Pellet Fueling Scoping Studies for NSTX

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Pellet Fueling Rationale and Vision for NSTX

- A pellet injection system can provide the fueling flexibility to optimize ST performance.

- The vision of an optimized fueling system for NSTX is one that provides:
  - > Edge or central fueling
  - > Minimized recycling
  - > Repetitive - 10 Hz with ~10% perturbations
  - > Reliable operation
  - > Alternative injection locations for optimized penetration
  - > Matched to NSTX high performance discharges

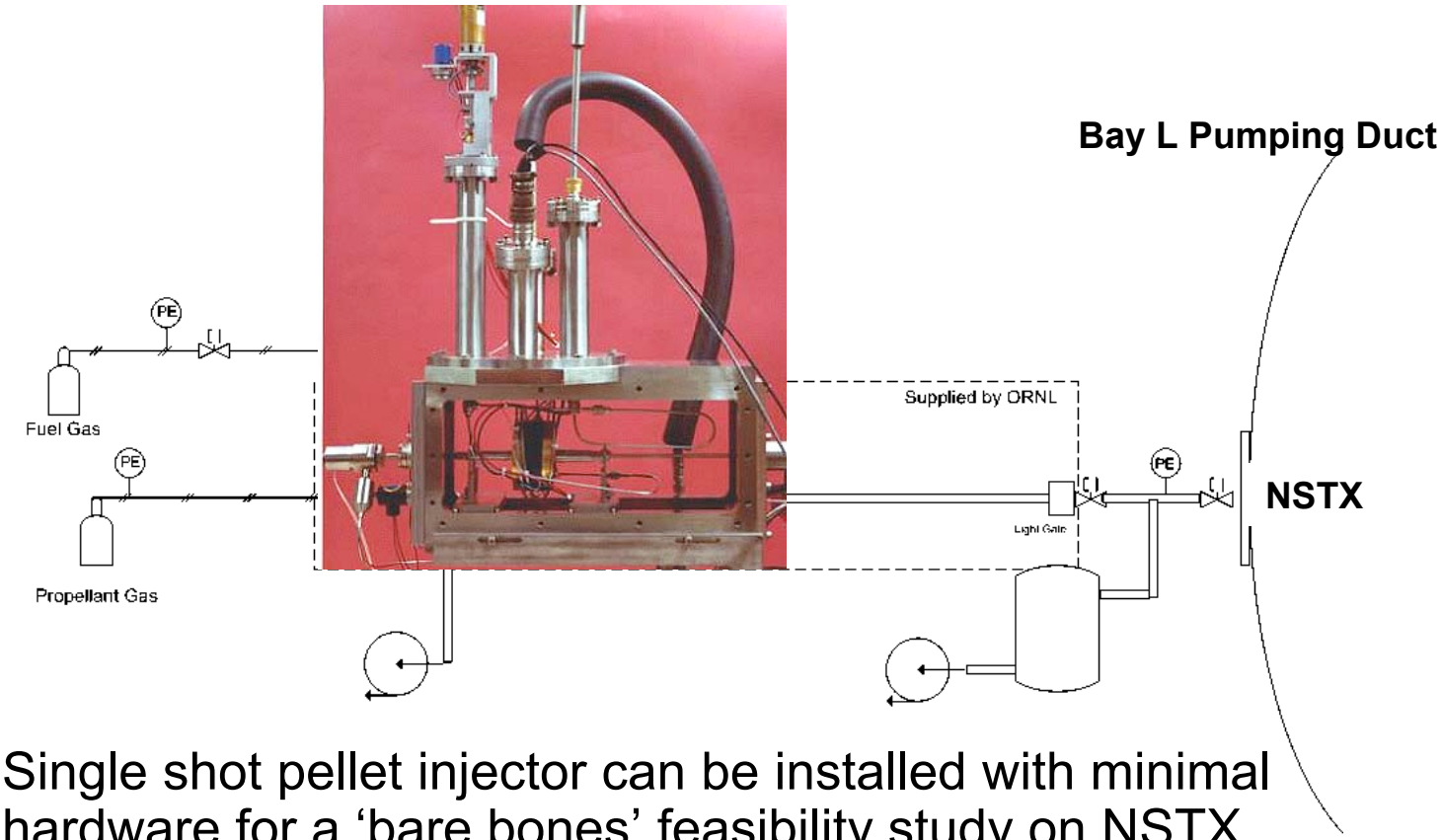
- A single-shot pellet injector could be the first step toward realization of these goals. A future step is the use of a simple multi-shot injector (pellet injector in a suitcase).

