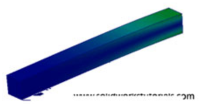
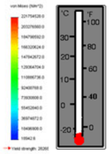
Flash Therapy @ PITZ

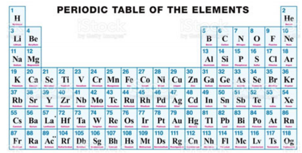
CFC-based Window, Status

Michael Schmitz, Oct. 13, 2021

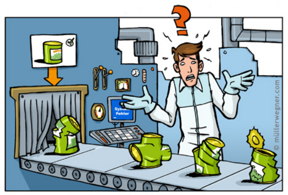
Agenda

1) Constraints ⇒ Material Selection

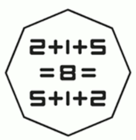




2) Technical Realization of Window and Issues



3) Summary and Outlook



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

PITZ Photo Injector Test Facility at DESY, Zeuthen site

Constraints, Disc Window: Radius R, Thickness t, Edge cooled

Load on Window	Involved Parameters: beam	Involved Parameters: material	Resulting Limits	Goal
static by p_{atm}		$\sigma_{0.2}, R$	$\Rightarrow t$	
	E_b	t, X_0	$\Rightarrow \theta_m$	small
instantaneous-cyclic by bunch-train	σ, q_t	c, α σ_{cycl}, ν, E	$\frac{\Delta Q}{\Delta m} < tol\left(\frac{\Delta Q}{\Delta m}\right) \Rightarrow \sigma_{min}(q_t)$	small
quasi-static by I_{ave}	I_{ave}, σ	ρ, λ	$\Rightarrow T_{eq}(x, y, z) \Rightarrow \sigma_{min}(I_{ave})$	small

Parameter	Description
t , R	thickness & radius of window
θ_m	Moliére angle
p_{atm}	pressure on air-side of window
$\frac{\Delta Q}{\Delta m}$, $tol\left(\frac{\Delta Q}{\Delta m}\right)$	instantaneous-cyclic energy deposition in window by charge q_t & its tolerable limit
σ , σ_{min}	spot size at window & its lower limit
q_t , ν_t	charge & repetition rate of bunch train
$I_{ave} = q_t \cdot \nu_t$	average beam current
E_b	beam energy

Material Property	Description
X_0	rad. lenght
ρ	mass density
c	spec. Heat
λ	therm. cond.
α	therm. expansion
$\sigma_{0.2}$	tensile strenght
σ_{cycl}	endurance limit
E	E-modulus
ν	Poisson number

Constraints, Static Load by Air Pressure

Range of Validity:

- **Disk** with Radius **R** & Thickness **t**
- **Fixed** at Circumference (r=R)
- $\mathbf{p_{atm}}$ from one Side

max. Stress appears radially at Circumference:

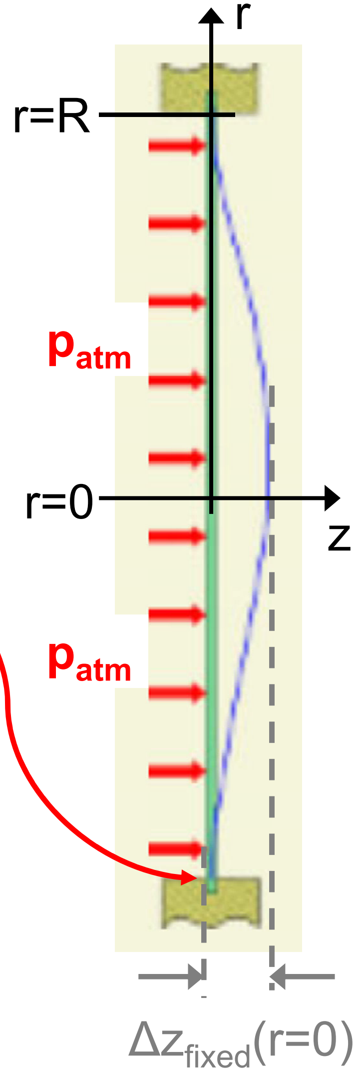
$$\sigma_r(r=R) = \frac{3}{4} \cdot p_{atm} \cdot \left(\frac{R}{t}\right)^2$$

