Ioffe Institute

The main results of the 0.5 T Globus-M experiments

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Outline

- Introduction
- Energy confinement
- Fast ion confinement
- Alfvén eigenmodes
- Discharge disruption
- Radiation losses
- SOL Physics
- Summary

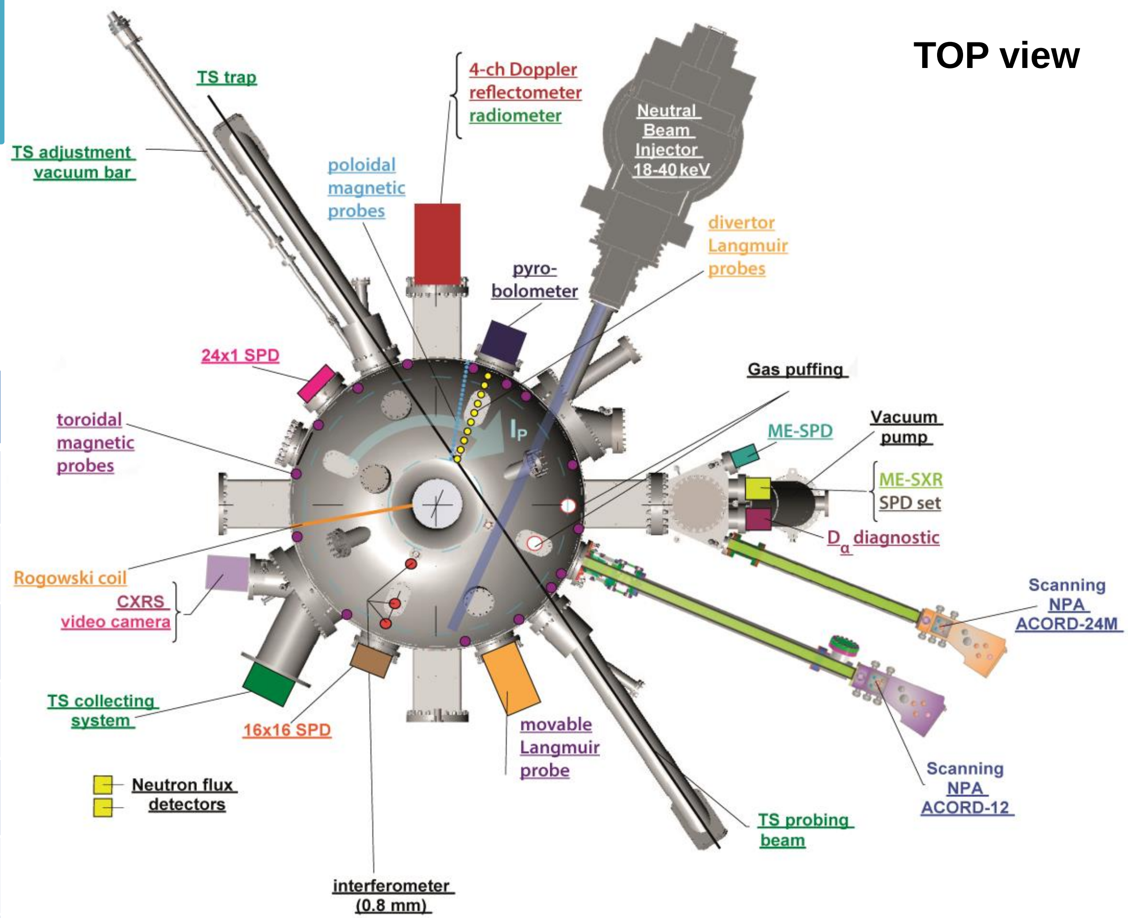
Introduction

New Globus-M2 power supplies were used in the last Globus-M experimental campaign:

B_t: 0.4 T → 0.5 T
I_p: 200 kA → 250 kA

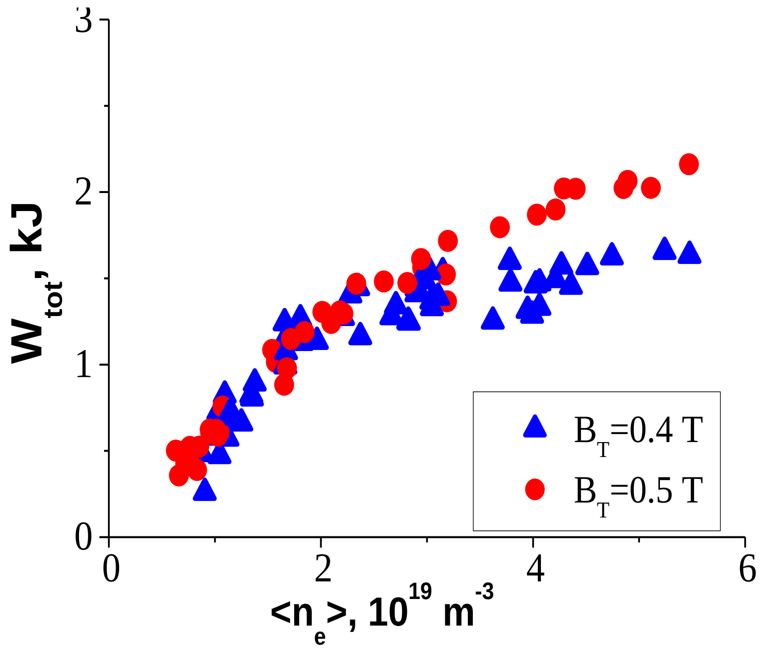
New diagnostics: **4-ch Doppler Reflectometer, 2X24-channel and 16x16 SPD arrays, movable probe**

parameter	value
R [cm]/a [cm]	36/24 = 1.5
k	≤ 2.0
δ	≤ 0.5
B_t, T	0.5
I_p , kA	≤ 250
t_{pulse} , ms	≤ 130
NBI E [keV] / P [MW]	≤ 27 / 0.7



