Steady state control of fuel recycling for long pulse discharges in EAST tokamak with full metal first wall

by

Yaowei Yu[1]*

Mizuki Sakamoto[2], Deze Zhou[1], Bin Cao[1], Guizhong Zuo[1], Rui Ding[1], Juan Huang[1], Jiansheng Hu[1]

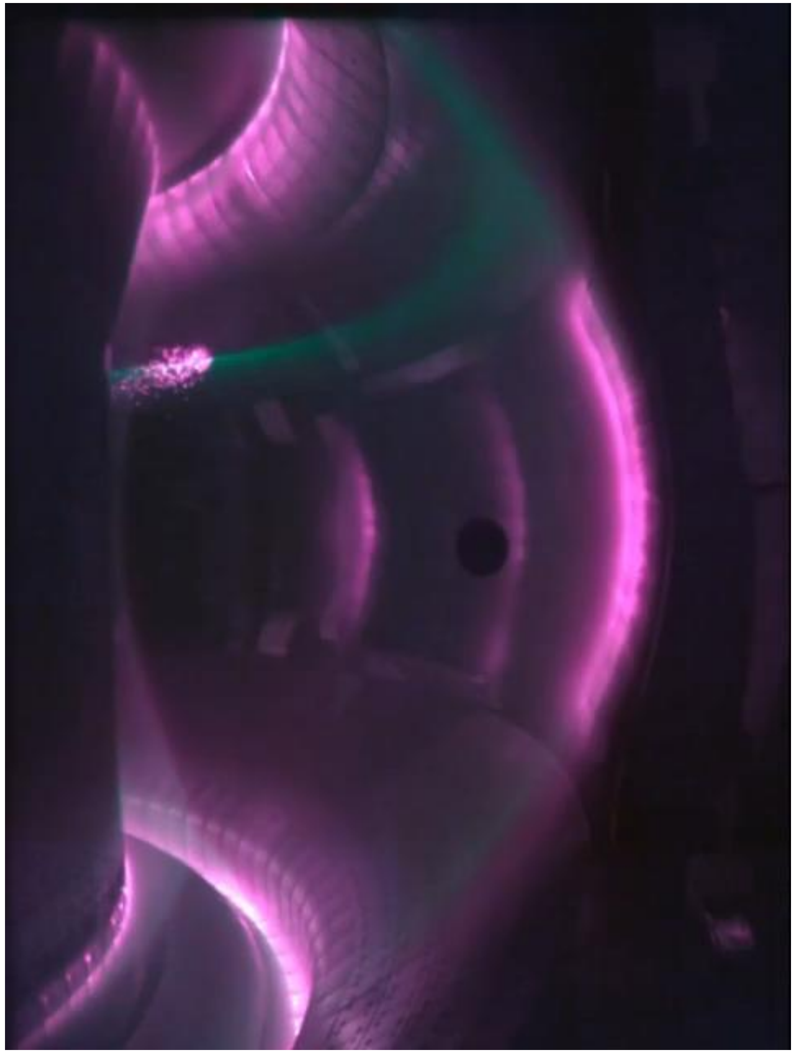
[1]Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China
[2]2Plasma Research Center, University of Tsukuba, Japan

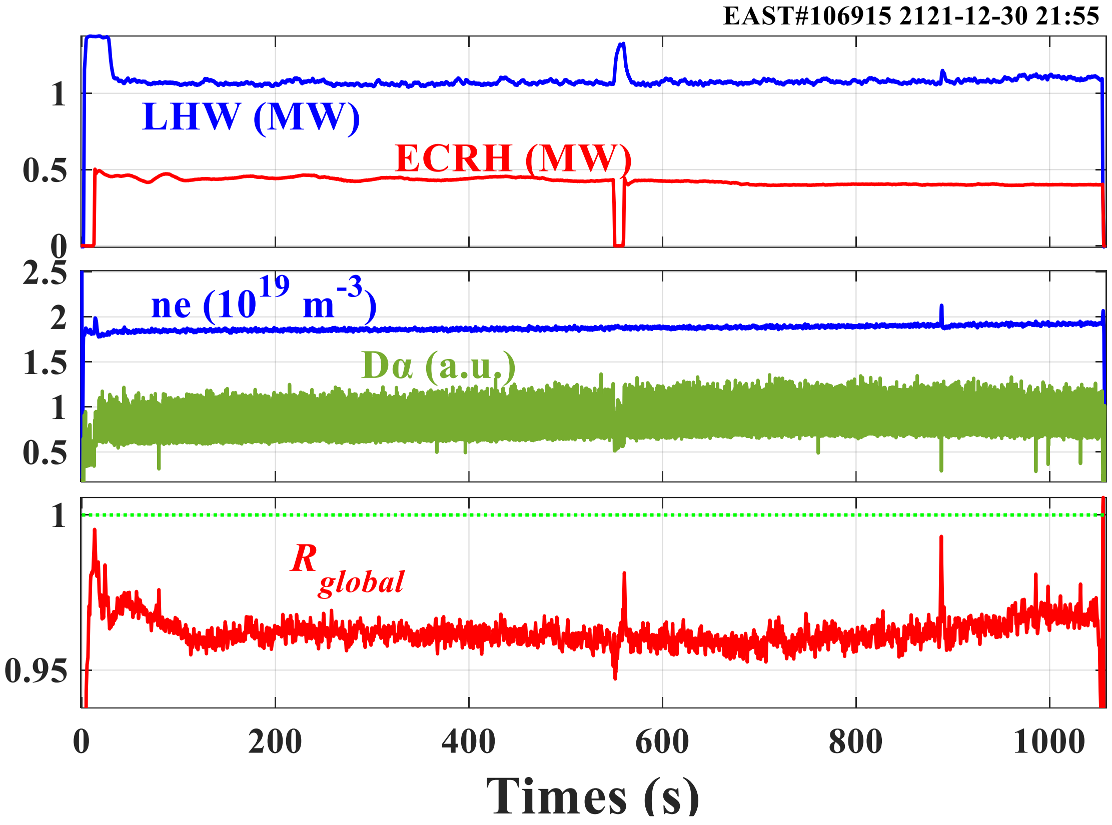
Presented at the
Technical Meeting on Long-Pulse Operation of Fusion Devices
Vienna, Austria, IAEA Headquarters

November 2022

***E-mail: yuyaowei@ipp.ac.cn**

1056 s plasmas in EAST superconducting tokamak





- ✓ Double Null, 1 MW LHW + 0.4 MW ECH
- ✓ Stable density control during **1056 s** discharge
- ✓ Recycling control: R_{global} ~ **0.95 – 0.97**

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Recycling control strategy

Recycling control is vital for long pulse plasma operation.

$$\frac{dNe}{dt} = (R_{global} - 1) \cdot \frac{Ne}{\tau_p} + \Phi_{ex} \cdot f_{ex}$$

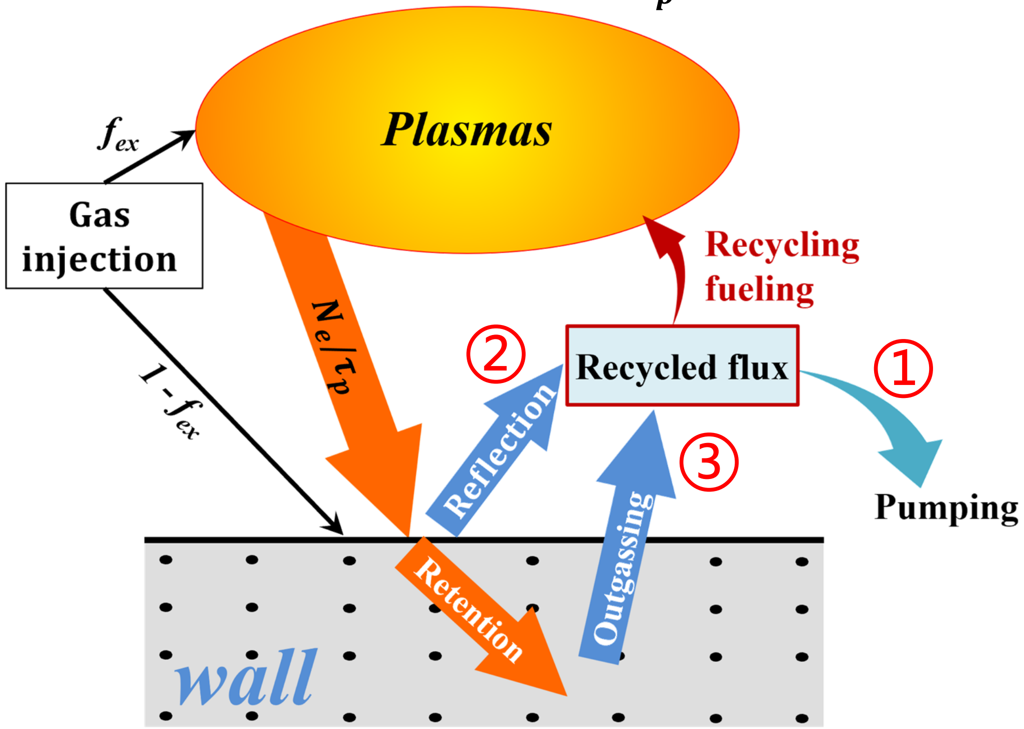
Recycling flux depends on

① Particle exhaust

② Wall reflection

③ Wall outgassing

- Fuel retention/inventory
- External fueling efficiency
- Wall temperature



Integrating methods to control different recycling processes.

