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EURATOM Assoziation

Overview of the RF source development at IPP Garching

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Outline

1. Introduction
2. Experimental set-up
3. Results H- / D-
4. Future work on long pulse and size scaling

1.) Introd.

H^-/D^- RF source for ITER NBI

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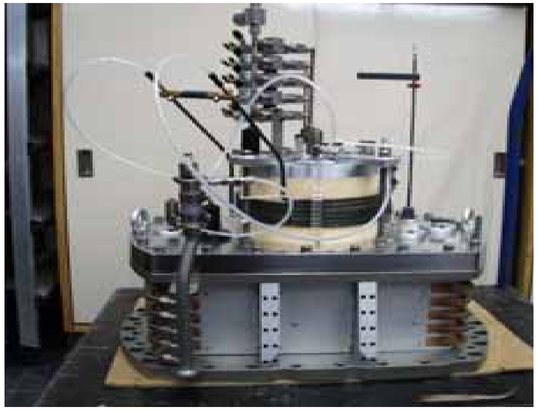
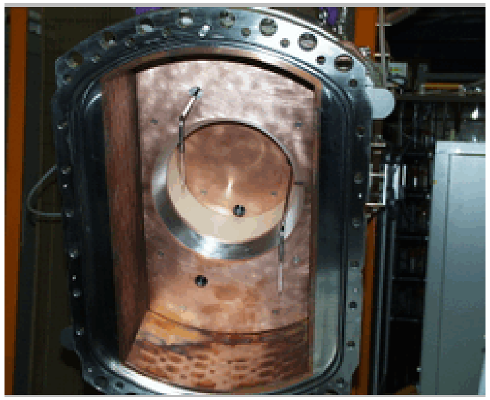
Incentive

for the development of the RF source as an alternative to fil. source





===> no maintenance

EFDA contract (9/2002 - 6/2005):

	testbeds
demonstrate 20 mA/cm² D- at 0.3 Pa; Ie/I- ≤ 1	„BATMAN“
demonstrate 3600 s pulse length	„MANITU“
demonstrate scalability to ITER size	„RADI“

Testbeds

BATMAN: optimis. j-, Ie/I-, press., Cs

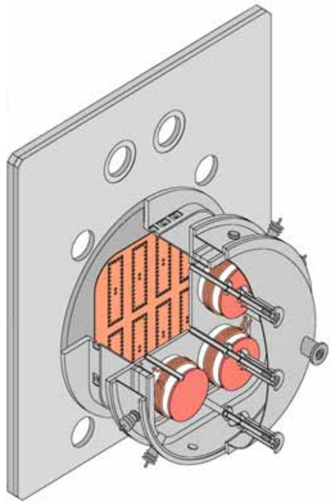
- pumping speed: 120 m3/s, Ti Getter
- 70 cm^2 extraction area, 10 sec
- P_{RF} < 140 kW, HV: 30 kV, 5A, 10 s
- deuterium operation: remote control

MANITU: uniformity, long pulse

- pumping speed: 700 m^3/s, cryosorpt.
- < 380 cm^2 extraction area
- P_{RF} 180 kW c.w.
- HV: 15 kV, 35 A/ 35 kV, 15 A, c.w.
- deuterium operation: neutron shield

RADI: size scaling (under construction)

- 1/2 size ITER;
- no extraction, 10 sec only



Schematic design of H^- RF source

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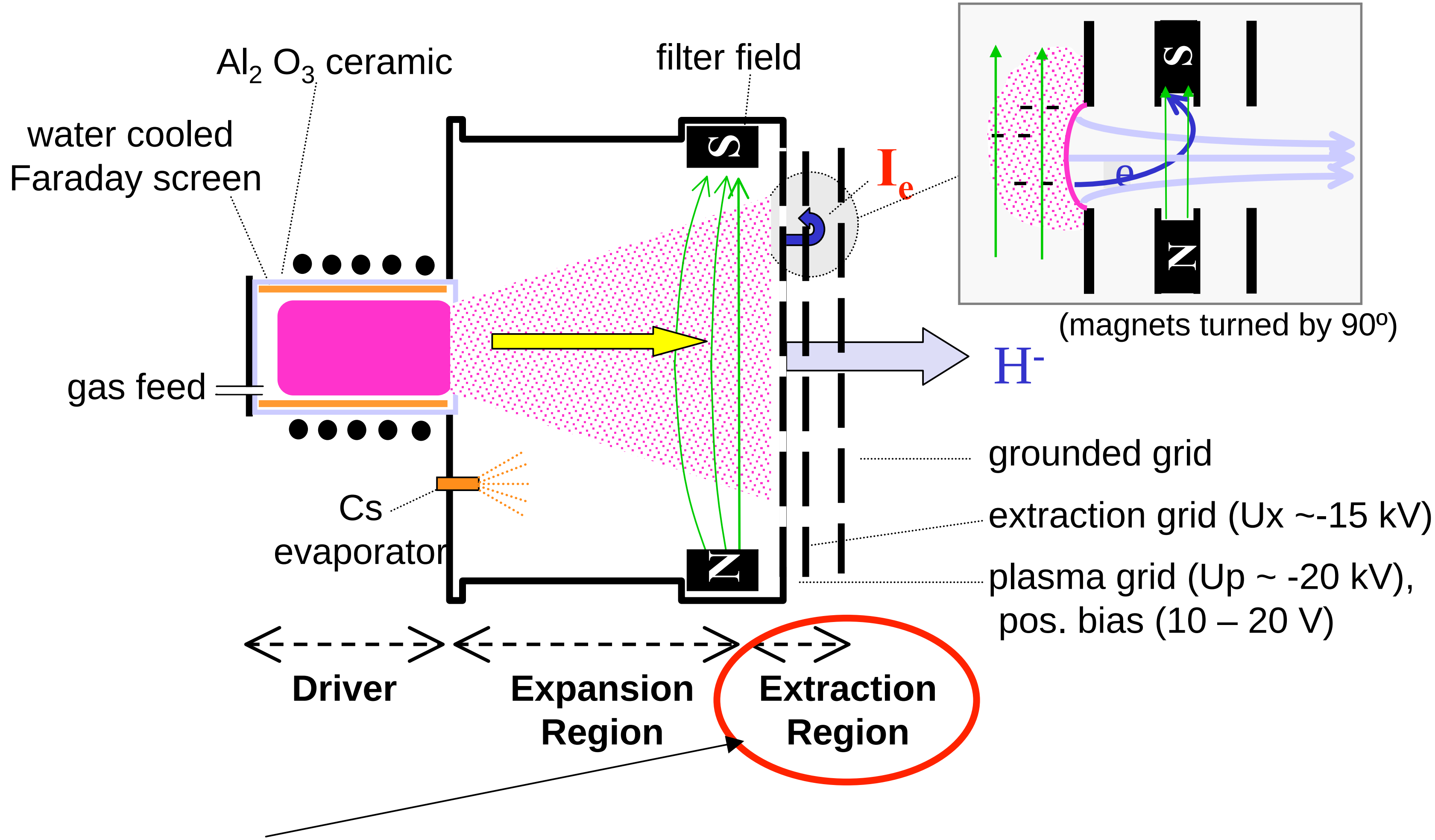

critical: power to extr. grid = I_e x $(U_p - U_x)$

==> suppression of electrons ==> strong filter field

Source configurations

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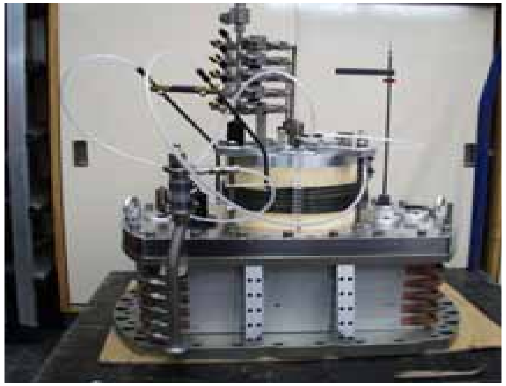
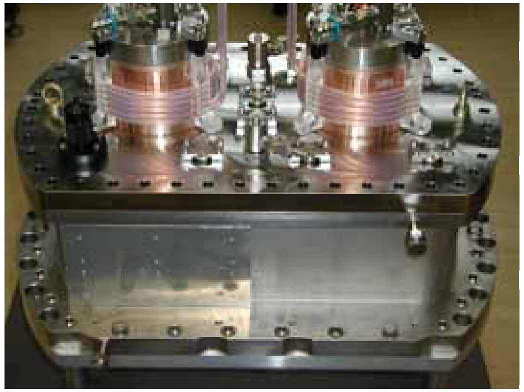
RF source is modular:
number and shape of drivers adaptable to specific needs





type 6/1:
most of H-/D-experiments

type 6/2:
two drivers; optimisation of uniformity

type 5:
single race-track driver; internal coil

Extraction geometries

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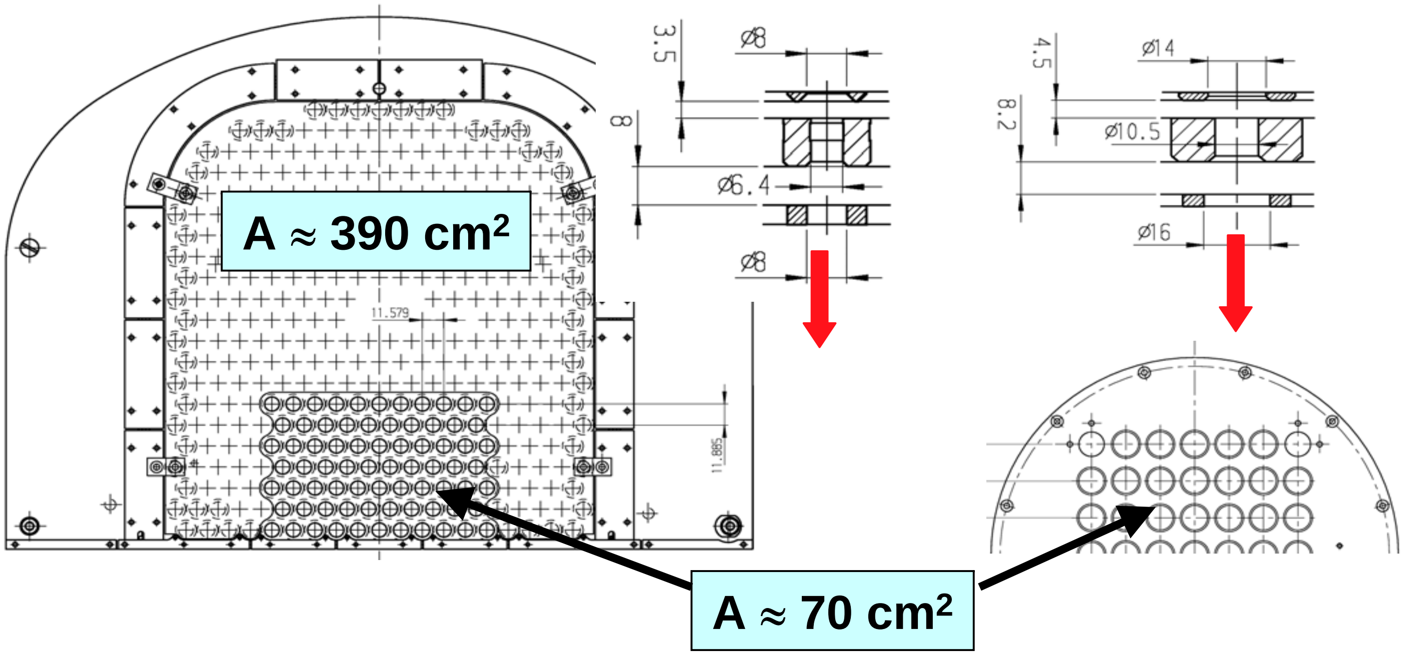
Drilling pattern and spacing of the accelerators used at IPP for negative ion extraction.



