FLOW RATE ISSUES IN THE ALICE SPD COOLING

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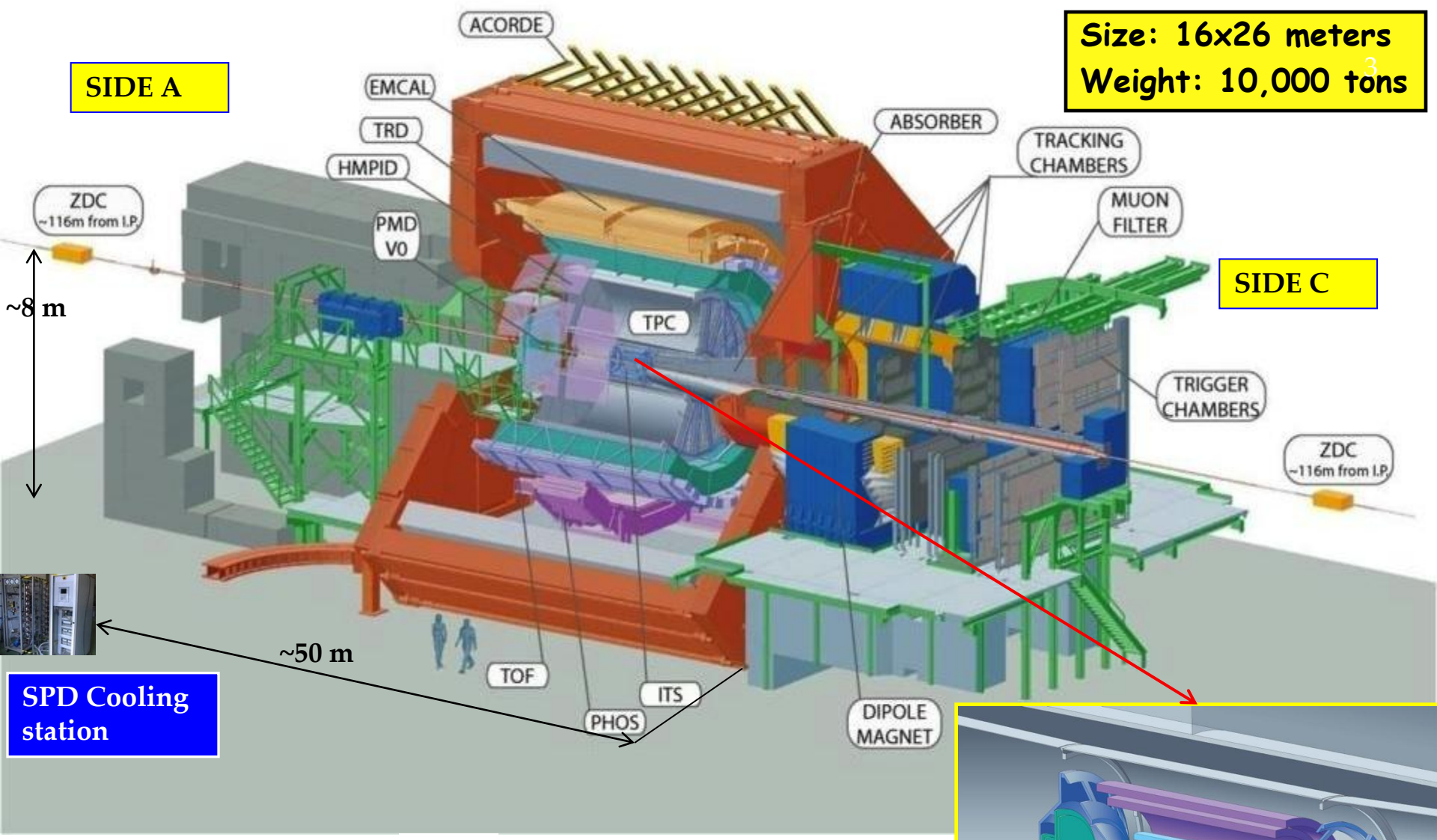
2nd inter-experiment workshop on pixel operational experience

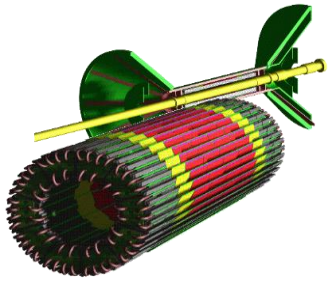
CERN, March 8, 2012

In this talk

- Cooling layout
- Performance history
- Tests
- Main suspect
- Viable solutions
- Results of the interventions

