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Modelling of Beryllium Erosion/Deposition and Local Transport at ITER First Wall Blanket Modules Using the ERO code

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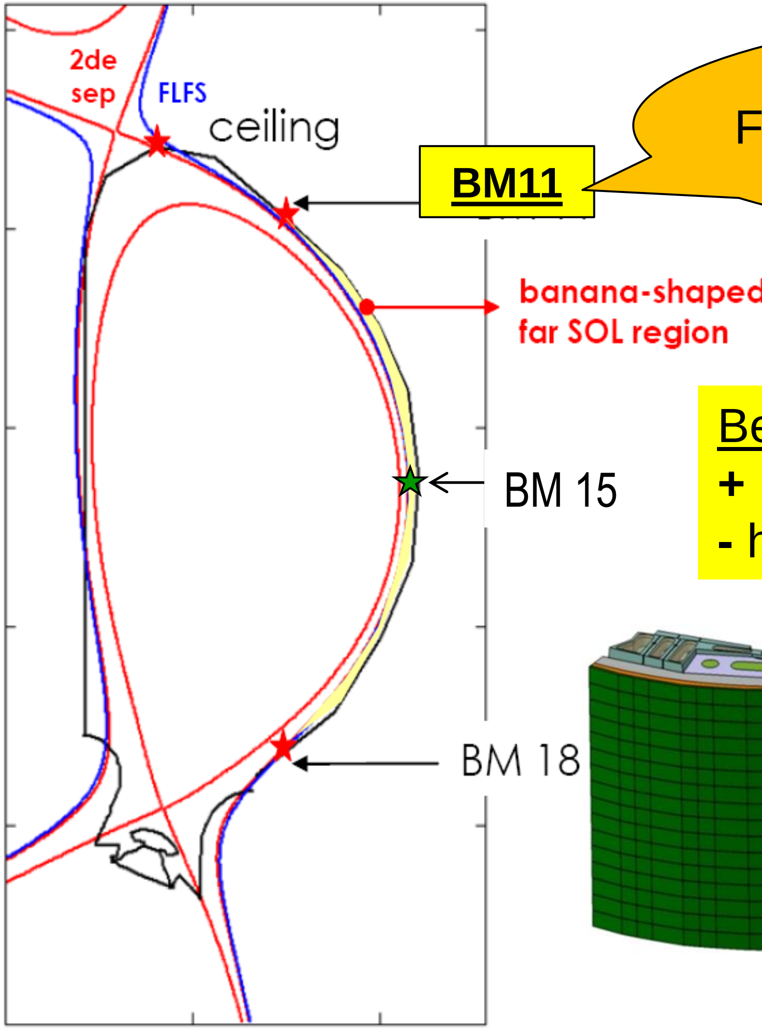
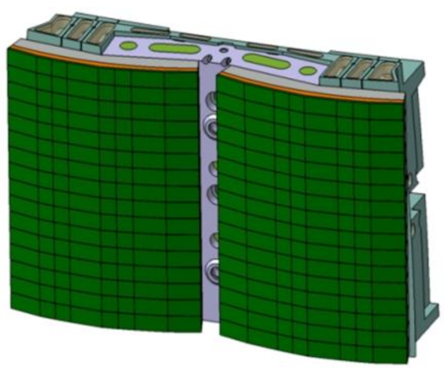
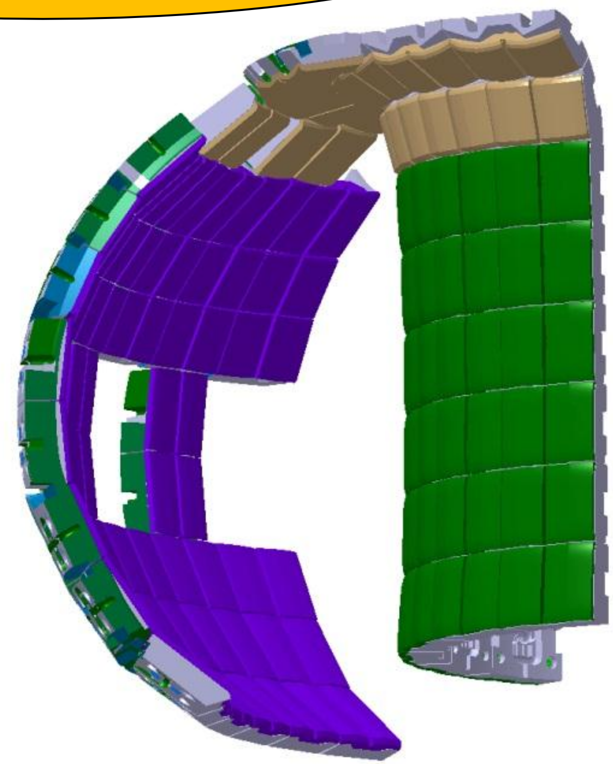
ITER Be wall – BM erosion



FLFS close to 2nd separatrix =>
First PFC ***life time*** estimates assuming limiter-like contact on outboard BM11

<u>Be</u>
+ low Z
- high erosion





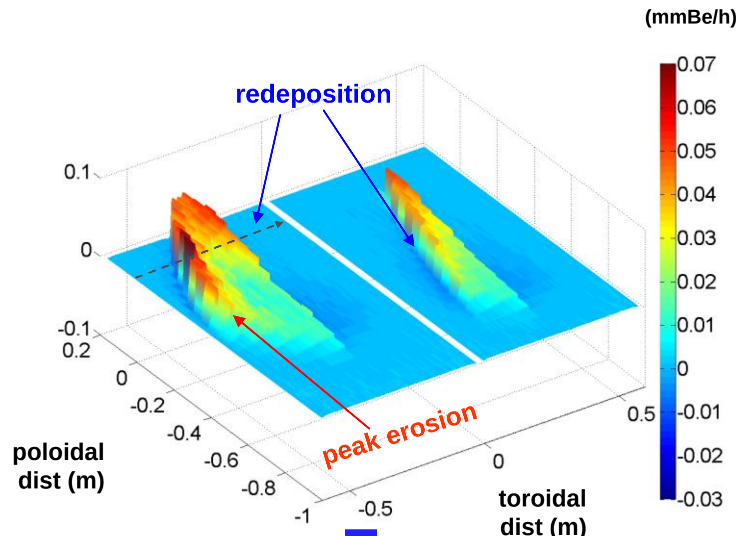
- *Blanket module (BM) shapes optimized for heat loads (P.C.Stangeby)*

<u>Aim</u> – predictive modelling of ITER, including first wall life time

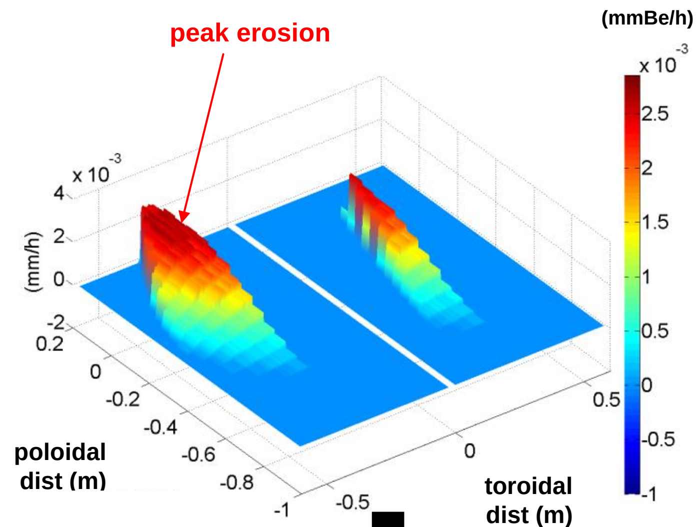
LIM code results

[S.Carpentier et.al, PSI-19, J.Nucl.Mater. (2010), in press]

2D Net erosion-redeposition patterns on BM11



High density case



Low density case

- ✓ <Y_{eff}> ~ 7%, ~50% particles locally redeposited
- ✓ Net peak erosion ~ 0.06 mm/h
  - ➔ PFC lifetime ~ 1500 shots
- ✓ T-retention* ~ 0.083 gT/h for one module
  - ~ 3 gT/h for 36 BM11-18
  - ➔ Limit ~ 1920 shots

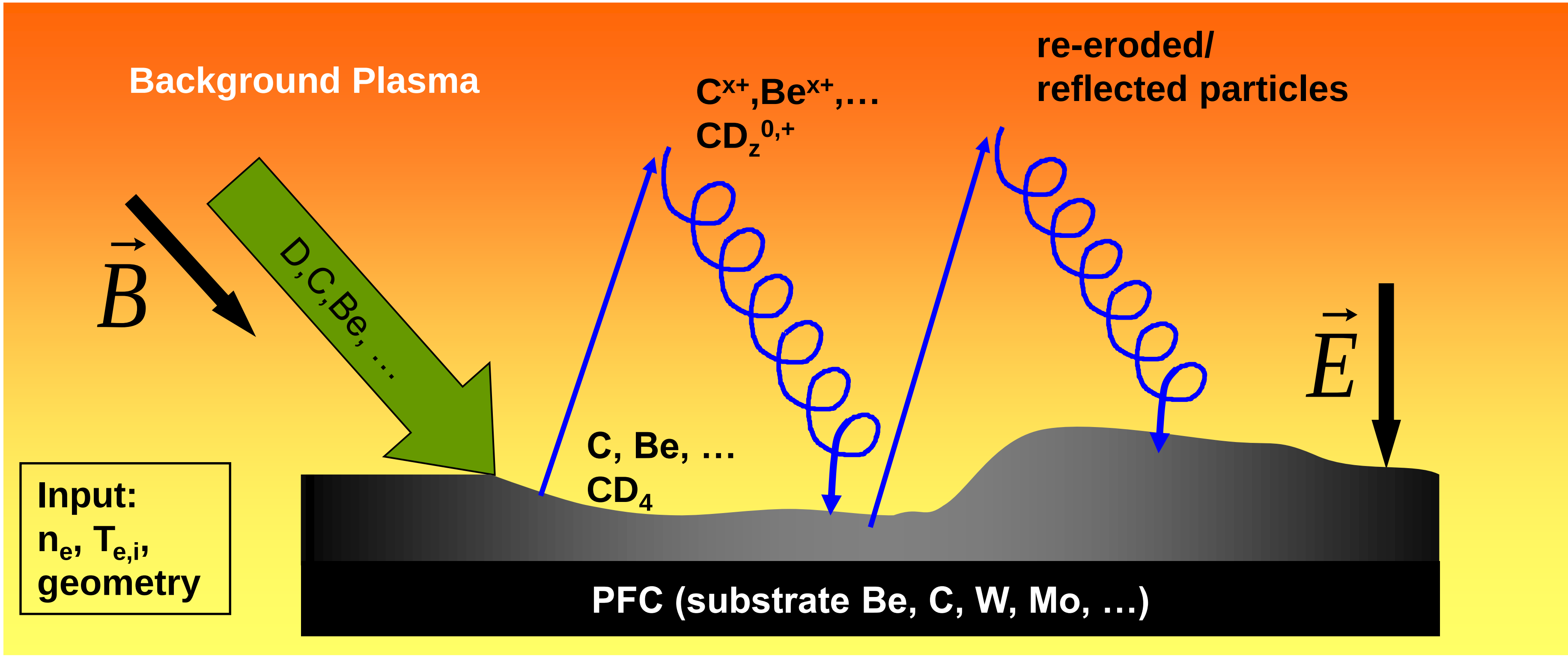
(assuming: 50:50 D:T plasma, maximum safety limit ~640g)

- ✓ <Y_{eff}> ~ 6%, ~10% particles locally redeposited
- ✓ Net peak erosion ~0.0025 mm/h
  - ➔ PFC lifetime ~ 36 000 shots
- ✓ T-retention* < 1.3 mgT/h for 36 BM11-18

Important issue for ITER: benchmark with ERO focusing on **life time**

* 2D estimation of (D+T)/Be = f(T_{surf}, E_{imp}, Γ_D/Γ_{Be})
[PICSES-B scaling law, G. De Temmerman, R. Doerner]

3D MC impurity transport code ERO



Local transport:

- ✓ ionisation, dissociation
- ✓ friction (Fokker-Planck), thermal force
- ✓ Lorentz force
- ✓ cross-field diffusion

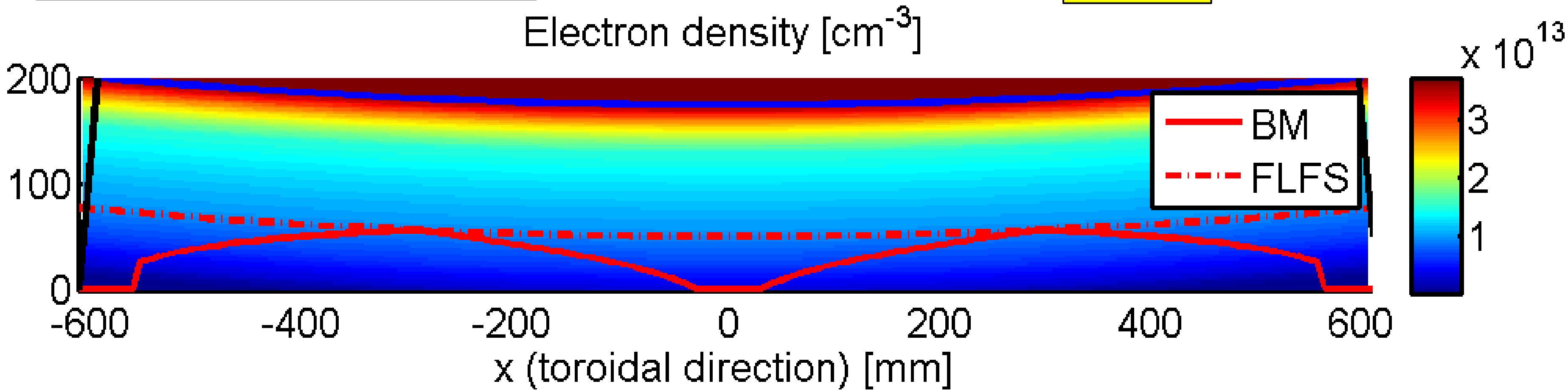
Plasma-surface interaction:

- ✓ physical sputtering/reflection
- ✓ chemical erosion (CD_4)
- ✓ (re-)erosion and (re-)deposition
- ✓ HMM and SDTrimSP surface models

ITER Be wall – plasma parameters

high density case (HDC)

BM11



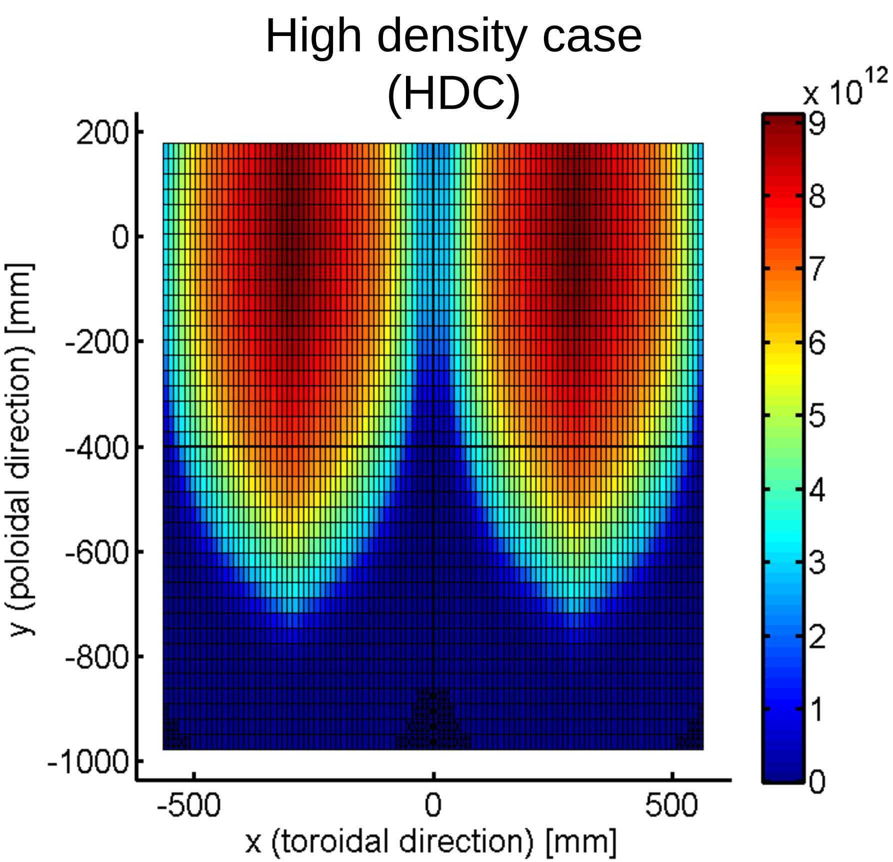
Aim – predictive modelling of ITER first wall **life time**

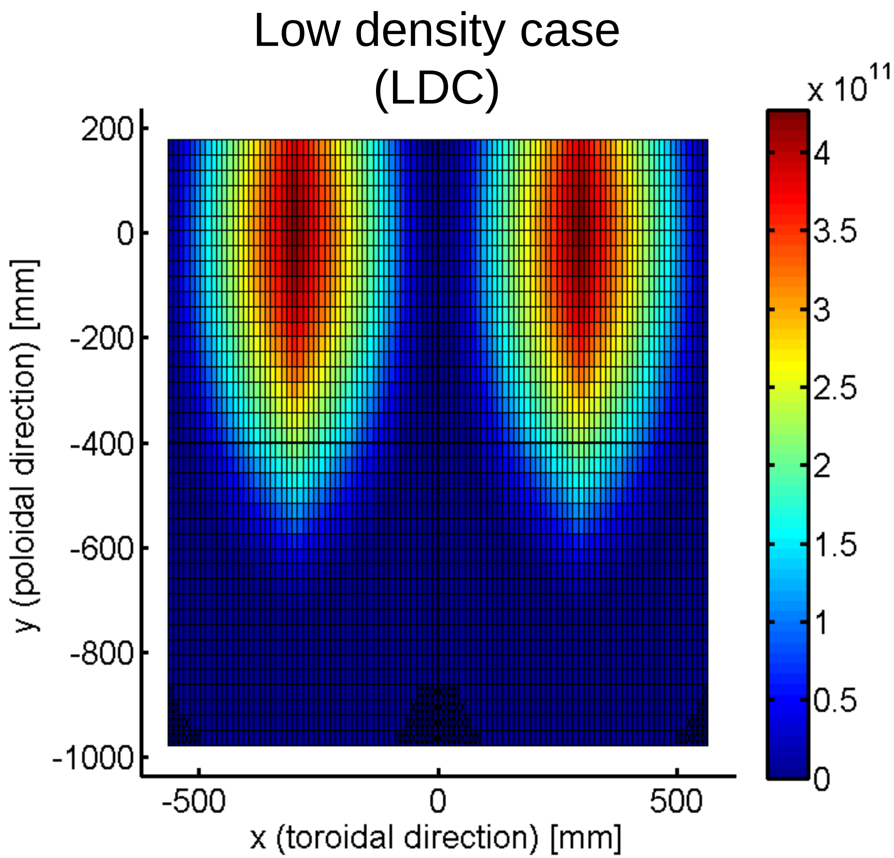
LIM predicted life time due to transient events is not a limiting factor – we concentrate on **steady state**

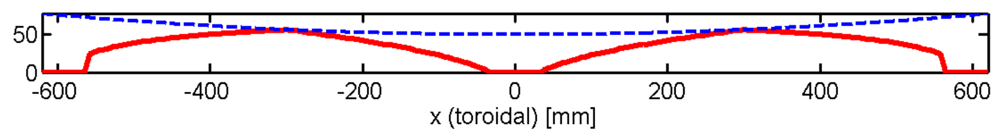
Complications:

- Complex geometry e.g. leading to shadowing
- Uncertainty in atomic and surface data for Be
- Other uncertainties: enhanced re-erosion, carbide and alloy formation, Be-D molecules, etc.

Plasma parameters at limiter surface





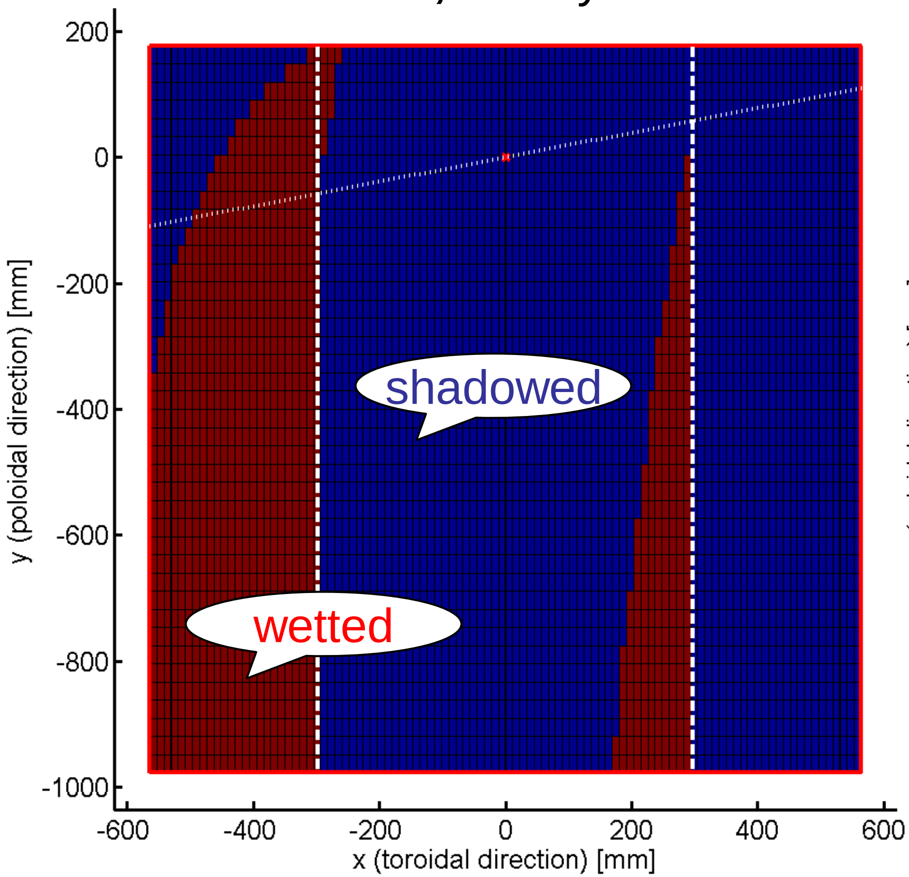


T_e = 10eV = const
T_i = 20eV = const

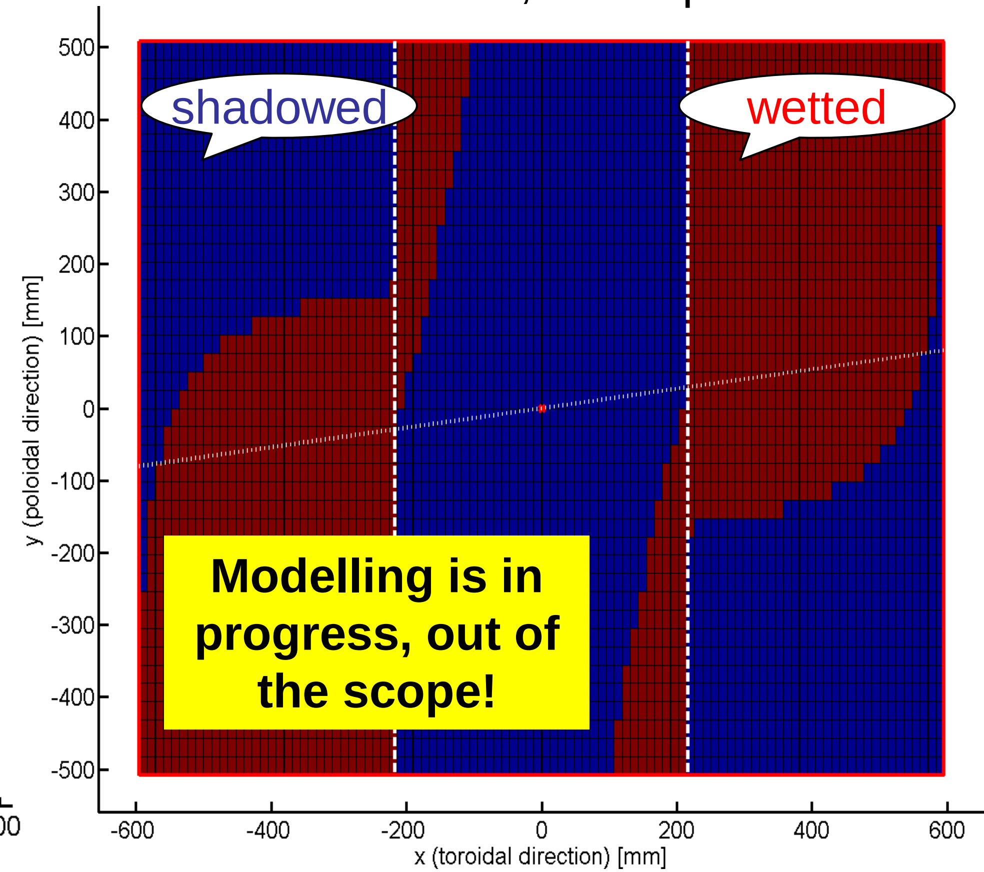
T_e = 7.1eV = const
T_i = 18.6eV = const

