EUROfusion

A Pellet Injector for performing Plasma Fuelling Studies Pellet on TJ-II

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Outline of Talk

- Introduction
- TJ-II & Pellet Injector Overviews
- Review of Pellet/Plasma Interactions in TJ-II
- First Plasma Density/Power Scan
- Summary

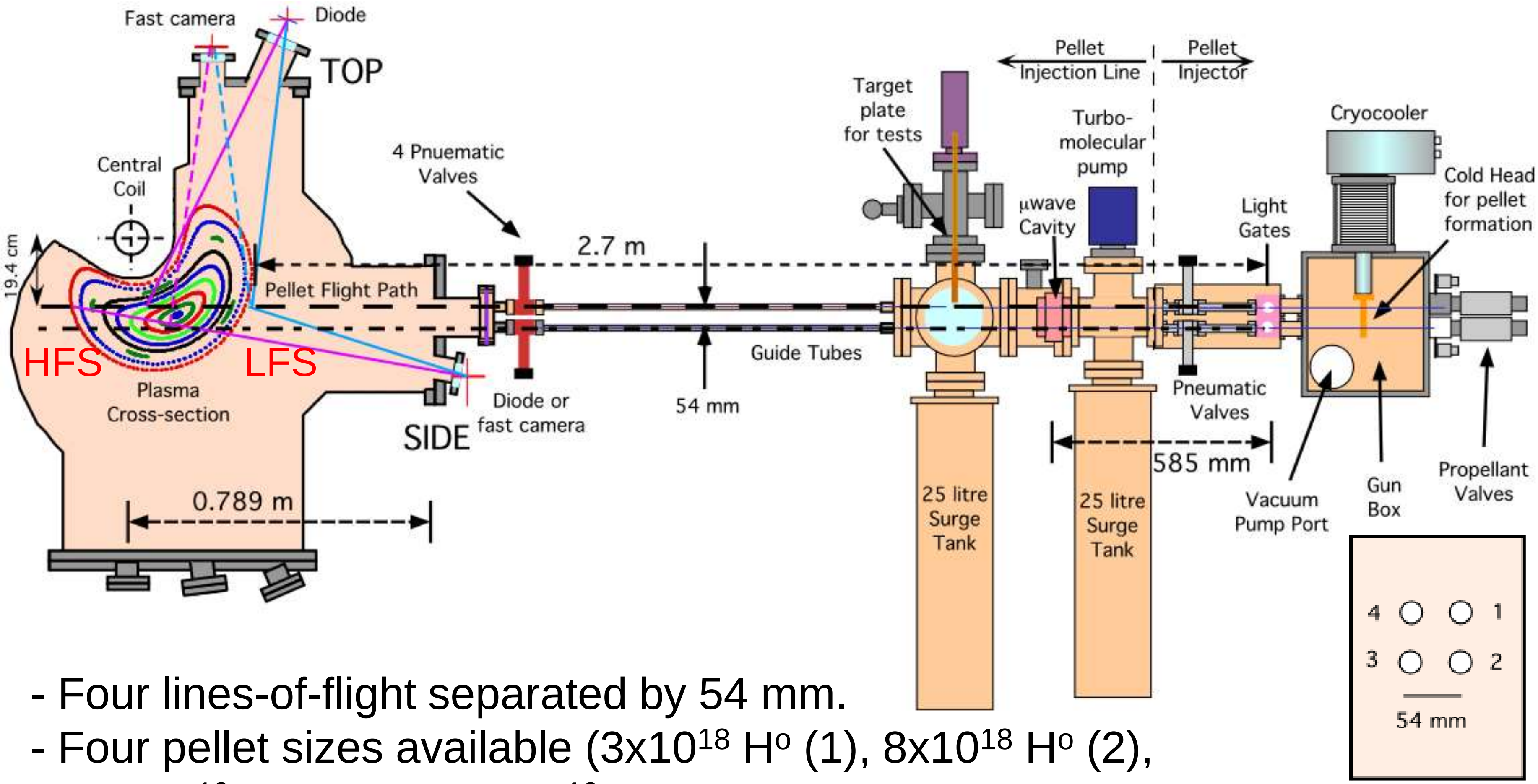
Introduction

- First studies on TJ-II with pellet injector performed are intended as a learning process for the TJ-II group.
- Results of plasma density/power scan to be included in "Comparative Study of Pellet Fuelling in 3-D Magnetically Confined Plasma Devices" to be presented by K.J. McCarthy at 20th ISHW in Greifswald.
- Provide data for particle transport studies (J. L. Velasco).
- Knowledge/experience acquired will allow us to participate in future W7-X pellet injection studies.

TJ-II Stellarator

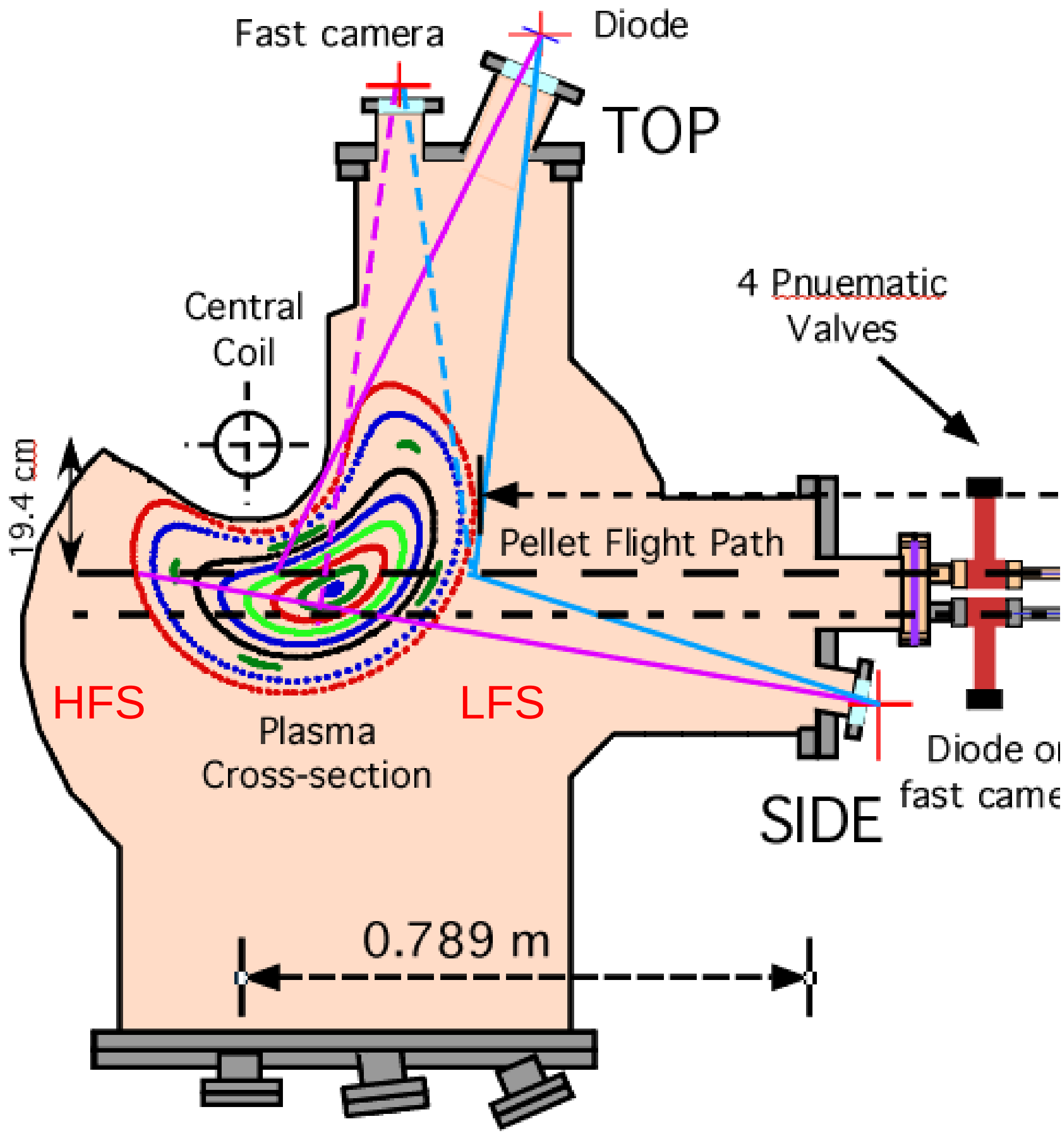
- 4-period, low magnetic shear, stellarator (R = 1.5 m, $\langle a \rangle$ = 0.22 m, B(0) = 1 T, $t_{pulse} \leq 300$ ms, $0.9 \leq \iota(0)/2\pi \leq 2.2$).
- Plasmas are created with H_2, D_2 or He as the working gas.
- Plasma volume ~1 m^3.
- With 500 kW of ECRH at 53.2 GHz; $n_e(0) \leq 1.7 \times 10^{19}$ m^{-3} & $T_e(0) \leq 1$ keV (out of service 2014 to June 2015).
- 1 MW of NBI (co- & counter); $n_e(0) \leq 10^{19}$ m^{-3}, $T_e(0) \leq 400$ eV.
- Wall conditioning with lithium coating (over boron) on inner walls plus short helium glow discharge.
- Wide range of plasma diagnostics.
- Magnetic gradient ~0.9 T/m.
- Traditionally we have used gas puffing -> pellets since June 2014.

