Max-Planck-Institut
für Plasmaphysik

November 2021

AWAKE Helicon Plasma Source

MAX PLANCK GESELLSCHAFT

EUROfusion

Campaign goals

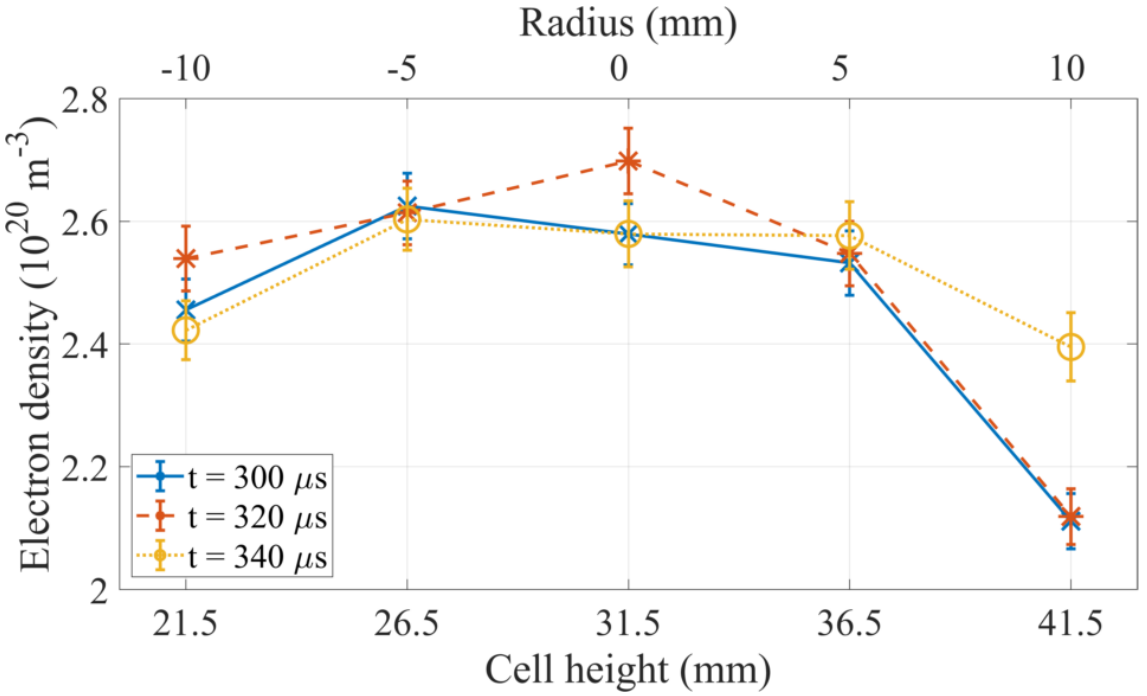
- **interferometer-based benchmark measurement(s) for recent TS results**

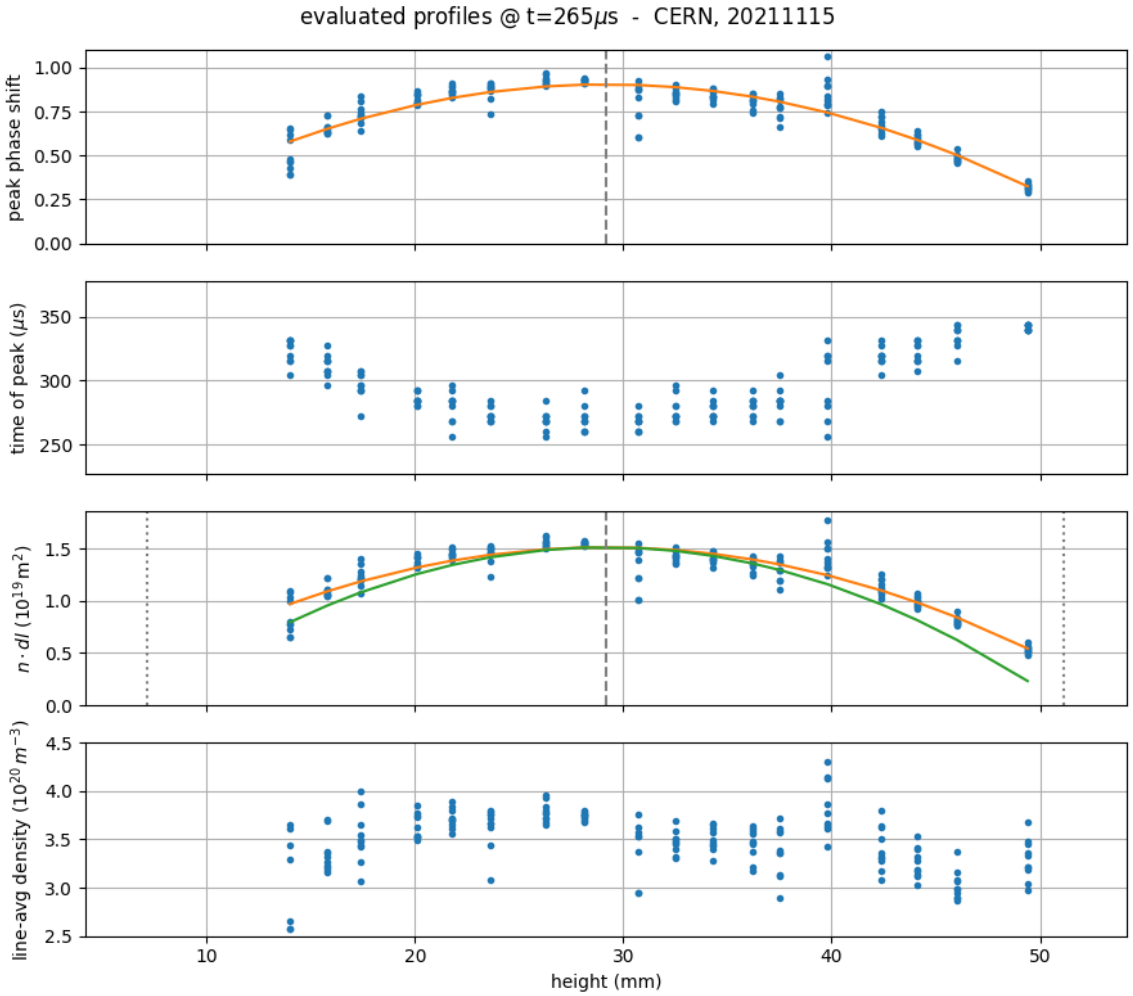
- **„full“ radial density profile for all available antennas**
  → comparison of antenna performance:
  - braided copper ring
  - solid copper ring
  - half-turn helical (HGW reference antennas)

