Absorption properties of X3 top-launch ECH on TCV

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Outline

> TCV EC heating system.

> Why X3 top-launch ECH ?

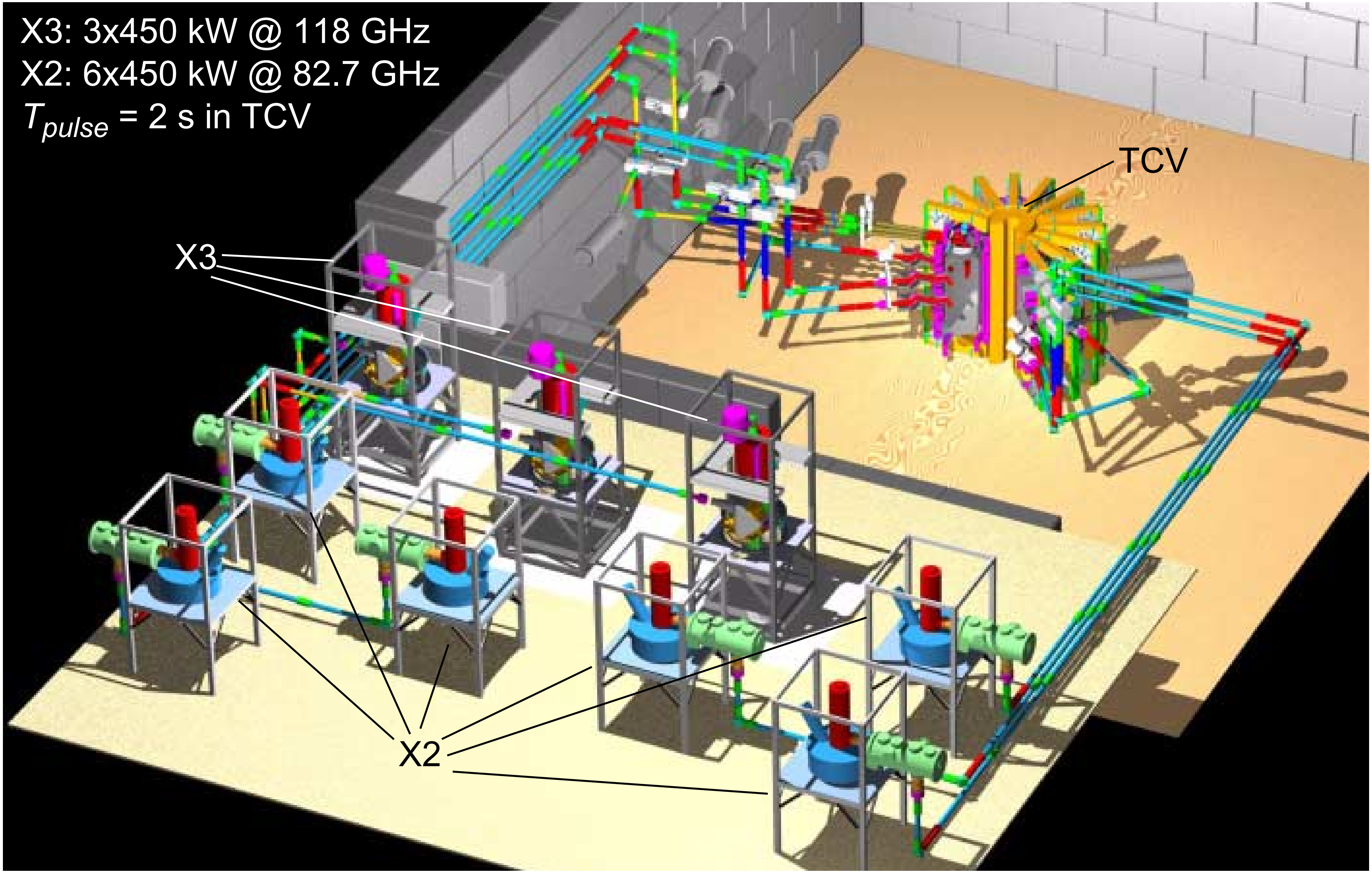
> Absorption sensitivity on the launcher poloidal angle.

> X3 absorption dependence on the density.

> X3 absorption dependence on the injected power

> Conclusion

TCV EC heating system



Why X3 top-launch ?

Low magnetic field: B_0=1.45 T

Low X2 cut-off density X2 : $ne_{cutoff}=4.2\times10^{19}\ m^{-3}$

Extending the density range **X3** : $ne_{cutoff}=11.5\times10^{19} m^{-3}$

=> H-mode heating, ...

