EuPRAXIA@SPARC_LAB
Start to end Simulations

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on behalf of WA1- Beam Physics collaboration team

Outline

WA1 : Activities and Roadmap to TDR update

S2E Simulations progress and results

Conclusions

Computing resources-WP9 (F. Fortugno)

- The installation of the new five AC922 units for the plasma simulations is on going from **Sept. 10th 2021**
- The infiniband connection cards and switches for the cluster setup must be purchased.
- The purchase procedure of the WS rack module for Linac simulations has been finalized on **Oct. 20th 2021**, delivery in one month.

Activities with the Architect code-WP9 (P. Santangelo)

- Investigation (and solution) of (known) intermittent problems
- Parallelization of much of the code using OpenMP
- Result: (July release)

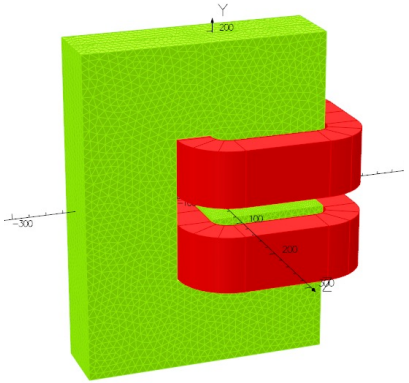
distance (um)	100	1000	10000	60000
serial (seconds)	200	1720	17426	103789
Processors				
1	149	1542		
2	95	1011		
4	54	610		
8	35	413	4093	23502
16	48	372		

- The new version is better, with 6 speedups on eight processors
- The parallel code produces results «visually» as the same as the serial code
- First Artchitect tests now possible on long times and distances
- Multiple runs of parallel code in the same machine
  (not immediate but it works well)
- More to investigate: parallel method for the "current deposition" of bunches
  - particles are only in bunches
  - the position of the particles is limited to a small part of the grid

Magnets & PS design-WP17 (L. Sabatini, A. Vannozzi)

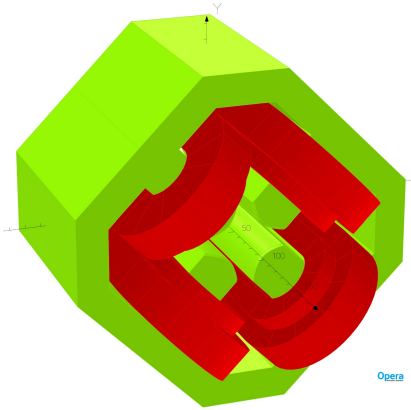
WORK IN PROGRESS:

- DIPOLES: magnetic design ready for:
  - BLH (4x laser heater chicane)
  - BC (4x compressor chicane)
  - DIPSPL (first spectrometer)
- QUADRUPOLES: magnetic design ongoing for all the three families ⇒Optimization
- Control System for power supplies: first estimation of specs.



WHAT NEXT:

- DIPOLES:
  - detailed magnetic design including quality and harmonic analysis
  - review of magnetic design with BD by providing field maps
- QUADRUPOLES:
  - focus on integrated quadrupole (the one including steering and diagnostics)
- DUMP dipoles



Roadmap to TDR update (from last WA meeting)

Upcoming milestones

July 2021 machine layout «coarse» finalization in terms of :

- Number and type of undulators
- Number and type of transfer lines
- Spectrometer /extraction lines
- 5GeV plasma acceleration line
- Submitted to «first magnets design and feasibility verification (April-May 2021)»

Not completed

-> delay to be quantified

Personnel

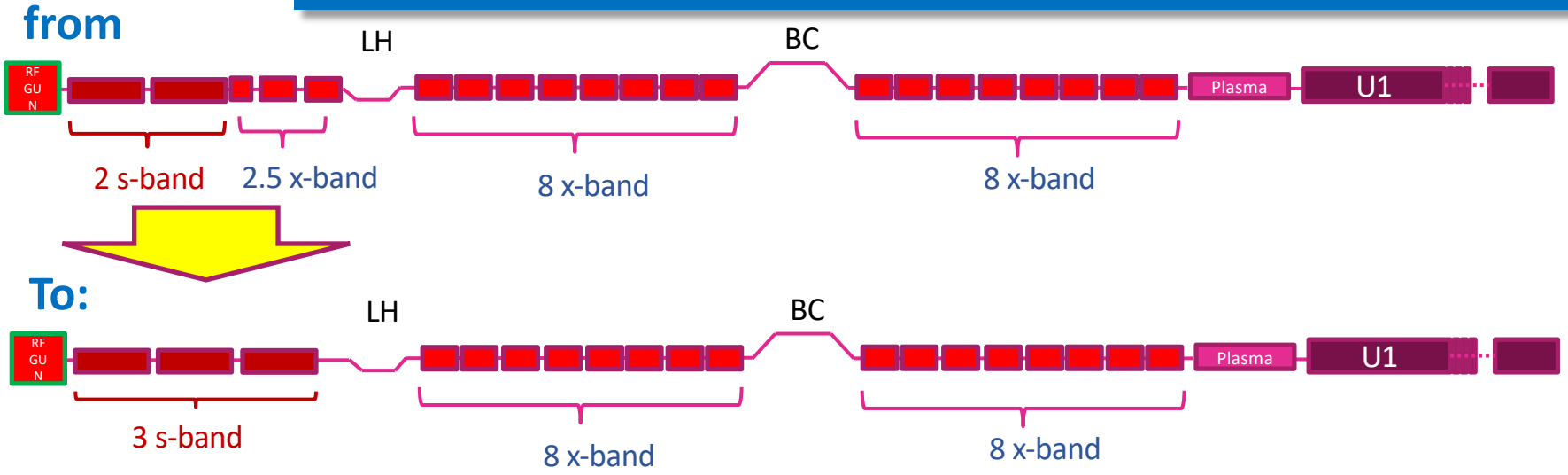
- **Between end of May and beginning of October: two less full-time people for WP1-WP2**
- **One full-time people on parental leave from July 2021 at least until February 2022 on WP1**
- **One part-time people on WP1 now more devoted to SPARC_LAB restart and new parts commissioning**

- **Under negotiation in these days:**
  - **Two senior and One Postdoc part –time (30%) from other structures/projects for WP1**
  - **2-3 students from the 37th PhD Course in Accelerator Physics (Sapienza University- Sept 9th 2021) for WP1-WP2-WP17**

S2E Simulations progress and results

- With the available resources both of computing power and personnel, two main topics were given priority and efforts:
  - Energy spread compensation scheme for plasma acceleration (WoP1 Linac working point)
  - Bunch compression scheme for the 200pC beam from Linac (WoP2), i.e. chicane vs dogleg comparison

On the basic all-in-one layout: (A Giribono)

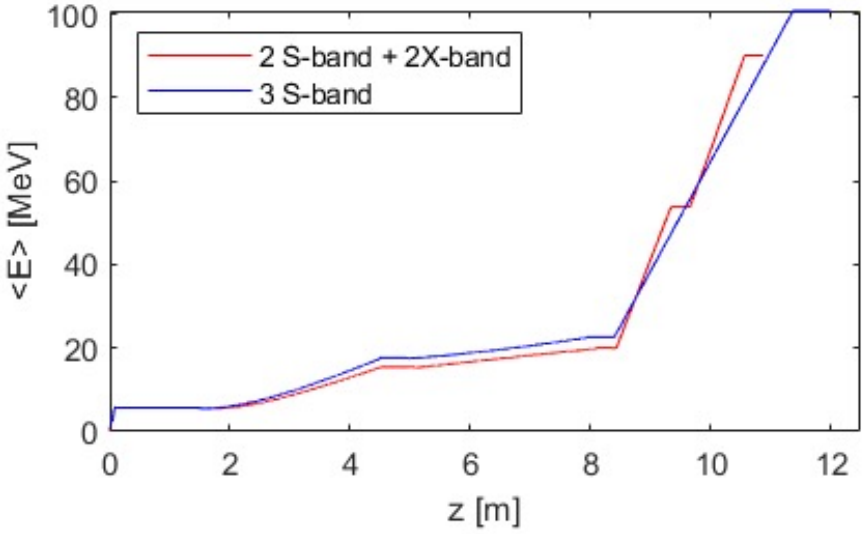


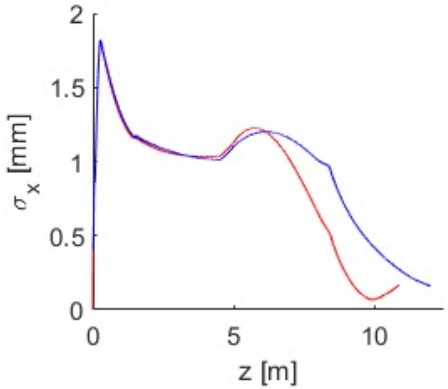
- Emax=1.03 GeV for all X-band configuration(w 10% contingency on Kly output power)
- Lmax =~ 60 m (ex. 59.52 m) from cathode + 1 m distance from the wall
  vs 59 m nominally available
- Extremely tight in:
  - plasma in&out matching
  - Diagnostic sections for beam characterization
  - No room for doglegs upstream the undulator

