第15回 ITPA（SOL/DIV）の概要
Material migration, Be erosion, W R&D
ITER-like Wall （JET）

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PWI 合同研究会
平成23年　7月20日- 22日

筑波大学プラズマ研究センターシンポジューム
プラズマ物理クラスター スクレープオフ層とダイバー タ物理サブクラスター(第1回会合)
炉工学クラスター ブランケット サブクラスター(第2回会合)
双方向型共同研究会合「ガンマ10装置における炉壁材料の損耗・再堆積の研究と
そのダイバータ開発戦略における位置づけ」

Migration and Be erosion

Material migration

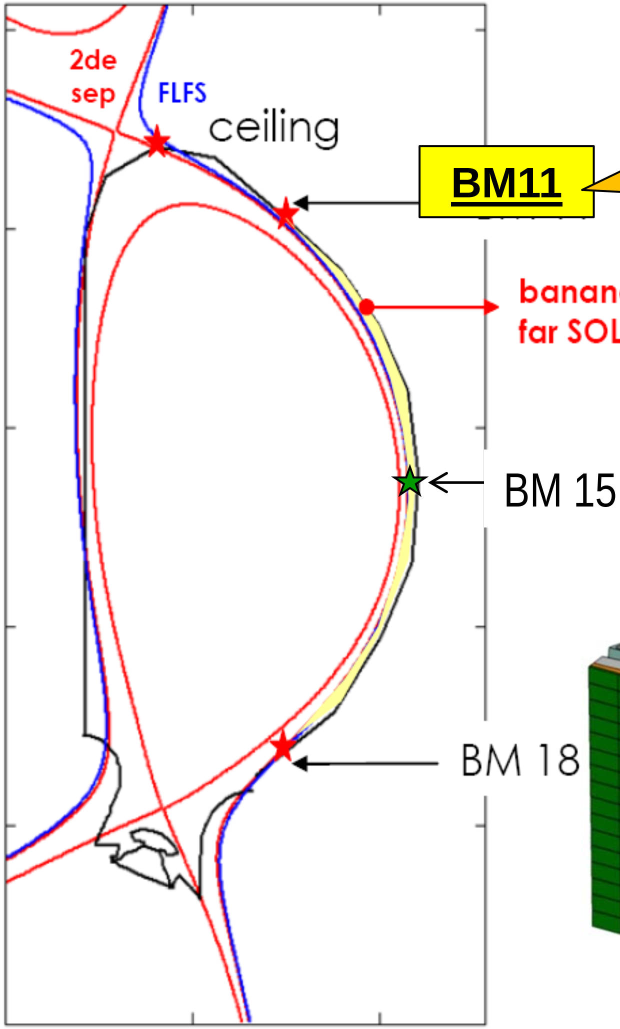
Be第一壁損耗と再堆積のモデリング

	intended presentation on modeling of ITER wall erosion/deposition
	medium scale modelling of ITER main chamber eorison/redeposition
	WallDYN applied to JET
	13C injection experiments in AUG and their modeling using DIVIMP and ASCOT, with the focus on the main chamber
	Long term tracer experiments for erosion / redeposition pattern on the first wall

Be erosion

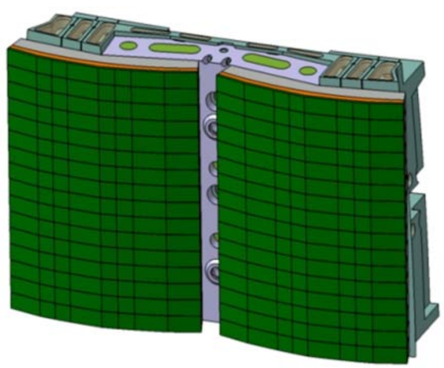
	New data on Be erosion obtained with QSPA plasma guns at ITER-like ELMs simulations
	Erosion/deposition balance in Be seeded high flux D discharges

