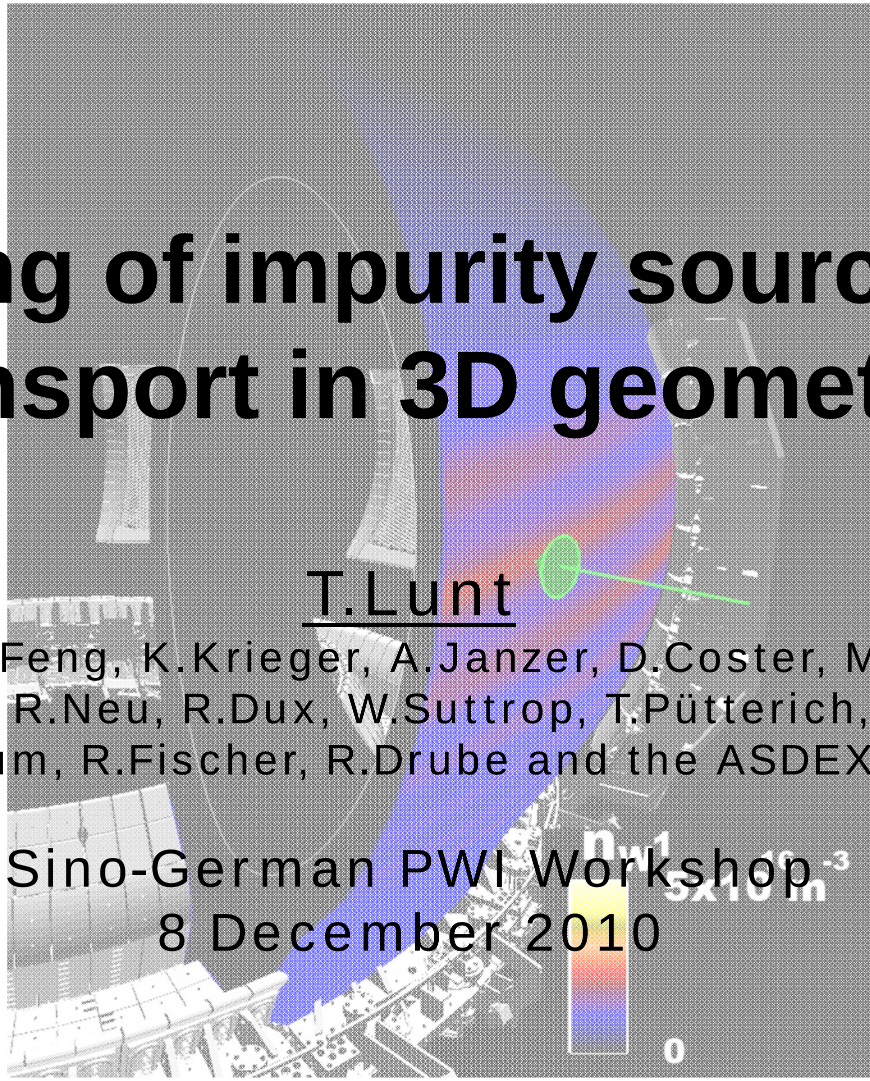
ASDEX Upgrade



Modelling of impurity sources and transport in 3D geometry

T.Lunt

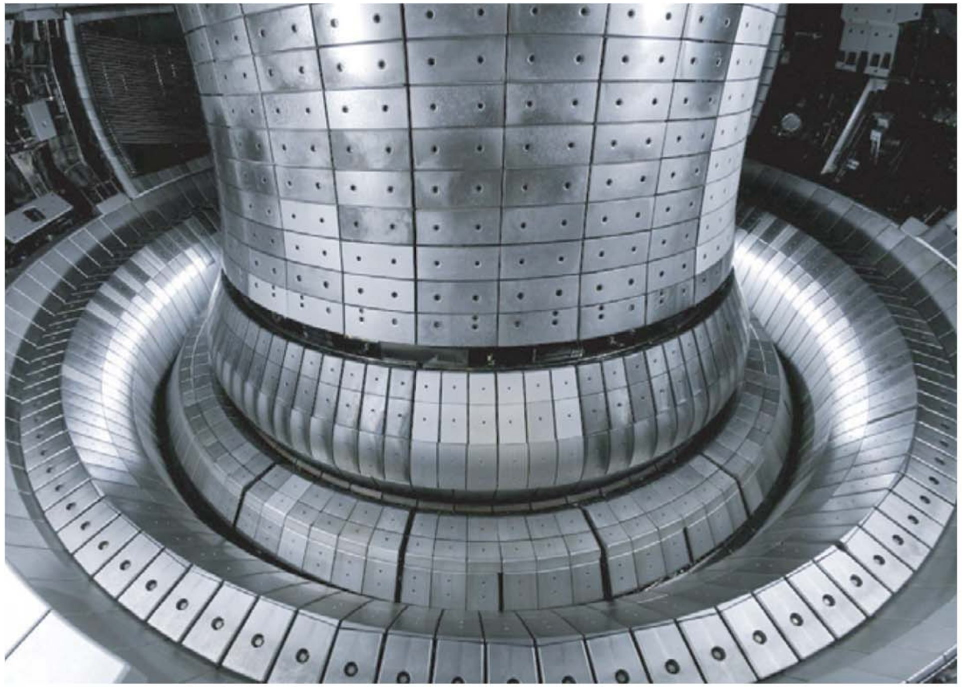
Contributors: Y.Feng, K.Krieger, A.Janzer, D.Coster, M.Wischmeier, A.Kallenbach, R.Neu, R.Dux, W.Suttrop, T.Pütterich, H.W.Müller, V.Rohde, E.Wolfrum, R.Fischer, R.Drube and the ASDEX Upgrade team

Sino-German PWI Workshop
8 December 2010

ASDEX Upgrade

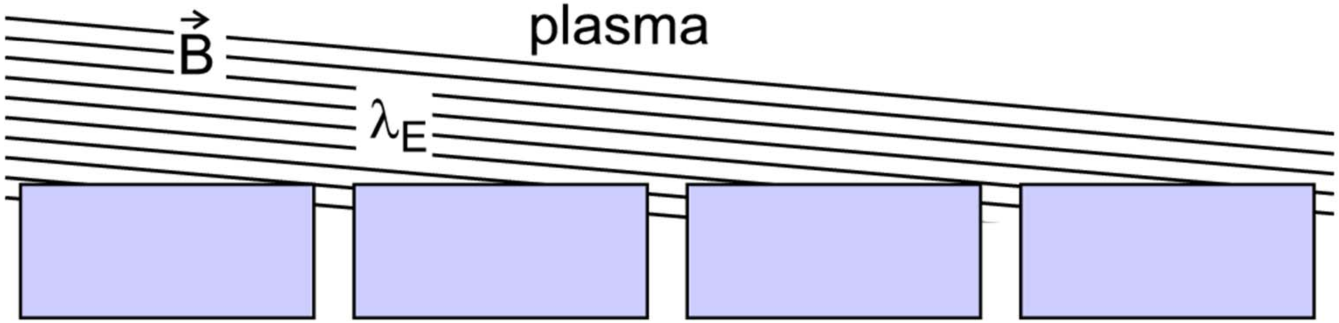
Introduction / Motivation

Tungsten as a plasma facing component material



ASDEX Upgrade full W device:

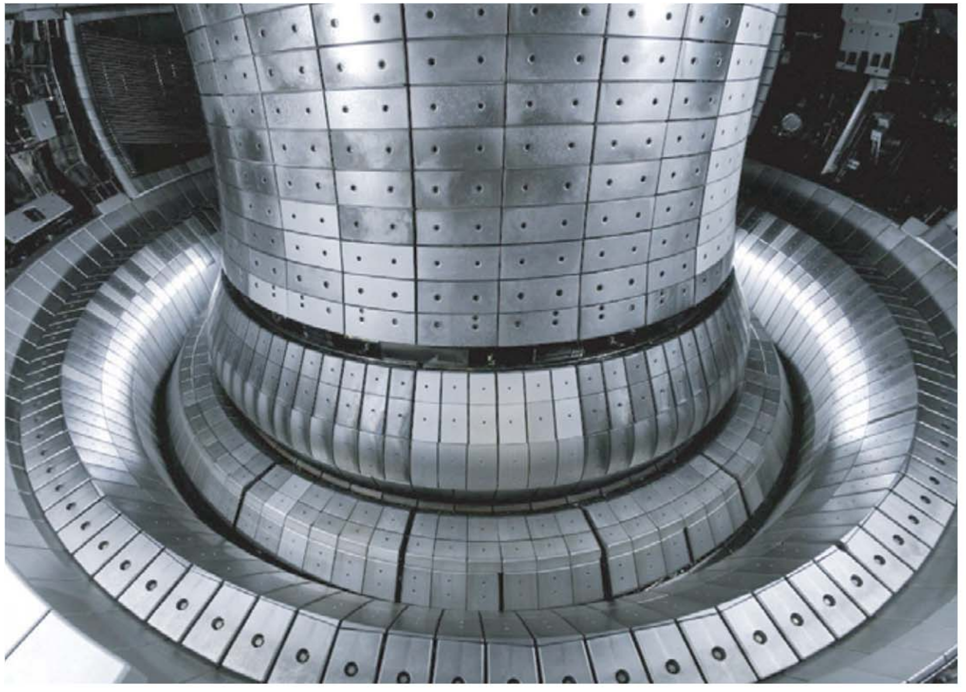
- ☺ High Z materials like W low sputtering yield
- ☺ no chemical binding of T
- ☹ strong reduction of energy confinement time when W penetrates core region
- ☺ High divertor retention
- ☹ danger of melting



Divertor tiles ITER

Introduction / Motivation

Tungsten as a plasma facing component material



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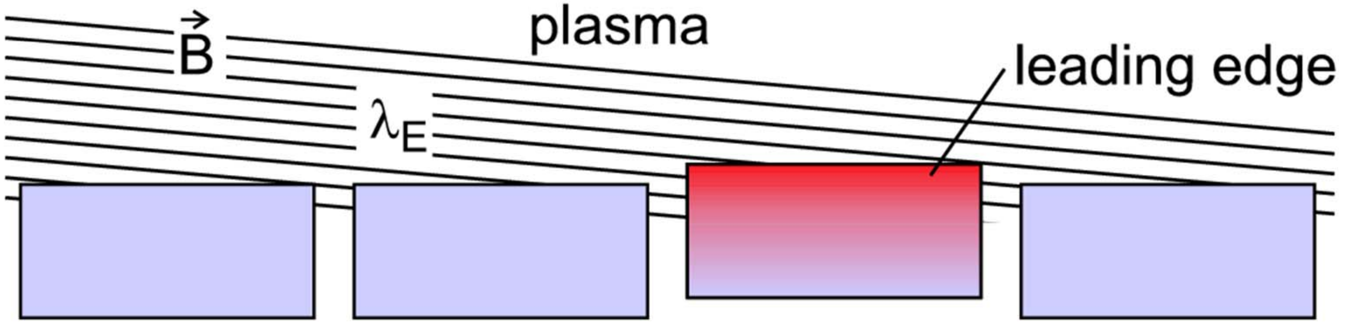
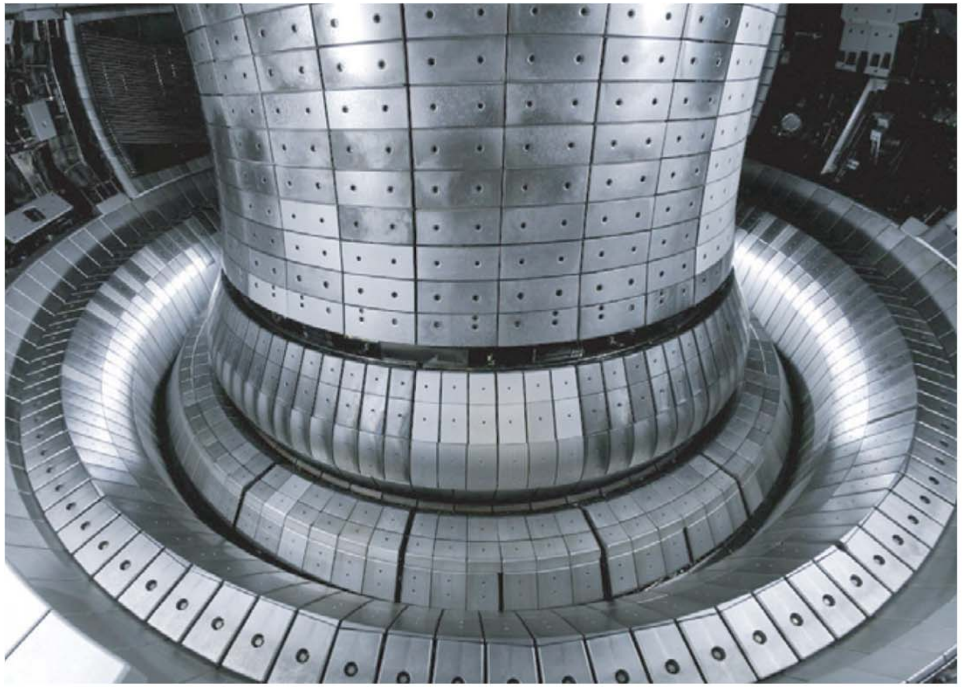


