EUROfusion

Edge transport analysis of PT and NT in high power tokamak scenarios

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Summary

1. **Edge transport modeling in present devices to asses transport parameters**
   - TCV PT-H and NT modeling different power same core temperature (2023)
   - TCV PT-L and NT at same power
   - AUG PT-L/PT-H and NT at low/medium power
2. **Modeling of DTT with extrapolated parameters**
   - SN-PT and SN-NT in pure D at low power
   - SN-PT and SN-NT
3. **Self consistent turbulent modeling**
   - TCV PT-H and SN-NT with S3X

Edge transport modeling in present devices

(DTT shapes)

TCV: PT-H and NT same core temperature

Pulses

PT-H#76702 VS NT#76735

Similar features

- Magnetic divertor configuration:
- $B_T \simeq 1.4$ T for TCV
- $I_{plasma} \simeq$ 200/174 kA for TCV

DTT Triangularity

PT → $\delta_{top} \simeq +0.35$; $\delta_{bottom} \simeq +0.45$

NT → $\delta_{top} \simeq -0.35$; $\delta_{bottom} \simeq +0.07$

Input power (NBI only)

P_{Tot} = 1090 (NBI) + 204 (P_{OH}) kw

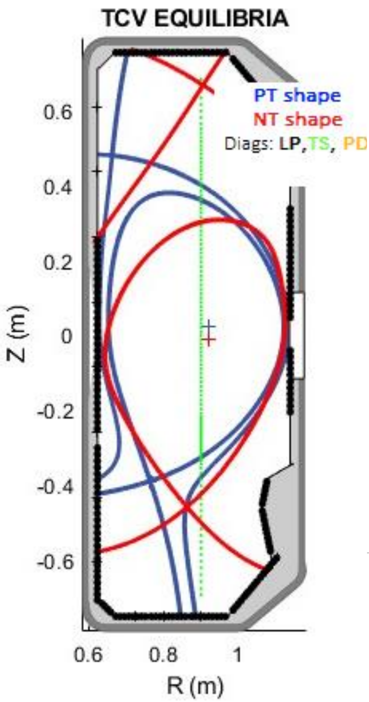
$P_{RAD,IN}$=290 kW

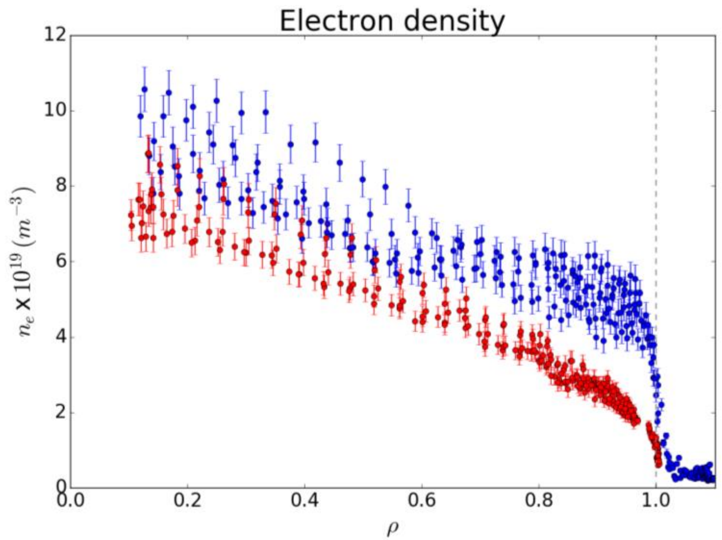
P_{SOL}=1040 kW

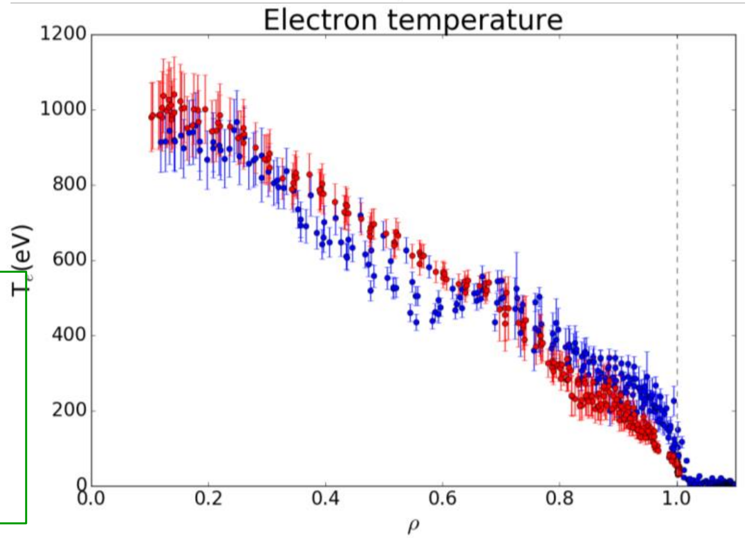
P_{Tot} =424(NBI) + 155 (P_{OH}) kW

$P_{RAD,IN}$ = 124 kW

P_{SOL} = 455 kW





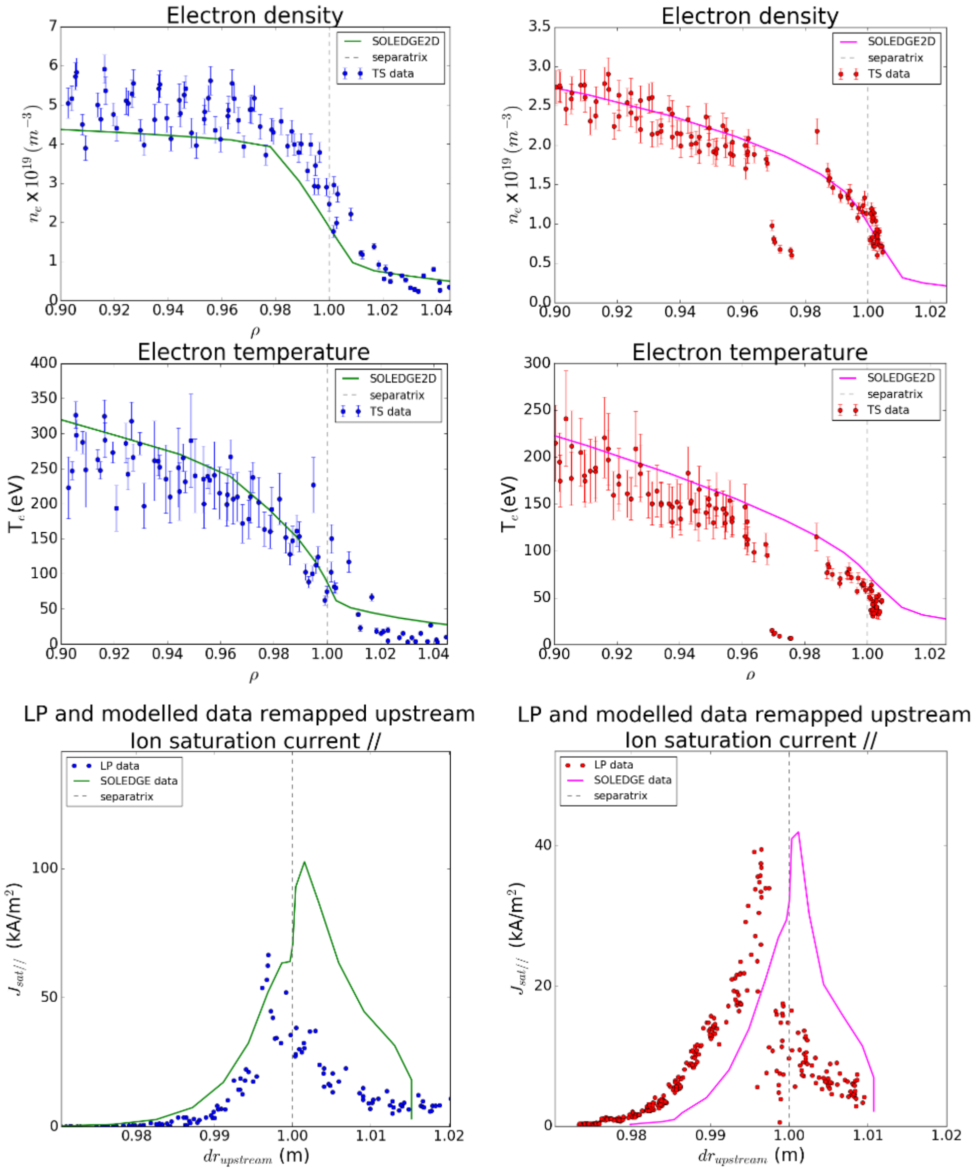


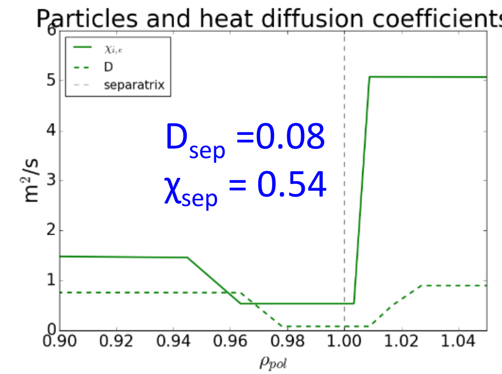
➔ **NT has a similar T and slightly lower density for much smaller power**

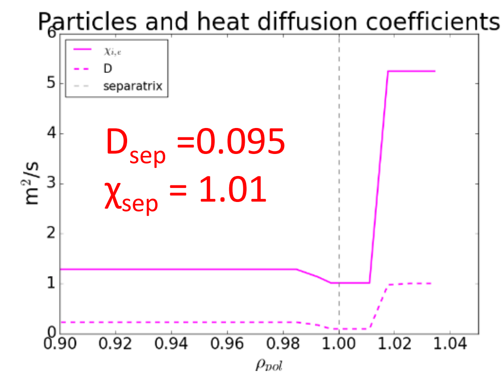
TCV: PT-H and NT same core temperature

#76702 – PT-H

NT#76735 – NT-L







- PT-H & NT-L have similar particle diffusion **(but narrow barrier)**
- NT-L has about a twice heat diffusion than PT-H

TCV: PT-H and NT similar power

<u>Pulses</u>

PT-L#73388 VS NT#73382

<u>Similar features</u>

- Magnetic divertor configuration: SN
- $B_T \simeq 1.4$ T for TCV
- $I_{plasma} \simeq 256/240$ kA for TCV

