3D Simulations of Impurity Transport in a Fusion Device Edge Plasma with the Massively Parallel Monte Carlo Code ERO2.0

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IEK-4:

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The Edge of a Fusion Plasma

Erosion of Plasma-Facing Components (PFCs)

- cannot be prevented completely
- reduces **PFC lifetime**
- source of plasma **impurities**
  - enhances erosion (**self-sputtering**)
- can enhance Tritium **retention** (co-deposition)

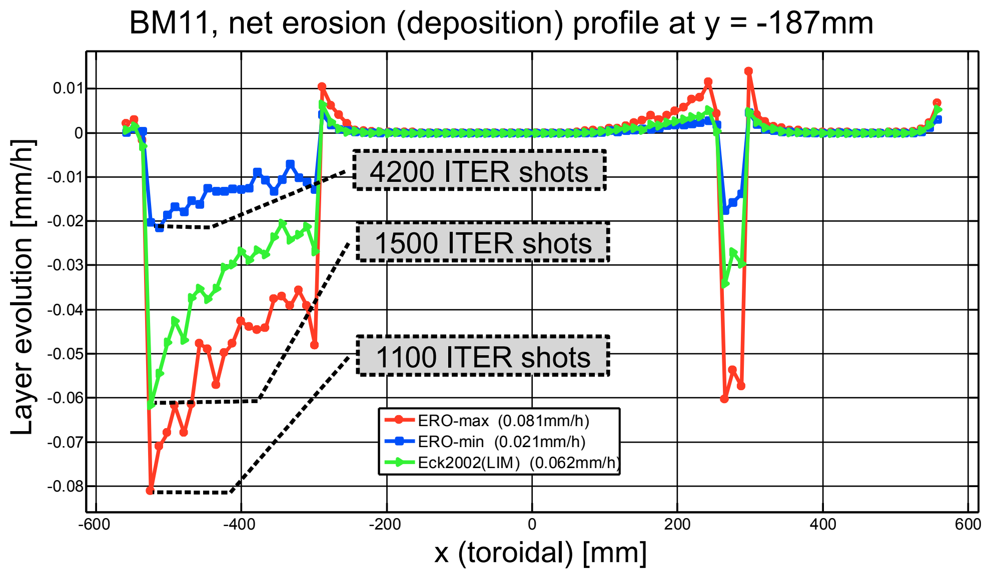
Erosion of JET Iter-like Wall

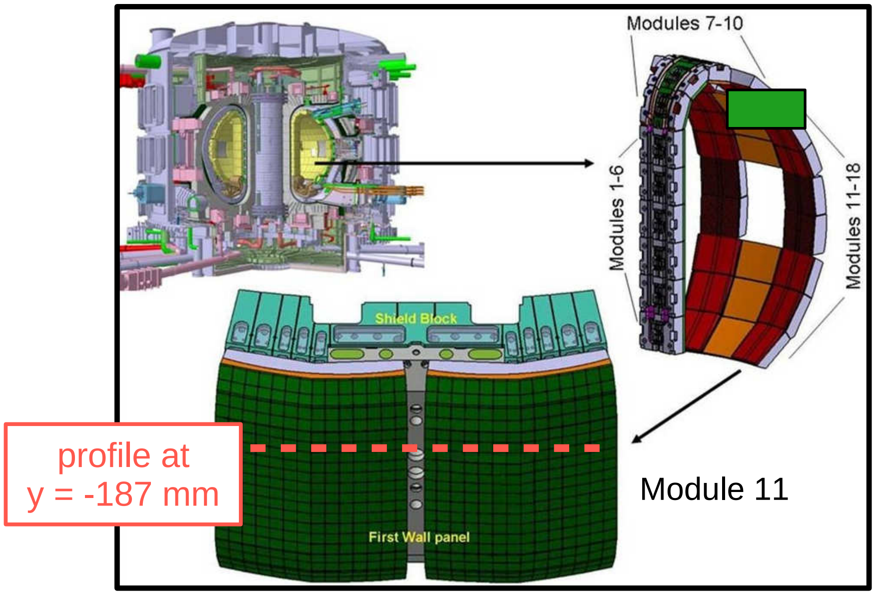
questions to modeling:

1) Material Migration
2) Net Erosion / Deposition

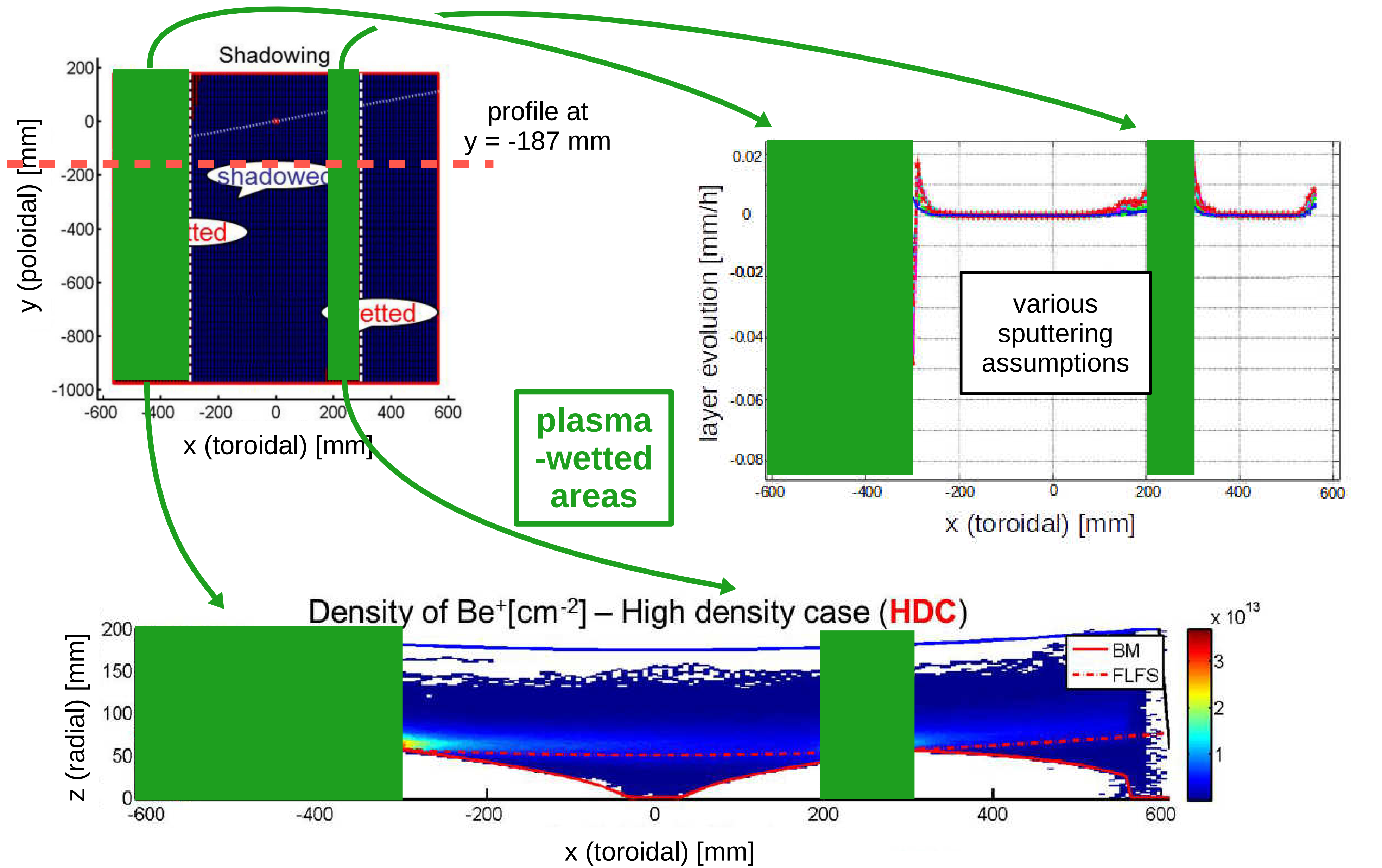
ERO Aims & Strategy

- studies **Plasma-Surface Interaction (PSI)** and **local 3D Impurity Transport**
- **inherent coupling** PSI and impurity transport
- 3D gyration for impurities for detailed energy/angle resolution
- **benchmarking** with existing experiments
  - JET, EAST, PISCES-B, …
- **predictive modeling** for ITER