Divertor tiles ITER

Introduction / Motivation

Tungsten as a plasma facing component material



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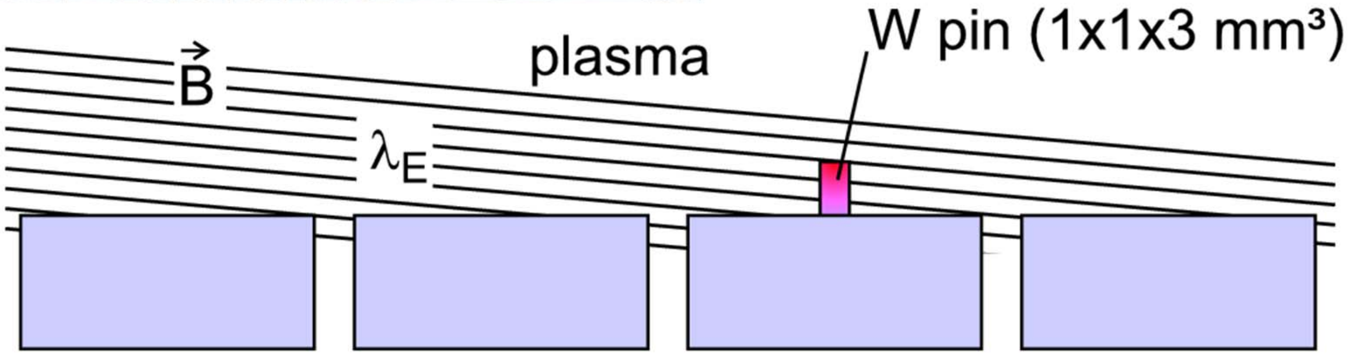


Divertor tiles ITER

Outline

Introduction / Motivation

Experimental results
+ Controlled W-pin melting experiments
+ Laser Blow-off
+ Impact on core concentration

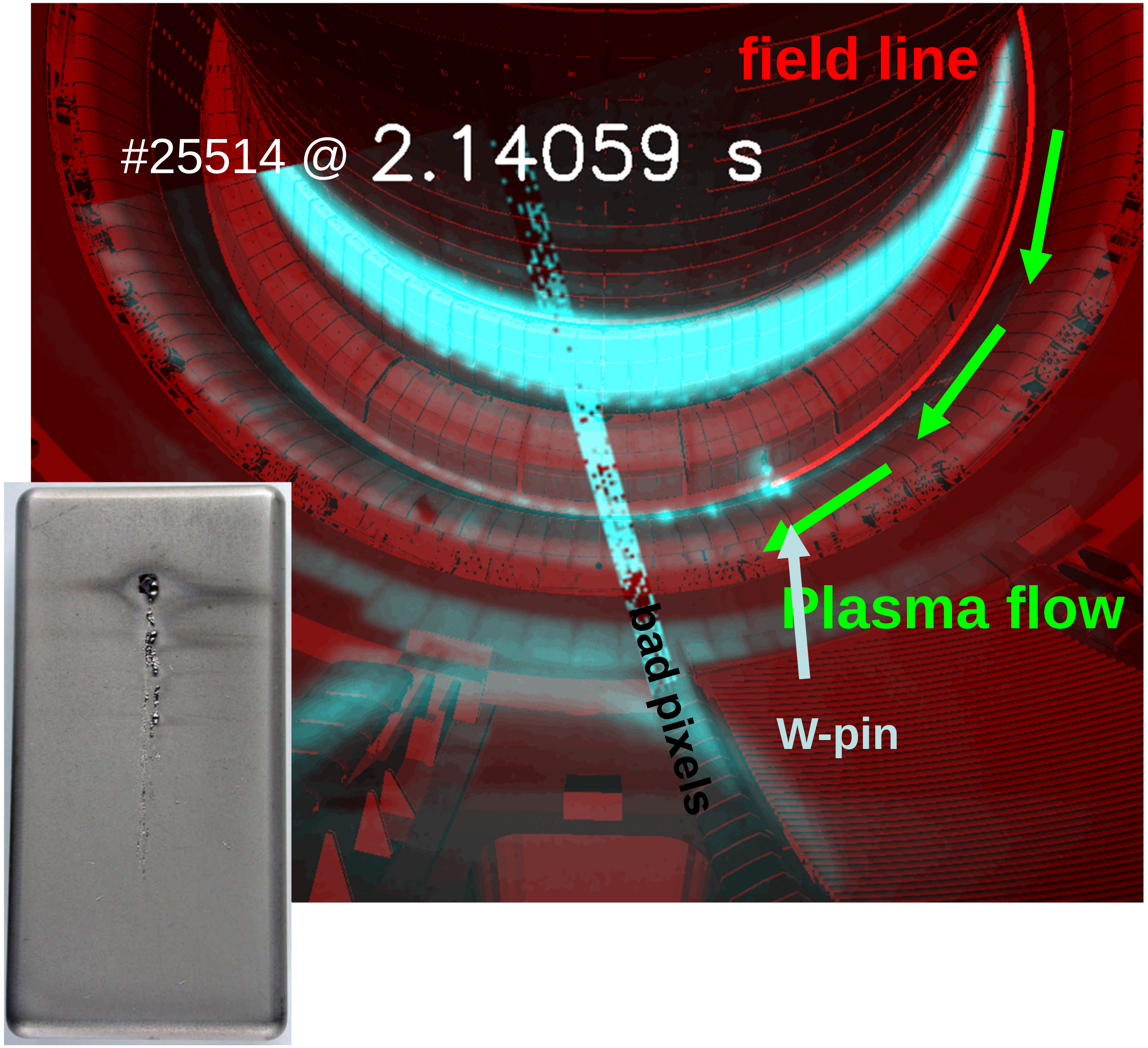
Edge Monte Carlo 3D (EMC3)-Eirene simulations
+ Equations, working principle and input for the code
+ Simulation on the plasma background
+ Simulation of a localized W source

