EUROfusion

Developing Steady State ELM-absent H-Mode scenarios with Advanced Divertor Configuration in EAST tokamak

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ASIPP

UNIVERSITÀ DEGLI STUDI DELLA Tuscia

CREATE

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Outline

✓ Context and Motivations

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- ✓ 2 Nearby Divertor Nulls (2-NDN) properties

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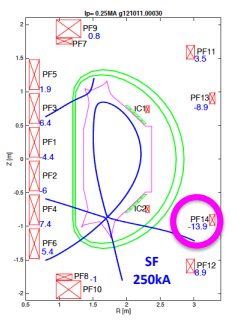
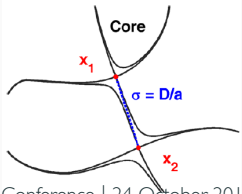
- ✓ (New) shape controller and next steps
- ✓ Conclusions

Context and motivations

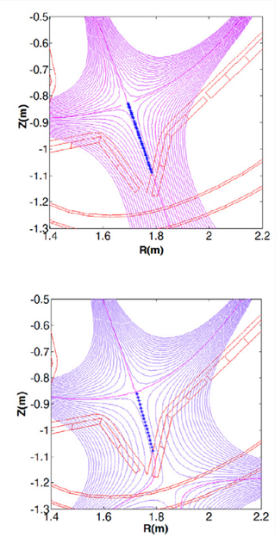


- ✓ **EAST** (R/a = 1.85/0.45 m) is a fully superconducting tokamak with upper ITER-like, water cooled W monoblock divertor
- ✓ **14 PFs** 14kA/turn & 12 PSs, DN/SN conf.s, far from the plasma (DEMO-like)
- ✓ **Not optimized** for SnowFlake (SF) – like conf. $\Longrightarrow$ can be realized only at **low IP**
- ✓ Higher $\mathbf{I}_p$ requires coils current exceed limit

Alternative divertor configuration, named 2-NDN **characterized by two-first order X-points** $\Rightarrow$ can easily achieved and controlled on EAST (Calabro *et al.* 2015)



2-NDN divertor properties

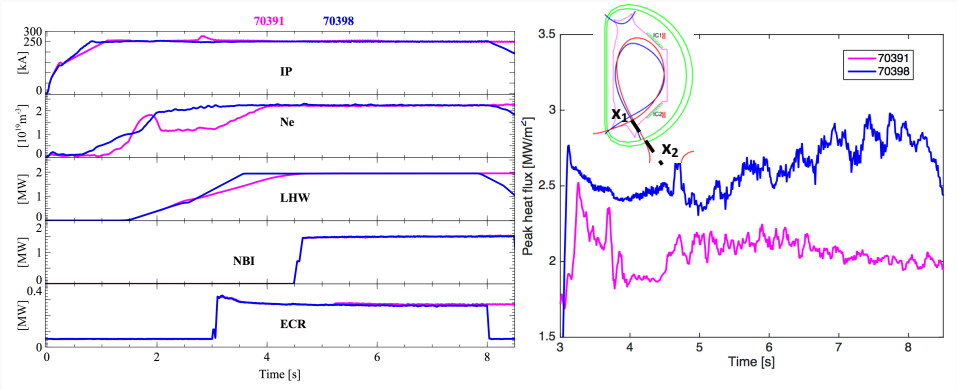


Due to the location of PF coils and target plates the 2nd x-point could be moved around from the 1st one to form a magnetic configuration that features either a contracting or flaring geometry near the plate (the latter being a feature of a single-legged X-divertor)

Case	$L_{\|\|}$	Flux expansion at outer SP	Distances x_1 -x_2
Single Null (SN)	95	**2.1**	-
2-NDN *far* ($I_{p,max} \approx$ 480kA)	103.5	**9.84**	0.92
2-NDN *close* ($I_{p,max} \approx$ 400kA)	129.7	**26.59**	0.45

