The ^{13}C tracer experiment at Wendelstein 7-X: results of (mainly) IBA analysis & modelling

17. Oct. 2022 | T. Dittmar[a], S. Brezinsek[a], C. P. Dhard[b], A. Hakola[c], C. Kawan[a], C. Killer[b], A. Kirschner[a], R. König[b], M. Krychowiak[b], S. Masuzaki[d], M. Mayer[e], S. Möller[a], D. Naujoks[b], P. Petersson[f], J. Romazanov[a], K. Schmid[e], T. Vuoriheimo[g], E. Wüst[a], M. Zhao[d], and the W7-X team

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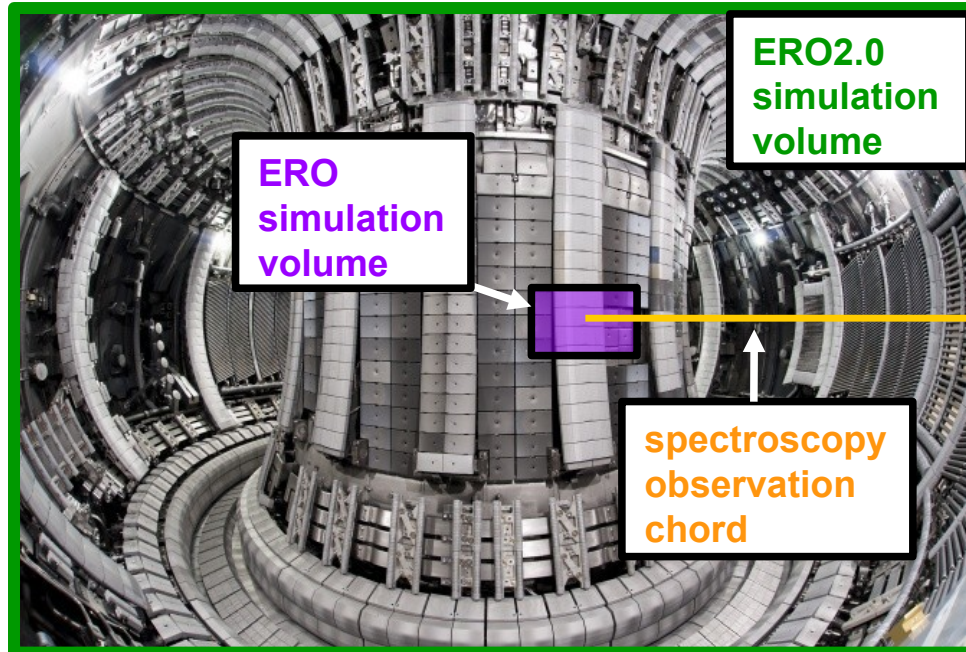
Why study PWI and long range transport in W7-X?

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Why study PWI and long range transport in W7-X?

- Because we can now simulate a full machine

JET-ILW

ERO2.0 simulation volume

ERO simulation volume

spectroscopy observation chord

- Change to massively parallel ERO 2.0 allows to cover "rich physics" simulations of whole vessel …
- … even in complicated 3D magnetic field structure

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Why study PWI and long range transport in W7-X?

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Why study PWI and long range transport in W7-X?

- Seldom opportunity: exchange of PFCs at end of OP1
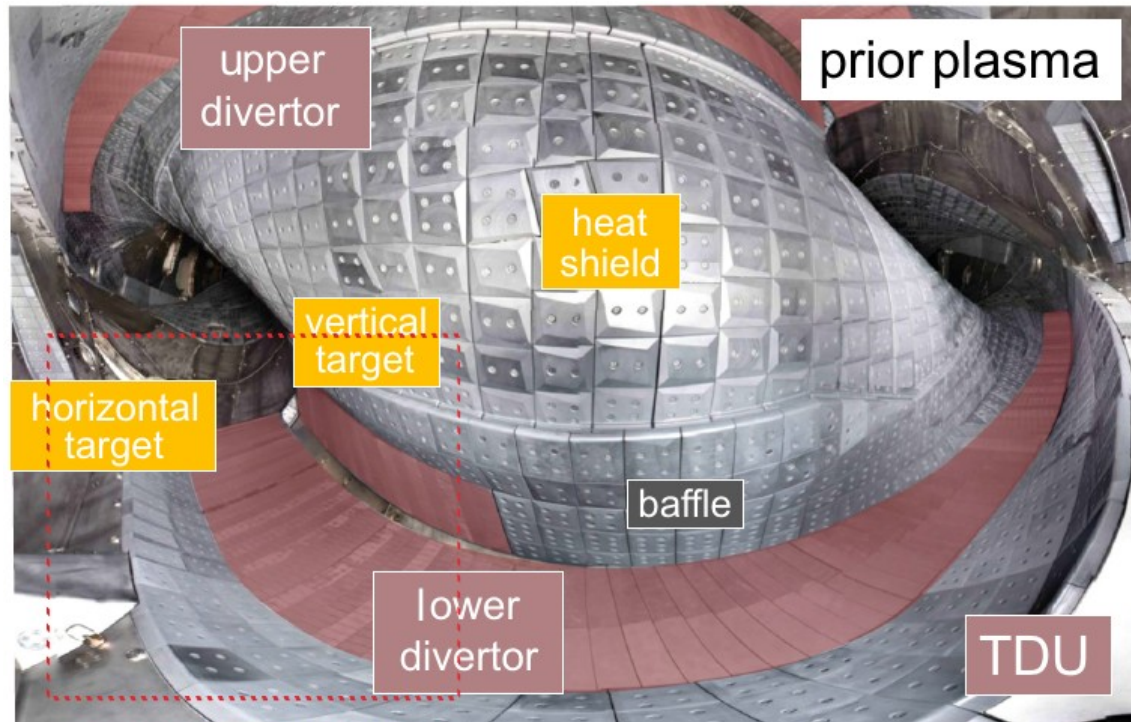
- large number of samples available
- from different places

The ^{13}C tracer experiment

Goals:

- study long range migration in W7-X

- provide benchmark data for impurity transport codes

- good seperation of introduced material from pre-experiment PFC surface

    => main candidate species : ^{13}C or ^{15}N
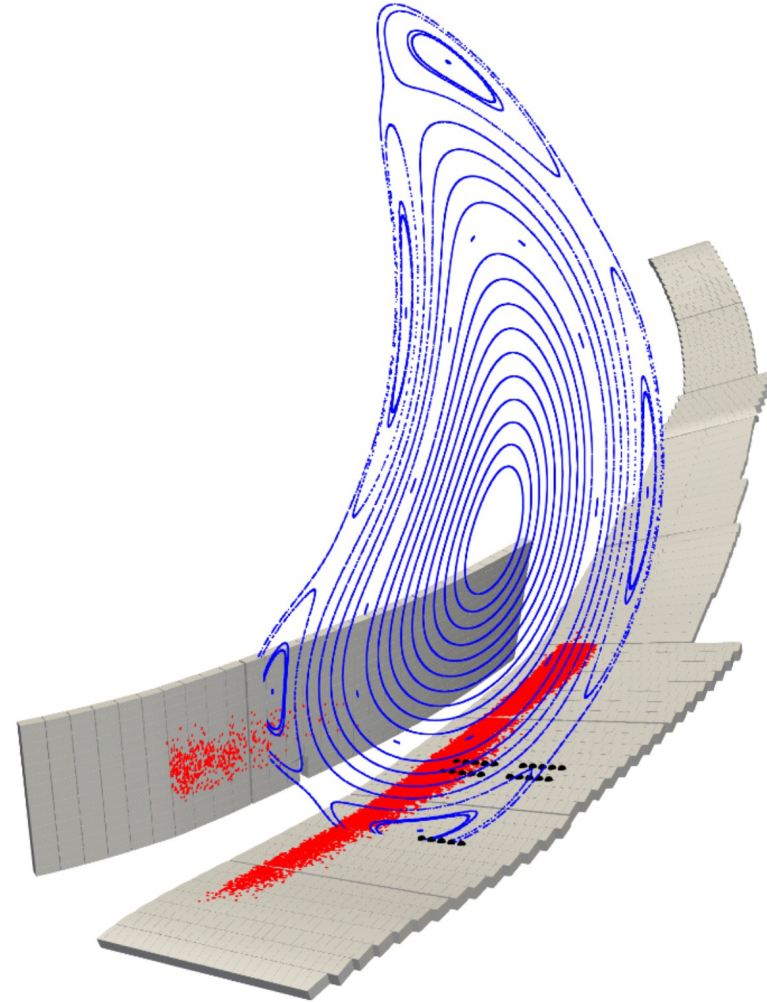
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Plasma conditions