Size: 16x26 meters
Weight: 10,000 tons



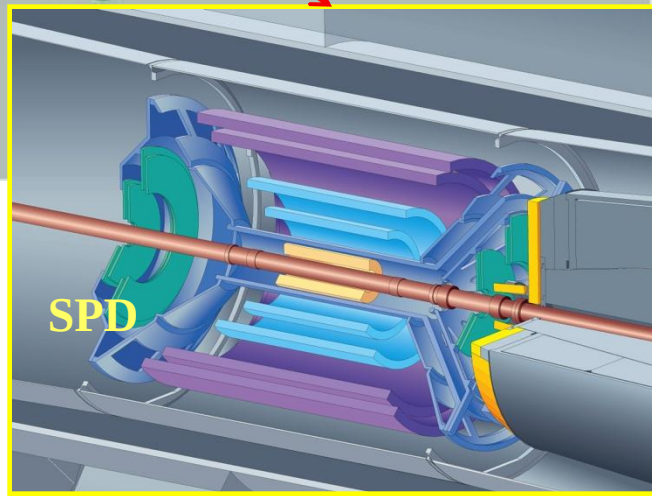


SPD **Silicon Pixel Detector**

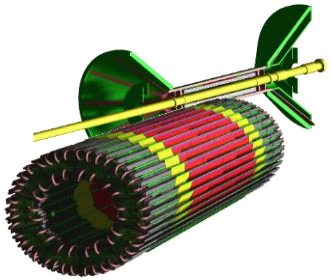
R_i = 39.3mm

R_o = 73.6mm

L = 282mm

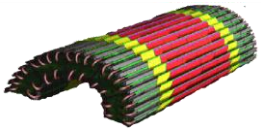


SPD structure

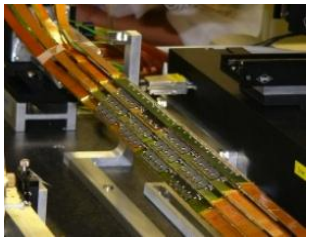


SPD → 2 half-barrels

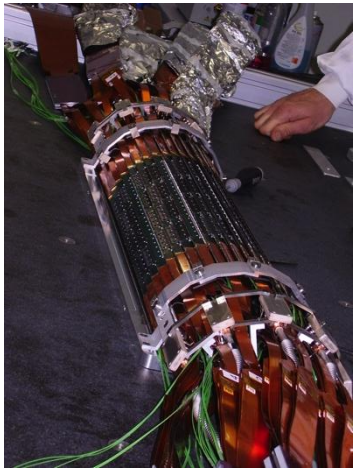
Totale:120 half-staves
1200 ASIC
9.83 M channels
half-stave= basic working unit

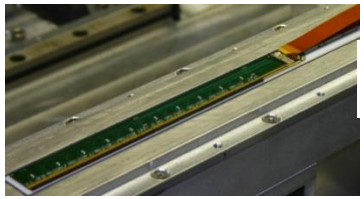


Half-barrel → 5 sectors

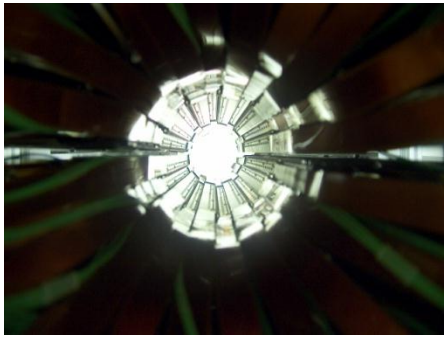


Sector → 12 half-staves





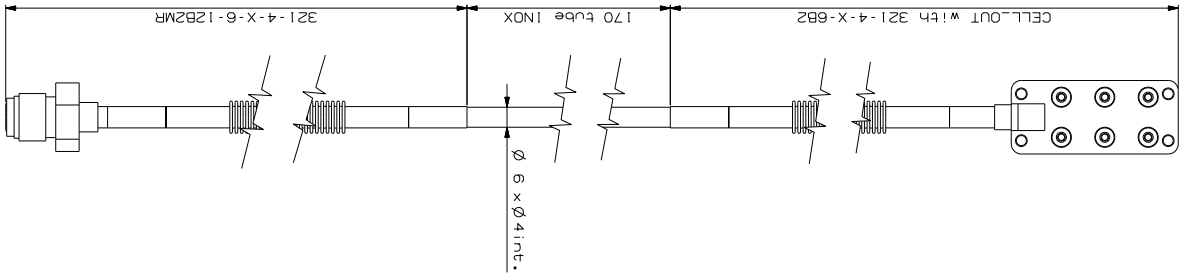
Half-stave → 1 multilayer bus
Half-stave → 1 MCM
Half-stave → 2 bump bonded ladders