"LAG" (Large Area Grid) masked, "CEA"

Diagnostics: ion & calor. currents

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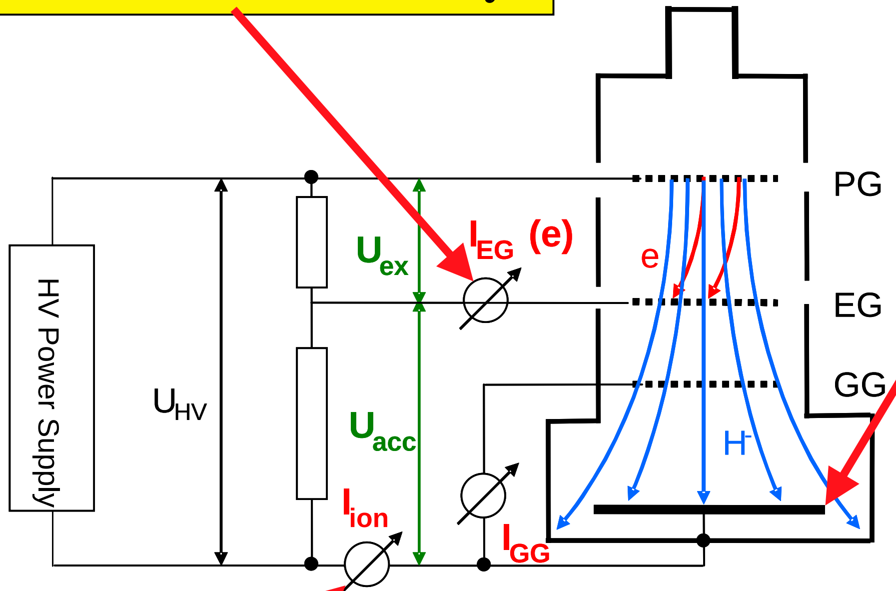
electron current density

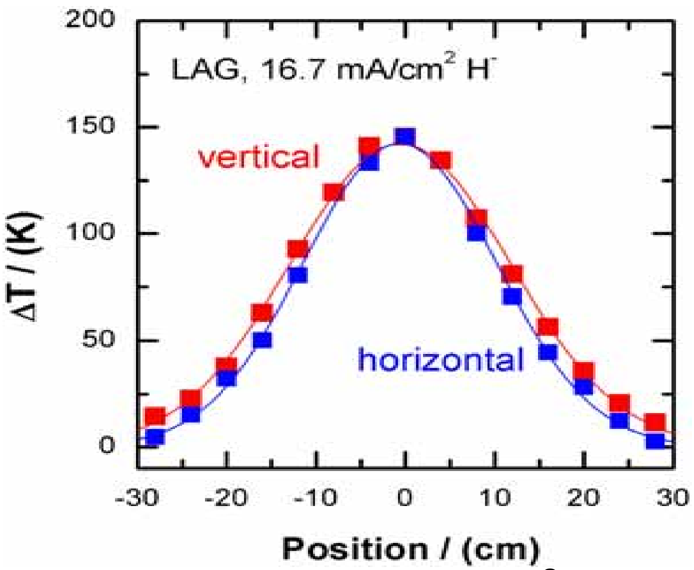
calorimetric current density



electrical ion current density

- # water calorimetry
  &
- # thermocouples (2D Gaussian fit)

$$J_{cal} + J_{GG} > 0.9 \times J_{ion}$$



2.) Exp. set-up

Diagnostics: spectroscopy

Optical emission spectroscopy :
standard diagnostic tool in all three teststands

The following parameters in the driver and the expansion region are obtained in hydrogen and deuterium discharges:

- # **H^0 density and H_2^0 density**
- # **gas temperature**
- # **T_e and n_e by using admixture of He &Ar**
- # **presence of impurities (oxygen, water, copper, …)**
- # **Cs- and Cs^+ -densities and fluxes**
- # **H^- -densities**

………

3.) Results

Low pressure issue

\# plasma flow

==> pressure gradient Δp

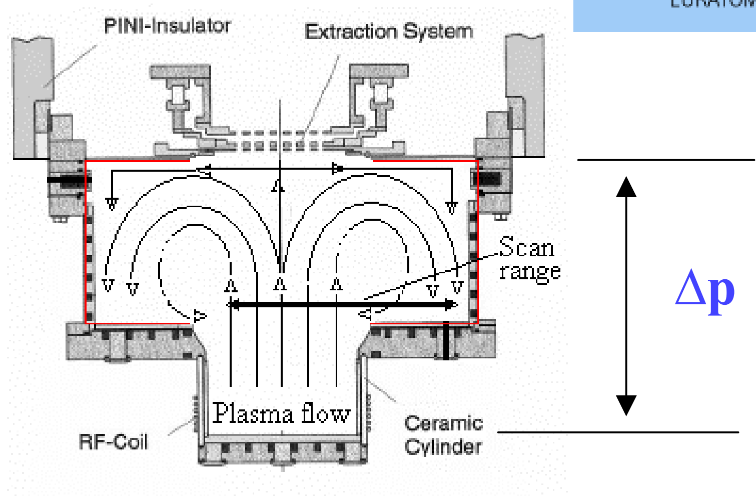
\# driver requires $p > 0.1$ Pa

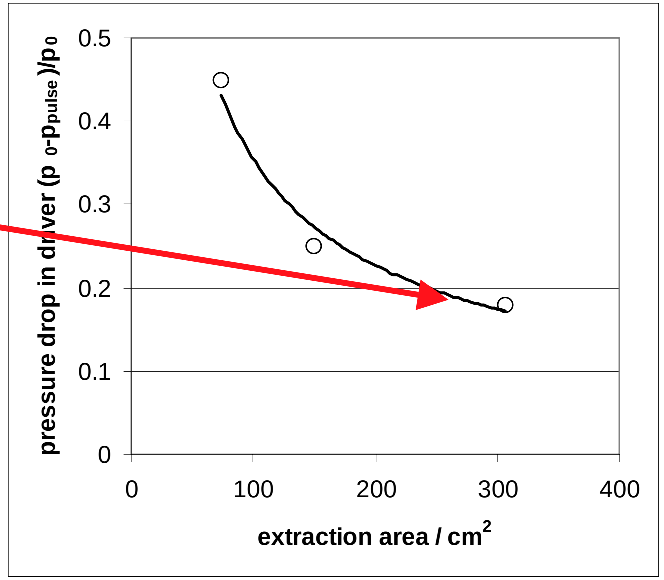
\# source filling pressure

$p_0 > 0.1 \text{ Pa} + \Delta p$

\# Δp decreases with increasing extraction area

(for 300 cm²: $\Delta p / p_0 < 0.2$)





==> for large extraction areas low pressure issue disappears

3.) Results

H^-- yields, LAG, ≤ 0.4 Pa, ≥100 kW

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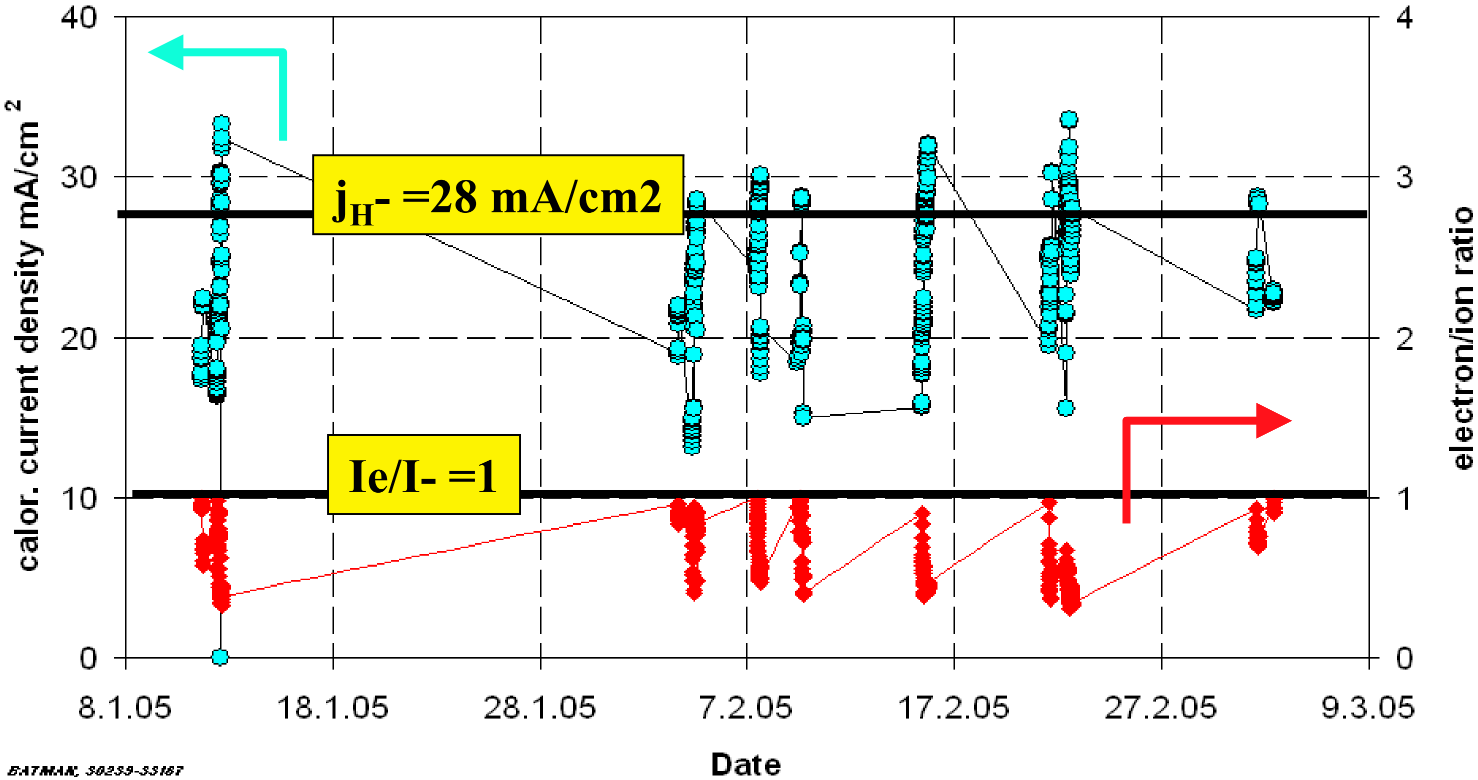
j_{H^-} > 28 mA/cm² at Ie/I- < 1 achieved reproducibly

