Confinement in Wendelstein 7-X Limiter Plasmas

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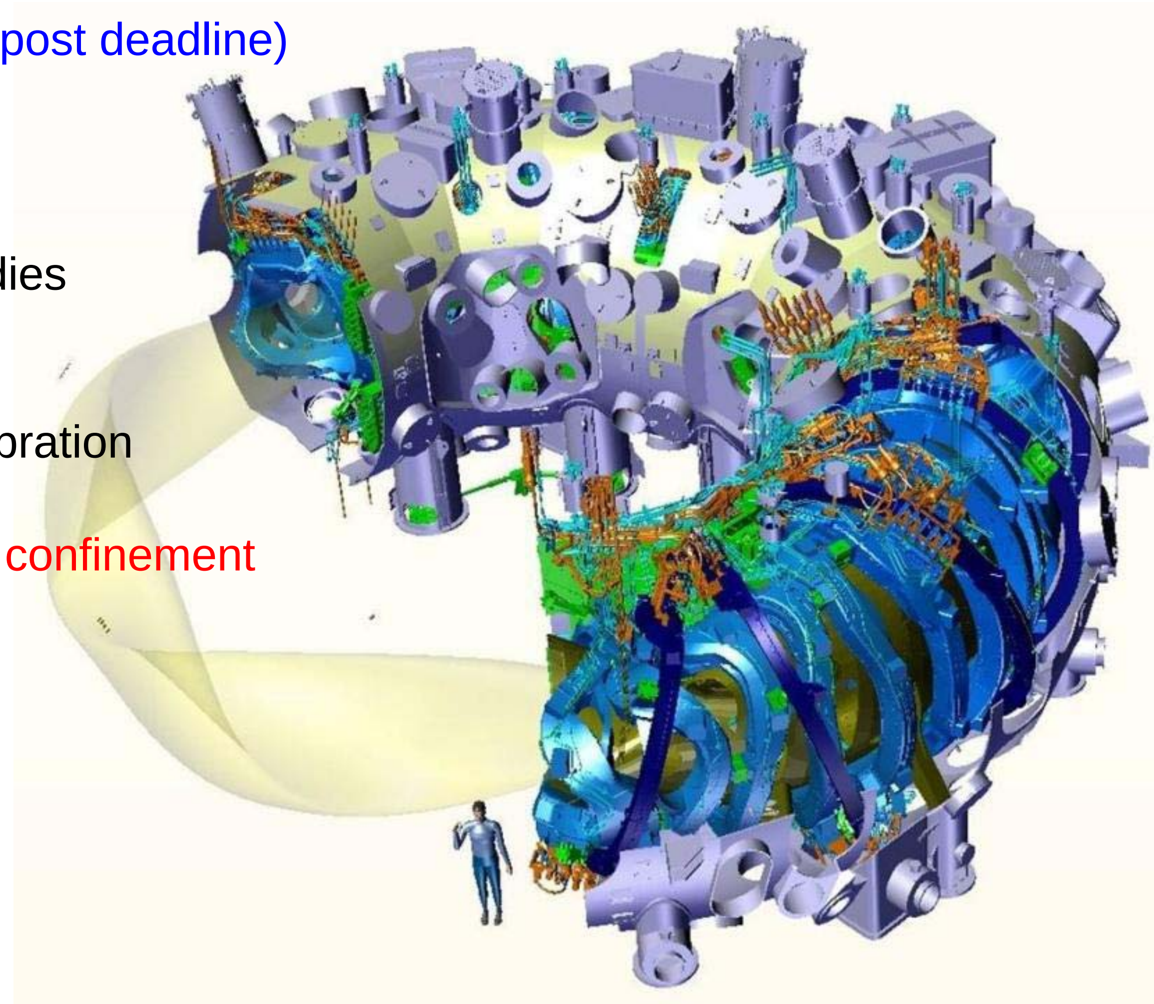
IAEA -FEC, Kyoto 2016, EX4-5

outline: Confinement in Wendelstein 7-X Limiter Plasmas

first operation -> overview talk OV/3-1: R. C. Wolf

commissioning -> H.-S. Bosch et al., FIP (post deadline)



o Experimental background for confinement studies

-> operational range

-> diagnostic commissioning and cross calibration

o Energy content, power balance, global energy confinement

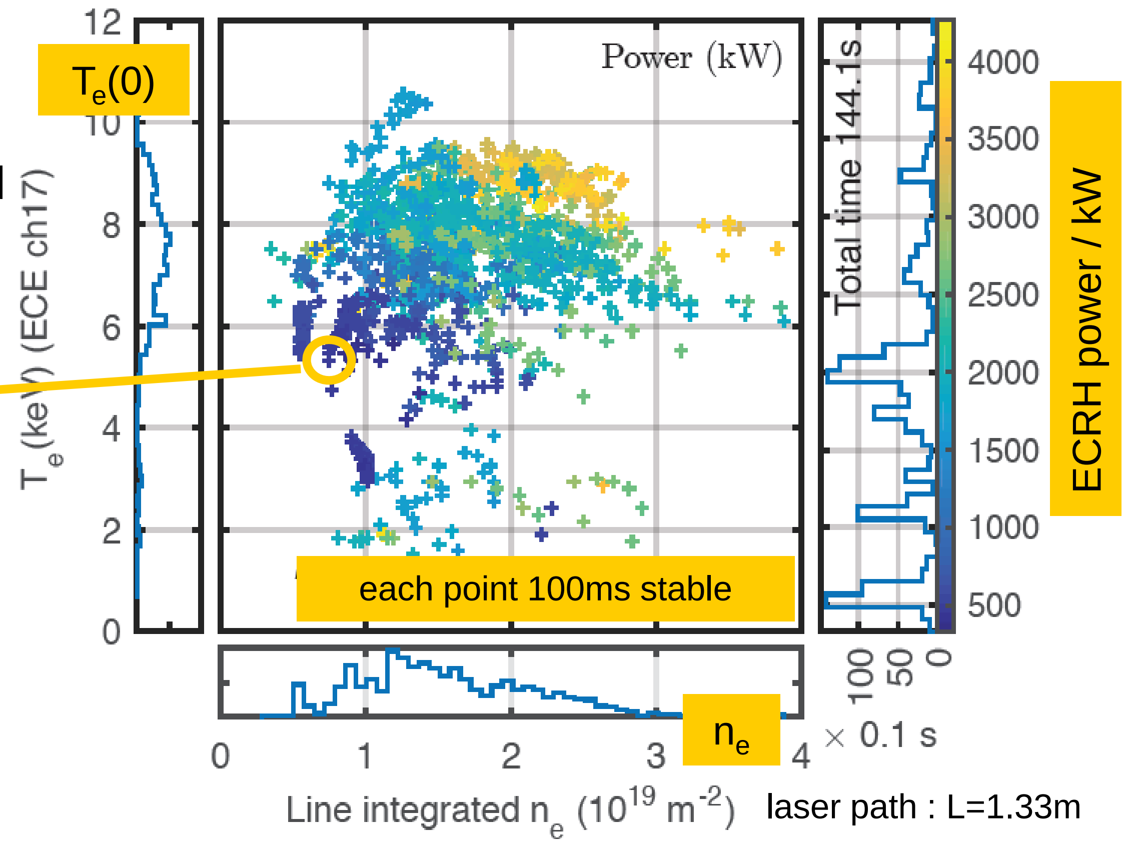
o Local transport analysis

-> Core Electron Root Confinement

-> on- and off- axis ECRH heating

parameter range of OP1.1 limiter scenarios

A. Alonso



First operation phase ...

