MICRO-PARTICLE PROBES FOR LABORATORY PLASMAS

Zhehui (Jeff) Wang

Plasma Physics Group, P-24
Los Alamos National Laboratory

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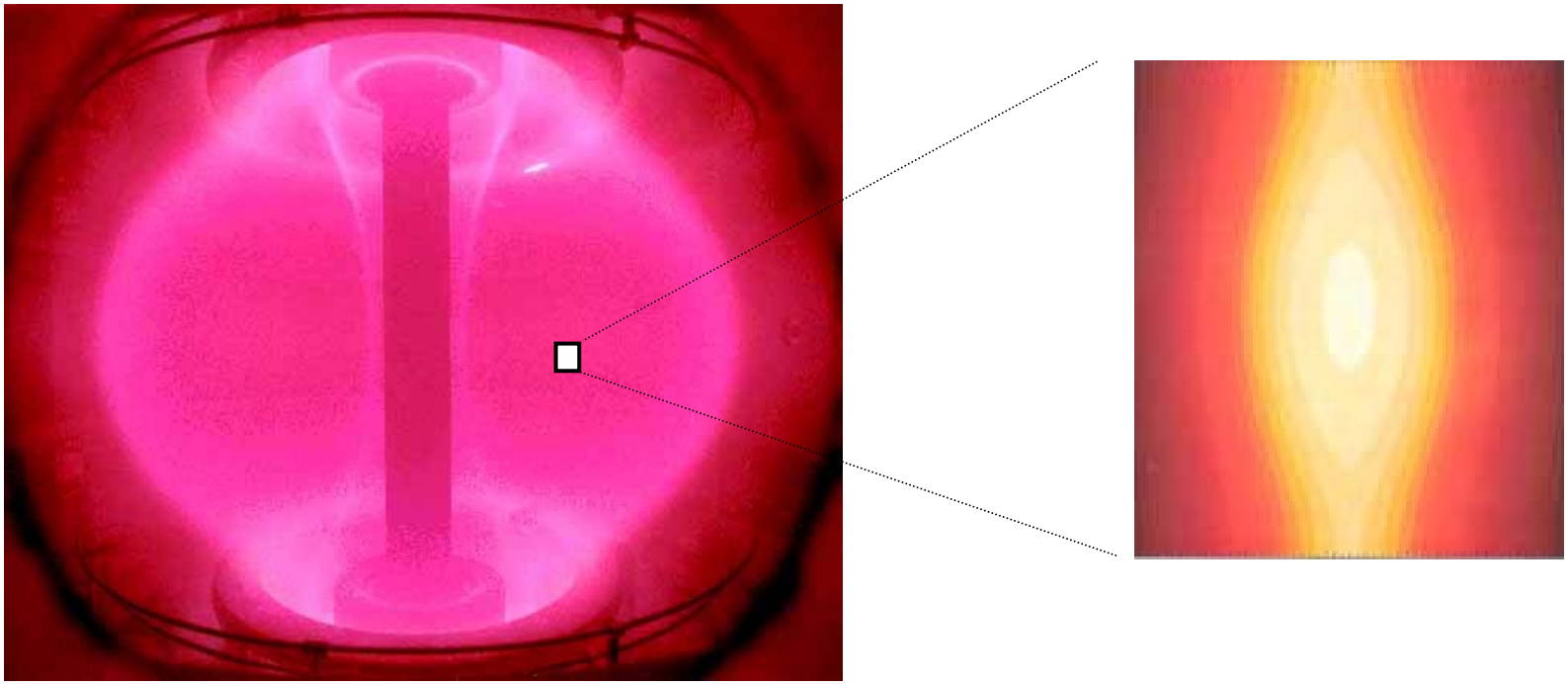
Collaborators: Leonid Dorf, Jiahe Si,
Catalin M. Ticos, and Glen A. Wurden

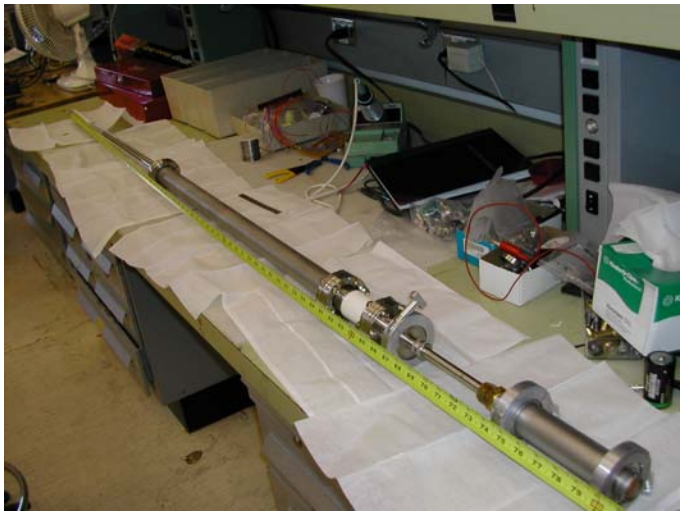
A plasma is a hostile environment for diagnostics/measurement



