Material Erosion and Redeposition during the JET MkIIGB-SRP Divertor Campaign

Forschungszentrum Jülich

Trilateral Euregio Cluster

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Outline

- Motivation
- Deposition on a quartz-microbalance
- Erosion/deposition of a tungsten-stripe
- $^{13}CH_4$ injection experiment
- Conclusions

Motivation (1)

Wall erosion – Material migration – Re-deposition

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Critical issues for ITER:

- Lifetime of wall elements

- Long-term tritium retention

- Availability of ITER

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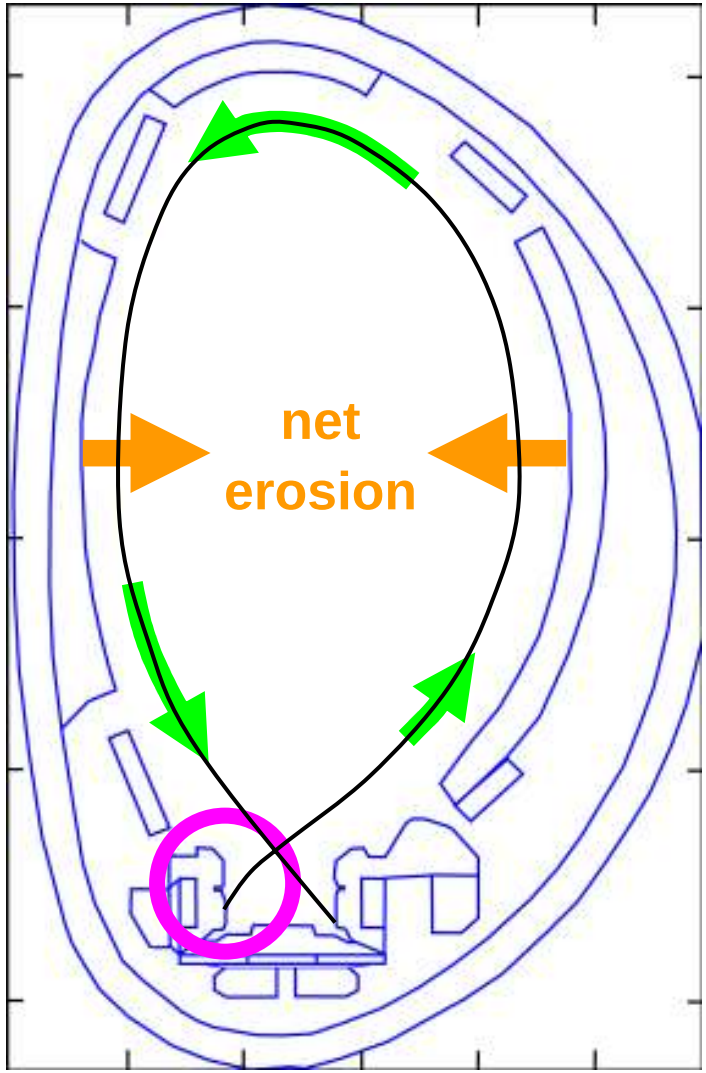
Existing experiments necessary for extrapolations to ITER

Motivation (2)



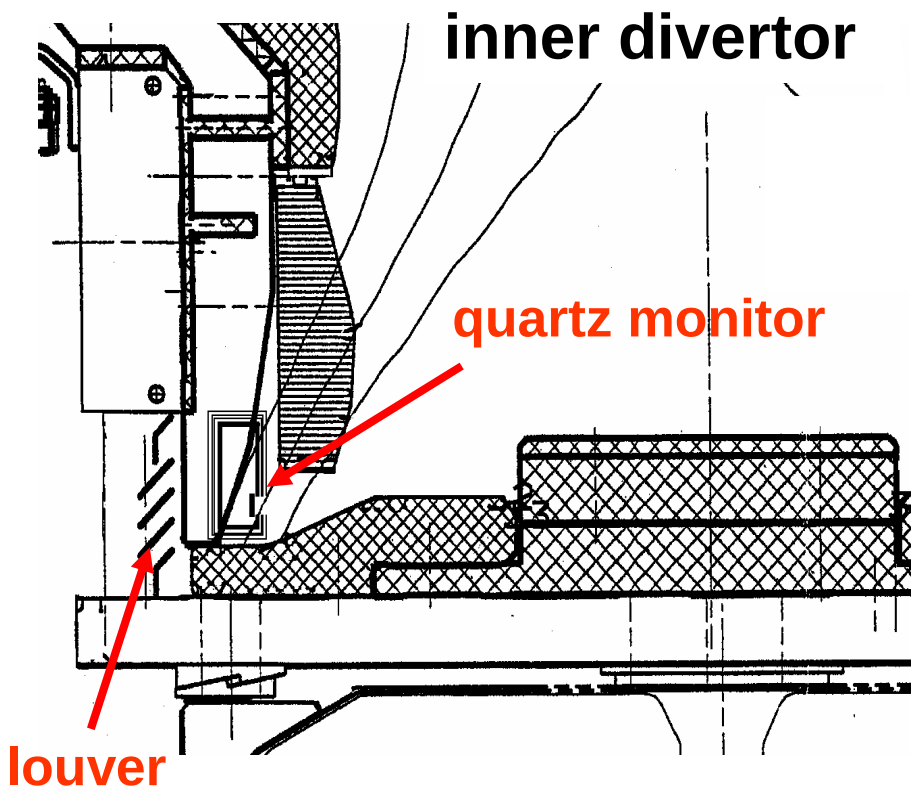
JET is currently the most ITER-relevant experiment with respect to:

- **size**
- **magnetic field**
- **high plasma current**

Before upgrade to ITER-like wall:

Understanding of material migration in full-carbon surrounding

The Quartz Micro Balance (QMB)



