Progress on sFLASH design

V. Miltchev on behalf of the sFLASH team

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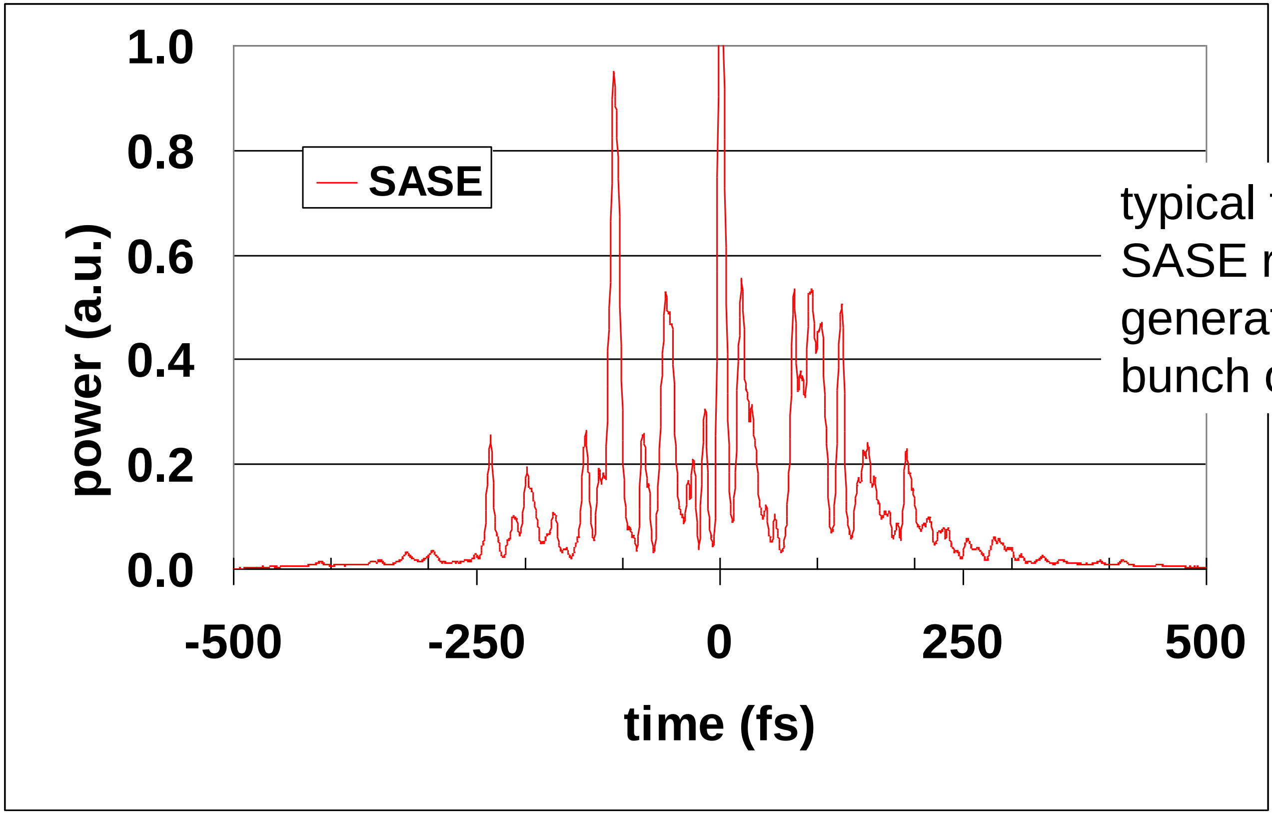
Motivation



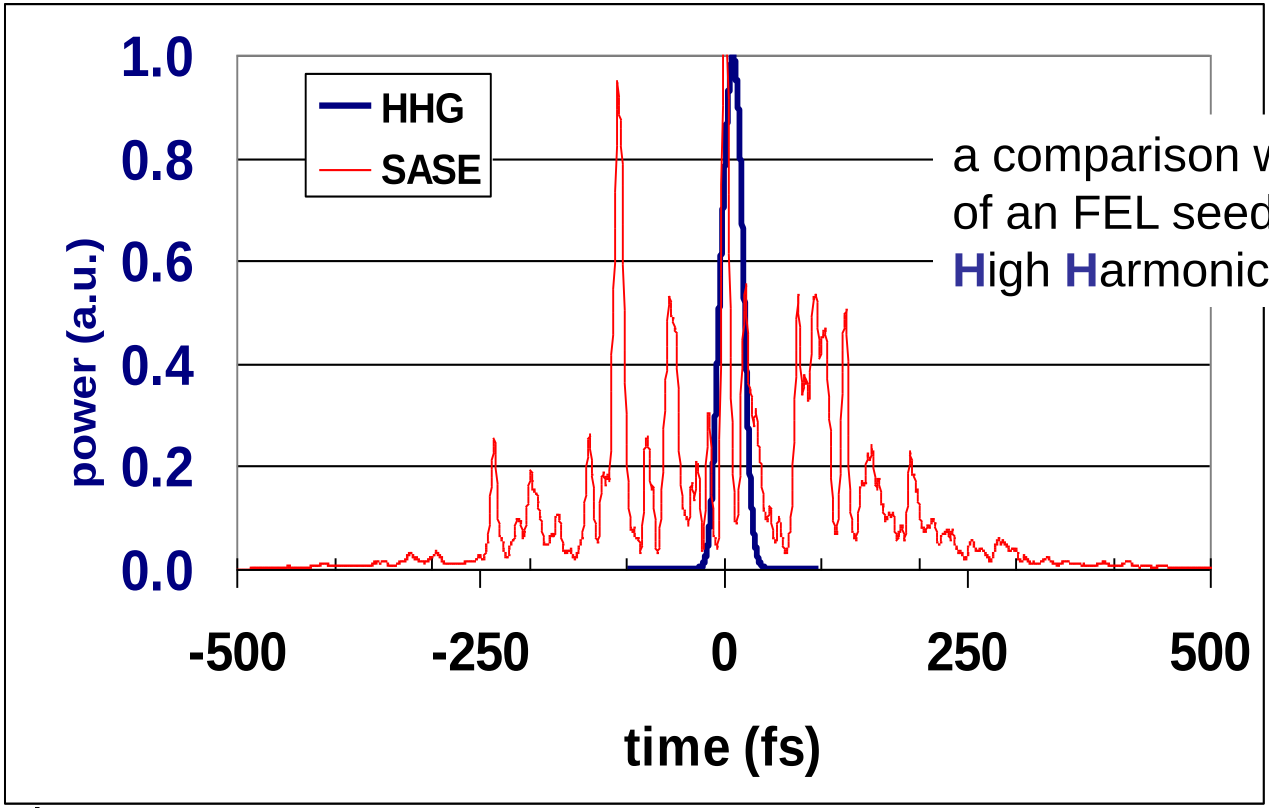
typical temporal profile of a SASE radiation pulse, generated by an electron bunch of $\sigma_t \approx 250$ fs

Due to the start up from noise:

$\Rightarrow$ shot-to-shot fluctuations of the pulse energy

$\Rightarrow$ the output consists of a number of uncorrelated spikes (poor temporal coherence)

Motivation



a comparison with the output of an FEL seeded using **H**igh **H**armonic **G**eneration (**HHG**)

goals:

⇒ high shot-to-shot stability and high peak power (GW level)

⇒ generation of fully coherent pulses of variable length (20–40 fs FWHM)

