INSTITUTE OF PLASMA PHYSICS
ACADEMY OF SCIENCES OF THE CZECH REPUBLIC

NSTX
NATIONAL SPHERICAL TORUS EXPERIMENT

Modeling of Optimization and Control of EBW Heating and Current Drive

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Introduction & motivation

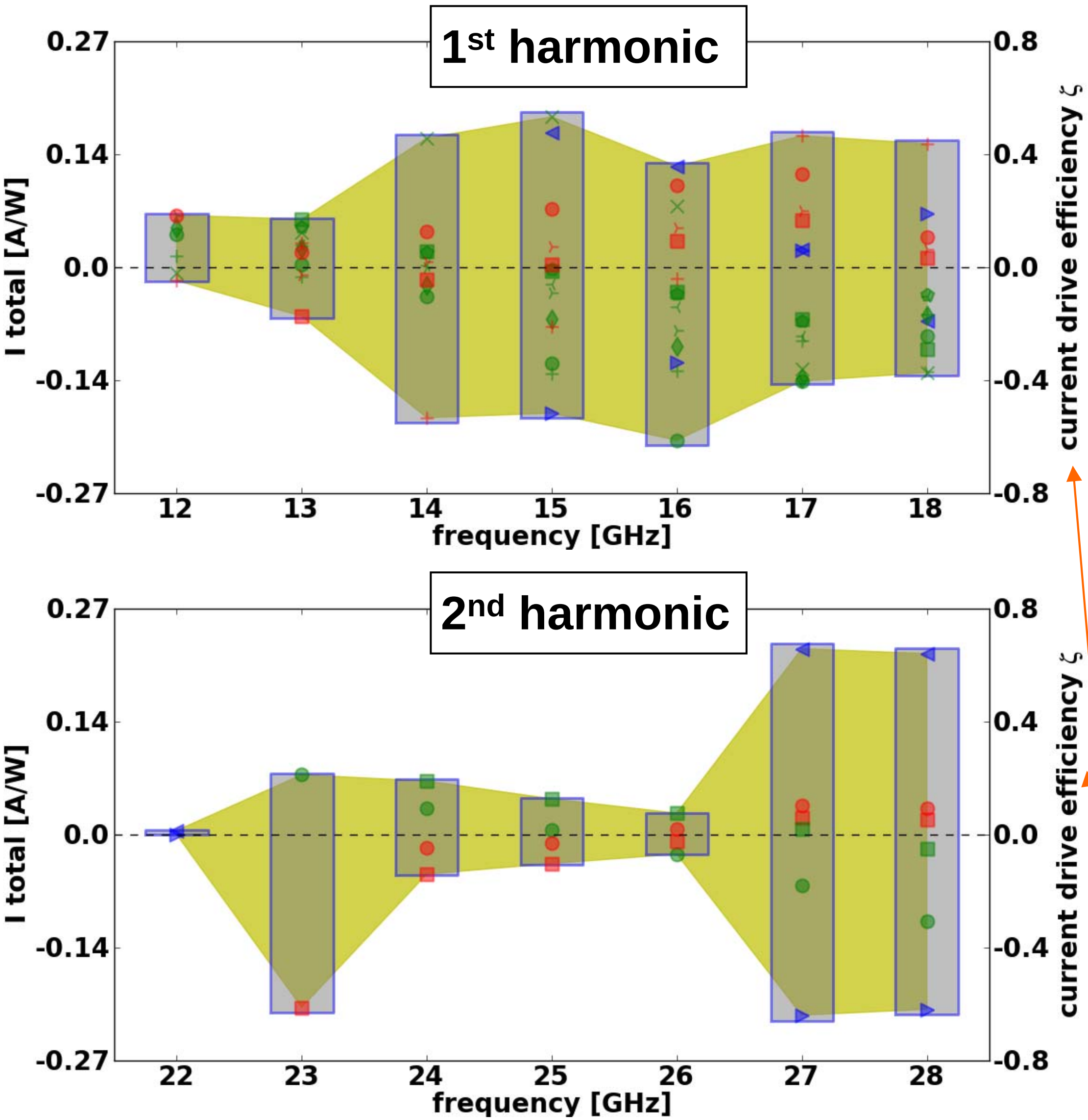
- **EBWs – Electron Bernstein waves**
  - The only waves in the **electron cyclotron (EC) range** that can propagate in **overdense plasmas** ($\omega_{pe} >> \Omega_{ce}$)
  - Must be excited by O/X-modes
  - Strong interaction with the plasma (electrostatic)
- **Potential goals – stabilization, profile shaping**
  - **Off-axis, localized current drive**
- **How to optimize and control?**

Simulation setup

- **AMR (Antenna, Mode-conversion, Ray-tracing) + LUKE (3D Fokker-Planck) codes**
  - AMR calculates optimum aiming and ray trajectories
  - LUKE calculates quasi-linear damping and current
- **O-X-EBW scheme**
  - Frequency and antenna vertical position can be chosen
  - $N_{||}^2$, N_{pol} determined → 2 $\pm\phi$ injections possible
- **Target plasma**
  - **NSTX L-mode,** B_0=0.5 T, n_{e0}=2.6x10^{19} m^{-3}, T_{e0}=2.9 keV, I_P=0.6 MA (#123435)
  - **NSTX H-mode,** B_0=0.5 T, n_{e0}=3.9x10^{19} m^{-3}, T_{e0}=1.4 keV, I_P=1 MA (#130607)
  - **NHTX TRANSP** scenario **,** B_0=2 T, n_{e0}=2x10^{20} m^{-3}, T_{e0}=5.7 keV, I_P=3.5 MA