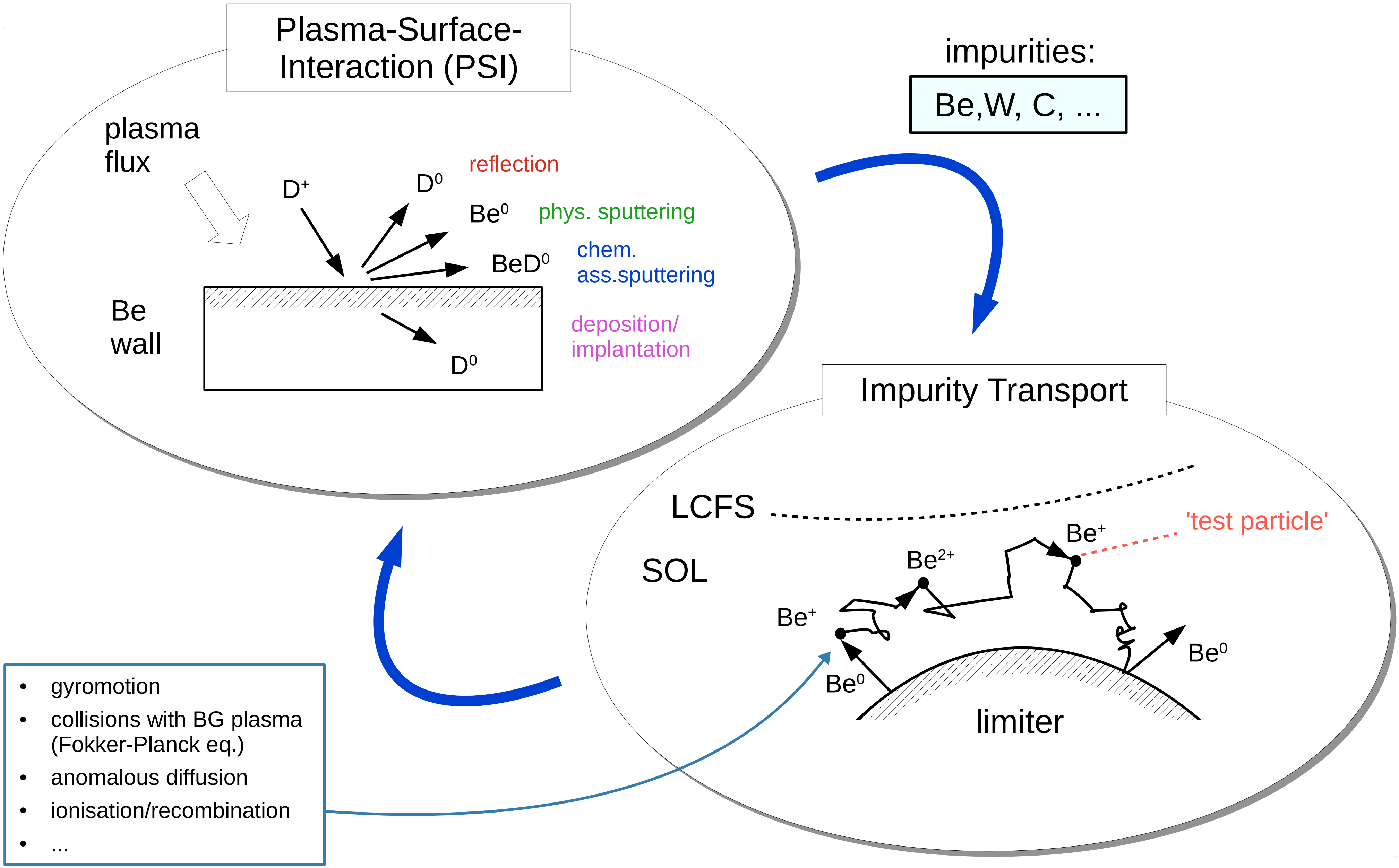




Example: Erosion of ITER Blanket Module

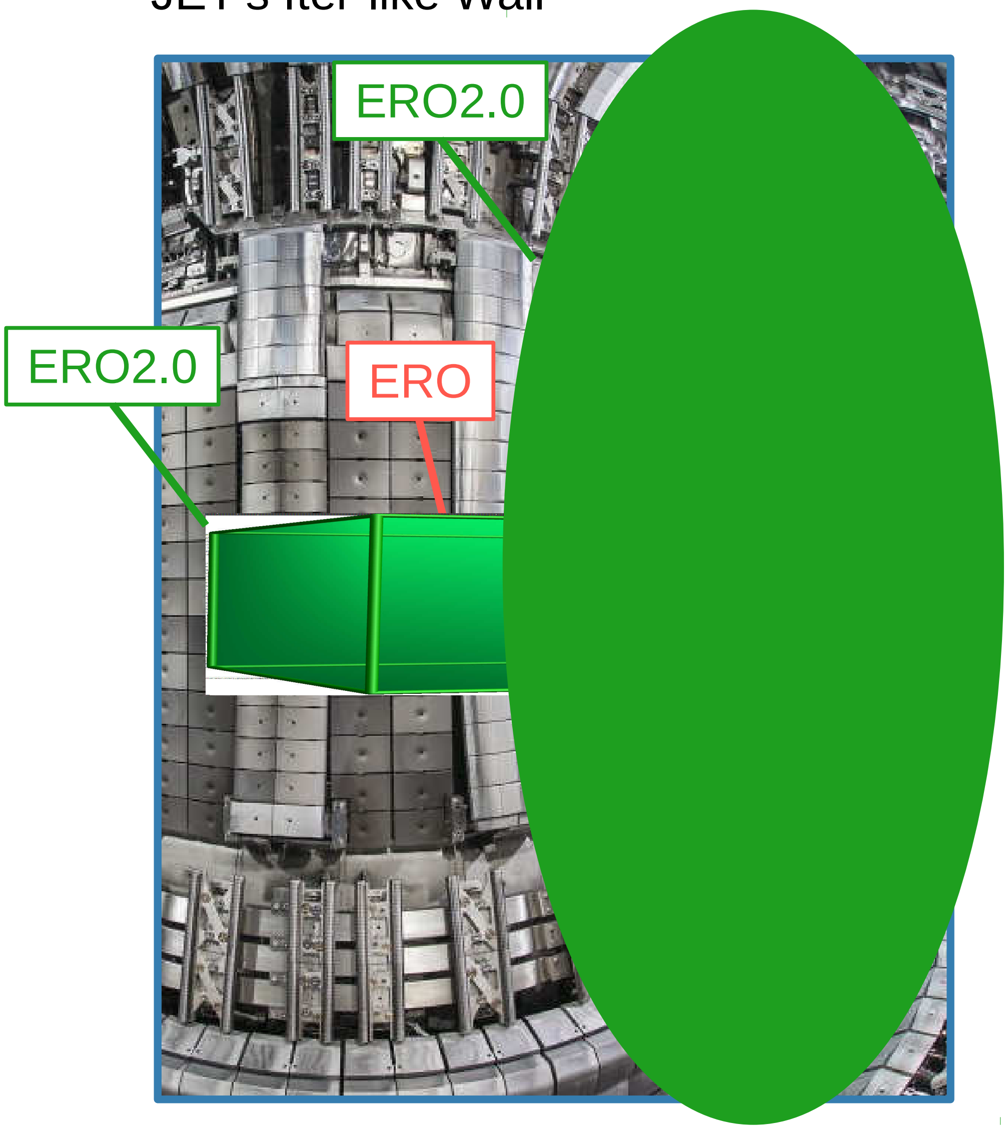


The ERO Main Loop



The Next Step: ERO2.0

JET's Iter-like Wall



The limits of ERO

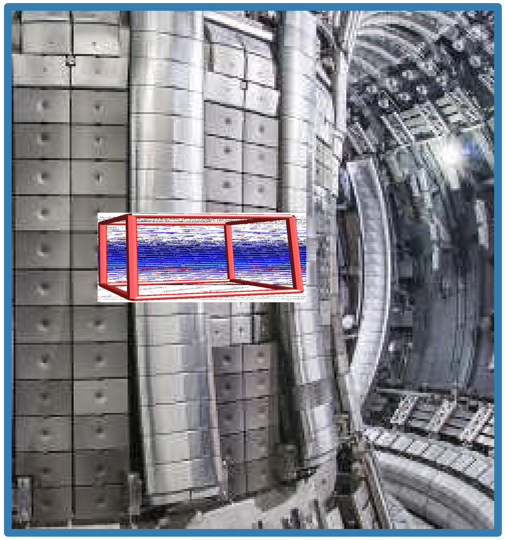
- small simulation volumes of ~(10 cm)³
- typically covering a single PFC part

Aims of ERO2.0

- increase simulation volume to relevant sizes
- requirements:
  - comp. efficiency
    - massive parallelisation
    - guiding-center motion (later)
  - efficient algorithms for 3D plasma parameters and geometry

