Modeling of ITER Pellet Fueling

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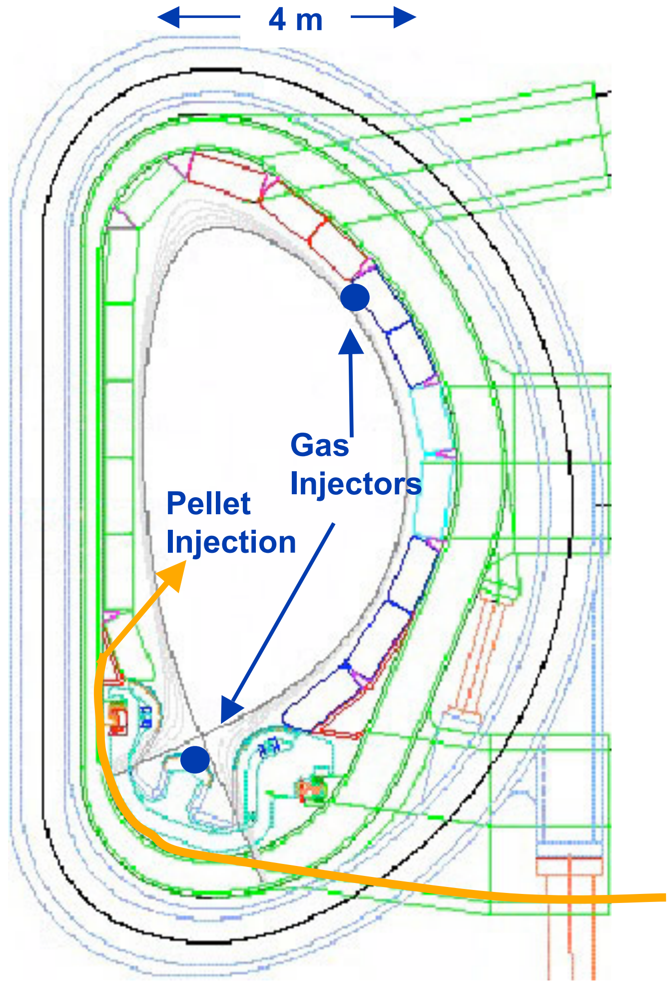
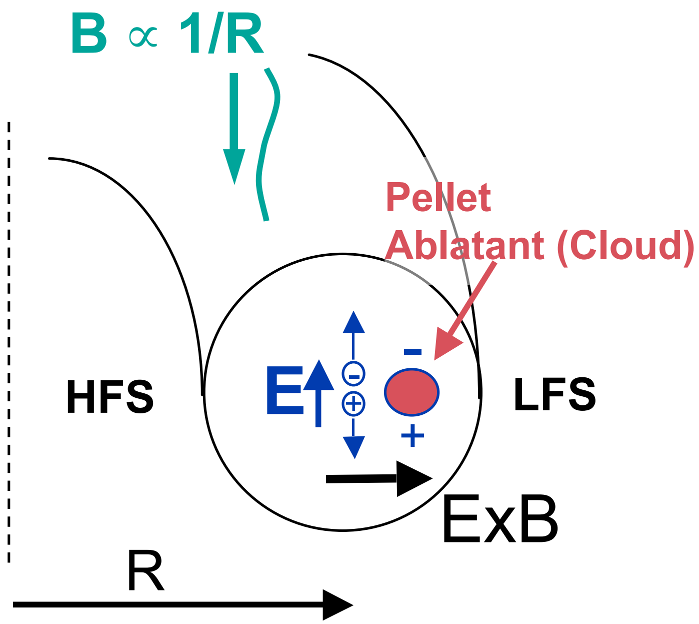
ITER Fueling Needs are Significant



- ITER plasma volume is 840 m^3 and scrape-off layer is ~30 cm thick. This compares to 20 m^3 and ~ 5 cm for DIII-D.
- ITER is designed to operate at high density (> 1x 10^{20} m^{-3}) in order to optimize Q.
- Gas to be introduce from 4 ports on outside and 3 in the divertor region
- NBI fueling to be negligible (< 2 x 10^{20} atoms/s or < 0.5 torr-L/s)
- Inside wall pellet injection planned for deep fueling and high efficiency. 300 m/s pellets can survive the guide tube (Combs, SOFE2005).
- ITER will require significant fueling capability to operate at high density for long durations
  - > Gas fueling will be limited by poor neutral penetration
  - > Inner wall pellet injection at 300m/s looks promising from PRL modeling

