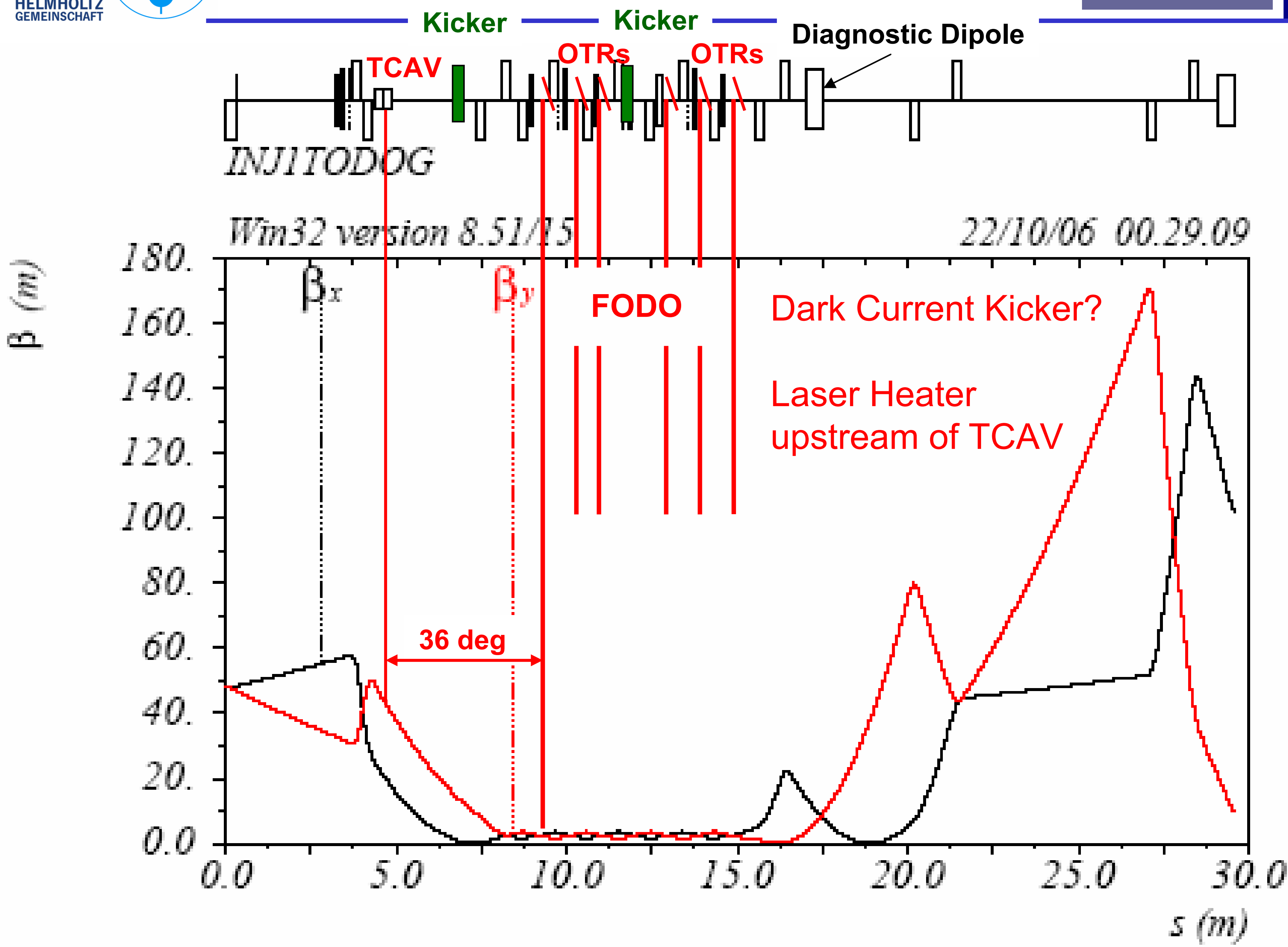
Special diagnostics for the XFEL injector

Holger Schlarb, Christopher Gerth, Michael Röhrs
DESY
22607 Hamburg

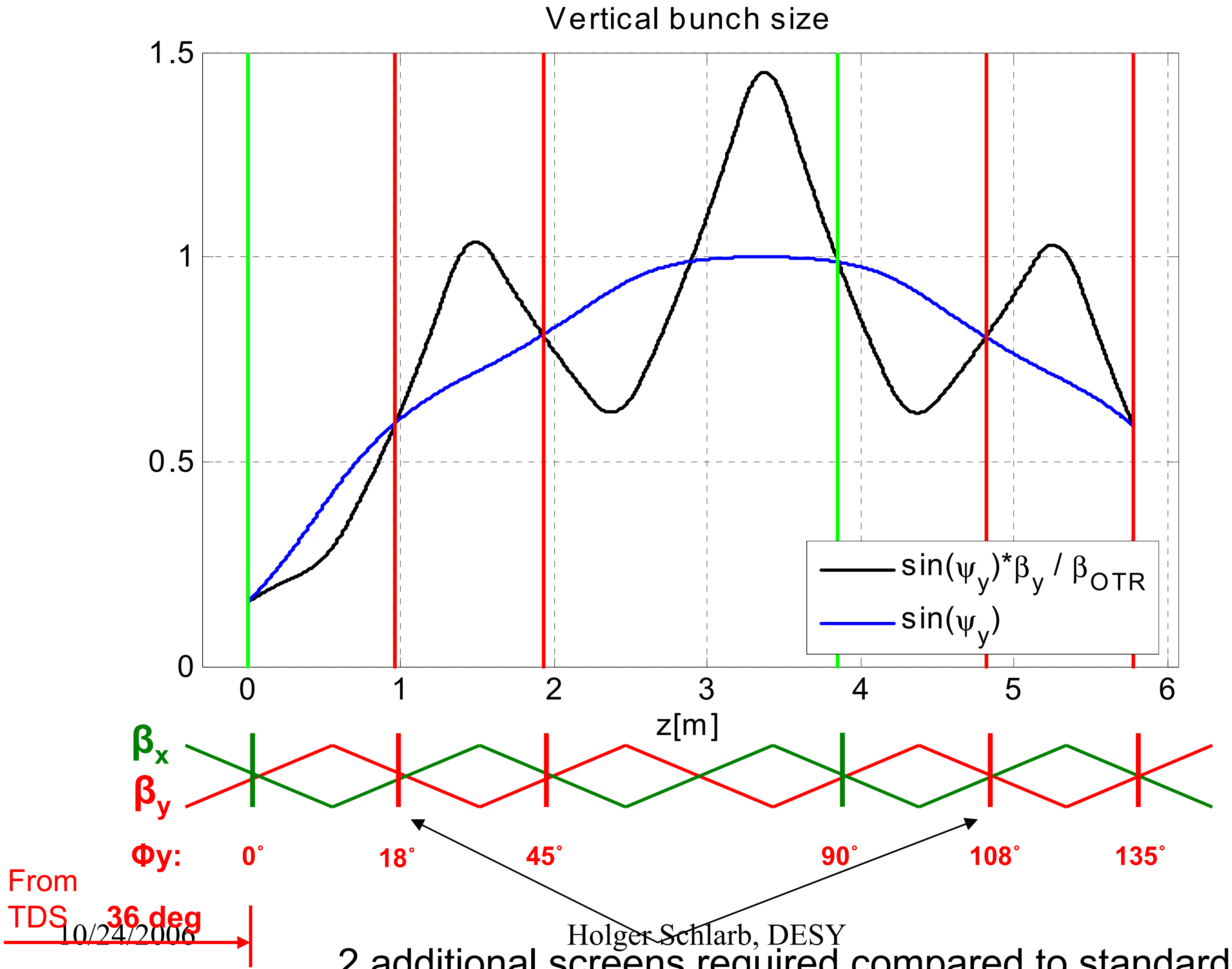
Special diagnostics

- **laser arrival time monitor (< 50 fs)** **(must)**
  - EOM technique
  - balanced DFG generation (LbSyn versus UV)
- **relative gun phase to laser phase monitor** **(can)**
  - launch of parasitic laser pulses (<50fs)
- **high precision e-beam arrival time monitor** **(must)**
  - specs: < 30fs arrival time precision w.r.t *LbSyn* @ 5MHz readout
- **transverse deflection structure for** **(recommended)**
  - longitudinal profile measurements: $\sigma_{res} < \sigma_t/20 = 300fs$
  - slice emittance measurements: $\sigma_{res} < \sigma_t/10$, $d\varepsilon_{res}/\varepsilon < 10\%$
  - slice energy spread: $\sigma_E < 1.3$ keV
- **online transverse profile control within macro-pulse (recommended)**
  - kicker and off-axis screens
- **online longitudinal profile control** **(recommended)**
  - low frequency detector (50-400GHz), [fast, no bunch info]
  - steak camera [only single shot, pure dynamic range]
  - EO [multi-bunch possible, medium dynamic range]

