Dark Current Simulations

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- DC simulations using periodicity
- DC simulations using full field
- DC simulations with asymmetric emission
- Conclusions

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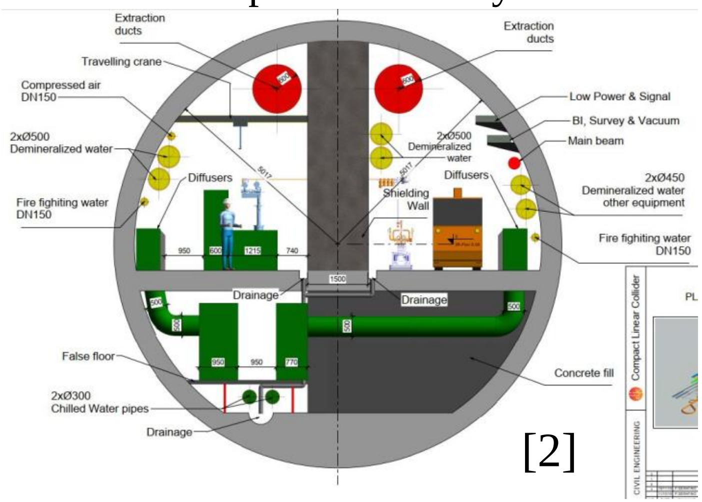
Introduction

Motivation

Radiation issue

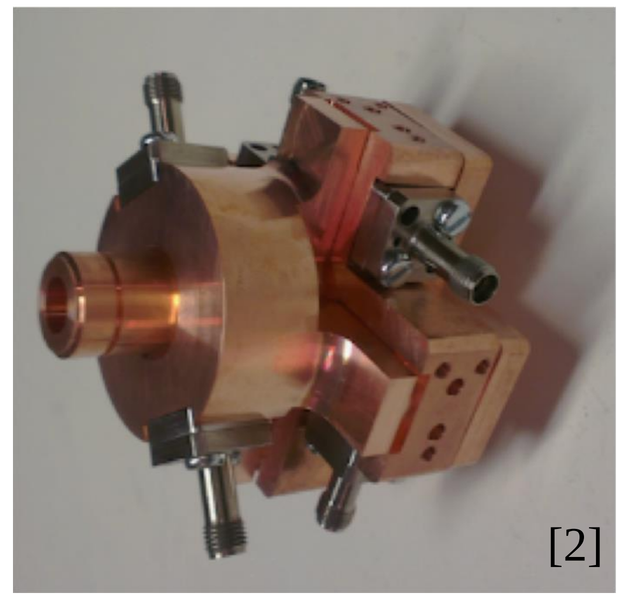
FE electrons accelerate through the structures and can reach energies of the order of 10 MeV. Later collision with material walls produces X-ray radiation.



Cross section of the tunnel for the 380 GeV Klystron based CLIC. Structures for this stage are different prototypes, with 72 MV/m gradient instead of 100 MV/m.

Possible BPM distortion

Asymmetric emission in the irises can lead to a not centered DC bunch that may have a bigger impact in the BPM readings, compared with the supposed homogeneous emission.

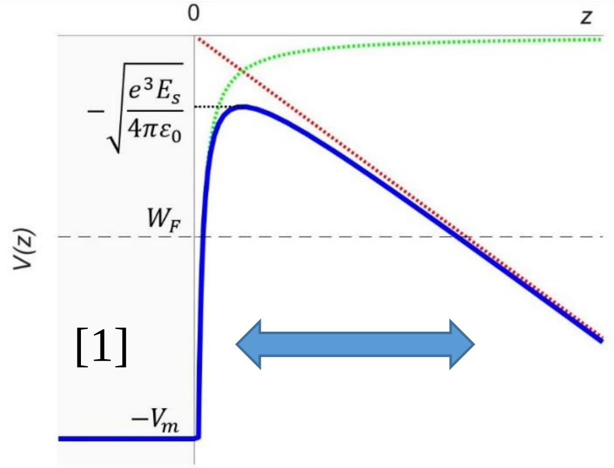


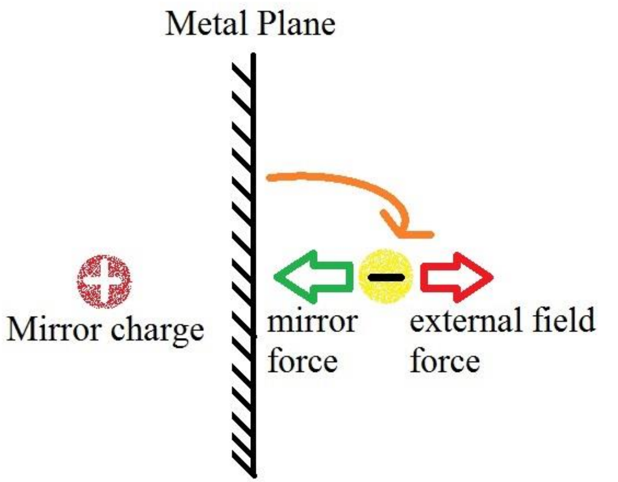
[2] CLIC Project Implementation Plan. CERN. 2018.

Introduction

Dark Current

It is originated by field emitted electrons that couple to the RF and start to bunch.

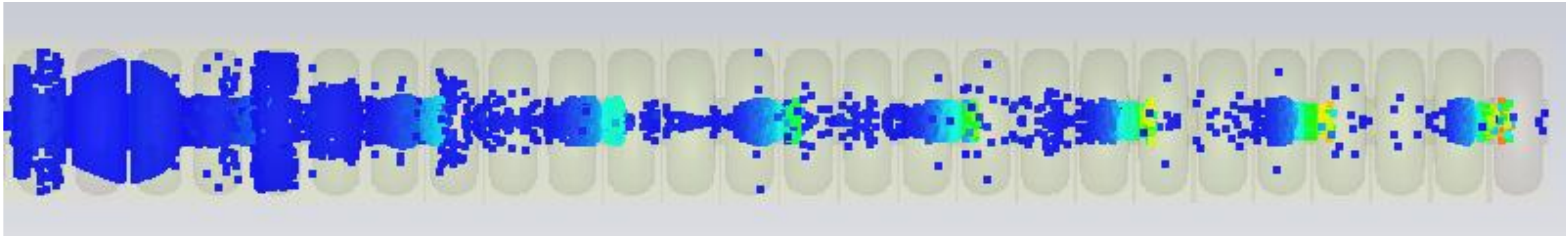




Fowler Nordheim

$$J = aE^2 e^{\frac{-b}{E}}$$

Quantum tunneling of the potential barrier gives an electron current



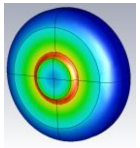
[1] Jorge Giner Navarro. Breakdown studies for high gradient RF warm technology in: CLIC and hadrontherapy linacs. PhD thesis, Universitat de València, 2016.

