LA-UR-12-23930

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Title:	Applications of high-speed dust injection to magnetic fusion
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Intended for:	For discussion with potential collaborators, including foreign nationals.

Applications of high-speed dust injection to magnetic fusion

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August 6 , 2012

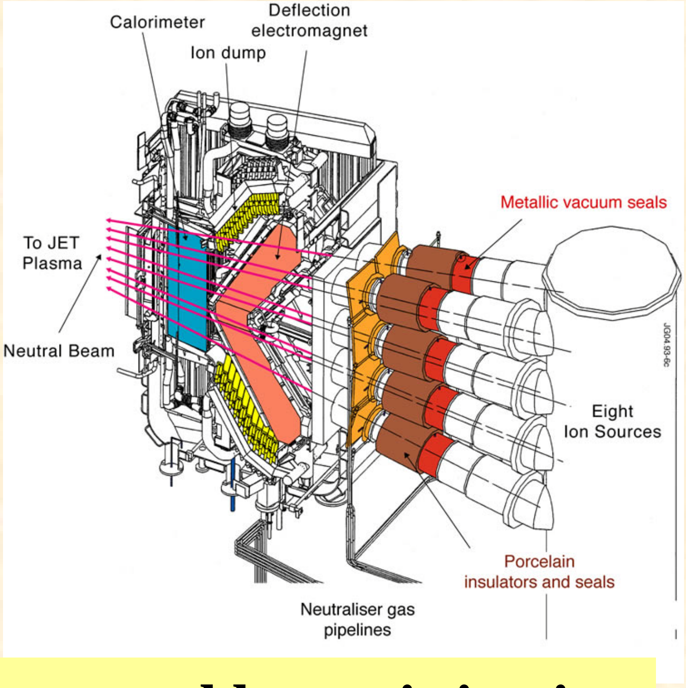
Abstract

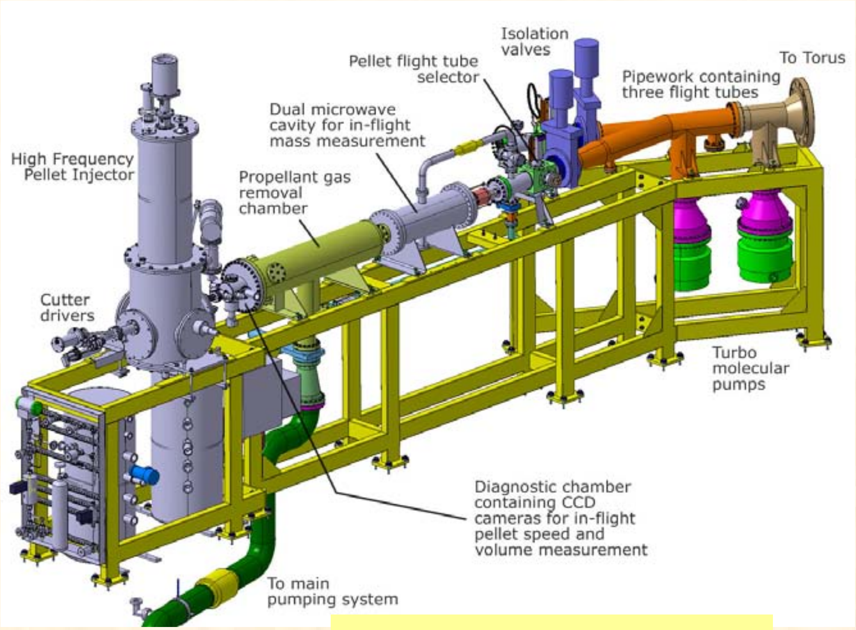
It is now an established fact that a significant amount of dust is produced in magnetic fusion devices due to plasma-wall interactions. Dust inventory must be controlled, in particular for the next-generation steady-state fusion machines like ITER, as it can pose significant safety hazards and degrade performance. Safety concerns are due to tritium retention, dust radioactivity, toxicity, and flammability. Performance concerns include high-Z impurities carried by dust to the fusion core that can reduce plasma temperature and may even induce sudden termination of the plasma. We have recognized that dust transport, dust-plasma interactions in magnetic fusion devices can be effectively studied experimentally by injection of dust with known properties into fusion plasmas. Other applications of injected dust include diagnosis of fusion plasmas and edge localized mode (ELM)'s pacing. In diagnostic applications, dust can be regarded as a source of transient neutrals before complete ionization. ELM's pacing is a promising scheme to prevent disruptions and type I ELM's that can cause catastrophic damage to fusion machines. Different implementation schemes are available depending on applications of dust injection. One of the simplest dust injection schemes is through gravitational acceleration of dust in vacuum. Experiments at Los Alamos and Princeton will be described, both of which use piezoelectric shakers to deliver dust to plasma. In Princeton experiments, spherical particles (40 micron) have been dropped in a systematic and reproducible manner using a computer-controlled piezoelectric bending actuator operating at an acoustic (0,2) resonance. The circular actuator was constructed with a 2.5 mm diameter central hole. At resonance (~ 2 kHz) an applied sinusoidal voltage has been used to control the flux of particles exiting the hole. A simple screw throttle located ~1mm above the hole has been used to set the magnitude of the flux achieved for a given voltage. Particle fluxes ranging from a few tens of particle per second up to thousands of particles per second have been achieved using this simple device. To achieve higher dust injection speed, another key consideration is how to accelerate dust at controlled amount. In addition to gravity, other possible acceleration mechanisms include electrostatic, electromagnetic, gas-dragged, plasma-dragged, and laser-ablation-based acceleration. Features and limitations of the different acceleration methods will be discussed. We will also describe laboratory experiments on dust acceleration.