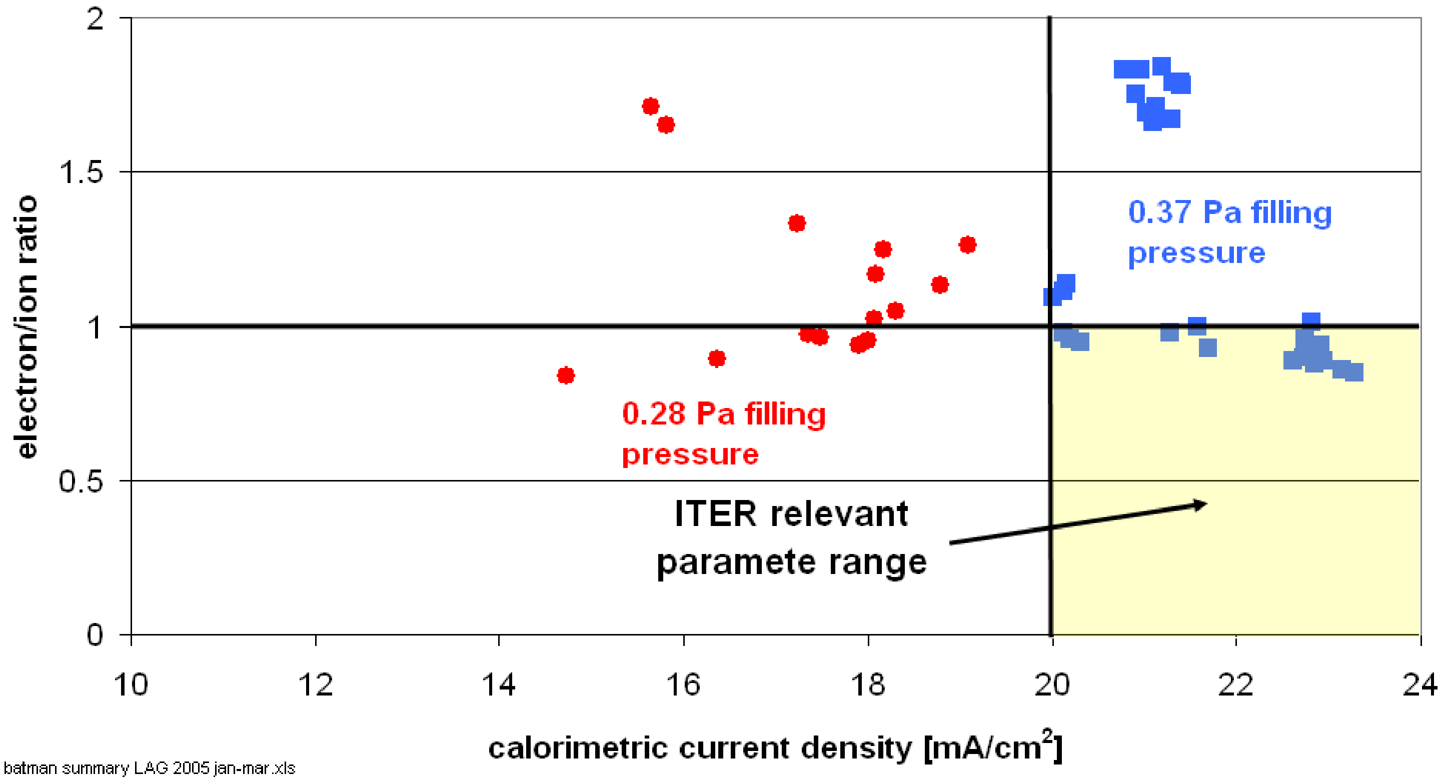


3.) Results

D^-- yields, LAG, ≥100 kW

$j_{D^-} > 20$ mA/cm^2 at Ie/I- < 1 achieved reproducibly

(but is more difficult because e- suppression requires higher filter B than with H-)



3.) Results

Reproducibility of D- yields

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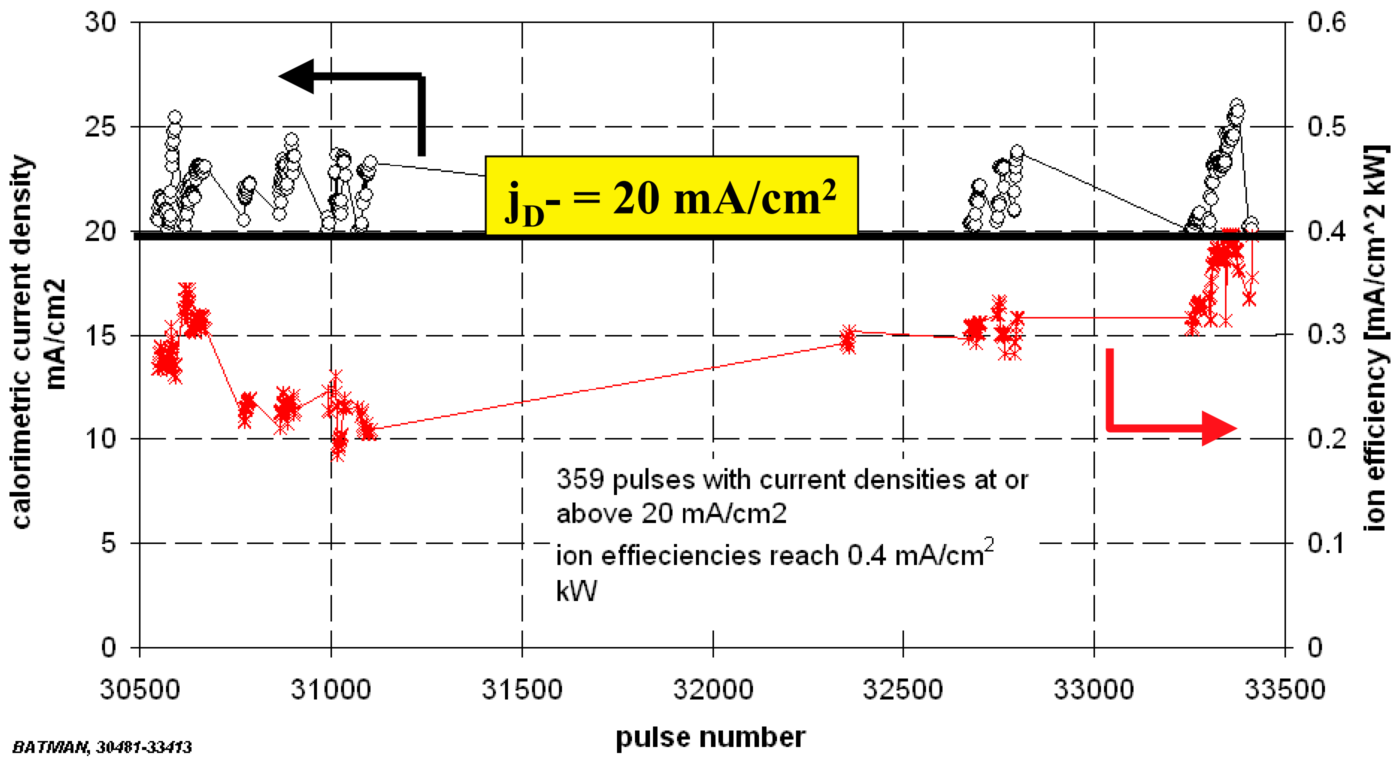

reliable & reproducible operation over 2 months (Jan-March 05)

current density for deuterium is limited by the power deposited by the co-extracted electrons on the extraction electrode

a better electron suppression would allow higher D^- currents

3.) Results

Improvements 2004 ==> 2005

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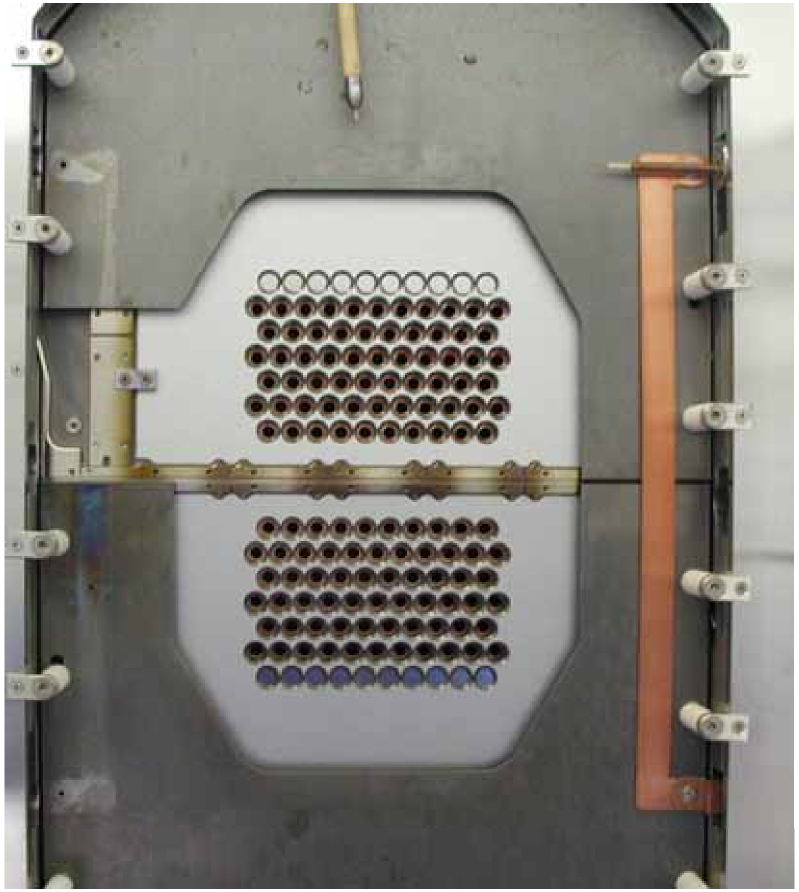
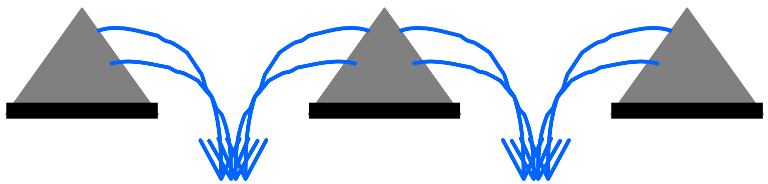