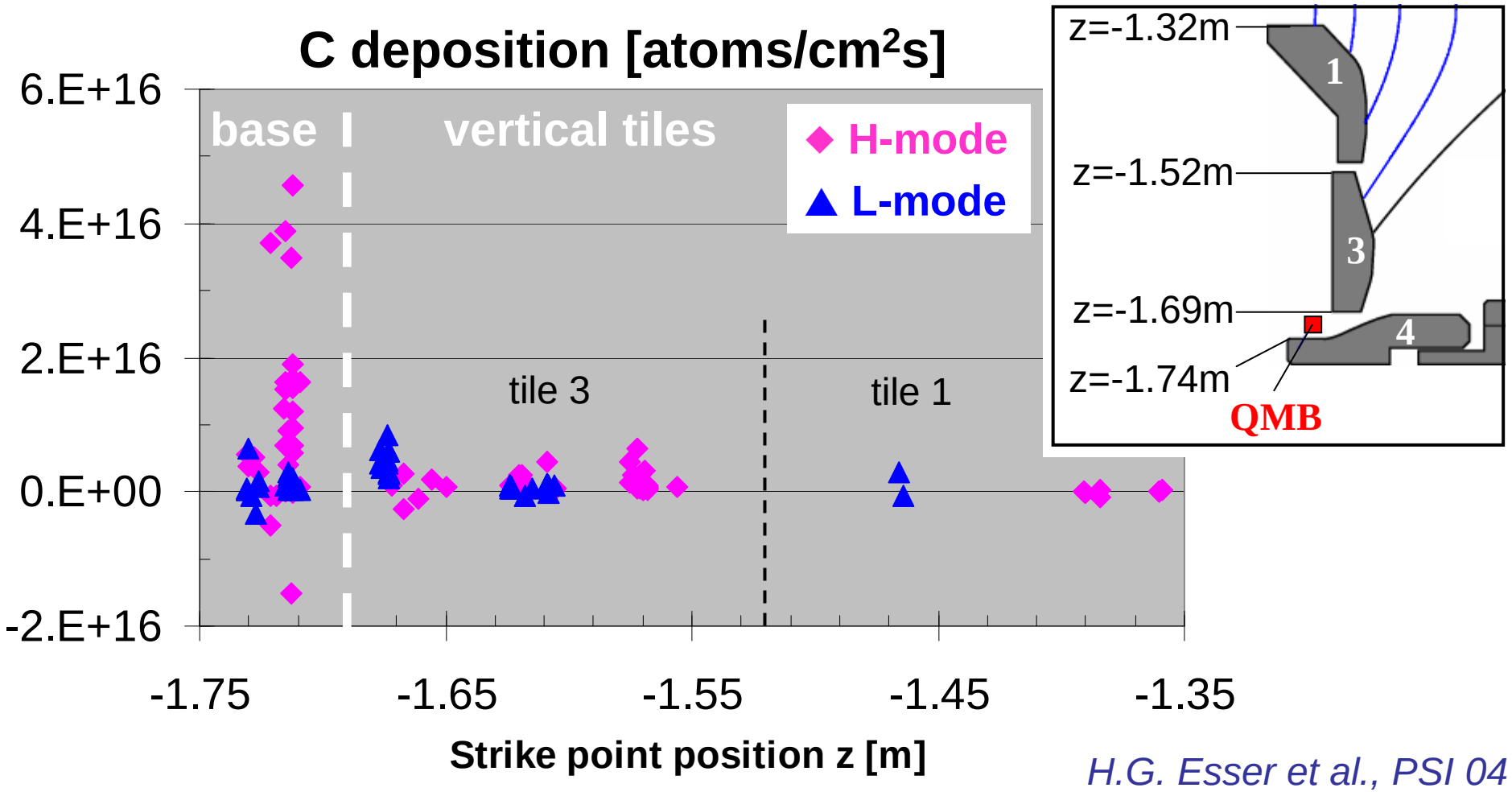
Principle:

Resonance frequency of quartz changes with mass

Thickness resolution: ~0.2 nm

***Shot-resolved* measurement of deposition (erosion) at one specific location.**

QMB deposition in dependence on strike point position

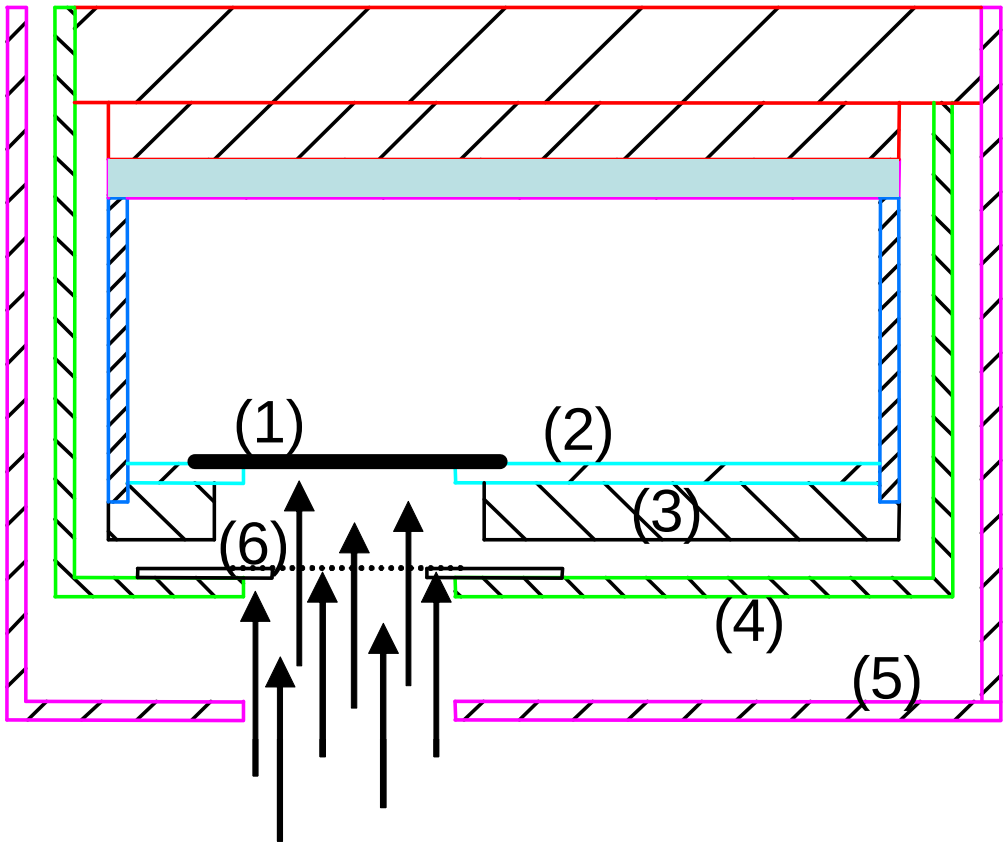


H.G. Esser et al., PSI 04

Largest deposition if strike point is on base plate

Post-mortem analysis of QMB (1)

