Correlation H⁻ beam properties to Cs-coverage

J Lettry[1], A Vnuchenko[1], S Bertolo[1], C Mastrostefano[1], M O'Neil[1], F di Lorenzo[1], Y Coutron[1], D Steyeart[1], B Riffaud[1], J Thiboud[1], R Guida[1], K Kapusniak[1], C Charvet[1], B Teissandier[1], P Moyret[1], F Roncarolo[1], S Bart Pedersen[1], M Duraffourg[1], C Vuitton[1], S Joffe[1], C Machado[1], U Fantz[2], S Mochalskyy[2], D Wunderlich[2], M Lindqvist[2], N den Harder[2], S Briefi[2], A Hurlbatt[2], T Kalvas[3], T Minea[4], A Revel[4]

- Operation modes of the IS03b H⁻ source of CERN's Linac4
- Cs-coverage measurements
- Asymmetries in beam profiles
- BES measurements Horizontal vs. Vertical plane

This contribution provides the experimental side of the ONIX beam formation Poster
«*H⁻ Beam formation simulation in negative ion source for CERN's Linac4 accelerator*»

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U. Fantz[2], M. Lindqvist[2], A. Revel[4], T. Minea[4]

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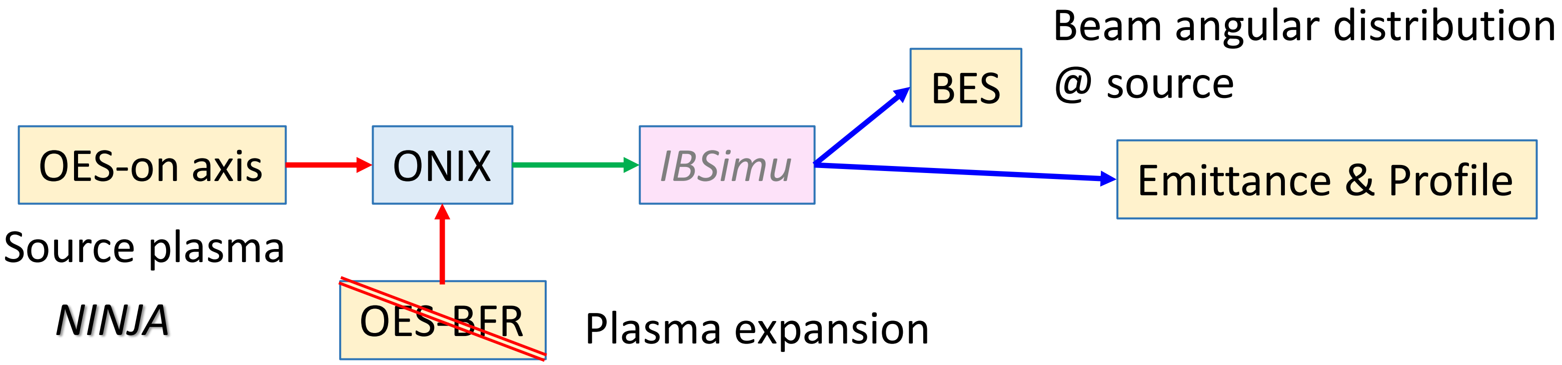
[3] Department of Physics, University of Jyväskylä, Finland
[4] Laboratoire de Physique des Gaz et des Plasmas, Orsay, France

H^- Beam formation studies : CERN, LPGP, IPP collaboration

- ONIX PIC MC & IBSimu codes
  - LPGP: T. Minea, A. Revel
  - IPP: U. Fantz, S. Mochalskyy, D. Wunderlich, M. Lindqvist, N. den Harder, A. Mimo
  - CERN: A. Vnuchenko
- OES / BES analysis
  - IPP: U. Fantz, S. Briefi, A. Hurlbatt
- Emittance- Profile-meter
  - CERN: F. Roncarolo, S. Bart Petersen, M. Duraffourg, C. Vuitton
- Test stand and prototypes, Cs coverage
  - CERN: S. Bertolo, C. Mastrostefano, M. O'Neil, F. di Lorenzo, Y. Coutron, D. Steyeart, B. Riffaud, J. Thiboud, R. Guida, K. Kapusniak, C. Charvet, P. Moyret
- *ISTS Measurement 9 Nov. – 17 Dec. 2020 & 22 Feb. – 18 Apr. 2021, Feb & July 2022*
  - CERN: A. Vnuchenko, J. Lettry

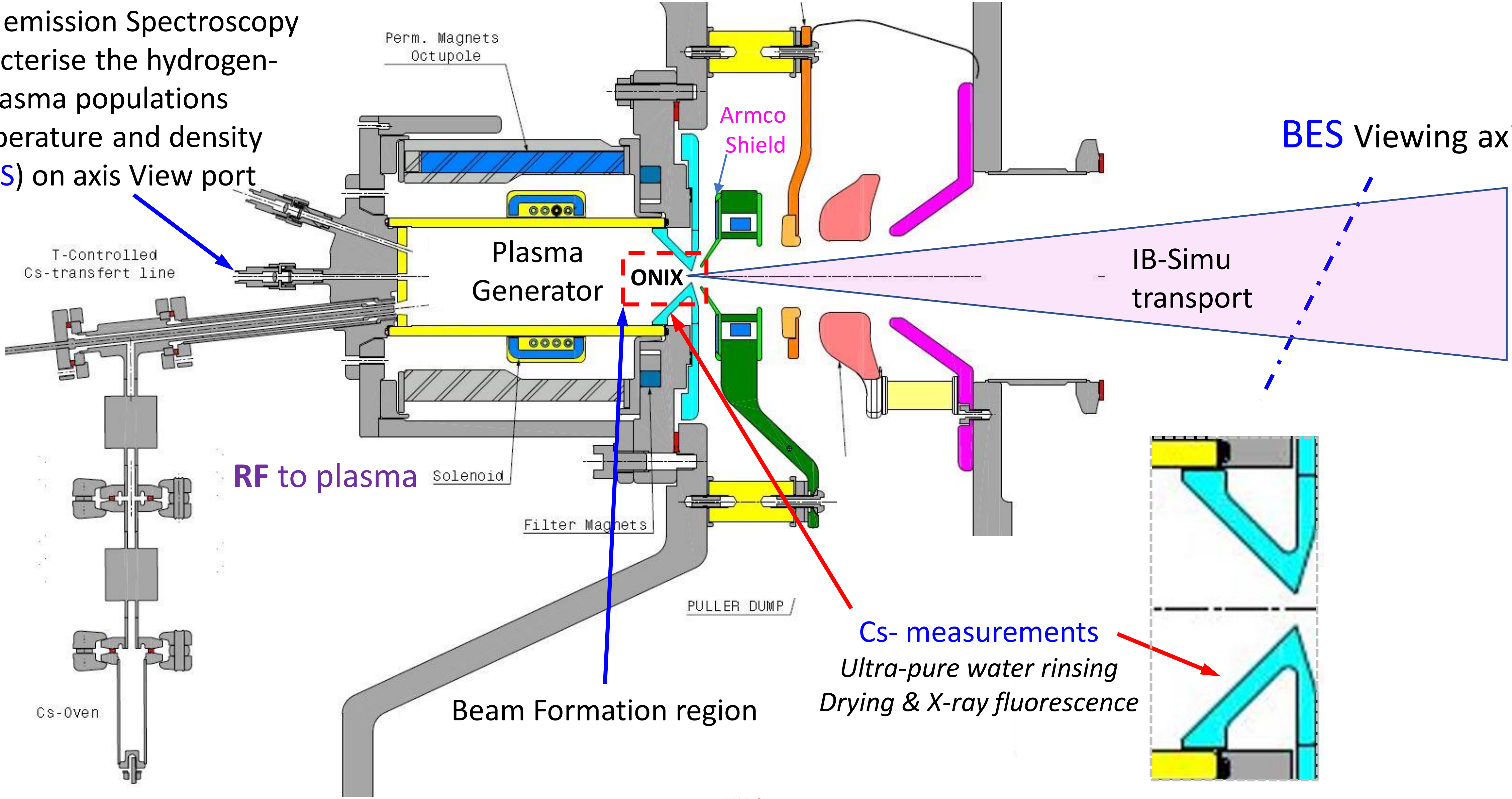


✓ H^- beam
✓ D^- Beam
✓ Protons, H_2^+, H_3^+

Vol. & Cs-Mo surf. modes

RF-ICP driven, Cs-surface H^- source L4-IS03b

Optical emission Spectroscopy
Characterise the hydrogen-plasma populations temperature and density (OES) on axis View port



IBSimu L4IS-test stand 152

Profile &

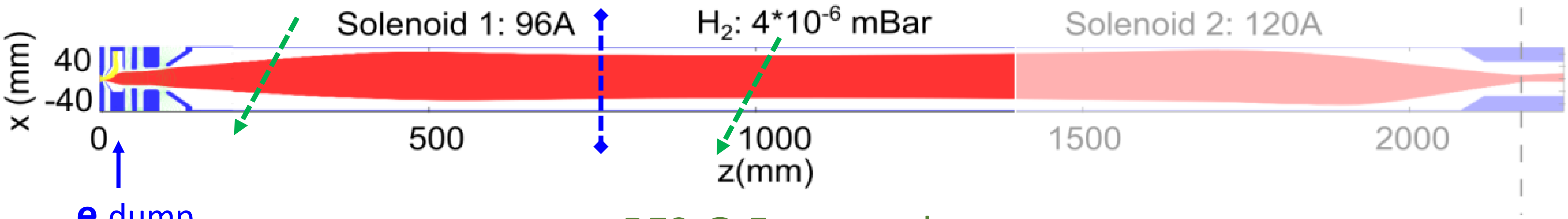
ε-meter

Slits *Grids*

H_2: 1.6 – 2 10^{-4} hPa

BES @ LEBT start

BCT



e dump current

BES @ E-meter plane

D. A. Fink, T. Kalvas, J. Lettry, Ø. Midttun, D. Noll, *H− extraction systems for CERN's Linac4 H− ion source*, Nuclear Inst. and Methods in Physics Research, A 904 (2018) 179–187.

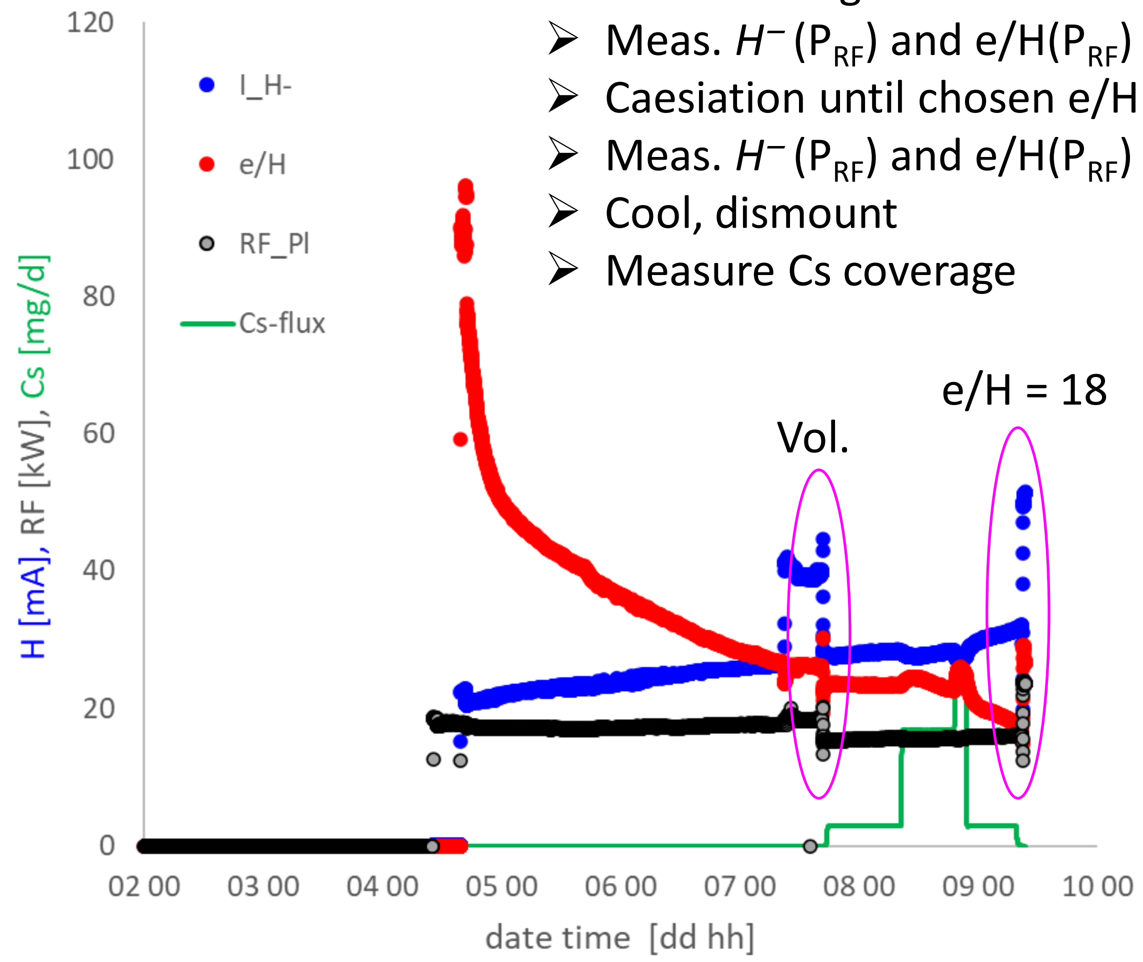
IBSimu : T. Kalvas Uni. Jyvaskyla Finland

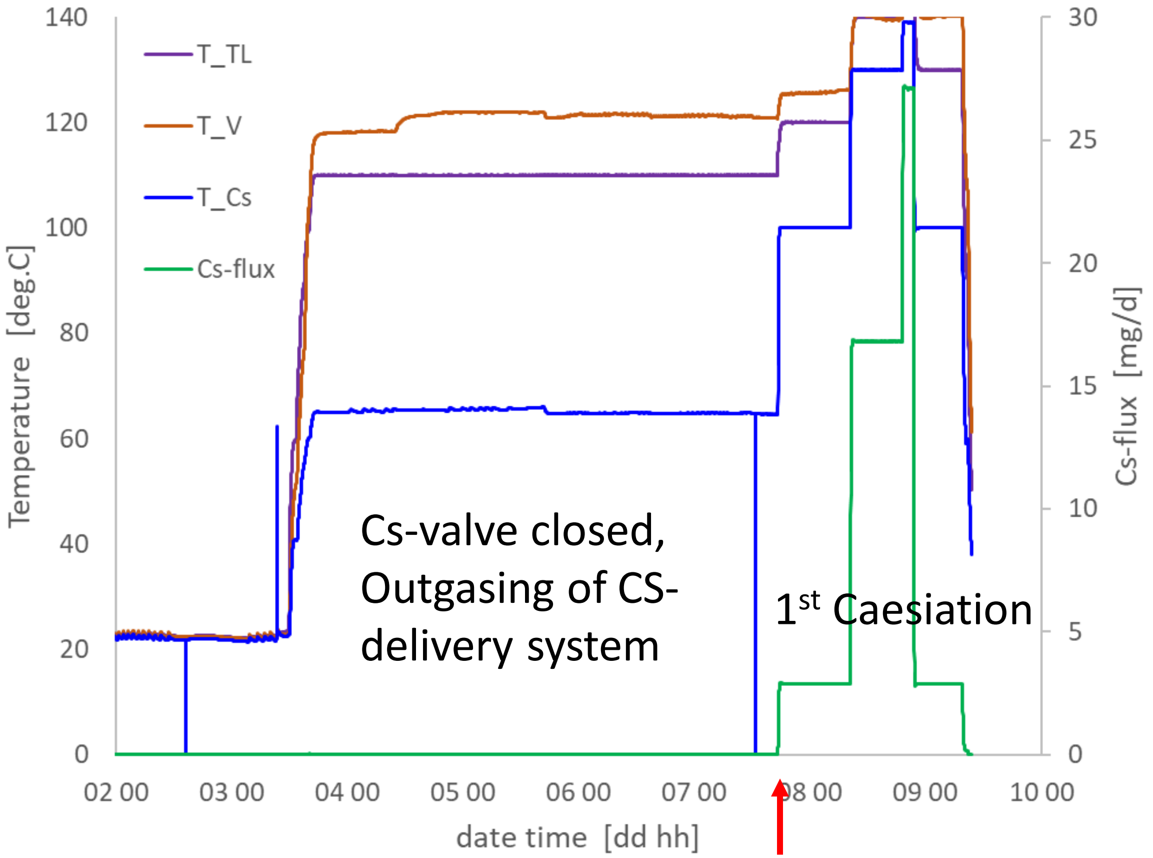
Cs-coverage test procedure

i.e. PE#1 Feb. 2-9 →

PE #	start	end	Cs mg	e/H nom	Cs mono	
1	1/2/22 11:00	7/2/22 10:00	0.00	24.50	0.00	Vol. mode
1	7/2/22 11:00	9/2/22 9:00	13.19	18.24	0.09	
2	9/2/22 14:00	14/2/22 9:00	2.69	0.95	2.50	
1	14/2/22 15:00	21/2/22 9:00	3.89	1.37	3.10	
2	21/2/22 14:00	23/2/22 9:00	2.04	1.85	0.79	
1	23/2/22 17:00	25/2/22 12:00	0.76	7.67	0.74	