A Single Shot Pellet Injector is Available for Scoping Studies on NSTX in FY'03.

- A single shot pipe-gun pellet injector has returned from use on W7-AS, which recently shut down.
- The injector and associated electronics are available for use on other confinement experiments – e.g. NSTX.
- Minimal effort is necessary to install the injector on Bay L for initial scoping studies of pellet fueling during FY'03.
- Such an injector can be used as a prototype for a more extensive multi-pellet injection system to be installed in the future.

Single Shot Pellet Injector Installation on NSTX

ORNL Single Shot Pellet Injector



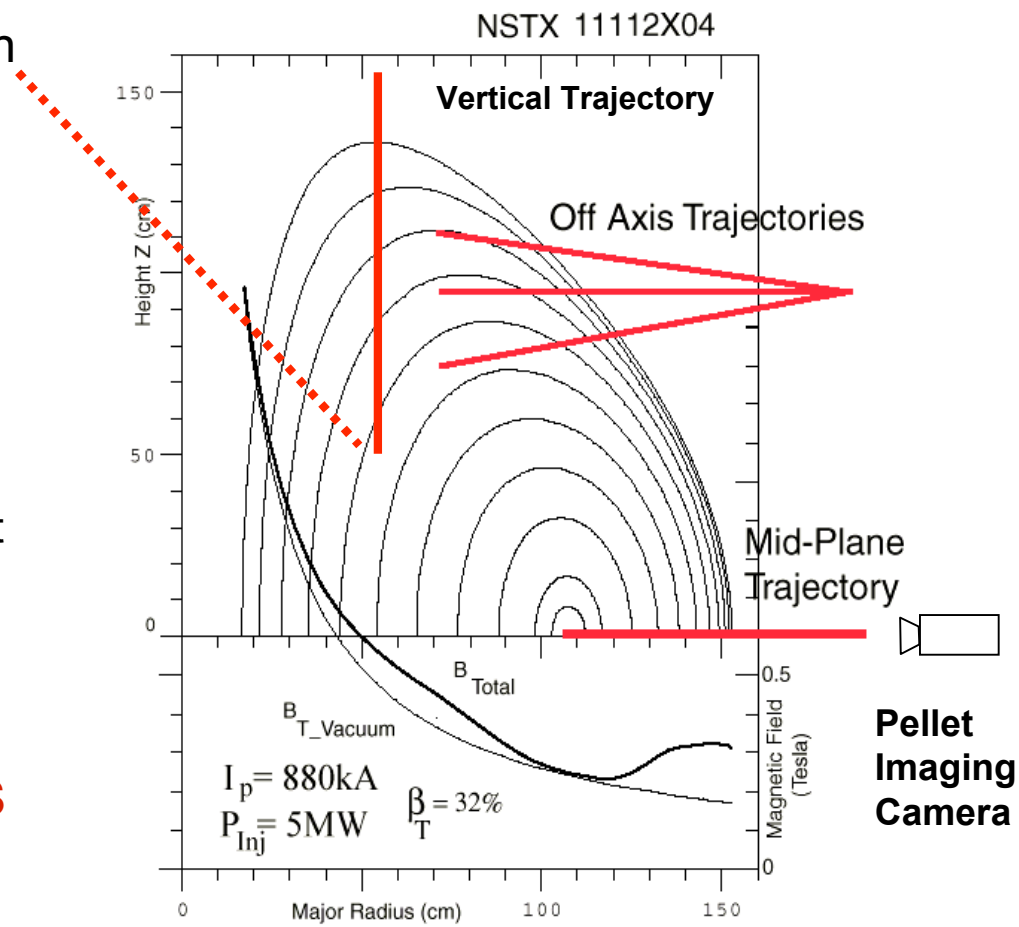
- Single shot pellet injector can be installed with minimal hardware for a ‘bare bones’ feasibility study on NSTX.