.. limiter configuration and otherwise a bare metal device with uncooled structures installed only.

-> restricts energy per program to 4MJ to avoid local overheating -> max duration 6s

-> small configuration variation acceptable only

heating by 6 long pulse gyrotrons (30min) providing < 4.3 MW ECRH

D. Moseev et al. EX/P5-1

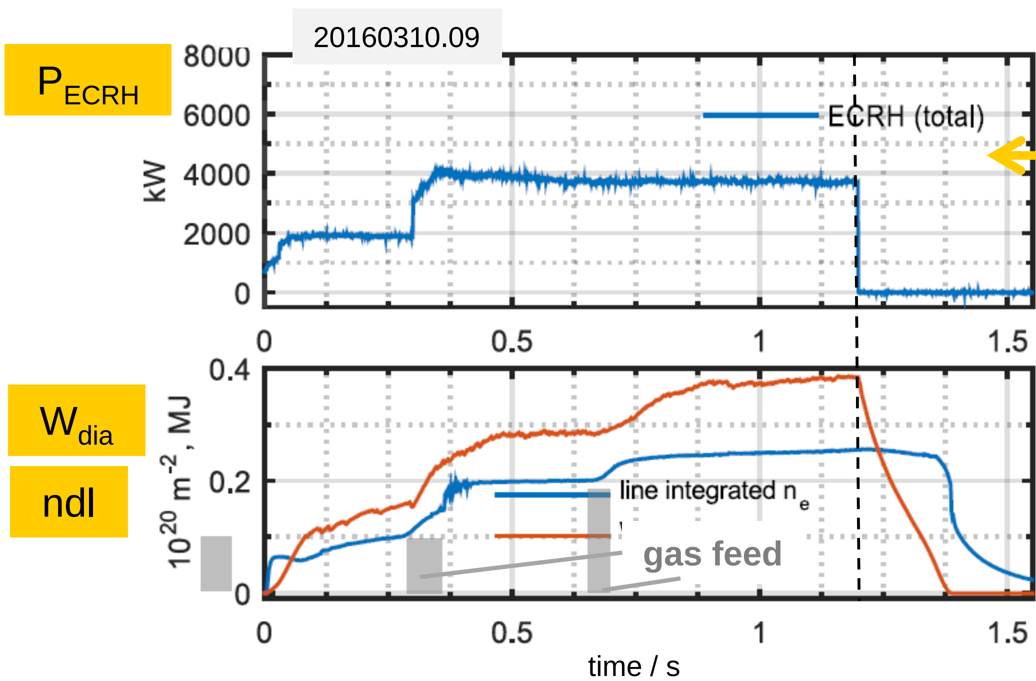
S. Marsen et al., EX/P5-13

-> more than 900 exp. programs conducted accumulated total plasma duration > 300s

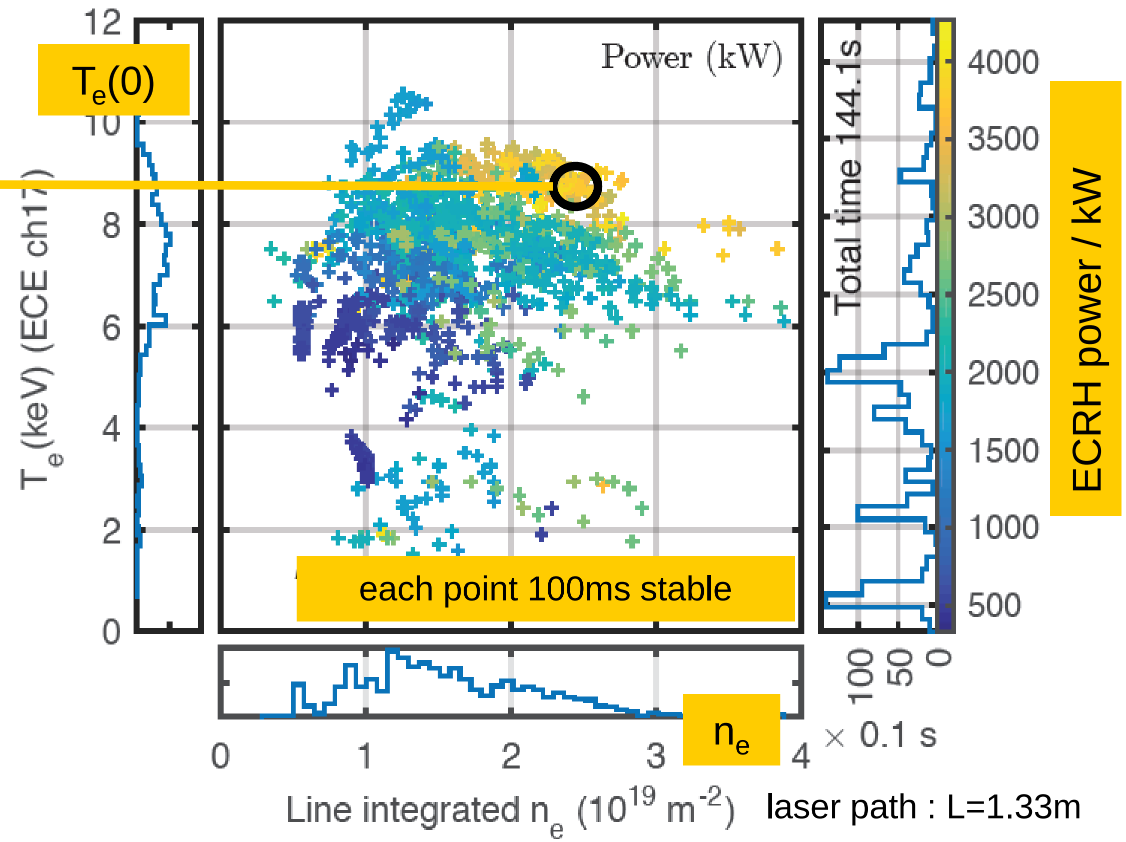
-> high reproducibility !