The absorption coefficient for 3rd harmonic X-mode is lower than the absorption coefficient for 2nd harmonic X-mode

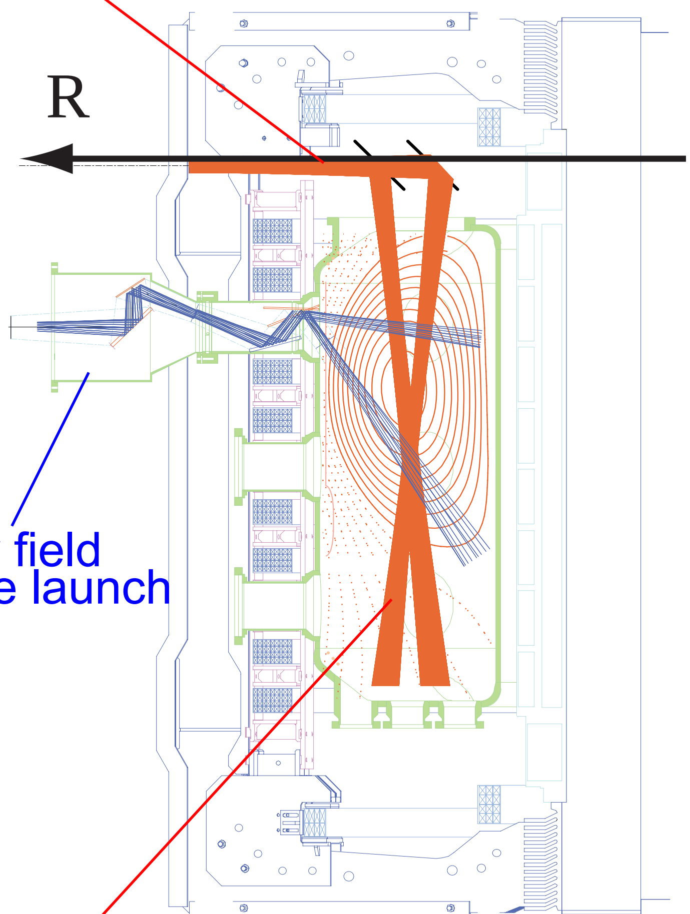
$$\frac{\alpha_3^{(X)}}{\alpha_2^{(X)}} \sim \left(\frac{v_{th}}{c}\right)^2 = \frac{T_e[keV]}{511}$$

Top launch increases the beam path along the resonance

=> Maximize the optical depth: $\tau = \int \alpha_n^{(X)} \boldsymbol{ds}$

X3 launching system [1]