Outline

- **Applications of dust injection in magnetic fusion**
- **Examples of recent laboratory progress**
  - Acceleration of dust to hypervelocities
  - Study of dust in flowing plasmas
- **What's next?**

Matter injection is used to magnetic fusion & diagnostics in different ways





neutral beam injection

pellet injection

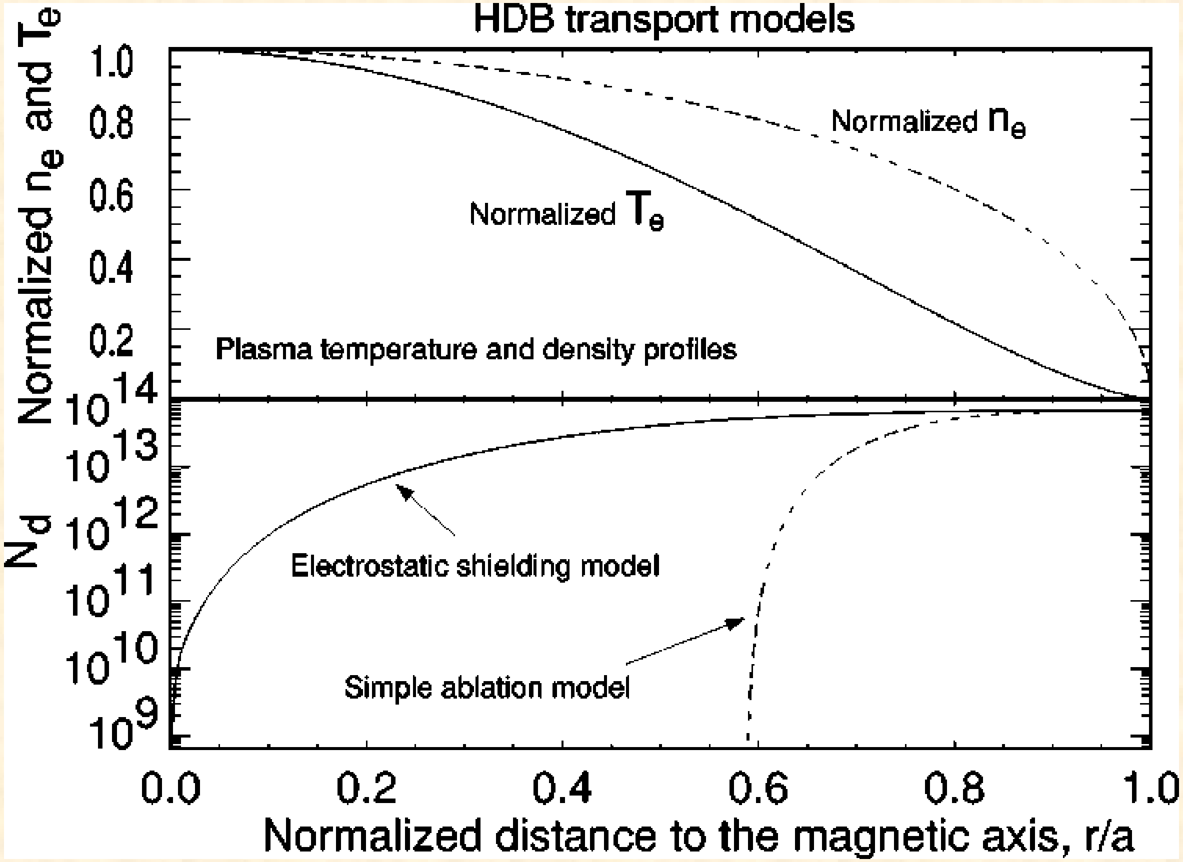
There are plenty of rooms in-between

Dust injection

0.001 0.01 1 100 ~ 500 1000

Size (μm)

Necessity of hypervelocity dust for fusion plasmas



Li 7 μm, 2 km/s,Te ~ 200 eV, 10^{14} /cc

Wang & Wurden, RSI **74** (2003) 1887

A brief summary of ELM's

- ELM is an periodic instability related to breakdown of H-mode edge transport barrier (pressure limit).
  - Many types: Type I, II, III, IV, V,...
- ELMs appear as filaments, release particle and energy
- ELM related power load on diverter grows with machine size ⇨ ITER worse than existing machines.
- Type I ELMs (≥ 5 - 10 MJ/m^2) should be avoided.

Pellet injector for ELM pacing

- Lang *et al*. (2007) for ASDEX-U H-mode.

♦ Quasi-continuous operation.

♦ Minimizing ‘un-desired’ fuelling effect.

☛ Small, slow pellets resulting in shallow particle deposition causing little fuelling.

