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FÜR PLASMAPHYSIK

Collective Thomson Scattering at Wendelstein 7-X: achieved results and glance into the future

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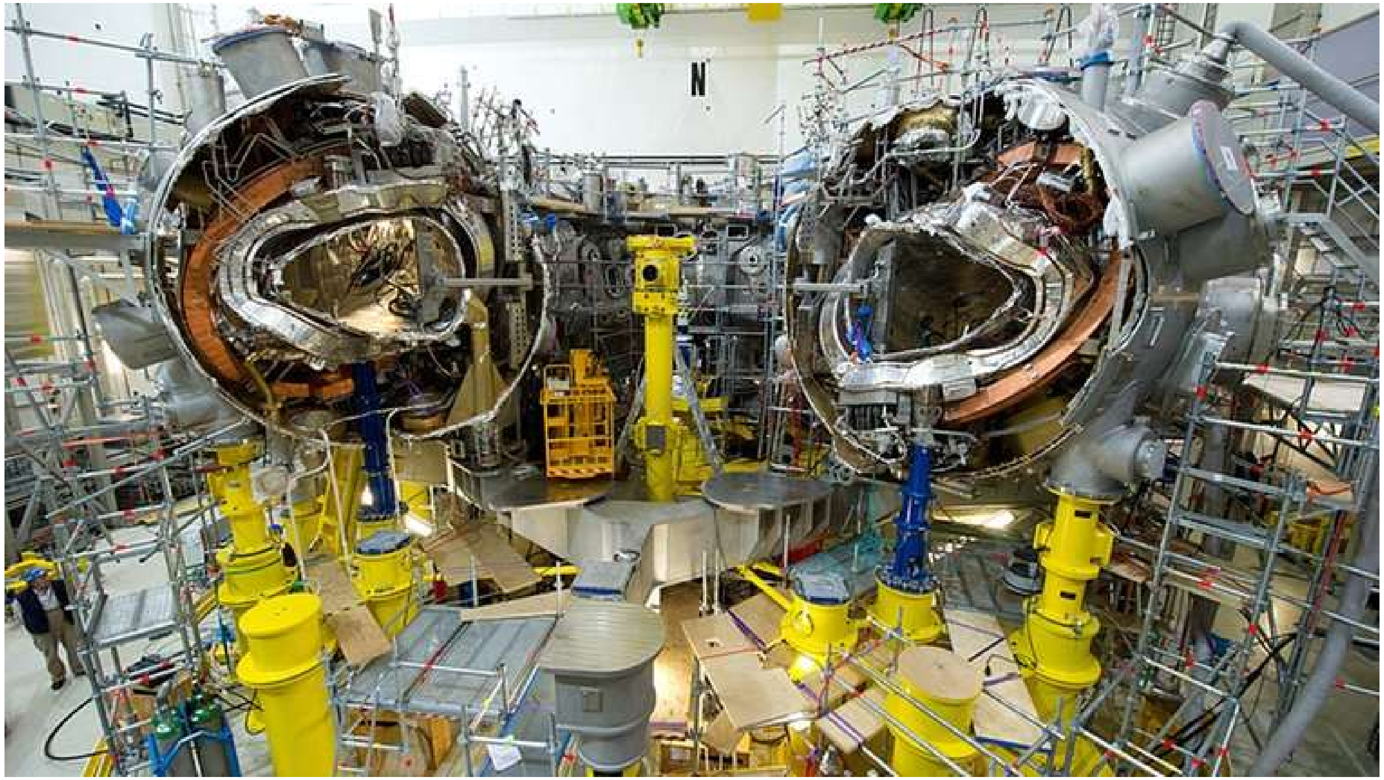
Introduction: purpose of the Collective Thomson Scattering (CTS) diagnostic

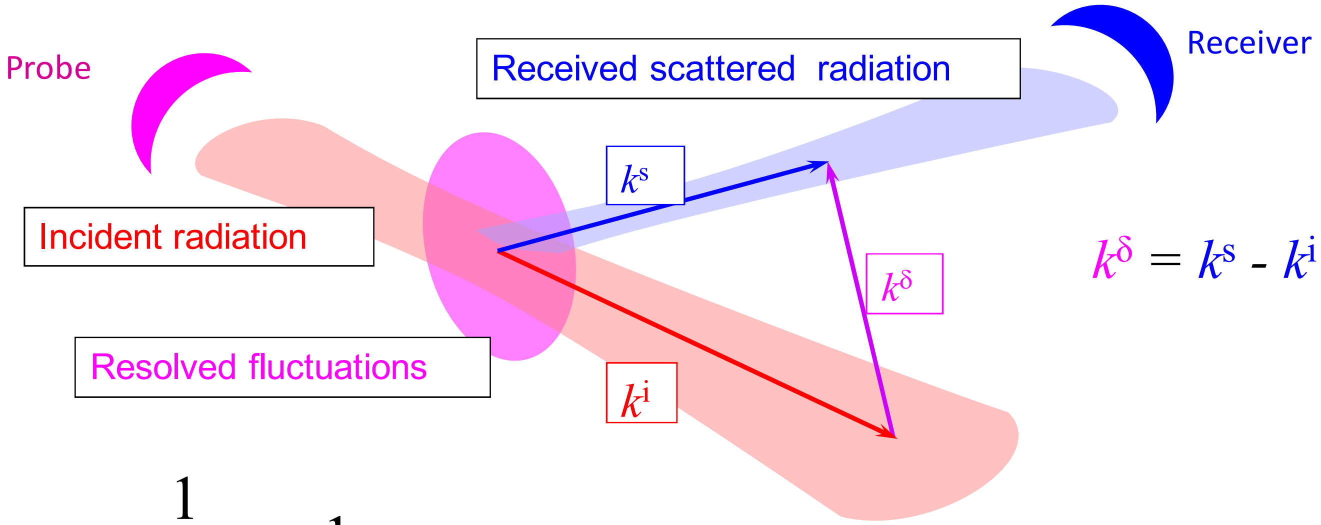


- W7-X is an optimized superconducting stellarator
- Particularly optimized for good fast ion confinement at high beta

Purpose of CTS

- Ion temperature measurements (primarily)
- Fast ion measurements
- Fundamental microwave physics investigations