X3 top-launch

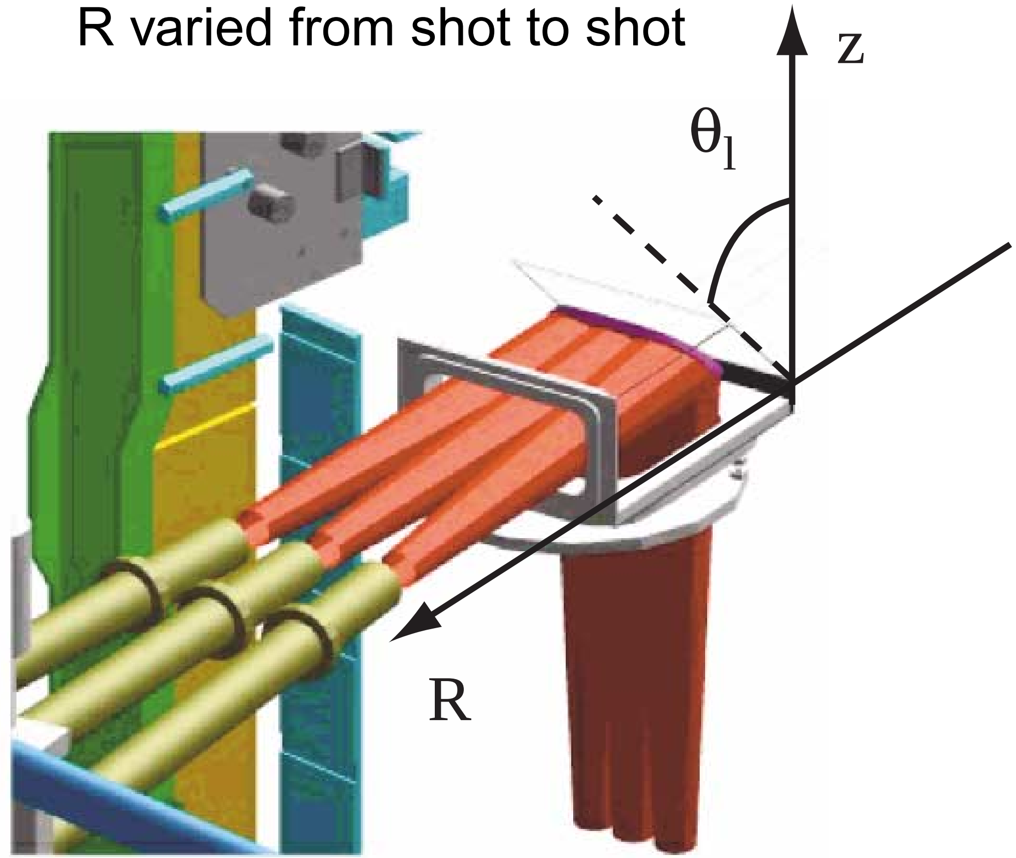


X2
low field
side launch

$d\theta_{inj}/dt=40^{o}/s$

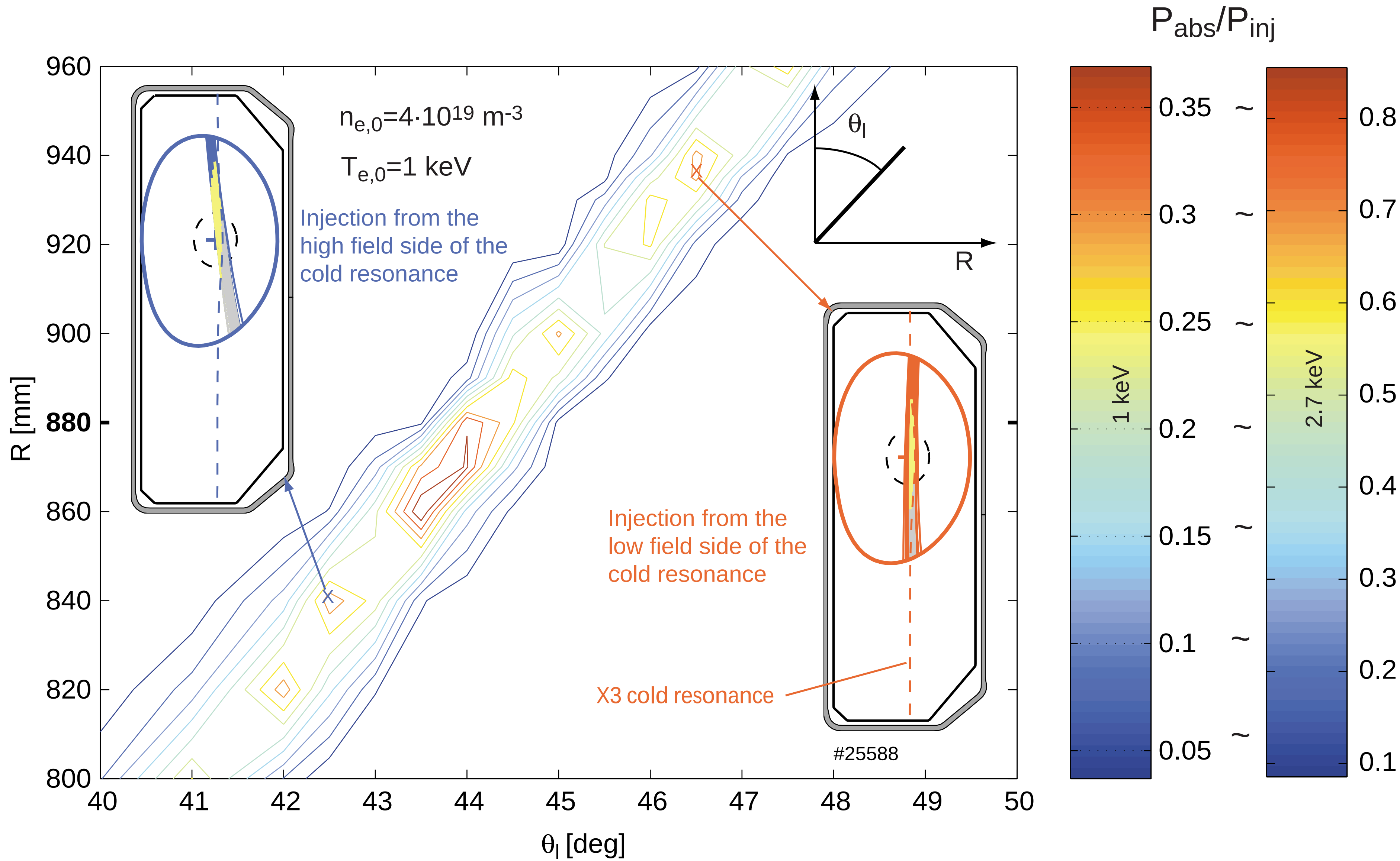
$d\theta_l/dt$ = 20 ^{o}/s during the shot

