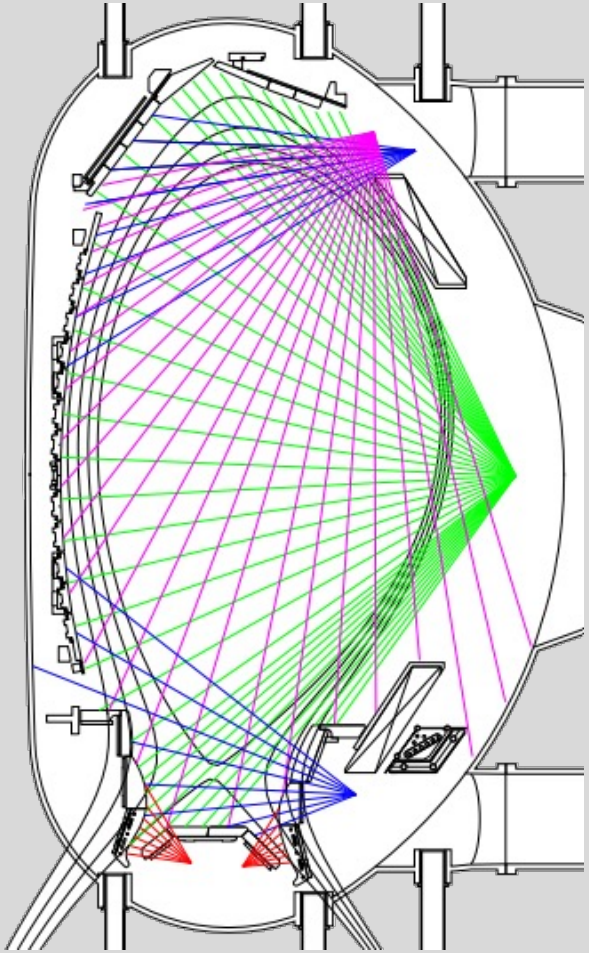

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Plasma diagnostics

- Plasma parameter

- Magnetic measurement
- Aktiv EM
- Passiv EM
- Particle beams
- Probes

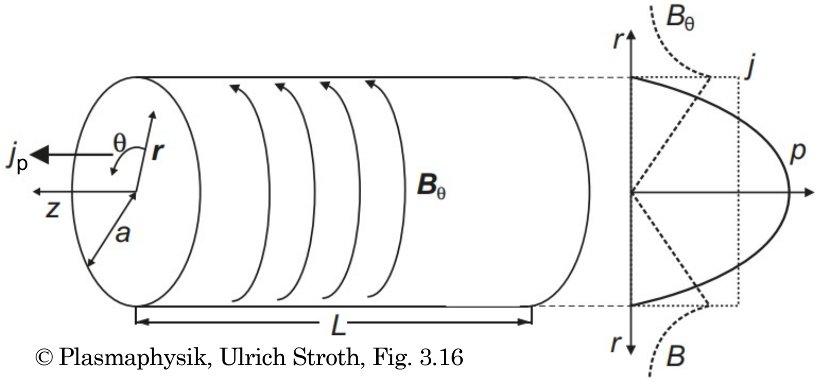
Plasma parameters to measure

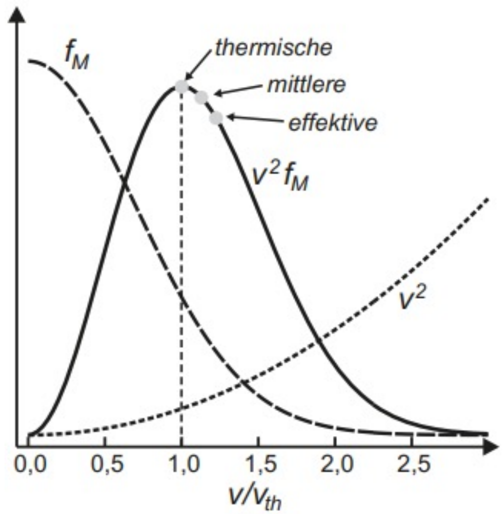
- Magnetic field B and plasma current I_p
- Plasma pressure p
- Density of ions n_i and electrons n_e
- Temperature of electrons T_e and ions T_i
- Distribution function for ions f_i and electrons f_e
- Plasma potential Φ_p

