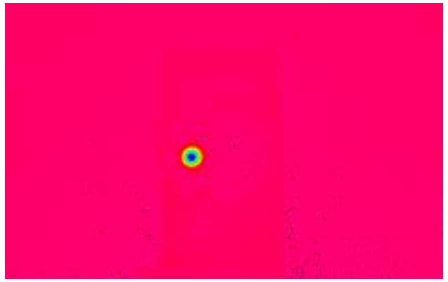
AWAKE e- linac including CTF2 injector status

- ❑ Awake electron injectors
- ❑ CTF2 prototype status
- ❑ Conclusion and outlook



CLIC Mini Week, Dec 11-13, CERN
Steffen Doebert

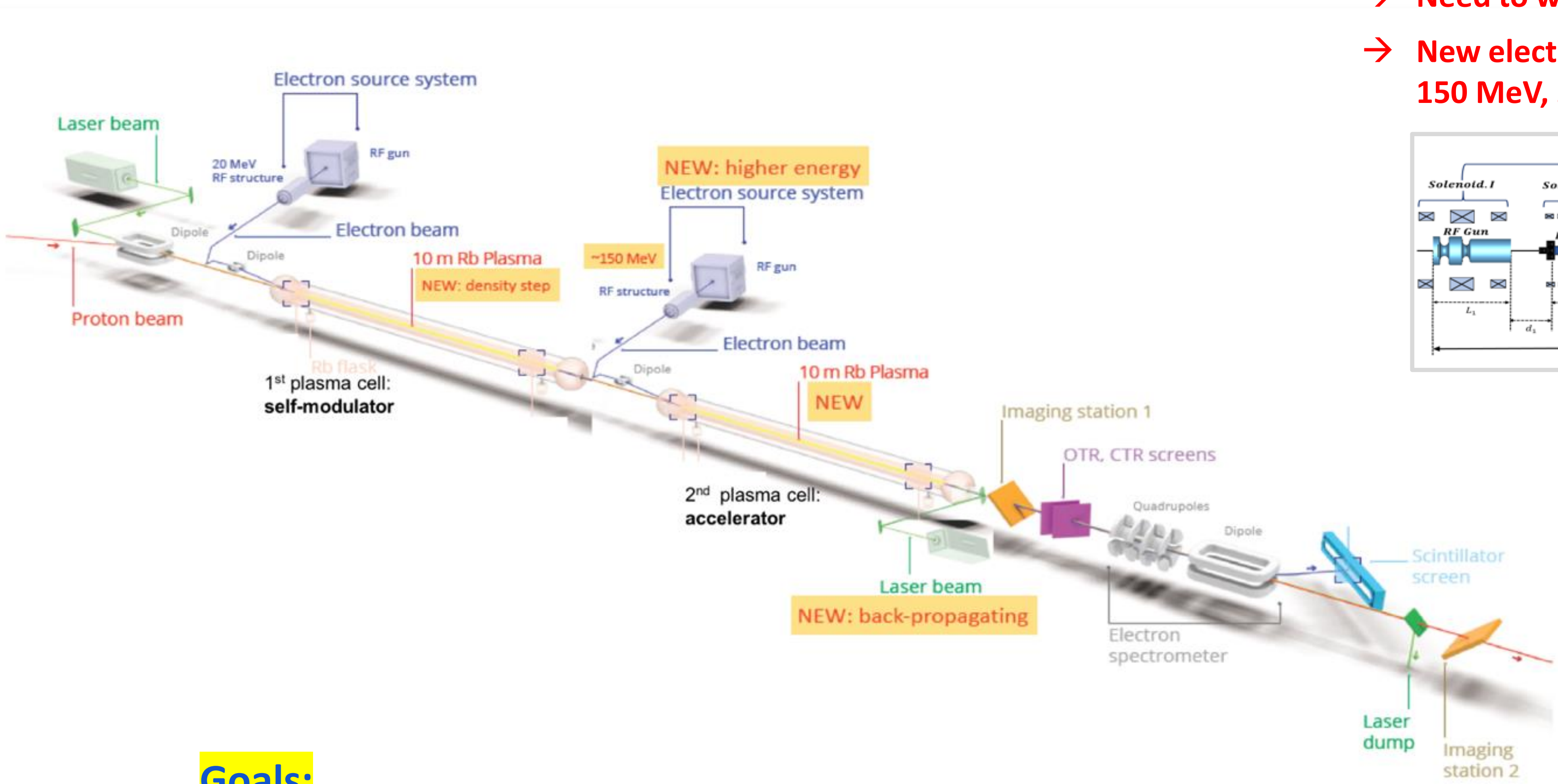
AWAKE Run 2

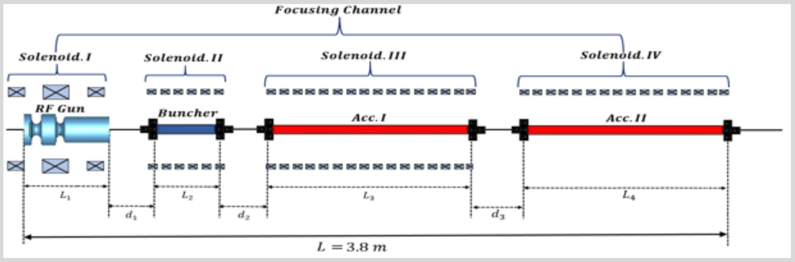
➔ **Demonstrate possibility to use AWAKE scheme for high energy physics applications in mid-term future!**

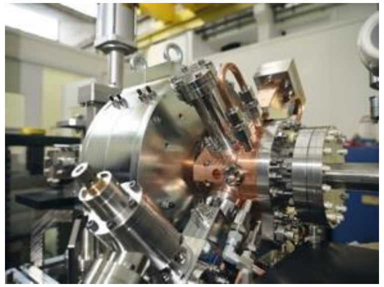
➔ Start 2021! Staged program for ~ 10 years

→ **Need to work in blow-out regime and do beam-loading**

→ **New electron beam based on x-band:**
150 MeV, 200 fs, 100 pC, σ = 5.75 µm







Goals:

Accelerate an electron beam to high energy (gradient of 0.5-1GV/m)

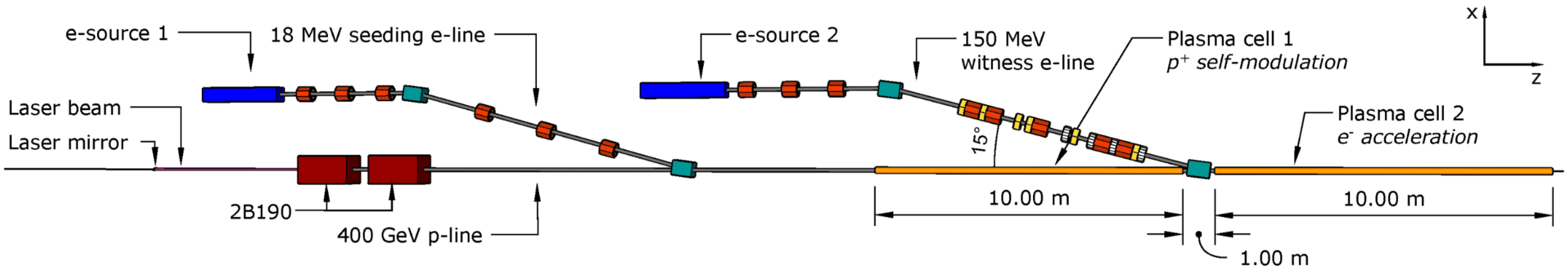
Preserve electron beam quality as well as possible (emittance preservation at 10 mm mrad level)

Demonstrate scalable plasma source technology (e.g. helicon prototype)

Parameters for both injectors

Working documents held by Rebecca (Injector 2, EDMS 2378918) and John (Injector 1, EDMS 2417022,2588263)

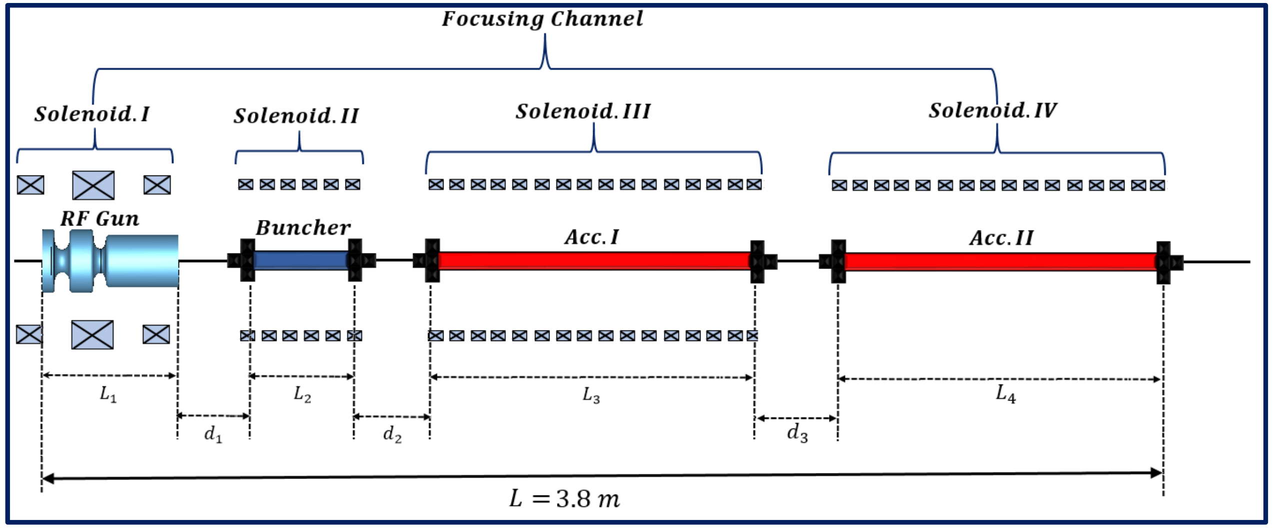
	Beam Energy	Energy Spread	Energy stability	RMS Bunch Length	Bunch Charge	Emittance	Beam size plasma focus
Injector 1	18.5 MeV	0.5 %	1 x 10^{-2}	$\approx 2-3$ ps	100 – 600 pC	2 - 5 μm	~ 190 μm
Injector 2	150 MeV	0.2 %	1 x 10^{-3} ?	$\approx 200-300$ fs	100 pC	2 μm	5.75 μm



- Energy as high as affordable ?
- Energy spread as low as possible !
- Energy stability as good as possible !
- Emittance reasonably low, no need for ultra-low

Reference design

- Well advanced concept and beam dynamics design



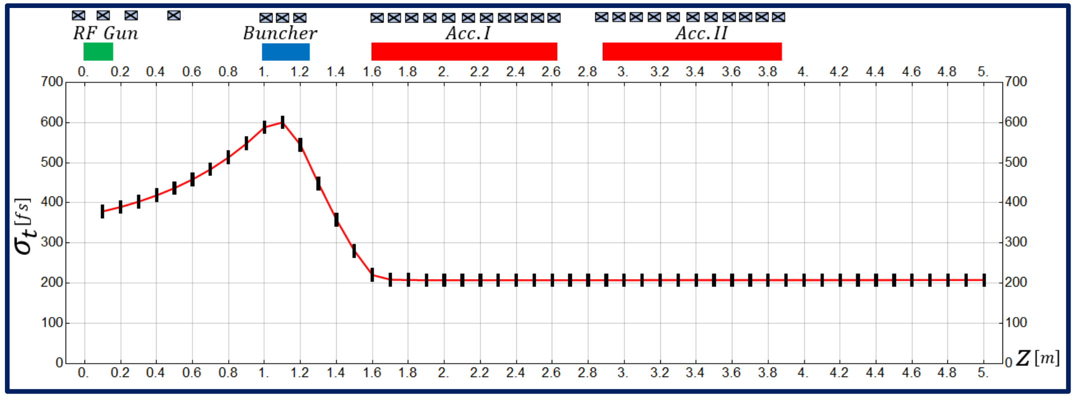
Laser parameters

$\lambda[nm]$	$w[ev]$	$r[mm]$	$t[ps]$	$q[nc]$
262	4.31	1.0	1.0 – 5.0	0.1-1.0

RF parameters

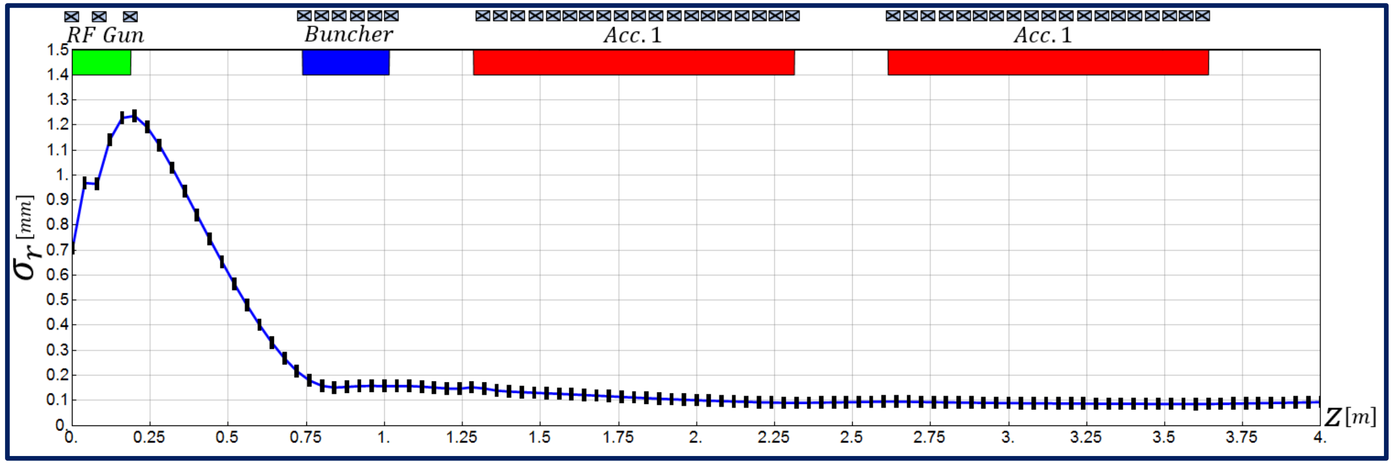
Parameter	RF Gun	Buncher	Acc. I	Acc. II
Frequency	3.0	12.0	12.0	12.0
Gradient	$120MV/m$	$35MV/m$	$80MV/m$	$80MV/m$
N. Cell	1.5	30	120	120

