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Lithization on RFX-mod reversed field pinch experiment

by

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Outline

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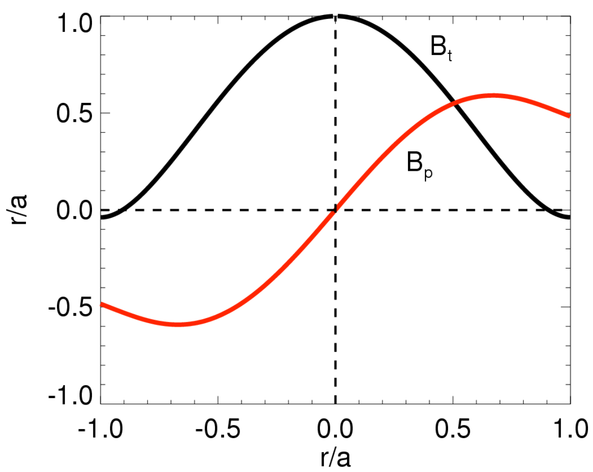
- RFX-mod experiment
  - Graphite first wall and related density control issue
  - Wall conditioning techniques
- Lithization techniques
  - Lithium pellet injection
  - Liquid Lithium Limiter (LLL)
- Experimental results with Lithium pellets
  - First wall gas retention
  - Impurity control
  - Edge density and temperature effects
  - Confinement results
- Experiments with Liquid Lithium Limiter
  - Test as liquid limiter
  - Used as evaporator
- Post-lithization effects
  - Sample analysis
  - After-venting recovering
- Next steps

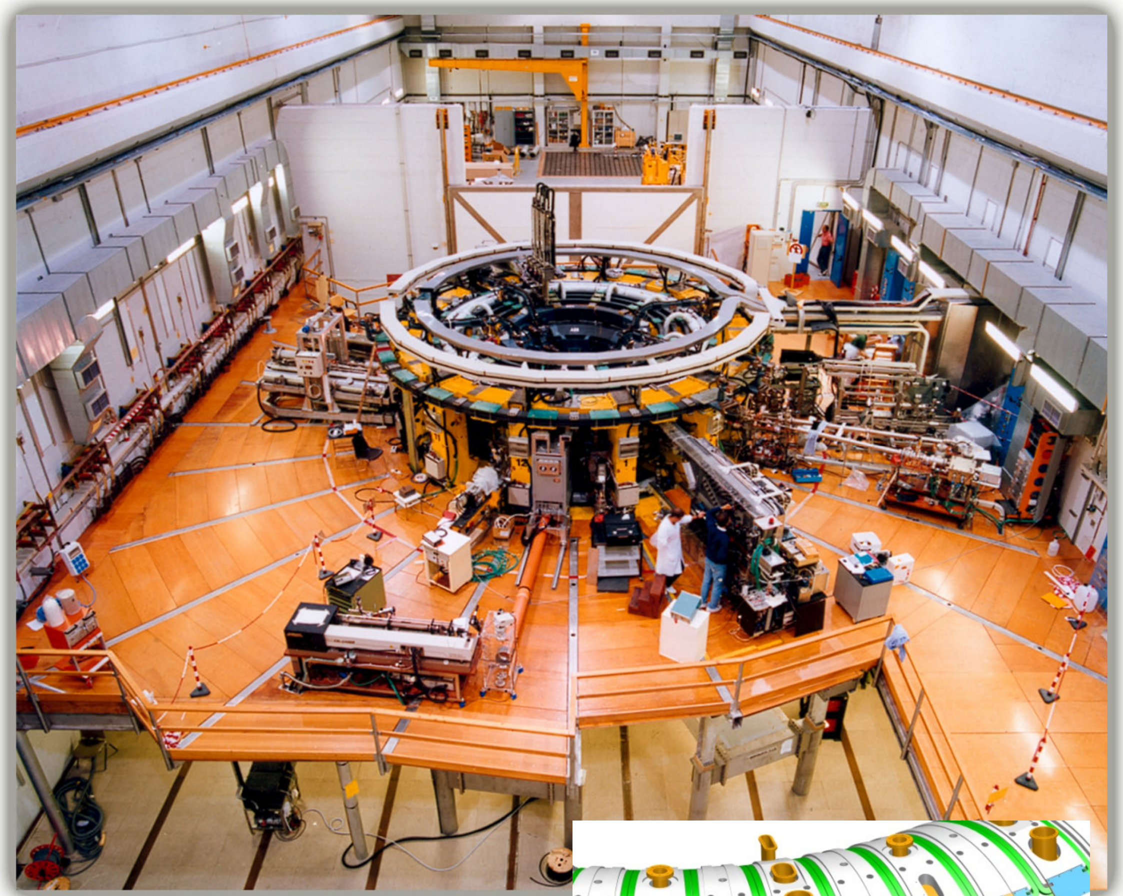
1

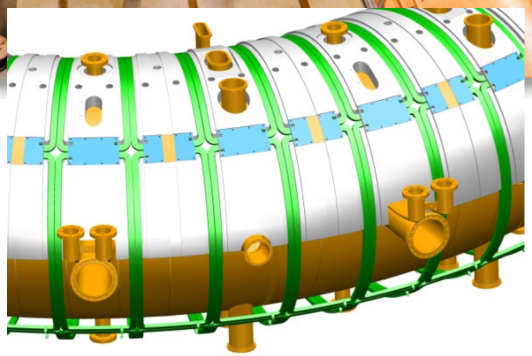
RFX-mod experiment

RFX-mod experiment

$R_0 = 2$ m
$a = 0.46$ m
$I_p = 2$ MA
$n = 2\text{-}5 \cdot 10^{19}$ m^{-3}
$T_e \cong 1$ keV







192 saddle coils for active control

RFX-Mod first wall

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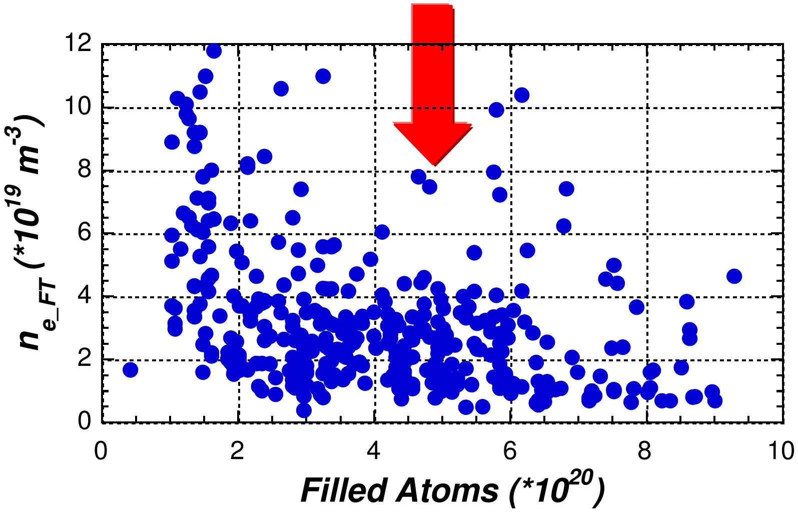
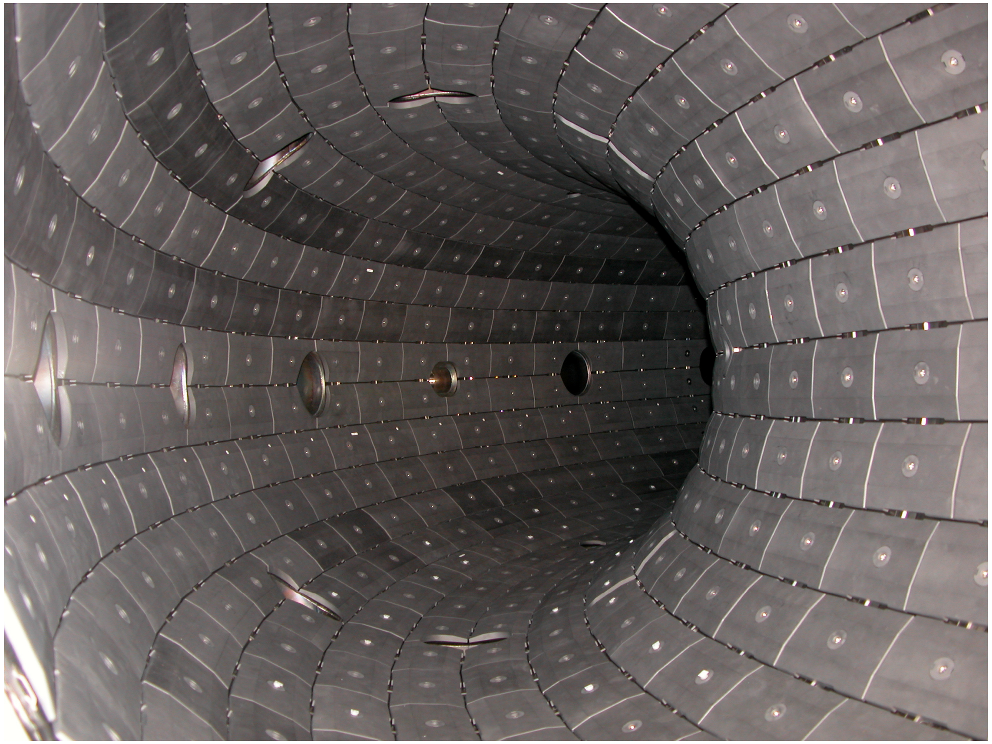
First wall is entirely covered by polycrystalline graphite tiles

At room temperature graphite wall is an almost infinite reservoir of H_2 particles

➔ density at flat top (FT) does not depend on the fuelled particles but it is entirely sustained by particles fluxes from the wall





density control requires to be able to control the status of the wall

RFX-mod wall conditioning techniques

1. **Baking**

   T limited to 170°C to not damage the in vessel probes

   Aim: Outgas of contaminating atoms from tiles (H_2O, H_2, O_2, N_2, He,...)

2. **RF-assisted Glow Discharges with flowing gas**

   2 anodes at 180 toroidal degrees, voltage up to 1000V

   Aims: - He GDC mainly to remove H_2 (by physical sputtering)

   - H_2 GDC to remove O_2 (and C) (by chemical sputtering)

3. **Boronization by the GDC plant**

   Used gas: B_2H_6 (Diborane) 10% - He 90%

   Aim: Getter effect for O_2, reduction of H_2 fuelling from the wall

Wall conditioning effectiveness

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1. **Impurity reduction**

   Described treatments are of primary importance as wall conditioning techniques after exposure of the wall to air. They are effective in reducing the impurity level in discharges. In particular when boronization is performed the influx of C and O is halved. The effect last for a maximum of 100-200 shots.

2. **Density control at high plasma current:**

   - ➔ Baking alone (in our T operational range) was found to be ineffective
   - ➔ He-GDC removes H from graphite but for a few shots (5-10)
   - ➔ Baking + GDCs gives minor advantage
   - ➔ Baking + GDCs + Boronization gives an absorbing wall but for a limited number of shots (some tens). Saturation of the Boron layer?

