Fast ions in VNS

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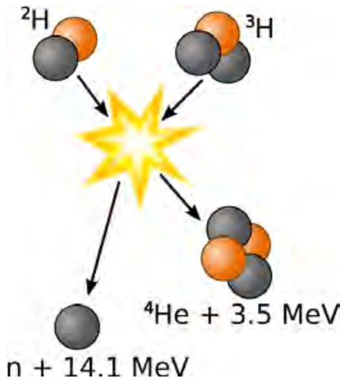
27/05/2024 VTT – beyond the obvious

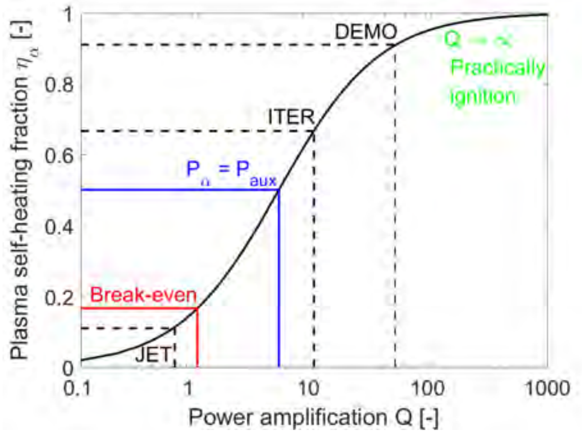
Outline

- Introduction to fast ions and VNS
- ASCOT tools
- NBI and alpha confinement (and shine-through)

Role of fast ions in a fusion reaction

- Power amplification factor $Q = \frac{P_\alpha}{P_{AUX}}$
- For DT reaction, $P_\alpha = \frac{P_{fus}}{5} = \frac{QP_{AUX}}{5}$
- Therefore, fraction of alpha heating is
  $\eta_\alpha = \frac{P_\alpha}{(P_\alpha + P_{AUX})} = \frac{Q}{Q+5}$
- For burning plasmas, i.e. η_α>0.5, Q>5 is needed
- For high P_α / Q, alpha particles must be well confined!

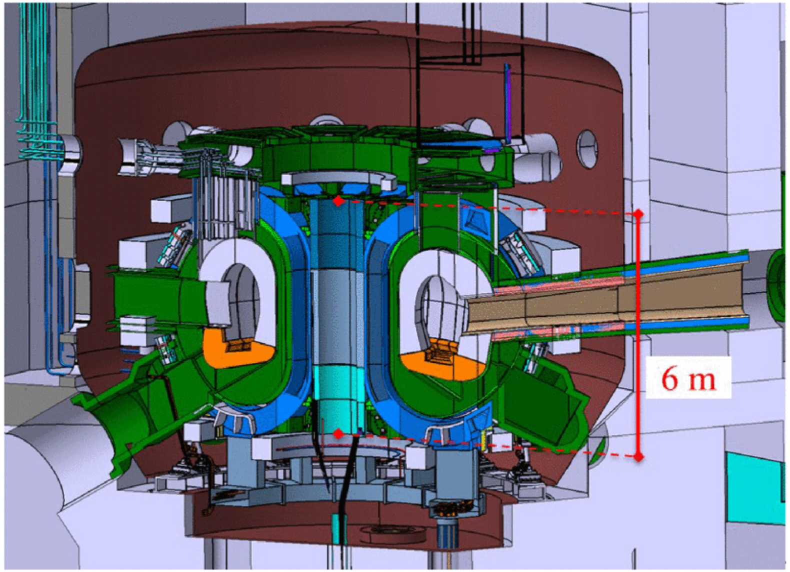




M. Salewski et al 2018 Nucl. Fusion 58 096019

What and why of VNS

- VNS=volumetric neutron source
- ~AUG/JET size machine
- To qualify/increase TRL of specific reactor components (e.g. breeding blanket)
- To produce neutrons (NWL key parameter)
- How: beam thermal (fast D, thermal T)
- Fast ion design considerations:
  - Are fast D beam ions confined?
  - Are alphas causing hot spots?
- Interestingly: **no need to confine alphas!!!**



L. Giannini et al. *IEEE Transactions on Applied Superconductivity* **34**, 2024

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R_0 [m]	2.55
B_0	6
A	5.3
I_{plasma} [MA]	1.45
k_{95}/q_{95}	1.35, 3.1
<Te> [keV]	14.82
t_{burn}	Steady State
β_N [T m/MA]	4.03 %
P_{NBI} [MW]	40
P_{fus} [MW]	30.4
P_{div} [MW]	48.7
NWL [MW/m^2]	0.58

