RICH
Cooling

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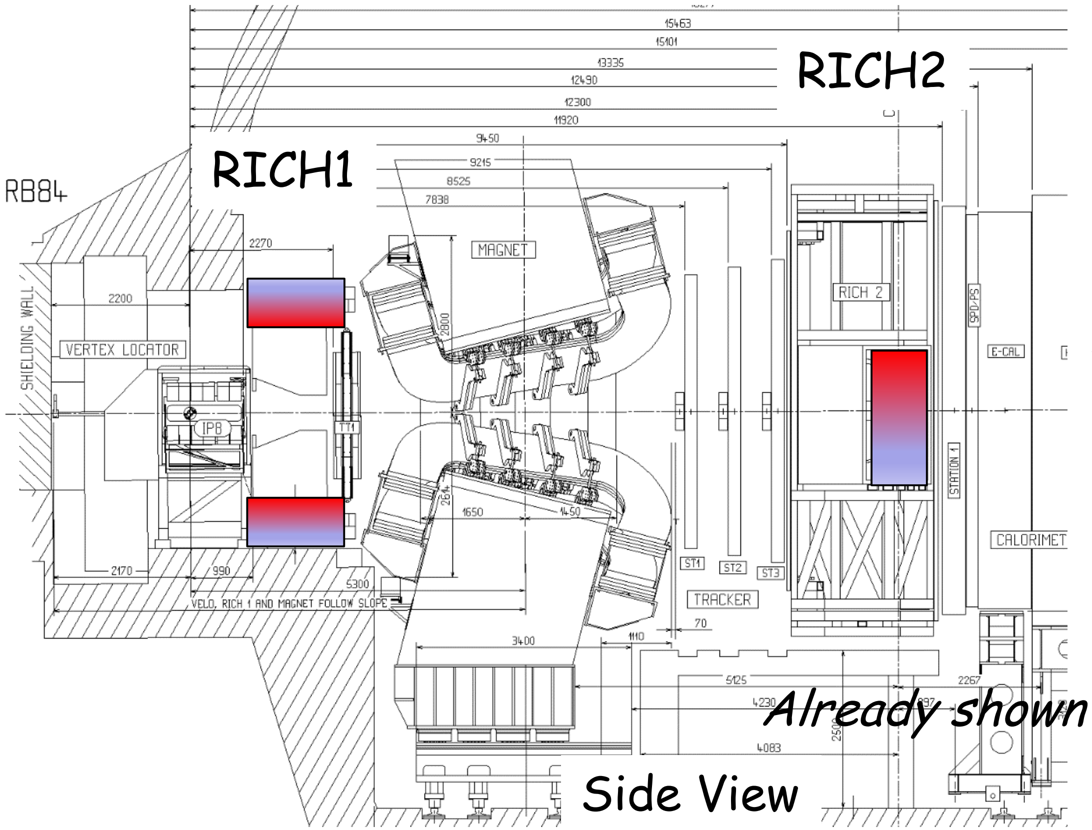
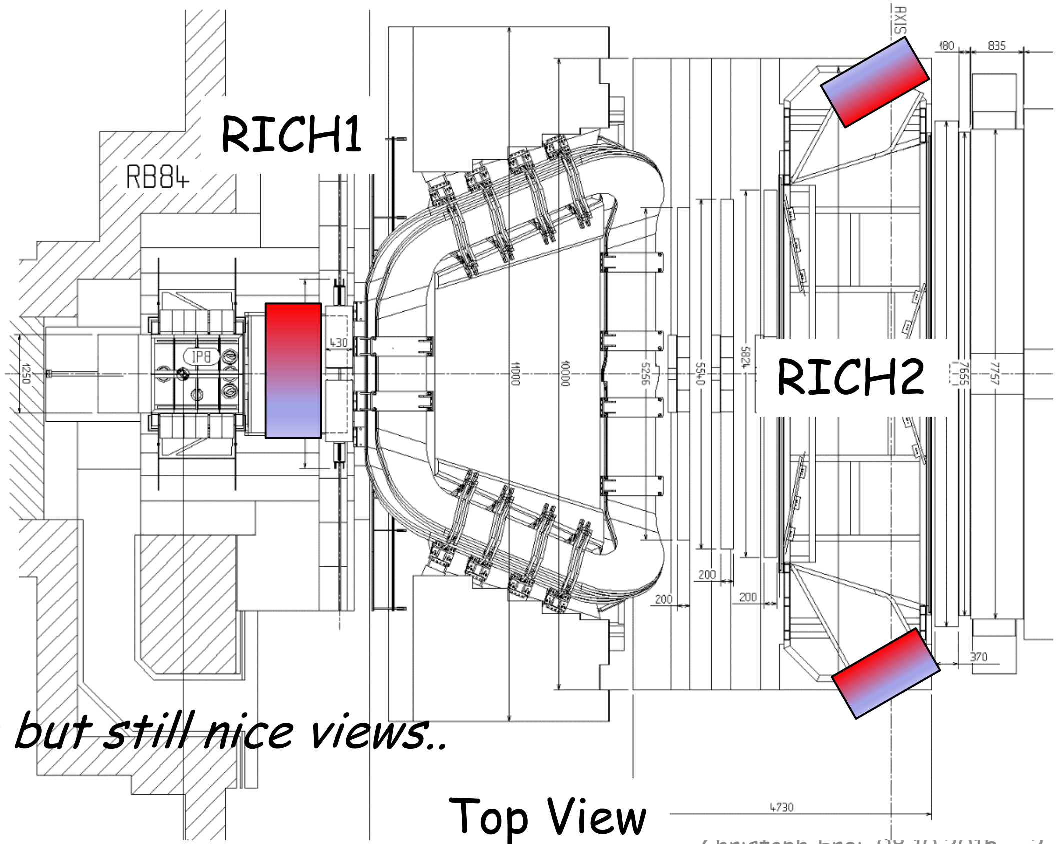
(On behalf the RICH team)

