

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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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



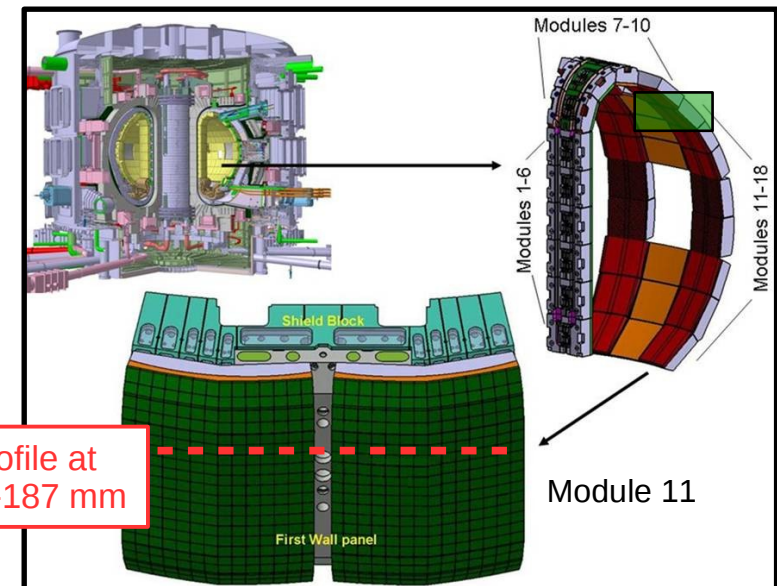
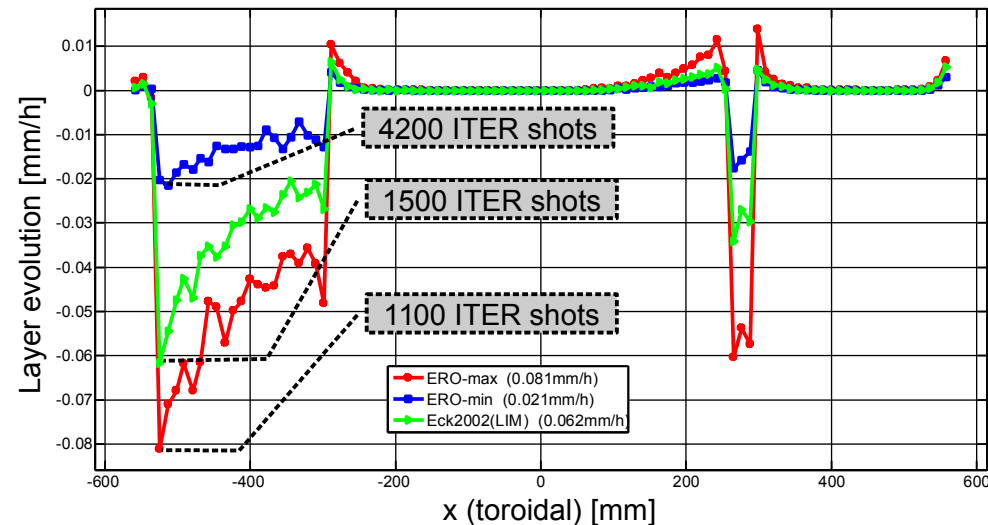
questions to modeling:

- 1) Material Migration
- 2) Net Erosion / Deposition

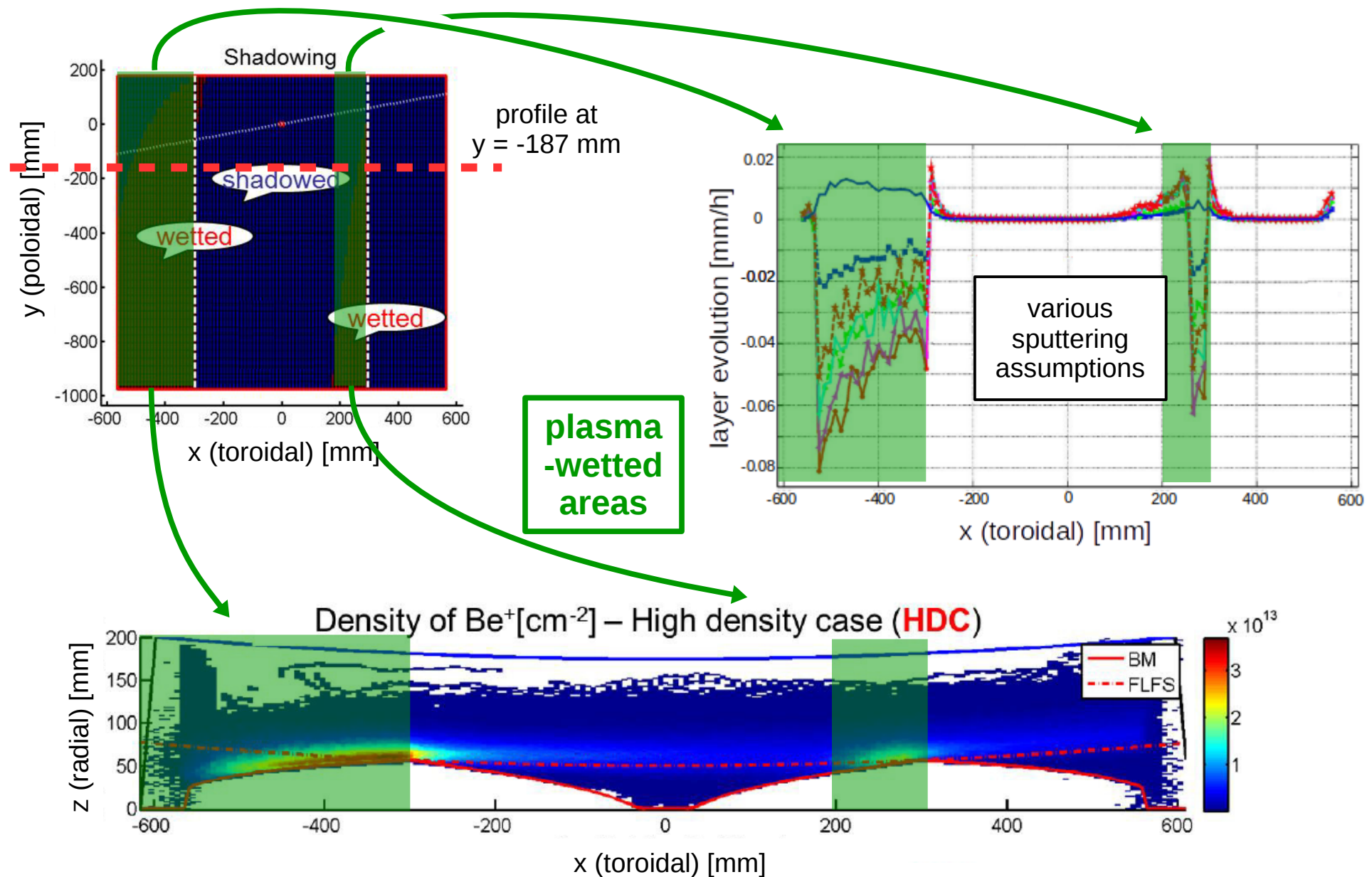
ERO Aims & Strategy

- 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

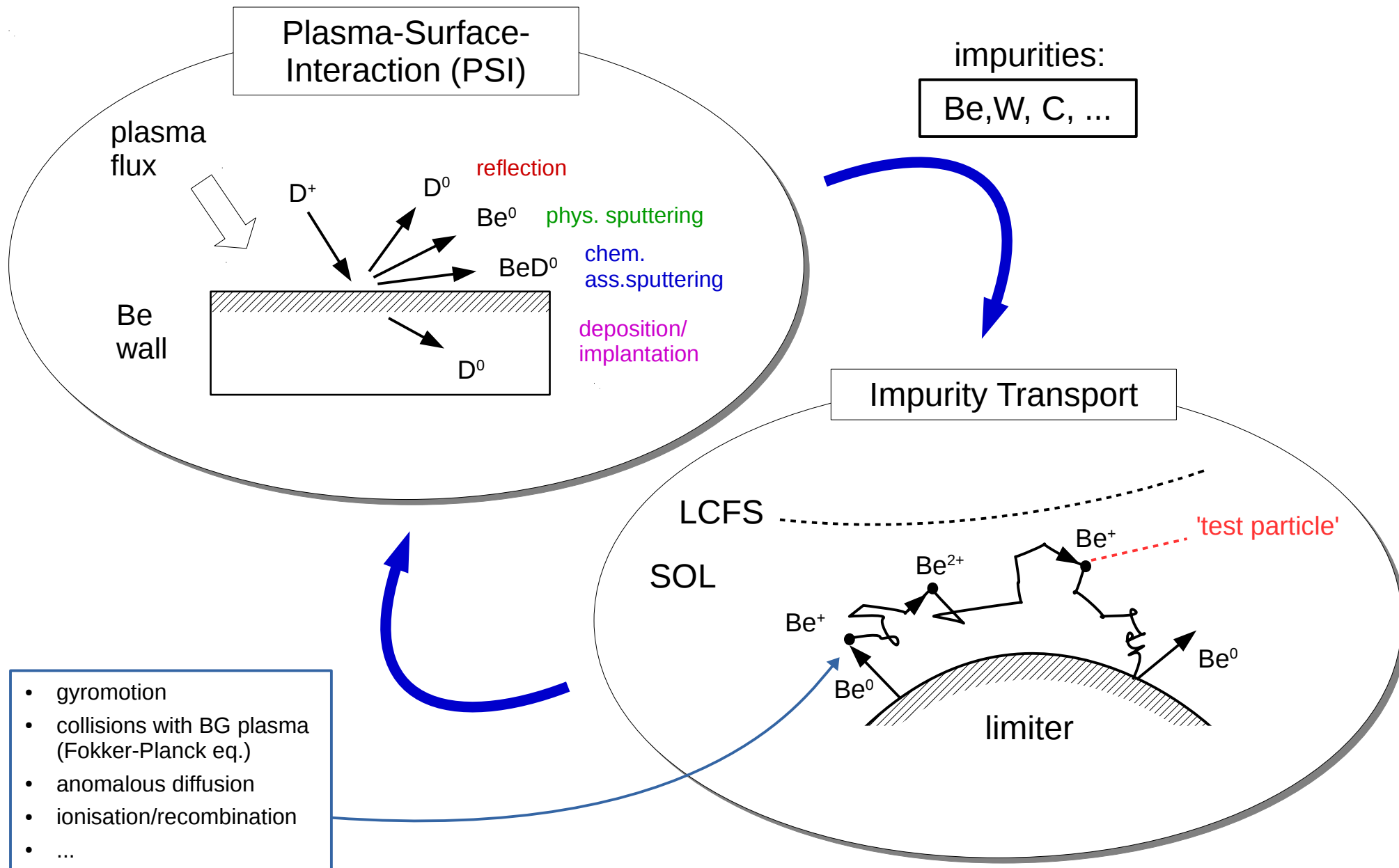
BM11, net erosion (deposition) profile at $y = -187\text{mm}$