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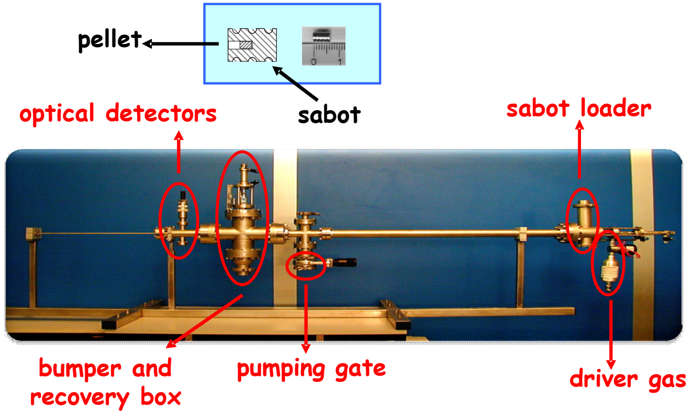
Lithization techniques in RFX-mod

Lithization by pellet injector

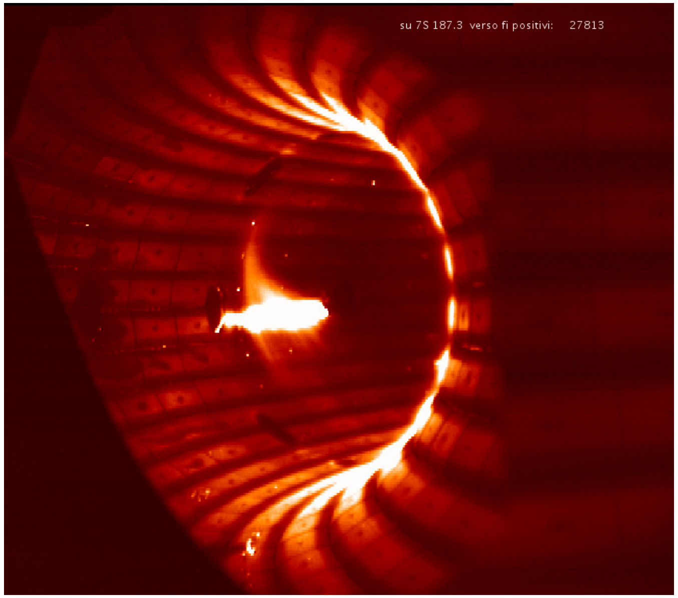


Injector characteristics
- Pellet speed: 50÷200 m/s
- Pellet size: Ø 0.2÷1.5 mm x 1÷5 mm
- Magazine: 25 pellets
- Materials: Li, C, B, Al, …

Lithium pellet features

Size = Ø1.5x5 mm
Vol = 8.8 mm^3
Weight = 5 mg

4×10^{20} atoms
$\Delta n_e \sim 10^{20}$ m^{-3}

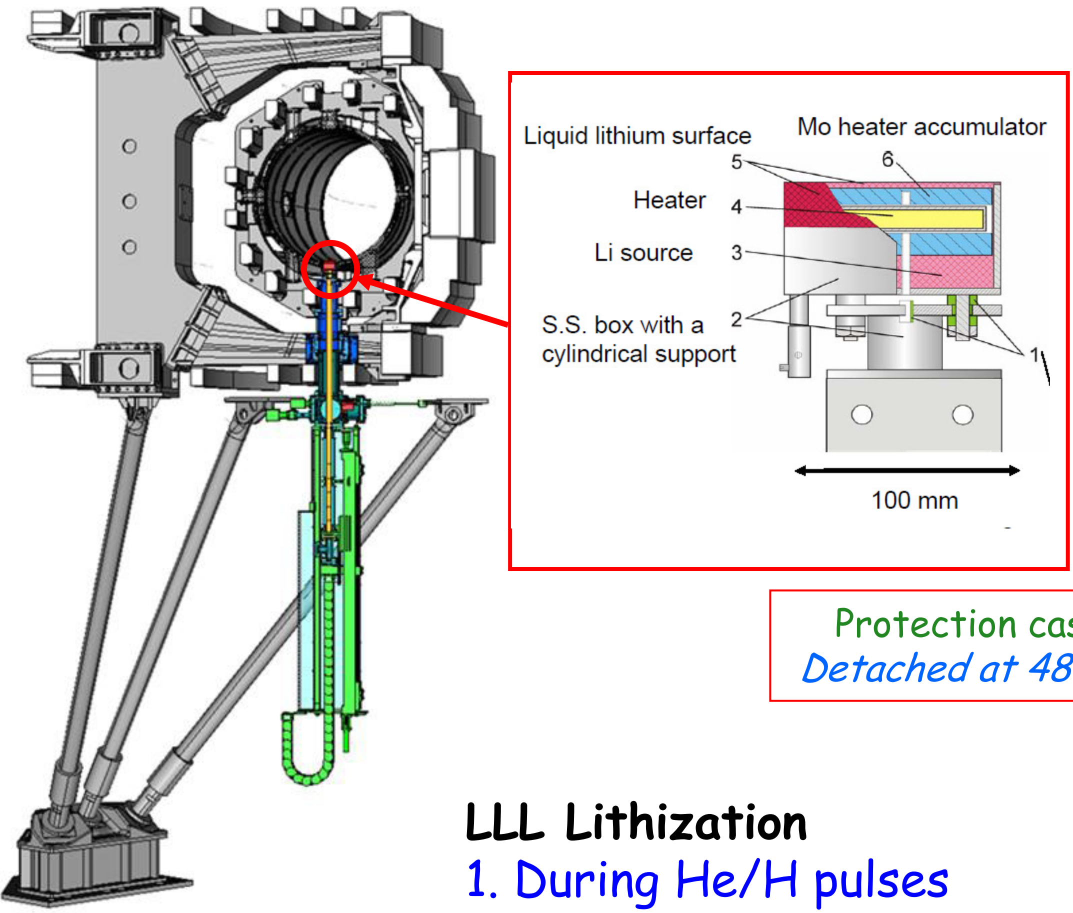


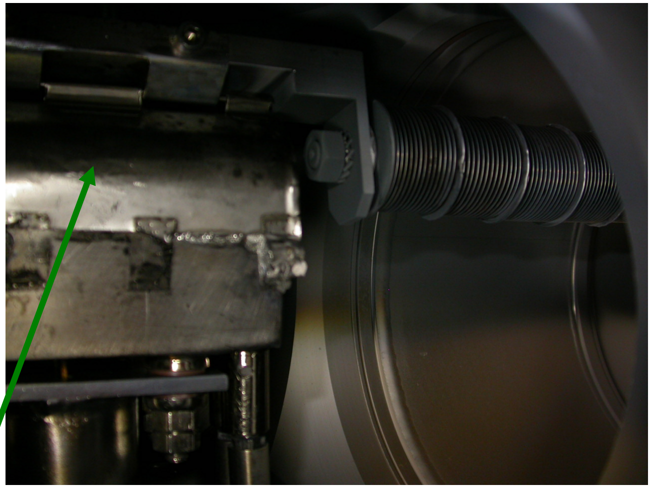
Lithization campaigns
1. Over graphite, thickness 5 nm (21 pellets)
2. Over graphite, thickness 4 nm (16 pellets)
3. Over light Boron, thickness 9 nm (38 pellets)
4. Over graphite, thickness 14 nm (56 pellets)
5. Over heavy Boron, thickness 13 nm (52 pellets)

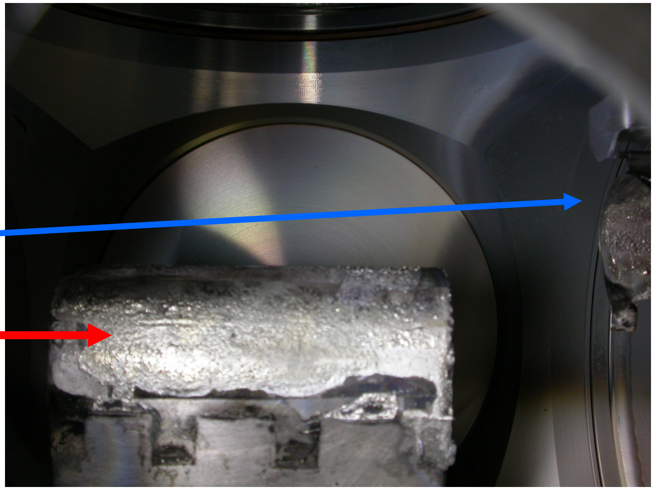
By all lithizations, we deposited in or on (?) the wall approximately 1 g of Lithium

Lithization by Liquid Lithium Limiter (LLL)

LLL is based on Capillary Porous System (CPS) configuration.
(1mm thick mat of wired stainless steel mesh)
On loan from the ENEA laboratories in Frascati, Italy







Protection case
Detached at 480 °C

Li

LLL Lithization

1. During He/H pulses
2. As evaporator

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Experimental results with Lithium pellets

Optimization of Lithization technique

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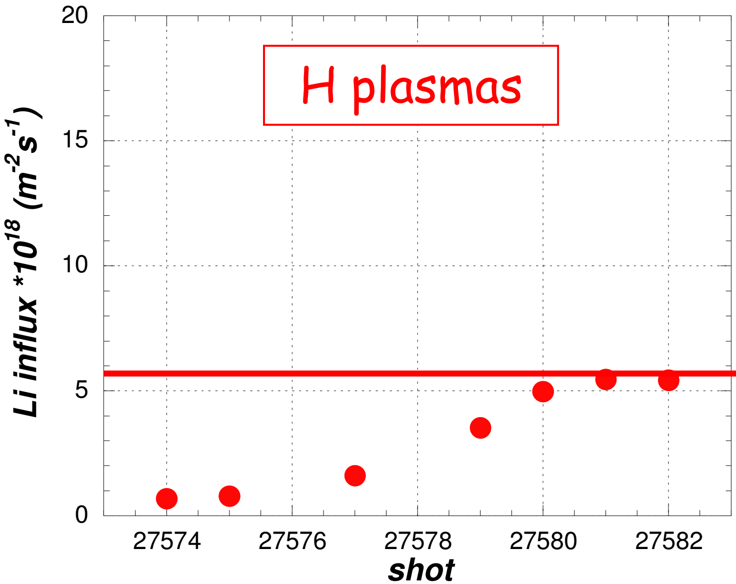
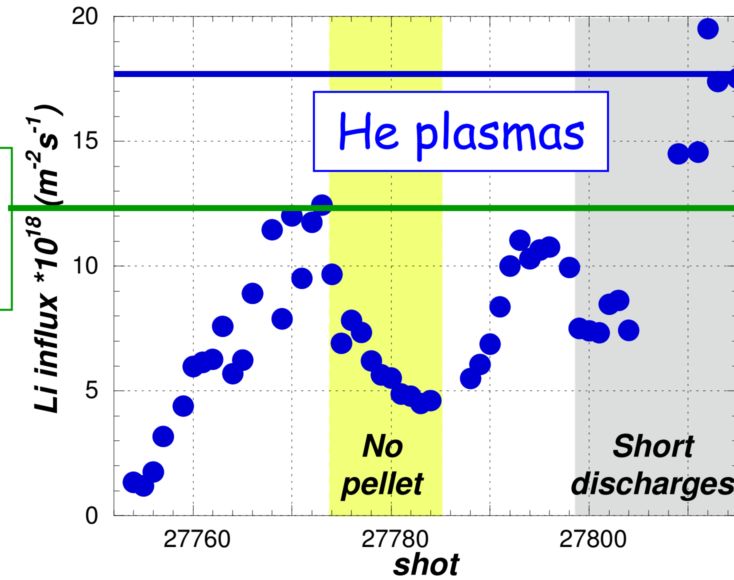
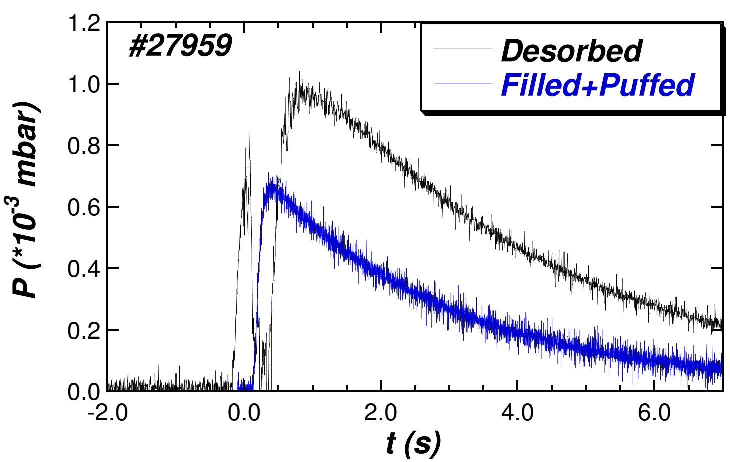
Short He discharges is the best choice for Li pellet wall conditioning



Li influx increases injecting on He discharges



Li influx increases decreasing pulses length



He discharges removes H atoms from the wall

He filling + Li pellet

Filled atoms = $1.3*10^{20}$

Desorbed atoms = $3.0*10^{20}$

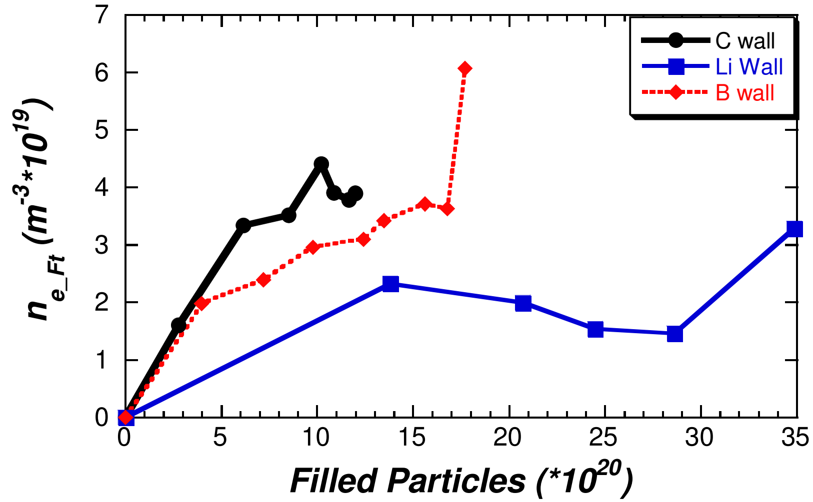
➔ Desorbed > Filled

Lithization effect on density control

Increased wall gas adsorbing capacity

Flat top **electron density** versus **total filled particles** between two He-GDC performed to remove H from the wall