parameter range of OP1.1 limiter scenarios

“high-performance”: 4 MW @ 2.5 10^{19} m^{-3}



A. Alonso

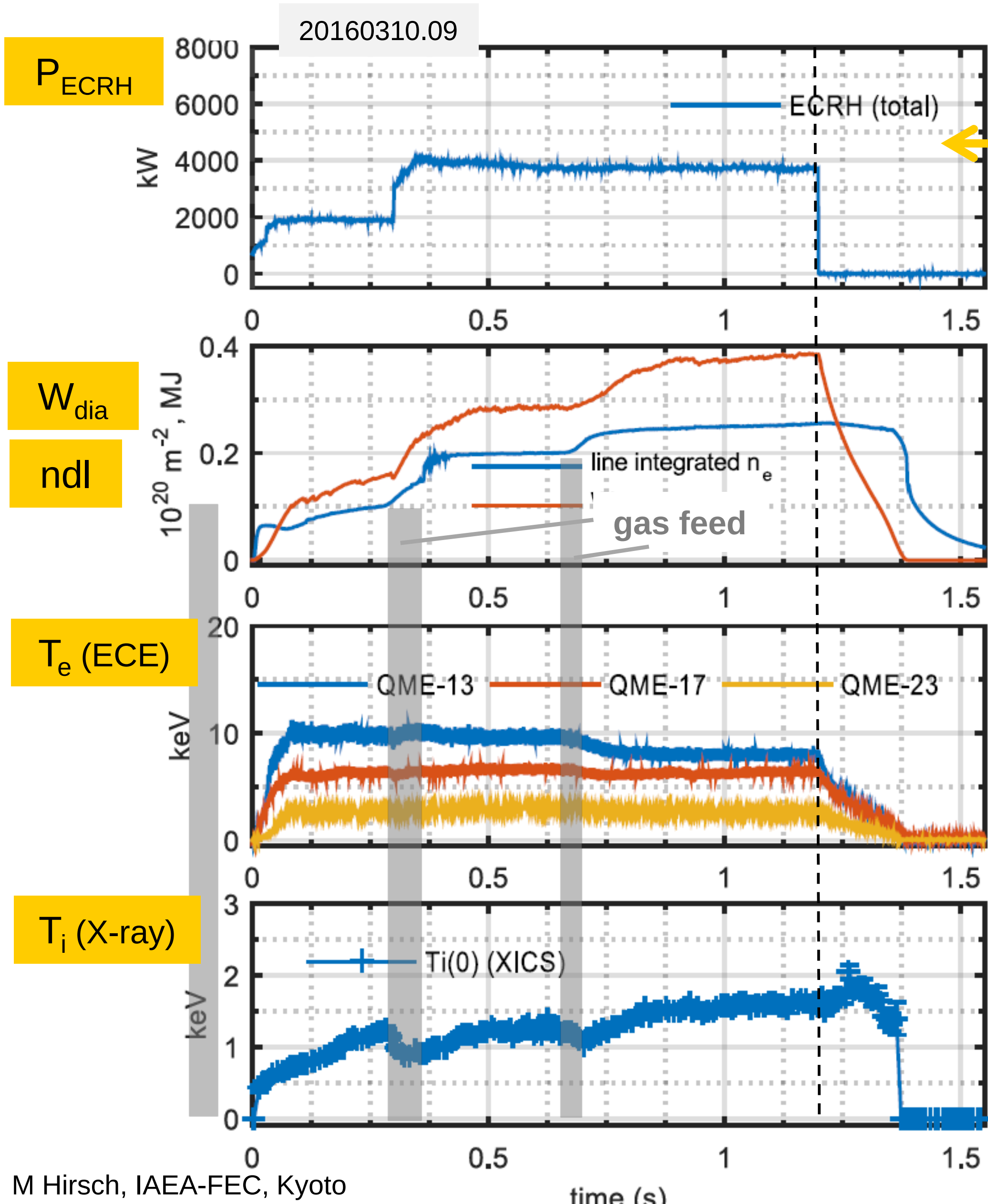


-> gas balance: fuelling dominated by outgassing about a factor of 4-5 over fuelling from valves (no feedback density control)

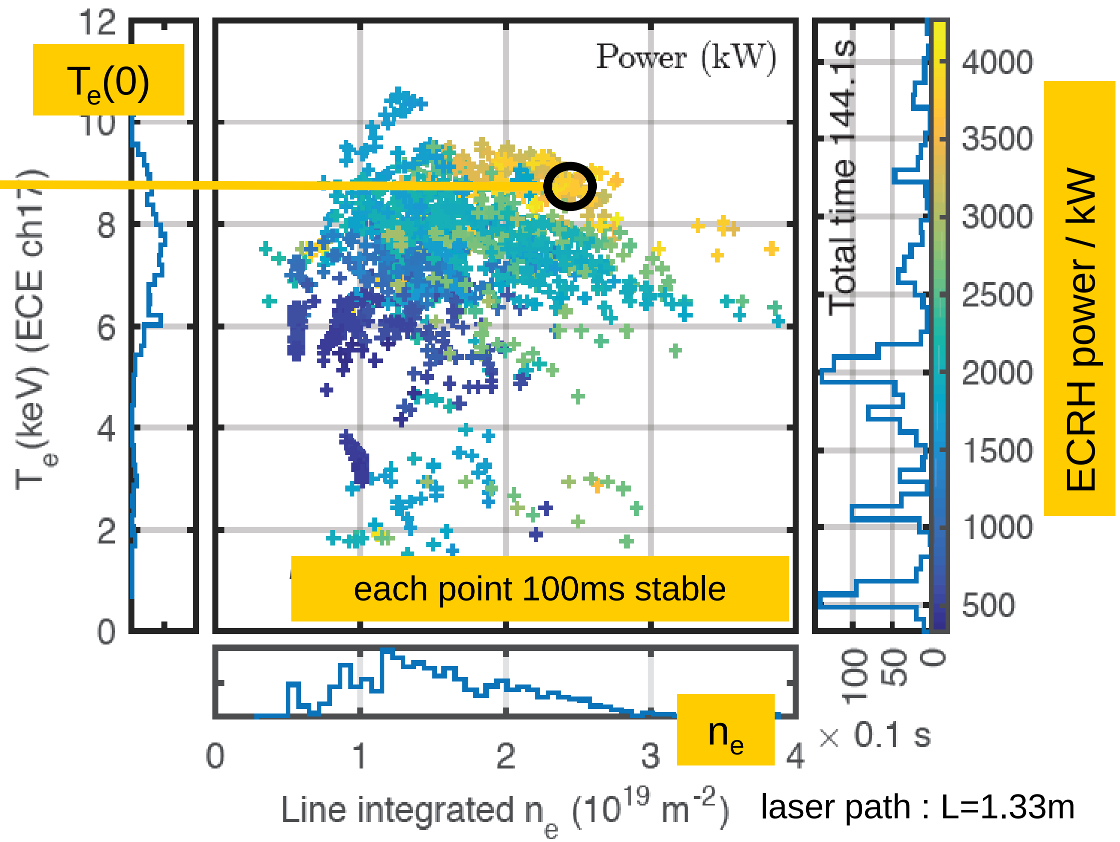
-> impurity content increased with discharge time since last wall conditioning and limited plasma duration eventually by radiation.

