Design Options for the XFEL Undulator Vacuum Chamber

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Outline

- relevant beam/radiation parameters
  beam power, spont. radiation power, opening angle, beam dimensions and required aperture
- mechanical layout, materials
  alignment requirements, aperture dimensions/shape, absorbers, pumps/BPM's/bellows
- pressure requirements/estimations
  radiation vs. thermal desorption, pressure profile, conditioning times, pumping concept
- wakefield related aspects
  resistive wall, roughness requirements, choice of material

Beam and Radiation Parameters

		XFEL	LCLS	PETRA III
beam	energy	(10)..20 GeV	4.3..13.6 GeV	6 GeV
	avg. power	300 kW	2.4 kW	
	avg. current	15..32 μA	0.12 μA	100mA
spont.	dP_γ /dl (max)	6 W/m	22 mW/m	45 W/m
radiation	E_c (max)	348 keV	154 keV	2.4 keV
	$d^2n_\gamma/dt\,dl$ (max)	$8 \cdot 10^{14}$ $m^{-1}s^{-1}$	$6 \cdot 10^{12}$ $m^{-1}s^{-1}$	$4 \cdot 10^{17}$ $m^{-1}s^{-1}$
	vertical $1/\gamma$	25..50 μrad		
	horizontal K/γ	153..310 μrad		

Comments on XFEL Parameters

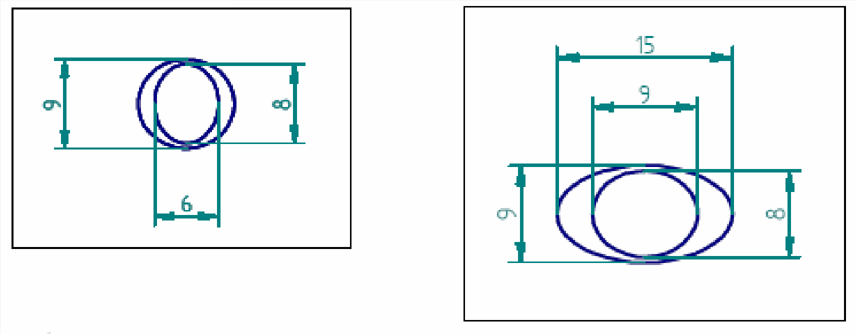
- average beam and radiation power are significant → possible heat source in undulator
- even with absorbers photon desorption may dominate pressure
- horizontal opening angle of radiation is relatively large → requires tight absorbers

Chamber Geometry

circular vs. elliptical

inner shape: absorber

outer shape: chamber



shielding angle 300μrad / 600μrad

advantages wide chamber

- less collimator wakefields
- better vacuum conductance
- more horizontal aperture for misalignments / orbit errors