TJ-II Pellet Injector



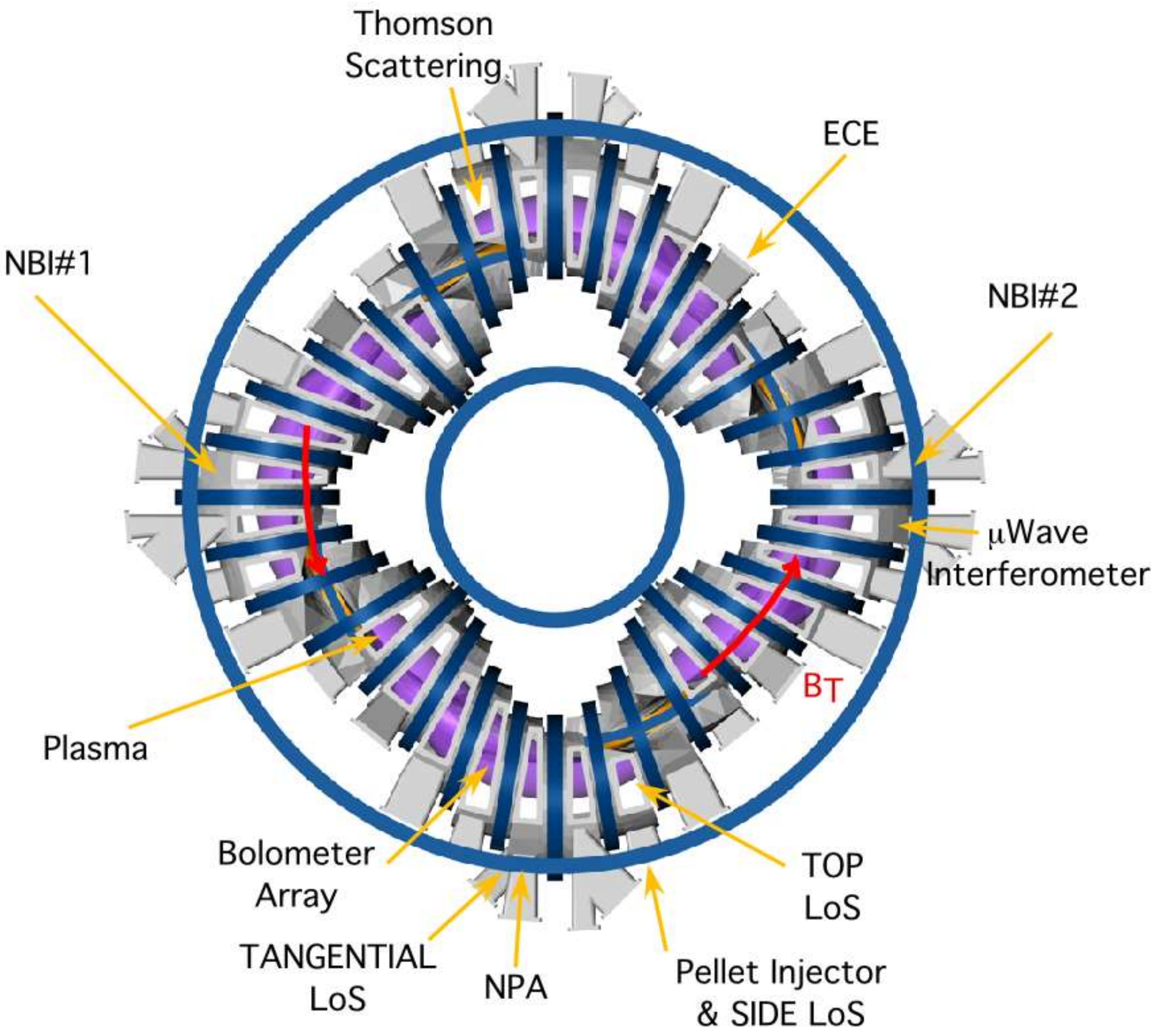
- Four lines-of-flight separated by 54 mm.
- Four pellet sizes available ($3x10^{18}$ H^o (1), $8x10^{18}$ H^o (2), $1.5x10^{19}$ H^o (3) and $3 x10^{19}$ H^o (4)) with +/- 30% variation in mass.
- Injection from LFS only (straight guide tubes).
- Injection velocities (800 to 1200 m/s) - propellant gas system.
- Hydrogen pellets (deuterium also possible).

TJ-II Pellet Injector



- In-line Lightgate and Microwave Cavity provide timing (velocity) and mass signals.
- Hα emission from pellet cloud followed using wide view-angle Si diodes or APD.
- Fast camera with coherent fibre bundle images from above (side & tangential ports available).

Associated Diagnostics



- Thomson Scattering: once per discharge.
- 16 channel ECE (10 ms resolution).
- Ion temperature from 2 NPAs.
- μWave Interferometer provides line-averaged density.
- Bolometer arrays, HIBP, Mirnov coils.

Pellet/Plasma Interaction

To date different pellet types have been injected into standard configuration plasmas (100_44_64) with the aim of

- Achieving correct operation of PI and associated diagnostics.

- Correlating Hα signals with pellet radial location in plasma for each pellet type.

- Correlating Hα signals with pellet ablation rates and particle radial deposition.

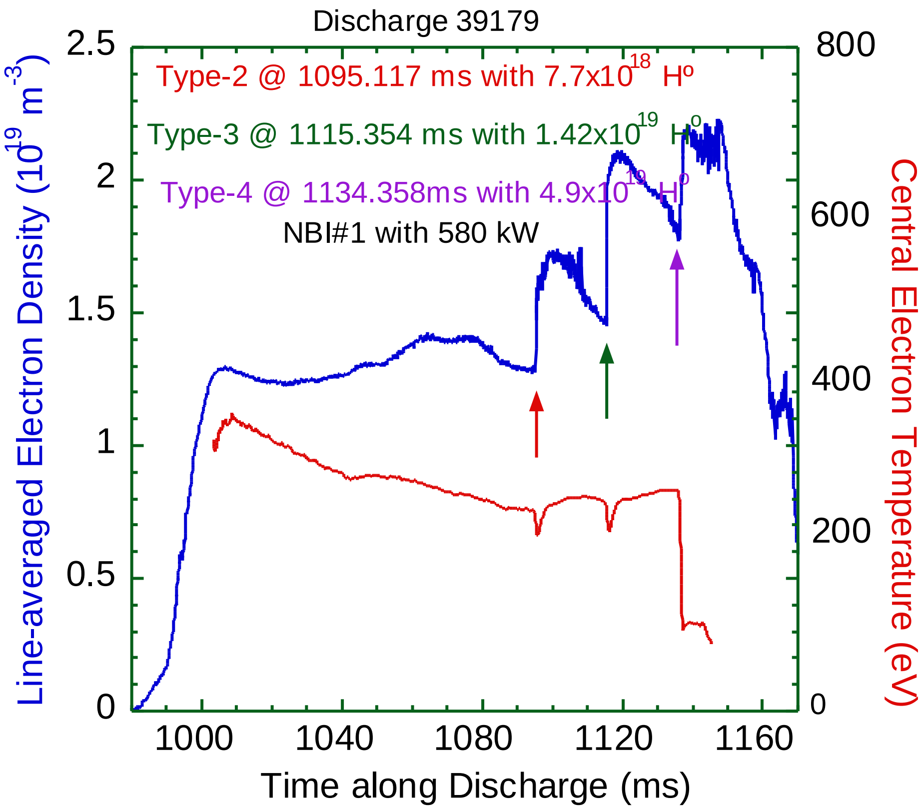
- Benchmarking Hα signals with modelled Hα signals for NGS.