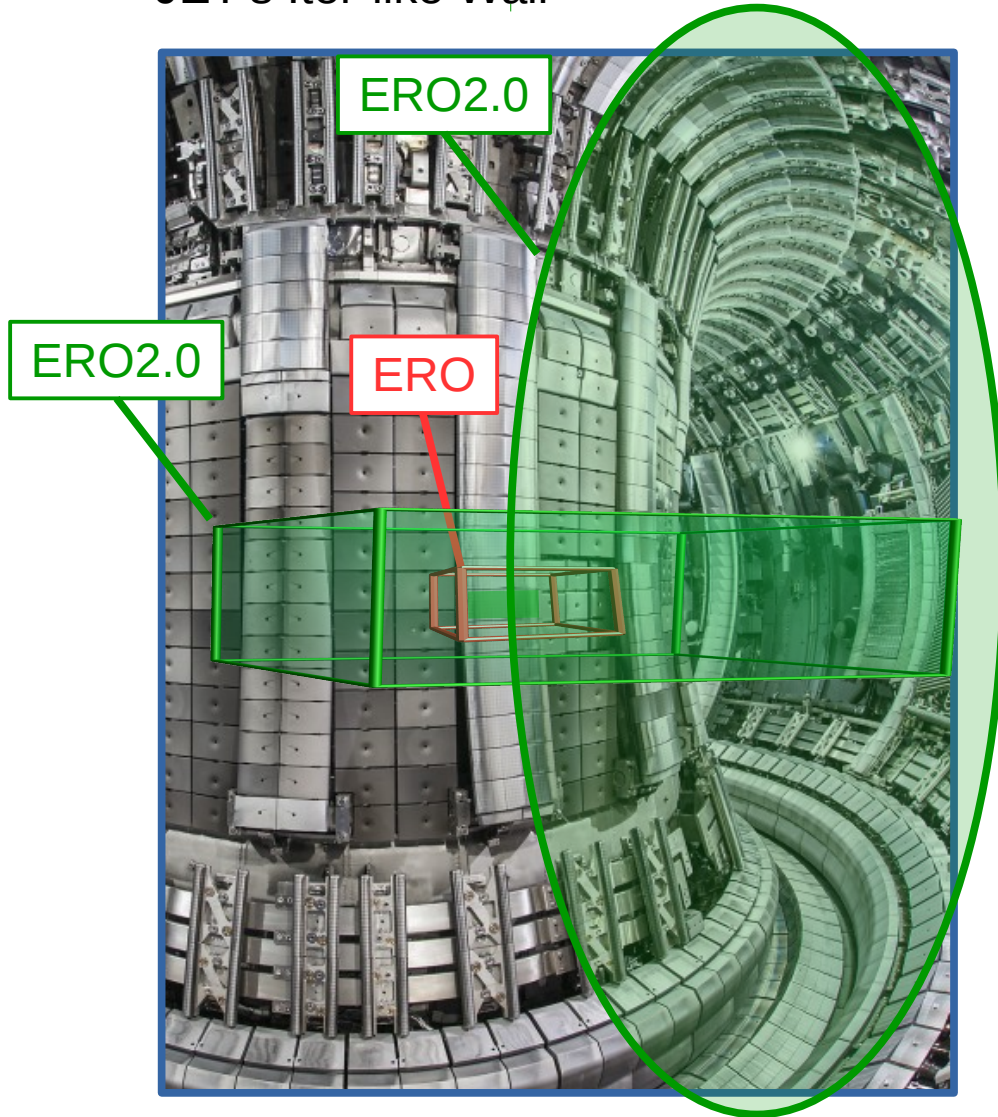
Example: Erosion of ITER Blanket Module



The ERO Main Loop



JET's Iter-like Wall



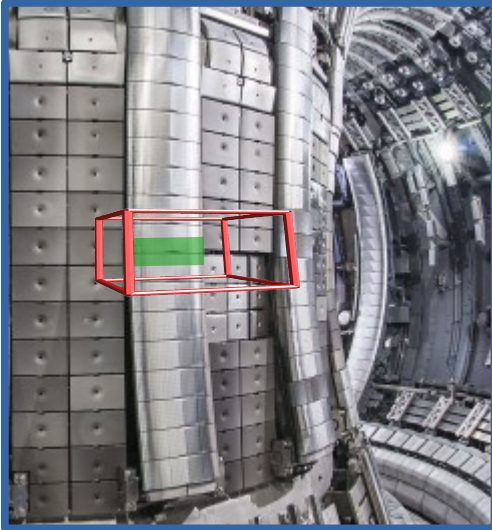
The limits of ERO

- small simulation volumes of $\sim (10 \text{ cm})^3$
- typically covering a single PFC part