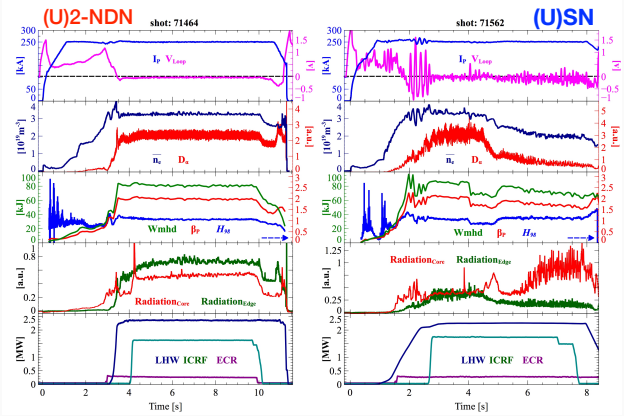
Modeling by CREATE-NL tools

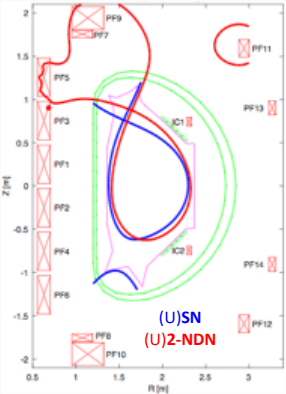
H-Mode: (Lower) SN vs (Lower) 2-NDN



- ✓ **Flux expansion** of **(L)2-NDN** at outer strike point is a factor ∼ 3 w.r.t. **(L)SN**
- ✓ IR measurements point out a **peak heat load reduction** for **(L)2-NDN** of a factor ∼ 1.5 w.r.t. **(L)SN**
- ✓ **SOLPS** (Si *et al.* 2016) and **EDGE2D-Eirene** modeling prediction confirmed (Viola *et al.* 2017)

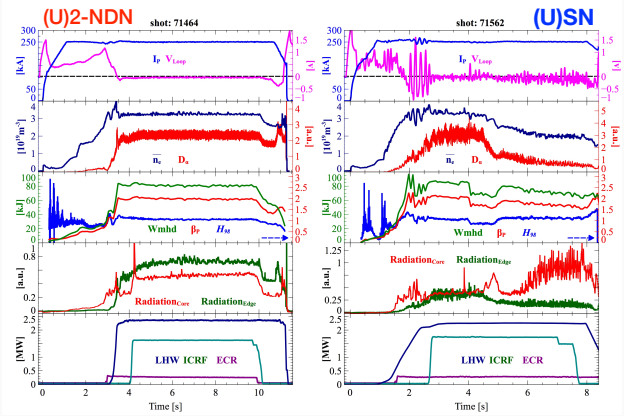
H-mode ELMs-absent Upper 2-NDN

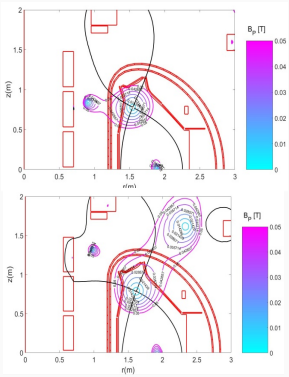




- ✓ **Flux expansion** of **(U)2-NDN** at outer strike point is factor 3 w.r. to **(U)SN**
- ✓ Core and edge Radiation almost constant, no impurity accumulation is observed
- ✓ ELMy absent ⇒ which mechanism characterizes this behavior?