08.10.2015

Cooling – Photon Detector Assemblies (PDA)

Same location as the existing
Photon Detector Assemblies (HPD boxes)

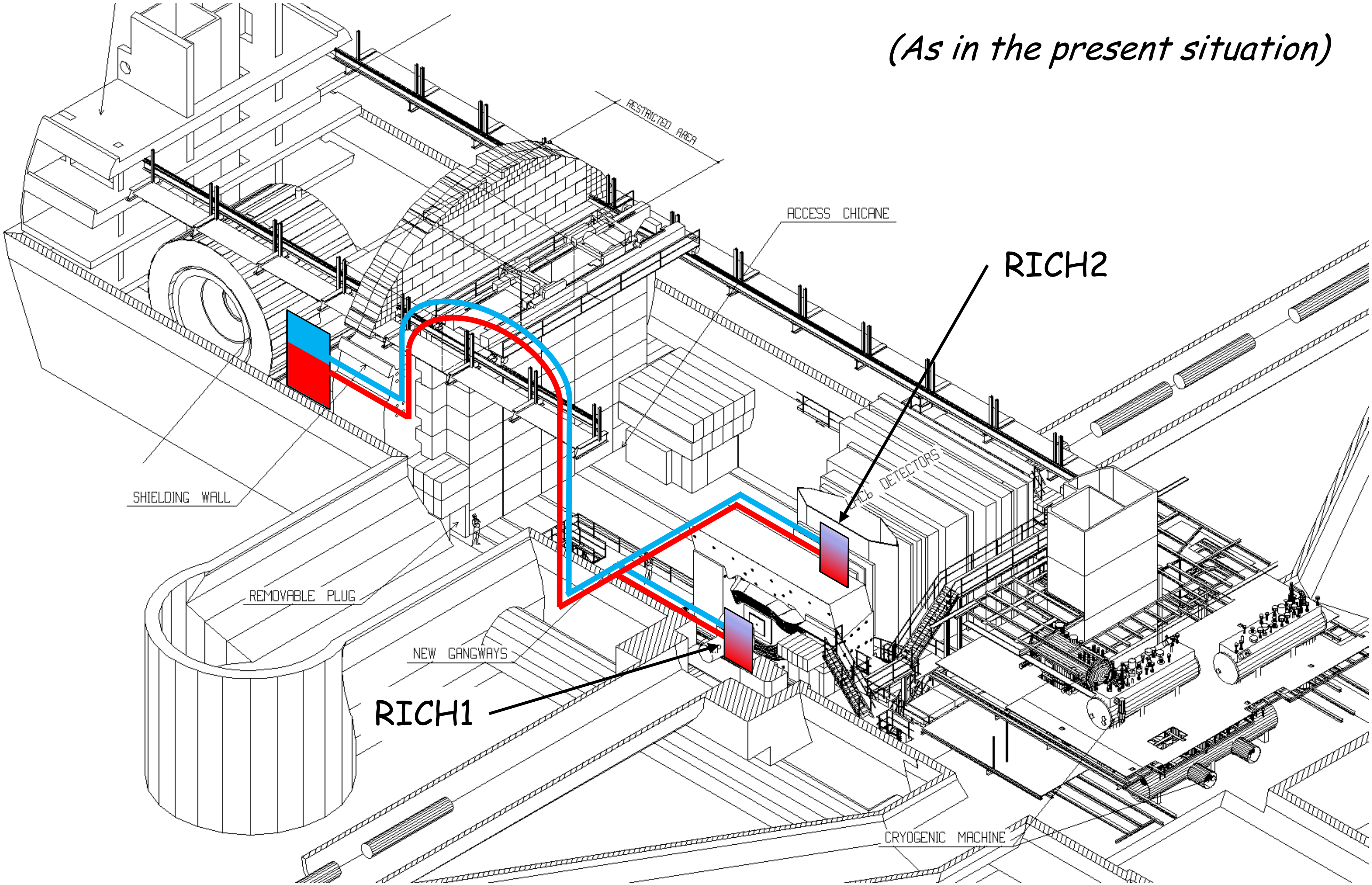




Already shown but still nice views..