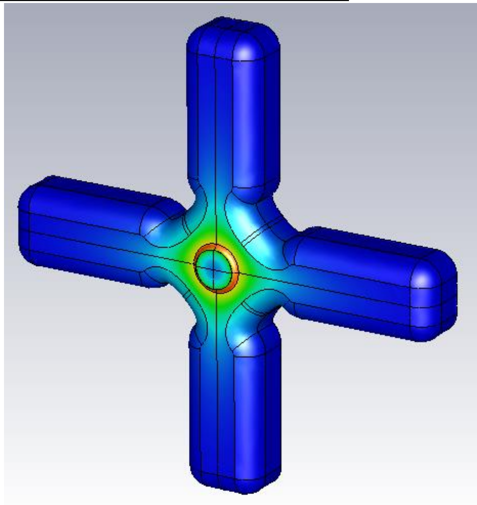
Introduction

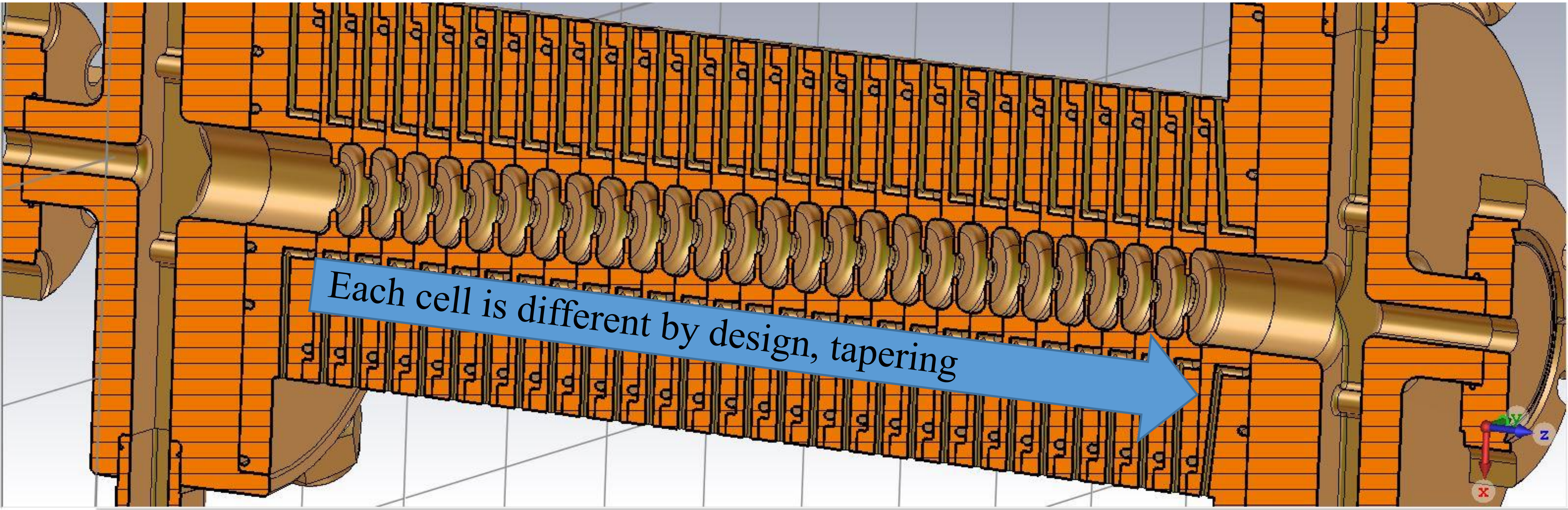
Choosing T24PSI

- There is a good variety of CLIC prototype accelerating structures, one can mainly distinguish between the T series (undamped) and the TD series (damped) with damping waveguides for HOM absorption.

- T24 PSI is undamped so it needs less calculation volume in the simulations. It is a structure that performed very well in the high power test stands during conditioning, and was the one installed when performing radiation measurements, simulation was required.





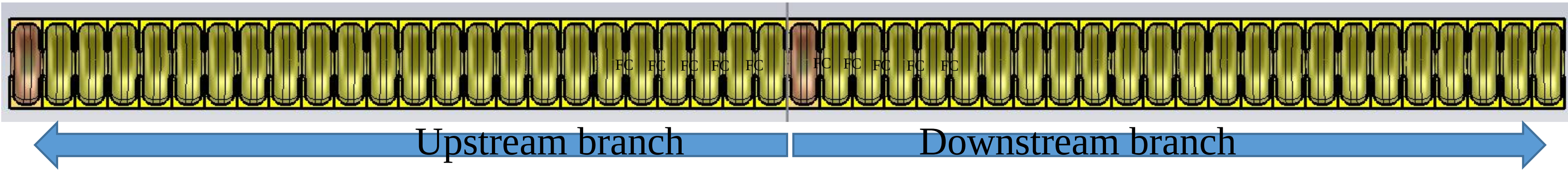


Introduction

Types of DC simulations in CST - Particle In Cell

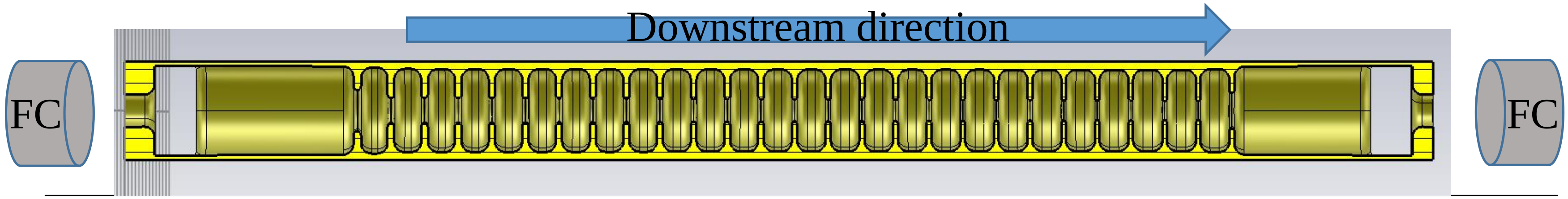
Periodic structure simulation

- The EM fields of 1 cell (Eigenmode solver) are imported and replicated using Floquet theorem with 120º of phase advance.
- Only 1 iris emitting, the central one, and the particles are analysed with a 2D monitor in each one of the other irises. It provides clean information about the charge propagation along the structure.



Full field simulation with tapering

- The EM fields of the hole structure (Frequency Domain Solver) are imported.
- One can choose which iris to set on, for analysing the Upstream and Downstream behaviour.
- For a realistic simulation all 27 irises are emitting (2 coupling + 25 accelerating irises). The particles are analysed with a 2D monitor in the position of the Faraday Cups.



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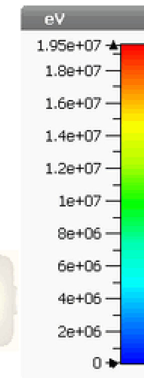
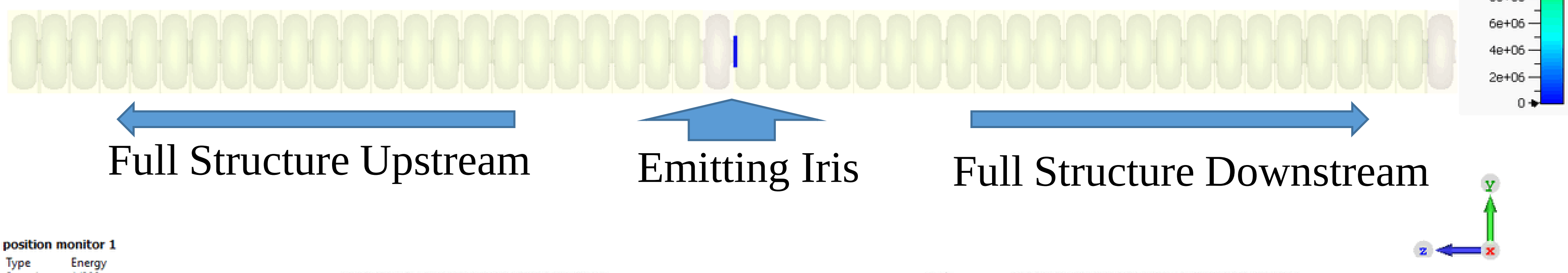
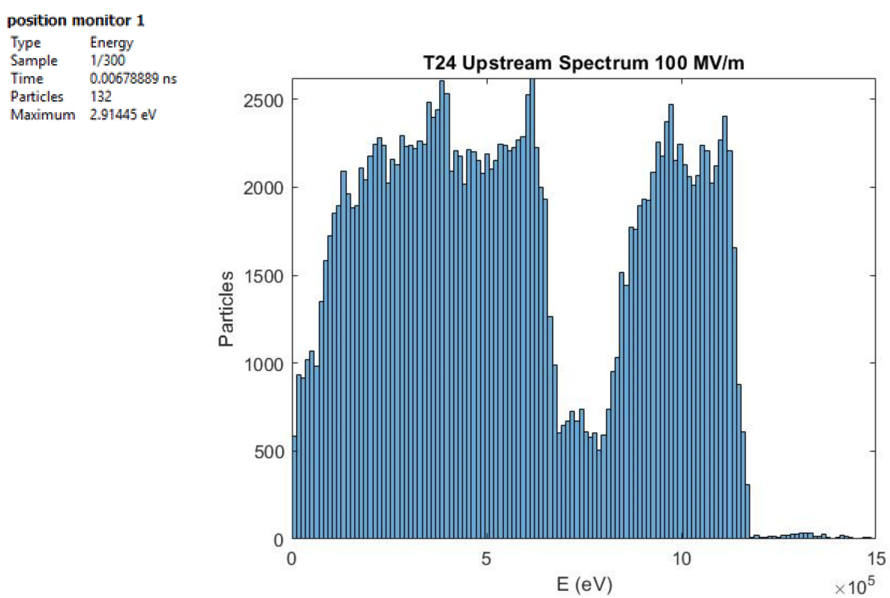
DC simulations using periodicity

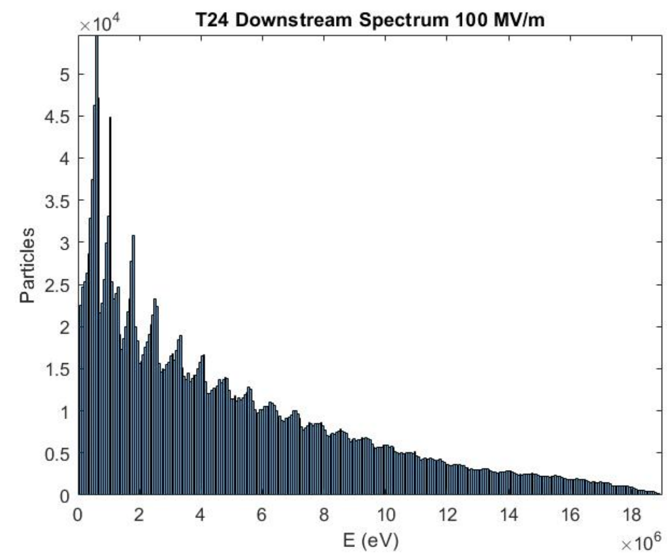
T24PSI - Simulation and energy espectrums