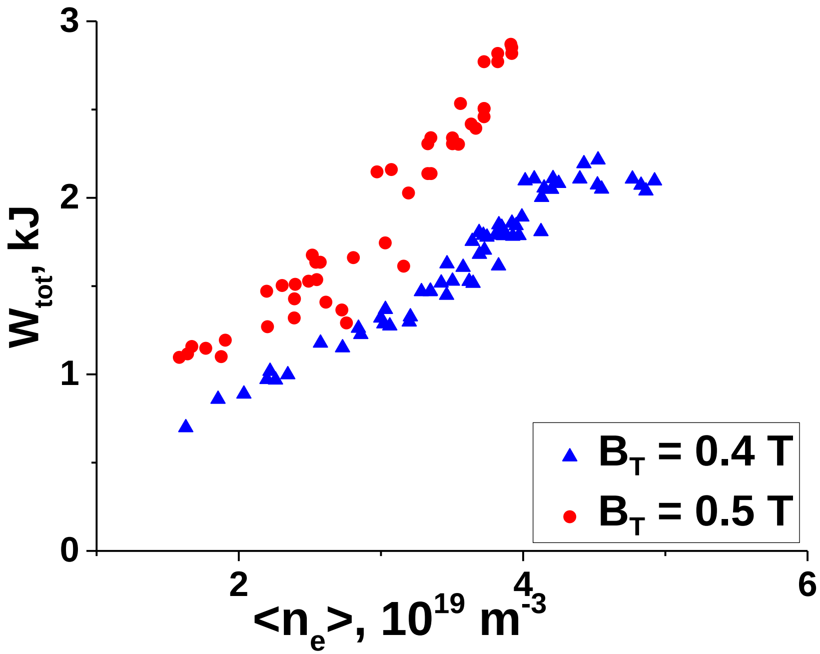
Energy confinement

OH, D plasma,
I_p = 200 kA



Difference if $\langle n_e \rangle > 3\cdot10^{19} m^{-3}$ due to τ_E growth

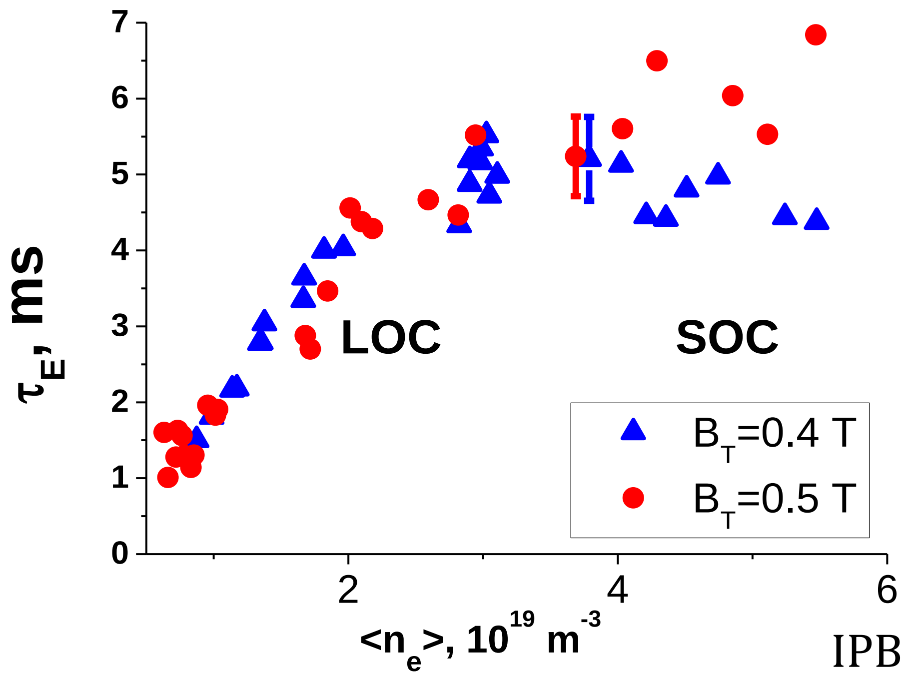
26 keV D NBI 0.7 MW, D plasma, H-mode, I_p = 200 kA



