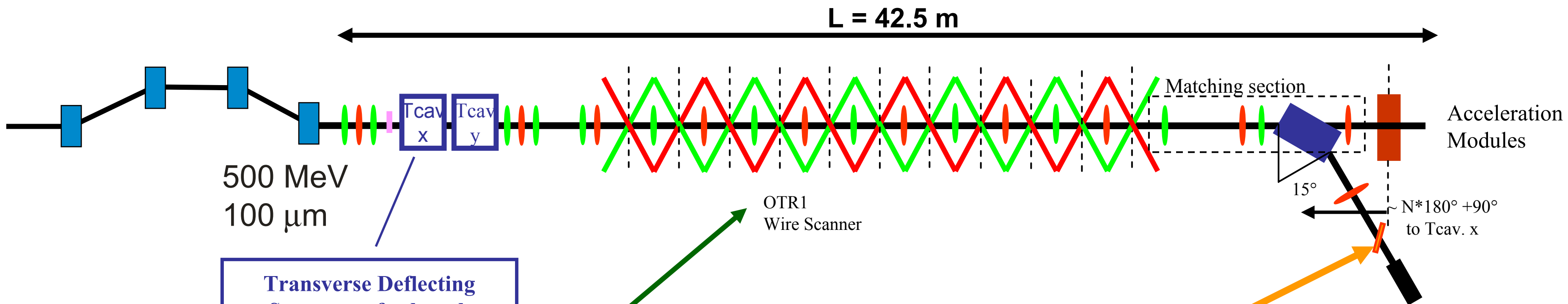
Optics Layout of the Diagnostic Sections BC1 & BC2

Christopher Gerth, Michael Röhrs, Holger Schlarb

DESY Hamburg

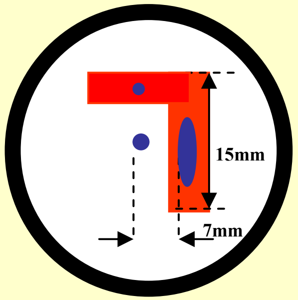
General Layout of Diagnostic Section BC1

Multi-screen slice emittance measurements



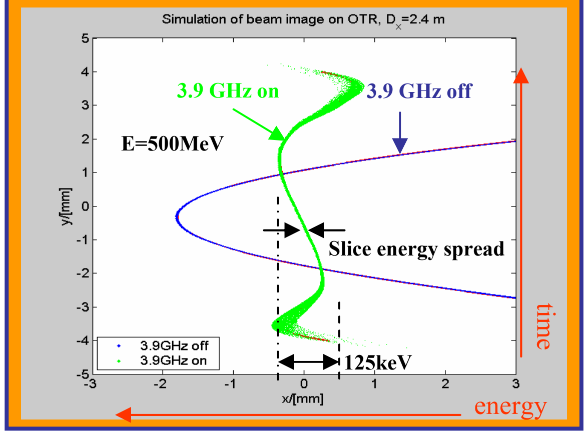
Transverse Deflecting Structures for bunch profile and slice emittance measurements

Off-axis screen design



- **kicker enable single bunch measurements**
- **Phase space tomography**
- **Slice emittance measurements**

Measurement of the correlated and residual energy spread of the bunch
Tuning of 3rd harmonic cavity
D = -2m, β_{OTR} = 0.3 m, Res.: ~ 7.9 keV



Slice emittance diagnostics and dump section have major impact on lattice layout

Diagnostic Section BC1

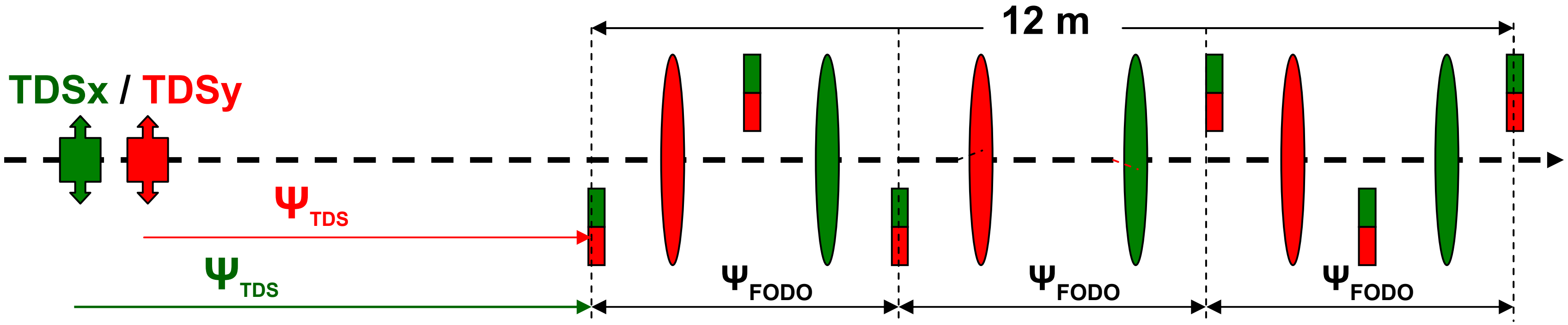
1. Optimisation of lattice layout for slice emittance measurement
2. Optics layout / matching and integration in overall lattice (matching with Mad8)
3. Add Dump section
4. Add other special and standard diagnostics
5. Sensitivity study, integration into S2E simulations (to be done)

Diagnostic Section BC2

1. Specific requirements (what is different?)
2. Optics layout / matching

Operation modes and lattice optics:

FEL mode - parasitic	**- Commissioning of long pulse trains** **- On-line beam characterisation - Correction of drifts (in x and y plane)** Medium beta function at TCAV (~15-25 m) Low space charge & chromatic effects Longitudinal resolution: < 1/10 of rms bunch length ~ 30 fs Slice emittance measurement using kickers (optic 1) Projected emittance measurement (optic 2)
FEL mode 2 **High Resolution** - (parasitic)	**- High resolution longitudinal profile and slice emittance (one plane)** High beta function at one TDS (>50m) / special optic (optic 3) Small beta function at screen with 90 deg phase adv. Longitudinal resolution: < 10fs
Dump mode 1 **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 $\Delta E/E \sim 10^{-5}$ (uncorrelated energy spread) Single bunch mode
Dump mode 2 **Long pulses** - not parasitic	**- Commissioning of LLRF upstream BC1** **- Studies of orbit stability and energy variation across macro-pulse** Dipole to dump is switched on Large beta function at dump screen (optic 5) Up to 800us operation (1Hz) High resolution BPM based energy measurement across macro-pulse



Main criteria:

- Precision of slice emittance values
- Longitudinal resolution

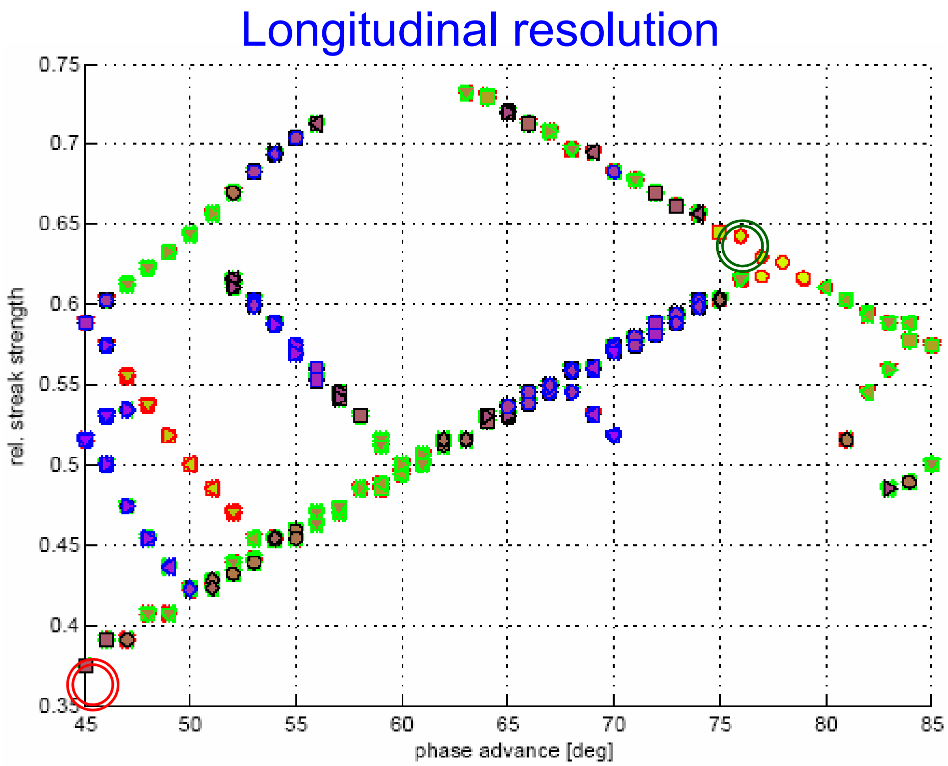
Soft criteria (simplicity & flexibility):

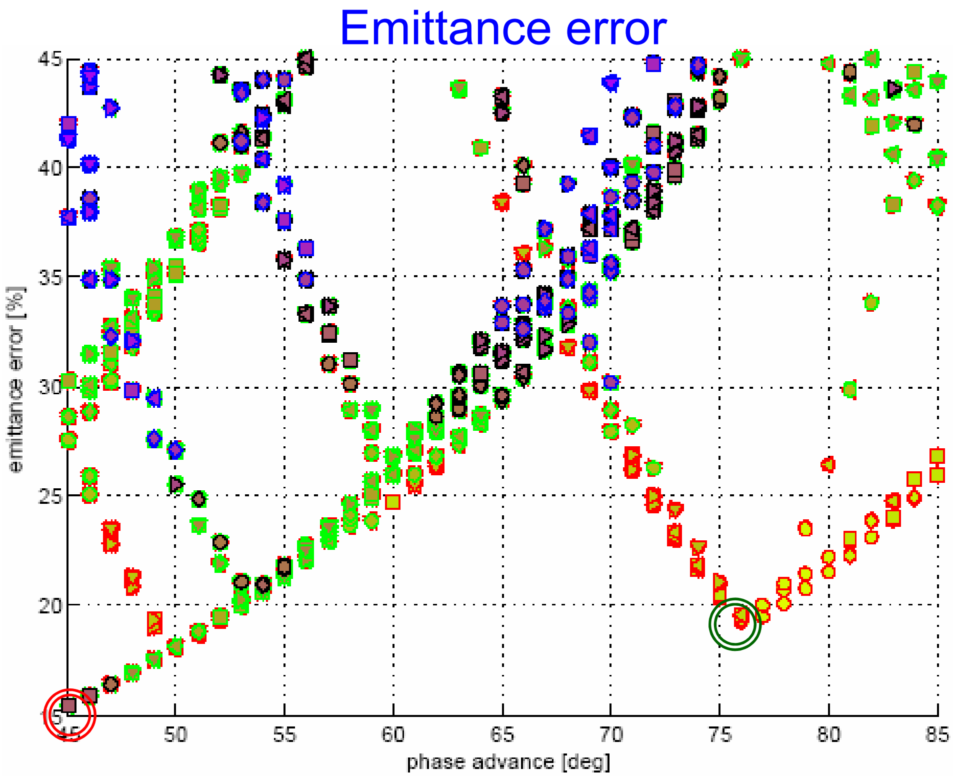
- Symmetrical FODO lattice (same phase advance in x and y)
- Total length < 12 m
- max 3 cells
- max 6 OTR screens (4 per plane)
- OTR screens in the centre of drifts

