He-cooled Divertor Design Approach

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BASIC W – DIVERTOR DESIGN CONCEPTS

1. **Tungsten caps**

   (current European concepts HEMJ, HEMS, HETS)

2. **Tungsten tubes**

   (new alternative concept: **T**ungsten **T**-**T**ube Divertor)

3. **Tungsten plates**

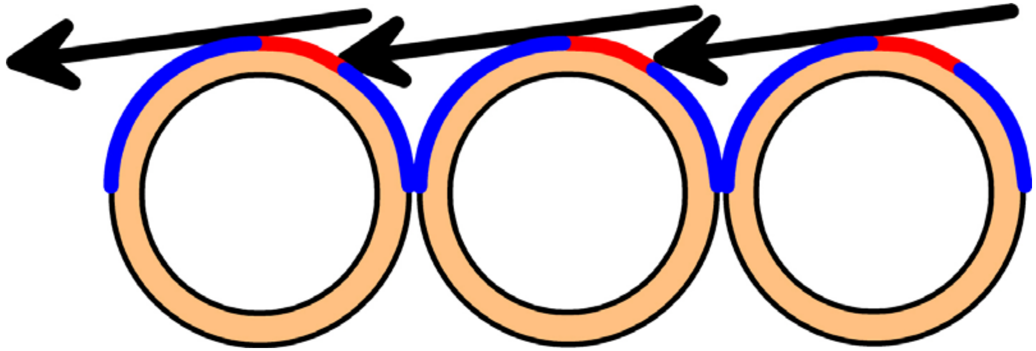
   (e.g. former FZK designs)

→ Different heat transfer enhancement techniques possible for all concepts

Do we need a flat target surface ?

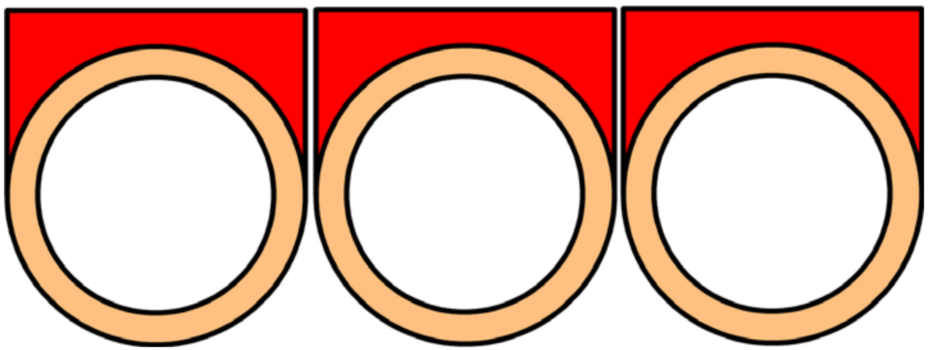
Round tubes have to be oriented in direction of the field lines

Otherwise: excessive shadowing



→ shadowing

Flat target surface is favorable



→ free orientation

sacrificial layer thickness for
Compact Stellerator : tbd

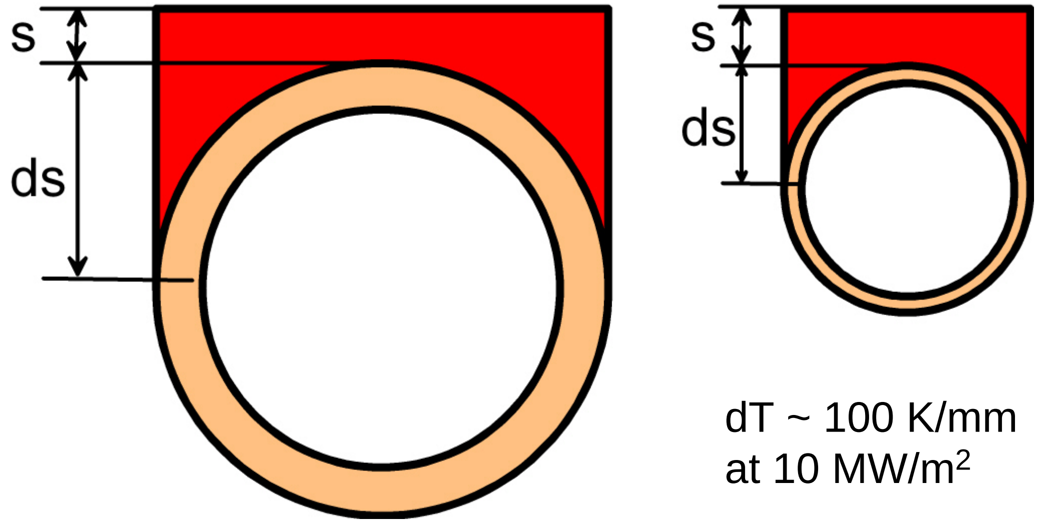
Long tubes or tube segments ?

1. **Small wall thickness for low temperature gradients and high cooling performance**
   → small diameter (e.g. 15 mm)
   → limited mass flow

2. **Parts from brittle materials should be small to reduce probability of failure (test before assembly)**

3. **Flexible structure for low thermal stress levels**

4. **Uniform heat load for parts favorable**

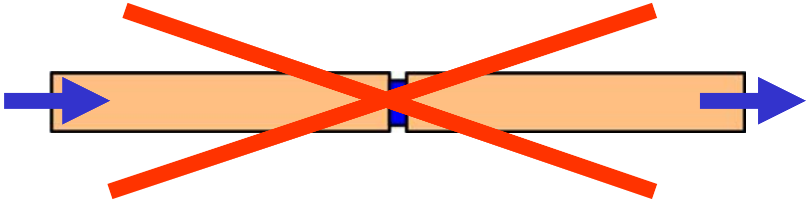


dT ~ 100 K/mm
at 10 MW/m^2

→ Tube segments

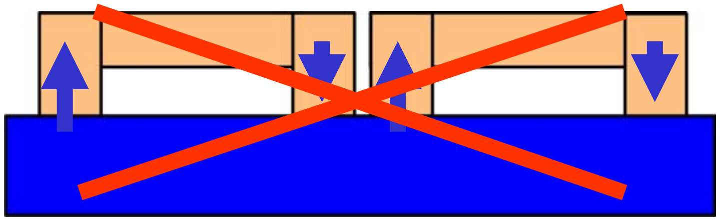
Connection of tube segments ?