- Comissioning until vol. mode
- Meas. H^-(P_{RF}) and e/H(P_{RF})
- Caesiation until chosen e/H
- Meas. H^-(P_{RF}) and e/H(P_{RF})
- Cool, dismount
- Measure Cs coverage

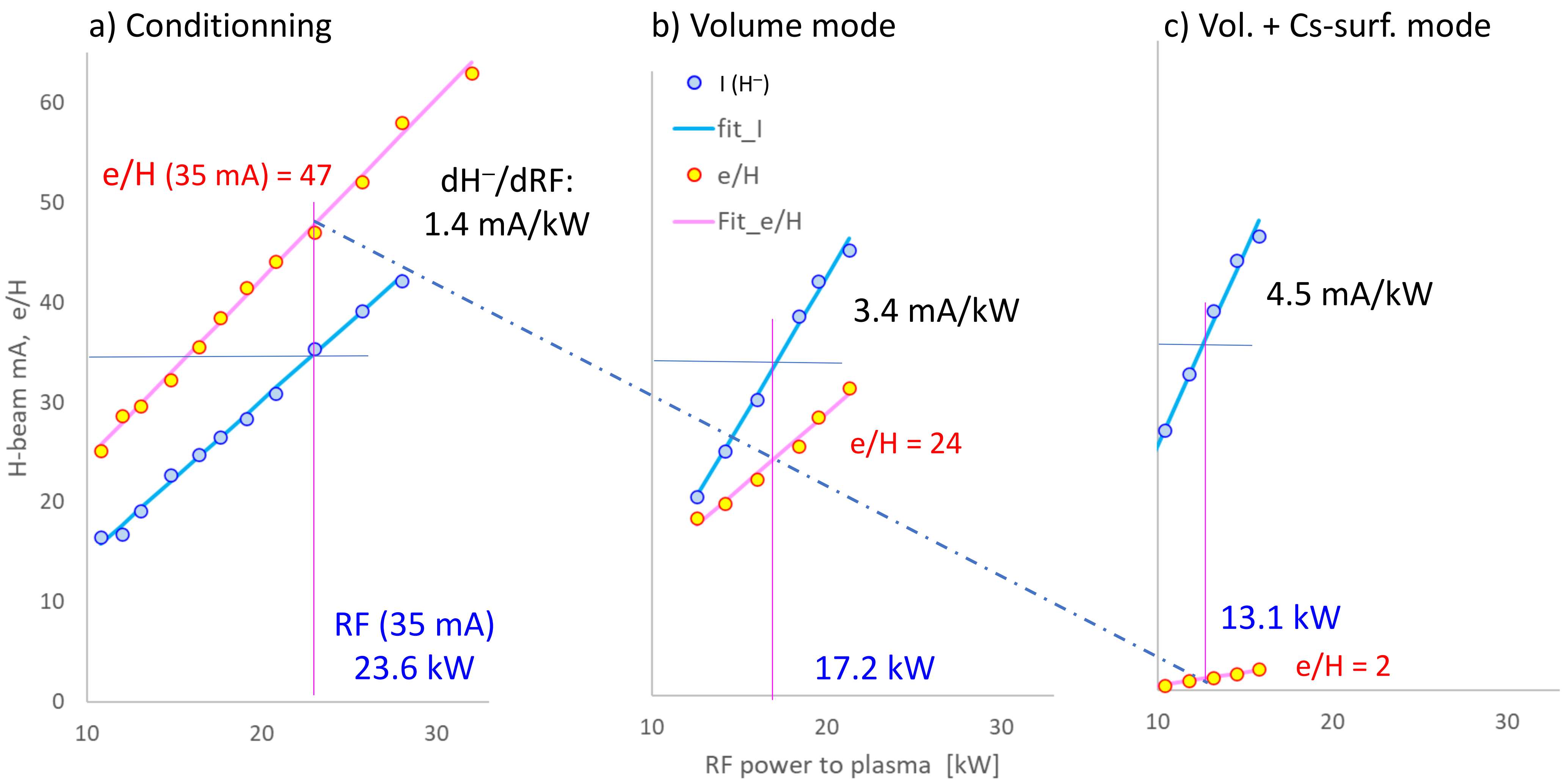


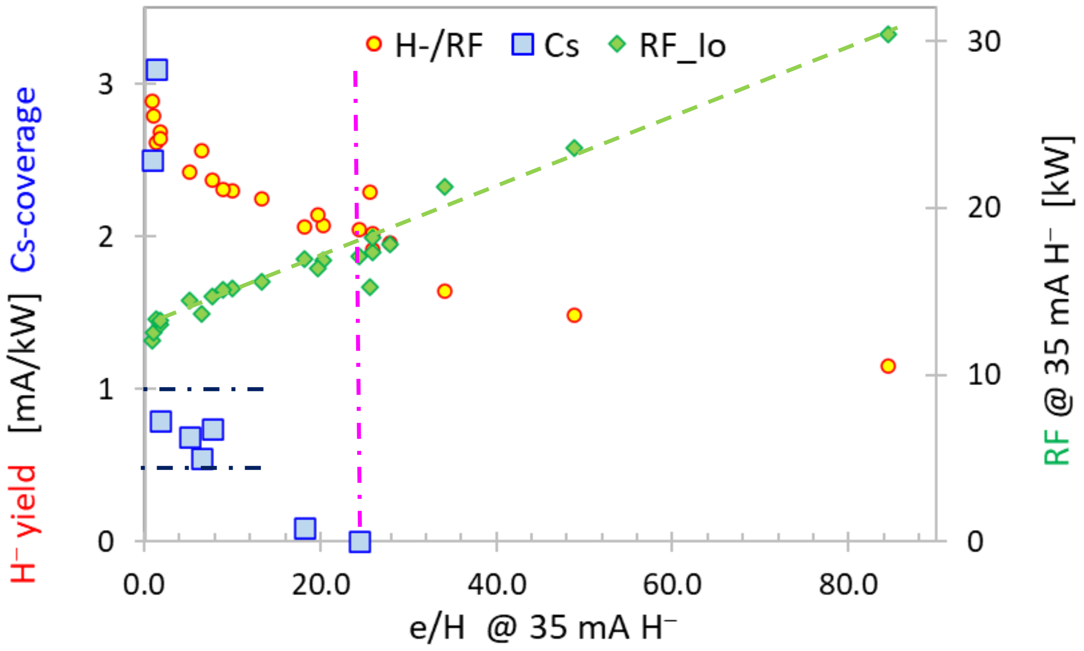


Cs-valve opening

IS03b-modes @ L4 operation (H⁻ beam intensity: 35 mA)

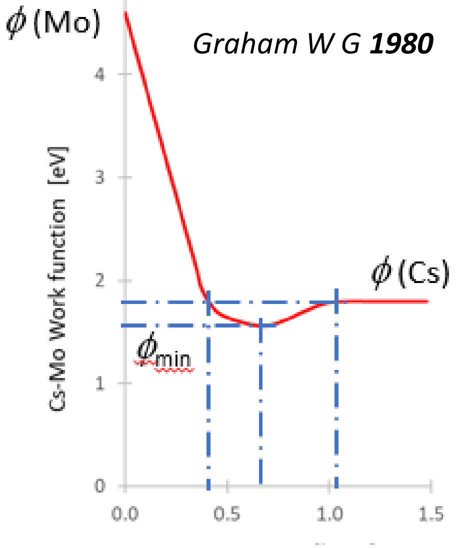
IS03b, PE ϕ7.5 mm

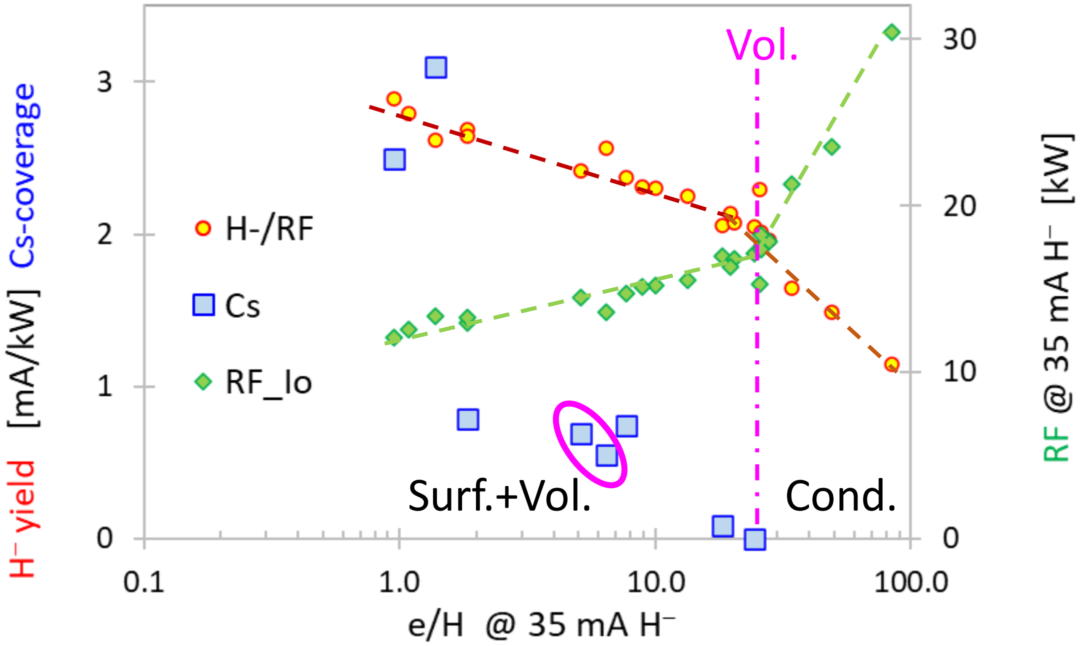


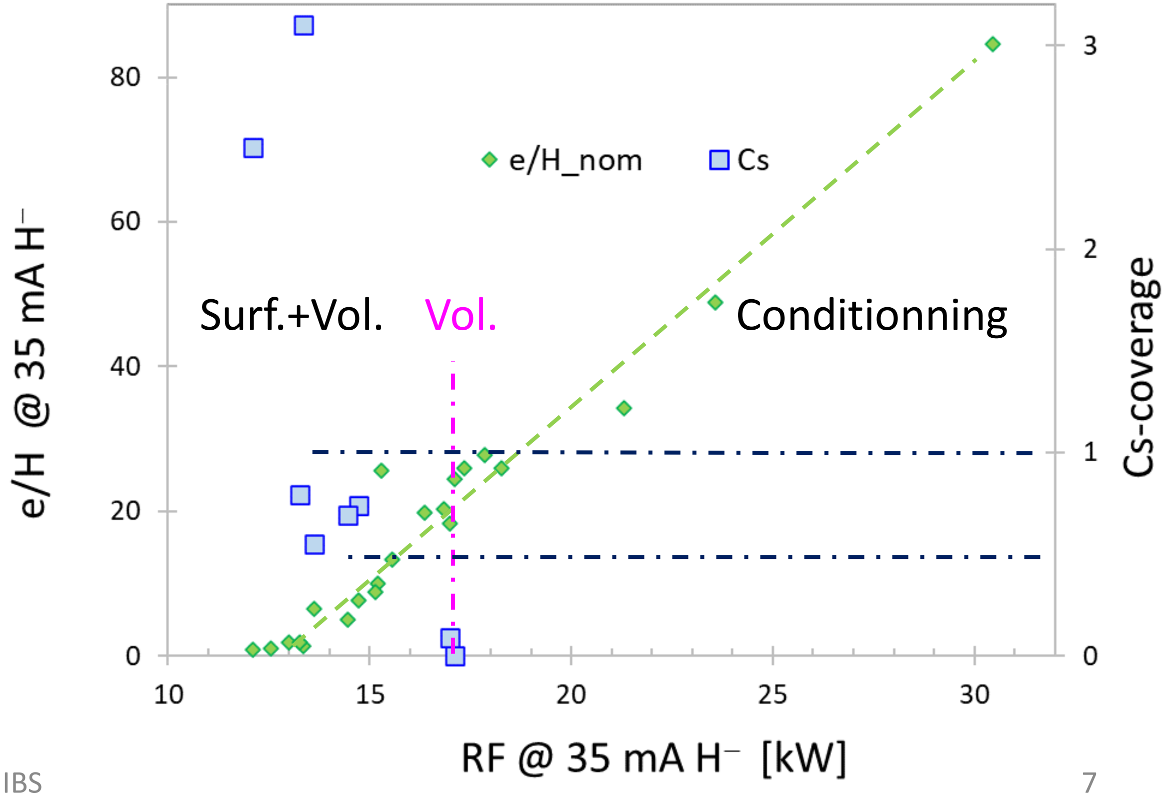


Cs-Coverage campaign:

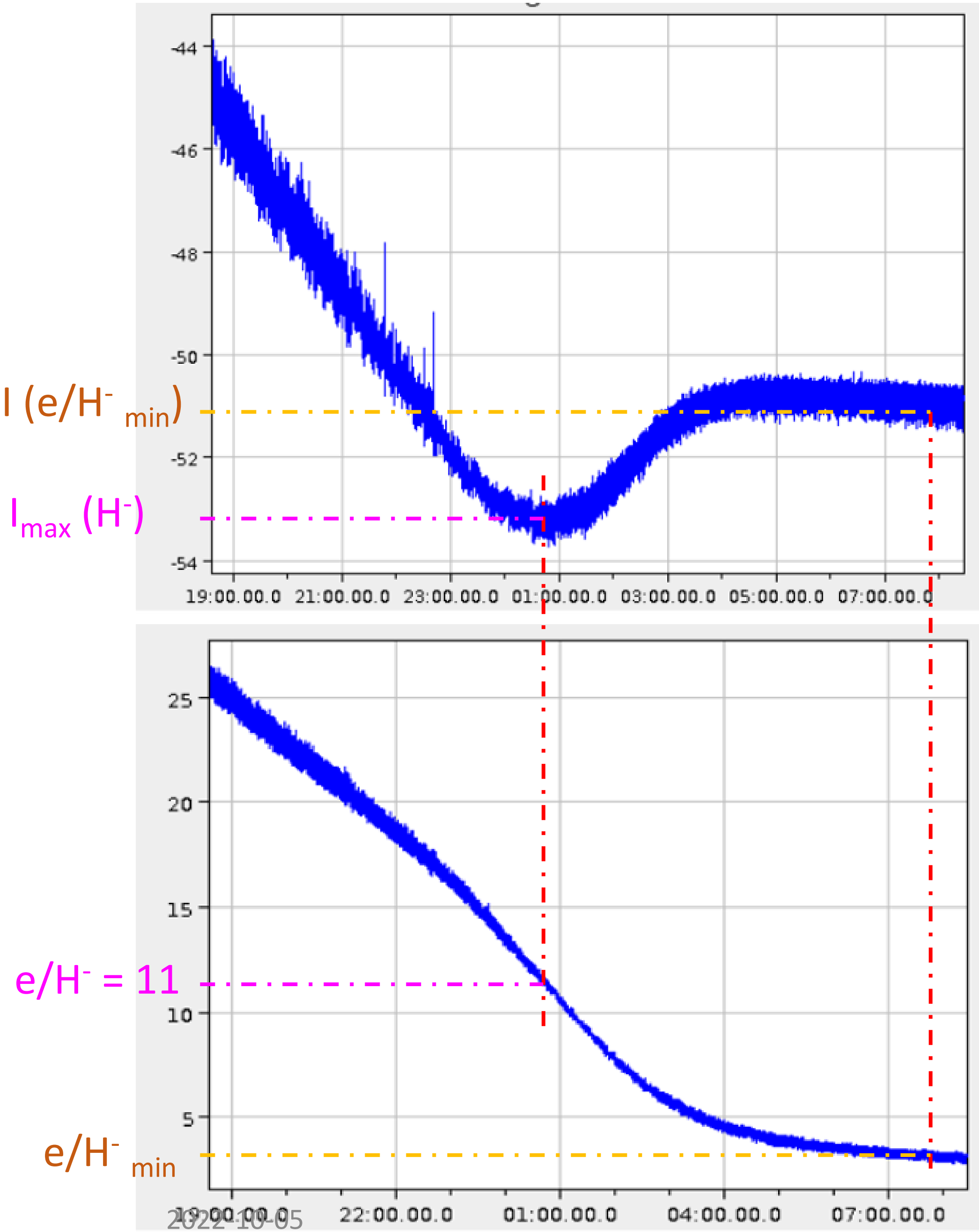
- ✓ 2 Plasma Electrodes,
- ✓ 7 meas. Points
- ✓ 0.1 to 3 Cs-monolayers