parameter range of OP1.1 limiter scenarios

"high-performance": 4 MW @ 2.5 10^{19} m^{-3}



A. Alonso



quasi stationary discharges
up to maximum allowed launched energy (4MJ)

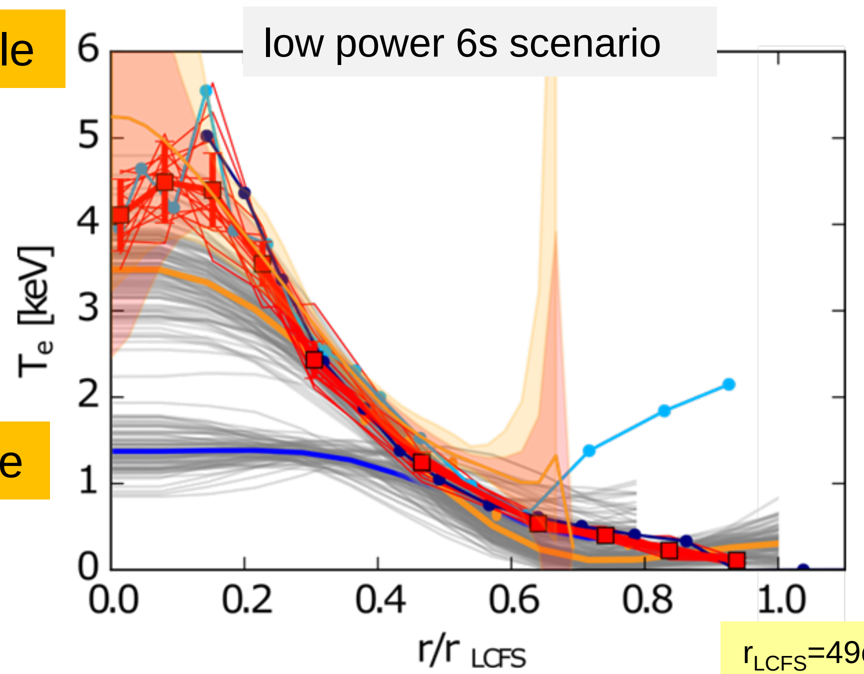
(T_e stationary, n_e slightly rising, T_i still rising)

T_e = 8...10 keV, T_i= 1.5...2 keV, n_e = 2... 3 10^{19} m^{-3}

commissioning and cross calibration of diagnostics

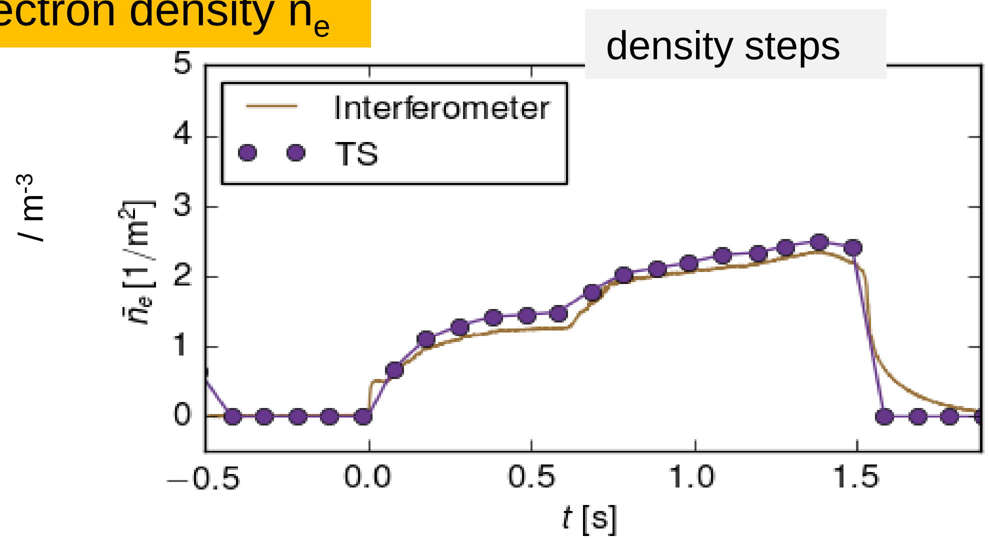
T_e profile

T_i profile



r_{LCFS}=49cm

electron density n_e



Thomson scattering:

-> absolute calibration of channels

-> radiation background increases with Te

ECE radiometer (outboard / inboard) :

-> absolute calibration

-> identify spectral components that do not display blackbody emission

X-ray imaging (Ar-tracer): Te, Ti

-> Ar as tracer

-> confidence ranges of profile inversion (different inversion procedures)

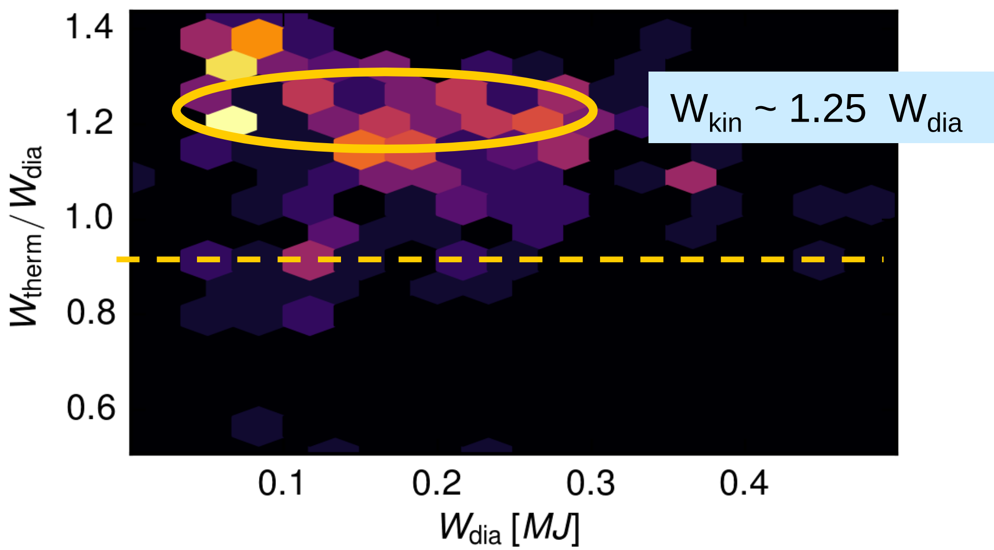
Dispersion Interferometer and Thomson scattering 10 Hz