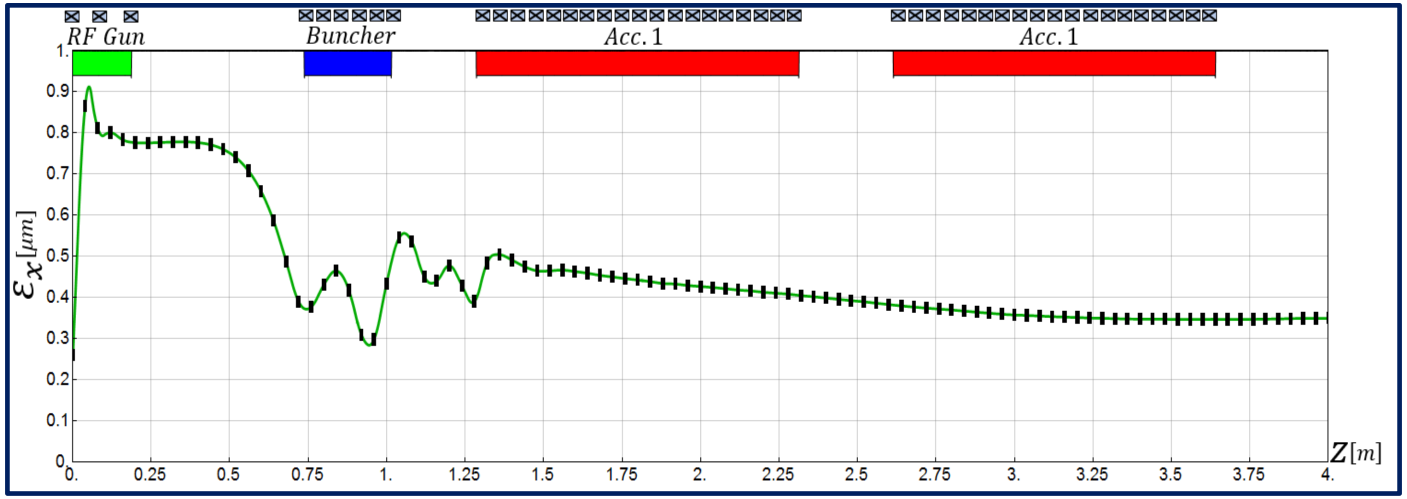
$E_k[MeV]$	$\sigma_r[mm]$	$\sigma_t[fs]$	$\varepsilon_x[\mu m]$	$\sigma_E[\%]$	$I_{av}[A]$
165	0.14	**207**	0.44	**0.09**	168

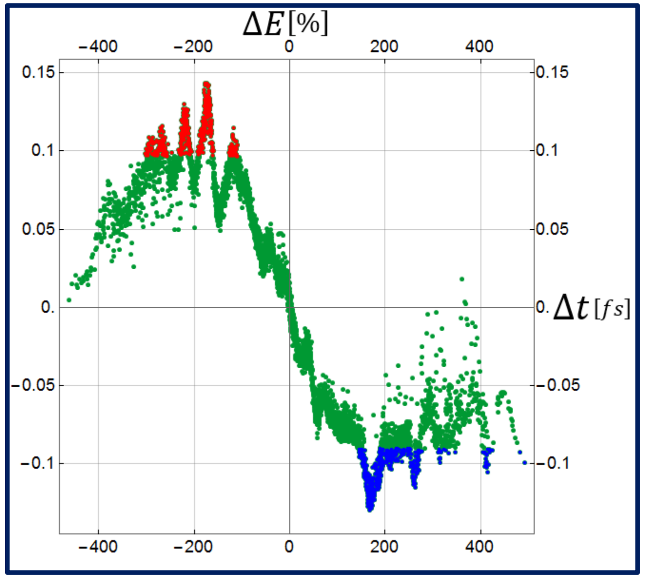


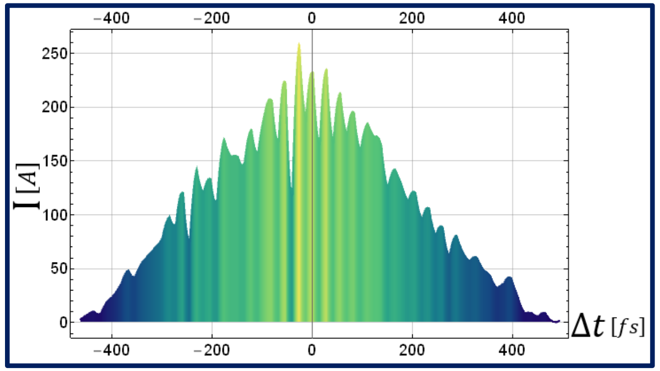
Mohsen Dayyani Kelisani

Reference design









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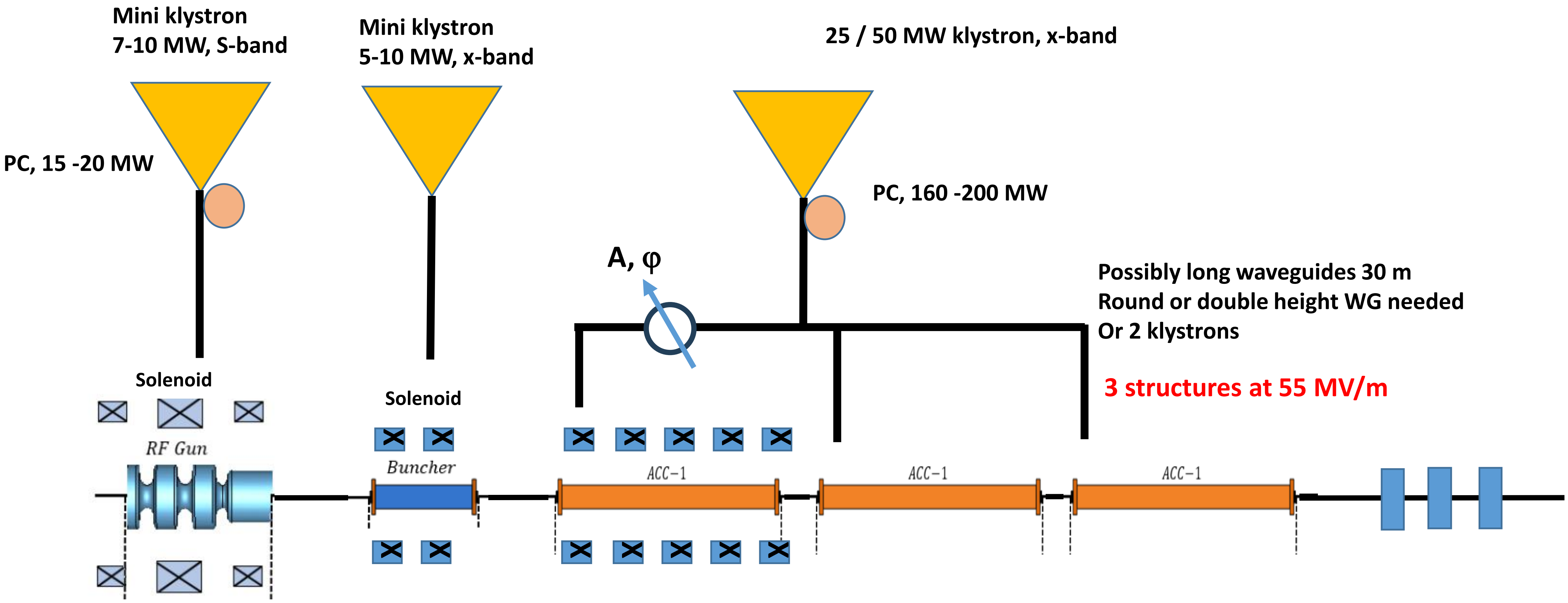
Awake schematic RF layout



Total Energy 100- 160 MeV, 10 Hz rep. rate, single bunch
Will try to use CLIC developed x-band components as much as possible

Studied alternative scenarios

Beam dynamics:

- 3 identical structures, one 50 MW klystron → Save small klystron, waveguide run and buncher structure

RF power variants:

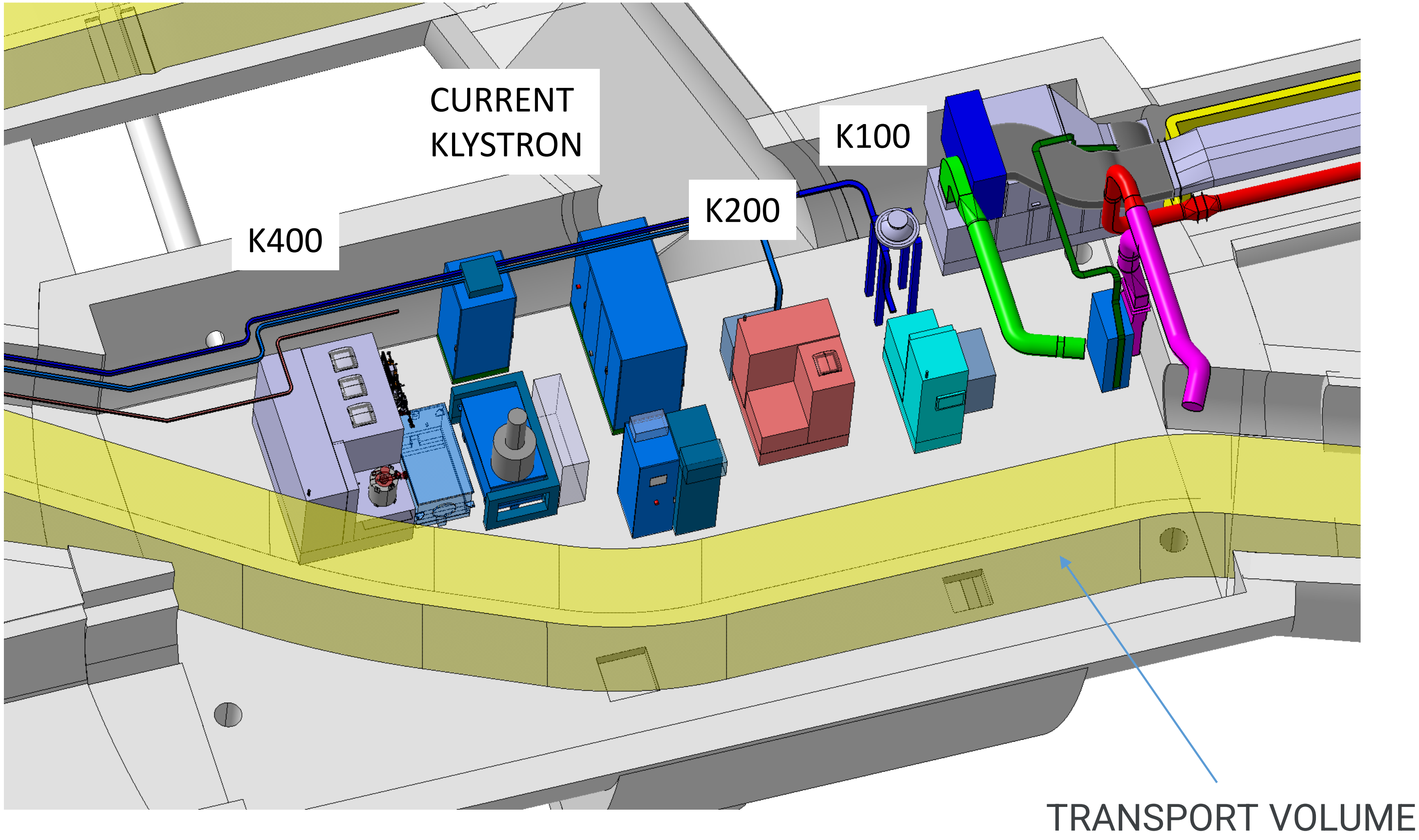
- One 25 MW klystron for acceleration, small 8 MW klystron for bunching → less expensive klystron and modulator
- Only one 25 MW klystron for everything → less expensive klystron, save second waveguide run and small klystron

Integration scenarios:

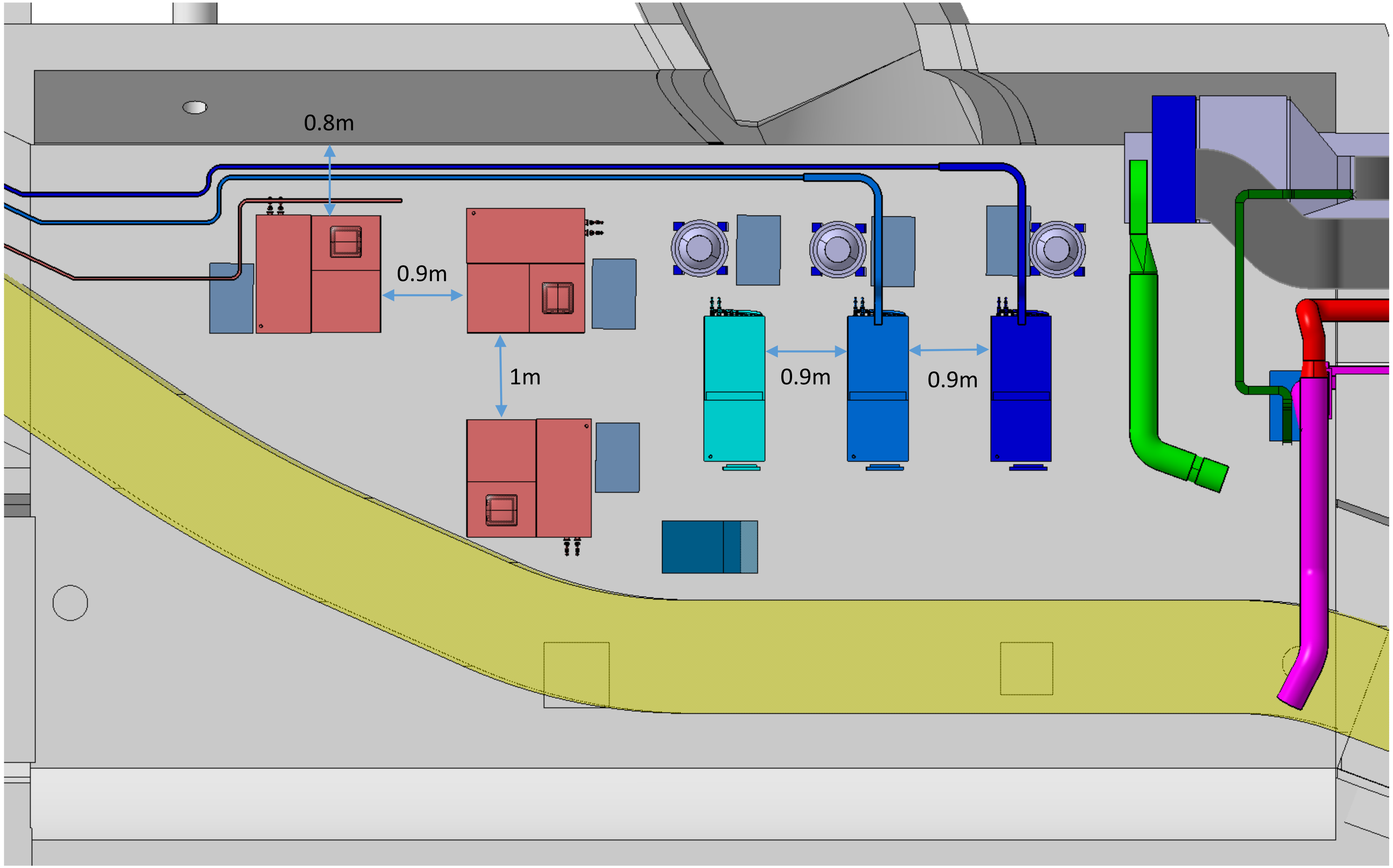
- Keep Run 1 modulator (PPT) for LINAC 1, instead of two K100 modulators → no new hardware needed
- Use K400 modulator instead of PPT → better performance and stability
- Replace K400 x-band with 2x K200 x-band → essentially staged scenario to upgrade energy later

