Fast Particle Behavior in Globus-M

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INTRODUCTION

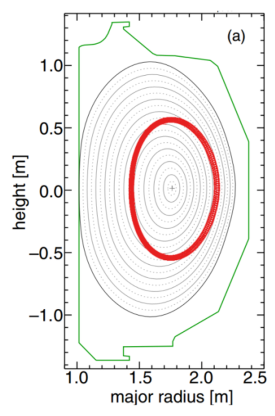
Fast ions in ST

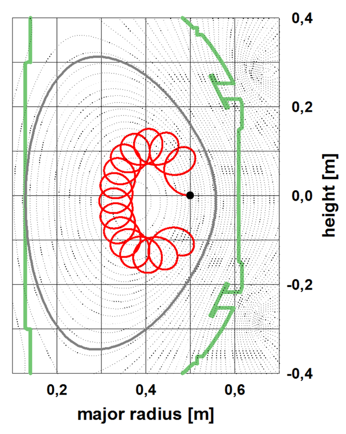
Conventional tokamaks:	Spherical tokamaks:
- High B_T - Low β + Good fast ion confinement	+ Low B_T + High β - Poor fast ion confinement

80 keV D+

$B_{tor} >> B_{pol}$

Fast gyrating is negligible



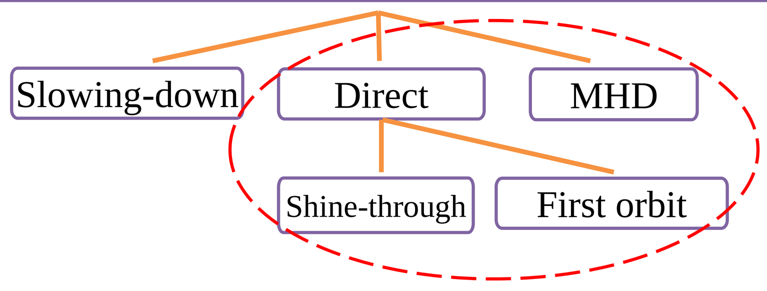


18 keV H+

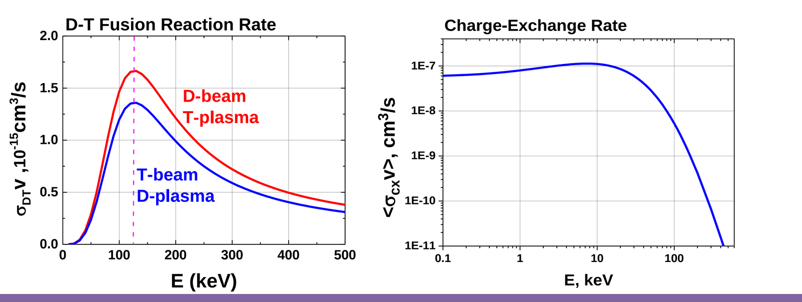
$B_{tor} \sim B_{pol}$

Fast gyrating is significant

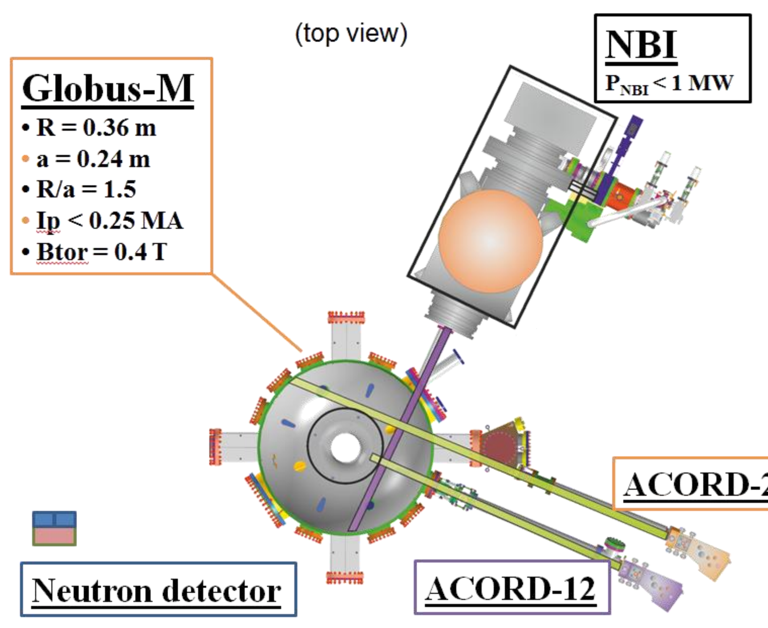
Fast ion losses



For the CFNS slowing-down losses are less important because of the two main reasons. First, the fusion reaction rate is strongly dependent on fuel nuclei energy distribution, so the fastest ions will make the major contribution to the neutron yield. Second, CX rate drops significantly for the energies higher than several tens of keV.

