IMPACT OF NEUTRAL BEAM PARAMETERS ON CURRENT AND NEUTRON YIELD IN DEMO-FNS

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https://indico.cern.ch/event/1098715/

DEMO-FNS Parameters	
Aspect ratio R/a, m	3.2/1
Toroidal magnetic field, T	5
Electron/ion Temperature, keV	10-15
Av. plasma Density, 10^{20}, m^{-3}	0.5-1
Beta normalized β_N	2.1
Plasma current I_p, MA	5
6 injectors (tangential)	
Neutral injection power P_b, MW	**30**
D atoms Energy, keV	**500**
Ion source current, A	40
Pulse length, s	1000
Consumed / generated power, MW	200

LNB → **LITE NEUTRAL BEAM beam response in plasma**

GOALS

- optimum NB absorption and efficient CD
- profiles (CD and fusion) controllability
- Steady-state beam-plasma operation
- shine-through losses/power reduction
- high neutron yield from beam-plasma fusion

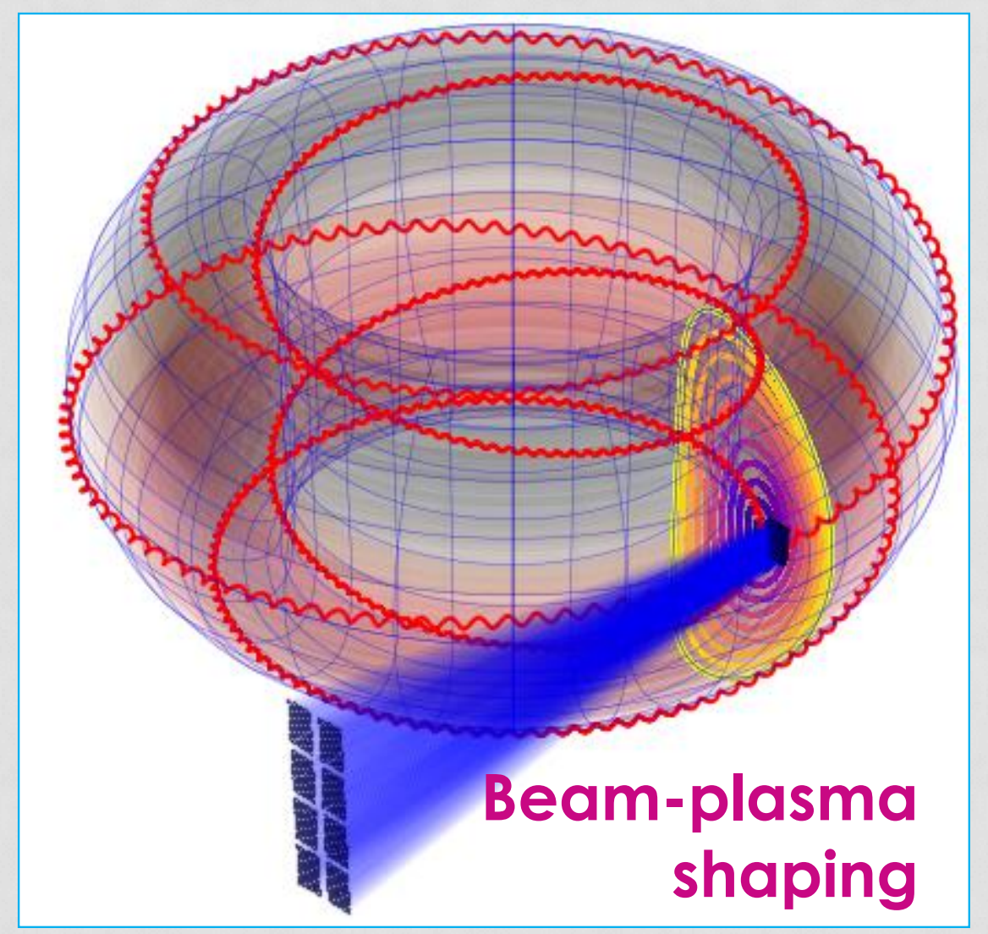
MOTIVATION

- Previous modelling has shown NB effects to be highly sensitive to NB and plasma shaping, plasma kinetic profiles and magnetic topology;
- High-performance and detailed methods are needed (e.g. real-time) simulation: analytical + 3D

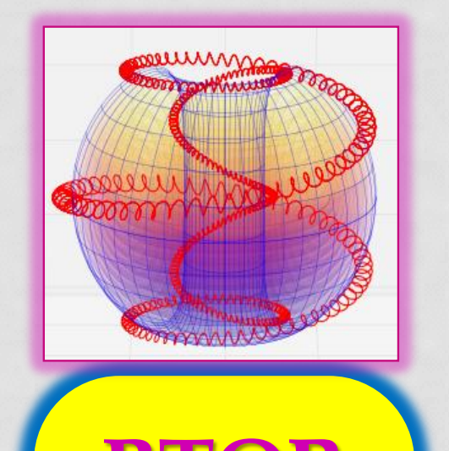
ASSUMPTION

- beam-plasma operation can be efficiently simulated by LNB approach ("Lite model") = combination of 3D statistics + analytics (BTR + BTOR workflow)

DEMO-FNS model in BTOR



Detailed 6D injected beam geometry and statistics (~10^9 particles) is taken from BTR code (Beam TRansmission) for NBI design and optimization