- "Standard configuration": 5/5 islands

- Hydrogen plasma

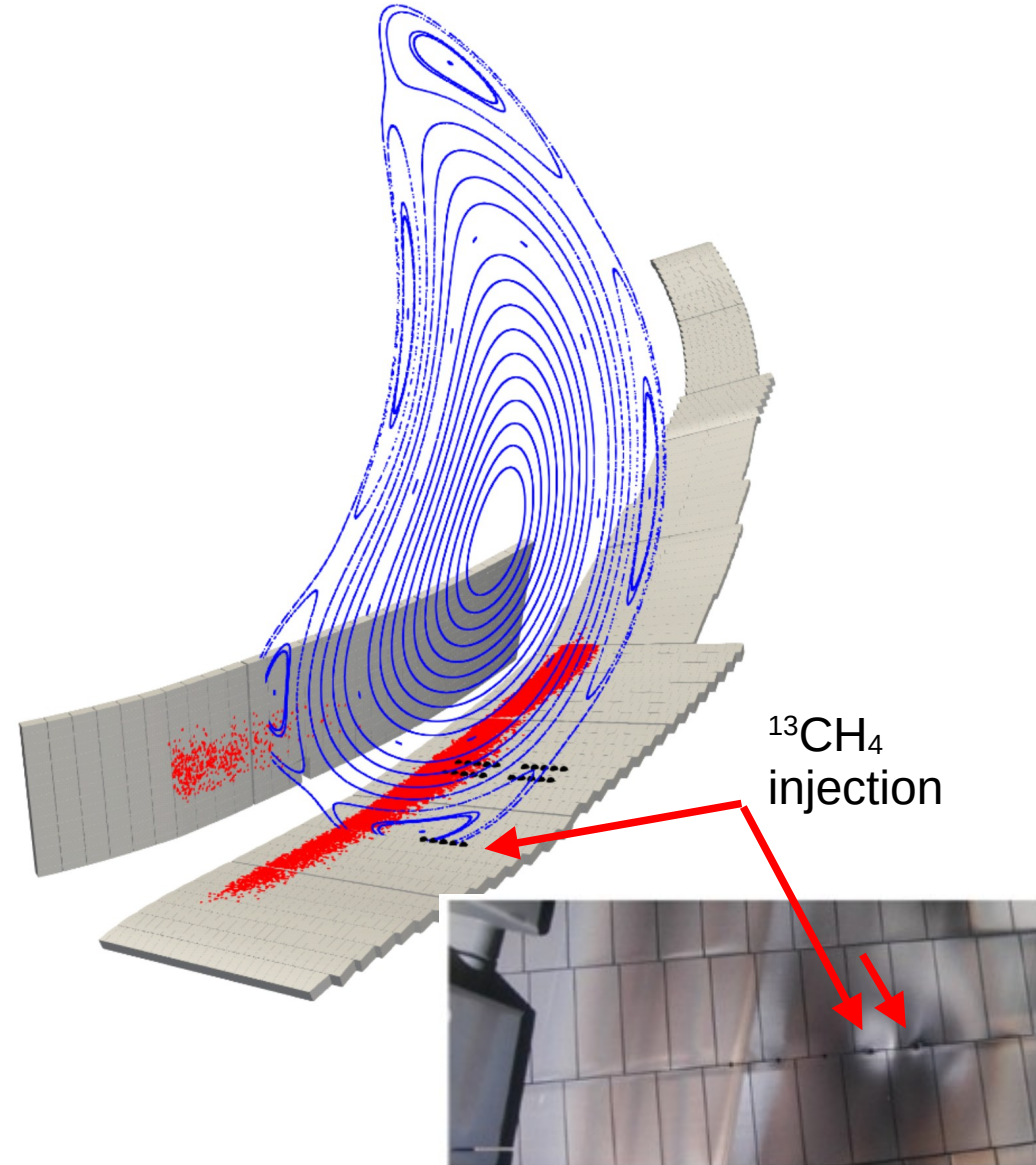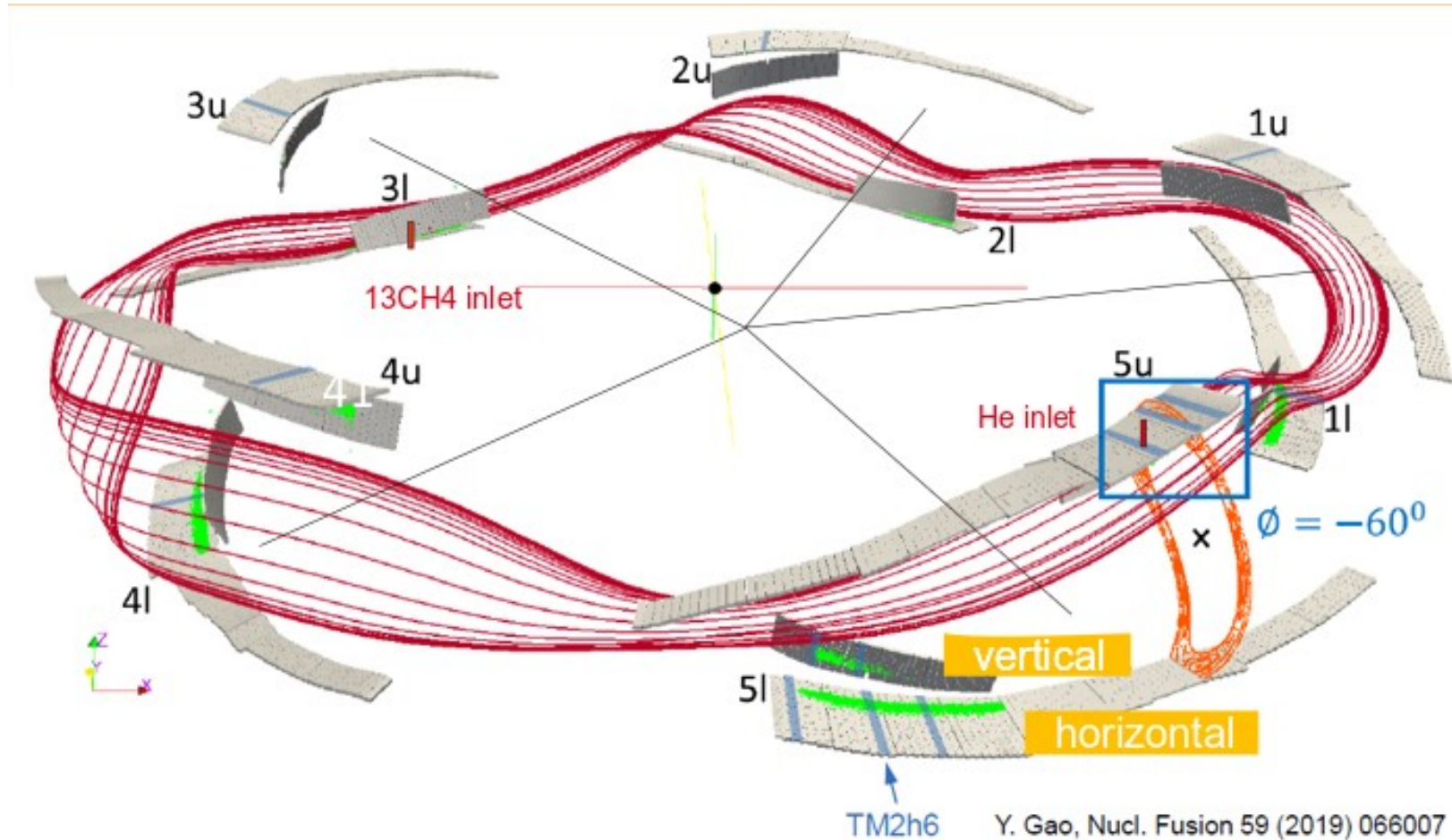# Plasma conditions

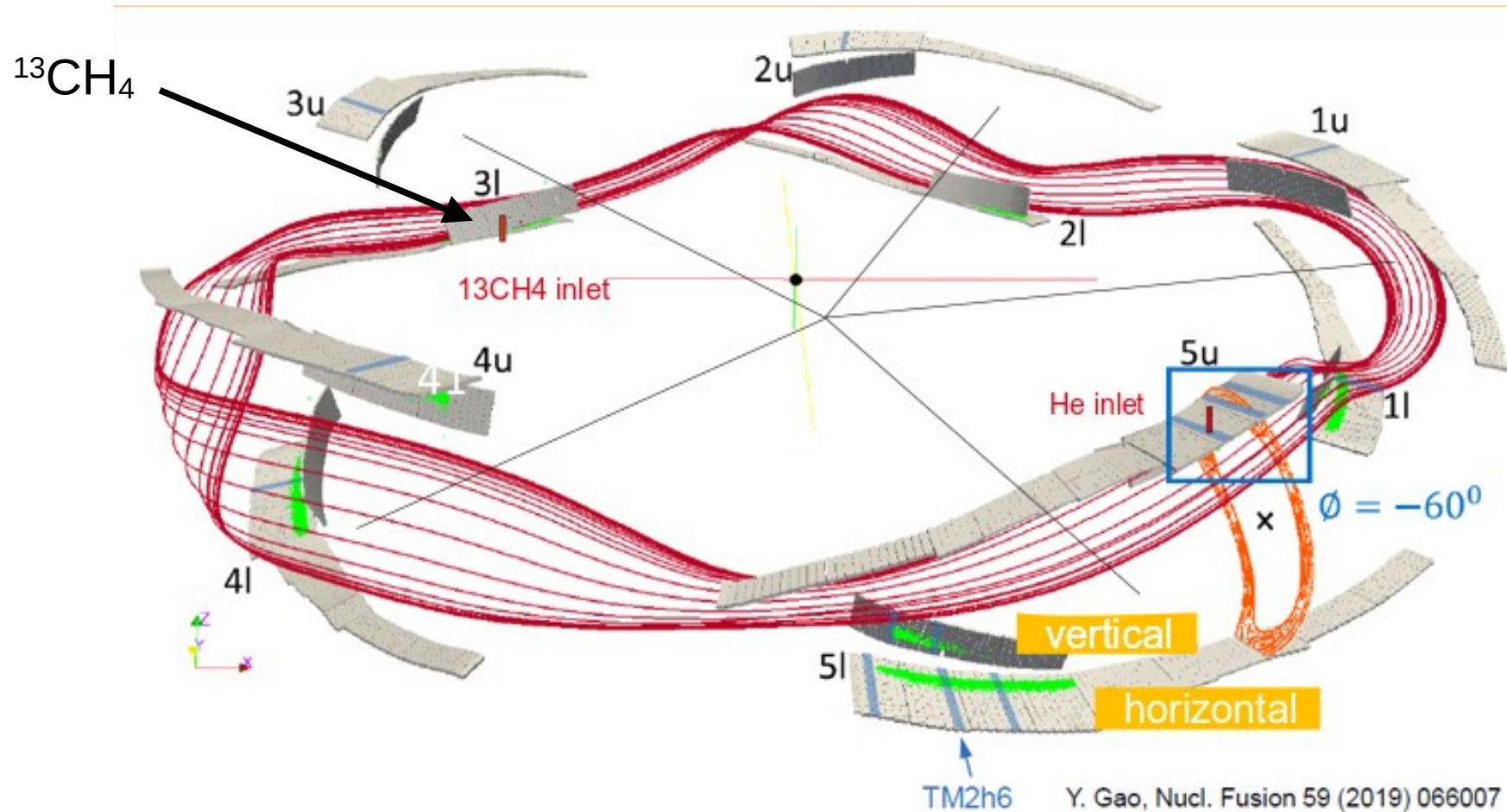- "Standard configuration": 5/5 islands

- Hydrogen plasma

- "robust" plasma scenario

  - $P_{ECRH} = 3.4 \ldots 3.9$ MW

  - $T_e = 2.8 \ldots 3.2$ keV

  - $n_e = (5.5 \ldots 6.0) \times 10^{19}$ m^{-3}

  - $f_{rad} = 0.25 \ldots 0.6$, attached plasma

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Plasma conditions

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- $^{13}CH_4$ injections:

  - 2 discharges from MPM

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Plasma conditions

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- $^{13}CH_4$ injections:

  - 2 discharges from MPM

  - 30 discharges with divertor
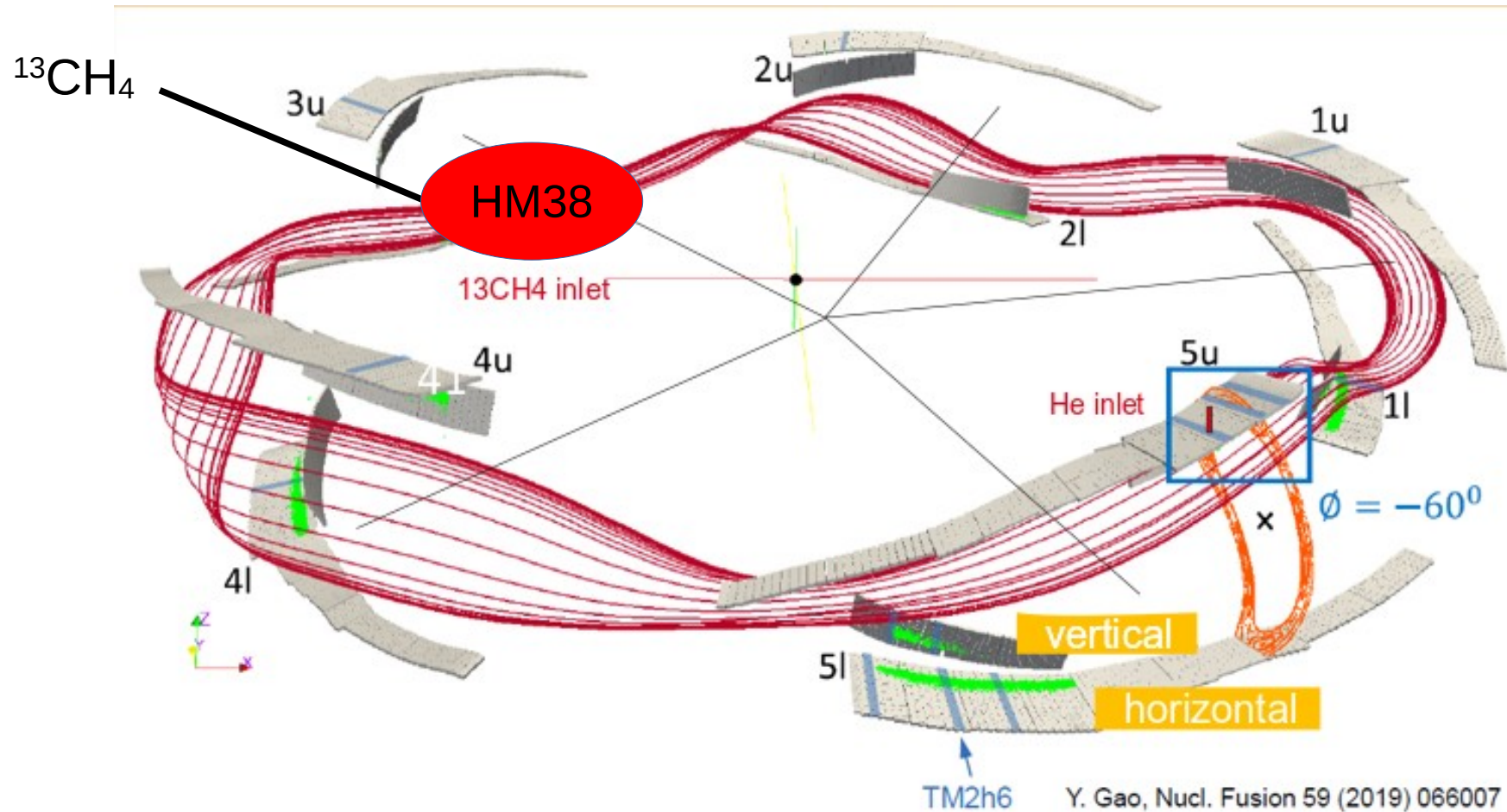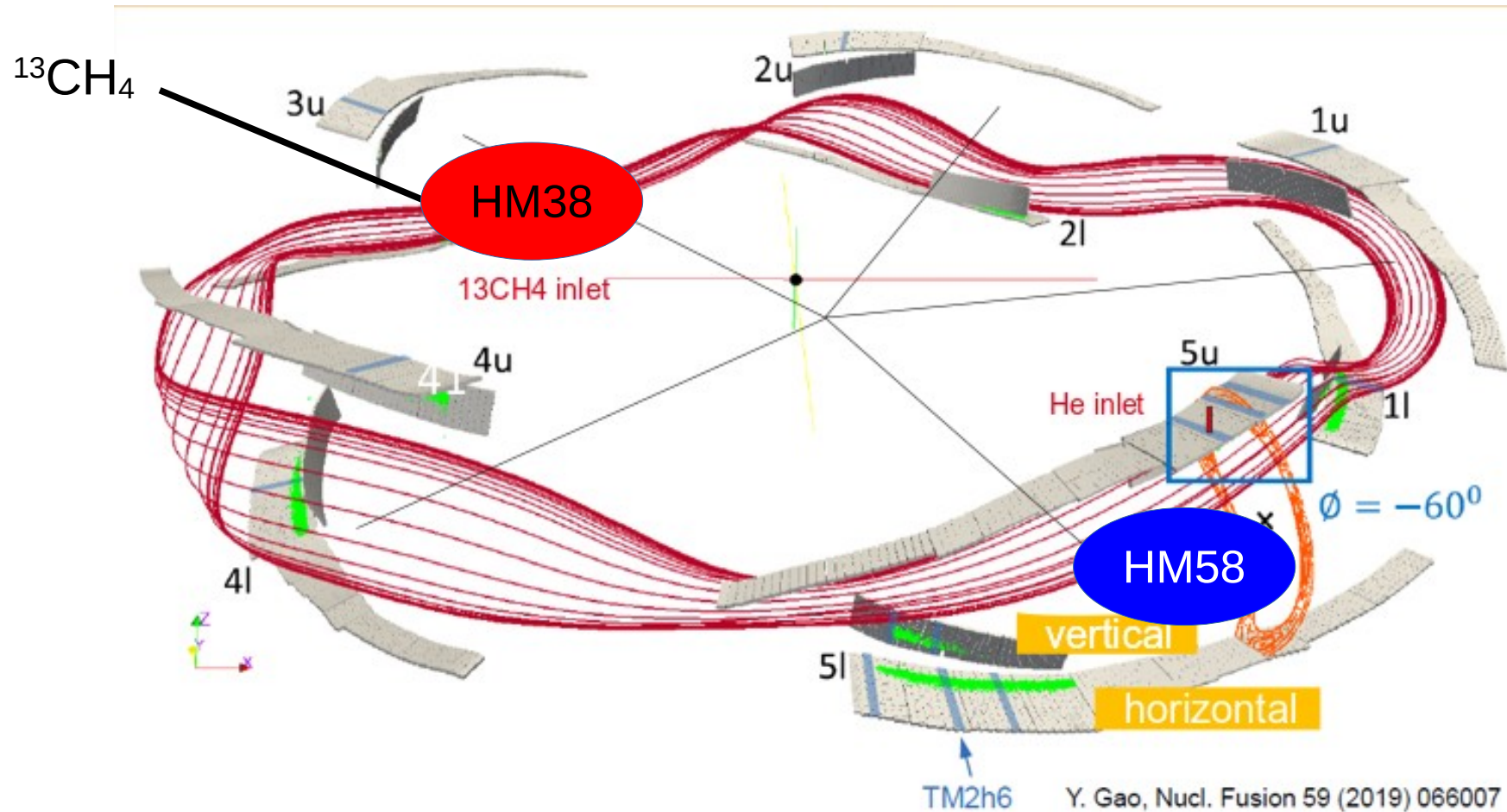   injections with
    total plasma time of 330 s

$^{13}CH_4$ injection

$^{13}CH_4$ injection

Samples and locations

3u
2u
1u
3l
2l
13CH4 inlet
4u
4l
5u
He inlet
1l
$\emptyset = -60°$
5l
vertical
horizontal
TM2h6   Y. Gao, Nucl. Fusion 59 (2019) 066007

Samples and locations

$^{13}CH_4$

3u 2u 1u

3l

$^{13}CH4$ inlet 2l

4u 5u

4l He inlet 1l

$\emptyset = -60^0$

5l vertical

horizontal

Samples and locations

13CH4 inlet

He inlet

$\phi = -60°$

vertical
horizontal

TM2h6   Y. Gao, Nucl. Fusion 59 (2019) 066007

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Samples and locations

$^{13}CH_4$

HM38

3u 2u 1u

2l

13CH4 inlet

4u
4l

5u
He inlet
1l

HM58

$\emptyset = -60^{0}$

vertical

4l
5l
horizontal

TM2h6   Y. Gao, Nucl. Fusion 59 (2019) 066007

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Samples and locations

Y. Gao, Nucl. Fusion 59 (2019) 066007

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Samples and locations

TM1v
TM2v
TM3v

TM1h
TM2h
TM3h
TM4h
TM5h
TM6h
TM7h
TM8h
TM9h

13CH4 inlet

He inlet

vertical

horizontal

Ø = −60°

X. Gao, Nucl. Fusion 59 (2019) 066007

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Samples and locations

TM1v

TM2v

TM3v

vertical

Horizontal

TM1h

TM2h

TM3h

TM4h

TM5h

TM6h

TM7h

TM8h

TM9h

3u

2u

1u

3l

2l

13CH4 inlet

4u

5u

He inlet

1l

Ø = −60°

4l

vertical

5l

horizontal

TM2hS

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Samples and locations

^{13}C Analysis via IBA

- use of the FZJ „µNRA" setup: down to 30 µm spot size, automated data acquisition

- 1 or 1.25 MeV deuteron beam: $^{13}C(d,p_0)^{14}C$ and $^{13}C(d,\alpha)^{11}B$

  - scheme sucessfully employed for EAST samples (Möller NF, 2020)

- 4.5 MeV ^{3}He beam: $^{13}C(^3He,p)^{15}N$ and $^{13}C(^3He,\alpha)^{12}C$

sample holder

FZJ „µNRA"

