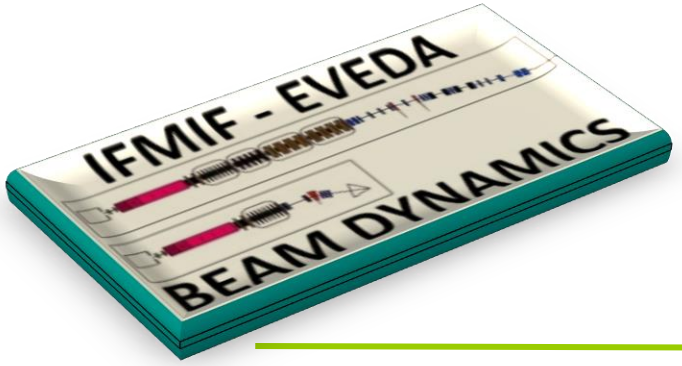
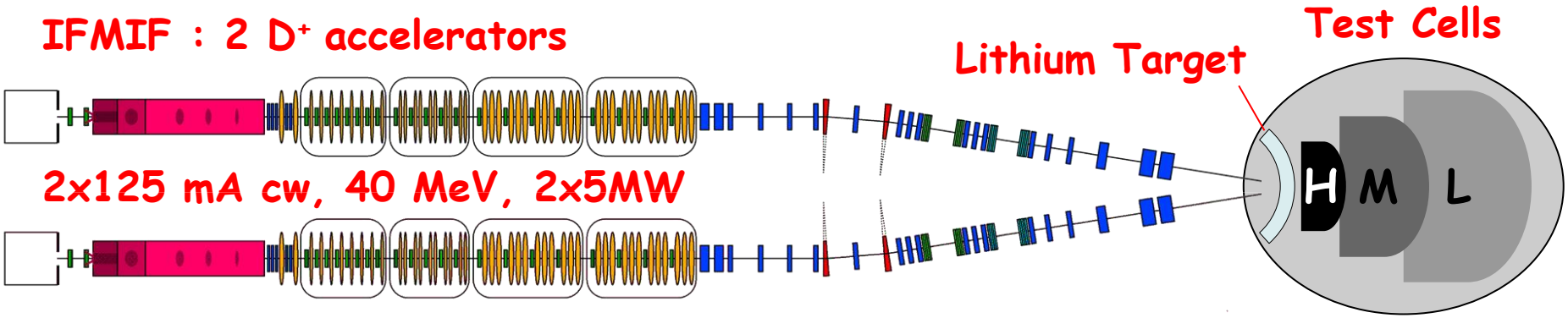
Beam Core-Halo issues

P. A. P. Nghiem, N. Chauvin, W. Simeoni, D. Uriot



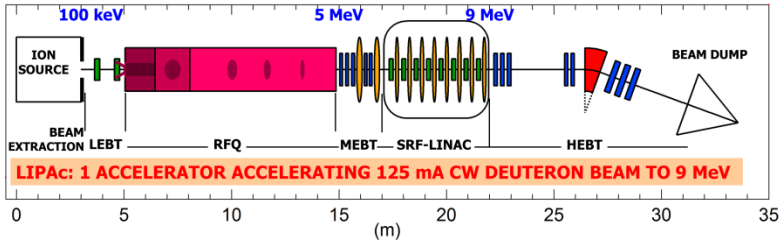
The IFMIF accelerators

IFMIF : 2 D^+ accelerators



2x125 mA cw, 40 MeV, 2x5MW

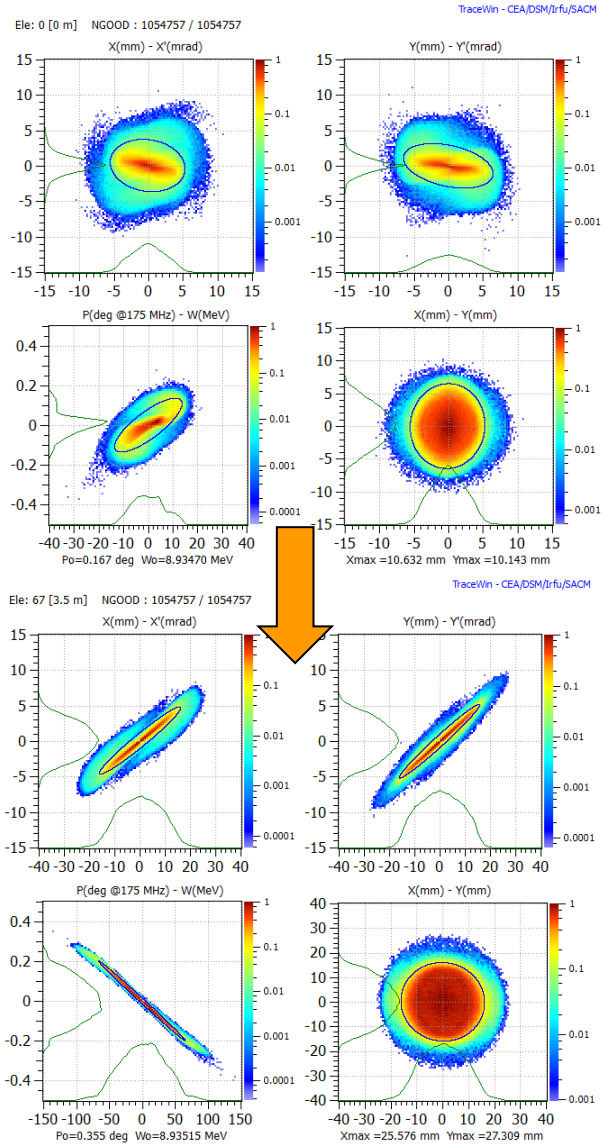
LIPAc: Linear IFMIF Prototype Accelerator



125 mA cw, 9 MeV, 1.1 MW
Under construction by Europe
to be installed in Japan

STRONG SPACE CHARGE REGIME

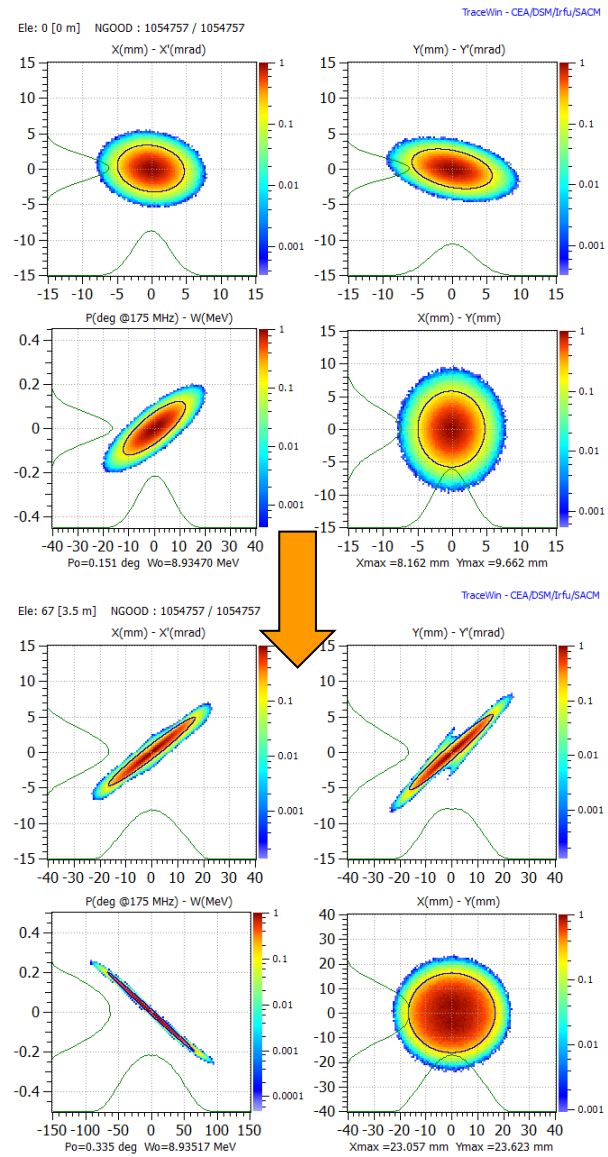
"Nominal" distribution



HEBT entrance exactly same $\alpha,\beta,\gamma,\varepsilon$

3.5 m downstream

Gaussian distribution



STRONG SPACE CHARGE REGIME

IFMIF-LIPAc HEBT: 125 mA CW, 9 MeV

X-X'
ε = 0.3878 mm.mrad (Norm)
β = 1.4773 mm/mrad
α = 0.1201
Y-Y'
ε = 0.3736 mm.mrad (Norm)
β= 2.2011 mm/mrad
α= 0.3689