Gradient = 100 MV/m



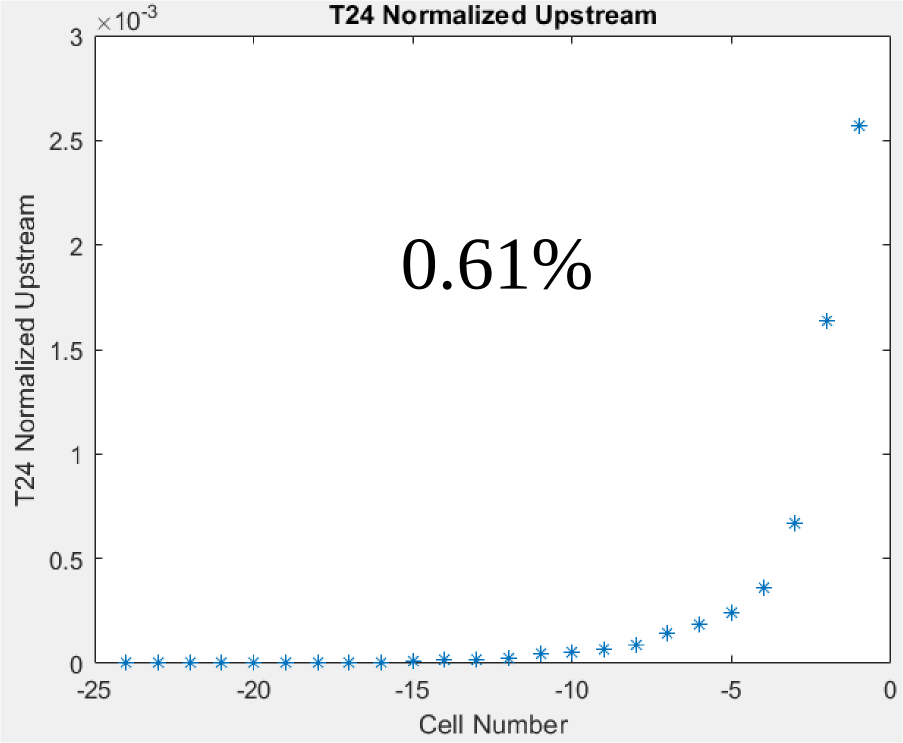


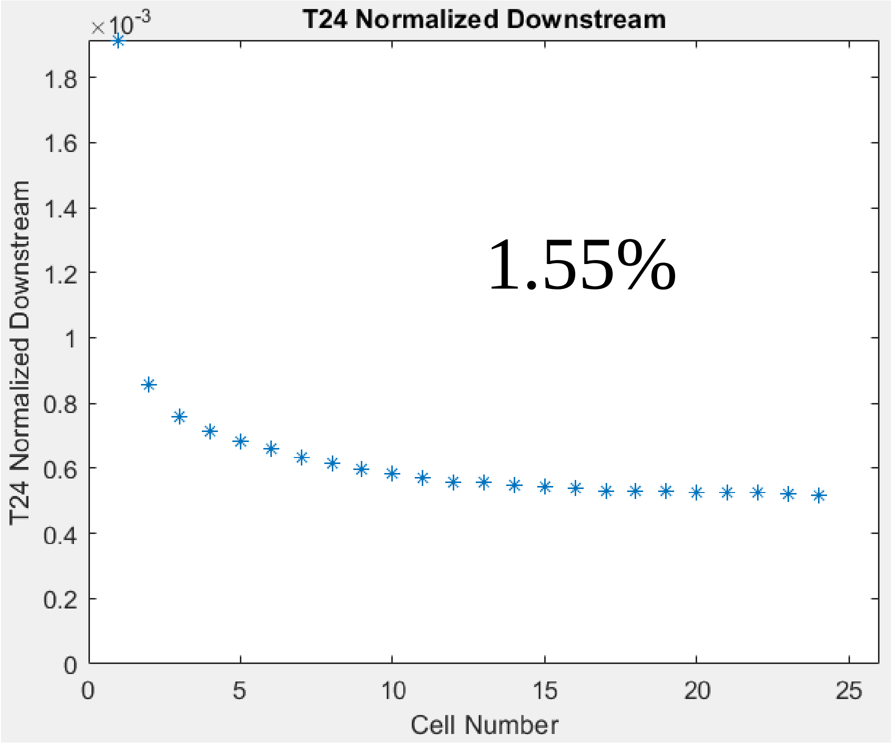


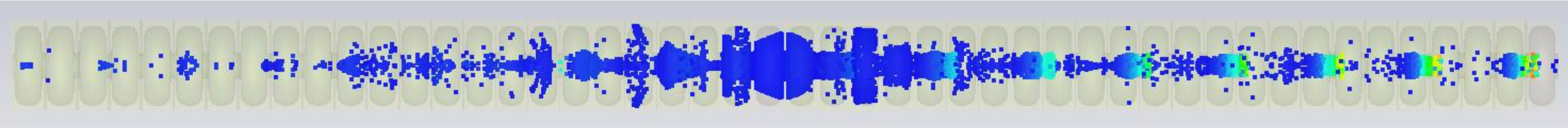


DC simulations using periodicity

T24PSI - Current along the structure

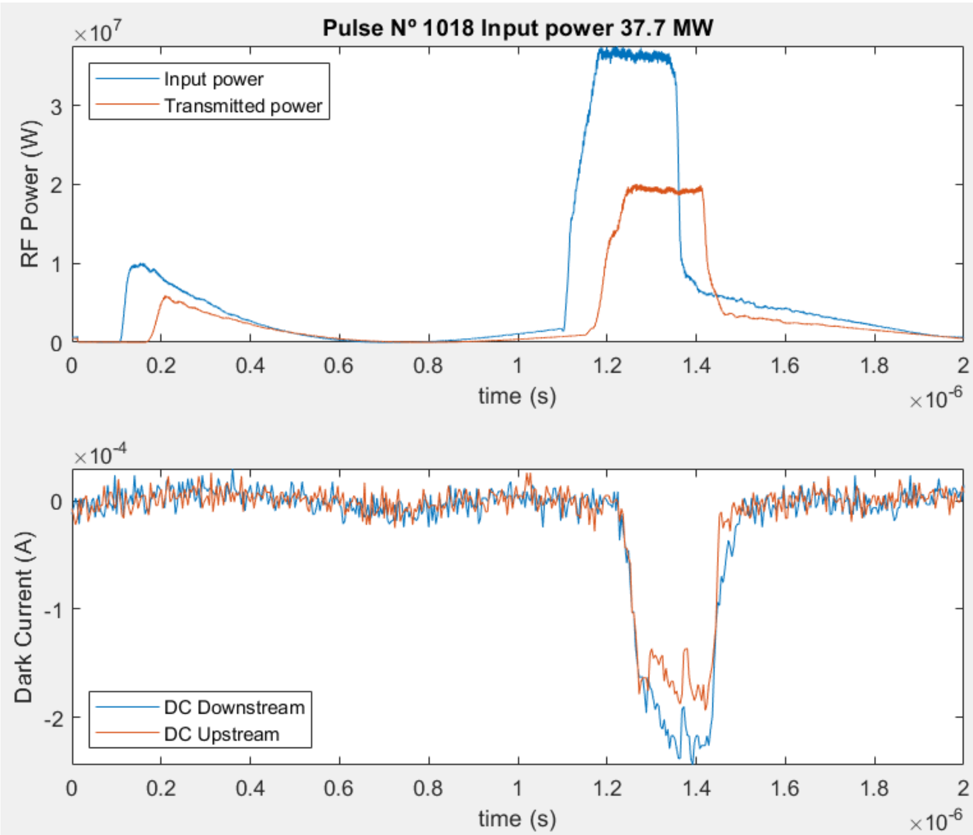






DC simulations using periodicity

T24PSI Normal measurement at 100 MV/m (37.7 MW)



According with the simulation one expect the ratio between currents in the Faraday Cups Upstream and Downstream to be around 39% :

$$\frac{FC_{US}}{FC_{DS}} = \frac{0.61\%}{1.55\%} = 0.39$$

However, in the DC measurements we made at Xbox 2 the ratio is higher. Comparing the integral average in the same time window:

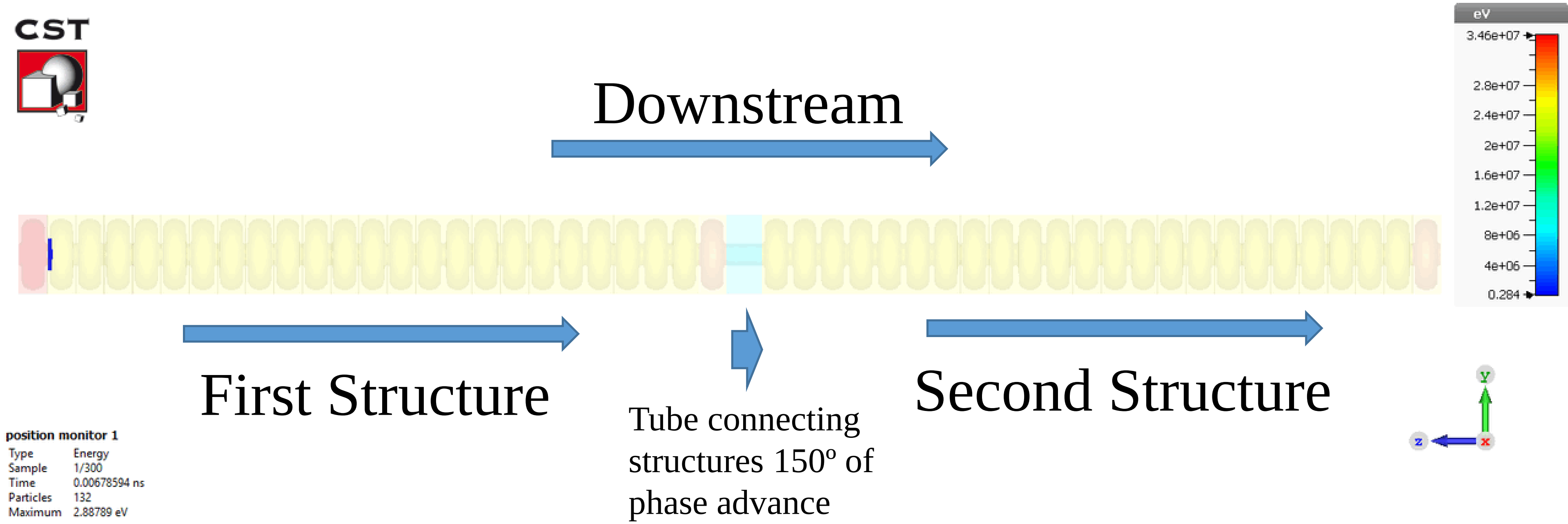
$$\frac{DC_{US}}{DC_{DS}} = \frac{-1.6024 \cdot 10^{-4} A}{-1.9871 \cdot 10^{-4} A} = 0.81$$

There is a big discrepancy between the simulation and the experiment, it may have to do with an underestimation of the emitting cells closer to the FC or the Upstream capture level.

DC simulations using periodicity

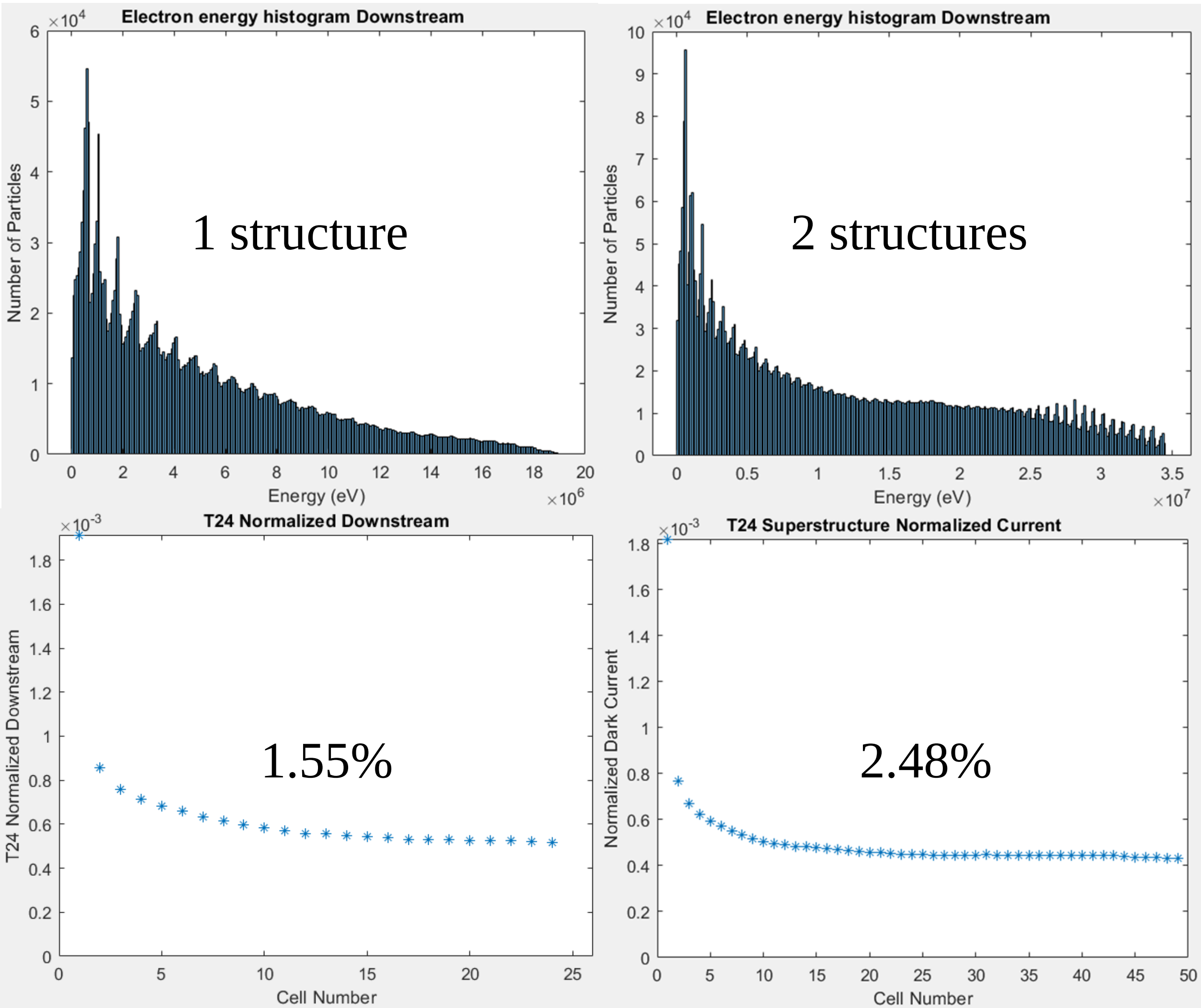
T24PSI double structure

- First approach to the simulation of the DC in a CLIC superstructure.
- RP Group at CERN need this information for estimating the radiation generated during the conditioning of a CLIC module, for the estimation of the length of the shielding wall between machine and operators inside tunnel.
- Xbox 2 is currently being adapted for testing the first superstructure.



DC simulations using periodicity

T24PSI double structure



The energy is not doubled but is close to that:

$$ratio = \frac{35\ MeV}{19\ MeV} = 1.84$$

The inefficiency can be related with the transition between structures.

The current is not doubled neither. One can see how the first cells have a bigger contribution to the integral value than the steady state reached later.