1.5 times W_{tot} increase due to τ_E growth an FI confinement improvement

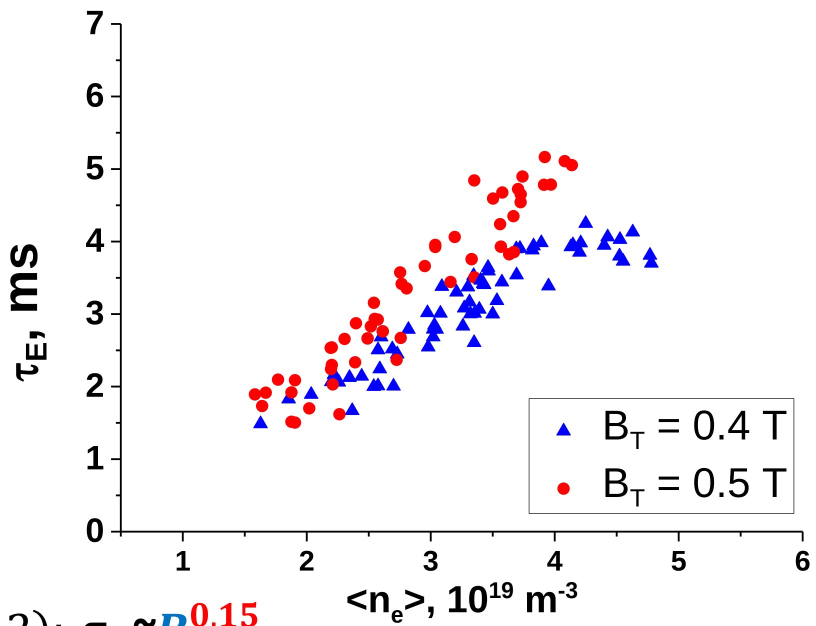
Energy confinement

OH, D plasma, I_p = 200 kA



$\tau_E \sim B_T^{1.1}$

26 keV D NBI 0.7 MW, D plasma, H-mode, I_p = 200 kA



$\tau_E \sim B_T^{0.9}$

IPB98(y, 2): $\tau_E \sim B_T^{0.15}$

MAST: $\tau_E \sim B_T^{1.4}$

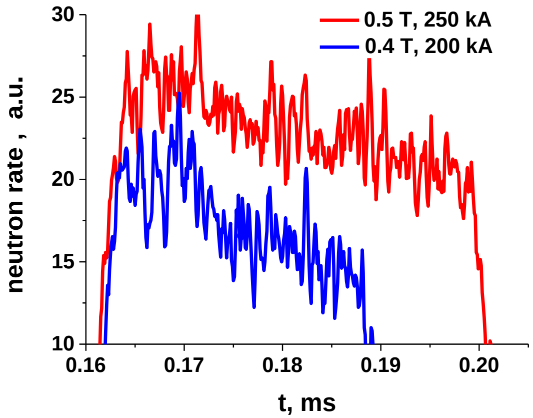
NSTX, boronization: $\tau_E \sim B_T^{1.08}$