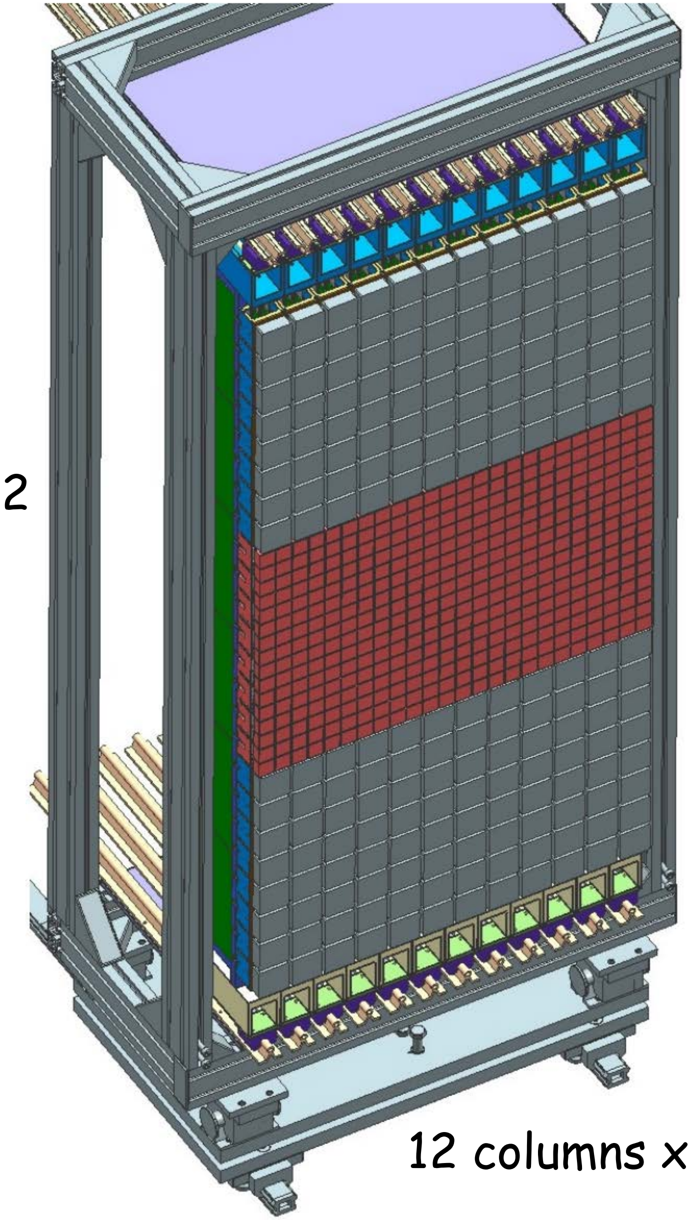
From Cooling Plant to the detectors

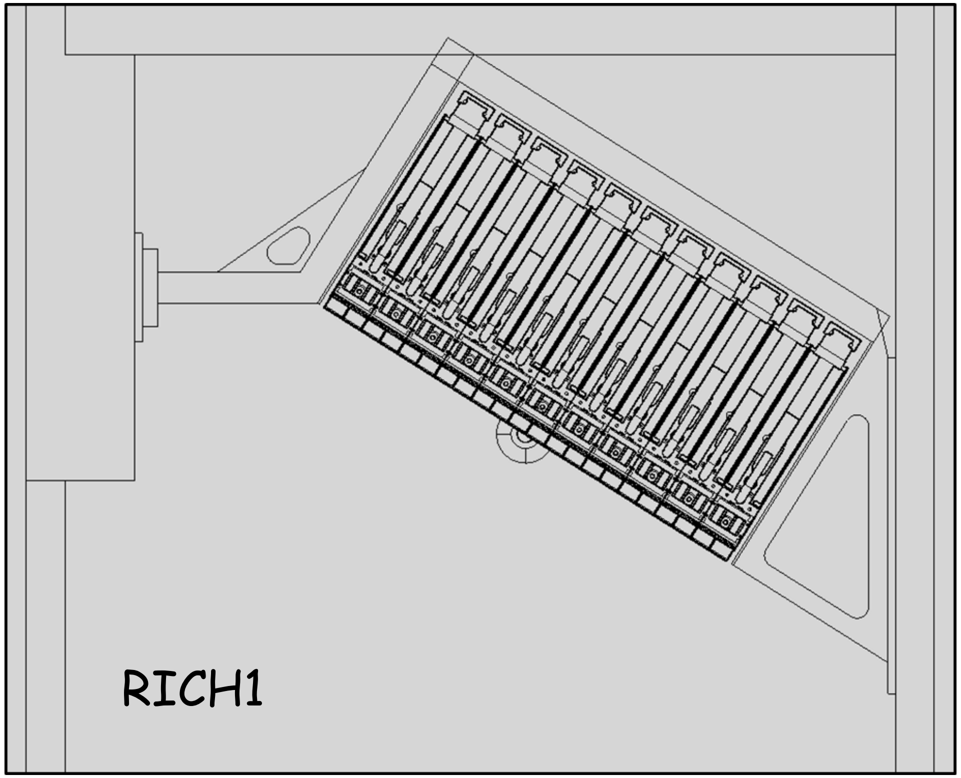
(As in the present situation)



