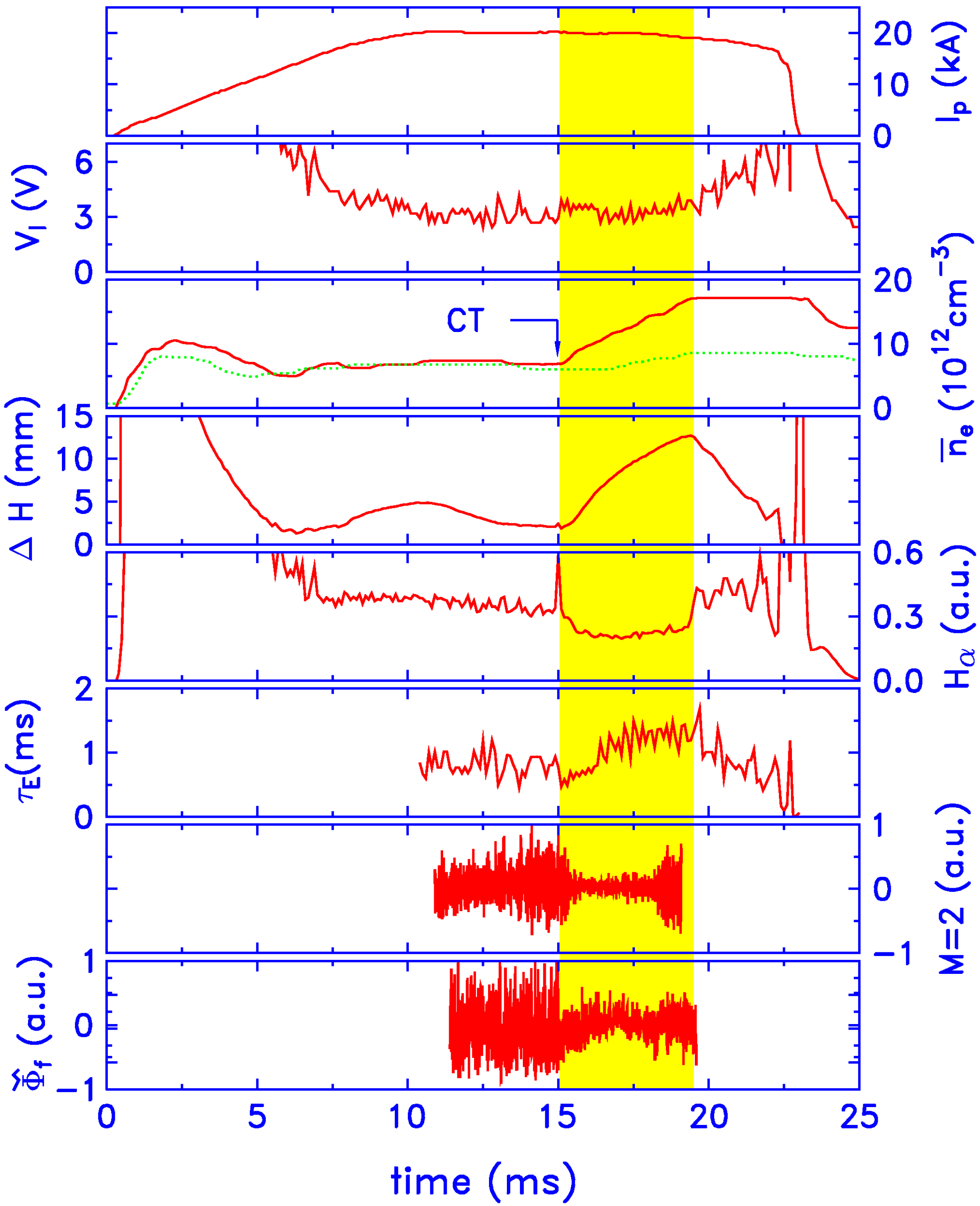
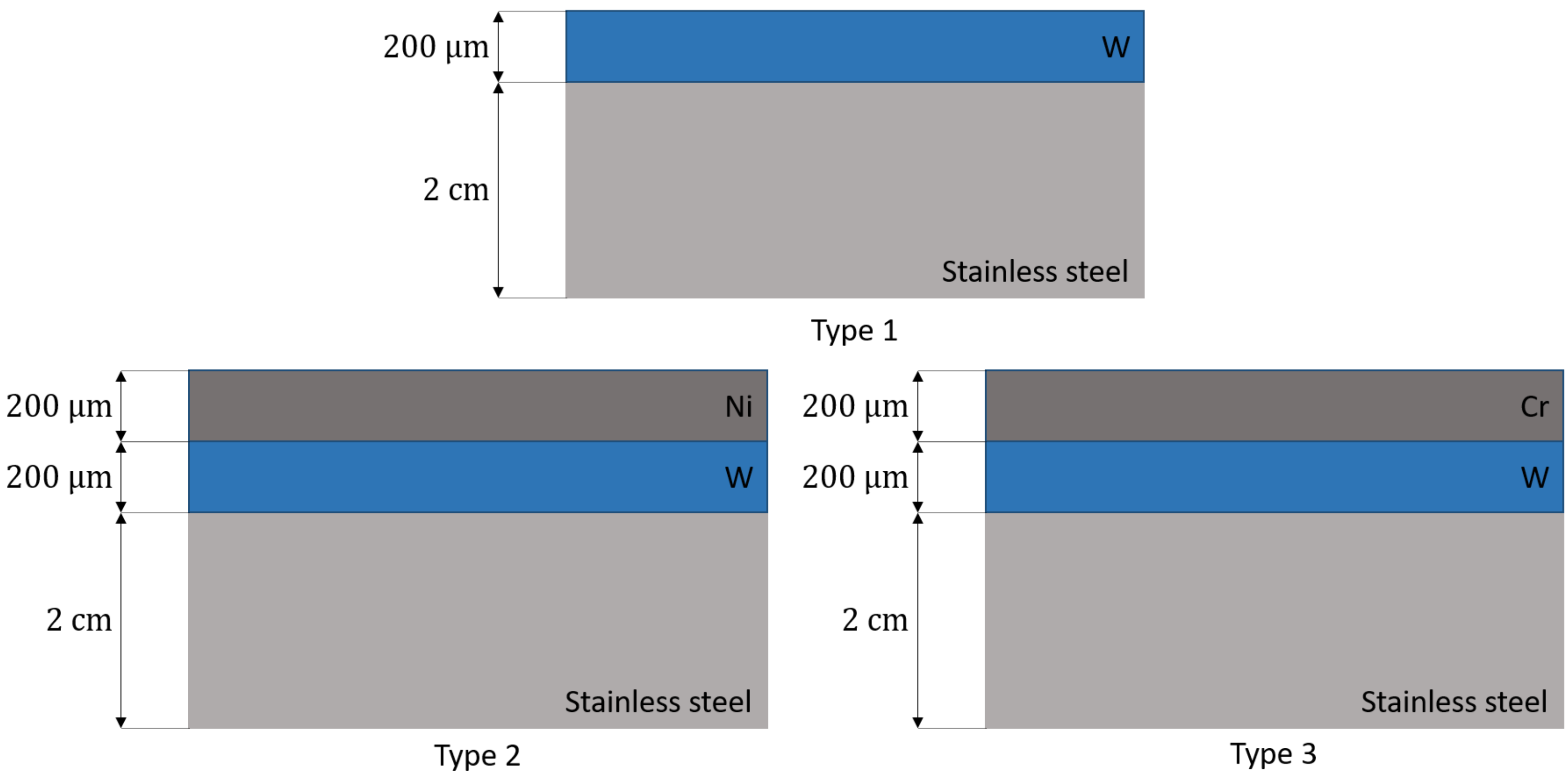


