Disruption Mitigation with Shattered Pellets

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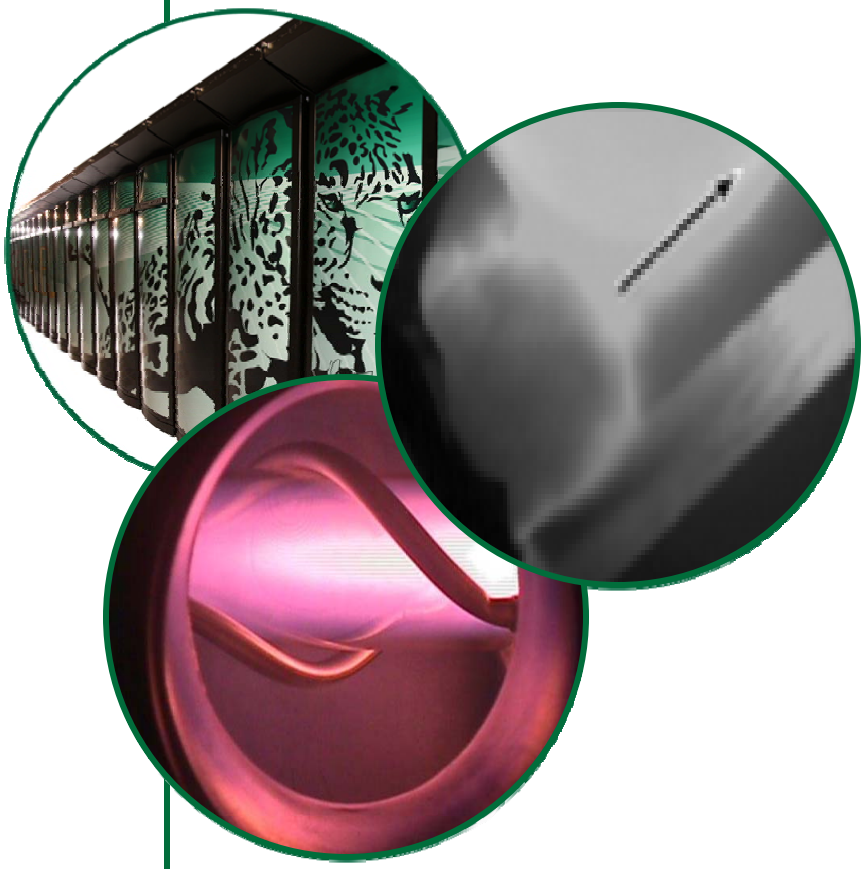

Presentation at:

VLT June 2009 TeleCon,

17-June-2009

U.S. DEPARTMENT OF ENERGY

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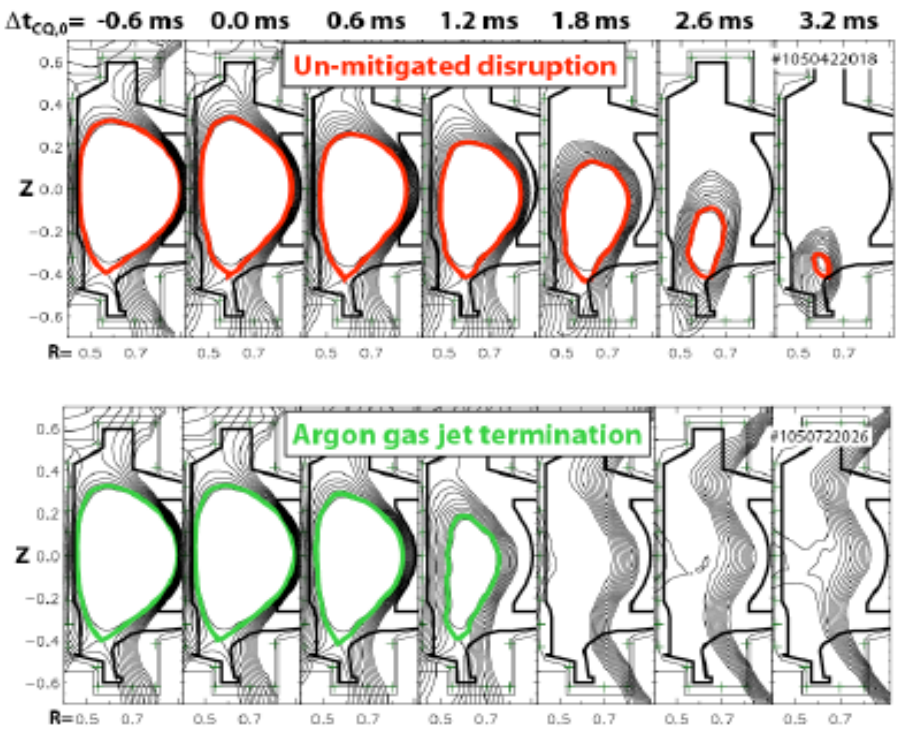
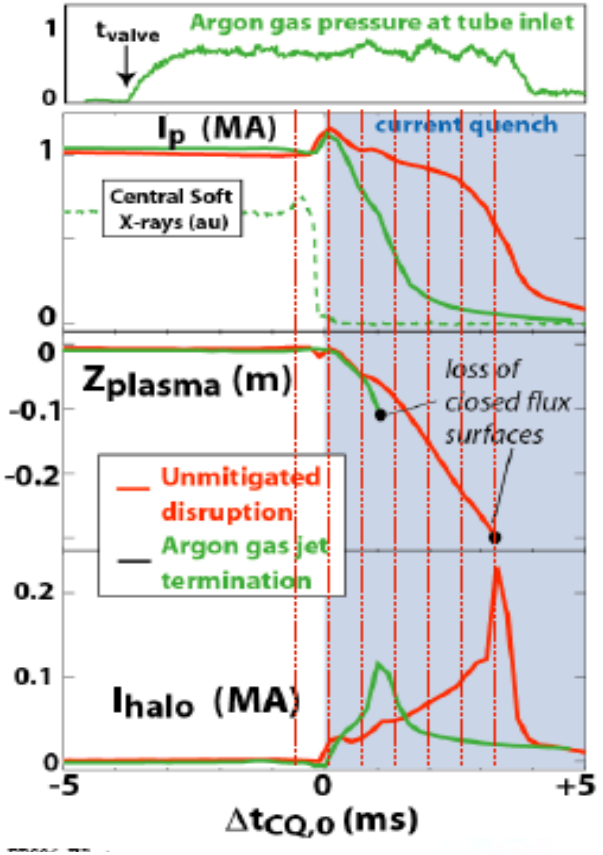
Disruption Threats and Their Mitigation