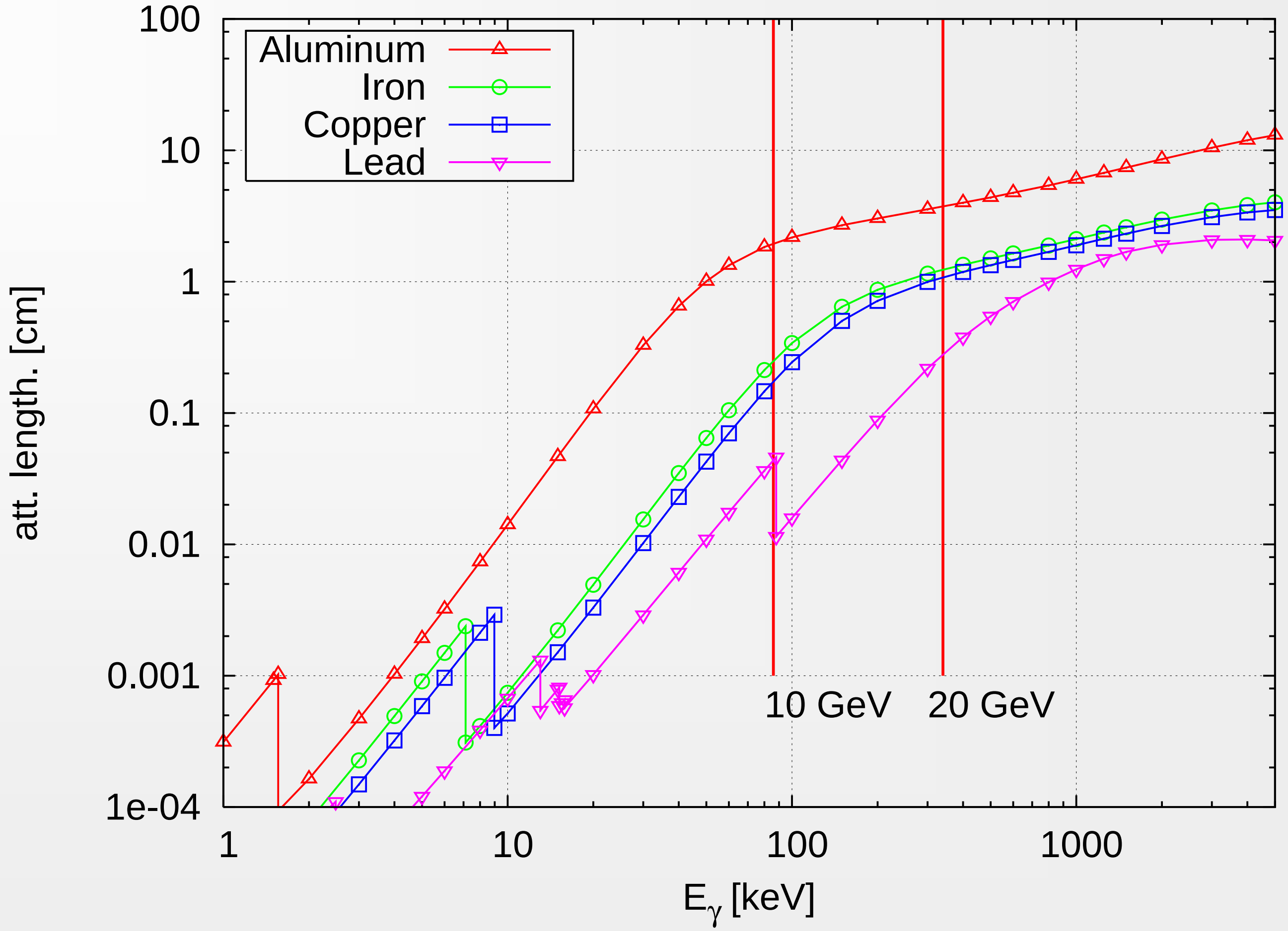
Chamber Materials

	Pro's	Con's
aluminum extrusion	▪ heat conductivity ▪ cooling channels by extrusion ▪ integrated pump possible ▪ better AC conductivity	▪ roughness at limit ▪ poor outgassing
electro polished steel pipes/sheets with coating (Al, Au, Cu..)	▪ very smooth ▪ low outgassing	▪ cooling difficult ▪ risk on magnetic permeability ▪ hard to make elliptic
copper pipe	▪ DC conductivity ▪ rel. low outgassing ▪ acceptable roughness	▪ elliptic/flat shape difficult

