Computer code modelling of material migration in JET

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Motivation: Dynamics of first wall material migration

PWI in a tokamak:

Plasma transport:
- Transport phenomena
- Plasma background

Kinetic processes:
- Sputtering of wall material
- Radiation damage
- Re-deposition

→ **Particle fluxes and energy**

Thermodynamic processes:
- Formation of chemical phases
- Diffusion, Sublimation
- Annealing of radiation defects

→ **Wall temperature**

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Local flux balance

Thermodynamic processes:
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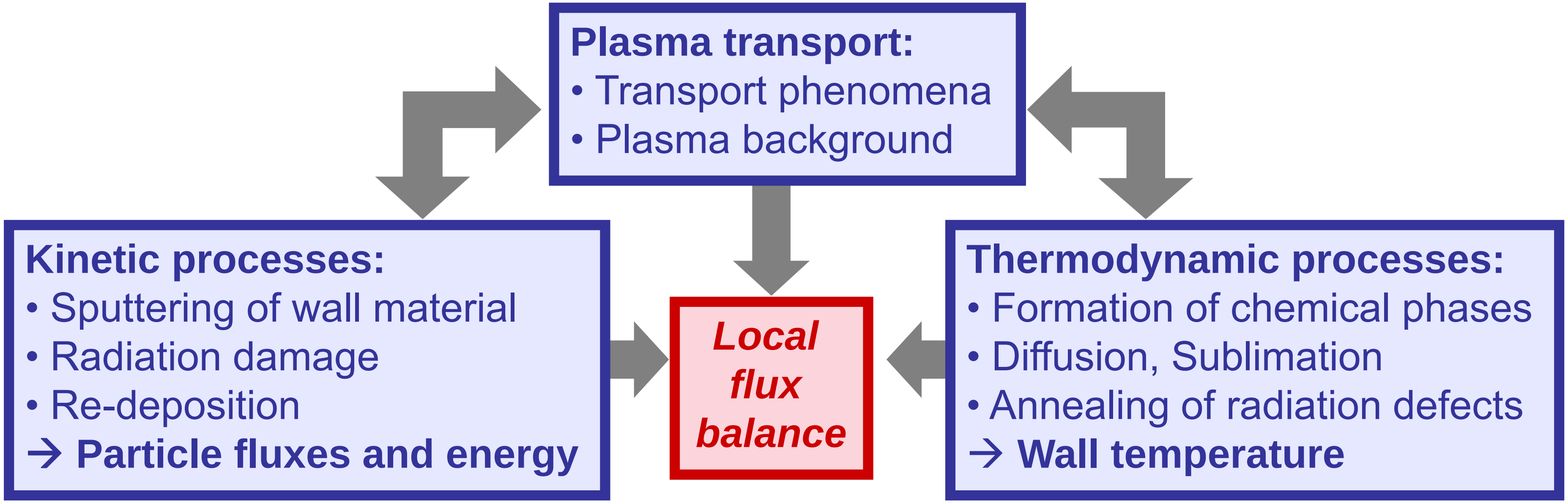
→ **Wall temperature**

► Iterative & global problem involving all types of processes

► Base concept:

Complex system can be described by
COUPLED ELEMENTAL processes



Outline:

- Validation of wall processes (sputtering, surface chemistry)
- Benchmarking of plasma transport

Model: General idea*

Background plasma

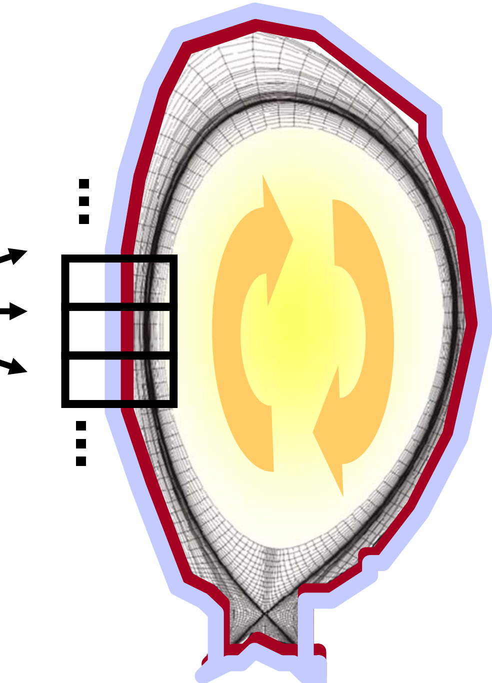
Impurity transport

Plasma facing surfaces

Impurity production

Bulk material

Source / sink for impurities



Wall dynamics code “WALLDYN”:

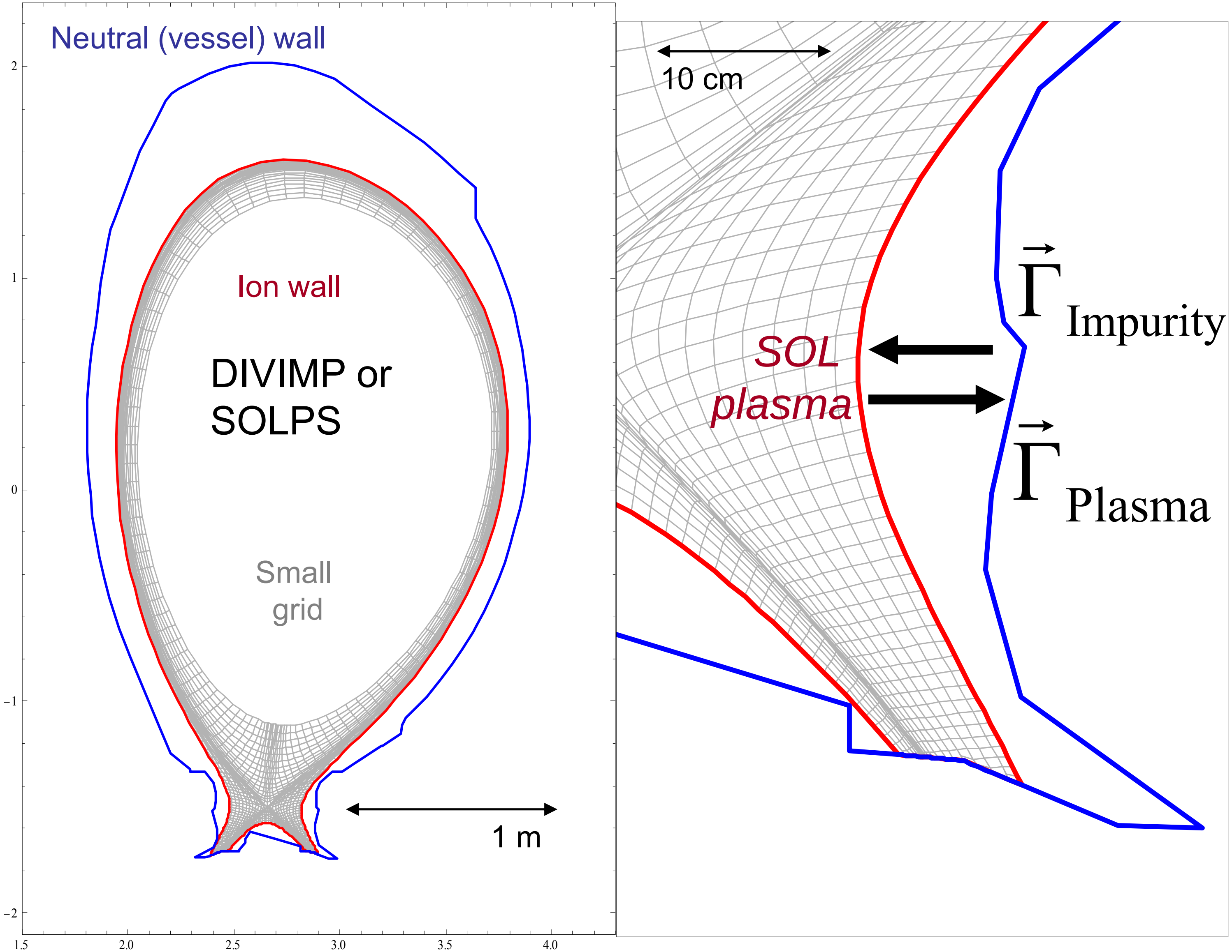
$$\frac{d\sigma_{k,b}(t)}{dt} = \Gamma_{k,b}^{Deposition}(t) - \Gamma_{k,b}^{Erosion}(t) + \Gamma_{k,b}^{Bulk}(t) + \Gamma_{k,b}^{Chemical}(t) + \ldots$$