To be cooled down

RICH2



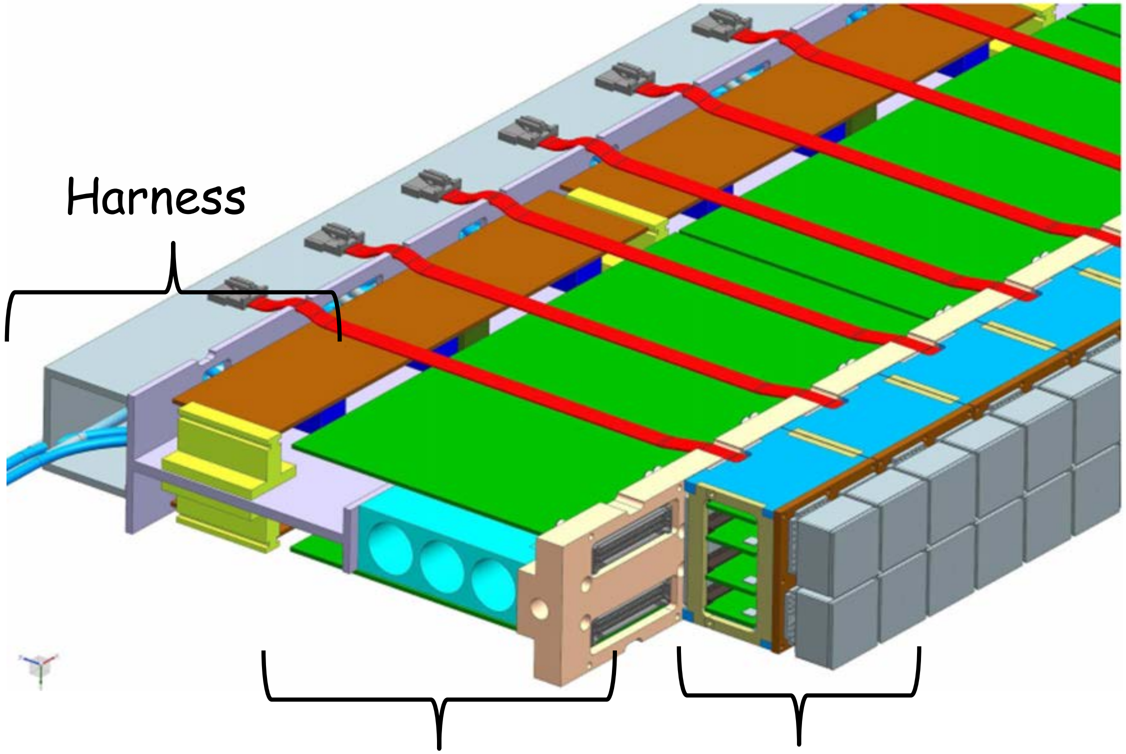


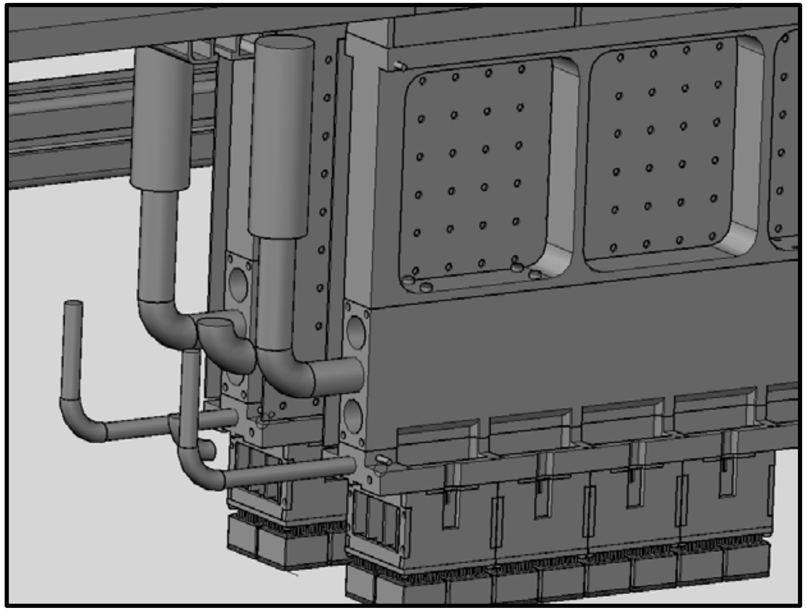
11 columns x 22 Elementary Cells

12 columns x (8 Elementary Cells 1" + 16 Elementary Cell 2")