Summary

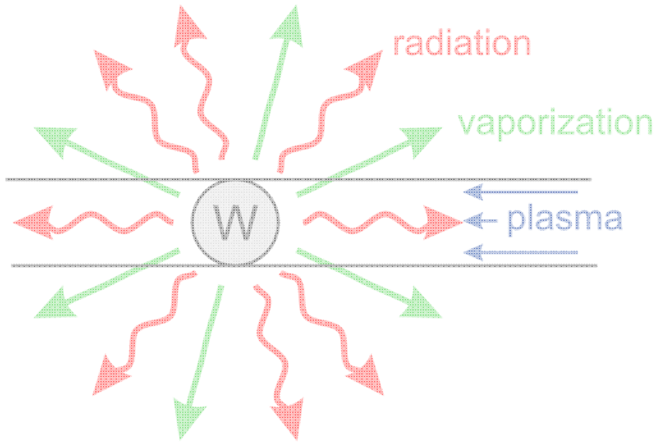
Experimental results

Experimental results

Controlled W-pin melting experiments



Eroded:
20.6 mg or 6.7×10^{19} W



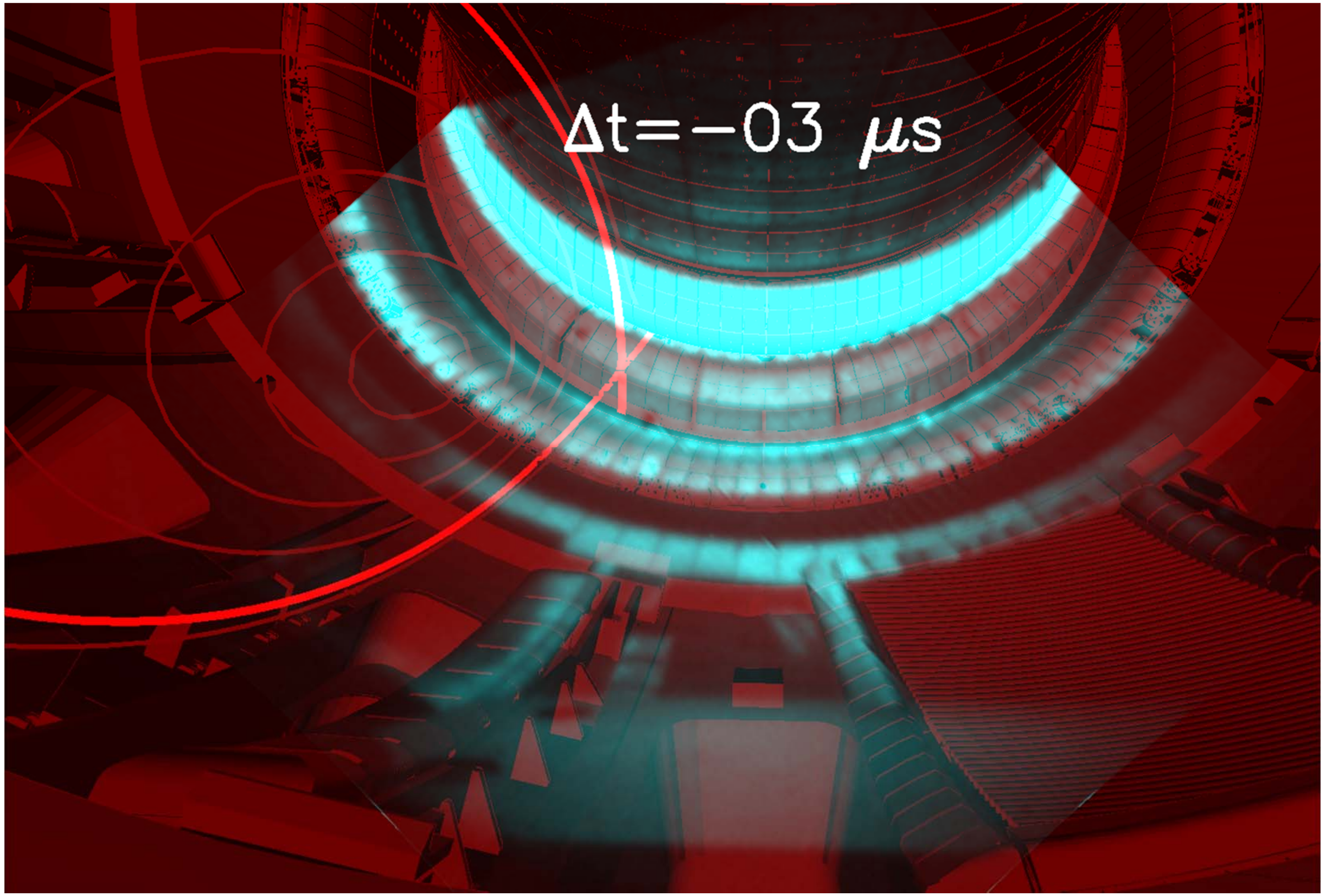
$Q_{||} = Q_{vap} + Q_{blackbody}$

into plasma
20…40 % $= 1.3..2.7 \times 10^{19}$W

K.Krieger, et al. JNM 2010

Experimental results

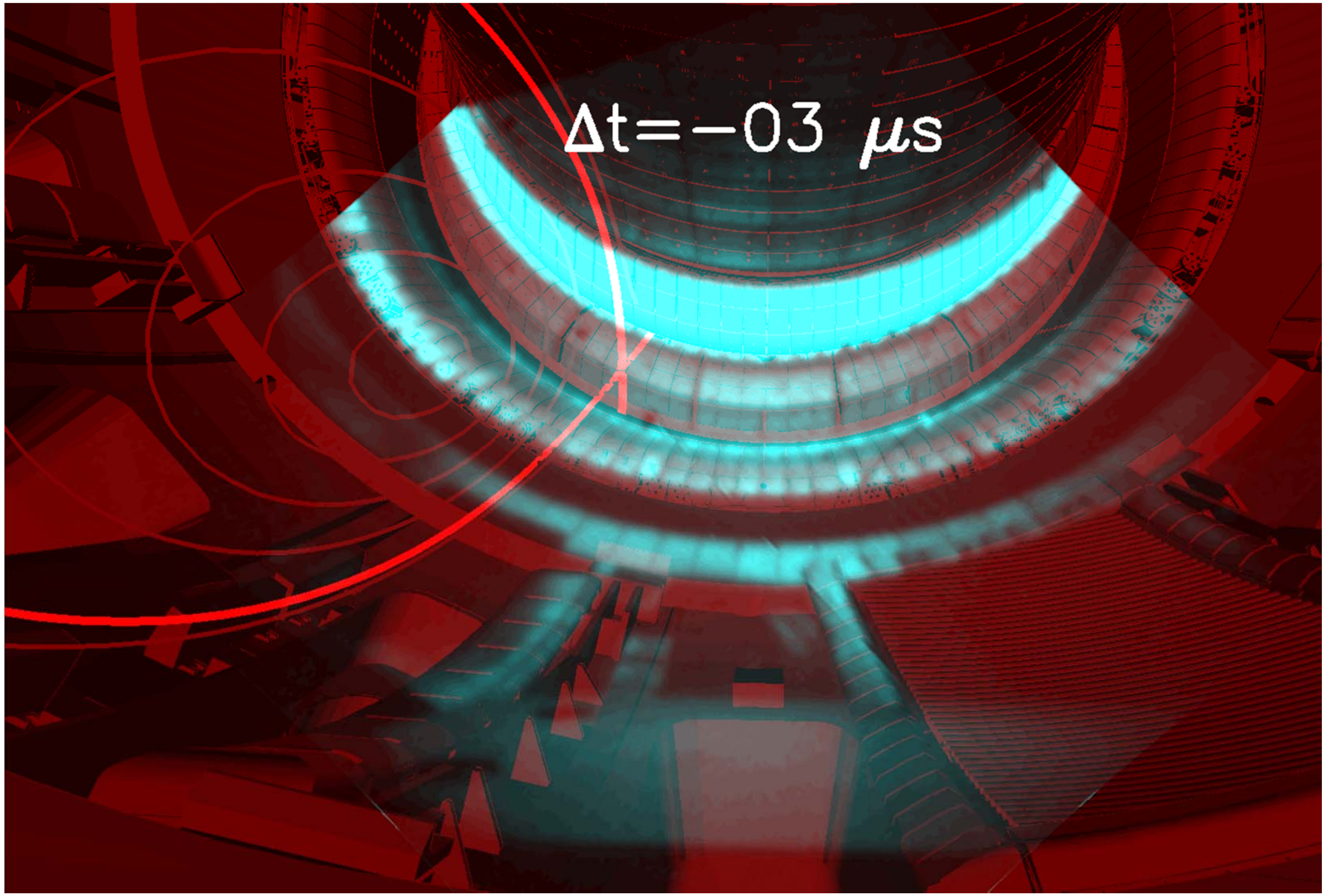
Laser blow-off



$N_{LBO} = 4 \cdot 10^{17}$ W atoms, i.e. 50 times less.

Experimental results

Laser blow-off



$N_{LBO} = 4 \cdot 10^{17}$ W atoms, i.e. 50 times less.

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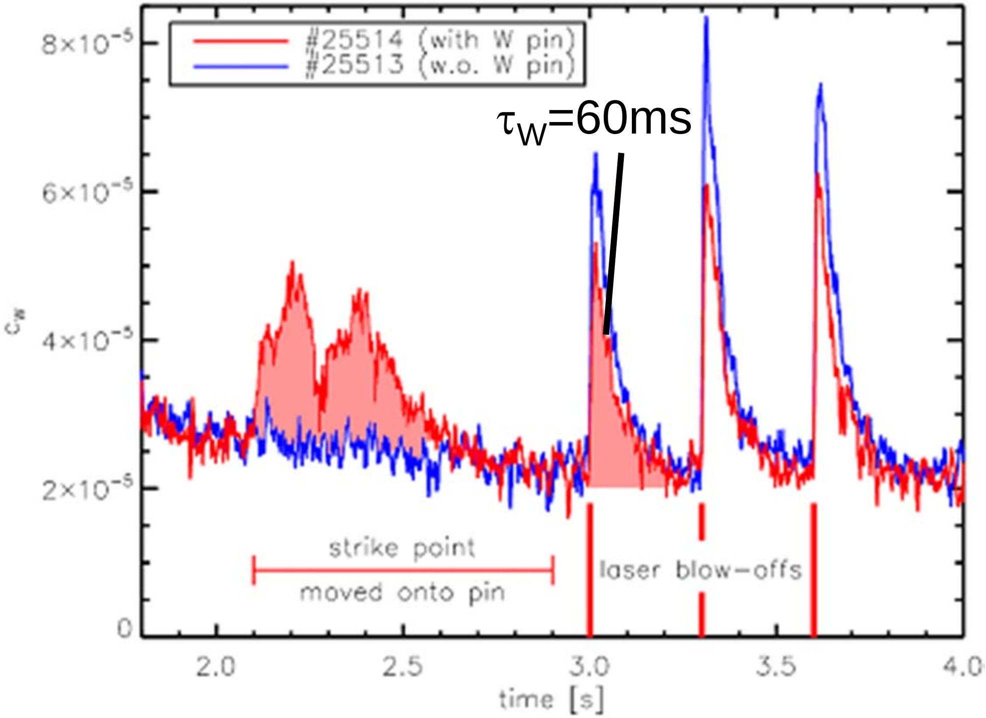
Experimental results

Impact on core concentration



$$\frac{dN_W^{core}}{dt} = \Phi^{core} - \frac{N_W^{core}}{\tau_W}$$

$$N_W^{core} = c_W \bar{n}_e V^{core}$$

$$\Phi^{core} = \Phi^{div} / S_{div}$$

$$\Phi^{core} = \Phi^{mc} / S_{mc}$$

$$R = S_{div} / S_{mc}$$

excluding droplets:

R_{exp}=25

including droplets:

R_{exp}=75..125

Edge Monte Carlo 3D (EMC3)-Eirene simulations

Equations, working principle and input for the code

ASDEX Upgrade

EMC3-Eirene Simulations

Braginskii's equations

IPP

EMC3

	D background	**Impurities**
Continuity (3D)	✓	✓
Momentum (3D)	✓	(simplified+F_{el}+F_{th}+F_f)
Energy (3D)	✓	T_Z=T_i

Eirene

	Neutral H, H2, …
Kinetic equation (3D)	✓

Target: Particle sink:
$\Gamma = n_e\, c_s$
(Bohm-Chodura)

Heat sink:
$Q = \gamma_e\, T_e\, \Gamma + \gamma_i\, T_i\, \Gamma$
Heat sheath transmission factors $\gamma_e = 4.5$ $\gamma_i = 2.5$

EMC3-Eirene Simulations

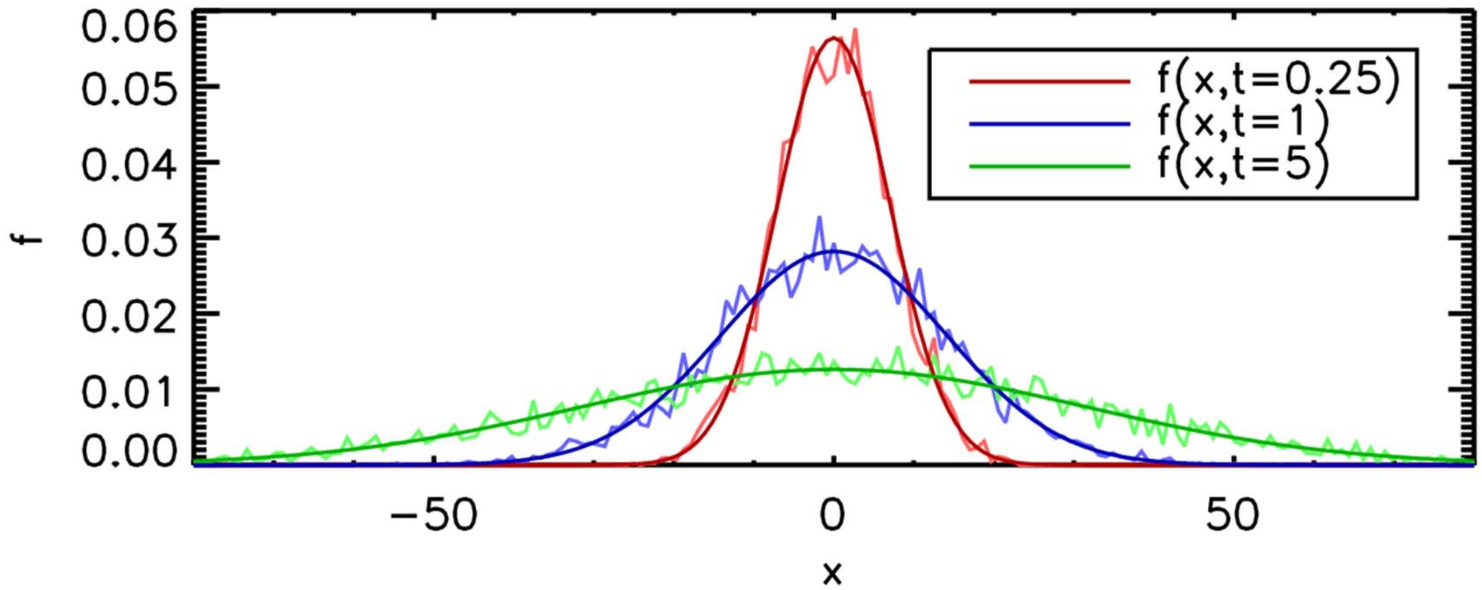
Monte Carlo principle

Generic form (general diffusion-convection equation):

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial x}\left(vf - \mathcal{D}\cdot\nabla f\right) = \mathcal{S} \text{ , where } f = n, V_{||}, T_e \text{ or } T_i$$

