Warm Vacuum Systems

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DESY, MVA

Outline

- some basics on **accelerator vacuum**; discussion on XFEL vacuum level
- warm sections **overview** and issues
- RF gun; bunch compressor
- transport lines; beam distribution
- collimator unit; water cooled Ti insert
- **undulator vacuum system**:
  - choice of material, intersection; cavity BPM; spont. radiation; pressure profile
- summary

Beam Vacuum

usually UHV (Ultra High) Vacuum systems

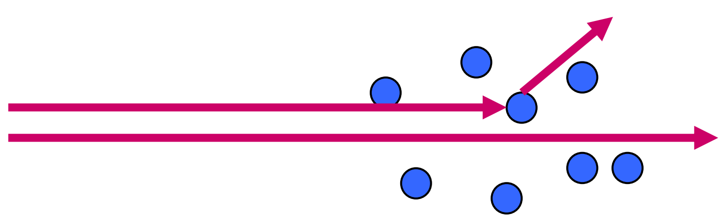
P ~ 10^{-9} mbar; storage ring: beam lifetime ~several 10h

standard air pressure 10^3 mbar → 12 orders of magnitude!

extreme care has to be taken during production of components; no contaminations, oil etc.

in XFEL conditions somewhat relaxed because beam passes only once!

P ~ $10^{-7}..10^{-6}$ mbar is acceptable in transport lines; close to cold cavities pressure should be better ~10^{-9}; particle free !



beam particles scatter at residual gas molecules → loss of beam

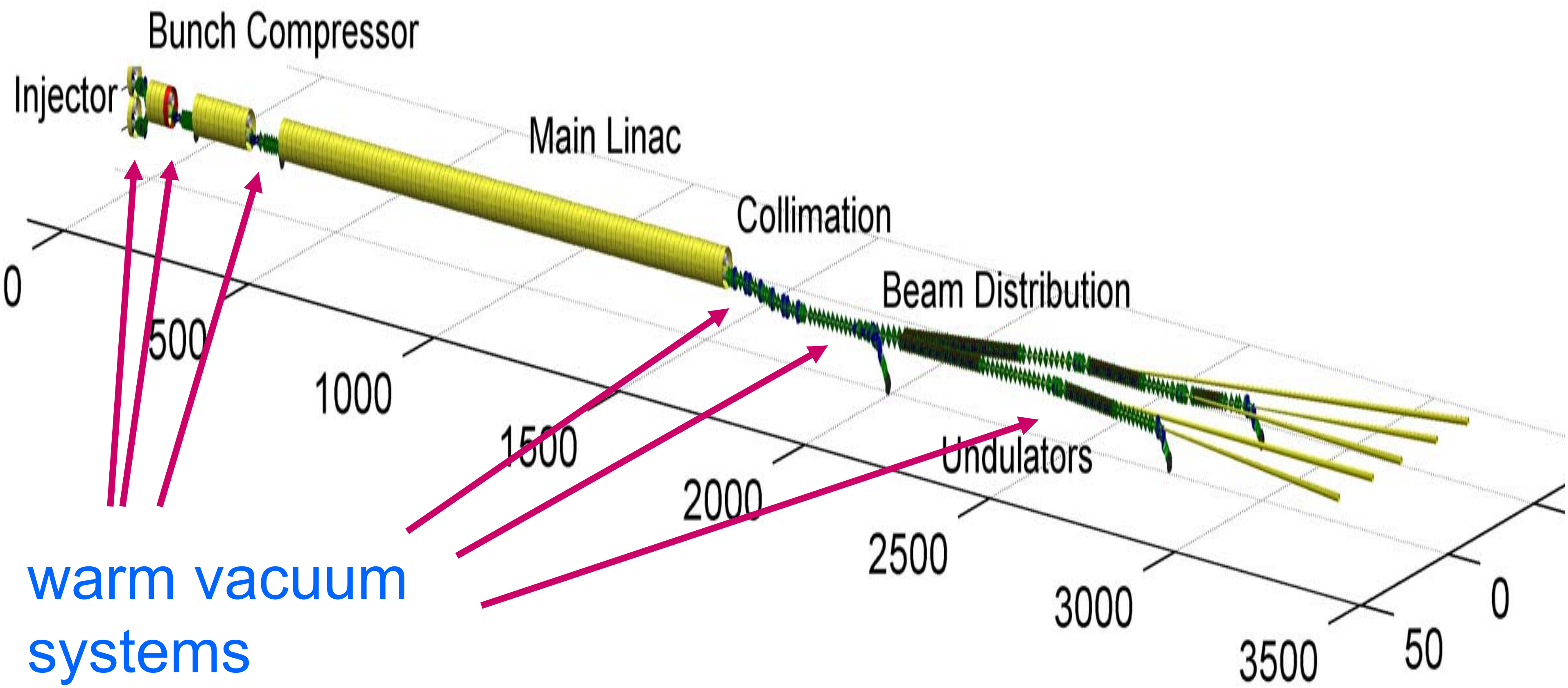
goal: loss/beam ≤ 10^{-9}

P_{max}=300kW → P_{loss} < 0.3mW

warm vacuum – materials, components

- chamber materials:
  - stainless steel (special chambers eg. bunch compressor)
  - copper (pipes in transport lines, absorbers)
  - extruded aluminum ? (undulator)
- pumps:
  - mobile turbo-pump units
  - ion getter pumps (appx 500units)
  - Ti sublimation pumps
- chamber supports, flange connections, diagnostics, tech. interlock systems, all metal valves…