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Outline

- Recycling control methods in EAST
- Influence of plasmas on recycling
- Recycling control for long-pulse discharges
- Summary

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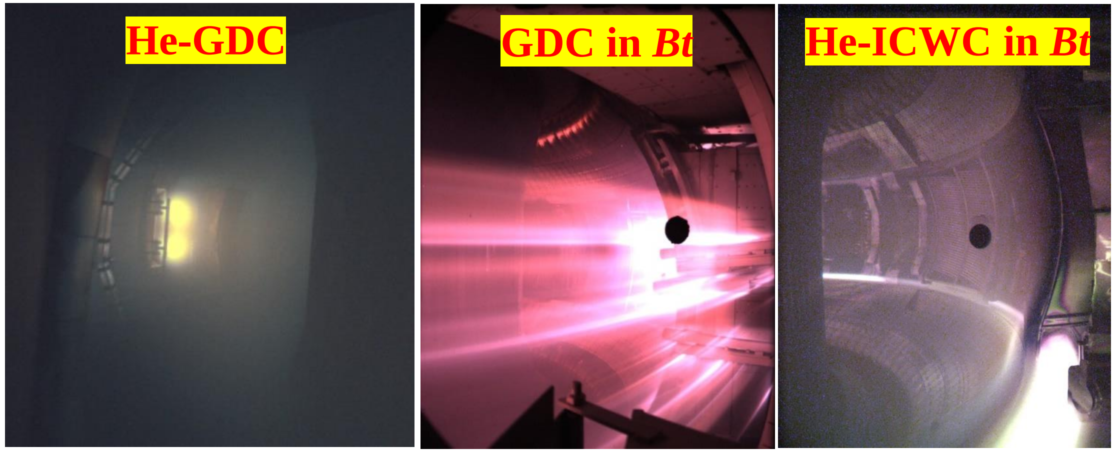
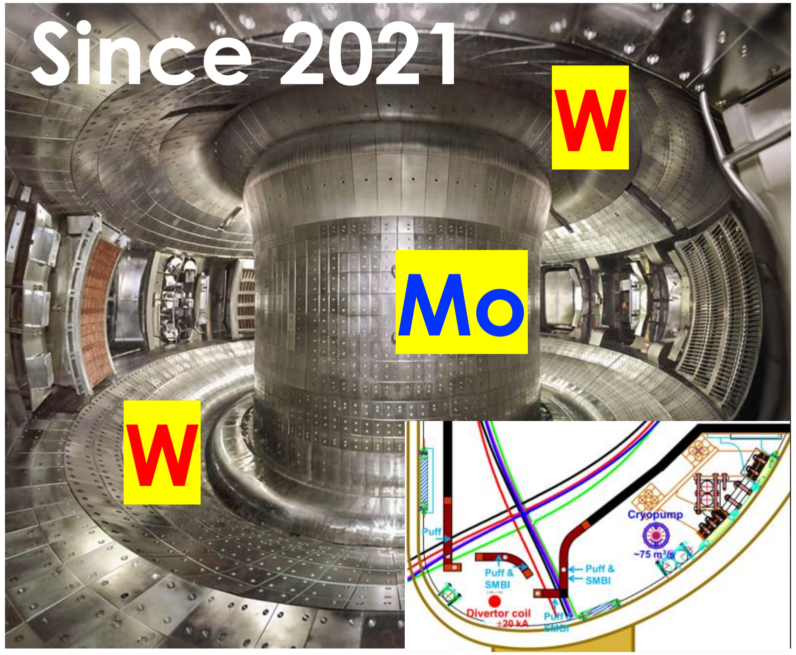
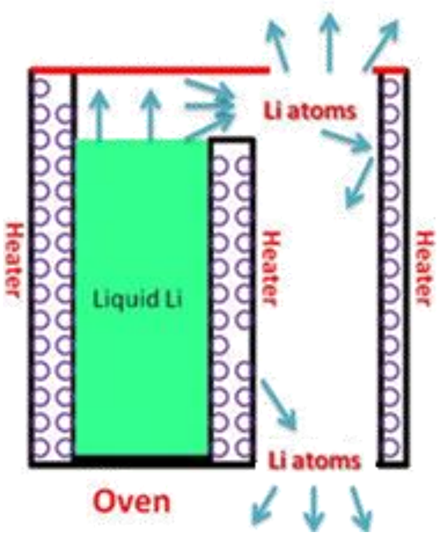
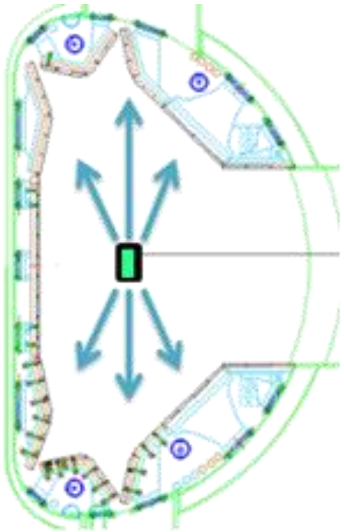
EAST divertor and wall conditioning system

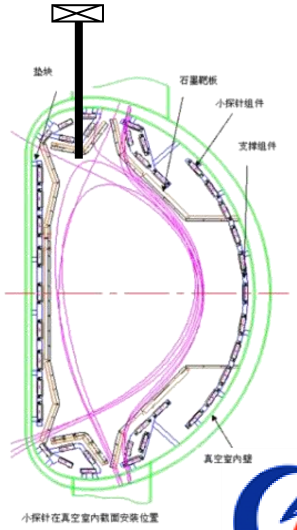
- **W divertors since 2021 with actively cooling**
- **In-vessel div. cryopumps: 75×2 m^3/s**
- **Advanced wall conditionings**
  - **GDC & ICWC under strong B_t**
  - **Lithium coating & real-time injection**