max. radial Tension

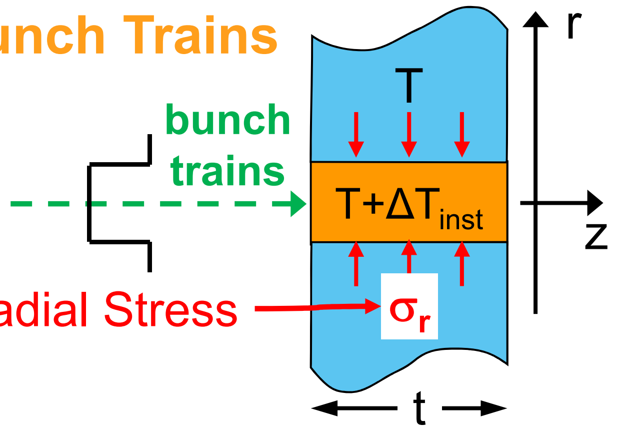
$$\xRightarrow{\sigma_r(r=R) \leq \sigma_{0.2}} \textbf{reasonable Window Thickness } t$$

$$\Rightarrow \Theta_{\text{Moliére,rms}} = \frac{13.6\frac{MeV}{c}}{\beta \cdot p_{beam} \cdot c} \cdot \sqrt{\frac{t}{X_0}} \cdot \left[1 + 0.038 \cdot ln\left(\frac{t}{X_0}\right)\right]$$

Sag at Center: $\Delta z_{fixed}(r=0) = \frac{3}{16} \cdot \frac{p_{atm} \cdot R^4}{E \cdot t^3} \cdot (1-\nu^2)$



Constraints, Cyclic Load by repeating Bunch Trains



Range of Validity:

- **Bunch Train heats Window** Material by $\mathbf{\Delta T_{inst}}$
- **Simplified mech. Model,** rectangular Beam resp. T-Profile: cylindrical Volume is radially bound, long. not $\Rightarrow$ cyclic radial Stress

Cyclic radial Stress:

$$\sigma_r = \frac{\Delta T_{inst}}{1-\nu} \cdot \alpha \cdot E \xRightarrow{\sigma_r \leq \sigma_{cycl}} tol(\Delta T_{inst}) \overset{c}{\Rightarrow} \mathbf{tol}\left(\frac{\Delta Q}{\Delta m}\right)$$

- **1 Bunch Train** with Charge $\mathbf{q_t}$ and **round Gaussian** (f_g) **Spot Size** σ
- **Thermal Diff.** during $t=1/\nu_t$ **neglected,** justified when $\Lambda \ll \sigma$
- **Shower Development negligible,** since $t \ll X_0$
- **Energy Deposition** $\Delta Q/\Delta m$ in Material **by e- Ionization Loss**
- $\left(\frac{1}{\rho}\frac{dE}{dx}\right)_{ion}$ for high Energy e- merely **independent of Energy & Material**

$$\Lambda(t) = \sqrt{\frac{\lambda}{\rho \cdot c}} \cdot \sqrt{t}$$

Max. Energy Deposition at Peak of Gaussian:

$$max\left(\frac{\Delta Q}{\Delta m}\right) = \frac{\Delta Q}{\Delta m}(r=0) =$$

$$\underbrace{\left(\frac{1}{\rho}\frac{dE}{dx}\right)_{ion}}_{\sim 2 MeV \cdot cm^2/g} \cdot \underbrace{f_g(r=0)}_{=1/(2\pi \cdot \sigma^2)} \cdot \frac{q_t}{e} \approx 0.032 \frac{J}{g} \cdot \frac{[mm^2]}{\sigma^2} \cdot \frac{q_t}{[nC]}$$

$$\xRightarrow{max\left(\frac{\Delta Q}{\Delta m}\right) \leq tol\left(\frac{\Delta Q}{\Delta m}\right)} \sigma_{min}(q_t)$$

lower Limit of Spot Size at Window

Constraints, Quasi-average Load by average Beam Current

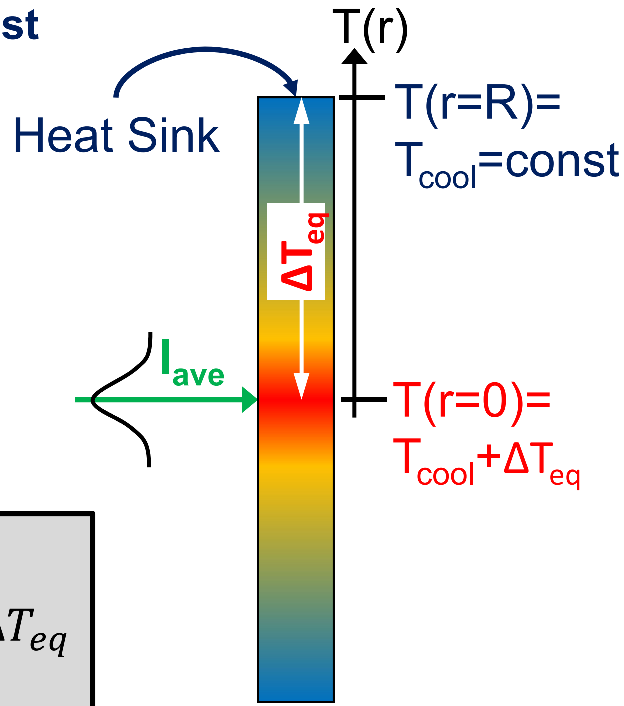
Range of Validity:

- **Repeating Bunch Trains** with **Charge q_t**, round Gaussian **Spot Size** σ and **rep. Rate** ν_t
- Pulsed Beam with $I_{ave} = q_t \cdot \nu_t$ **treated as pure DC-Beam**
- **Energy Deposition** treated as on previous slide
- **Heat Extraction ONLY** by **Heat Conduction** to Window Circumference (very conservative)
- **Window Circumference** @ r=R **is Heat Sink** with **T_{cool}=const**

T-Drop between Window Center & Circumference:

$$\Delta T_{eq} = \frac{1}{4\pi\,\lambda} \cdot \frac{dP_{ave}}{dz} \cdot ln\left[1 + \frac{R^2}{2\,\sigma^2}\right]$$

$$\text{with: } \frac{dP_{ave}}{dz} \approx 2\,\frac{W}{cm} \cdot \frac{\rho}{[g/cm^3]} \cdot \frac{I_{ave}}{[\mu A]}$$



Compare

max. quasi-Equilibrium Temperature-Level $T_{cool} + \Delta T_{eq}$

with Material Operation Limits

If risky $\Rightarrow \sigma_{min}(I_{ave})$

Constraints, Material Pros & Cons, Motivation for CFC-Graphite

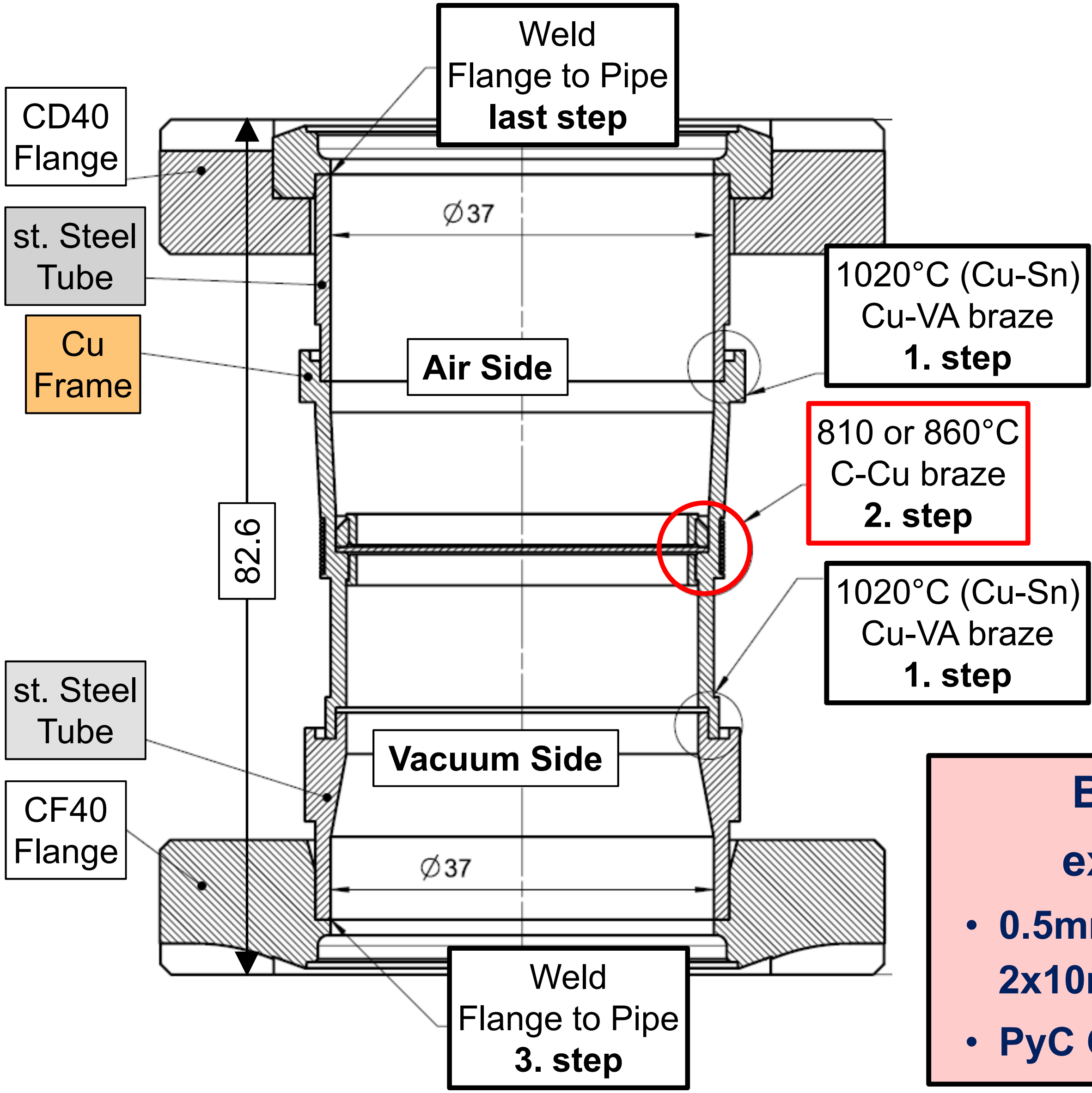