- Complex magnetic structures are common – magnetic island formation
- Measurement of magnetic structures is important to understand transport and confinement
- High temperature plasmas are tough to probe (T ~ 1 million degree)

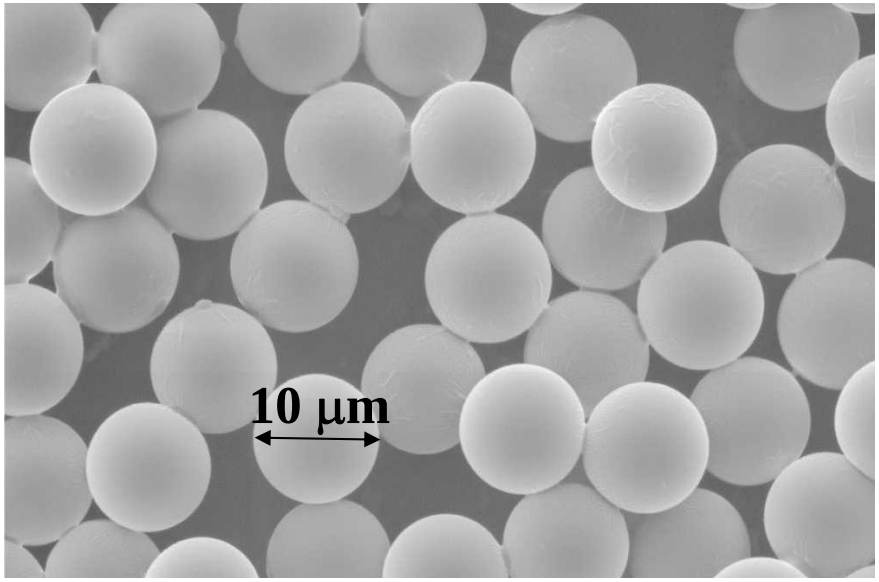
Probes are the oldest diagnostics of plasmas

- First probes were used by Langmuir
  → "Langmuir probes"
- Useful to measure a variety of plasma parameters
  - electron density
  - Temperature
  - Velocity
  - Magnetic field
- Features of probes
  - Simple to make, inexpensive
  - Challenges for probes
    - Uncertainty in theory – assumptions
    - Unknown surface conditions
    - Shaft
    - Arcing—secondary plasmas