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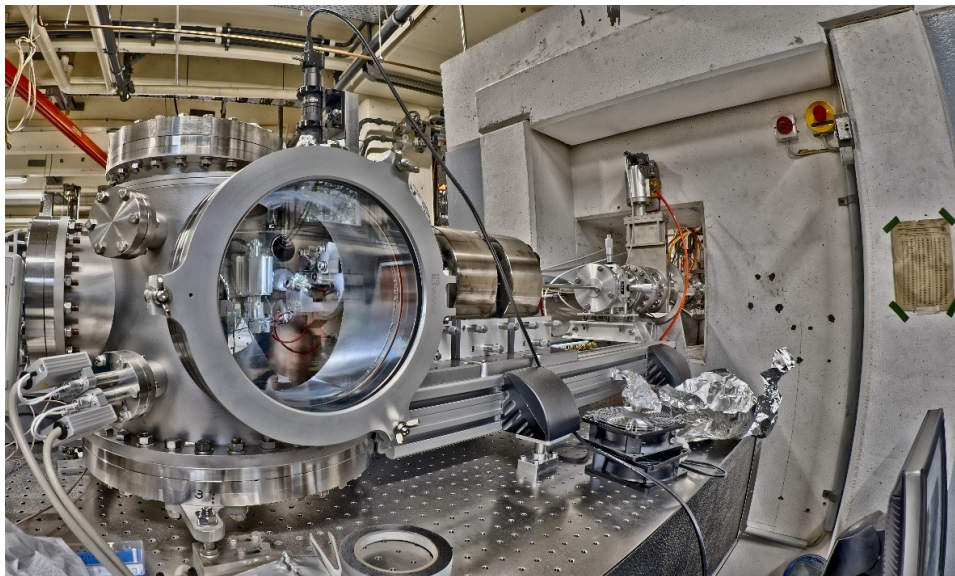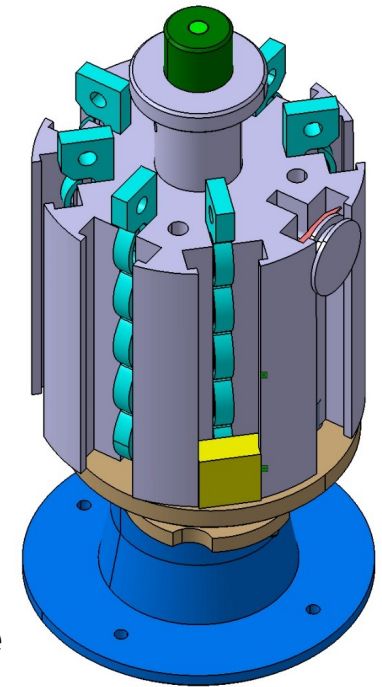
D beam sample spectrum
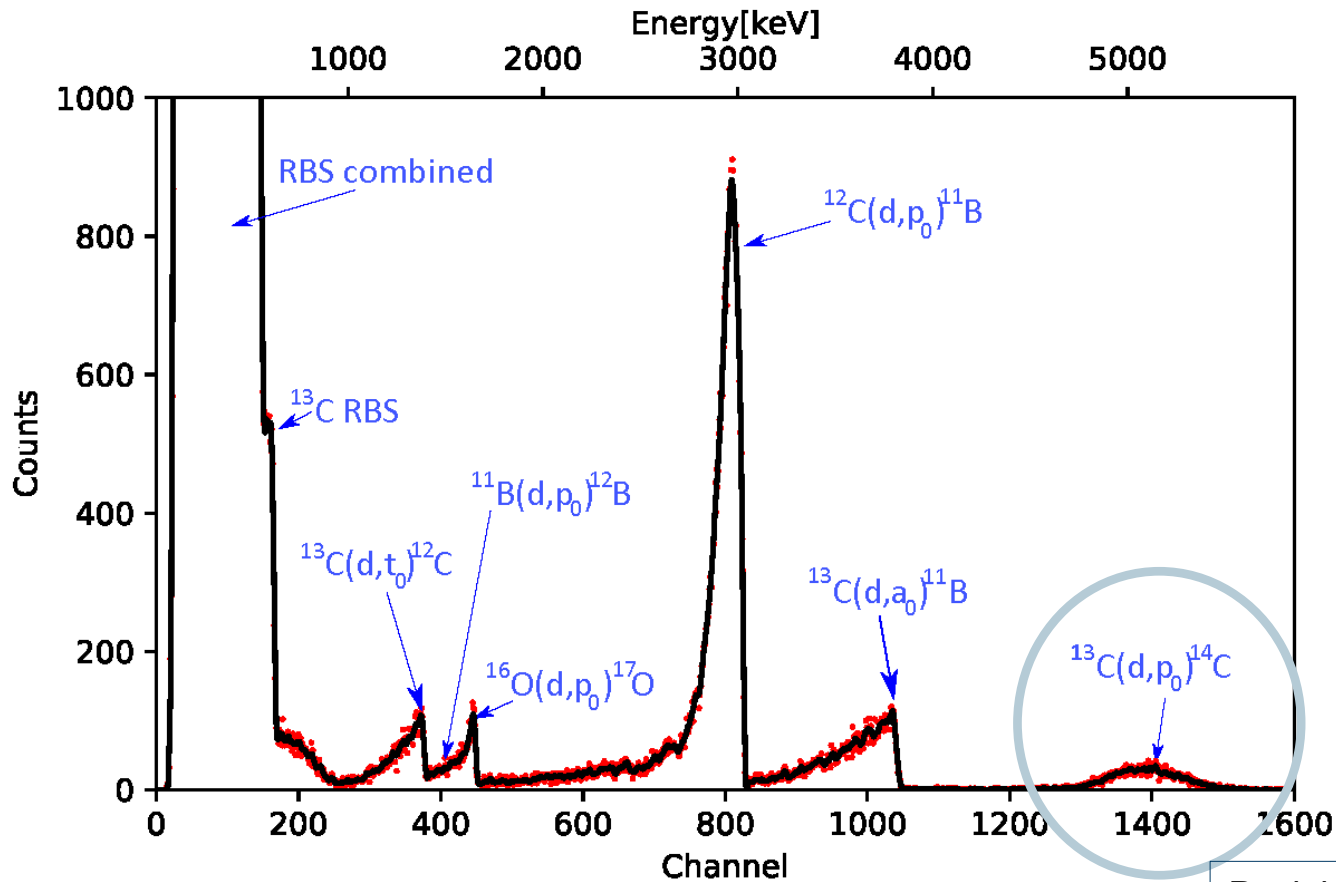
^{12}C: bulk
^{13}C: depositions
^{11}B: boronization
^{16}O: impurities

Peak integrals

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near the injection location

$^{13}CH_4$

HM38

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near the injection location

TM1v
TM2v
TM3v
TM1h
TM2h
TM3h
TM4h

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near the injection location

TM1v
TM2v
TM3v
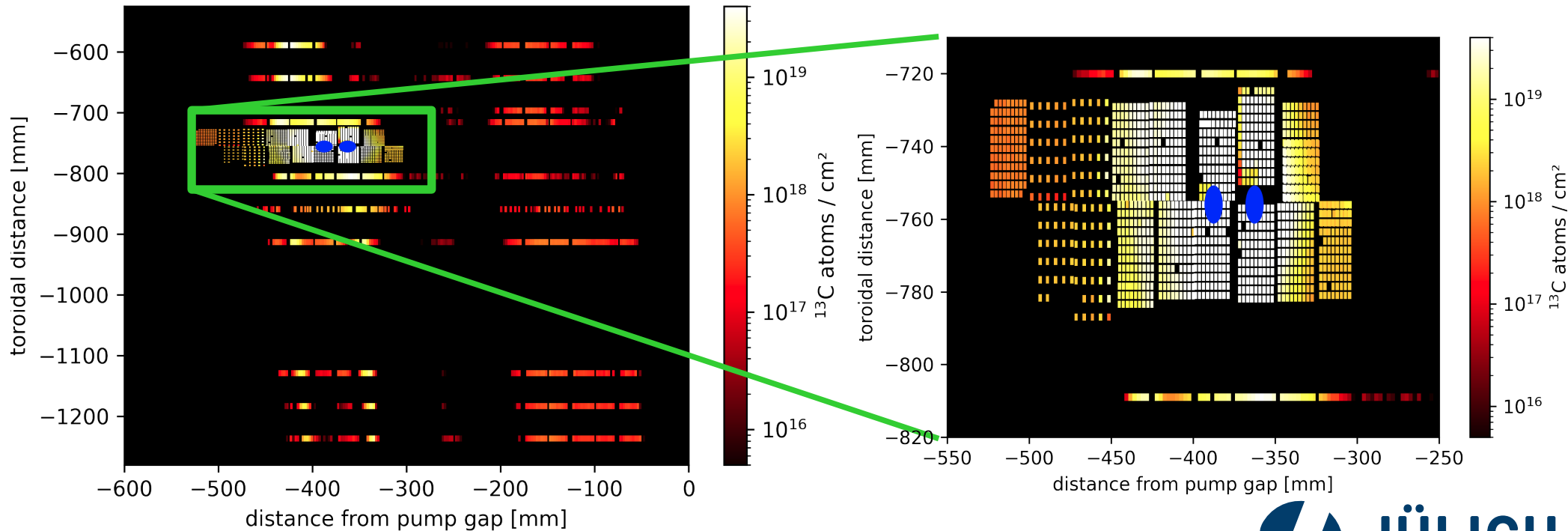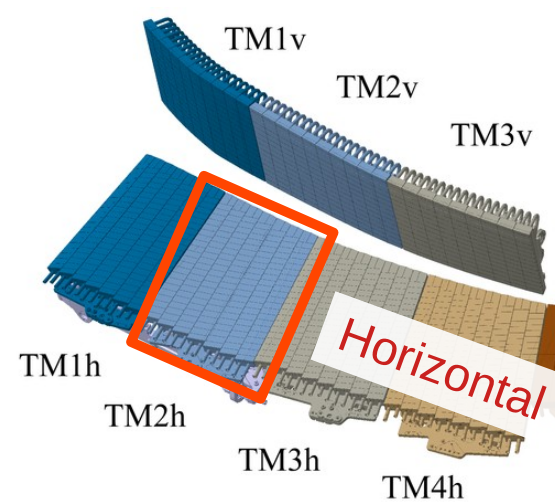TM1h
TM2h
TM3h
TM4h
Horizontal
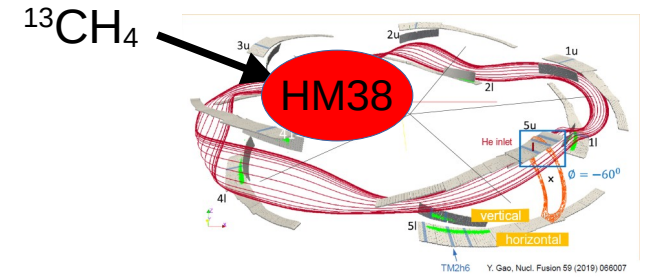
near the injection location