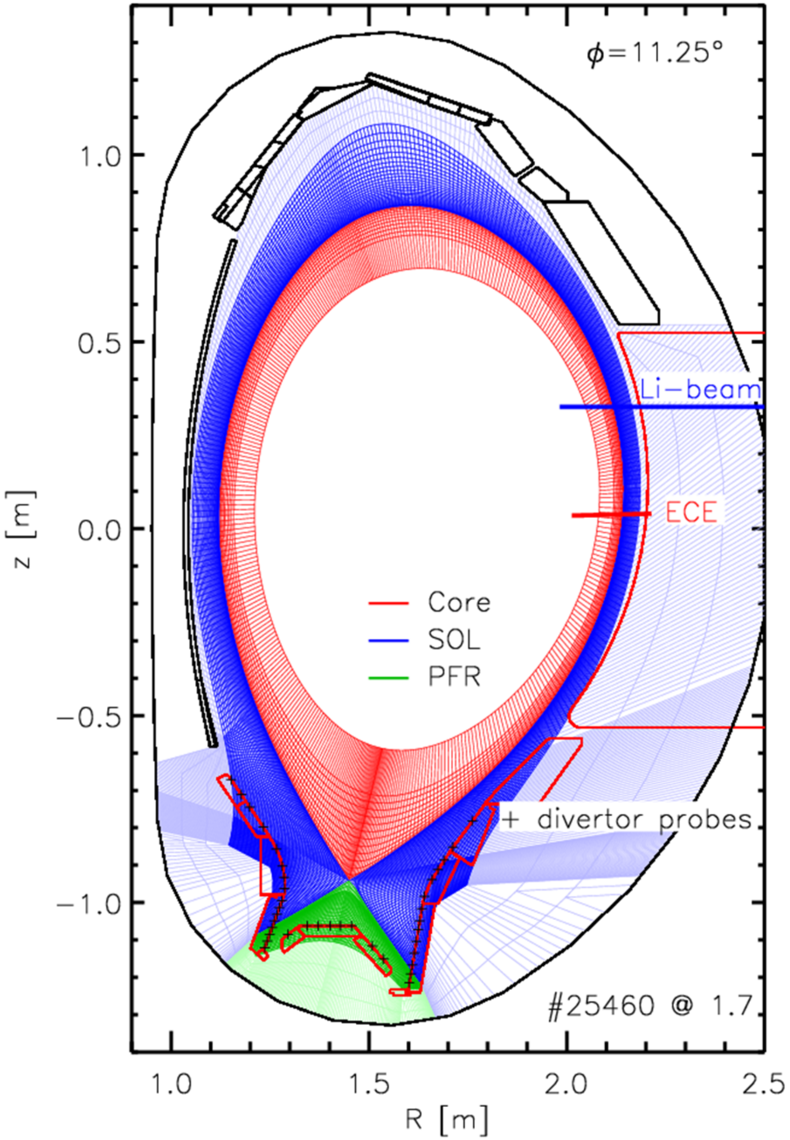
For $v = 0$, $\mathcal{S} = \delta(x)\delta(t)$ and $\nabla \rightarrow \partial/\partial x$ this Eqn. is solved by

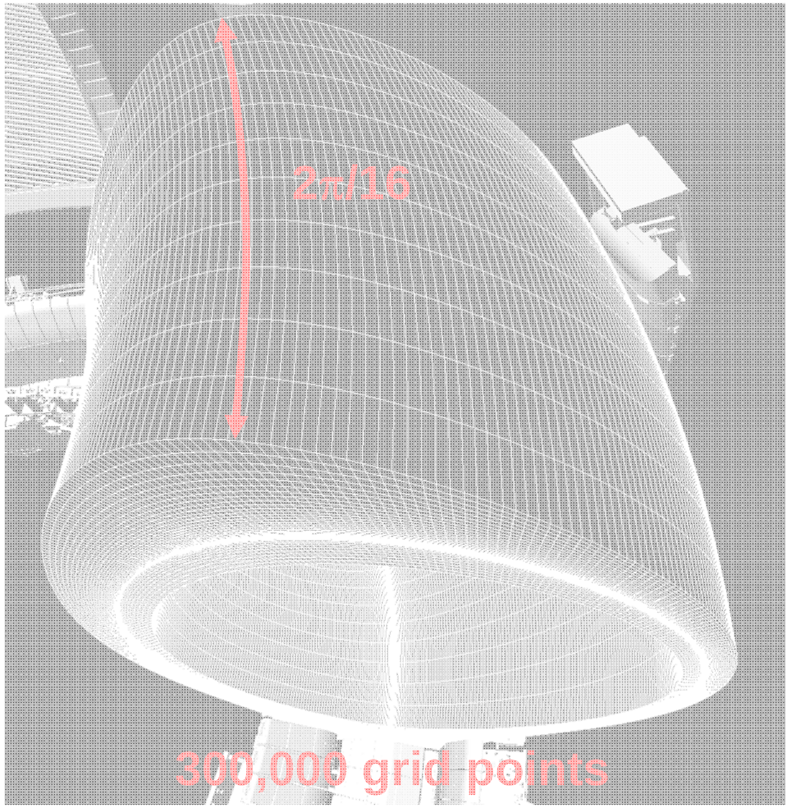
$$f(x,t) = \frac{1}{\sqrt{4\pi\mathcal{D}t}}\exp\left(-\frac{x^2}{4\mathcal{D}t}\right) \text{ . Random steps } \Delta x = v\tau \pm \sqrt{2\mathcal{D}\tau}$$



EMC3-Eirene Simulations

Geometry and grid

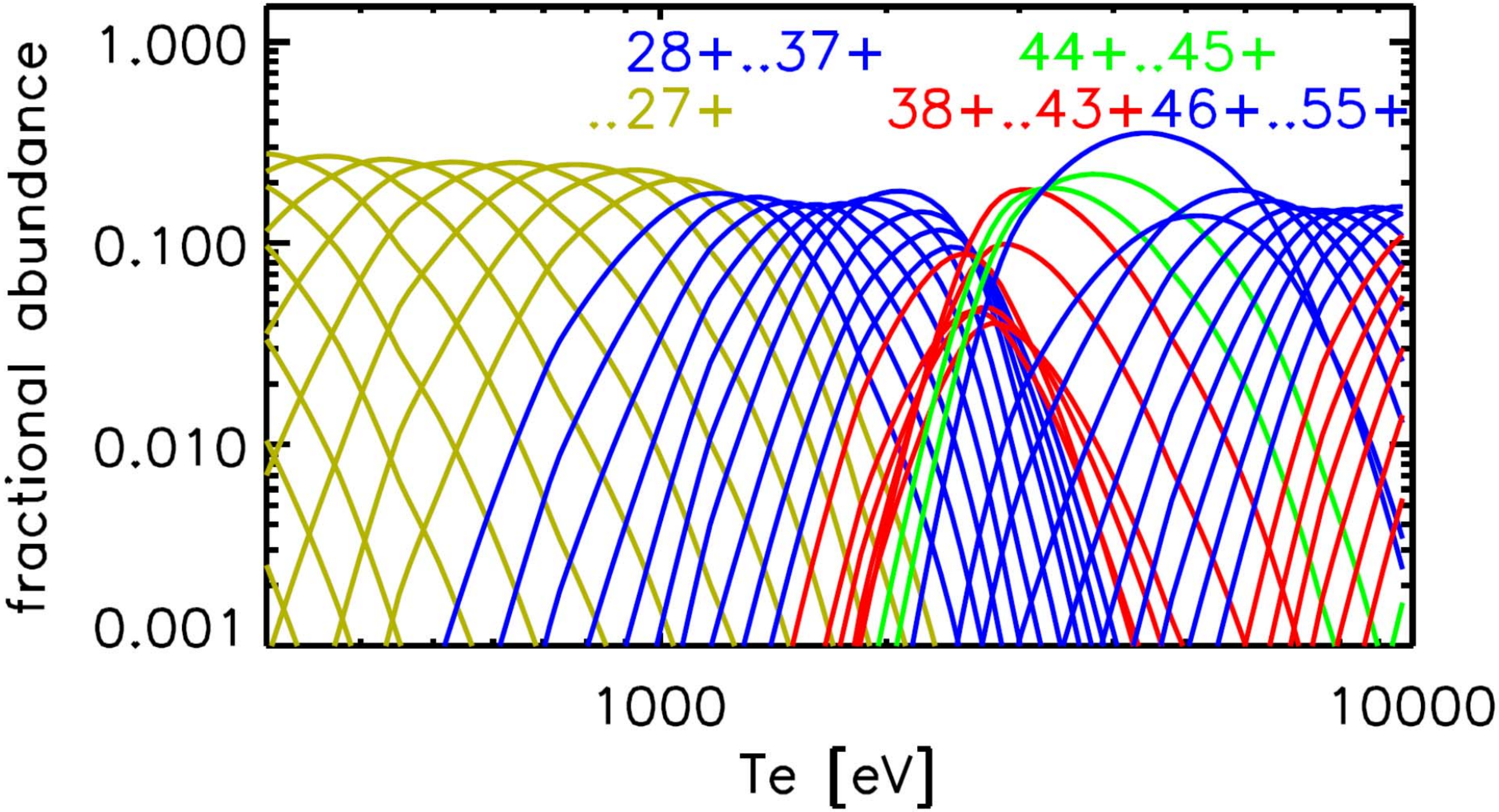




Grid contains all the information on the magnetic geometry

EMC3-Eirene Simulations

Atomic data



S. D. Loch et al. Phys. Rev. A 72 (2005) / T. Pütterich et al., Plasma Phys. Contr. Fusion **50** (2008)

A) 25460 @ 1.7 s (attached L-mode)

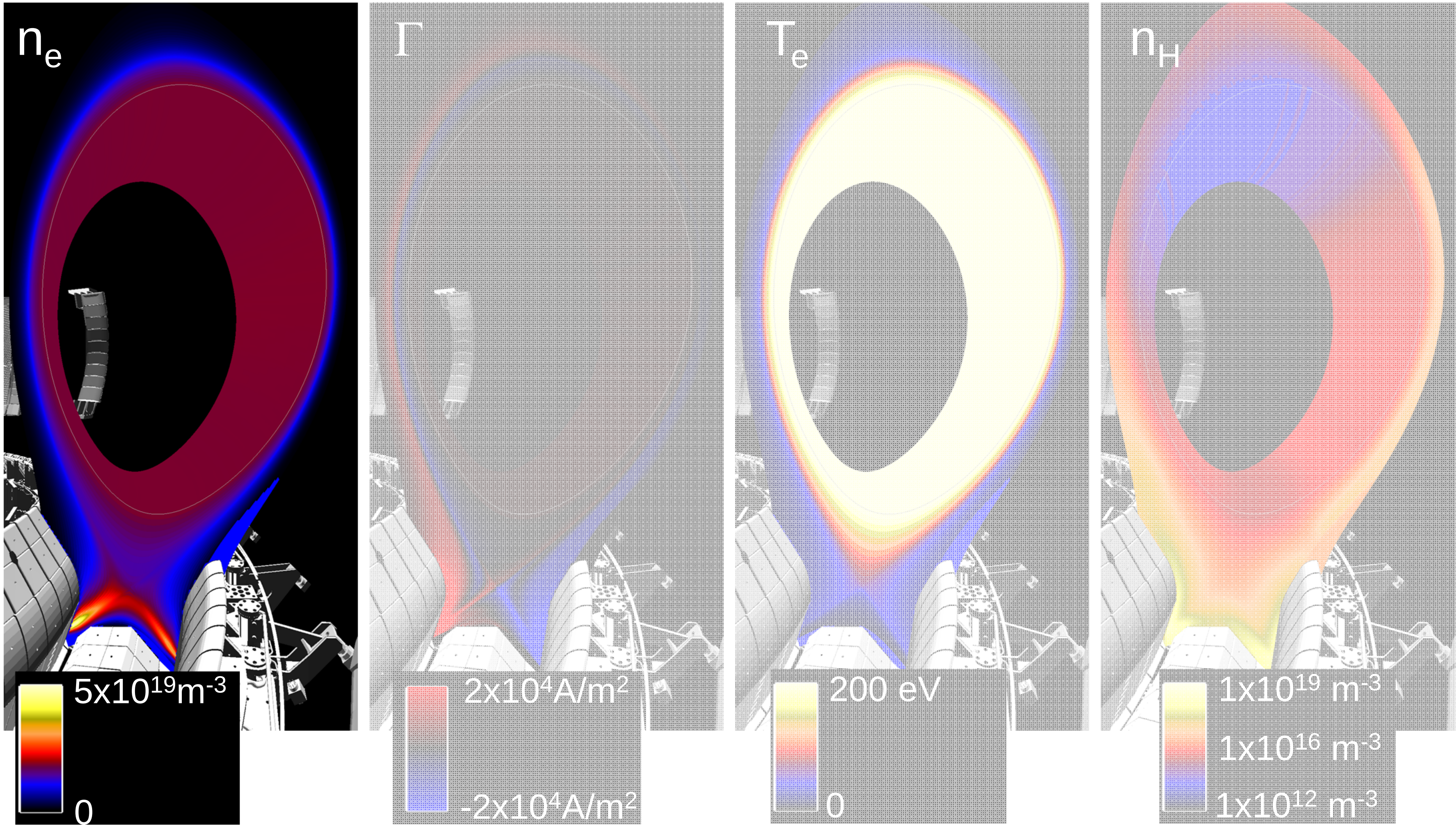
B) 25513 @ 2.2 s (partially detached H-mode)

