Exploration of Radiative Edge Cooling in the Island Divertor at Wendelstein 7-X

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Ackowledgments

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Outline

I. The **divertor heat flux** is governed by the 3D island divertor (ID) geometry

II. Radiative exhaust by light impurities concentrated within islands

III. The ID volume can be **cooled by active gas injection** of Ne and N2

IV. Edge P_{rad} and divertor cooling governed by **recycling** of coolant gases

Seeding experiments planned and analysed by 3D modeling with EMC3-EIRENE

ENERGY

$$\nabla\cdot\left(\tfrac{5}{2}n_eT_eV_{ill}\boldsymbol{b}-\kappa_e\nabla_{ll}T_e-\tfrac{5}{2}T_eD\nabla_{\perp}n_e-\chi_en_e\nabla_{\perp}T_e\right)=-k\left(T_e-T_i\right)+S_{ee}+S_{imp}$$

$$\nabla\cdot\left(\tfrac{5}{2}n_iT_iV_{ill}\boldsymbol{b}-\kappa_i\nabla_{ll}T_i-\tfrac{5}{2}T_iD\nabla_{\perp}n_i-\chi_in_i\nabla_{\perp}T_i\right)=+k\left(T_e-T_i\right)+S_{ei}$$

STREAMING

$$\nabla\cdot\left(n_iV_{ill}\boldsymbol{b}-D\nabla_{\perp}n_i\right)=S_p$$

$$\nabla\cdot\left(m_in_iV_{ill}V_{ill}\boldsymbol{b}-\eta_{ll}\nabla_{ll}V_{ill}-m_iD\nabla_{\perp}n_iV_{ill}\right)=-\nabla_{ll}p+S_m$$

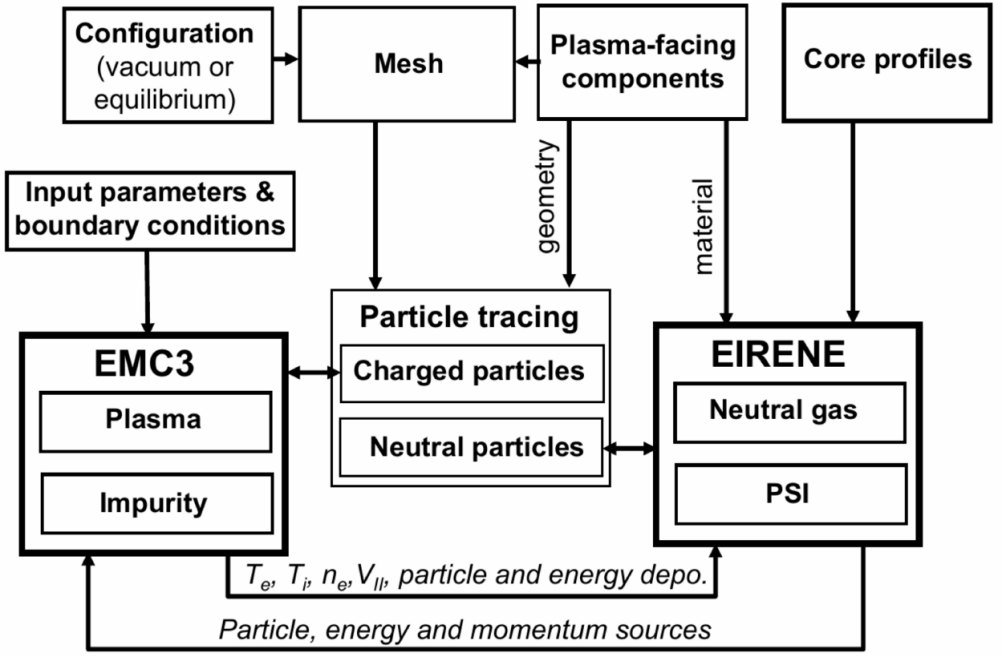
IMPURITY

$$\nabla\cdot\left(n_I^zV_{Ill}^z\boldsymbol{b}-D_I^z\nabla_{\perp}n_I^z\right)=S_{z-1\to z}-S_{z\to z+1}+R_{z+1\to z}-R_{z\to z-1}$$

$$U_{Ii}^z\left(V_{Ill}^z-V_{ill}\right)=-\boldsymbol{b}\cdot\nabla n_I^zT_I^z+n_I^zZeE_{ll}+n_I^zZ^2C_e\boldsymbol{b}\cdot\nabla T_e+n_I^zC_i\boldsymbol{b}\cdot\nabla T_i$$

NEUTRAL

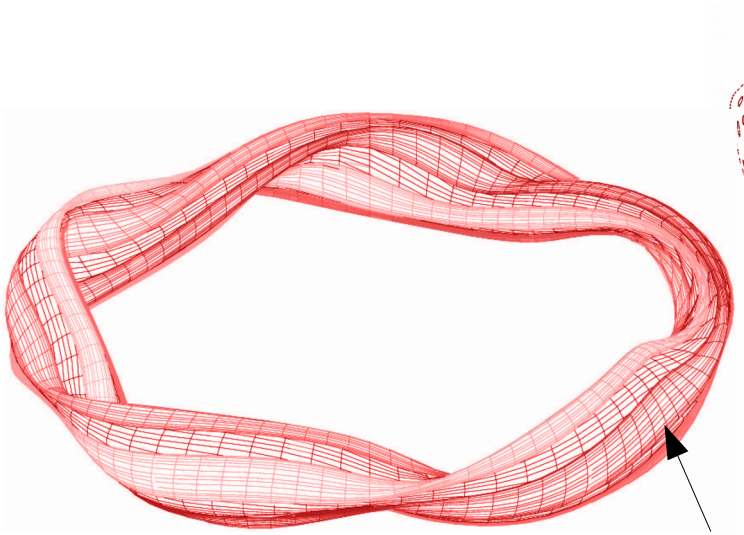
Neutral transport/EIRENE



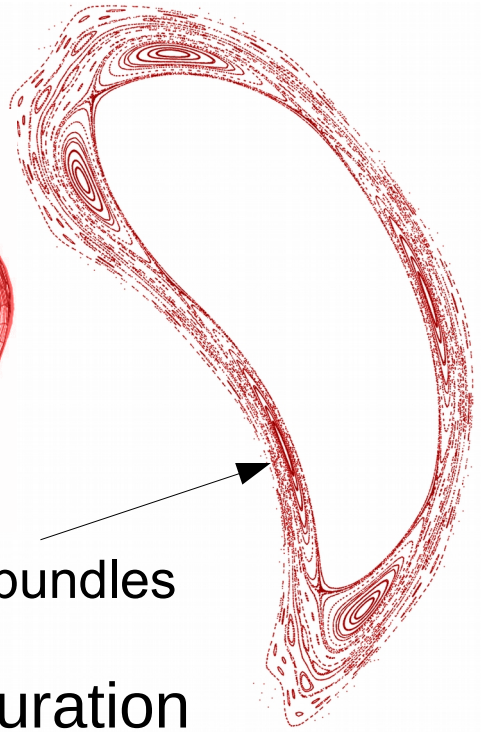
Courtesy of Y. Feng

→Poster Y. Feng **#29 (Th)** → Talk Y. Feng **(Su)**, D. Reiter **#72 (Tu)**

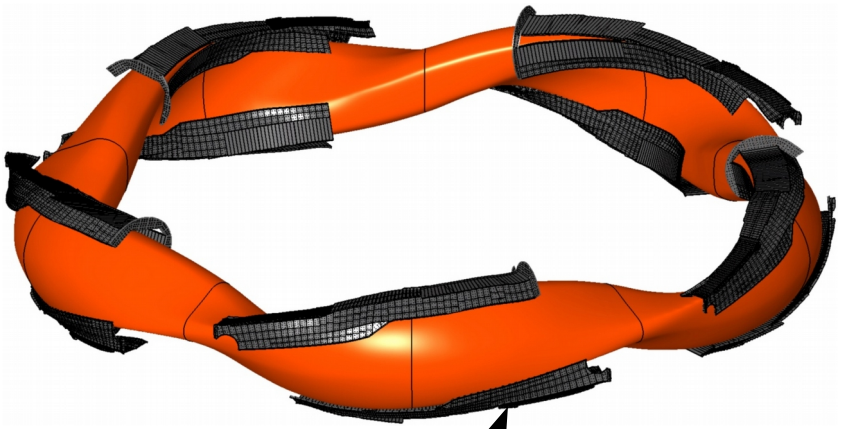
The island divertor at W7-X is formed by island flux tubes and close fitting divertor modules