CT fueling

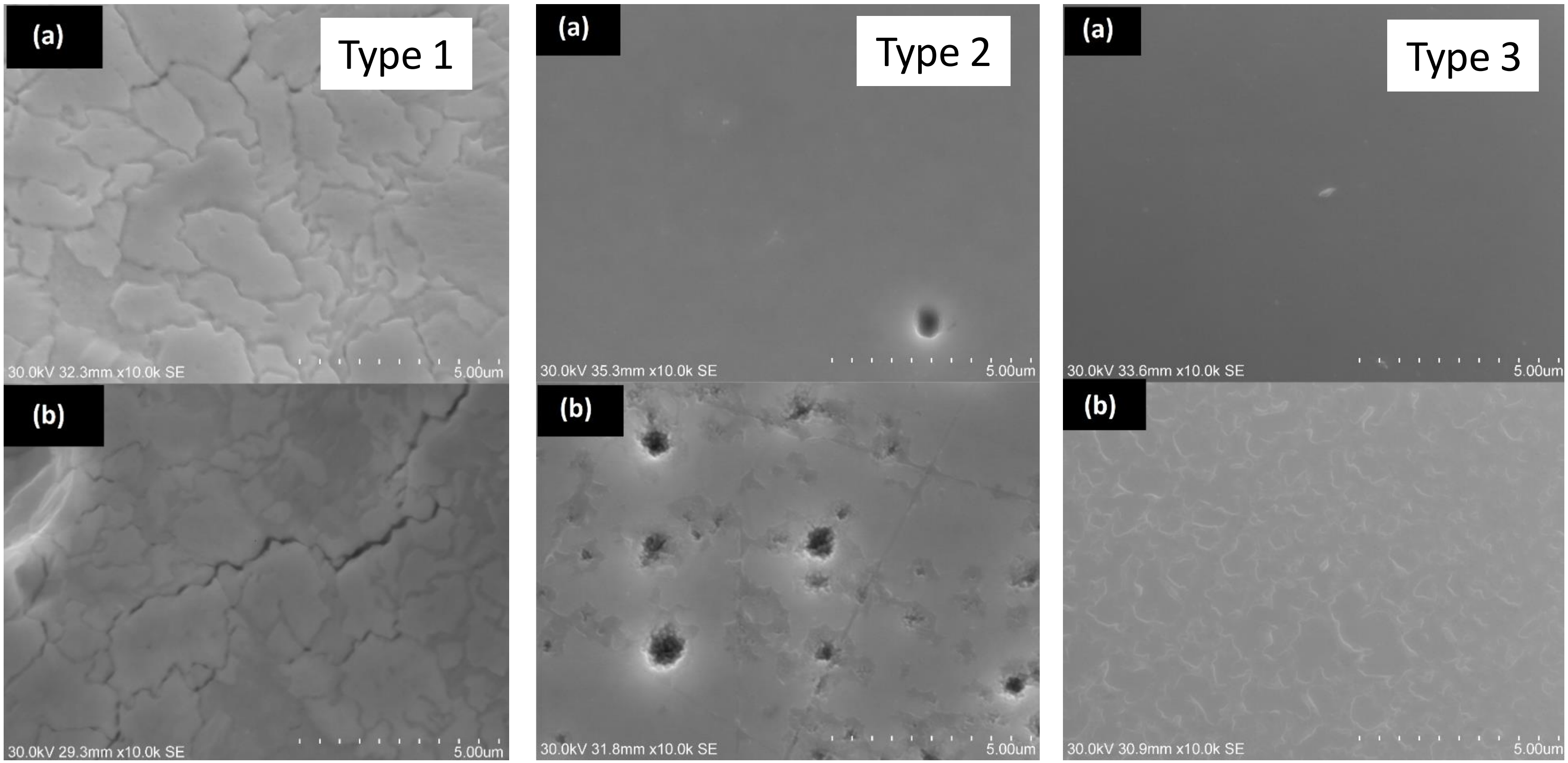
- Density Increase
- Other benefits

S. Sen, C. Xiao, A. Hirose, R.A. Cairns, PRL, **88**, 185991 (2002)

Types of Samples (provided by GF)