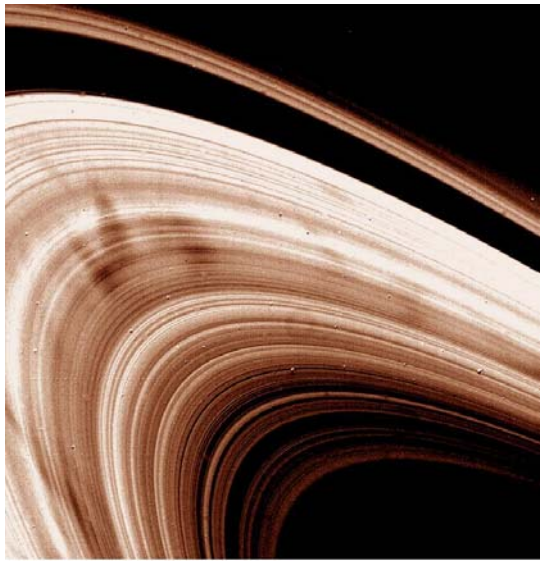


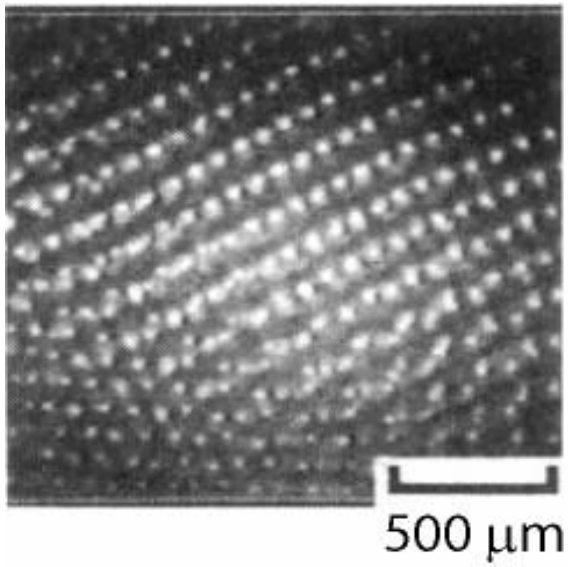
Microparticles can be ideal probes

- Features of microparticles
  - Simple to "make", inexpensive
  - no probe shaft
  - Large varieties & choices
    - Material type and properties
    - Geometry, size
  - Challenges – new & untested
    - ➢Use for what?
    - ➢Uncertainty in theory -- assumptions
    - ➢detection



Microparticles are universal





Outline

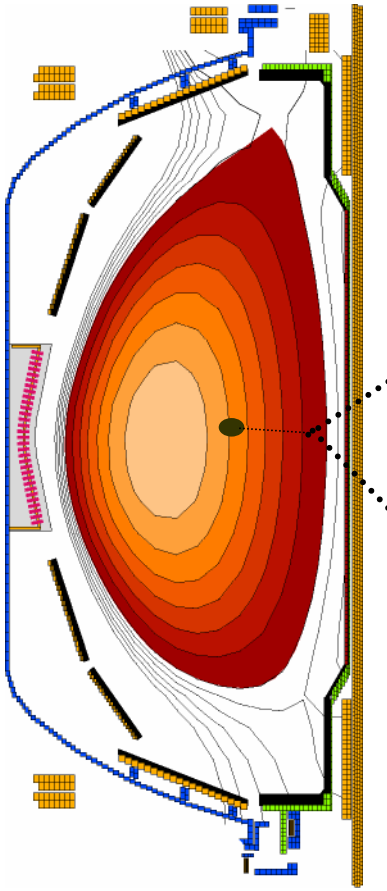
- Introduction
- **Probing of internal magnetic field in high temperature plasmas**
  - Dust-plasma interaction physics
  - Internal magnetic field mapping
  - Plasma acceleration scheme
- **Probing of plasma flows in low temperature plasmas ---microparticle tracer velocimetry (mPTV)**
    - mPTV principles
    - mPTV characteristics
- **Summary and conclusions**

Application I.

Hypervelocity microparticles for internal magnetic field visualization

(HDI = Hypervelocity Dust Injection)

HDI is essentially an imaging diagnostic for internal magnetic field and structures



Generic features of an HDI

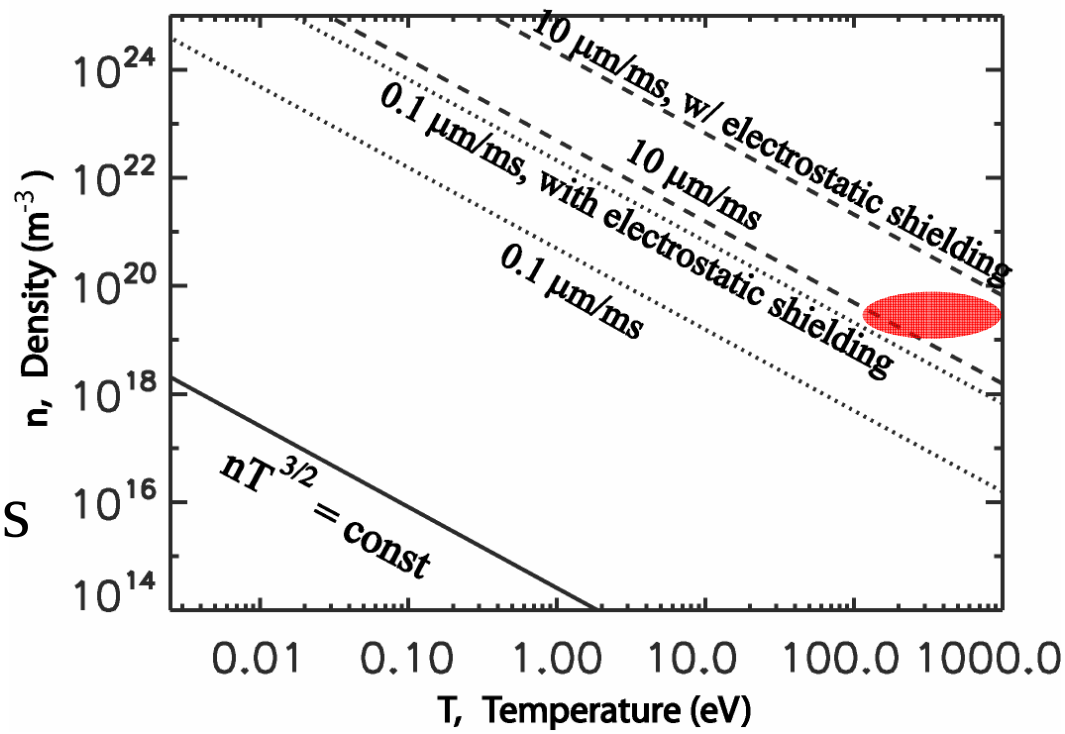
- Simultaneous injection of tens to thousands of microparticles (< 25 μm in radius)
  - Two-D and three-D imaging of multiple magnetic field vectors
  - May be used for internal fueling
- Number of particles in $N_d = 10^{11} - 10^{16}$ per microparticle
  - non invasive /local density perturbation
  - sufficient photons for detection with μs time resolution
- Velocity of each microparticle, U_d = 1 - 10 km/s
  - determined by microparticle-plasma interaction physics
  - uses demonstrated acceleration technology
- Unaffected by magnetic field
  - small charge-to-mass ratio
  - simple operation (no neutralization cell)