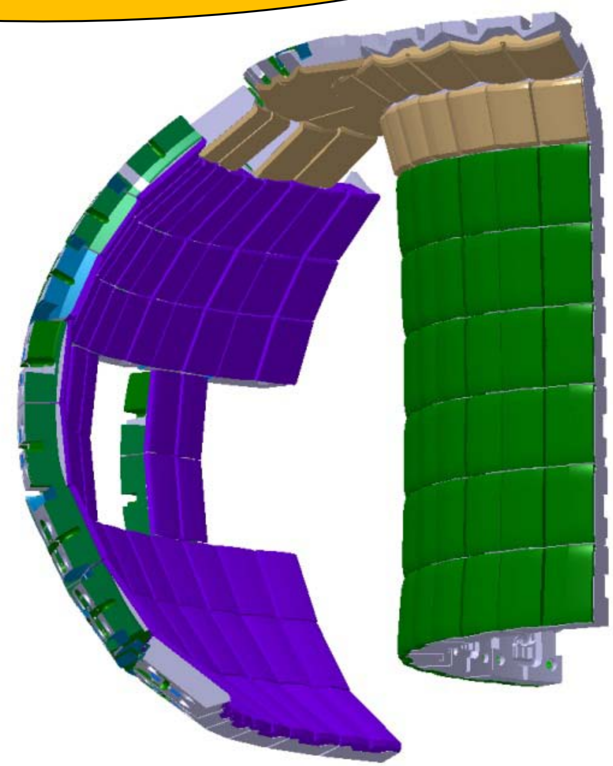
ITER Be wall – BM erosion



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

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

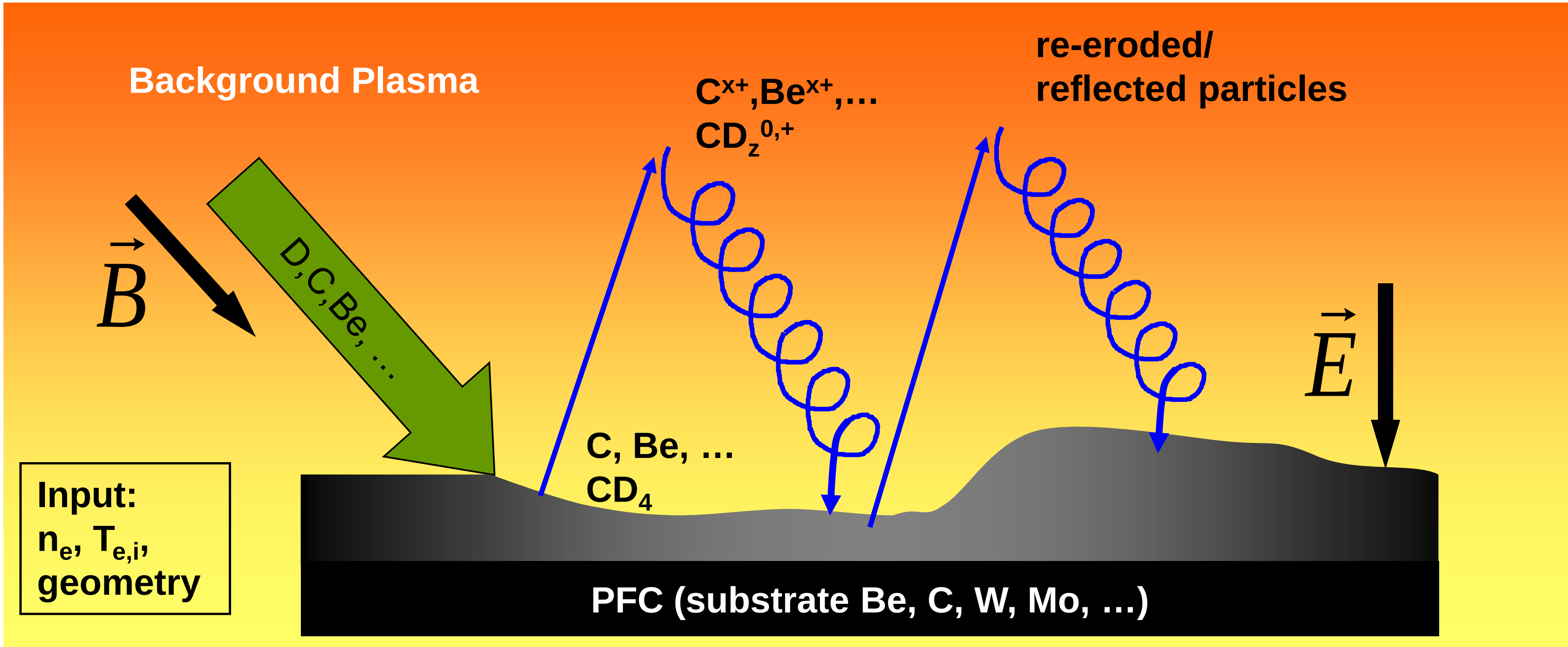




- *Blanket module (BM) shapes optimized for heat loads (P.C.Stangeby)*

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

3D MC impurity transport code ERO



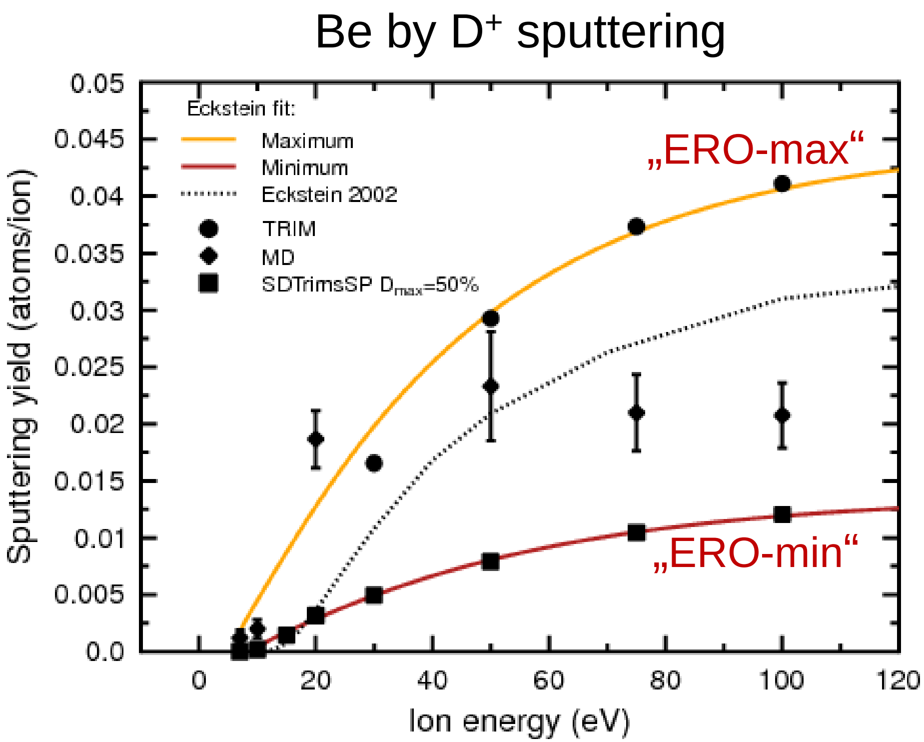
Local transport:

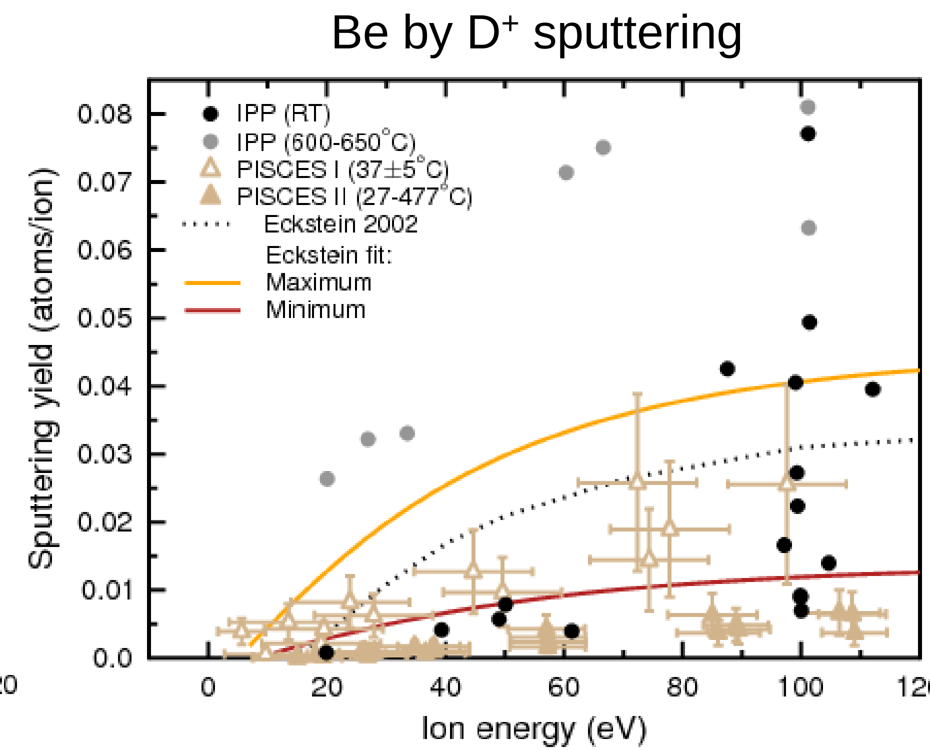
- ionisation, dissociation
- friction (Fokker-Planck), thermal force
- Lorentz force
- cross-field diffusion

Plasma-surface interaction:

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

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!

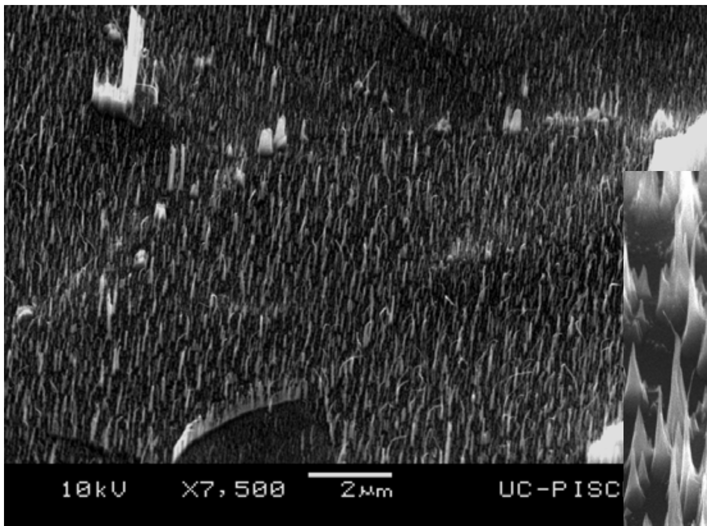
1) Large deviations: no sense to analyse shape of curves
2) Various effects are difficult to separate

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

surface morphology of PISCES-B targets: bias dependence

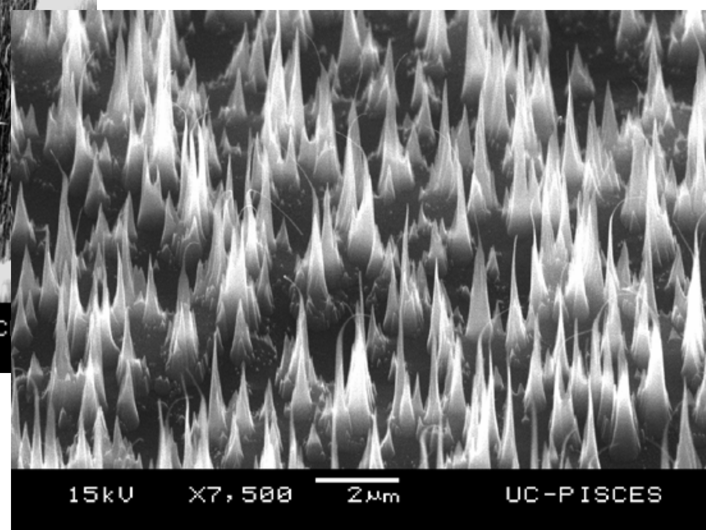
pure D exposure, < 330K: j_D = x·10^{22} D_x^+/cm^2 SEM under 40°

-50V bias (tmsBe19),
Y= 0.23% per ion



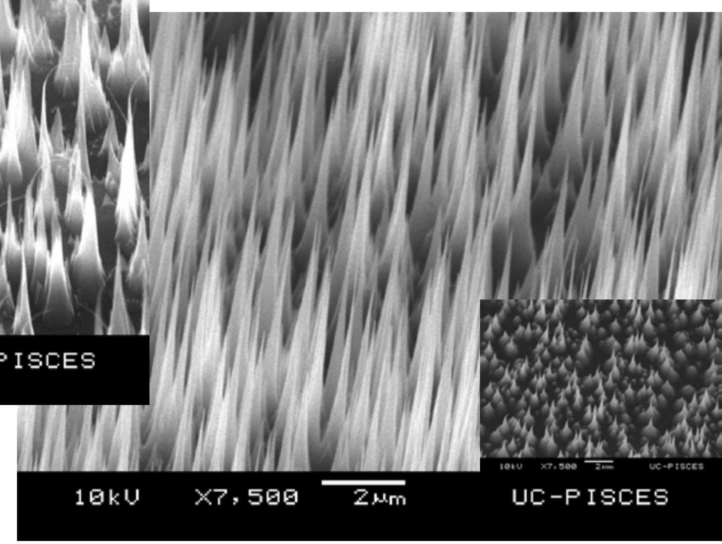
-100V bias (tmsBe17)

