

# 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

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

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# Comments on XFEL Parameters

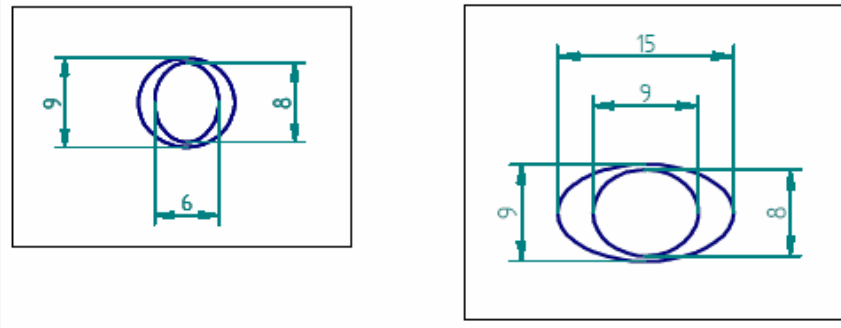
- average beam and radiation power are significant → possible **heat source** in undulator
- even with absorbers **photon desorption** may dominate pressure
- horizontal opening angle of radiation is relatively large → requires tight absorbers

# Chamber Geometry

**circular vs. elliptical**

inner shape: **absorber**

outer shape: **chamber**



**shielding angle  $300\mu\text{rad}$  /  $600\mu\text{rad}$**

**advantages wide chamber**

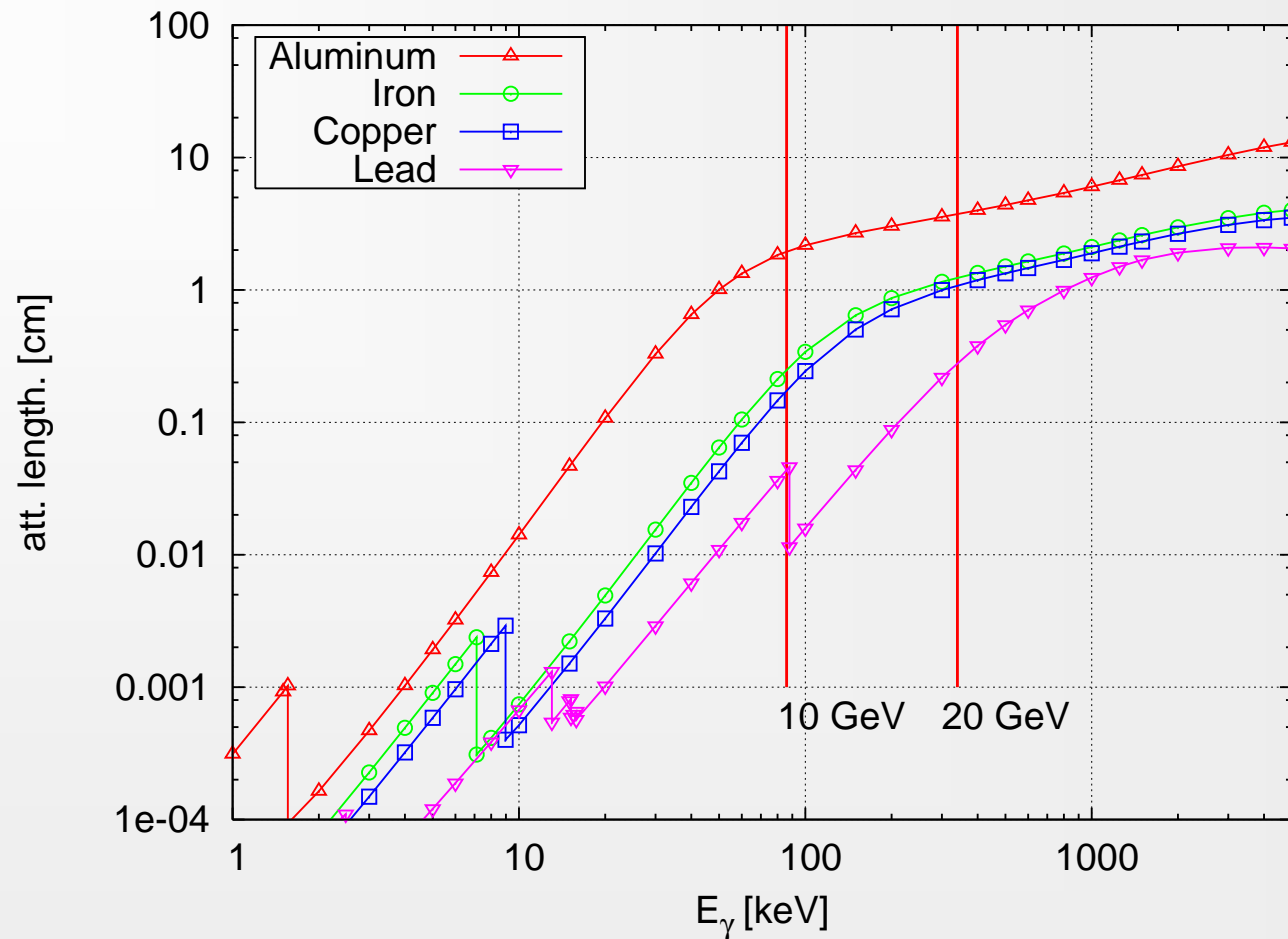
- less collimator wakefields
- better vacuum conductance
- more horizontal aperture for misalignments / orbit errors