"Nominal" distribution

HEBT entrance

3.5 m downstream

Gaussian distribution

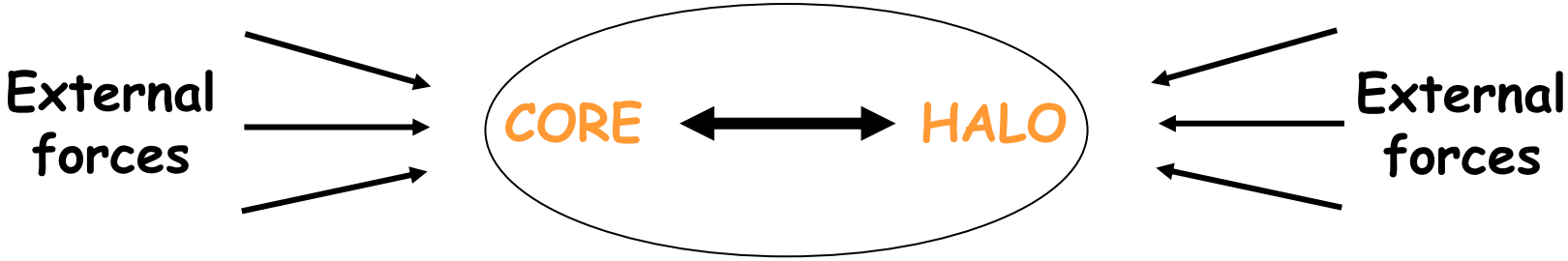
← exactly same α, β, ε

X-X'
ε = 0.4471 mm.mrad (Norm)
β= 14.2841 mm/mrad
α= -4.0765
Y-Y'
ε = 0.3760 mm.mrad (Norm)
β= 16.6333 mm/mrad
α= -5.3326

X-X'
ε = 0.4419 mm.mrad (Norm)
β= 15.4742 mm/mrad
α= -4.3269
Y-Y'
ε = 0.4545 mm.mrad (Norm)
β= 14.0746 mm/mrad
α= -4.5180

CORE - HALO issues (1)

Strong space charge: beam behaviour should be described as



What is CORE? What is HALO?

The CORE remains (implicitly) descibed classically
by $\varepsilon, \alpha, \beta$ → no new description for strong space charge regime
→ may be somehow relevant but clearly not enough

The HALO has been the object of much more efforts
HALO'03: no consensus for a definition of the halo

CORE - HALO issues (2)

HALO Definitions generally based upon
comparison between "far" and "close" beam center

- 4th / 2nd moment (Wangler & Crandall 1998 and Allen & Wangler 2002)
- Emittances (n sigmas) / (1 sigma)

→ an idea of the relative importance of the halo

Inconvenience:
- abstract parameter
- not a value specifying the halo itself
- decide in advance where should be the halo, where should be the core

CORE - HALO issues (3)

CORE can be described by Emittance ?
But which emittance ? rms, 60%, 80%, 90% ?

What is HALO? precisely and quantitatively?
- Lattice design or specific tuning to minimise halo, but which one?
- We want to measure the halo, but which part of the beam is it?

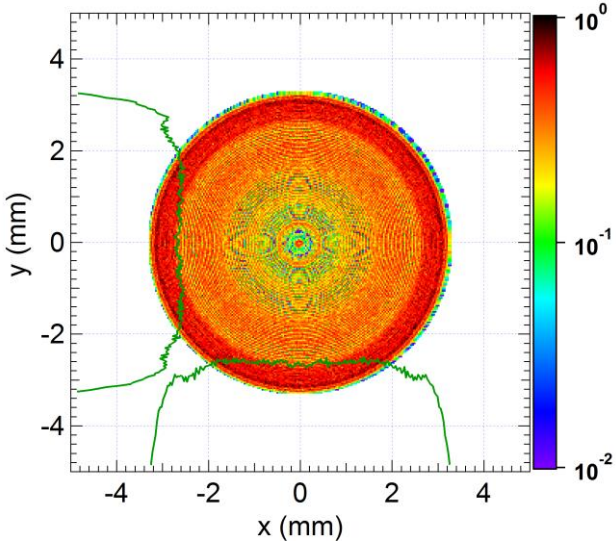
Is there a connection between CORE and HALO growths?

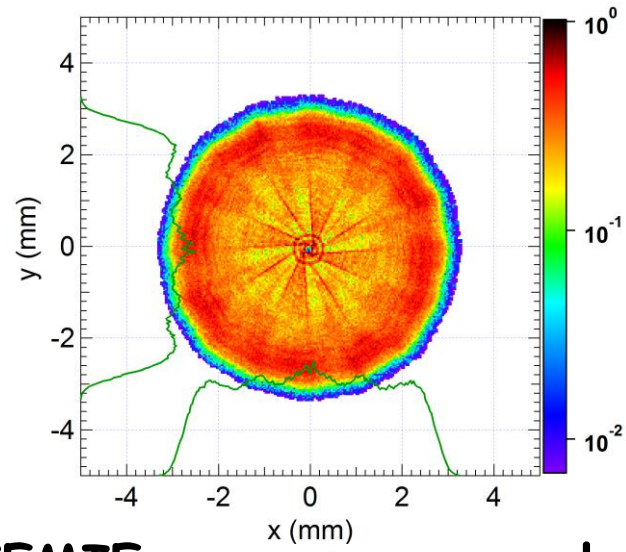
A clear definition of CORE / HALO is missing

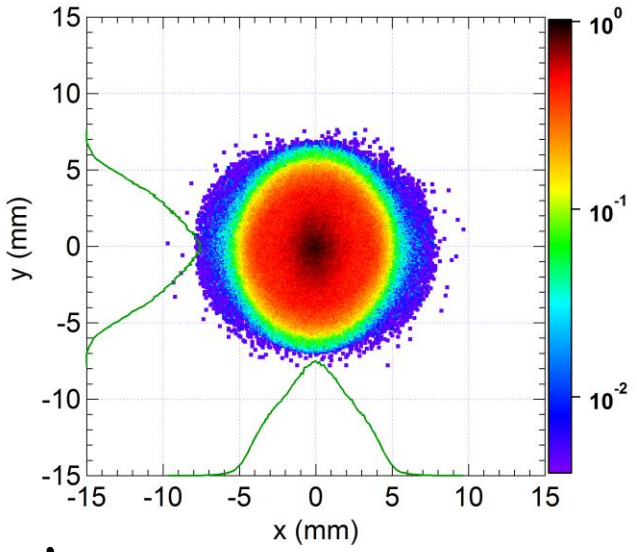
Yet, intuitively, beam profile → CORE and HALO parts can be easily identified

Only the limit between them is not precisely, quantitatively defined.