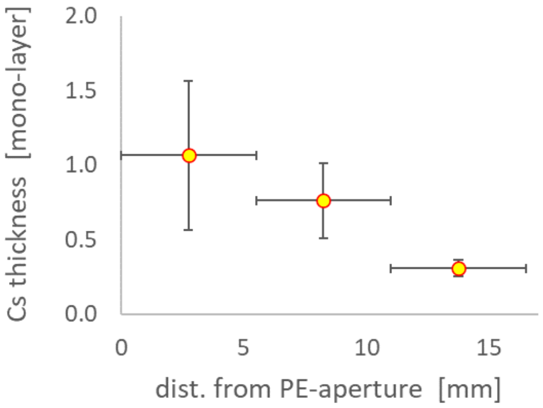


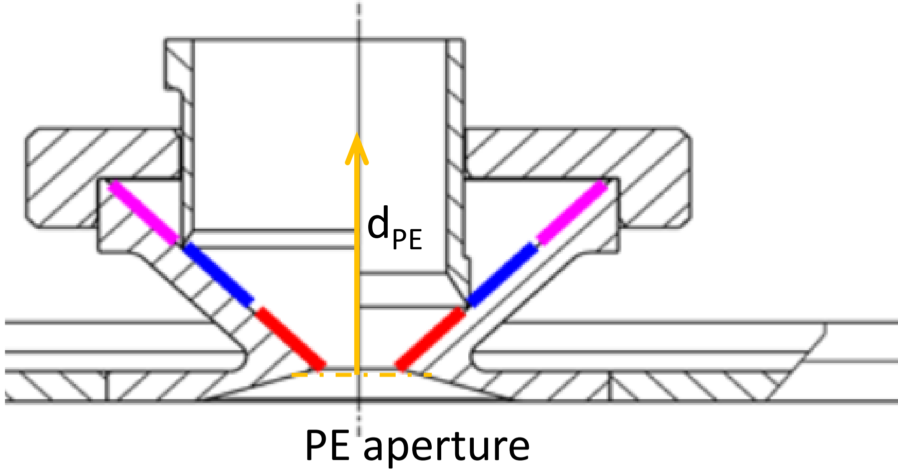




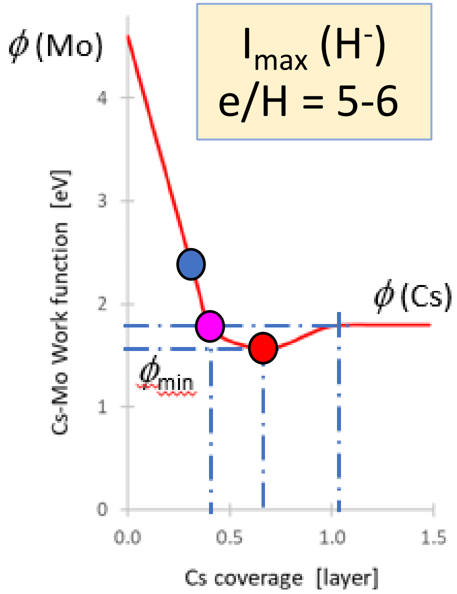
Sytematic observation: Peak curent before lowest e/H

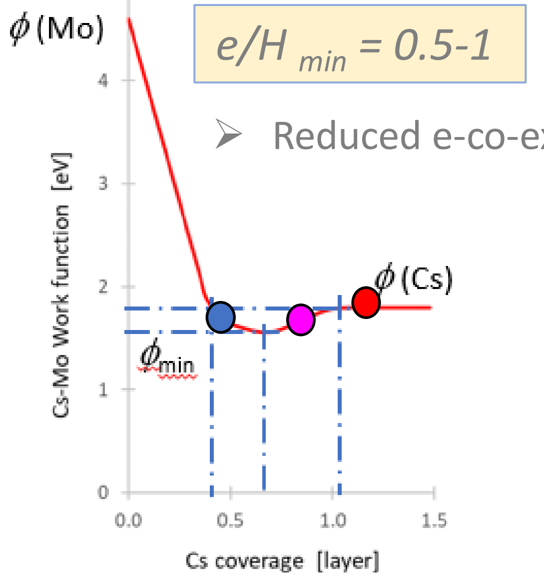






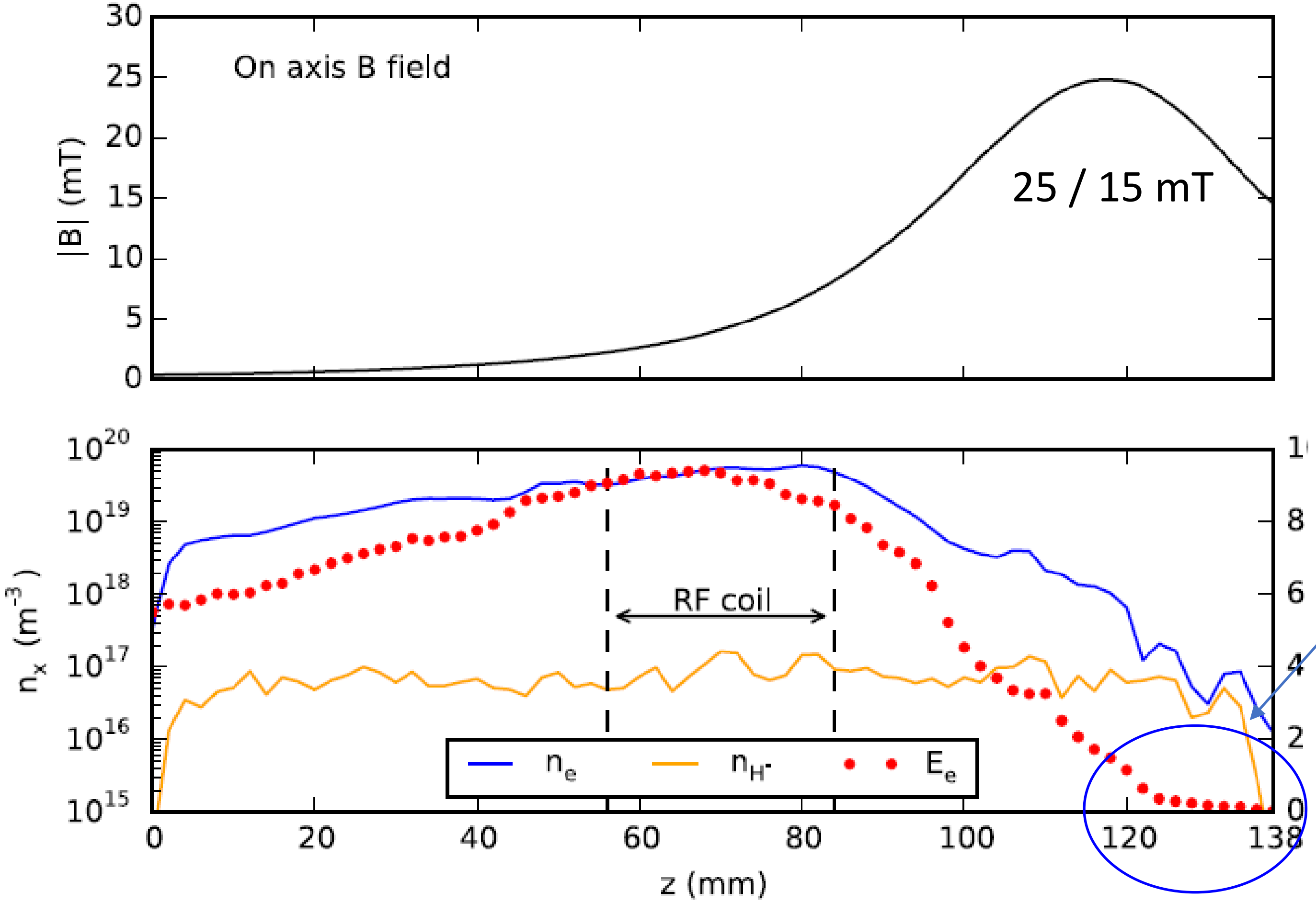
- ✓ For e/H = 5-6: Cs-coverage gradient Along the PE
- ➢ *Therefore: H⁻ surf emission gradient & Neg. potential well gradient*





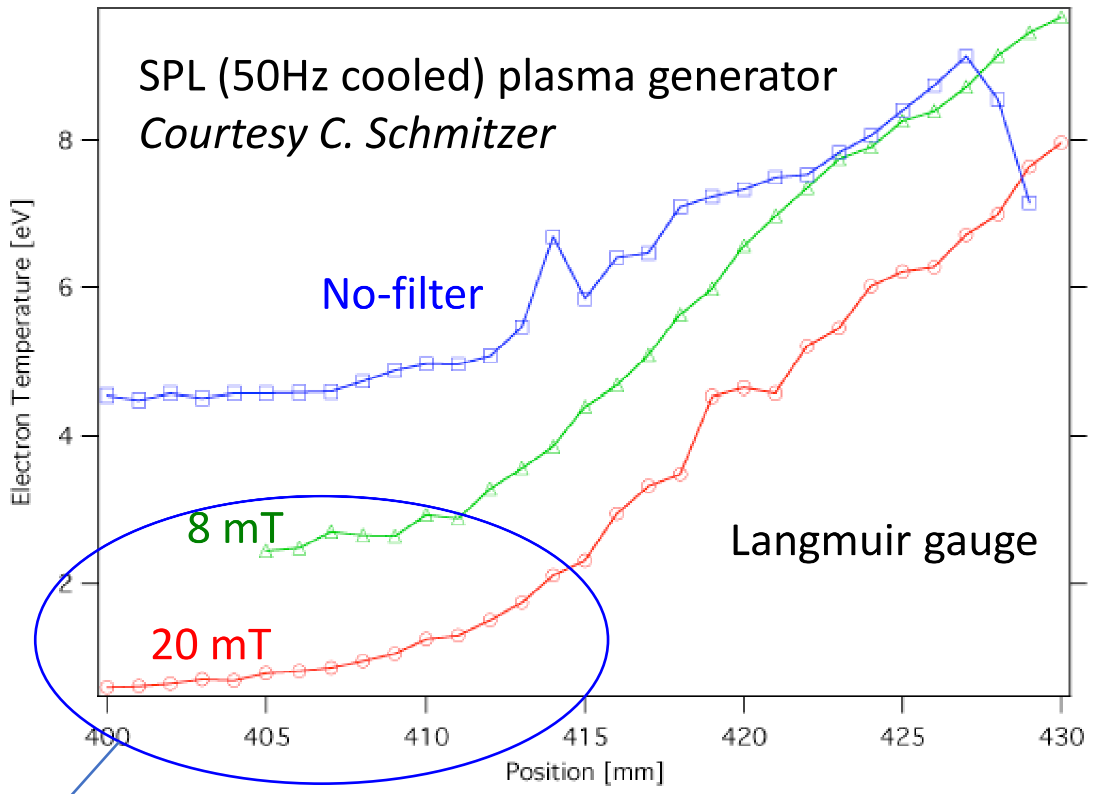
- ➢ Reduced e-co-extraction

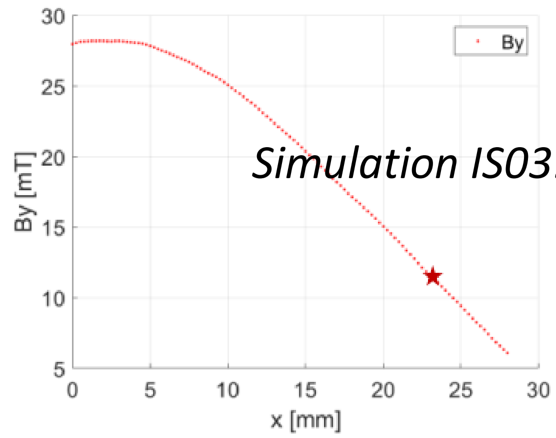
NINJA (L4IS) vs. Laugmuir gauge meas. (SPL Plasma generator)



e/H = 100

e/H = ~1

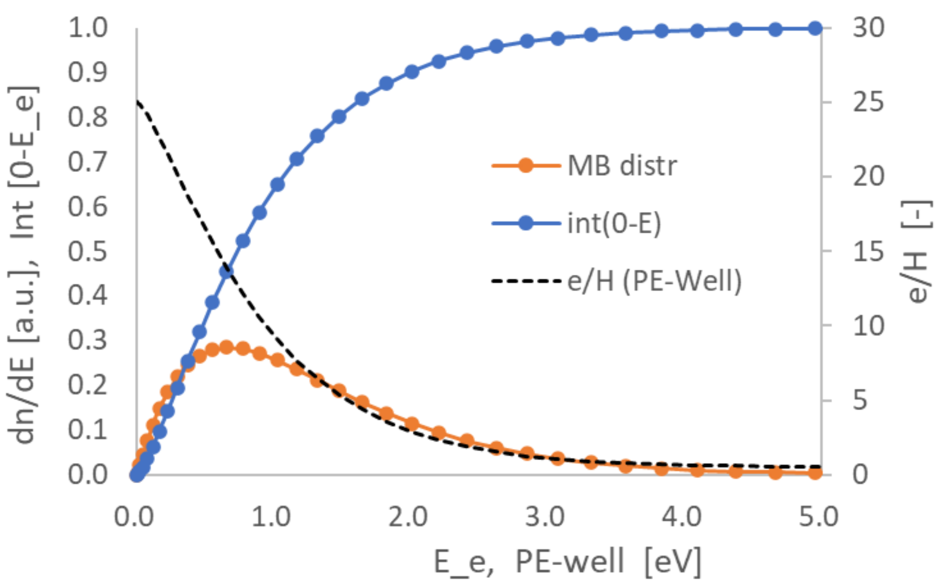




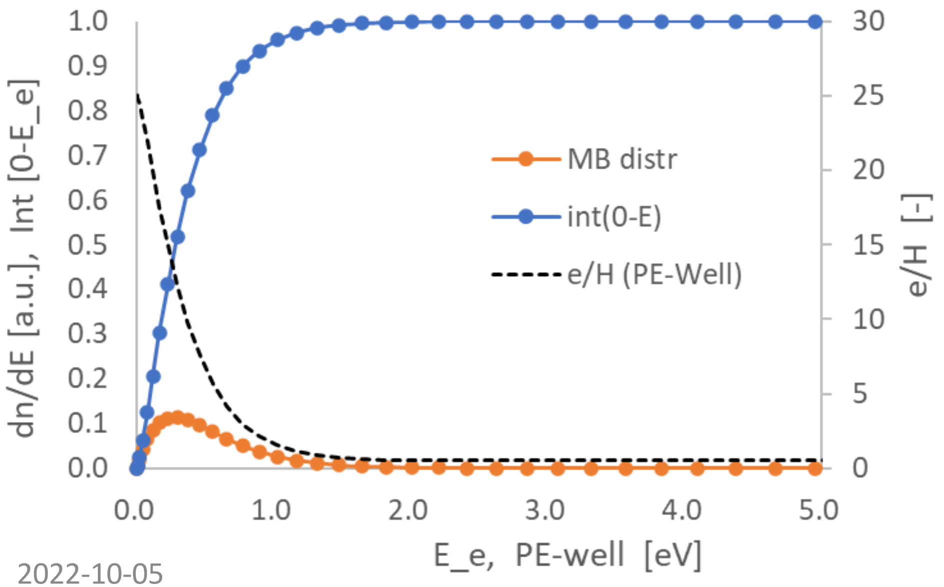
Electron energy distribution vs. Surf. Emis. induced Potential well

