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MAX PLANCK INSTITUTE
FOR PLASMA PHYSICS

BORON REDISTRIBUTION AFTER BORON POWDER INJECTION IN ASDEX UPGRADE

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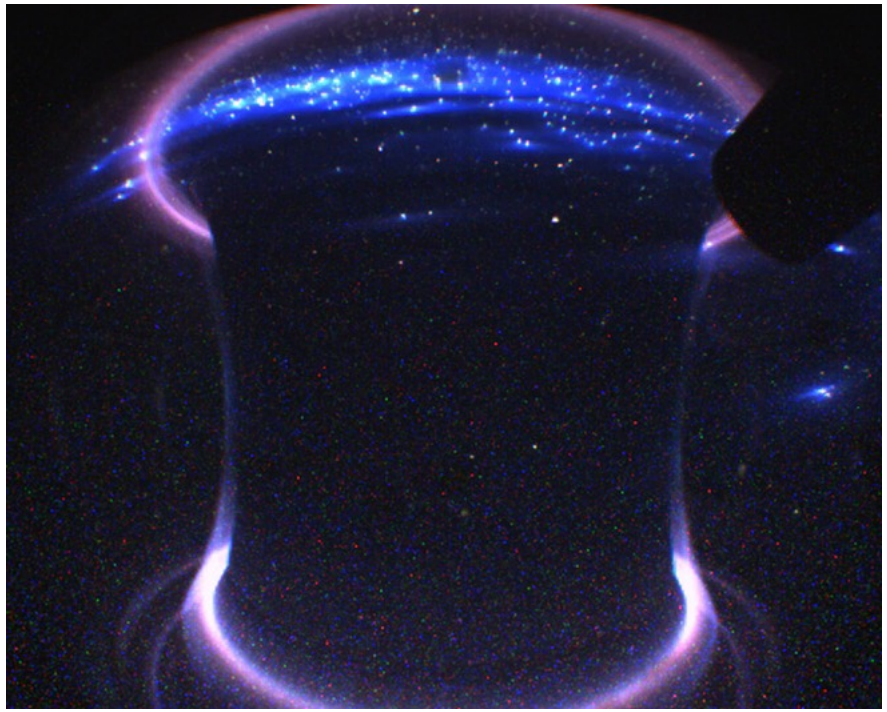
INTRODUCTION