Principle of the diagnostic



$$\alpha = \frac{1}{k^\delta \lambda_D} > 1$$

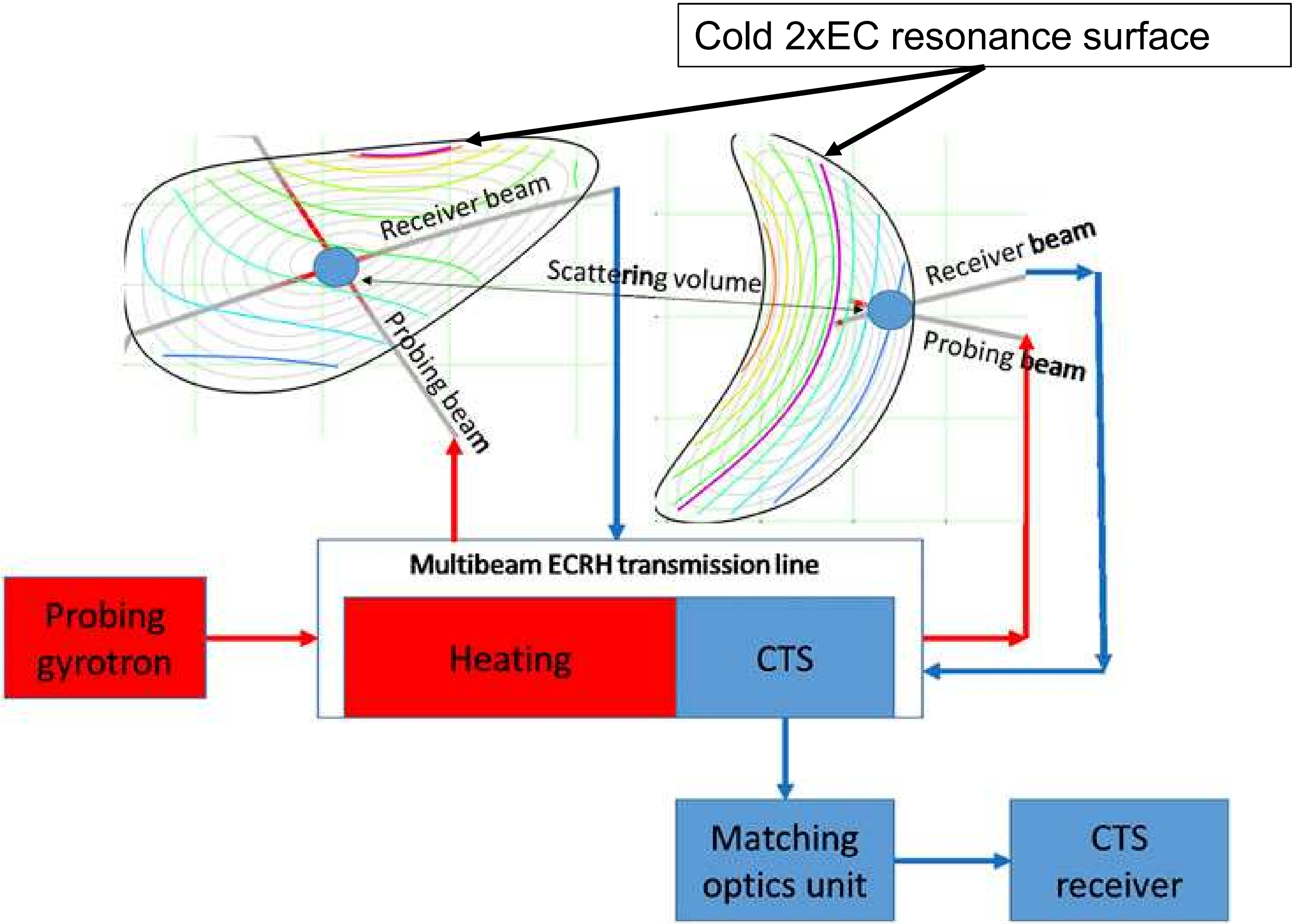
E. E. Salpeter **1960**, *Phys. Rev.* 120, 1528

$$\varphi = \angle(\vec{k}^\delta, \vec{B})$$

Flexible due to steerable mirrors

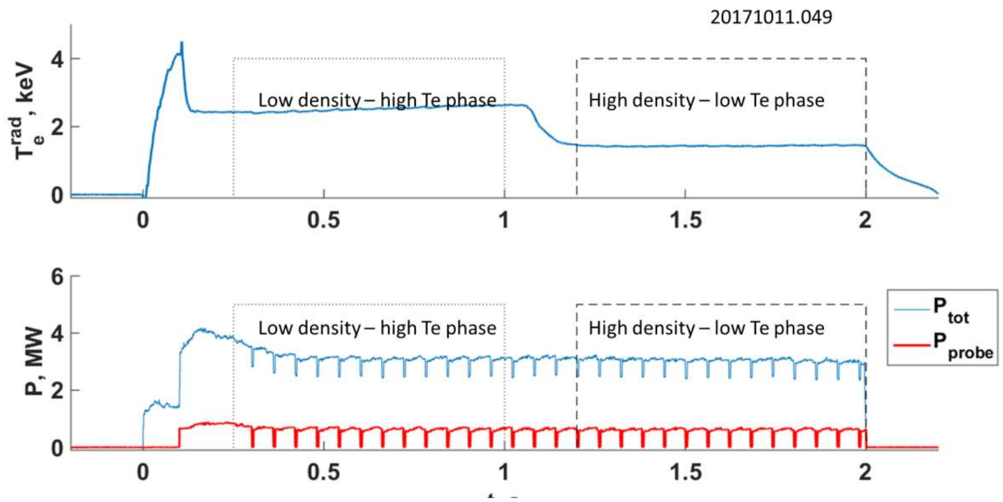
Microwaves allow a wide range of scattering geometries while fulfilling the Salpeter criterion

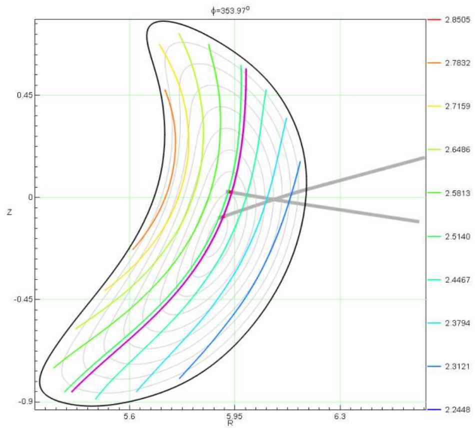
Layout of the existing set-up

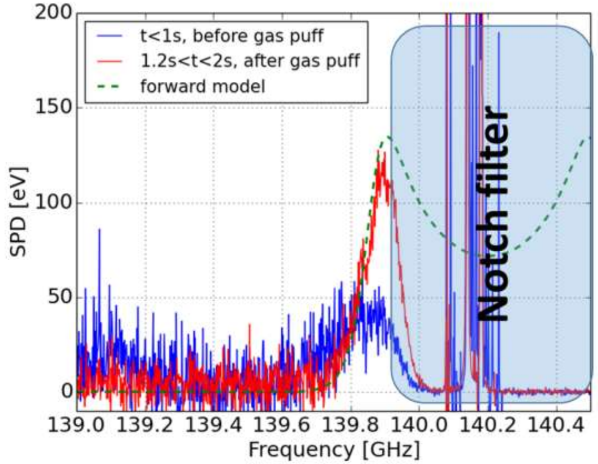


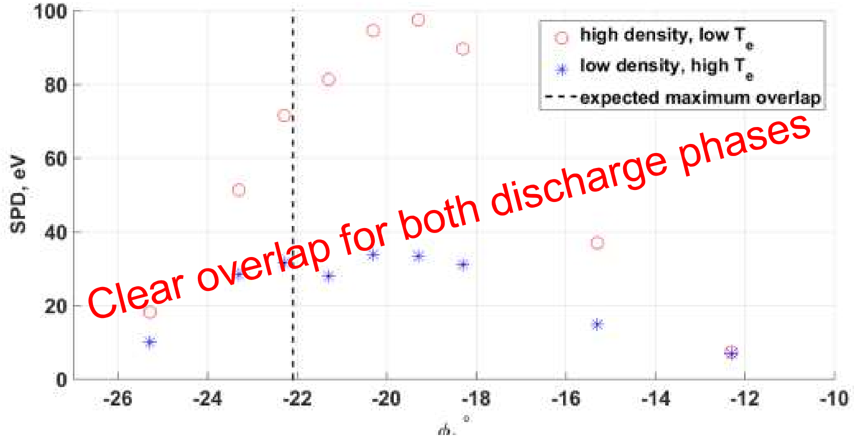
- Based on 140 GHz ECRH system
- Shares gyrotrons and transmission line.
- Suffers from high electron cyclotron radiation (high level of noise).
- Limitations on scattering geomentries.

