Electron source systems for AWAKE Run 2

LWFA4AWAKE meeting, 11.4.2022

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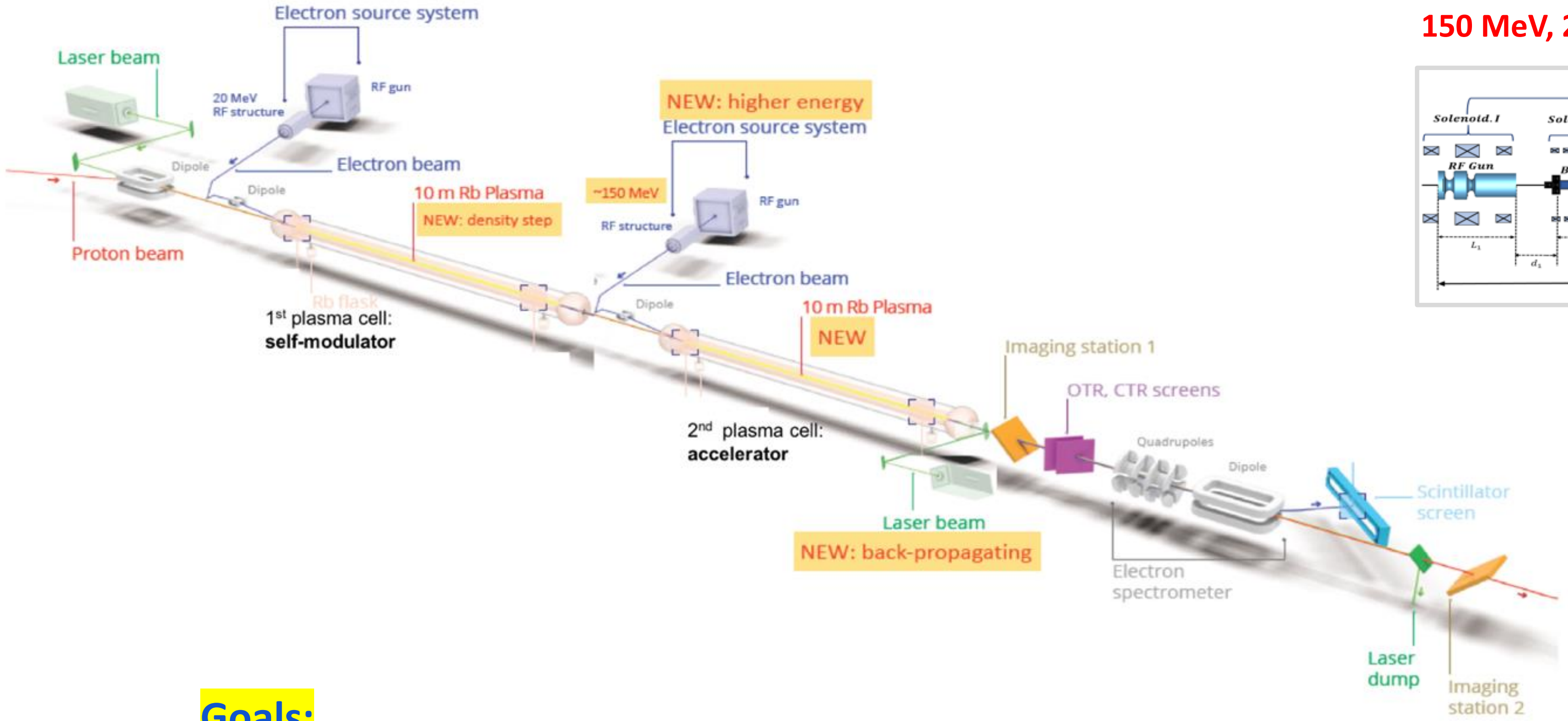
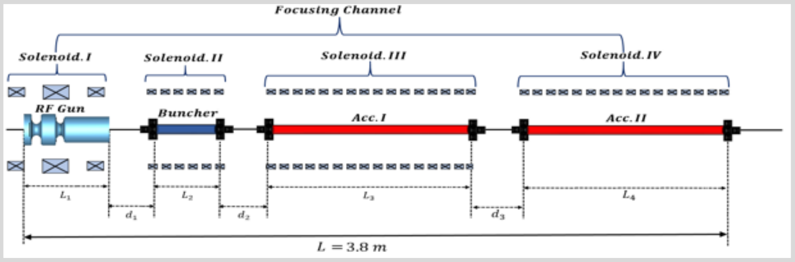
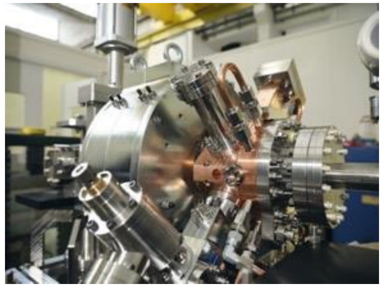
AWAKE Run 2

- ➔ **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**





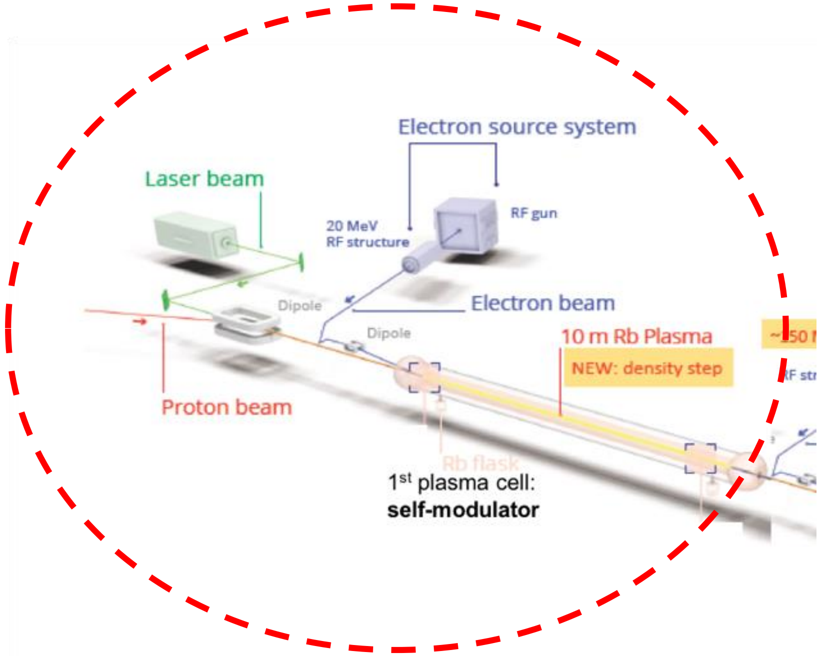
Goals:

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)

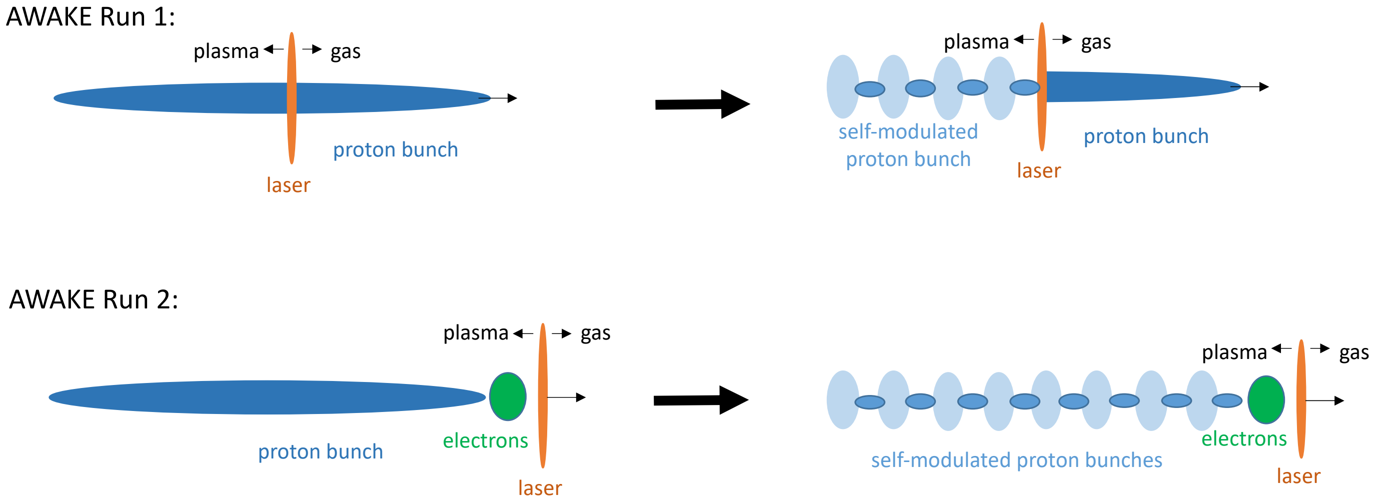
Demonstrate scalable plasma source technology (e.g. helicon prototype)

