Determination of the system function for the particle circulation process using perturbation technique in QUEST

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Summary.

- **Global balance for SSTO (up to 820 sec) in full-metal tokamak shows R~0.8.**
- **Independent tool developed to measure retention flux distribution.**
- **Response function introduced to predict retention behavior for certain perturbations.**
- **Transition from high recycling to low recycling in SSTO is observed. Dynamic *η* is required to predict uncontrollable release.**

Motivation and goals.

Understanding of H retention in steady state tokamak operation (SSTO) in the fusion devices is inevitably required. There are a few knowledge about retenition for the long time scale. In AUG with tungsten PFM wall saturation is observed for 1 sec, only a few % of $Q_{gas}(t)$ is retained after reaching steady state conditions. How does this condition hold in a long pulse discharge?

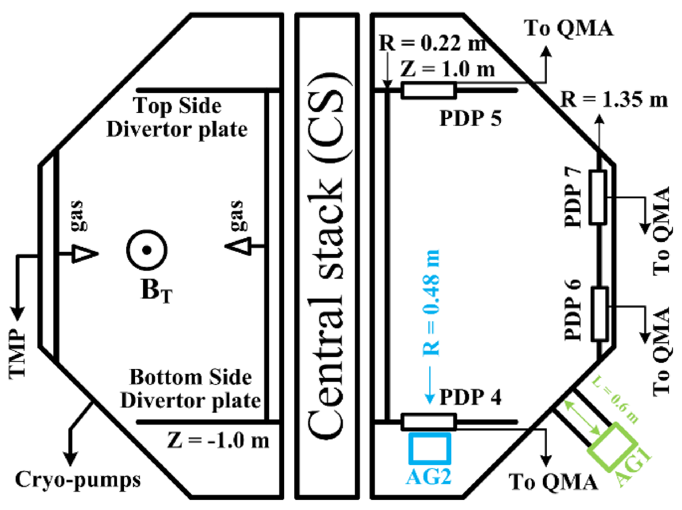
Goals:

1. **To measure or infer $Q_{rel}(t)$ and $Q_{ret}(t)$ by independent methods and understand their behaviors in the long time scale.**
2. **To develop approach to understand the particle circulation response to transient perturbations.**

New methods.

- New tool for direct retention flux measurements was introduced: permeation probes. With the help of TMAP7 [1] the permeated curves are reproduced, and thus the retention flux, which relates closely to q_{ret}, is deduced. Typical values of coefficients: $D = (2.9\pm0.2)\times10^{-9}$ m^{2}s^{-1}, $k_u = (1.3\pm0.5)\times10^{-33}$ m^{4}s^{-1}, $k_d = (7.0\pm0.4)\times10^{-34}$ m^{4}s^{-1}.
- Perturbation method is introduced to distinguish release and retention. Response function for different perturbations could be determined for discharges with well controlled *R* and applied to SSTO.

Experimental Set-Up.



Major radius: 0.68 m
Minor radius: 0.4 m
Vessel volume: 13.5 m^3
PFCs surface ~ 35 m^2
T_{wall} ~ 100°C
τ_{pump} = 2 sec

Vessel materials: SUS316, ~30% of PFCs – tungsten. Piezo-electric valves are used to inject H_2 with adjustable height and frequency of f_{puff}. The EC system consists of toroidally opposite two 8.2 GHz klystrons systems (100kW) at fundamental resonance R_{fce} = 0.29 m in off-axis heating scenario. For ECR discharge cleaning (ECRDC) a plasma is sustained by 2.45 GHz ECWs and the resonance layer is swept at the frequency f_{PWI} by varying the toroidal field B_t.

