Filamentary transport in high-power H-mode conditions and in no/small-ELM regimes to predict heat and particle loads on PFCs for future devices

N. Vianello, V. Naulin for Topic-21 Scientific Team

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2017 Top Objectives 12.12.2016

Deliverables listed during the call for manning of last December

1. Cross-machine L-Mode shoulder dependence on current both at constant B_t and at constant q_{95}. Rationale: disentangle the effect of current and parallel connection length
2. Establish robust scenario for density shoulder profile in H-Mode and establish dependence on fuelling/neutral profiles/divertor conditioon
3. Use the new HHF probe on AUG to study filamentary transport under high-power H-Mode conditions and under different plasma configurations (SN, DN)
4. Study the role of ELM regimes, neutral compression and particle density in filamentary transport and related shoulder formation
5. Identify the contribution of collisionality and seeding on filamentary transport and related shoulder formation
6. Determine the effect of filaments and shoulder formation on target heat loads in different H-mode plasmas

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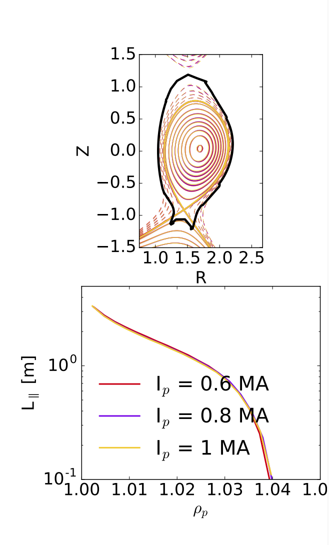
5. Identify the contribution of collisionality and seeding on filamentary transport and related shoulder formation
6. Determine the effect of filaments and shoulder formation on target heat loads in different H-mode plasmas

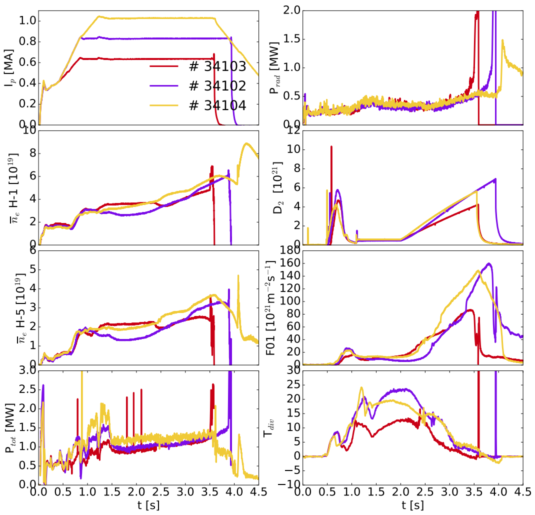
So far H-Mode operation has been limited to AUG since no operational scenario in high-density NBH heated plasma on TCV has been established

L-Mode analysis: I_p scan at constant q_{95}



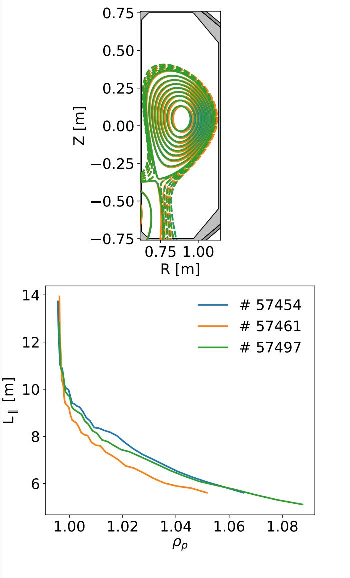
- ✓ AUG: All the shots were performed in the so-called Edge Optmized Configuration (EOC) shape.
- ✓ AUG: We matched correctly the shape and the $L_{||}$ here shown from outer divertor plate up to X-point

L-Mode analysis: I_p scan at constant q_{95}



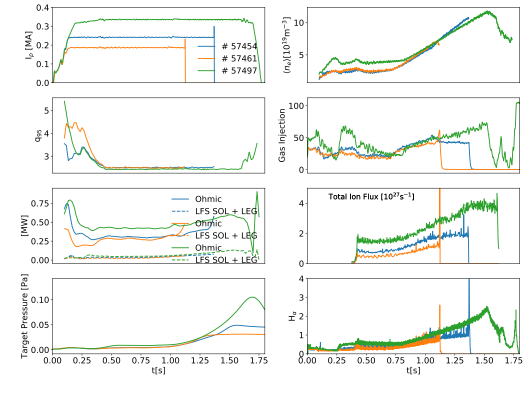
- ✓ AUG: The scan was performed with similar puffing rates for intermediate and higher current (0.8-1 MA) whereas we reduced it at lower current to avoid early disruption
- ✓ AUG: The total power (Ohmic plus NBI) was kept constant throughout the scan
- ✓ AUG: We have comparable edge density, divertor neutral pressure and divertor temperature

