Characterization of the helicon plasma generated inside the Cybele negative ion source with different magnetic field configurations

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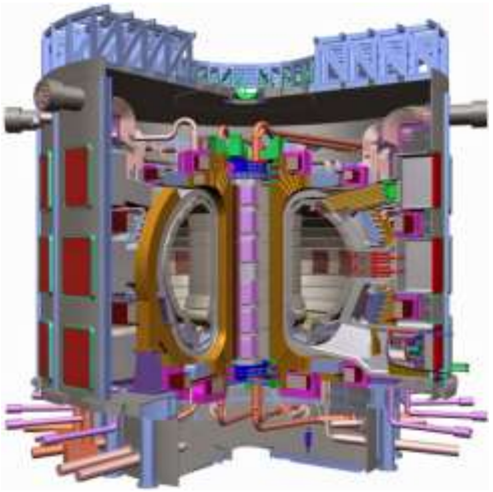
ITER 2030

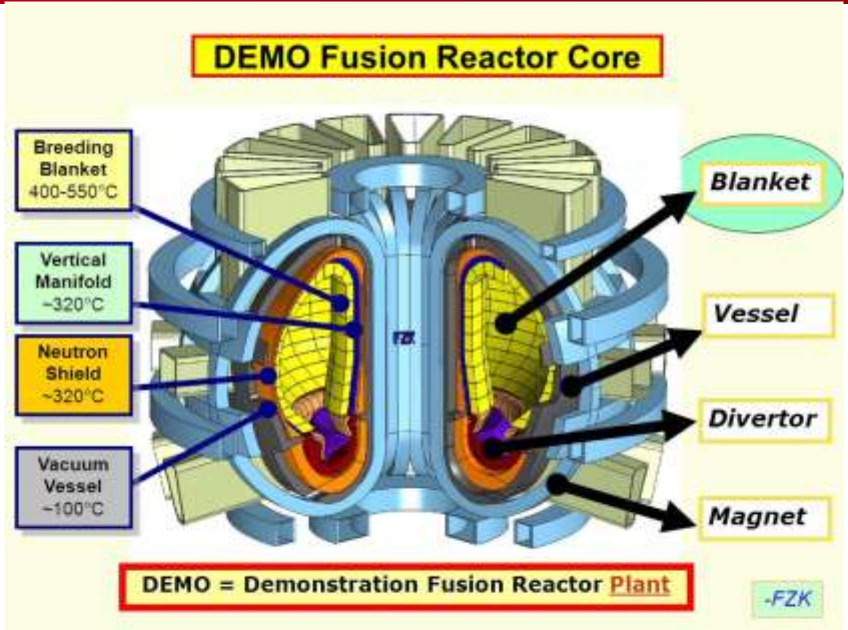


No electricity production

Plasma heating: NBI: 2*17MW D° at 1MeV

NBI Expected efficiency :<28% [1]

The ITER NBI is under construction RFX testbed (MITICA) commissioning in 2023



500MW of electrical power on the net

DEMO1: pulsed reactor

NBI: ~ 50MW D° at 1 MeV

Overall efficiency > 40 % [2]

DEMO2: Steady state

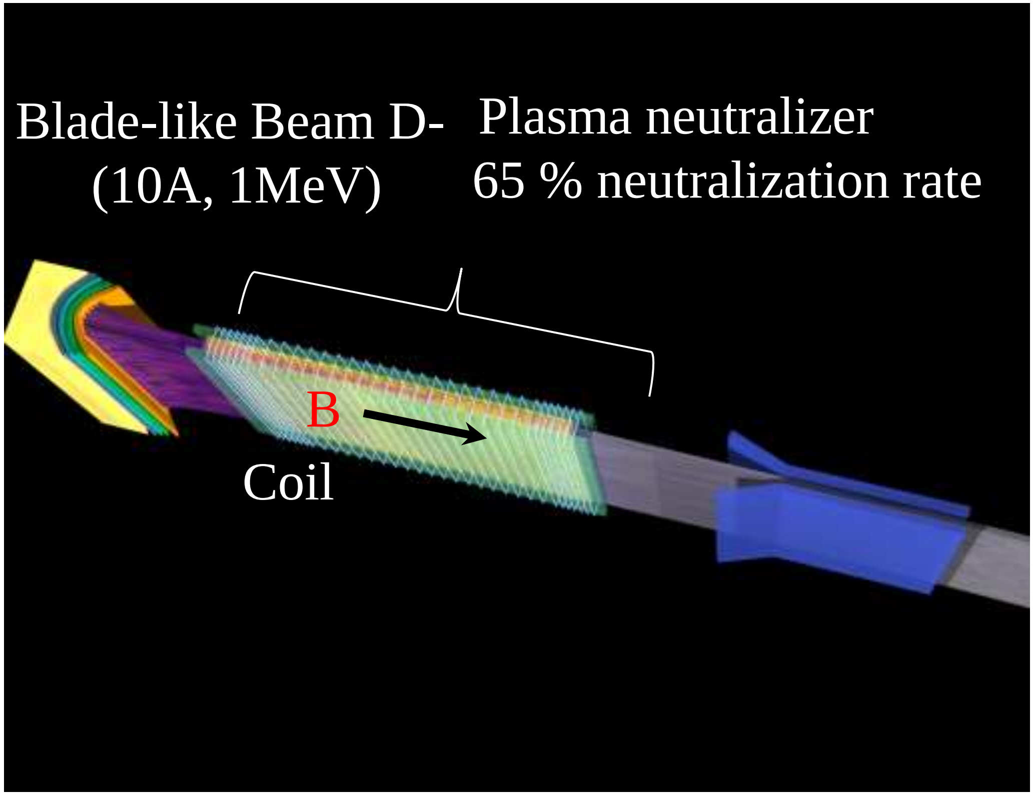
NBI: ~110MW D°, 1-2 MeV (current drive)

Overall efficiency > 60 %

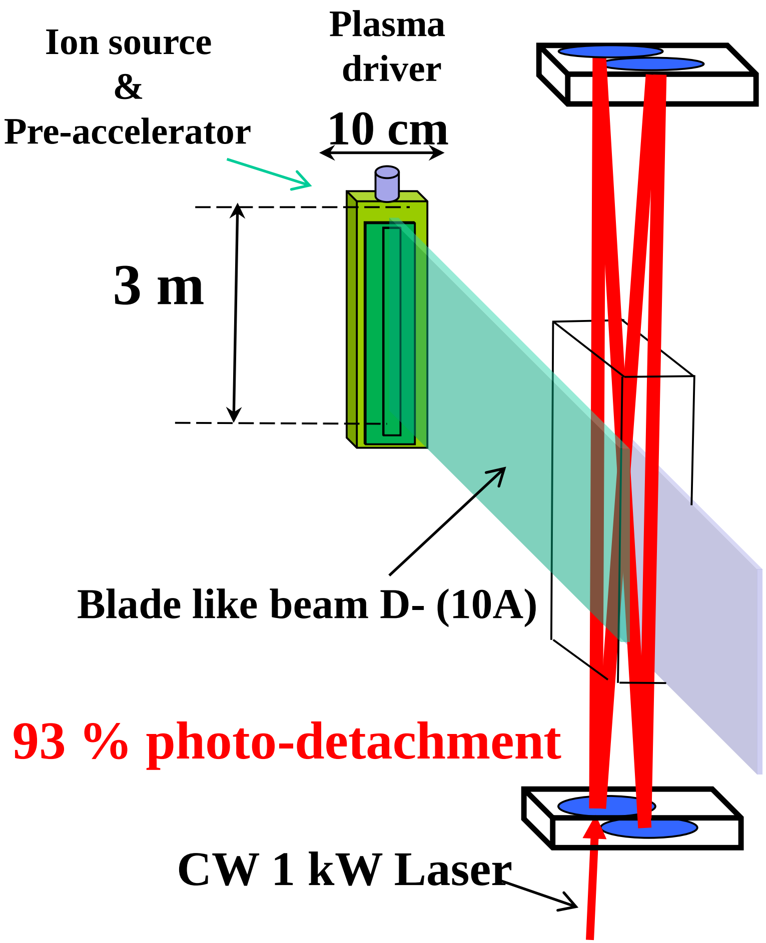
[1] R S Hemsworth *et al*, Overview of the design of the ITER heating neutral beam injectors, 2017 *New J. Phys.*

[2] P Sonato et al, 2016, Conceptual design of the beam source for the DEMO NBI , New J. Phys. 18 125002

NBI: with plasma neutralizer



with photoneutraliser [3]



Potential advantages of blade-like beams:

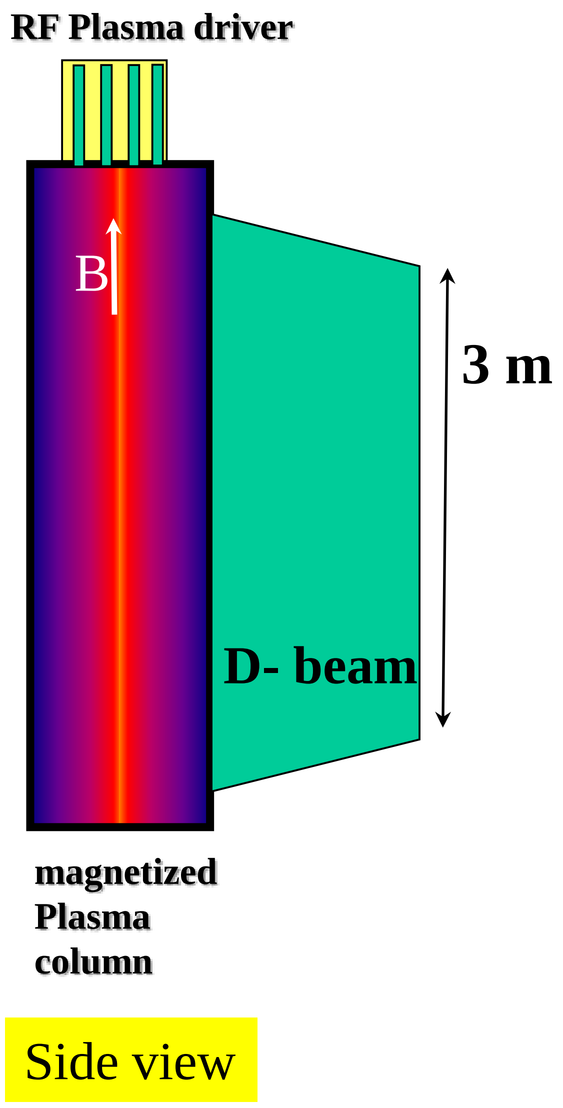
Reduce the gas load along the beam line

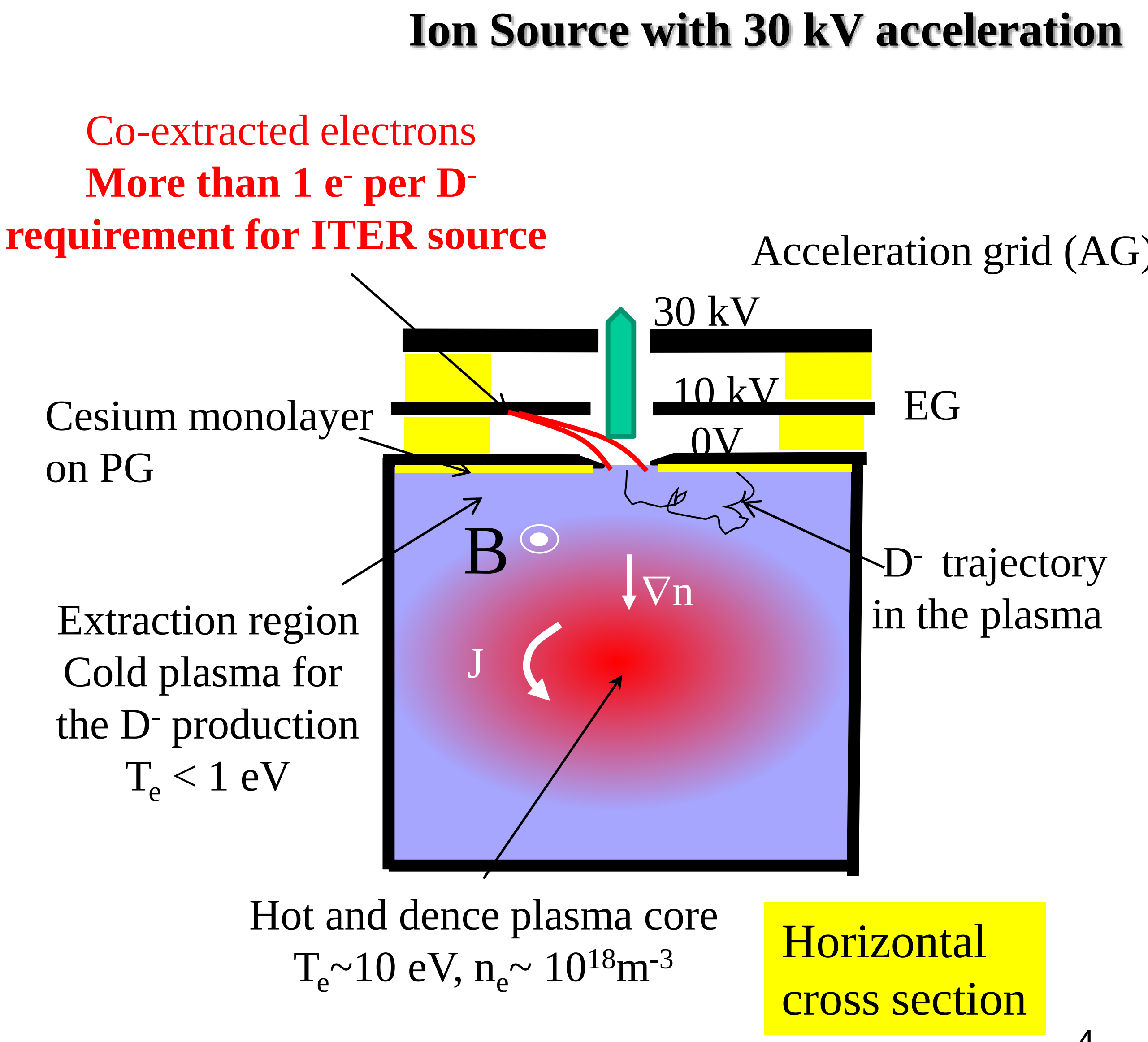
Increase the overall injector efficiency

Essential for plasma neutralizer and photoneutralizer

[3] A Simonin *et al*,, New J. Phys. 18 (2016) 125005

Ion Source concept based on magnetized plasma column for blade-like beams

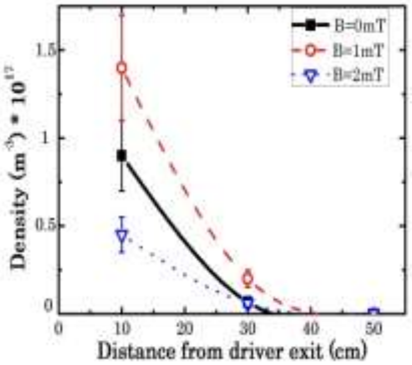




Investigation of plasma drivers for magnetized plasma columns at CEA

1) 2014 **Filamented cathode** [3]
   -) plasma vertically uniform along the vertical axis,
   -) peak N_e~$4*10^{17}m^{-3}$ and T_e~ 9eV
But, not relevant for Cs operation, due to the pollution by W

2) 2016 **ICP plasma driver:** **(results presented NIBS 2016)**
Plasma density drops rapidly along the vertical direction at the driver exit => Plasma non-uniform



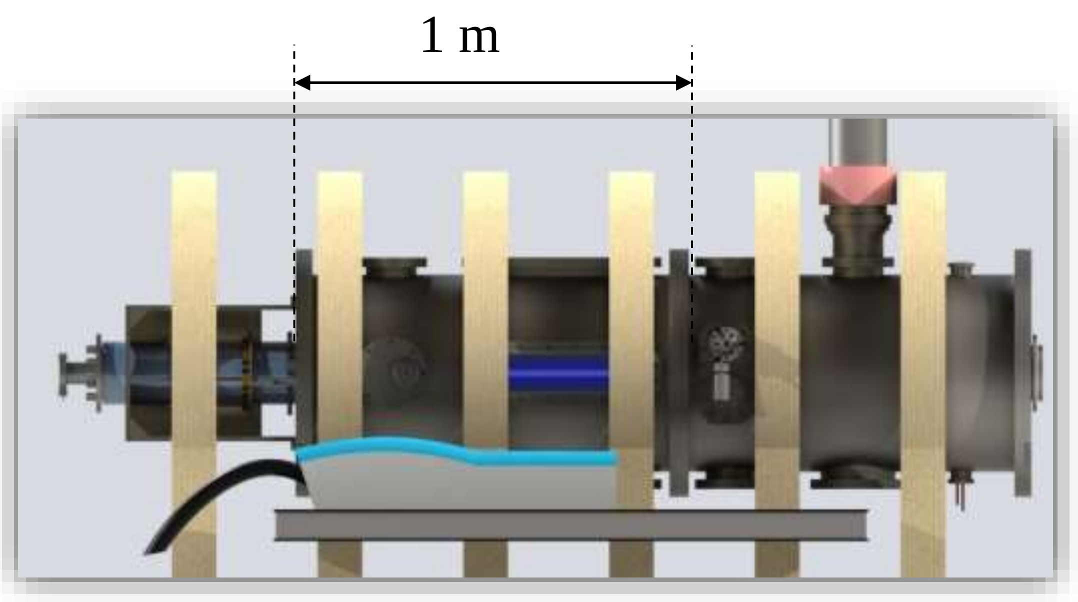
3) Since 2017 test of the **Helicon driver** developed by EPFL (see previous talk **WO8 R.Agnello**)

Operating conditions relevant for NI source:
- Low B-field (~10 mT)
- Quite Uniform plasma column (along 1.5m)
- High density in the center (>10^{18} m^{-3})
- Low T_e on the edge for NI production (~1-2eV)

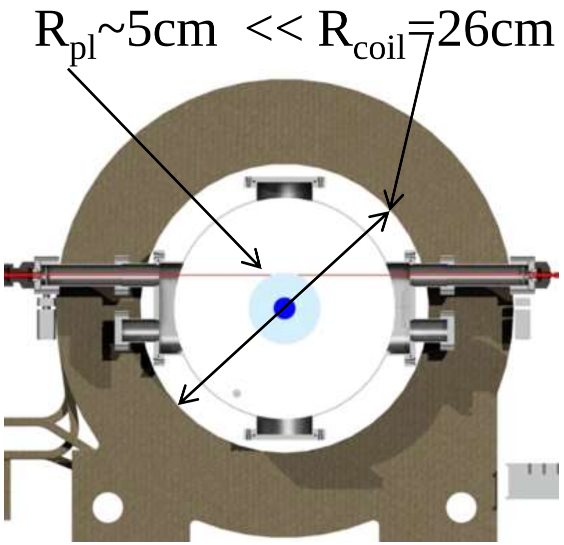
But, RAID geometry does not allow extraction of a long blade-like negative ion beam

[3] A Simonin *et al*,, New J. Phys. 18 (2016) 125005

RAID testbed geometry

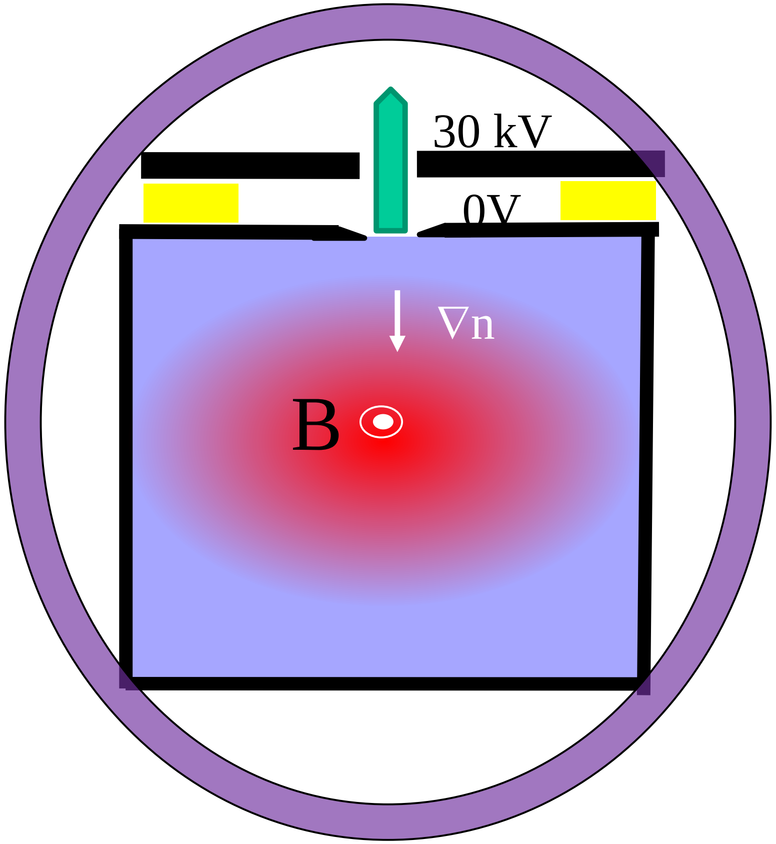


External magnets



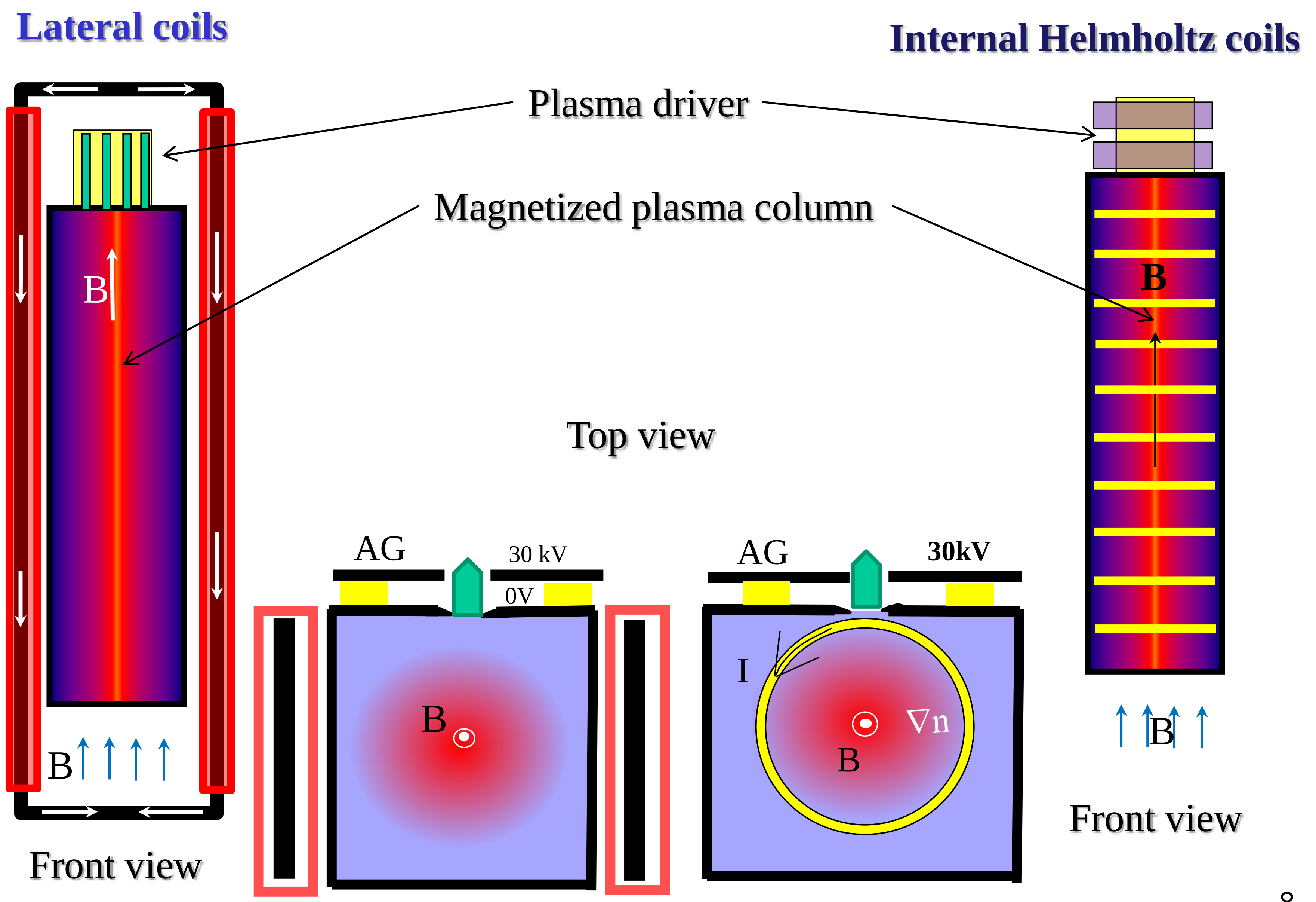
Uniform axial B-field (15-20mT), Negligible transverse B-field ($R_{pl} << R_{coil}$)
Very good conditions for the Helicon discharge

Ion source concept



Need to test the performance of Helicon antenna in another magnetic field topology than with external coils