Global gas balance in long pulse discharges.

$$N(t) = N(0) - \int_0^t S_{pump}P(t)dt + Q_{gas}(t) + Q_{out}(t) - Q_{ret}(t) + Q_{rel}(t) - N_{pl}(t) \quad (1)$$

$$\frac{dP}{dt} = -\frac{P}{\tau_{pump}} + q_{gas}(t) + q_{th}(t, T_{wall}) - q_{ret}(t, \Gamma_H, \Gamma_{inc}) + q_{rel}(t, \Gamma_H, \Gamma_{inc}) \quad (2)$$

N(t) - number of H atoms at the time *t*,
N_{pl}(t) – plasma inventory,
S_{pump} is the pumping speed,
Q_{gas}(t) - number of H atoms puffed *t*,
Q_{out}(t) – outgassed number of H atoms,

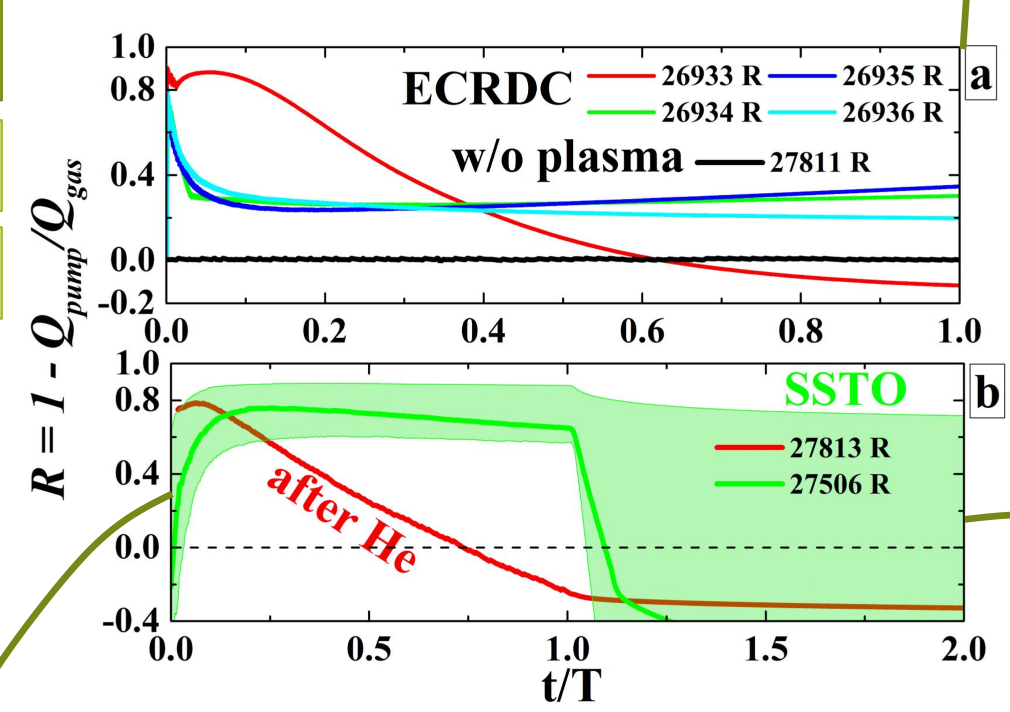
Unknown parameters:
Q_{rel}(t) - H atoms released from the walls due to plasma interaction
Q_{ret}(t) - H atoms retained in the walls.

τ_{pump} - pumping time constant, $q_i(t) = dQ_i/dt$
Γ_{inc} – incident ion flux, Γ_H – neutral hydrogen flux