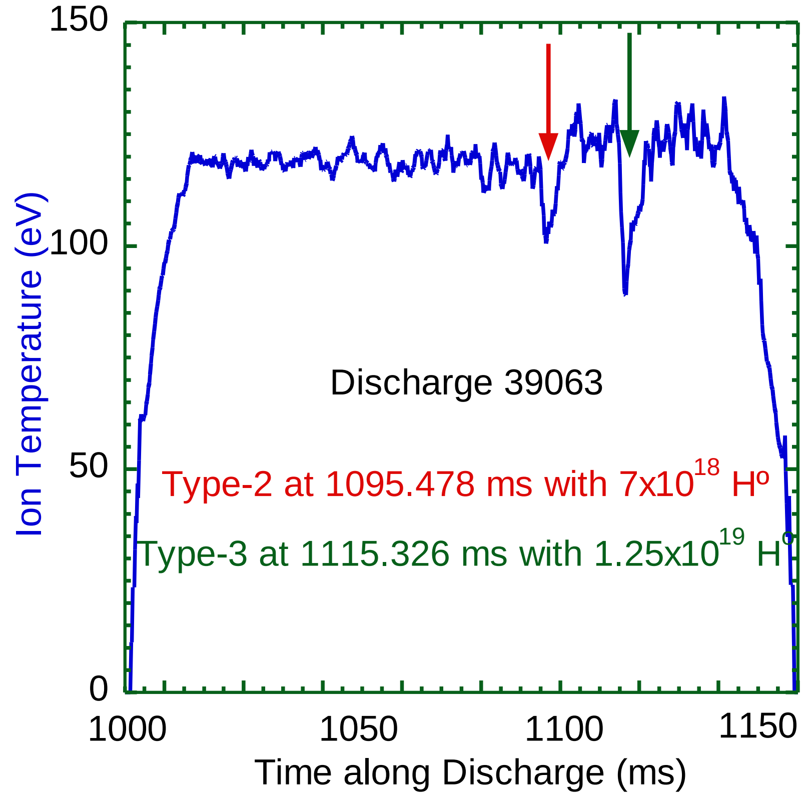
- Identifying structures in Hα signals (striations, etc).

- Correlating Hα signals with fast camera images.

- Studying the evolution of density/temperature profiles during and immediately after injection (drift, diffusion).

Pellet/Plasma Interaction



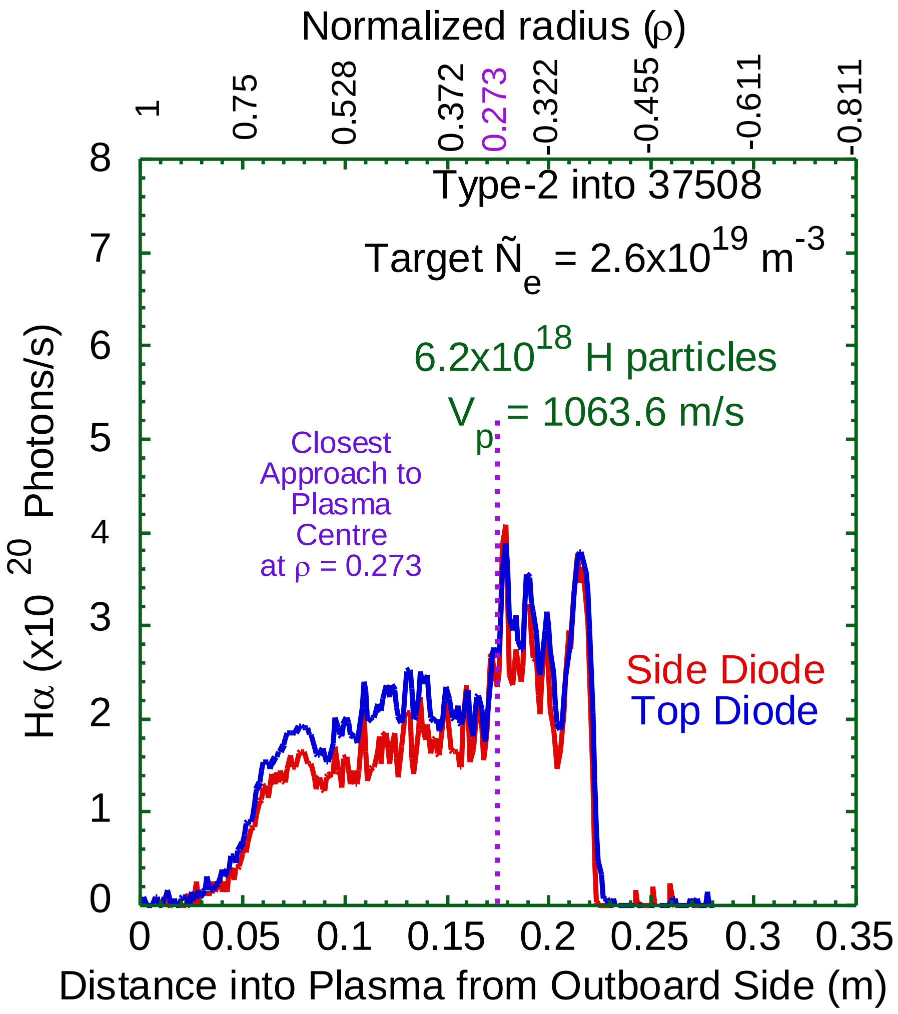


- Have injected up to 3 pellets per discharge (3 sizes) with $\Delta t \geq 20$ ms.

- NBI-only plasmas, $t_{discharge} \leq 160$ ms

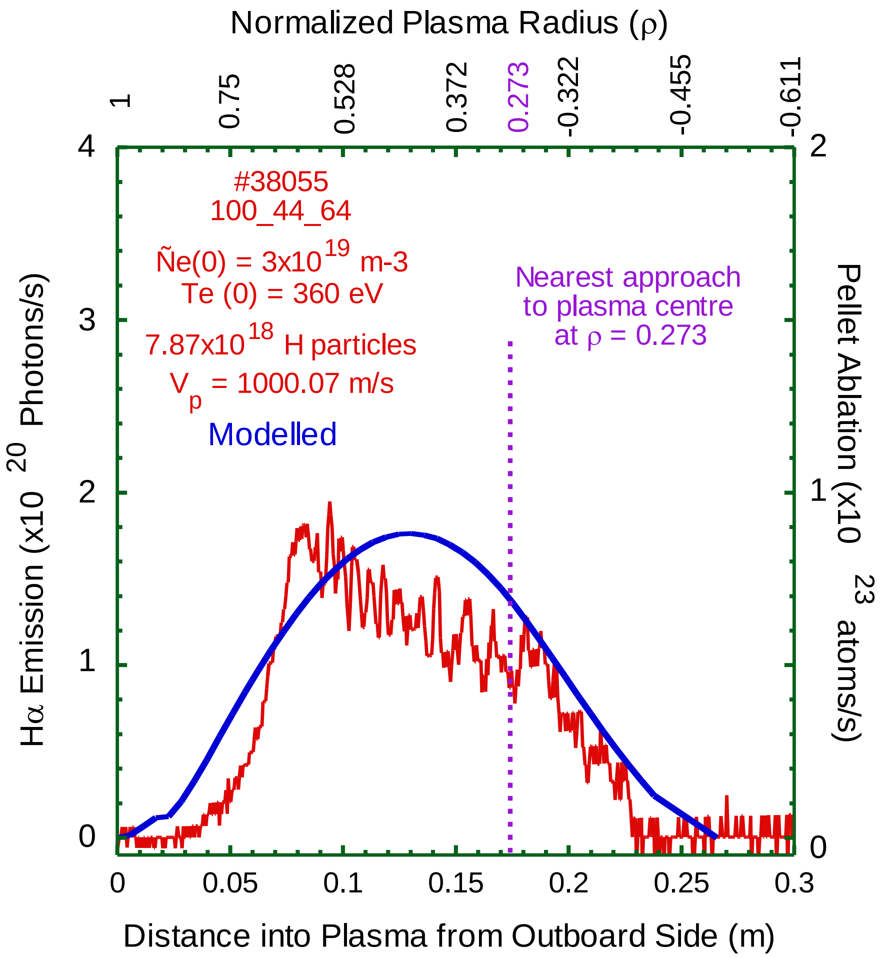
- For ECRH or ECRH & NBI, $t_{discharge} \leq 300$ ms.

