Electron-Beam Manipulation Techniques in the SINBAD Linac for External Injection in Plasma Wake-Field Acceleration

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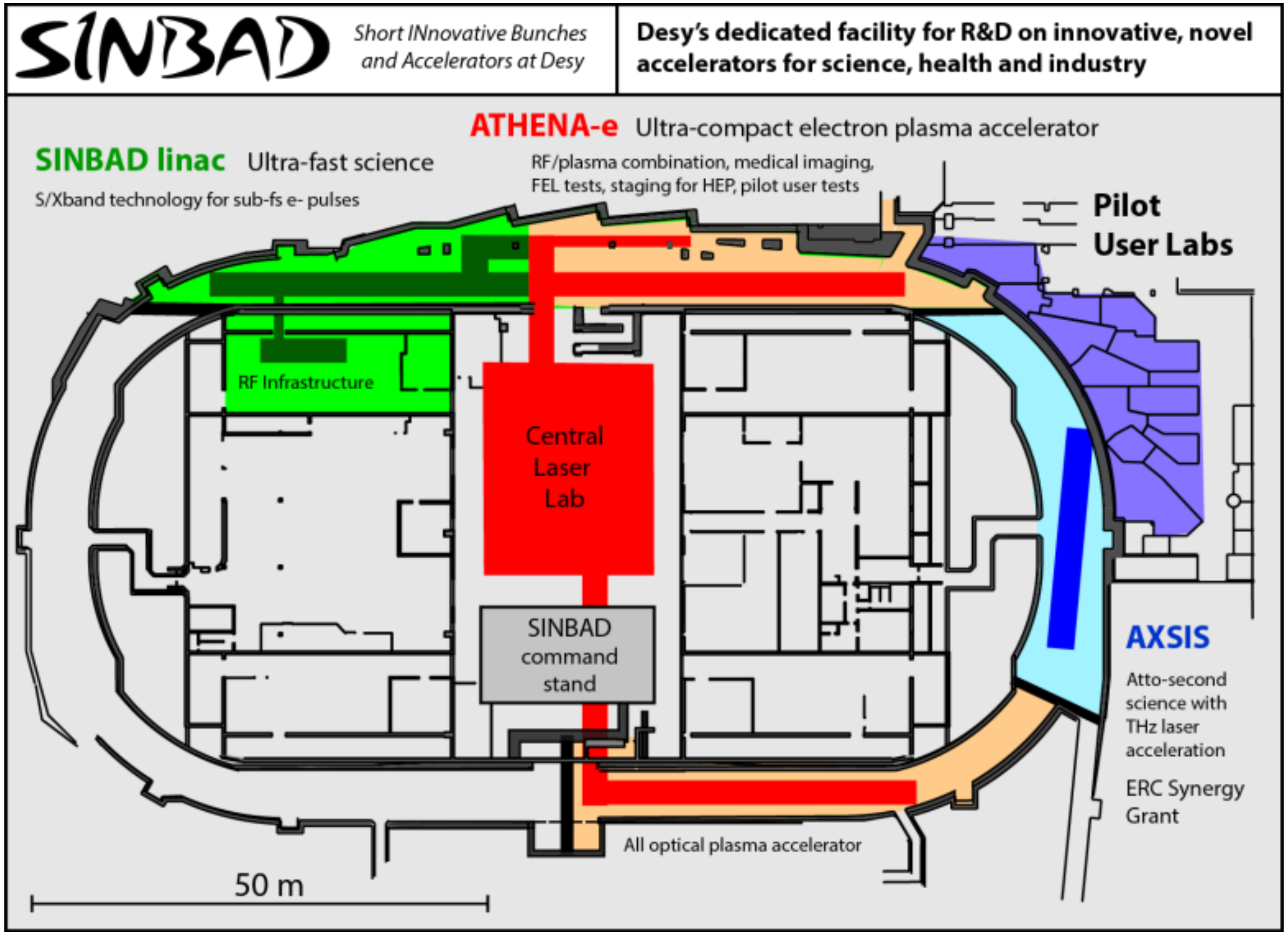
HELMHOLTZ | ASSOCIATION

DESY

Outlook

- Overview SINBAD/SINBAD linac:
  - SINBAD linac as an experiment itself
  - Linac requirements for future experiments
- Linac layout
  - Stage 1 - baseline
  - Stage 2 - upgrade
- Overview of the e-bunch compression techniques
  - Pure velocity bunching
  - Velocity bunching + bunch re-compression in the dogleg
  - Magnetic compression with slit-cut
  - Tolerances
- Conclusions and summary

SINBAD



Dedicated multi-purpose accelerator R&D facility with several experiments from **ultra-fast** science and **high gradient** accelerator modules.

Talk by U. Dorda in Session 1 WG4.

SINBAD
Short **IN**novative **B**unches and **A**ccelerators at **D**esy
PL: Ulrich Dorda

SINBAD linac as an experiment itself

- **<u>Goal</u>: production & characterization of ultra-short bunches (tFWHM≤1fs)**

→ Charge as high as possible
→ Relaxed transverse spot-size (>100 μm)

→ Mainly <u>technical challenges</u>

Challenges in beam diagnostics:

- Low charge:
  - Low signal/noise ratio
  - some diagnostics not yet available/under development
- Sub-fs longitudinal resolution is needed : state of the art are Xband TDS with 1 fs resolution.