Main tool for optimising wall conditions in AUG: glow discharge boronisation

J. Winter et al., J. Nucl. Mat. 162 (1989) 713-723
V. Rohde et al., J. Nucl. Mat. 363 (2007) 1369-1374

Complimented by boron powder injection into plasma discharges

A. Bortolon et al., Nucl. Mat. and Energy 19 (2019) 384-389
A. Bortolon et al., Review Talk WR03(D), this conference



Efficacy determined by thickness and uniformity of deposited B

Quantification by exposure and ex-situ analysis of witness samples

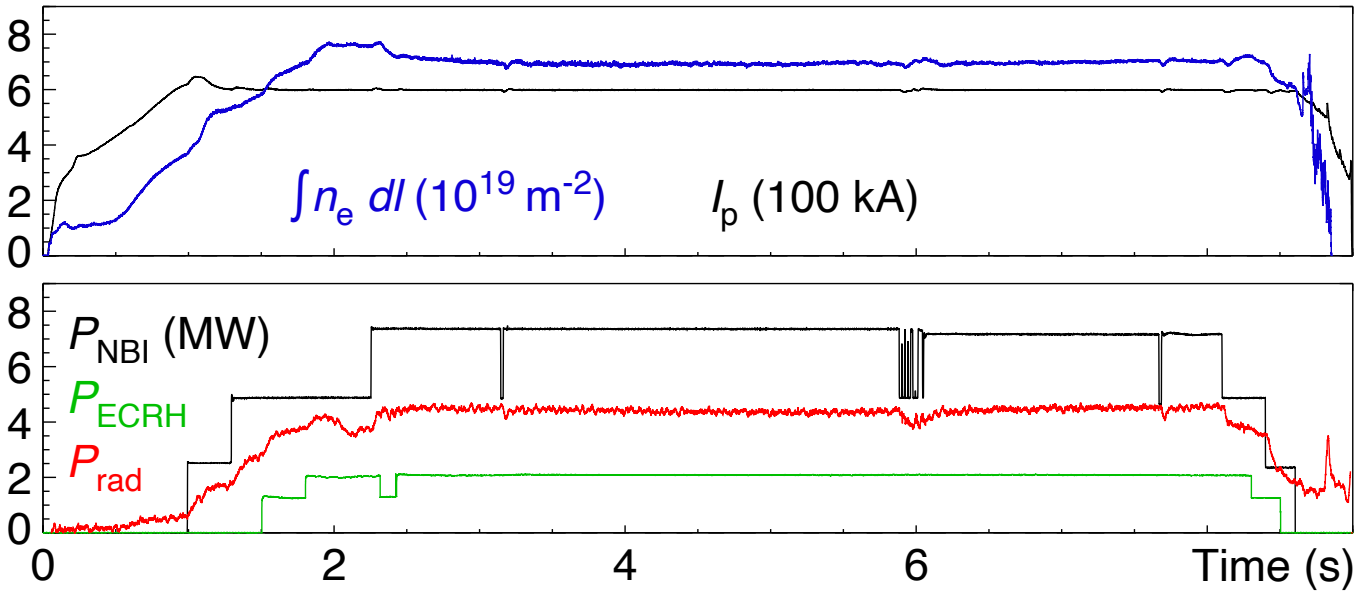
KEY QUESTIONS

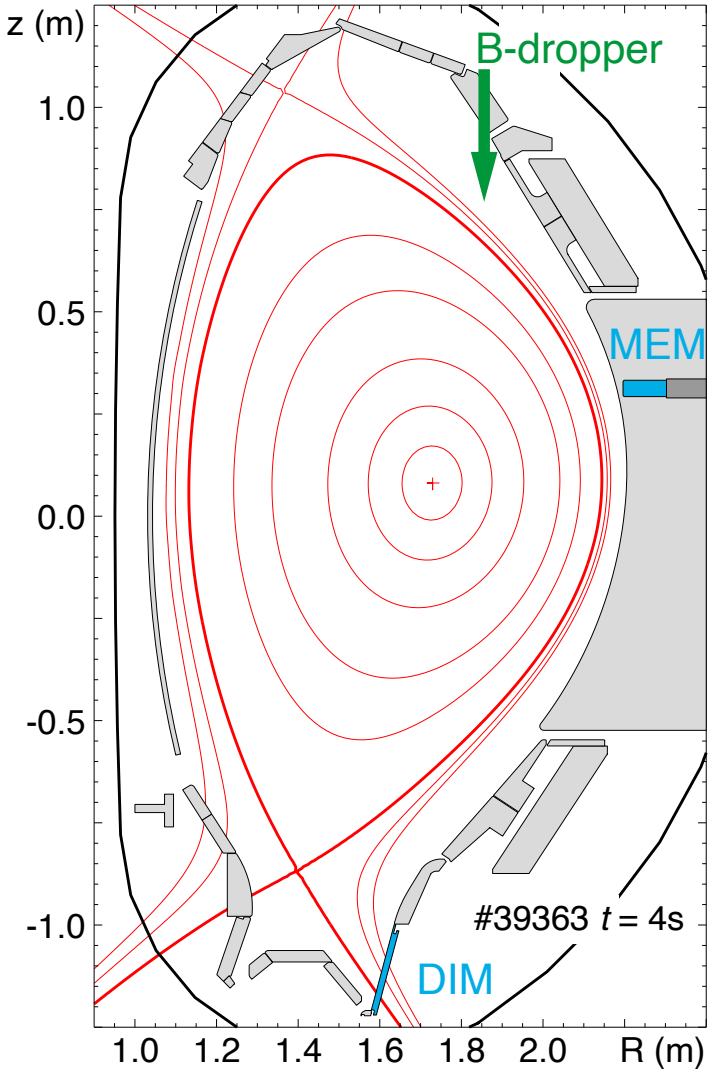
1) What is the spatial distribution of deposited boron?
2) (How) do boron layers scale with amount of injected B?
3) What fraction of injected boron vs residual boron is found in deposits?