Massive gas injection has been used to mitigate the three threats arising from disruptions:

- **Thermal loading:**
  - **Rapid heat load ablates material surfaces**
  - **Large quantities of gas used to dissipate plasma energy by radiation**
- **Halo currents: Large JxB forces on vessel and first wall**
  - **MGI causes rapid quench of the plasma, results in minimal plasma motion**
  - **Substantially reduces the vessel halo currents**
- **Runaway electrons:**
  - **ITER could have up to 10 MA of RE current in 10-20 MeV range of energies from avalanche amplification during current quench $G \sim e^{lp} \sim 10^{21}$**
  - **Penetration into PFCs - Component melting and water leaks are possible**
  - **Avalanche suppression in ITER needs $N_{inj} \sim 5 \times 10^{25}$**

Example of Disruption Mitigation on Alcator C-Mod

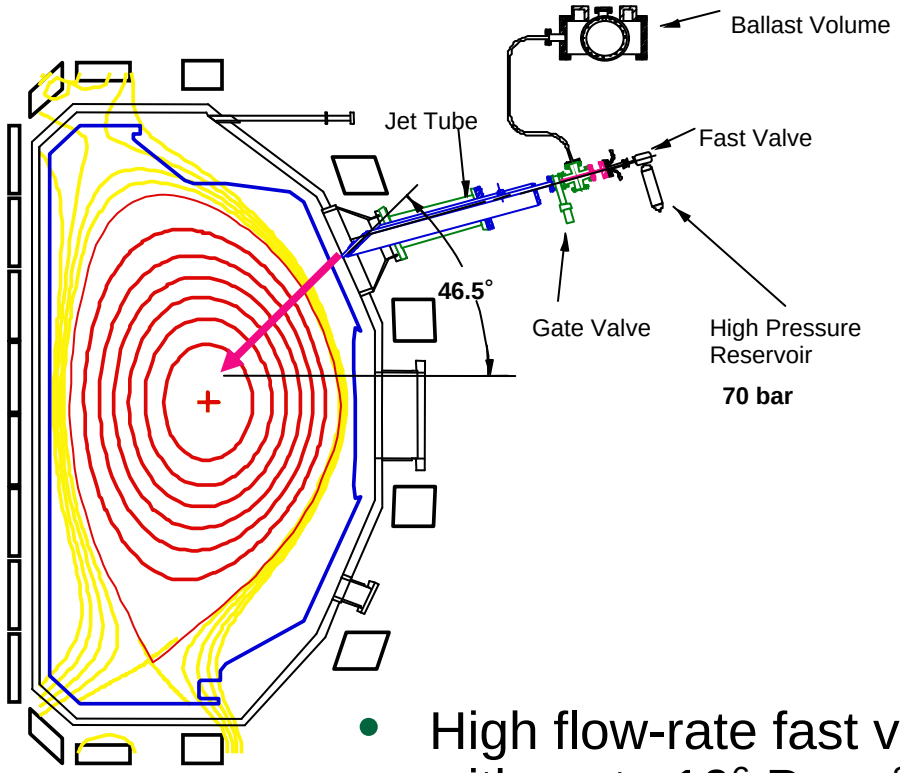


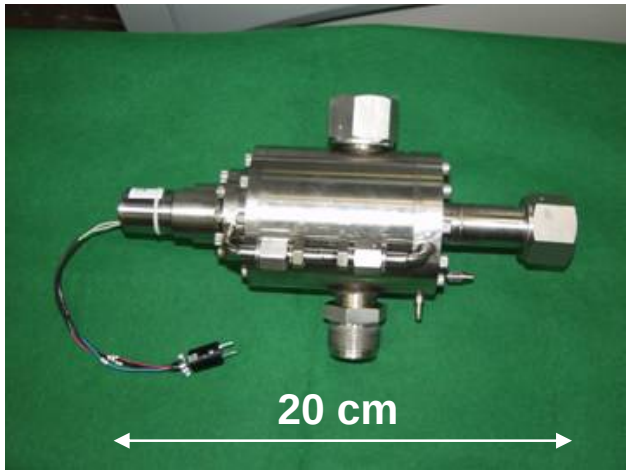


- **Comparison of unmitigated disruption with Ar gas jet mitigation showing faster current quench**

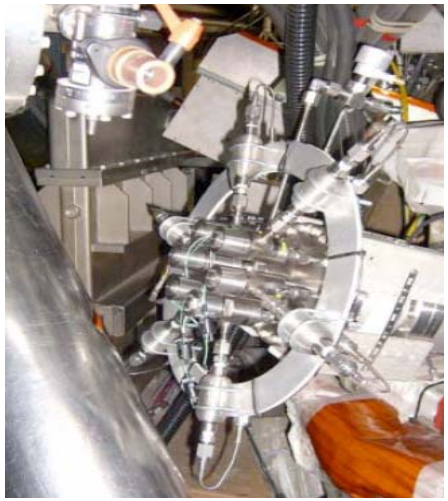
D. Whyte, EPS 2006

How is a Disruption Mitigated with a Gas Jet ?