„better“ Cs distribution on surfaces

new grid mask with chamfered holes



3.) Results

Improvement 2004 ==> 2005

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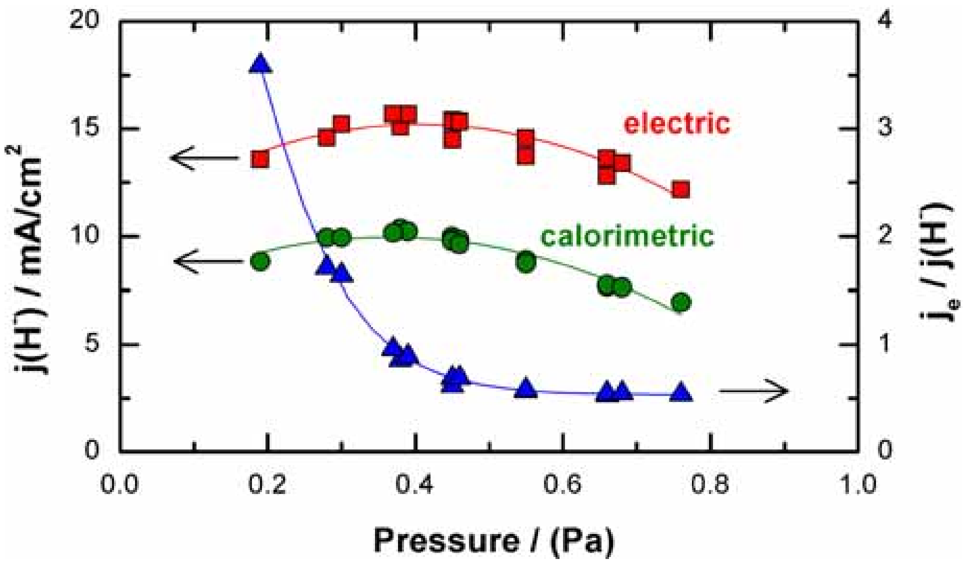
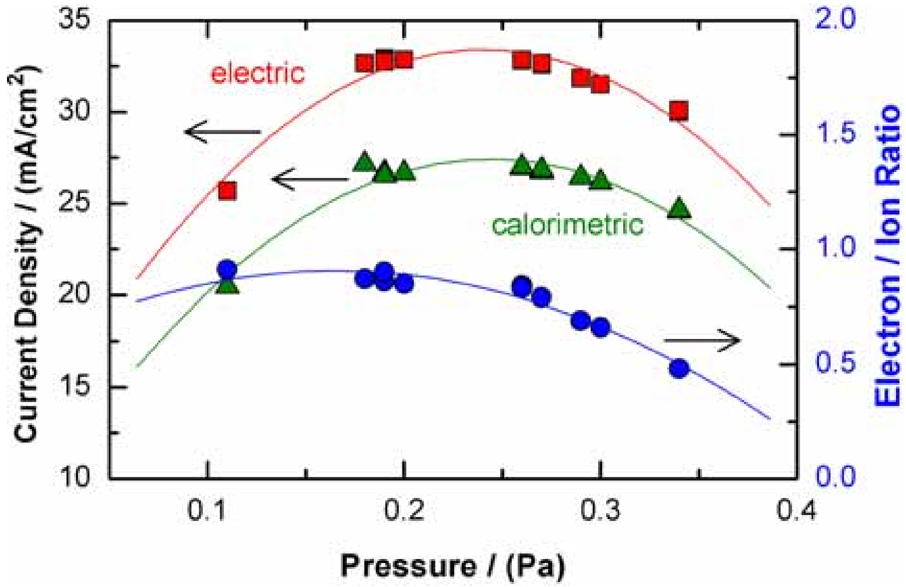
2004



2005



#	**H- /D- yields are 30% higher**
#	**weak pressure dependence 0.2 -.35 Pa**
#	**Ie / I- lower in particular at low pressure**

3.) Results

Improvement 2004 ==> 2005

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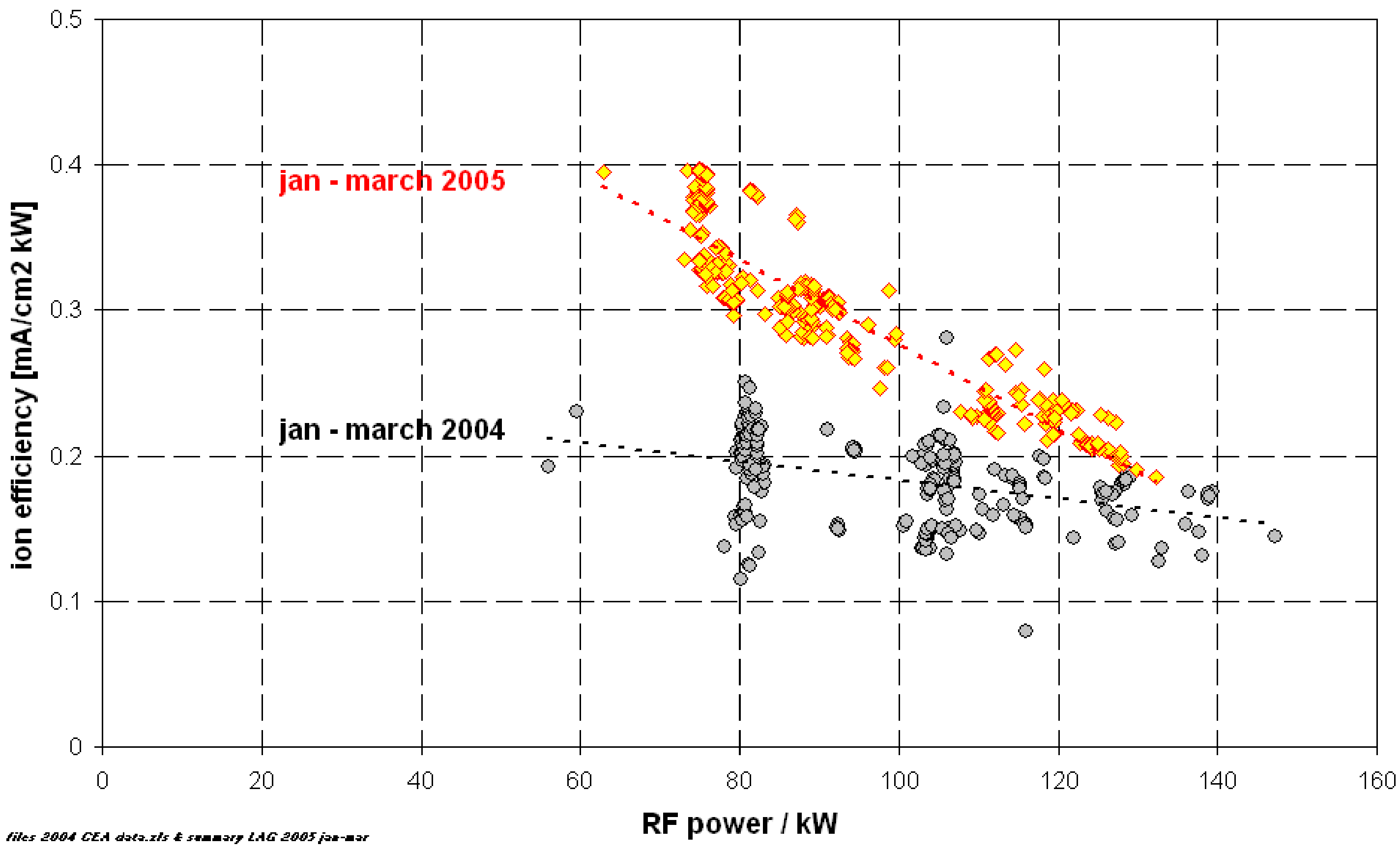
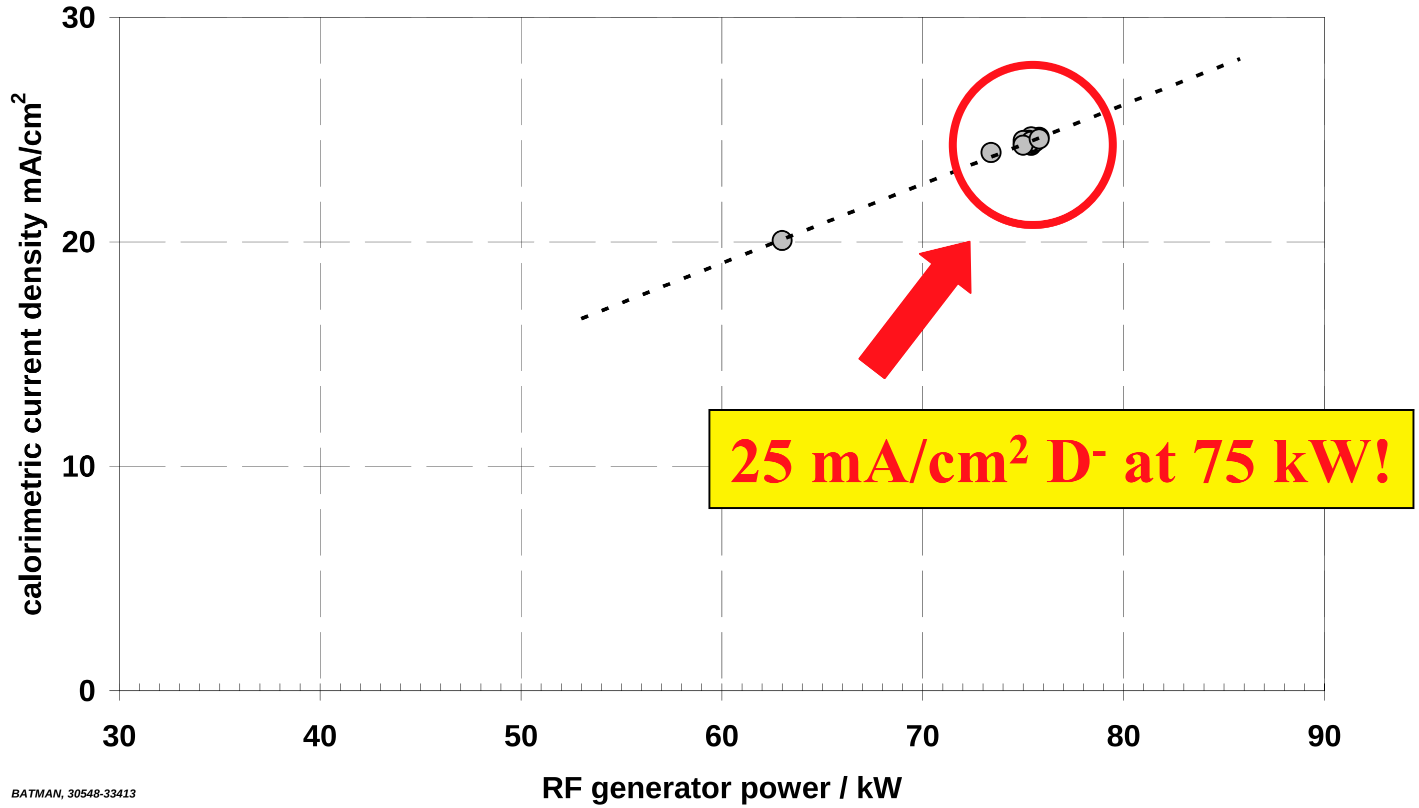
Another figure of merit for improved performance:
Increased efficiency = j_{H^-} / RF power



