EuPRAXIA@SPARC_LAB
Start to end Simulations

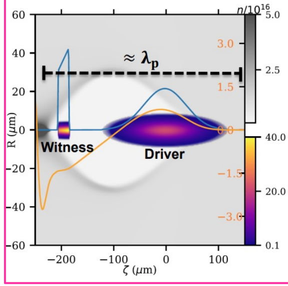
C. Vaccarezza
on behalf of WA1- Beam Physics & collaboration team

OUTLINE

- June 2023, where we were:
  - Reference Working point
  - First results on jitter analysis at the Linac exit
  - Recommendations from TDR-RC report Jun 2023
- Computing Resources update
- Jitter studies including acceleration in plasma
- Alternative solution for comb beam shaping
- Conclusions and To-do list

REFERENCE WORKING POINT BEAM DYNAMICS

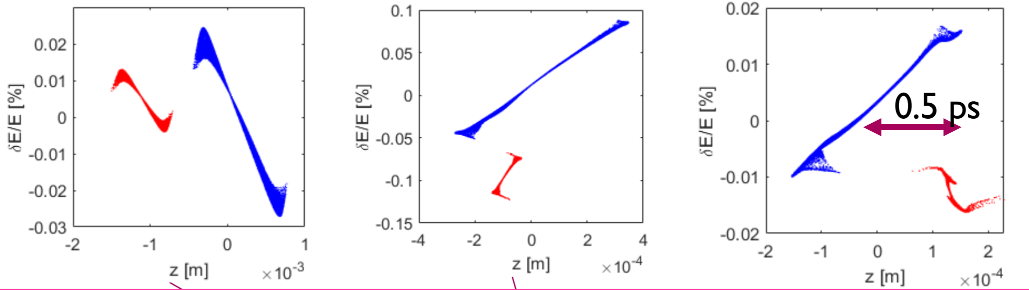
A. Giribono



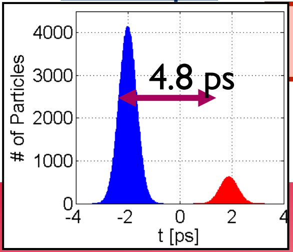
- Beside the FEL specifications, the **reference working point** has been determined by the plasma module
  - At least 500 MeV energy gain (in less than 1 m)
  - Weakly non-linear regime (bubble with resonant behaviour)

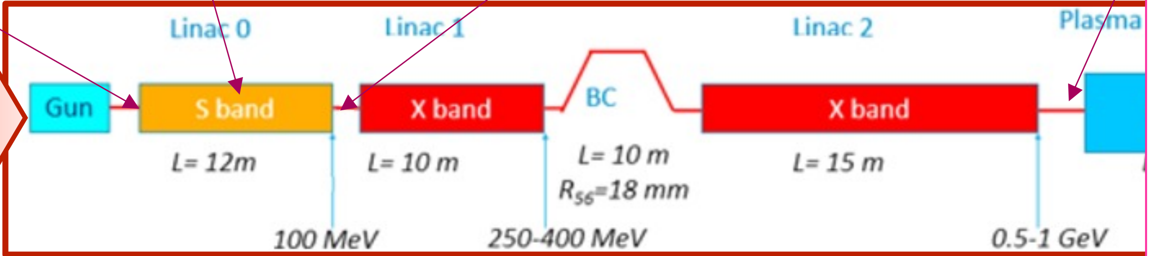
1. 200 pC driver + 30 pC witness
2. plasma density of the order of $10^{16} cm^{-3}$ (λ_p = 334 μm)
3. Driver-witness separation of around 0.5 ps (i.e. λ_p /2)
4. Driver and witness bunches of 200 fs and 10 fs rms
5. Driver and witness spot size of 4 and 1 μm with α=1

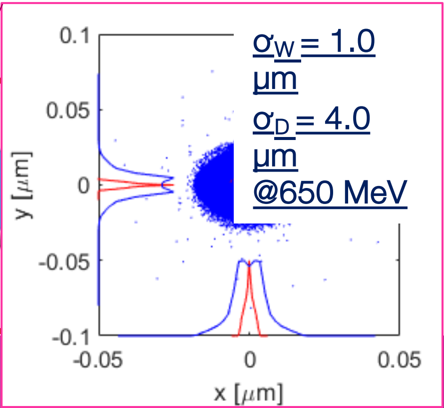
Velocity bunching technique



Laser comb technique





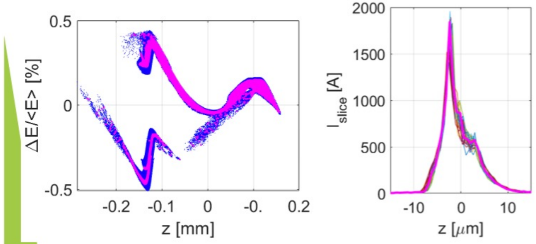


June 2023: first results on jitter analysis for the Linac

A. Giribono

MACHINE SENSITIVITY STUDIES – Results at Plasma Injection

- The analysis shows in the worst-case scenario a deteriorating of the emittance and of the peak current of maximum 10% (still in specification)
- The most critical parameter is the witness-driver delay
- Hints for the future:
  - Investigate lower RF phase jitter (down to 15 fs)
  - Heighten faster the beam energy to frozen the beam shape
  - X-band cavity right after the RF gun



Longitudinal phase space and witness current profile.
The magenta is related to the refence WP

	Witness		Driver		
	Without errors	With errors	Without errors	With errors	
Energy	537.44	537.45 ± 0.30	539.55	539.57 ± 0.33	MeV
Energy spread	0.71	0.7102 ± 0.007	0.92	0.92 ± 0.026	‰
Bunch length	5.460	5.927 ± 0.21	61.71	61.81 ± 0.73	μm
I_{peak}	1875	1683 ± 125	-	-	kA
Δt	0.503	0.501 ± 0.012	-	-	fs
$\varepsilon_{n_{x,y}}$	0.55	0.56 ± 0.015	4.18	4.24 ± 0.25	mm mrad
$\sigma_{x,y}$	1.5	1.52 ± 0.25	5.84	5.95 ± 1.21	μm
$\beta_{x,y}$	4.3	4.5 ± 1.4	9.3	9.3 ± 3.7	mm
$\alpha_{x,y}$	1.2	1.2 ± 0.25	3.34	3.39 ± 0.75	

Beam parameters at plasma injection. The mean value and the related standard deviation over the 50 samples is reported for each parameter in case of errors.

Review Committee June'23 - A. Giribono

RF Gun (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.03	*deg*
S-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.03	*deg*
X-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.1	*deg*
Cathode Laser System (max)		
Charge [ΔQ]	± 2	%
Laser time of arrival [Δ*t*]	± 100	fs
Laser Spot size [Δσ]	± 1	%

From TDR Rev Comm Jun 2023

2.3 Beam Dynamics S2E Simulations

Numerical studies of sensitivity of final parameters of the electron bunch and photon pulse continue, despite limitations in computing resources. Results presented show that most parameters of the electron bunches at the plasma entrance are weakly sensitive to random variations of input parameters. The exception is the bunch charge or current, and the drive-witness bunch delay. This is somewhat worrisome since acceleration in plasma is quite sensitive to these parameters, for example for optimal beam loading that is essential to reach the low relative energy spread necessary for the FEL.

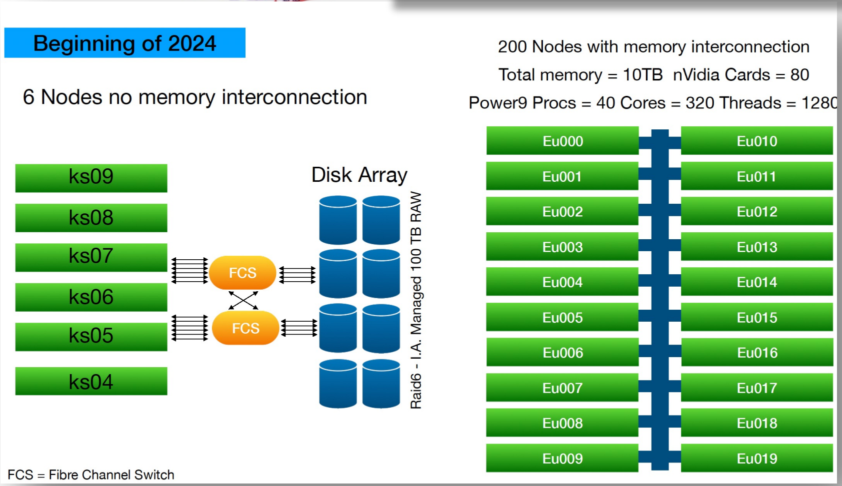
The RC recommends this issue to be addressed with high priority as soon as access to sufficient computing resources will be obtained. The RC also recommends that the loop between simulation parameters and tolerances be closed with the parameters expected from the corresponding hardware. This is essential for the consistency of the project.