Injector section up to Dogleg

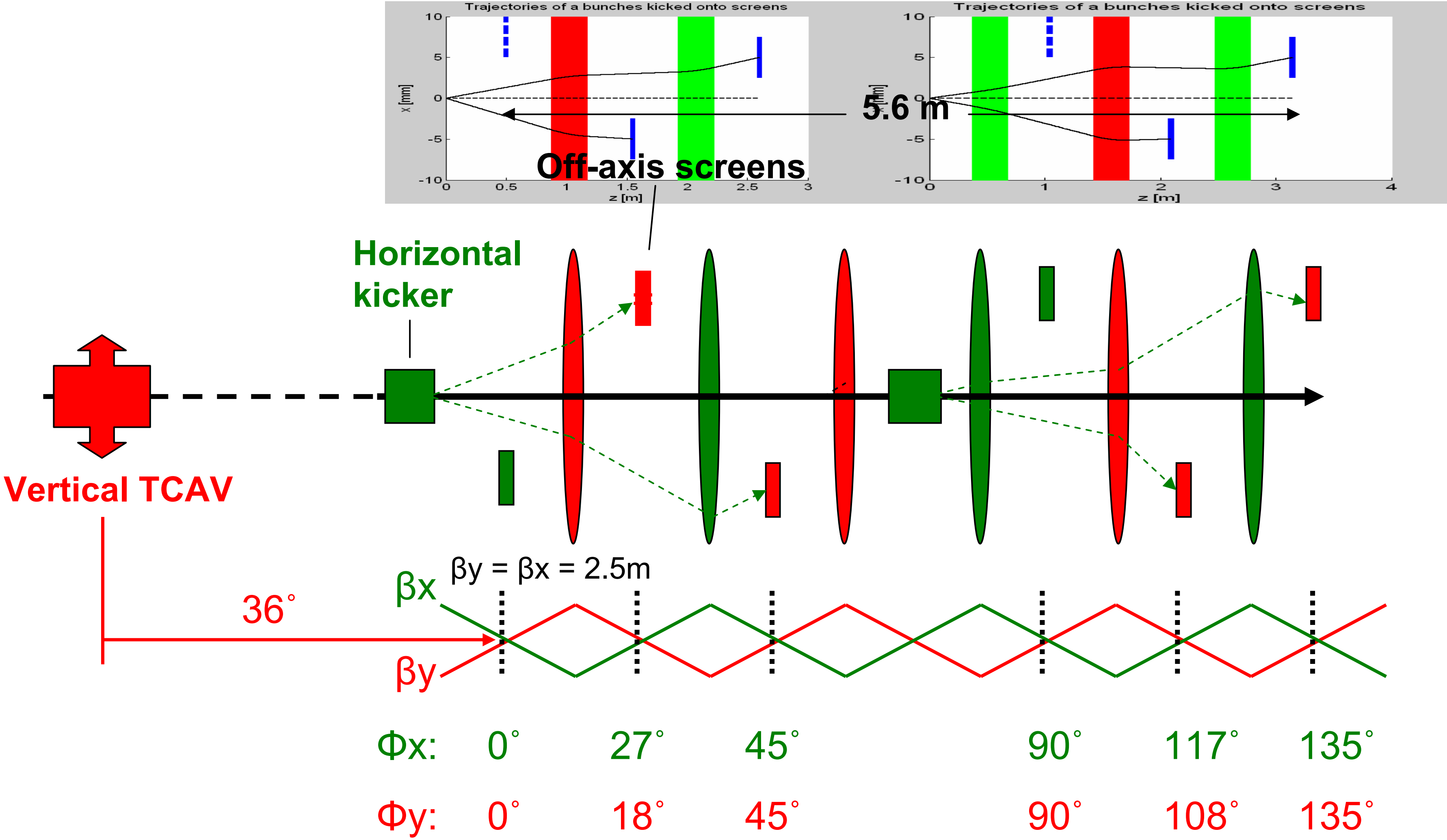


45°- FODO section (2 additional screens)

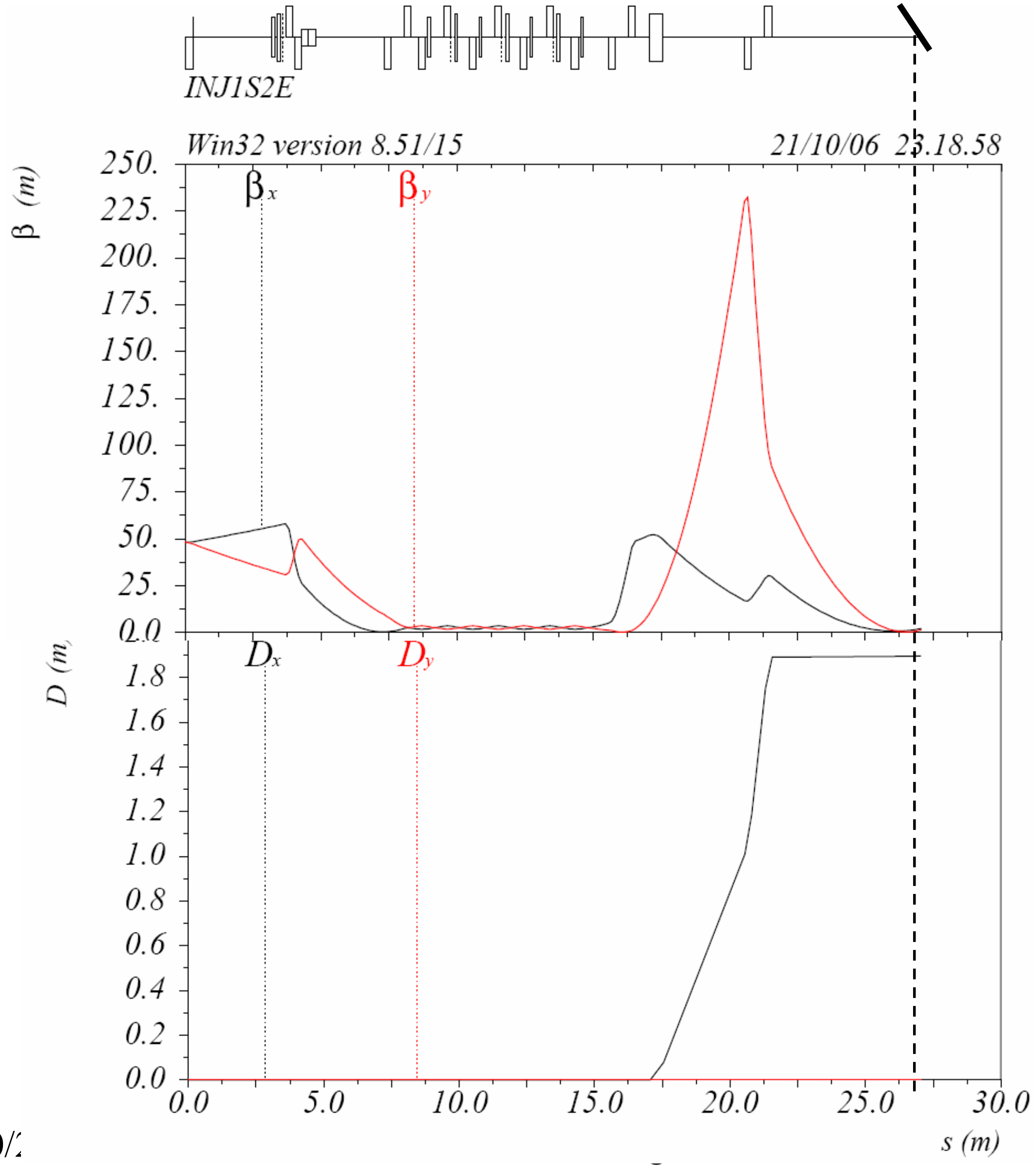


2 additional screens required compared to standard lattice

FODO section: kicker arrangement



Energy Spread Measurements (Injector Dump)



<u>Goal:</u> resolve uncorrelated energy spread ΔE ~ 5keV
→ $\Delta E/E \sim 3.8 \cdot 10^{-5}$
(from meas. at FLASH)

monitor Laser Heater
5 - 30 keV

Values at screen:
ßx = 0.7 m
ßy = 1.0 m
Dx = 1.9 m

→ $\Delta E/E \sim 2.8 \cdot 10^{-5}$
Slice $\varepsilon_N = 1 \cdot 10^{-6}$ µm

- Phase advance from TCAV: → 382° for current layout
- Higher order effects?
- Chromaticity?
- CSR effects