Definitions: R_0 = plasma radius, B_0 = magnetic field at plasma radius, A = ratio between plasma major and minor radii (aspect ratio), I_{plasma} = plasma current, k_{95}/q_{95} = plasma elongation over safety factor, T_e = plasma electron temperature, t_{burn} = time of plasma burn, β_N = plasma stability limit, P_{NBI} = power of the Neutral Beam Injectors, P_{fus} = fusion power, P_{div} = power deposited on the divertor, NWL = Neutron Wall Load

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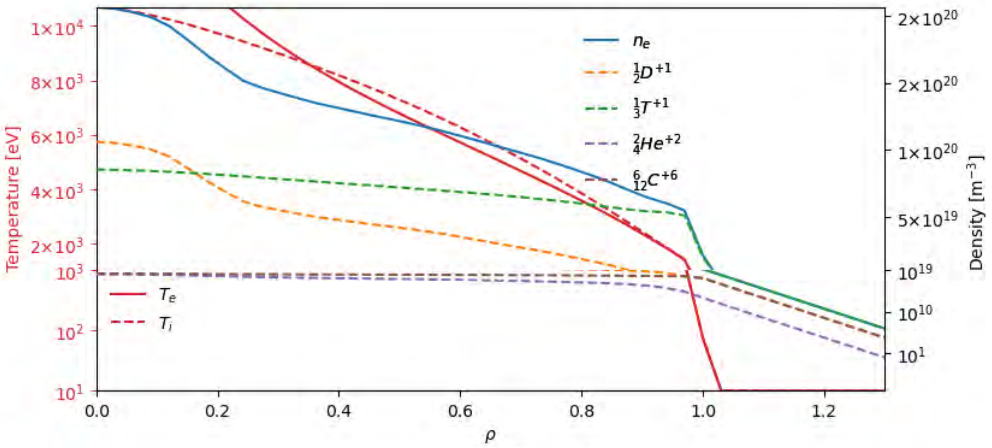
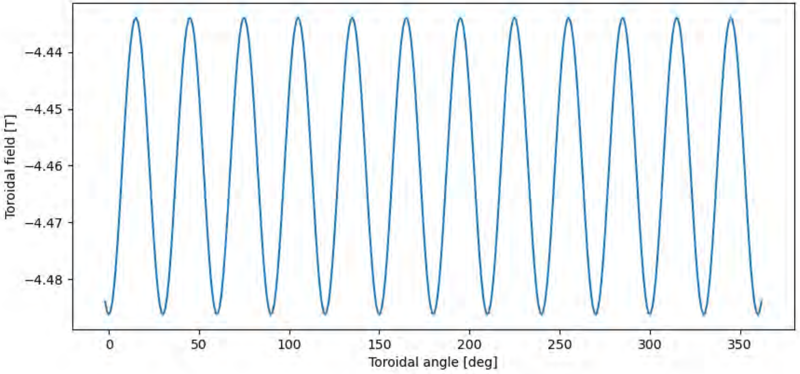
DT thermal plasma and high TF ripple

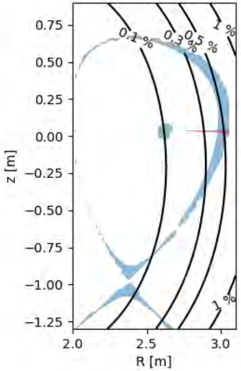
- ASTRA calculated kinetic profiles
- D and T bulk plasma



DT thermal plasma and high TF ripple

- ASTRA calculated kinetic profiles
- D and T bulk plasma
- TF ripple
  - Small machine, but only 12 TF coils
  - TF ripple 0.7%...1.3% vs. ITER ~1%
- With analytical formulas:
  - Blue area: stochastic banana diffusion
  - Red area: ripple well





