Investigation of edge velocity shear generation with NBI for QH-mode in DEMO

E. Fable

MPG-IPP Garching

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DEMO QH-mode scenario 2019

- DEMO parameters (scenario 2017):

  $R = 8.94$ m

  $a = 2.94$ m

  $B_T = 4.89$ T

  $Ip = 19.07$ MA

  $n_{avg} \sim 8 * 10^{19}$ m^{-3}

  $k = 1.7$

  triang = 0.33

- P_{aux} ~ to be calculated MW

- P_{fus} ~ 2 GW

- P_{rad},core ~ 300 MW

- P_{sep}/P_{LH} ~ 1.5

Physics to be investigated

- QH mode requires a certain velocity shear to be triggered
  [A. M. Garofalo et al., NF 2011]

- Basically, ExB shear > (value), linked to edge MHD (i.e. Alfvén speed)

- The dimensionless criterion chosen here is (0.16 is arbitrary):

  - $$\frac{a}{V_A} a \frac{d\Omega}{dr} \approx 0.16;$$

$$V_A = \frac{B}{\sqrt{(\mu_0 n M)}}; \qquad E_r = B_\varphi (V_{dia} - V_\theta) + B_\theta V_\varphi$$

$$\Omega = \frac{E_r}{R B_\theta} = \frac{B_\varphi}{R B_\theta}(V_{dia} - V_\theta) + \frac{V_\varphi}{R} = \frac{q}{r}(V_{dia} - V_\theta) + \frac{V_\varphi}{R};$$

- where *a* is the minor radius, *r* is the local minor radius

- Note that V_{dia} is large and negative, i.e. it is much more convenient to inject counter-current toroidal rotation rather than co-current

Value for DEMO

- Applying the criterion for DEMO we get (w_{ped} = 15 cm):

$$- \quad \frac{a}{V_A} a \frac{d\Omega}{dr} \approx 0.16 ; \qquad \frac{d\Omega}{dr} \approx \frac{\Omega}{w_{ped}}$$

$$\rightarrow \Omega \approx 2.55 \cdot 10^4 [rad/s] \rightarrow V_E \approx -19\, km/s$$

- First estimate of "natural" (i.e. without rotation) edge shear is
  V_E ~ - 8 km/s

- Missing ~ -10 km/s of perpendicular rotation, that is ~ - 120 km/s of toroidal rotation which have to come from NBI counter-current injection (or ~ + 360 km/s from co-current torque)

- So... how much torque is required to drive ~ -120 km/s of pedestal top rotation?

- Assuming that the angular momentum confinement time in the edge is the same as the energy confinement time, this would mean a torque of:

Torque for DEMO

• So... how much torque is required to drive ~ -100 km/s of pedestal top rotation?

• Assuming that the angular momentum confinement time in the edge is the same as the energy confinement time, this would mean a torque of:

•
$$S \chi_\varphi n R M \frac{V_\varphi}{w_{ped}} = T_\varphi$$

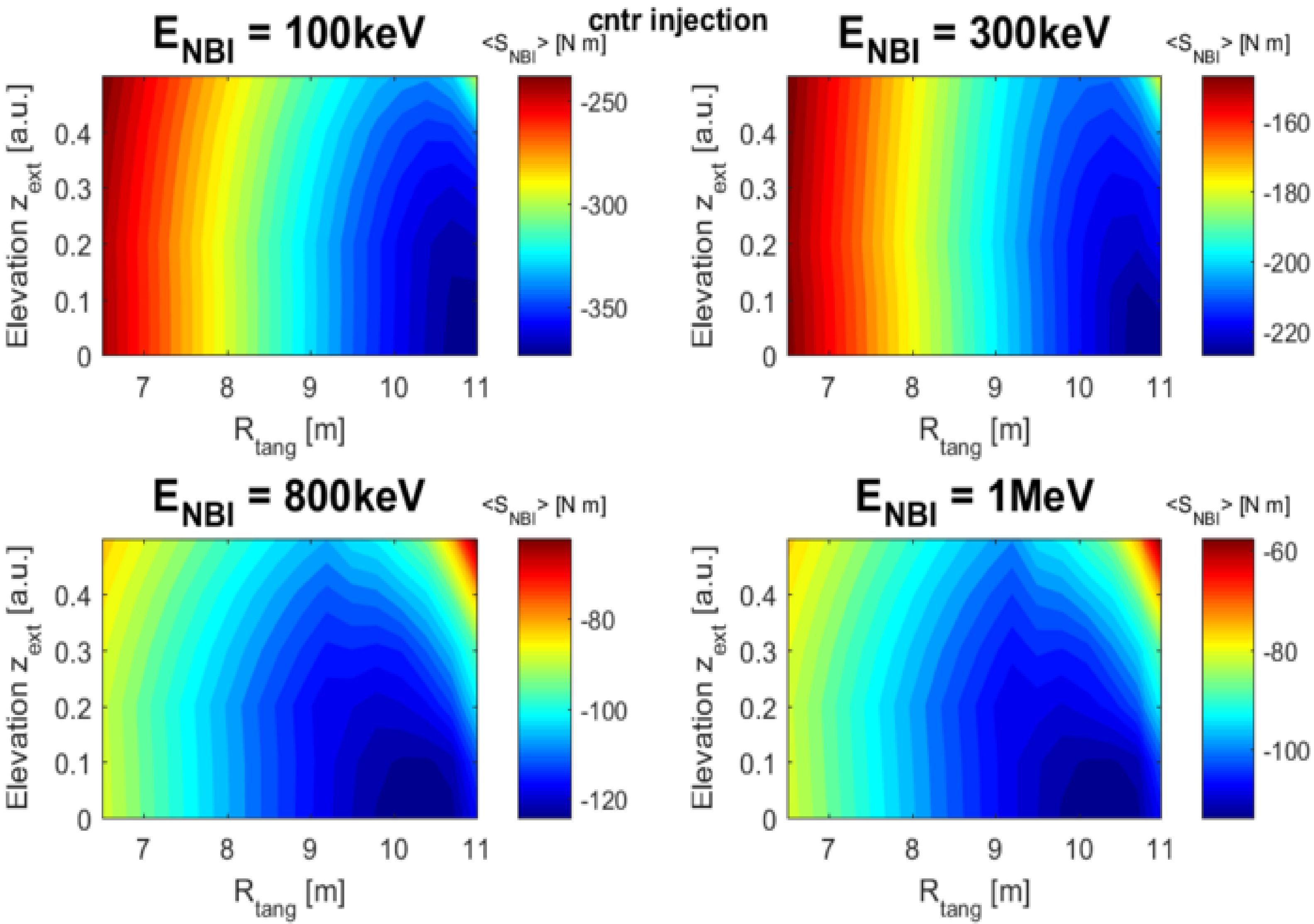
$$S = 1320 [m^2]; \qquad \chi_\varphi \approx 0.25; \qquad n = 4.2$$

$$T_\varphi [Nm] \approx 400 [Nm]$$

- very rough calculation, to be done with ASTRA properly.