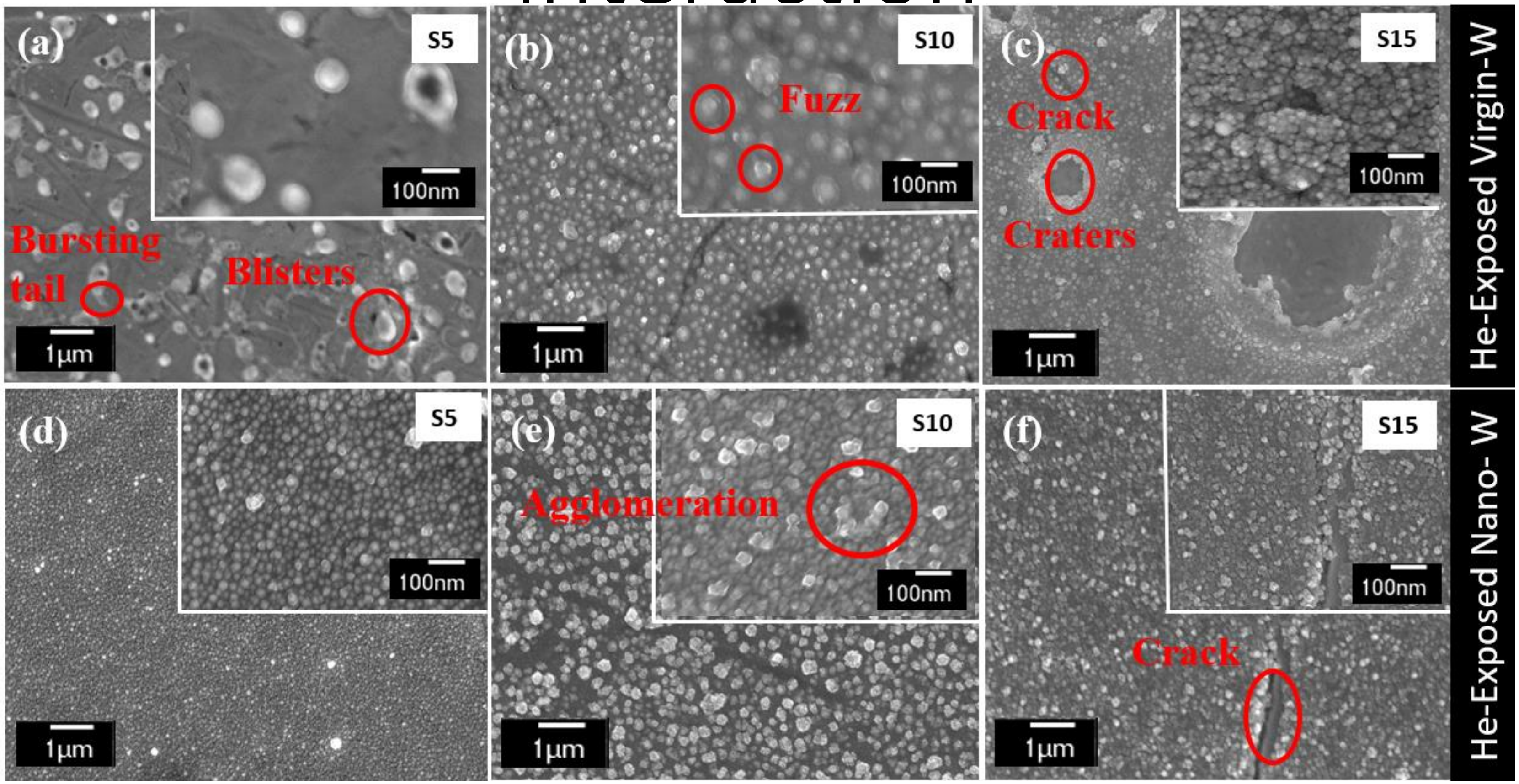


CT-Target Interaction



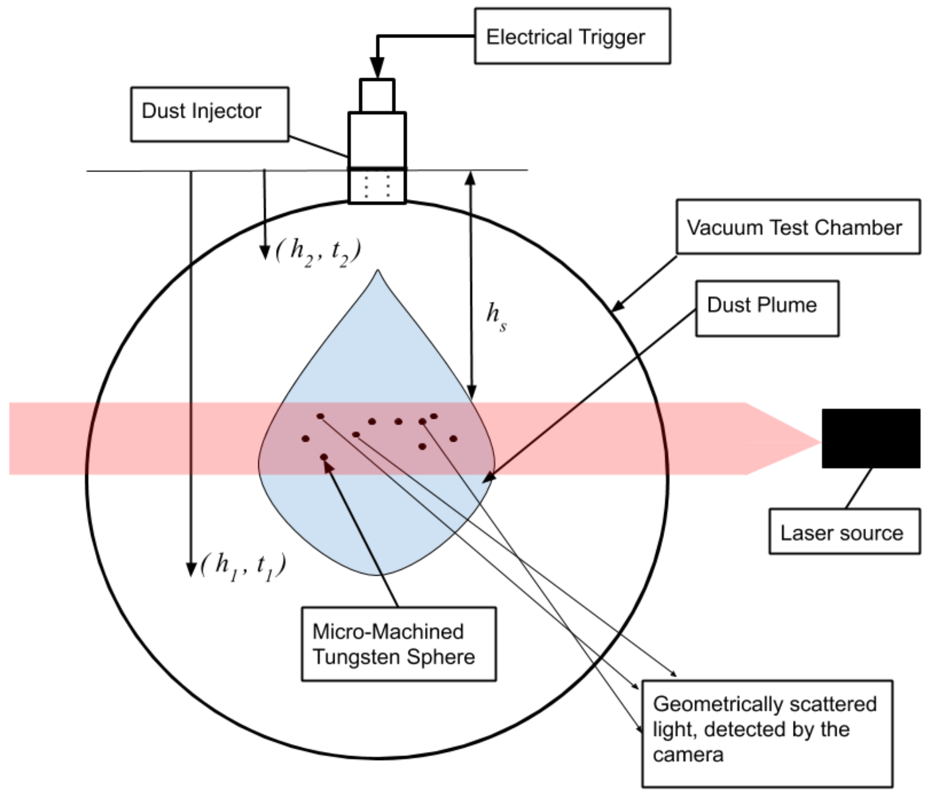
Top (a): (a) before exposure to CT plasma
Bottom: (b)after 500 CT shots

DPF (He plasma) and Target Interaction