AWAKE Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell



Why electron bunch seeding:

→ Modulates entire proton bunch with phase reproducibility



→ Run 2a: use the existing AWAKE Facility

→ **Physics program in ~2021/2022**

Parameters for both injectors

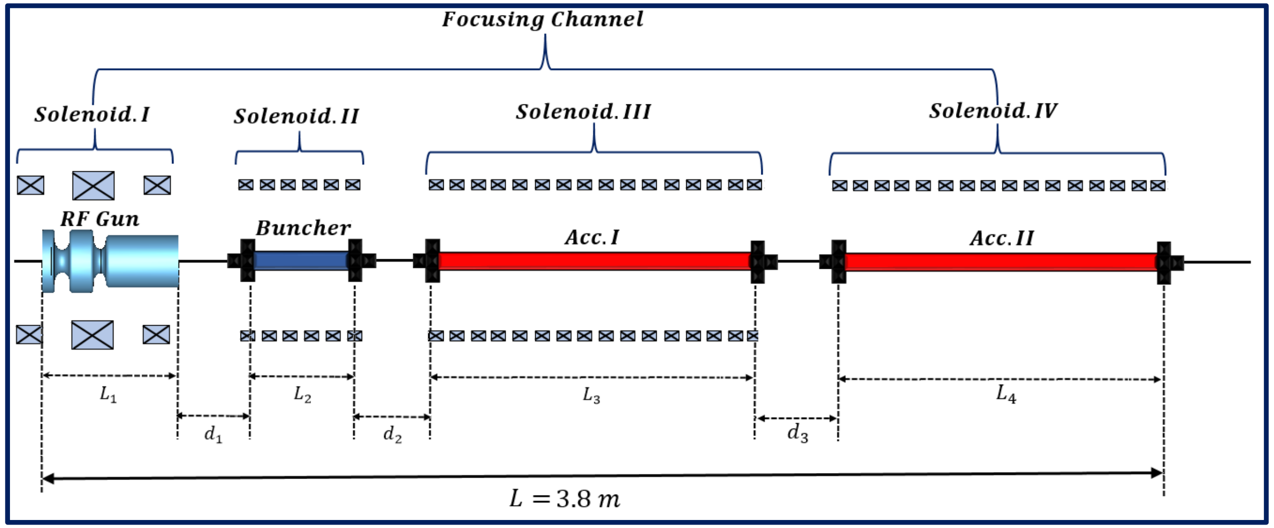
Working documents held by Rebecca (Injector 2, EDMS 2378918) and John (Injector 1, EDMS 2417022,2588263)

	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



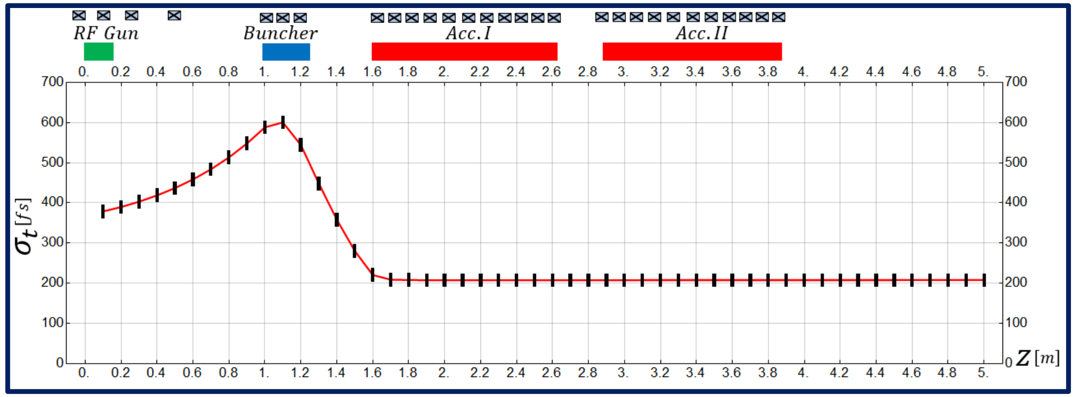
Laser parameters

$\lambda[nm]$	$w[ev]$	$r[mm]$	$t[ps]$	$q[nc]$
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



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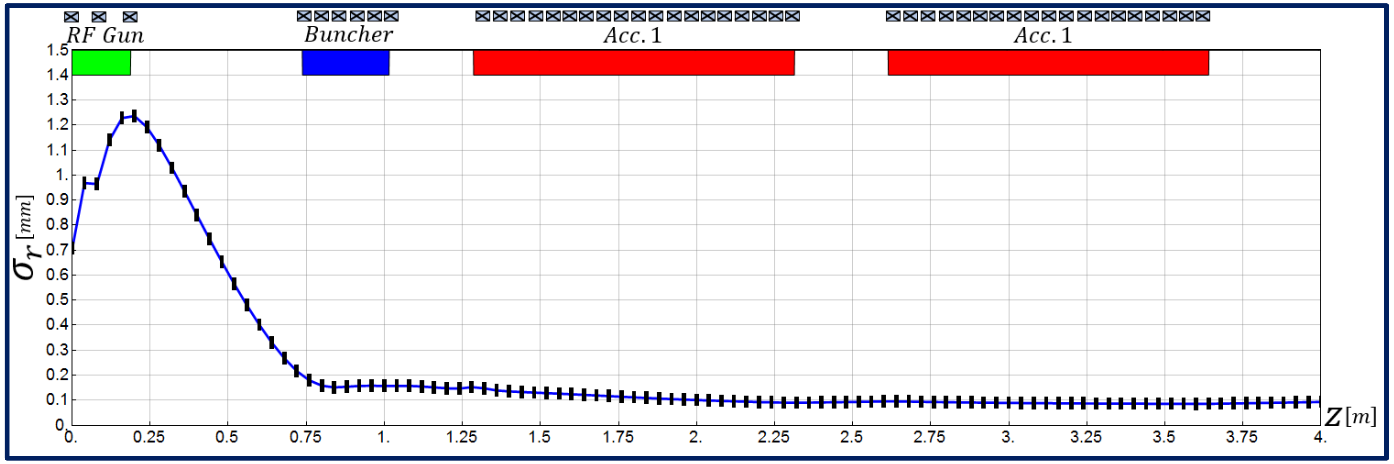
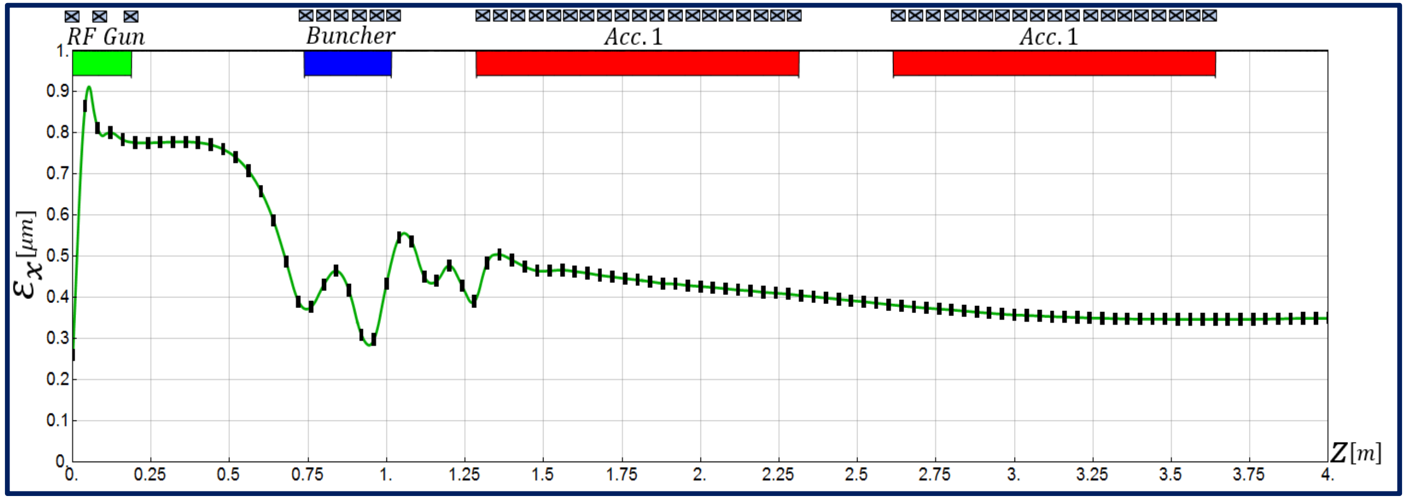
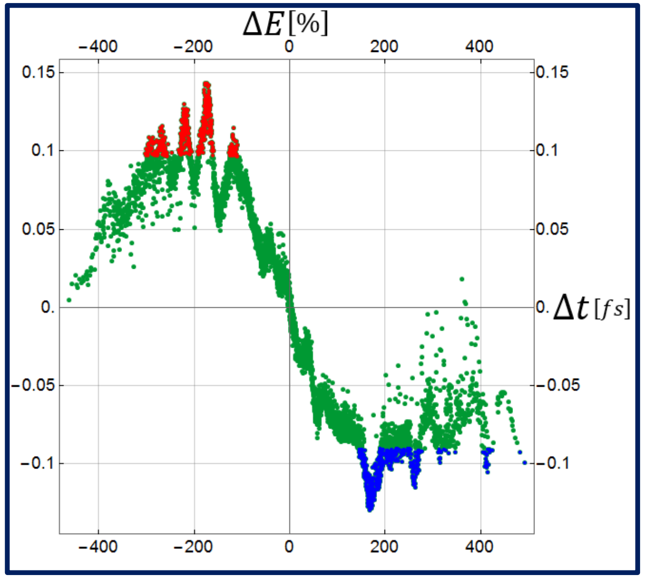
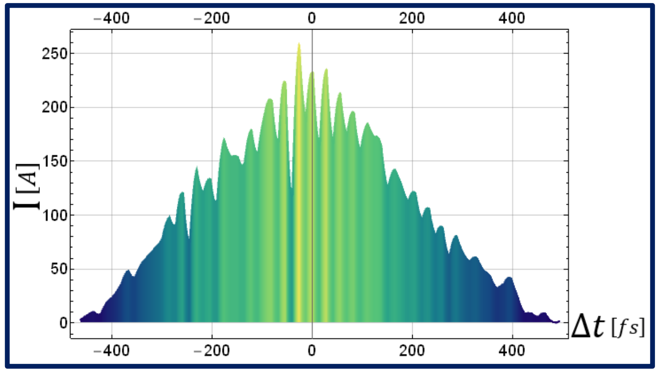
Reference design