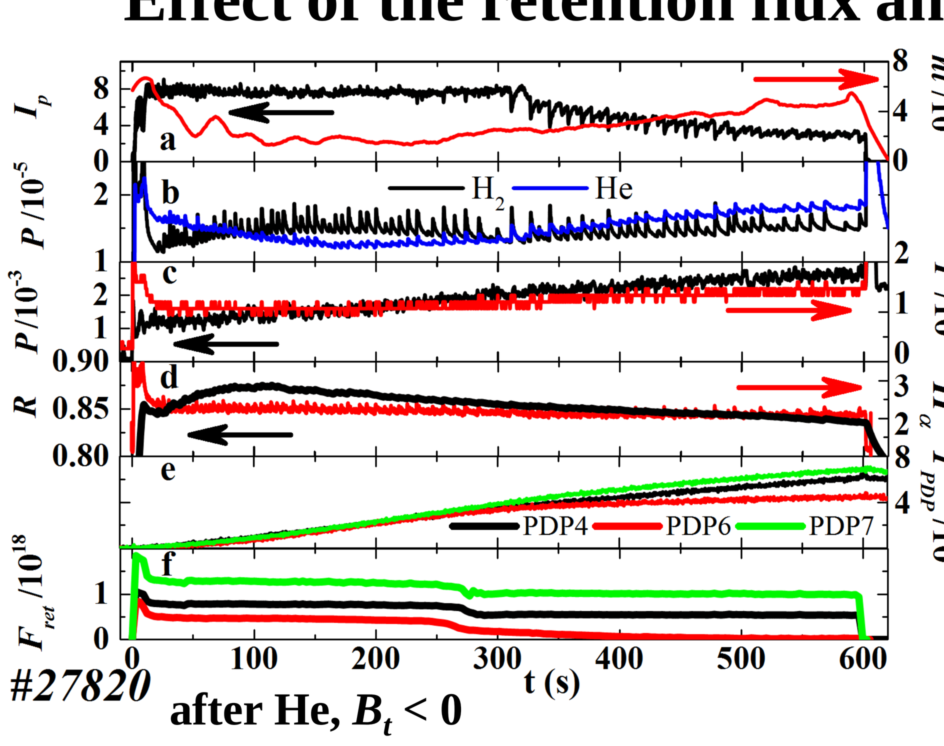
Γ_{pdp} – permeated H flux
F_{ret} – retention flux derived from PDP

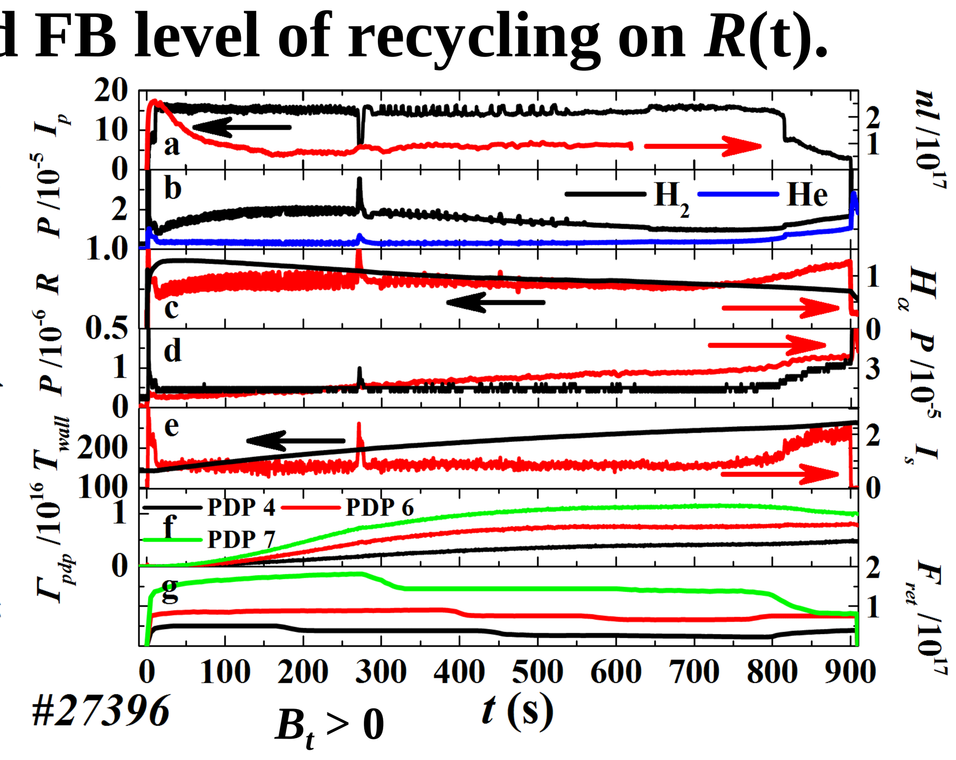
$$\Gamma_{pdp} = \left(\frac{dP_{H2}}{dt} + \frac{P_{H2}}{\tau_{pump}}\right) \Big/ A_{pdp}$$

