# Latest cooling simulations in Valencia

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# Introduction

This talk is strongly related to my second talk here:

'Cooling options for the Belle-II PXD'

→ In this talk I would like to explain the weight of $T_{environment}$ and $T_{coolingblock}$ terms in our PXD cooling final solution.

→ For details about the simulation… please, go through my talk in the Belle II PXD EVO meeting (12/Jan/2010).

http://134.107.24.12/indico/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=676

# In previous chapters…

A generic ladder was implemented (see my talk in Barcelona for details)

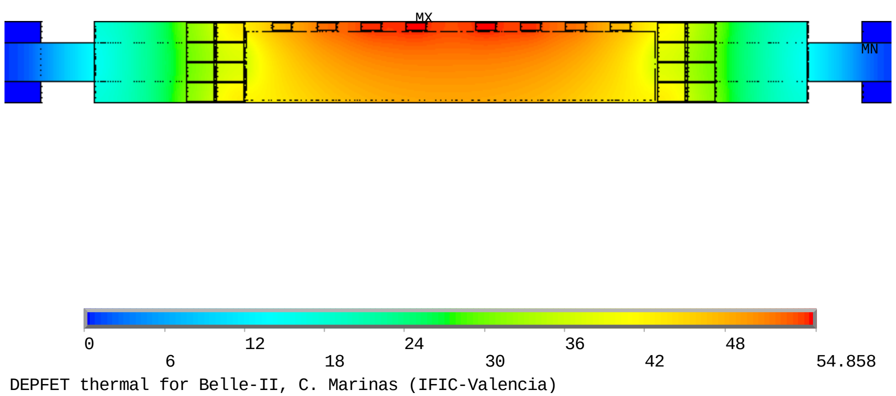
- CVD-Diamond finger conecting the ladder to the cooling block

Ladder length=65.5mm
Ladder width=15mm
Length DCD+DHP balcony=28mm
Width Switcher's balcony=2mm

Sensor width=12.5mm
Sensor length=37.5mm

Diamond width=7mm
Diamond length=10mm
Diamond thickness=400µm

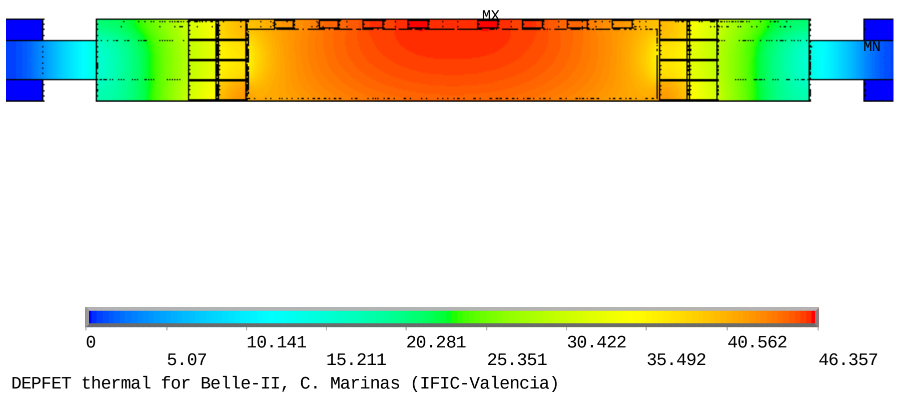
htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=10ºC | Tcb=0ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG




$T_{max}$=55ºC

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=10ºC | Tcb=0ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
With TPG

With TGP strip (1mm wide)




$T_{max}$=46ºC

The TPG strip underneath the SW's balcony was mandatory (~10ºC less)

# News

o Since Barcelona, the situation has changed a bit…

1.- New dummy modules are designed with dimensions close to the final ones (Laci's proposal).

2.- New cooling/support structure was presented with no need of CVD-diamond connecting the ladder and the support structure (Ch. Kiesling proposal).

→ After the results presented by Karlsruhe, we should refine the design… but this topic will be discussed on the next talk…

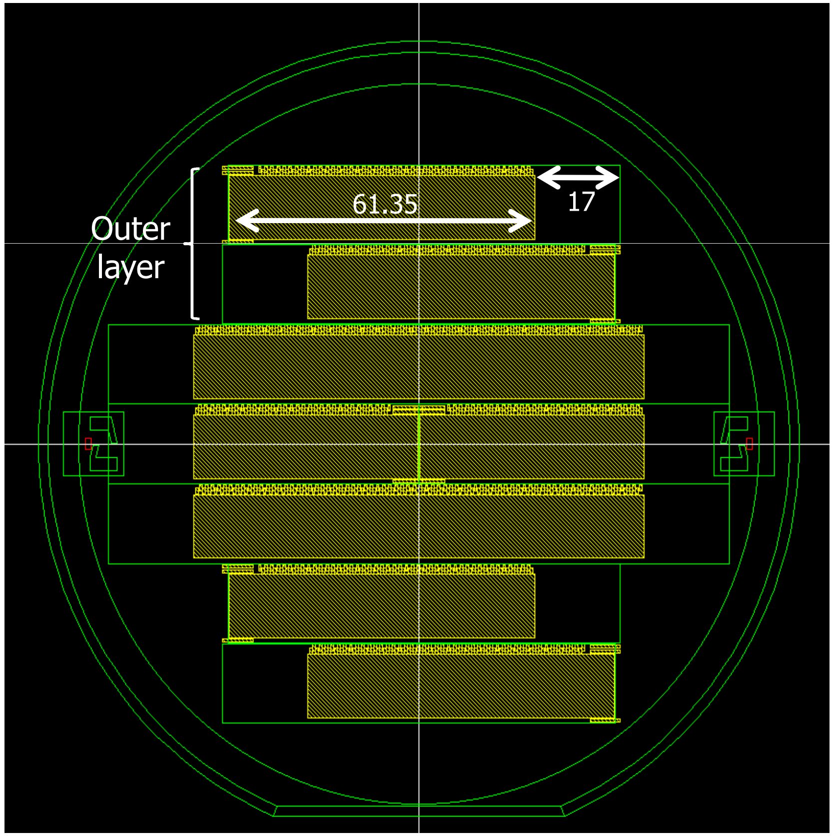
# 1.- Layout for the mechanical dummies (Laci's proposal)

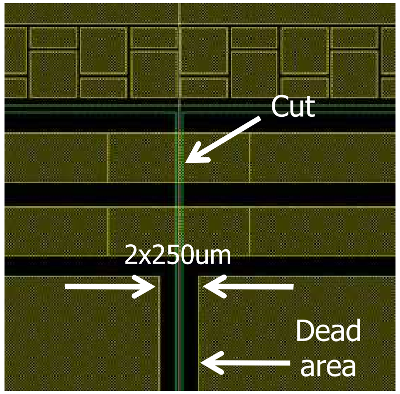
Ladder length=78.35mm
Ladder width=15mm
Length DCD+DHP balcony=17mm
Width Switcher's balcony=2mm

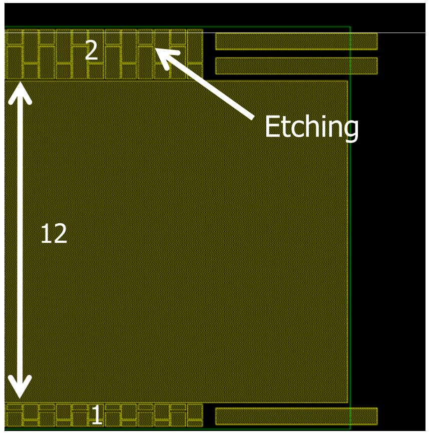
Sensor width=12mm
Sensor length=61.35mm

The geometry is now different

- New ladder dimensions
- Insensitive area to glue both halves
- Etching on balconies to reduce material



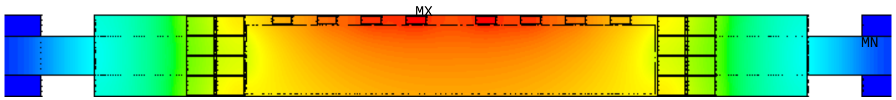

For details… 'Dummy modules'. L. Andricek, PXD EVO Meeting, Dec. 22, 2009

# Outer layer implemented in ANSYS (no etching)

## 'Old' generic geometry

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=10ºC | Tcb=0ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
→ Without TPG

$P_{sensor}$=1W



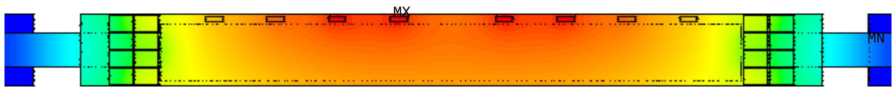


$T_{max}$=55ºC

## 'New' outer layer geometry

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=10ºC | Tcb=0ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
→ Without TPG

$P_{sensor}$=1.57W to compensate the bigger area, and compare both results





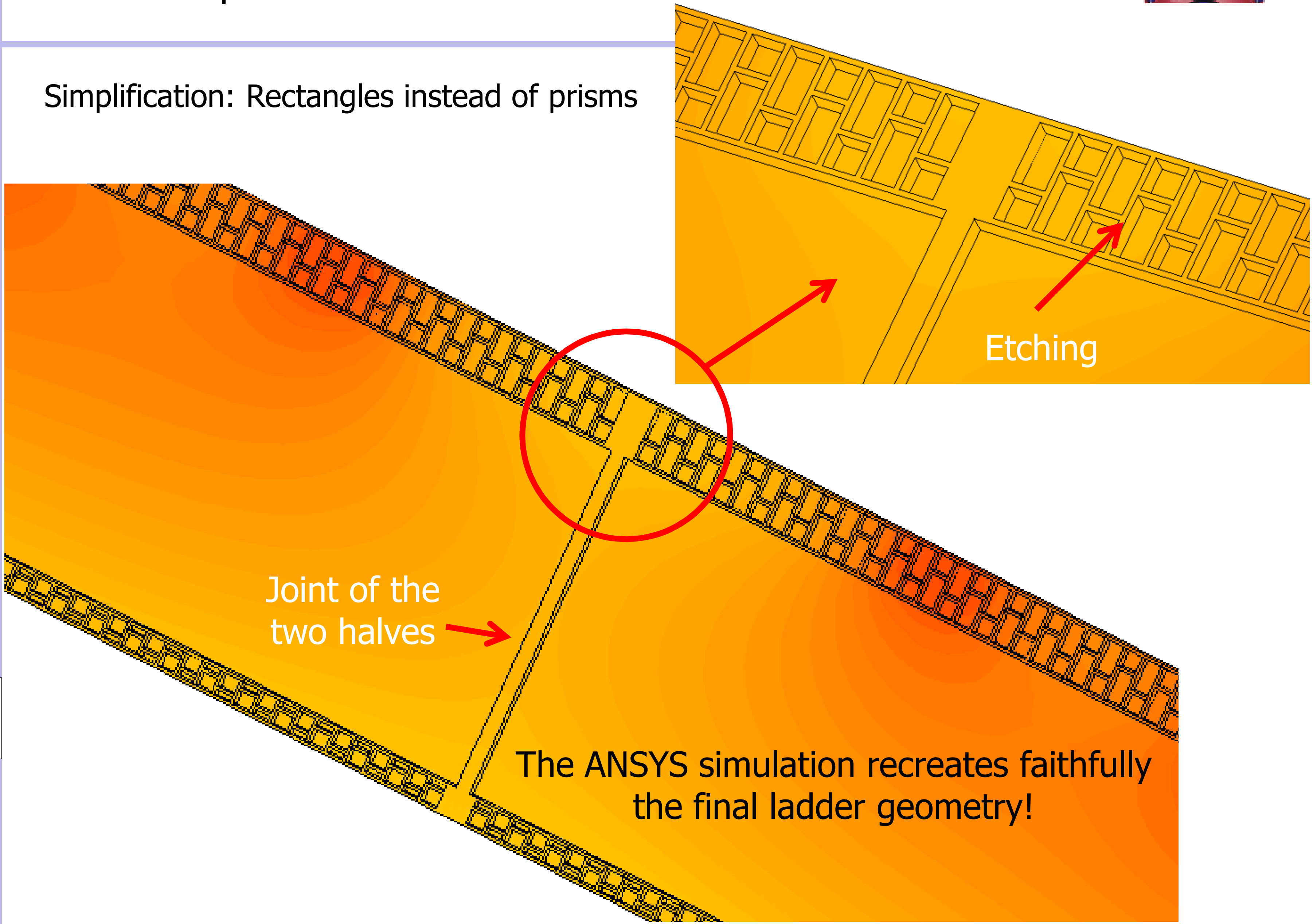
$T_{max}$=49.5ºC

$$\frac{\text{Power}_{\text{Old geometry}}}{\text{Power}_{\text{New geometry}}} = \frac{\text{Sensor Area}_{\text{Old geometry}}}{\text{Sensor Area}_{\text{New geometry}}}$$