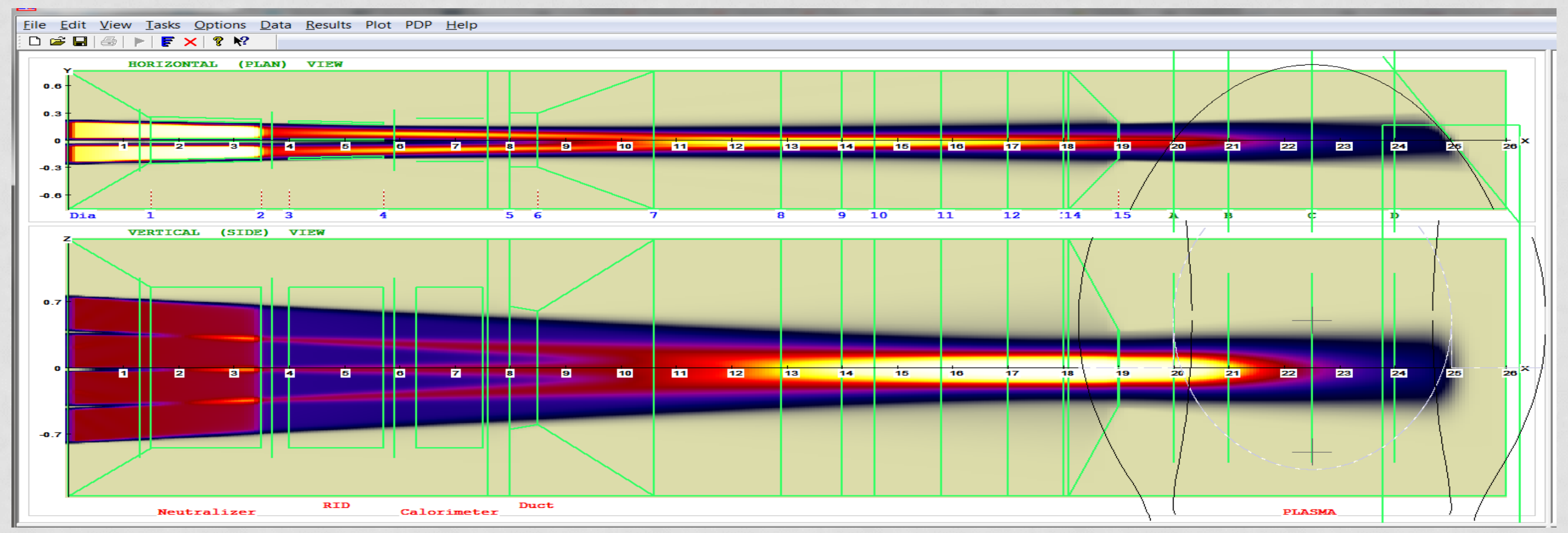


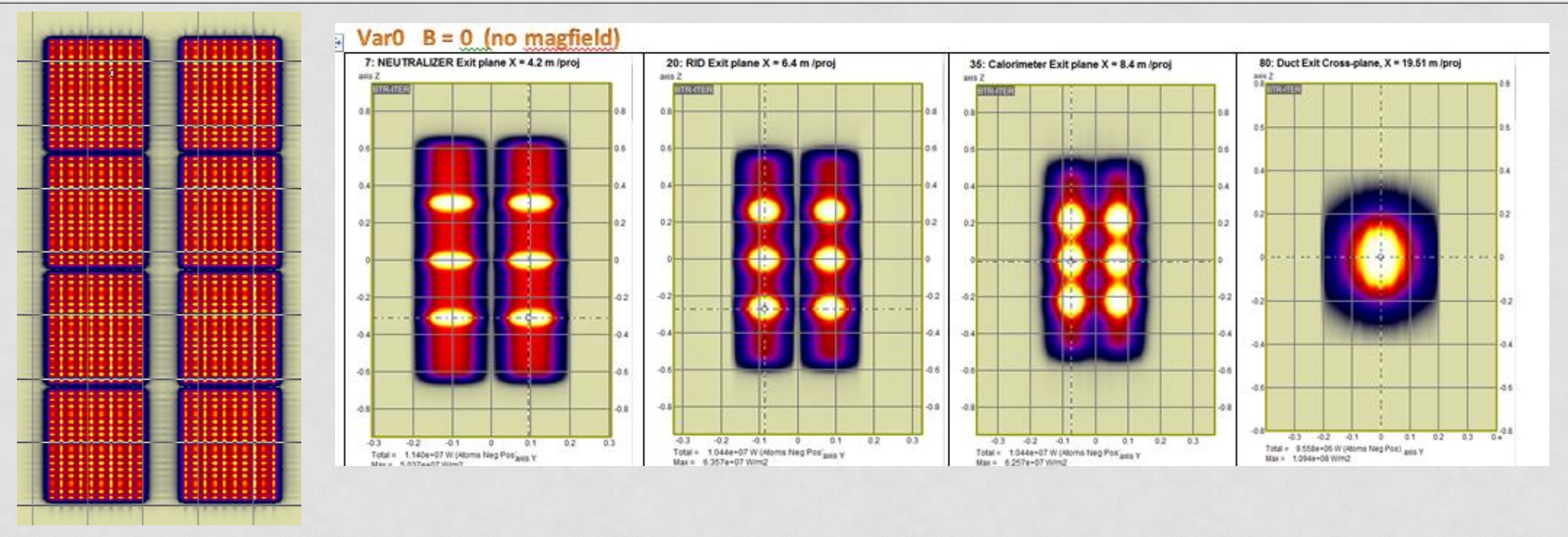
BTOR

Result: 10^{12} Fast Ions for plasma Heating and Current Drive + BTR methods of particle tracing with transformations

BTR beam geometry

10^7 – 10^9 source particles,
Lite analytical models,
deterministic approach,
Beamline geometry: ~300 elements