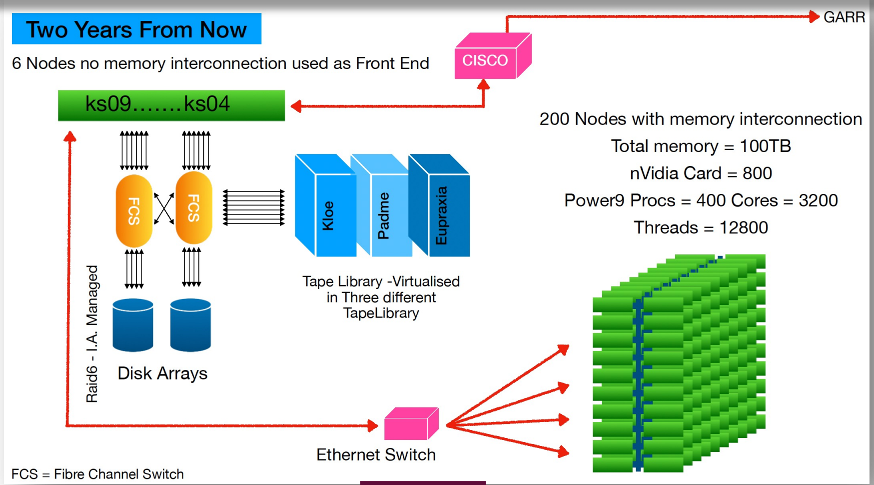
Computing Resources update

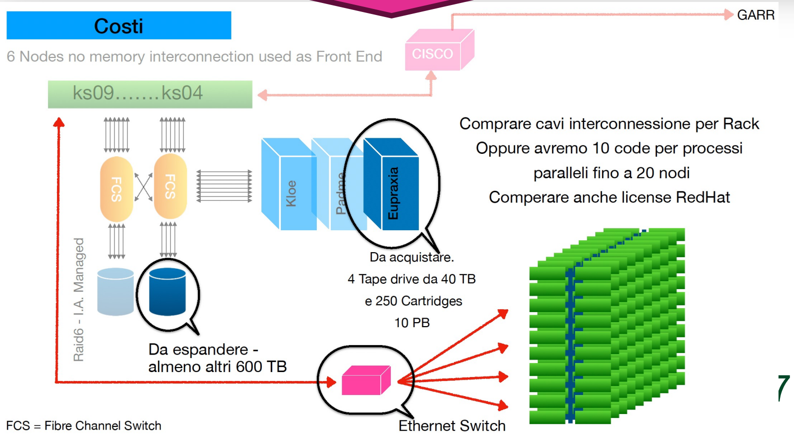
- It is made of 6 IBM Power 9, each equipped with 2 V100 GPU
- We are effectively running Architect code in parallel exploiting up to about 600 parallel process
- Other codes (i.e. Osiris, PIConGPU, WarpX, FBPIC) can be installed/used in the cluster
- Unfortunately, in April 2023 a major fault occurred on storage disk system causing a significant lack of storage memory that determined a stop in simulations activity
- A first batch of the storage disk supply was delivered and installed at the end of September and the simulation activity restarted in October 2023
- Additional storage memory dedicated to EuPRAXIA up to hundreds of TB is under procurement
- Additional IBM Power9s will be installed in the following months and infiniband connected

F. Fortugno

Computing Architecture & plan







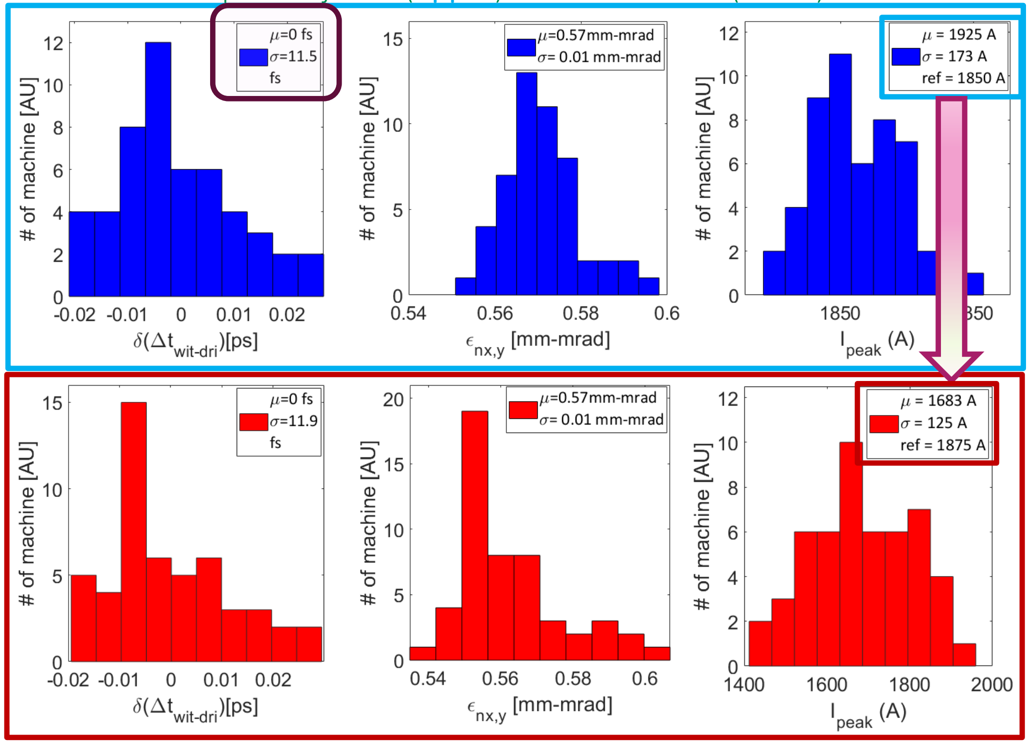
F. Fortugno

Some Details on the June Jitter analysis in the Linac

- The analysis is performed over 50 samples obtained by means of S2E simulations
- The **photoinjector** is the source of the jittering of the beam separation and final rms beam length and current
- The **X-band linac** is the main responsible for
  - the energy jitter that is negligible with respect to other parameters ← it operates almost on crest
  - final Twiss parameters that are almost stable ← the final focusing system is made of permanent magnet
  - the final profile of the witness peak current

The mean value over the 50 samples is reduced with respect to the photoinjector one with the benefit of a *reduced deviation* around the mean value

Jitter analysis in terms of beam delay, witness emittance and peak current at the photoinjector (upper) and X-band linac (lower) exit



Witness-Driver distance distribution at the plasma module

- Capillary length 60 cm
- Cut at 80% of 30 pC charge

Nominal jitter case :

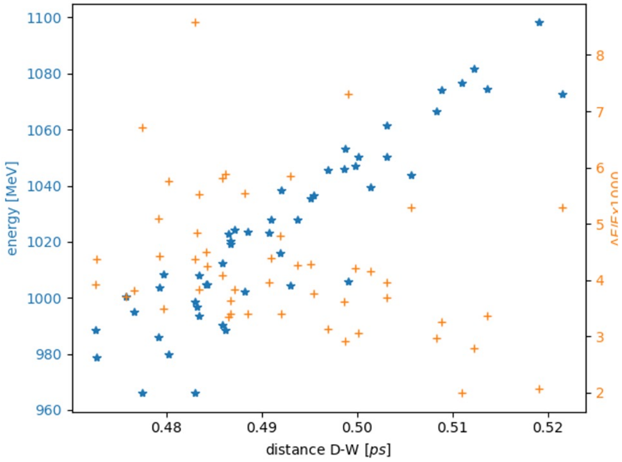
RF ampl ± 0.2 % (Sband)

RF phase ± 0.03° (Sband)

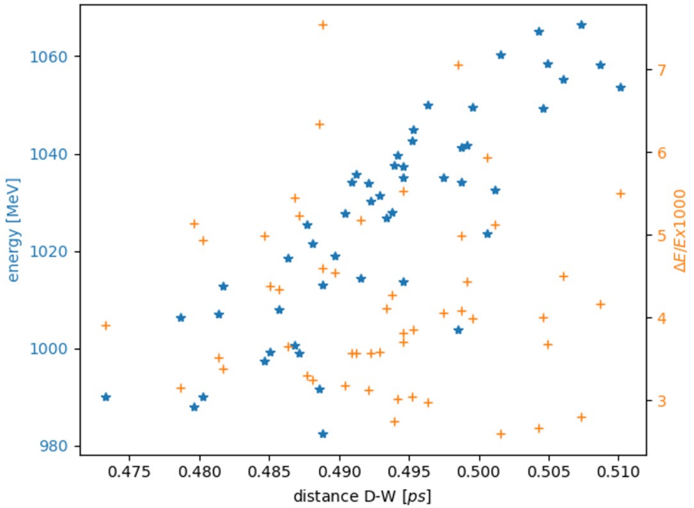
RF ampl ± 0.2 % (Xband)

RF phase ± 0.1 ° (Xband)

Nominal Jitter case



Half Sband phase&ampl jitter



Half Sband phase&ampl jitter only
(phase value based on C-band solid state modulator performances and amplitude best performance at SPARC_LAB)

A. Del Dotto, S. Romeo

Witness energy distribution at the plasma module exit

A. Del Dotto, S. Romeo

Nominal jitter case:

RF ampl ± 0.2 % (Sband),RF phase ± 0.03° (Sband), RF ampl ± 0.2 % (Xband), RF phase ± 0.1 ° (Xband)

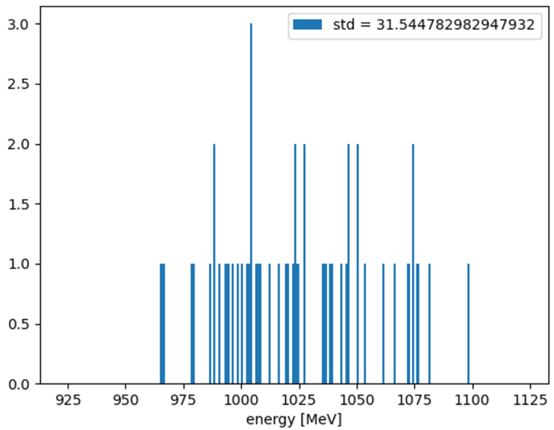
vs half of RF S-band phase&ampl value

Results: energy = 1025 MeV, std ~ 3%

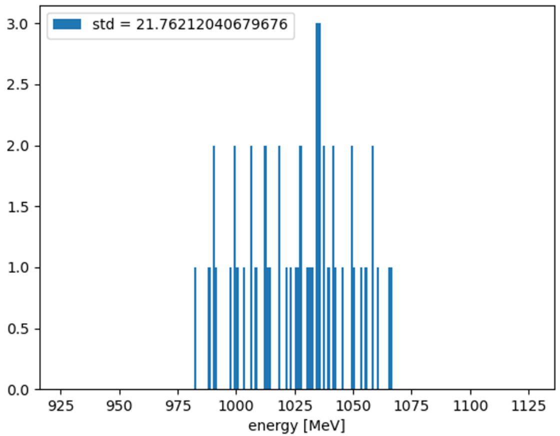
vs 1025 MeV, std ~ 2%

- Capillary length 60 cm
- Cut at 80% of 30 pC charge

Nominal case



Half sband-phase jitters



Witness energy spread distribution at the plasma module exit

A. Del Dotto, S. Romeo

Nominal jitter case:

RF ampl ± 0.2 % (Sband),RF phase ± 0.03° (Sband), RF ampl ± 0.2 % (Xband), RF phase ± 0.1 ° (Xband)