After Lithization a greater quantity of filled particles does not lead losing density control

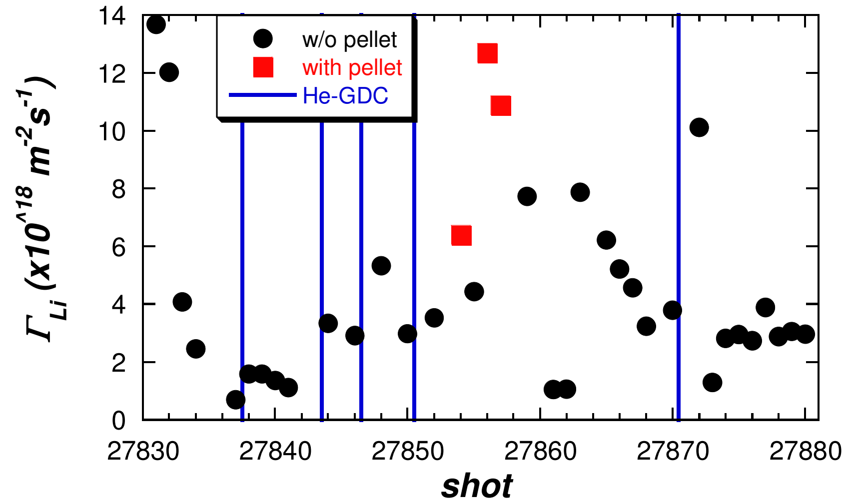


But gas adsorbing capacity is lost in few discharges

Losing adsorbing capacity is associated to a reduction on Li influx from the wall

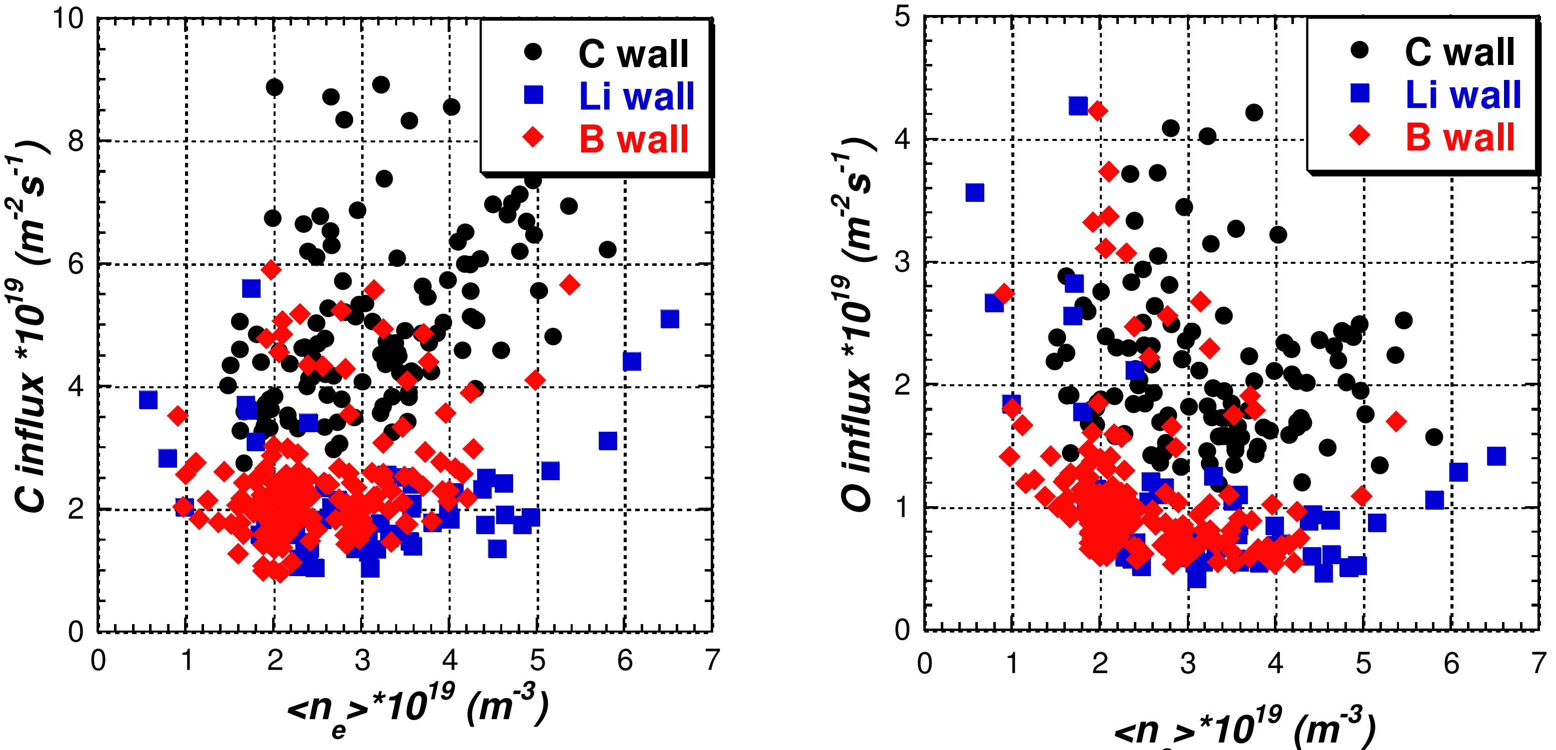
Is it related to **Lithium removal** or **Lithium binding** with H?

A small increase in Li influx is observed after each He-GDC



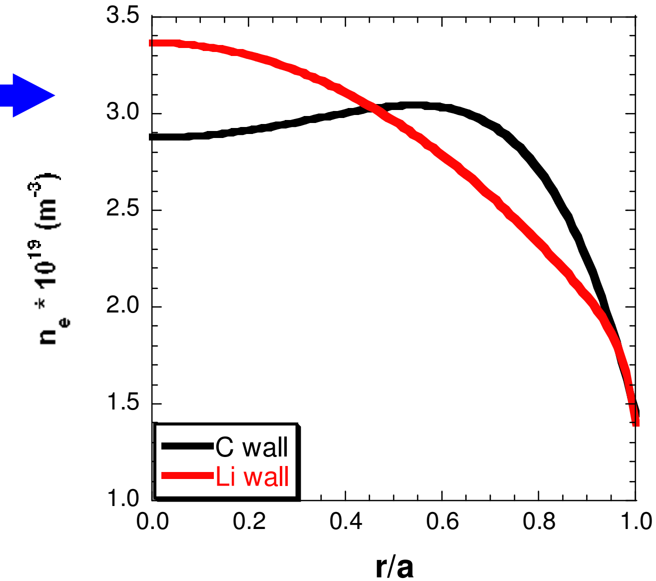
Impurity reduction with Lithium

- The main sources of impurity at RFX-mod are **C** and **O**
- After Lithization C and O **influxes** are **lower** than with clean graphite
- Lithization slightly **outperform** boronization at medium/high density



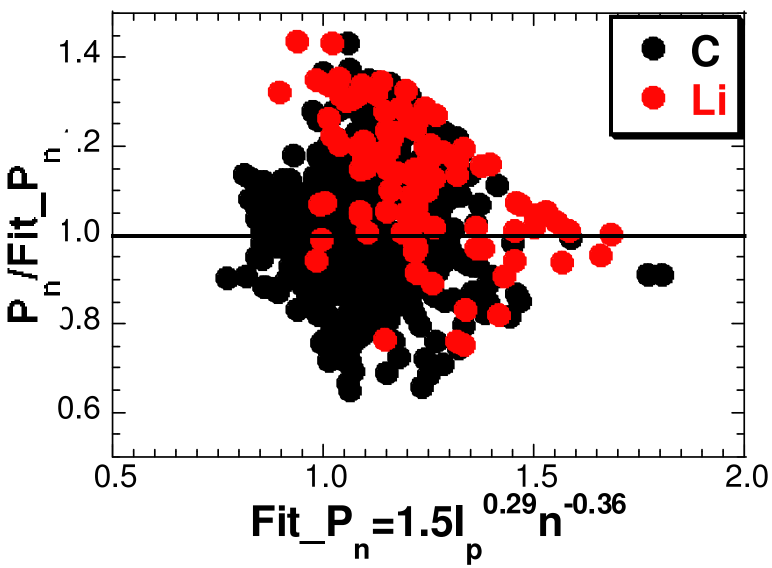
Electron density effect

- **Different** density radial profile →



- Statistically it can be verified by the Peaking Factor:

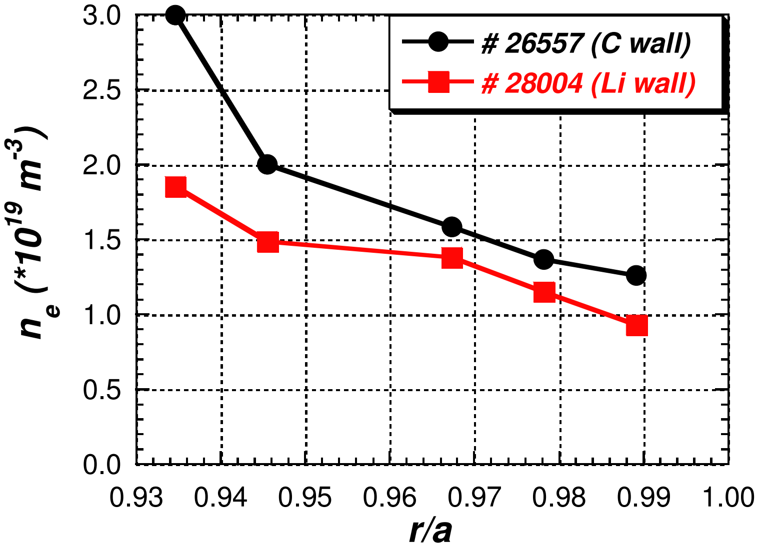
$$P_F = n(0)/\langle n \rangle$$



- On RFX-mod P_F is a **function** of plasma **current** and average **density**

- ***After*** the **Lithization** peaking factor is on average **higher** than with a clean **graphite** first wall

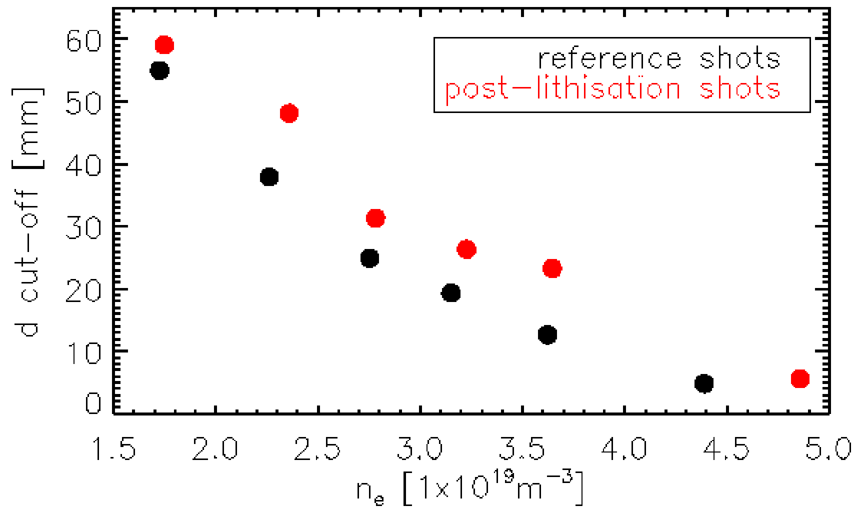
Edge effects: density



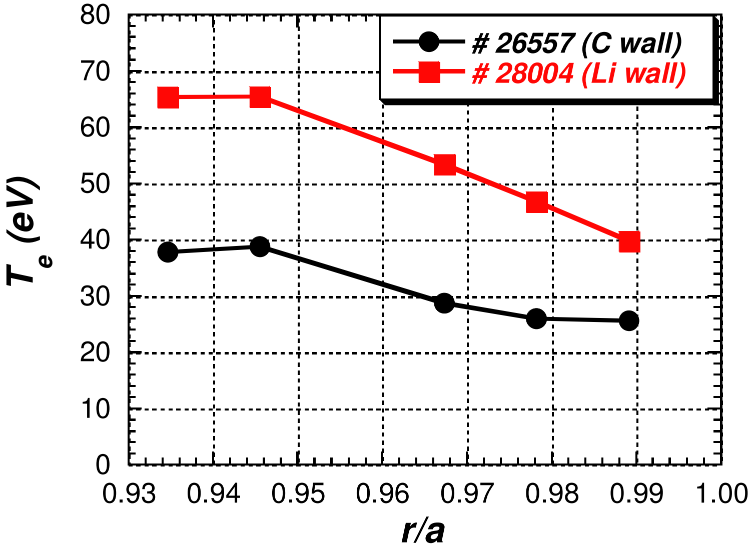
- **Edge density** with Thermal Helium Beam diagnostic
- After **Lithization** edge density is **lower** than on clean **graphite**