Variables:

- Locations of OTR screens
- Phase advance Ψ_{FODO} of FODO lattice
- Phase advance Ψ_{TDS} between TDSs and FODO lattice

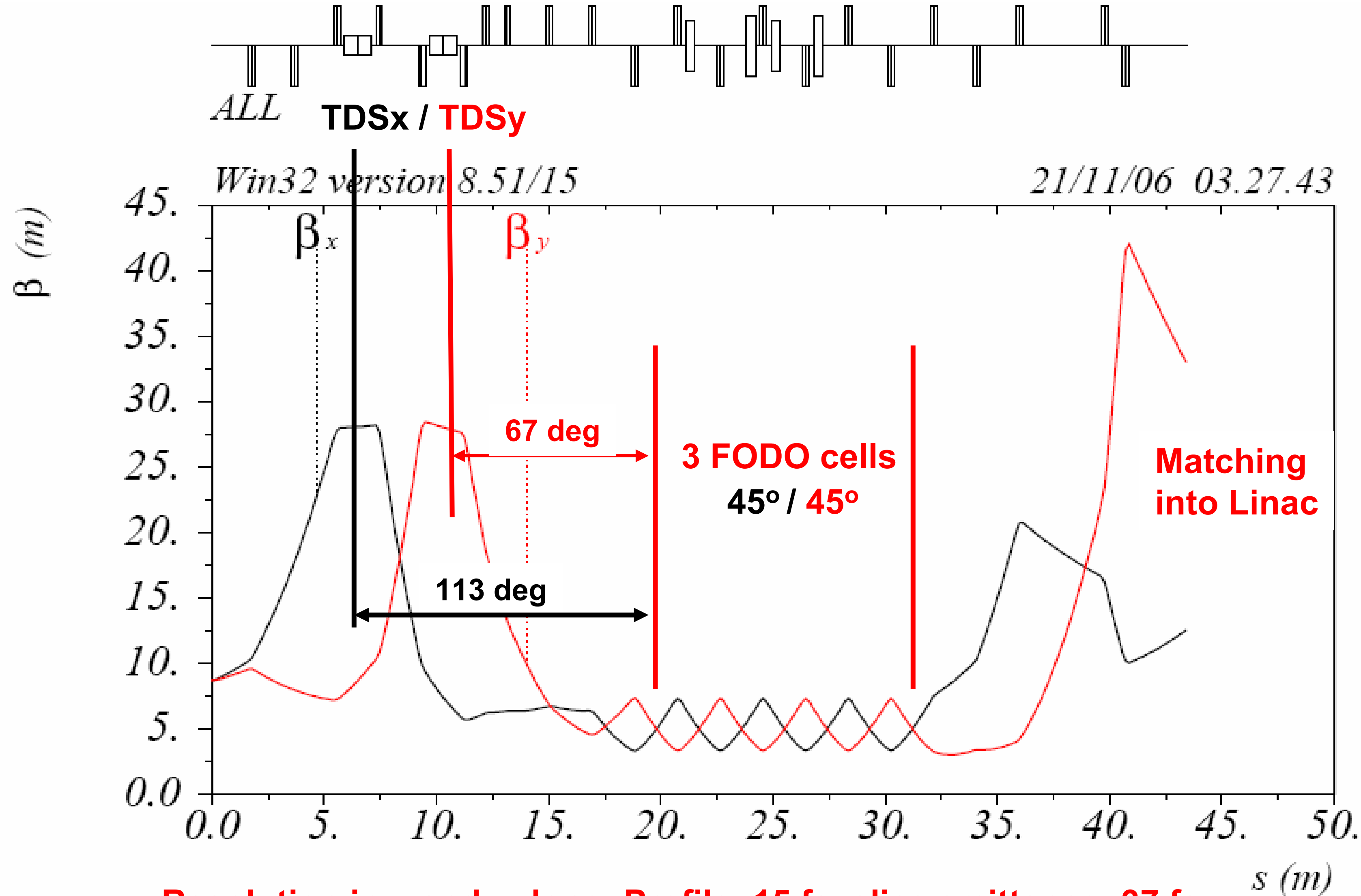
3 FODO cells / 4 screens in each plane





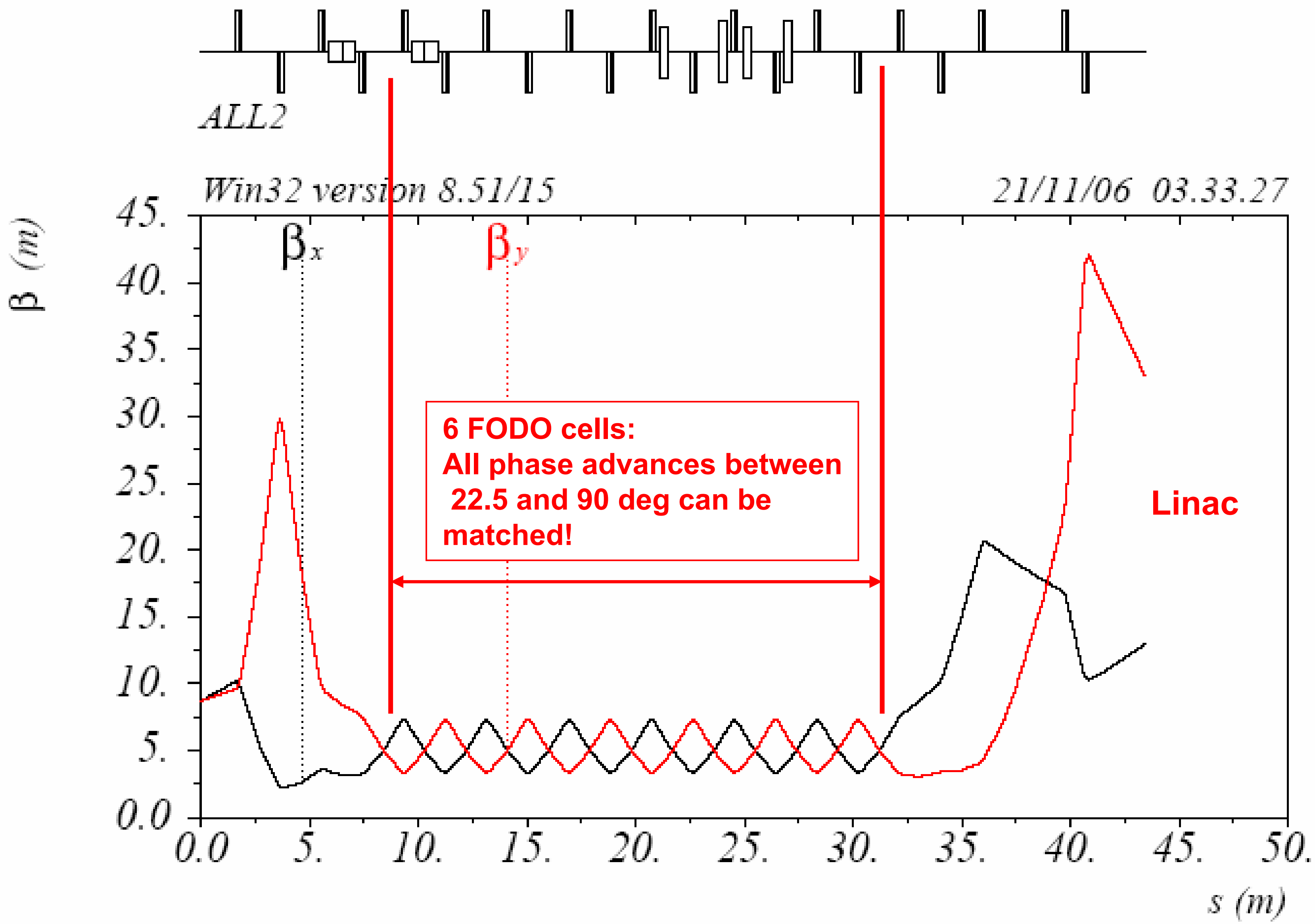
For each FODO cell phase advance exist several solutions with a specific combination of phase advances from the horizontal and vertical TDS to the FODO lattice!

Optics Layout Diagnostic Section 1
Slice emittance measurements (optic 1)

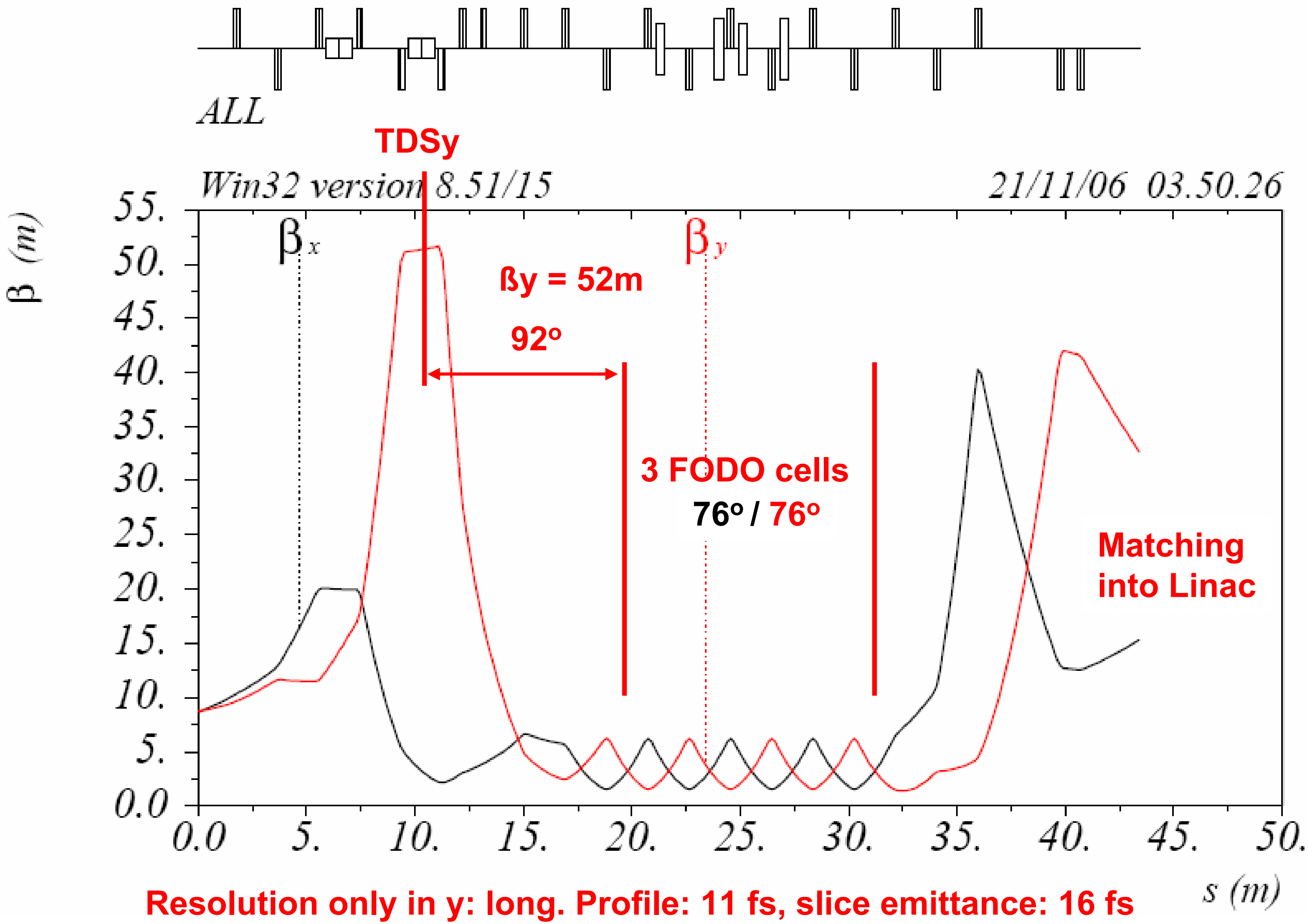


Resolution in x and y: long. Profile: 15 fs, slice emittance: 37 fs

Optics Layout Diagnostic Section 1
Projected emittance/ commissioning (optic 2)