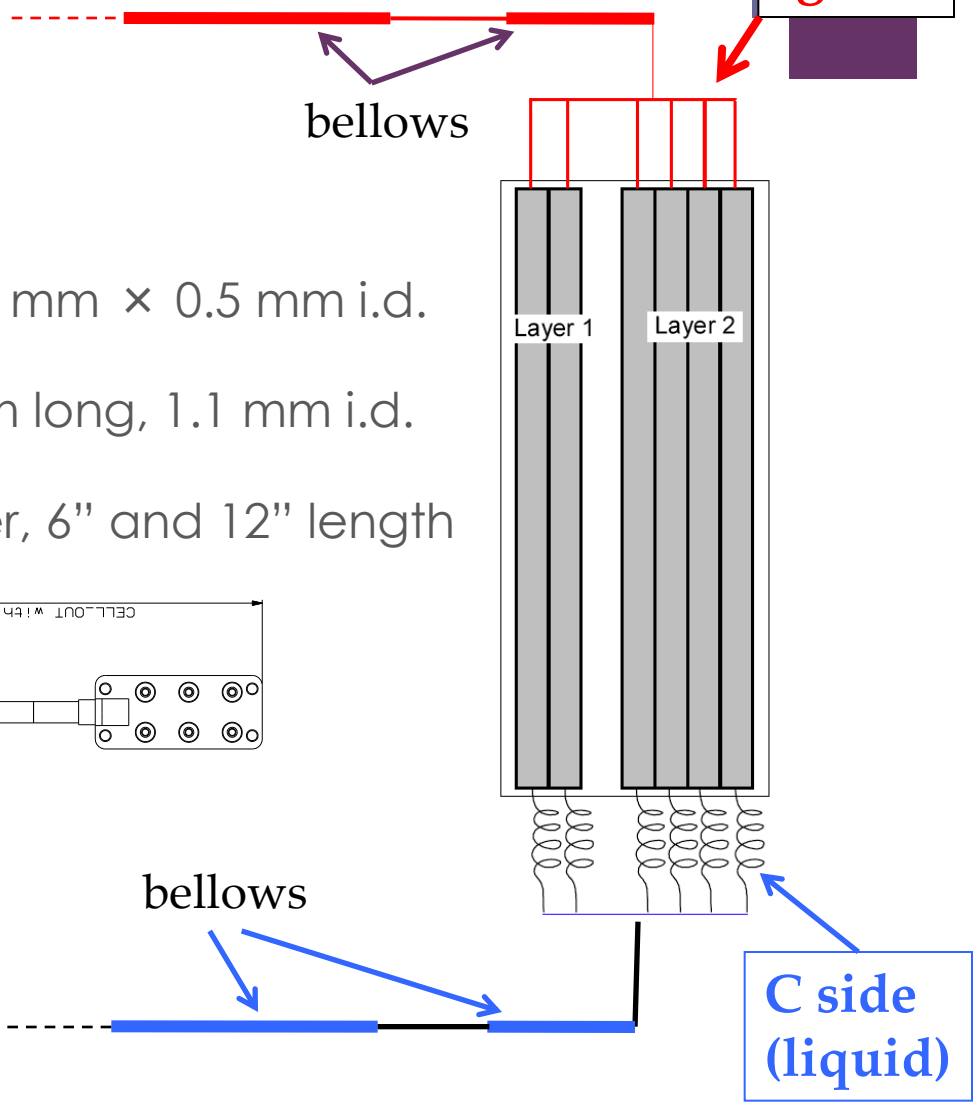


Ladder → 5 read-out chip
Ladder → 1 sensor

Detector's (in)side

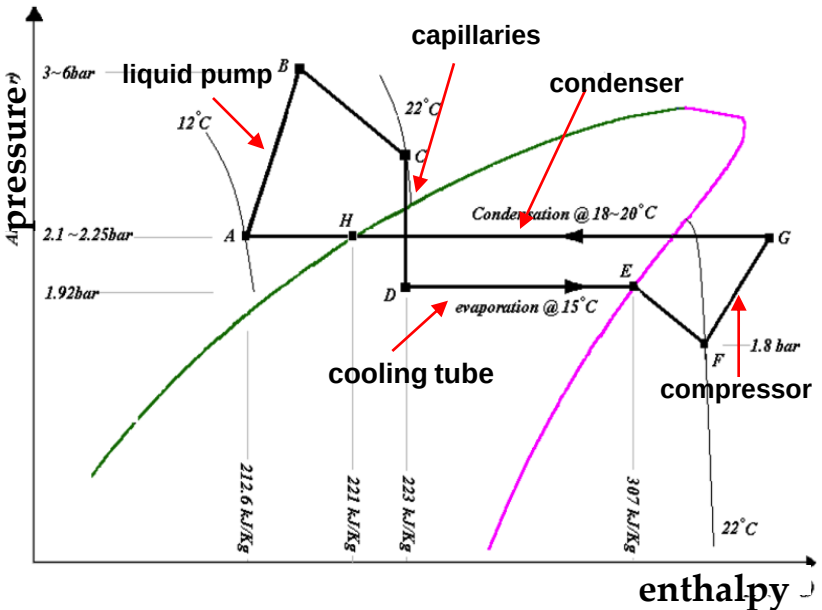
- 1sector = 1 cooling line
- 1 cooling line feeds 6 *staves*
- input: collector box, 6 capillaries 550 mm × 0.5 mm i.d.
- output: collector box, 6 pipes ~10 cm long, 1.1 mm i.d.
- 2 bellows in a row, ¼" tube diameter, 6" and 12" length