- Fluctuations of parameters and impurities

- Parameters are often related

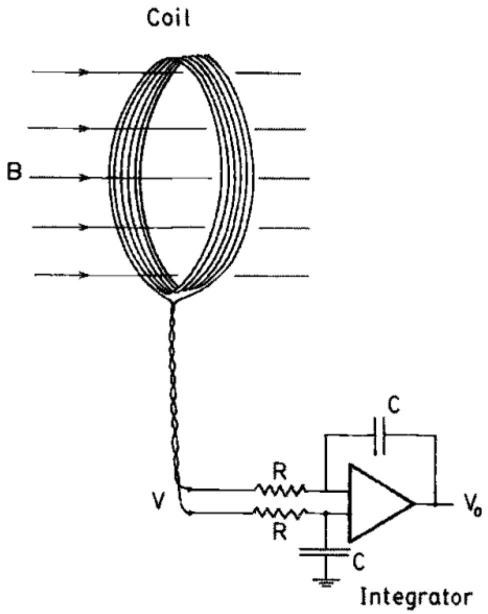
  → Combination of different diagnostics (50 in modern systems)



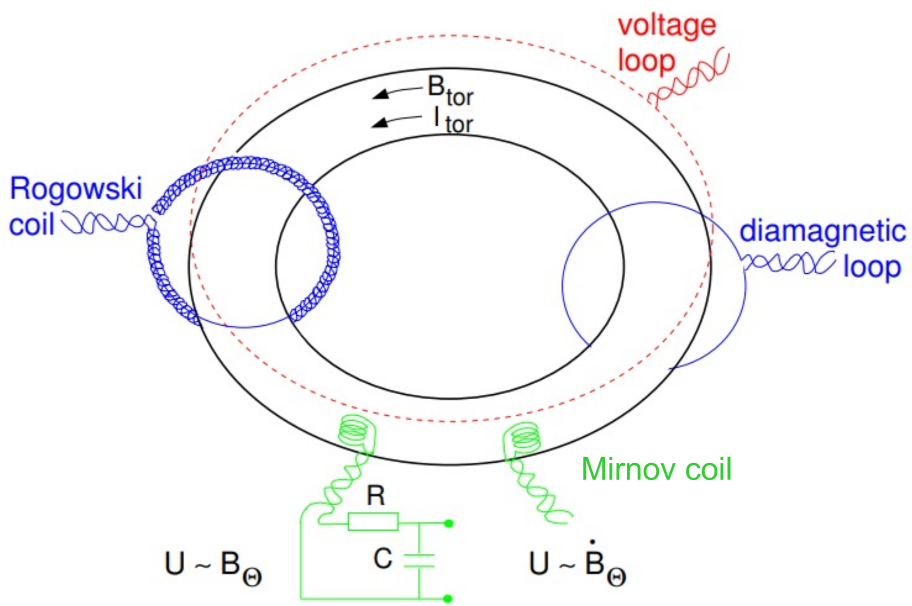


Magnetic measurement

- Parameters: magnetic field, plasma pressure and current
- Measure the voltage induced in small coils $U_{ind} = -N\dot{\Phi}$
- Obtain the magnetic flux change → Integration over time
- Devices: Rogowski-Coil, **Mirnov-Coil**, Loops



© Principle of Plasma Diagnostics, Hutchinson, Fig. 2.1



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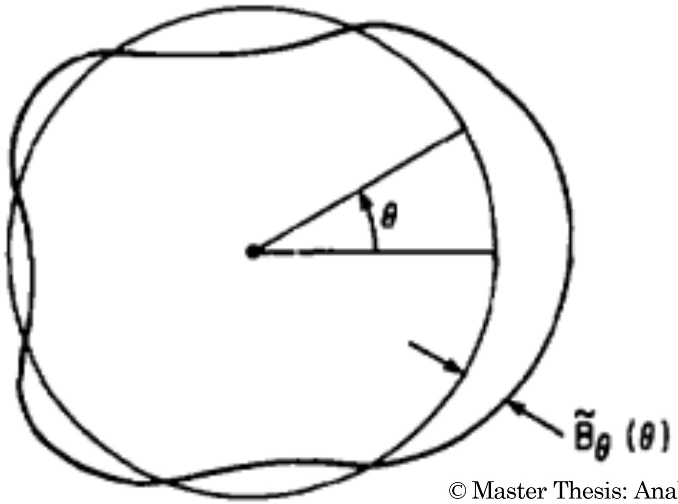
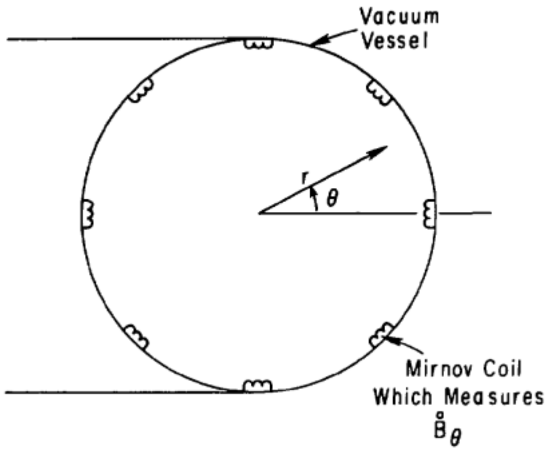
Mirnov Coil