EBW CD efficient across a wide range of parameters

IPP



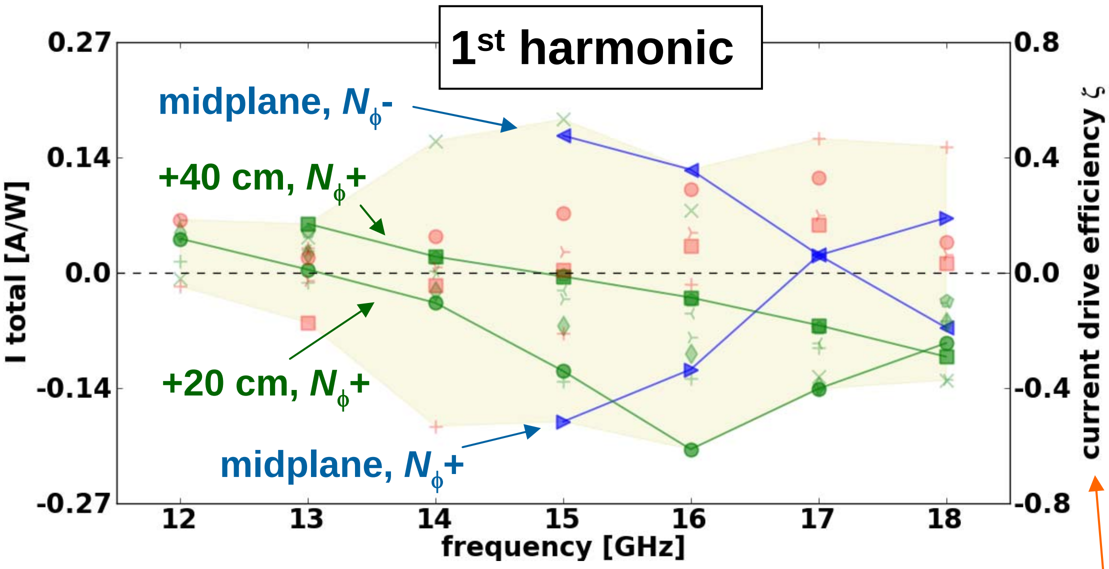
- **NSTX L-mode**, 1 MW power launched
- **1st (12 – 18 GHz)** and **2nd (22 – 28 GHz) harmonics**
- **Antenna *Z* position** -40 cm … +40 cm
- **CD efficiency varies with the frequency, the vertical antenna position and the initial N_ϕ sign**
- Above/below midplane launch nearly symmetrical
- Specific cases with >200 kA/MW (ζ >~ 0.6) exist

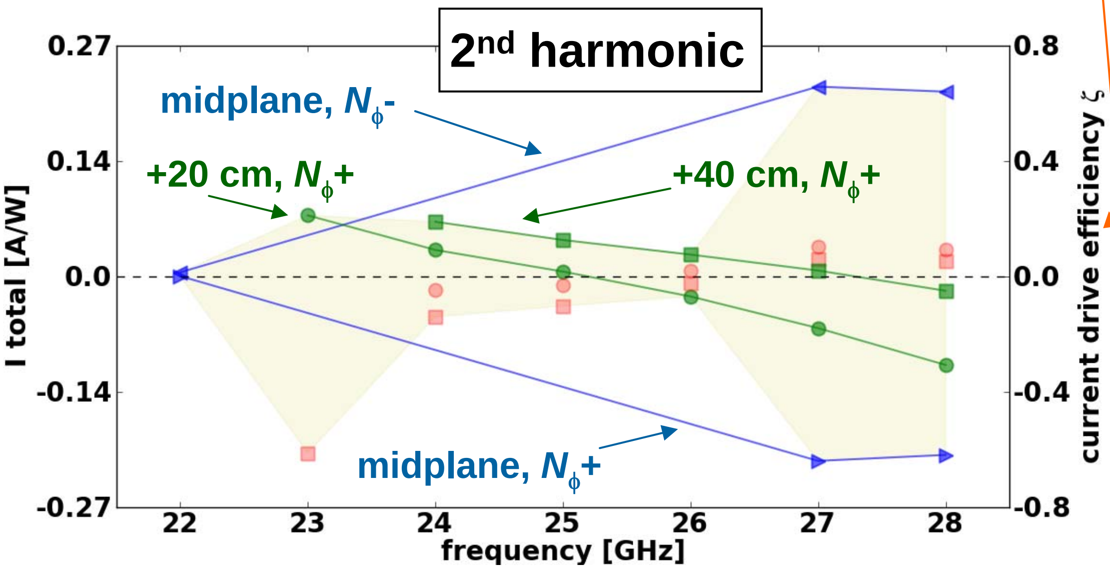
$$\zeta = \frac{e^3}{\epsilon_0^2} \frac{R n_e}{k T_e} \frac{I}{P}$$