ExB Drift of Pellet Cloud Leads to More Efficient Fueling from Inner Wall Location

ExB Polarization Drift Model
of Pellet Mass Deposition (Rozhansky, Parks)



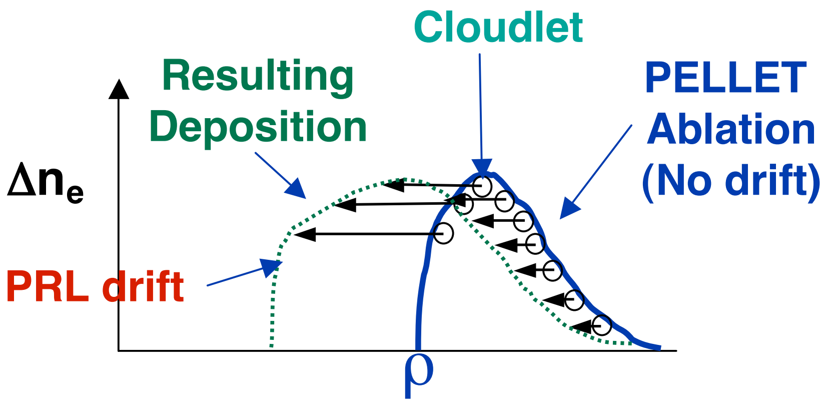
- Polarization of the ablatant occurs from ∇B and curvature drift in the non-uniform tokamak field:

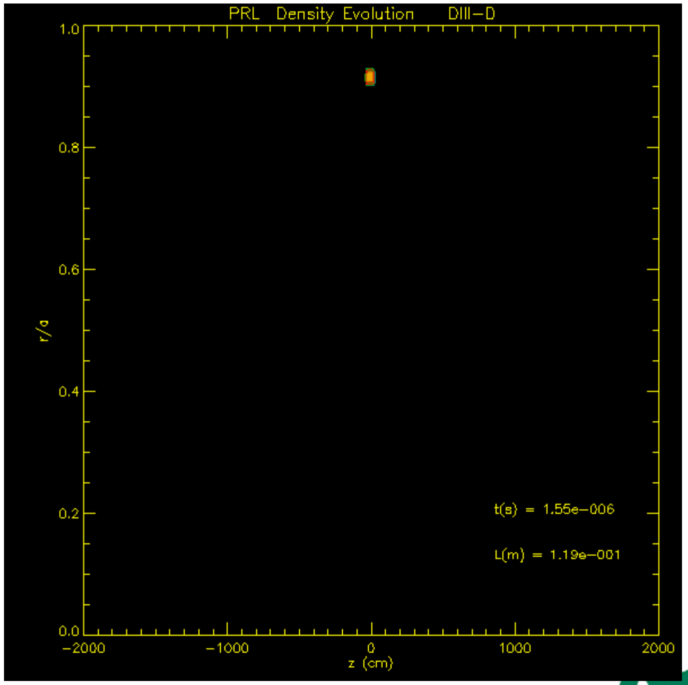
$$\vec{v}_{\nabla B} = \frac{W_\perp + 2W_\parallel}{eB^3}\vec{B}\times\overrightarrow{\nabla B}$$

- The resulting E yields an ExB force leading to drift in the major radius direction, $V_\perp = (ExB)/B^2$
- $J_{\nabla B} = -2p/RB$ and this balances the polarization return current $J_p = (\rho/B^2)\, dE/dt$. (p is cloud pressure and ρ is cloud density). Therefore the pellet cloud motion equation is $dV_\perp/dt = 2p/\rho R$
- ΔR drift distance is stronger at higher plasma β due to higher cloud pressure
- Detailed model by P.B. Parks, L.R. Baylor, [Phys. Rev. Lett. 94, 125002 (2005)].