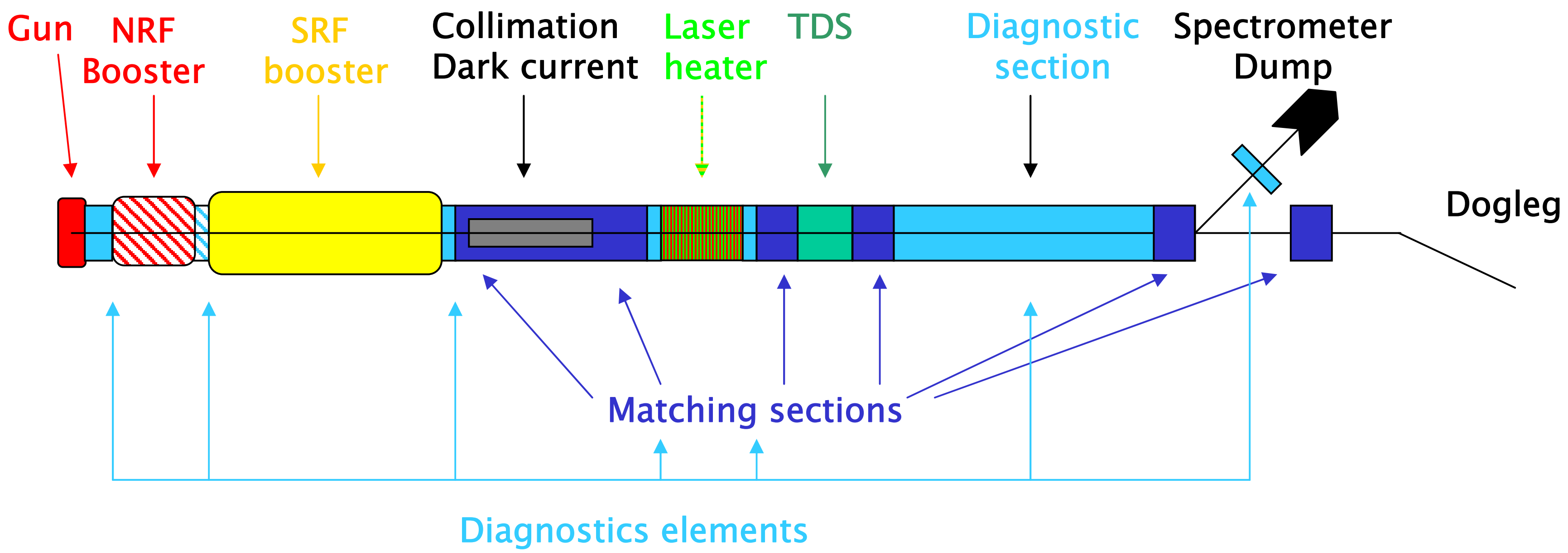
TDS parameters

Table 1.5: Parameter list for diagnostics section injector

Beam energy	E_0	130 MeV
Projected emittance	ϵ	1.4 μm
Slice emittance	ϵ_{slice}	1 μm
Bunch duration	σ_t	6 ps
Bunch repetition frequency	f_b	5.000 MHz
Beta function at TDS	$\beta_{x,y}$	5 m
Beta function at OTR	$\beta_{x,y}$	2.544 m
Phase advance FODO-cell	Ψ_{FODO}	45.0°
Length FODO-cell	L_{FODO}	1.927 m
Beam size at OTR	$\sigma_\perp$	141 μm
Beam slice size at OTR	$\sigma_{\perp,slice}$	100 μm
Acceleration RF frequency	f_0	1300.000 MHz
Frequency	f_{tds}	3000.000 MHz
Effective length	$L_{tds,eff}$	0.333 m
Cell length	L_{cell}	33.32 mm
Number of cells	N_{cell}	10
Physical length	L_{tds}	≈0.55 m
Deflecting voltage	Φ_{tds}	0.645 MV
Gradient	G_{tcav}	1.94 MV/m
Group velocity	v_{gr}	-1.89 %
Filling time	$t_{fill} = v_{gr} \cdot L_{cell}$	59 ns
Input power at cavity	P_{tds}	0.896 MW
Gradient(P)	$G_{tds}/\sqrt{(P_{tds})}$	2.05 MV/m/$\sqrt{(MW)}$
Attenuation waveguide	α_c	0.018 dB/m
Total waveguide losses	$L = 50m?!?$	-0.9 dB
Power klystron	P_{kly}	1.1 MW
Nominal streak at OTR	$dy_{OTR}/dt(90°)$	0.333 mm/ps
Nominal resolution	$\sigma_{\perp,slice}/(dy_{OTR}/dt)$	300.0 fs
Nominal streak beam size	σ_{streak}	2.2 mm
Maximum resolution (P_{kly} =27.5MW)	$\sigma_{\perp,slice}/(dy_{OTR}/dt)$	$<$ 60 fs

Beam line overview

• proposed beam line design:



Summary

- space insufficient to include dark current removal and laser heater

- to commission laser heater, installation upstream of TDS!!!!

- optics has to be redesign to optimize beam size at dark current sweeper and laser heater!!!

- in case of space constrains: ACC1 equipped with doublet

- ….

NRF booster

Advantages:

- space and simpler access for diagnostics after gun and behind NRF booster
- reduced gradient unbalancing in SRF (4*12.5+4*20 MV/m)
- gradients NRF and SRF can be balanced in certain range
- no addition space required if ACC1 is fixed in position
- fine tuning with another solenoid possible
- better condition for velocity bunching ?

Disadvantage:

- costs of one more RF station
- one more RF station as single point of failure

Gun-dark current removal

FLASH: largest part of dark current lost in BC2 (relaxes)
dark current kicker at 1 MHz (partially worked)

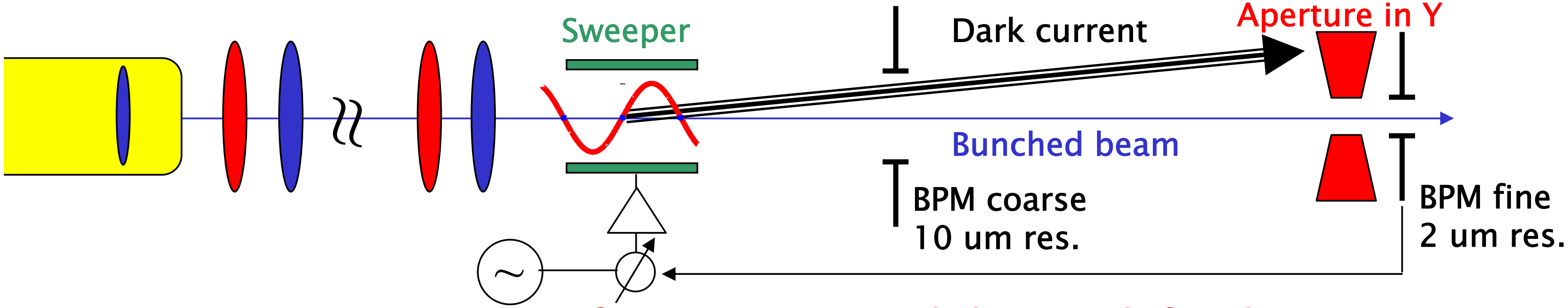
XFEL: larger dark current expected due to gun gradient!
Better cleaning & cathode preparation?
- Speculative if this compensates for gradient induced dark current increase!

significant fraction transported up to 500MeV point

Problem with energy collimation:
10-30% of dark current has same energy!

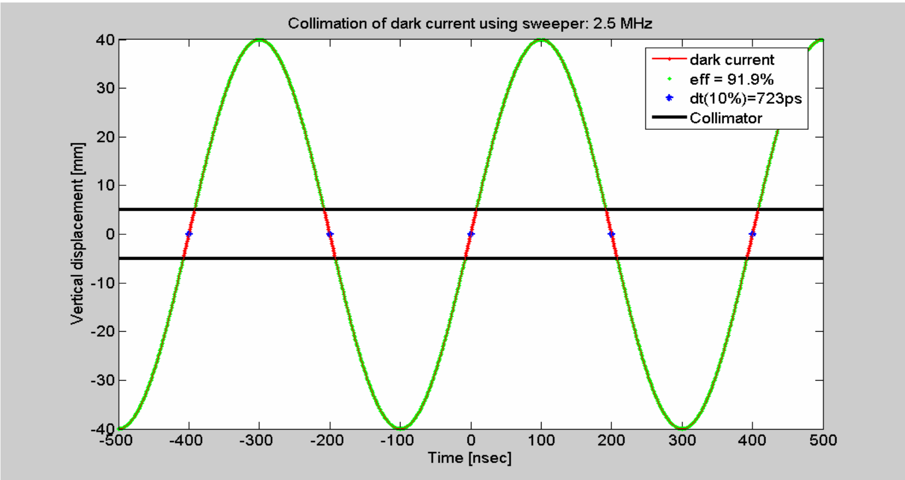
Recommended: Collimation also in time
- Specially easy because of 1.3GHz time structure

Dark current sweeper

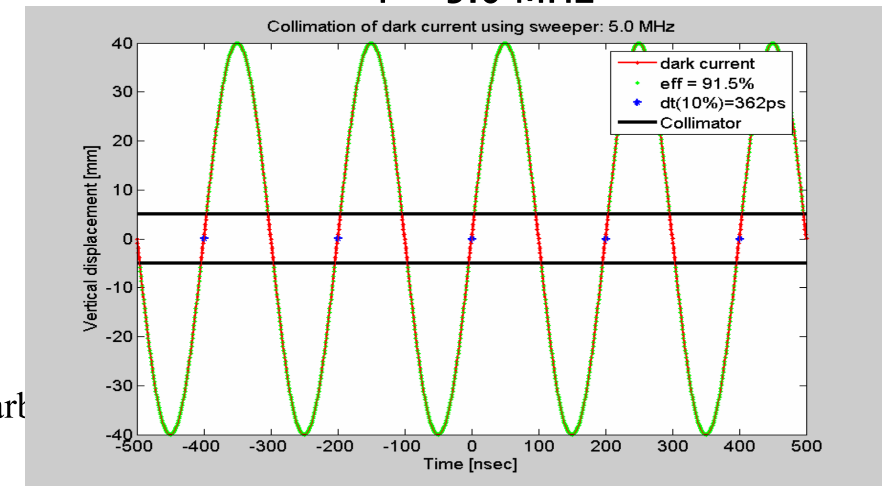


Location:	after ACC1 to remove dark current before diagnostic sections!!!!!
Sweep direction:	vertical since downstream laser heater in horizontal plan
Moderate beta function in y:	$\beta_y <= 10$ m because of phase tolerance
Optics:	best simple drift $R_{34} \sim 4$ m (to first order independent on optics)
Tolerance on phase	$< f * \sigma_{xp} / \alpha_{y,max}(eff, R_{34}, d_{aper}) \sim 0.01$deg (10%)
Beam based feedback	on sweeper phase required
Orbit stability	$f * \sigma_{xp}$ minimum f=10%, nominal f=5%, desired f=2%