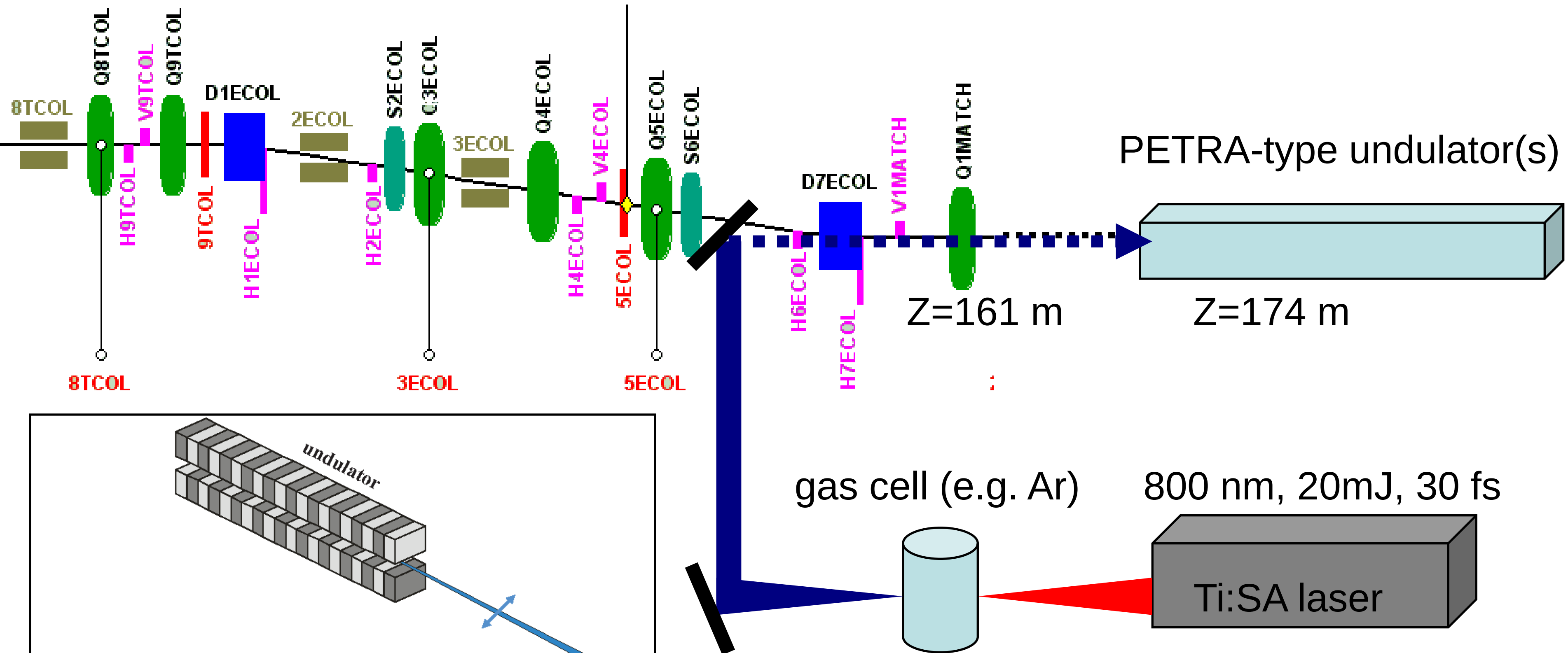
⇒ wavelength range ~12-40 nm

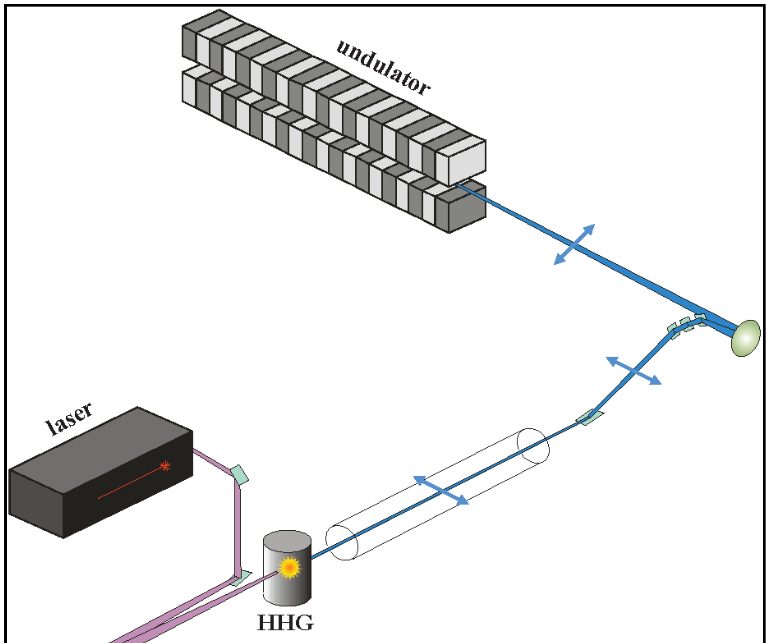
⇒ reduction of saturation length

⇒ HHG runs in ‘parasitic’ mode, i.e. parallel to the normal SASE operation

⇒ pump probe experiments with fs synchronization

sFLASH schematic set up



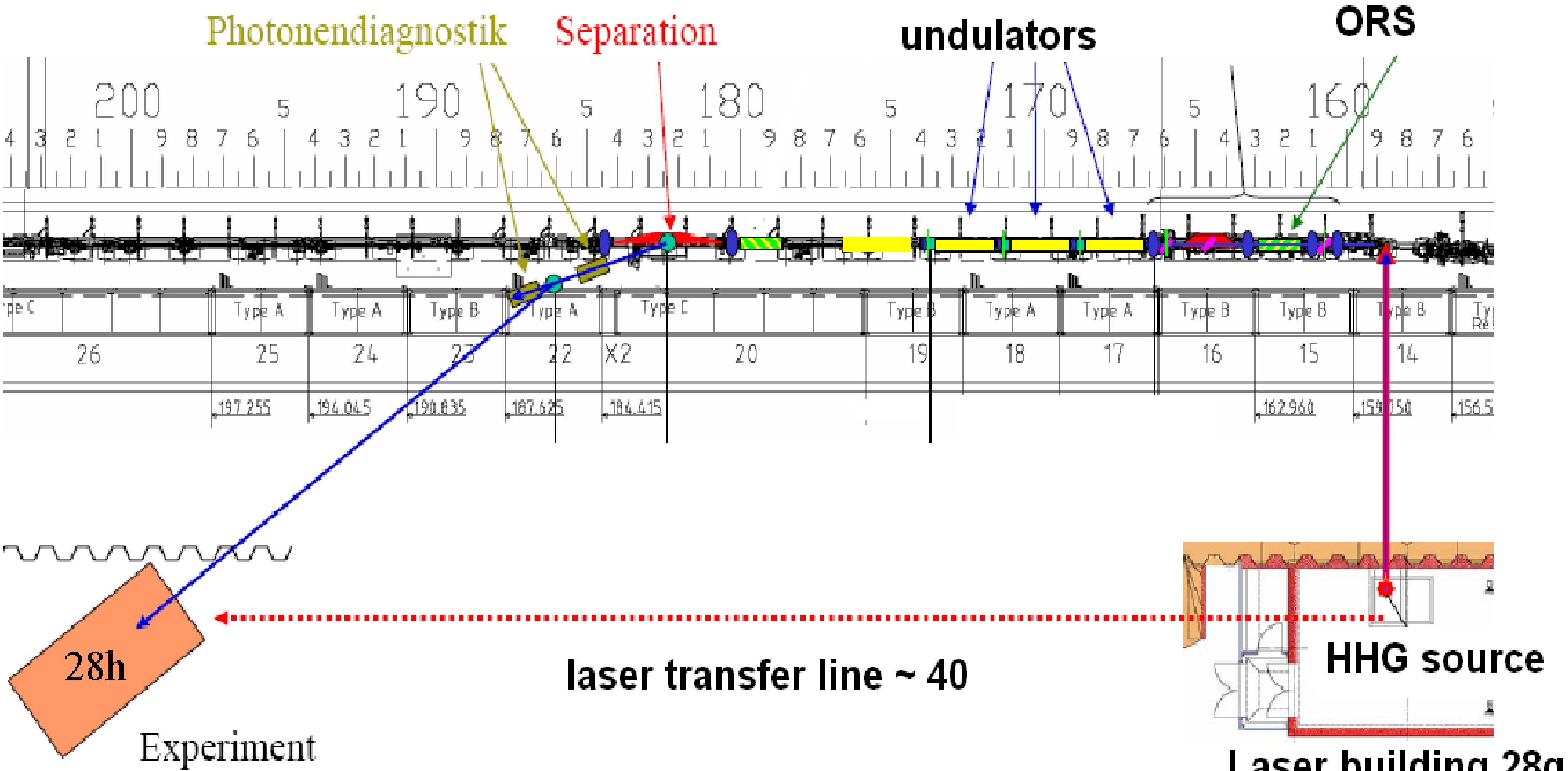


courtesy of S. Khan