A) Series connection



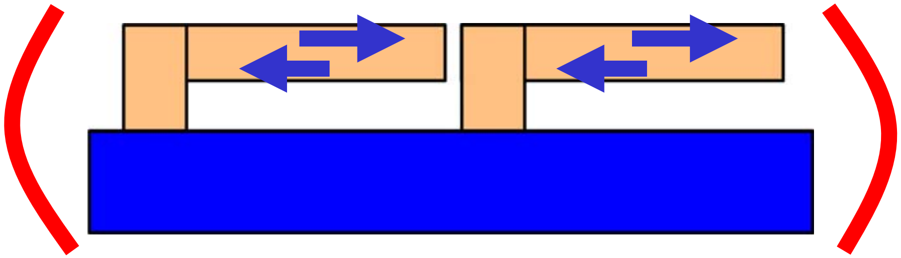
He velocity
deformation

B) U-Tubes in parallel



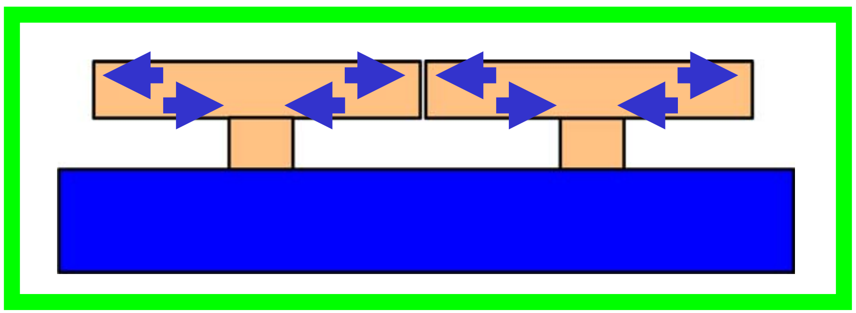
Different thermal
expansions

C) L-Tubes in parallel



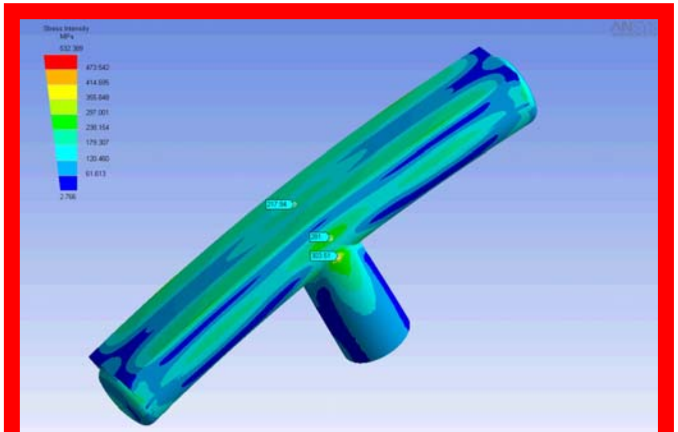
Short tubes
might be possible

D) T-Tubes in parallel

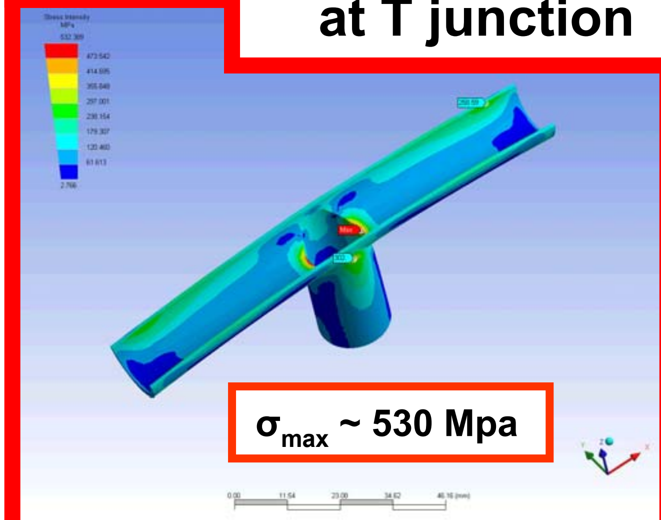


most promising

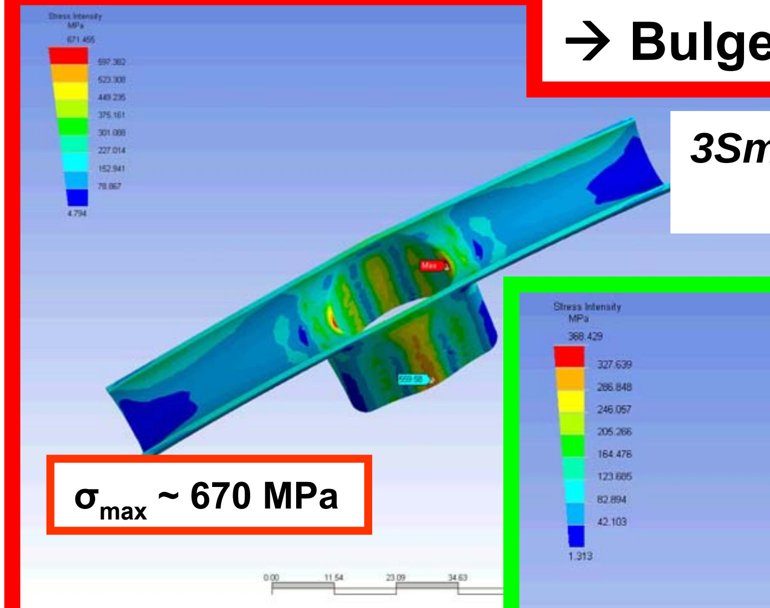
General design of the T junction ?



→ stress peaks at T junction



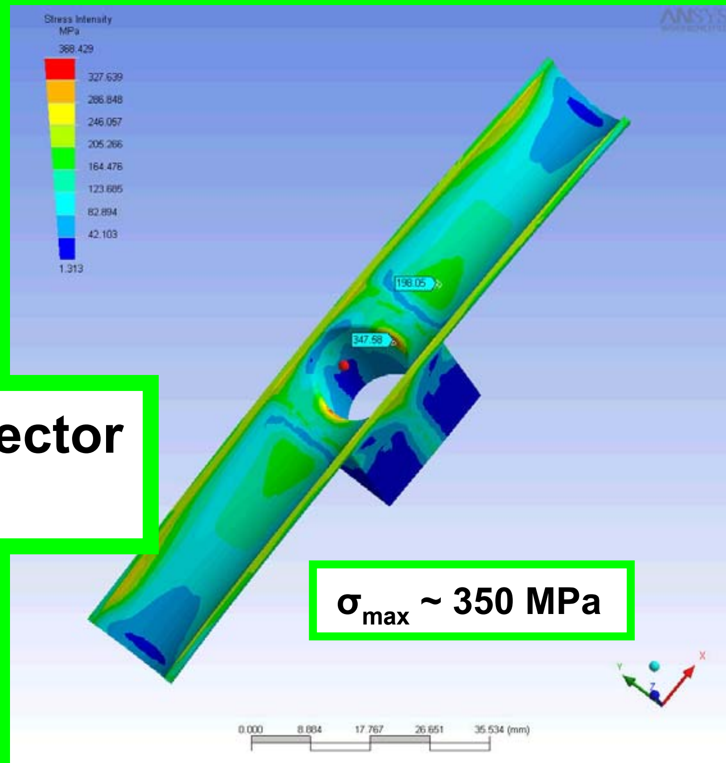
σ_{max} ~ 530 Mpa



→ Bulge for oval section

3Sm at 1100°C ~ 460 MPa
at 850°C ~ 580 MPa

σ_{max} ~ 670 MPa



→ rectangular connector with drilling o.k.

σ_{max} ~ 350 MPa

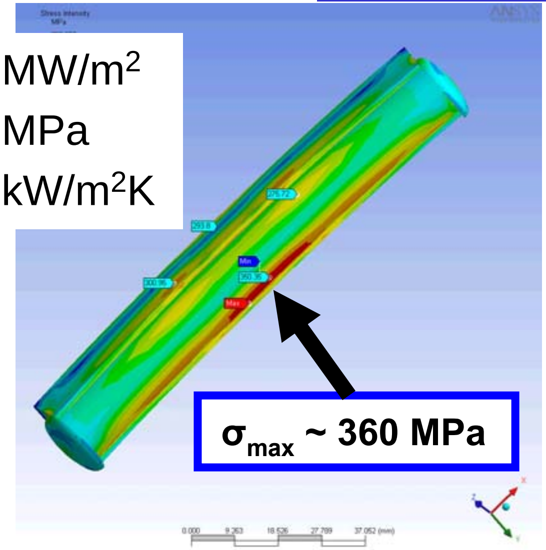
q = 10 MW/m^2
p = 10 MPa
h = 20 kW/m^{2}K

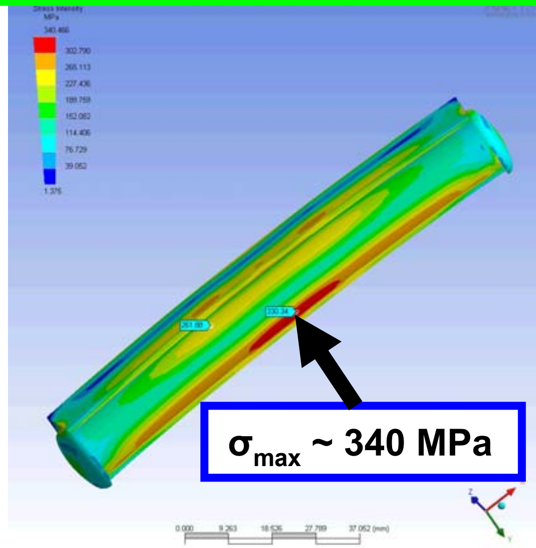
Reasonable T connector length ?

