Fusion-Related Experiments at UW

Jake Blanchard
blanchard@engr.wisc.edu
University of Wisconsin - Madison

PSI

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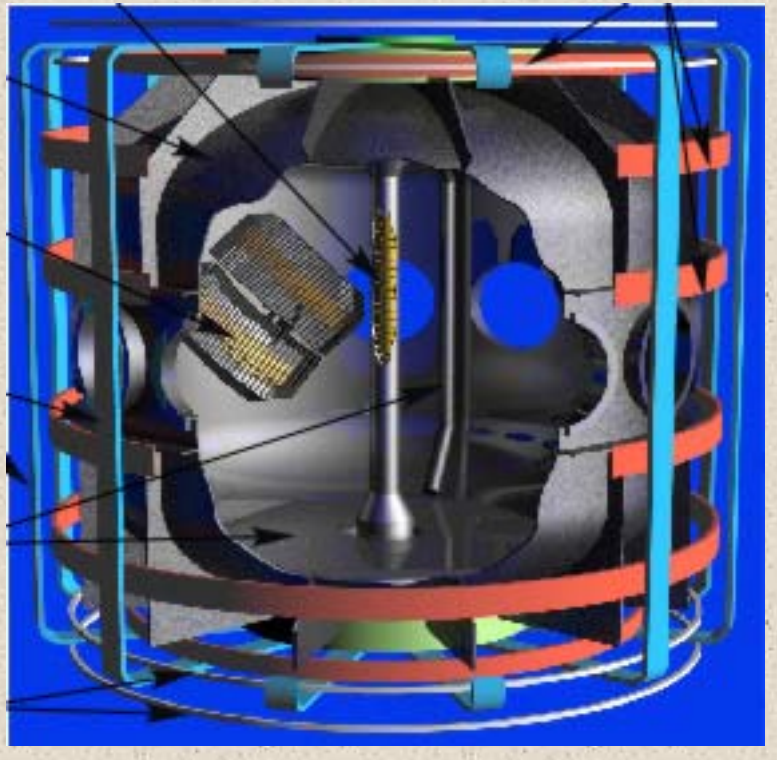
Outline

- **Plasma Experiments at UW**
- **PSI Experiments at UW (Dennis Whyte)**

PEGASUS – Spherical Torus – Ray Fonck

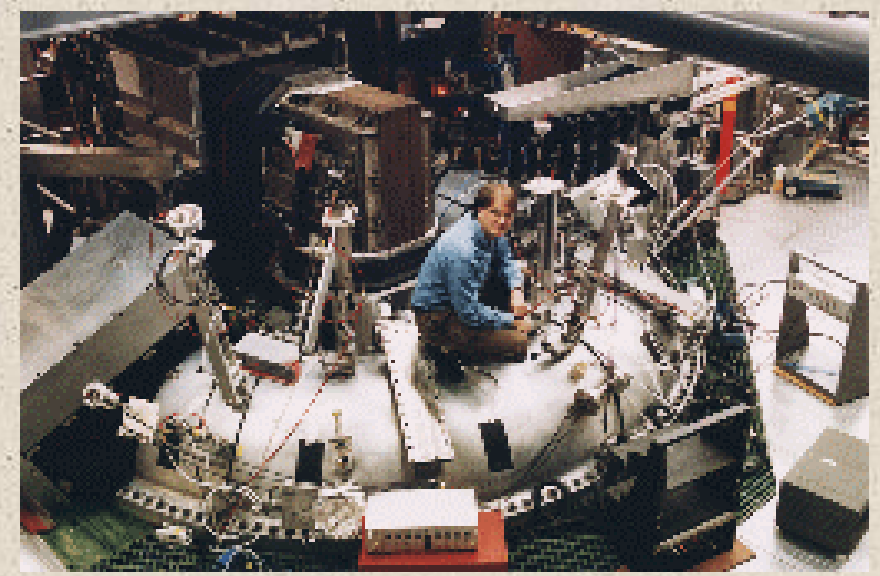
Parameters

- A=1.1-2
- R=0.2-0.45 m
- Plasma Current=0.1-0.3 MA
- Elongation=1.5-3.7
- Pulse Length=10-30 msec
- Inductive startup
- Inductive and RF sustainment
- 2 MW RF Aux. Heating
- Primary goals are to study performance as A approaches 1