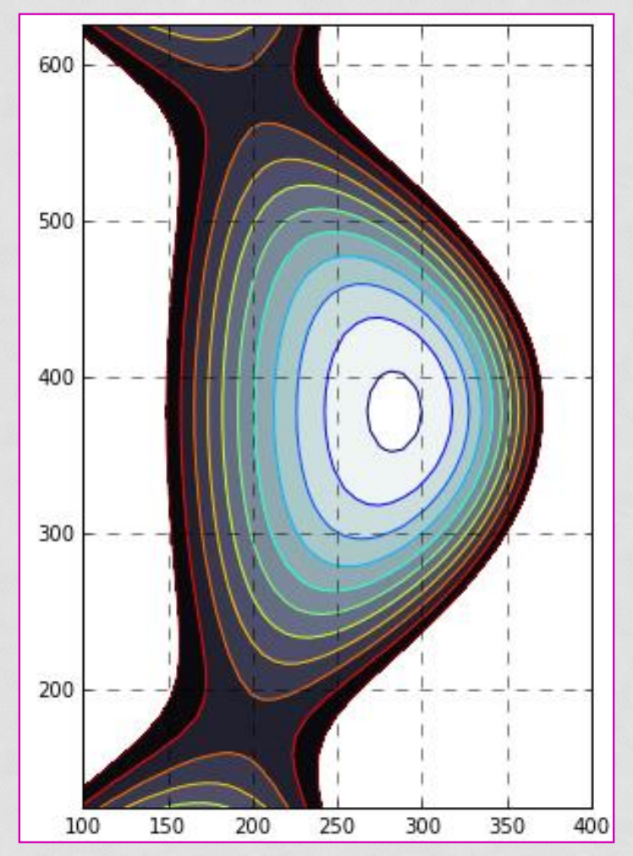




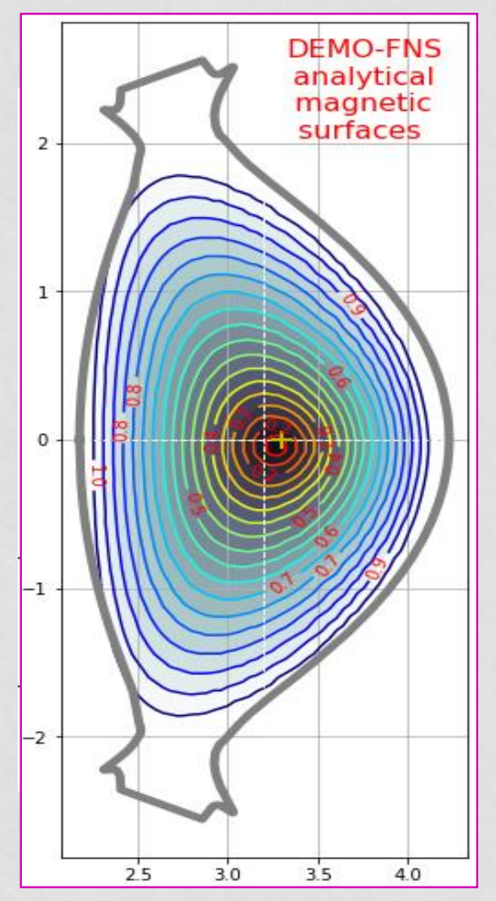
Beam footprint evolution (BTR)

BTOR plasma geometry

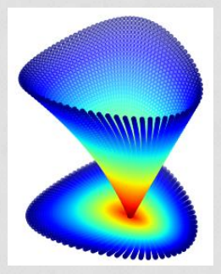
☐ R.L. Miller et al. Phys. Plasmas 1998 Vol. 5, No. 4, p. 973



EQDSK data



Analytical fit



$$R_i = R_0 + \Delta R_{sh} + a \times \cos(\theta + \delta \times \sin\theta)$$
$$Z = \kappa \times a \times \sin\theta$$
$$\Delta R_{sh} = \Delta R^0_{sh} \times (1 - (a/A)^2)$$

FAST IONS SLOWING-DOWN and CURRENT DRIVE CALCULATION

Fast ion slowing-down time
$$\tau_s = \frac{\tau_{se}}{3}\cdot ln\left[1+\left(\frac{E_b}{E_c}\right)^{3/2}\right]$$

Spitser time for electrons
$$\tau_{se} = \frac{3\sqrt{2\pi}T^{3/2}\,2\pi\varepsilon_0^2 m_b^2}{\sqrt{m_e}m_b \quad ne^4\, ln\Lambda} = K\cdot T_e^{3/2}\cdot\frac{A_b}{n}$$

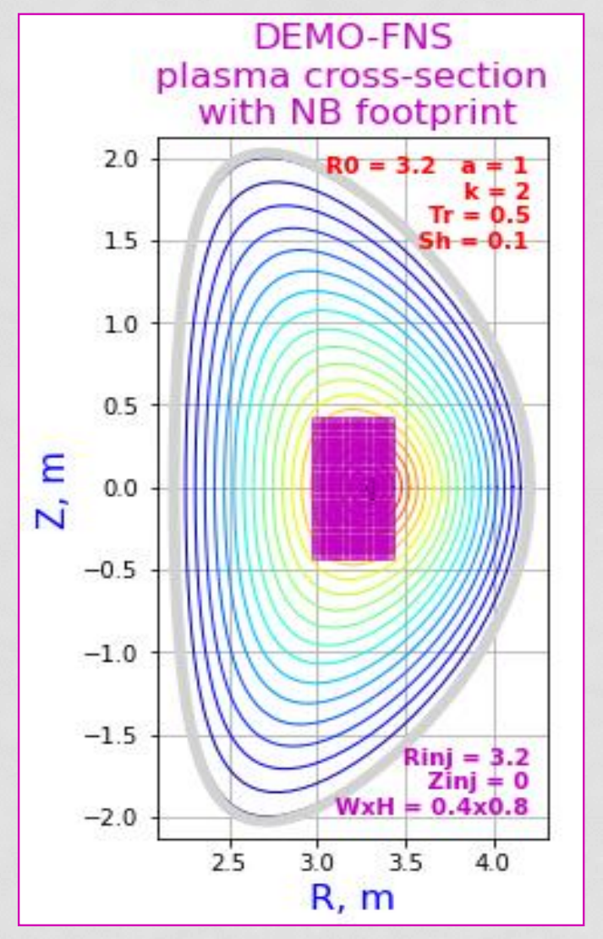
Critical energy
$$E_c = \left(\frac{3\sqrt{\pi}}{4}\right)^{2/3}\left(\frac{m_i}{m_e}\right)^{1/3}\frac{m_b}{m_i}\cdot T_e = K\cdot\frac{A_b}{A_i^{2/3}}T_e$$

m_i - average plasma ion mass
m_b - beam ion mass

☐ [J. Wesson, Tokamaks, 2011]