D_2 Pellet Fueling Experiments for NSTX in FY'03

- **Single pellets can be used to test feasibility of profile control for advanced confinement regimes**
  - Creation of peaked density profiles
  - Off-axis peaking of the bootstrap current and shear reversal, **PEP-mode ITB** with $T_e \sim T_i$ (JET, TFTR, DIII-D, C-MOD)
- **Core and edge particle transport studies**
  - **Density perturbations** of main species and impurity doped pellets for impurity studies (Ne, Ar, CH_4, …)
  - Tool for **L -> H mode transition** physics and pedestal control
- **Pellet injection to control density or extend the NSTX operating regime to high density -> high β**
  - Early injection can minimize wall loading and enhance density control
  - A single 2.7mm D_2 pellet can more than double the maximum n_D achieved on NSTX
- **Also a diagnostic for q-profile determination**
  - Pellet cloud inclination leads to direct **measurement of q profile** for assessment of high β NSTX plasmas.

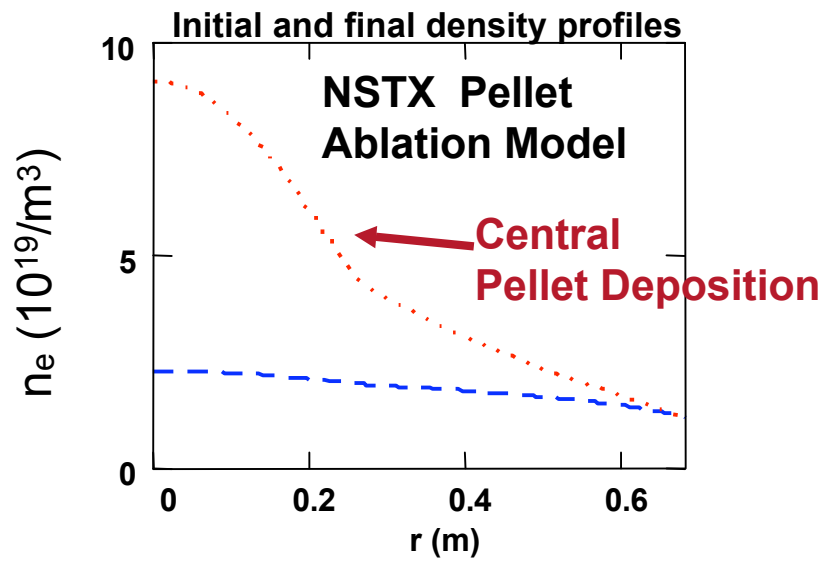
Proposed Injection Geometry for NSTX

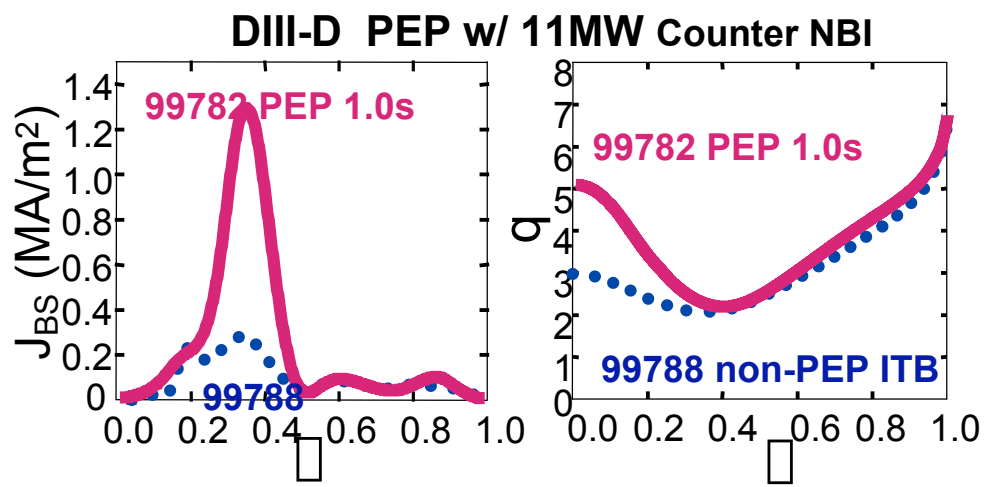
- Several injection trajectories can be used to investigate different NSTX physics objectives:
  - Outside midplane - ITB formation, density limit, transport, ∇B drift
  - Off axis - ITB formation with off axis shear in rotation
  - Vertical - HFS fueling, transport (comparison with DIII-D and JET)
  - Tangential
- For NSTX, ∇B is inward on LFS in high beta cases, which may yield inward drift of pellet ablatant instead of outward drift seen in tokamaks.