f = 2.5MHz



f = 5.0 MHz

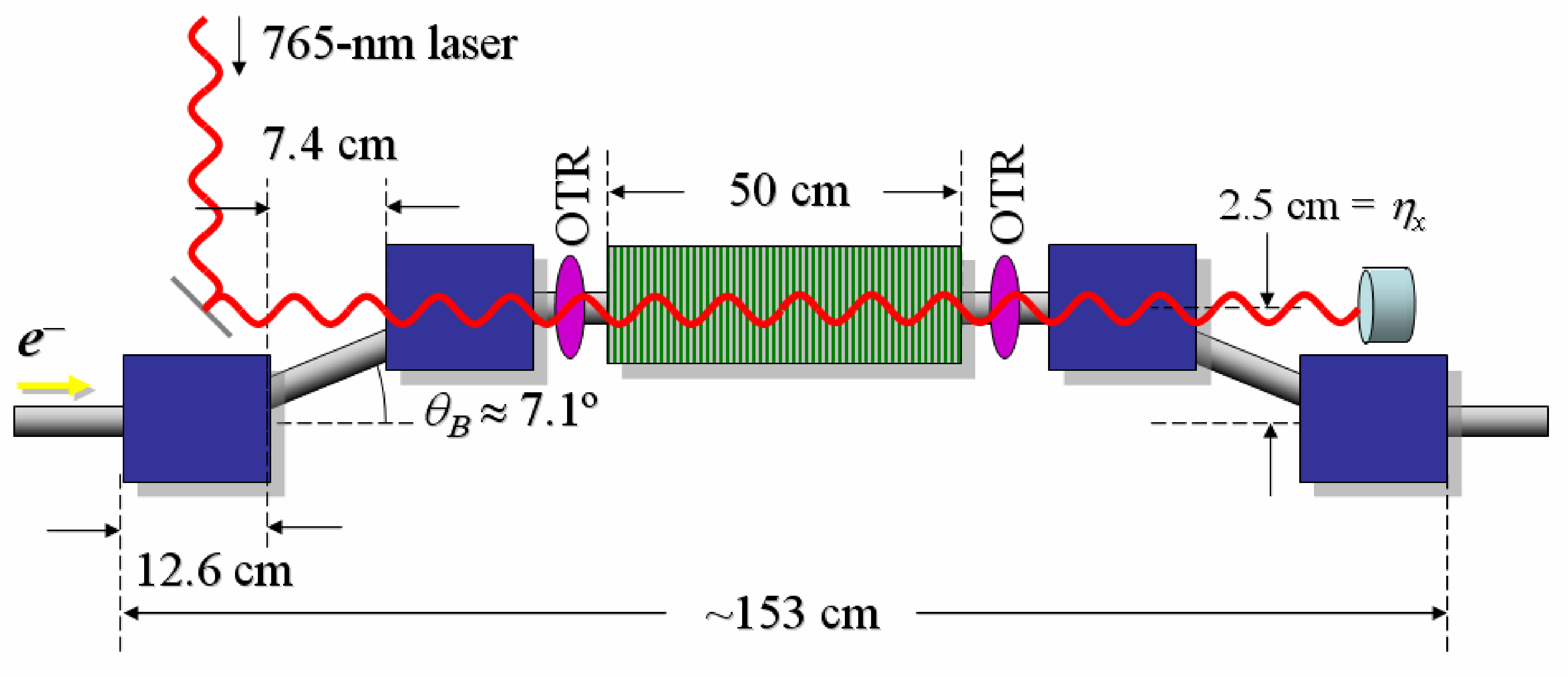


Laser heater

Motivation:

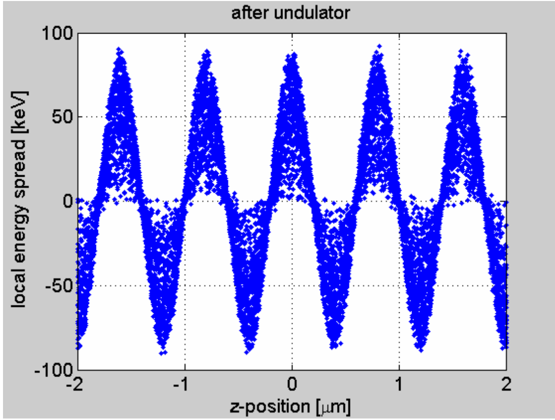
- Collective effect: SP/CSR drive micro-bunch instabilities
- Residual energy-spread ~ 1-3keV ⇒ No Landau damping
- Energy-spread can be larger for FELs ($\sigma_E/E < \rho \sim 5e-4$)

⇒ increase $\varepsilon_E \rightarrow$ 10-50 keV (compression factor C!)

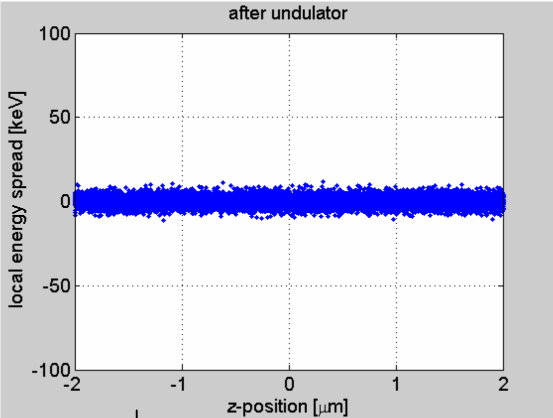


Laser heater

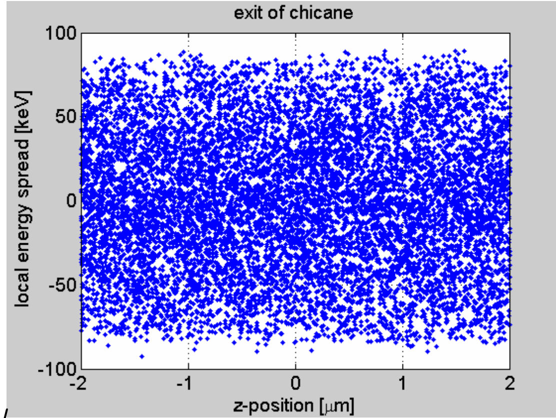
heating $\sigma_L \sim 40\text{keV}$

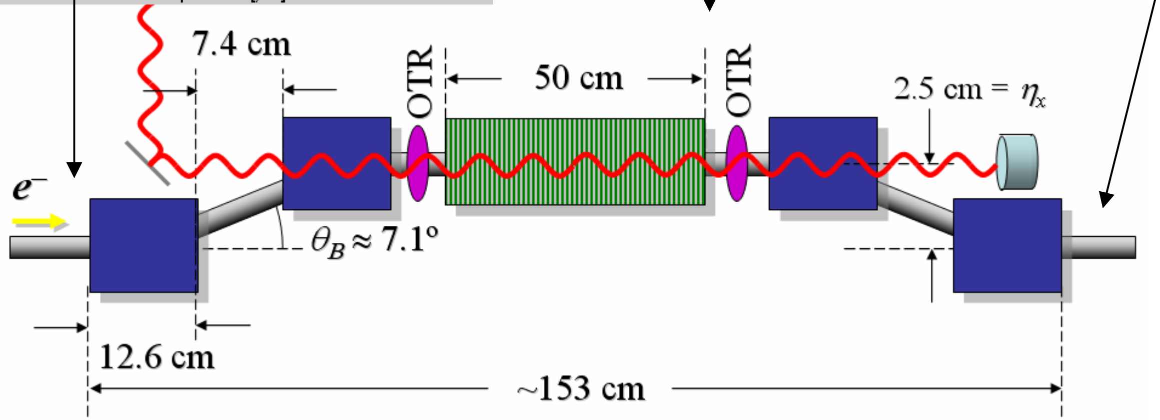


Residual $\sigma_E \sim 1\text{-}3\text{keV}$

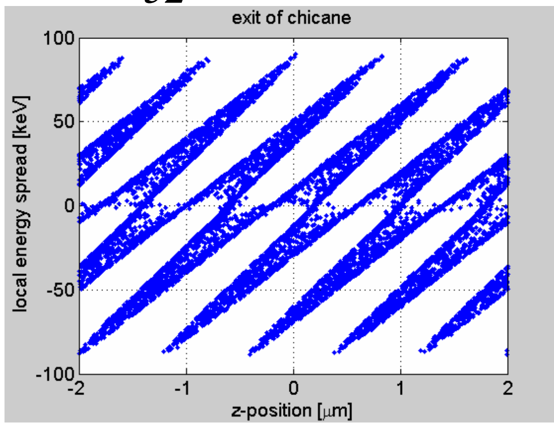


$R_{52} = -0.024$





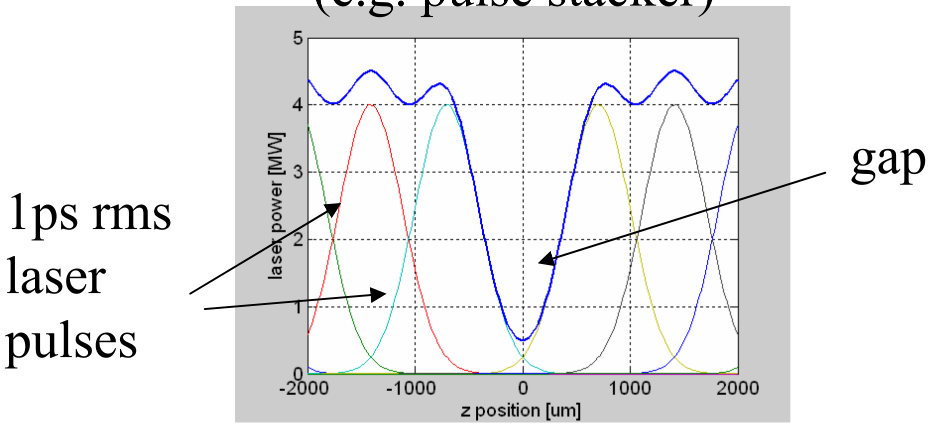
$R_{52}=0$



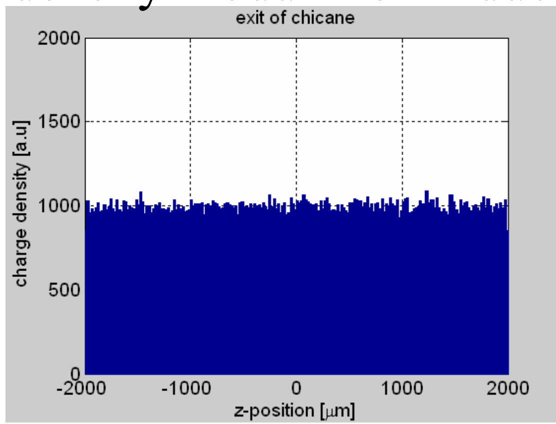
Laser heater

Laser heater to tune lasing duration

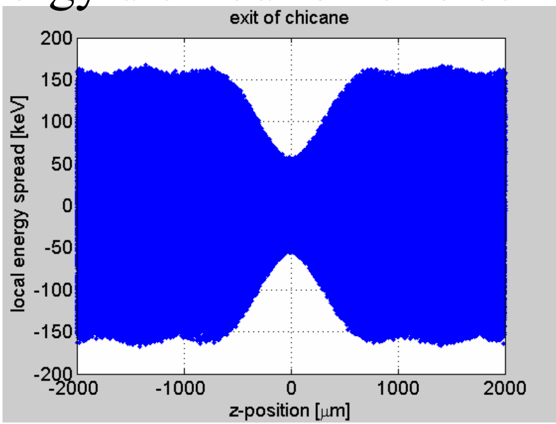
Laser profile
(e.g. pulse stacker)



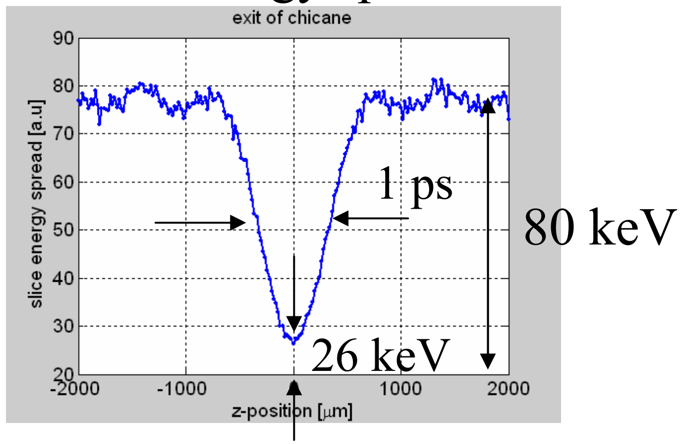
Longitudinal charge density
No density modulation induced!