Edge Monte Carlo 3D (EMC3)-Eirene simulations

Simulation of the plasma background

EMC3-Eirene Simulations

Simulation of the background plasma A) Attached L-mode

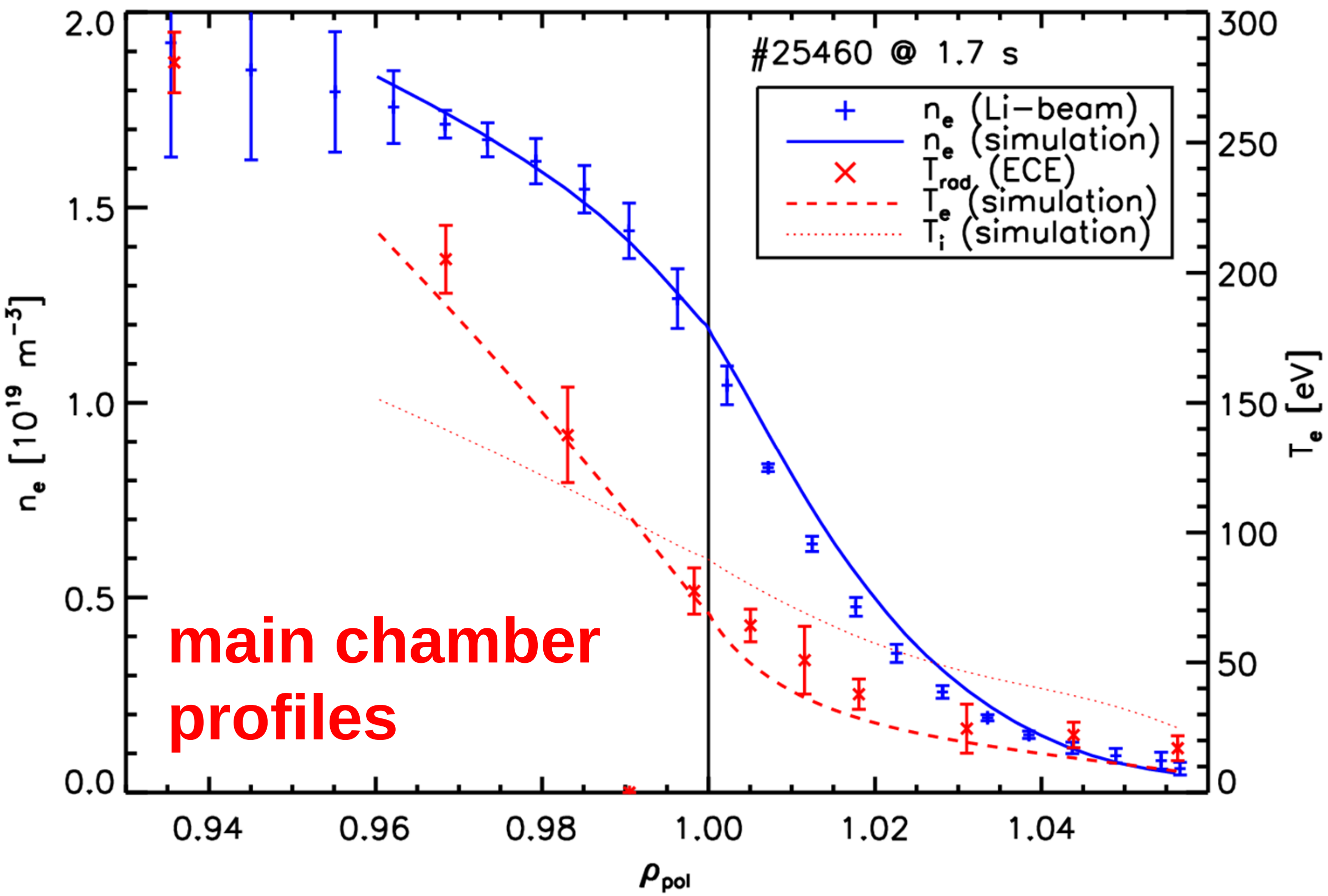


#25460 @ 1.7 s

ASDEX Upgrade

EMC3-Eirene Simulations

Simulation of the background plasma A) Attached L-mode

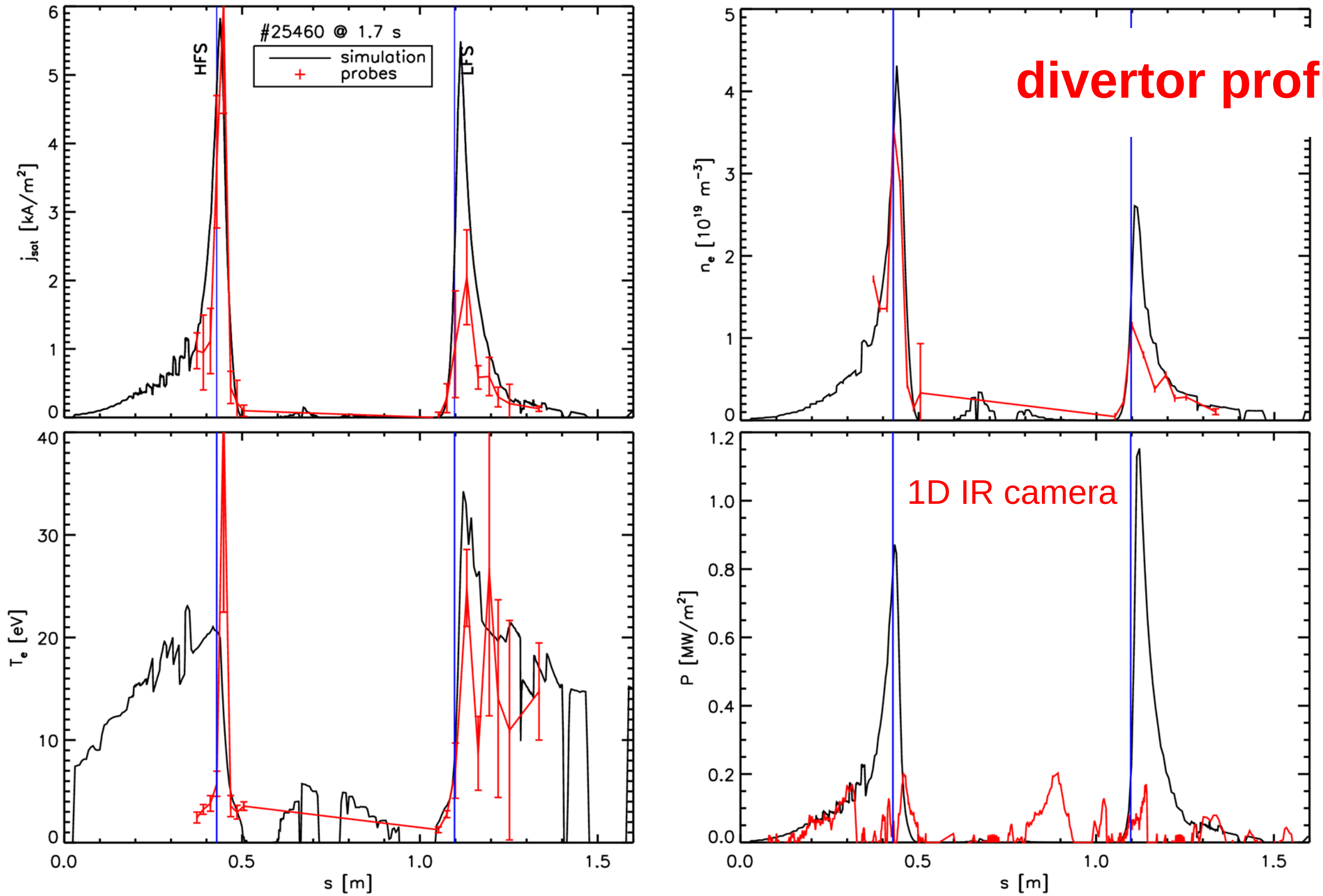


$n_{e,sep}$	P_{NBI}	P_{ECRH}	P_{OH}	P_e/P_i	P_{net}	$D_{\perp,i}$	$\chi_{\perp}$
1.34×10^{19} m^{-3}	0	+0.75MW	+0.7 MW	2.3	1.45 MW	0.25 m^2/s	2.5 m^2/s