SR Attenuation in Absorber

att. at >300keV

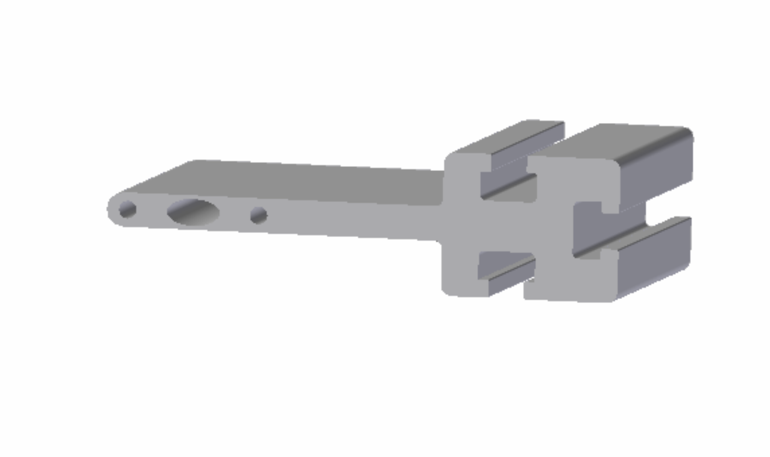
very weak!

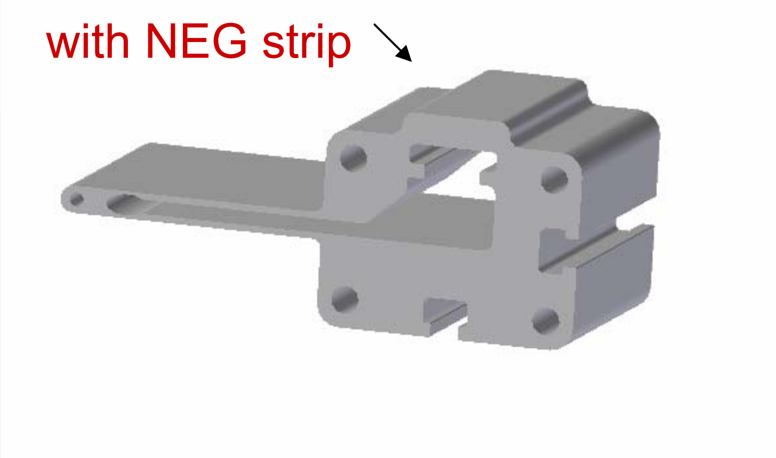


proposal for an Al extrusion

- includes water cooling
- gap: 10mm, aperture $9 \times 15 mm^2$
- precision support needed
- oxide layer critical!

T.Wohlenberg





Pressure Estimate

conductance limited c=0.18 m l/s; aluminum pipe

condition	outgassing [mbar l / s m]	avg. pressure [mbar]
thermal desorption (after few weeks)	$4 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
without absorbers without conditioning	$3 \cdot 10^{-6}$, η=0.09	$3 \cdot 10^{-5}$
without absorbers after 2000h	$2 \cdot 10^{-8}$, $\eta = 7 \cdot 10^{-4}$	$3 \cdot 10^{-7}$
with absorbers, 1% residual rad.	$3 \cdot 10^{-8}$, η=0.09	$3 \cdot 10^{-7}$
with absorbers after 2000 h	no improvement!	dito!

Comment on Pressure

- pressure typically in 10^{-7}mbar range
  → better with integrated pump
- Bremsstrahlung is no issue because experiments not in straight line (mirror)
- but: fast ion instability could be a problem
  molecules captured for A>5
  estimated rise time: $\tau \sim 60\mu s$! (to be verified)
- numerical simulations necessary

Fast Ion Instability

- theory: coupled oscillator system beam/ions
- decoherence of ions with time important