H-mode ELMs-absent Upper 2-NDN

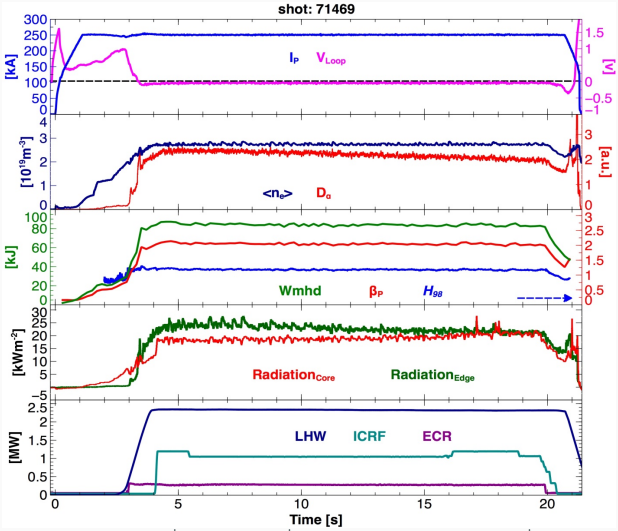




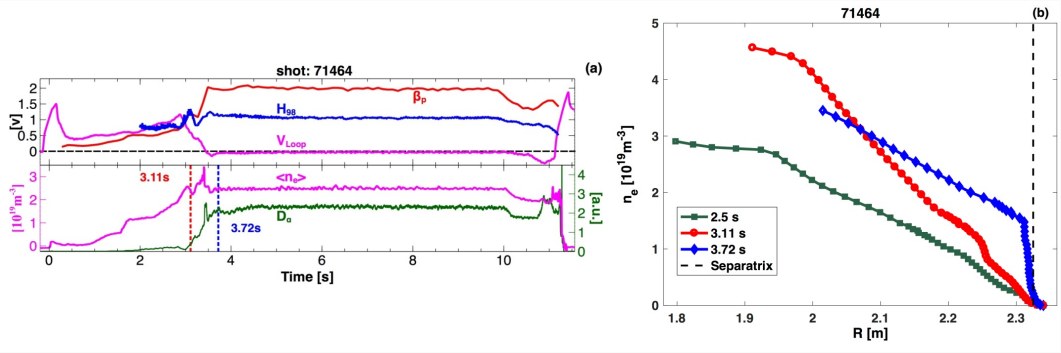
- ✓ **Flux expansion** of **(U)2-NDN** at outer strike point is factor 3 w.r. to **(U)SN**
- ✓ Core and edge Radiation almost constant, no impurity accumulation is observed
- ✓ ELMy absent ⇒ which mechanism characterizes this behavior?

Long pulse ($\sim$ 21 s) non-inductive 2-NDN

- ✓ $H_{98} \sim 1.1$
- ✓ $n_e \sim 2.8\,10^{19} m^{-3}$
- ✓ $\beta_p \sim 2.1$
- ✓ $I_p \sim 250$ kA, B_T=2.4T
- ✓ $P_{heat} \approx 6.2$ MW
- ✓ Steady state
- ✓ Non-inductive
- ✓ ITER like z stabilizer + ISOFLUX shape controller



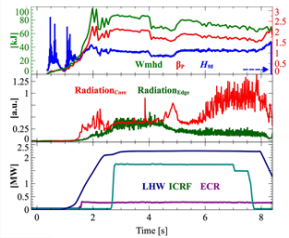
Looking at (U)2-NDN edge behavior



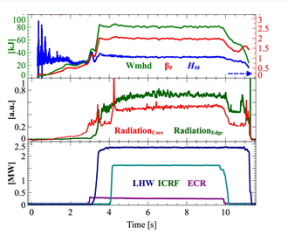
- ✓ Stable density is maintained in whole discharge (MARFE between 3.3s-3.4s)
- ✓ Strong pedestal gradient build up at the onset of H-Mode

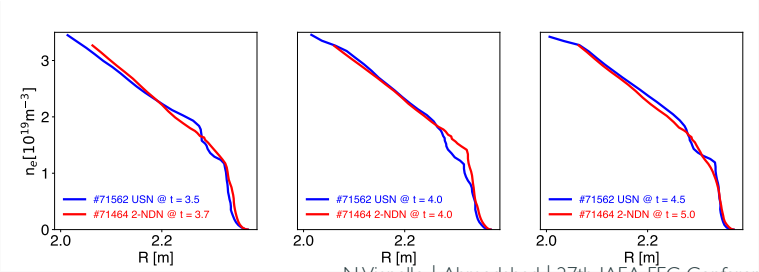
Comparison of (U)SN *vs* (U2-NDN)