<u>DTT Triangularity</u>

PT → $\delta_{top} \simeq +0.40$

NT → $\delta_{top} \simeq -0.22$; $\delta_{bottom} \simeq +0.0$

<u>Power (NBI only)</u>

P_{Tot}=418 (NBI) + 350 (P_{OH}) kw

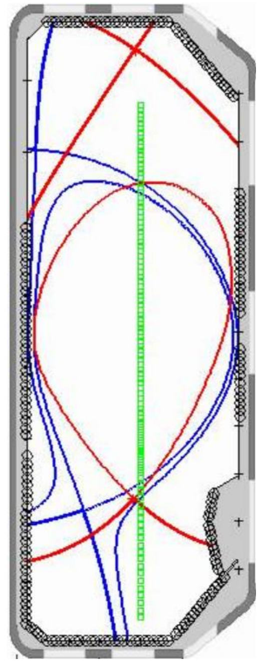
$P_{RAD,IN}$=149 kW

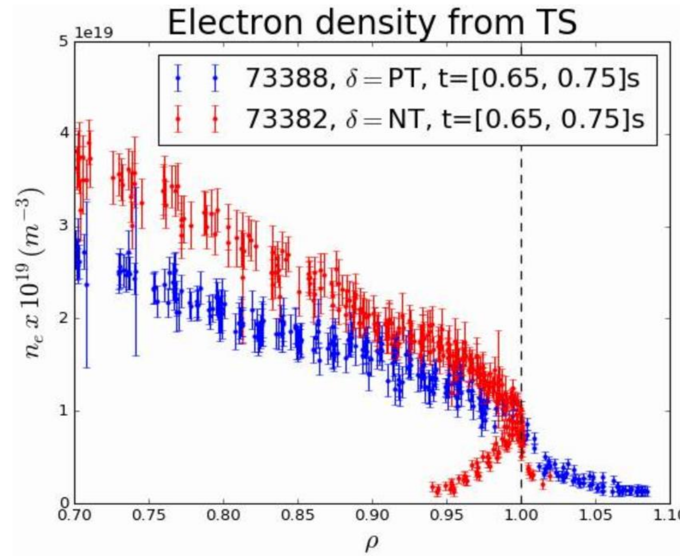
P_{SOL}=619 kW

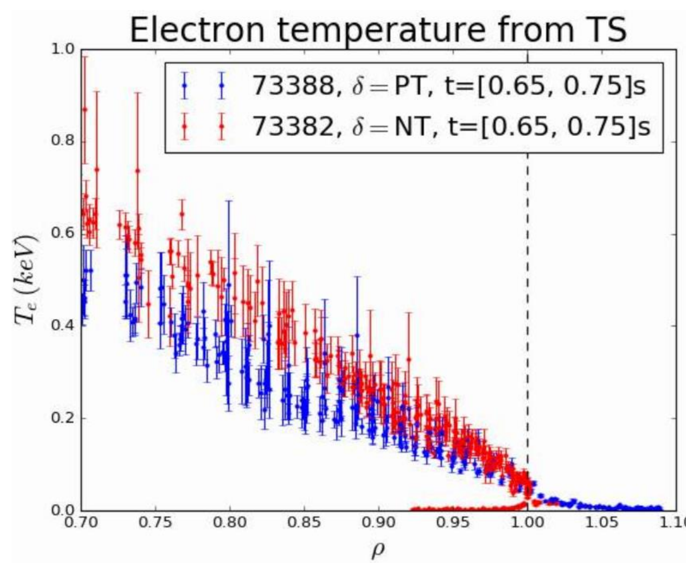
P_{Tot} →418 (NBI) + 264 (P_{OH}) kW

$P_{RAD,IN}$ = 123 kW

P_{SOL} = 559 kW

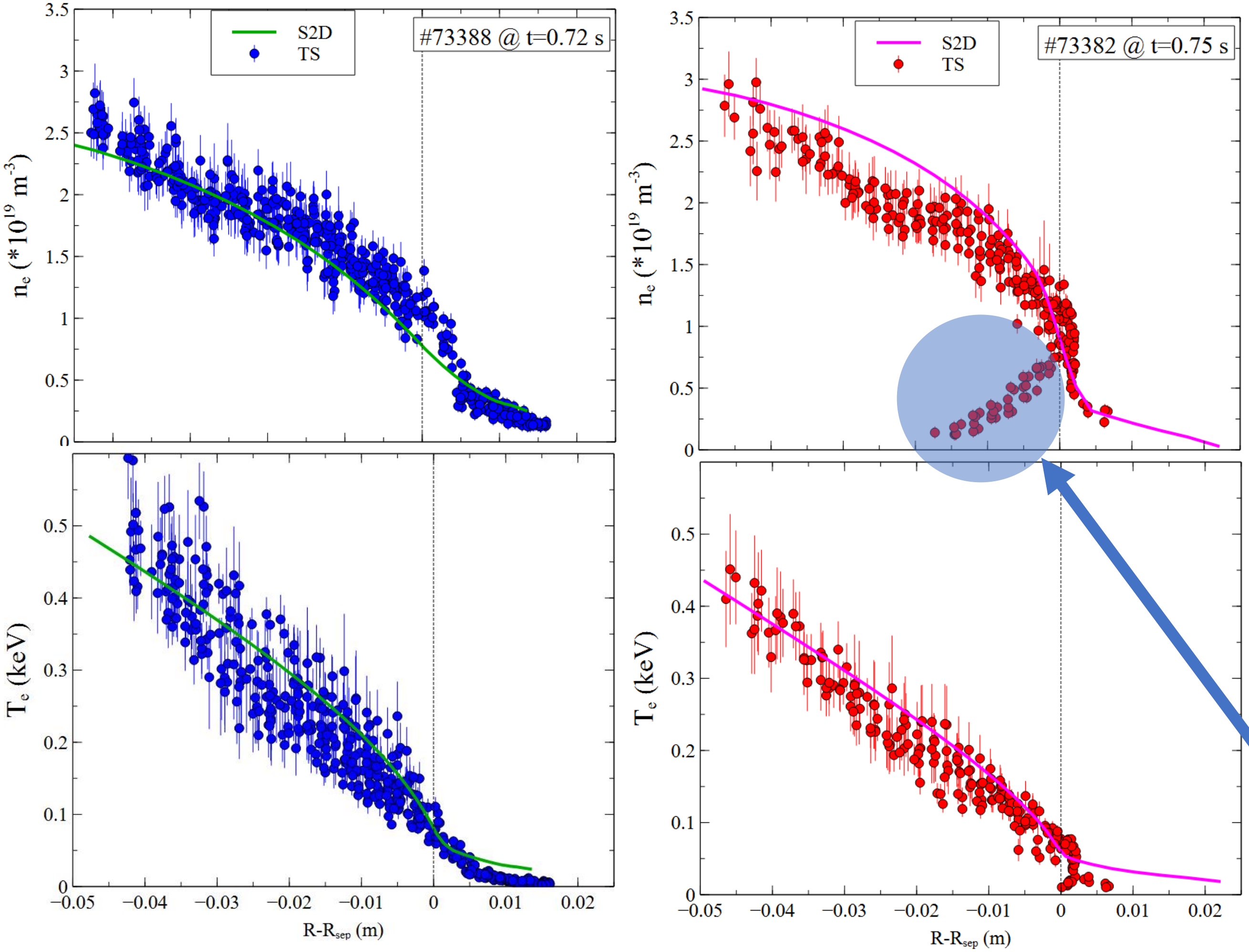






➔ In the core NT has higher T and density for lower power

TCV: PT-L and NT similar power – modeling OMP

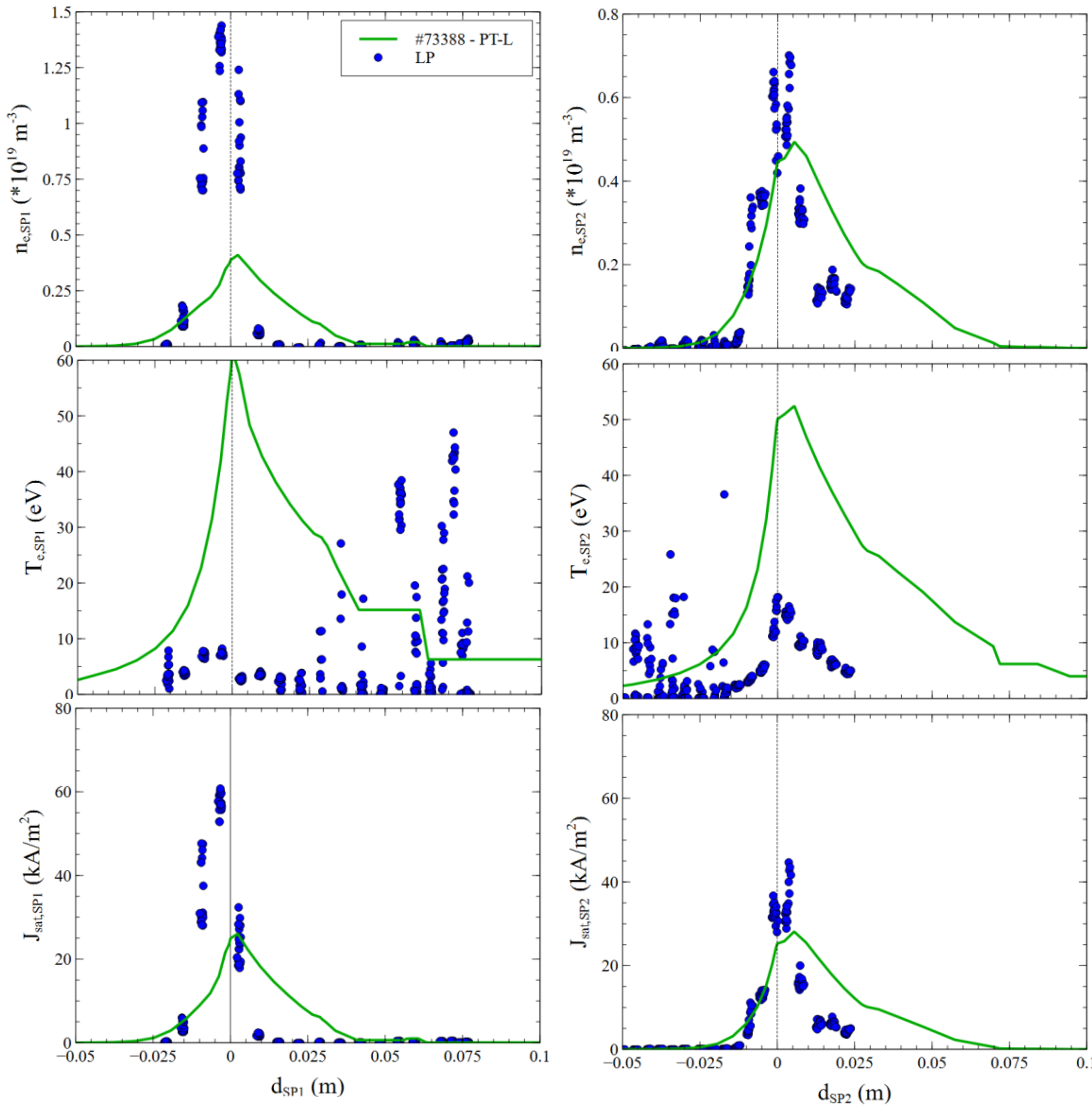


Good matching of OMP profiles

But some improvements are still possible

TS points below the x-point

TCV: PT-L and NT similar power – modeling OMP

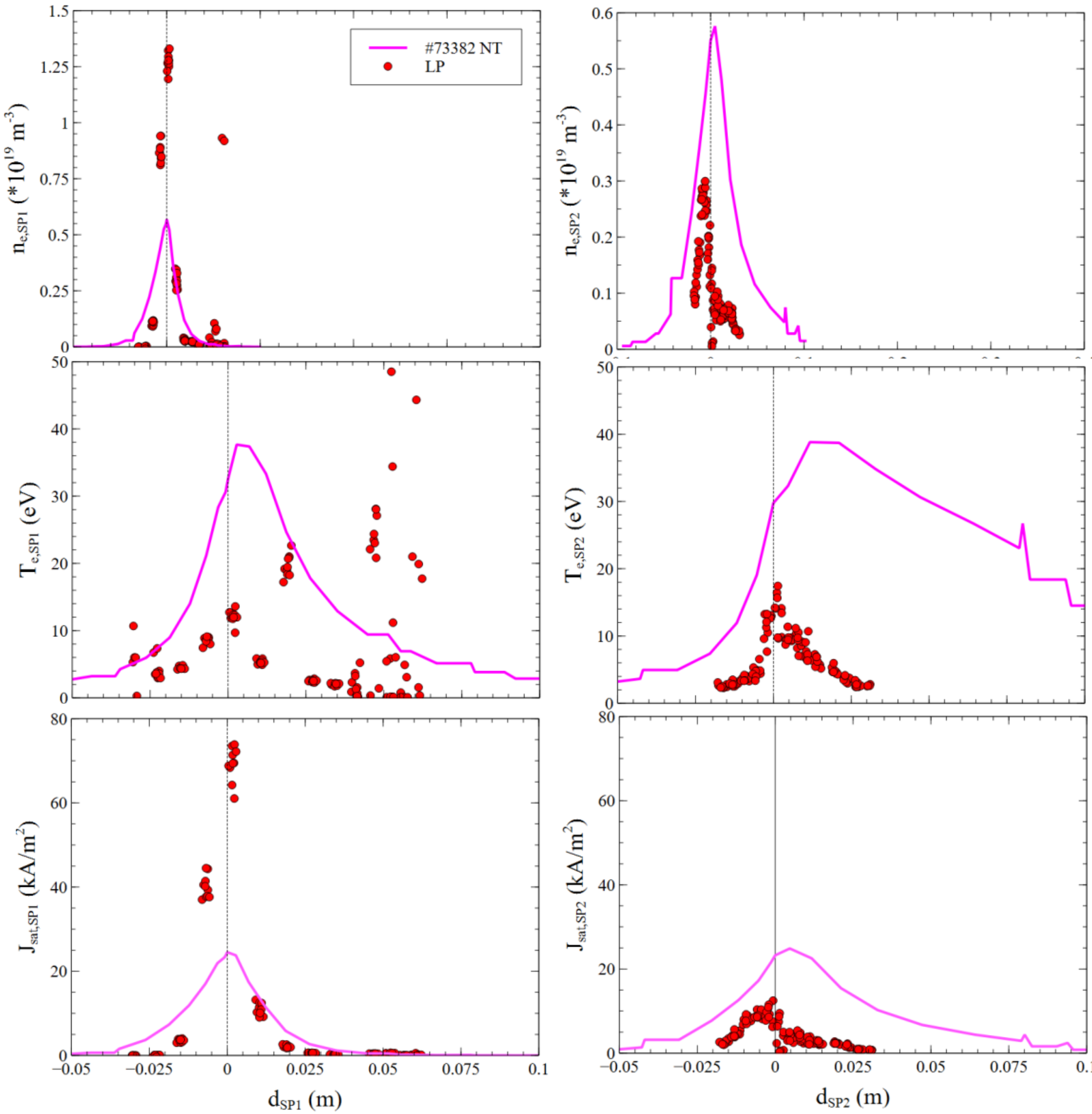


<u>PT-L modeling at targets</u>

Reasonable agreement for density and $_{Jsat}$

Higher experimental J_{sat} ➔ particle diffusivity is slightly underestimated

TCV: PT-L and NT similar power – modeling targets



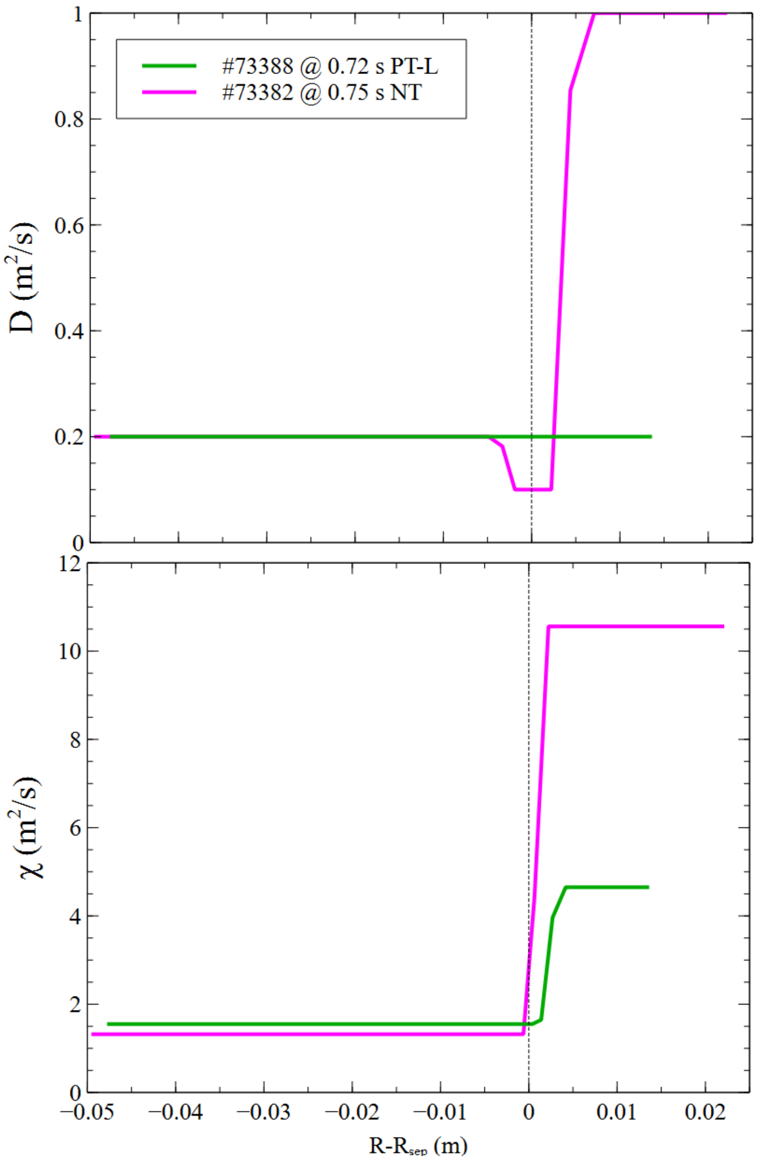
<u>NT modeling at targets</u>

Reasonable agreement for density, temperature and J_{sat}

In/out under/overestimation of density and J_{sat} probably due to missing drifts in modeling

But In/Out averaged value seems ok

