Shaping the Future of the European XFEL: Options for the XTD3/XTD5 Tunnels

European XFEL Beam Distribution Geometry

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DESY

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European XFEL Layout

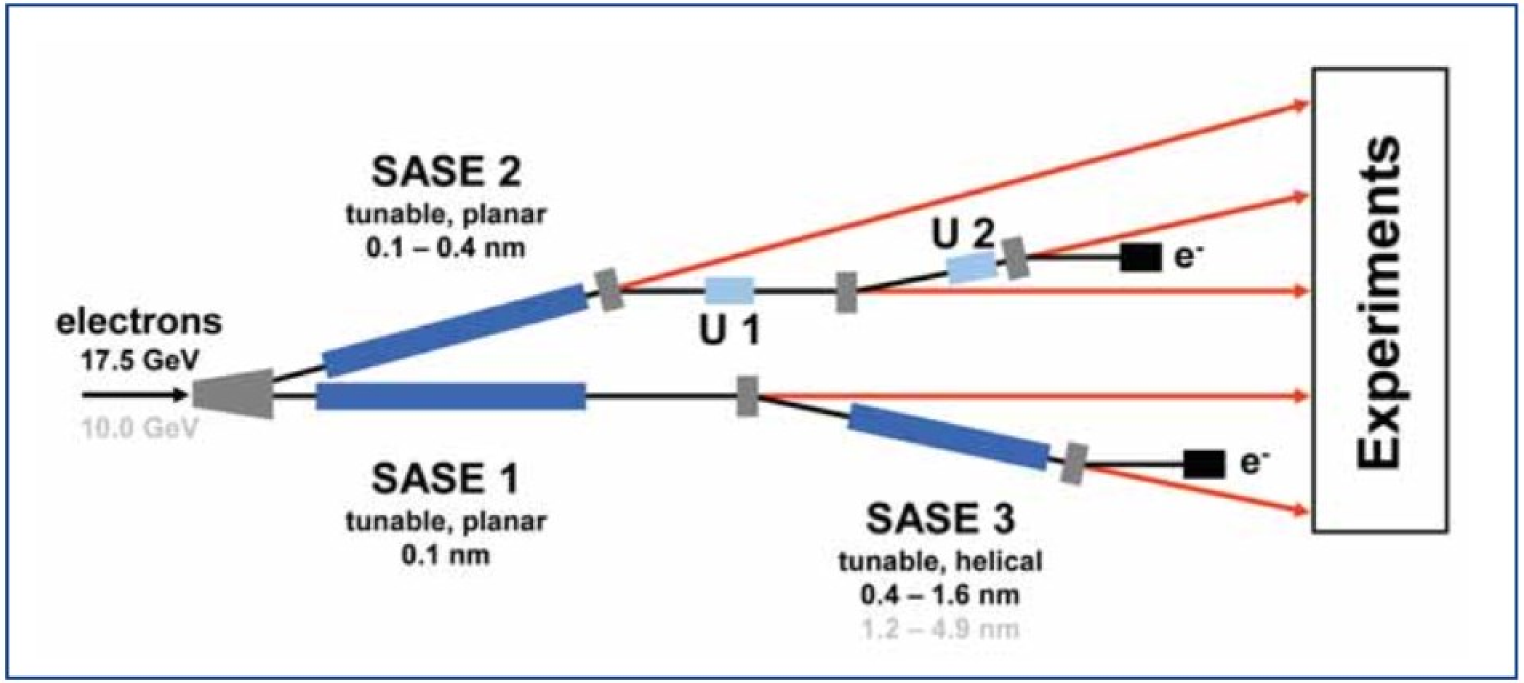


Figure 3.1.2 *Schematic view of the branching of electron (black) and photon (red) beamlines through the different SASE and spontaneous emission undulators. Electron beamlines terminate into the two beam dumps, photon beamlines into the experimental hall.*

Maximum linac energy:
20 GeV
Beam line components:
Up to 25 GeV

European XFEL TDR 2007

Distribution Design Criteria

If you want to shape the future you should know the past ….

Beam dynamics considerations for arcs:

Assumptions: E = 25 GeV, $\gamma\varepsilon = 0.5$ *mm mrad*

Emittance increase due to **incoherent Synchrotron Radiation** < 1 % per 1 deg deflection

$$\Delta\gamma\varepsilon \propto E^6 I_5,\ I_5 = \int_{dipole} \frac{H}{|\rho^3|} ds,\ H = \gamma D^2 + 2\alpha D D' + \beta D'^2$$

Coherent Synchrotron Radiation

- as little bending as possible
- smaller bending radius favorable $\Delta E \propto \rho^{\frac{1}{3}}$

=> Average radius of arcs around 300 m

Bending Systems: Requirements

- Beam transport for large energy spread/chirp or energy variations along bunch train => achromatic (R_{16} ,R_{26} etc. =0)
- Maintain (or even fine tune) compression for energy chirped bunches (left over from previous compression, longitudinal space charge, wakes) => tune R_{56}
- Minimize CSR induced energy spread increase => minimize total bending angle
- Minimize CSR induced transverse emittance growth => optimize beam optics
- Prevent additional micro-bunching instability gain => tune R_{56},optimize beam optics
- Energy collimation => decouple dispersion and beta function, provide large dispersion to maximize collimation apertures
- Match all geometric and engineering constraints
- ….

Distribution Design Criteria

If you want to shape the future you should know the past …

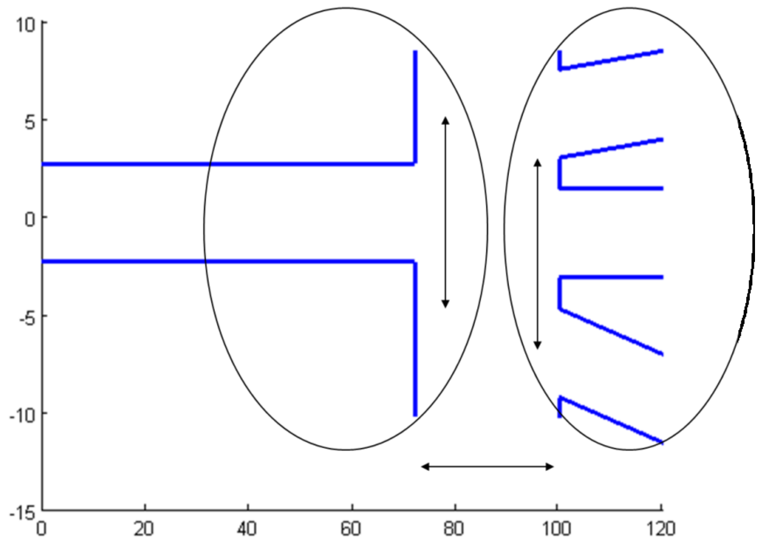
Experimental hall specifications:

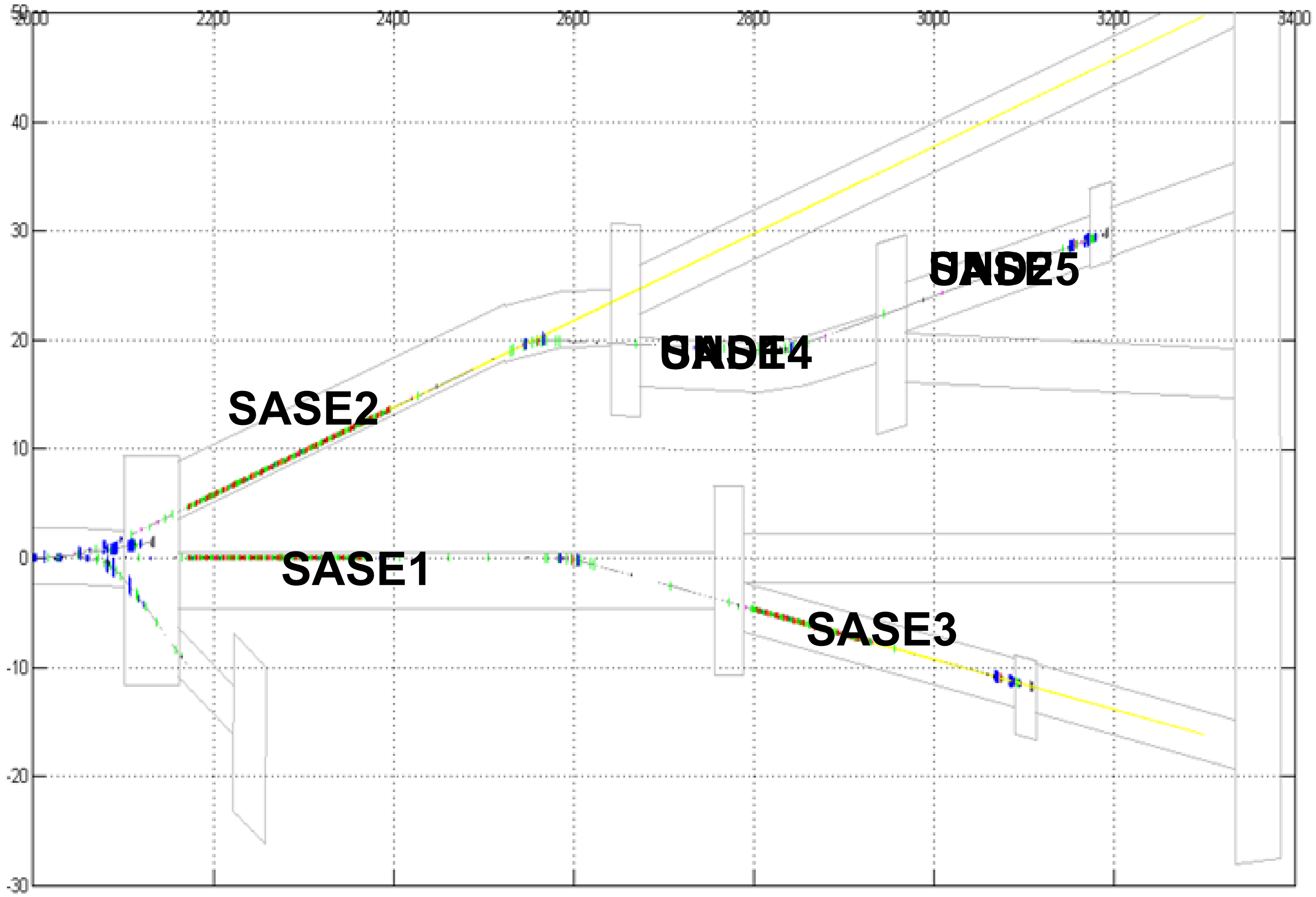
- SR-Experiments with 17 m spacing
- SASE1 and SASE2 beamlines are 800 m long
- SASE1 and SASE2 are 250 m plus options
- ≈1300 m from end of XS1 shaft