(U)SN



(U)2-NDN





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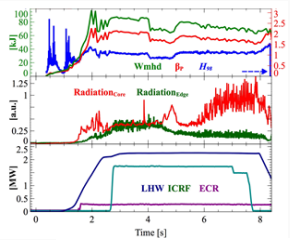
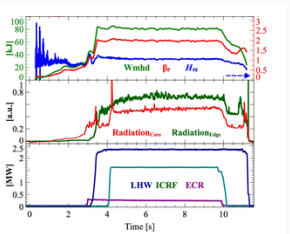
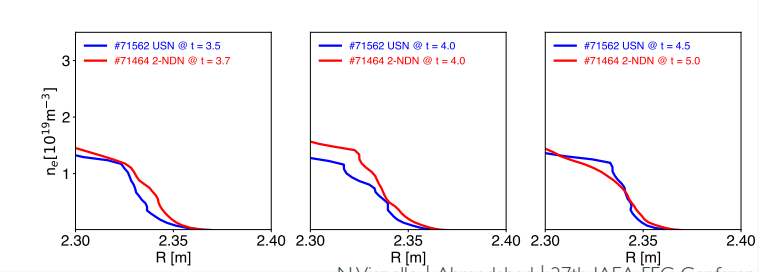


(U)2-NDN

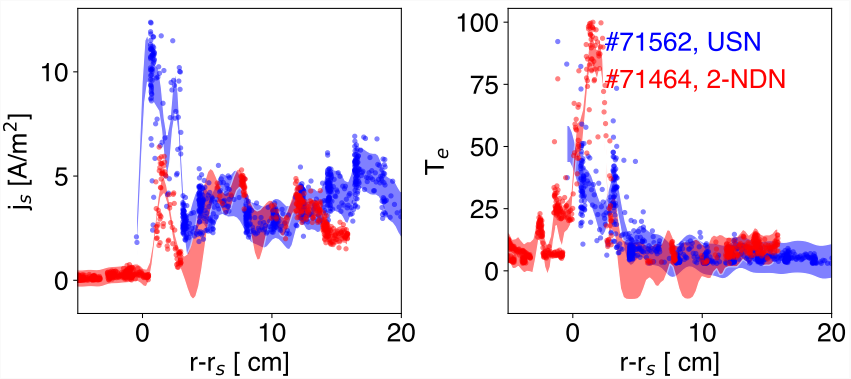




Investigation of ELMs behavior in 2-NDN

- ✓ Absence of ELMs activities in the 2-NDN scenarios analyzed in terms of physics that connects downstream and upstream properties
- ✓ Recent experiments, both in L mode (Carralero *et al.* 2015), s well as in H mode (Carralero *et al.* 2017), have confirmed that the theoretical (Krasheninnikov *et al.* 2008) prediction that increasing the downstream local collisionality affects the filaments behavior driven by interchange instabilities
- ✓ When the normalized divertor parameter Λ_{div} exceed the threshold of 1, a **shoulder** is formed in the upstream SOL gradient density, as a consequence of the transition from the sheath limited regime to the inertial regimes and to an enhancement of the perpendicular transport

Upper Outer divertor Langmuir probes



- ✓ $\Lambda_{div} = \frac{L_{\parallel} \nu_{ei} \Omega_i}{c_s \Omega_e}$
- ✓ Target profile changes between USN and (U)2-NDN only in the near not in the far SOL. Λ_{div} increases because of increase of $L_{\parallel}$ from 50 to 64 m