EXPERIMENT DESIGN

DISCHARGE SCENARIO AND DIAGNOSTICS

Two experiments with same H-mode plasma scenario





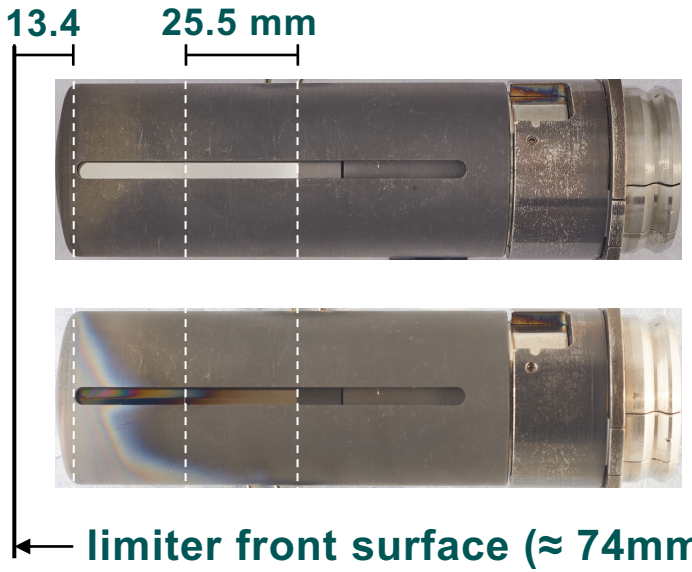
WITNESS SAMPLE ARRANGEMENT EXPERIMENT 2

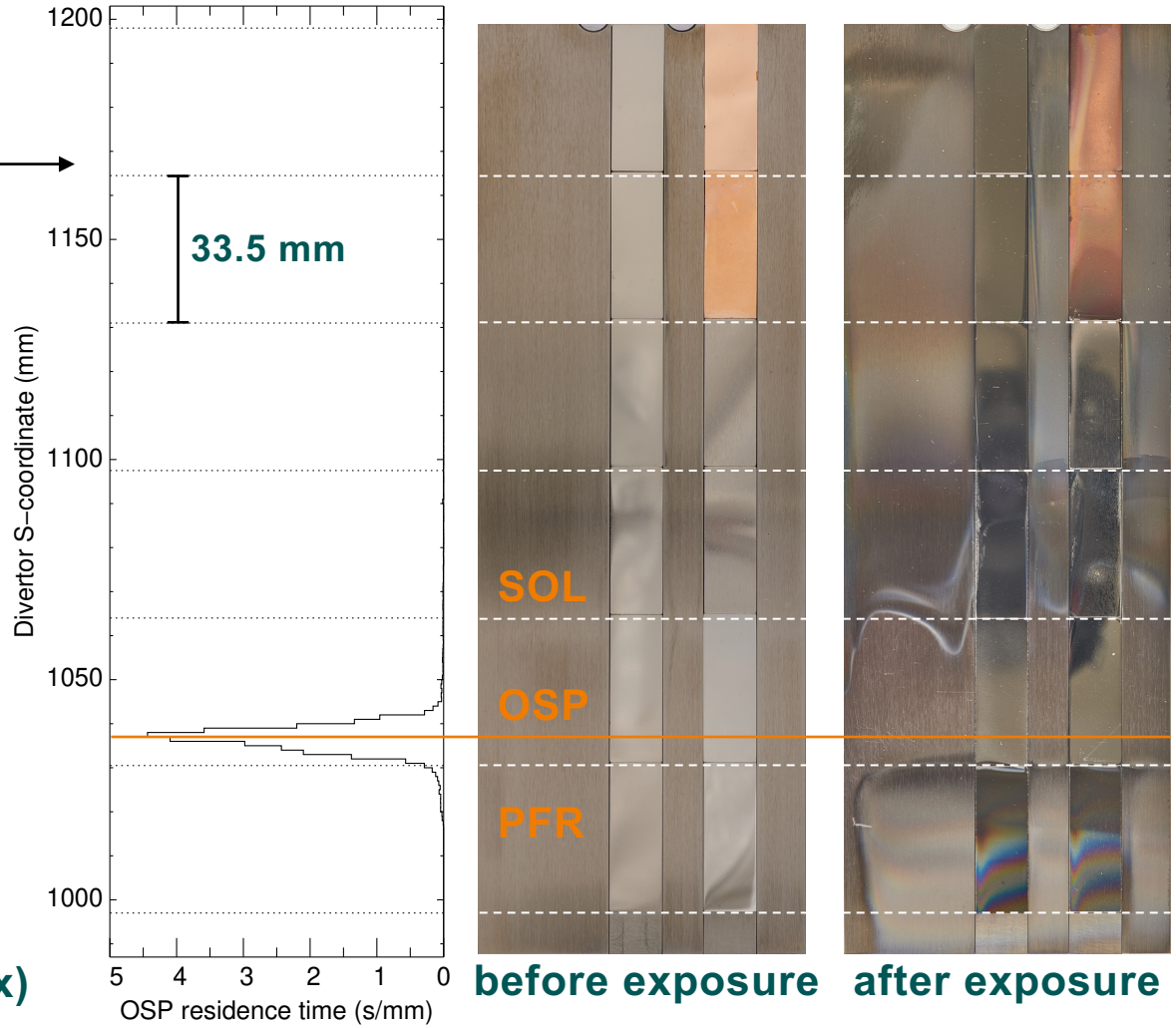
Divertor

2 rows of W intarsia in divertor tiles

Mid-plane

2 samples oriented radially





BORON INJECTION RATE AND TOTAL AMOUNT

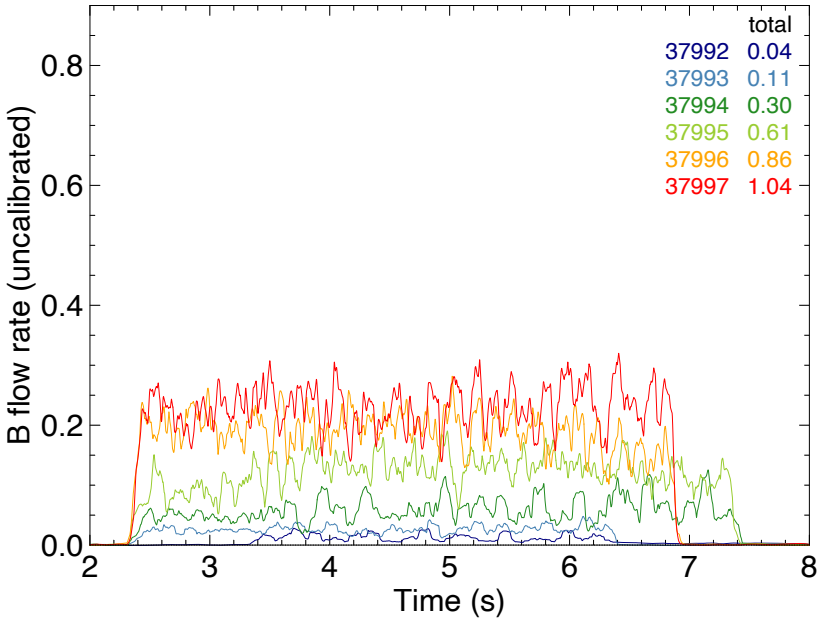
Note: integrated FlowM and injected masses do not fit. Different calibration factors in both experiments?