ASDEX Upgrade

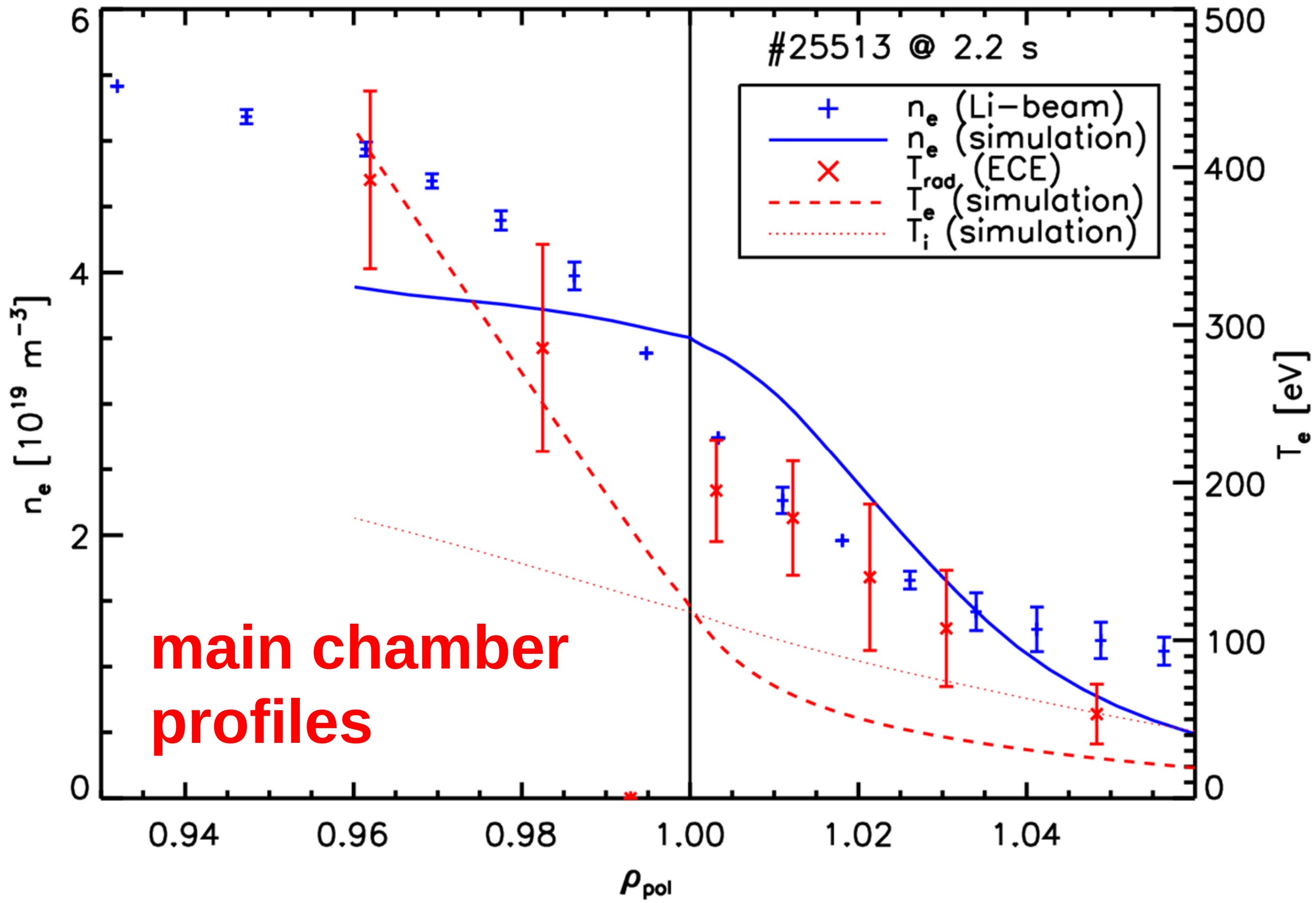
EMC3-Eirene Simulations

Simulation of the background plasma A) Attached L-mode



EMC3-Eirene Simulations

Simulation of the background plasma B) H-mode

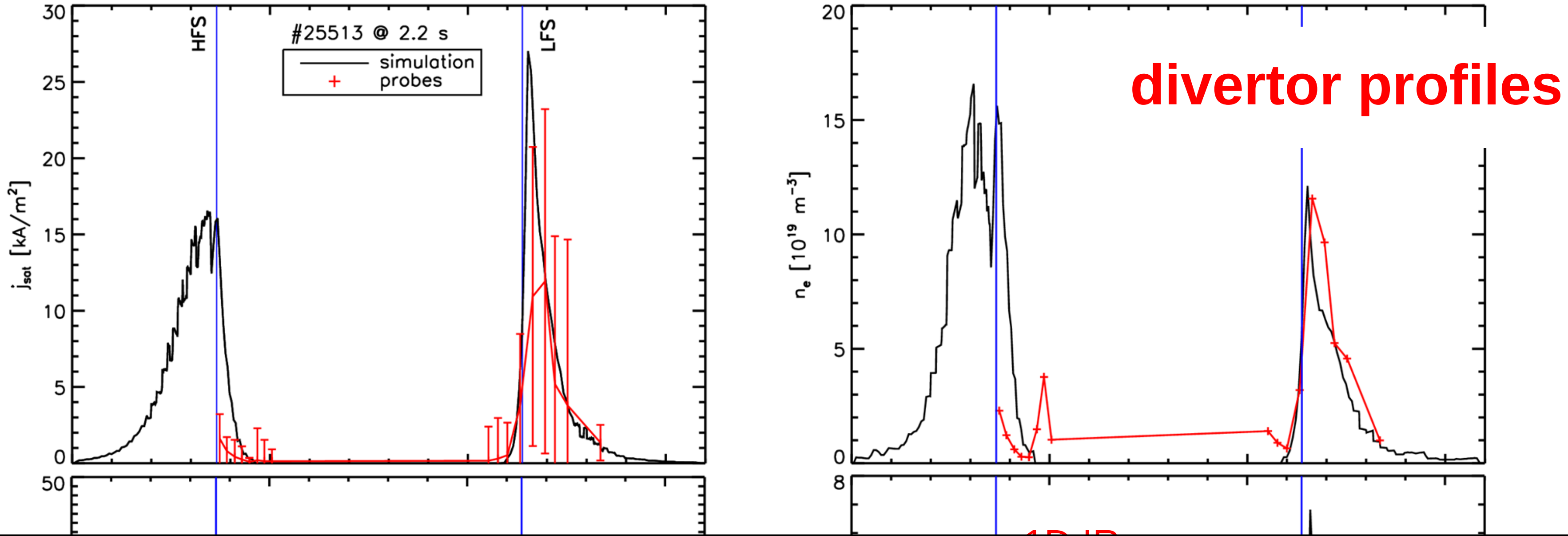


$n_{e,sep}$	P_{NBI}	P_{ECRH}	P_{OH}	P_e/P_i	P_{net}	$\mathbf{D}_{\perp,i}$	$\chi_\perp$
3.7×10^{19} m^{-3}	5 MW	+0.7MW	+0.2 MW	2.3	5.9 MW	0.15 m^2/s	2.0 m^2/s

ASDEX Upgrade

EMC3-Eirene Simulations

Simulation of the background plasma B) H-mode



+ EMC3-Eirene can simulate a (stationary) attached L-mode

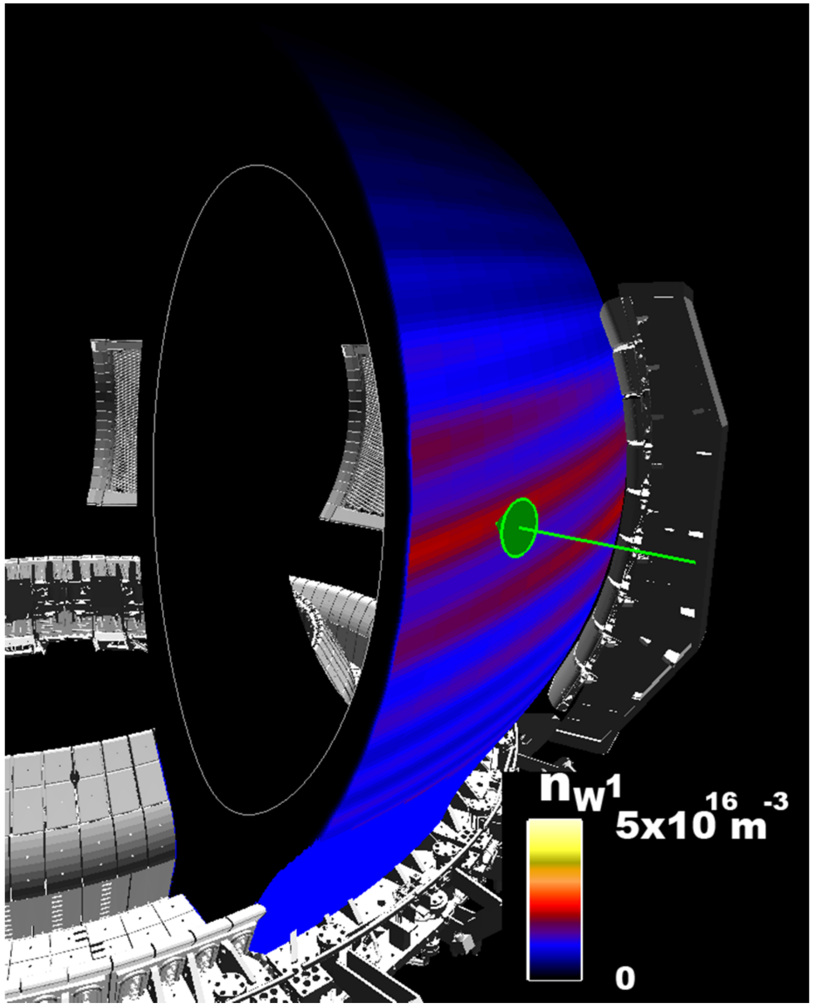
+ however, neither the detachment effect, nor the high confinement regime are described satisfactory so far by the code

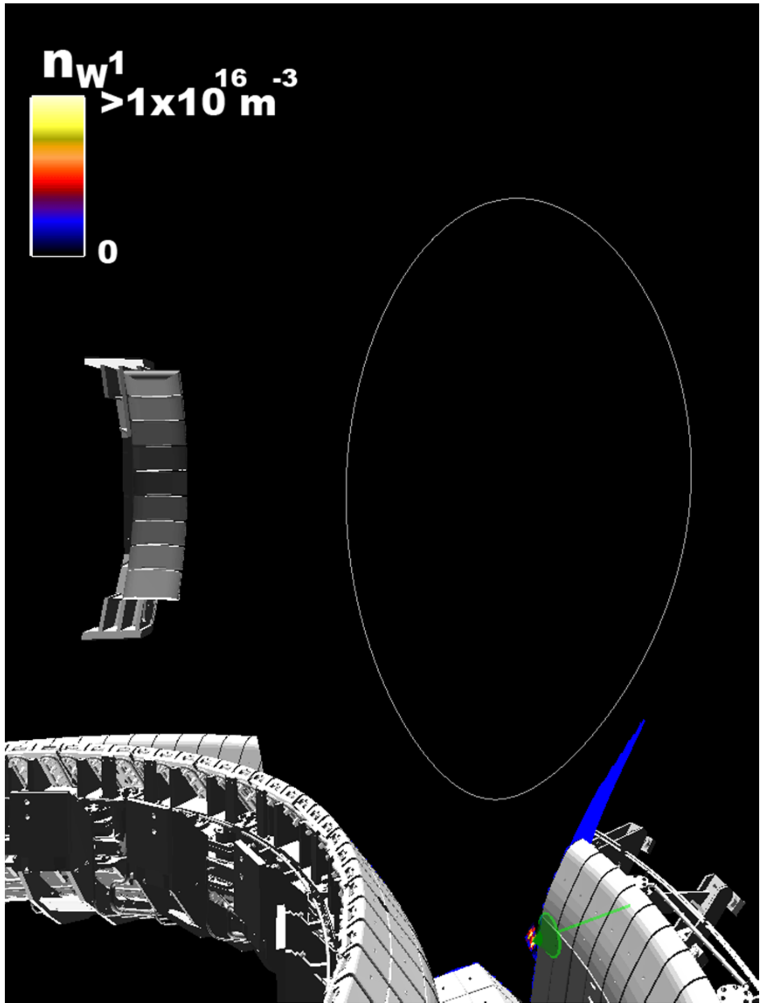
Edge Monte Carlo 3D (EMC3)-Eirene simulations

