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SMR 1273 - 4

WORKSHOP ON PLASMA DIAGNOSTICS AND INDUSTRIAL APPLICATIONS OF PLASMAS

12 - 13 OCTOBER 2000

FUSION RELATED DIAGNOSTICS AND THE DEVELOPING NATIONS

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These are preliminary lecture notes, intended only for distribution to participants.

Fusion related diagnostics and the developing nations

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Outline

- Introduction
- World fusion programme
- Overview of diagnostic methods for magnetic fusion
- Future trends
- Scope for participation
- Discussion

World fusion programme

- Europe, Japan, Russia and USA have major programmes in magnetic and inertial fusion
- many other countries have supporting programmes
- IAEA survey in 1997 lists ~ 250 institutions in ~ 50 countries involved in fusion research
- Europe, Japan and Russia are collaborating in the design of ITER
- inertial confinement - France, Japan and USA building MJ laser facilities.

Fusion experimental conditions

- Lawson condition

  density x temperature x confinement time

  $> 3 \times 10^{21}\ m^{-3}\ keV\ s$

- temperature 10 - 30 keV (100 - 300 M°C)
- magnetic confinement

  density ~ $10^{20}\ m^{-3}$ & t ~1s

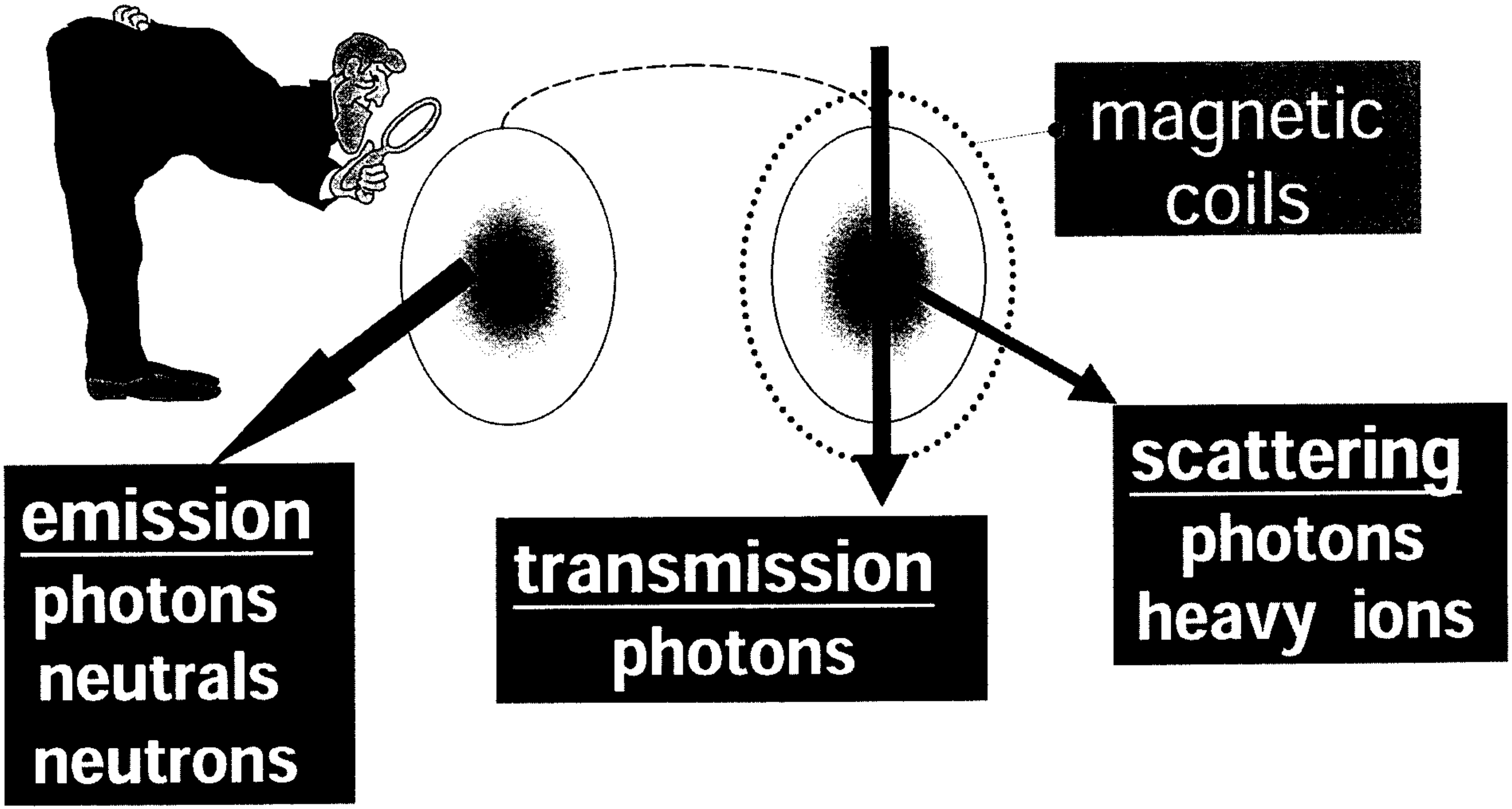
- inertial confinement

  density ~ $10^{29}\ m^{-3}$ & t ~ 10^{-9} s

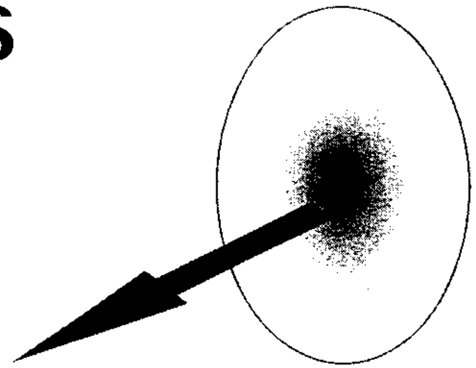
Magnetic fusion diagnostics

- purpose
  - machine control & protection
  - optimisation of operation
  - physics understanding
- implementation
  - typical large experiment has ~ 50 diagnostic systems
  - some diagnostics measure several parameters
  - most parameters require several diagnostics to provide reliability & redundancy, cross-calibration, interpretation, & for the wide range of conditions (core, edge, divertor)

Main diagnostic methods



Emission diagnostics



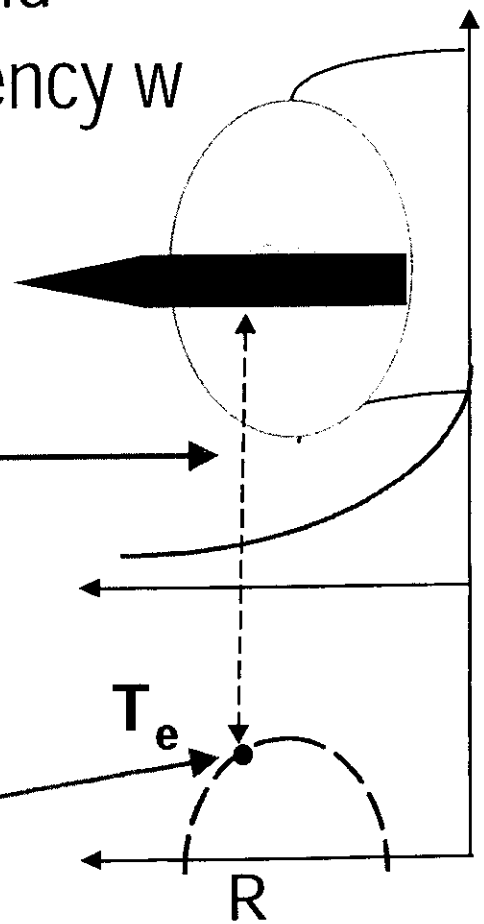
- photons - measure many parameters
  - electron cyclotron emission
  - emission spectroscopy - visible, uv and soft X-rays
  - charge exchange spectroscopy - visible and uv
  - beam emission spectroscopy
- charge exchange neutrals - ion temperature
  - passive and active
- neutrons - ion temperature and fusion reaction rate
  - flux and energy spectra

Electron cyclotron emission

electrons rotating in the magnetic field
emit at harmonics of the cyclotron frequency w