# Chamber Materials

	Pro's	Con's
<b>aluminum extrusion</b>	<ul style="list-style-type: none"><li>▪ heat conductivity</li><li>▪ cooling channels by extrusion</li><li>▪ integrated pump possible</li><li>▪ better AC conductivity</li></ul>	<ul style="list-style-type: none"><li>▪ roughness at limit</li><li>▪ poor outgassing</li></ul>
<b>electro polished steel pipes/sheets with coating (Al, Au, Cu..)</b>	<ul style="list-style-type: none"><li>▪ very smooth</li><li>▪ low outgassing</li></ul>	<ul style="list-style-type: none"><li>▪ cooling difficult</li><li>▪ risk on magnetic permeability</li><li>▪ hard to make elliptic</li></ul>
<b>copper pipe</b>	<ul style="list-style-type: none"><li>▪ DC conductivity</li><li>▪ rel. low outgassing</li><li>▪ acceptable roughness</li></ul>	<ul style="list-style-type: none"><li>▪ elliptic/flat shape difficult</li></ul>

# SR Attenuation in Absorber

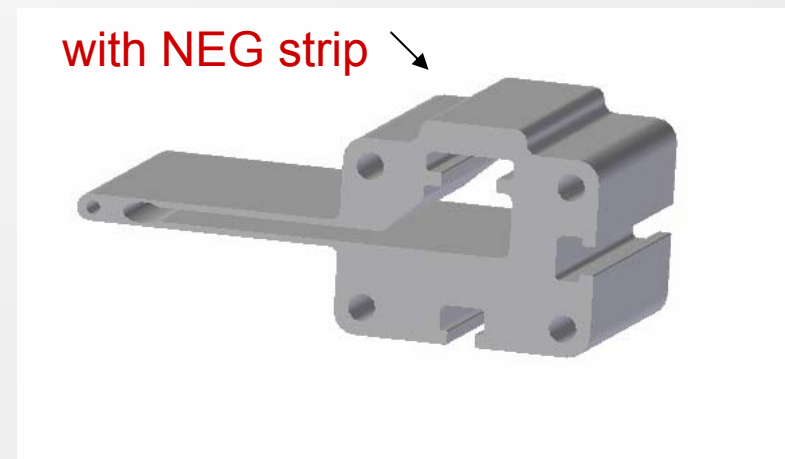
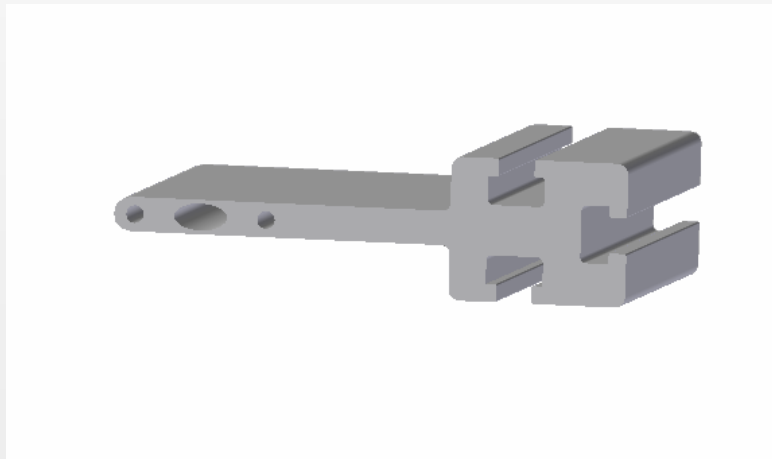
att. at >300keV  
very weak!