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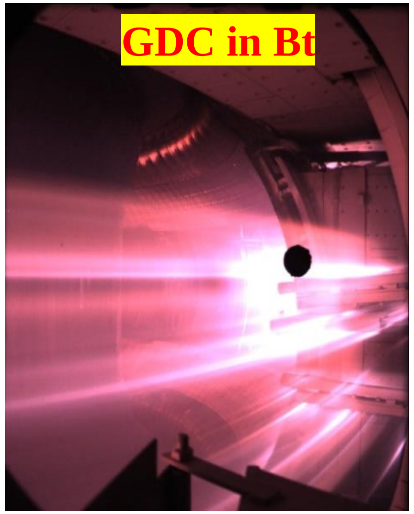
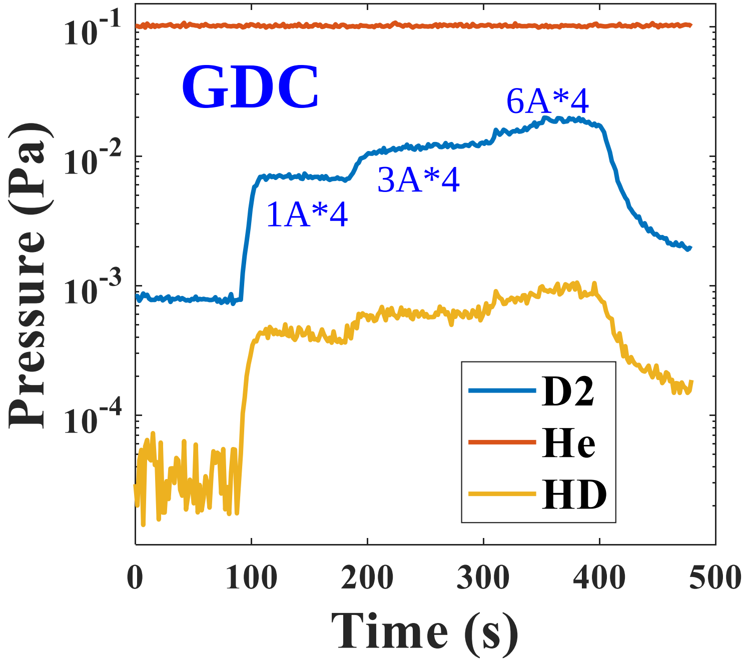
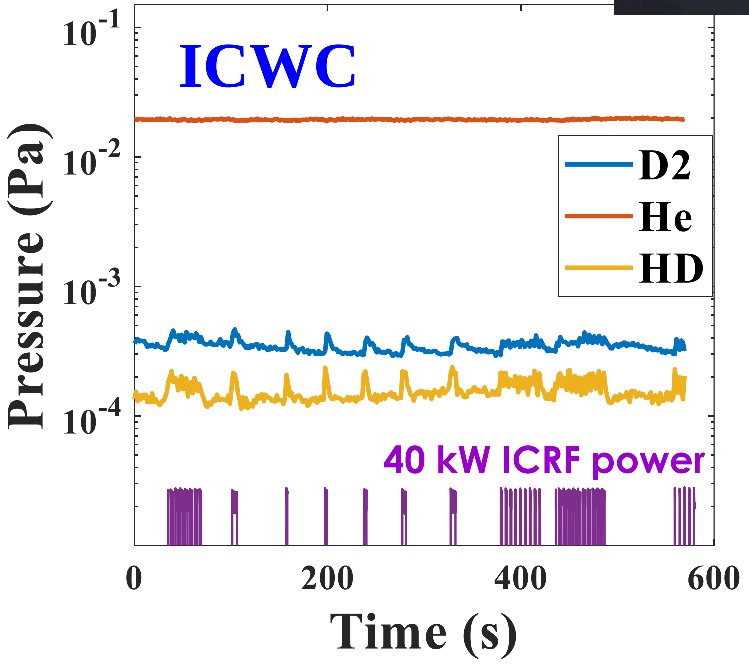
Discharge cleanings to remove retention

- Both GDC & ICWC works well under strong B_t
- Higher efficiency of GDC due to better homogeneity
- GDC & ICWC to remove deuterium retention
  - between shots without any change of B_t
  - during night to decrease deuterium retention
  - assist lithium coating







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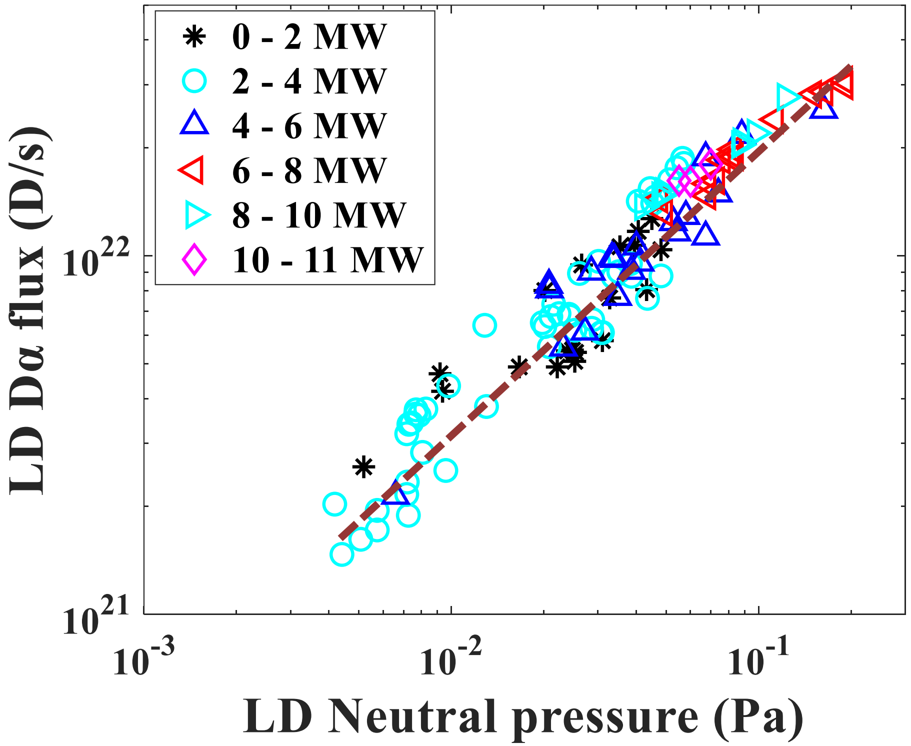
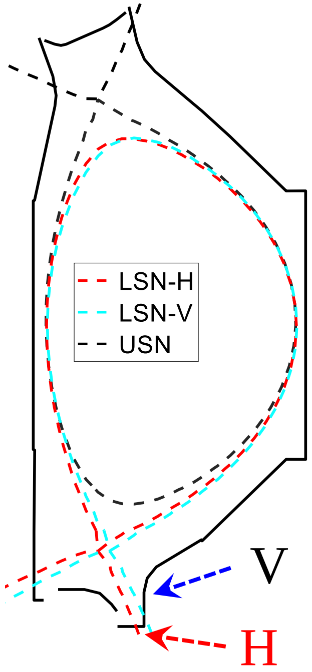
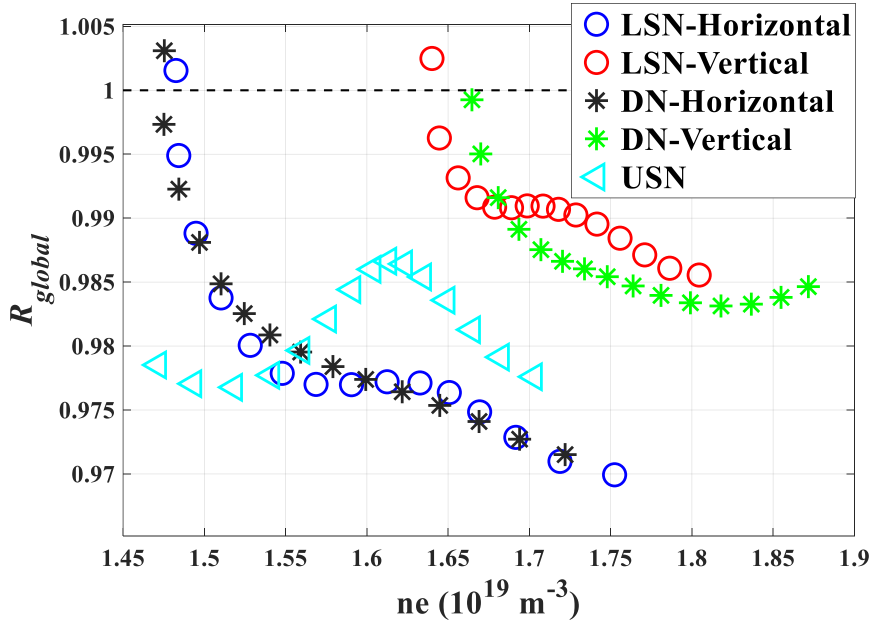
Divertor cryopumps and magnetic configuration







- Dα: Recycling + external injection
- Decrease div. pressure by div. cryopumps to control recycling

Recycling control capability

- R_{global} ~ 0.97 – 1.00
- LSN-H > LSN-V
- DN-H > USN > DN-V
- **Tiny difference**