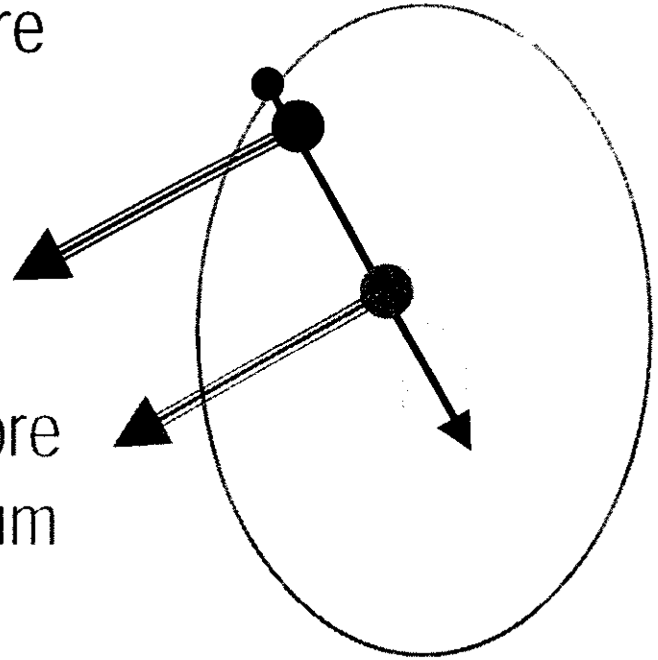
the toroidal field depends on radius
so the frequency of the radiation
determines the position

the plasma emits as a black body
intensity of the radiation
measures the temperature



Emission spectroscopy

impurities are ionised progressively as they penetrate to the plasma core



low ionisation states radiate in the visible and uv from the plasma edge

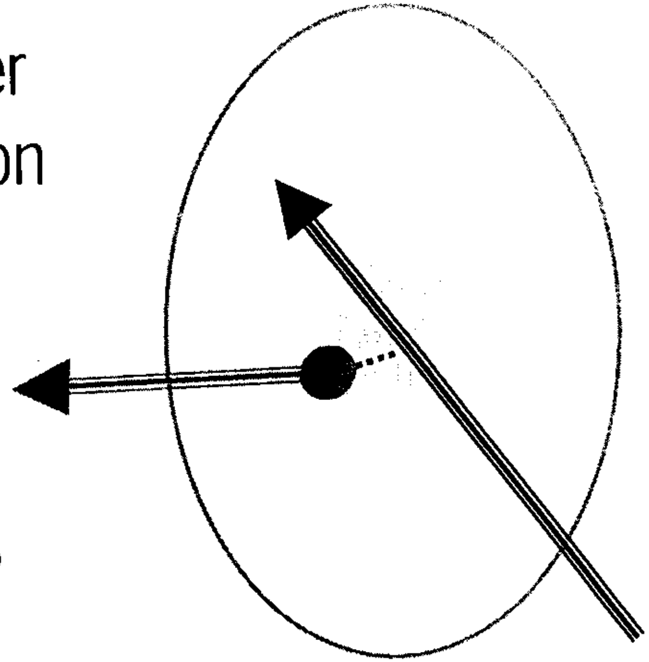
highly ionised states radiate from the core in the vacuum uv and soft X-ray spectrum

main application is for impurity concentrations and ion temperature

Charge exchange spectroscopy

in high temperature plasma, impurities in the core are fully ionised and do not emit photons

they can be made to emit from a lower ionisation state by capturing an electron by charge exchange from an injected neutral atom beam



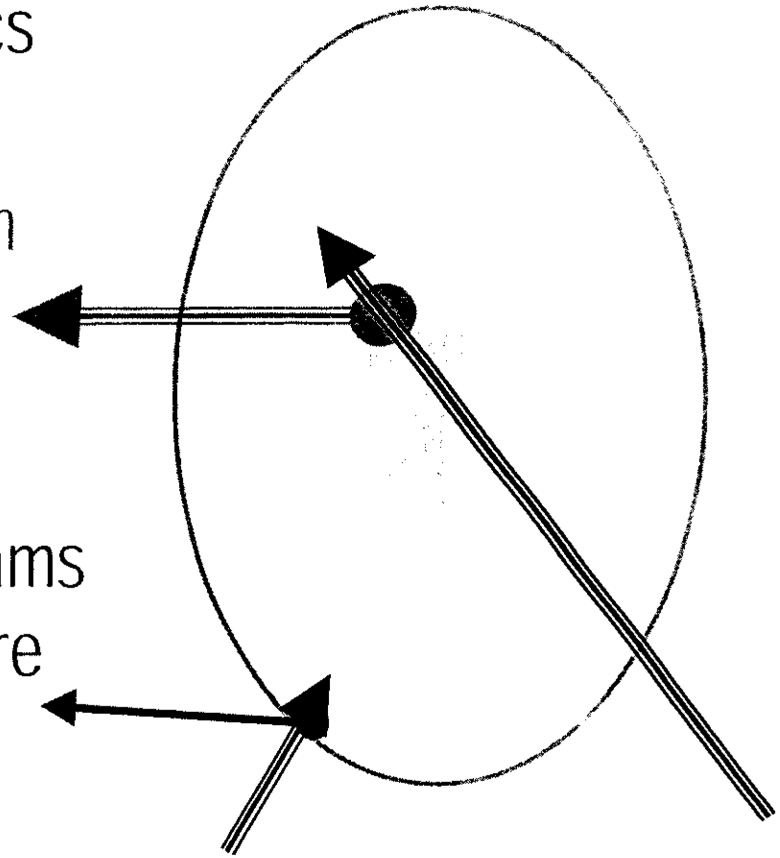
charge exchange spectroscopy measures plasma rotation and ion temperature