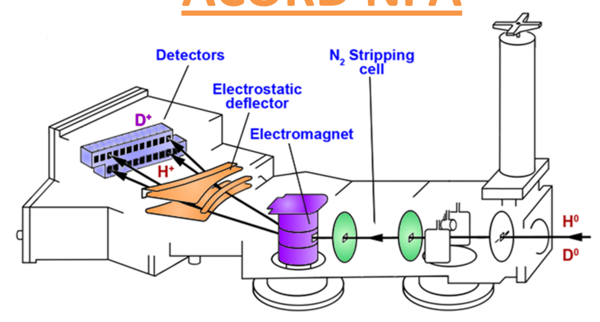


Experimental setup and main technics



Main modeling techniques: NUBEAM, 3D fast ion tracking algorithm + Solution of Boltzmann kinetic equation + NPA LOS sim. Secondary techniques: EFIT, Double.

ACORD NPA

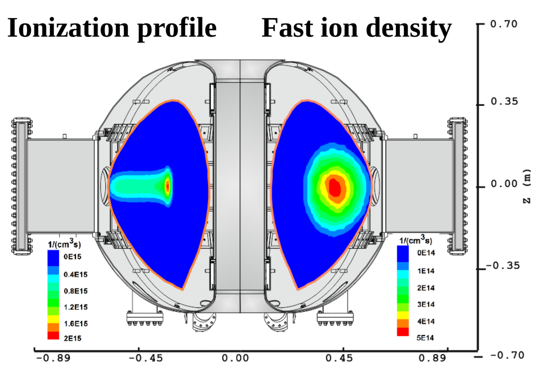


MAIN RESULTS

"Good" confinement

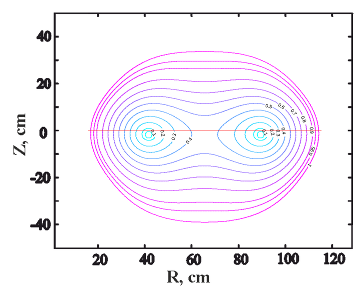
E_{NBI} = 18 keV, H

1



Orbital modeling: source function + direct losses

2



Solution of the Boltzmann equation + Simulation of the NPA LOS

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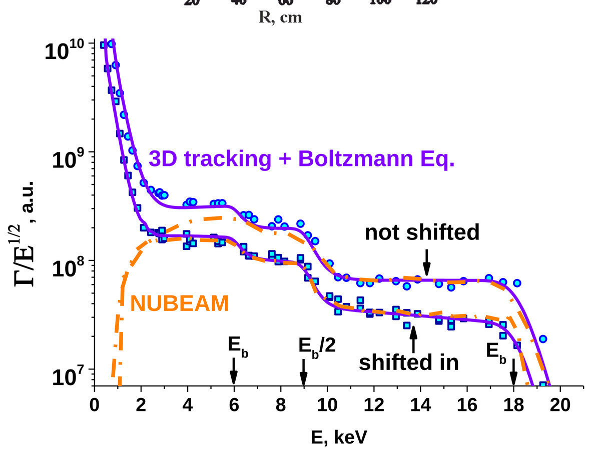
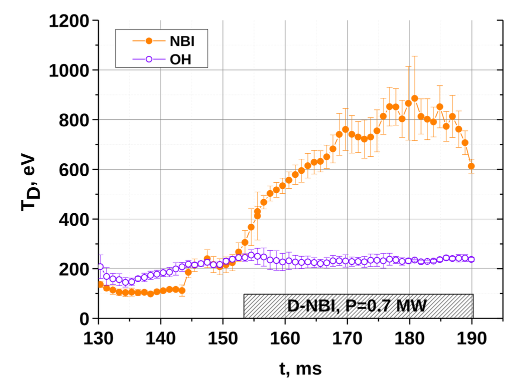