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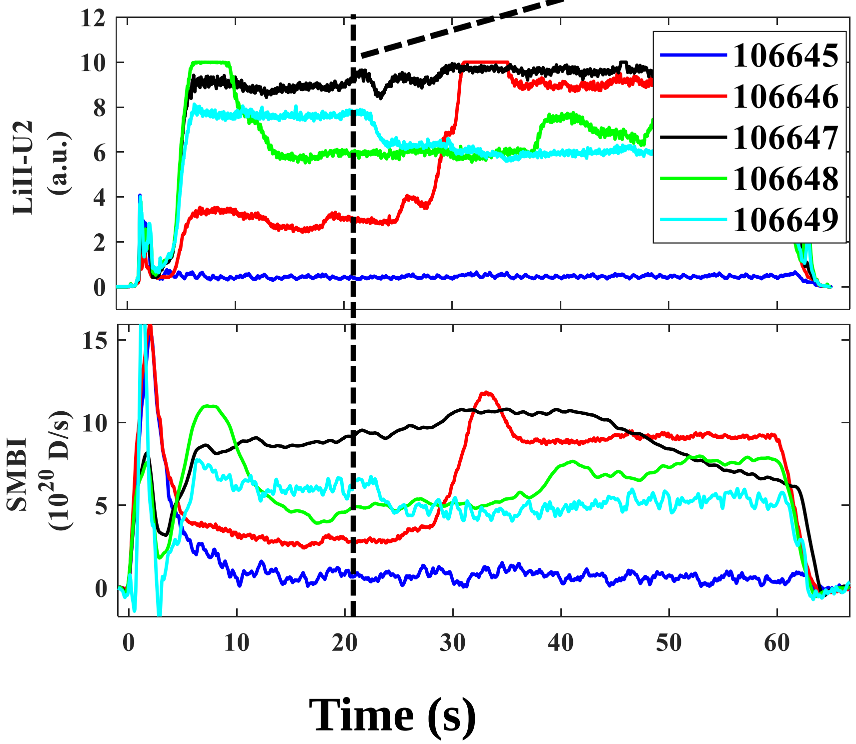
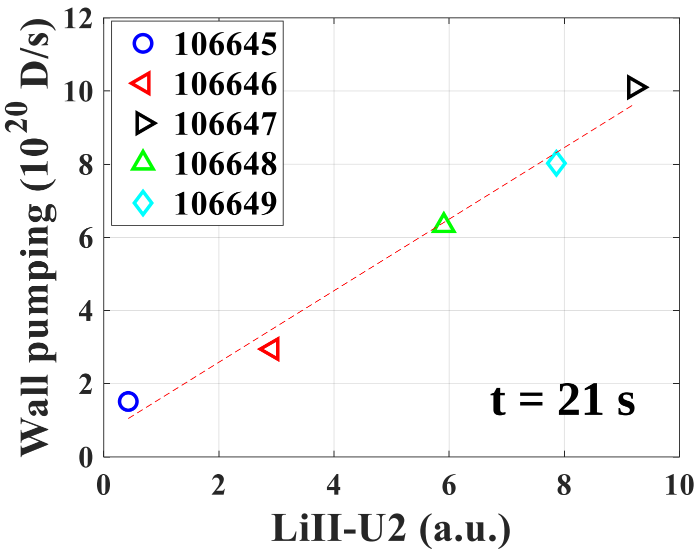
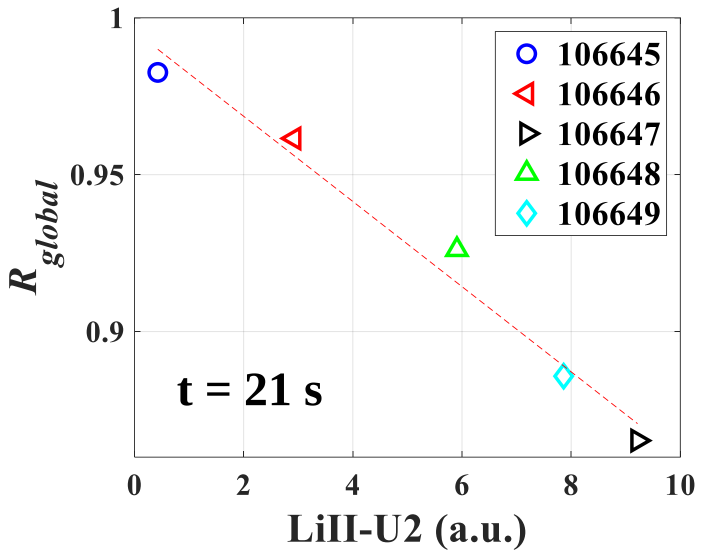
Lithium real-time injection

- Lithium coating wall condition
- DN, 0.3MA, 1.8×10^{19} m^{-3}
- 1.5MW LHW + 0.5MW ECH
- Lithium real-time injection







- Enhanced wall pumping by lithium injection
- **Wall pumping rate proportional to Li-II**
- **R_{global} decreased from 0.98 to 0.86**
- Very strong recycling control by lithium injection

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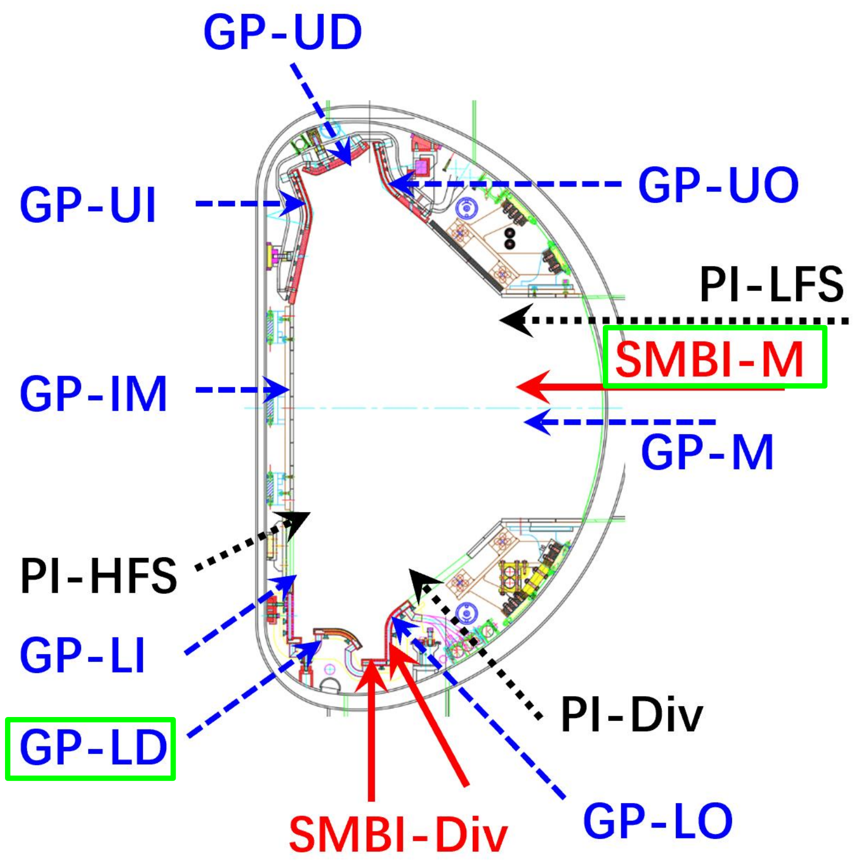
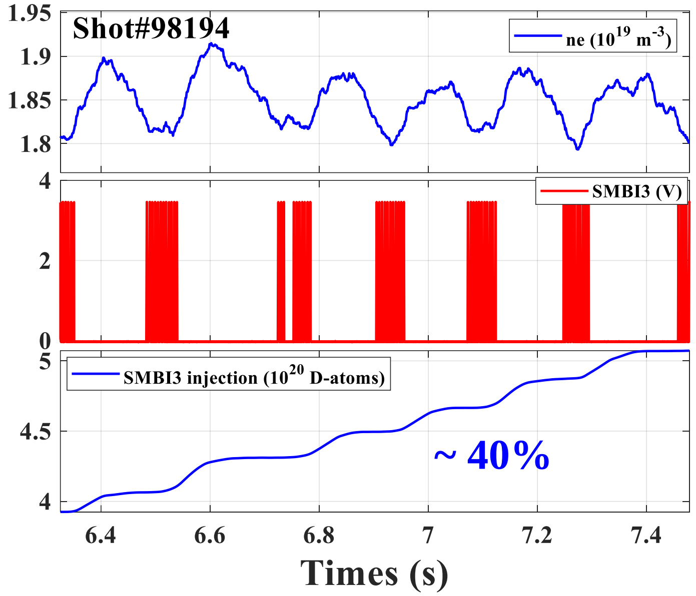
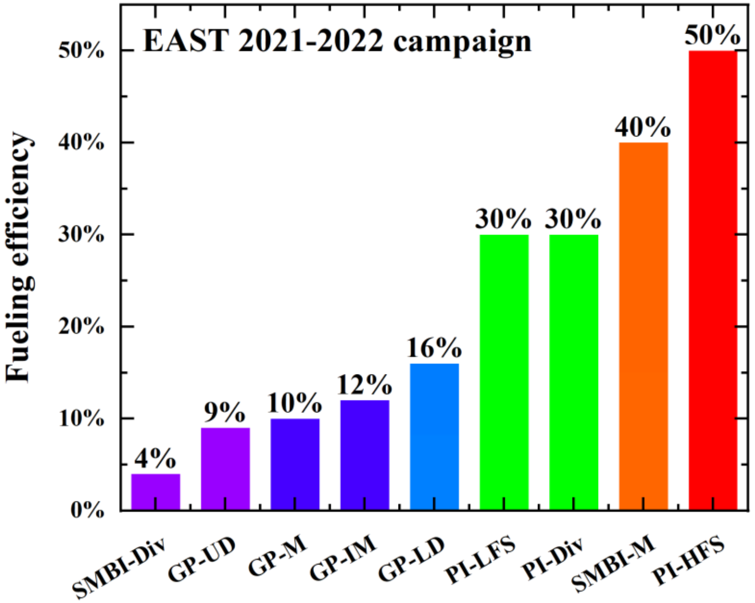
EAST fueling system