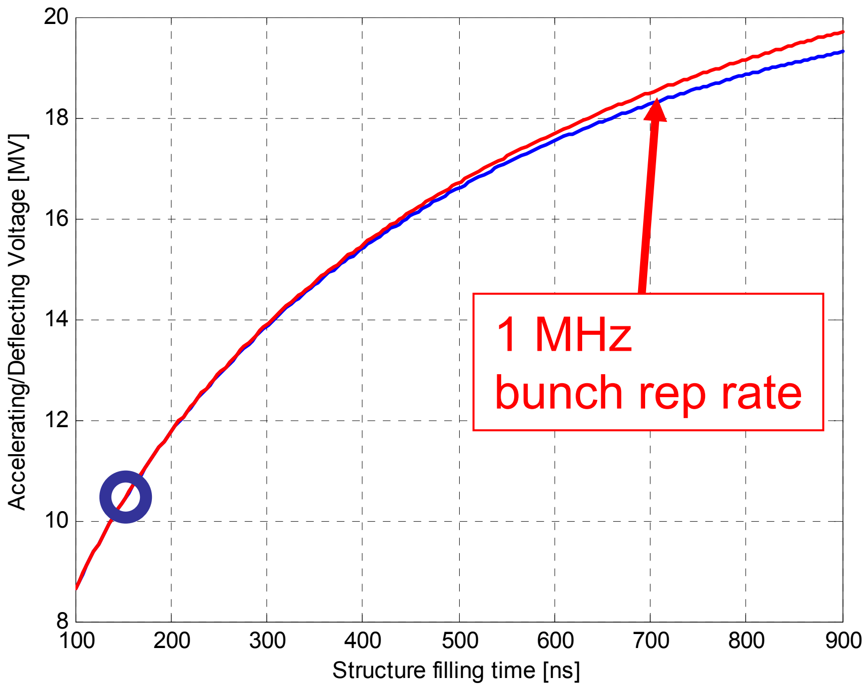


Optics Layout Diagnostic Section 1
Slice emittance measurements 76 deg (optic 3)



Resolution only in y: long. Profile: 11 fs, slice emittance: 16 fs

Streak Strength of Transverse Deflecting Structure



$$\sigma_{\mathrm{streak}} = \sqrt{\beta_d\,\beta_s}\,\frac{V_{\mathrm{eff}}\,\omega_{\mathrm{rf}}}{pc}\,\sigma_s\,\sin\Psi \qquad (1)$$

$$V_{\mathrm{eff}} = 2Q\frac{\sqrt{r_Q\,P_0\,L}}{\sqrt{\omega_{\mathrm{rf}}\,t_{\mathrm{fill}}}}\left(1-e^{-\tau}\right) \qquad (2)$$

$$\tau = \frac{\omega_{\mathrm{rf}}\,t_{\mathrm{fill}}}{2\,Q} \qquad (3)$$

$$r_Q = \frac{r_s}{Q} \qquad (4)$$

r_Q : normalised shunt impedence
P_0 : Input power at TDS

A factor of 1.6 would be gained at 1 MHz bunch rep rate

Resolution in x and y: long. Profile: 9 fs, slice emittance: 23 fs

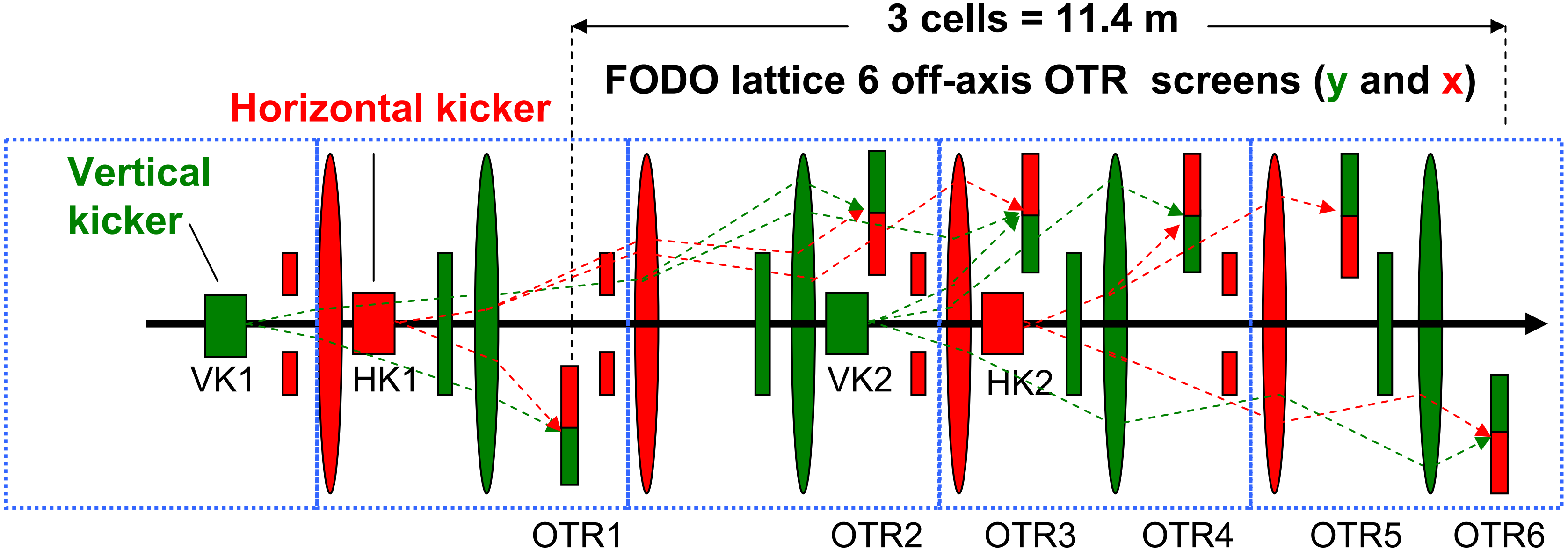
Screen / Kicker arrangement (1)

Horizontal slice emittance / vertical streak

	45deg	76deg
HK1	OTR1	OTR1
HK1	OTR2	OTR3
HK2	OTR4	OTR4
HK2	OTR6	OTR6

Vertical slice emittance / horizontal streak

	45deg	76deg
VK1	OTR1	OTR2
VK1	OTR2	OTR3
VK2	OTR4	OTR4
VK2	OTR6	OTR5



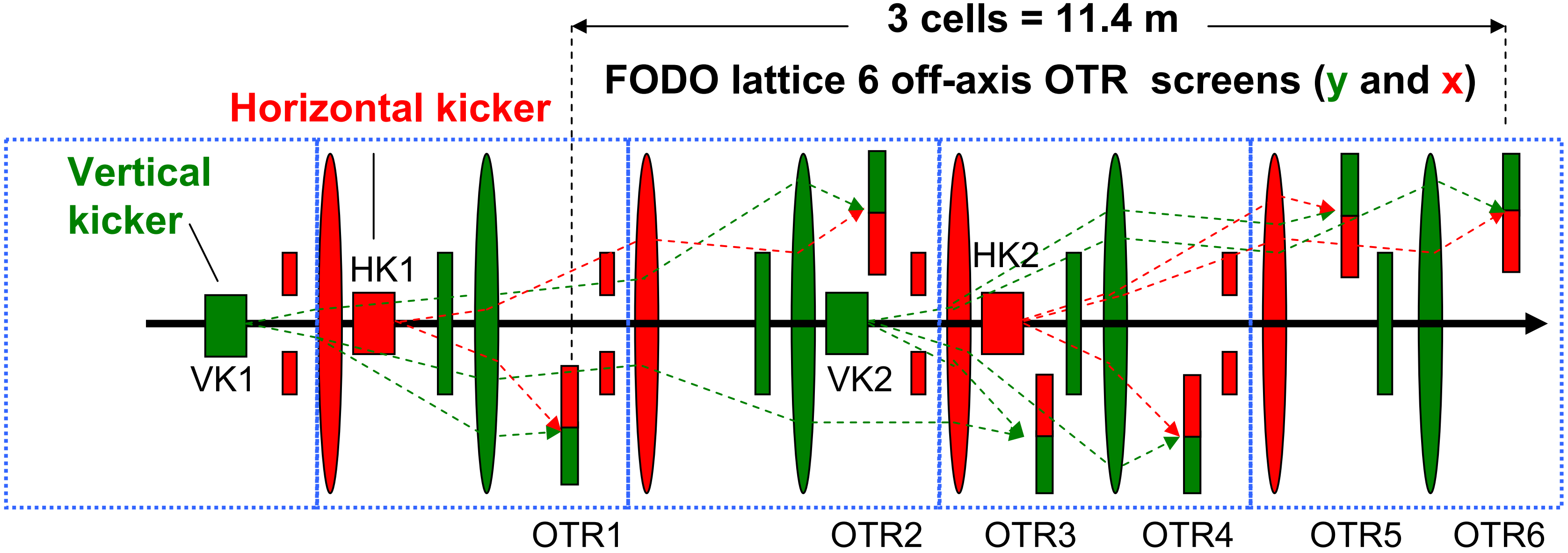
Screen / Kicker arrangement (2)