Y= 0.45% per ion

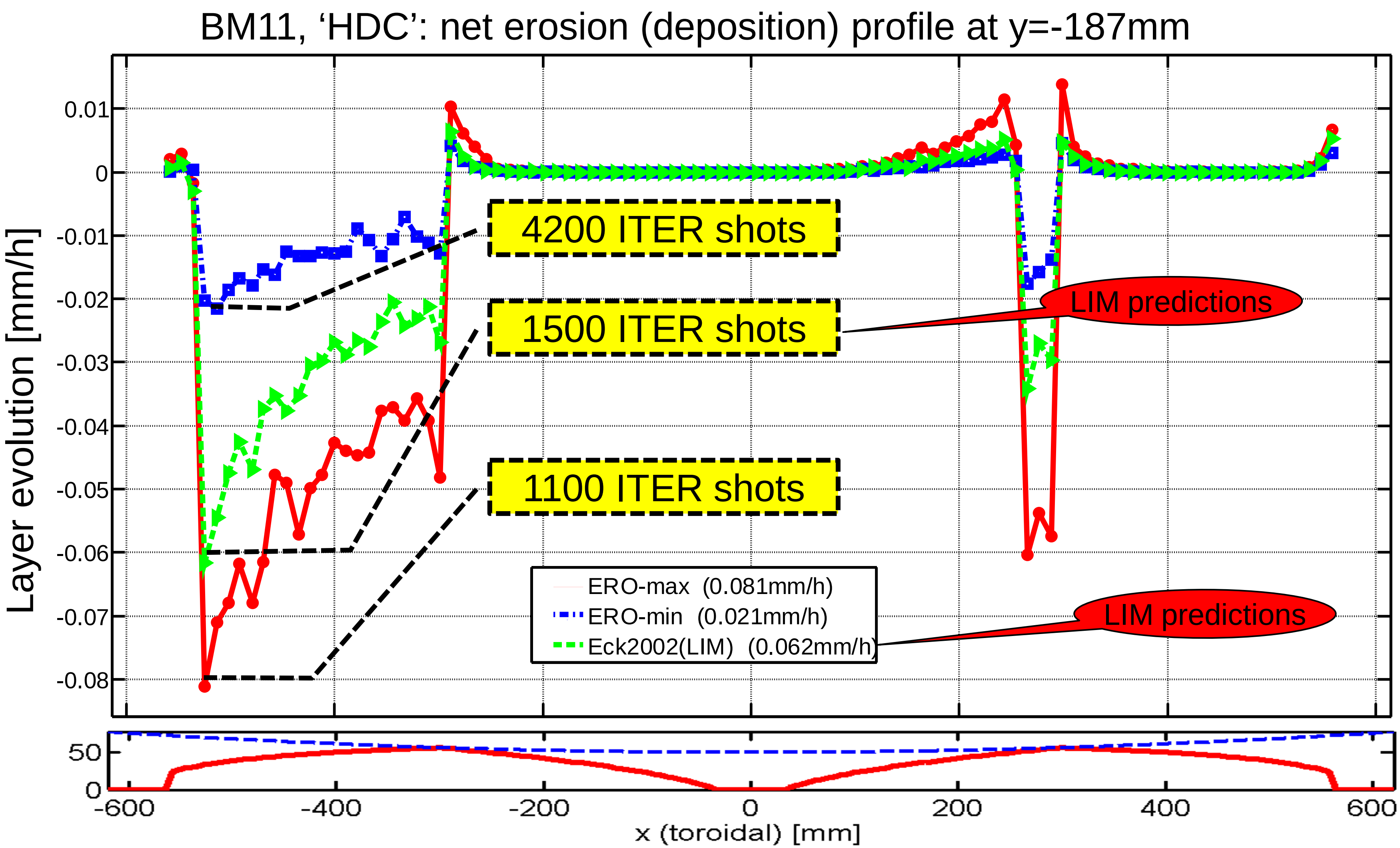


-170V bias (tmsBe3back)

Y= 0.63% per ion



Sputter yields assumptions and net erosion



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

Be migration と Be erosionのまとめ

- EROコードとLIMコードによるシミュレーション結果は、おおむね一致
- 特に損耗が懸念される場所（BM11）における損耗による寿命（Be厚：1mm）は、4,200ショットから1,100ショットまで大きくばらつく（EROコード）。
  - 実験値の最大損耗量（IPPのデータ）を用いるとさらに寿命は短くなる（< 1,100 shot）
  - ダイバータ交換の目安は3,000ショット程度
    - 少なくとも、これ以上の寿命が必要と考えられる
- 実験においてスパタリング率に大きなばらつきが生じる理由
  - 表面形状の影響？
    - コーン形状の影響→イオンの入射角に依存するので、実機で同様の表面形状が現れるかは不明
  - フラックス影響？

Tungsten R&D

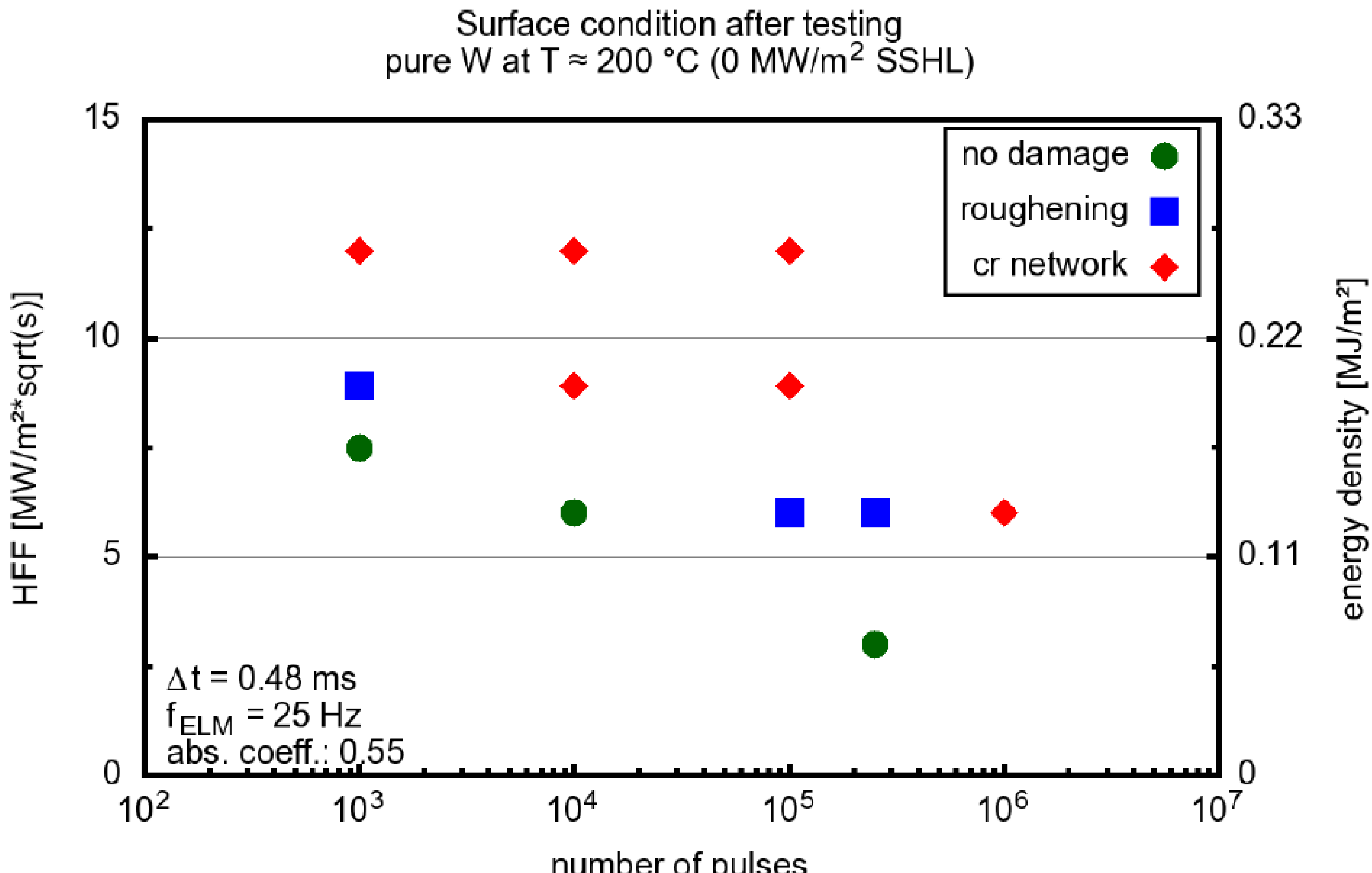
W damage

タングステン（金属壁）の溶融挙動

	Transient heat load tests on monolithic tungsten with high repetition rates - 電子ビームによるELM模擬実験
	W melt experiments in tokamaks - （TEXTOR）
	W melting and melt layer motion experiments in Pilot-PSI -
	Melting of tungsten sample and metal first wall in LHD -
	tungsten recrystallization after melting/erosion