TCV: PT-L and NT similar power



Transport parameters

- NT still shows a narrow edge barrier in particle diffusion like in previous modeling with a similar minimum value
- Heat conductivity is smaller in NT than in PT-L
- NT heat conductivity is higher but not far from previous NT edge modeling
- But the small barrier in NT heat conductivity is not present (but probably it can be introduced without a relevant profile variation)

AUG: similar temperature

Pulses

PT-H #740647 @2.7 s VS NT#40866 @ 2.7 s

Similar features

- Magnetic divertor configuration: SN
- $B_T \simeq 2.5$ T
- $I_{plasma} \simeq 600/60$ kA

DTT Triangularity

PT → $\delta_{top} \simeq +0.4$; $\delta_{bottom} \simeq +0.5$

NT → $\delta_{top} \simeq -0.28$; $\delta_{bottom} \simeq +0.09$

Power (ECHR only)

P_T → 1460 (ECHR) + 180 (P_{OH}) kw

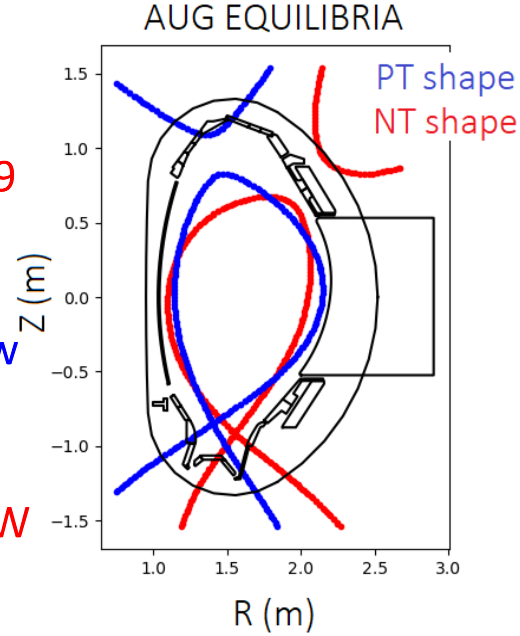
$P_{RAD,IN}$= 808 kW

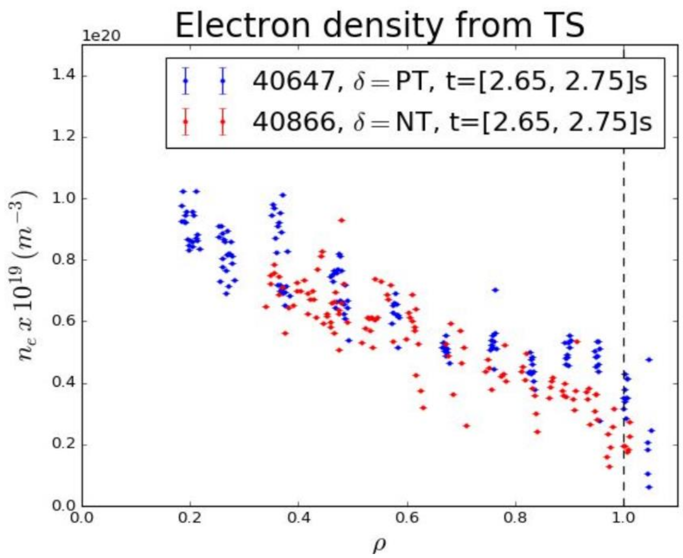
P_{SOL}=778 kW

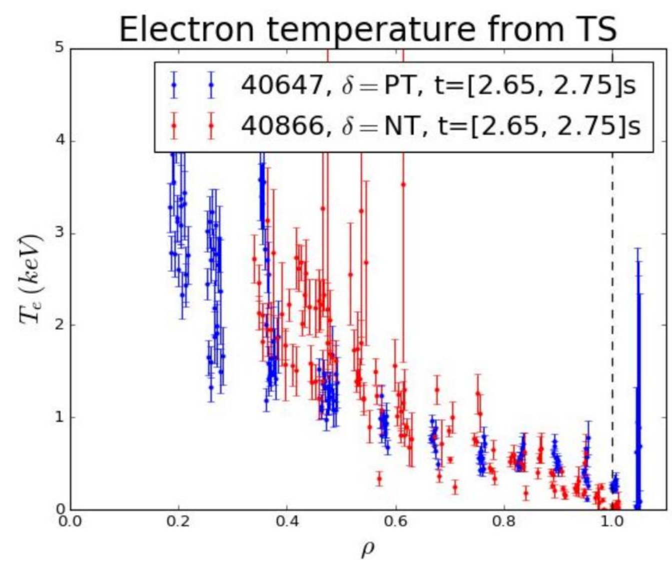
NT →1485 (ECRH) + 194 (P_{OH}) kW

$P_{RAD,IN}$ = 1160 kW

P_{SOL} = 519 kW







AUG: similar power

<u>Pulses</u>

PT-L#740647 @7.9 s VS NT#40866 @ 2.7 s

<u>Similar features</u>

- Magnetic divertor configuration: SN
- $B_T \simeq 1.4$ T
- $I_{plasma} \simeq$ 600/600 kA