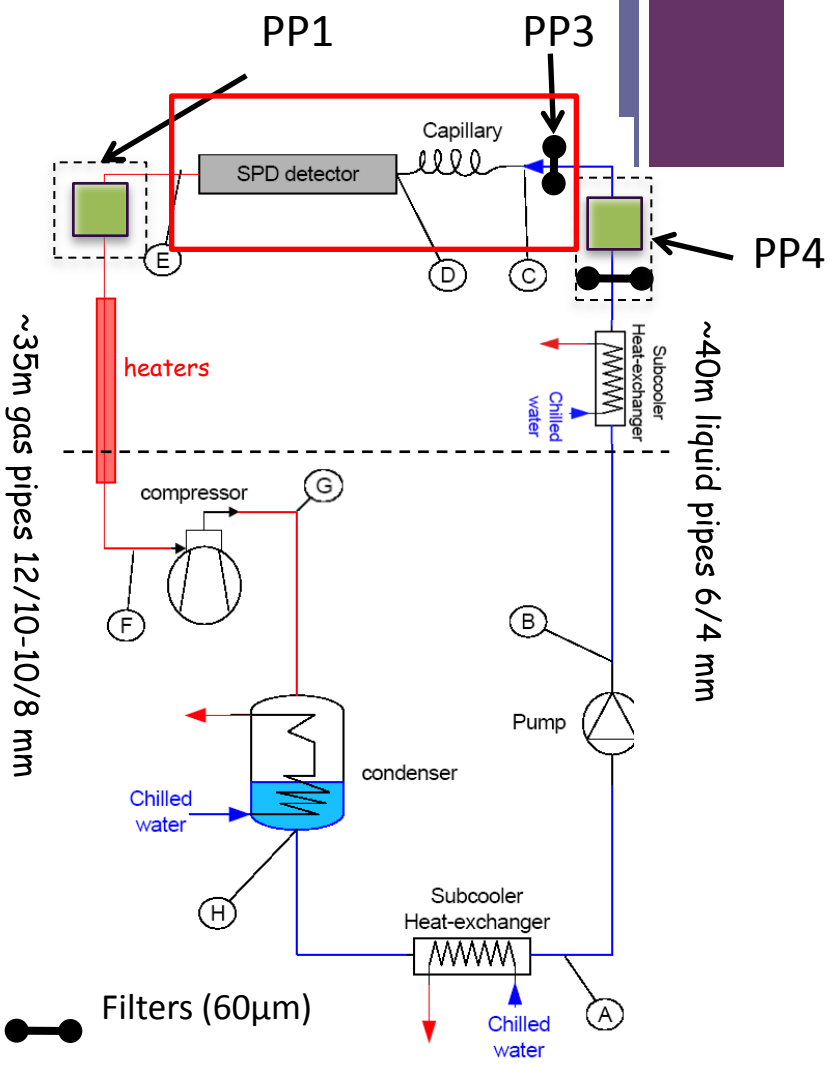




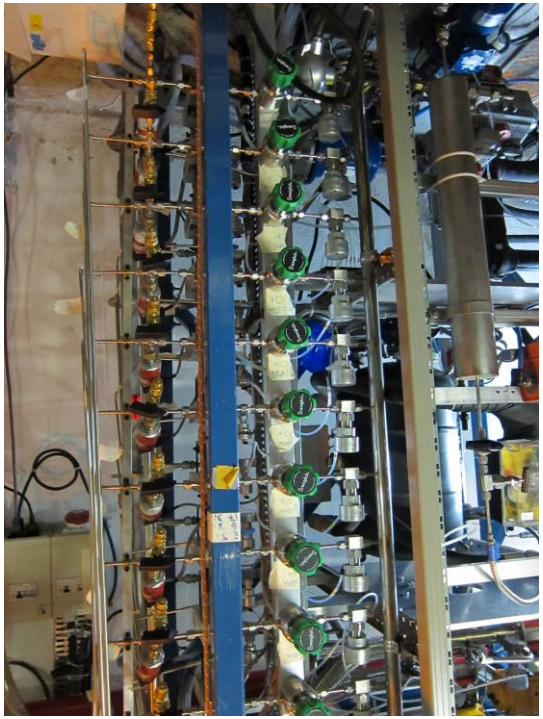
Principle of cooling operation

- Joule-Thomson cycle
  - sudden expansion + evaporation at constant enthalpy
- Fluid C_4F_{10}: dielectric, chemically stable, non-toxic, convenient eos
  - Nominal evaporation: 1.9 bar, 15° C
- PP≡patch panels
  - PP3: close to the detector, not (immediately) accessible, PP4: ~6 m upstream SPD



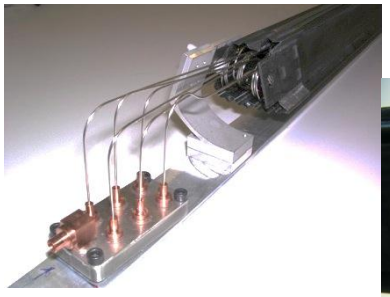


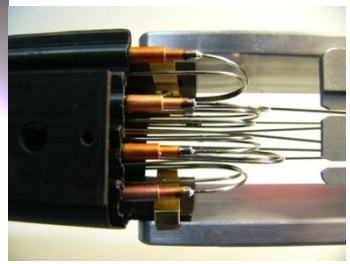
The plant



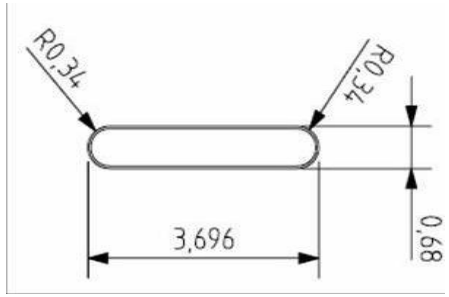
Critical components - 1

- Capillaries
  - used to enter the coexistence phase
  - CuNi, 550 mm long, 0.5 mm i.d.





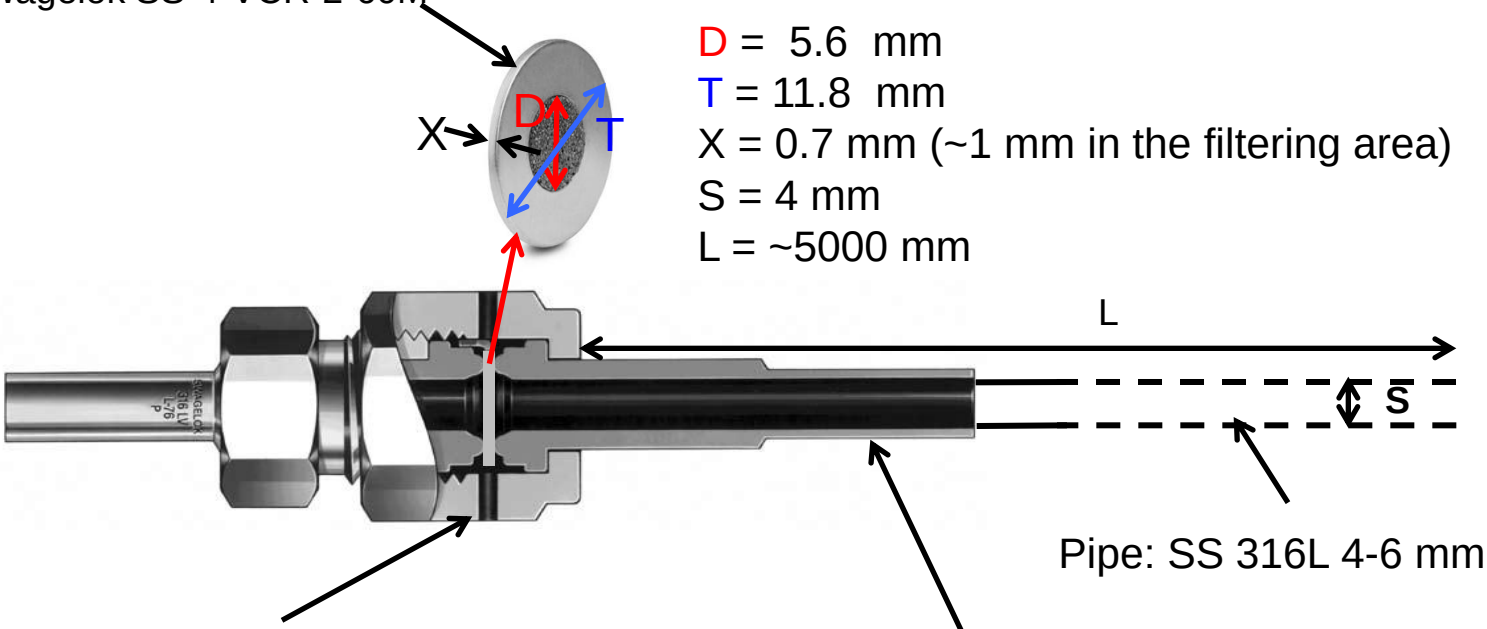
- Cooling pipes
  - where the heat absorption happens
  - Phynox, 40 μm wall
  - round 3 mm pipes squeezed to 0.6 mm inner size