* K.Krieger, J. Nucl. Mater. **290-293** (2001), 107-111

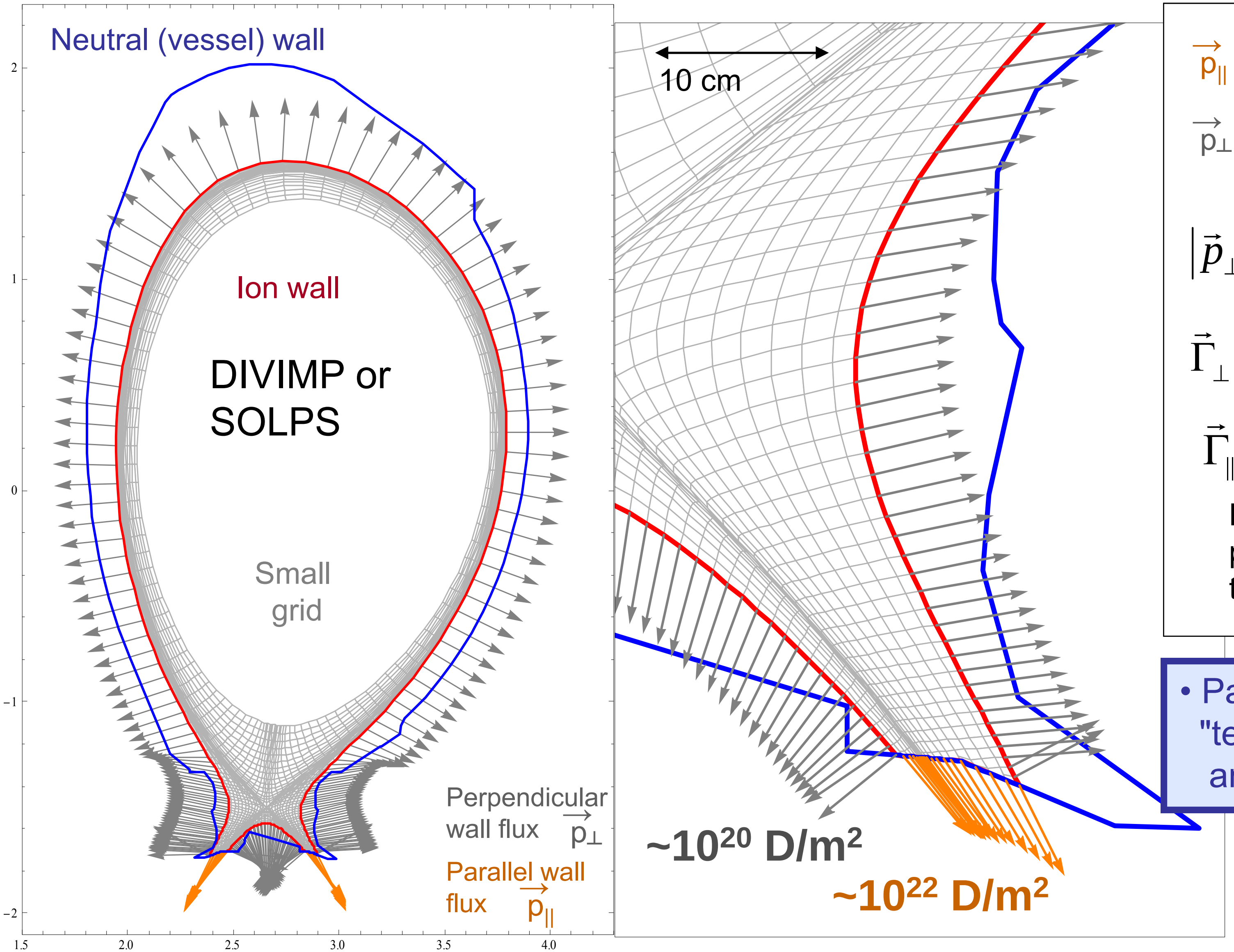
Parameterisation of coupled processes:

background plasma

Plasma wall fluxes



Plasma wall fluxes



$\vec{p}_\parallel$ along B flux surfaces

$\vec{p}_\perp$ along centers of neighboring grid cells

$$\left|\vec{p}_\perp\right| = \left|\vec{p}_\parallel\right| = 1$$

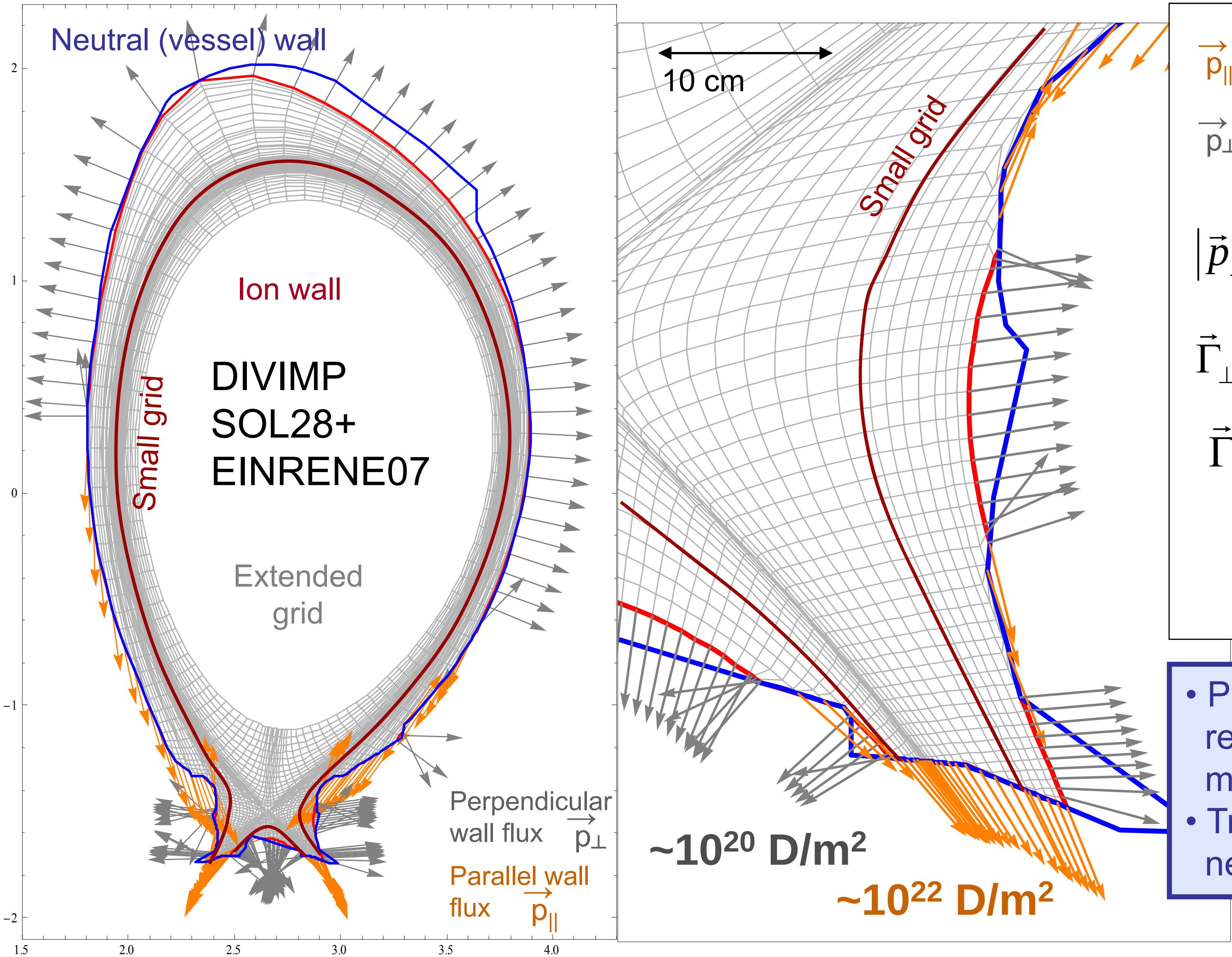
$$\vec{\Gamma}_\perp = -D\frac{dn_e}{dr}\vec{p}_\perp$$

