Accuracy of TEXTOR He-beam diagnostics

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Introduction – standard He-beam diagnostics on TEXTOR

Atomic processes involved

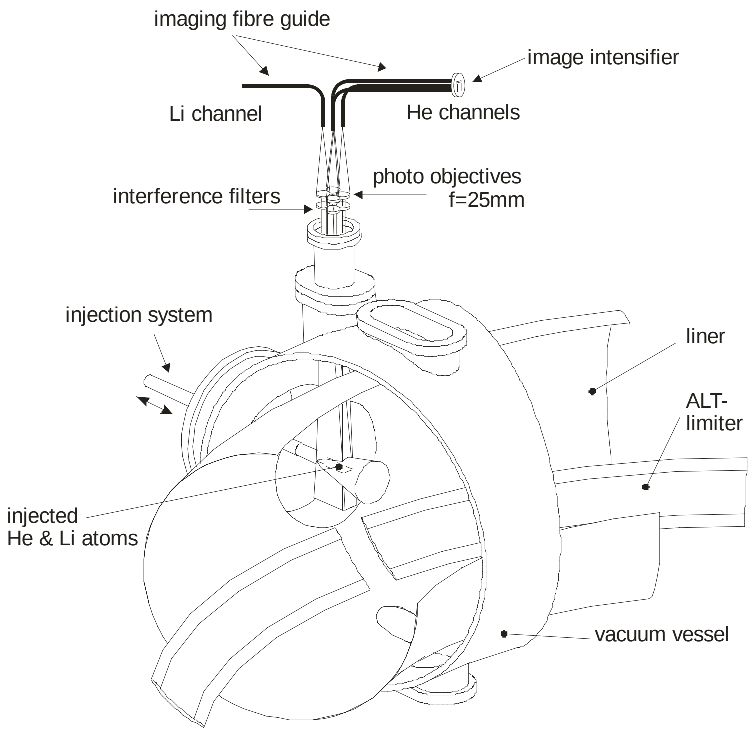
Evaluation procedures

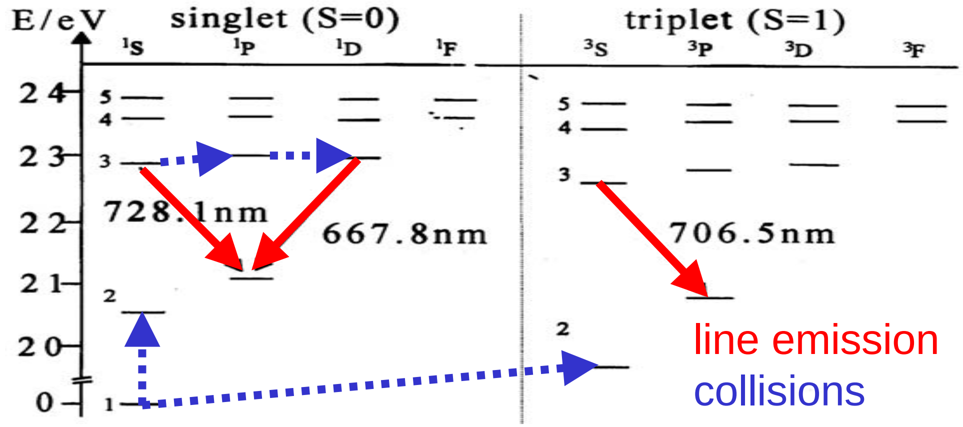
Atomic data - standard, new

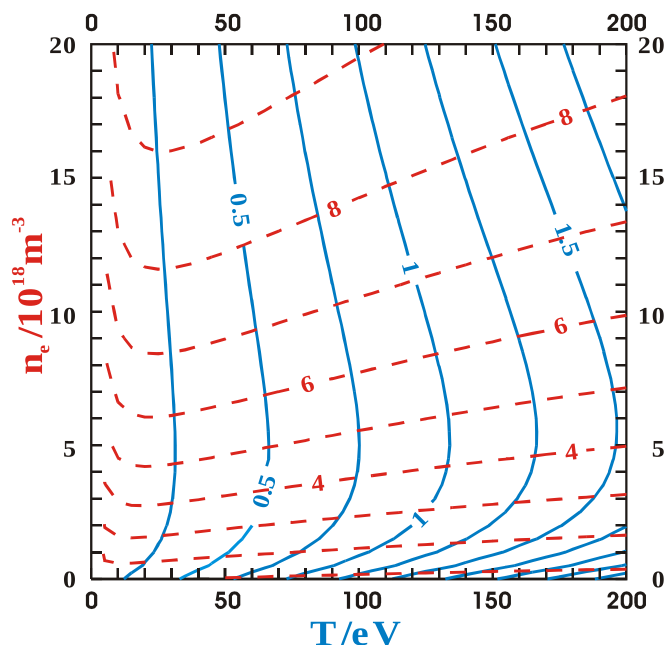
Results
- comparison of intensity profile fits
  comparison for different atomic data
  comparison for different discharge conditions
  comparison of different diagnostics

Summary & conclusions

Standard TEXTOR He-beam diagnostics







linie intensity ratios:

singlet : singlet

I(668nm) / I(728nm)

n_e dependent – – –

singlet : triplet

I(728nm) / I(706nm)

T_e dependent ——

M.Brix (2000)

$n_i/n_1 \cong$ constant

- relaxation time τ_r sufficiently small
- temporal resolution: $\Delta t = \tau_r$(max)
- spatial resolution: $\Delta x = \Delta t \cdot v_{Strahl}$
- no p & d collisions

Atomic processes

	pop. processes	depop.processes	
$\upsilon_b \frac{d}{dx} n_i =$	$+\sum_{j,j\neq i}\langle\sigma_{e,ji}\mathrm{v}\rangle n_e n_j$	$-\sum_{i,j\neq i}\langle\sigma_{e,ij}\mathrm{v}\rangle n_e n_i$	electron collision excitation
	$+\sum_{j,j\neq i}\langle\sigma_{p,ji}v\rangle n_{ion} n_j$	$-\sum_{i,j\neq i}\langle\sigma_{p,ij}v\rangle n_{ion} n_i$	ion collision excitation
	$+\sum_{j,j>i} A_{ji} n_j$	$-\sum_{j,j<i} A_{ij} n_i$	spontaneous emission
		$-\langle\sigma_{e\rightarrow ionis,i}\mathrm{v}\rangle n_e n_i$	electron collision ionisation
		$-\langle\sigma_{p\rightarrow ionis,i}\mathrm{v}\rangle n_{ion} n_i$	ion collision ionisation
		$-\langle\sigma_{cx,i}\mathrm{v}\rangle n_{ion} n_i$	charge exchange