Achieved results. Bean-shaped cross-section.



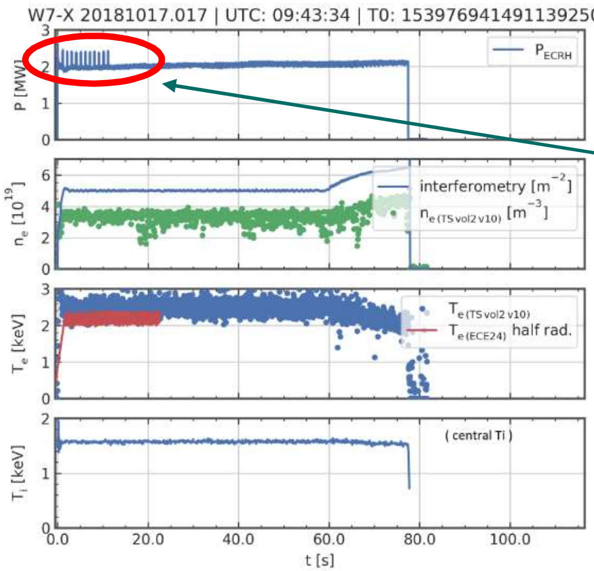




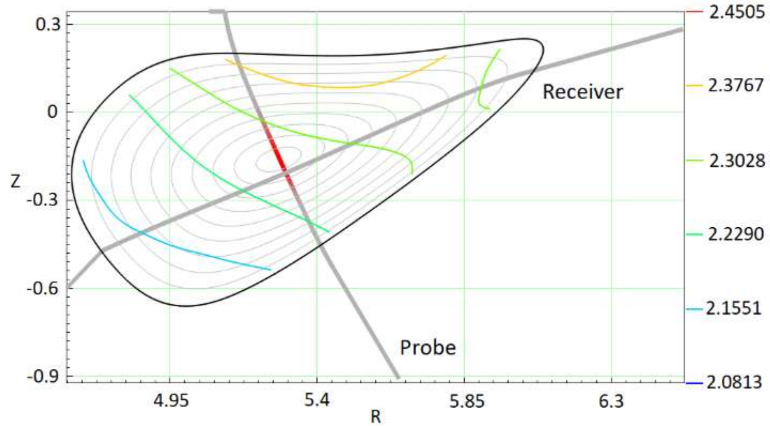


D. Moseev et al., RSI 2019

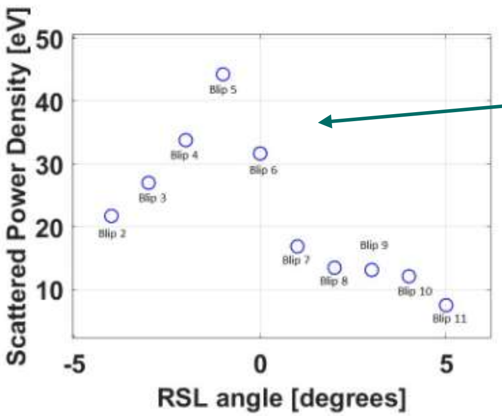
Achieved results. Triangular cross-section.



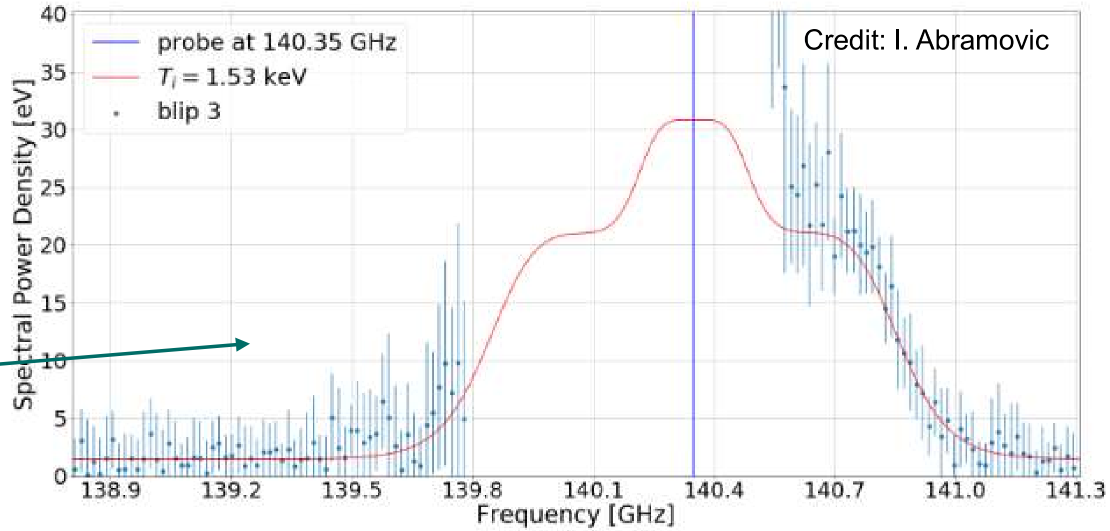
11 ECRH blips from the remote steering launcher, gyrotron beam was swept across the receiver



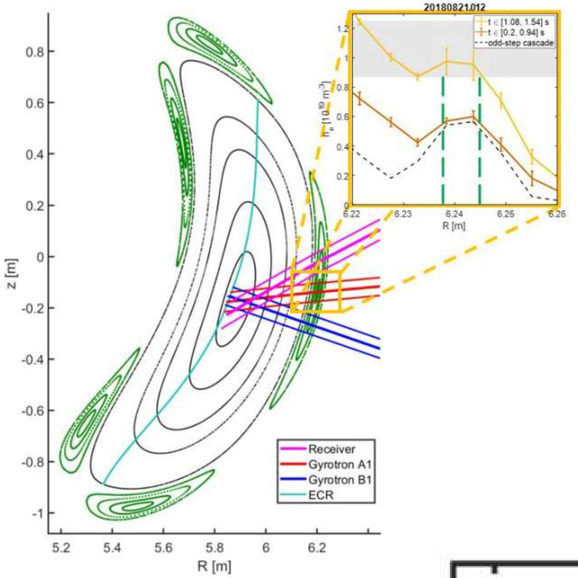
Corresponding average PSD in the signal -> clear overlap