→ The new 'spacing' helps to cool down the detector

# Frame perforation

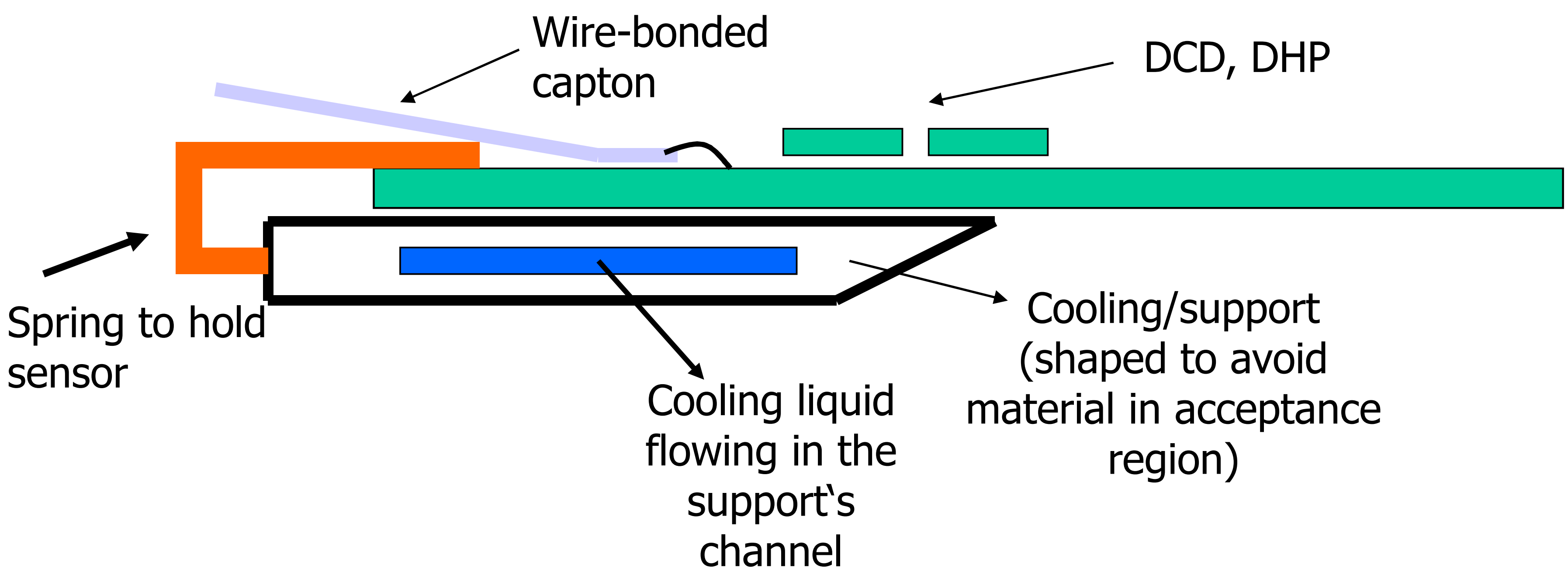
Simplification: Rectangles instead of prisms



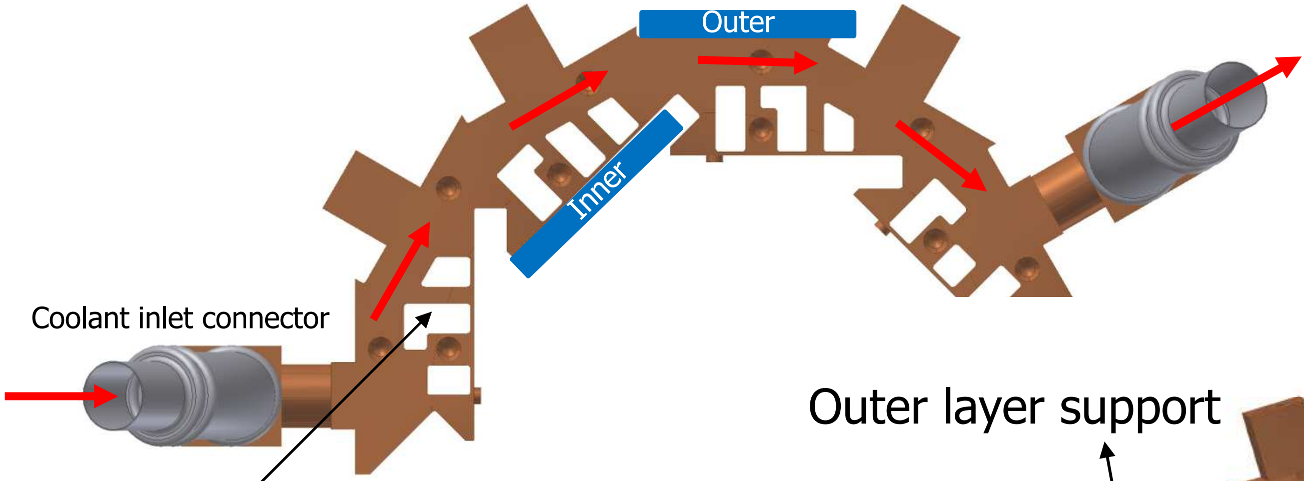
# 2.- New schematic support: 'Diamond less design'

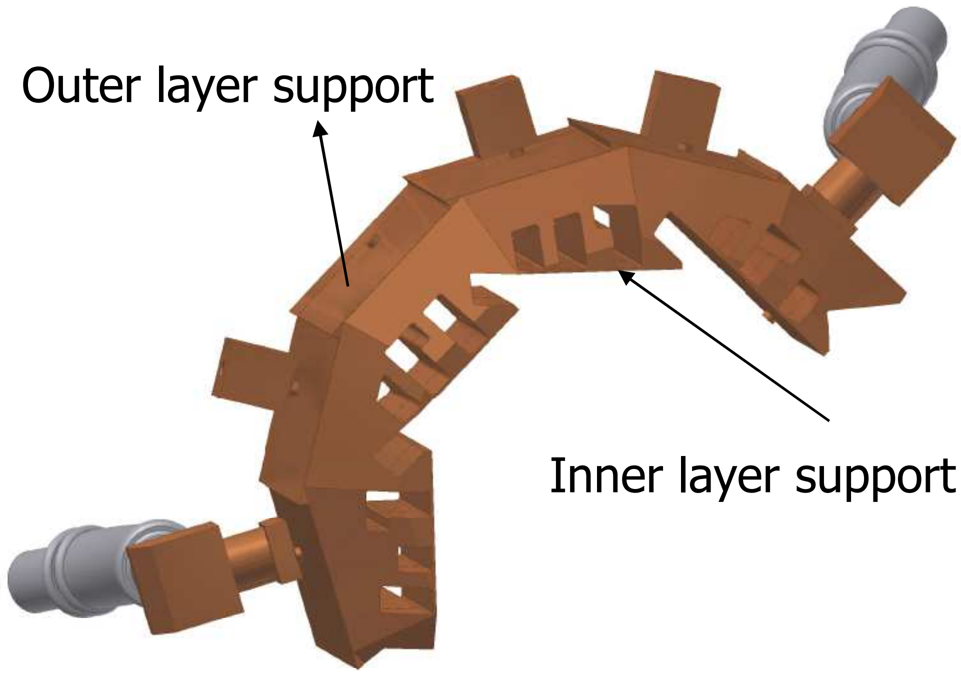
Idea: Put the cooling block directly under the sensor and the electronics

→ This way, the cooling structure and support are the same unit



# Belle-II PXD support structures



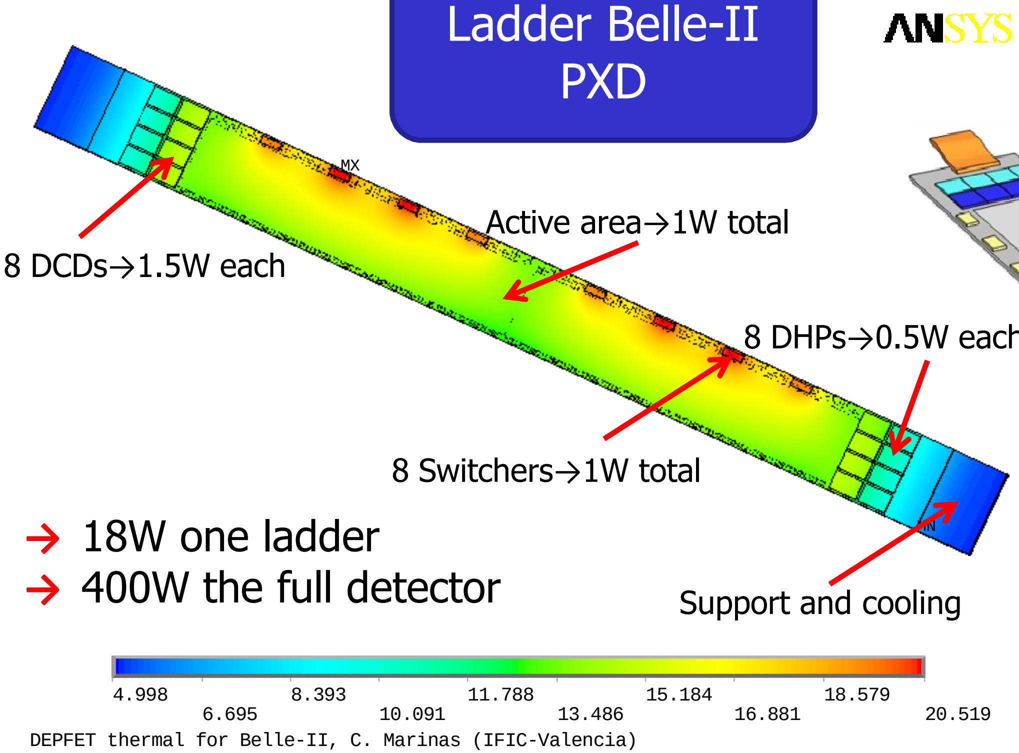



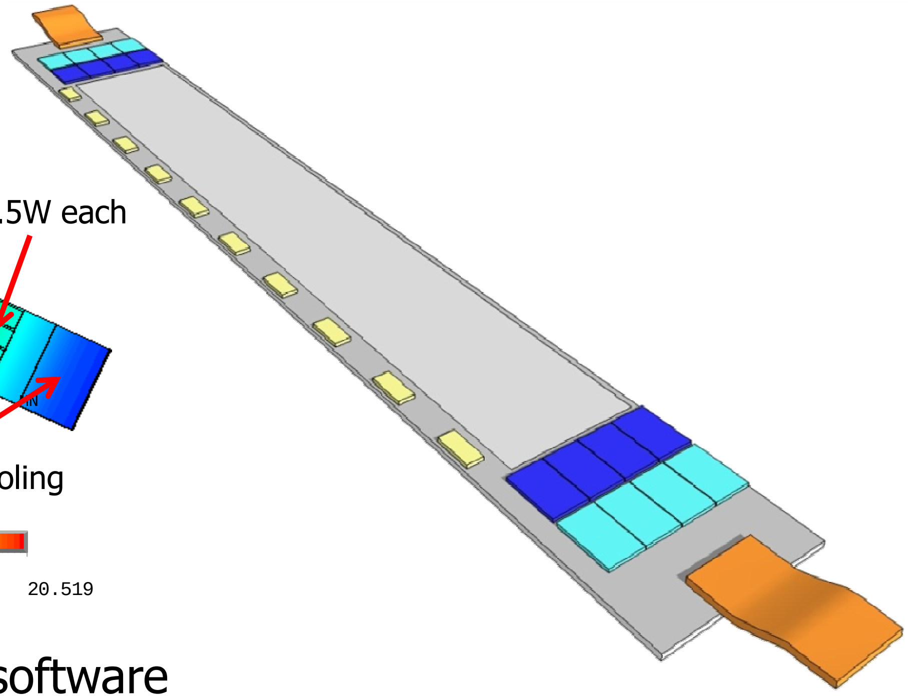

- Half cooling/support module
- Water cooling scheme is assumed

For details… 'News on PXD Mechanics'. C. Kiesling, PXD EVO Meeting, Dec. 22, 2009

# Thermal studies

Ladder Belle-II PXD



→ 18W one ladder

→ 400W the full detector

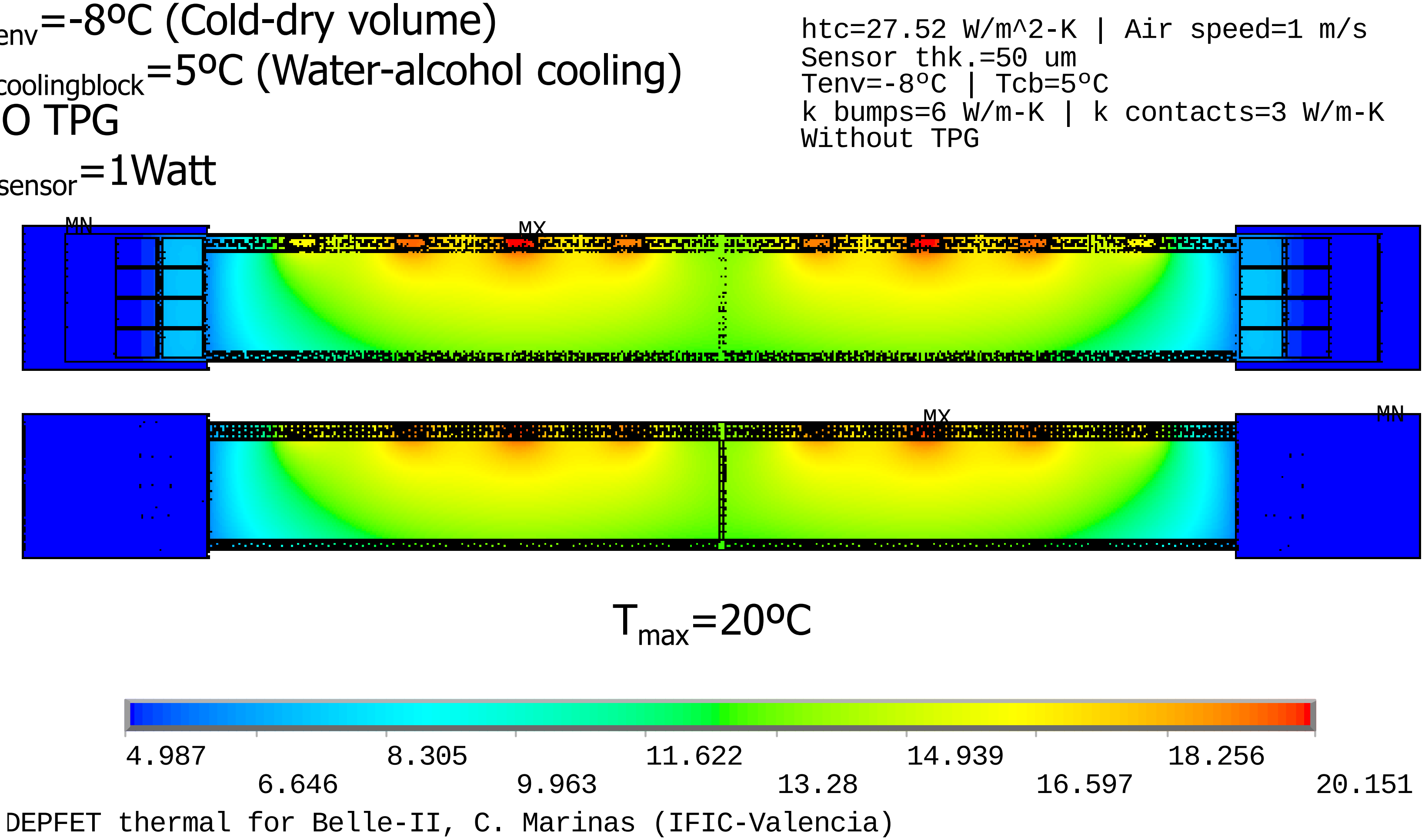
- Full Belle-II ladder implemented in FE software
- Development of cooling options imposing upper limits on the temperatures:

  $T_{max}$ (Sensor)<30ºC

  $T_{max}$ (Chips)<60ºC

# Water cooling (Ideal world)

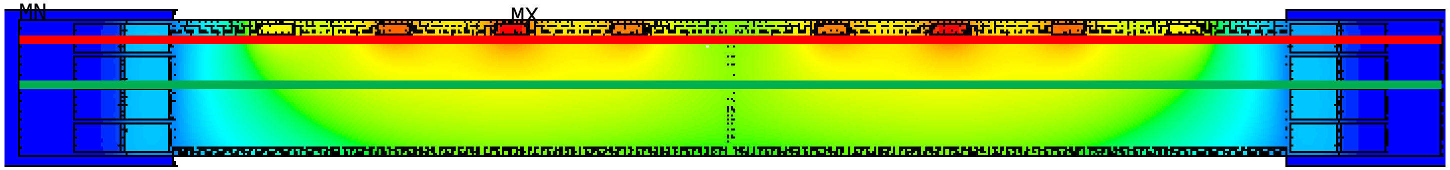
$T_{env}$=-8ºC (Cold-dry volume)
$T_{coolingblock}$=5ºC (Water-alcohol cooling)
NO TPG
$P_{sensor}$=1Watt



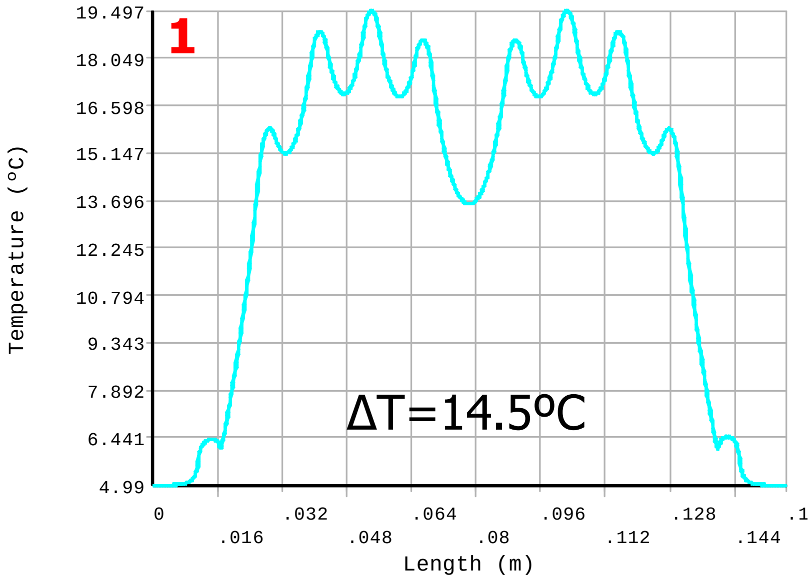

$T_{max}$=20ºC

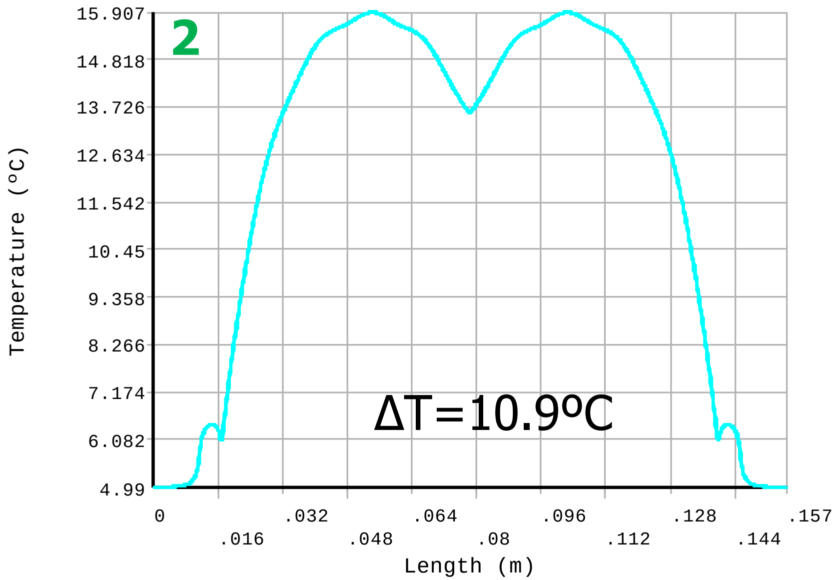
The center of the ladder is always cooled down by the air blowing

# Water cooling. Full ladder paths




htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=-8ºC | Tcb=5ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG



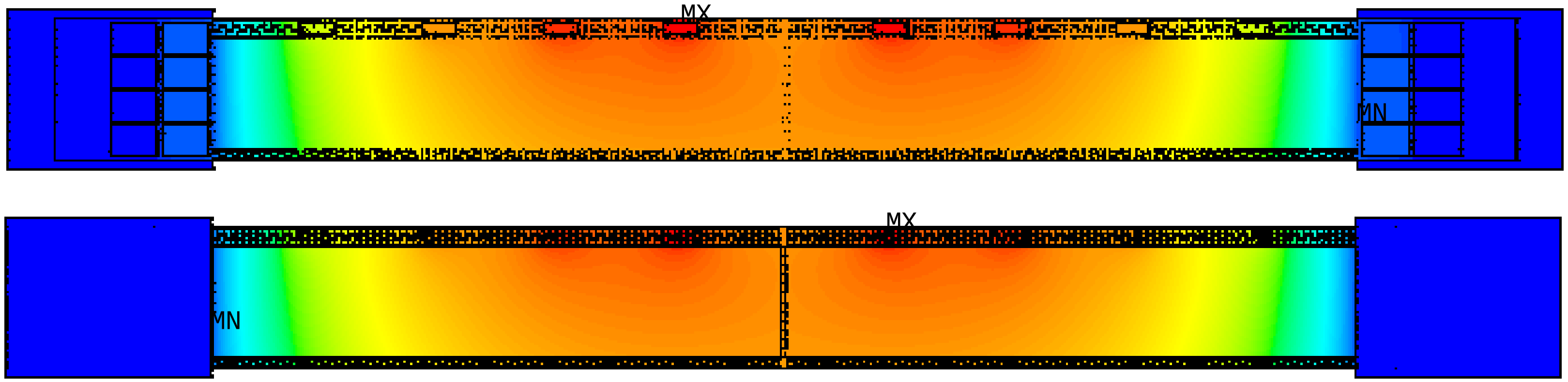

Temperature distribution all over the path points

DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)

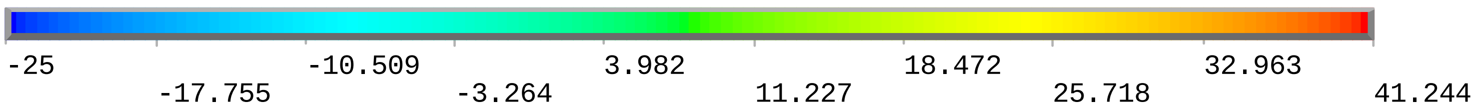
# Evaporative cooling **without** cold-dry volume (Ideal)

$T_{env}$=15ºC (**Without** cold-dry volume)
$T_{coolingblock}$=-25ºC ($CO_2$ cooling)
NO TPG
$P_{sensor}$=1Watt

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=15ºC | Tcb=-25ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG




$\Delta T_{Sensor}$=60ºC $T_{max}$=41ºC !!!




DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)

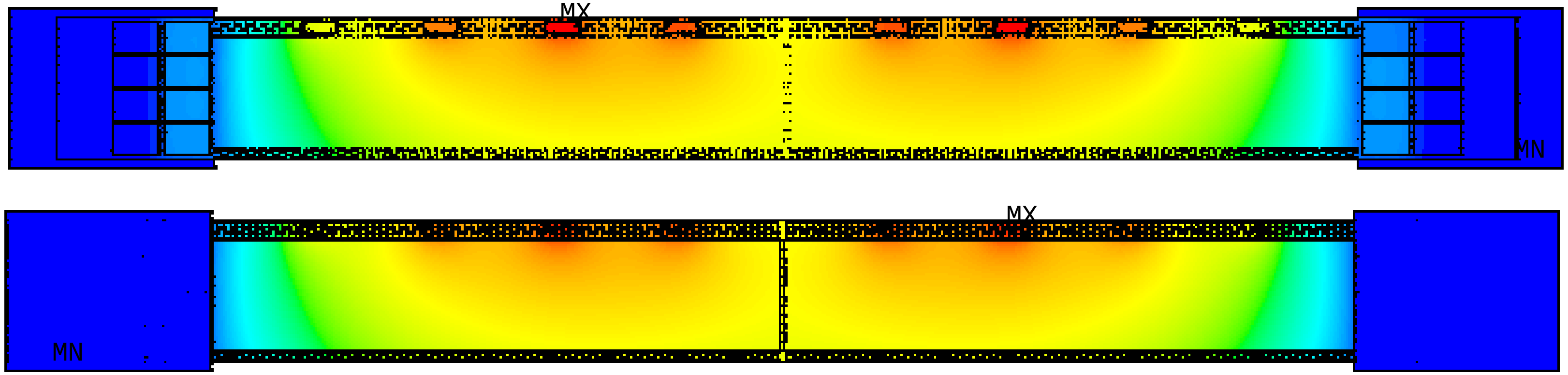
→ Even with $CO_2$... **the cold-dry volume is mandatory!!!**

# Evaporative cooling with cold-dry volume (Real)

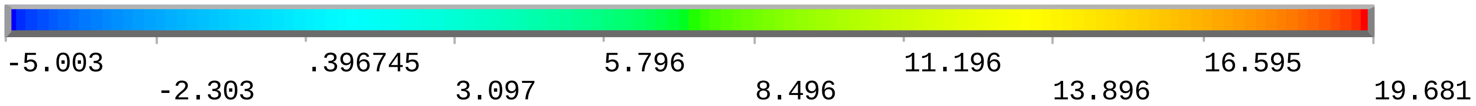
$T_{env}$=-8ºC (With cold-dry volume)
$T_{coolingblock}$=-5ºC (-25 ºC → $CO_2$ cooling inlet)

In this case… water is out of the game…

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=-8ºC | Tcb=-5ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG




$\Delta T_{Sensor}$=24ºC $T_{max}$=20ºC !!!




DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)

# Summary

- The simulations are in a good shape and ready to produce plots to be included in the TDR (final comparisons with Karlsruhe simulations are needed!)
- The end of stave is cooled using the cooling blocks
  - Water at 5ºC could be enough to cope with our requirements… but we have learned that a thermal gradient (~20ºC) will appear…
  - See my next talk for discussion and evaporative cooling details
- The center… is an issue for the air blowing!
  - A cold dry volume is mandatory!!!

Thank you very much!