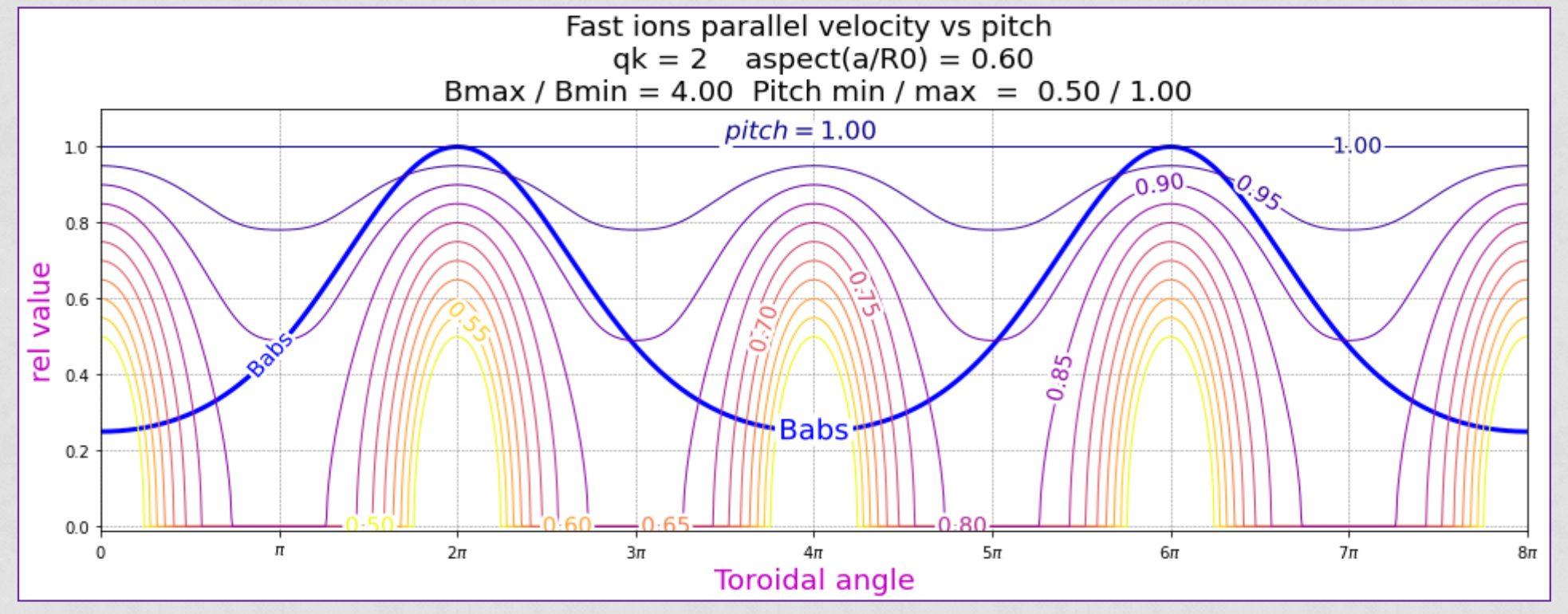
FAST IONS RELEASE CONTROL

Thick beam 0.4 x 0.8m

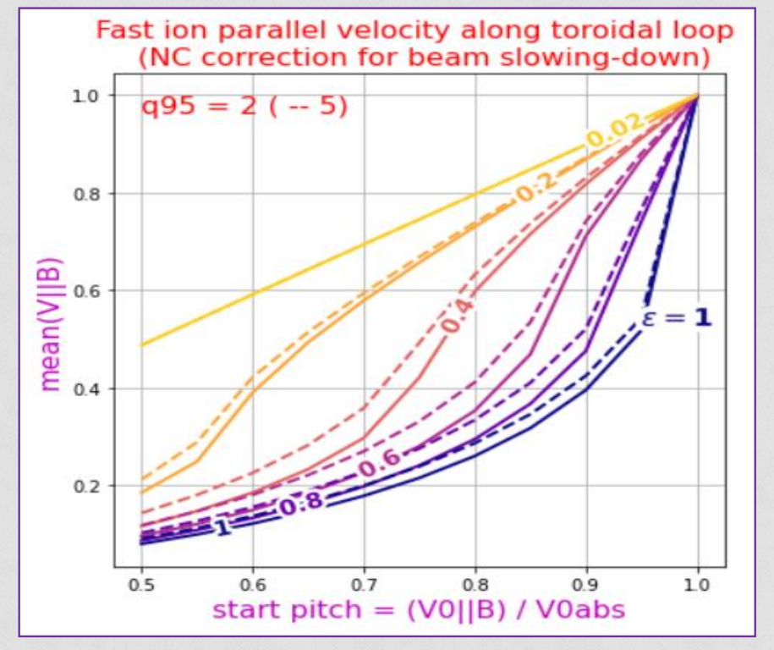


- Optimum beam deposition and CD profile control can be managed by adjusting NB energy and axis aiming (target position);
- T/D beams need less beam current compared to H (Pinj = const) for same CDeff;
- Spatial profiles of Current and Neutron flux distribution are highly sensitive to injection geometry, plasma kinetic profiles, plasma shaping and magnetic topology;
- CDeff varies from 76 kA/1A to 82 kA/1A when R_{inj} is varied from 2.7m to 3.7m (E_b = 500 keV)
- E_b variation (at Rinj = R_0 = 3.2m) gives CDeff = 37 kA/1A – 190 kA/1A (~5 times!)

TOROIDAL CORRECTIONS



Ion parallel velocity fluctuations (q_{95} = 2)