Energy distribution of electrons



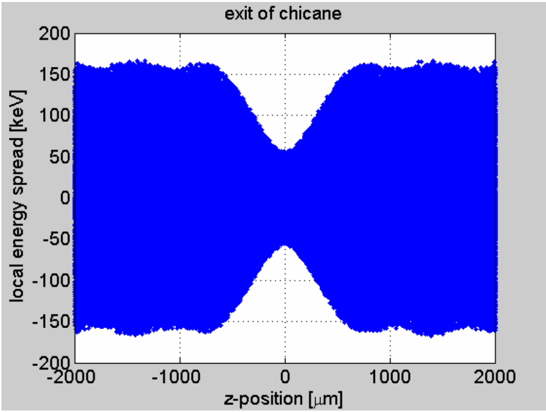
rms energy spread

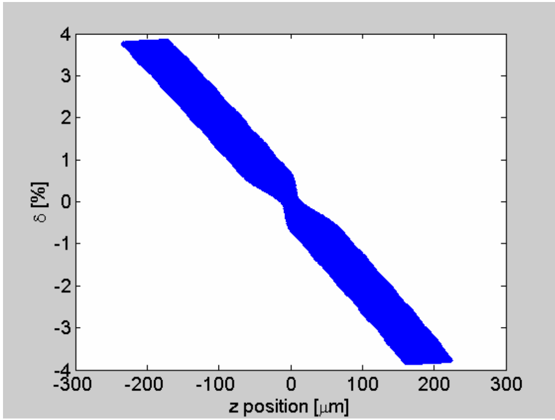


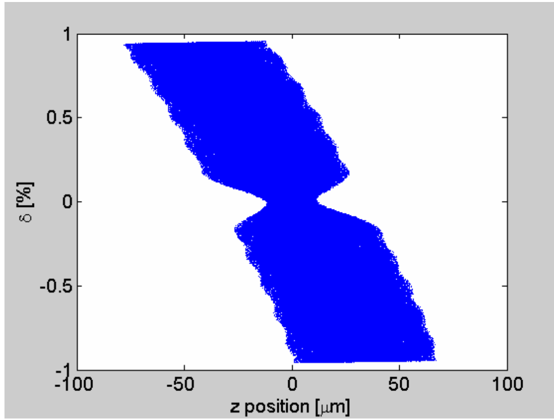
Laser heater to tune lasing duration

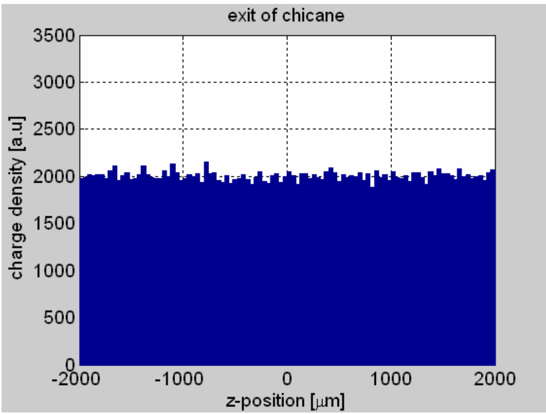
- bit more difficult -

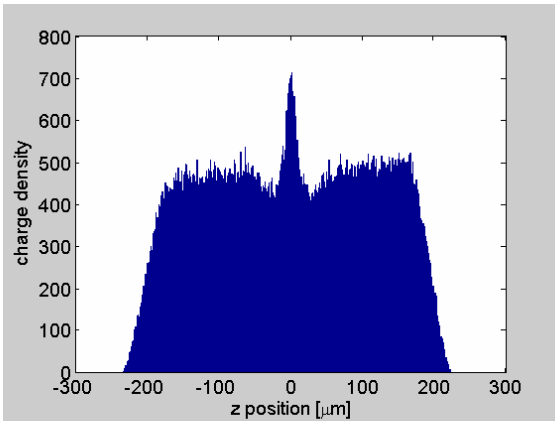
After heater	After BC1	After BC2

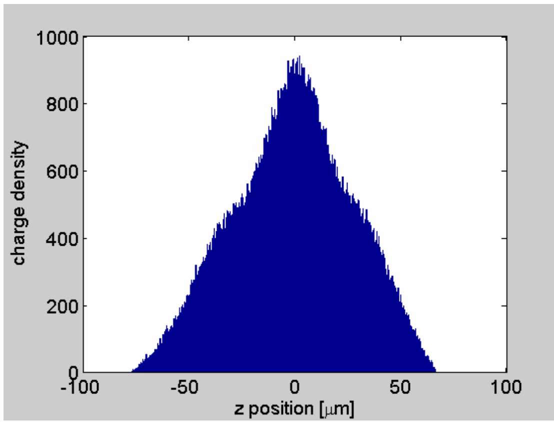








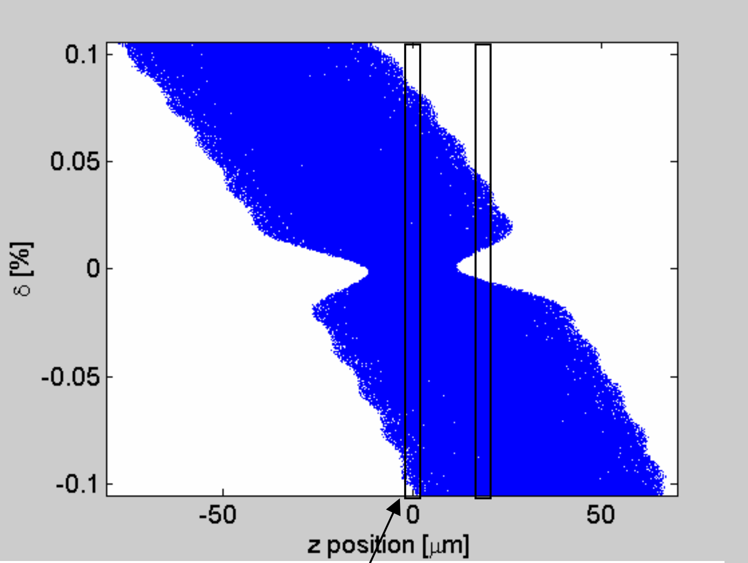




135 MeV	500 MeV	2.0 GeV

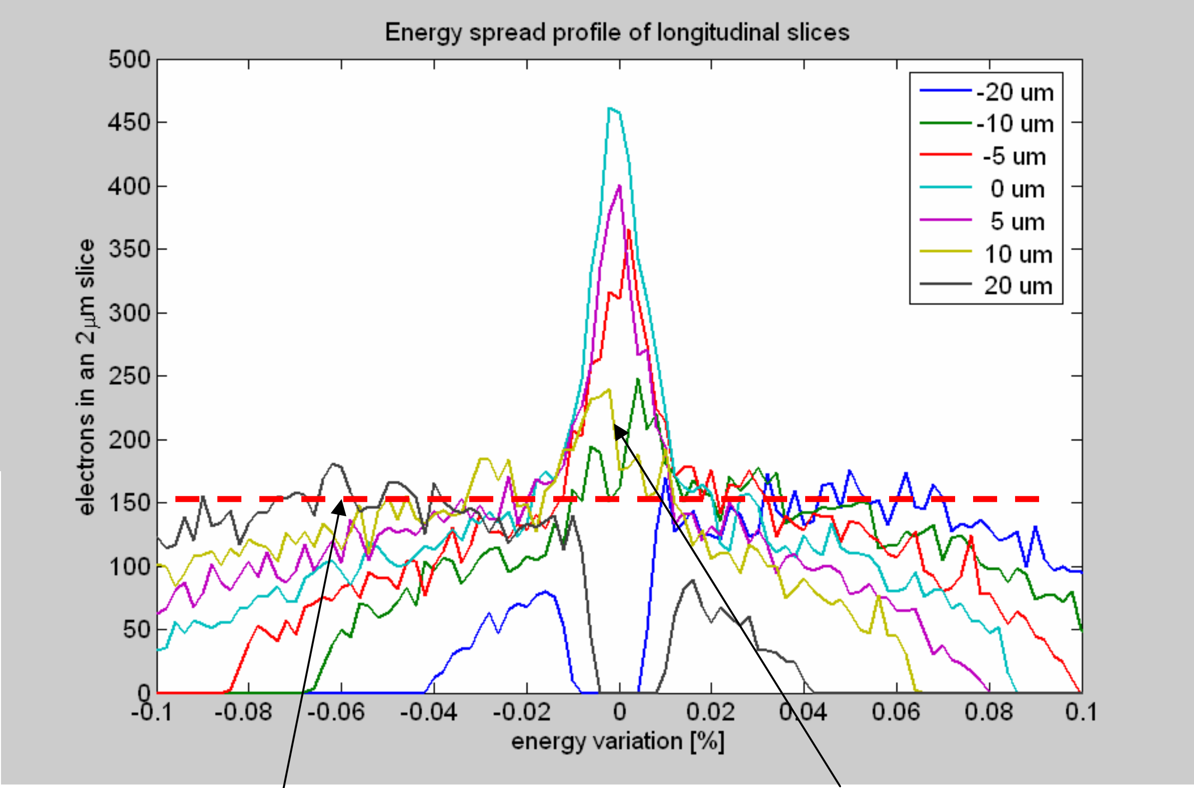
Laser heater to tune lasing duration
- bit more difficult -

Longitudinal phase space (UND)



Short slices (+-2um)