5 island bundles

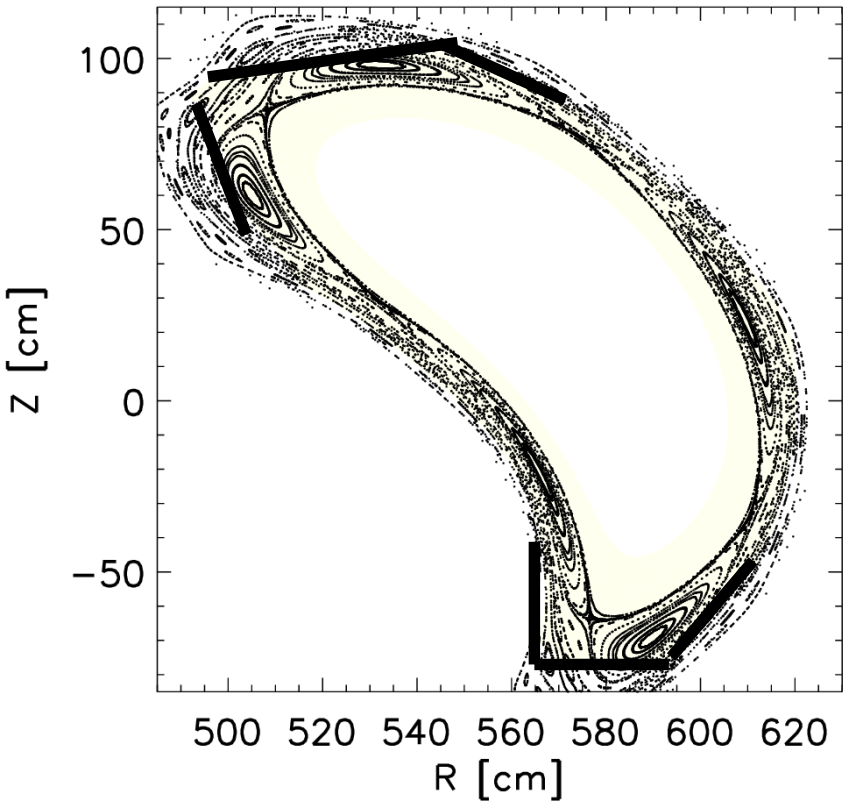


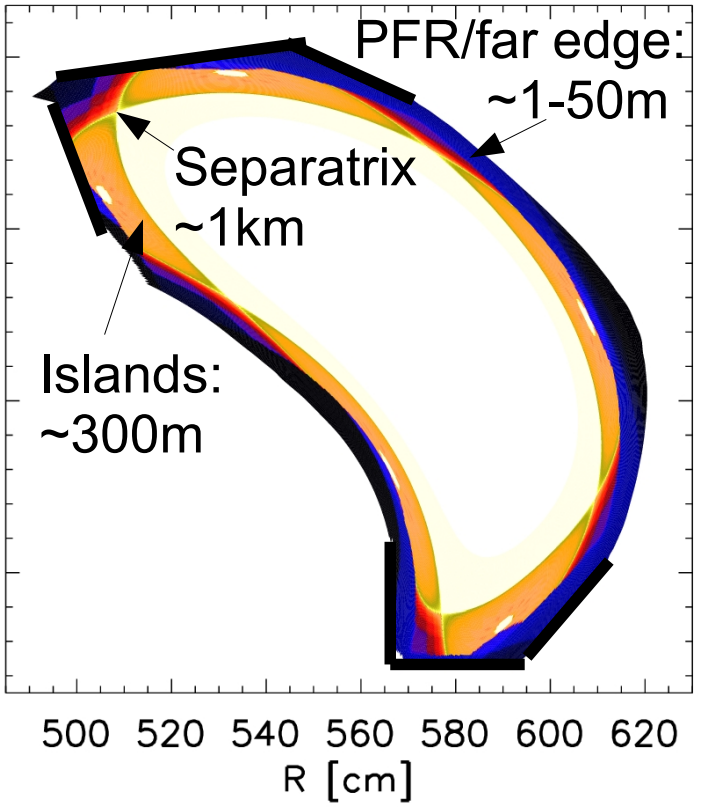
Standard Divertor Configuration

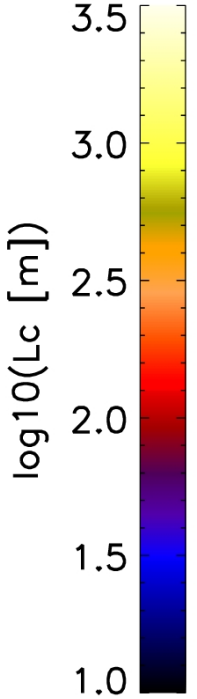


10 divertor modules (graphite)

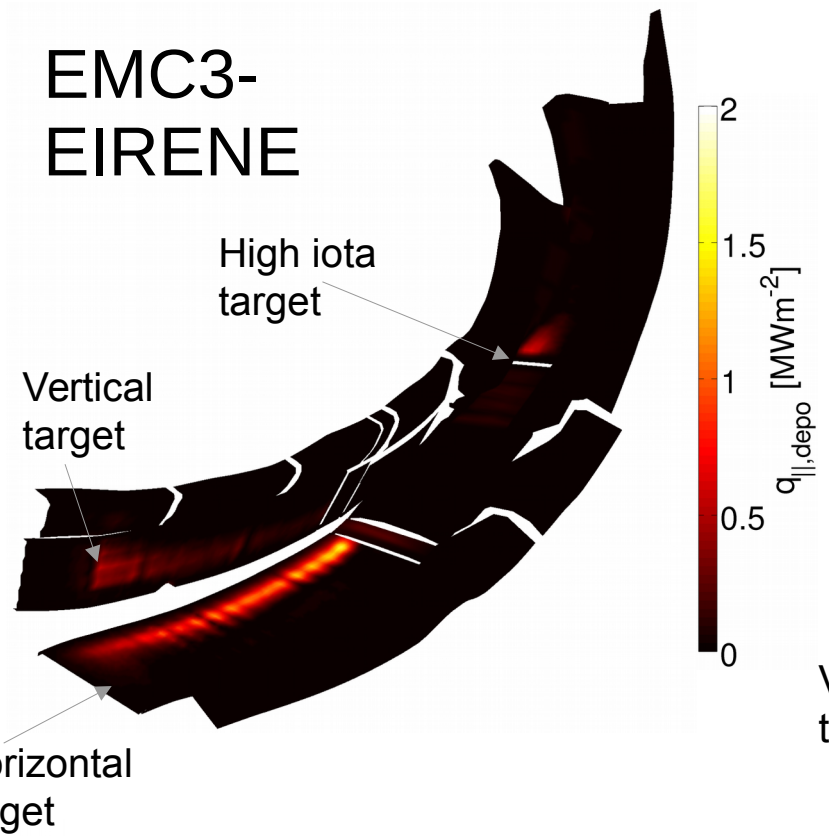
The island divertor flux bundles consist of long target-to-target connection length