SOLUTION 1

Keep PPT modulator from Run1 for Linac 1

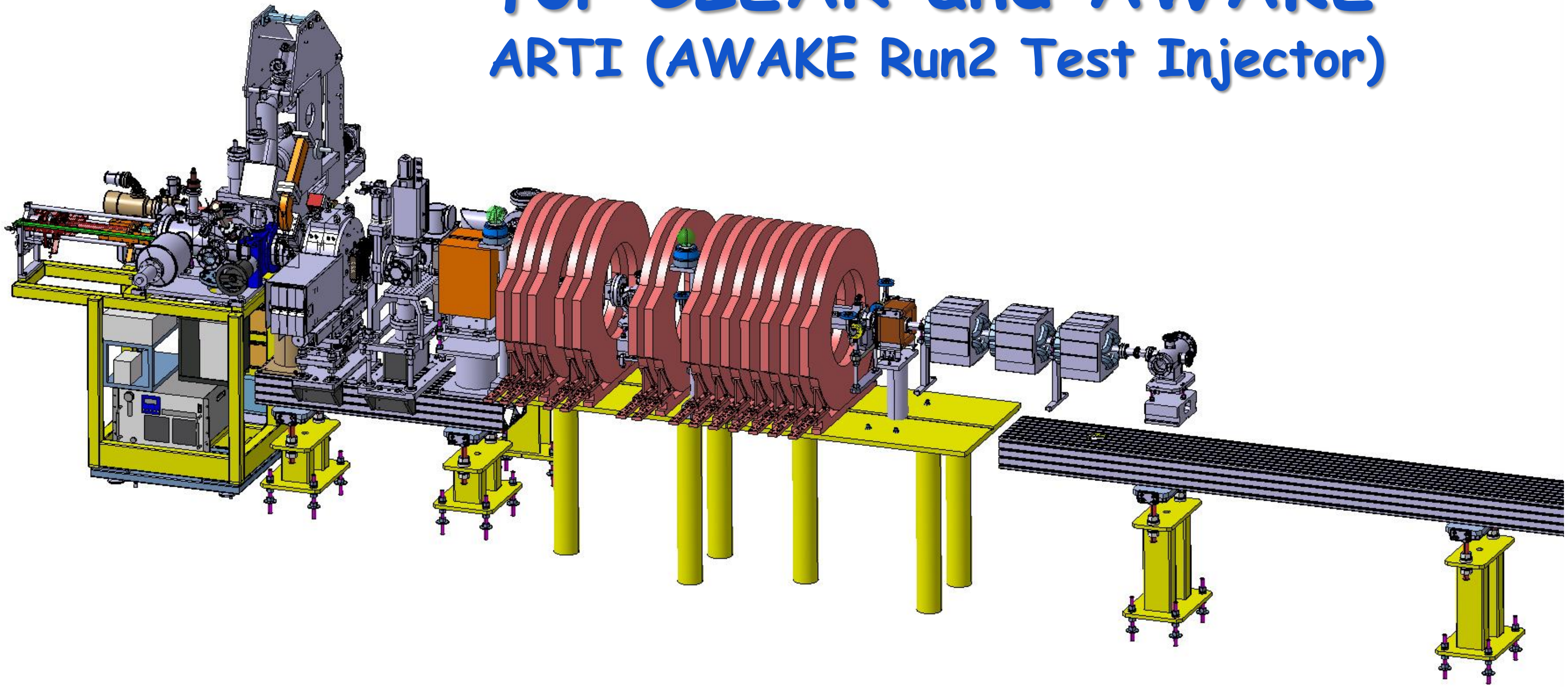


SOLUTION 2-B



Injector prototype in CTF2 for CLEAR and AWAKE

ARTI (AWAKE Run2 Test Injector)

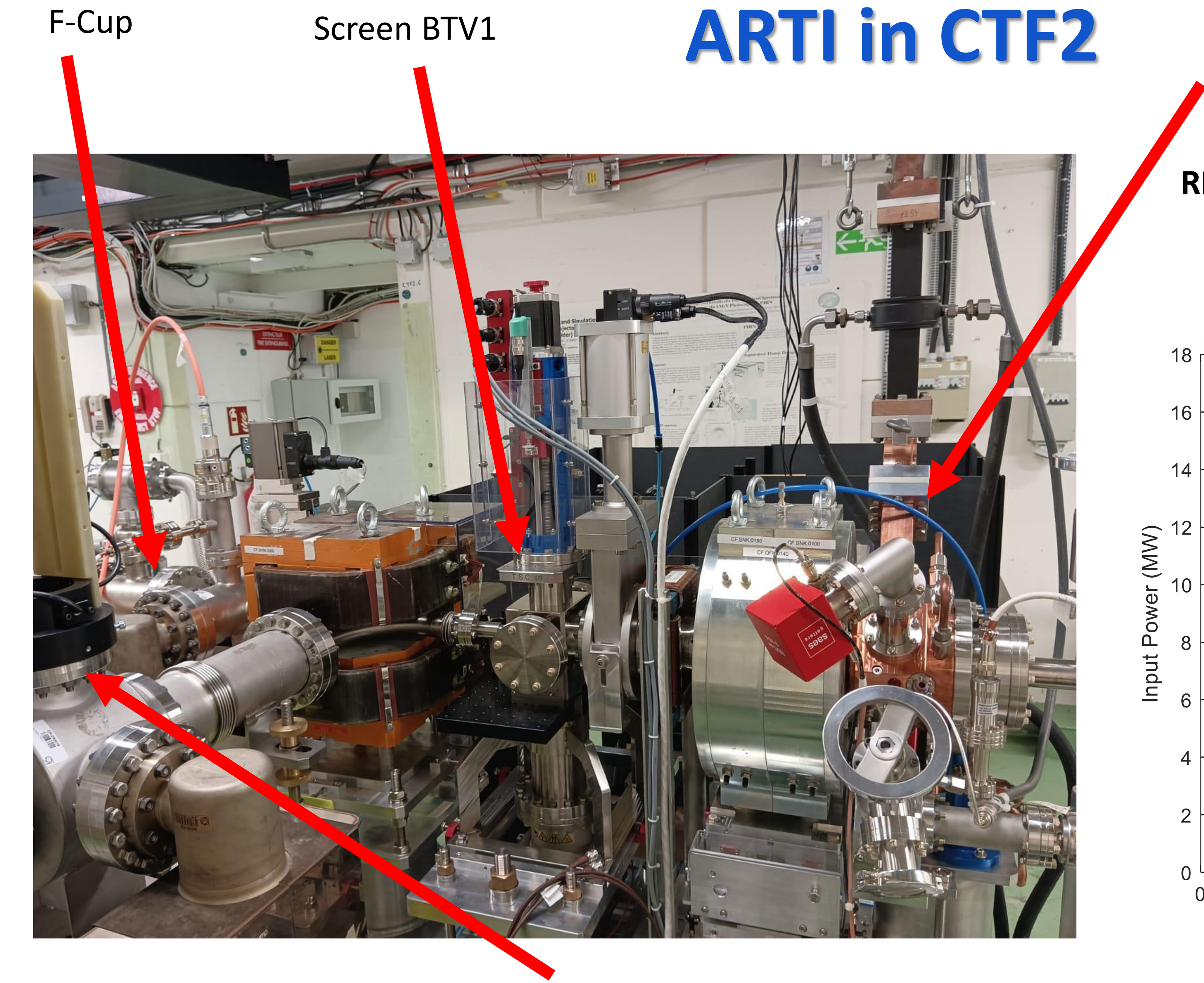


Reduced scale prototype, 60 MeV, T24 as buncher and PSI-linearizing structure for acceleration.
Goal: demonstrate the velocity bunching and emittance preservation with x-band
Prototyping of key hardware

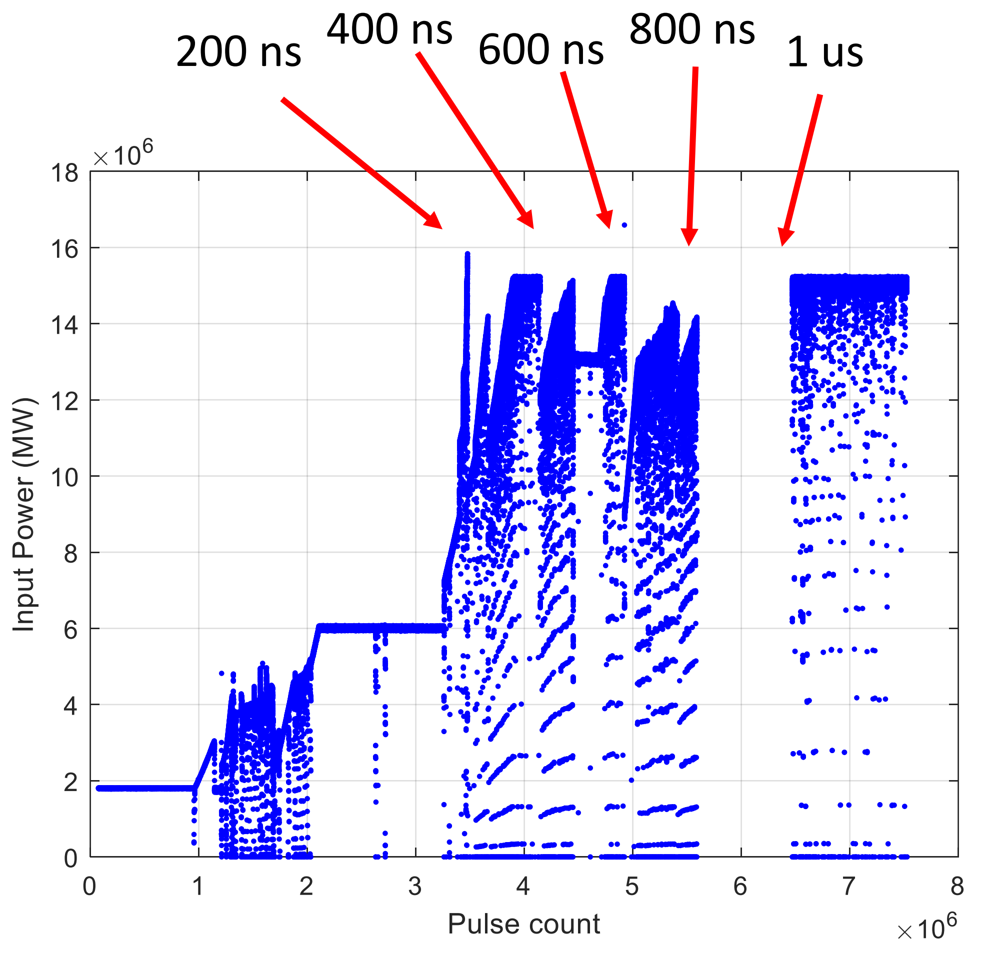
ARTI status

- RF-gun and diagnostics operational
- (under commission)
- Magnets for second phase installed
- Vacuum system will be next (this shutdown)
- Missing the x-band waveguide system and the klystron (still at CPI for repair)
- First ‘user’ experiment planned next spring: Vlad’s CBS experiment