Horizontal slice emittance / vertical streak

	45deg	76deg
HK1	OTR1	~~OTR1~~
HK1	OTR2	~~OTR3~~
HK2	OTR4	~~OTR4~~
HK2	OTR6	~~OTR6~~

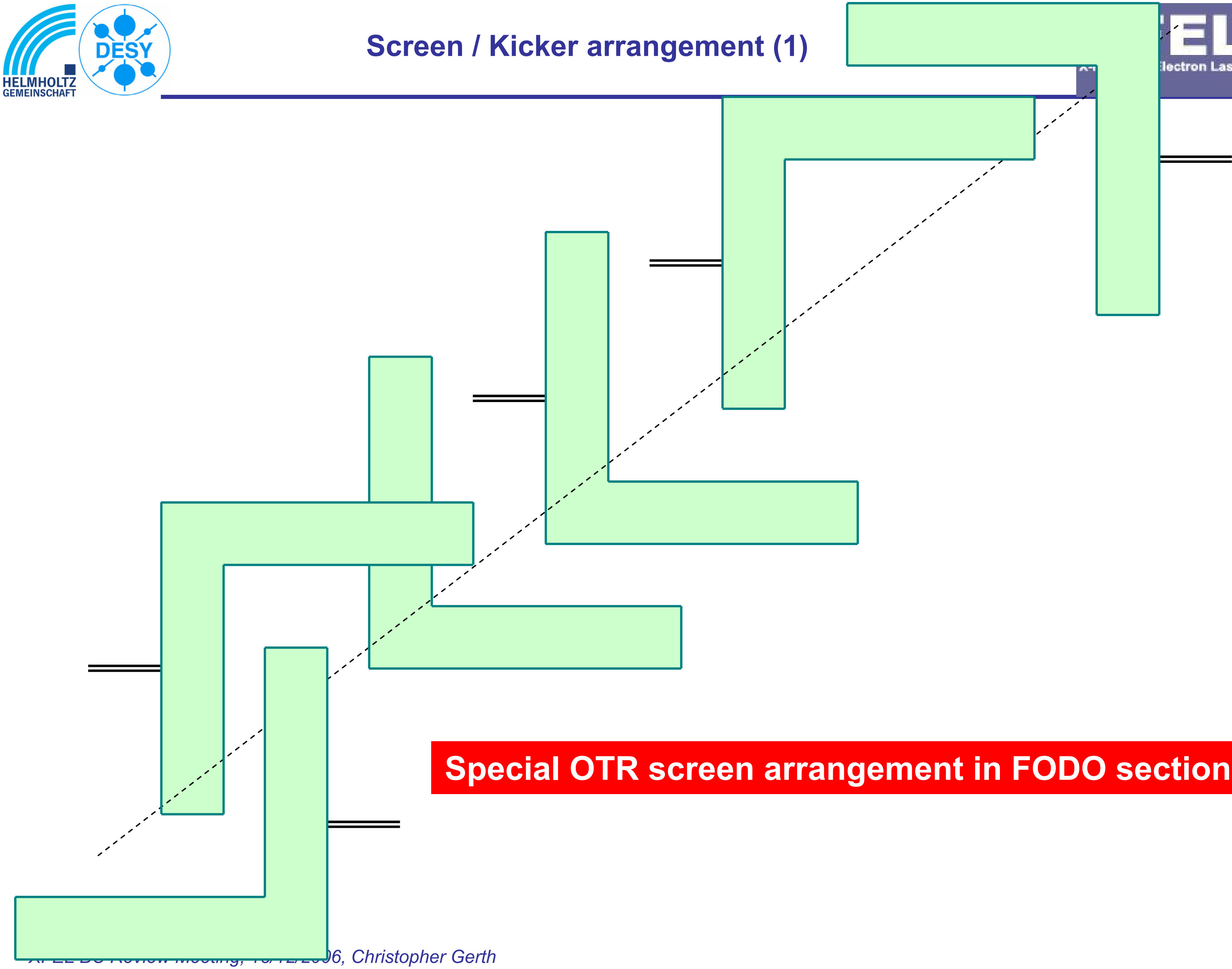
Vertical slice emittance / horizontal streak

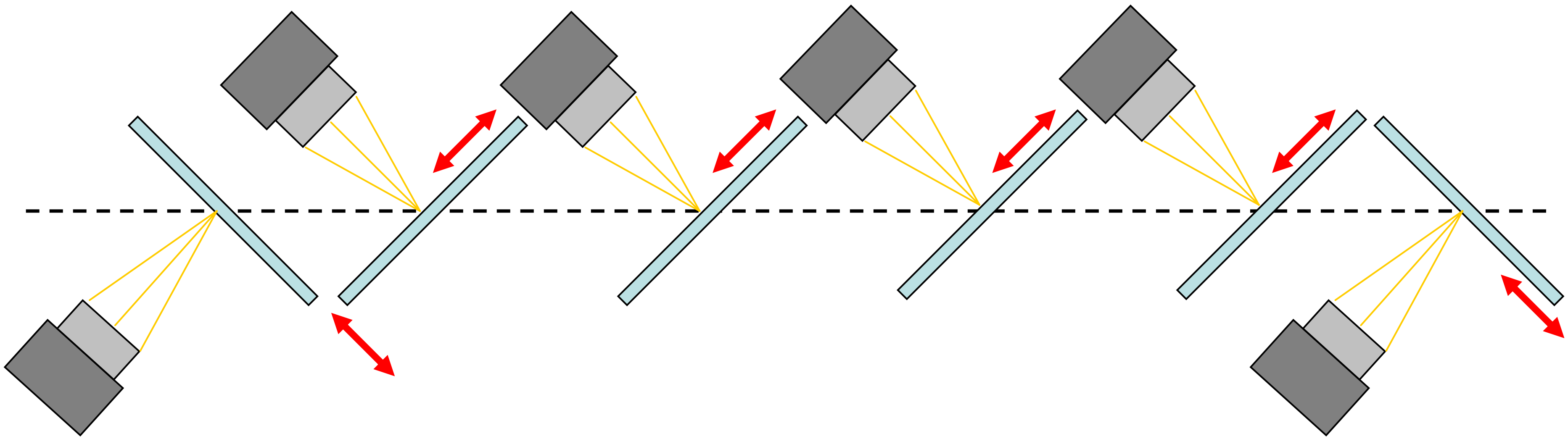
	45deg	76deg
VK1	OTR1	OTR2
VK1	OTR2	OTR3
VK2	OTR4	OTR4
VK2	OTR6	OTR5

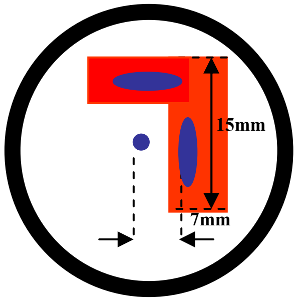


Bend plane of BCs defines the OTR arrangement

Screen / Kicker arrangement (1)

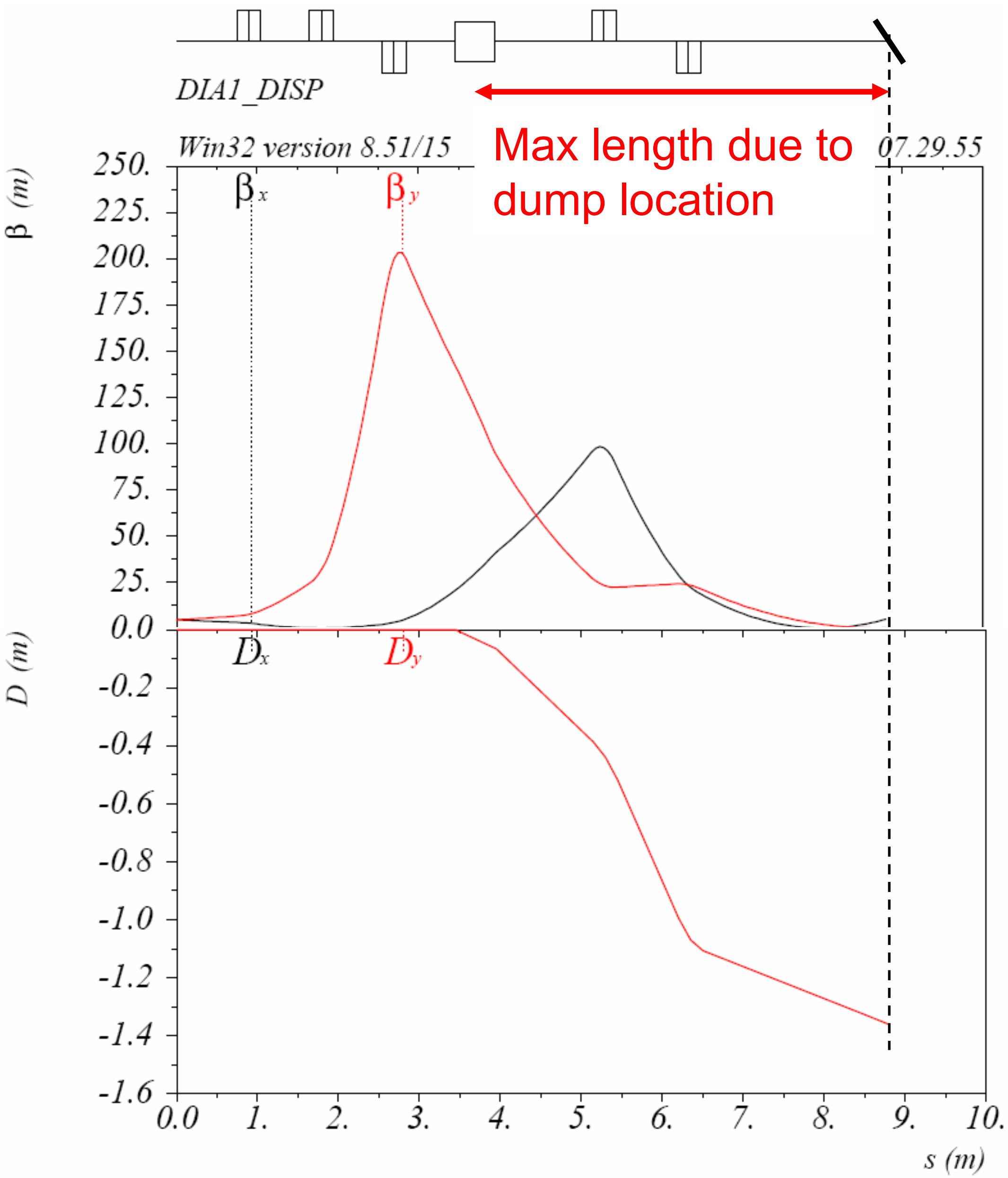






Special OTR screen stations in FODO section: Camera perpendicular to screen to get full resolution over entire screen (no limitation by field of depth)

Diagnostic mode 2: Energy Spread (optic 4)



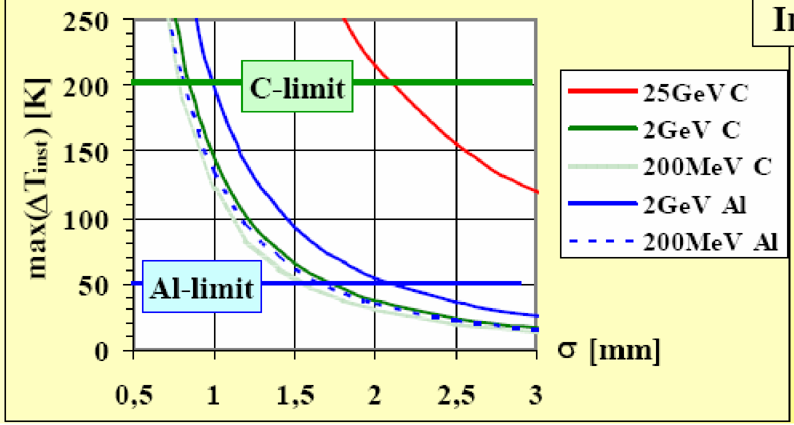
Goal: $\Delta E/E \sim 10^{-5}$
→ $\Delta E \sim$ 5keV
from meas. at FLASH

Laser Heater (30 keV)

Values at screen:
ßx = 1.992 m
ßy = 0.356 m
Dy = -1.327 m

→ $\Delta E/E \sim$ 1.5*10-5
$\Delta E \sim$ 7.2 keV
ε_N = 1*10-6 µm

Higher order effects?
Chromaticity?
Needs to be studied



Courtesy of M Schmitz, MIN

Instantaneous Heating

⇒ spot size limit for full bunch train

σ ≥ 1.7 - 2mm for Al dump resp.