FESEM micrographs of (a-c) Virgin-W exposed at 5, 10 and 15 He shots rand, and (d-f) Nano-W exposed at 5, 10 and 15 He shots, respectively.

The Dust Injector Characterization Experiment



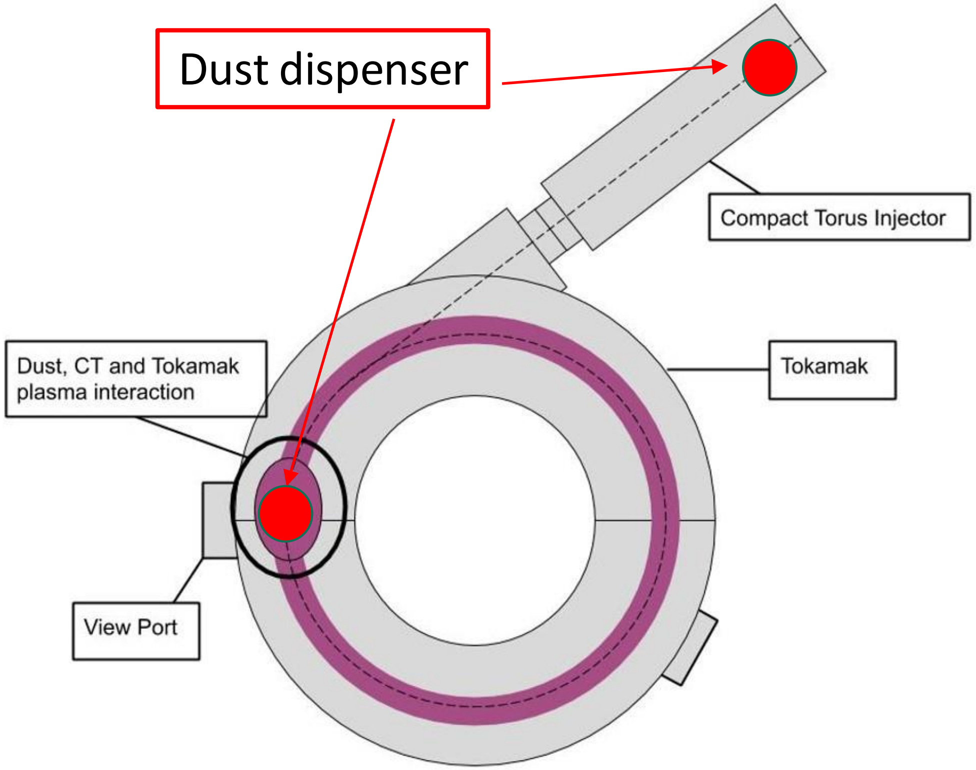
Data Acquisition Scheme for Dust Injector Calibration