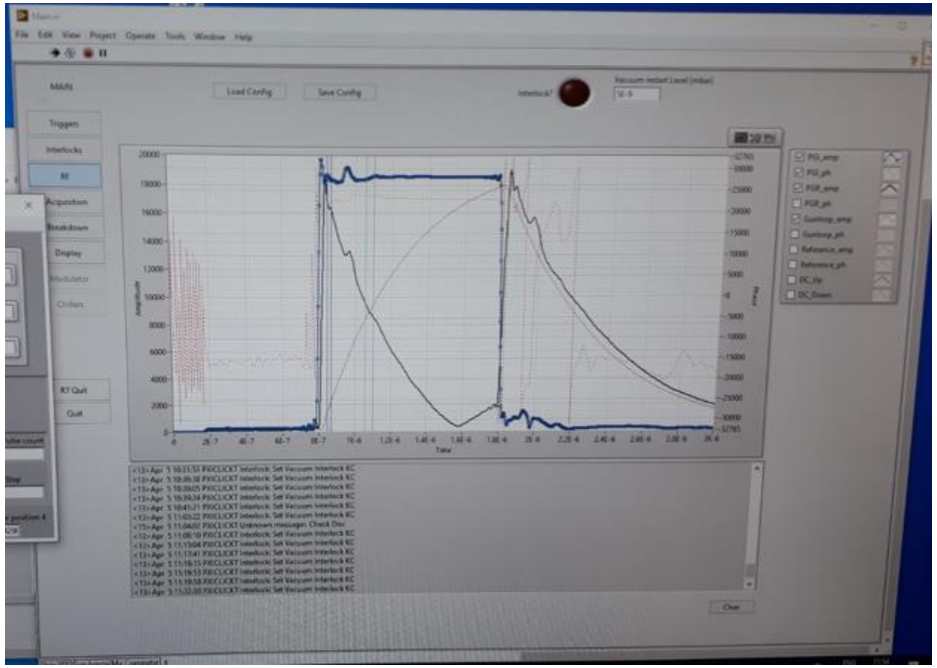
ARTI in CTF2

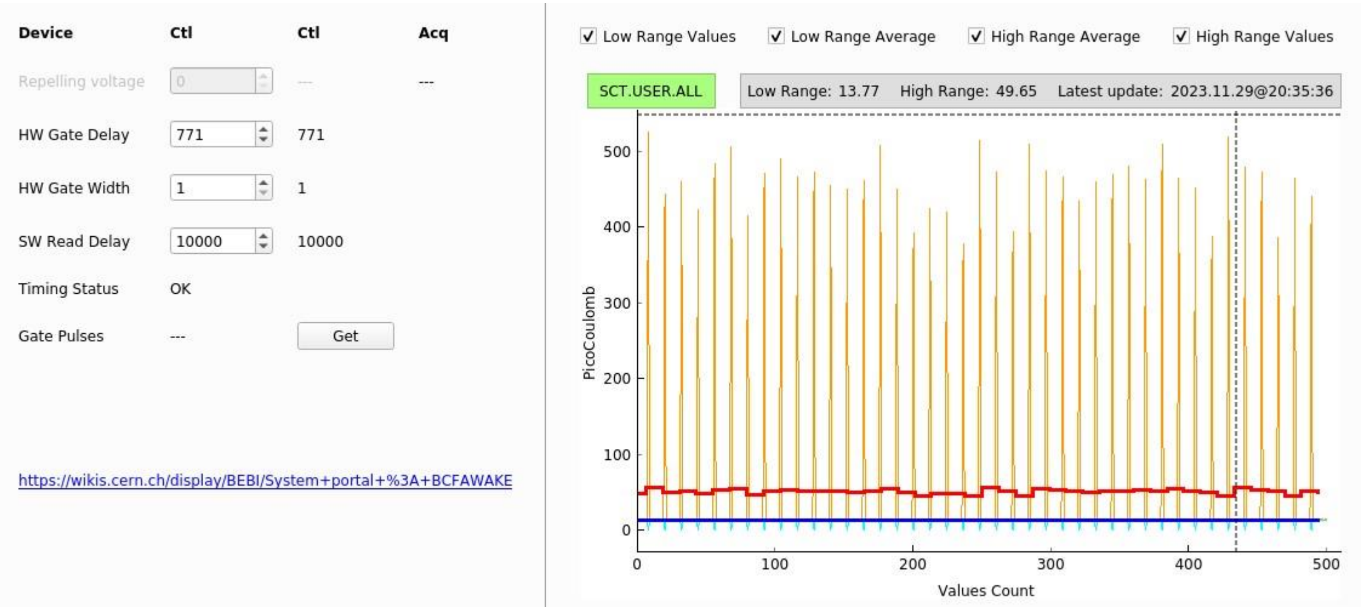


RF-gun conditioned to 120 MV/m on the cathode



First results with beam





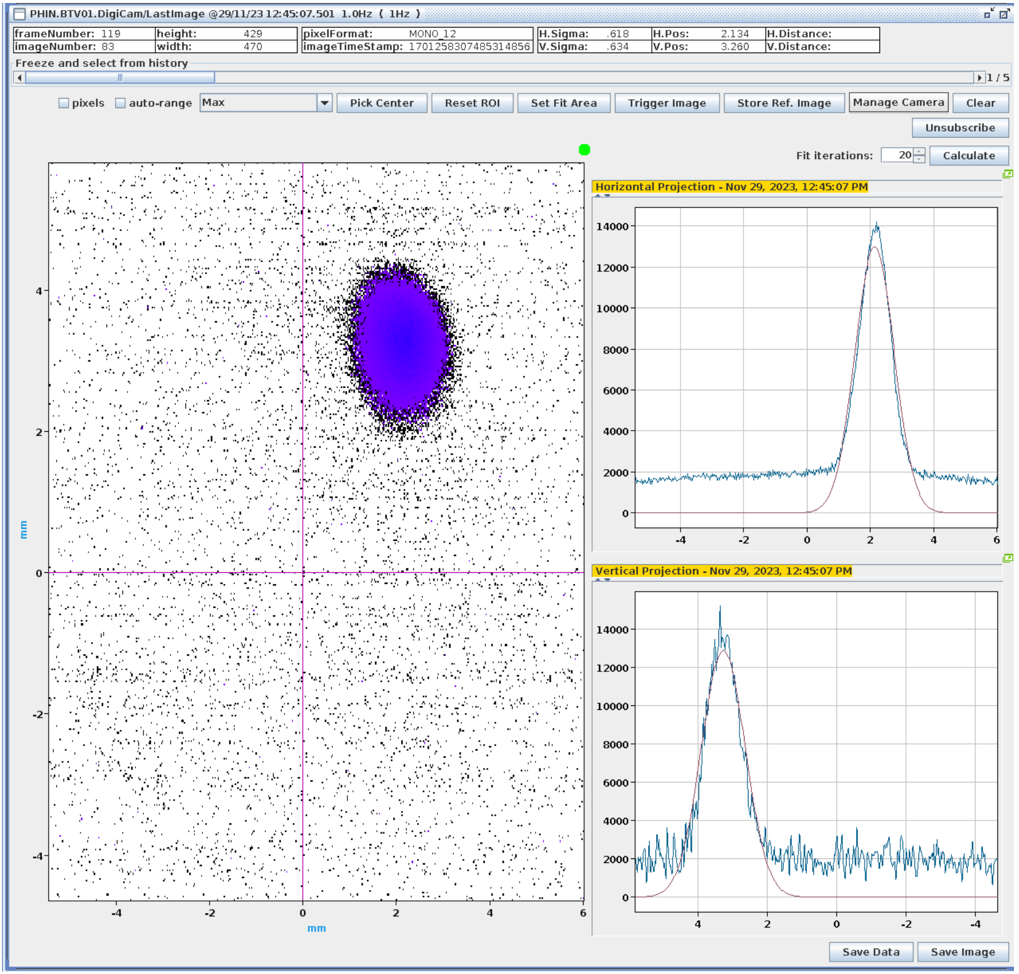
RF set-up:
Input Power: 13 MW
Gradient: 114 MV/m

Beam charge:
Faraday Cup: up to 440 pC
Copper Qe: 9 x 10^{-4}
Very promising for Copper cathodes
No dark current basically not measurable for time being:
< 5 pC (preliminary)

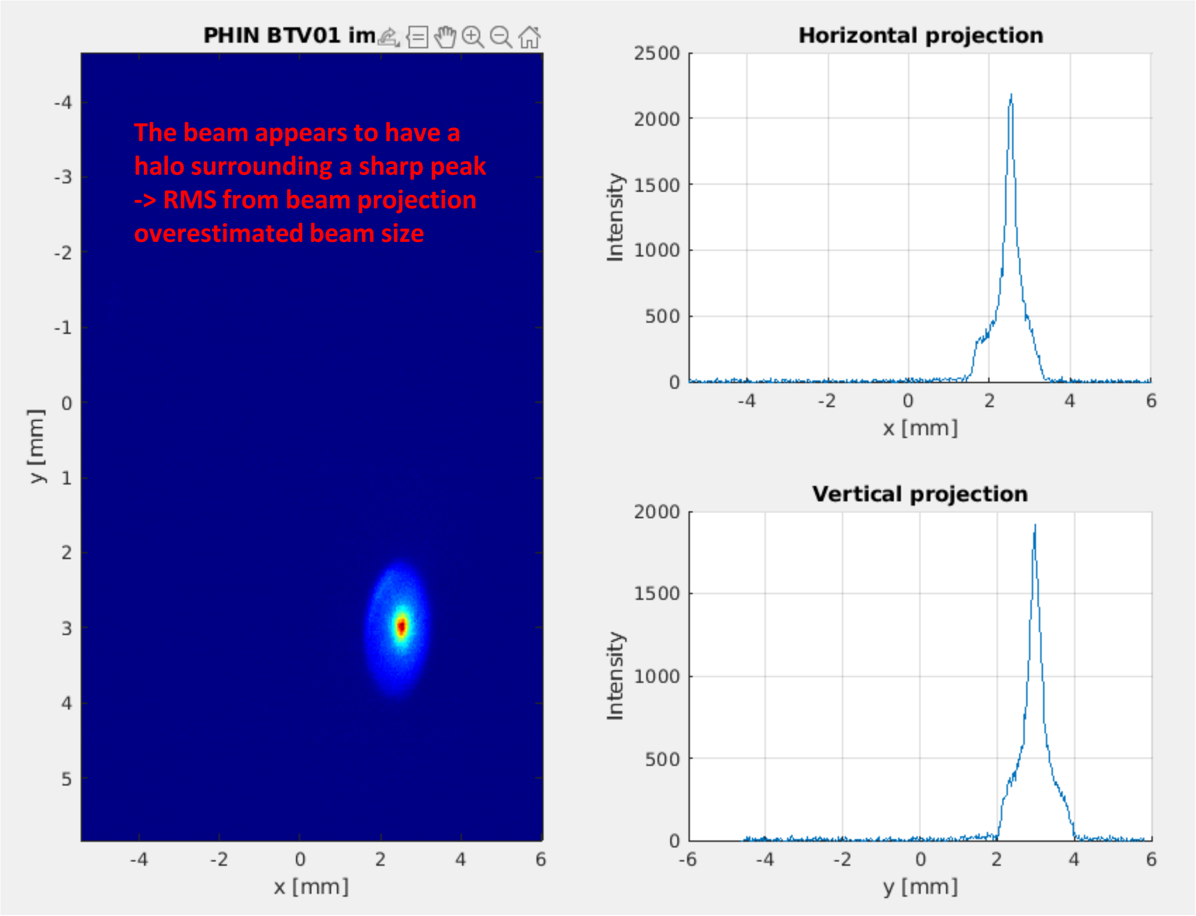
Warning: calibrations still floating

Beam profile characterisation

Screenshot of unfocused beam

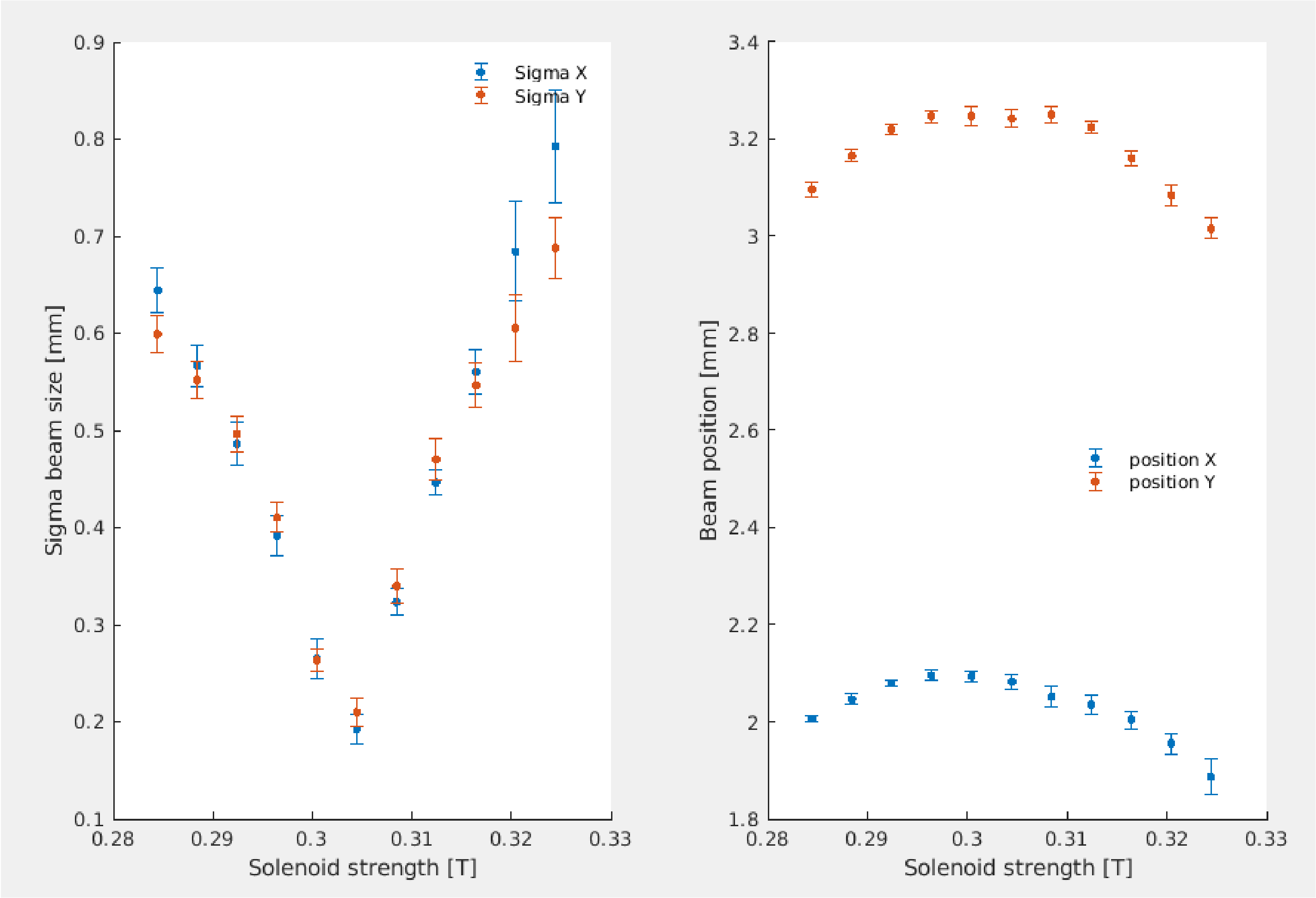


Screenshot of focused beam



Vlad Muscat

Solenoid scan at 400 pC



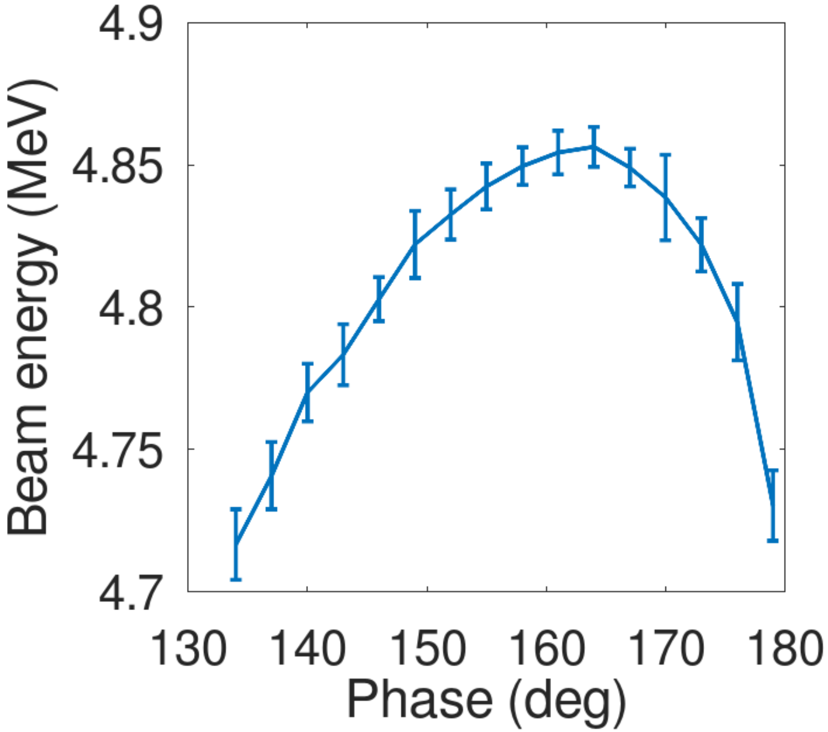
200 um RMS spot reached!

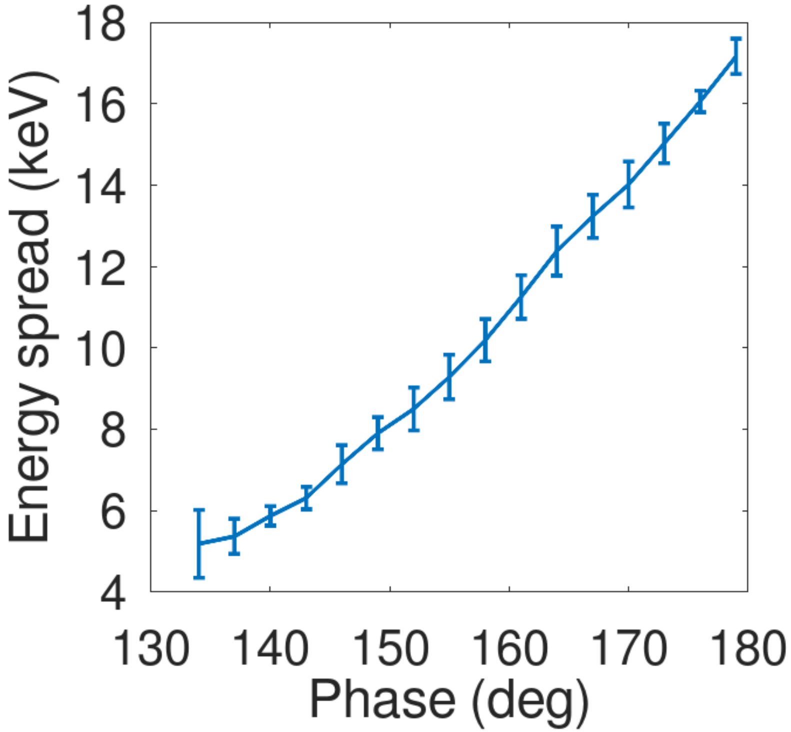
Results closer to expectations I had from simulations (130 um RMS).

We currently try understand the results with simulations. Work in progress

Phase scans

- The on-crest phase was shifted by 20 deg. On-crest now at 163 deg.