C. C. Petty *et al.*, Nucl. Fusion **42**, 1366 (2002)

estimate – central values

EBW CD efficient across a wide range of parameters





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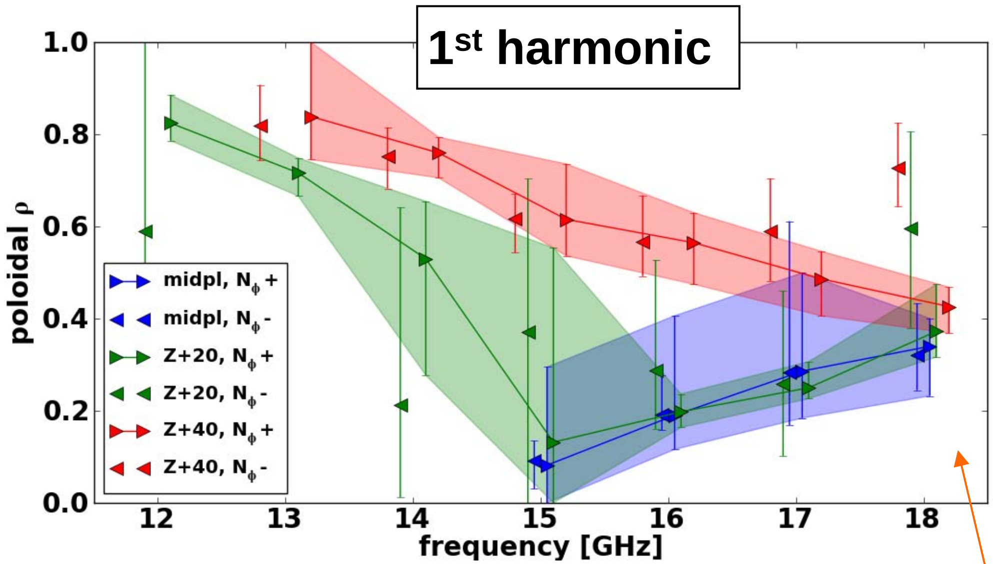
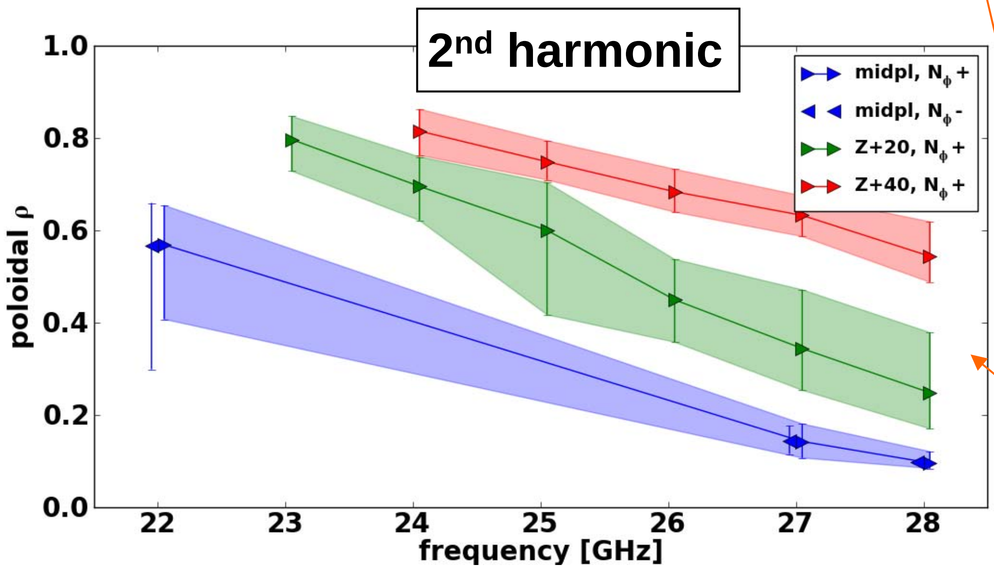
Deposition possible at any radius