Ee = 1 eV

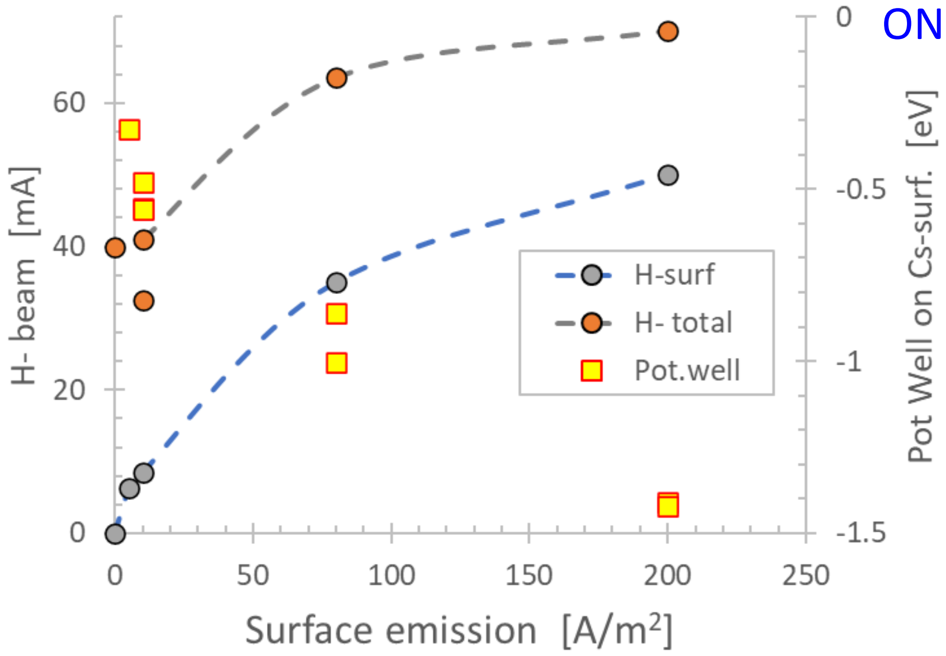
Maxwell Boltzmann



Ee = 0.4 eV

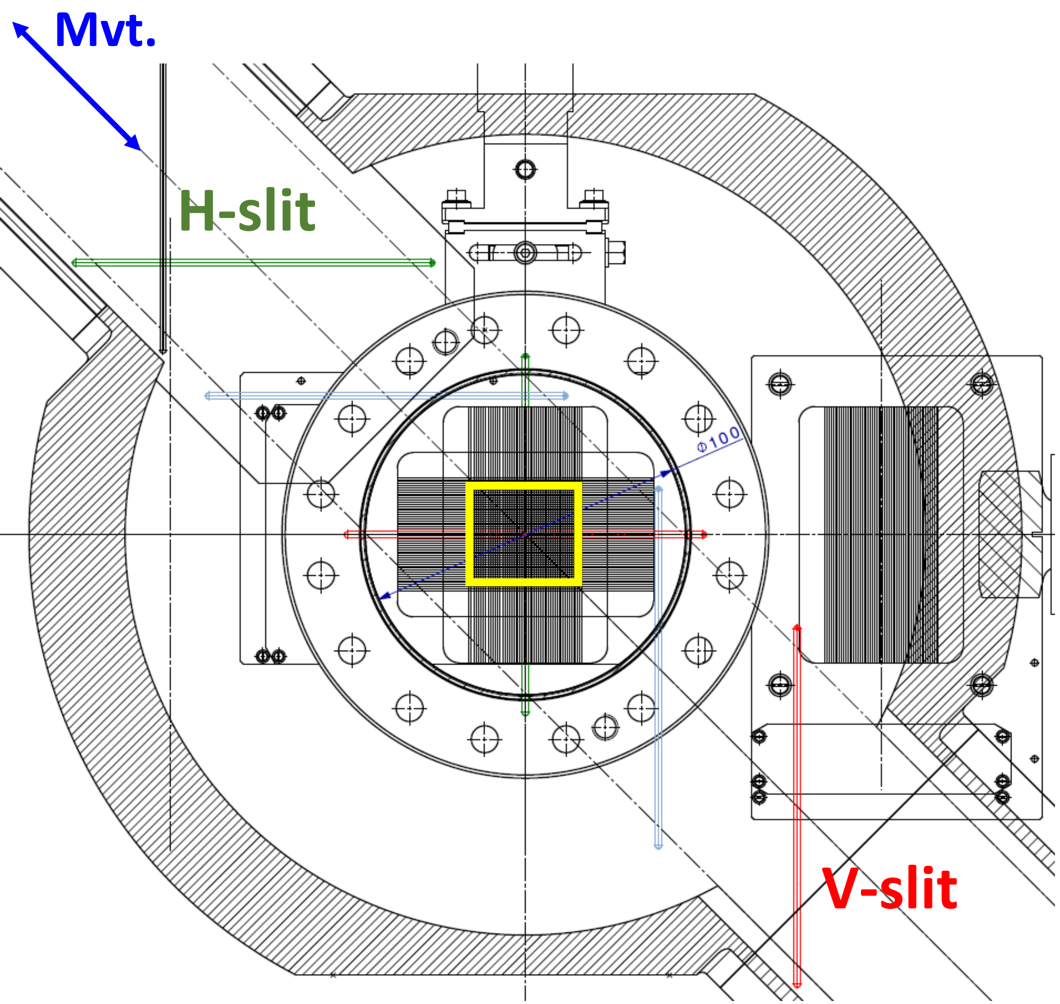


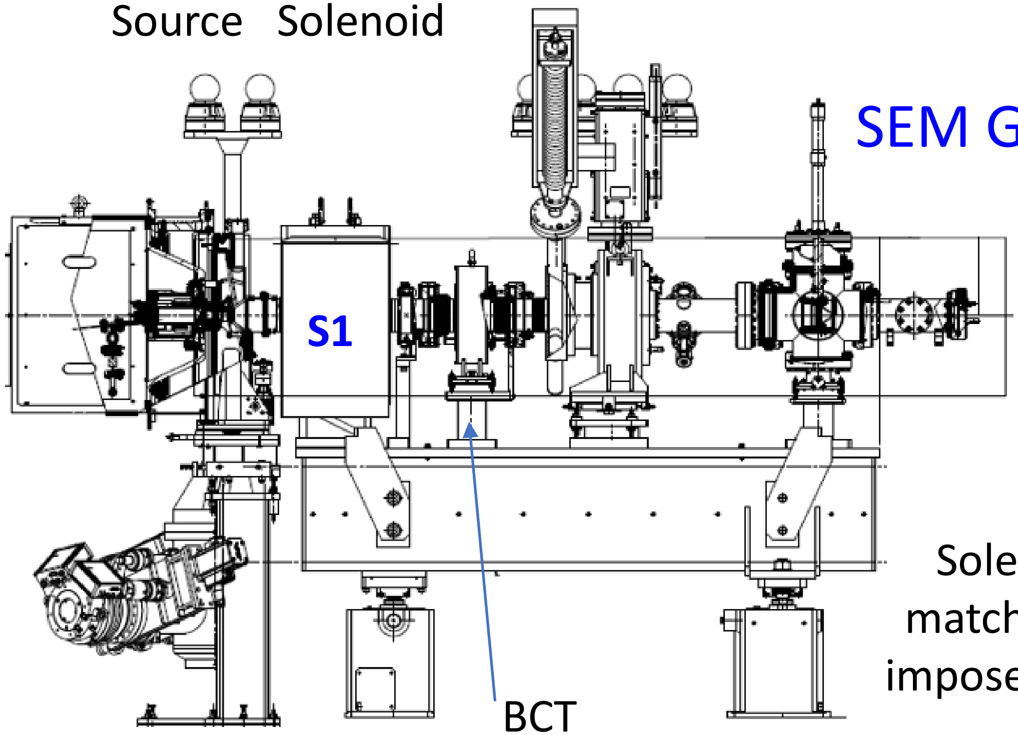
ONIX



- The order of magnitude of the simulated Potential well corresponds to the energy barrier required to supress électrons from reaching the plasma electrode aperture
- Triggered simulations with surf emission gradients
- Note: *MB-distr. is not in the version ONIX-single aperture.*

Test stand's Emittance meter: Slits & Grids and SEM grids





Solenoid S1 tuned to match the Grid size, this imposes a focussing beam

E-meter distance Slit-Grids: 200 mm

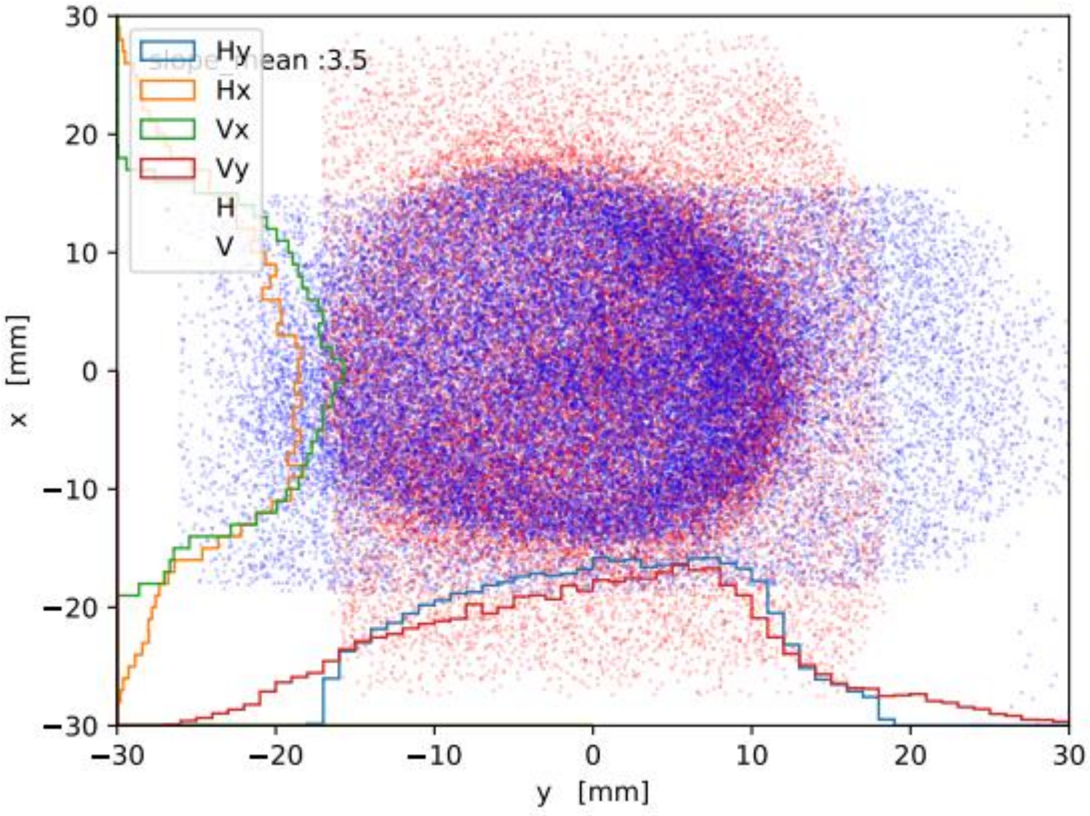
Effective meas. surface : 30×30 mm^2

Grids: (48 total) 40 active wires at 0.75 mm interval, Angle 0.75/200 > 3.75 mrad/wire spacing

Profile during and after Space Charge Compensation

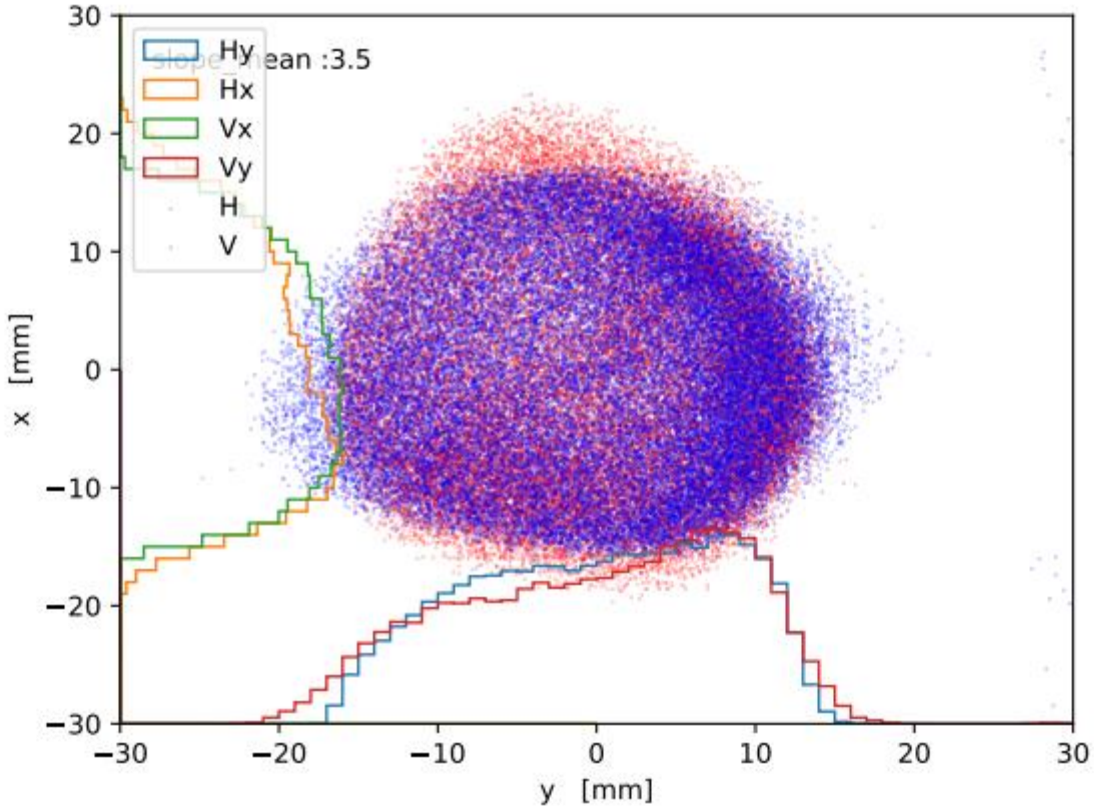
Horizontal and vertical slit-grid measurement of the beam profile

Left right and top down assymmetries



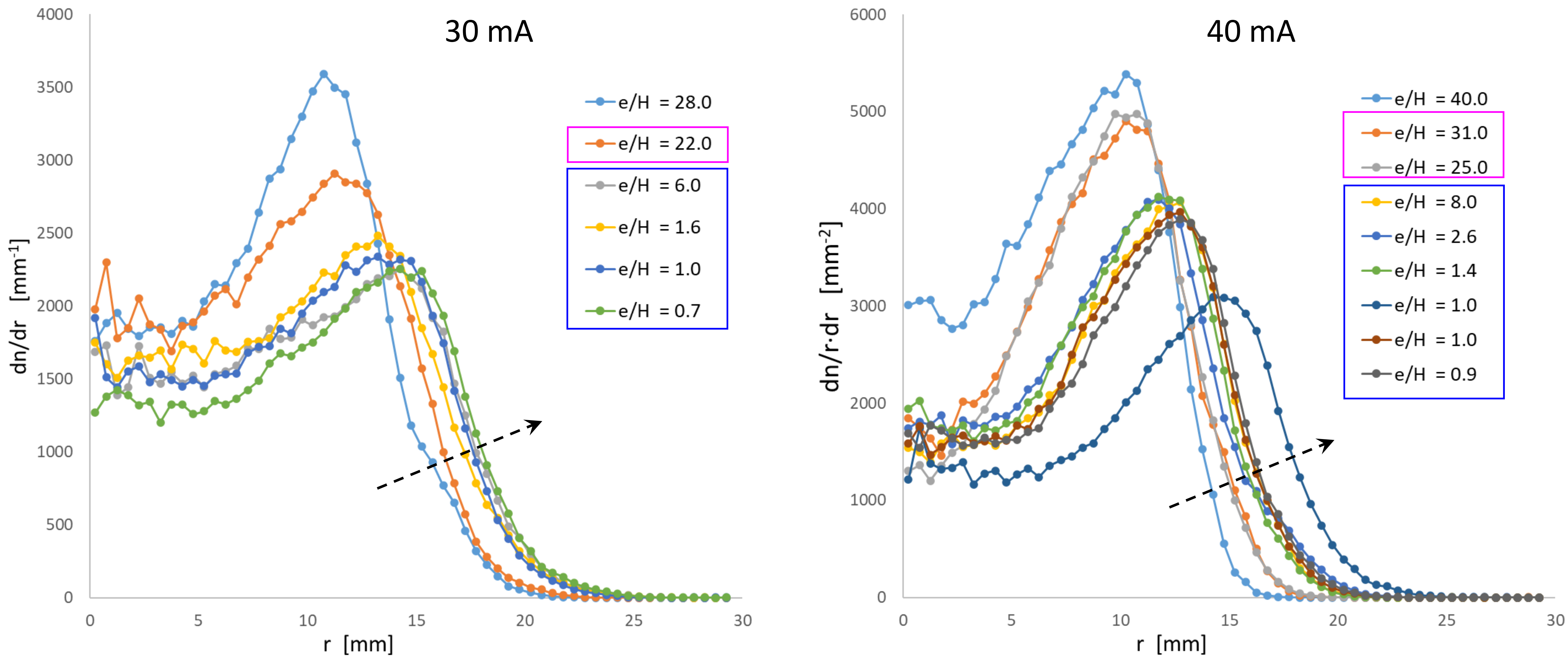
Beam Halo before space charge compensation

τ_{scc} = 150 μs f(Residual gas pressure)