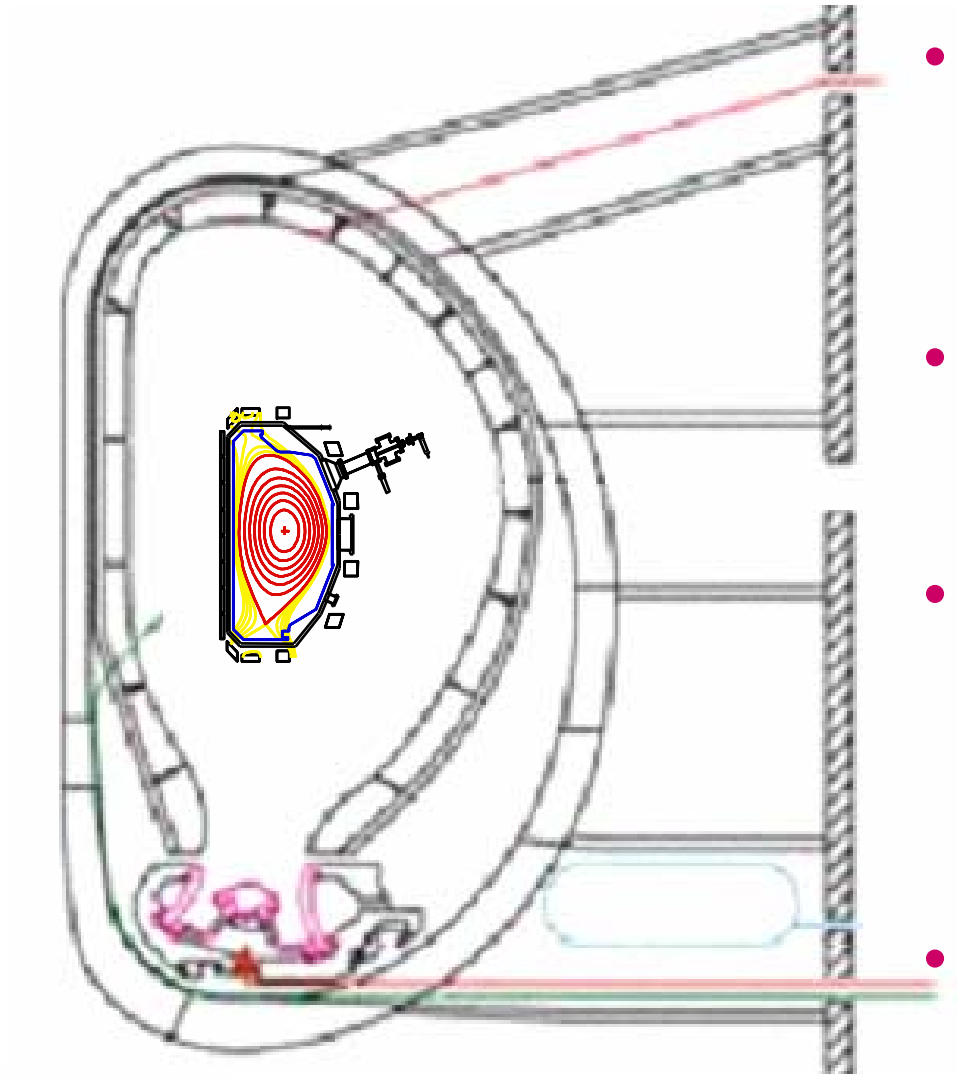
Jumbo Valve – 10^6 Pa-m^3/s



Medusa Valve – 3x10^5 Pa-m^3/s

- High flow-rate fast valves with up to 10^6 Pa-m^3/s (10^4 bar-L/s) flow rates for 2 ms produce gas jets into plasma.

MGI on ITER



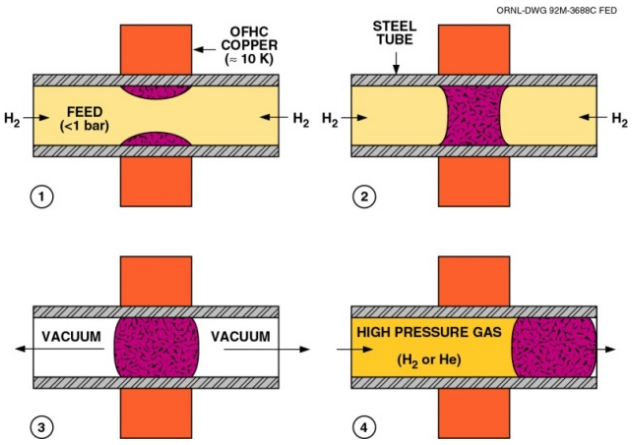
- All DIII-D experiments so far done on upper port with gas valve more than 1m from plasma.
- ITER has two upper ports dedicated for DM. (One is above NBI so no access)
- Gas jet injection may not be optimal in such a large machine, especially if valve must be located outside the biological shield.
- A faster more efficient method to inject the material is needed.