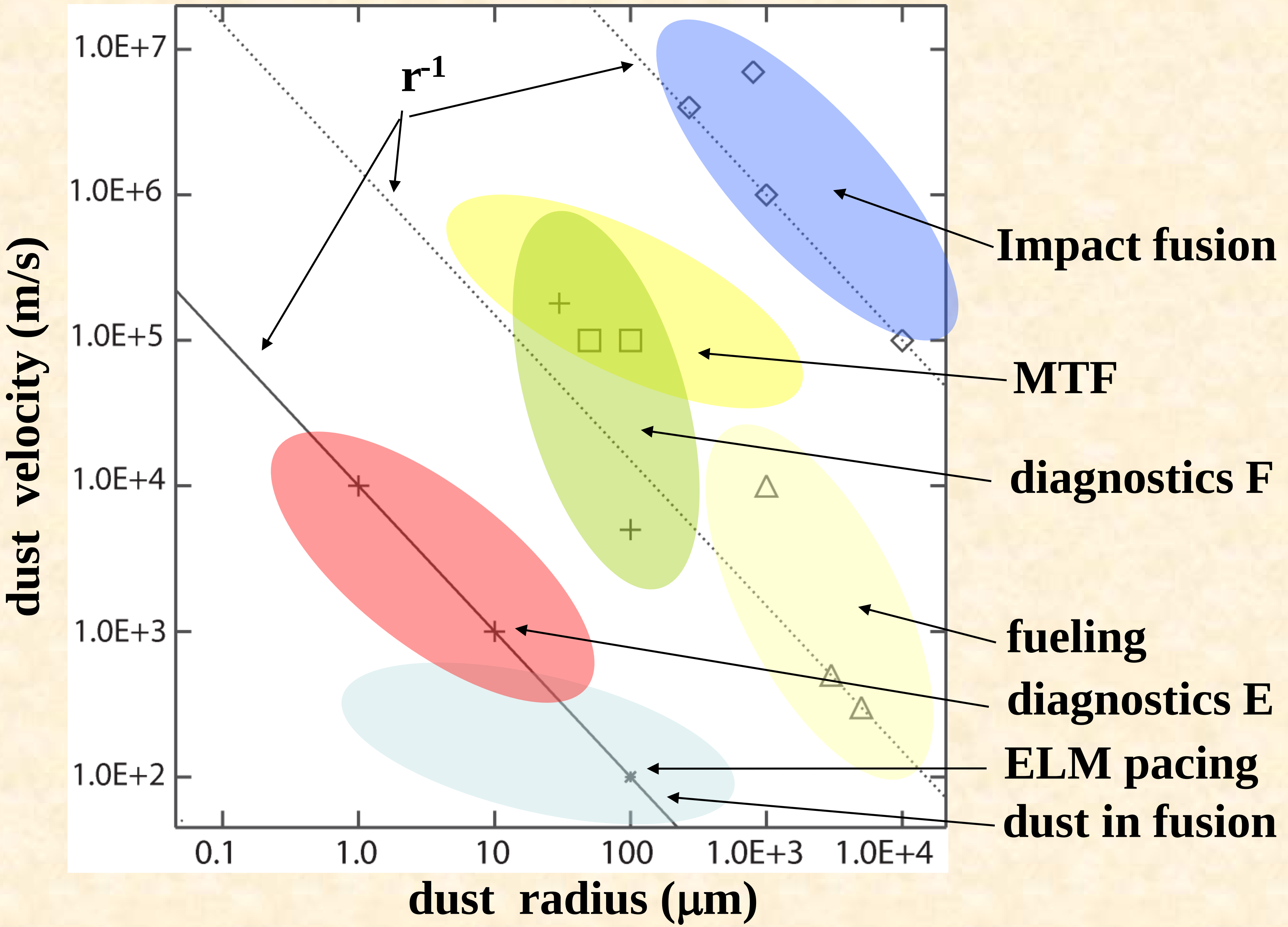
- Different from the standard pellet injector for fueling:
  - High rep. rate ≤ 143 Hz
  - ‘Small pellet’ sizes, 200 -300 μm, icy D-‘dust’
  - Small pellet velocities 200 m/s (can not be lower than this)
  - Icy pellet sublimation → initial size ~ 2 mm
  - Pressurized gas as accelerating medium
  - 10 ms delivery time.

Dust injector for ELM pacing

- Electrostatic dust injection
  - Particles of different sizes (sub-μm to hundereds of μm)
  - Electrostatic acceleration. Easier to achieve ‘low’ velocities (≤ 1 km/s) than high (> 10 km/s) velocities.
  - Both continuous and pulsed operations are possible (not limited to ~150 Hz rate) by tuning the acceleration voltage.
- Main advantages: Mechanical/pneumatical systems replaced by a purely electrical system (faster time response, flexibility in control, no additional gas injection needed.)