Pellet/Plasma Interaction



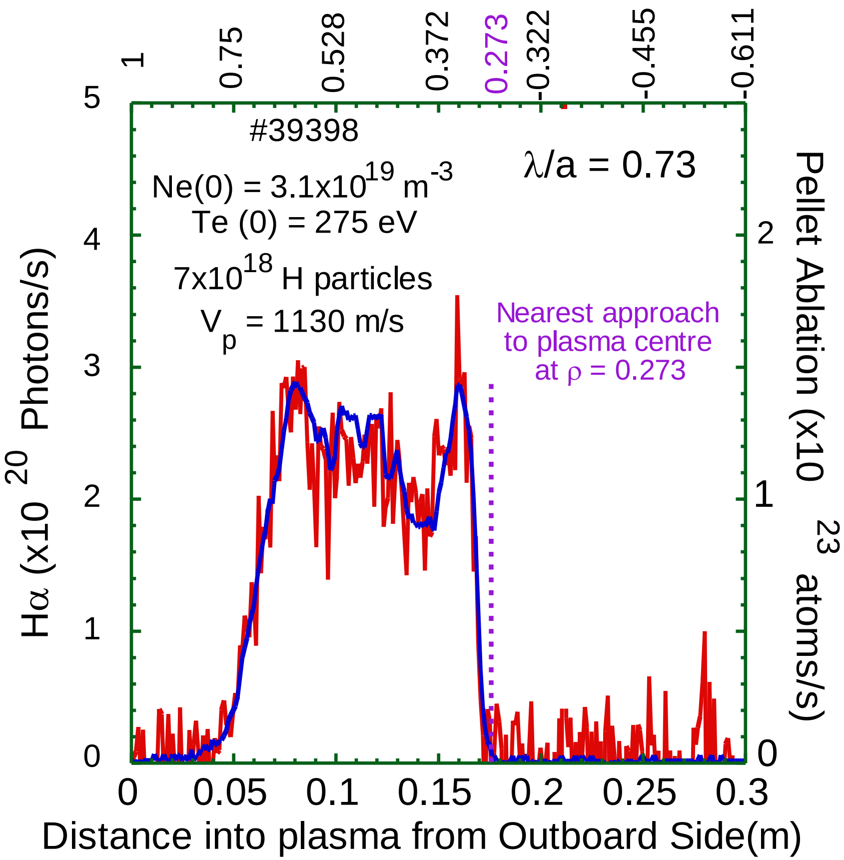
- Hα signals allow us to follow pellet penetration into plasma and to determine penetration depth.

Pellet/Plasma Interaction



- Reasonable agreement with modelled curve (i.e. NGS with NBI heating - Y. Nakamura et al., Nucl Fusion 26 (1986) 907).

Pellet/Plasma Interaction

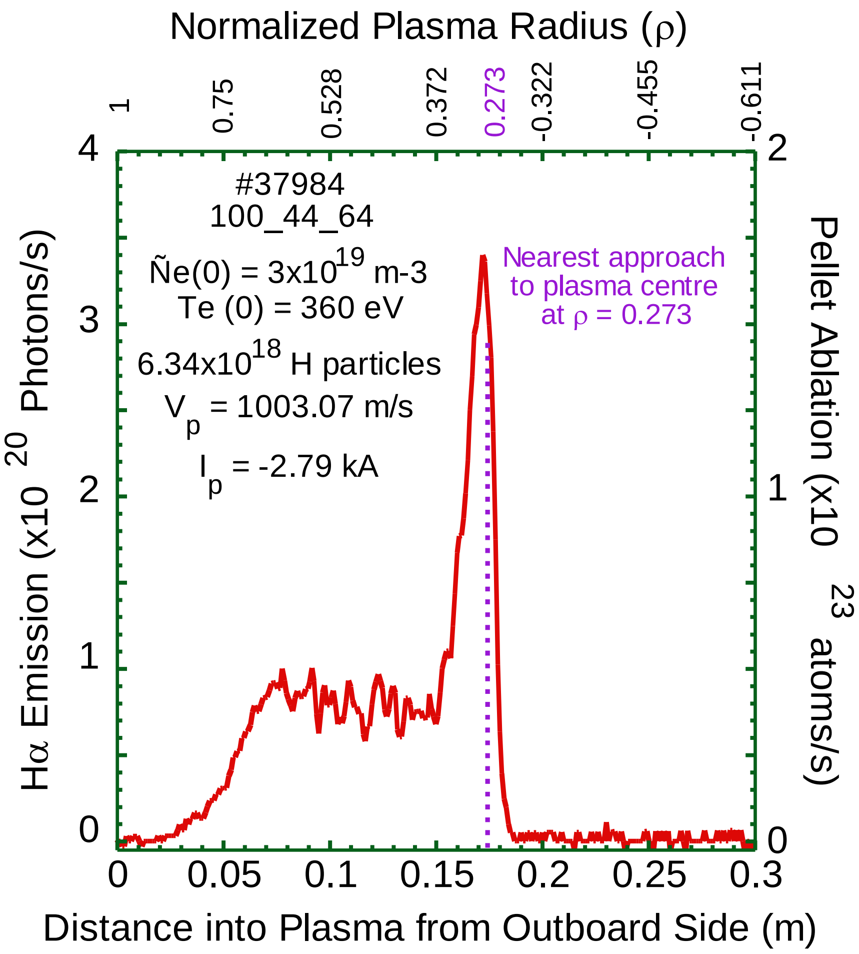


- Penetration Depth, λ/a, use C = 0.05 with NGS Scaling.

$\lambda/a = C\, T_e(\text{keV})^{-5/9}\, N_e(10^{20}\ \text{m}^{-3})^{-1/9}\, m_p(10^{20}\ \text{atoms})^{5/27}\, V_p(\text{m/s})^{1/3}$ where C = 0.079

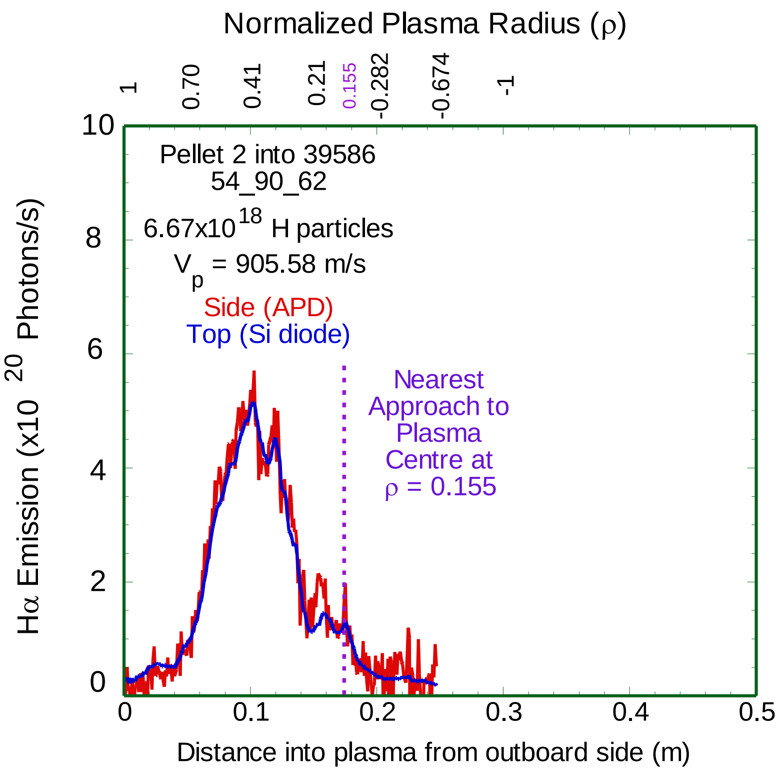
International Pellet Ablation Database by L. Baylor