- Both sensitive to pollution!

Critical components - 2

Filter Swagelok SS-4-VCR-2-60M

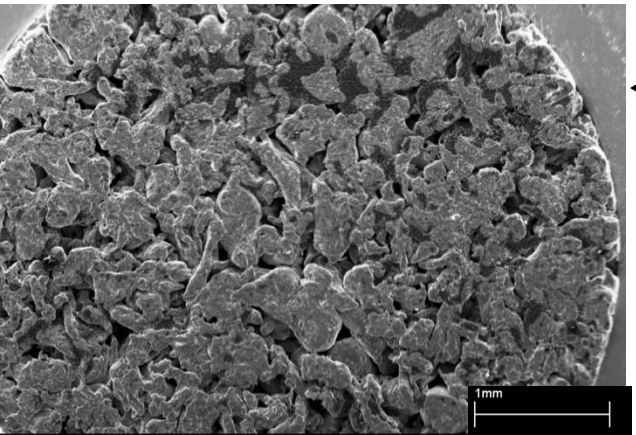


D = 5.6 mm
T = 11.8 mm
X = 0.7 mm (~1 mm in the filtering area)
S = 4 mm
L = ~5000 mm

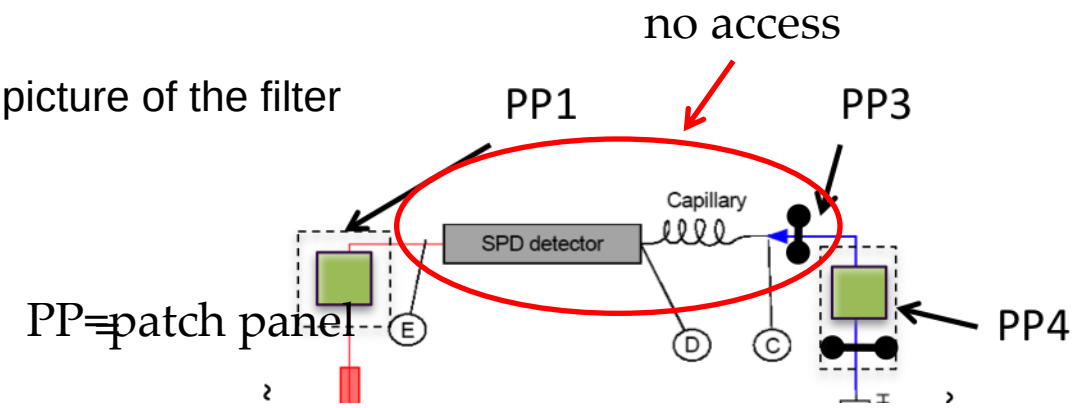
Pipe: SS 316L 4-6 mm i-o diameter

Swagelok 316 SS VCR Face Seal Fitting, 1/4 in.
Female/Male Nut: SS-4-VCR-1 & SS-4-VCR-1