- It has been **confirmed** by the n=10^{19} m^{-3} cut off layer position measured with a fixed frequency **reflectometer**
- **Averaging cut-off** layer position over similar **density** discharges:

➔ In **Li** discharges cut-off layer position moves **inward** by about 1-2 cm

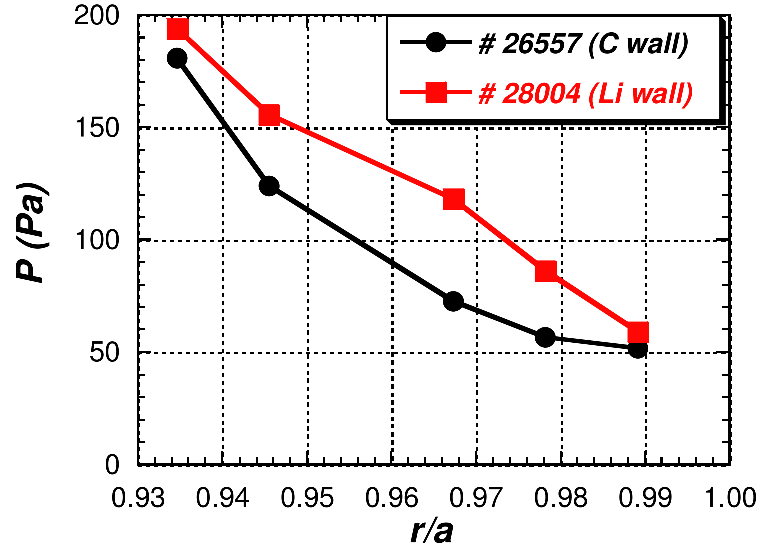


Edge effects: temperature & pressure



- **Edge temperature** with Thermal Helium Beam diagnostic

- After **Lithization** edge temperature is **higher** than on clean **graphite**



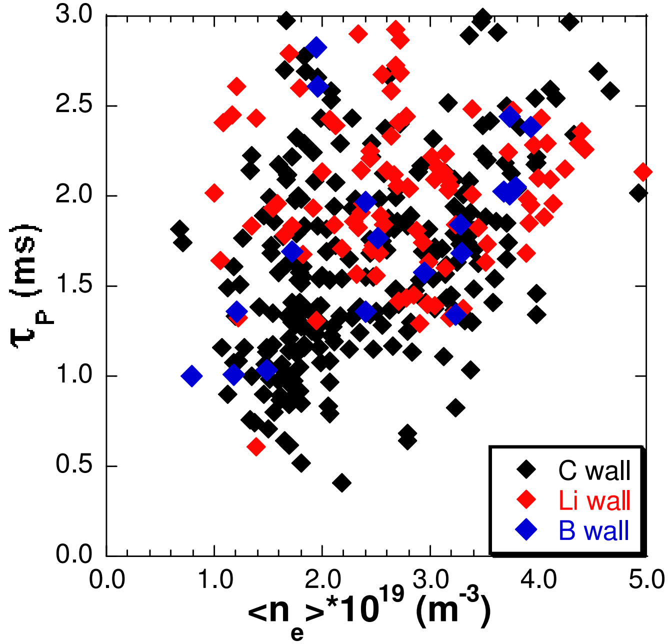
With Li: edge temperature increases exceed density reduction

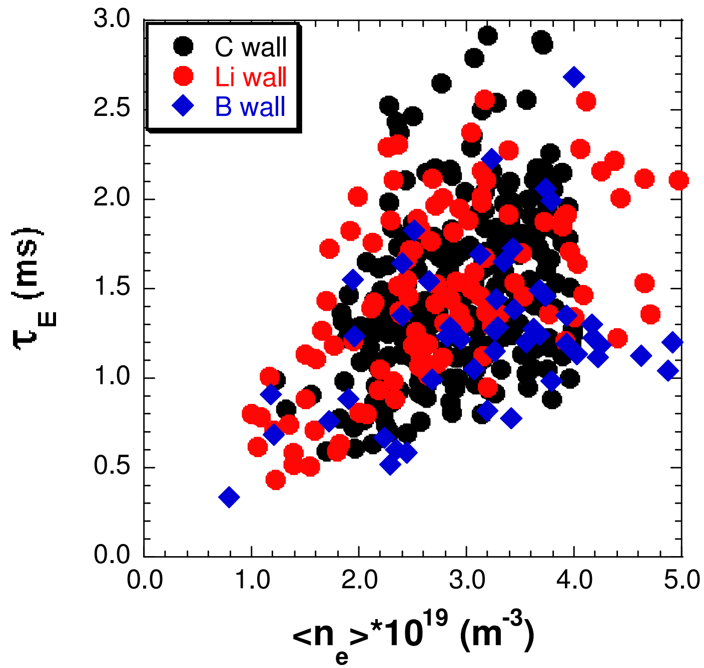
➔ **Edge pressure increases with Li conditioning**

Global confinement

Lower H_α emission at the edge at the **same density** with a Li wall

Small average improvement of the particles confinement time





No difference on the **energy confinement time** with respect to the Graphite wall

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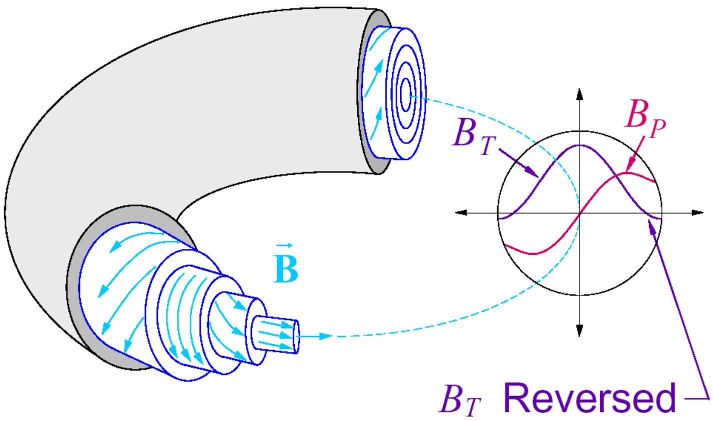
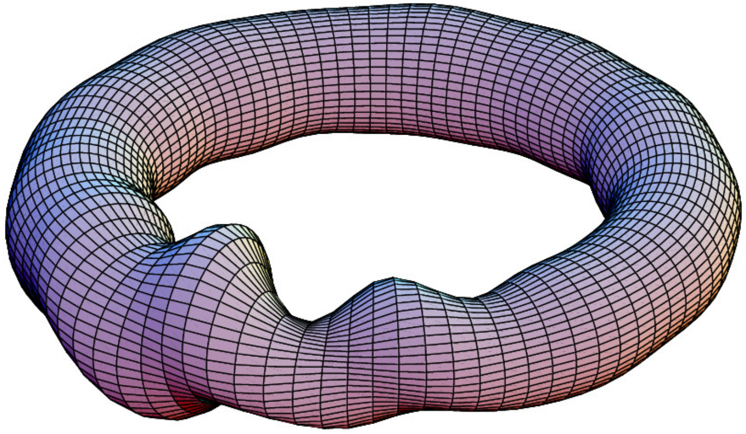
Experiments with Liquid Lithium Limiter

LLL issues on RFPs

1. Edge field is nearly poloidal
   ➔ Low toroidal distribution of ablated lithium



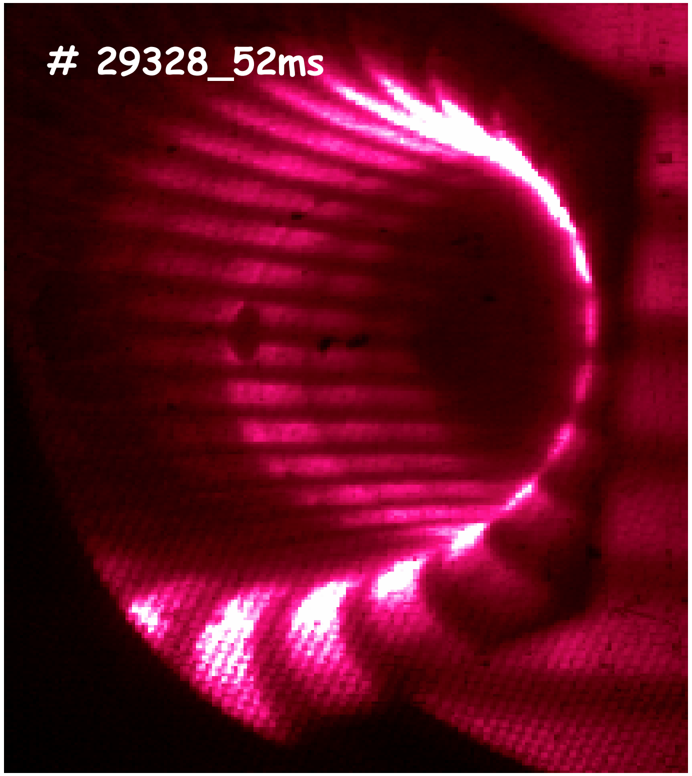
2. Large edge deformation
   ➔ Local interaction/local deposition
   ➔ Strong interaction with LLL



LLL strategies on RFX-mod

- **Wall conditioning on tokamak discharges**
  RFX-mod can operate in tokamak configuration with plasma current up to 150 kA and pulse-length up to 1 s.
  ➔ LLL orientation was optimized for tokamak but…
  A toroidal coil accident has prevented tokamak operation for all the 2010 year

- **Wall conditioning on RFP discharges with:**
  ➔ **relatively high reversal (higher edge toroidal field)**
  ➔ **externally induced time localized helical deformation**

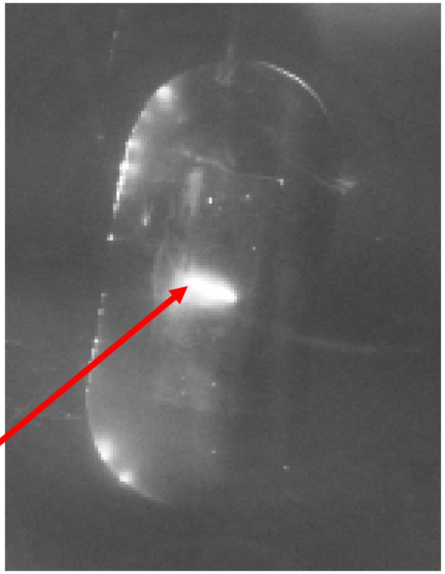


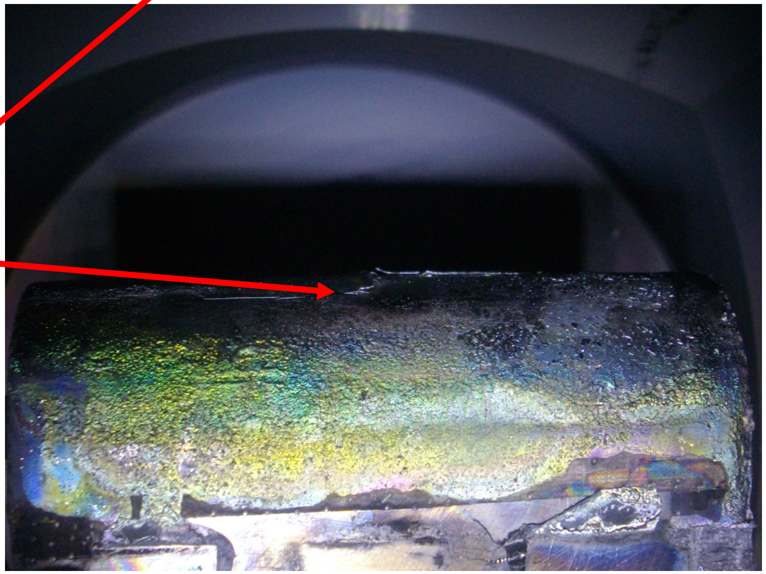
LLL results

Few tests performed on limiter configuration:

- Plasma current ≅ 0.6 MA
- He filling
- Insertion up to 3 mm (1 shot)
- About 200 mg of evaporated Li (like ≈ 40 pellets) and 20 mg ablated Li (like ≈ 4 Li pellets)

  ➔ Li influx at 90° ~ 1/2 vs 1 pellet
  ➔ Li influx at 180° ~ 1/5 vs 1 pellet





Stopped by a damage of LLL
(a breaking on wire mesh)