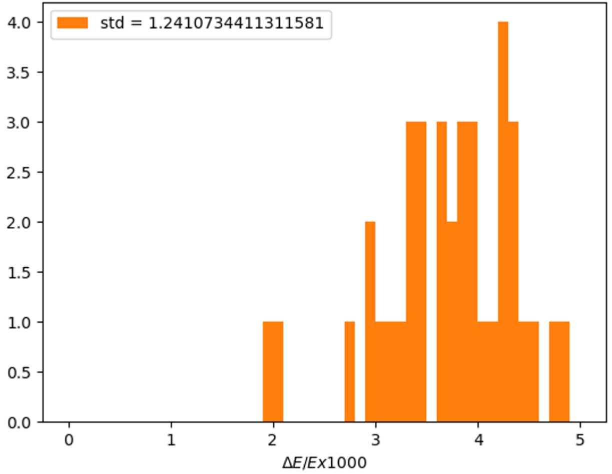
vs half of RF phase&ampl value

- Capillary length 60 cm
- Cut at 80% of 30 pC charge

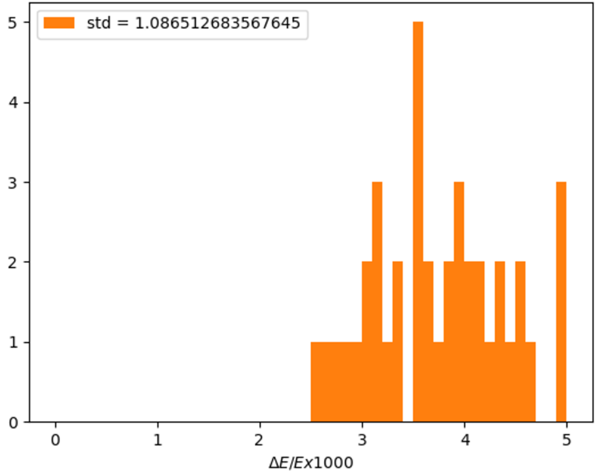
Results: $\sigma_\delta = 0.4\%$, $std\ 0.1\%$

vs $\sigma_\delta = 0.4\%, std\ 0.1\%$

Nominal case



Half sband-phase jitters

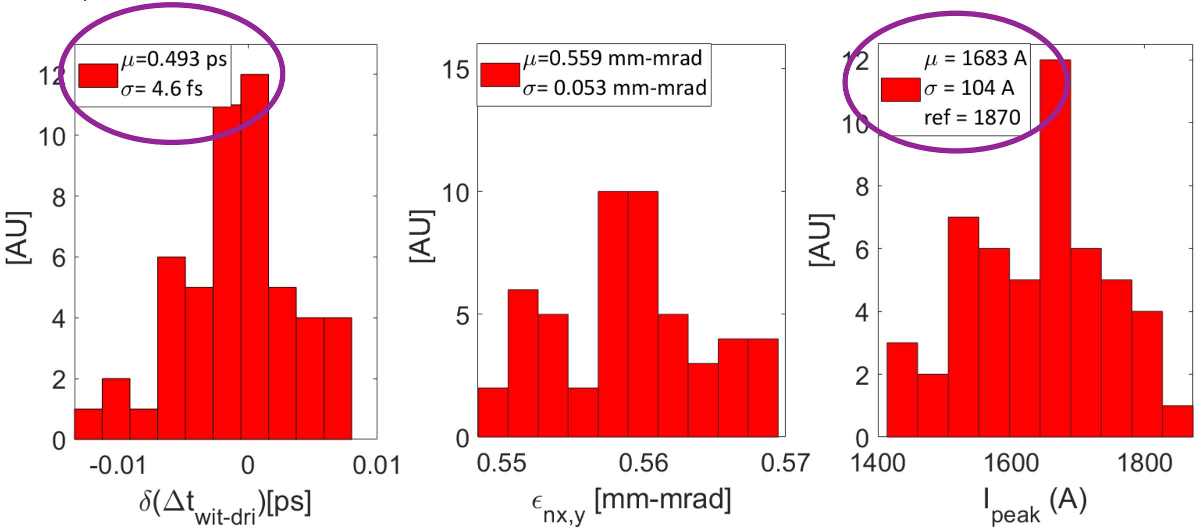


Updated analysis for Photoinjector w S-band ampl. jitter contribution comparable w phase jitter contribution and neglecting the laser time arrival

Updated machine performances

→ ~ $^1/_2$ of Wit-Dri distance and Peak current variation

- Updated jitter values have been evaluated as in Table
- The major upgrade of the machine regarded the photocathode laser TOA jitter → 0 fs
- In the chosen range the timing jitter depends quite linearly on the considered quantities



RF Gun (rms)		
RF Voltage [ΔV]	± 0.030	%
RF Phase [Δϕ]	± 0.015	*deg*
S-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.030	%
RF Phase [Δϕ]	± 0.015	*deg*
X-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.02	%
RF Phase [Δϕ]	± 0.10	*deg*
Cathode Laser System (rms)		
Charge [ΔQ]	± 0.3	%
Laser time of arrival [Δt]	± 0	fs
Laser Spot size [Δσ]	± 0.3	%

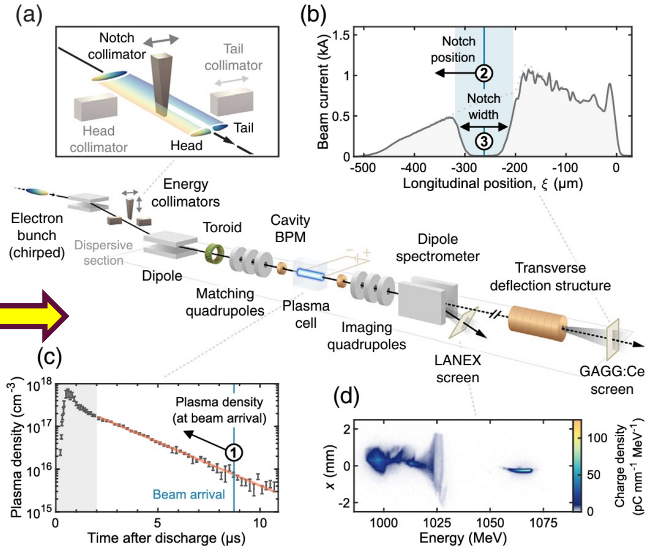
Alternative solution for COMB beam shaping

- To reduce the jitter sensitivity of the Witness-Driver electron beam configuration an alternative solution has been explored:

magnetic compression + transverse beam shaping

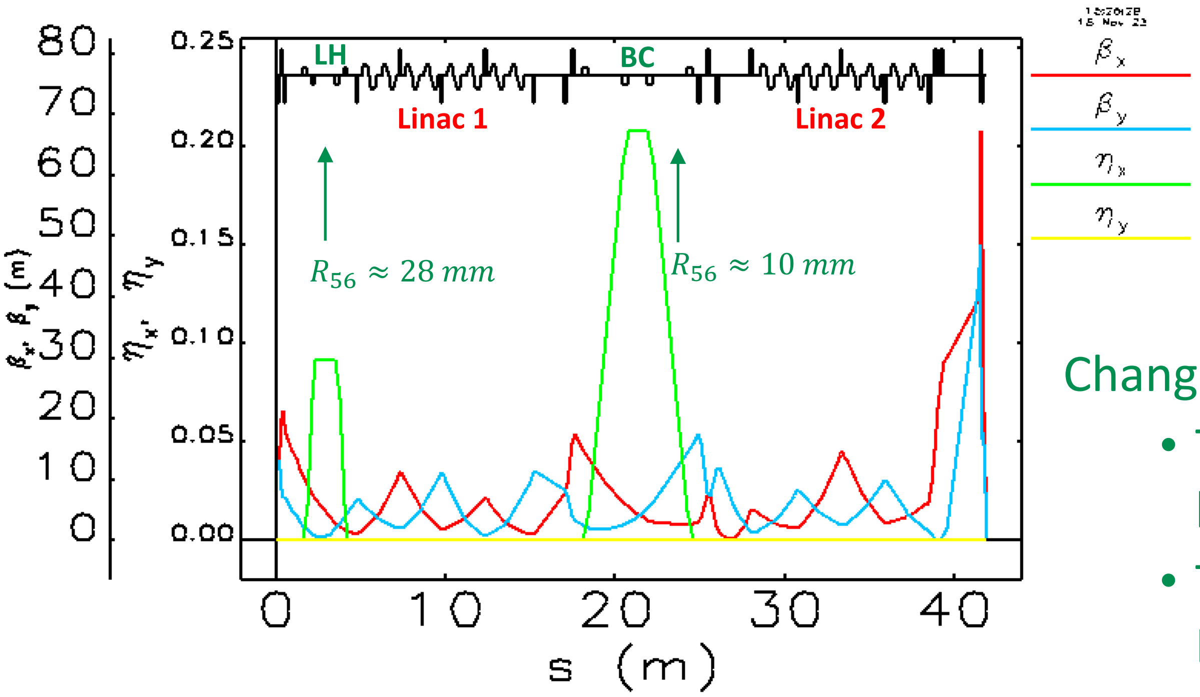
in the dispersive section

- A numerical cut has been applied to the particles close to the third magnet of the BC chicane to simulate the effect of a vertical wedge-shaped collimator like the one realized at Flash.
- To obtain the desired asymmetric current distribution a slightly chirped 400 pC beam (Φ = 90°,80°,60°,60°), has been generated in the photoinjector (Tstep code) to be longitudinally compressed in the LH and BC magnetic chicanes.
- Taking advantage of the typical double peak current configuration at the bunch edges, applying a central 550 mm cut in the horizontal plane resulted in a Witness-Driver configuration tracked up to the plasma exit by means of Elegant and Architect codes.
- A jitter analysis taking into account RF-phase and Voltage of the first Linac section, plus Dipoles Magnetic Field has been performed on 50 runs of the first considered working point



Energy-Spread Preservation and High Efficiency in a Plasma-Wakefield Accelerator
C.A. Lindstrøm (DESY), et al. Phys.Rev.Lett. 126 (2021) 1, 014801

Linac lattice



Nominal parameters:

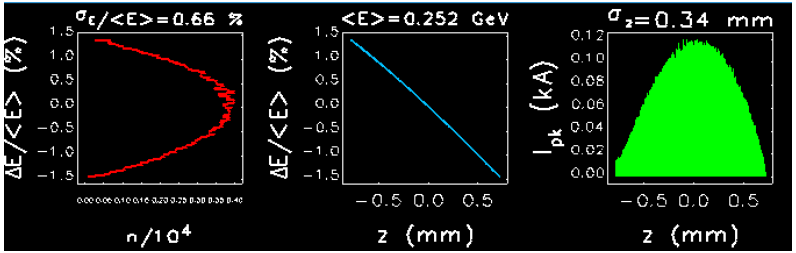
RFX_TW1 Φ=82.3, θ_1=17.9E-2 rad, θ_2=8.8E-2 rad

Changes:

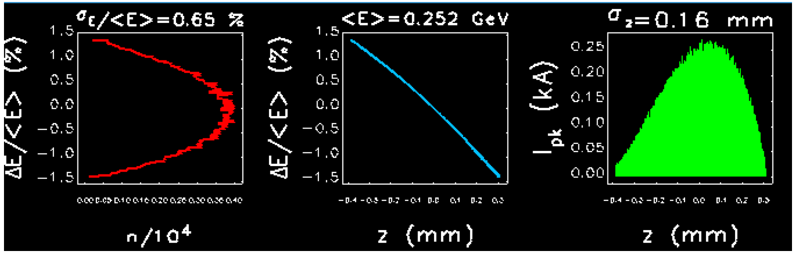
- The LH chicane magnetic length from 12 cm to 20 cm
- The matching upstream Linac2 slightly longer

```
s1x: script,command="comb_slitArrayx %i %o -1.88000  0.15000   0.70   2.5"
```

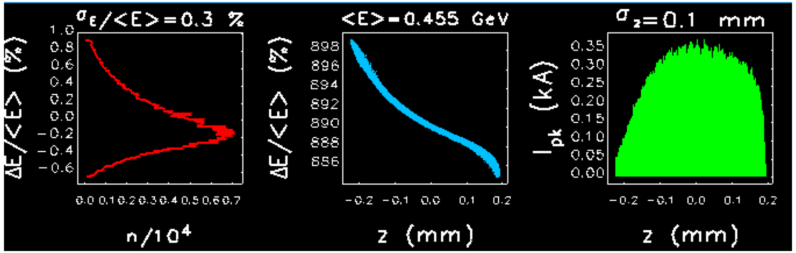
Longitudinal phase space evolution



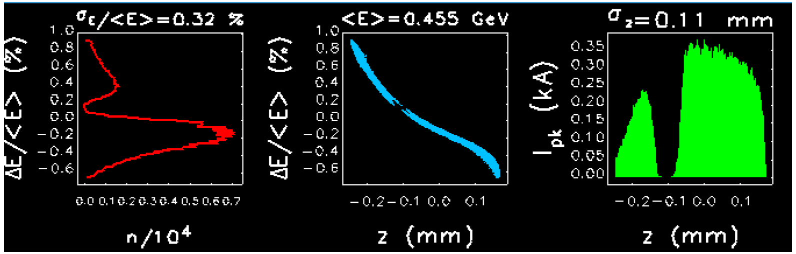
Photoinjector exit



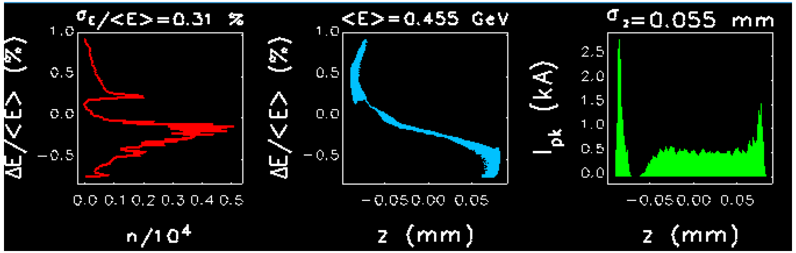
LH chicane exit



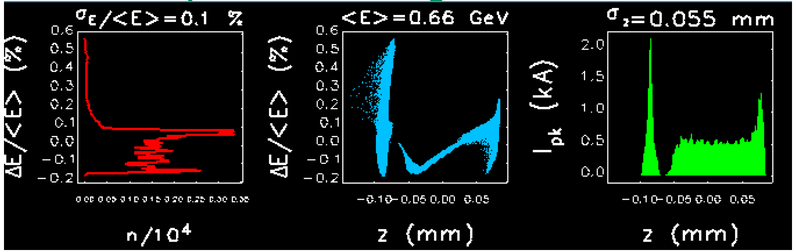
Upstream BC 3rd magnet



Upstream BC 3rd magnet after the cut

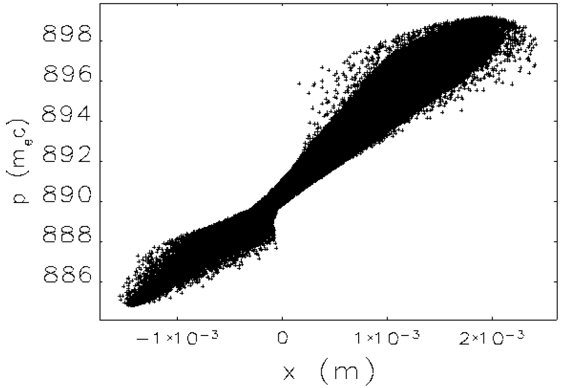


BC chicane exit

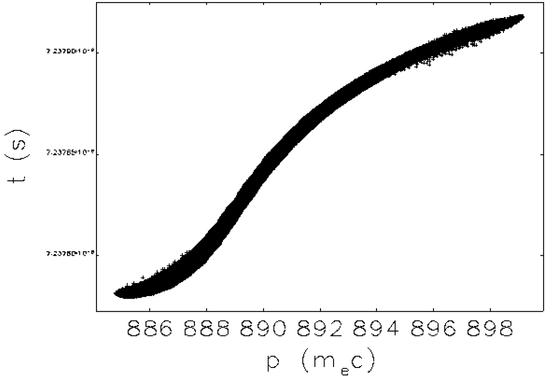


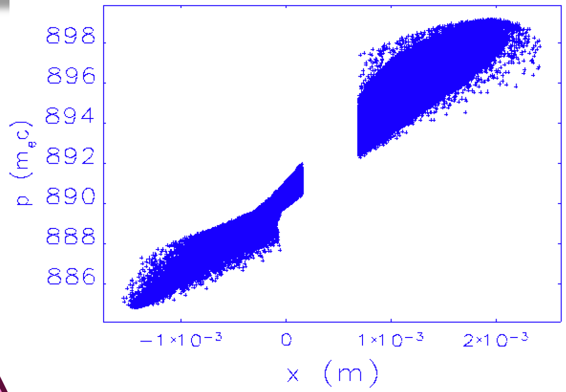
Capillary entrance

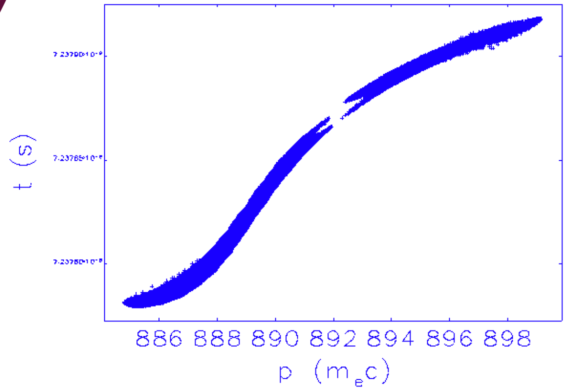
From Longitudinal to transverse phspace




```
s1x: script,command="comb_slitArrayx %i %o -1.88000  0.15000   0.70   2.5"
```

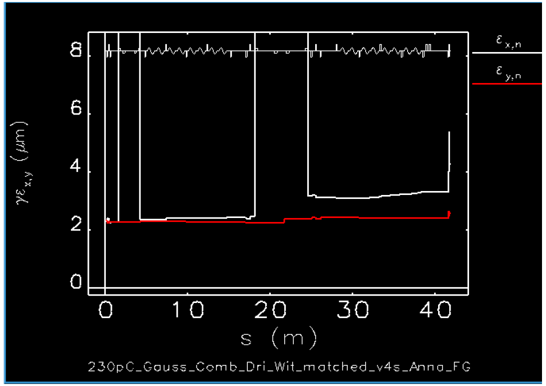






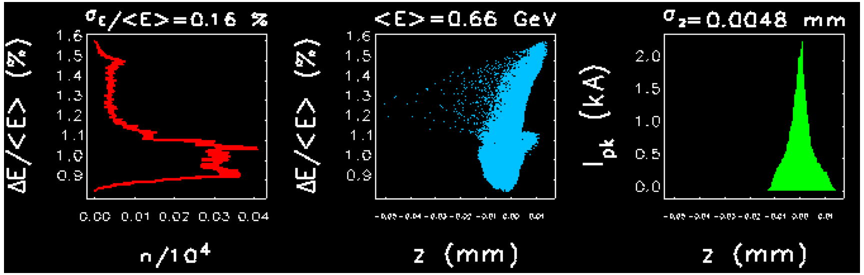
Witness & Driver analysis

```
Printout for SDDS file Wit_w0.out

Particles =       59810

Printout for SDDS file Wit_w0.out.ana

     enx            eny            Sx             Sy             St             Sdelta
      m              m              m              m              s
-------------------------------------------------------------------------------------------
  9.914898e-06   2.063363e-06   6.029986e-06   5.264951e-06   1.593571e-14   1.548020e-03
Printout for SDDS file Dri_w0.out

Particles =     252036

Printout for SDDS file Dri_w0.out.ana

     enx            eny            Sx             Sy             St             Sdelta
      m              m              m              m              s
-------------------------------------------------------------------------------------------
  2.412465e-06   1.557550e-06   2.807111e-06   1.576398e-06   1.366284e-13   8.109252e-04
```

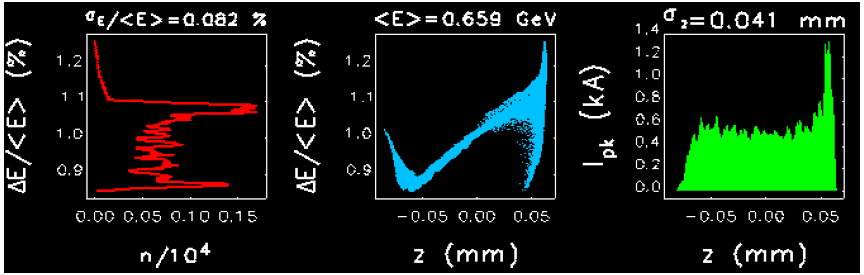



```
QWit =

    59.8100


QDri =

   252.0540
```