R [mm]	*17*	C isotropic	Mersen CFC-A-KFM	SGL SigraBond mechanical	Schunk CF-222	Schunk CF-12136 (Vlies)	Kapton Polylmid	Be	Al	Ti	Fe	Cu
p [MPa]	*0.1*											
Consequences from Static Load												
tensile strenght ($\sigma_{0.2}$, CFC: flexural)	**MPa**	60	120	65	100	110	120	300	110	350	300	130
t_{fix}	**mm**	0.60	0.43	0.58	0.47	0.44	0.43	0.27	0.44	0.25	0.27	0.41
								*) preforming reduces required thickness !				
Δz_{fixed}	**mm**	0.80	0.42	0.22	0.18	0.70	5.15	0.28	0.22	0.82	0.43	0.16
$\Theta_{Moliere}$ @22MeV	**mrad**	23.2	19.2	21.2	19.2	19.0	17.9	12.4	34.9	41.9	64.3	90.0
Consequences from Pulsed Beam Heating												
tol(ΔQ/Δm) C brittle->70%ΔT_{inst}	**J/g**	225	**98**	**137**	**53**	**337**	196	66	14	79	25	6
σ_{min}	**mm**	0.8	**1.3**	**1.1**	**1.7**	**0.7**	0.9	1.6	3.4	1.4	2.5	5.2
q_t [nC]	*5000*						low T_{melt}					
Consequences from Quasi-Average Beam Heating												
Λ(t)	**μm**	273	170	194	191	163	100	296	284	83	148	331
t [ms]	*1*											
ΔT_{eq}	**K**	80	174	144	120	243	378	37	28	911	244	34
ν_t [Hz]	*10*											