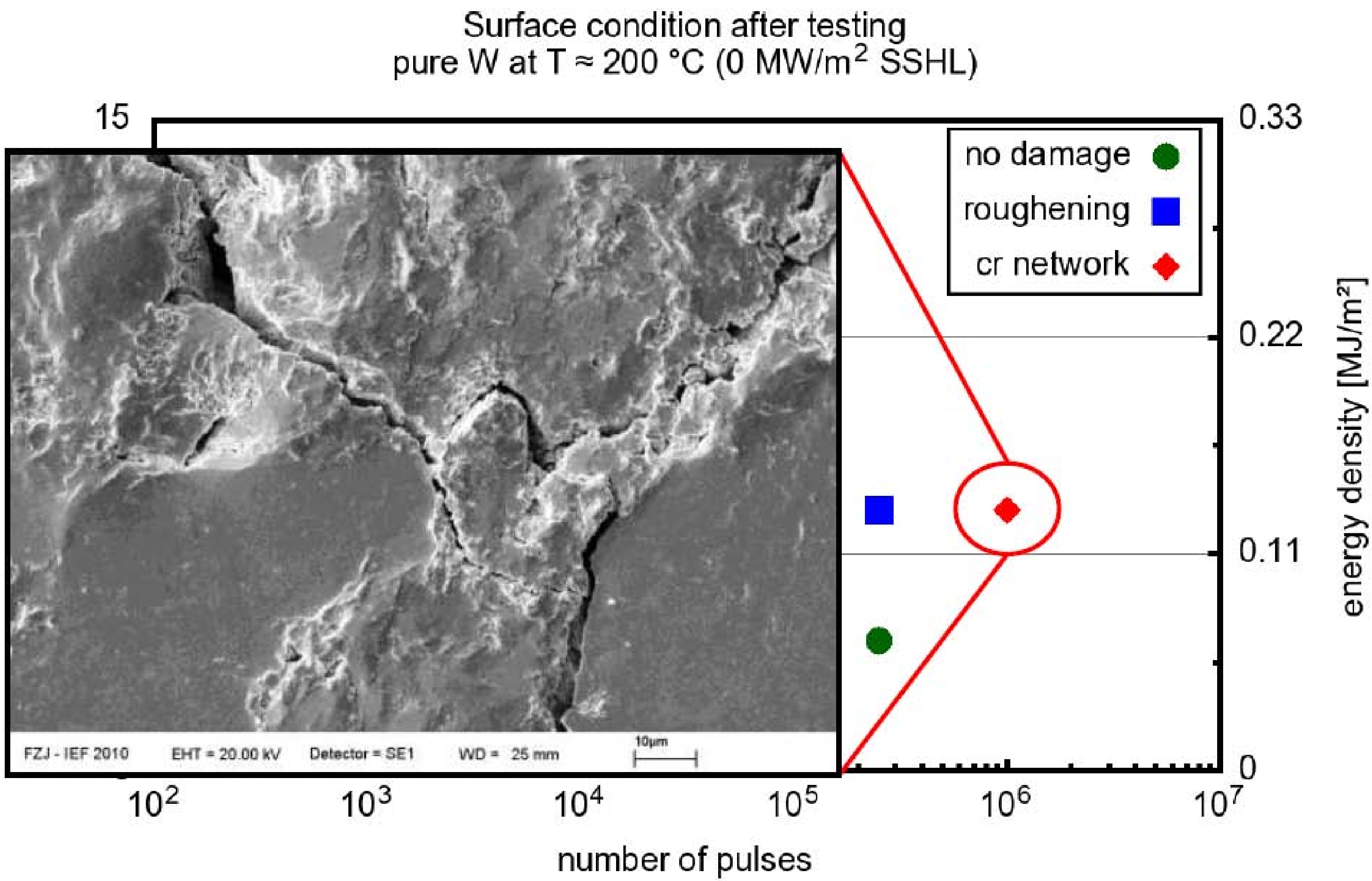
ELM simulation tests on tungsten

Melting limit ~ 1MJ/m²



溶融限界（～1MJ/m²）より大幅に低い熱パルスでも、繰り返し照射により亀裂が生じる

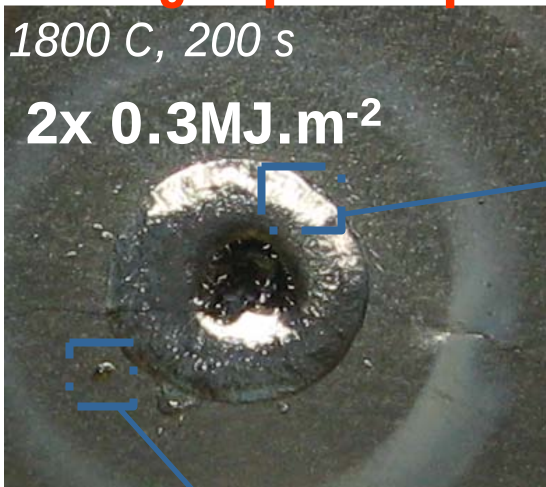
ELM simulation tests on tungsten

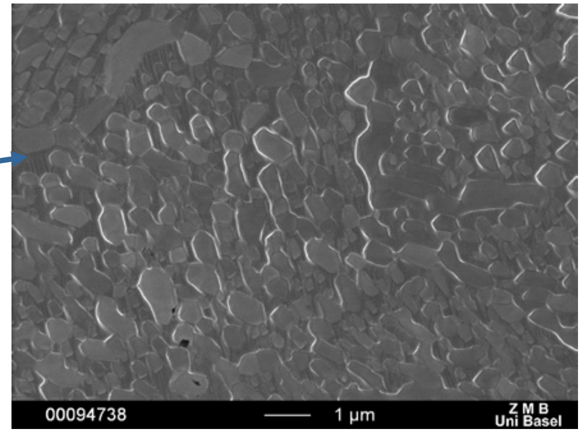


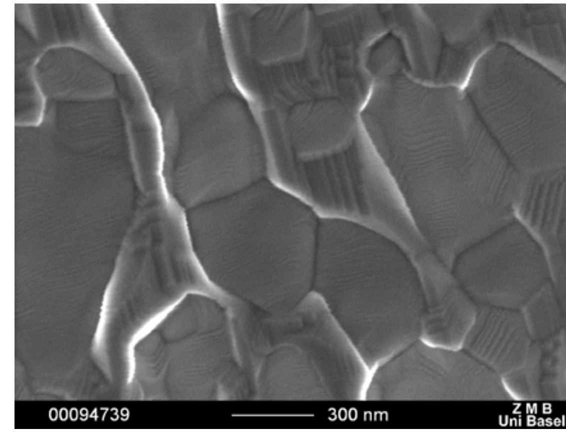
Effect of He pre-exposure on melting

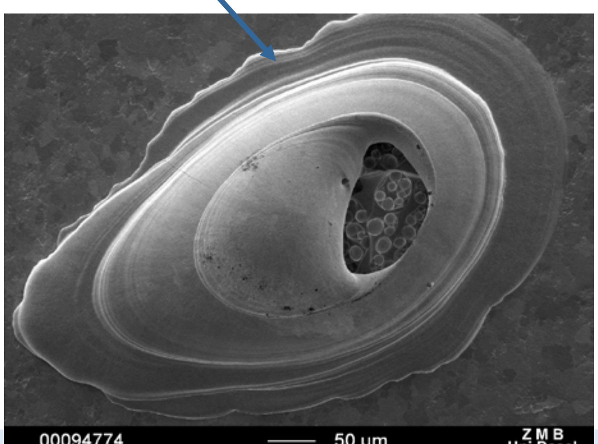
- Helium pre-exposure of tungsten surface
- Exposure to pulsed plasma (combined with steady-state plasma)