- **axial density scan for at least one suitable antenna**

TS „reference“ – braided ring antenna

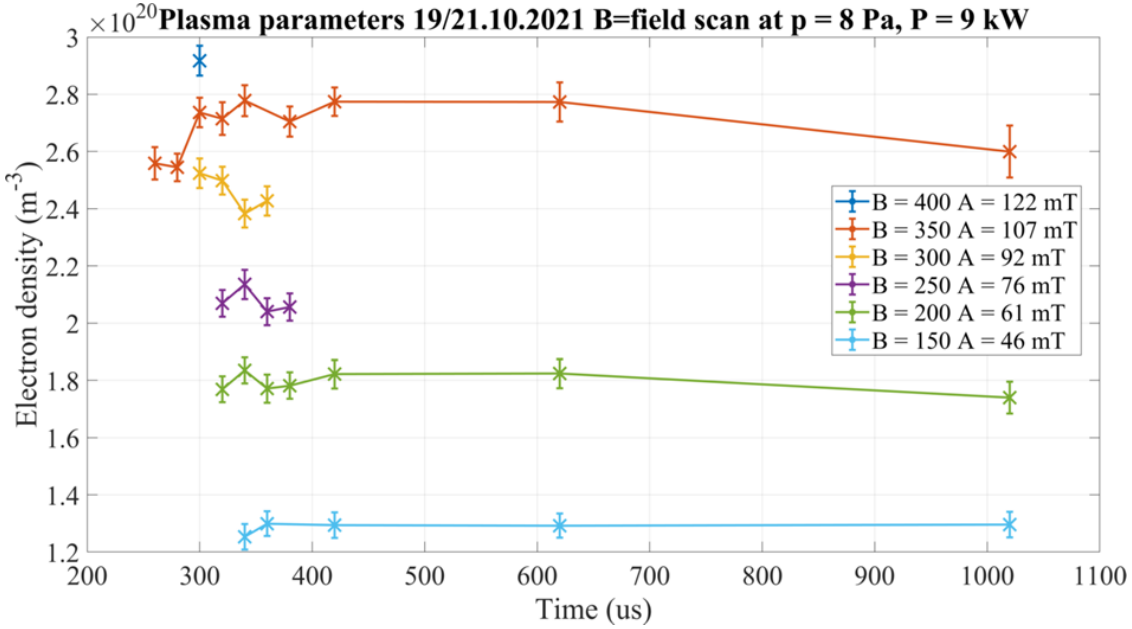
- p_0 = 8 Pa (argon)
  P_{rf} = 9 kW/ant
  I_{coil} = 350 A