NSTX, Li conditioning: $\tau_E \sim B_T^{-0.15}$

More today at 10:45 – Status of the Globus-M2 project

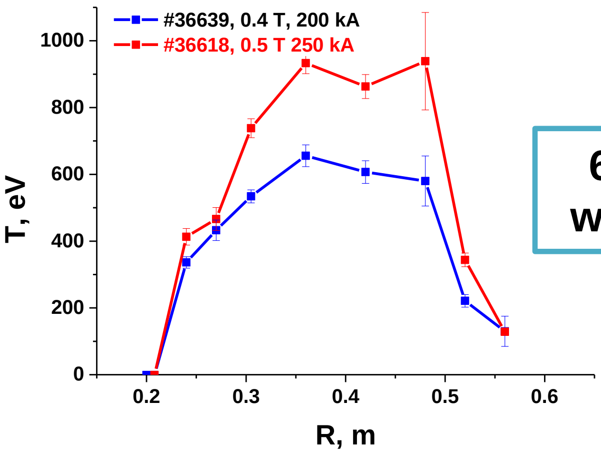
Fast Ion confinement

30-40% neutron rate increase was observed in D-D experiments



Orbital modeling: First Orbit losses decreased: ≈30% neutron rate difference

NUBEAM: T_e increase led to ≈ 20% difference

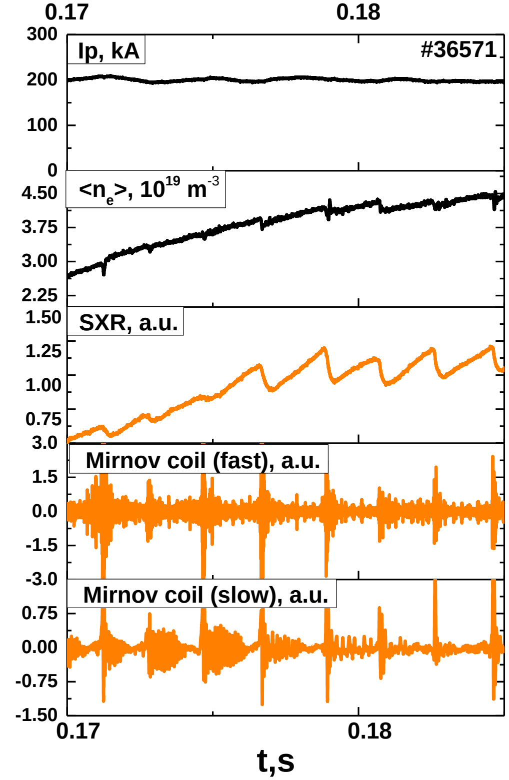


60% growth was expected

classical FI confinement calculations overestimate neutron rate growth

0.4 T: sawtooth oscillations dominates

0.5 T: sawtooth-induced losses decrease, however many instabilities coexist

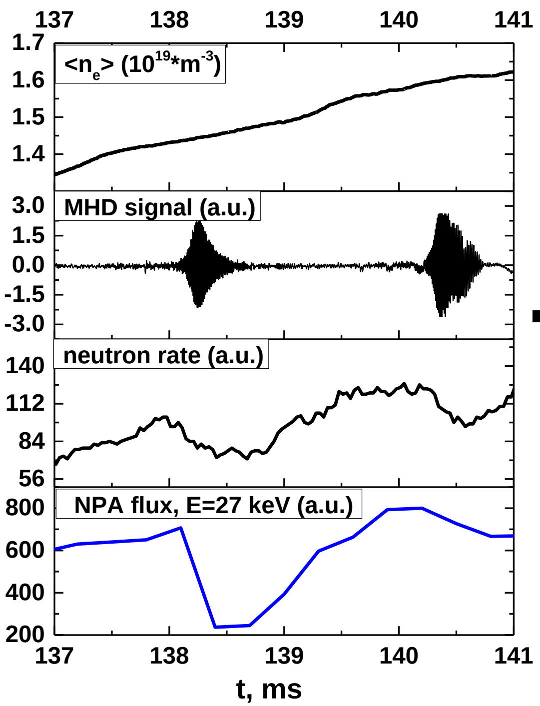


Sawtooth oscillations, fishbones and TAE exist simultaneously

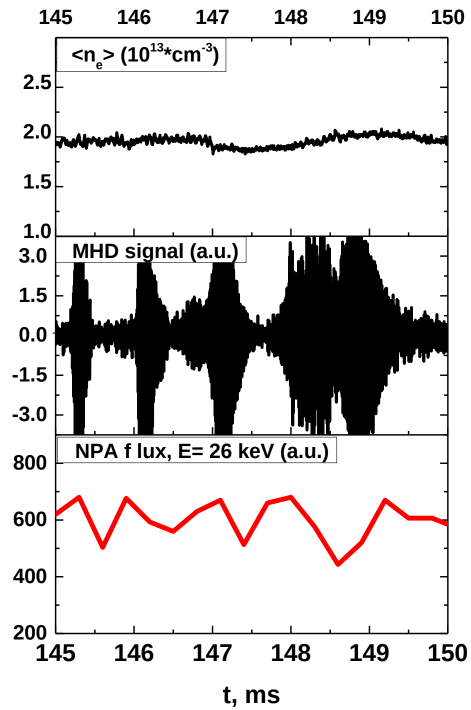
TAE

D NBI

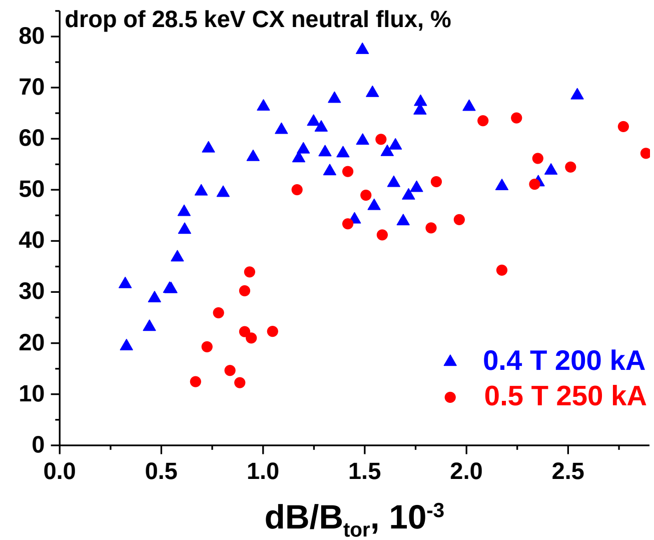
0.4 T



0.5 T



TAE-induced Fast Ion losses

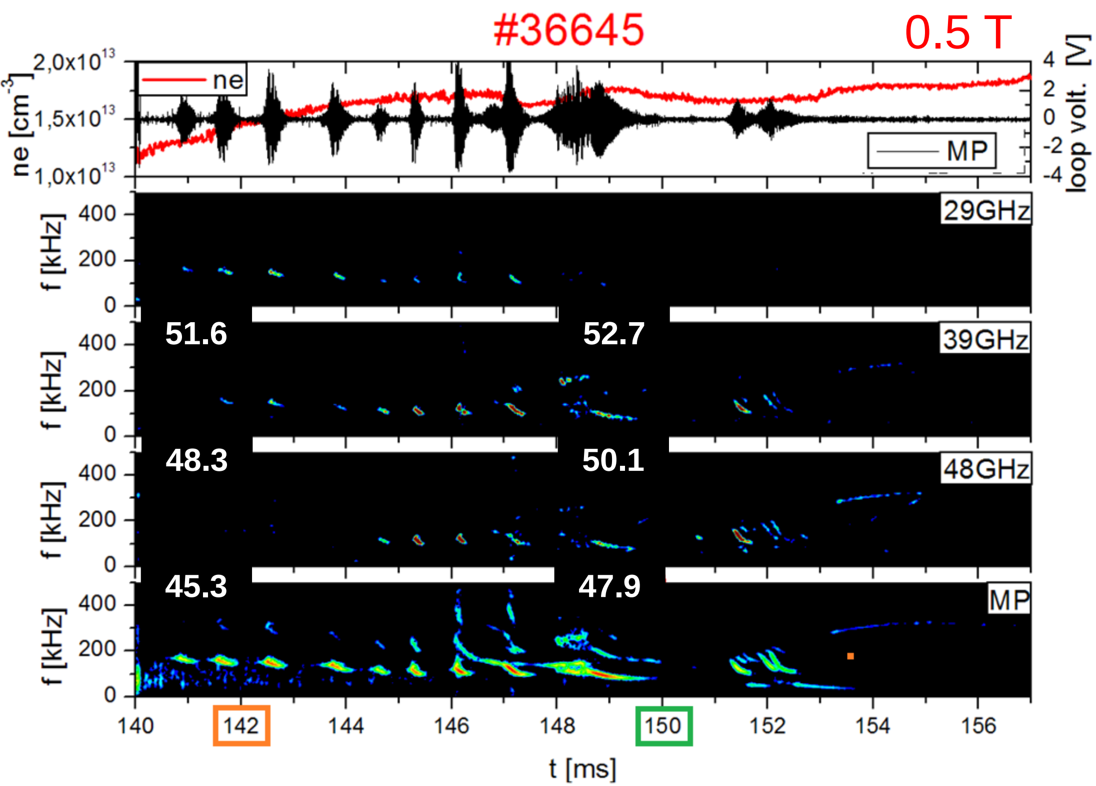


More frequent modes because of FI accumulation due to the better classical FI confinement and lower AM-induced losses

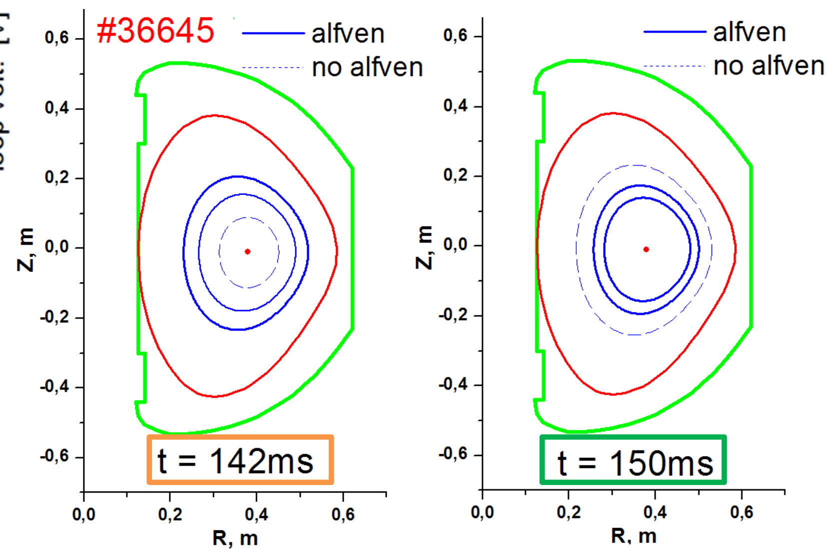
More today at 10:45 – Status of the Globus-M2 project

TAE location

- Doppler backscattering was applied for the first time to detect Alfven eigenmodes.
- Alfven oscillations of plasma rotational velocity were compared with magnetic probe signals.