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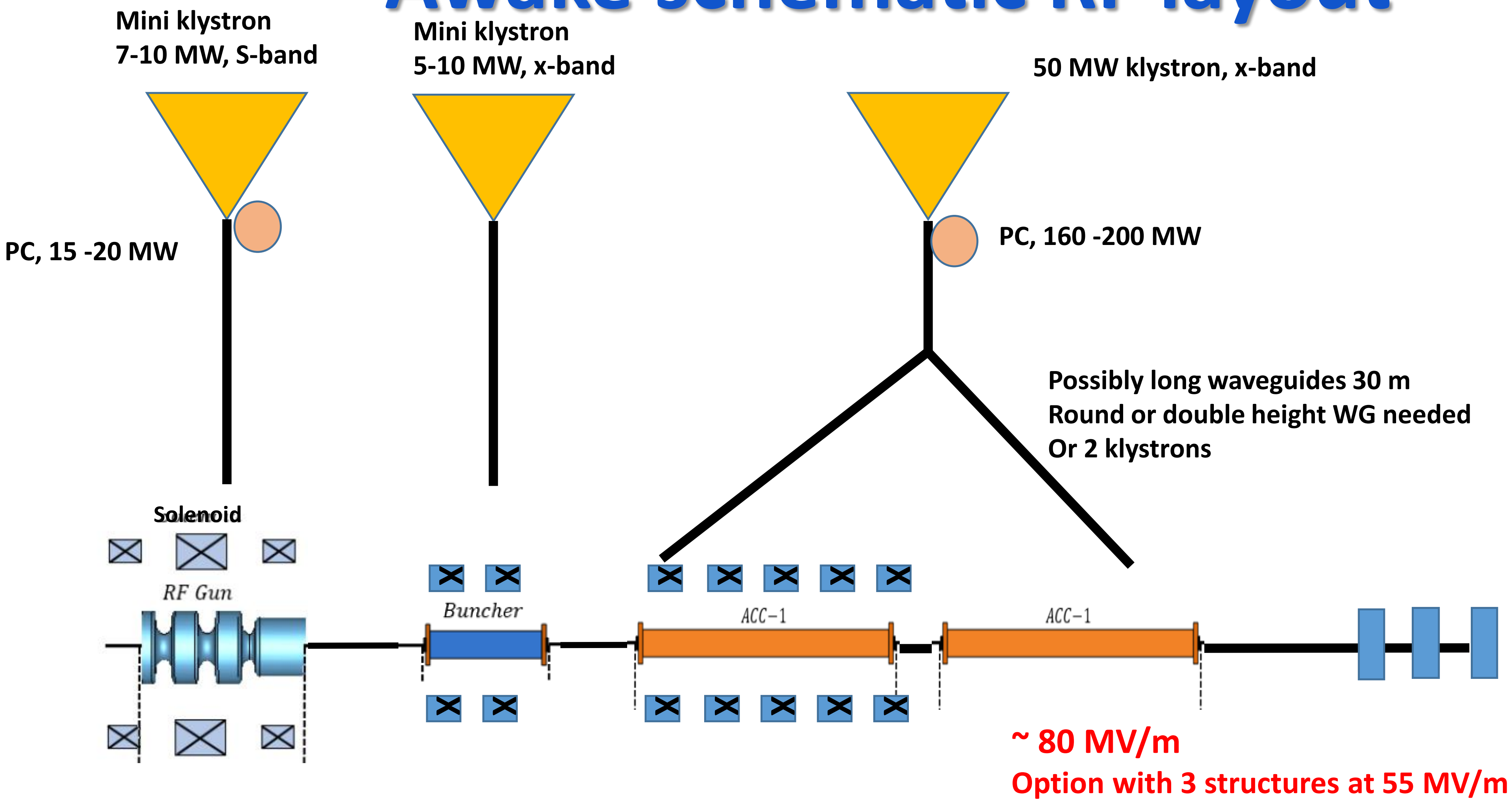
Awake schematic RF layout



Total Energy 150- 160 MeV, 10 Hz rep. rate, single bunch

Will try to use CLIC developed x-band components as much as possible

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

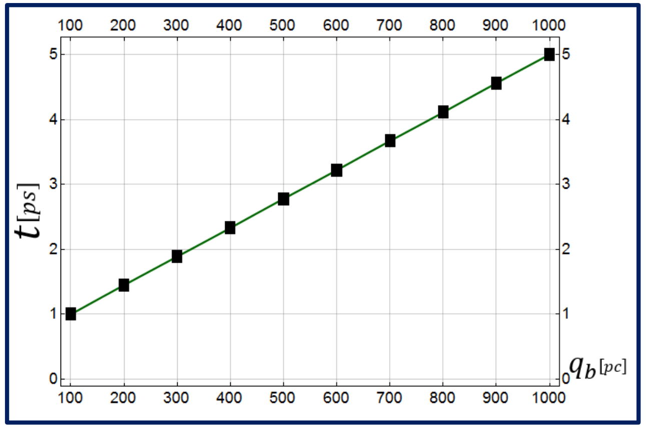
- Excellent timing stability and synchronisation with laser and self modulation device
  30 fs stability

Flexibility to produce higher charge

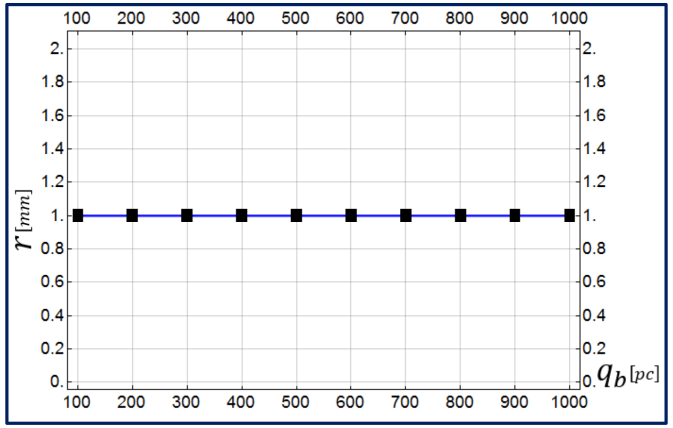
(for lower plasma density or experimental reasons)