R varied from shot to shot

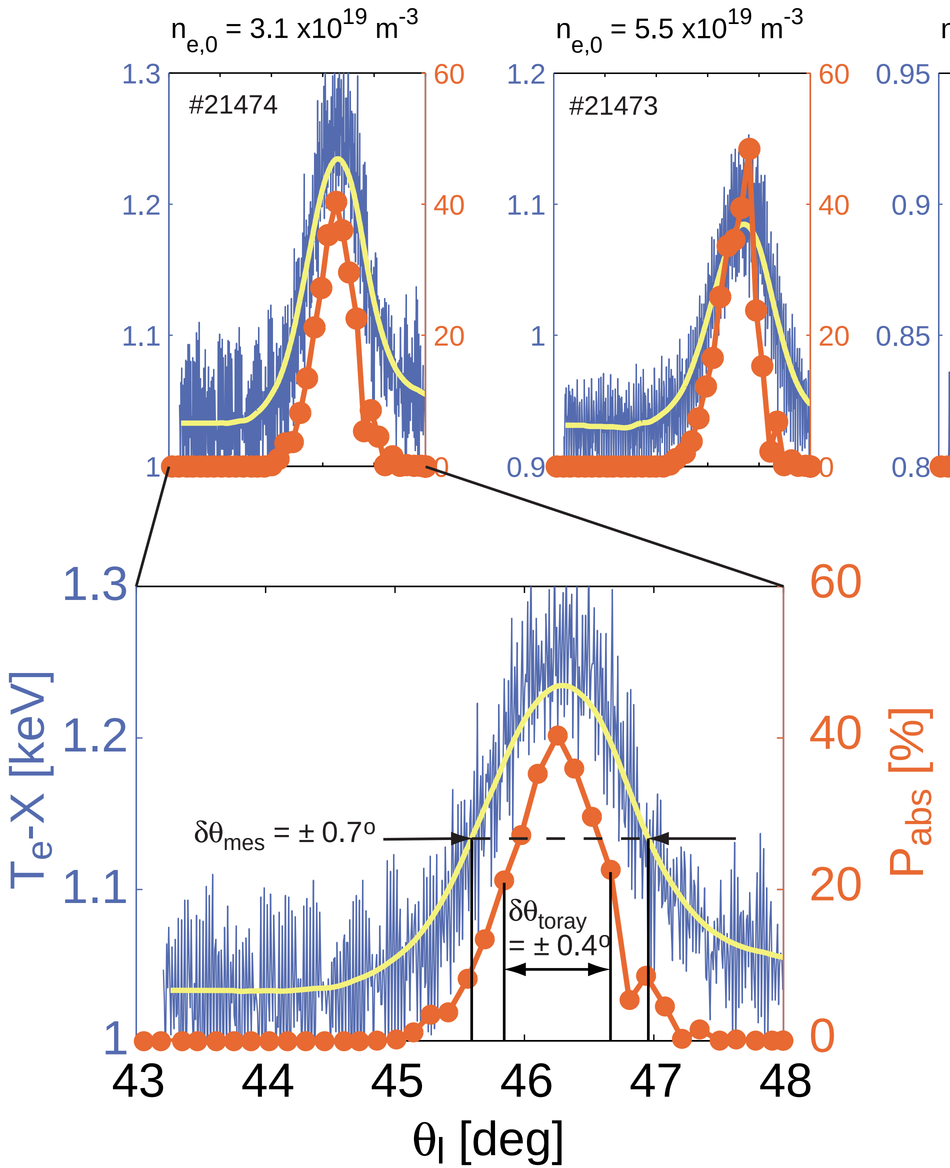


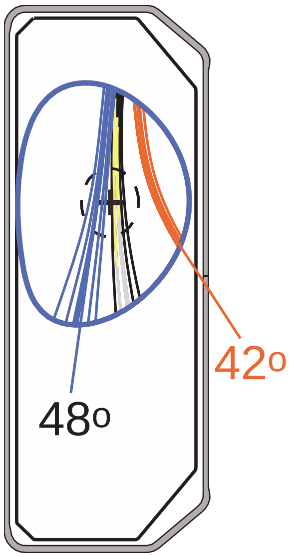
[1] J.-Ph. Hogge and al., Nucl. Fusion (43), 2003

R-θ_l X3 absorption domain from TORAY-GA



X3 top-launch experiments sweeping θ_l





Goal:

- Determine $\theta_{l,\,opt} \pm \delta\theta$
- Calculate and measure as a function of the density:
- $\theta_{l,\,opt}(n_{e,\,0})$
- $P_{abs}(n_{e,\,0})$
- $\Delta W_e(n_{e,\,0})$

Experimental parameters:

- θ_l is swept from 42° to 48° => pass through optimal absorption
- $3.3 \leq n_{e,0} \leq 8.0 \times 10^{19}$ m^{-3}
- P_{inj} = 450 kW

Strong sensitivity on θ_l => real time feedback control

Sensitivity independent of the density:

- If θ_l varies from $\theta_{l,opt}$ of 0.4^o, P_{abs} decreases of 50 %
- If θ_l varies from $\theta_{l,opt}$ of 0.7^o, T_e-X decreases of 50%

The required accuracy corresponding to this sensitivity suggests to install a real time feedback control[3] on the X3 launcher.

Such a control system has been installed and an exploitable error signal has been obtained.

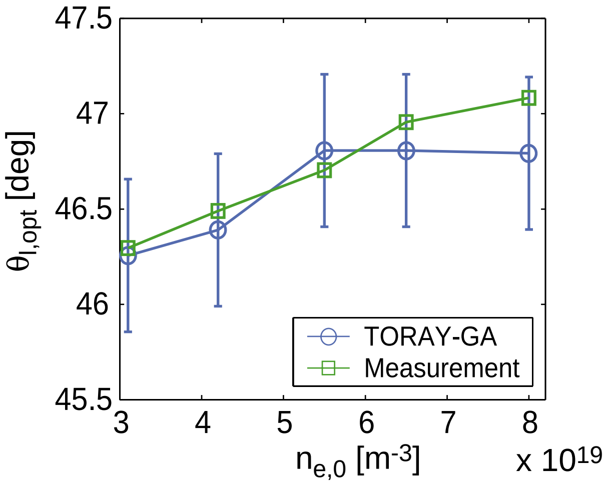
This error signal will be used through a PID controller (already installed) in order to close the control loop (summer 2004).