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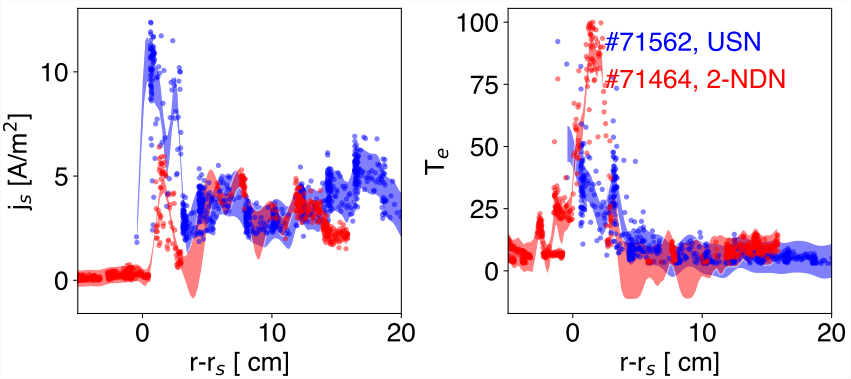

- ✓ $\Lambda_{div} = \frac{L_{\parallel} \nu_{ei} \Omega_i}{c_s \Omega_e}$
- ✓ Λ_{div} increase by flux expansion inefficient in modifying upstream profile and filamentary transport in TCV (Vianello *et al.* 2017)

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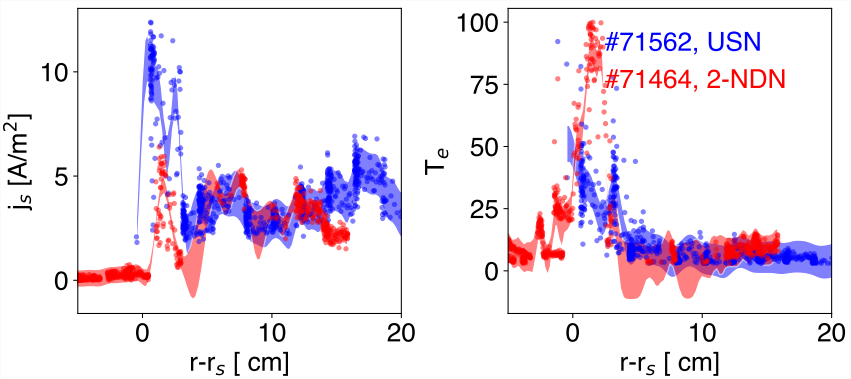

- ✓ $\Lambda_{\text{div}} = \frac{L_{\parallel}\nu_{ei}\Omega_i}{c_s\Omega_e}$
- ✓ Possible other mechanism is an enhancement of filamentary transport in the divertor region (as in TCV-SF- (Walkden *et al.* 2018))

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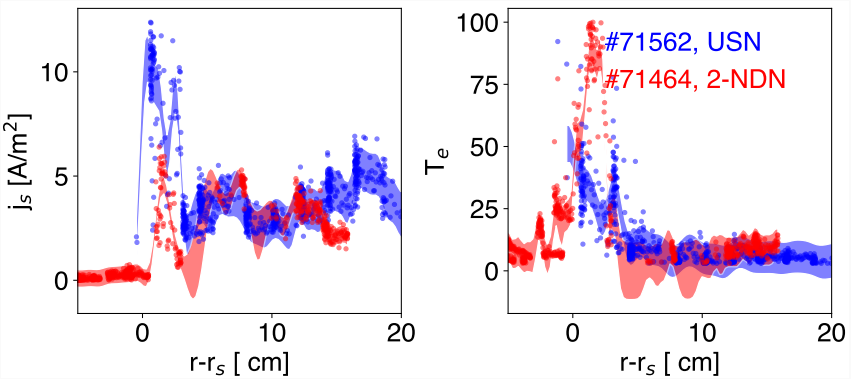
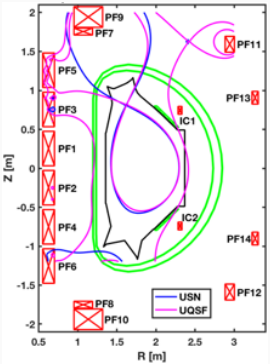
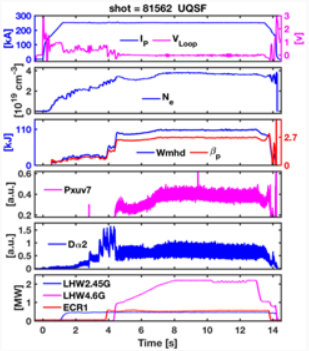
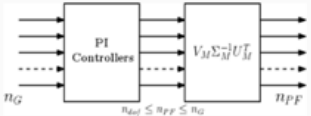