- Gas puffing (GP), Supersonic Molecular Beam Injection (SMBI), Pellet Injection (PI)







High fueling efficiency → low retention

→ Depress wall outgassing

→ **Improve recycling control**

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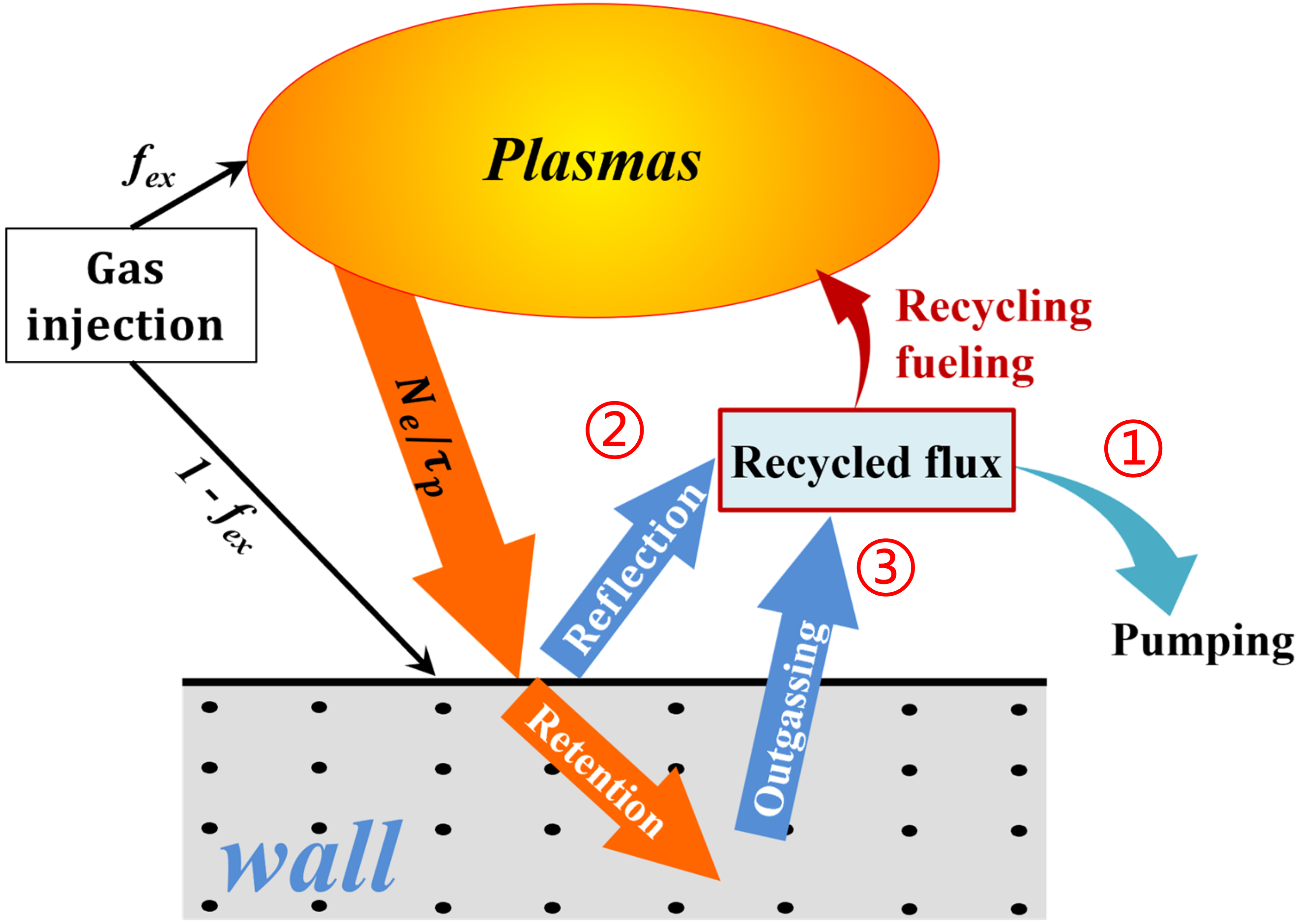
Recycling control methods in EAST



① High particle exhaust rate

- Divertor cryopumps: $75m^3/s\times2$
- Magnetic configuration optimization

② Low wall reflection rate

- W (0.9) → Lithium (0.1)
- Lithium coating & real-time injection

③ Low wall outgassing rate

- GDC & ICWC + Lithium
- Gas puffing → SMBI
- Actively cooling of divertors

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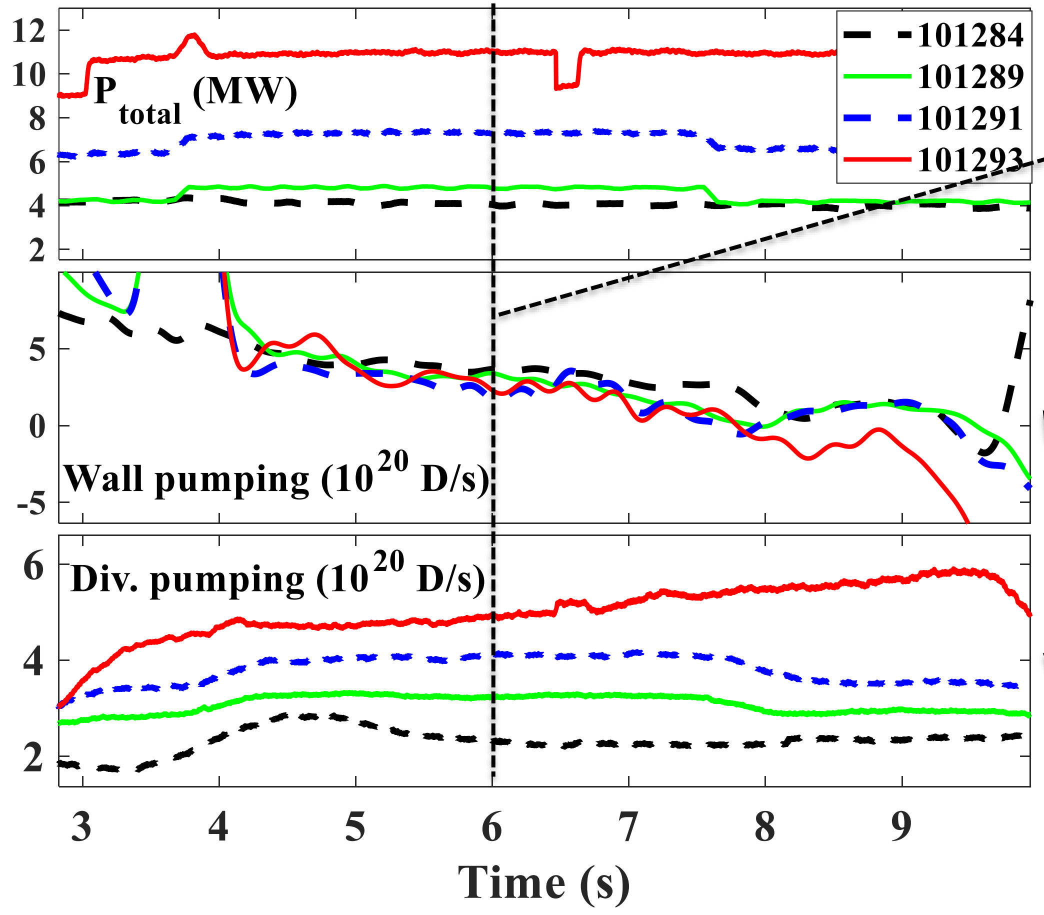
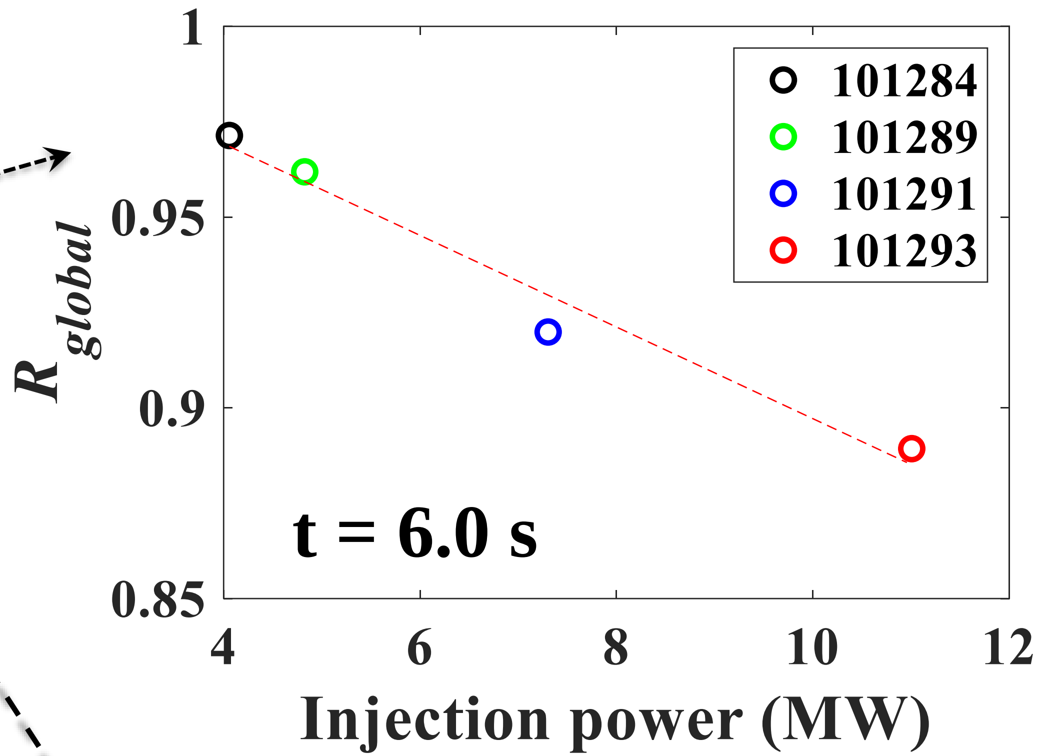
Influence of heating power on recycling