σ ≥ 0.8 - 1mm for C dump

Average Heating

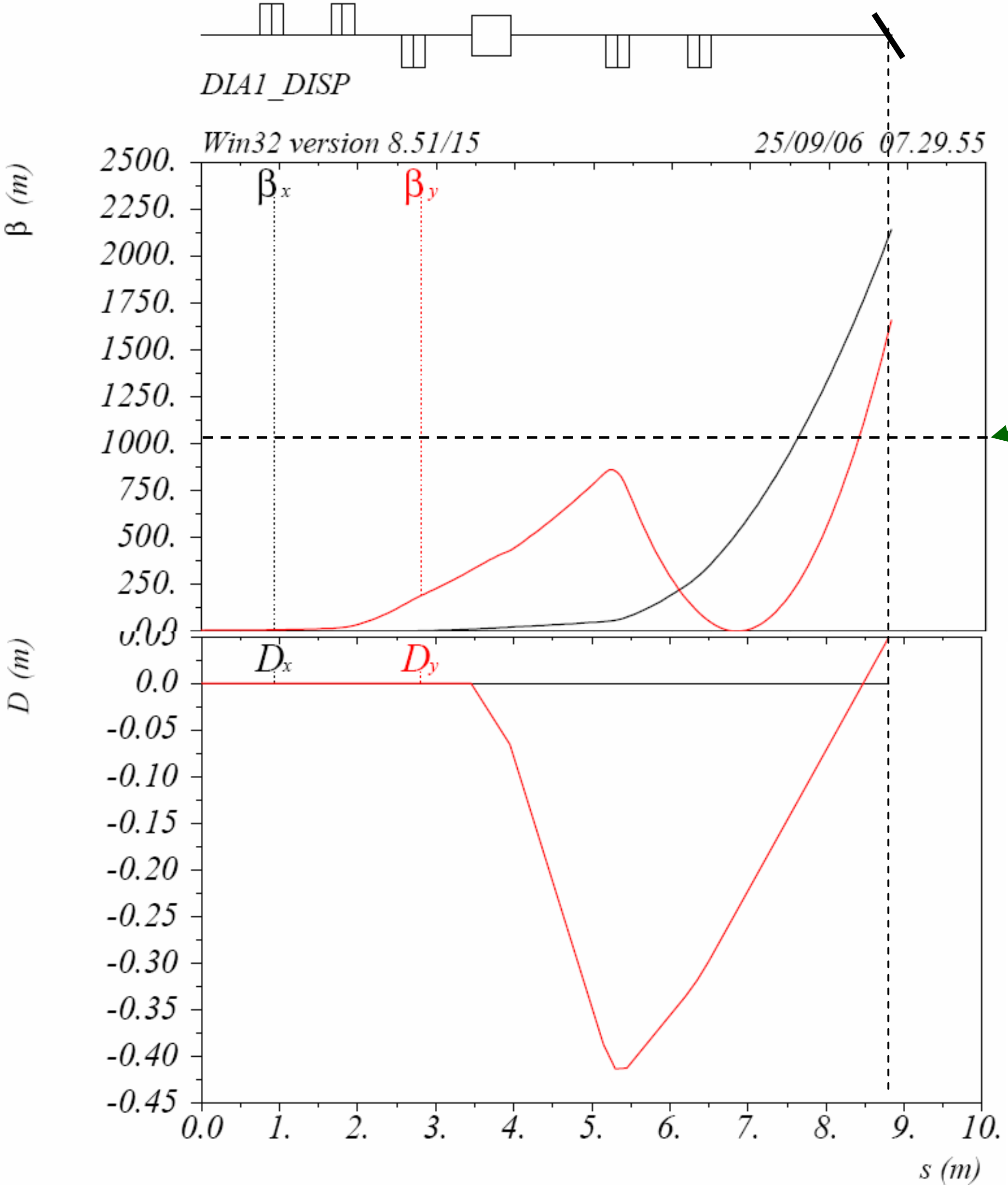
⇒ dP/dz limit w/o slow sweep

C-CU dump: 350W/cm @ σ =1mm

Al dump: 400W/cm @ σ =2mm

	max. beam: 40μA⇔10Hz			thermal op. limits of dump w/o slow sweep	
E_0	P_{ave}	dP/dz [W/cm]			
		C	Al	C-Cu: ≤ 350W/cm	Al: ≤ 400W/cm
2.5 GeV	100 kW	770	1800	16μA / 4Hz / 40kW	8μA / 2Hz / 20kW
2 GeV	80 kW	640	1500	20μA / 5Hz / 40kW	10μA / 2.5Hz / 20kW
500 MeV	20 kW	240	500	max. beam	32μA / 8Hz / 16kW
300 MeV	12 kW	190	380	max. beam	max. beam

Diagnostic mode 3: Long pulse trains (optic 5)