Comparison with the experiment

3D tracking + Boltzmann Eq.			NUBEAM		
Type of losses	Power losses, %	Power losses, %	Type of losses	Power losses, %	Power losses, %
	Not shifted	Shifted in		Not shifted	Shifted in
			internal CX	21	15
slow down	25	17	external CX	5	5
shine-through	7	8	shine-through	7	7
bad orbit	14	13	bad orbit	7	3
TOTAL	46	38	TOTAL	40	30

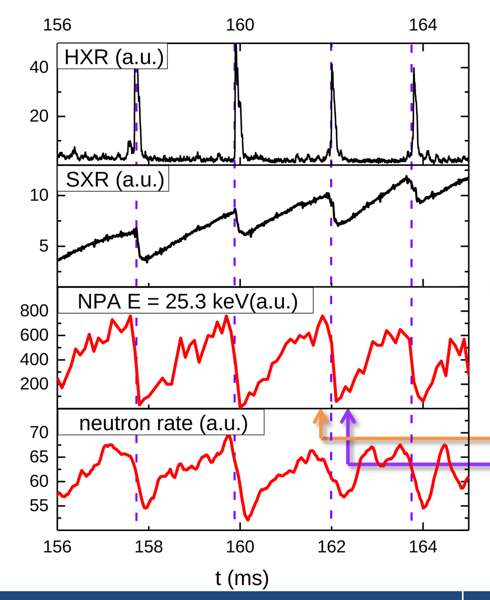
"Bad" confinement

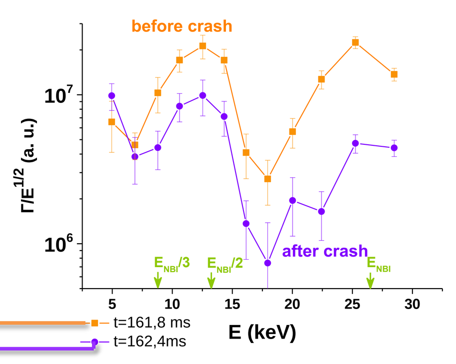
E_{NBI} = 26 keV, D



Record ion temperature of about 800 eV has been achieved using 26 keV D NBI

However, fast ion losses are much higher + additional channel of losses – sawtooth oscillations.