Simulation of a localized W source

EMC3-Eirene Simulations

Simulation of a localized W source

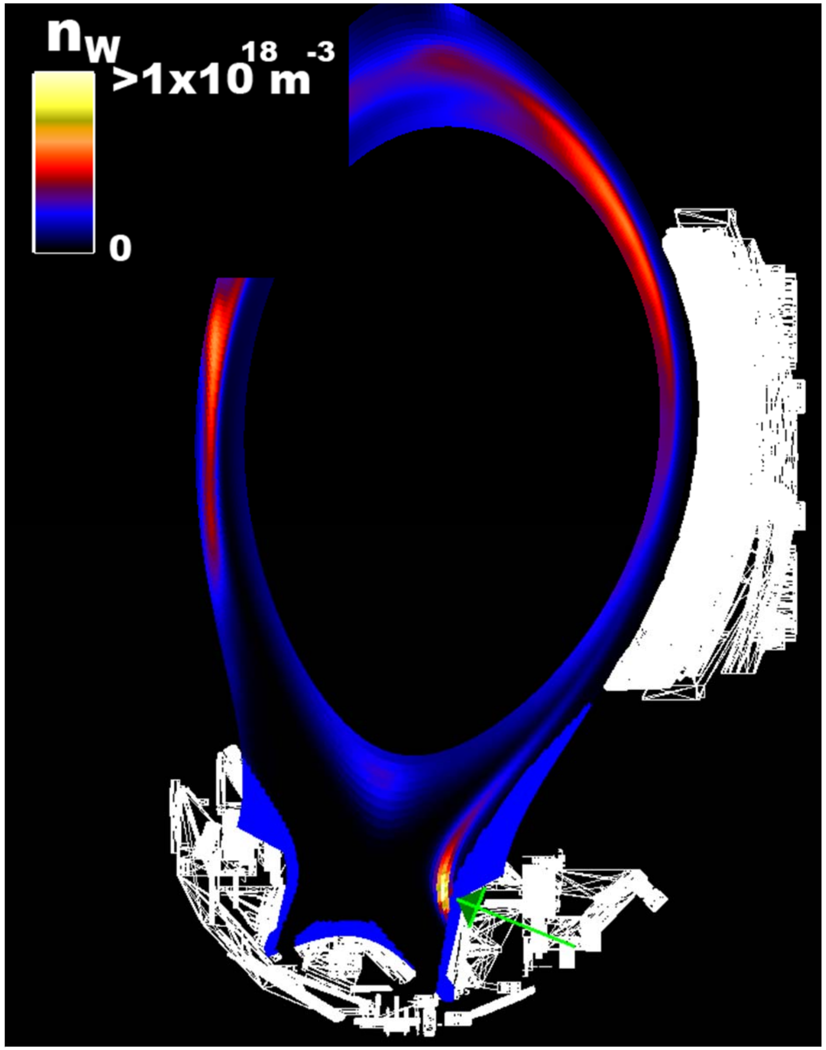


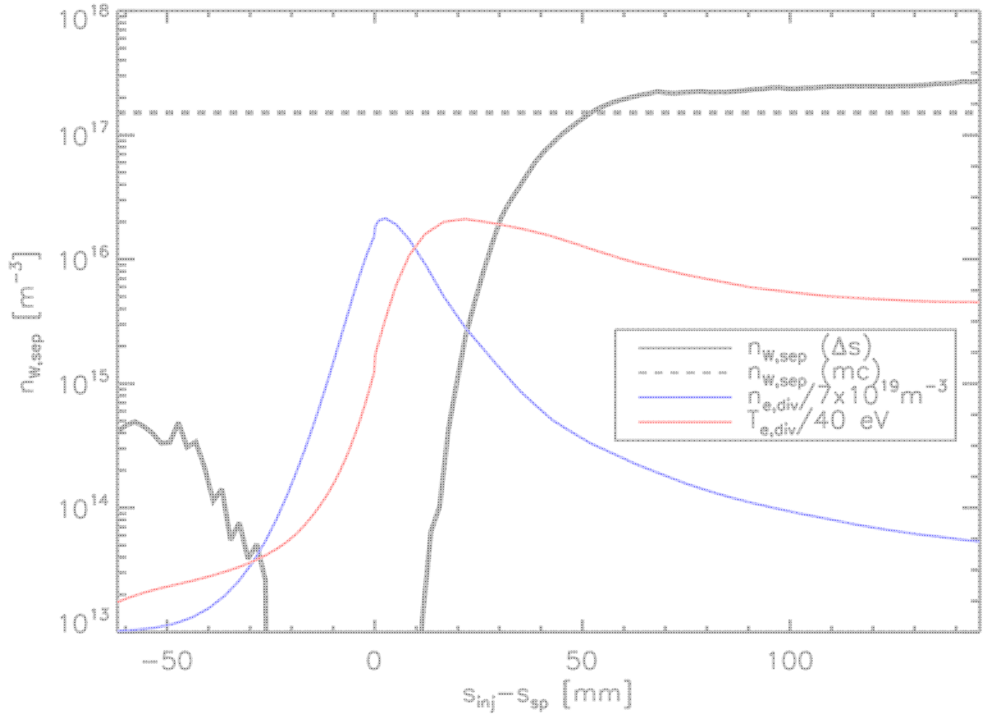


$D_{Z,\perp} = D_{i,\perp}$ Φ_W=6.2x10^{18} W/s (= 1 A/e) $R = n^{div}_{W,sep}/n^{mc}_{W,sep}$

EMC3-Eirene Simulations

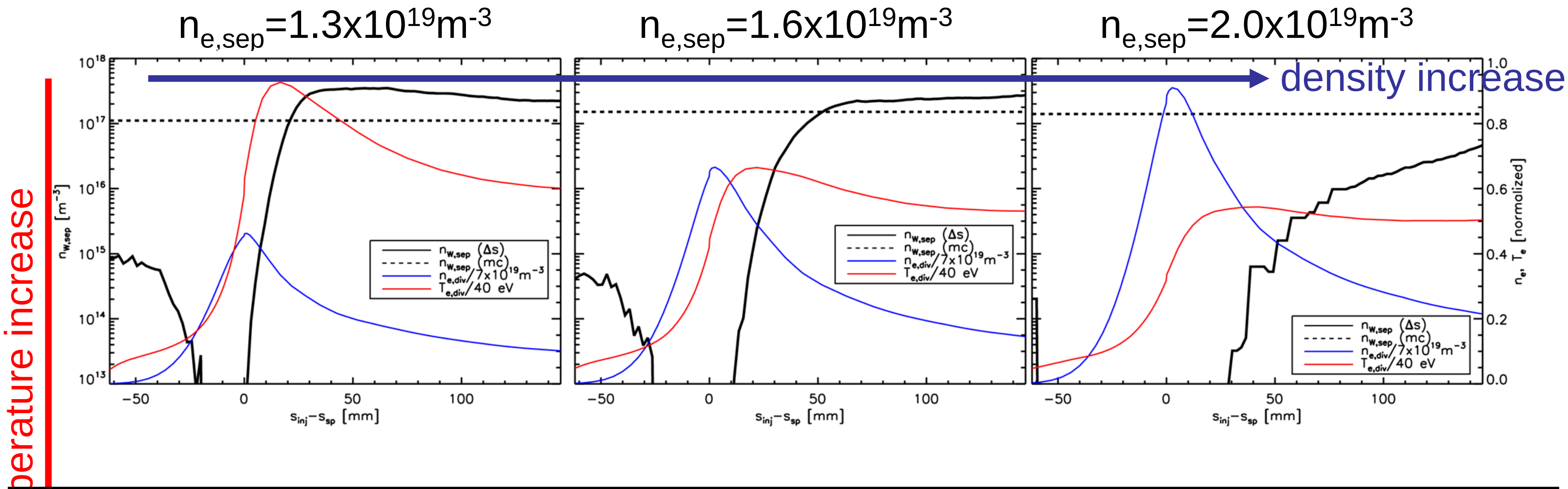
Simulation of a localized W source





EMC3-Eirene Simulations

Simulation of a localized W source



+ The divertor retention depends sensitively on the position of injection and on density and temperature (collisionality)

+ For configuration B (H-mode) the simulated retention is about R=40 directly at the strike point.

+ Since this result has a very high uncertainty, experiments are planed for 2011 to test the dependences found in the simulation

Summary & Outlook

+ Controlled W-pin melting experiments were performed sucessfully

+ Discharge survived massive W impurity event

+ Macroscopic transport assists divertor to retain impurities from core region

+ EMC3-Eirene simulations sucessfully performed:
  - good agreement attached L-mode
  - detachment and high confinement conditions cannot be described well
  - W transport: strong dependence on position of injection and on n_e and T_e
  - simulated retention R=40 (± a lot) not inconsistent with experimental one

Outlook

+ dedicated experiments are planed in 2011 to test the dependencies found in the simulation

Backup slides

ASDEX Upgrade

Controlled W-pin melting experiments

EMC3-Eirene simulations – Braginskii's equations

Continuity D and impurities

$$\nabla \cdot \left(n_i V_{||} \mathbf{b}_\perp - D_{i\perp} \mathbf{b}_\perp \mathbf{b}_\perp \cdot \nabla n_i \right) = S_p$$

Momentum balance D background

$$\nabla_\perp \cdot \left(m_i n_i V_{||} V_{||} \mathbf{b} - \eta_{||} \mathbf{b}\mathbf{b} \cdot \nabla V_{||} - D_i \mathbf{b}_\perp \mathbf{b}_\perp \cdot \nabla m_i n_i V_{||} \right) = -\mathbf{b} \nabla \cdot p + S_m$$

Momentum balance impurities

$$\text{lhs.} = -\mathbf{b} \cdot \nabla n_Z T_Z + n_Z Z e E_{||} + n_Z Z^2 C_e \mathbf{b} \cdot \nabla T_e + n_Z C_i \mathbf{b} \cdot \nabla T_i - \frac{m_Z}{\tau} \left(V_{Z,||} - V_{i,||} \right)$$

Energy equation D background

$$\nabla \cdot \left(\frac{5}{2} n_e T_e V_{||} \mathbf{b} - \kappa_e \mathbf{b}\mathbf{b} \cdot \nabla T_e - \frac{5}{2} T_e D_i \mathbf{b}_\perp \mathbf{b}_\perp \nabla n_e - \chi_e n_e \mathbf{b}_\perp \mathbf{b}_\perp \cdot \nabla T_e \right) = -k(T_e - T_i) + S_{ee}$$

$$\nabla \cdot \left(\frac{5}{2} n_i T_i V_{||} \mathbf{b} - \kappa_e \mathbf{b}\mathbf{b} \cdot \nabla T_i - \frac{5}{2} T_i D_i \mathbf{b}_\perp \mathbf{b}_\perp \nabla n_i - \chi_i n_i \mathbf{b}_\perp \mathbf{b}_\perp \cdot \nabla T_i \right) = +k(T_e - T_i) + S_{ei}$$

Energy equation impurities

$$T_Z = T_i$$

where $\mathbf{b} = \vec{B}/|B|$ and $\mathbf{b}_\perp \mathbf{b}_\perp = \mathbf{I} - \mathbf{b}\mathbf{b}$. Drifts are not (yet) included in the code.

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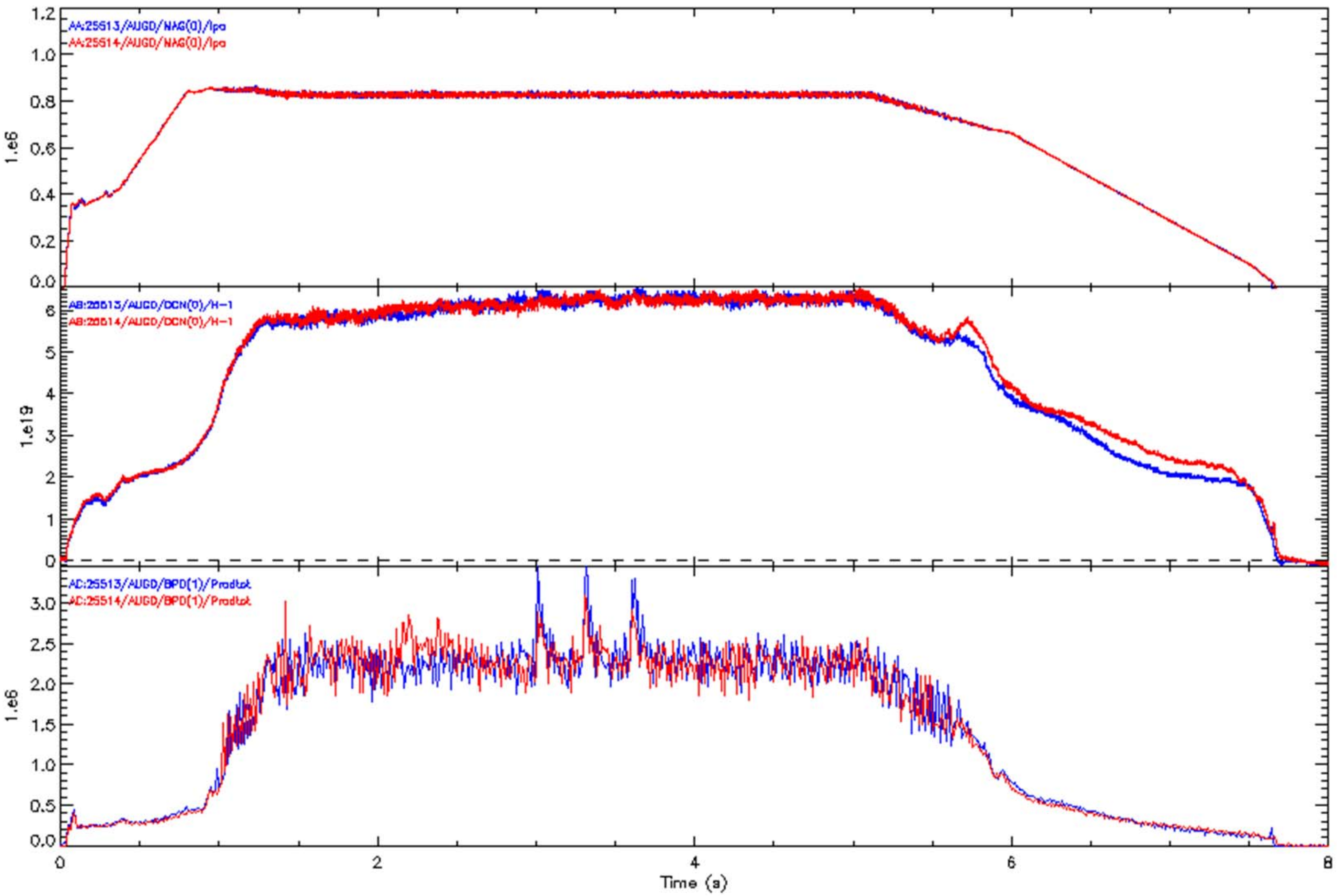
Controlled W-pin melting experiments