near the injection location
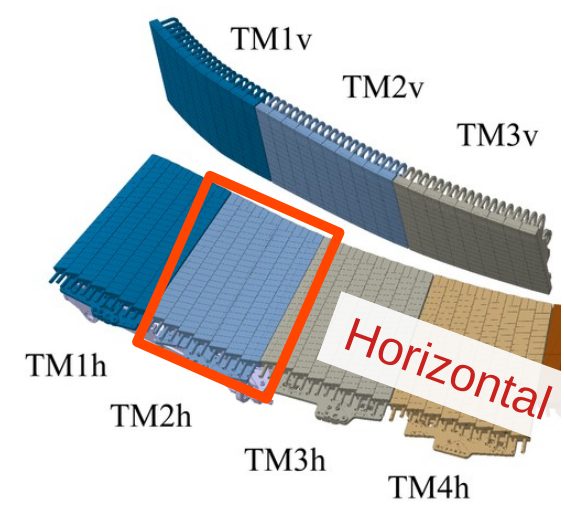
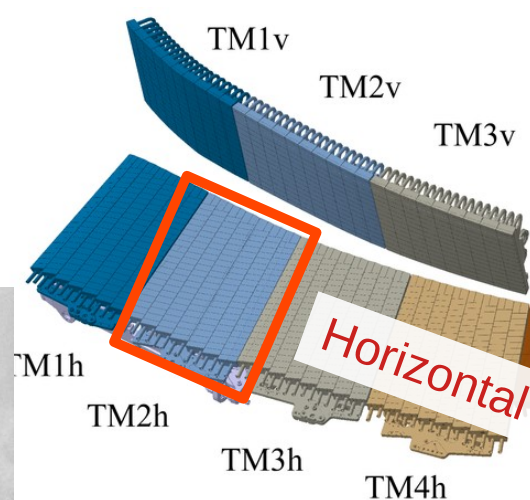NRA/RBS ion beam analysis
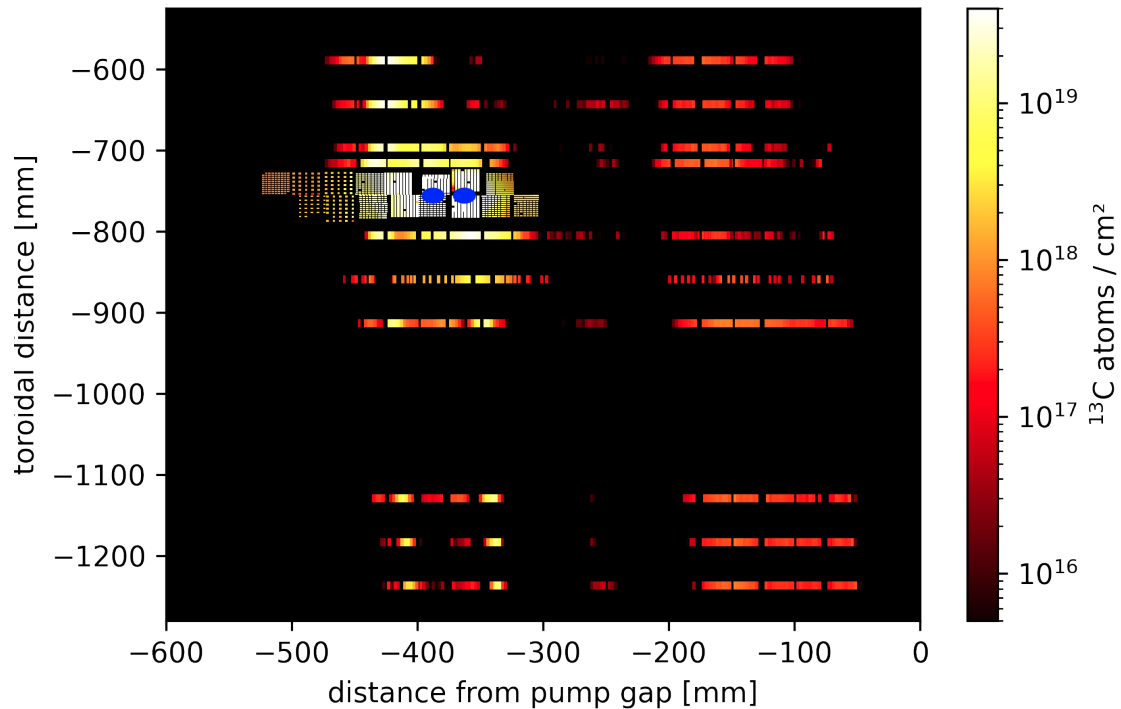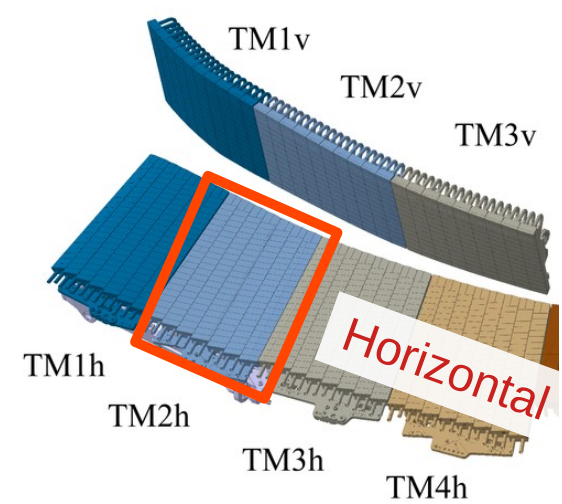
Horizontal target

near the injection location

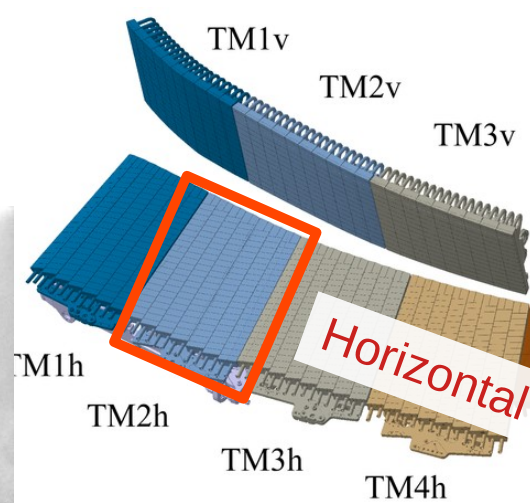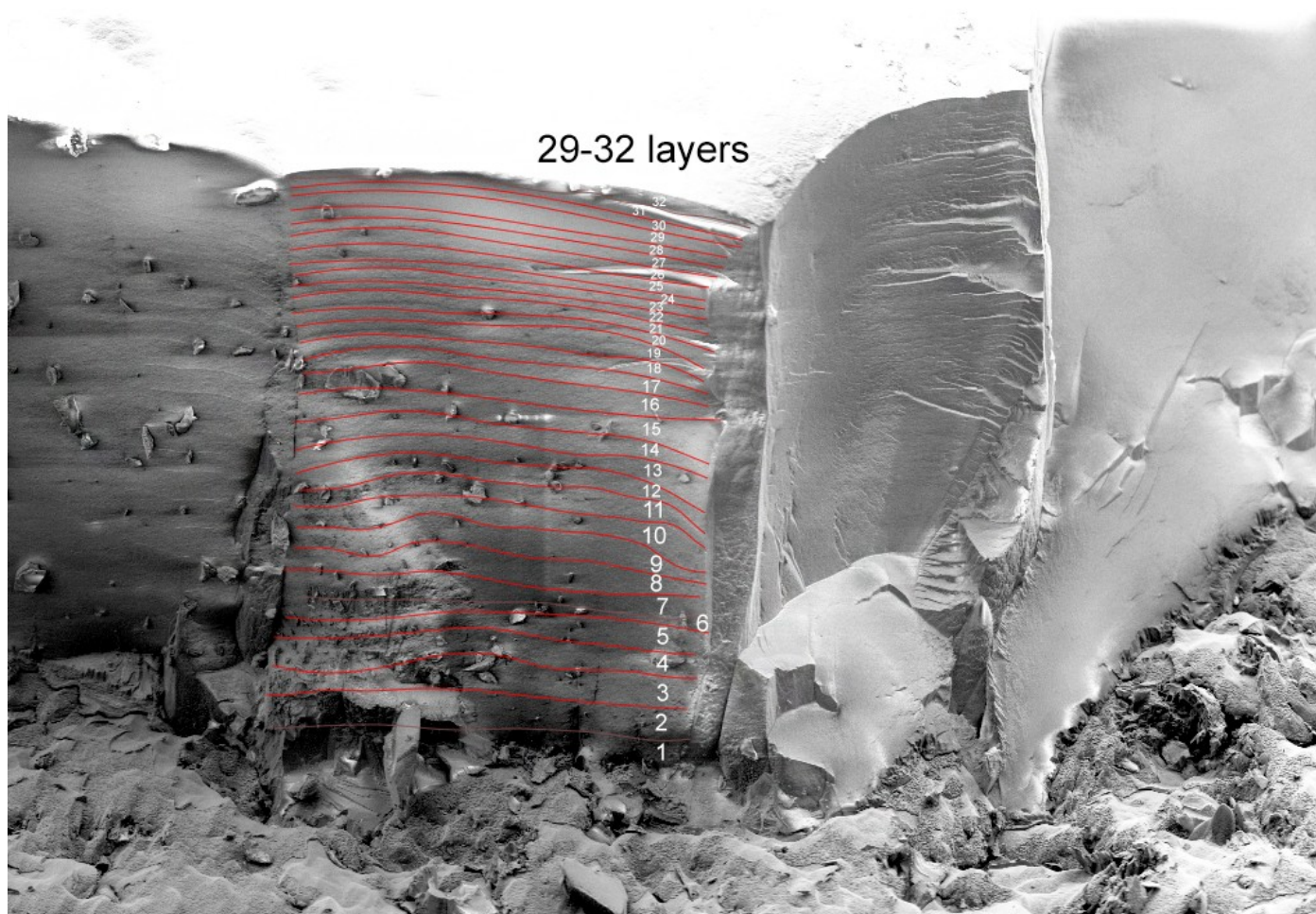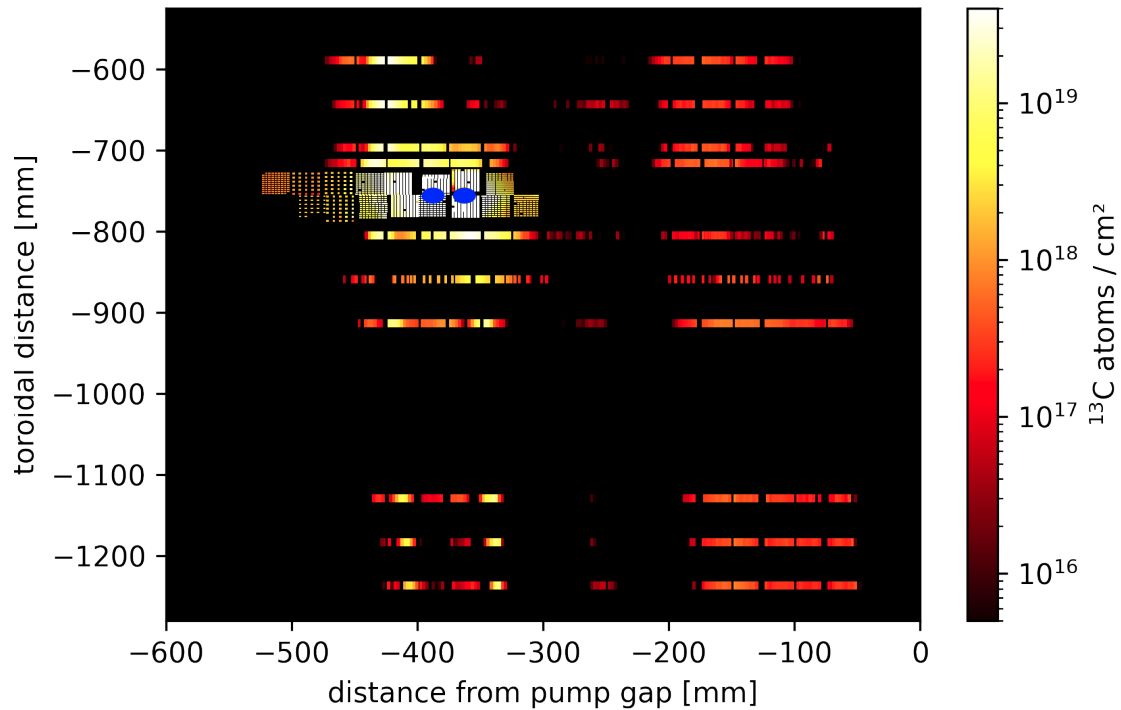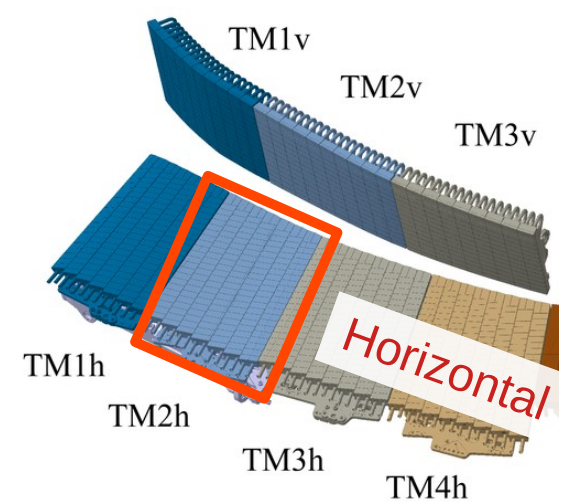NRA/RBS ion beam analysis