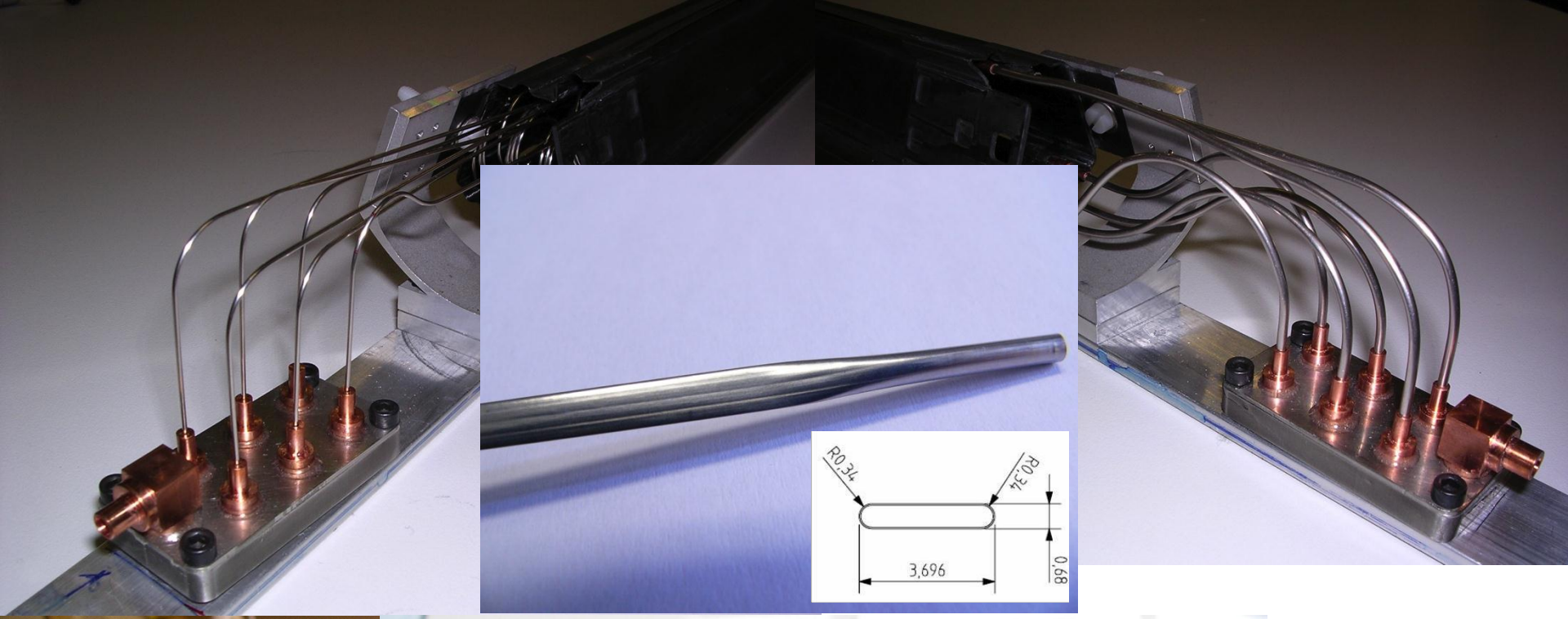
Swagelok gland 6LV-4-VCR-3-6MTB7



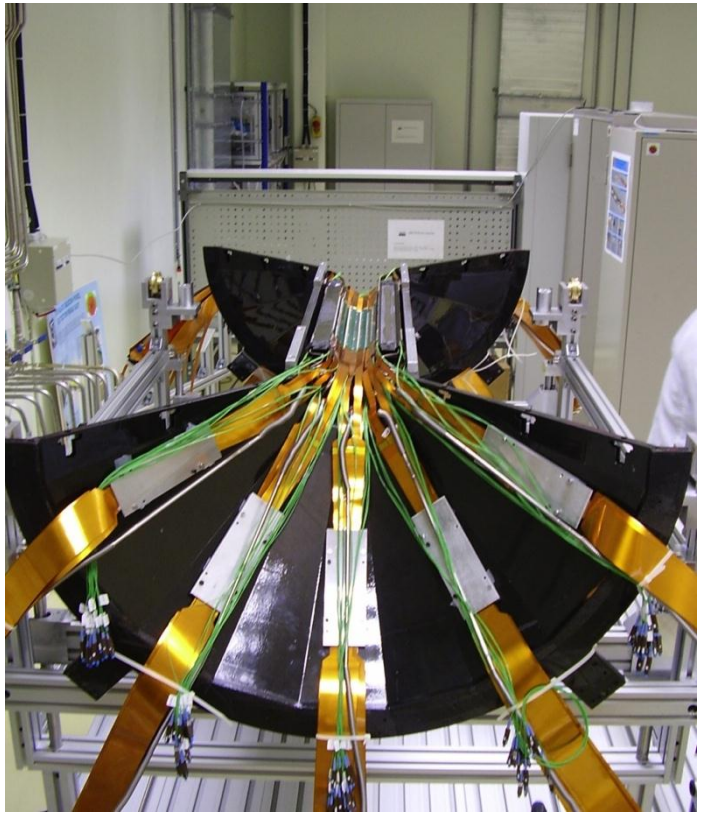
← SEM picture of the filter



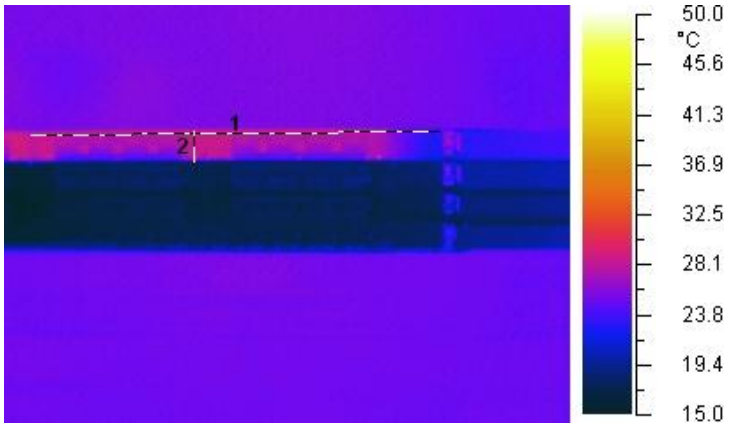
PP=patch panel

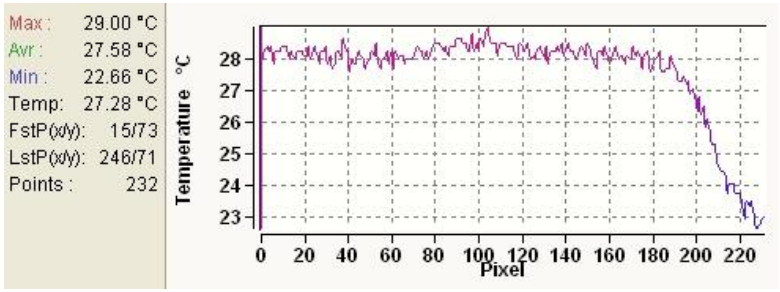

R0,34
R0,34
3,696
0,89

Test in the lab

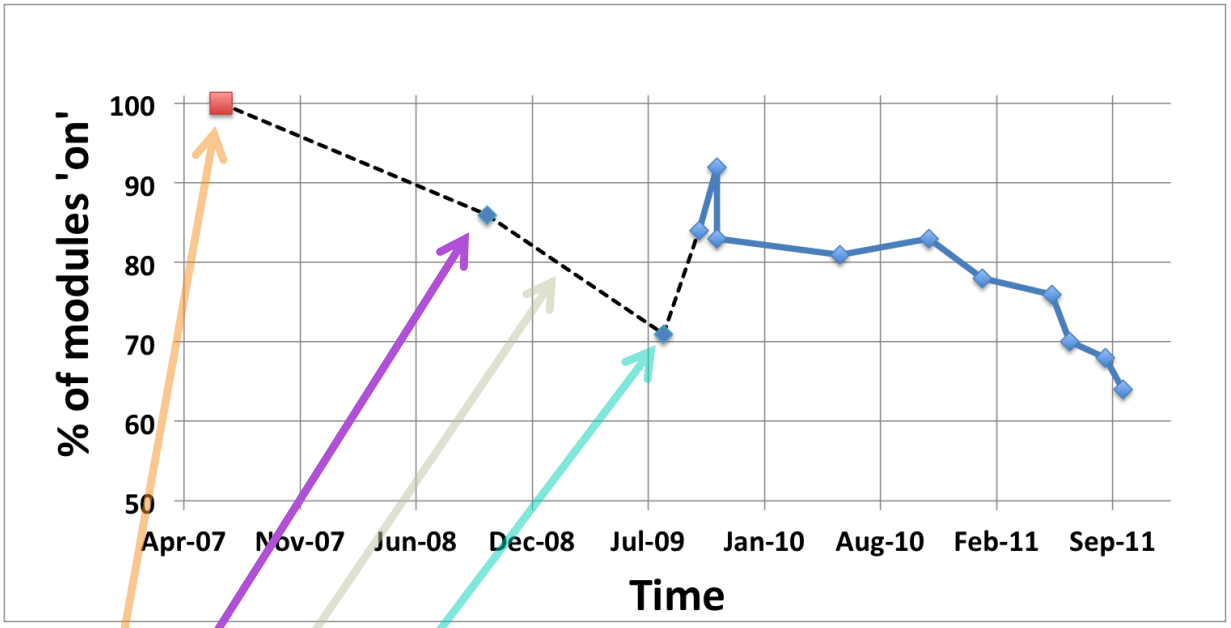


- For ~ 3 years the system has been tested in the DSF at CERN