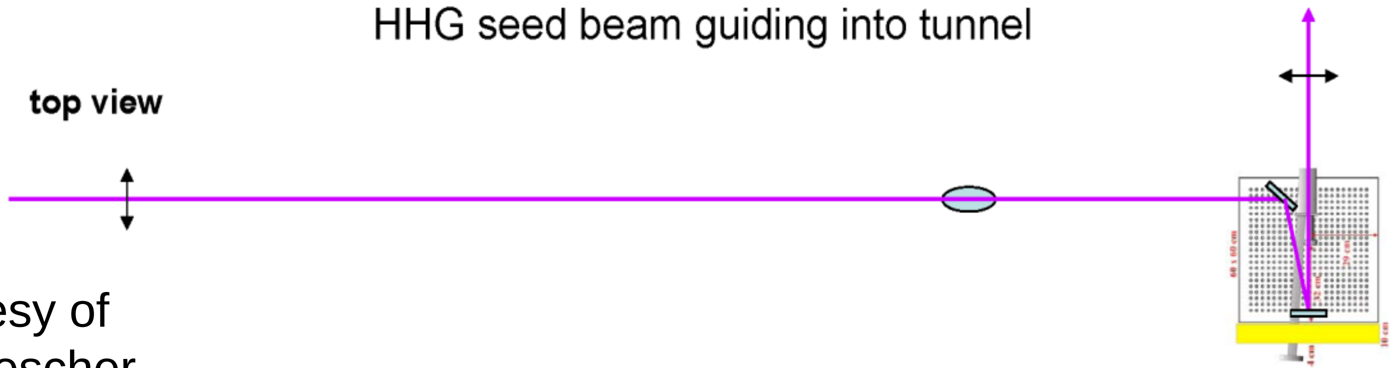
simultaneous generation of odd harmonics of the fundamental 800 nm. n=1,3...27...

Basic set up

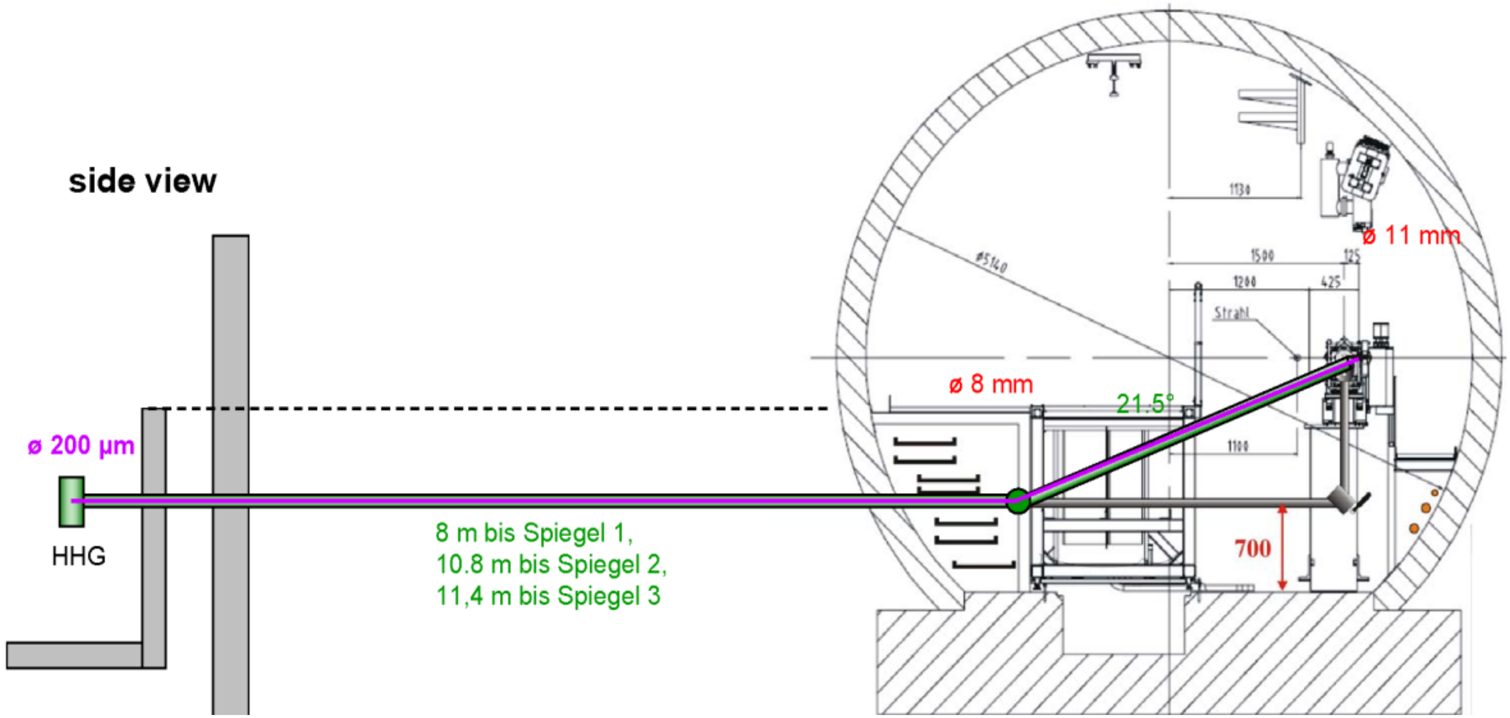
Top view



Transport of HHG seed into tunnel

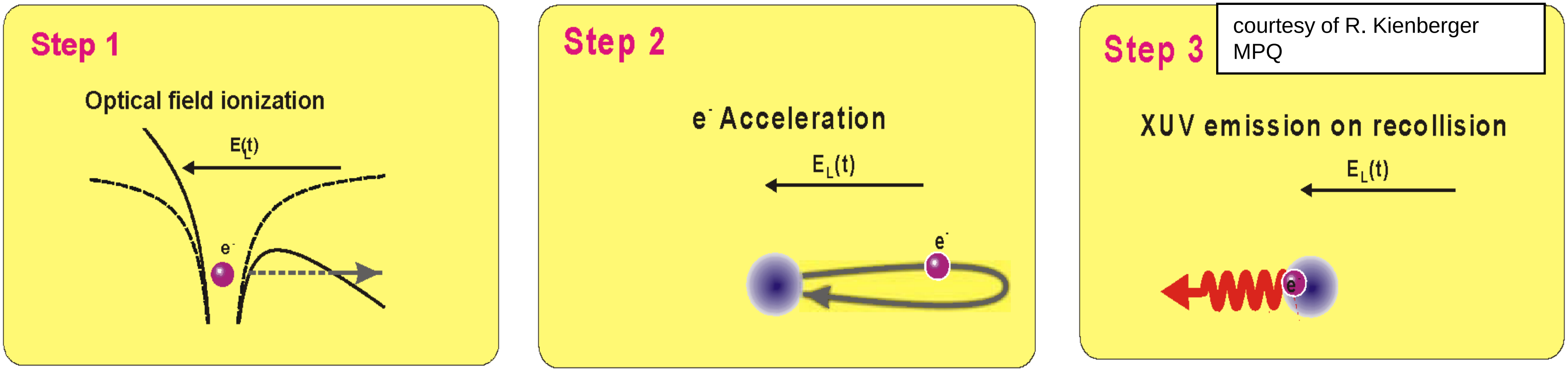


courtesy of
M. Drescher



Properties of the HHG radiation

HHG generation



Semi-classical three step model [1,2]:

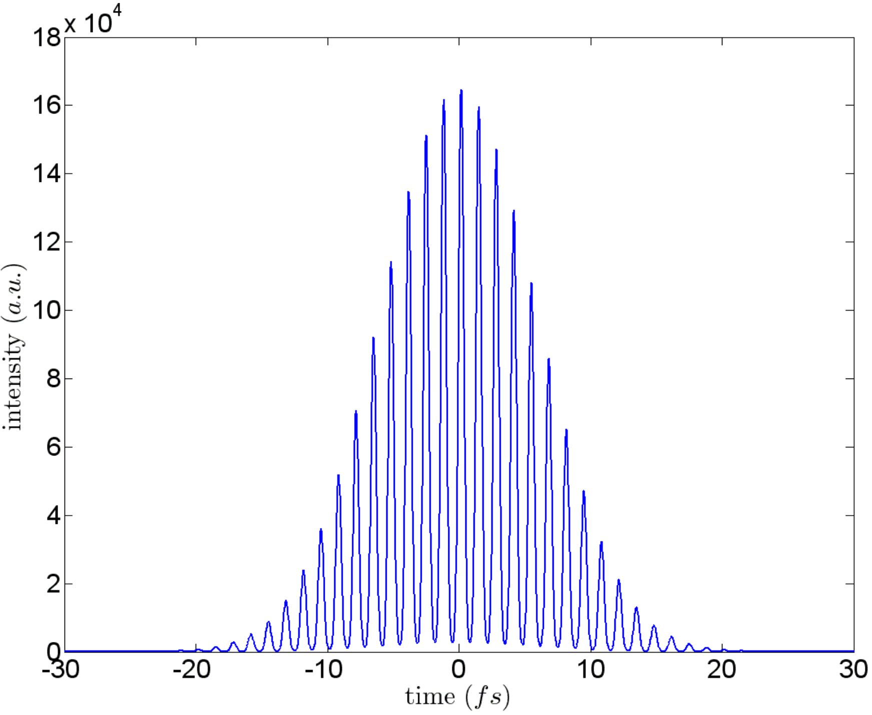
1. Close to the peak of the laser electric field, electron tunnels through the potential barrier formed by the combined Coulomb and laser fields
2. It oscillates almost freely in the laser field, gaining kinetic energy
3. The energy gained is converted into a high-energy photon through recombination with the parent ion

1. P. B. Corkum, Phys. Rev. Lett. 71, 1994 (1993).
2. K. J. Schafer, et.al., Phys. Rev. Lett. 70, 1599 (1993).

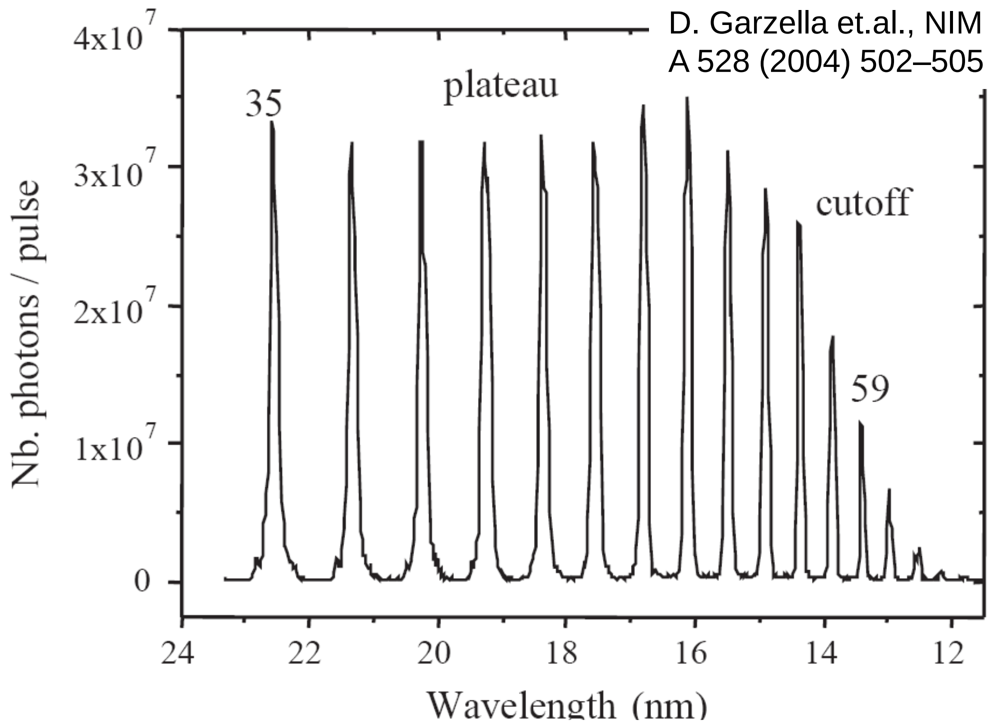
Properties of the HHG radiation

• The interaction between the intense laser pulse with rare gas atoms results in the generation of higher-odd harmonics of the driving laser frequency (HHG)

• The HHG radiation forms '*combs*' in frequency and time domains, resulting in *as* pulse structures separated by half driving laser period



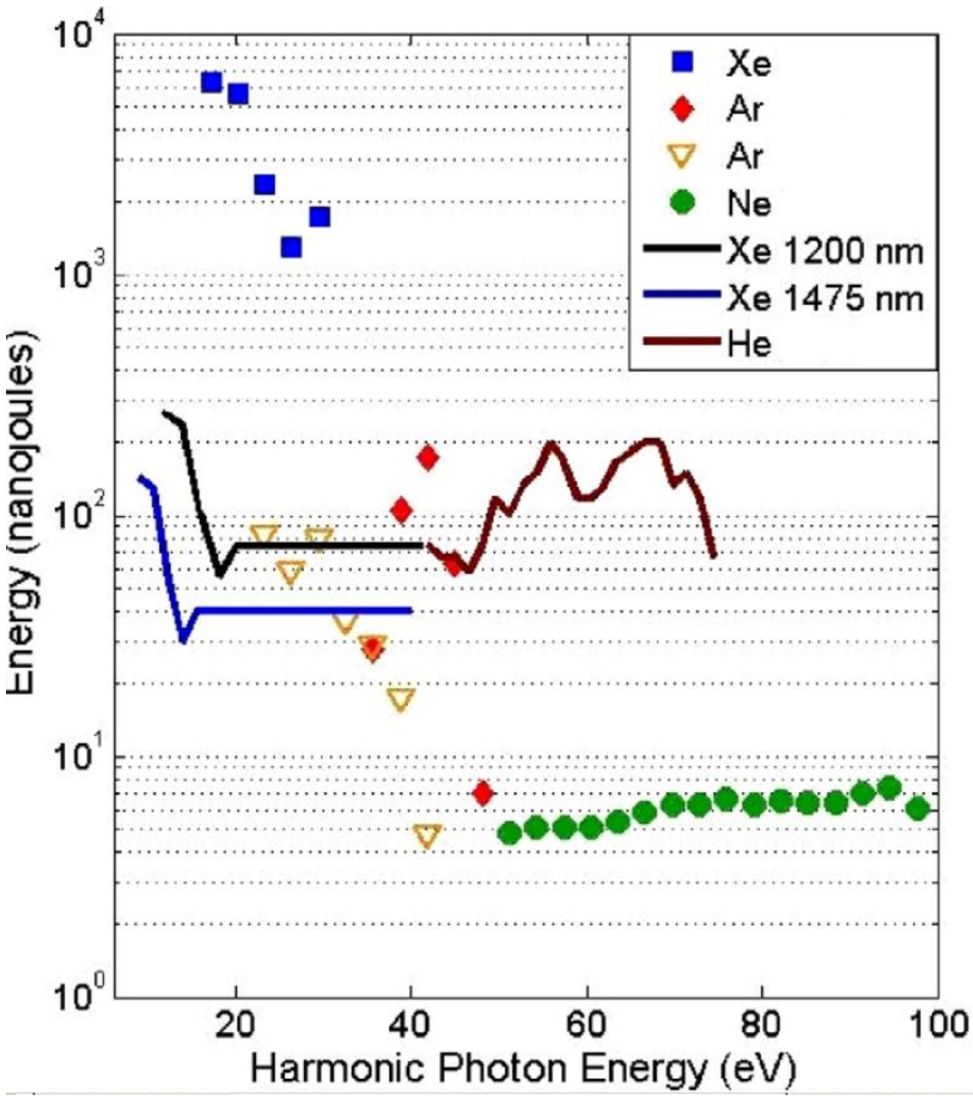
simulated time profile of the seeding HHG pulse