$$\vec{\Gamma}_\parallel = n_e \cdot c_s \cdot R_B \cdot \vec{p}_\perp$$

Raytracing and projection of fluxes to neutral wall

- Particles are "teleported" from and to vessel wall

Plasma wall fluxes



$\vec{p}_{||}$ along B flux surfaces

$\vec{p}_\perp$ along centers of neighboring grid cells

$$\left|\vec{p}_\perp\right| = \left|\vec{p}_{||}\right| = 1$$

$$\vec{\Gamma}_\perp = -D \frac{dn_e}{dr} \vec{p}_\perp$$

$$\vec{\Gamma}_{||} = n_e \cdot c_s \cdot R_B \cdot \vec{p}_\perp$$

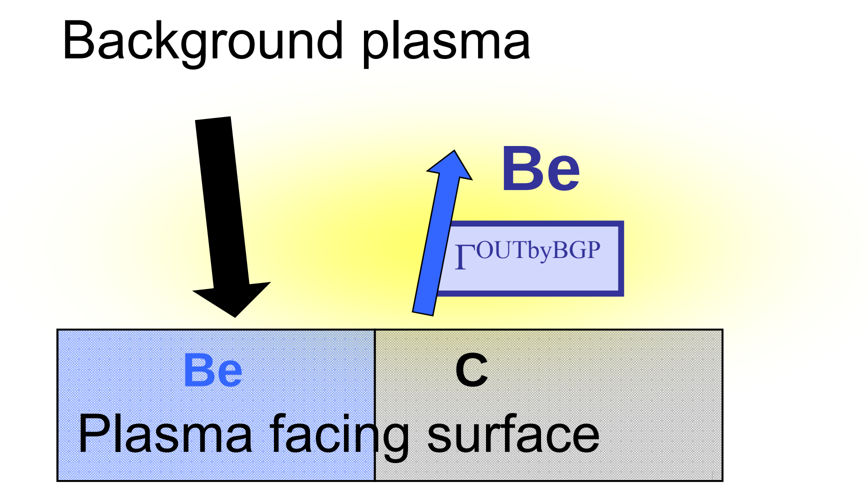
Raytracing and projection of fluxes to neutral wall

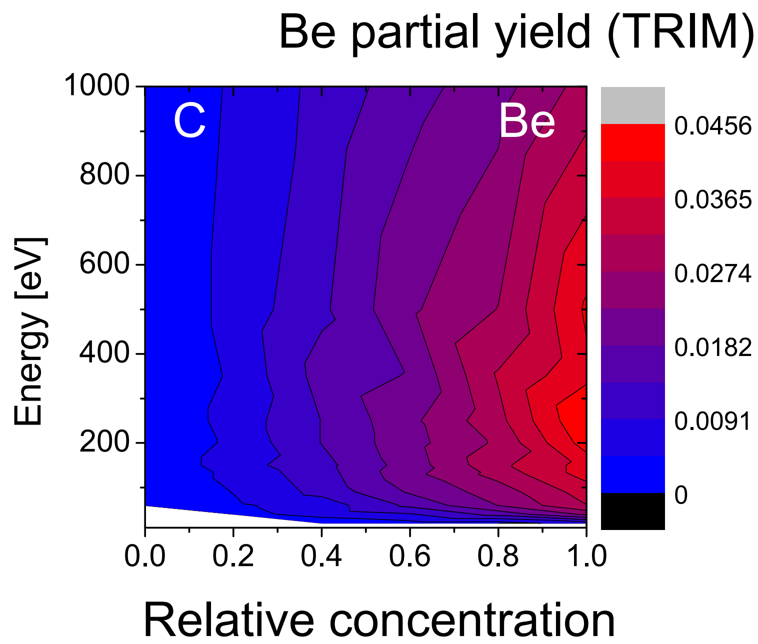
- Parallel fluxes reach parts of the main wall
- Transport processes near the wall

Parameterisation of coupled processes:

physical sputtering

Parameterisation of physical sputtering

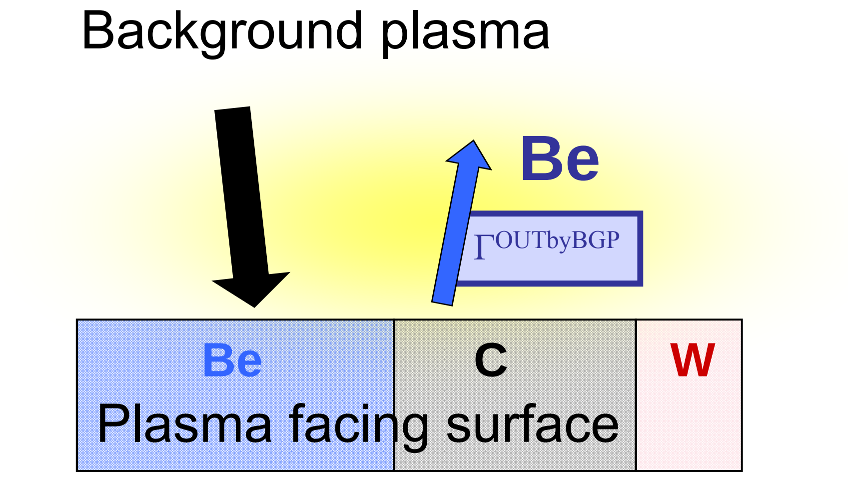




Sputtering of elements with similar mass:

$$\Gamma^{OUTbyBGP}{}_{(\text{Be with C})} = C_{(Be)}\Gamma^{BGP} Y^{Sputter}{}_{(\text{Pure Be; Bhodansky formula})}$$