Challenges in synchronization:

- Short signal, fs level synchronization is needed (both RF-RF and laser-RF).

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Much experience at DESY thanks to European XFEL, REGAE etc…

Just few examples:

- G. Kube et al., "Transverse Beam Profile Imaging of Few-Micrometer Beam Sizes Based on a Scintillator Screen", Proc. IBIC 2015.
- S. Bayesteh, „Transverse electron beam diagnostics at REGAE", PhD thesis (2014).
- M. Hansli et al. „A BEAM ARRIVAL TIME CAVITY FOR REGAE AT DESY", Proc. of IPAC 2014.
- M. Hoffmann et al., "HIGH SPEED DIGITIAL LLRF FEEDBACKS FOR NORMAL CONDUCTING CAVITY OPERATION", Proc. Of IPAC 2014
- M. Titberidze et al., „PRESENT AND FUTURE OPTICAL-TO-MICROWAVE SYNCHRONIZATION SYSTEMS AT REGAE FACILITY FOR ELECTRON DIFFRACTION AND PLASMA ACCELERATION EXPERIMENTS", Proc. IPAC 2015.
- J. Mueller at al., „ALL-OPTICAL SYNCHRONIZATION OF PULSED LASER SYSTEMS AT FLASH AND XFEL", Proc. IPAC 2015

... And many more.

SINBAD linac - general philosophy for future experiments

- **Who will be the „users“ of the SINBAD linac?**

→ **Experiments involving Novel High Gradient Acceleration Techniques**: e.g. LPWA, Dielectric Wake-Field Acceleration, THz laser acceleration in dielectric-loaded structures…

- **What types of e-beam will such experiments need?**

Initially
→ **characterization of the acceleration method** and optimization of the beam quality of the accelerated beam

At a later stage
→ pilot user experiments involving e.g. **radiation production** (via FEL, ICS …)

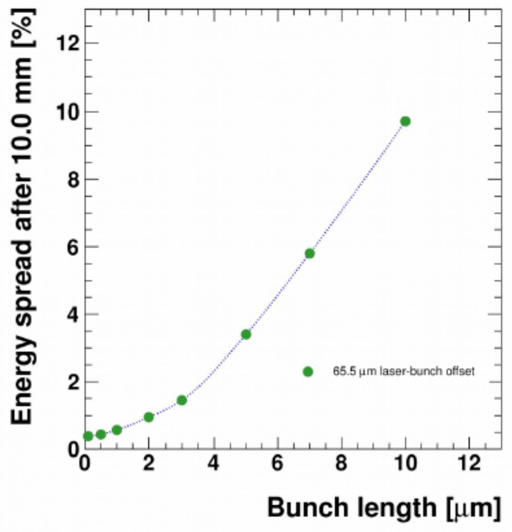
- **Ultra-short probes** → time resolution
- **Ultra-high stability** → synchronization
- **Small transverse focus (tens of μm – few μm)**

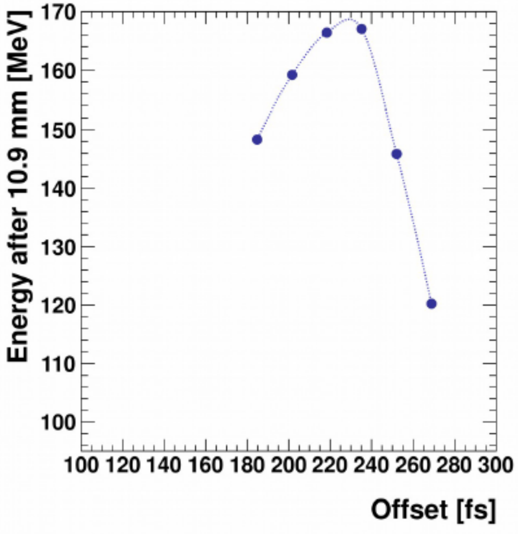
- **Sufficiently high brightness** → radiation generation
- The **e-bunch duration has to be tuned**, according to the requirements for the production of radiation.

External injection into LWFA with usable beam quality
Requirements for the injected e-bunches

- Energy ~ 100 MeV (less de-phasing issues for n~10^{16}-10^{17}cm^{-3})
- Bunch length < 5 fs (small final energy spread)
- Time jitter stability < 10 fs
- Small transverse spot-size: matched ß functions range from cm (n~10^{14}) to mm (n~10^{17})