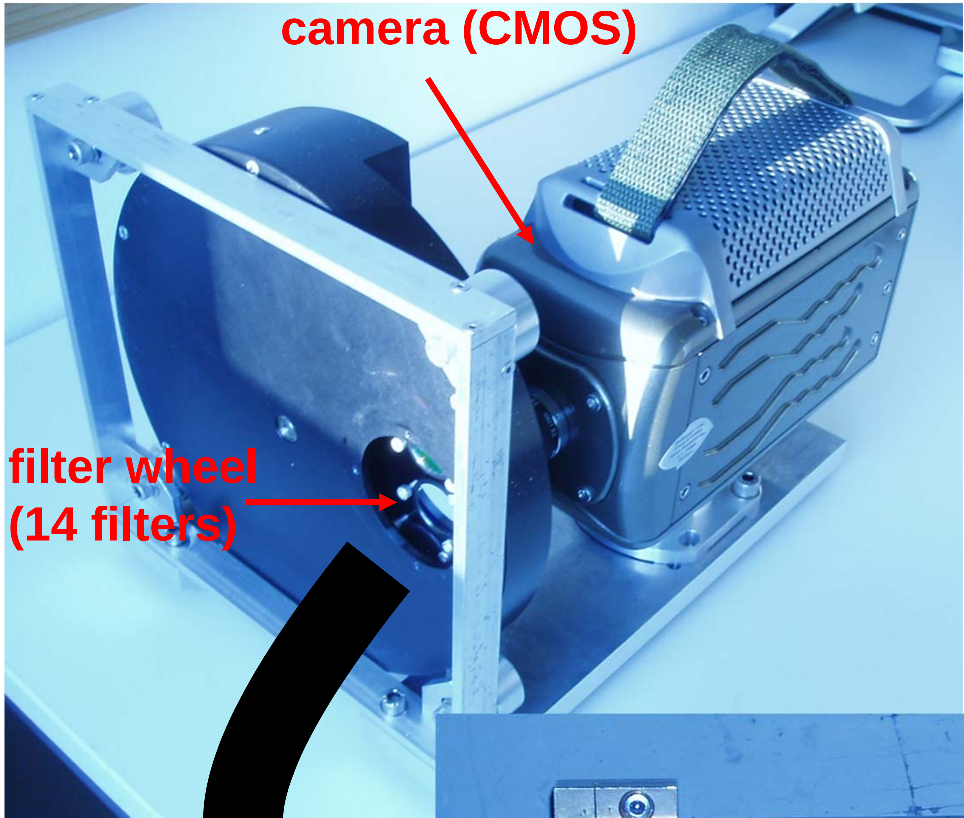
discharge

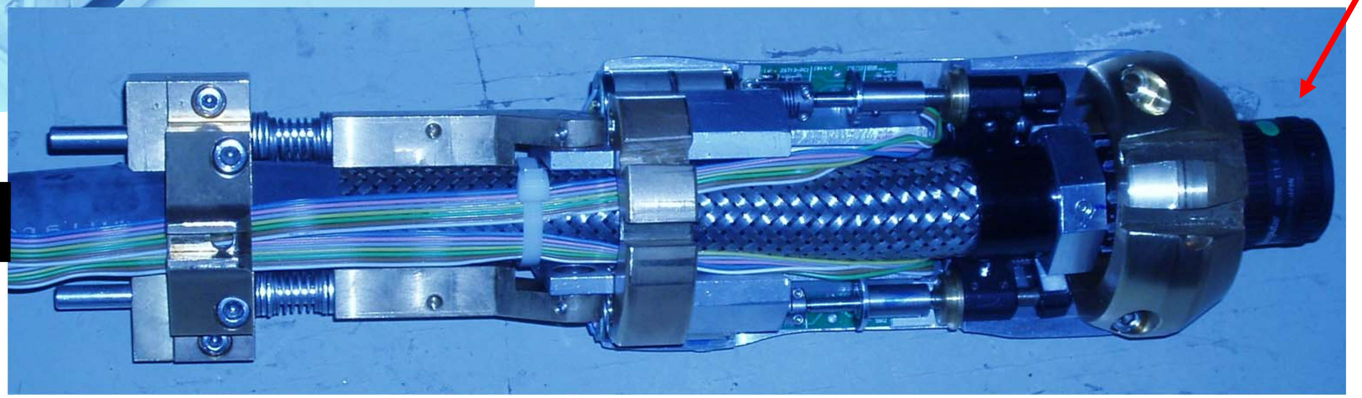


Fast framing camera

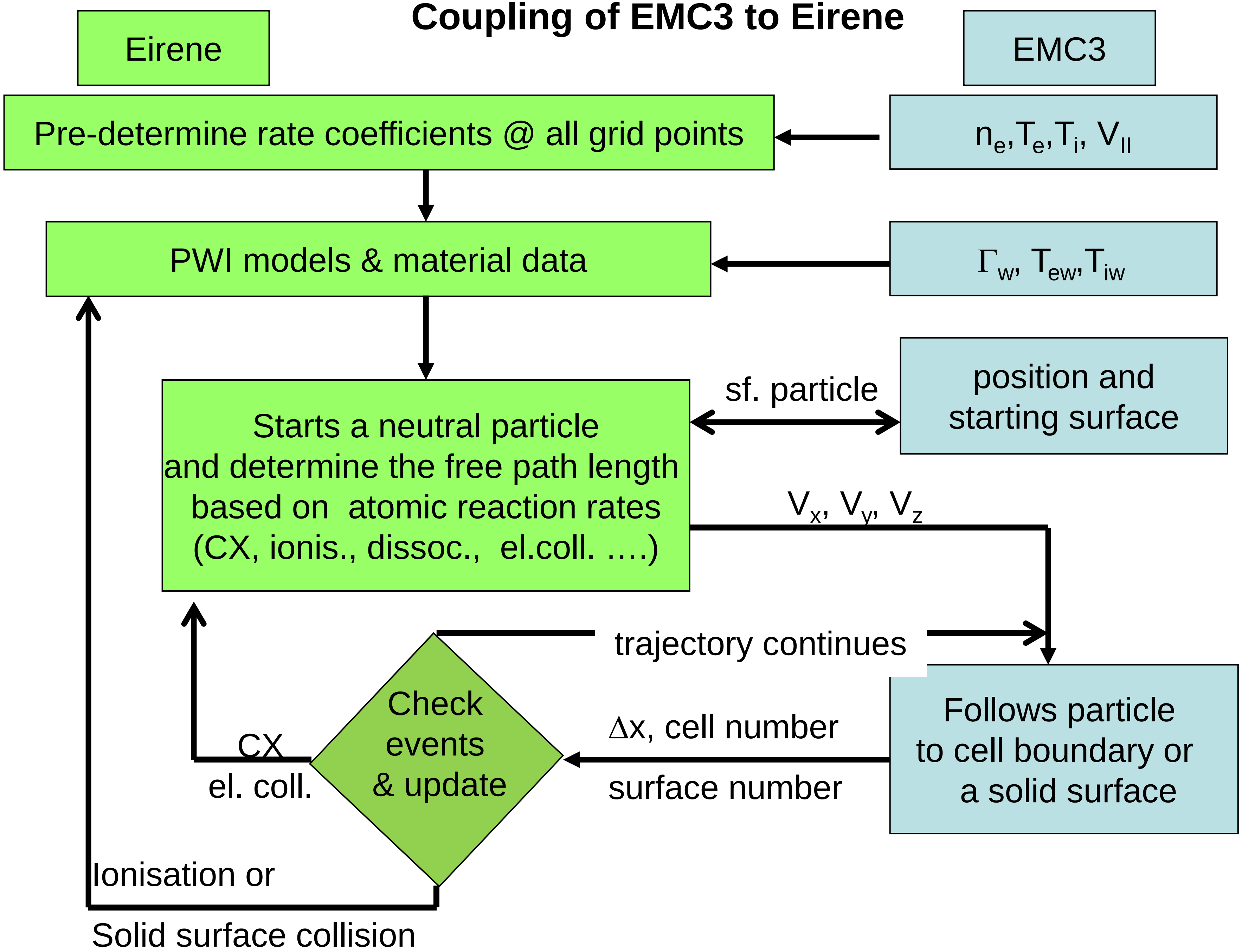
resolution (pixel)	max frame rate
800 x 600	6,700 Hz
512 x 512	11,000 Hz
256 x 256	<u>36,000 Hz</u>
128 x 128	89,000 Hz
64 x 64	143,000 Hz
32 x 32	190,000 Hz

memory 8GB=75000 f (@ 256x256)





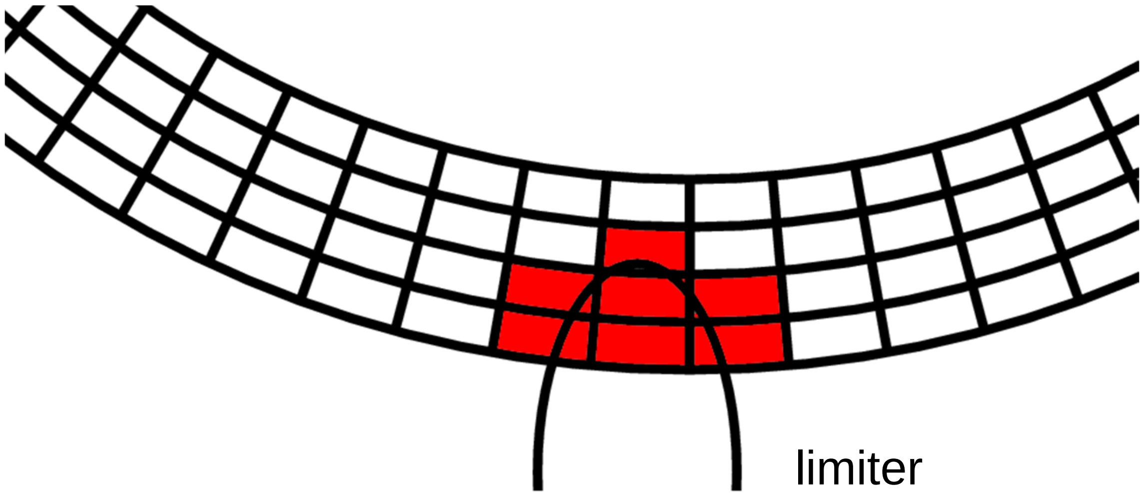
Coupling of EMC3 to Eirene



Edge Monte Carlo 3D (EMC3) - Eirene

Boundary conditions

Target:



Particle sink:

$\Gamma = n_e\, c_s$

Bohm-Chodura

Heat sink:

$Q = \gamma_e T_e \Gamma + \gamma_i T_i \Gamma$

Heat sheath transmission factors

$\gamma_e = 4.5 \quad \gamma_i = 2.5$

Simulation of a localized W source

Force balance