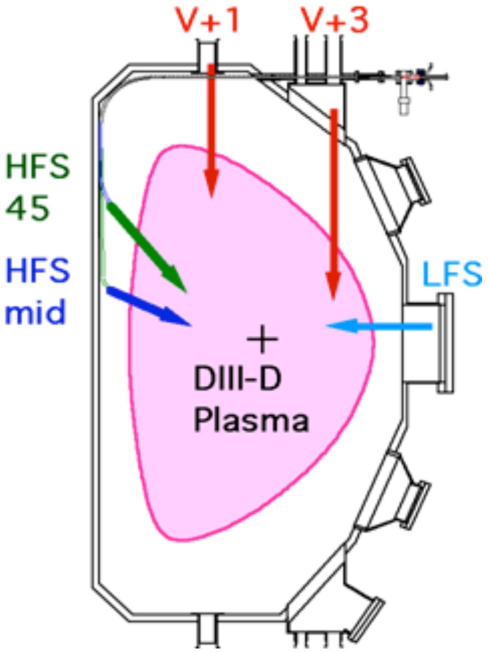
Modeling with Pellet Relaxation Lagrangian (PRL) Code

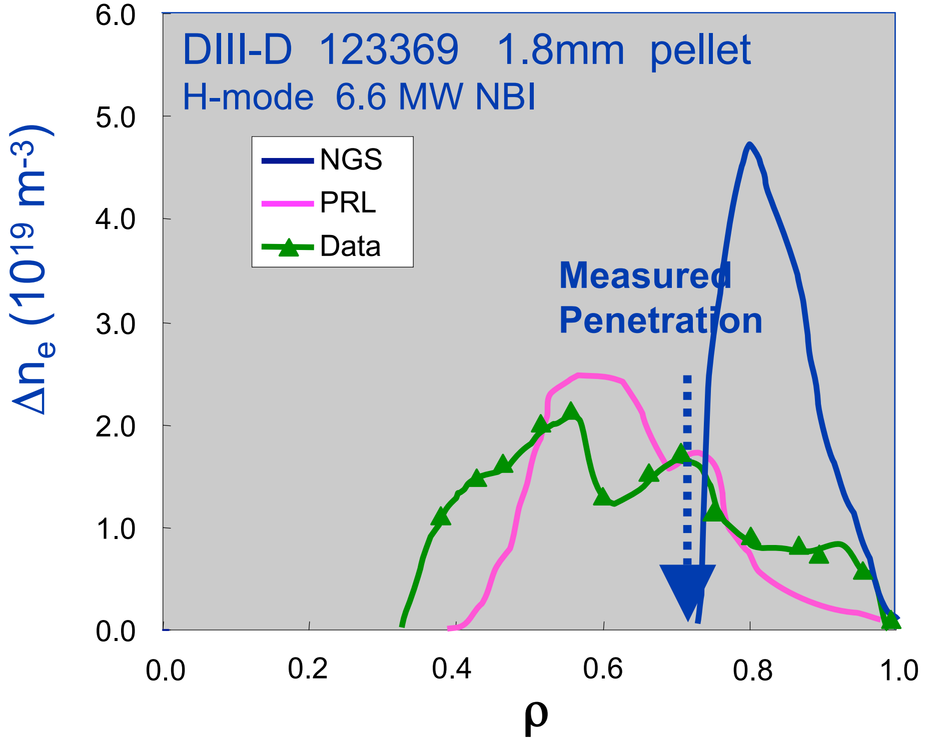
- The PRL code uses the pellet size and plasma parameters at each point along the ablation track determined by PELLET ablation code [Houlberg, 1988] to calculate the penetration of a cloudlet originating at that point.
- The experimental plasma profiles are used by PRL to calculate the subsequent cloudlet pressure relaxation and drift velocity.
- The ablation deposition is then shifted for each cloudlet to give a resulting net plasma density profile, which can be compared with experiment.
- Cloudlet density evolution (DIII-D 98796) is shown on a density contour plot with minor radius vs field line length.