During operation observed also LLL carbonization

LLL as evaporator

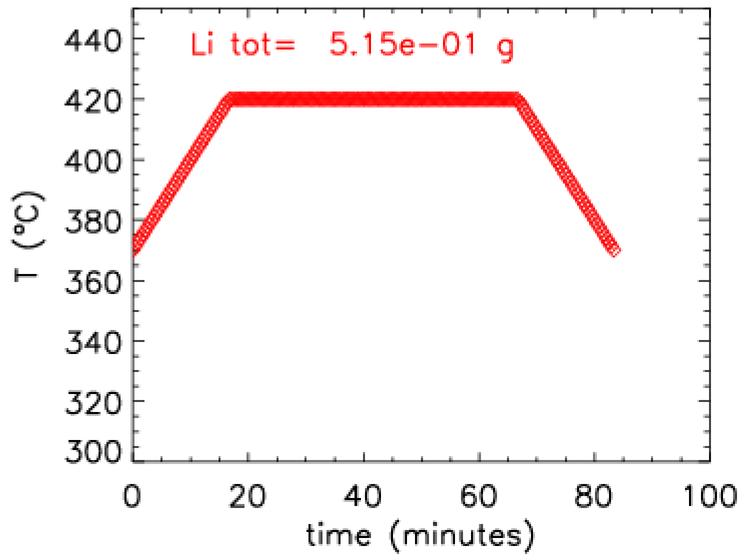
- In vacuum evaporation with LLL at +100 mm
- Evaporated about 500 mg of Li (like ≈ 100 pellets)
- Two He shots to re-distribute and check Lithium influxes
  - Li influx at 90° ~ 3 vs 1 pellet
  - Li influx at 180° ~ 2 vs 1 pellet

  ➔ High toroidal asymmetry

- Few H shots at low plasma current

  ➔ Wall adsorbing capacity similar to the Lithium pellet case

  ➔ Low impurity content



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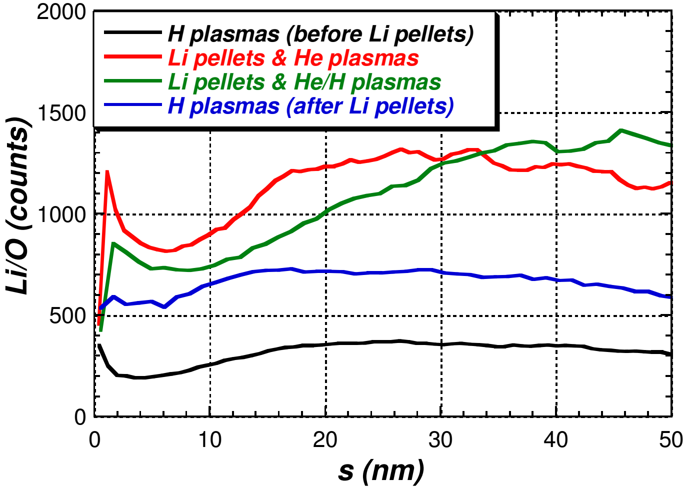
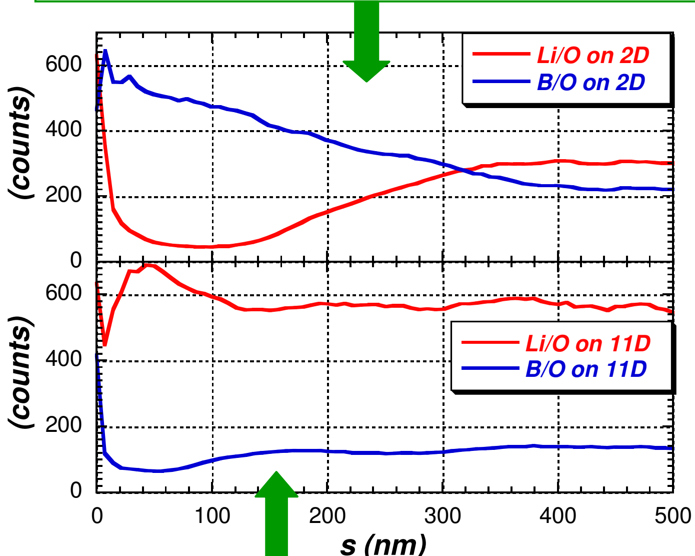
Post-lithization effects

SIMS graphite samples analysis



180° from LLL / 0° from GDC anode



30° from LLL / 90° from GDC anode

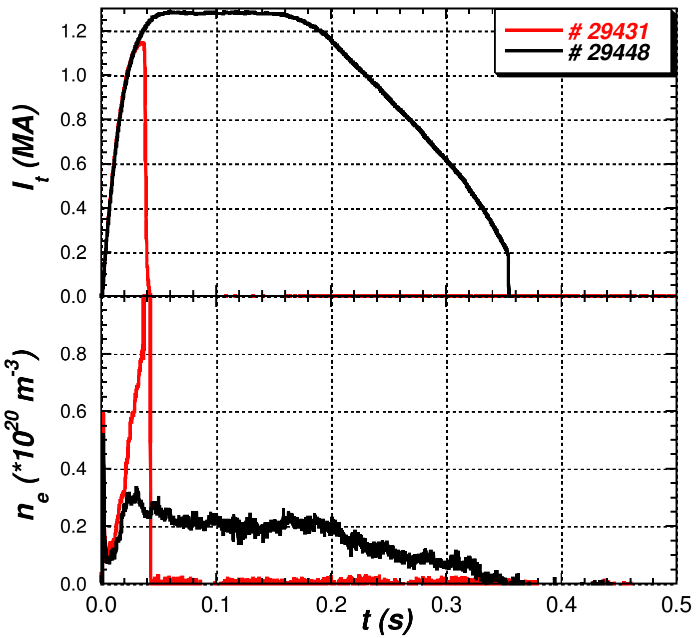
- Li diffuses on graphite (not easily seen a surface layer with higher Li concentration)
- Li is not removed by plasma discharges but diffuses deeper into graphite
- Clean graphite samples inserted after lithization collects a lot of Lithium

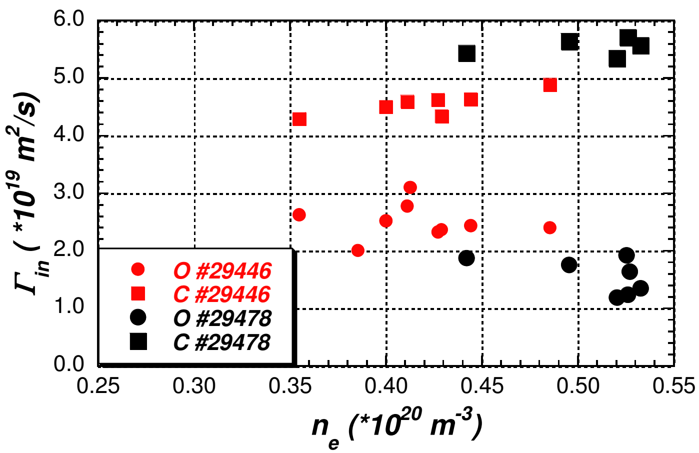
Boronization after LLL operation

- Boronization can cover Lithized graphite
- Unfortunately in RFX-mod boronization toroidal asymmetry prevents complete Li covering

➔**No safe vessel venting:** Lithium Carbonate (Li_2CO_3) formation!

Vessel venting with Lithium/Plasma





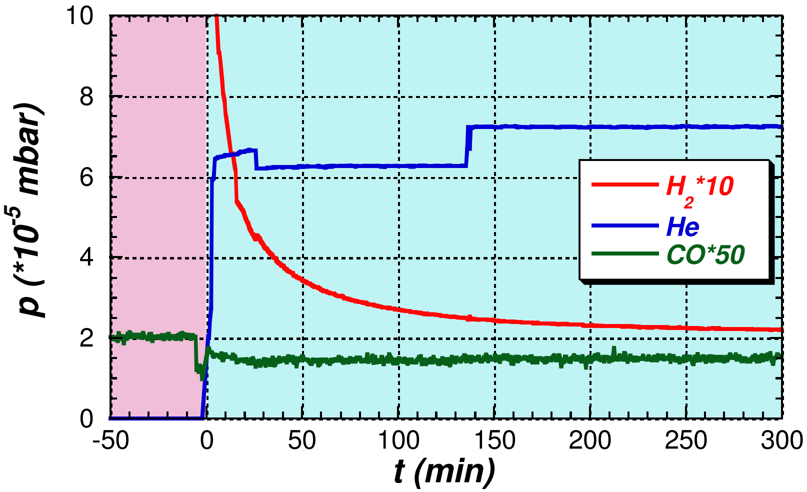
 # 29431 First H shot after vessel venting:

- High density terminated discharge due to high influx from wall
- High O influx (particularly on He discharges)

#29448 After less than 20 H/He discarges and about 10 He-GDCs:

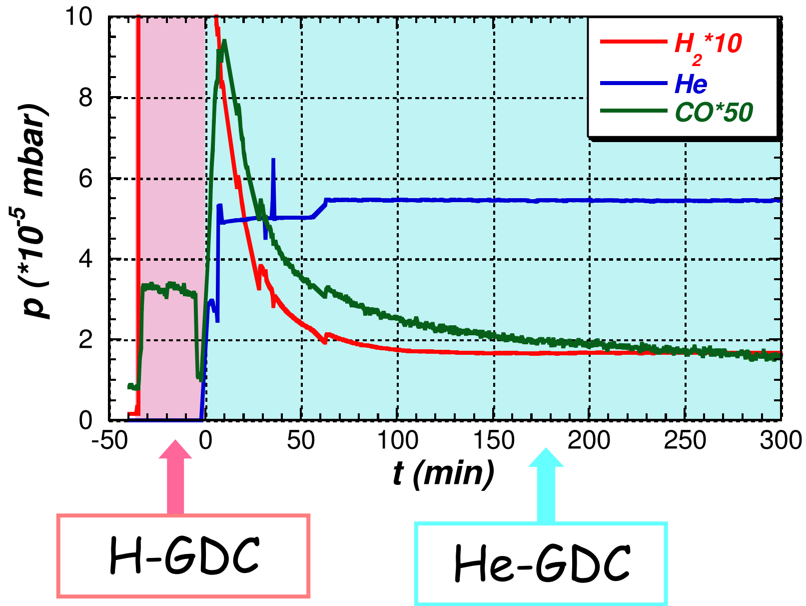
- Recovered good H discharges
- Reduced O influx
- But C influx not changed (still slightly higher than usual)

Vessel venting with Lithium/GDCs



Just after closing vessel

➔ H/He GDCs and backing do not extract CO impurity



But after one/two medium plasma current shots

➔ H-GDC slowly extract CO impurity

➔ He-GDC fast extract CO impurity in the first 60-120 minutes

Plasma discharges break Li_2CO_3 in 2Li+3CO and then He-GDC removes CO?

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Next Steps

LLL experiments already planed

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1. Experiments with LLL used as an evaporator (if possible installed on the equatorial plane)
2. LLL used as limiter on tokamak configuration
3. LLL used as limiter on RFP configuration but 90° rotated

After that…..