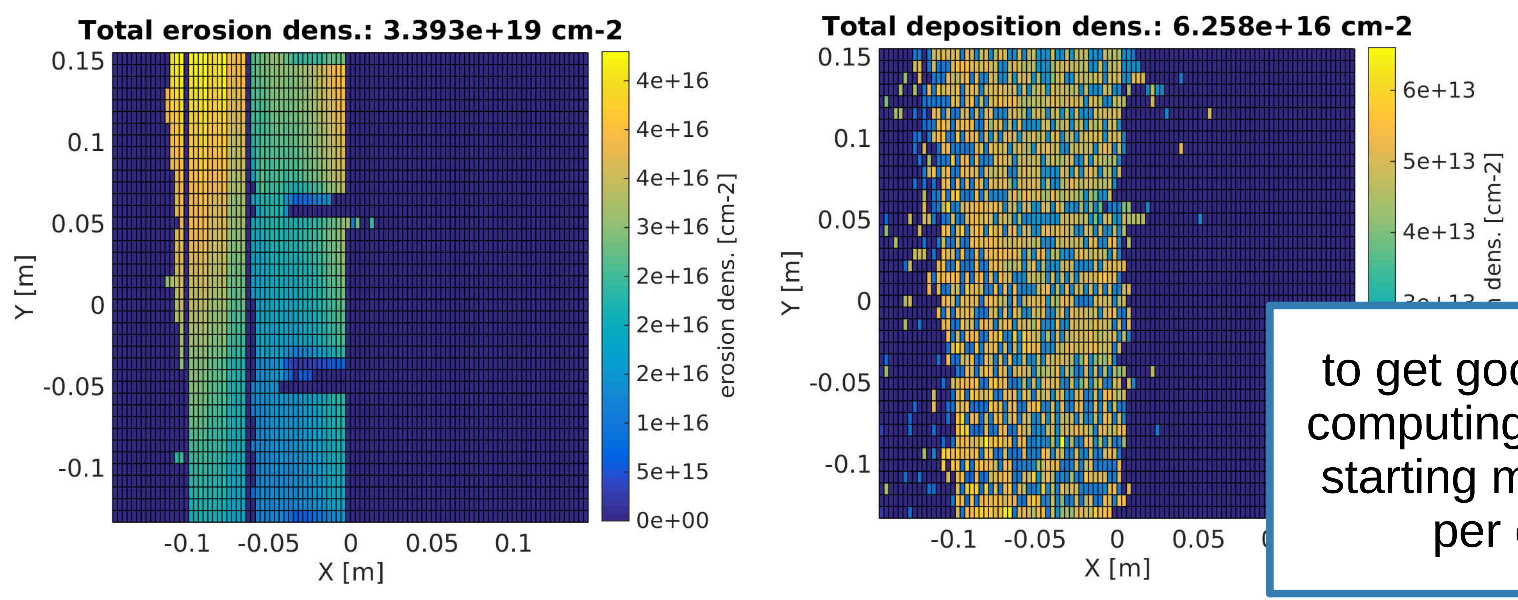
Reference Scenario for ERO2.0 Testing

JET's Iter-like Wall



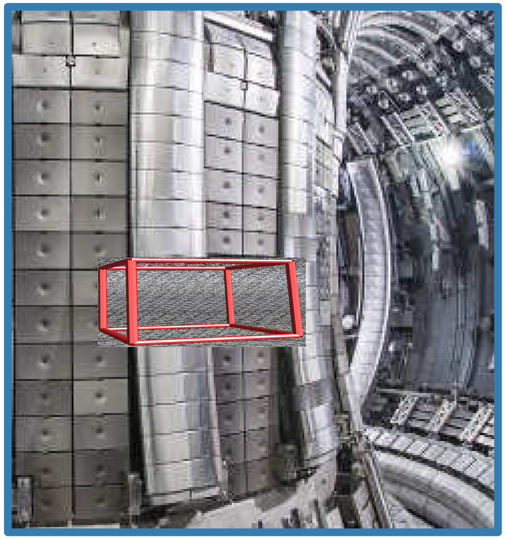
'Reference' Scenario:

- Beryllium Limiter
- Sputtered by D and Be
- Assumption: No erosion in shadowed regions
- fine surface mesh (40 x 100 cells)
- typically <1 % of particles return to surface



to get good statistics, most computing power is used for starting many test particles per cell (~1000)!

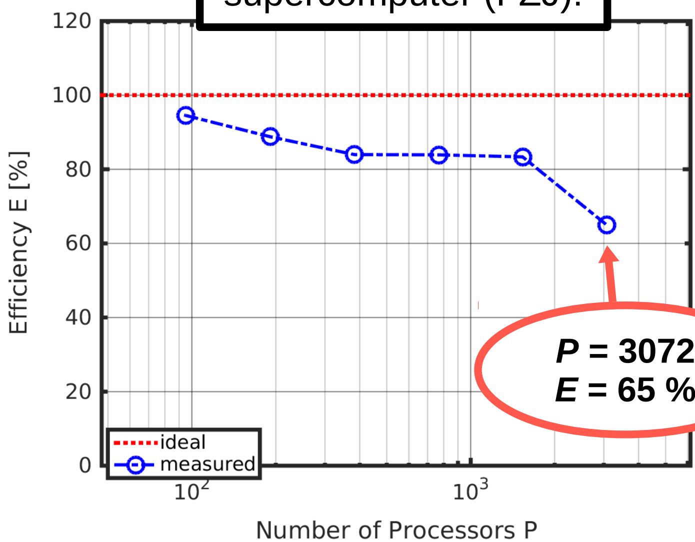
Testing Parallel Efficiency



cores ↓ particles ↓

P	N_P
1	30
2	60
4	120
...	...
3072	92160

testing on JURECA supercomputer (FZJ):



***P* = 3072**
***E* = 65 %**

Weak Scaling

- ***N*$_P$: number** of test particles simulated on ***P* processors**
- weak scaling: increase N_P proportionally with P:

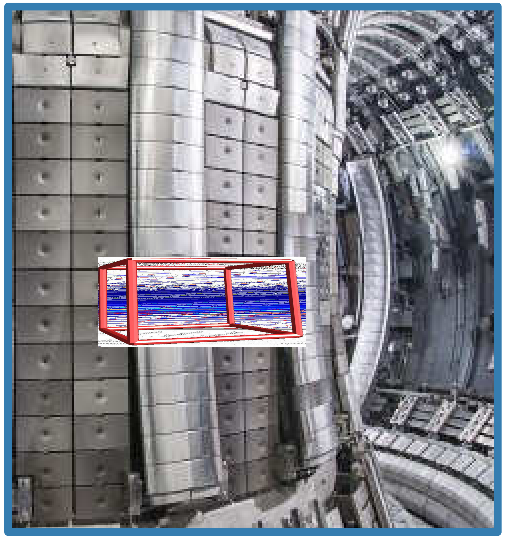
$$N_P = P * N_1 \quad , \quad \text{here:} \quad N_1 = 30$$

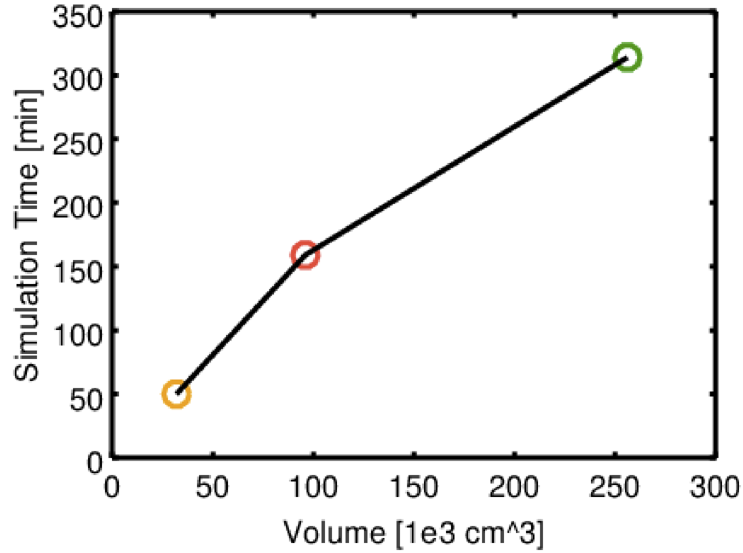
- measure **time t_P** needed to finish simulation
- define **efficiency *E***:

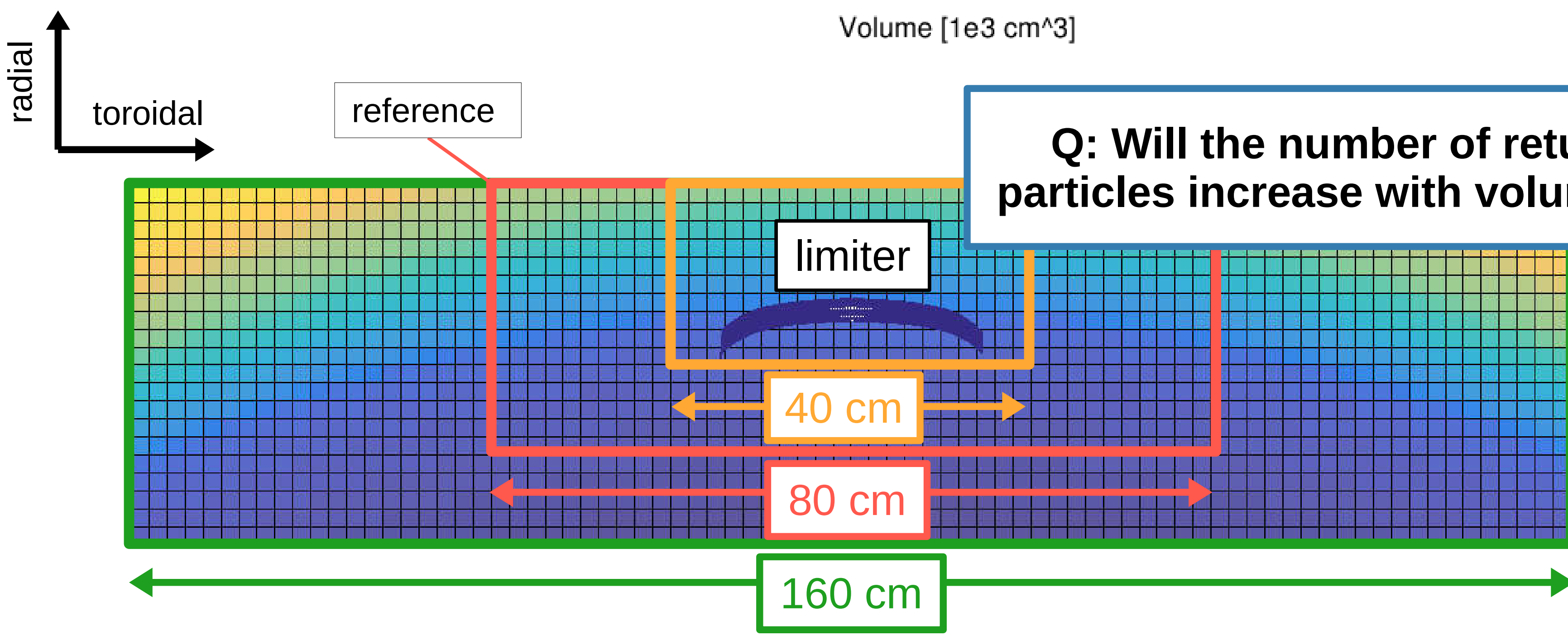
$$E = t_1 \;/\; t_P * 100\ \%$$

we can simulate 3072 x 0.65 ≈ 2000 more particles without increase of comp. time

Increasing the Volume



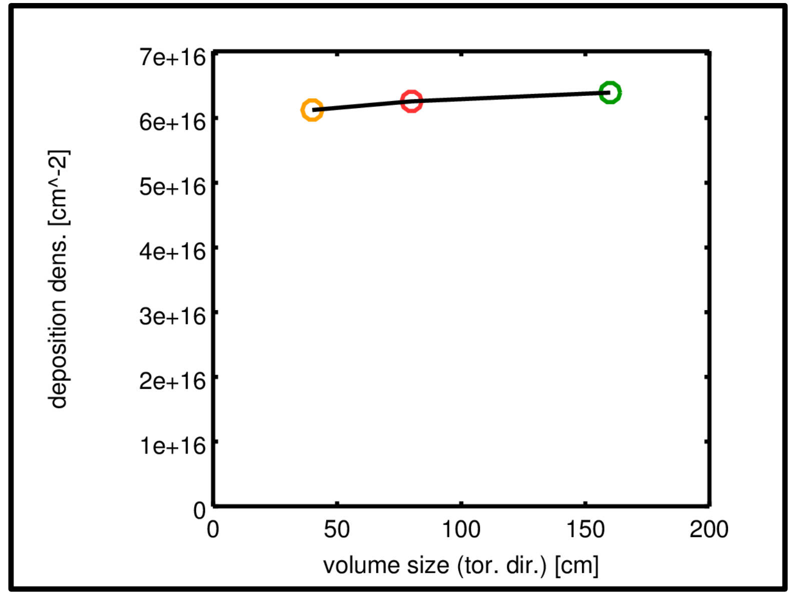


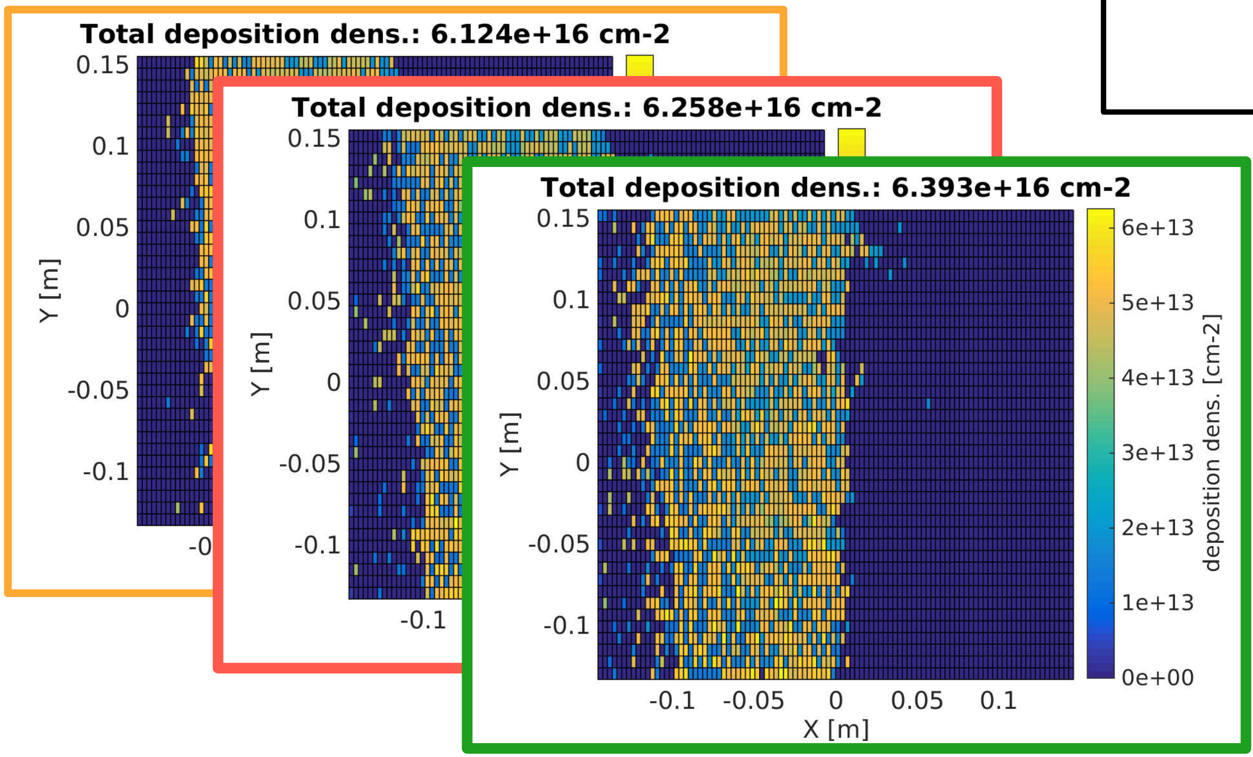


Q: Will the number of returning particles increase with volume size?

Results

A: Only <5 % increase!





Caution: Anomalous Diffusion was not included yet!