Implementation of the photondetectors + electronics

To be cooled down

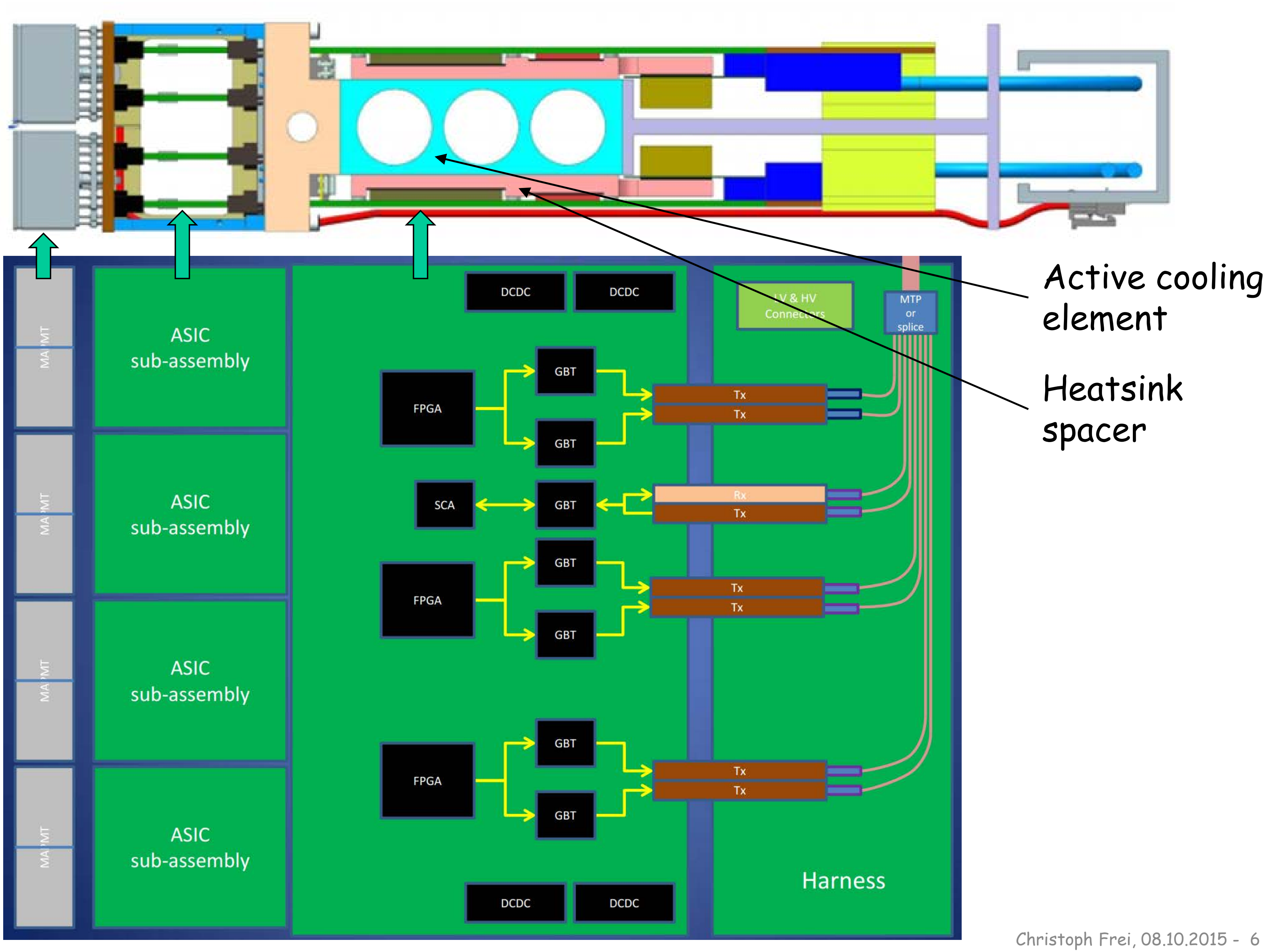




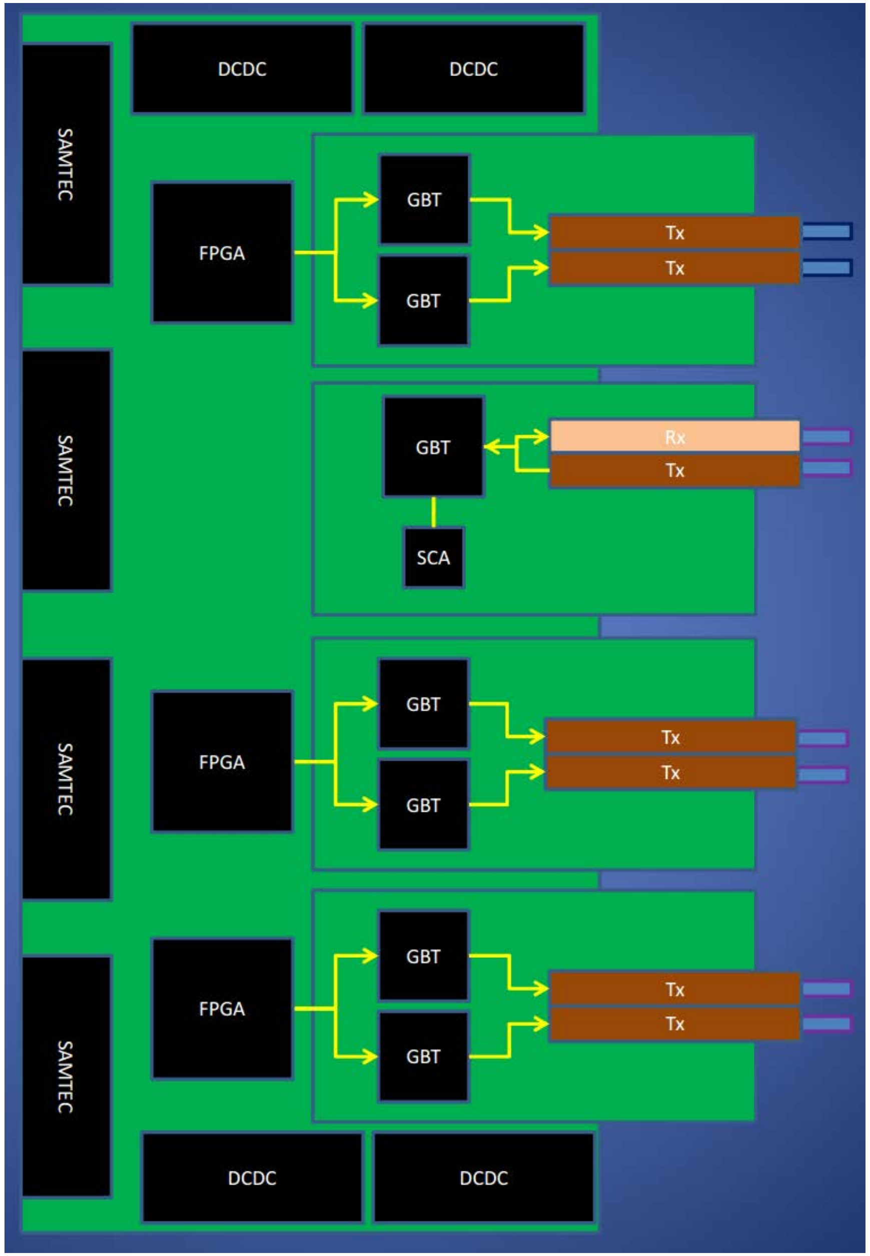
Digital Readout
- VTX/GBTx
- FPGAs
- DC-DC converters

Elementary Cells:
- MaPMTs
- HV divider
- Frontend electronics

Sink the heat



Modular Digital Board



Staggering boards
FPGA / GBTs

Will complete
the coupling to cool
element.

Heat Power

Low Voltage:

- 3.5 V, single voltage.
- ~8.5 A per Digital Board (for Elementary Cell 1").
- Maraton rated 40 A per channel currently.
- 36 channels RICH1
  - 1": 12* DBs per column x 11 columns x 2 sides ⇒ 2 kA.
- 48 channels RICH2
  - 1": 4 DBs per column x 12 columns x 2 sides ⇒ 0.8 kA.
  - 2": 4 DBs per column x 12 columns x 2 sides ⇒ 0.8 kA.