- In the lab, filters where missing (60 μm in line and the final 2μm filter on the plant)
- very stable against changes in parameters settings (1-2 sectors at a time)
- **100%** efficiency
  - tested one half barrel at a time
  - full power to the detector (~150 W/sector)





Efficiency history



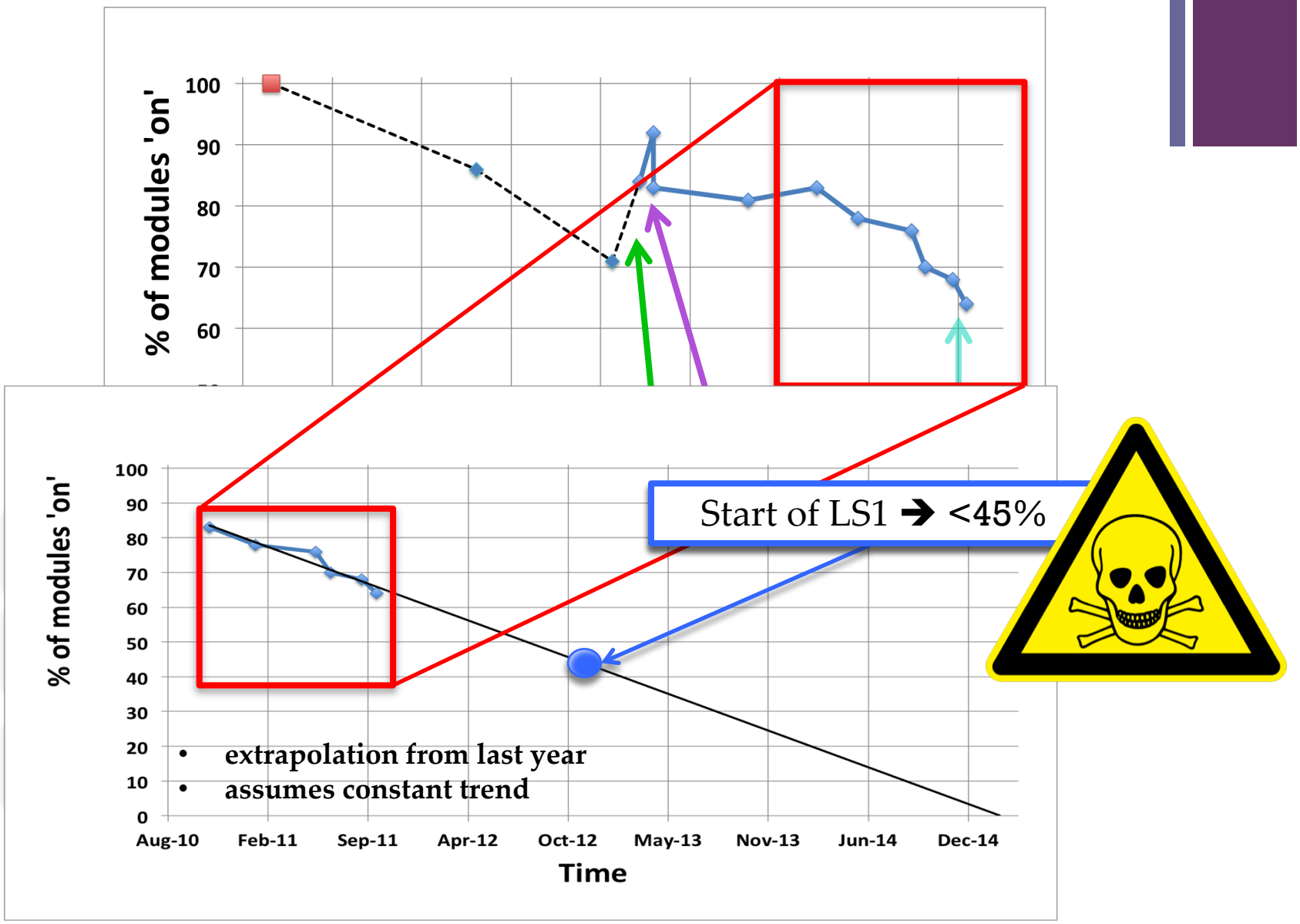
DSF status (tests pre-installation): efficiency = 100%