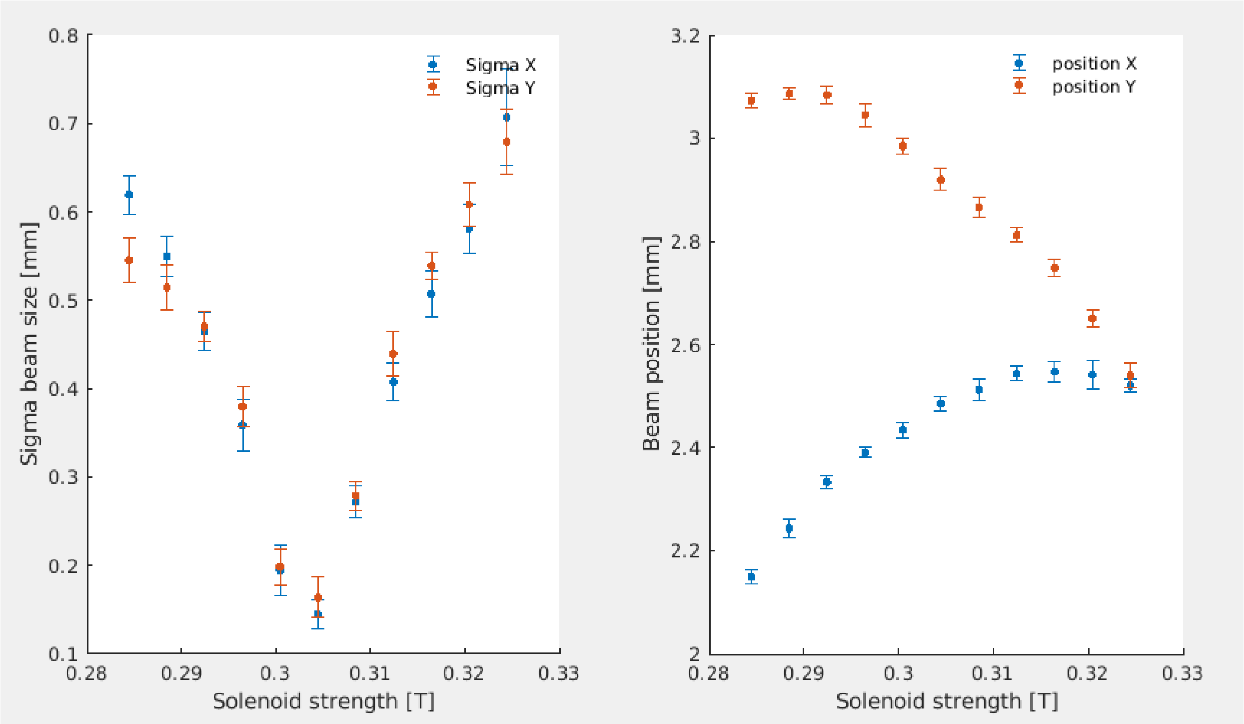


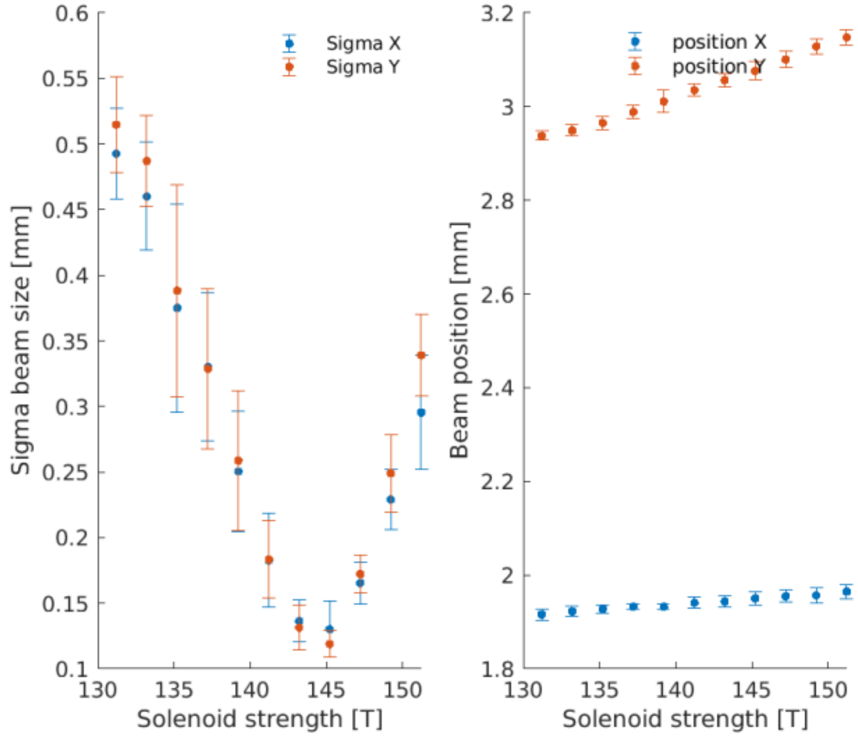


Warning: calibrations still floating

Vlad Muscat

More solenoid scans





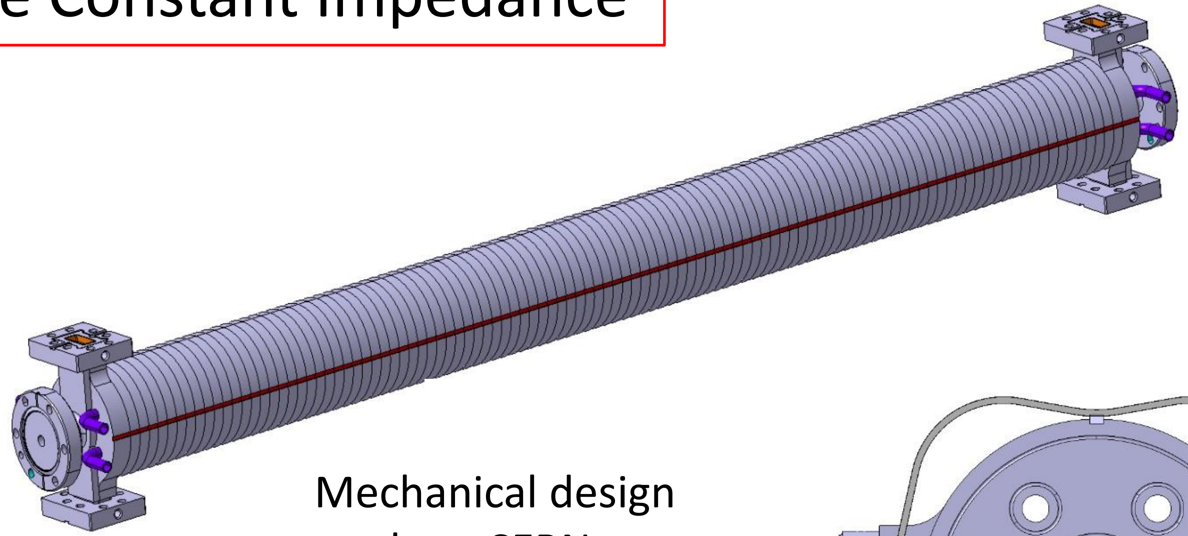
Laser pulse length = 112.7 fs RMS

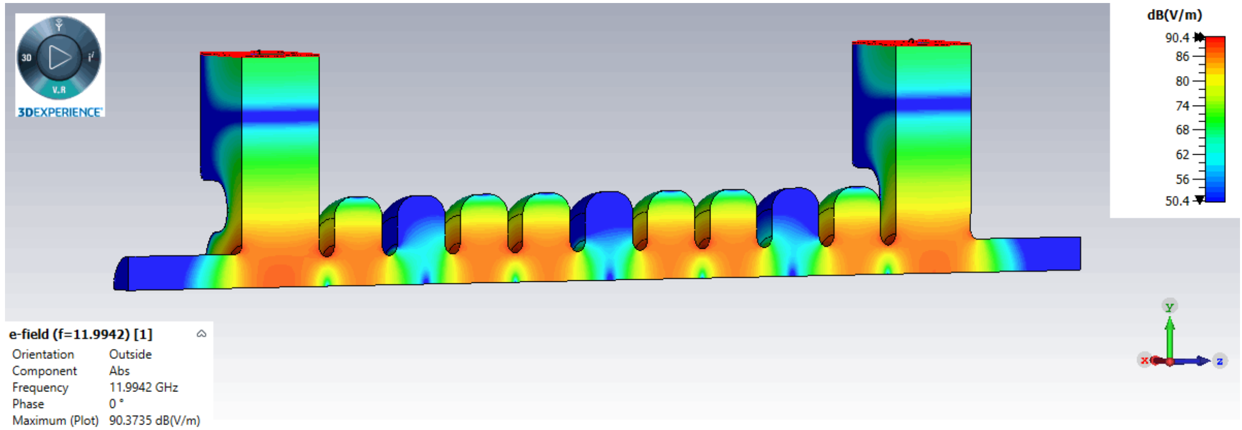
Laser pulse length = 327 fs RMS

X-band structure developments

Travelling wave Constant Impedance

Shunt Impedance [MΩ/m]	100
Group Velocity vg/c [%]	2.4
Q-Factor	7061
Attenuation [1/m]	0.7
Length [m]	0.9

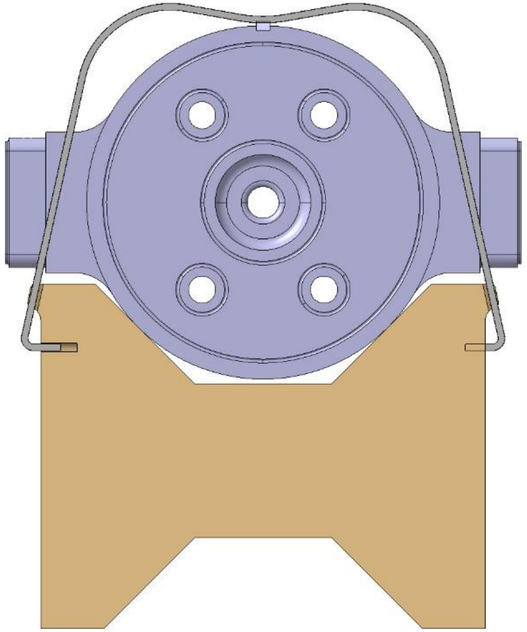




Mechanical design made at CERN

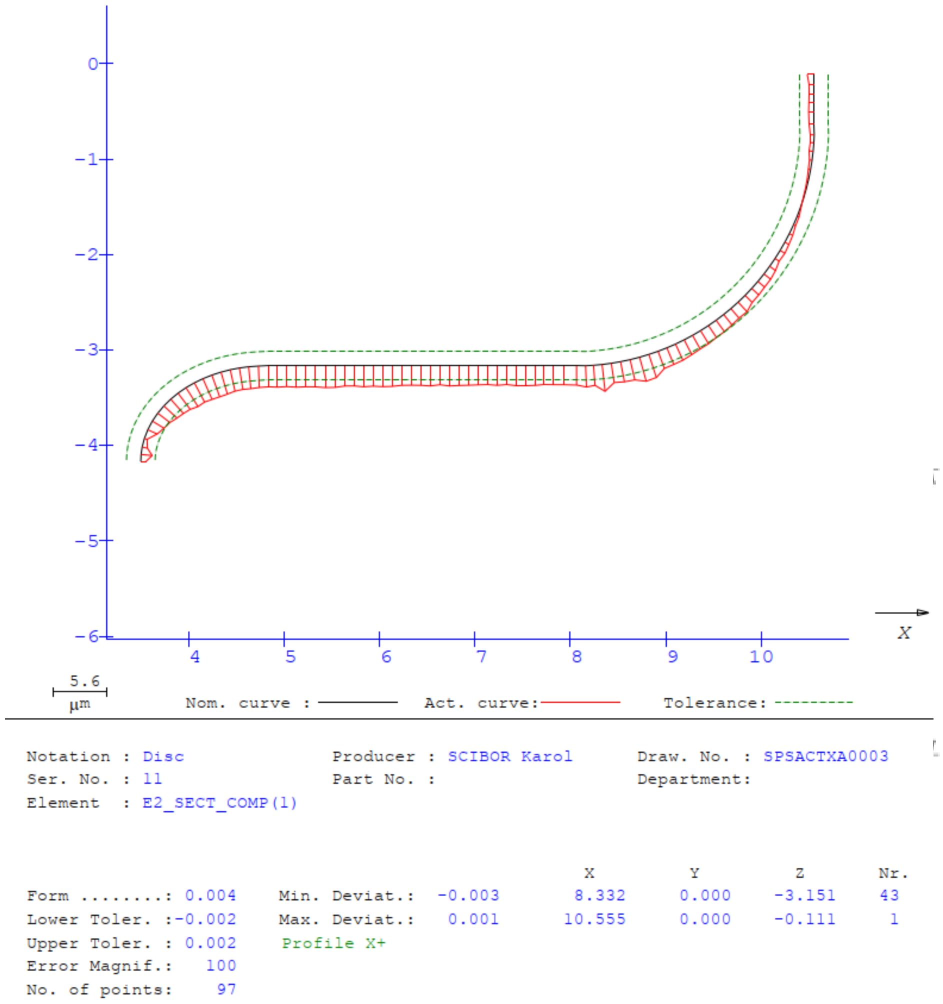
CLIC style tolerances
Vacuum brazing design

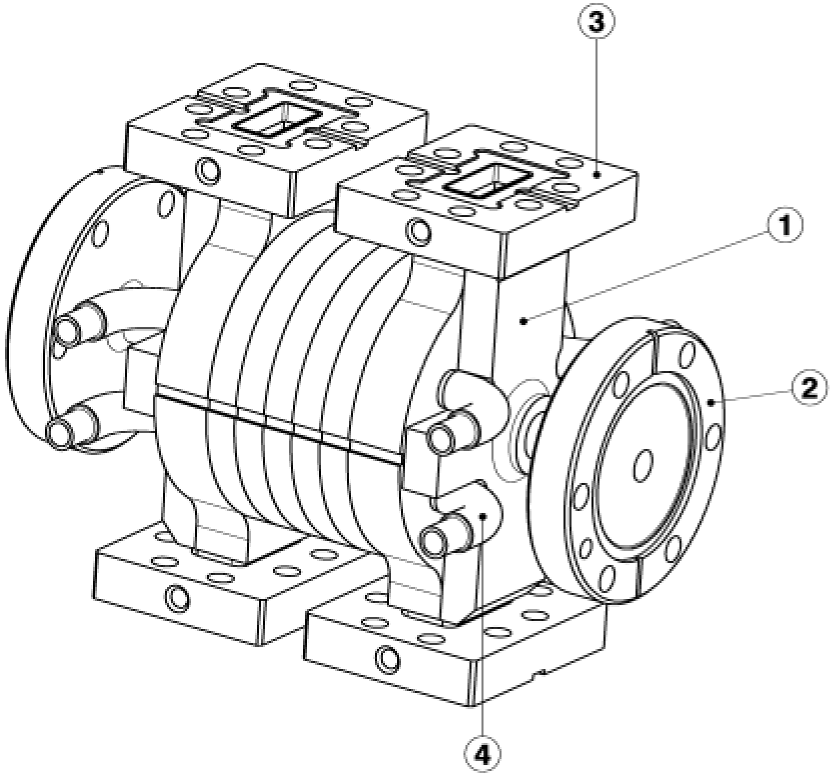
Structure to be inserted in a solenoid of 150 mm diameter bore radius



Designed by INFN Frascati, D. Alesini, M. Diomede, for CompactLight and EuPraxia

First short prototype under construction





C. Capelli, N. Chritin

Verify mechanical design, brazing assembly and tolerances needed
Maybe low power RF measurements but no high-power test planned

μ–TCA development for LLRF with Uppsala

- **System shipped to CERN from Uppsala, installed in the form CLIC test facility.**
- **RF signal acquisition, generation and feedback/forward loops tested.**
- **Use of DESY BSP and python GUI.**
- **External trigger injection through RJ45 connector on SIS8300KU AMC, distributed to mLVDS lines.**
  - Currently under test/development (still some bugs to iron out)
- **Work progressing well on a DESYRDL to CERN/Cheby convertor script.**

Modulator and S-band 40MW klystron (above)

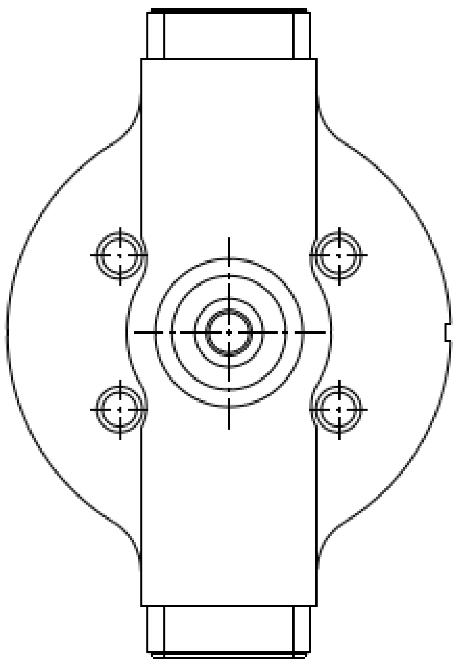
MicroTCA crate and LO, CLK generators (right)