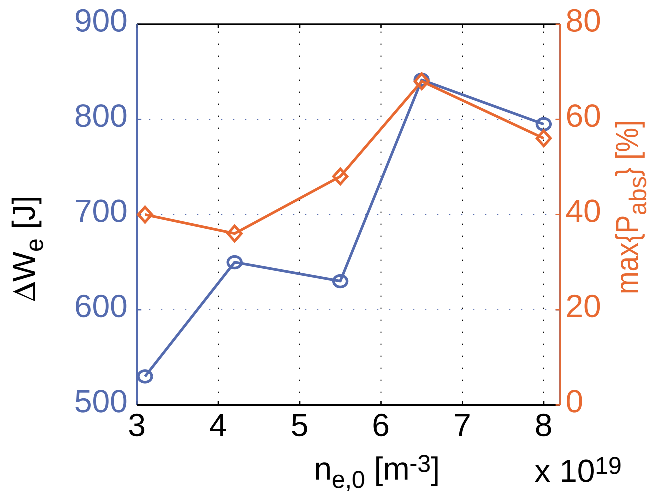
[2] G. Arnoux and al., IAEA TM on ECRH for ITER, Kloster Seeon, 2003.

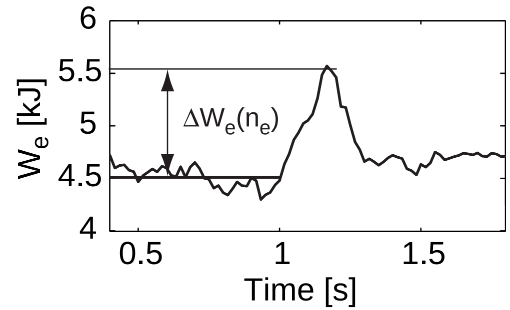
Impact of the density on $\theta_{l,opt}$ and P_{abs}

$\theta_{l,opt}$: TORAY-GA in good agreement with the measurements

The optimum density is experimentally as well as theoretically $n_{e,0} \cong 7 \cdot 10^{19}$ m^{-3}







$\theta_{l,opt}$ increases with $n_{e,0}$ because refraction must be compensated.

The global electron energy increase is qualitatively consistent with the absorbed power predicted by TORAY-GA

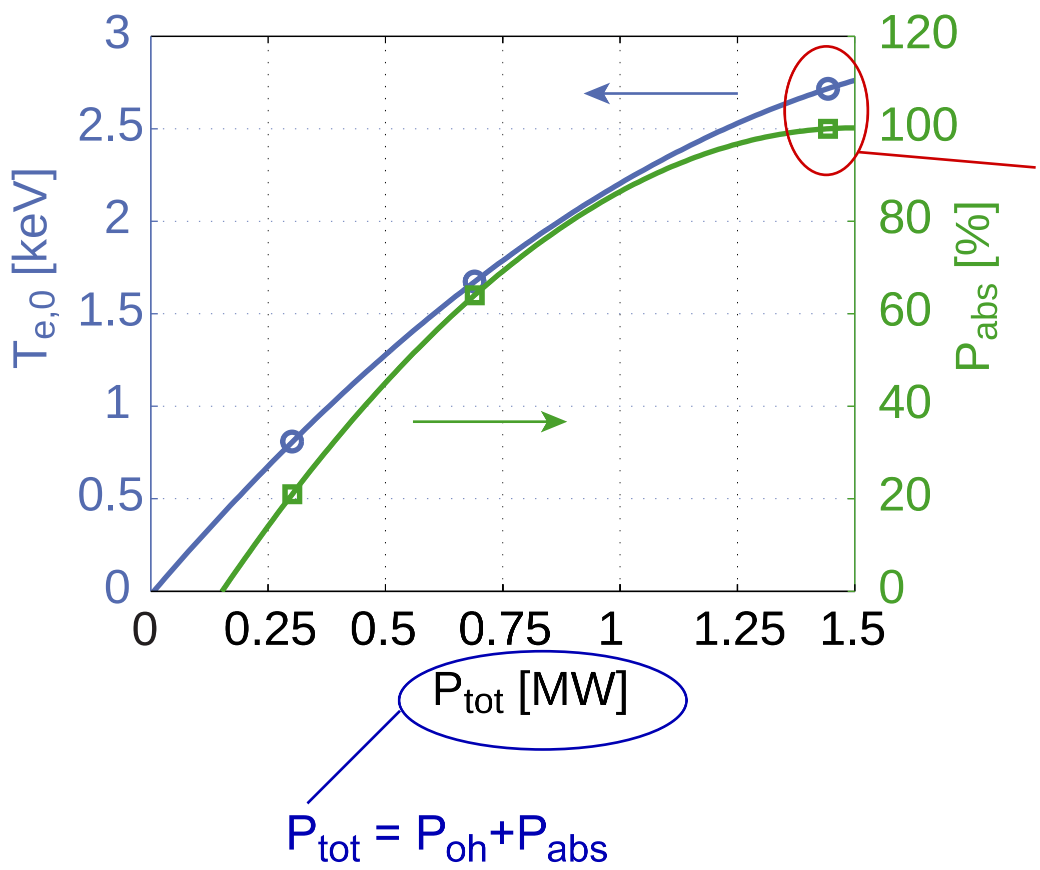
$\Delta W_{e,opt}$=18% with P_{inj}=450 kW... How is the absorption if P_{inj} is increased ?