Spectrograms of plasma velocity and MP signals



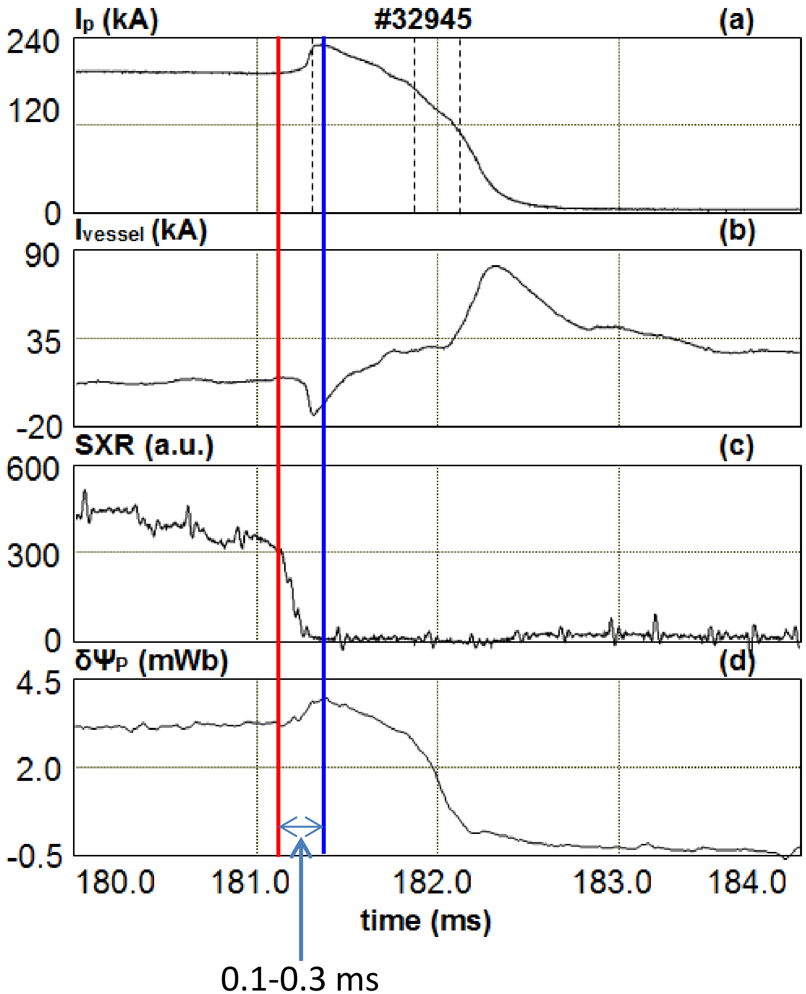
Flux surfaces of Alfven mode observation

Alfven region:

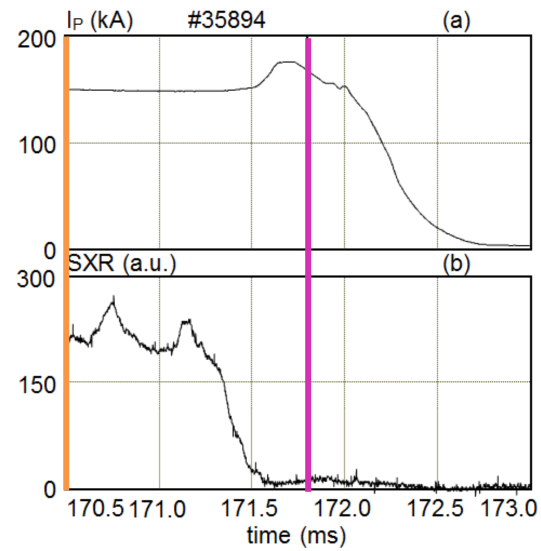
$$\rho = 0.45 - 0.85$$

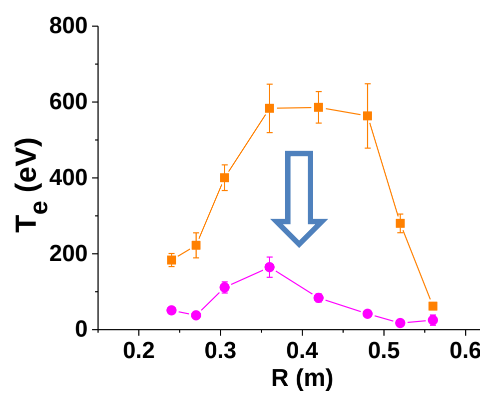
Major plasma discharge disruption

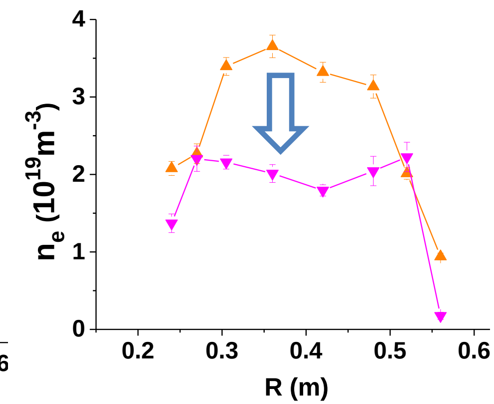
Thermal quench → Current quench



Thermal quench

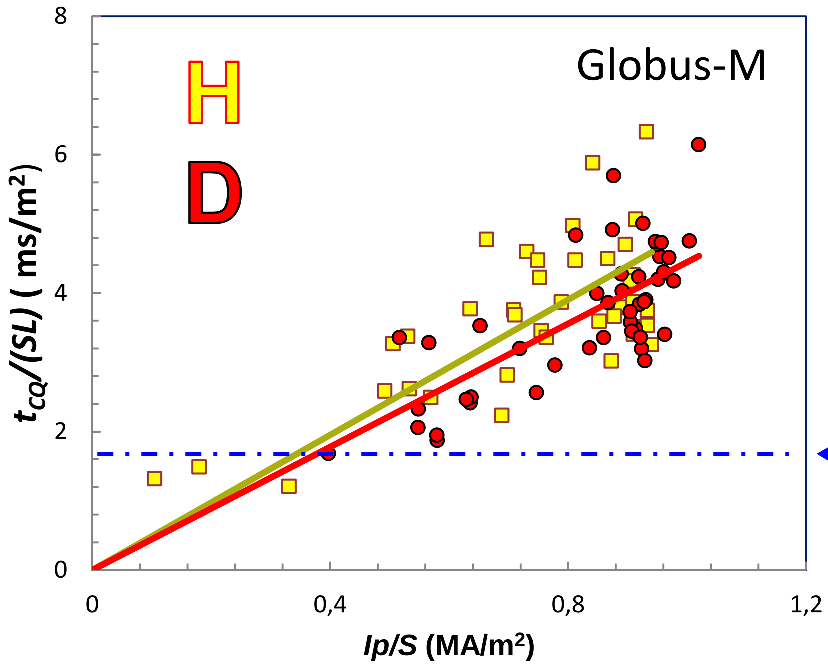






more that 80% of the energy is lost during thermal quench

Major plasma discharge disruption



IDDB: $t_{CQ} = (t_{20}-t_{80})/0.6$

IDDB: t_{CQ}/SL : 1,7-10 ms/m^2

← ITER$_{min}$: $t_{CQ}/SL \geq 1.67$ ms/m^2

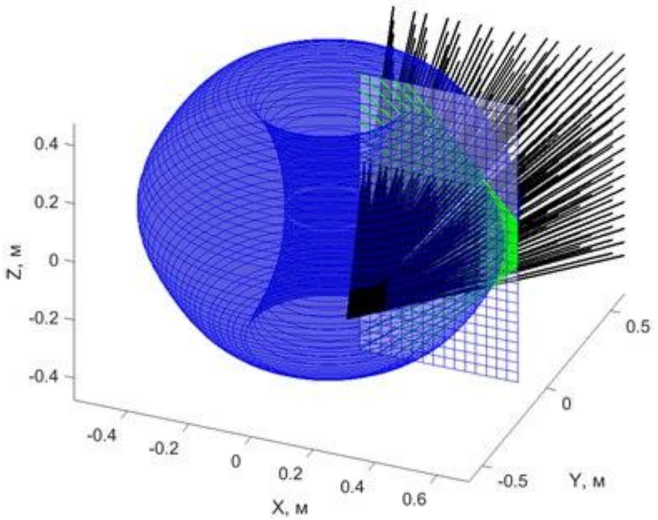
- **$t_{CQ} \sim I_p$ like in NSTX, but not in IDDB**
- **Linear dependence, almost no difference for H and D**
- **$I_p/t_{CQ} \approx const(I_p/S)$ like in NSTX and EAST**

Radiation losses

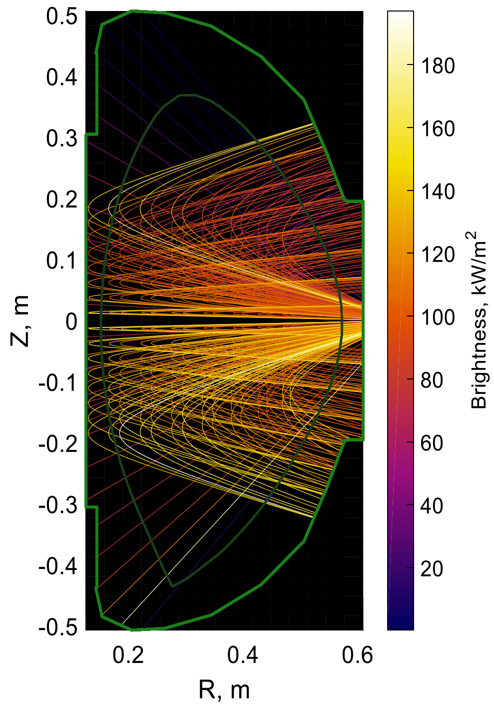
OH

Tomography reconstruction of radiation losses profile

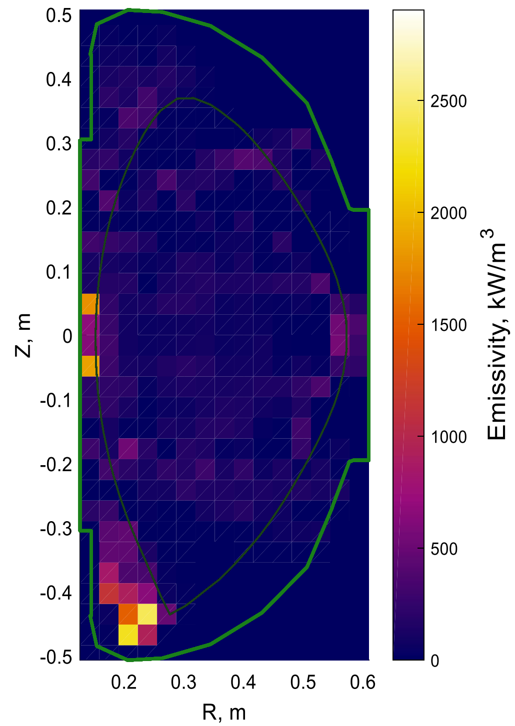
LOSs of SPD-arrays



Measured Brightness (projection of SPD-arrays LOSs)