Evaluation procedures

For known $T_e(r)$ and $n_e(r)$ -> line intensity profiles $I_\lambda(r) = n_k \; A_{ki}$

However, we need for known $I_\lambda(r) = n_k \; A_{ki}$ -> $T_e(r)$ and $n_e(r)$

M. Brosda and M.Brix have already shown that it is possible to restore T_e and n_e profiles from line profiles $I_1(r); I_2(r); I_3(r)$

Possible approaches:

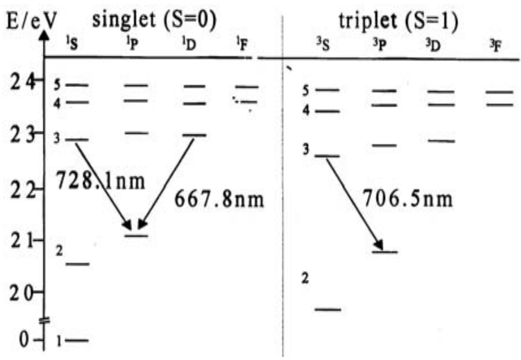
non-stationary (NS): direct solution of the general (time / space) dependent equation and fit $I_\lambda(r) = n_k \; A_{ki}$ to the measured one.

quasi-stationary (QS): approx. solution of the NS equations: on the right the St-solution of the balance equations for rel. populations n_k / n_1 of the excited states is inserted.

stationary (St): the derivatives are neglected assuming that the time constant of the measured processes are larger than the relaxation times τ for the transitions used.

Atomic data - levels

The following atomic levels of He I have been included in the model:



(1): $1s^2\ ^1S$; $1snl\ ^1L$; $1snl\ ^3L$; $n = 2; 3; 4$, $l = 0; 1; 2$
(1i): $1s4f\ ^1F$; ^3F
(2): $1sn\_1$ (singlets), $1sn\_3$ (triplets), $n = 5; 6; 7$ summed over all l
(3): $1sn$; $n = 8; 9$ summed over all l and S
(c): $c = 1s$ ground state of He II

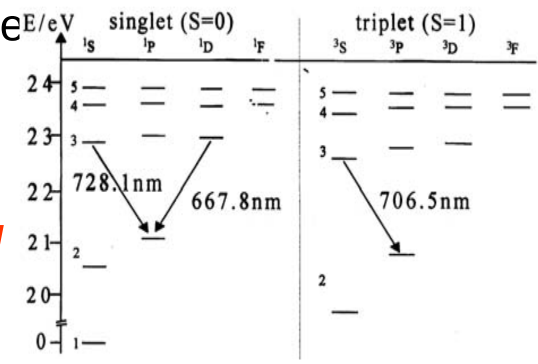
"effective" levels have been introduced, which describe group of levels summed over some quantum numbers (decreases drastically the dimensions of the statistical matrix).

group (1): *SL* coupling is a good approximation.
group (1i) and any levels with $l > 2$: deviation from the *SL* coupling is significant.
The matrix of the eigen-vectors in intermediate coupling was obtained for the states (1i) using the GRASP92-code (*Drake*).

For the levels $1sn$; $n = 8; 9$ summed over all l and S the type of coupling is not important.
For the levels $1sn\_1$ (singlets), $1sn\_3$ (triplets), $n = 5; 6; 7$ an effective mixing due to deviation from the *SL* coupling was introduced.

Atomic data – energies, radiation, collision with e

The following atomic levels of He I have been included in the mode



(1): $1s^2\ ^1S;\ 1snl\ ^1L;\ 1snl\ ^3L;\ n = 2;\ 3;\ 4,\ l = 0;\ 1;\ 2$
(1i): $1s4f\ ^1F;\ ^3F$
(2): 1*sn*_1 (singlets), 1*sn*_3 (triplets), $n = 5;\ 6;\ 7$ summed over all *l*
(3): $1sn;\ n = 8;\ 9$ summed over all *l* and *S*
(c): $c = 1s$ ground state of He II

Energy levels: from NIST

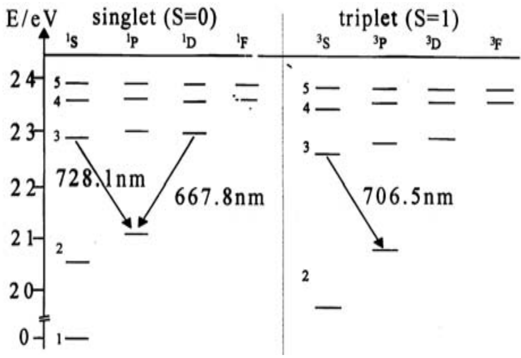
A for $1s2p\ ^{1,3}P – 1s^2\ ^1S$ from *Wiese* (NSRDS-N.B.S.)
A for groups (1), (1i) from ATOM, intermediate coupling for 1s4f – 1s3d, SL for others
A for transitions inside and between groups (2), (3): Kramers formula

$<\sigma v>_{ex}$ for group (1): CCC-89 cross sections (*Bray*)
$<\sigma v>_{ex}$ from group (1) to groups (1i),(2),(3),c: ATOM code (Norm.BA)
$<\sigma v>_{ex}$ inside groups (1),(2),(3): semiclassical method (*Beigman*)
transitions to group (1i): intermediate coupling

Atomic data – collisions with p,d, CEX

The following atomic levels of He I have been included in the model:

(1): 1*s*^{2} ^1S; 1*snl* ^1L; 1*snl* ^3L; *n* = 2; 3; 4, *l* = 0; 1; 2
(1i):1*s*4*f* ^1F; ^3F
(2): 1*sn*_1 (singlets), 1*sn*_3 (triplets), *n* = 5; 6; 7 summed over all *l*
(3): 1*sn*; *n* = 8; 9 summed over all *l* and *S*
(c): *c* = 1*s* ground state of He II