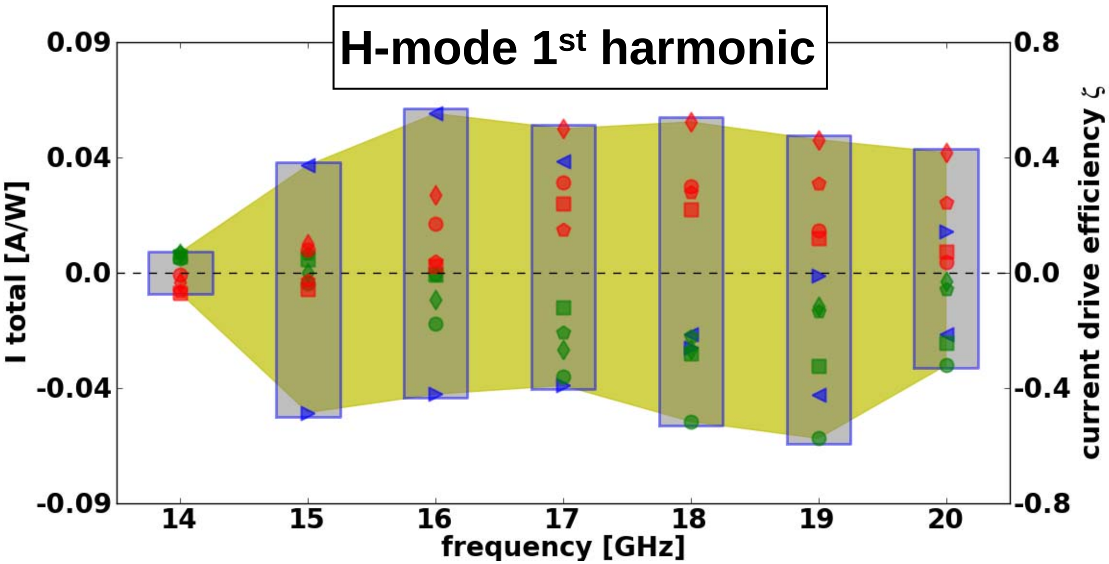


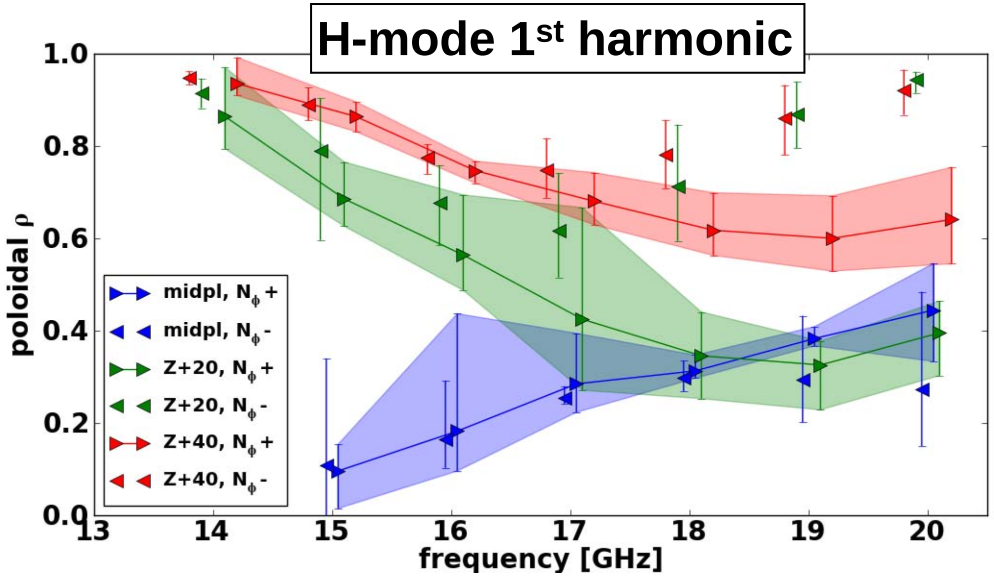


- **The dependence on the launching parameters is clearly seen**
  - Vertical launch position influences the $|N_{||}|$ growth
  - Frequency selects the EC resonance location
- **Broad coverage possible** with either
  - **single frequency, multiple antenna *Z***
  - **multiple frequency, single antenna *Z***
- ***However, CD efficiency varies***