Example: Simulations at n =10^{17}

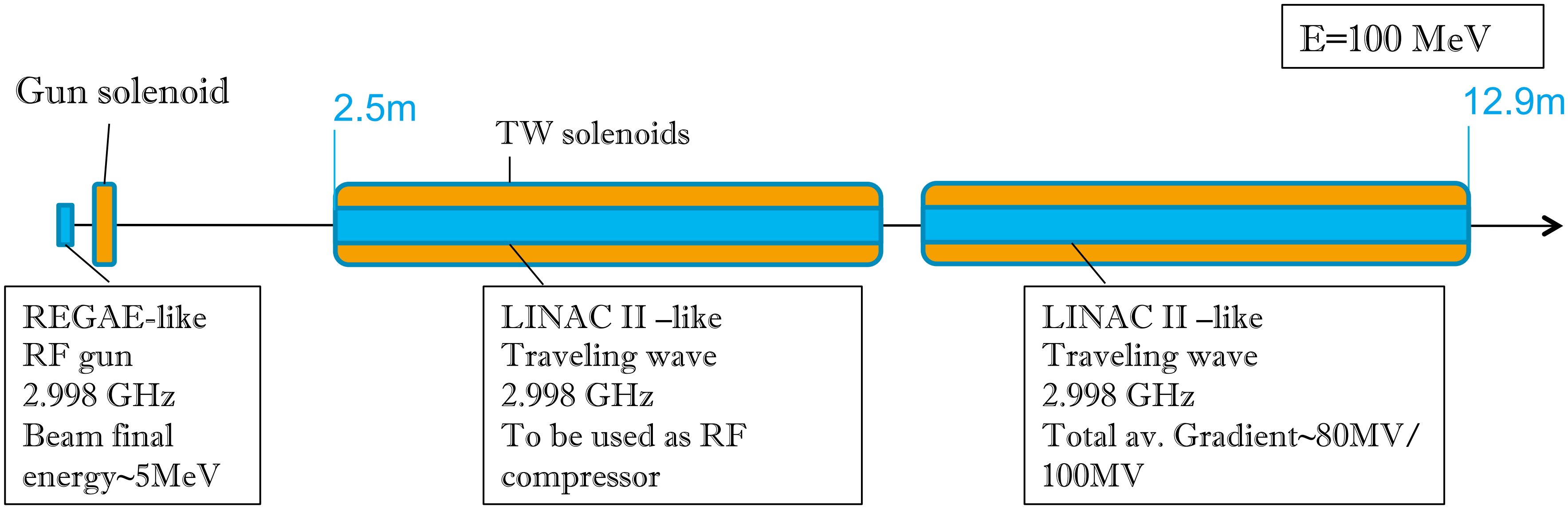




Simulations by J. Grebenyuk

- R. Assmann, J. Grebenyuk, TUOBB01, Proceed. IPAC 2014.
- J. Grebenyuk et al., TUPME064, Proceed. IPAC 2014

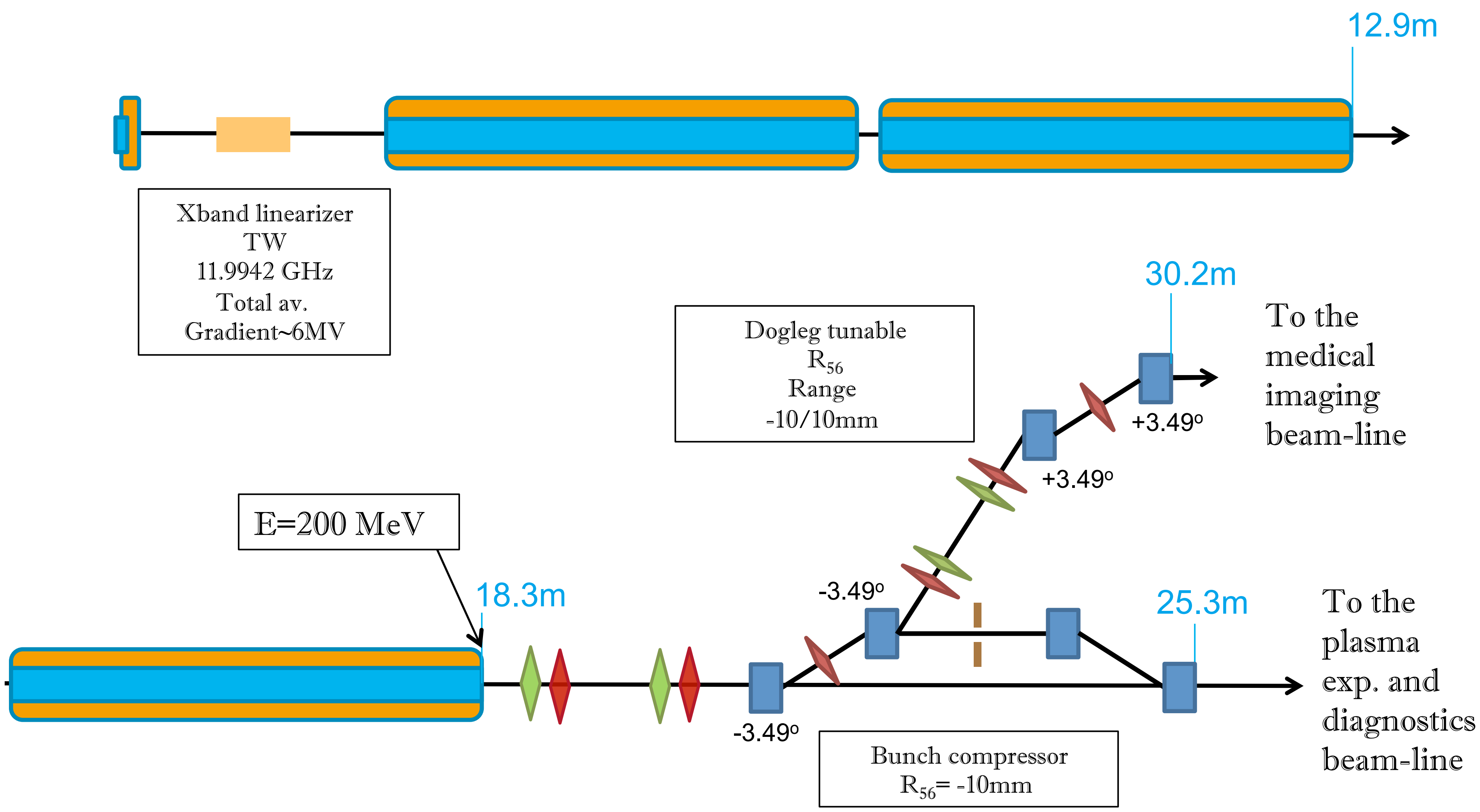
SINBAD LINAC layout – baseline



Special attention is being given to the **flexibility** and the **stability** of the elements:

- Load-lock system for cathode exchange (Cs_2Te for laser pulse length ≥1ps, metallic cathodes for shorter laser pulses)
- 2 gun solenoids respectively for low charge/high charge WPs (in the sketch above only the one for the low charge WP is shown)
- Flexible photo-cathode laser system: Yb doped mJ laser with tunable pulse duration 190fs-10ps.
- Each RF cavity fed by one klystron. No SLEDs.

SINBAD LINAC layout – upgrade

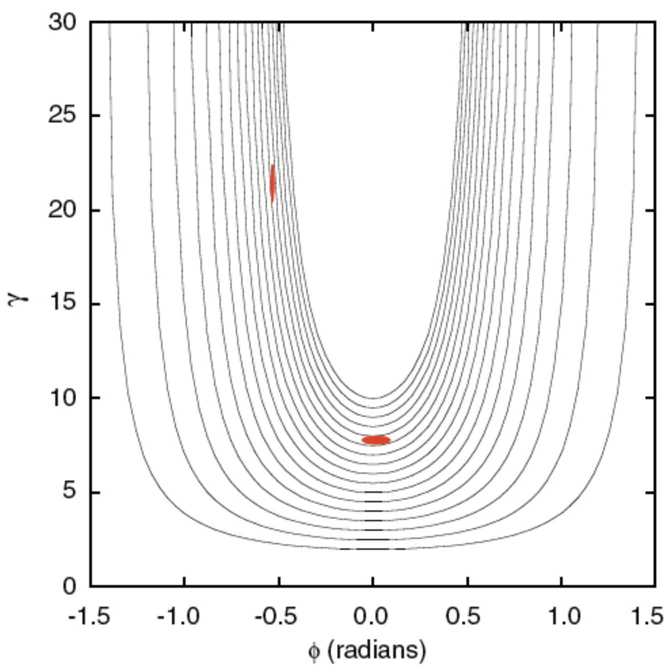


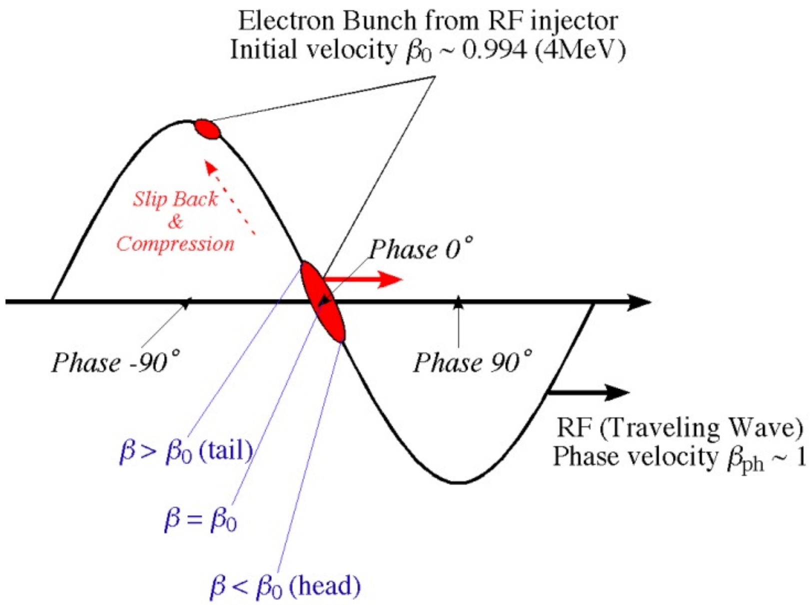
VELOCITY BUNCHING

- L. Serafini and M. Ferrario, AIP Conf. Proc. 581, 87-106 (2001).
- S.G. Anderson et al. PRSTAB 8 014401 (2005).
- M. Ferrario et al. PRL 104 054801 (2010).
- A. Bacci, A.R.Rossi NIM A 740 (2014) 42-47.