Foreseen Dust Injection Experiment

Two main dust injection schemes are prepared for STOR-M:

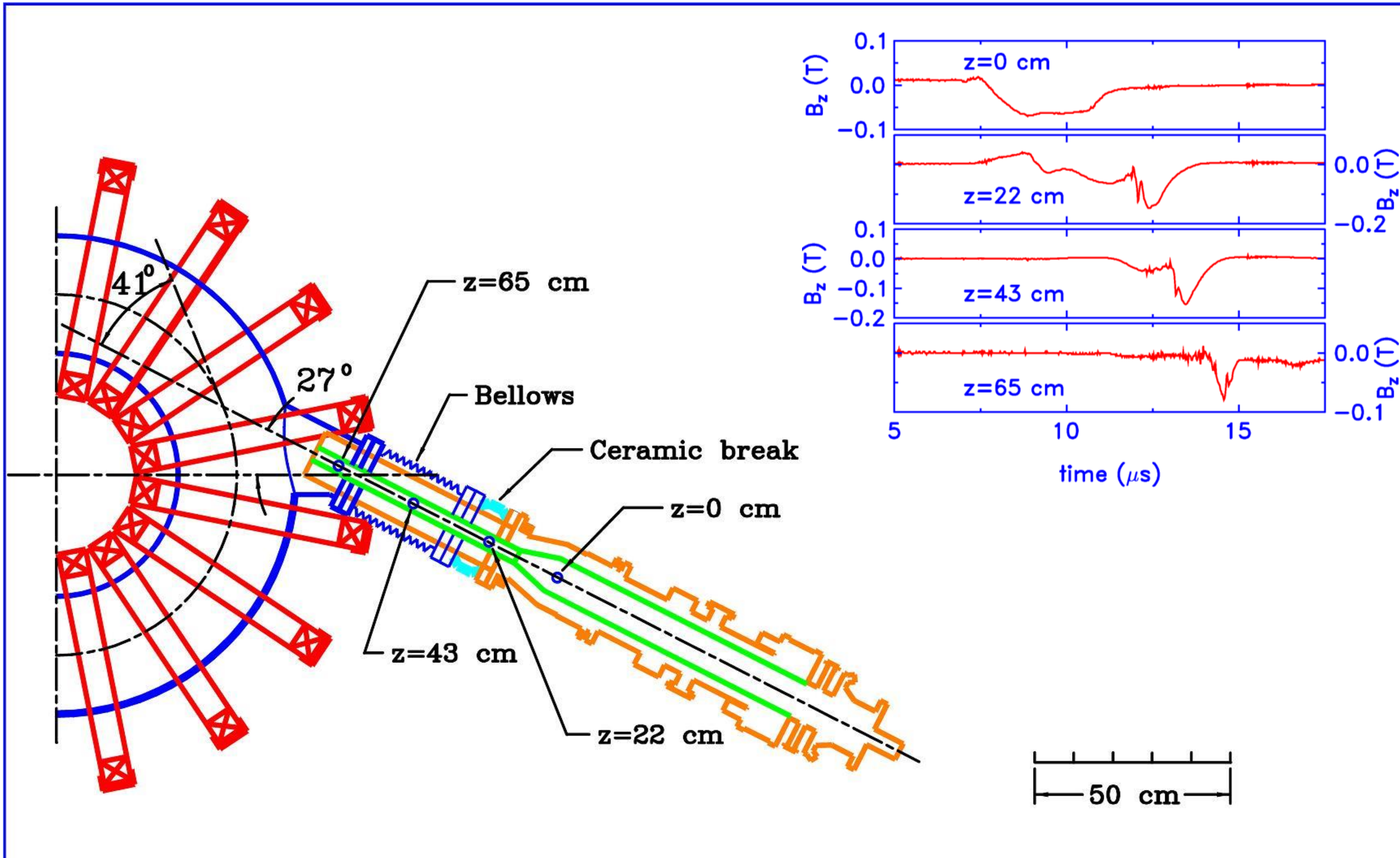
1. Directly disperse dust from a vertical port into STOR-M (edge entrance)