# Cooling options for the Belle-II PXD

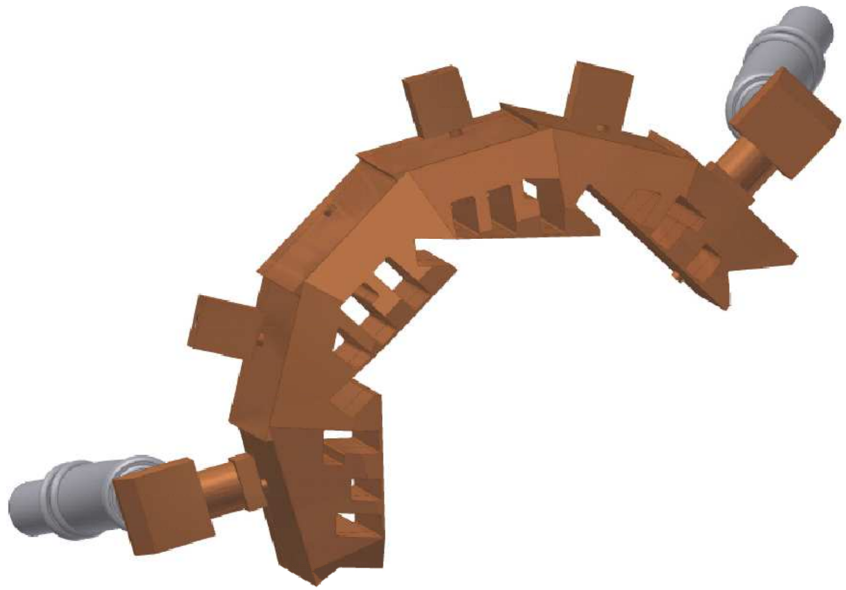
*C. Lacasta, C. Mariñas, M. Vos*
*IFIC-Valencia*

## Outline

- Cooling options: Water or evaporative
- Summary Vienna’s PXD-SVD joint meeting (18-19 January)
- Implications of the coolant election

# Option 1: Water cooling

- Well known conventional technology
- Low pressures
- Serialized pipes without pressure drop possible.
- Density of liquid water is ~1 g/cm$^3$ (compared to $CO_2$ ~ 1.03 g/cm$^3$)
- Needs no big engineering effort (we have done one design already!)



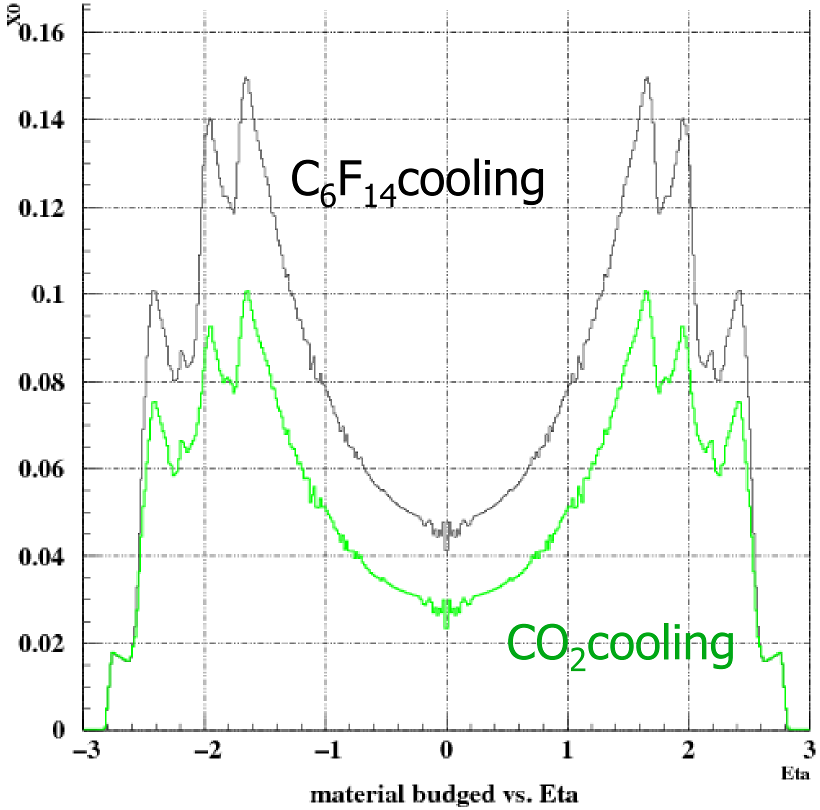
- Because of low heat removal capacity, big mass flow needed (bubbles, cavitation).
- Be aware of corrosion!
- Big pipes and connectors
- Small capacity for heat removal

## Option 2: Evaporative cooling ($CO_2$ or $C_3F_8$)

- Cooling loops (radius of 5mm) with very small pipes (outter radius ~1.3mm, wall thickness ~50µm)
- The material budget is reduced ($CO_2$)
- LHCb, AMS, CMS, ATLAS, industry → Growing interest in this coolant ($CO_2$)
- $C_3F_8$ → Big experience
- Low mass flow needed
- No corrosion

- Bigger engineering studies are required
- High pressures

CMS Material distribution budget for 3 barrel layers




→ With $CO_2$ we can remove seven times more heat than with chilled water!

## DEPFET proposals presented in HEPHY (Vienna)

- DEPFET is the baseline technology chosen by the Belle-II PXD commitee
  - High gain, low material budget, good spatial resolution technology

- An “all in one” cooling/mechanical support structure was presented
  - First design to work with water cooling
  - Could be modified to work with evaporative cooling if needed ($CO_2$ and $C_3F_8$ are under evaluation)
  - → **Possible common cooling system for PXD+SVD together??**

- Thermal studies
  - FE simulations were presented
  - Reasonably low temperature on the cooling blocks is needed to cool down the readout chips
  - The center of the ladder must be cooled by forced convection with very cold air!
  - → **Possible common “cold-dry” volume for PXD+SVD together??**

# HEPHY PXD-SVD Meeting

- Latest mechanical and thermal results (diamond-less option) were presented in a HEPHY Seminar
- Proposals very well received!
- Positive attitude to work together and find a common solution
- Feedback between groups
- Both groups agreed on a common cooling system and cold dry volume

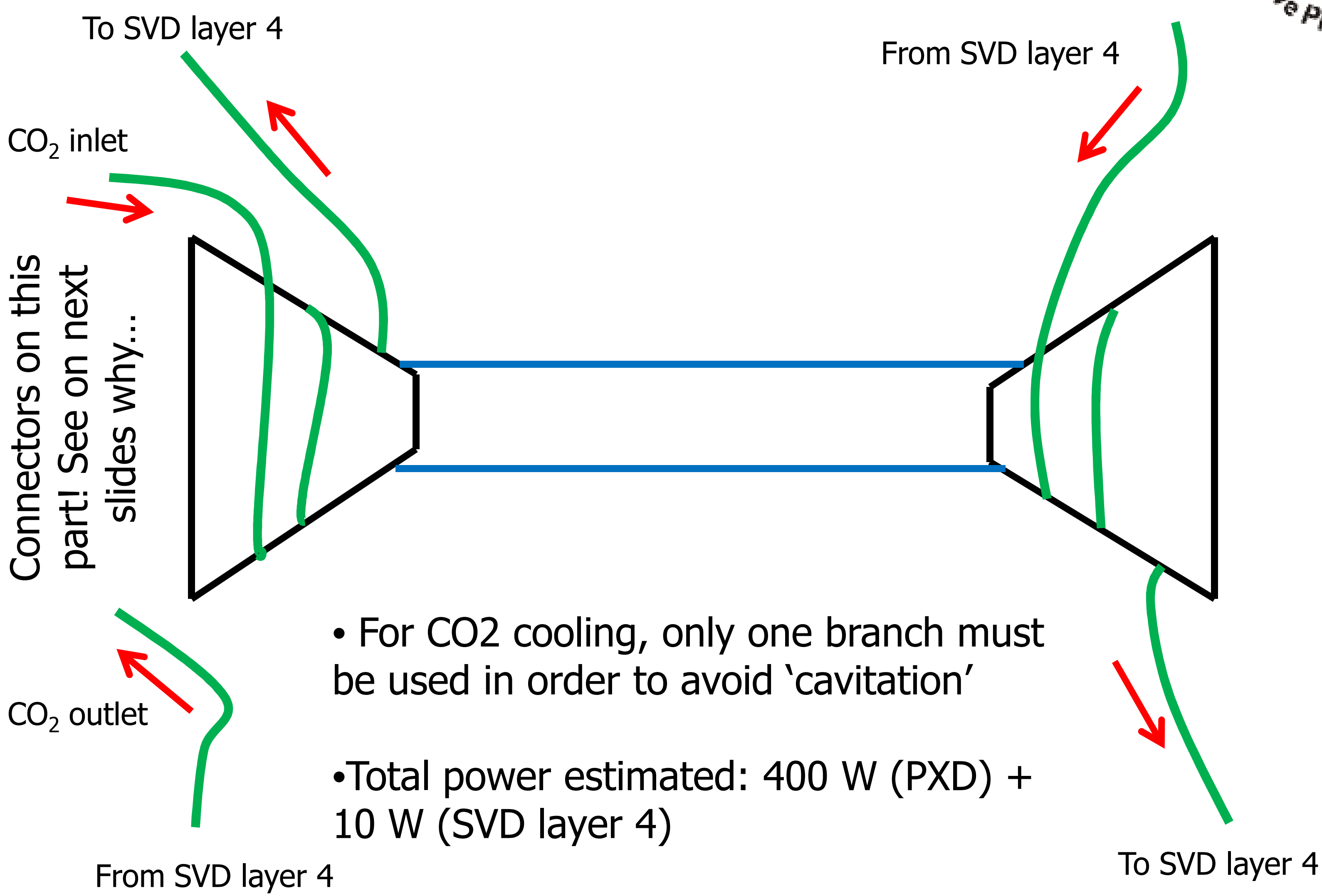
- The work has started!

→ HEPHY is working on $CO_2$ as baseline, together with a cold dry volume for the SVD

**We have to decide wich coolant do we want to use!!**

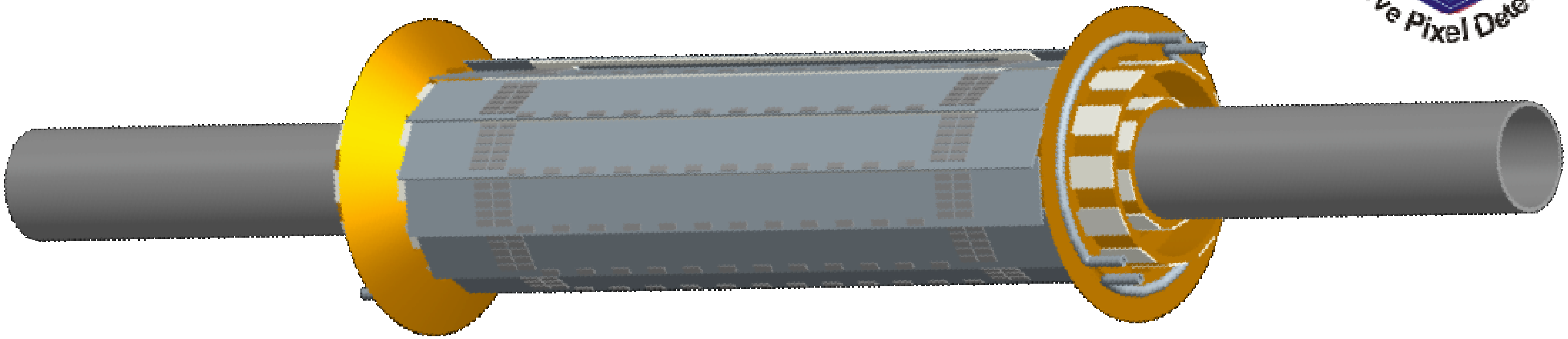
➢ **Proposal:** If $CO_2$, a common branch should cool down the full PXD detector and the SVD layer 4 (to be discussed with our engineers)

# Schematical view

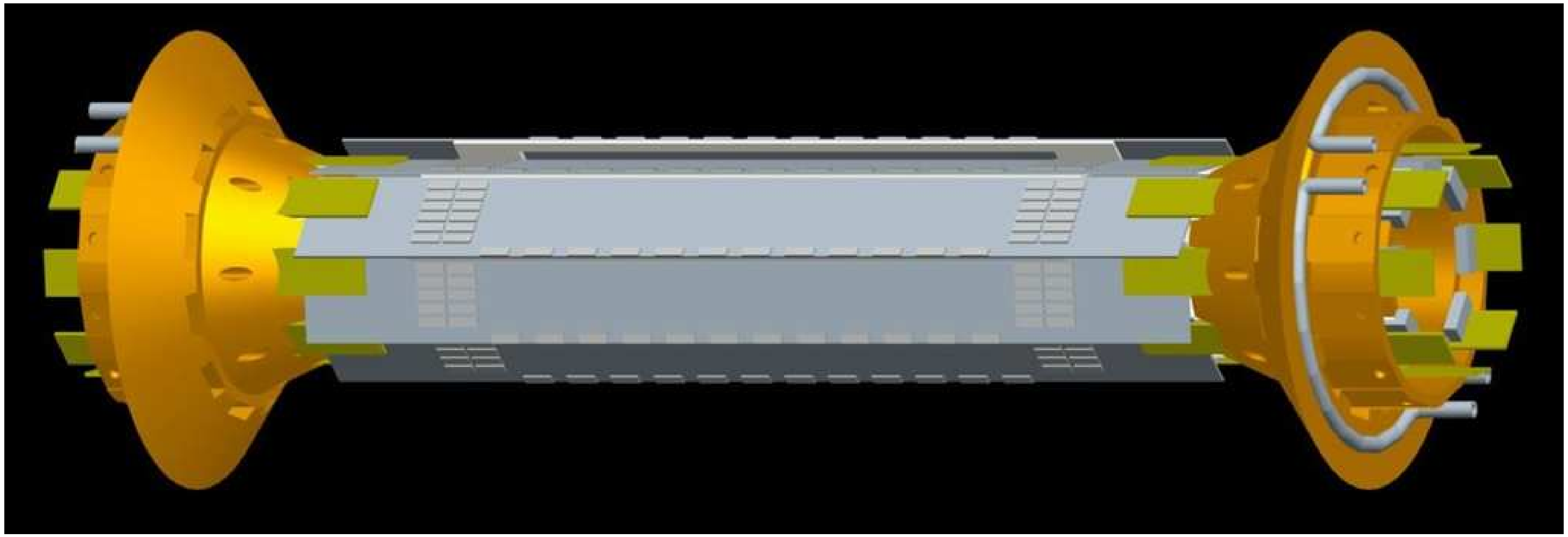



- For CO2 cooling, only one branch must be used in order to avoid 'cavitation'
- Total power estimated: 400 W (PXD) + 10 W (SVD layer 4)