Schematic horizontal cut of QMB-system across crystal



(1) Quartz

(2) Electronic board (Al_2O_3)

(3) Lid of copper box

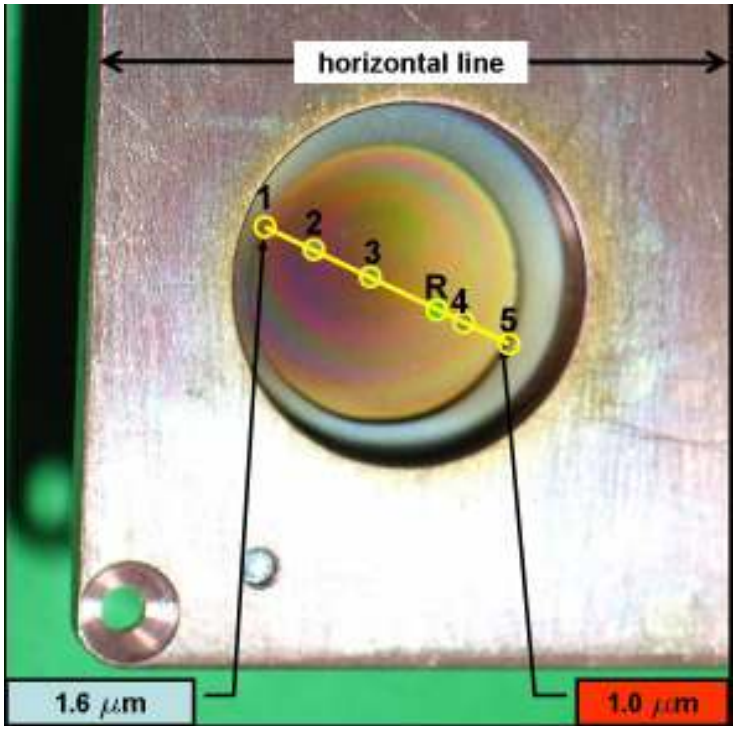
(4) Inner heat shield (stainless steel)

(5) Outer heat shield (stainless steel)

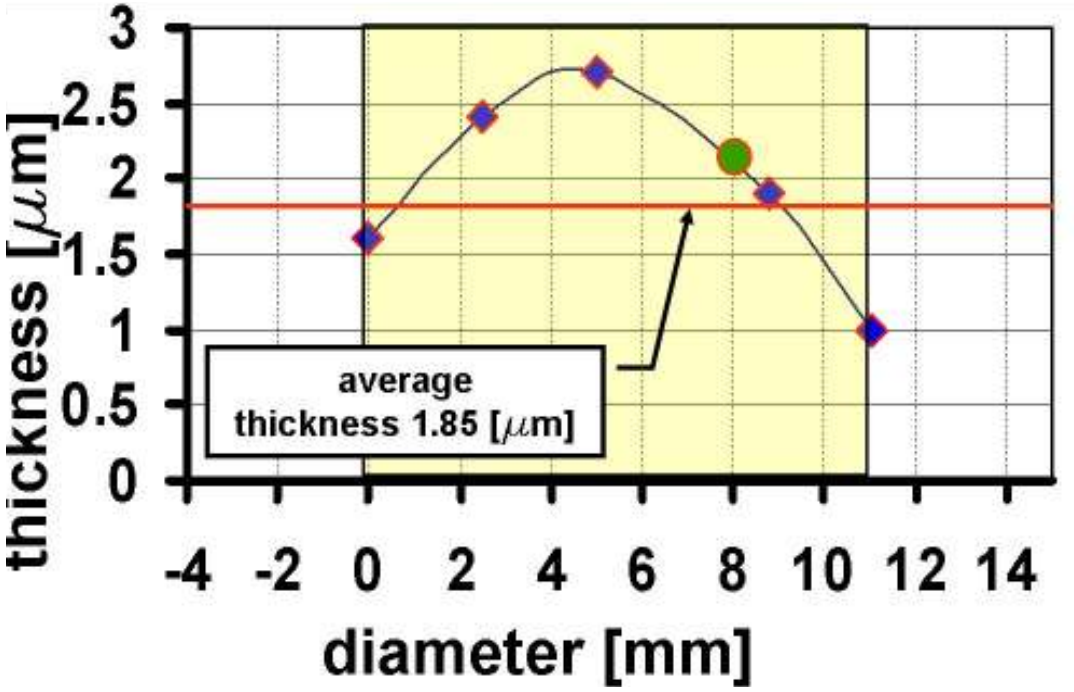
(6) Stainless steel ring with metal mesh

Post-mortem analysis of QMB (2)

Deposition on quartz



Layer Thickness (SIMS)