L-Mode analysis: I_p scan at constant q_{95}



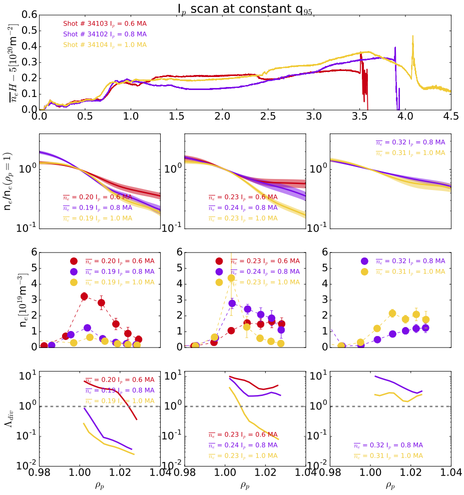
✓ TCV: We repeat the same excercise at TCV with a slight difference in the profile of parallel connection length. This required operation at unusual low toroidal field (up to 0.8T)

L-Mode analysis: I_p scan at constant q_{95}



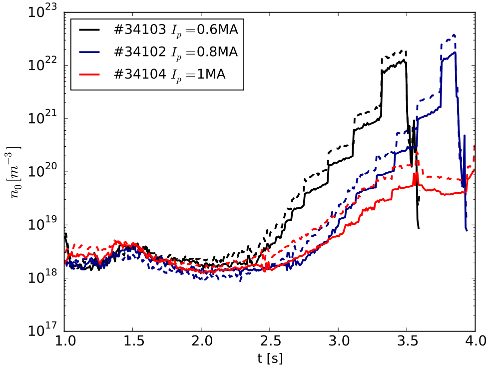
- ✓ TCV: no additional heating has been used. Nevertheless the difference in power crossing the separatrix is small
- ✓ TCV: The difference in target pressure similar to AUG behavior.

L-Mode analysis: I_p scan at constant q_{95}



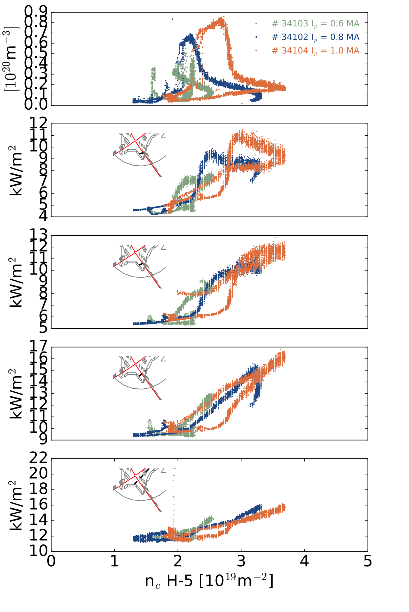
✓ AUG: At comparable edge density Upstream profiles are different with the tendency to develop shoulder easier at lower current. We have flattening of the upstream profiles only when Λ_{div} is well above one on all the profile

L-Mode analysis: I_p scan at constant q_{95}



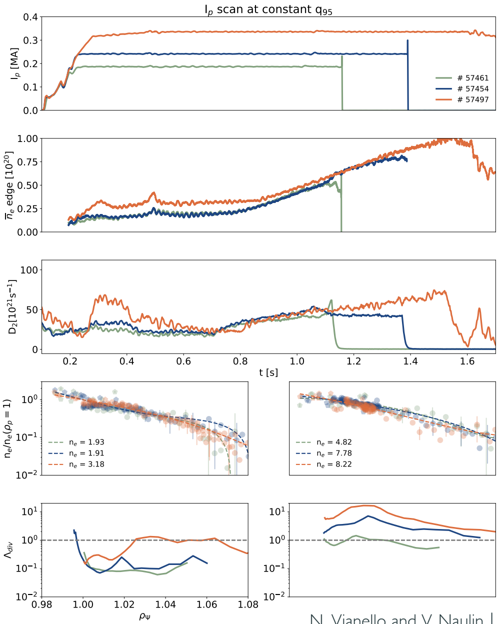
- ✓ AUG: Neutrals estimated using calibrated D_α cameras coupled with values of density and temperature at the target suggest a larger neutral density at lower current (even with comparable values of edge electron density)

L-Mode analysis: I_p scan at constant q_{95}



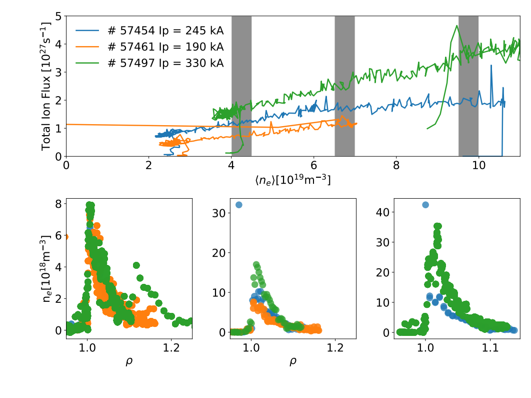
- ✓ AUG: At all the current a clear roll-over in peak density observed and we can also track the radiation front move away from target earlier in density at lower current

L-Mode analysis: I_p scan at constant q_{95}



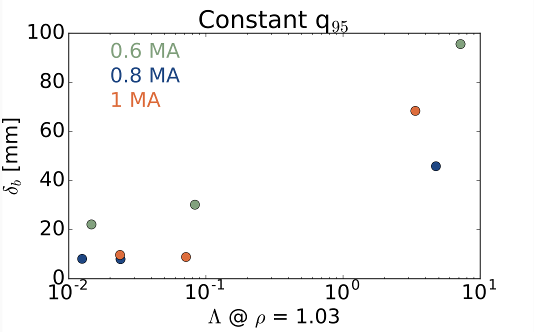
- ✓ TCV: This tendency is not observed for TCV where profiles seem resilient to modification of Bt even though we reached pretty high value of Λ_{div} all along the profile.