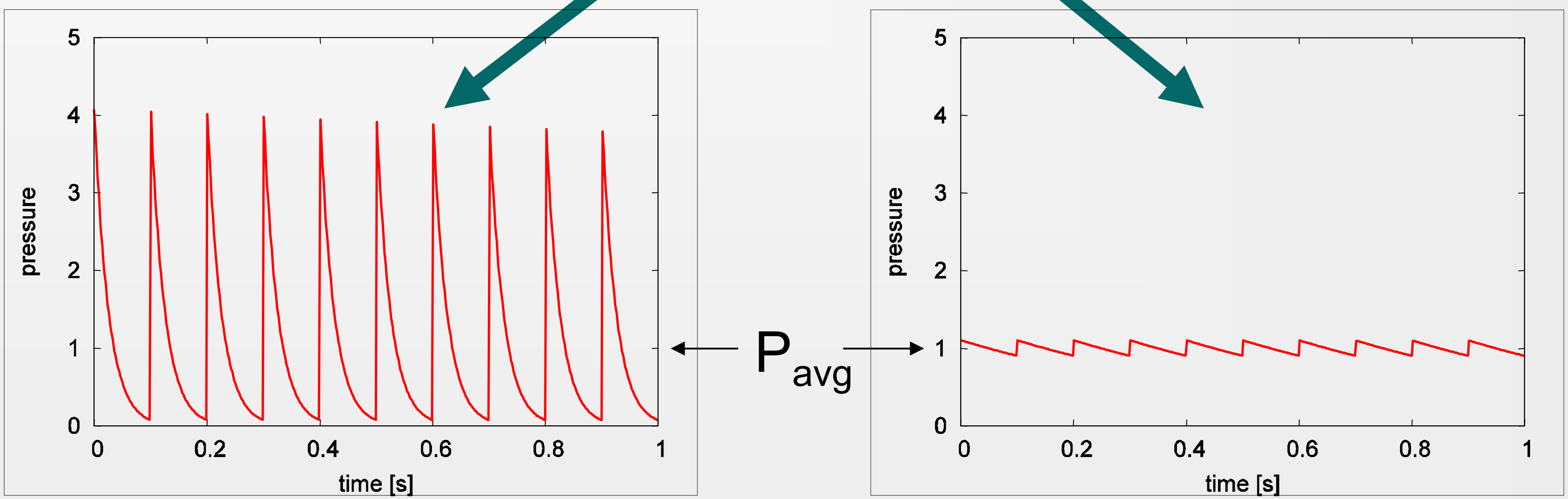
ion mass captured: $$A_{crit} = \frac{N_b L_{sep} r_p}{2\sigma_y(\sigma_x + \sigma_y)} \approx 5.5$$

initial rise time: $$\tau = \frac{\gamma\sigma\sigma}{N_b n_b c r_e \beta_y \sigma_{ion}} \left(\frac{k_B T}{p} \right) \sqrt{\frac{8}{\pi}} \cdot 0.1 \approx 60 \mu s$$

high pressure burst during bunch train ?

Problem: pulsed operation, radiation desorption happens in 1% of time → unacceptable pressures during beam-on times?

do we have this behavior, or that ?



The answer is no!

time dependent one-dim. diffusion equation:

$$c\frac{\partial^2}{\partial z^2}P(z,t) + q(z,t) = v\frac{\partial}{\partial t}P(z,t)$$

volume per length; 0.11 l/m

outgassing (rad. desorption)

spec. conductance; here: 0.18 l m/s

diffusion coefficient: $D = \frac{c}{v} = \frac{\langle \Delta z^2 \rangle}{\Delta t}$

for typical diffusion length Δz = 2m: **Δt = 2.4 sec >> 0.1 sec**

pressure variations are slow → deviations from average pressure small

Wakefield Effects

extremely short bunches (25μm), energy spread critical for SASE
wakefields: geometric, resistive, dielectric layer/roughness

unavoidable: resistive wake from narrow chamber → use this as a measure for the other effects

rms energy spread:

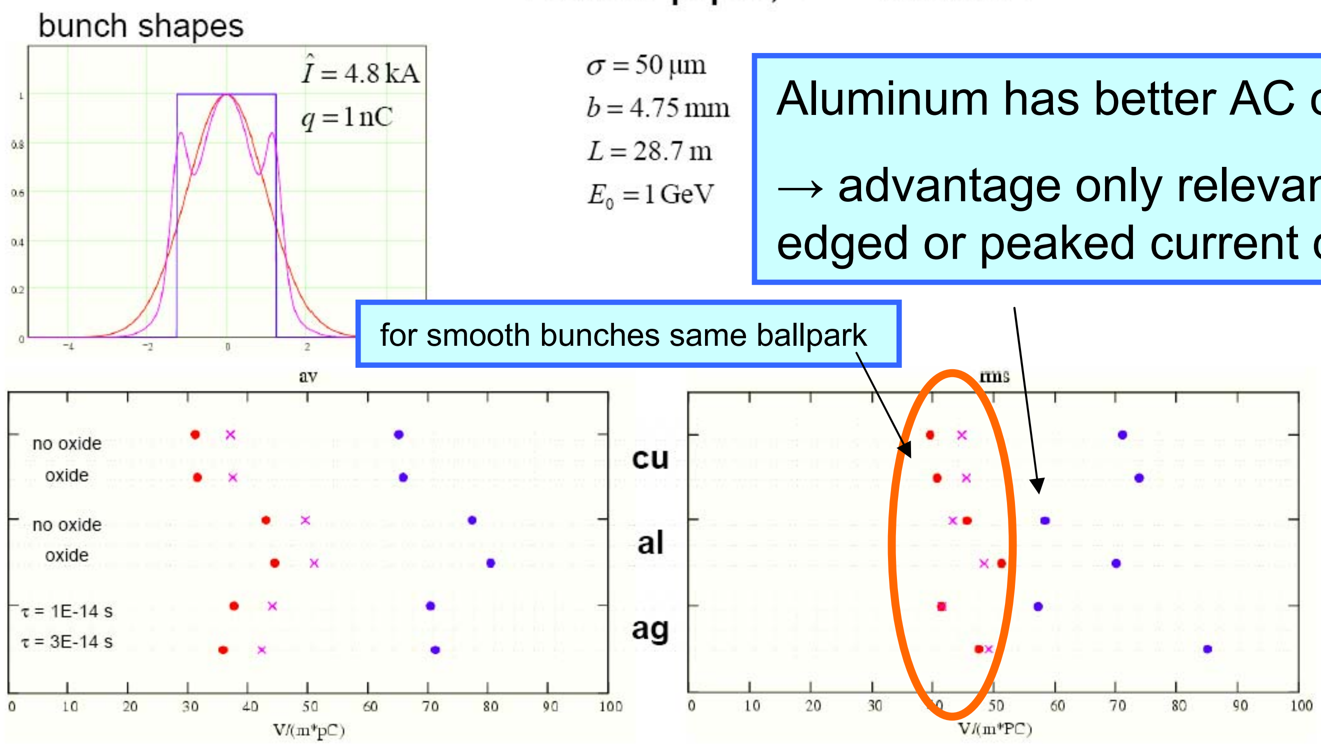
M.Dohlus
I. Zagorodnov:

resistive (Cu):		39.5 V/pC m
geometric	absorber (10mm taper)	74 V/pC
	bellows	11 V/pC
	flange gap	5 V/pC
oxide layer	Cu 1nm	1.1 V/pC m
	Al 5nm	5.7 V/pC m
roughness	Al 600nm(!)	9 V/pC m

avg. HOM power: in beam pipe: **P_{max} = 2.1 W/m**

Wake Calculations (M.Dohlus)