Designer: Walter Graeff

Tunnel specifications:

- 5.2 and 4.5 m diameter
- Minimize size of shaft buildings
- Minimum distance between some tunnels due to radiation protection

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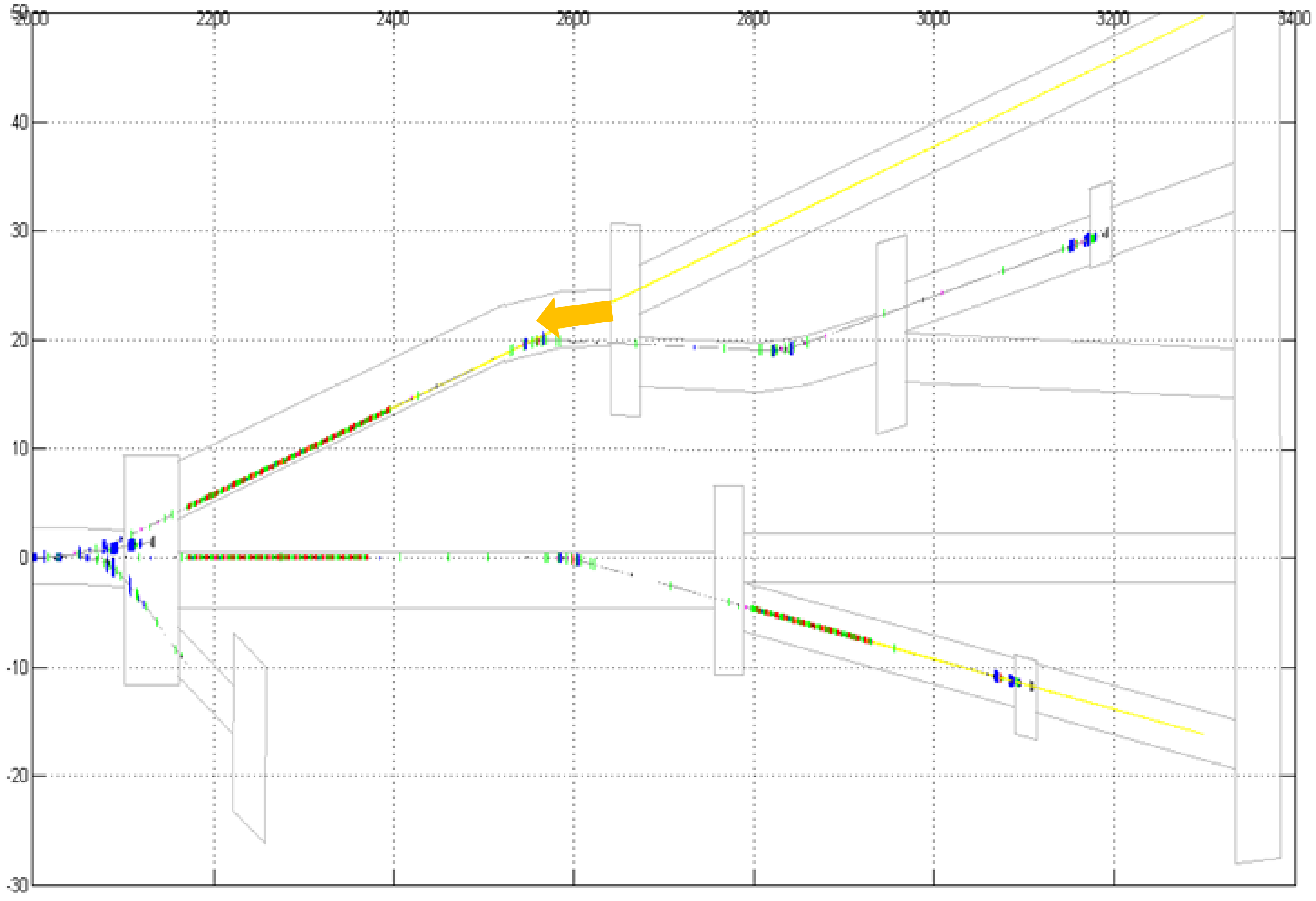
SASE2
SASE1
SASE3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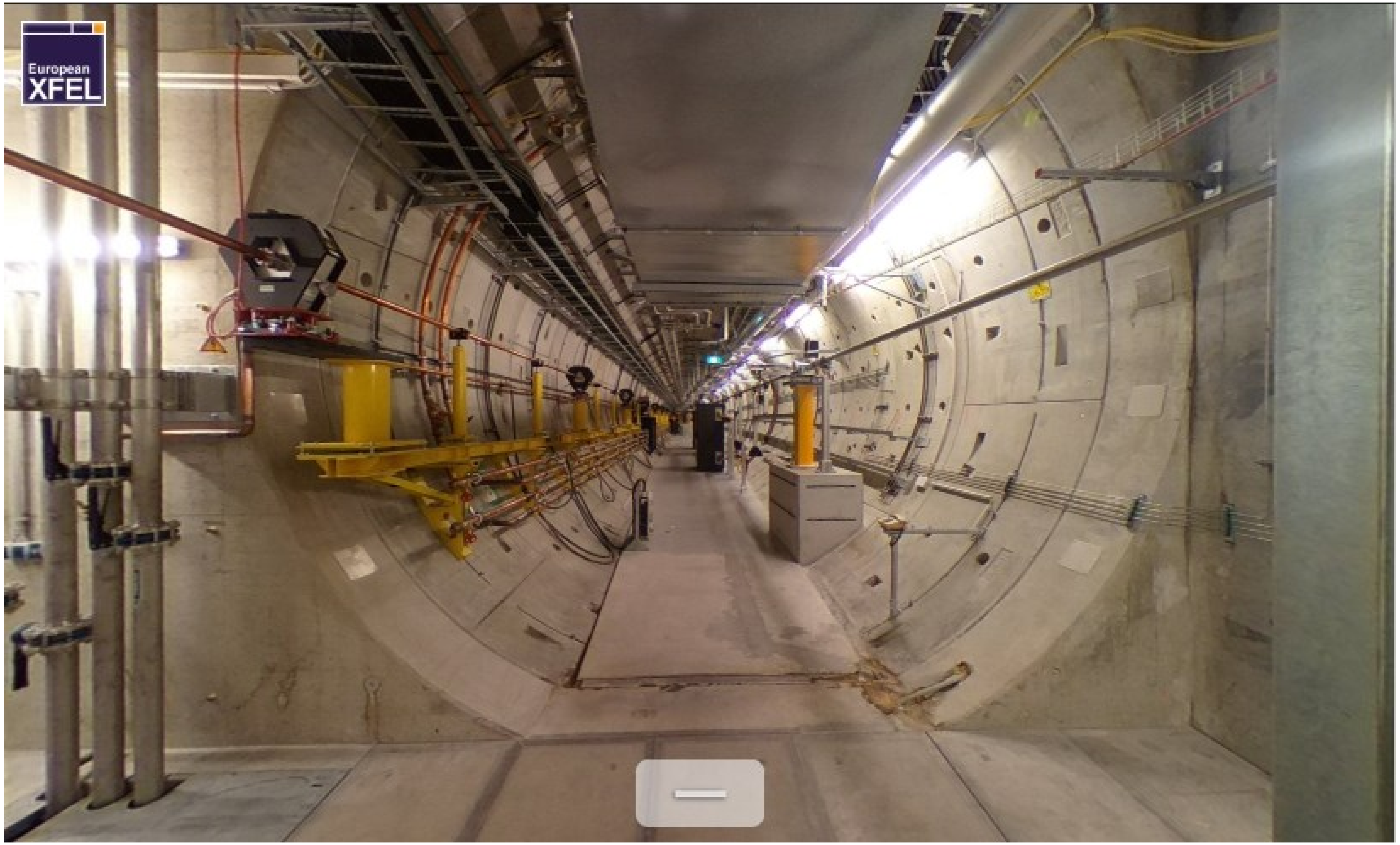
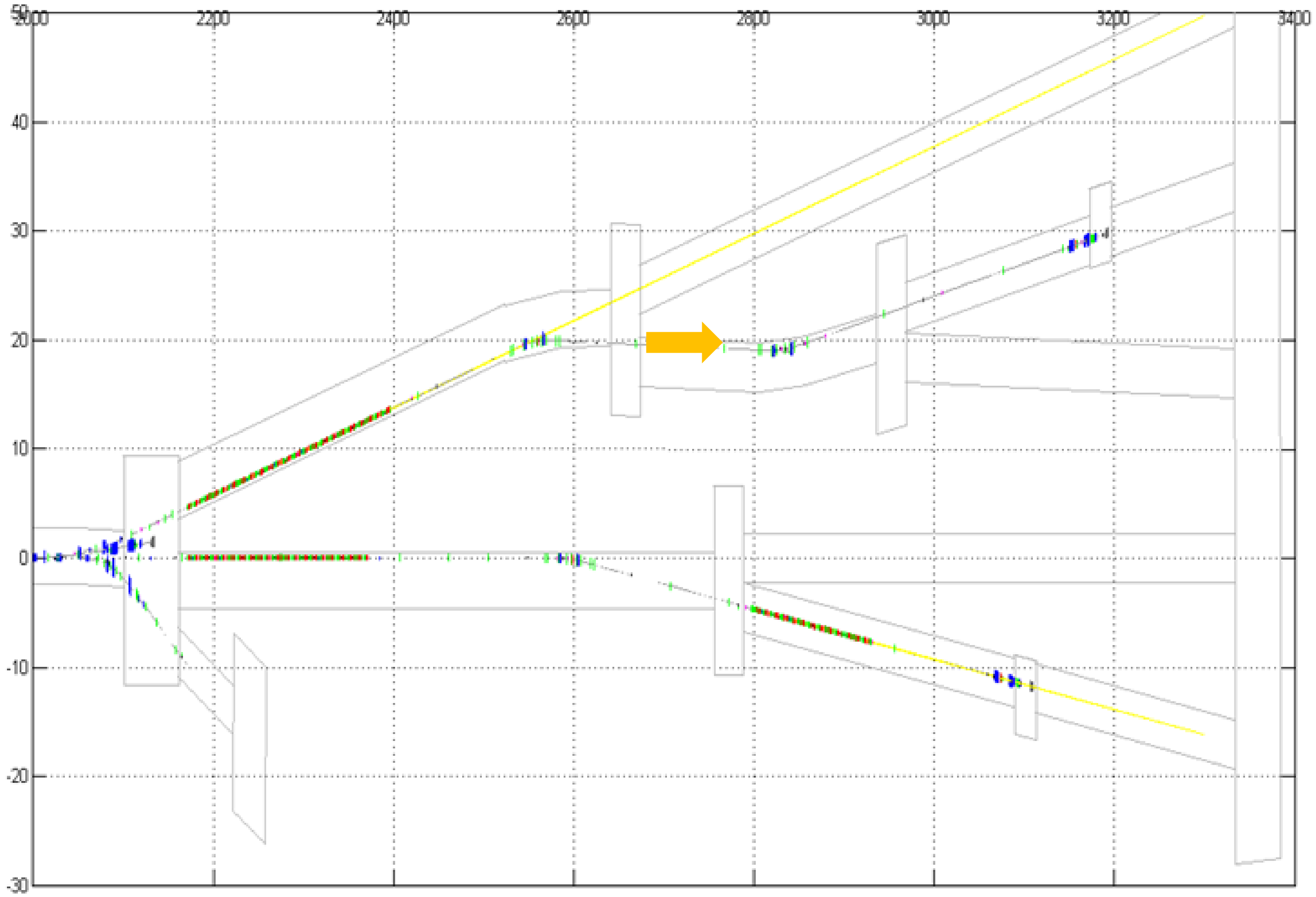
http://xfelmd.desy.de/vtour/