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    - Downstream/Upstream comparison
    - All irises emitting
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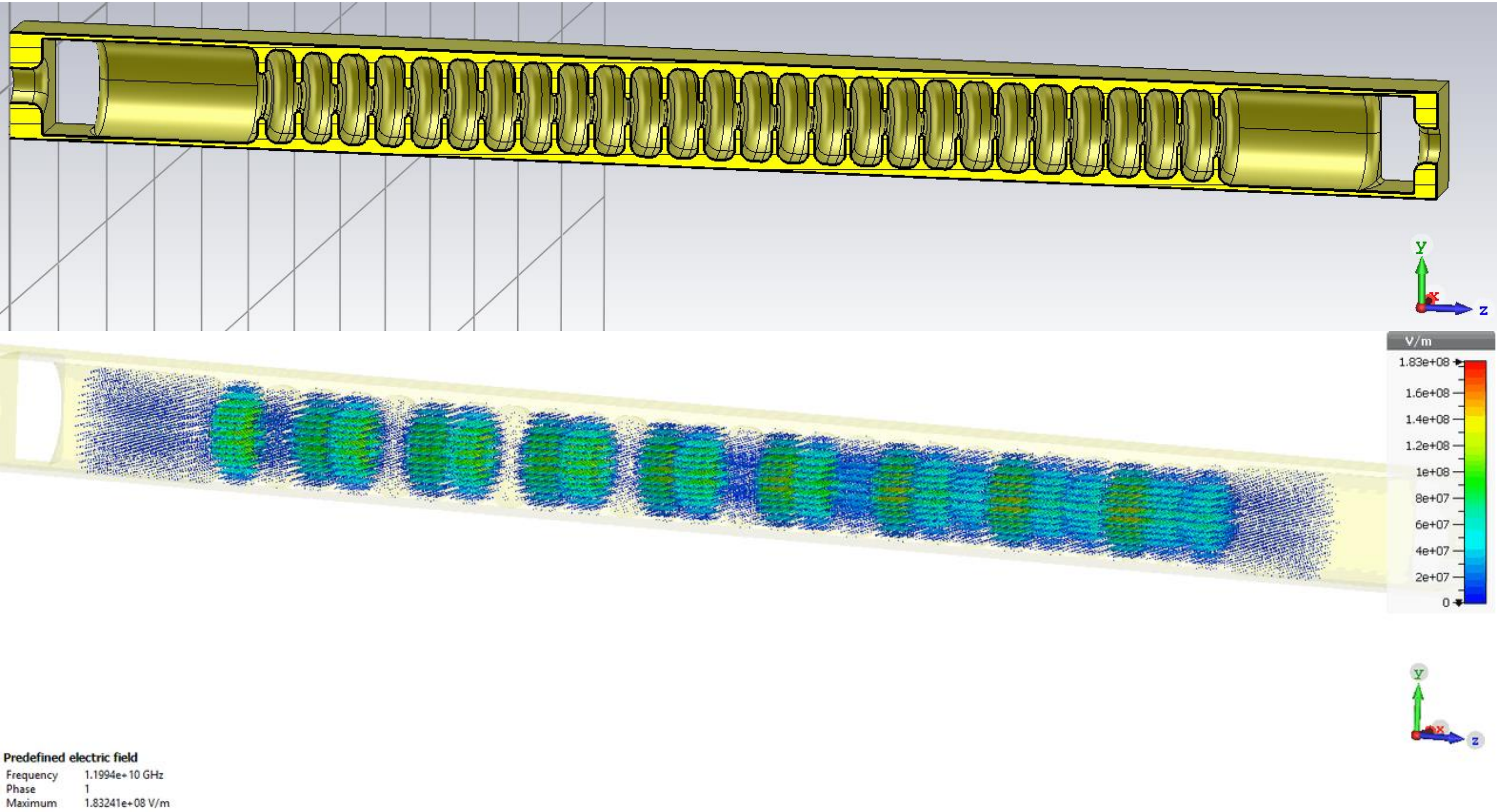
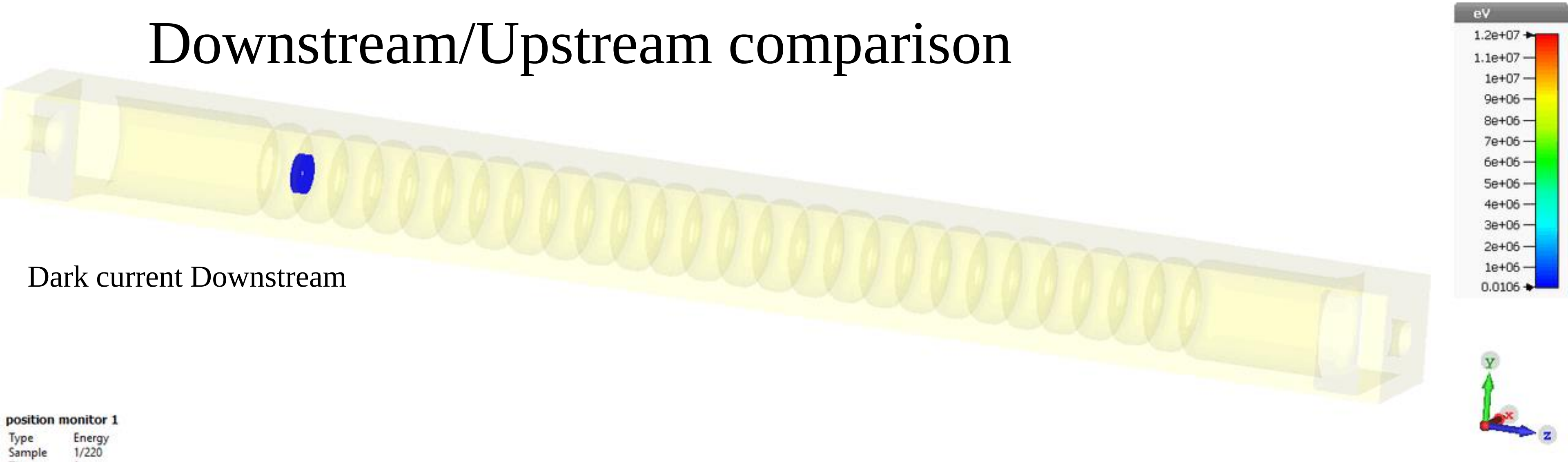
DC simulations using full field