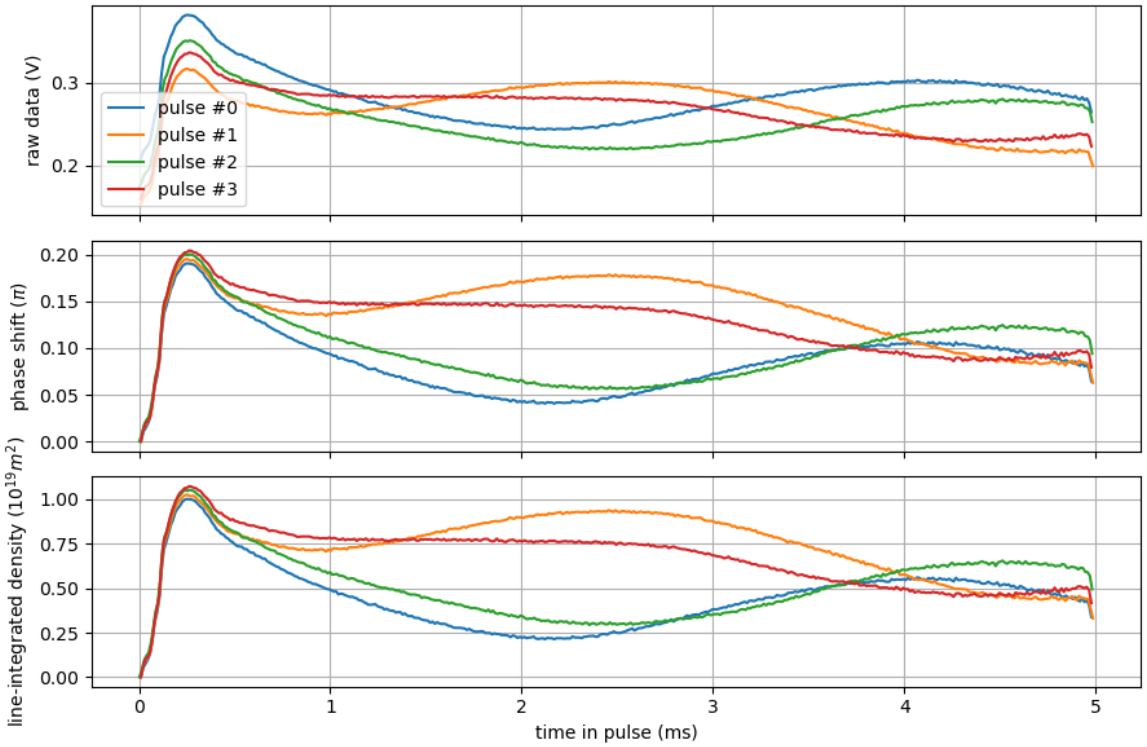


time evolution of plasma density

- based on TS



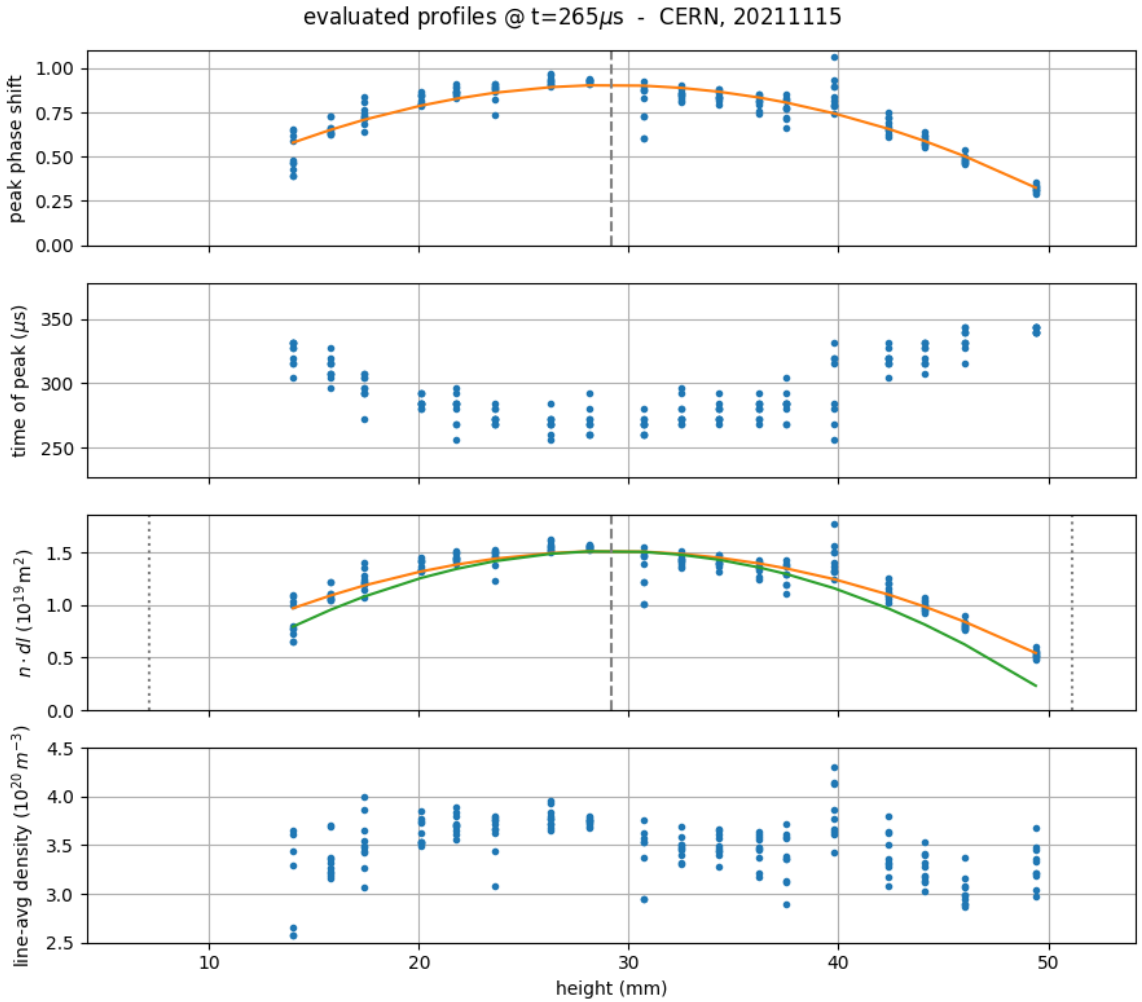
- based on interferometer

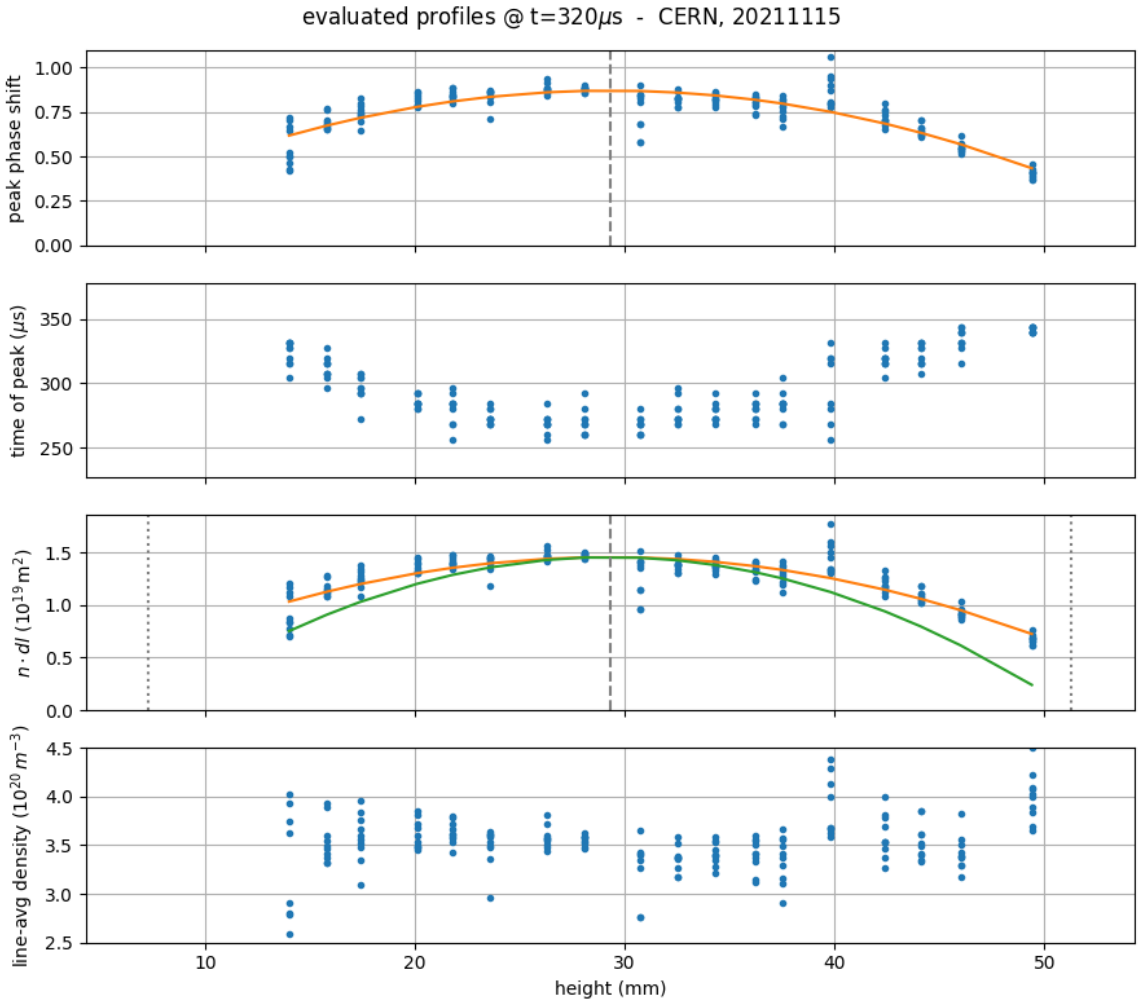