Energy profile for different slices



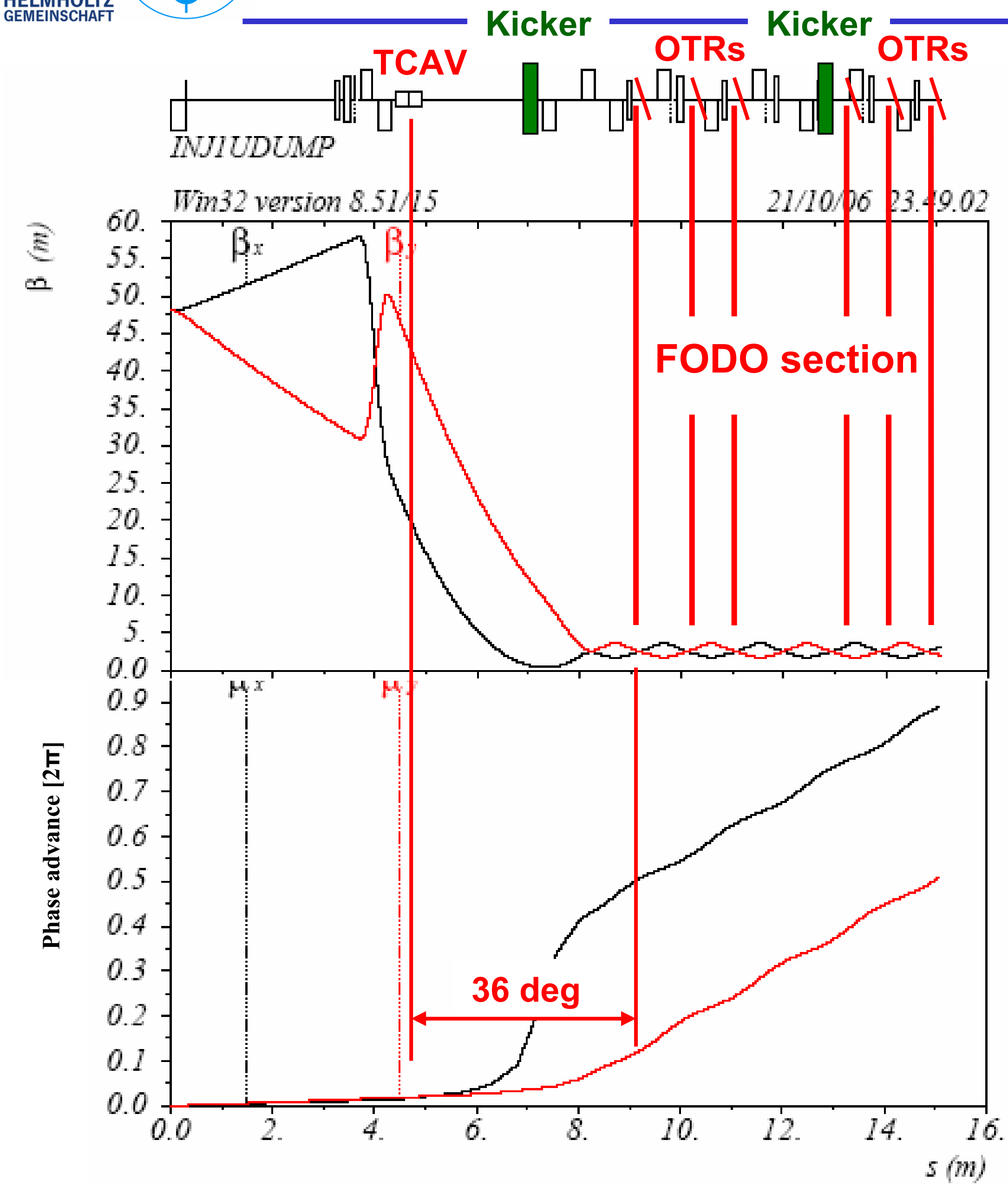
Back ground

unperturbed

Operation modes for the Diagnostic Section

FEL mode - parasitic	**- Commissioning of long pulse trains** **- On-line beam characterisation** **- Correction of drifts** Medium beta function at TDS (~15-25 m) Low space charge & chromatic effects Time resolution of TDSs ~ 30 fs Slice emittance measurement using kickers (optic 1) Projected emittance measurement using kickers (optic 2) Kicked bunches dumped in collimator Dipole to dump is switched off
Diagnostic mode 1 **Long. Profile** - not parasitic	**- High resolution longitudinal profiling with TCAVS** High beta function at one TCAV (>50m) / special optic (optic 3) Small beta function at screen with 90 deg phase adv. Resolution better 10fs Dipole to dump is switched off
Diagnostic mode 2 **Energy spread** - not parasitic	**- Precise determination of RF phases & amplitudes** **- Studies of collective effects on longitudinal phase space** Dipole to dump is switched on Small horizontal and vertical beta at OTR and large dispersion (optic 4) Relative energy resolution at screen $\Delta E/E \sim 10^{-5}$ Single or few bunch mode
Diagnostic mode 3 **Long pulses** - not parasitic	**- Commissioning of LLRF upstream BC1** **- Studies of orbit stability and emittance variation across macro-pulse** Dipole to dump is switched on Off-axis screen in dispersive section Large beta function at dump screen (optic 5) Low loss operation in dump line Up to 800us? operation (1Hz) High resolution BPM based energy measurement across macro-pulse

Matching into FODO Section



Dark Current Kicker?

Laser Heater upstream of TCAV?
βx and βy ~ 2m

New lattice design and more space required

Current beam line design

Hallo Holger,
hier die orbit-plots mit OTR-schirmen und quadrupolen. kicked_orbit_1 bezieht sich auf den ersten Kicker, den ich 0.5 m vor den ersten OTR-Schirm gesetzt habe. Die noetigen Kicks sind 2.6 mrad bzw. -4.4 mrad. Driftlaenge ist 0.75 m, horizontal fok. quadrupole sind rot.

Beim zweiten Kicker sind Kicks von -2.6 mrad bzw. 1.9 mrad noetig.
Wenn irgendwas geaendert werden sollte, sag bescheid.
Gruss
Michael

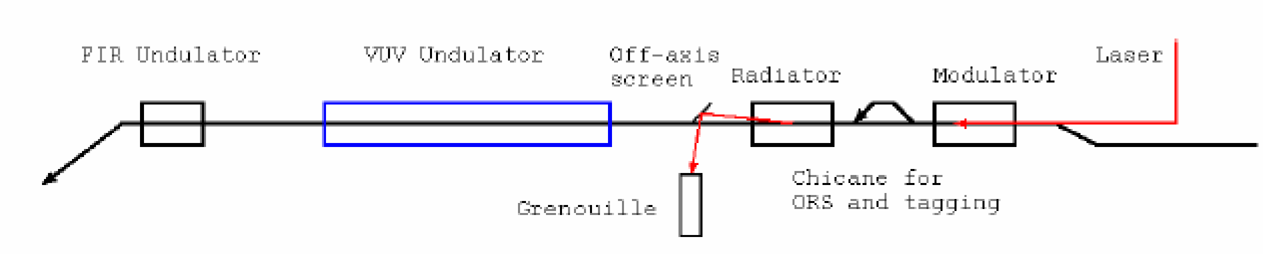
Hallo Holger,
hier der Plot zur 'condition number'; habe das gewaehlte Lattice mit den Standard 45 und 60 Grad Optionen verglichen. Der Mismatch parameter ist B=0.5*(beta1*gamma2 - 2*alpha1*alpha2 + beta2*gamma1); die vertikale Linie gibt den maximalen slice mismatch an, den wir in unseren Messungen gesehen haben. Bis zu diesem Wert ist die Schirmanordnung vergleichbar mit dem standard 60 Grad lattice und nicht dramatisch schlechter als die standard 45 Grad Option, darueber muesste man fuer das grobe matching dann wohl die projizierte emittanz mit den standard schirmen messen.

Anmerkung: die (180-Grad-periodische) Abhaengigkeit von der Mismatch-Phase Theta habe ich herausgenommen, indem ich fuer jeden Mismatch Parameter B den maximalen Fehler im 180 Grad Intervall von Theta genommen habe.

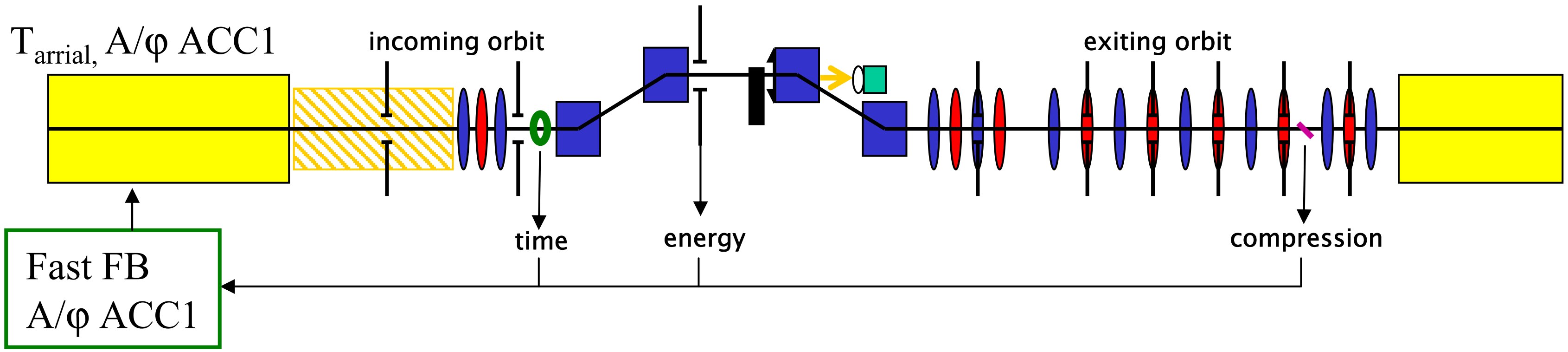
Minimale Strahlgroesse dividiert durch maximale Strahlgroesse, die man auf den Schirmen erhaelt: 0.73 fuer die gewaehlte Option, 0.4 fuer 45 Grad standard, 0.5 fuer 60 Grad standard. Bei einer nominellen AUfloesung von 300fs bedeutet das 411 fs, 750 fs bzw. 600 fs effektive Aufloesung bei den drei Anordnungen.
Gruss
Michael