Beam emission spectroscopy

excitation of the neutral atoms in the beam itself is also used for diagnostics

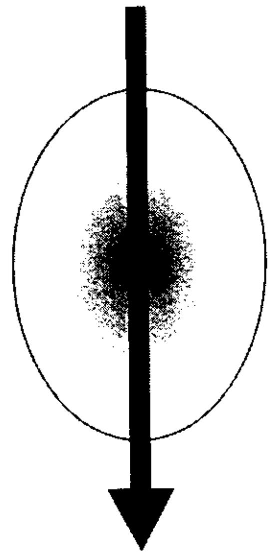
emission from an energetic H^0 beam that penetrates to the core measures fluctuations

emission from low energy Li or He beams measures edge density & temperature

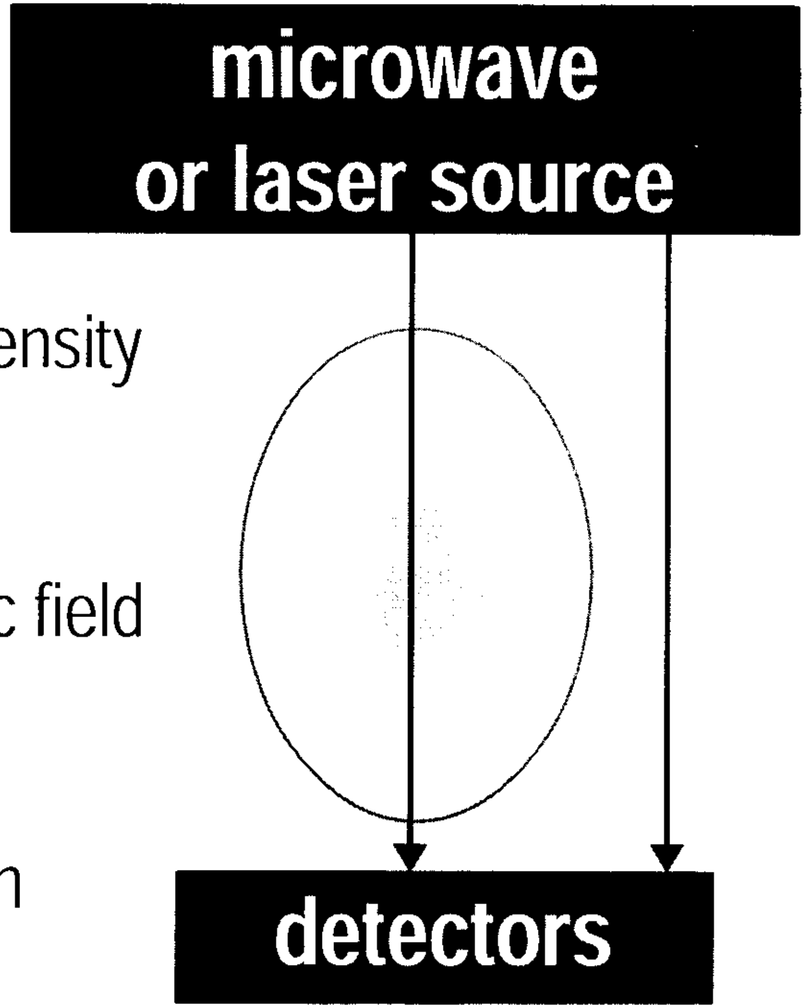


Transmission diagnostics

- Photons
- microwave and infra red interferometry
  - plasma electron density profile
- infra red polarimetry
  - poloidal current profile
- microwave reflectometry -
  - electron density profile