Witness bunch



Driver bunch



Jitter studies including acceleration in plasma for magnetic-mask shaping

- **50 machines have been tracked trough the Linac up to the plasma entrance applying the RF phase and amplitude jitters in the accelerator according to:**
  - **LNF measurements at TeX**

```
&error_element name=RFX_TW_?, item=PHASE, amplitude = 0.08, bind = 1, bind_number=2, type="gaussian" &end
&error_element name=RFX_TW_?, item=VOLT , amplitude = "26e3  0.2 * ", bind = 1, bind_number=2, type="gaussian",&end
&error_element name=BLH?, item= angle, amplitude = 2.0e-5, bind=1, bind_number=4, type="gaussian" &end
&error_element name=BC2_?, item= angle, amplitude = 1.2e-5, bind=1, bind_number=4, type="gaussian" &end
```

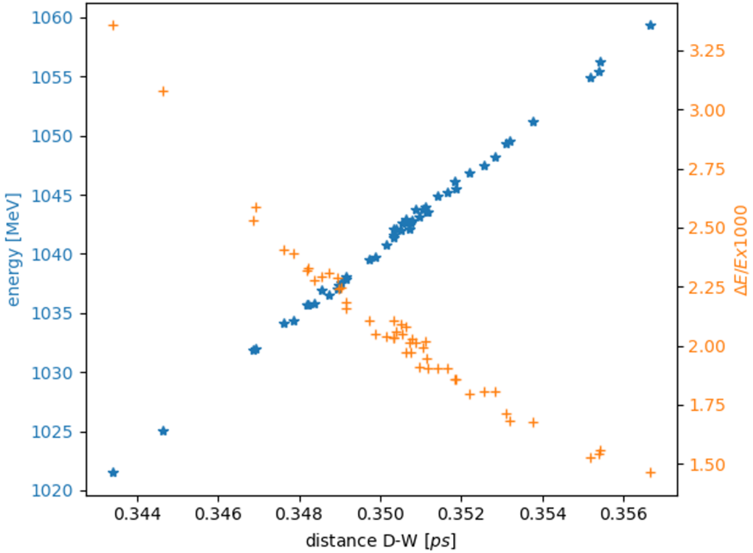
  - **PSI measurements** (“RF System Performance in the SwissFEL Linac”, C. Beard et al , JACoW LINAC2022 (2022), TH2AA02)

```
&error_element name=RFX_TW_?, item=PHASE, amplitude = 0.06, bind = 1, bind_number=2, type="gaussian" &end
&error_element name=RFX_TW_?, item=VOLT , amplitude = "26e3  0.5 * ", bind = 1, bind_number=2, type="gaussian",&end
&error_element name=BLH?, item= angle, amplitude = 2.0e-5, bind=1, bind_number=4, type="gaussian" &end
&error_element name=BC2_?, item= angle, amplitude = 1.2e-5, bind=1, bind_number=4, type="gaussian" &end
```

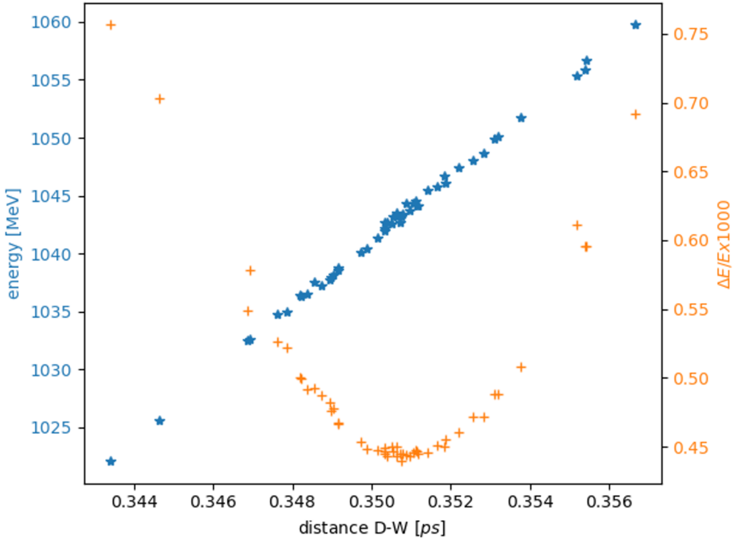
First Results for magnetic-mask shaped beam 1

Dri-Wit distance correlation with energy end energy spread (Capillary length 40 cm)

Cut at 80% of 60 pC charge



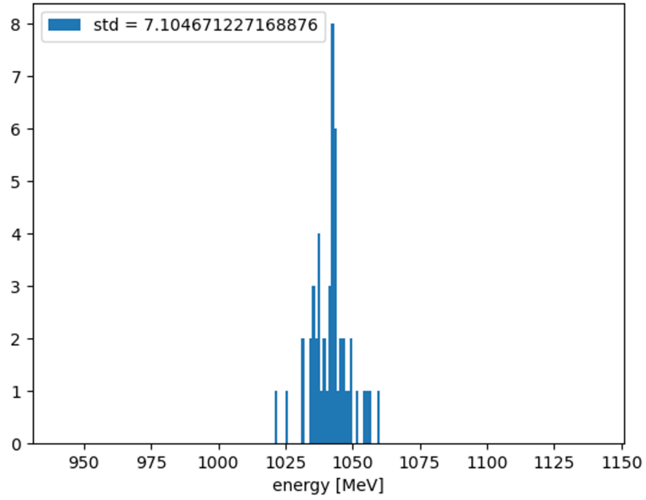
Cut at 40% of 60 pC charge



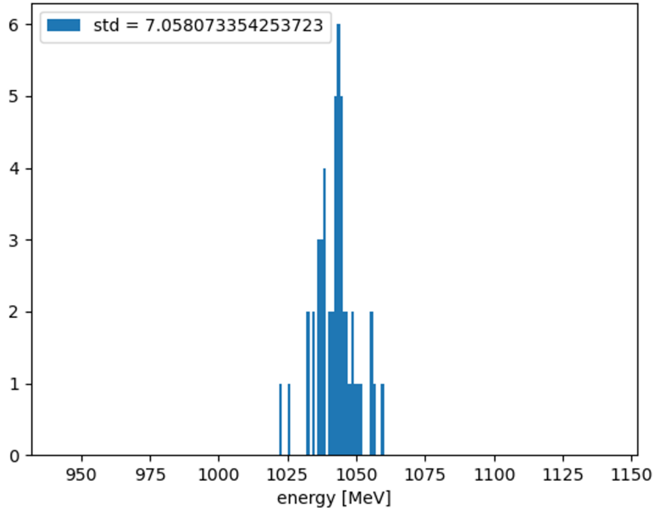
First Results for magnetic-mask shaped beam 2

Energy variation (Capillary length 40 cm)

Cut at 80% of 60 pC charge
energy = 1045 MeV, std~0.7%

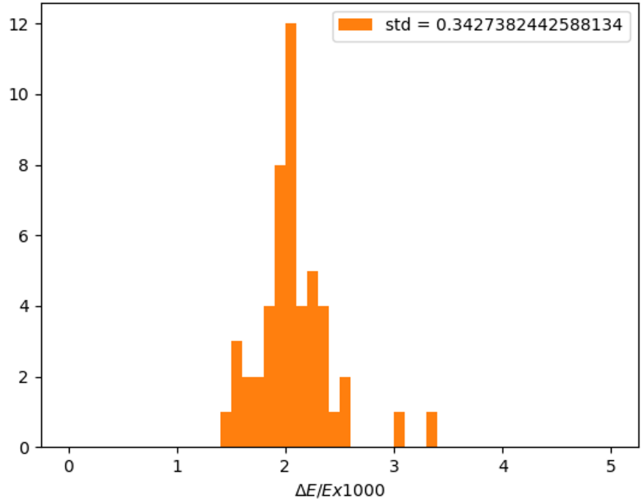


Cut at 40% of 60 pC charge
energy = 1045 MeV, std~0.7%

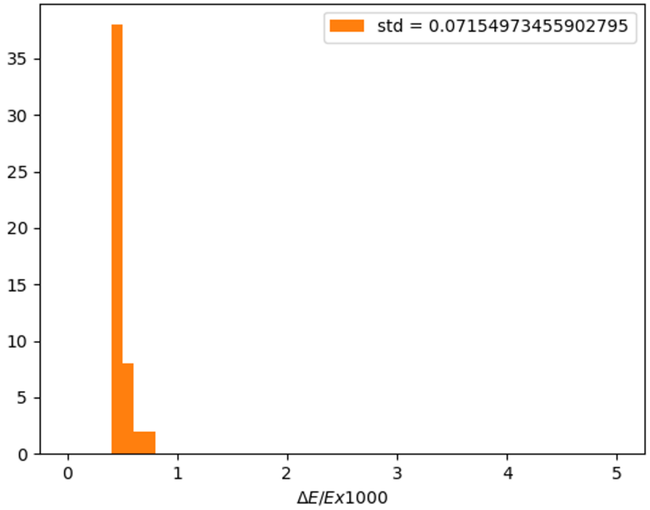


Energy spread variation (Capillary length 40 cm)

Cut at 80% of 60 pC charge
energy spread mean value 0.2% with
std~0.03%



Cut at 40% of 60 pC charge
energy spread 0.05 % with
std~0.007%



Jitter analysis Summary Table & Open Points

Summary Table

Comb scheme	Q pC	Final Energy std 80% charge	Final Energy Spread 80% charge	Final Energy std 40% charge	Final Energy Spread 40% charge
Velocity Bunching	30	3⇨2 %	0.4% std=0.1%		
Magnetic -shaping	60	0.7 %	0.2% std=0.03%	0.7%	0.05 % std=0.007%

Magnetic Shaping open points:

- Witness Transverse emittance optimization
- Beam loading check and optimization
- Geant4 simulation of the wedge
- Complete start2end jitter analysis
- Technological solution
- Microbunching Instability now priority item

Conclusions and To-do List

- The BD simulation work restarted from October 2023
- For the Velocity Bunching Comb scheme, the obtained results show an energy std for the witness beam of about 3-2% with the previous jitter values (June 2023) and one half of these values respectively. For the energy spread we got $\sigma_\delta = (0.4 \pm 0.1)\%$ in both cases.
- With updated and better Jitter values Oct 2023 the studies in photoinjector showed one half of the sensitivity for Wit-Dri distance and Witness peak current.
- An alternative solution has been studied based on a "quasi" on crest single electron bunch provided by the Photoinjector (Φ = 90°,80°,60°,60°), longitudinally compressed and shaped by a numerical "mask" in the two available chicanes. The jitter studies concerning the Linac 1 plus chicanes system show an energy stability of 0.7 % and $\sigma_\delta = (0.2 \pm 0.07)\%$ with an 80% charge cut and $\sigma_\delta = (0.05 \pm 0.007)\%$ with a 40% charge cut.
- The magnetic solution has to be optimized in terms of transverse emittance of the Witness bunch and BD evolution in plasma for the Driver, and mostly the Jitter analysis must be completed including the Photoinjector.
- Moreover, a Montecarlo simulation of the beam interaction with a physical wedge collimator is necessary, together with the feasibility study of the mechanical system.
- Finally, the MIB effect and LH efficiency must be included.