L-Mode analysis: I_p scan at constant q_{95}



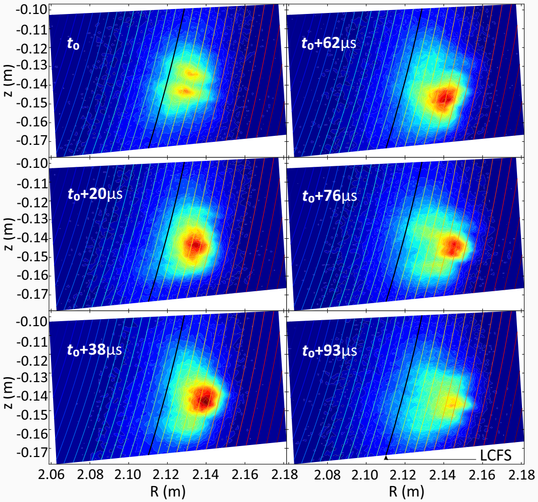
- ✓ TCV: This is due to the fact that we can't observed during the density ramp any signature of rollover or detachment, whereas upstream profile modification at TCV are only observed well after rollover

L-Mode analysis: I_p scan at constant q_{95}



- ✓ AUG: There is the tendency towards larger blobs at lower current at all values of Λ_{div}

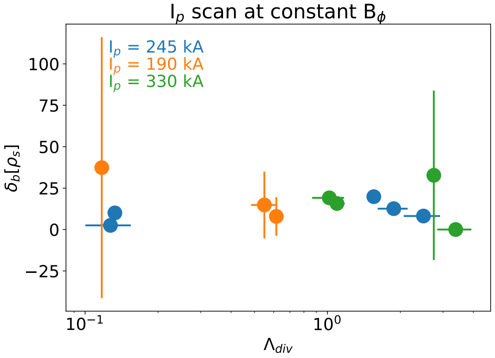
L-Mode analysis: I_p scan at constant q_{95}



AUG GPI shot 34228

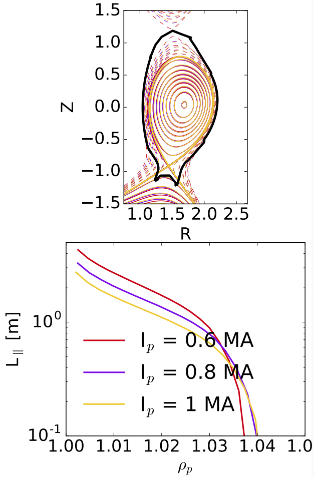
- ✓ AUG: This need to be further confirmed independently by GPI measurements. The present setup allows for space resolution of the order of mm with a 397 kframe/s sampling rate. Small amount of He gas flux needed ($\sim 1.5e^{17} atoms/ms$)

L-Mode analysis: I_p scan at constant q_{95}



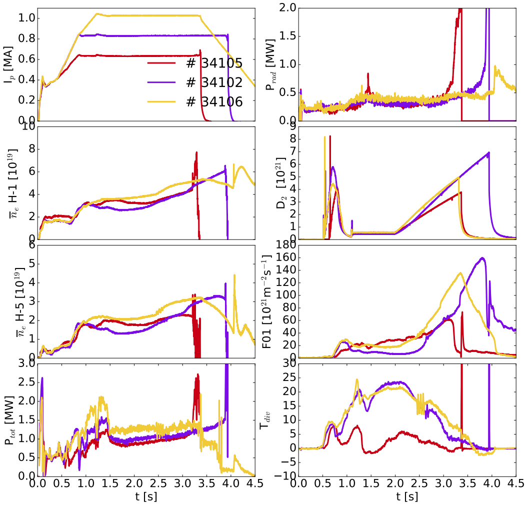
- ✓ TCV: this is not confirmed for TCV where blob sizes is rather constant over a rather large range of Λ_{div}. At the same time we do not observe target density rollover neither upstream profile flattening

L-Mode analysis: I_p scan at constant B_t



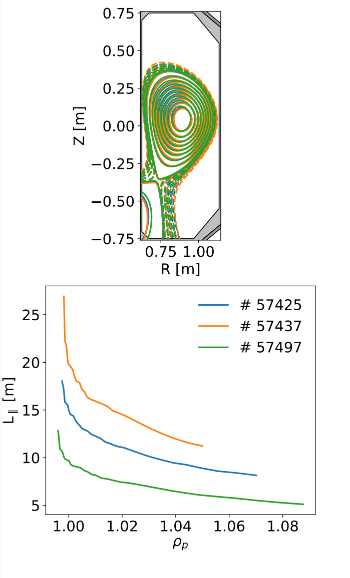
- ✓ AUG: We matched correctly the shape the parallel connection length $L_{||}$ is modified consistently
- ✓ AUG: The scan was performed with similar puffing rate (0.8-1 MA) whereas we reduced it at lower current to avoid early disruption