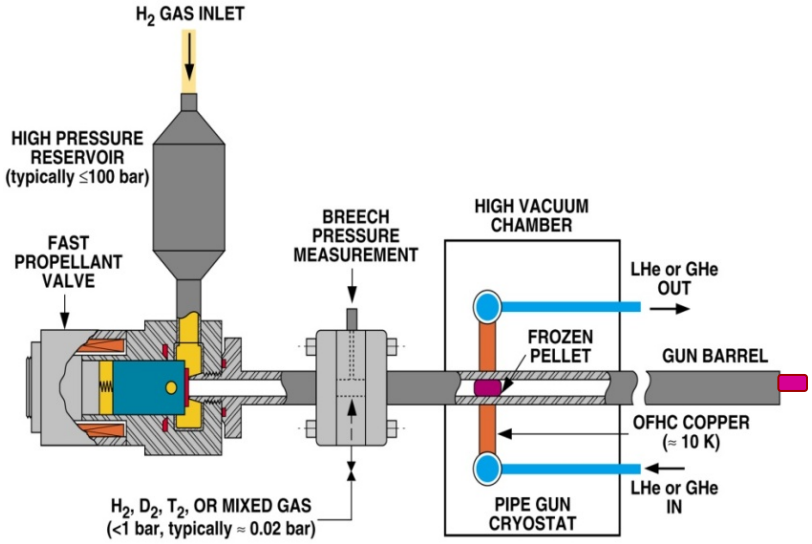
Shattered Pellets an Option for DM

- **Whole pellets of the size needed for DM are potentially harmful to the first wall and not likely to fully ablate. Impurity Killer pellets generate runaway electrons.**
- **Shattered pellets reduces the danger to PFCs and provides more surface area for ablation.**
- **Pellets are known to shatter on impact with hard surfaces.**
- **Normal velocities in excess of 25 m/s result in shattered D_2 pellets.**
  (Combs, S.K. et al, Fus. Tech. 1998)
- **Optimal design of a shatter plate needed for the DM application.**

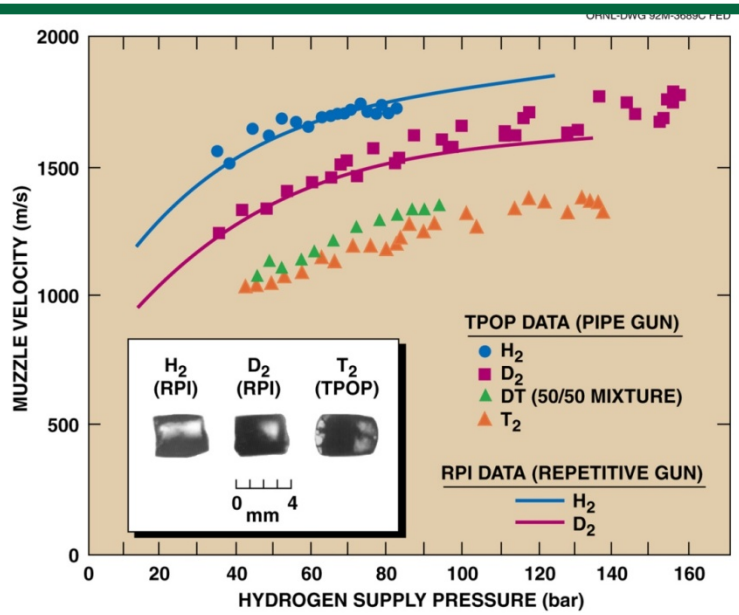
Photographs of 10-mm D_2 Pellets After Impact on Inclined Flat Plate

Pipe-Gun Pellet Injector for Large Pellet Formation



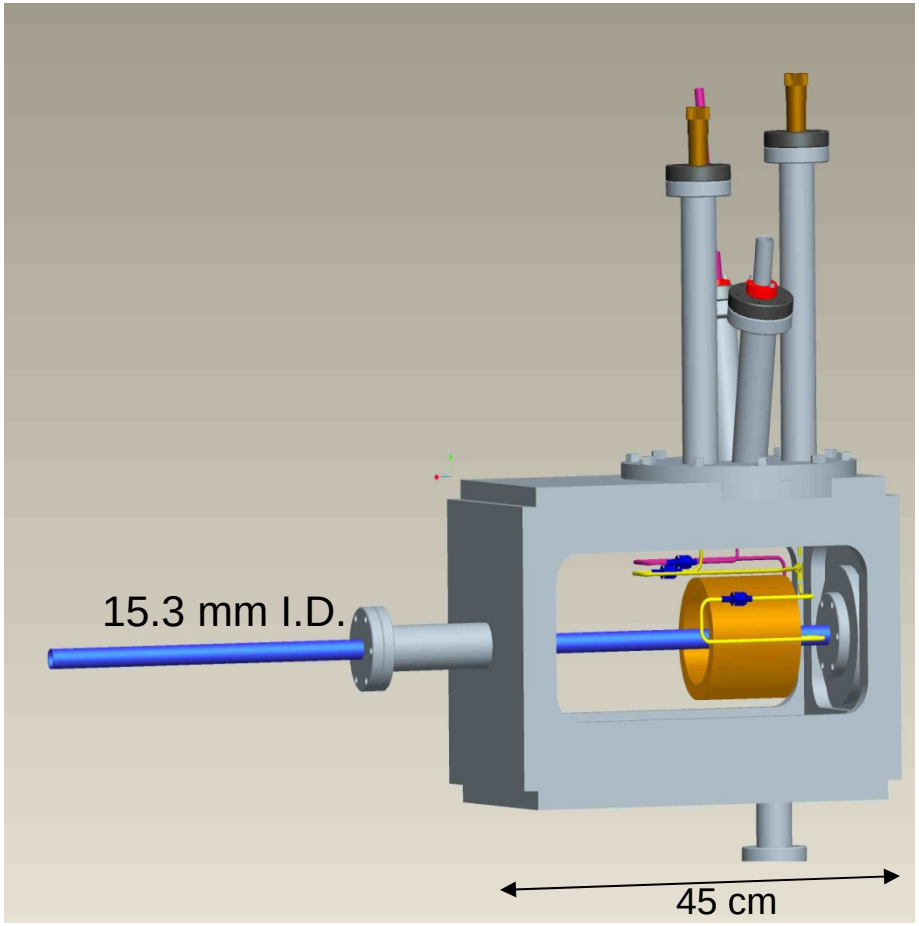


(Combs, RSI 1993)