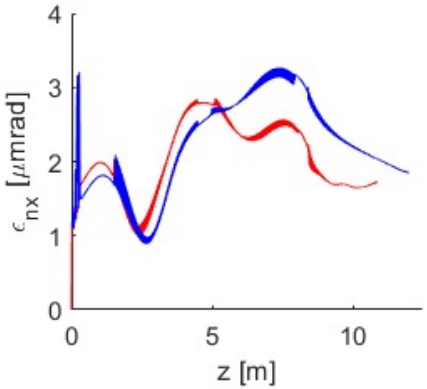
Update on beam dynamics simulations for WoP1 and WoP2

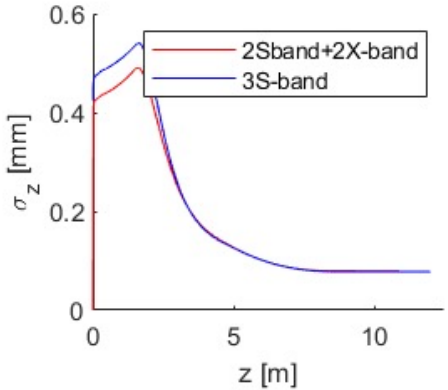
- WoP1 → comb beam re-optimised with ASTRA (NB: X-band E_{acc}=40 MV/m for beam quality preservation)

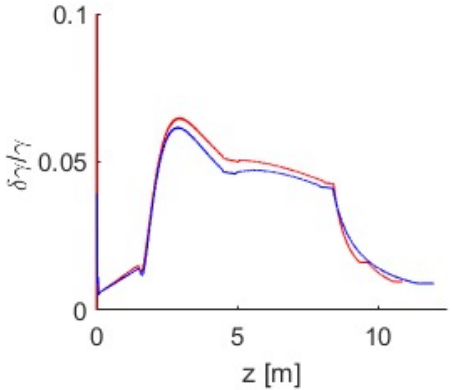
  - red: Tstep
  - Blue ASTRA







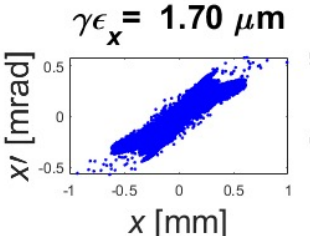




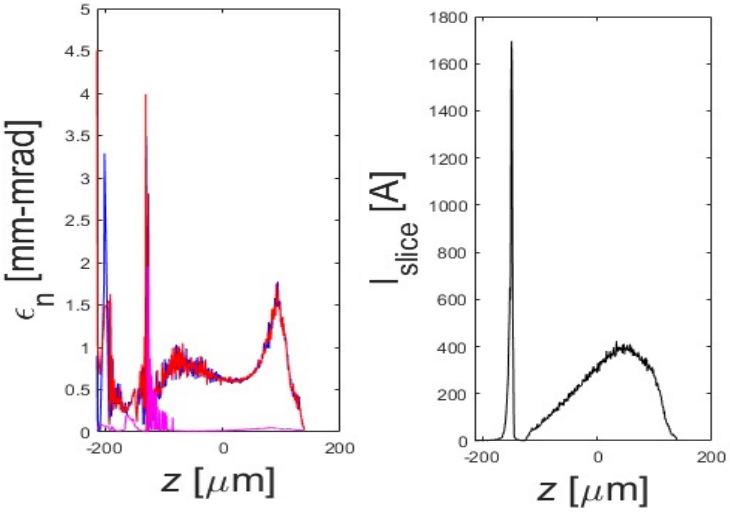
WoP 1-PWFA

WoP1- PWFA previous results (where we were)

@ Photoinjector exit: <E>=91.5MeV

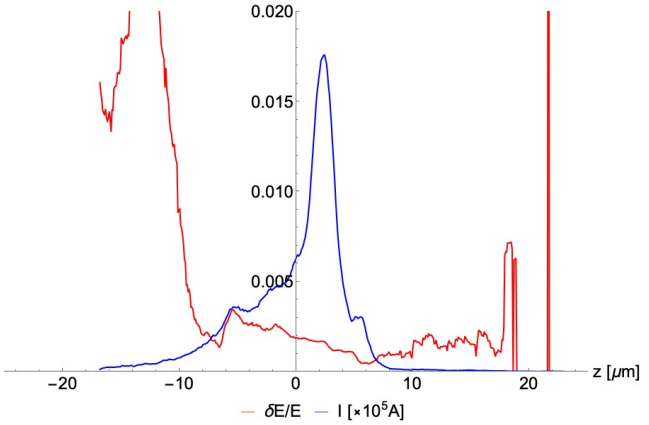


Transverse (up) and longitudinal (down) phase space at the Photoinjector exit



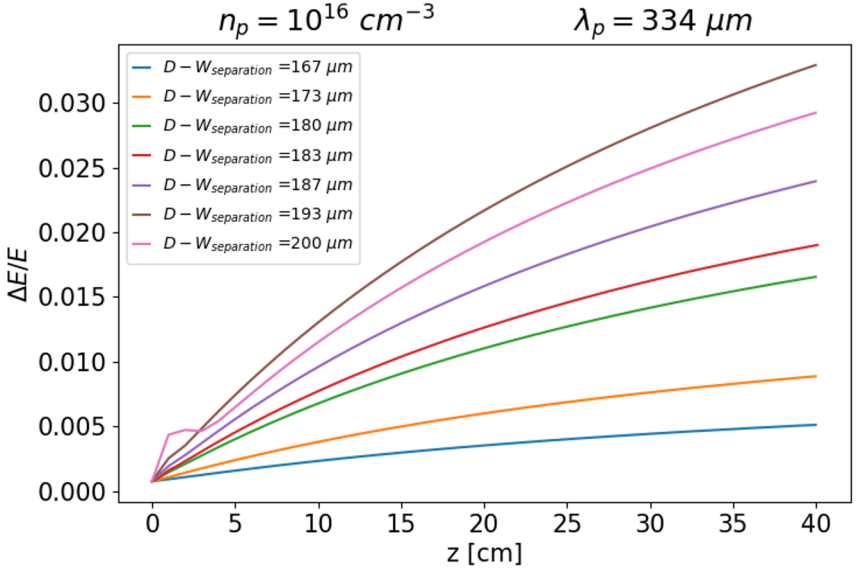
Transverse (left) and longitudinal (right) slice analyses at the Photoinjector exit

@ Plasma exit: E≈1 GeV

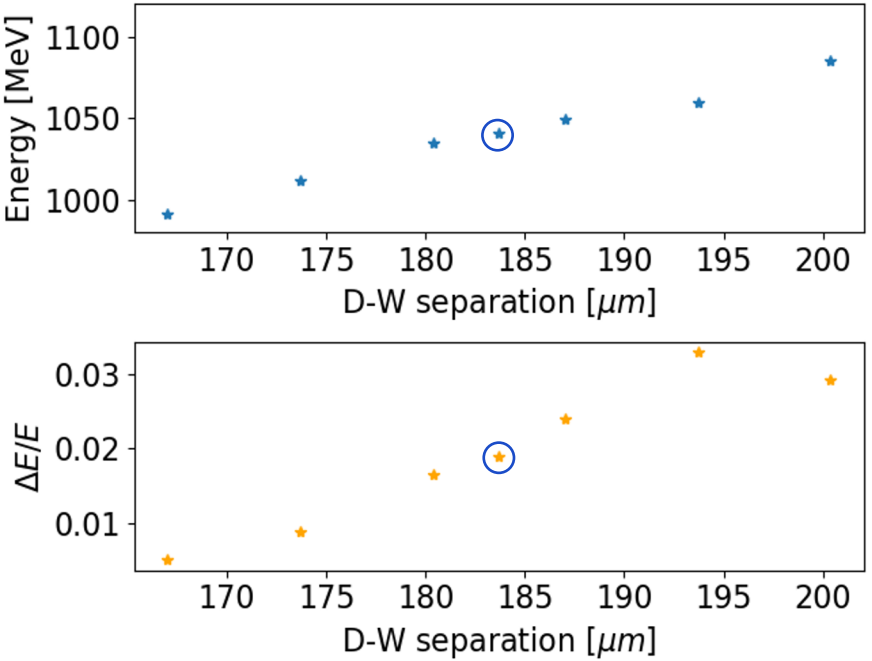


However, an effort is needed to improve the value of the projected energy spread in order to increase the efficiency of the radiation source.