L-Mode analysis: I_p scan at constant B_t



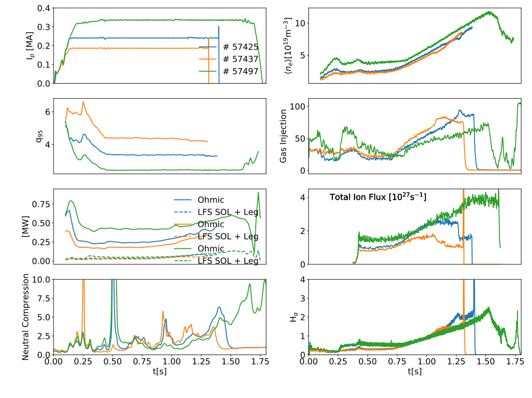
- ✓ AUG: We have comparable edge density and divertor neutral pressure even though pressure increase earlier at higher current
- ✓ AUG: The total power (Ohmic plus NBI) was kept constant throughout the scan

L-Mode analysis: I_p scan at constant B_t



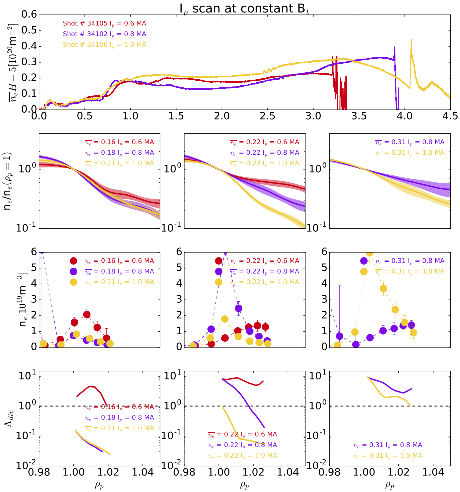
- ✓ TCV: We repeat the same excercise at TCV with a consistent variation of parallel connection length

L-Mode analysis: I_p scan at constant B_t



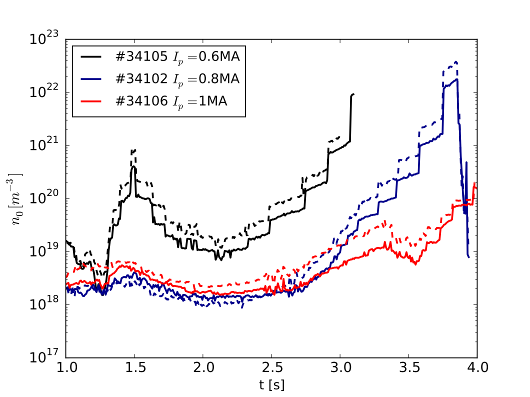
- ✓ TCV: no additional heating used. Nevertheless the difference in power crossing the separatrix is small
- ✓ TCV: Neutral compression is roughly constant between

L-Mode analysis: I_p scan at constant B_t



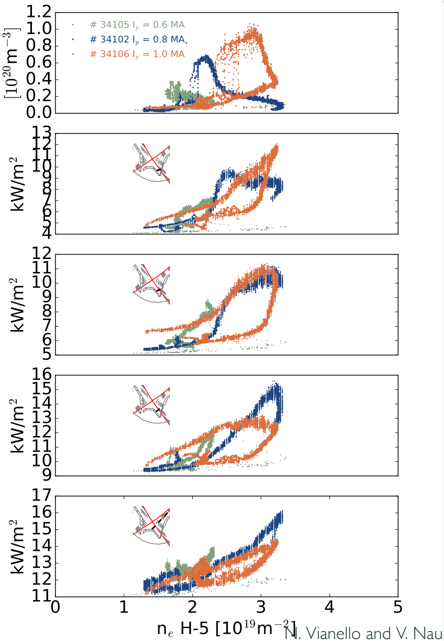
- ✓ AUG: At comparable edge density Upstream profiles are different with the tendency to develop shoulder easier at lower current. We have flattening of the upstream profiles only when Λ_{div} is well above one on all the profile

L-Mode analysis: I_p scan at constant B_t



- ✓ Neutrals at lower current are substantially higher even with similar edge density profiles.

L-Mode analysis: I_p scan at constant B_t



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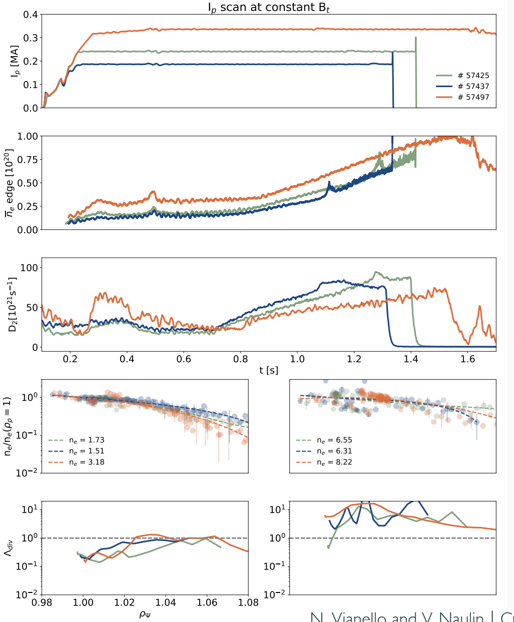
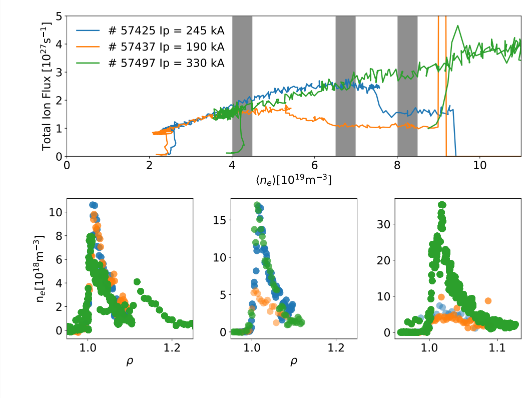