Reconstructed 2D plasma emissivity profile



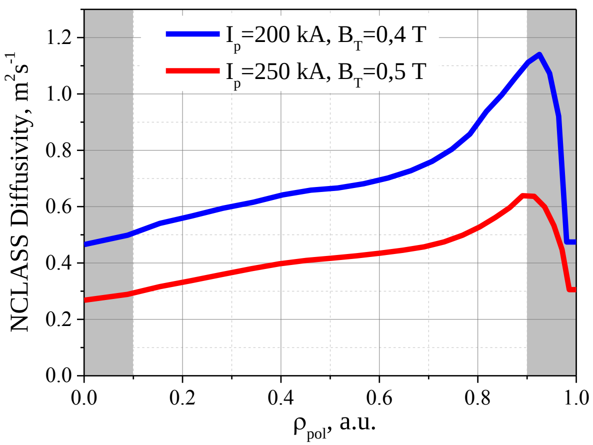
- P_{rad} total - 90 kW (30% of P_{heat})
- P_{rad} from main plasma -50 kW (15% of P_{heat})

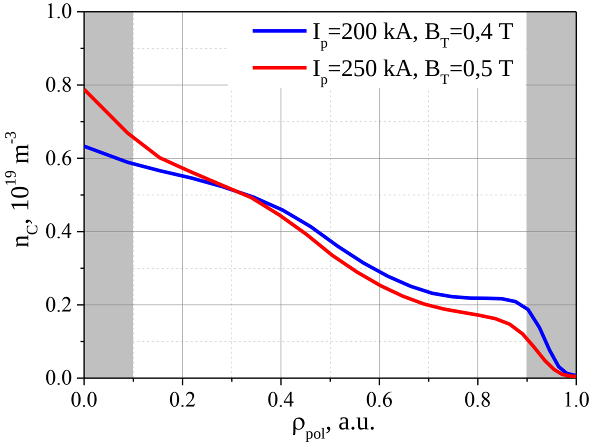
Radiation losses

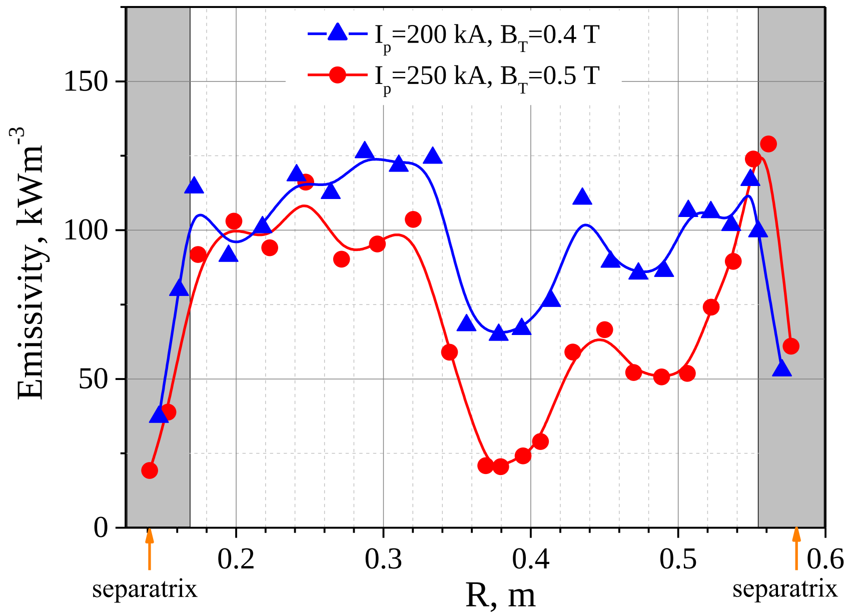
OH, H-mode

Carbon transport analysis

ASTRA coupled with STRAHL code. NCLASS for transport coefficients.





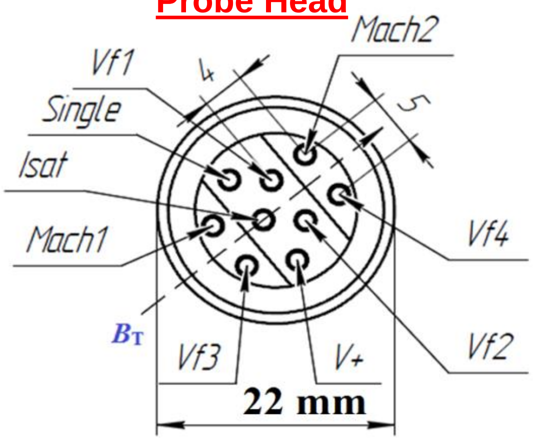


- Carbon diffusivity at neoclassical level
- n_C/n_e = 6% enough to reproduce P_{rad} and U_{loop}
- B_{tor} and I_p increase led to radiation losses decrease

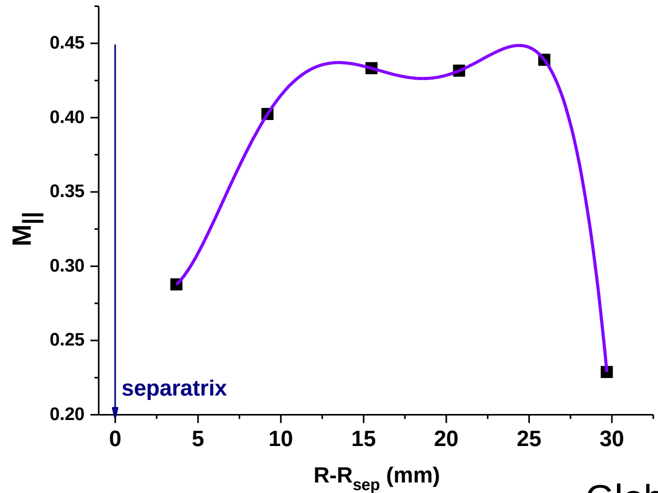
SOL Physics

New movable 9-pin probe was installed at the outer midplane.