Overview XFEL, Warm Sections

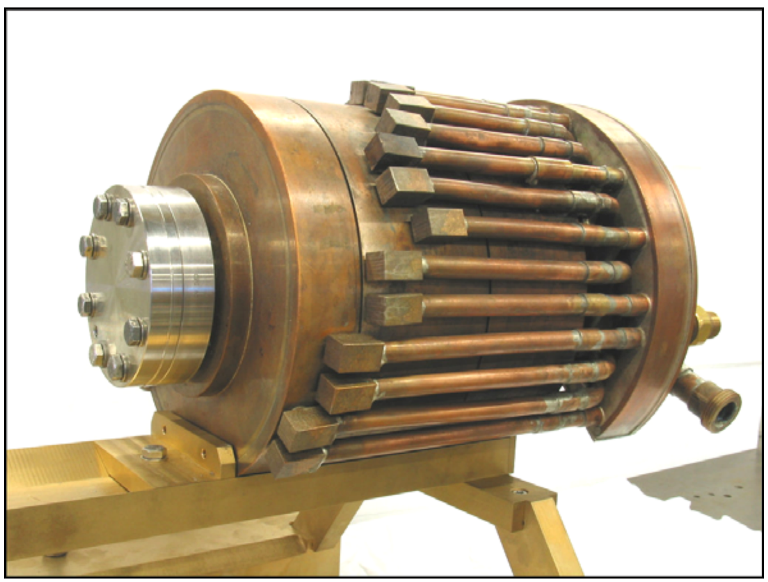


Categories of Sections/Components

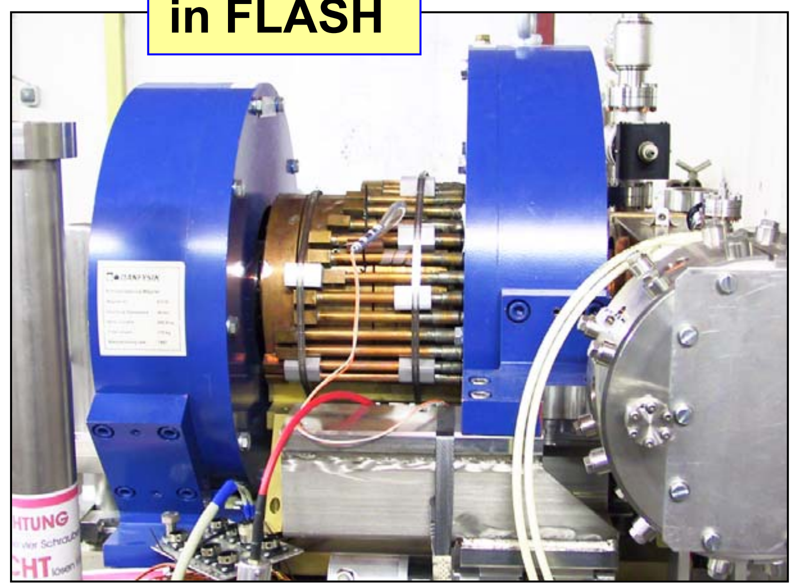
section	length	issues
injectors I,II	111,5m	RF-guns: continuous R&D program, particle free, high complexity (WP19, WP8)
compressors, diagnostic	160m	flat steel chambers, copper coating, narrow tolerances (WP19, WP8)
collimator section	209m	precision collimator units, material: Ti, complex diagnostic section
undulator chambers	713m	small aperture, low roughness, high conductivity
beam distribution	1.737m	optimized for cost, low complexity, copper pipes

RF Gun – Particle Source

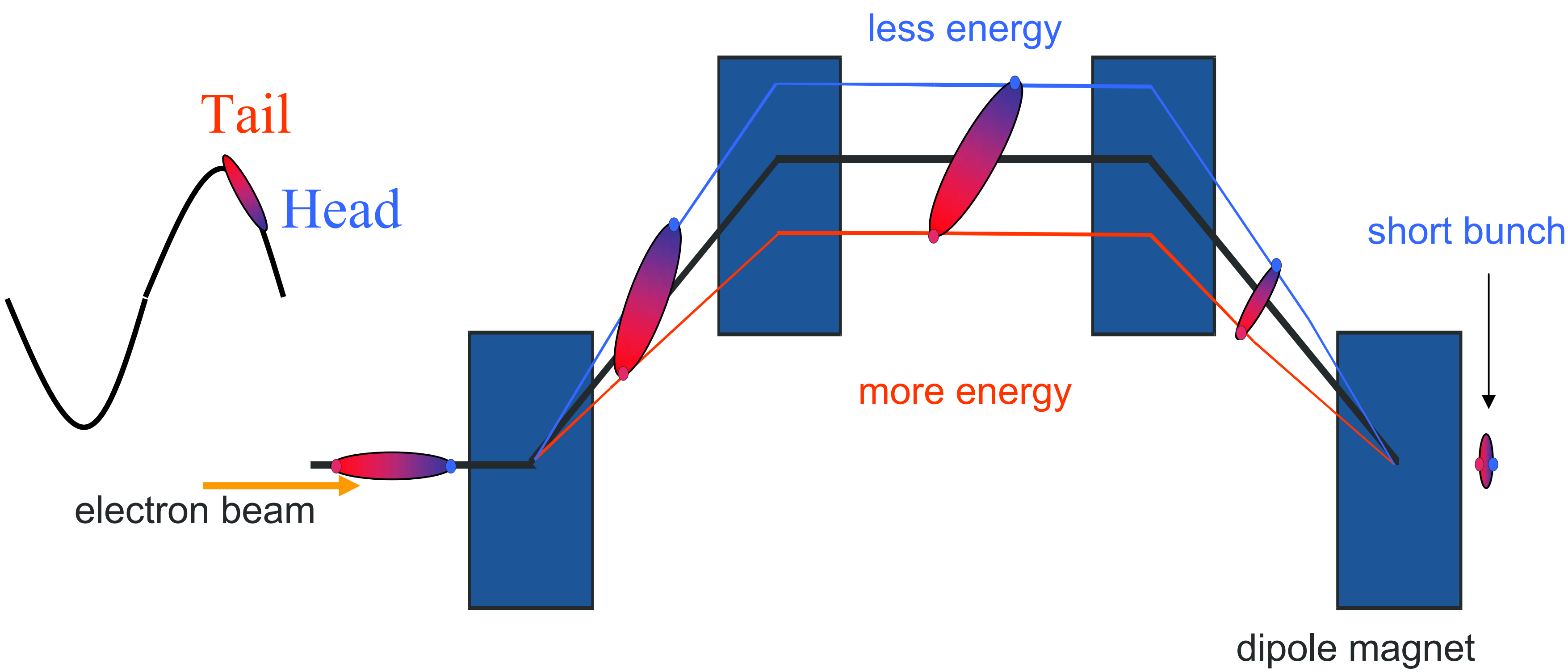
- high accelerating gradient to counteract repelling space charge forces → large heat dissipation, good cooling essential to maintain dimensions!
- 1½ cell RF acc. structure, brazing in vacuum furnace
- cathode specially prepared, eg.Cs_2Te for low electron work-function; needs constantly low pressure ~10^{-10}mbar to maintain properties



in FLASH



Bunch Compressor Section

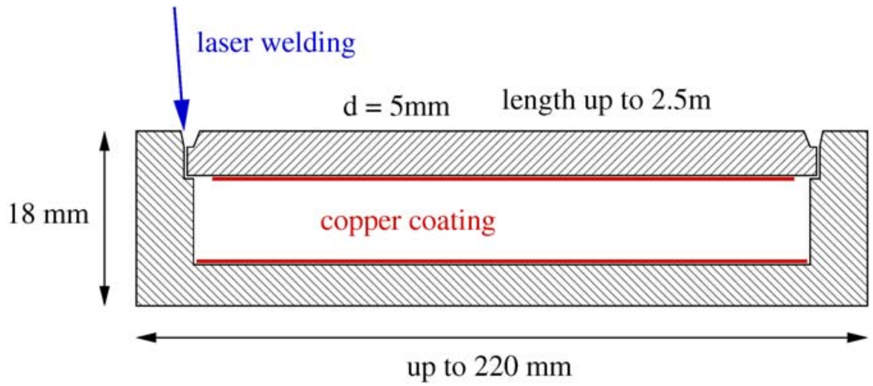


desired: varying compression ratio via varying bump strength/amplitude

→ vacuum chamber: flat and wide aperture!

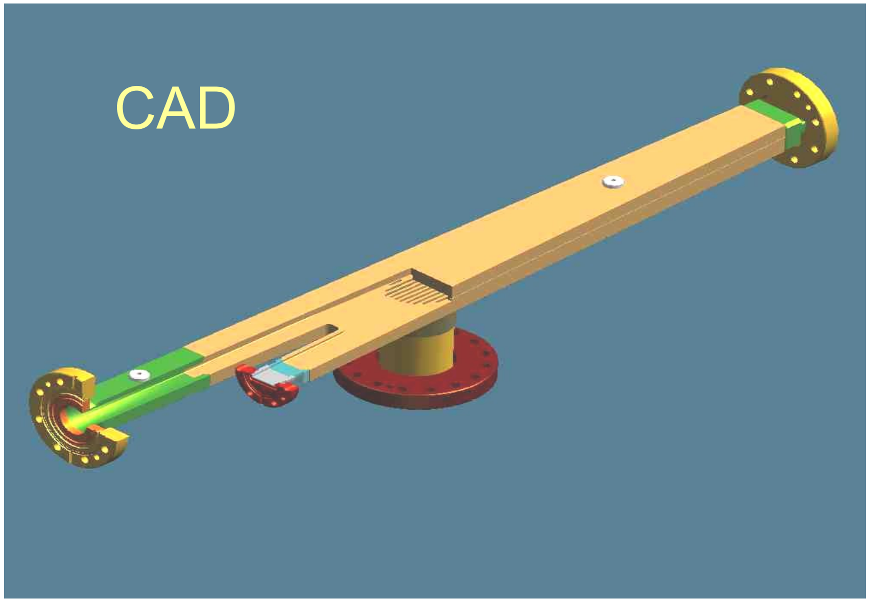
Compressor Chambers

- from steel sheets, laser beam welded, small μ_r
- particle free prepration (close to cold cavities)
- many diagnostics ports for beam monitoring, SR observation