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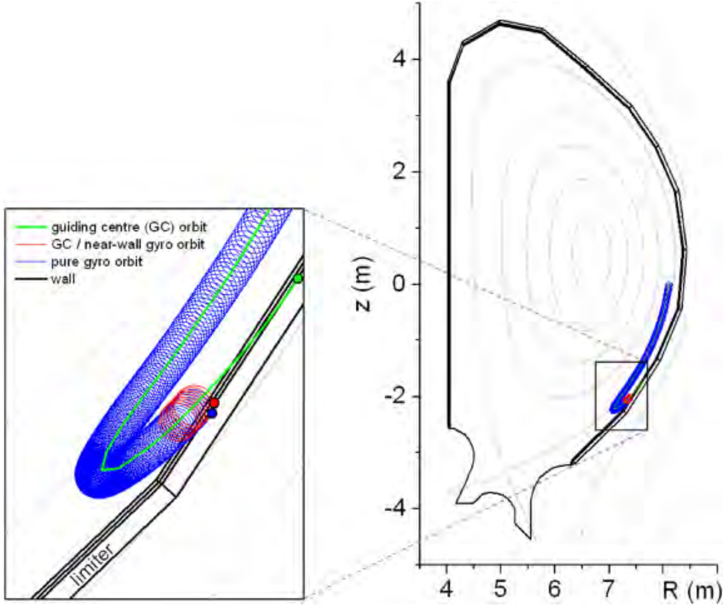
ASCOT chain-of-tools

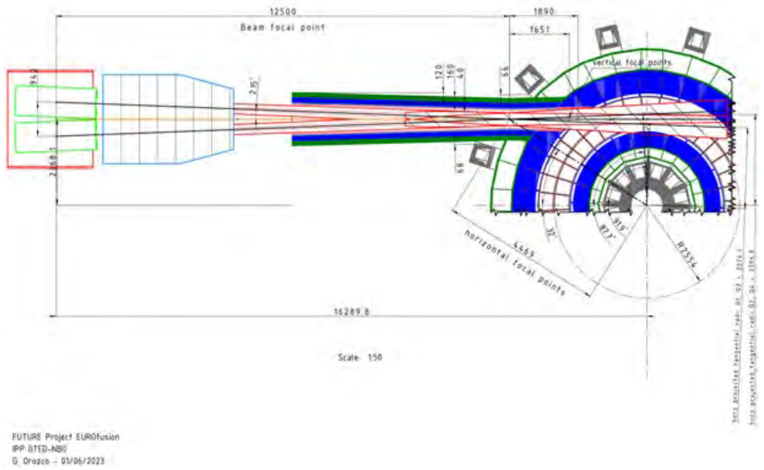
- ASCOT E. Hirvijoki et al., Computer Physics Communications, **185**, 2014
  - Orbit-following Monte Carlo code for minority species
  - Solving Fokker-Planck (=distribution function)

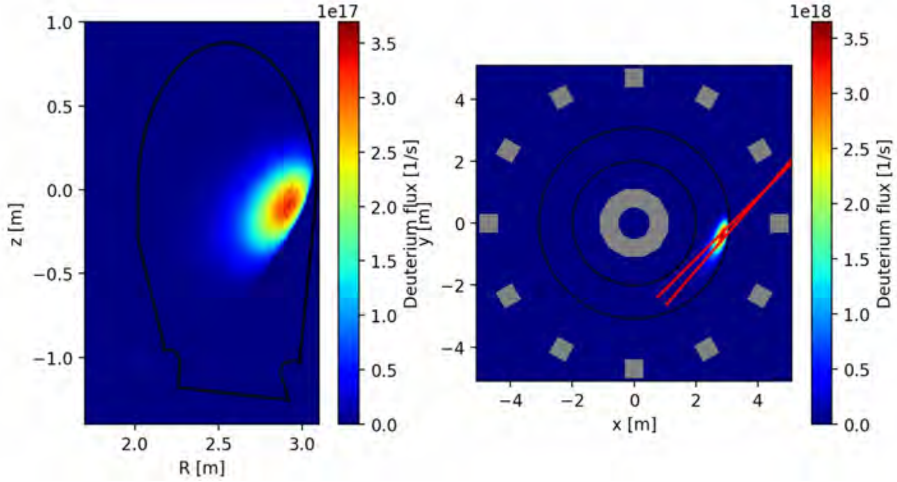


ASCOT chain-of-tools

- ASCOT
- BBNBI
  - Beamlet-based neutral beam ion solver
  - Produces ensemble of NBI ions (to ASCOT)