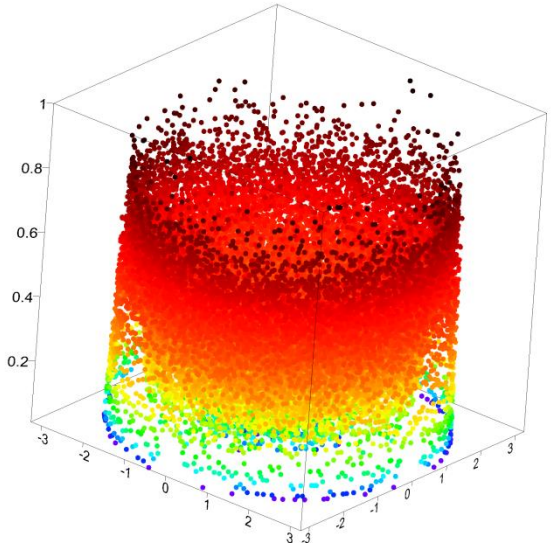
Various situations

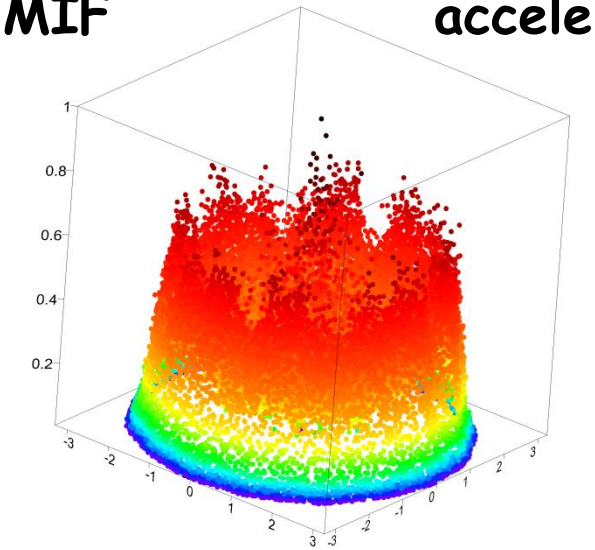


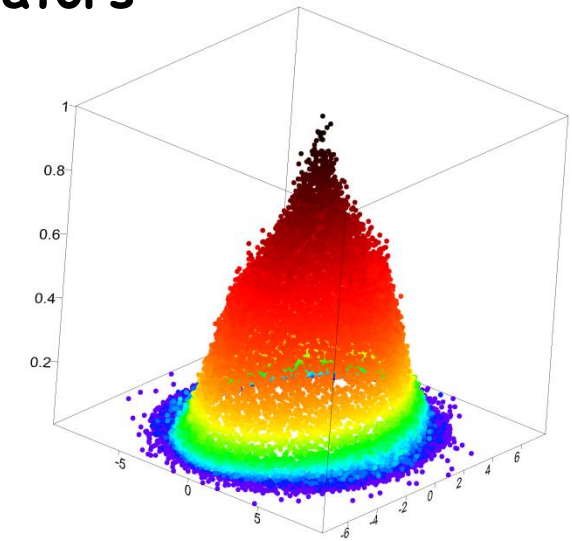




IFMIF accelerators







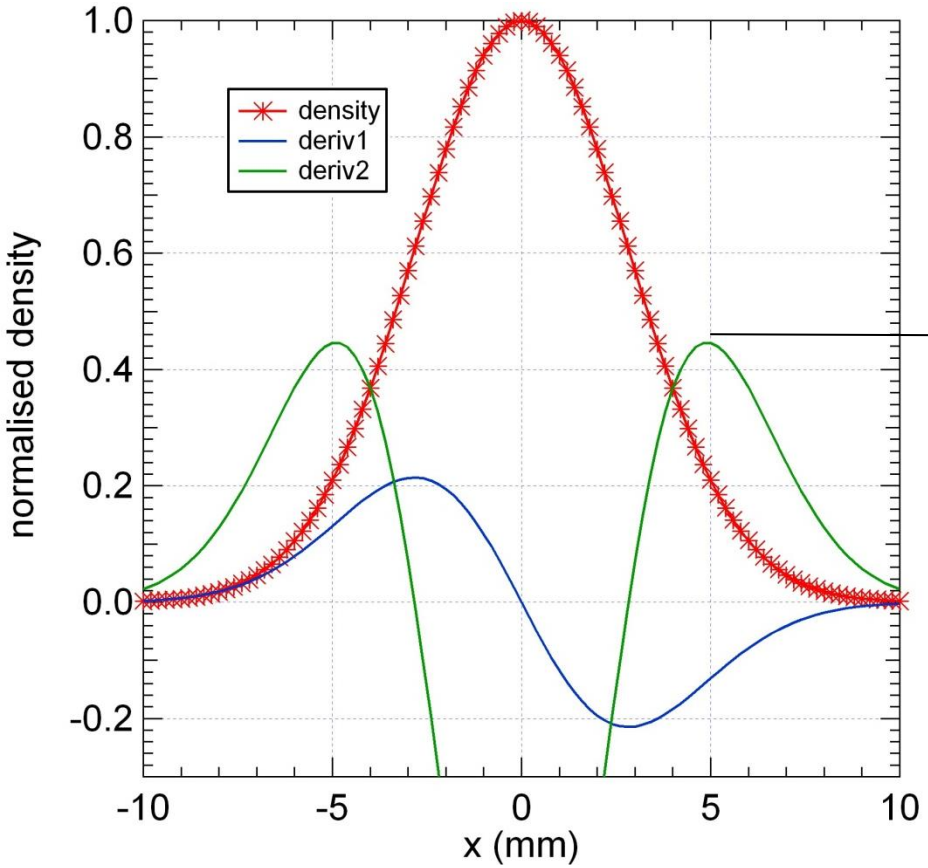
Physics of two "gas" of particles

CORE = much more dense, HALO = much less dense
For a gas of particles where there is a continuously varying density gradient, we can consider that this gas is composed of two different parts:
when there exists a border between them
→ where the gradient variation is the steepest
→ where the second derivative of the density is maximum.

The diffusion equation
$dn/dt = D\Delta n$
states that the diffusion is maximum where the Laplacian of the density is maximum: this is the border between the two parts

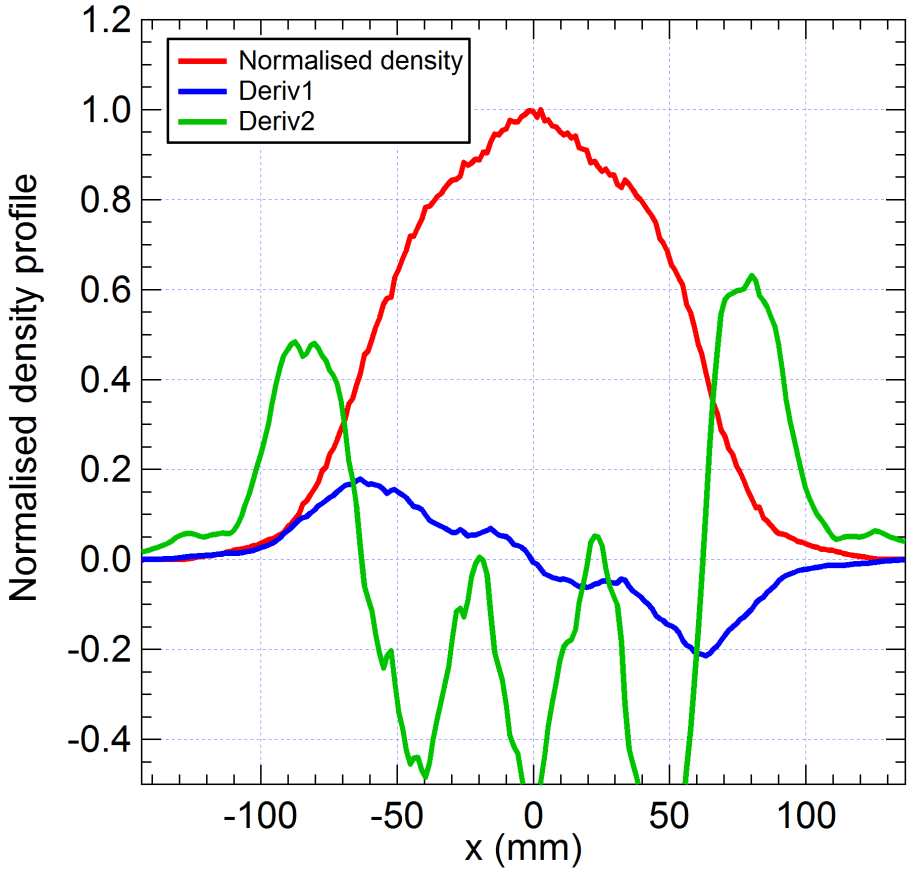
1 dimension: max of the second derivative
n dimensions: max of the Laplacian