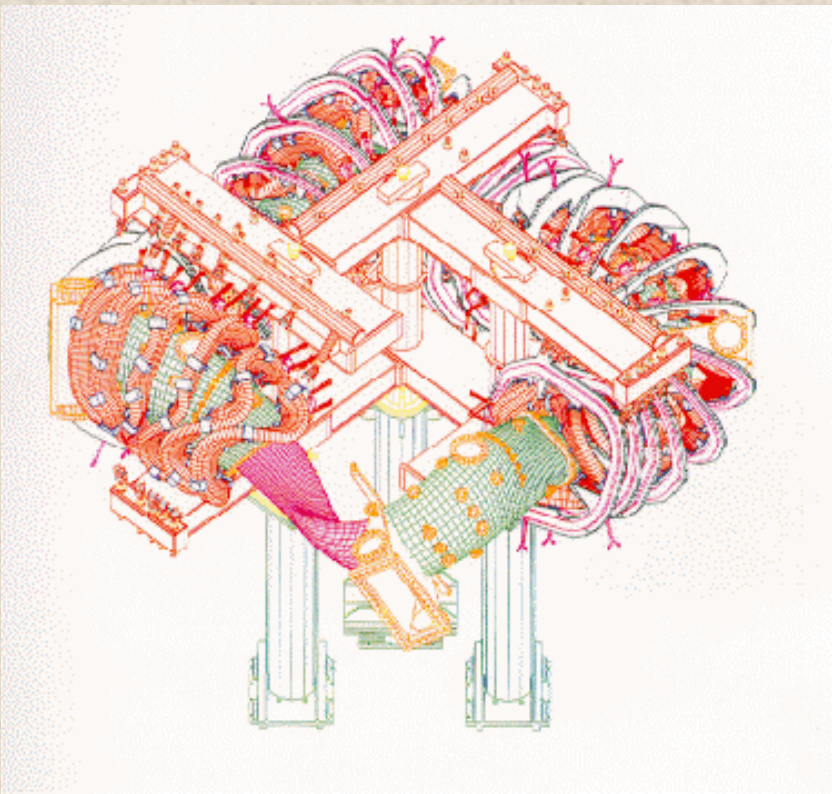
MST – RFP – Stu Prager

- Minor Radius: 0.52 m
- Major Radius: 1.5 m
- Wall Thickness: 0.05 m (aluminum)
- Plasma Current: < 0.65 MA
- Loop Voltage: > 5 V
- Poloidal Flux Swing: 2 Wb
- Pulse Length: < 90 ms
- Electron Temperature: < 600 eV
- Ion Temperature: < 350 eV
- Electron Density: < 4 x 10^{13} / cc
- Poloidal Beta: < 10%
- Energy Confinement Time: < 5 ms
- Goal: study stability and turbulence