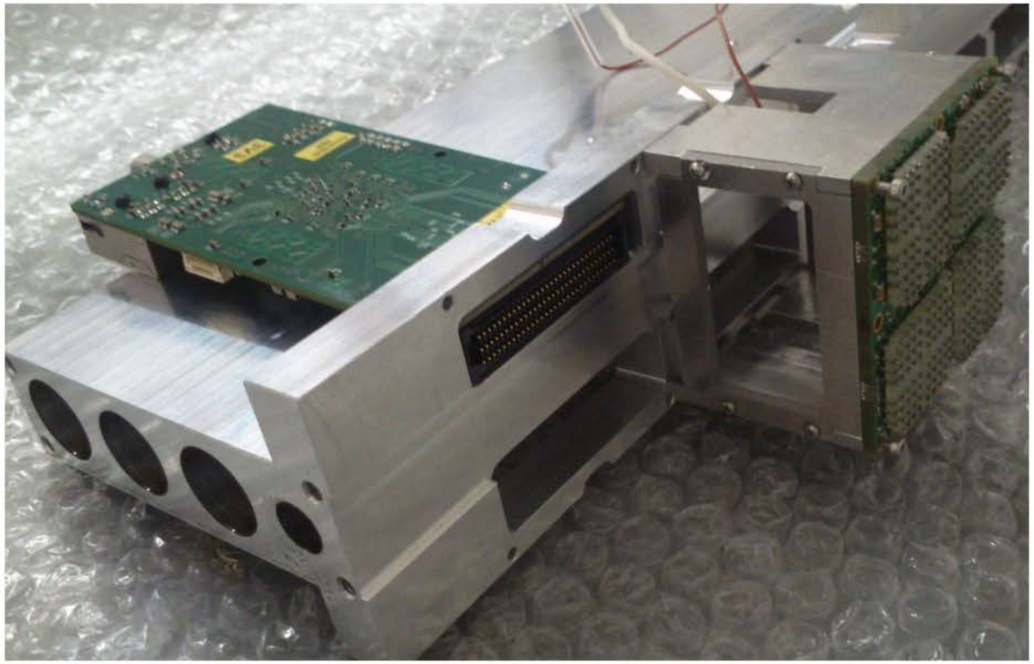
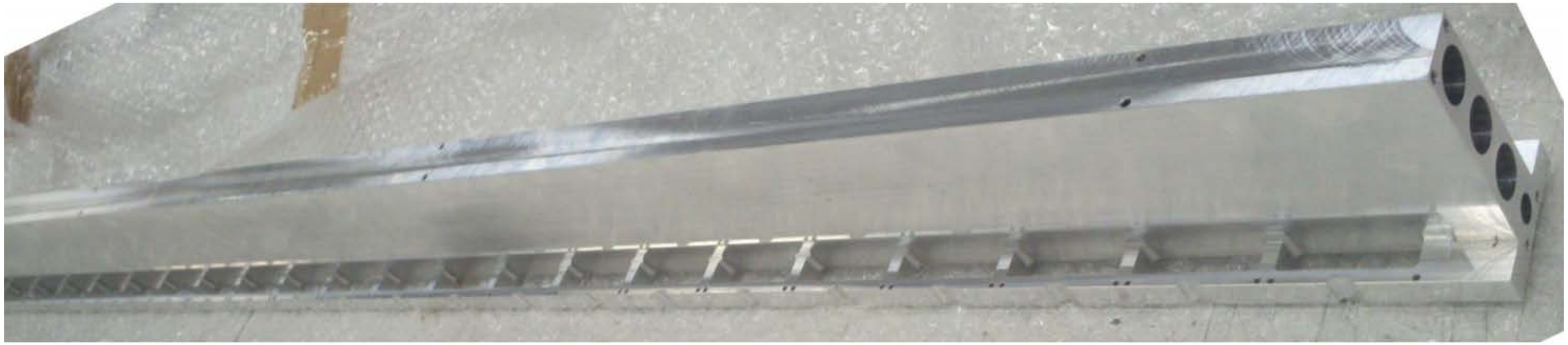
High Voltage:

- 1 kV.
- RICH1: ~160 W.
- RICH2: ~100 W.

RICH1 Power: ~8.2 kW
RICH2 Power: ~5.4 kW

} ~14 kW

Machining of cold bar

Machining of prototype:

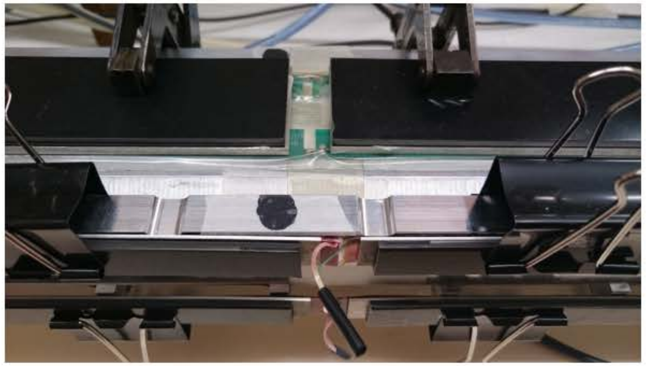
- Deep hole feasibility (1.4 m).
- Precisions.
- Test cooling performance.