→ time of evaluation has (massive) influence on numbers and profile shape!

profile comparison at different times – braided ring ant.

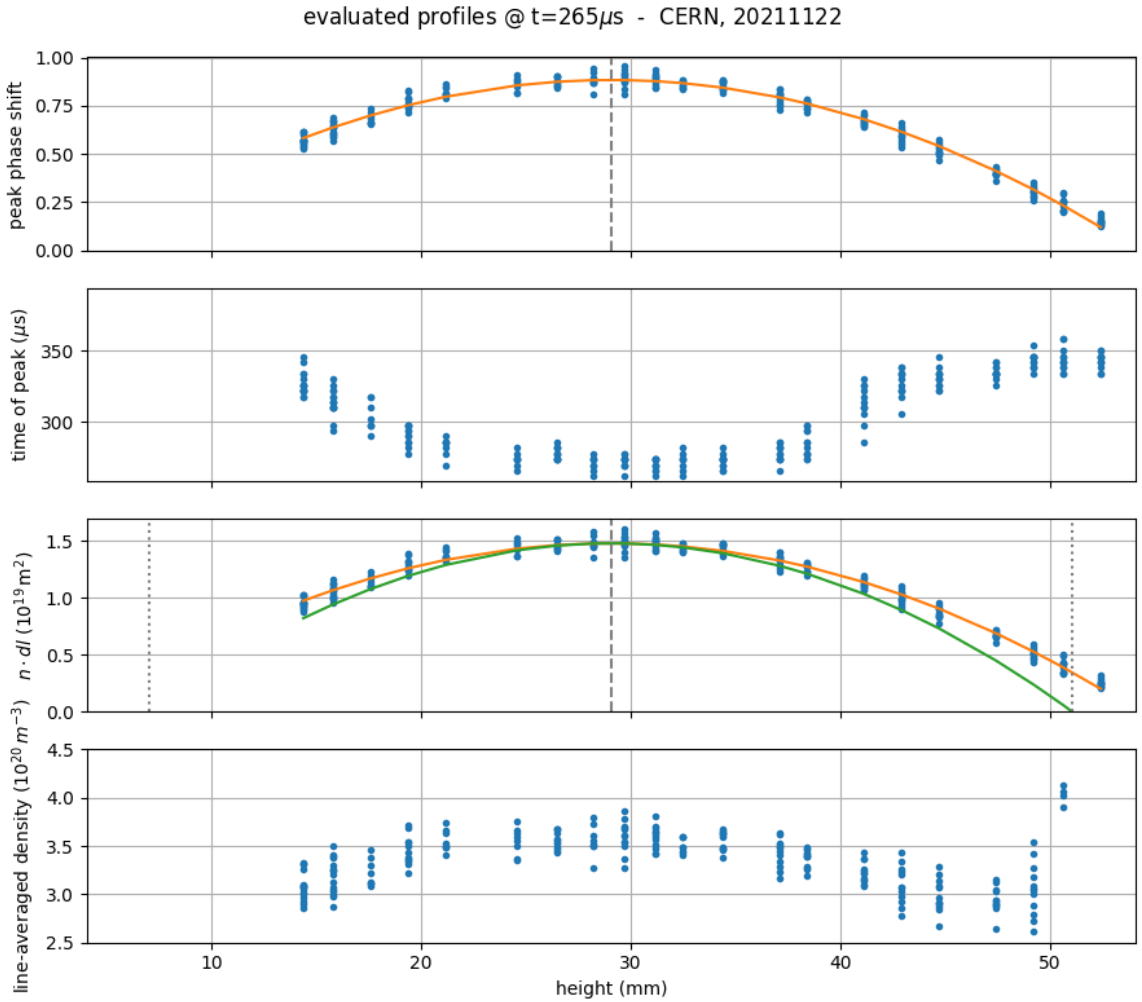
- p_0 = 8 Pa (argon) / P_{rf} = 9 kW/ant / I_{coil} = 350 A