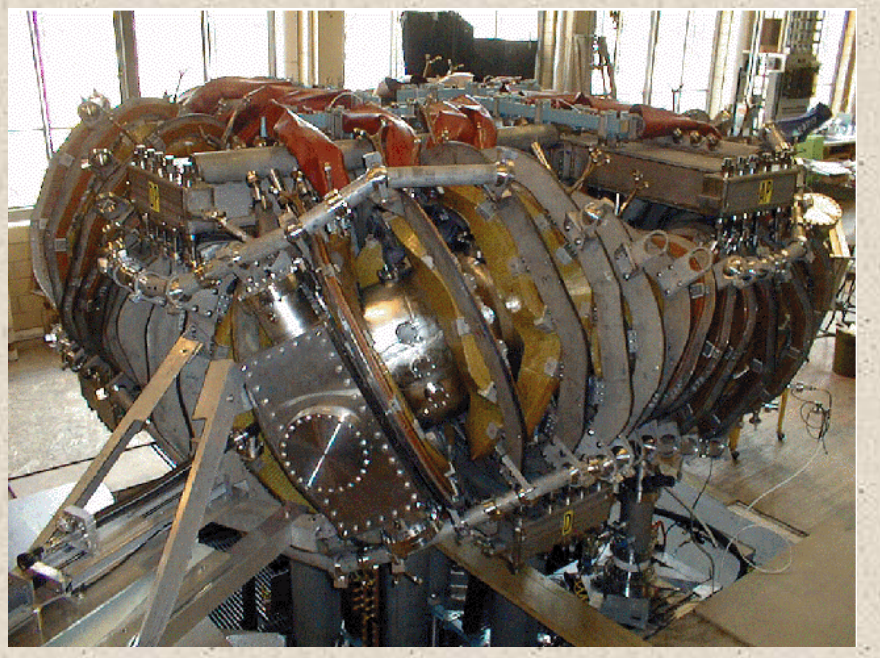


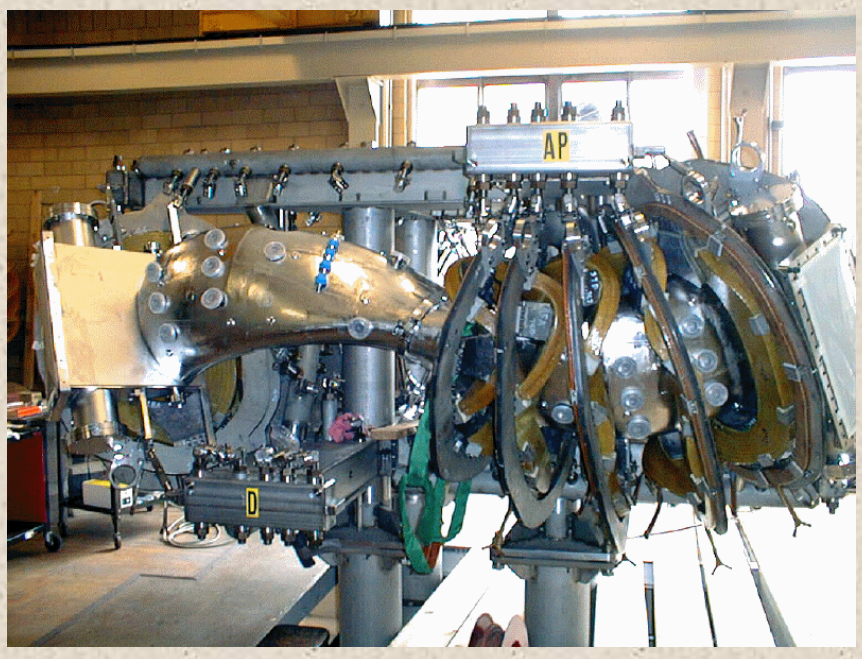
HSX – Stellarator – Dave Anderson

- **Average Major Radius: 1.2 meters**
- **Average Plasma Minor Radius: 0.15 meters**
- **Aspect Ratio (Major Radius/Plasma Radius): 8**
- **Plasma Volume: 0.44 cubic meters**
- **Number of coils/Field Period: 12**
- **Average Coil Radius: ~0.30 meters**
- **Magnetic Field Strength (maximum): 1.37 Tesla**
- **Magnet Pulse Length (full field): 0.2 seconds**



HSX





Our present lack of confidence in PSI issues primarily arises from the poor diagnosis of PSI effects

- Most of the controlling PSI physics is in hand or in a "mature" research stage
  - Physical sputtering, chemical sputtering
  - Plasma edge sheath theory
  - Atomic physics (ionization, etc.)
  - *Notable exception: ⊥ particle transport in edge plasmas.*

- By the same token, edge plasma diagnosis is mature.

- However we have essentially no direct diagnosis of how & when plasma-facing surfaces are being modified by the plasma.

The PSI diagnostic challenge

- The plasma edge is dominated by its own self-consistent recycling pattern of fuel and impurities
  - Easily implemented plasma diagnosis cannot inform us about the net surface effects (H retention, erosion, etc.)

- The lack of direct surface diagnosis cripples our ability to understand the net effects of PSI.