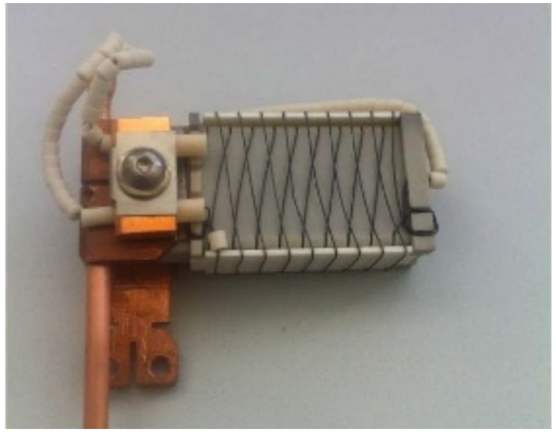
- Several coils arranged in arrays
- For measuring B_{Θ} and B_{φ} at certain positions





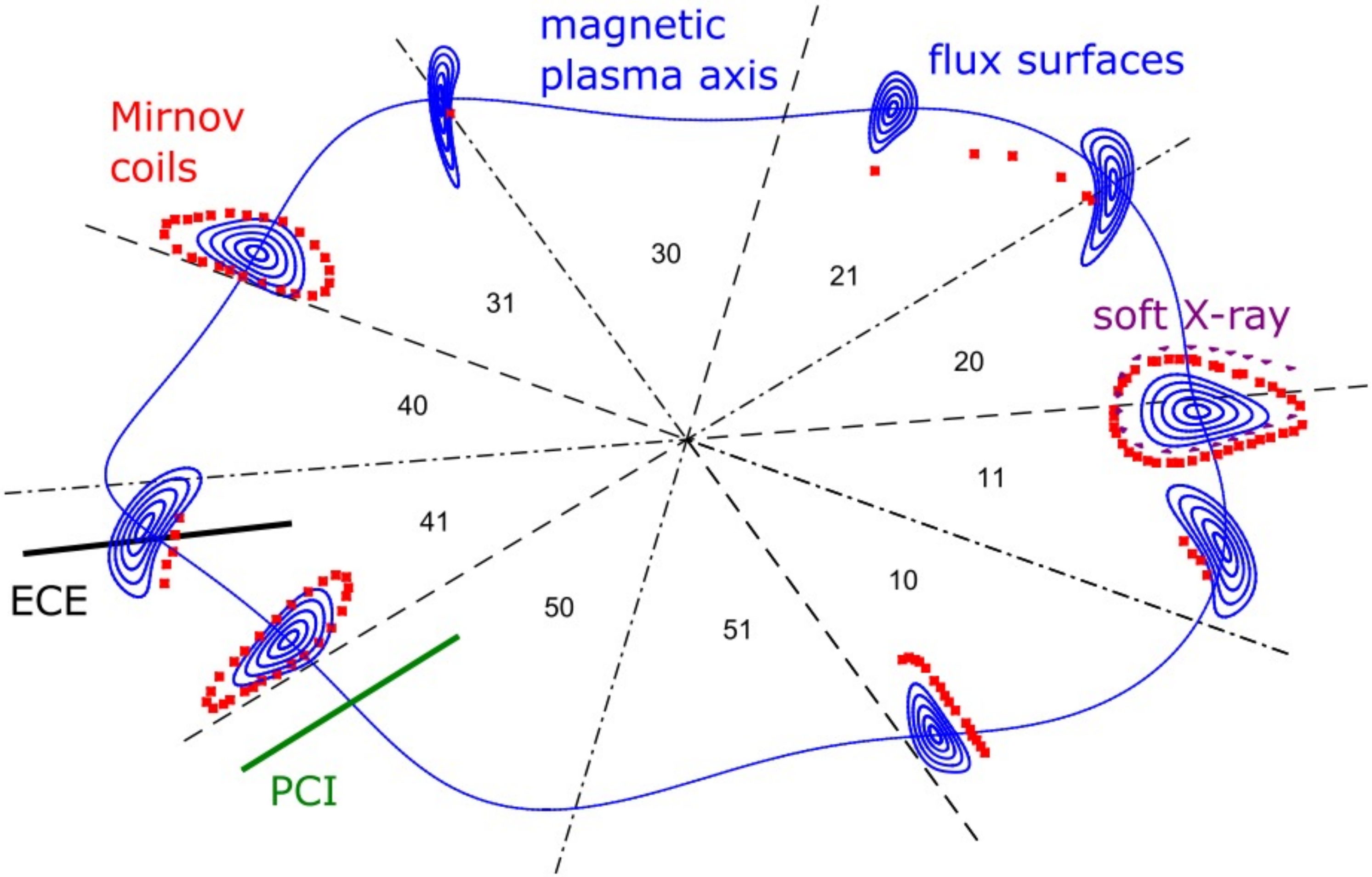
© Master Thesis: Analysis of Mirnov Oscillations on PDX, Hammett/McGuire