Collisions with heavy particles at thermal energies may only contribute for transitions with $\Delta n = 0$

$\langle\sigma v\rangle_{p,d}$ for the most important 3l – 3l': from CC-method (code ATCC (*Borodin*))
for all other transitions: Norm. Born approximation (*Borodin*)

$\langle\sigma v\rangle_{CEX}$ from the metastable state 1s2s from code CAPT (*Shevelko*) with cross sections for $n \geq 4$ from (*Janev*)

Normalized Born Approximation

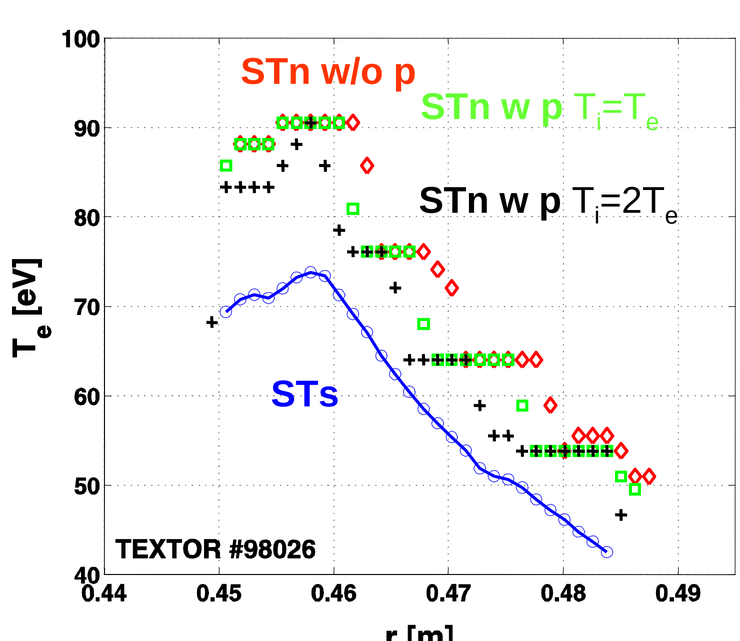
$$\left\langle v\sigma_p^B\right\rangle = z^{-3}\frac{A\beta_\mu^{1/2}}{(\beta_\mu+\chi)(\beta_\mu/b_D+1)}\cdot\exp(-\Delta E/kT);$$

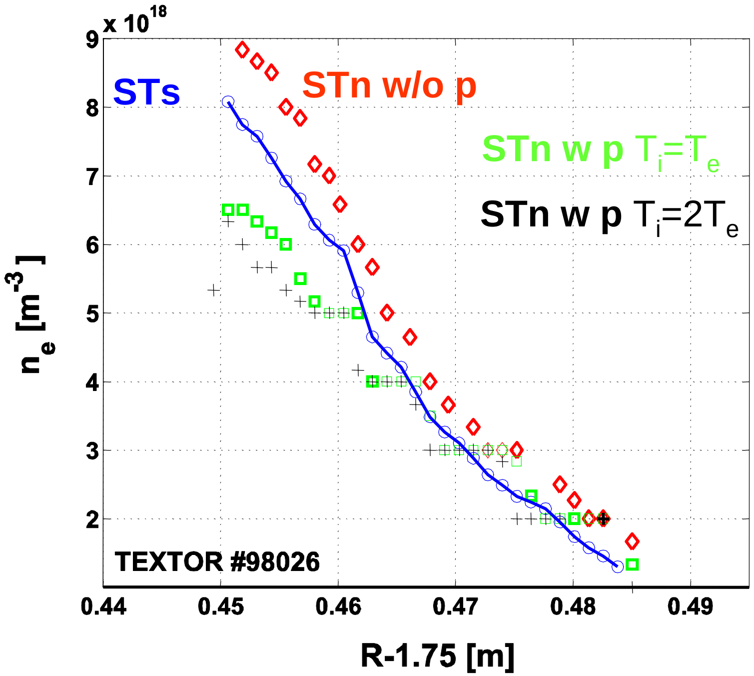
$$\beta_\mu = Z^2 Ry/kT\cdot(\mu/m);\;\; b_D = 2^{5D-6};$$

Close coupling method

$$\left\langle v\sigma_p^C\right\rangle = \left\langle v\sigma_p^B\right\rangle\cdot\exp(-\sqrt{(D/50)\beta_\mu}$$