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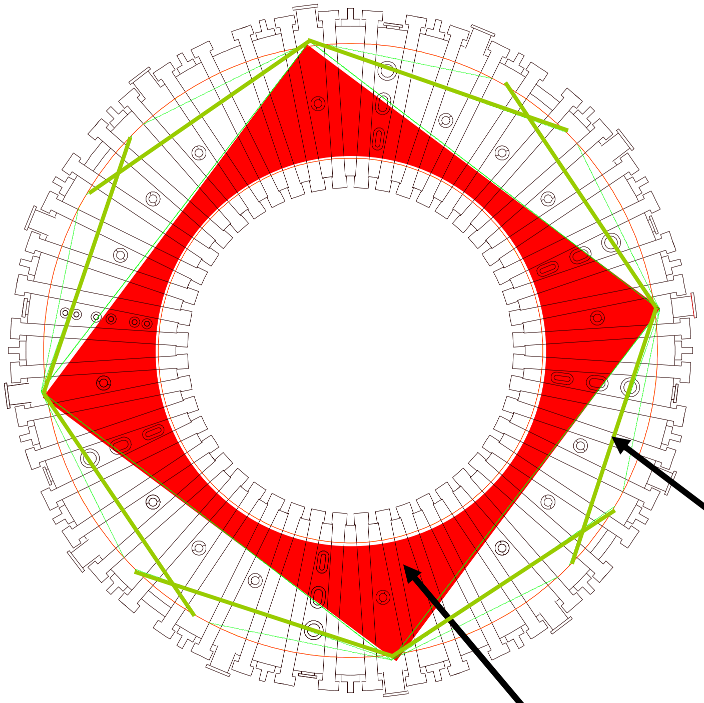
4 evaporators on the equatorial plane



- Installation on pumping ports
- Coverage of all the inner wall with intensity > 50%
- Low/no deposition to the windows

Area with deposition larger than 20%

Area with deposition larger than 50%

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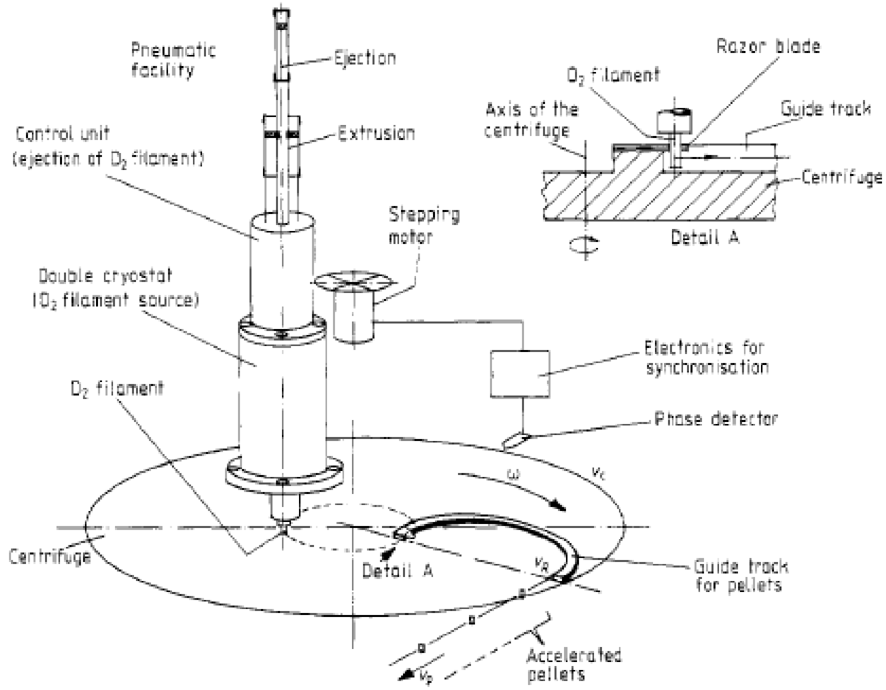
A centrifugal Lithium multi-pellet injector ...



With a repetition rate of 50 Hz:

- About 10-15 pellets on one shot
- 2-3 nm Li layer on the wall per shot
- Uniform deposition
- 50 nm Li layer on a day

Conclusions

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- **Lithization has been tested on RFX-mod by Li pellet**
  - Thin Li wall coating provides clear effect on recycling and edge transport
  - Lithium conditioning disappear very rapidly
  - Loosing of conditioning ability is not related to 'true' Lithium removal
- **Liquid Lithium Limiter has been also tested**
  - Not an easily technique on RFPs with a carbon wall
  - Easily used as evaporator but with high toroidal asymmetry on deposition
- **Post-lithization effects**
  - Lithium is present in graphite when no effects are observed on plasma
  - After vessel-venting impurity and density control deny good operation
  - Good performance are recover by 10-20 medium current shots and 30'-60' of He-GDC in between
- **Future experiments**
  - New Lithization tests are planed this year on RFX-mod with LLL used first as evaporator and then as limiter
  - To improve toroidal deposition symmetry multi-evaporator or centrifugal pellet injector are also foreseen

Spare slides

Wall loading status

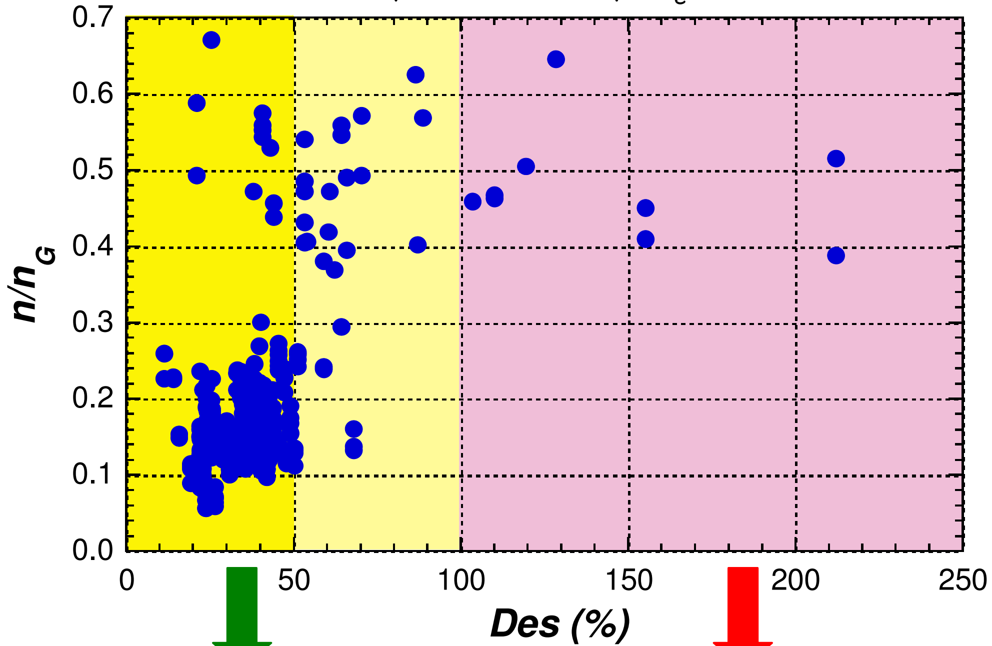
$$Des\% = \frac{\text{Extracted particles after the end of the pulse}}{\text{Total fuelled particles}} * 100$$

The Desorption Factor Des% expresses, shot by shot, the capability of the wall of absorbing the fuelled particles

The status of the wall determines the accessible regime

Des% leads n/n_G
No correlation found between Des% and n or I alone

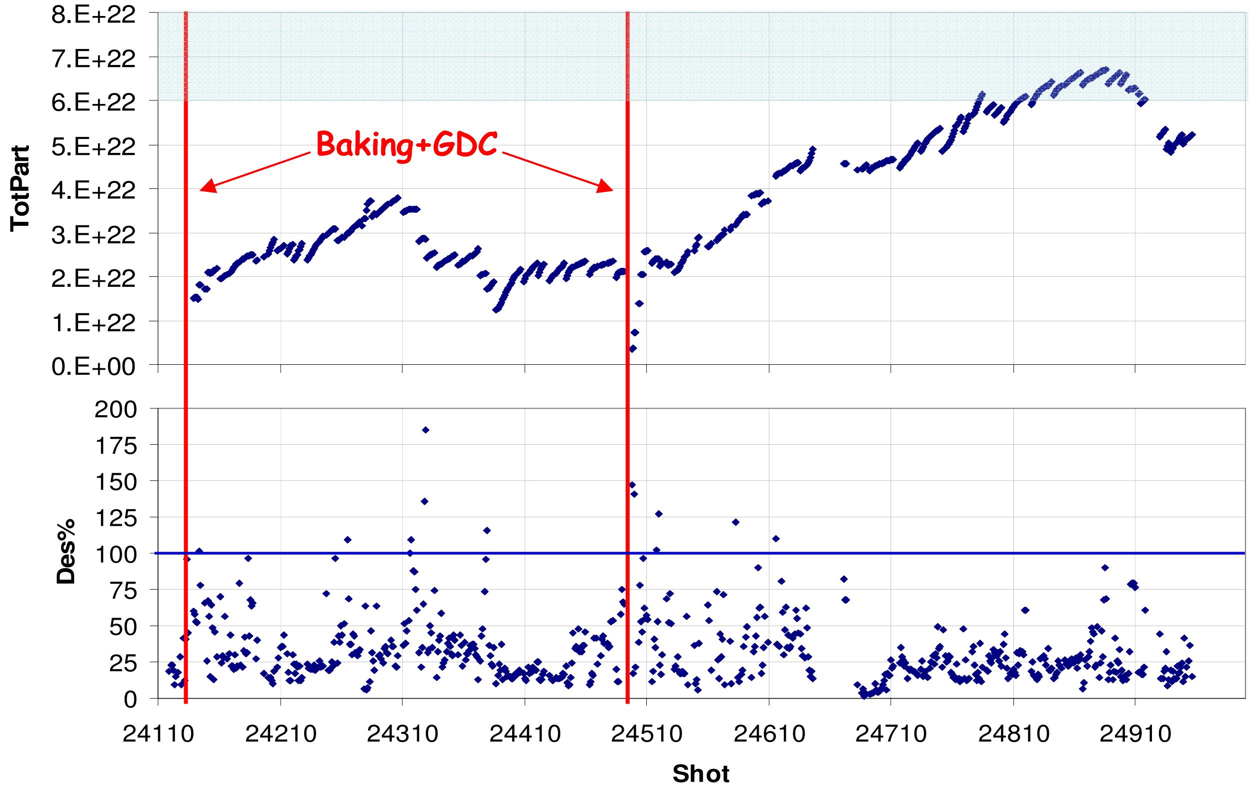
~ 700 shots, $0.3<I<1.6$ MA, $1<n_e<14 \cdot 10^{19} m^{-3}$