Horizontal target

FIB cuts

29-32 layers

10 µm 1.60 kV I Probe = 800 pA SE2 54.0° On W7X OP1.2b IEK 4
750 X Width = 152.4 µm WD = 8.7 mm 20 Jul 2022 SEM 2 Rasinski

TM1v
TM2v
TM3v
Horizontal
TM1h
TM2h
TM3h
TM4h

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FIB cuts

29-32 layers

```
32
31  30
29
28
27
26
25  24
23
22
21  20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
```

TM1v
TM2v
TM3v
TM1h
TM2h
TM3h
TM4h
Horizontal

10 µm   1.60 kV   I Probe = 800 pA   SE2   54.0°   On   W7X OP1.2b   IEK 4
         750 X   Width = 152.4 µm   WD = 8.7 mm   20 Jul 2022   SEM 2   Rasinski

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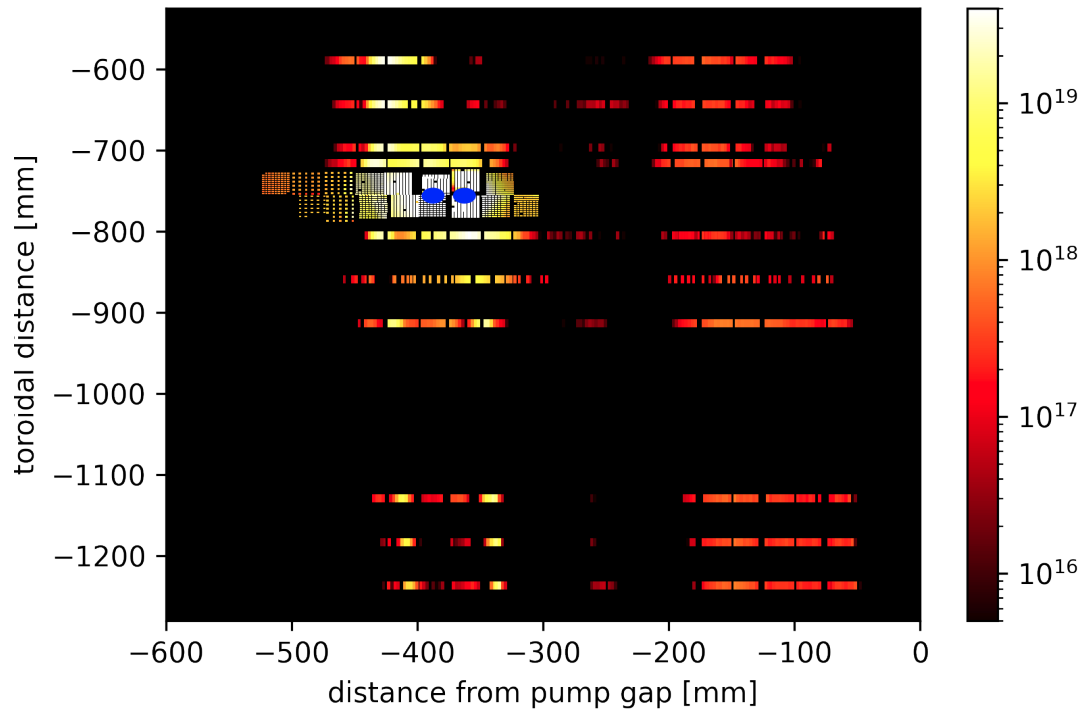
near the injection location

NRA/RBS ion beam analysis
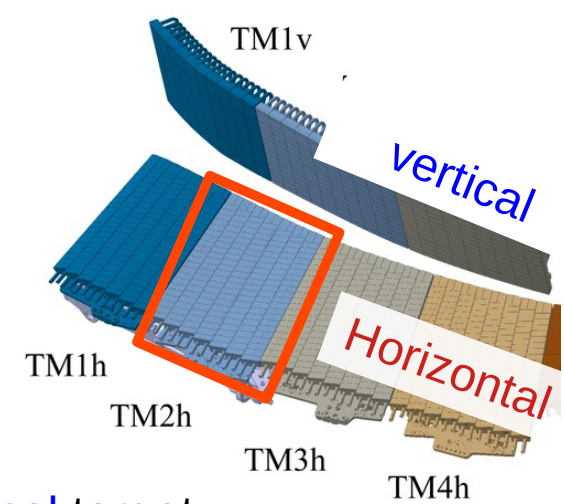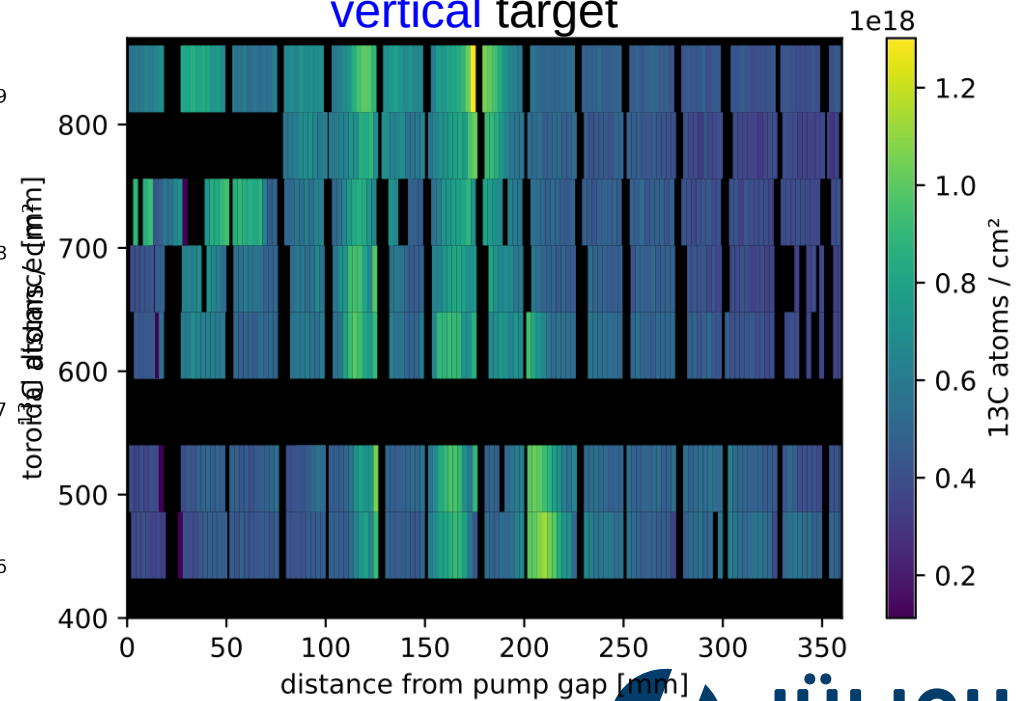
Horizontal target

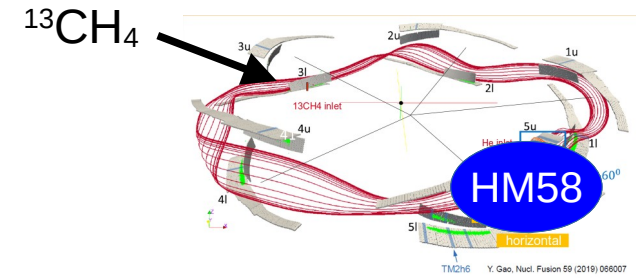# near the injection location

NRA/RBS ion beam analysis

Horizontal target

vertical target

Far from injection: HM58

$^{13}CH_4$

HM58

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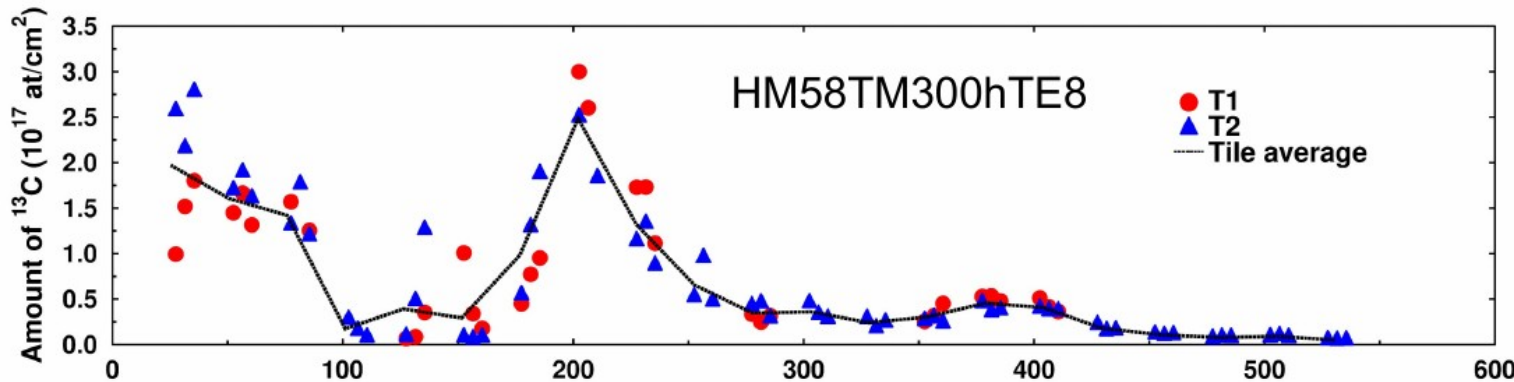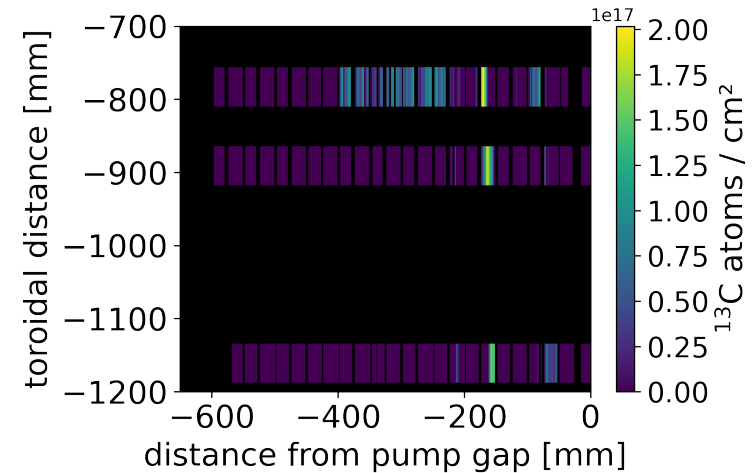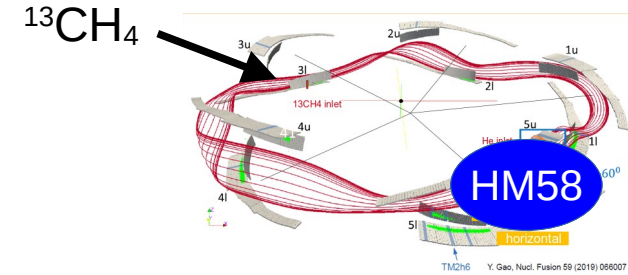
Far from injection: HM58