2. Mix dust into CT (inject dust into the plasma core directly)

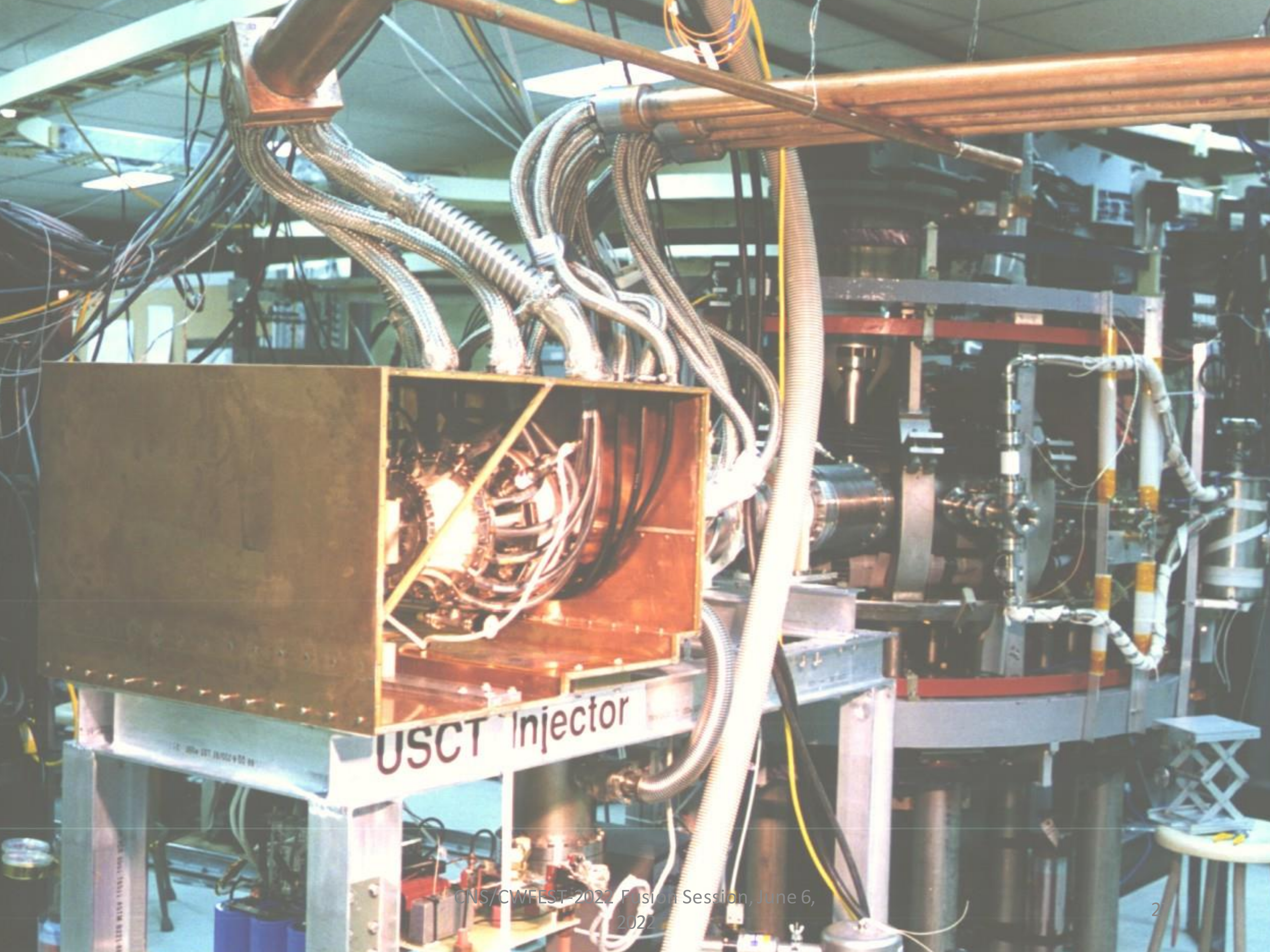


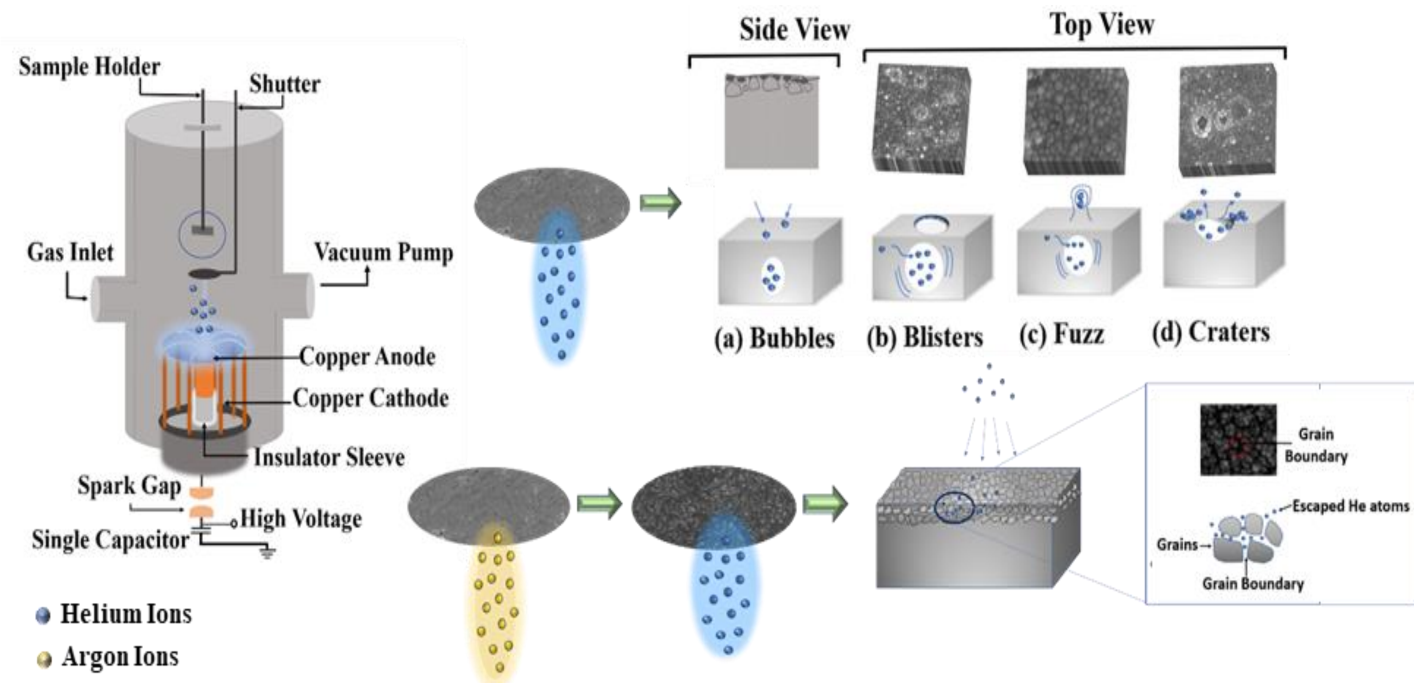
Thank You!