Aims of ERO2.0

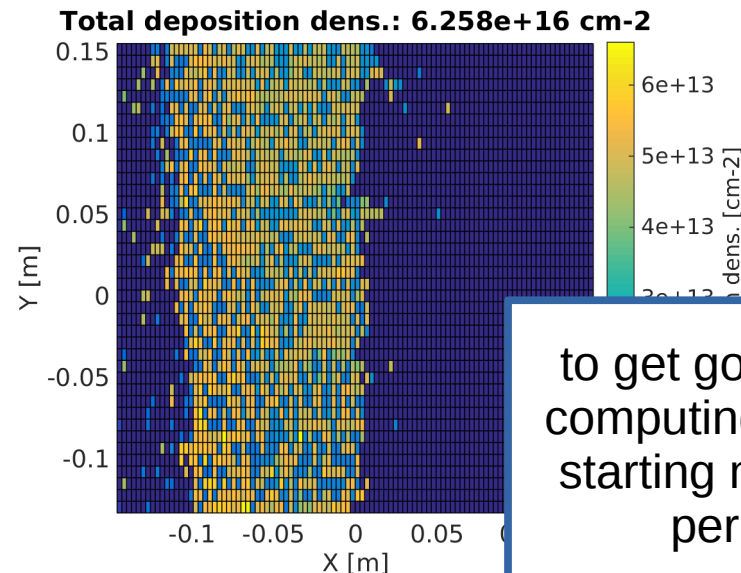
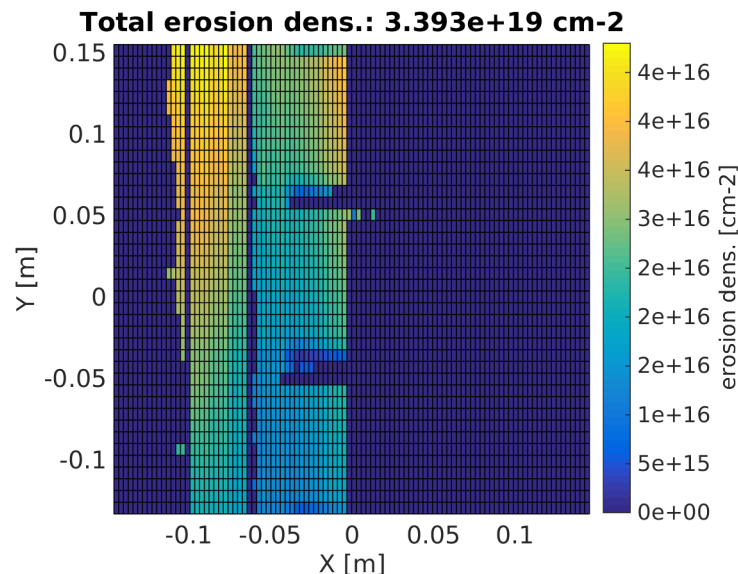
- increase simulation volume to relevant sizes
- requirements:
 - comp. efficiency
 - massive parallelisation
 - guiding-center motion (later)
 - efficient algorithms for 3D plasma parameters and geometry

JET's Iter-like Wall

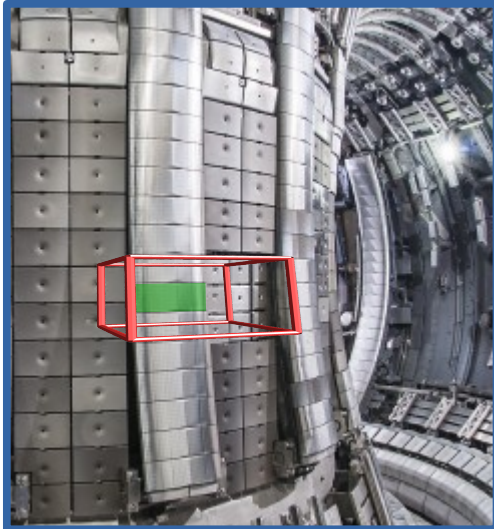


'Reference' Scenario:

- 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)!



cores ↓ P	particles ↓ N_p
1	30
2	60
4	120
...	...
3072	92160

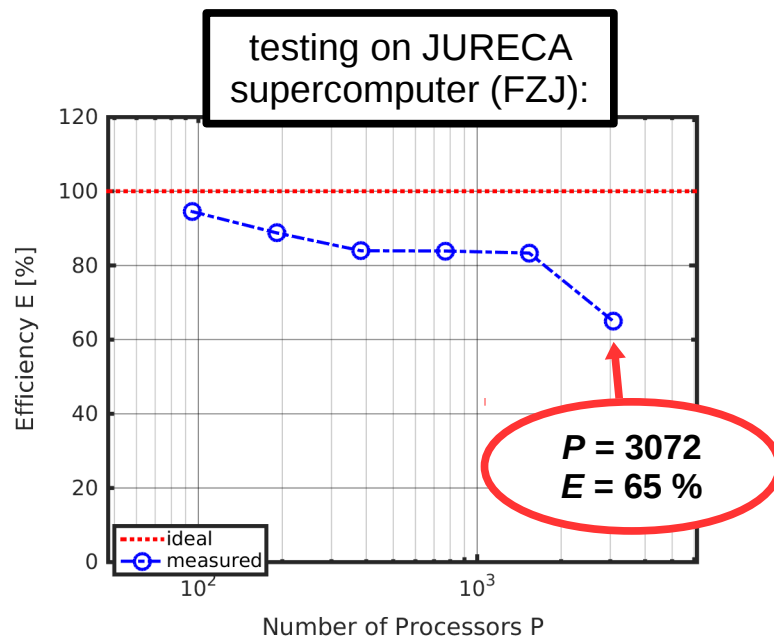
Weak Scaling

- N_p : **number** of test particles simulated on P **processors**
- weak scaling: increase N_p proportionally with P :