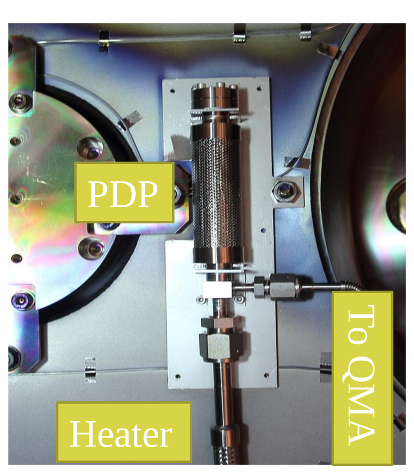
- No retention w/o plasma
- Low retention (R ~0.2) in ECRDC
- High retention (R ~0.8) in SSTO



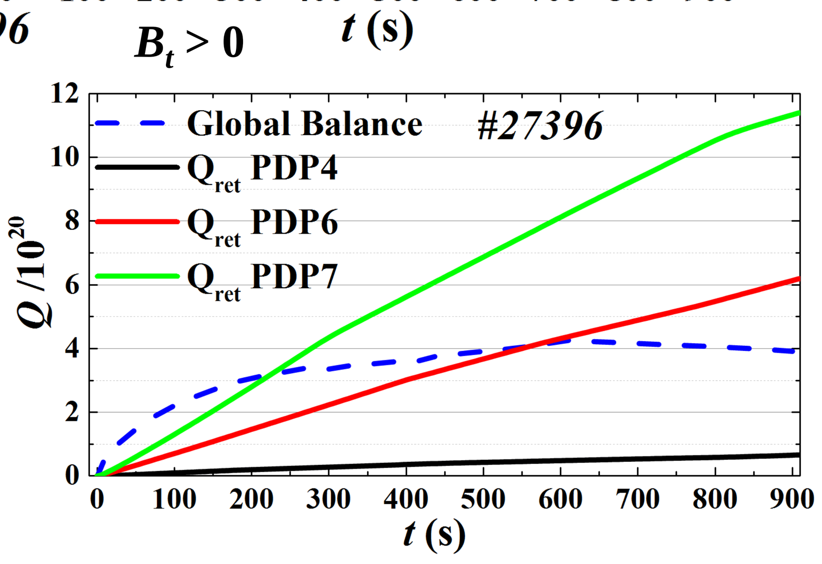
Effect of the retention flux and FB level of recycling on *R*(t).





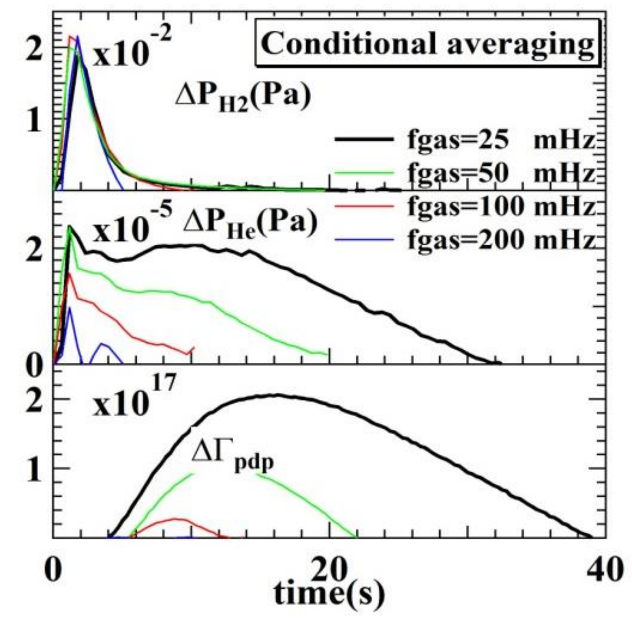


- **SSTO** is achieved for **820 sec**.
- Spatial distribution of F_{ret} is derived from PDP.
- Q_{ret} derived from PDP compared with global balance.