Two magnetic field topologies compatible with implementation of an accelerator



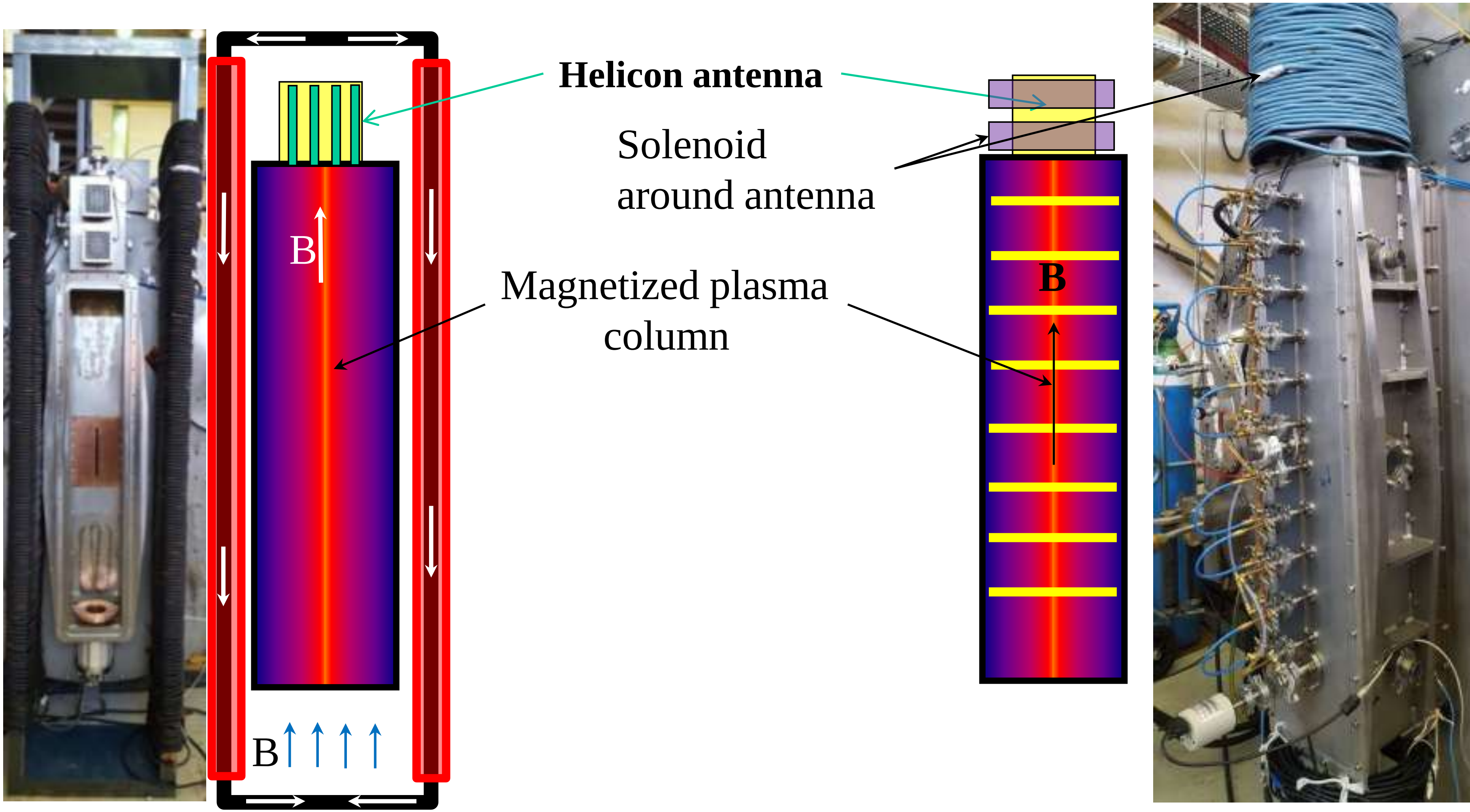
Experimental setup 2018

Lateral coils

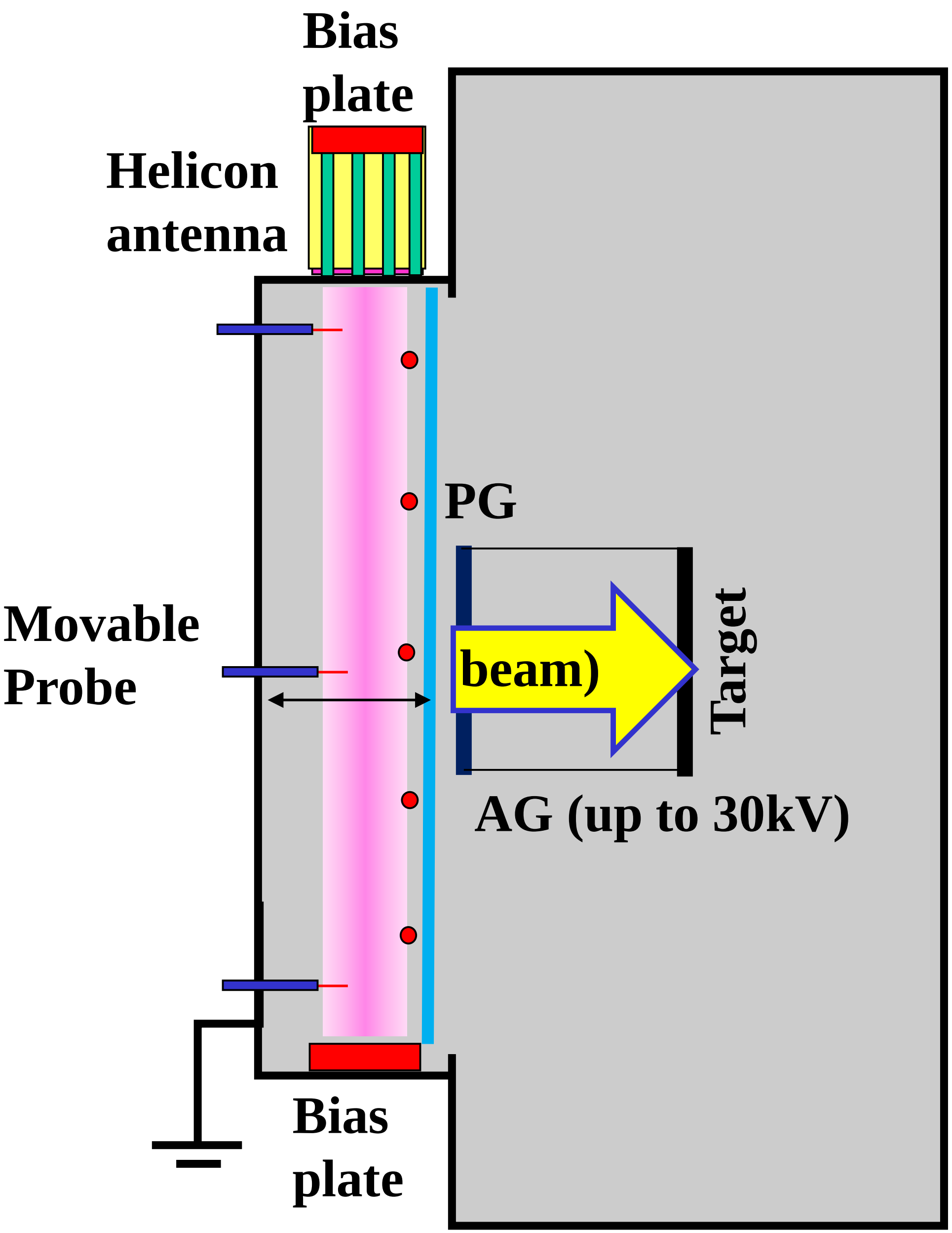
B~100 G

Internal Helmholtz coils

B_{axis} ~100-160 G



Experimental setup Lateral coils



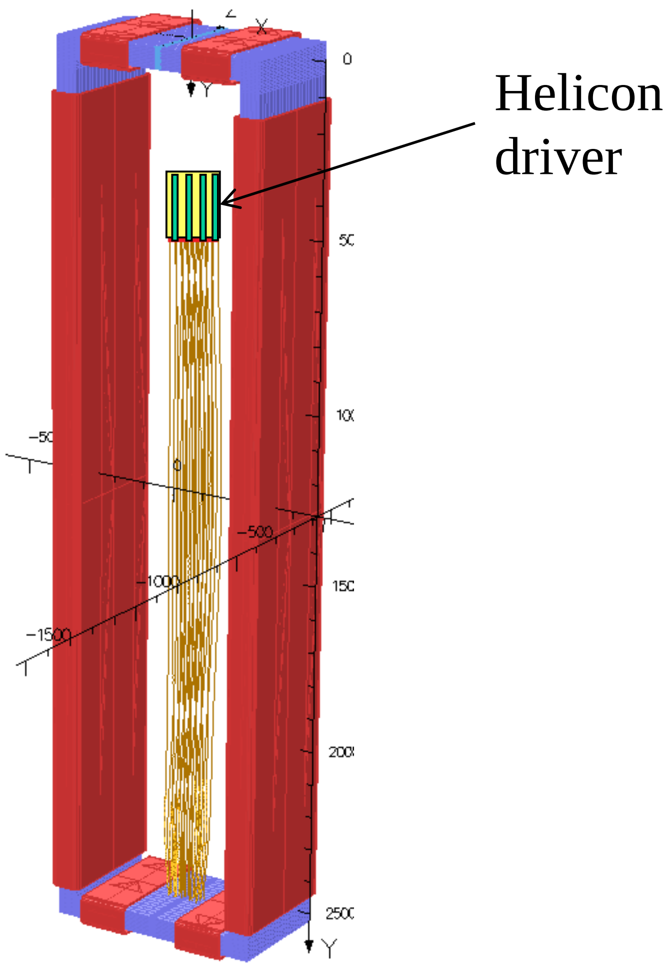
Source side view

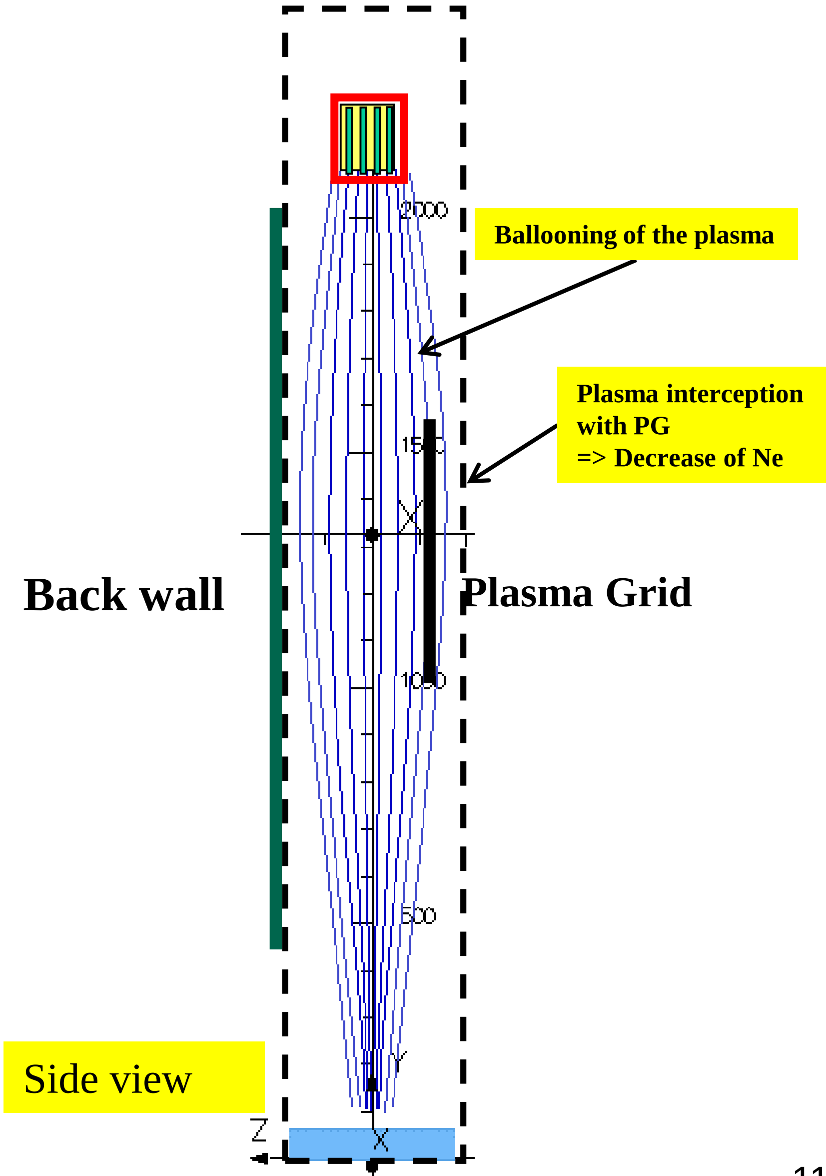
Experimental conditions:
Magnetic field – 100 G
RF power – 3kW
Gas pressure - ~ 0.3 Pa (H)
Bias plates : 0V : -90V

Horizontal measurements
Movable Langmuir probe can move horizontally from the wall to the PG

Vertical measurements
Five fixed Langmuir probes for Vertical measurements

3D simulations of e-trajectories (without plasma) with lateral coils



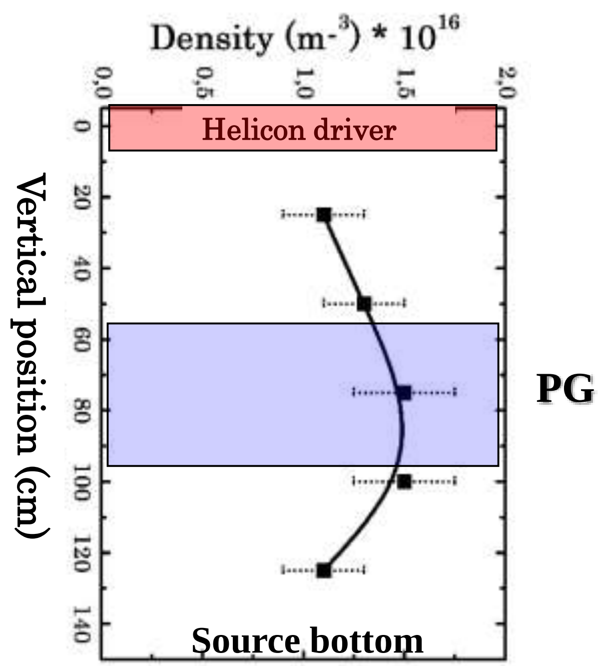


Vertical plasma density distribution

Vertical profiles close to PG (extraction region):

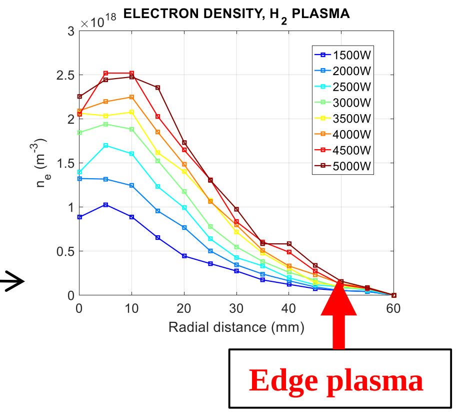
RF power – 3kW
Gas pressure - ~ 0.3 Pa (H)

Average plasma density is 1-1.5*10^{16} m^{-3}



Lateral coils

	Filament IRFM	Helicon IRFM	Helicon EPFL RAID
Power	30kW	3kW	3kW
Ne (plasma edge)	2*10^{17}	~1.2*10^{16}	~2*10^{17}



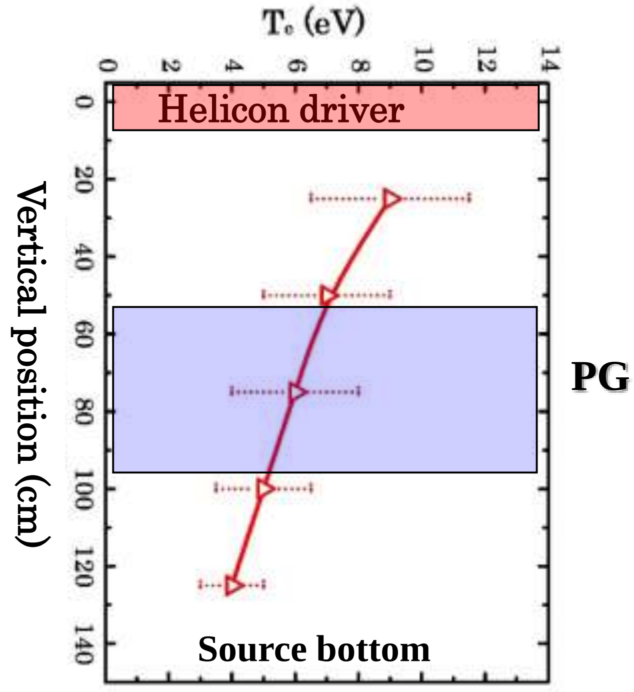
WO8 Agnello, EPFL

Plasma characterization with Langmuir probes

Vertical plasma temperature distribution

Vertical profiles T_e measured close to PG:

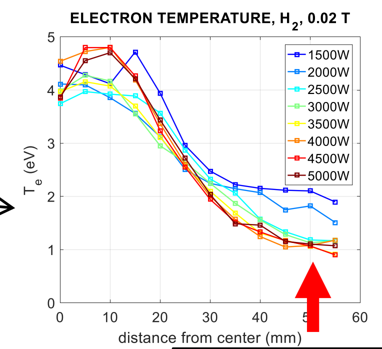
RF power – 3kW
Gas pressure - ~ 0.3 Pa (H)



Temperature drops from 9 eV on the top to 4eV in the bottom

Lateral coils

	Filament IRFM	Lateral IRFM	EPFL RAID
Power	30kW	3kW	3kW
T_e	~4-5eV	~4-9eV	~1-2eV (50cm from driver exit)



Edge plasma

WO8 Agnello, EPFL

High T_e with Helicon at IRFM with lateral coils

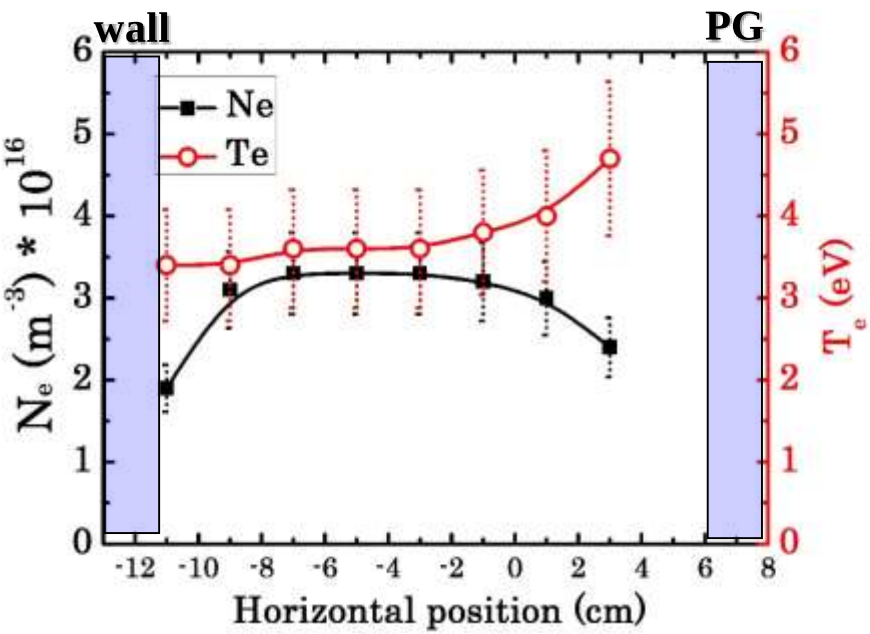
Horizontal plasma distribution

1)Low peak density $3*10^{16}$ m^{-3}
(compared to ~10^{18} m^{-3} at RAID EPFL)

2)Broad horizontal profile due to curved magnetic field lines

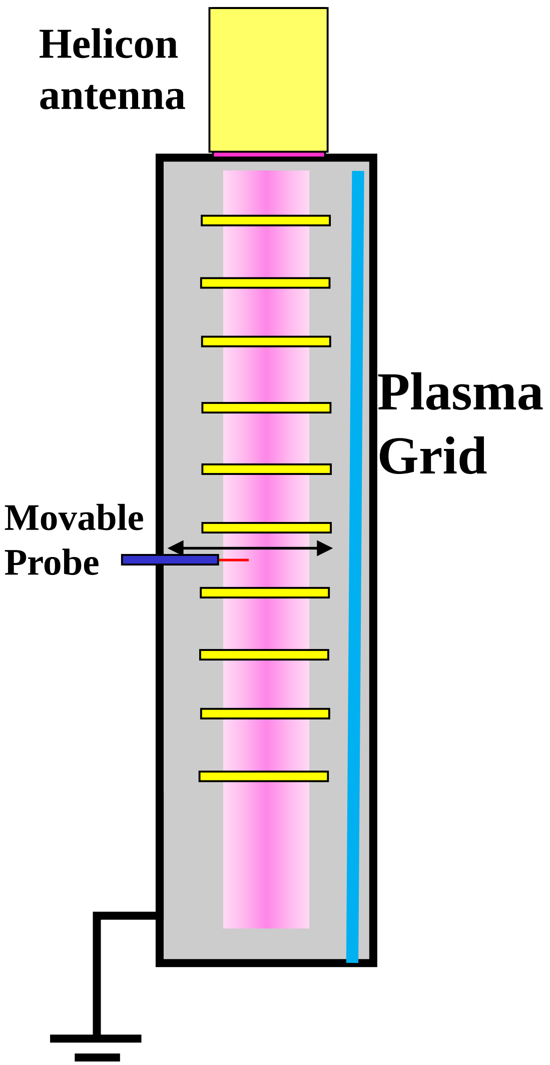
3) N_e and T_e don't have Gaussian distribution

4) Hot electrons on the front side of the source close to PG

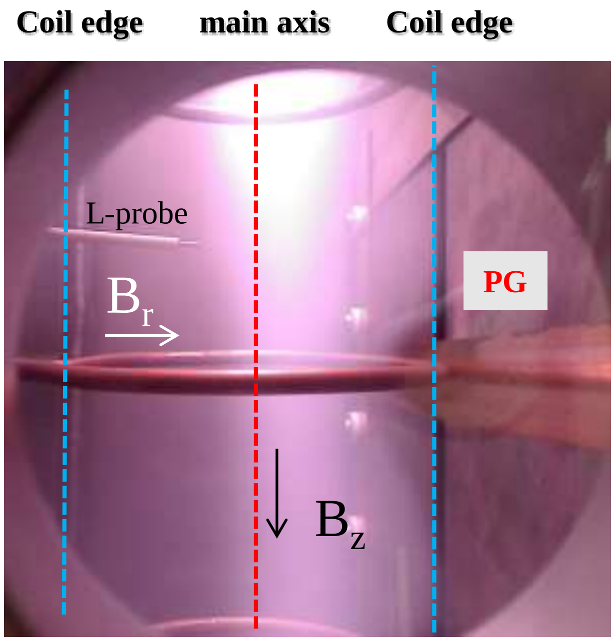


Questions : Hot e- results from plasma drift or local heating processes by interaction with the waves ???
=> Need further investigations

Plasma characterization with Internal Helmholtz coils

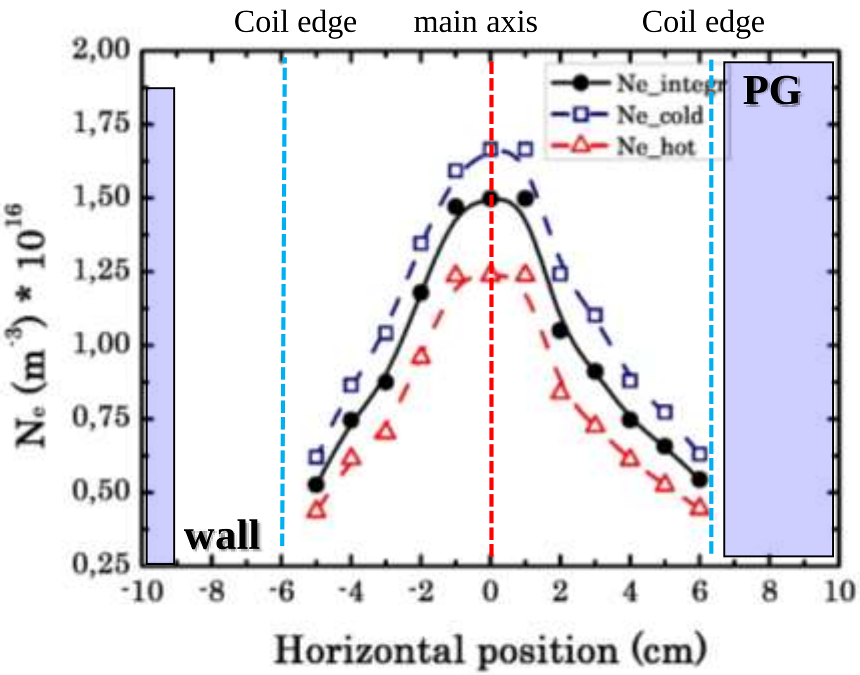


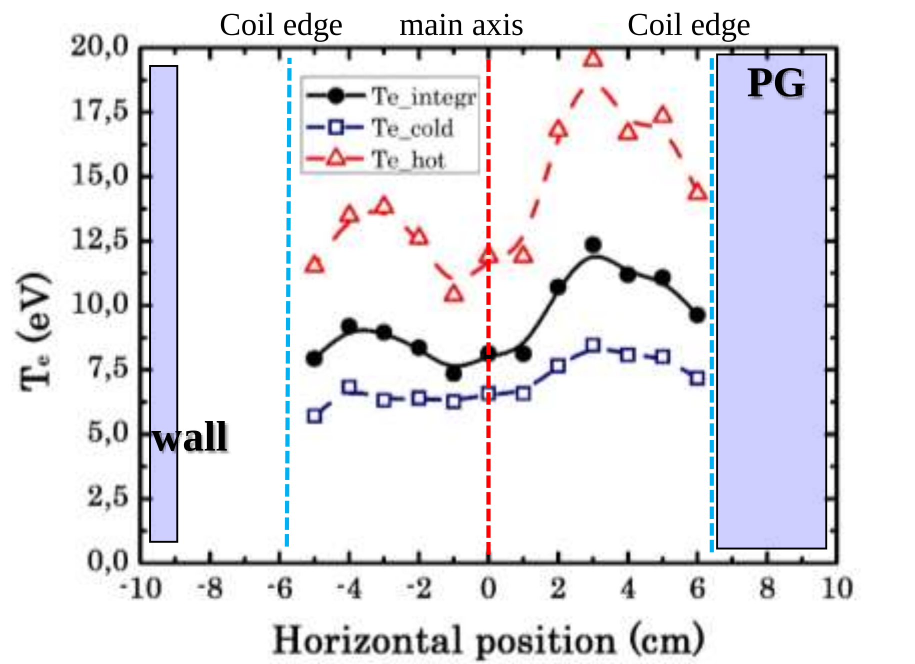
Top view



R_{pl}~5cm ~ R_{coil} = 5,5cm

Horizontal plasma distribution





-i) Plasma density is peaked (nearly Gausian profile)

-ii) Two e- populations :

~60% of total amount of e- are “cold” with uniform distribution (~6eV)

~40% “Hot” e- are localized at the edge of plasma column (~10-20eV)

The two humps of hot e- suggest Inductive plasma generation in the antenna !!

-iii) For the same operating conditions low N_e~**1.5*10^{16} m^{-3}** (compared to ~10^{18} m^{-3} RAID EPFL)

Question: Does the antenna generates an ICP or Helicon wave in the column ?