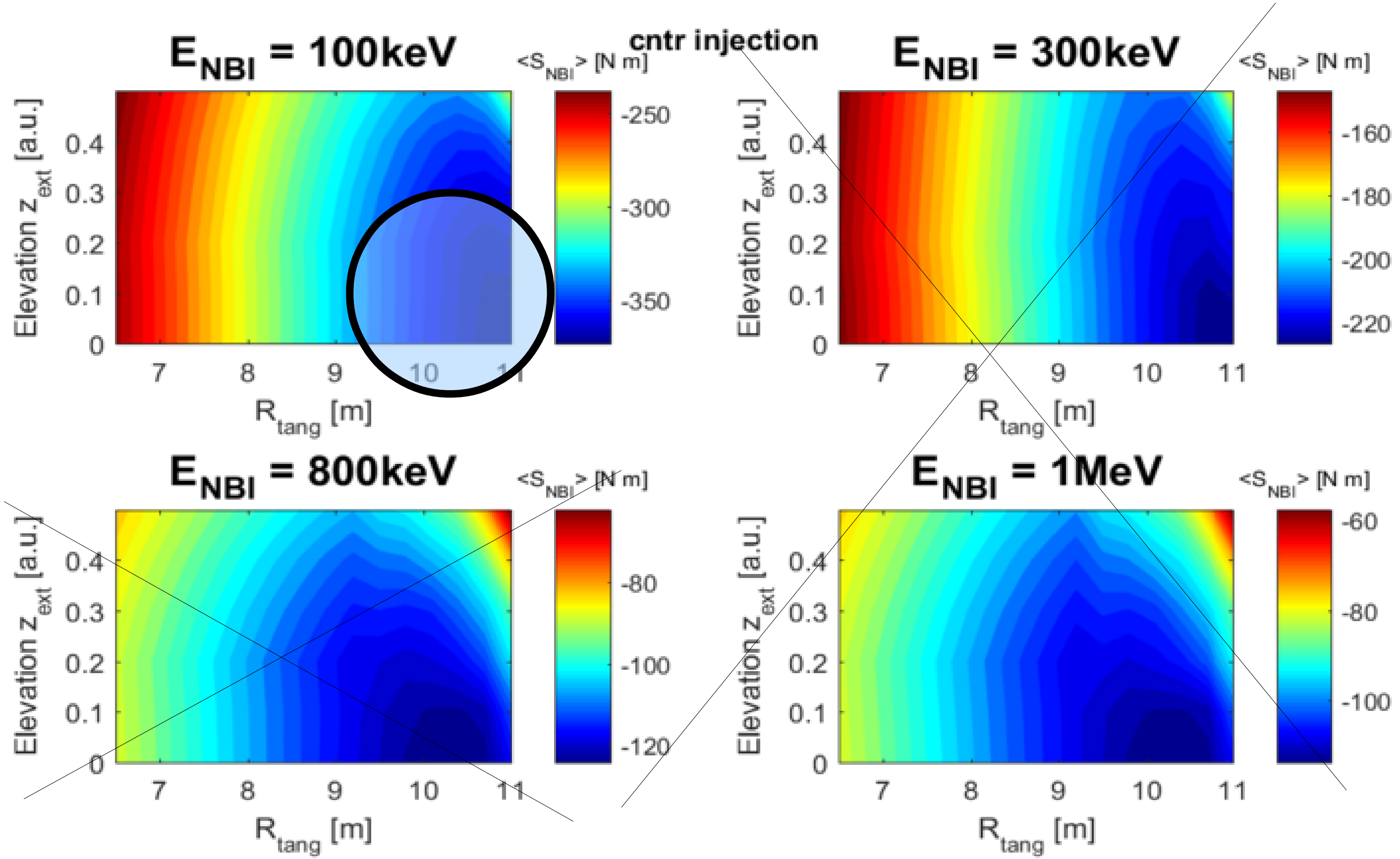
• Result: confirmed by ASTRA

Results from P. Vincenzi @ 76 MW



Operational space @ 76 MW

- very narrow operational space
- expect linearity in power, which would make e.g. 300 keV available @ 140 MW



Discussion

• If a dimensionless parameter for the QH mode entrance is assumed, for DEMO this leads to a certain requirements in edge radial electric field shearing

→ as already mentioned by Pietro, needs large torque

• Since DEMO naturally has already a rather large counter-current ExB rotation, to reach the desired value it is better to inject counter-current torque to add the remaining rotation on top of the natural rotation

• This remaining counter-current rotation/torque is estimated and is the ultimate result of the study. The relation by torque and power is provided by the work done by P. Vincenzi

• Regarding pedestal rotation vs torque, the model assumes a pedestal confinement time which is the same in angular momentum as well as in ion energy, and given by the local transport coefficients

→ to check against experimental evidence

Conclusions & outlook

• The chosen criterion is just the DIII-D one times a machine size to make it dimensionless → absolutely no first principles here

• It could be that the reality is more favourable (more unfavourable means no QH-mode)

• Present results show that with the assumptions used here the required torque is at the limit of the lowest energy, highest tangency radius cases done by Pietro.

• Main things to improve:
- QH criterion
- pedestal transport model for toroidal rotation