Z. Wang *et al*, AIP Proc. **1041** (2008) 135

A summary of dust-injection applications



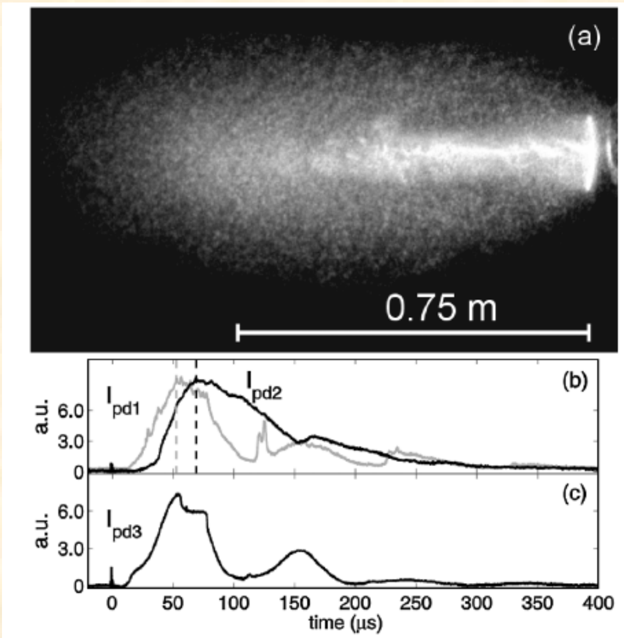
Outline

- Applications of dust injection

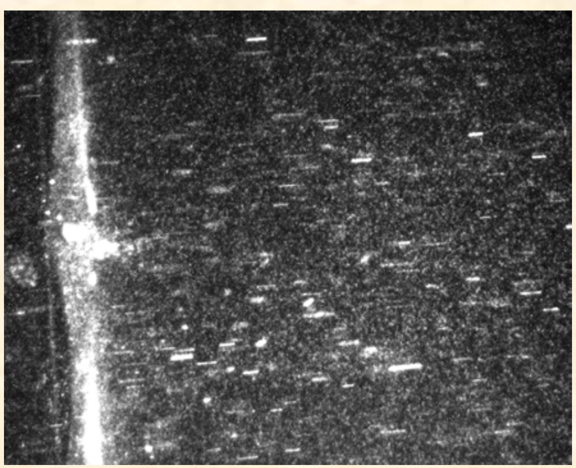
- **Examples of recent laboratory experiments**
  - Acceleration of dust to hypervelocities
  - Study of dust in flowing plasmas

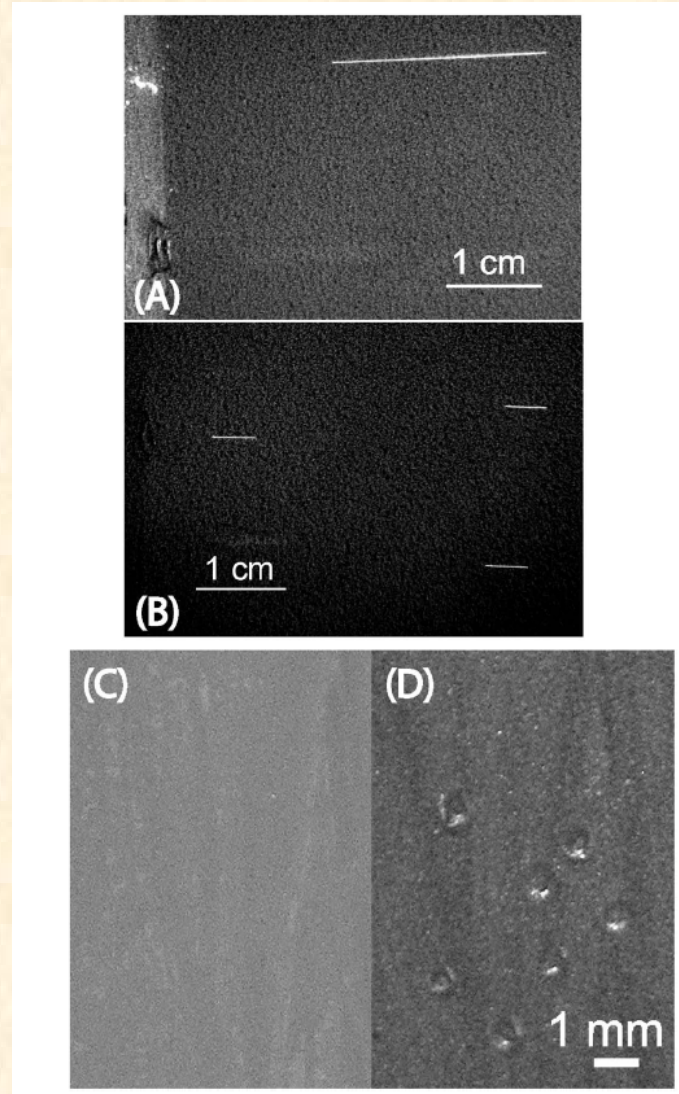
- What's next?