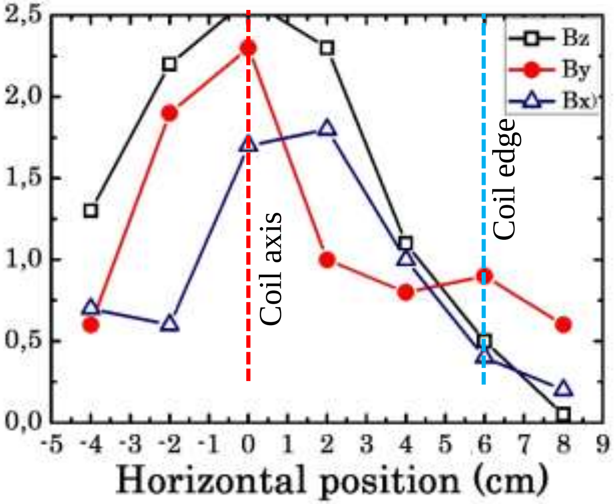
=> Need to implement magnetic probes in the plasma => Collaboration with EPFL

Wave characterization in the plasma column

The B-dot probe (provided by EPFL)

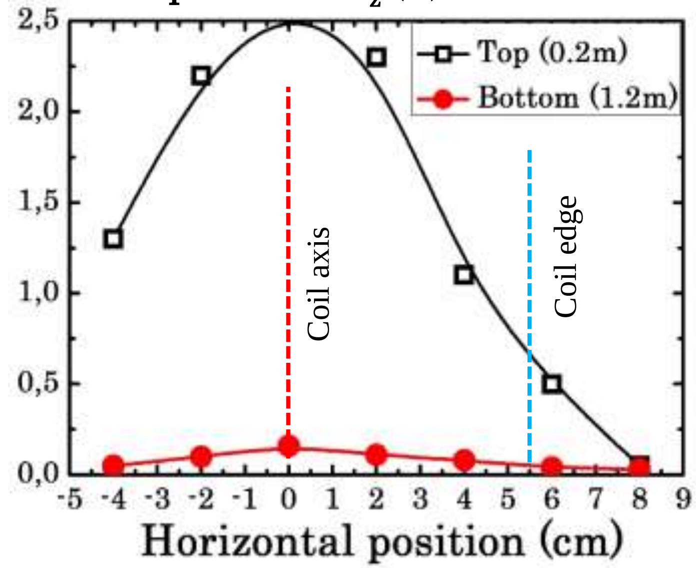
3 coils head. in the 3 axes

Three components of the Helicon wave measured



Preliminary measurements indicate the presence of helicon wave in the plasma

Amplitude of B_z (V)



Damping of the helicon waves

Along the column (Top to bottom)

Conclusion

1) Ideal conditions in the RAID testbed for helicon plasma generation
- **Wall of the vacuum tank far away from the plasma column (~20cm) compare to CEA**
- **Uniform axial magnetic field ~150-200 G**
- **Negligible transverse magnetic field R_{plasma} (5cm) << R_{coils} (25cm)**

2) A twin Helicon antenna implemented in 2017 at CEA ion source:
- **two magnetic field configurations (compatible with implementation of the accelerator are under characterization)**
- **the Helicon plasma column exhibit very different parameters than in EPFL:**
  - **-i) Low Ne for two configurations (5-10 times): plasma losses on the wall ?**
  - **-ii) Hot e- population at the edges close to PG (~ 7-15eV)**

  "these parameters are not compatible with production of high density NI (w/wo Cs)

Open questions (Hypothesis): Identification of this "Abnormal" e- heating process
- **-i) Resonant heating with Helicon waves, plasma turbulence, ???**
- **-ii) Interaction of the wave with the horizontal component of B ???**
  - **-) Low Hybrid resonance? f_{LH} ~ 10 – 50 MHz (helicon antenna at 13,56MHz)**
  - **-) Alfven waves ? Alfven wave velocity same order than electron velocity**

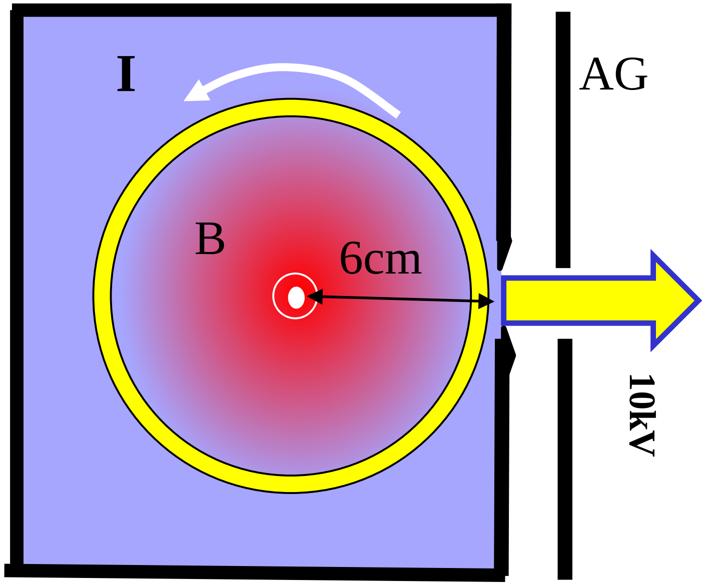
    => Electron heating by Landau damping

➔ Further investigations are required

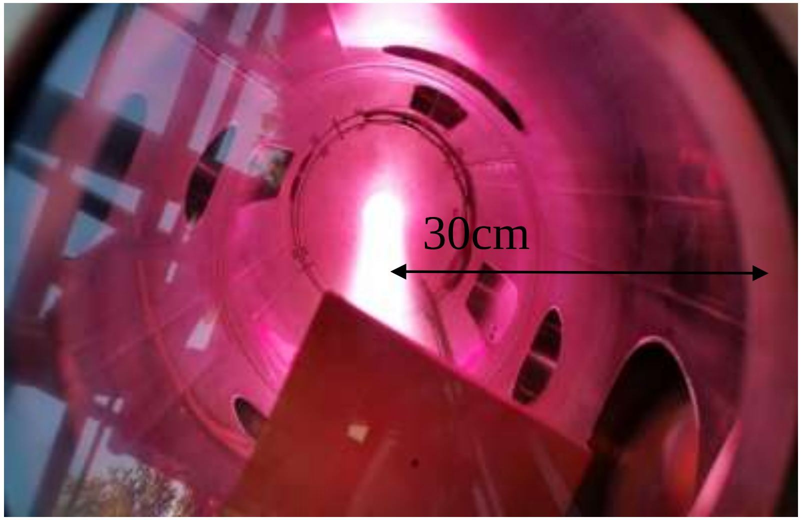
Thank You
for attention!

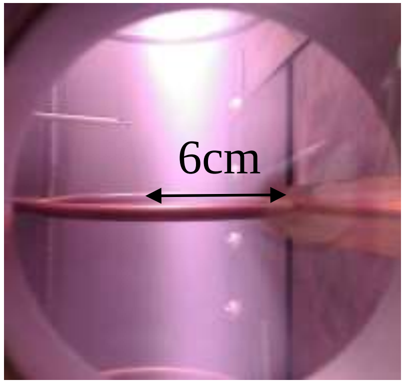
Boundary conditions

CEA Cadarache



EPFL

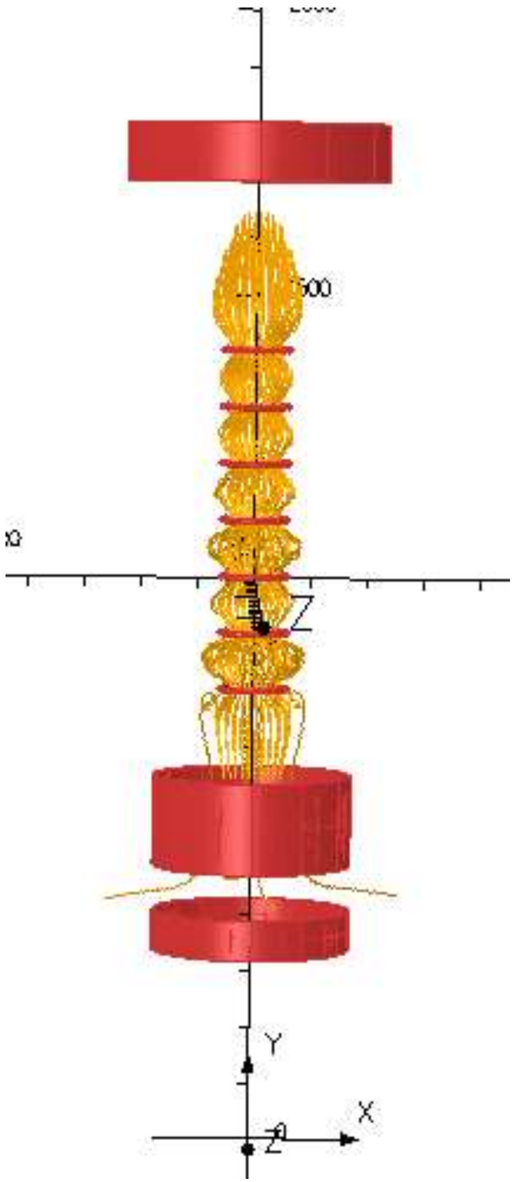


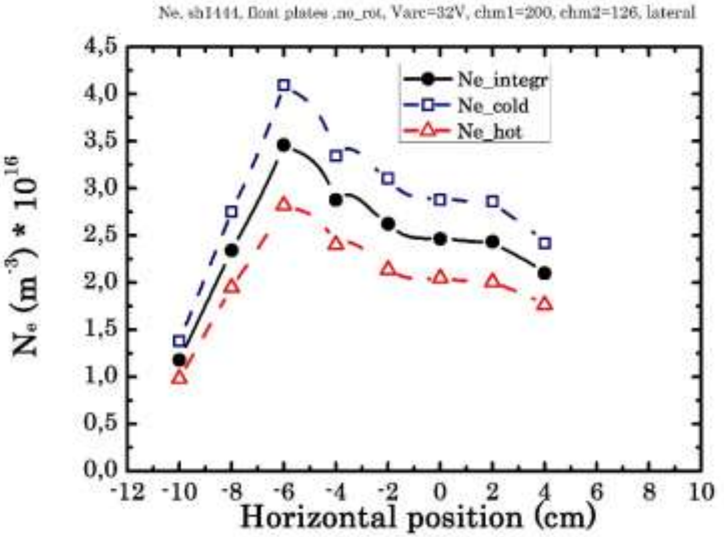


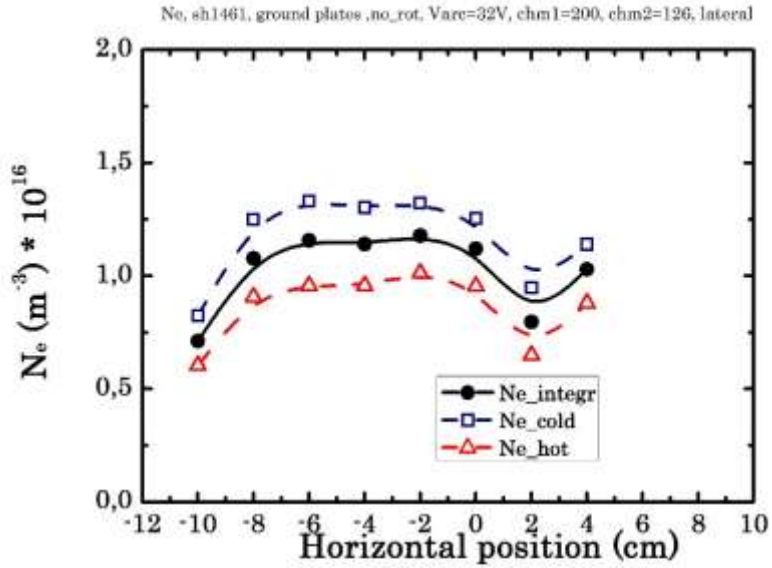
Effect of the big conduction plate at the distance 6 cm from the plasma column has to be checked

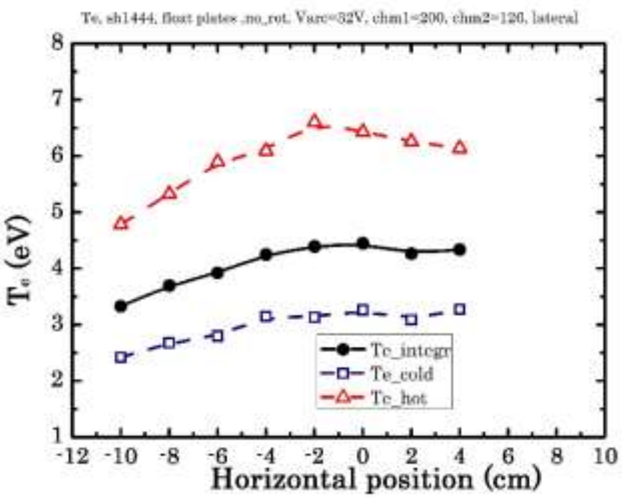
Studies of the magnetic column with helmholtz coils

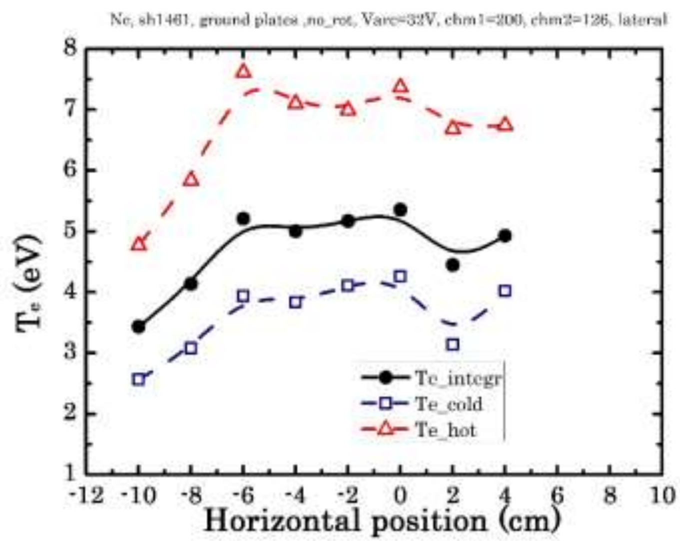
3D simulations of e-trajectories (without plasma)



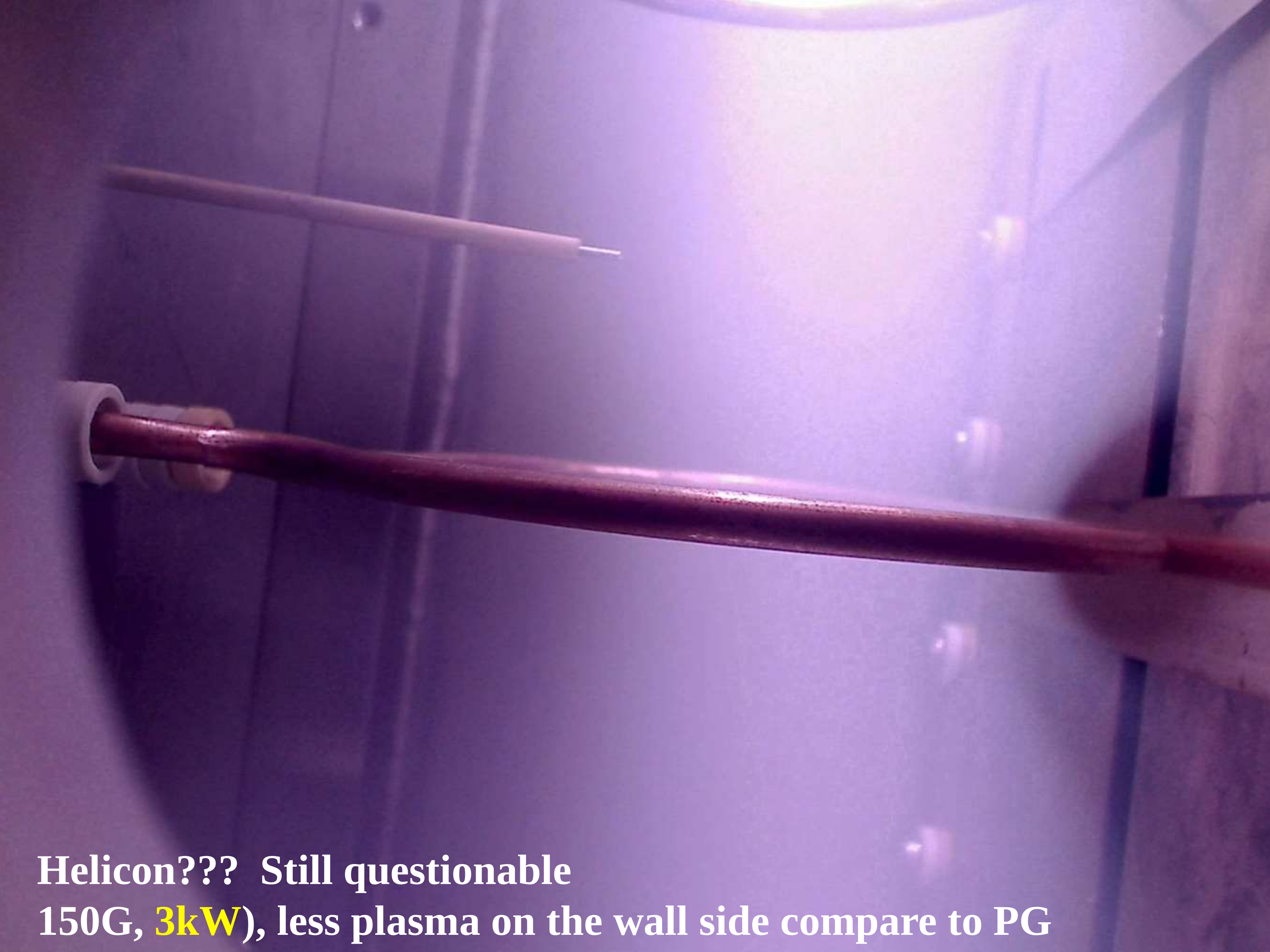

Ne, sh1444, float plates ,no_rot, Varc=32V, chm1=200, chm2=126, lateral
N_e (m^{-3}) * 10^{16}
Horizontal position (cm)
Ne_integr
Ne_cold
Ne_hot

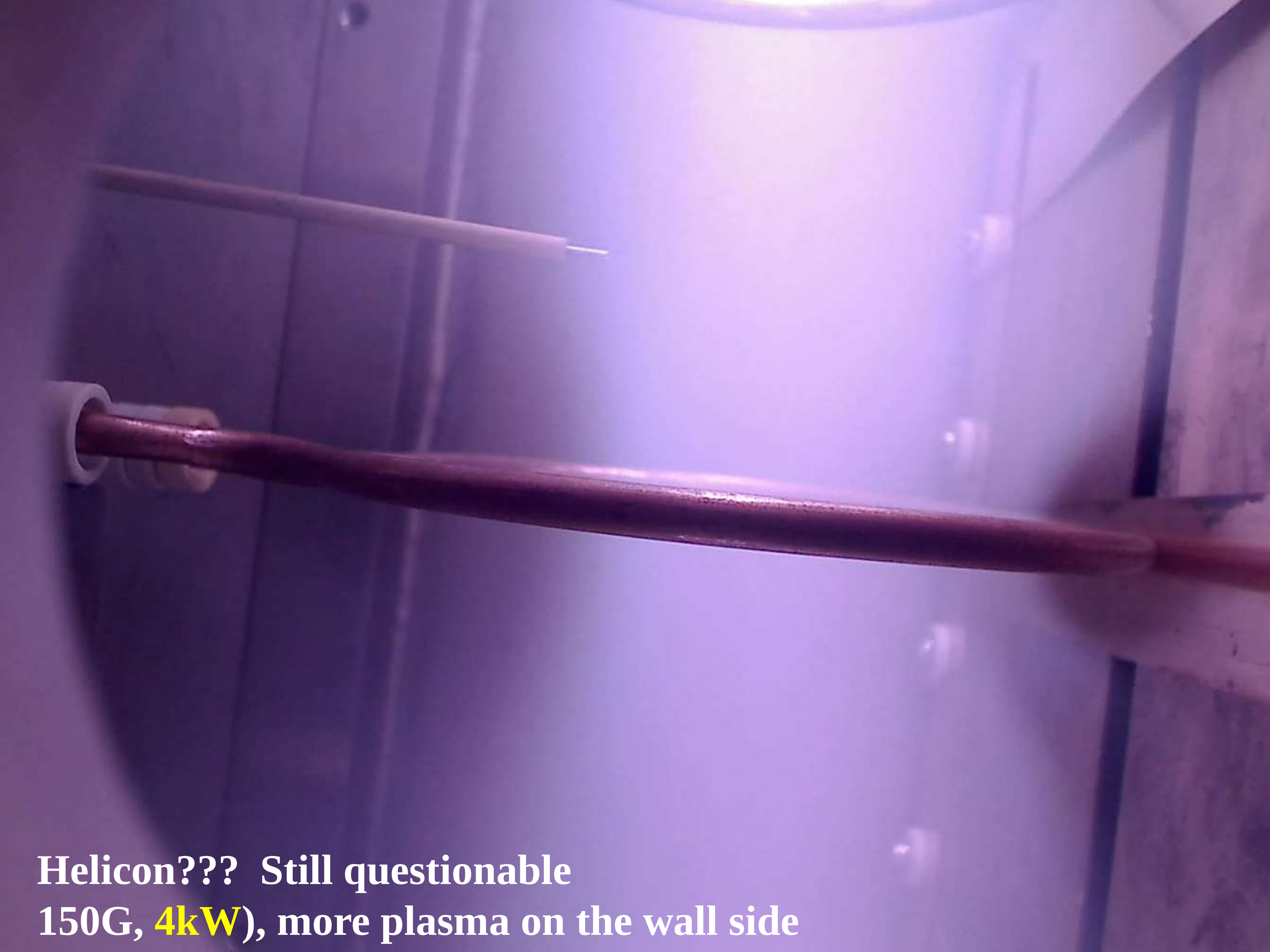

Ne, sh1461, ground plates ,no_rot, Varc=32V, chm1=200, chm2=126, lateral
N_e (m^{-3}) * 10^{16}
Horizontal position (cm)
Ne_integr
Ne_cold
Ne_hot

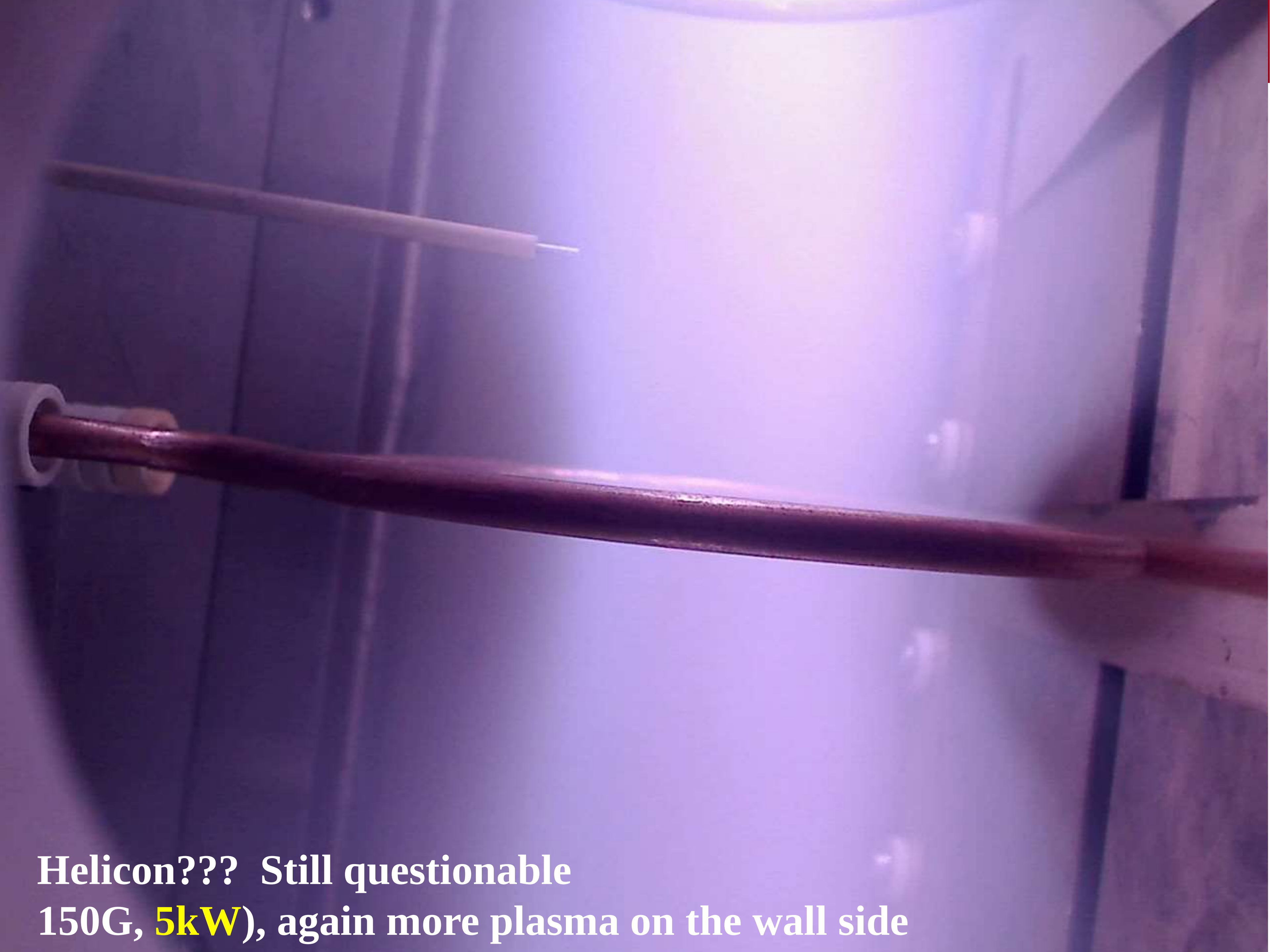

Te, sh1444, float plates ,no_rot, Varc=32V, chm1=200, chm2=126, lateral
T_e (eV)
Horizontal position (cm)
Te_integr
Te_cold
Te_hot


Ne, sh1461, ground plates ,no_rot, Varc=32V, chm1=200, chm2=126, lateral
T_e (eV)
Horizontal position (cm)
Te_integr
Te_cold
Te_hot


Transition from ICP to Helicon???
Low B filed (80-90 G, 3kW)

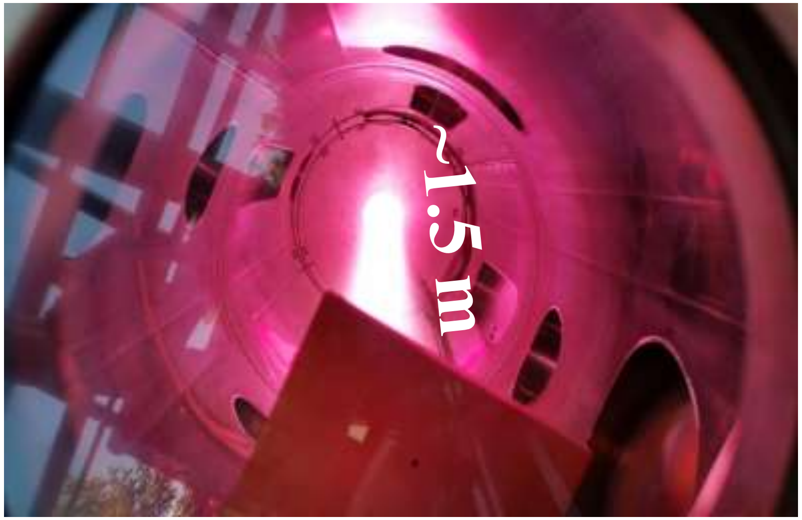

Helicon??? Still questionable
150G, 3kW), less plasma on the wall side compare to PG


Helicon??? Still questionable
150G, 4kW), more plasma on the wall side


Helicon??? Still questionable
150G, 5kW), again more plasma on the wall side

Development of a 10 kW Helicon antenna (Bird-cage type) at RAID testbed (EPFL) to provide a dense magnetized plasma column

3 kW, 0.3 Pa, B= 12 mT, H_2 plasma jet

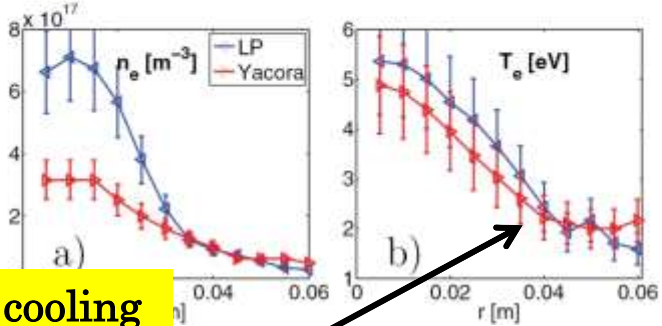


Helicon antenna is essential for creation of the homogeneous plasma column

- Low B-field (~10 mT)
- ITER relevant operating pressure (~0.2 Pa)