typical spectrum measured in Ne. Seeding with superimposed harmonics possible provided that $1/n>\rho$

Properties of the HHG radiation

Energy of the HHG pulse



from B. McNeil et.al.,

New Journal of Physics 9 (2007) 82

Recent HHG experimental results scaled by energy and wavelength. The unconnected points are taken with an 800 nm fundamental, and are scaled to a fundamental pump pulse energy of 14 mJ.

The minimum pulse energy needed for seeding ~1nJ @ 30fs

Requirements to HHG seed

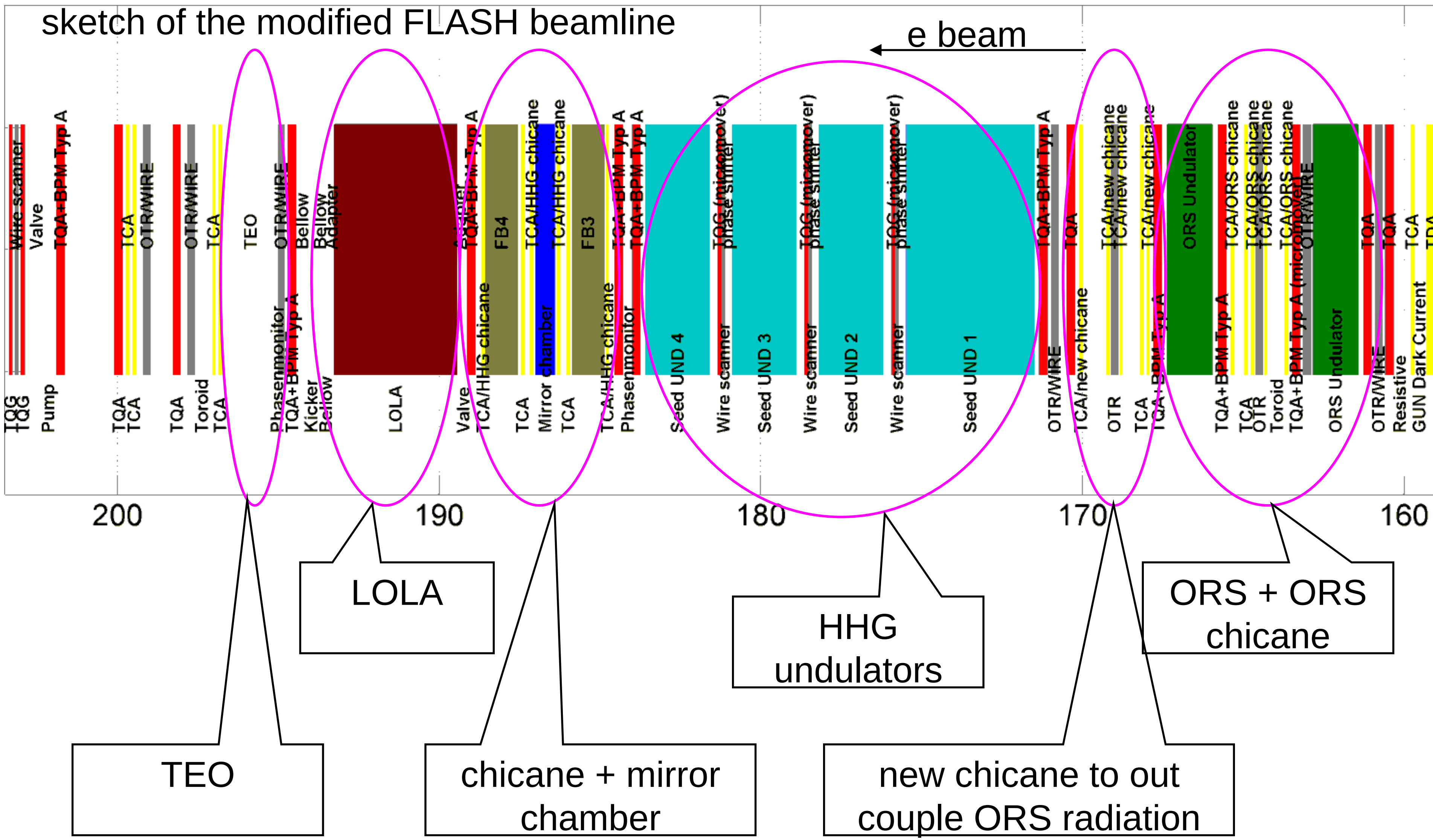
• spatial overlap between electron bunch and HHG pulse
⇒ good pointing stability of optical laser
⇒ eventually fast orbit feedback in seed undulator
• stable HHG parameter (pulse energy, chirp, frequency …)
• good temporal overlap between electron bunch and laser pulse
• with 3th harmonic cavity $\sigma_t \sim 250$ fs @ few kA peak current
⇒ time jitter should be much smaller than << σ_t for reliable operation

Modifications of FLASH beamline

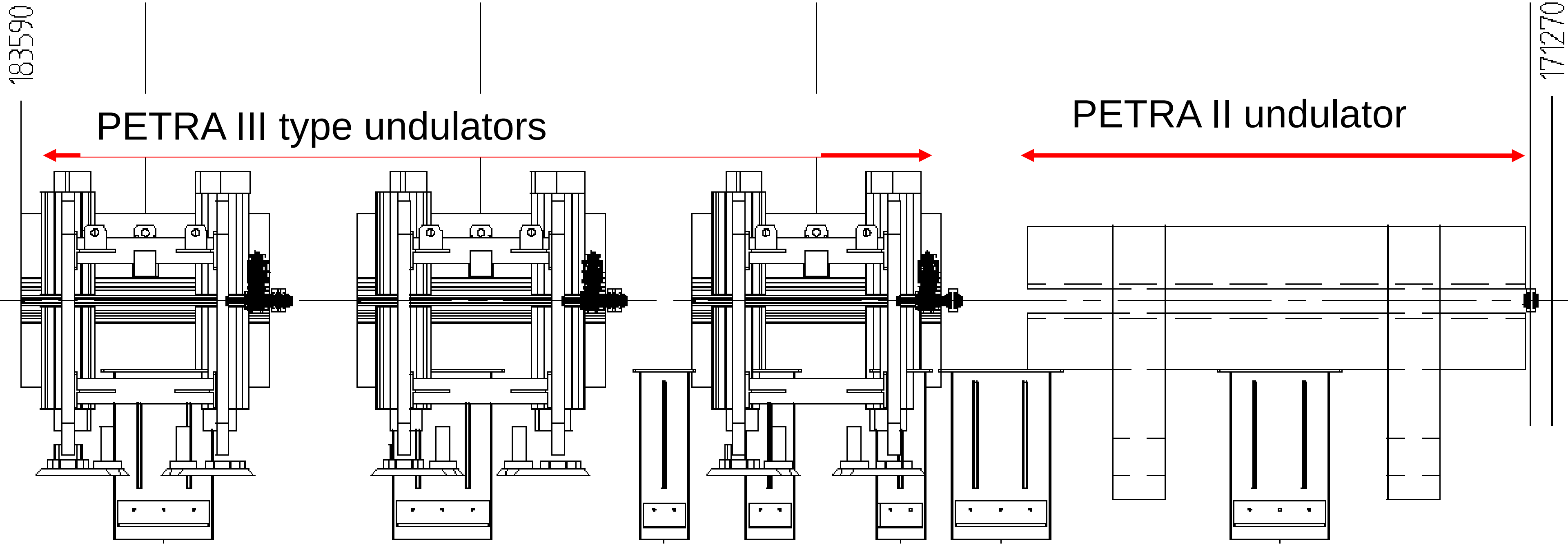
Modifications apply to the section between the collimator and SASE undulators