Outlook and future developments

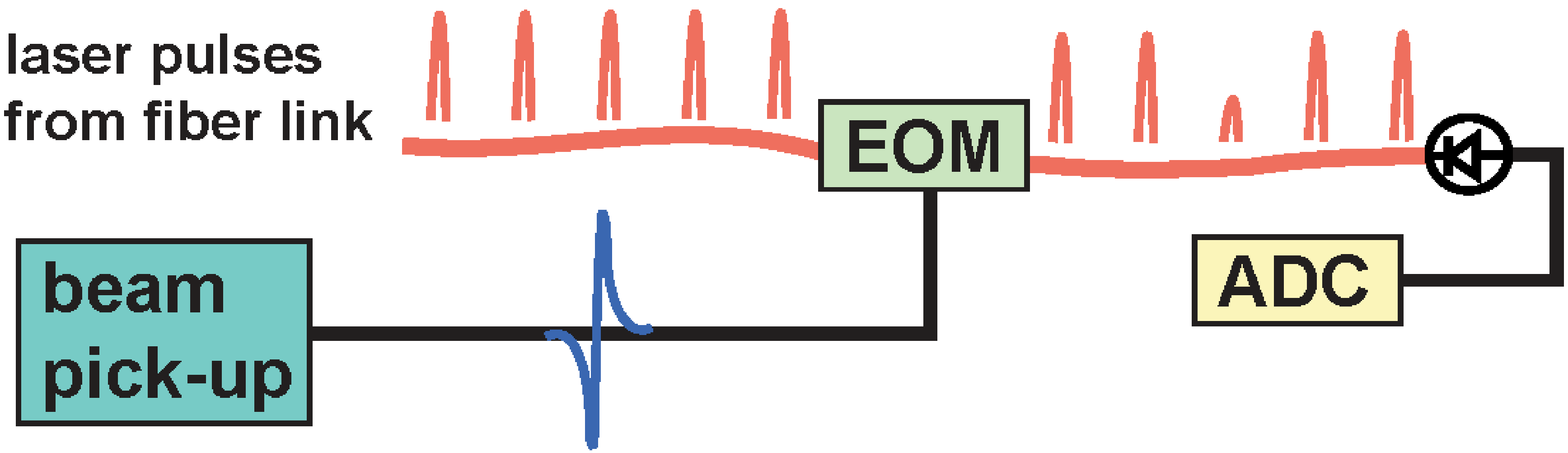
• 2007 installation of optical replica synthesizer (< 5fs resolution) in cooperation with Uppsala & Uni. Stockholm



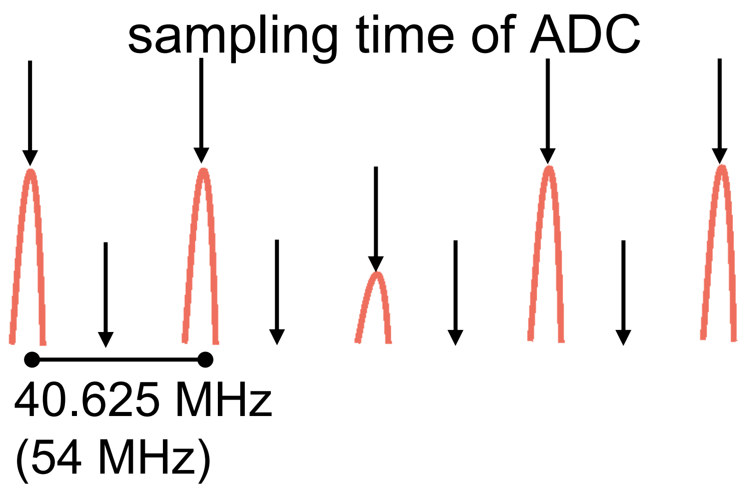
• preparation of longitudinal feedback system (mainly new monitor systems)



• allow for laser based beam manipulation and external seeding option:
requires ~ 30-60 fs rms arrival time stability

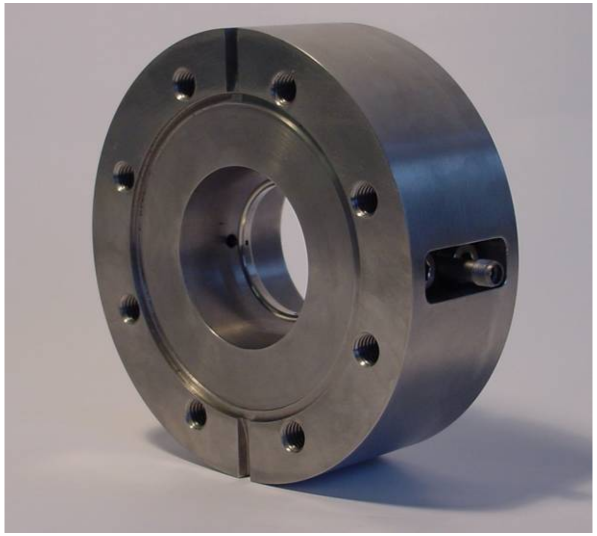


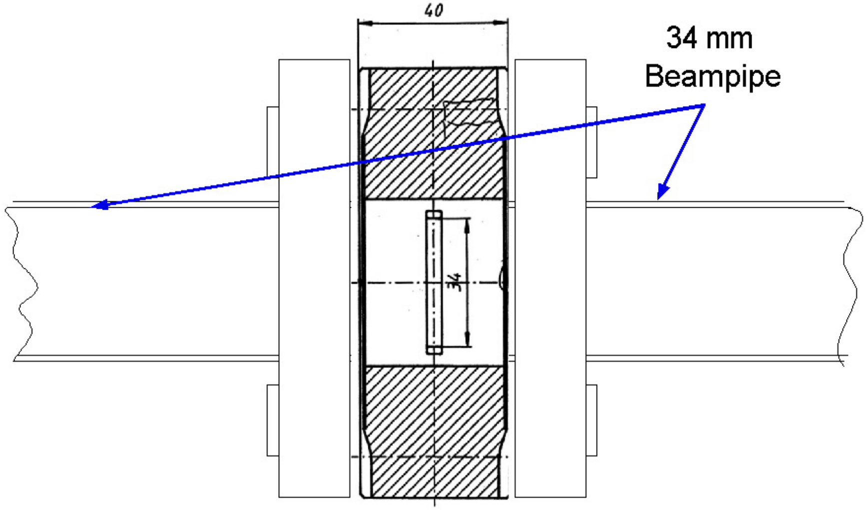
The timing information of the electron bunch is transferred into an amplitude modulation. This modulation is measured with a photo detector and sampled by a fast ADC.