Thanks for your attention

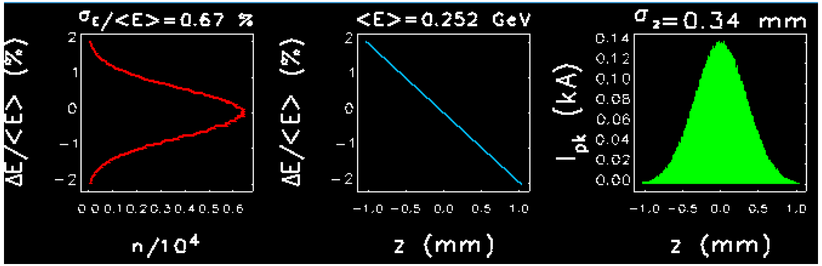
Backup Slides

SLIT NELLA CHICANE
RFXTW PHASE=84°
400kp iniziali
298.584kp finali

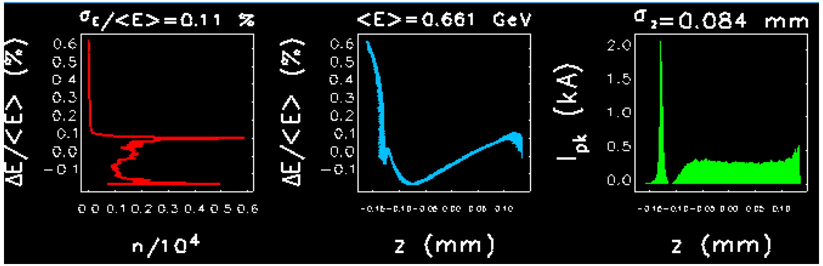
```
QWit =

    46.8380

QDri =

   251.7420
```

```
Printout for SDDS file Wit_w0.out

Particles =       46834

Printout for SDDS file Wit_w0.out.ana

       enx              eny               Sx               Sy               St
        m                m                m                m                s
---------------------------------------------------------------------------------
    3.893028e-06     2.770565e-06     2.310304e-06     2.612034e-06     1.749879e-14
Printout for SDDS file Dri_w0.out

Particles =      251726

Printout for SDDS file Dri_w0.out.ana

       enx              eny               Sx               Sy               St
        m                m                m                m                s
---------------------------------------------------------------------------------
    2.789591e-06     2.643381e-06     2.222813e-06     2.132044e-06     2.258678e-13
```

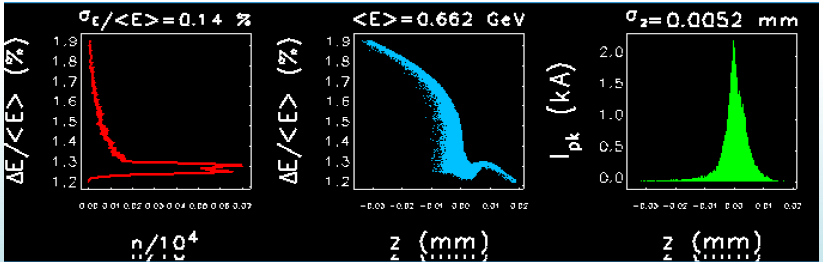
PInj exit



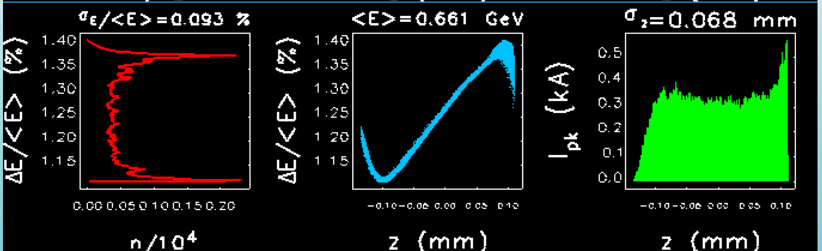
@capillary entrance

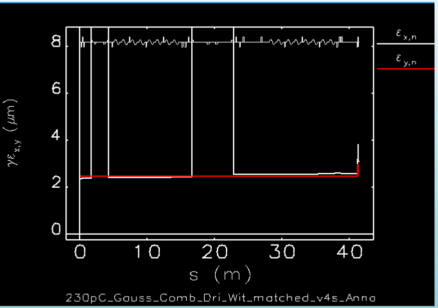


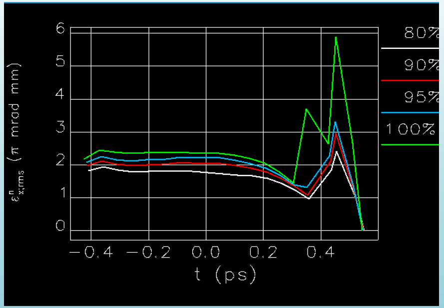
Witness



Driver





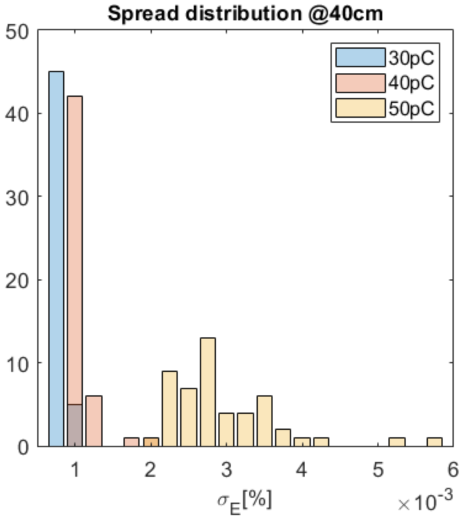


Some statistics on accelerated Witness bunch

$\langle\sigma_\delta\rangle = 0.08\%\ w\ 30\ pC$

$\langle\sigma_\delta\rangle = 0.1\ \%\ \ w\ 40\ pC$

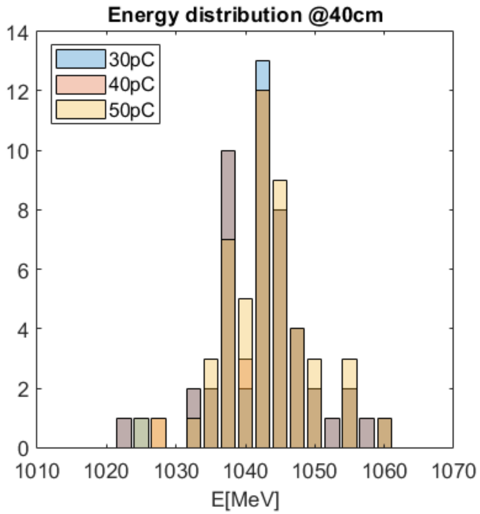
$\langle\sigma_\delta\rangle = 0.3\ \ \%\ w\ 50\ pC$