O. Asunta et al.,Computer Physics Communications,**188** 2015,

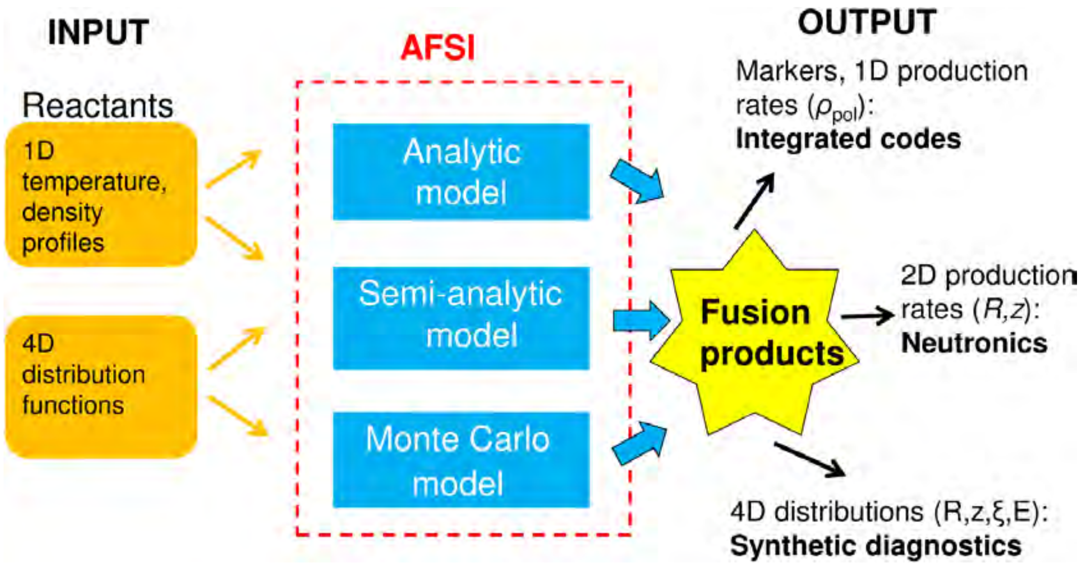




ASCOT chain-of-tools

- ASCOT, BBNBI
- AFSI
  - Fusion source integrator
  - Multiple reactions, 4D distributions for reactants

P. Sirén et al 2018 Nucl. Fusion **58** 016023



ASCOT chain-of-tools

- ASCOT
- BBNBI
- AFSI
- Integrated within the same open-source package: https://github.com/ascot4fusion/ascot5
- Here workflow is:
  1. BBNBI for NBI D ion ensemble
  2. ASCOT for NBI D slowing down distribution
  3. AFSI for D_NBI+T_th alphas
  4. ASCOT for alpha slowing down distribution

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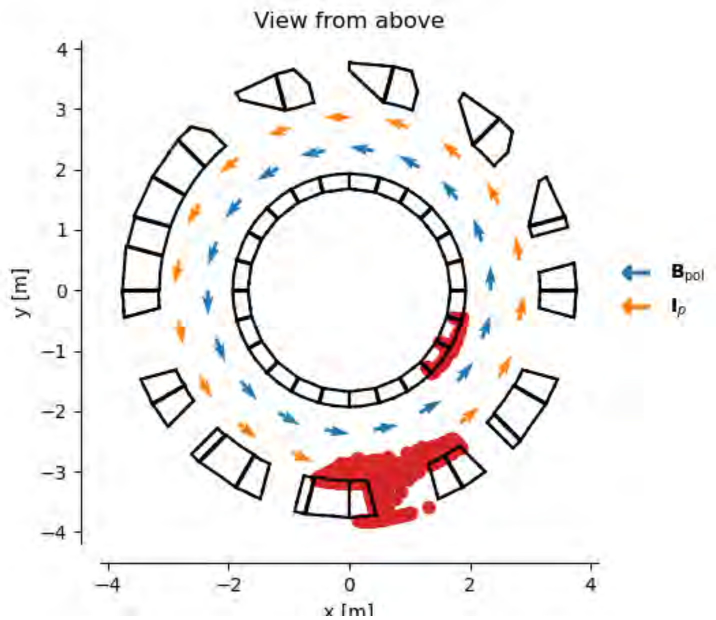
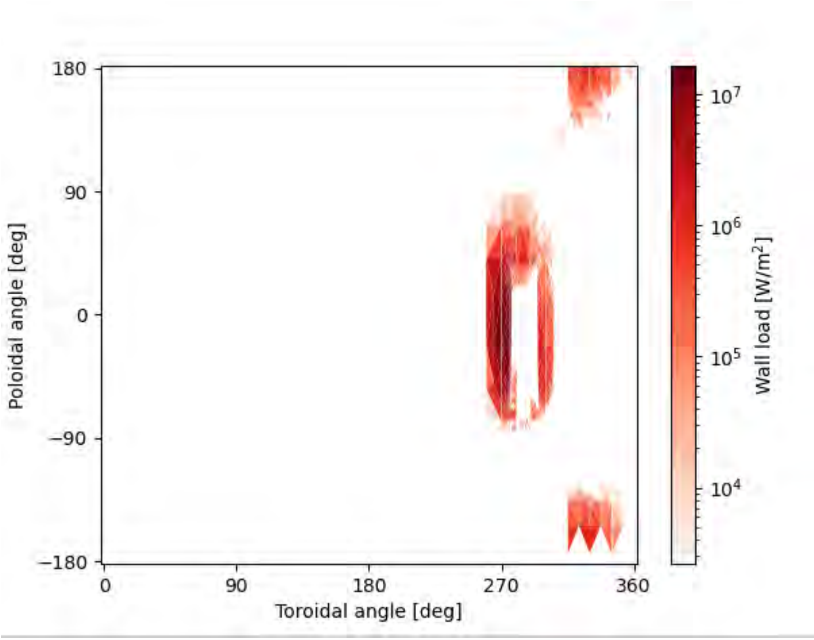
NBI shine-through (NBI with no plasma)