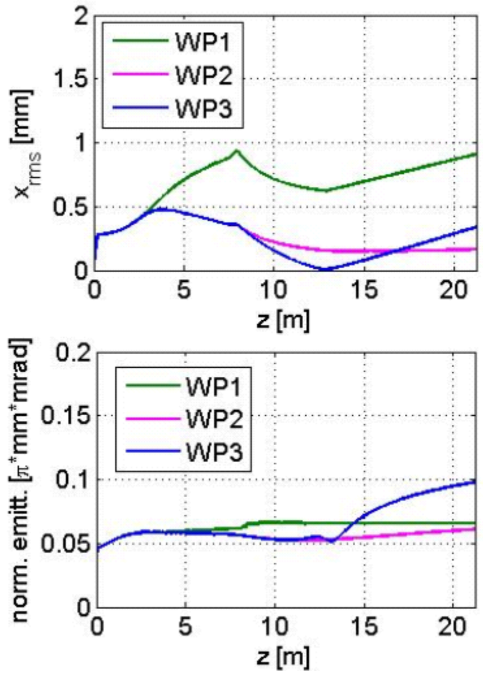
Pro: very good transverse emittance, no CSR, no charge loss, small spot size at the exit

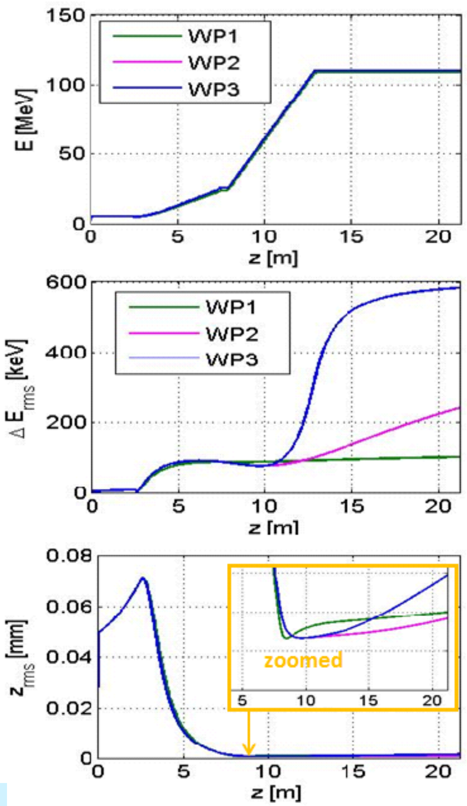
Contra: tight phase tolerances on the RF compressor, long. non-linearity





VELOCITY BUNCHING



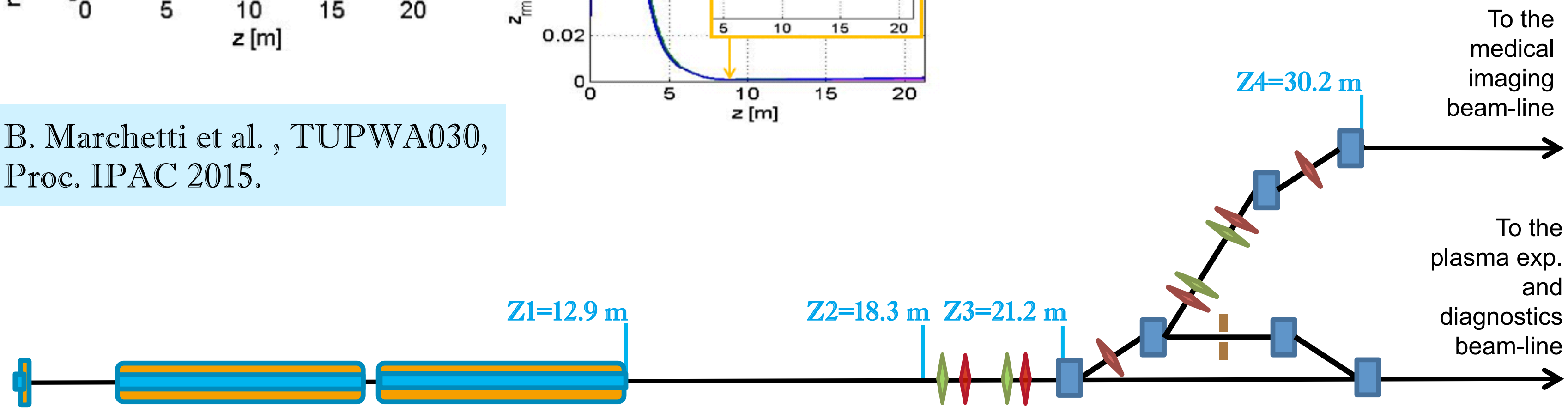


Examples of WPs providing different final spot-sizes.

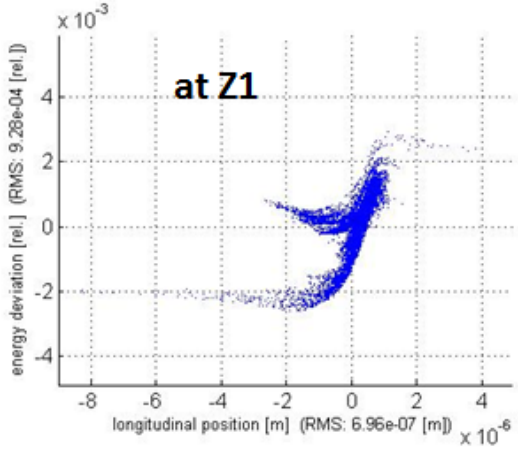
Table 1: Low Charge Working Points at Z1