Spare slides



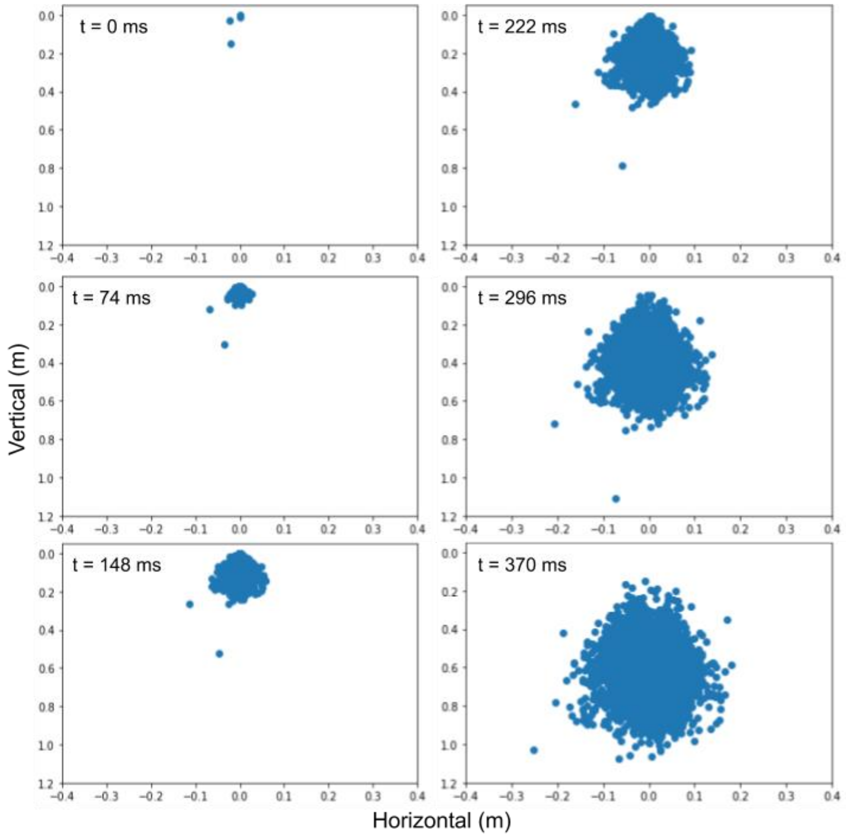
41°
27°
z=65 cm
Bellows
Ceramic break
z=0 cm
z=43 cm
z=22 cm
50 cm
z=0 cm
z=22 cm
z=43 cm
z=65 cm
B_z (T)
0.1
0.0
−0.1
−0.2
5
10
15
time (μs)


USCT Injector



Summary of the applied technique and expected outcomes after He exposure of virgin-W and synthesized nano-W