Summary & Outlook

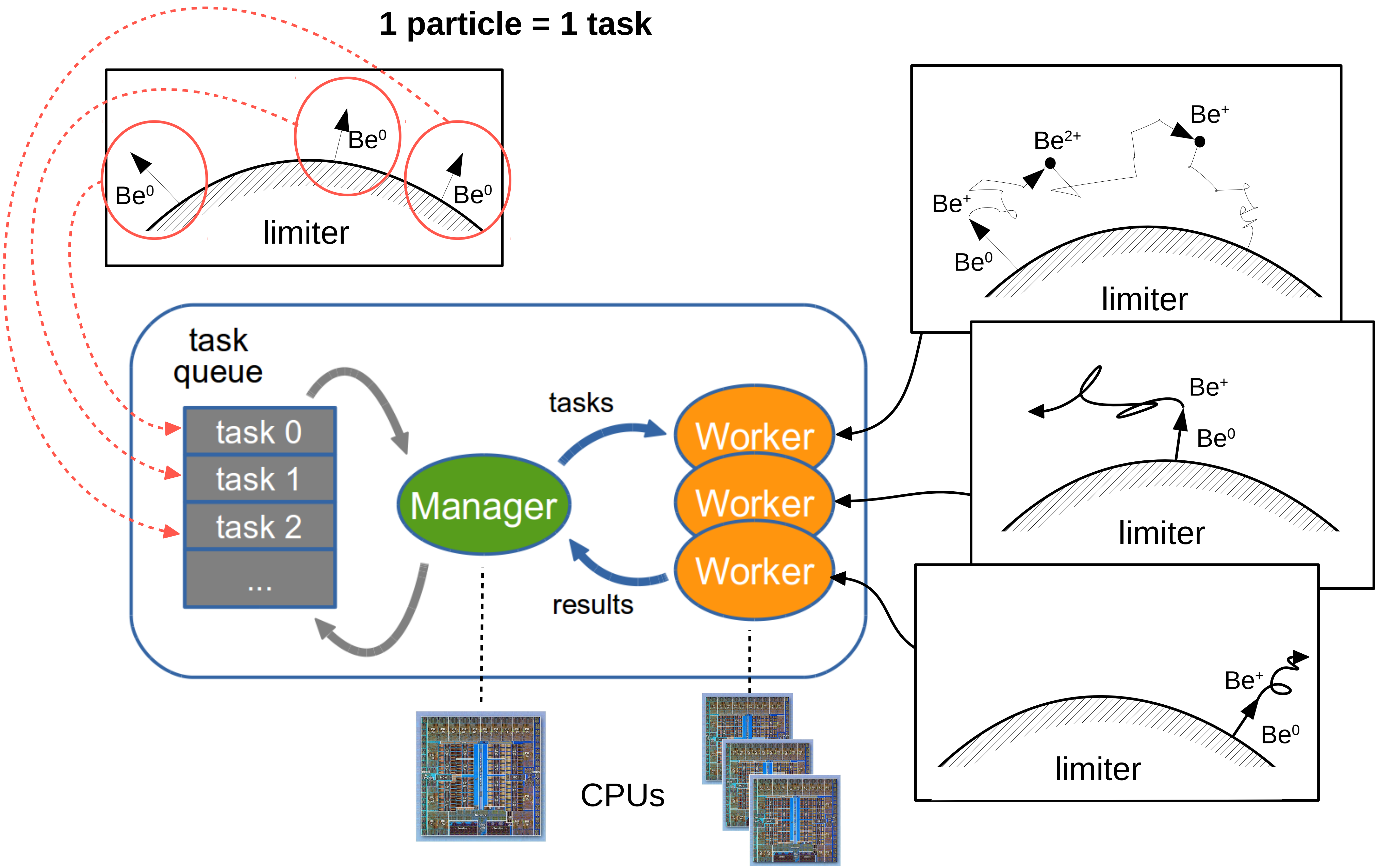
Summary

- ERO studies PFC erosion and local 3D impurity transport
- ERO2.0 has increased comp. performance → more particles, larger volume
- first tests gave small increase in particle return rate

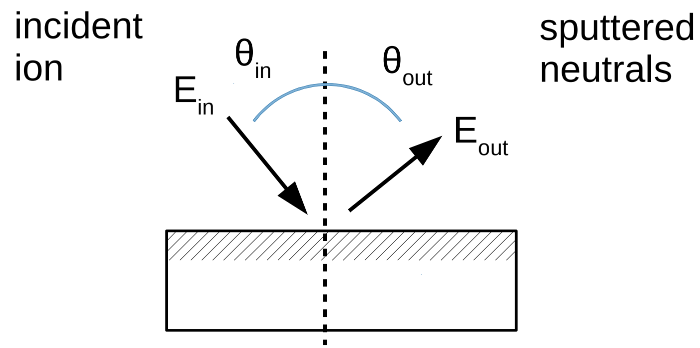
Outlook

- repeat volume study with
  - anomalous diffusion
  - migration to/from neighboring limiters
- both are expected to increase impurity conc. and self-sputtering

Parallelisation Concept: Bag of Tasks (BoT)