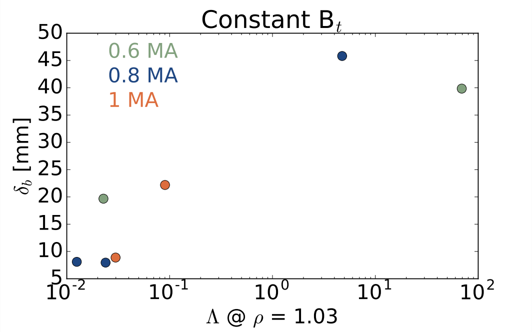
✓ TCV: This tendency is substantially confirmed at TCV where profiles

L-Mode analysis: I_p scan at constant B_t



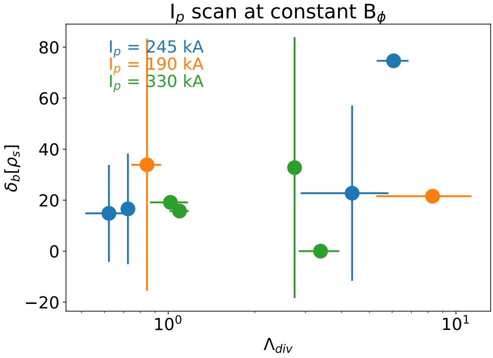
- ✓ TCV: This is consistent with onset of detachment (at least in intermediate and lower current)

L-Mode analysis: I_p scan at constant B_t



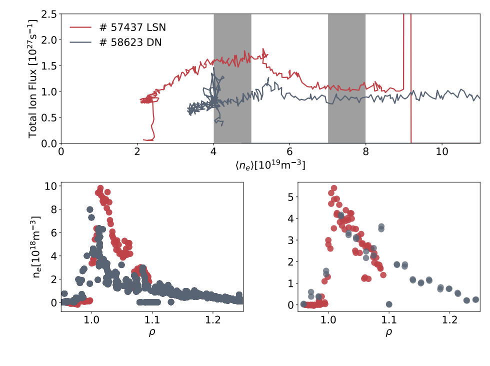
- ✓ AUG: While the general observation of increasing blob size with Λ_{div} is confirmed there are no differences between the current

L-Mode analysis: I_p scan at constant B_t



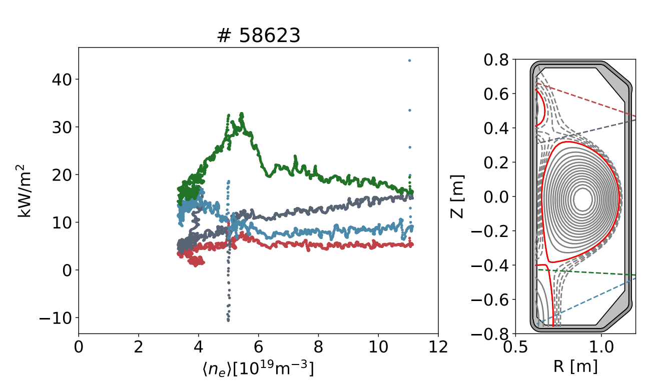
- ✓ TCV: confirm the observation of AUG.

LSN *vs* Double null on TCV



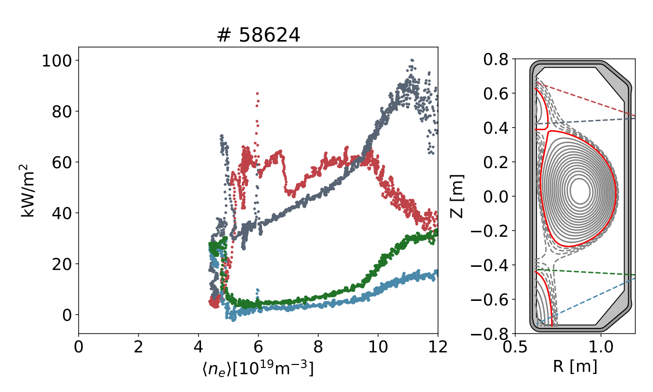
- ✓ Comparing similar L-Mode density ramp at same current in LSN and DN with ion $\mathbf{B} \times \nabla B$ pointing towards the floor. Lower ion flux to lower target observed in DN and profiles before rollover seem more broad in LSN. After rollover the profiles are actually similar

LSN *vs* Double null on TCV



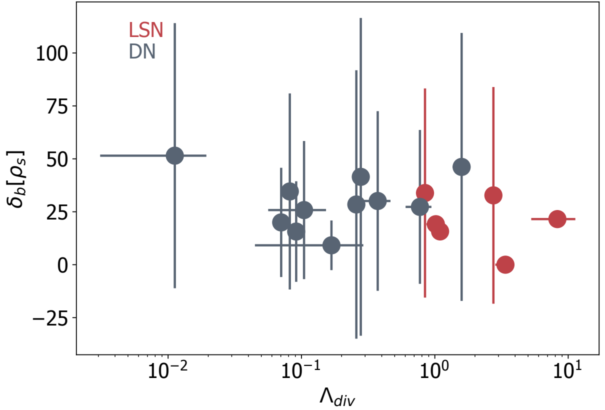
✓ From bolometry we can observe an unbalanced movement of the radiation front suggesting a non perfectly balanced DN