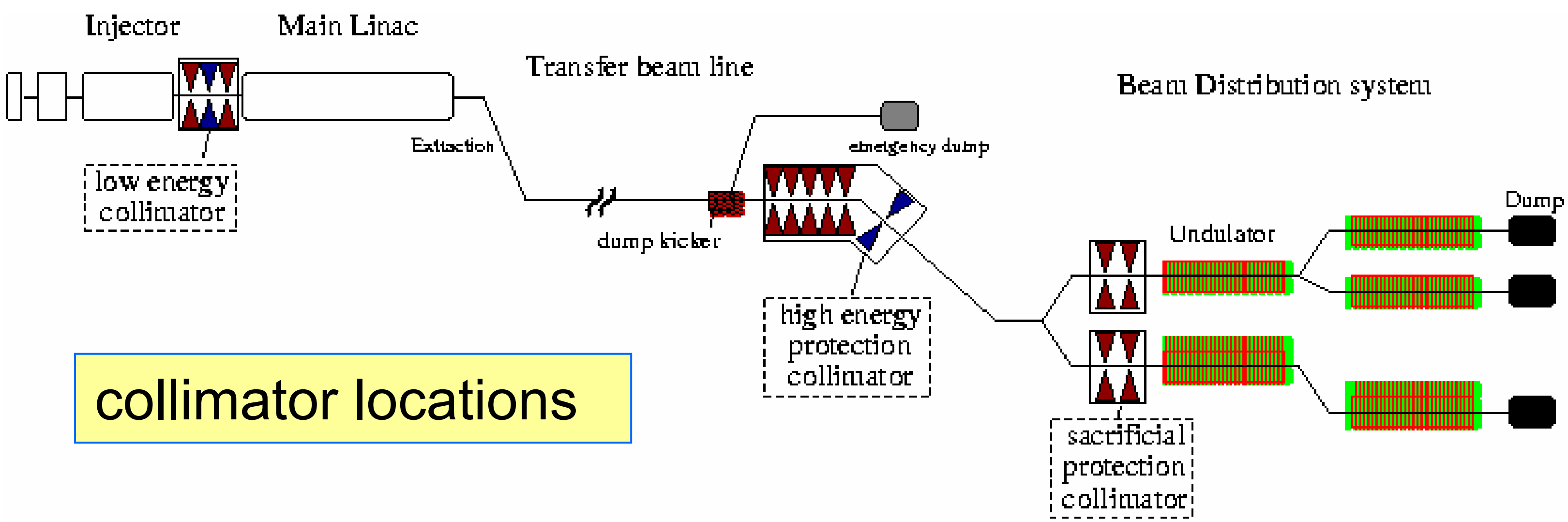
stainless s. copper coated;
5mm wall; large width;

straightness critical!



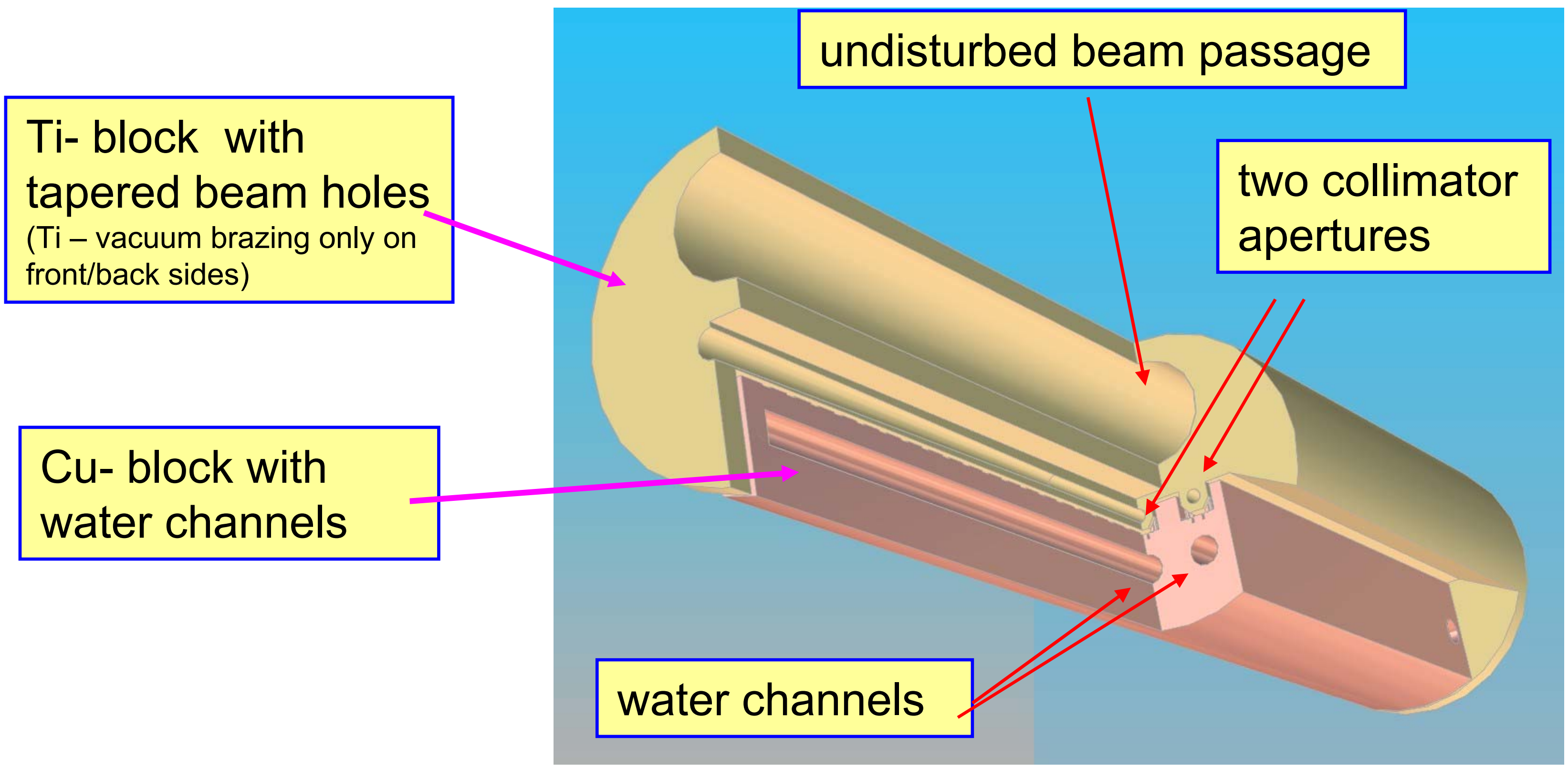
Collimation System

- purpose: avoid direct beam hits (mis-steered) or loss (halo) in the undulator (radiation may demagnetize permanent magnets)
- remove dark-current generated in cavities
- collimator should withstand beam hit for few bunches; made from Ti