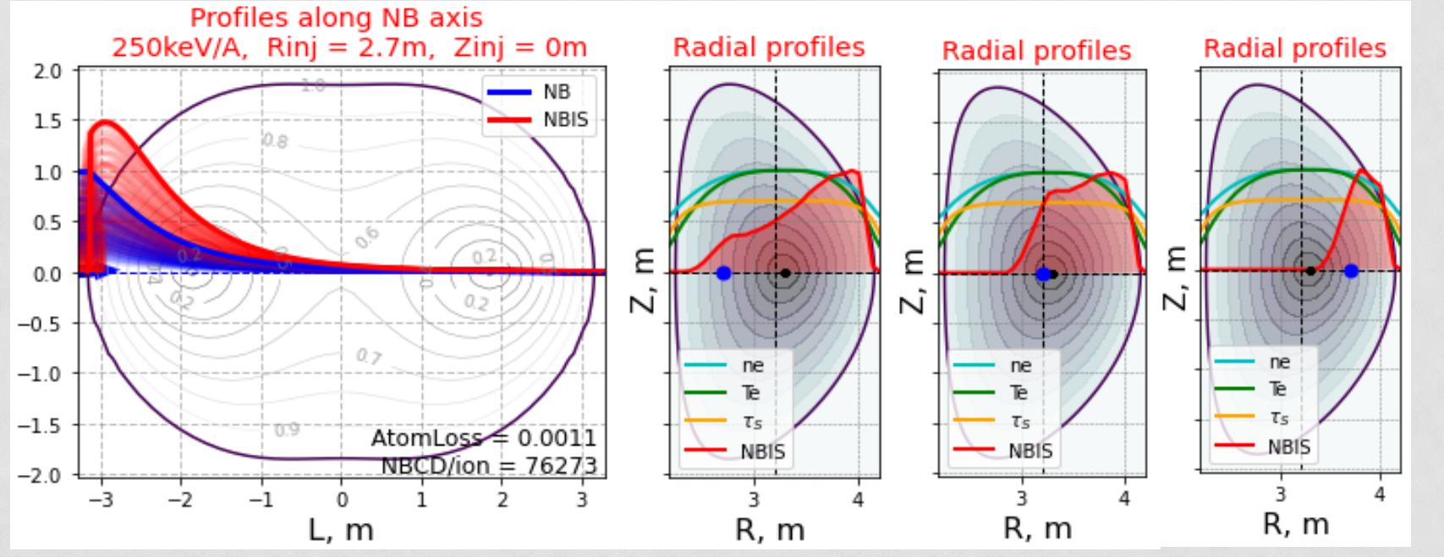


Mean parallel velocity

Beam deposition profile control

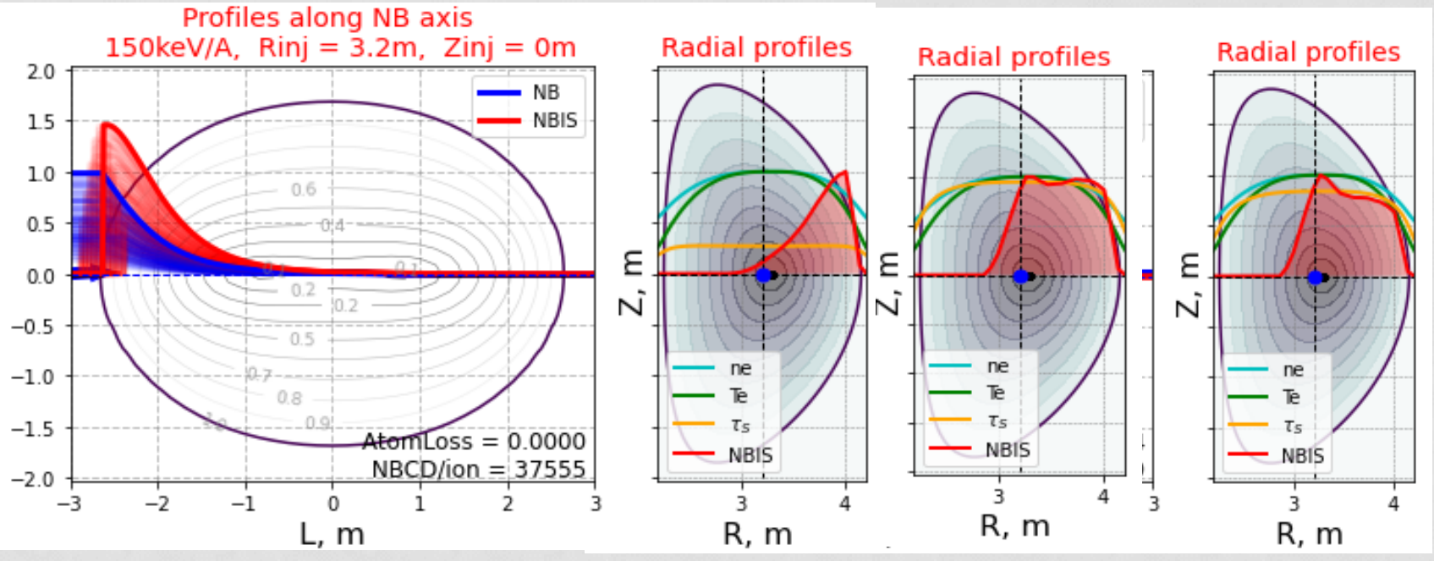
Beam target Radius R_{inj}

R_{inj} = R_0 - 0.5m R_0 R_0 + 0.5m



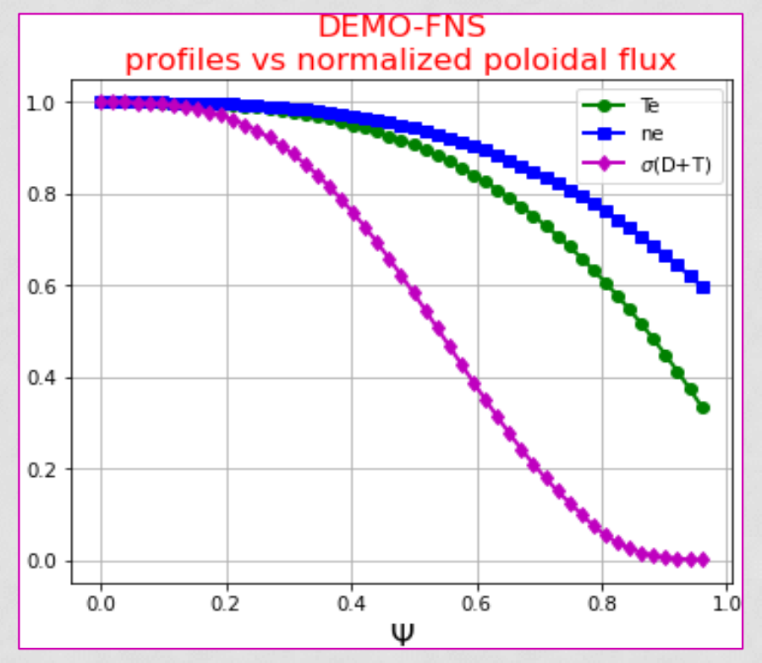
Beam energy E_b

E_b = 300keV   750keV   1000keV

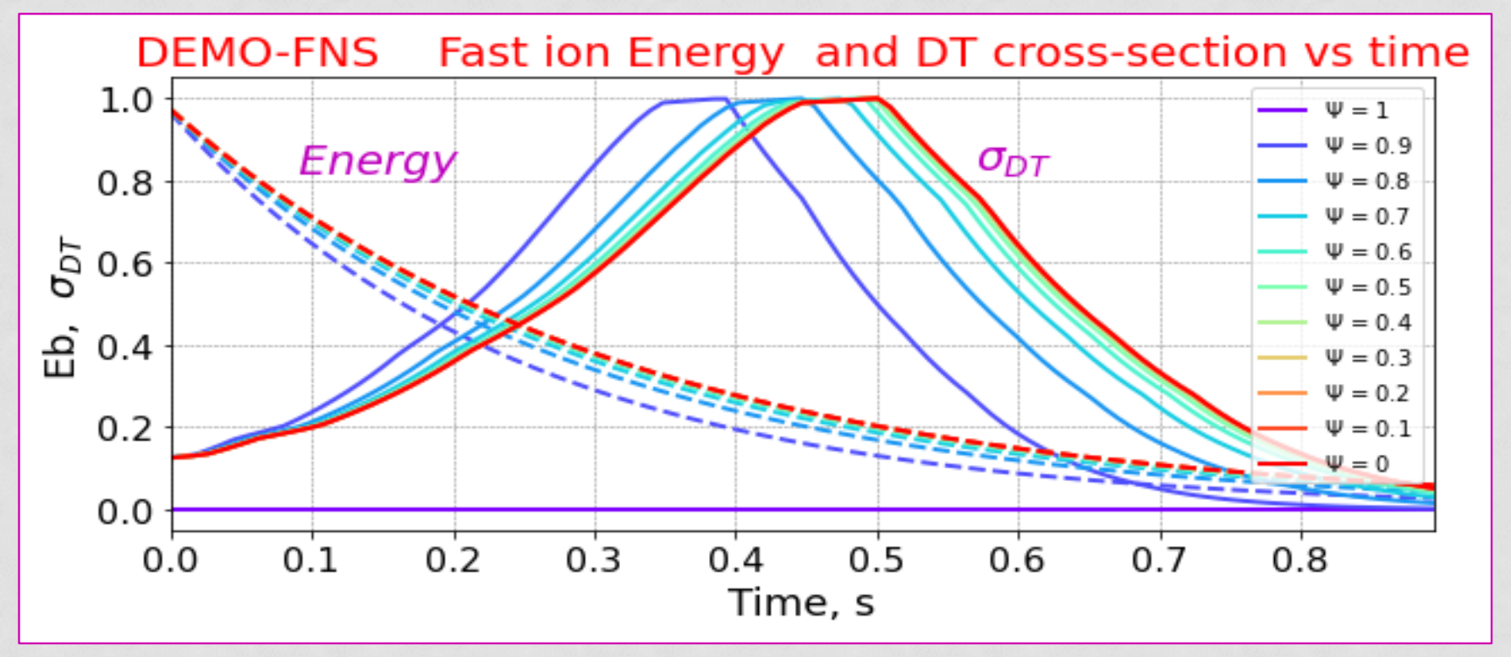


Toroidal (neo-classical) effects are incorporated through spatial variation of B-field along a magnetic line. They vanish with decrease of inverse aspect ratio