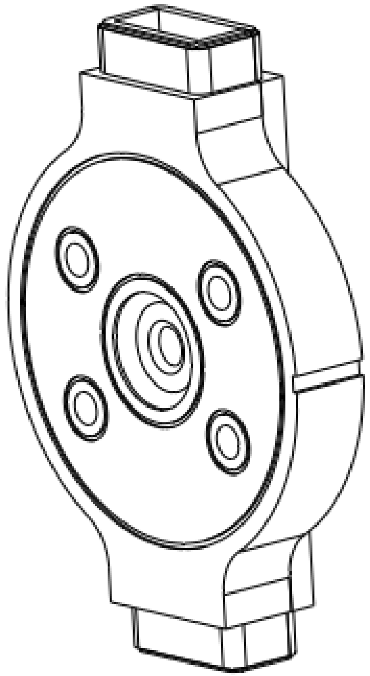
Conclusion and outlook

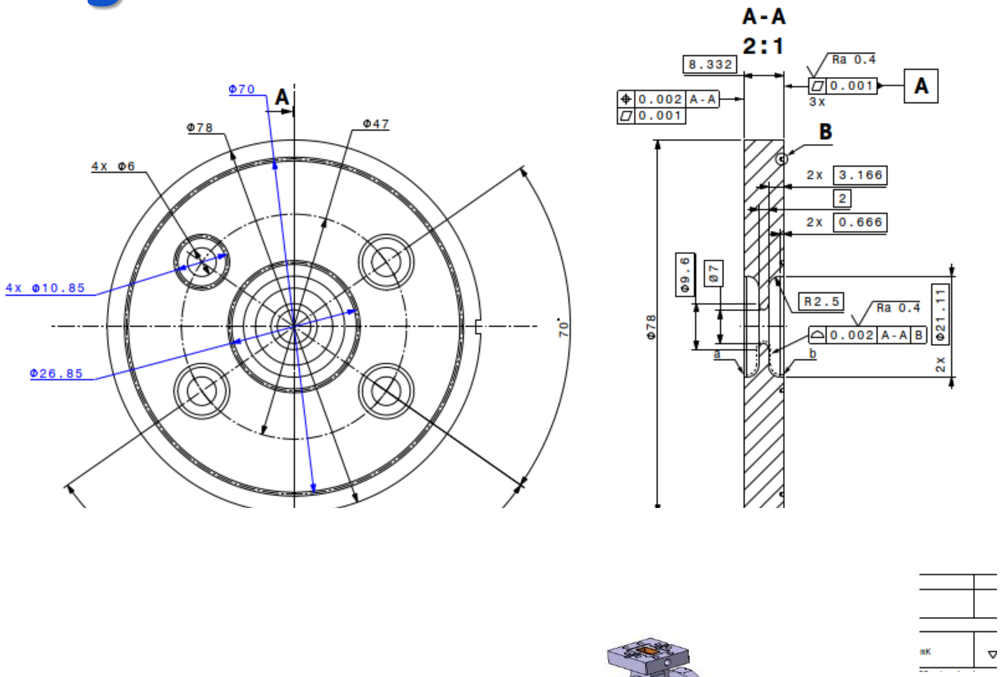
- Further optimisation of the existing baseline injector for Run 2c with respect to performance, cost and integration
- Very good start of the beam commissioning. No major problems spotted so far
  Of course, fine tuning is needed and systematic measurements.
  Clearly much more work to do !
- Will alternate commissioning periods with installations periods to complete the injector
- Interesting times ahead, a first visible piece of hardware for Run 2c and a first ‘user’ experiment on CBS at low energy. See Vlad’s presentation
- Thanks to Jordan Arnesano for his contributions to AWAKE
  Welcome to Anton Eager to take over in December

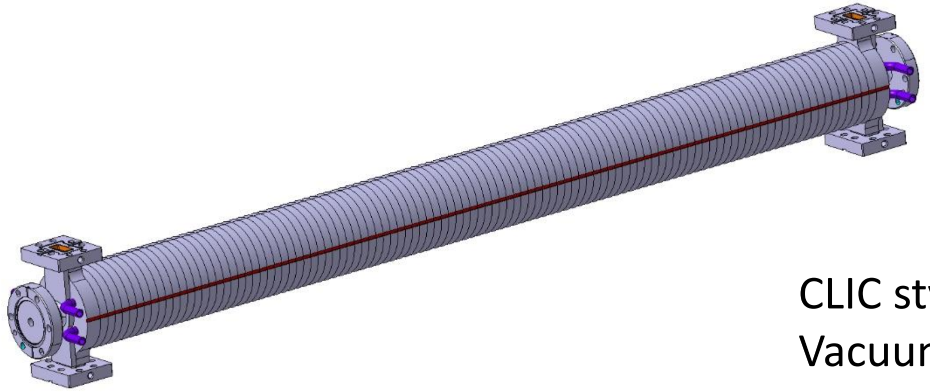
Additional material

X-band accelerating structure
Mechanical design









Structure to be inserted in a solenoid of
150 mm diameter bore radius

CLIC style tolerances
Vacuum brazing design

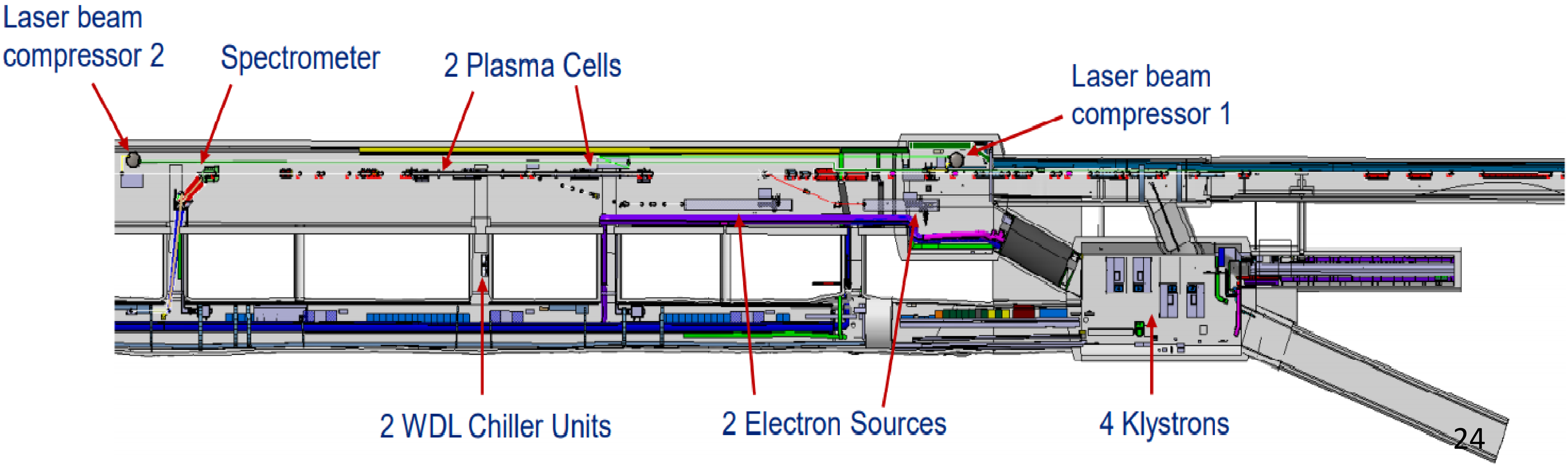
RF-Design made by D. Alesini, M. Diomede, INFN Frascati

Other requirements

- A certain flexibility in the beam parameters which can be delivered keeping good energy spread and emittance
  Energy: +- 10%, Charge +400% ?, Bunch length: 100%, beam size : see transport

- Constraint space for hardware

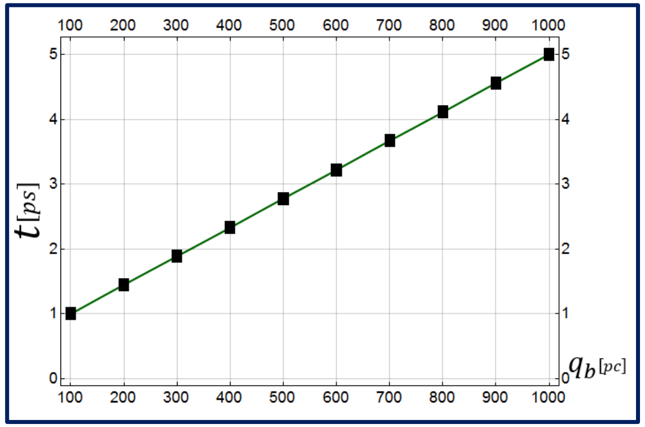
- Excellent timing stability and synchronisation with laser and self modulation device
  30 fs stability



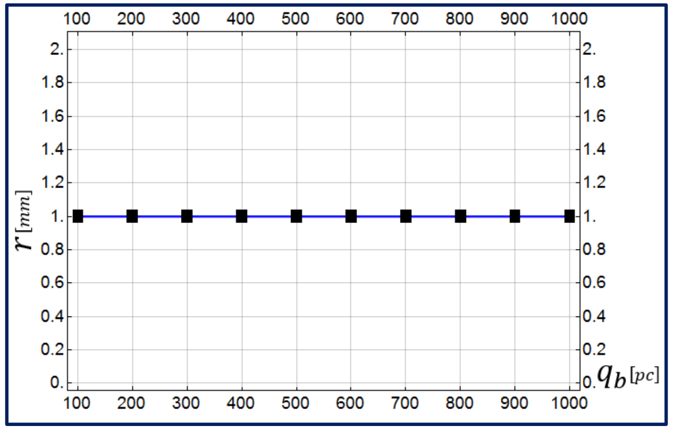
Flexibility to produce higher charge
(for lower plasma density or experimental reasons)

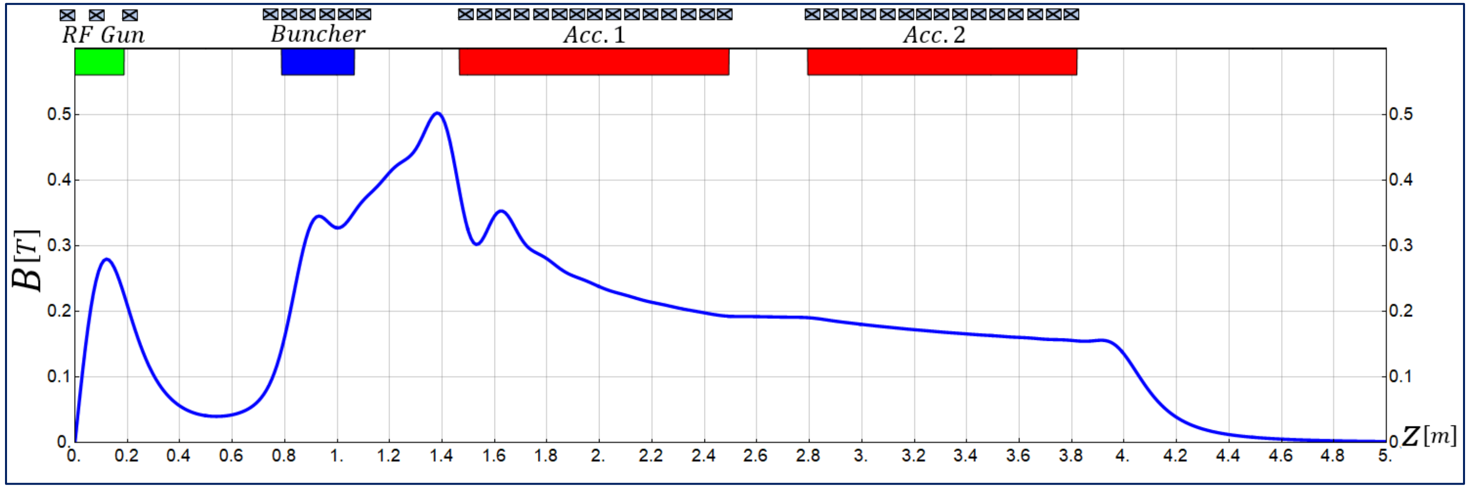
Changing only laser pulse length and adapting magnetic field slightly

Laser Pulse Duration



Laser Spot Size





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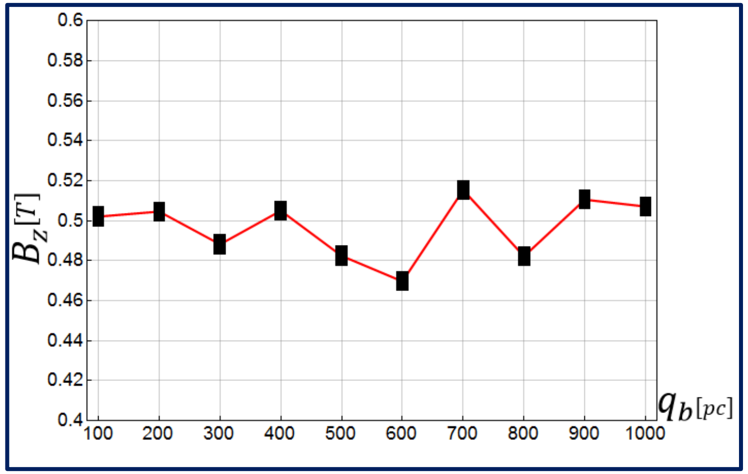
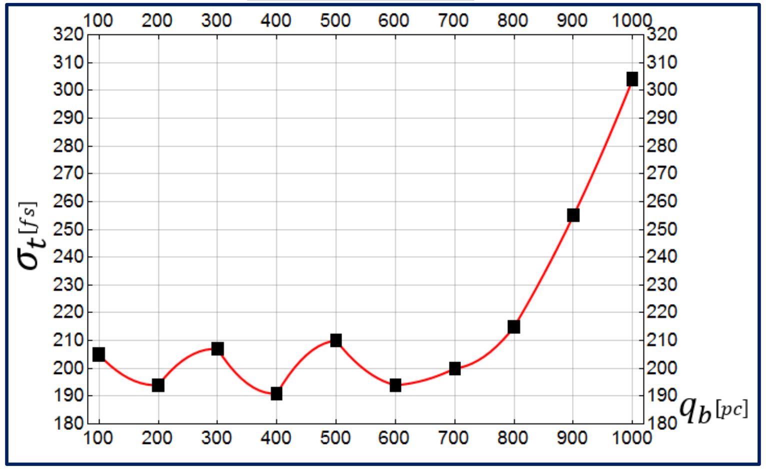
Flexibility to produce higher charge