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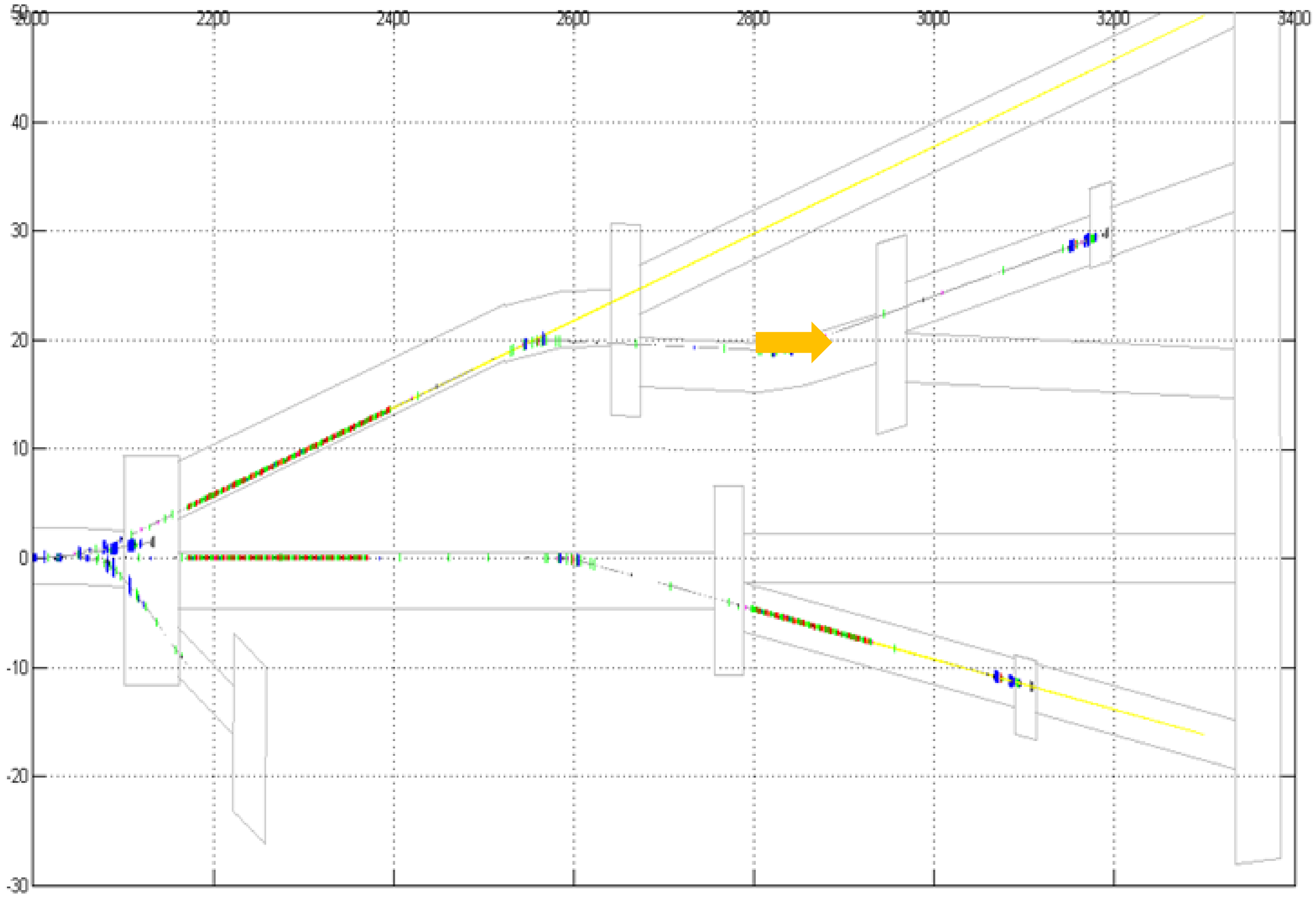
Current virtual tour 1: XS2 > 2018-09-07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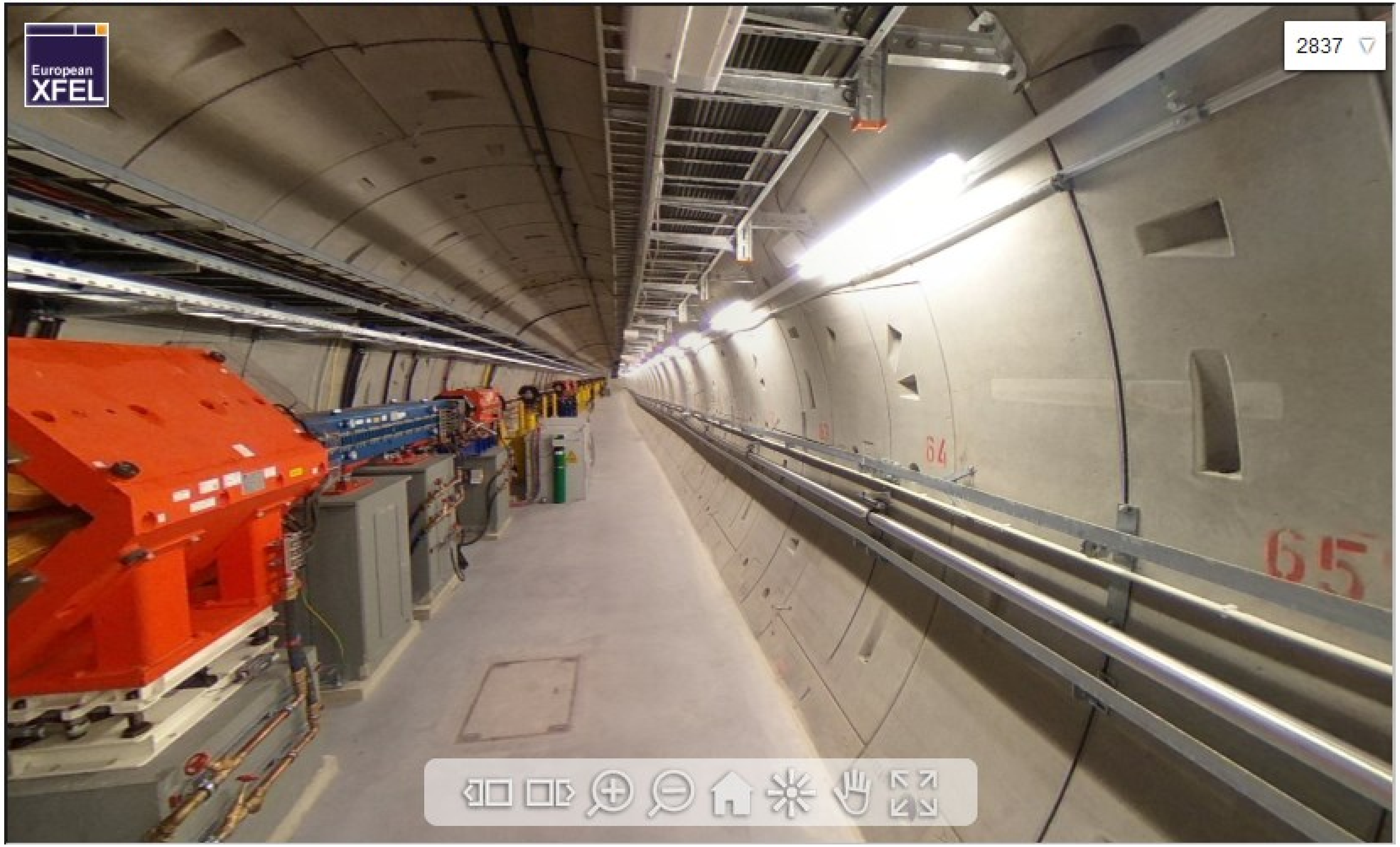
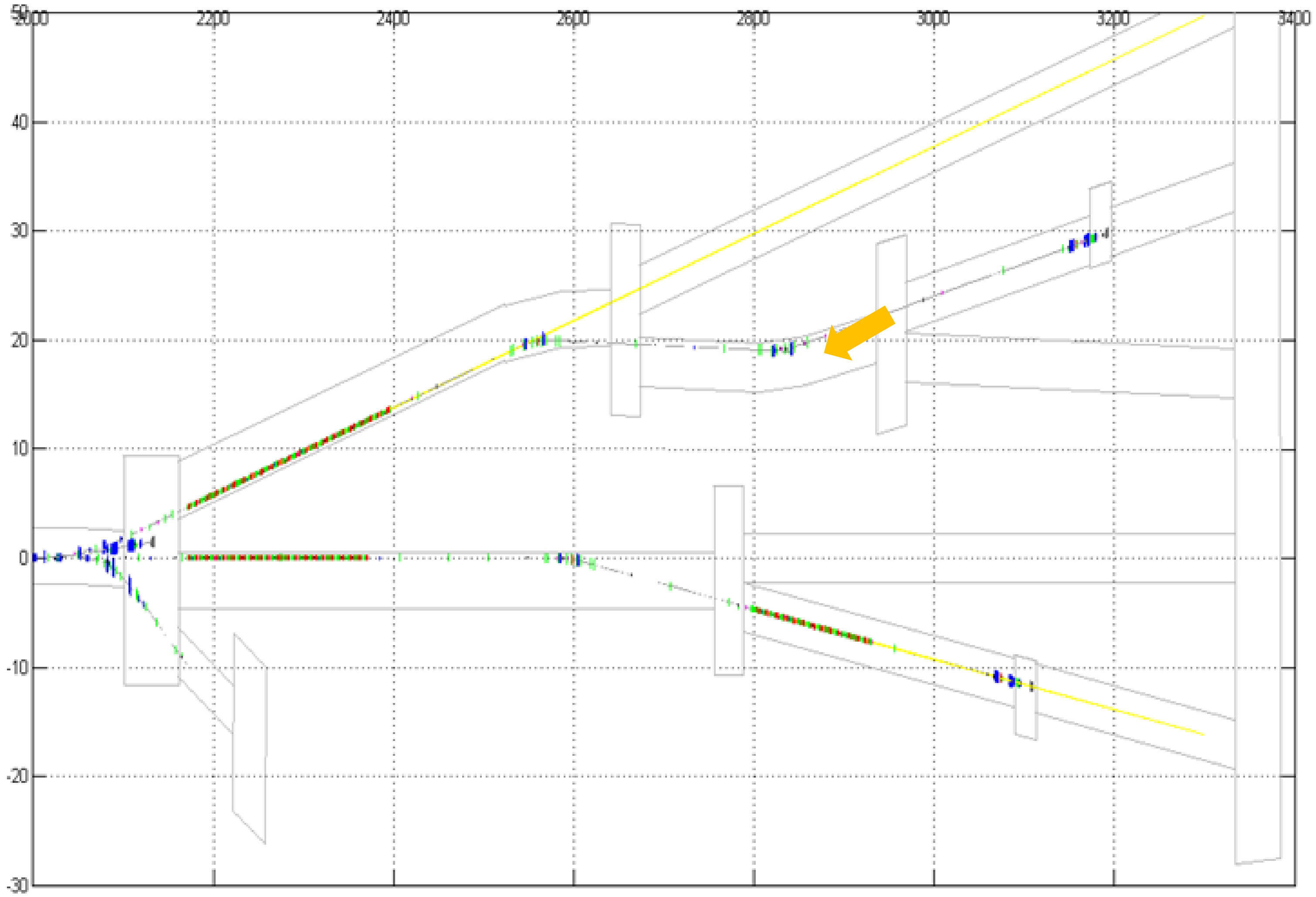
Current virtual tour 1: XTD03 > 2018-07-25