ε = r/R. They get maximum at the plasma periphery and negligible near magnetic axis. The toroidal reduction of the ion current has a strong impact on the current profile and the overall CDeff due to ion parallel velocity bouncing along deceleration path.

NB FUSION & NEUTRON YIELD



Plasma radial (ψ) profiles: T_e, n_e, σ_{DT}



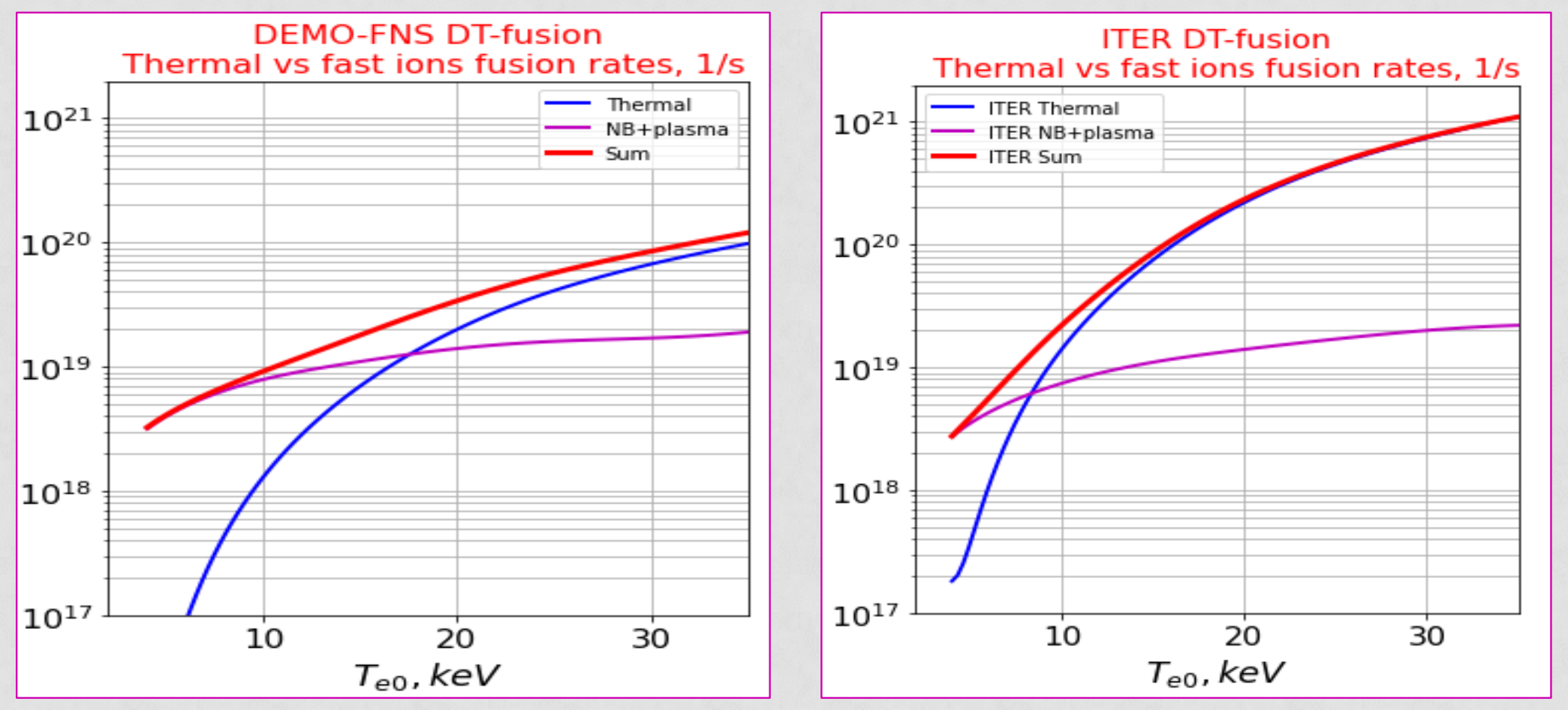
Beam ions energy decrease and beam-plasma fusion cross-section change in time during ion deceleration across radial layers