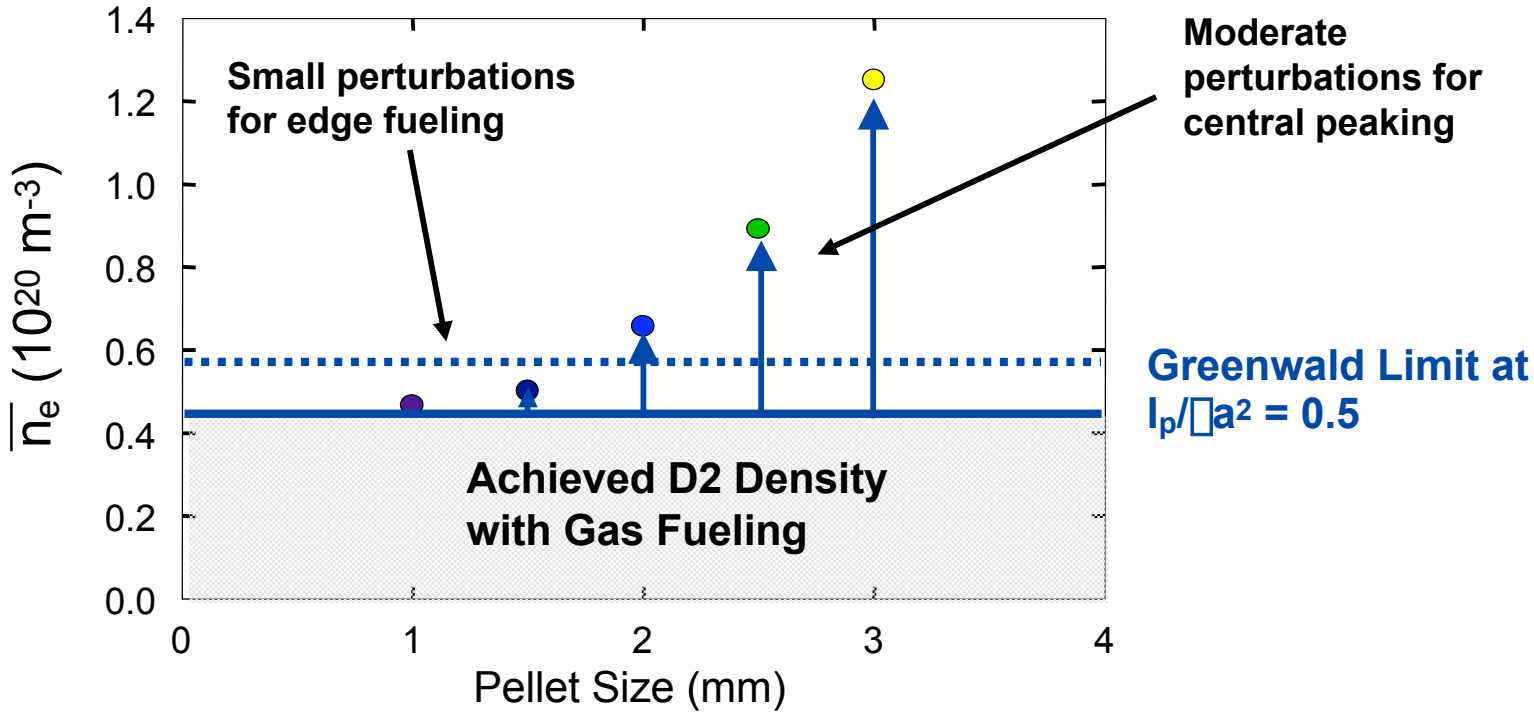
Central penetration gives steep density gradients for advanced performance

- Example when pellet "expires" on axis :
  - 1.8mm, 1 km/s, $T_e(0)$ = 1.5keV
  - Shafranov shift reduces distance to axis
  - model uses self limiting ablation (finite heat reservoir of flux surfaces)
- Expected to produce strong off axis peaking of the bootstrap current and shear reversal as observed on DIII-D.
- PEP-ITB using NBI and HHFW with $T_e \sim T_i$