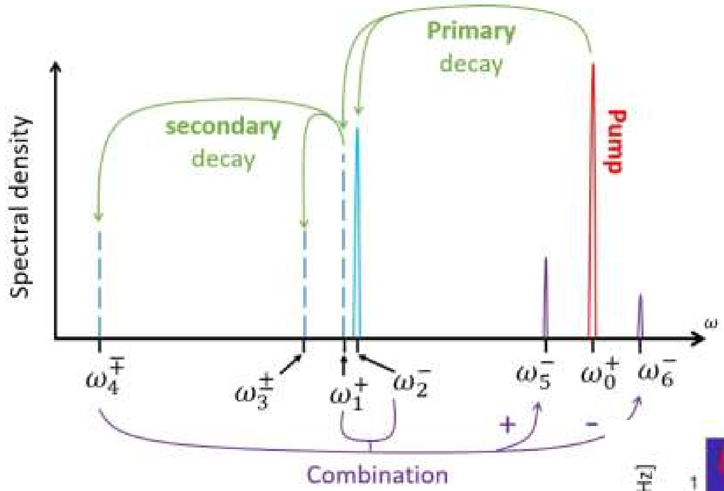


Ti is inferred by Minerva

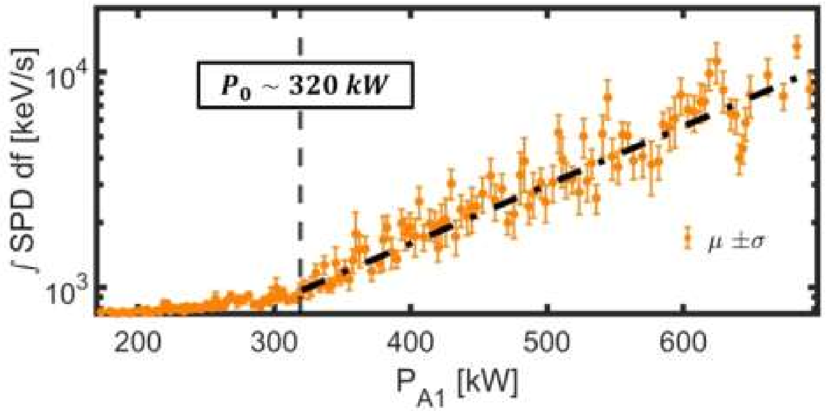


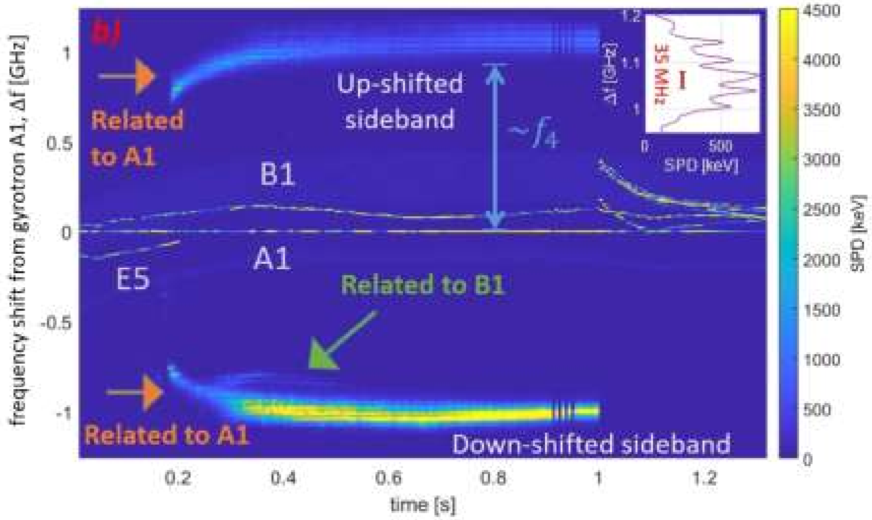
Achieved results. Parametric decay instability.





A. Tancetti et al., NF 2022





Transition to another frequency

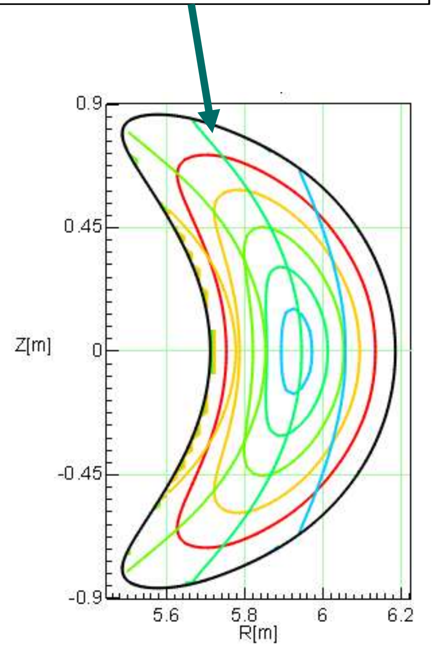
140 GHz:

Background is very high.

Plasma absorbs 140 GHz in the middle of the bean-shaped cross-section.

Low cut-off density for X mode ($1.2 \cdot 10^{20}$ m^{-3}).

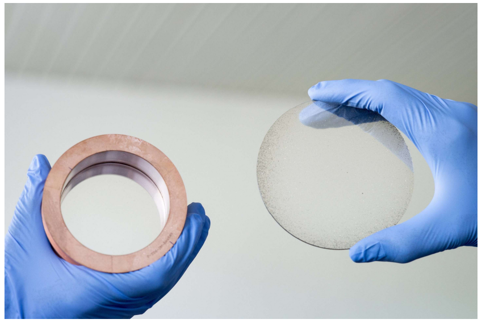
140 GHz is absorbed here



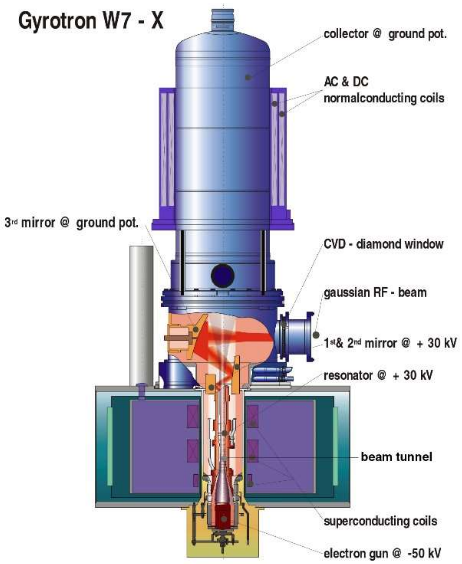
Other frequencies

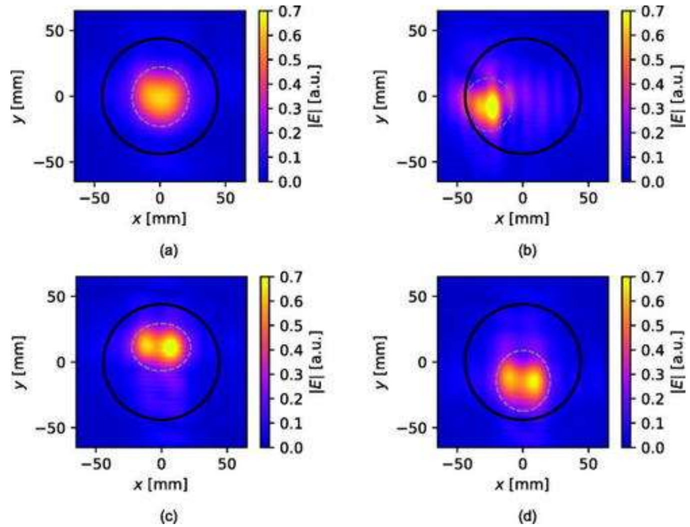
- Gyrotrons should support it.
- Low reflection from vacuum windows.
- Low background and reasonable spectral power density (SPD) for scattering signal.