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

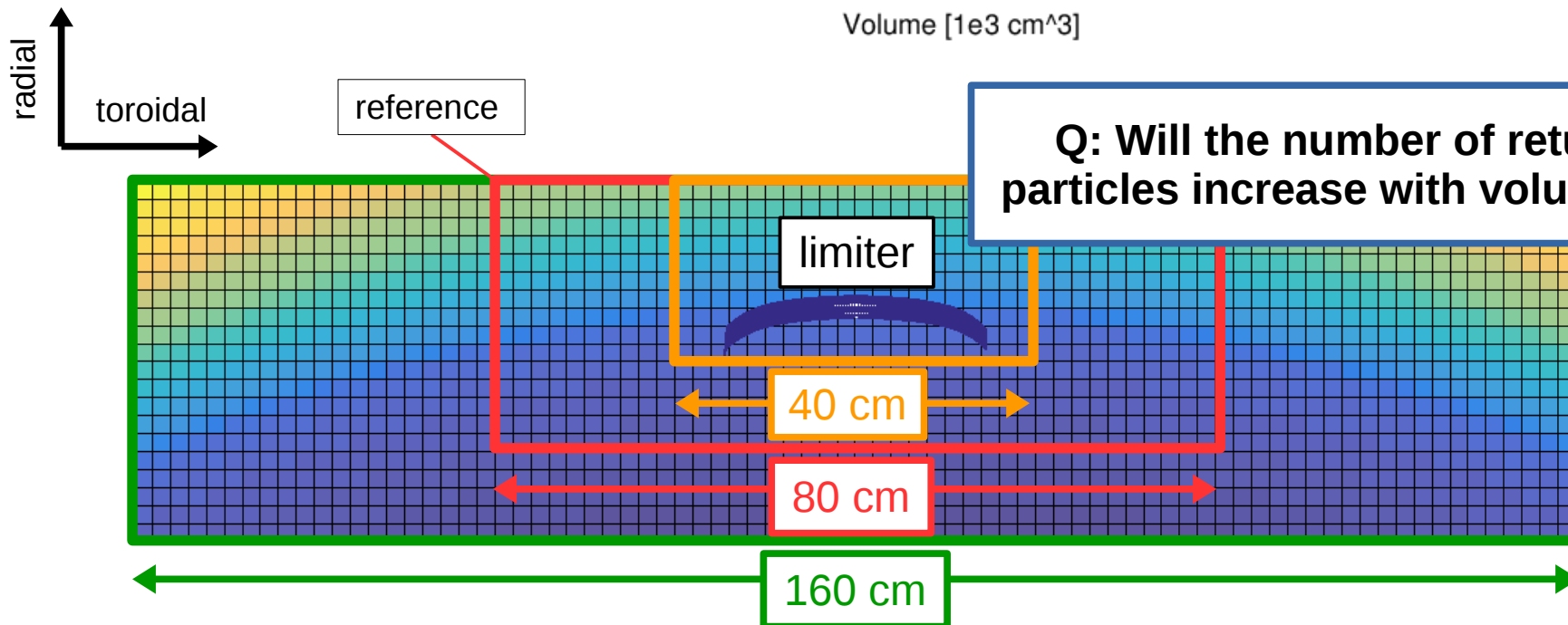
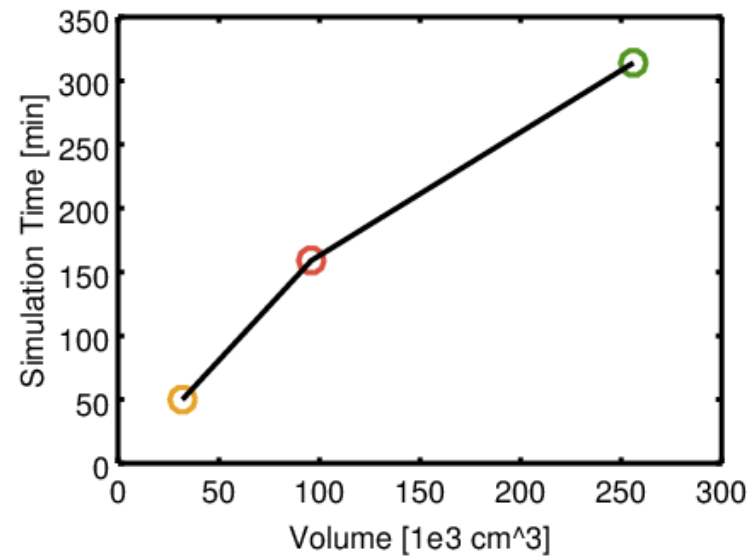
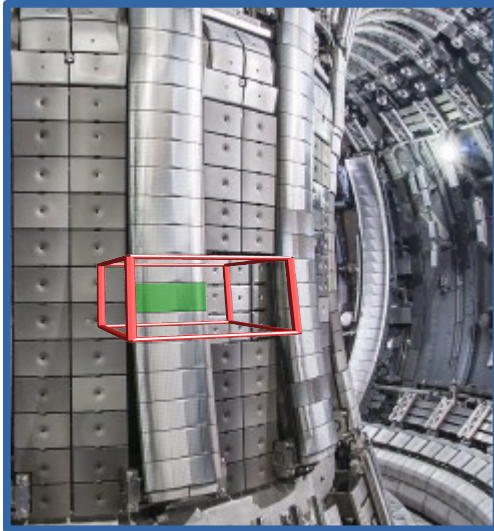
- measure **time** t_p needed to finish simulation
- define **efficiency** E :