Field import

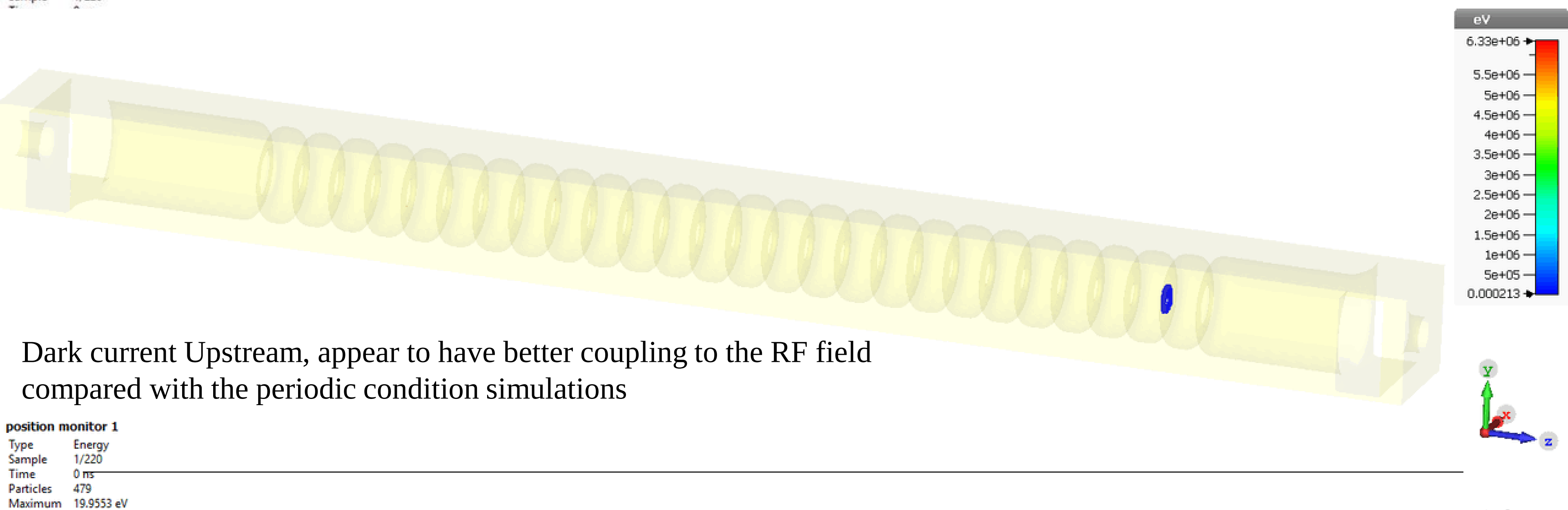


DC simulations using full field

Downstream/Upstream comparison



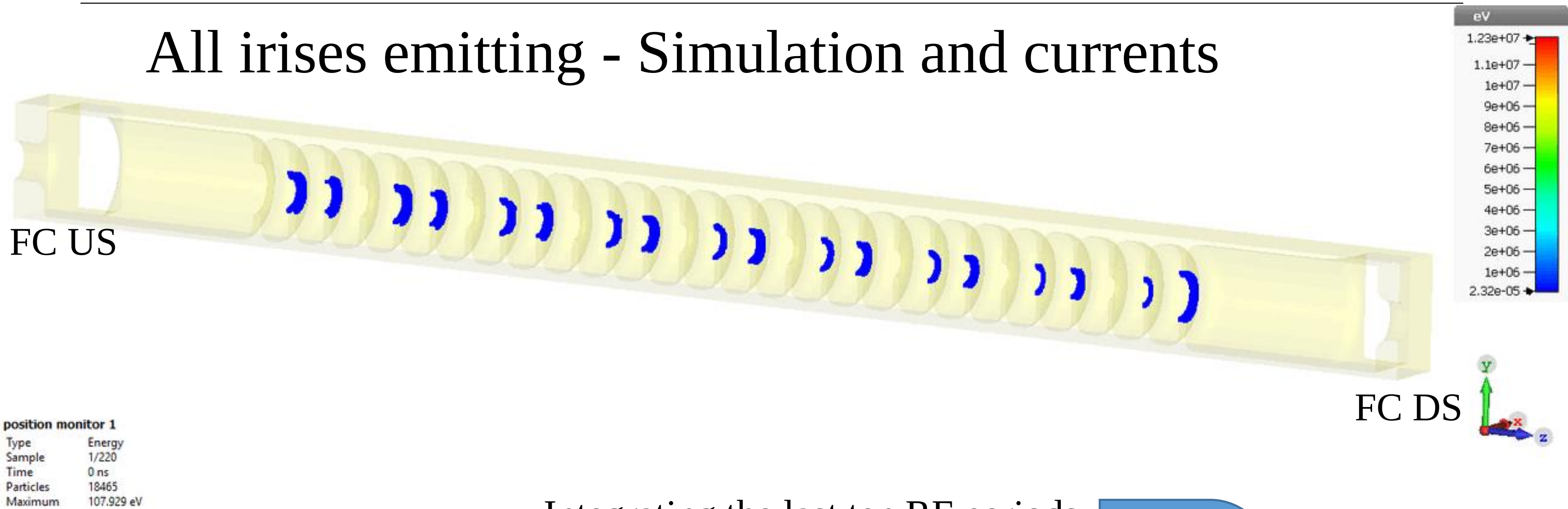
Dark current Downstream



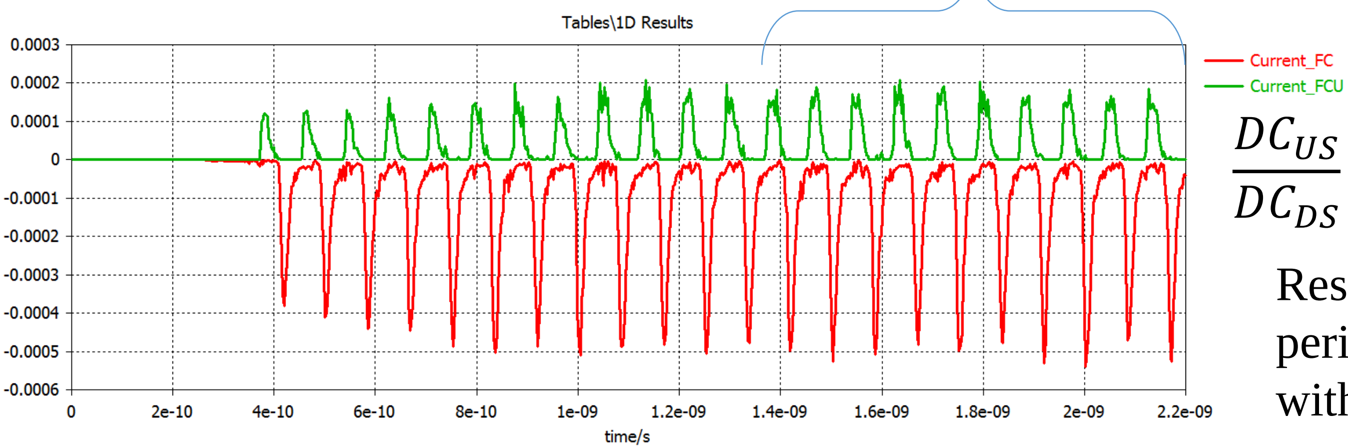
Dark current Upstream, appear to have better coupling to the RF field compared with the periodic condition simulations

DC simulations using full field

All irises emitting - Simulation and currents



Integrating the last ten RF periods

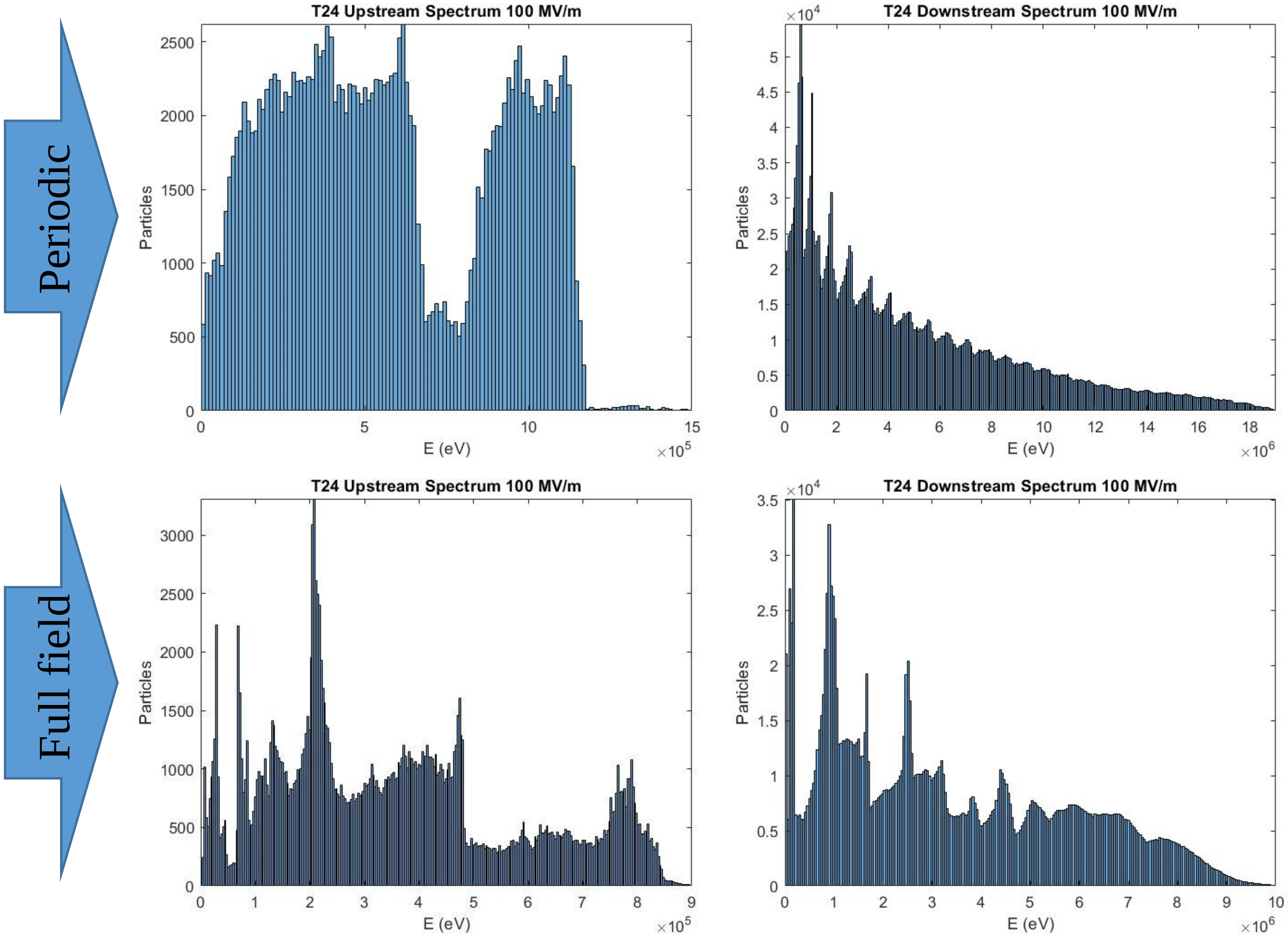


$$\frac{DC_{US}}{DC_{DS}} = \frac{4.5672 \cdot 10^{-5} A}{1.1336 \cdot 10^{-4} A} = 0.40$$

Result compatible with the periodic simulation, but not with the measurements.

DC simulations using full field

All irises emitting - Energy spectrum



There is a clear difference between results. Especially regarding to the maximum energy achieved in the full field Downstream case.

It is probably related with the capture level once the electrons are emitted. As the field import change a lot from one kind to the other it can affect, especially to the phase velocity of the wave.

We still need to dig more to understand this issue.