Collimator Block - Titanium Insert

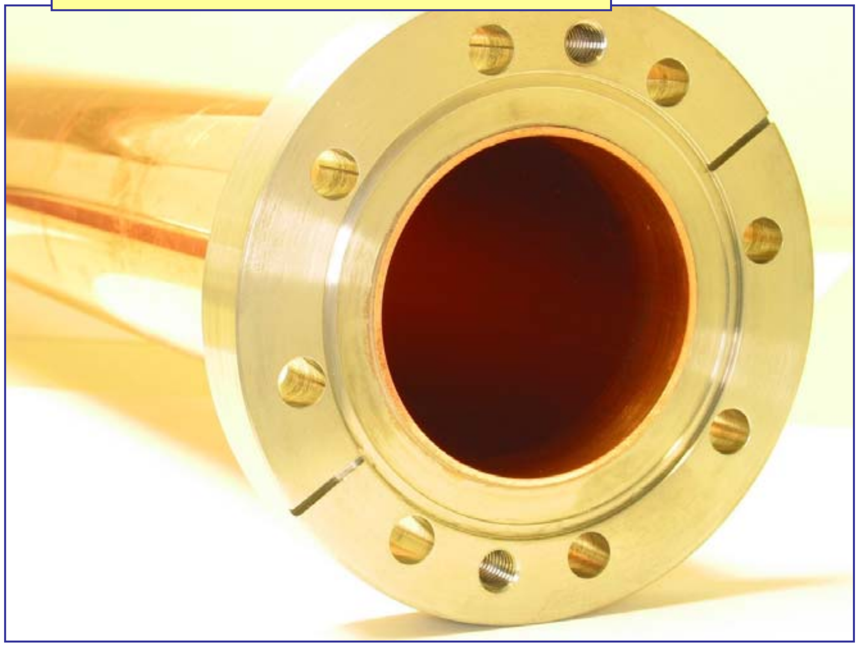
- **Collimator Units** ensure that mis-steered beam or dark-current cannot hit undulator magnets
- choose Ti for high stress resistance in case of mis-steered beam hit concept: three interchangeable apertures (holes)
- Ti insert with brazing connection to water cooled Cu block (continous loss of dark current possible); need to test brazing



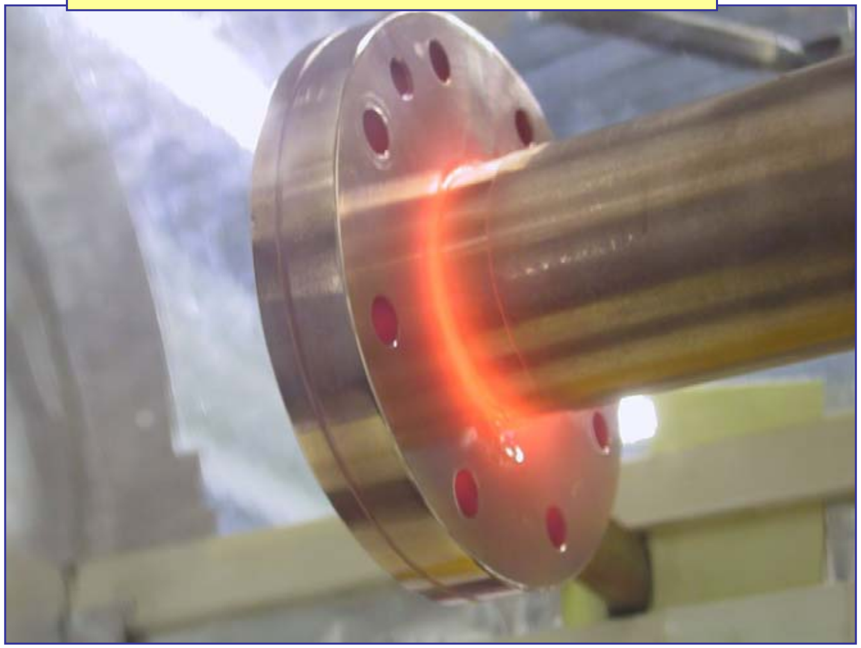
Beam Distribution System

- length 1.7km; optimized for cost; ID 50mm circular pipes;
- high electrical conductivity required; material copper; brazing connection to CONFLAT flanges
- ion getter pumps (60l/s) every ~6m; est. pressure $5 \cdot 10^{-9}$mbar
- issue: cleaning of the chambers and keeping oxidation at a minimum

Cu pipe with CF flange



inductive brazing of flange

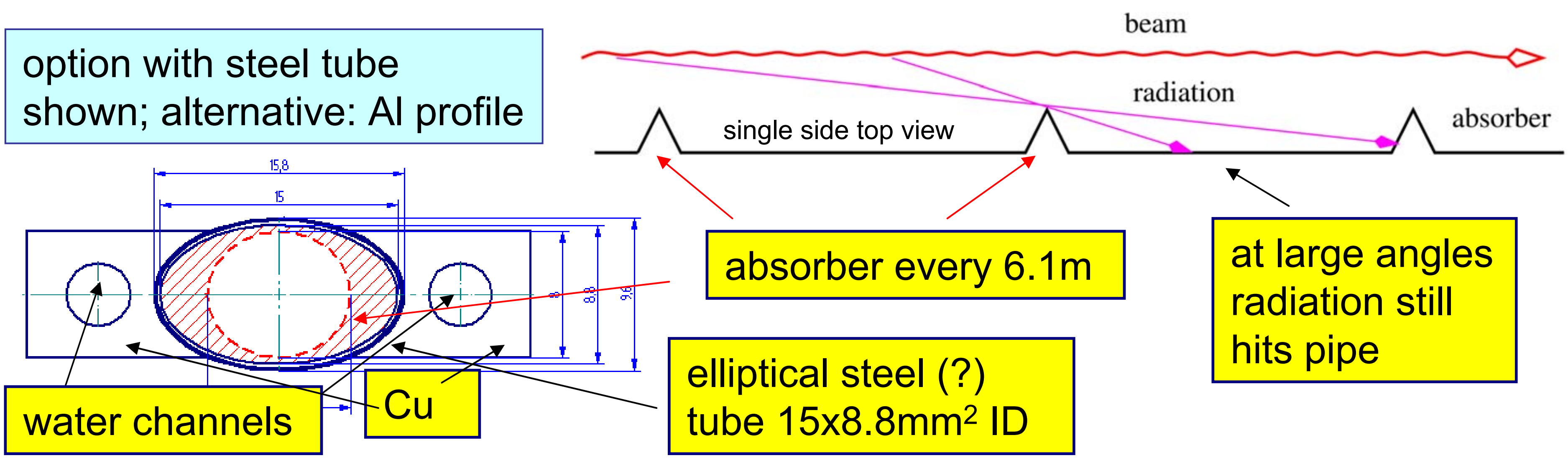


Undulator Section Vacuum System

- each undulator section contains ~40 undulator units (5m) and 40 intersections (1.1m); length ~240m; 3 sections planned
- spontaneous X-ray radiation amounts to maximally 8W/m; absorbers needed!
- small aperture chamber (~9mm inner height) to allow for small magnet gaps → high field strength
- **high conductivity; small roughness!**
- small aperture leads to poor vacuum conductivity and rel. high pressure
- intersection (1.1m) with bellows unit, radiation absorber, cavity BPM, phase shifter (chicane to vary beam path length on nm scale), quadrupole
- for chamber two possible solutions under study: elliptical steel chamber or extruded Al profile