Full single pass absorption if P_{inj}=1.35 MW

P_{inj} = 0.45 MW (1 Gyro)
P_{inj} = 0.90 MW (2 Gyro)
P_{inj} = 1.35 MW (3 Gyro)

$\langle ne_{max} \rangle$=4.0-4.8
Ip = 193-240 kA

First θ_l sweep ==> $\theta_{l,opt}$
1s pulse with P_{abs} measurement



100% single pass absorption is measured with 1.35 MW of X3 injected.

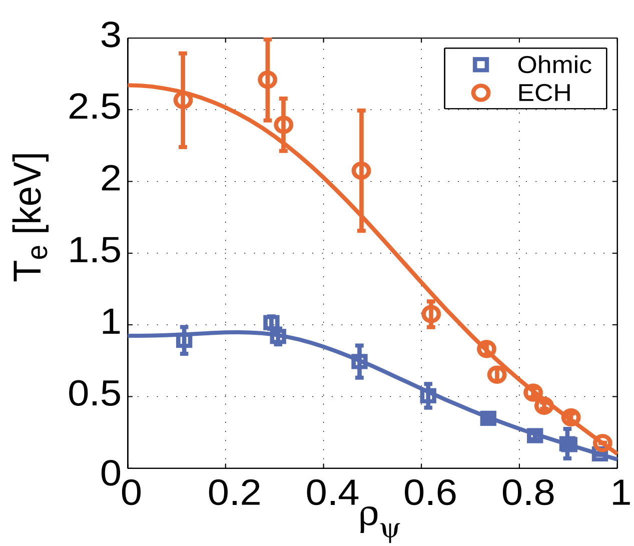
P_{abs} > 80% is expected if
$T_{e,0}$ > 2.0 keV and
if $n_{e,0} = 4 \cdot 10^{19}$ m^{-3}

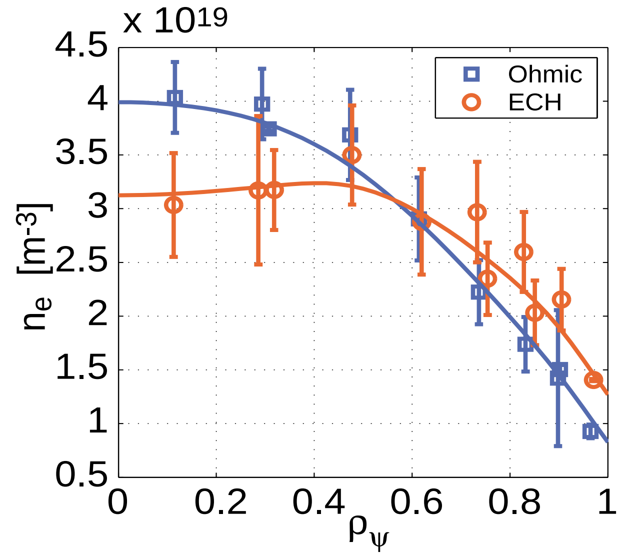
What about profiles ?

P_{inj} = 1.35 MW: density profiles is flattened

n_e profile flattening is observed at P_{inj}=1.35 MW.

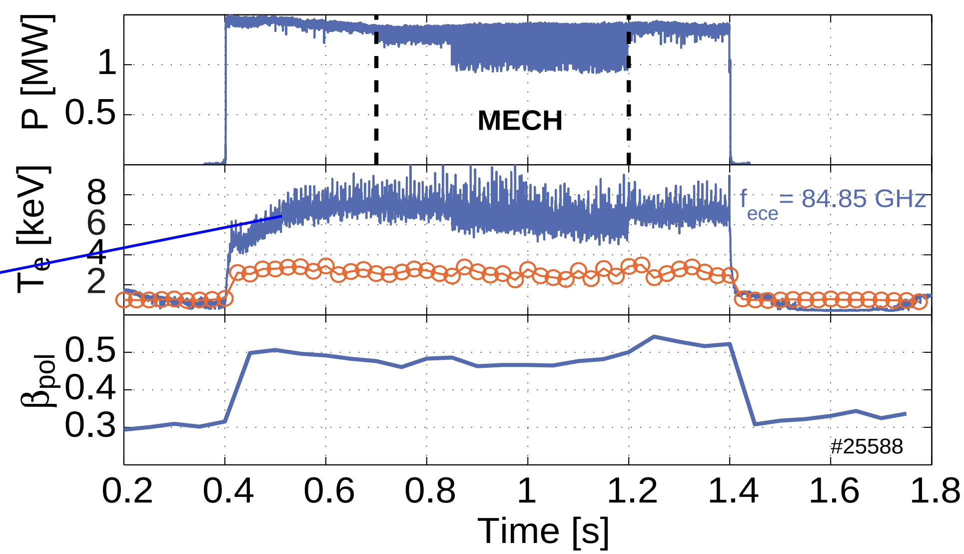
X3 power deposition in a broad (inside ρ=0.5) central region.