Parameterisation of physical sputtering



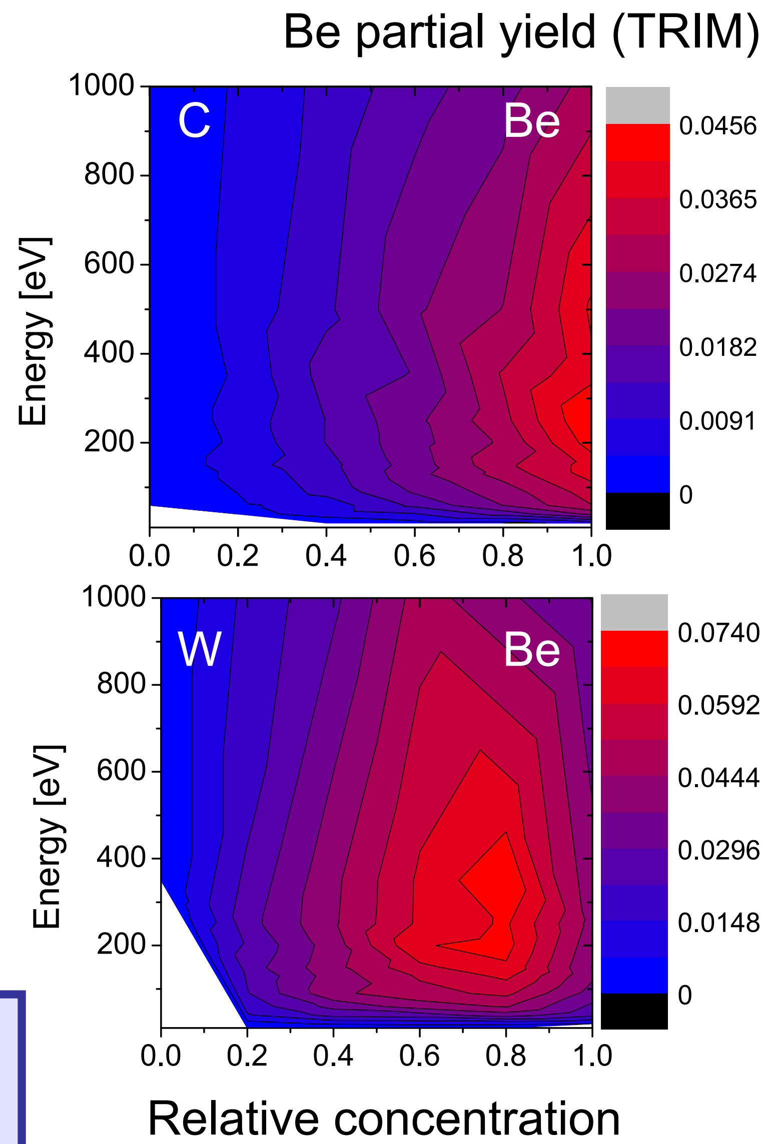
Sputtering of elements with similar mass:

$$\Gamma^{OUTbyBGP}{}_{(\text{Be with C})} = C_{(Be)}\Gamma^{BGP}Y^{Sputter}$$

Heavy elements (W) change the sputter yield of light elements:

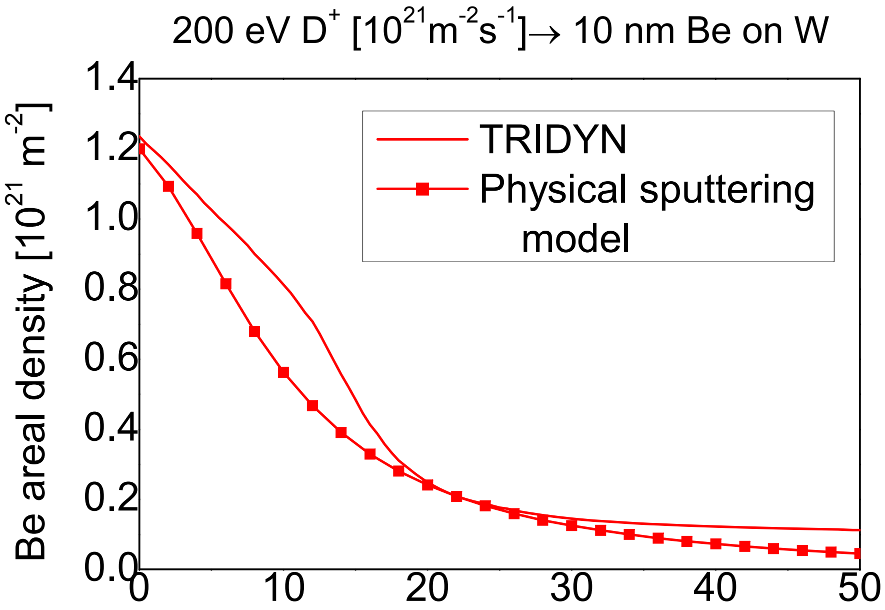
$$\Gamma^{OUTbyBGP}{}_{(\text{Be with C,W})} = C_{(Be)}\Gamma^{BGP}Y^{Sputter}{}_{(\text{Pure Be})}F_{(C_{(W)})}$$

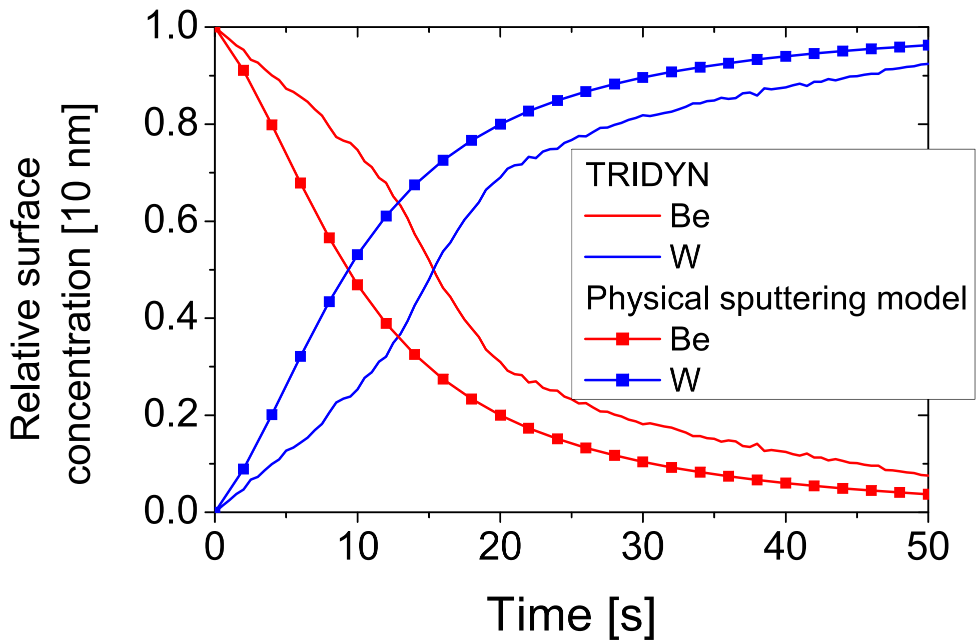
Polynom (2nd order) $F_{(C(W))}$ is obtained from parametrisation of TRIM