But no NI extraction possible in such topology

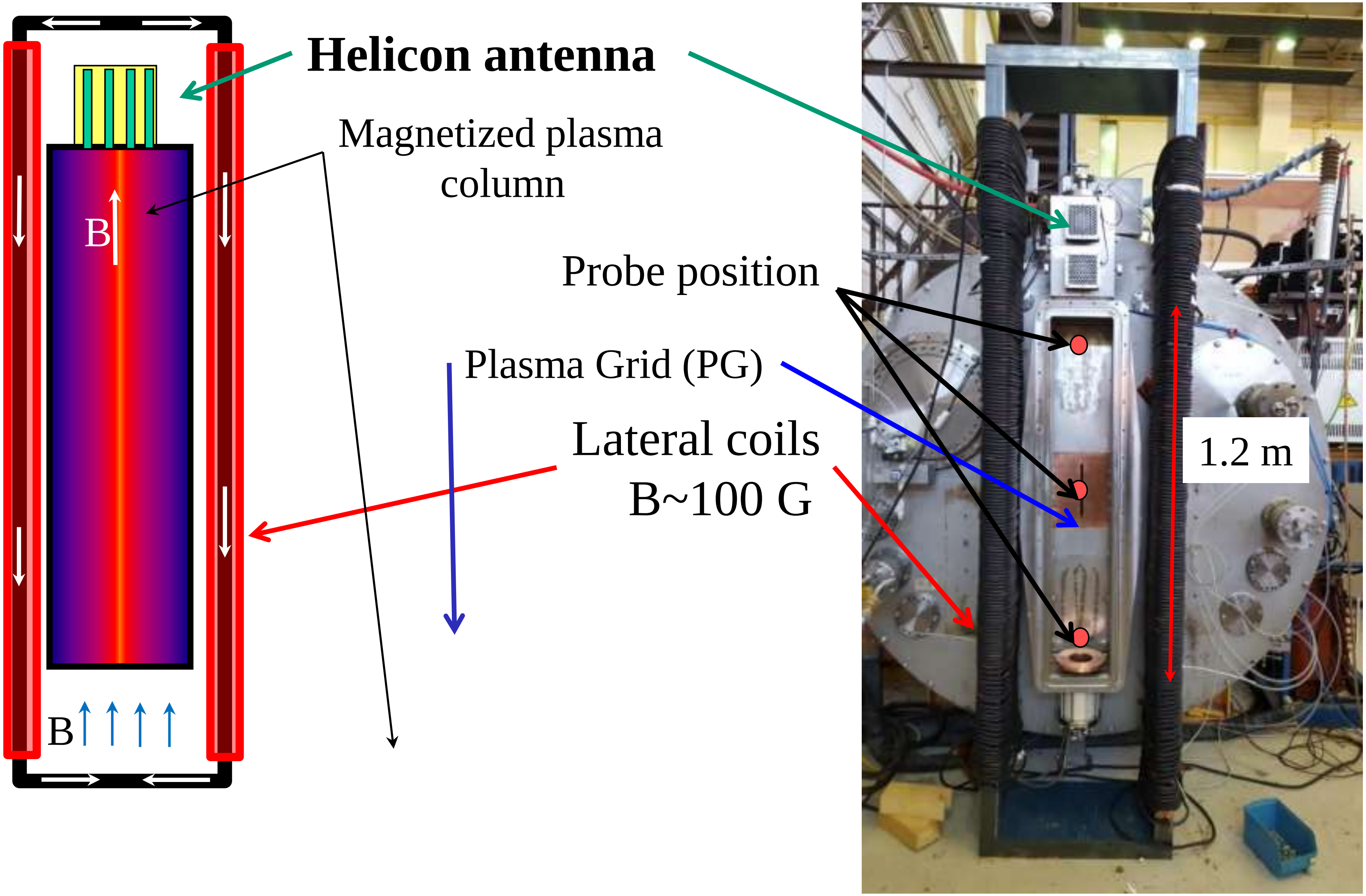
The GOAL at CEA IRFM is to get similar results as in EPFL [4]
With another magnetic topology



Radial cooling (Te < 2eV)

Cybele with Helicon driver

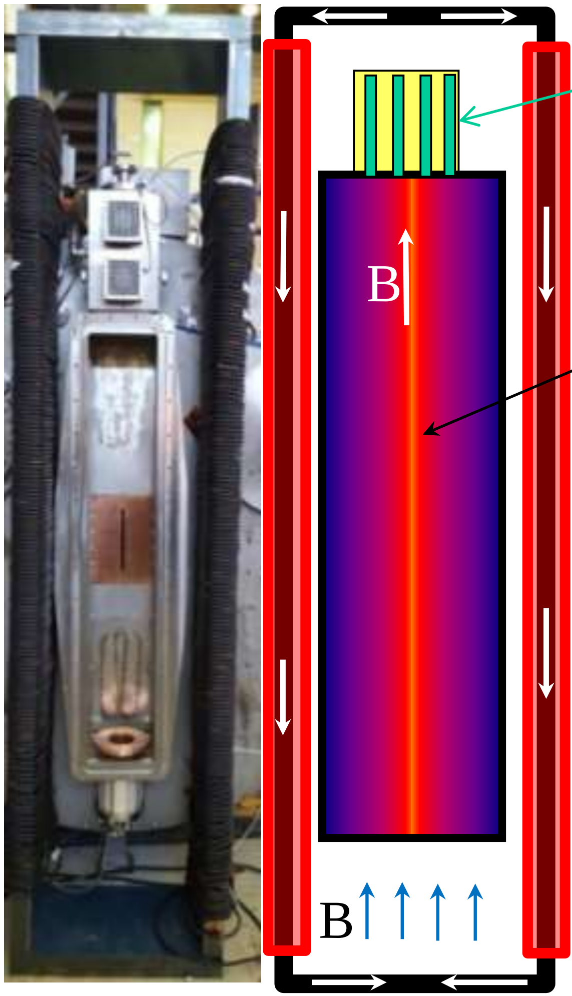
Lateral coils (configuration 2017)

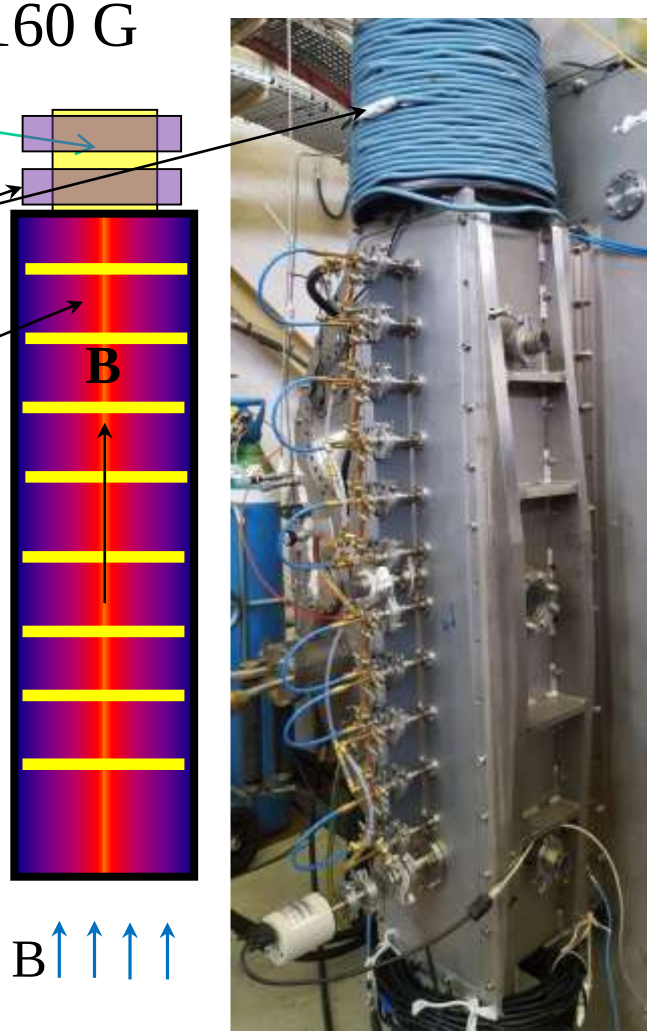


Experimental setup 2018

Lateral coils
(**OLD configuration**)
B~100 G

Set of 11 vertical coils
(**NEW configuration**)
Baxis ~100-160 G

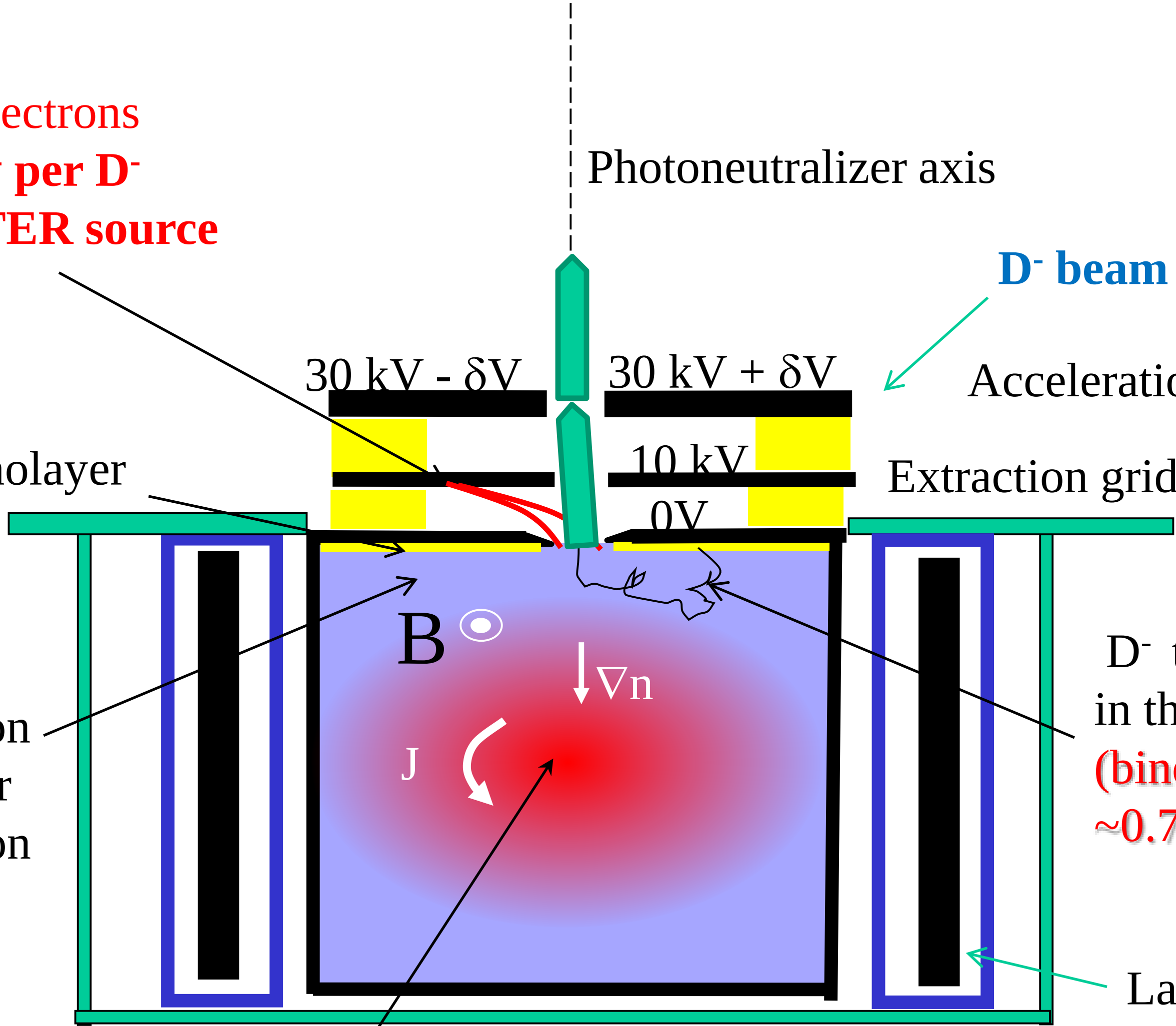




Experiments started in March 2018

Ion Source top view (concept)

Ion Source with 30 kV acceleration



[3] H. Hotop and W. C. Lineberger, J. Phys. Chem. Ref. Data 4 (1975) 539

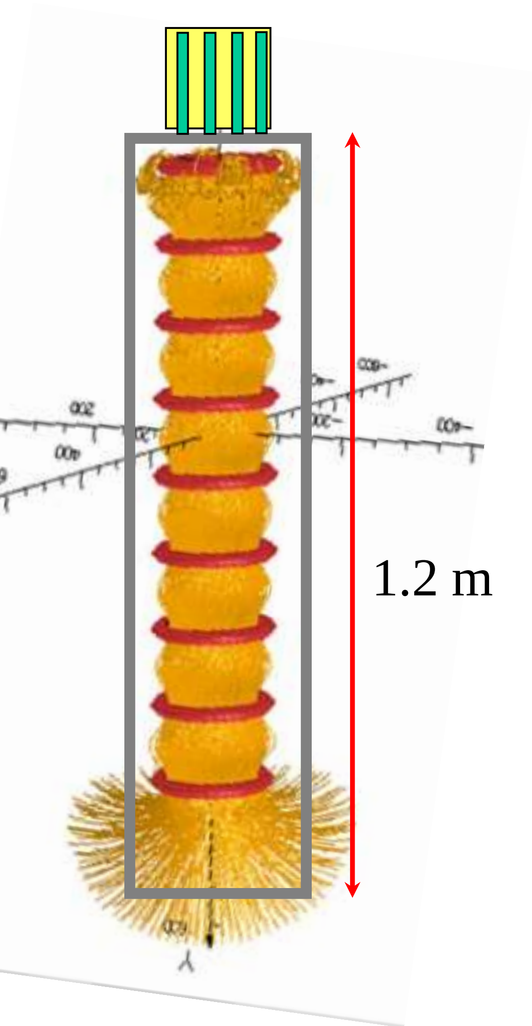
Conclusions

1) Two specific magnetic field configurations (Lateral coil and set of Helmholtz coils) were tested.
2) The Langmuir probes measurements have highlighted a plasma asymmetry between the back and front side (PG) of the source , a dense plasma core is shifted to the back wall of vacuum chamber, while on PG, the plasma is hotter (6-7eV) due to the primary electron drift – not favorable for production of NI.
3) A new magnetic configuration composed of Helmholtz coils implanted within the source vacuum chamber , tested and characterized in 2018.
4) The Langmuir probes measurements revealed also a plasma asymmetry between the back and front side (PG) of the source , a dense plasma core is shifted to PG, while on PG, the plasma is hotter – not favorable for production of NI.
5) New set of experiments will be performed in August for detection of the Helicon wave propagation inside the source volume.
6) Need to compare the results with EPFL with implementation of the metal plate close to the plasma border.

Simulations

1) The lateral coil configuration requires the perfect transverse (or lateral) alignment of the Helicon antenna with vertical magnetic field (sensibility is few mm range)
2) With the perfect alignment we have slab plasma shape. It is can be the advantage for the NI extraction in the future.
3) The small misalignment induce a strong drift of e- and inhomogeneous plasma in the transverse direction.
4) Cylindrical plasma column (EPFL type) can be obtained in with the implementation of solenoidal coil --> the program for the 2018 (Characterization of the plasma in this magnetic field topology)

Simulations of th 3D e-trajectories in the set of Helmhotz coils

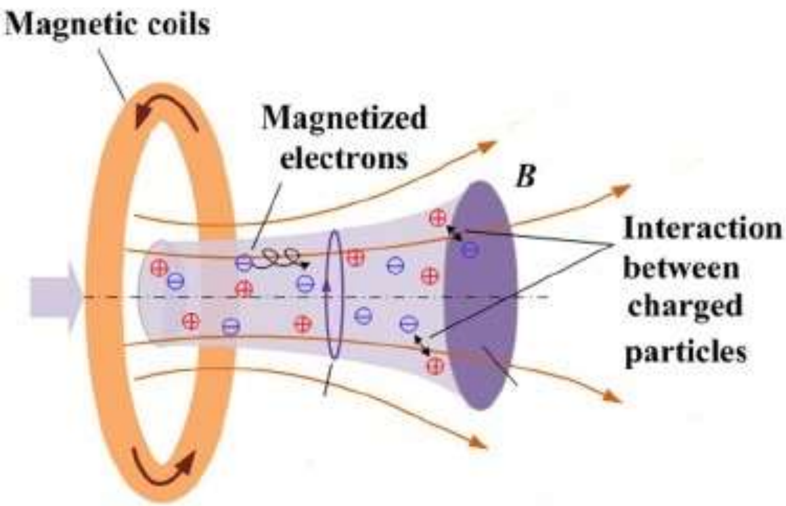


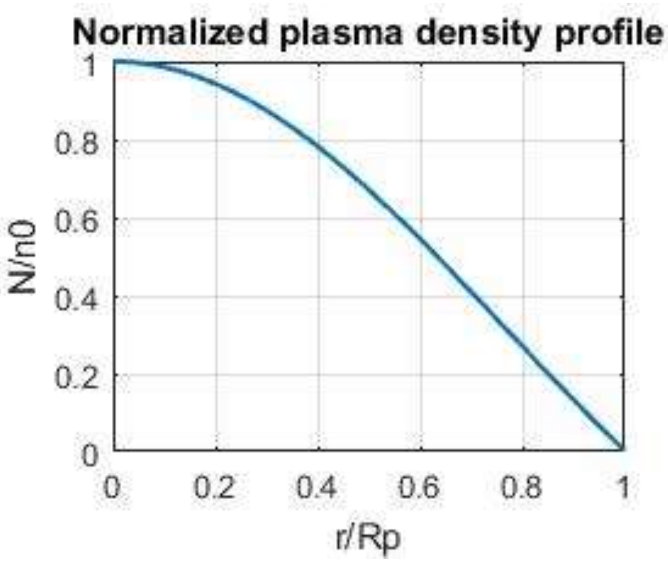
Plasma column produced by the Helicon driver surrounded by **Set of 9 coils inside vacuum chamber**
B_{vert} = 110 Gauss

A new magnetic field configuration is under development for Cybele.

Start of the experiment in February 2018

Magnetized bulk plasma





Low temperature (T_e ~10ev), and weekly magnetized (B=100-500 G) plasma

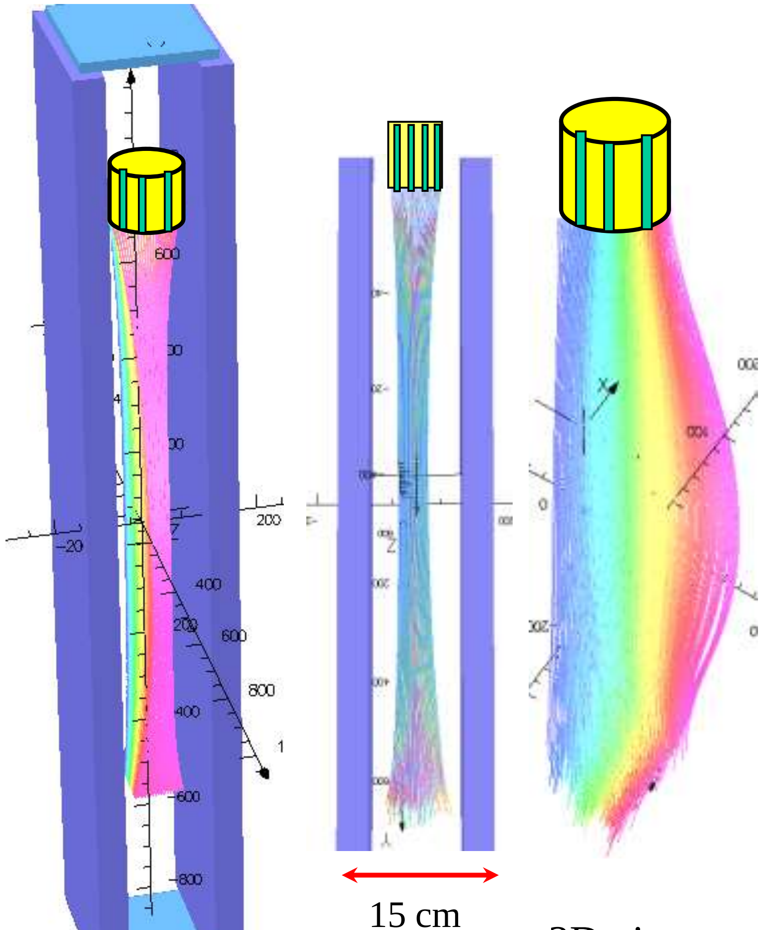
e^- magnetized (move mainly along MF lines)
i^+ unmagnetized (can move across MF lines). Ambipolar $\mathbf{E_r}$ biulds to confine i^+

Axial MF creates:
1) Sharp $\nabla \boldsymbol{n}(\boldsymbol{r})$ $\nabla \boldsymbol{T}(\boldsymbol{r})$
2) Hot and dense plasma core, lower density and colder plasma edge
3) Ambipolar $\mathbf{E_r}$ due to ion diffusion ($\boldsymbol{D_i}$) across MF
4) Different types of instabilities (rotational, ExB drift, diamagnetic drift,)

$$\boldsymbol{n}(\boldsymbol{r}) = \boldsymbol{n_0} \boldsymbol{J_0}\left(\frac{\boldsymbol{\alpha r}}{\boldsymbol{R_{pl}}}\right), \boldsymbol{\alpha} = \boldsymbol{f}(\boldsymbol{\mu_i}, \boldsymbol{\mu_e}, \boldsymbol{\vartheta_{ei}}, \boldsymbol{D_i}, \boldsymbol{D_e})$$

Simulations

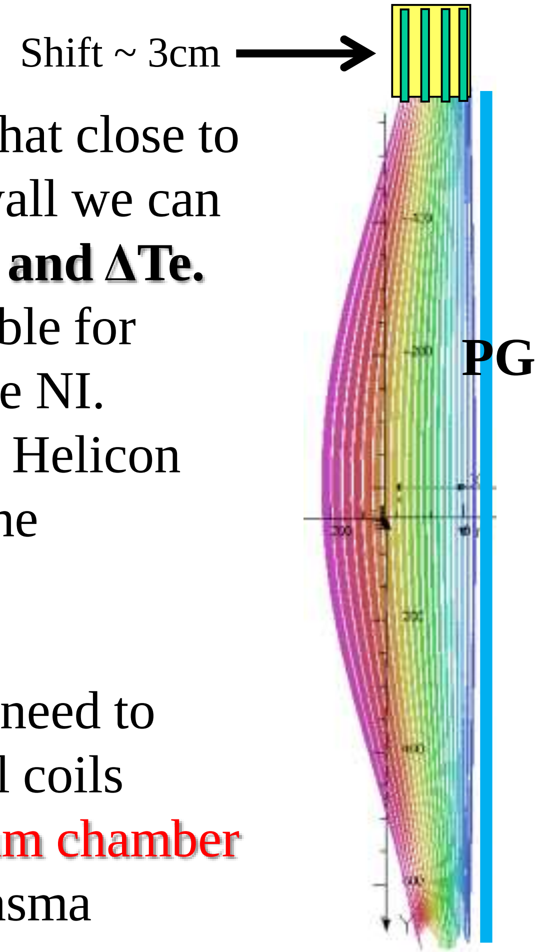
Simulations of th 3D e-trajectories in the small lateral coils
Implemented inside the source volume under vacuum



3D view

Front view

3D view (without frame)

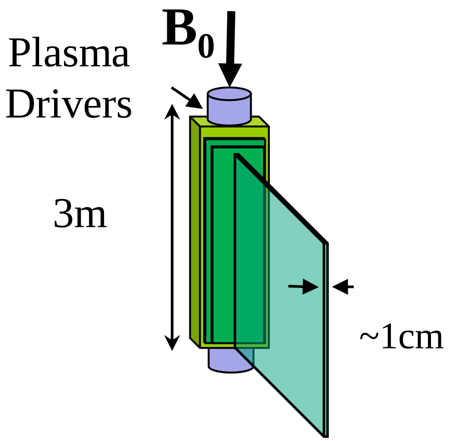


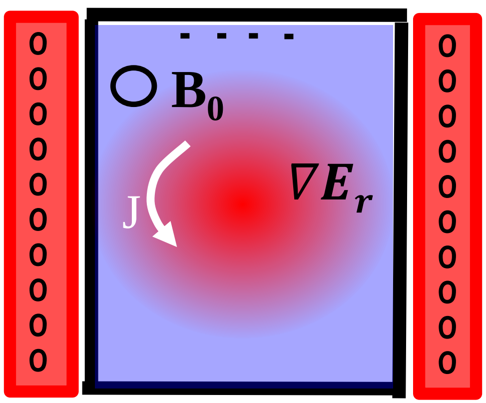
We discovered that close to The grounded wall we can have sharp **ΔNe and ΔTe.** Which is favorable for production of the NI. We can shift the Helicon driver close to the grounded PG.

But for this, we need to install the lateral coils inside the vacuum chamber very close to plasma column.