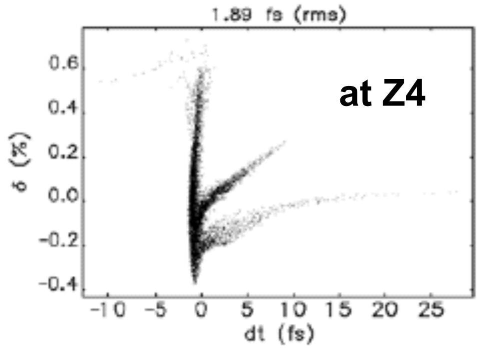
Parameter	WP1	WP2	WP3
Charge [pC]	0.5	0.5	0.5
FWHM [fs]	2.1	2.7	4
E [MeV]	109	111	111
$\Delta E/E[\%]$	0.1	0.1	0.3
$\sigma_{x,y}[mm]$	0.6	0.15	0.009
$n\epsilon_{x,y}[\mu m]$	0.07	0.05	0.05
I_p (in 1 FWHM) [A]	133	115	87

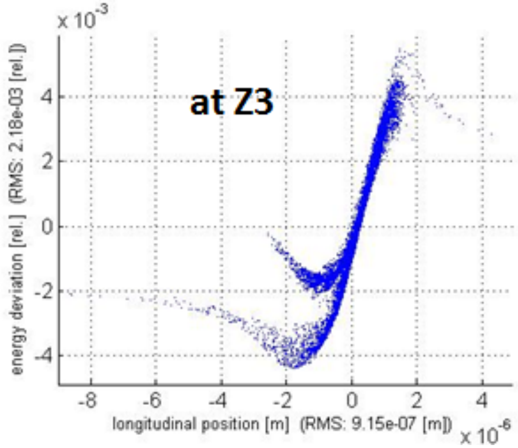
B. Marchetti et al. , TUPWA030, Proc. IPAC 2015.