energy content and power balance

Fuchert et al to be published

kinetic energy from profile diagnostics
assuming vacuum magnetic field and Z_{eff}=1

$$W_{kin} = (3/2)\int (n_e T_e + n_i T_i)(dV/dr)dr$$



$$P_{ECRH} = \frac{dW}{dt} - P_{rad} - P_{CX} - P_{limiter}$$

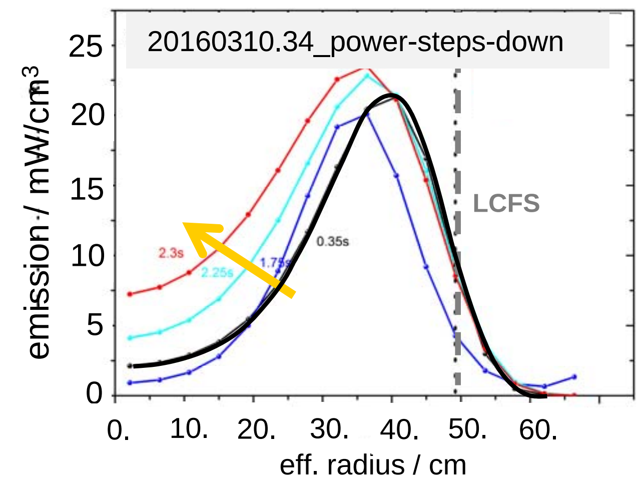
P_{ECRH} : calibrated diodes (accuracy ~5%) in duct
-> absorption of X2-mode is near 99%
(verified by inboard-side diodes)

P_{lim} : from two IR-cameras, **assuming symmetry**
-> 25 to 50% @ stationary conditions,
decreasing with P_{ECRH} G. Wurden et al., EX/P5-7

S. Bozhenkov et al., EX/P5-8

P_{rad} : from bolometer, **assuming symmetry**
-> 25 – 35% @ stationary conditions.
Increasing towards radiative collapse
which depends on actual wall condition.

bolometry: emissivity profiles show radiative belt



-> Z_{eff} ? - First estimates yield Z_{eff} = 3 to 5
-> profile and mapping accuracy

~10 % of P_{ECRH} missing
increasing with P_{ECRH} to up to 30%
(CX-losses ? asymmetric limiter loads ?)

first results on energy confinement time in the limiter plasmas

Fuchert et al APS conference to be published

<u>database</u>: $\tau_E \sim$ **P^{α} n^{β}**, using W_{kin} (larger data set)

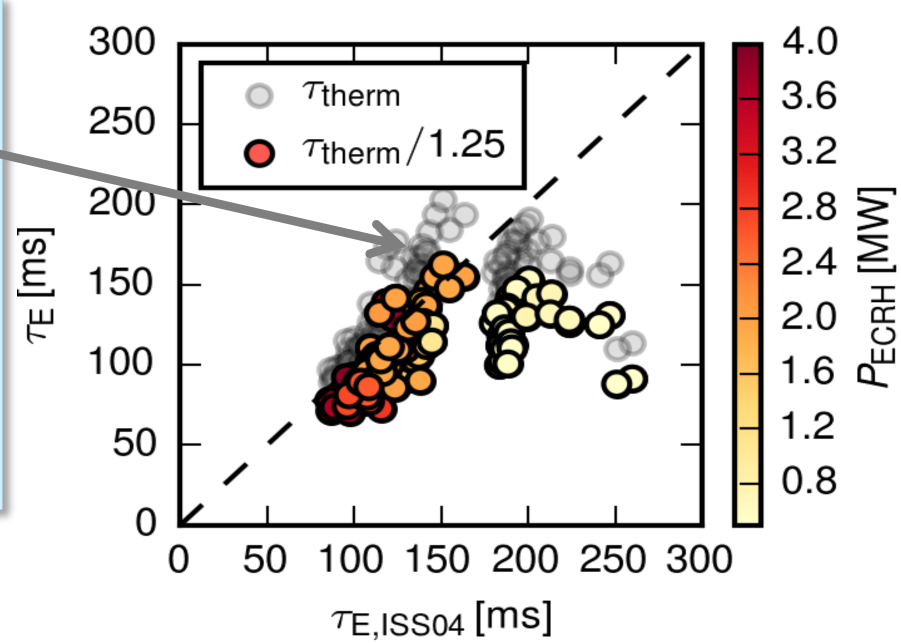
for P_{ECRH} >1MW

low power discharges form a separate group

α = - 0.75 (ISS: -0.61) -> power degradation

β = 0.84 (ISS: 0.54) -> small density variation only

τ_E ~ 80 – 160 ms ~ $\tau_{E,\,ISS04}$



energy confinement time – comparison with ISS04

database: $\tau_E \sim$ **P** $^{\alpha}$ **n** $^{\beta}$, using W_{kin} (larger data set)

for P_{ECRH} >1MW

low power discharges form a separate group

α = - 0.75 (ISS: -0.61) -> power degradation

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τ_E ~ 80 – 160 ms ~ $\tau_{E,\ ISS04}$