Results – Comparison of different models



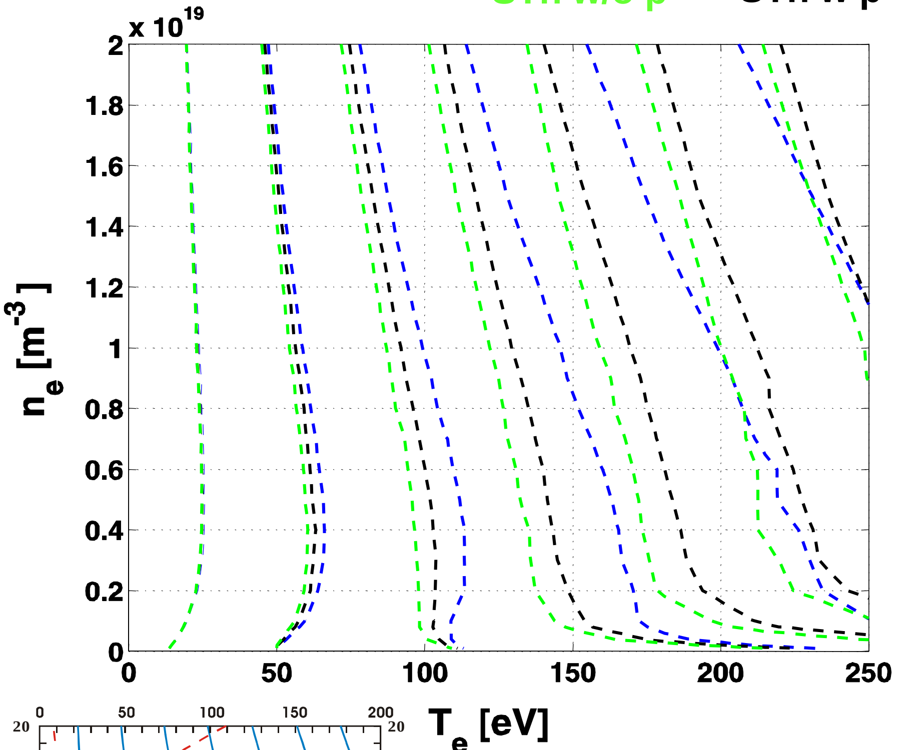


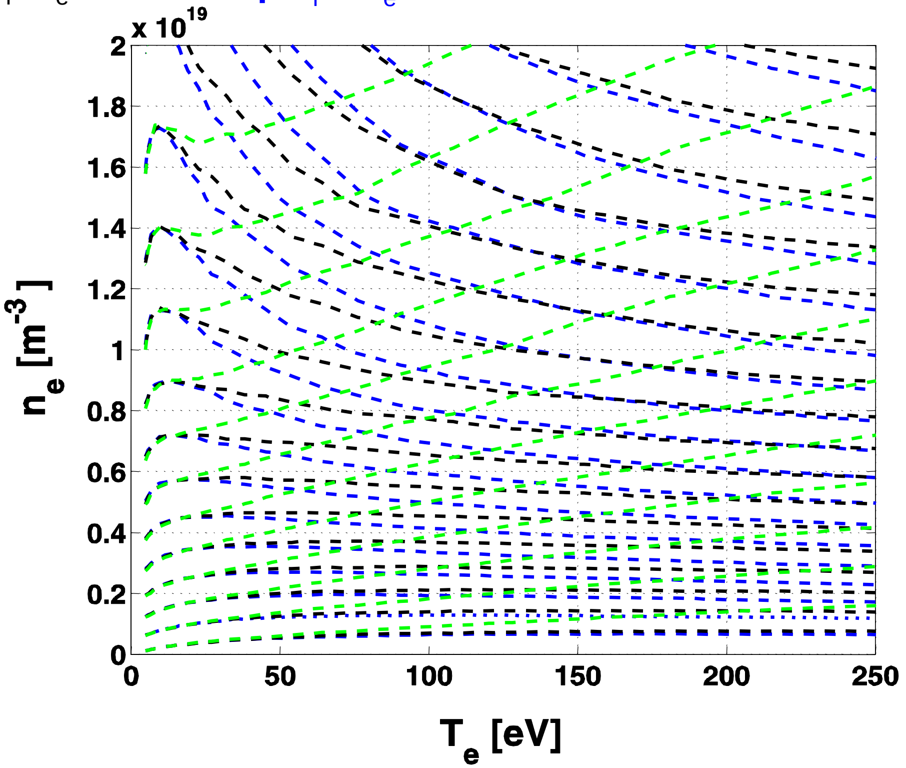
proton collisions do not seem to play a strong role

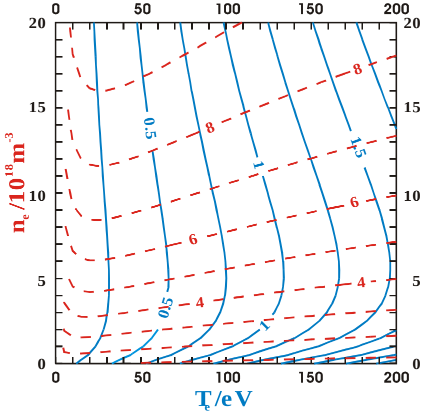
some effect is of course expected at high densities – T_i effects are still weak

Results – T_e & n_e diagram (new)