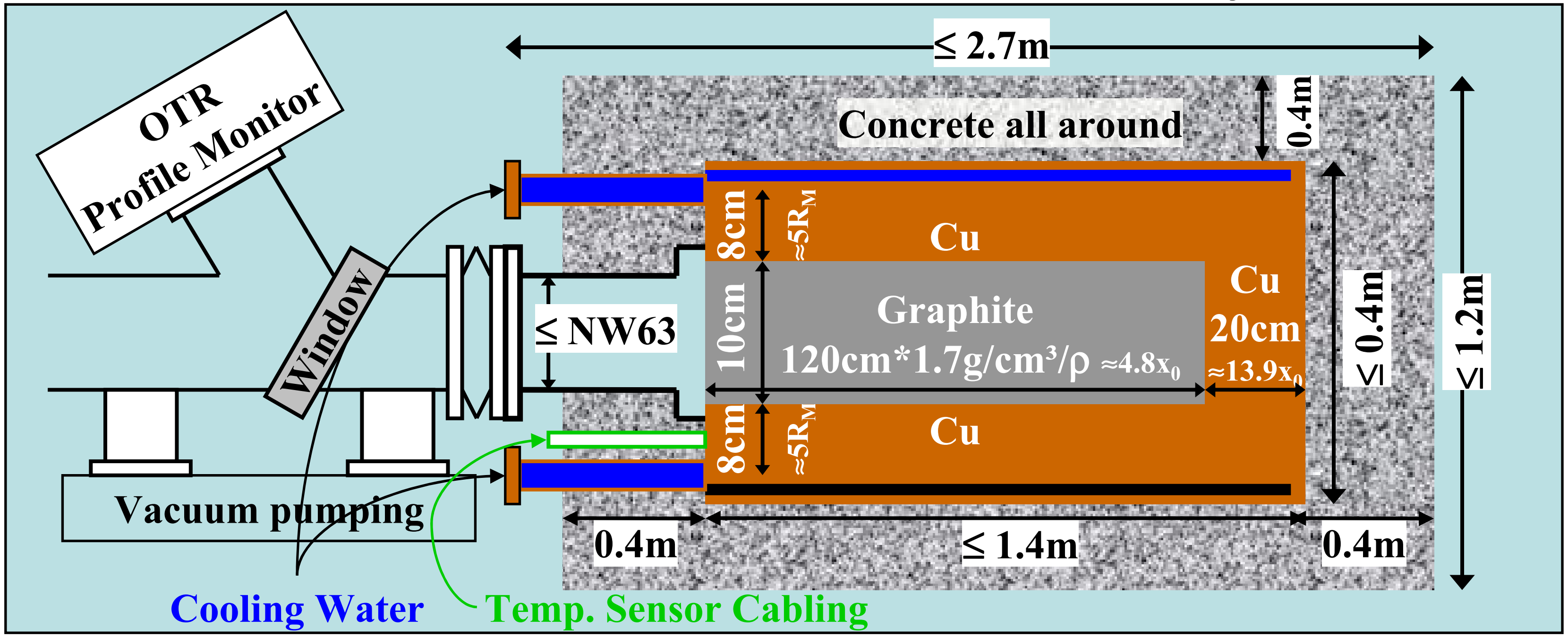


ßx = 1825 m
ßy = 1192 m
Dy = 3 mm

Beam size 1mm

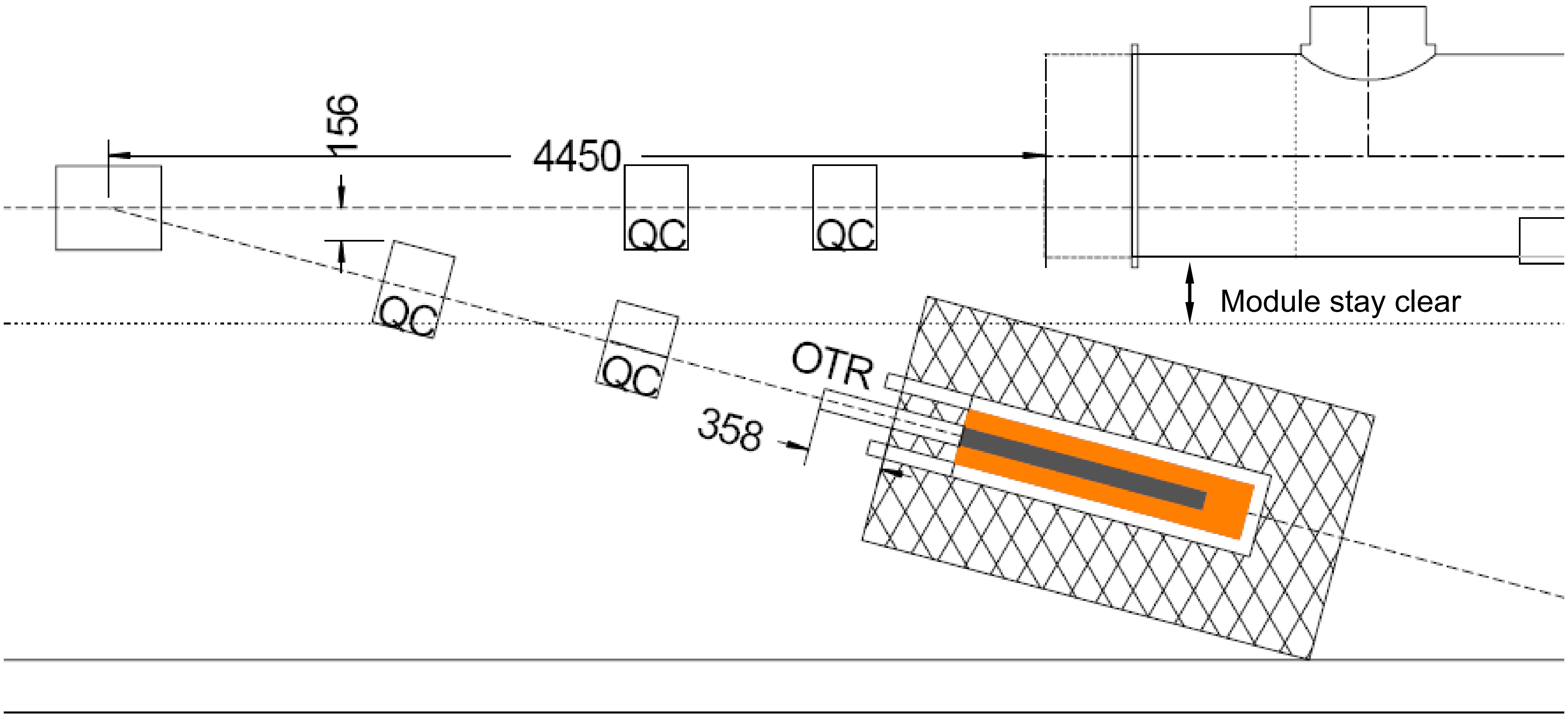
Sketch of BC1-Dumpmodule (C-Cu version) 500MeV

Courtesy of M Schmitz, MIN



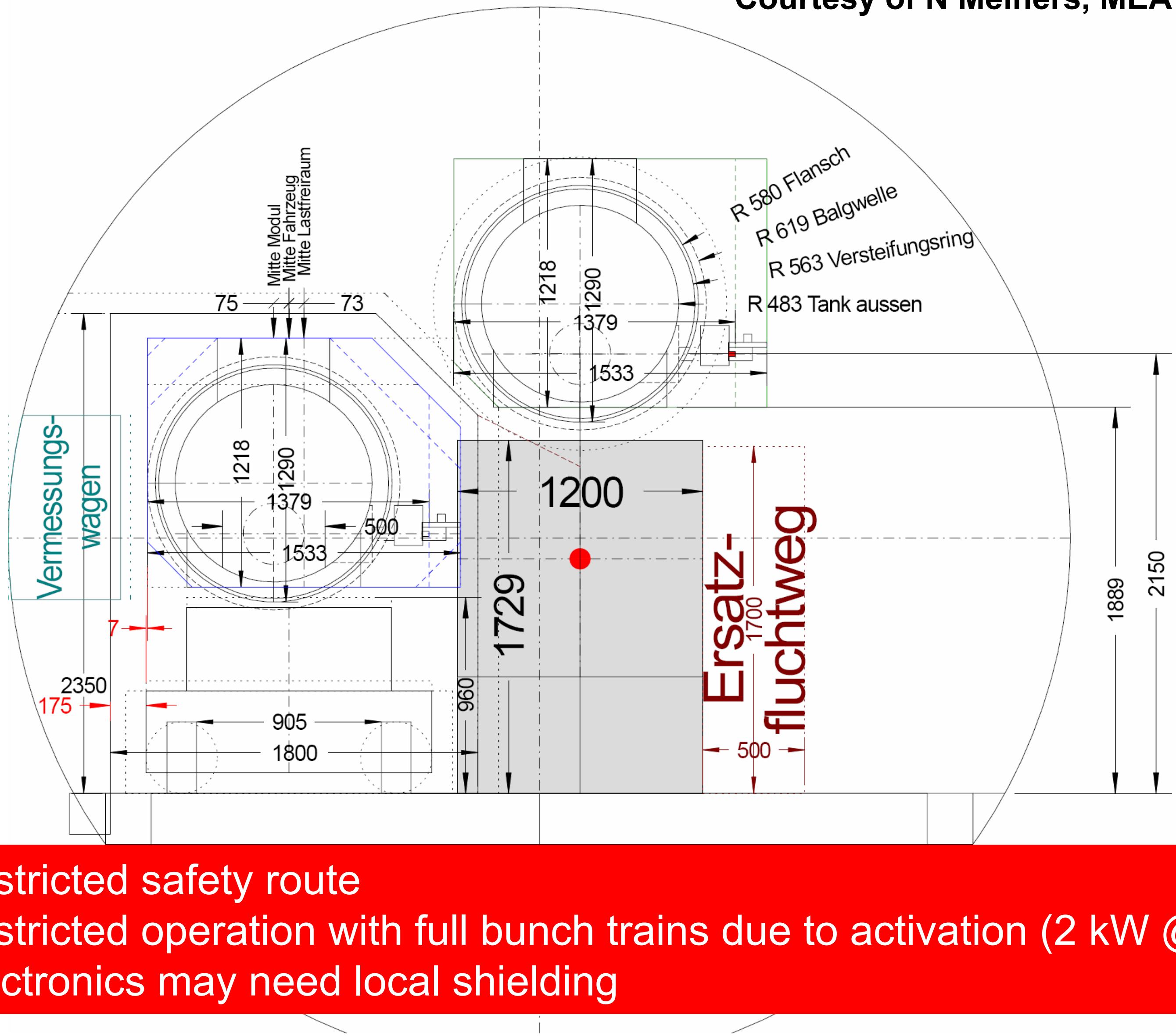
	density [kg/l]	volume (max. estimate)	mass (max. estimate)
Graphite core	~ 2	120cm*π*(5cm)²=9l	~ 20kg
Cu back stop	~ 9	20cm*π*(20cm)²=25l	~ 230kg
Cu radial layer	~ 9	120cm*π*[(20cm)²-(5cm)²]=140l	~ 1250kg
Concrete shield	~ 2	220cm*π*(60cm)² - 140cm*π*(20cm)² =2300l	~4600kg
	total	220cm*π*(60cm)²=2500 l	~ 6100 kg