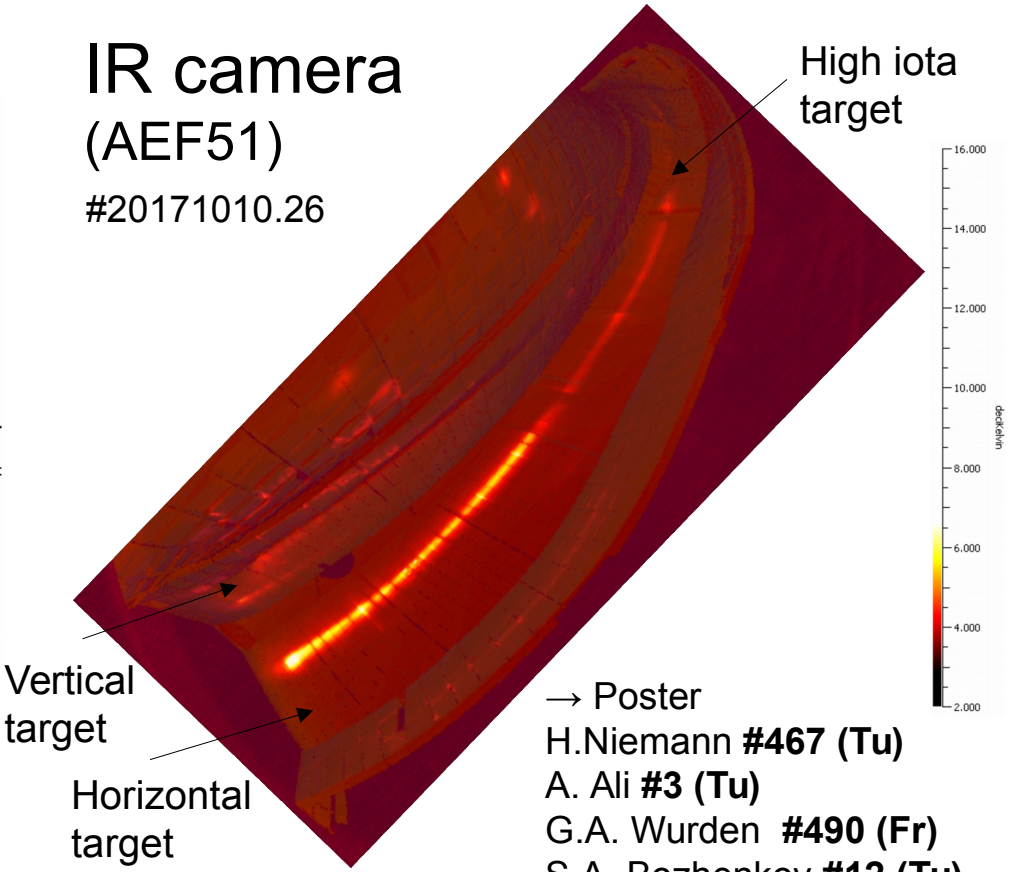






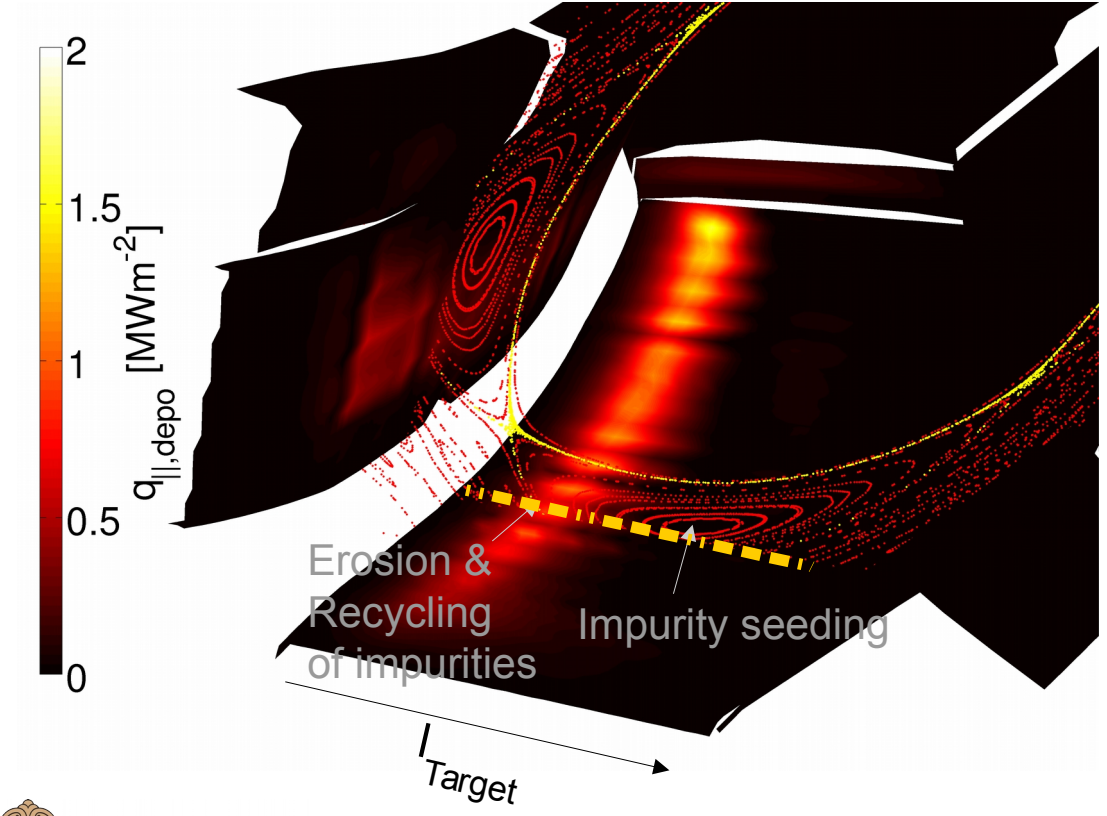
Resulting heat flux distributions predicted by 3D model agree qualitatively with measurement