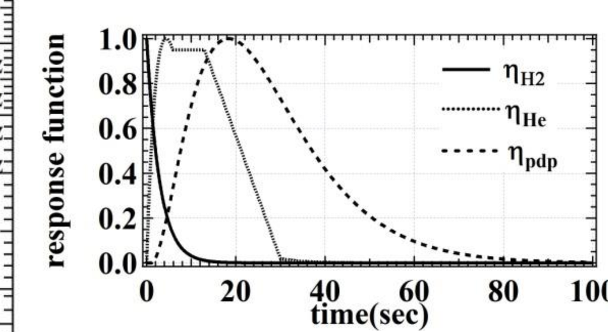


System function with respect to perturbations

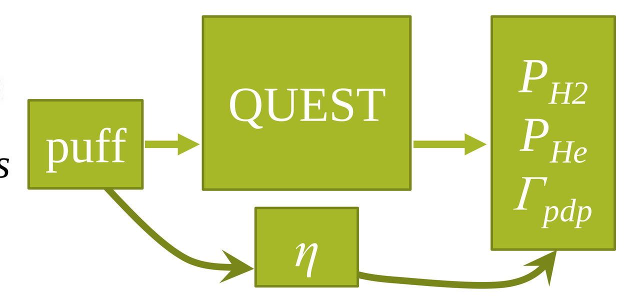
$$F_{out}(t) = \int_{-\infty}^{t} F_{in}(\tau)\eta(t-\tau)d\tau,\ S_{in\text{-}out}(f) = H(f)S_{in\text{-}in}(f) \quad (3)$$

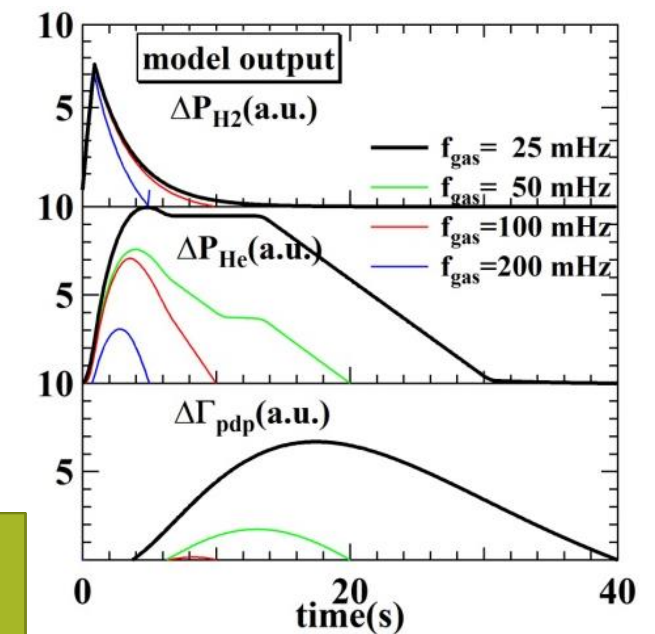


Conditional-averaged time evolutions of (a) ΔP_{H2}(Pa), (b) ΔP_{He}(Pa) and (c) $\Delta\Gamma_{pdp}$ (H_2/m^2/s) at various f_{gas}.