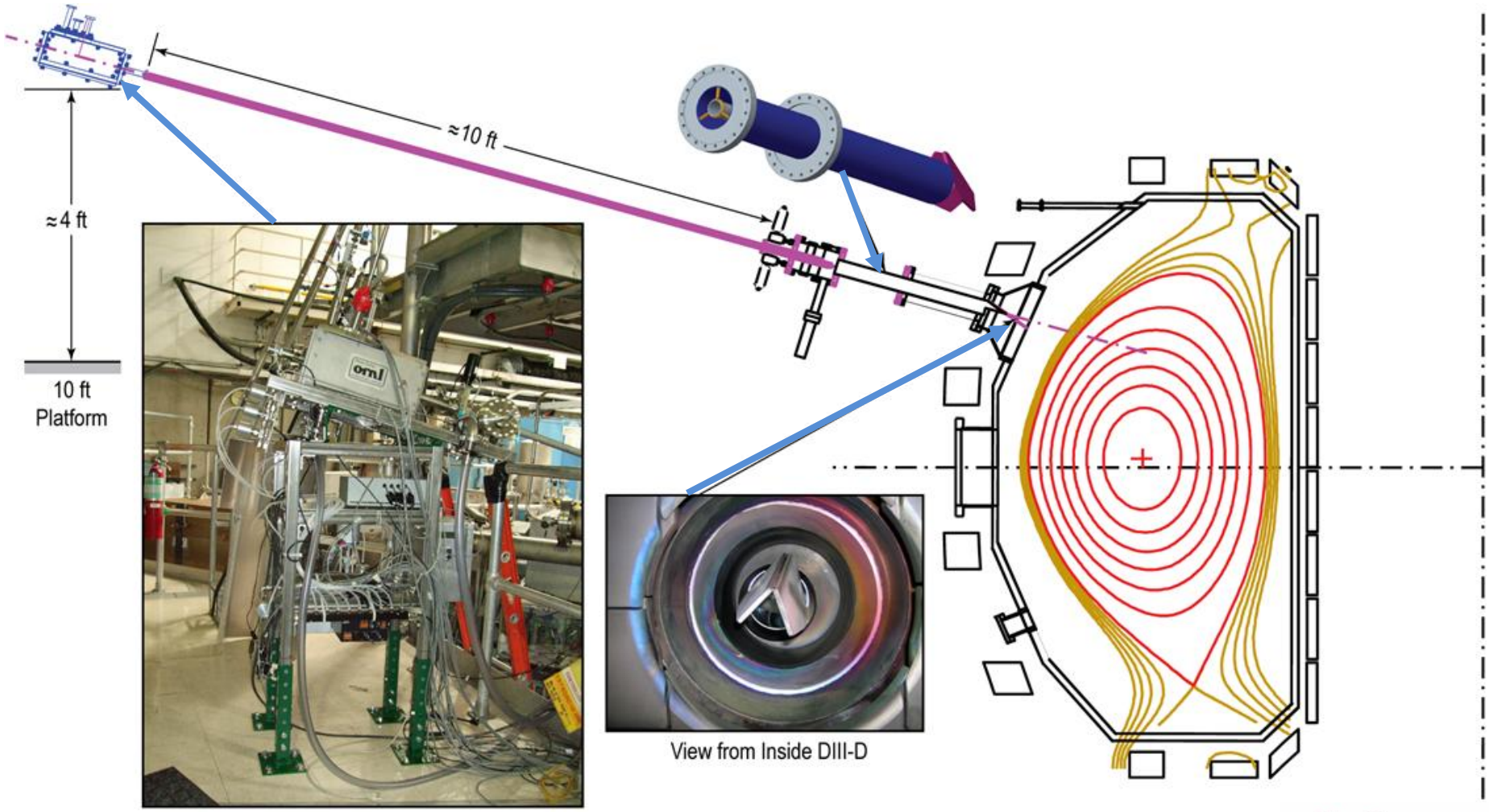
- **The pipe-gun uses LHe to freeze a pellet in situ in a SS barrel.**
- **A fast propellant valve is pulsed to release a high pressure burst of gas behind the pellet that accelerates it down the barrel.**
- **Note: Without a pellet you have a gas jet !**

Pellet Injector for Shattered Pellets for Planned Disruption Mitigation Testing on DIII-D