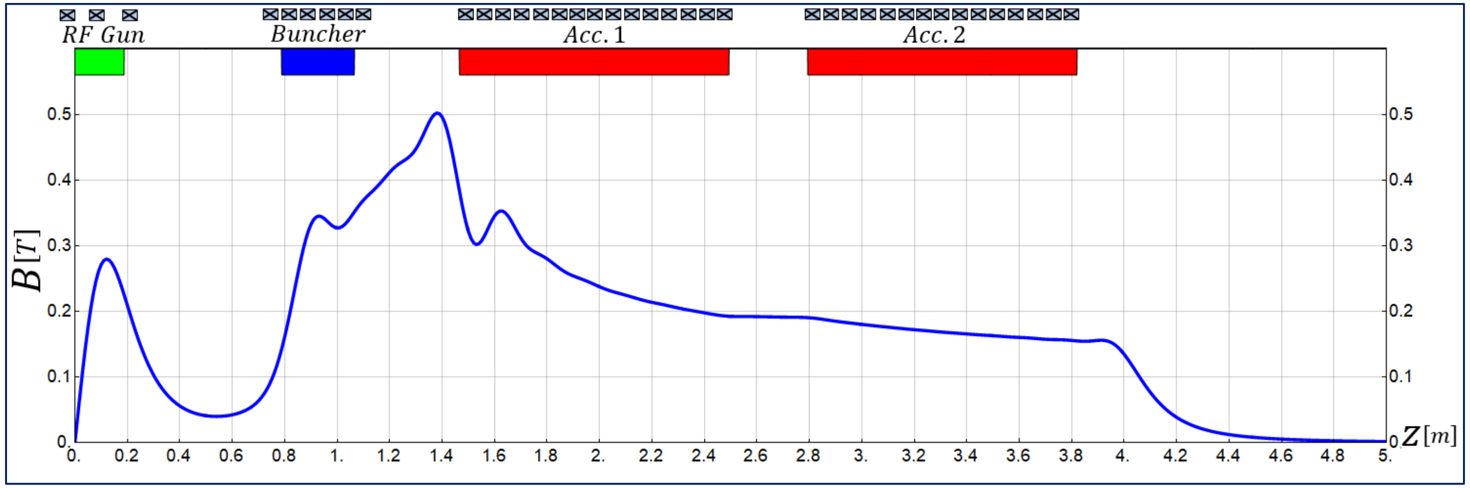
Changing only laser pulse length and adapting magnetic field slightly

Laser Pulse Duration



Laser Spot Size





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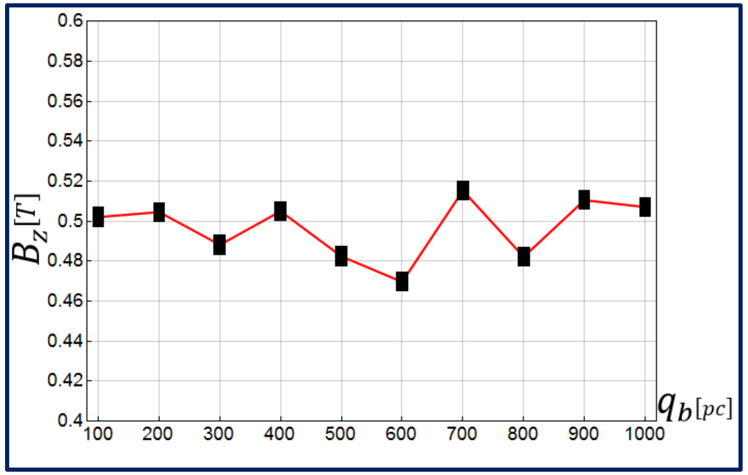
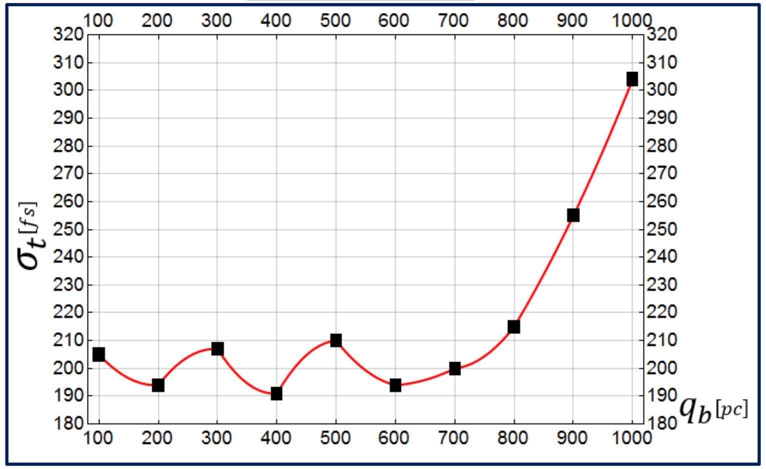
Flexibility to produce higher charge