Previous results on Stability (A. Del Dotto)



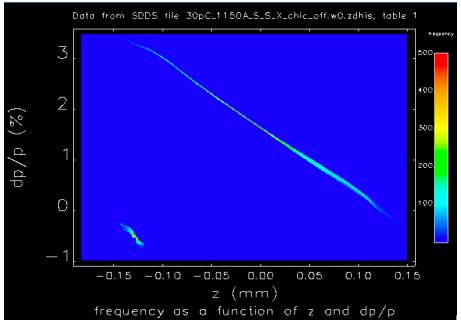
Witness beam final energy and energy spread as a function of the Driver-Witness separation

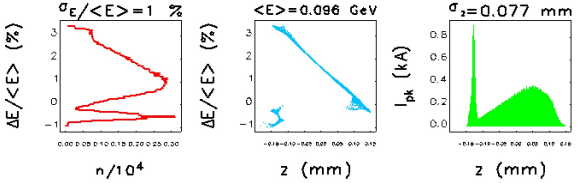


Witness beam final energy and energy spread as a function of the Driver-Witness separation

New beams from Photoinjector: 0.8 kA on Witness & reverse slope for Wit energy spread

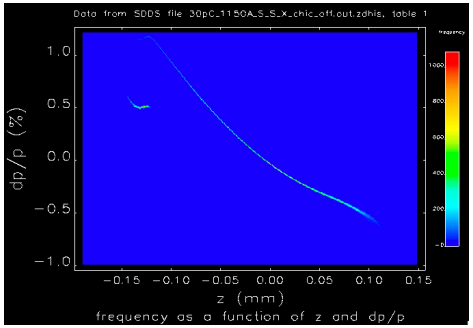
From Photoinjector



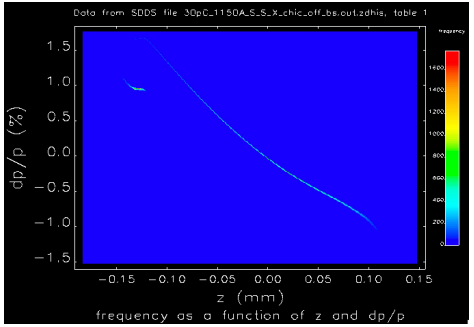


Case 1

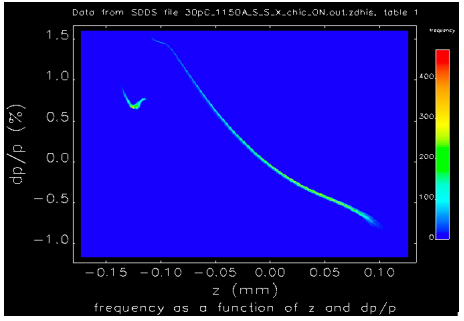
At Linac exit



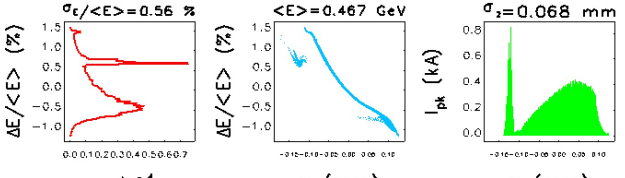
Case 2



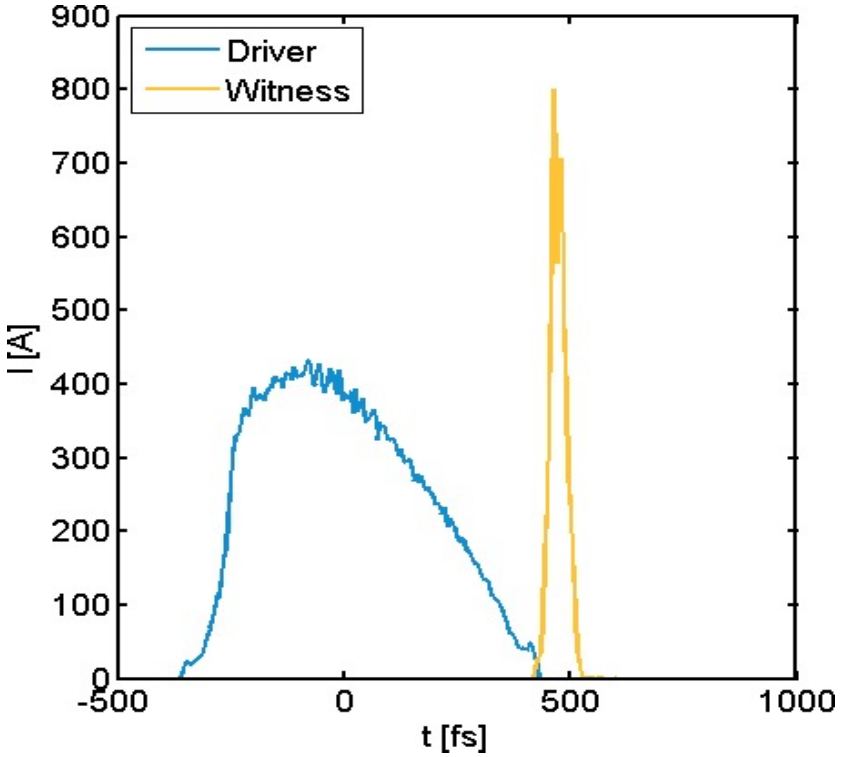
Case 3 (Chicane ON for better separation)



As suggested by Rev. Committee and needed for long space manipulation.



WoP1 I_w=800 A (S. Romeo)



Start to end simulation from Elegant data:

- Simulation with Architect code
- 40 cm propagation in plasma channel
- Density scan to optimize the energy spread

Witness parameters

$\sigma_{x,y} = 2.6, 2.8\ \mu m$

$\sigma_z = 5.11\ \mu m$

$\varepsilon_{n\,(x,y)} = 1.2, 1.0$ mm mrad

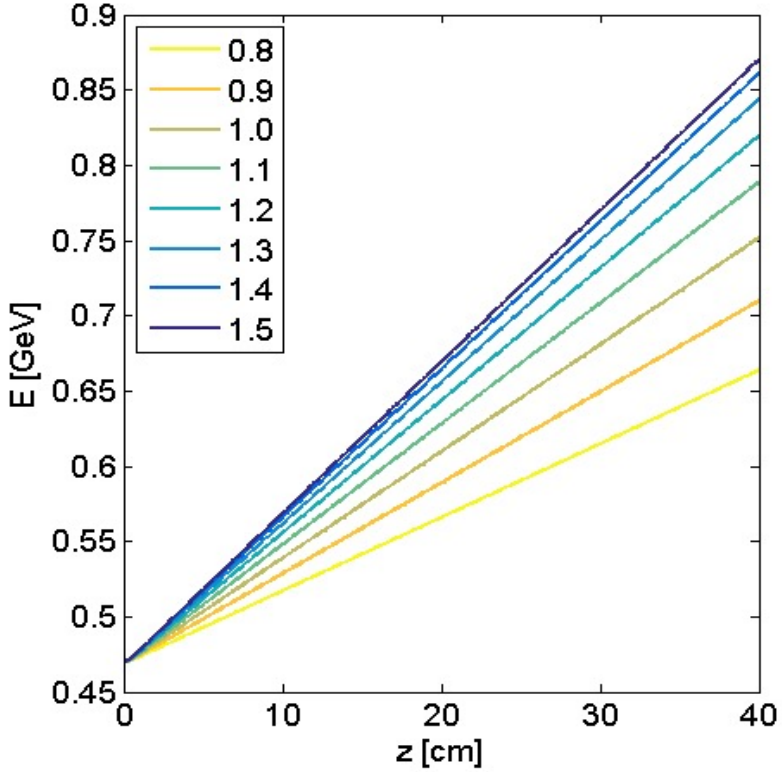
$\gamma = 921$

$\sigma_E = 0.076\%$

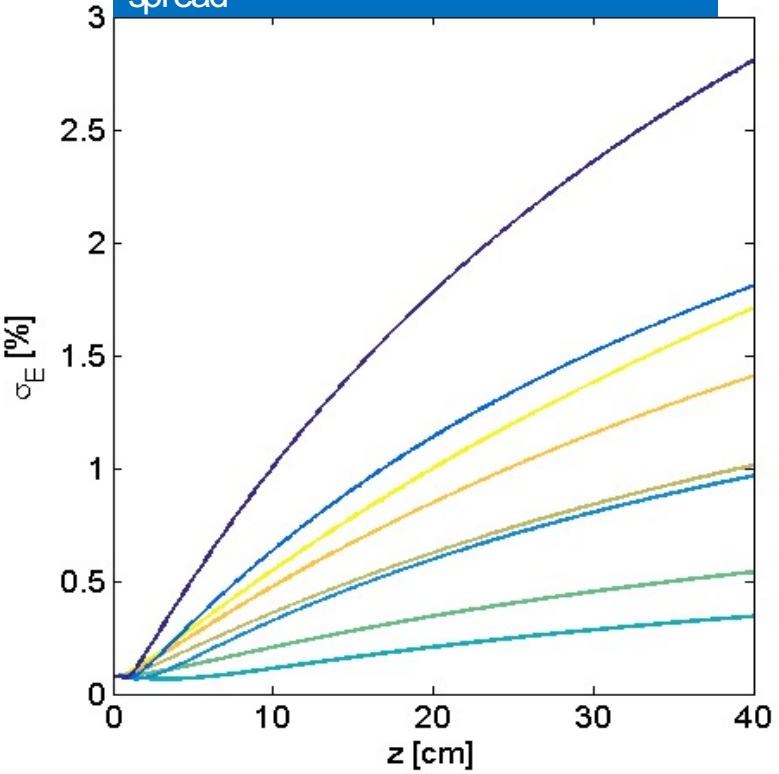
$I \approx 800$ A

First results I_w=800 A

Density scan result (Energy/spread)