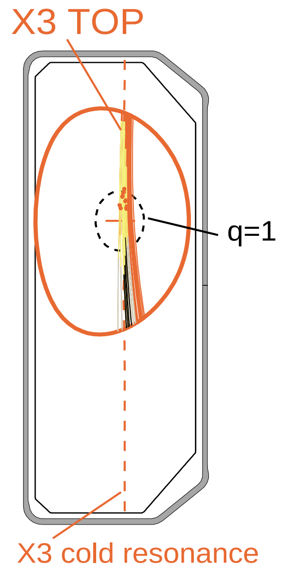




The DML[4] measures P_{abs} using a power modulation method.

Presence of suprathermal electrons ECE HFS view.

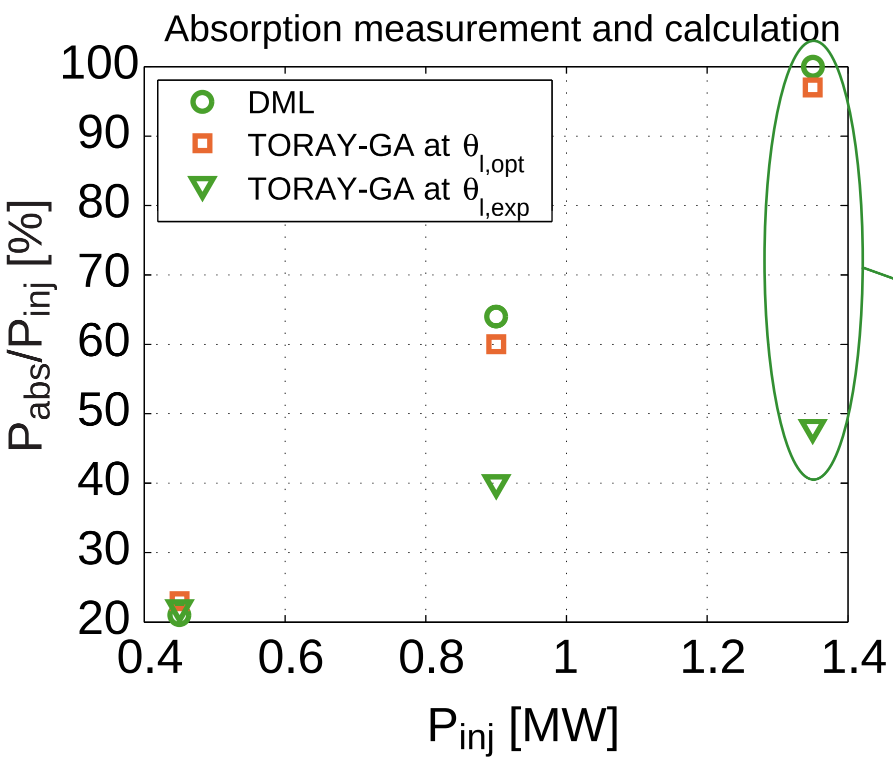


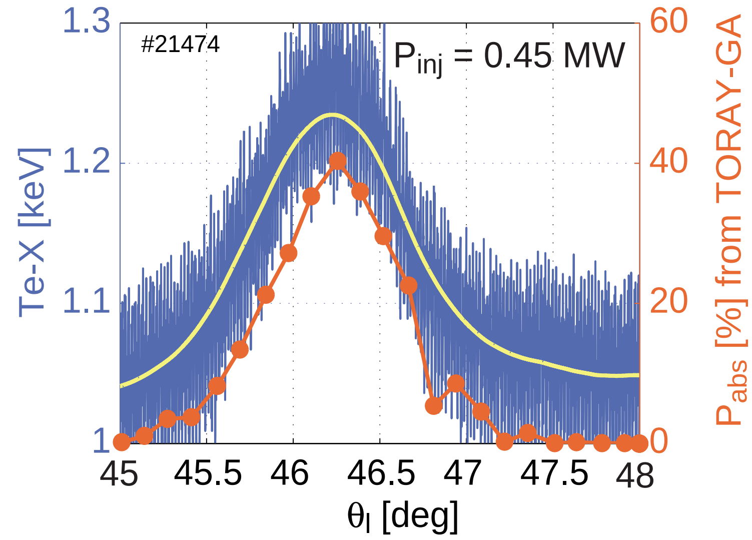


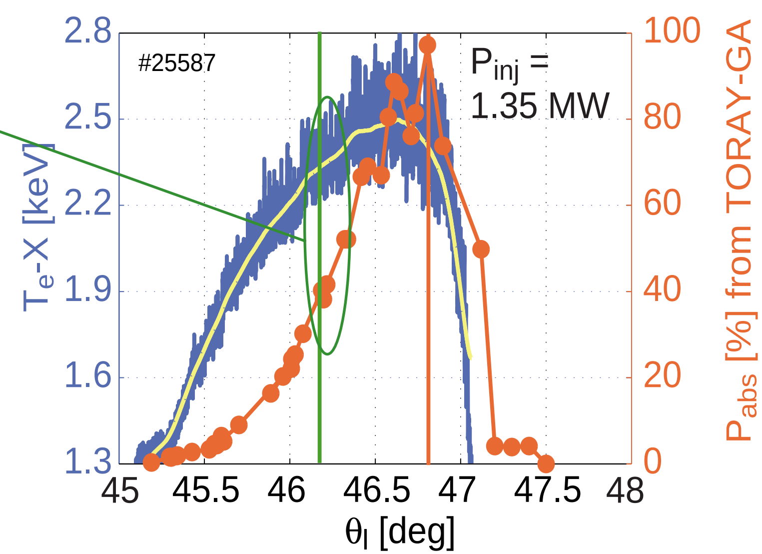
P_{abs} comparison : TORAY-GA / measurement

Discrepancy between TORAY-GA and measurement due to an asymmetry of T_e-X response.