0.1 to 1 nC per bunch

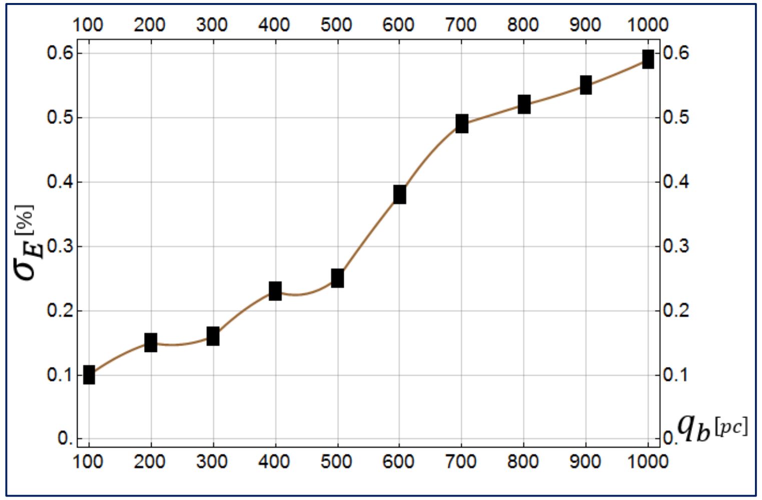
Max_B_z



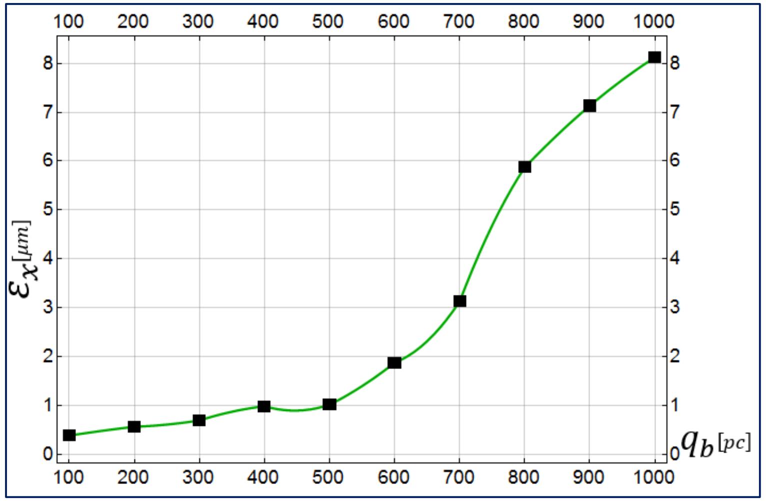
Bunch Length



Energy Spread



Bunch Emittance



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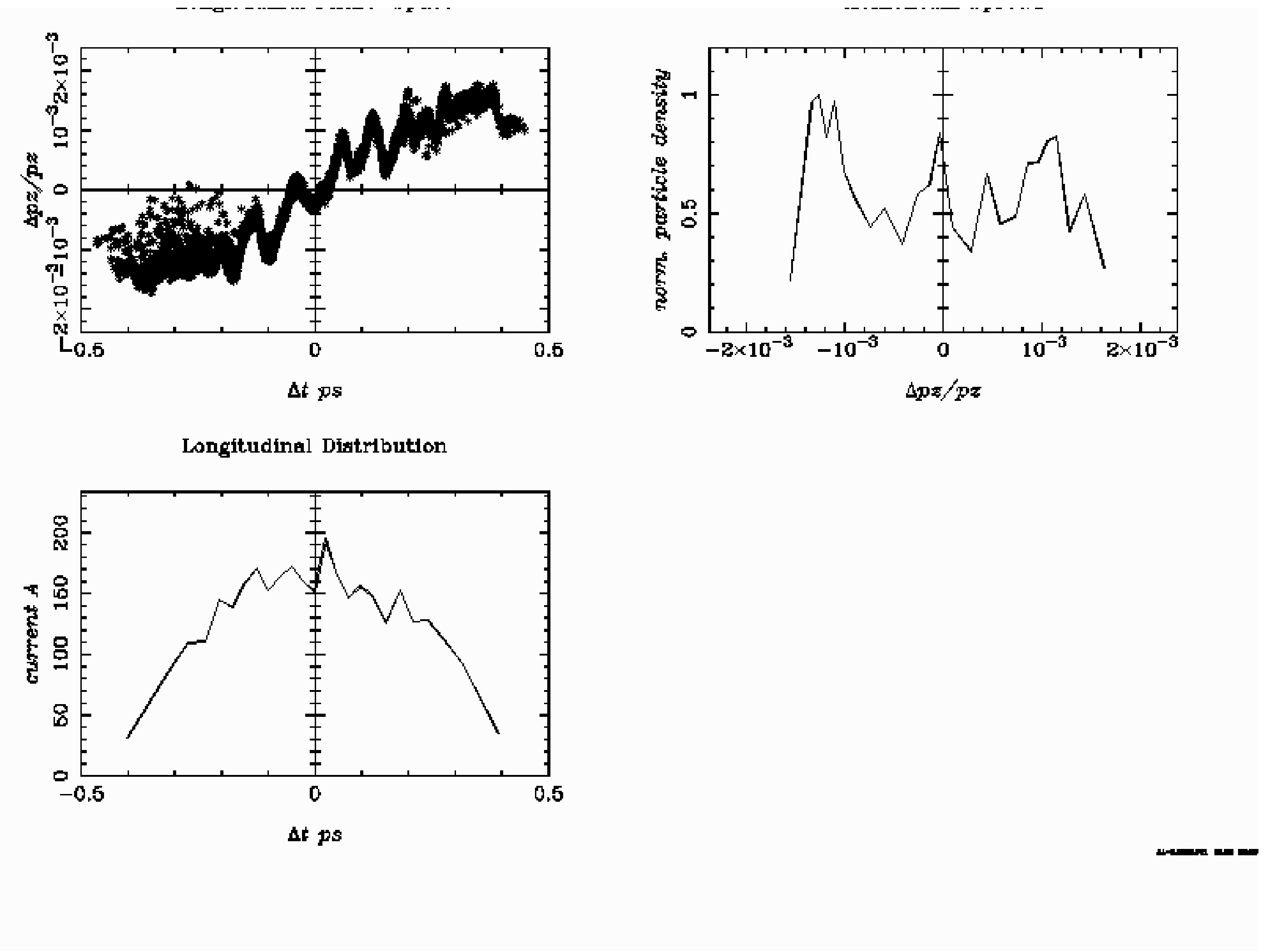
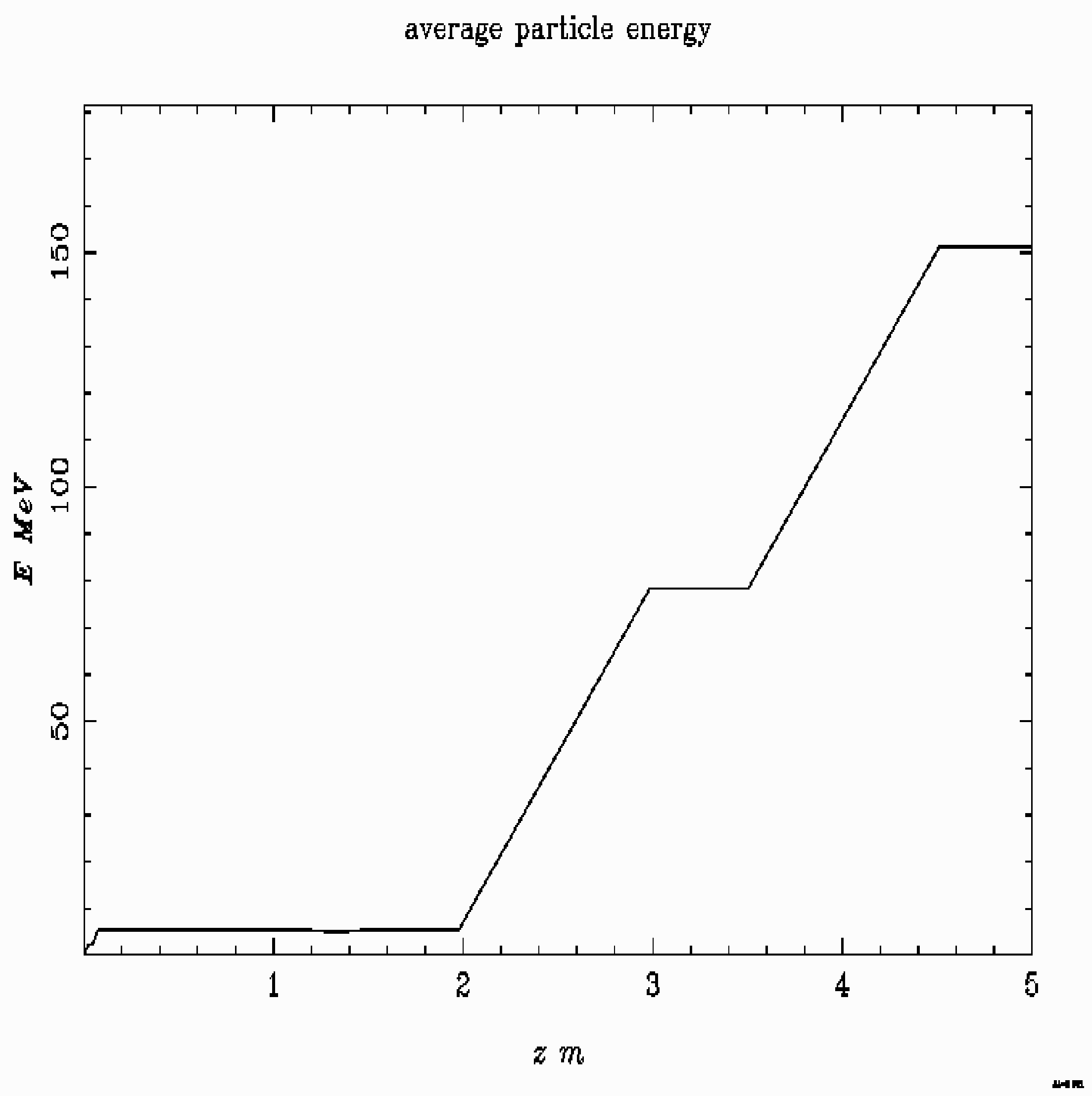
Tentative RUN 2 injector parameter for 150 MeV

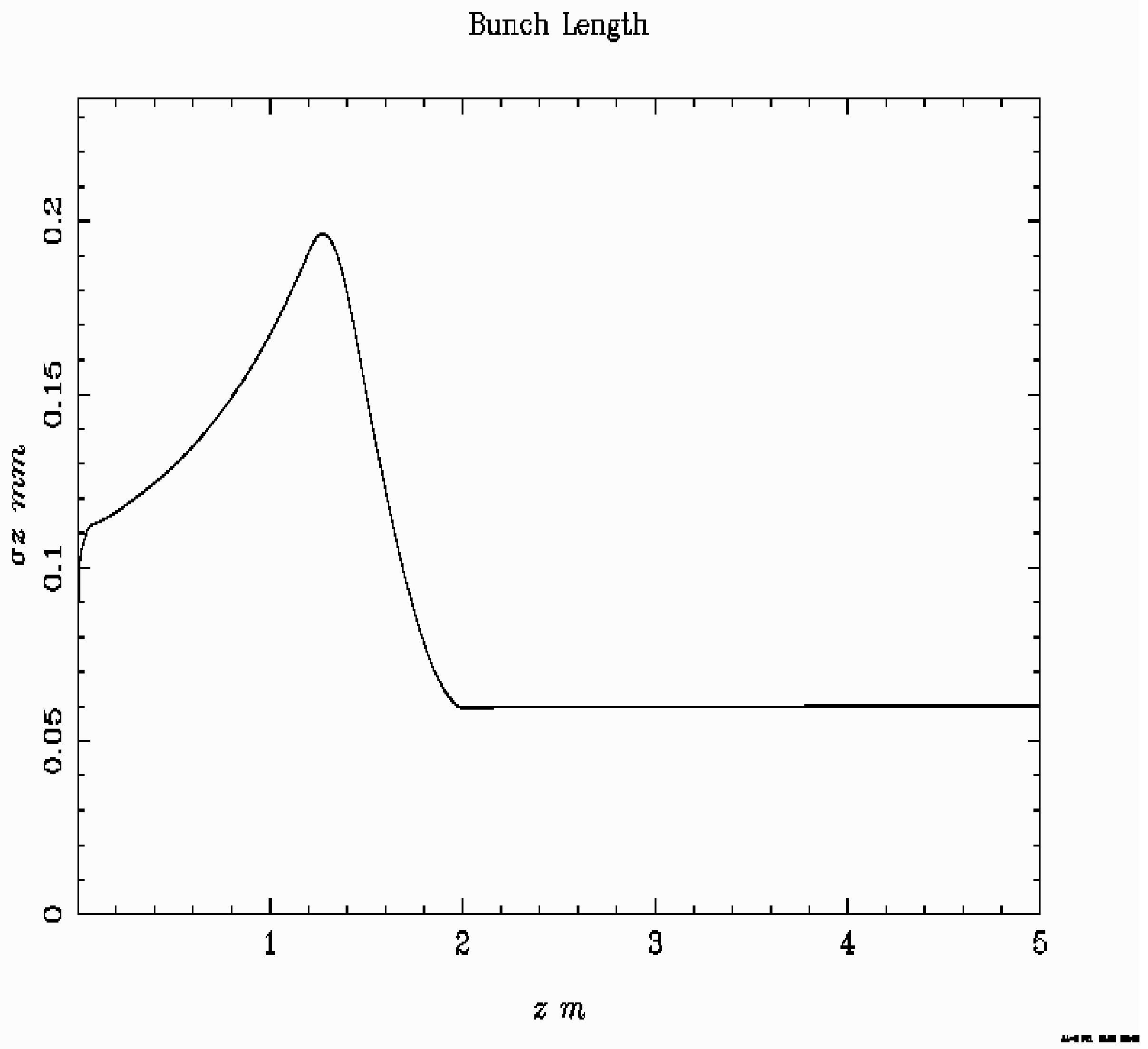
Only scaled down accelerating gradient, identical initial distributions, no new optimization