η for P_{H2}, P_{He} and Γ_{pdp}



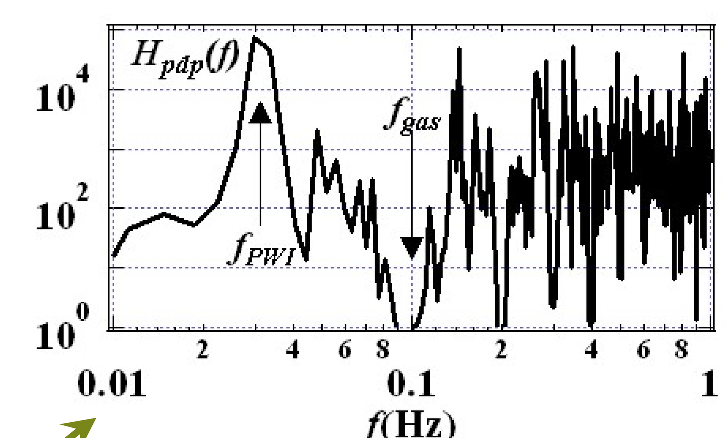


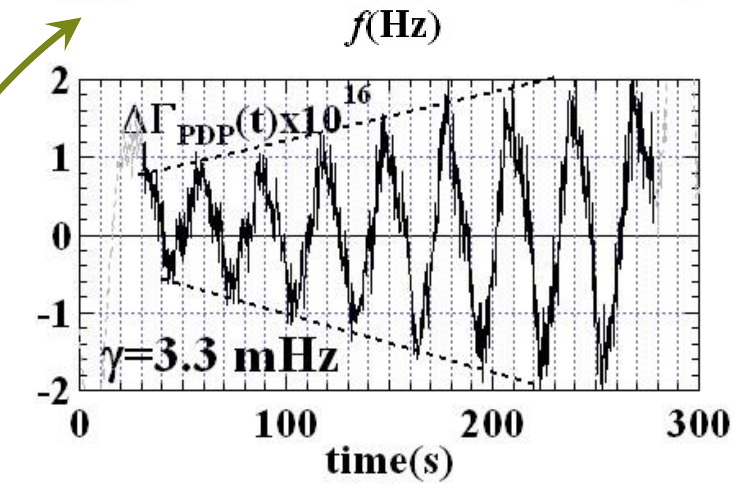
Output signals using response functions;(a) ΔP_{H2}, (b) ΔP_{He} and (c) $\Delta\Gamma_{pdp}$ at various f_{gas}.

Response function η is derived for ECRDC.