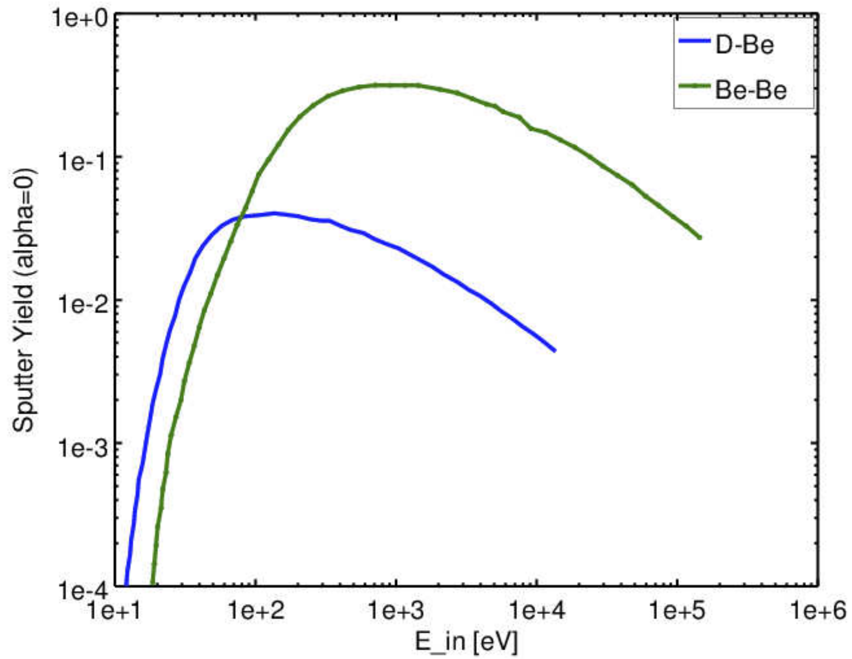
Plasma-Surface Interactions



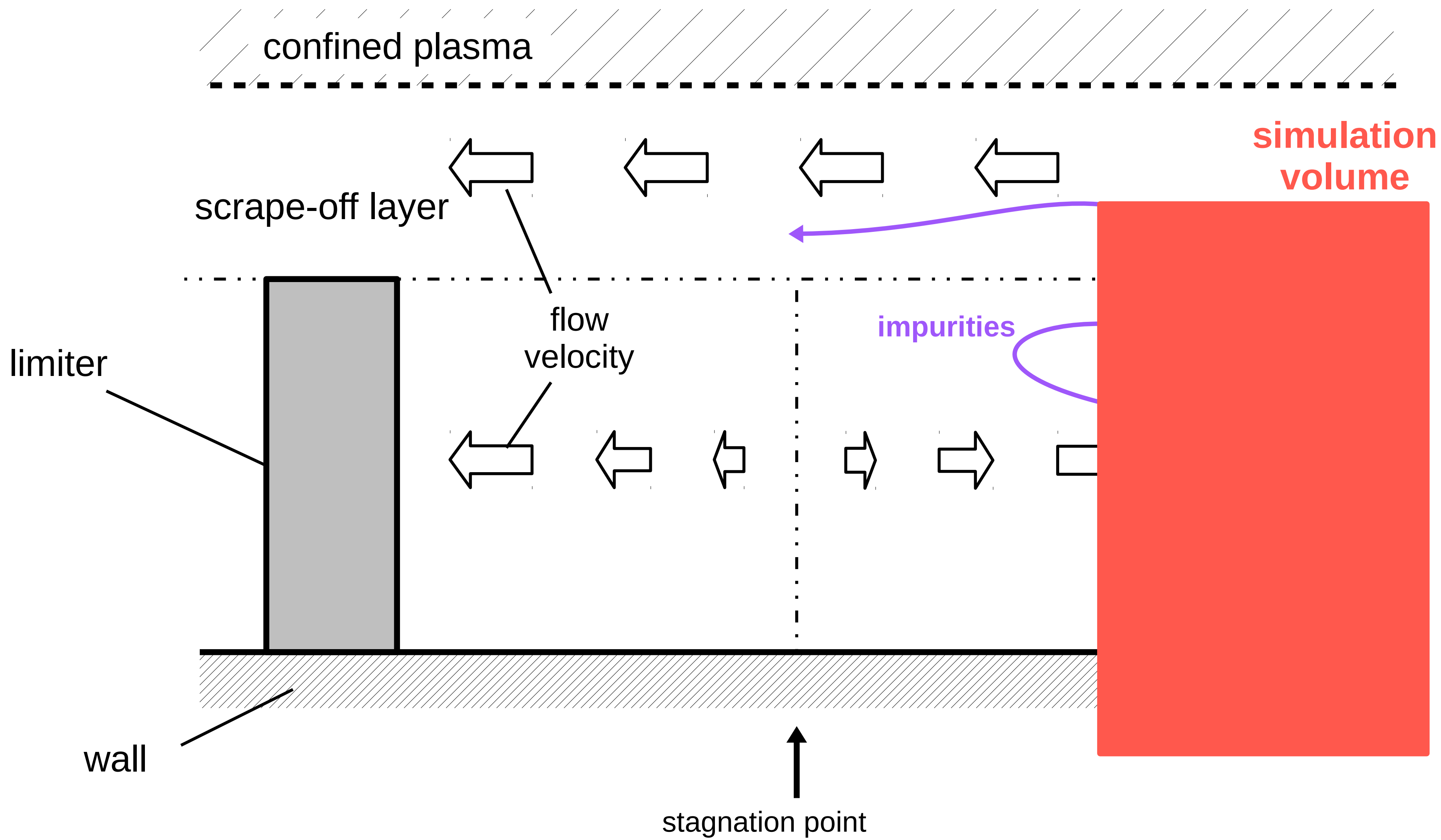
Physical Sputtering

- **sputter yield**: ratio sputtered neutrals per incident ion
- function of incident energy & angle
- impurities have higher sputter yield than hydrogen

normal incidence sputter yield $Y(E_{\rm in}, 0)$



Particle Trajectory Cropping

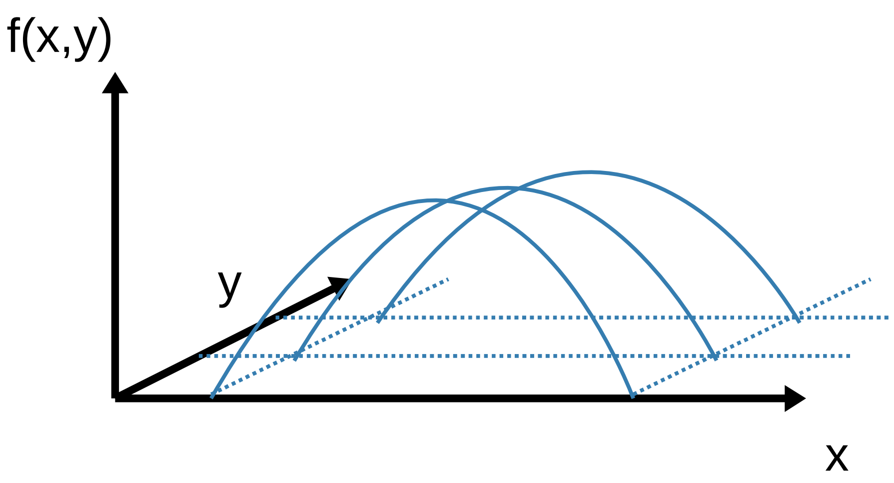


Local vs. Global Geometry

Example: Wall Geometry

ERO1.0

Limiter Surface = Function f(x,y)



ERO2.0

Limiter Surface = Polygon mesh