DEMO-FNS VS ITER

n_{e0} = 1×10^{20} $м^{-3}$
Eb = 500 keV (D)

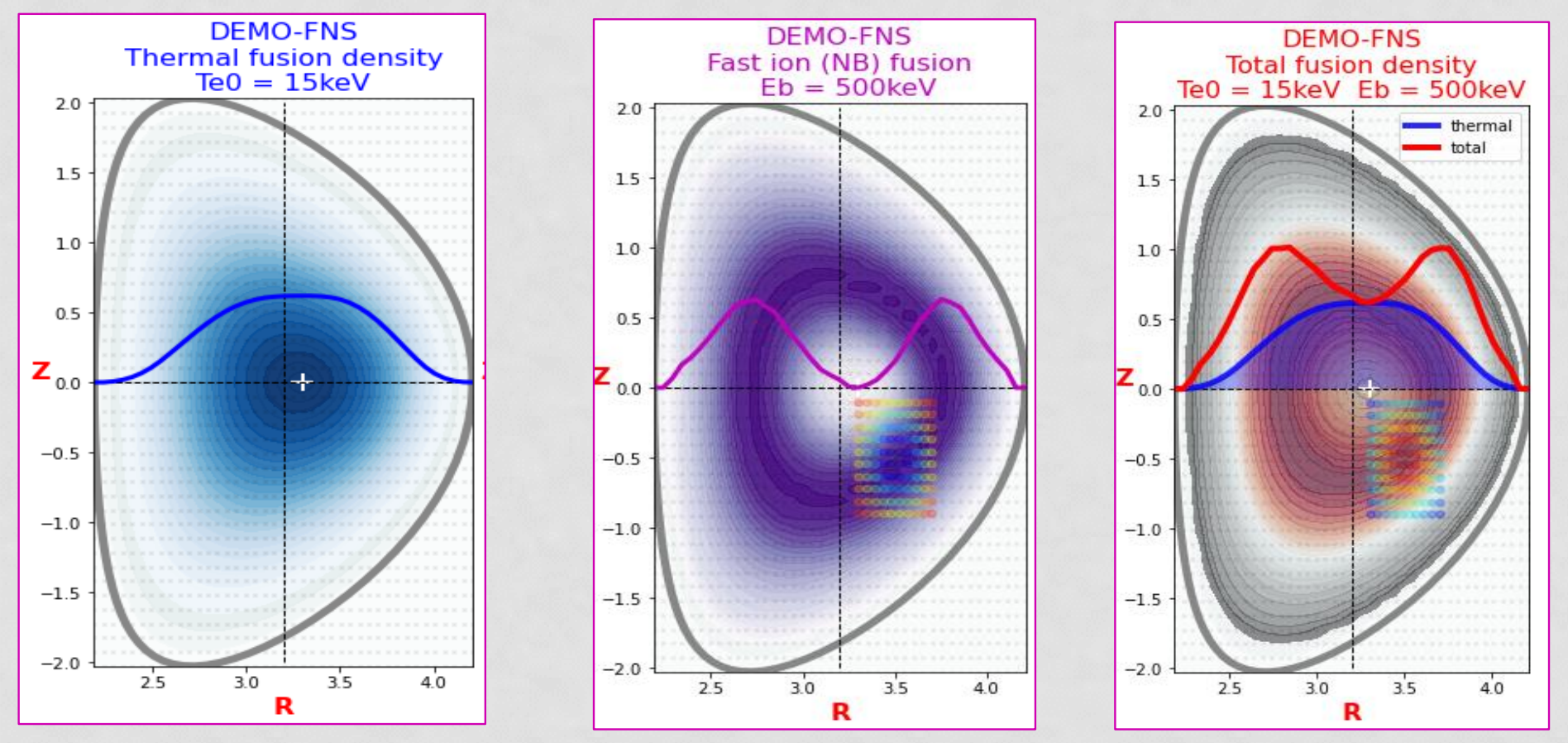
D/T = 0.5/0.5

n_{e0} = 1.2×10^{20} $м^{-3}$
Eb = 1 MeV (D)