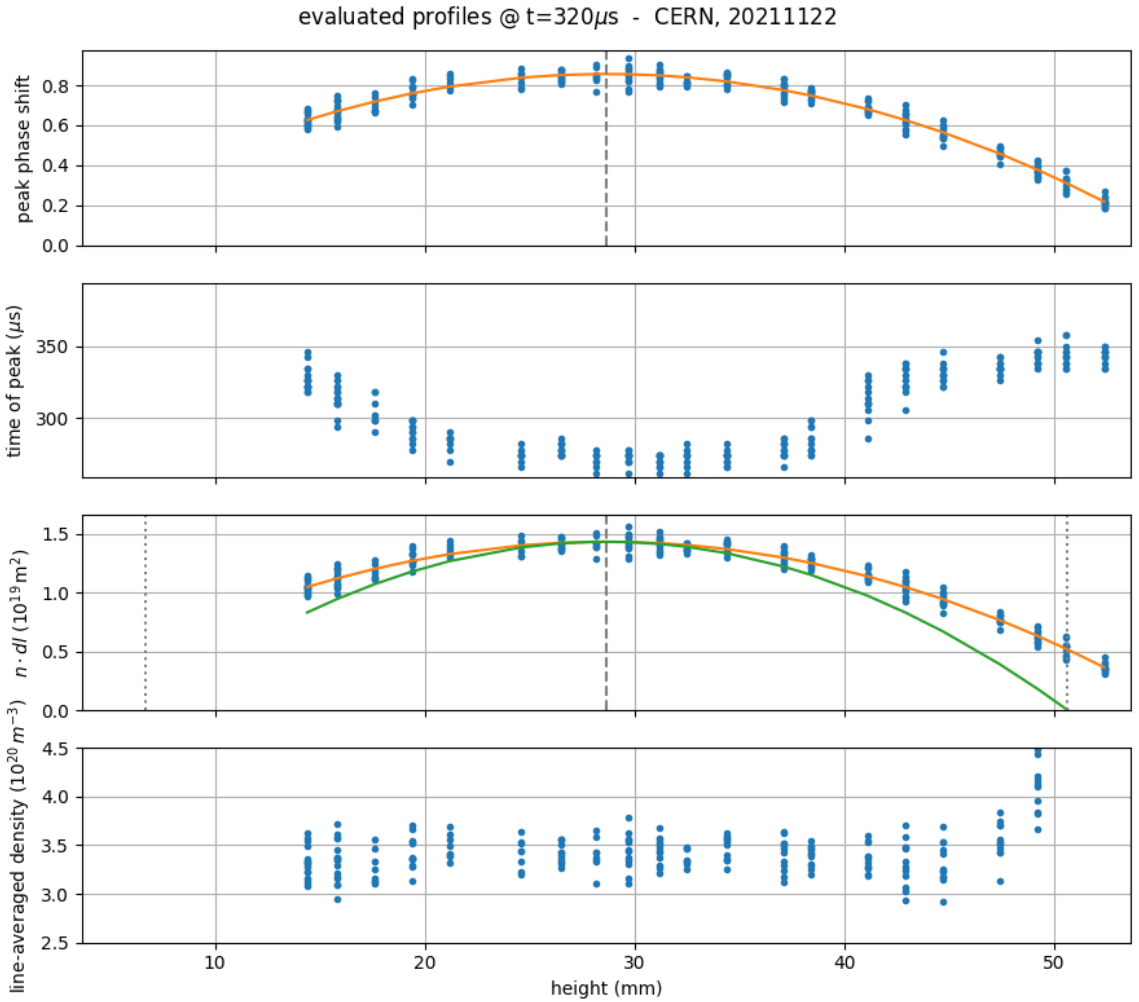




profile comparison at different times – solid ring ant.

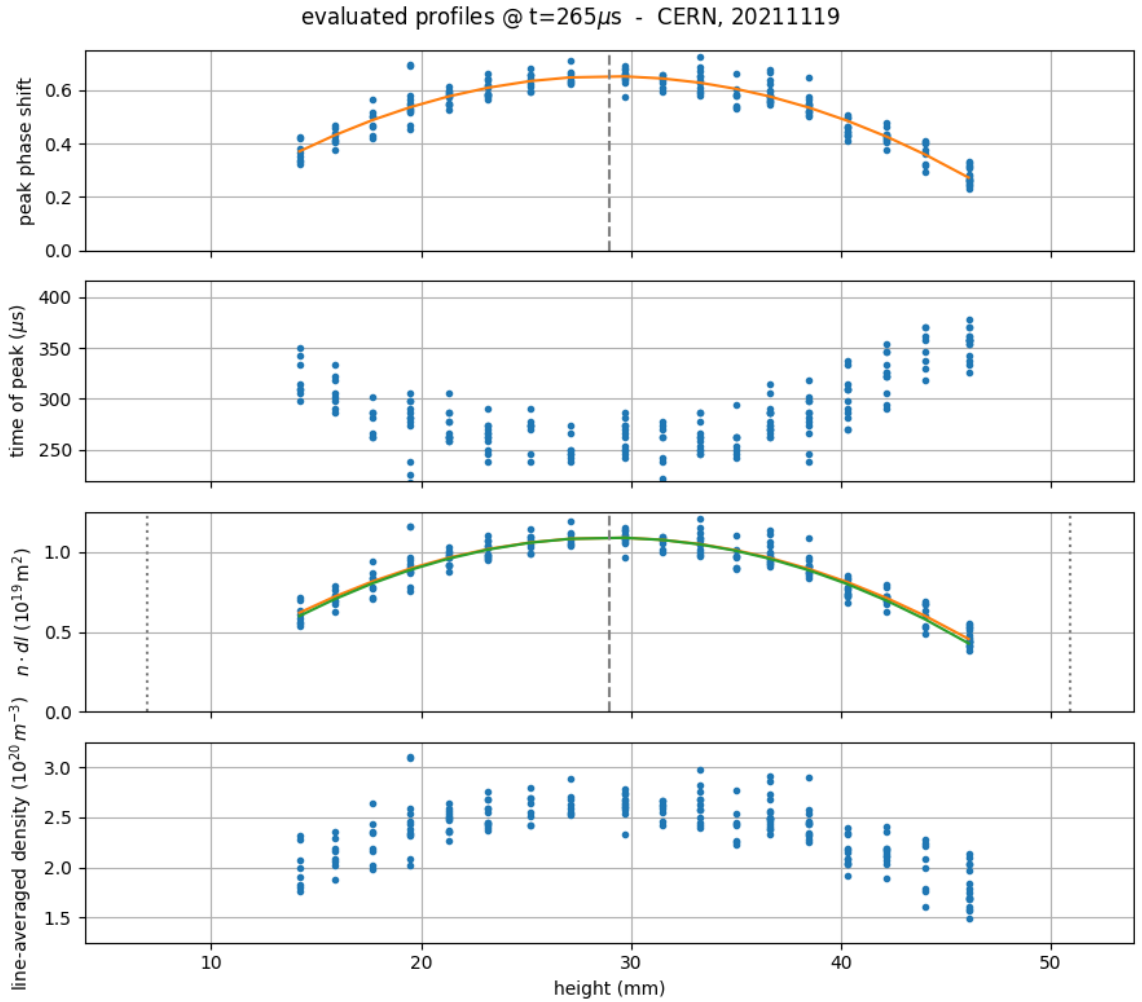
- p_0 = 8 Pa (argon) / P_{rf} = 9 kW/ant / I_{coil} = 350 A