<u>DTT Triangularity</u>

PT → $\delta_{top} \simeq +0.4$; $\delta_{bottom} \simeq +0.5$

NT → $\delta_{top} \simeq -0.28$; $\delta_{bottom} \simeq +0.09$

<u>Power (ECHR only)</u>

P_T → 583 (ECHR) + 360 (P_{OH}) kw

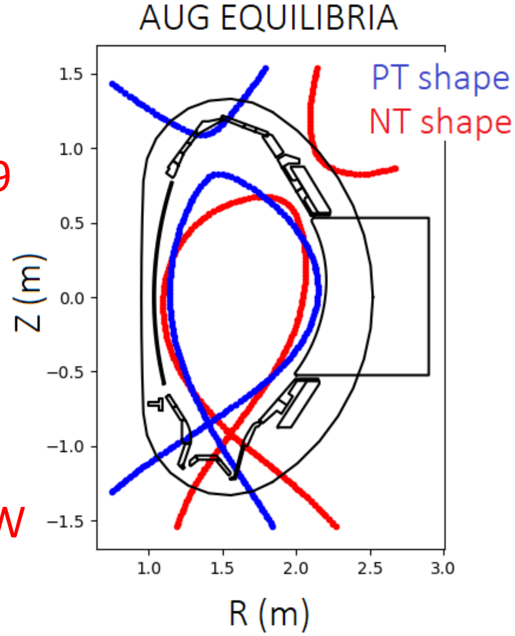
$P_{RAD,IN}$= 365 kW

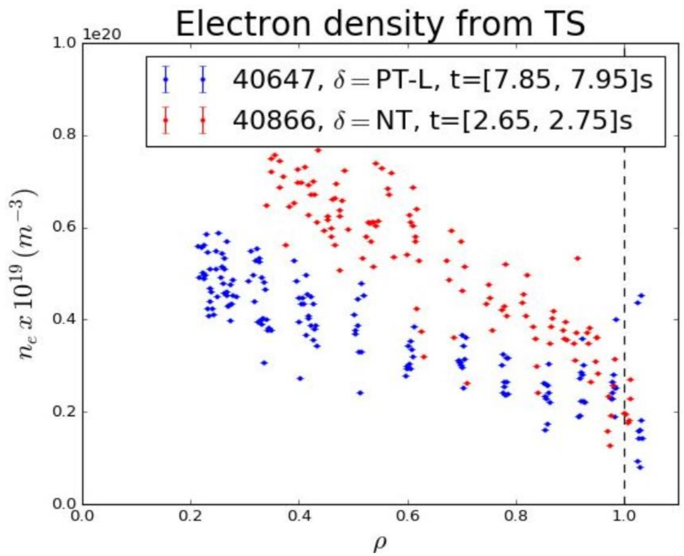
P_{SOL}=580 kW

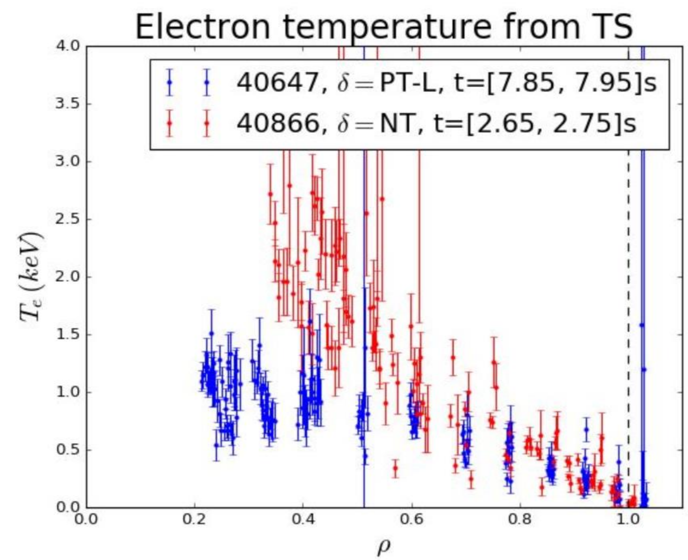
NT →1485 (ECRH) + 194 (P_{OH}) kW

$P_{RAD,IN}$ = 1160 kW

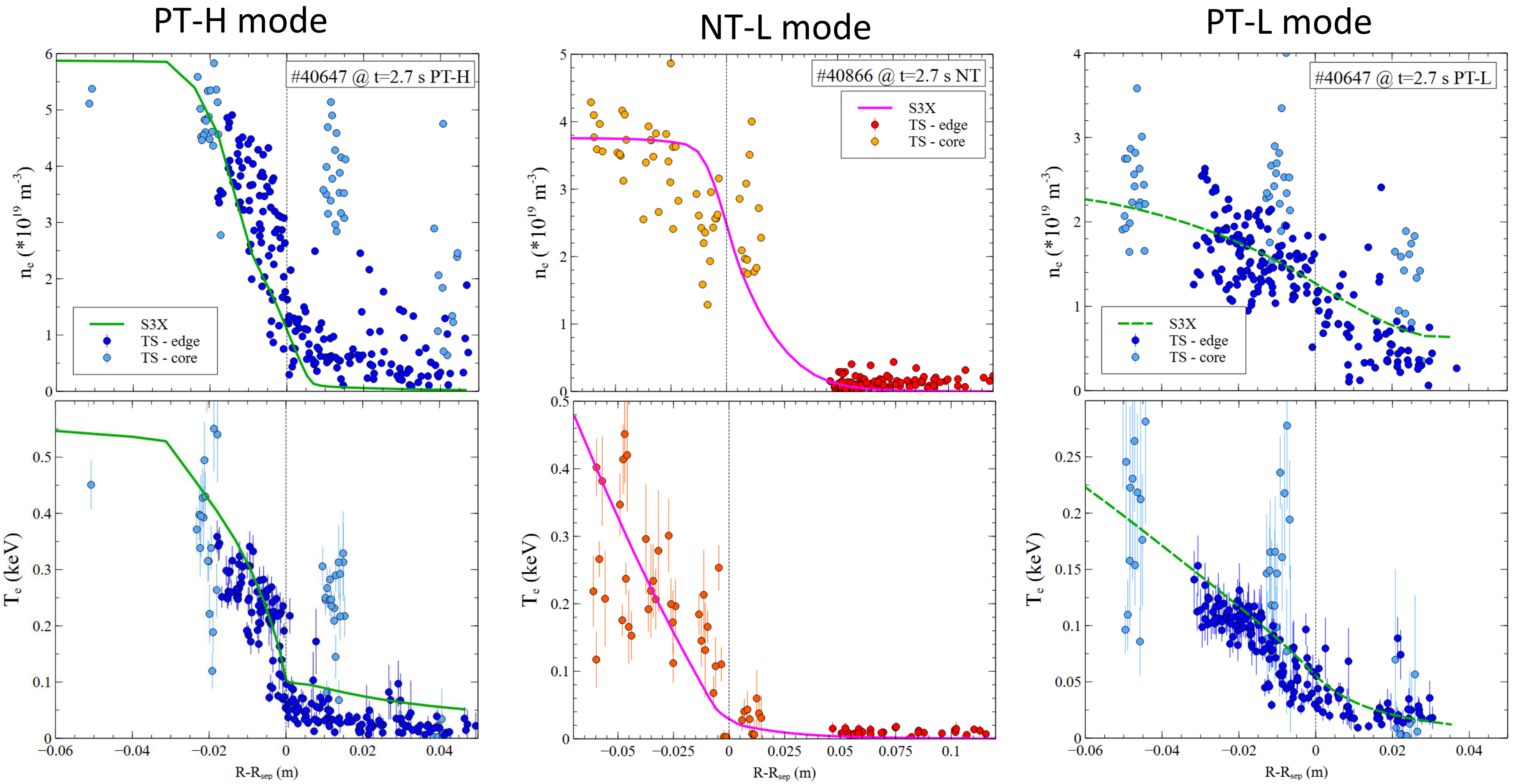
P_{SOL} = 519 kW







AUG: Edge modeling comparison at OMP

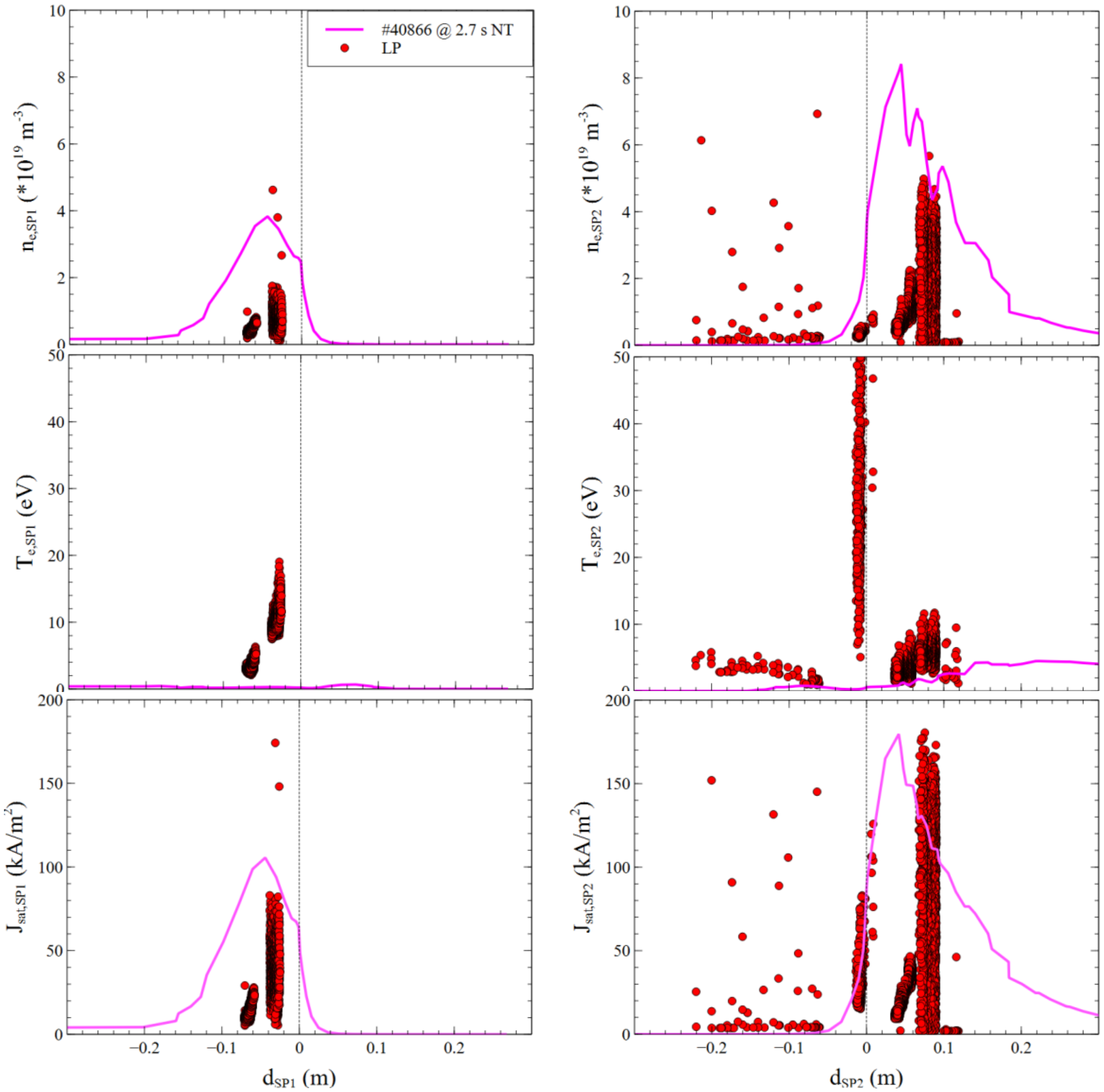


Poor quality of some TS data

Transport values (in particular inside the separatrix) closed to their final values

Still to be optimized transport profiles in PT-L and some adjustment required in PT-H

AUG: Edge modeling comparison at targets



<u>NT Langmuir probe data</u>

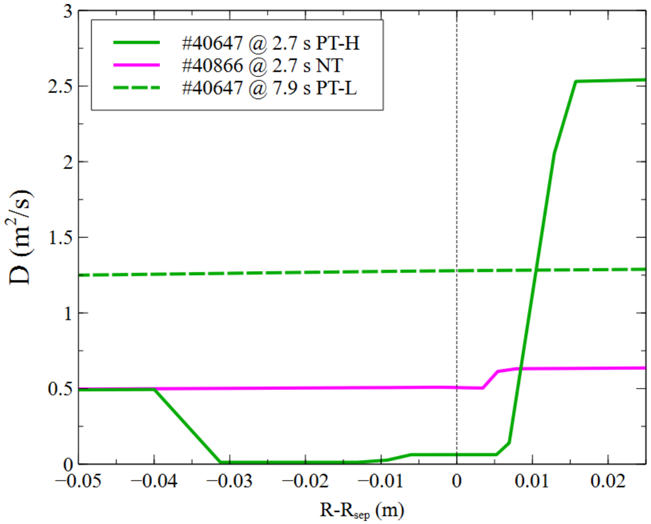
Poor quality of Langmuir probe data (due to NT strike point position and equilibrium reconstruction)

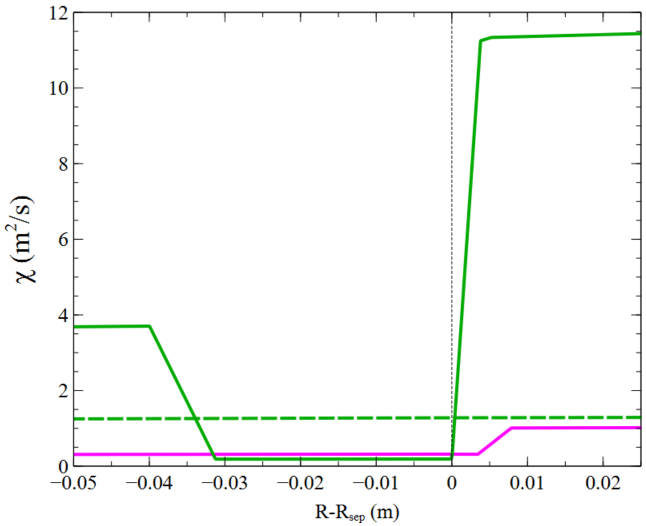
But density and J_{sat} amplitude relatively well matched