How to get uniform blade-like beam

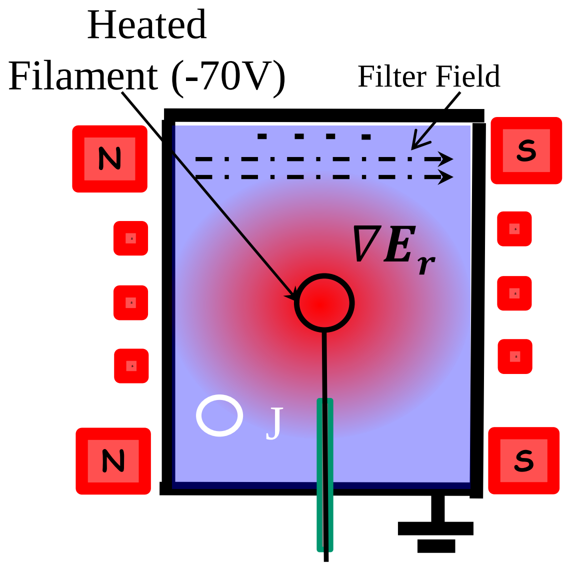
The vertical inhomogeneity of the beam required < 10%

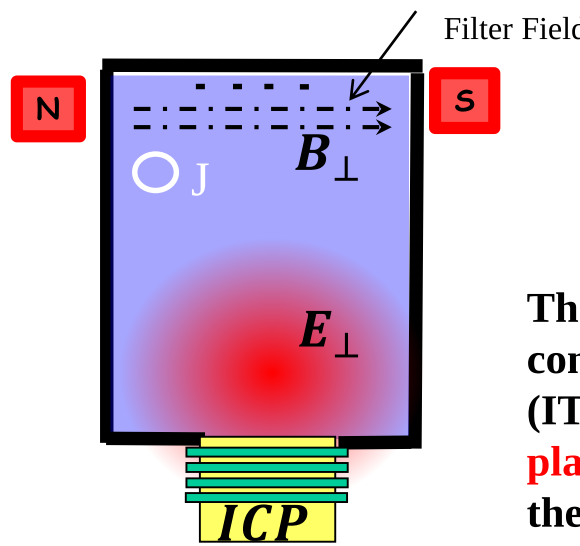




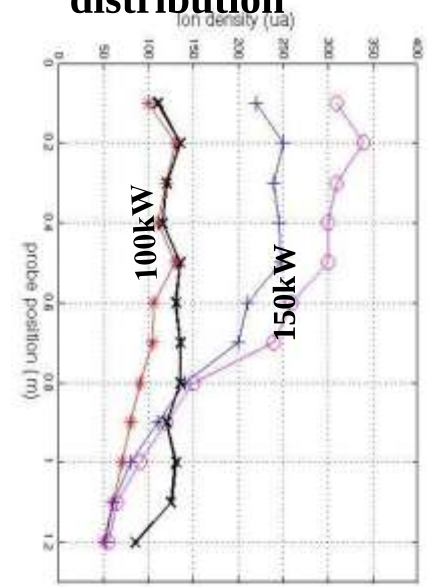
Magnetized plasma column along B_0
Plasma is homogeneous along the vertical axis ExB drift can cause only azimuthal plasma rotation

Plasma particles injected along B field





Vertical plasma distribution

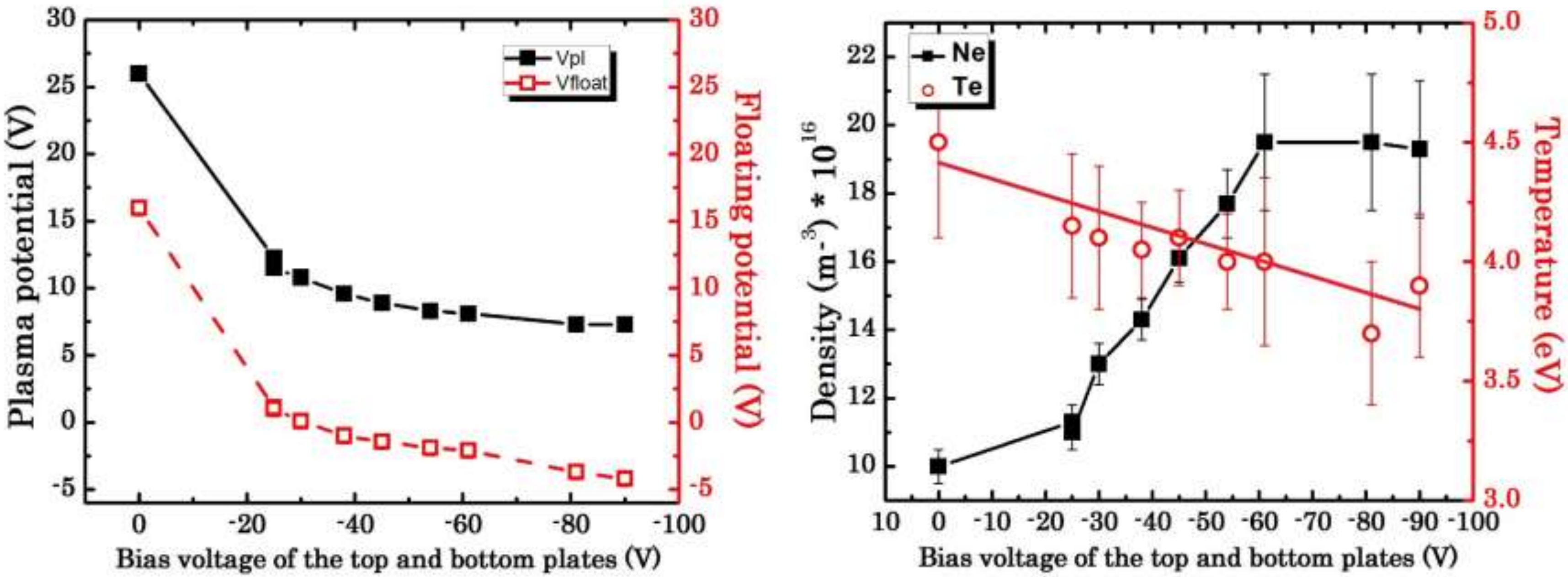


strong plasma inhomogeneity along vertical axis

The main problem of conventional ion sources (ITER like in IPP Garching) is plasma vertical drift which they can not overcome

Effect of the bias on the top and bottom plates

Variation of the top and bottom bias potential ~4 cm from the back wall



With increasing of the negative bias

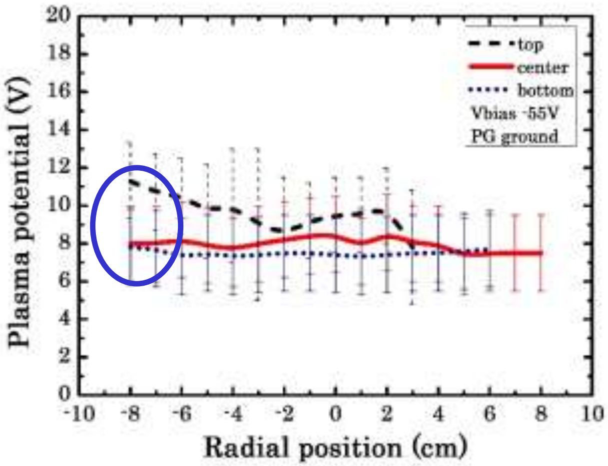
1) Both Vpl and Vfl drops by ~ 15V
2) Ne increases until -60V of bias, after that constant
3) Te linearly decreasing from ~4.5 to ~ 3.5eV

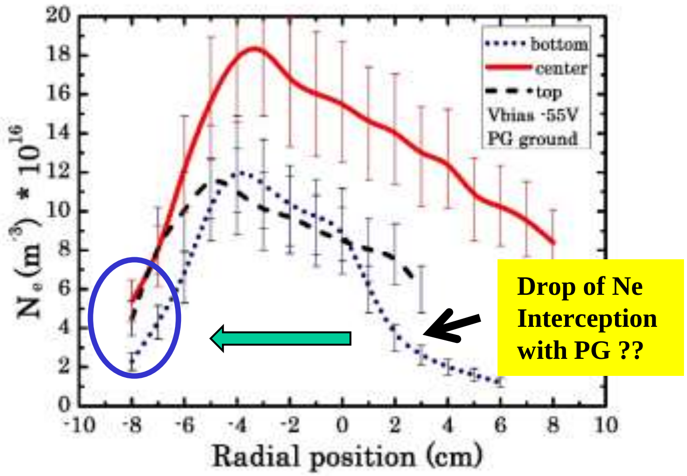
(60 cm from the Helicon driver, PG is grounded, Prf 3kW, p=0.3 Pa, B=100G, H).

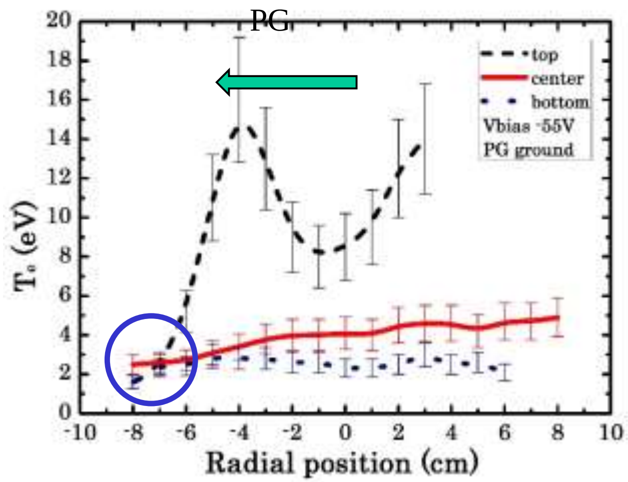
Plasma distribution from top to bottom

Transverse distribution of plasma parameters

-----Top 10cm, center 60cm, ...bottom 110 cm from the exit of Helicon driver







1) Vpl is nearly the same in the all source volume
2) Vfl drops towards the bottom
3) Ne is almost twice higher on the center (close to PG) with respect to extremities
4) Te has two maximums at -4cm and close to PG at the top.

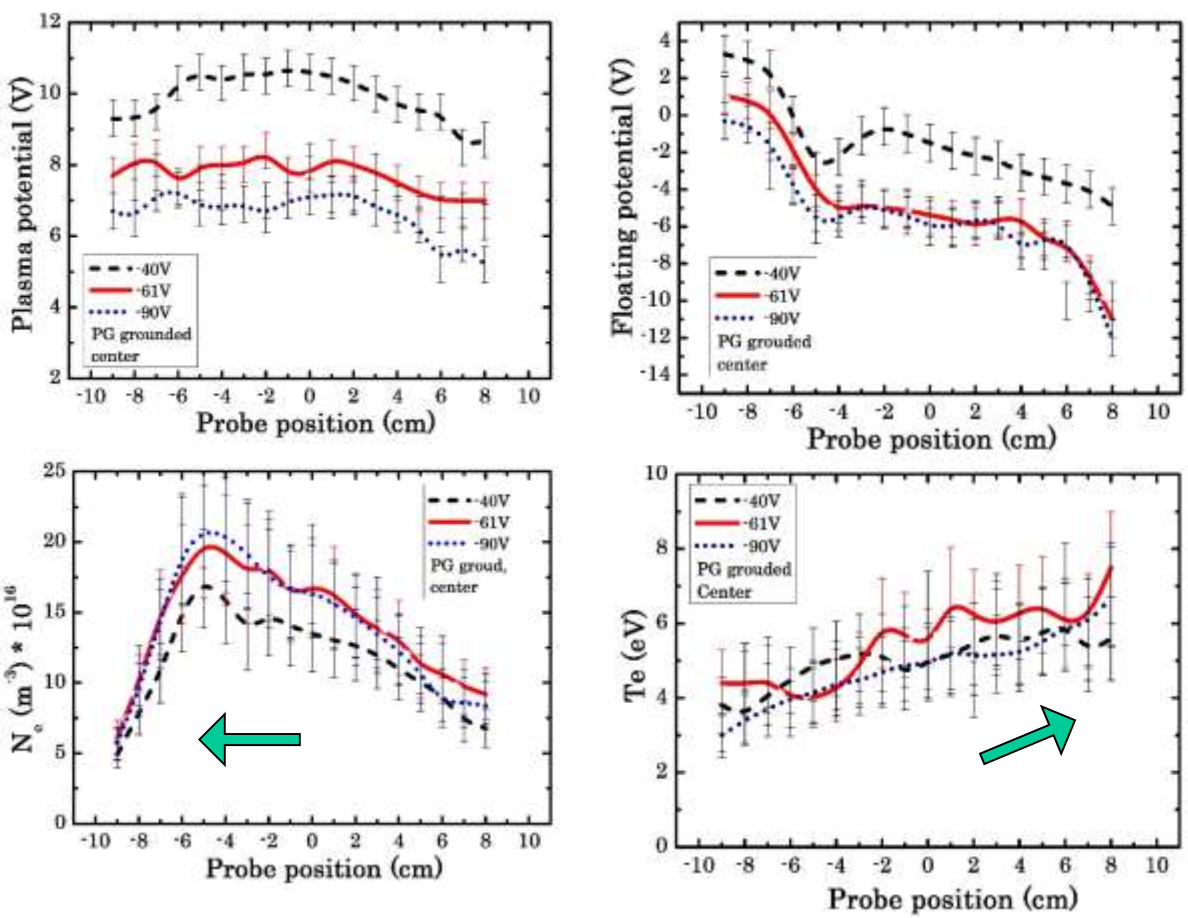
There are two plasma electron populations:
First closer to wall at -5-4cm with high density
Second is low density e- population which drifts close to PG

(PG grounded, V bias -47V, Prf 3kW, p=0.3 Pa, B=100G, H).

Effect of the bias on the top and bottom plates

Transverse distribution of plasma parameters

Probe location: centre position (behind the PG)



Increasing of Negative bias

1) Vpl drops
2) Vfl drops
3) Ne increases
4) No effect on Te

Behavior of profiles from wall to PG

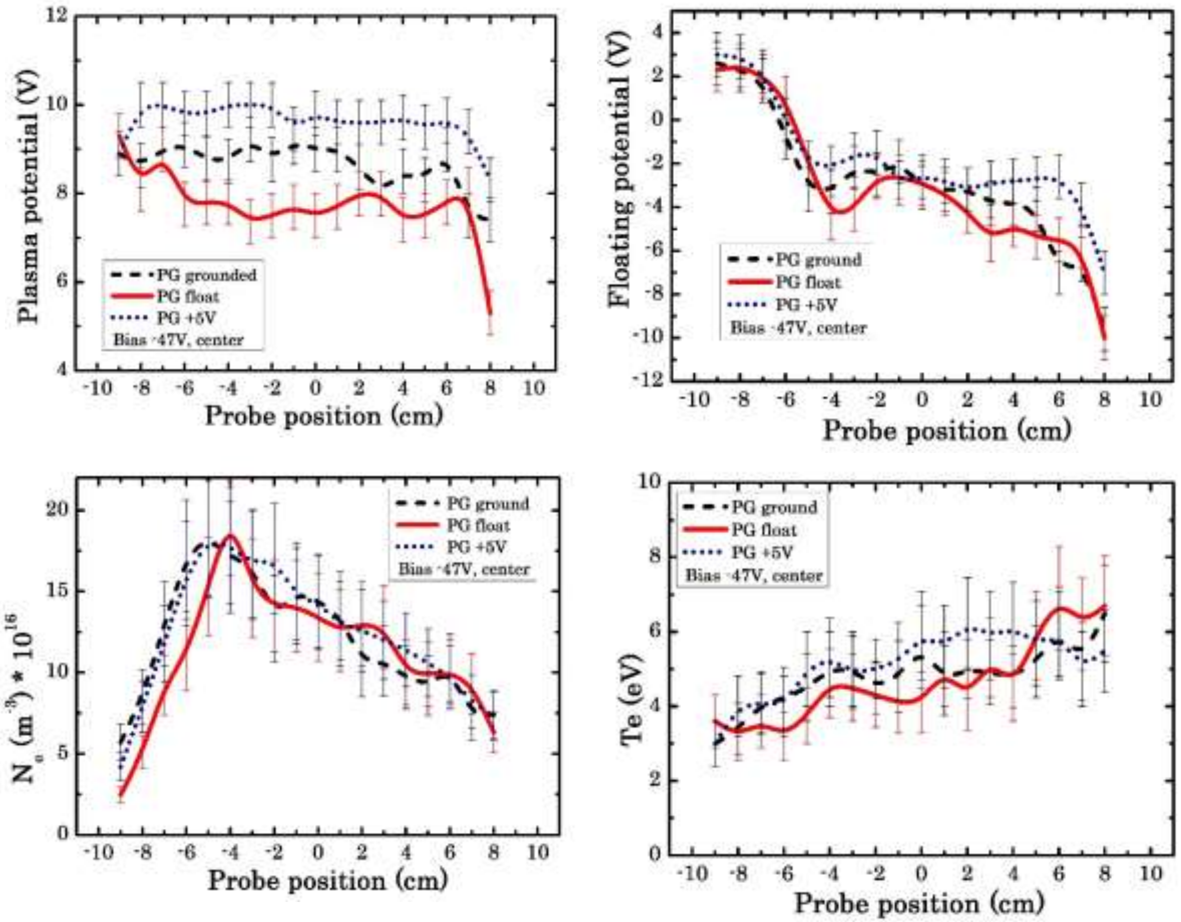
1) Vpl is almost constant
2) Vfl drops toward PG by 7-10V
3) Ne has maximum at -5cm
4) Te increases from 4 to 6 eV

(60 cm from the Helicon driver, PG is grounded, Prf 3kW, p=0.3 Pa, B=100G, H).

Effect of The Plasma Grid polarization

Transverse distribution of plasma parameters

Probe location: centre position behind the PG

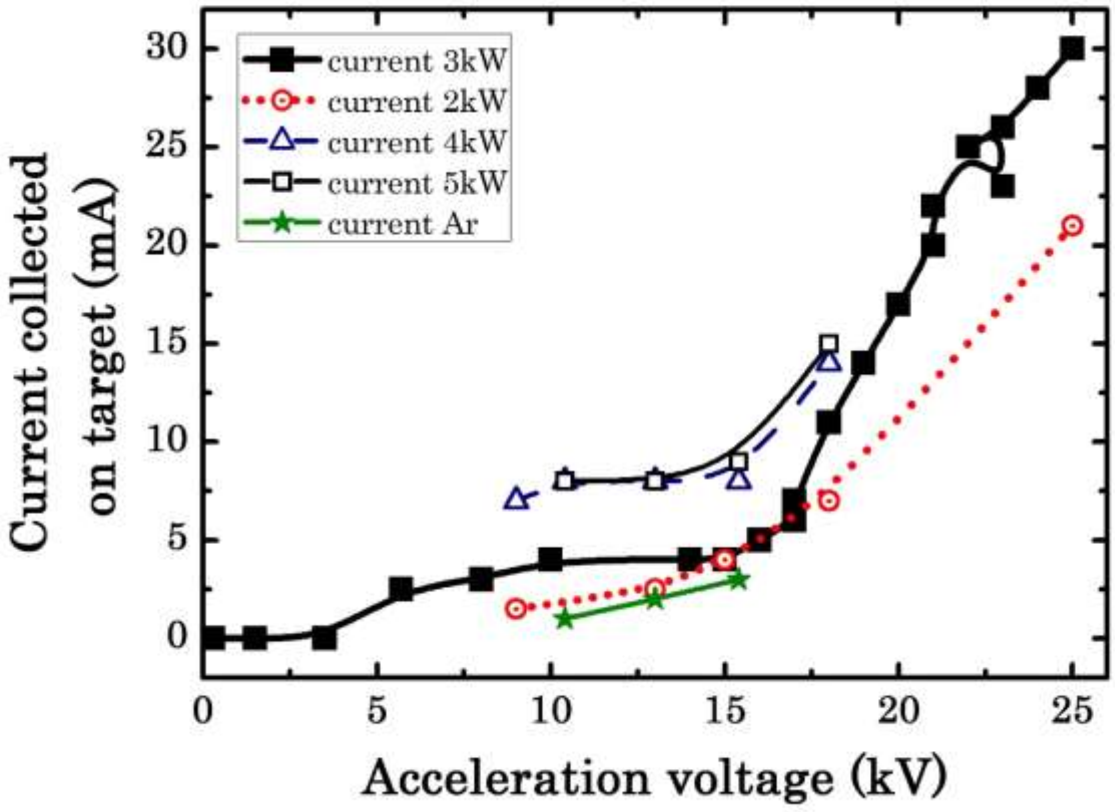


1) Vpl drops close to PG by 2-3V
2) Vfl drops towards PG by 8-10V, no effect from PG polarization
3) Ne has maximum at -5
4) No effect on Te, increases towards PG at 3eV

No real effect from the PG polarization. Other experiments decided to perform with grounded PG

(60 cm from the Helicon driver, V bias -47V, Prf 3kW, p=0.3 Pa, B=100G, H).

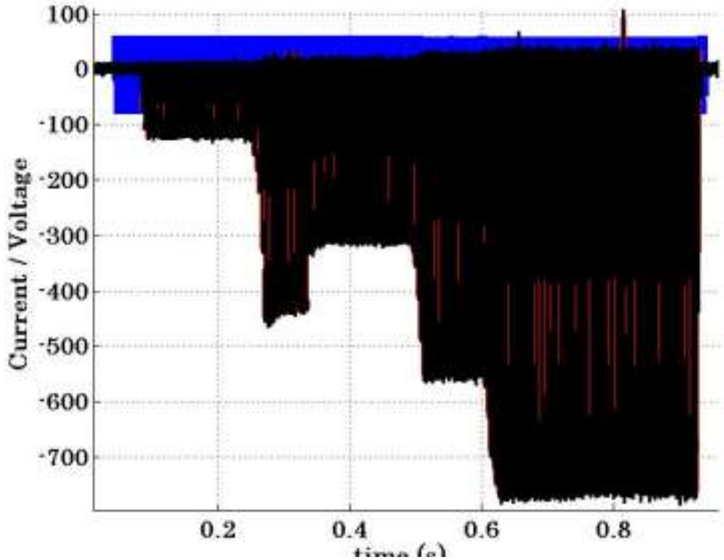
Extracted current

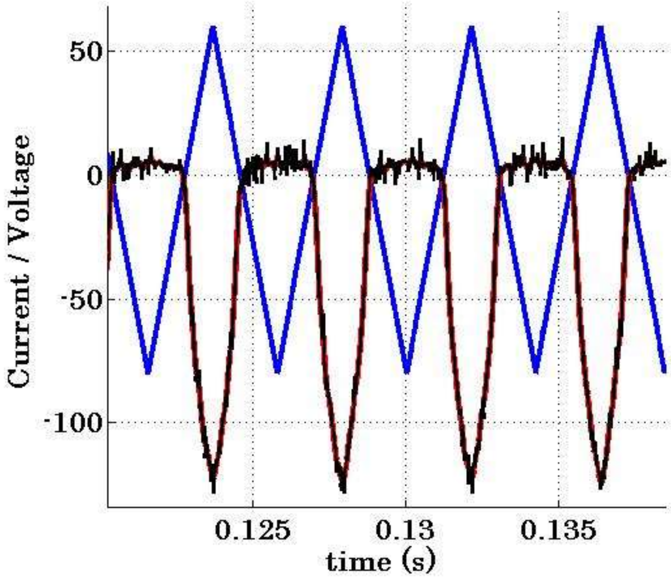


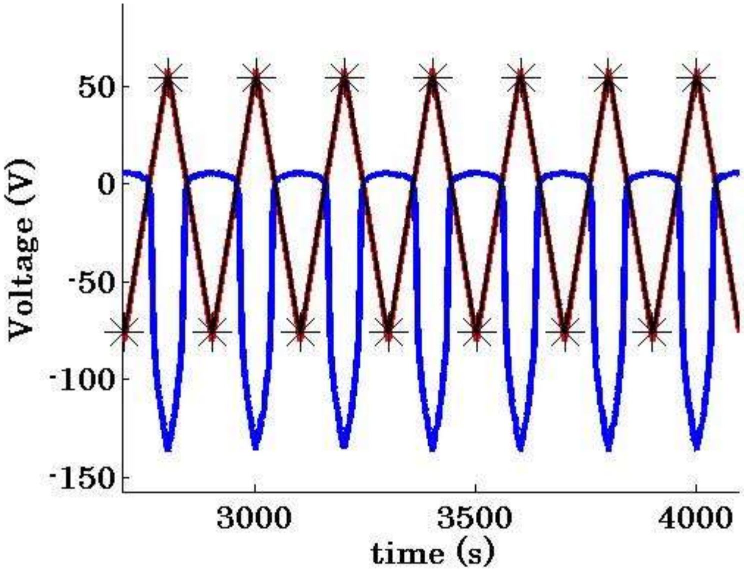
Different RF power
Different gas (H2 or Ar)

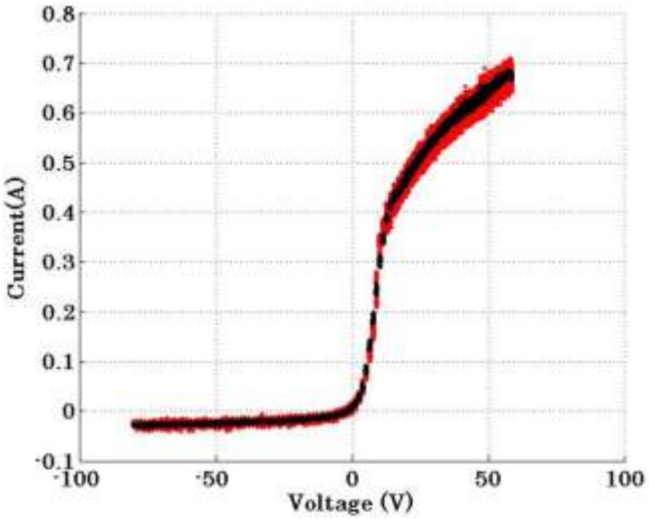
Above 16kV the breakdowns occur more frequently