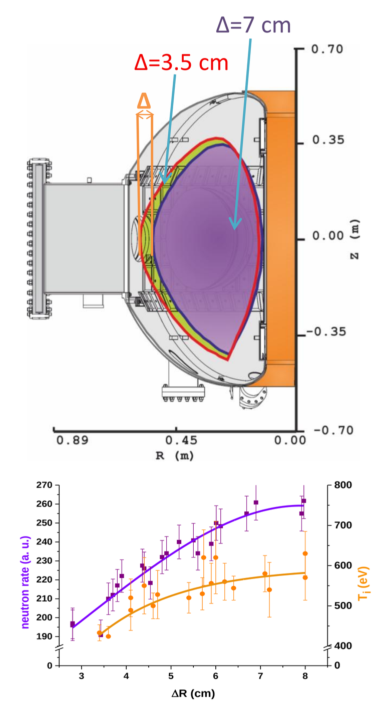




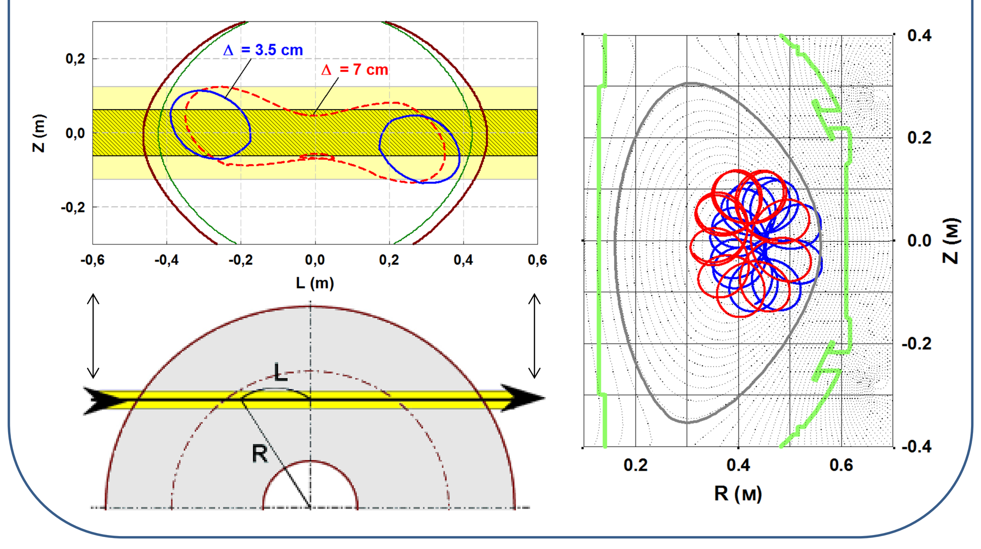
3D tracking + Boltzmann Eq.			NUBEAM		
Type of losses	Power losses, %	Power losses, %	Type of losses	Power losses, %	Power losses, %
	Not shifted	Shifted in		Not shifted	Shifted in
			internal CX	18	8
slow down + sawtooth	25	20	external CX	12	32
shine-through	8	8	shine-through	5	6
bad orbit	50	30	bad orbit	52	29
TOTAL	83	58	TOTAL	87	73

Plasma shift experiments

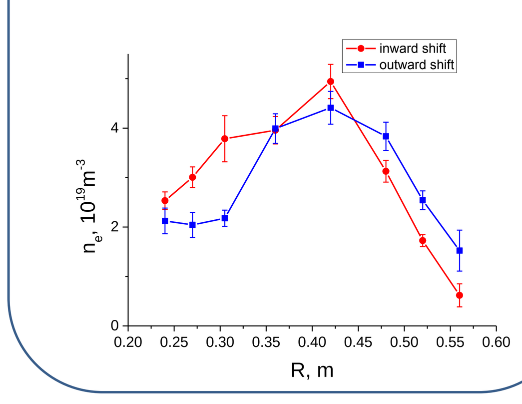
A way to improve the fast ion confinement and increase the neutron rate and ion temperature was found. It is the inward shift of the plasma column. There are three main reasons for this improvement.



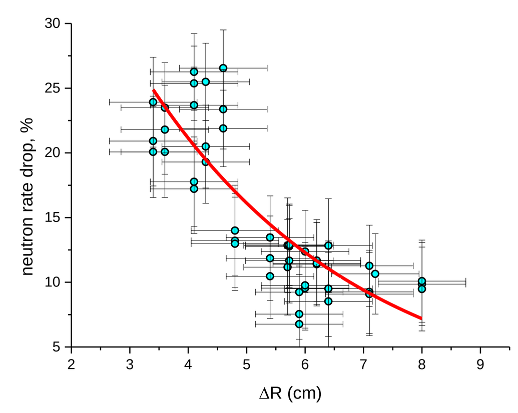
1 Because of the more tight magnetic configuration, the fast ions orbits shift inwards, leading to lower direct and CX losses.



2 The density profiles change their shape, contracting inwards, amplifying first effect.



3 Sawtooth-induced losses decrease, which is very important for ions with high energies (~ 25 keV).



Summary: total power losses of the main neutral beam energy component vary from 40% (for 18 keV H beam and shifted inside plasma column) up to 90% (for 26 keV D beam and shifted outside plasma column).