Best result 0.87 GV/m 0.35% energy spread

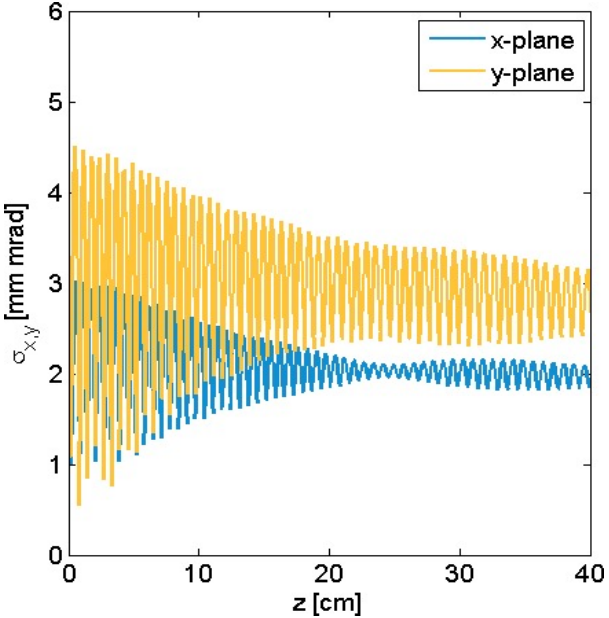


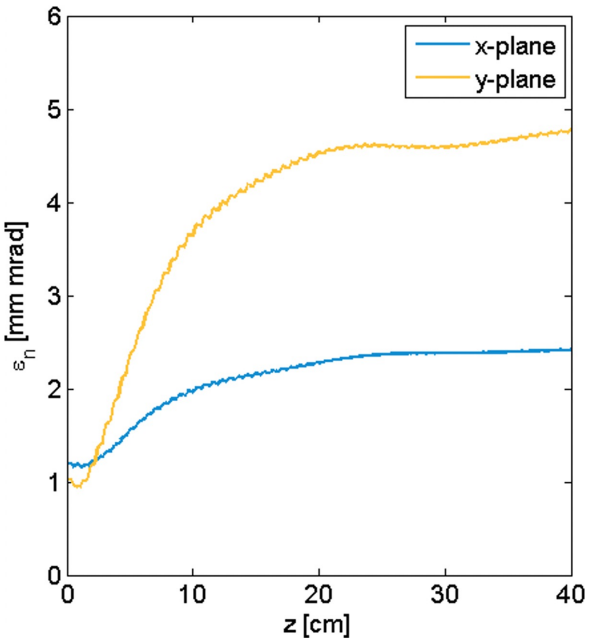
Transverse Matching for $n_p = 1.2 \cdot 10^{16}$ cm^{-3}

Results show a transverse mismatching

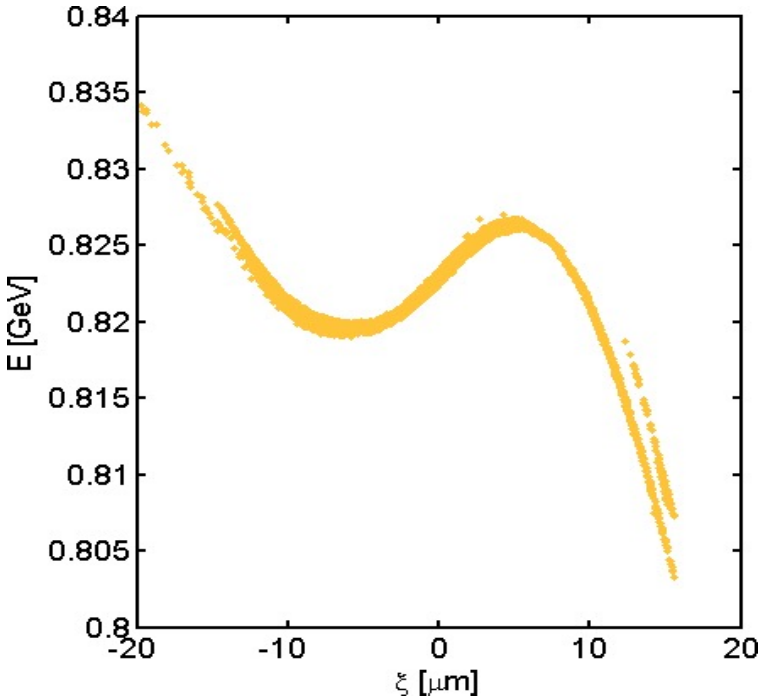
$$\beta_m = \frac{\sqrt{2\gamma}}{k_p} \approx 2.1\ mm$$

- $\beta_{x,y} = 5.2, 6.8$ mm
- Emittance increase of a factor 4-5 due to betatron dephasing
- Could be solved by means of plasma ramps



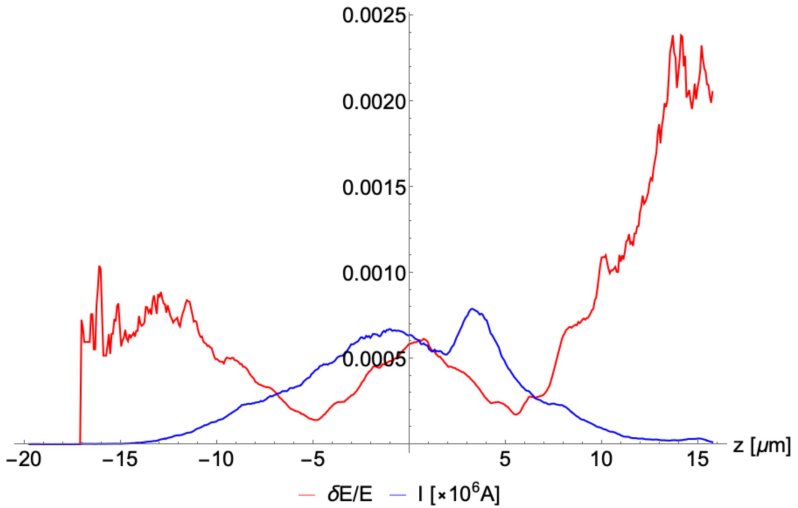


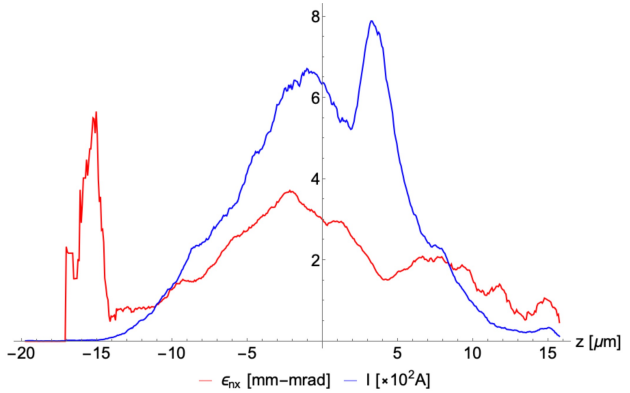
Witness LPS

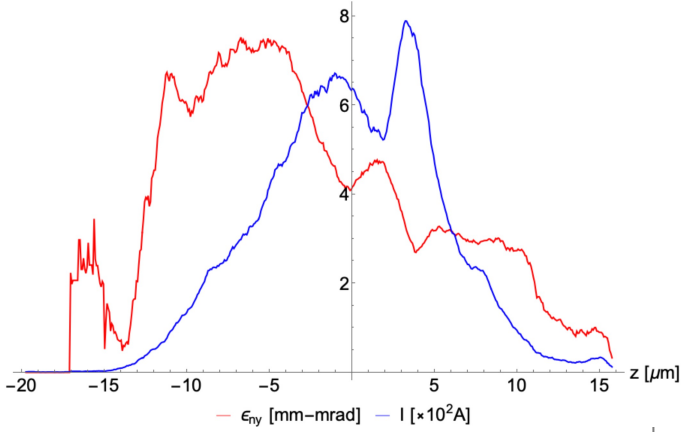


- We are working in over beam loading regime
- Minimum energy spread corresponds to pure non linear contribution of plasma wake
- Longitudinal phase space is not flat in the witness core
- Strategies for energy spread mitigation are still under investigation