Improvement in 2005

D- shots at highest source efficiency:



RF power is NOT the limitation to the yield, but electron suppression
==> lots of margin for the RF source

Comparison H^- / D^-

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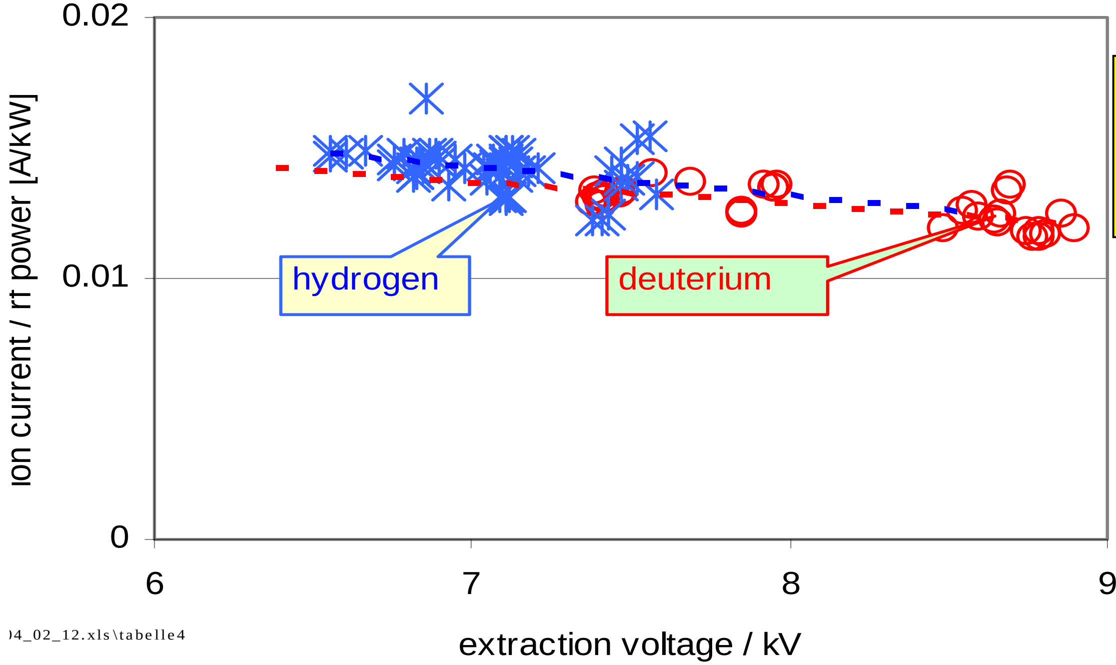

for given RF power:
same yield in H- and D-

D- requires higher (x1.4) extr. voltage U_x

power limit on extr. grid: $I_e \times U_x = const$

==> for given I_e / I_{D}-: lower I_D-

3.) Results

Increase in extraction area

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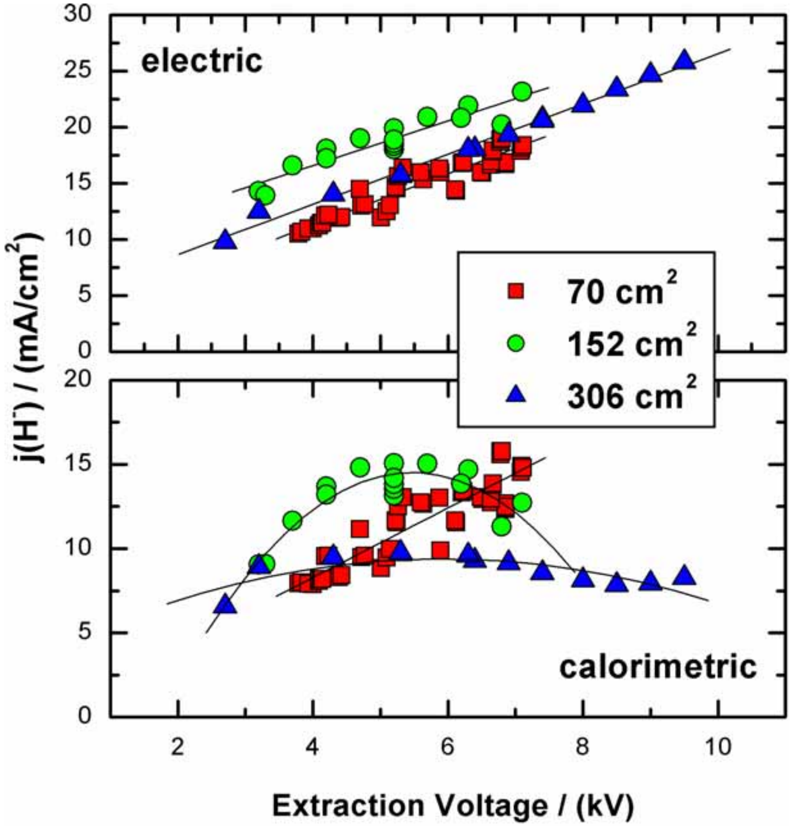

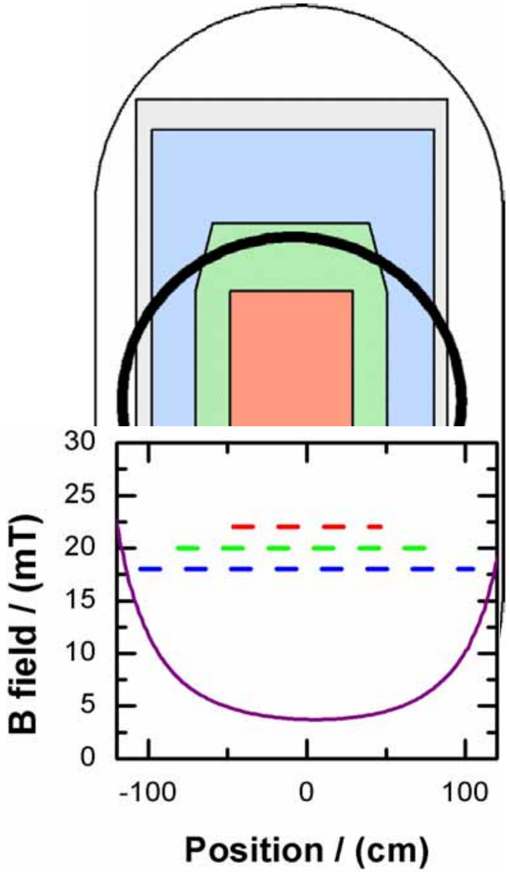

no adverse effect on electrically measured ion current density
calorimetric signal deteriorates for large width: effect of B!

3.) Results

How much do we understand?

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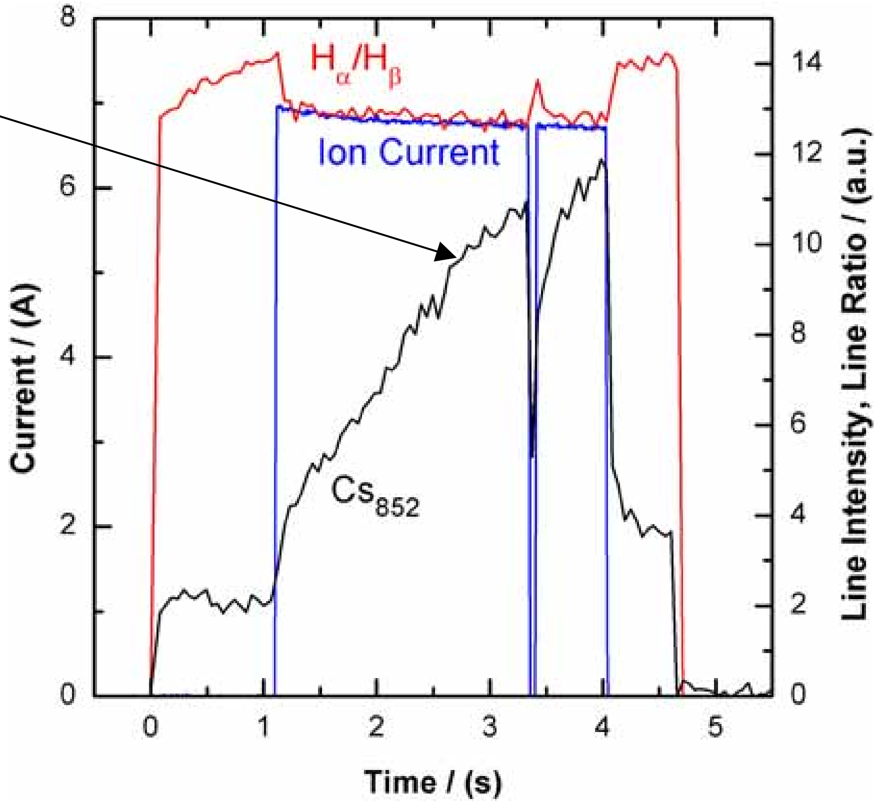
dominant process:
surface, not volume

dominant primary species:
H^0 not H_x^+
(more experiments to be done:
biased mesh, variation B-field)

adequate distribution of Cs
on grid surface is essential
requires control of
Cs inventory
(temperature control
of oven, grid , body)

(U. Fantz):



modelling ongoing:
volume production, extraction, surface production

3.) Results

ITER requirements vs. actual RF source data

	ITER	IPP NNBI RF-Source
Extracted Current Density	20 mA/cm² D^- 28 mA/cm² H^-	25 mA/cm² D^- 33 mA/cm² H^-
Source Pressure	0.3 Pa	0.3 Pa
Electron Content (j_e/j_{H^-})	1	< 1 (PG bias, filter)
Source Dimension	1.5 x 0.6 m²	0.32 x 0.59 m²
Extraction Area	2000 cm²	< 300 cm²
Uniformity	± 10%	t.b.d.
Pulse Length	3600 s	< 20 s (tech. limitations)