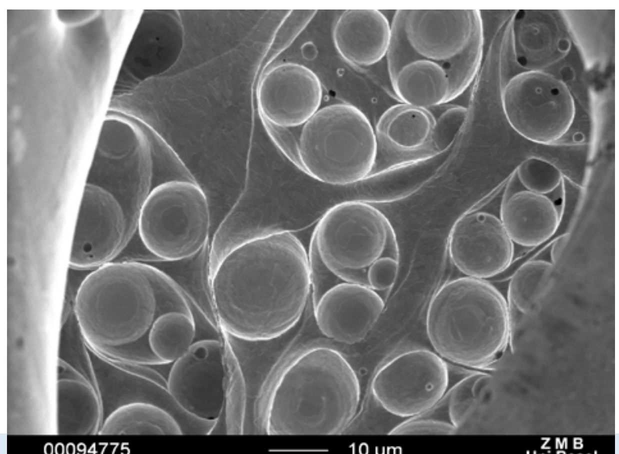
W target pre-exposed









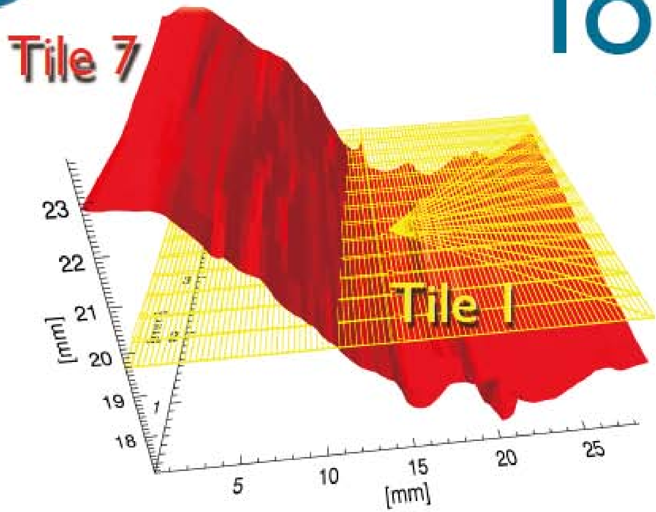


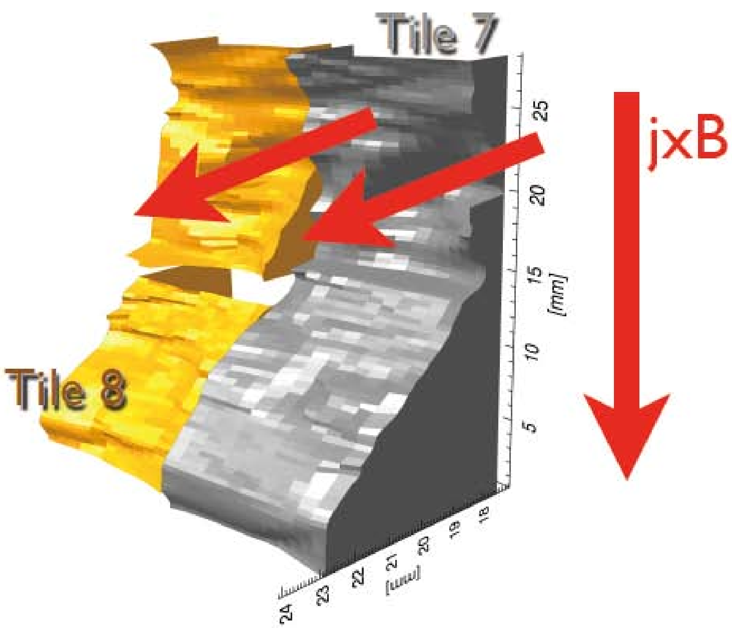
Reason for such significant melting not totally clear

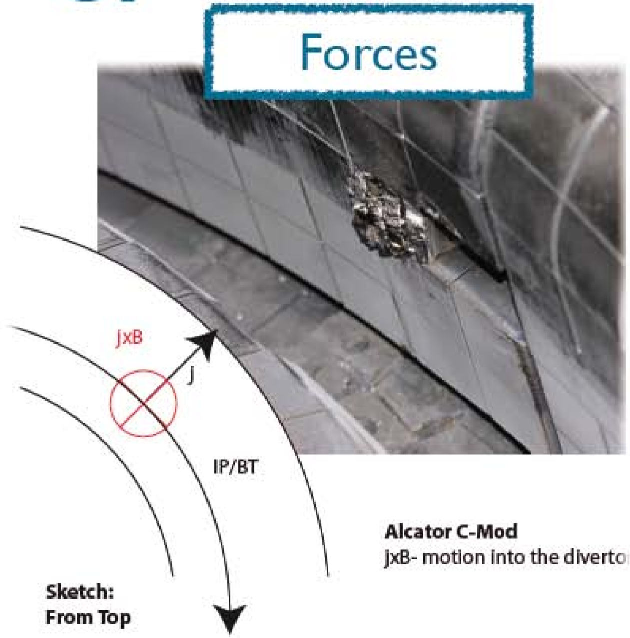
Consistent observation, biasing increases the probability of melting

Accidental Melting (A-CMod)