Interferometry and polarimetry



relative phase - integral of density

Faraday rotation angle -
integral of density x magnetic field

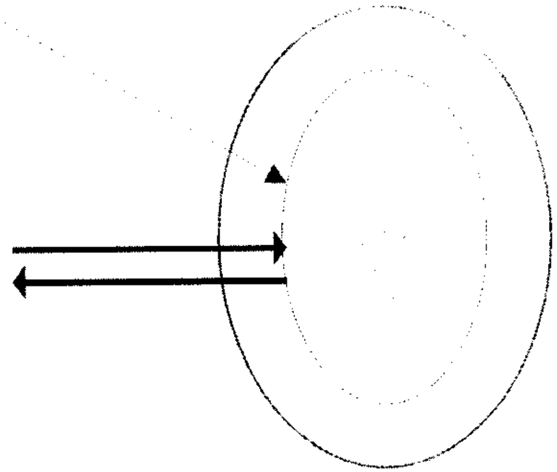
multiple chords give
profiles by Abel inversion

Reflectometry

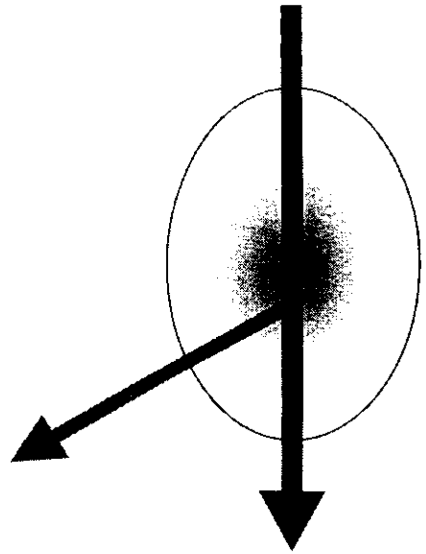
microwave beam is reflected at
the critical density layer
where
microwave frequency
= plasma frequency

$\omega_p = (n_e^2/\varepsilon_0 m_e)^{0.5}$

changing frequency scans to
different radial positions to
measure density profiles and
fluctuations