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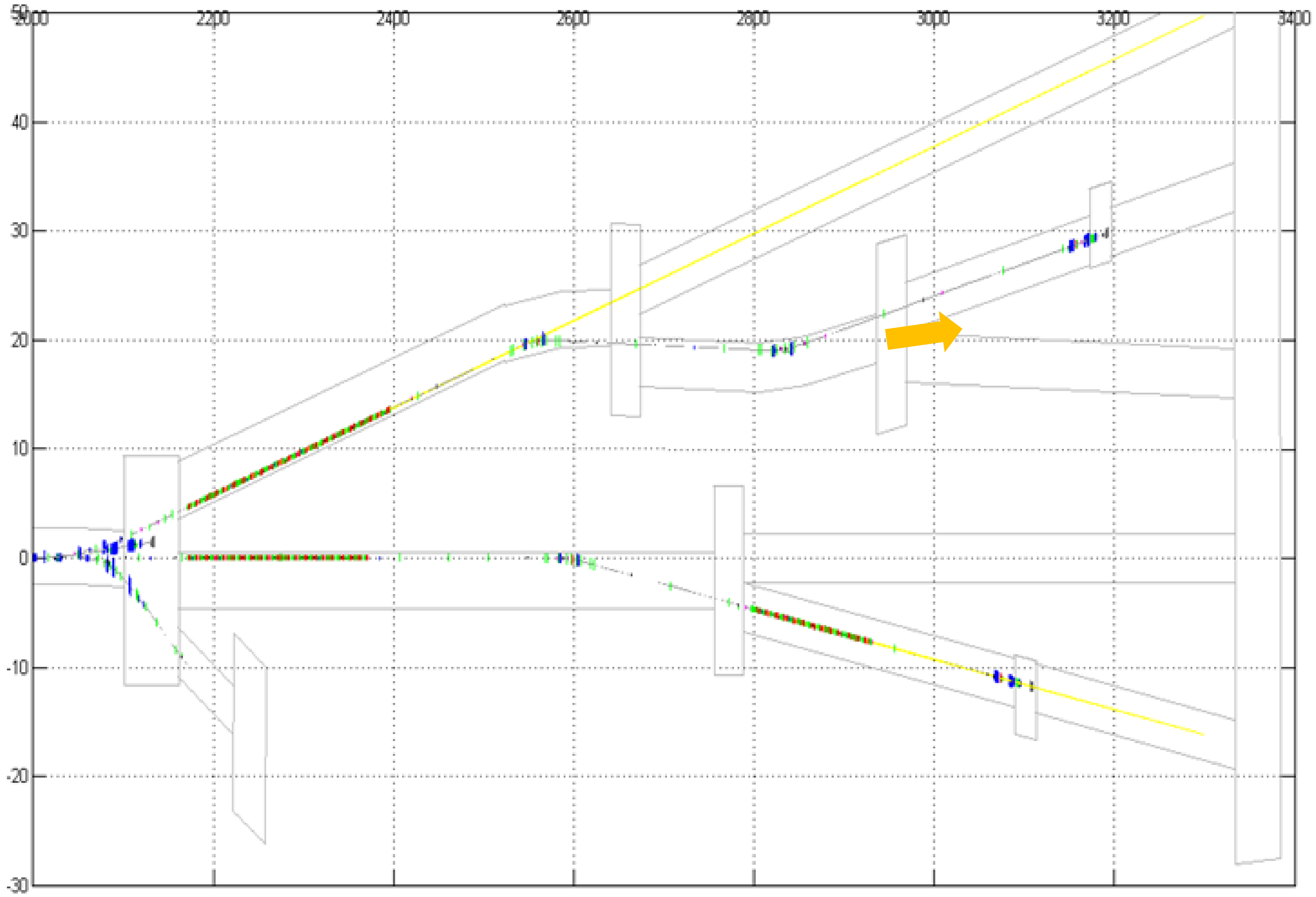
Current virtual tour 1: XS4 > 2018-07-25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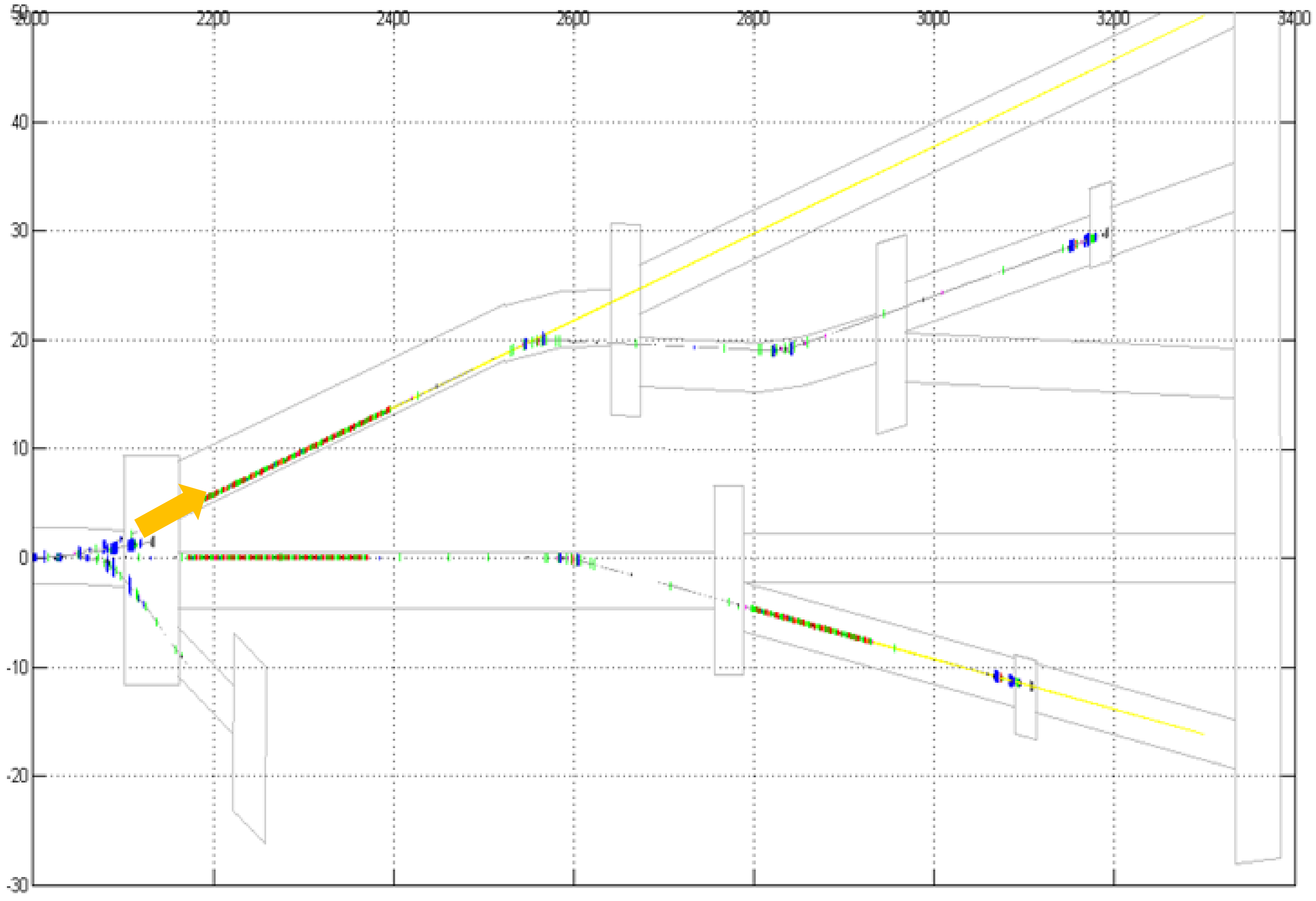
Current virtual tour 1: XS2 > 2018-09-07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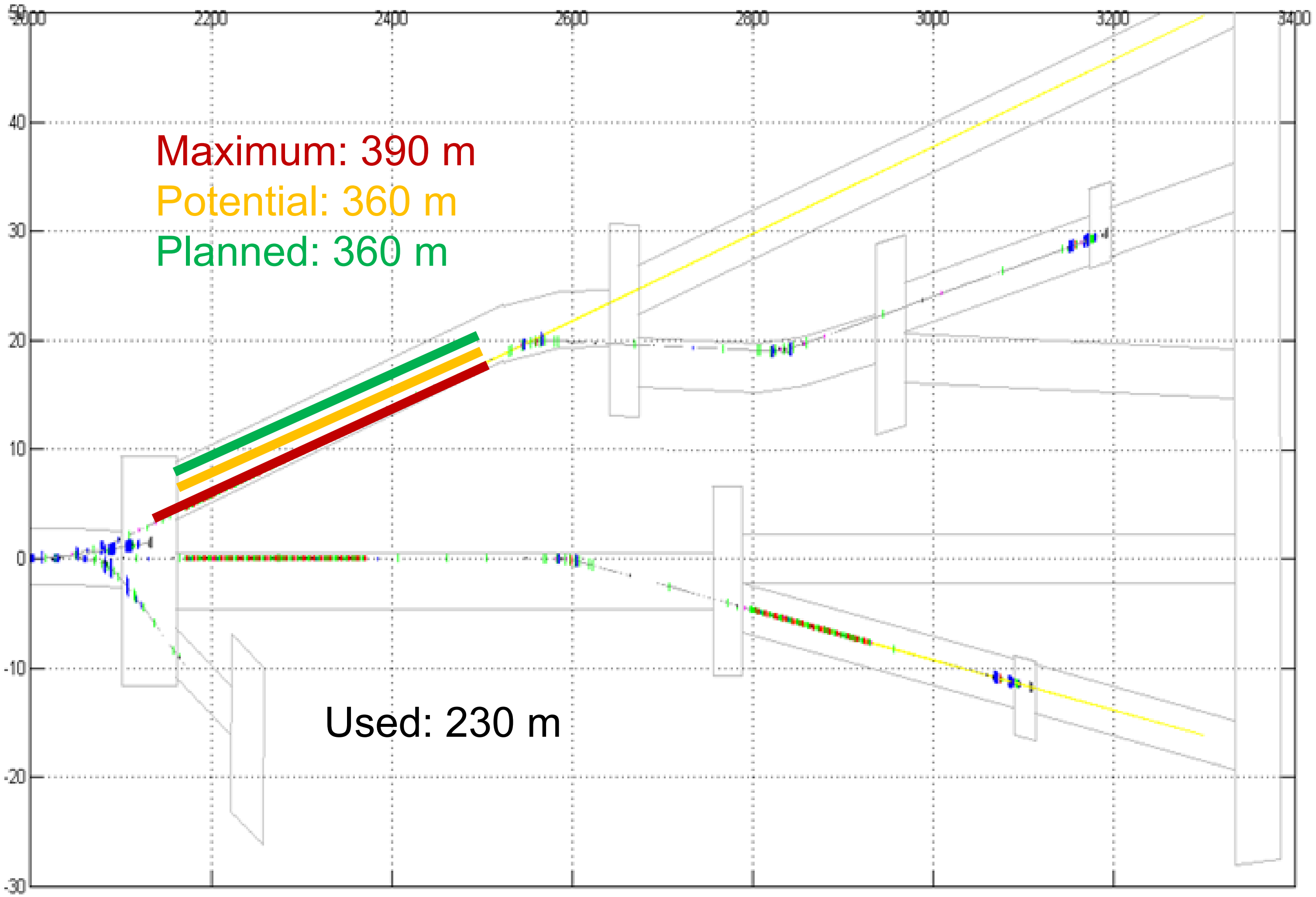
Current virtual tour 1: XTD02 > 2018-04-13