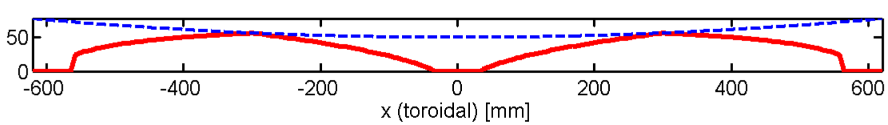
Shadowing patterns (LIM and ERO)

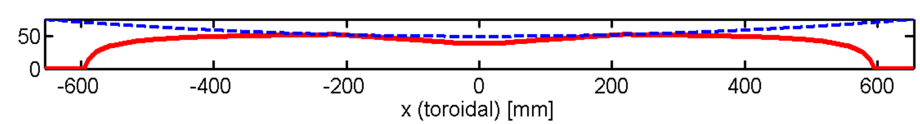
BM11, steady state



BM15, start-up







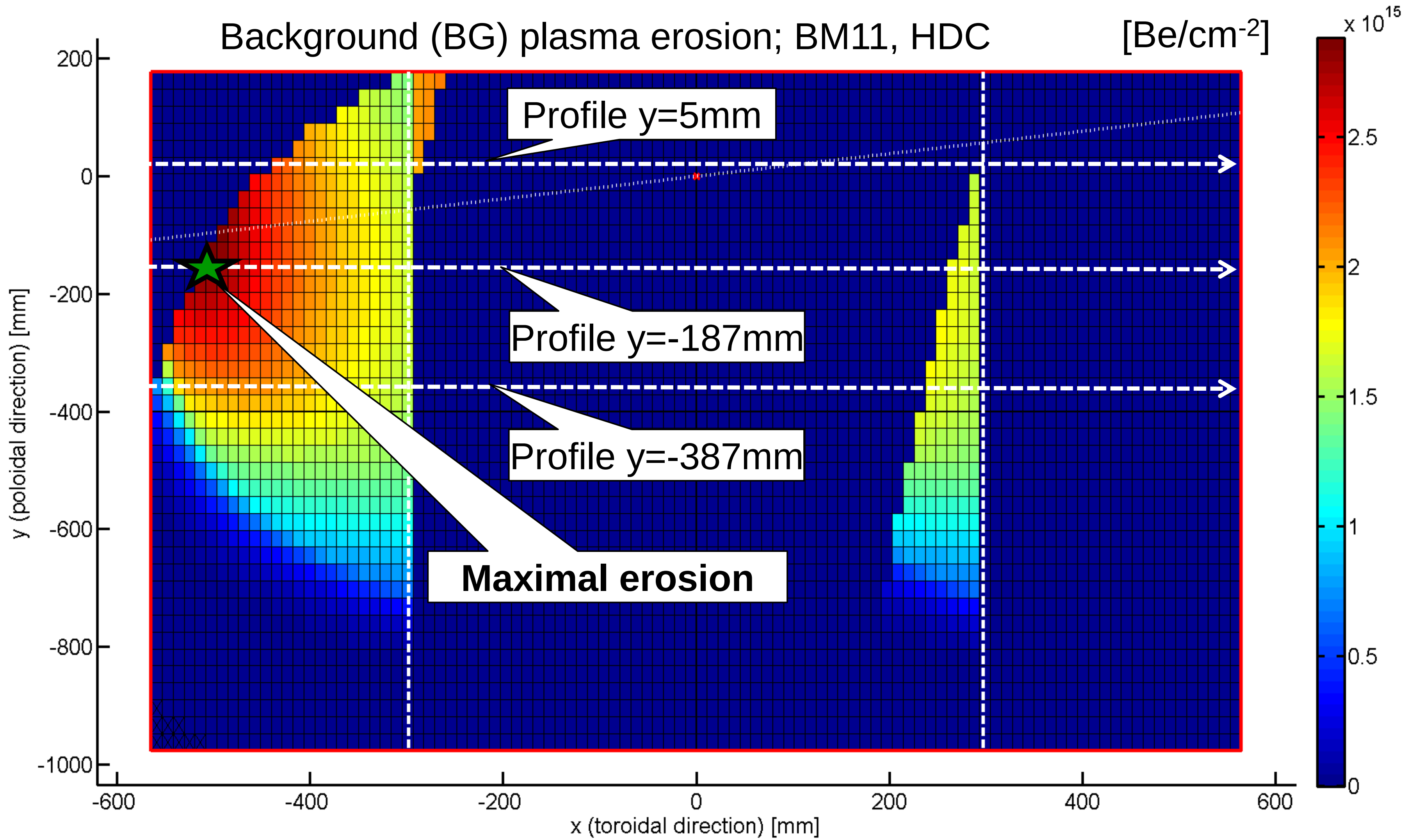
In shadowed areas we assume no BG erosion and re-deposition of intrinsic Be impurity

LIM and ERO overview

Code	ERO	LIM
Type	Monte-Carlo impurity tracing (BG plasma import)	
BM implementation	Shape, shadowing, plasma parameter, etc. - SIMILAR	
Geometry	3D	2D
Test-particle tracing	resolving gyro-motion	guiding centre
Intrinsic Be impurity	concentration in D^+ flux	possible
Collisions with surface	resolved angle and energy	sheath potential
Multiple BM tiles	periodic boundary	particle "mirrors"

Many routines in ERO for ITER BM are “imported” from the LIM code.

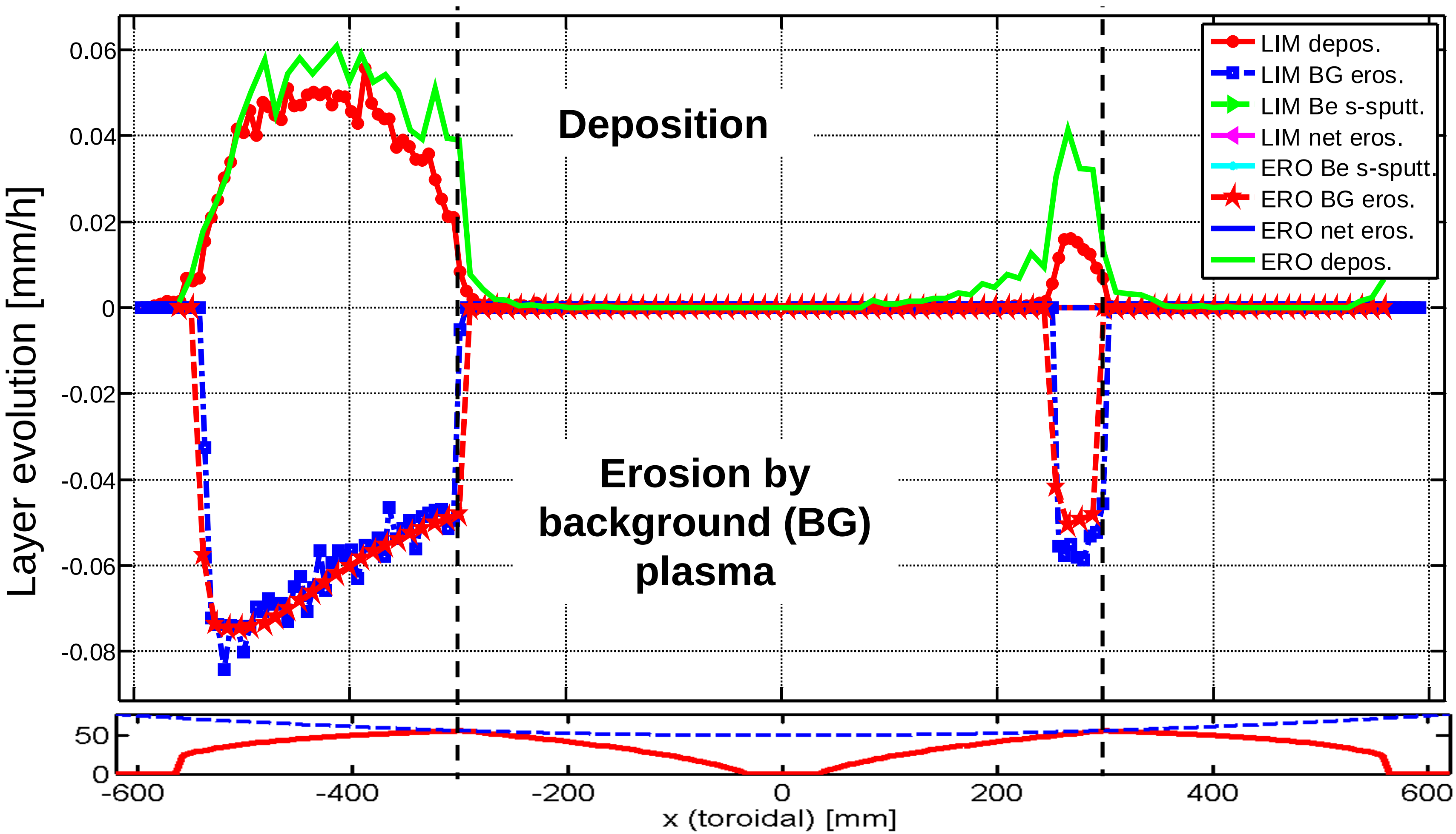
Poloidal positions of toroidal profiles



For LDC the maximal erosion point is elsewhere . . .