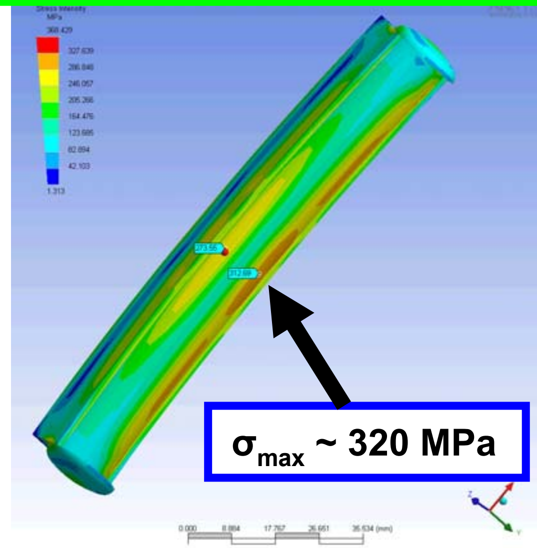
$q = 10\ MW/m^2$

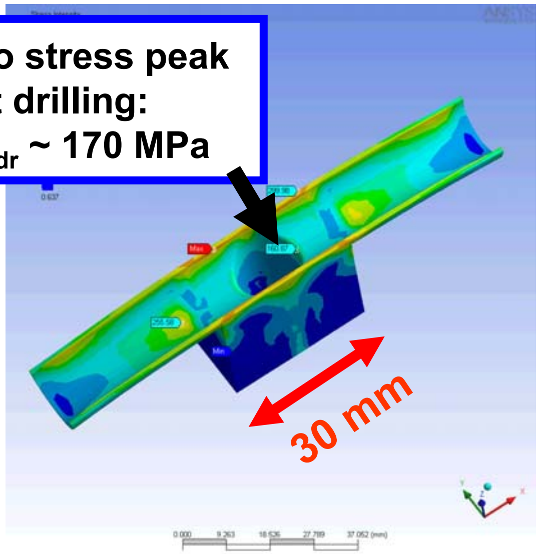
$p = 10\ MPa$

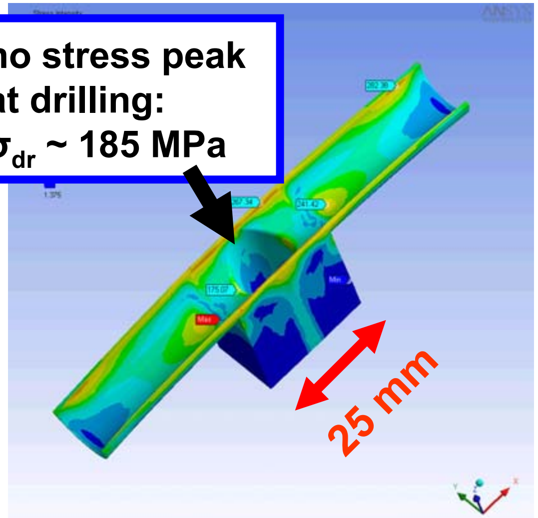
$h = 20\ kW/m^2K$

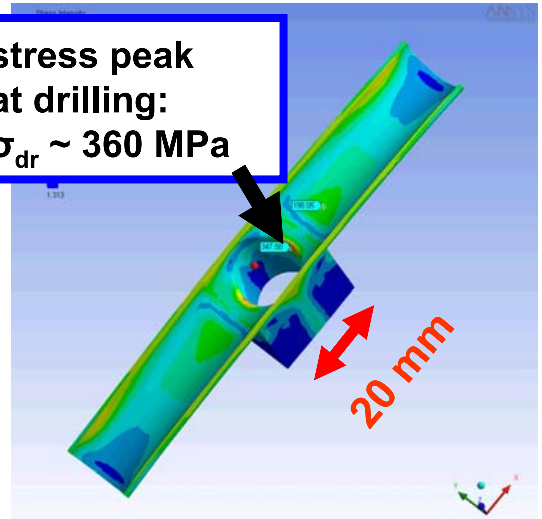








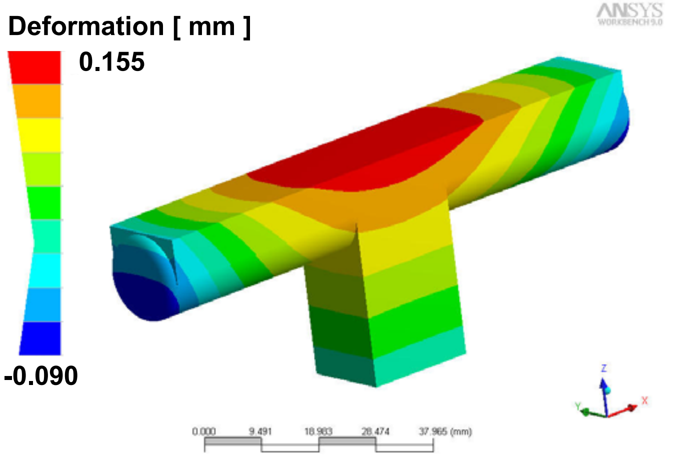




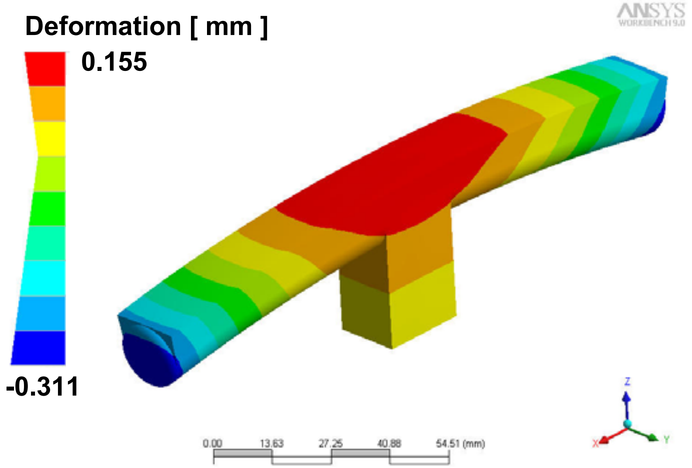
Reasonable tube length ?

length [mm]	stress intensity [MPa]	deformation (Δz) [mm]	angle variation along tube	He velocity [m/s]
100	368	0.175	± 0.10°	62
150	367	0.385	± 0.15°	94
250	366	1.155	± 0.26°	157