Isotopically enriched B to distinguish from residual B

Isotope	^{10}B	^{11}B
Natural	20%	80%
Exp 1	5%	95%
Exp 2	95%	5%

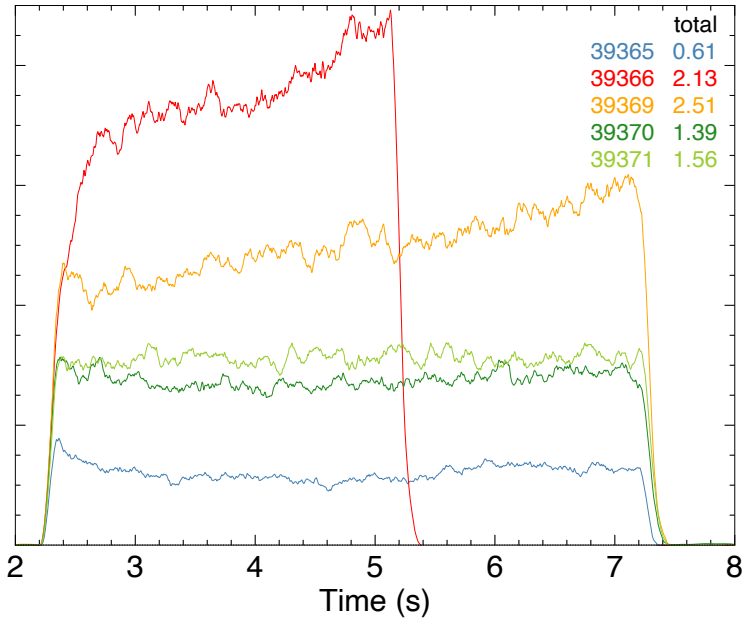
Integrated FlowM = 2.96

Exp 1 total ≈ 200 mg



Integrated FlowM = 8.20

Exp 2 total ≈ 1400 mg



EXPERIMENTAL RESULTS

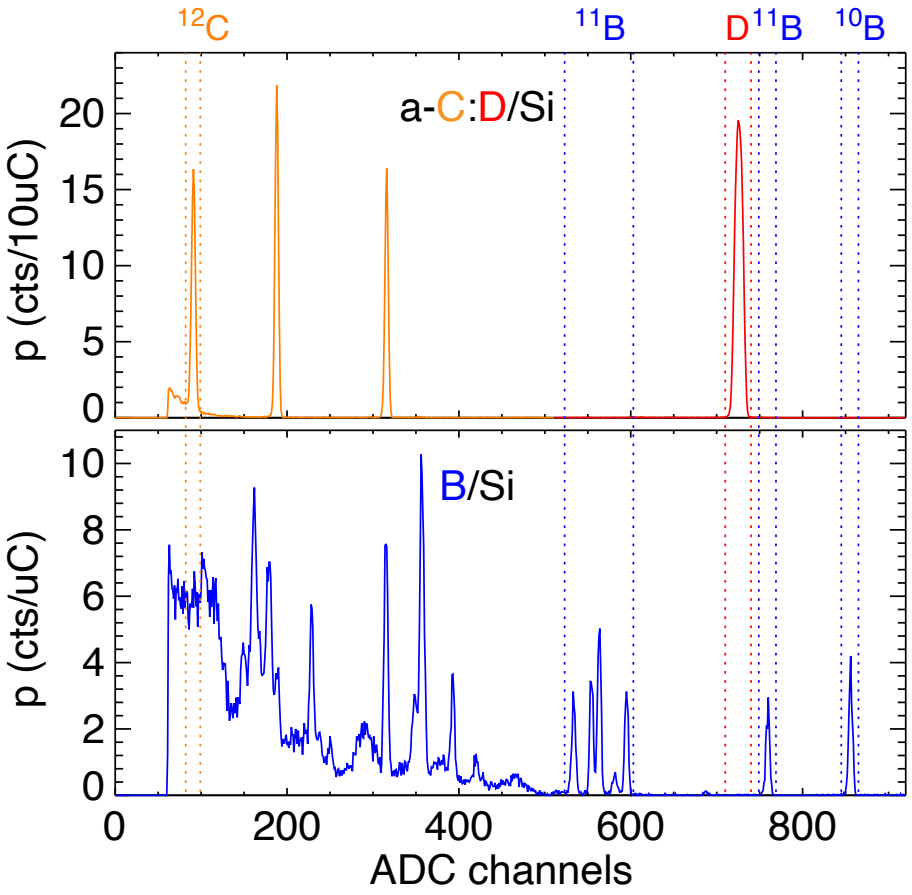
QUANTIFICATION OF DEPOSITED BORON

Nuclear reaction analysis using 2.5 MeV ^{3}He ions

D	^{3}He(D,p)^{4}He
^{10}B	^{3}He(^{10}B,p)^{12}C
^{11}B	^{3}He(^{11}B,p)^{13}C
^{12}C	^{3}He(^{12}C,p)^{14}N