LSN *vs* Double null on TCV

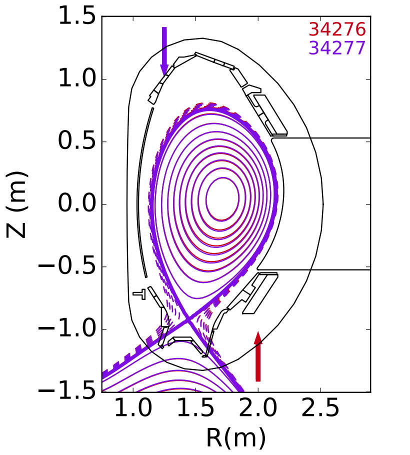


✓ This is confirmed at higher current where the more active X-point is the upper one with a consequent higher radiation from bolometry chords

LSN *vs* Double null on TCV

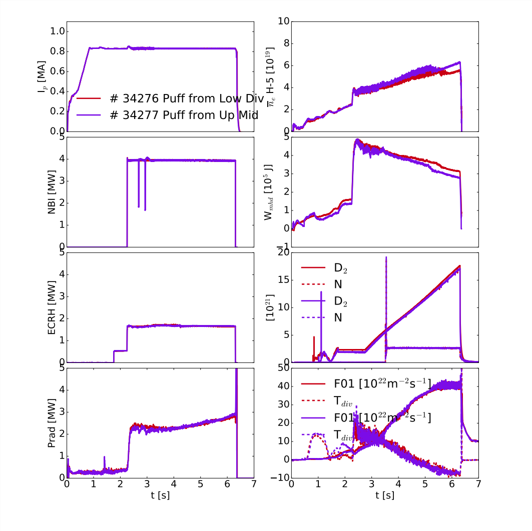


H-Mode investigation: puffing location



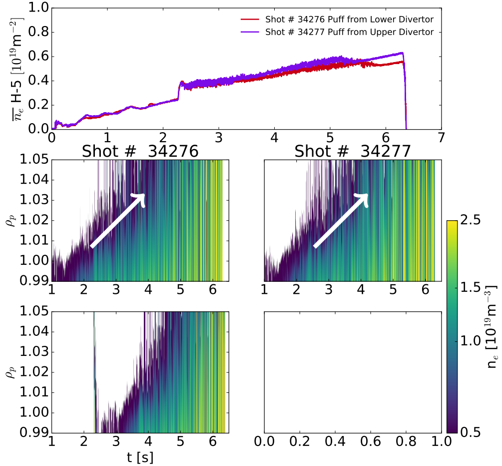
- ✓ Similar puff from Lower and Upper divertor valves (we asked for divertor/midplane valves)

H-Mode investigation: puffing location



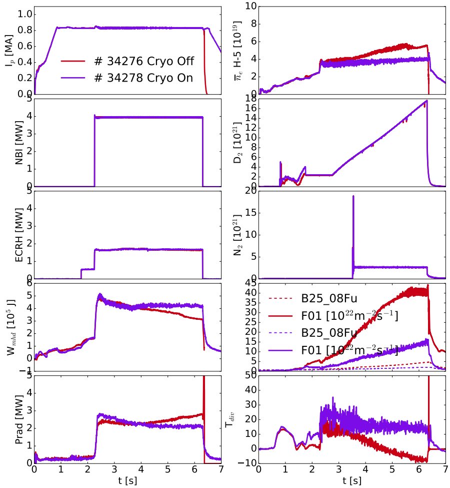
- ✓ Similar puff from Lower and Upper divertor valves (we asked for divertor/midplane valves)
- ✓ Discharge with a total amount 6.5 heating power with equivalent behavior also in the lower divertor independently from the puffing location

H-Mode investigation: puffing location



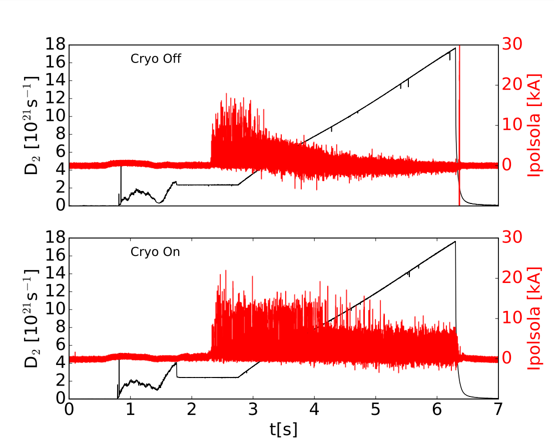
- ✓ Similar puff from Lower and Upper divertor valves (we asked for divertor/midplane valves)
- ✓ Discharge with a total amount 6.5 heating power with equivalent behavior also in the lower divertor independently from the puffing location
- ✓ Edge density profiles from Li-Beam evolution are pretty similar
- ✓ Similar behavior observed from RIC Antenna 4 for the available shot

Compare fueling with/without cryopumps



- ✓ Same fueling but with cryo-pumps
- ✓ H-5 density is different and remain constant, both divertor and midplane pressure are reduced (to 1/3 approximately) no sign of detachment