- only thin layers detected

- layers mainly dominated by background ^{12}C

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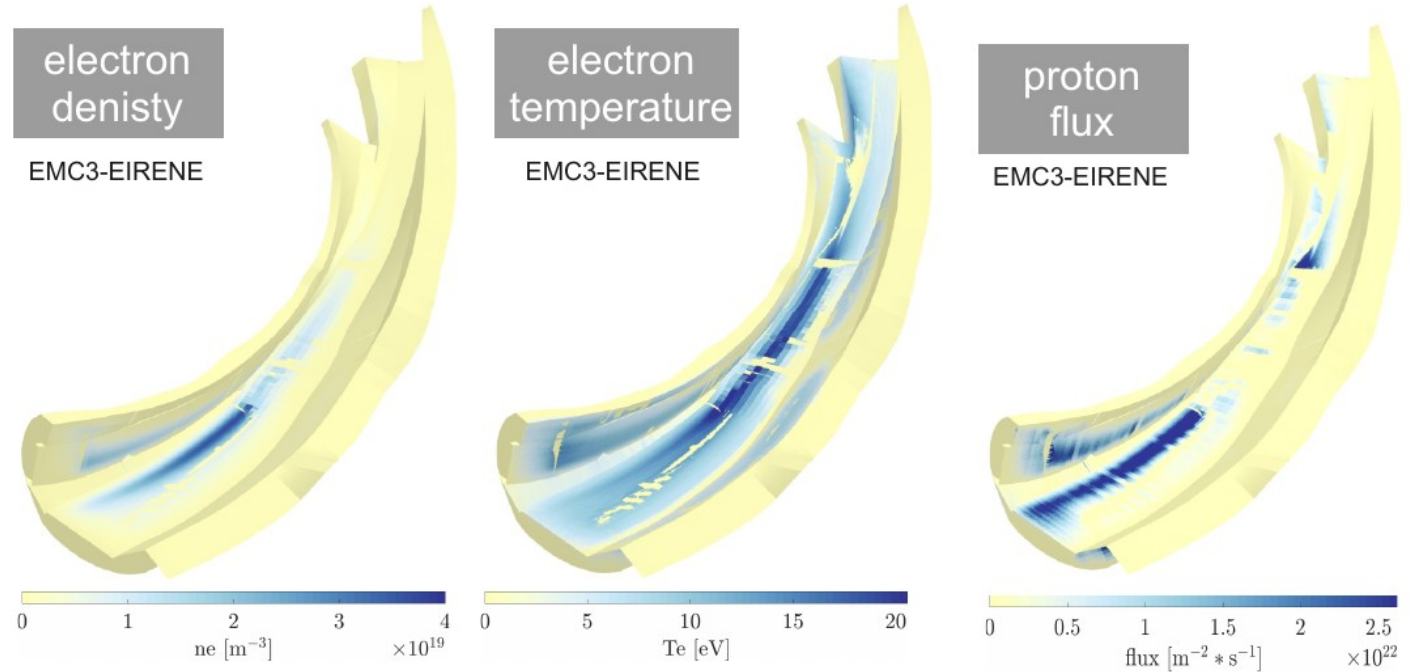
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$^{13}CH_4$

HM58

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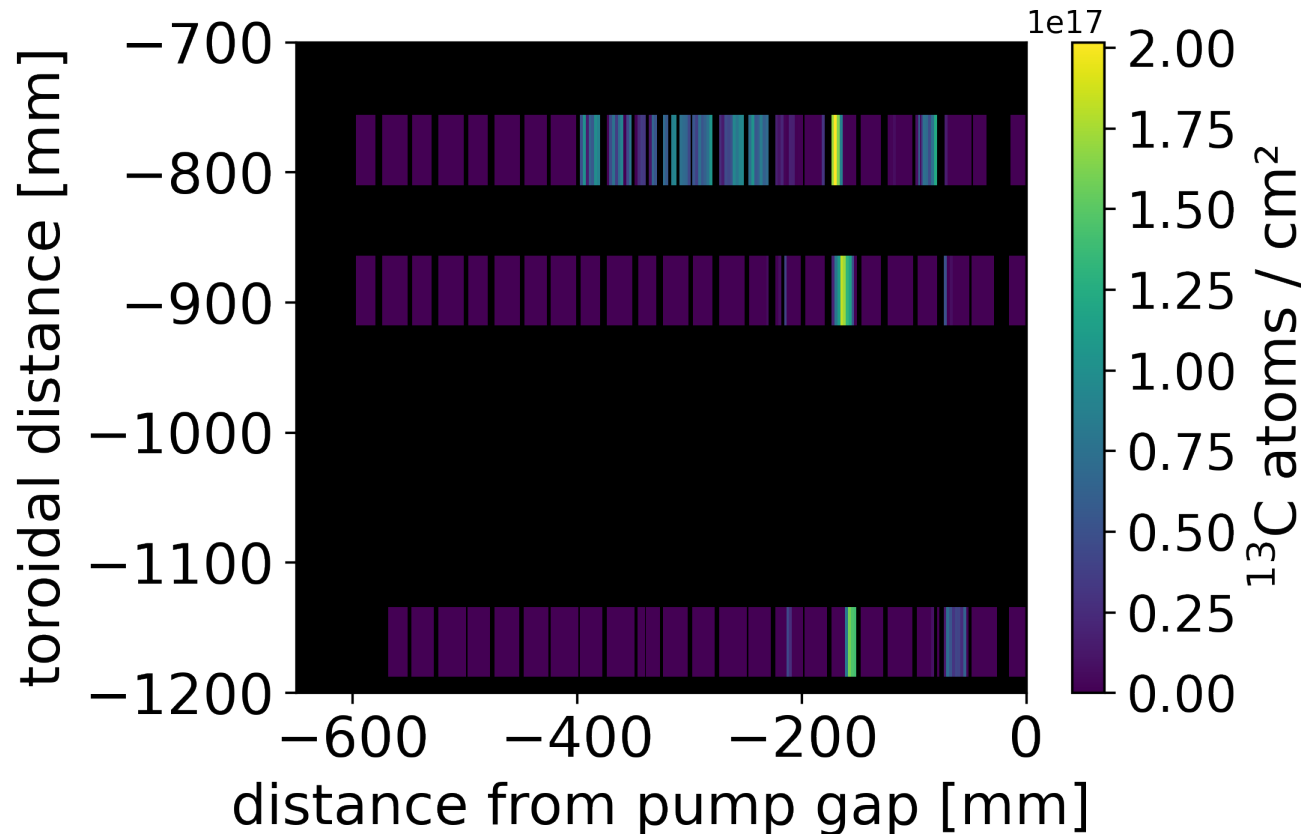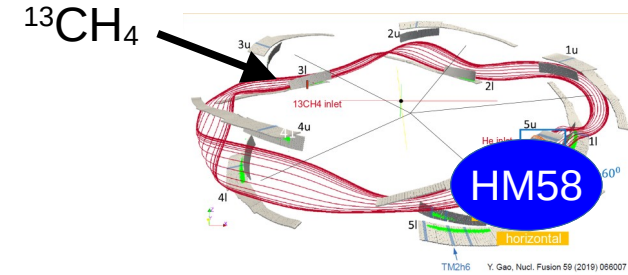
SIMS measurements
(U Helsiki, VTT)

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Modelling

- Plasma background:
  - via EMC3-EIRENE
  - 1/10 of torus
  - included C seeding

electron denisty — EMC3-EIRENE — n_e [m^{-3}], $\times 10^{19}$

electron temperature — EMC3-EIRENE — T_e [eV]