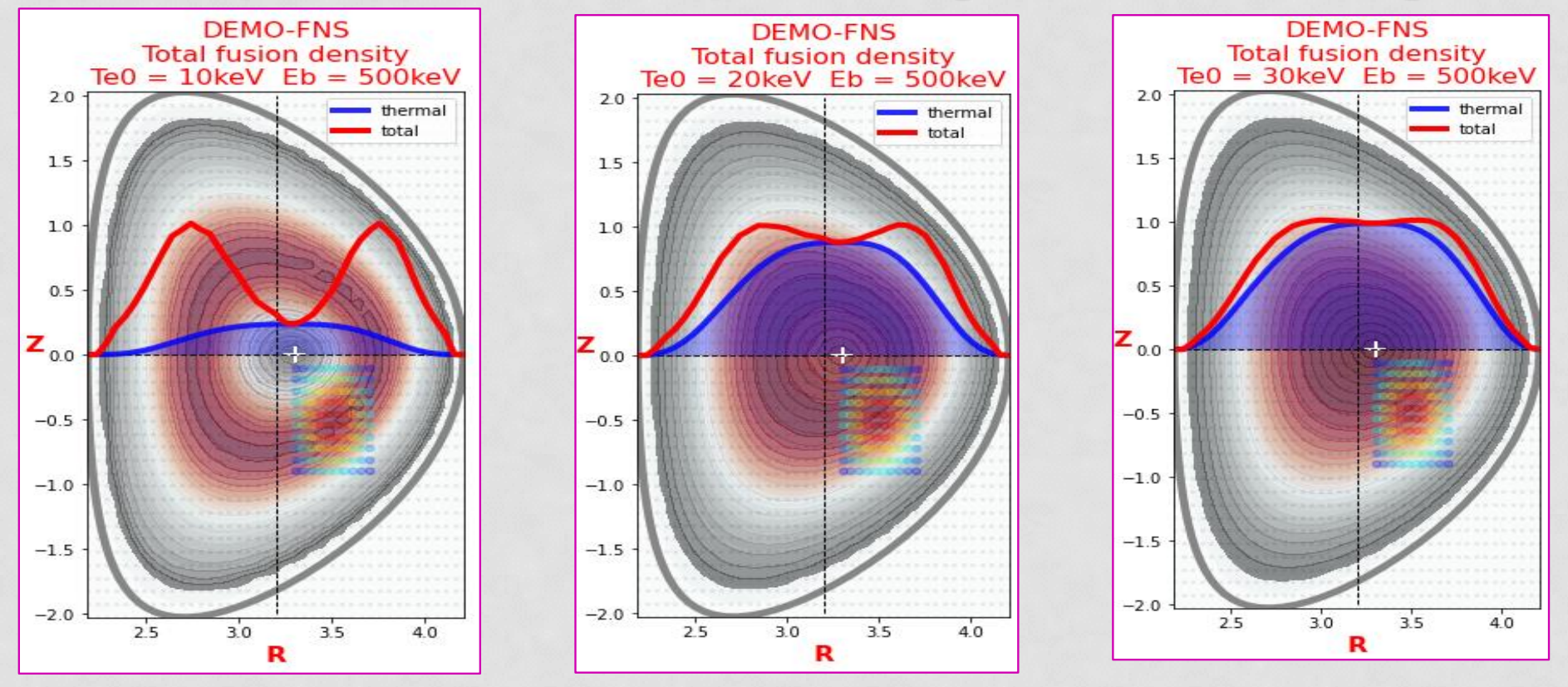
Fusion rate dependence on T_e: thermal, beam-plasma, total

NB contribution to fusion (DEMO-FNS)

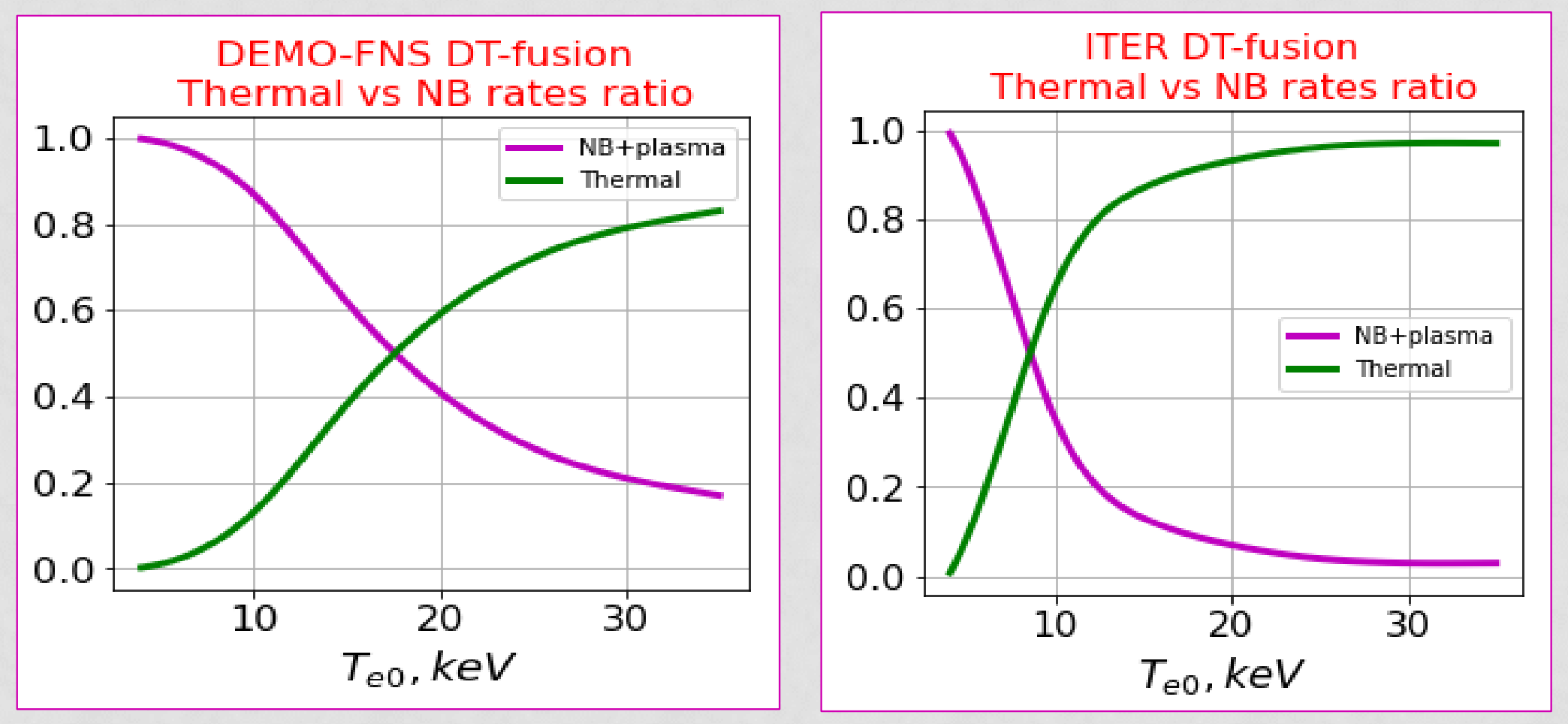


Beam-plasma fusion rates and NB share in neutron yield for given plasma depend on NB energy ratio to plasma temperature (Eb / Te) and on thermal energy confinement time. NB fusion rates in DEMO-FNS and ITER are almost identical (for fixed Te), while NB share in ITER neutrons is low - due to 7 times higher plasma volume.

Temperature impact (DEMO-FNS)



T_{e0} = 10 keV T_{e0} = 20 keV T_{e0} = 30 keV



Beam contribution to fusion output (neutron yield) across T_e: thermal, beam-plasma

[1] BTR web-page https://sites.google.com/view/btr-code/home
[2] BTR Source https://github.com/EDlougach/BTR