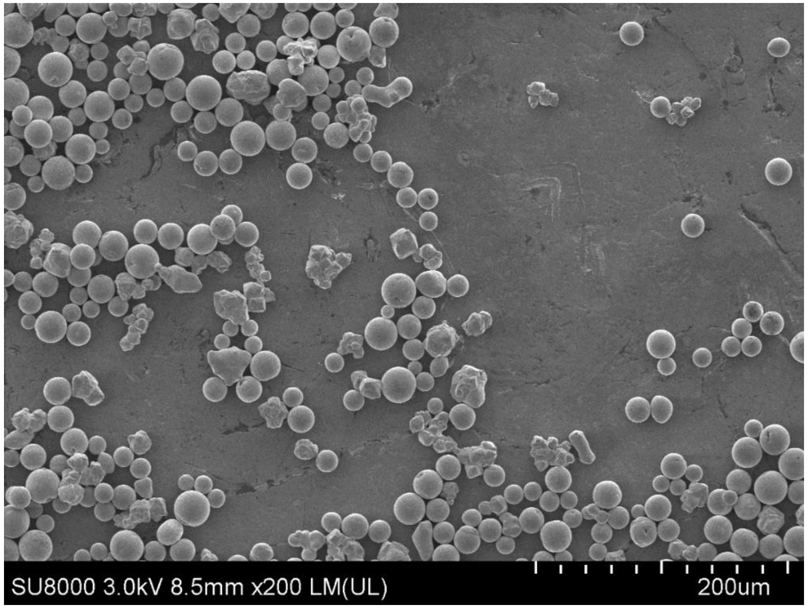
Data Analysis: Plume Dynamics



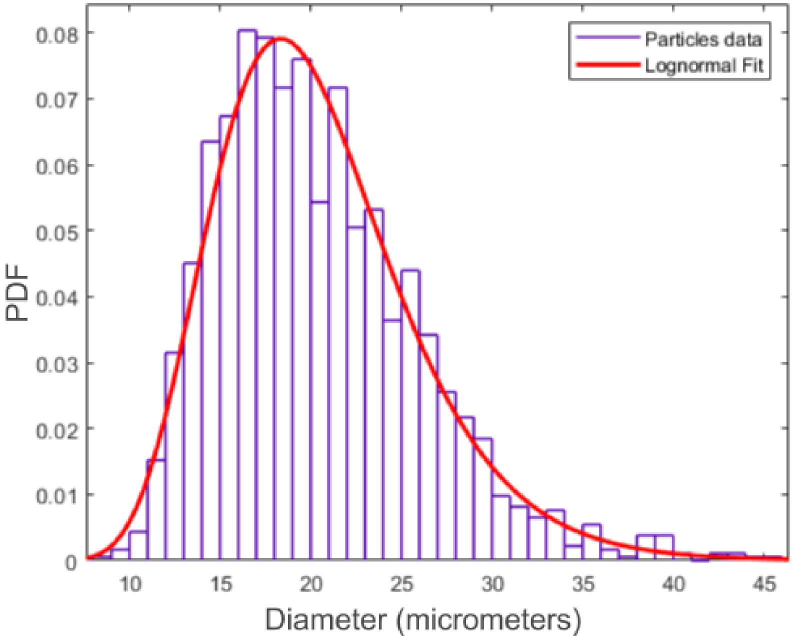
Dust Plume Evolution in Time

- Based on the velocity and time at which particles are found within the laser sheath, the particle distribution of the dust plume may be reconstructed.
- Gravity is found to be the dominant force in this reconstruction. The initial velocity of particles liberated from the injector located at (0,0) are determined using free-fall analysis.
- Knowledge of the dust plume shape and position allows for accurate placement of dust particles within a STOR-M discharge.

Tungsten Micro Powder



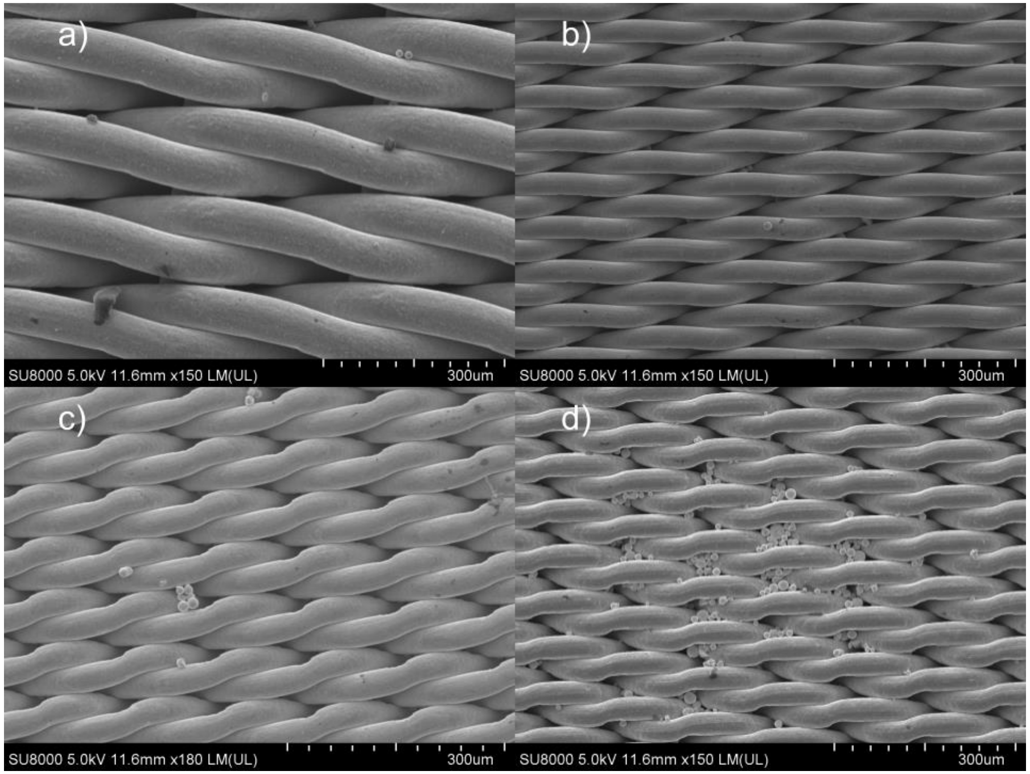
Spherical tungsten micro-powder imaged with the Hitachi SU8010, FE-SEM at the University of Saskatchewan (Produced by Tekna Plasma Systems)



Probability distribution of spherical micro-particle sizes.

Dust Injector Screens

- Effective sieve sizes of 5, 10, 14 and 25 μm's are used for dust particle filtering.
- Few particles are found to pass through smaller sieve sizes, while particles avalanche is observed for larger sieve sizes.
- Sieve size sets the size limit of particles which may pass.



Dust injector screens imaged with the Hitachi SU8010, FE-SEM at the University of Saskatchewan (After Use)