Compare fueling with/without cryopumps



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- ✓ Different ELMy regimes reached with reduced size and increased frequency without the cryopumps

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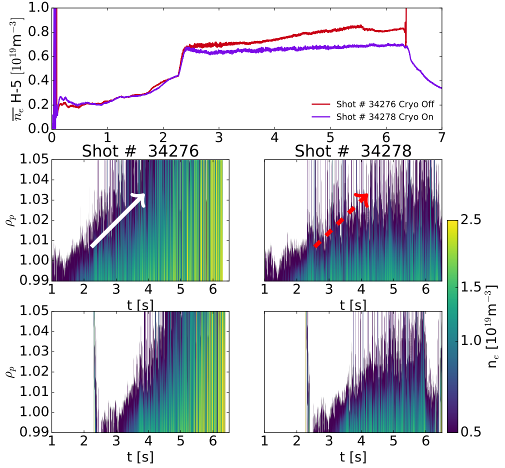

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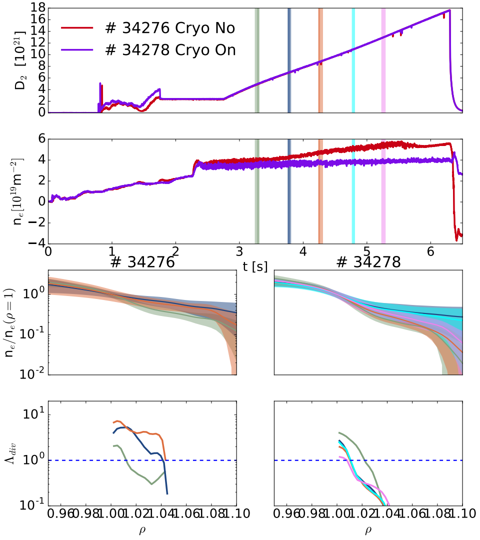
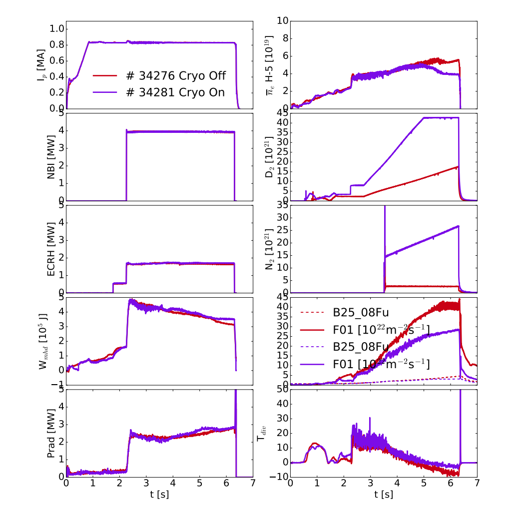
- ✓ Also with this amount of fueling weaker indication of SOL saturation observed as confirmed by Li-Beam and by RIC (Antenna 4)

Compare fueling with/without cryopumps



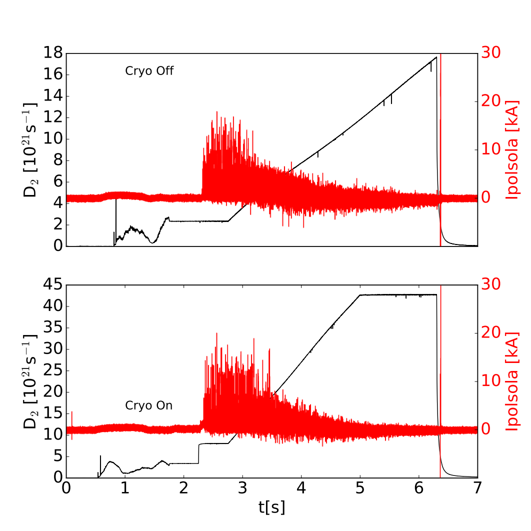
- ✓ Same fueling but with cryo-pumps
- ✓ H-5 density is different and remain constant, both divertor and midplane pressure are reduced (to 1/3 approximately) no sign of detachment
- ✓ Different ELMy regimes reached with reduced size and increased frequency without the cryopumps
- ✓ Also with this amount of fueling weaker indication of SOL saturation observed as confirmed by Li-Beam and by RIC (Antenna 4)
- ✓ Inter-ELM resolved profile suggest a flattening even with the cryompumps still even though Λ_{div} is marginal above 1 only in the near SOL

Matching scenarios with cryo-pumps



- ✓ To match similar edge density and divertor pressure and to reach the same level of detachment we increase the fueling by almost a factor of 3, increasing also the rate. In addition to that we also increase substantially the N puffing. Degraded H-Mode reached earlier in density without the cryopumps

Matching scenarios with cryo-pumps



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- ✓ Similar ELMy behavior obtained during the density ramp

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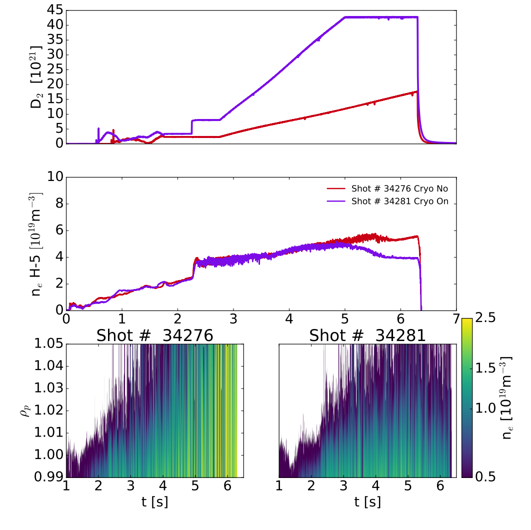