IV characteristics

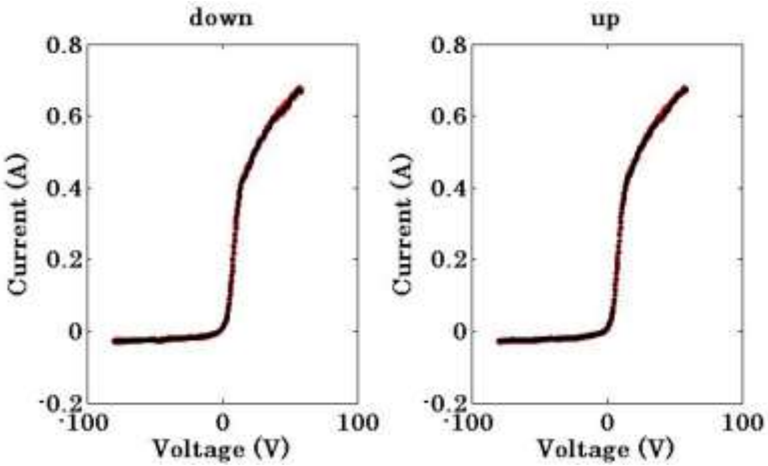


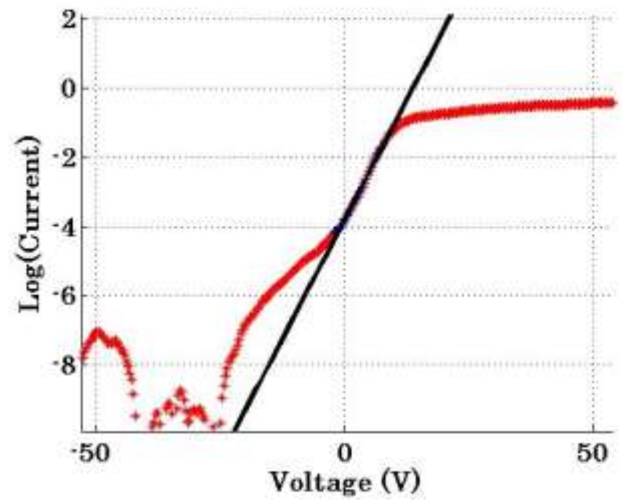


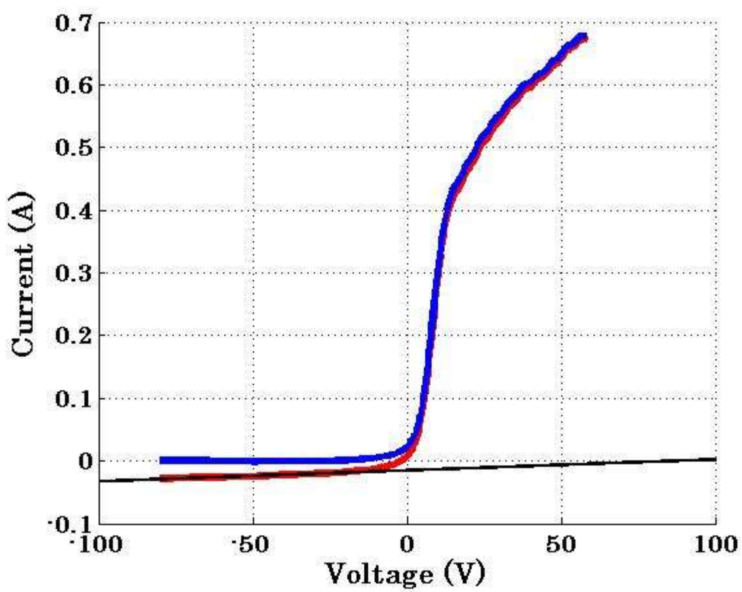


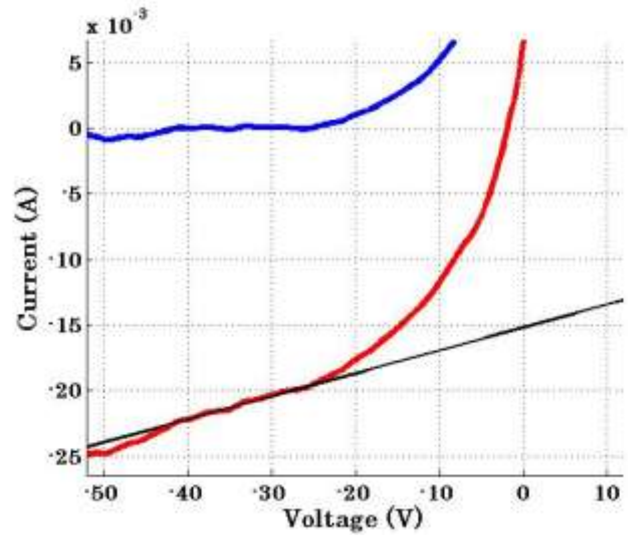


IV characteristics

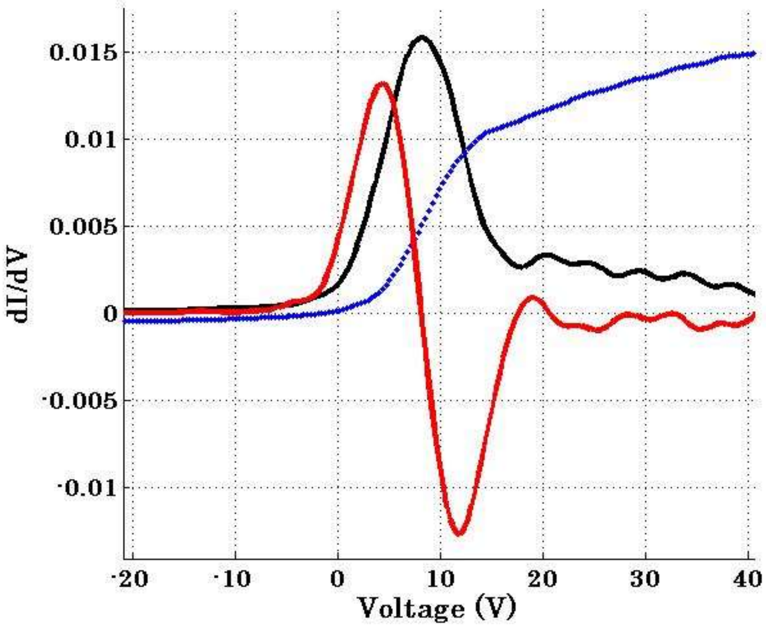


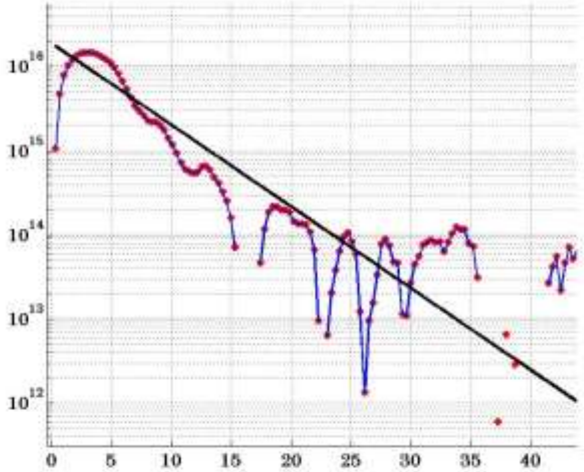






IV characteristics

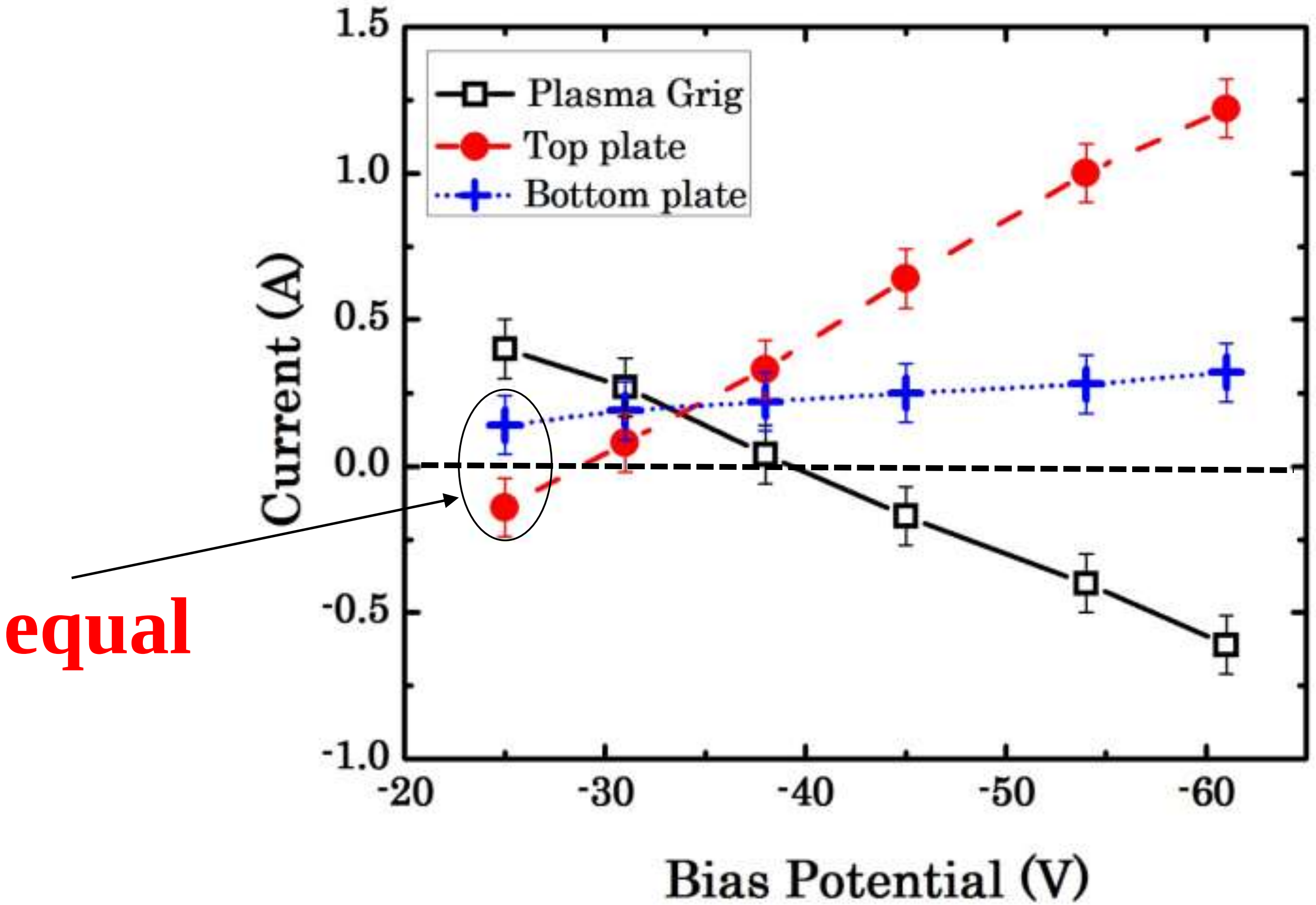




Prf = 3kW
Gas H, p=0.3Pa
B_field ~ 100G (280V set on the born)
PG grounded
V bias top and bottom plates = -55V (350V set on the born)
probe ramp -80V : +60V
serial resistor 15 Ohm

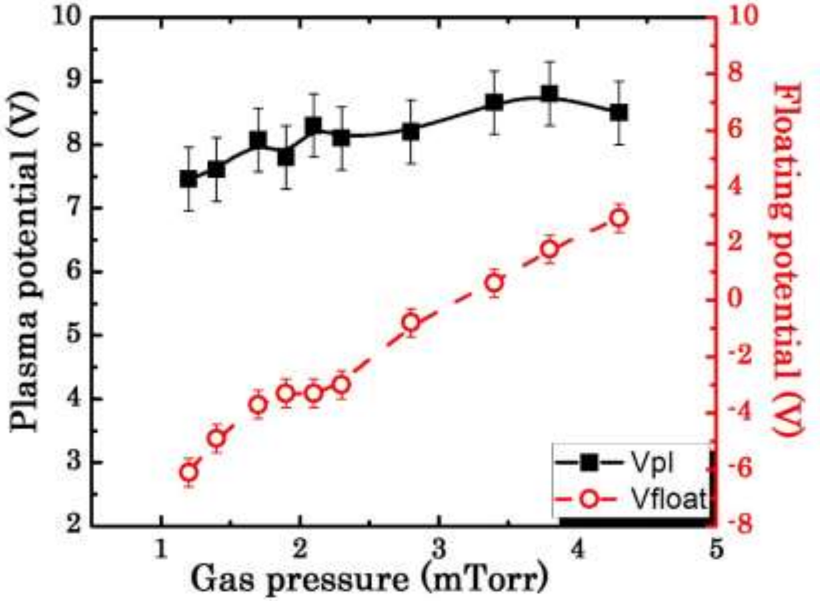
Plasma_potential = 8.8835 V
Float_potential = -1.9139 V
Ion_saturation_current = -0.0155 A
dens_int = 2.9865 10+17 m-3
Te_int = 3.9158 eV
dens_EEDF = 1.8521 10+17 m-3
Te_EEDF = 4.0506 eV

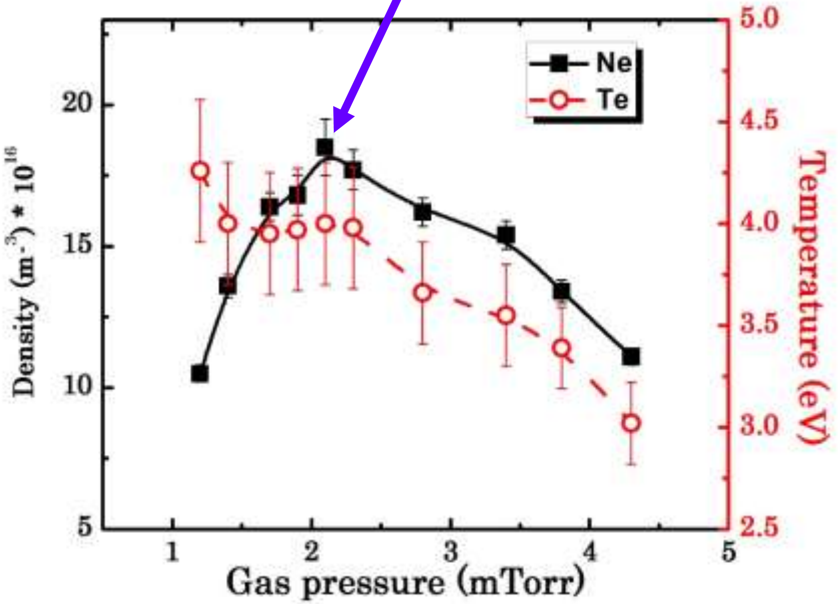
Current measured separately on the Plasma Grid, top and bottom bias plates
Variation of the bias potential. Plasma Grid grounded



Effect of the pressure

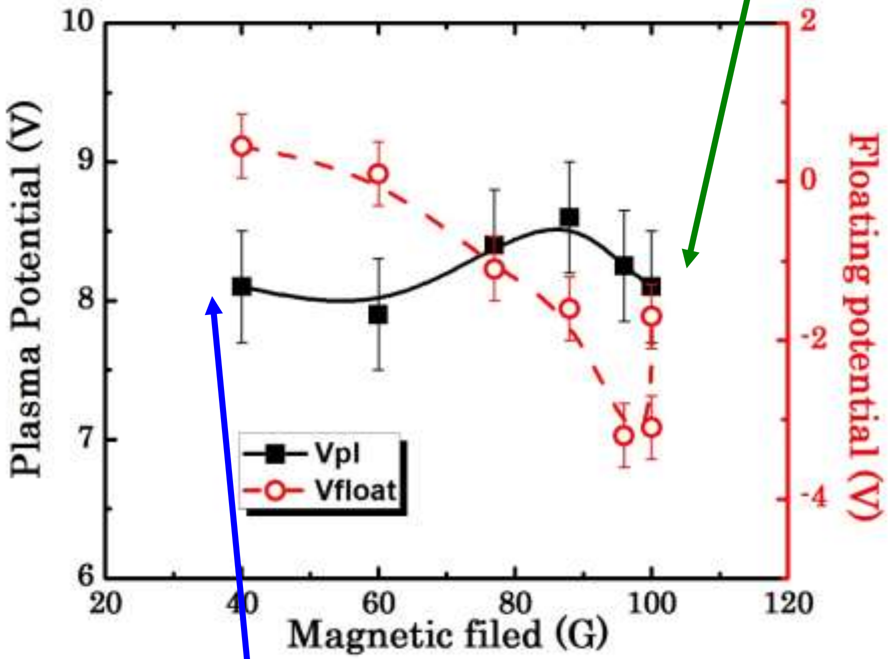
Optimal pressure = 2.1mTorr (0.3Pa)
Highest plasma density

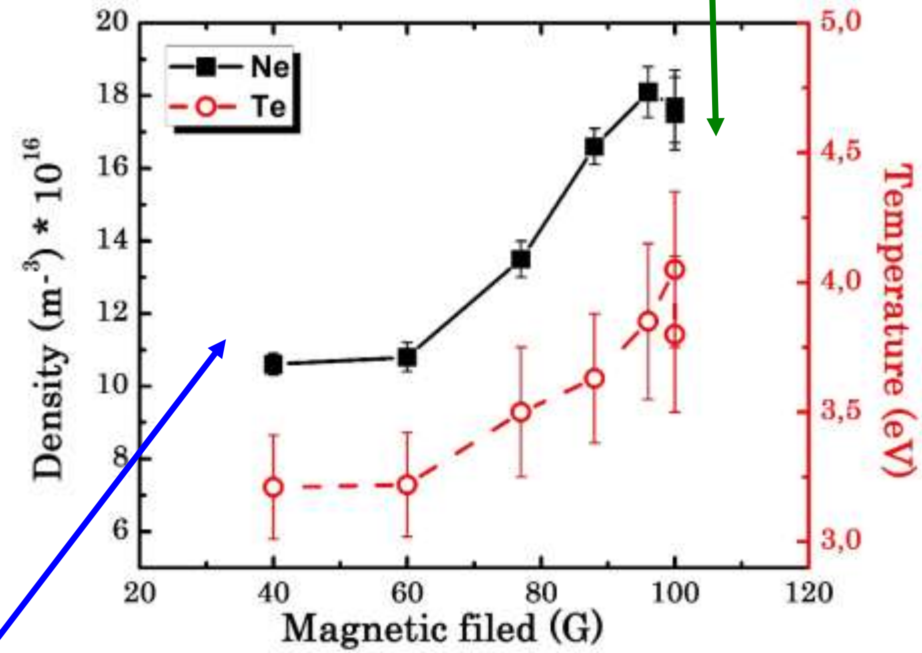




Effect of magnetic field

Saturation of the frame coil
(can not increase the Magnetic field higher that 100G)



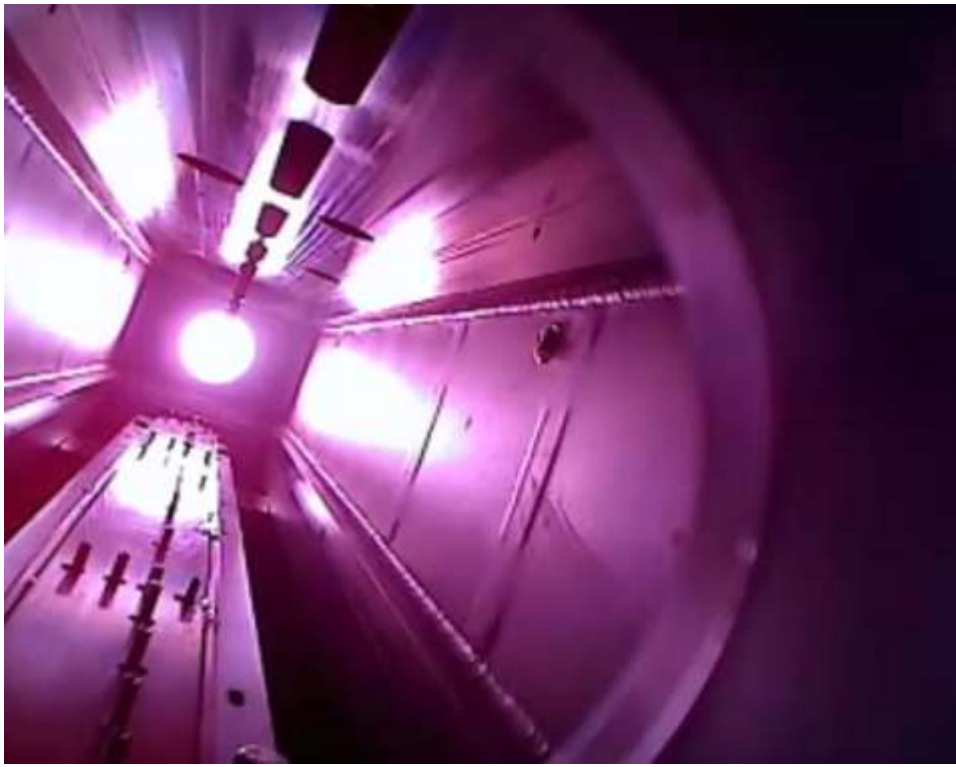


Magnetic field is not high enough
to support the propagation of the helicon wave

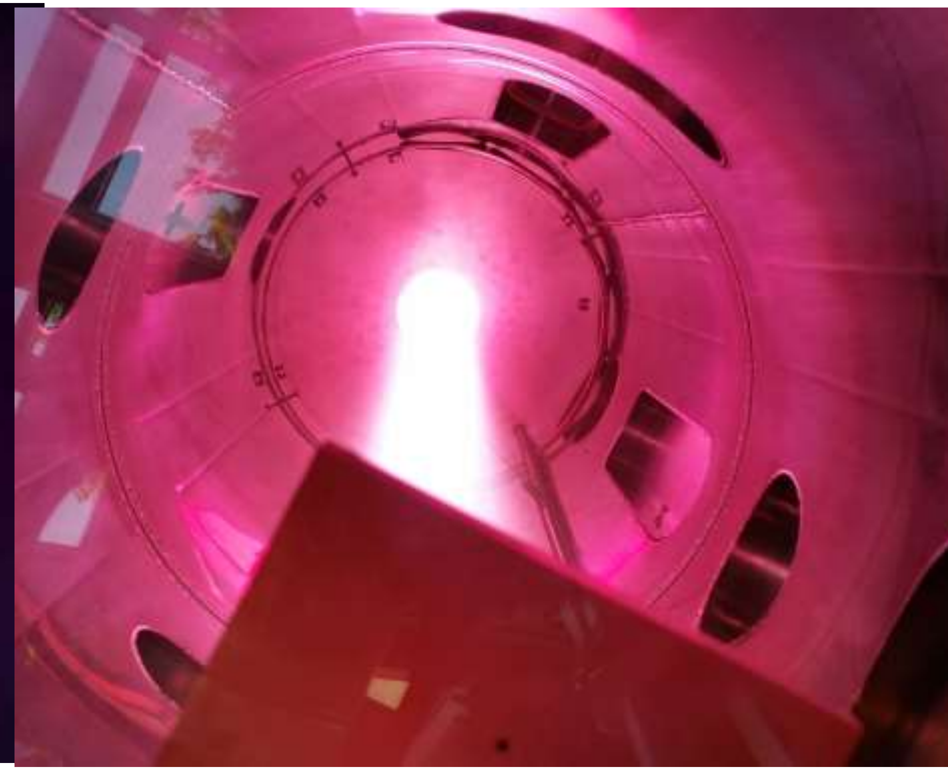
Helicon driver for Cybele

Comparison between ICP and Helicon

ICP RF plasma on Cybele
P_{RF}=25 kW, no magnetic field



Helicon plasma on the RAID testbed (EPFL) ***P_{RF}= 3 to 5 kW***



Plasma from ICP driver does not diffuse far in the Cybele source volume

Helicon plasma driver is essential for the magnetized plasma column of Cybele

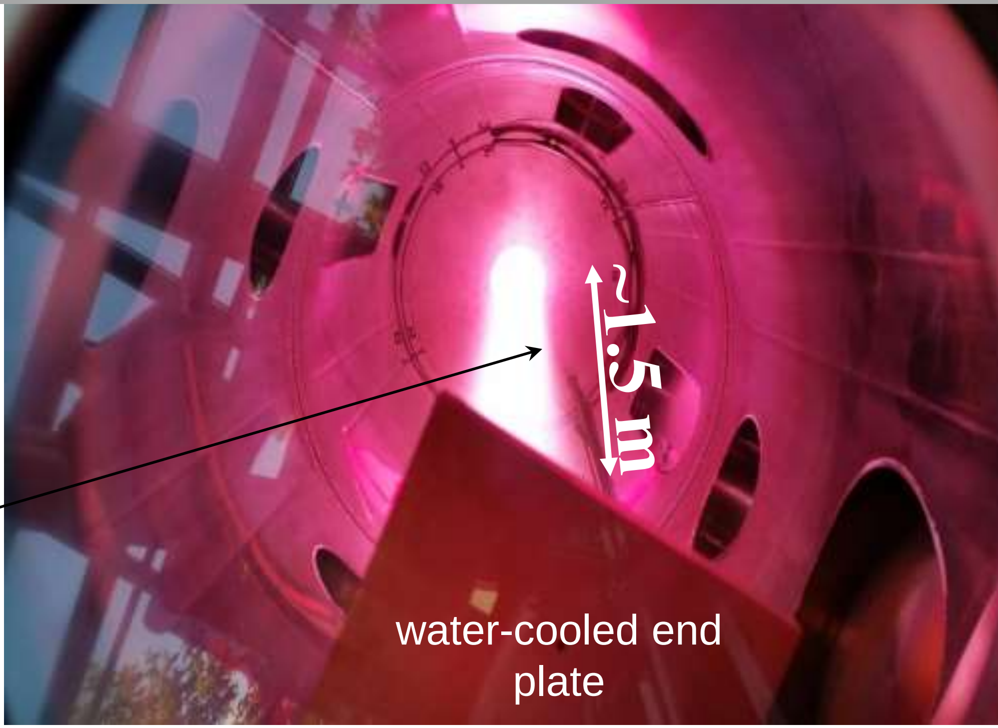
Helicon driver for Cybele

Development of a 10 kW Helicon antenna (Bird-cage type) at RAID testbed (EPFL) to provide a dense magnetized plasma column

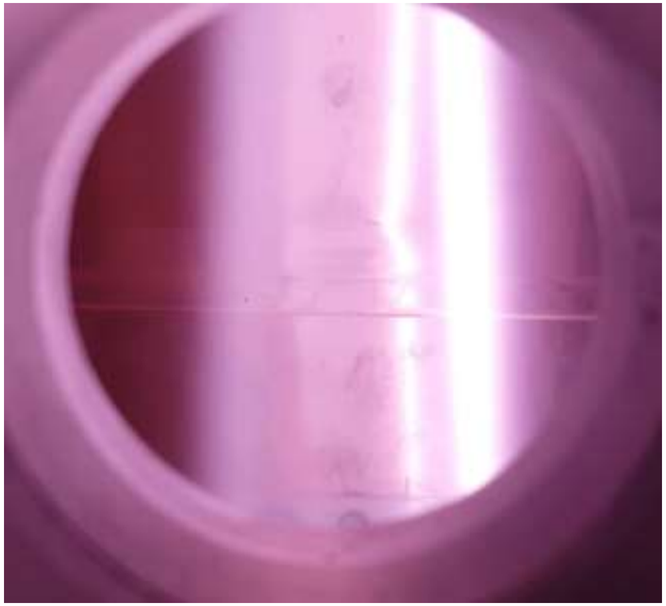
Helicon Bird-cage antenna meets the specifications:

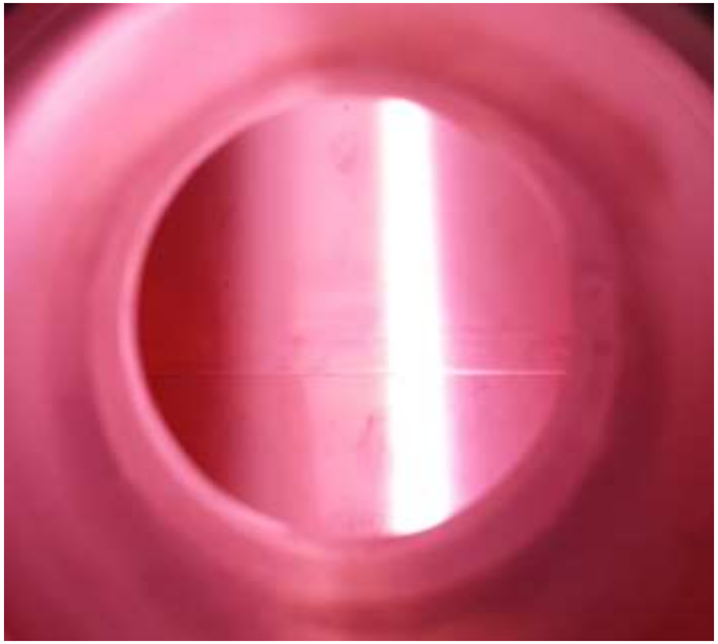
- Low B-field (~10 mT)
- Low operating pressure (~0.2 Pa)
- Stable plasma discharges in H_2 and D_2 up to 10 kW plasma (achieved)
- Nearly constant section
  ⇔ Uniform plasma distribution along $B_{//}$

A 3 kW, 0.3 Pa, B= 12 mT, H_2 plasma jet

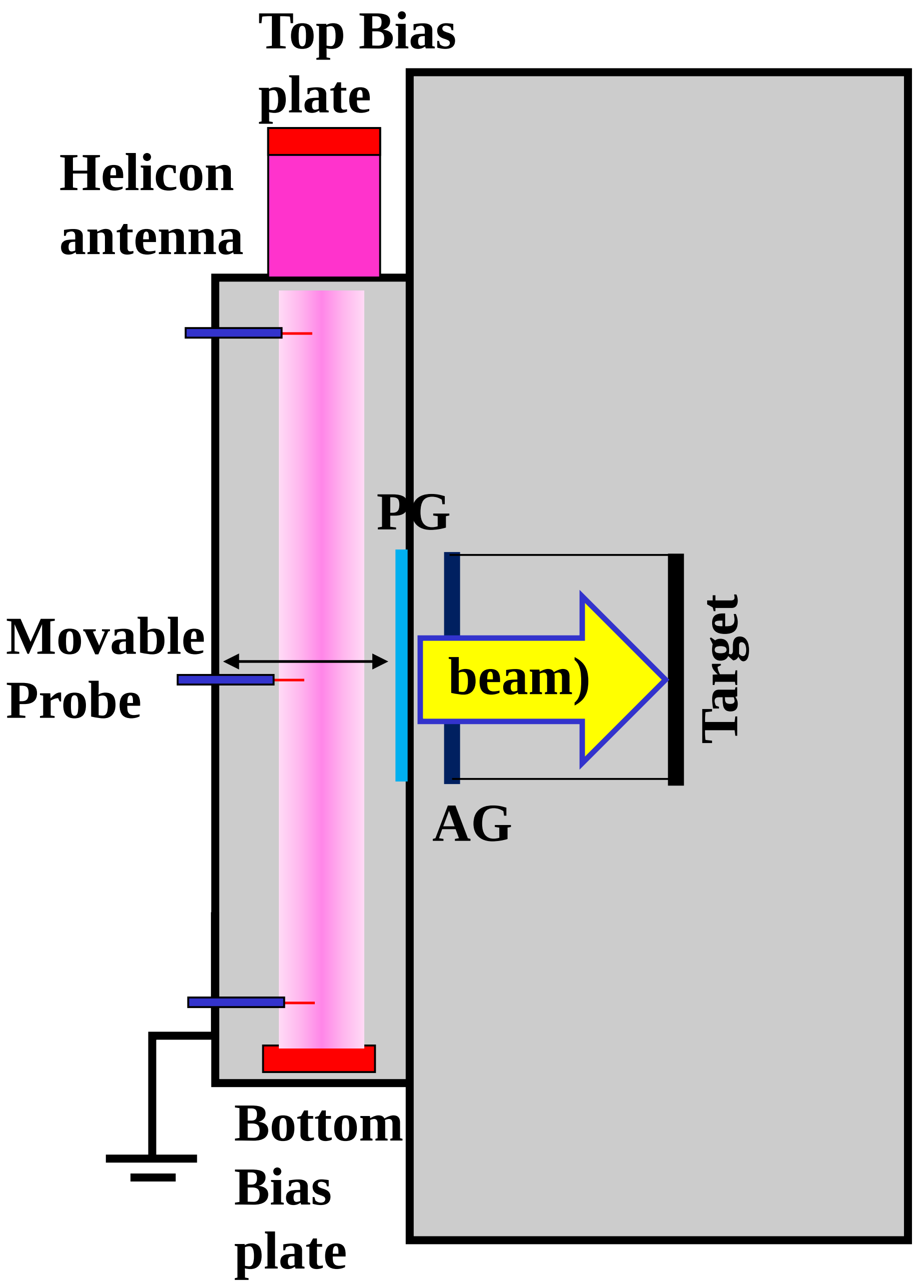


Plasma instability??
Conditioning??