- 4 – 12 MW source heating power
- No change on wall pumping with power
- Increased div. pumping rate with power
- R_{global} decreased with increasing power

0.5 MA, DN, ne ~ 4.5×10^{19} m^{-3}

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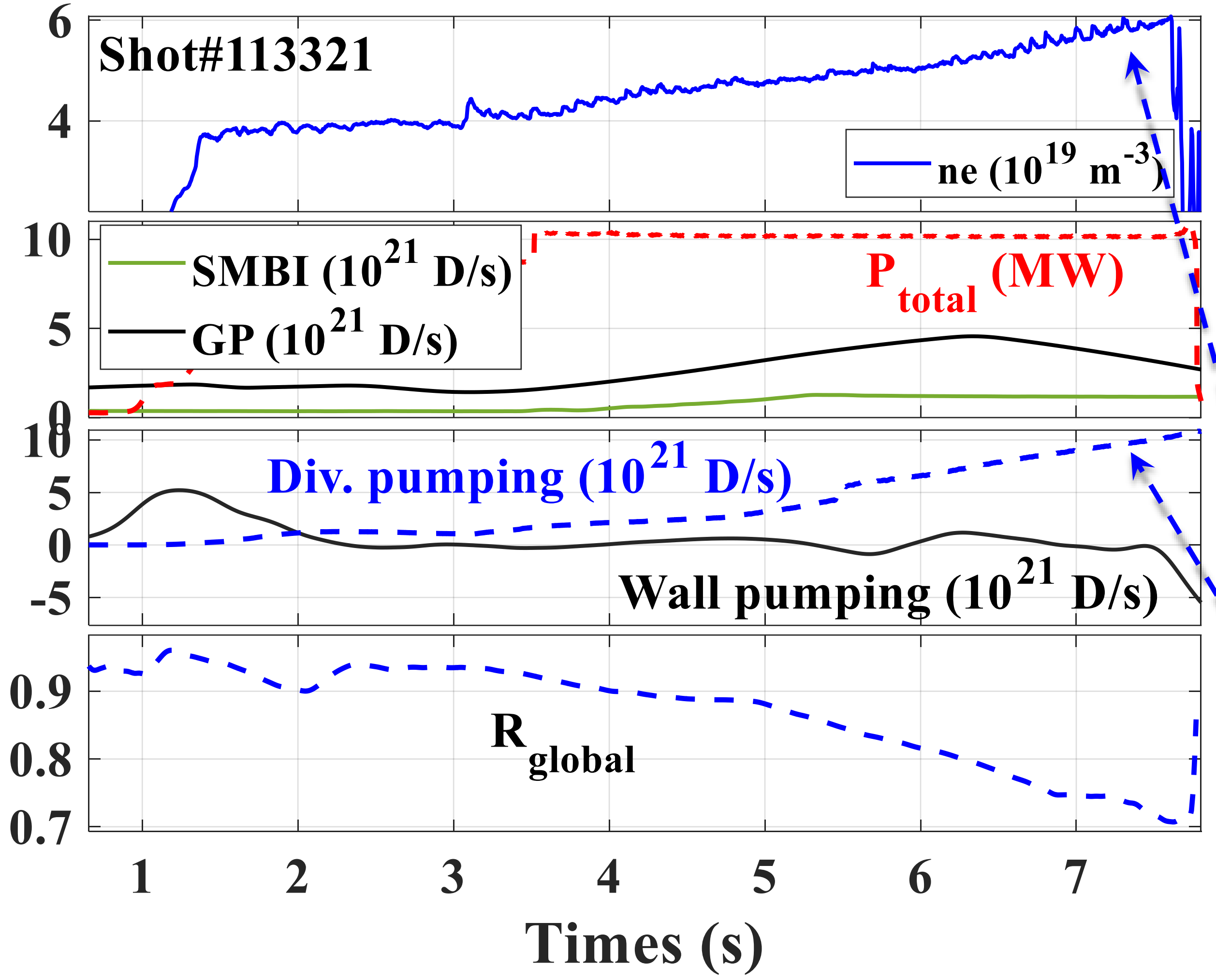
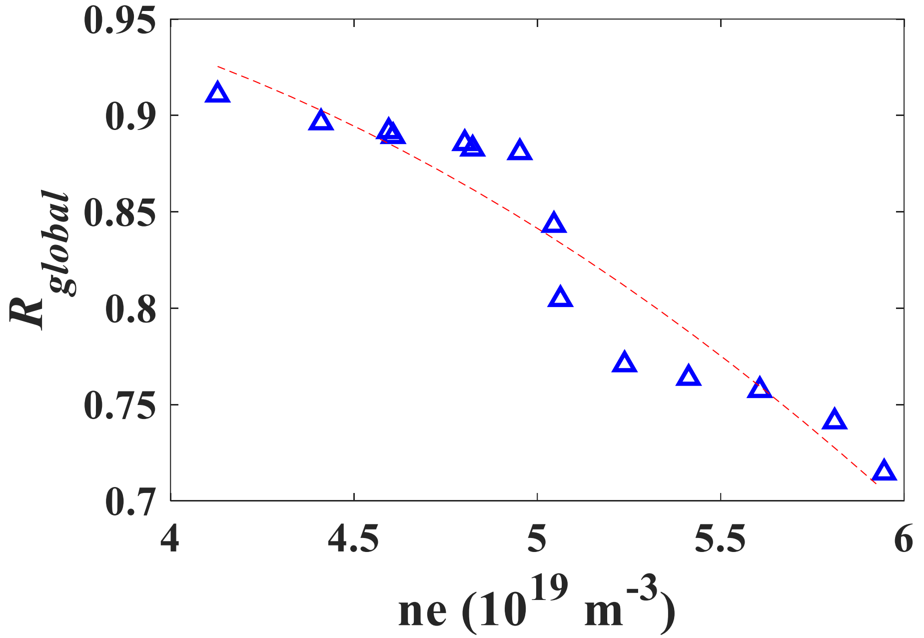
Influence of plasma density on recycling



0.3 MA, Double Null, ~10MW



- No obvious of wall pumping with *ne*
- Increase of div. pumping with *ne*
- Higher *ne* → lower R_{global}
- Recycling control is more difficult in lower density operation