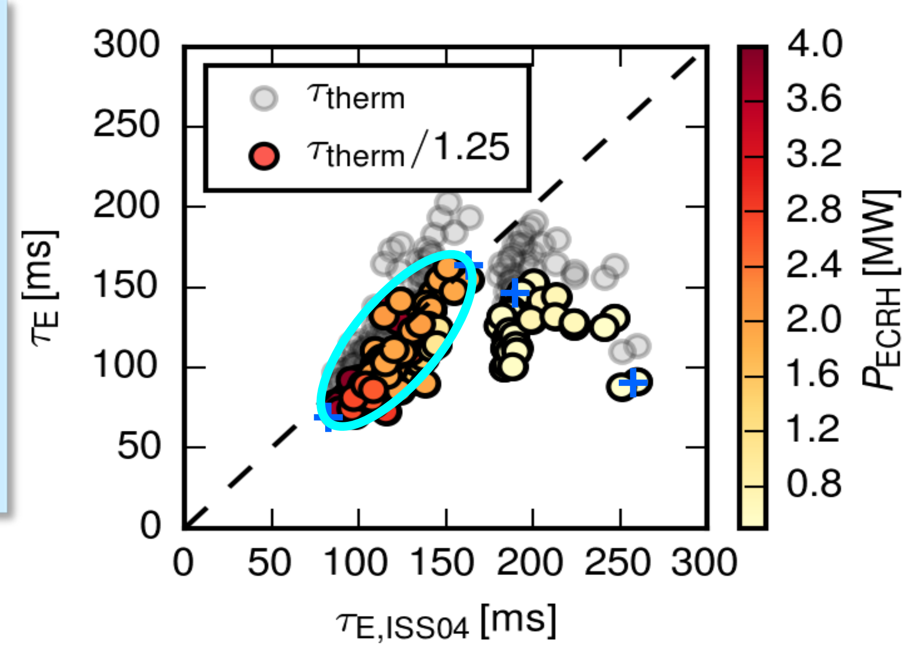
$$\tau_E^{ISS04} = 0.134 a^{2.28} R^{0.64} \underline{P^{-0.61}} \, \underline{\bar{n}_e^{0.54}} B^{0.84} \iota_{2/3}^{0.41}$$ [1]

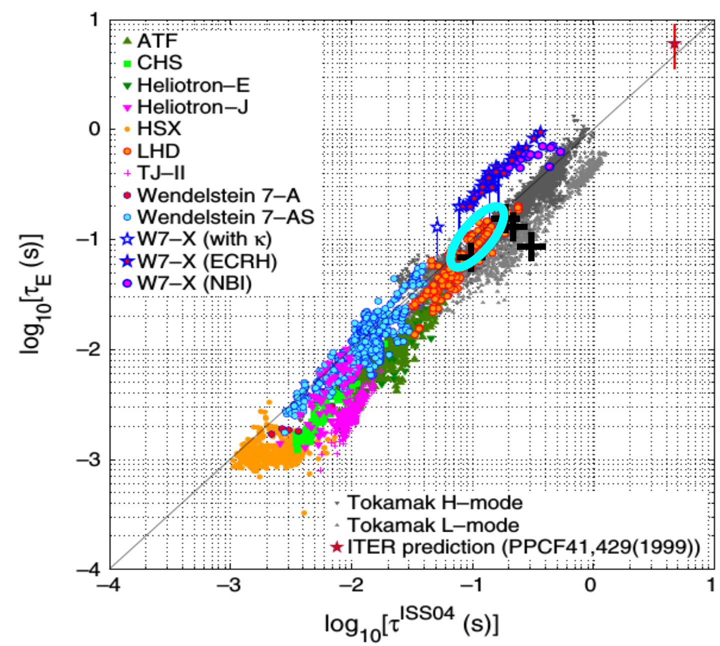
+ configuration factor τ_E= f * τ_E^{ISS04} reflects the effect of the magnetic configuration (9 devices)

W7-AS (iota=1/3): f=1 (highest value in ISS04)
W7-X neoclassical modelling : f=2
W7-AS (CERC): f=0.65

-> indicating a configuration factor f=1 for OP1.1

Fuchert et al APS conference to be published





[1] Yamada H. et al, Nucl. Fusion. 45 (2005), 1684

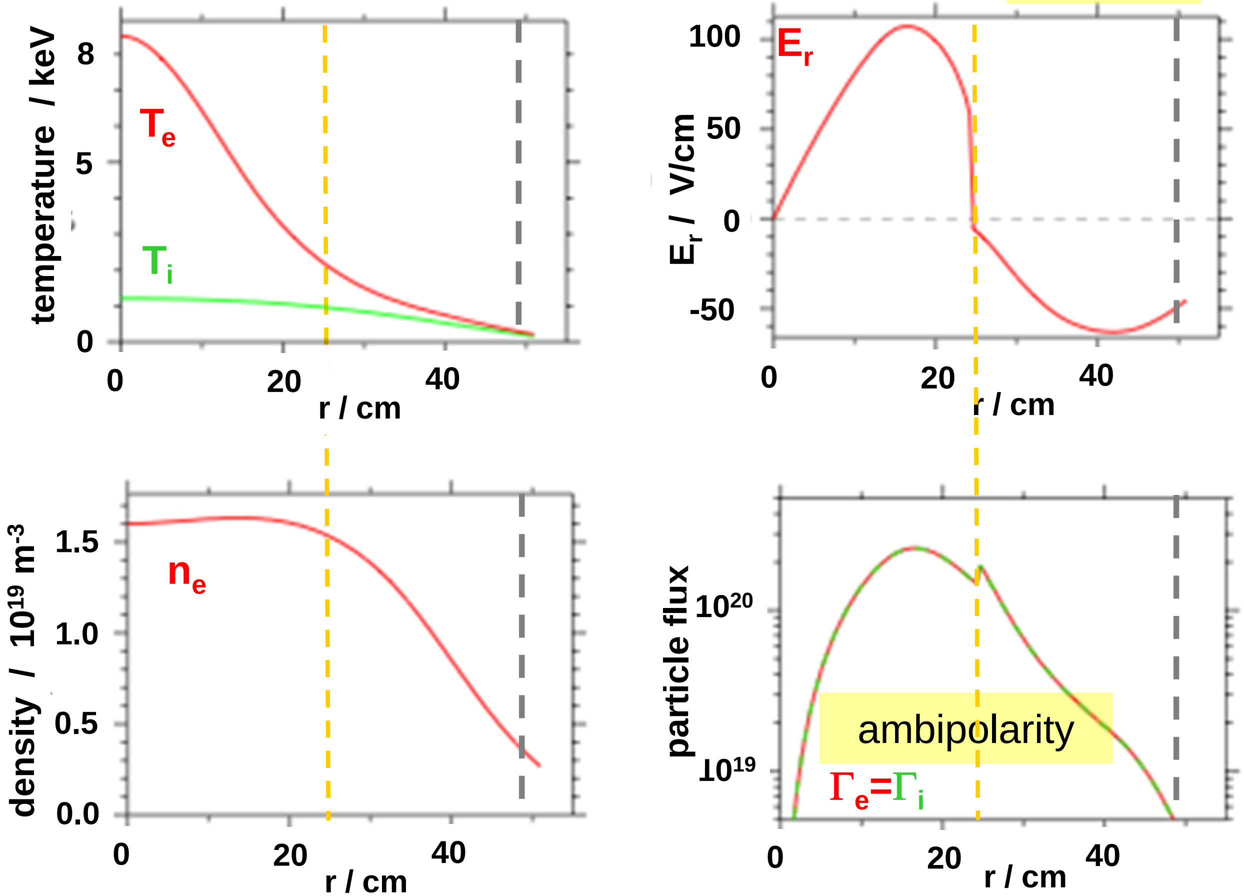
transport analysis: particle- and heat-fluxes

roots of ambipolarity coindition

representative profiles

electron root $E_r>0$

ion root $E_r>0$



DKES code

H. Maassberg, Y. Turkin

stellarator fluxes depend explicitly on E_r

Core **E**lectron **R**oot **C**onfinement [1]