- ✓ $\Lambda_{div} = \frac{L_{\parallel}\nu_{ei}\Omega_i}{c_s\Omega_e}$
- ✓ However also other mechanisms as the Edge Coherent Mode (ECM) already invoked for EAST (Hu *et al.* 2015) may play a role

Recent upgrade on shape controller



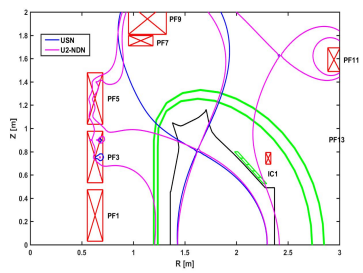


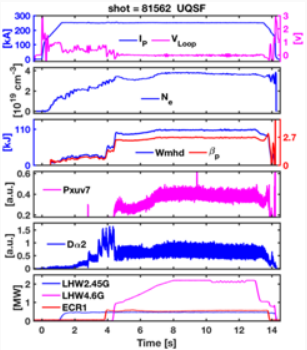


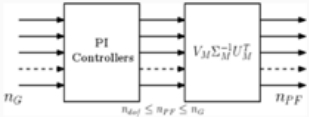
(Albanese *et al.* 2017)

- ✓ Recent progress on flexible and robust MIMO (JET/XSC-like) controller ⇒ similar (U)SN and (U)2-NDN shapes
- ✓ Further efforts will be devoted to actively control the 2nd x-point

Recent upgrade on shape controller







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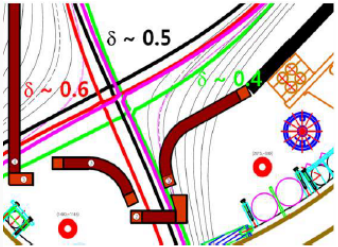
Lower divertor upgrade (FY 2019)

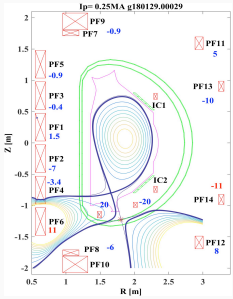


Bottom C→ W upgrade

- ✓ Power exhaust: 10 MW/m^2
- ✓ Strong pumping, low W sputtering
- ✓ **2 new divertor coils → more flexible shaping**

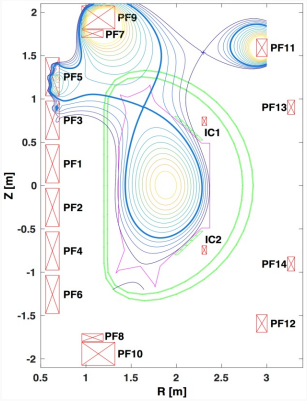
Current challenges of lower divertor

- ✓ **C tiles**: 2 MW/m^2, high retention
- ✓ Limited pumping capability



[Calabrò SOFT 2018]

Conclusions



- ✓ Achieved (reproducible) 2-NDN fully non-inductive steady-state H-mode discharges up to 21s in EAST tokamak
- ✓ Observed a peak heat load reduction of factor $\sim$ 1.5
- ✓ ELMs activity quite quiescent $\rightarrow$ a possible non-linear interaction between the downstream magnetic topology and the upstream kinetic gradients is under investigation
- ✓ Progress on shape controller $\rightarrow$ better comparison with SN configuration
- ✓ upgrade to the lower divertor is currently being planned for EAST, including 2 divertor coils $\rightarrow$ more flexible shaping