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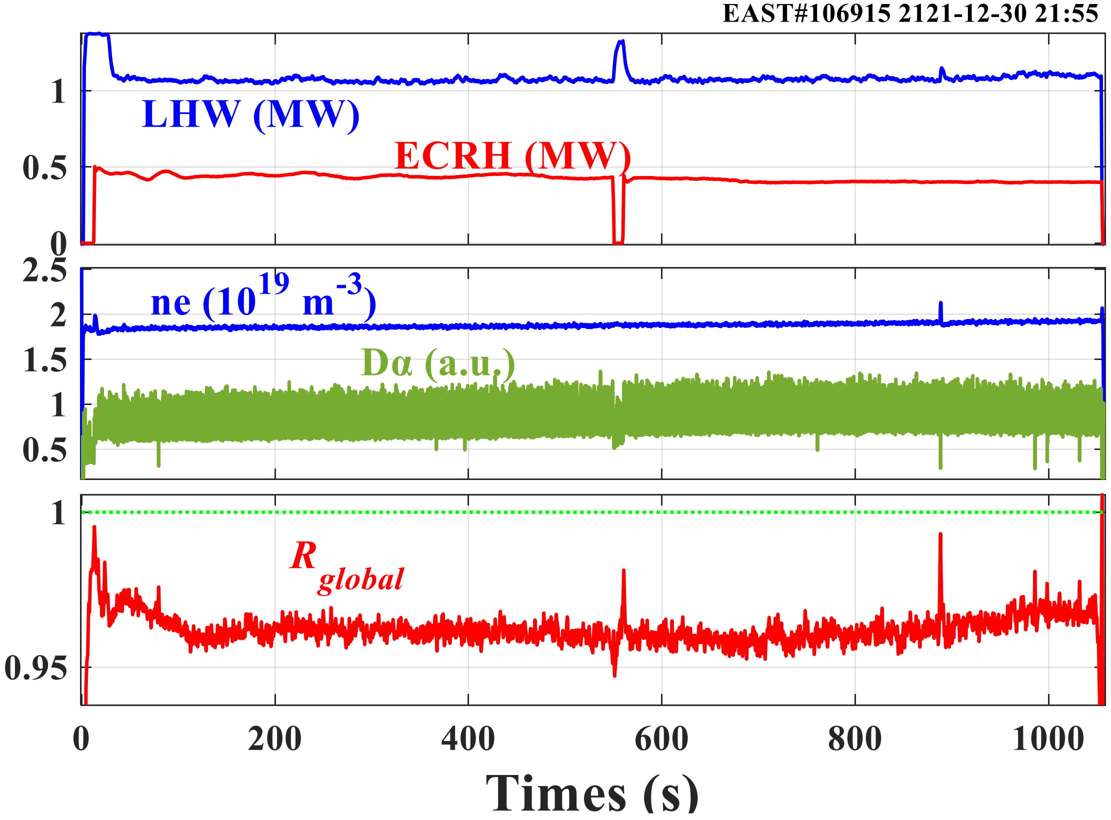
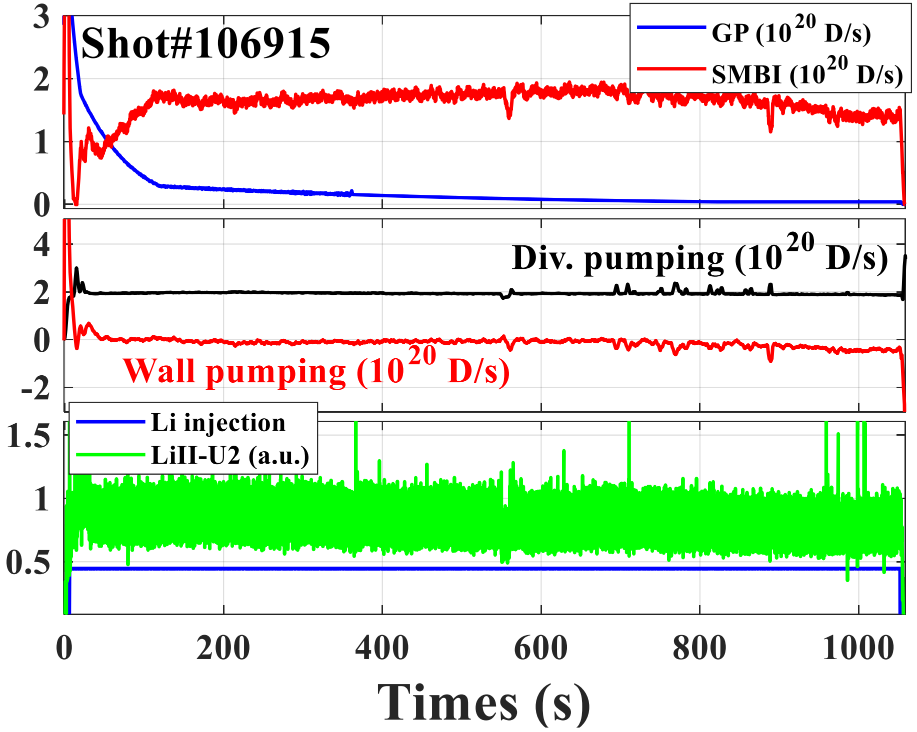
Recycling control in 1056 s plasmas

- ✓ Double Null, 1 MW LHW + 0.4 MW ECH
- ✓ Stable density control during **1056 s** discharge





- ✓ Real-time lithium injection
- ✓ *ne* control via SMBI: (1.8 → 1.4)×10^{20} D/s
- ✓ Wall saturation: ~700 s, 25% pumping
- ✓ Recycling control: R_{global} ~ **0.95 – 0.97**

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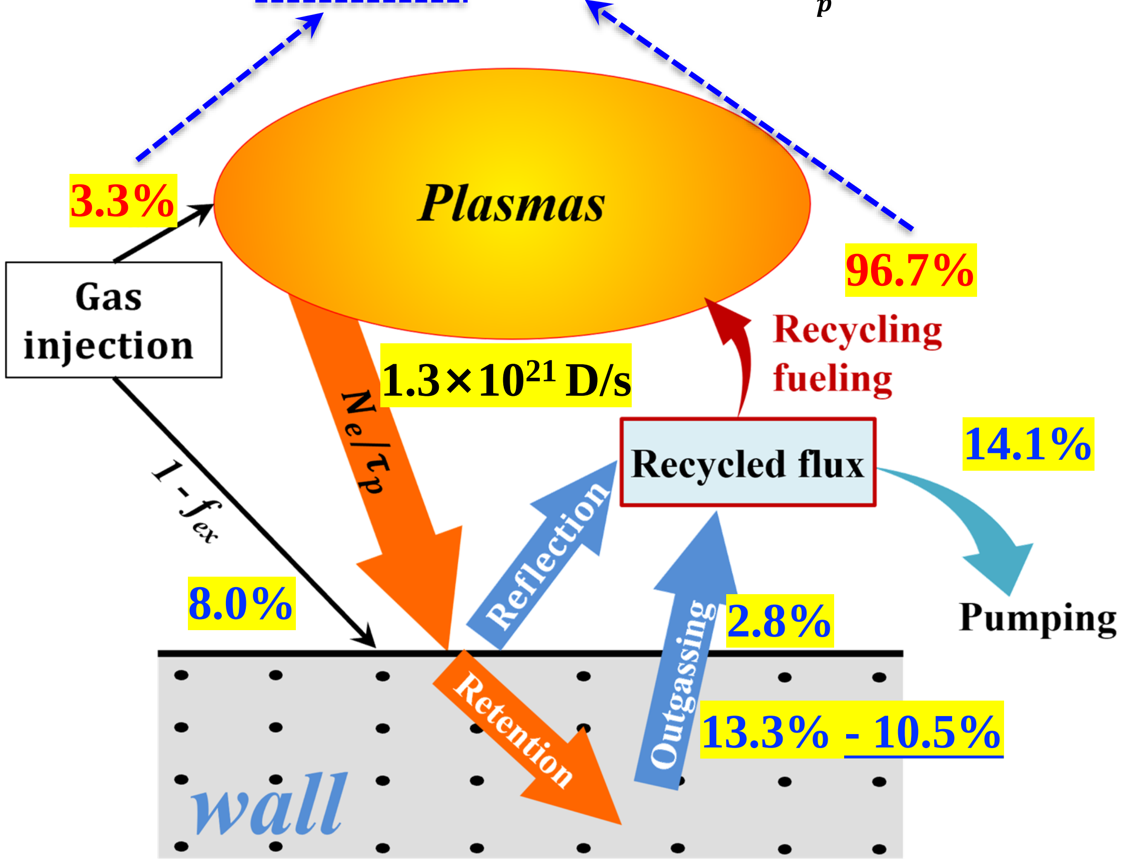
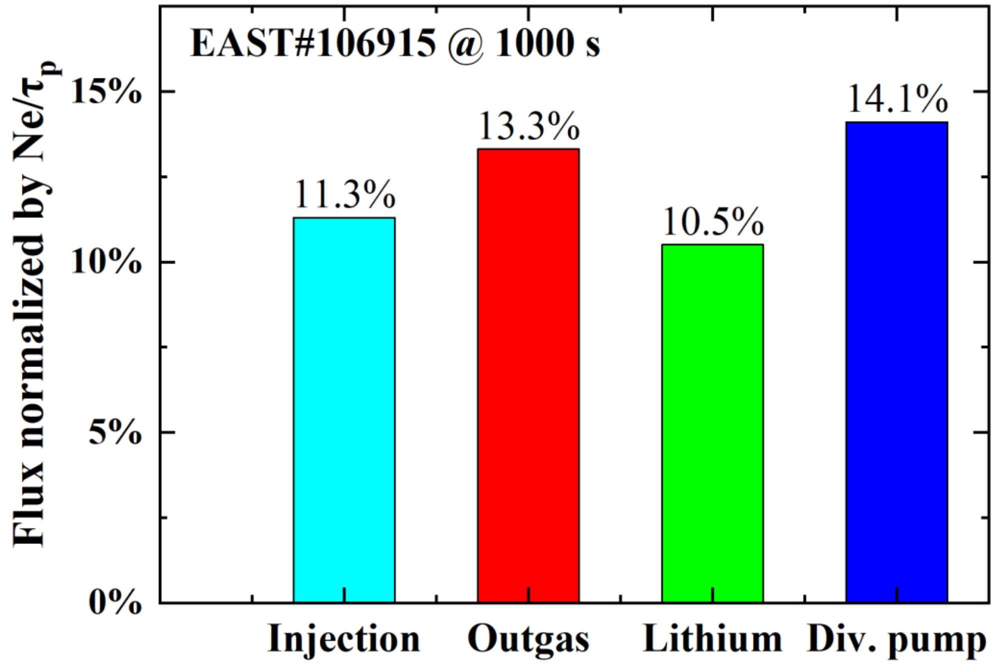
Particle balance in long pulse discharge