  - We have largely relied on surface "archeology" to inform us about surface modifications. This is unacceptable; the equivalent of basing ITER burn predictions on one-year integrated neutron fluence from JET!!)
  - Dedicated ex-situ PSI experiments (e.g. DiMES) very expensive to implement (run-time) and covers << 1% of wall surfaces.

- The challenge is to develop reliable in-situ surface diagnostic techniques that can operate in real-time and be placed in many locations.

In-situ PSI diagnosis topics

1. Erosion & deposition using quartz crystal microbalances

2. DIONISOS: Accelerator-based ion beam surface analysis experiment being developed at UW-Madison

3. Isotope-tracing plasma transport experiments.

QMB: Quartz crystal microbalances

- Measures net mass change on surface coating of a crystal by changed resonance frequency.

- **Advantages**:
  - Extremely sensitive: can measure ~mono-layer net changes in surface
  - Large dynamic range: 0.1-> 1000 nm
  - Can measure both deposition and erosion of a pre-deposited film.
  - Commercially available technology.

- **Drawbacks**:
  - No element discrimination.
  - Cannot tolerate any significant heat flux: small thermal mass.
  - Highly temperature / environment sensitive
  - Limited absolute range: ~ 1 micron << expected deposit layers.

Proposed "Particle-control" divertor modification for DIII-D stress use of QMBs to measure retention and recovery of codeposited deuterium from temperature controlled surface

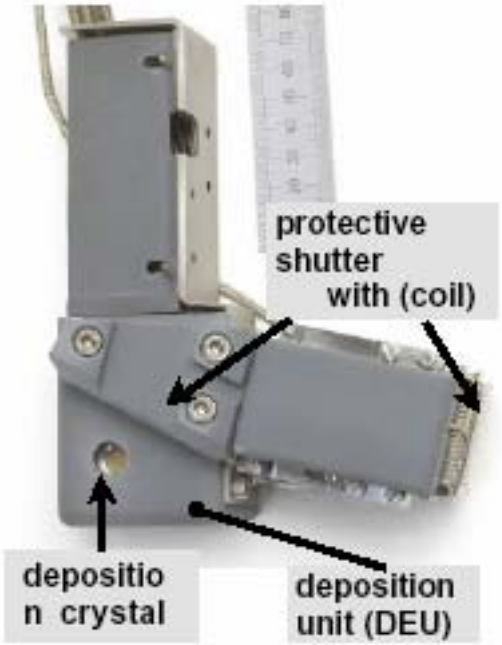
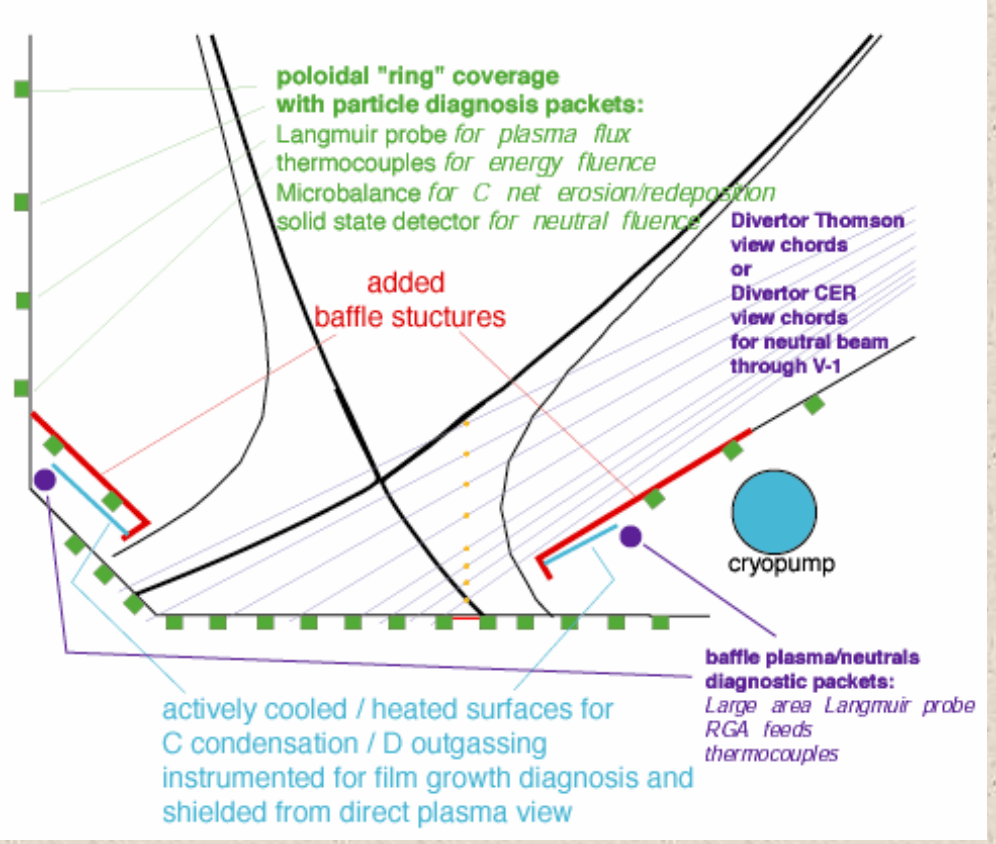