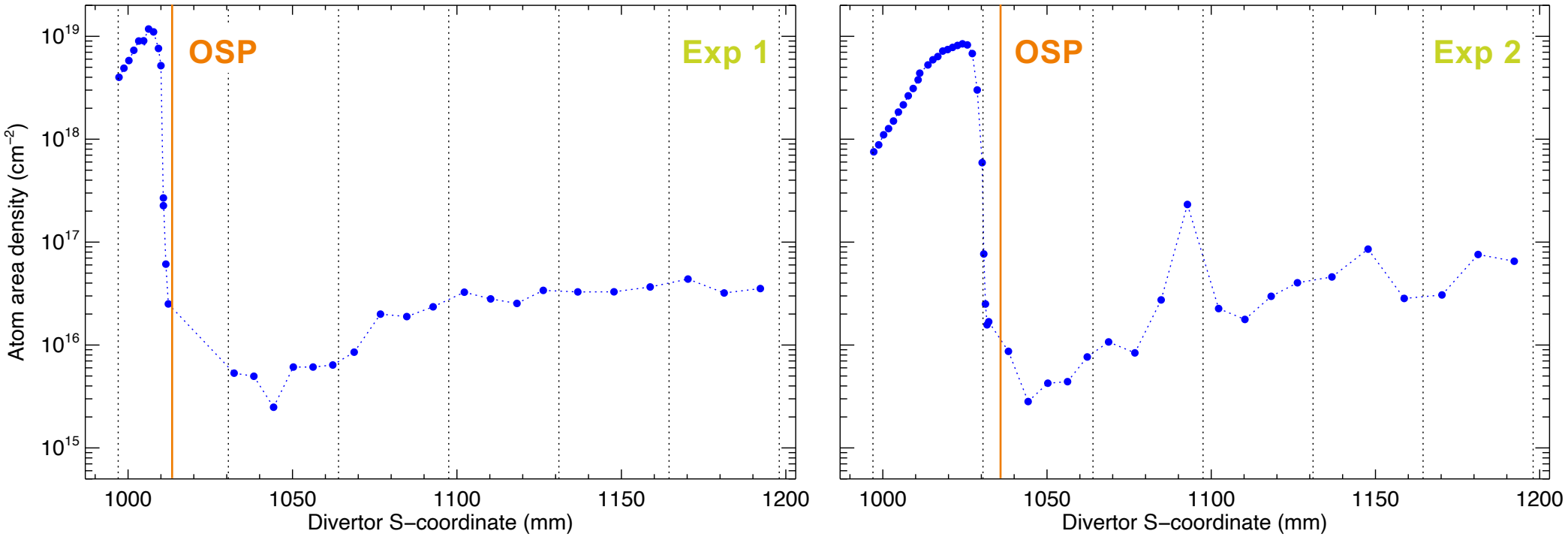
Detect energy spectra of created protons

Compare to calibration samples →



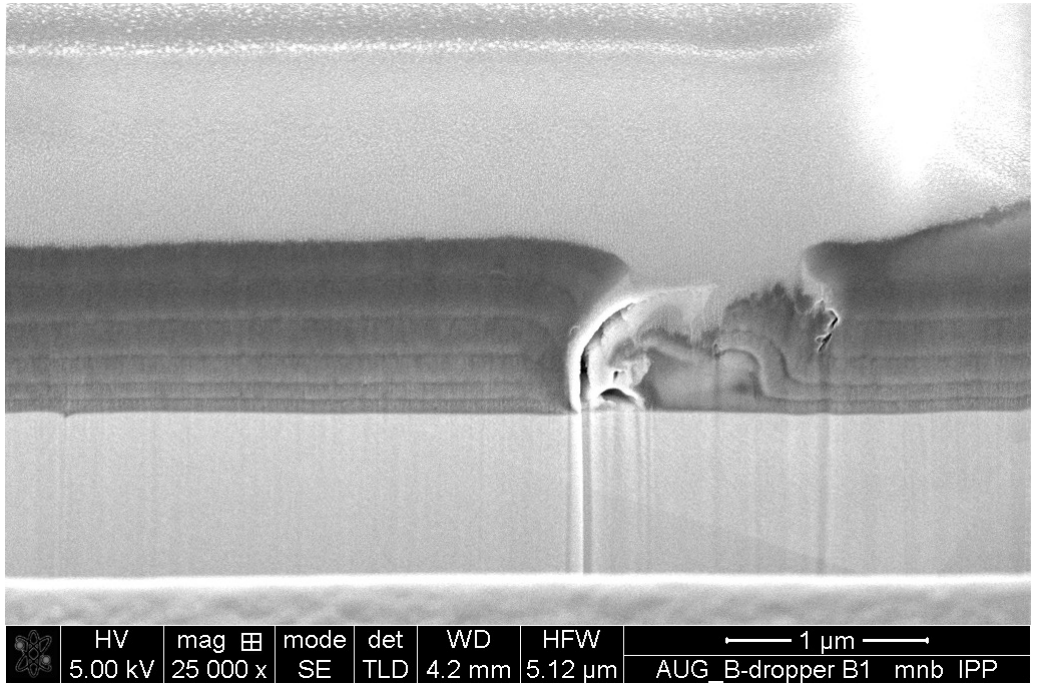
DEPOSITION IN DIVERTOR

- Thick B deposits up to ≈ 1.4 µm in area exposed to private flux region plasma
- Mono layers in high heat flux region → increasing ≈ ×10 towards outer SOL region
- 2nd experiment: thickness in PFR similar to 1st despite ×7 total B injected!