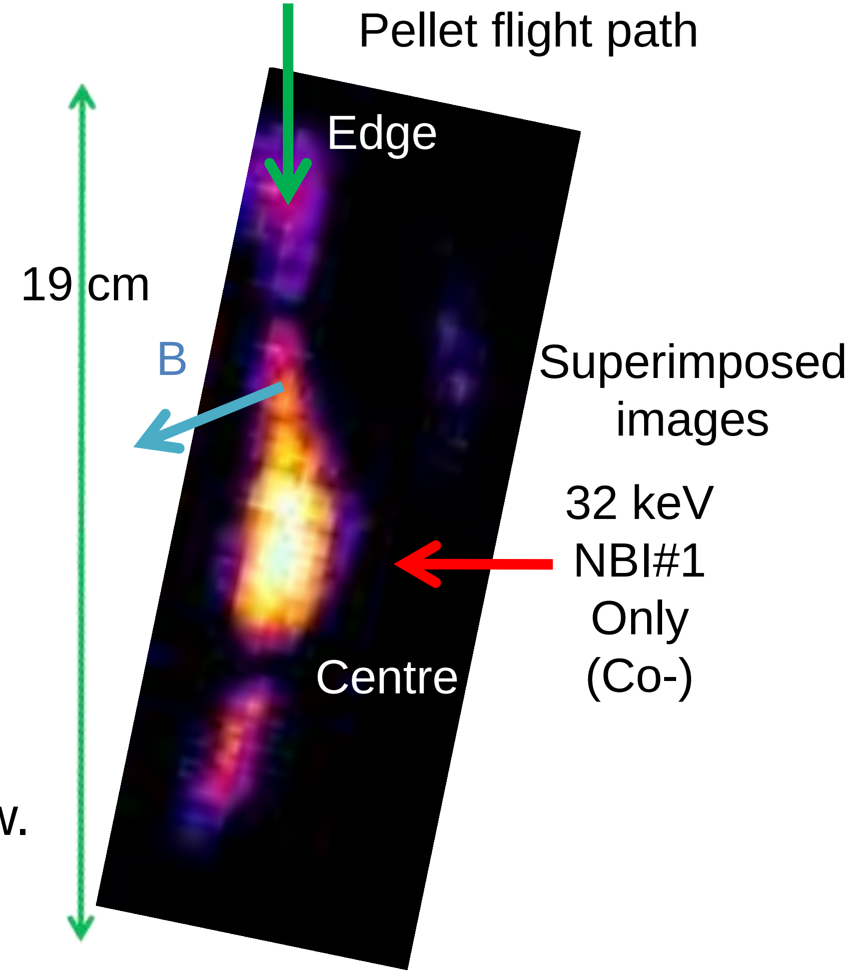
Pellet/Plasma Interaction



- Enhanced ablation & pellet destruction observed when $I_p \geq \sim 2$ kA (suprathermal electrons near plasma centre generated during plasma start-up in this NBI only operation mode).

Pellet/Plasma Interaction

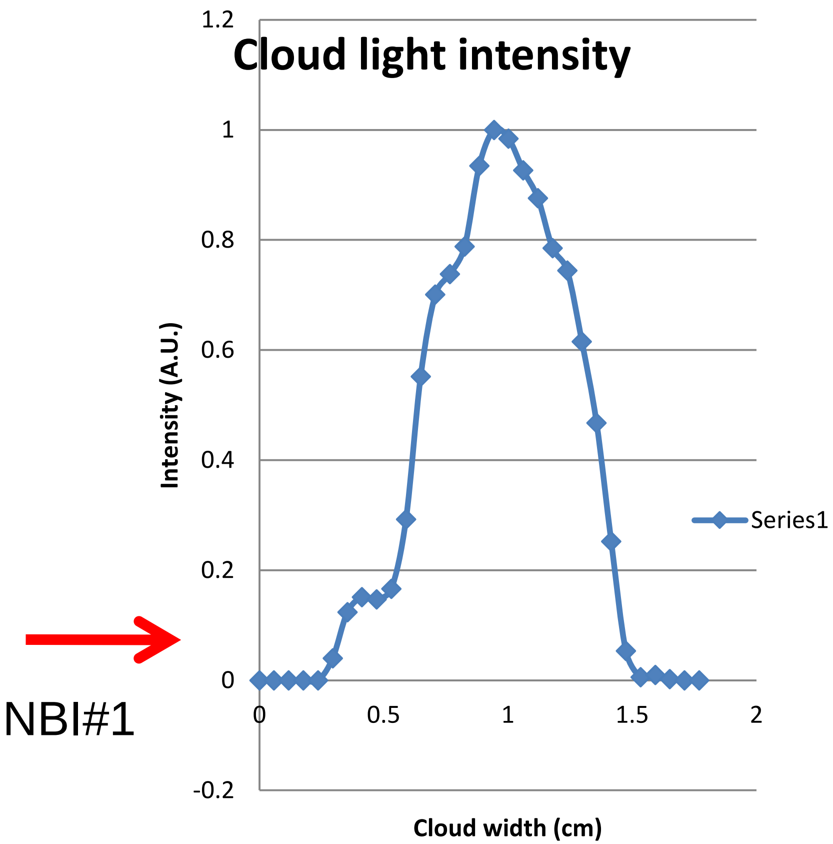


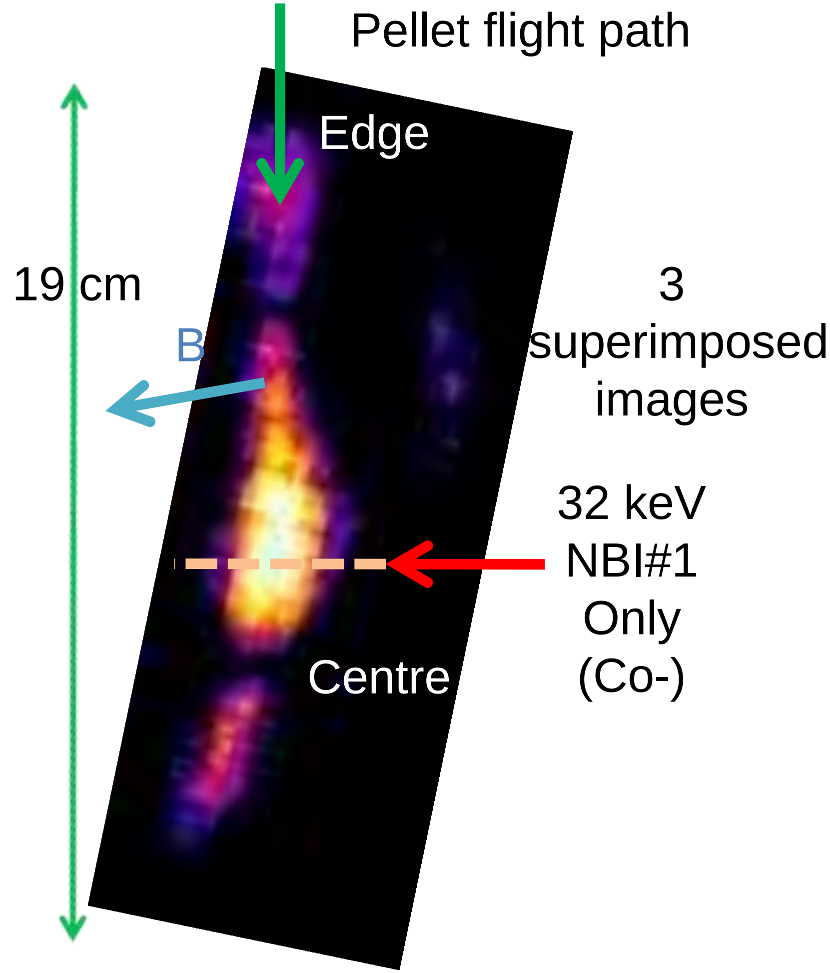


- Fast camera operating from Upper Window.
- Curvature of pellet trajectory (ablation by fast ions or difference of heat fluxes onto pellet surface in this direction?).
- Cloud narrowing after centre -> strongly reduced ablation due to drop in T_e caused by pellet when approaching centre.