0.1 to 1 nC per bunch

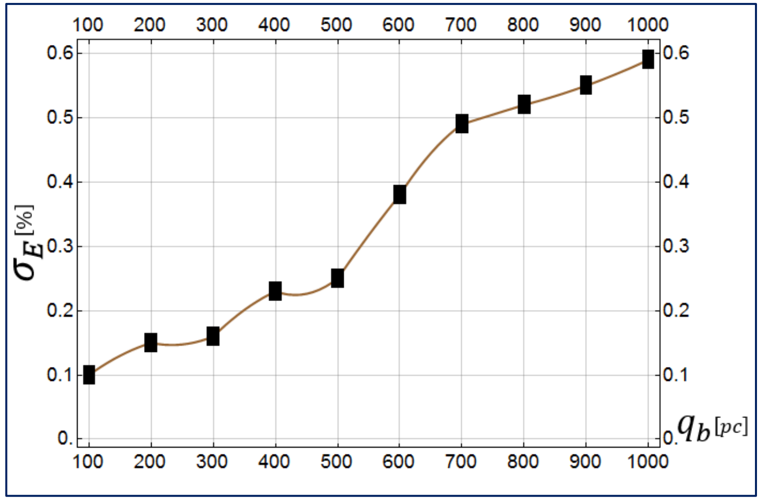
Max_B_z



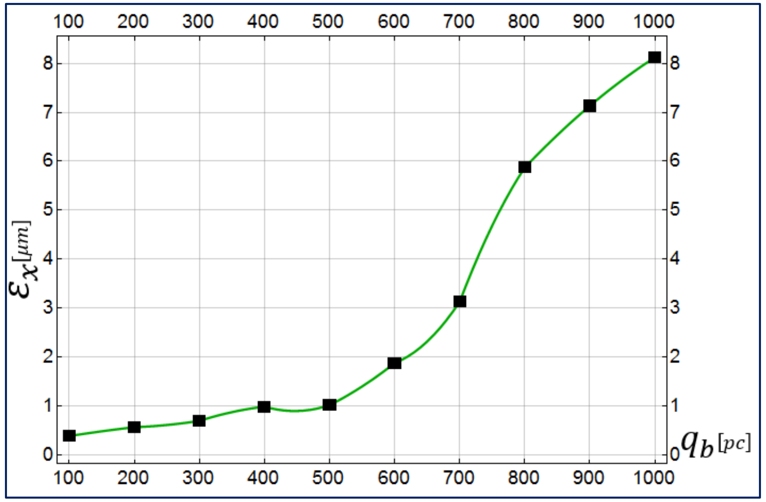
Bunch Length



Energy Spread



Bunch Emittance



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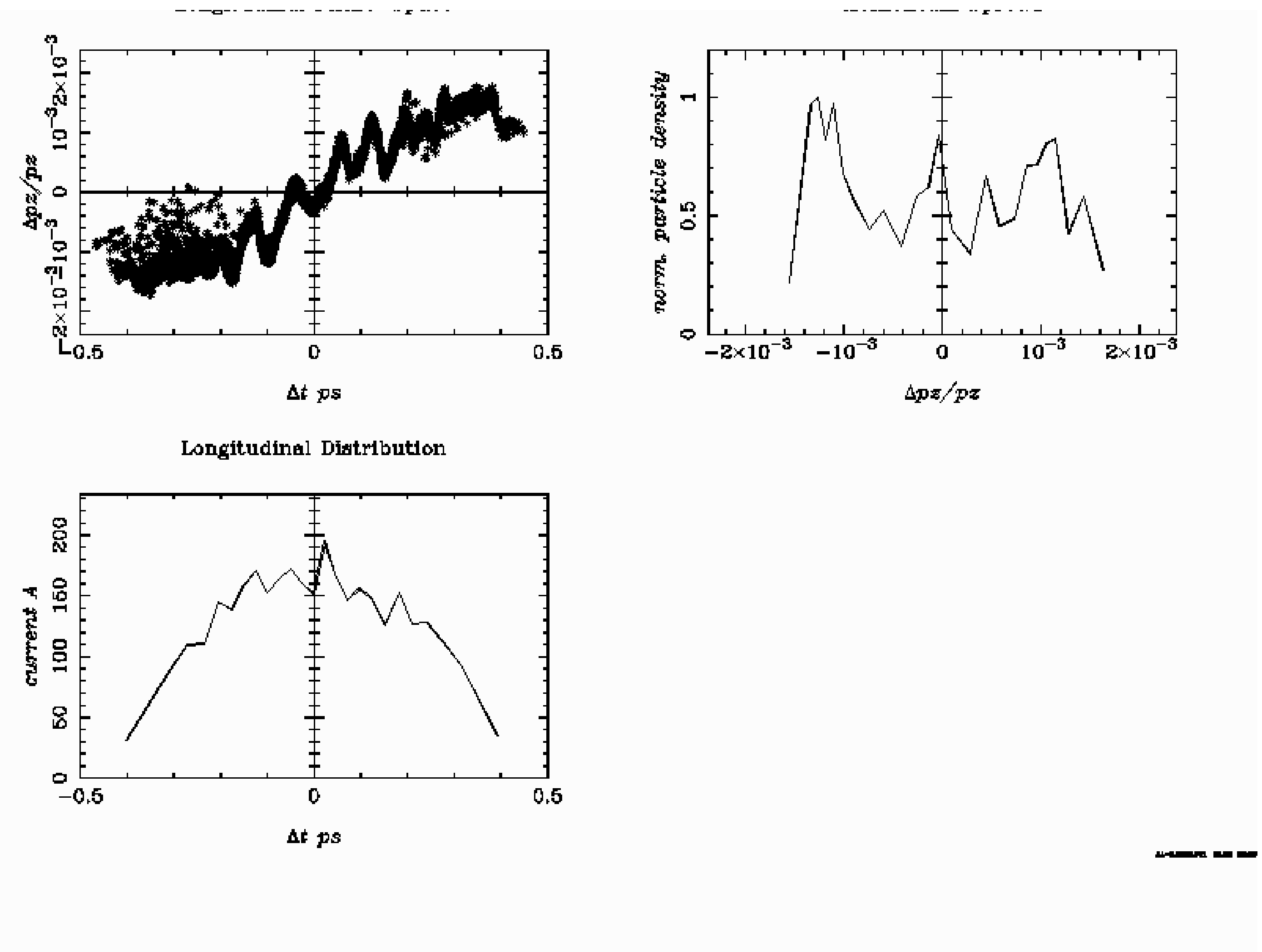
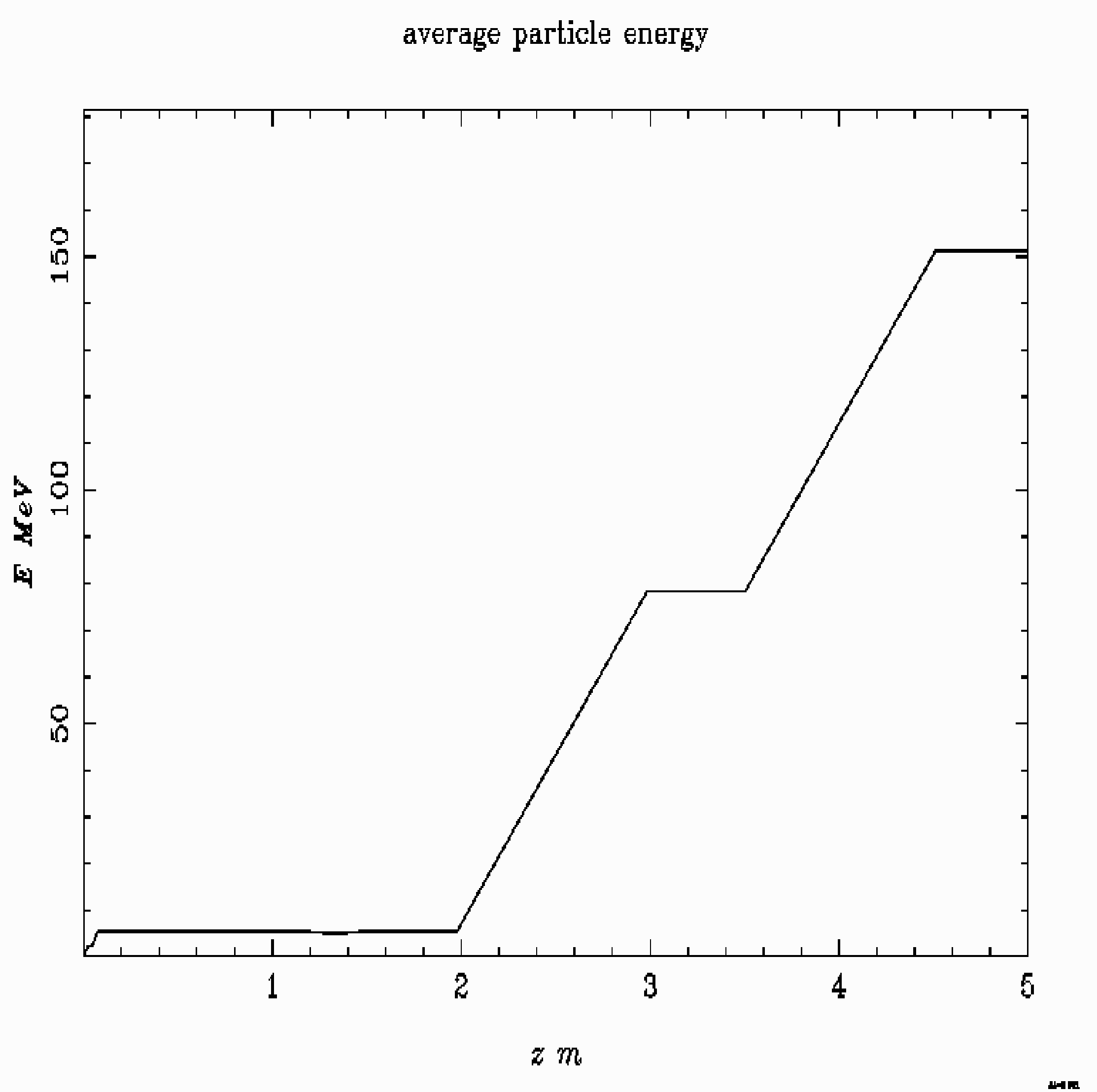
Tentative RUN 2 injector parameter for 150 MeV

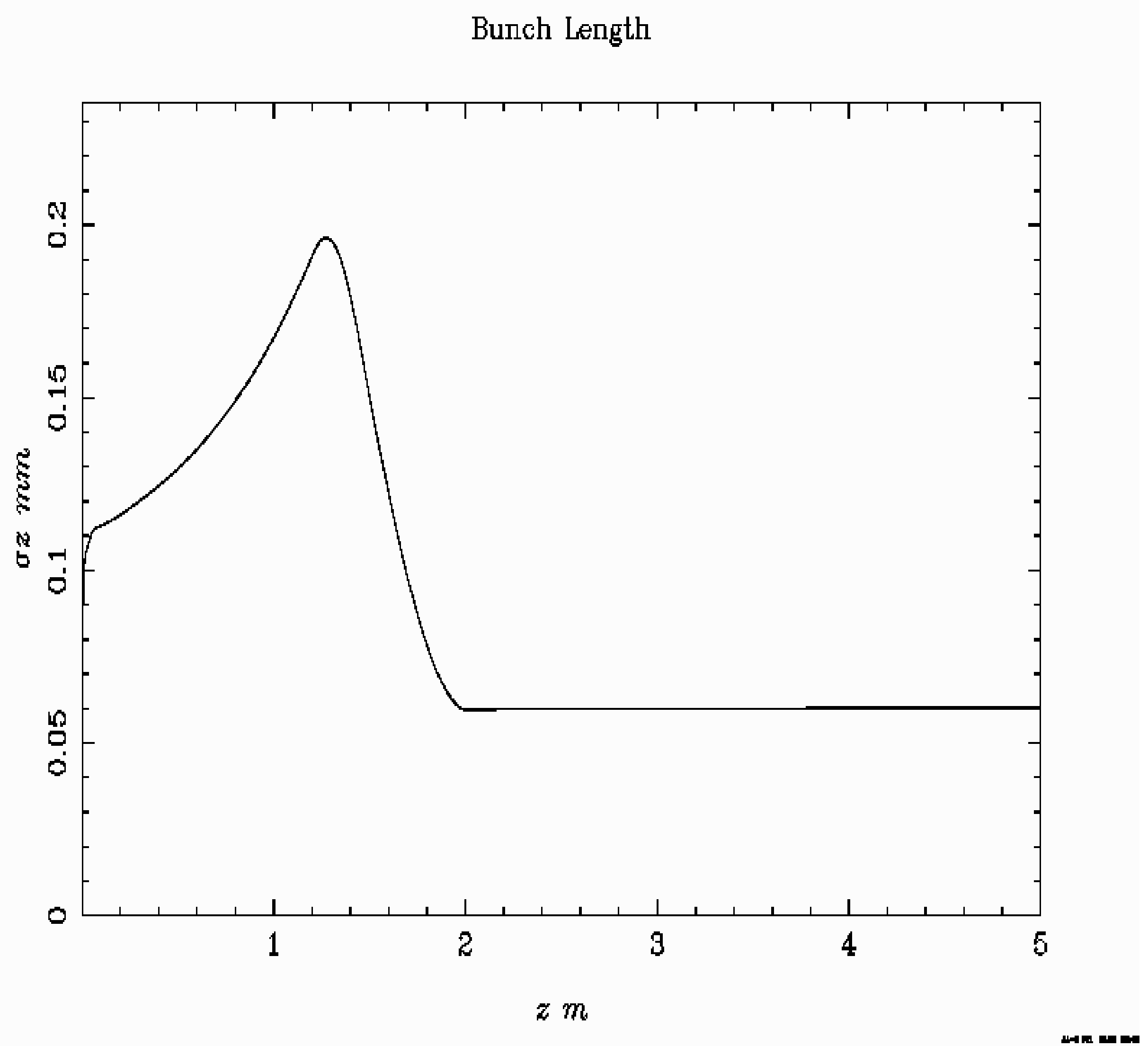
Only scaled down accelerating gradient, identical initial distributions, no new optimization

Energy:	**151.8 MeV**
Energy Spread:	**144.5 keV rms =9.5 10^{-4}**
Emittance: x/y:	**0.7 mm mrad**
Bunch length:	**60 um rms**
Bunch Charge:	**100 pC**