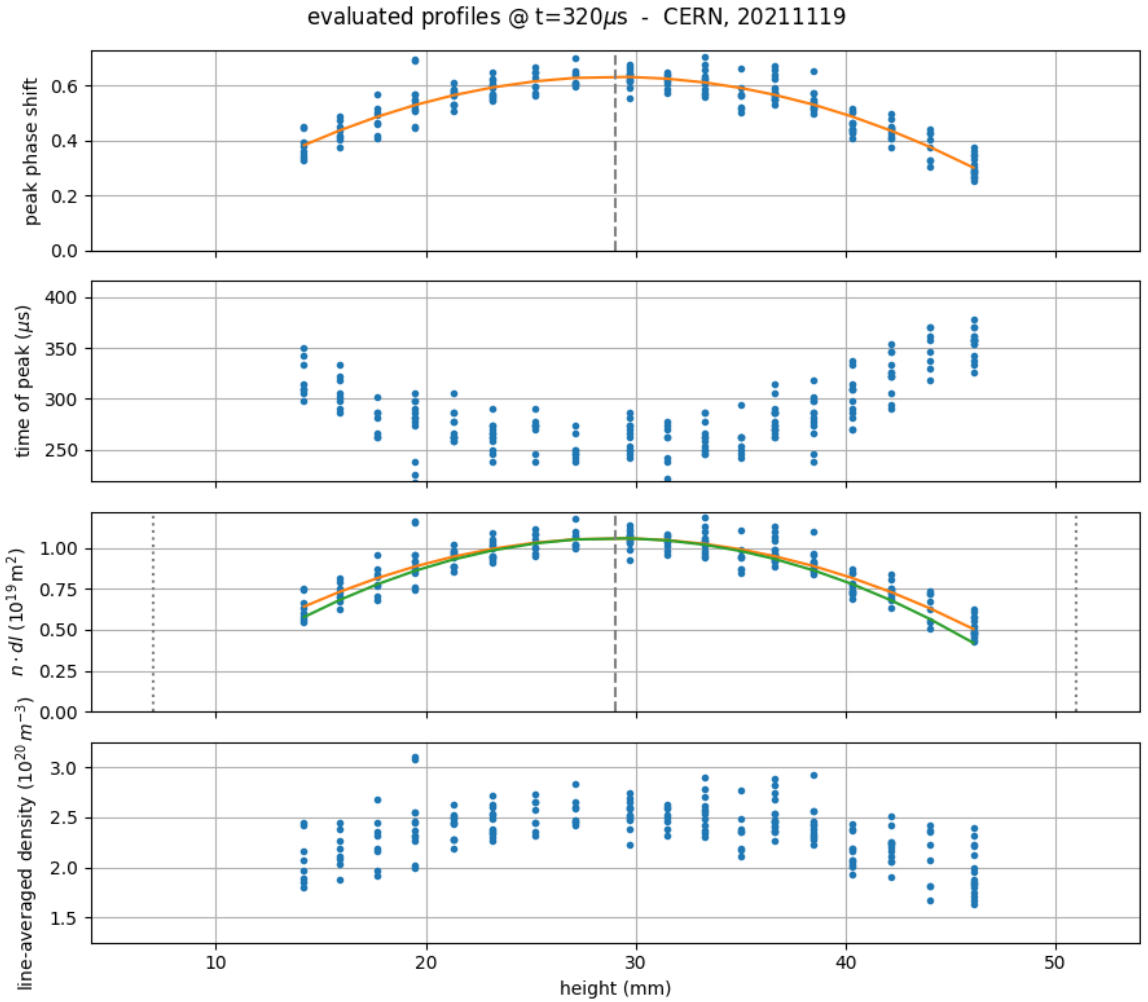




profile comparison at different times – half-turn helical ant.

- p_0 = 8 Pa (argon) / P_{rf} = 6 kW/ant / I_{coil} = 350 A





profile comparison at different times – half-turn helical ant.