# proposal for an Al extrusion

- includes water cooling
- gap: 10mm, aperture  $9 \times 15 \text{mm}^2$
- 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	$3 \cdot 10^{-6}$ , $\eta=0.09$	$3 \cdot 10^{-5}$
without absorbers after 2000h	$2 \cdot 10^{-8}$ , $\eta=7 \cdot 10^{-4}$	$3 \cdot 10^{-7}$
with absorbers, 1% residual rad.	$3 \cdot 10^{-8}$ , $\eta=0.09$	$3 \cdot 10^{-7}$
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:  $\tau \sim 60 \mu\text{s}$  ! (to be verified)
- numerical simulations necessary

# Fast Ion Instability

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

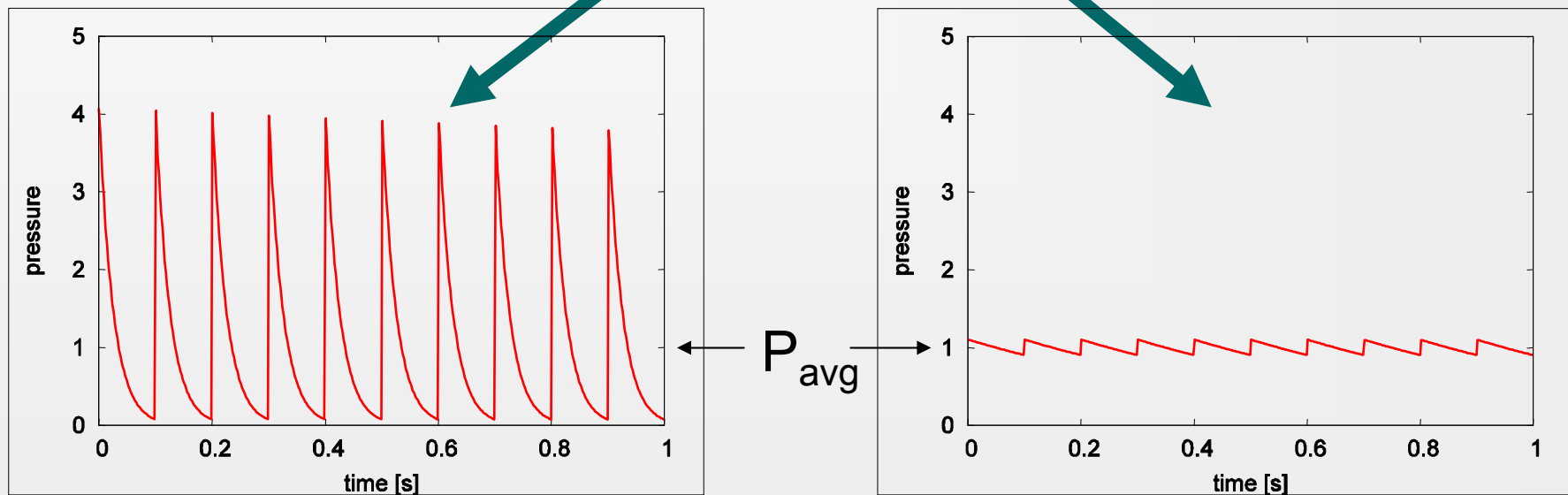
ion mass captured: 
$$A_{crit} = \frac{N_b L_{sep} r_p}{2\sigma_y (\sigma_x + \sigma_y)} \approx 5.5$$