Topology





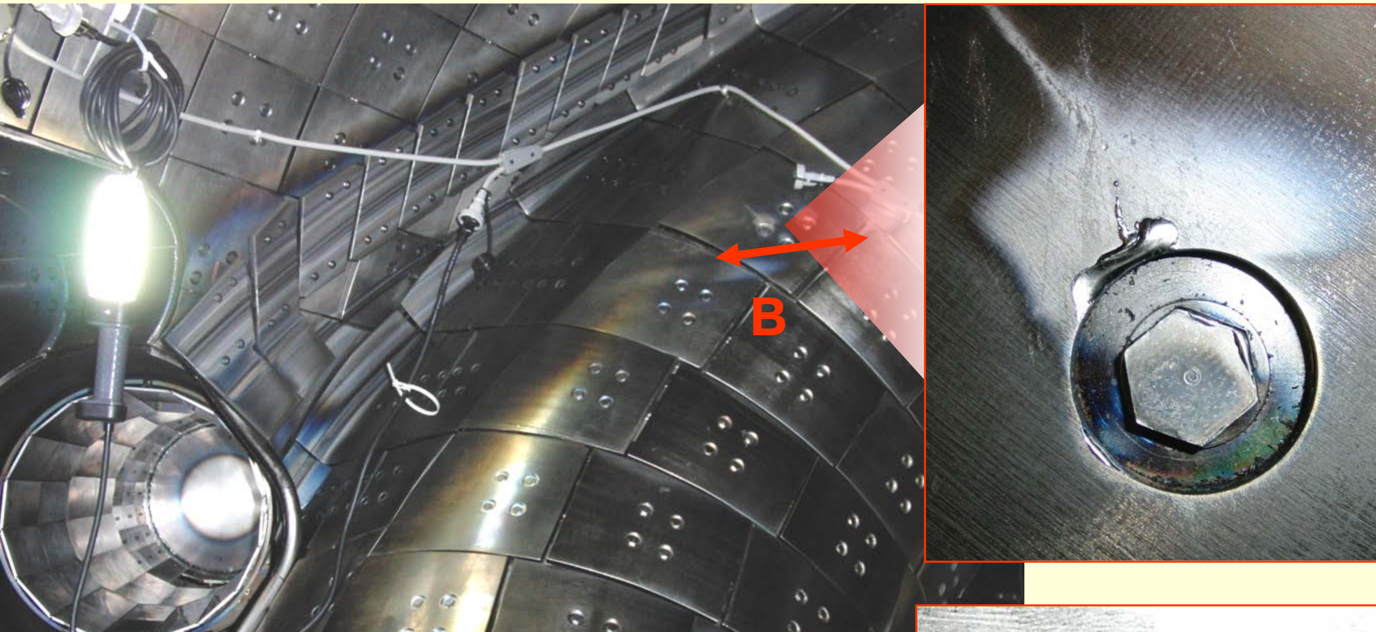


Material moved predominantly following jxB forces and gravity

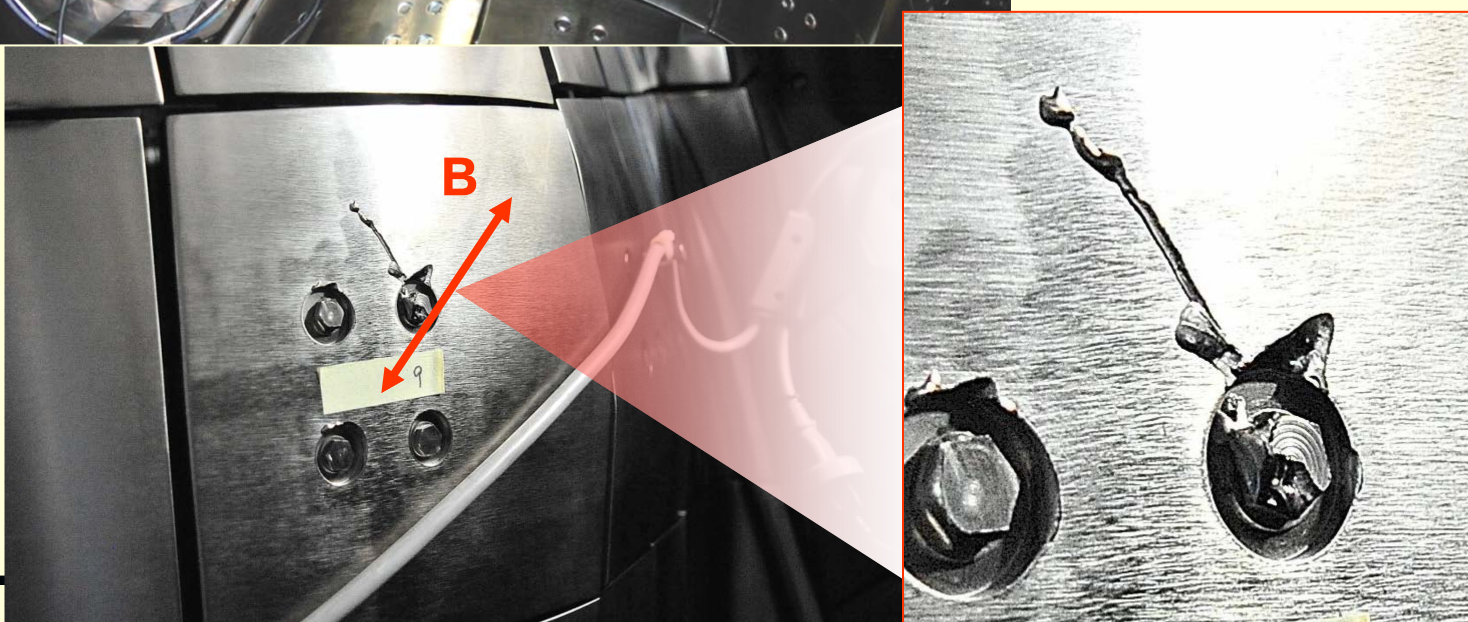
Indentations hint at additional pressure driven motion

Stainless steel first wall panels were melted locally.

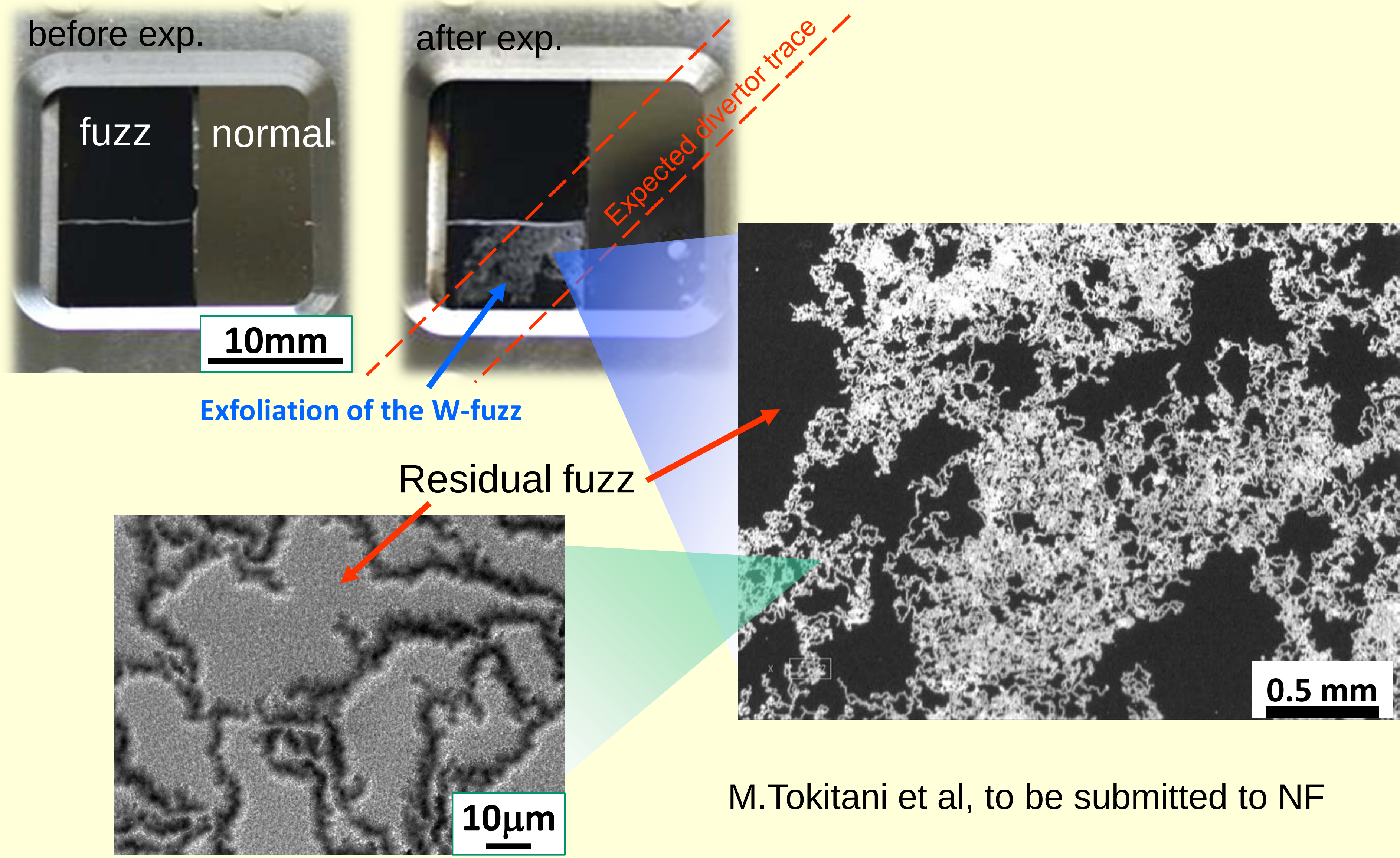
Accidental Melting (LHD)



- In these cases, melted layer motions were upward against gravity.
- Directions of their motion were roughly perpendicular to **B** direction.



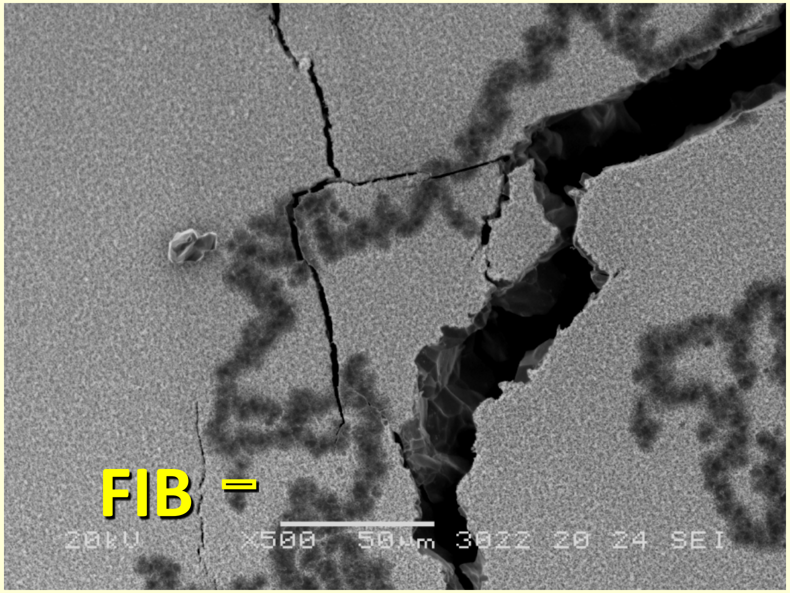
First observation of W-fuzz erosion by arcing in fusion device



M.Tokitani et al, to be submitted to NF

Cross section view of W-fuzz made in NAGDIS

Obs. by N. Yoshida
(Kyusyu univ.)