Fig. 3. JET Quartz Microbalance; view onto the complete system including deposition unit and shutter; shutter in open position allows direct view onto the deposition quartz



Ion Beam Analysis of Surfaces

- Interaction of ~MeV ions with surface atoms is accurately described from well-known physics
  - Rutherford elastic scattering ($M_{target}>M_{projectile}$)
  - Forward elastic recoil ($M_{target}<M_{projectile}$)
  - Inelastic nuclear reactions (all reaction σ known)
- Exploit this understanding to diagnose near-surface (~1-10 microns) properties of materials.

- **Advantages**:
  - Great flexibility: element/isotope sensitivity, erosion/deposition/H retention available in single diagnostic.
  - Measurement accuracy over appropriate depth range for PSI.
  - Proven application in fusion PSI (see examples from DiMES)
  - Simple solid-state detectors for scattered charged particles

- **Drawbacks**:
  - Need ~MeV energy ions

DIONISOS:

Dynamics of IONic Implantation & Sputtering On Surfaces

- **A new experimental facility being constructed at UW-Madison.**

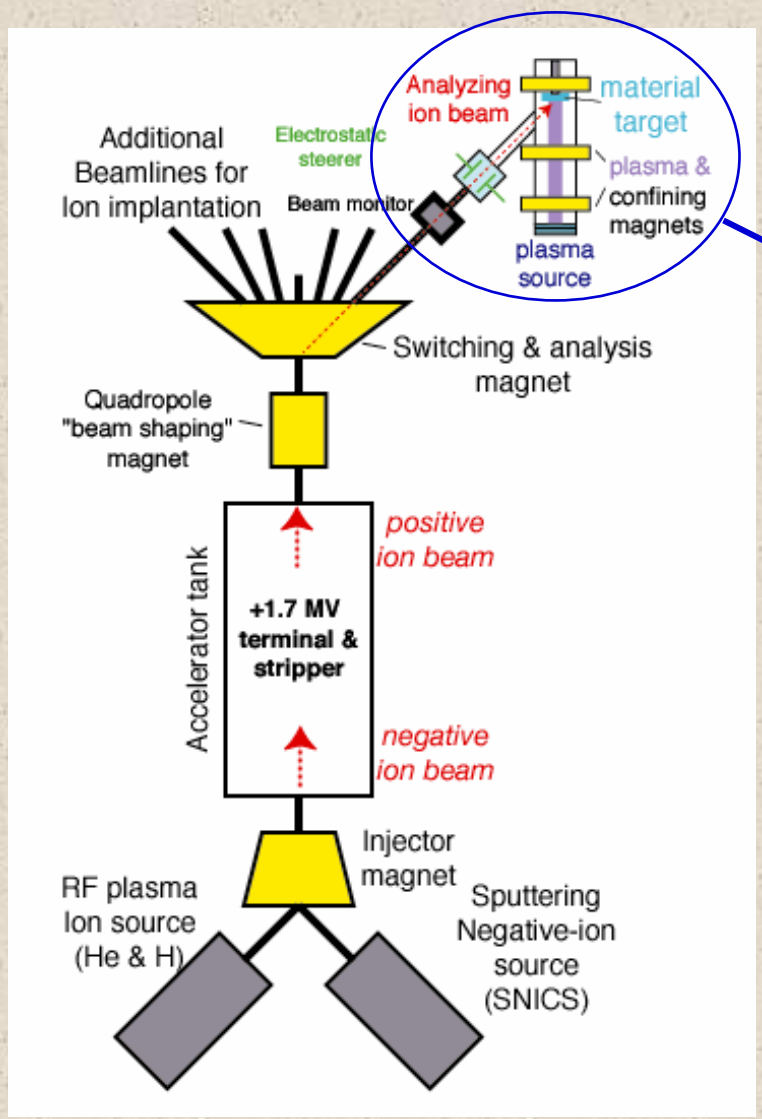
- ***Goal:* Accurately measure the real-time response of the PFC material surface to plasma bombardment using in-situ high-energy ion beam analysis.**