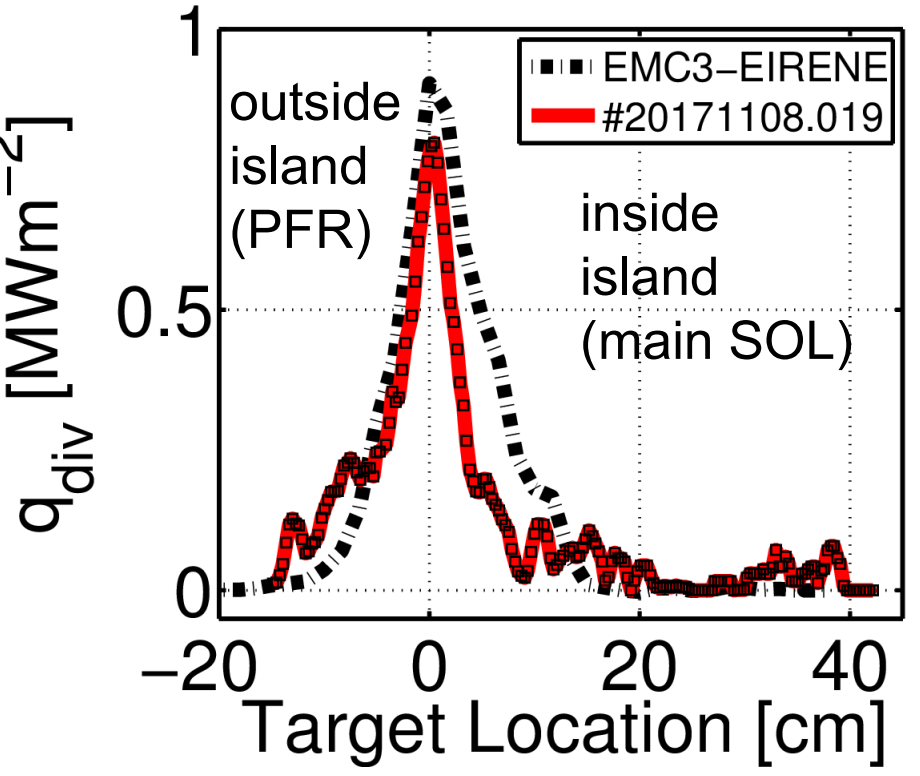




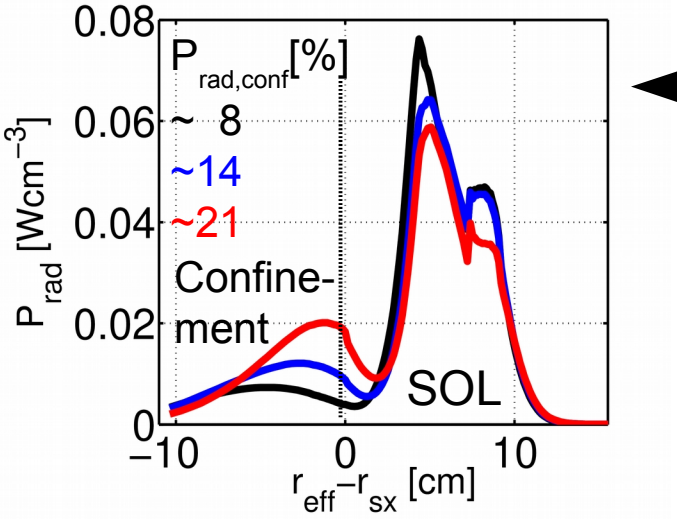
→ Poster
H.Niemann **#467 (Tu)**
A. Ali **#3 (Tu)**
G.A. Wurden **#490 (Fr)**
S.A. Bozhenkov **#12 (Tu)**

The divertor target heat flux features a PFR-like and an island SOL component

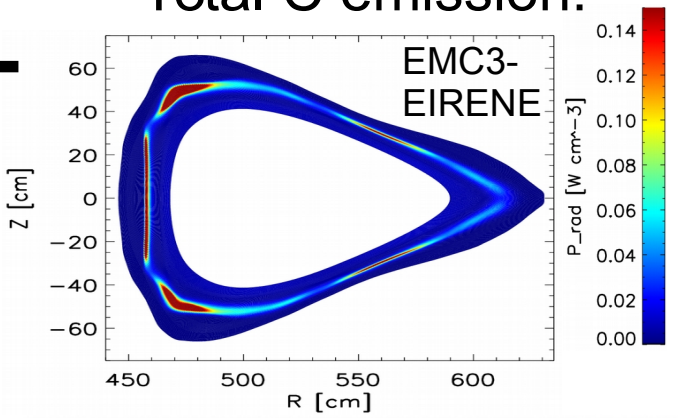




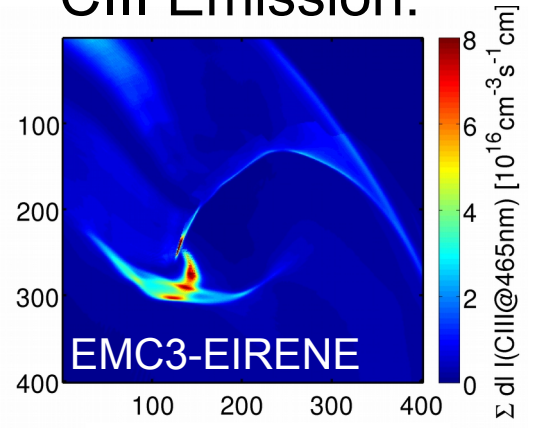
Intrinsic radiation concentrated in edge and island SOL volume due to dominating friction force

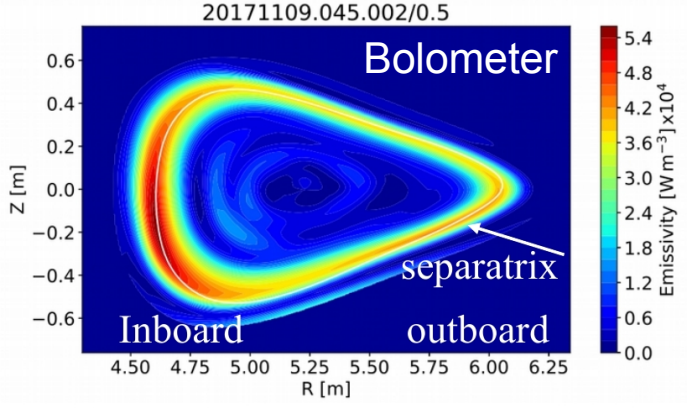


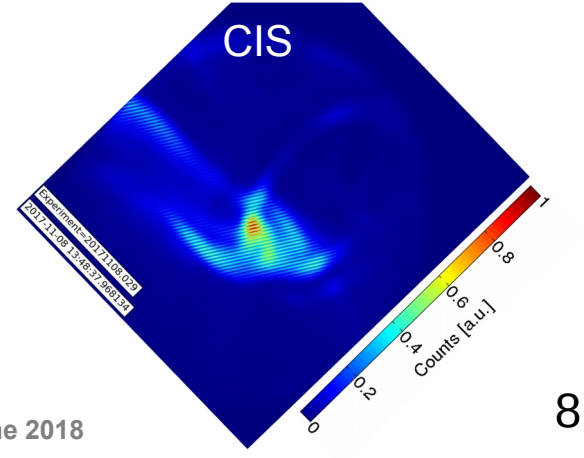
Total C emission:



CIII Emission:







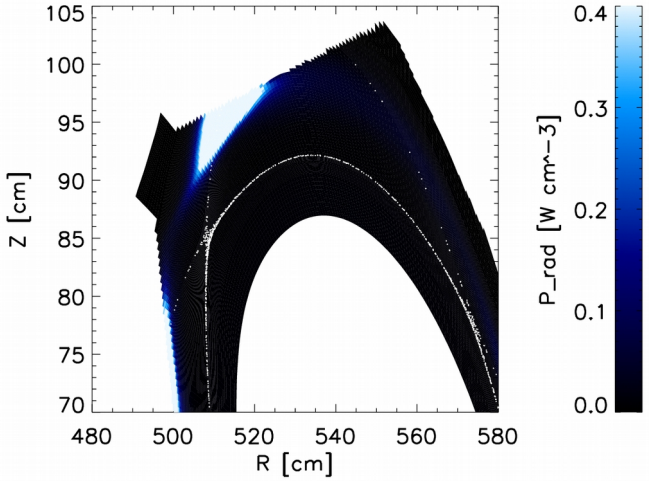
P=2.5, 5.0, 10.0MW,
$n_{up}=1\cdot10^{19}m^{-3}$, $P_{rad,C}=0.5MW$,
$D_\perp=0.5m^2 2s^{-1}$, $\chi_\perp=3D_\perp$