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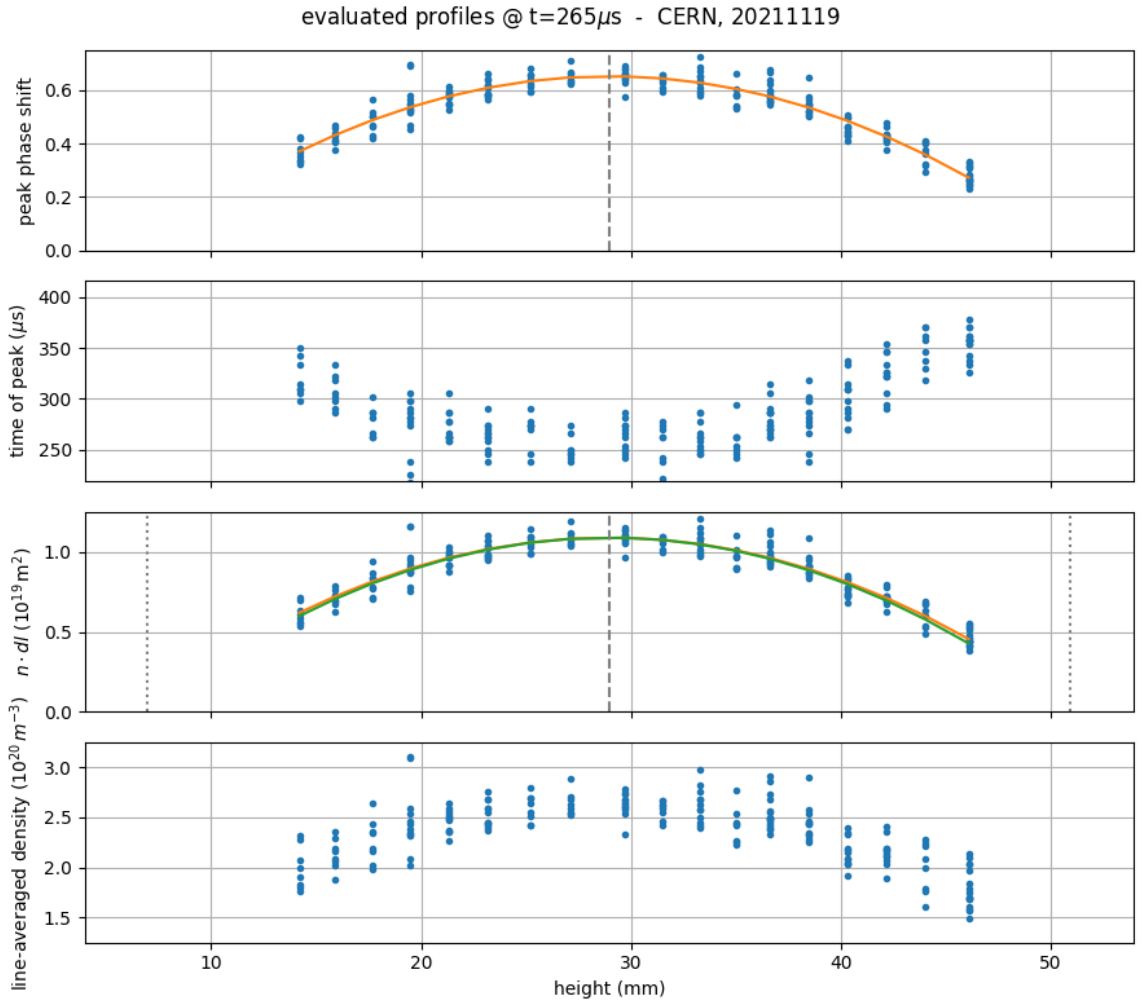


- profiles identical to 2018 measurements in HGW
- parabolic shape of line-integrated density robust against changes of operation conditions
- credible inversion of profile
- peak local density ~2×10^{20} m^{-3} *significantly* lower than expected for 6 kW input power (5×10^{20} m^{-3})

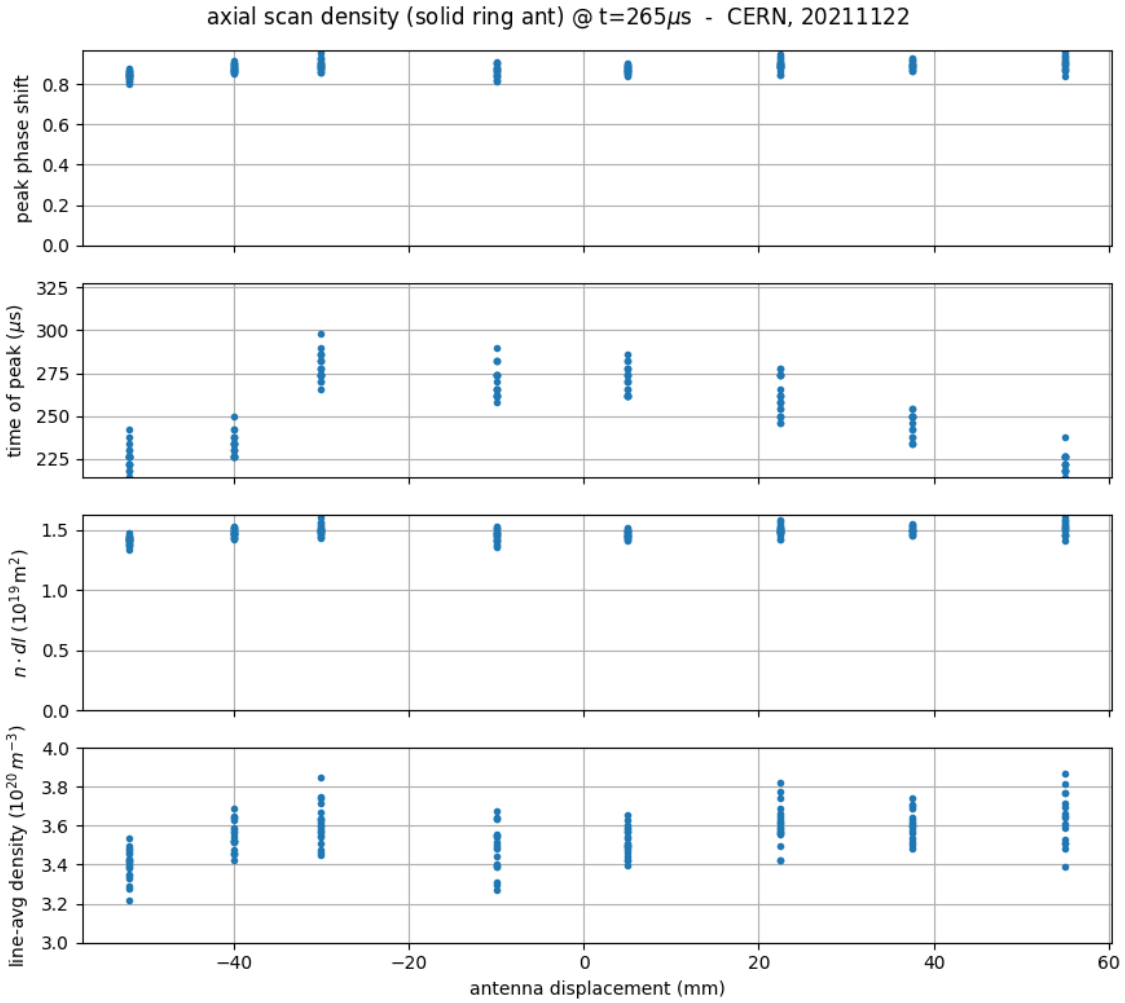
→ this plus massive arcing at antennas: check, understand and improve rf system!