Definitions

- Maximum available straight length: Distance between up- and downstream bending systems (note that this starts/ends about 30m before a bending magnet to allow for optics matching)
- Potential available straight length for undulator installations: Obeys fixed building constrains like tunnel walls / shielding walls
- Planned available straight length: Obeys infrastructure limits like ventilation walls, transport and escape routes that might be altered

SASE2 (XTD1)


Maximum: 390 m
Potential: 360 m
Planned: 360 m
Used: 230 m
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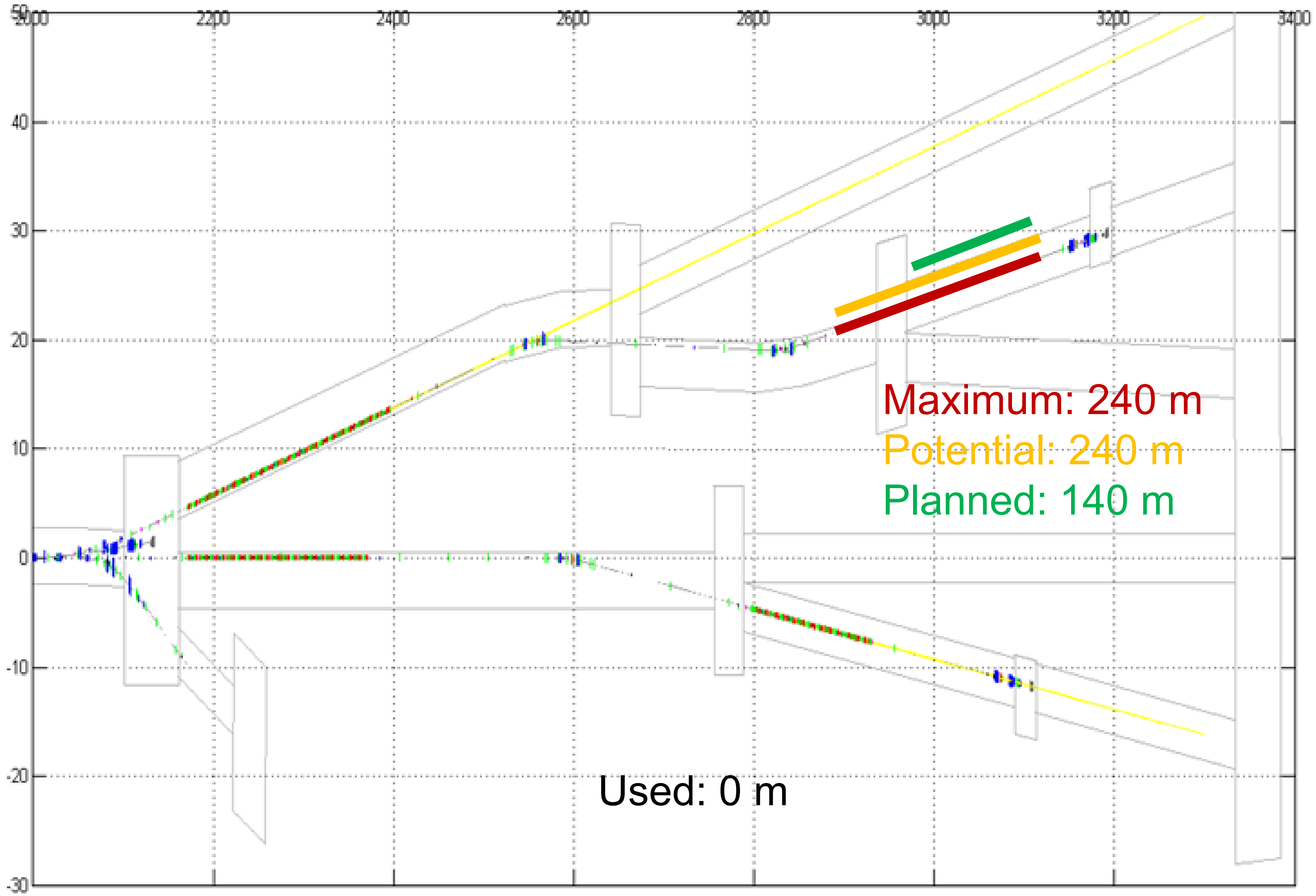
SASE5 (XTD5)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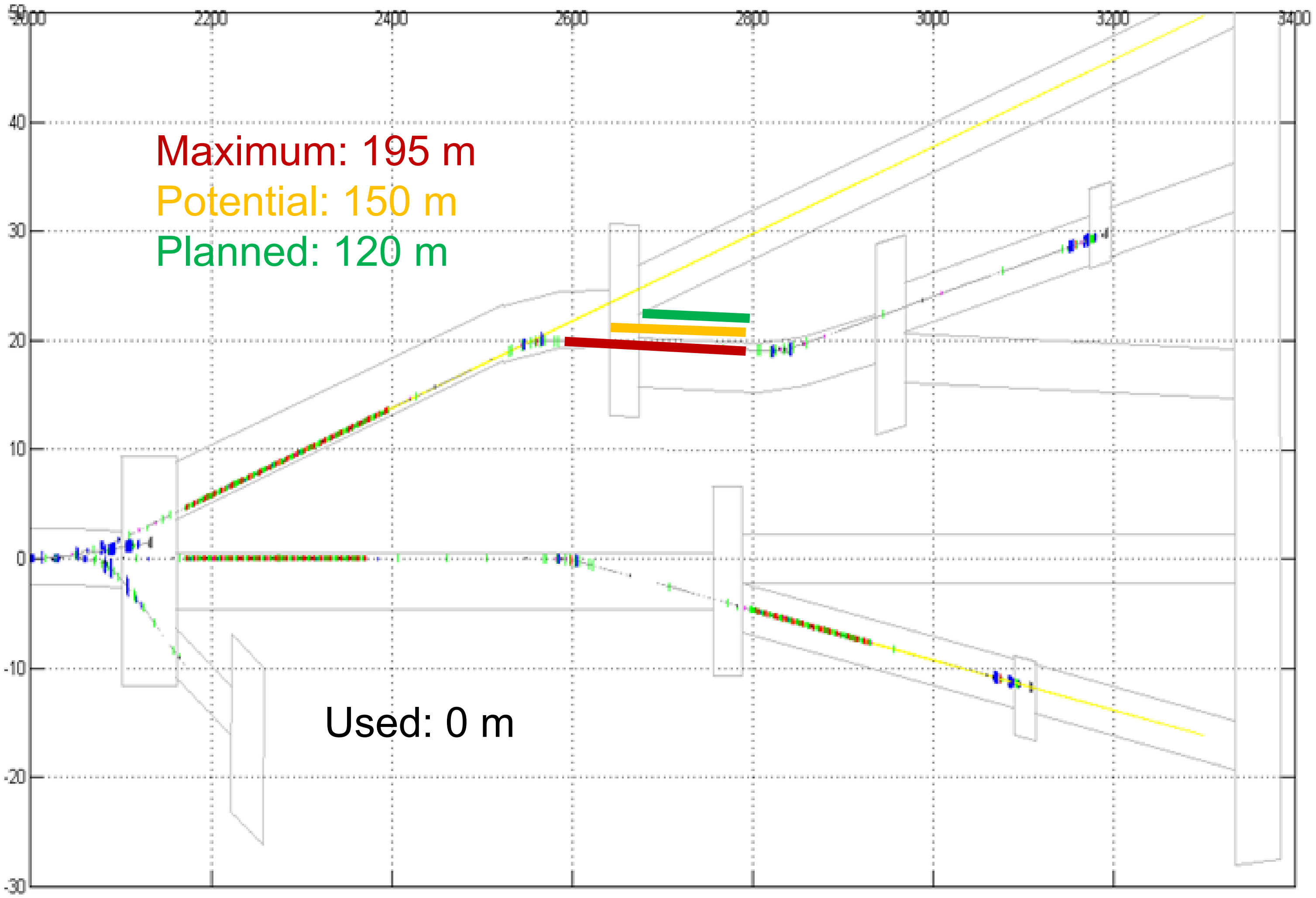
Maximum: 240 m
Potential: 240 m
Planned: 140 m
Used: 0 m

SASE4 (XTD3)