Slice analysis:





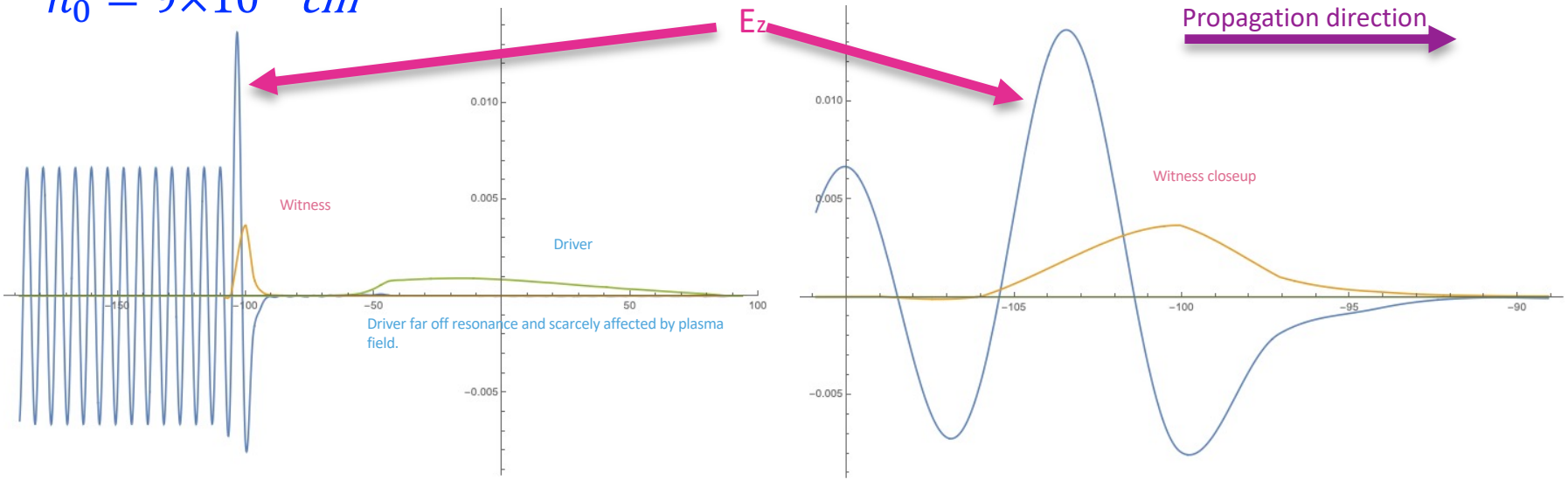


Option 2: Plasma pre-chirper (A.R. Rossi)

We are investigating the possibility to pre-compensate the energy chirp by using a higher plasma density stage. Back of the envelope, 1D evaluations seem to qualitatively confirm the possibility to pre-compensate energy chirp.

Pre-compensation for the excess beam loading case

$n_0 = 9\times10^{18}\,cm^{-3}$

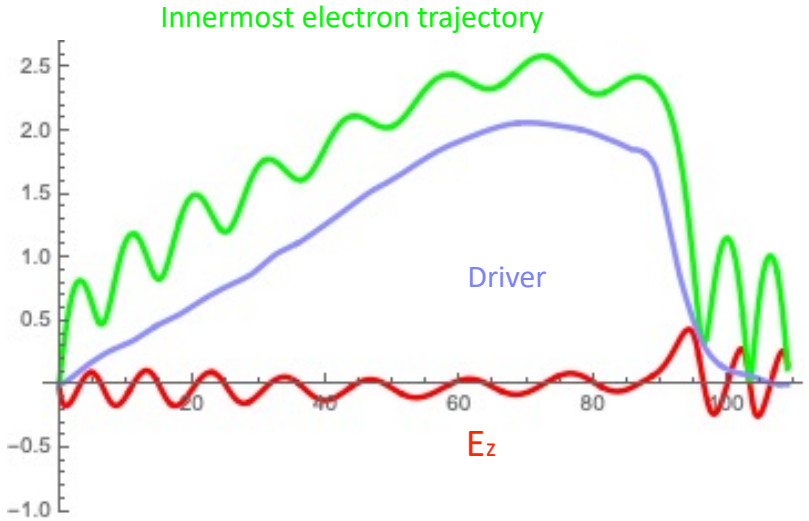


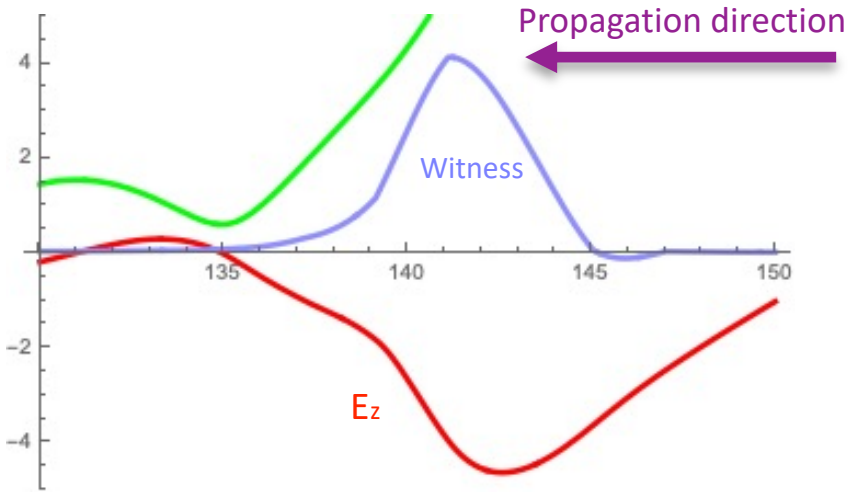
NB: all units are normalized. Current profiles are in a.u. D and W profiles are do not have the same scale.

Plasma pre-chirper

Pre-compensation for the excess beam loading case

$$n_0 = 4\times10^{18}\,cm^{-3}$$





NB: all units are normalized. Current profiles are in a.u.

* Phys. Plasmas **28**, 063103 (2021).

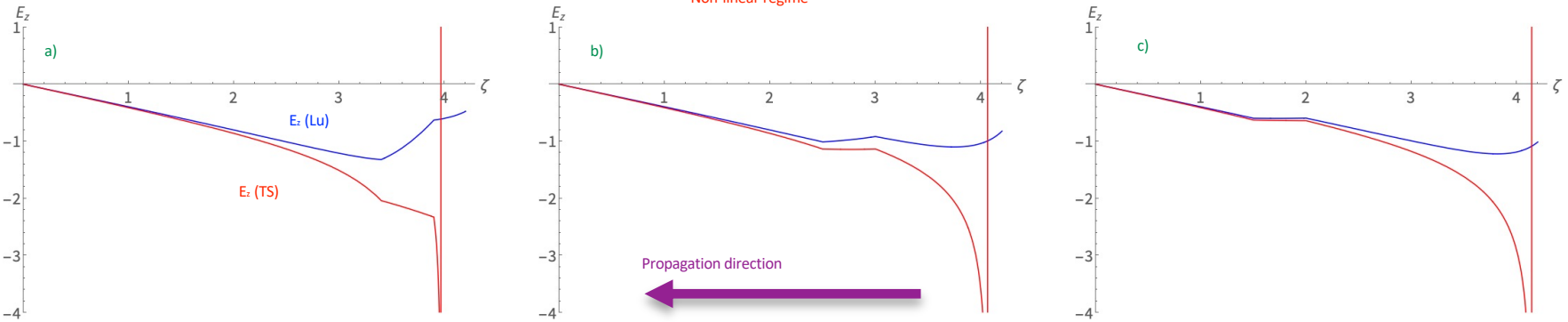
Comparison between Lu and two-sheath (TS) models

Def: $\Lambda = 2\pi\sigma_x\sigma_y\alpha$

$\Lambda_d \approx 2.25$

$\Lambda_W \approx 2.55$

Non-linear regime



NB: units are normalized. Only back portion of the bubble is shown. Witness current profile is flat with length = 0.5 (FWHM), while $\sigma_z = 1$ for driver. Plasma density is 10^{16} cm^{-3}