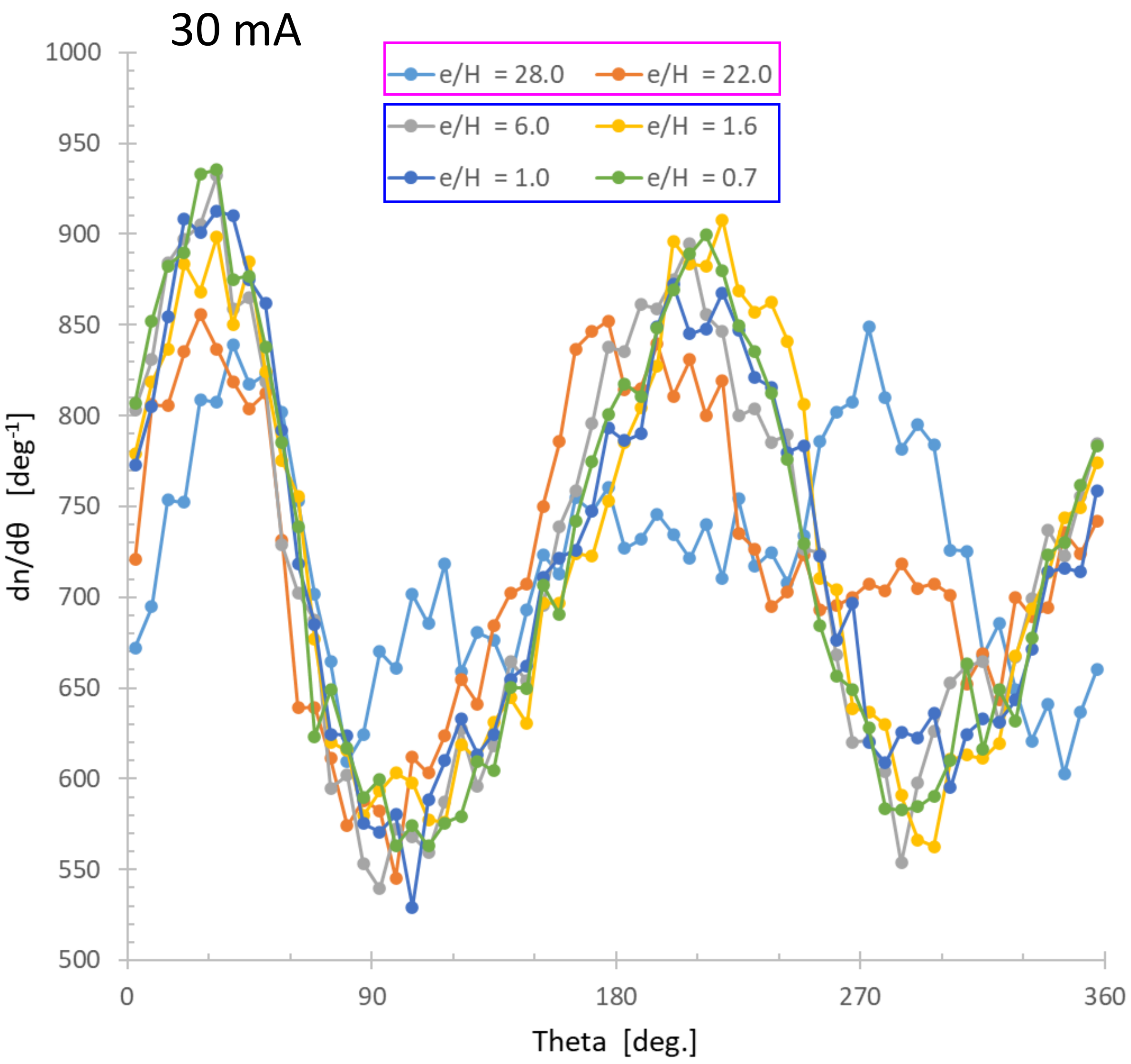
After space charge compensation

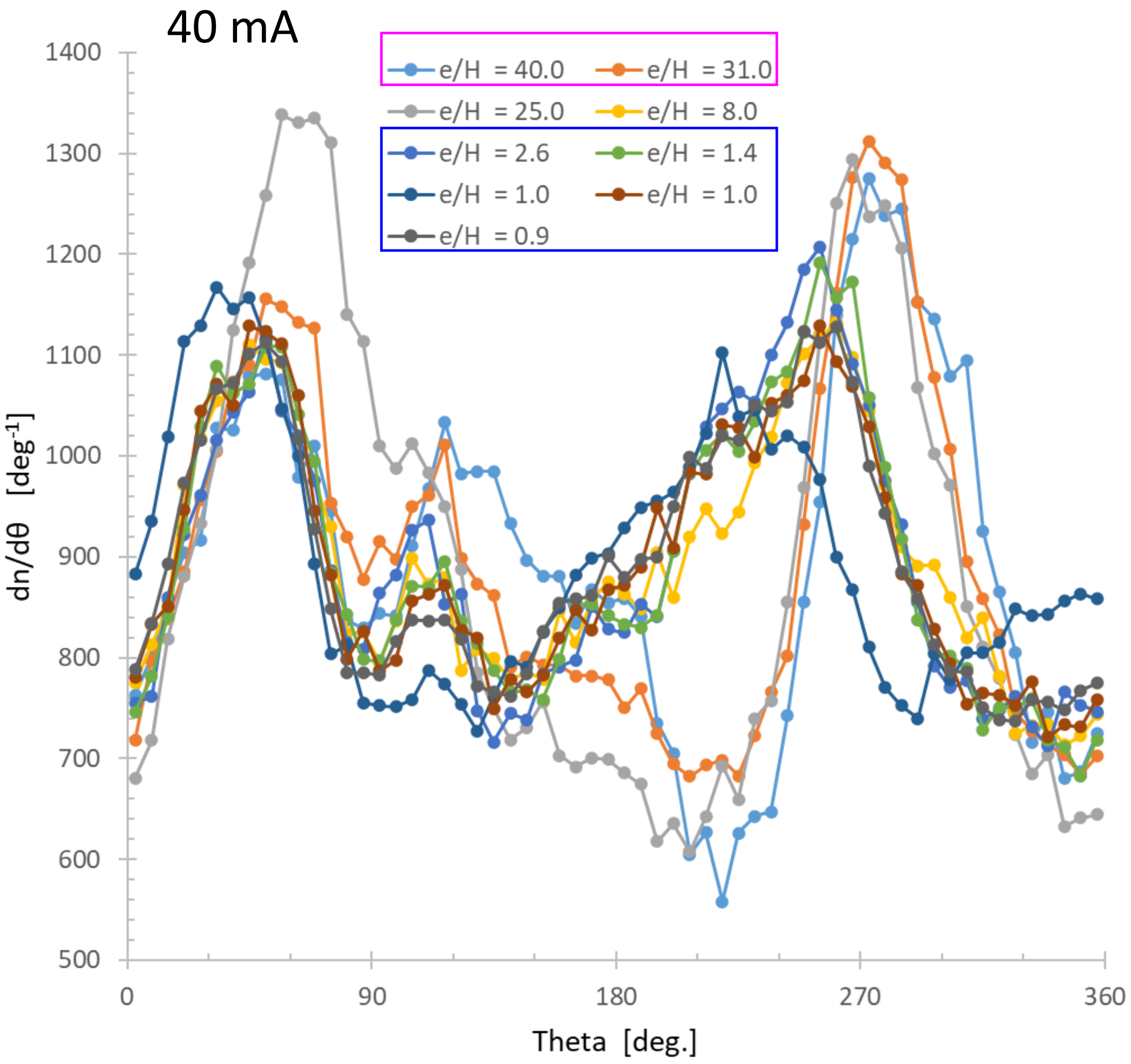
Norm Radial density distr. from volume to caesiated mode



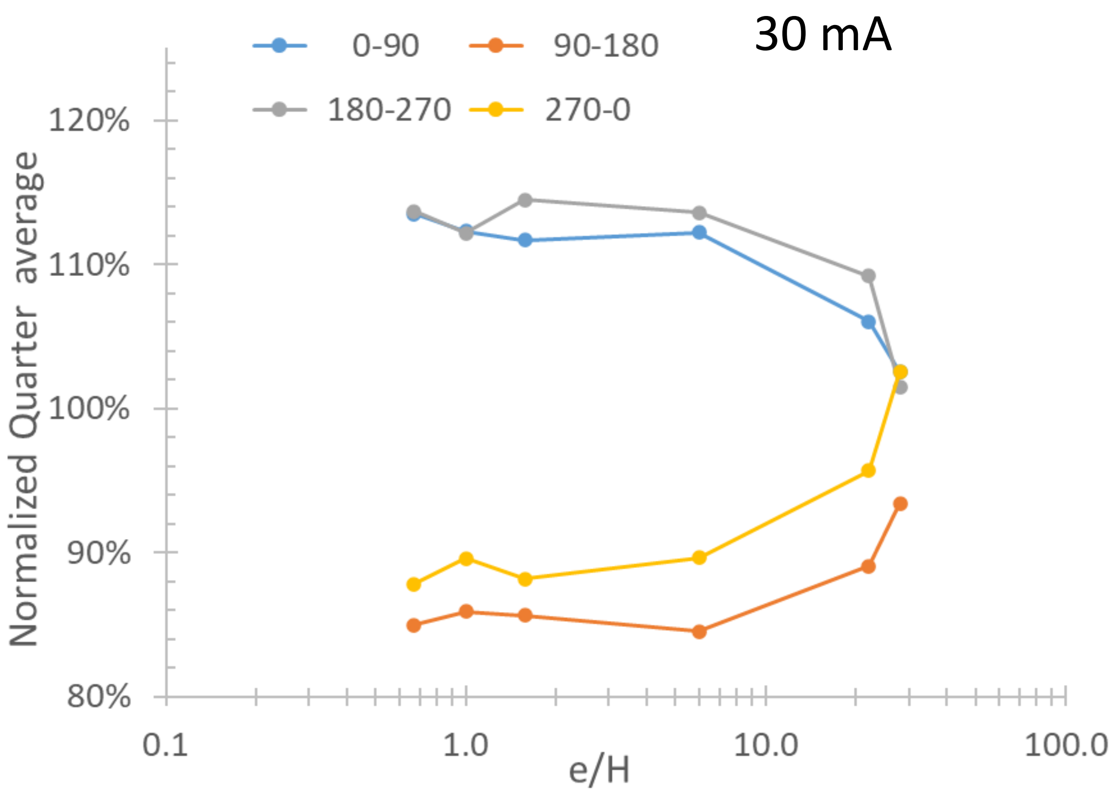
- ➢ The radial distribution as measured with the slit grid in Horizontal and Vertical orientations presents a consistent evolution to larger radii along with the lowering e/H (corresponding to an increase of the surface mode contribution).

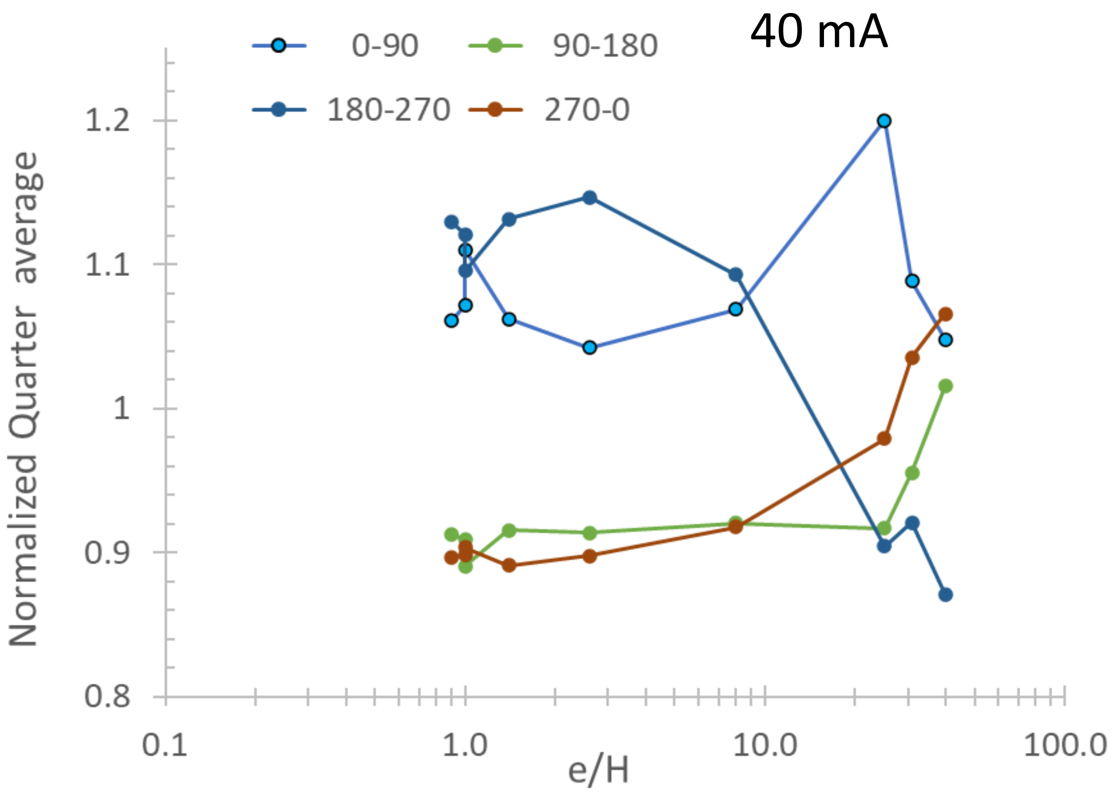
Profile angular distribution





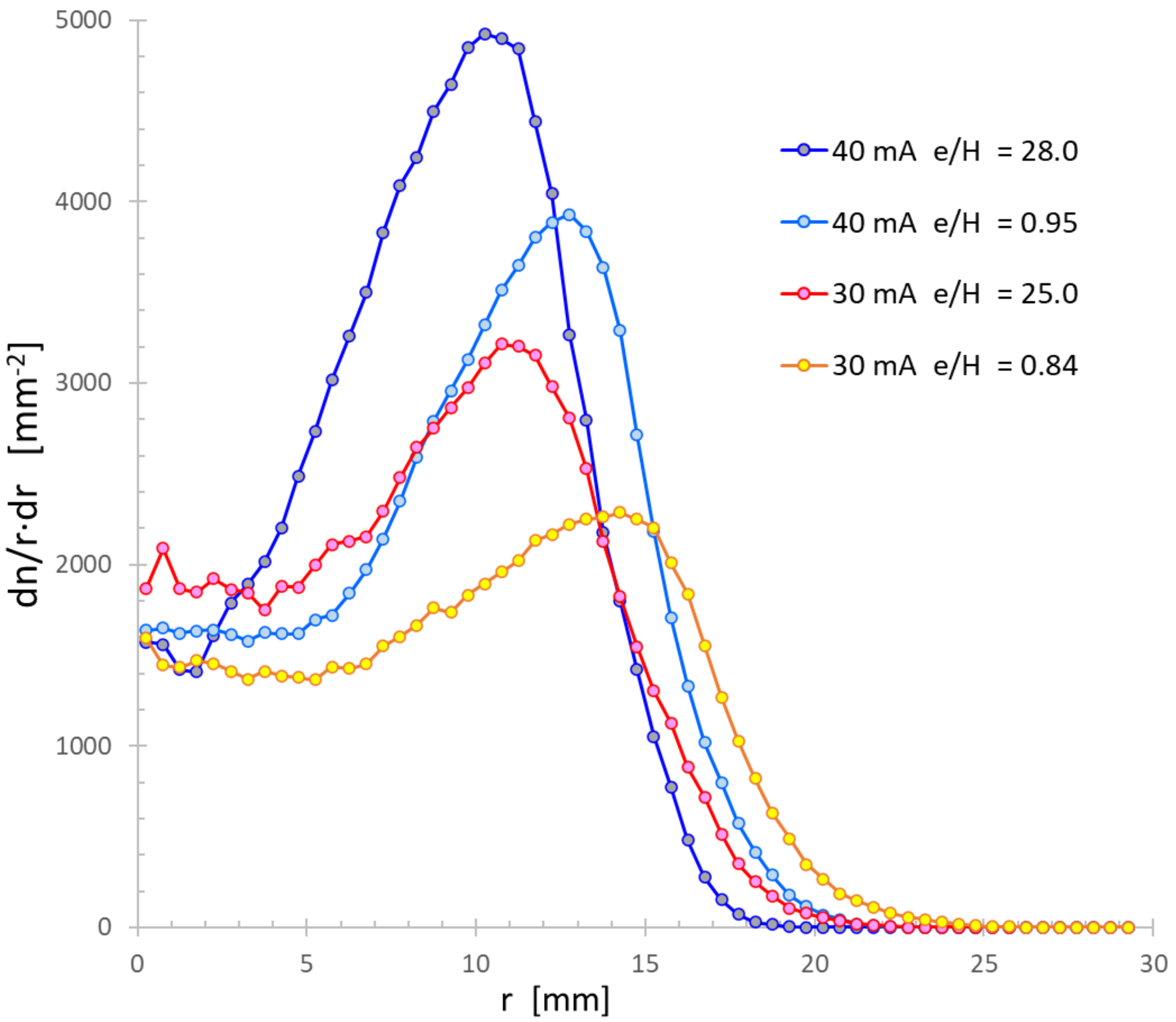
Angular distribution's Asymmetry (e/H)