Choice of 175 GHz frequency



Existing diamond windows retain antireflective properties at 175 GHz

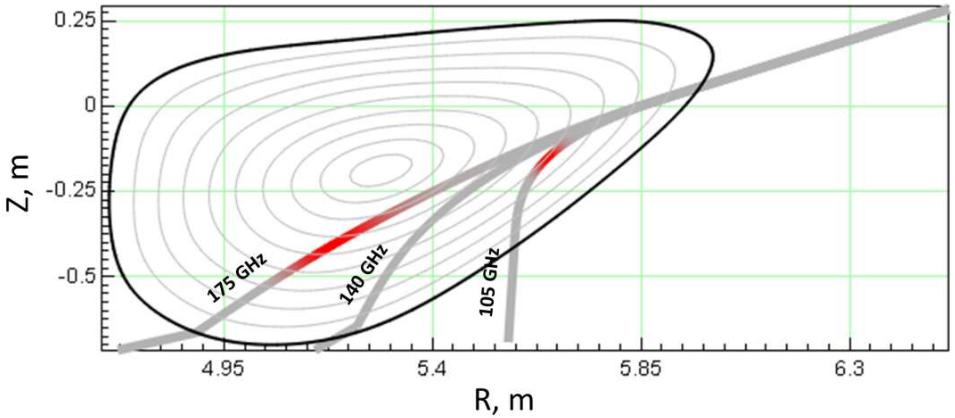




Gyrotron can operate at higher cavity mode $TE_{34,10}$ (c) instead of $TE_{28,8}$ (a)

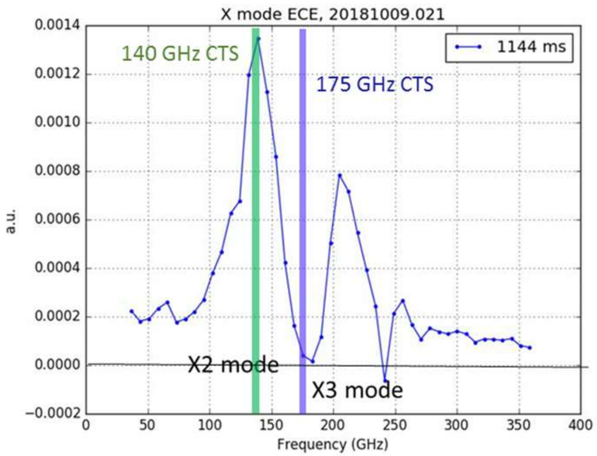
L.Krier et al., PoP 2020

Min. ECE and good refraction properties



Refraction strongly affects lower frequencies, especially at the oblique launch.

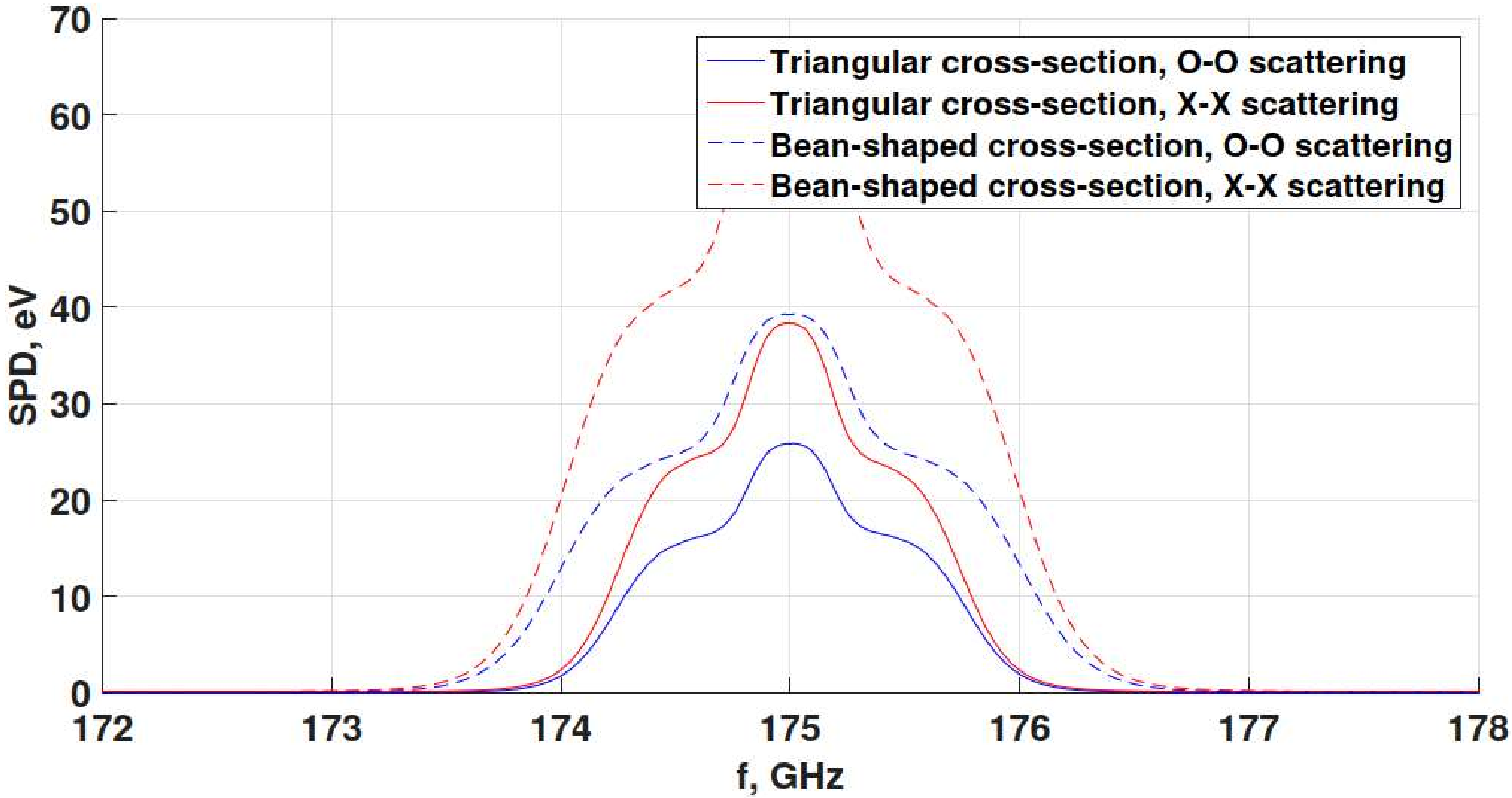
Here are O-mode beams from the CTS antenna in the triangular cross-section. Higher frequency -> less of a problem.



Background should be minimized for better signal-to-noise ratio. 175 GHz seems to have minimum ECE.