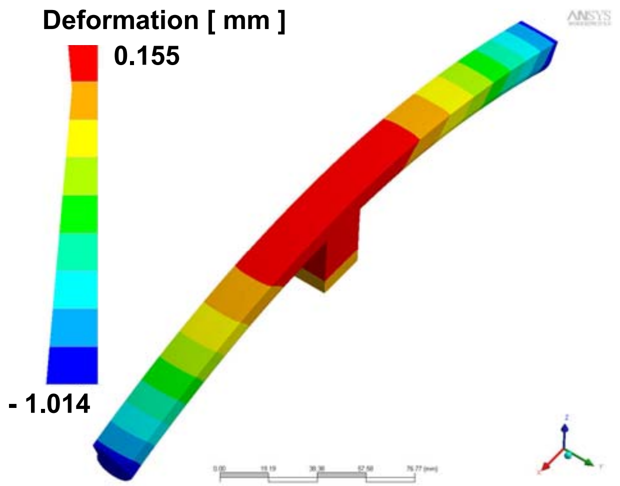
L = 100 mm; D = 15 mm



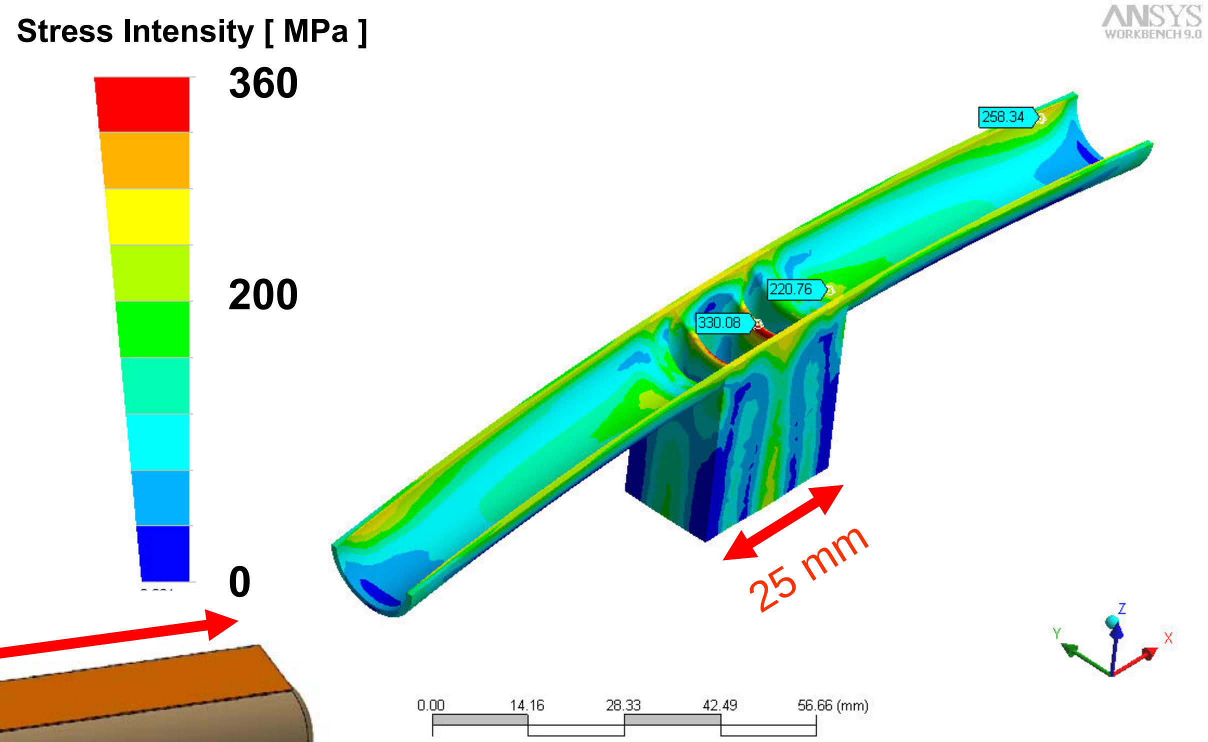
L = 150 mm; D = 15 mm



L = 250 mm; D = 15 mm

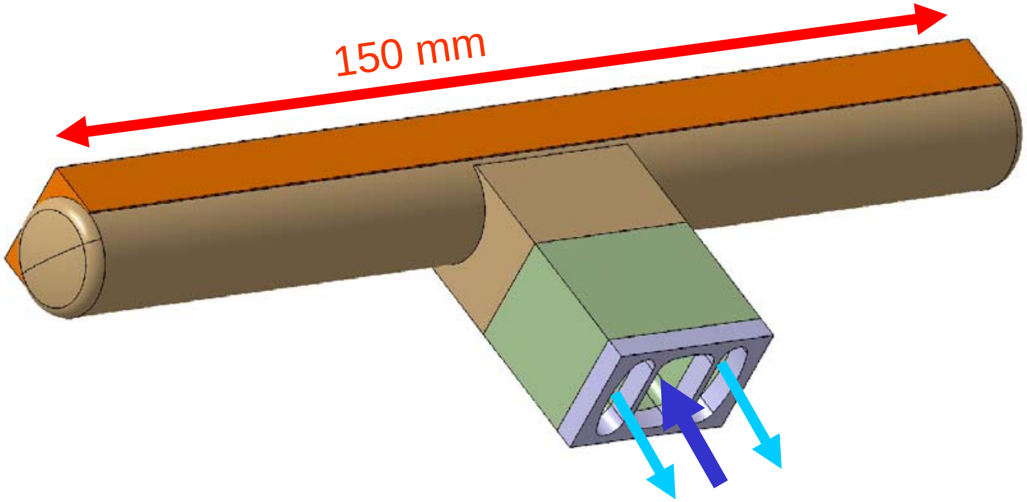


Detailed design of the T junction



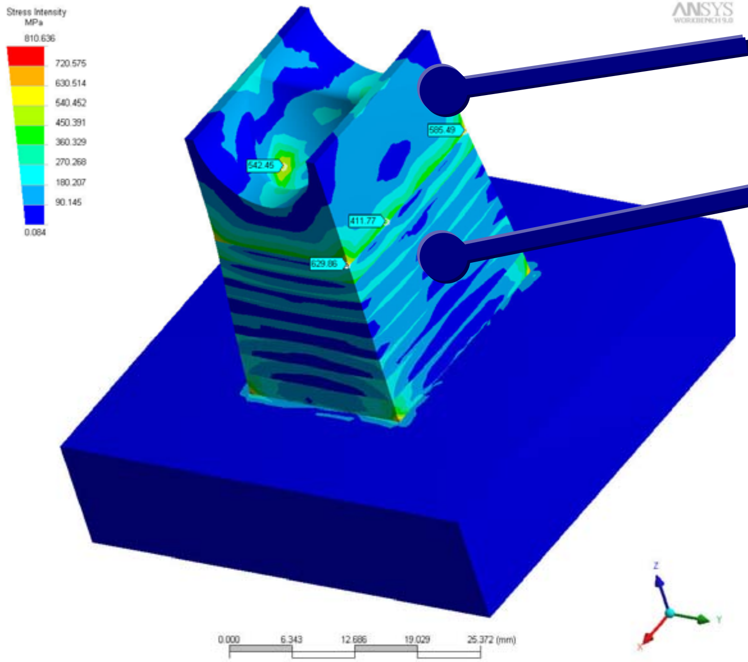
T-connector with central inlet and two outlet sections:

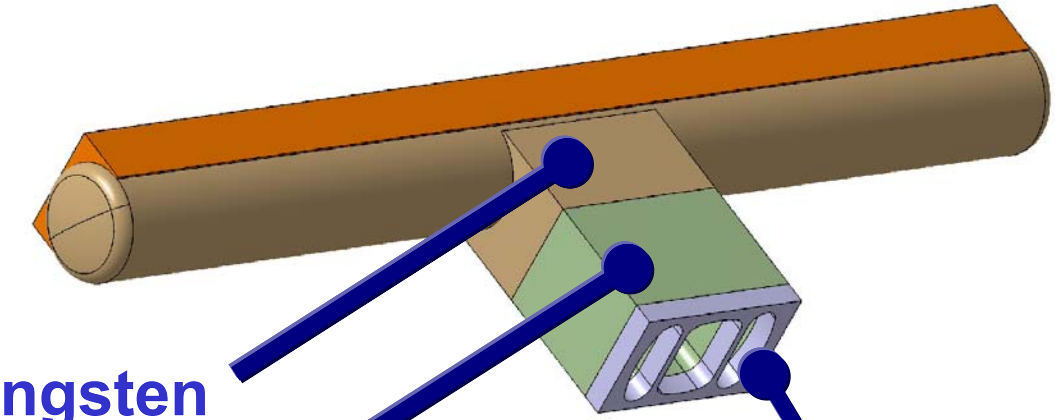
+ Large cross section
+ Low stress levels



Option:
L = 150 mm; D = 15 mm

W – Fe transition ?



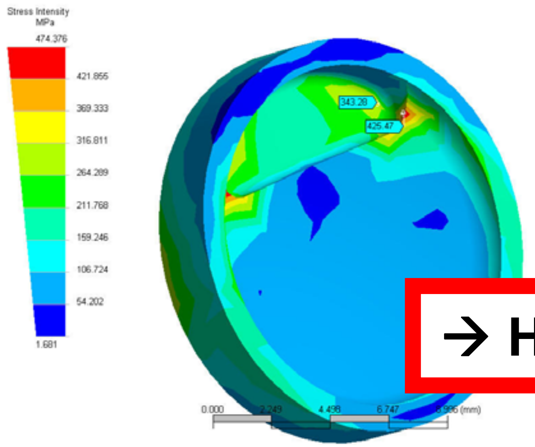


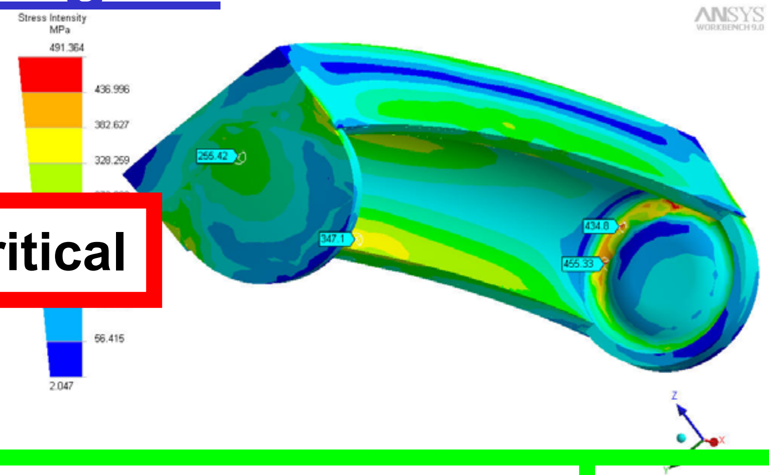
W-FE gradient transition:

Slices for stepwise adjusting of thermal expansion,

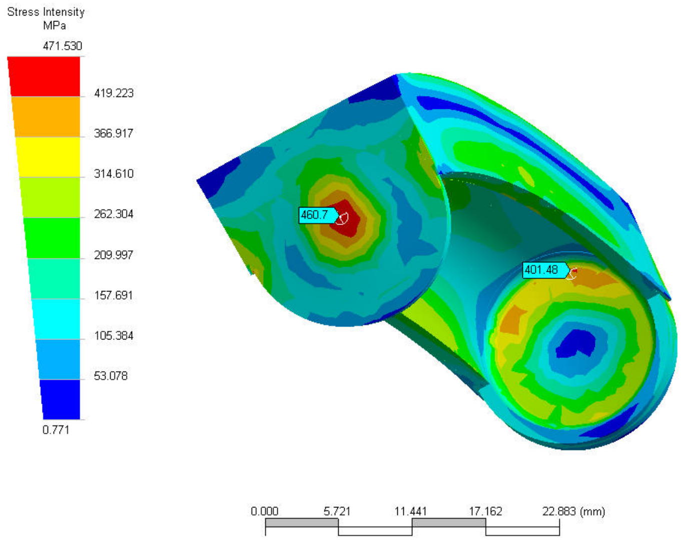
Brazed and/or HIPped

Tube end design ?