Test Cooling

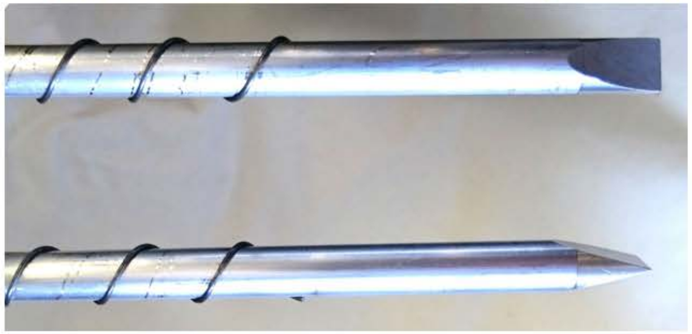
Heating elements

Cold Bar

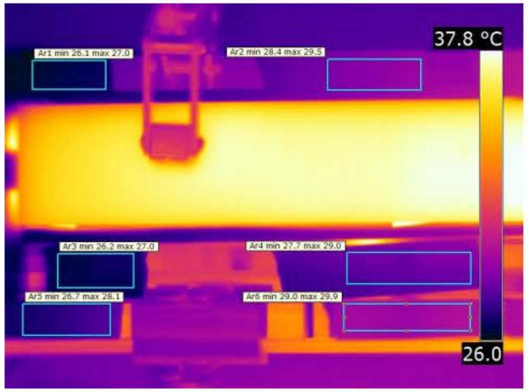
water



Inserts to leave 1mm thick circular ring for coolant

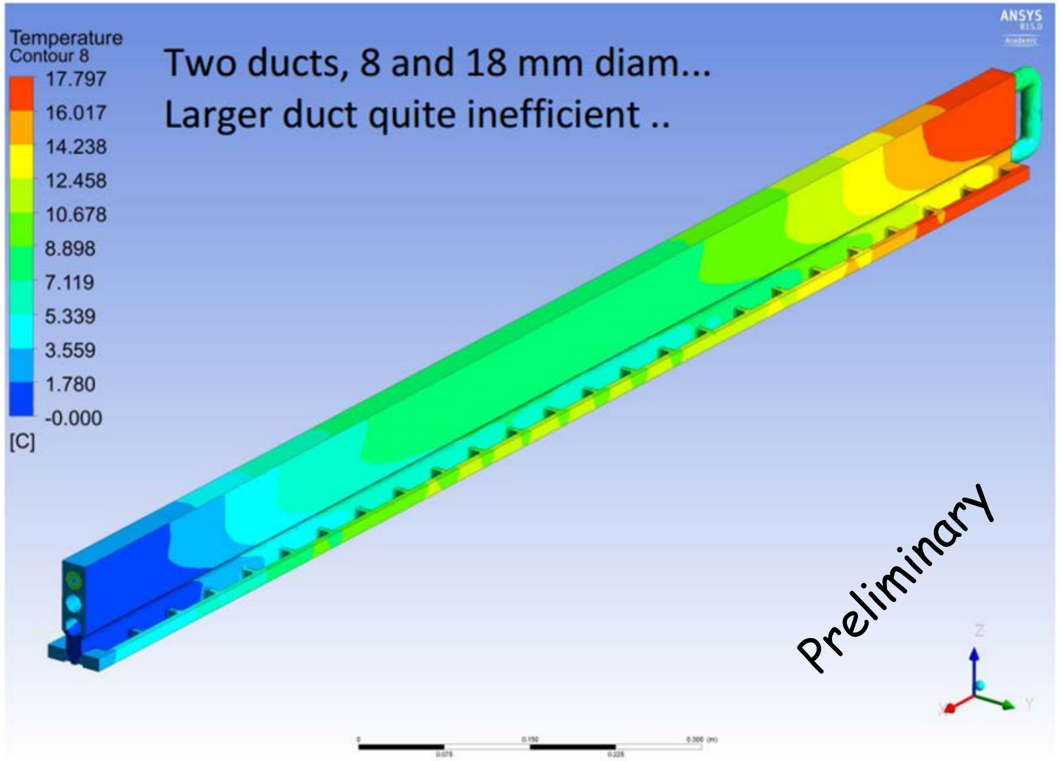


To get turbulent conditions into the duct

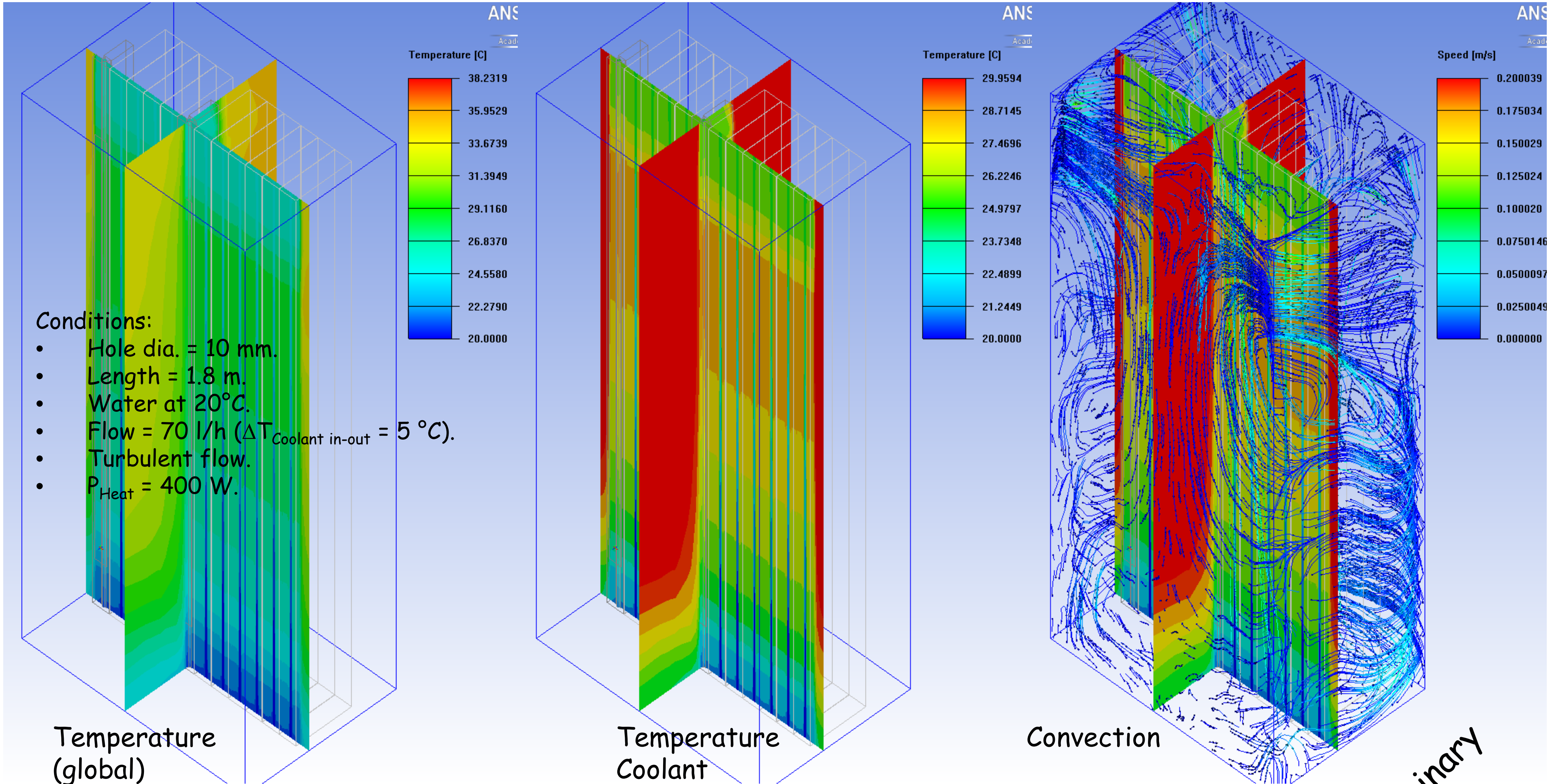


Simulations

Create a CFD correct model
Which matches the prototype



Compare single column to an array



Conditions:

- Hole dia. = 10 mm.
- Length = 1.8 m.
- Water at 20°C.
- Flow = 70 l/h ($\Delta T_{Coolant\ in\text{-}out}$ = 5 °C).
- Turbulent flow.
- P_{Heat} = 400 W.