Comparison with D_α is underway

Waiting for #40647 data for SN-PT

AUG: comparison PT-H ⇔ NT ⇔ PT-L





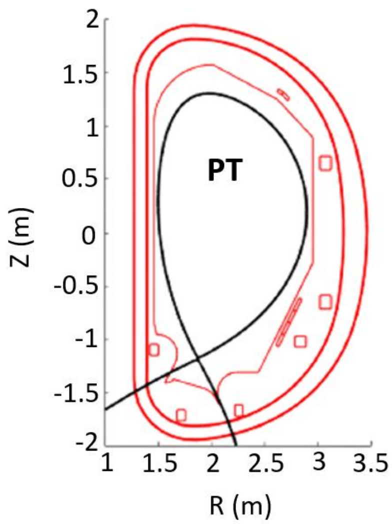
Transport parameters

- In AUG the prticles diffusion seems much smaller in PT-H than in NT at the transport barrier (but the result could depend from poor quality of data)
- Heat conductivity instead is not much different between PT-H and NT
- Inside the separatrix particles diffusion and heat conductivity are much higher in PT-L than in NT
- Transport estimation might be improved with better data (some are coming)
- In any case it is confirmed than NT transport is in between PT-H and PT-

To DTT modelling

DTT PT H-mode full power scenario prediction

- Single Null
- $\delta_{up} = 0.33$
- $\delta_{bottom} = 0.35$



For core performance

from core modelling[6]

$B_T = 6$ T ↓
$I_p = 5.5$ MA
H-mode
→Core radiation ≅ 15MW
Power = 45MW
~ 2% Neon

For detachment

from edge modelling[7]
$P_{inner\ boundary}$=30MW*
(considering ELMs losses)
+
diffusion parameters estimated[8]

↓

n_{sep} ~ $8x10^{19}$
D_2 ~ $9.5x10^{22}$
→ $Z_{eff,core}$ ~ 2.2

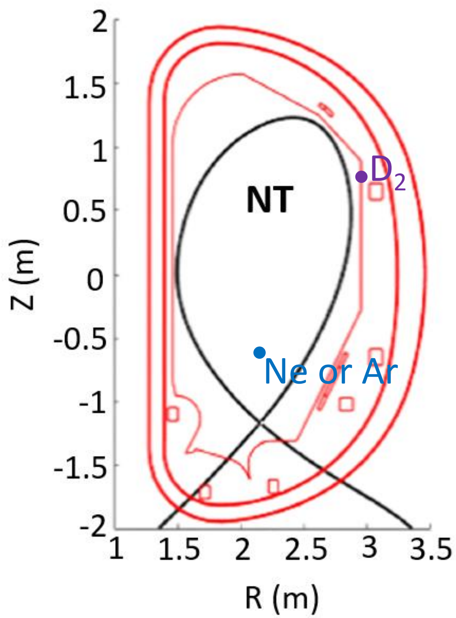
$P_{rad,SOL+edge}$ ~ 25MW
Neon ~ $0.075x10^{22}$ molecules/s
→detachment

*P-10MW$_{core_rad}$-5$_{ELMs}$

[6] I. Casiraghi et al 2023 Plasma Phys. Control. Fusion 65 035017
[7] P. Innocente et al 2022 Nucl. Mater. Energy 33 101276
[8] L. Balbinot et al 2023 Nucl. Mater. Energy 34 101350

From DTT PT H-mode to DTT NT «L-mode»

- Single Null
- δ_{up} = -0.3
- δ_{bottom} = 0.05



We want

- $Z_{eff,core}$ ~ 3 for core performance

- Detachment for PEX performance

We impose

- $P_{inner\ boundary}$= 36MW (no ELMs)
- In NT there is no limitation in n_{sep} unlike PT where n_{sep} affects the L-H threshold power, but we have to limit the core density to reach high temperature (low loop voltage) for this reason

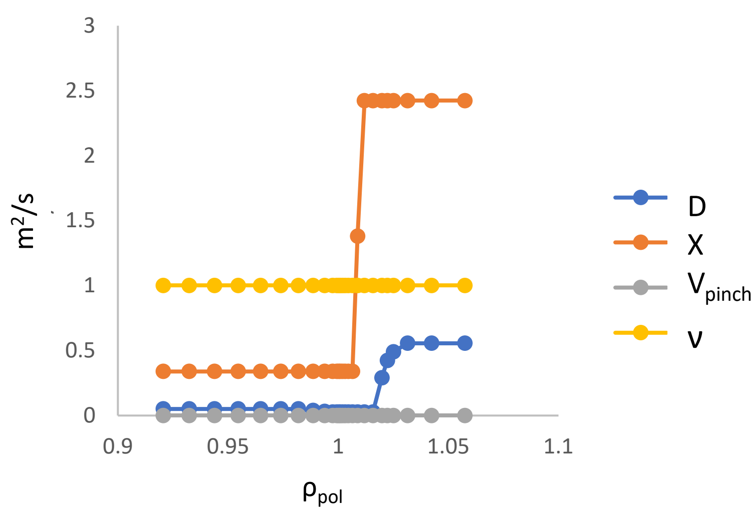
  ➔ n_{sep} < ~ 9×10^{19}
- Neon/argon puffing
- Diffusion extrapolated to TCV studies

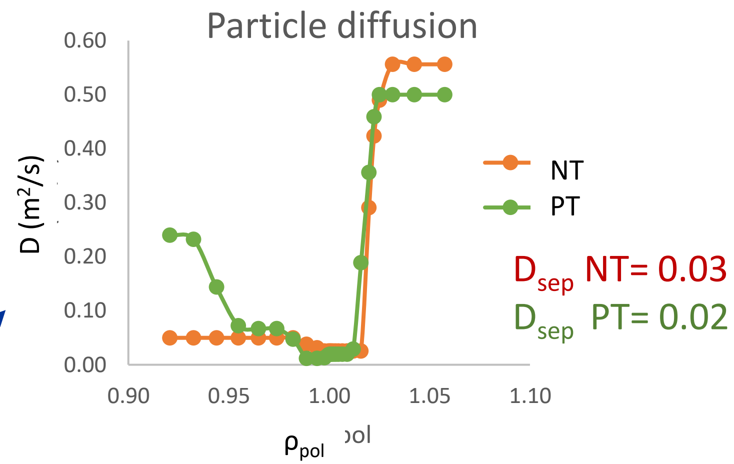
From DTT PT H-mode to DTT NT «L-mode» / diffusion

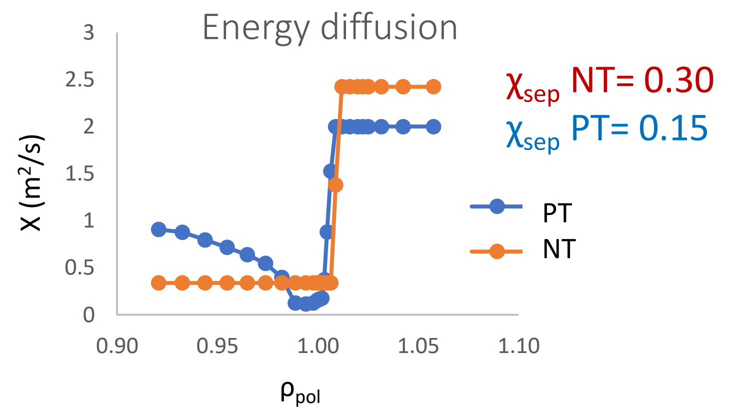
Starting from TCV transport

- ➢ ratio between PT H-mode and NT diffusion in the different main point
- ➢ Extrapolate D and χ for NT DTT starting from PT
- ➢ H-mode transport foreseen for DTT[8]

- **assuming $\chi_i = \chi_e$ (as in TCV)**

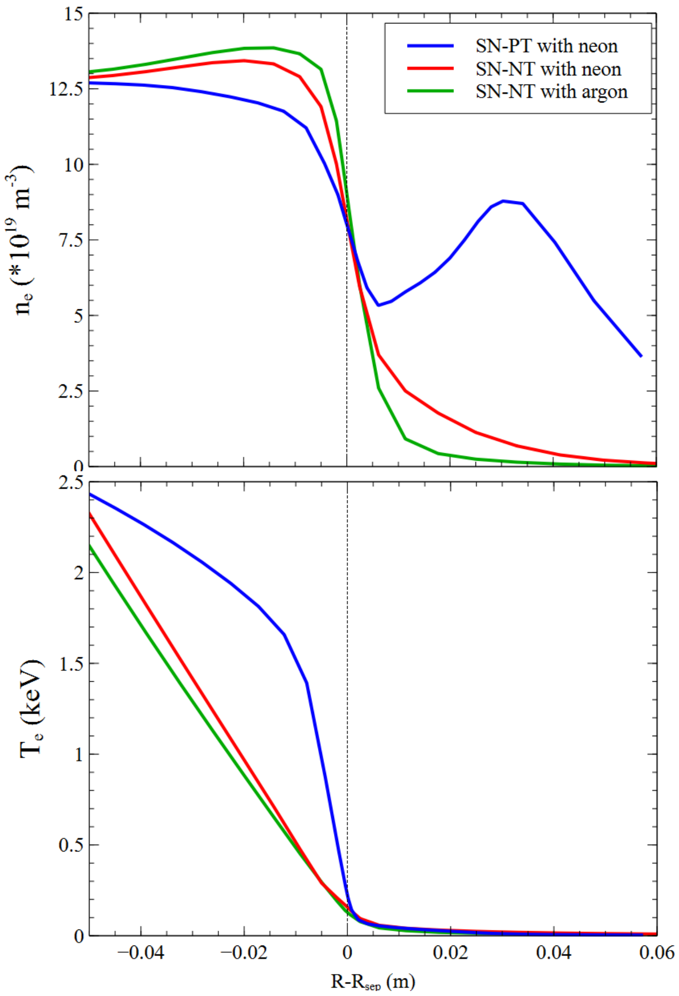






[8] L. Balbinot et al 2023 Nucl. Mater. Energy 34 101350

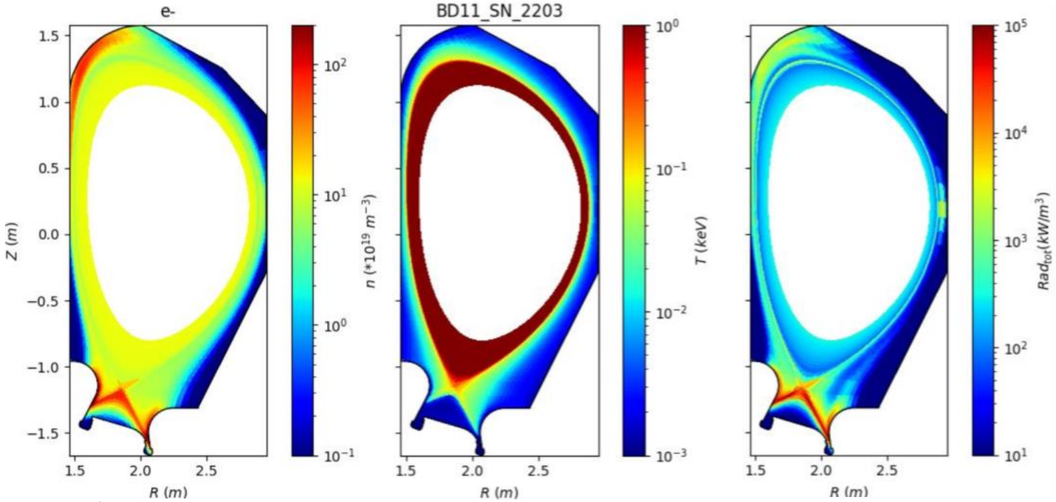
DTT: SN-PT ⇔ SN-NT



NT modeling with neon and argon is still ongoing/non-stationary

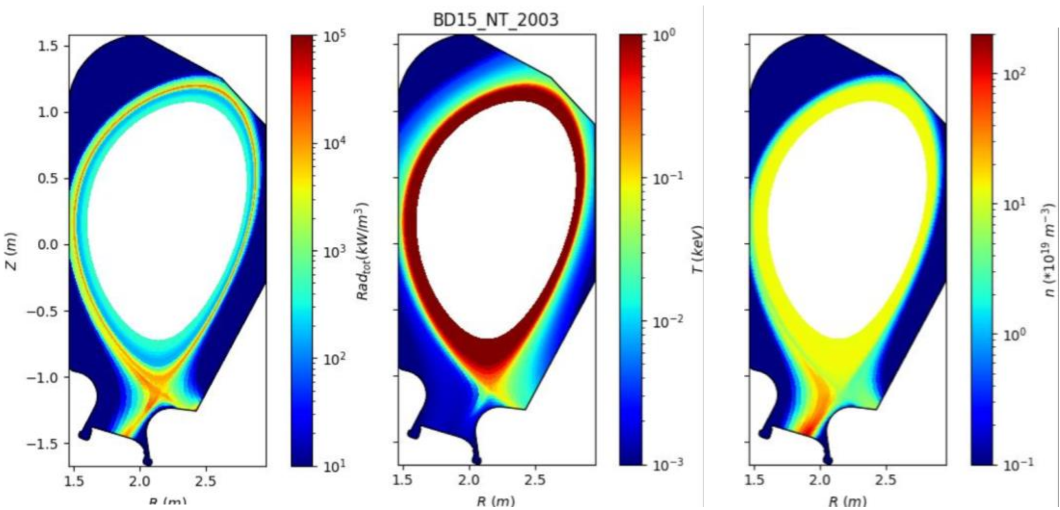
- n_{sep}= 9-10·10^{19} m^{-3} partially above target value
- T_{sep} is lower in NT than in PT due to the higher density
- T recovers in the core due to the chosen constant heat diffusivity **(but this requires a further experimental assessment)**
- In DTT much smaller gas-puffing is required to the lower pumping efficiency (pumping slots are far from strike points)