Absorbing wall: wide range of density regimes

Not absorbing wall: n/n_G forced to ≈0.5

Effectiveness in density control

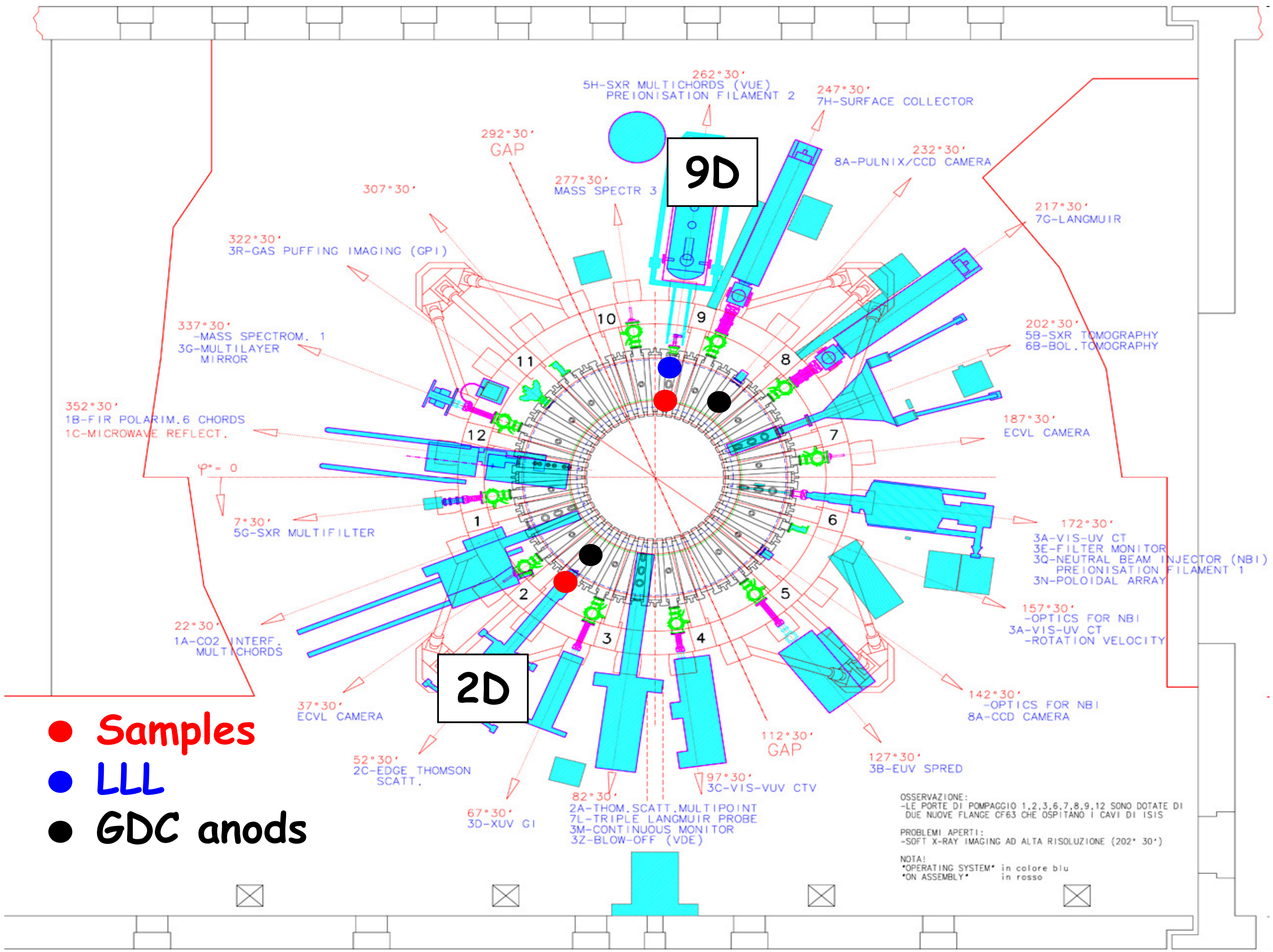


Total particle stored in the wall

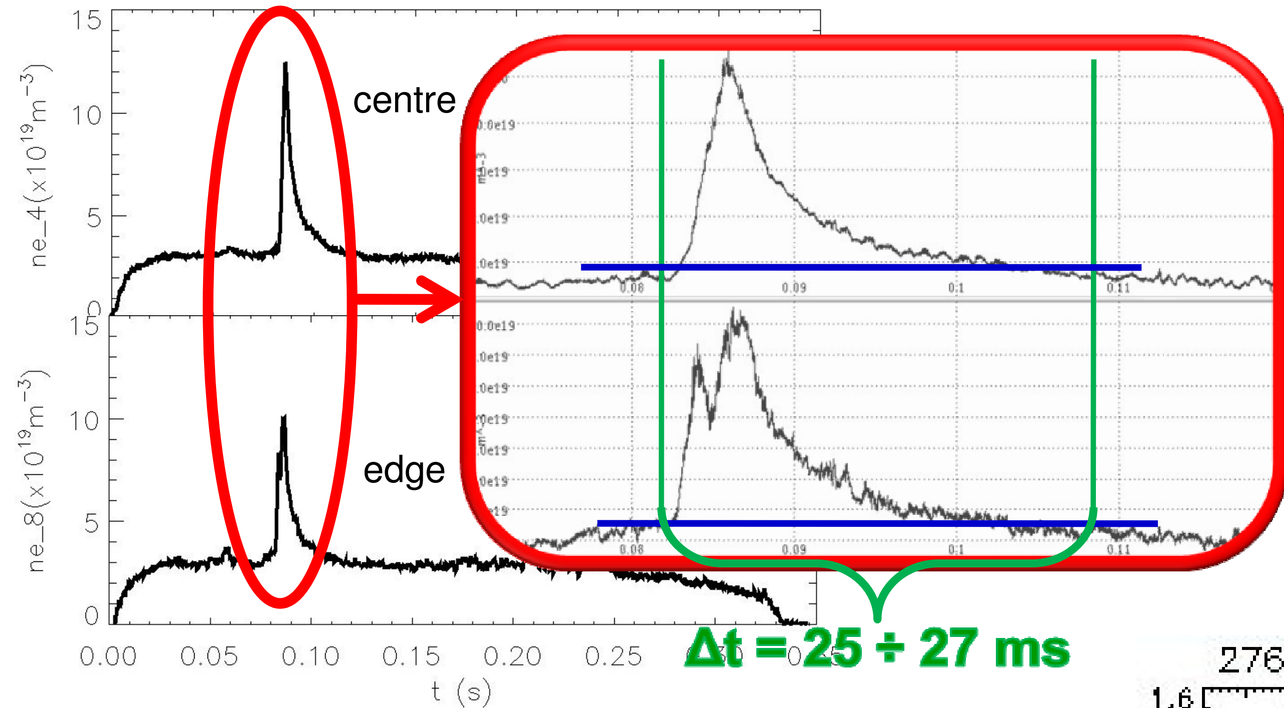
Desorption factor

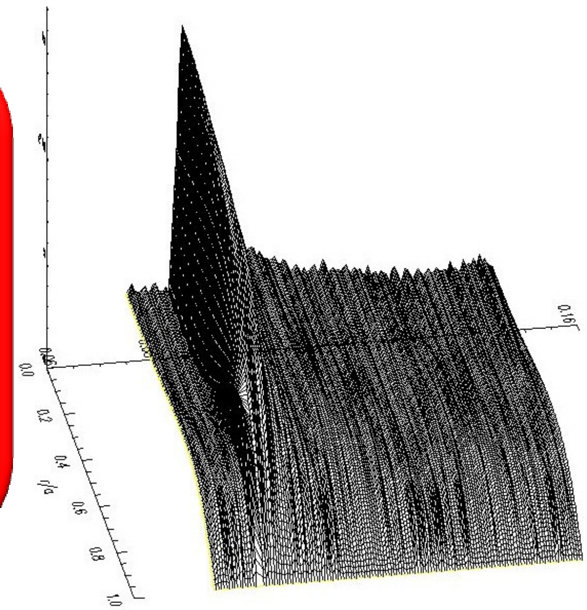
20-60 min He GDC remove 1-2x10^{21} H atoms and allow operation, but they are not effective in preventing particle accumulation in the wall