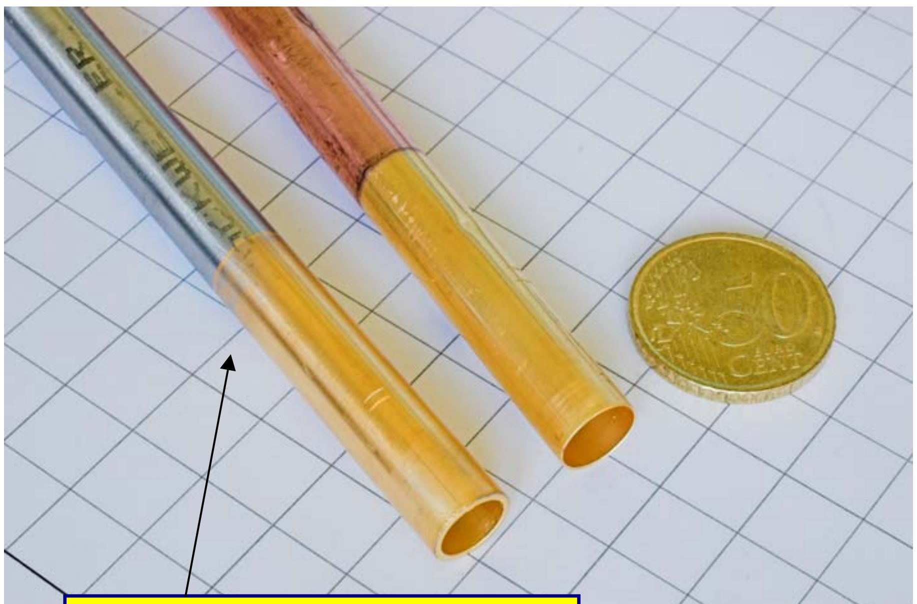
radiation parameters/geometry

	parameters (example)
beam/undulator	$E=20GeV$, $B_{max}=1.3T$, $\lambda_u=48mm$, $K=6$
spontaneous radiation	typ. opening angle: $\theta_x=150\mu m$, $\theta_y=25\mu m$ shadow angle: $\psi_x=500\mu rad$, $\psi_y=75\mu rad$
radiation power	$P'=6.5W/m$ on absorbers (LCLS: 22mW/m)
HOM Power:	$P'=2W/m$, unavoidable, with air cooling $\Delta T \approx 6^{o}C$!



Options for Undulator Chamber Material

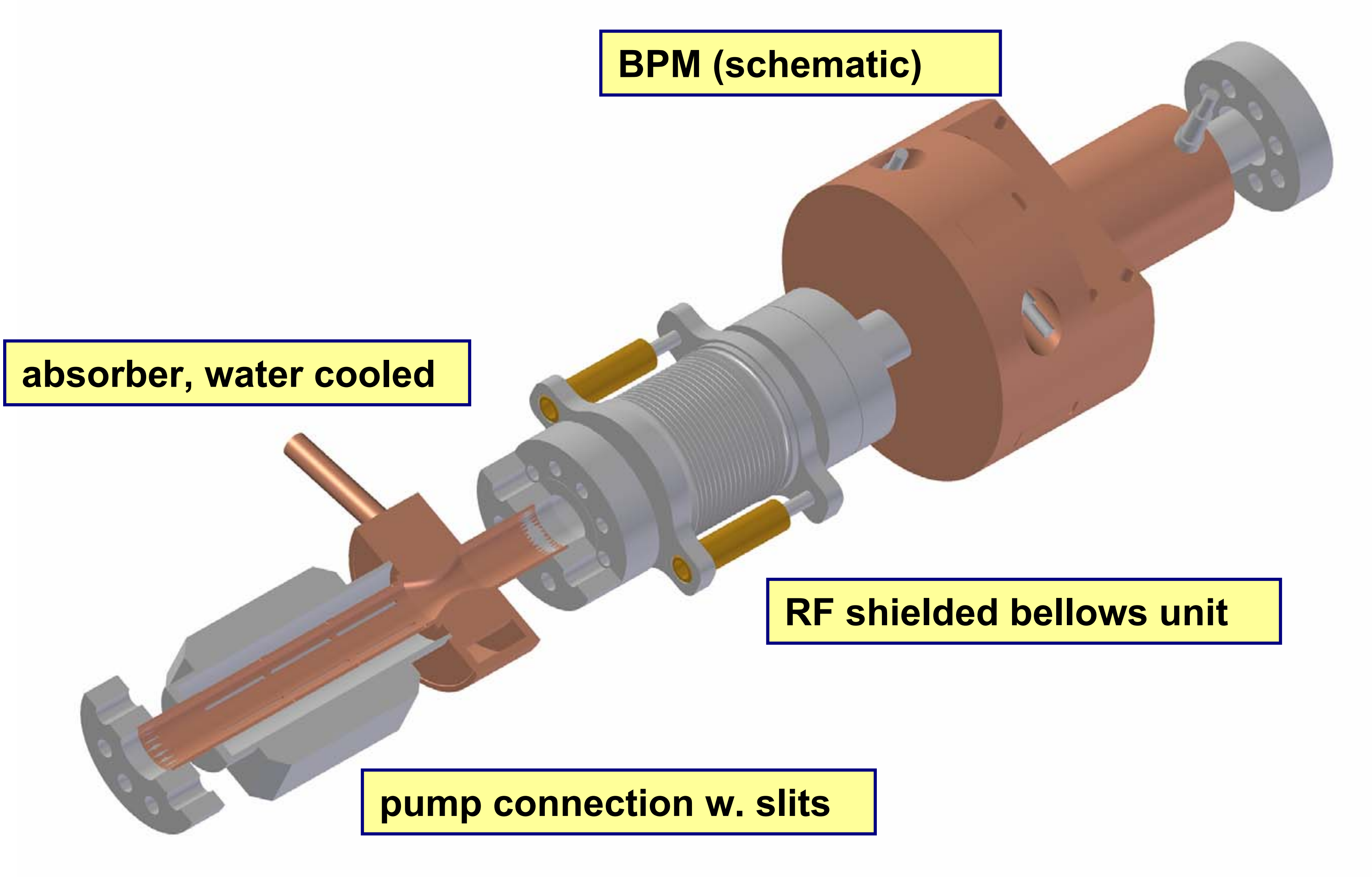
- steel tube – difficult to find manufacturer; formed to elliptical shape, brazing connection (tolerances!) to water channel; μ_r critical!
- Al tube – easier to make; integrated water channel; presumably higher roughness; tolerances critical for wall thickness; larger photon desorpt.
- optimization of coating/oxide layer in collaboration with swedish colleagues; vacuum quality of coating?



steel tube, test sample, gold plated

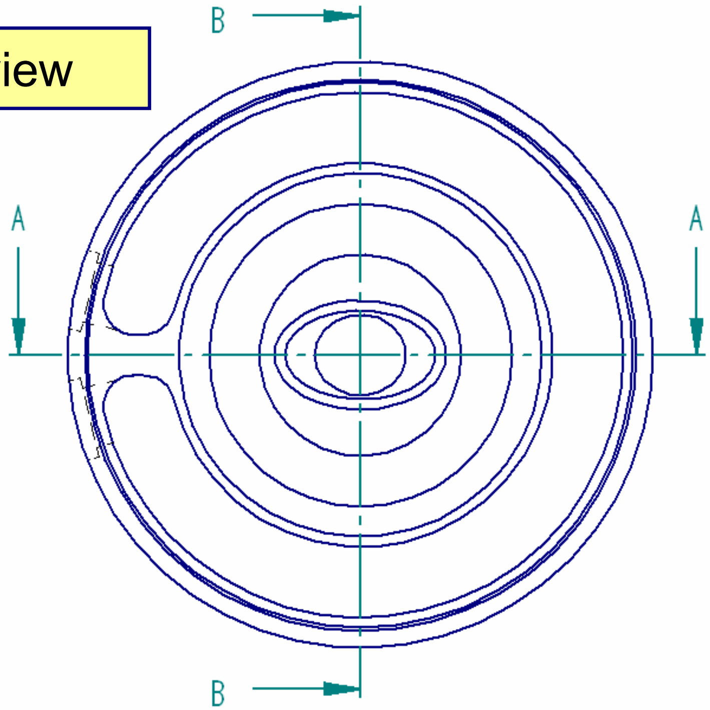
Al profile, test sample, integrated cooling