= first test comparing with Neoclassics.

positive radial electric field observed by X-ray imaging spectroscopy and Correlation Reflectometry :

A. Dinklage et al. EPS 2016

A. Krämer Flecken et al. EX/P5-4

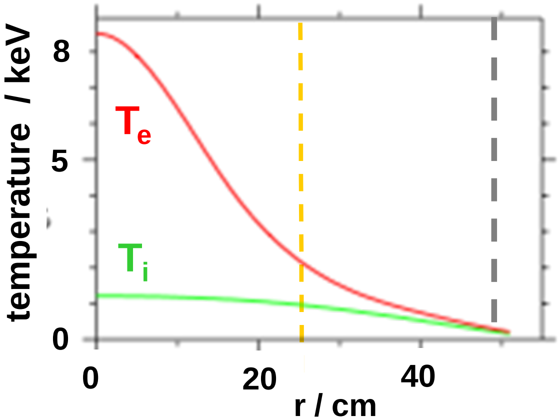
N. Pablant et al. EX/P5-3

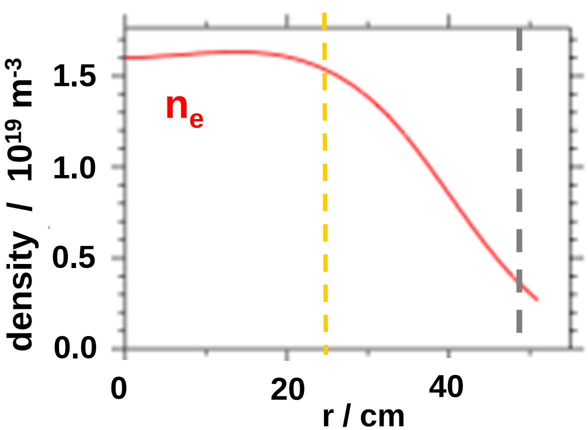
(assuming E_r=0
would result in 4 times higher
electron than ion fluxes)

[1] YOKOYAMA, M., et al., Nuclear Fusion 47(9) (2007), 1213

transport analysis: particle- and heat-fluxes

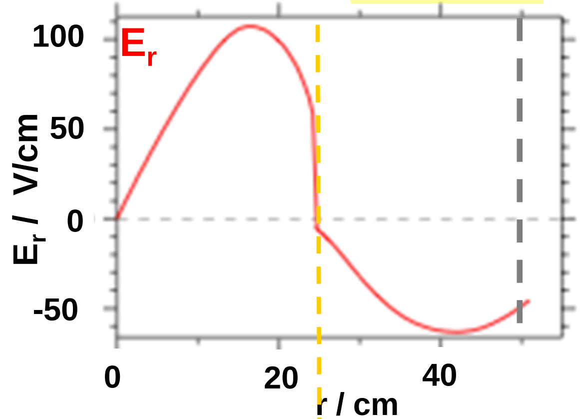
representative profiles

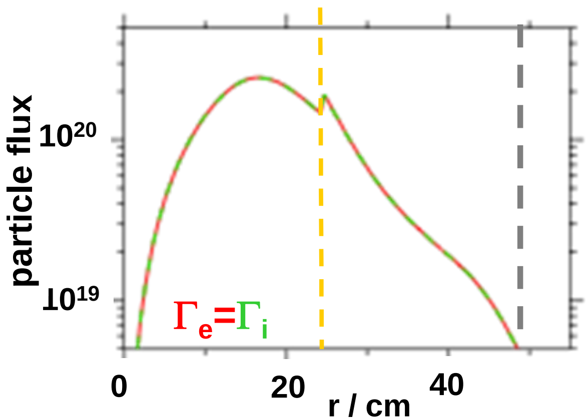




electron root
$E_r>0$

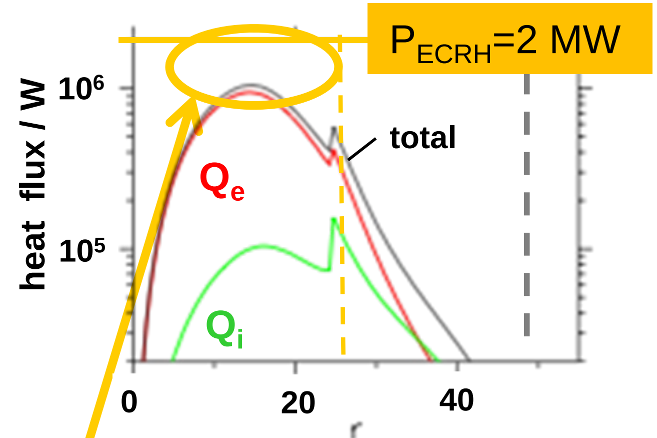
ion root
$E_r>0$





-> "usual": edge far beyond neoclassics
(turbulence, radiation, CX)

heat-flux from DKES code



-> yet the total central heating power
exceeds neoclassical fluxes for all radii

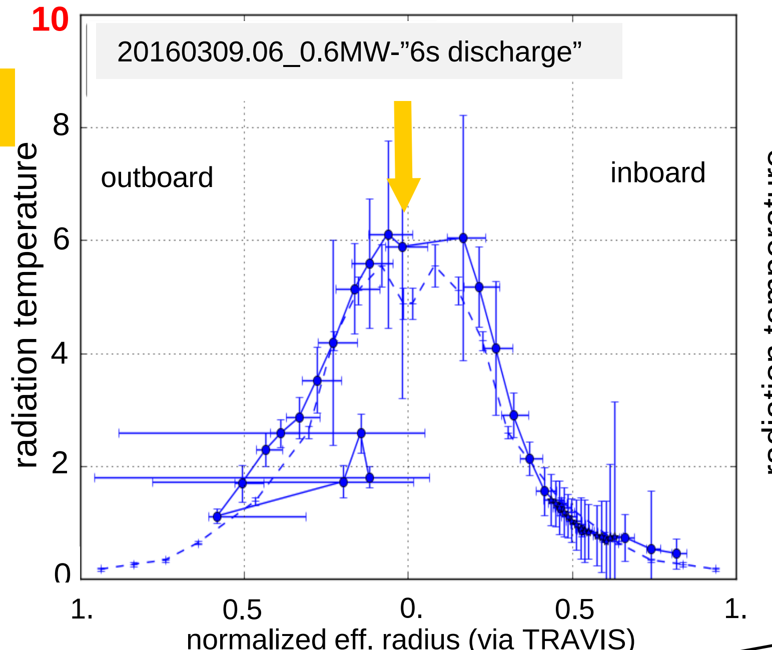
[1] YOKOYAMA, M., et al., Nuclear Fusion 47(9) (2007), 1213