Erosion/deposition profiles

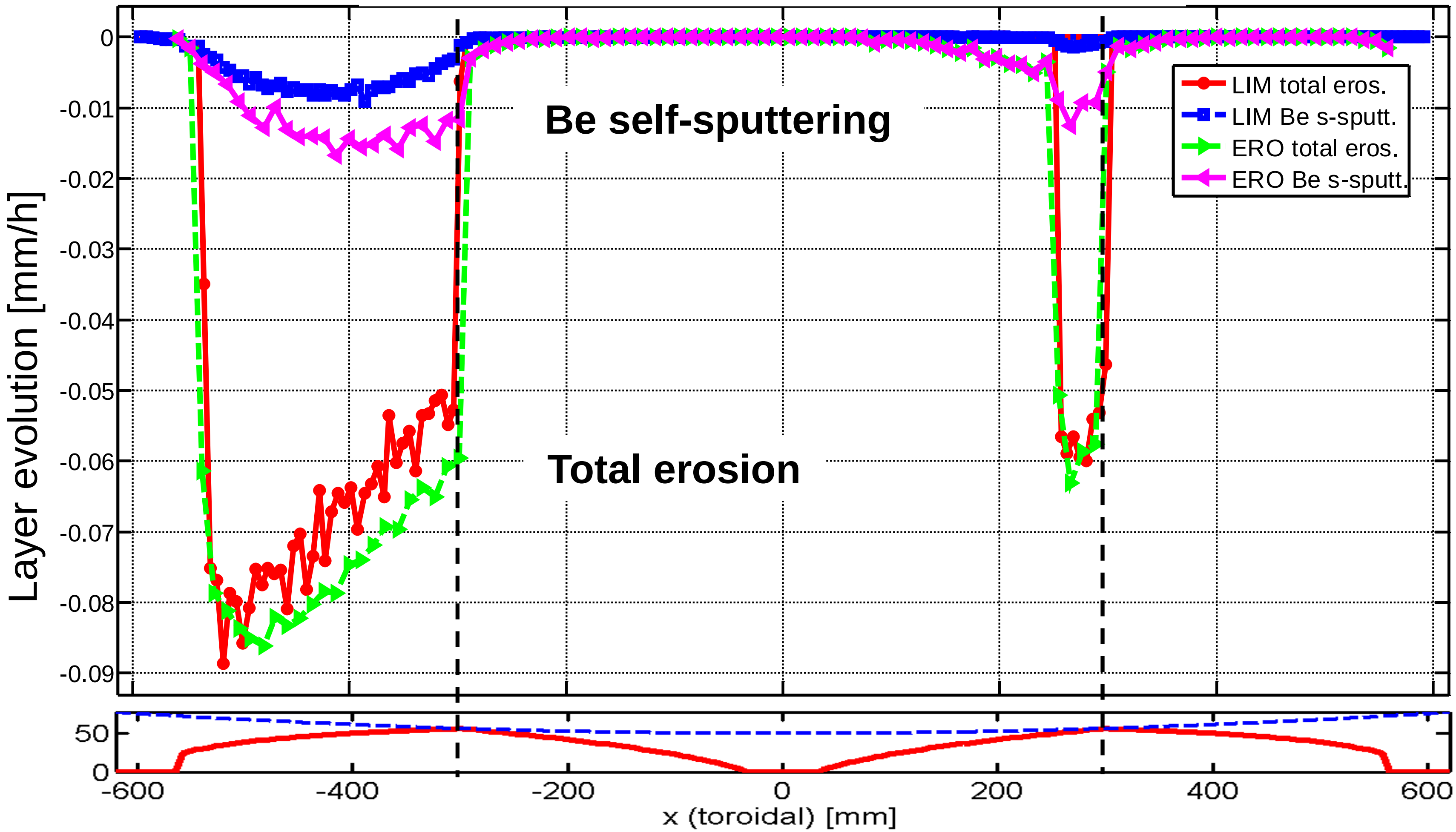
BM11, ‘HDC’: profile at y=-187mm



Very good agreement between ERO and LIM

Erosion profiles

BM11, 'HDC': profile at y=-187mm

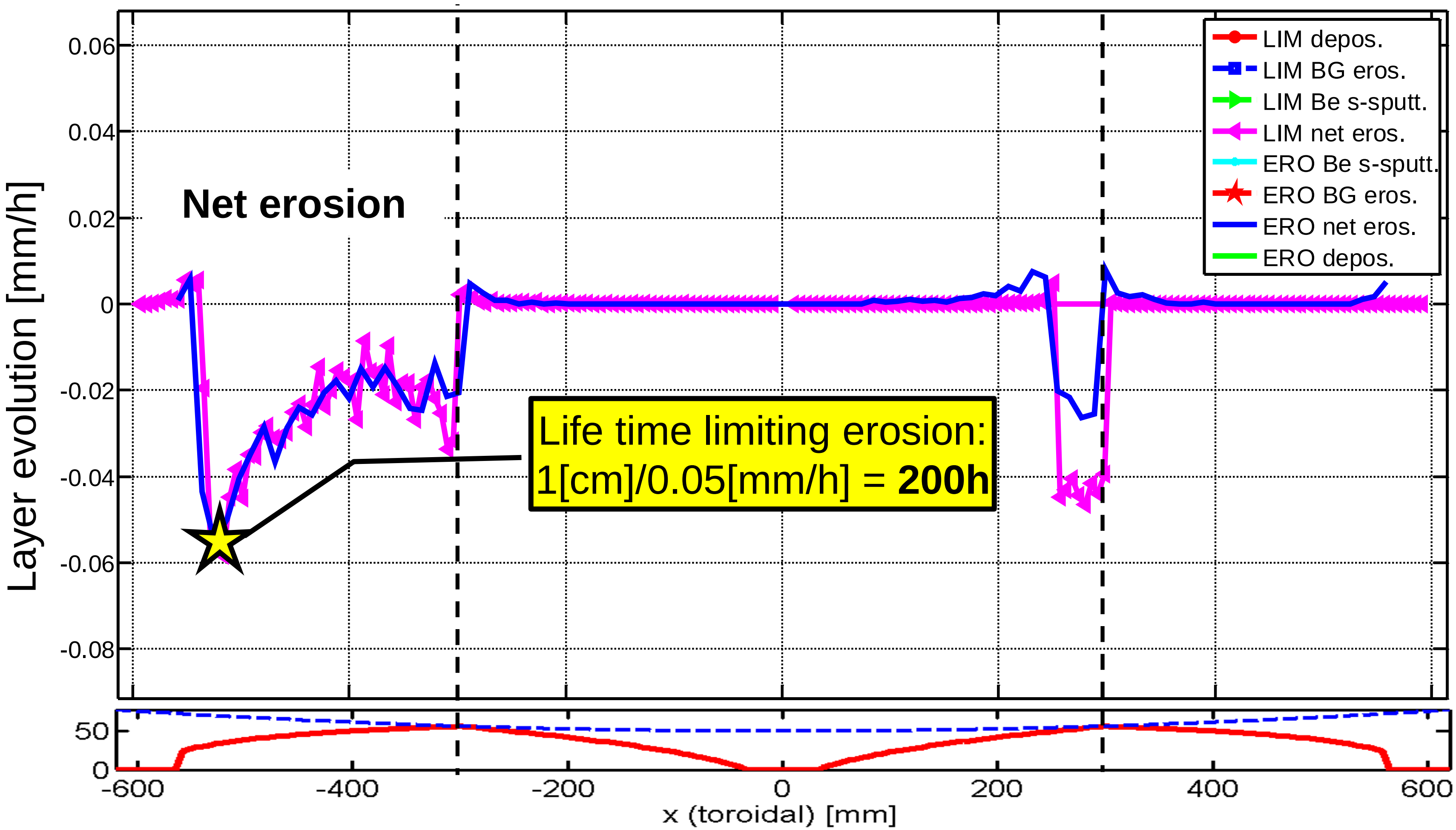


Self-sputtering in ERO is larger and more concentrated near the ridge

Small influence on total erosion . . .