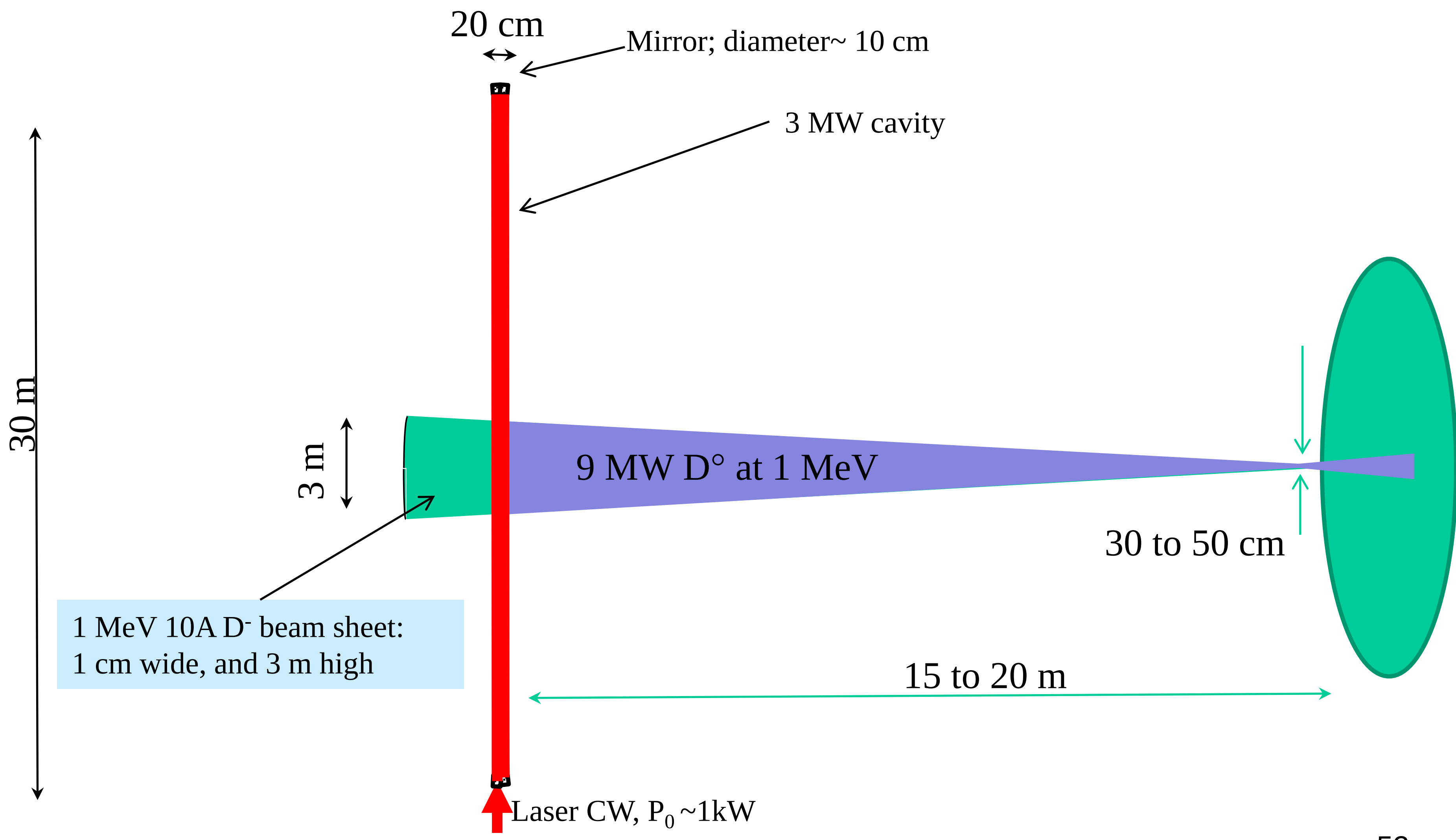
Experimental setup



Cybele with negatively biased Top and bottom plates and Plasma grid (grounded, floating or positively polarized +5V)

Magnetic field – 100 G
RF power – 3kW
Gas pressure - ~ 0.3 Pa
Bias plates : -25V : -90V
Plasma Grid : grounded, floating , +5V
Probe sweep – [-80V : 60V]
Sweep frequency – 10 Hz

Side view of one beam-sheet with a single 3 MW cavity



Electrical setup installation of the 30 kV pre-accelerator

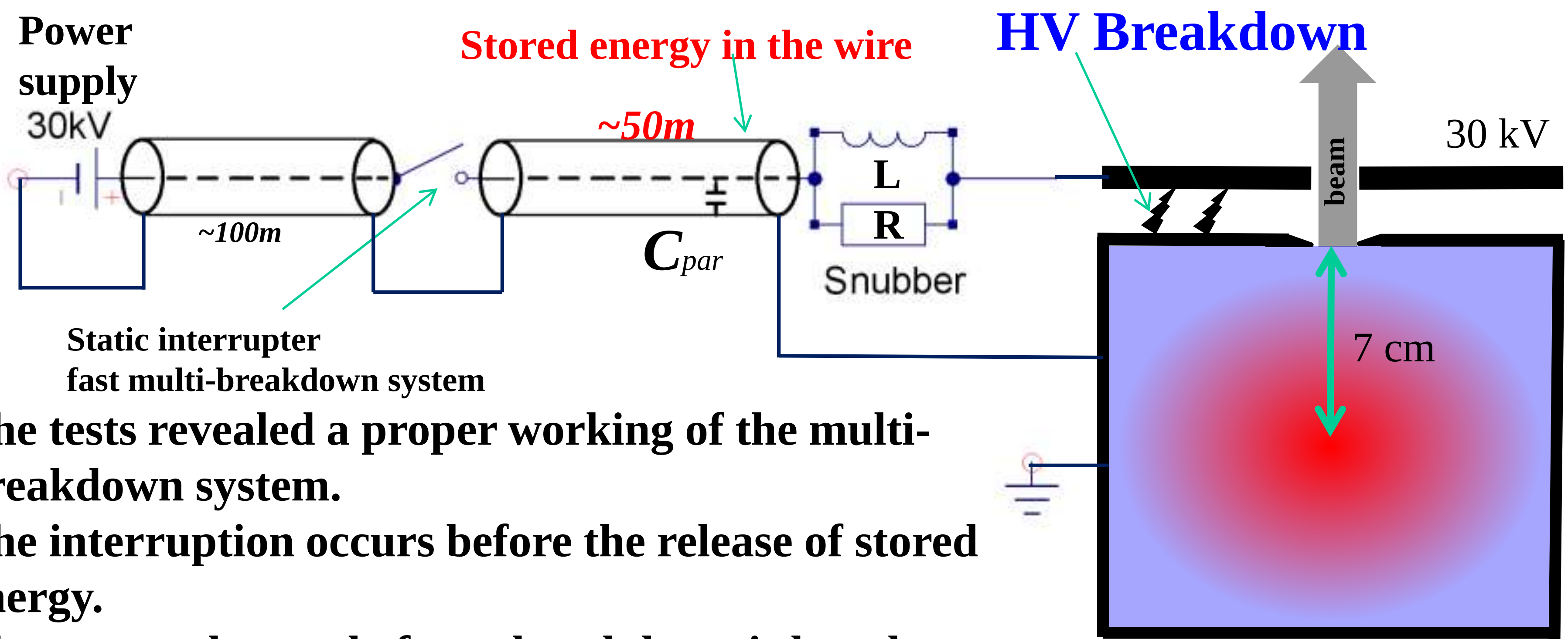
With High Voltage breakdown – risk of damaging PG, arcing etc.

⇒ Interruption of the current in the µs range (fast switch multi-breakdown system)

⇒ Removing the stored energy in the HV wires by a snubber (to avoid grid damages)

⇒ The reset of the Static interrupter in the 10 ms range

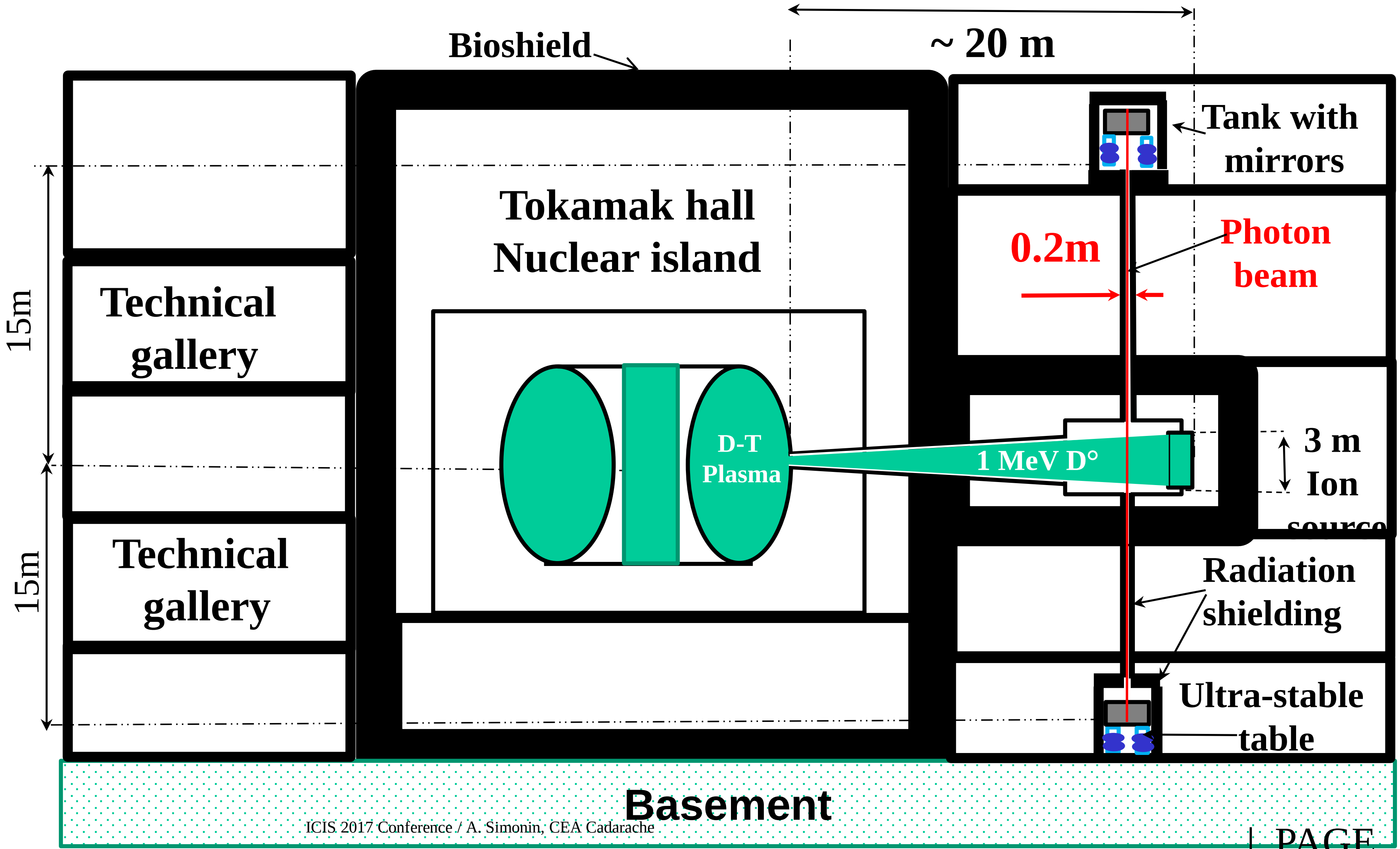
⇒ HV holding and beam <u>conditioning involves several tenses of HV breakdowns per second</u>



The tests revealed a proper working of the multi-breakdown system.

The interruption occurs before the release of stored energy.

The energy detected after a breakdown is less than 5mJ.



Bioshield
~ 20 m
Tank with mirrors
Tokamak hall
Nuclear island
0.2m
Photon beam
Technical gallery
15m
D-T Plasma
1 MeV D°
3 m
Ion source
Technical gallery
15m
Radiation shielding
Ultra-stable table
Basement

Implantation of the NB systems on the reactor
(Top view)

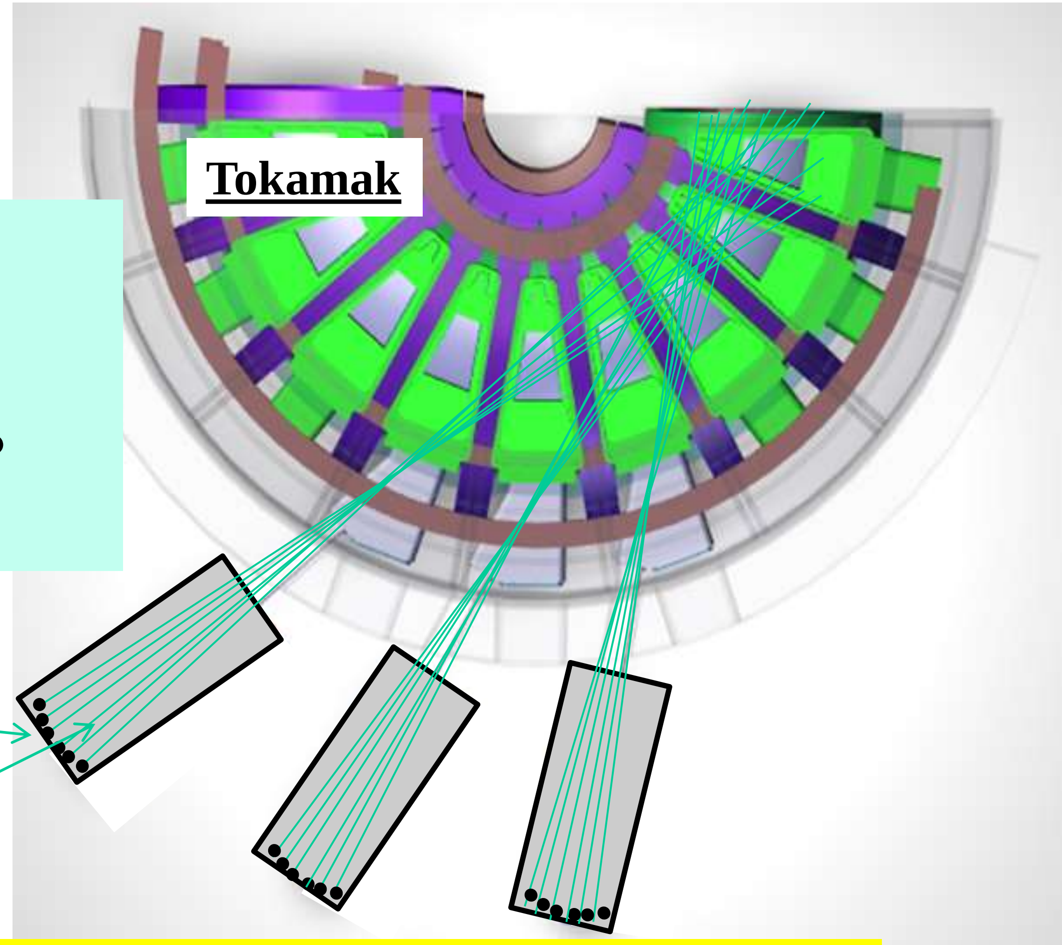
Modular concept

⇒ **Six beamlines in // per tank**

⇒ **50 MW D° per tank**

⇒ **Three tanks in //: ~ 150 MW D°**

⇒ **Overall efficiency: ~70%**

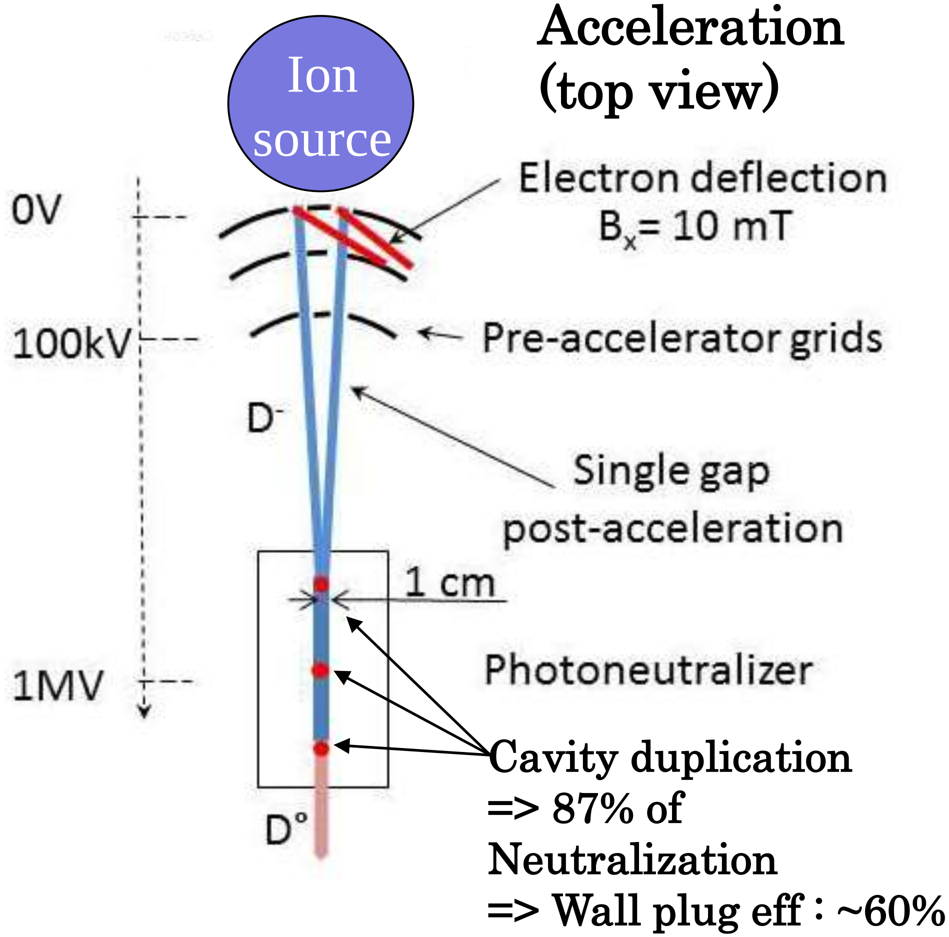


NB vacuum Tank

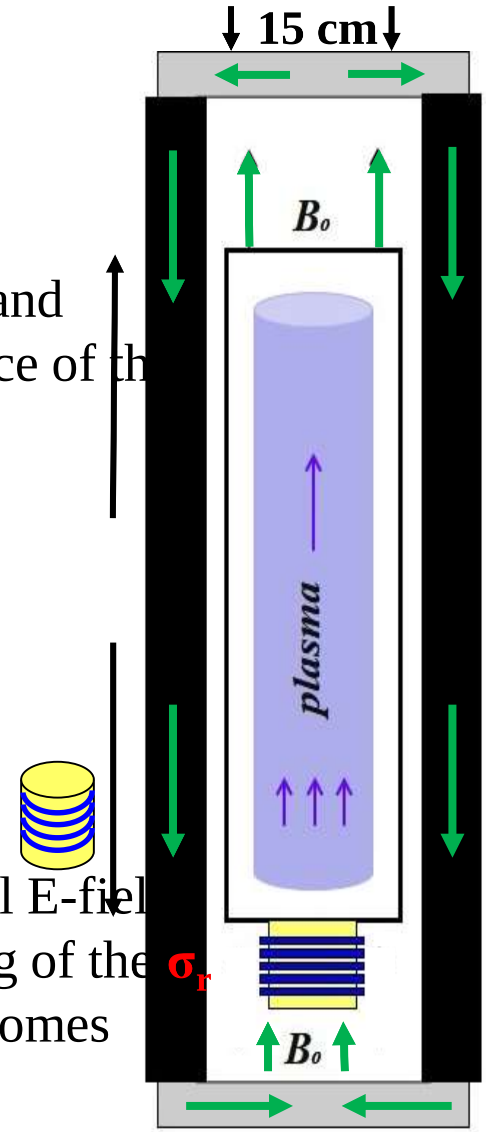
Six beam sheet in // per tank

Photo-neutralization allows to achieve powerful neutral beam with high efficiency

Remind Siphore concept

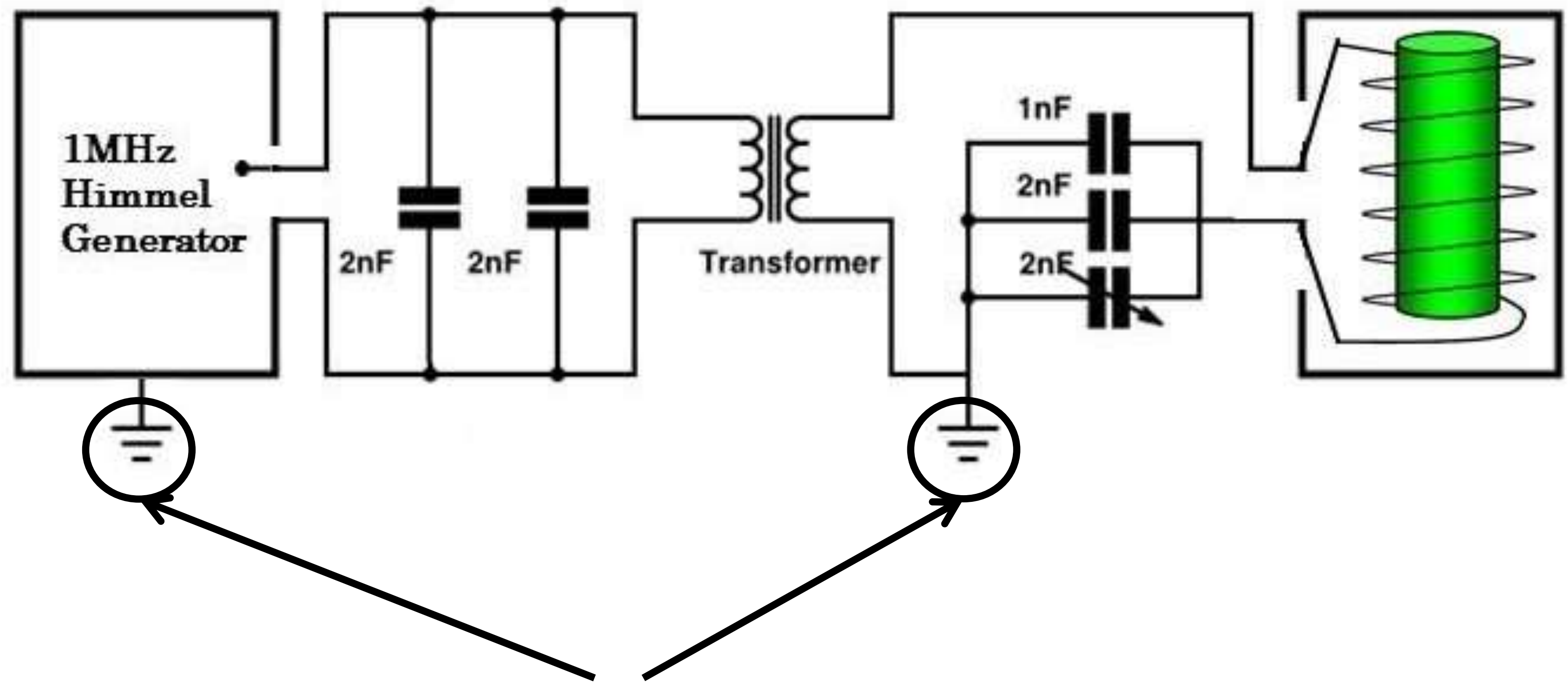


Vertical B-field increases vertical diffusion => radial diffusion and conductivity decreases => increasing of the skin-depth => reduce of th RF-induced current



The electrons in ICP driver are accelerated by the RF azimuthal E-fiel (E_φ) experience a radial Lorentz force (**F_r=v_φ x B_z**) => reducing of the σ_r => decreasing I_{plasma}. => For B-fields larger than 2.5 mT, it becomes impossible to couple the RF active power to the plasma.