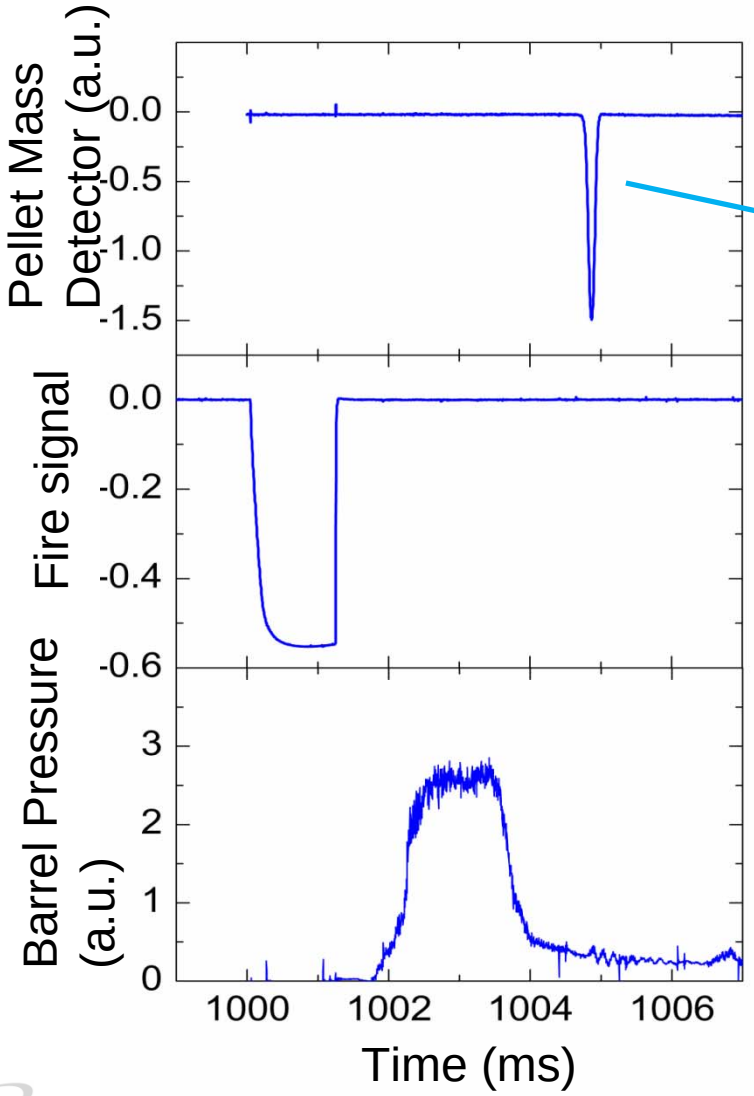


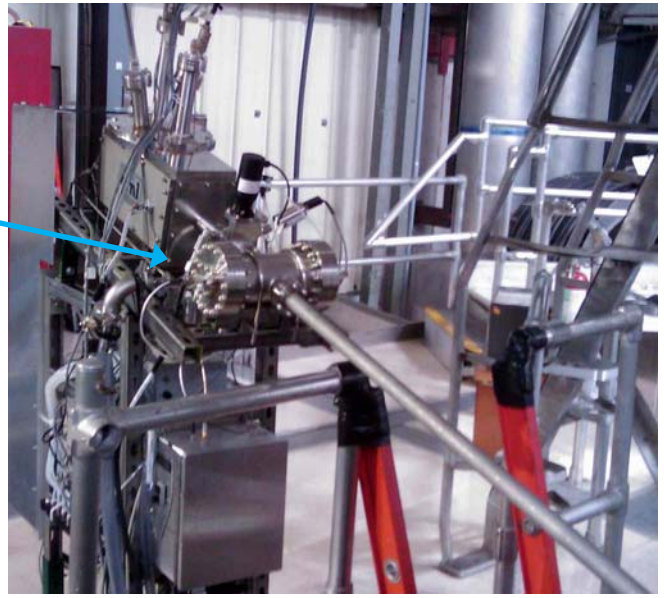
- **A pellet injector pipe gun is being modified from 1mm to 15.3 mm barrel.**
- **Pellets will contain ~2x10^{23} atoms (3.4 cm^3, 9 mm spherical radius equivalent)**
- **Tested in the lab to verify pellet formation and shattering pattern.**
- **Installed now and is planned for DM experiments in 2009.**

Pellet Injector for Shattered Pellets Installed for Disruption Mitigation Testing on DIII-D



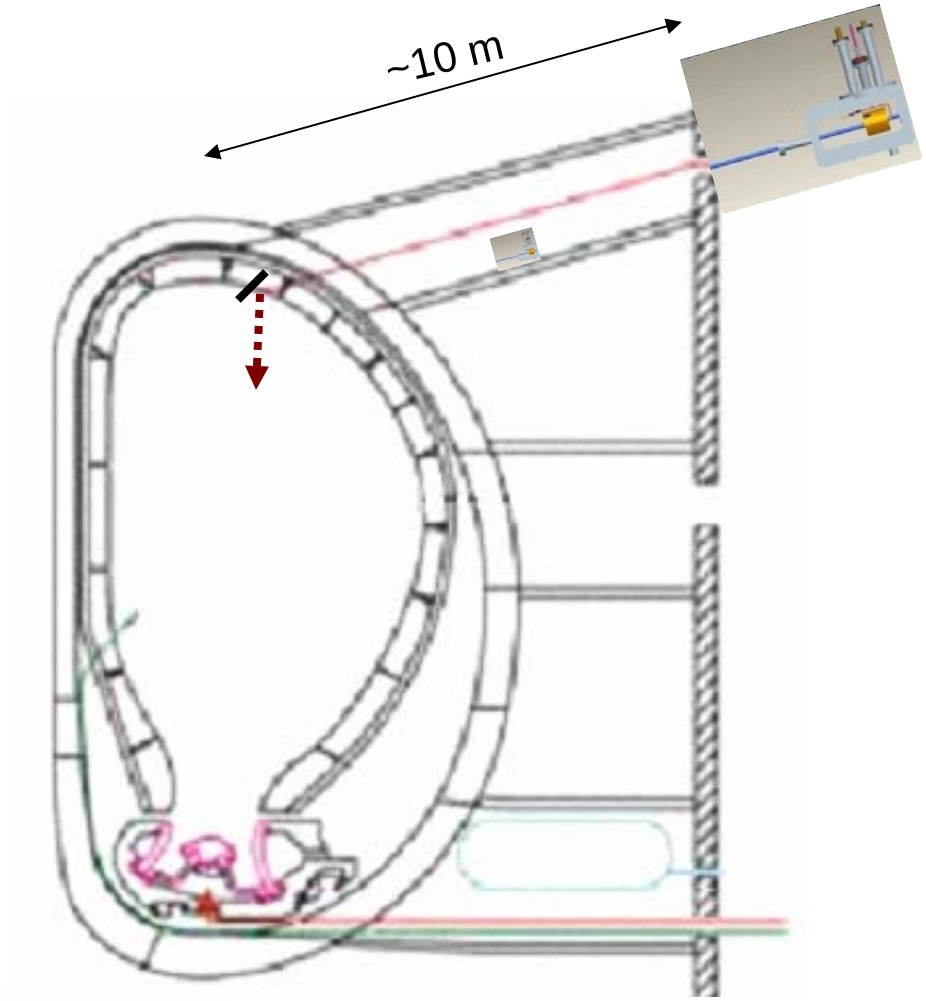
Shotgun Pellet Injector Commissioned on DIII-D