STn w/o p   STn w p T_i=T_e STn w p T_i=$2T_e$





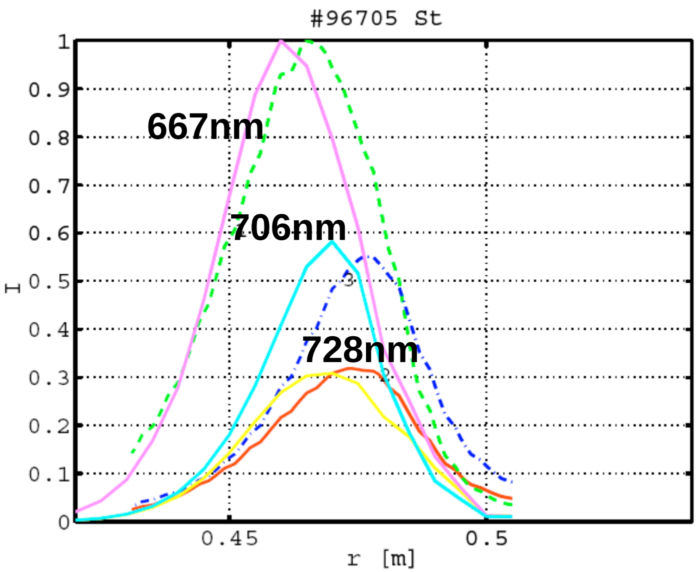


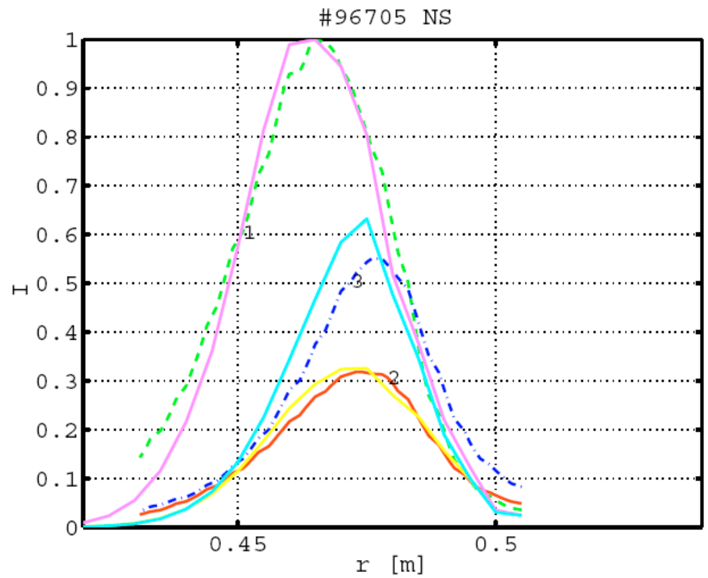
evaluation ranges could be extended

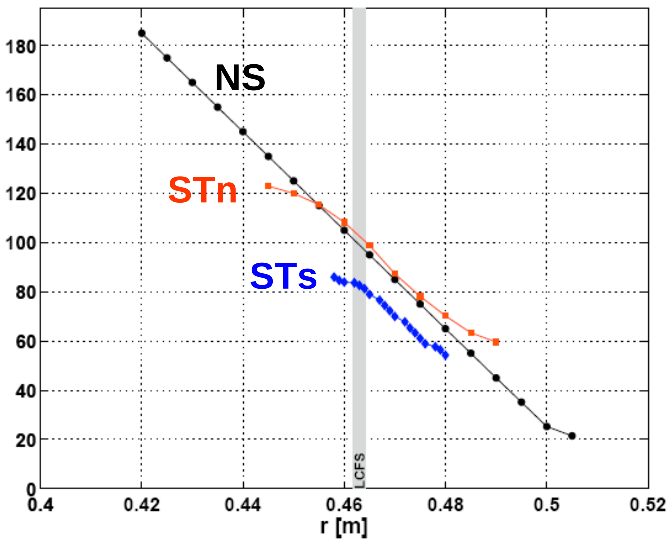
proton collisions reduce the electron densities

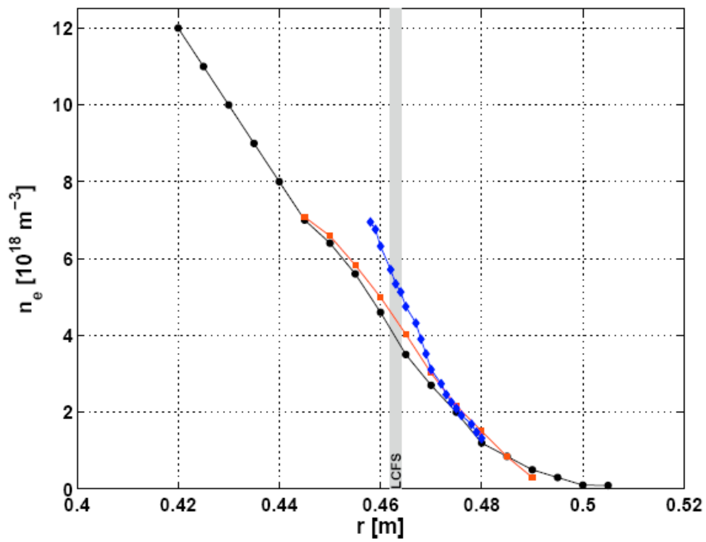
"   "   increase the electron temperatures

Results – Comparison for intensity profile fits (Ohmic discharge) (# 96705)









for large radii:

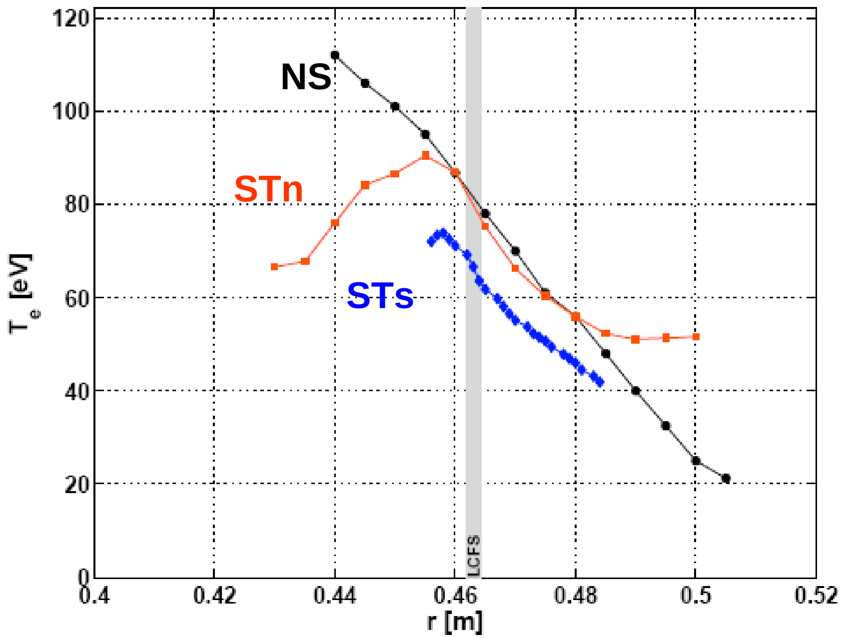
τ_r is too large

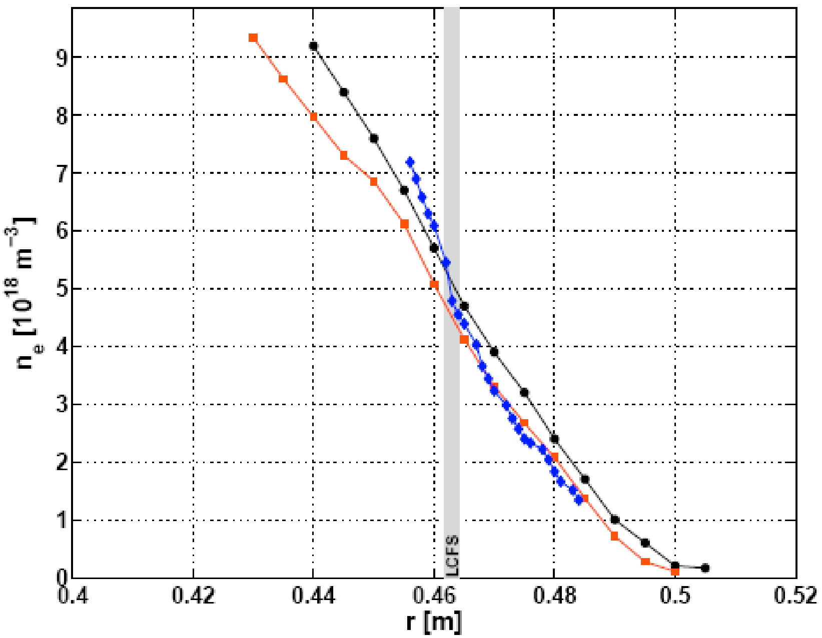
for small radii:

stronger impact of higher l-mixing

(not yet considered)

Results – Comparison for Ohmic discharges (# 98026)





for large radii:

τ_r is too large

for small radii:

stronger impact of higher l-mixing

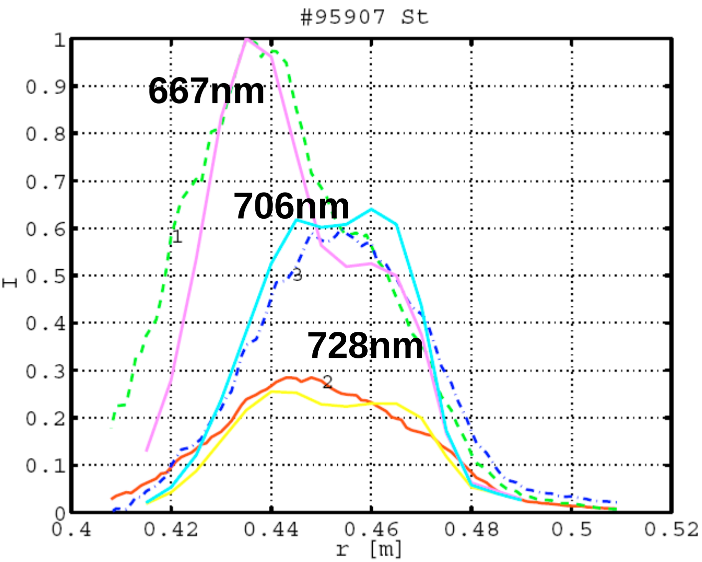
(not yet considered)

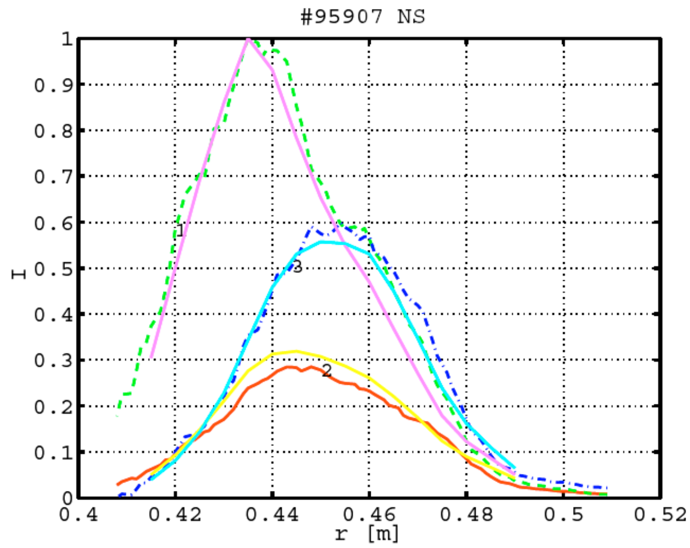
For Ohmic discharges:

The deviation between Brix's CRM and the new one accounts to 10% for T_e and is negligible for n_e.

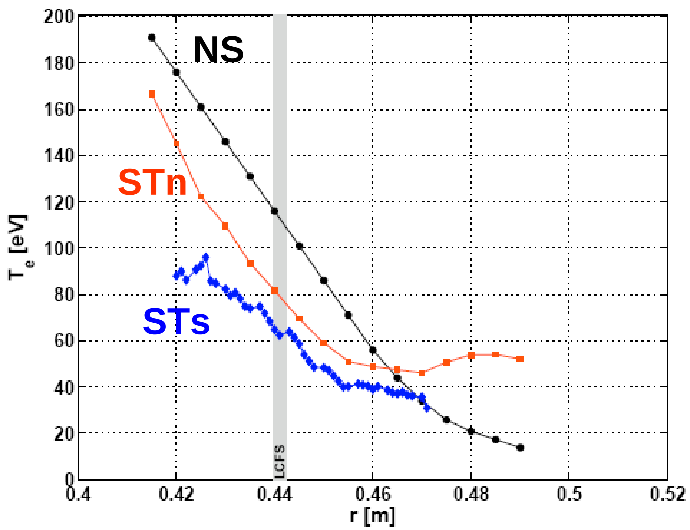
The impact of proton collisions as well as of the new atomic processes (CXRS and a new ionisation rate coefficient) seems to have a minor effect.

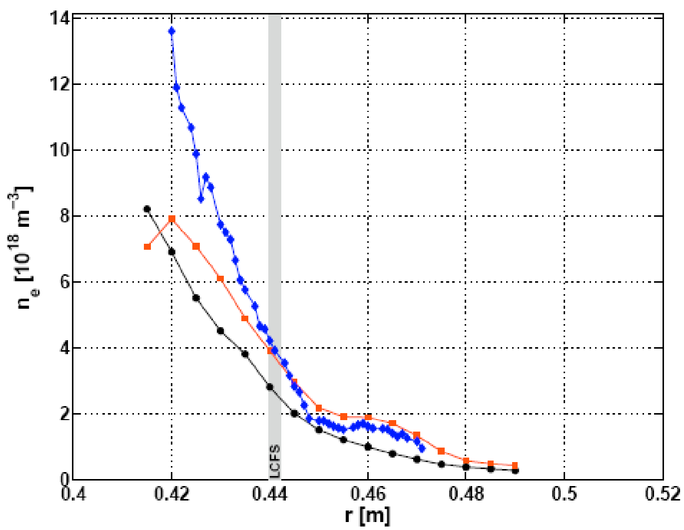
Results – Comparison for intensity profile fits (small NBI-heating) (# 95907, 300kW)