Speed = 31.5 kfps
τ_{exp} = 31.75 μs
W X H = 128 X 320 pixel
1 pixel = 0.59 mm

Pellet/Plasma Interaction

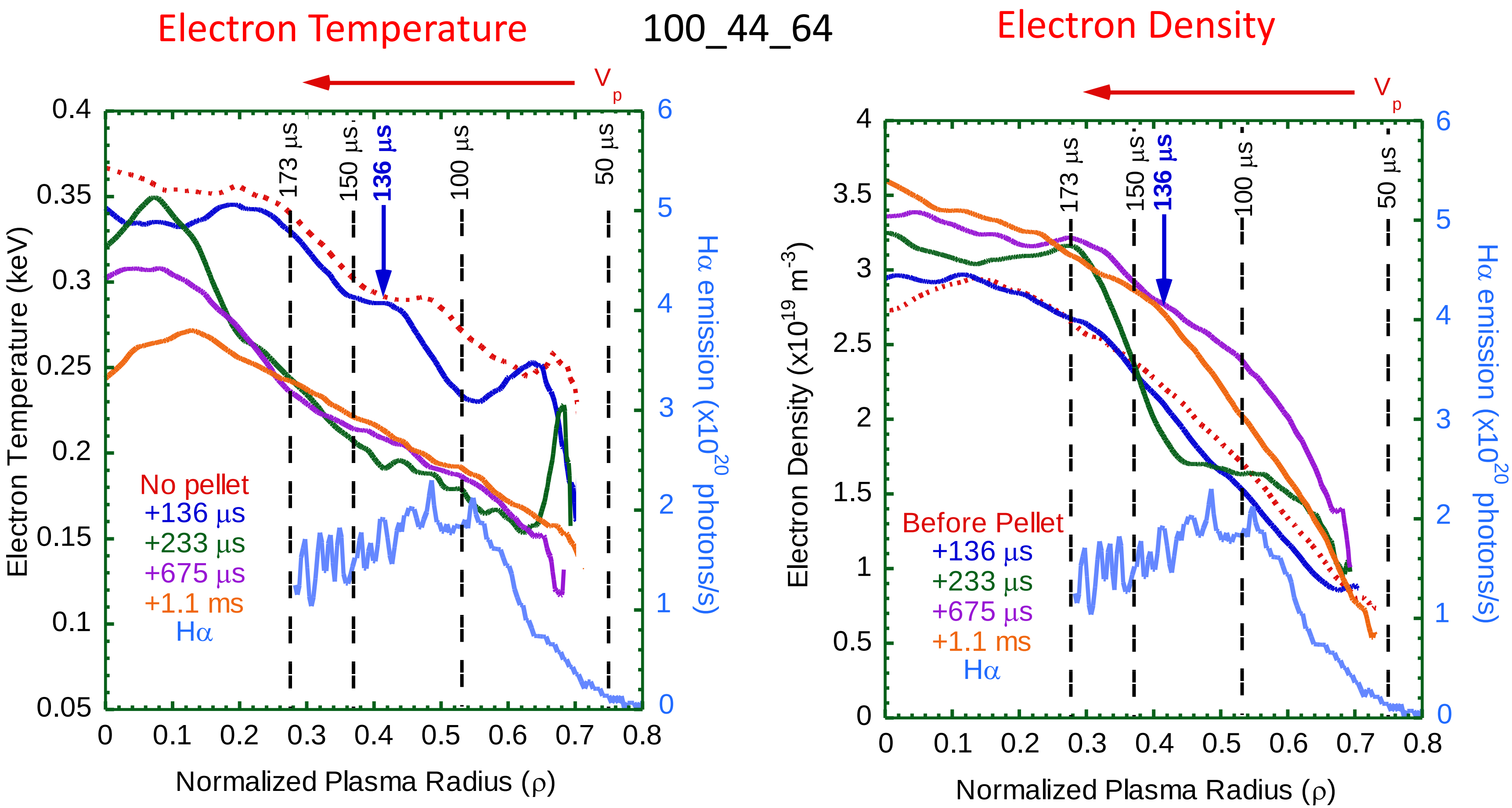




- Slight asymmetric light distribution seen in toroidal direction.

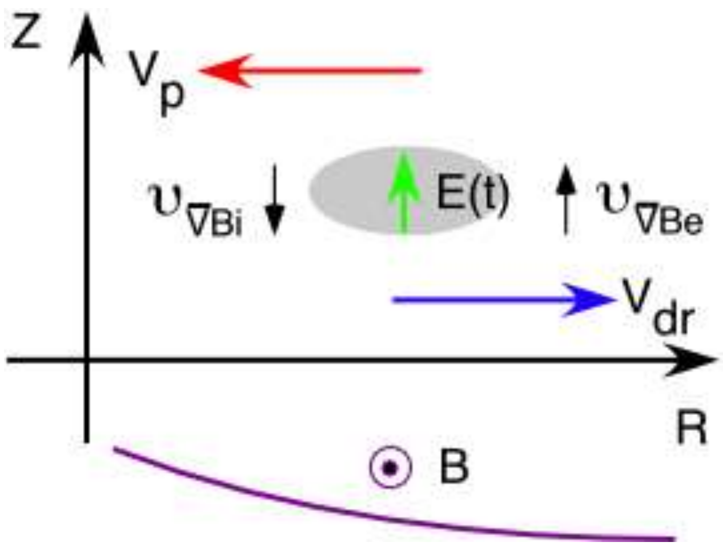
Speed = 31.5 kfps
τ_{exp} = 31.75 μs
W X H = 128 X 320 pixel
1 pixel = 0.59 mm

Pellet/Plasma Interaction

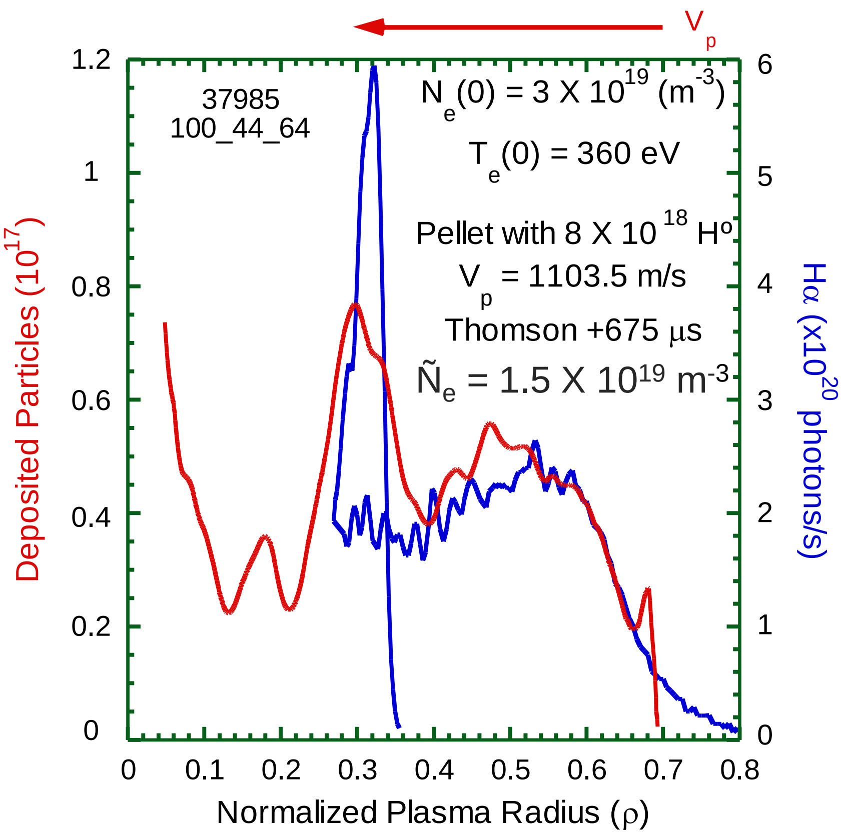


- No Pre-cooling wave observed -> similar behaviour seen by ECE.
- Plasma cooled locally by passing pellet -> followed by outward and inward cooling.
- Density perturbation seen to develop after pellet injection.