Probe Head

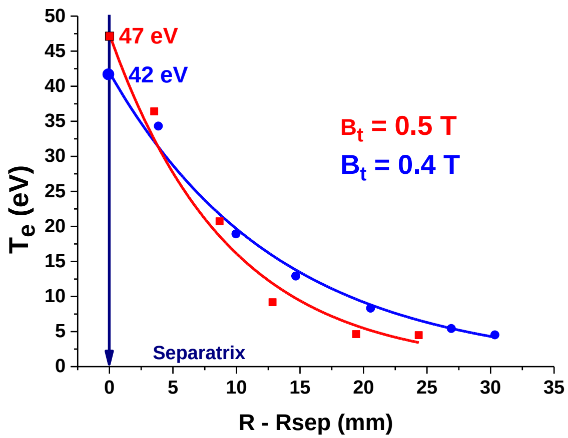


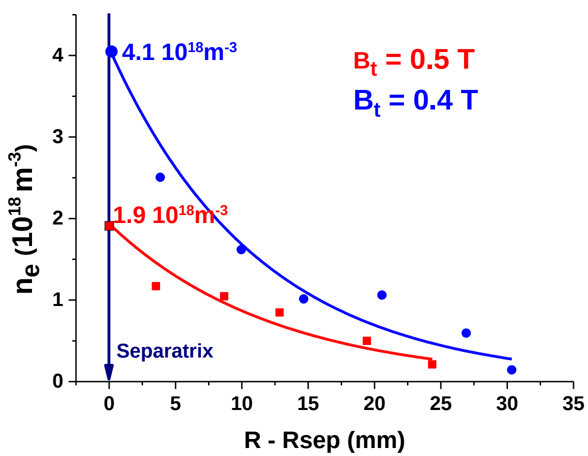
Mach number values are close to typical values from other tokamaks such as JT-60U, MAST, ASDEX-U.



LSN, “forward” B_T

Globus-M T_e and n_e profiles





Globus-M experiments:

$$\lambda_{q\ MP} \sim I_p^{-1.4} B_T^{0.6}$$

Eich 2011,Scaling for Conventional tokamaks:

$$\lambda_q \sim I_p^{-1.1} B_T^{0.42}$$

Eich 2013, Scaling for Spherical tokamaks:

$$\lambda_q \sim I_p^{-1}$$

Summary

In the experiments with the increased magnetic field :

- **Energy content increased, in NBI discharges ~1.5 time rise was observed.**
- **τ_E increase in SOC and NBI regimes were observed.**
- **30-40% neutron rate growth was observed due to classical and sawtooth-induced fast ion losses decrease, however new instabilities arised.**
- **TAE losses decreased, TAE behaviour changed. TAE spatial localization was measured using 4-ch Doppler reflectometer.**
- **t_{CQ} was in a good agreement with IDDB. Almost no dependence on m_i and linear dependence on I_p was observed.**
- **Radiation losses decreased, neoclassical transport and C concentration of several percent were confirmed.**
- **λ_q midplane dependence was estimated as ~ $I_p^{-1.4} B_T^{0.6}$.**

More today at 10:45 – Status of the Globus-M2 project

Thank you

Alfven amplitude

- Recovering Alfven magnetic field amplitude $\widetilde{B_\theta}$ from velocity oscillations $\widetilde{V_\perp}$

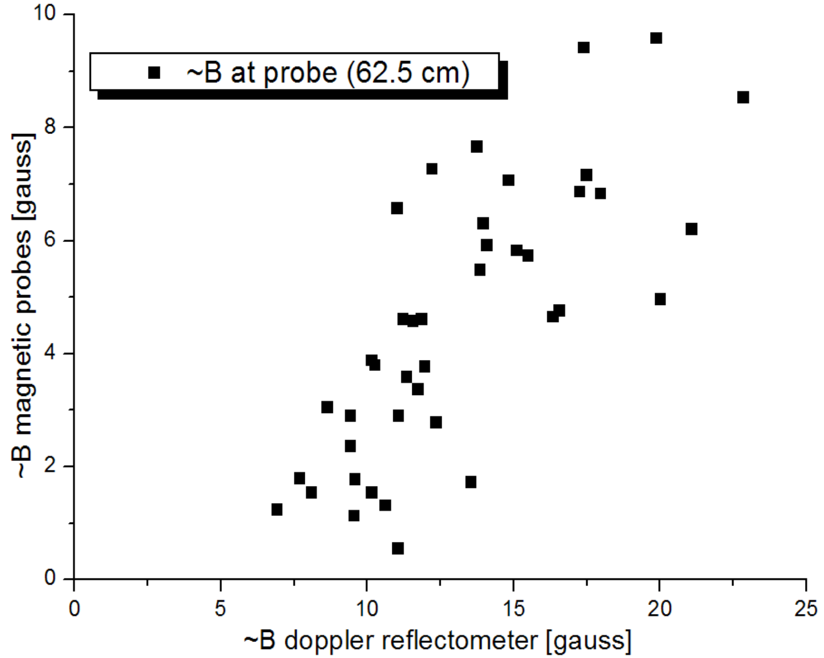
- $\widetilde{E_r} = \widetilde{V_\perp} B$
- $\widetilde{B_\theta} = \widetilde{E_r}/c_A$

DBS measurements:

$$V_\theta = 2 - 9 \text{ km/s}$$

$$E_r = 0.5 - 3 \text{ kV/m}$$

$$B_\theta = 7 - 25 \text{ G}$$



$B_{MP} < B_{DBS}$