Maximum: 195 m
Potential: 150 m
Planned: 120 m
Used: 0 m
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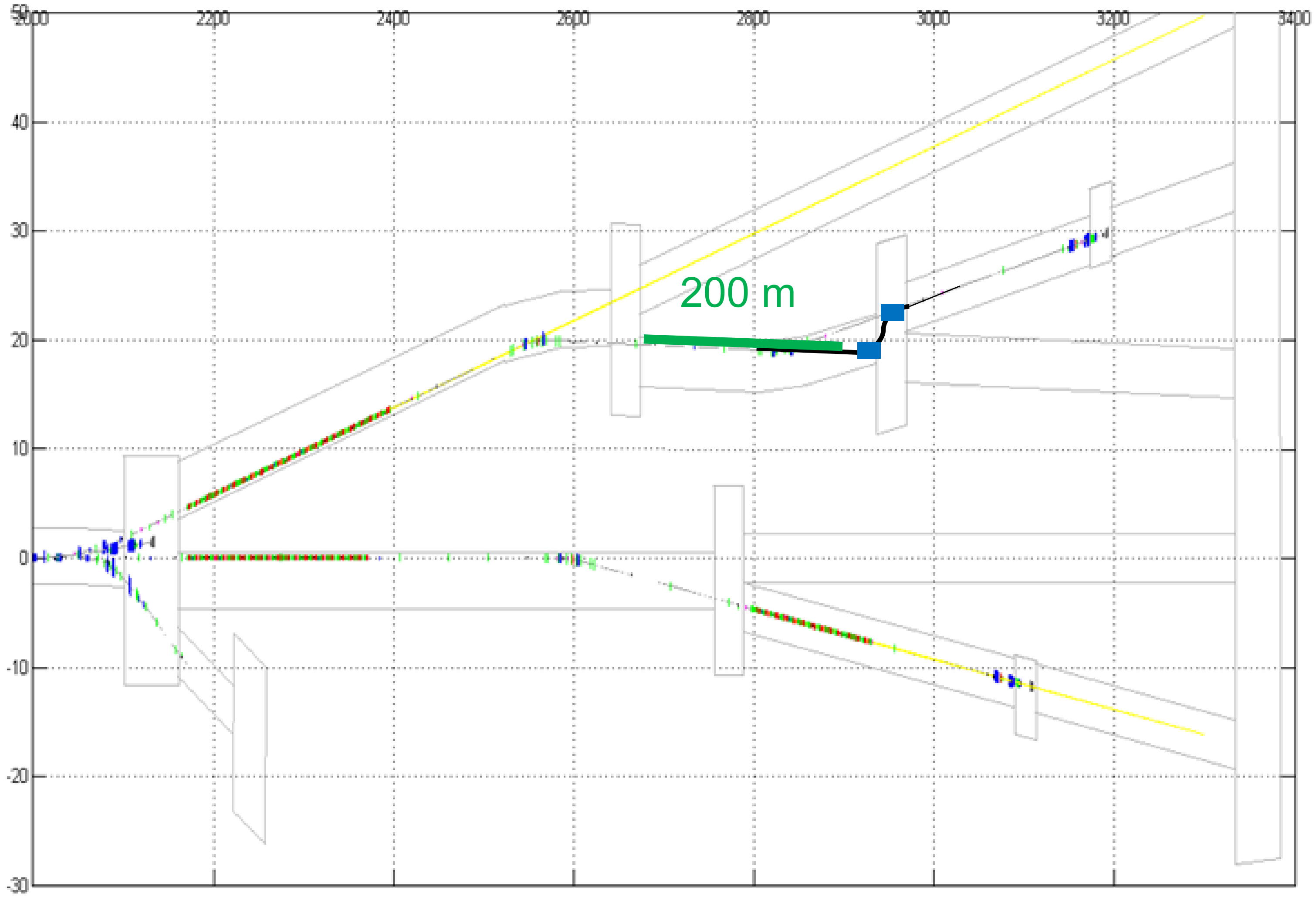
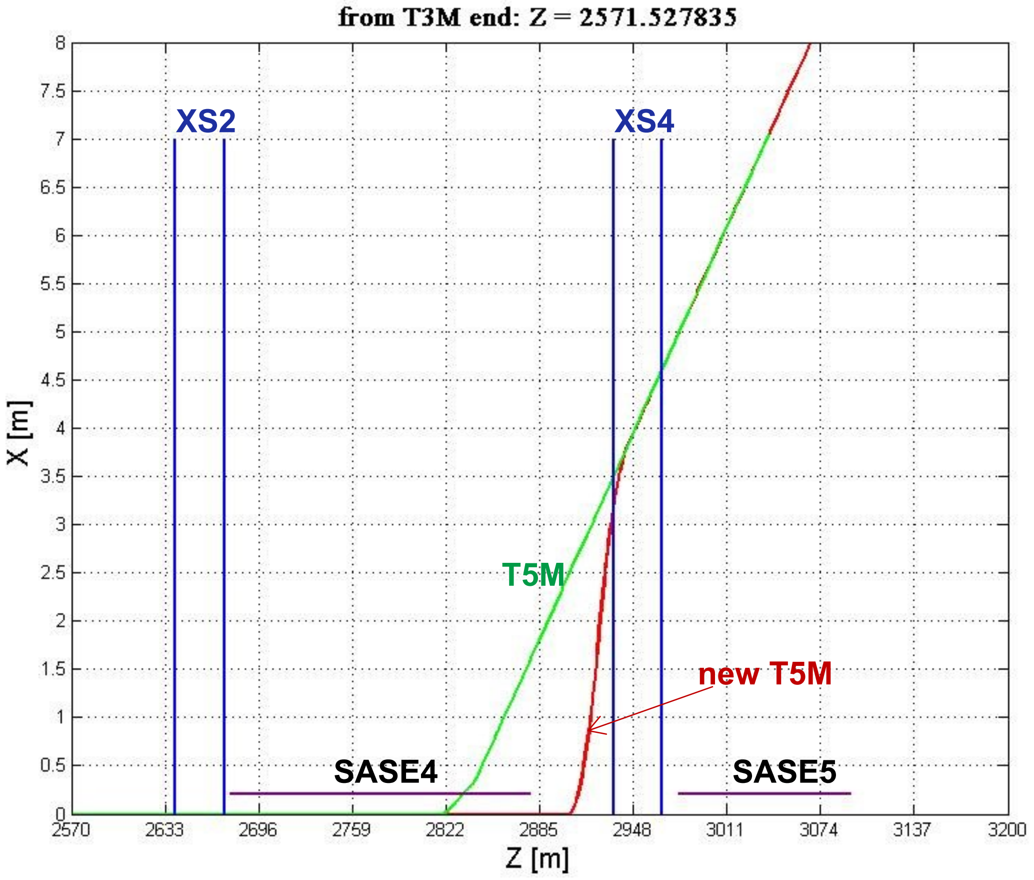
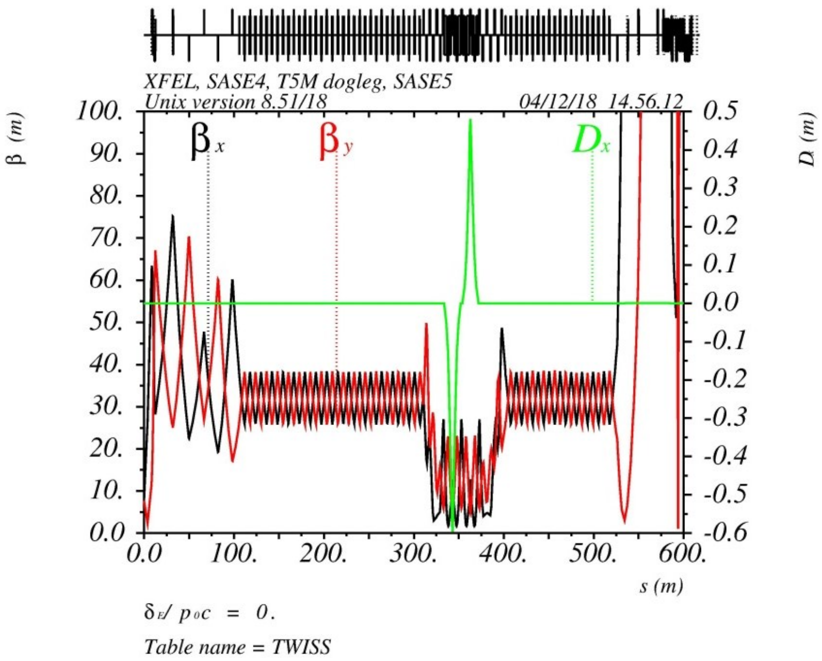
SASE4 (XTD3) – Shift of bending system



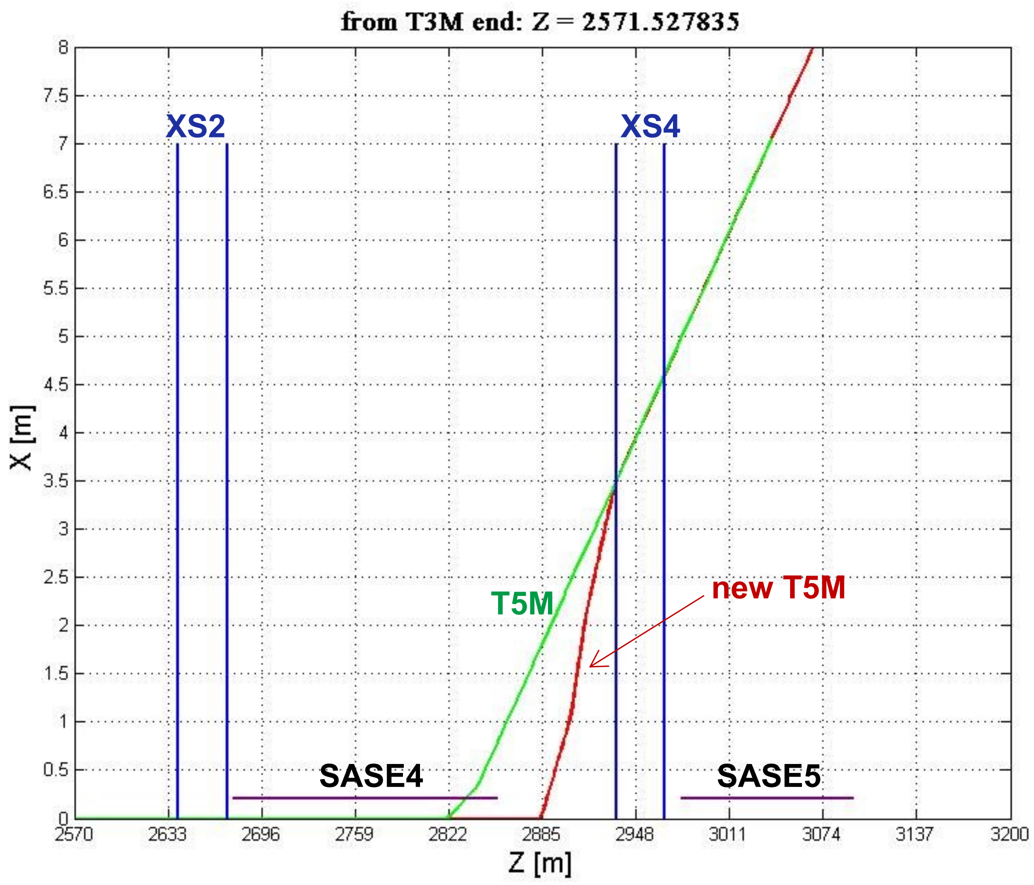
new T5M: dogleg



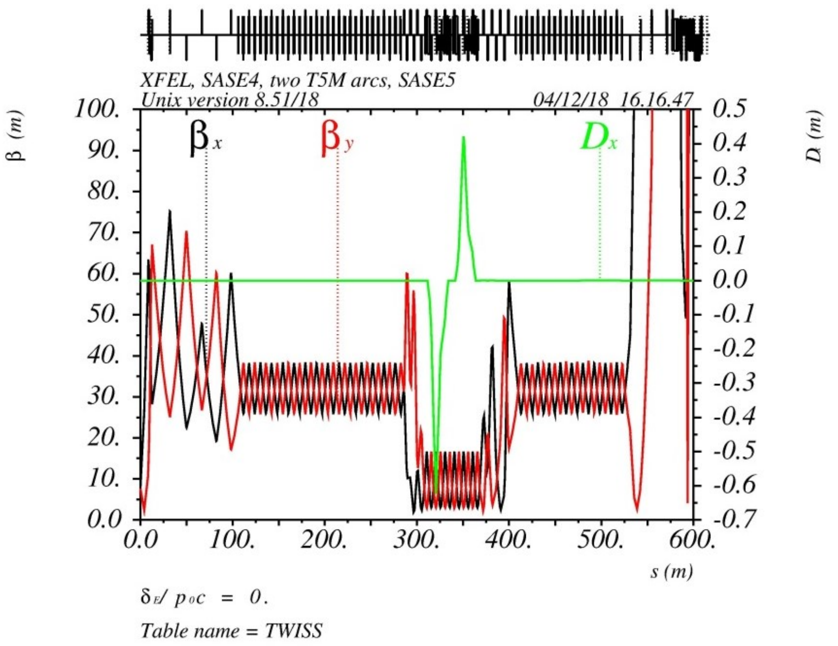
- SASE4: 33 segments, 6.1*33=201.3 m (5*33=165 m)
- matching section between SA4 and new T5M: ~ 25 m
- matching section between new T5M and SA5: ~ 28 m
- SASE5: 19 segments, 6.1*19=115.9 m (5*19= 95 m)
- T5D section (tuning of beam size at T5D dump): L ≈ 60m
- new T5M arc: dogleg
  - L ≈ 40 m
  - 4 BV dipoles: -10 deg (2.5 deg per magnet)
  - 4 BV dipoles: +10 deg - 1.9423 deg
  - R56 = -0.047 m



new T5M: two T5M arcs



- SASE4: 29 segments, 6.1*29=176.9 m (5*29=145 m)
- matching section between SA4 and new T5M: ~ 25 m
- matching section between new T5M and SA5: ~ 38 m
- SASE5: 19 segments, 6.1*19=115.9 m (5*19= 95 m)
- T5D section (tuning of beam size at T5D dump): L ≈ 55m
- new T5M arc: two T5M arcs
  - L ≈ 60 m
  - 2 BV dipoles: -6 deg (exceed the limit at 22 GeV)
  - 2 BV dipoles: +6 deg - 1.9423 deg
  - R56 = -0.0033 m