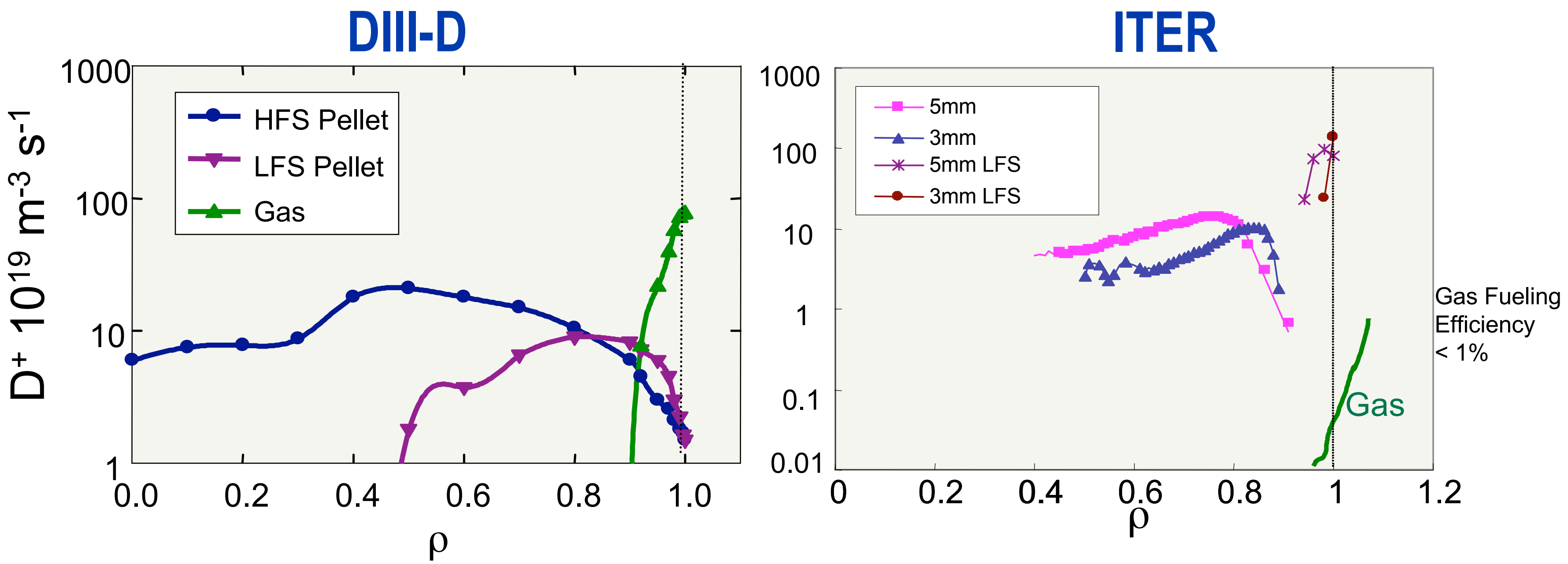
Inner Wall Injected Pellets Result in Deeper Deposition than Ablation Model Predictions





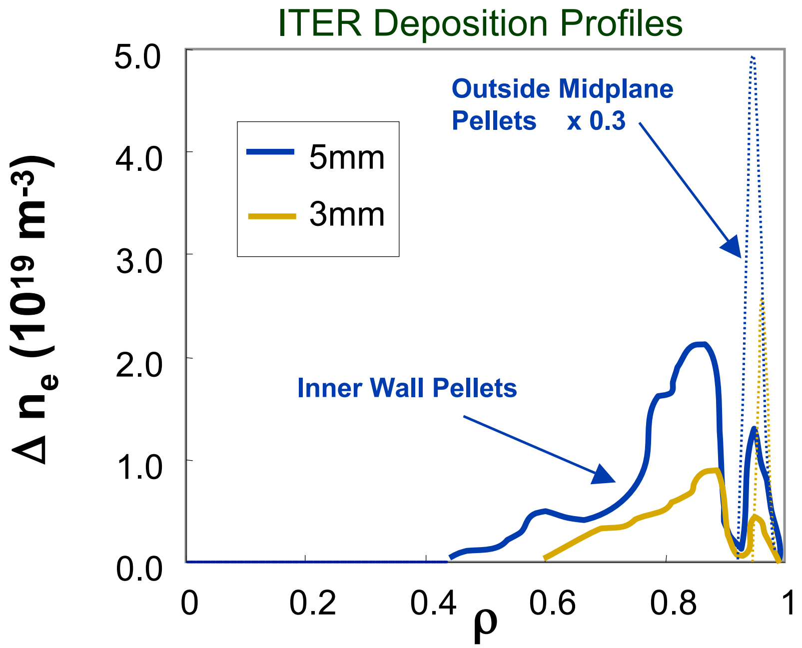
- The measured mass deposition depth from Thomson scattering measurements is significantly enhanced over that from the NGS ablation model. When ExB drift effect is added good agreement is obtained.