Destruction of μ-particles due to heating

- Electron heating is the primary heating

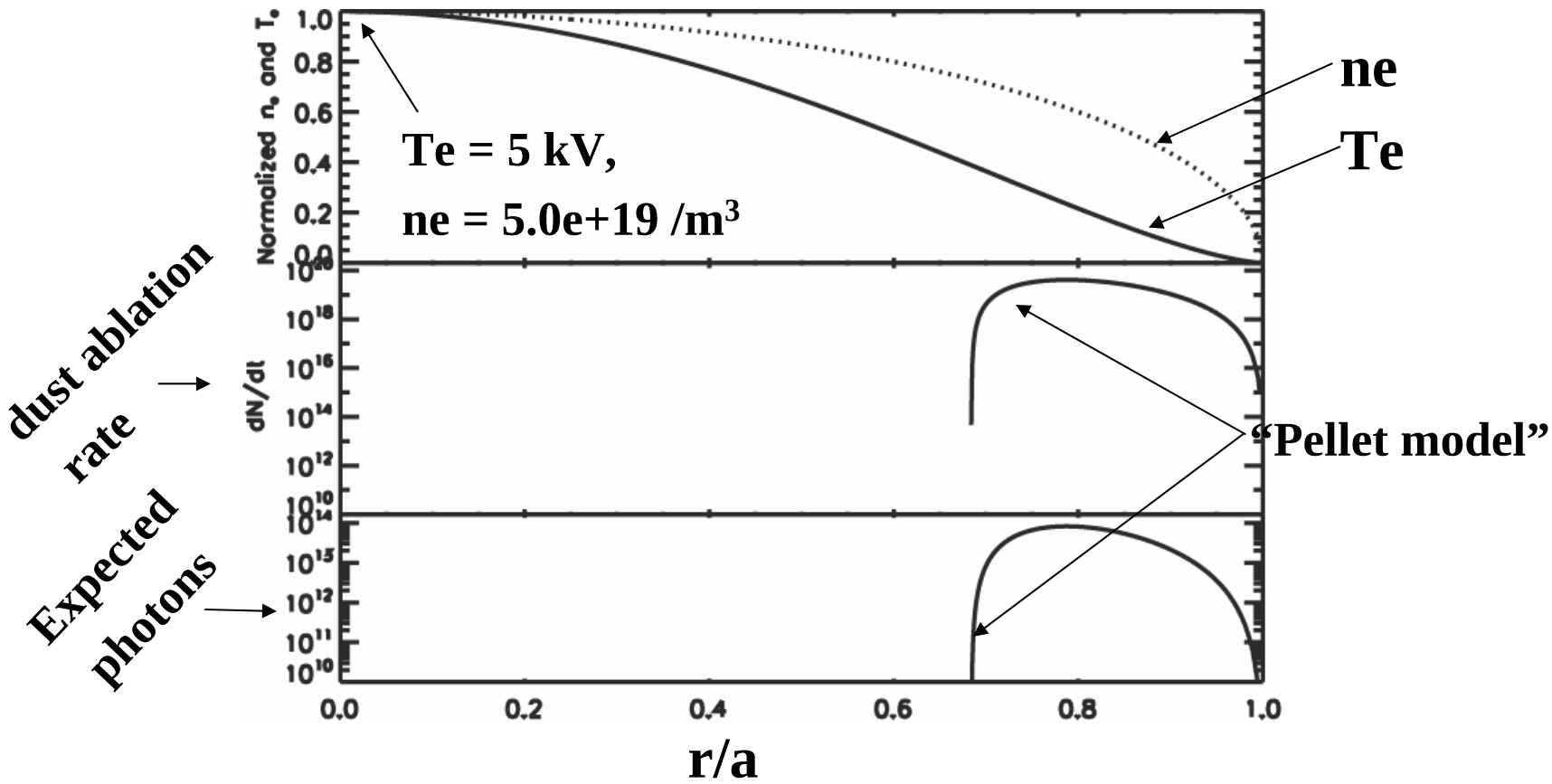
$$\frac{dR_{gr}}{dt} = \frac{q_\infty f_{el.}}{E_0 n_{gr}}$$