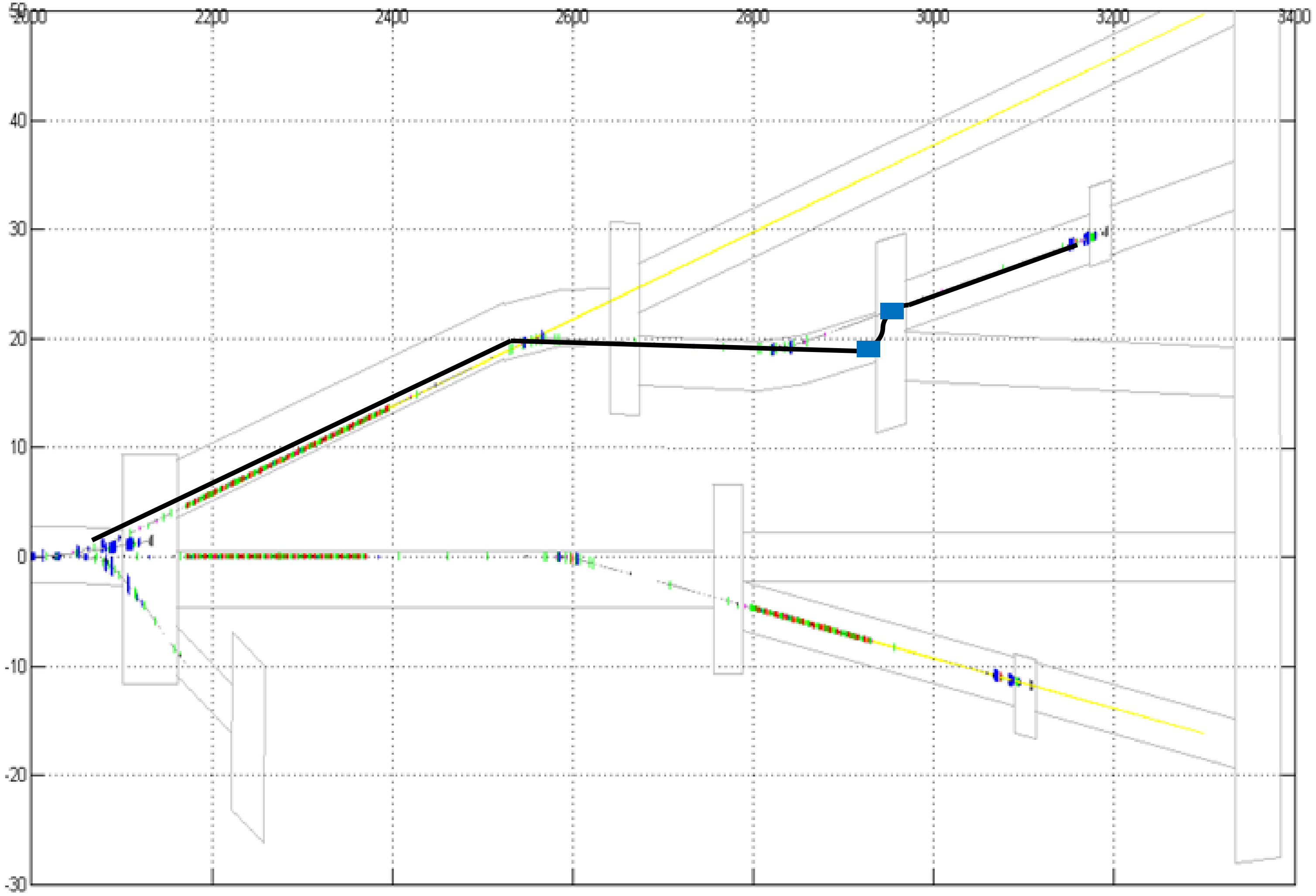
Summary tunnel length

	SASE2 (XTD1)	SASE4 (XTD3)	SASE5 (XTD5)
Presently used length	230	0	0
Presently possible max. length	360	120	140
Possible max. length with alterations to tunnel infrastructure	360	150	240
Possible length with alterations to electron lattice	360	200	120
Length of photon beamline	900	400	200

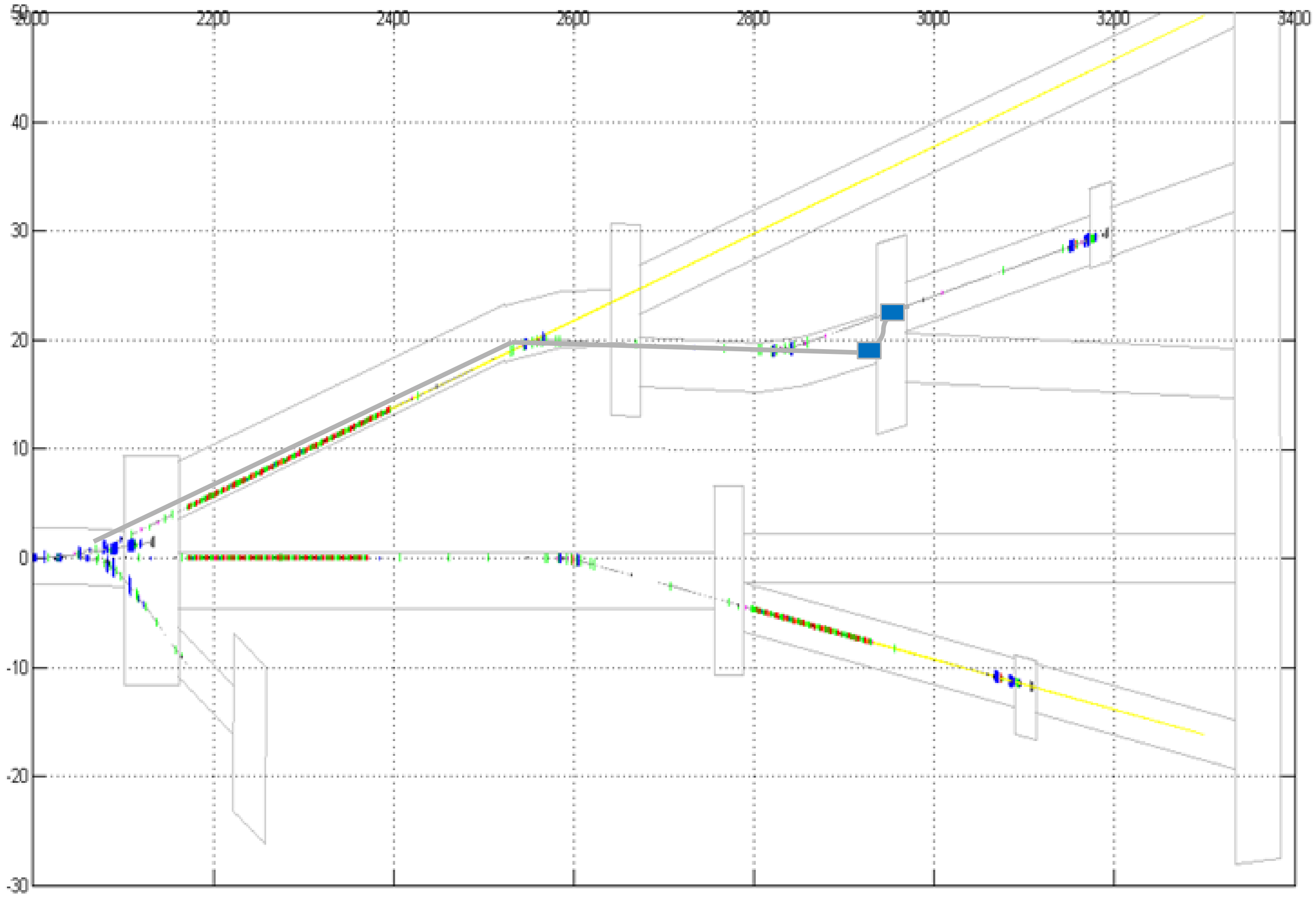
Beam Distribution Aspects

- SASE2/4/5 in series (like SASE1/3)
- Fresh bunch technique works but imposes severe constrains on flexibility and experimental conditions
- Study alternative solutions with bunch separation in XS1 (as for SASE1/2) and bypass lines
  - More flexibility for experiments
  - Avoids beam quality deterioration due to wake fields and incoherent synchrotron radiation
  - Requires construction of many hundred meters of bypass beamlines

SASE4 beam



SASE2/5 beam



Conclusions

- Usage of XTD3/5 for long SASE undulators is possible but will require serious construction work

- Several engineering aspects have to be investigated in addition to physics aspects:
  - Tunnel ventilation
  - Tunnel transport
  - Fire safety
  - Smoke extraction
  - Tunnel escape routes
  - Plan approval impact
  - …

- The present layout is the result of a many year optimization process. Similar effort has to be taken for implementation of SASE4/5 options.

- Reconstruction will take time