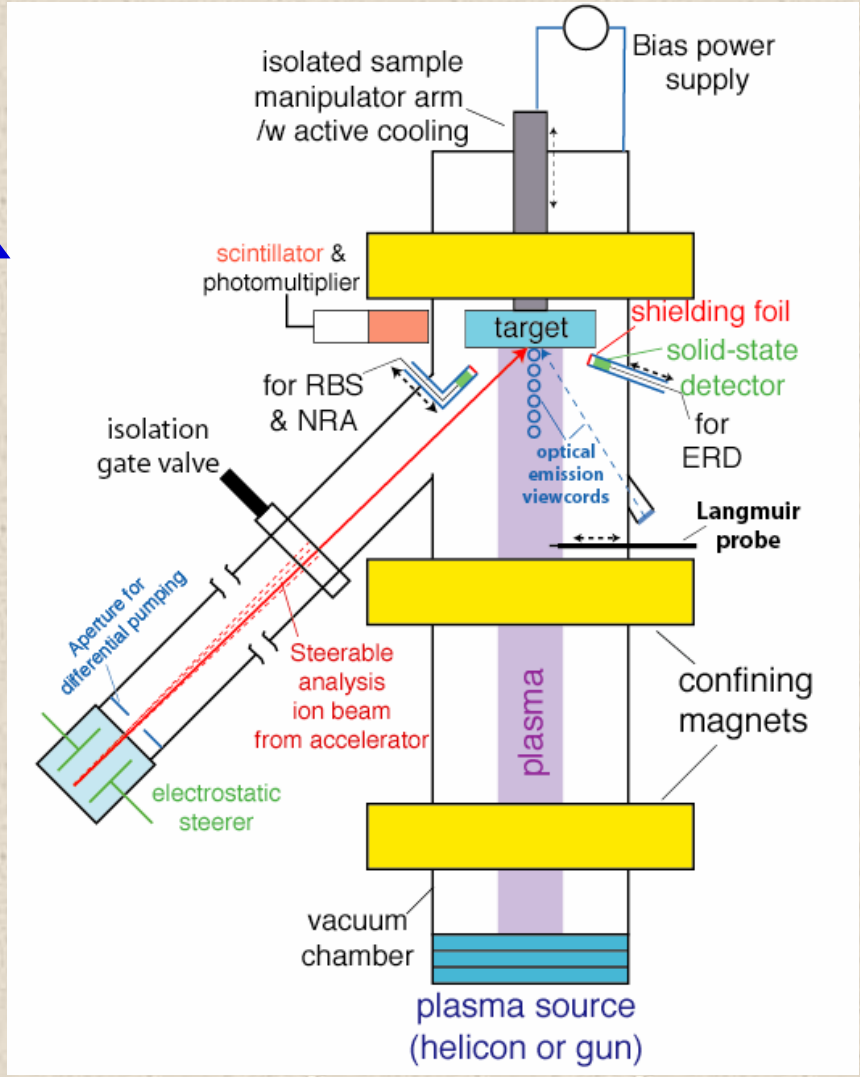
- **Design philosophy:**
  - **Exploit ion beam analysis (IBA) techniques**
    - **Mature analysis tool widely used in R&D.**
    - **Vastly different ion energies (30 eV vs. > 1 MeV) allow for simultaneous surface interaction with little interference.**
  - **Use previously developed axisymmetric plasma sources**
    - ***Helicon:* Steady-state plasma /w good density control.**
    - ***Plasma gun*: high density/flux pulsed plasma source.**
  - **Initially focus on fusion experiments, but generic PSI tool.**

Principal component of DIONISOS is now operational at UW-Madison: *1.7 MV tandem ion accelerator*

- Purchased from Bell Labs / Lucent surplus.
- Features:
  - Dual sources (sputtering and RF plasma), > 100 beam species available.
  - High energy (≤ 10 MeV for higher Z beams)
  - High current beamlines (> 0.1 mA) for implantation and irradiation.