SEM ANALYSIS OF DEPOSITS IN PFR – EXP 1

- Sharp transition to deposition below OSP
- Total thickness across FIB cut 1.4 µm
- Distinct strata for successive discharges



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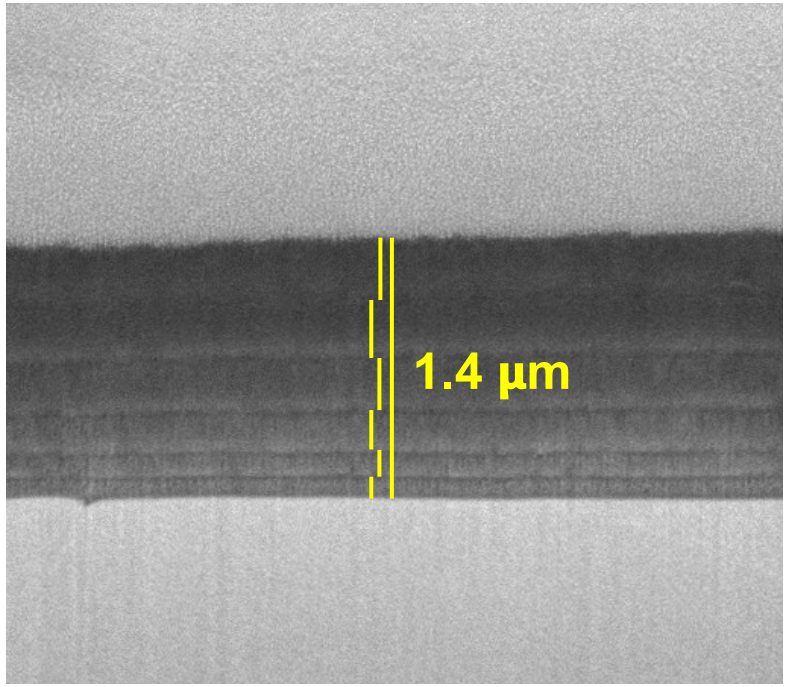
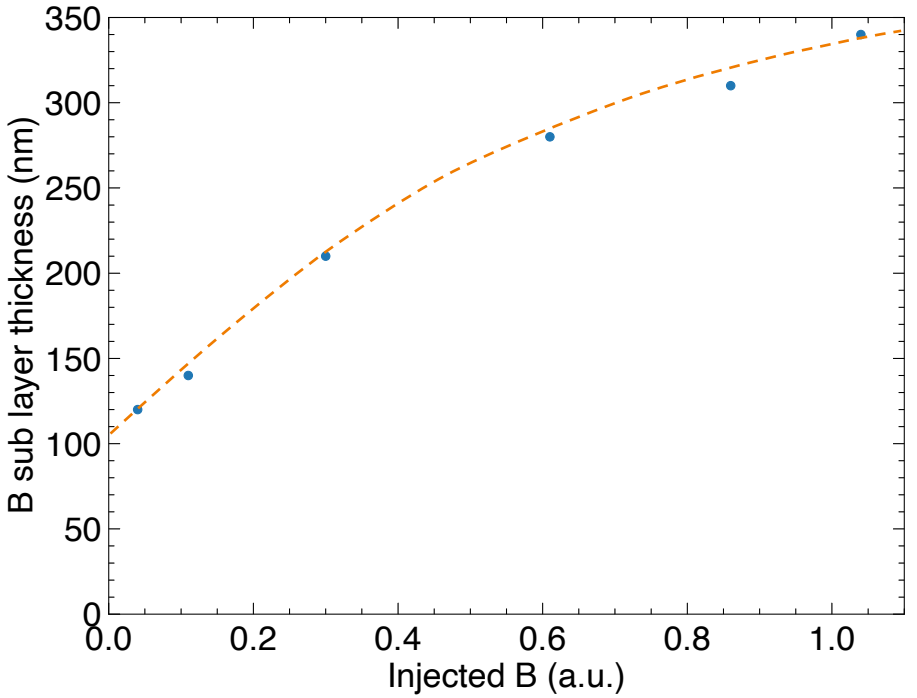
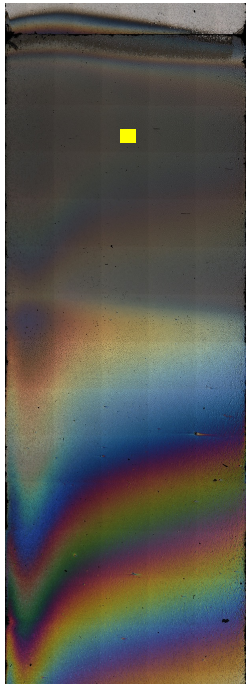


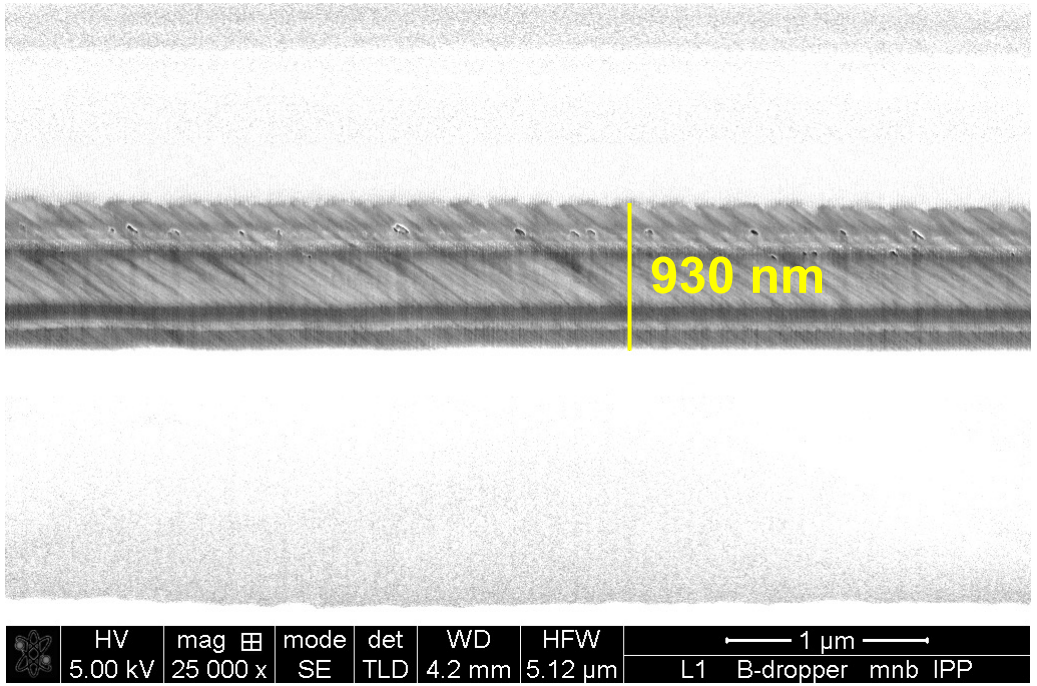
- B deposition rate decreasing with injected amount of B
- Indication for saturation