Dust acceleration to km/s



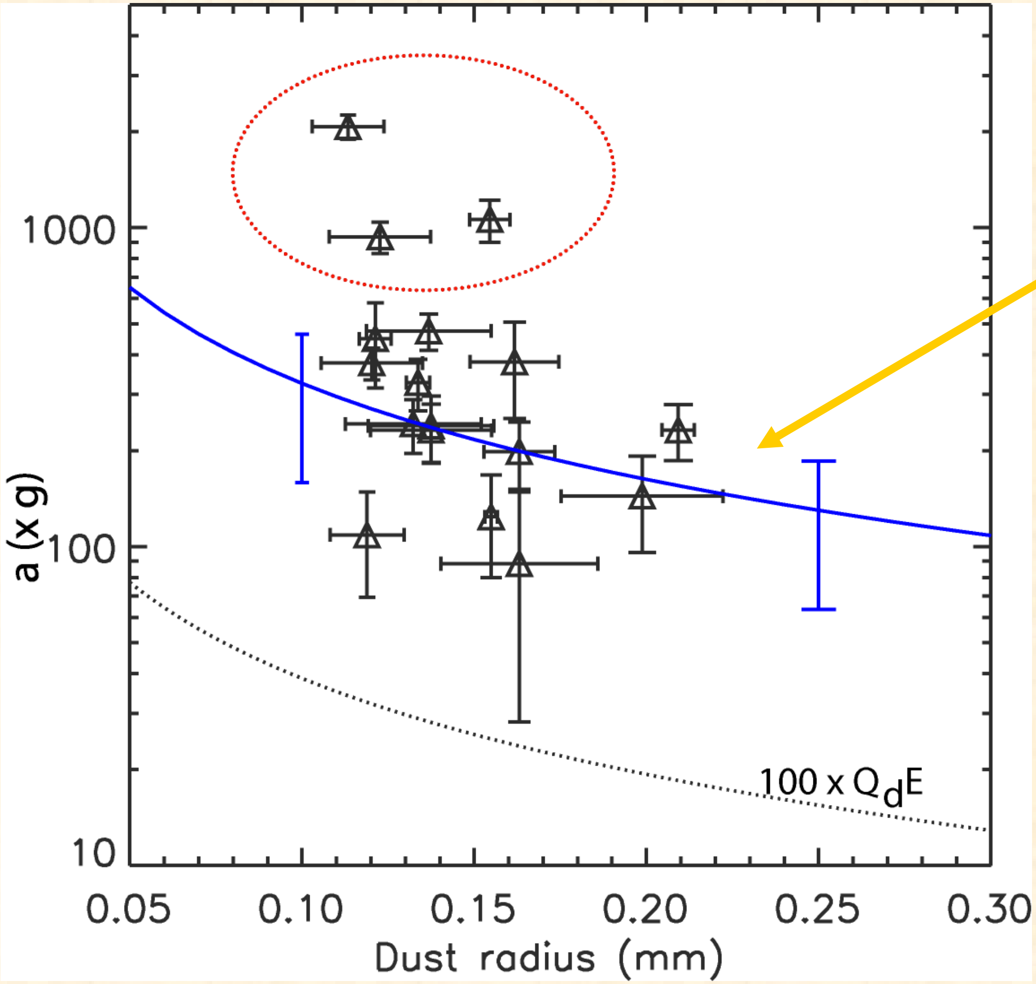
C. Ticos *et al*, PRL **100** (2008) 155002