- The arc trail were cut by FIB (Focused Ion Beam) milling process.
- The cross sectional view of the arc trail, the base W was not eroded by arc.

S. Kajita

タングステンR&Dのまとめ

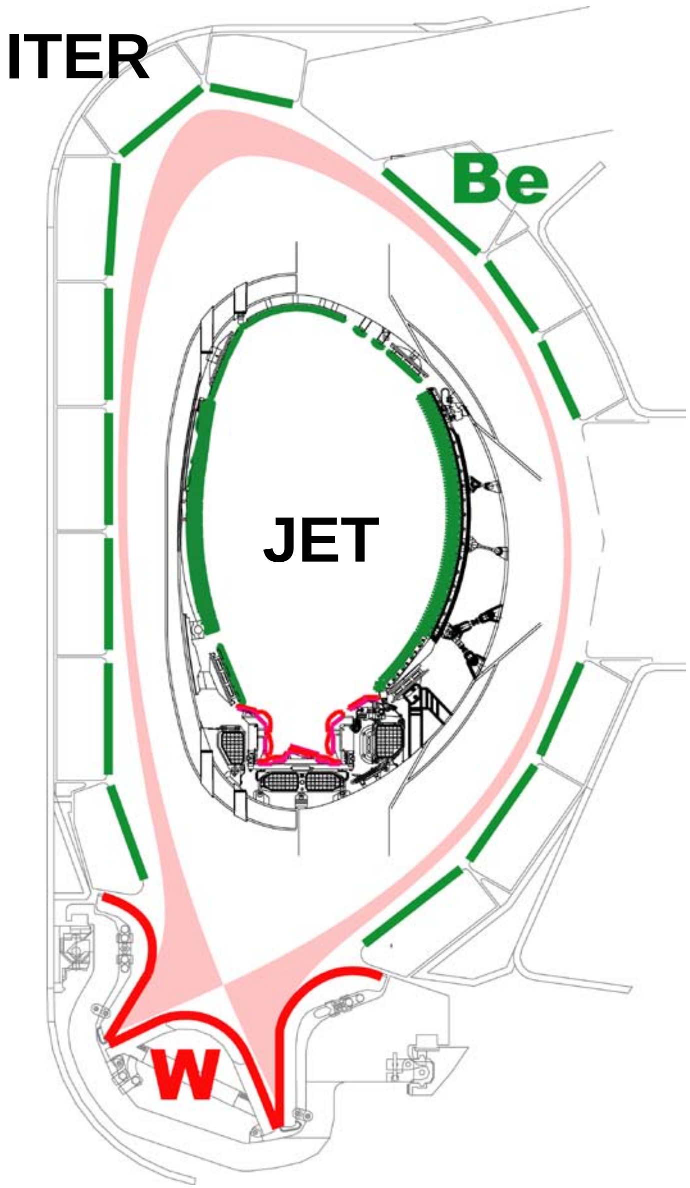
- 表面損傷と溶融層挙動の研究成果
  - 実験室実験結果（低エネルギー繰り返しパルス熱負荷、パルス熱負荷＋定常熱負荷）
  - 実機での溶融実験（多くの装置で、Bに垂直な溶融層の運動を観測、A-CMod、TEXTOR、LHD）
- 熱負荷と粒子負荷の相乗効果
  - Heプラズマ照射とパルス熱負荷の同時照射時に表面の融点が下がる？（Pilot-PSI）
- 実験室実験と実機実験との対応
  - Fuzz上のアーキング（LHD）
  - Fuzzの生成（A-CMod）
  - この分野は、モデリングのベンチマーク実験という意味合いも含め特に重要である。

Experimental Program for the Exploitation of the ITER-Like Wall at JET 2011/2012

S. Brezinsek
For TFE1 and TFE2 leaders

JÜLICH
FORSCHUNGSZENTRUM

The Wall Combination for the DT Phase in ITER



Be wall and W divertor in JET

- Material combination for the first time used
- Replacement of the wall in one shutdown

- "Carbon-free" environment
  - Reduced material migration to rem. areas
  - Reduced tritium retention
  - Loss of carbon as main radiator

- Change in operational space
  - Need for better plasma control
  - Need for heat load mitigation schemes
  - Need for semi-detached divertor
  - Need for impurity-seeded plasmas

NBI upgrade in JET

- Parallel upgrade of neutral beam system
  - Maximum power from 20 to 34 MW
  - Maximum duration from 10 to 20 s

Plasma-Wall Interaction Issues

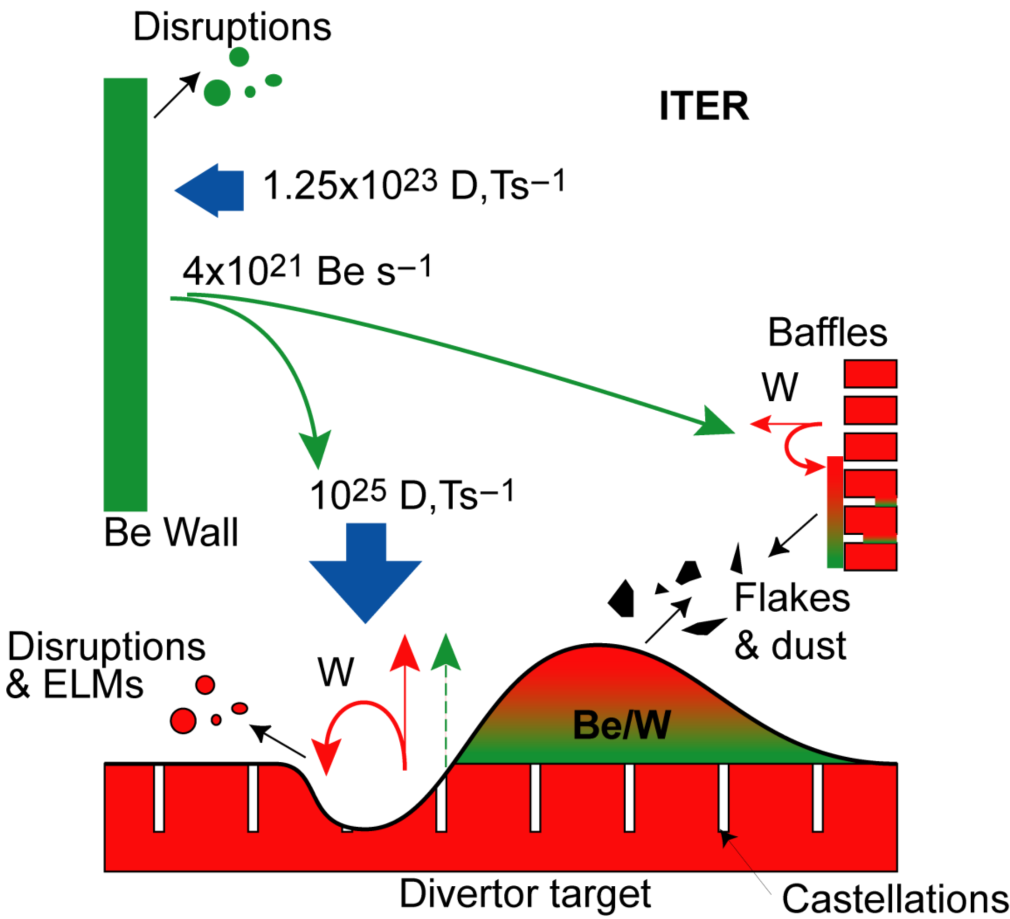
Important PWI questions for ITER will be addressed in JET with the ILW

Steady-state operation

- **Be wall erosion and transport**
- **Be-W material mixing**
- **Be:D layer formation and retention**
- **Re-erosion of (mixed) layers**
- **Material Transport to remote areas**
- **W erosion and prompt deposition**