SEM ANALYSIS OF DEPOSITS IN PFR – EXP 2

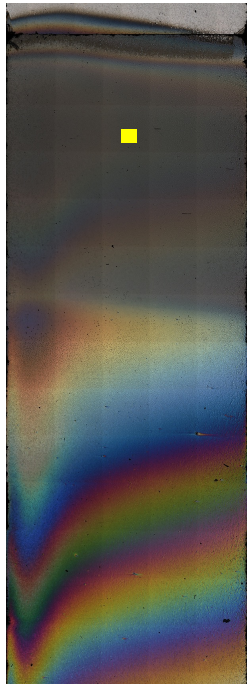
- **Sharp transition to deposition below OSP**
- **Total thickness across FIB cut 930 nm**

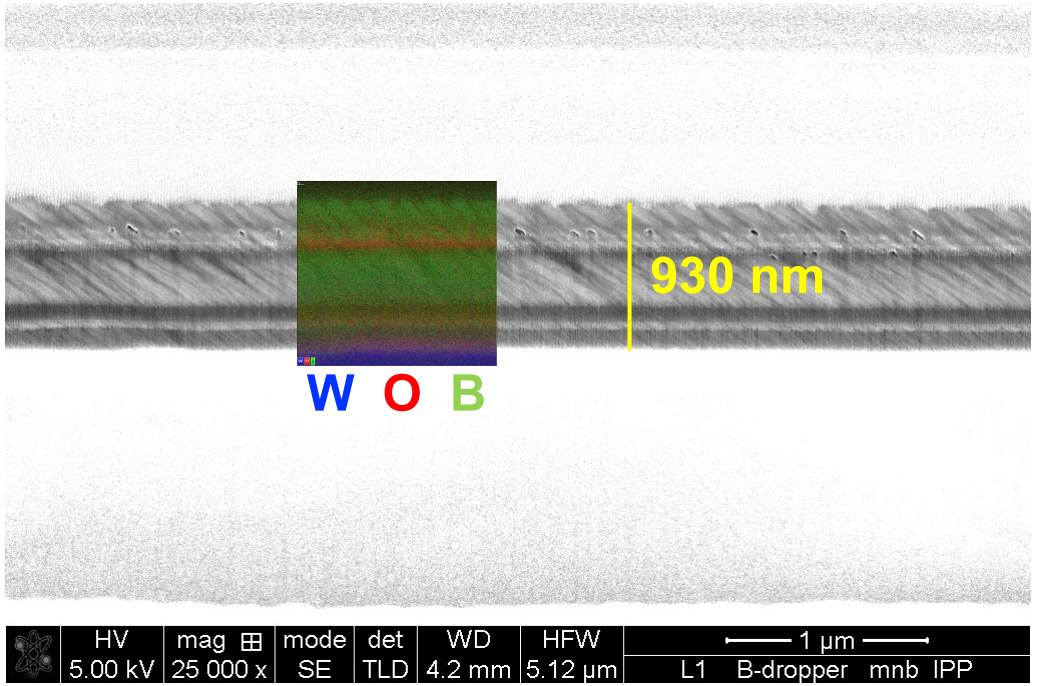




SEM ANALYSIS OF DEPOSITS IN PFR – EXP 2

- Sharp transition to deposition below OSP
- Total thickness across FIB cut 930 nm
- Deposition strata not clearly correlated to successive discharges