- Electrostatic shielding can protect microparticles



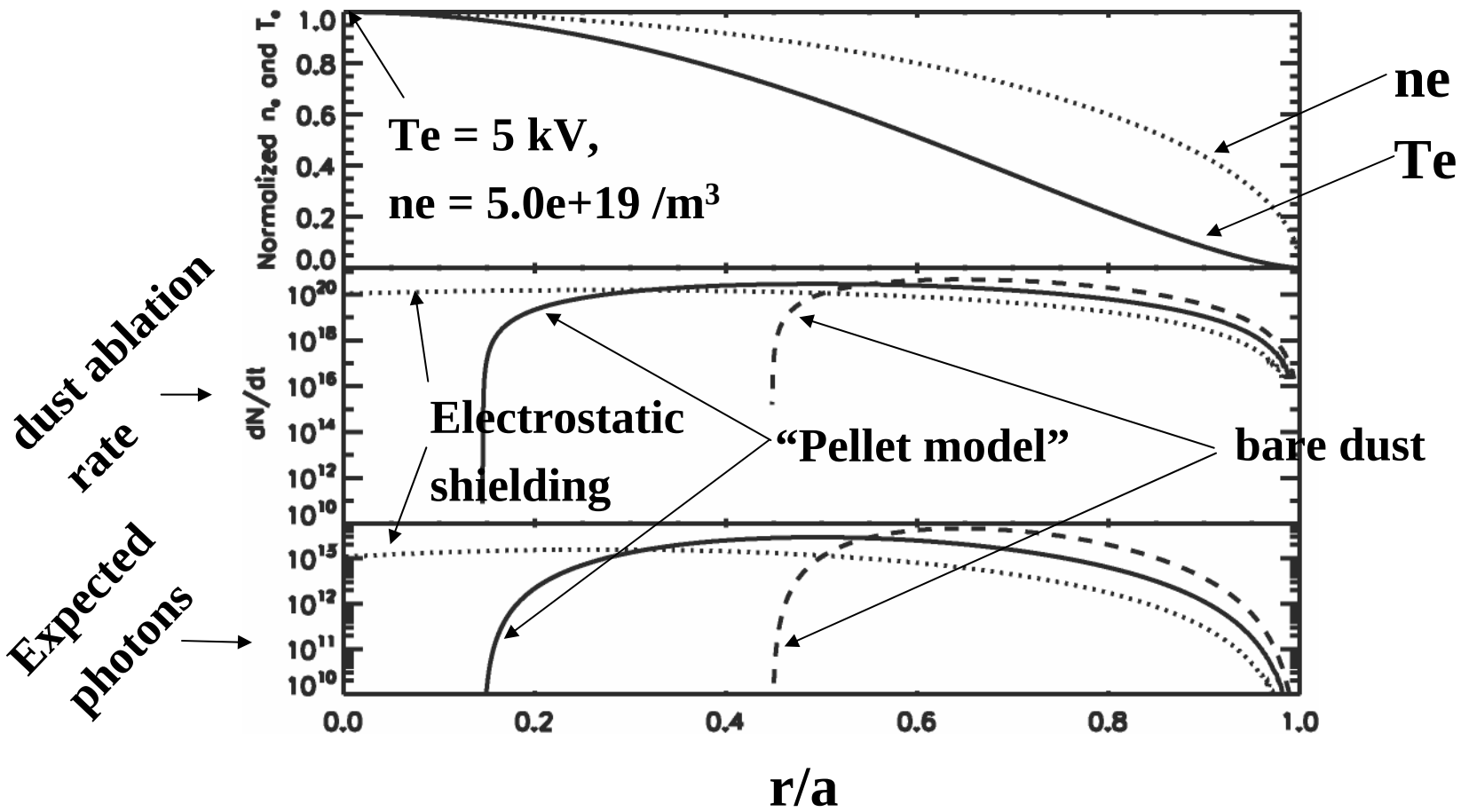
(1 eV ~ 12000 °k)