- Generation of suprathermal electrons.







Conclusion and future

Strong X3 absorption sensitivity on the launcher poloidal angle independent of the density ==> a real time feedback control is actually studied.

TORAY-GA is in good agreement with measurements for determining the optimal launcher angle.

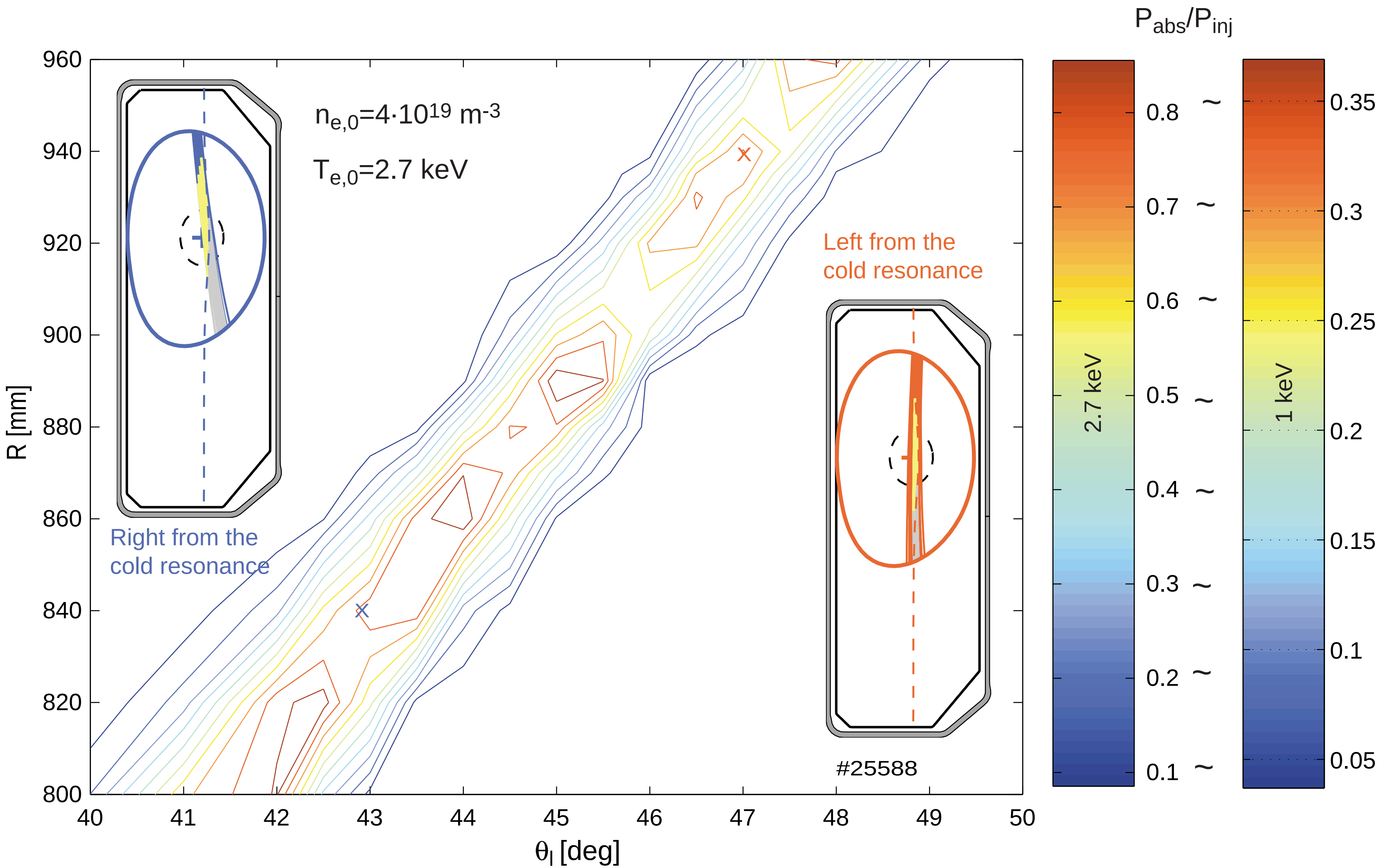
Full single pass absorption of X3 has been measured injecting the maximum power of 1.35 MW

TORAY-GA calculations and P_{abs} measurements are not always in agreement in part due to the presence of suprathermal electrons.

A comparison between TORAY-GA and a Beam-tracing code is presently studied (S. Nowak, CNR Milano)

A set of experiments scanning the density ($3<n_{e,0}<10$ x10^{19} m^{-3}) and the injected Power (P_{inj} up to 1.35 MW) will be performed this year.

R-θ_l X3 absorption domain from TORAY-GA



A global X3 system approach