$$E = t_1 / t_p * 100 \%$$

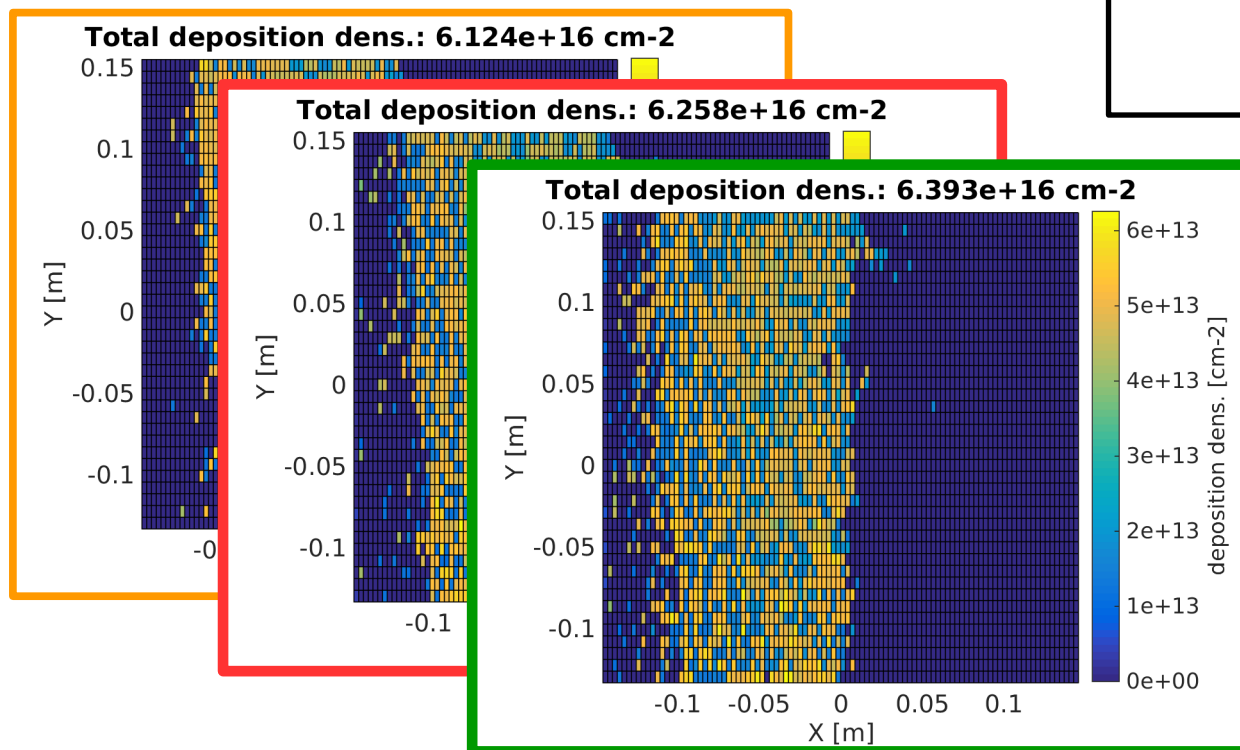
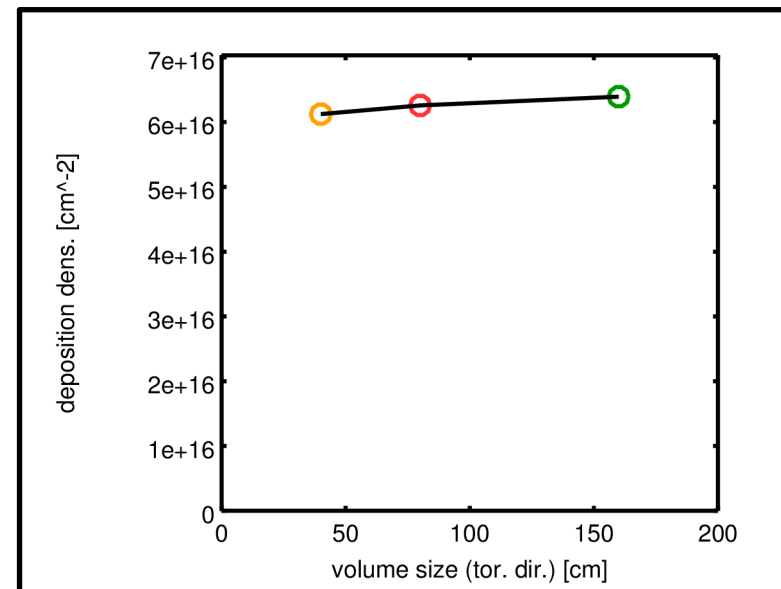


we can simulate $3072 \times 0.65 \approx 2000$ more particles without increase of comp. time

Increasing the Volume



A: Only <5 % increase!



Caution: Anomalous Diffusion was not included yet!