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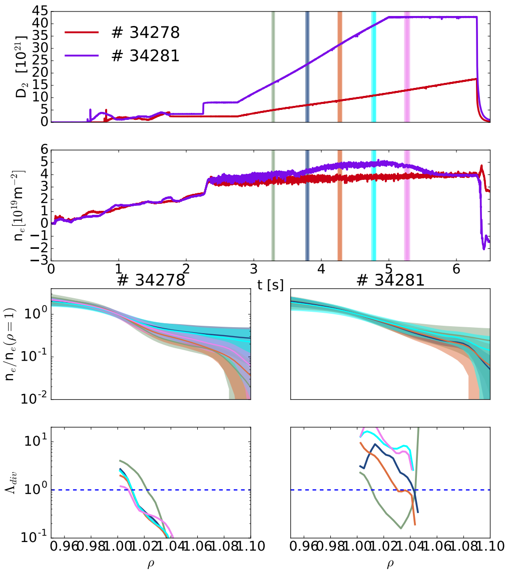
- ✓ Similar ELMy behavior obtained during the density ramp
- ✓ Now the scenario suggest a strong profile flattening even with the cryopumps

Matching scenarios with cryo-pumps



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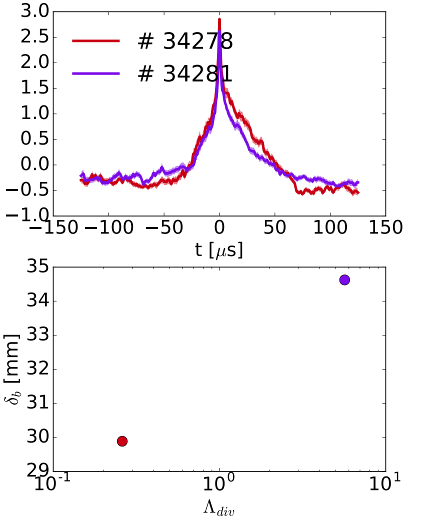
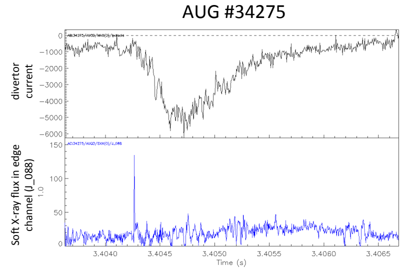
- ✓ Similar ELMy behavior obtained during the density ramp
- ✓ Now the scenario suggest a strong profile flattening even with the cryopumps
- ✓ Inter-ELM resolved Li-Be profiles confirm this with shoulder formed with similar strength even with the cryopumps in operation.

Matching scenarios with cryo-pumps



- ✓ To match similar edge density and divertor pressure and to reach the same level of detachment we increase the fueling by almost a factor of 3, increasing also the rate. In addition to that we also increase substantially the N puffing. Degraded H-Mode reached earlier in density without the cryopumps
- ✓ Similar ELMy behavior obtained during the density ramp
- ✓ Now the scenario suggest a strong profile flattening even with the cryopumps
- ✓ Inter-ELM resolved Li-Be profiles confirm this with shoulder formed with similar strength even with the cryopumps in operation.
- ✓ We can also confirm that additional fueling change substantially the blob size which increases consistently with the modification of Λ_{div}

Fast electron generation



- ✓ Bursts of nonthermal 2nd harmonic electron cyclotron emission and edge soft X-ray emission often occur at start of ELM filament eruption in low collisionality AUG pulses – evidence of filament reconnection
- ✓ Soft X-ray bursts were seen at start of ELM filament eruption in T21-AUG pulses, but not ECE bursts, probably due to higher collisionality in these pulses
- ✓ Peak nonthermal ECE emission appears to originate from top of pedestal
- ✓ Work is ongoing to determine conditions for occurrence of ECE & SXR bursts, e.g. in terms of pedestal collisionality – there is no clear correlation between ELM size & SXR flux

Comments on difficulties for H-Mode in TCV

plored

Program for 2018: AUG

- ✓ X-point manipulator (hopefully with NPH) triggered at the same time as MPM
- ✓ X-point vertical shift in order to have SP at different vertical heigth at the target. This could suggest us if similar behavior as the one observed on JET are visible at AUG
- ✓ DN discharges. With slow movement of the second X-point into the vessel to be performed at constant power/density where shoulder alreay exists. This is mandatory to complement the information obtained on TCV
- ✓ USN with midplane/X-point manipulator to monitor the upstream SOL

Program for 2018: TCV

- ✓ H-Mode ?
- ✓ Long divertor legs (probe in the lower port)
- ✓ SnowFlake to monitor the fluctuations in between the 2 separatrix to be done in high density discharges
- ✓ Try to move the second X-point in SN divertor at a different Z position while keeping the same radial distances between the points

Program for 2018: MAST-U

- ✓ Influence of neutral recycling source in establishing upstream profiles and comparison between Low-RT and Vertical target. Look also ath the heat loads
- ✓ Current scan at constant q95/constant Bt