T_e & n_e



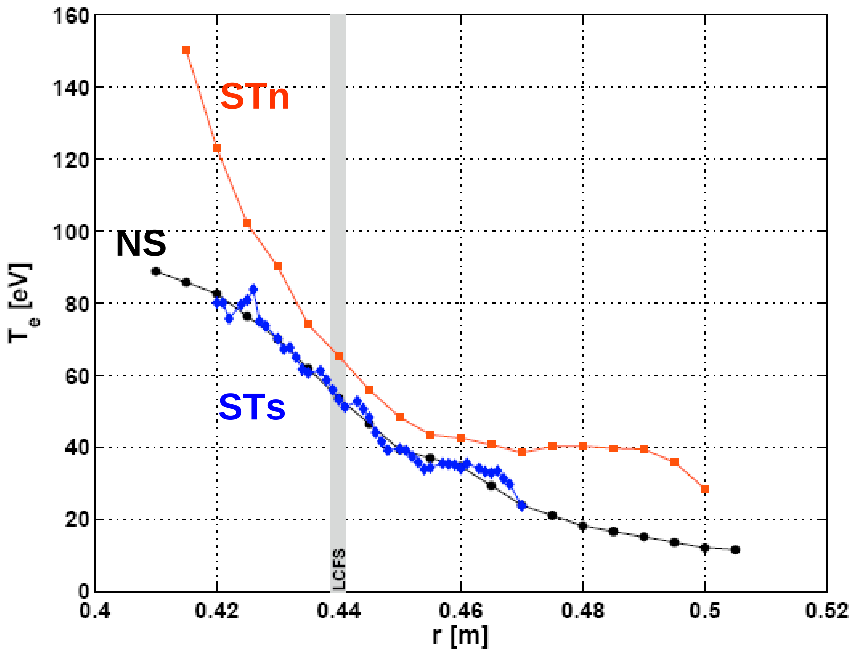


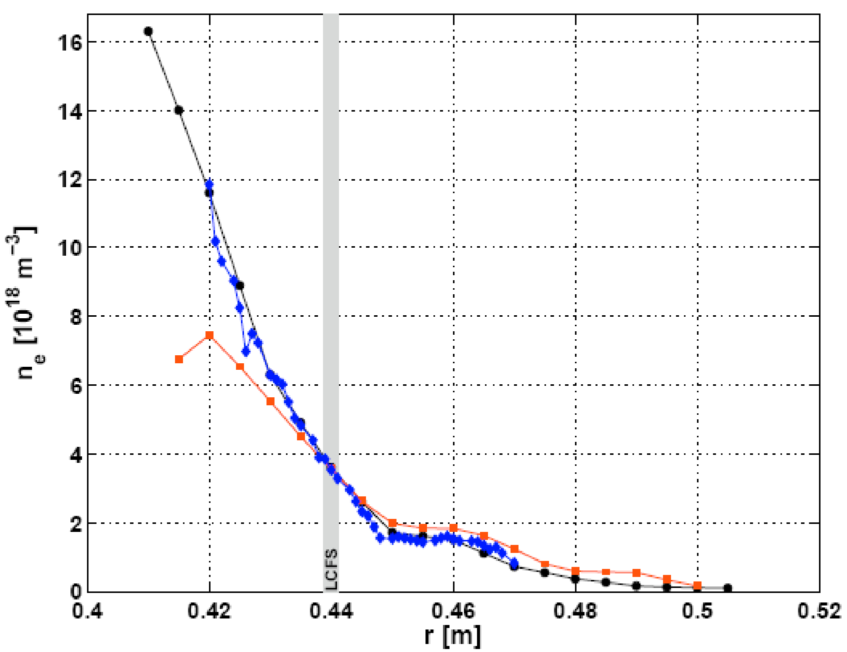
strong deviations (especially for T_e)

for all models at small radii

Influence from higher levels !?

Results – discharges with small NB-heating (# 95896, 300kW)

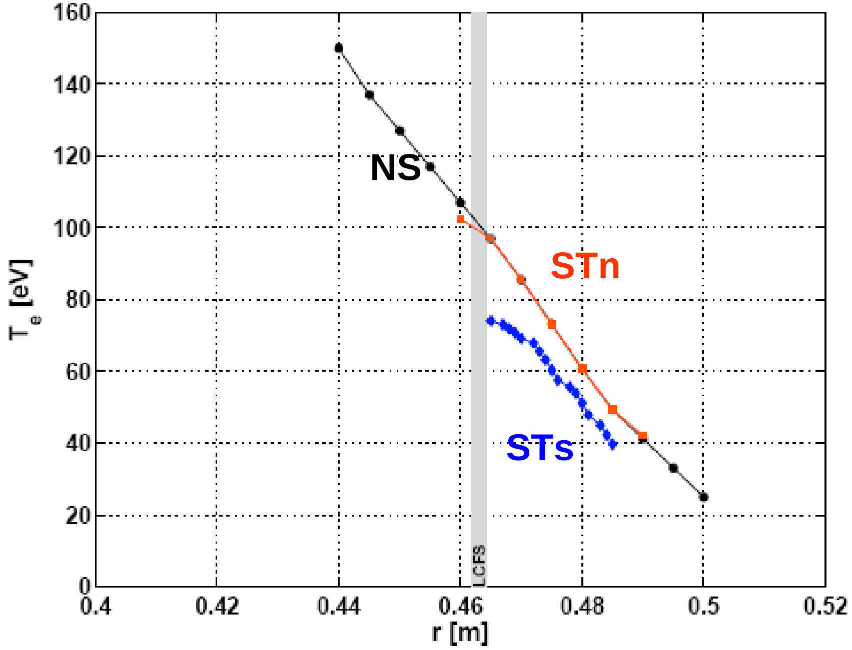


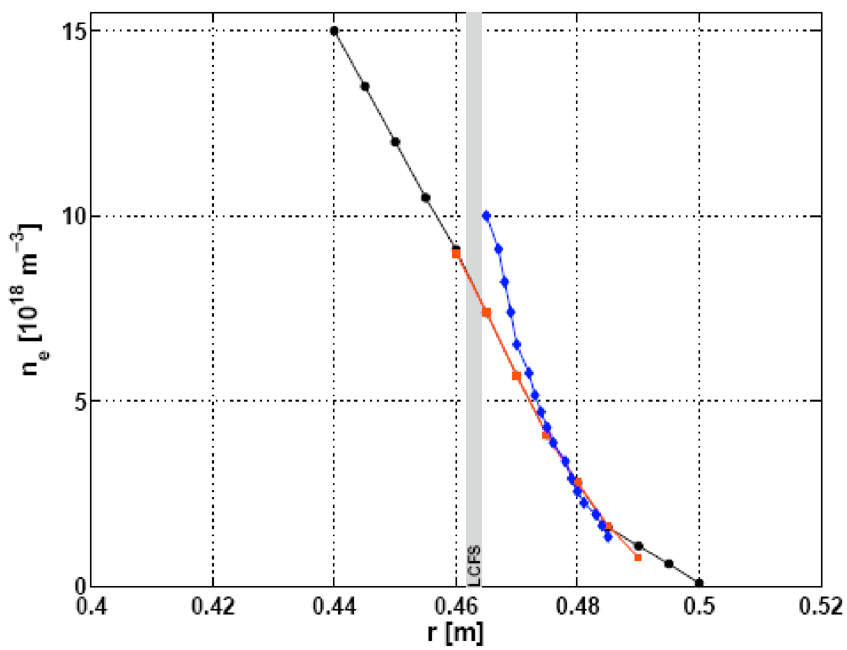


T_e & n_e

much better coincidence now

Results – discharges with strong NB-heating (# 96710, 1200kW)