- additional hardware to be installed
  - four HHG undulators: 1x4(m) and 3x2(m)
  - phase shifters, additional steerers
  - mirror chamber to separate HHG radiation and electron beam
  - diagnostics
  - LOLA/screen (due to installation of ACC7 in future)
- ORS+chicane to be moved upstream ⇒HHG undulators closer to input window
- 10(mm) beam pipe in HHG undulator section. Vacuum chamber 15x7.7 mm
- Some quadrupoles should be moved ⇒different optics is required
- Compatibility between SASE operation, HHG, ORS, LOLA is required
- Assure full transmission with no losses

FLASH beamline modifications

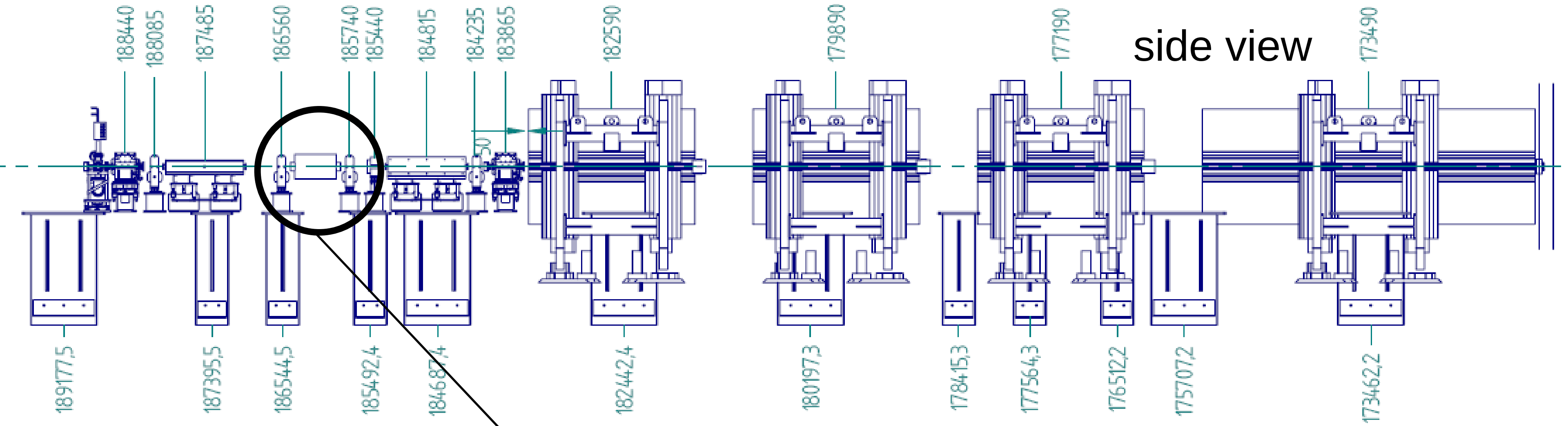


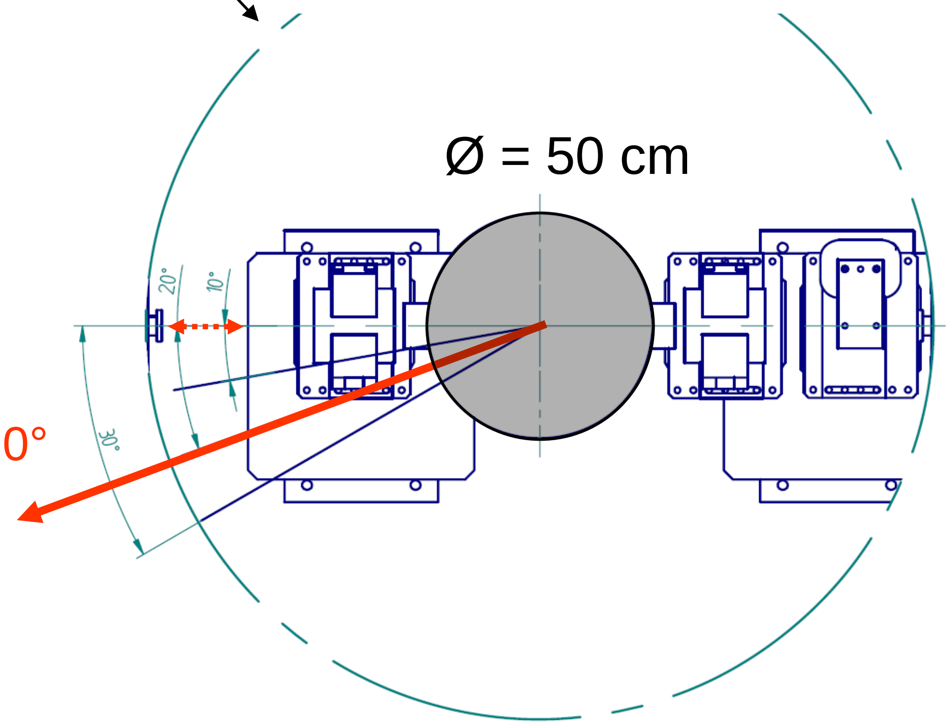
The seeding section



- variable gap undulators. min gap about 9 mm. Vacuum chamber inner size 15x7.7 mm
- total undulator length 10 m
- 3 PETRA III undulators of 2 m length + PETRA II undulator of 4m
- λ_u=31.4 mm (PETRA III), 33 mm (PETRA II)
- distance between undulators 70 cm
- FODO-like focusing