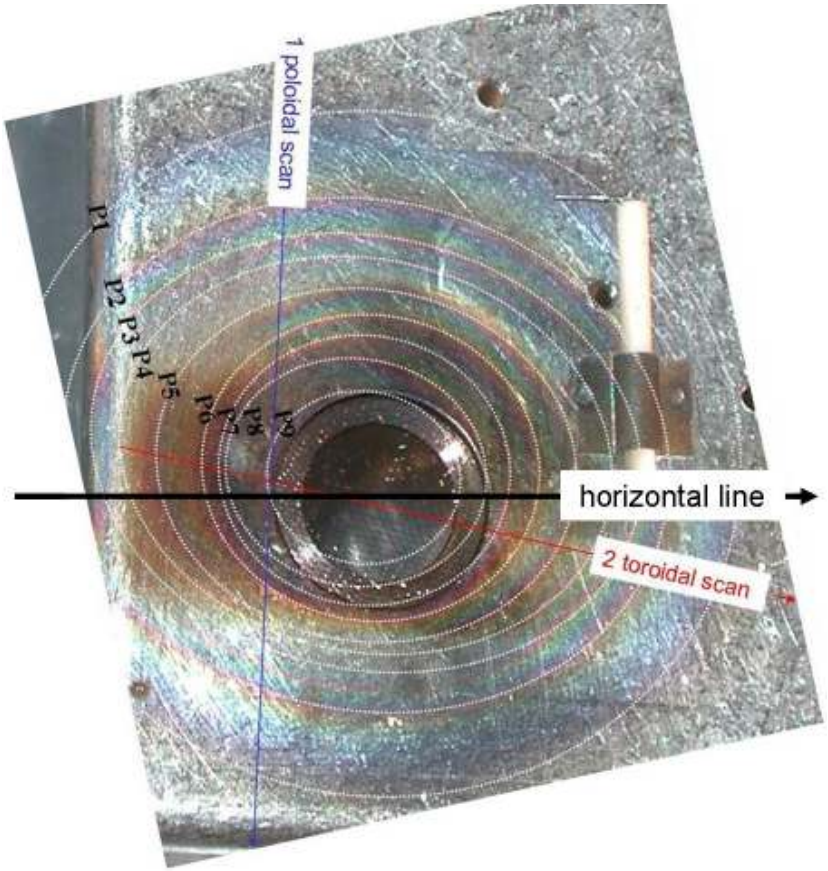


Average layer thickness on quartz: 1.85 µm

⇒ in accordance with total frequency shift:
$9 \cdot 10^{18}$ C atoms, layer density: ~1 g/cm³

Post-mortem analysis of QMB (3)

Deposition on inner heat shield



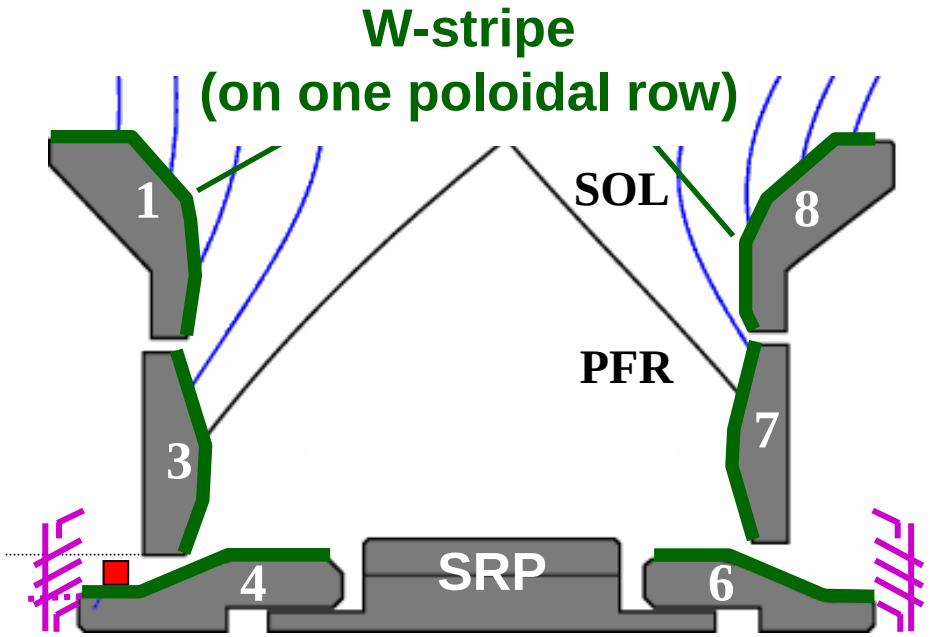
Significant deposition on inner heat shield:

$6.2 \cdot 10^{18}$ atoms

(compared to $9 \cdot 10^{18}$ on crystal)