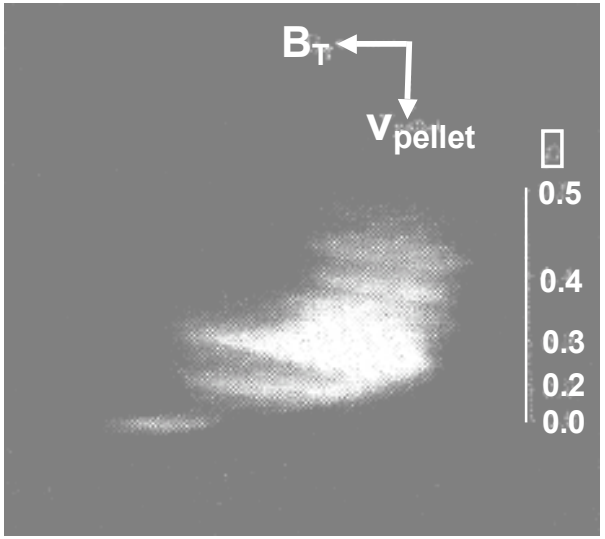


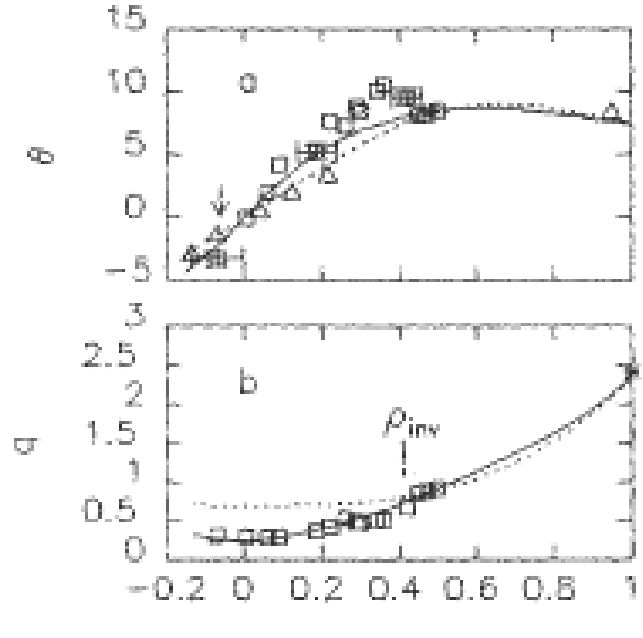
Flexibility in Density Control with Pellet Size is Possible in NSTX



- Early injection of small pellets (1-1.8mm) can minimize wall loading and modify pedestal density.
- Large pellets (2.7mm) can centrally fuel for peaked density profiles
- START achieved $n_e(0)$ of 5×10^{20} m^{-3}, n_{GW} of 1.6 with vertical pellet injection

Determination of q-profile with Pellet Cloud Imaging



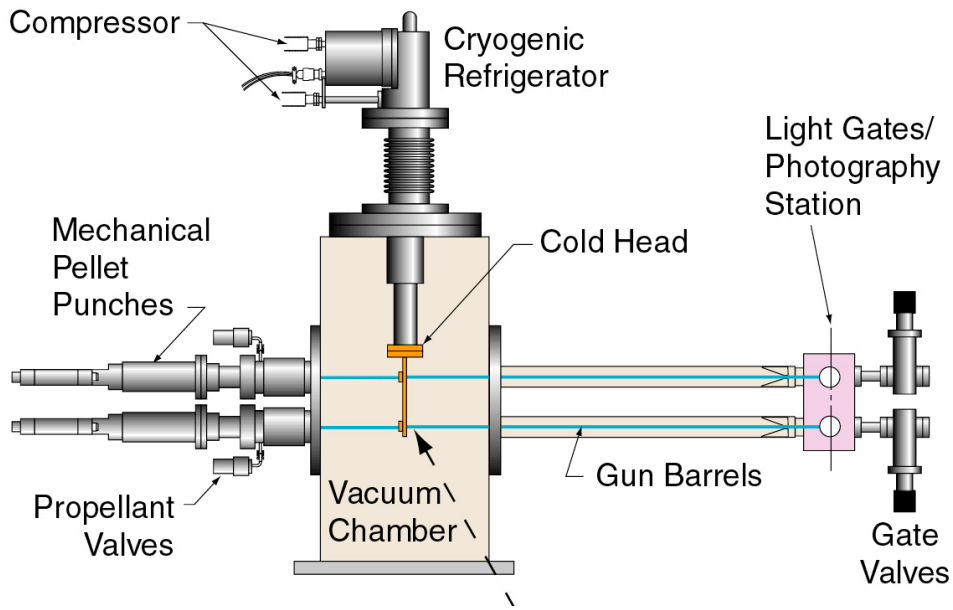


- Time integrated camera image of pellet cloud shows that the inclination varies with penetration. (Durst et al, RSI (1988) 1623; Bose C-Mod). Faster CCD camera technology can greatly improve the images and q profile determination.