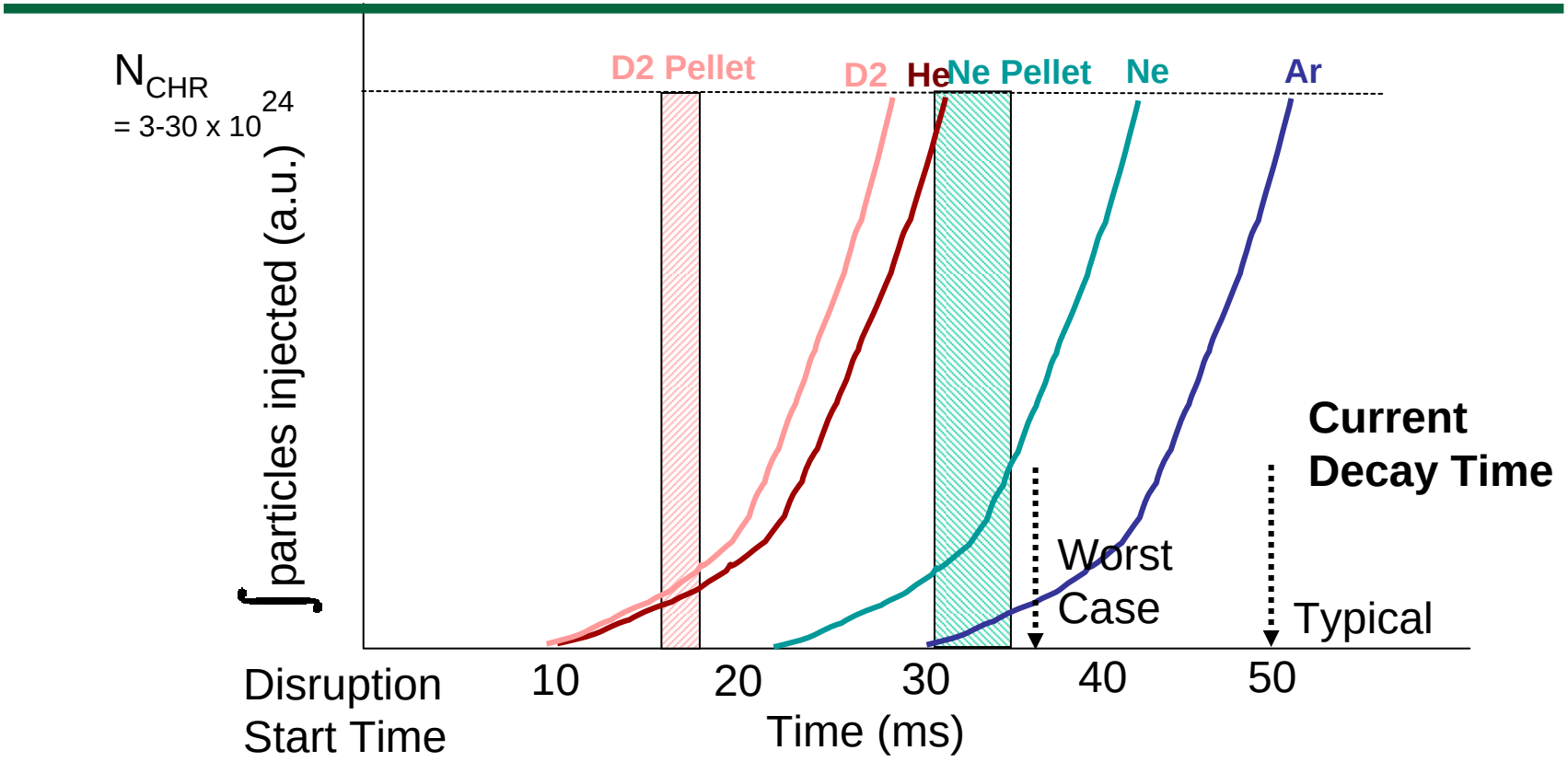
Data from a 15.3mm deuterium pellet fired into DIII-D from the shotgun pellet injector showing the trigger signal, pressure burst behind the pellet and pellet mass detector signal. The mass detector signal indicates a full size whole pellet traveling at ~ 500 m/s.