(Design integration into the ITER injector is progressing: collab. Padua)

RF source design for ITER

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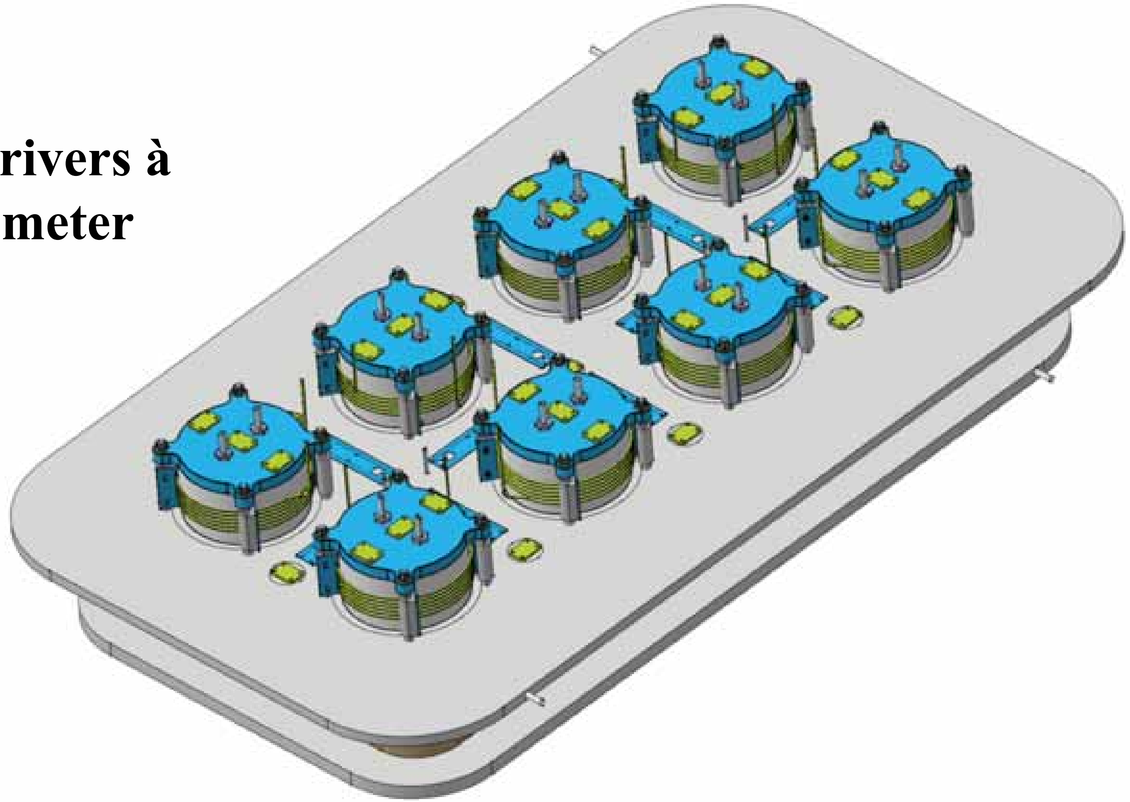
Diego Marcuzzi, RFX

8 circular drivers à 240 mm diameter



4.) Future

Long pulse operation

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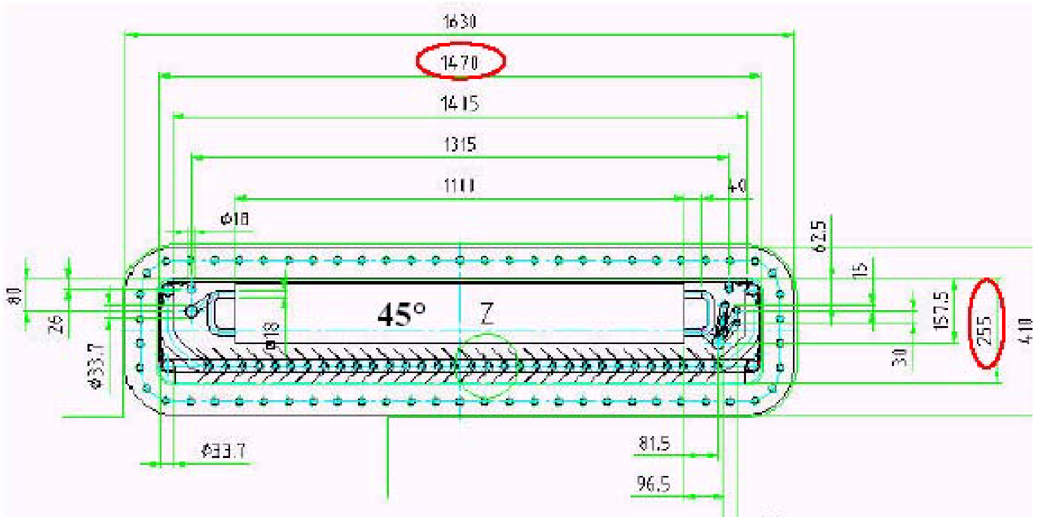
technical prerequesites:

\# 2 cryo sorption pumps
800.000 l/s; collaboration FZK
(being commissioned)

\# HV power supply
15 kV, 35 A, c.w. (extr.)
35 kV, 15 A, c.w. (accel.)
(operational)

\# RF power supply
1 MHz, 180 kW, c.w.
(operational)

\# Neutron shielding
(operational)



Flanschöffnung: 1485mm * 265mm

4.) Future

Long pulse (20 s)

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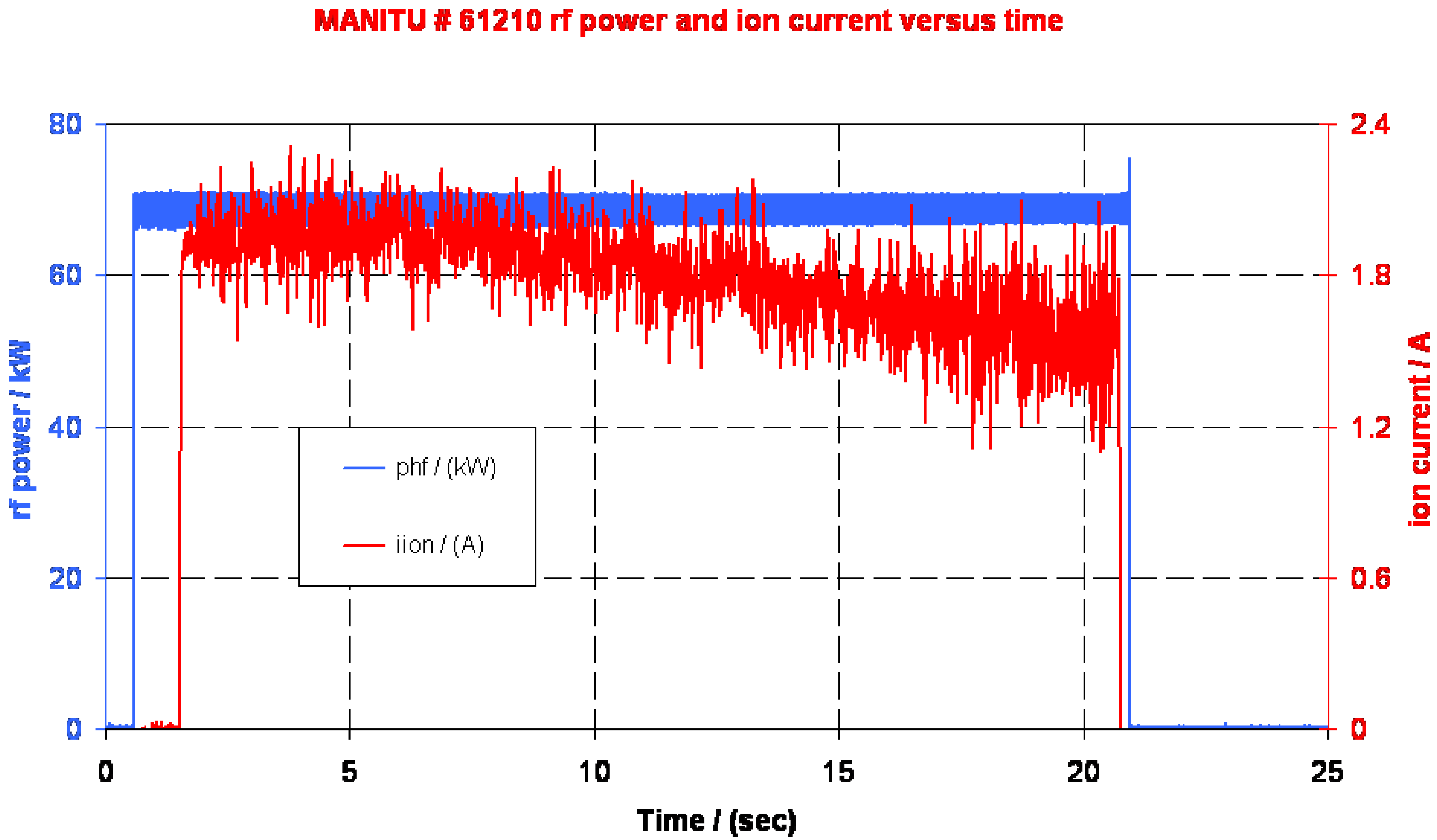

4.) Future

1/2- size ITER source

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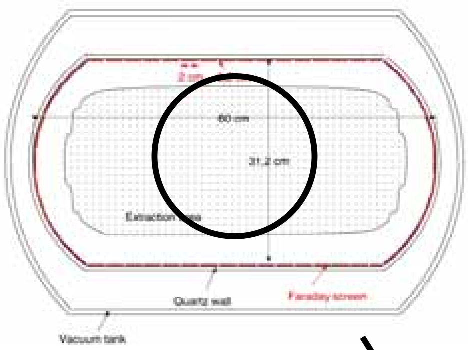
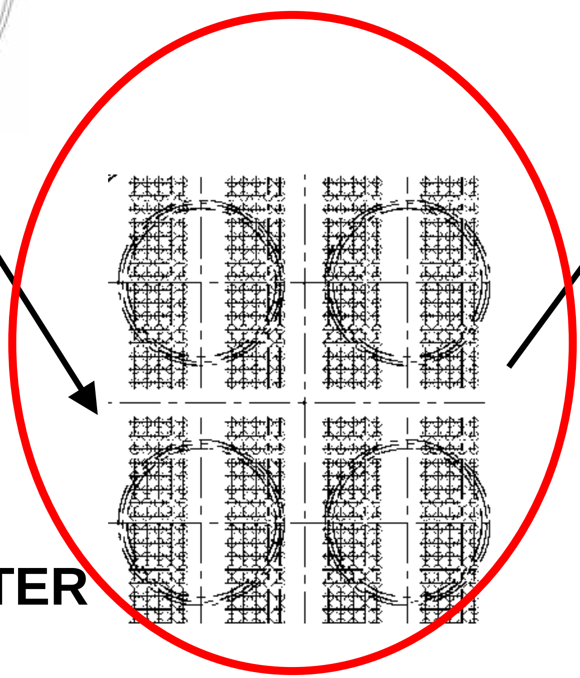
is the main step from present size to ITER size