RF electrical set up



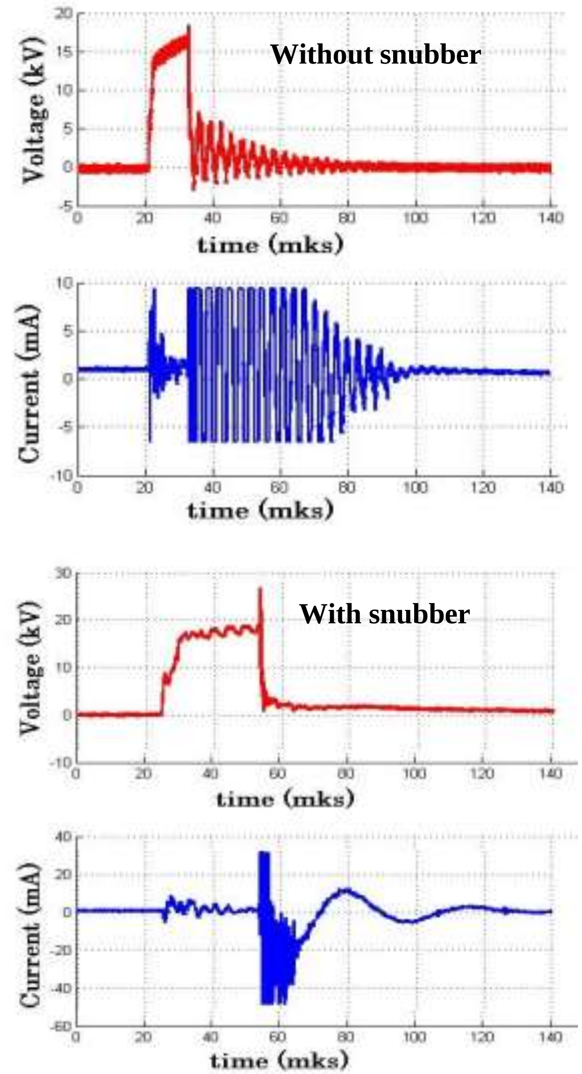
Ground Decoupling between the RF generator and the antenna circuit

Static interrupter
fast multi-breakdown system

2m

Snubber

70 cm



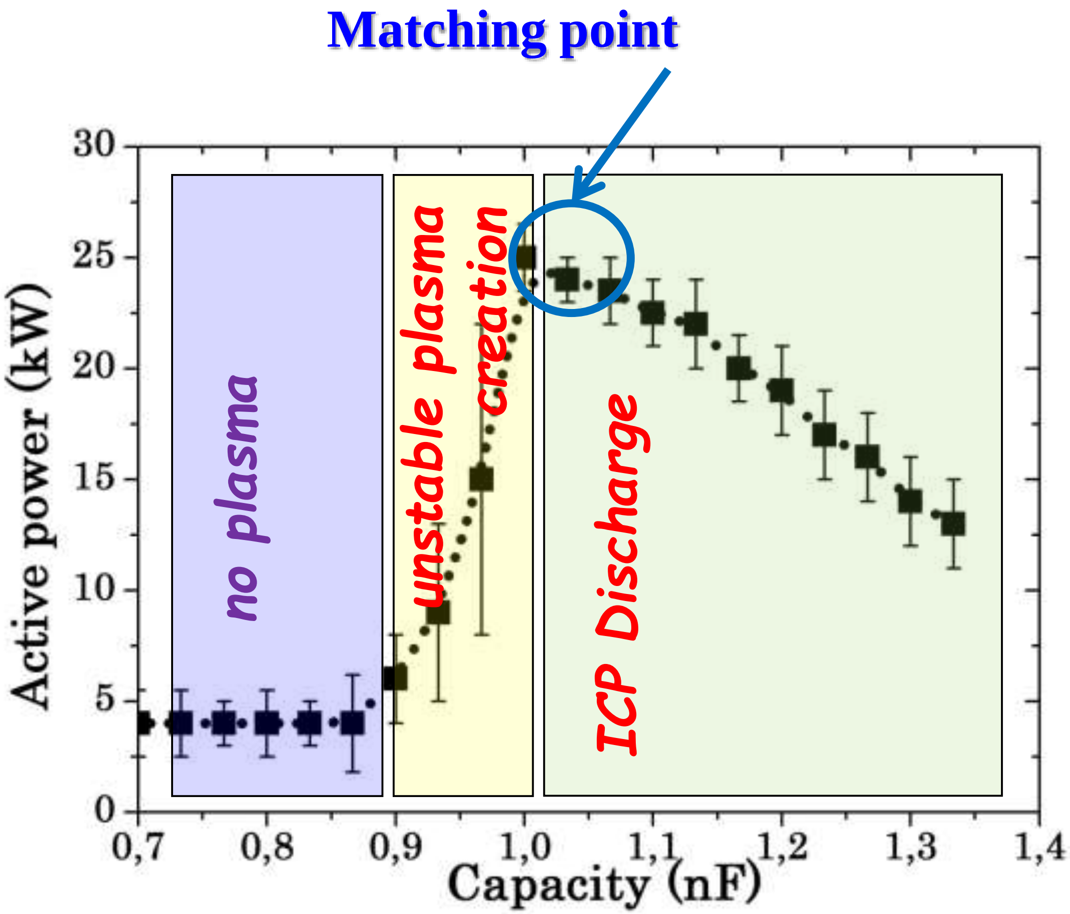
The tests revealed a proper working of the multi-breakdown system.
The interruption occurs before the release of stored energy.
The energy detected after a breakdown is less than 5mJ.

Matching impedance

Gas – Hydrogen
Pressure – 0.3 Pa (ITER condition)
Set point of the generator power : 30 kW

Measured Frequency :~0.94 MHz

Active power coupled to the plasma 23-26 kW at the matching (~ 0.75-0.85 of total power)



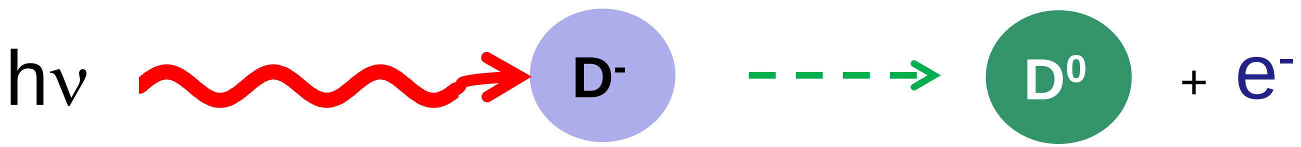


Photo-neutralization seems ideal

- **No gas injection => Strong reduction of D^- losses**
- **Clean : No pollutant**
- **Potential High neutralization rate (η> 90%)**

But

- **Low photo-detachment cross-section**

$$\sigma \sim 3.6 \ to \ 4.5 \, . \, 10^{-21} \ m^2 \text{ for } \lambda = 1064 \text{ nm}$$

Photo-neutralization requires high photon power !!

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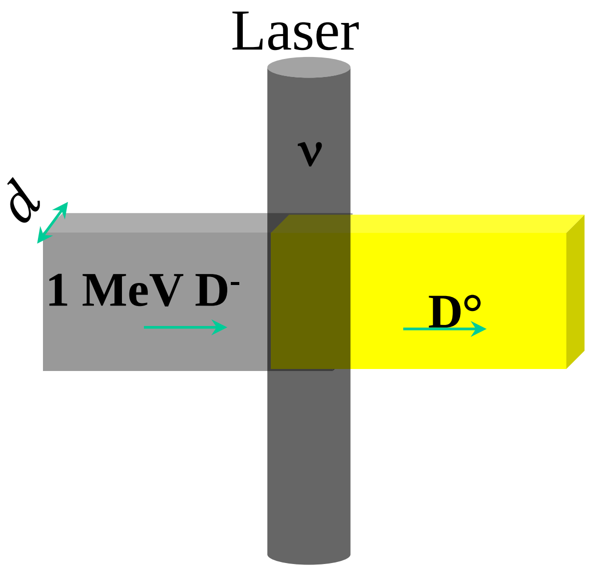
Evaluation of the photon power

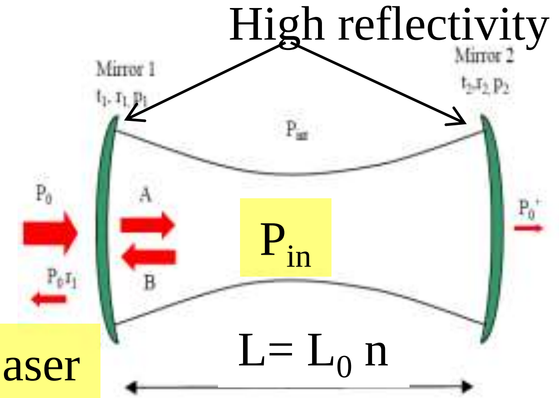
- ***1MeV D⁻ blade-like beam***
- ***D⁻ beam width: d ~ 1cm***
- ***50 % photo-detachment rate***



D⁻ Ion velocity,
|v|~ 10^7 m/s at 1MeV

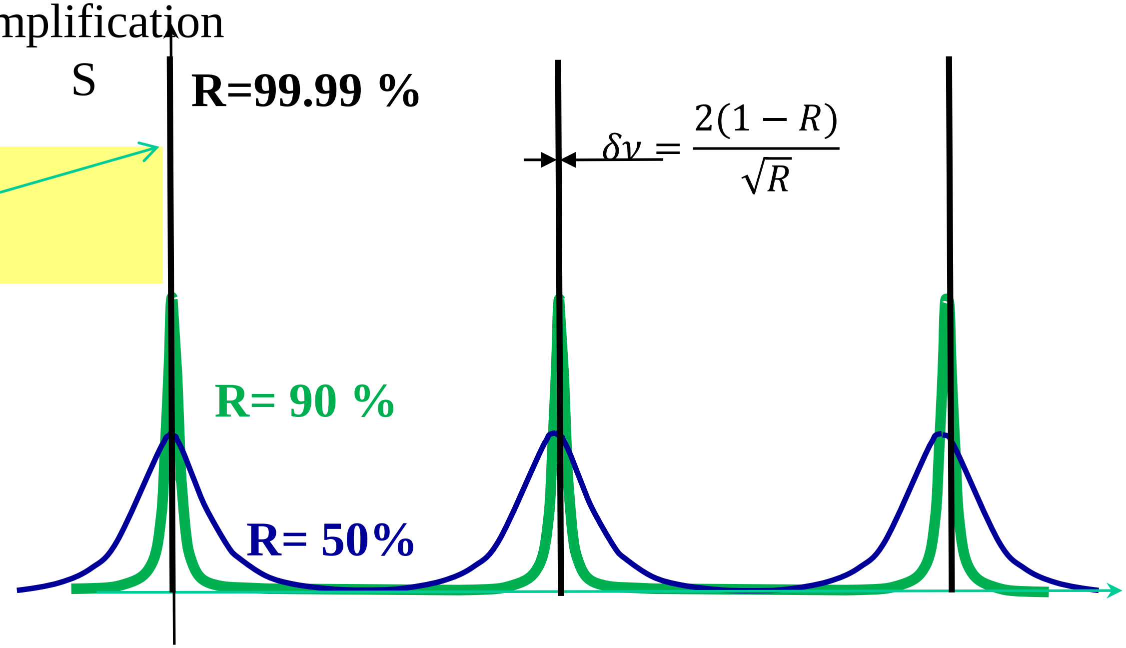
$$P_{photon} = hc.\frac{|v|\ d}{\sigma\ \lambda}$$

$P_{photon} \sim$ **3 MW**



Laser
P_0

Resonance ⇔ 2 L = q λ ⇔ Constructive interferences

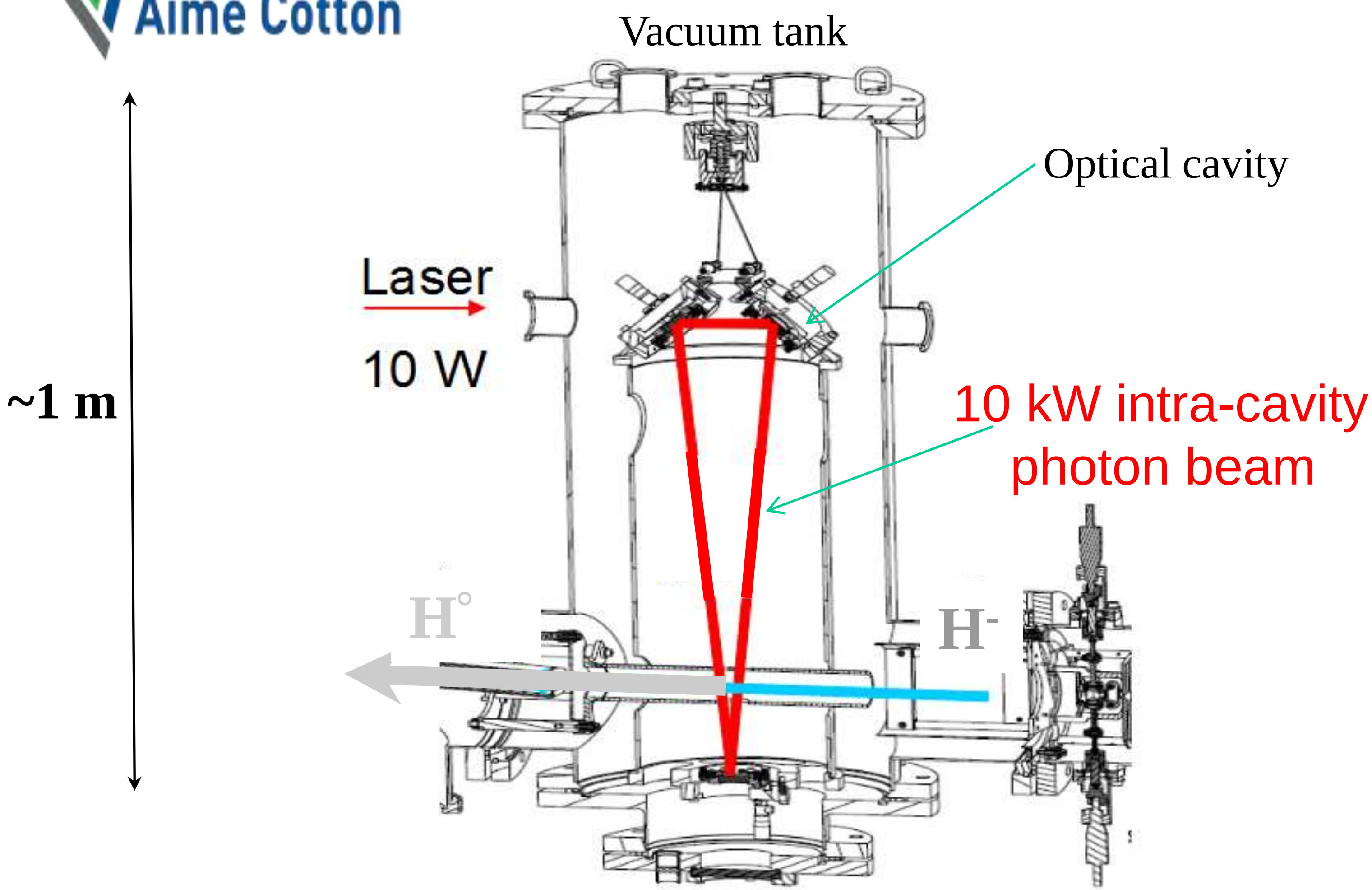


Photon power stored within the cavity:
$P_{in} = P_0 \times S$

P_{in} ↗ => δν ↘

High cavity sensitivity to variations of the optical length:
vibrations, etc.

Photo-neutralization experiment in cavity



➢ **H- beam: 1 keV and 1 mm diameter**

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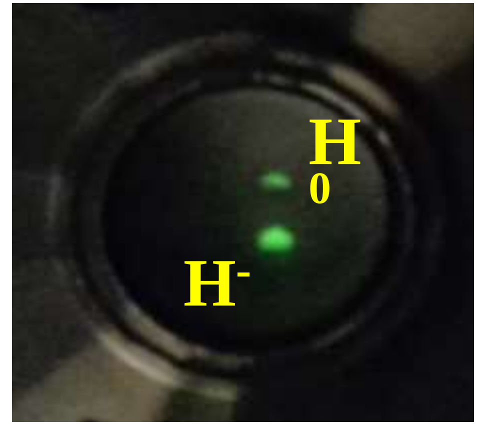
Photo-neutralization experiment in cavity

Preliminary results

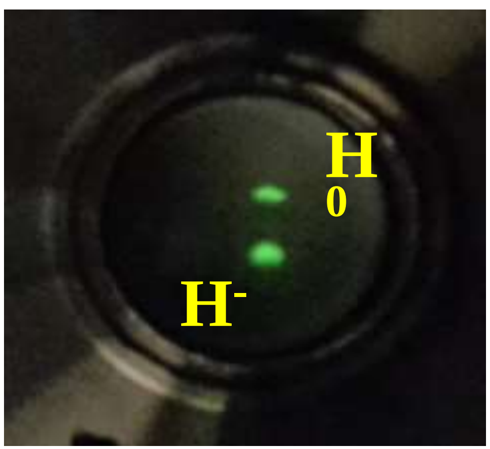
Photon power 0 kW

Photon power 13 kW



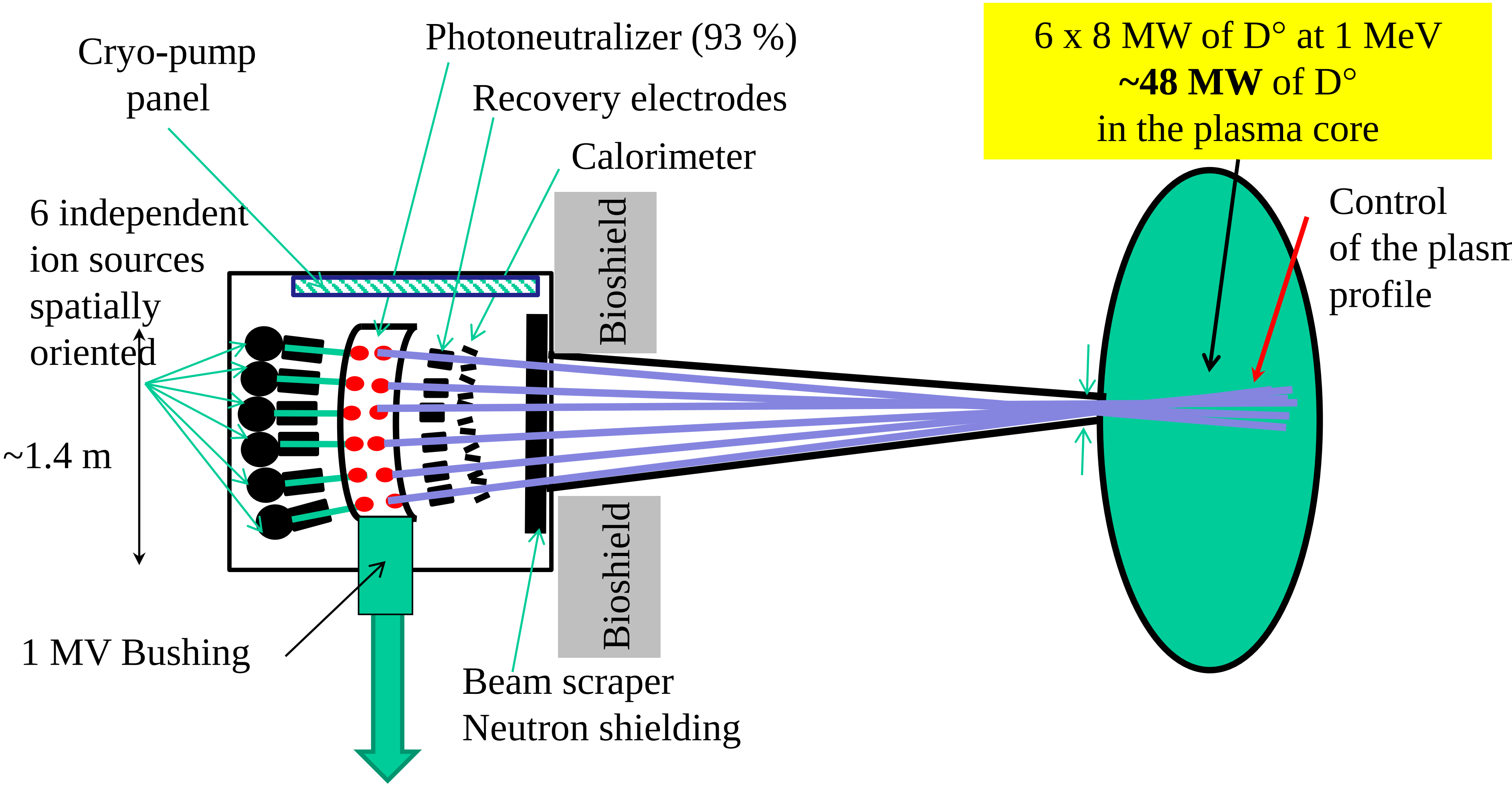
Observation of H^- and H° on micro-channel detectors

Photon power 23 kW



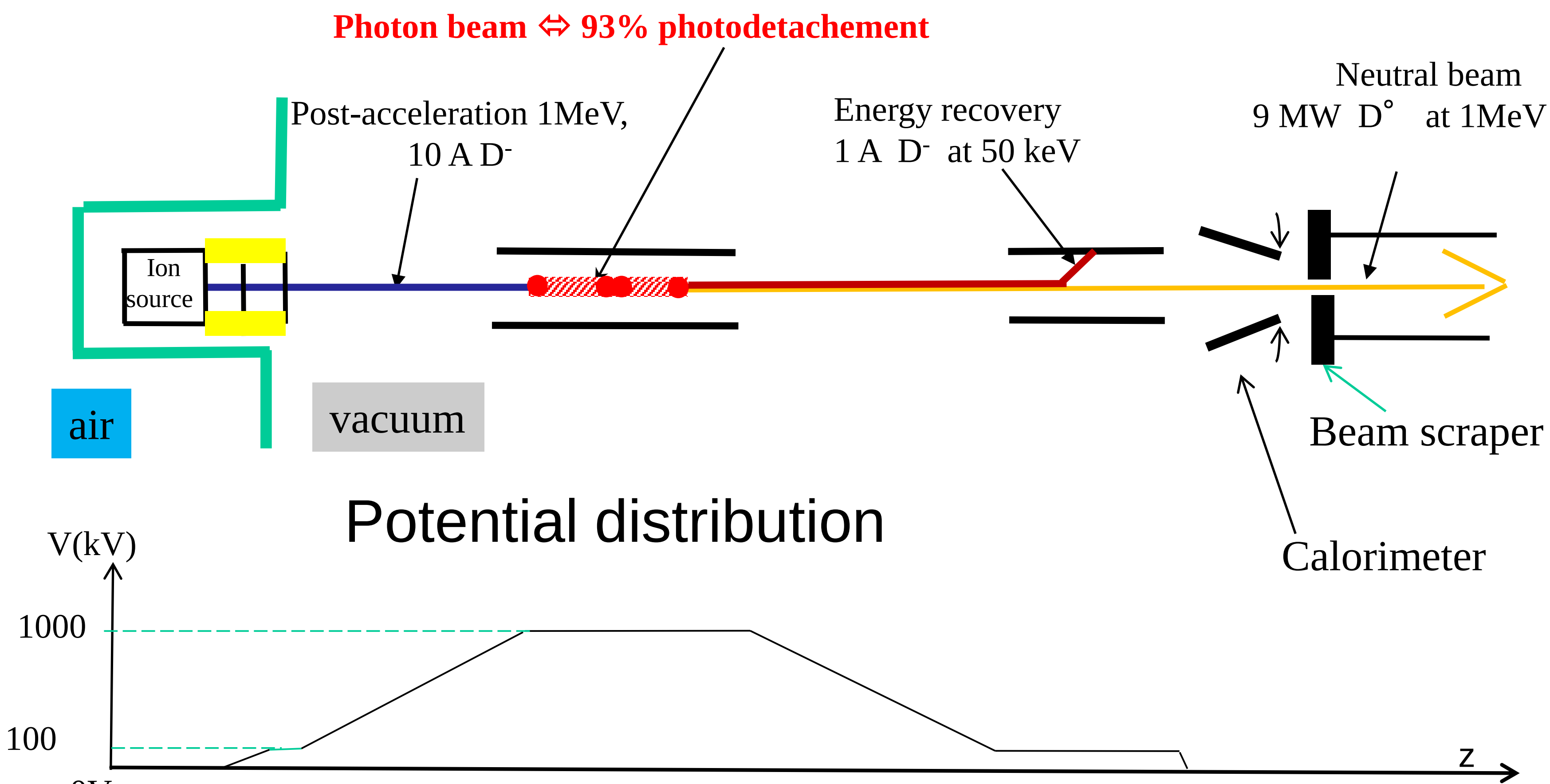
⇔ 50 % photo-detachment achieved in CW regime

Publication: « Saturation of the photoneutralization of a H- beam in continuous operation »; D. Bresteau, C. Blondel, C. Drag; Rev. Sci. Instrum.; 2017; in press.


6 x 8 MW of D° at 1 MeV
~48 MW of D°
in the plasma core
Cryo-pump panel
Photoneutralizer (93 %)
Recovery electrodes
Calorimeter
6 independent ion sources spatially oriented
Bioshield
Bioshield
Control of the plasm
profile
~1.4 m
1 MV Bushing
Beam scraper
Neutron shielding

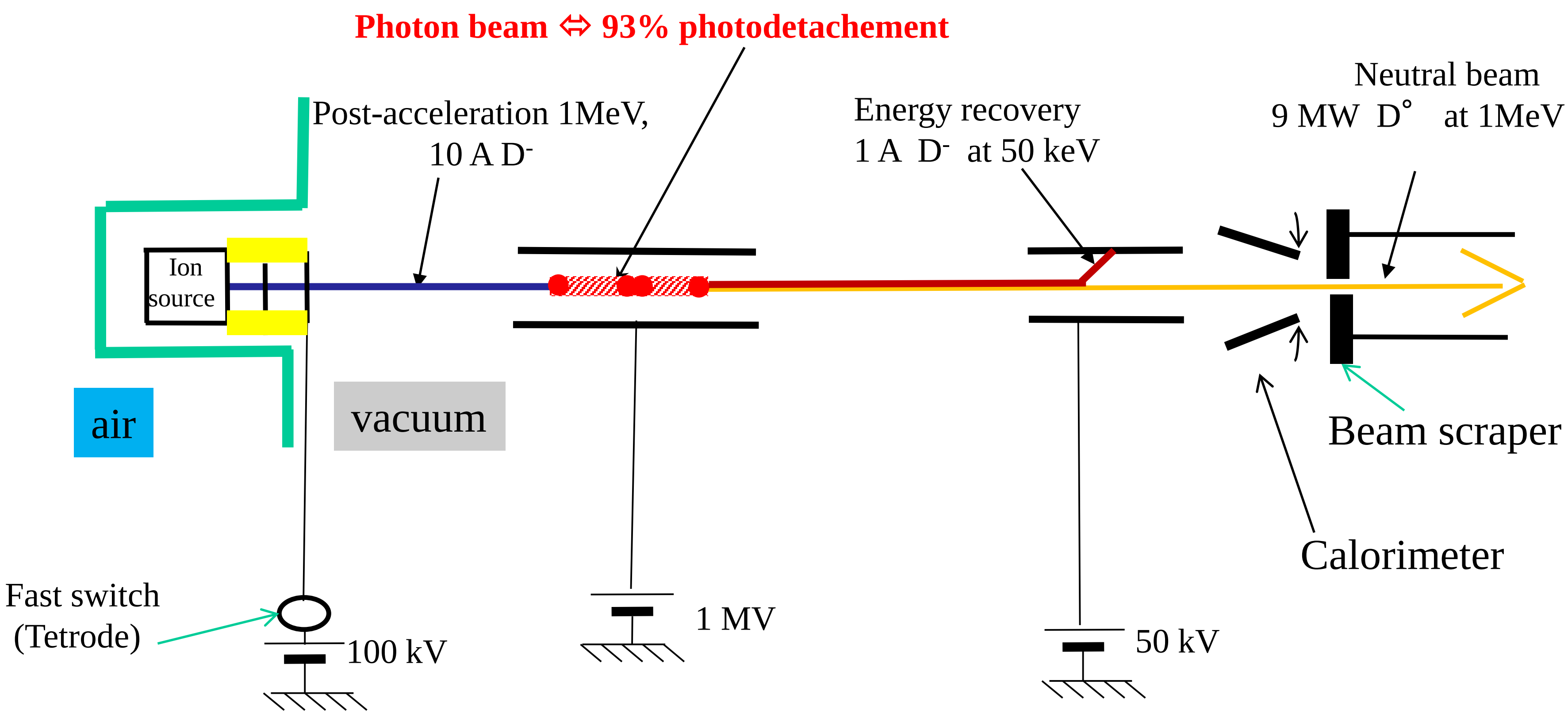
One SIPHORE beam-sheet principle

(Top view)



The ion source and pre-acc. are referenced to the ground potential

One SIPHORE beam-sheet principle
(Top view)



Ion source grounded => Huge simplification of the electrical set-up

- Fast switch in the pre-accelerator allows to switch on /off the 10 A D^- beam in **the µs range**
- It is conventional technology of present NBI systems (JET, etc.)

➢ **Temporal modulation of the D° beam**