Parameterisation of physical sputtering

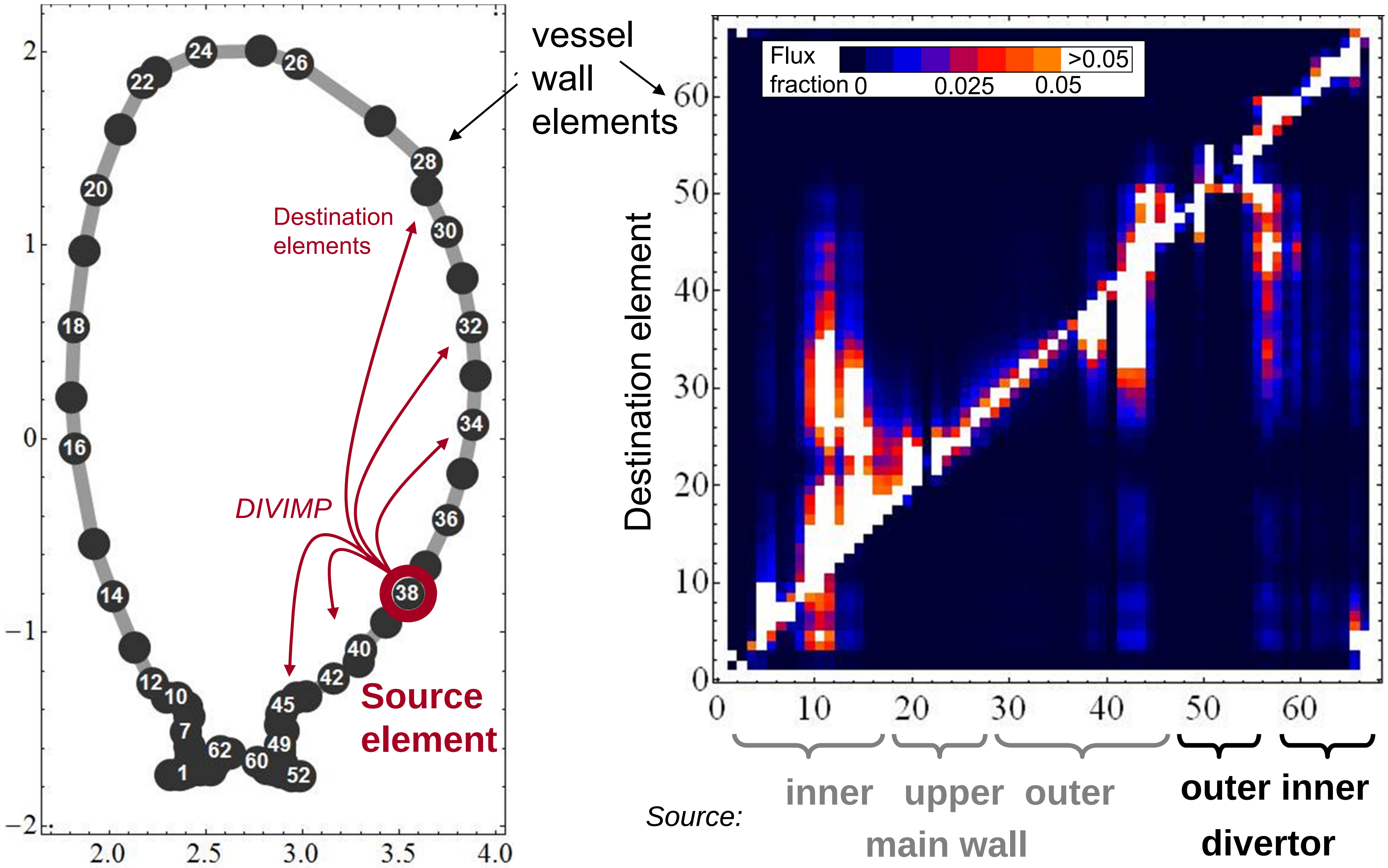
- Linear concentration dependence of partial sputter yield, non-linear contribution of heavy elements (W)
- Energy dependence according to Bhodansky formula
- Similar approach for reflection yields





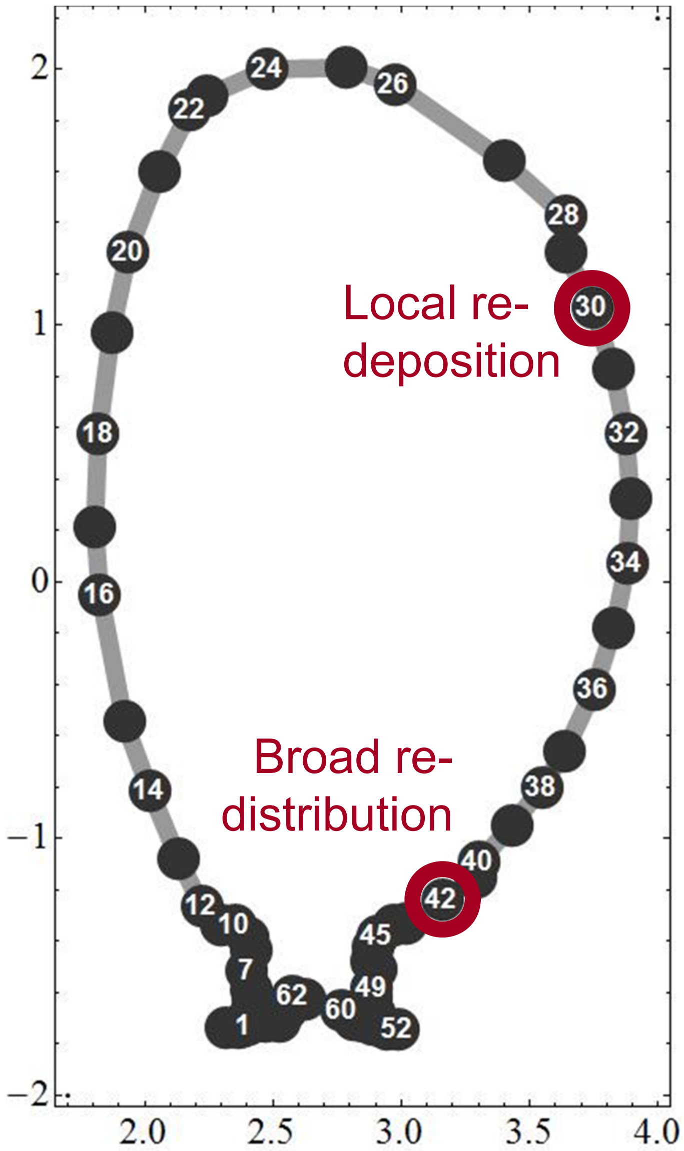
Parameterisation of impurity re-distribution