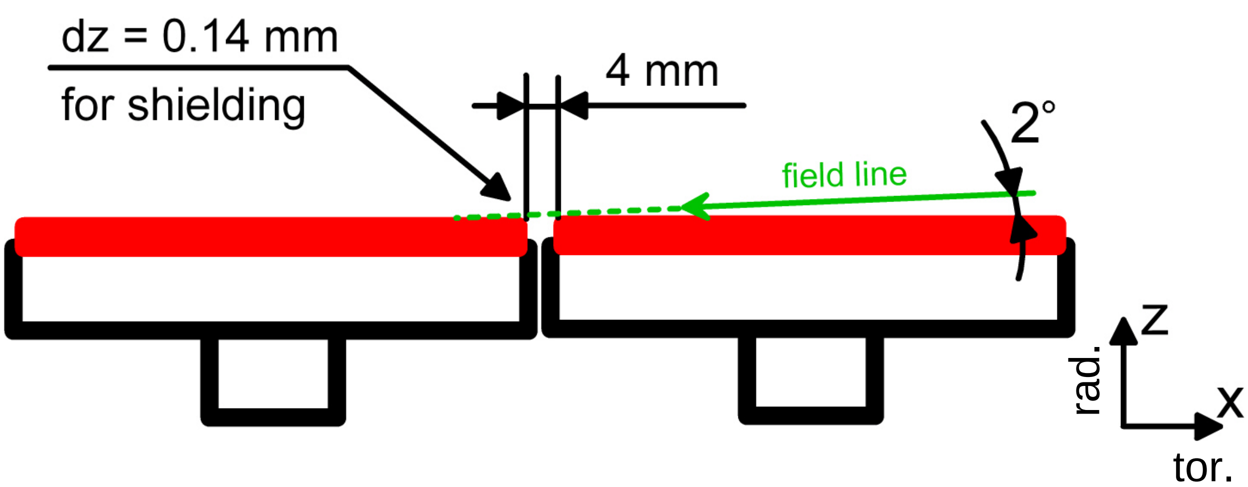




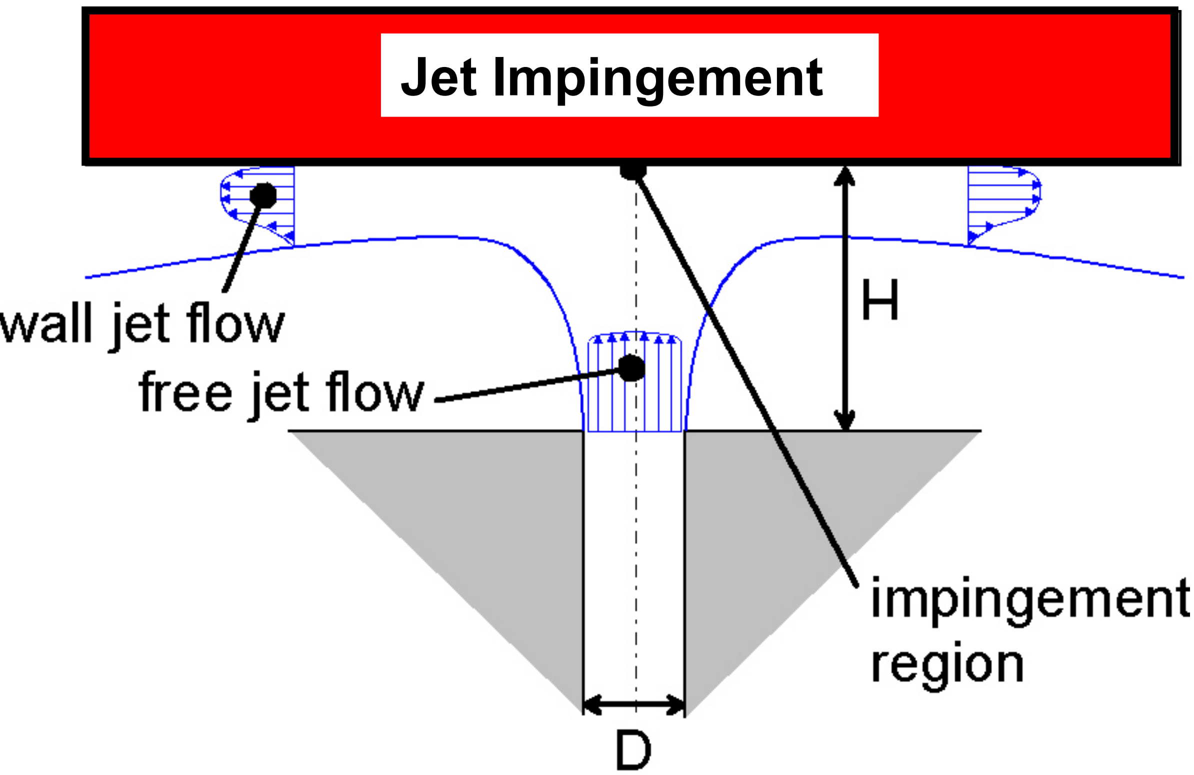
→ Heat loaded caps critical

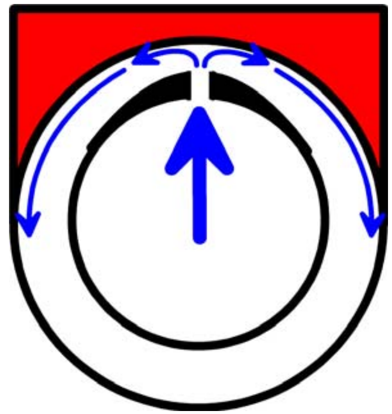


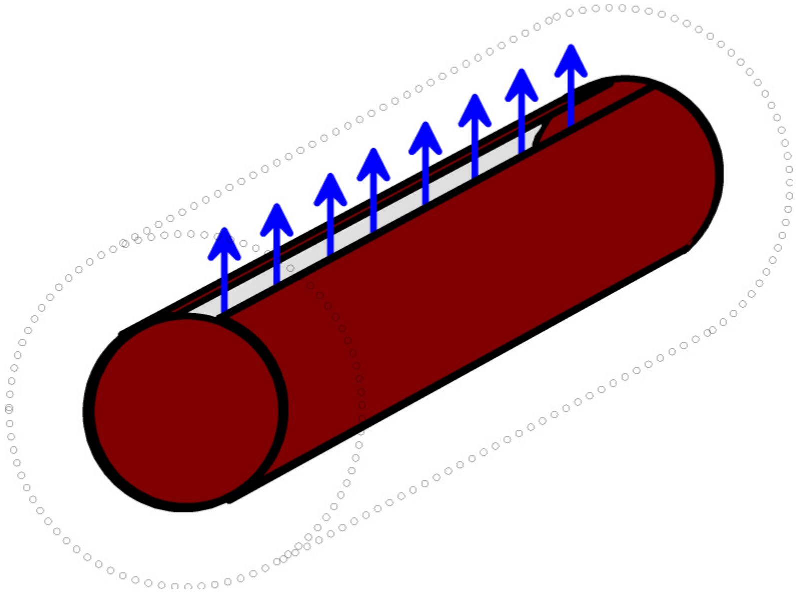
Shielded caps favorable



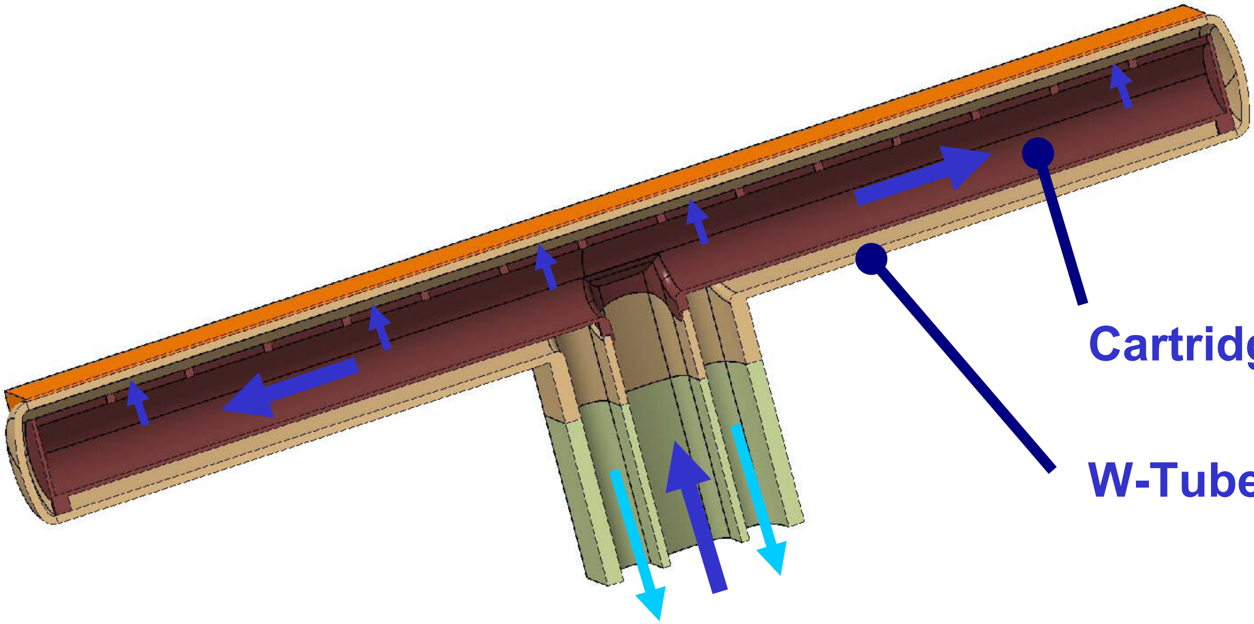
Heat transfer enhancement





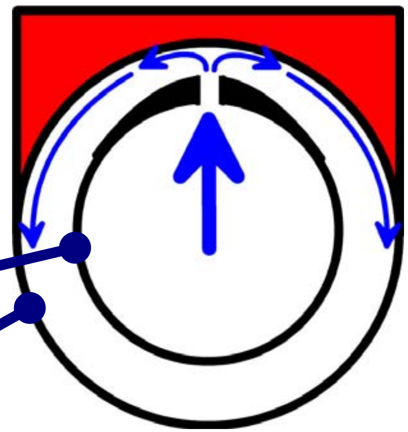


Heat transfer enhancement

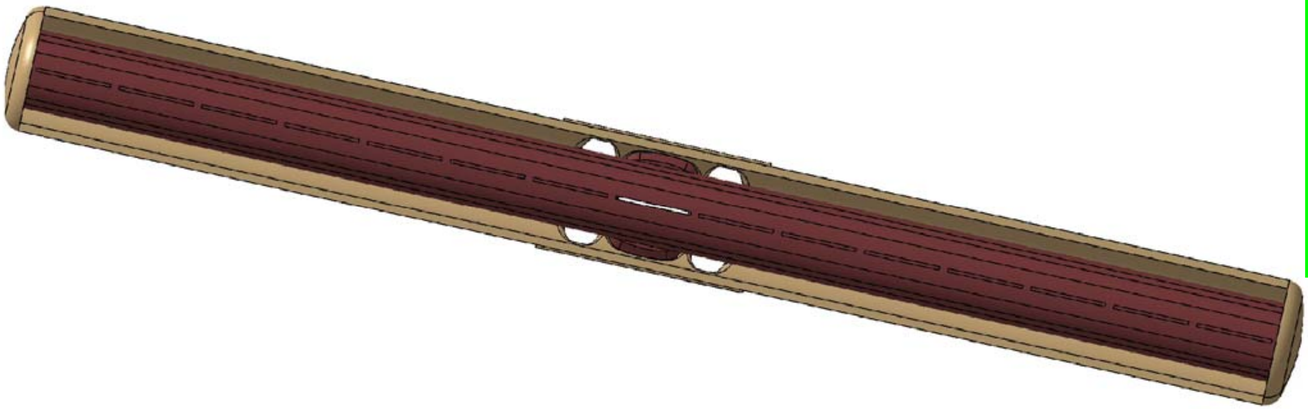


Cartridge

W-Tube

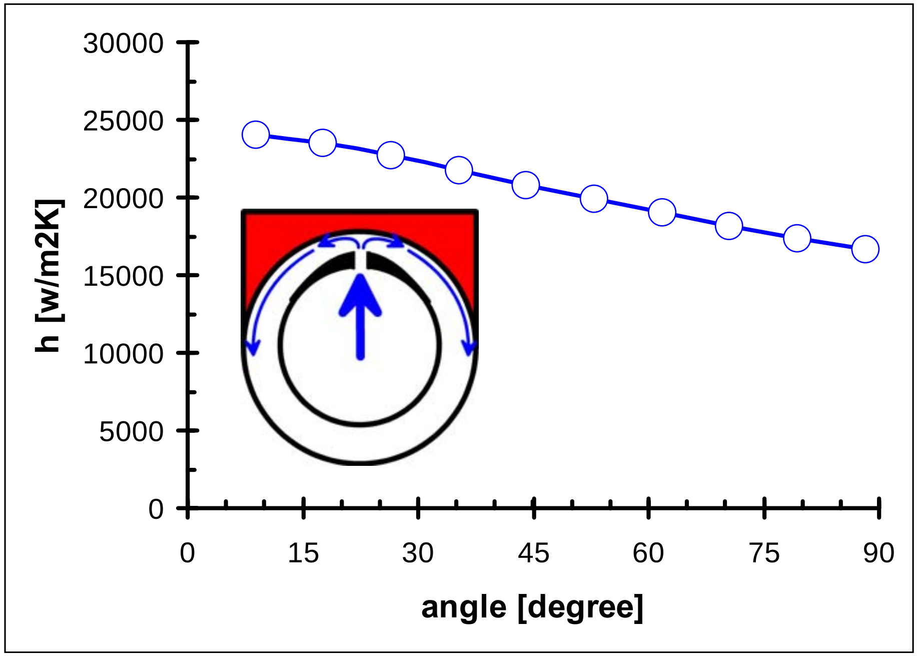


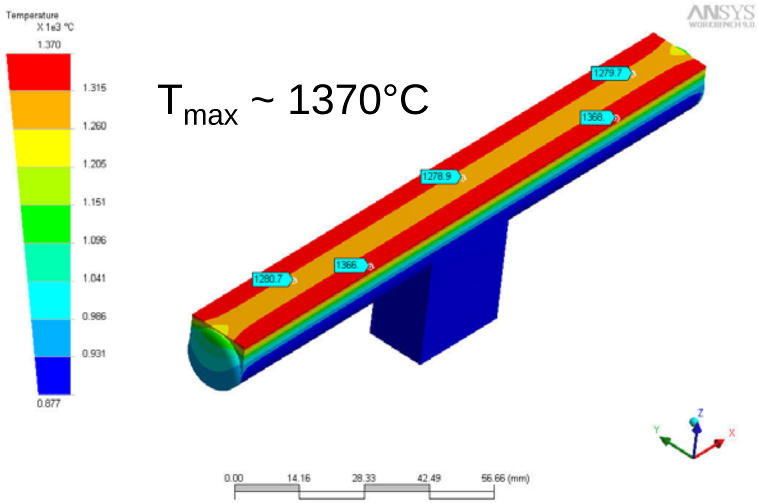
Layout example:
- jet slot width: 0.4 mm
- jet-wall-spacing: 1.2 mm
- specific mass flow: 2.12 g/cm^2
- mass flow per tube: 48 g
- p = 10 MPa, dp ~ 0.11 MPa
- dT ~ 90 K at 10 MW/m^2