<- ECE meaurements by Michelson interferometer. Courtesy of N. Chaudhary and J.W. Oosterbeek. TRAVIS shows pure zero ECE in this frequency range, possible instrumentation effect or bremsstrahlung.

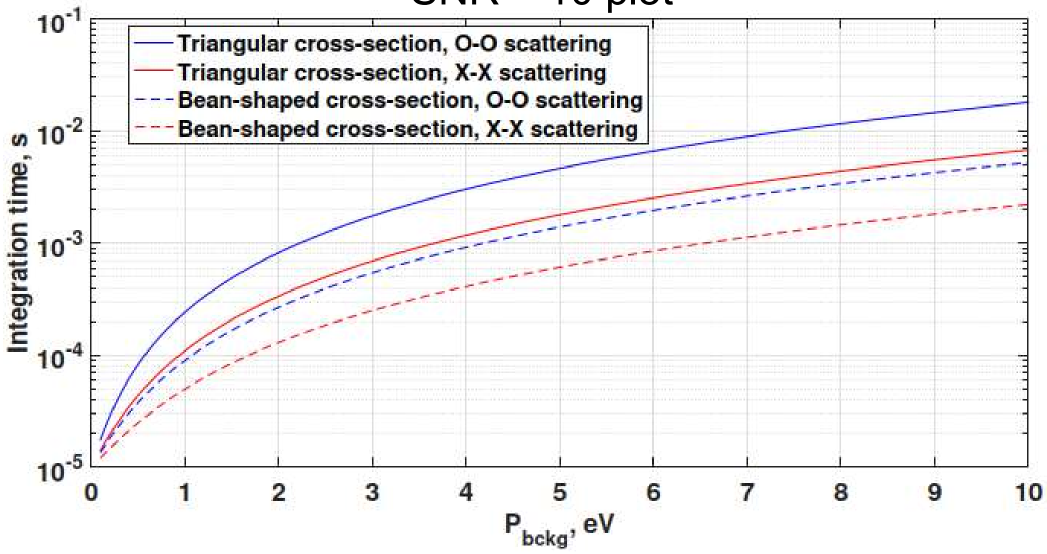
Thermal ion spectrum (simulated) at 175 GHz



Signal-to-noise ratio for Ti measurements

$$SNR = \frac{P_s\sqrt{WT}}{\sqrt{2(P_s + P_b)^2 + 2P_b^2}}$$

SNR = 10 plot

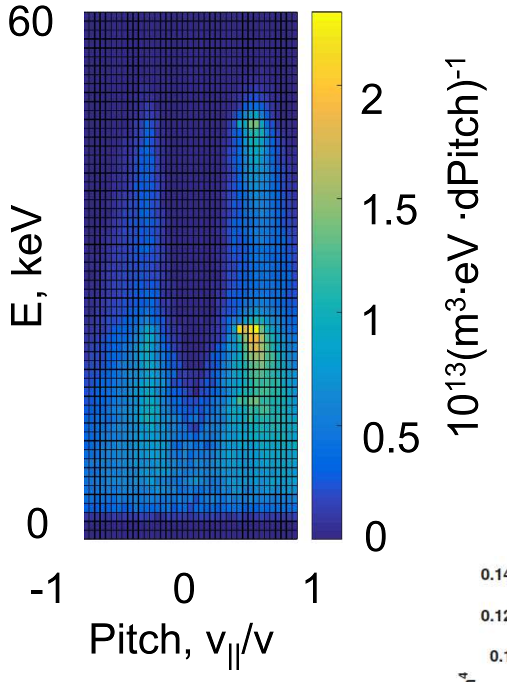


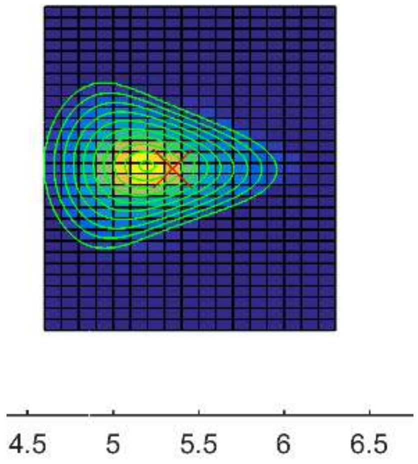
To the background level of 140 GHz CTS → 10^3

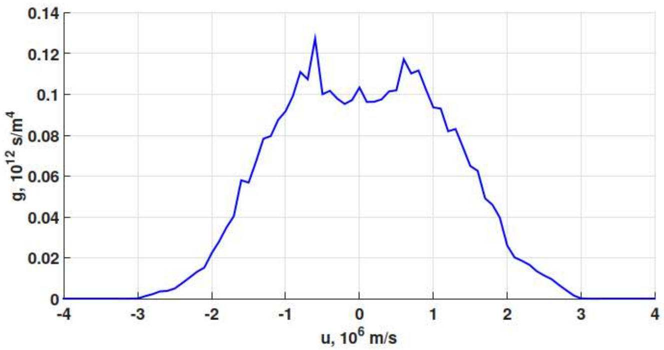
Plasma parameters:
ne = $6 \cdot 10^{19}$ m^{-3}
Te = 2.3 keV
Ti = 2 keV
B = 2.5/2.3 T in bean-shaped/triangular cross-sections
φ = 80° angle of k^{δ} to the magnetic field
θ = 160°/95° in bean-shaped/triangular cross-sections
ψ = 350°/30° in bean-shaped/triangular cross-sections

D. Moseev et al., JInst 2021

175 GHz CTS for fast ion measurements







Plasma parameters:

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Te = 2.3 keV

Ti = 2 keV

B = 2.5/2.3 T in bean-shaped/triangular cross-sections

φ = 80° angle of k^{δ} to the magnetic field

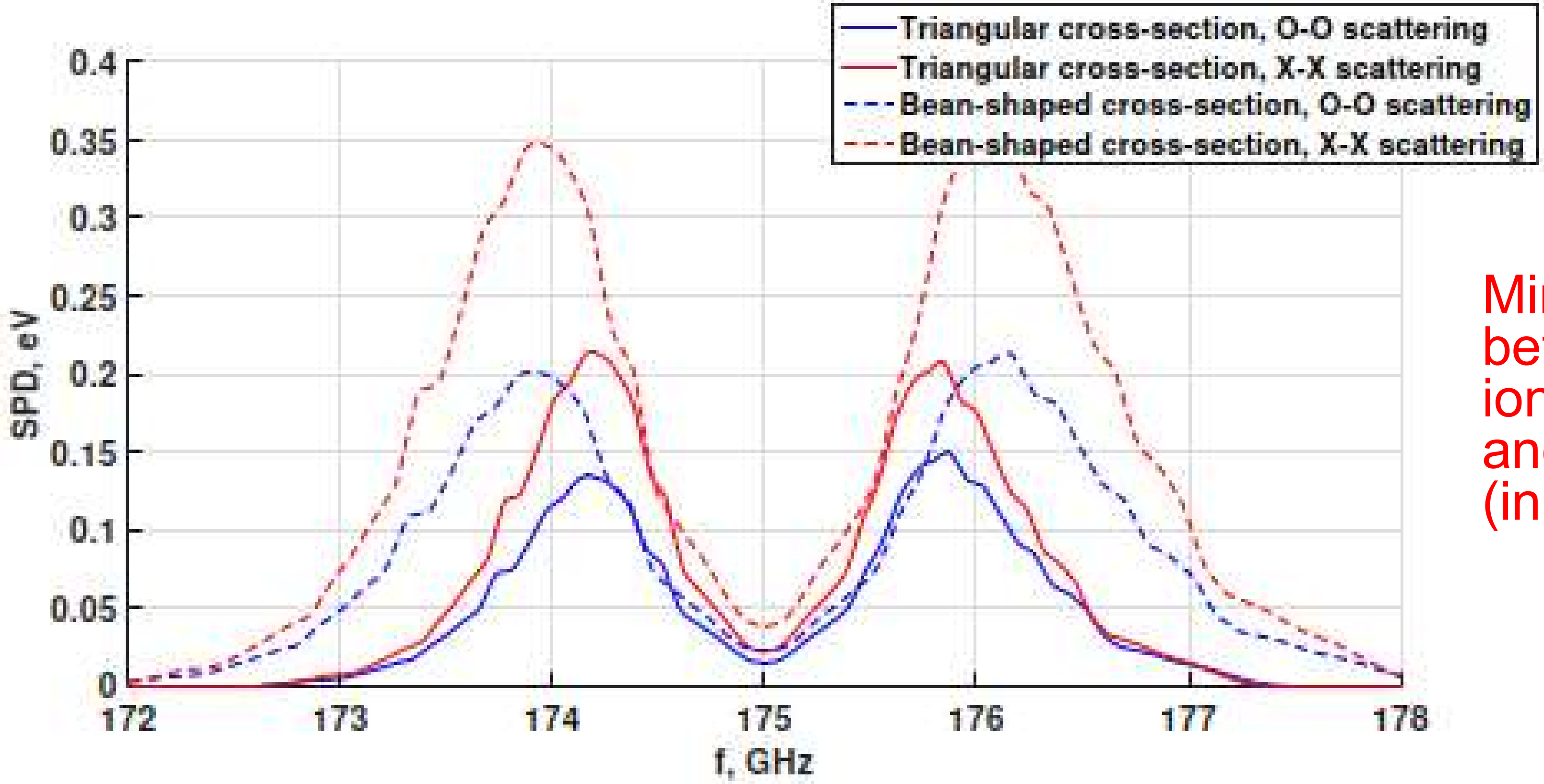
θ = 160°/95° in bean-shaped/triangular cross-sections

ψ = 350°/30° in bean-shaped/triangular cross-sections

P_{NBI} = 2.9 MW

<- CTS is sensitive to a projection of the fast ion velocity distribution function on the direction of k^{δ}

Fast ion spectrum (simulated) at 175 GHz

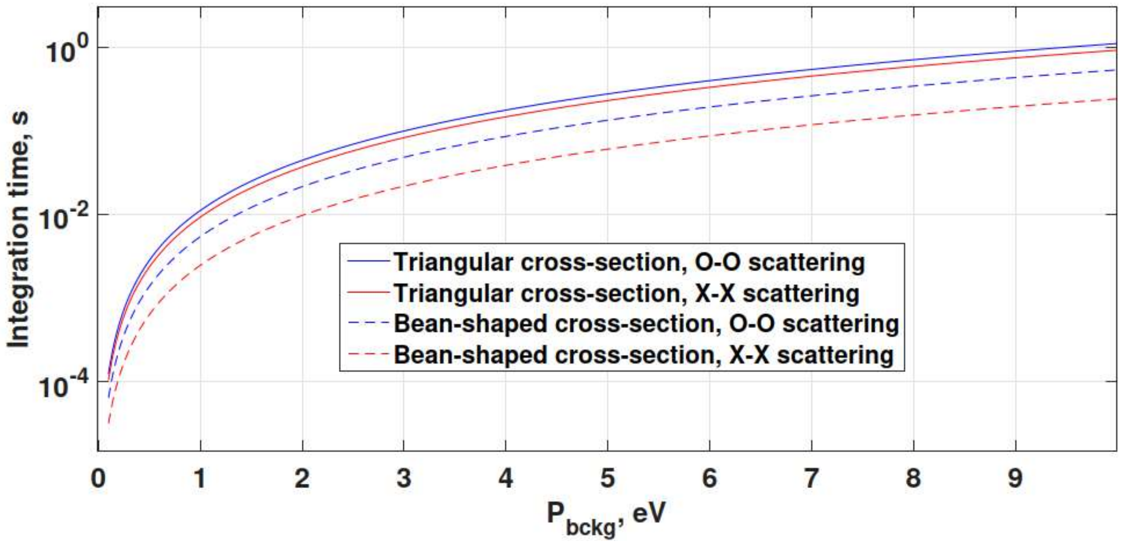


Mind the difference between simulated fast ion (in the order 10^{-1} eV) and thermal ion spectra (in the order 10^{2} eV)

Signal-to-noise ratio for fast ion measurements

$$SNR = \frac{P_s\sqrt{WT}}{\sqrt{2(P_s + P_b)^2 + 2P_b^2}}$$

SNR = 10 plot



10^3

D. Moseev et al., JInst 2021

Plasma parameters:

ne = $6\cdot10^{19}$ m^{-3}

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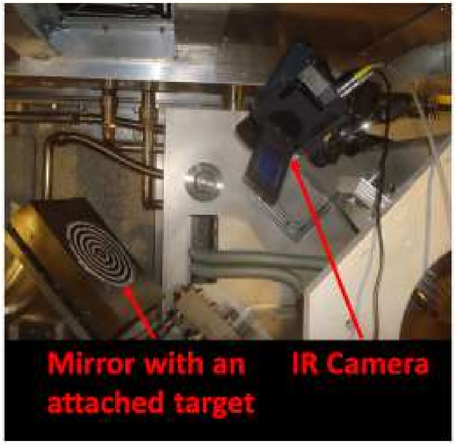
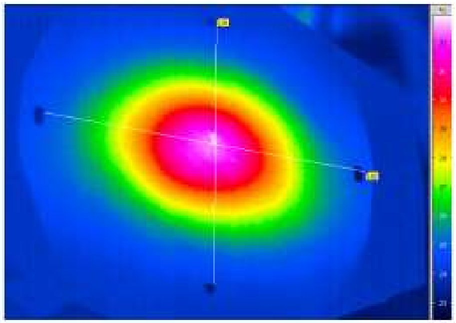
Clinotron development for alignment at 175 GHz

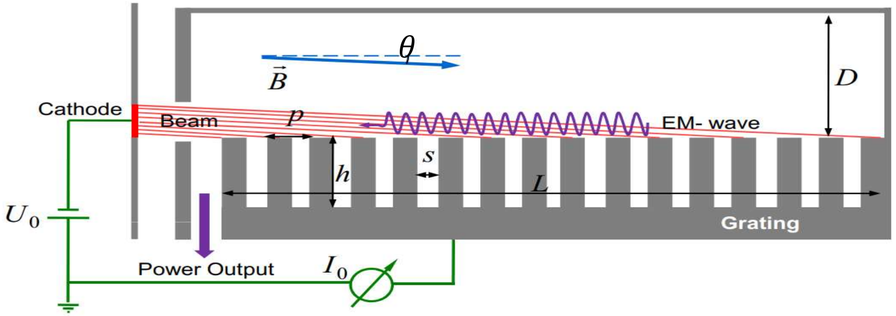


(a)