symbols – max |*j*| location
error bars – FWHM of |*j*| profile

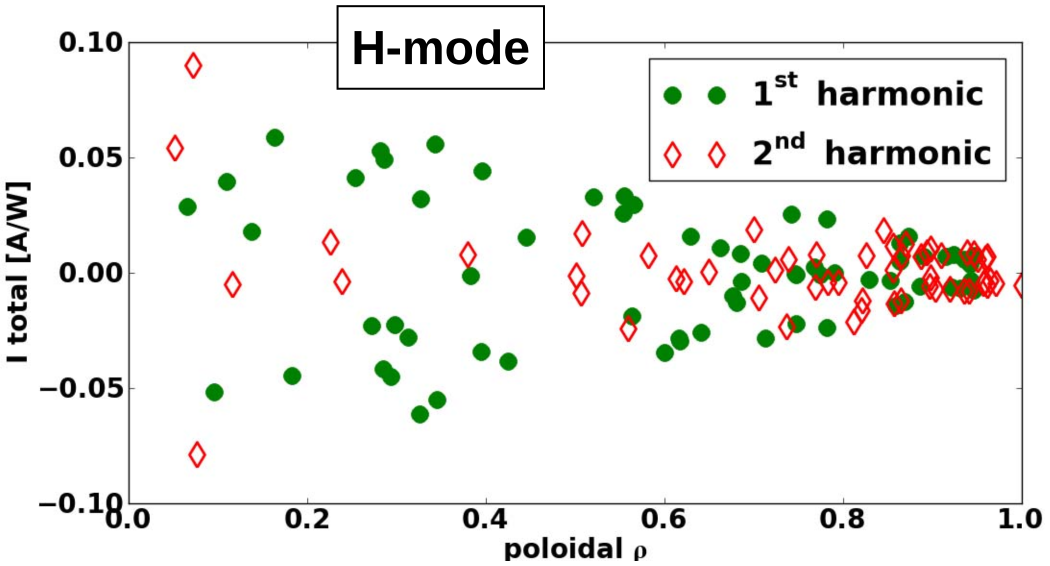
CD efficiency similar in H-mode

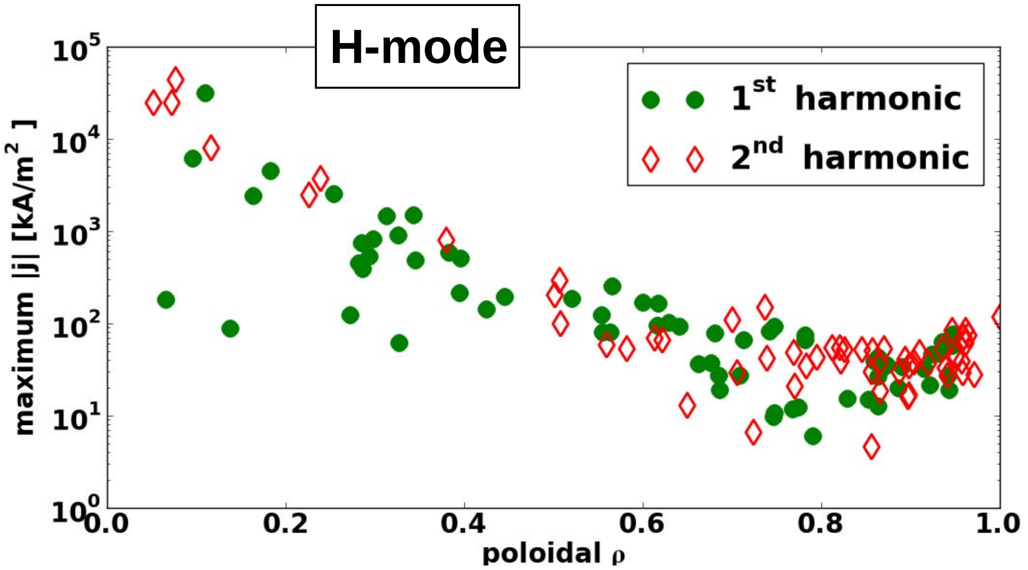




- 1st (14 – 20 GHz) and 2nd (23 – 29 GHz) harmonics assessed
- **CD efficiency very similar to the L-mode**
  - ***I/P is* lower because of the higher collisionality**

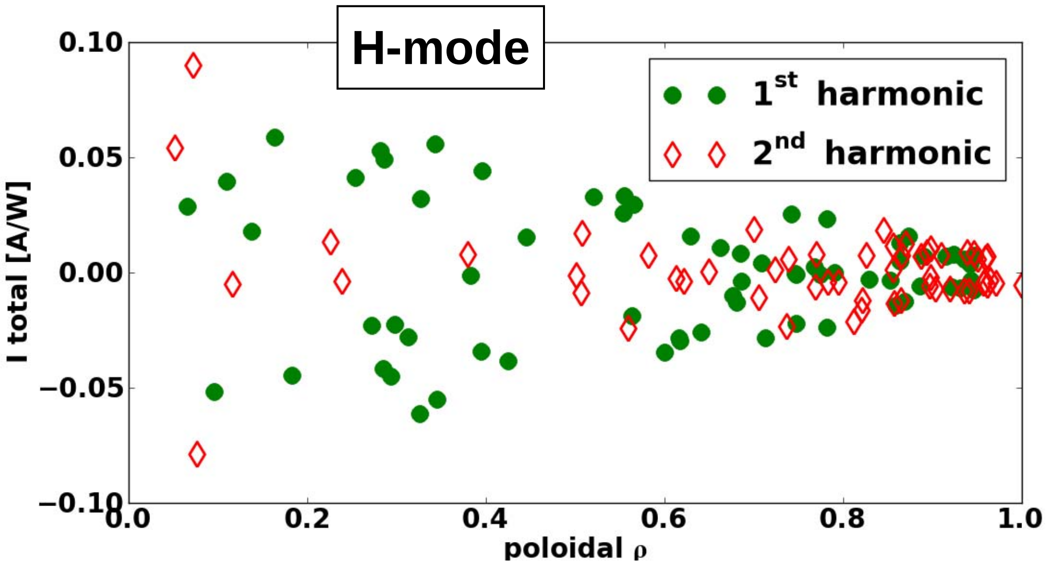
Driven current decreasing towards the edge

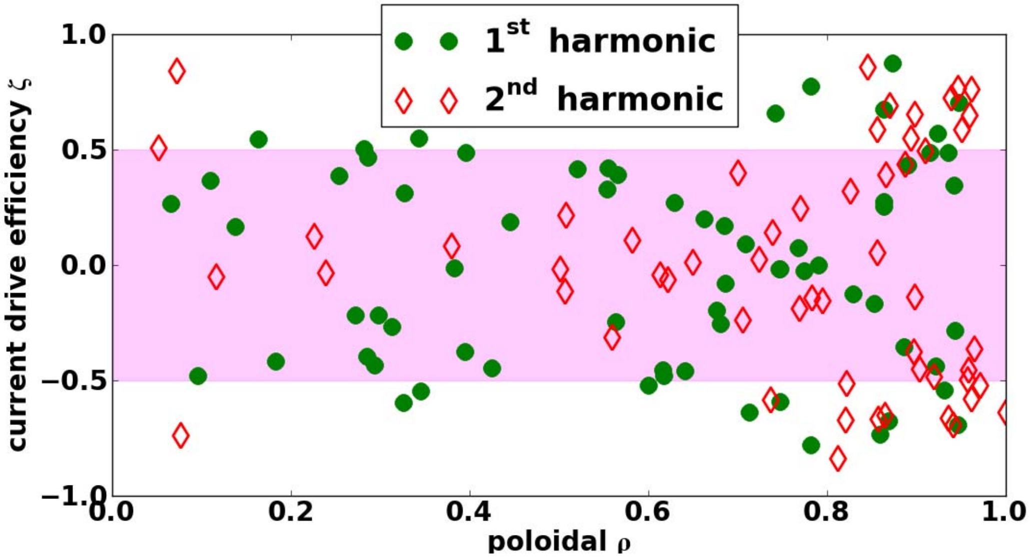




- Several factors dependent on ρ
  - **collisionality (n_e/T_e)**
  - **trapped particle fraction**
- Total current decreases with radius
- Current density decreases towards the edge
  - **At ρ~0.9 it starts to increase**