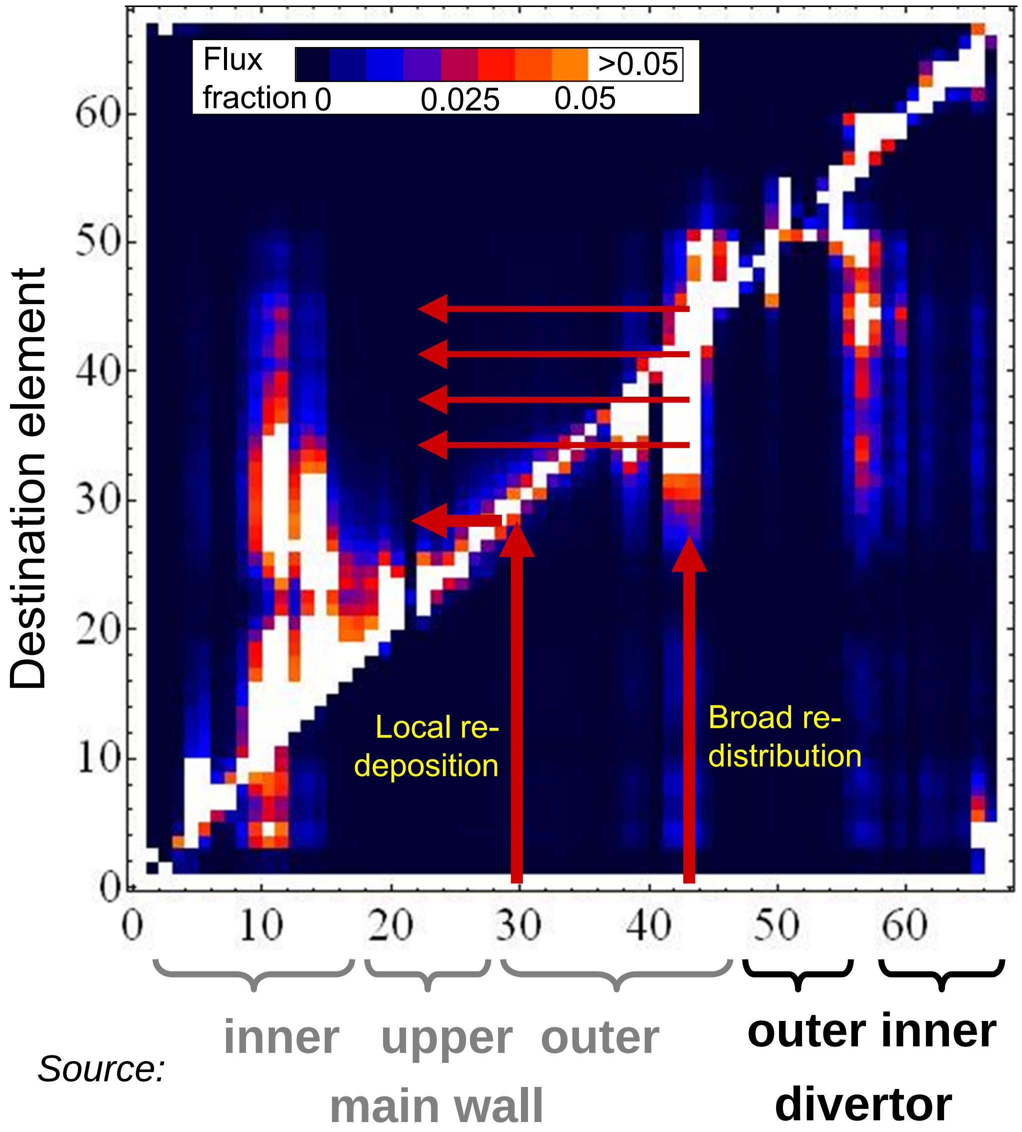
Parameterisation of re-distribution *



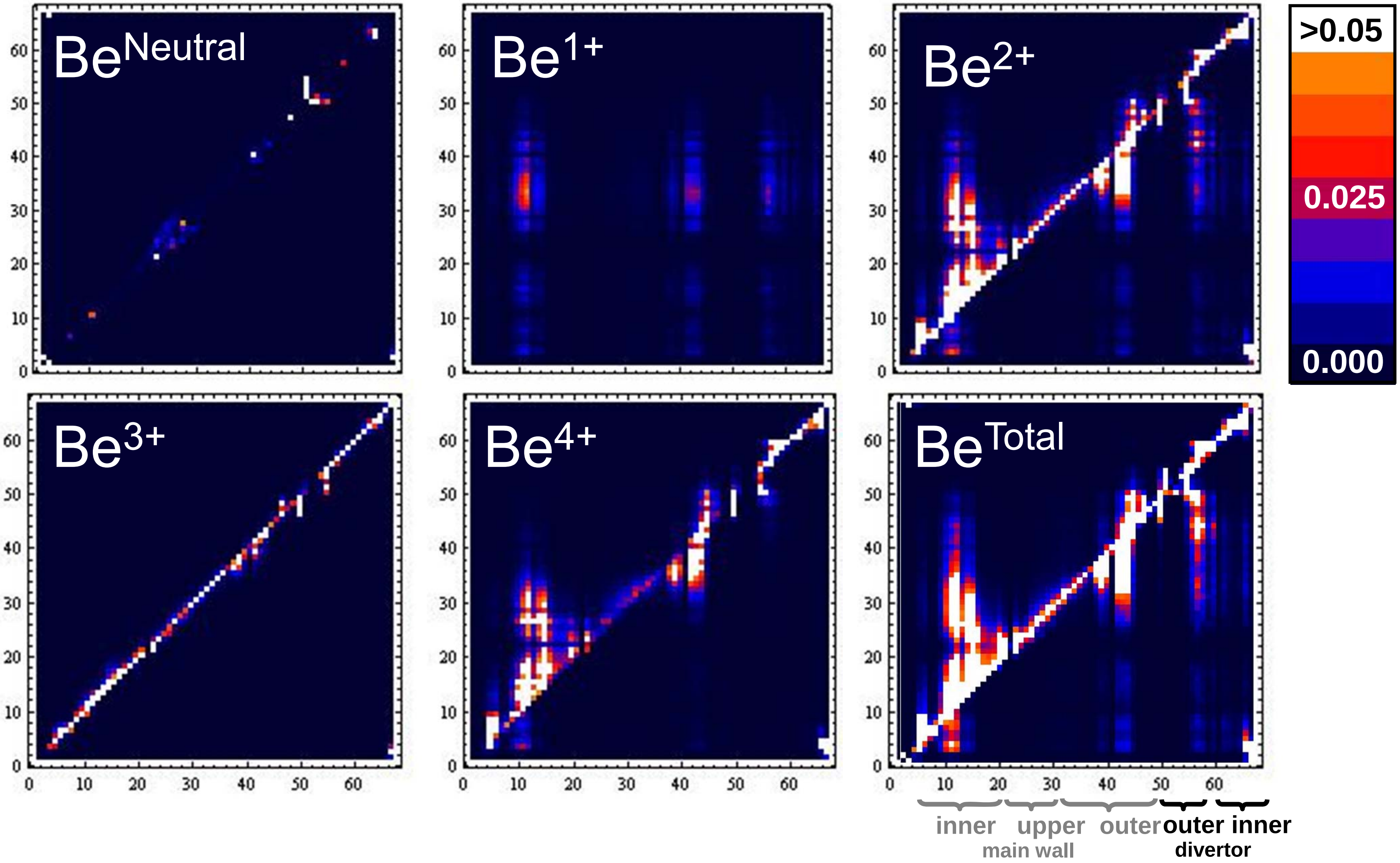
* *K.Schmid, Nucl. Fusion* ***48*** *(2008) 105004*

Re-distribution matrix





Charge resolved re-distribution

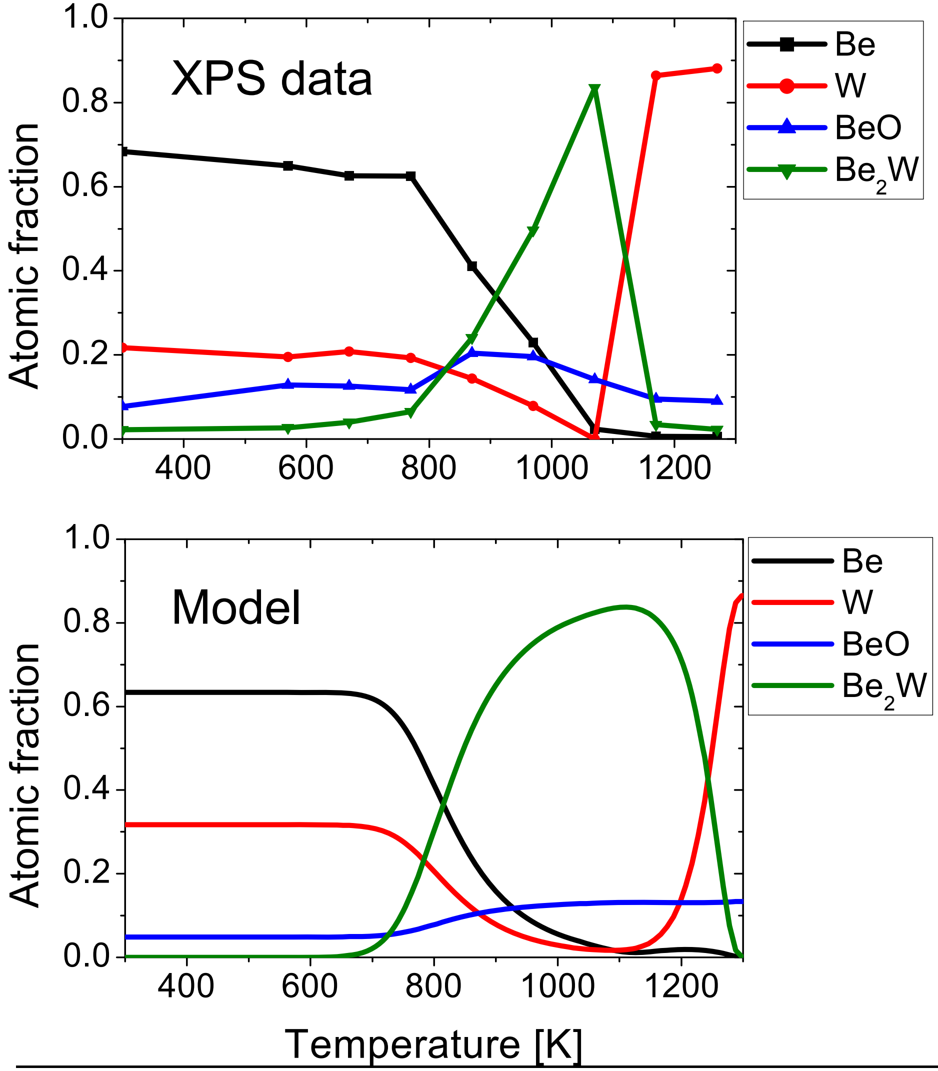


Parameterisation of coupled processes:

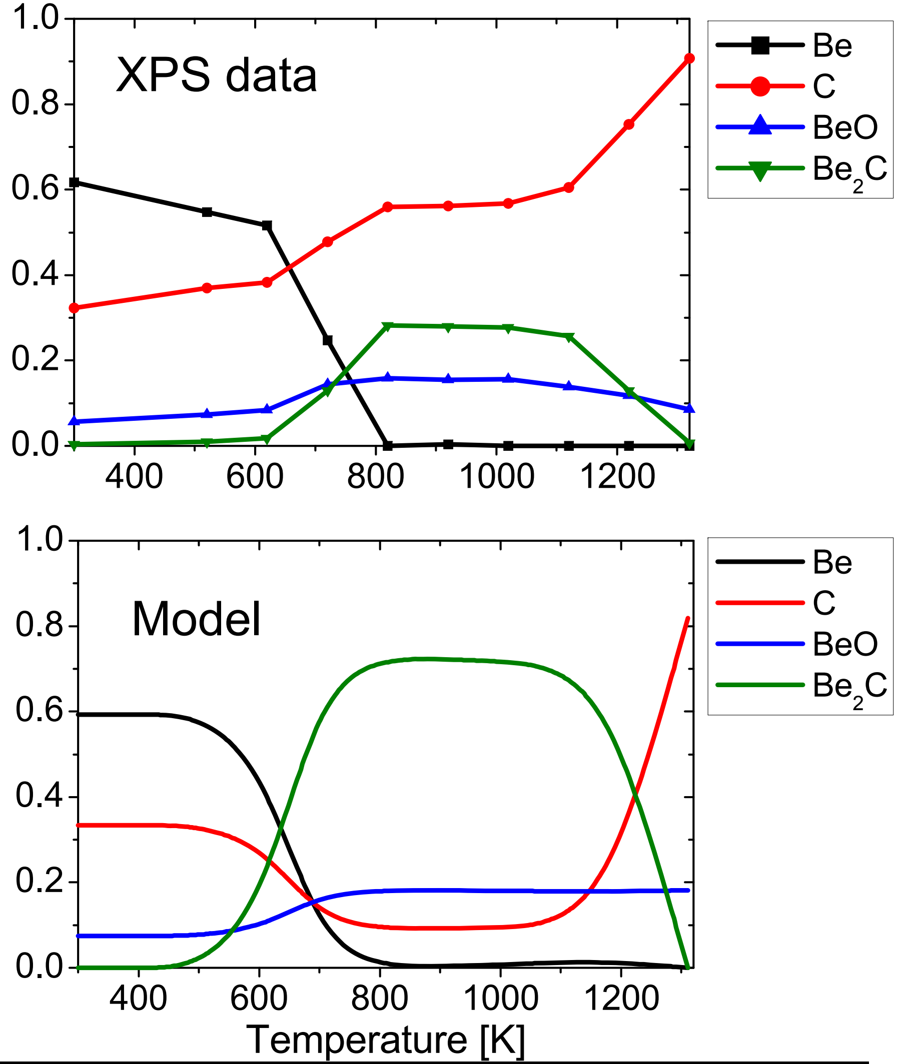
surface chemistry

Parameterisation of first wall chemistry

Be - W - O



Be - C - O



Benchmarking of BGP impurity transport on EG

Experiments at JET

Be migration studies:

"Be wall sources and migration in L-mode discharges after Be evaporation in the JET tokamak"

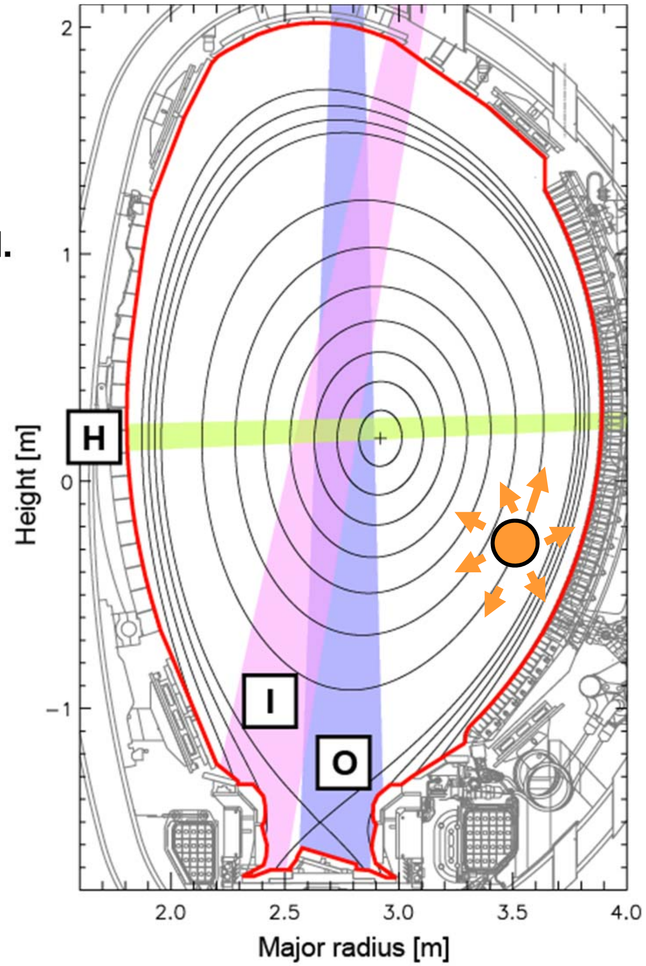
K. Krieger, S. Brezinsek, S. Jachmich, S. Lisgo, M. Stamp, H. Esser, A. Kreter, S. Menmuir, Ph. Mertens, V. Philipps, P. Sundelin, JET EFDA contributors