Summary

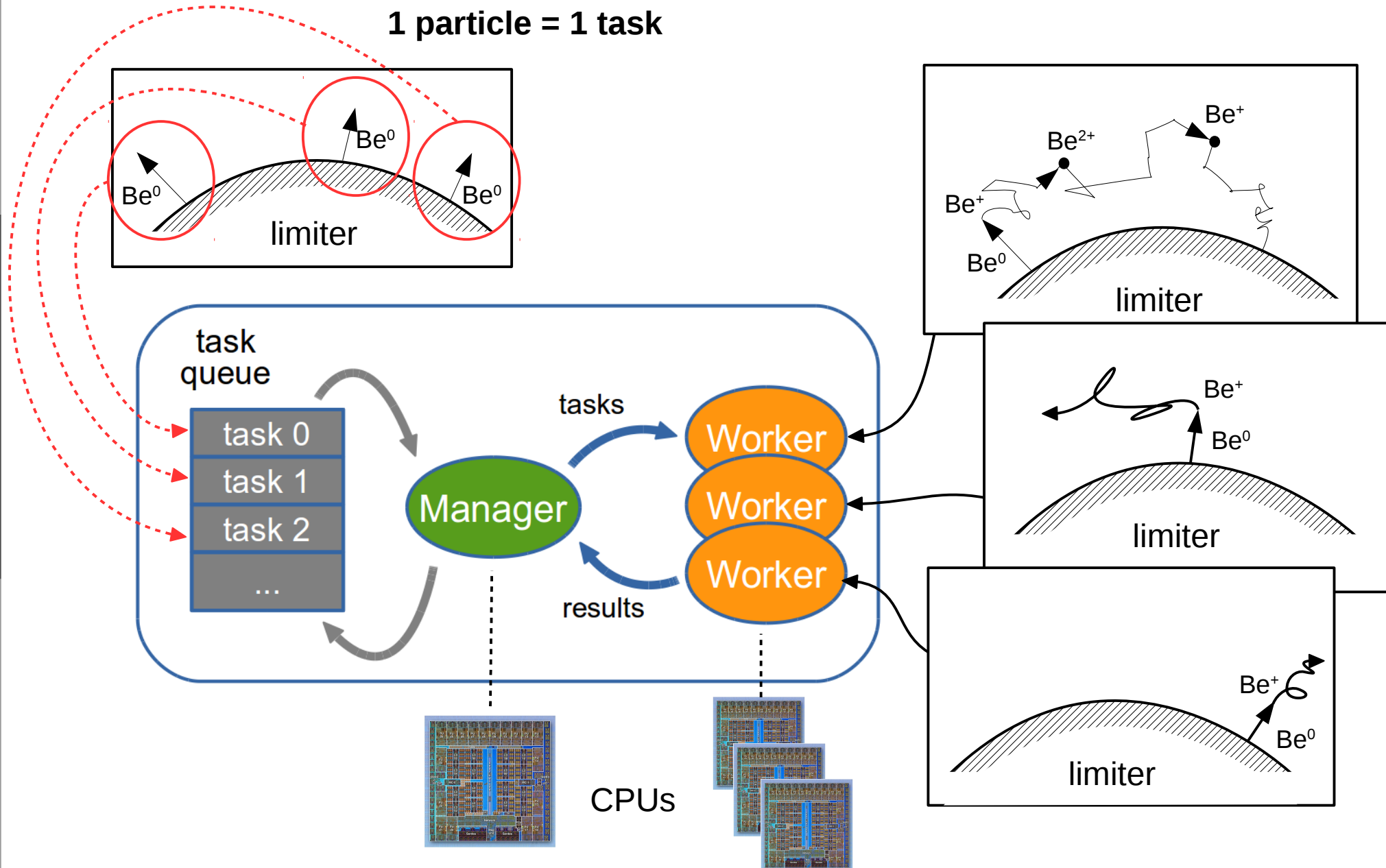
- ERO studies PFC erosion and local 3D impurity transport
- ERO2.0 has increased comp. performance → more particles, larger volume
- first tests gave small increase in particle return rate

Outlook

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

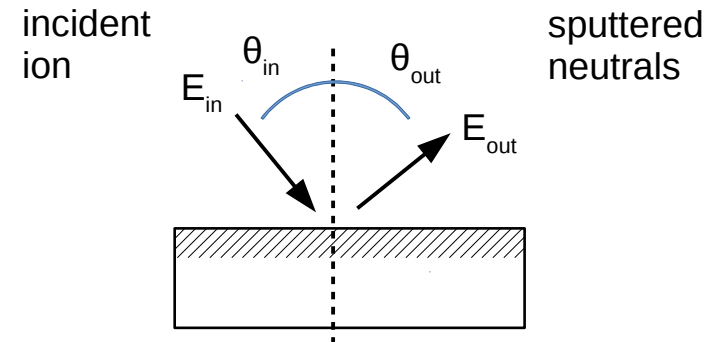
Parallelisation Concept: Bag of Tasks (BoT)