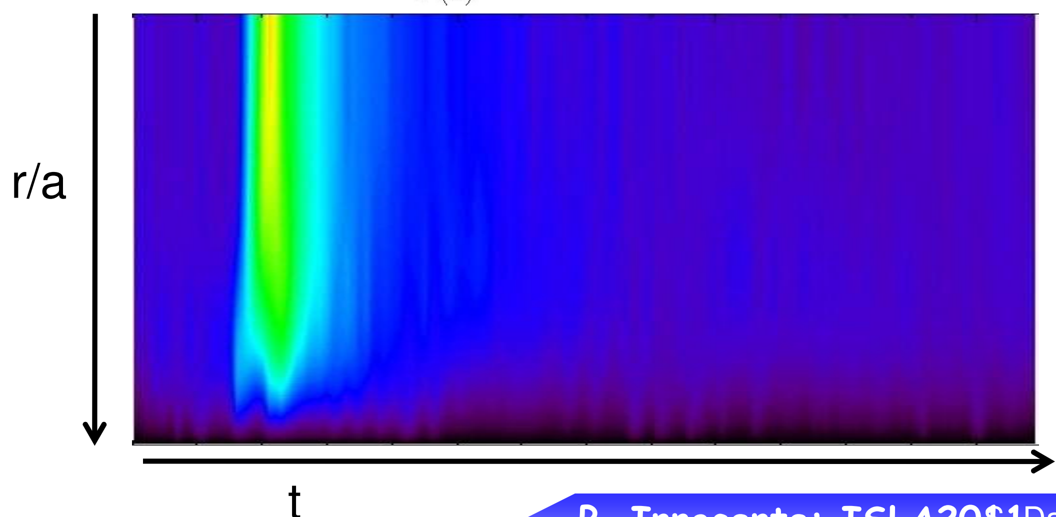
Samples, LLL and GDC layout

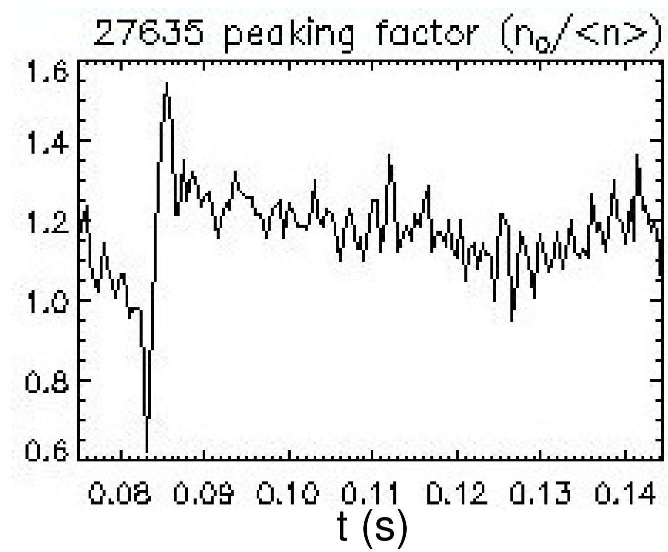


Li pellet injection

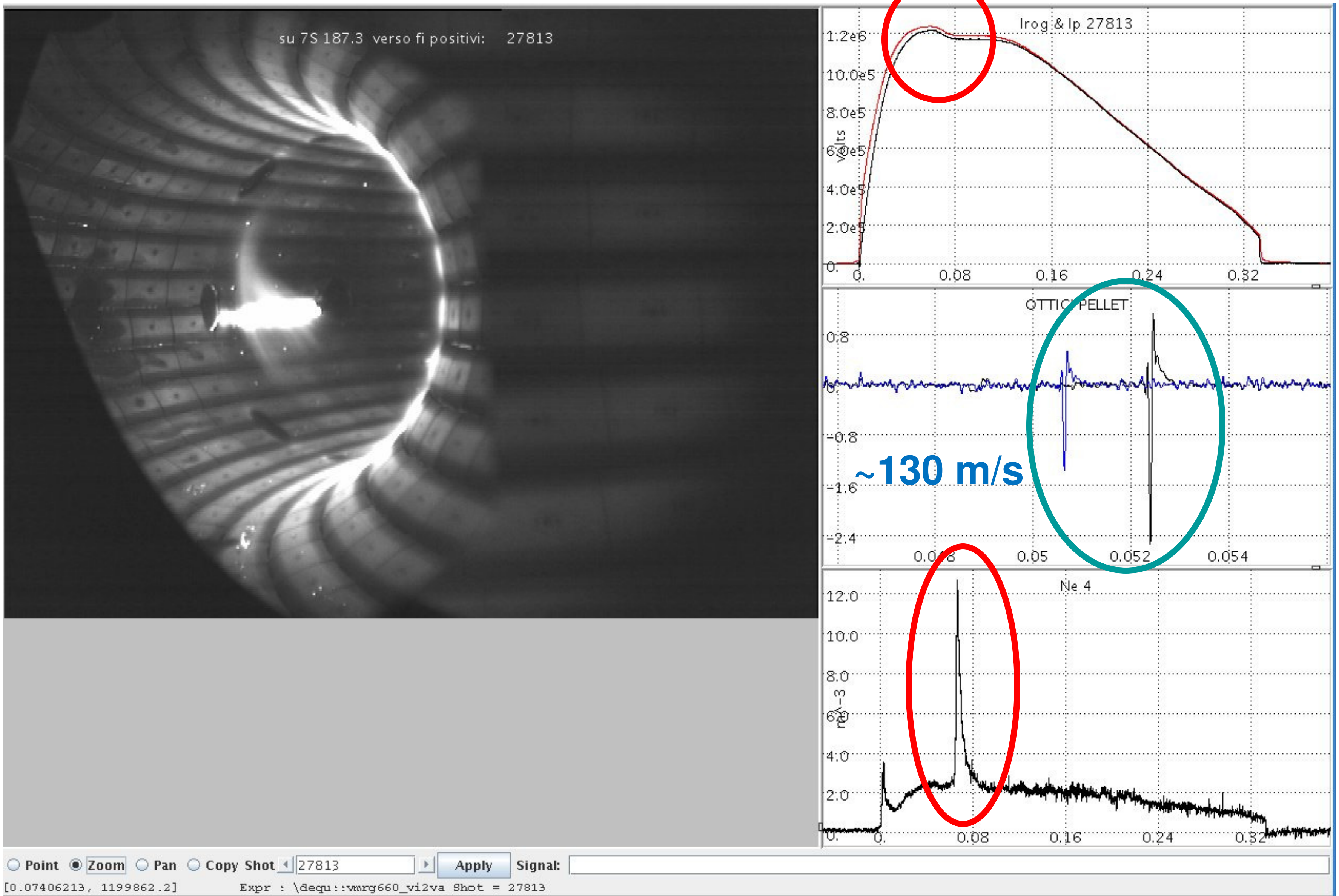




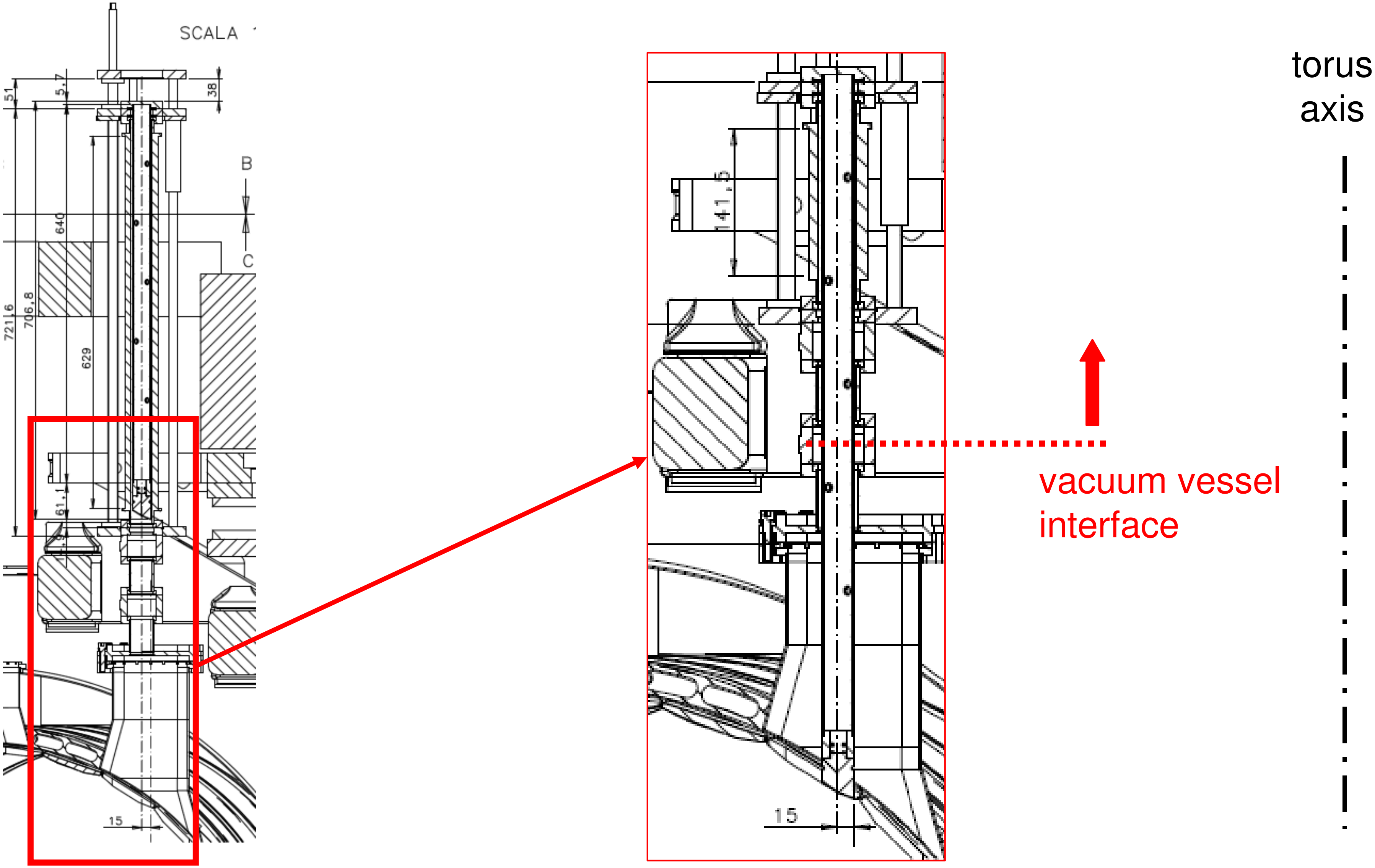




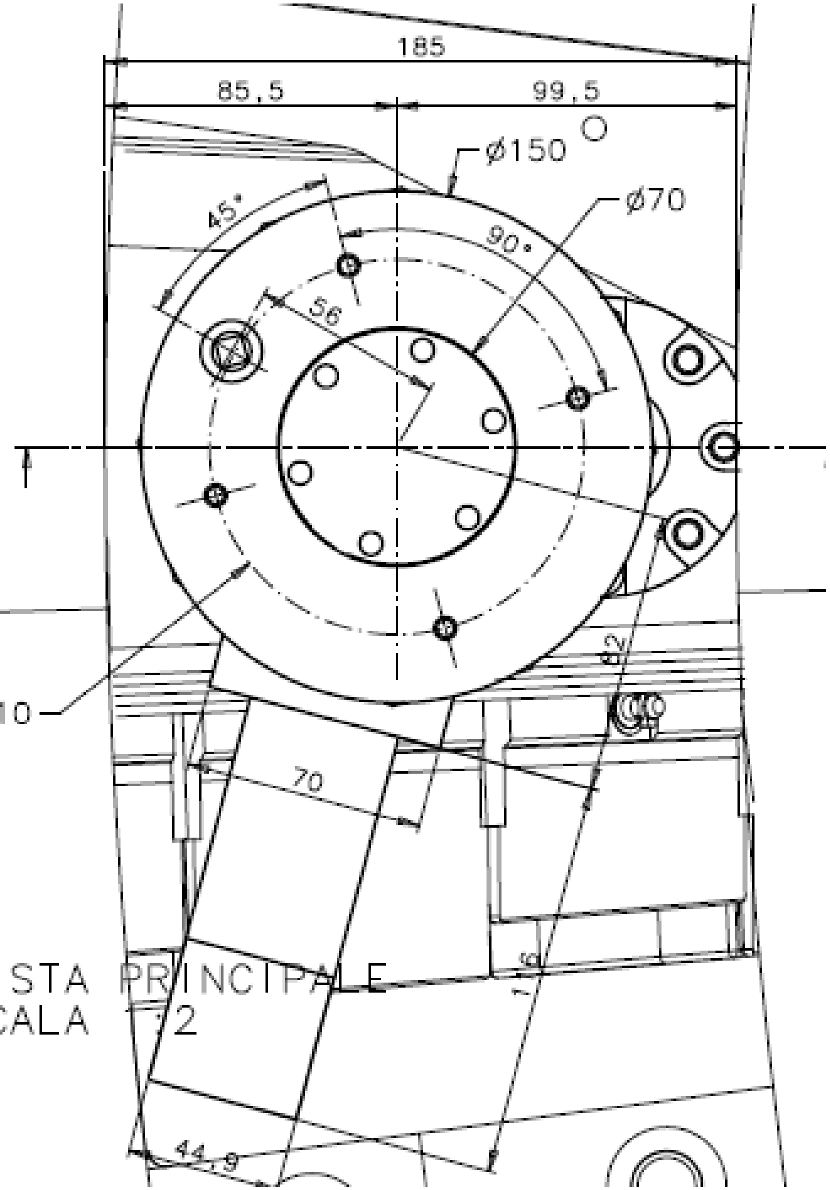
Li pellet injection

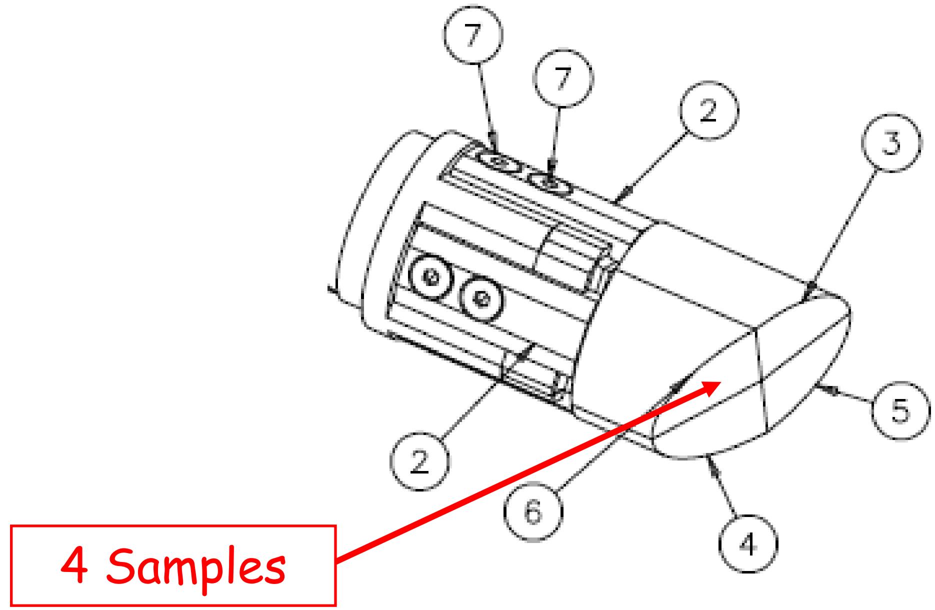


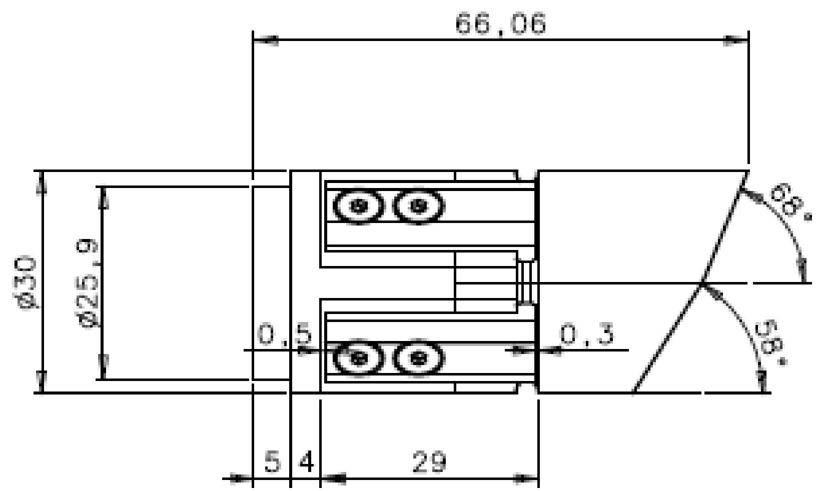
Samples manipulator



Samples geometry







Edge effects: turbulent particle transport

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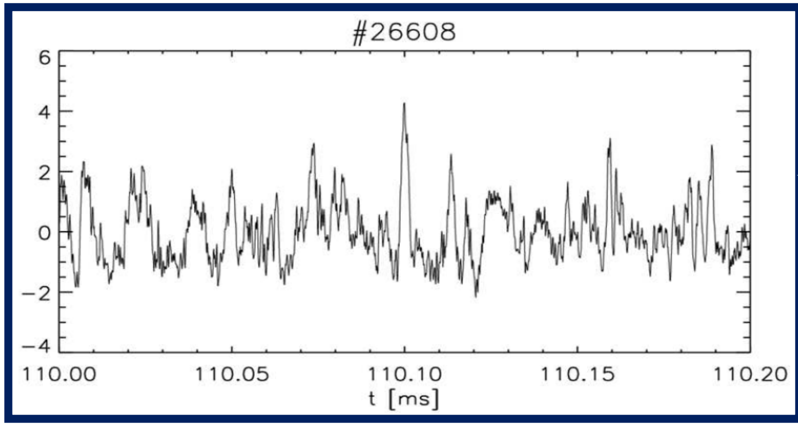
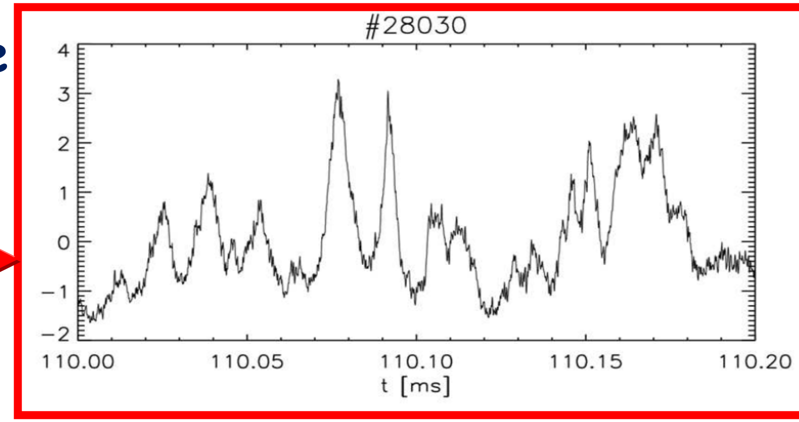
Gas Puffing Imaging diagnostic raw signals: measurement of **edge density fluctuations**



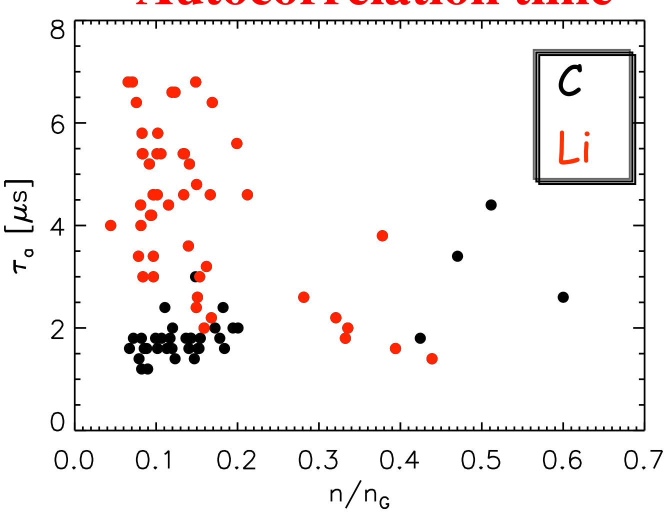
Reference

After Li



to quantify the differences

Autocorrelation time



- larger edge blobs
- less plasma volume occupied
- different turbulent particles transport at the edge

Packing fraction