Example: Gaussian profile



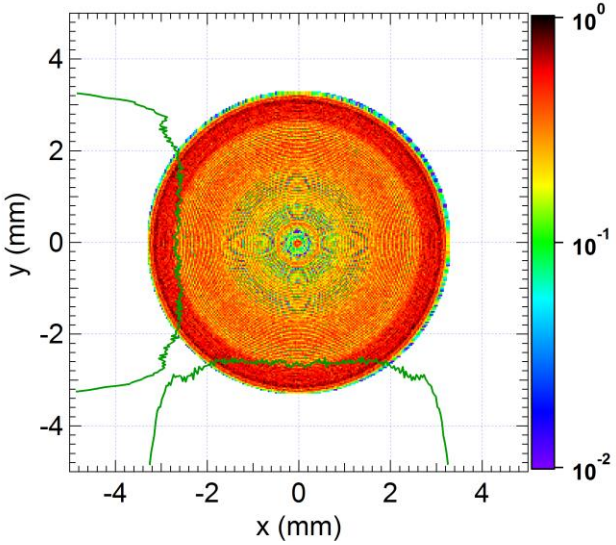
$\sigma\sqrt{3}$

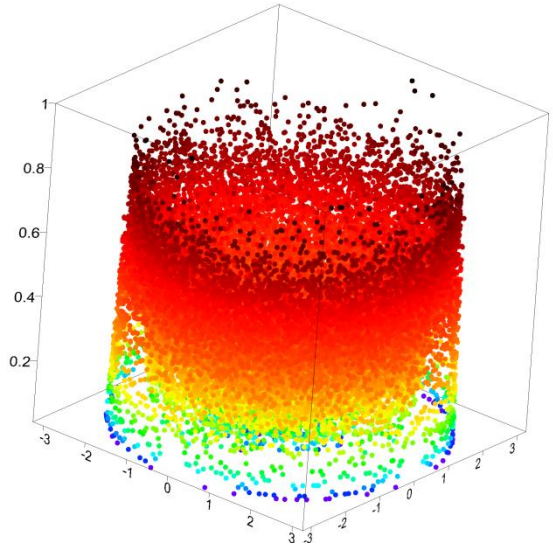
Other Example

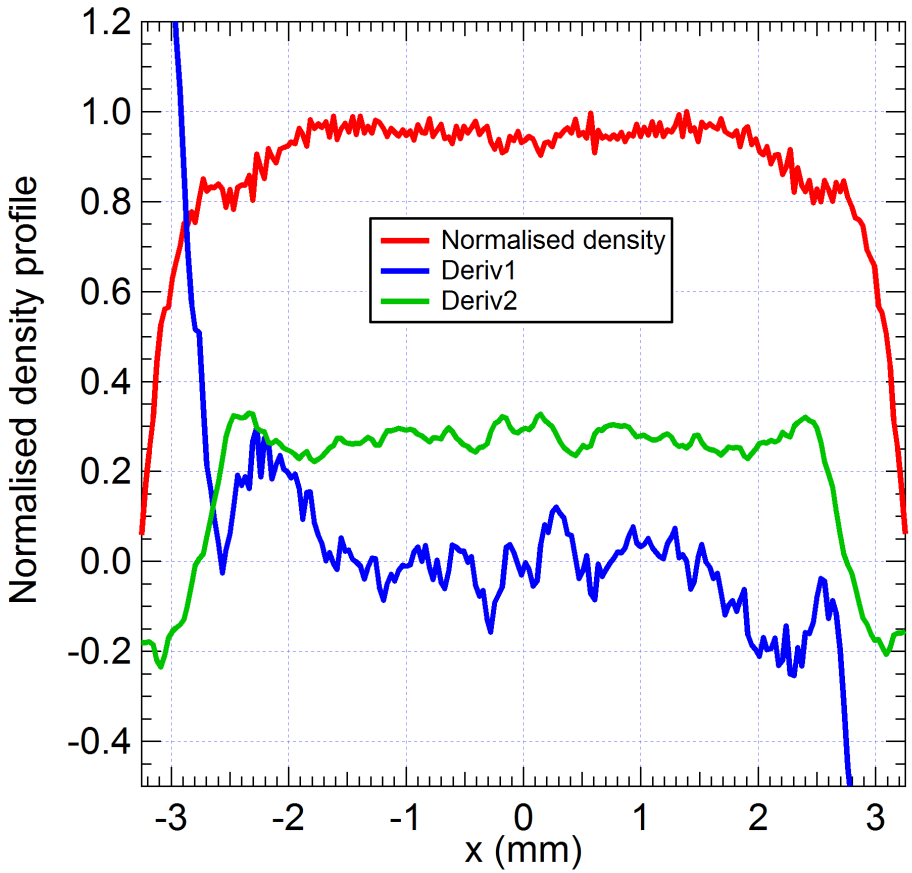


Caution: numerical derivative ! Use average of 10 derivatives

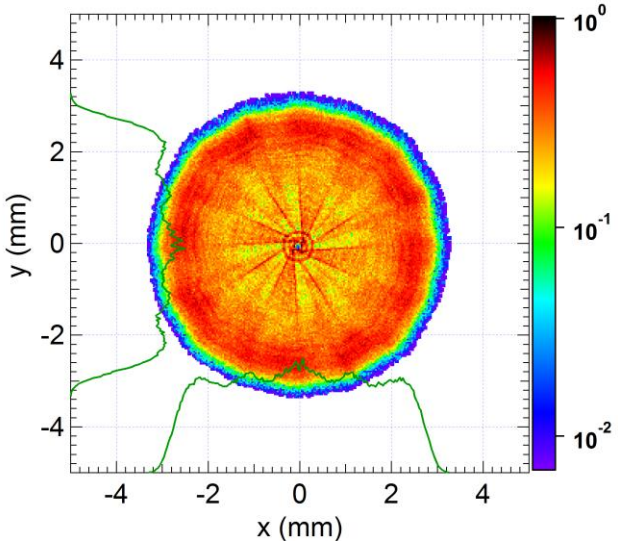
Extraction output

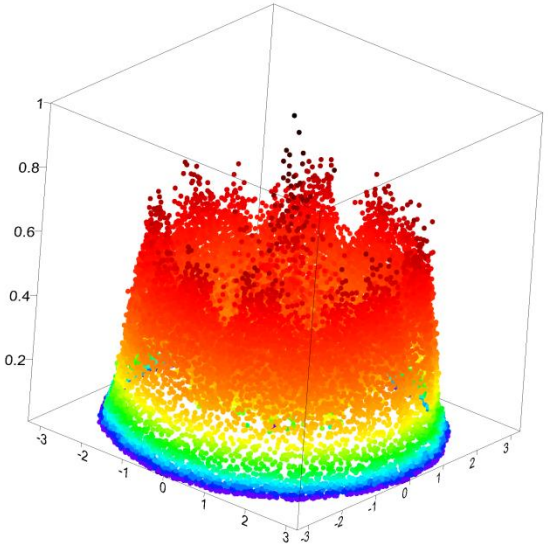


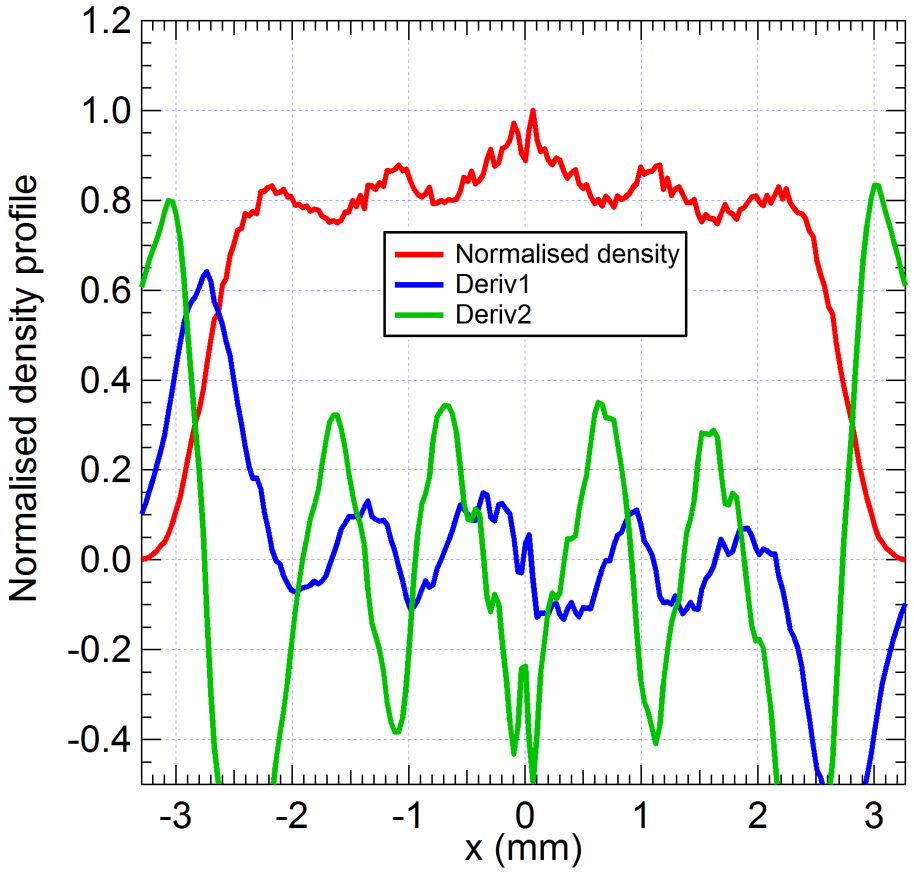




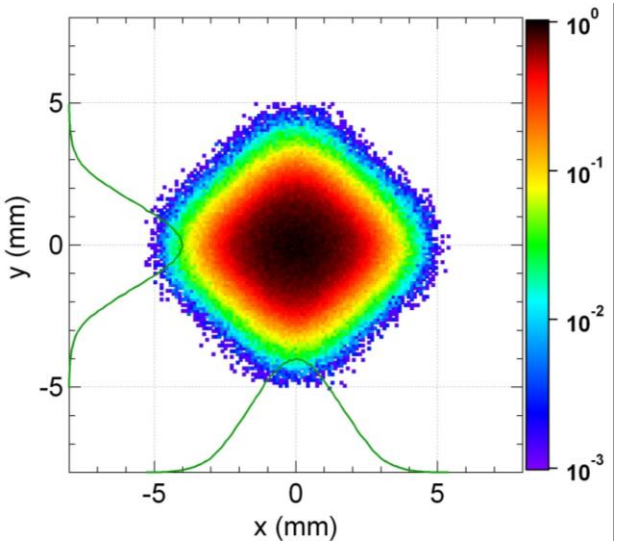
LEBT output

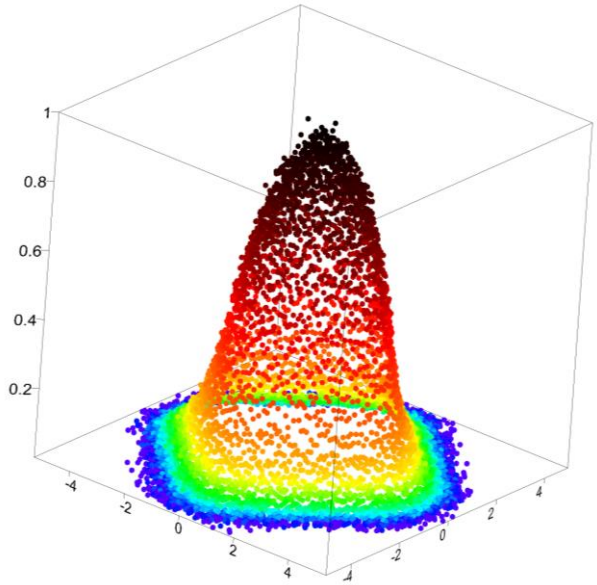

y (mm)
x (mm)
10^0
10^{-1}
10^{-2}