Pellet/Plasma Interaction



$V_{dr} = E(t) \times \mathbf{B} / B^2$



B Pégourié et al., NF 47 (2007) 44

- Close agreement between ablation and particle deposition profiles -> no apparent drift acceleration as seen in other devices.
- However, we account for only ~50% of pellet particles in this TS profile (3.8×10^{18} H^o).

Plasma Density Scan

We have made a first plasma density scan. For this, pellets were injected into reproducible plasmas for

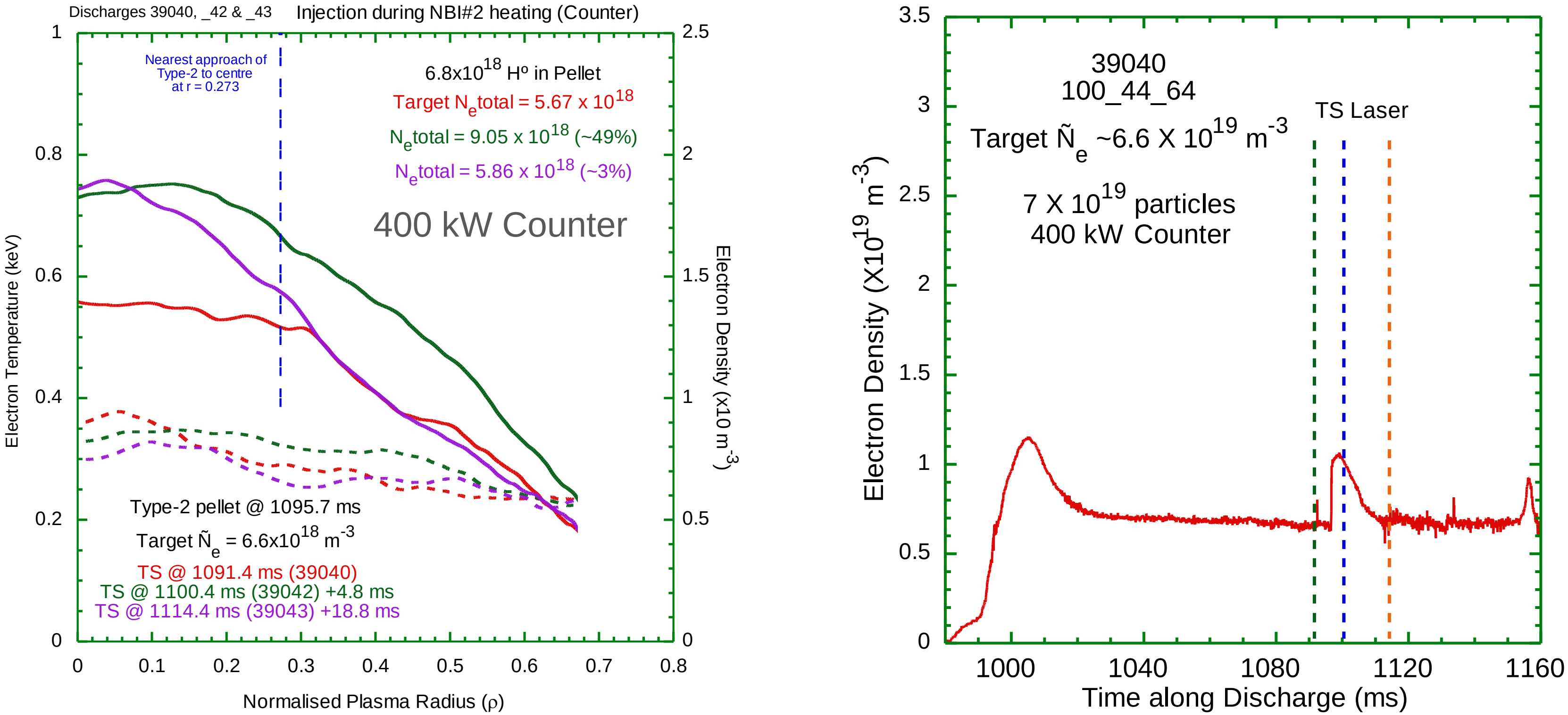
- Standard magnetic configuration (100_44_64) - (volume = 1 m^3, $\iota(0)$ = 1.55, ι(edge) = 1.65, W = 2.27%, magnetic gradient = 0.9 T/m).
- Co- or Counter NBI-heated plasmas.
- Target line-averaged densities from 0.7 to 2 X 10^{19} m^{-3}.
- Two pellet sizes (Type-2 and -3).
- Thomson Scattering profiles taken before as well as ~few ms and ~20 ms after injection.

with the aim of studying particle deposition, fuelling efficiency, and how density profiles and temperature profiles evolve with time along discharge in these NBI-only heated plasmas (here $E_r < 0$).

-> Data feed for particle transport studies by J. L. Velasco (next talk)