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:

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



spec. conductance; here: 0.18 l m/s



outgassing (rad. desorption)



volume per length; 0.11 l/m

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

for typical diffusion length  $\Delta z = 2\text{m}$ :  $\Delta t = 2.4 \text{ sec} \gg 0.1 \text{ sec}$

**pressure variations are slow** → **deviations from average pressure small**

# Wakefield Effects

extremely **short bunches** ( $25\mu\text{m}$ ), energy spread critical for SASE  
wakefields: geometric, resistive, dielectric layer/roughness

unavoidable: resistive wake from narrow chamber  $\rightarrow$  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

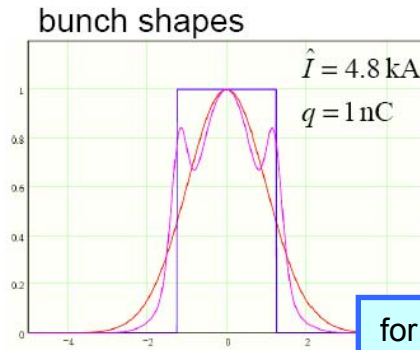
avg. HOM  
power:

in beam pipe:

$P_{\text{max}} = 2.1 \text{ W/m}$

# Wake Calculations (M.Dohlus)

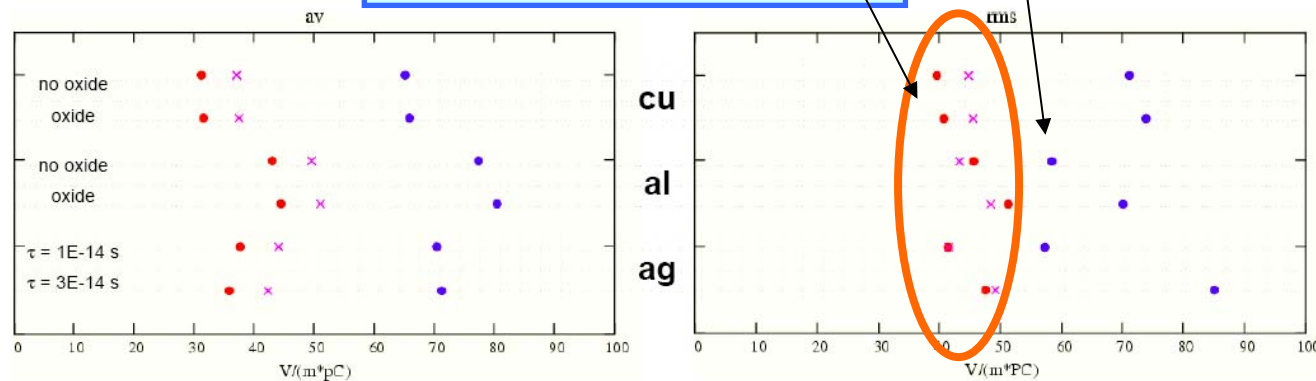
summary: resistive wakes  
round pipe,  $r = 4.5\text{mm}$



$\sigma = 50\ \mu\text{m}$   
 $b = 4.75\text{ mm}$   
 $L = 28.7\text{ m}$   
 $E_0 = 1\text{ GeV}$