(b)

Thermographic alignment @ 140 GHz



S. Ponomarenko, seminar at IPP Greifswald, 03.06.2022

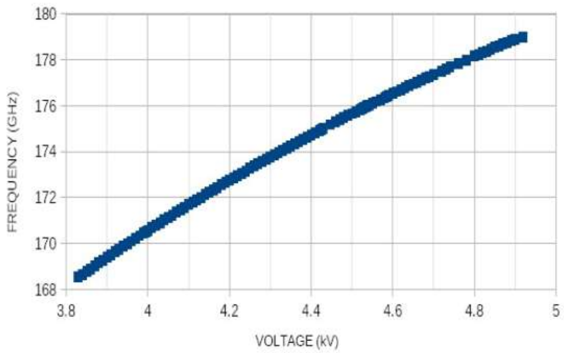


Fig 1. Frequency-voltage characteristic of the 175 GHz CW clinotron.

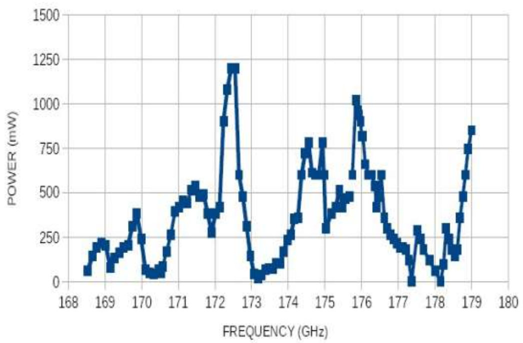
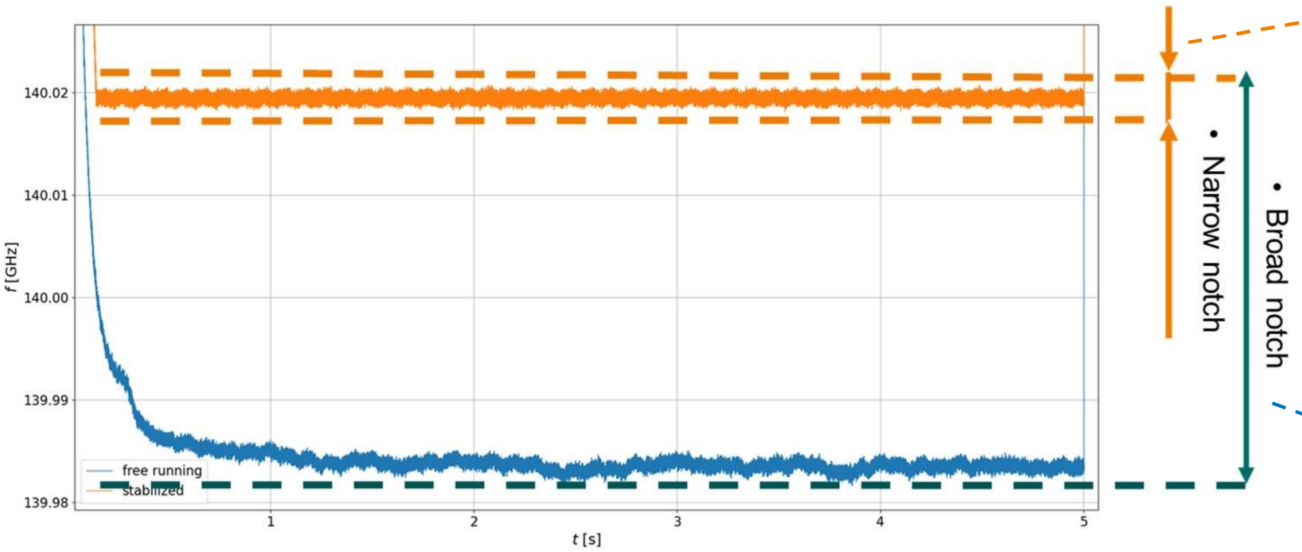


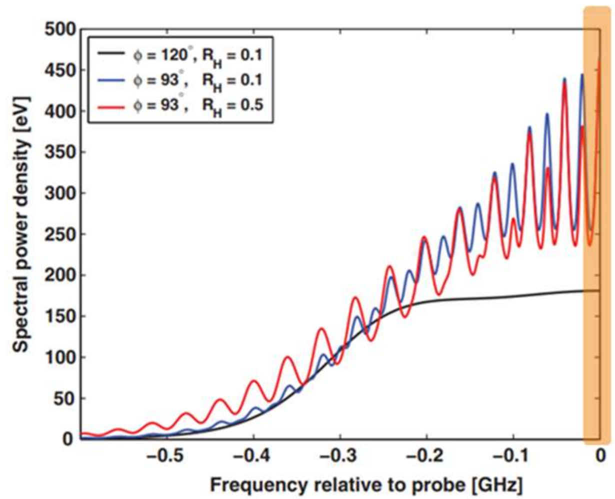
Fig 2. Dependence of the output power on operating frequency of 175GHz CW Clinotron Oscillator at beam current of 150mA, filament voltage 6.1V and filament current 1.45A.

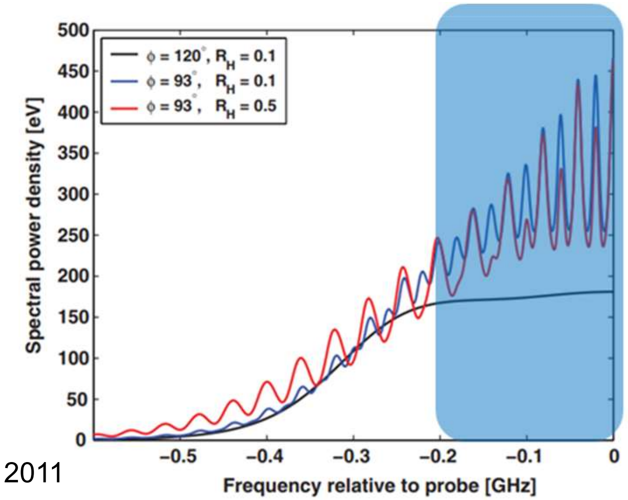
A. Likhachev et al., IVEC 2021

Importance of the gyrotron frequency stabilization

Ref: presentation of Laurent Krier on Monday







S.B. Korsholm et al., PRL 2011

Conclusions

- **140 GHz CTS proved to be working and capable of ion temperature and parametric instability measurements**
  - **Significant noise from ECE prevents from high accuracy measurements**
  - **Some geometries are inaccessible due to the resonances present in the plasma**
  - **Refraction is strong at higher densities**

- **175 GHz measurements are possible**
  - **Gyrotron operation at this frequency is possible**
    - A new 7T magnet is purchased and being tested
    - Gyrotron tests follow
  - **Receiver is being upgraded, also to frequencies of 70-90 GHz and 210 GHz**
  - **A clinotron for 175 GHZ @ 1W for the transmission line alignment is developed and produced**
  - **Frequency stabilization system soon be implemented at the probing gyrotron**