DTT: SN-PT ⇔ SN-NT



P_{rad}=21.1 MW
$P_{rad,IN}$=2.6 MW
Z_{eff}=2.36

P_{rad}=32.8 MW
$P_{rad,IN}$=20.5 MW
Z_{eff}=3.44

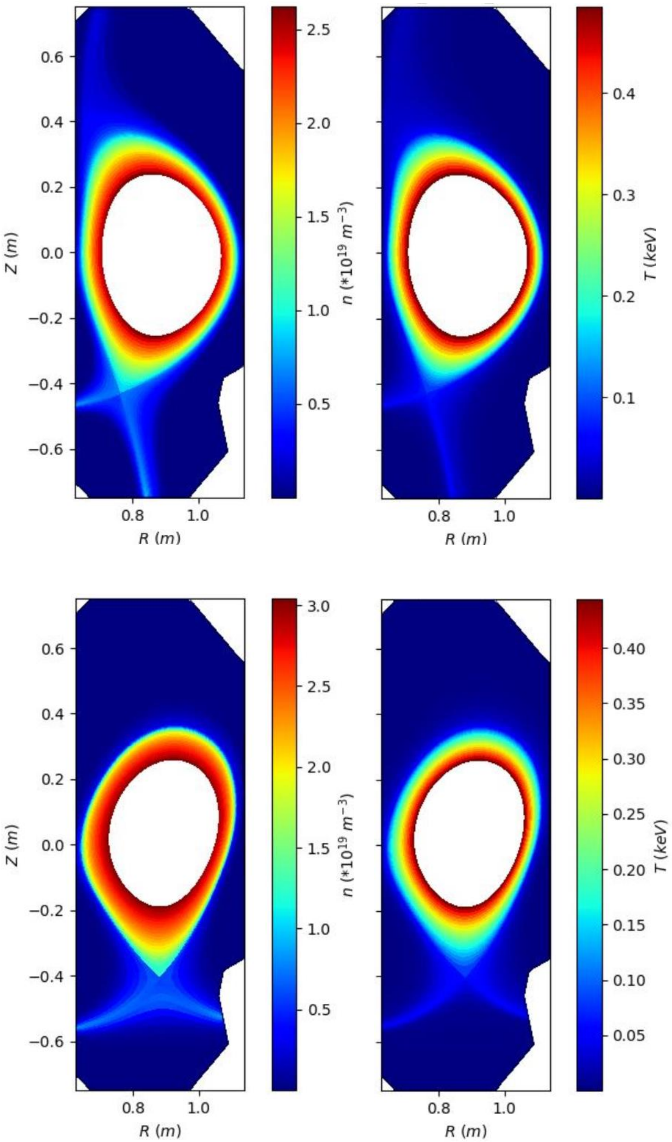


- A higher Z_{eff} is necessary in NT than in PT
- A much higher radiation seems necessary in NT to detach
- In NT a lot of radiation is inside the separatrix
- The main problem of NT seems related to the short length of the external leg

  ➔ It is difficult to detach at the external strike point
- The internal strike point detached quite early but is unable to drive the detachment of the external one