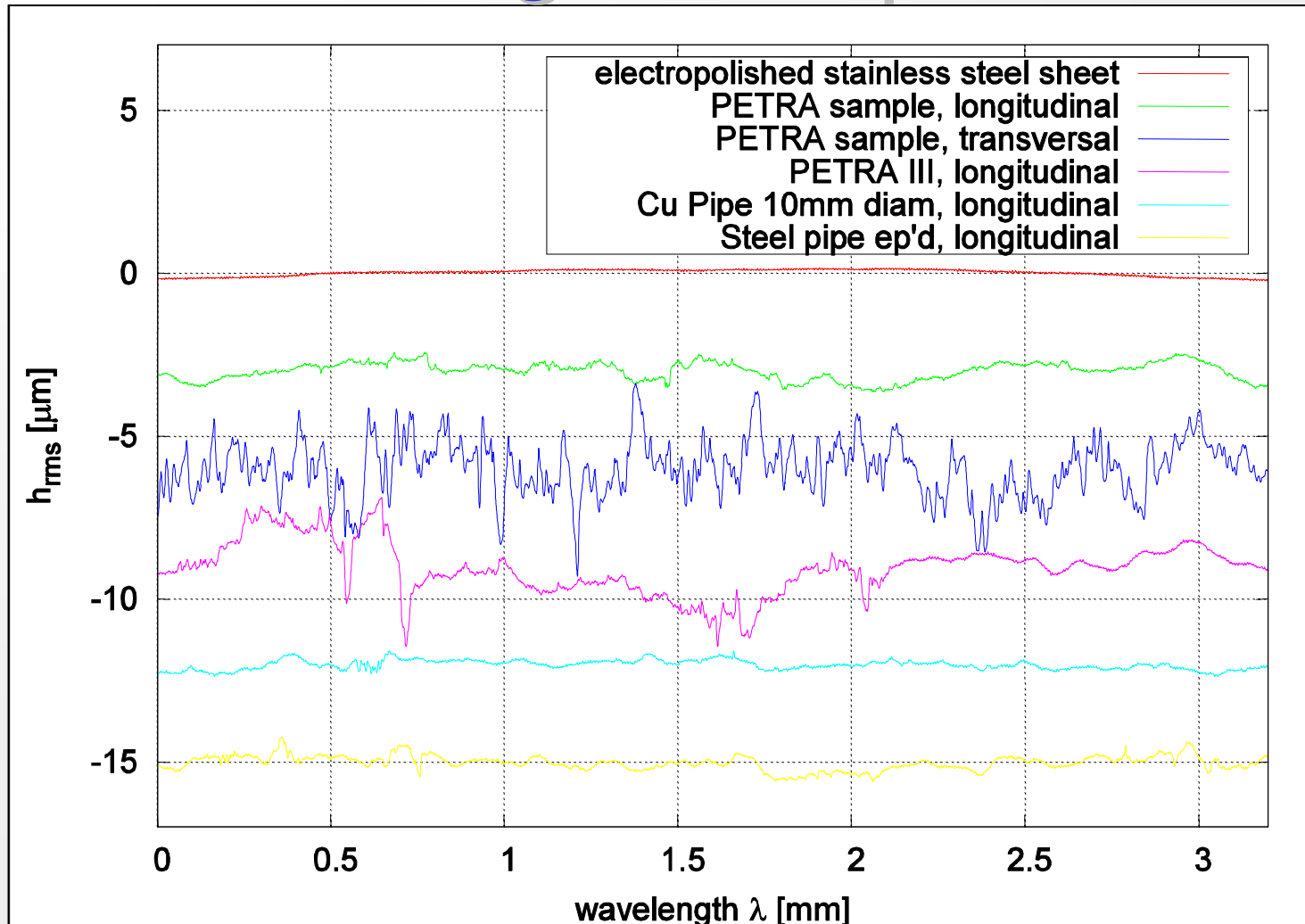
Aluminum has better AC conductivity  
→ advantage only relevant for sharp edged or peaked current distributions