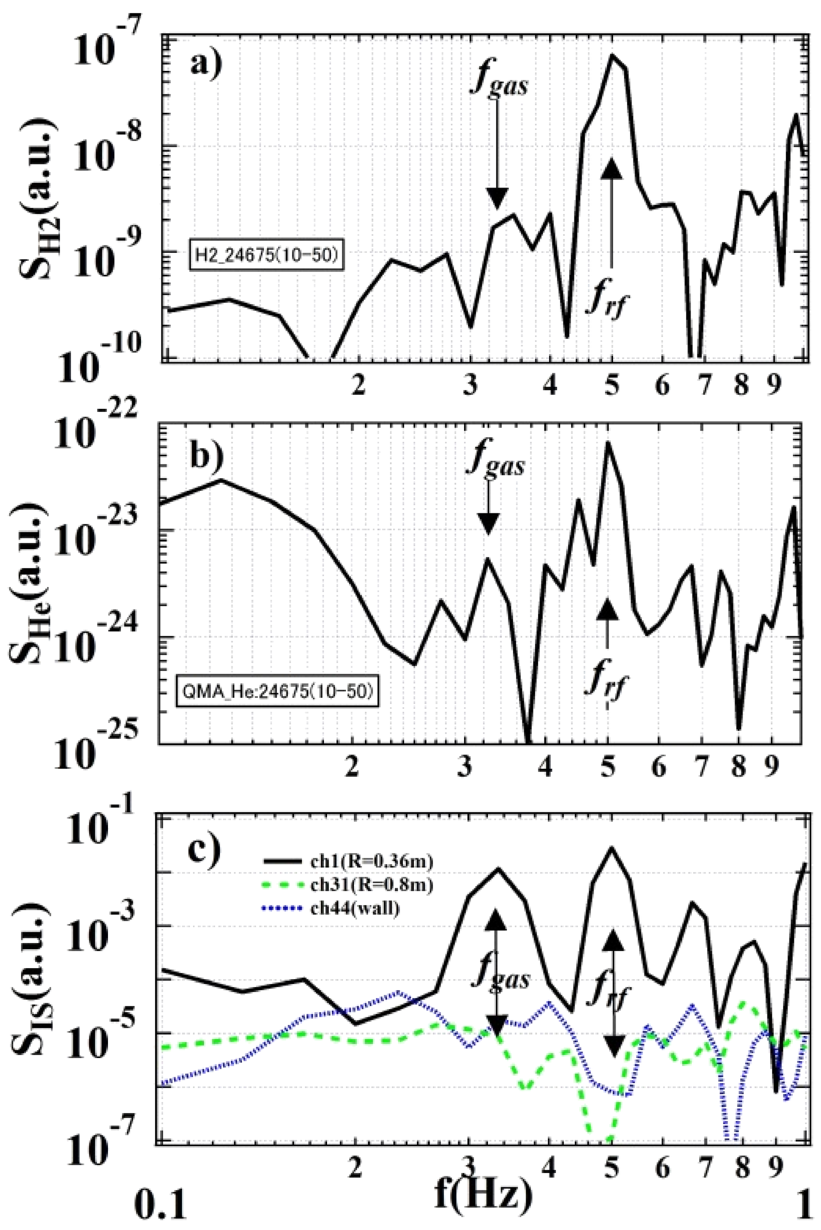
Particle circulation in ECRDC plasma is well understood by stationary η.

$$\eta_{H2} = \exp(-t/\tau_d);\ \eta_{He} = t\cdot\exp(-t/2\tau_d);\ \eta_{pdp} = t^2\cdot\exp(-t/3\tau_d);$$





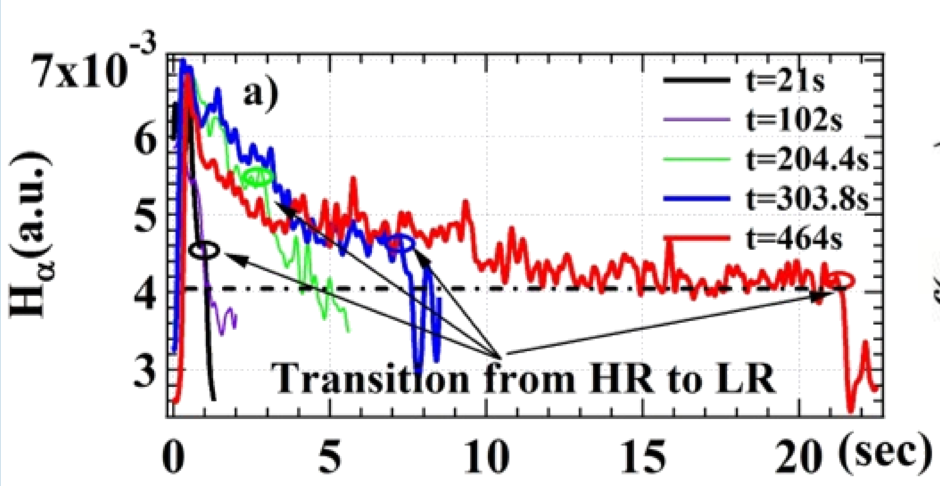
Frequency response function H_{pdp} to H_2 puff in vacuum. Arrows indicate f_{gas} and f_{PWI}. Minima for $f>f_{gas}$ in H(f) correspond to hamonics of f_{gas}. (b) The amplitude of $\Delta\Gamma_{pdp}$ at f_{PWI} grows with a time constant of 3.3 mHz, which causes non-stationary particle circulation.