DIONISOS Experiment Setup

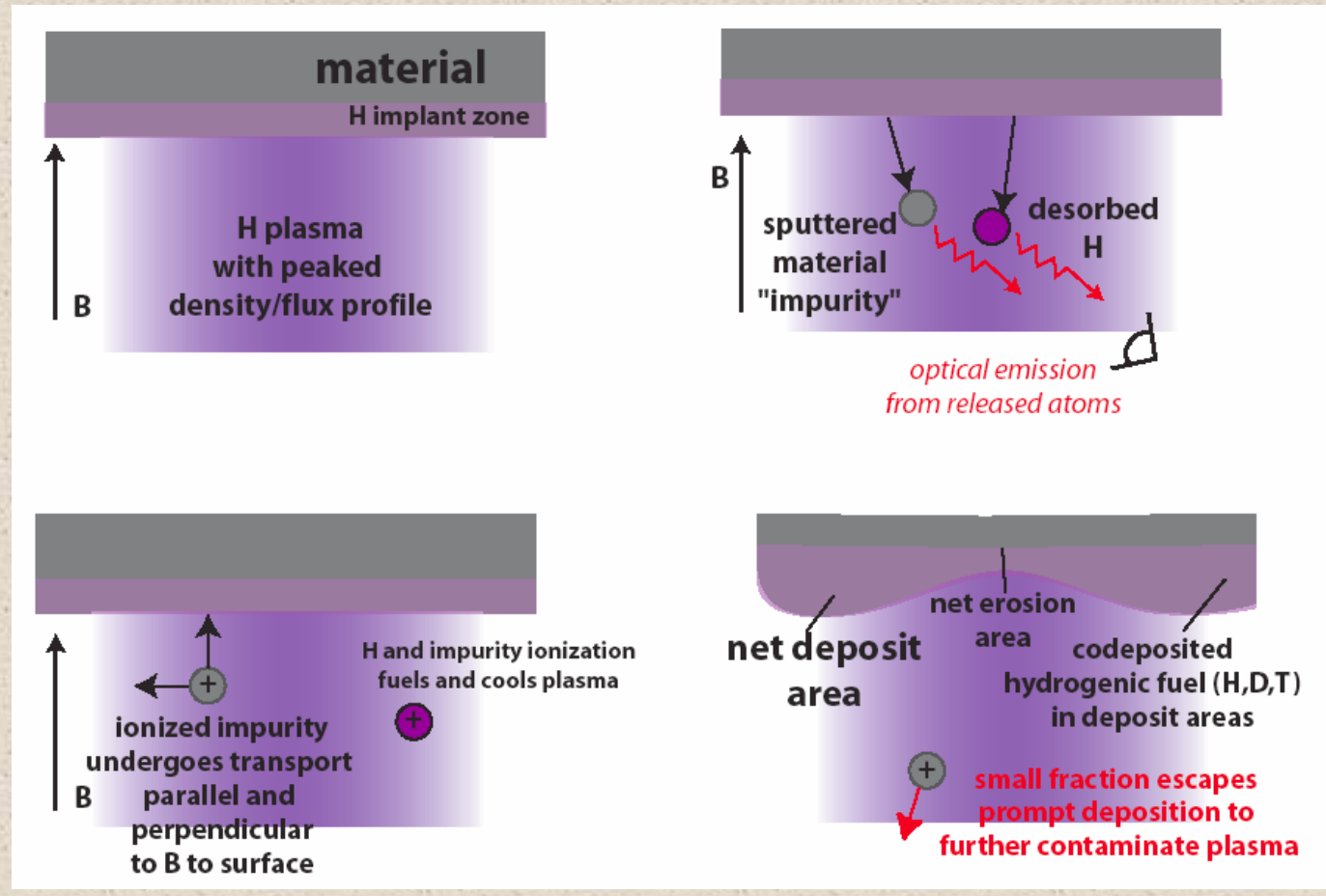




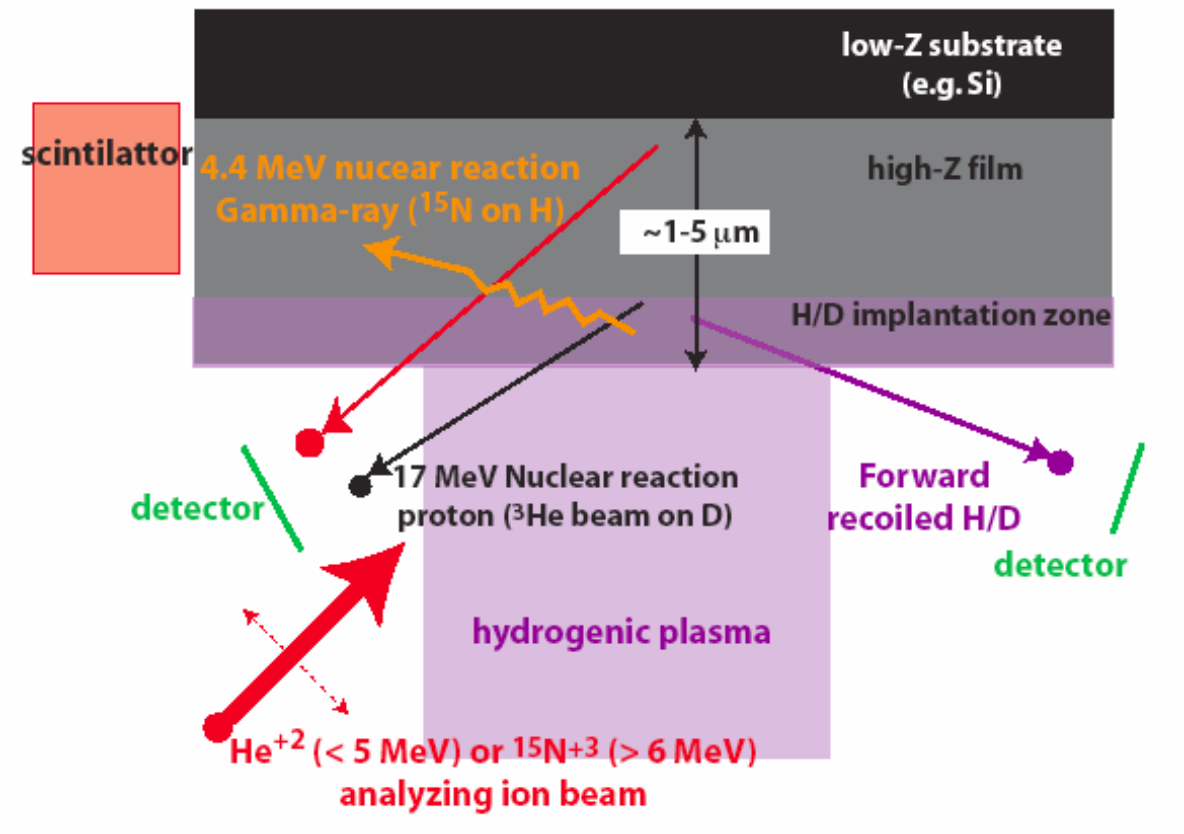
Three proposed areas of study for DIONISOS