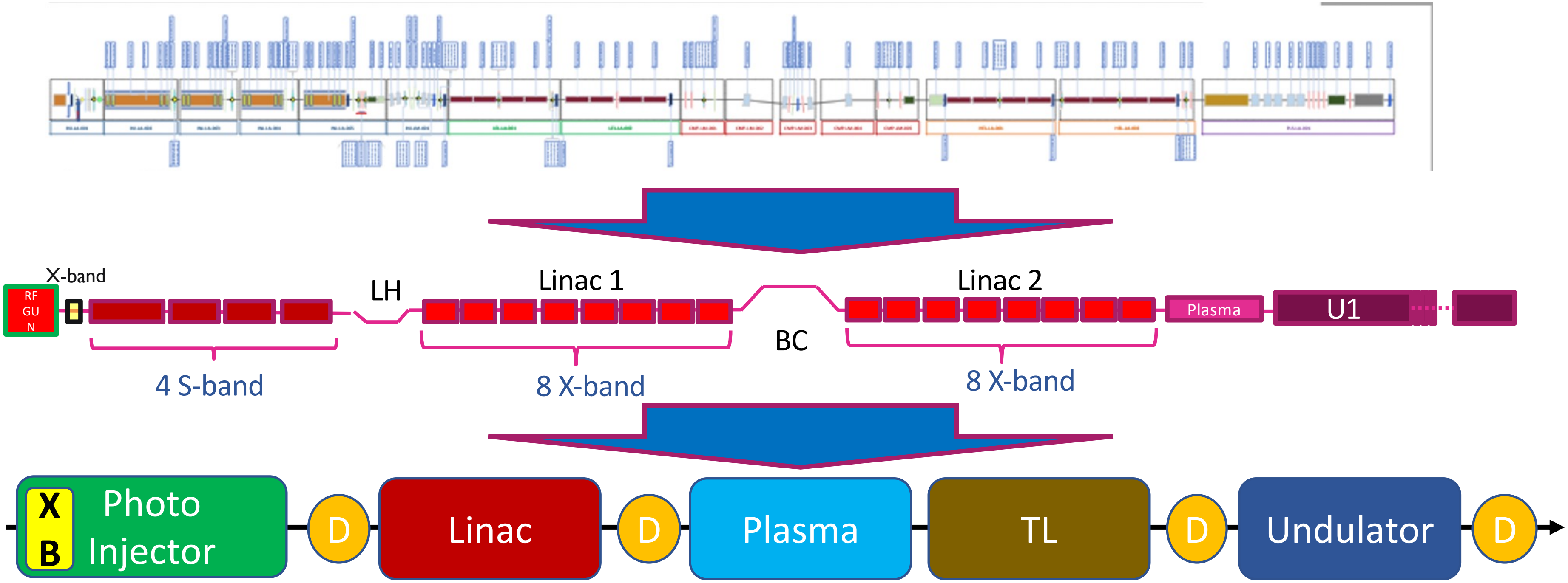
$\Delta E/_E = 0.68\%\ w\ 30pC$

$\Delta E/_E = 0.66\%\ w\ 40pC$

$\Delta E/_E = 0.64\%\ w\ 50pC$



The Basic Layout

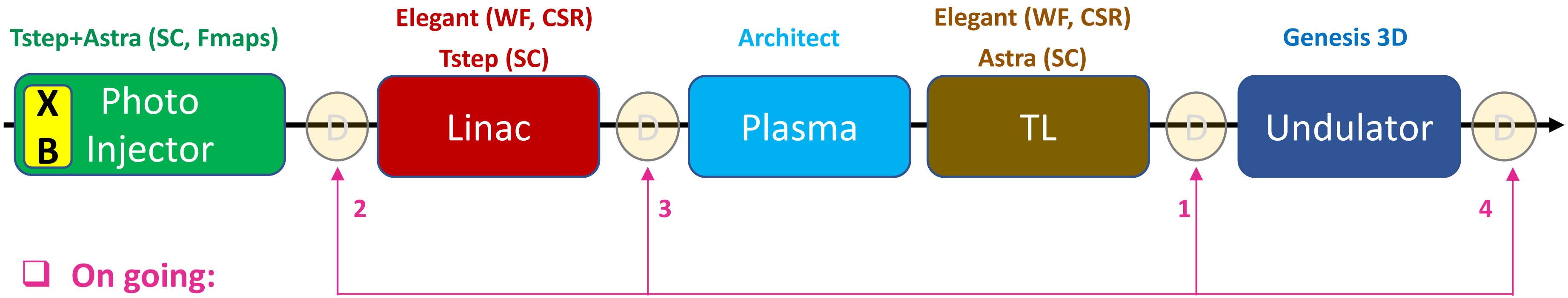


- **Focused on Plasma acceleration operation scheme = WoP1**
- **Checked at each iteration for the High Charge Single Bunch boosted by an *All-RF* Linac up to 1 GeV = WoP2**

Start2End for the basic layout

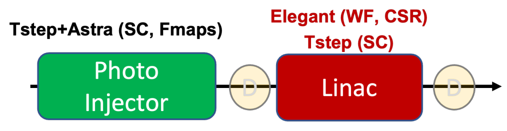
- PhotoInjector Layout consolidation with 3m +3x2m S-band scheme:
  - Revision of nominal 30+200 pC WoP1 scheme for plasma acceleration: Photoinjector (no Xband)+ Linac + Plasma
  - Transfer Line with CSR & SC for Undulator optics matching
  - Undulator results

done



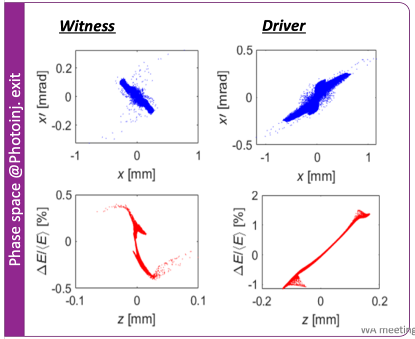
- On going:
  - Diagnostics feasibility/efficiency check w virtual measurements (priority order) to finalize the basic layout

S2E «basic» details:

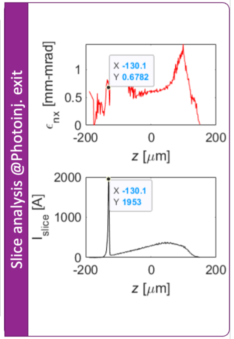


A. Giribono

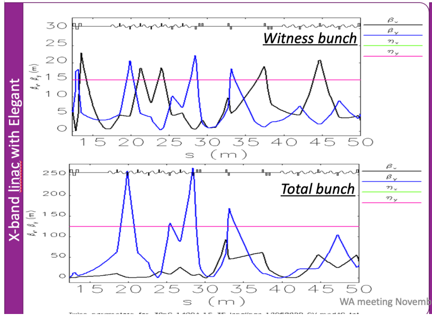
PhotoInjector

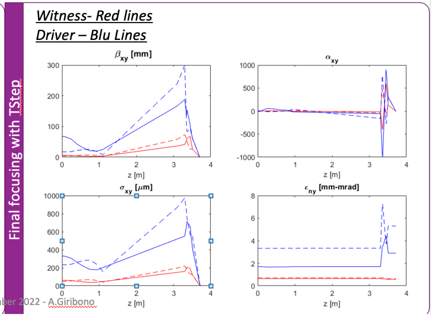


Beam parameters @Photoinj exit		
	Witness	Driver
E [MeV]	124.75	126.46
$\varepsilon_{x,y}$ [mm mrad]	0.70	1.52
$\sigma_{z\text{-}rms}$ [μm]	4.923	62.320
ΔE/E [%]	0.117	0.547
Δt [μm] (ps)	151.5 (0.505)	
$\sigma_{x\text{-}rms}$ [μm]	118	127
$\beta_{x,y}$ [mm]	6.127	2.609
$\alpha_{x,y}$	2.475	-1.534

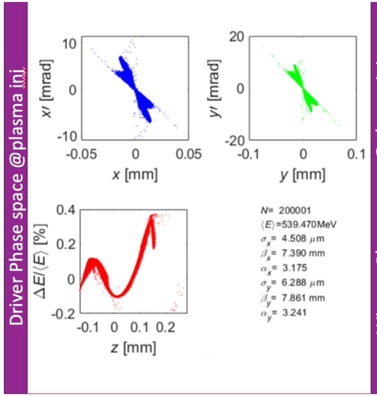


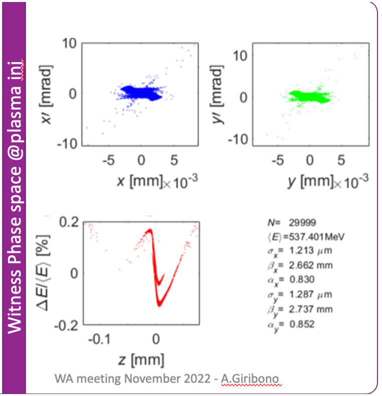
Linac





Capillary entrance



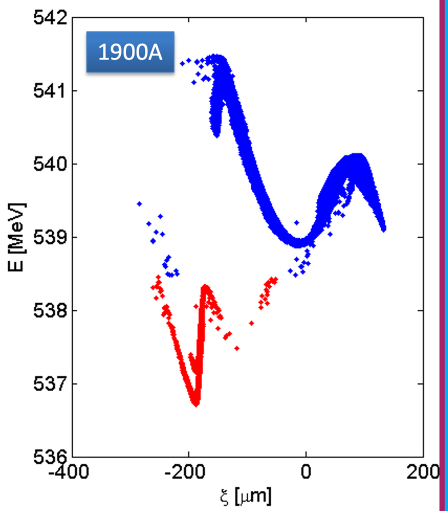


Beam parameters @Plasma inj.		
	Witness	Driver
E [MeV]	537.6	539.5
$\varepsilon_{x,y}$ [mm mrad]	0.68-0.70	2.9-5.3
$\sigma_{z\text{-}rms}$ [μm]	5.460	59.620
ΔE/E [%]	0.057	0.095
Δt [μm] (ps)	151 (0.505)	
$\sigma_{x\text{-}rms}$ [μm]	**1.2-1.3**	**4.5-6.3**
$\beta_{x,y}$ [mm]	**2.7-2.7**	**7.4-7.8**
$\alpha_{x,y}$	**0.83-0.85**	**3.2-3.2**

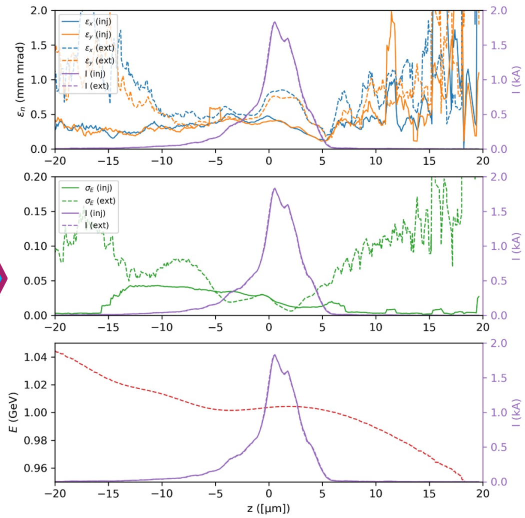
30 + 200 pC

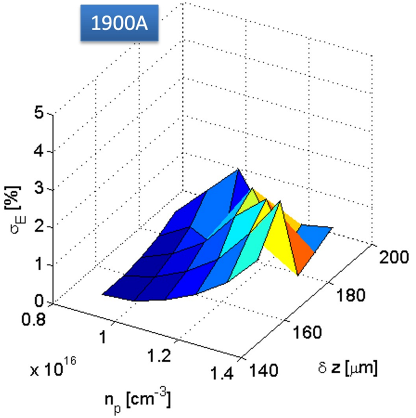
S2E «basic» details:

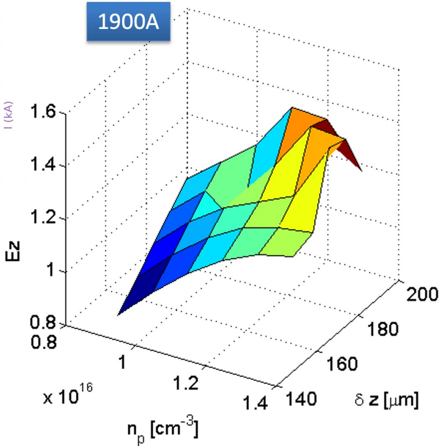
Architect
Plasma



- ❑ $\Delta z = 158\ \mu\text{m}$
- ❑ $n_p = 0.9 \cdot 10^{16}\ \text{cm}^{-3}$
- ❑ $\sigma_E = 0.06\%$
- ❑ $E_z = 0.9\ \text{GV/m}$ (including 1 cm injection ramp, so, actually, slightly higher)
- ❑ Slice energy spread, virtually untouched (or reduced)
- ❑ Slight emittance increase (to be improved with ramps)
- ❑ Accelerating length 0.56 m