- Easy way to measure magnetic fluctuations
- 125 Mirnov-coils in Wendelstein 7-X



© Alfvénic fluctuations measured by in-vessel Mirnov coils at the Wendelstein 7-X stellarator, Fig. 1(b)

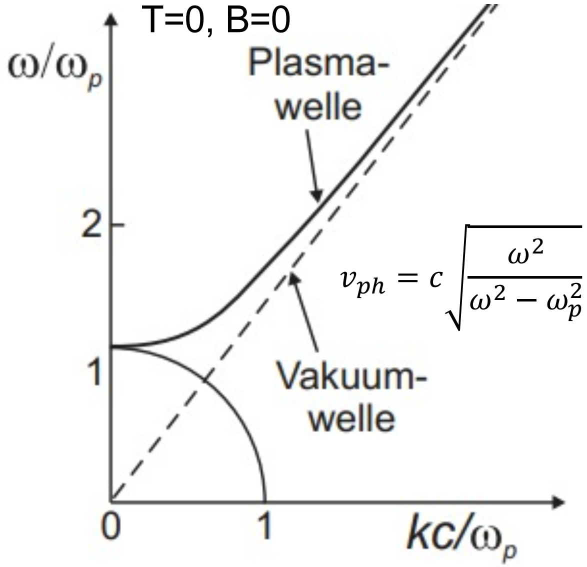
Mirnov coils in Wendelstein 7-X



© Alfvénic fluctuations measured by in-vessel Mirnov coils at the Wendelstein 7-X stellarator, Fig. 1(a)

Refractive index measurment

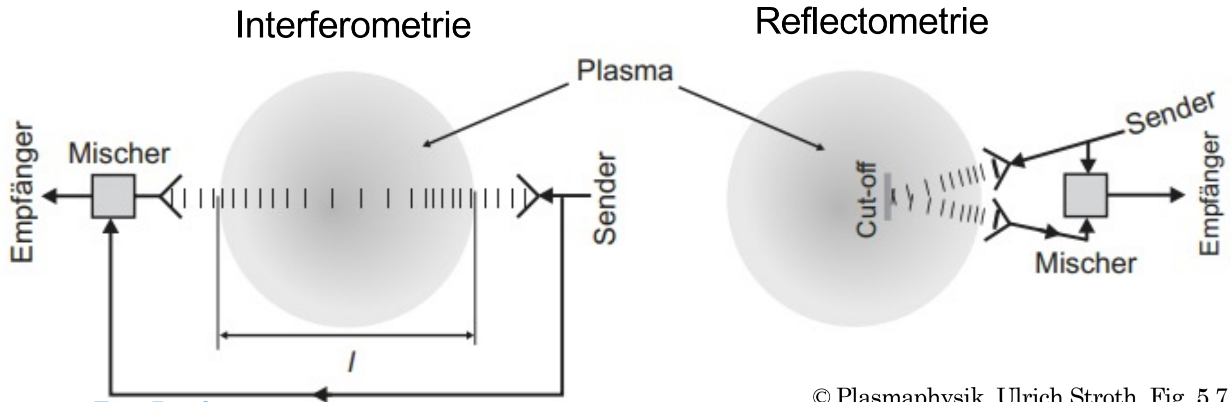
- Dispersion $v_{ph} = \frac{\omega(k)}{k}$ leads to a phase shift $\Delta\varphi$



© Plasmaphysik, Ulrich Stroth, Fig. 5.6

Methodes:

- Interferometrie ($\omega > \omega_{p,max}$): Phase shift → line-averaged n_e
- **Reflectometrie** ($\omega < \omega_{p,max}$): reflection point for different ω → $n_e(r)$
- Polarimetrie ($\omega > \omega_{p,max}$): change of linear polarisation angle → n_eB