→ Poster D. Zhang **#305 (Fr)**

3D modeling approach: consider Ne sourced from main recycling domain and no recycling for N during puff

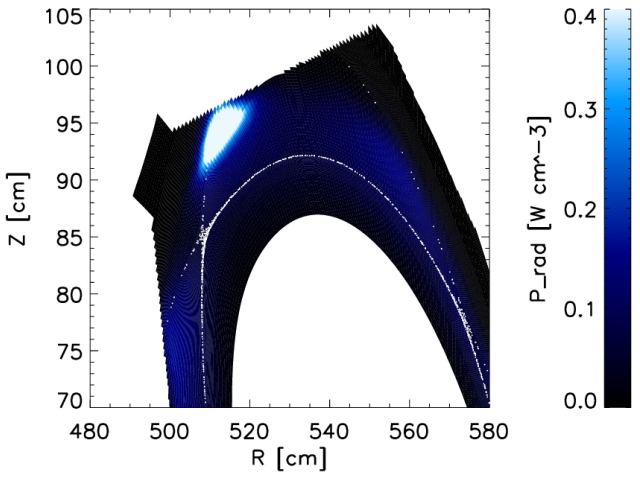
Carbon: f_{rad}=20%

erosion



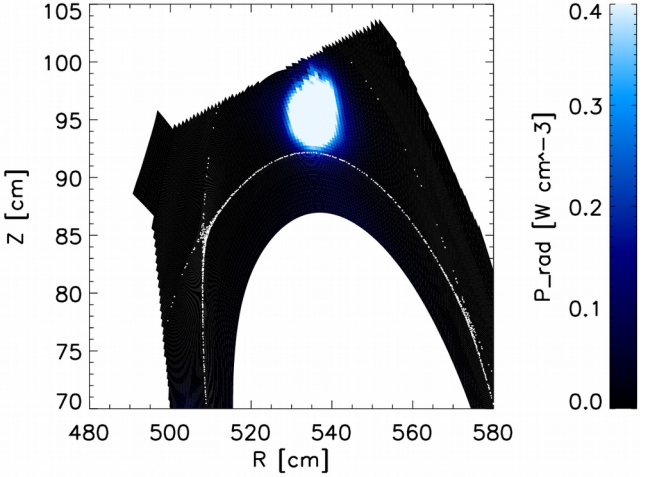
Neon: f_{rad}=40%

recycling



Nitrogen: f_{rad}=40%

puff,no recycling



$n_{up}=1\cdot10^{19}m^{-3}$, P=2.5MW, $D_\perp=0.5m^2s^{-1}$, $\chi_\perp=3D_\perp$

$\rightarrow\ \Gamma_{Ne}=1.1\cdot10^{21}s^{-1}$, $\Gamma_N=2.0\cdot10^{21}s^{-1}$

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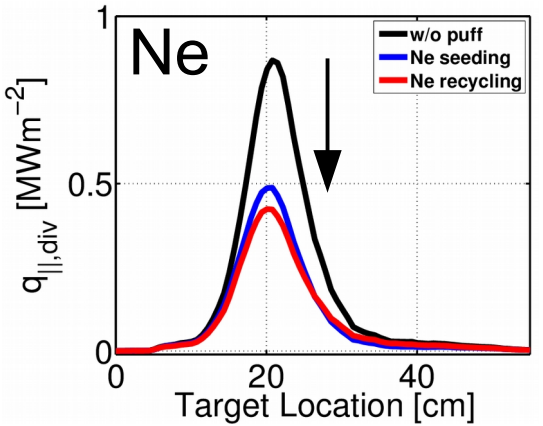
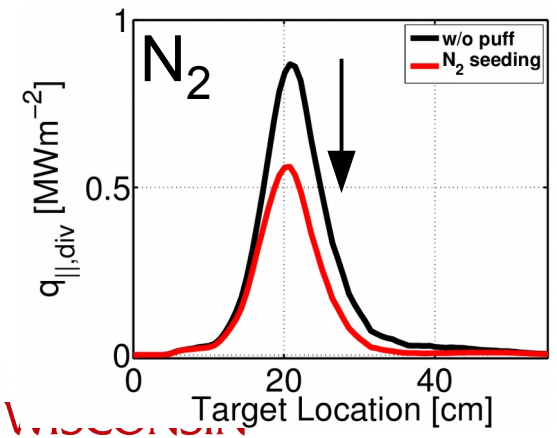
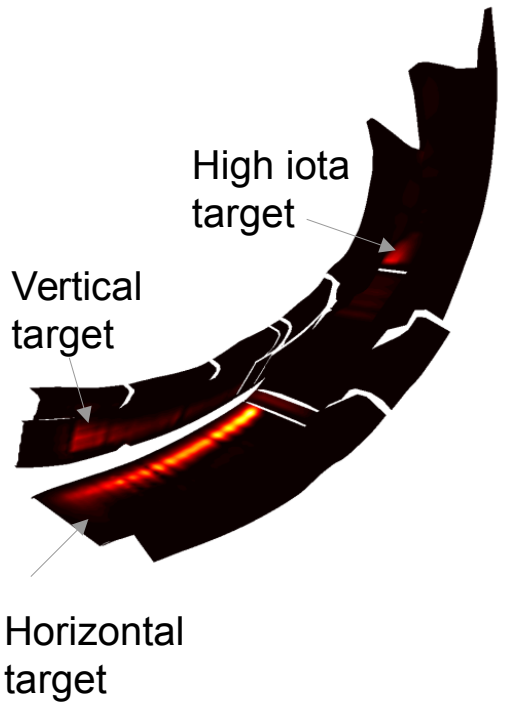
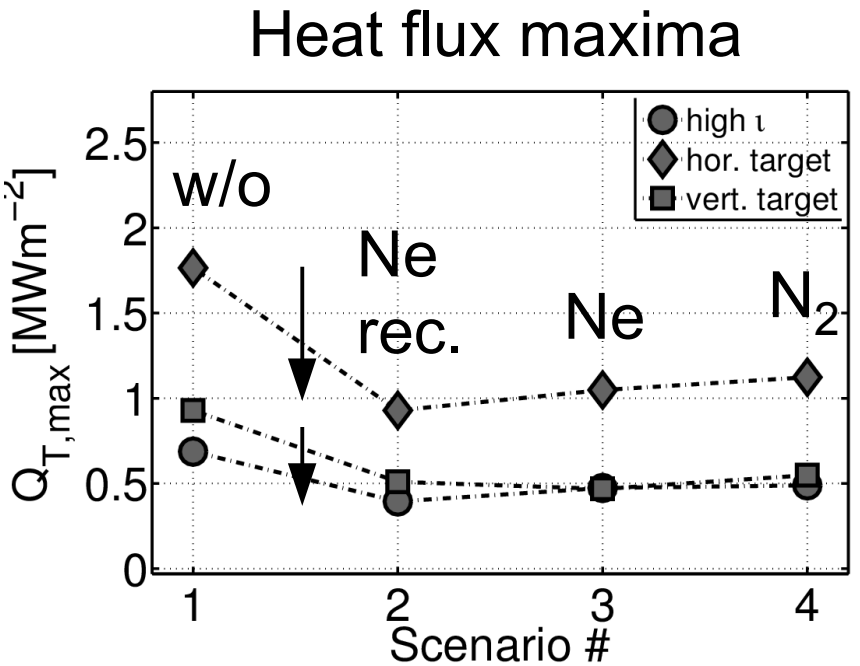
3D modeling: Ne and N allow for reduction of deposited heat fluxes ~ P_{rad}