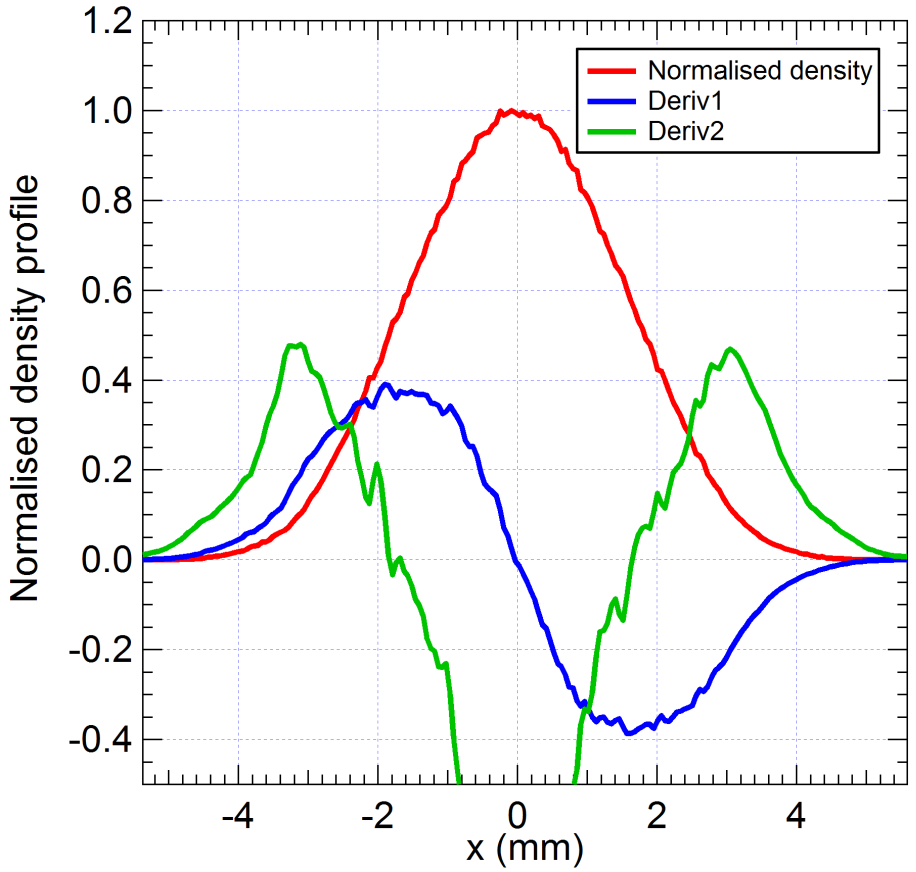



Normalised density profile
x (mm)
Normalised density
Deriv1
Deriv2

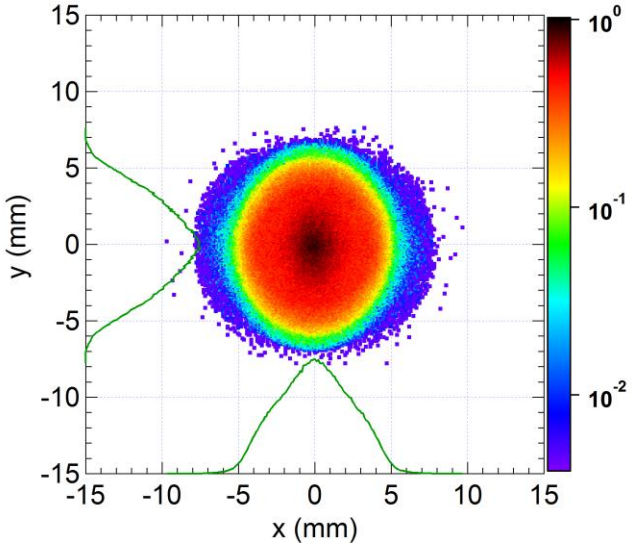
RFQ output

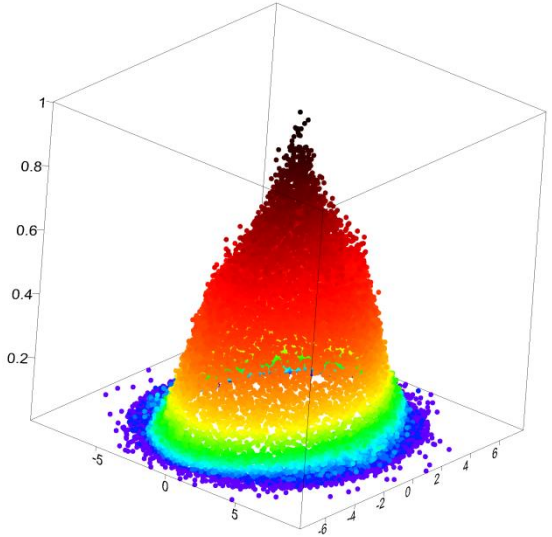

y (mm)
x (mm)
5
0
-5
-5
0
5
10^{0}
10^{-1}
10^{-2}
10^{-3}

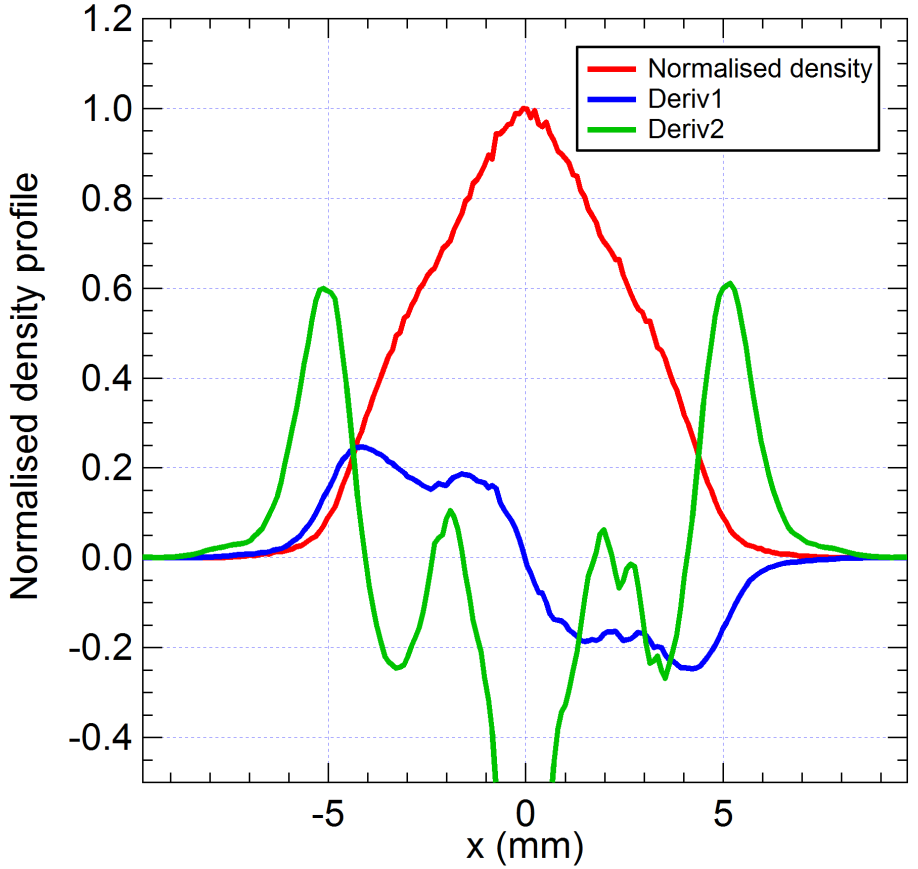

1
0.8
0.6
0.4
0.2
-4
-2
0
2
4


Normalised density profile
x (mm)
Normalised density
Deriv1
Deriv2
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-4
-2
0
2
4

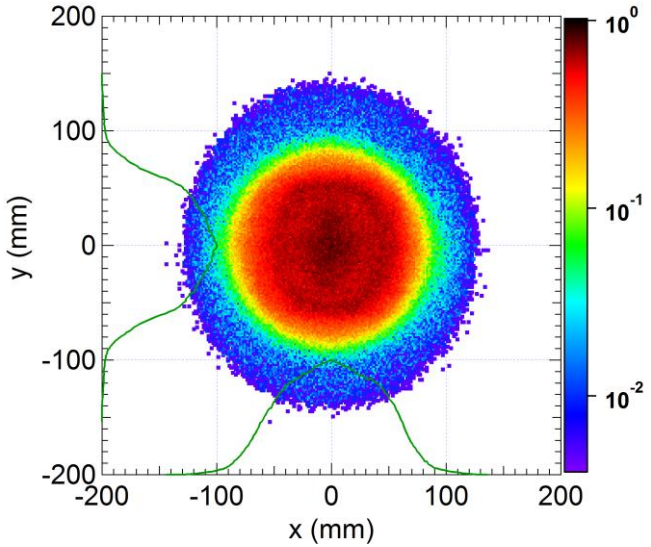
SRF Linac output (IFMIF LIPAc)