Considerations

- TS model is much more robust wrt injection phase and witness current value (not shown) compared to Lu's
- Flat top current profile does NOT perform much worse than triangular profile in reducing energy spread

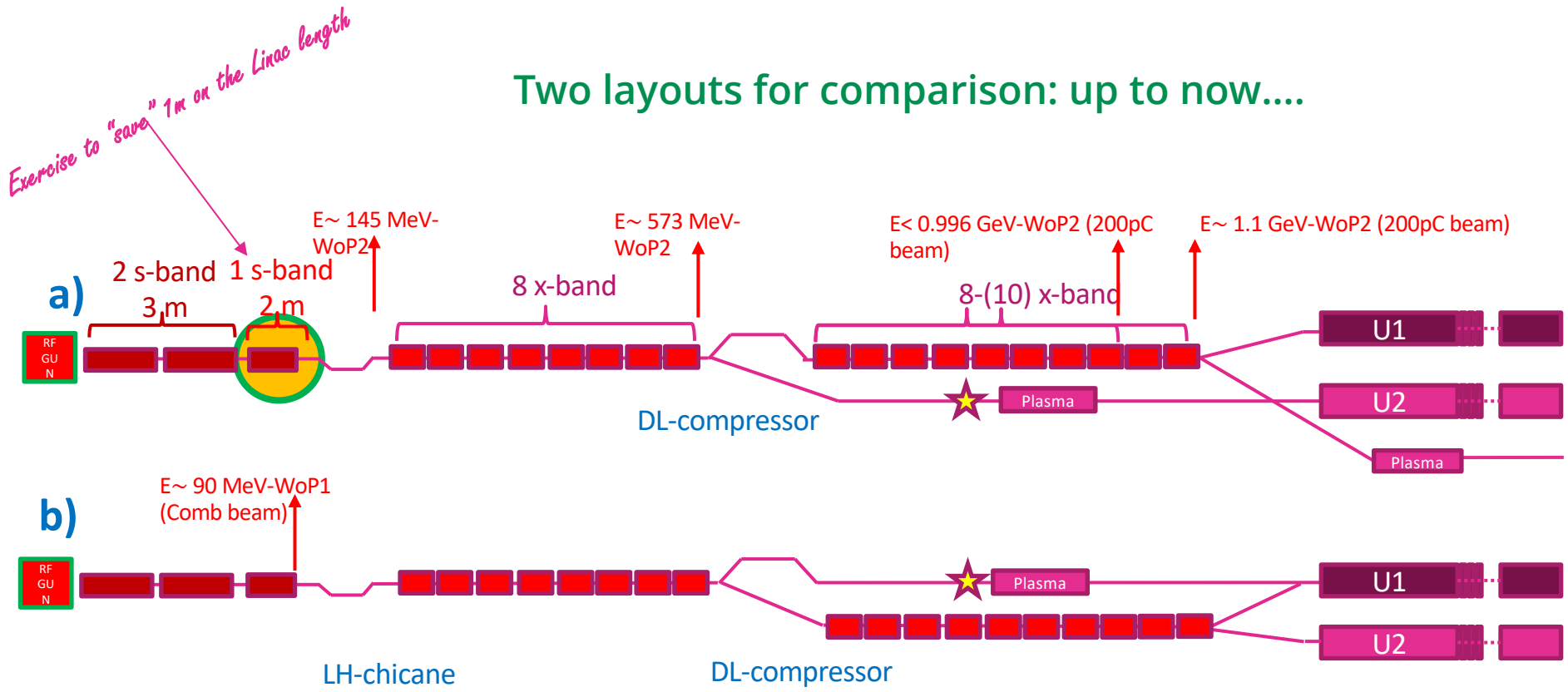
Previous considerations allow to consider non-linear regime a viable way to deliver low energy spread beams

On going:

- Systematic analysis of the space charge effect on the matching before and after the plasma acceleration (plus driver removal) to verify lattice acceptance and robustness (Astra & Tstep plus genetic optmizer)
- Same analysis for the dogleg TL and chicane to evaluate the splitted layout for plasma and all X-band linac.
- X-band cavity after the Gun: design and optimization with iterative BD simulations
- Diagnostic BD simulation to check the virtual measurements
- Microbunching instability budget and mitigation for all the options
  $\Longrightarrow$ LH system and diagnostic section finalization

WoP2- All X-band 200pC

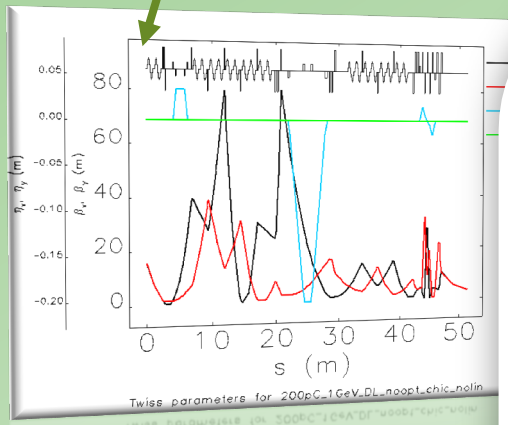
Two layouts for comparison: up to now....