intersection between undulators – major components

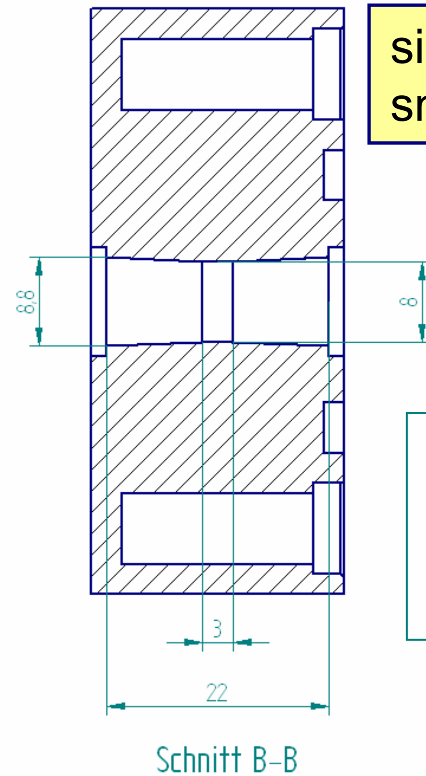


layout of tapered absorber

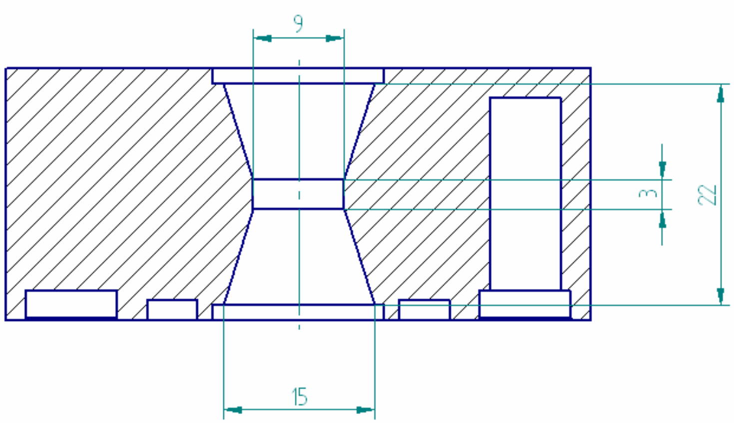
front view



side view –
small shadow angle



possibly W insert
needed since Cu
too transparent for
radiation (300 keV)!

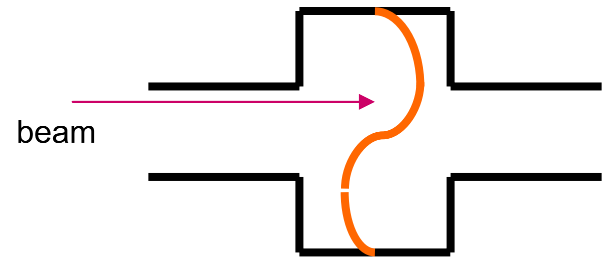


top view – large
shadow angle

Cavity BPM

principle:

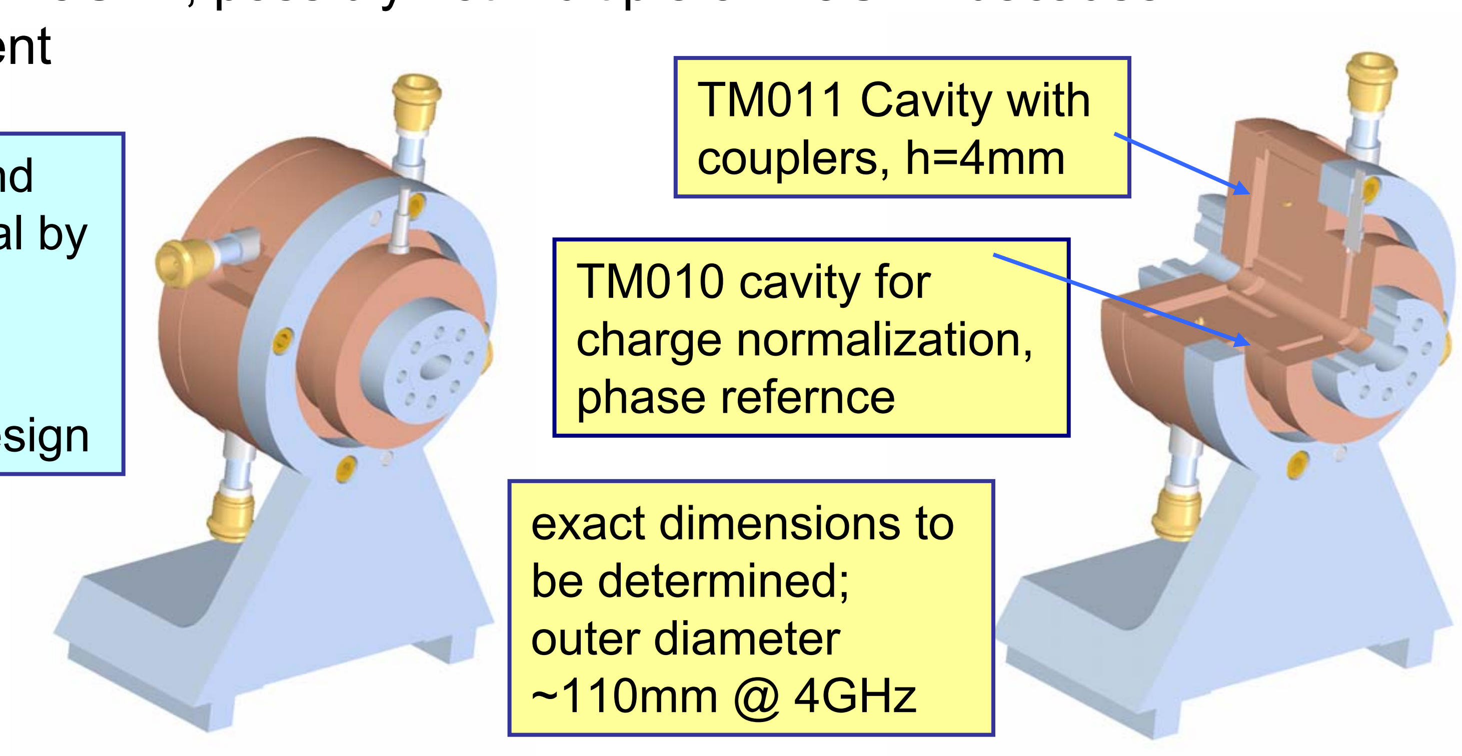
offset beam excites dipole mode; strength of signal is prop. to beam offset