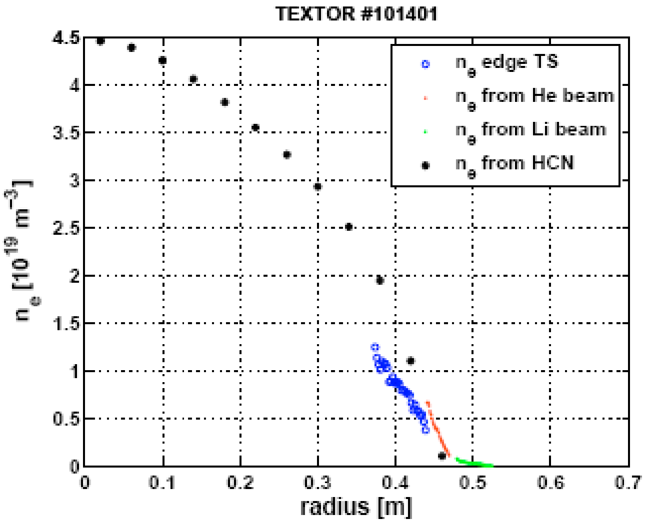


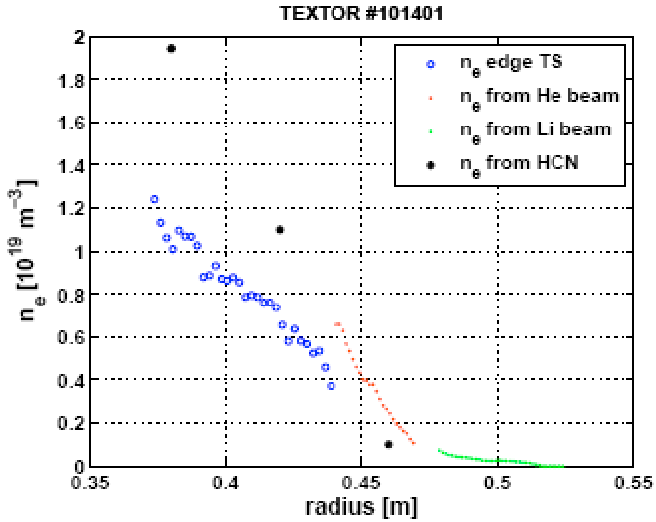


T_e & n_e

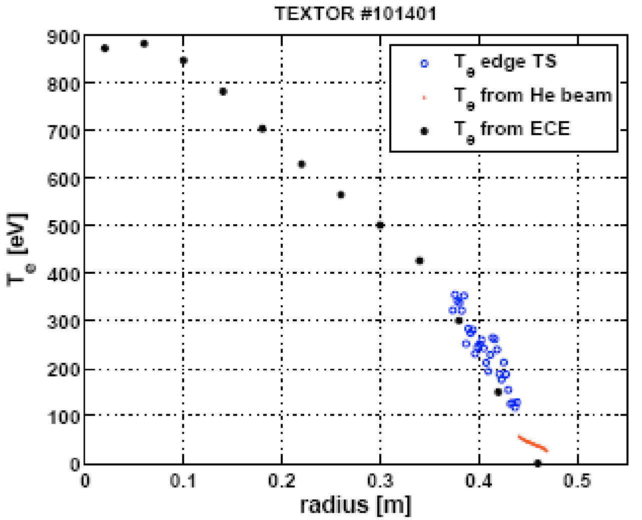
again much better coincidence now, **NS** allows extension into the confined plasma

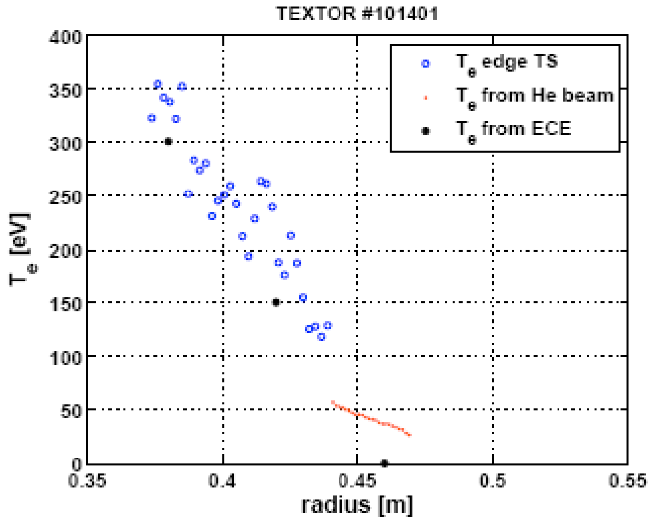
Results – comparison with different diagnostics





→ Zoom





n_e

He- & Li-beam data extrapolate well into the HCN data

TS seems too small (calibration error ?)

T_e

He-data extrapolate well into the HCN & TS data

Summary & Conclusion

An extended model (to Brix 2000) with **proton collisions and CEX processes** has been tested on TEXTOR discharges.

Only marginal deviations => impact of the proton collisions is weak under the target plasma conditions investigated.

Evaluation with the non-stationary approach **(NS) enhances the radial extension** of the profile and **cancels relaxation phenomena**.
A method to apply the NS method as standard evaluation is under development.

For the measurement errors **the range of ΔT_e = 30% and Δn_e = 10% given by Brix 2000 is still valid.**
Proton collisions (with $T_i = T_e$) do not exceed these margins.

Comparison of the $n_e(r)$ and $T_e(r)$ profiles obtained with other edge **are in reasonable agreement** with those from He.

BES on thermal He should be a reliable method for measurements within
$2.0\times10^{18} m^{-3} < n_e < 3.0\times10^{19} m^{-3}$ and $20\ eV < T_e < 300 eV$.