Alfven Eigenmodes

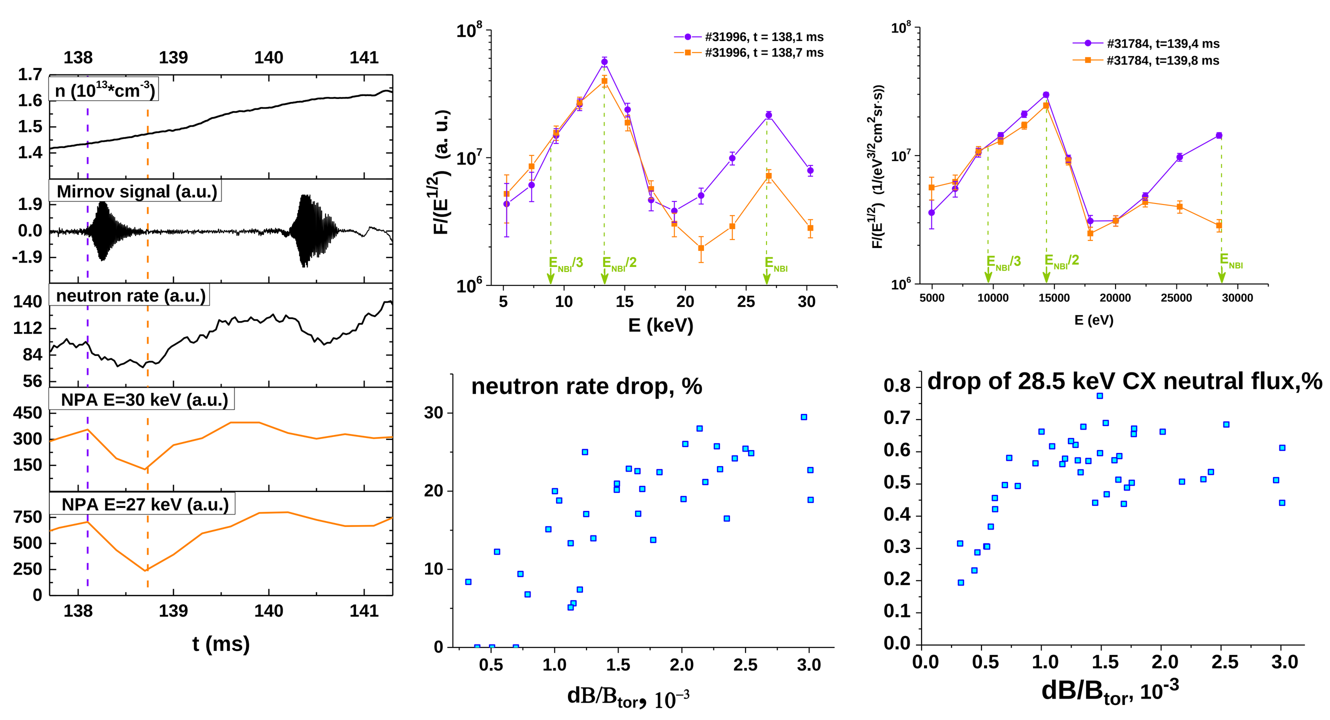
n = 1, m = 3 TAEs were observed in the experiments with D injection experiments. Additional n = 2 modes were observed in the H NBI experiments.

Different influence of the TAE on fast ion confinement:
- at D-injection: high losses during strong chirping bursts of 0.5 ms duration
- at H-injection negligible losses during long-lasting mode of several ms duration with weaker amplitude

Correlation of TAE with neutron rate and NPA fluxes, D→D case

NPA spectra at TAE development, D→D case

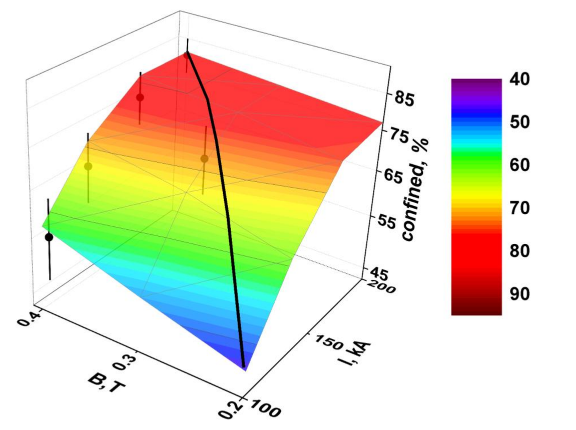
NPA spectra at TAE development, D→H case