H.G. Esser et al., PSI 06

Tungsten stripe on one poloidal row in the divertor

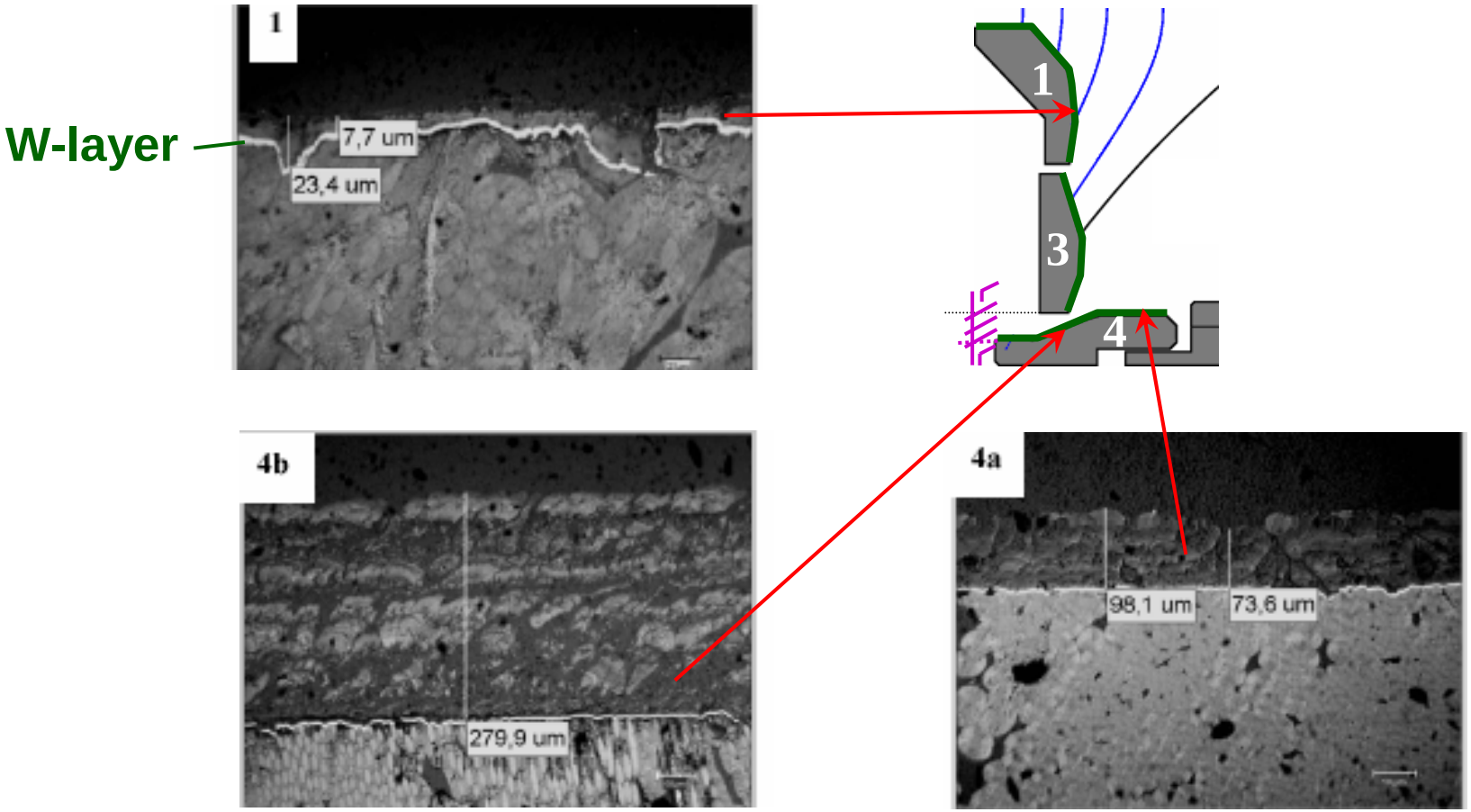


W-stripe:

- 3 µm thickness
- 2 cm width

- *Study of erosion and deposition behaviour in the divertor*
- *ITER-like wall project: assessment of required W-layer thickness for outer divertor*

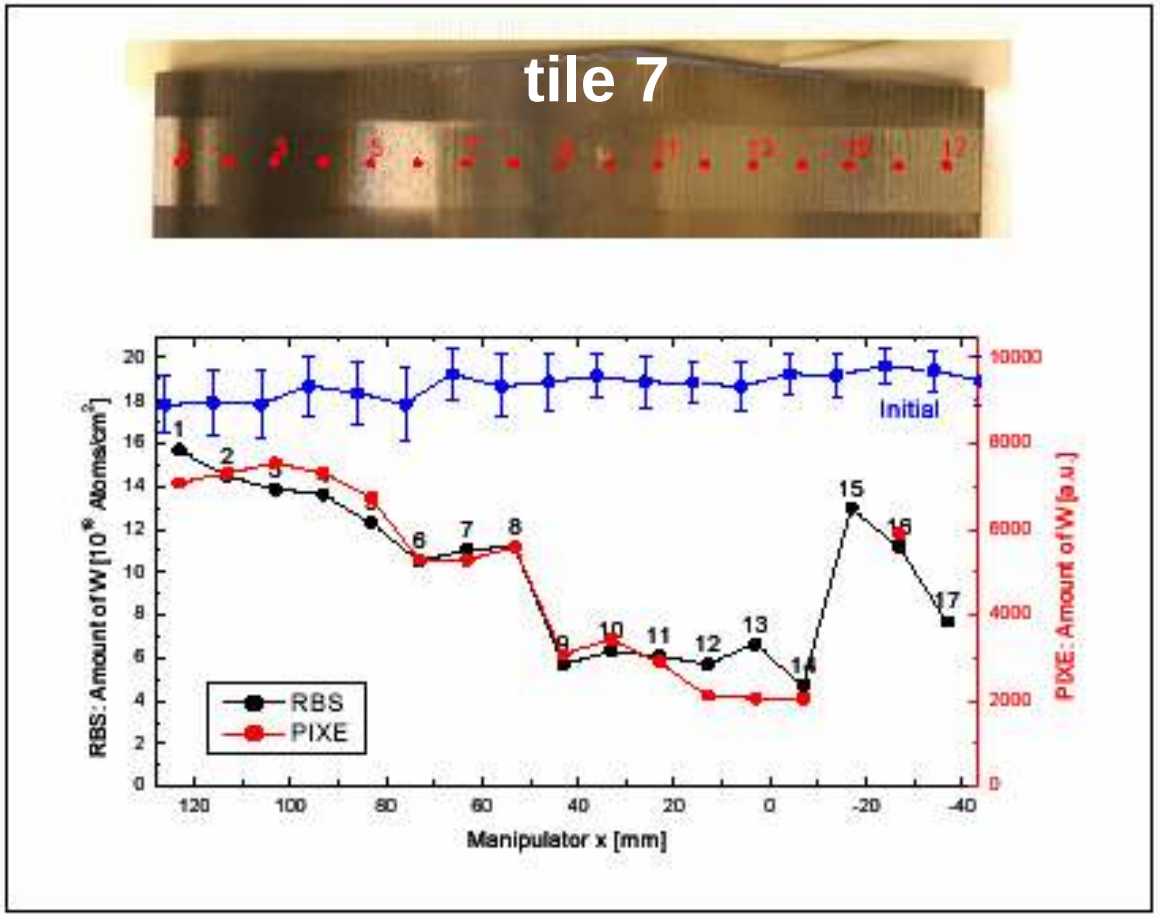
Inner divertor: metallographic cross sections of W-stripe