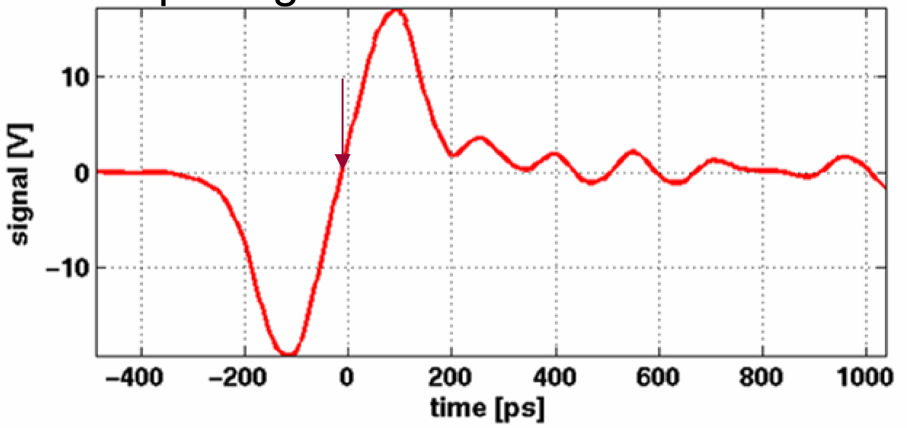
Courtesy: F. Löhl

Beam Pick-up



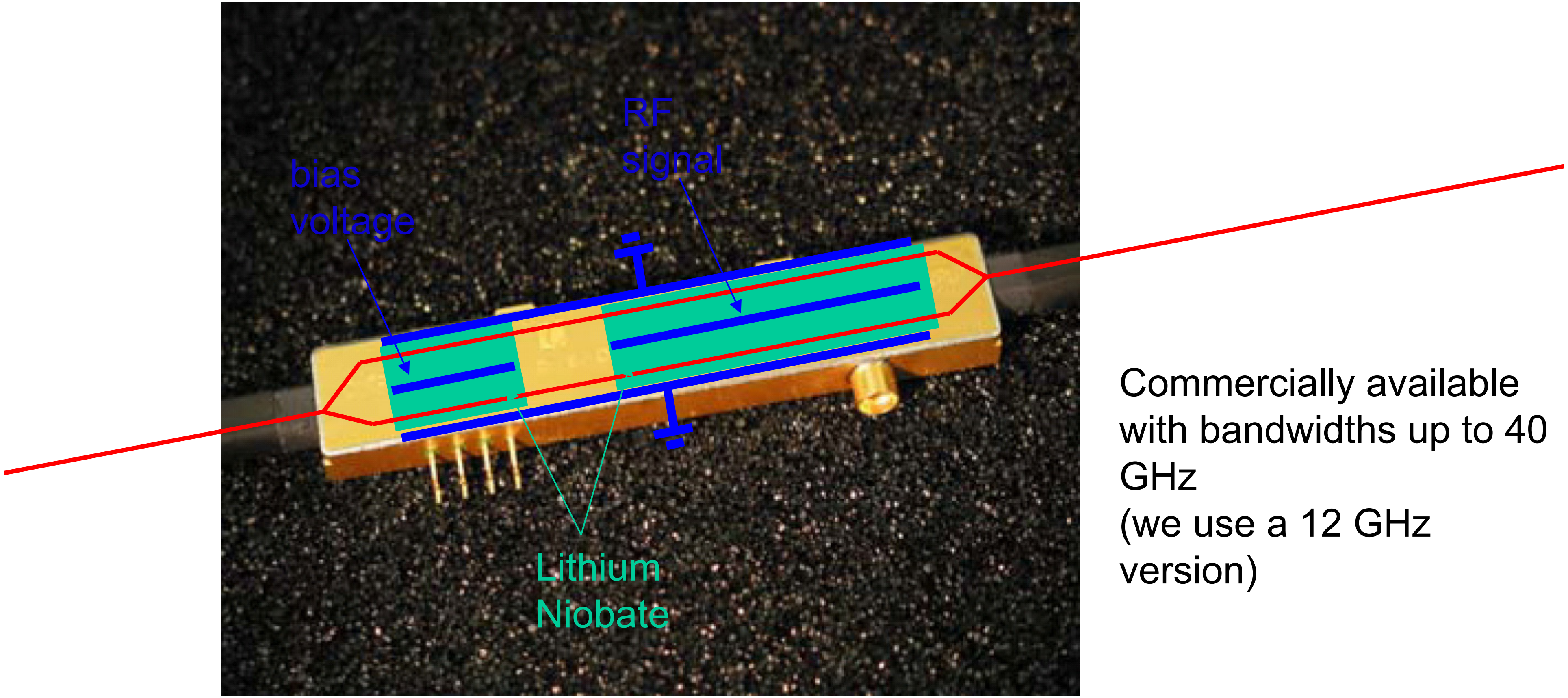


Output signal measured in EOS hutch



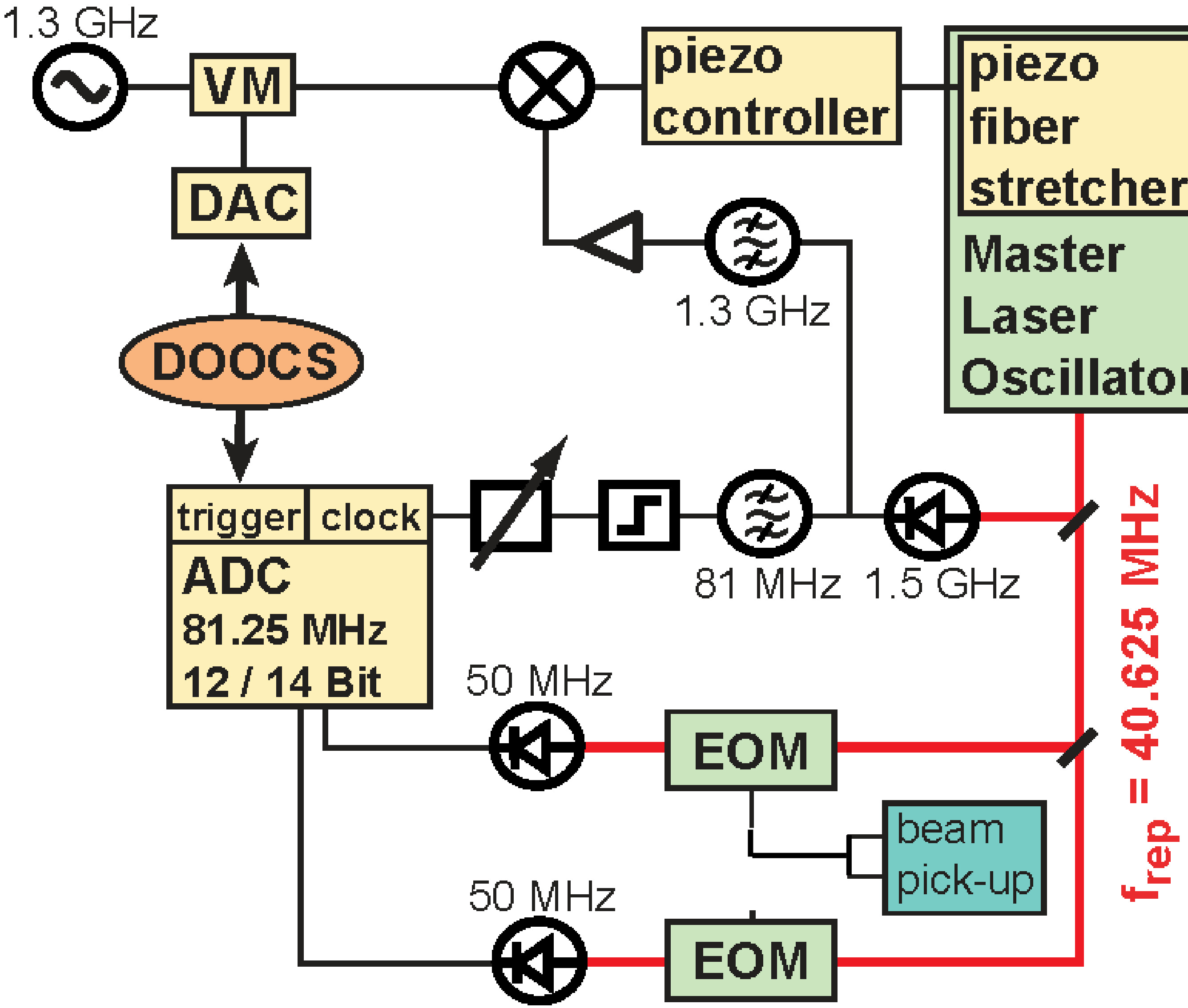
- Isolated impedance-matched ring electrode installed in a „thick Flange“
- Broadband signal with more than 5 GHz bandwidth
- Sampled at zero-crossing with laser pulse

Electro-Optical-Modulator (EOM)



Commercially available with bandwidths up to 40 GHz
(we use a 12 GHz version)

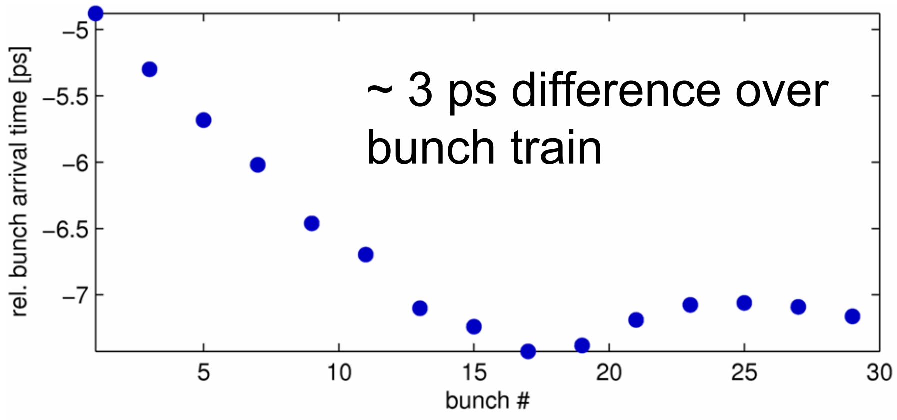
Test Bench for the Arrival-time Monitor System

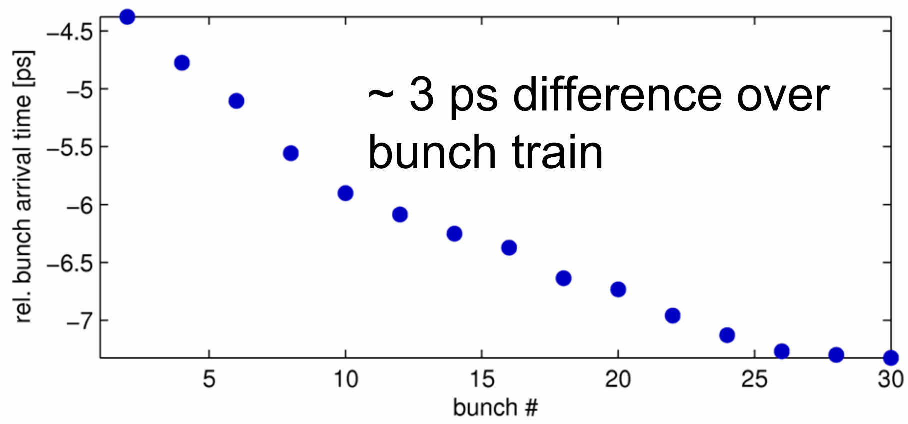


Courtesy: F. Löhl

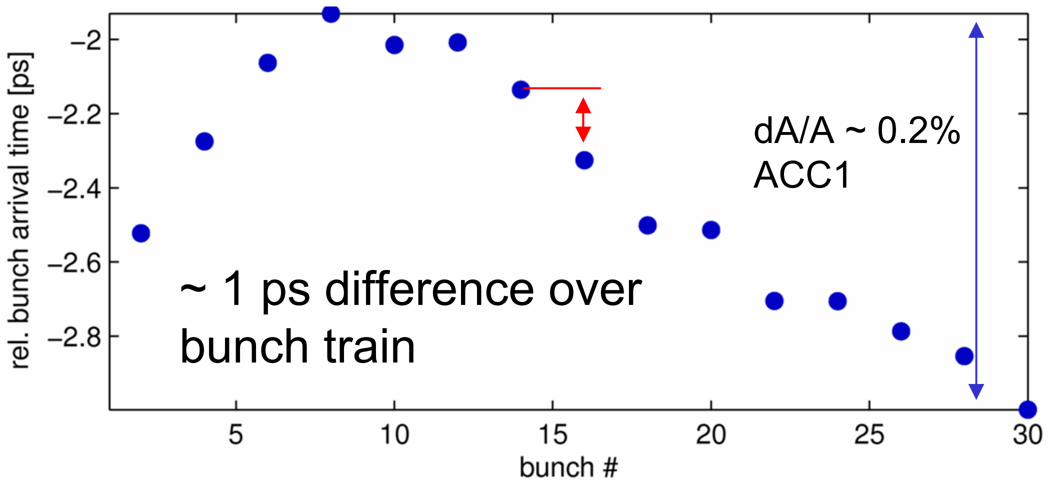
Measurement of Bunch Arrival Time over Bunch Train

Beam loading compensation off





Beam loading compensation on (not optimized)



Bunch to bunch time jitter
$rms(t_n - t_{(n+1)}) \sim 30fs$

Courtesy: F. Löhl

Current beam line design

- header lines