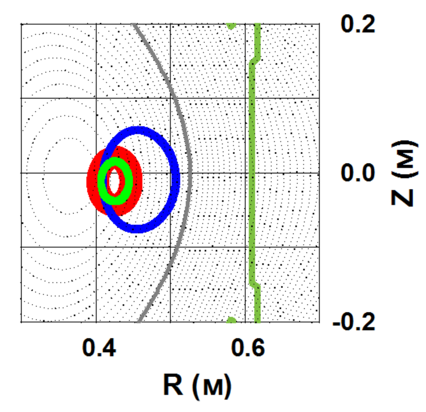
FO losses dependence on I_p and B

Direct losses dependence on I_p and B

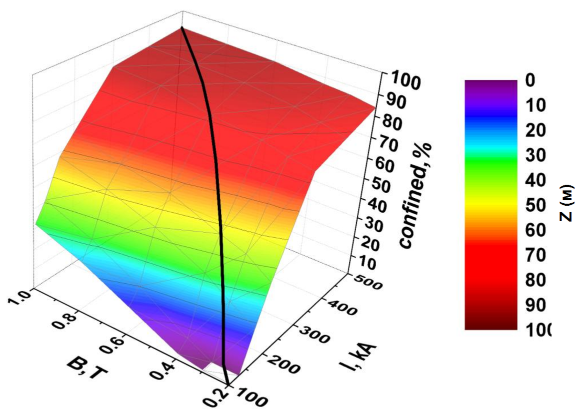
18 keV H NBI, D plasma



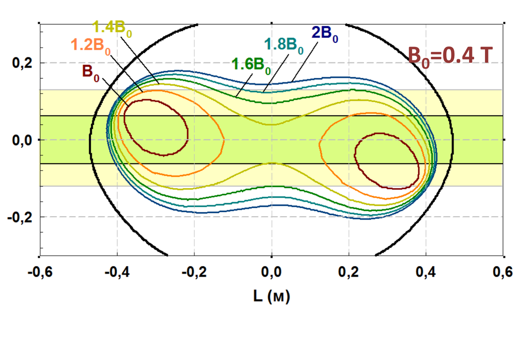
18 keV H 200 and 105 kA 0.4 T, and 200 kA 0.2T



26 keV D NBI, D plasma



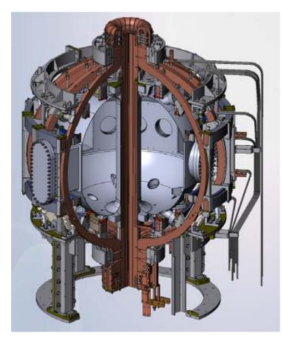
Increase in I_p → orbits shift inwards; increase in B → the Larmor radius become smaller

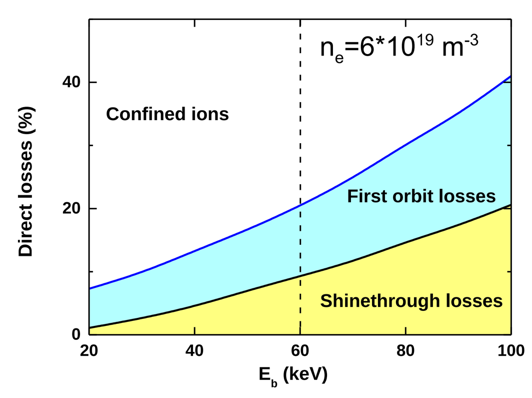


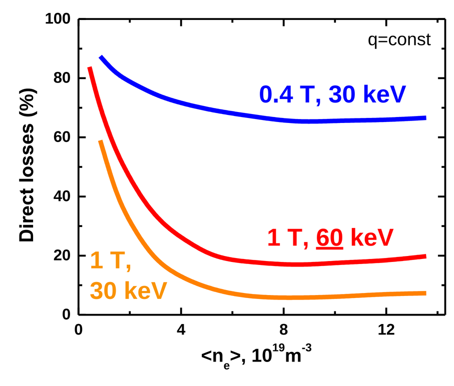
Predictions for Globus-M2

- **I_p and B_{tor} increase in Globus-M2 will lead to much better fast ion confinement.**
- **Significant reduce of sawtooth-induced losses and losses due to TAEs is expected too.**
- **Modeling shows, that utilization of the fast ions with energies up to 60 keV is quite reliable in Globus-M2.**
- **NUBEAM simulations show that total losses will be tolerable.**

I_p = 0.5 MA B_{tor} = 1 T







NUBEAM modeling simulations show that for 60 keV beam total losses won't exceed 50% and neutron rate will be increased more than two orders of magnitude (≈5*10¹³ n/s).

SUMMARY

Despite enormous ion losses, significant results on the ion heating were achieved in Globus-M.

- **The main problem for the NBI – direct losses. However, for low energies CX-losses are significant too.**
- **Sawtooth oscillations and TAE enhance fast ion losses.**
- **Direct, slowing-down and sawtooth-induced losses decrease with an increase of plasma-wall gap on the low-field side.**
- **I_p and B_{tor} increase in Globus-M2 will lead to much better fast ion confinement.**

Acknowledgements

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