Extraction area: 390 cm^2



PINI

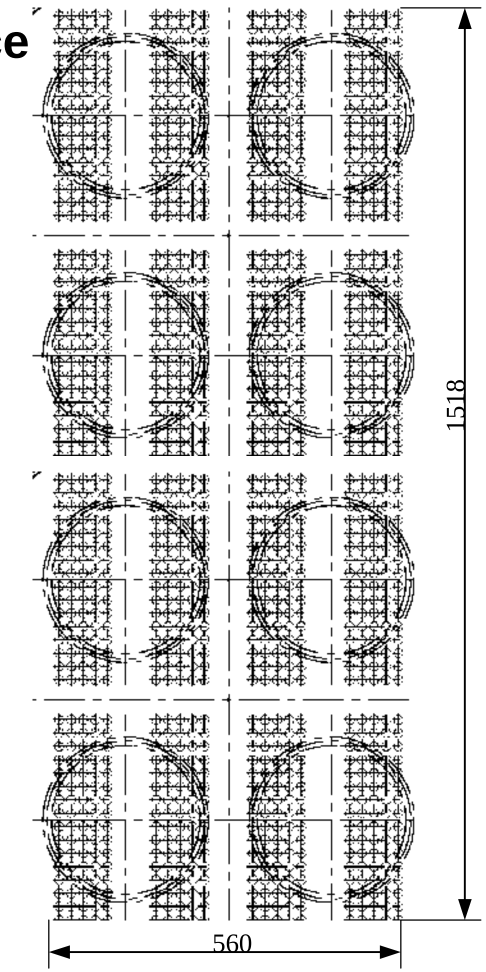
intermediate step



1/2 size ITER source

Extraction area: 1280 cm^2

full size ITER source



4.) Future

1/2- size ITER source

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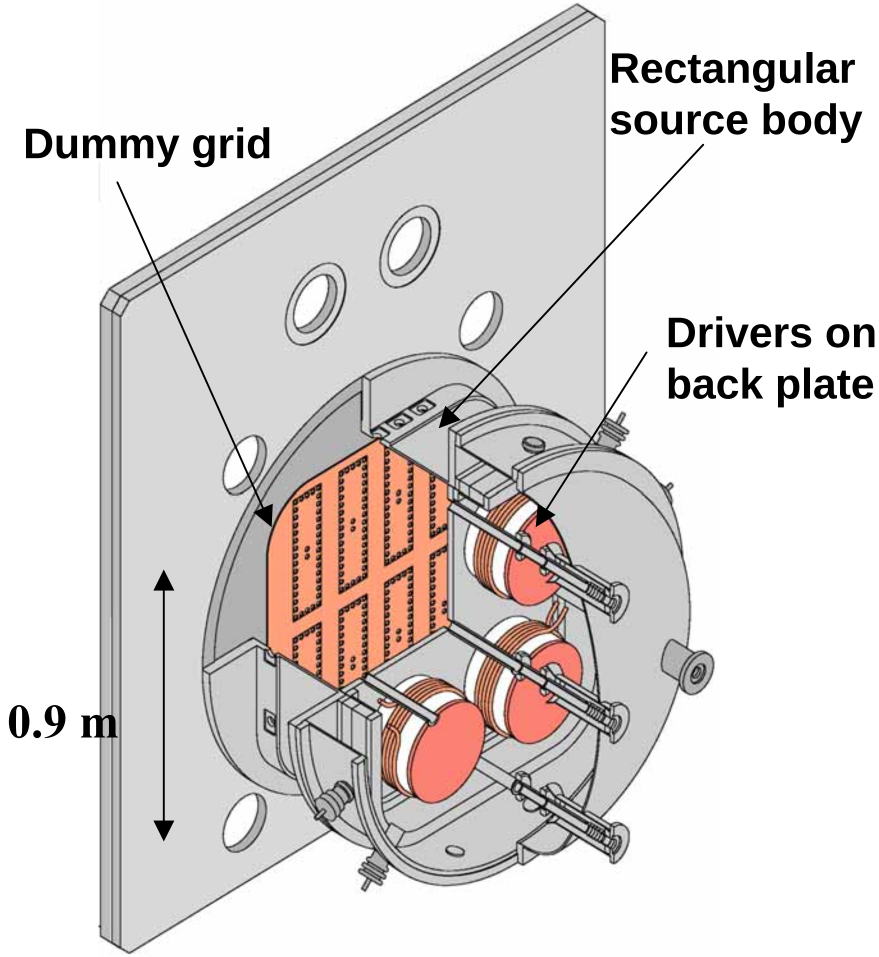
Scope:

- determine number, size, arrangement of drivers
- optimise operation of multi-driver Rf generators and matching
- optimise H- uniformity



constraint: minimise effort

- no extraction, 10 sec only,
- but with Cs, D_2 etc.

design parameters:

- 0.9 x 0.8 m^2 body
- four circular drivers
- 2 rf generators à 180 kW, 1MHz

SUMMARY

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Current densities of H- and D- exceed the ITER target, at the required e-/ion ratio and equivalent filling pressure

D- yield is limited by electron power on extr. grid: electron suppression requires stronger filter field than in H-

Pressure issue will disappear with larger extraction areas

Long pulse operation has started; size scaling experiments (half-size ITER source) are in preparation

In essence an integrated development programme is being carried out indicating that the ITER targets are within reach for the RF source

SUMMARY (cont´d)

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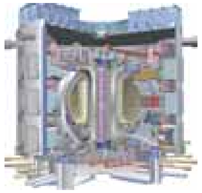
Co-workers (scientific staff):

H.D.Falter, M.Bandyopadhyay, S. Christ, A.Encheva, U.Fantz, P.Franzen, M.Fröschle, B.Heinemann, D.Holtum, M.Kick, W.Kraus, A. Lorenz, P.McNeely, R.Riedl, A.Tanga, R.Wilhelm, D.Wünderlich

Collaborations:

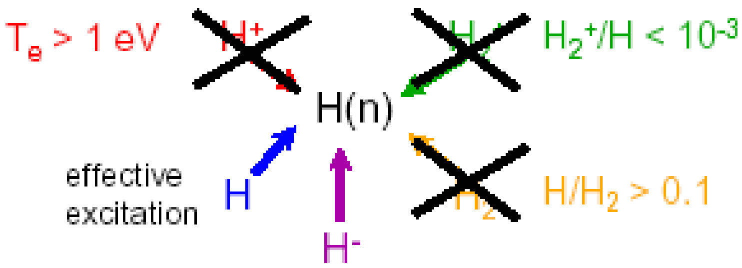
FZK Karlsruhe, Germany,
University of Augsburg, Germany
CEA Cadarache, France,
University of Lublin, Poland
University of Charkov, Ukrainia,
University of Sofia, Bulgaria
ENEA RFX, Padua, Italy
UKAEA, Culham, England
EFDA, Garching, Germany



H- volume density monitored by Balmer line ratios

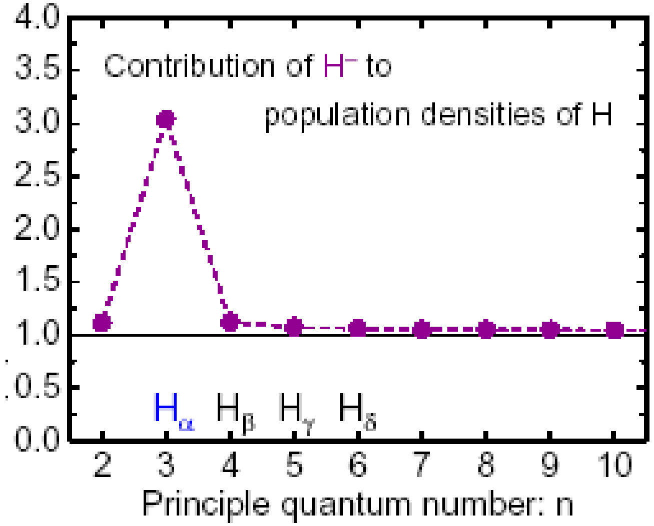
(U. Fantz)

Population mechanisms for H — require — Population modelling

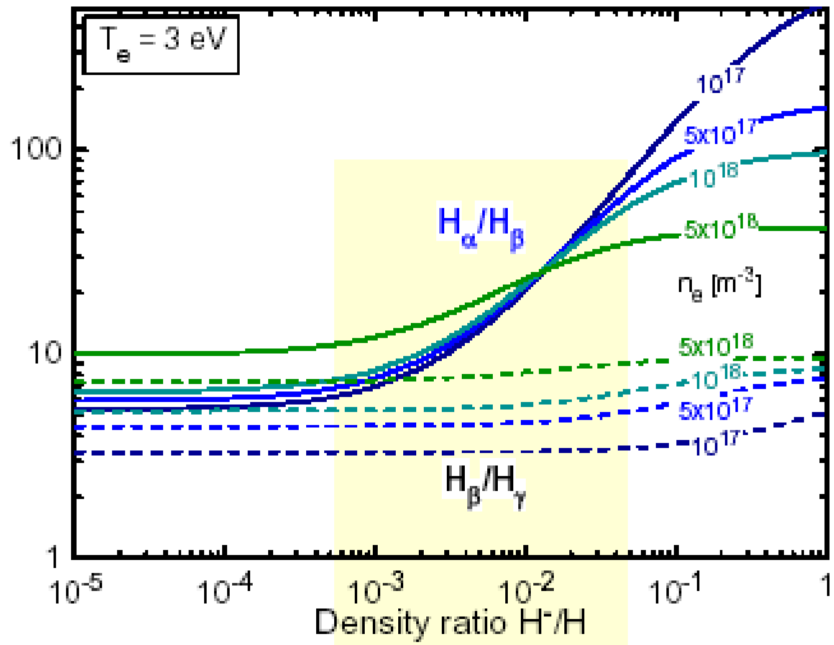


mutual neutralisation

$H^+ + H^- \rightarrow H(n) + H$

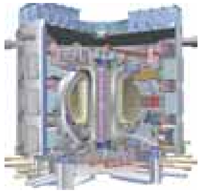


Line ratios depend on n_e, T_e and H^-/H

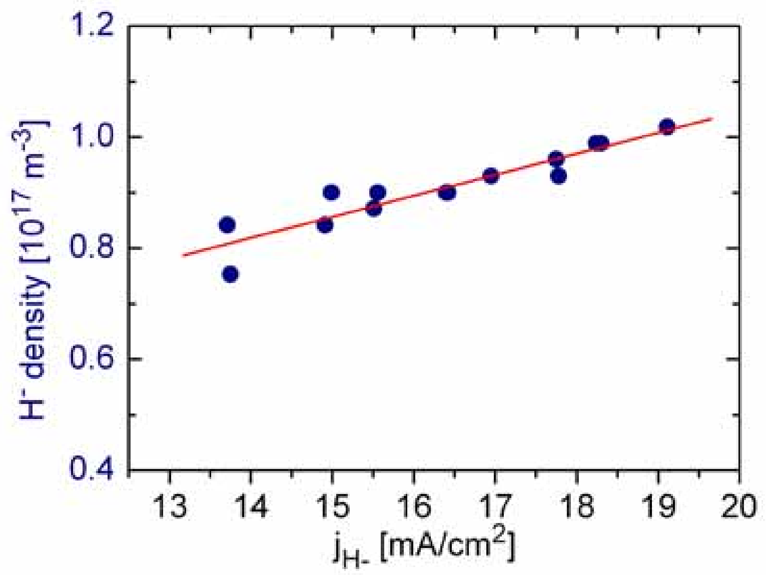


H_α/H_β depends on H^-

H_β/H_γ reflects n_e and T_e



Attempts of "understanding": modelling and diagnostics



Optical Emission Spectroscopy (U. Fantz):

Innovative measurement of H- density

from H_α/H_β ratio:

(mutual neutralization $H^- + H^+ \rightarrow H(n) + H$

populates predominantly n = 3 (H_a)

needs knowledge of plasma parameters

and model calculation)

==> allows correlation of

H- density in the plasma <====> H- current density in the beam !