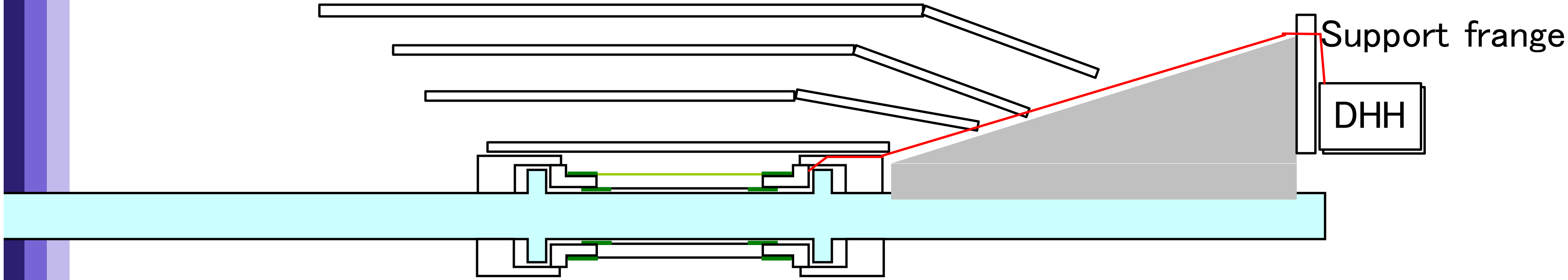
# Schematical view



- Conical structure should be optimized for the “diamond-less” option
- Pipes wrapped around the cooling blocks



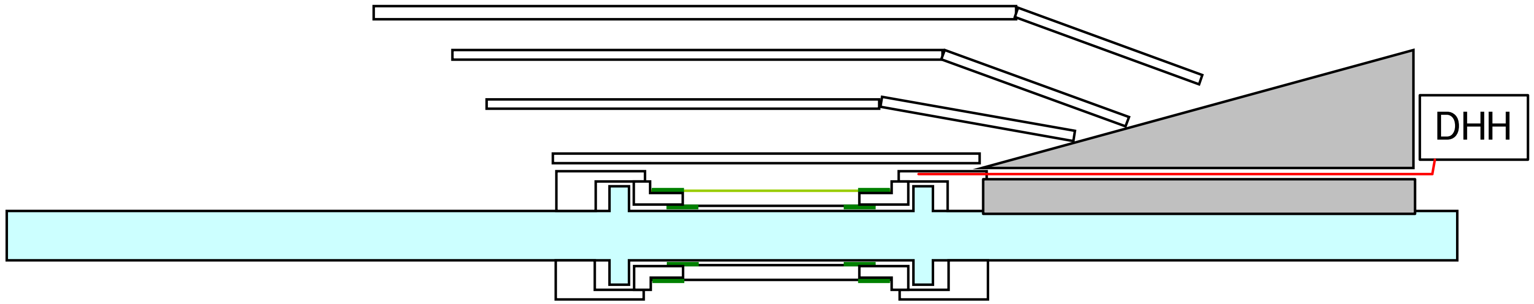
Case 2 (“News from KEK”, S.Tanaka)




- Beam mask is keep with SVD support frame.
- PXD cabling path is surface of beam mask.
  - I and Kohriki-san prefer is option but I want to know which option the PXD group ask for (Tsuboyama-san expect to select case 1)

→ Absolutely no free space! See the I. Gfall talk about SVD support…

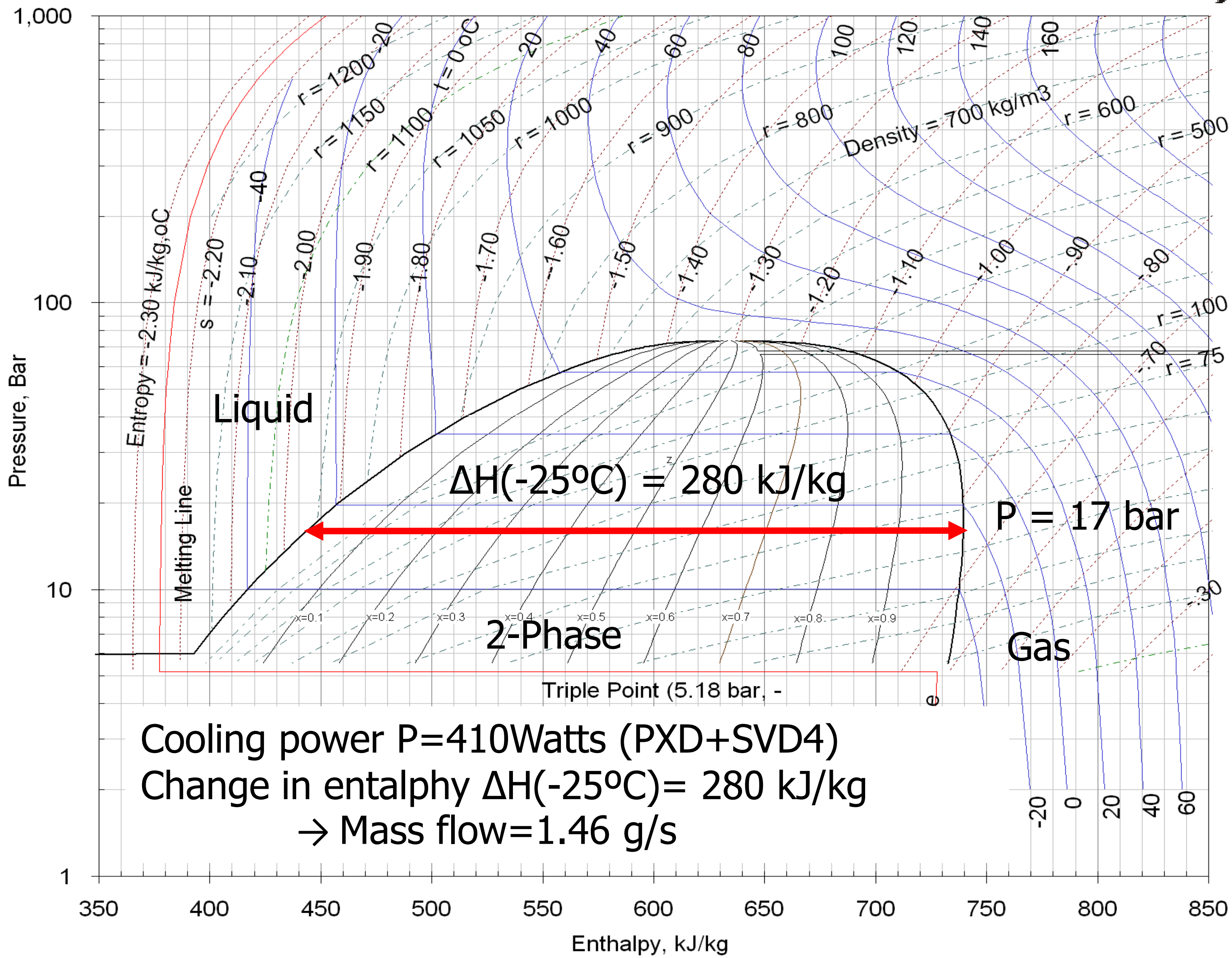
# Case 1 (Inner detector assembly)




- PXD cabling is independent with SVD
- Readout Cable is sitting between beam masks.

→ Only this solution is feasible…

# $CO_2$ Mass flow estimation




Cooling power P=410Watts (PXD+SVD4)

Change in entalphy ΔH(-25ºC)= 280 kJ/kg

→ Mass flow=1.46 g/s

## Run conditions at T=-25ºC

| | $C_3F_8$ | $CO_2$ |
|---|---|---|
| $P_{evaporation}$ | 1.7 bar | 17 bar |
| ΔT for ΔP=+-0.1bar | +1.4 C / -1.5C | +0.2 C / -0.2 C |
| ΔT for ΔP=+-1.0bar | +12 C / ~-20 C | +1.8 C / -1.9 C |
| **ΔH for evaporation** | **100 J/g** | **280 J/g** |
| **Flow for 100 W** | **1.0 g/sec** | **0.4 g/sec** |
| Volume flow | 0.6 $cm^3$/sec | 0.4 $cm^3$/sec |

Taken in account that the pipes are proven to resist up to 110 bar…
I see no reasons to use $C_3F_8$…

# Implications

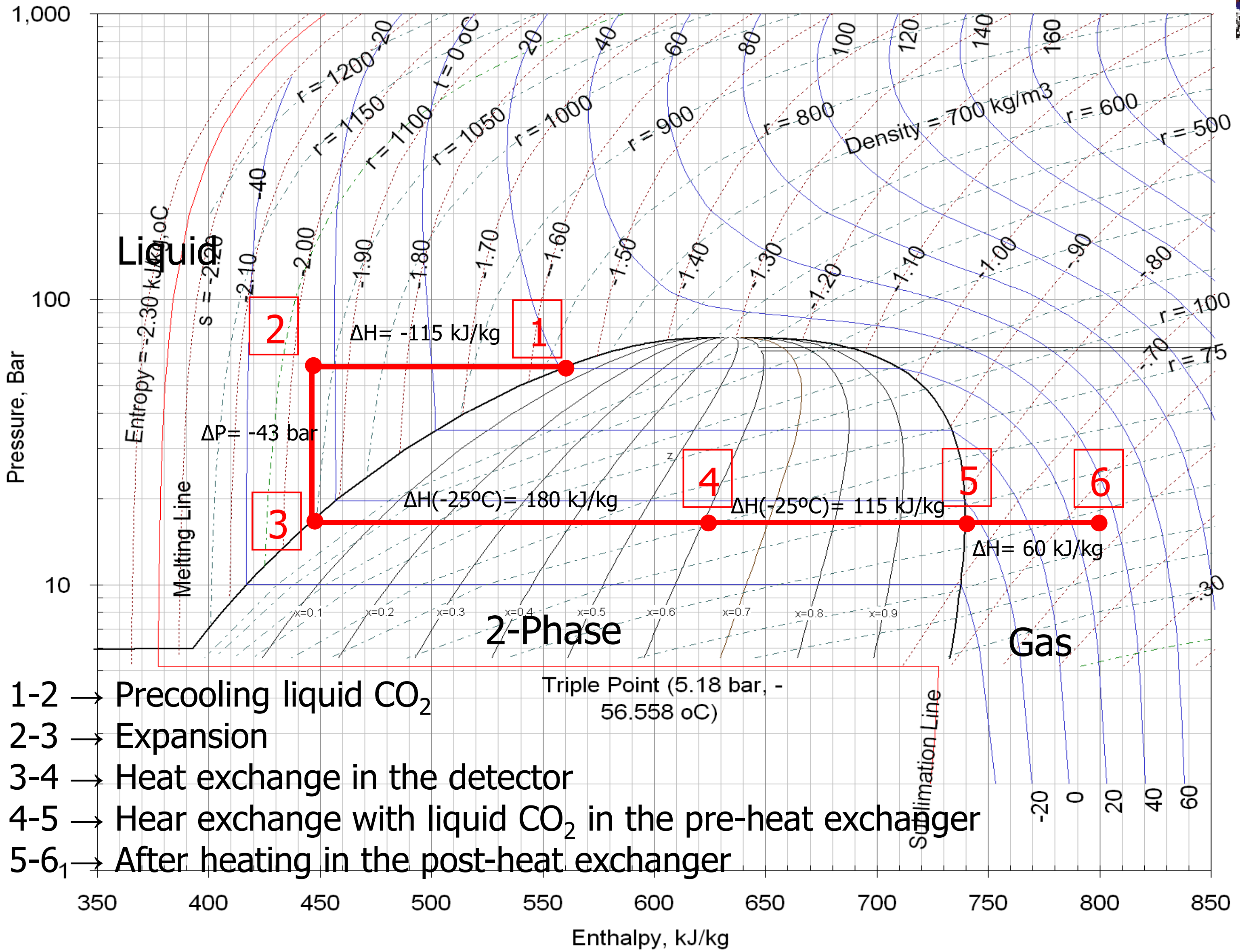
- ❑ <u>Dew point:</u> The temperature of the outer surface of the pipes going to and coming from the detector must be higher than the dewpoint in the experimental area… Two options possible:

1. Warm pipes ($T_{surface}$>15ºC):
   - Mass flow should be increased or
   - Pre-cool the liquid $CO_2$ using the returning flow, close to the thermal enclosure (see next slide)