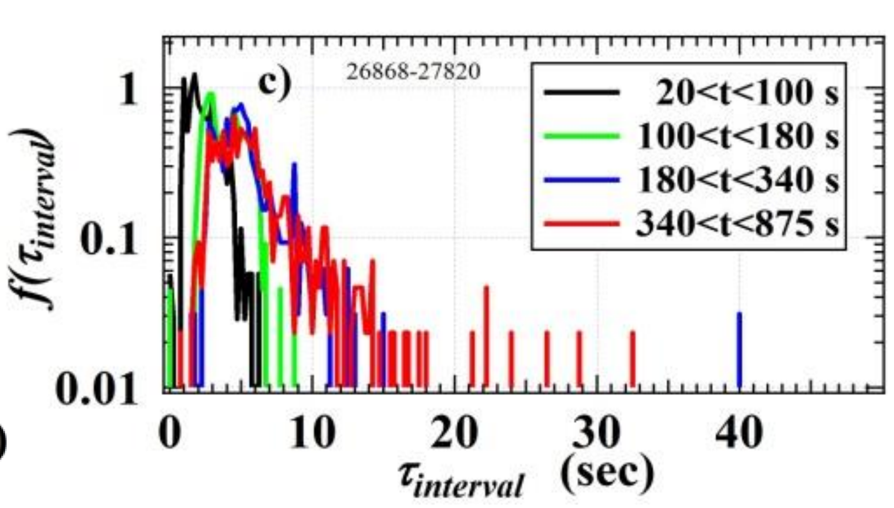


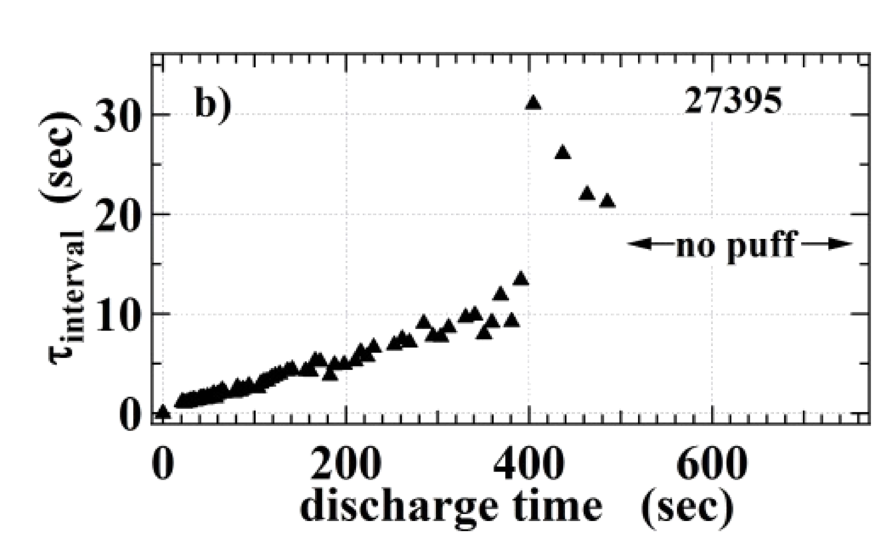
Auto power spectra (a) S_{H2},(b) S_{He} and S_{Is} are plotted. f_{gas} and f_{rf} are 333mHz and 500mHz, respectively. S_{Is} at R=0.36, 0.8m and the side wall are shown.

Simultaneous change in PWI region and puff duration in ECRDC and SSTO localized position of interaction could be understood.

Transition from HR to LR and their statistical feature.







Time dependent probability function derived from several SSTO. Evolution of this function in time indicates transaction from wall pumping to wall fueling.

Dynamic *η* is required to understand response.

[1] G. R. Longhurst J. Ambrosek, Idaho National Laboratory, report INEEL/EXT-04-01657