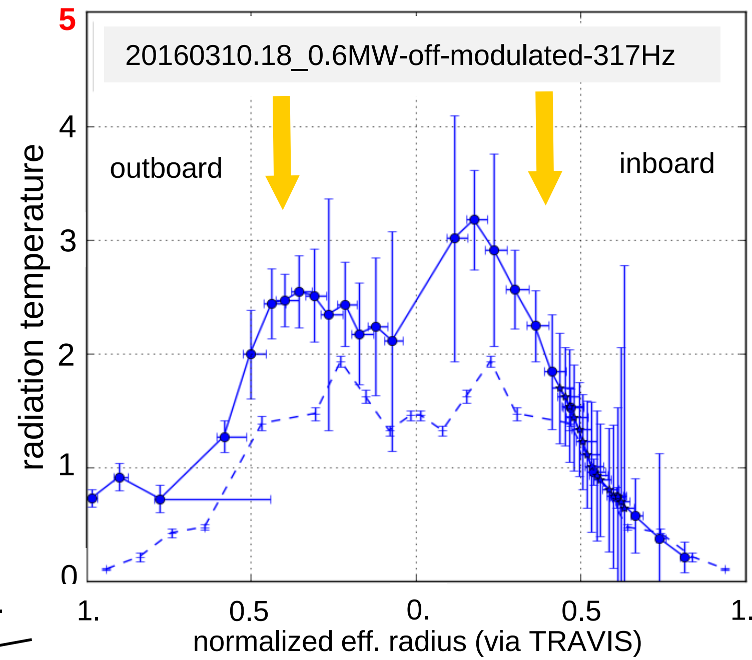
on-axis and off-axis ECR Heating

T_e profile shape follows the ECRH Power deposition
-> no indication for profile stiffness

ECE

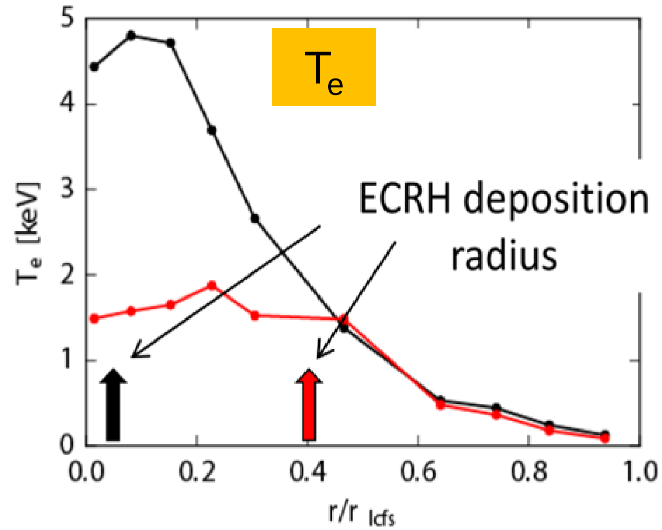
T_e / keV



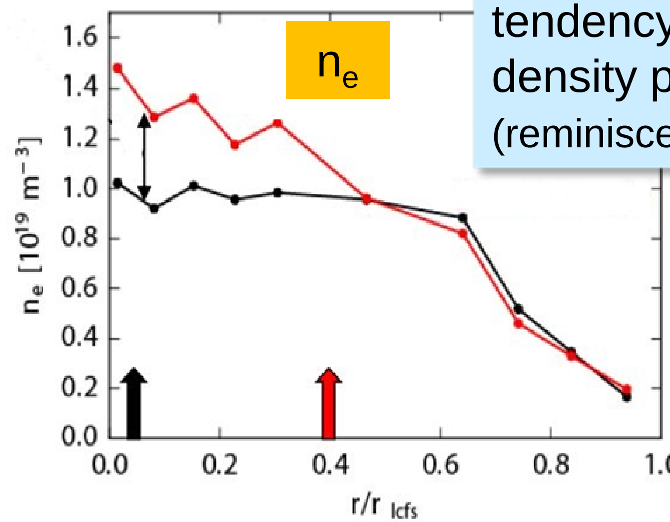


Thomson Scattering

on-axis **off-axis**



on-axis **off-axis**

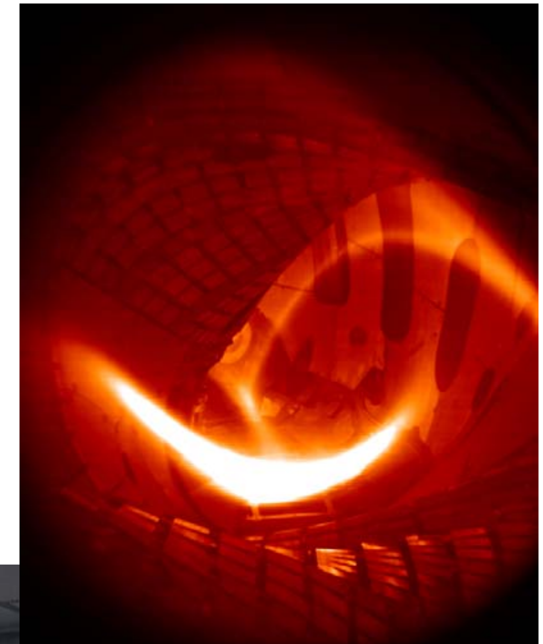


tendency for
density profile peaking
(reminiscent to W7-AS results)

Summary: Confinement in Wendelstein 7-X Limiter Plasmas

overview on first operation talk OV/3-1: R. C. Wolf
commissioning -> H.-S. Bosch et al., FIP (post deadline)

first H plasma



- o Experimental background in the first Operational Phase
  - -> operational range: outgassing, quasi-stationary, high reproducibility, radiative belt
  - -> commissioning and cross calibration of diagnostics
- o Energy content, power balance and global energy confinement
  - -> τ_E= 80 - 160ms ~ τ_E^{ISS04}
  - -> configuration factor ~1 (limiter plasmas)
- o Local transport analysis
  - -> Core Electron Root Confinement not reaching fully neoclassical conditions in the core
  - -> on- and off- axis ECRH heating no profile stiffness observed