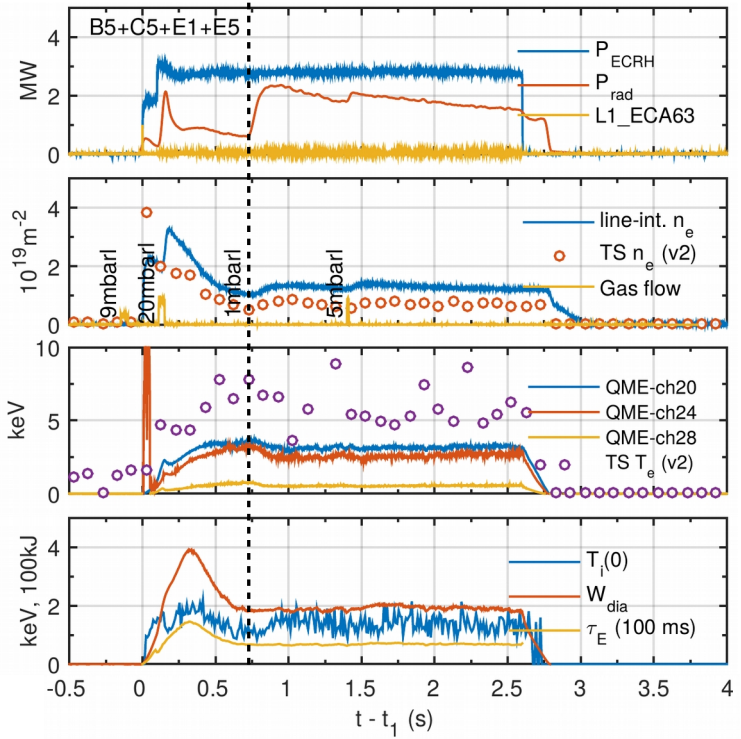








Enhancement of edge P_{rad} and reduction of divertor heat fluxes demonstrated experimentally with Ne puff sequence

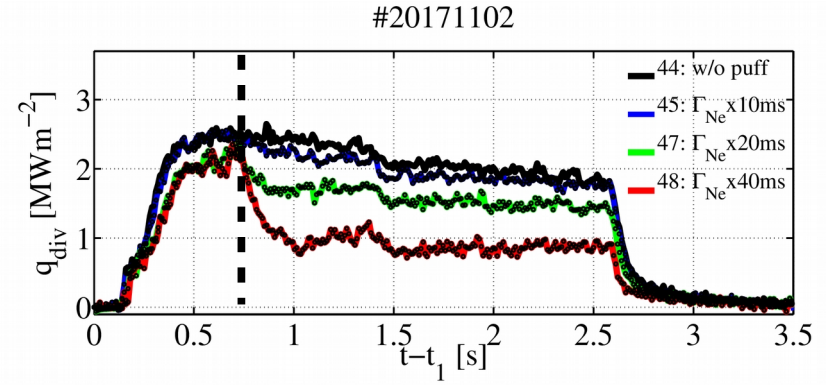


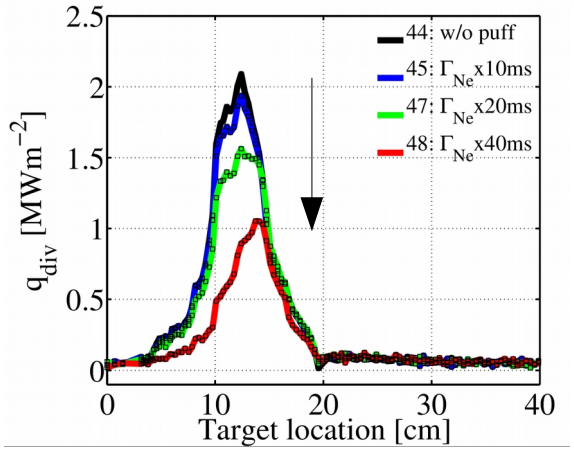
Ne puff 1.3bar
remote port
at t-t_1=700ms

ΔP_{rad} ~ +50-250%

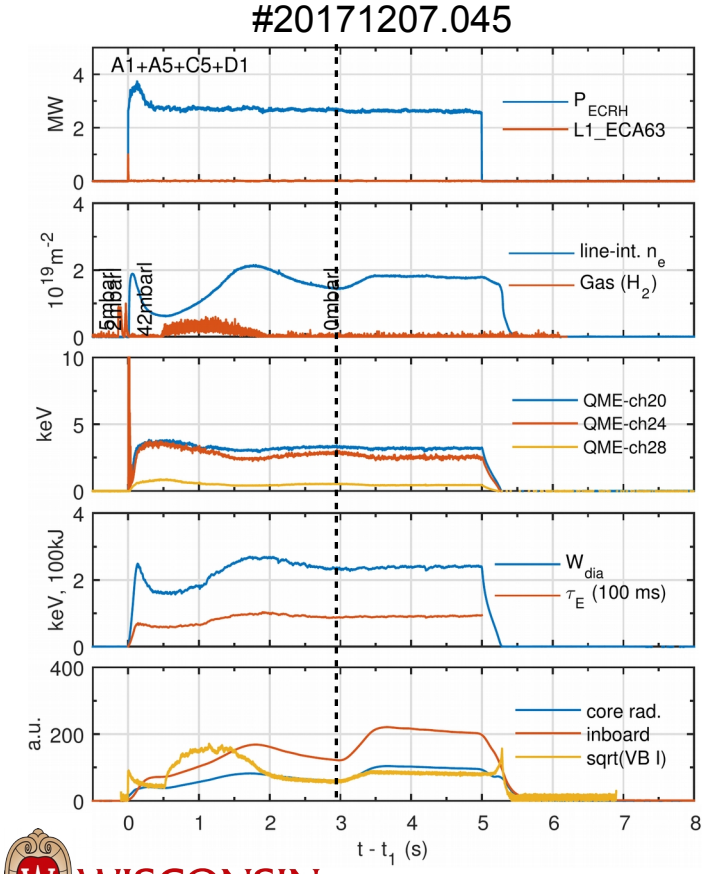
ΔW_{dia} ~ 0%

$\Delta \tau_E$ ~ 0%





Enhanced edge P_{rad} and reduced divertor heat fluxes sustained after Neon injection