Case a) Chicane layout

Old

2 X-band section 0.9 m long E_{acc}=60 MV/m

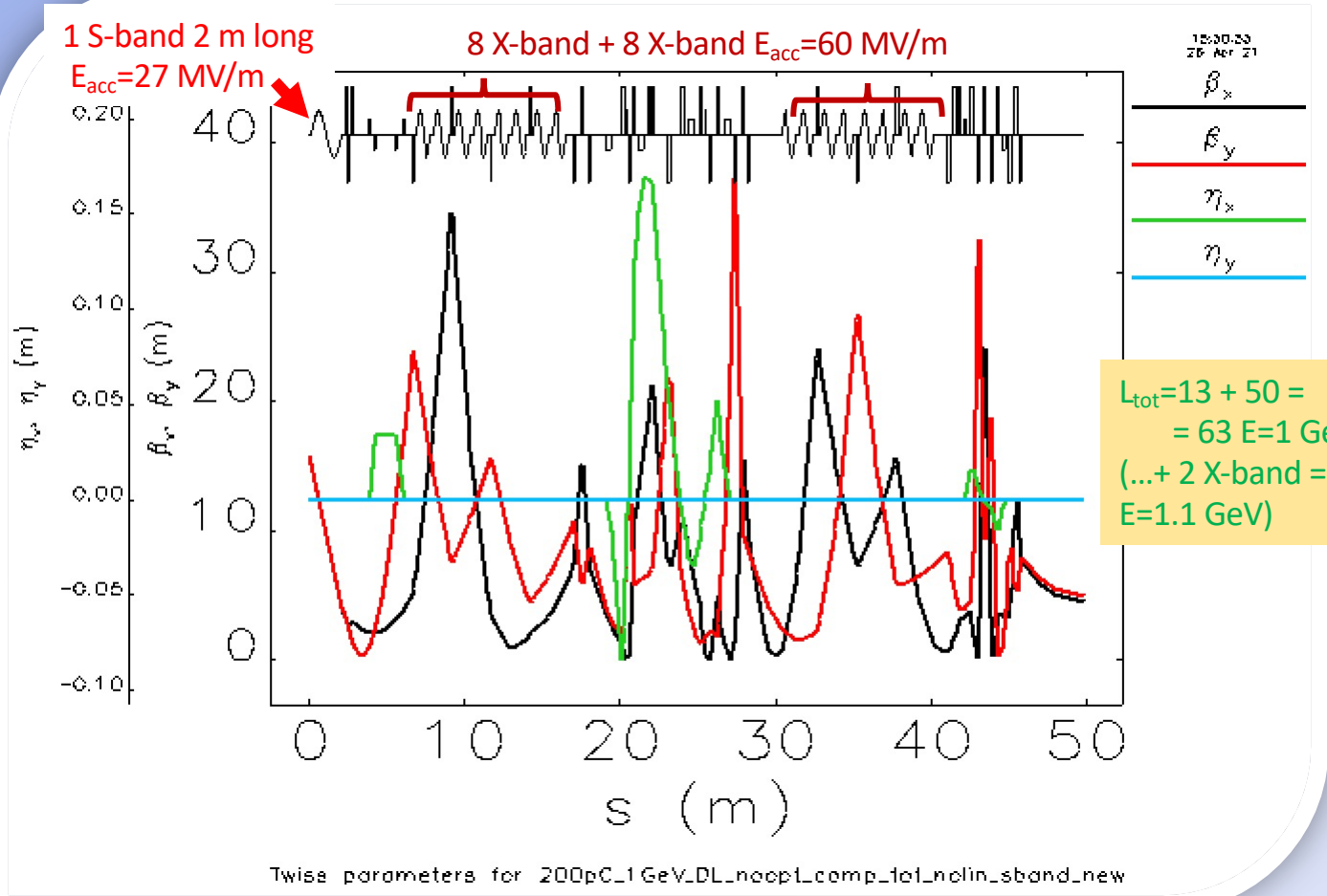


1 S-band 2 m long
E_{acc}=27 MV/m

8 X-band + 8 X-band E_{acc}=60 MV/m

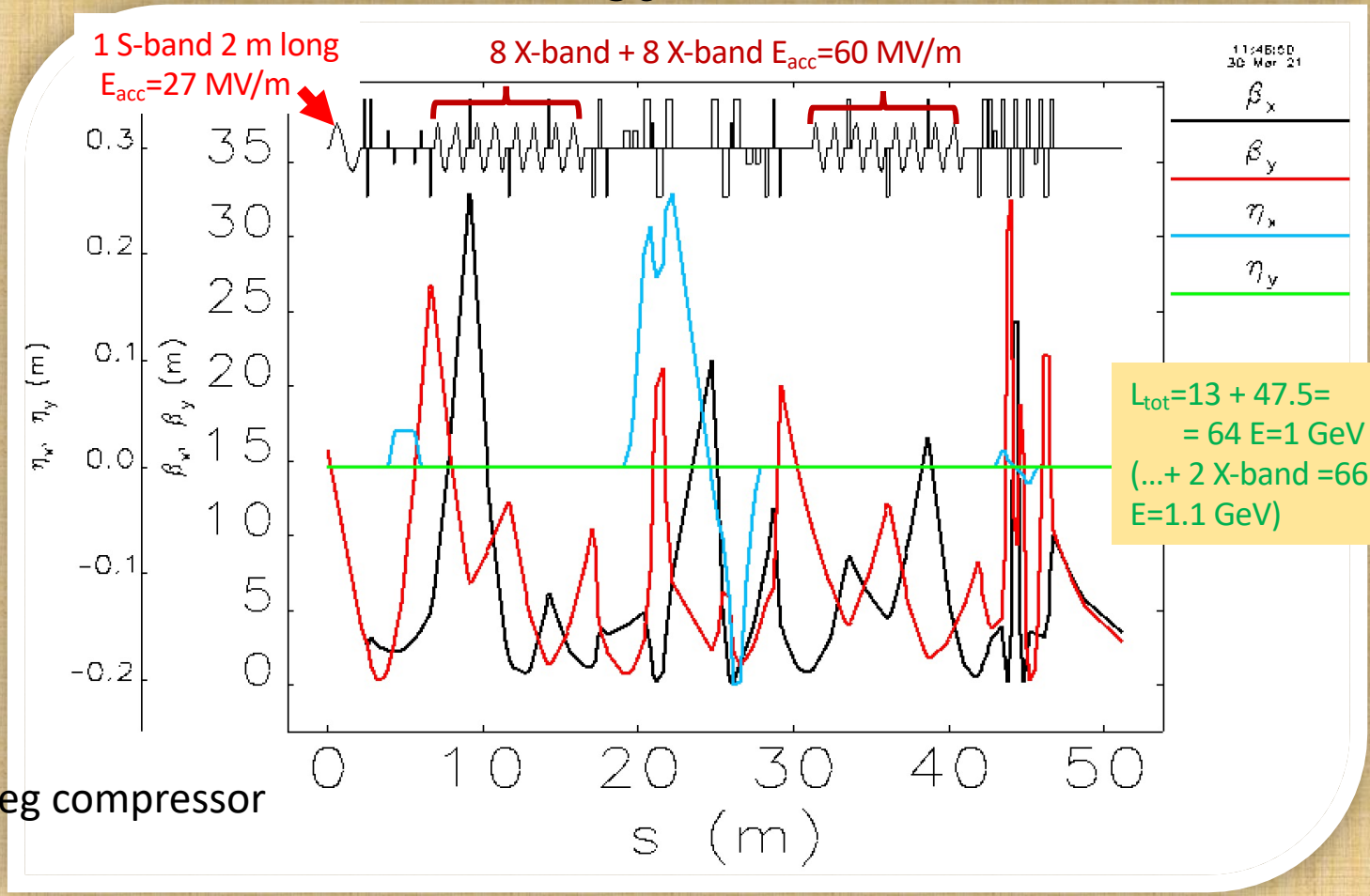
L_{tot}=13 + 47.5=
= 60.3 E=1 GeV
(…+ 2 X-band =63 m
E=1.1 GeV)

Case b) Dogleg compressor with R_{56} >0



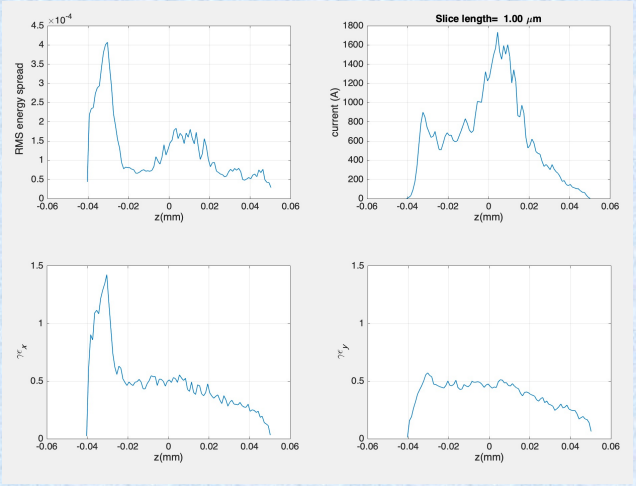
L_{tot}=13 + 50 =
= 63 E=1 GeV
(…+ 2 X-band =65 m
E=1.1 GeV)

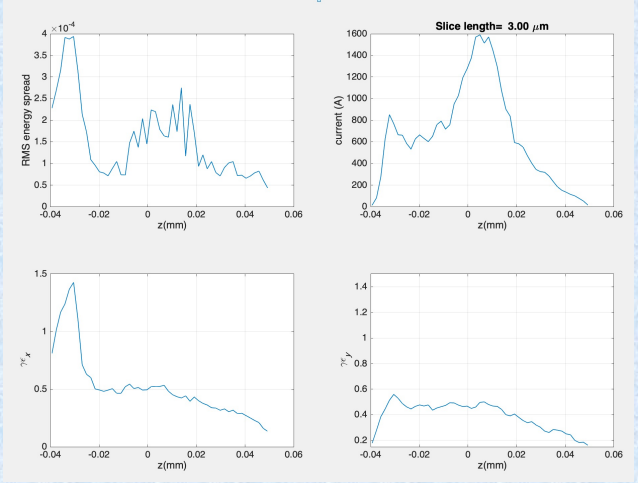
Case c) Dogleg with R_{56}<0 considered layout