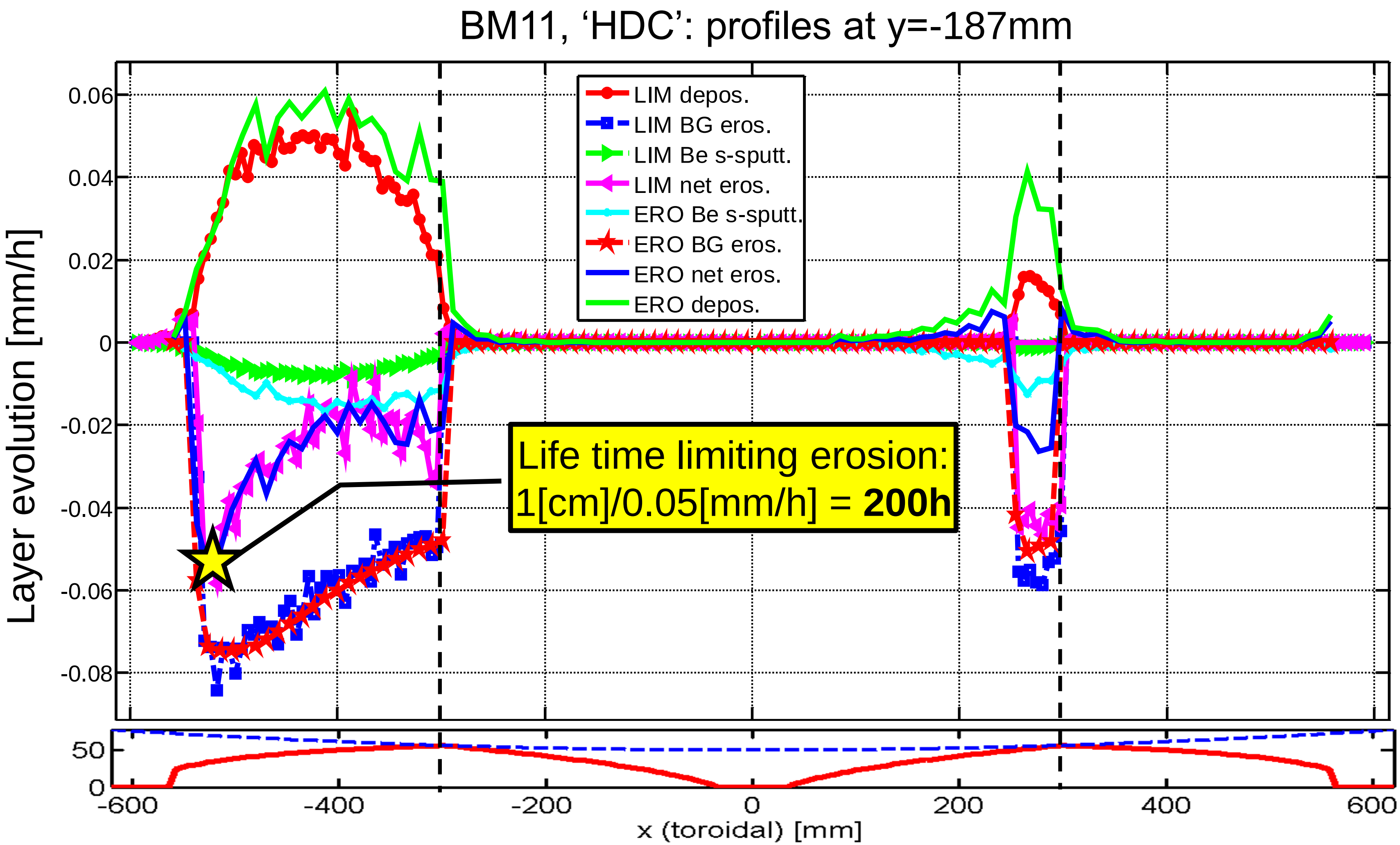
Net erosion profiles

BM11, 'HDC': profile at y=-187mm



The net erosion in LIM and ERO is in a very good agreement

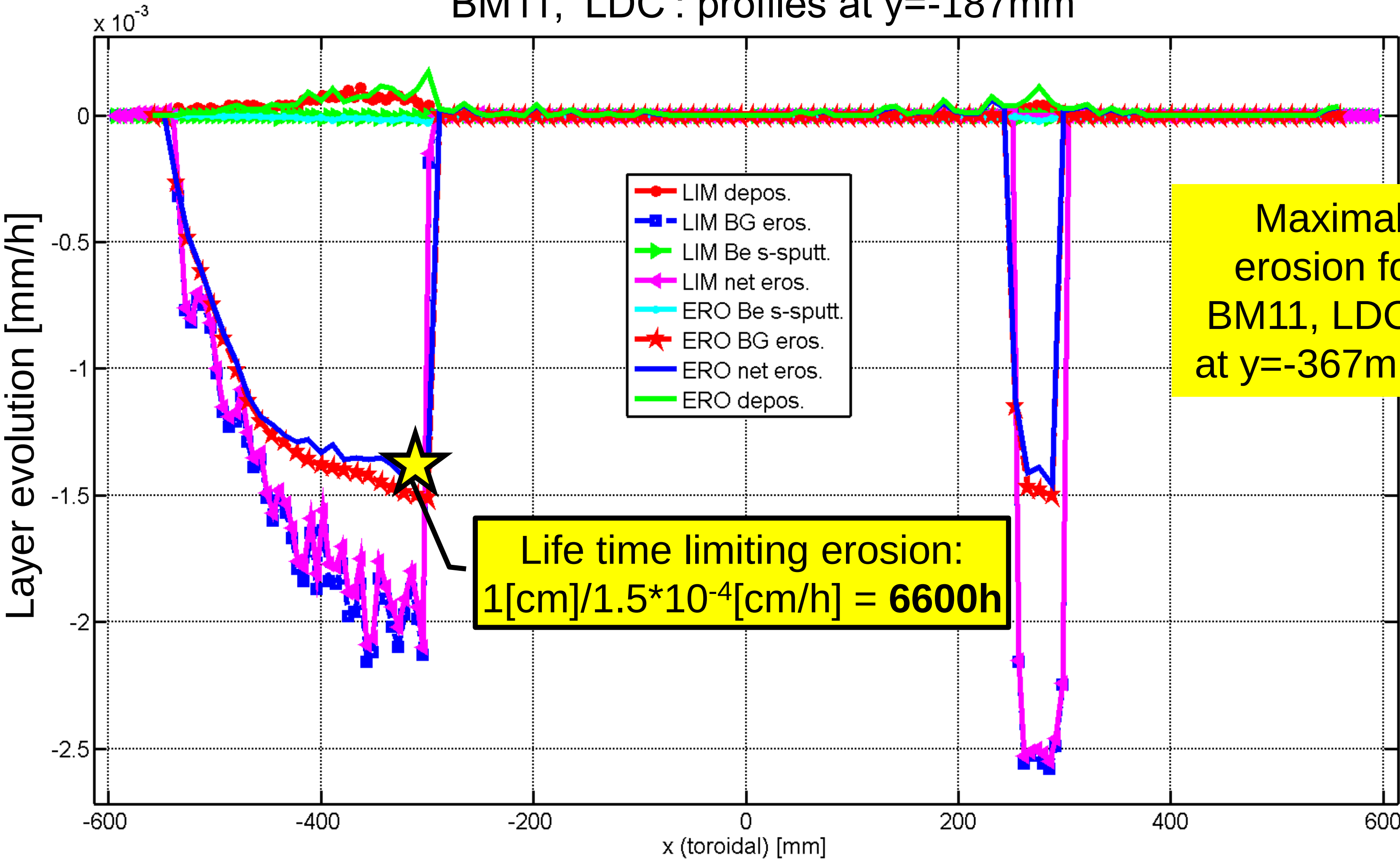
Erosion/deposition profiles



ERO uses in this case angle averaged W.Eckstein 2002 data for sputtering yields from LIM and ADAS '93' Be ionization . . .

Erosion profiles

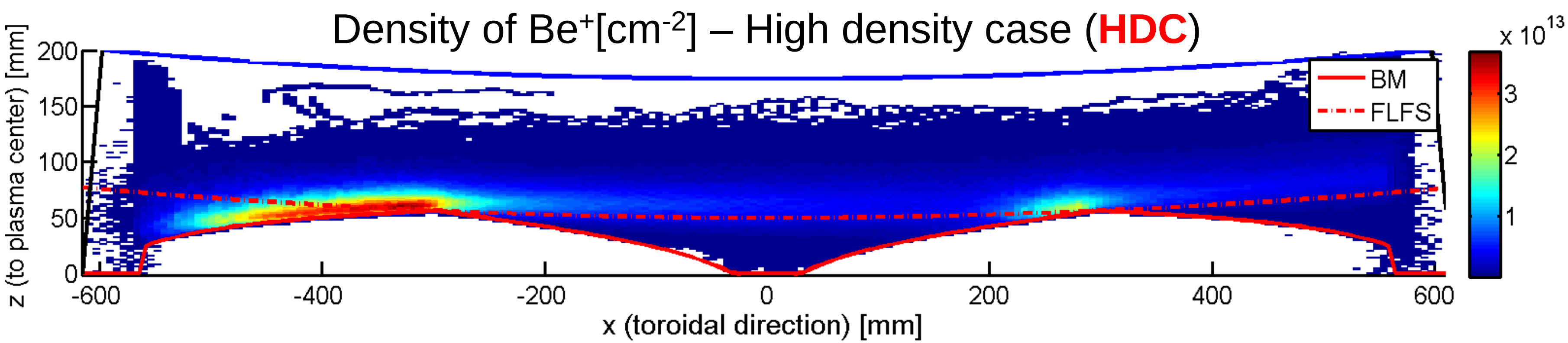
BM11, 'LDC': profiles at y=-187mm



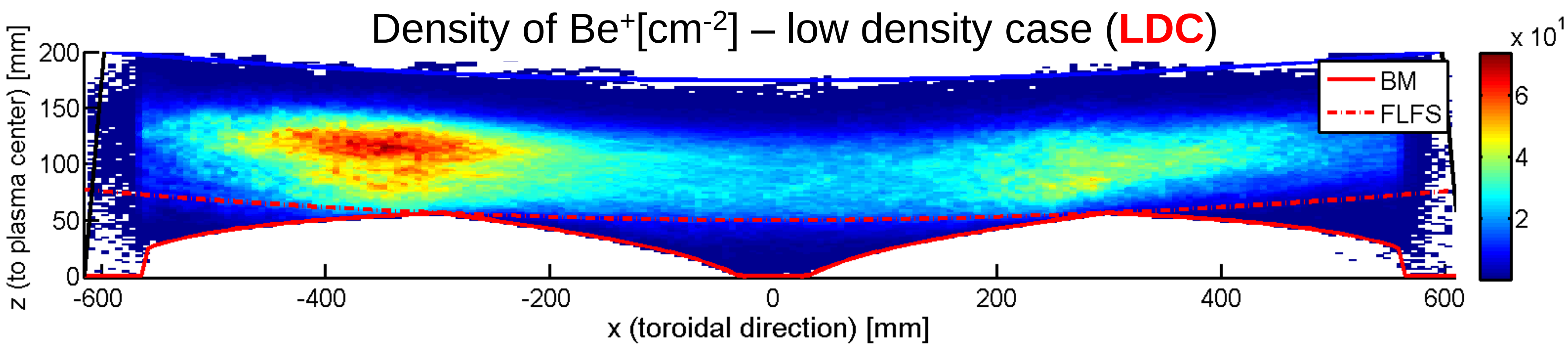
Maximal erosion for BM11, LDC is at y=-367mm!..

Deposition in LDC is very low (in diffrence to HDC)

Deposition: low vs. high density plasma



Be is ionized close to surface . . . Large redeposition.



Be is ionized far away from surface . . . Small redeposition.

In both LIM and ERO deposition dependence on plasma parameters is feasible!

ERO vs. LIM benchmark summary

- **ERO in agreement with LIM . . .**

a) *Shadowing patterns, plasma parameters, etc. implemented in a similar way.*

b) *Erosion, deposition and finally net erosion profiles are in good agreement for BM11 (steady state).*

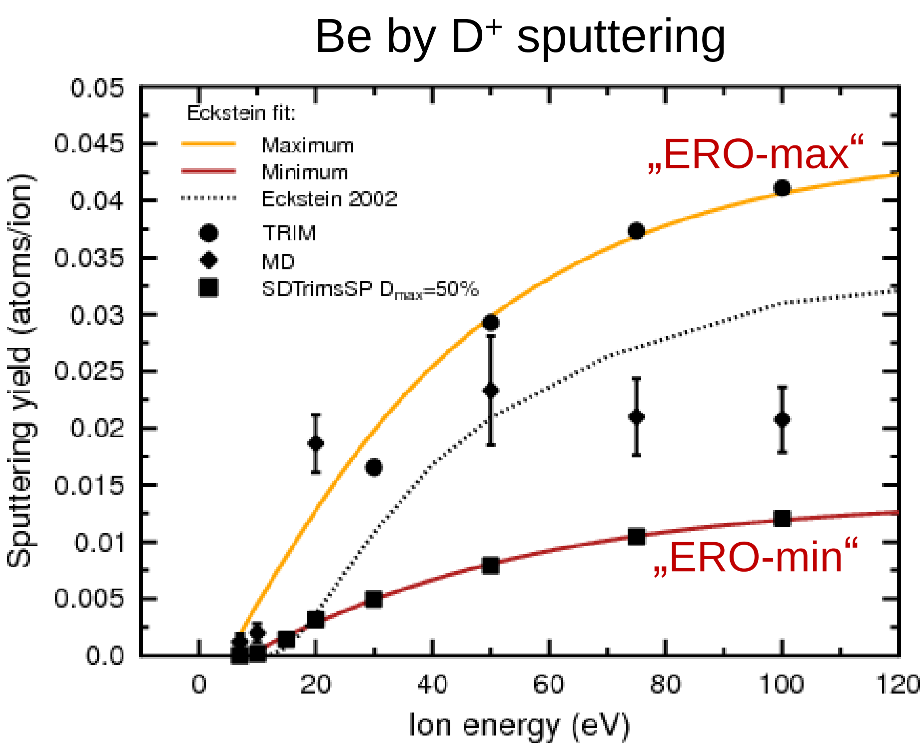
c) *Plasma conditions dependence is in agreement.*

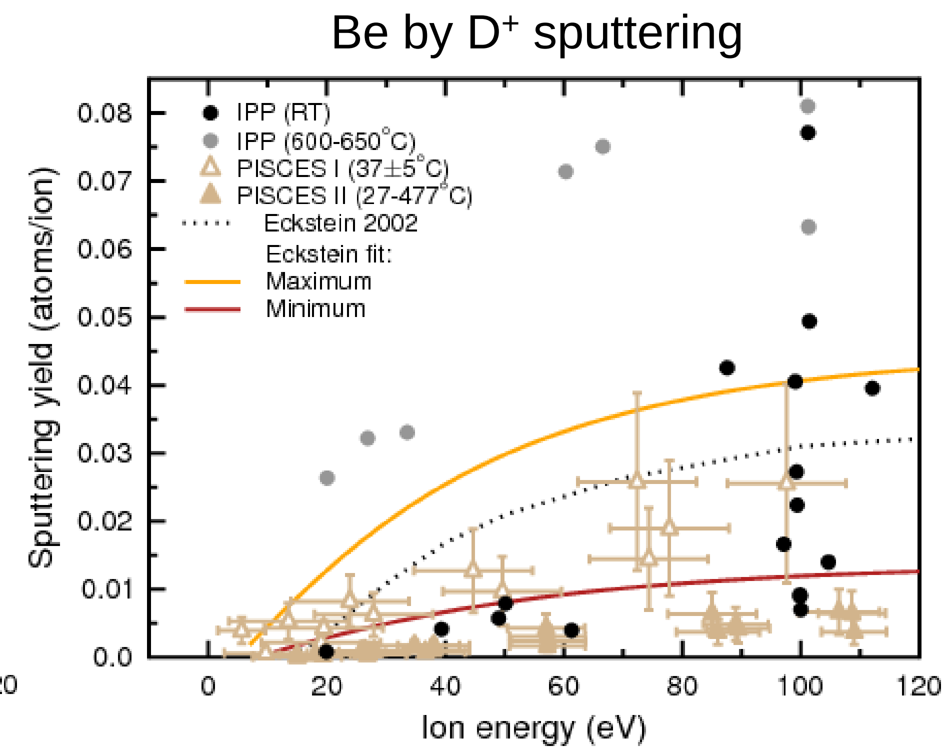
- **ERO vs. LIM disagreements**

a) *Self-sputtering in ERO is larger and more concentrated near the ridge. May indicate some difference in Be transport assumptions . . .*

Benchmark with existing experiments would be useful!

Be sputtering yields – extreme assumptions





Only the 'calculated' data are included!