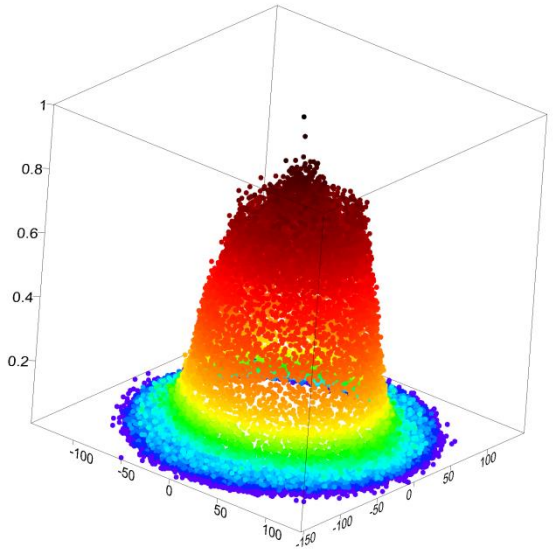


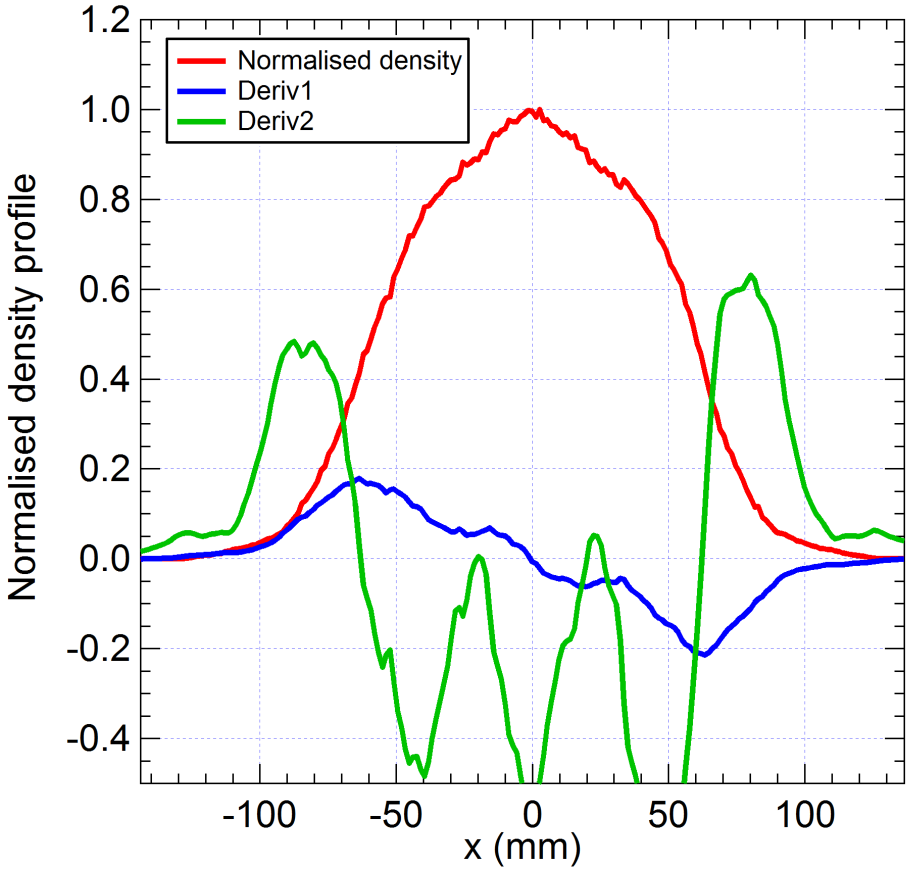




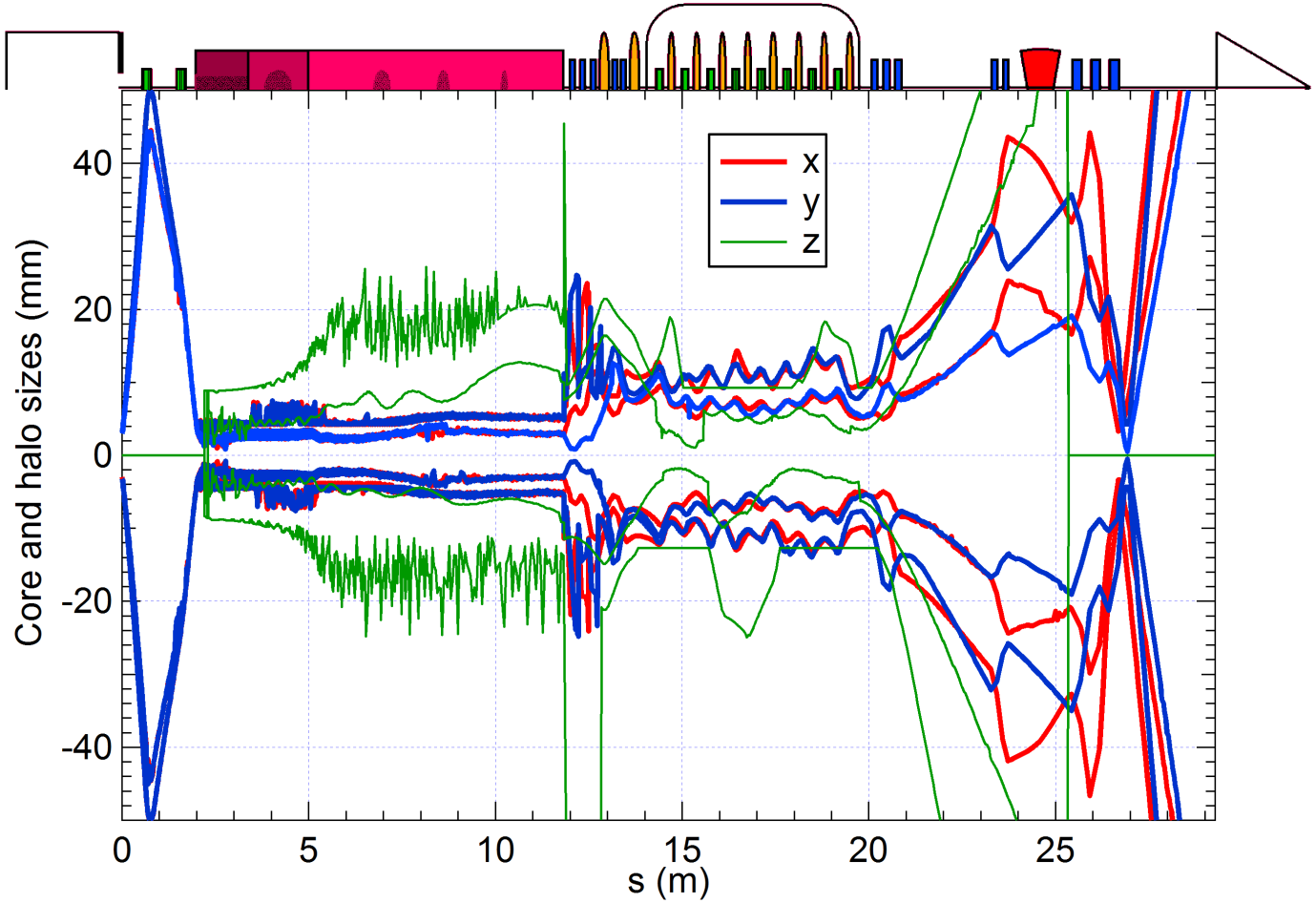
At the beam dump (IFMIF LIPAc)