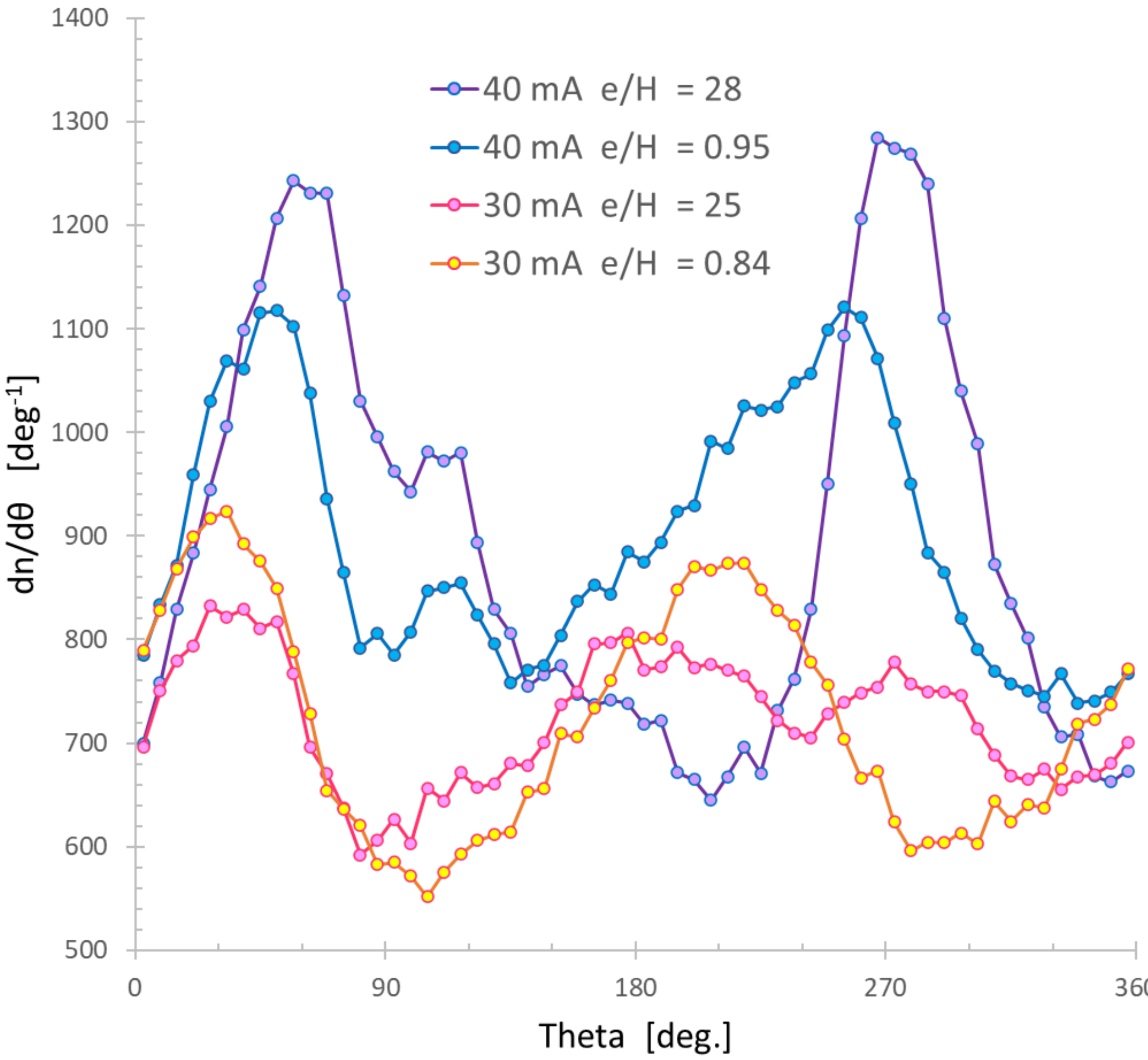




- The angular distribution as measured with the slit grid in Horizontal and Vertical orientations present the same oscillation, a factor close to two between min and max is observed.
- An asymetry at the level of ±10% (averaged over a $\pi/2$ sector) is observed for low e/H, the tendency is lower for volume conditions.
- It seems that Cs-surface mode enhances the asymetry

Non-caesiated vs. well caesiated PE surface (summary)





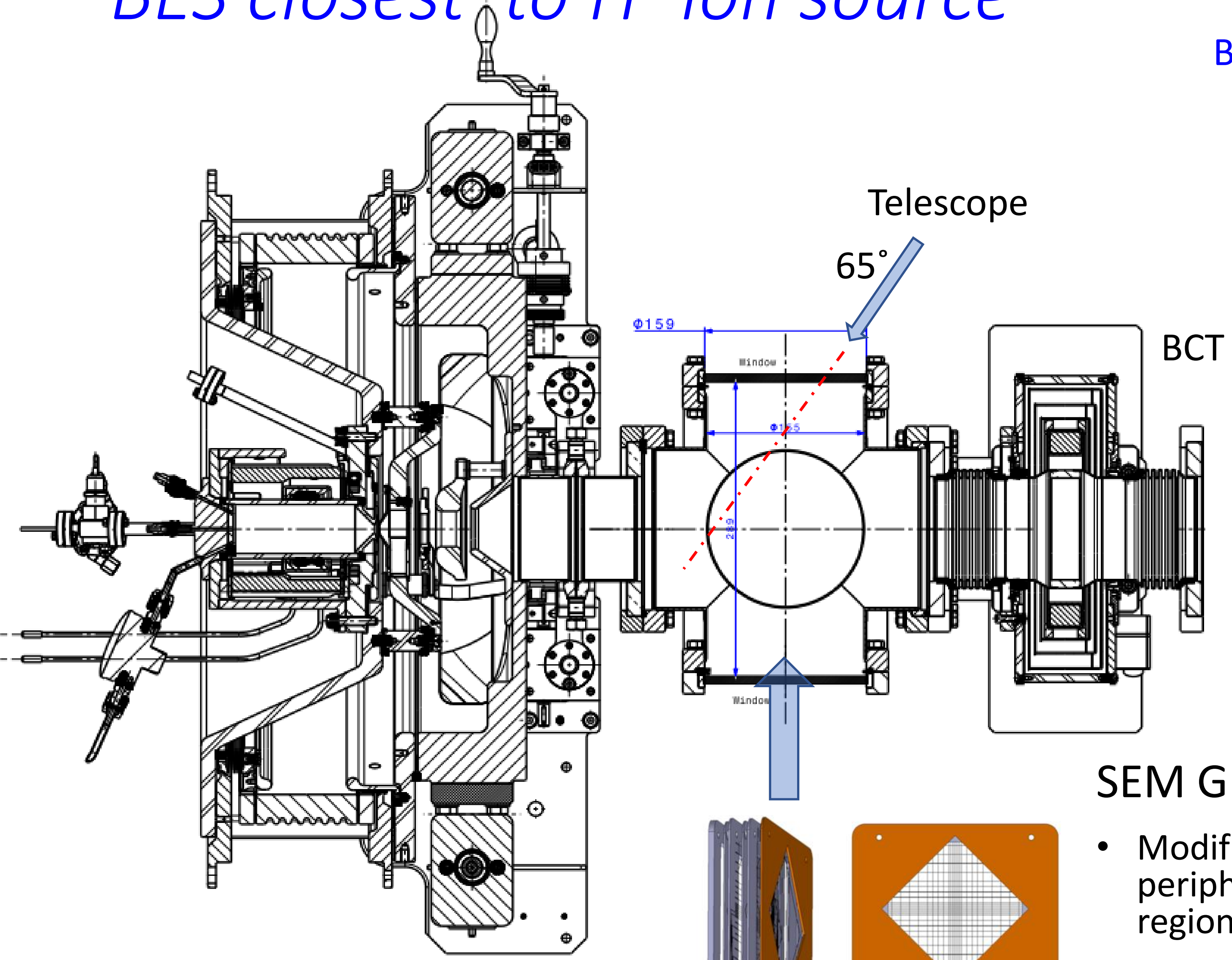
BES closest to H⁻ion source

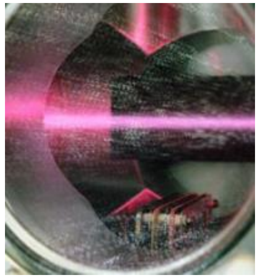
BES Provides an averaged angular distribution of the neutralized (H^- to H_0) fraction of the H^- beam

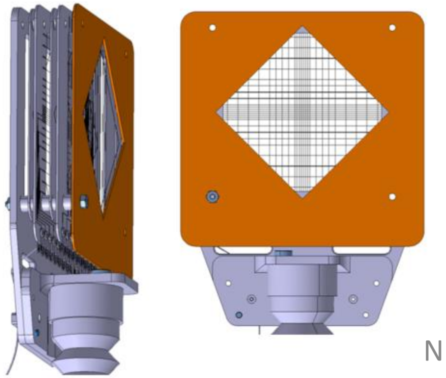
H^- source operated without einzel lens

LEBT H2 pressure of 0(1E-4 hPa)

BES insight: A. Hurlbatt_2019_J._Phys._D _Appl._Phys. 10.1088_1361-6463_ab6145



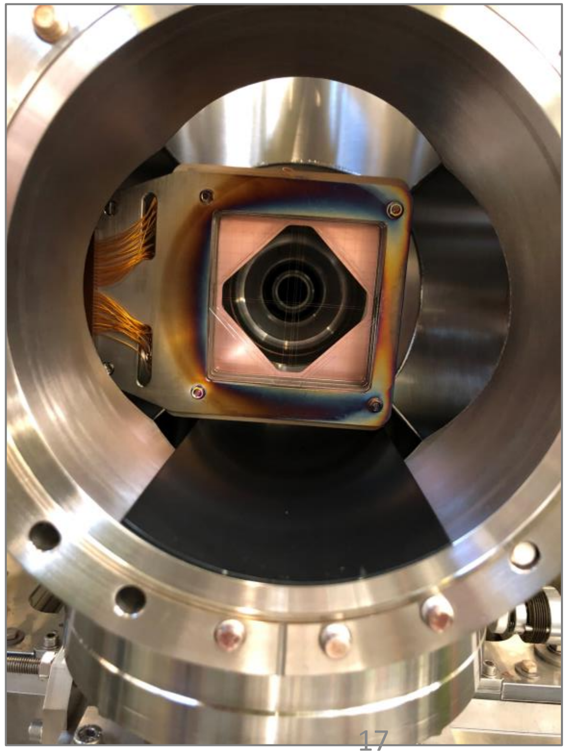




SEM grids
@ BES location

SEM Grids H & V profiles

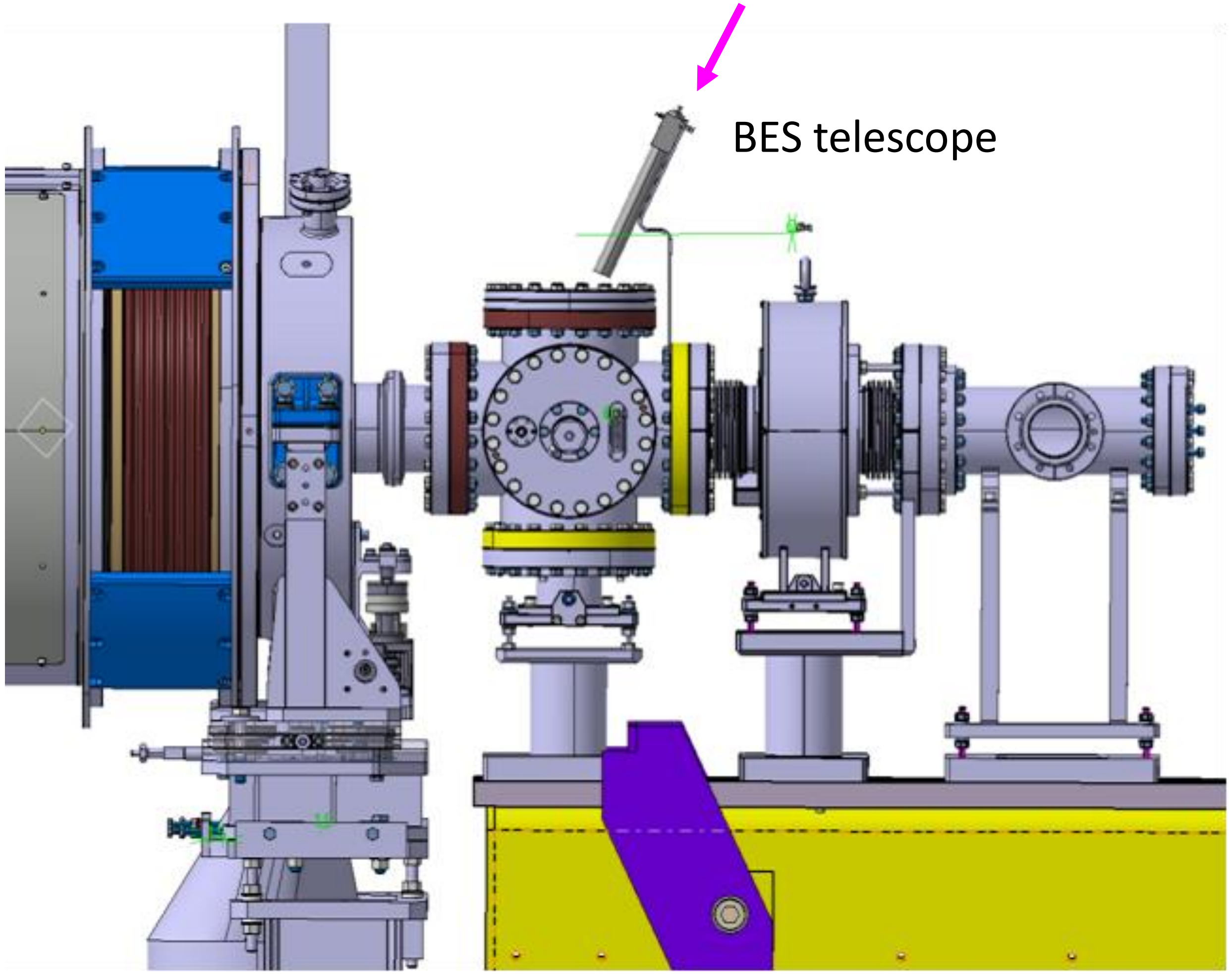
- Modified by shields covering the periphery of the active detection region
- Remained operational even in the closest to source position (up to ϕ30 mm)



Measurement of Horizontal and vertical BES

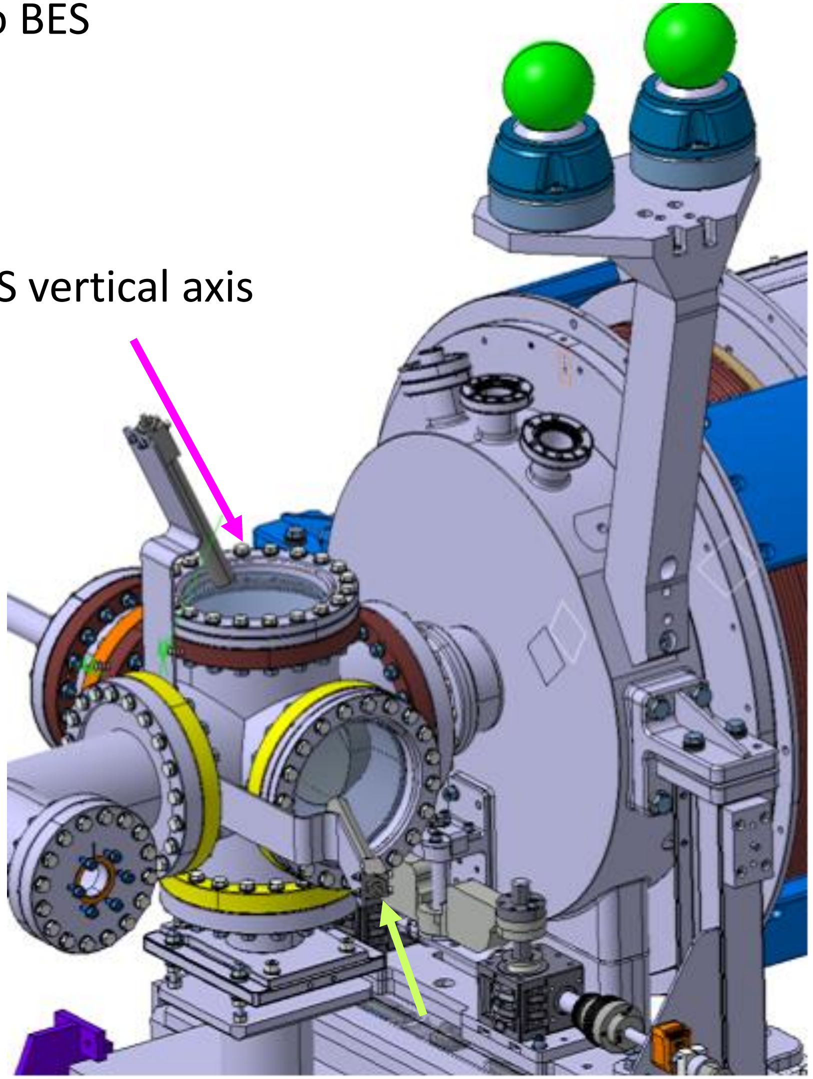
- Outlook: ONIX beam formation phase space, transported via IBSimu to the BES chamber.
- Beam density @ BES folding to the telescope efficiency and compare to BES measurement.