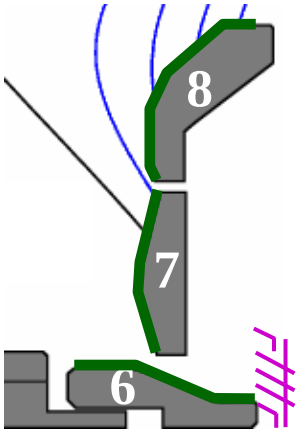


- *Inner divertor is deposition-dominated*
- *Largest deposition on inclined part of tile 4*
- *In total: 540 g ($3.2 \cdot 10^{20}$ atoms)*

Outer divertor: ion beam analysis of W-stripe

M. Mayer et al., PSI 06

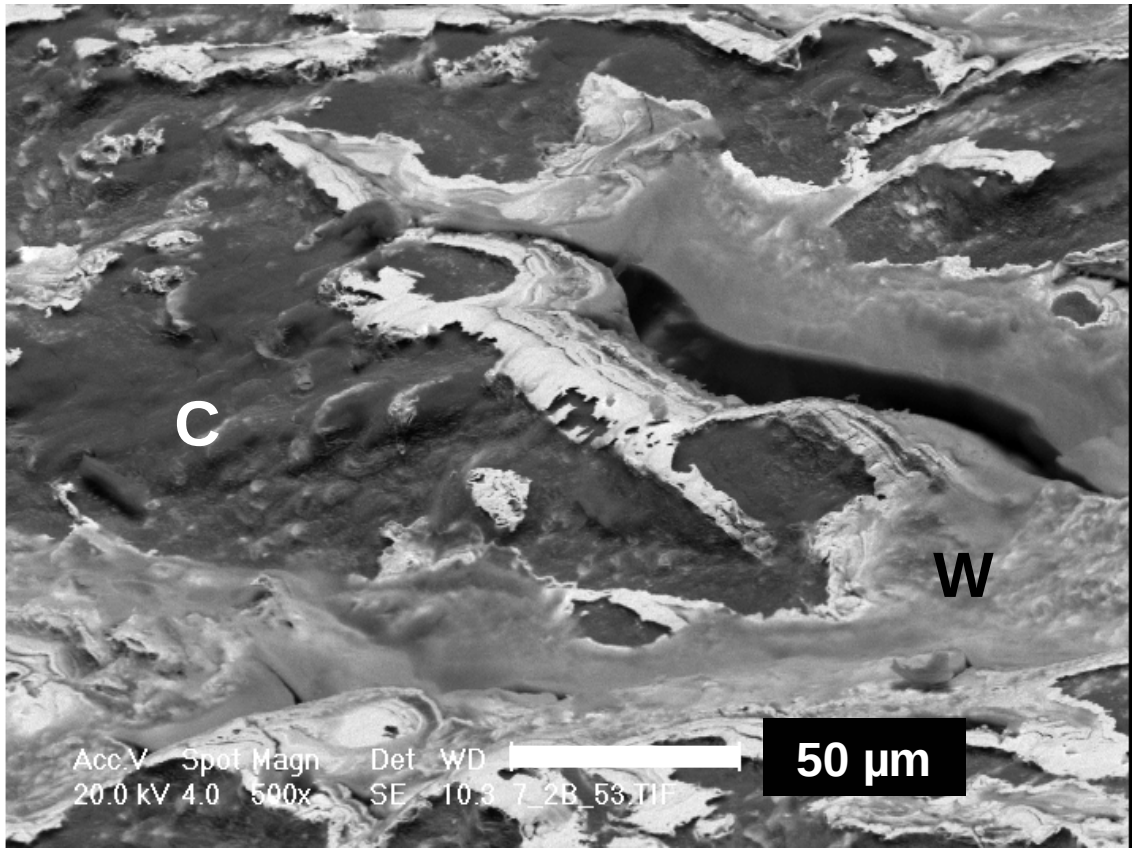




- ***Vertical tiles 7, 8 are erosion-dominated***
- ***Largest erosion at position with highest fluence (tile 7)***
- ***Large erosion at apron of tile 8***

Outer divertor: microscopic analysis of W-stripe

SEM picture of tile 7



- ***Non-uniform erosion on a scale-length of 10 – 30 µm***
- ***Possible explanation: surface roughness***