Case b) Dogleg compressor
w R56 <0

R_{56} =30 mm:
Case a) I=1.6 kA slice analysis





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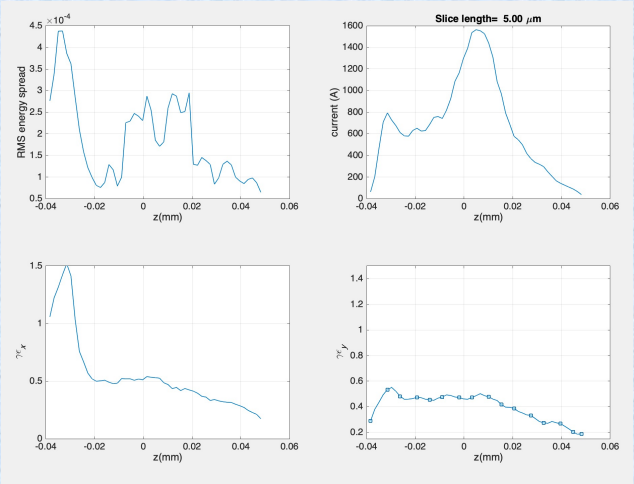
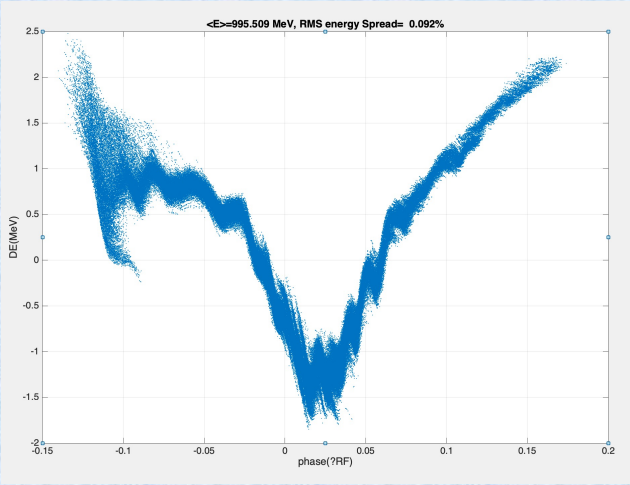
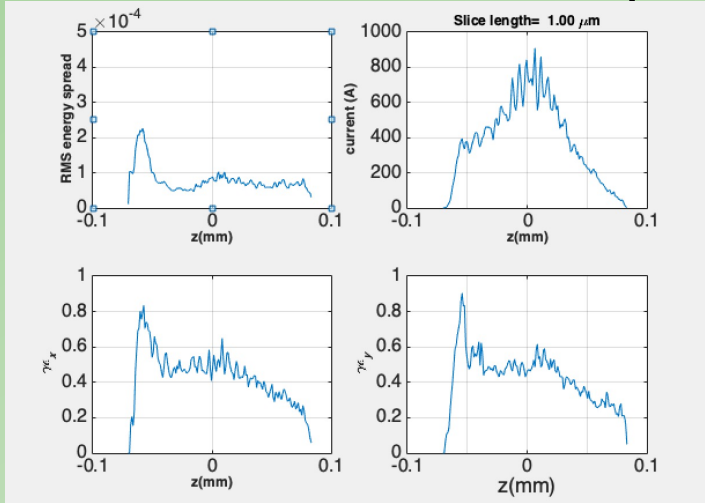
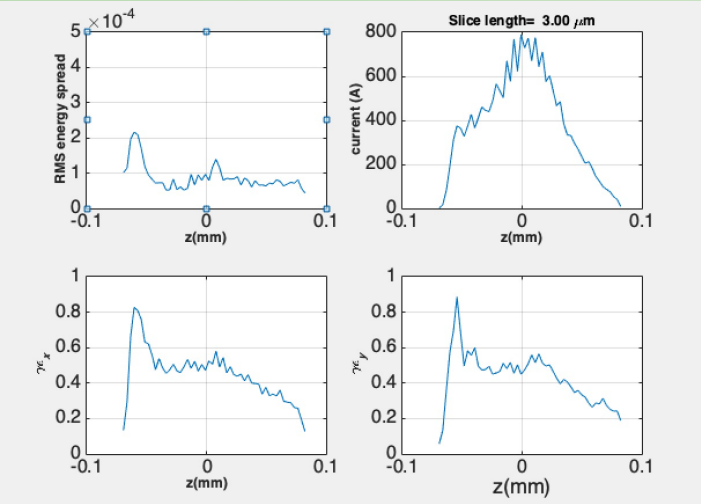




Case a) Magnetic chicane

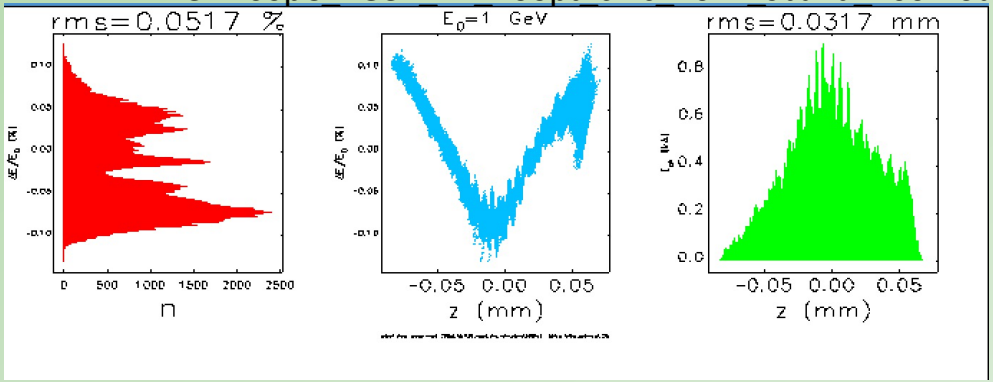
Case a) I=700 A slice analysis

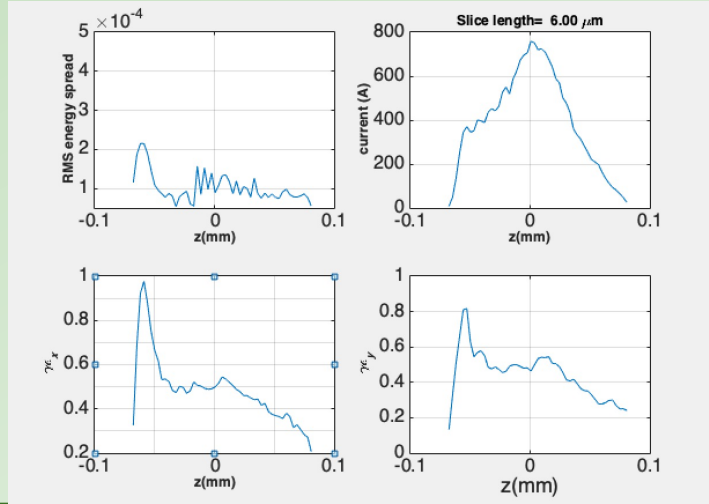




Case a) Magnetic chicane

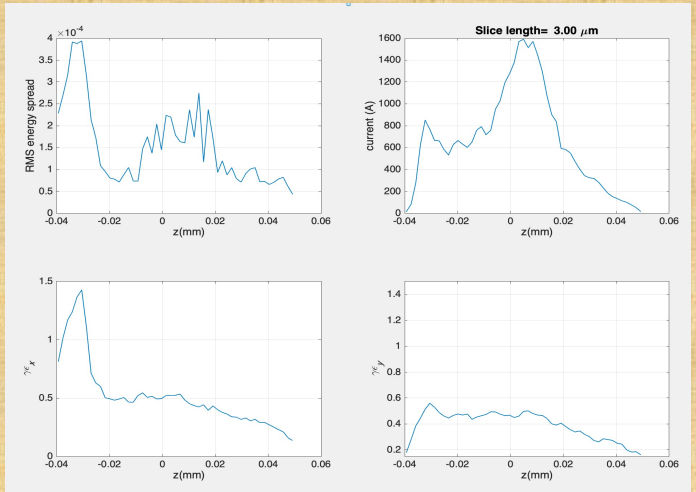
File= 200pC_1GeV_DL_noopt_chic_nolin_sband_700A.outm.asci



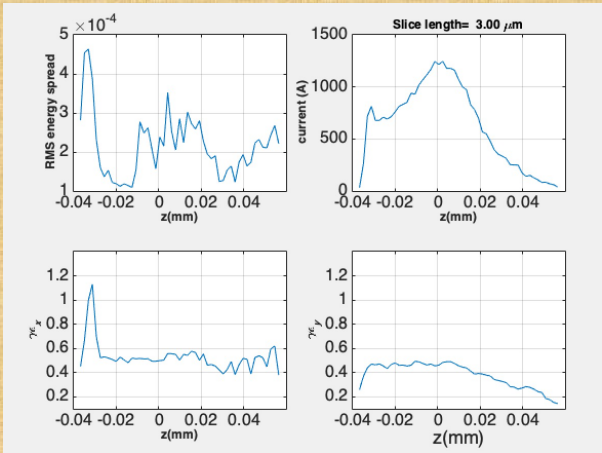


For Comparison:

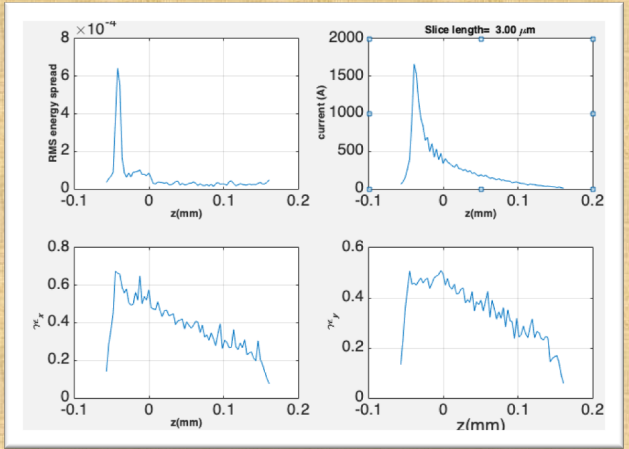
Case a) Magnetic Chicane R_{56} = 30 mm



Case b) Dogleg Compressor R_{56} = 18 mm



Case c) Dogleg Compressor R_{56}= -40 mm



Conclusions

- Despite the personnel situation some of the BD main topics have been addressed for the considered WoP's.
- Some of the presented configurations have been found suitable for the considered undulators.
- Next effort will be focused to improve the aspects still not compliant with lasing at 3-4 nm necessities.

Thanks
for your
attention