- **Measurement and modeling of near-surface cross-field ion transport**
  - **Determine controlling parameters for the magnitude and locations of net erosion / redeposition of PFC relevant to fusion (C, W, Mo)**
- **The dynamic release of fuel and impurity particles from surfaces exposed to transient, high-density plasmas.**
- **The dynamics of hydrogenic / tritium fuel trapping in plasma-deposited films, for single and multiple species materials.**

In-situ ion beam analysis of surface changes provides highly sensitive tool to study near-surface ion plasma transport

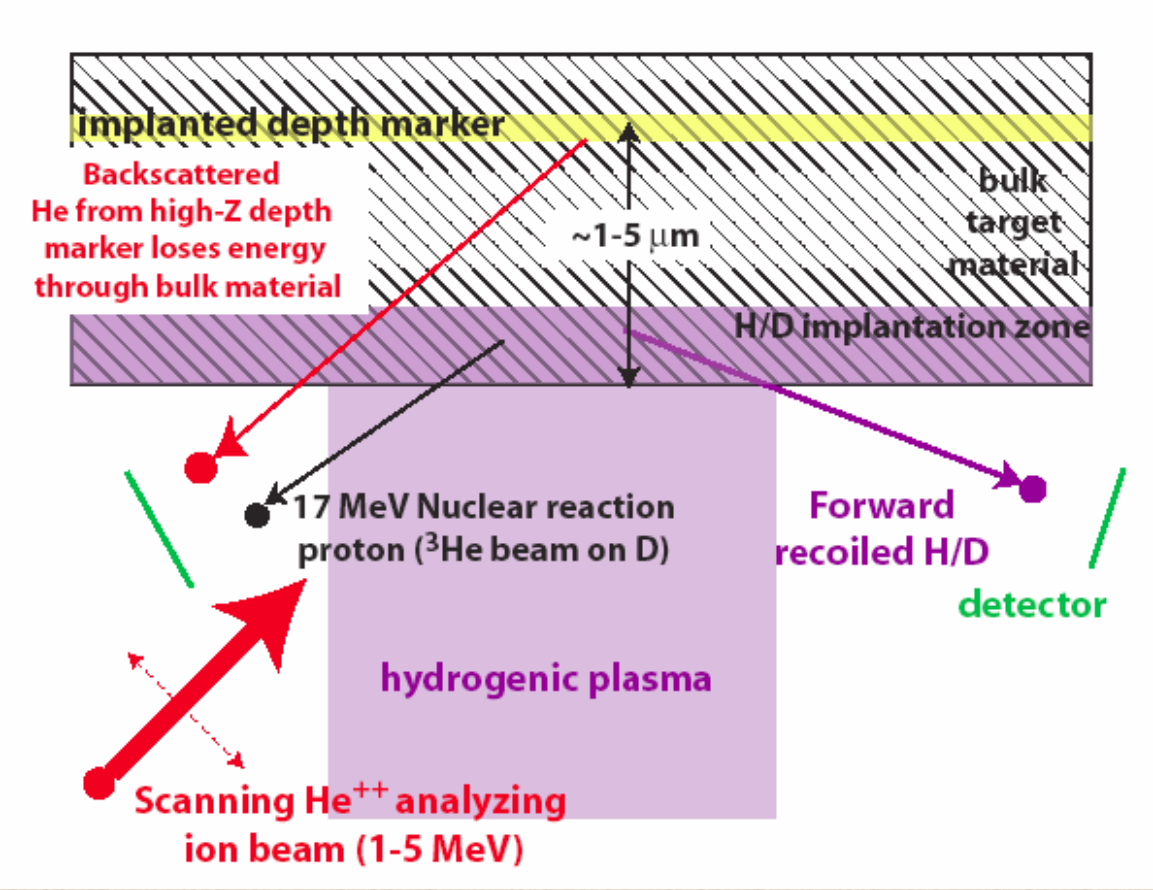


Schematic for IBA diagnosis of high-Z PFC materials



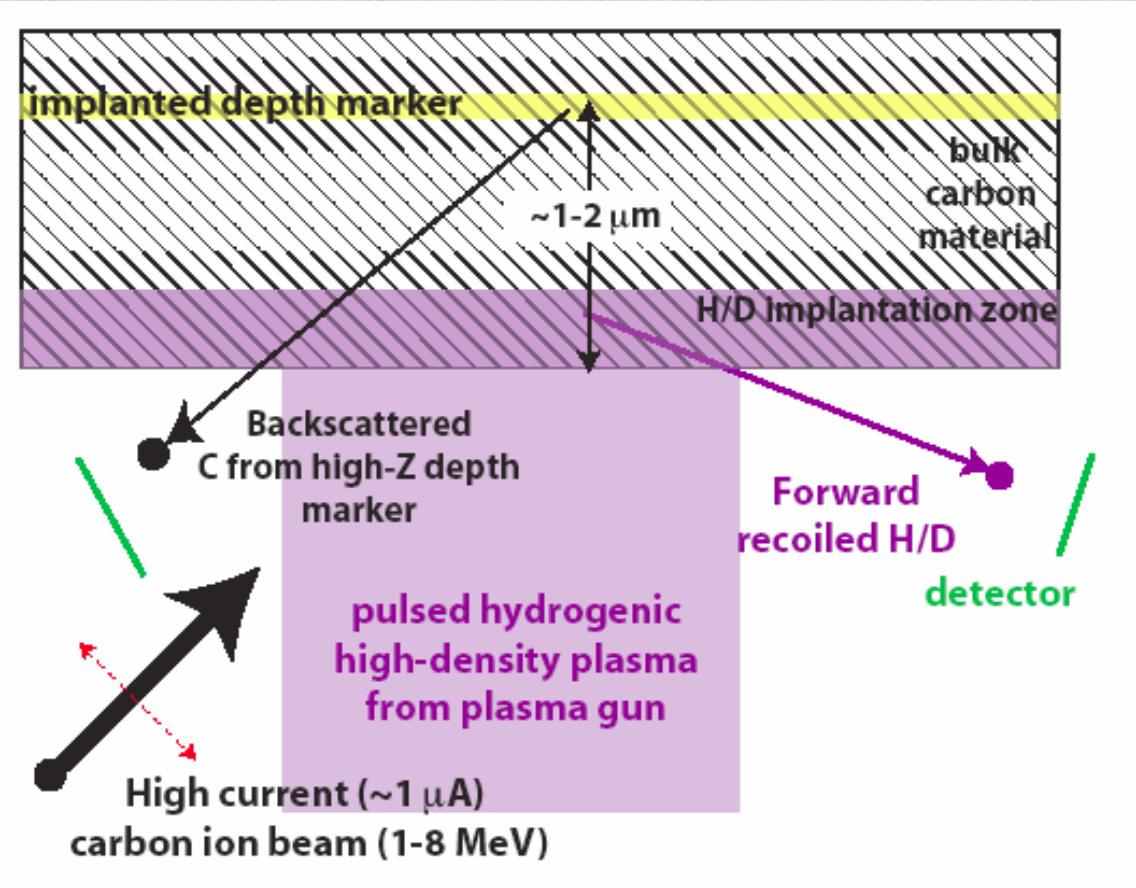
- **RBS measures net erosion rate of high-Z film to ~ 5 nm.**
- **Forward recoil (ERD) provides depth-resolved H/D concentration.**
- **Highly resolved spatial profiles of isotope resolved H species with NRA.**

Schematic for IBA diagnosis of low-Z PFC materials



- RBS measures net erosion rate of bulk material by changes in high-Z marker previously implanted with ion beam.
- ERD and NRA provide real-time hydrogenic concentrations and diffusion in deposited films

Schematic for IBA diagnosis of H dynamics in PFC



- Exploit large forward recoil cross-section for high mass projectiles
- Same ion-PFC species allows for high current, fast hydrogenic diagnosis
  - Case shown: ERD using C-H recoil can measure H profile in ~ 10 ms time
- Allows for dynamic study of H implantation, diffusion and release under transient conditions.

Who is involved?

- **Locally**
  - Whyte, Principal investigator
  - Two graduate students (arriving Fall 2003).
  - ~3 undergraduates.
  - Part-time technician.
  - Collaborations with IEC, fission, etc.

- **Collaborations**
  - Large U.S. tokamak confinement experiments:
    - » DIII-D: carbon PWI, disruption mitigation.
    - » Alcator C-Mod: refractory metals PSI, disruption mitigation.
  - Argonne National Laboratory: PSI modeling.
  - University of Toronto: carbon chemical erosion and modeling
  - JET & ITER: disruption mitigation.

UW-Madison PSI research strategy

- **Goal: Establish fundamental understanding of the physical processes controlling erosion / deposition in fusion plasmas.**

1. **Develop novel diagnosis techniques for real-time material transport measurements in plasmas.**
   - **In-situ diagnosis of erosion and deposition rates and hydrogenic (=Tritium) fuel retention.**
   - **Turbulence plasma diagnostics, focusing on fuel and impurity particle transport.**

2. **Combine efforts of our local, dedicated plasma experiments and collaborations with large confinement devices (DIII-D, C-Mod)**
   - **Strong ties to theoretical and modeling community (UW, ANL, LLNL, U Toronto).**

3. **Develop and test *pro-active* design solutions for next-step burning plasma experiments.**
   - **Active control of edge plasma and wall conditions.**

Workshop Agenda