- cavity → stronger signal, more precise than buttons
- frequency ~4..5GHz; possibly not multiple of 1.3GHz because of dark current

principle design and machining proposal by T.Wohlenberg

ideas taken from NLC/ILC/SSCS design



TM011 Cavity with couplers, h=4mm

TM010 cavity for charge normalization, phase refernce

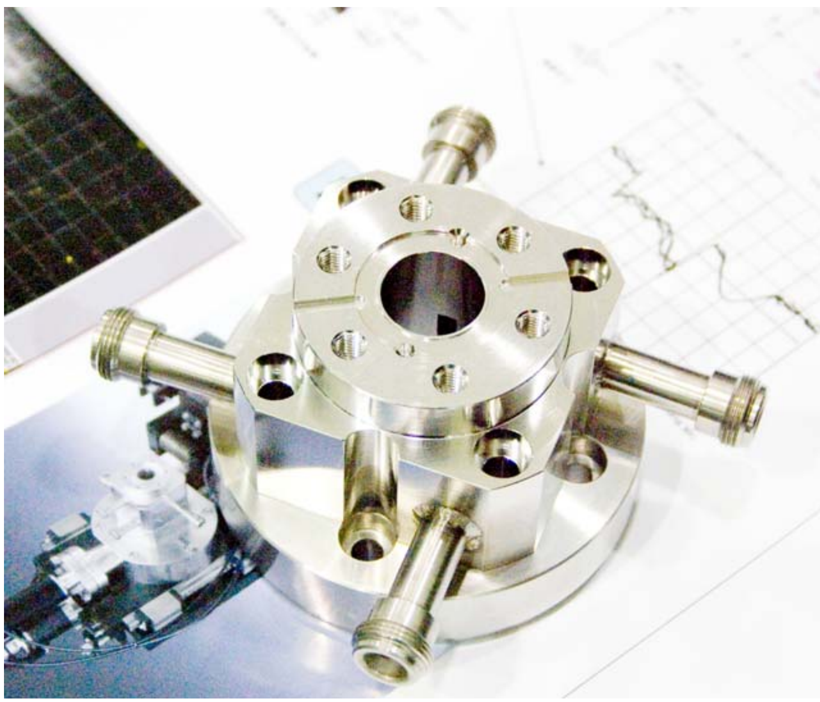
exact dimensions to be determined; outer diameter ~110mm @ 4GHz

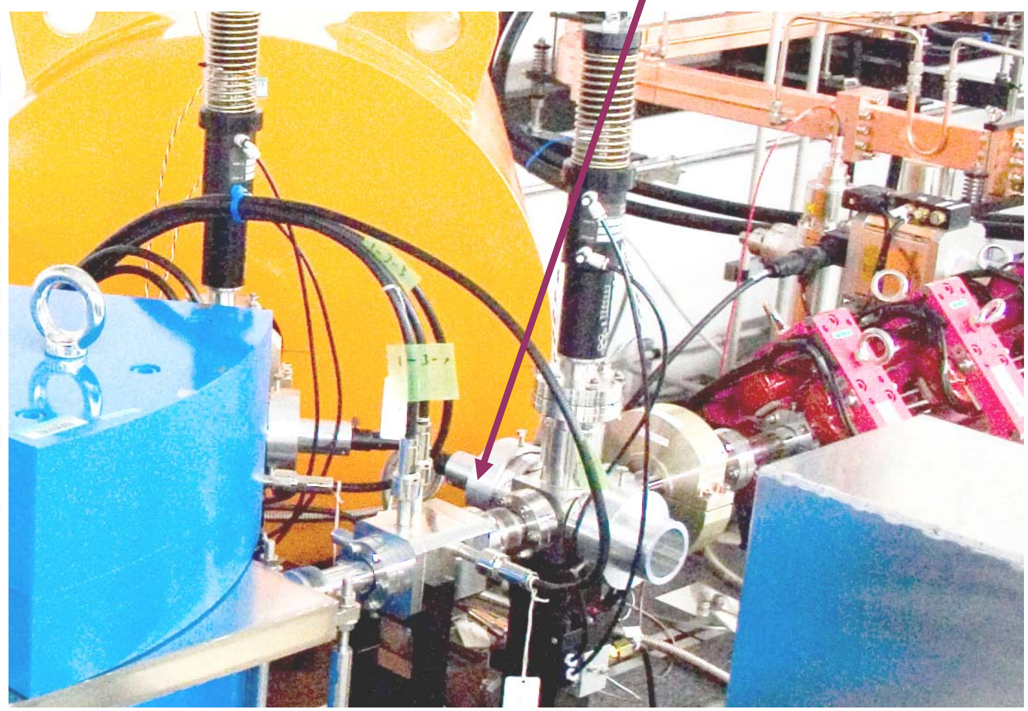
Cavity BPM – SPRING8(SCSS) Design

- TM011 cavity at 4.76GHz, brazed stainless steel, Q~130
- integrated TM010 cavity as charge monitor, ext. phase reference!
- much emphasize on ADC – 11Bit at 238MHz (spring8 internal development!?), anticipated res. <1μm

→ **good prototype for us !**

in beamline, with reference cavity

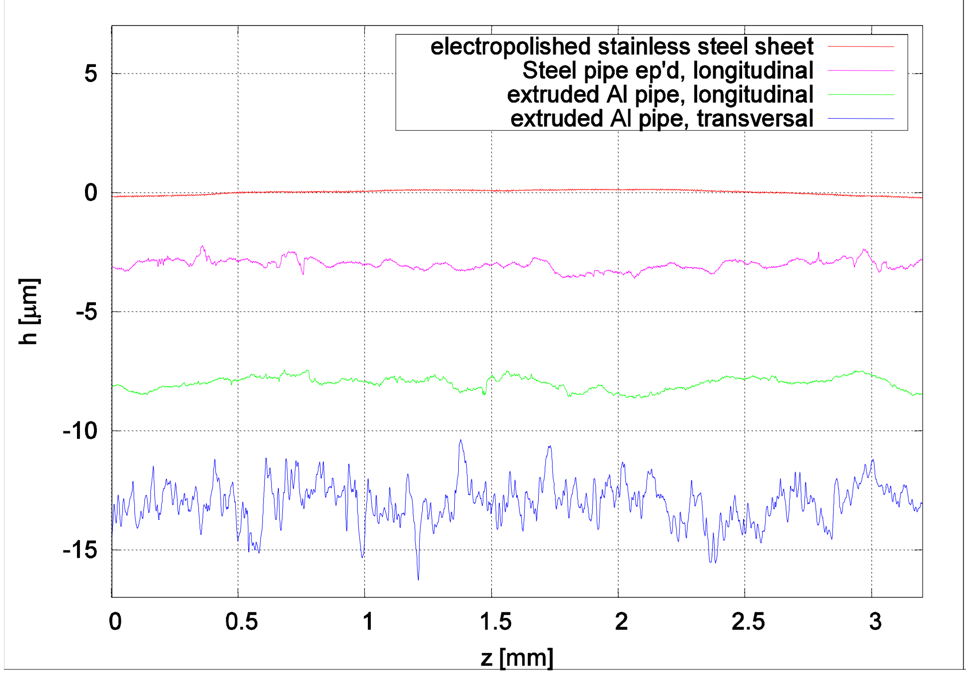




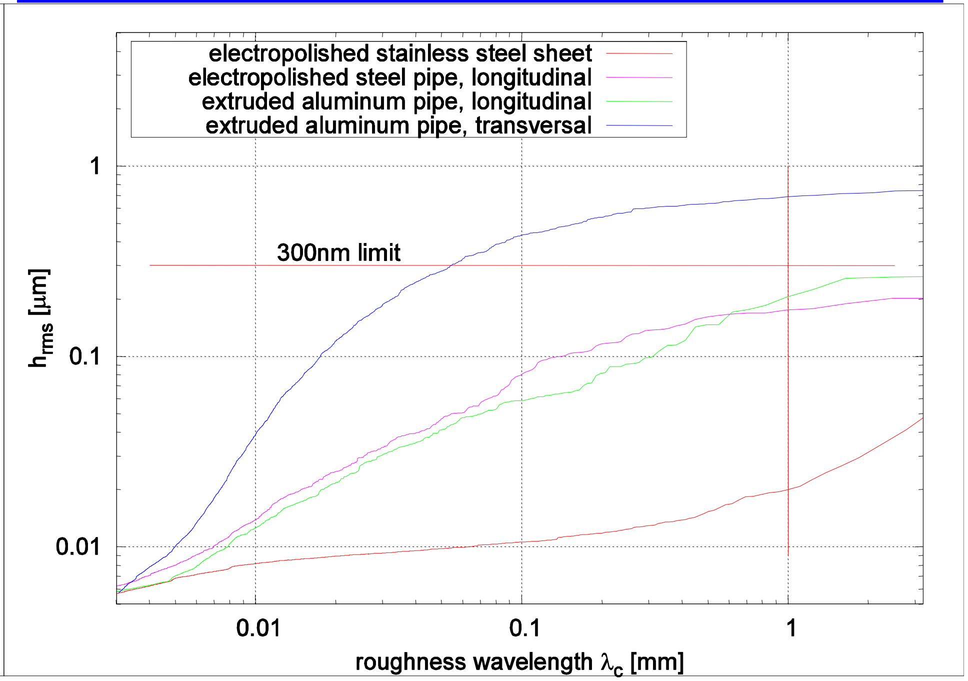
Mechanical Properties of Vacuum Pipe in Undulator