proton flux — EMC3-EIRENE — flux [m$^{-2} * $s^{-1}], $\times 10^{22}$
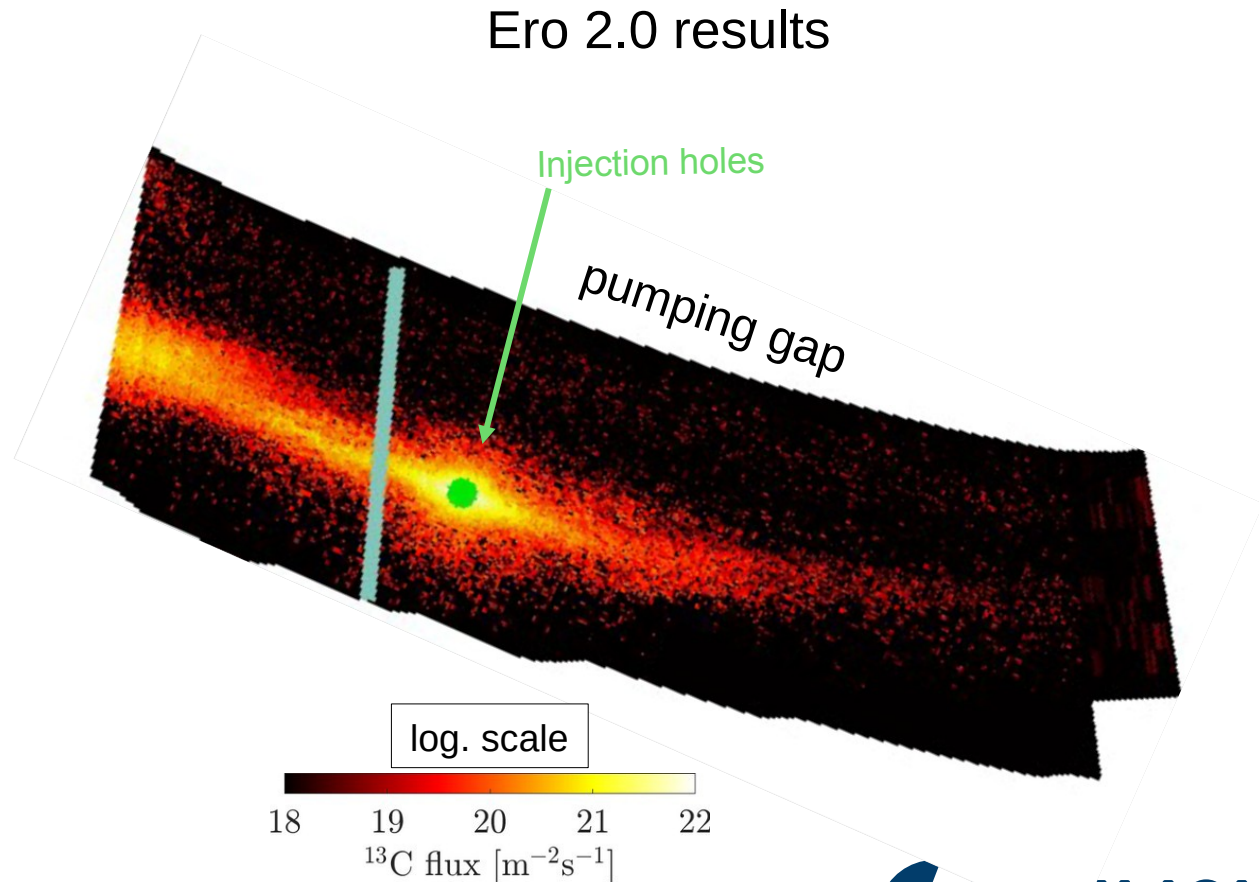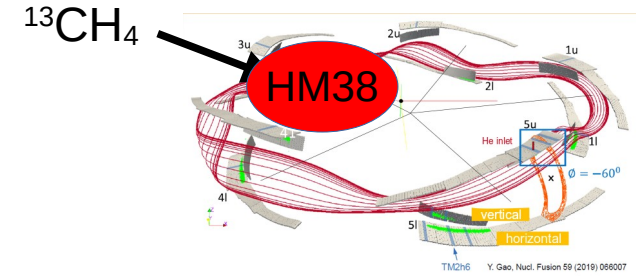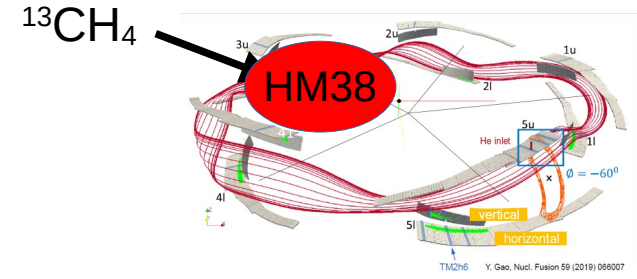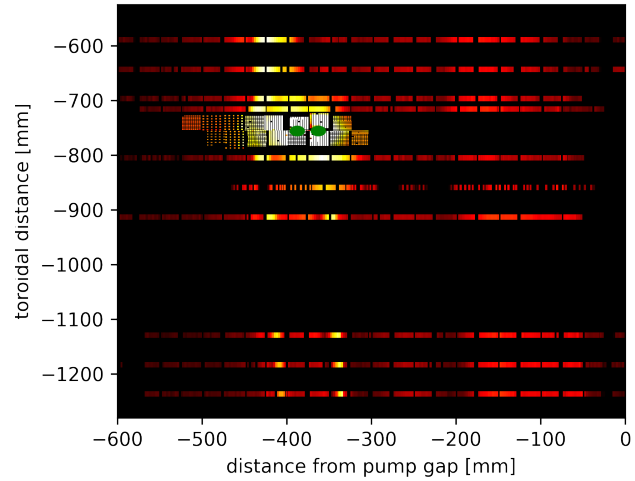
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Modelling

- Plasma background:
  - via EMC3-EIRENE
  - 1/10 of torus
  - included C seeding

- Modeling
  - single inlet position
  - WallDyn-3D:
    - 13C atomar injection
    - includes re-erosion
  - ERO 2.0
    - includes 13CH4 breakdown
    - up to now: no re-erosion included

Ero 2.0 results

Injection holes

pumping gap

log. scale

18   19   20   21   22
^{13}C flux $[m^{-2}s^{-1}]$

35

Comparision: LAMIS and ERO2.0

$^{13}CH_4$

HM38

He inlet

$\emptyset = -60^0$

vertical

horizontal

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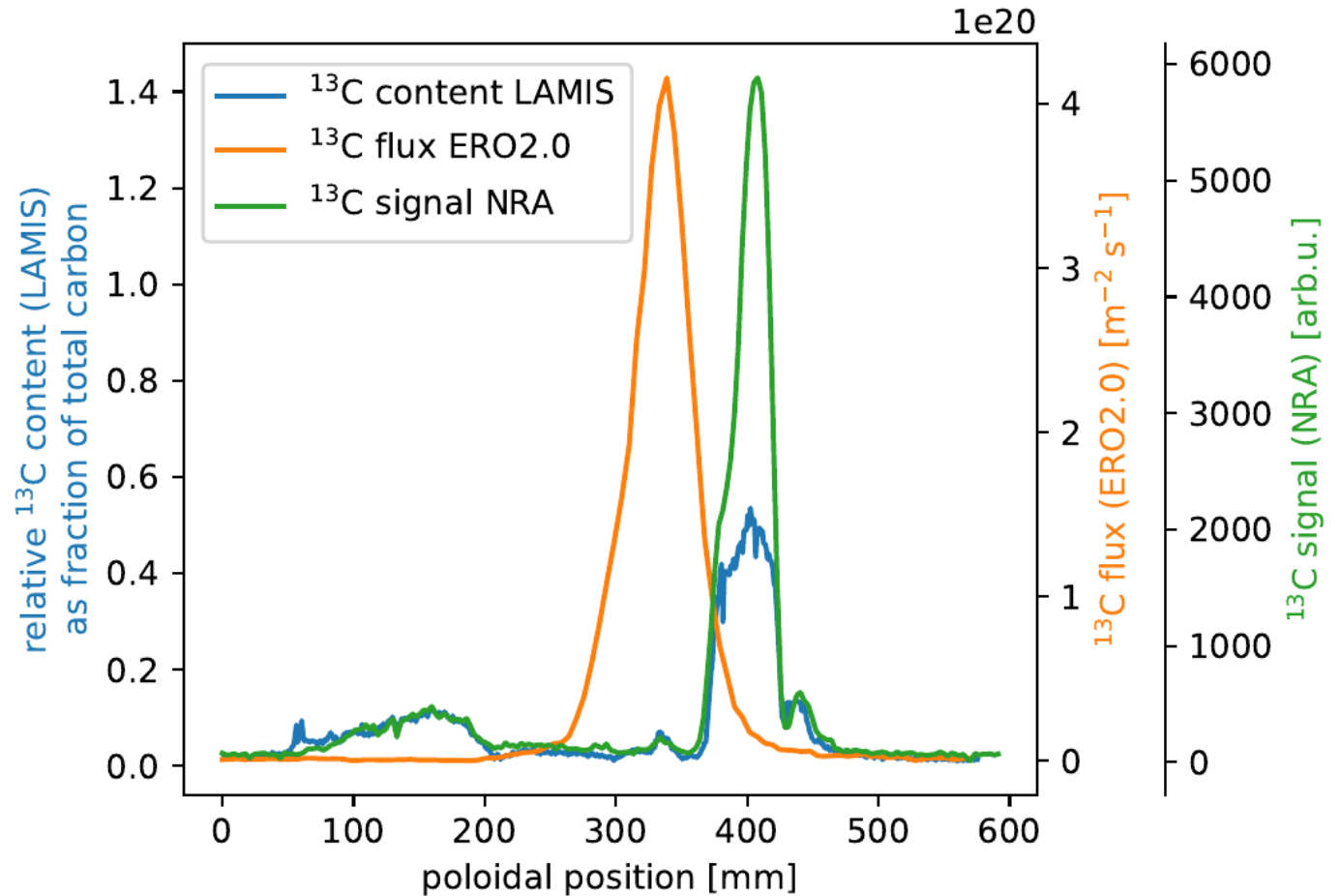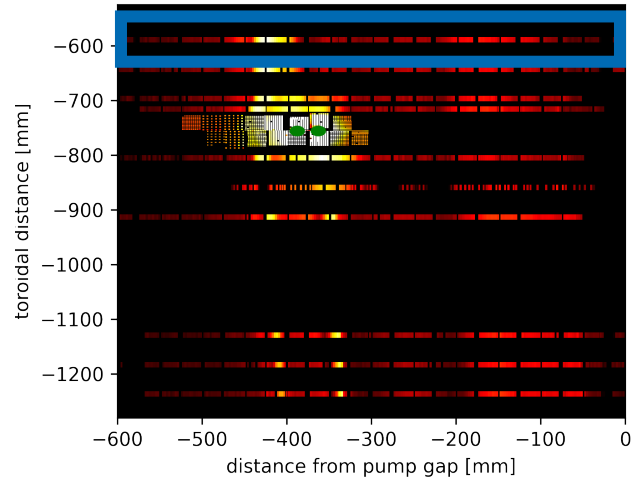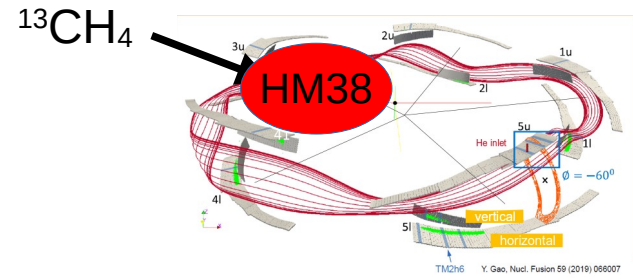
Comparision: LAMIS and ERO2.0

Comparision: LAMIS and ERO2.0

Summary

- End of W7-X OP1 was unique opportunity for migration experiment

- ~ 6000 measurements with IBA on 18 target elements:
  → good benchmark data for modelling efforts

- strong local deposition:

  - ~ 80% within 10 cm radius → the divertor does its job

  - peaked deposition patterns throughout machine → long range impurity transport

- WallDyn and ERO 2.0 simulations:

  - reproduce local deposition

  - deviate in details & long range

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Draco dormiens nunquam titillandus

(Motto of the *Hogwarts School of Witchcraft and Wizardry* and also pretty good live advice)

„one waking", Jackie Morris, 2008

please ask your questions

- and/or -

contact me at
t.dittmar@fz-juelich.de