Transients

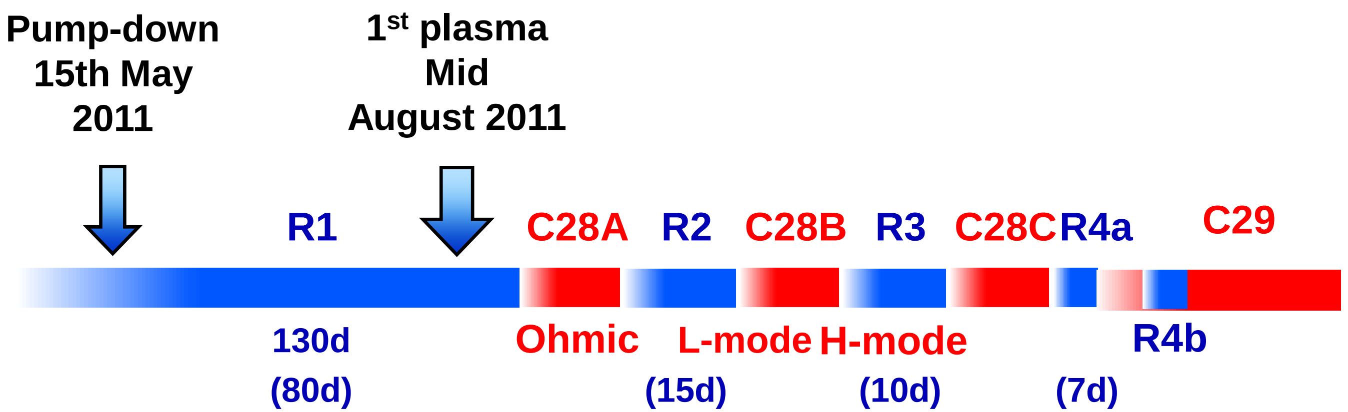
- **Be/W Melt layer motion, loss and stability**
- **Metallic dust formation**



Program Sequence – ILW 2011/2012

Maximise operating time and optimise with respect to Headlines and ITER priorities

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011								C28	C28	C28	C28	C29
2012	C29	C29	C30a	C30a	C30b	C30c	Shutdown					

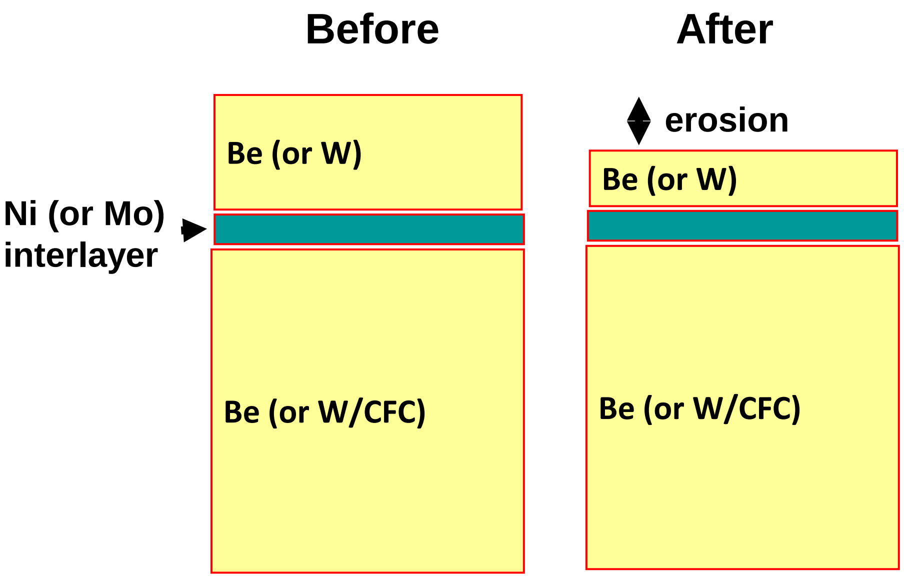


- Restart blocks interleaved with Campaign C28 blocks
- Controlled start with scientific supervision
- C28-C29 (fixed timeline) and C30 (provisional plan)
- C30 to be consolidated in Nov 2011 in a general planning meeting

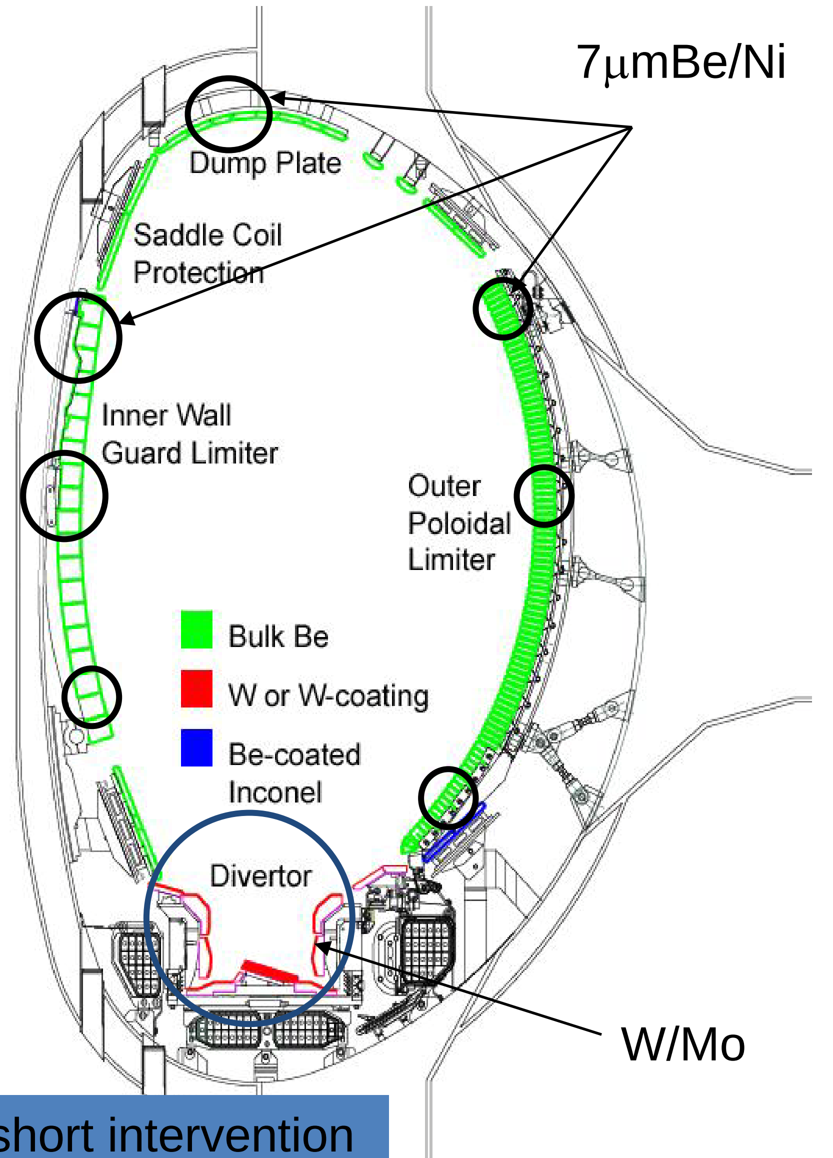
Campaign Overview

Campaigns	Duration		Target plasma
C28a	8 days	- Initial Be and W erosion and migration	Ohmic
C28b	~15days	- Fuel retention and migration in L-modes - Characterisation of L-mode at high and low shape in all metal environment.	High & low shape L-mode + P_{IN}=5MW/5s
C28c	~20 days	- Initial studies of low power H-mode. - Fuel retention and migration in low power H-mode.	High & low shape H-mode + P_{IN}=12MW/5s
C29	~46 days	- Development of capabilities and tools for high power operation. - Fuel retention and migration in robust H-modes	High & low shape H-mode (2.5MA/2.7T) + P_{IN}=15MW/8s First hybrid at 2T, b_N=3.
C30a	~36 days	- Safely expanding the operating space towards ITER relevant regimes at high power.	High & low shape H-mode (3.5MA/3.4T) + P_{IN}=32MW/4s Hybrid scenario up to 3T & b_N=3.
C30b	~ 21 days	- Physics issues in support of a the Be/W wall exploitation.	Work within established safe operating space
C30c	~13 days	- Preparation long term removal sample.	Robust H-mode one NIB

P. Coad , PFCM Rosenheim 2011



- **Marker tiles**
  - **2 full poloidal sets of divertor tiles**
  - **Outer poloidal limiter tiles**
  - **Inner wall guard limiter tiles**
  - **Dump plate tiles**
  - **Inner Wall Cladding tiles**



First set of tiles will be removed in 2012 during short intervention