- thin oxide layer (dielectric) Al: 5nm, Cu: 1nm, Au:?
- roughness rms<300nm@1mm wavelength
- high el. conductivity, low outgassing, thin wall, water cooling

surface profiles of materials



integrated power spectrum of profiles



Overview Wakefield-Effects

unavoidable: resistive wakes from narrow pipe → sets the scale for other effects

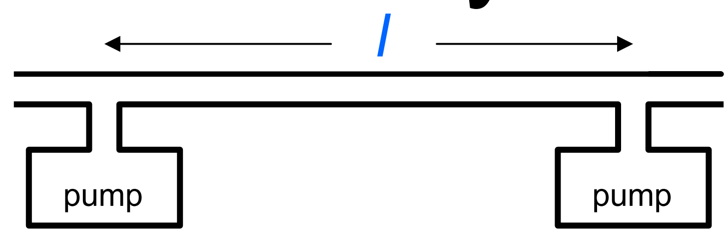
M.Dohlus
I. Zagorodnov:

		rms energy spread from l.wake:
resistiv (Al):		49.5 V/pC m
geometric	absorber	16 V/pC
	bellows unit	5 V/pC
	flange gap	2.4 V/pC
	long pumping slit	<0.2 V/pC
oxid layer	Cu 1nm	1.1 V/pC m
	Al 5nm	5.7 V/pC m
roughness	Al 600nm(!)	9 V/pC m

→ oxide layer is rel. important; above quoted numbers ambitious, consider Au coating → collaboration with Swedish university, Lars Westeberg

conductance limited vacuum system

- pumps at a distance of *l*=6.1m
- small pipe is conductance limited;



conductance = $\dfrac{\text{amount of gas (moles or molecules)}}{\text{time} \cdot \text{pressure difference}}$ [mbar l / mbar s]

gas equation ***pV = nRT*** → [mbar l] is a measure for the amount of gas!

is constant (293K)

conductance ~ d^3 → strong scaling with pipe dimensions

average pressure

$$P_{avg} = Aq\left(\frac{l^2}{12c} + \frac{l}{S}\right)$$

term remains/dominates, even for S → ∞

Aq – outgassing; thermal but mainly photon radiation

l – length, pump distance

c – conductance

S – pumping speed

pressure simulation with photodesorption

- this system is extremely conductance limited (c = 0.125 l m / s)
- expected average pressure ≈ $7 \cdot 10^{-7}$ mbar (Al), ≈10^{-7} mbar (SS)
- vacuum will improve from conditioning!

with lumped pumps as planned, Al pipe (full 300kW beam, improved by /=2 after 60 days)

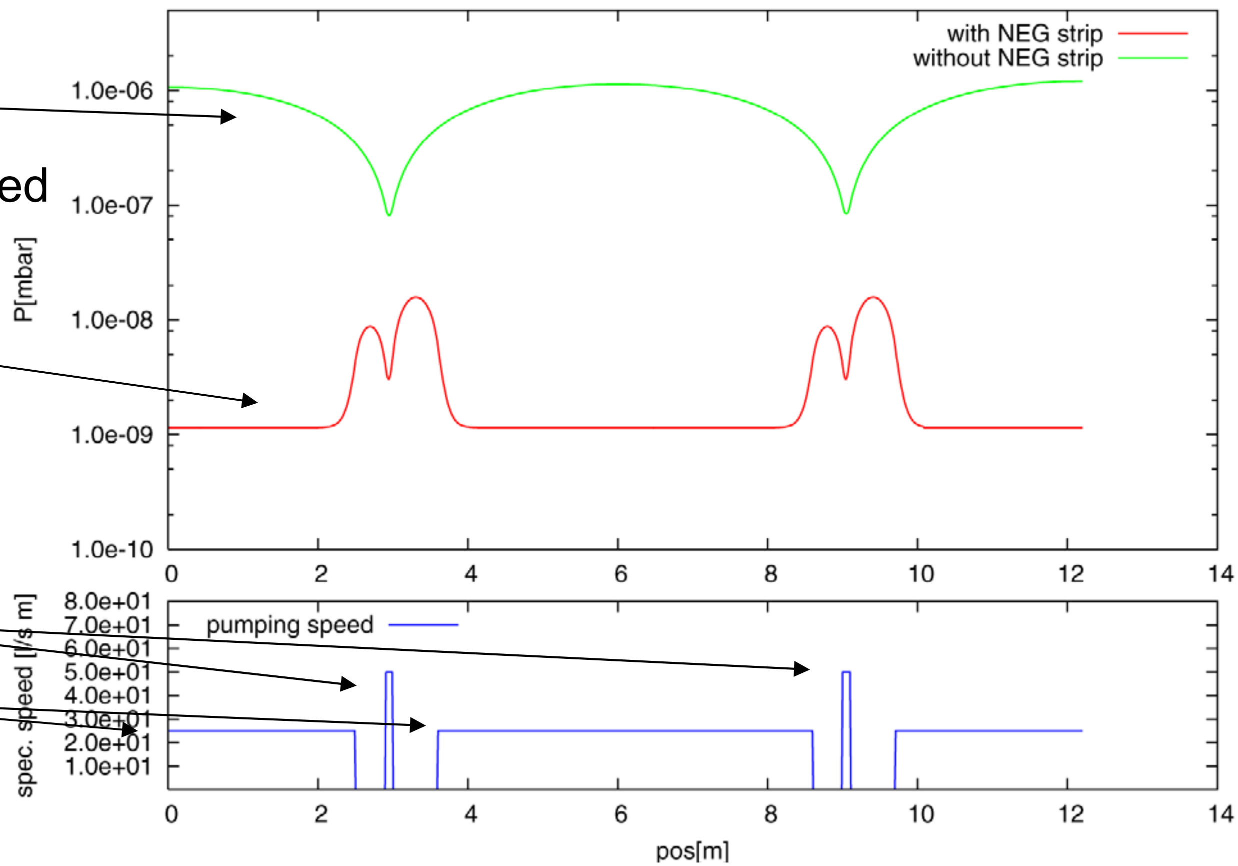
with NEG pump

(not needed)

pumping speed per m

lumped pump

NEG strip



Status and Summary

- presently "cataloging" of all vacuum sections completed; detailed cost and manpower estimate available
- **technologically difficult** sections: undulator/collimator are under work to develop strategy (issues: tolerances, roughness, oxide layer, brazing exotic mat. combinations)
- **technically complicated** sections: bunch compressor flat chambers with tight tolerances; particle free preparation
- other sections standard technology – Cu pipes; ion getter pumps etc.; although **large quantity**