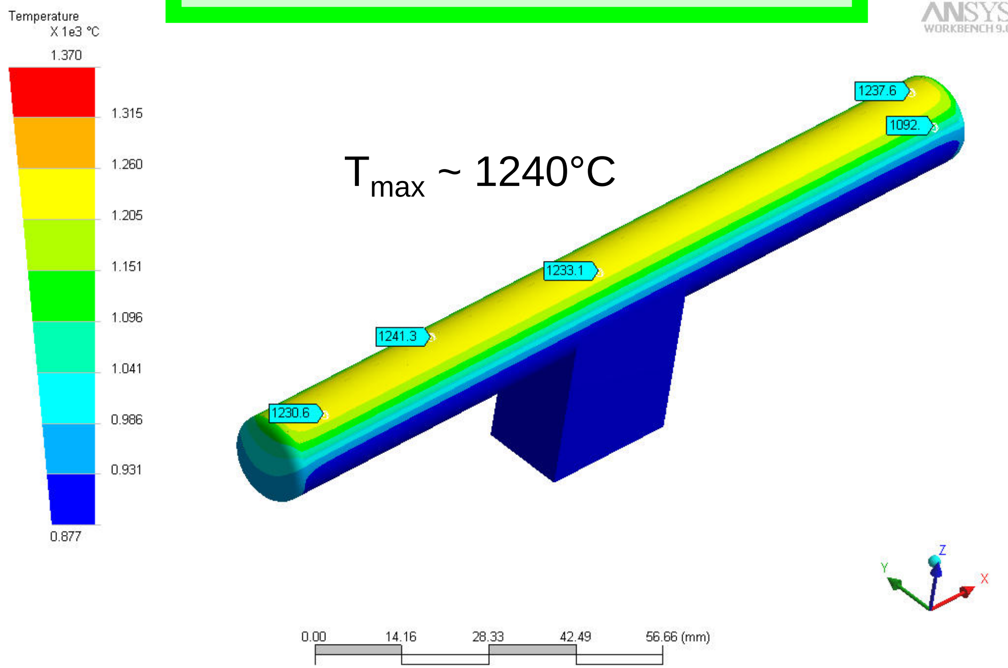


Layout Example

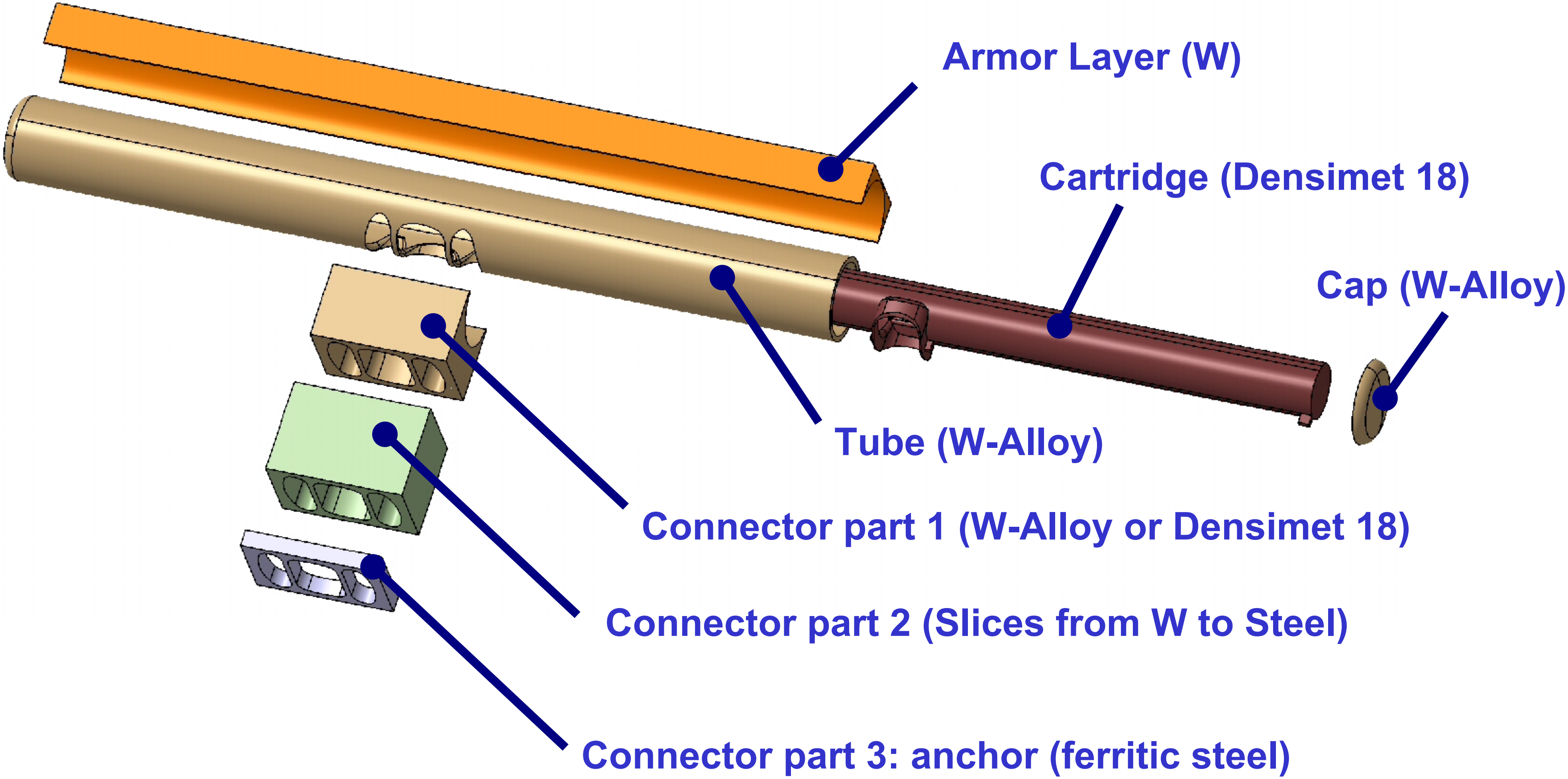
- jet slot width: 0.4 mm
- jet-wall-spacing: 1.2 … 1.6 mm
- specific mass flow: 2.12 g/cm^2
- mass flow per tube: 48 g
- p = 10 MPa, dp ~ 0.11 MPa
- dT ~ 90 K at 10 MW/m^2
- T_{He} ~ 605 … 695°C