Hypervelocity is needed to probe *B* in high temperature regions of NSTX plasmas



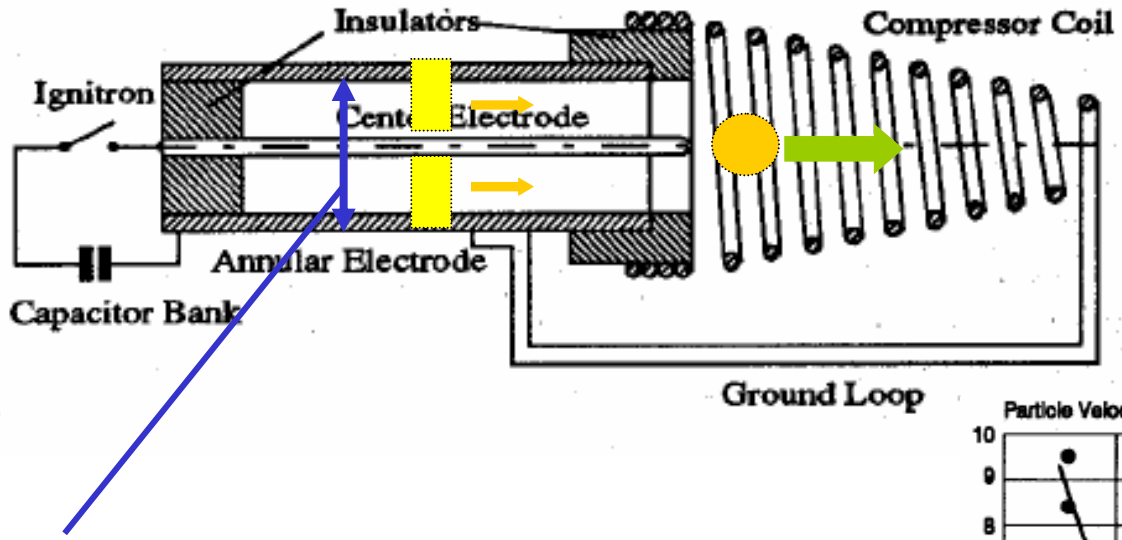
Carbon dust, 25 μm, 0.5 km/s

Three models for HD deposition on in high temperature regions of NSTX plasmas

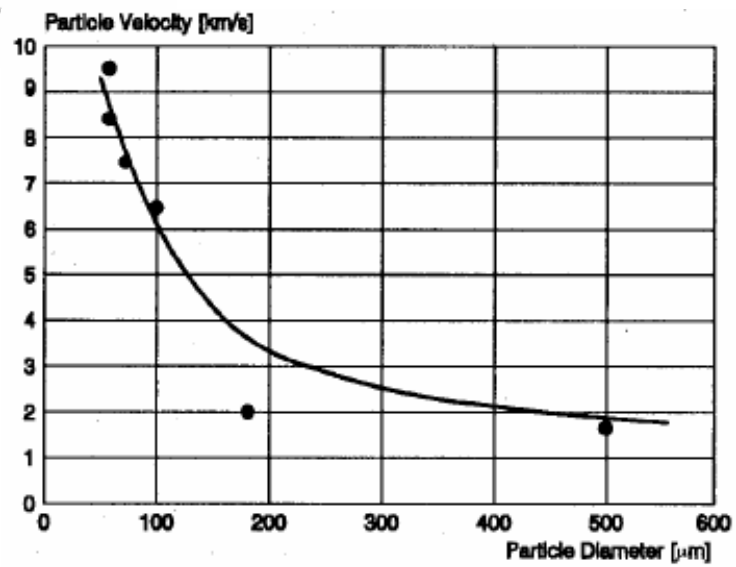


Carbon dust, 25 μm, 10 km/s

Concept of the plasma accelerator



6 cm



From P. Thomas, E. Igenbergs, H. Tamura, A. B. Sawaoka, *IEEE Trans. Mag.* **29**, 609 (1993).