2. Cold pipes:
   - Pipes insulation needed...

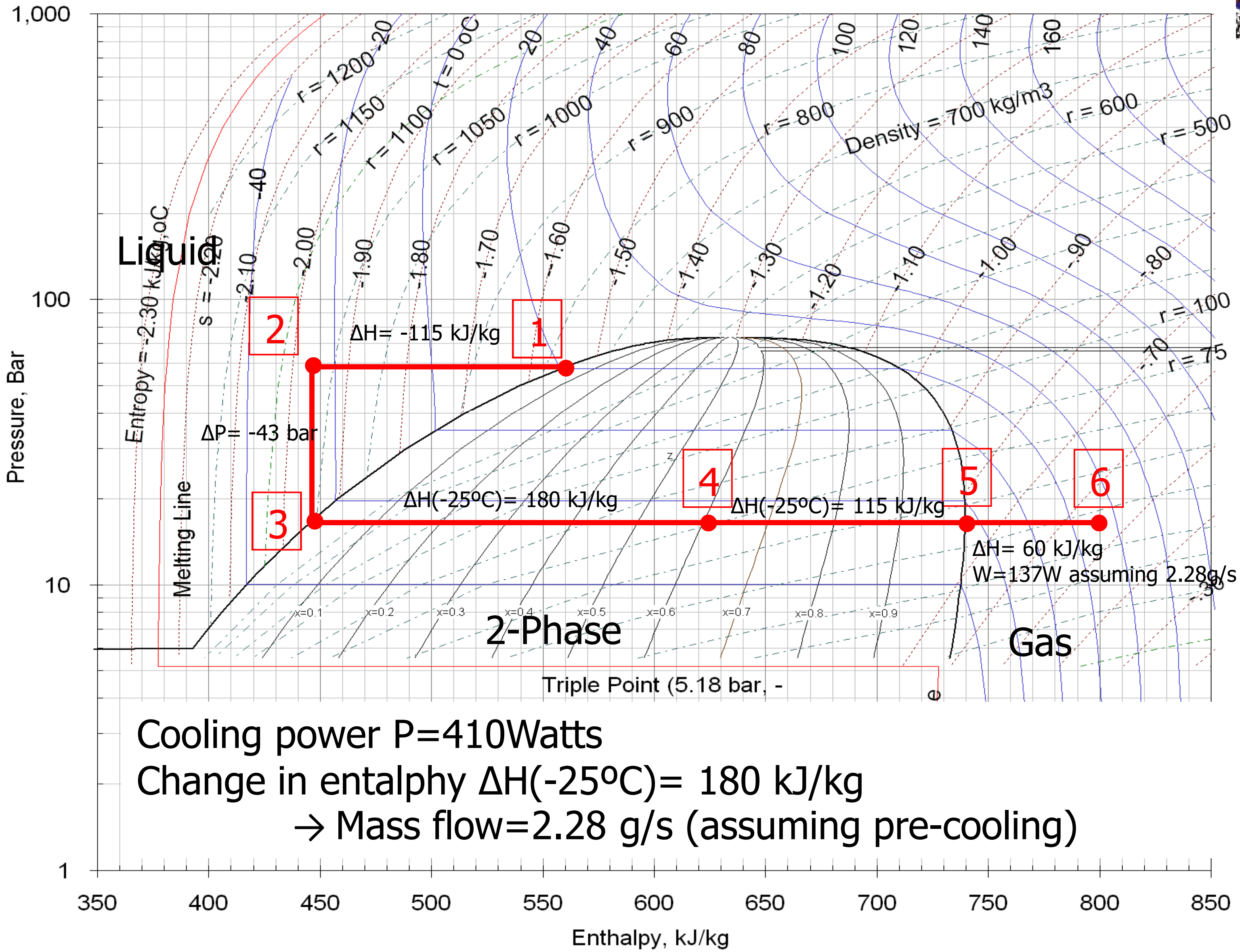
- ❑ <u>Cooling blocks:</u> Should be redesigned but (probably) a simpler option is avaliable, without curved channels inside the copper blocks!

# Easiest $CO_2$ blow circuit (assuming post-heat exch.)




1-2 → Precooling liquid $CO_2$
2-3 → Expansion
3-4 → Heat exchange in the detector
4-5 → Hear exchange with liquid $CO_2$ in the pre-heat exchanger
5-6 → After heating in the post-heat exchanger

# Easiest $CO_2$ blow circuit (assuming post-heat exch.)

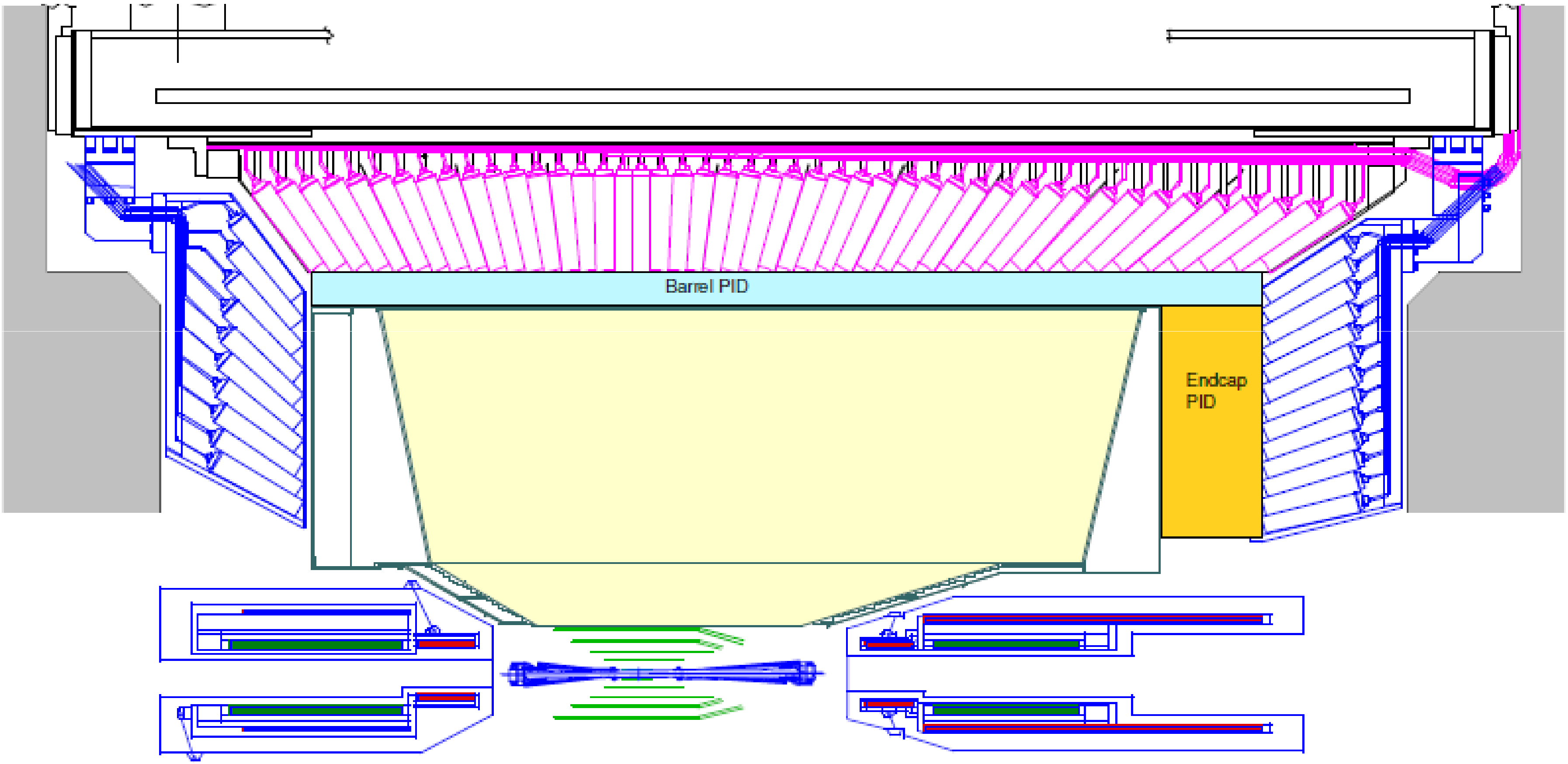



Cooling power P=410Watts

Change in entalphy ΔH(-25ºC)= 180 kJ/kg

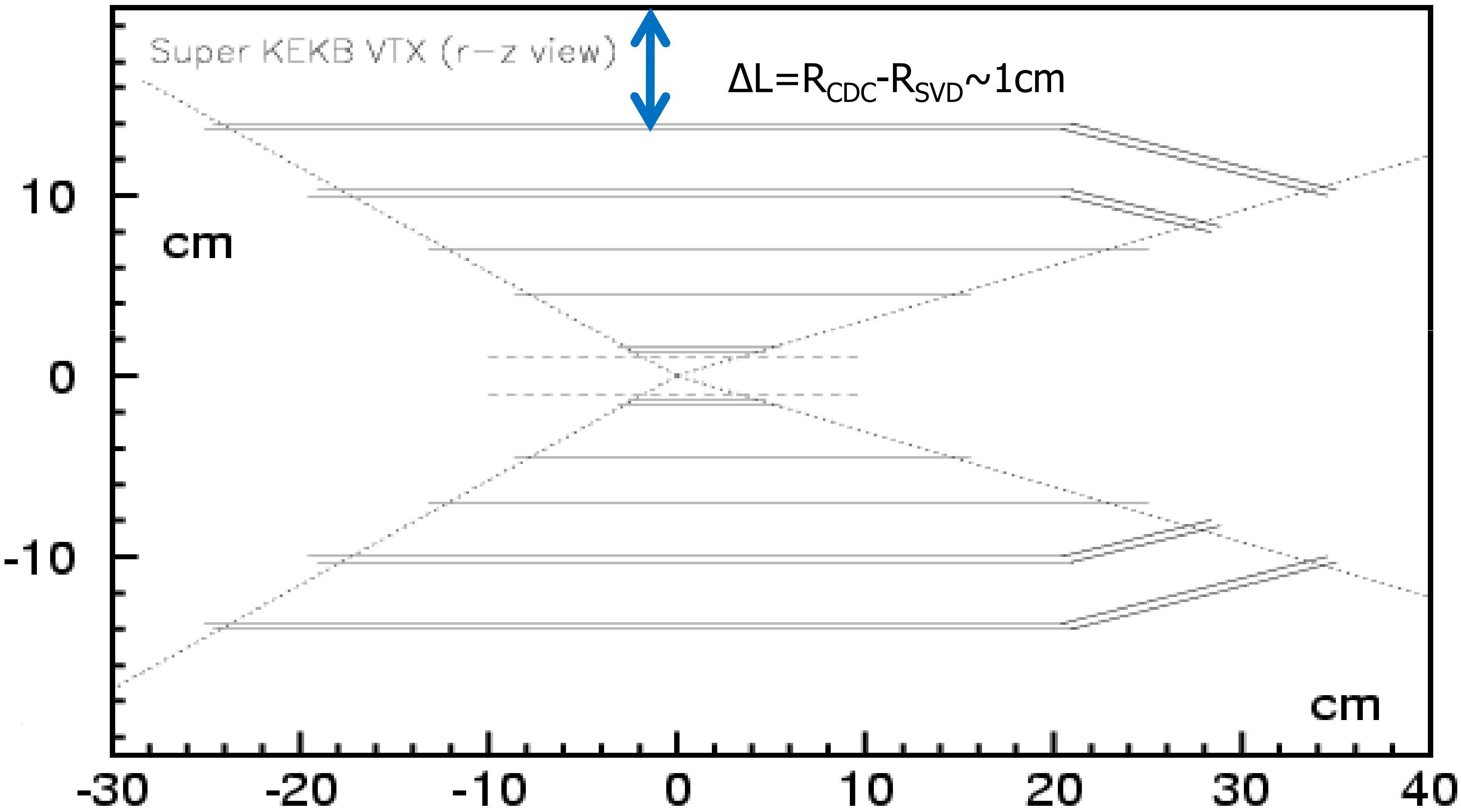
→ Mass flow=2.28 g/s (assuming pre-cooling)