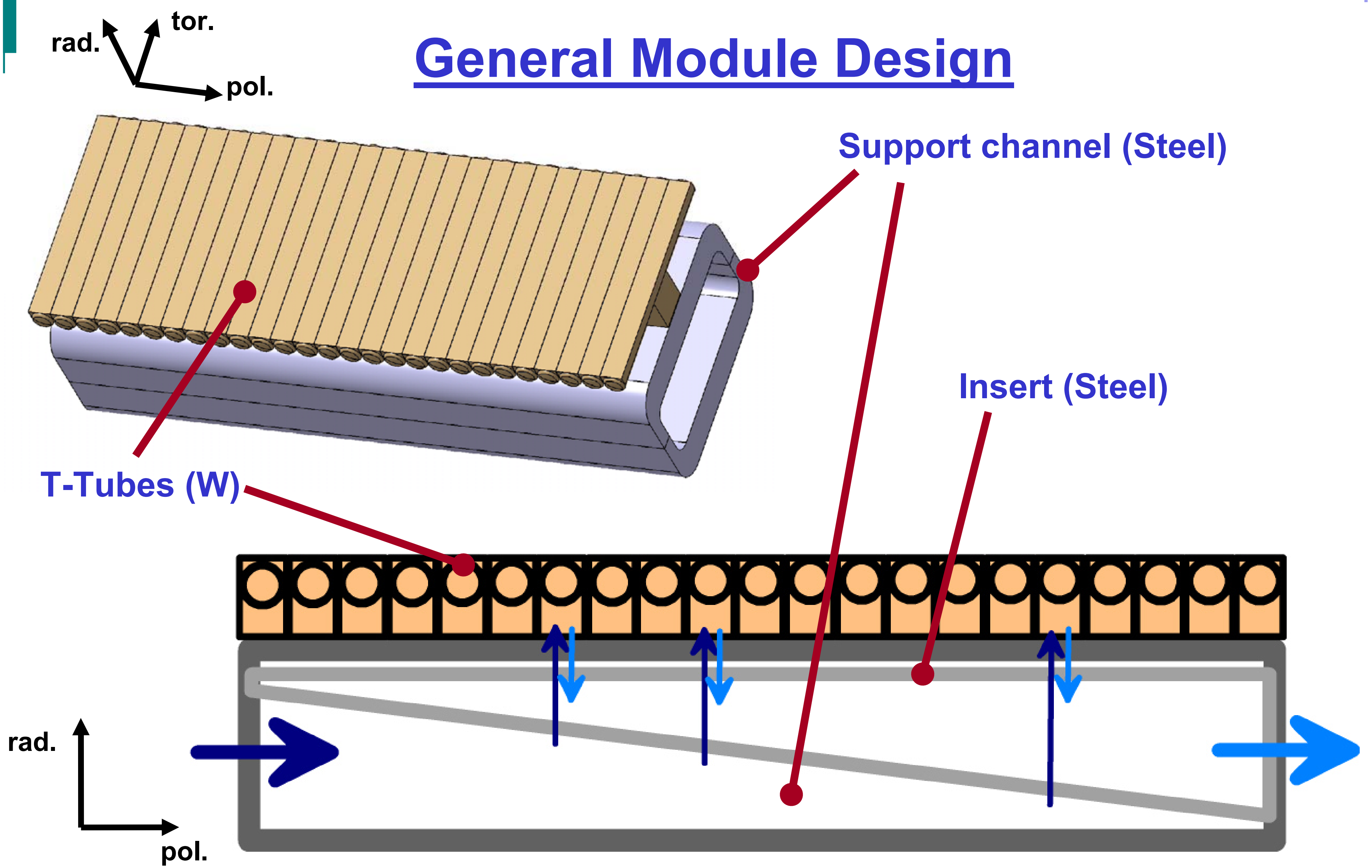




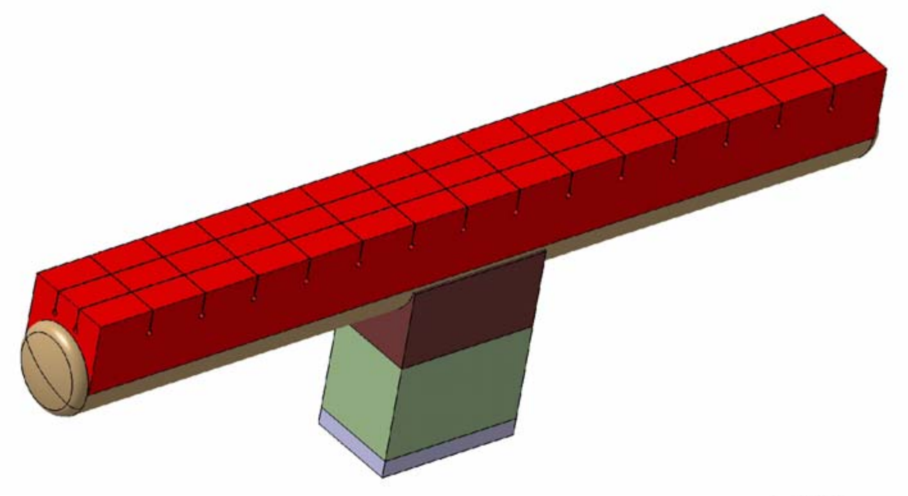
General T-Tube Design

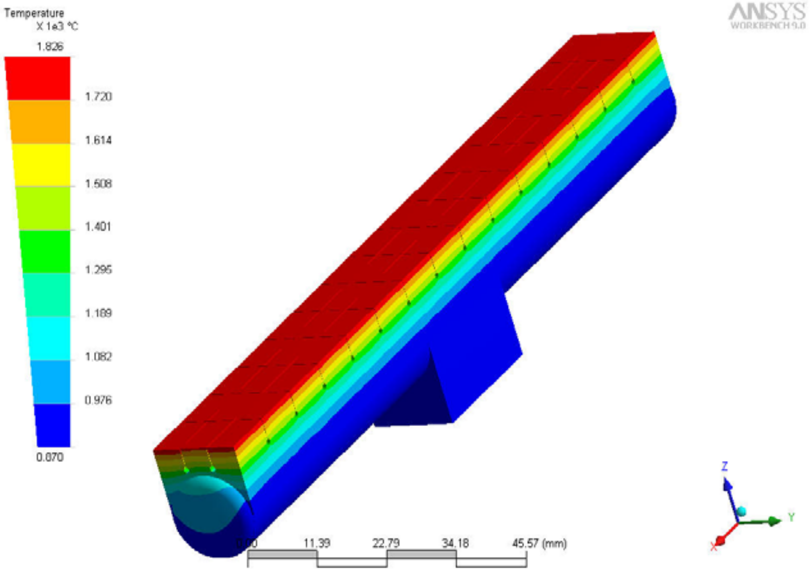


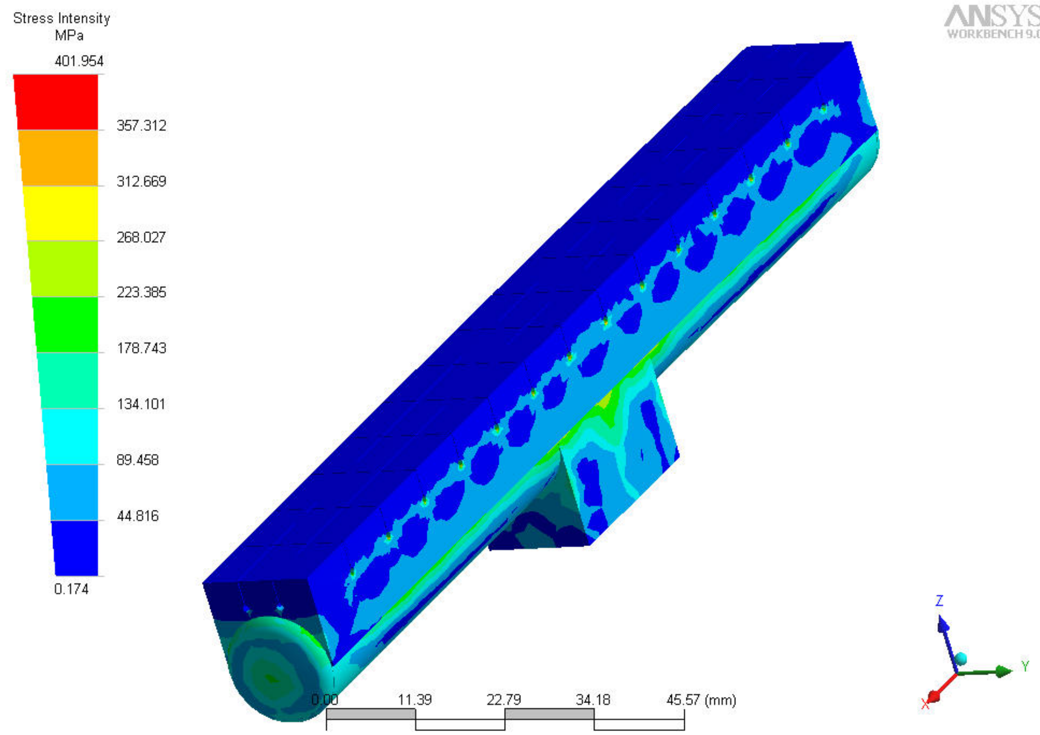
General Module Design



Thick armor option







Armor layer 5 mm:
- **Castellated (5 mm x 10 mm)**
- **reduced Young's modulus (?)**

Considerations and further Objectives

The new T-Tube design seems to be a promising alternative concept:

- Thermal stress within design limits for 10 MW/m^2
- Simple manifolding concept possible
- Simple slot based jet impingement sufficient

Next steps:

- Additional considerations on alternative geometry options e.g. tungsten plates
- Manifolding/integration concept for ARIES CS