- Transient event -> loss of plasma
  - NBI stays on for a short time
  - Shine-through severe risk
  - Example: W7-X, 50 MW/m^2!!!
- Estimate the local power load for VNS
- BBNBI follows ballistic neutrals
- Adapt CAD 3D wall to map power load

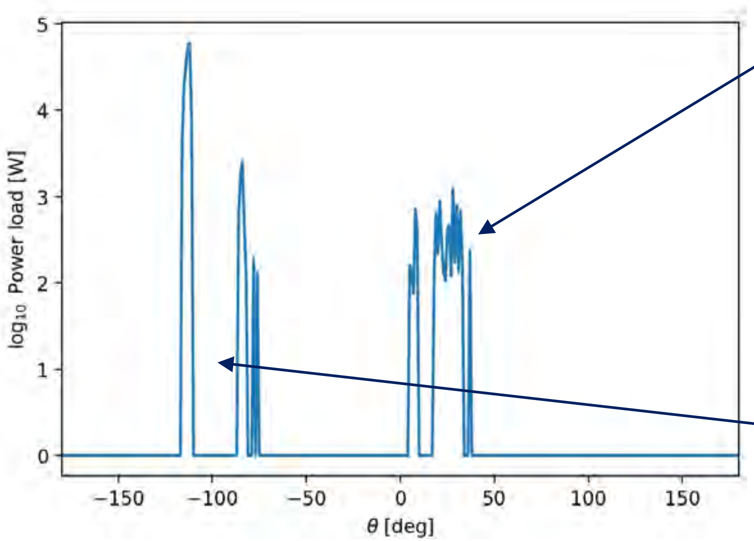


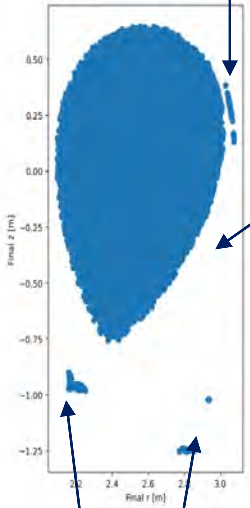
NBI shine-through loads on 3D wall



ASCOT results for NBI confinement

- Lost power: 0.2% (~20kW)-1.5% (~200kW)
  - No hot spots found
  - Wetted pattern as expected
  - Statistics poor (read: values too high)





Plasma wall gap small

Wall far here

Divertor plates

Alphas particle losses

- Beam thermal the dominant channel
  - Three beams produce ~5.2MW of alphas
- ~7-10% alphas lost
  - Loss patterns slightly different vs. beams
  - Level of power loads small vs. material thresholds

Conclusions

- EUROfusion is designing a volumetric neutron source
  - Principal goal: leverage breeding blanket TRL
  - Tokamak of ~AUG/JET size proposed with BT neutrons
- ASCOT used to assess fast ion confinement in VNS
  - Beam ions are well-confined (~1% losses)
  - BT alphas less confined, due to high TF ripple (~10%)
  - Due to specific goal of the machine, alpha losses can be tolerated

beyond
the obvious

A. Snicker