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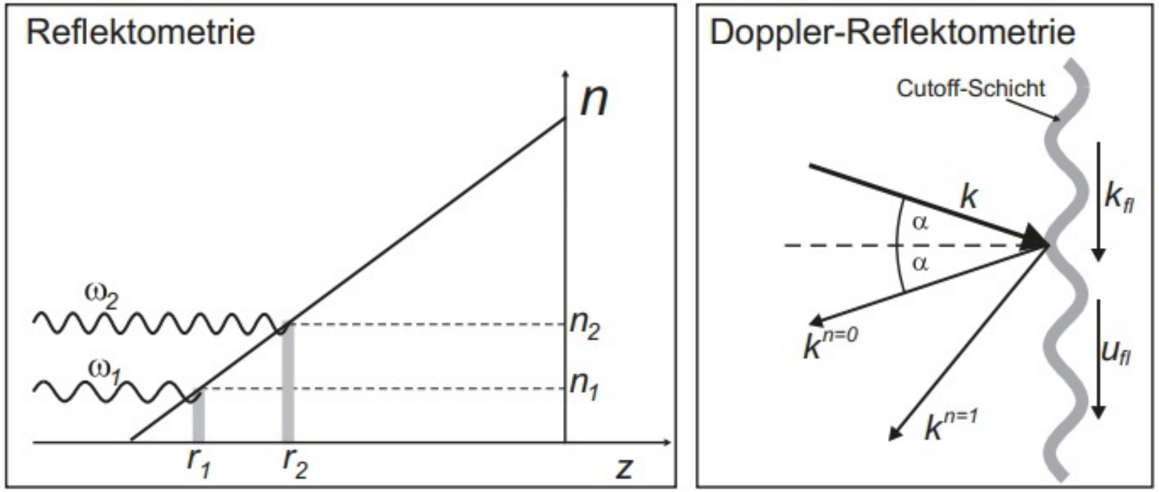
Reflectometrie



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- EM-Waves are reflected at $\omega = \omega_p$
- Measure $\Delta\varphi = \omega\ \Delta t$ for different ω
- Change of $\Delta\varphi$ between ω_m and $\omega_\mathrm{m-1}$ connects Δr with $\Delta n \rightarrow n_e(r)$

Special Case: Doppler-Reflectometrie

- Measuring density fluctuations with fixed ω
- Cutoff acts as optical grating
- Reflection angle α depends on fluctuation wavelength
- Frequency shift $\Delta\omega$ depends on fluctuation velocity

Spectroscopy

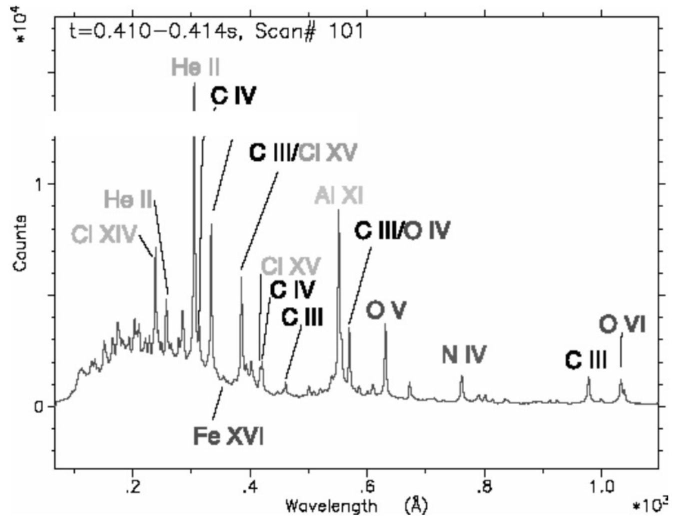
▸Measure photon spectrum emitted by particles

Methodes:

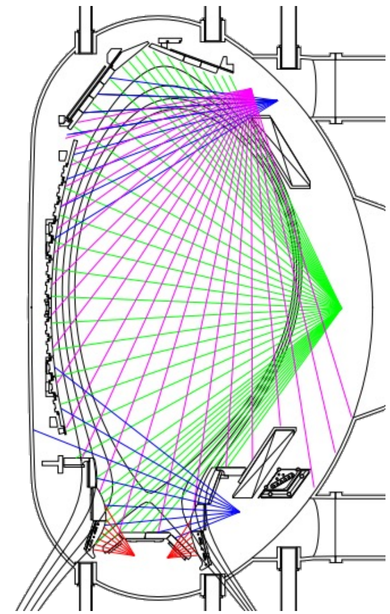
- Bremsstrahlung of electrons on ion-background → T_e
- Electron-cyclotron-radiation as blackbody-radiation → T_e
- Doppler-shift of ions-emissions → T_i
- Recombination radiation of excited particles

  → Concentration of various elements (impurities)
- Bolometrie: Intensity of whole spectrum