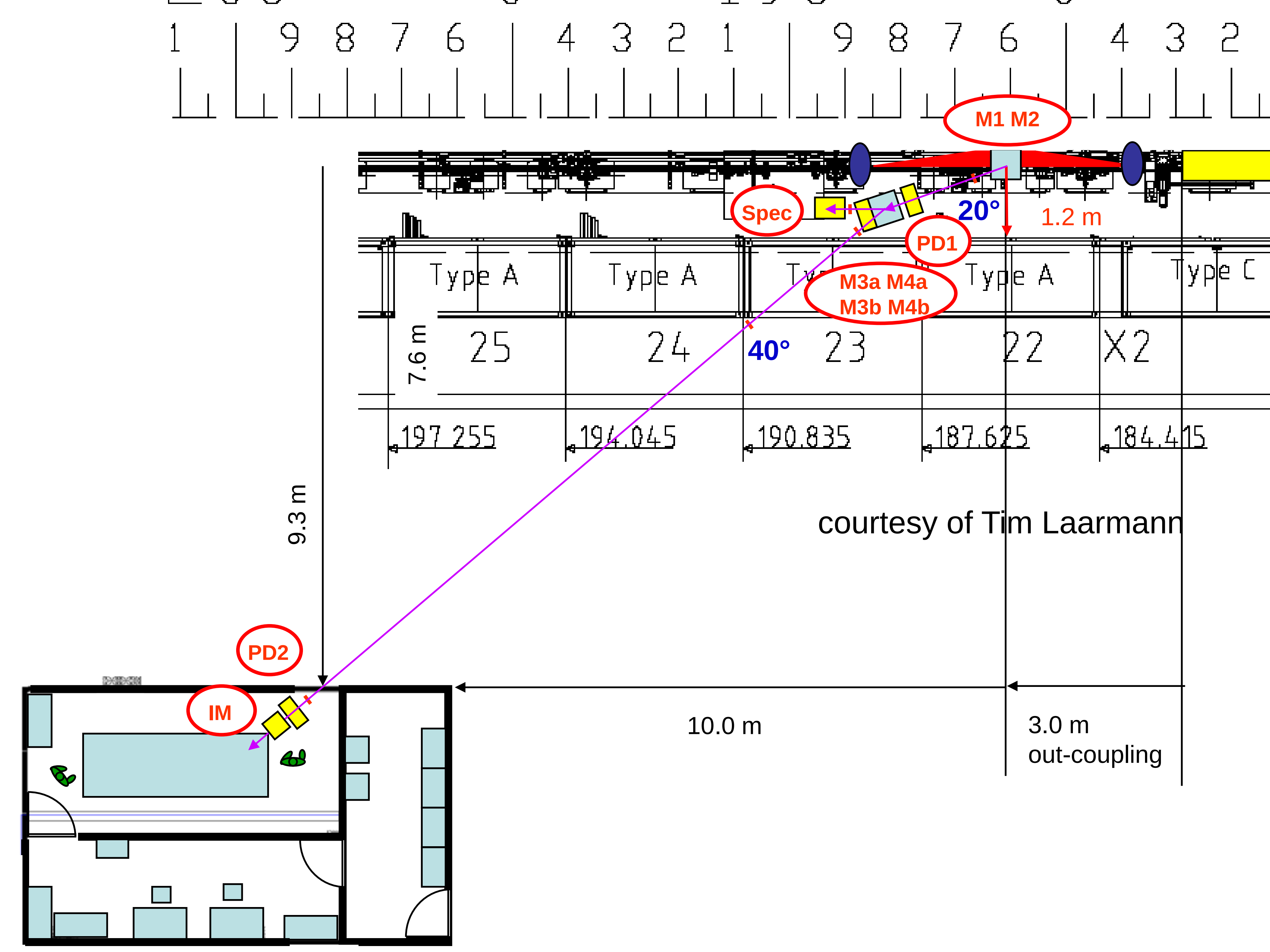
Mirror chamber





top view

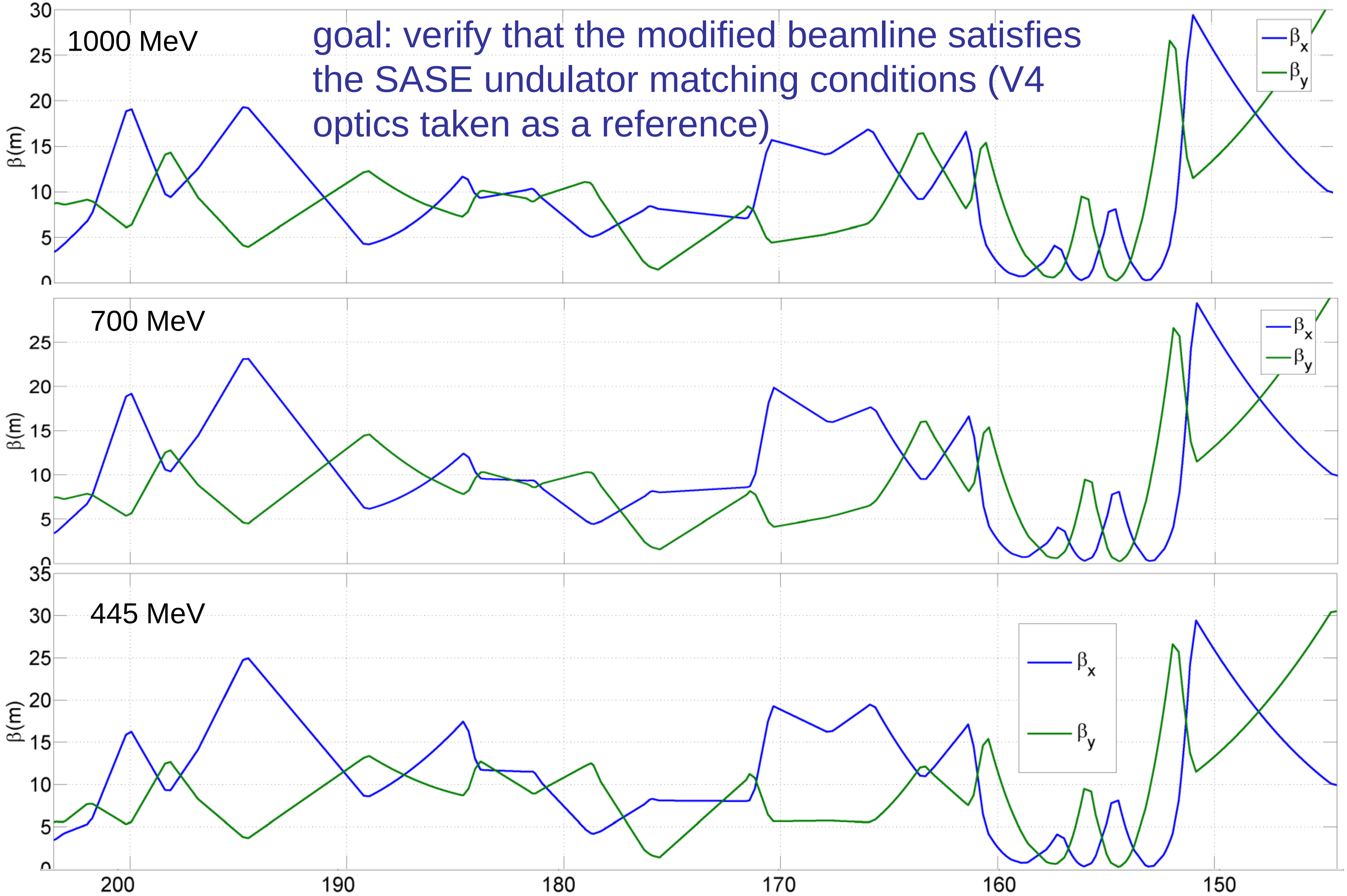
courtesy of Tim Laarmann



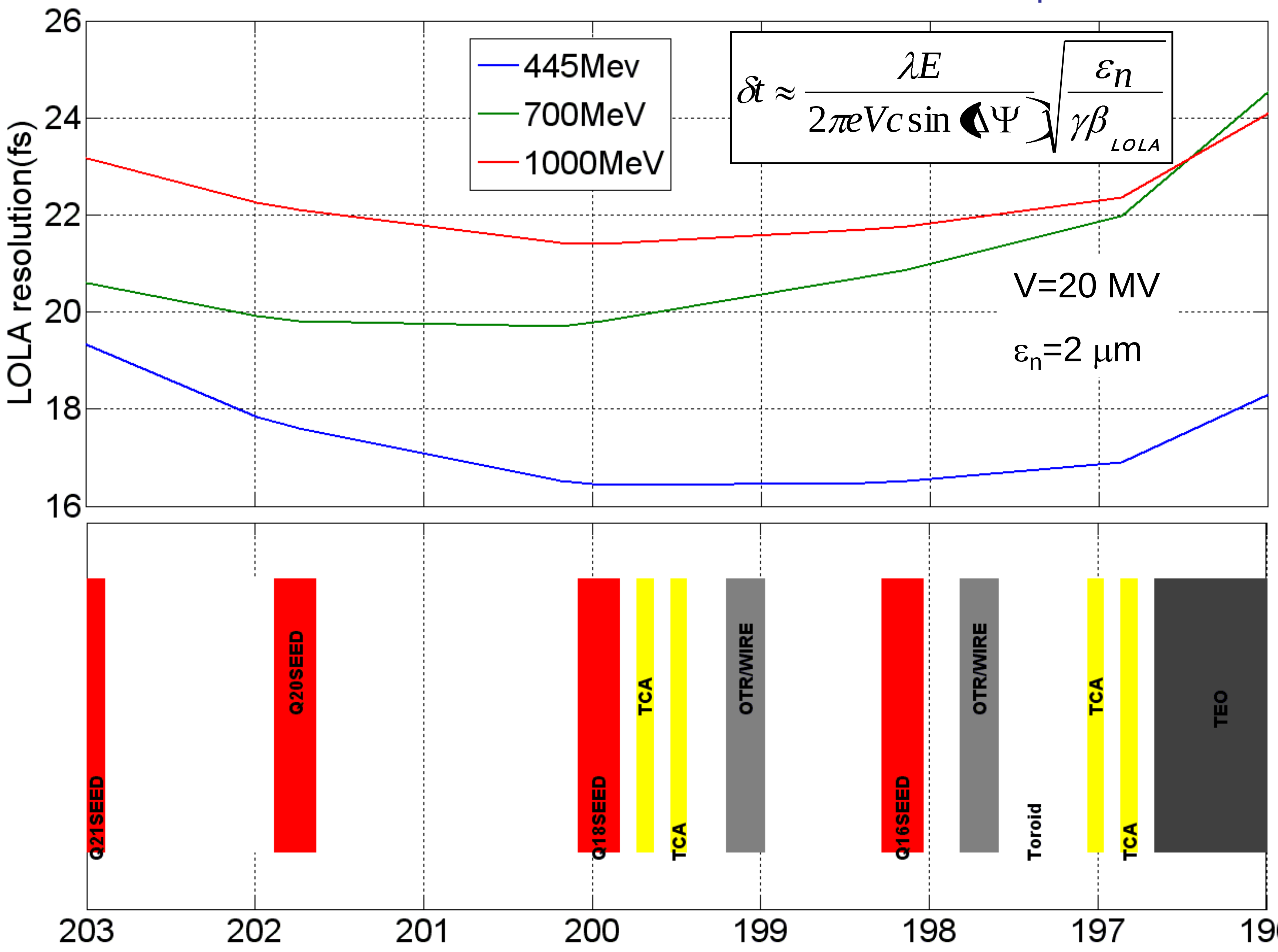
M1 M2
Spec
20°
1.2 m
PD1
M3a M4a
M3b M4b
Type A
Type A
Type A
Type C
7.6 m
25
24
40°
23
22
X2
197.255
194.045
190.835
187.625
184.415
9.3 m
courtesy of Tim Laarmann
PD2
IM
10.0 m
3.0 m
out-coupling

Optics at different energies

goal: verify that the modified beamline satisfies the SASE undulator matching conditions (V4 optics taken as a reference)



Estimated LOLA resolution as a function of the screen position

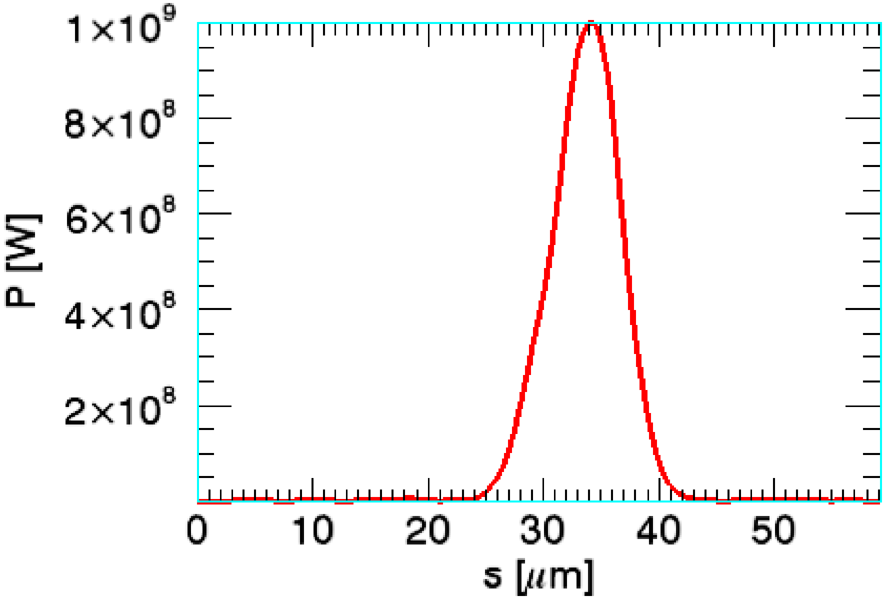


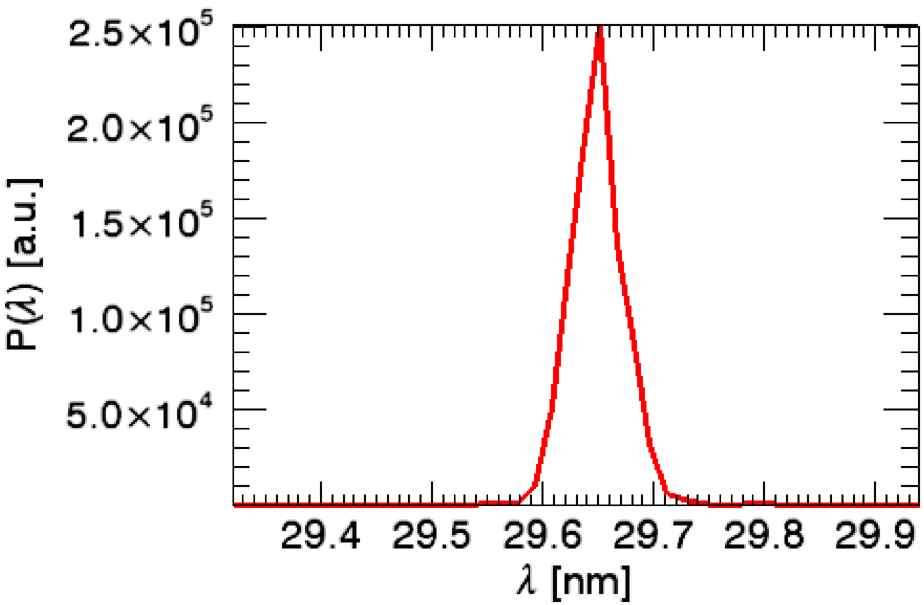
Output radiation properties (simulations)

- consider the seeding beamline and electron optics as presented above
- λu=31.4 mm (PETRA III), 33 mm (PETRA II)
- duration HHG pulse: 20 fs (FWHM)
- energy of the 27th harmonic (29.6 nm): 1 nJ

transverse emittance, $\varepsilon_n = 2\ \mu$m
pear current, $I_{peak} = 1.5$ kA
bunch length, $\sigma_z = 80\ \mu$m
E = 850 MeV
rms energy spread $0.2\ MeV$

longitudinal profile and spectrum after about 8 m effective undulator length





Tentative time schedule

- installation and commissioning of HHG generation - end 2008
- installation of HHG transfer line in tunnel - Feb 2009
- installation of undulators - Apr. 2009
- installation of mirror chamber - Apr 2009
- installation of HHG-FEL beamline - May 2009
- commissioning with beam - Aug 2009

work in progress

- design and construction of phase shifters (‘Efremov’ institute)
- construction of diagnostic blocks for undulator intersections
- vacuum chambers to be ordered (external company)
- design and construction of mirror chamber (T. Laarmann)
- ...