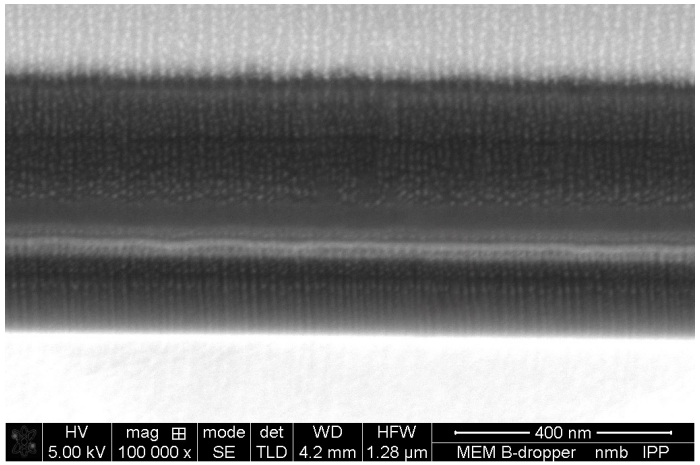


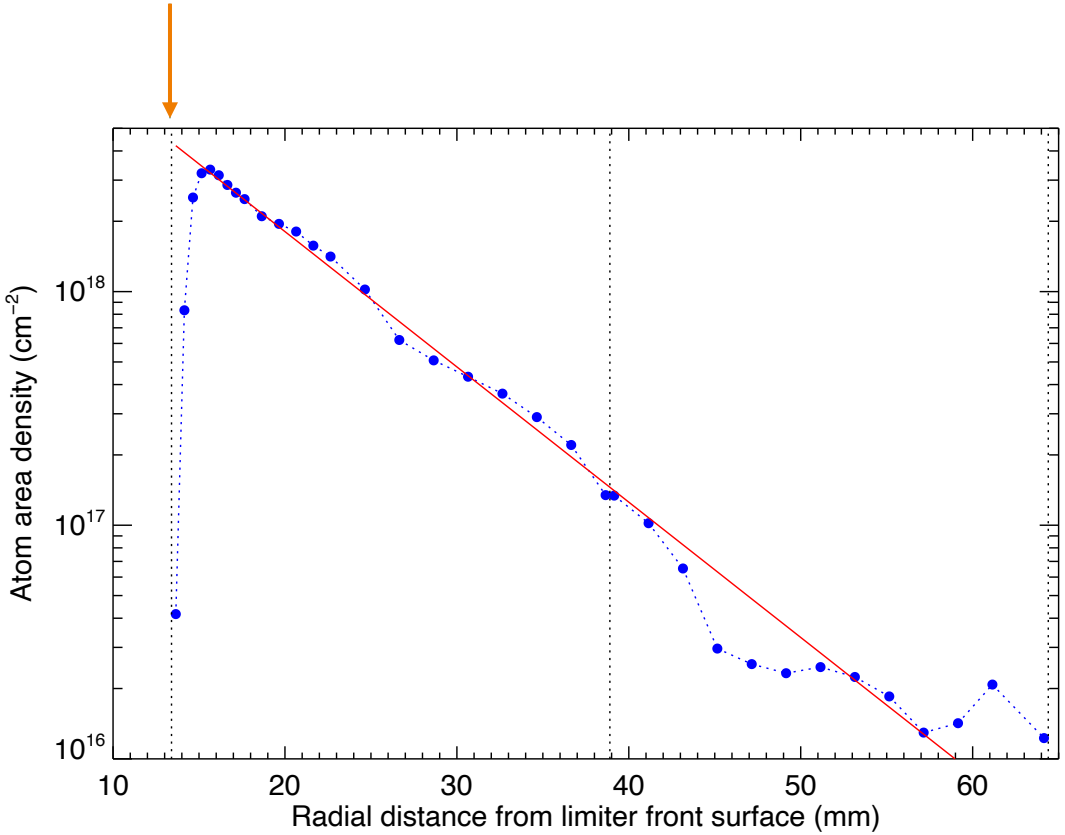


Visible structure partly correlated to oxygen content

DEPOSITION AT OUTER SCRAPE-OFF LAYER

- Deposition in antenna limiter shadow starting ≈ 77 mm outside separatrix
- Exponential fall-off with **λ ≈ 7.5 mm**
- Maximum thickness ≈ 0.4 µm
- Deposition strata again not clearly correlated to successive discharges





FRACTION OF INJECTED VS RESIDUAL BORON

- Isotope fractions in divertor and far-SOL deposits:

		^{10}B	^{11}B
Experiment 1	PFR:	6.7%	93.3%
Experiment 2	PFR:	73.0%	27.0%
	MEM:	70.1%	29.9%

- **Express isotope fractions as linear combination of injected and residual (natural) isotope mix:**

		residual	injected
Experiment 1	**PFR:**	**11%**	**89%**
Experiment 2	**PFR:**	**29%**	**71%**
	MEM:	**33%**	**67%**

BORON INJECTION VS DEPOSITION BALANCE

- Integral of B deposited in PFR area of divertor tile assuming toroidal symmetry
- Integral of B deposited at main chamber antenna limiter side faces assuming measured profile and extrapolated to limiter front
- **Experiment 1**
  Divertor: $1.05\times10^{22} \cong 188$ mg vs 200 mg injected B powder
- **Experiment 2**
  Divertor: $1.49\times10^{22} \cong 267$ mg vs 1400 mg injected B powder
  Limiters: $0.85\times10^{22} \cong 153$ mg (36% of total deposited boron)
- **Lower deposition efficiency in 2nd experiment from both isotope ratio and total mass**
- **No strong evidence for influence of preceding GD boronisation:**
  115 discharges before exp 1, 88 discharges before exp 2

SUMMARY

- Efficacy of boron dropper in terms of wall coverage studied in two discharge series by exposure and ex-situ analysis of witness samples
- Injected B found mainly at divertor tile areas in private flux region
- B in divertor high heat flux zone ≈ 10 monolayers increasing ≈ ×10 to outer SOL area
- MEM results indicate ≈ 1/3 fraction deposited at main chamber limiters
- Deposition efficiency decreasing with boron dropper rate and total injected amount
- Also evidence for saturation of deposition efficiency at high dropper rates/amounts
- No evidence for influence of preceding GD boronisation
- Coverage of plasma wetted surfaces sufficient to explain observed effects of improved wall conditions