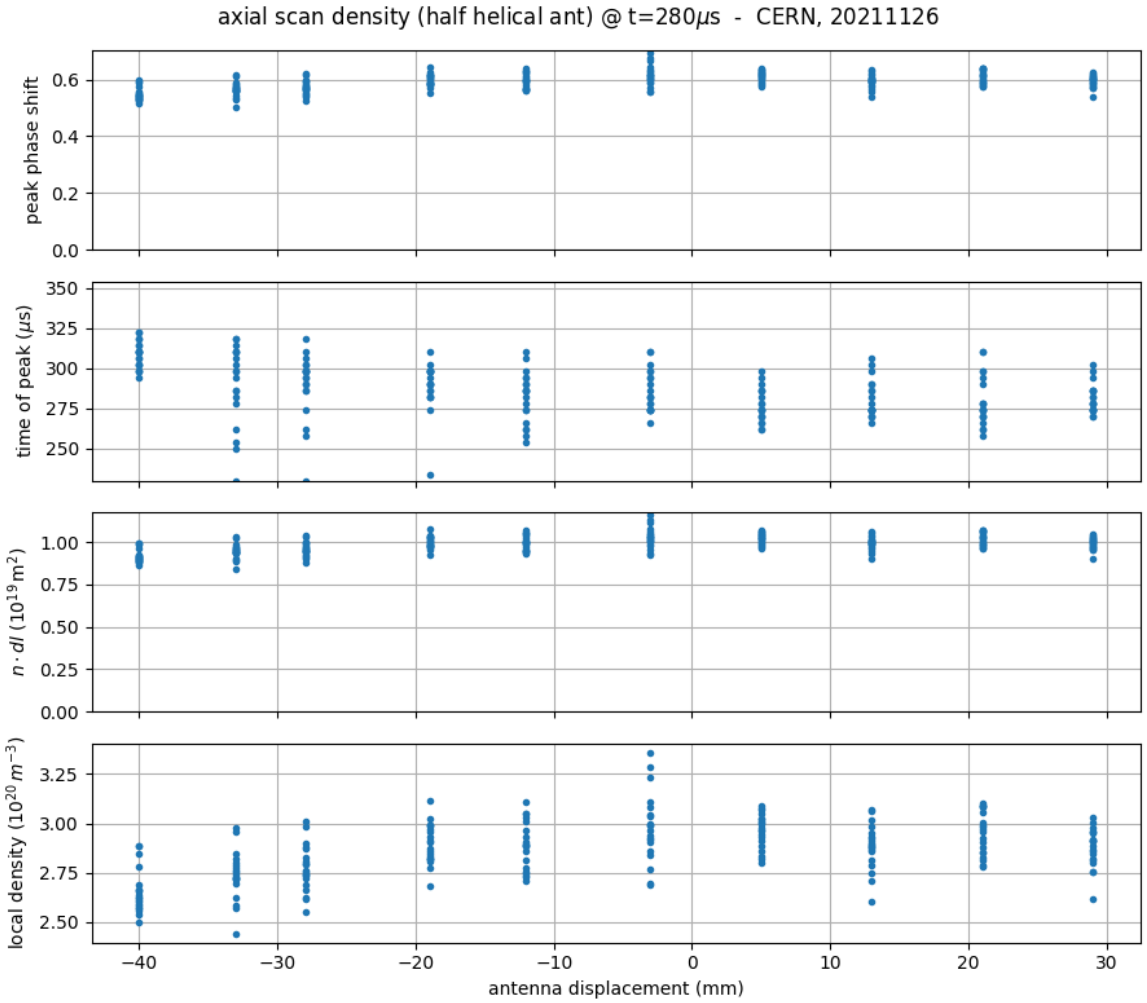
rf system: reasons for arcing

- **cross-coupling between antennas**
  phase scans including all 3 antennas to find „sweet spot“
  → possible, but no significant influence

- **large voltages on antenna conductors (Cu rods between matchbox and antenna)**
  measured with high-voltage probe at MB output, both legs
  - voltages up to 3.7 kV w.r.t. ground (= optical table)
  - best case around 2.5 kV after matching / phase adjustments / grounding scheme adjustments
  - potential culprit: rf cable length ($\leq$ 8.5m at CERN, were $\leq$ 5m in HGW)
    → to be investigated by varying cable length using old rf cables from HGW

axial density: solid ring antennas





→ **less than 10% variation** (assuming no profile change!)

Results – rf system

- **rf system issues significant annoyance**
  - rf stray signals via random lines disturbing devices (pump, piezo ☩)
  - best grounding scheme largely still unclear

- **rf phase shift between antennas**
  - optimized phase shift required for good performance at higher rf power
  - scan using all involved antennas necessary to find working point

- **high voltage on antennas**
  - rf cable length influence to be checked
  - potentially re-design (parts of) the rf circuit:
    - resonant antennas?
    - balun between matchbox and antenna (but dimensioning unclear)?
    - …?

Results – physics

- **choice of antenna**
  - ring antennas limited to $n_e \leq 4\times10^{20}$ m^{-3} at operational parameters limits → insufficient for AWAKE
  - half-turn helical antennas up to $n_e = 3\times10^{20}$ m^{-3} at reduced rf power

→ half-helical antennas „best choice“

- **axial density distribution**
  - variations of the order 10% for both tested antennas, with different behavior between the antennas

→ first measurement done, more necessary including radial profile information

- **radial density profile**
  - broad, flat profile with ring antennas, high density at plasma edge → hint to high inductive coupling (skin depth few mm at these density values)
  - parabolic line-integrated profile for half-turn helicals as in HGW, clear blue core → more helicon-like, centrally peaked impression

→ half-helical antennas better suited