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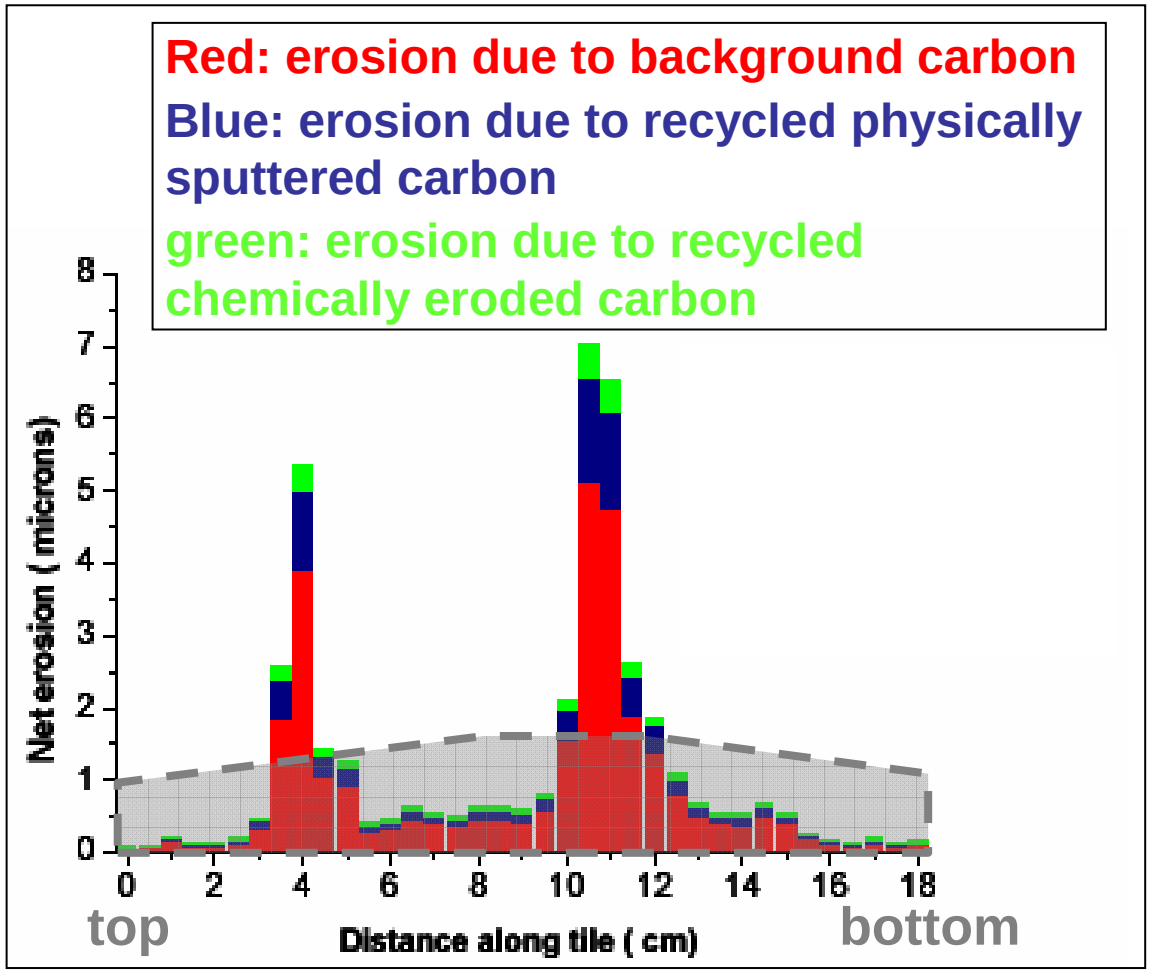
Preferential erosion of hills, less erosion (or even deposition) in valleys

Outer divertor: ERO modelling of net erosion of W-stripe

Modelled net erosion along tile 7



- Using campaign-averaged plasma parameters
- C^{3+} - influx: 0.5%
- Symmetry in toroidal direction

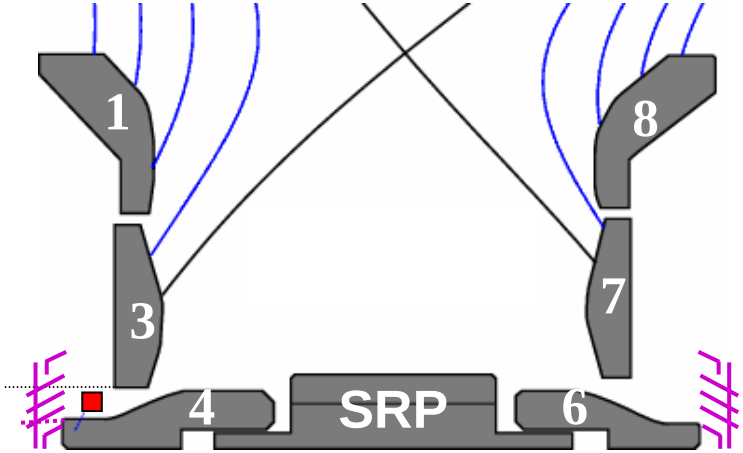
- *~ 50% W-redeposition on stripe*
- *Erosion-dominated by background carbon*
- *Max. erosion ~ 7 µm*

Overall deposition in the divertor

- *Inner divertor tiles 1, 3, 4:* **540 g**
  (from metallographic cross-sections)
- *Outer divertor tile 6:* **380 g**
  (from metallographic cross-sections)
- *Inner louver region:* **60 g**
  (from QMB)
- *In total:* **980 g**

or **$5.9 \cdot 10^{20}$ atoms/s**

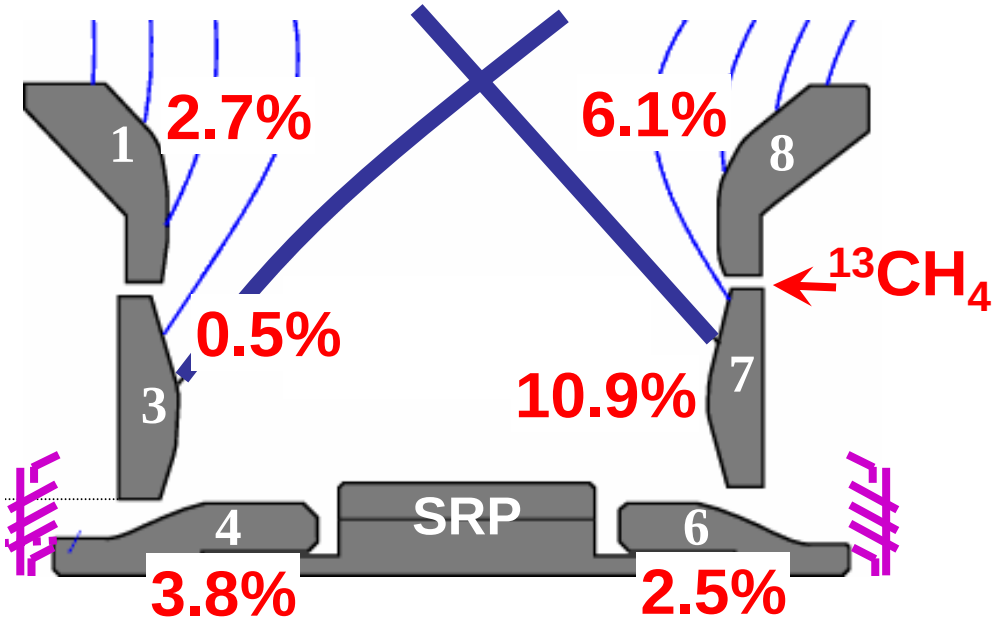
Not included: SRP, gaps and main chamber !