Journal of Nuclear Materials, 390-391 (2009), 110-114

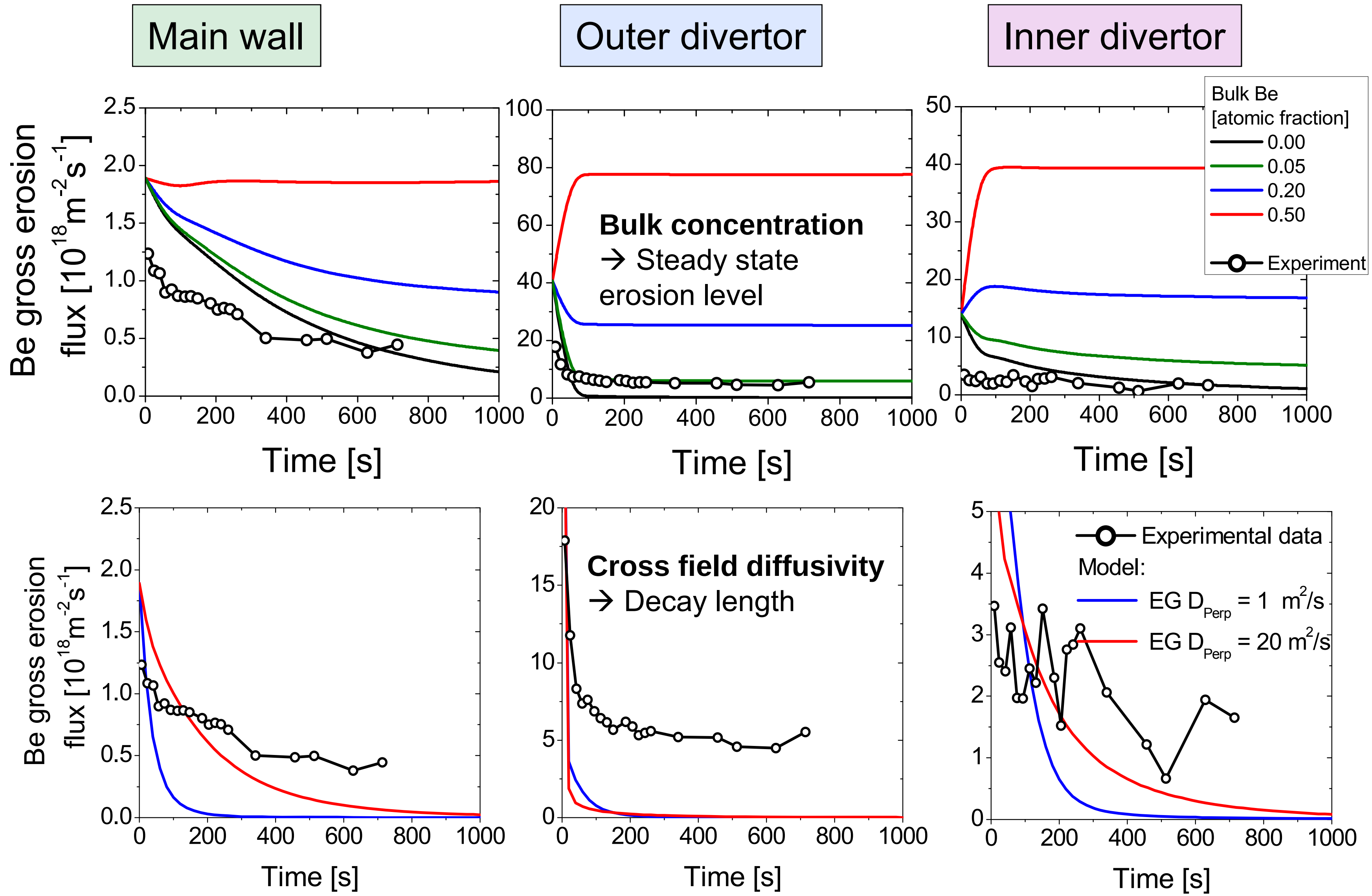
- Be evaporation (~0.2 g)
- Erosion fluxes by spectroscopy (Be II)

- Identical discharges:
  L Mode, High wall clearance, ~ 800 s

  → Change of Be impurity sources with time
  → Long term global material migration

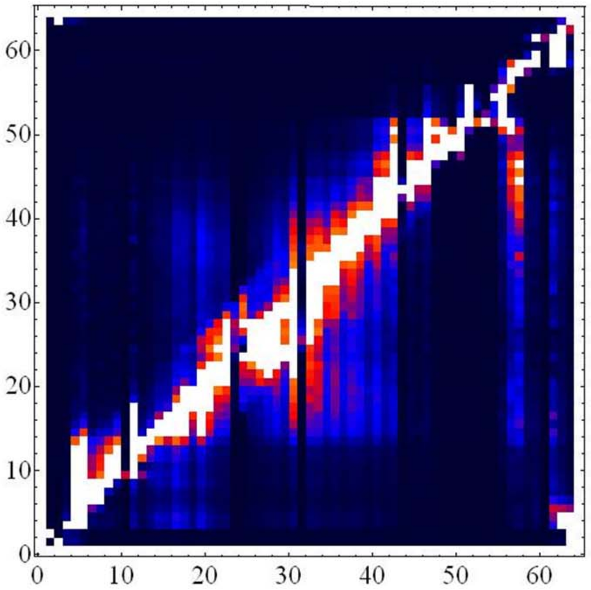


Comparison with experimental results

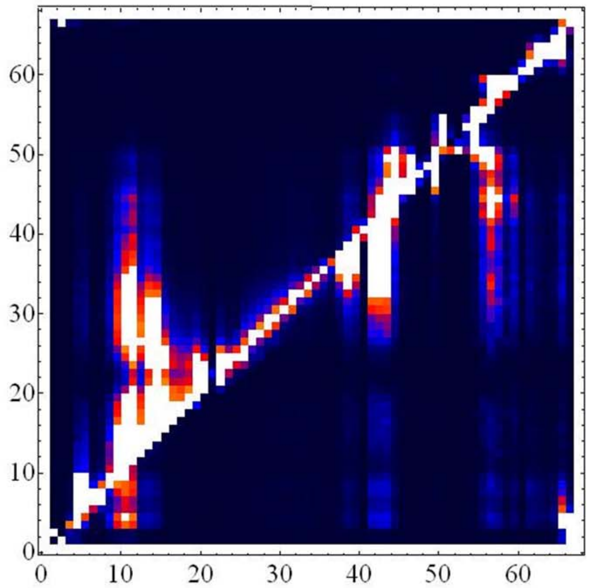


Impurity transport

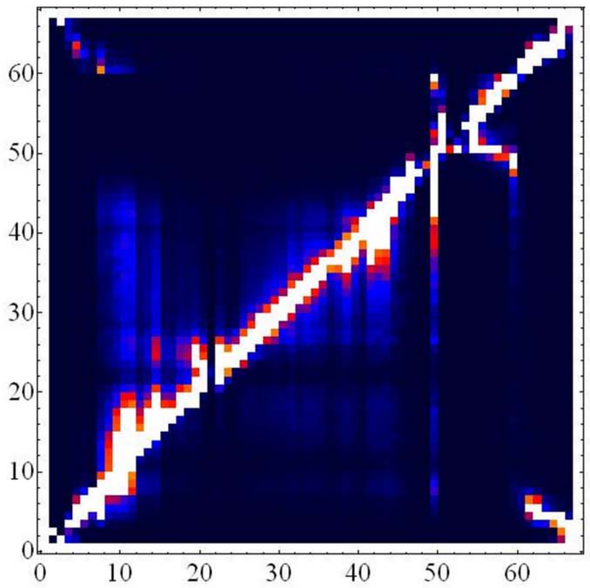
Small grid



Extended grid
Cross field diffusivity 1 m^2/s



Extended grid
Cross field diffusivity 20 m^2/s



→ Grid geometry, cross field diffusivity massively influences re-distribution.
What else ? Influence, sensitivity of parameters ?
→ Next step:
Scan plasma properties on the extended grid (close to the main wall)

Summary

- New time dynamic model for **global** and **long term** first wall material migration: WALLDYN

- Wall processes implemented and validated:
  - Sputtering of light / heavy elements, Reflection
  - Chemical phase formation and destruction, sublimation
  - Simple gas / surface interaction
  - Chemical erosion

- Plasma transport:
  - Extended grid
  - Charge resolved redistribution

- Outlook:
  - Parameter scans, sensitivity studies for plasma parameters in extended grid region
  - Benchmark plasma transport with JET data
  - Hydrogen inventory by co-deposition (Be/H, W/H)