Preliminary

If possible..
simulate a full assembly (simplified)
including convection effect.

A perfect Coolant

- Non-flammability.
- Inertness.
- High specific heat.
- Not too low boiling point.
- High electrical resistivity.
- Radiation resistance.
- Low viscosity.
- Environment friendly.

Coolant - HFE vs C6F14

- GWP (1 / 300): 3M Novec 649 or 7100 is much better.
- 649 less compatible with water (e.g. leak+condensation)!
  ⇒ Perfluoropropionic acid (PFPA). (can be down to pH=3..1);
- 7100 less critical with water.

- Cooling plant: needs upgrade of the desiccant filters (alumina, zeolytes ⇒ silicagel, metal sulfites).
- Moisture and acidity have to be monitored.
- Material compatibility:
  - Poor material compatibility tests (plastics, PCB).
  - Safe: stainless steel, titanium, copper.
  - Corrode: nickel-plated brass.
- Cost ⇒ same.

Coolant – HFE Radiation issue

- No experience yet.
  - Expected < C6F14 (C-C bond: ~4 eV vs. ~8 eV in C6F14).
  - Test has started (up to 100 kGy).
- Radiolysis (dissociation of the molecules under radiation), at elevated doses:
  - Change in viscosity
  - Loss of dielectric strength
  - Polymerization
  - Increase of acidity
  - Single phase cooling is less sensitive to all that.
- Formation of HF (due to water or H-compounds) and CF2O (AL corrosion).
- Conclusion: should be OK!
  ..but it low GWP one could expect also less stable!

[Based on Petr Gorbounov's inputs]

Coolant – Water

- Water: if it leaks: short circuit on electronics + ~corrosive.
  If no leak no point to not use HFE (..or C6F14).
- Leak issue: with the present path (alcove) of the cooling pipe, it cannot be at under pressure into the detector part [TBC].
  (What about adding pumps close to the detector.)
- Need an specific equipment to demineralize the water in-situ.
- Demineralized water is weakly corrosive including on metal, (oxydo-reduction).
  Do not mixed up Al + Cu.
- Good experiences in several detectors.

Coolant - What to conclude?

- C6F14: If we can guaranty no leak ⇒ why not keep it.
  In respect to the past, it might be hard to swear!
- Water: In case of connection failure ⇒ might damage our equipment but..
- HFE: corrosive + radiation aspect look the most critical.
  Main pro (to me): to operate at low temperature.

If it can be demonstrated that HFE (safe option):

- Will not corrode "normal grade mechanical components".
- Cooling plant + maintenance stay at reasonable cost.
- In case of connection failure or micro leaks ⇒ do not damage our electronics + PMs.

Water (simple option)..

- What about having a pump close to the PDA for working at under pressure?

Coolants Characteristics

At room conditions		C6F14	Novec 649 / 7100	Water
Boiling Point	°C at 1 atm	56	49 / 61	100
Pour Point	°C	-90	-108 / -135	n/a.. >0
Molecular Weight	g/mol	338	316 / 250	18
Critical Temperature	°C	176	169 / 195	374
Critical Pressure	MPa	1.83	1.88 / 2.23	22.1
Vapor Pressure	kPa	30	40 / 27	2.3
Heat of Vaporization	kJ/kg	88	88 / 112	2260
Liquid Density	kg/m3	1680	1600 / 1510	1000
Coefficient of Expansion	K^{-1}	0.0016	0.0018 / 0.0018	
Kinematic Viscosity	mm^2/s	0.38	0.4 / 0.38	1
Dynamic Viscosity	Pa s	0.64×10^{-3}	0.64×10^{-3}	1×10^{-3}
Specific Heat	J/kg-K	1100	1103 / 1183	4180
Thermal Conductivity	W/m-K	0.057	0.059 / 0.069	0.6
Surface Tension	mN/m	10	10.8 / 13.6	
Solubility of Water in Fluid	ppm / wt	10	20 / 95	
Dielectric Strength, 0.1" gap	kV	>40	>40 / ~40	poor
Dielectric Constant @ 1kHz	-	1.8	1.8 / 7.4	
Volume Resistivity	Ohm-cm	10^{15}	10^{12} / 10^{8}	poor
Global Warming Potential	GWP	9300	1 / 300	n/a ..0

Requirement for the Cooling

- Maximum temperature of the Photon Detectors (PMTs), photocathode: <35 °C
- Maximum temperature of the electronics components: 50..80 °C.
  (PMT constrain is anyway dominant).
- Coolant temperature, as low as possible but above dew point, T_input: ~10 °C
  Heat transfer along the path ⇒ T_coolant = above dew point.
- Targeting in-out ΔT of the coolant = ~5 °C
  To keep efficient heat convection (if any).

End

General Requirements

	RICH1	RICH2
Fluid	Fluorocarbon, C_6F_{14} liquid mono-phase	Fluorocarbon, C_6F_{14} liquid mono-phase
Nominal Heat Dissipation	~6 [1] kW	~3.6 [1] kW
Number of Loop (= PDA)	2	2
Flow rate /per PDA	~1900 l/h	~1100 l/h
Inlet temperature	< 12 ± 1 °C	< 12 ± 1 °C
Inlet Pressure	4 [1] bars	4 [1] bars
ΔT in the PDA	~5 °C	~5 °C
ΔP in the PDA at nom. flow	< 2 [2] bars	< 0.7 [2] bars
Leak rate	< 0.1 l/day	< 0.1 l/day
Ionizing Radiation n_equ. 1 MeV n/cm^2	~40 krad 6×10^{11}	~4 krad 2×10^{11}

To be updated

[1] Operational margin to be added. With water preferred < atm.
[2] To be investigated.