1) "maximum" – static TRIM + MD
2) "minimum" – SDTrimSP with 50% of D (reasonable limit)

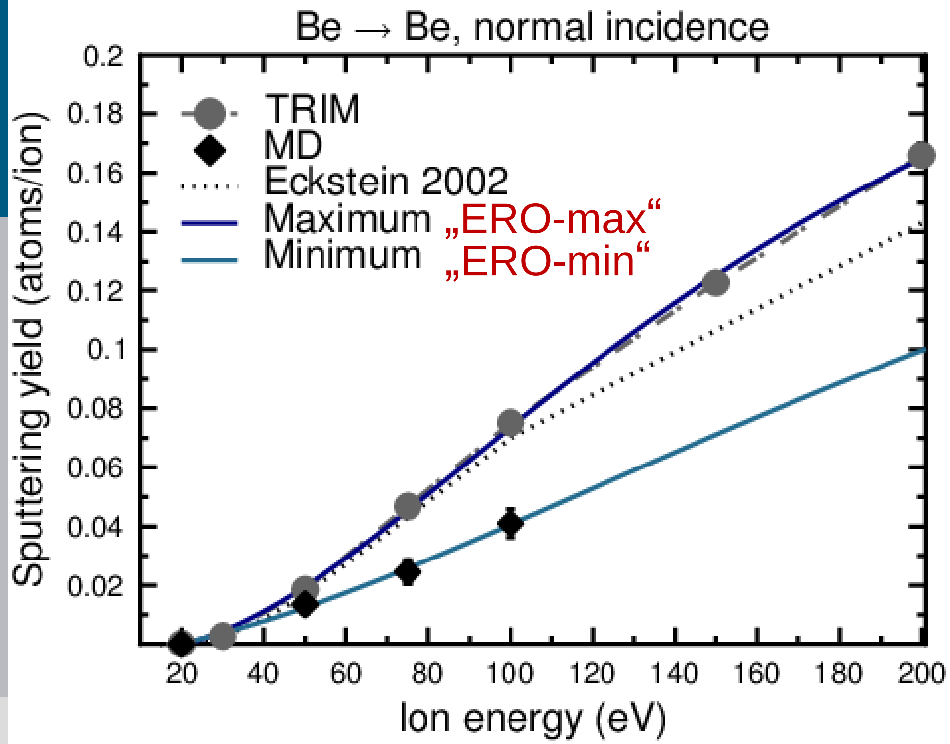
Experimental data too much scattered!

1) Large deviations: no sense to analyse shape of curves
2) Various effects are difficult to separate

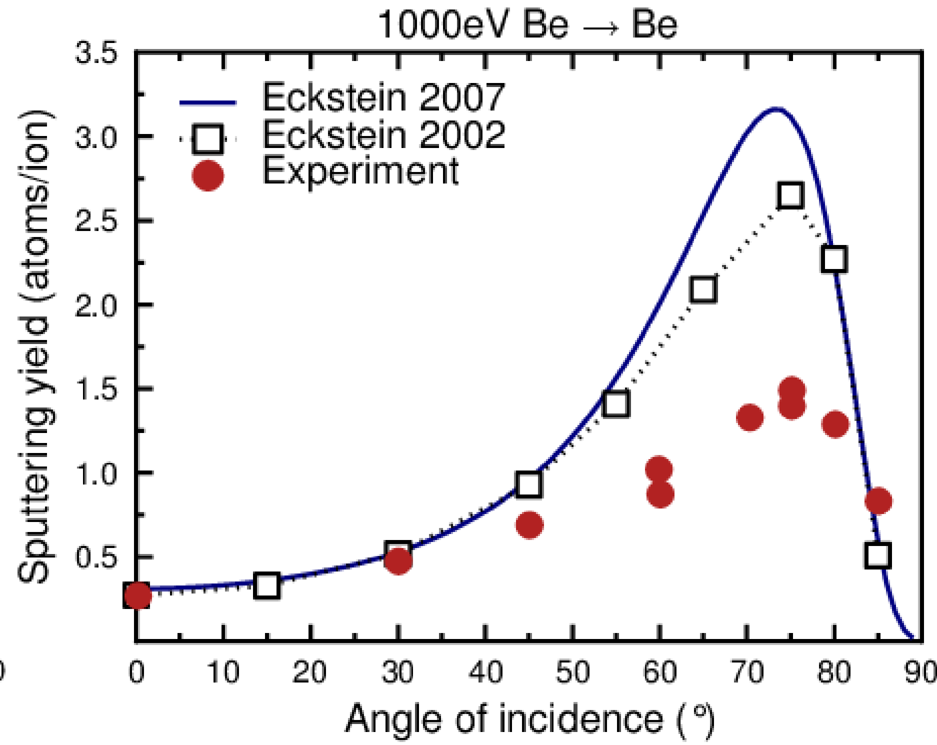
Normal incidence! Angle dependence should be taken into the account!

Be sputtering yields – self sputtering

Normal incidence



Angular dependence



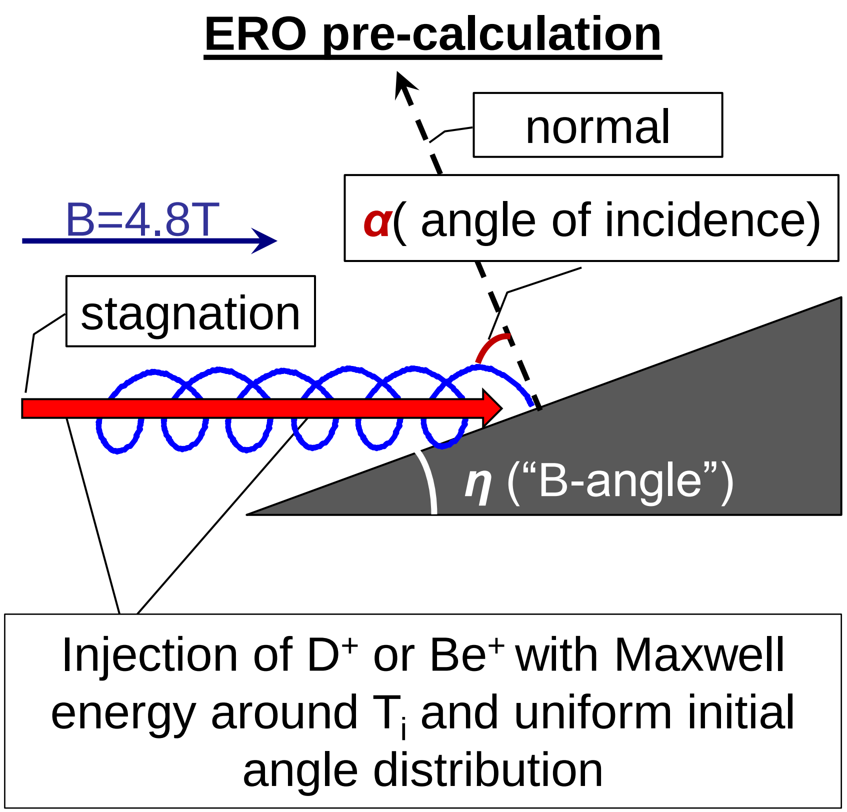
Estimation based on calculated data as for Be by D^+ sputtering

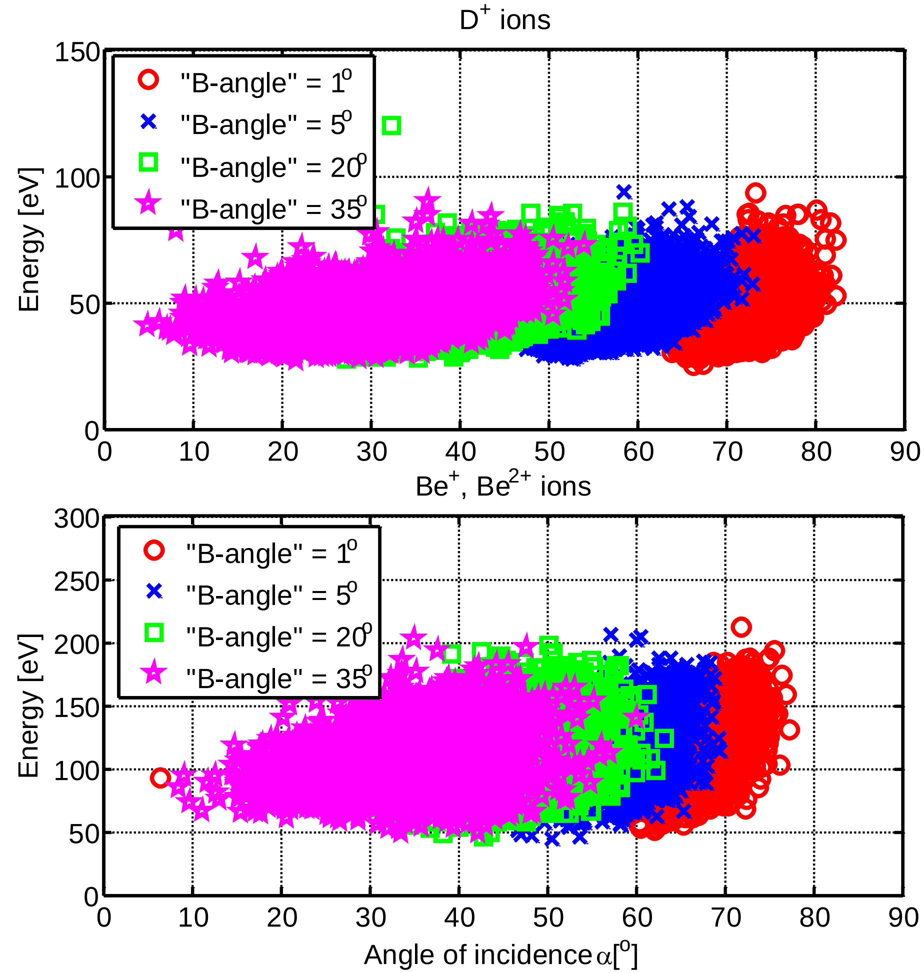
Angular part is essential!

For following BM simulations ERO uses Eckstein 2007 fit.

Sputtering by BG plasma (and intrinsic Be)

- "integration" produces effective sputter yields -

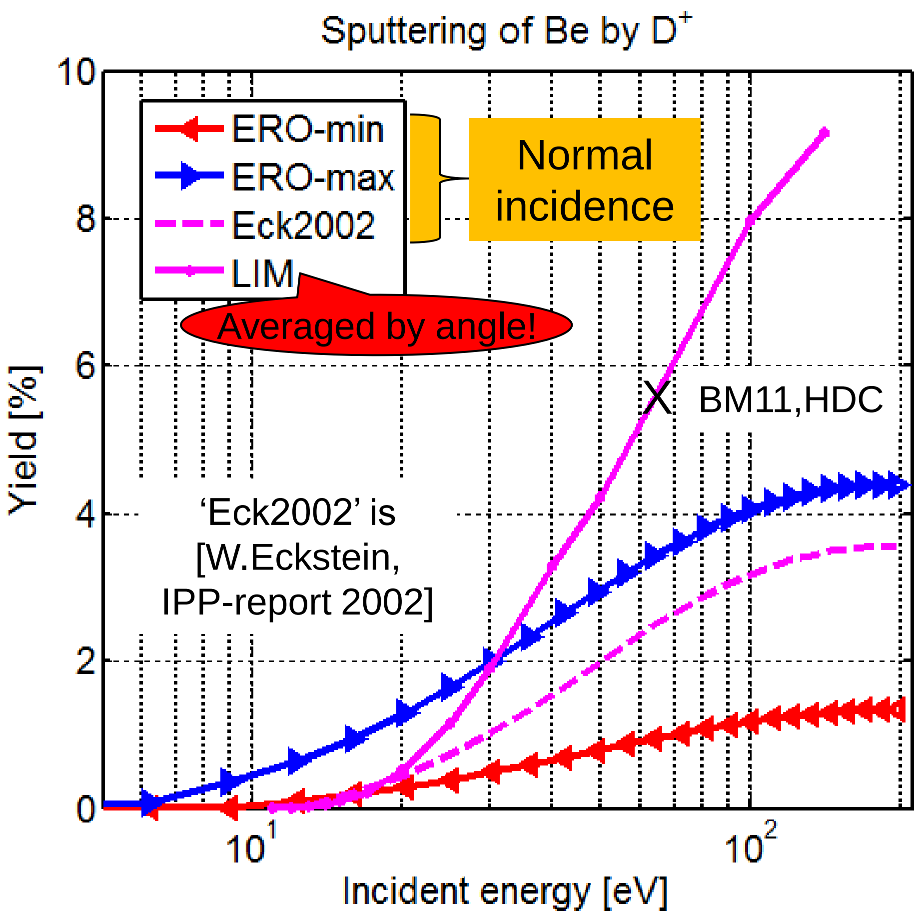




Calculation of sputtering yield according to Eckstein's fit 2007 for Y(E, α), using angle and energy distribution as calculated by ERO (including gyration and sheath)