EAST #106915 @ 1000 s

$$\frac{dNe}{dt} = \Phi_{ex} \cdot f_{ex} + (R_{global} - 1) \cdot \frac{Ne}{\tau_p} = 0$$



Normalized by Ne/τ_p



$$\Phi_{wall}(-2.8\%) = \Phi_{Injection}(11.3\%) - \Phi_{Div.}(14.1\%)$$

$$\Phi_{wall}(-2.8\%) = \Phi_{Lithium}(10.5\%) - \Phi_{Outgas}(13.3\%)$$

Recycling control mainly by lithium + Div. cryopumps

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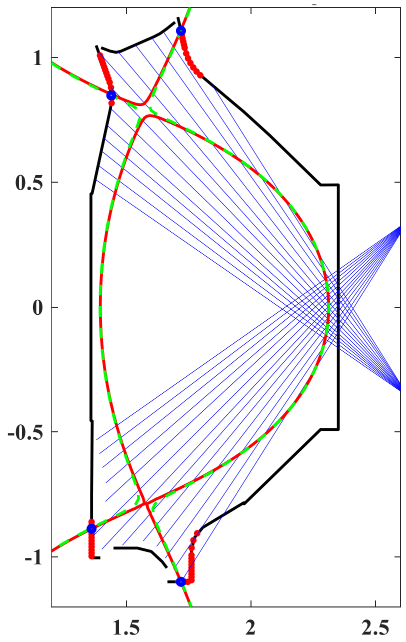
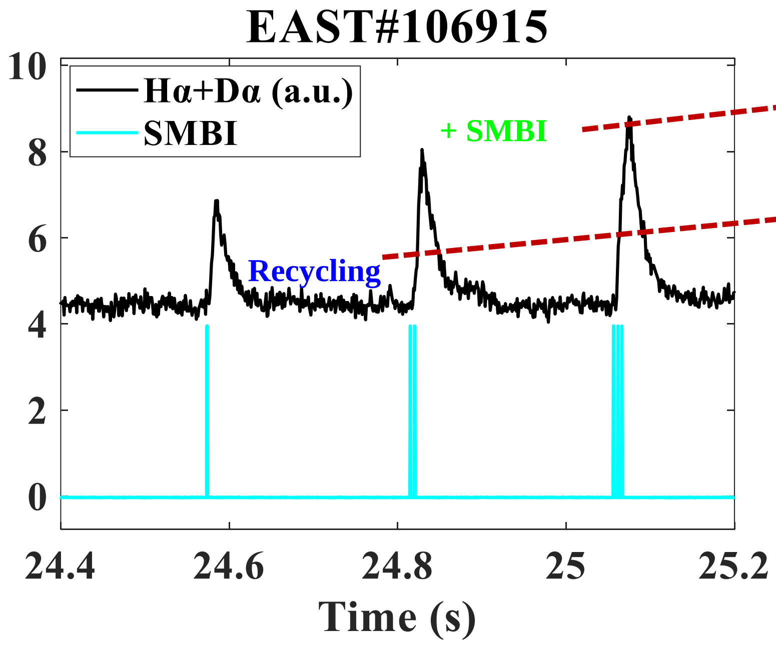
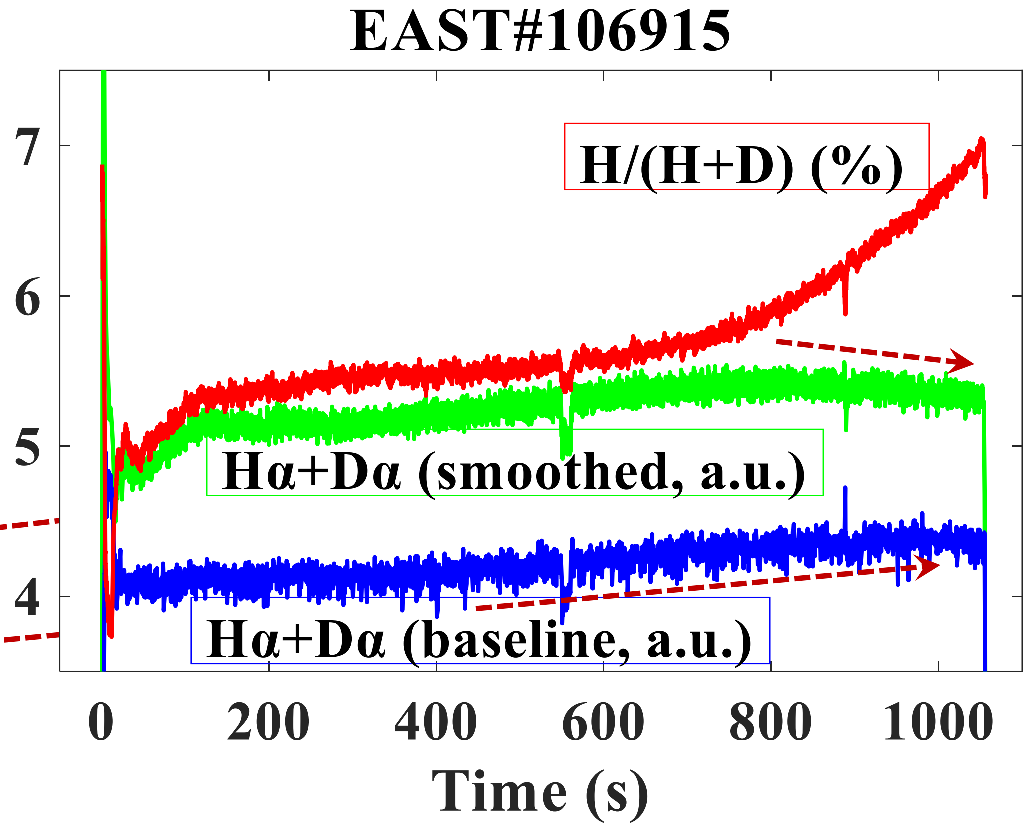
Recycling with first wall temperature

- **Hα+Dα = Recycling** (baseline) + **SMBI**
- Recycling: increased by 8%
- H/(H+D) increased by 30%
- Hα+Dα decreased from ~700 s due to reduced SMBI







- Successful global recycling control
- Slightly increasing fuel recycling with wall temperature / accumulated retention

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Summary

- **Fuel recycling is related to plasma heating power & density**
- **Effective recycling control in EAST tokamak**
  - Intensive discharge cleanings to decrease retention
  - High efficiency SMBI to further control retention
  - Lithium coating & real-time injection & divertor cryopumps
- **Successful recycling control in 1056 s discharges**
  - Wall changed to outgassing from ~700 s
  - Outgassing rate: 13.3%
  - Successful recycling control: div. cryopumps 14% + lithium 10.5%
  - Slightly increasing fuel recycling with wall temperature/accumulated retention

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Thank You

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