Detection of dust plumes

- Assumptions
  - Optically thin plasma
  - Unpolarized light of plume
- Photon flux associated with plume, 10^{14} -10^{15} s^{-1}
  - 1μs duration ~ 10^8-10^9 photons
  - Bremstraalung background < 1 photons expected for 1 μs, 1 cm^3 volume, 1 nm filter at the expected photon wavelength.
- Apparatus efficiency ~1 x 10^{-5} (collecting solid angle, transmission of optics, detector quantum yield)
- Total number of photo-electrons within the detector view
  - 10^3 to 10^4 .

  (plenty for intensified CCD cameras)

Summary of parameters of HDI for NSTX

- **Dust selection**
  - size, 1 - 25 μm in radius
  - type, C, LiD, plastic (*C*, *H*)
  - launch velocity, 1-10 km/s
  - acceleration rate, 10 - 1000/ pulse
- **Accelerator and Pulsed power**
  - Deuterium gas as medium
  - Accelerator channel length ~ 1 m
  - total energy ~ 100 kJ, pulse length ~ 200 μs
  - duty cycle ~ 5 min.
- **Dust detection system**
  - 10 mW photodiode lasers + PMT's for dust velocity and number
  - Intensified DiCAM Pro camera for plume imaging (single photo-electron capability), ns time resolution, two-frames per shot

Application II.

Microparticles as plasma flow tracers

(mPTV=microParticle Tracer Velocimetry)

Flow measurement is critical to understanding of many fundamental phenomena

- Couette flow → *Magneto-Rotational Instability*.
- Non-axisymmetric flows → *dynamo action* according to Cowling's antidynamo theorem. The dynamo problem is a classical and the most famous problem in MHD
- Double-Alfvenic-jet flows are expected from *magnetic reconnection*, which converts magnetic energy to kinetic energy
- Flow is required for *magnetic helicity transport*. Magnetic helicity is known to be conserved when ion flows are neglected (Taylor relaxation)

Ion drag is the basis for mPTV

- Electrostatic and Lorentz force
- Temperature gradient
- Neutral particle drag
- Ion drag = momentum transfer between plasma and microparticles
- Electromagnetic radiation
- gravity