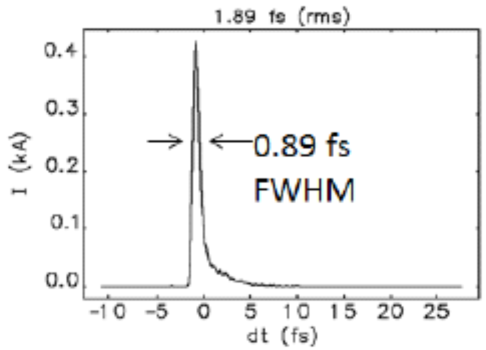


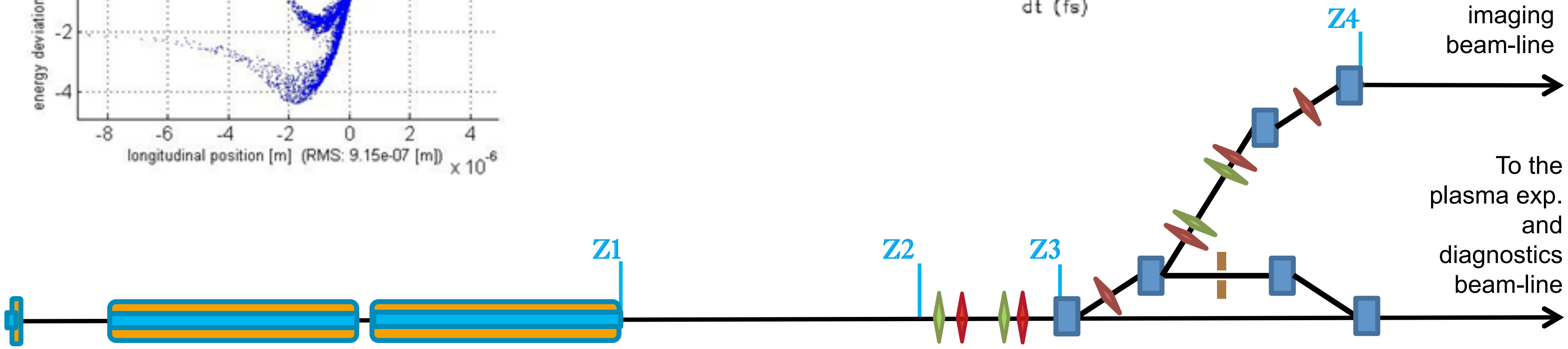
VELOCITY BUNCHING + POSITIVE R56









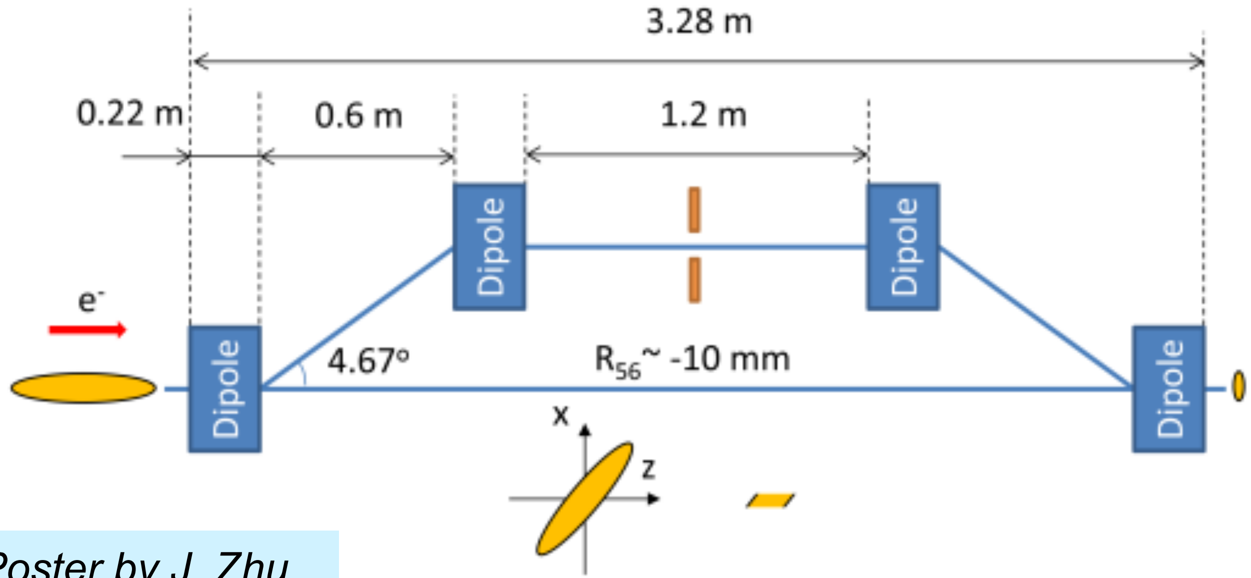


MAGNETIC COMPRESSION WITH THE SLIT CUT

- P. Emma et al., TUBIS01, Proc. FEL2004.
- P. Emma et al., PRL 92 7 (2004).
- S. Di Mitri et al., PRSTAB 16, 042801 (2013).

Pro: very high current+ short beam, non-linearity cut out, distributed RF phase tolerances

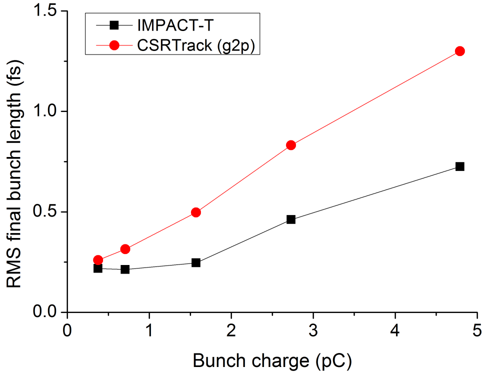
Contra: charge loss

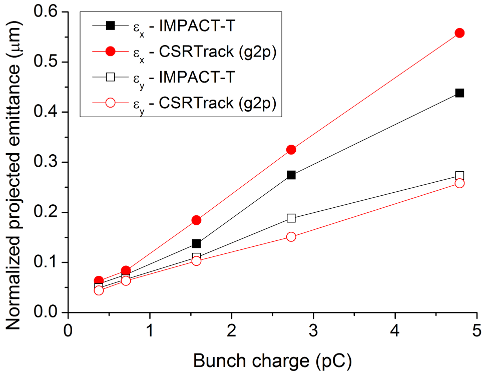


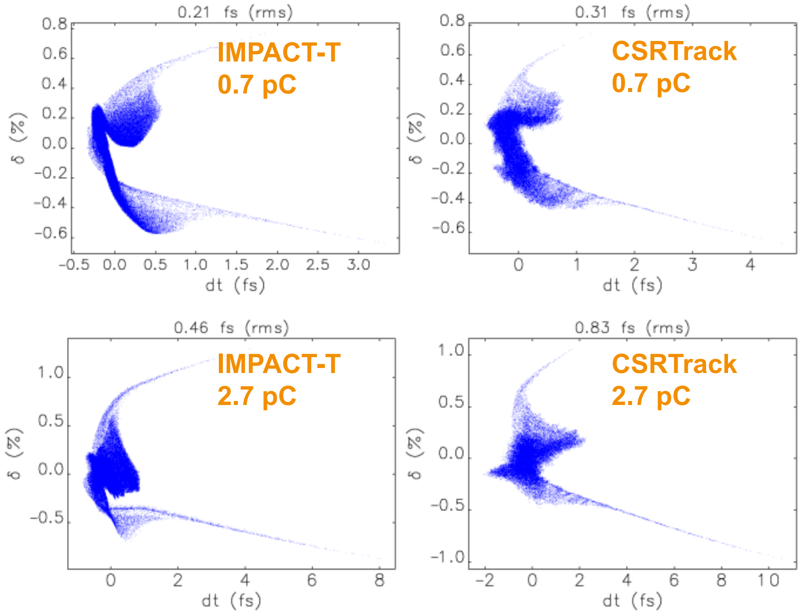
Poster by J. Zhu in WG4.

MAGNETIC COMPRESSION WITH THE SLIT

J. Zhu et al., MOPWA042, Proc. IPAC 2015.
J. Zhu et al., submitted paper







Bunch parameters before and after compression (slit width 0.4 mm)

Bunch charge (pC)	10	20	50	100	200
RMS bunch duration (ps)	2.0	2.1	2.2	2.5	2.8
Normalized slice emittance (μm)	0.04	0.06	0.10	0.15	0.26
Final bunch charge (pC)	0.4	0.7	1.6	2.7	4.8