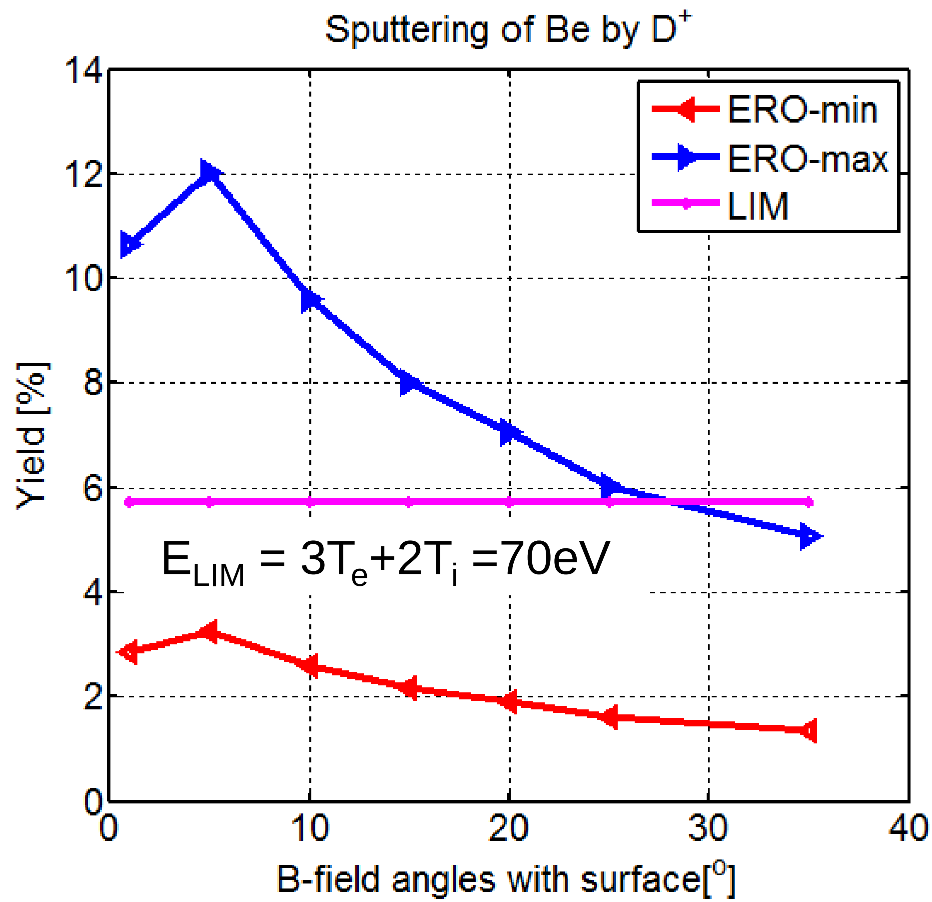
Be by D^+ sputtering yields – assumptions

Incidence energy dependence



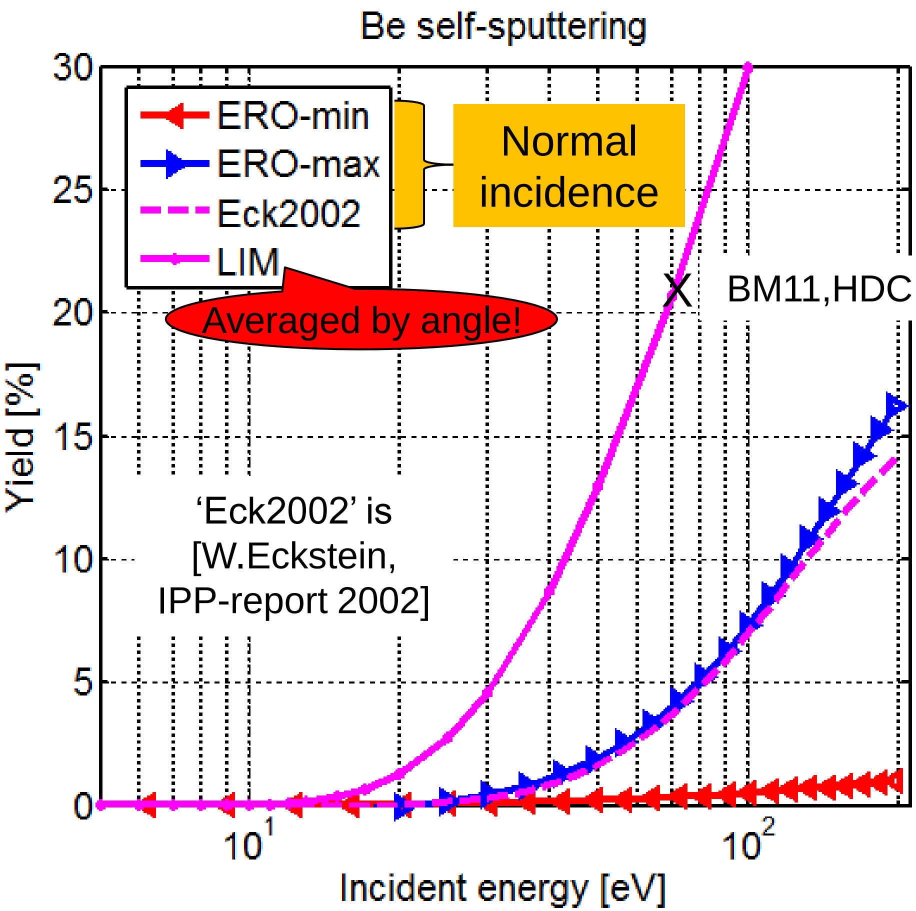
Integrated yields

- HDC conditions (T_e=10eV, T_i = 20eV)



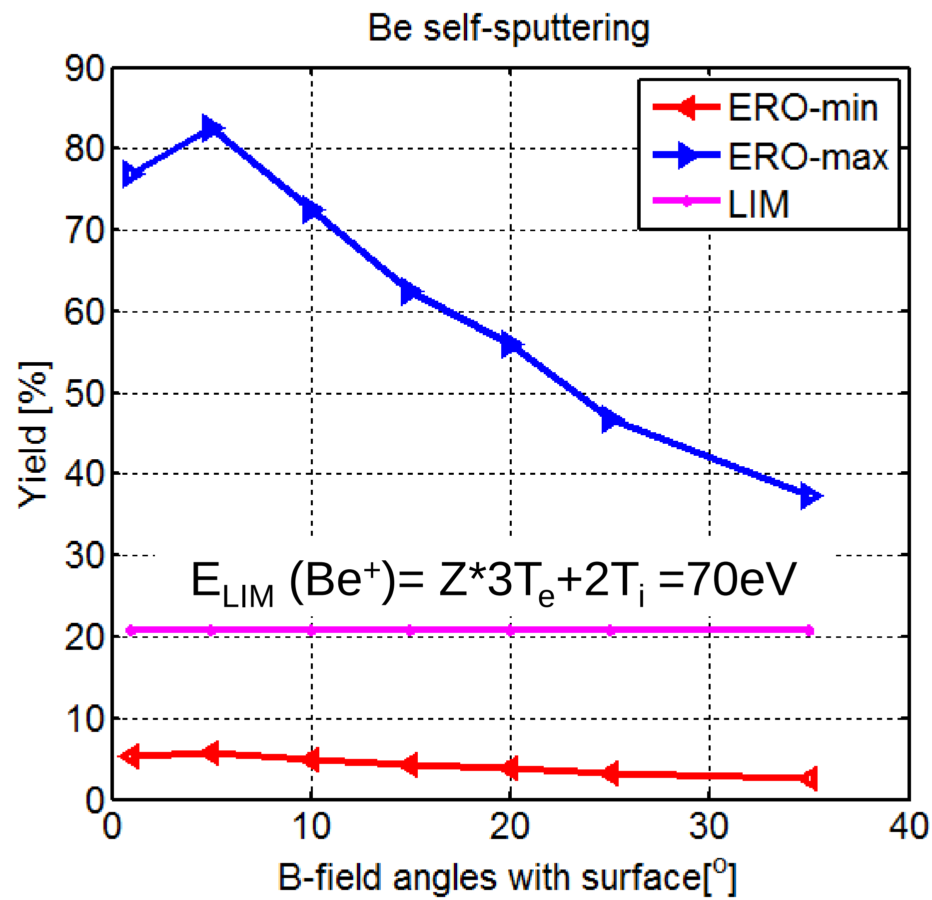
*LIM data is 'Eck2002' averaged by incidence angle assuming **uniform** distribution*

Incidence energy dependence



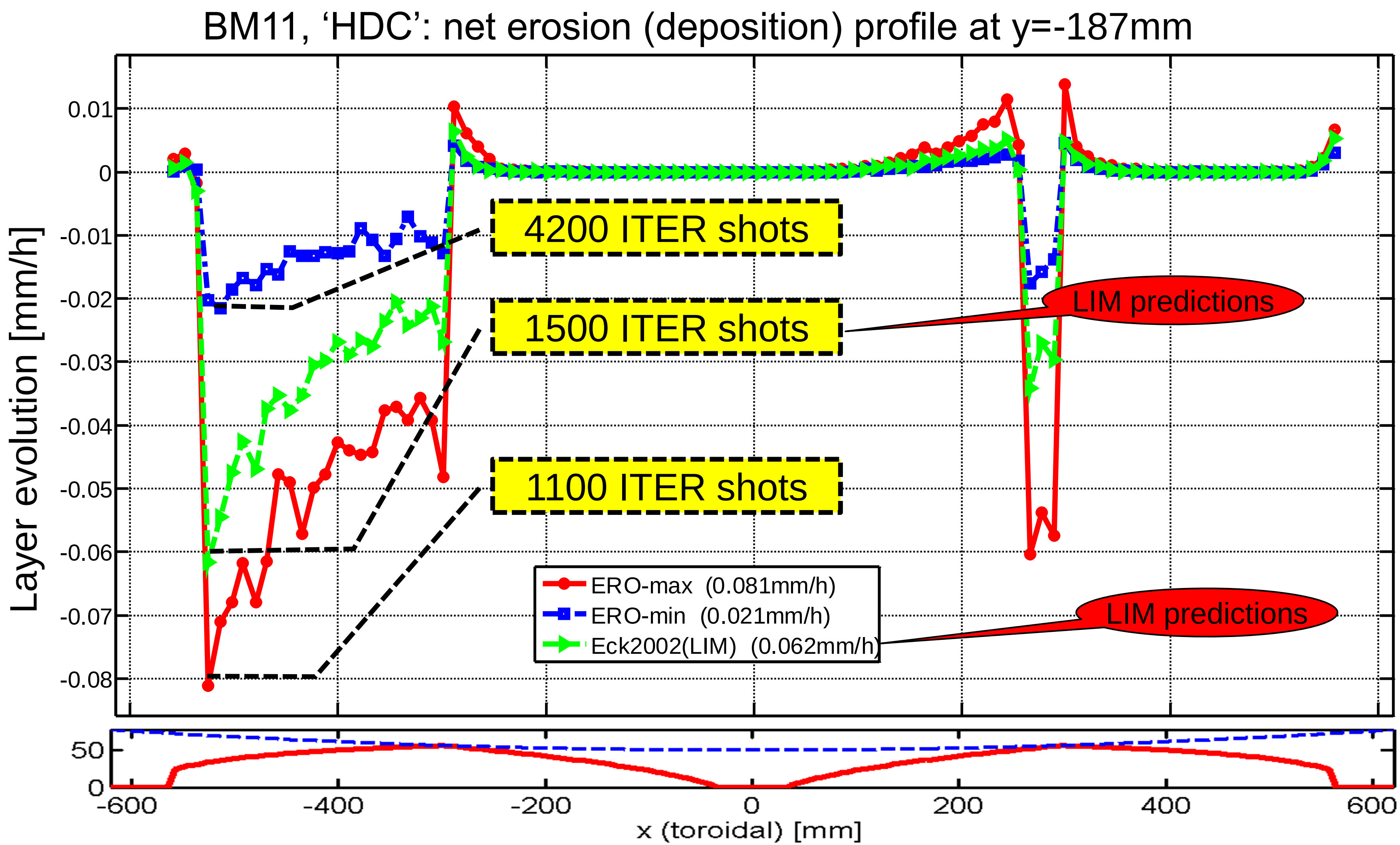
Integrated yields

- HDC conditions (T_e=10eV, T_i = 20eV)



*LIM data is 'Eck2002' averaged by incidence angle assuming **uniform** distribution*