  → Energy loss by radiation



© Script IPP Summer University for Plasma Physics, Fig. 7.4



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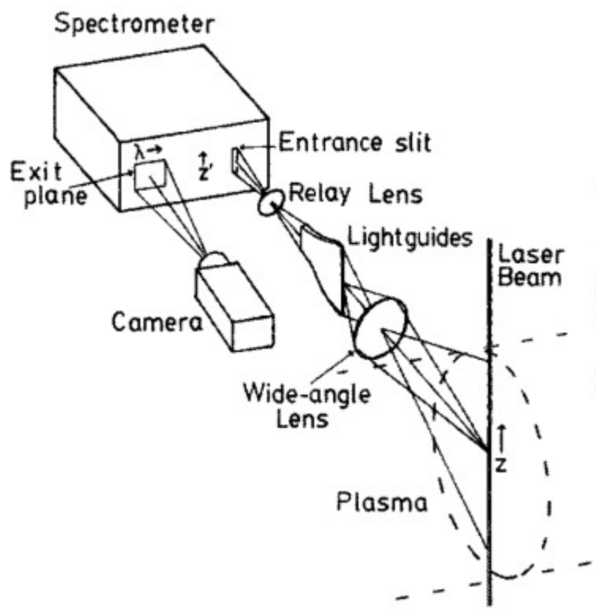
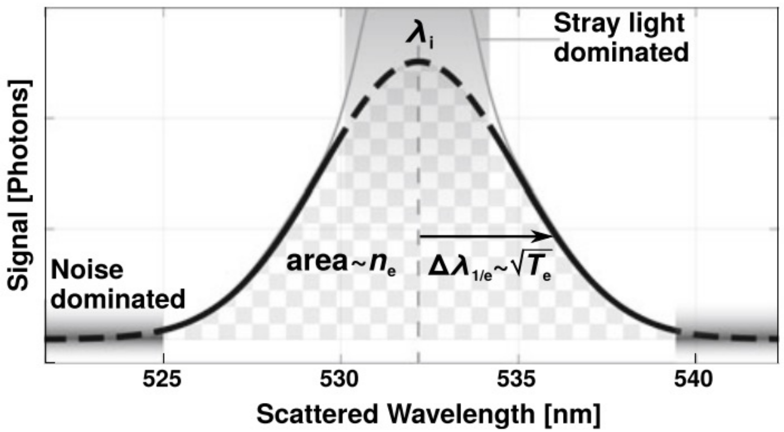
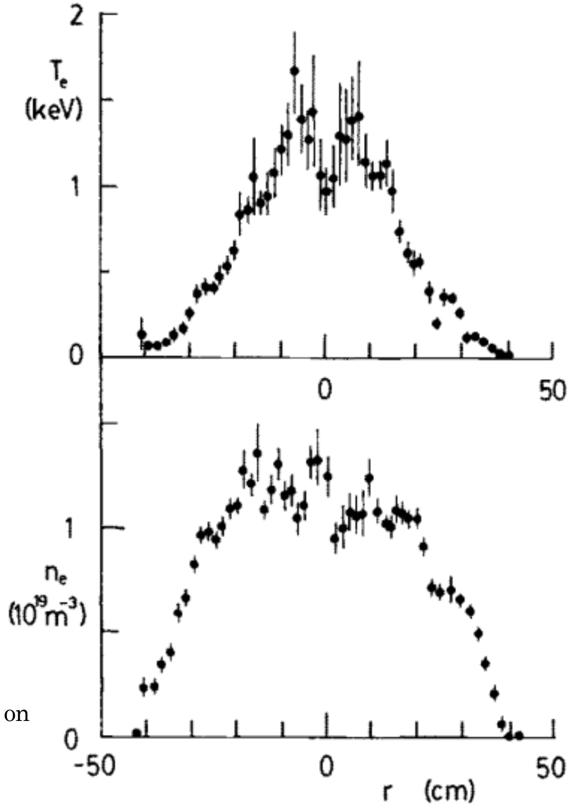
Scattering of EM-Radiation
Thomson Scattering

- Emission of photons via acceleration of charged particles by EM-waves
- Use of lasers (Nd:YAG) with fast fire rate ~ 100 Hz
- ω_s is doppler-shiftet, depends on velocity distribution $f_e(T_e, n_e)$







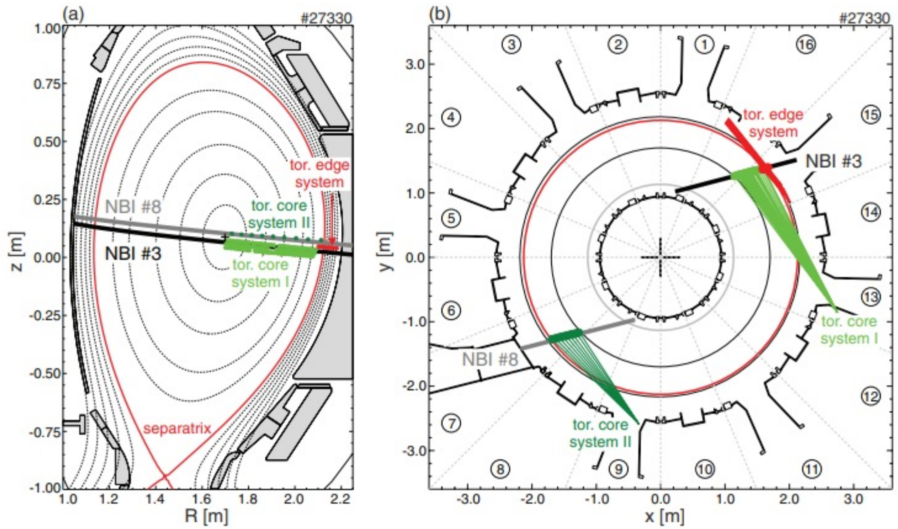
Charge-Exchange recombination

- Send a neutral beam through the plasma center
- Neutrals A exchange electrons with ions I^{n+}:

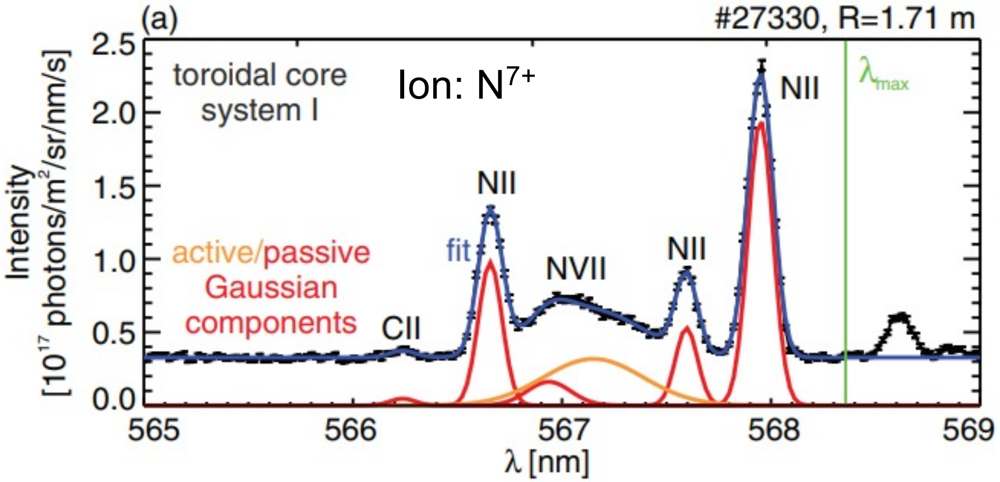
  $A + I^{n+} \rightarrow A^{+} + (I^{(n-1)+})^{*}$

- Excited ion relaxes by photon (vis) emission
- Spektrum depends on ion sort, $f_i(T_i, n_i)$

  and plasma rotation (Doppler shift)



© High-resolution charge exchange measurements at ASDEX Upgrade, Fig. 1

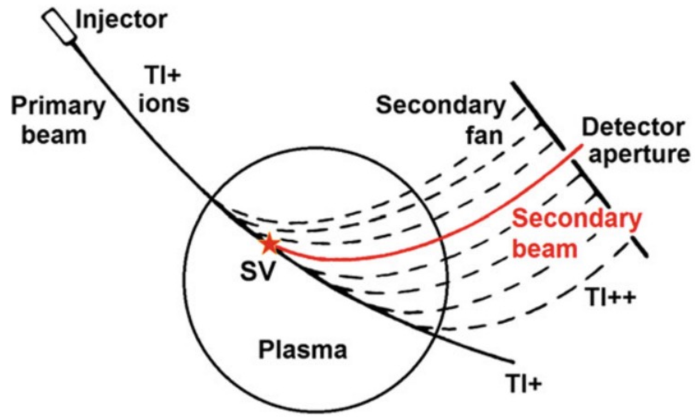


© High-resolution charge exchange measurements at ASDEX Upgrade, Fig. 3 (a)

N II: λ=566,6 nm
λ=567,6 nm
λ=567,9 nm

Particle beam Measurment

- Use of neutral or charged ions
- Ionizing by electron/ ion collisions or charge-exchange
- Detecting of photon emission or the used particles



© Electric Potential on Toroidal Plasmas, Melnikov, Fig. 2.2

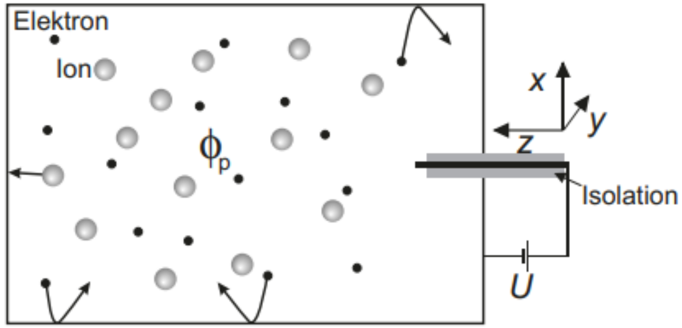
Methodes:

- Li-Beam: Photon emission of Li, excited by electron collisions → n_e
- Heavy ion beam probe: Change of gyro-radius due to ionization

  Measure the energy gain $e\Phi_\mathrm{p}$ and place of ionization → Φ_p, n_e, T_e
- **Charge-Exchange**: Photon emission by fully ionized ions via electron exchange from beam ions → $f_\mathrm{i}(T_\mathrm{i},n_\mathrm{i})$

Langmuir Probe

- Direct plasma contact with metal rods (Tungsten, Graphite)
- Only possible at low temperature (plasma edges)
- Measure current against voltage
- Depends on U which energy (velocity) is needed to reach the probe
- Fit depends on n_e, T_e, plasma and floating potential



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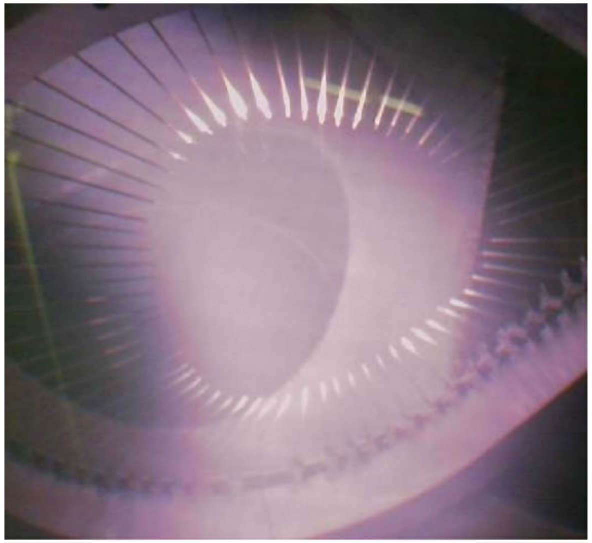

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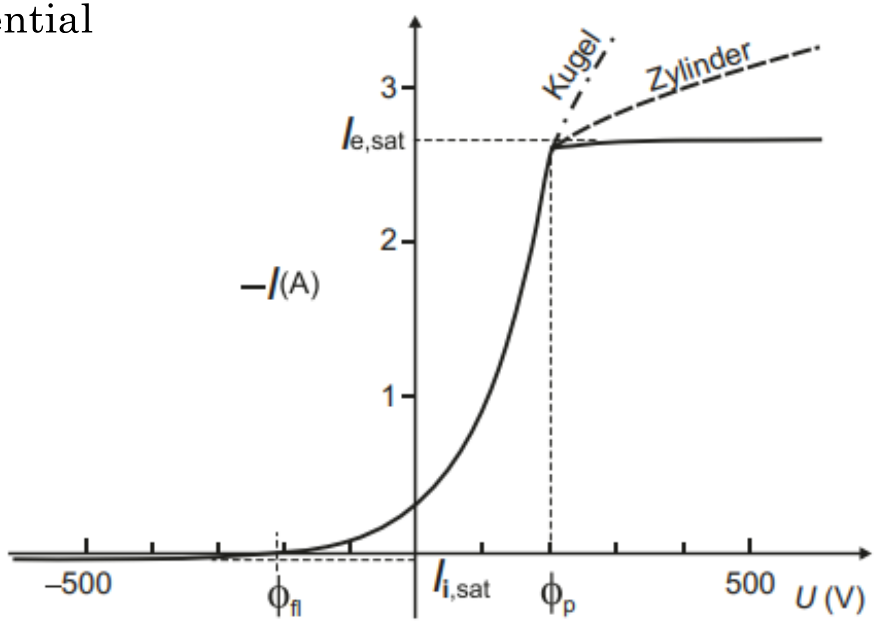

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Summary

Magnetic	Ragowski-Coil	B_Θ, p, I_p
	Mirnov-Coil	B_Θ, B_φ
	Diamagnetic-Loop	I_{Dia}, β
Aktiv EM	Interferometrie	n_e
	Reflectrometrie	n_e, $\mathrm{u_{fl}}$, fluc. level
	Polarimetrie	n_e, B
	Thomson -Scattering	$f_e(T_\mathrm{e}, n_\mathrm{e})$
Passiv EM	Bremsstrahlung/Cyclotron	T_e
	Passive spectroscopy	T_i, $\mathrm{n_i}$, $\mathrm{v_i}$
	Bolometry	P_rad
Particle Beams	Li-Beam	n_e
	Heavy-Ion-Beam	Φ_p, n_e, T_e
	Charge-Exchange	$f_i(T_\mathrm{i}, n_\mathrm{i})$, $\mathrm{v_i}$
Probes	Langmuir-Probe	n, T_e, T_i, Φ_p (on edges)

Special: Polarimetrie

$\vec{k} \parallel \vec{B}$