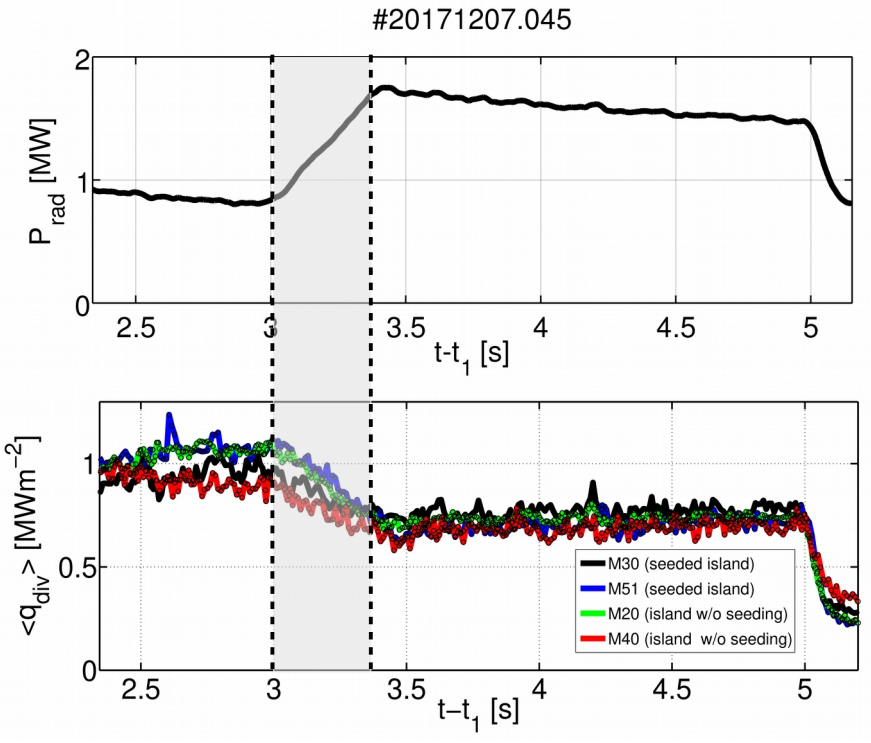
Divertor seeding

Γ_{Ne} ~ $5 \cdot 10^{19} s^{-1}$

ΔP_{rad} ~ +90%

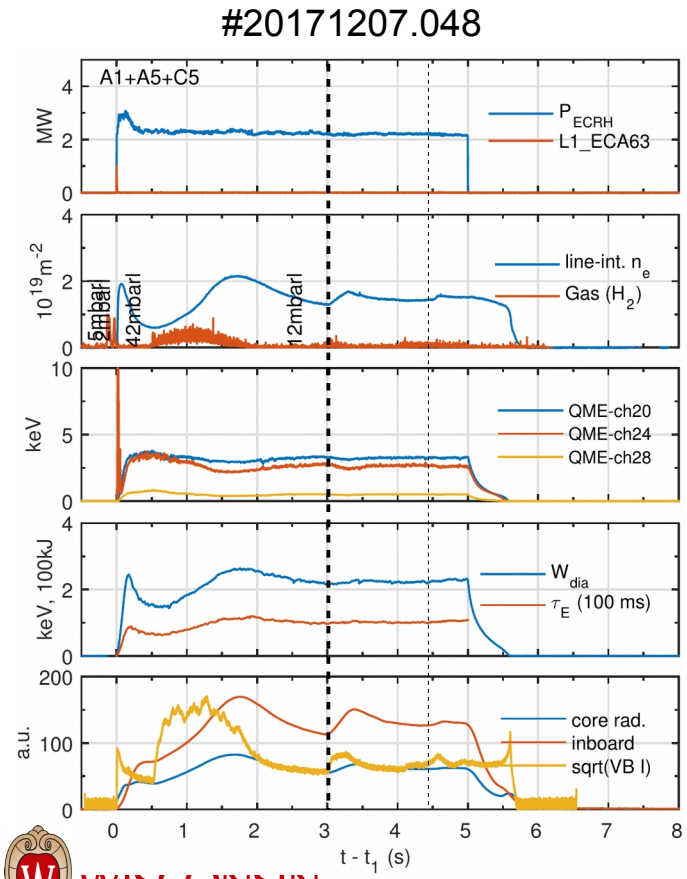
ΔW_{dia} ~ +-0%

$\Delta \tau_E$ ~ +-0%



$\tau_{Ne\ inj.}$=400ms

Nitrogen seeding indicates shows fast recovery of P_{rad} and T_e after injection in agreement with low recycling property



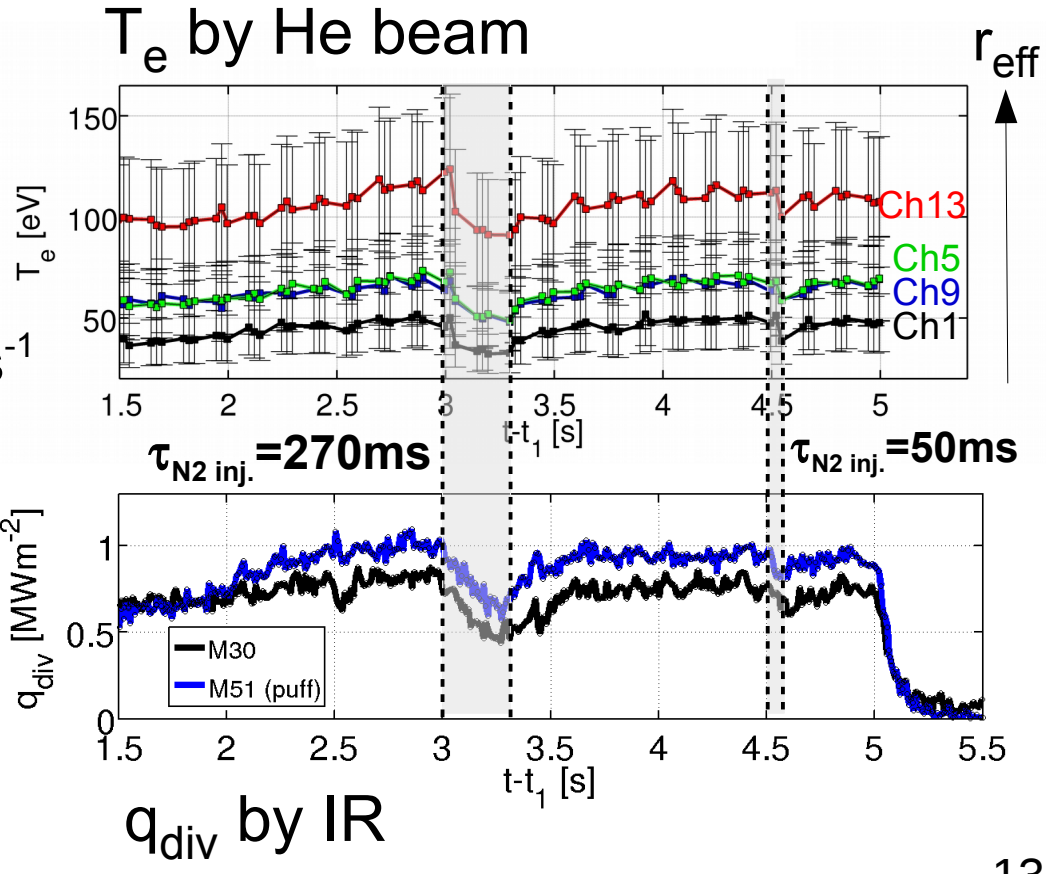
Divertor seeding

$\Gamma_N \sim 2 \cdot 10^{20} s^{-1}$

$\Delta P_{rad} \sim +40\%$

$\Delta W_{dia} \sim +-0\%$

$\Delta \tau_E \sim +-0\%$



Summary and outlook

- The **divertor heat flux** peaks at the separatrix and with tails in the PFR and the island
- C as **intrinsic radiator** is trapped in the ID volume according to 3D modeling
- The ID volume can be **cooled by active gas injection**
- **Ne** shows long sustained P_{rad} enhancement and divertor heat flux reduction after puff
- **N_2** shows fast recovery of T_e and heat fluxes after injection