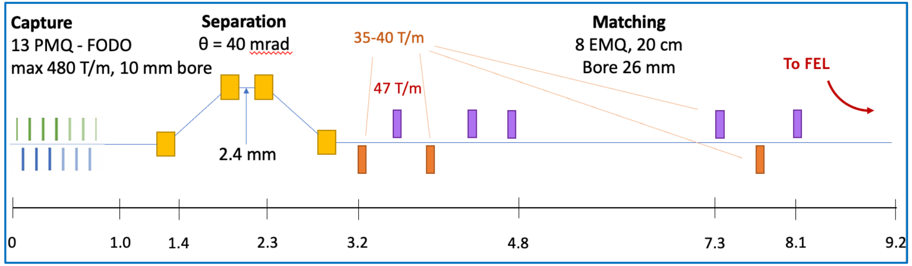


S2E «basic» details:

Elegant (WF, CSR)
Astra (SC)
TL

M. Rossetti Conti

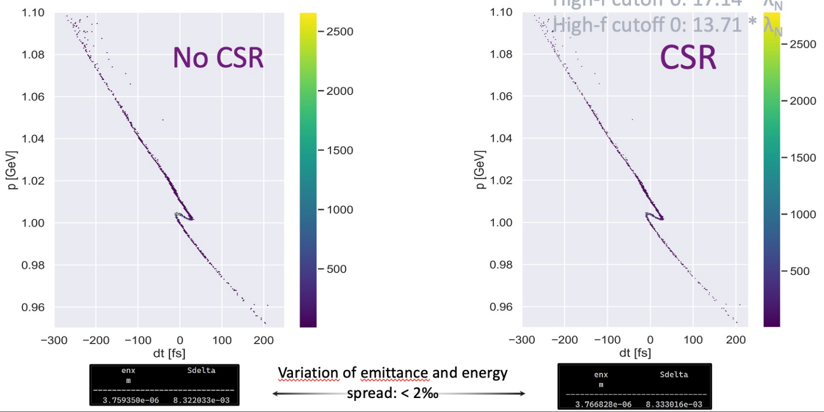
Layout



Evaluation of CSR (Elegant)

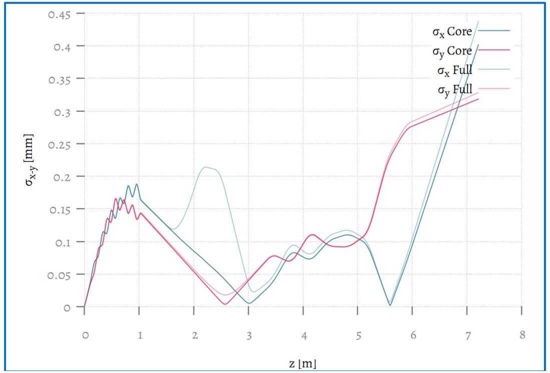
70 Bins

Nyquist wavelegth : 3.4 µm
High-f cutoff 0: 17.14 * λ_N
High-f cutoff 0: 13.71 * λ_N

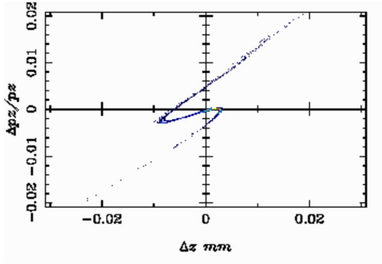


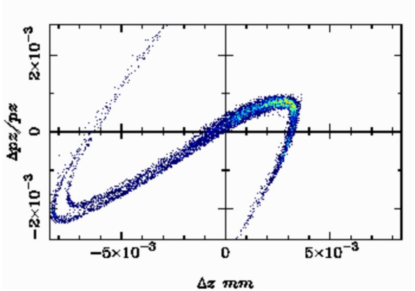
Variation of emittance and energy spread: < 2‰

Transverse beam size evolution w Space Charge (Astra)



Aperture
0.250 mm diameter (11% cut)
8.35 MeV to 1.12 MeV





S2E «basic» details: $\lambda_r = 4\ nm$

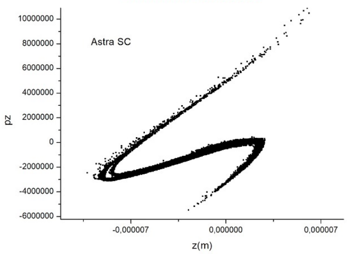
Genesis 3D

Undulator

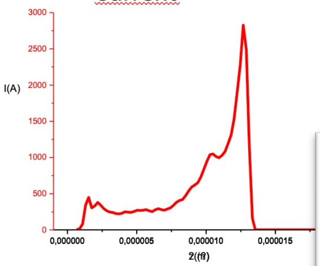
V. Petrillo

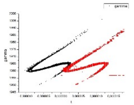
Beam from TL with space charge E=1GeV, Q= 30 pC.

Phase space

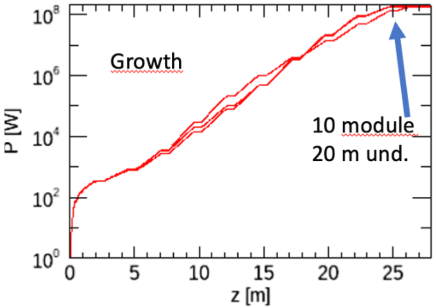


Current

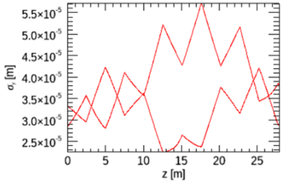


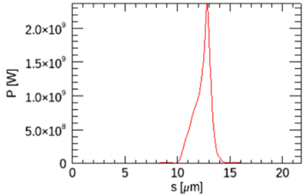


Comparison Astra(black)/Genesis 1.3 (red)

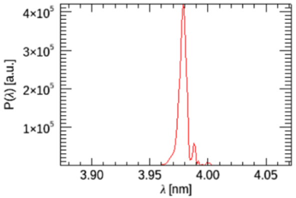


Matching





Clean single spike at 25 m



Energy	**J**	**11.5 10^-6, 16. 10^-6**
bw	%	0.1
size	m	1.4 10^-4
div	rad	1.7 10^-5
Photon number		**2.2 10^11, 2.85 10^11**
wavelength	nm	3.975

S2E «basic» details: $\lambda_r = 3.3\ nm$

Genesis 3D

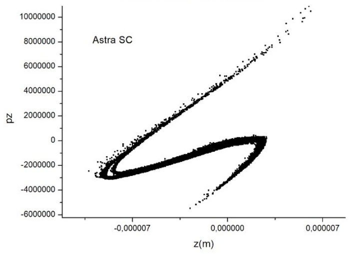
Undulator

4/4

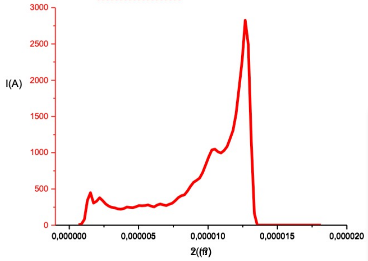
V. Petrillo

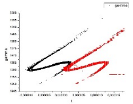
Beam from TL with space charge E=1GeV, Q= 30 pC.

Phase space



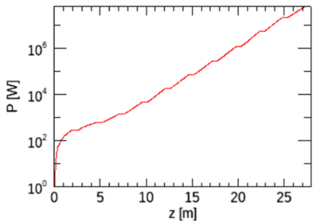
Current

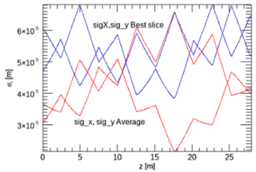


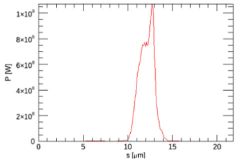


Comparison Astra(black)/Genesis 1.3 (red)

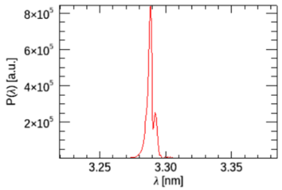
Same beam, undulator tuned at 3.3 nm







Energy	**J**	**6,6 10^-6**
bw	%	0.1
size	m	1.4 10^-4
div	rad	1.7 10^-5
Photon number		**1.09 10^11**
wavelength	nm	**3.3**



EuPRAXIA@SPARC_LAB Parameter List update 1

Nominal FEL parameters from CDR

Parameter	Unit	PWFA	Full X-band
Radiation Wavelength	nm	3	
Photons per Pulse	$\times 10^{12}$	0.1	1
Photon Bandwith	%	0.9	0.5
Undulator Area Length	m	30	
$\rho(1D/3D)$	$\times 10^{-3}$	1	2
Photon Brilliance per shot	$mm^2 mrad^2$ $bw(0.1\%)$	1×10^{27}	

FEL Parameters Nov 2022

Parameter	Unit	PWFA	Full X-band
Radiation Wavelength	nm	**3-4**	**4**
Photons per Pulse	$\times 10^{12}$	**0.1- 0.25**	1
Photon Bandwith	%	**0.1**	0.5
Undulator Area Length	m	30	
$\rho(1D/3D)$	$\times 10^{-3}$	**2**	2
Photon Brilliance per shot	$\left(\frac{s\ mm^2 mrad^2}{bw(0.1\%)}\right)$	$\mathbf{1\text{–}2 \times 10^{28}}$	1×10^{27}

EuPRAXIA@SPARC_LAB Parameter List update 2

Electron Beam parameters from CDR

Parameter	Unit	PWFA	Full X-band
Electron Energy	GeV	1	1
Bunch Charge	pC	30	200
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	1.1	0.1
RMS Bunch Length	μm	6-4	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	0.03	0.02
Slice norm Emittance	mm-mrad	0.5	0.3

Electron Beam Parameters Nov 22

Parameter	Unit	PWFA	Full X-band
Electron Energy	GeV	**1**-*1.2*	1
Bunch Charge	pC	**30**-*50*	**200**-*500*
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	**0.1**	0.1
RMS Bunch Length	μm	6-3	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	≤0.05	≤0.05
Slice norm Emittance	mm-mrad	0.5	0.5