CD efficiency ζ high at any radius





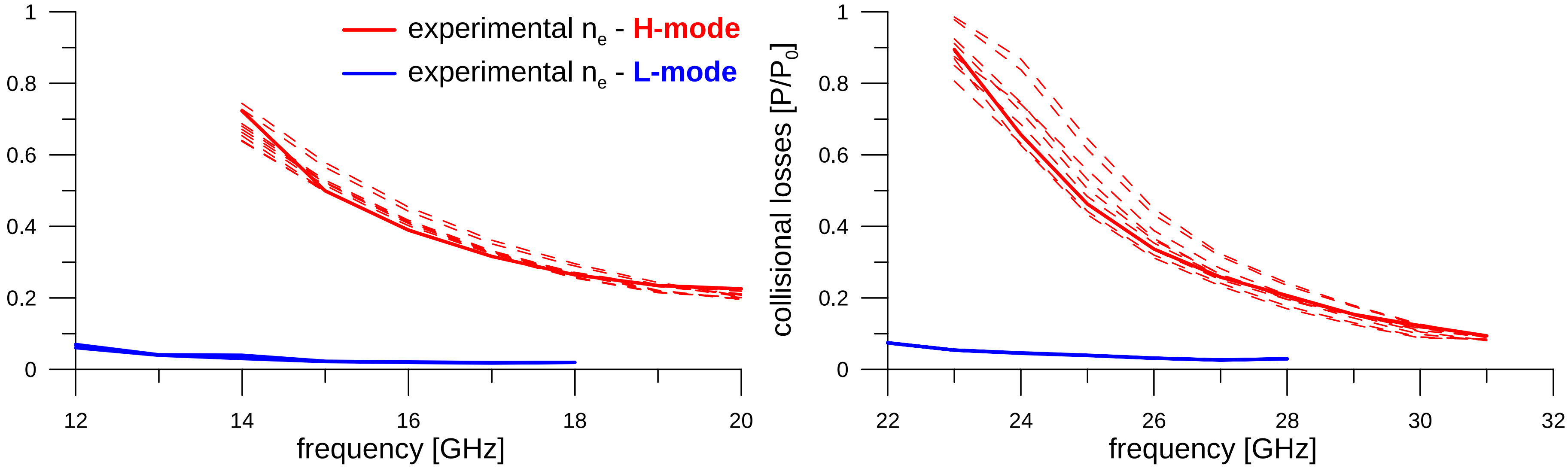
- Several factors dependent on ρ
  - **collisionality (n_e/T_e)**
  - **trapped particle fraction**
- Total current decreases with radius
- **Current drive efficiency ζ remains around 0.5 for ρ<0.7**
- **Even an increase in ζ for ρ>0.7 is predicted**

$$\zeta = \frac{e^3}{\epsilon_0^2} \frac{R n_e}{k T_e} \frac{I}{P}$$

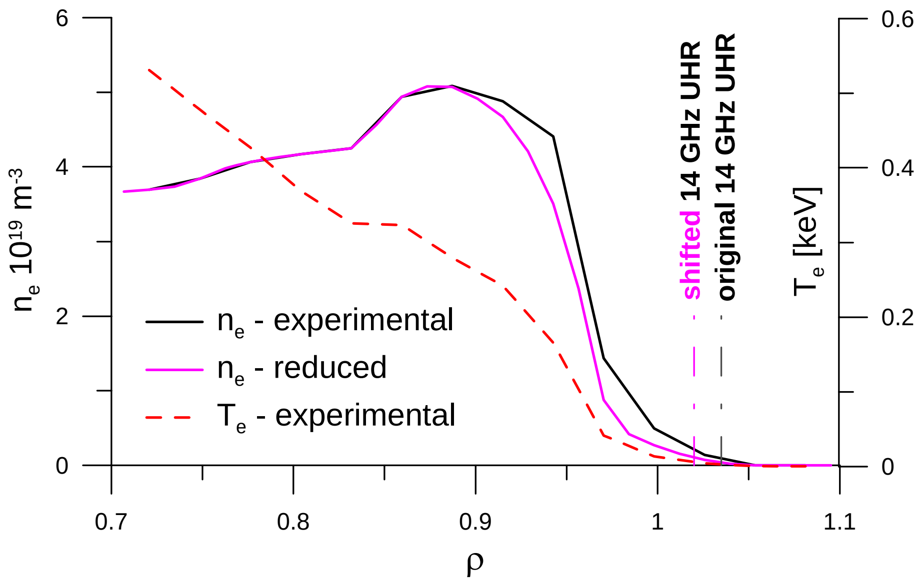
local values

Collisional losses critical in H-mode

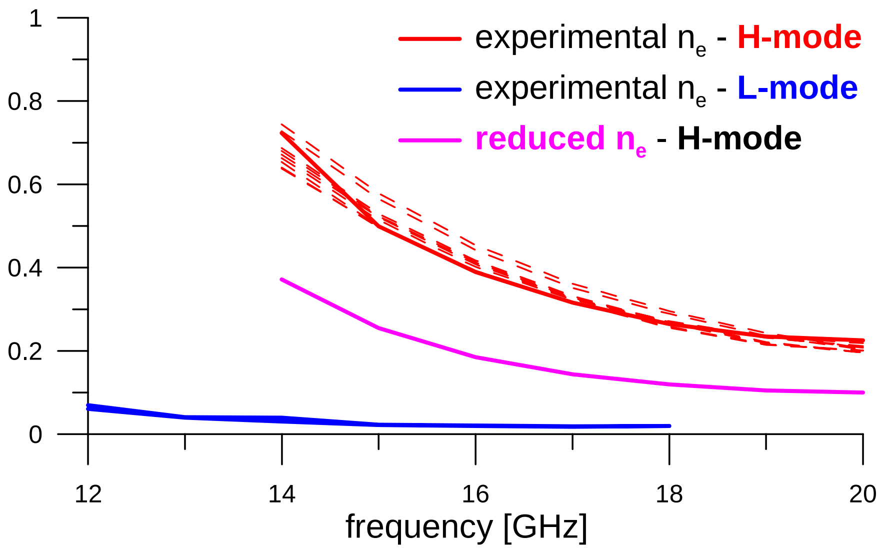
- Losses due to strong **EBW collisional damping** were predicted and observed experimentally [S.J. Diem et al., Phys. Rev. Lett. 103, 015002 (2009); Nucl. Fus. 49, 095027 (2009)]
  - Much larger effect in H-modes
  - Can be mitigated by reducing the edge density (e-i collisionality)