Outlook:

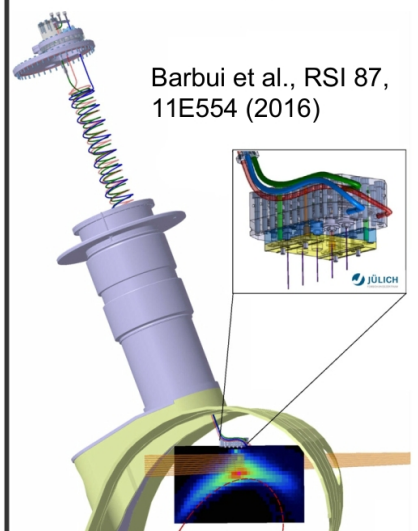
- New experiments at higher power and density in OP1.2.b
- Refined analysis with optimized edge spectroscopy
- Investigate impact of impurity source location on cooling effects
- Detachment by seeding

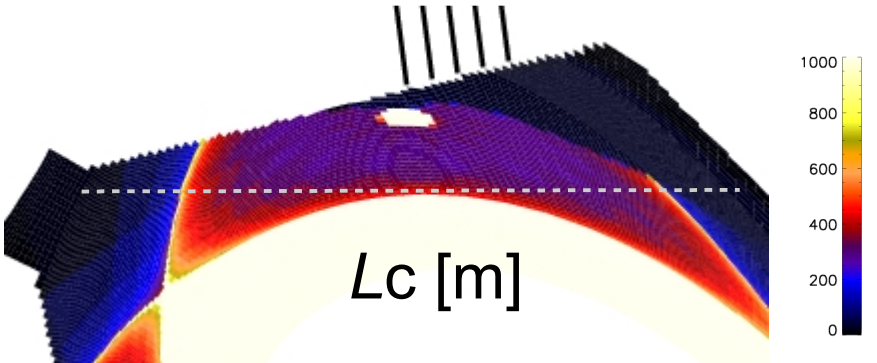
Y. Feng **#29 (Th)**
R. Koenig **#455 (Tu)**
S.A. Bozhenkov **#12 (Tu)**
P. Drewelow **#440 (Tu)**

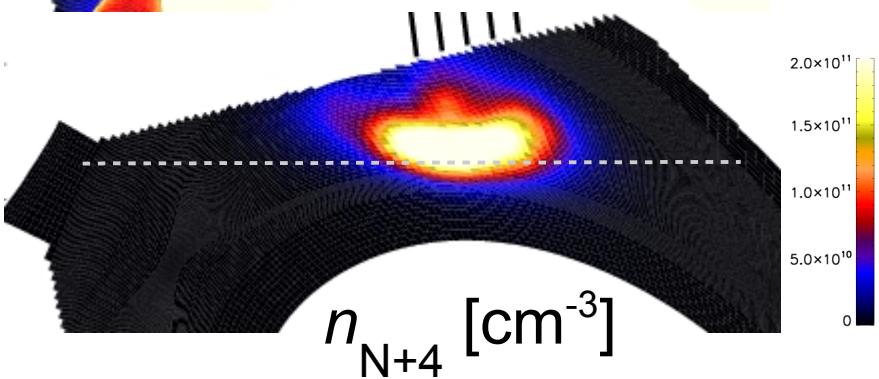
Appendix

Versatile piezo valve gas injection in use for fine controlled island impurity seeding injection

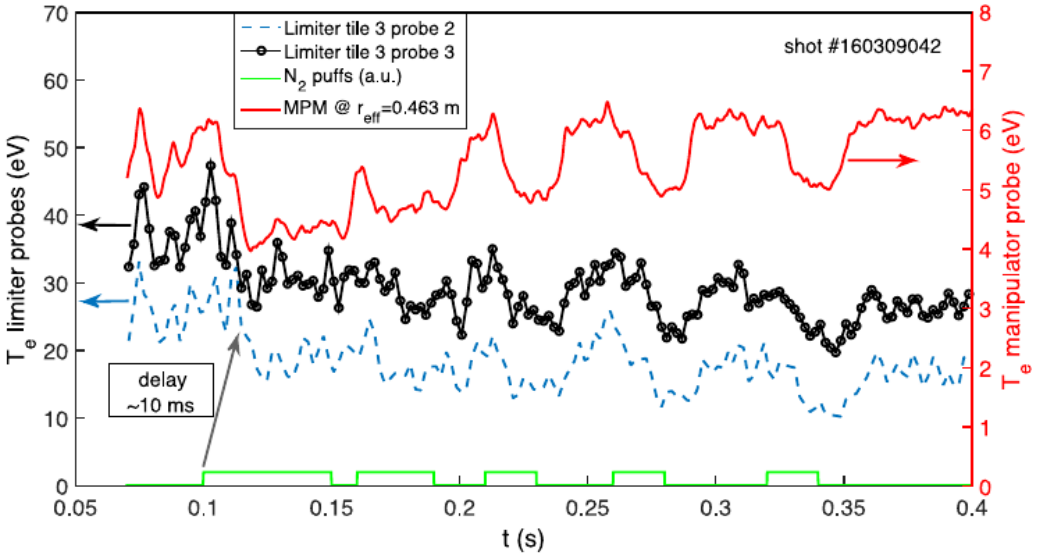
Divertor gas injection system:
1) impurity seeding
2) He/Ne beam spectroscopy







Fast recovery of edge Te observed during N2 seeding in W7-X limiter campaing



M. Krychowiak et al., Rev. Sci. Instrum. **87**, 11D304 (2016)

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Bolometer: increased P_{rad} sustained after Ne puff, but relaxes to original level shortly after N2 puff

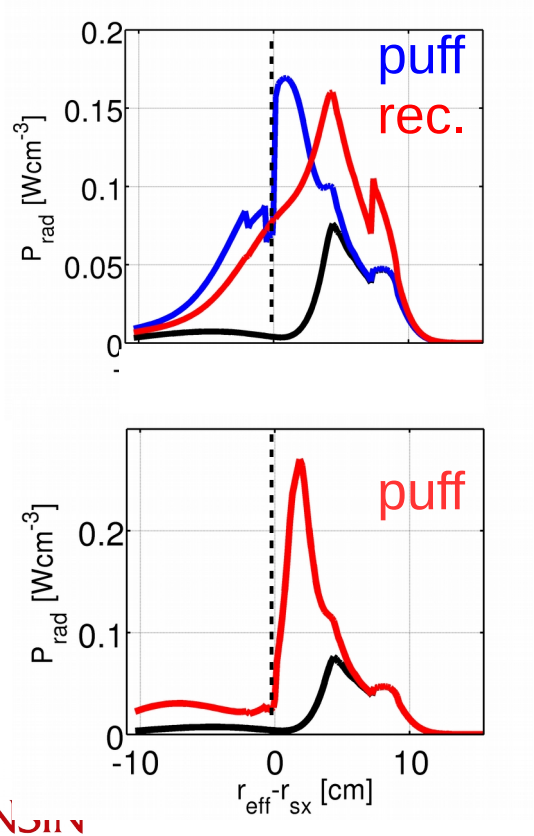
Ne

$P_{rad,C}$ +$P_{rad,Ne}$

N_2

$P_{rad,C}$ + $P_{rad,N}$

EMC3-EIRENE



$\Gamma_{Ne}=5\cdot10^{19}s^{-1}$

puff

1.3s
2.7s
3.0s
4.1s

$\Gamma_{N}=2\cdot10^{20}s^{-1}$

Bolometer