Damage to μ-particles due to heating is small for mPTV

- Electron heating is the primary heating

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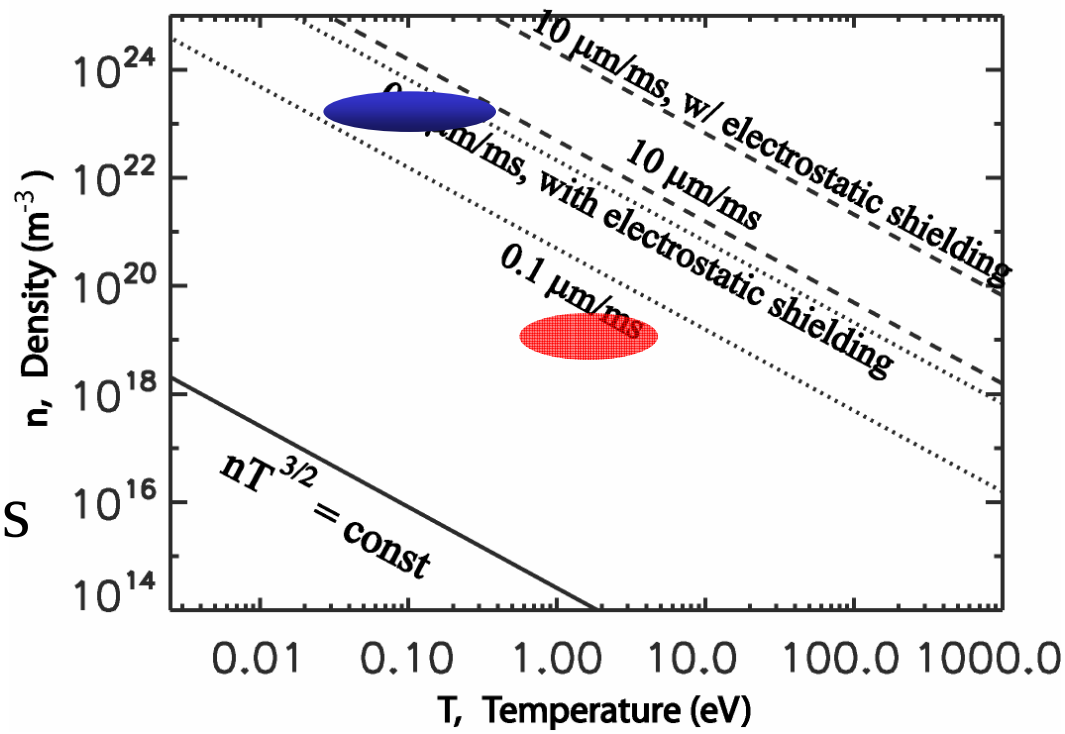
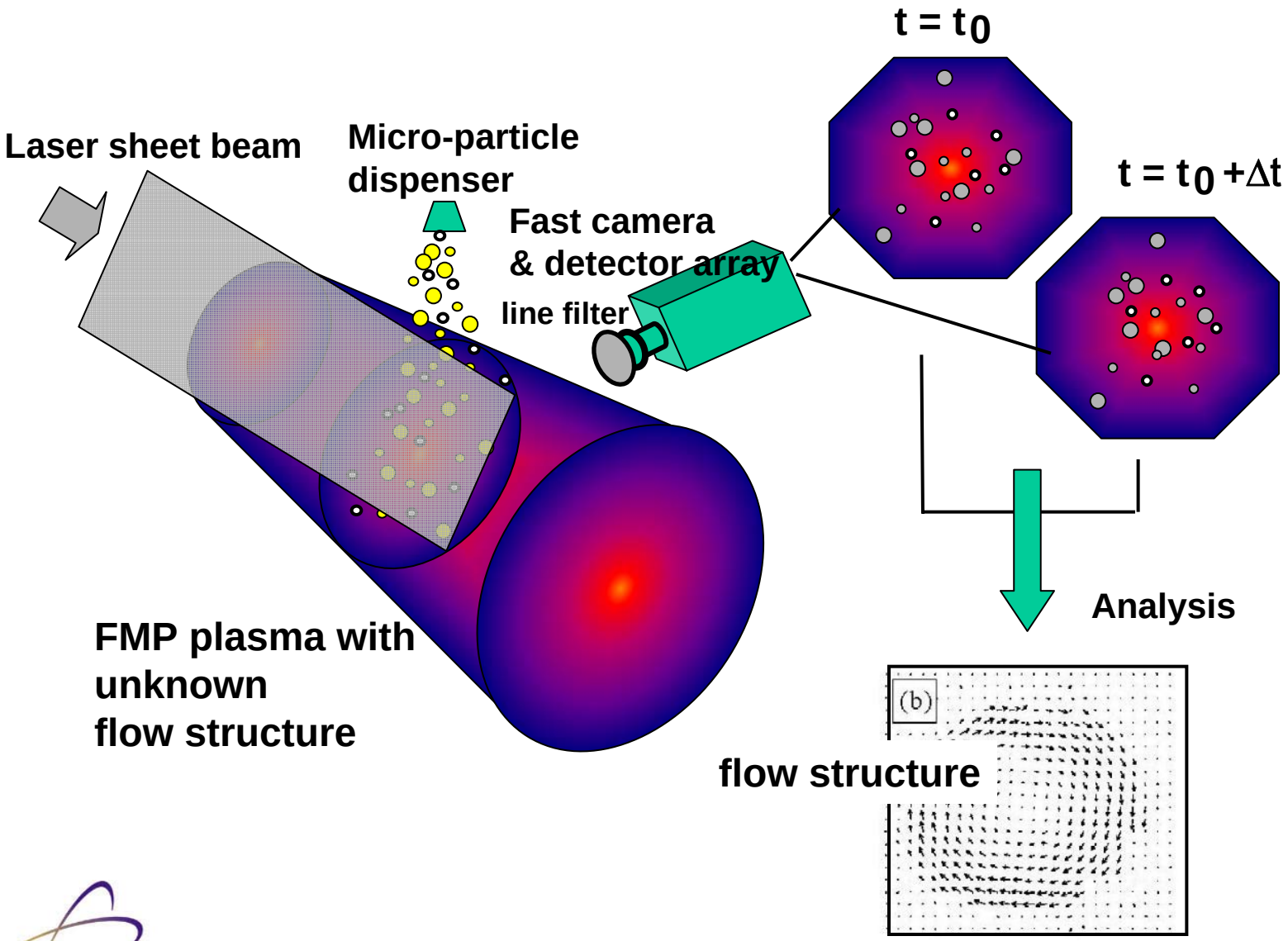
- Electrostatic shielding can protect microparticles



The basic setup of mPTV



Summary & Conclusions

- Microparticles can become useful diagnostic tools for laboratory plasmas
  - † For fusion plasmas, hypervelocity dust injection (HDI) is a new technique to seed high temperature plasmas with neutrals, work towards internal magnetic field mapping in NSTX at Princeton is underway
  - † For 10 eV, 5 x10^{13} class plasmas, which are important test grounds for basic plasma science, mPTV is a promising technique to measure plasma flows.