Pellet Injector for Shattered Pellets Looks Feasible for ITER



- **A pipe-gun injector with multiple barrels can provide the necessary particle inventory to the plasma in ~ 15 ms with the injector outside the biological shield. Faster with injector in the port plug.**
- **Ne or Ar with mixtures of D_2 pellets are easily formed and can be injected at speeds of ~500 m/s.**
- **Propellant gas follows the pellets into the vessel or can be trapped.**
- **Combination of pellets and gas jets possible**

Representation of the ITER Time Scale for Different Gas/Pellet Species



This assumes DM system is 10m from plasma (ignores initial gas shock)

Clearly need to have gas valves inside of port for fast mitigation

Summary

- **Time scales and gas quantities for DM on ITER will be challenging for gas jets.**
- **Shattered Pellets might have advantages. Mixture of injection systems may be needed to mitigate all effects.**
- **Shattered pellet system now operational on DIII-D and will be used next week for initial DM experiments. Comparison with gas jet results will be key outcome.**
- **Shattered neon pellets could be useful for ITER to help mitigate disruptions beyond that from gas jets and/or dust.**

References

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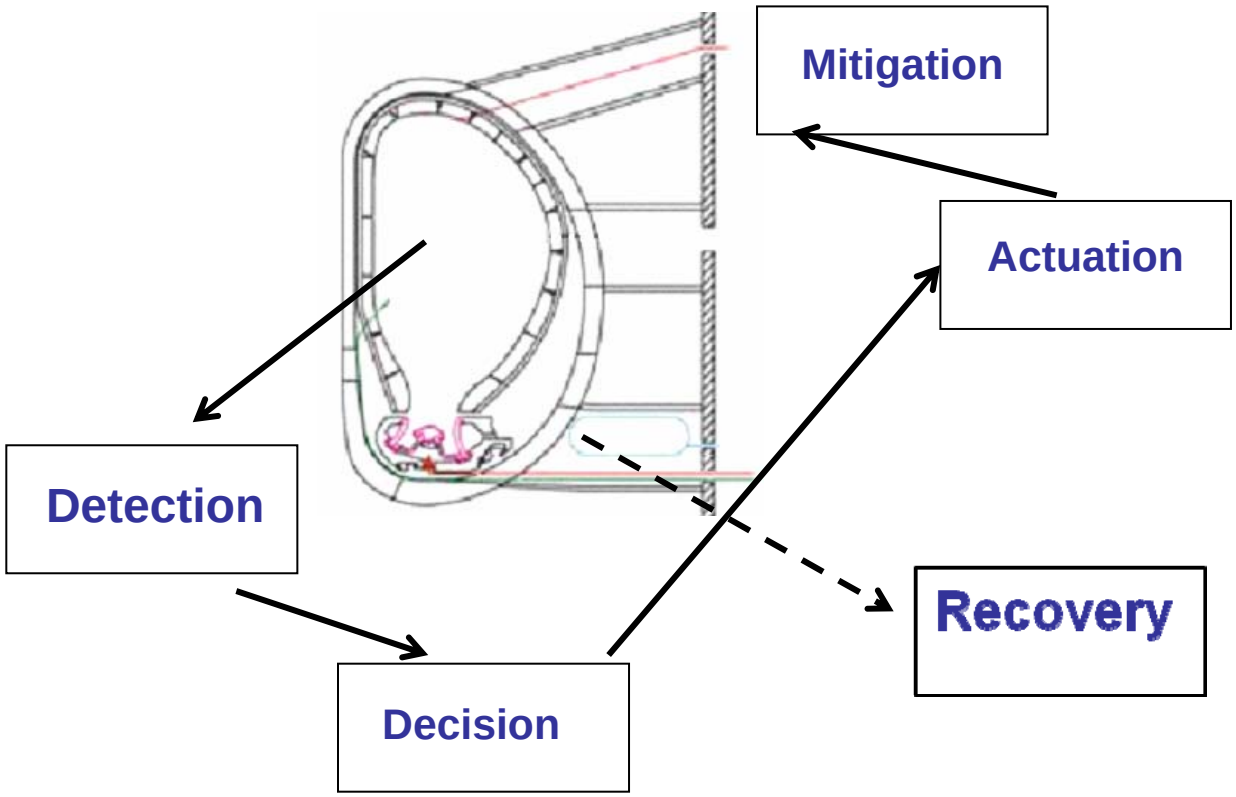
- **[3] Parker, R.R., Nucl. Fusion 40 (2000) 473.**
- **[4] Nygren, R., Implications for Runaway electrons, FEDC 1995.**
- **[5] Whyte, D., Disruption mitigation experiments, EPS 2006.**
- **[6] Jernigan, T.C., et al, SOFE 2006**
- **[7] Rosenbluth, M.N., and Putvinski, S.V., Nucl. Fusion 37 (1997) 1355.**
- **[8] Wesley, J.C., Memo on ITER DM for Design Review 2007.**
- **[9] Granetz, R., Disruption Mitigation on C-Mod, APS 2006**
- **[9] Day, C. et al, ITERVAC, IAEA 2006, IVC 2007**
- **[10] Jernigan, T.C., DM Mitigation Technology, EPS 2007**
- **[11] Finken, K.H., et al., Nucl. Fusion 48 (2008) 115001.**
- **[12] Bozhenkov, S.A., et al, Rev. Sci. Instr. 78 (2007) 33503**

All Aspects of DM Need to be Considered



- **The overall DM system needs to be considered from detection to recovery.**