for smooth bunches same ballpark

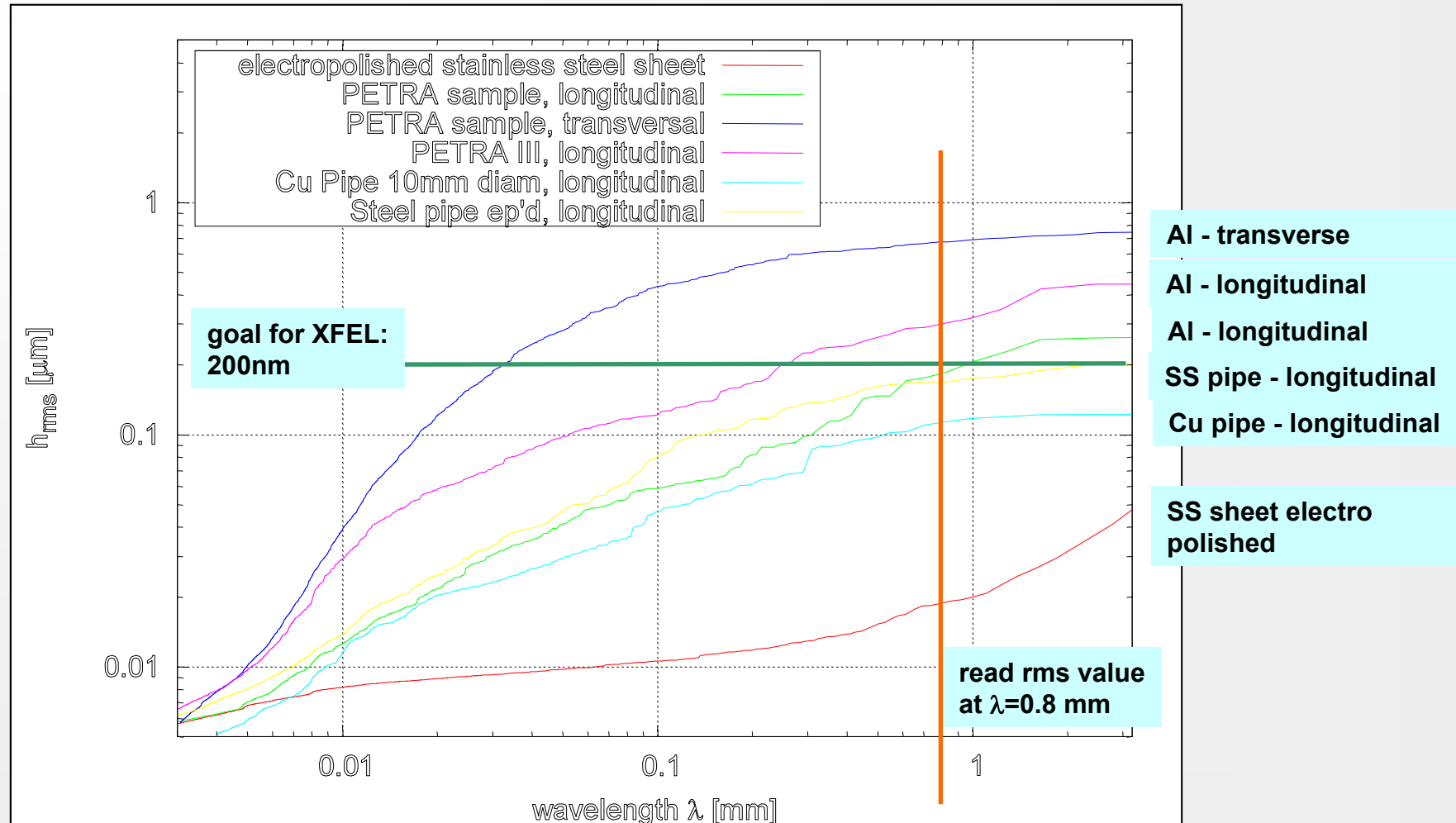


XFEL: avoid peaks in charge distrib. → Cu, Al, Au, Ag ... are roughly equivalent  
high DC conductivity desirable though..

# some roughness profiles...



# integrated power spectrum roughness rms vs. wavelength $\lambda$



# 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**