Energy:	**151.8 MeV**
Energy Spread:	**144.5 keV rms**
Emittance: x/y:	**0.7 mm mrad**
Bunch length:	**60 um rms**
Bunch Charge:	**100 pC**

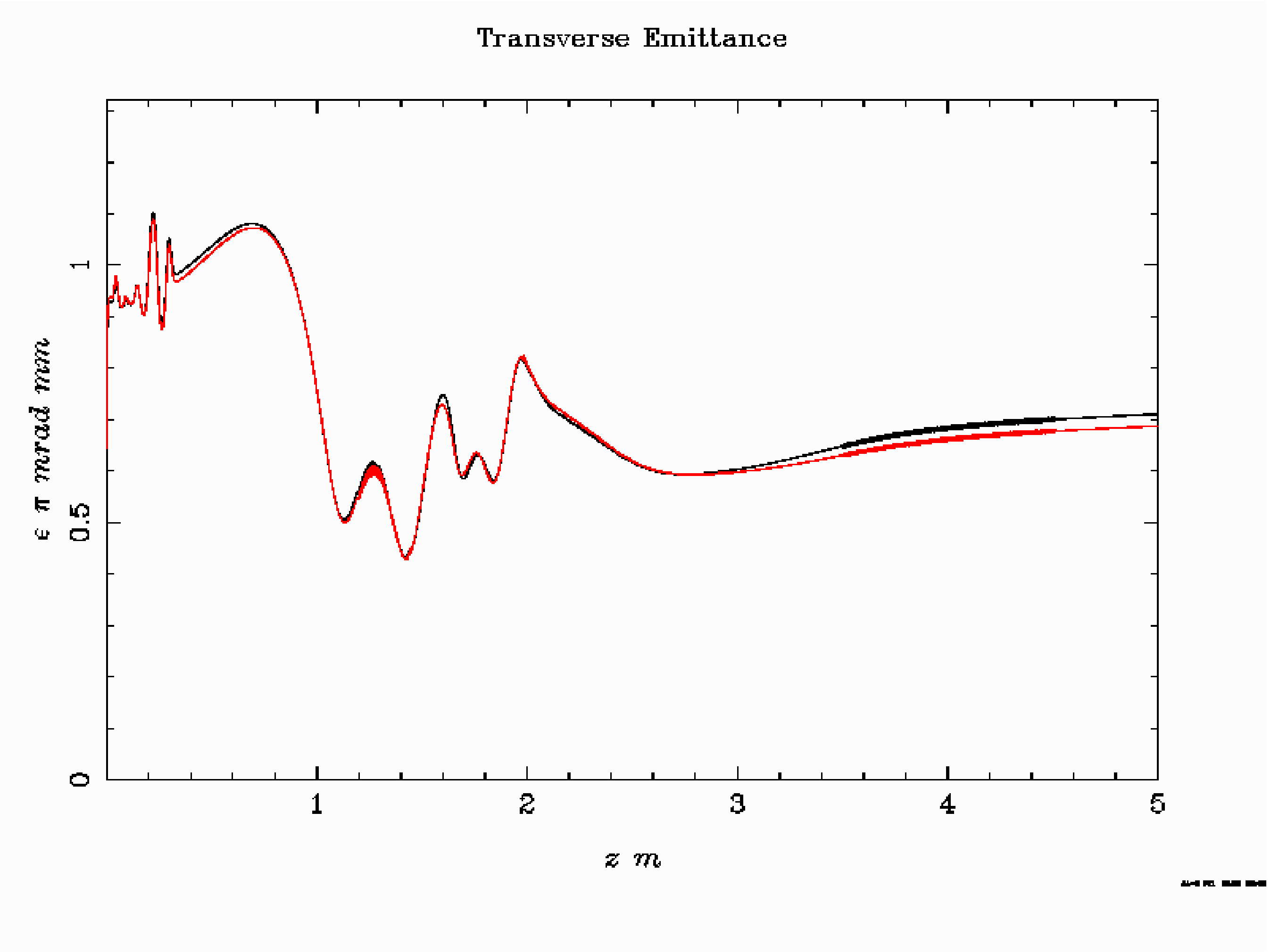


Tentative RUN 2 injector parameter for 150 MeV



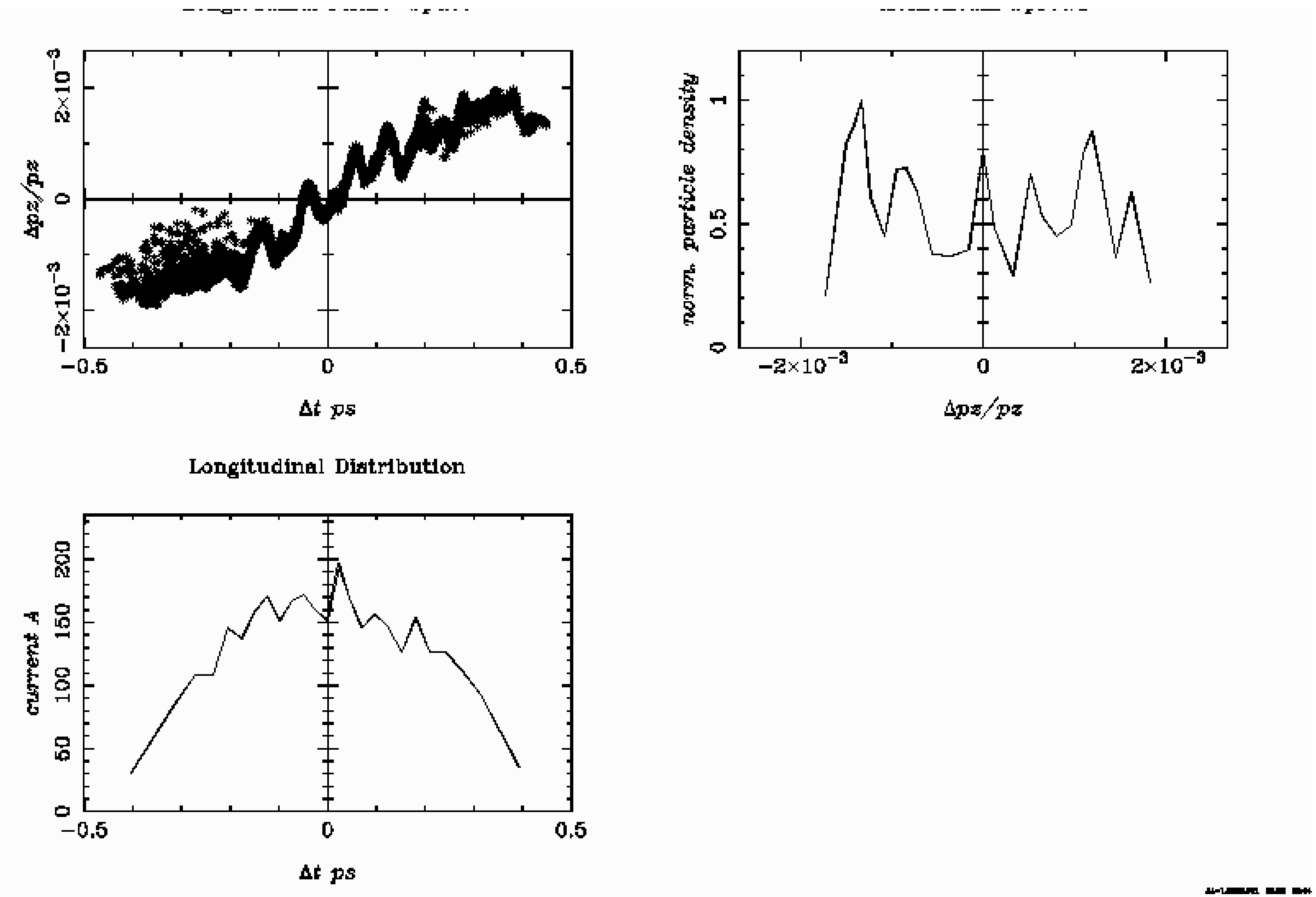


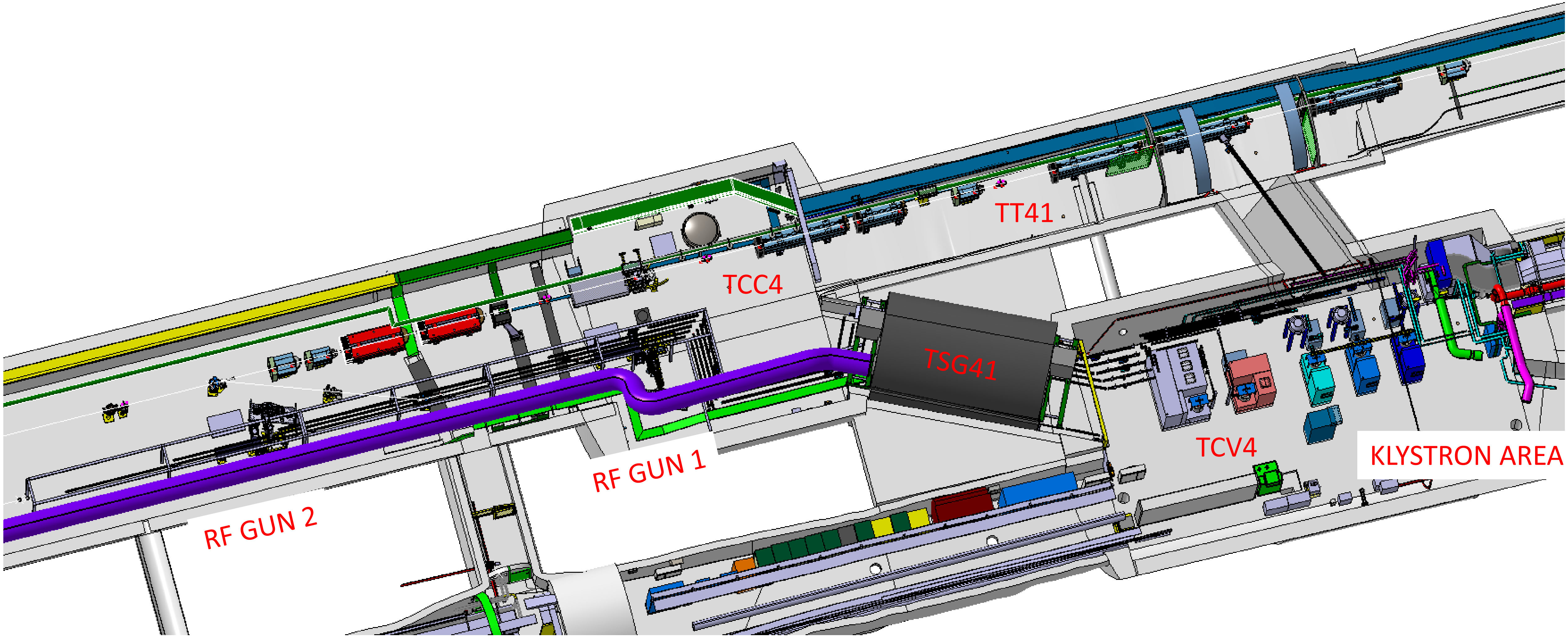
Tentative RUN 2 injector parameter for 150 MeV



Original tentative RUN 2 injector parameter for 160 MeV