Start-to-End IFMIF LIPAc

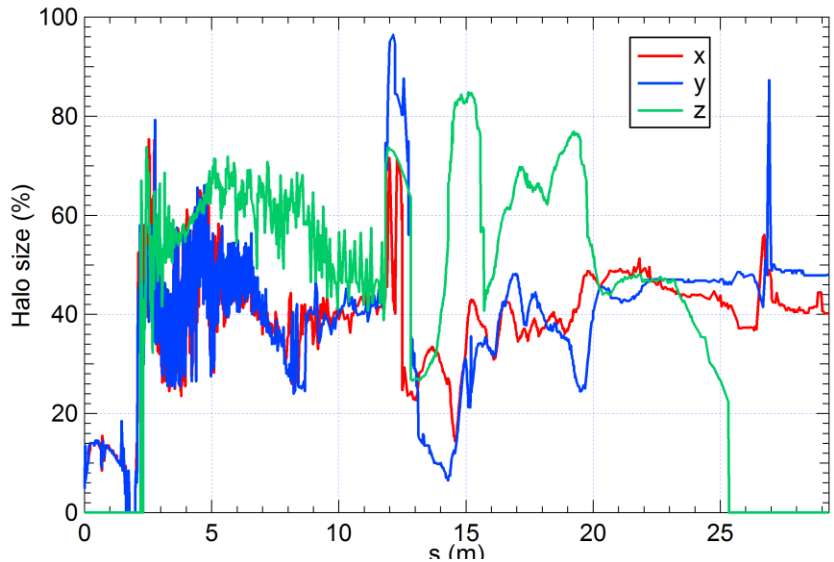


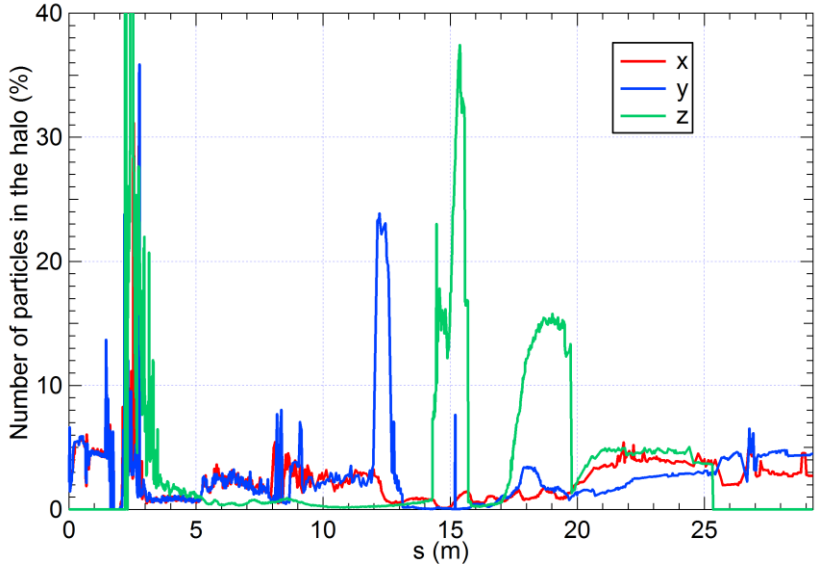
Once the limit core-halo is defined, the halo can be chracterised by

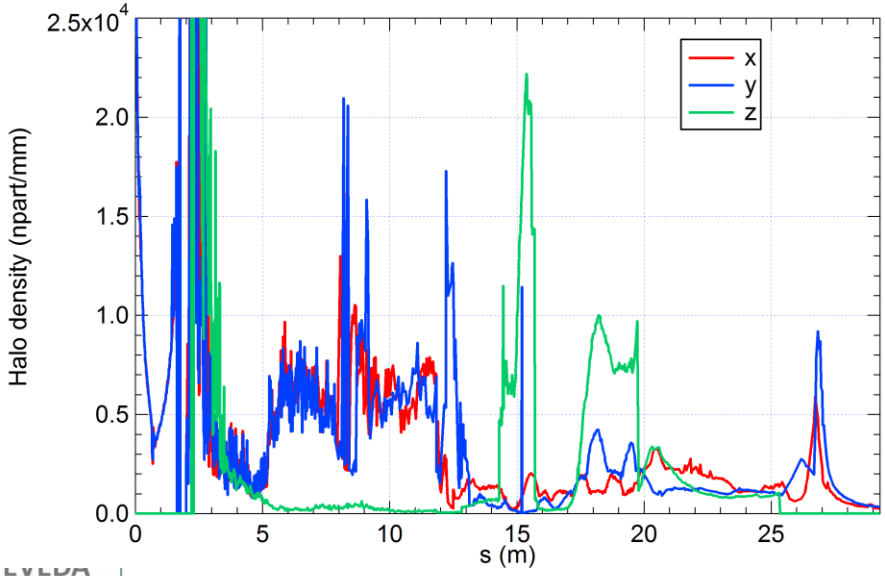
→ its total size or its size / whole size

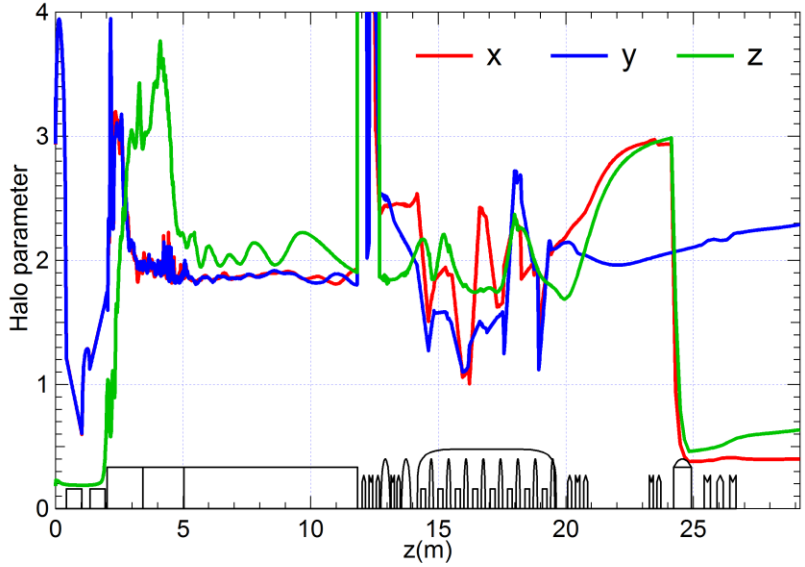
→ the number of particles within it / whole number of particles