Plasma Density Scan

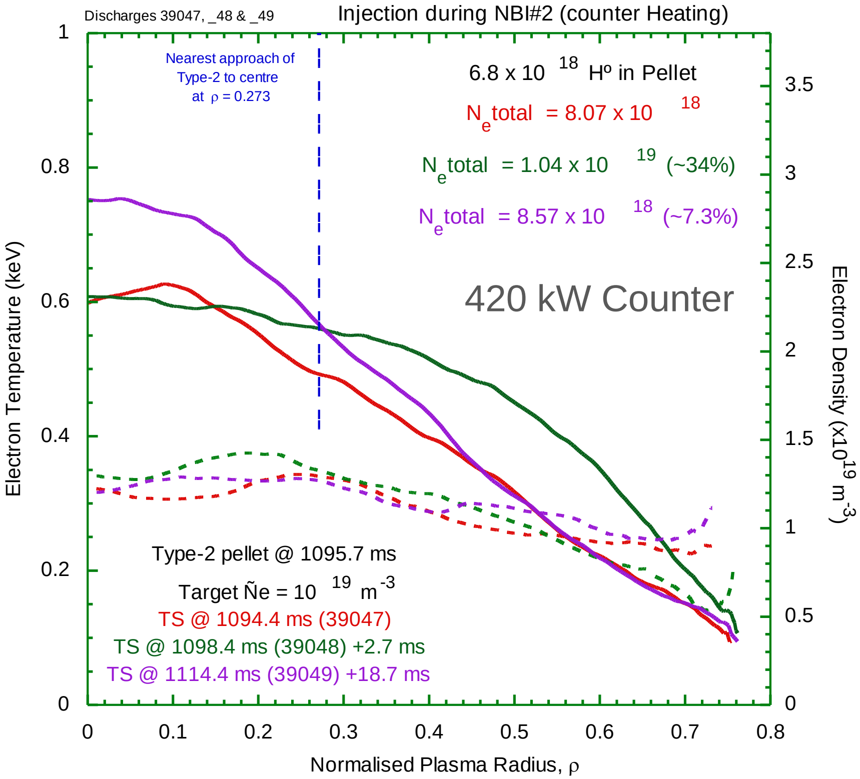
100_44_64

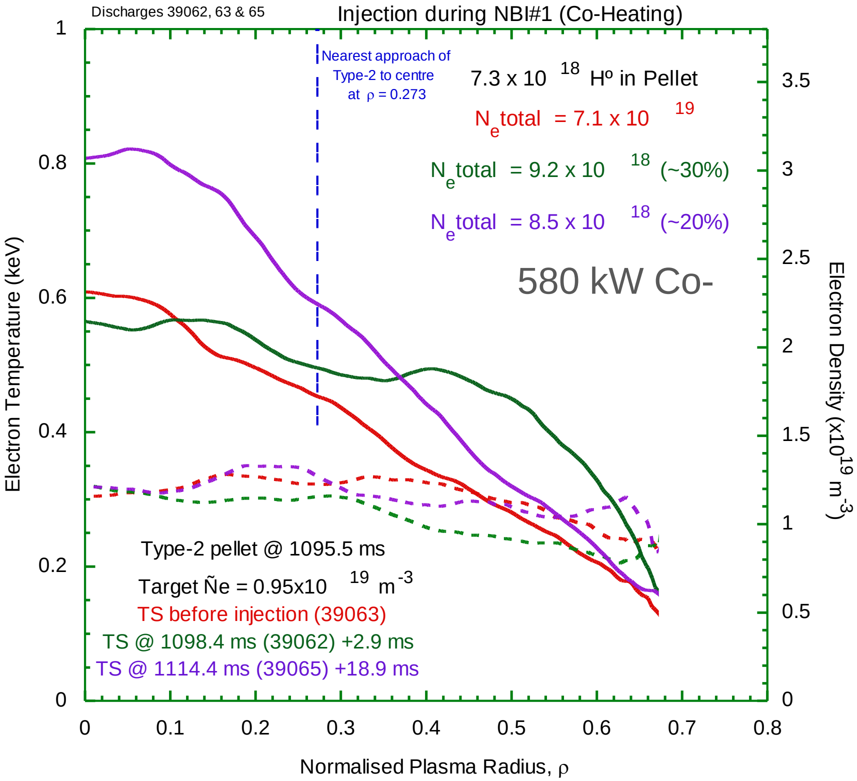


- Target line-averaged density = $6.6 \times 10^{18}\ m^{-3}$.
- % of pellet particles deposited = 49%.
- Subsequent particle diffusion with core confinement.
- Significant particle loss (49% to 3%) within 20 ms for counter-heating.
- Similar for Co- heating case

Plasma Density Scan

100_44_64

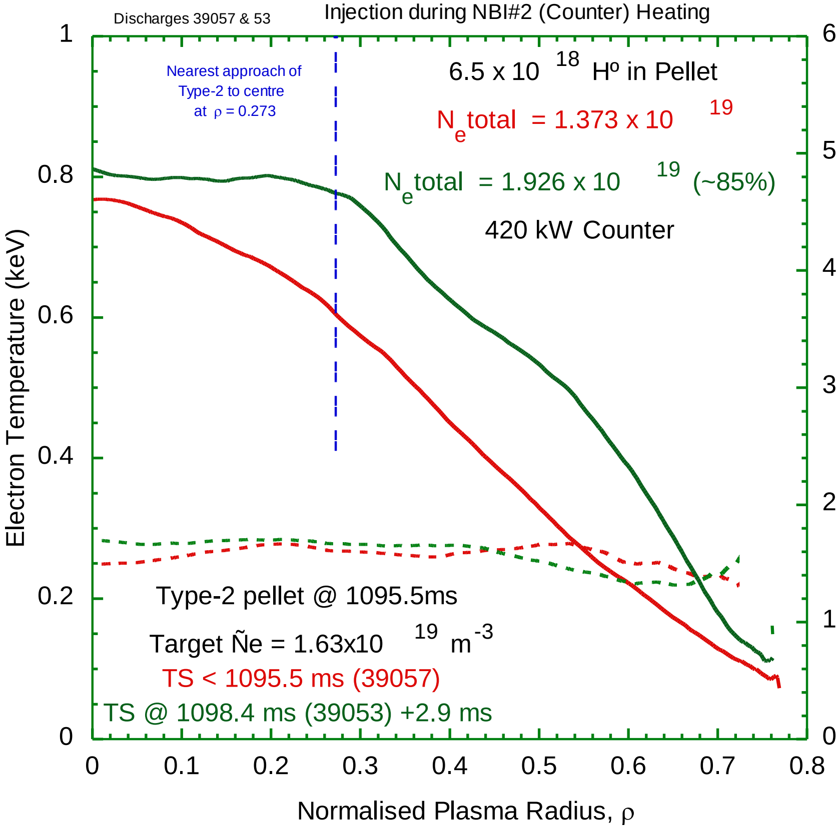


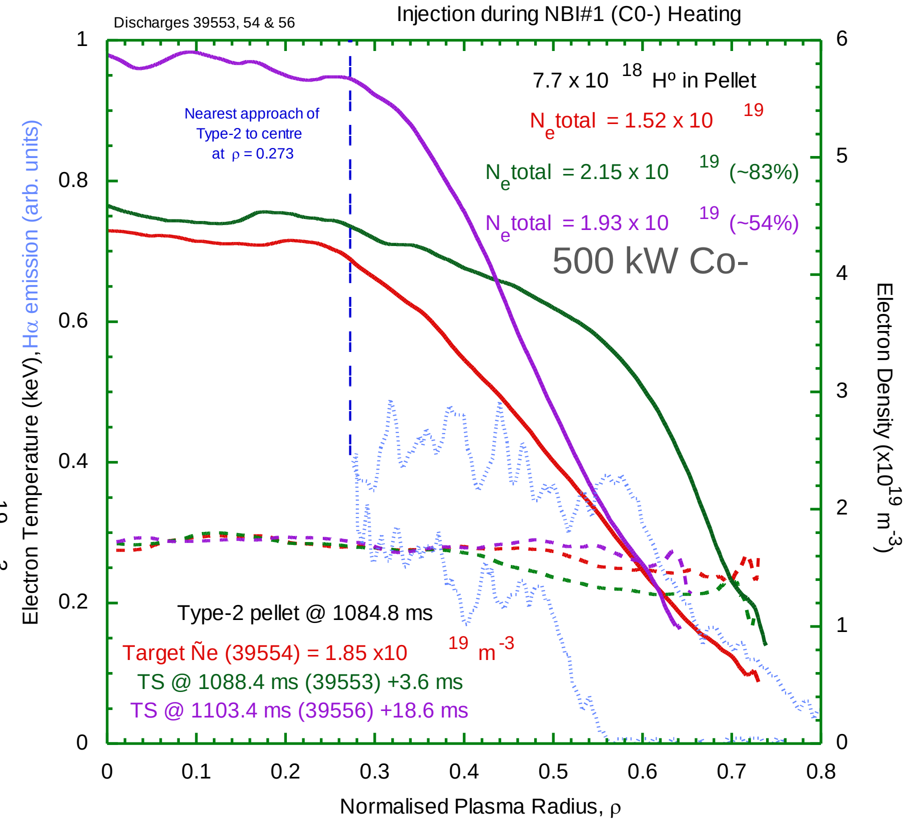


- Target line-averaged density = 10^{19} m^{-3}.
- % of pellet particles deposited = 34 & 30%.
- Subsequent filling of plasma core.
- Significant particle loss (34% to 7%) within 20 ms for counter-heating.

Plasma Density Scan

100_44_64





- Target line-averaged density = 1.85 X 10^{19} m^{-3}
- High particle deposition (84%).
- Slower particle loss (84% to 54%).
- Different particle depositions (friction loss in tubes or plasma effect?).
- Transport analysis by J. L. Velasco.

Summary

Pellet interaction with plasma

- PI systems working, pellet localization when crossing the plasma, Hα signal correlated with ablation (no pellet acceleration seen along trajectory path), fast camera images still requires correct correlation with Hα signal.

Plasma density scans

- Injected pellets into reproducible NBI-only plasmas ($\tilde{N}_e$ from 0.9 to 2 x10^{19} m^{-3}) and collected TS data before and up to 20 ms after injection -> % particles deposited, particle radial diffusion, etc.
- First ECRH injections made last week (data to be analysed).

Future Work

- Prepare joint contribution for ISHW.
- Fast camera image analysis -> asymmetries in cloud heating.
- Improve pellet ablation modelling (require some help)
- Undertake a pellet injection scans for ECRH plasmas in autumn campaign.