Energy: 161.8 MeV
Energy Spread: 172.8 keV rms
Emittance: x/y: 0.7 mm mrad
Bunch length: 60 um rms
Bunch Charge: 100 pC



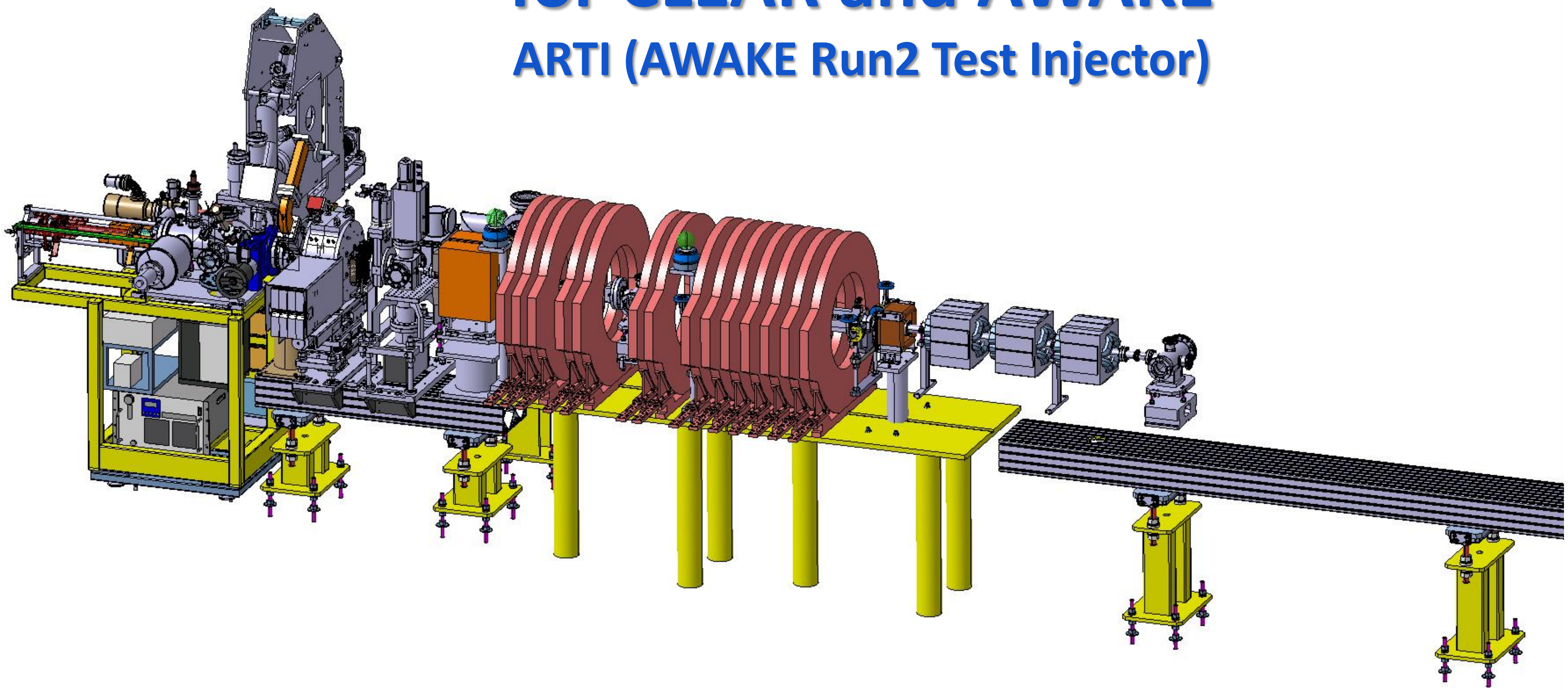

TT41
TCC4
TSG41
RF GUN 1
RF GUN 2
TCV4
KLYSTRON AREA

Collaborations:

- Uppsala, rf hardware and personnel
- Lancaster, personnel
- CLIC in kind contribution
- CLEAR support for the prototype (infrastructure, services, laser)
- INFN Frascati, RF-gun, acc-structure design