Scattering diagnostics

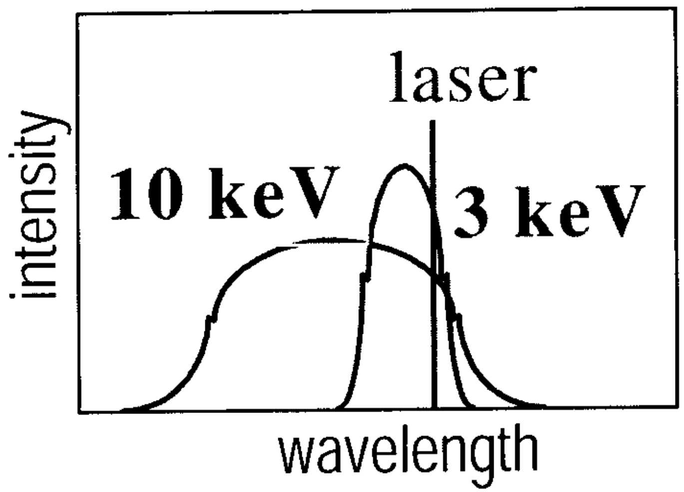


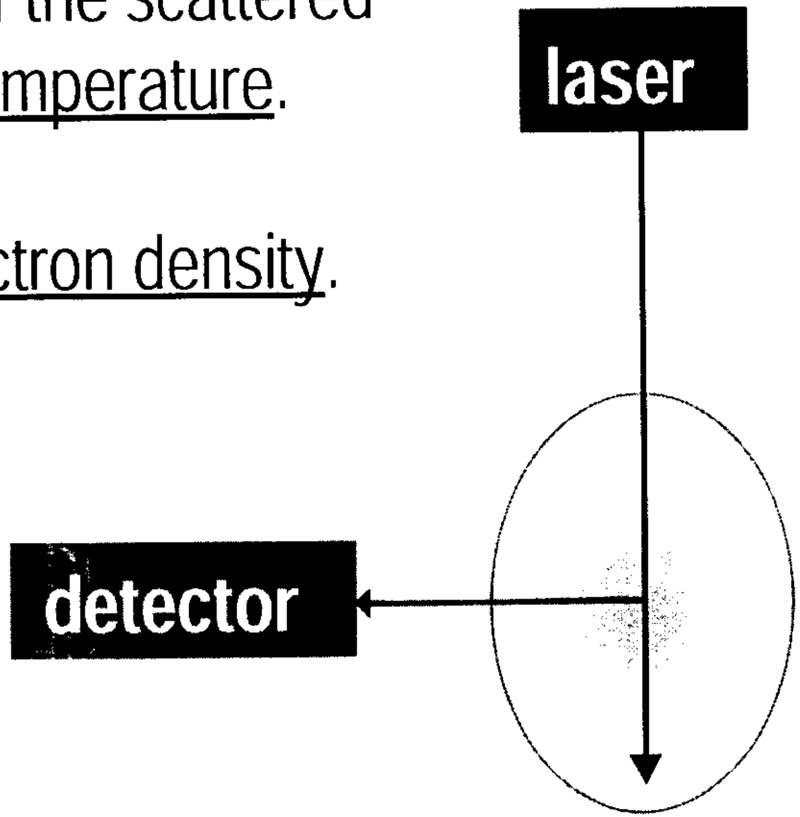
- photons
  - Thomson scattering
    - electron density and temperature
  - microwave, infra red collective scattering
    - ion density, temperature, fast ions, alpha particles
- particles
  - heavy ion beams -
    - plasma potential
  - (neutral beams for charge - exchange spectroscopy and neutral particle analysis - see emission diagnostics)

Thomson scattering

The width of the spectrum of the scattered light gives the electron temperature.

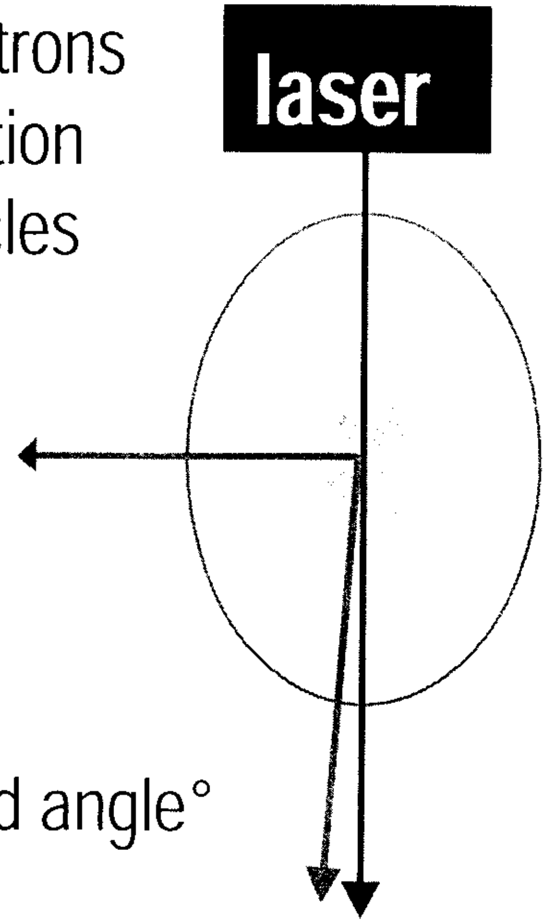
The intensity gives the electron density.





Collective scattering

Ion distributions and temperatures can be measured by scattering off the cloud of electrons in the Debye screen. An important application would be to measure confined alpha particles



FIR laser scattering at ~ 90°

CO_2 laser scattering at ~ small forward angle°

Future trends and requirements

- improved accuracy, time & space resolution
- real-time data analysis
- feedback control of plasma operation -safety and improved performance
- measurement of additional parameters - eg alpha particles, tritium and helium concentrations in core

Scope for participation

- some important parameters are difficult-impossible to measure - new diagnostics need to be developed, existing techniques improved
- interpretation - methods can be improved - especially on-line data reduction for long pulse experiments
- control algorithims and scenarios need developing
- many of these tasks can be carried out initially on smaller experiments
- remote participation being developed

Summary

- diagnostics are important for fusion research
- main diagnostic methods and future trends
- scope for participation
  - developing new diagnostics etc. on small experiments
  - improving methods of interpretation
  - developing control algorithims and scenarios
  - participation in ITER and international projects
- discussion to identify areas of interest