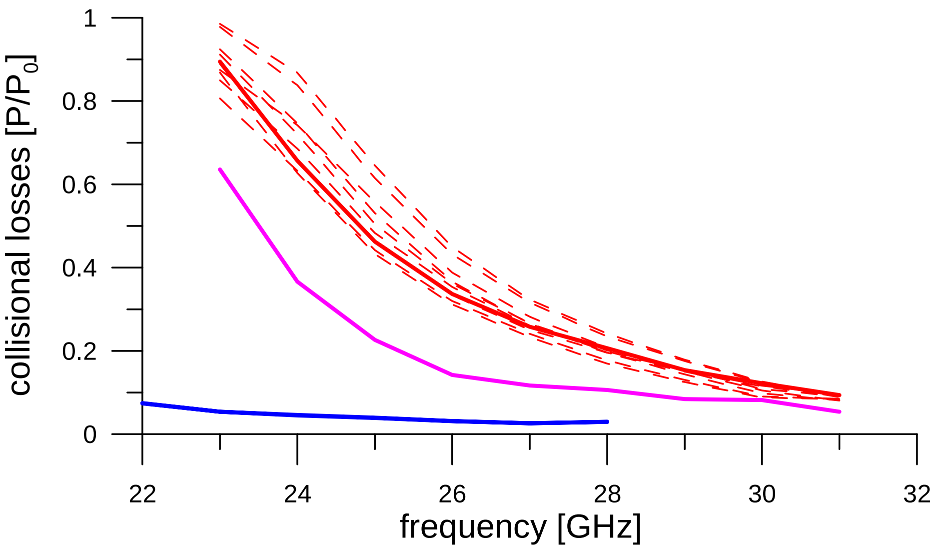


Collisional losses – mitigation possible

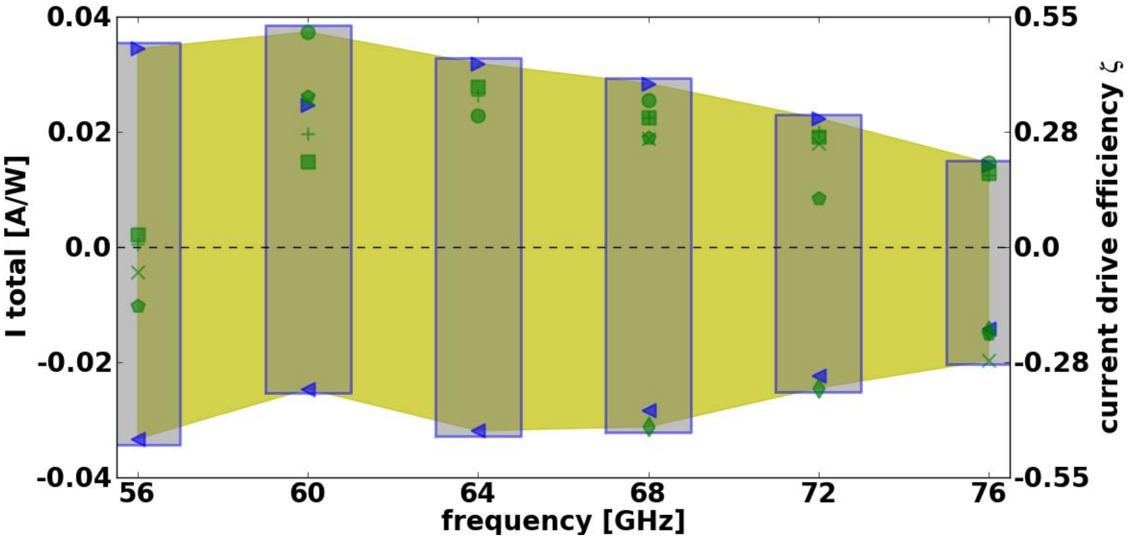


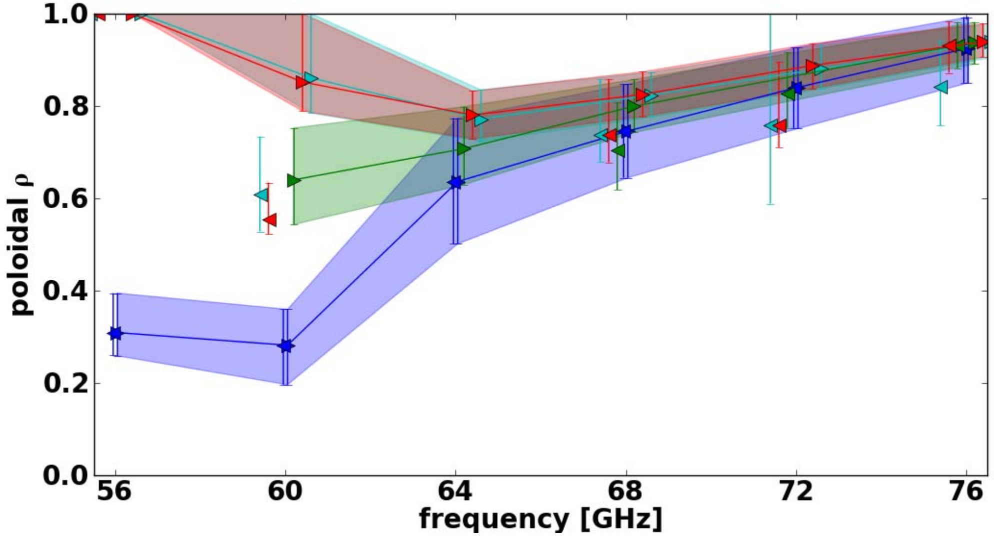
- Lower edge density shifts the O-X-EBW mode conversion layer inwards
- Lower losses at higher frequencies
  - Less time spent in the MC region (higher group velocity)
  - Mode conversion more inside





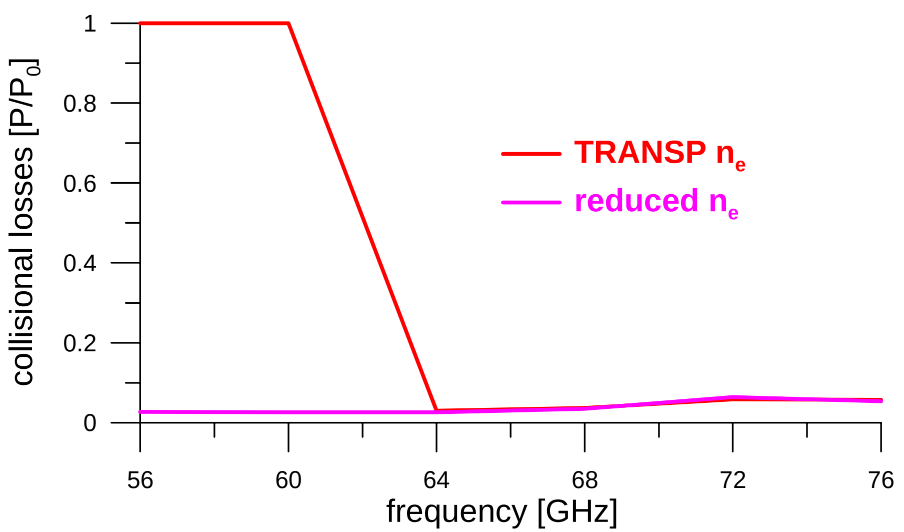
NHTX EBW CD similar to NSTX

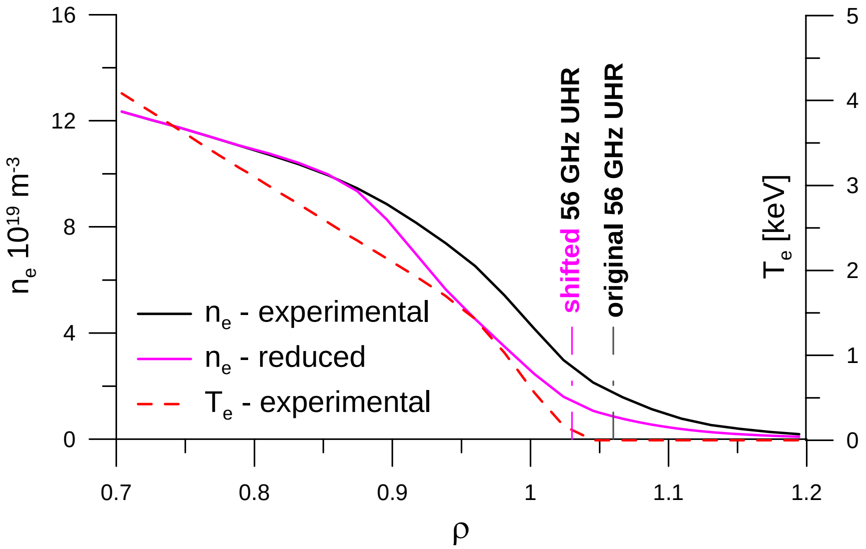




- 10 MW power launched
- **1st (56 – 76 GHz) harmonic** assessed
- **Antenna *Z* position** -120 cm … +120 cm
- **CD efficiency ζ on the same level as NSTX**
- Radial location almost does not vary with the antenna vertical position
- Worse accessibility for higher frequencies

Collisional losses not severe for NHTX





- **Collisional losses also predicted**, although for the lower frequencies only
- Similar edge density decrease can **completely suppress** the collisional losses

Summary & conclusions

- **EBW heating & current drive investigated with AMR + LUKE codes**
  - Large number of different cases examined
  - Detailed aspects need to be analyzed
- **CD efficiency ζ~0.5** can be reached at **any radius**
- **Collisional losses might be critical**
  - Present theory should be appropriate
  - Particularly dangerous for NSTX H-mode, NHTX lower frequencies

Supported by

EFDA

EURATOM

DoE DE-AC02-09CH11466

AS CR project AV0Z-20430508

Czech Science Foundation grant 202/08/0419

… and viewers like you …

Thank you for your attention