summary: resistive wakes
round pipe, r = 4.5mm



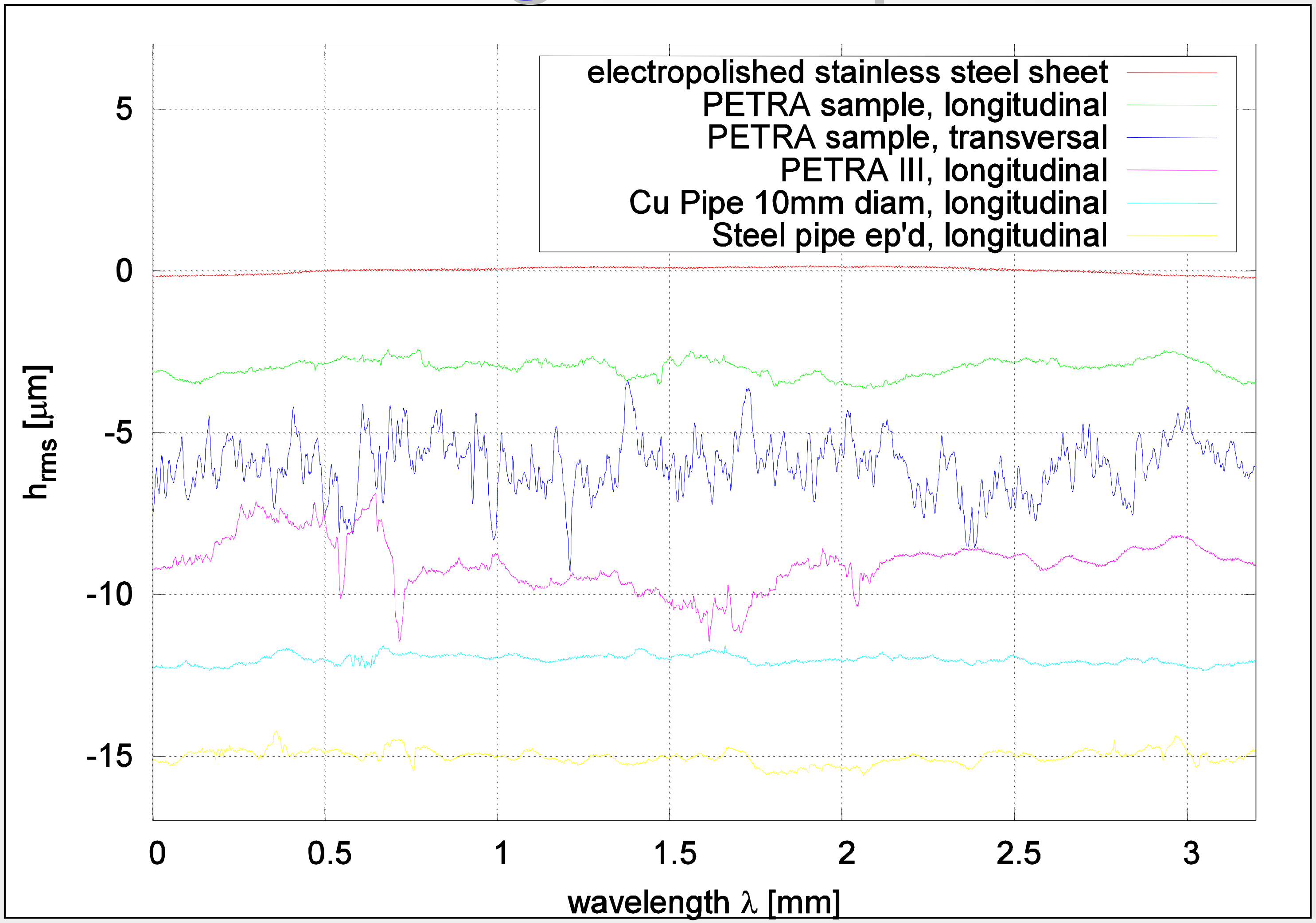
Aluminum has better AC conductivity

→ advantage only relevant for sharp edged or peaked current distributions

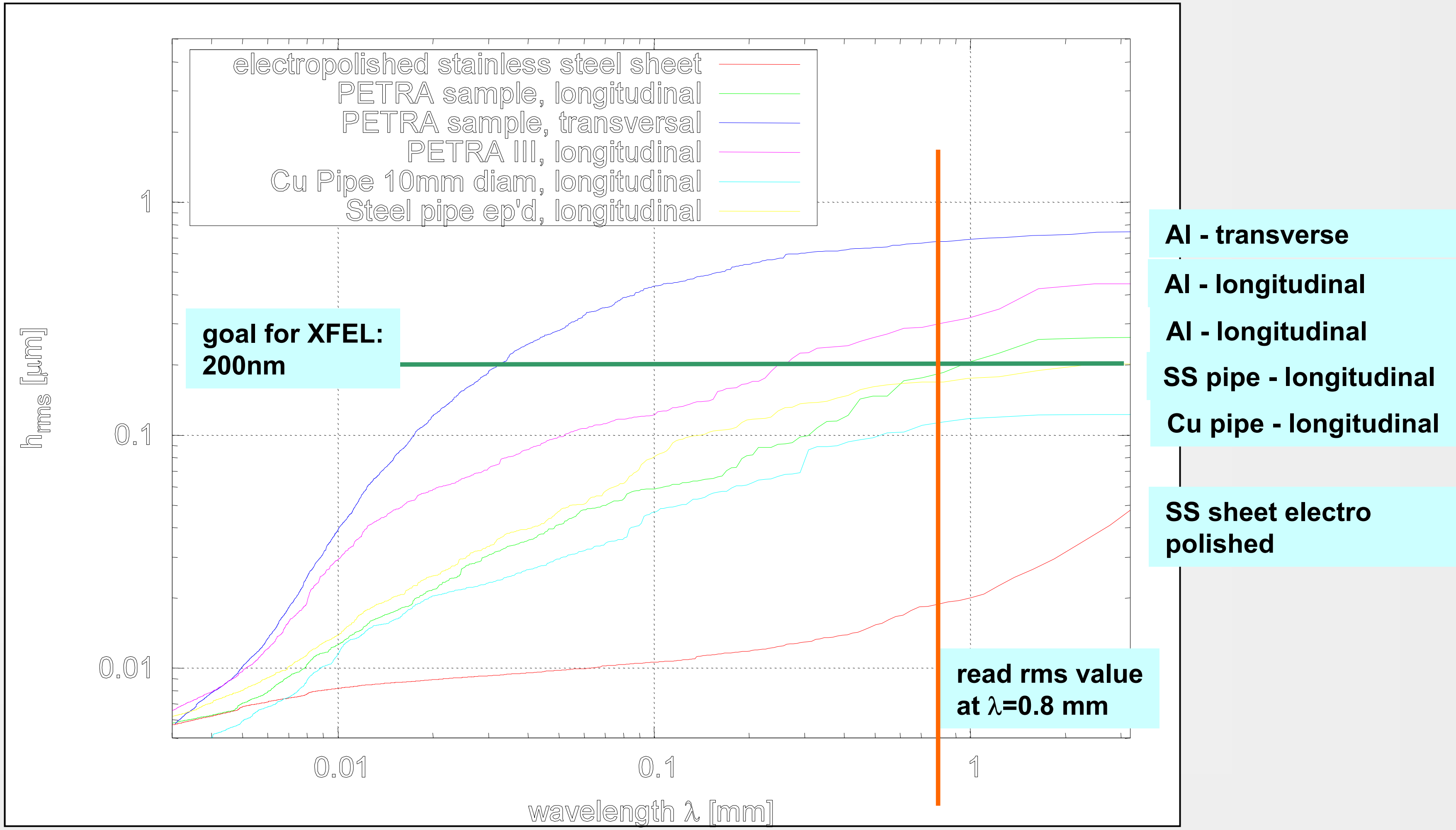
for smooth bunches same ballpark

XFEL: avoid peaks in charge distrib. → Cu, Al, Au, Ag … are roughly equivalent
high DC conductivity desirable though..

some roughness profiles...



integrated power spectrum roughness rms vs. wavelength λ



Summary

• chamber design still in conceptual phase
problems: how to optimize wakefields, pressure

• pressure critical due to small conductance;
fast ion instability possible, internal pump required?

• probably cooling of beam pipe preferred for temperature stability of undulator; working solution: extruded Al profile
alternatives: Cu pipe; e-polished, coated (Au?) SS profile

• abs./pump/BPM(cavity?)/bellows insertion under study

remarkable differences between LCLS and XFEL are higher current, long bunch trains and smoother bunch shape