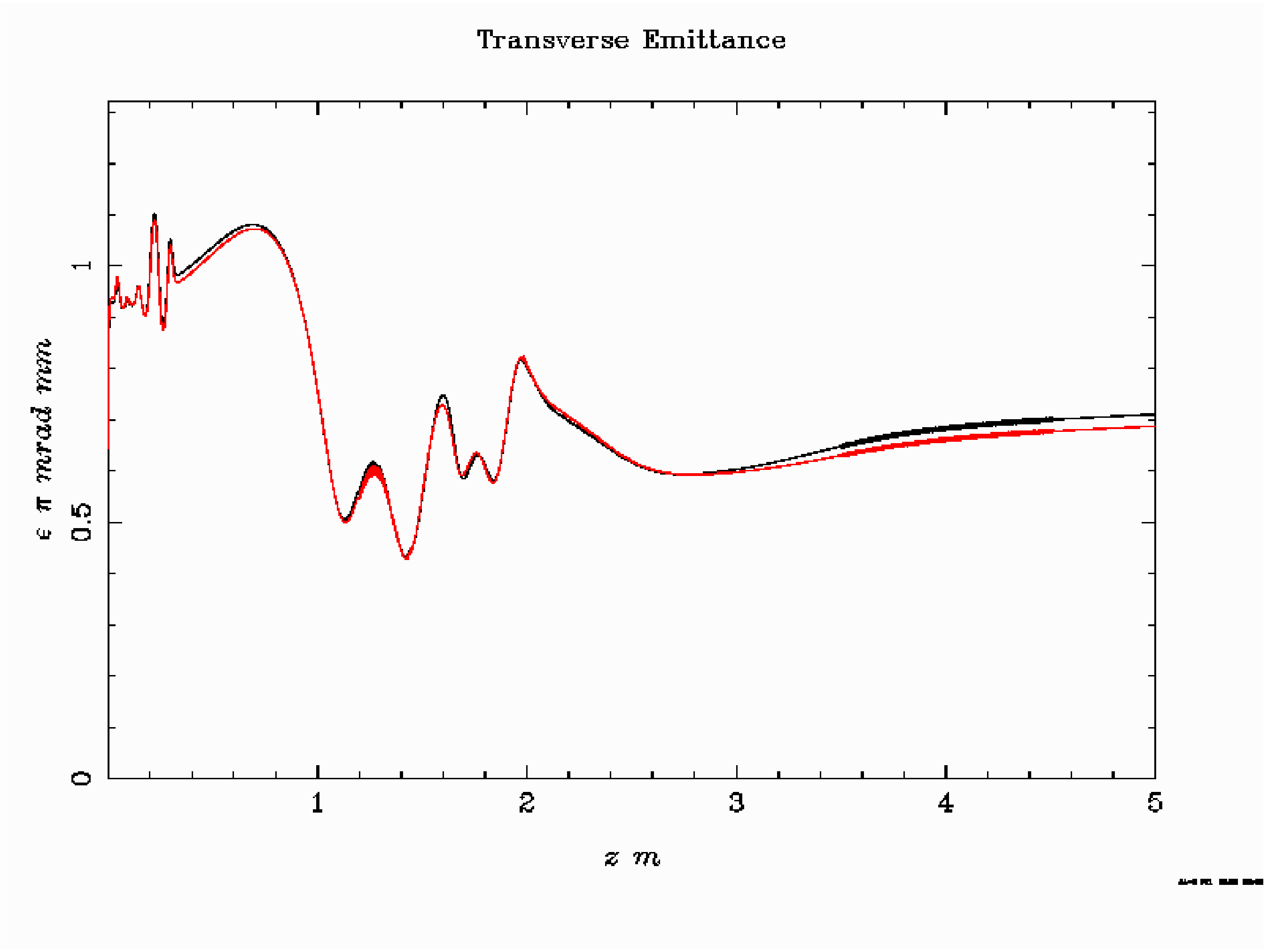


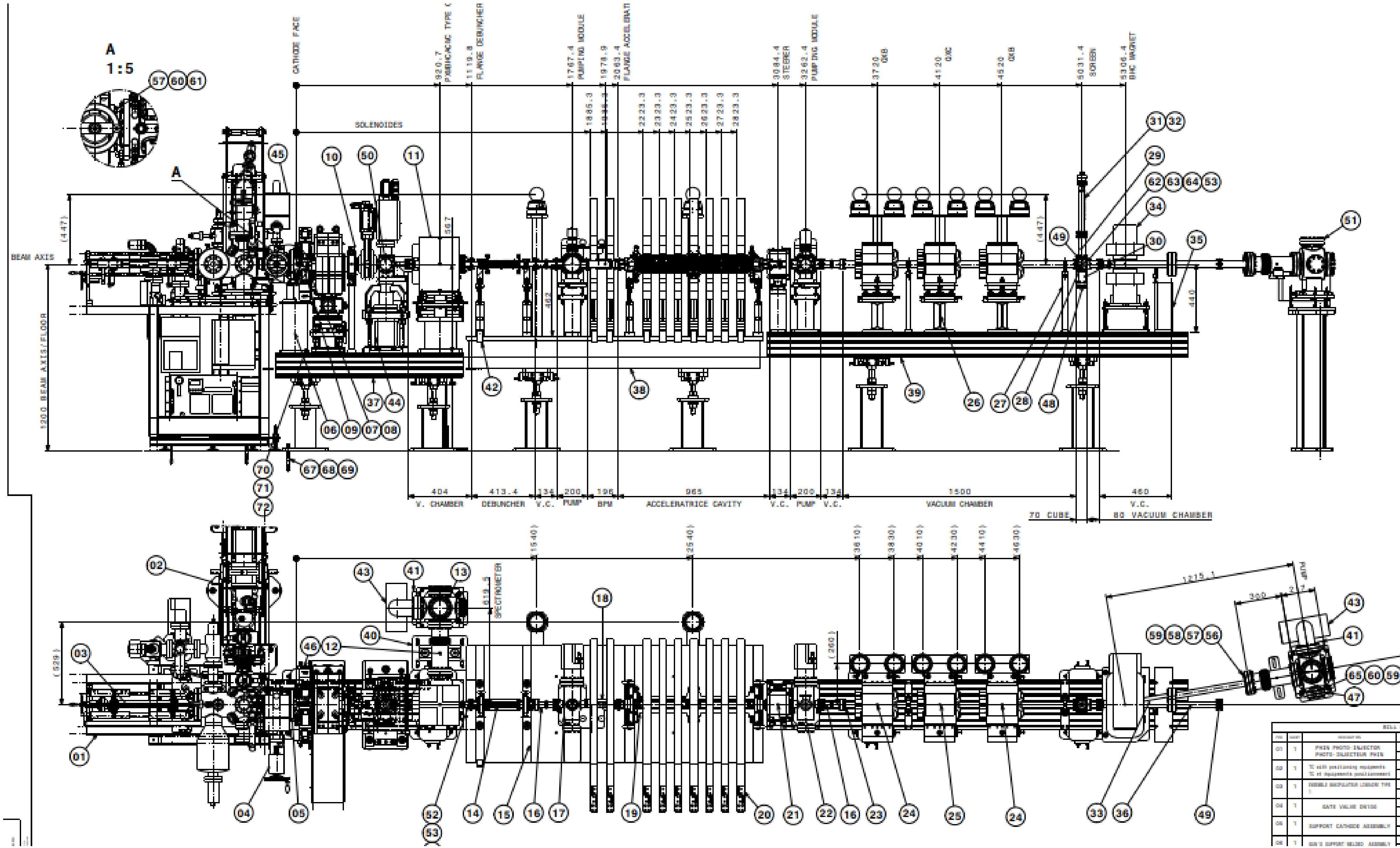
Tentative RUN 2 injector parameter for 150 MeV





Tentative RUN 2 injector parameter for 150 MeV

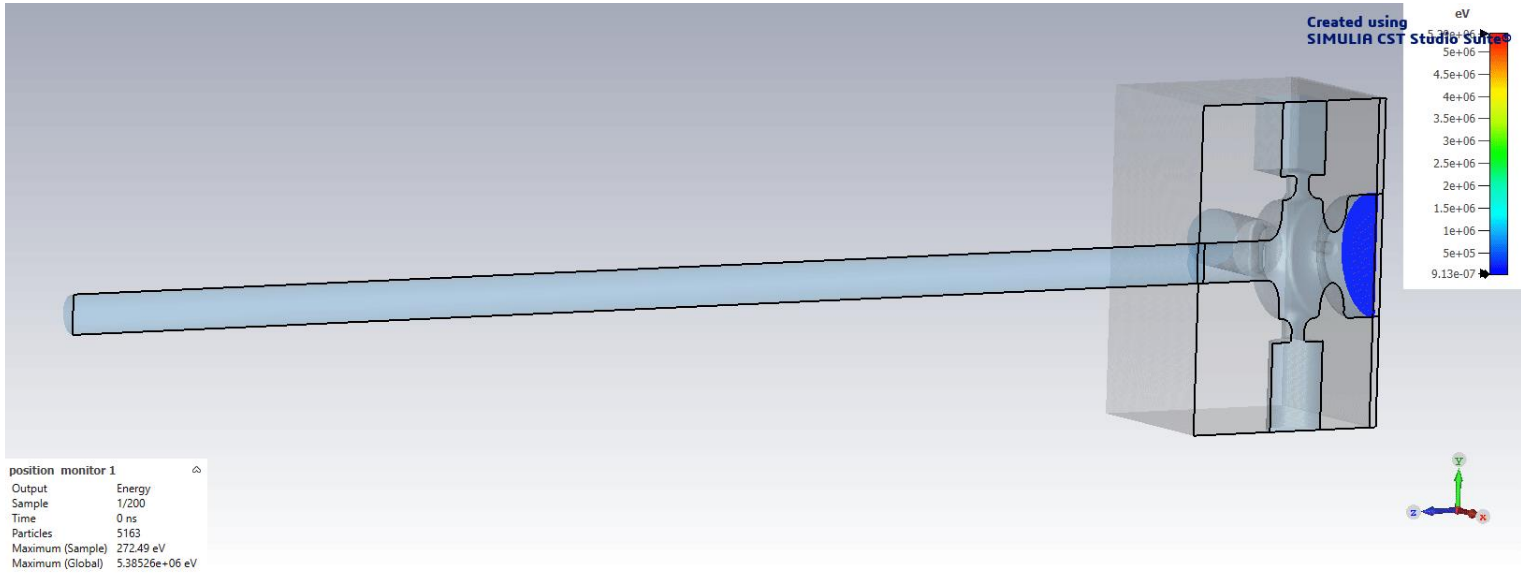




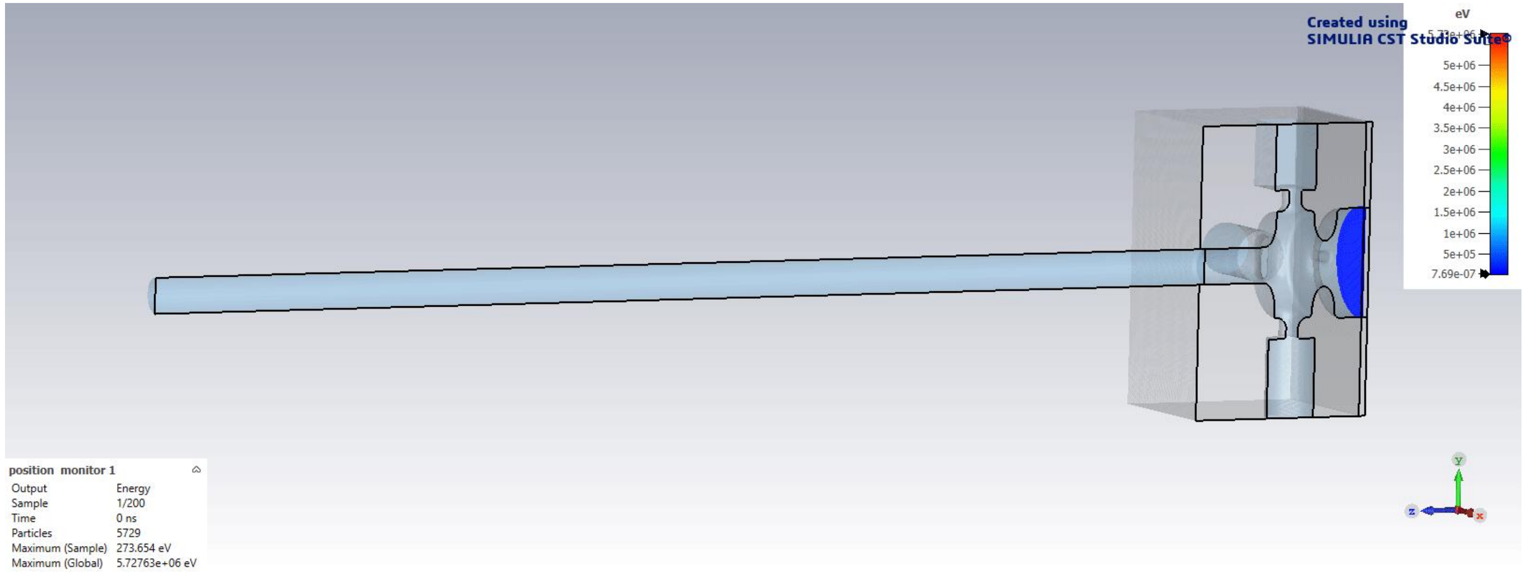
BILL OF MATERIALS					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01	1	PHIN PHOTO-INJECTOR PHOTO-INJECTEUR PHIN	[illegible]		
02	1	TC with positioning equipments TC et équipements positionnement	[illegible]		
03	1	[illegible]	[illegible]		
04	1	GATE VALVE [illegible]	[illegible]		
05	1	SUPPORT CATHODE ASSEMBLY	[illegible]		
06	1	GUN'S SUPPORT WELDED ASSEMBLY	[illegible]		

PIC Dark Current Simulations

No Solenoid

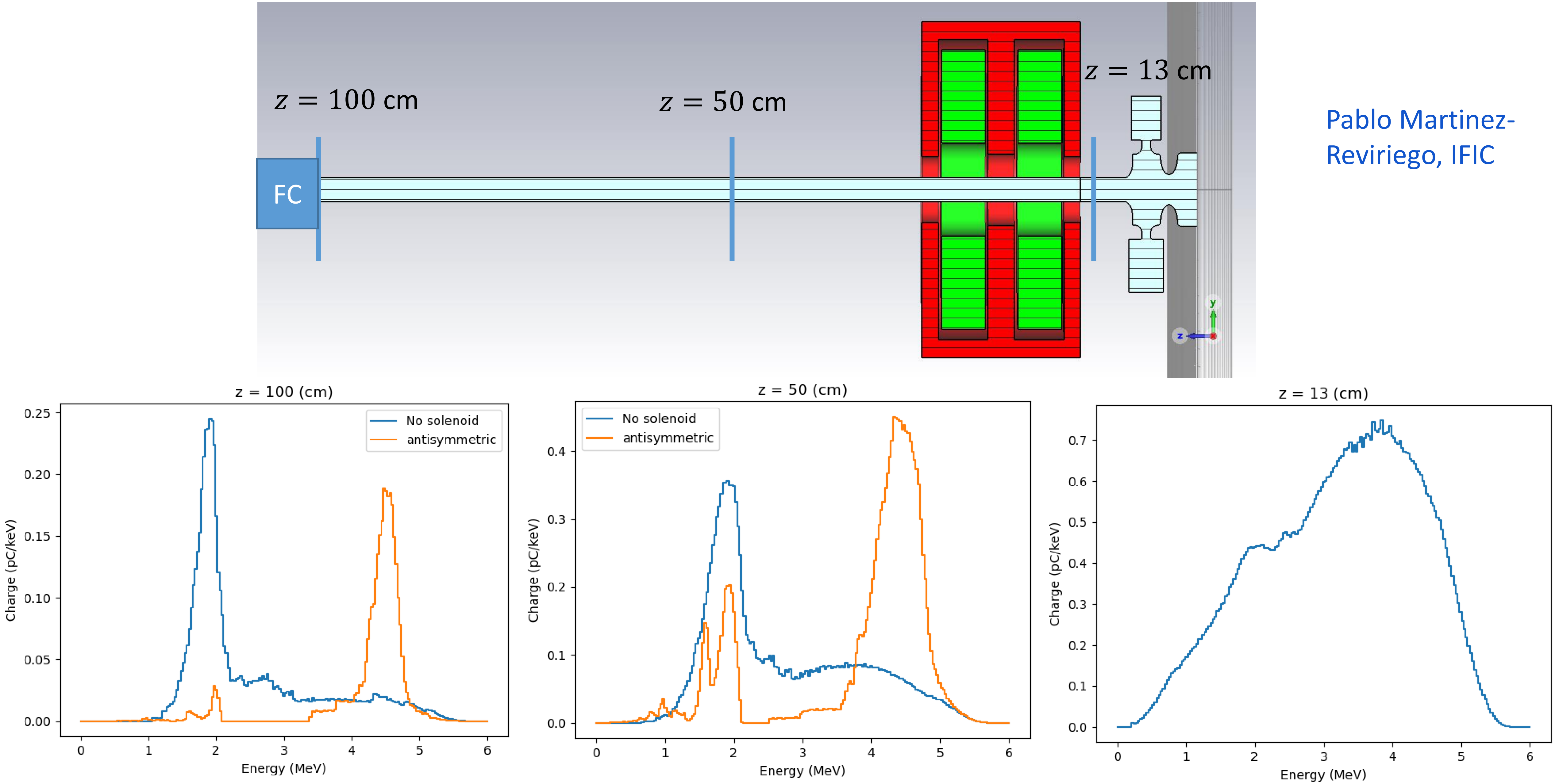


Solenoid: Antisymmetric mode



Pablo Martinez-Reviriego, IFIC

Dark Current Simulations



Pablo Martinez-Reviriego, IFIC