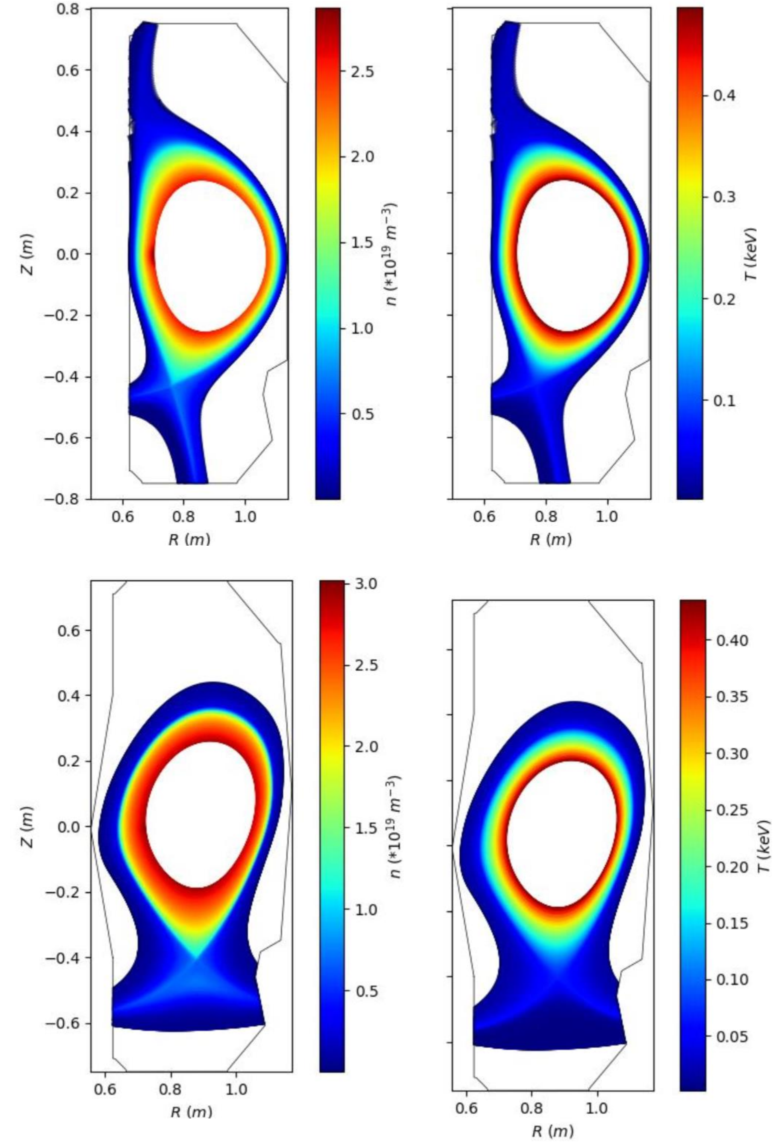
Turbulent modeling with S3X

Steps to turbulent modeling

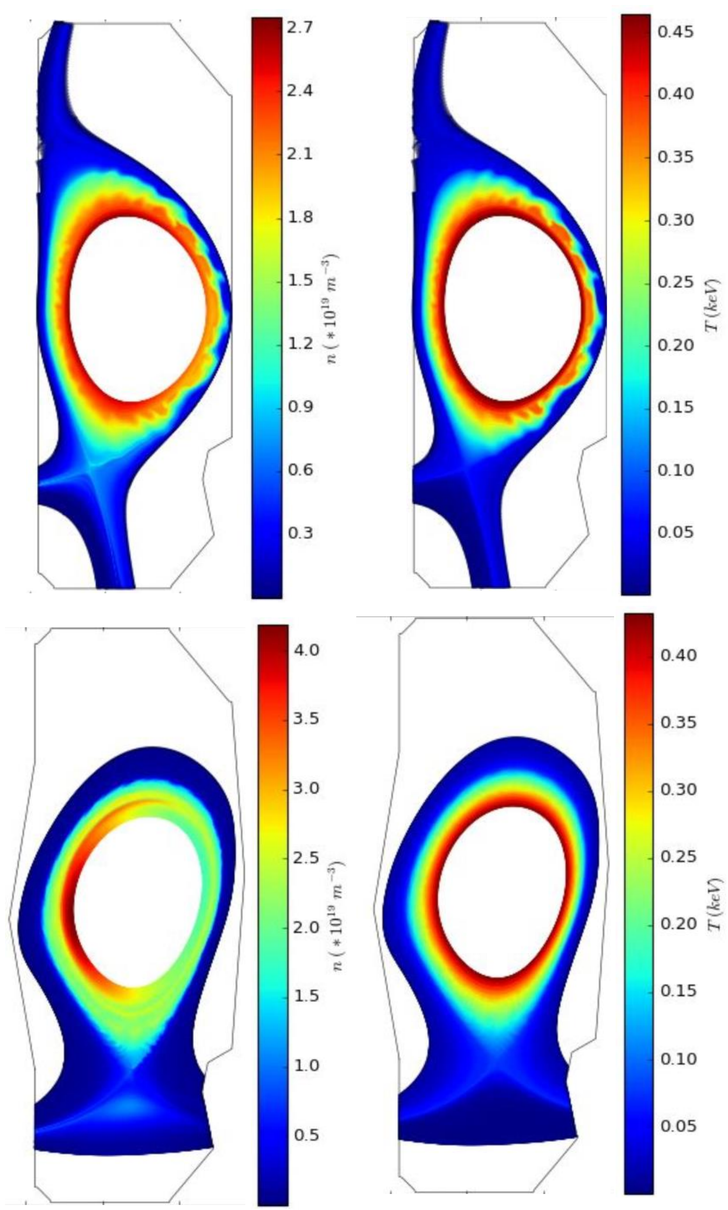


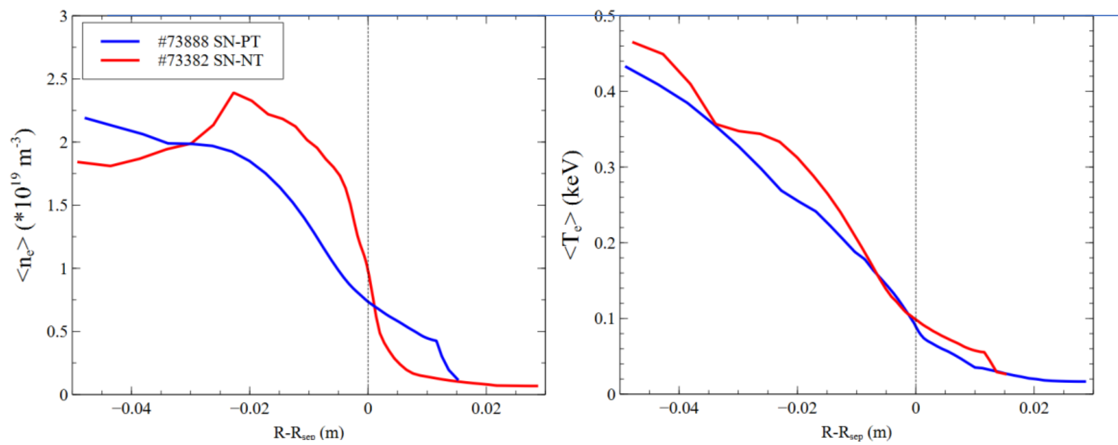
From S3X-EIRENE

to fluid neutrals
still 2d transport
model



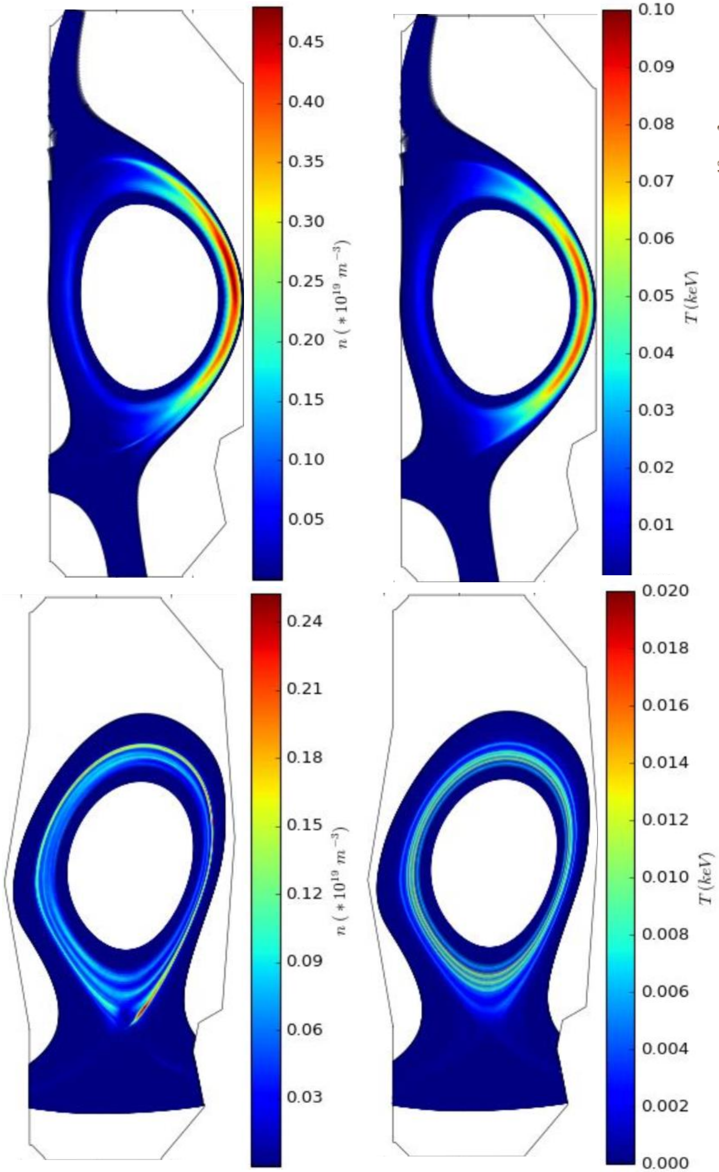
Turbulent modeling of PT & NT

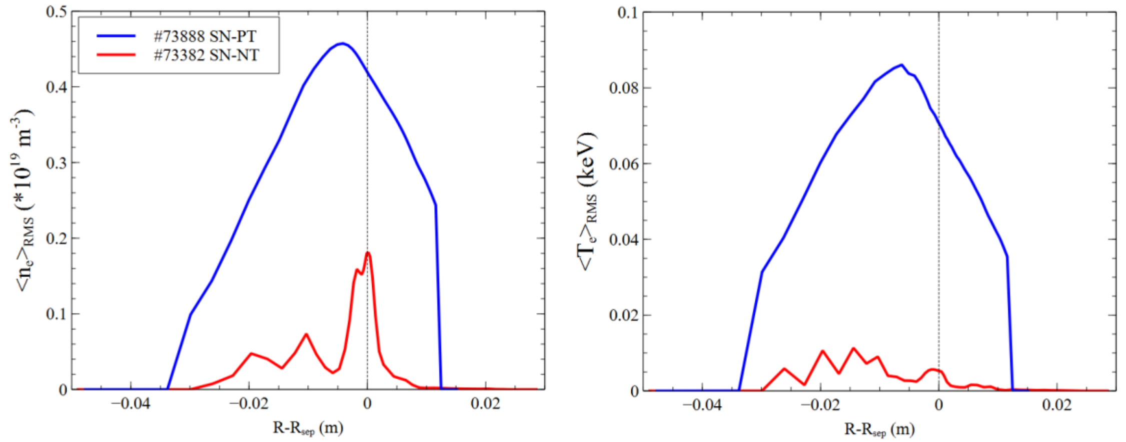




- Modeling is very far from stationarity but crash problems seems partially solved
- PT case shows a clear effect of turbulence with well developed structures
- Smaller amplitude structures are present also in NT as well as initial drifts effect
- Average profiles at OMP show agreater variations in density

2D fluctuation amplitude plots PT & NT





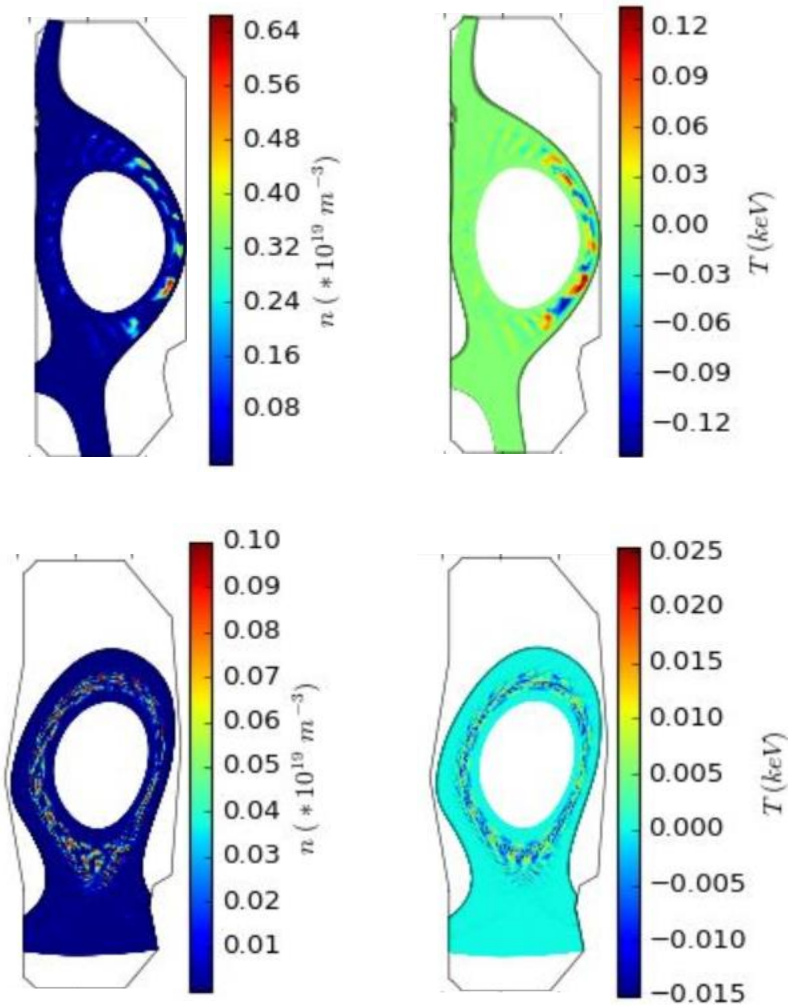
- Fluctuation amplitude is higher in PT than in NT but it can depend on the status of the modeling
- Fluctuations are localized in the low field side for PT
- Fluctuations are more poloidally symmetric in NT

Conclusions

- A first comparison of the edge transport parameters was performed in TCV showing the presence in NT of a narrow particle transport barrier at the separatrix
- In TCV the transport parameters around the separatrix for the NT configuration are between PT-H and PT-L
- The edge transport modeling in AUG partially confirms the TCV results in terms of transport values in NT configuration between PT-H and PT-L, but further modeling on pulses with better measurements is needed to finalize the results
- The transport profiles extrapolated from those resulting from the TCV modeling were used to model the DTT scenario in NT configuration. The detachment seems particularly difficult at the outer impact point due to the short leg.
- The turbulent modeling was started with S3X code for previously modeled PT and NT pulses. The computation times are quite long, but the first effects of turbulence are already present in the modeling

Spare slides

2D fluctuation in one section PT & NT



TCV pulse #76702 – PT H-mode (δ_{top} = +0.4)

MAIN PARAMS discharge

Time =0,7s (NBI-only phase)

I_p	**-200 kA**
$\langle n_e \rangle$ (FIR)	xxx x 10^{19} m^{-3}
T_e max (TS)	xx keV
B_T at R=0,88m	-1.42 T

GAS PUFFING:

valve	**0,7 s**
1	D2: xxx mbar/s xxxe20 molecules/s →xxxe20 atom/s
2	-
3	-

DENSITY_BC (in *overview_hmode.jscp*)

time	**0,7 s**
NBI electrons/s - Density_BC (flux)	2.77e20

POWER

time	**0,7 s**
P_rad_tot	406 kW
P_divertor	116 kW
P_bulk	290 kW
P_NBI (with the loss due to the duct)	1090 kW
P_ICRH	-
P_OHM	204 kW (V=1.02 V)
ELMs power	Xxx kW

P_inp = P_NBI + P_OHM + P_ICRH – P_rad_tot – P_ELMs = xxx W (without impurity)

P_inp = P_NBI + P_OHM + P_ICRH –P_ELMs = (with impurity)

TCV pulse #76735 – NT (δ_{top} = -0.35)

MAIN PARAMS discharge

Time =0,7s (NBI-only phase)

I_p	-174 kA
$\langle n_e \rangle$ (FIR)	xxx x 10^{19} m^{-3}
T_e max (TS)	xx keV
B_T at R=0,88m	-1.42 T

GAS PUFFING:

valve	0,7 s
1	D2: xxx mbar/s xxxe20 molecules/s →xxxe20 atom/s
2	-
3	-

DENSITY_BC (in *overview_hmode.jscp*)

time	0,7 s
NBI electrons/s - Density_BC (flux)	2.77e20

POWER

time	0,7 s
P_rad_tot	202 kW
P_divertor	78 kW
P_bulk	124 kW
P_NBI (with the loss due to the duct)	424 kW
P_ICRH	-
P_OHM	155 kW (V=0.89 V)
ELMs power	Xxx kW

P_inp = P_NBI + P_OHM + P_ICRH – P_rad_tot – P_ELMs = 377 W (without impurity)

P_inp = P_NBI + P_OHM + P_ICRH –P_ELMs = (with impurity)

TCV pulse #73388 – PT L-mode (δ_{top} = +0.4)

MAIN PARAMS discharge

Time =0,7s (NBI-only phase)

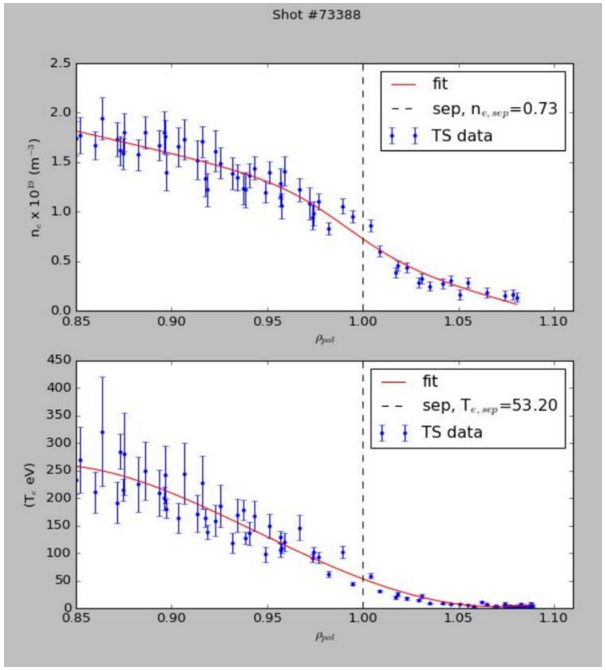
I_p	-256 kA
$<n_e>$ (FIR)	2,84 x 10^{19} m^{-3}
T_e max (TS)	1,1 keV
B_T at R=0,88m	-1.42 T

GAS PUFFING:

valve	0,7 s
1	D2: 1,79mbar/s 1,36e20 molecules/s →2.72e20 atom/s
2	-
3	-

DENSITY_BC (in *overview_hmode.jscp*)

time	0,7 s
NBI electrons/s - Density_BC (flux)	1.55e20



POWER

time	0,7 s
P_rad_tot	223 kW
P_divertor	74 kW
P_bulk	149 kW
P_NBI (with the loss due to the duct)	418 kW
P_ICRH	-
P_OHM	350 kW (V=1.37)
ELMs power	

P_inp = P_NBI + P_OHM + P_ICRH – P_rad_tot – P_ELMs = 545 W (without impurity)

P_inp = P_NBI + P_OHM + P_ICRH –P_ELMs = (with impurity)