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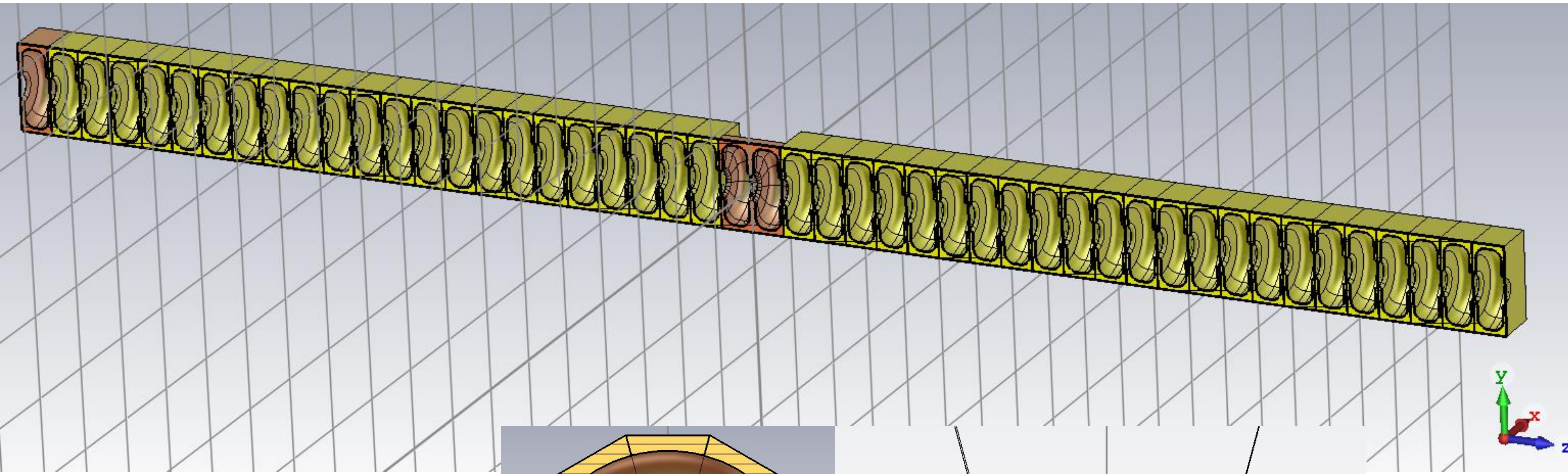
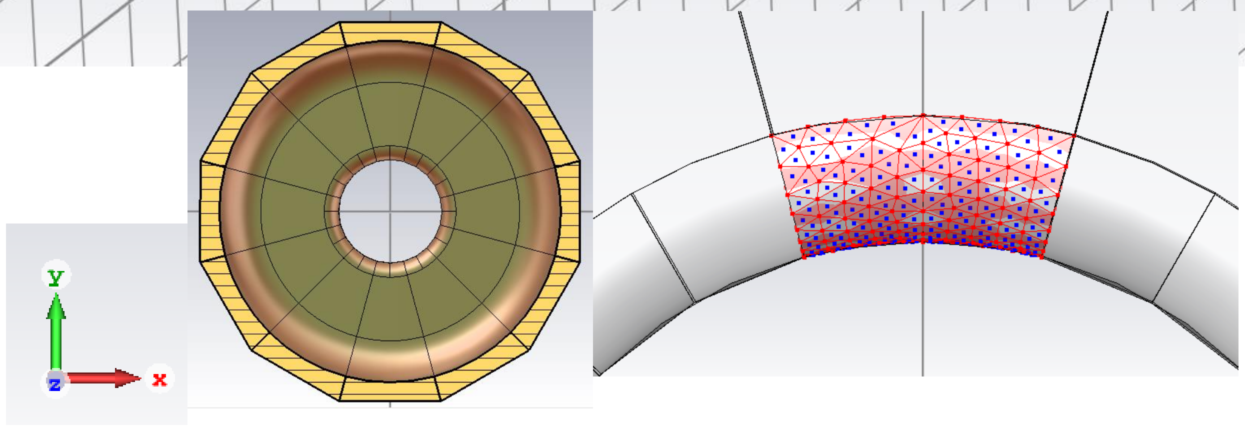
DC simulations with asymmetric emission