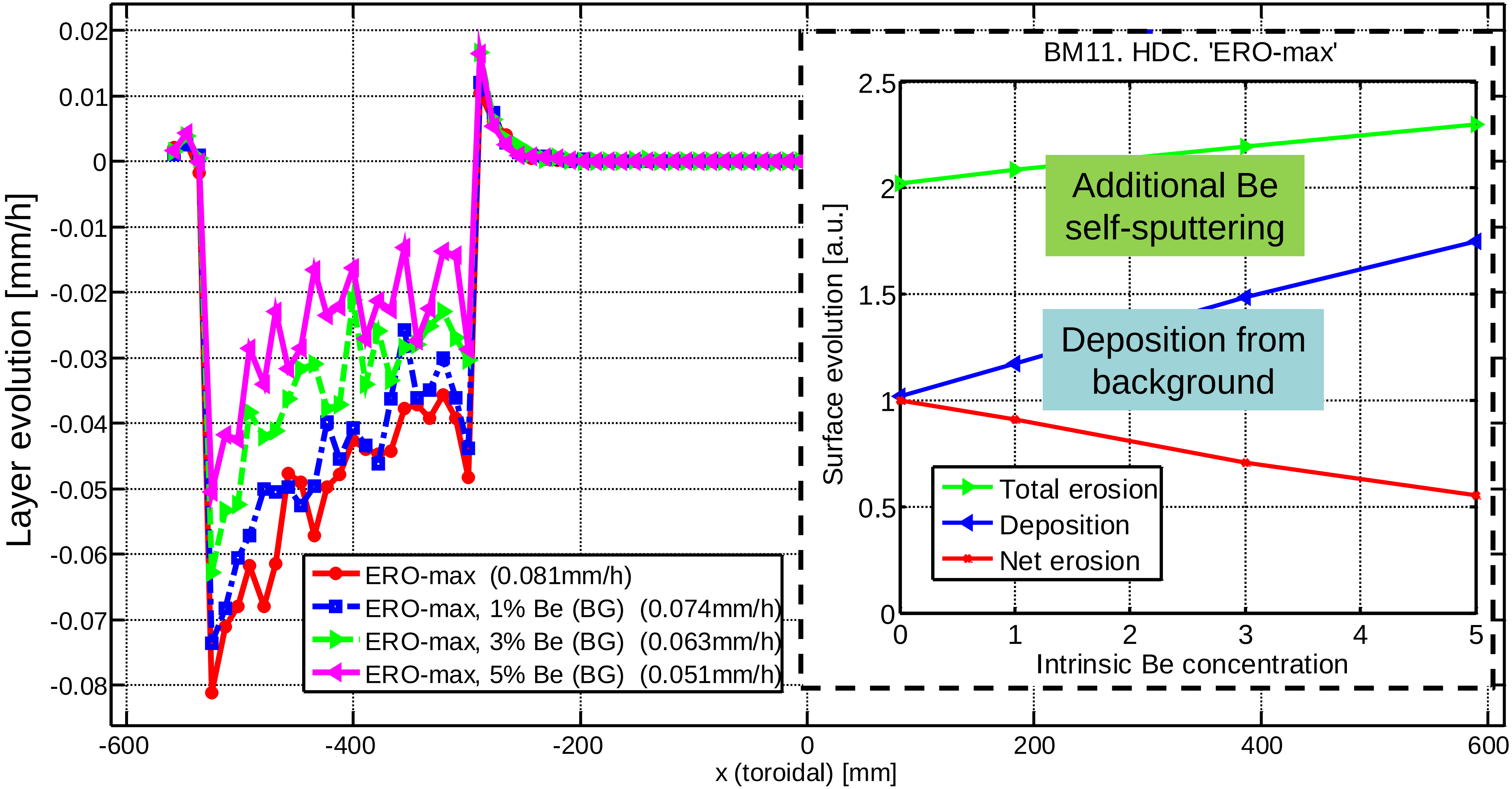
Sputter yields assumptions and net erosion



In most pessimistic case life time about 30% less than in earlier LIM predictions

Intrinsic Be impurity influence on net erosion

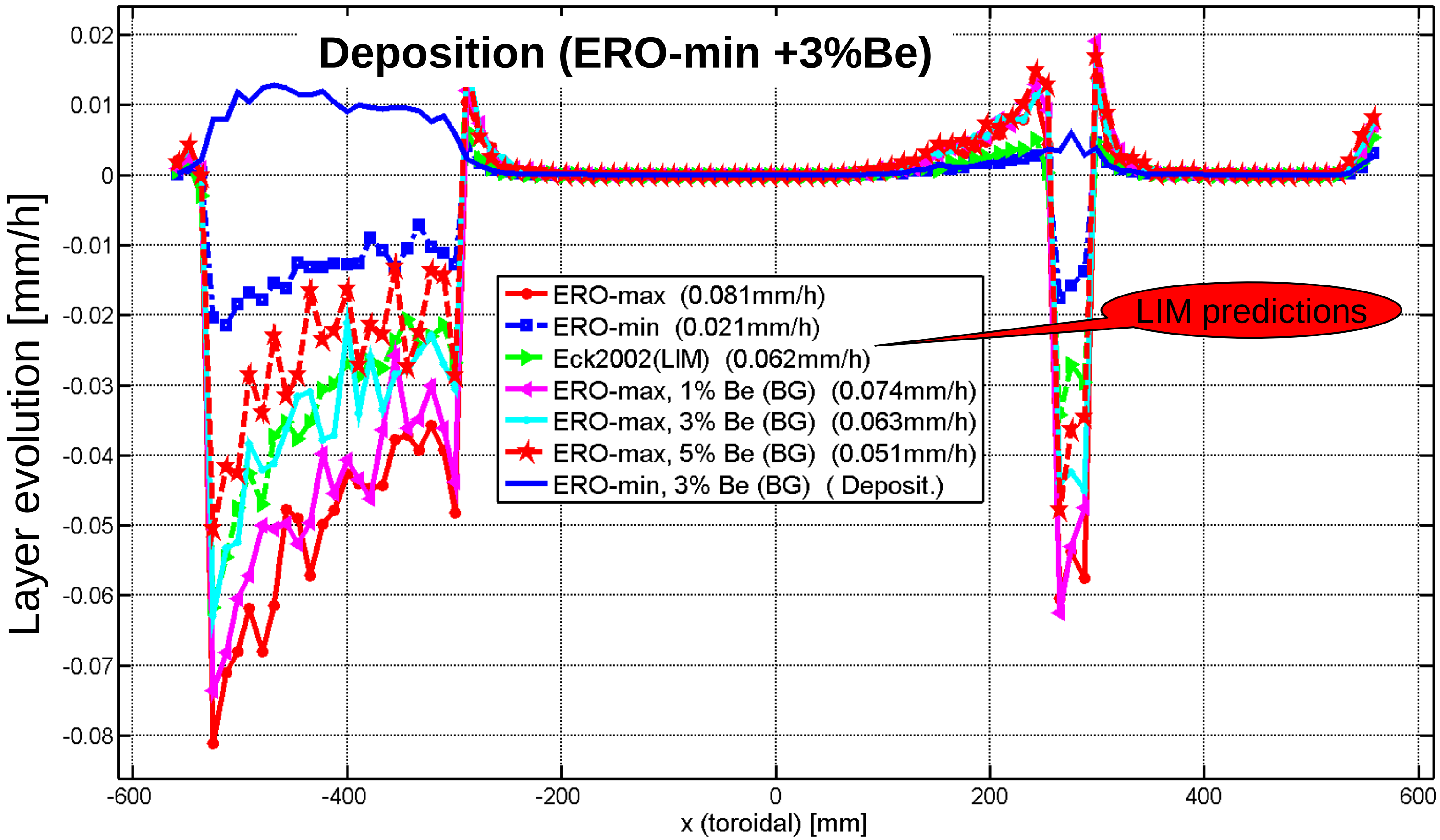
BM11, 'HDC': net erosion (deposition) profile at y=-187mm



Deposition of Be impurity from plasma dominates over additional Be self-sputtering

Intrinsic Be impurity and sputter yields effect

BM11, 'HDC': net erosion (deposition) profile at y=-187mm



Sputering yield and intrinsic Be assumptions determine the outcome to a large extent!

Influence of enhanced Be re-erosion (typical ERO assumption) of is not yet studied!

Summary

1) ITER Organization requested a benchmark of LIM erosion-re-deposition simulations made for steady state plasma exposure on shaped, Be-armoured FW panels
   → ERO code

2) Using same input plasma parameters, shadowing geometry, Be sputtering yields, ERO (3D) in excellent agreement with LIM (2D)
   → LIM low limit for FW panel erosion lifetime reproduced by ERO (~**1500** ITER reference Q_{DT} = 10 discharges)

3) Large range of erosion lifetime dominated by uncertainties in input plasma parameters and Be sputtering yields
   → inclusion of different sputtering models in ERO yields variation of lower limit from 1100 ↔ 4200 reference discharges for BM11, HDC. This variation can also be influenced by other assumptions e.g. intrinsic Be impurity.

Outlook – A

To make progress now we require:

A) Experimental benchmarking of the impurity transport codes in ITER-relevant geometry

→ IO planning dedicated benchmark on EAST (MAPES manipulator with shaped tiles similar to ITER FW panel profile

→ JET ILW the ideal location for a dedicated experiment looking at erosion of Be tiles (e.g. upper part of the vacuum vessel in the secondary X-point region)

Outlook – B

B) Improvement in sputtering yield uncertainty

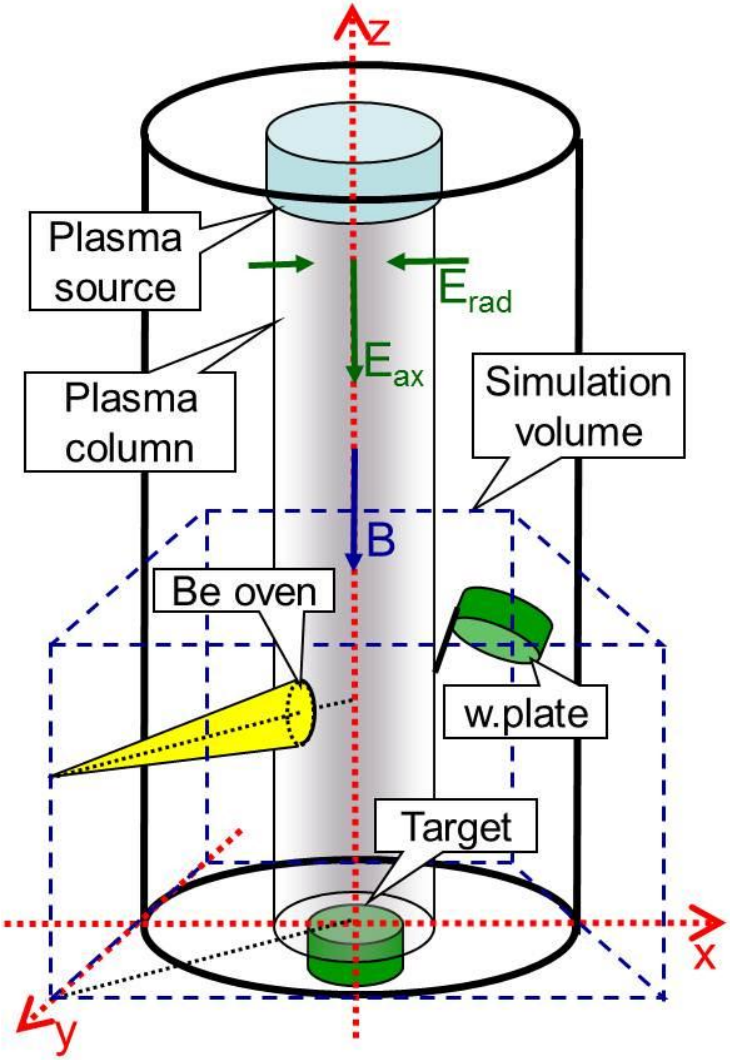
→ model testing in PISCES-B

Perfect for Be sputtering yields benchmark

1. Spectroscopy
2. Target weight loss
3. Witness plate

The ERO was earlier applied for modelling of PISCES-B

PISCES-B



The End