# Common cold dry volume

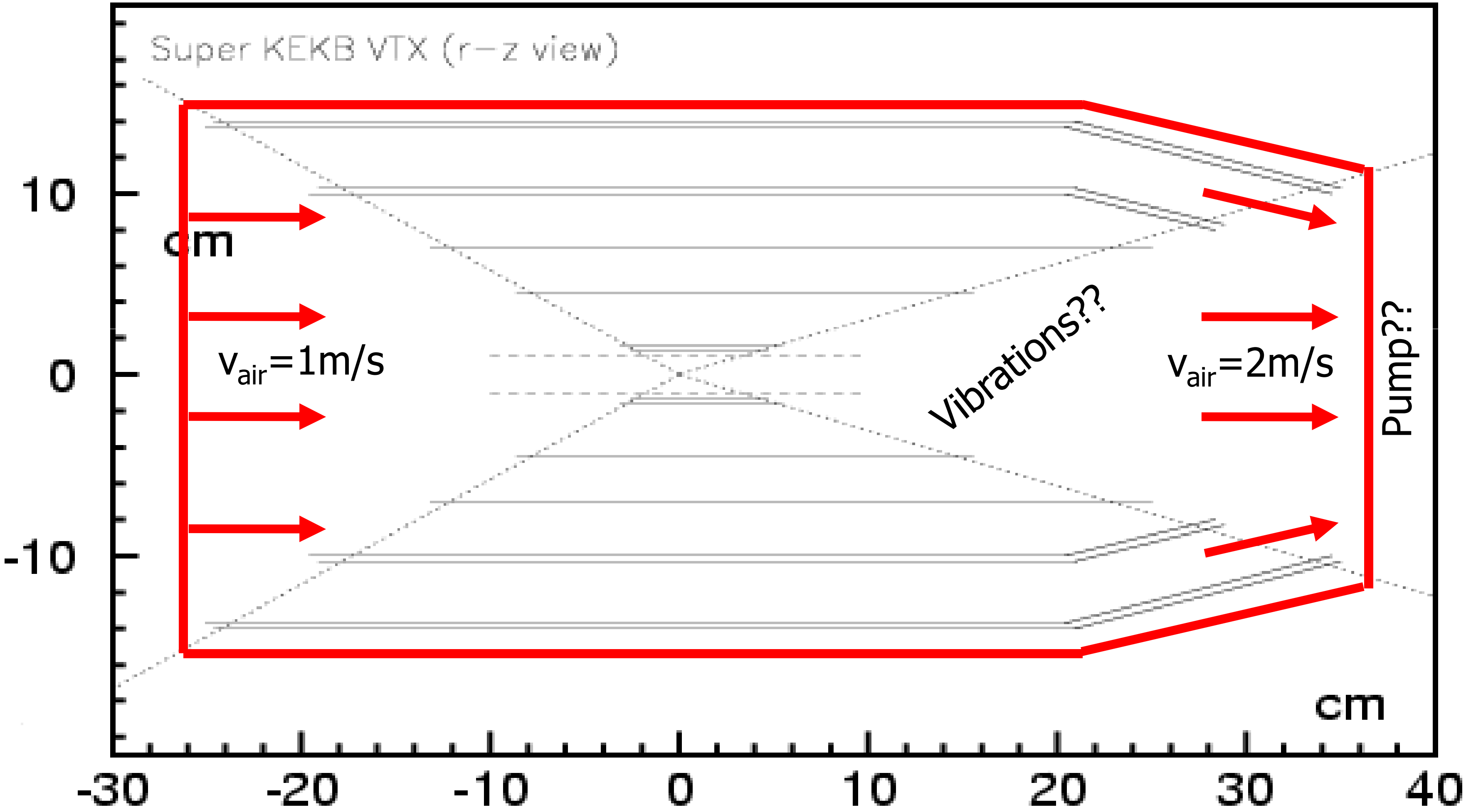


# Common cold dry volume

Very short distance! We need very nice insulation between detectors



- Common cold dry volume

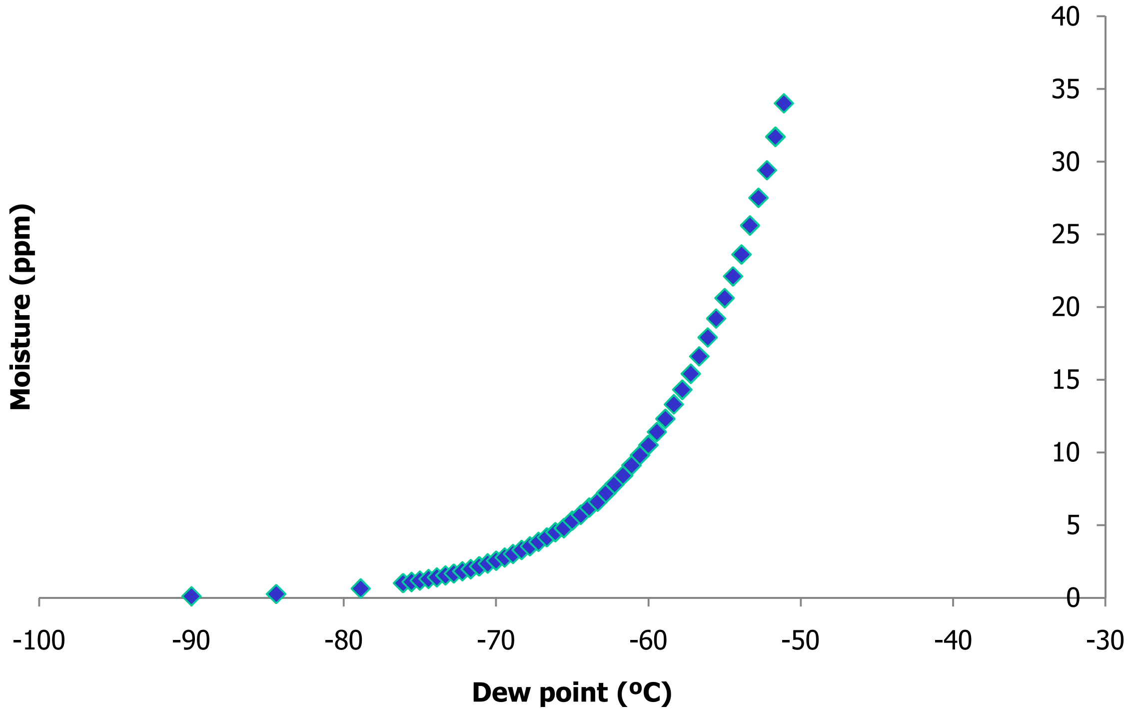


# Common cold dry volume

Assuming a sufficient margin for operation:

$T_{dewpoint} < T_{coolant} - 15^oC = -40^oC$

→ Moisture~160ppm

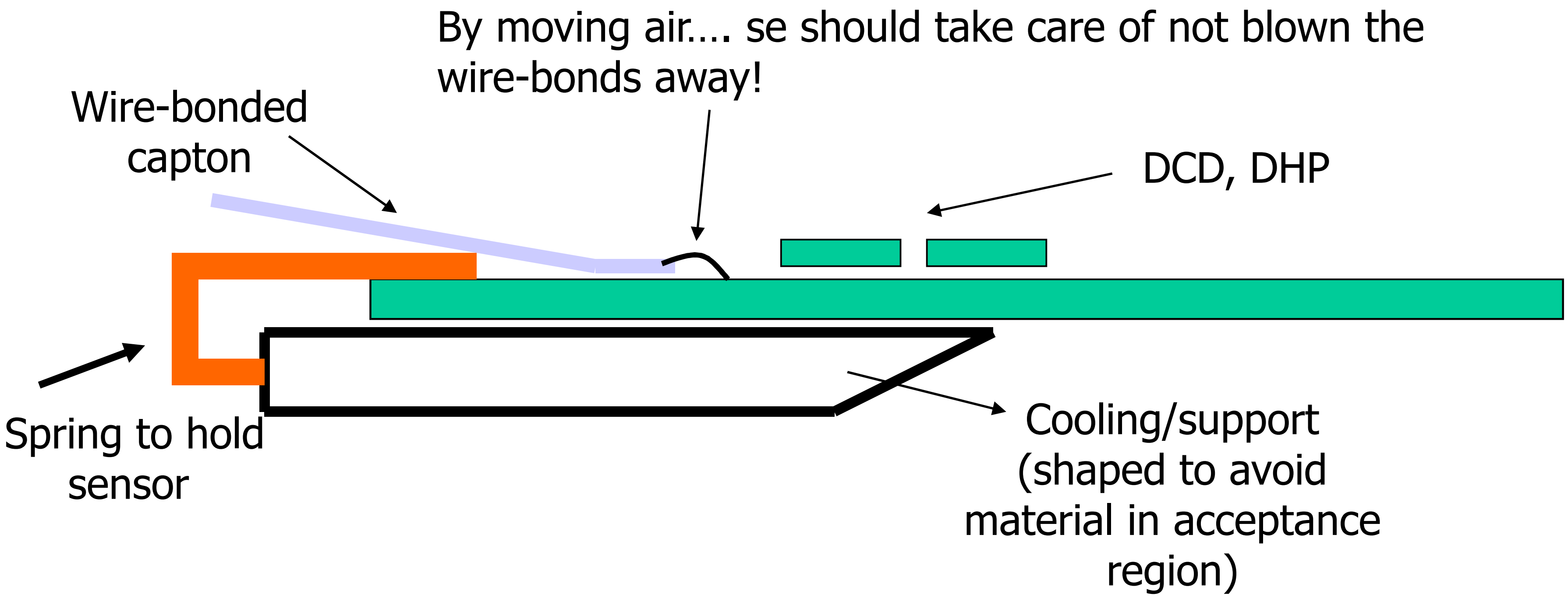



Comparison:

- ATLAS → $T_{dewpoint}$=-30ºC; Moisture=390ppm
- ATLAS upgrade → $T_{dewpoint}$=-50ºC; Moisture=39ppm

## PXD forced convection

Cooling/support proposal



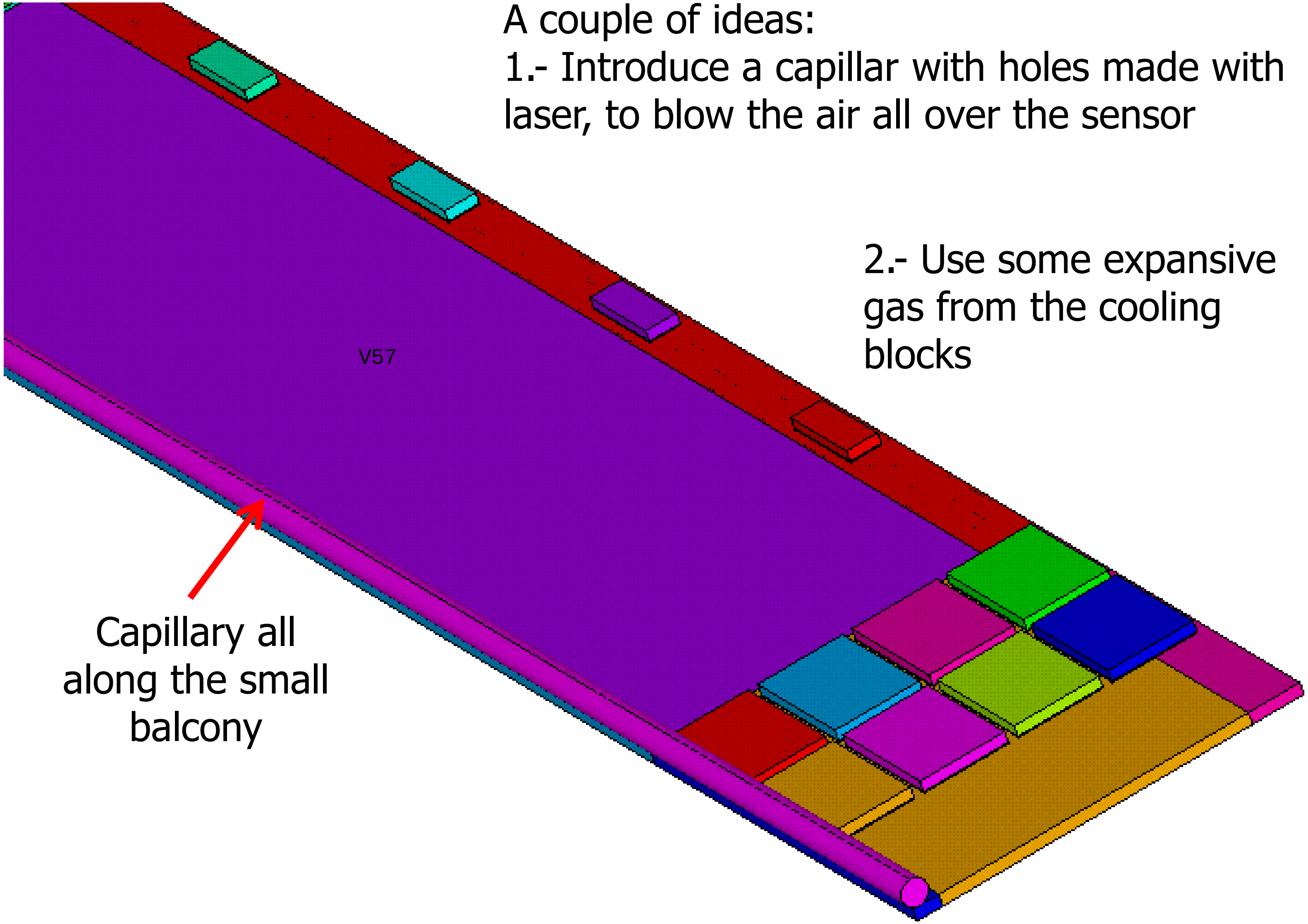

SVD group is worried too…

# PXD forced convection

A couple of ideas:

1.- Introduce a capillar with holes made with laser, to blow the air all over the sensor

2.- Use some expansive gas from the cooling blocks

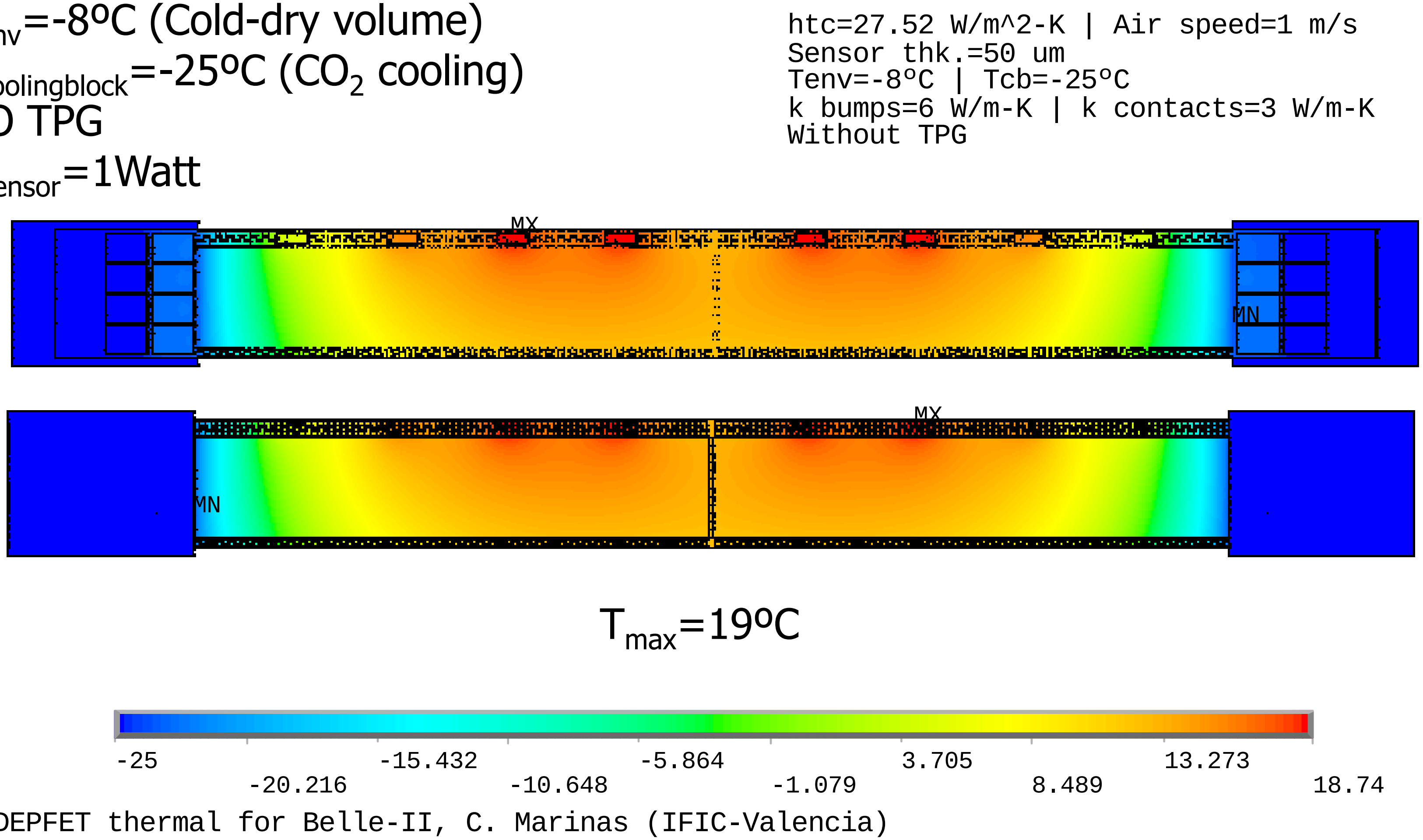



Capillary all along the small balcony

Thank you very much!