CF-C best *Allrounder,* besides Be

- **Schunk CF-12136**
- **SGL Sigrabond mechanical**
- **Mersen CFC-A-KFM**

Evaluation of ***wrt.***	**CF-C**	**Kapton**	**Be**	**Ti**	**Al**
Scattering			*)	*)	*)
Pulsed Beam					
DC-Beam					

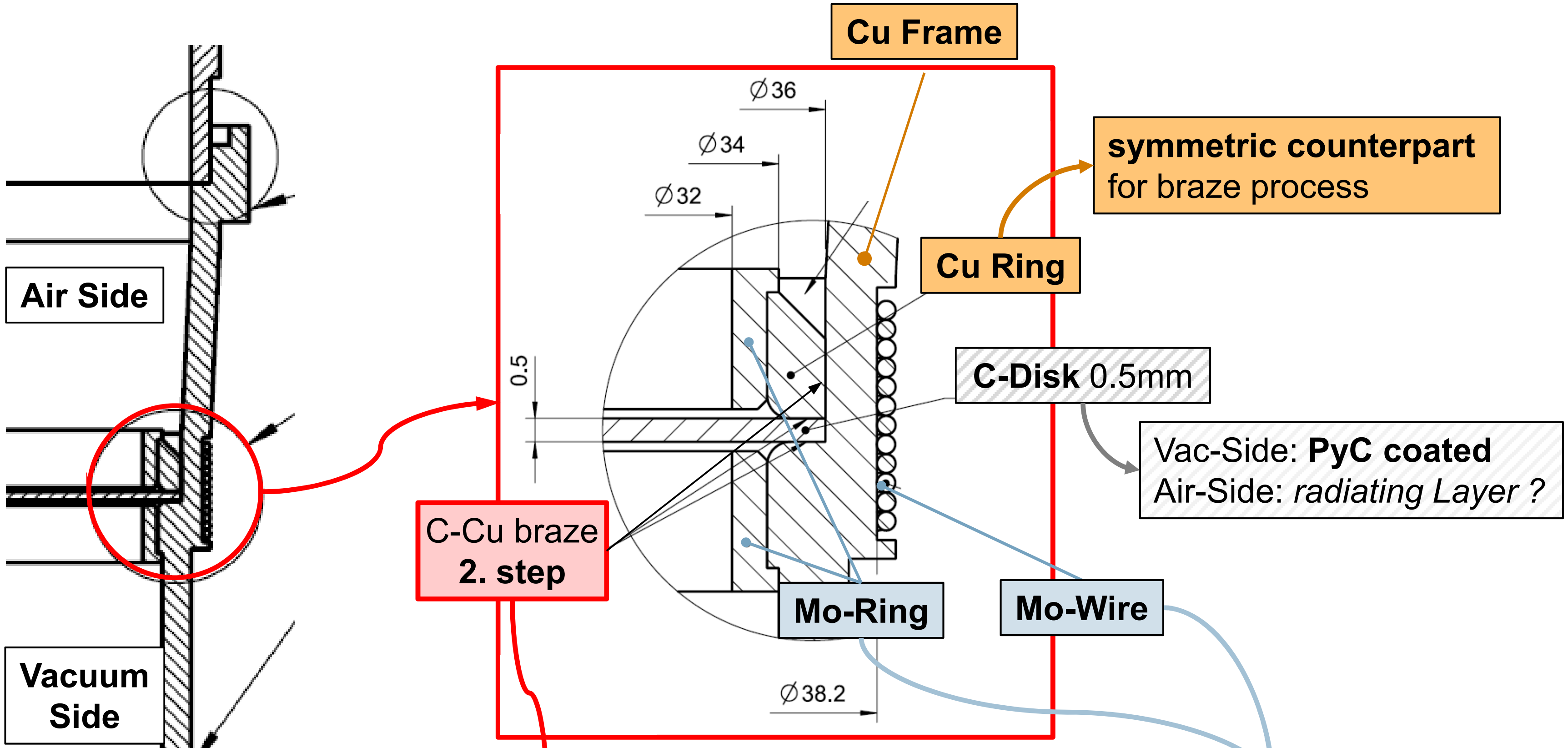
Window Design, Adopt & Modify FLASH & XFEL Scheme



BUT Differences wrt. experienced Scheme:

- **0.5mm C instead of 2x10mm C + 0.6mm Ti** in between
- **PyC Coating**

Window Design, Key Point: C-Cu braze



Either 1 Step

active braze paste CB10 (860°C)

Or 2 Steps

1. metallize C with CB10
2. eutectic (810°C) braze to Cu

<u>therm. Expansion C vs. Cu is large</u>

@ heat up would cause gaps/rel. move (>0.1mm),
Wires hinder Cu-expansion

@ cool down Cu would compress C,
Rings hinder Cu-shrinkage

Window Production, Status and Perspective

Status:

- reasonable Design exists
- **PyC coating on CFC:** UHV leak tight, weak bonding to CFC → avoid shear stress
- CB10 paste brazes PyC, C and Cu
- **Contact to 3 Suppliers (Schunk, SGL, Mersen)**
  - general Reaction is reluctant, seems to be out of their production and financial scope
  - nevertheless delivered samples for leak and brazing tests, but not thinner than 1mm
  - **SGL & Mersen now try to produce 0.5mm PyC coated CFC-Disks with ∅36mm**
  - **No response from Schunk yet**

Perspective:

a) **Check C-Cu Fabrication Step in real Geo.** ***(with Cu-Frame only ?)***
  - fabricate Cu-Frames, Cu-Rings, Mo-Parts and st. Steel Pipes → Sebastian
  - design and fabricate Support on Air-Side Mo-Ring during Brazing → Sebastian
  - brazing at HH → Michael

b) **When a) successful, produce final window(s)**

Summary and Outlook

Summary:

- **CFC Material is a promising Candidate for an e- Window @ PITZ Flash Therapy**
- **A reasonable Design for the Window is ready**
  - Decision on 1 or 2 step CFC - Cu Brazing Procedure depends on Pretests
- **Crucial Issues are:**
  - Getting 0.5mm CFC disks, PyC coated
  - CFC - Cu braze, without applying critical stress to the disk and the PyC Coating

Outlook:

- **Suitable Samples for realistic brazing Pretests are coming soon,** hopefully
- **Window Parts (esp. for Pretests) have to be manufactured**
- **When 1. Window exists, Beam Tests at PITZ to find out Destruction Limits**
  - Find suitable space in PITZ Beam Line
- **Radiating Coating on Air-side for transv. Profile & Position Measurement**