Start-to-End
IFMIF LIPAc



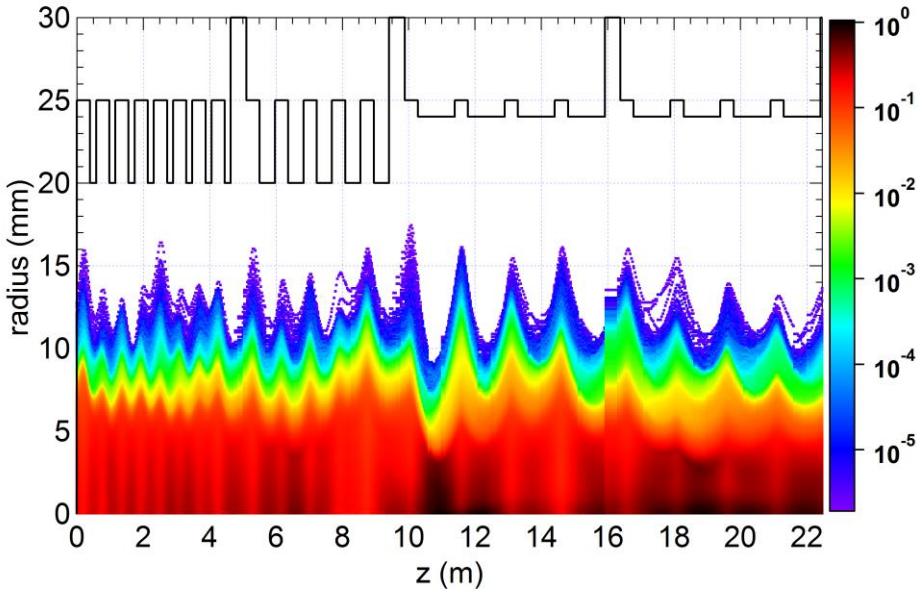


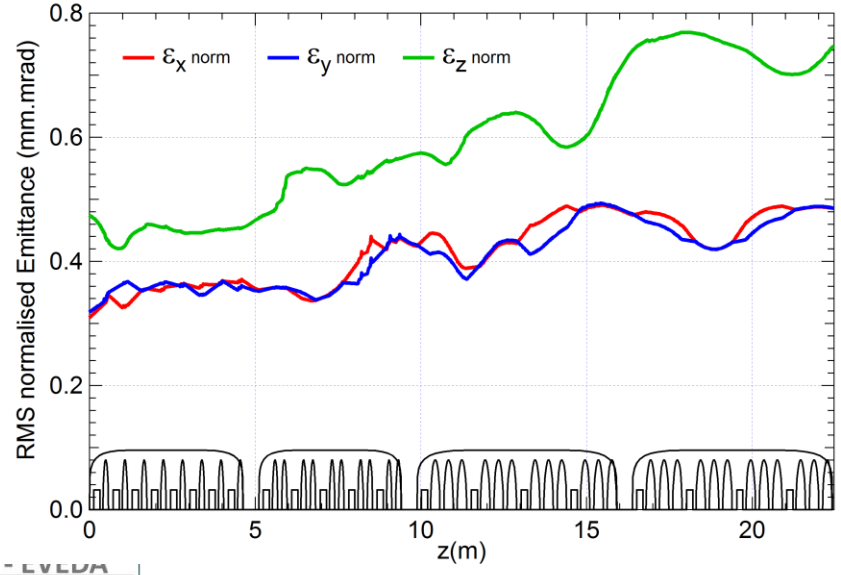




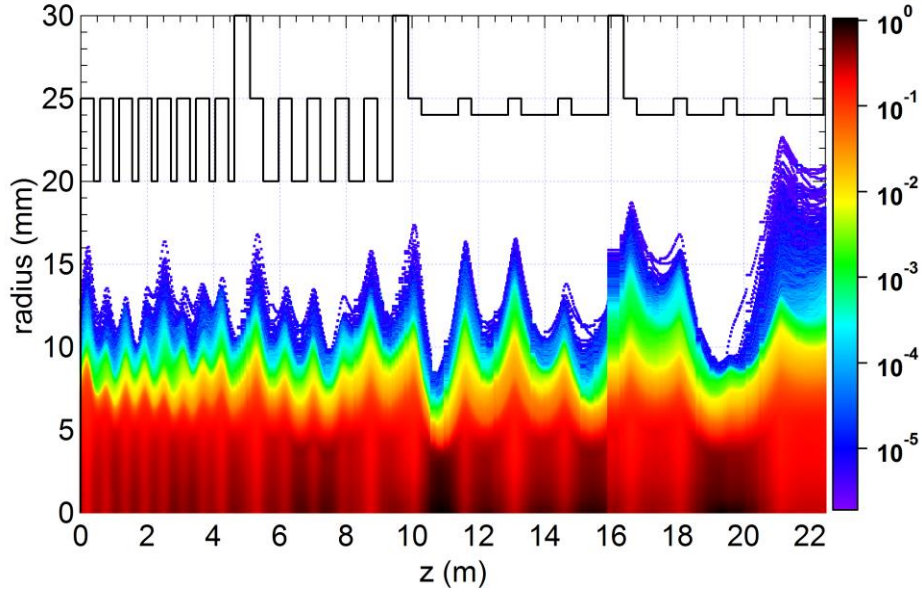
IFMIF- SRF Linac

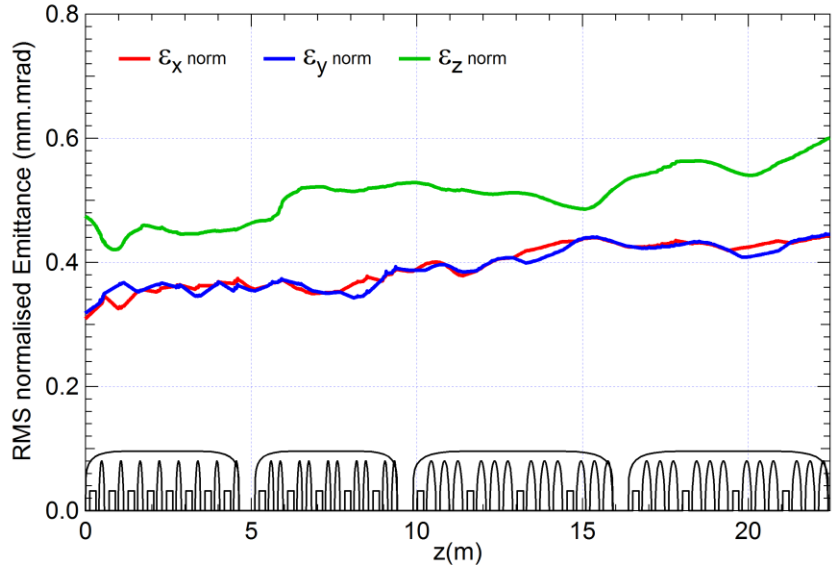
Nominal case





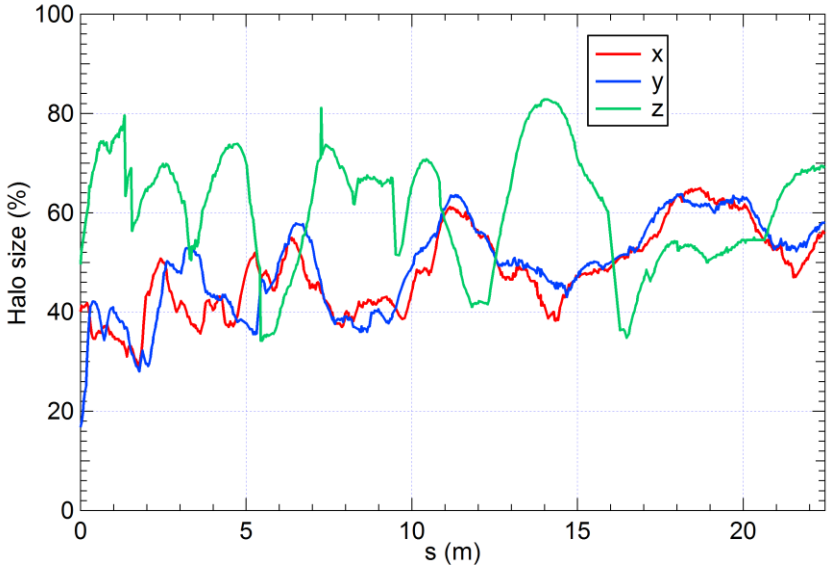
Explored case

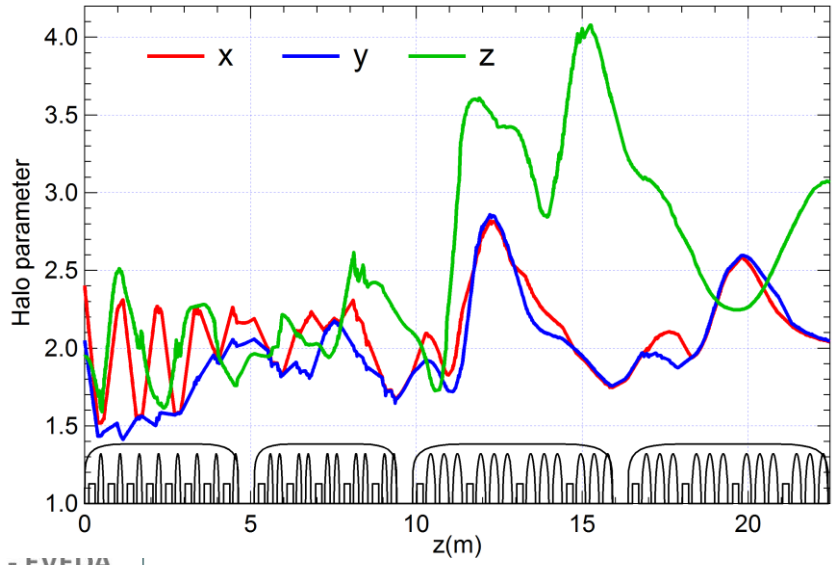




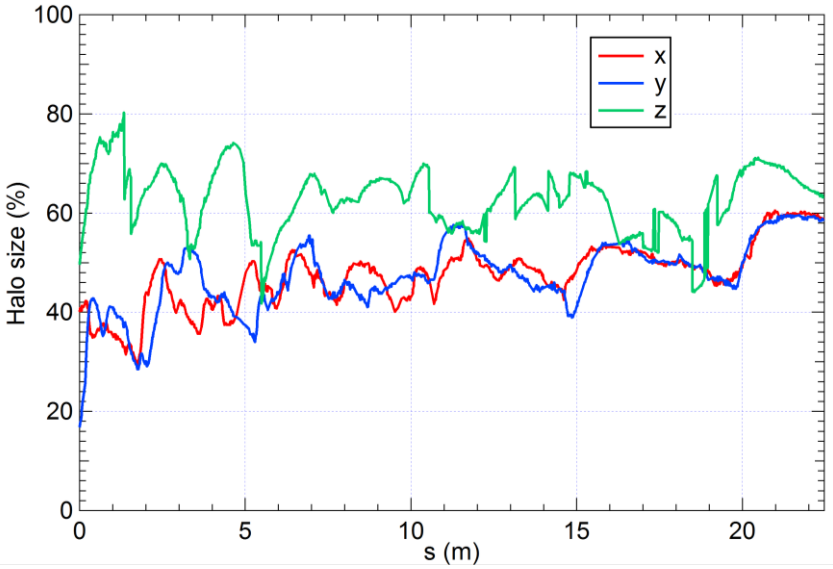
IFMIF- SRF Linac

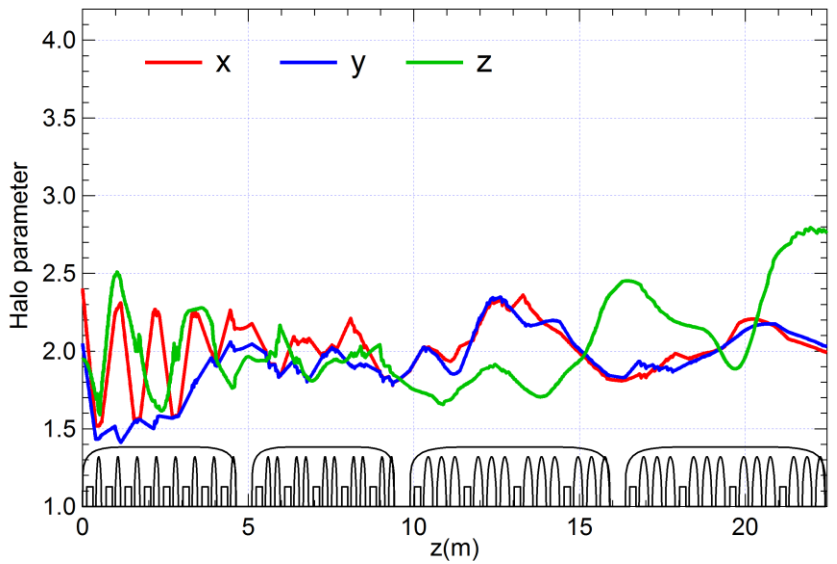
Nominal case





Explored case





FIRST conclusions

- Connections between Core/Halo and Emittance are not obvious

- Halo size (%) or NbrPart (%) within the halo, or Halo density seem to be more relevant than Emittance or Halo parameter

- Deifinition of "Core emittance" to be further explored

- Noisy

All simulations have been made with TraceWin code