# Evaporative cooling

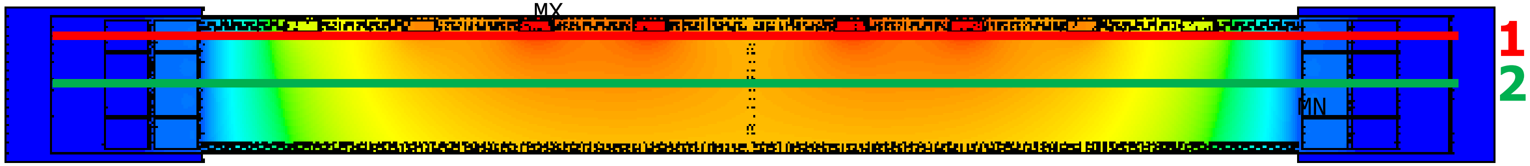
$T_{env}$=-8ºC (Cold-dry volume)
$T_{coolingblock}$=-25ºC ($CO_2$ cooling)
NO TPG
$P_{sensor}$=1Watt



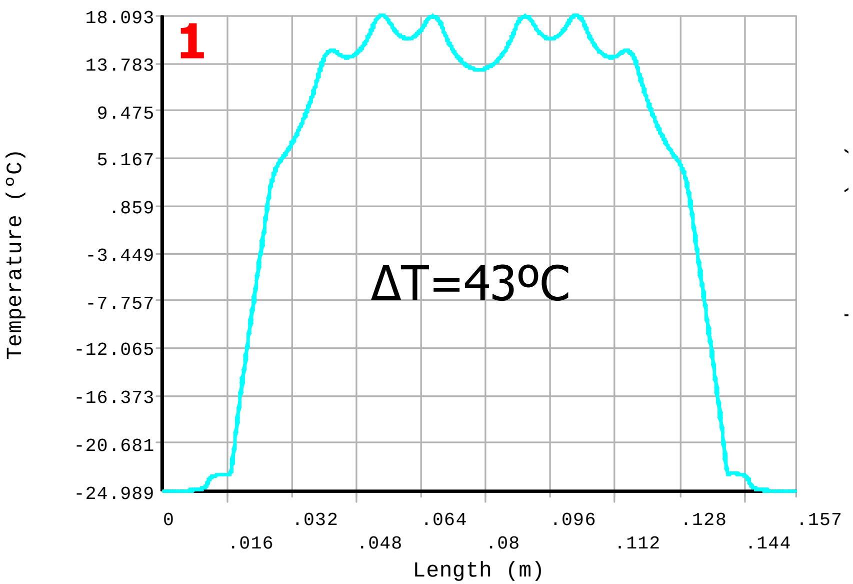

$T_{max}$=19ºC

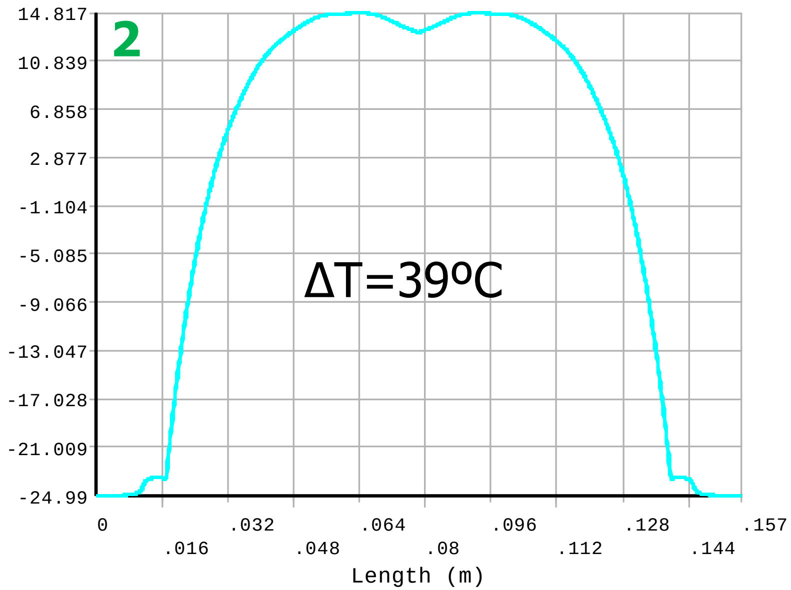
→ Extremely high temperature gradient!

# Evaporative cooling. Full ladder paths




htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=-8ºC | Tcb=-25ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG



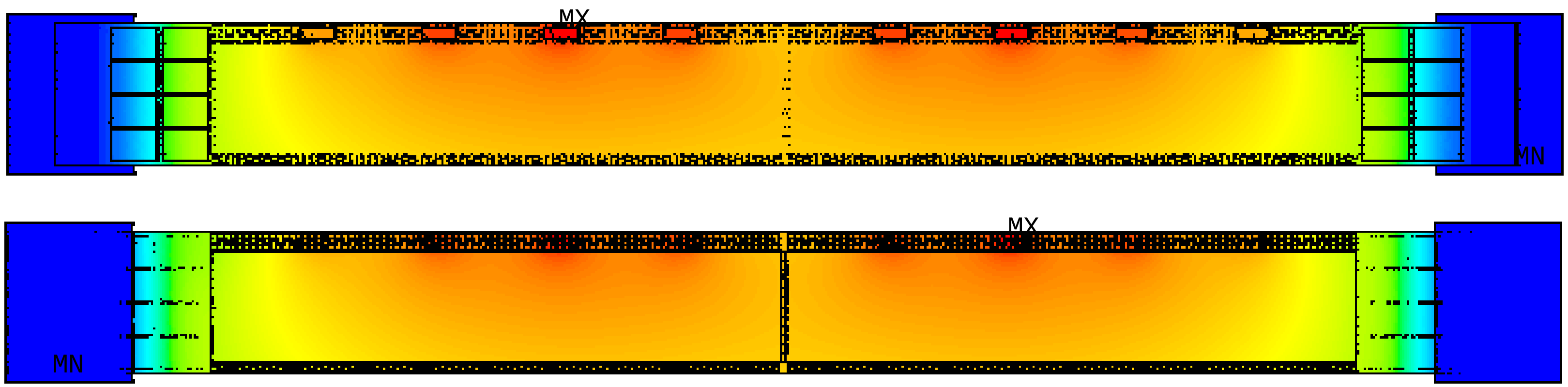

Temperature distribution all over the path points

DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)

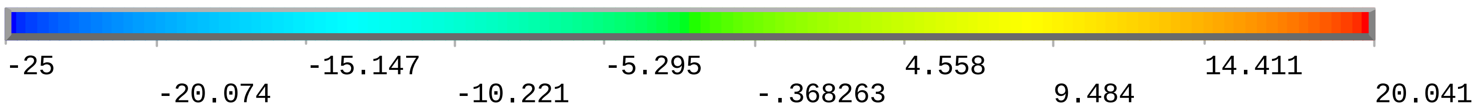
# Evaporative cooling (shorter contacts)

$T_{env}$=-8ºC (Cold-dry volume)
$T_{coolingblock}$=-25ºC ($CO_2$ cooling)
NO TPG
$P_{sensor}$=1Watt

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=-8ºC | Tcb=-25ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG




$T_{max}$=20ºC

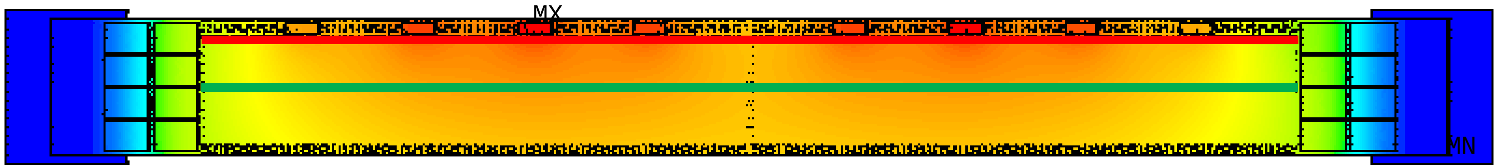



DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)

→ The temperature is more homogeneously distributed!

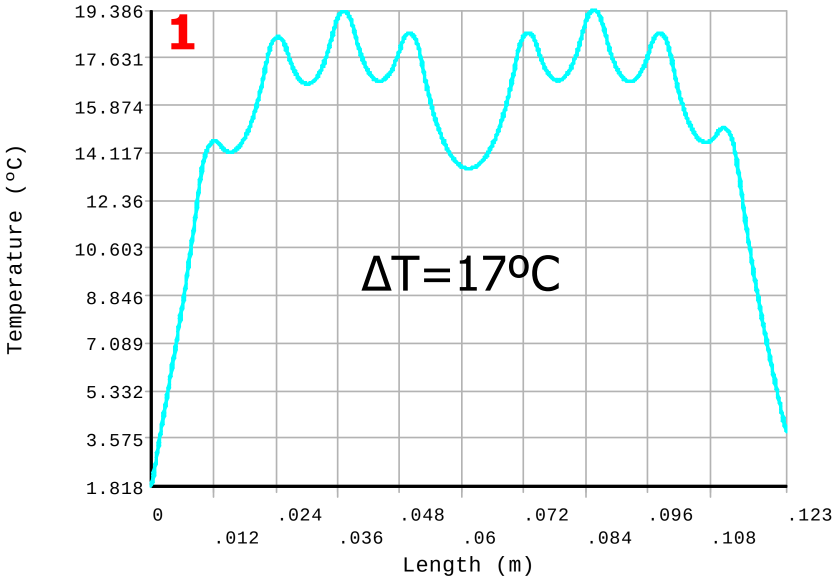
# Evaporative cooling (shorter contacts). Sensor paths

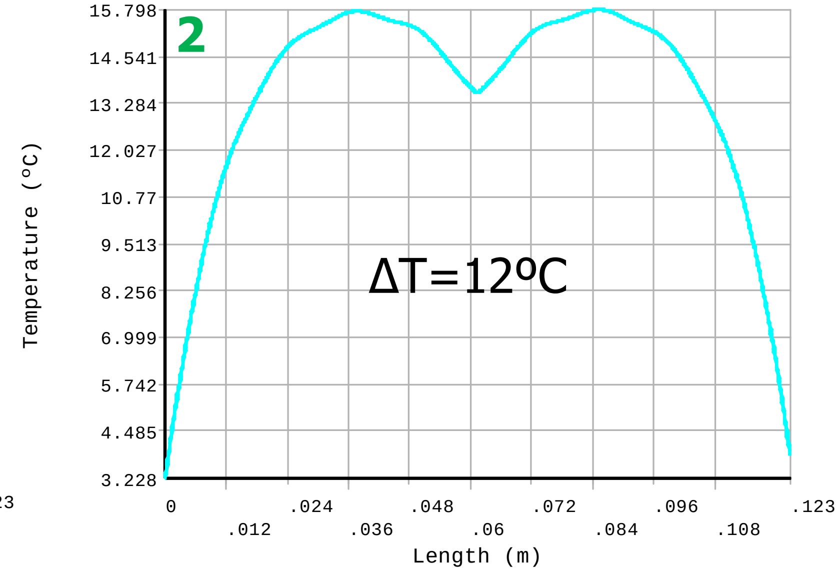
$T_{max}$=19ºC




1
2

htc=27.52 W/m^2-K | Air speed=1 m/s
Sensor thk.=50 um
Tenv=-8ºC | Tcb=-25ºC
k bumps=6 W/m-K | k contacts=3 W/m-K
Without TPG




Temperature distribution all over the path points

DEPFET thermal for Belle-II, C. Marinas (IFIC-Valencia)