Pellet Injection is Crucial for Effective Core Fueling in ITER as Shown in H-mode Fueling Source Profile Comparison



- **Gas puff core fueling in ITER will be much less effective than in DIII-D**
  - **ITER pellet profiles are from PRL** (P. Parks) **(5-mm @ 16 Hz)**
  - **gas fueling rate of ~1000 torr-L/s for ITER case B2-Eirene slab calculation** (L. Owen and A. Kukushkin)

Density Change in ITER as a Function of Inner Wall Pellet Size



- Pellet fueling deposition calculations from PRL for ITER with different size pellets. Larger pellet size yields marginally deeper mass penetration. Mass drifts well beyond the pedestal for both pellet sizes. Outside midplane injection deposition profiles (dashed) with no drift are shown for comparison.
- Pellets injected into the same discharge conditions from the inner wall guide tube port. (H-mode, $T_e(0)$ = 20 keV, T_{ped} = 4 keV, Δ_{ped}=0.04)

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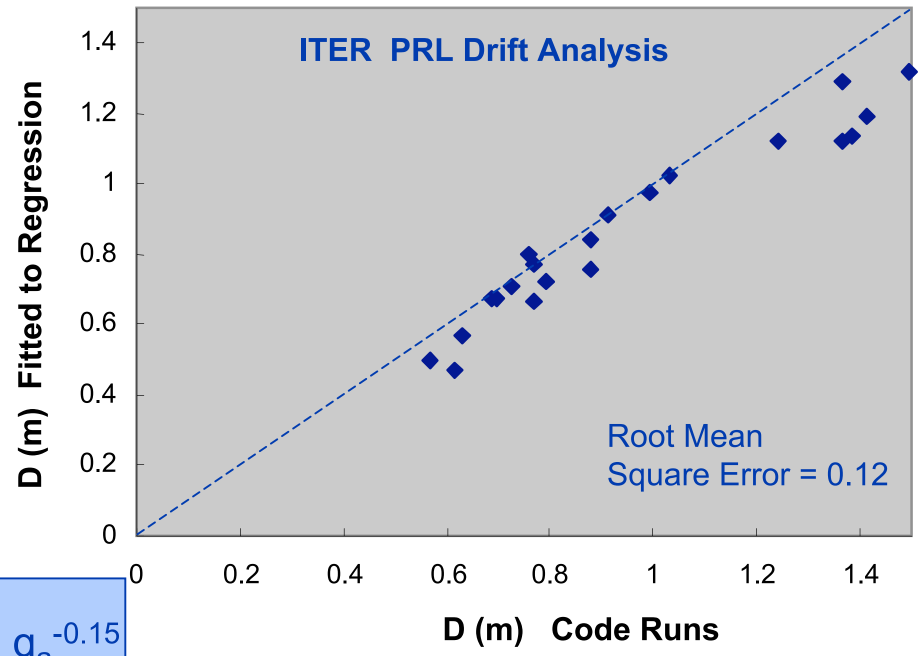
PRL Drift Distance Scaling for ITER – Similar to DIII-D Experimental Scaling

- Deriving the drift scaling from the PRL model is complicated and requires a statistical approach.
- Regression analysis and Analysis of Variances (ANOVA) is used on a set of PRL runs for ITER inner wall pellet injection with different input parameters to obtain the following scaling:



$$\text{Drift} = C * B_t^{-0.15} * T_{e0}^{-0.13} * T_{eped}^{0.5} * r_p^{0.76} * q_a^{-0.15}$$

D	Constant	Bt	Te0	Teped	rp	qa
Exponent	-0.538	-0.147	-0.128	0.5	0.764	-0.149
SD		0.116	0.09	0.06	0.094	0.082
T		-1.275	-1.4	8.28	8.15	-1.82
P		0.227	0.187	0	0	0.094

Most significant contributions

Final Comments

- **ITER will require significant fueling beyond that provided by gas**
    - Gas fueling and recycling expected to be very inefficient
- **Inner wall injection port will allow up to 300 m/s pellet injection**
- **Modeling of the proposed ITER pellet injection scenario looks promising for core fueling well beyond the H-mode pedestal**
    - Further validation of the ExB polarization drift model is needed with diagnostics and scaling studies
- **ELM Mitigation with small pellets may be another application for the pellet injection system.**
- **The pellet fueling system for ITER presents challenges for the technology developers in throughput and reliability, concepts look promising**
    - Development is underway and expected to take ~ 5 yrs
    - Extruder and accelerator prototypes will be produced which can be available to test on existing tokamak devices