1 particle = 1 task

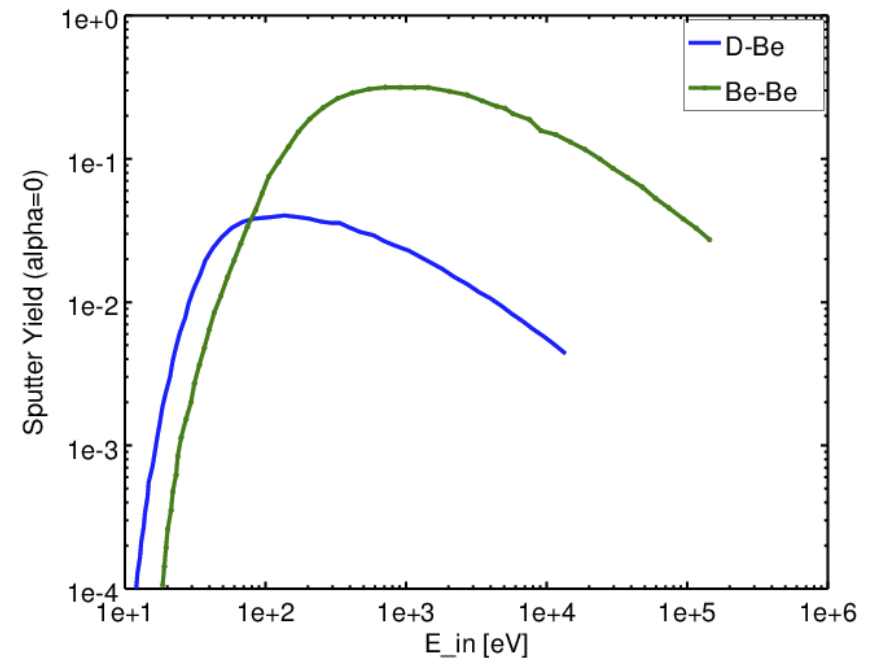


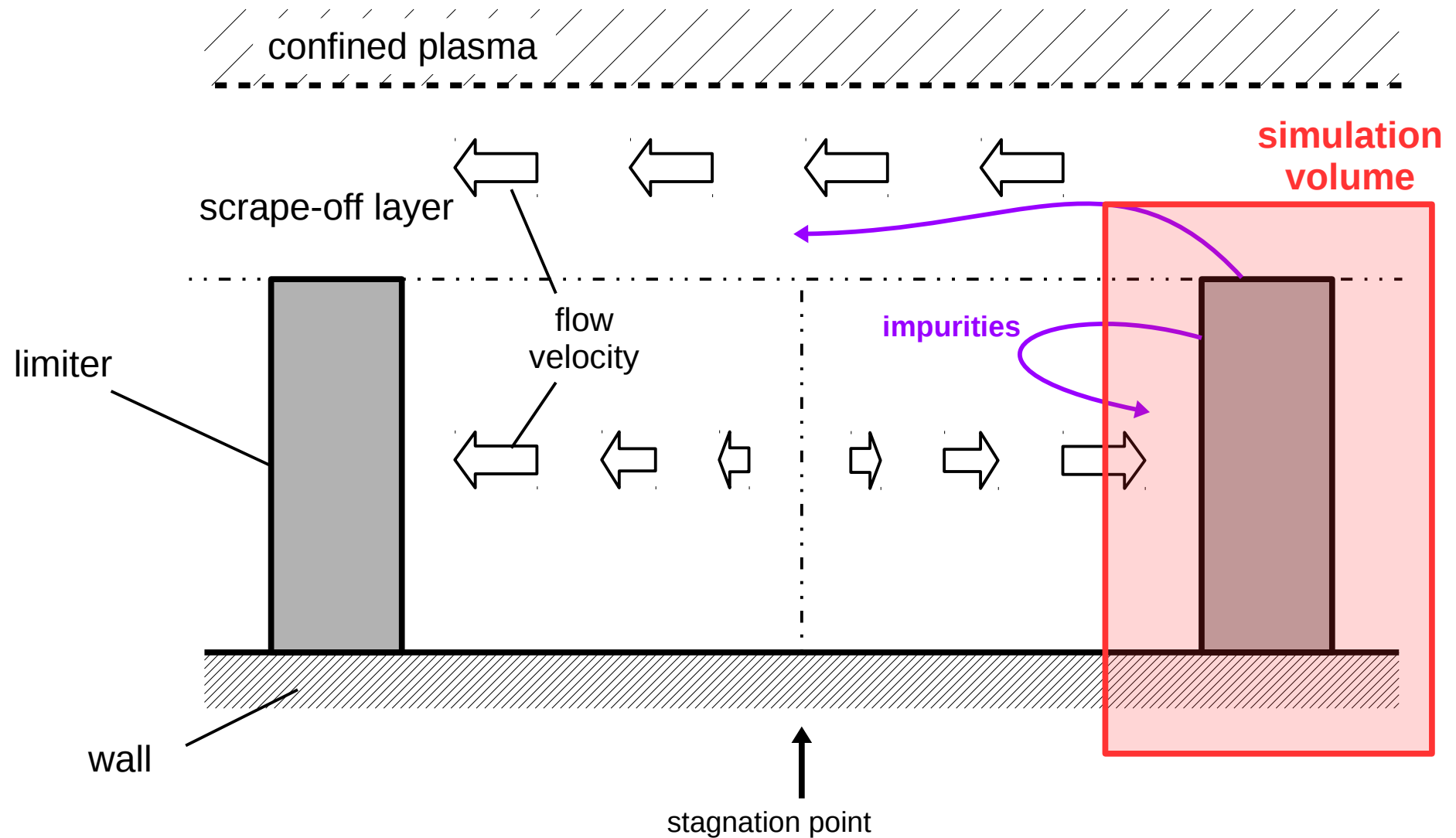
Physical Sputtering

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



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

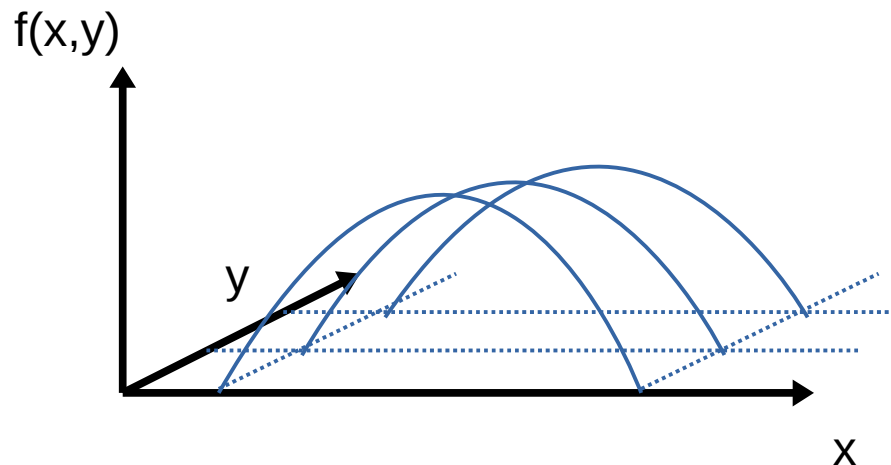




Example: Wall Geometry

ERO1.0

Limiter Surface = Function $f(x,y)$



ERO2.0

Limiter Surface = Polygon mesh