Z. Wang *et al*, PoP **14** (2007) 103701

Laboratory measurement of forces on dust

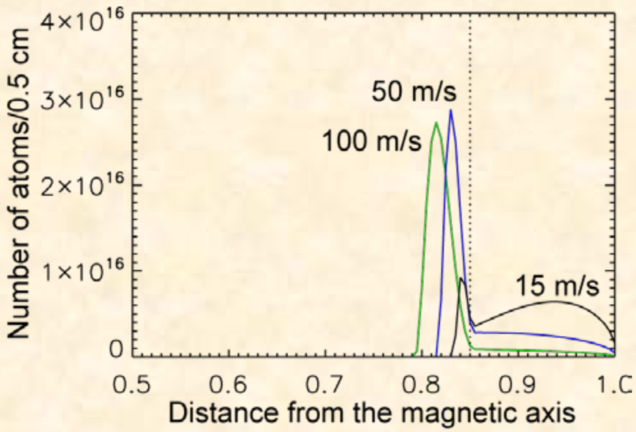


$$\mathbf{F}_{pf} = 2\pi r_d^2 k_B T_i n_i \xi \mathbf{w}$$

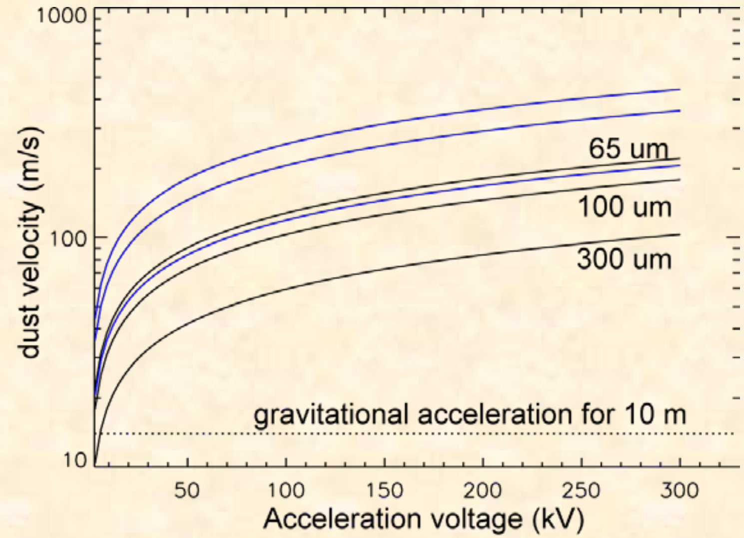
- other forces are small

Z. Wang *et al*, PoP **14** (2007) 103701

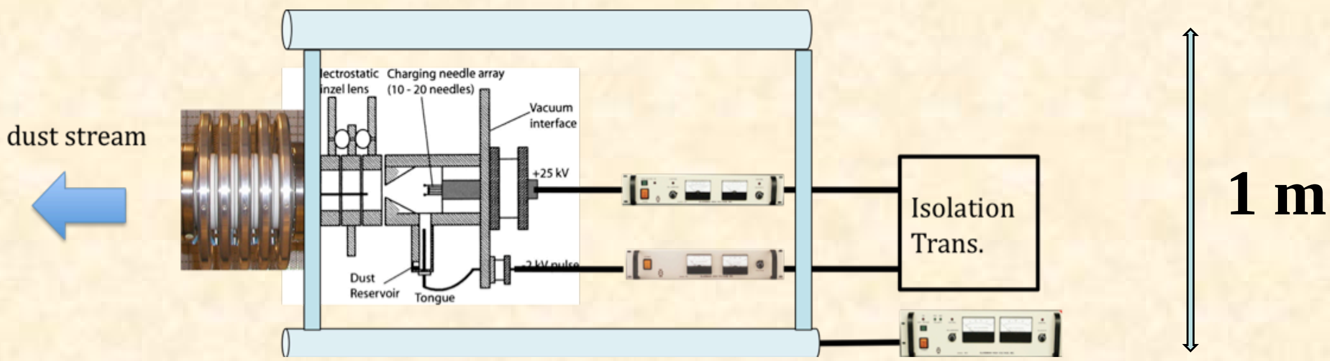
What's next? -- compact electrostatic injector



Dust-induced ELM's



Required injector performance



Experimental approach