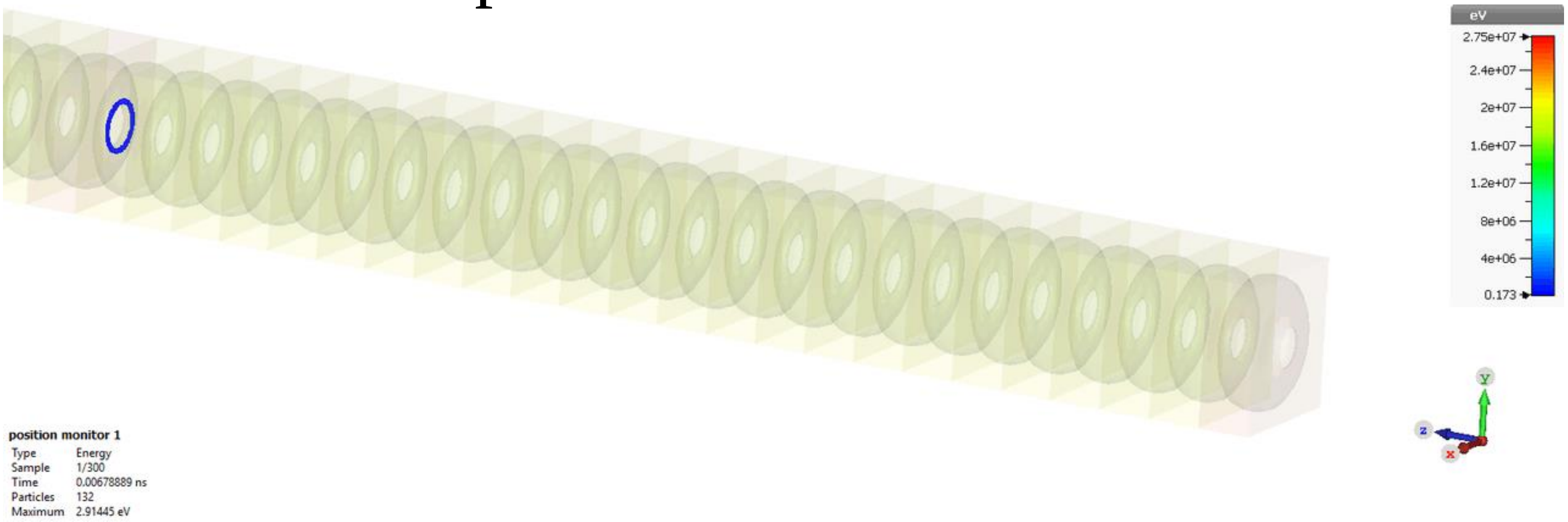
Emission area divided in sectors

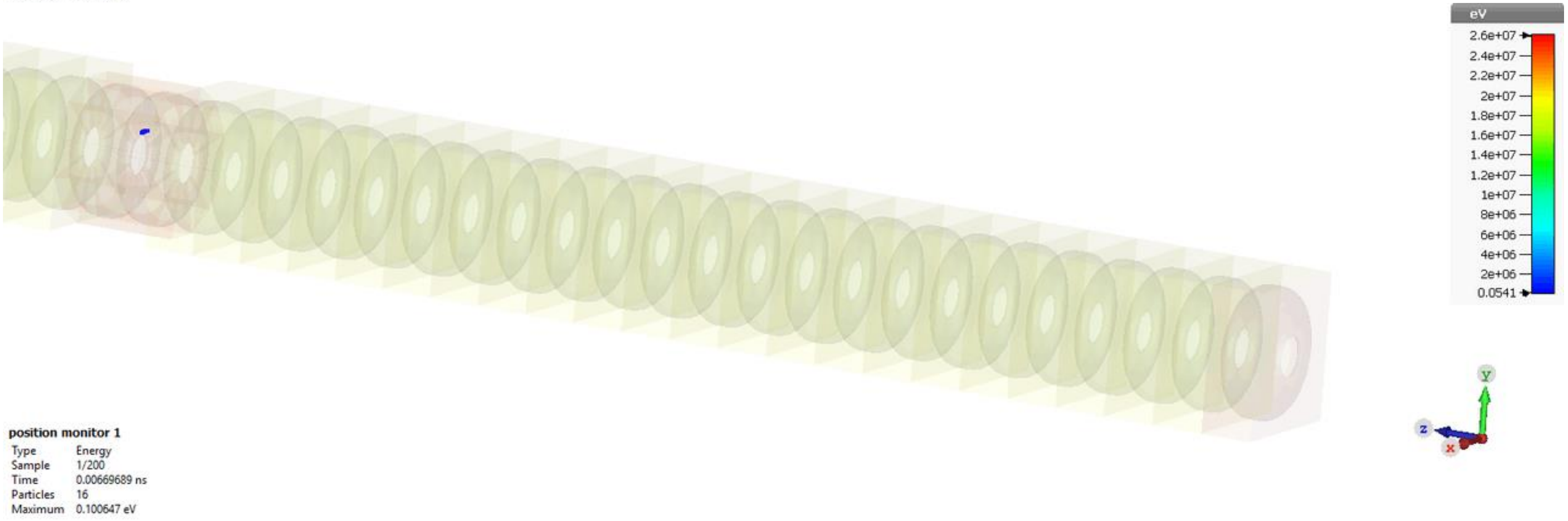




DC simulations with asymmetric emission

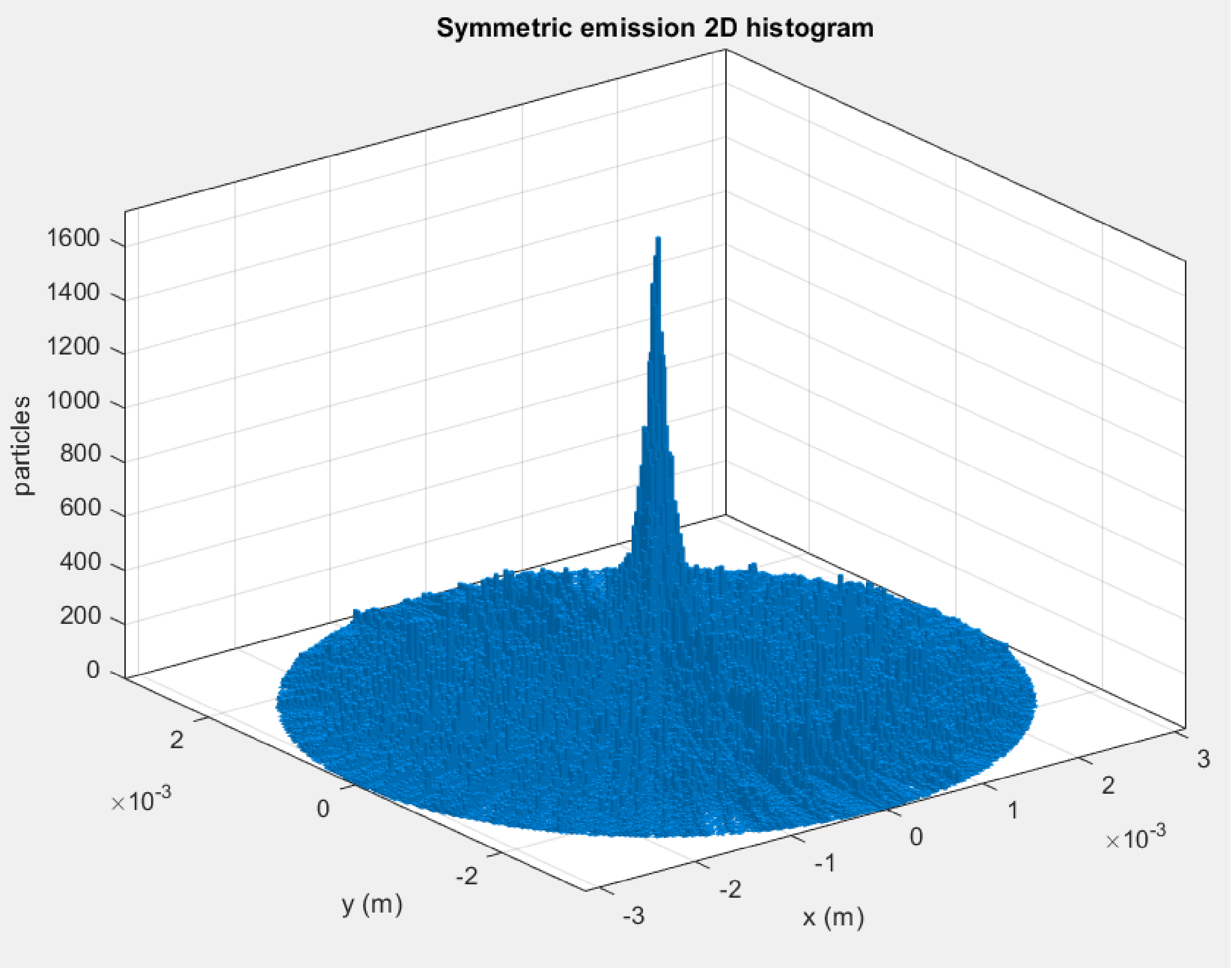
Simulation comparison





DC simulations with asymmetric emission

Particle distribution - Symmetric case

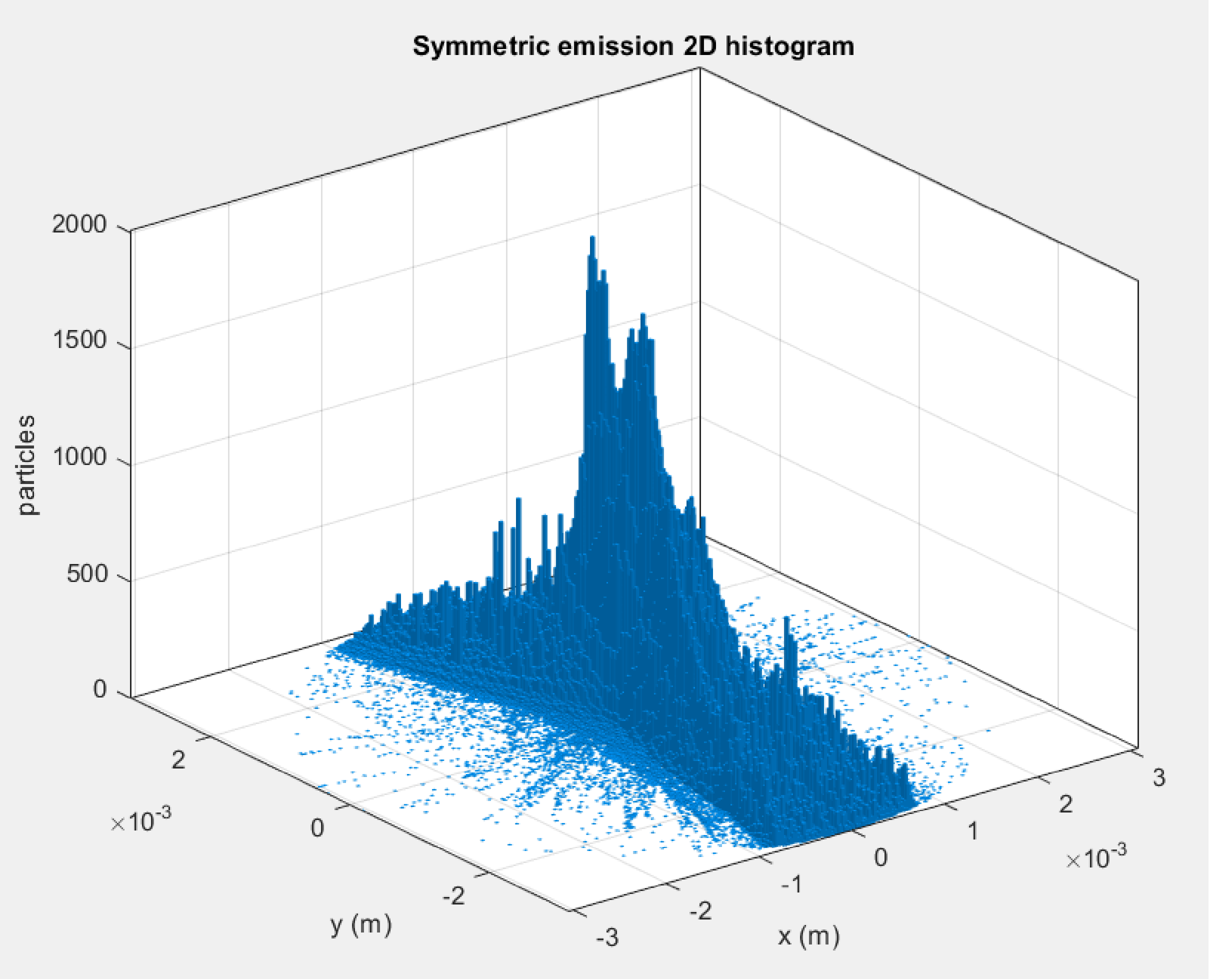


<x> = -2.8870e-05 mm
<y> = -6.9195e-06 mm

r = 3.1324 mm

DC simulations with asymmetric emission

Particle distribution - Asymmetric case



<x> = -4.5652e-04 mm
<y> = -0.41228 mm

r = 3.1324 mm

0.4 mm deviation would affect to the BPM readings

This situation can happen in the context of a hot cell with higher emission in a sector, prior to an RF Breakdown for example.

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Conclusions

- In this talk we have presented two different ways of simulating in CST the Dark Current present in the high gradient RF accelerating structures. The first one using the eigenmode of one cell and replicating it using Floquet's theorem. The second one is using the full field provided by the frequency domain solver.

- There is a good agreement between simulations in terms of the current analysis, despite of the discrepancy with the measurements that we still need to understand. However, in terms of energy gain, the periodic simulations achieves the double of the energy of the full field simulation, with exactly the same gradient. Changes in the phase velocity leading to capture inefficiency can be the reason.

- Among the practical reasons of this analysis we can highlight the potential impact in the BPM readings, in the case of asymmetrical emission in the irises. The radiation generated is also a problem, bigger DC leads to more X-ray radiation and more shielding is required. The next talk will go further in this special topic.

thank you very much
for your attention