TCV pulse #73382 – NT L-mode (δ_{top} = -0.22)

GAS PUFFING:

valve	0,7 s
1	D2: 0,5e20 molecules/s →1,0e20 atom/s
2	-
3	-

MAIN PARAMS discharge

Time =0,7s (NBI-only phase)

I_p	-240 kA
$<n_e>$ (FIR)	xx x 10^{19} m^{-3}
T_e max (TS)	xx keV
B_T at R=0,88m	-1.42 T

DENSITY_BC (in *overview_hmode.jscp*)

time	0,7 s
NBI electrons/s - Density_BC (flux)	1.5e20

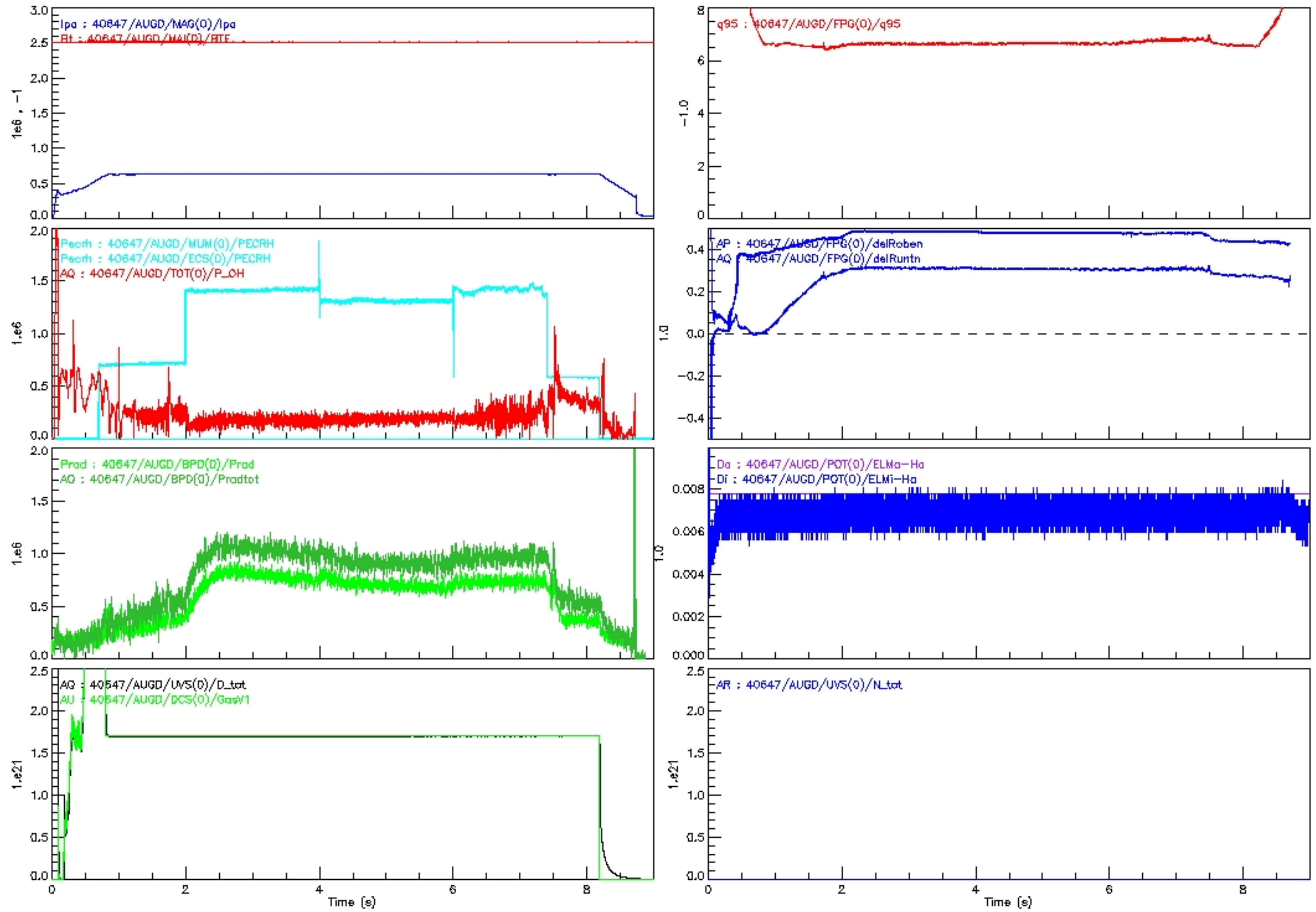
POWER

time	0,7 s
P_rad_tot (core/div)	220 kW
P_divertor	97 kW
P_bulk	123 kW
P_NBI (with the loss due to the duct)	418 kW
P_ICRH	-
P_OHM	264 kW (V=1.1 V)
ELMs power	0

P_inp = P_NBI + P_OHM + P_ICRH – P_rad_tot = 462 kW (without impurity)

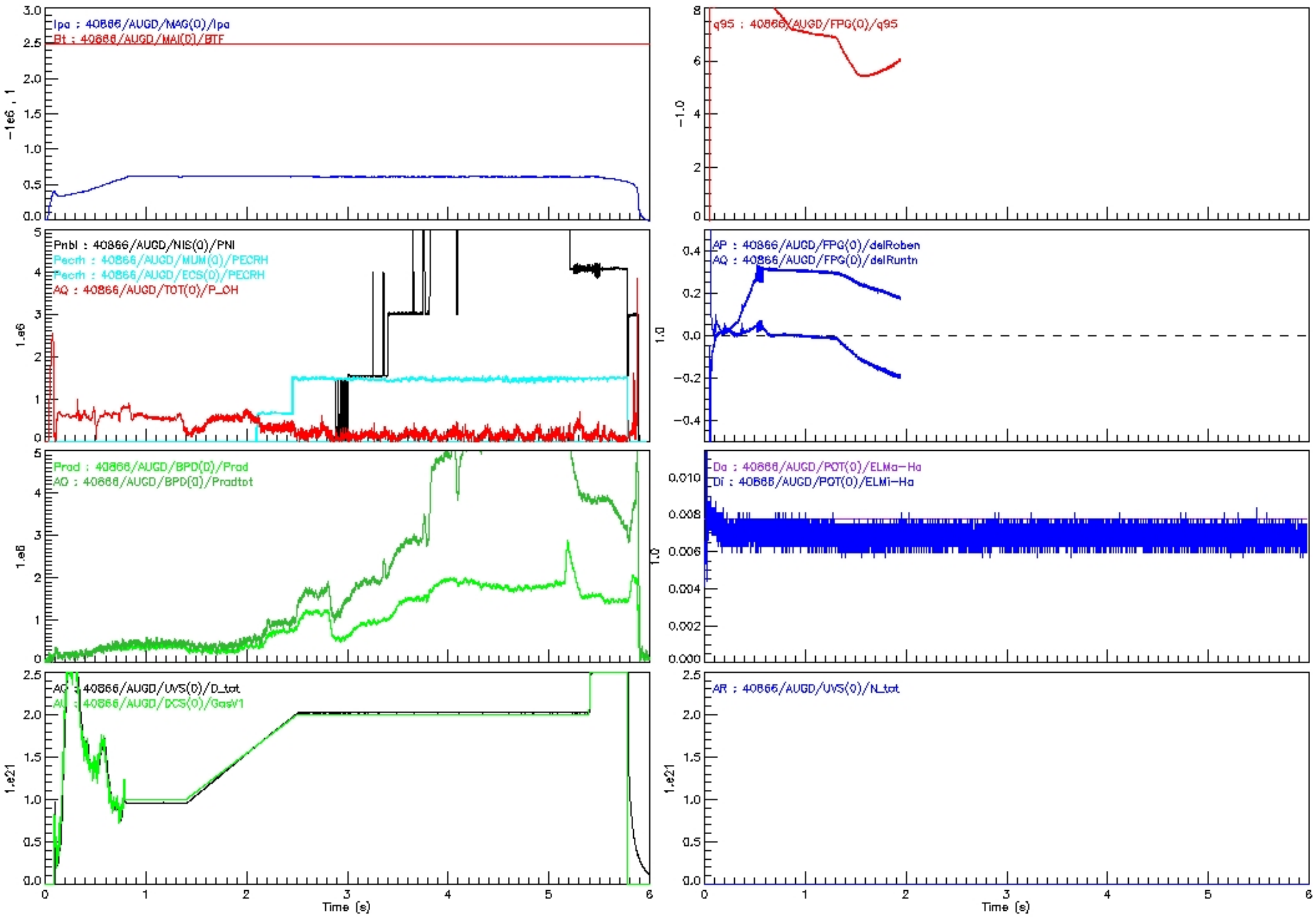
P_inp = P_NBI + P_OHM + P_ICRH – P_bulk = (with impurity)

AUG 40647



Ipa : 40647/AUGD/MAG(0)/Ipa
Bt : 40647/AUGD/MAI(0)/BTF
q95 : 40647/AUGD/FPG(0)/q95
Pecrh : 40647/AUGD/MUM(0)/PECRH
Pecrh : 40647/AUGD/ECS(0)/PECRH
AQ : 40647/AUGD/TOT(0)/P_OH
AP : 40647/AUGD/FPG(0)/delRoben
AQ : 40647/AUGD/FPG(0)/delRuntn
Prad : 40647/AUGD/BPD(0)/Prad
AQ : 40647/AUGD/BPD(0)/Pradtot
Da : 40647/AUGD/POT(0)/ELMa-Ha
Di : 40647/AUGD/POT(0)/ELMi-Ha
AQ : 40647/AUGD/UVS(0)/D_tot
AU : 40647/AUGD/DCS(0)/GasV1
AR : 40647/AUGD/UVS(0)/N_tot
Time (s)

AUG 40866



Ipa : 40866/AUGD/MAG(0)/Ipa
Bt : 40866/AUGD/MAI(0)/BTF
q95 : 40866/AUGD/FPG(0)/q95
Pnbi : 40866/AUGD/NIS(0)/PNI
Pecrh : 40866/AUGD/MUM(0)/PECRH
Pecrh : 40866/AUGD/ECS(0)/PECRH
AQ : 40866/AUGD/TOT(0)/P_OH
AP : 40866/AUGD/FPG(0)/delRoben
AQ : 40866/AUGD/FPG(0)/delRuntn
Prad : 40866/AUGD/BPD(0)/Prad
AQ : 40866/AUGD/BPD(0)/Pradtot
Da : 40866/AUGD/POT(0)/ELMa-Ha
Di : 40866/AUGD/POT(0)/ELMi-Ha
40866/AUGD/UVS(0)/D_tot
40866/AUGD/DCS(0)/GasV1
AR : 40866/AUGD/UVS(0)/N_tot
Time (s)
Time (s)

	SHOT	40647 PT	40866 NT
	Time (s)	2,7s	2,7s
Comparison Parameters	I_p	+635 kA	-620 kA
	Volume	1 m^3	1 m^3
	q0/q95	1,8/6,7	1,2/6,5
	β_{pol}		
	betaE norm= =betae_tor*100*a*B_0/(I_p [MA])		
	δ_{top} / δ_{bottom} / δ_{tot} (LCFS)	<u>**0,3**</u> / 0,48 / 0,4	<u>**-0,3**</u> / 0,07 / -0,1
	B_T (at R=0.88m)	+2,5 T	-2,5 T
	T_e max (TS)	3 keV	3 keV
	$<n_e>$ (FIR) / $<n_e>$ (TS)	6,1 x 10^{19} m^{-3} / 6,2 x 10^{19} m^{-3}	5,2x 10^{19} m^{-3}/ 5,3 x 10^{19} m^{-3}
Powers	P_{NBI}	0	0
	P_{ECRH}	1,41 MW	1,48 MW
	P_{OHM}	200 kW	200 kW
	$P_{rad,tot}$	1MW	1,5MW
	P_{ELMs}	kW	
	P_{input} (without impurity) = $P_{NBI}+P_{OHM}+P_{ICRH}-P_{rad,tot}-P_{ELMs}$	610 kW	200 kW
	P_{input} (with impurity) = $P_{NBI}+P_{OHM}+P_{ICRH}-P_{bulk}-P_{ELMs}$		
Gas	D2	1,7 x 10^{21}	2,0 x 10^{21}