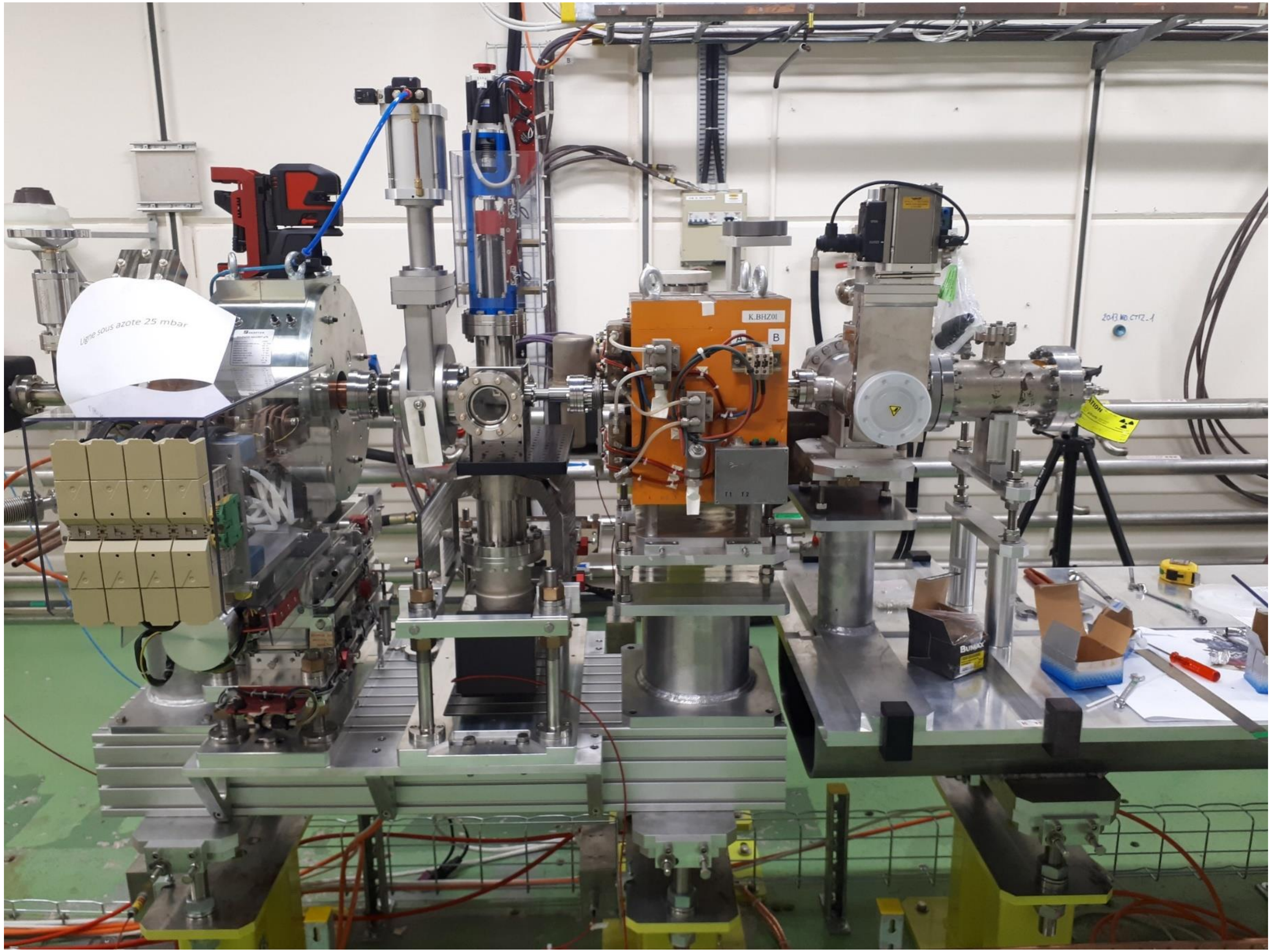
Injector prototype in CTF2 for CLEAR and AWAKE

ARTI (AWAKE Run2 Test Injector)



Reduced scale prototype, 60 MeV, INFN RF-GUN, T24 as buncher and PSI-structure for acceleration.
Goal: demonstrate the velocity bunching and emittance preservation with x-band

ARTI in CTF2



Conclusion and Outlook

- **Solid baseline of the new injector is existing**

- **Technical Design, Integration and Parameter optimisation for both injectors ongoing**

- **Prototyping of key elements (rf-gun, acc-structures, RF –system, diagnostics) and corresponding test injector already well advanced**

- **Several important and active collaborations in place to support the tasks with significant contributions.**

Additional material

Schedule

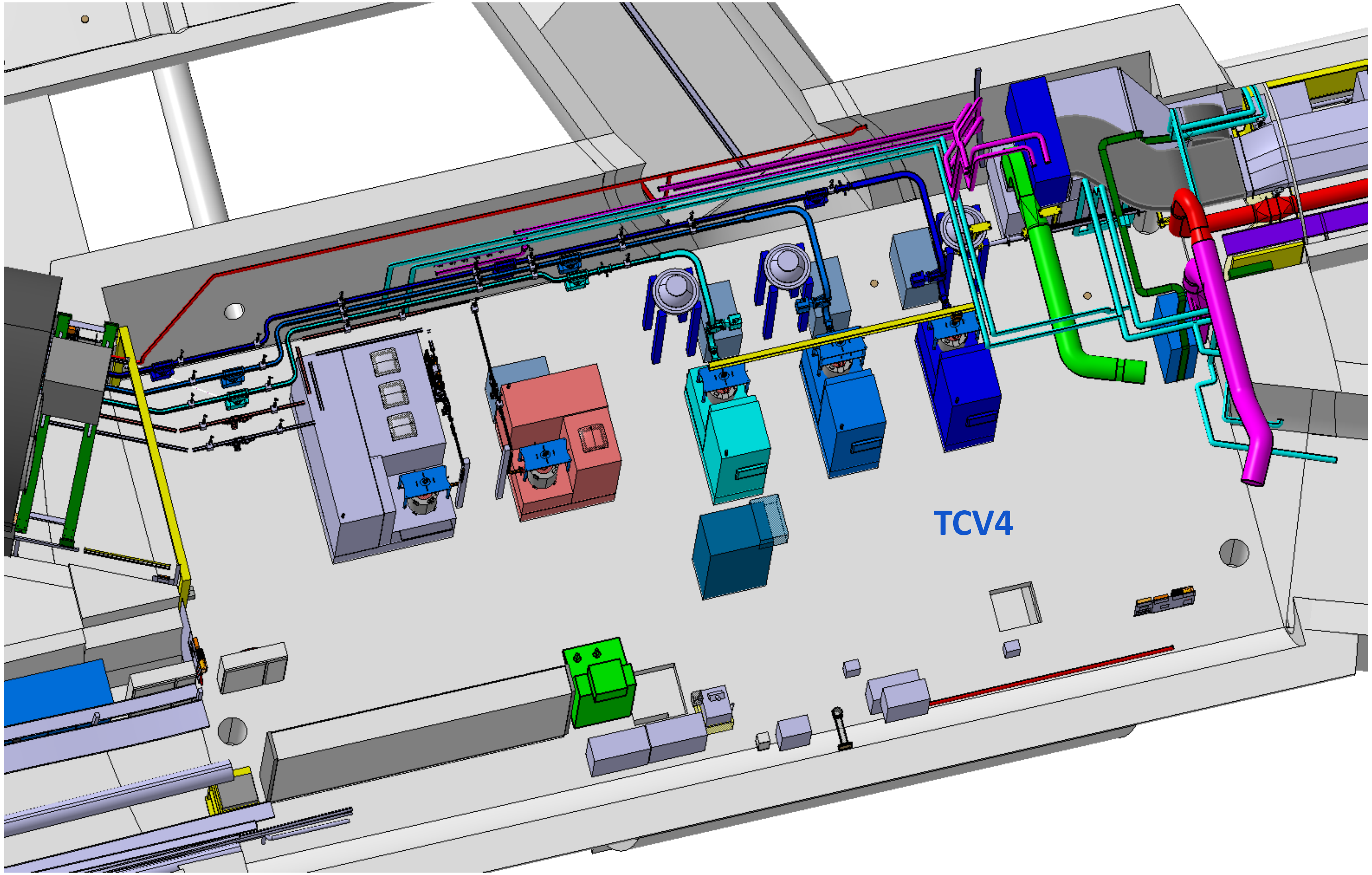
AWAKE 150 MeV								
Schedule	2022	2023	2024	2025	2026	2027	2028	2029
Final design								
Mechanical design/Integration								
Procurement								
Installation								
Commissioning								
Start experiments								

Critical items	2022	2023	2024	2025	2026
Modulators/Klystrons		Prepare Specs	Procurement		Accepted at CERN
accelerating structure	define proto	build proto	proto test	production	Ready for installation
load lock system		production	gun tests		Ready for installation
solenoids		design/build	use with proto	production	Ready for installation
wavguide system x-band		define	proto if needed	production	Ready for installation

No more conflicts with CLEAR for time being

New layout proposal from Uppsala

AWAKE



K. Pepitone, V. Clerc