Diagnostic Dump BC1



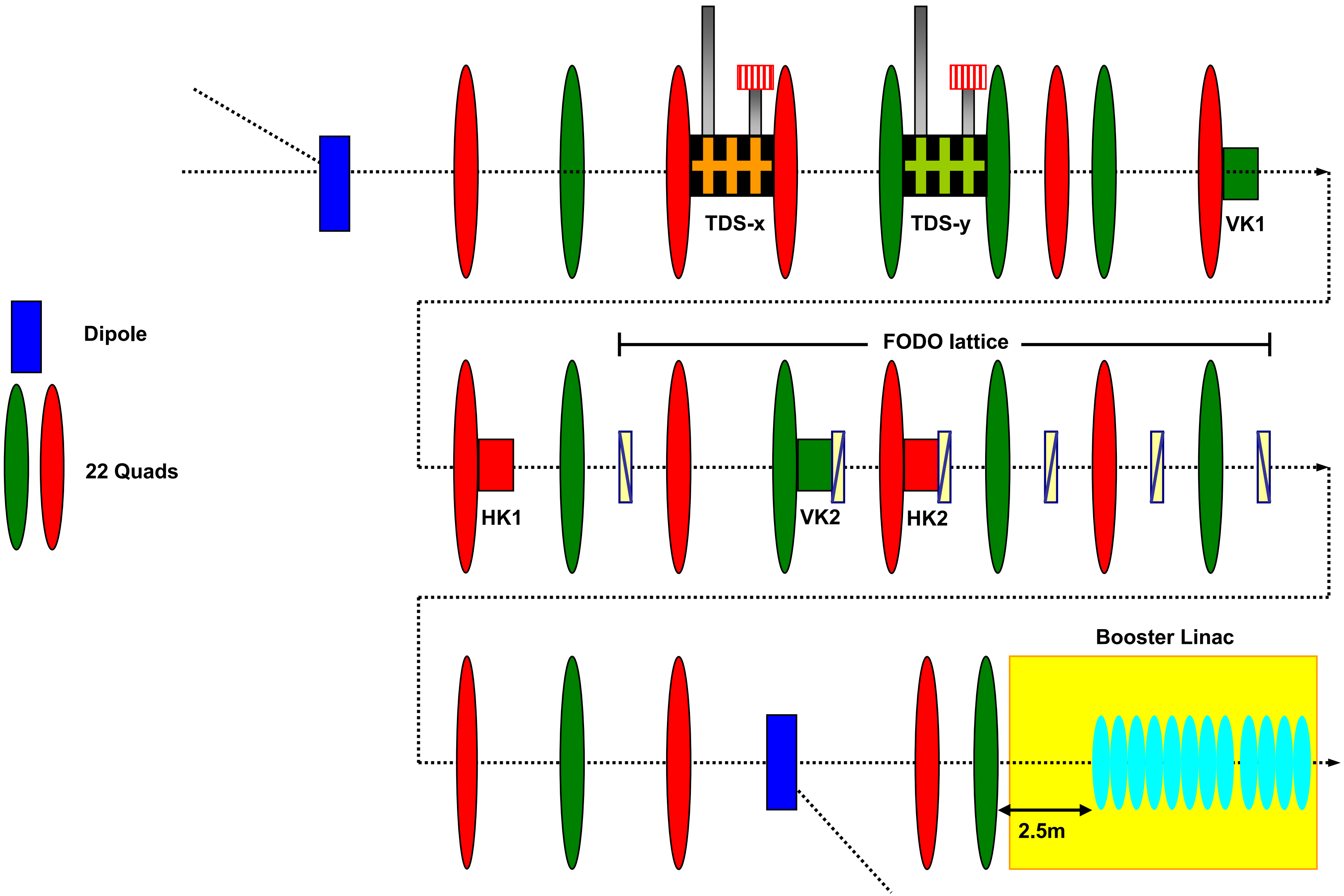
Diagnostic Dump BC1

Courtesy of N Meiners, MEA

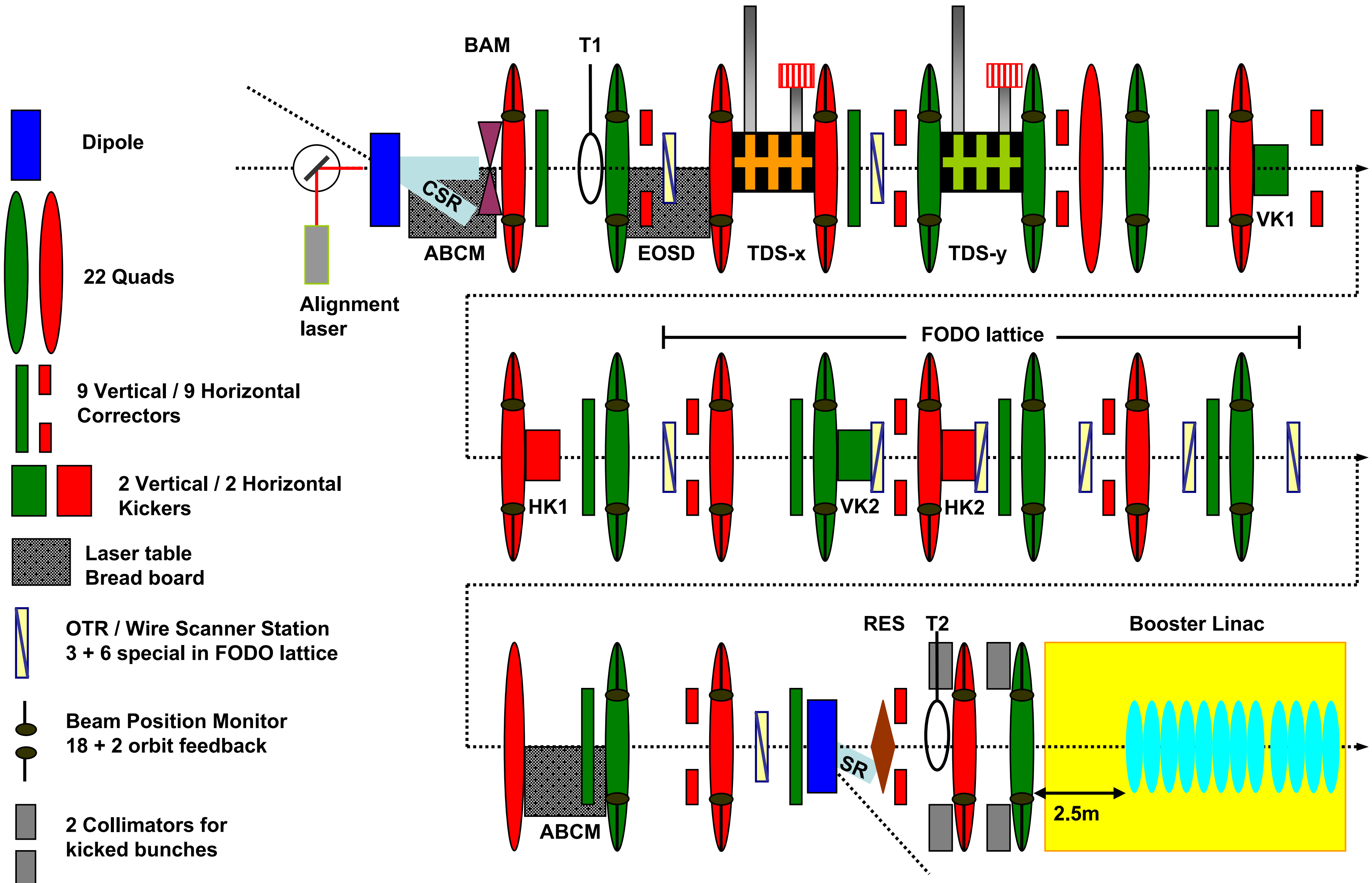


- Restricted safety route
- Restricted operation with full bunch trains due to activation (2 kW @ 1Hz)
- Electronics may need local shielding

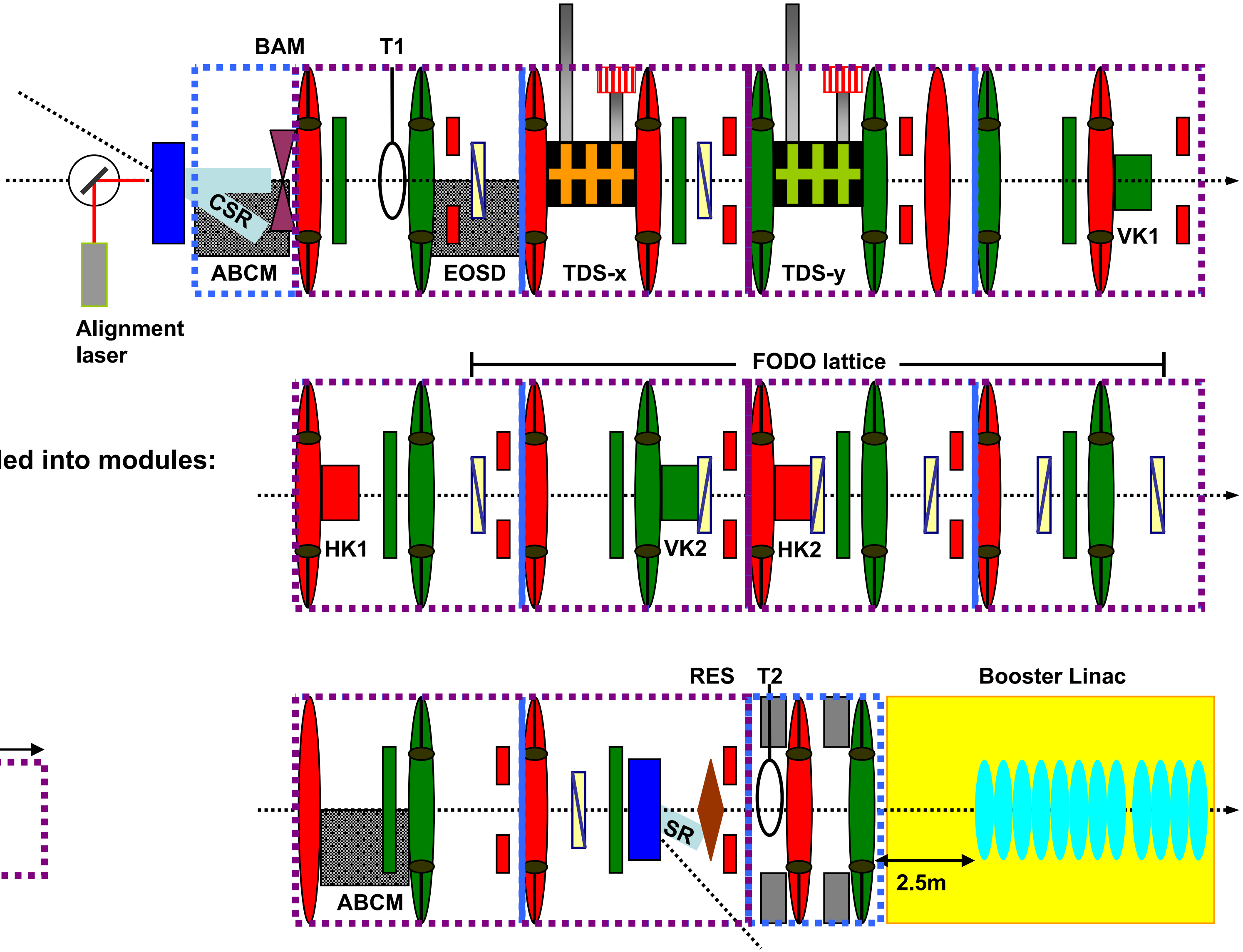
Diagnostic Section Engineering layout (1)



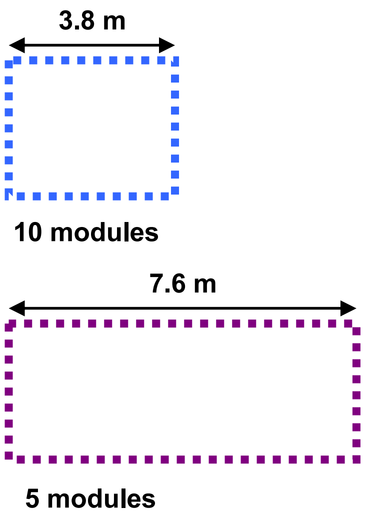
Diagnostic Section Engineering layout (2)



Diagnostic Section Engineering layout (3)



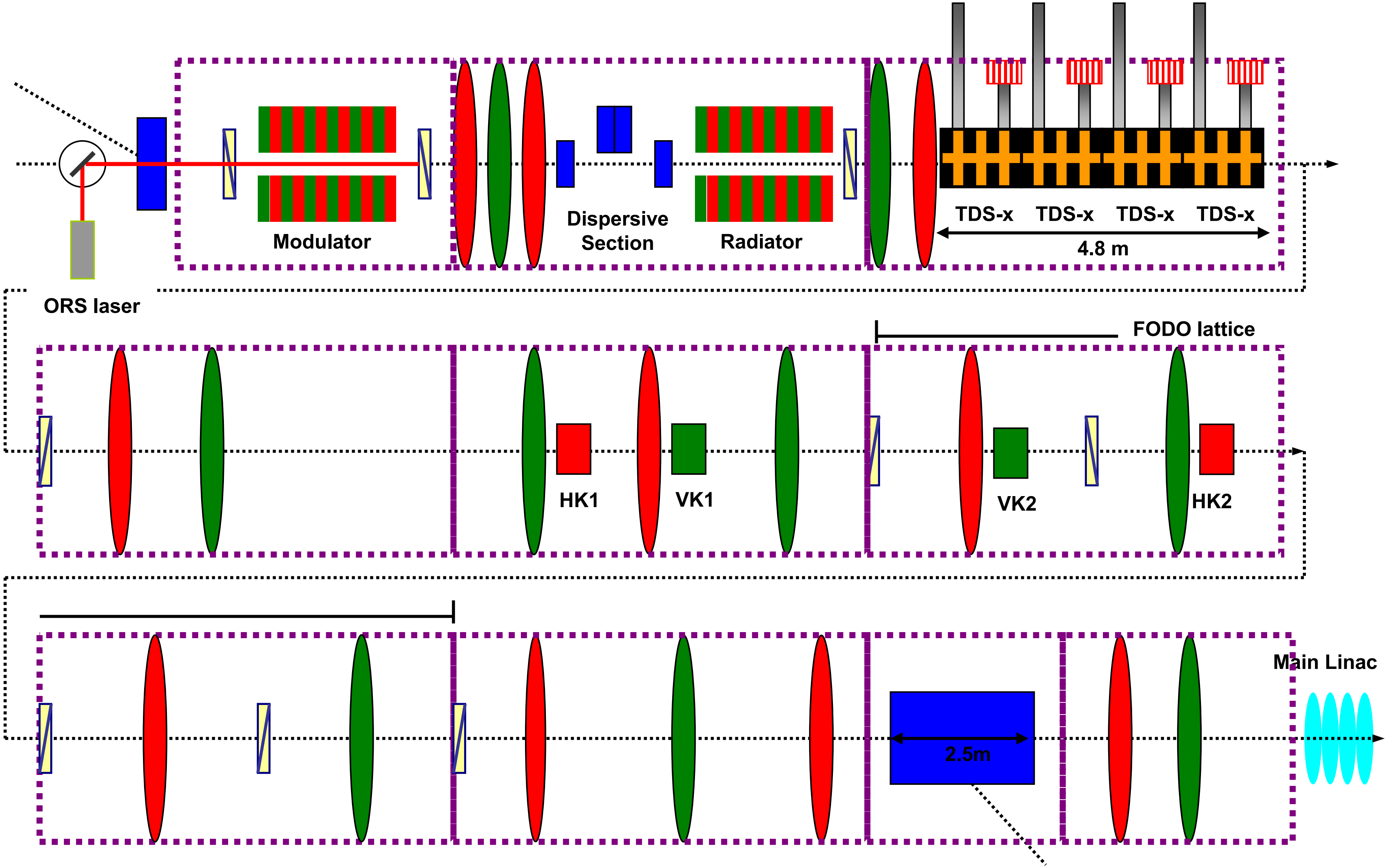
Lattice can be divided into modules:



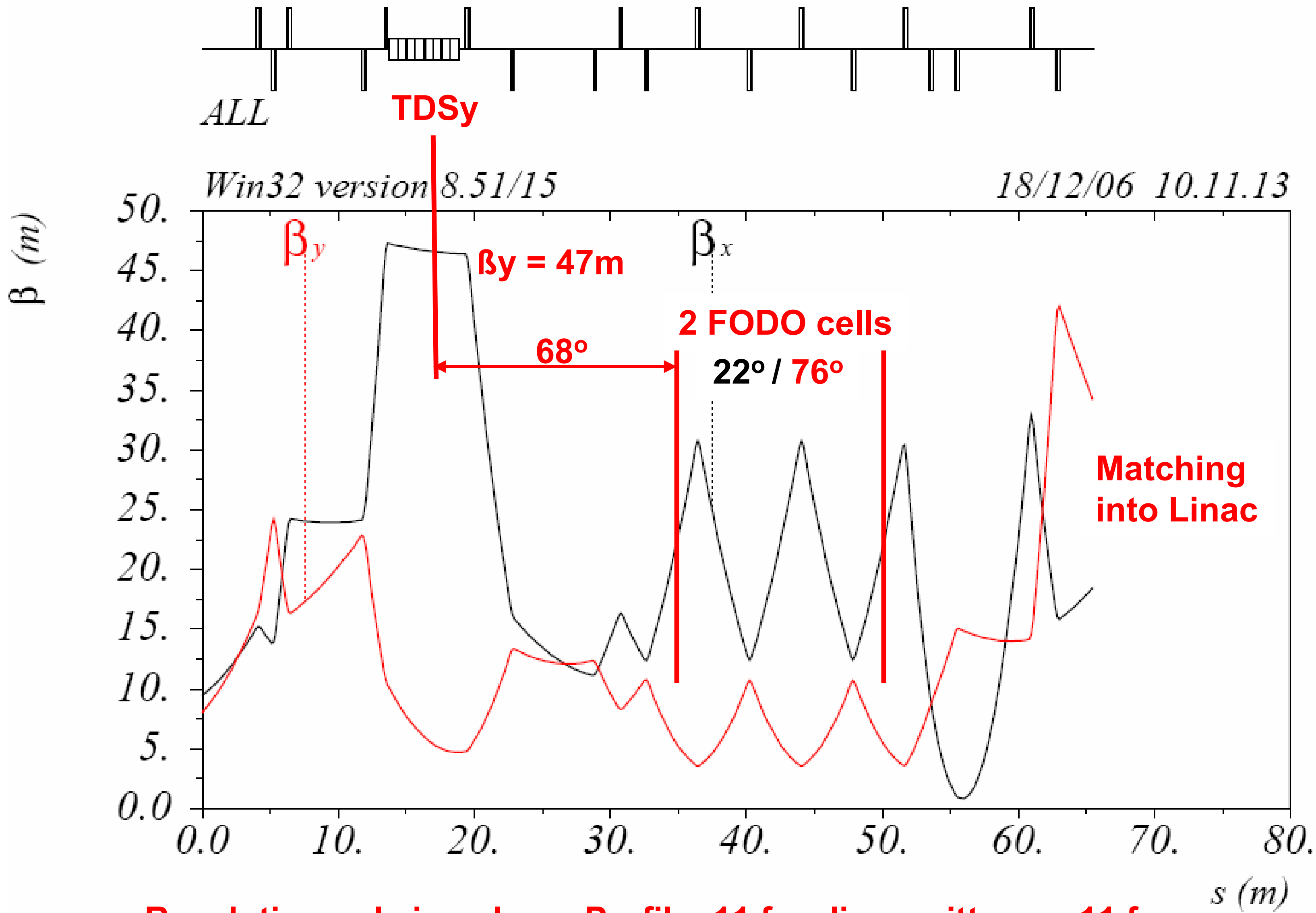
- 8 times more streak strength of TDS required: scales with energy (0.5-2 GeV) and bunch length (100-25 um)
  → operation 1MHz
- Only 1 TDS foreseen
  → horizontal streak given by dump
- Optical Replica Synthesizer (ORS) needs to be integrated

- FODO cell length = 7.6 m
  → only 2 FODO cells

Diagnostic Section Engineering layout (1)

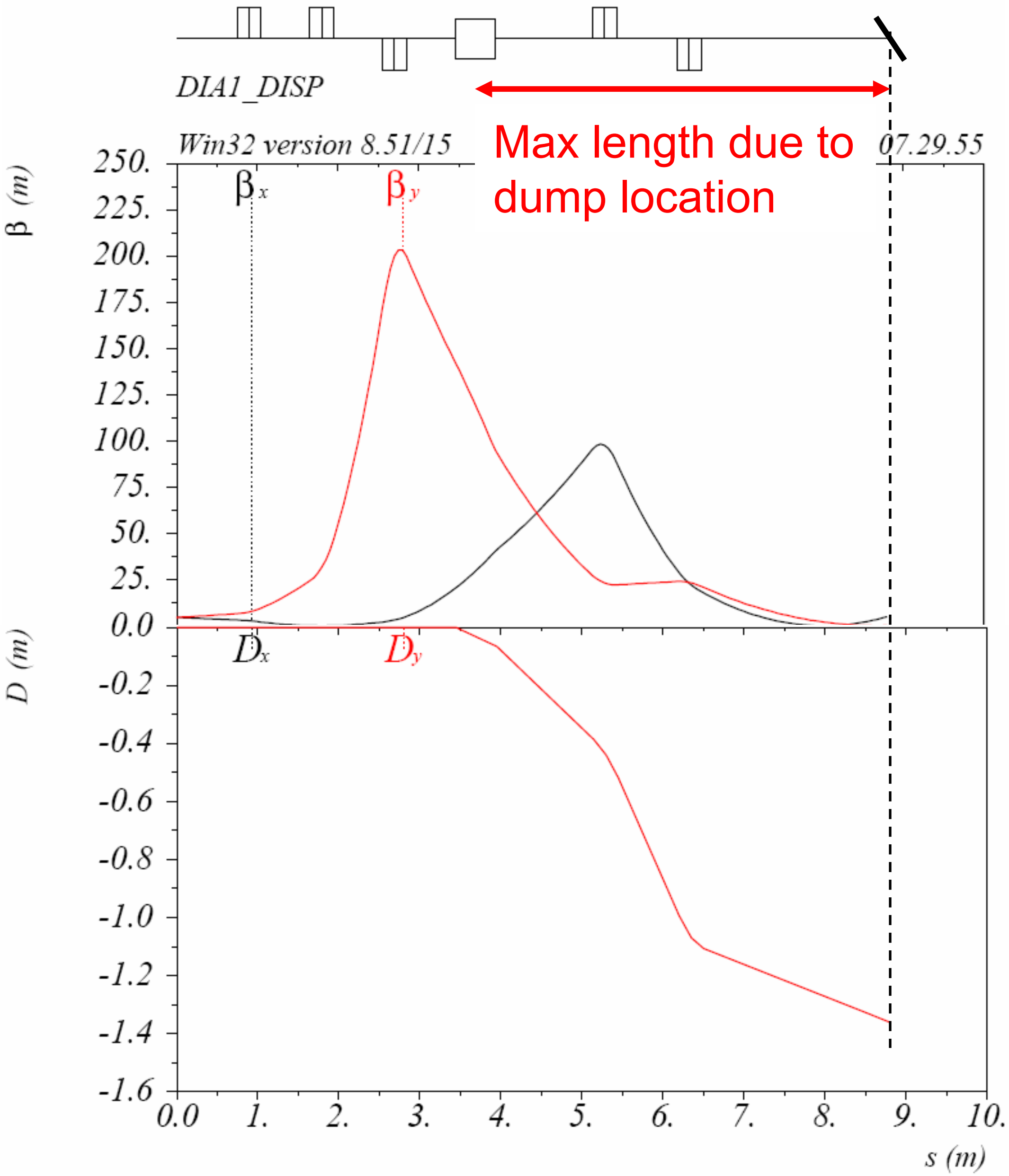


Optics Layout Diagnostic Section 1
Slice emittance measurements 76 deg (optic 1)



Resolution only in y: long. Profile: 11 fs, slice emittance: 11 fs

Diagnostic mode 2: Energy Spread (optic 4)



Goal: $\Delta E/E \sim 10^{-5}$
→ $\Delta E \sim$ 5keV
from meas. at FLASH

Laser Heater (30 keV)

Values at screen:
ßx = 10.5 m
ßy = 8.0 m
Dy = -2.2 m

→ $\Delta E/E \sim$ 2.1*10-5
$\Delta E \sim$ 40 keV
ε_N = 1*10-6 µm

Higher order effects?
Chromaticity?
Needs to be studied

Conclusions (1):

For which bunch rep rate, 5MHz or 1MHz, shall the on-line slice emittance diagnostics be designed in BC1:

- Desired resolution can easily be reached at 1 MHz but is just at the theoretical limit for 5 MHz.

- Kickers with the required kick strength for 1MHz are in operation in several machines at DESY ('off-the-shelf').
5 MHz would requires new design and prototype development.

- If standard FEL operation will be 5 MHz slice emittance diagnostics cannot be operated parasitically if designed for 1 MHz (or might not be used if resolution is not sufficient).

- If standard FEL operation will be 1 MHz one would lose at least a factor of 1.6 in resolution if designed for 5 MHz

Conclusions (2):

Dump defines the horizontal streak direction in BC2.
If the BCs are installed vertically slice emittance could be measured in the bend plane of BCs.

Number of quads in current layout
BC1 was 22 now 22
BC2 wsa 13 now 19

New lattice layout requires slightly more space
BC1: 1.5 m in BC + 0.9 m in diag section = 2.4 m
BC2: 1.0 m in BC + 1.5 m in diag section* = 2.5 m
***Additional FODO cell for 45 deg lattice requires 7.6 m more space**

Layout of the dignostics sections can be arranged in modules. Components can be prealigned and tested. This saves time during installation and commissioning.

Layout of BC1 diagnostic section almost finalized.
After beam dynamic and sensitivity studies (2 months) the vacuum and engineering layout could be started

Thanks to

Markus Huening	(TDS calculations)
Norbert Meiners	(Tunnel layout)
Michael Schnitz	(Dump)
Frank Obier	(Kicker)
Dirk Noelle	(Standard Diagnostics)
Bernhard Schmidt	(Special Diagnostics)
Albrecht Leuschner	(Radiation Safety)
Winni, Nina, Vladimir	(Lattice layout & matching)