Experiment in rough agreement with 0-D calculation (R. Wilhelm)

$$j^- = e \cdot f \cdot A \cdot n_{H^-} \cdot \frac{v_{H^-}}{4}$$

f = extraction probability $\Gamma_{H-} \rightarrow j^-$ (= 0,5...1)
A= "collection factor" (= 1 ...3 → ~ 1/T; T=grid transparency)
v_{H-} = mean H^--velocity (~ $1\cdot10^6$ cm/s at 1eV)
assume: f=1 and A=3:

$j^- = 20\ mA/cm^2$ ==> $n_{H-} = 10^{11}\ cm^{-3}$ (for $E_{H^-} = 0.8$ eV)

Low pressure

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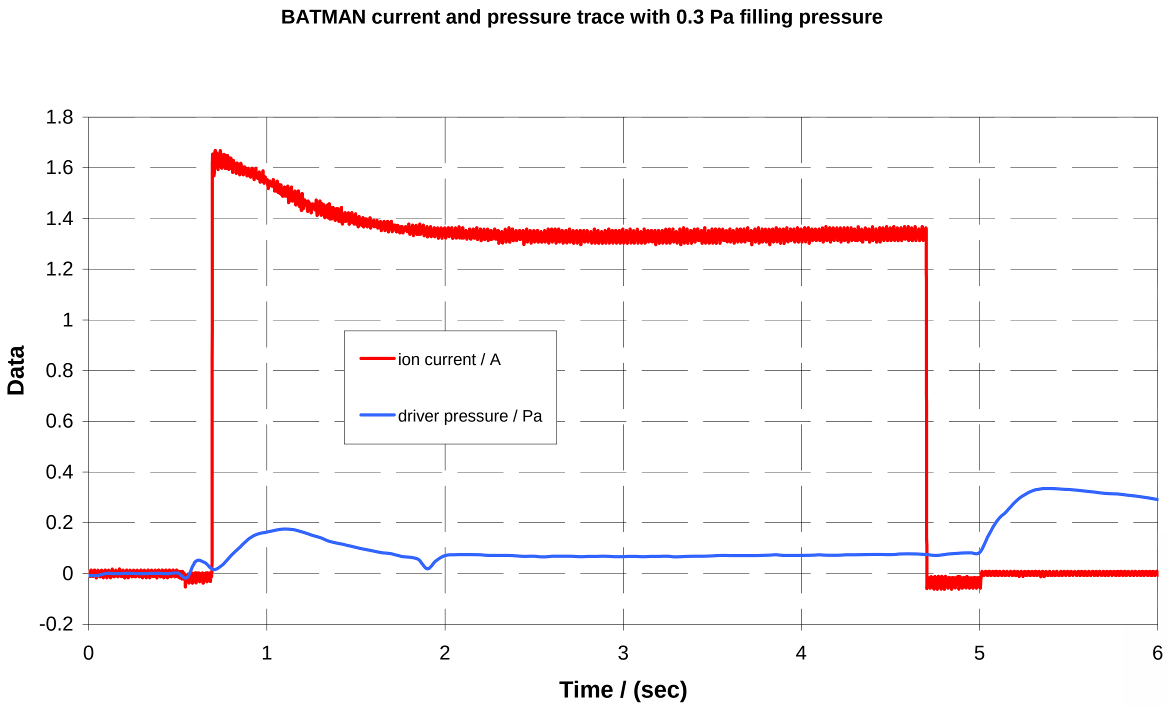

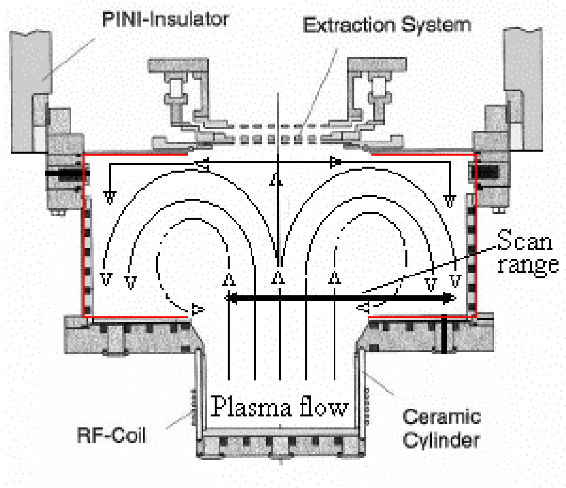

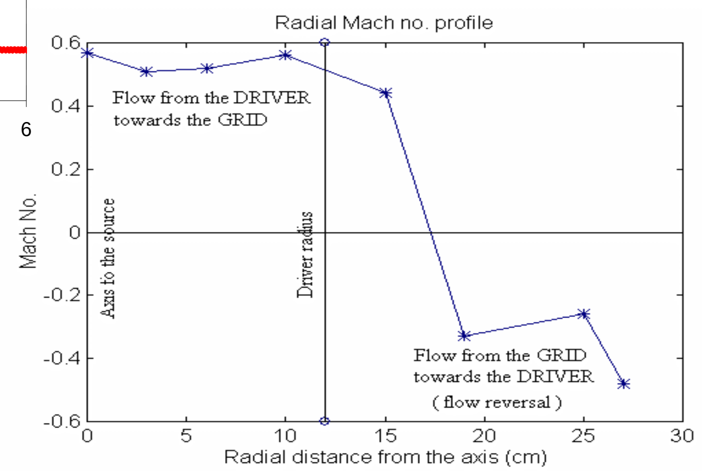

Operation with low filling pressure is possible

Improvements (w.r.t. 2003/2004)

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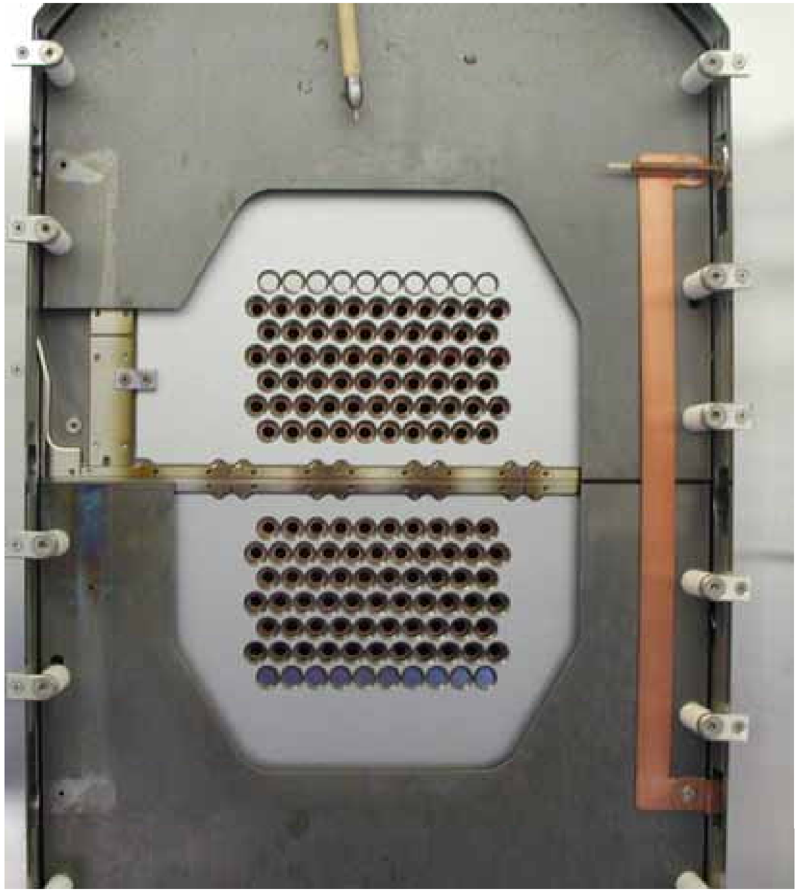
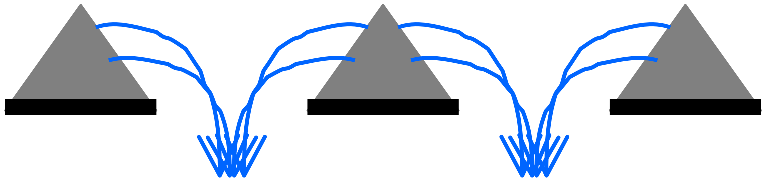


„better“ Cs distribution on surfaces

new grid mask with chamfered holes



==> increases effective converter area in immediate vicinity of ex hole

==> increases solid angle for incoming H^0

==> improves „starting angles“ of H^- leaving grid surface

Modelling

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Modelling of ion production and transport

- **3-D Monte-Carlo codes (PhD thesis by M. Bandyopadhyay)**
- **driver and expansion region**
- **up to now: volume processes only**
- **improvement: surface processes, in particular Cs (D. Wünderlich)**

Modelling of ion production and extraction from a negative ion source

collaboration with the University of Lublin (Prof. Sielanko)

- **3D-Monte Carlo particle-in-cell program, expansion and extraction region**
- **trajectories (grid surface) with background plasma**
- **profile of the extracted ion beam**
- **distribution of walls and electrodes being hit by ions / electrons.**

Combination of both codes, physical studies and comparison with diagnostics

D. Wünderlich