- The inclination and determined q profile as functions of flux-surface coordinate on TEXT indicate the ability to determine the q profile in high □ NSTX plasmas (Te(0) ~ 1 keV allows deep pellet penetration).

Advanced pellet fueling system can be obtained at low-cost using existing designs and components

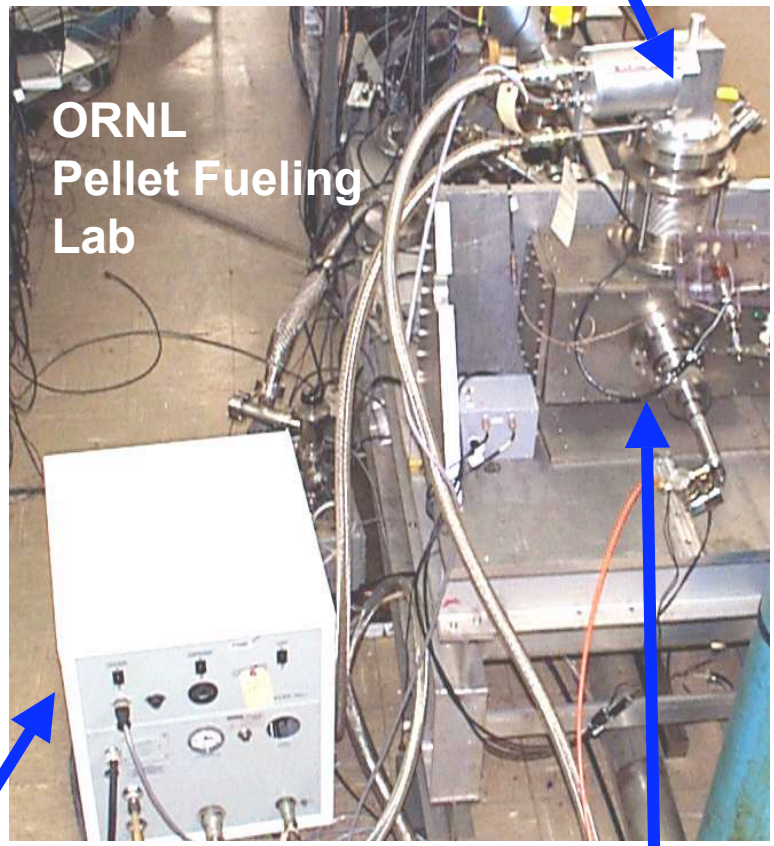
- NSTX machine size and target plasmas well matched to simplified pellet injection system
  - 4 - barrels , 1.0 - 2.7 mm diameter ($5x10^{19}$ – $9x10^{20}$ atoms), 200-1500 m/sec pellet speed
- Simplified advanced design utilizes self contained LHe refrigerator – external LHe supply not required



Proposed Pellet Injection System for NSTX

- Pipe-gun (in situ condensation) developed in technology program using cryorefrigerator and minimal pumping system ("Pellet injector in a suitcase")
  - 1.0 - 2.7 mm diameter ($5x10^{19}$ – $9x10^{20}$ atoms), 200-1500 m/sec pellet speed
- Steerable guide tube for tangential/poloidal injection for central or off-axis density pertubations

Cryorefrigerator - cold head



Cryorefrigerator compressor

Pipe-gun with mechanical punch

Summary

- **Pellet injection provides several new capabilities to NSTX:**
  - Early injection to minimize wall loading
  - Peaked density profiles for off-axis bootstrap and shear reversal (PEP-mode ITB) with $T_i \sim T_e$, (unlike other ITB regimes)
  - Extending operating regime to high density ($n > n_{GW}$)
  - Particle confinement and transport studies (including doped pellets)
  - q-profile determination with pellet cloud imaging
  - Triggers for L to H-mode transitions for reduced power threshold
- **Flexible low-cost pipe-gun injector system proposed for installation on NSTX**
  - 1 - 4, ~1.8 & 2.7 mm pellets, 200-1500 m/s, injection line for central or steerable off-axis density perturbation
  - More flexible than MAST system, which uses low speed outside midplane injection
- **Physics program to assess high confinement, high β scenarios and pellet-plasma interactions**