*Average deposition rate during MkIIGB-SRP is similar to previous campaigns (**$6.6 \cdot 10^{20}$ in MkIIA and $3.5 \cdot 10^{20}$ in MkIIGB**)*

^{13}C marked methane injection

J.P. Coad et al., PSI 06

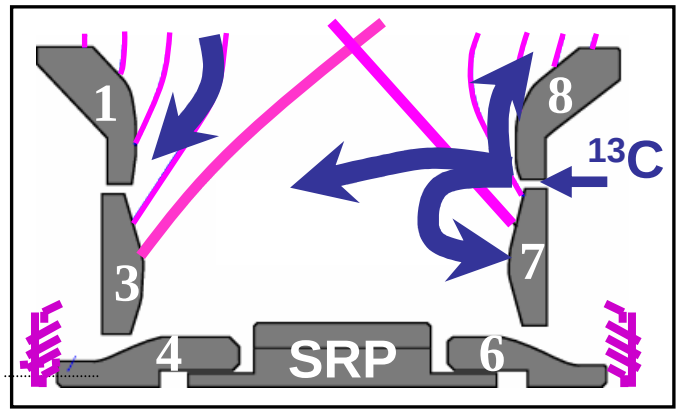


- Carried out at last shot day of the campaigns
- $^{13}CH_4$ injection into outer divertor during 32 identical discharges (ELMy H-mode, strike points on vertical tiles)
- In total: $4.3 \cdot 10^{23}$ ^{13}C atoms
- No further plasma operation

- *About 20% of injected ^{13}C deposited at outer divertor tiles*
- *About 7% of injected ^{13}C at inner divertor tiles*
- ^{13}C also detected on fast reciprocating probe at top of low field side ⇒ transport around main plasma
- Only small amount of ^{13}C at shadowed areas

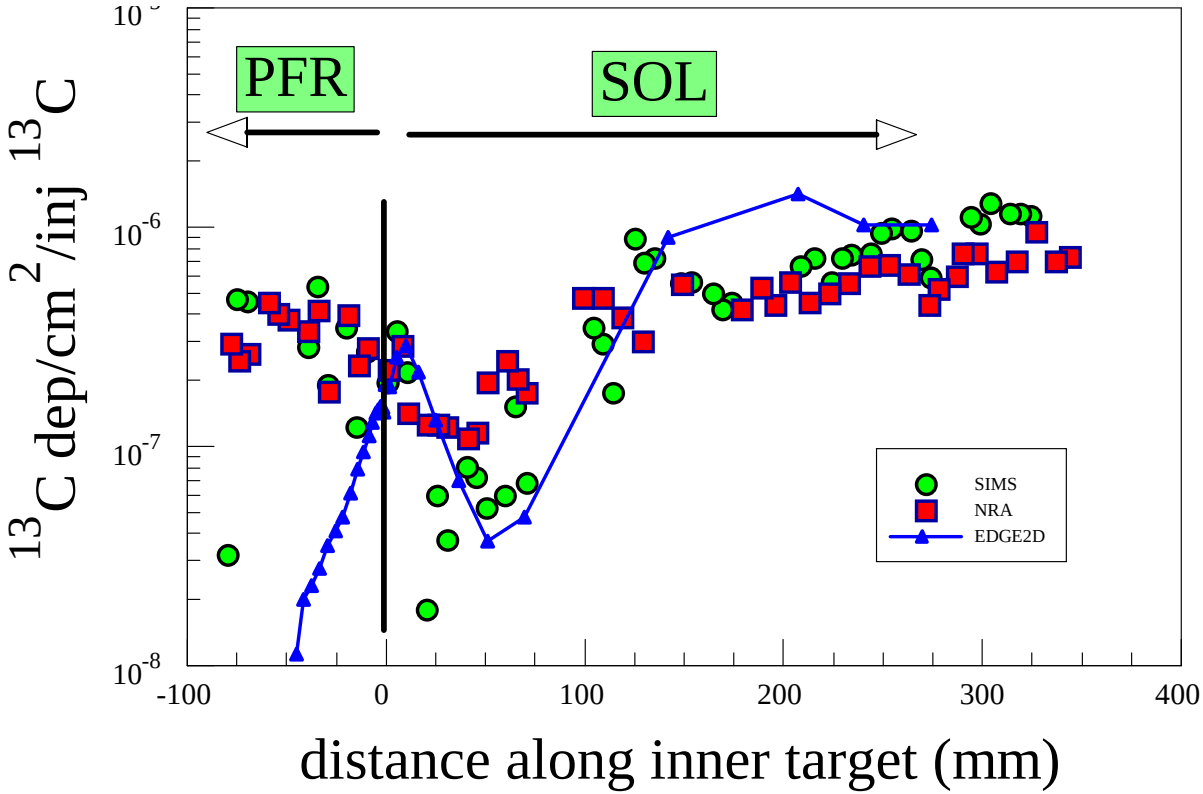
^{13}C marked methane injection: EDGE2D modelling

- NIMBUS code for neutrals, EDGE2D for ions
- SOL flow adjusted to measured data
- No re-erosion of ^{13}C



J.D. Strachan et al., APS 06

^{13}C deposition along inner targets



- *Long-range ^{13}C transport mainly in between ELMs*
- *Most of ^{13}C deposited on outer target (~90%)*
- *^{13}C deposition on inner target in SOL in good agreement with exp.*

Conclusions

- **Inner divertor**: everywhere **deposition-dominated**
- **Outer divertor**: **vertical tiles erosion-dominated**, **base plate: deposition**
- **Tungsten stripe**: at **outer vertical tile heavy erosion**
  ⇒ **ITER-like wall: 200 µm suggested**
- **Material transport to remote areas** mainly in specific magnetic configurations (**strike point on base plate**)
  ⇔ QMB, $^{13}CH_4$ tracer injection
- Estimated **fuel retention** rate : **2.7%**
  (w/o gaps, SRP and main chamber ⇒ plus 50%)