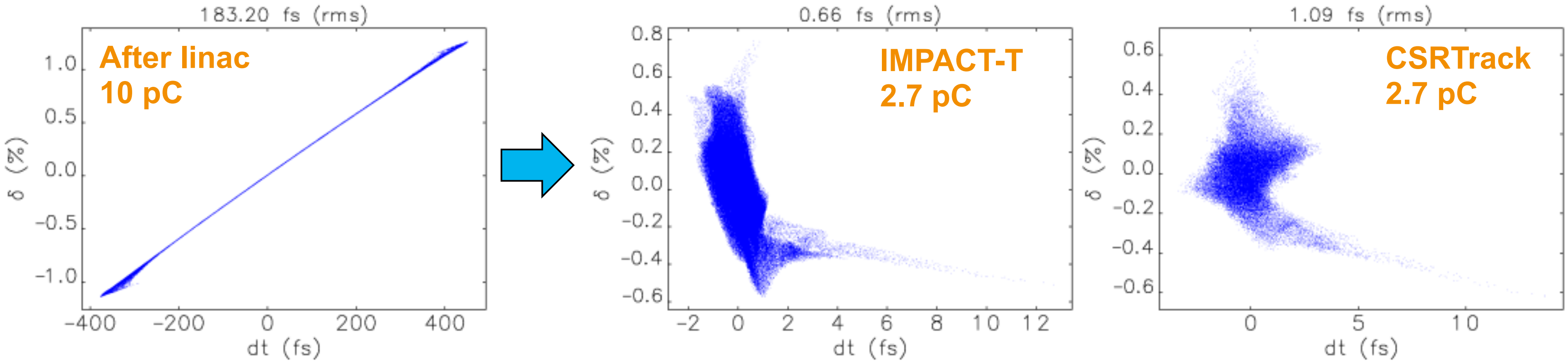
Poster by J. Zhu in WG4.

MAGNETIC COMPRESSION WITH THE SLIT (HYBRID)

Velocity bunching → Acceleration → Magnetic bunch compressor with slit cut

Cathode laser	200 fs Gaussian
Slit full-width	0.3 mm
ε_x	0.22 μm
ε_y	0.21 μm

- The charge loss is reduced
- Relaxed tolerances for the charge jitter
- RF stability of TWS more demanding



J. Zhu et al., MOPWA042, Proc. IPAC 2015.
J. Zhu et al., submitted paper

Poster by J. Zhu in WG4.

SUMMARY TABLE WORKING POINTS

	WP3 (vb)	WP2 (vb)	WP (BC)	WP (VB+BC)
Q final [pC]	0.5	0.5	0.7	**2.8**
Q initial [pC]	0.5	0.5	20	10
tRMS [fs]	2.486	2.321	**0.21**	0.66
tFWHM [fs]	4.1	2.777	**0.22**	1.54
E [MeV]	110.9	110.9	100.2	101.6
ΔE/E	0.3%	**0.1%**	0.2%	0.2%
xRMS [mm]	**0.009**	0.152	0.059	0.087
yRMS [mm]	**0.009**	0.152	0.057	0.090
nεx [μm]	**0.054**	0.072	0.076	0.22
nεy [μm]	**0.054**	0.073	0.066	0.21
Peak current [A]*	57	62	950	**1200**
Local peak current [A]**	85	111	**1730**	1490
B [A/m^2]***	$1.97 * 10^{16}$	$1.16 * 10^{16}$	**$1.89 * 10^{17}$**	$2.60 * 10^{16}$

*Peak current
$I=(Q_{TOT})/(3.5*t_{RMS})$

**Local peak current:
$I=(Q_{FWHM})/(t_{FWHM})$

*** Brightness
$B=I/(\gamma^2\varepsilon_x\varepsilon_y)$

TOLERANCES

Jitter source	Unit	Sensitivity for 10-fs BATJ				RMS Tolerance			
		0.7 pC *BC*	2.7 pC *BC*	2.7 pC *Hybrid*	0.5 pC *VB*	0.7 pC *BC*	2.7 pC *BC*	2.7 pC *Hybrid*	0.5 pC *VB*
Laser-to-RF	fs	42437.1	5949.7	159.8	125.0	200	200	50	50
Gun Charge	%	5.8	1.6	301.6	1010.1	1.0	0.3 (1.0)	4.0	4.0
Gun Phase	deg	1.75	0.78	0.61	0.49	0.06	0.06	0.06	0.06
Gun Voltage	%	0.61	1.14	0.72	0.40	0.06	0.06	0.06	0.06
TWS1 Phase	deg	0.021	0.021	0.011	0.0098	0.013	0.013 (0.010)	0.009	0.008
TWS1 Voltage	%	0.055	0.055	0.073	0.10	0.013	0.013 (0.010)	0.009	0.008
TWS2 Phase	deg	0.022	0.022	0.13	42.1	0.013	0.013 (0.010)	0.011	0.060
TWS2 Voltage	%	0.064	0.064	0.040	1.2	0.013	0.013 (0.010)	0.011	0.060
Magnetic field	%	0.030	0.030	0.030	\	0.01	0.01	0.01	\
Total BATJ	fs	\	\	\	\	9.91	9.93 (10.01)	9.94	9.34

J. Zhu et al., WEPMA031, Proc. of IPAC 2015.

Summary and conclusions

- The layout and the goals of the SINBAD linac have been illustrated.
- The procurement of the baseline layout is ongoing.
- We have reviewed the bunch compression techniques that will be feasible.
- Simulations confirmed us that the goal parameters concerning the beam quality are achievable.
- The fulfillment of the tolerances for the arrival time jitter is challenging but reasonable.


Thank you for the attention!

Backup