Note: Beam must be within a cone of 10° to avoid wall collision



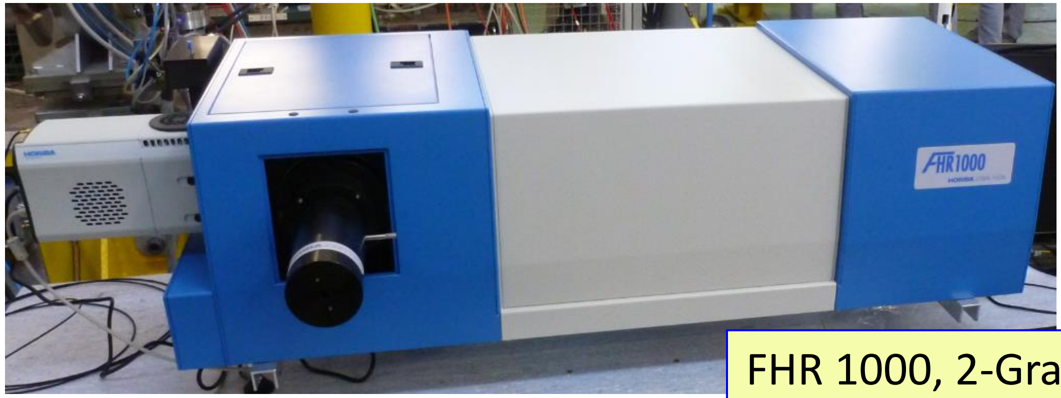
BES telescope

BES vertical axis

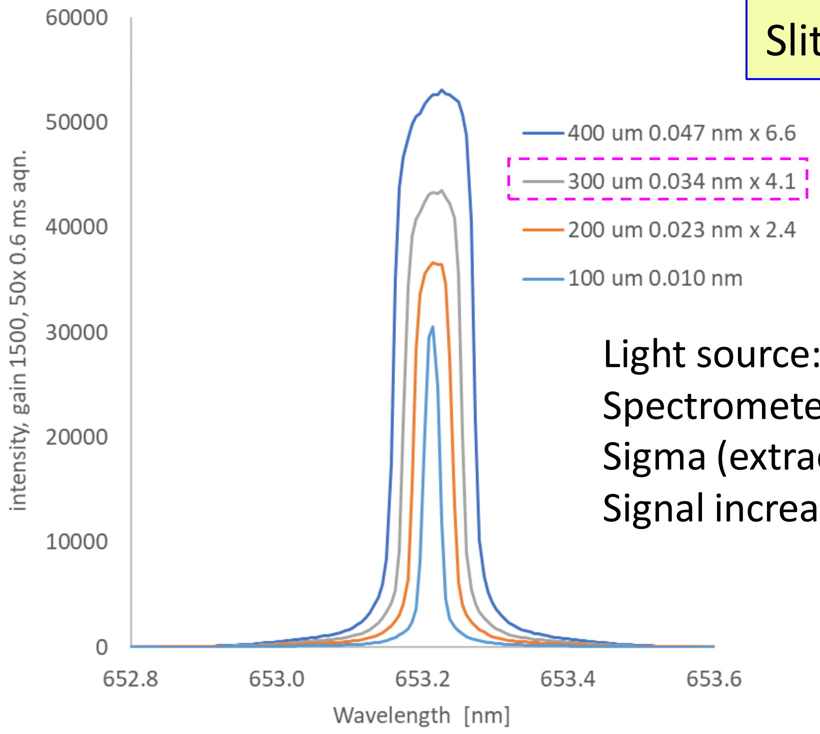


BES horizontal axis

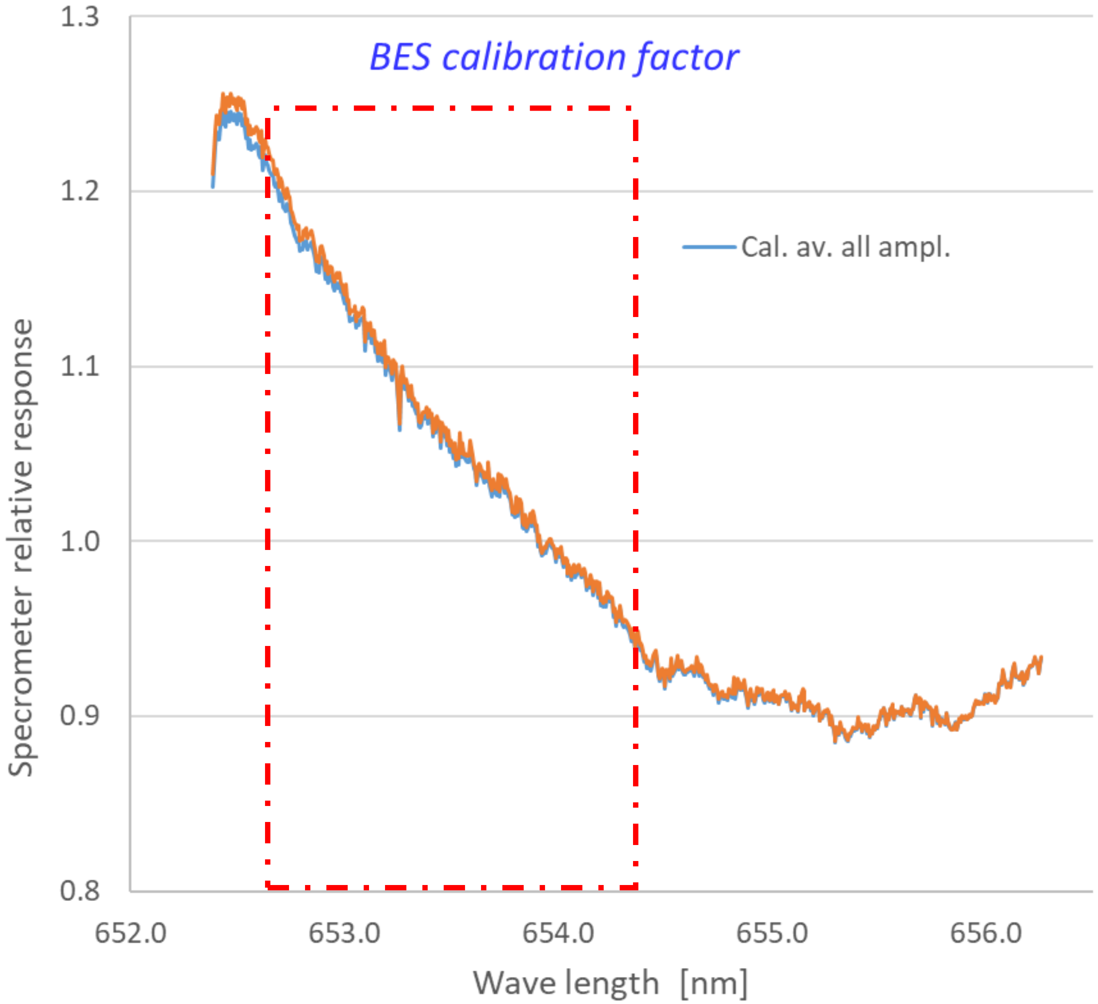
Spectrometer resolution, BES calibration, ROI.



FHR 1000, 2-Gratings
100 and 2400 lines/mm
Slit 300 μm, σ = 34 pm



Light source: Neon penray lamp
Spectrometer slit: 100-400 μm
Sigma (extracted from FWHM)
Signal increase vs. 100 μm slit

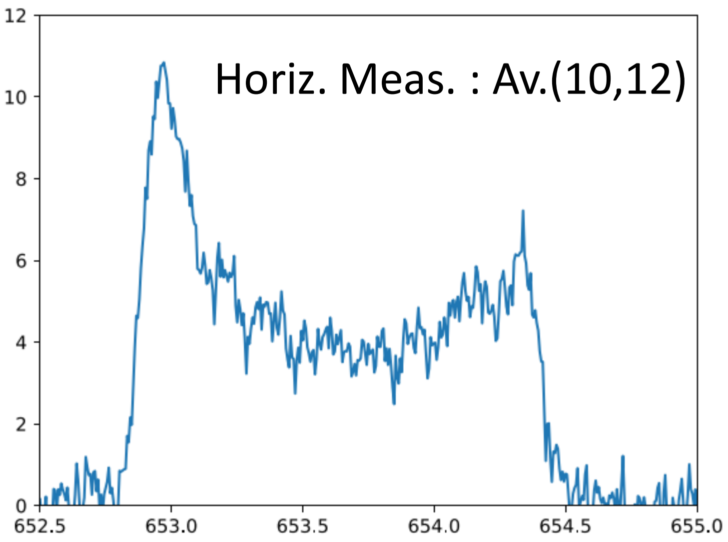


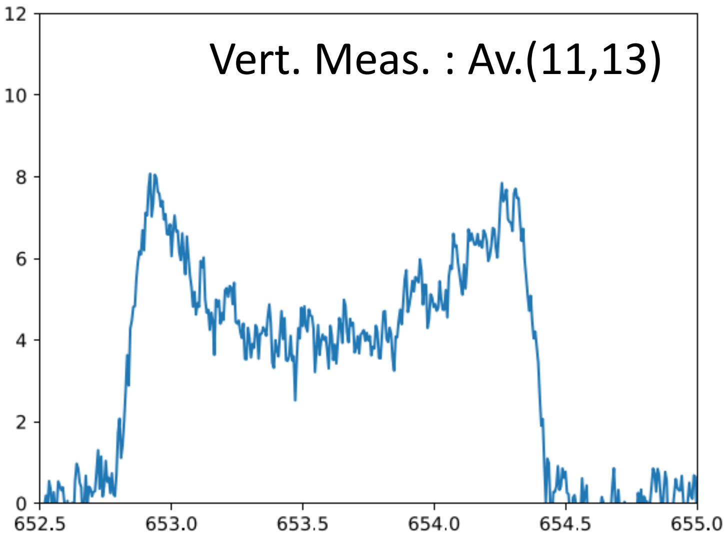
BES measurement H&V, *16-18 07/2022*

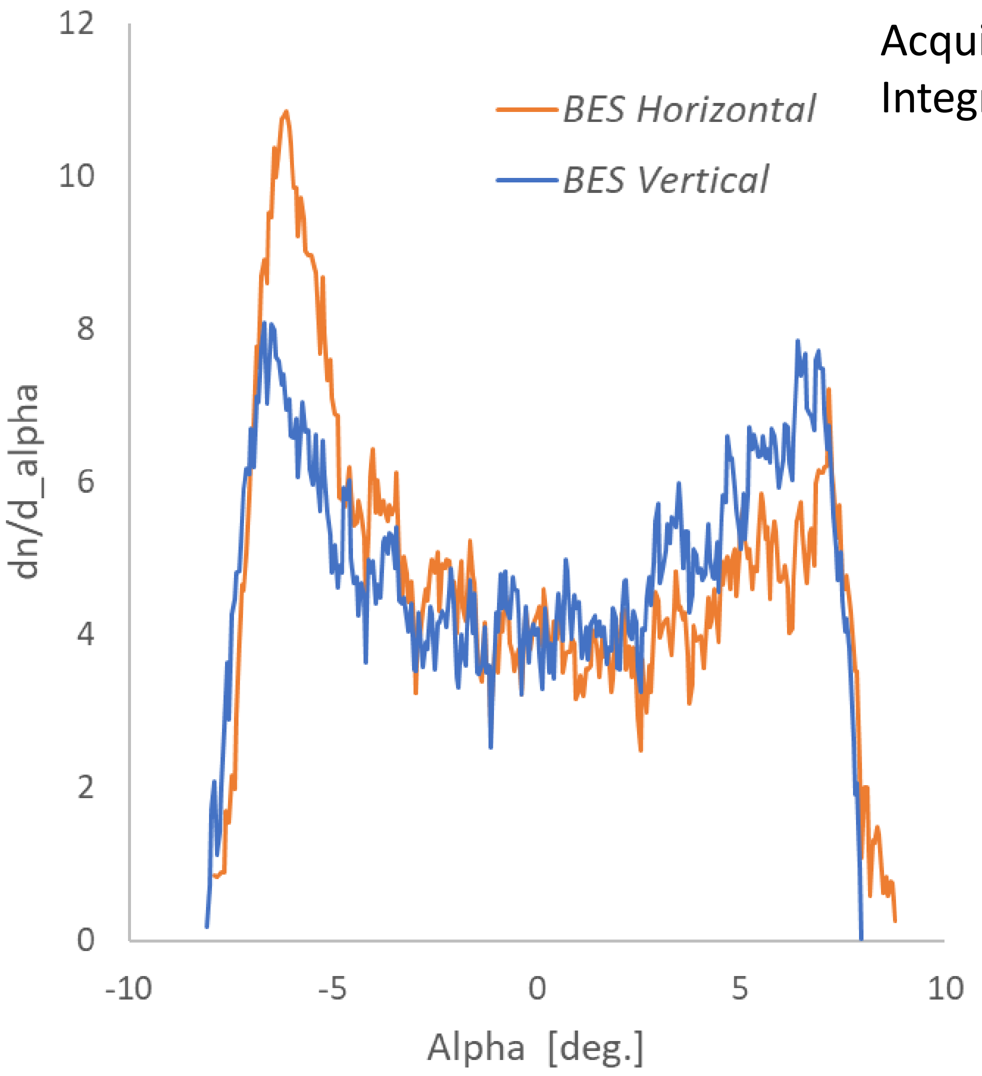
RF-power to plasma 20 kW, e/H ≈ 2-3
H^- beam ≈ 50 mA

Acquisition: 30k pulses of 600 µs @ 0.83 Hz
Integrated beam time ≈ 18-21 s

10) H, 30 k
11) V, 29 k
12) H, 32 k
13) V, 35 k





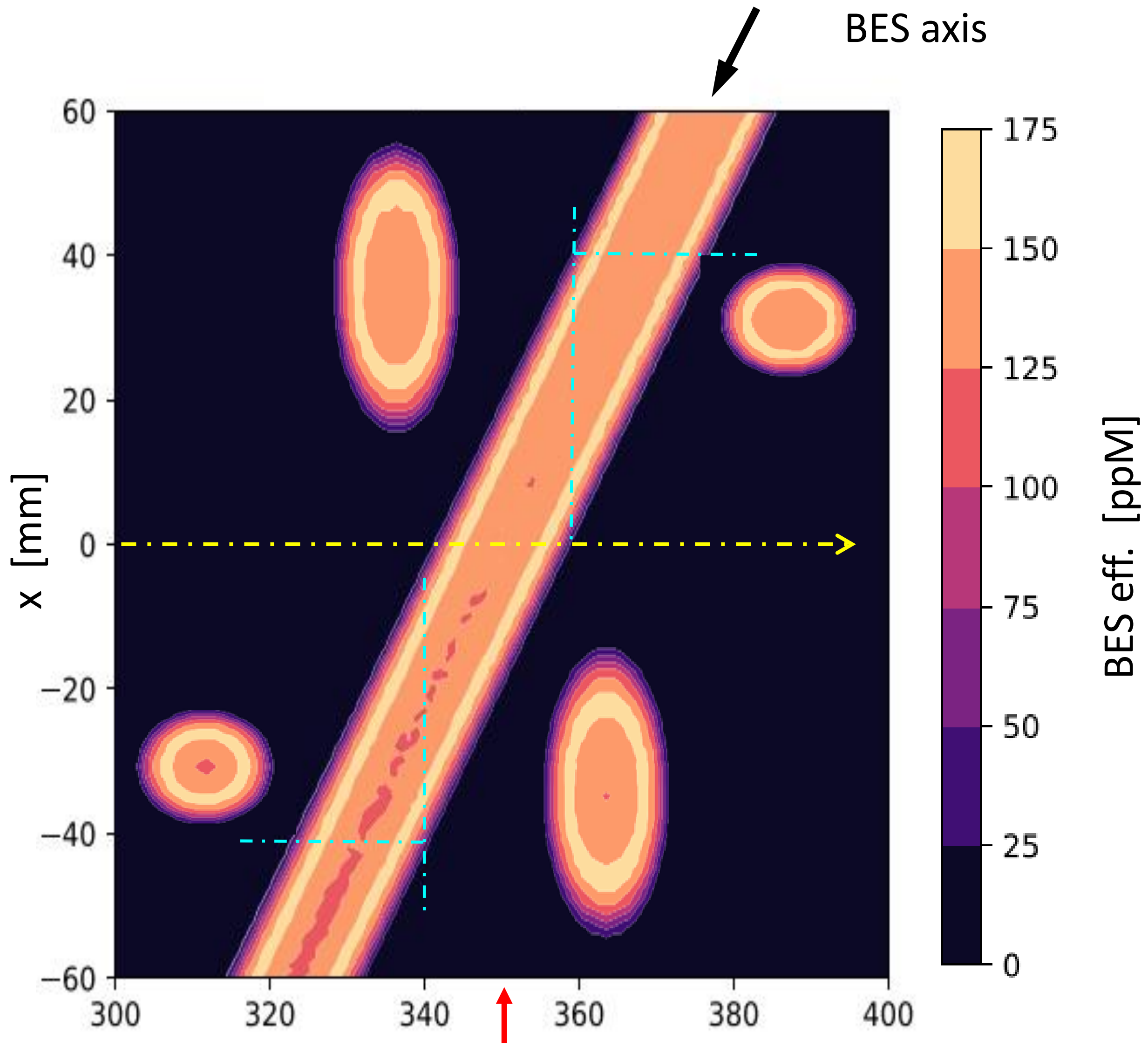


Data handling:

1) Back ground subtraction and spectrometer calibration with an Ulbricht Sphere
2) Translation of the Doppler wave length blue shift to angle vs. telescope axis

Telescope efficiency

Courtesy A. Hurlbatt

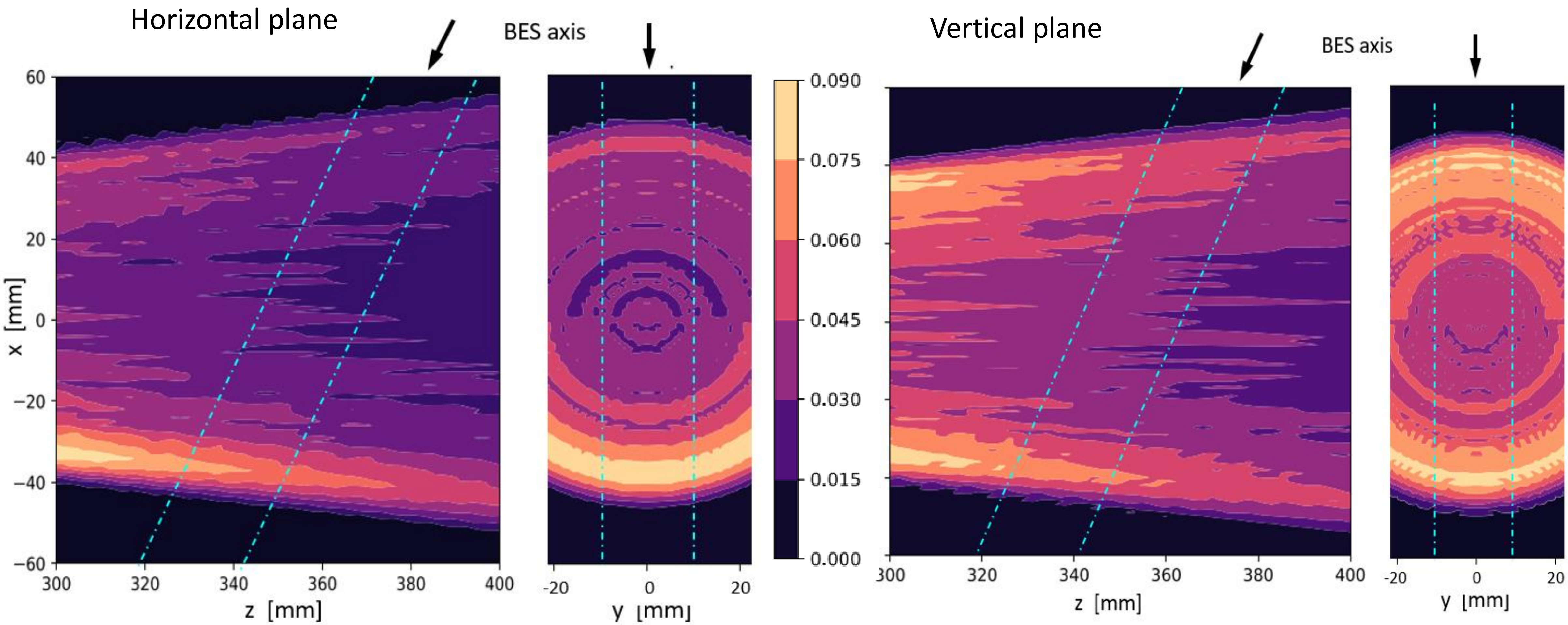


z [mm] (*distance to Plasma Electrode aperture, z crosses Telescope axis at 350 mm*)

BES-measurements' telescope efficiency: The 'x' axis in the lab frame is either vertical or horizontal and z is on beam axis.
The efficiency at the **xz** plane is shown.
Along dashed-dotted lines, Illustrative snapshots on the **yz** plane are shown for x=±40 mm and z=350 ±10 mm.

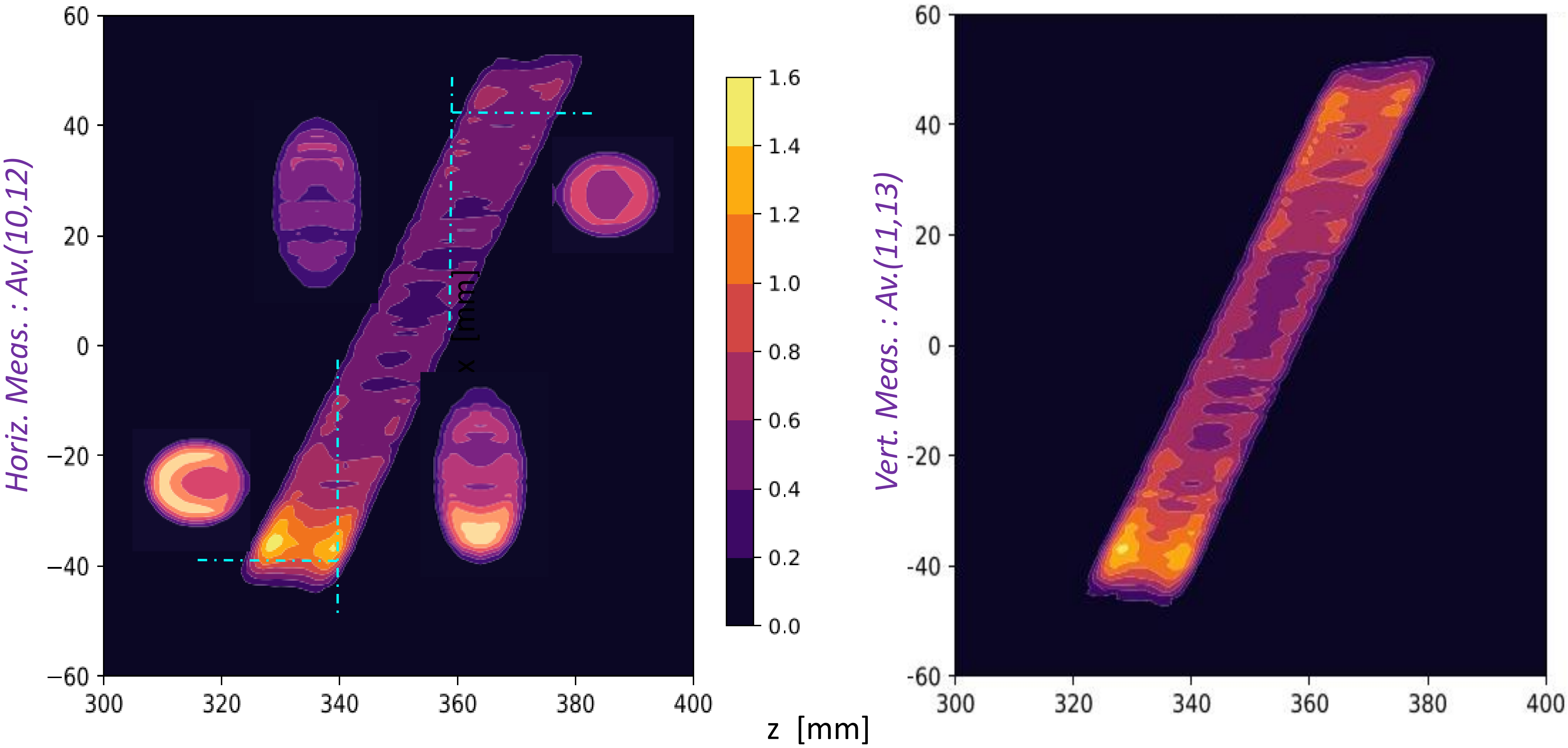
The detection response results from the folding of the beam angular distribution vs. beam axis (α) with the telescope efficiency.
Implicit: we assume a point like source for first order analysis. Outlook at a later stage: direct folding of the IBSimu(ONIX) beam densities with BES efficiency and comparison to BES data

Horizontal and Vertical Fluxes from angular distr. & point source



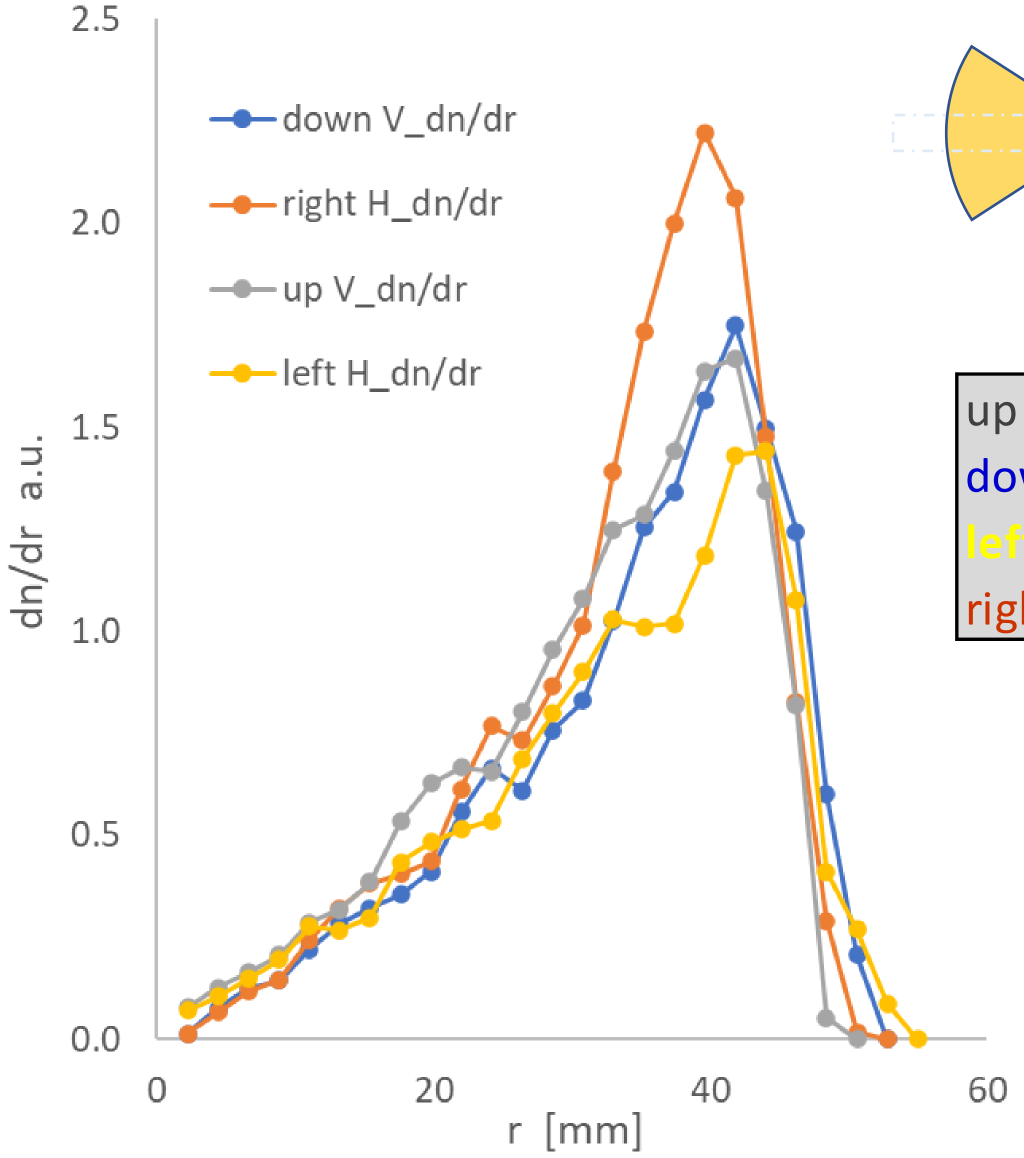
The analysis is ready to swallow ONIX simulated phase space transported via IBSimu to the BES detection plane…

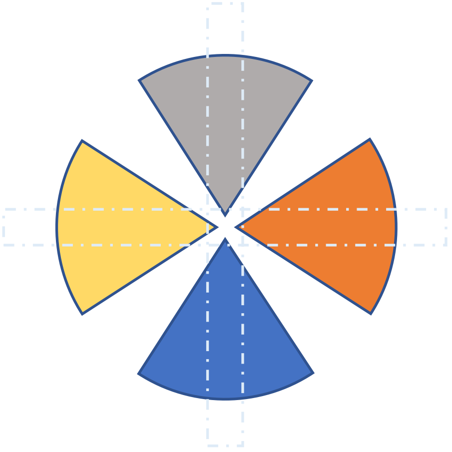
BES: Flux × Telescope eff.
Horizontal and Vertical BES acquisition regions



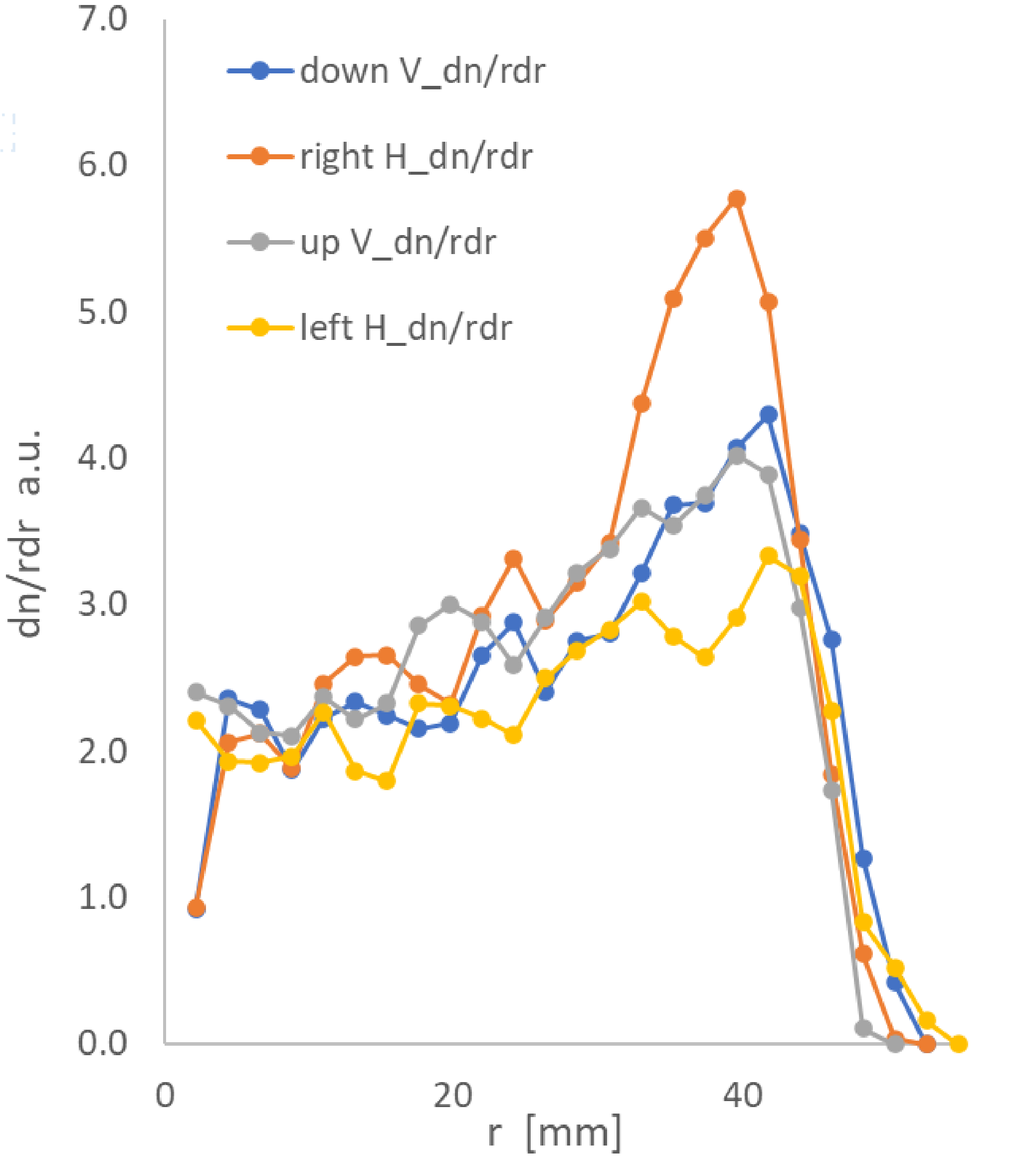
Radial distribution from BES H & V

Check of Left-right asymmetry noticedted in ONIX simulation





up	101.1%
down	98.7%
left	88.1%
right	112.1%



Conclusion summary outlook

CERN's Linac4 IS03b H^- source is being operated very reliably at 35 mA

- The correlation between RF-power transmitted to Plasma, beam intensity and electron to ion ratio is presented; Once conditioning is completed, the volume mode identified via stabilization of its electron to inn ratio is the sign to launch caesiation.
- At nominal beam intensity (35 mA) the correlation between Cs-coverage, RF power to plasma and electron to ion ration is presented.
- Under constant Cs-flow and RF-power, we observed a delay between the highest yield and low electron to ion ratio. The IS03b plasma Electrode reaches 18 mm into the plasma chamber in a region where the plasma density drops by 2 orders of magnitude. The effect on Cs-coverage was measured on 3 plasma electrodes, Cs-coverage is inhomogeneous and the inner most point is systematically the lowest. We conclude that the surface production rate results from an inhomogeneous work function folded with the impacting proton and H_0 fluxes. Initial ONIX simulation with gradients of surface emission are presented in the poster *A.Vnucheko et.al*
- Reduction of the electron to ion ratio (after conditioning) is due to the H^- emission from the surface, the order of magnitude of electron energy in the beam extraction region (Langmuir gauge meas.) in the beam formation region to ONIX potential well depth are comparable.
- The beam measured with the slit grid method on a converging beams of 30 and 40 mA showed angular anisotropy and clear corelation between the e/H ratio (linked to surface vs. volume H^- origin) and the radial distribution. As the beam intensity was constant, the fraction of surface produced ions should be the cause besides effects of beam optics non linearities.
- In response to the dipole filter field induced symmetry breaking ONIX simulation showed a left right asymmetry of the H^- beam, Beam emission spectroscopy closest to the source (without Einzel lens) confirmed the expected asymmetry. ONIX beam transport to the BES measurement plane is still pending.