First switch on after installation: efficiency = 87%

Long stop (you know why…) – minor rerouting of return pipes

Restart after long stop: efficiency = 71%

Efficiency history



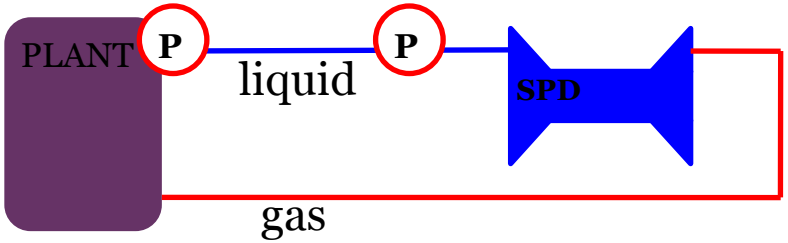
Looking for the ''unsub''

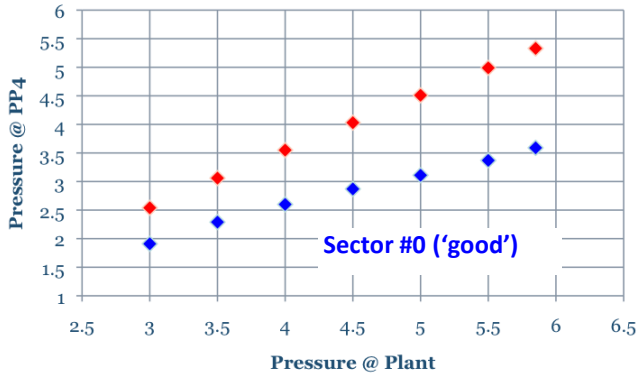
- Pressure increase line by line
  - Check if performance can be recovered by increasing the flow
  - **The flow is enhanced by the pressure increase**
- Lines swapping
  - Could be something related to the lines' path/conditions
  - **Some dependence is found – replaced lines with symmetric and shorter path**
- Lines insulation
  - Heating up the fluid can cause early bubbling
  - **Impossible to insulate the lines – too much surface w.r.t. the volume**
- SEM analysis of 'first-stage' filters
  - Clogging material in the lines?
  - **Keystone test…see later**
- ''Ice age'' test
  - Further subcooling to avoid early evaporation: 8 m of pipe in a bucket filled with ice (thanks Restaurant #1) in PP4 (~6 m before the detector)
  - **Two lines tested, flow increased, 6-7 hs/sector recovered, in one line +50% of flow**

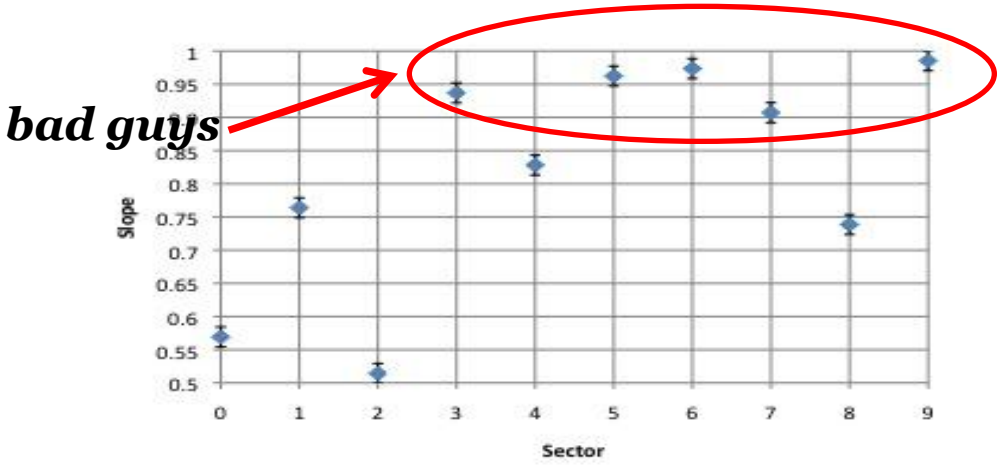
Pressure correlations

- Principle: look at the correlation (slope) between the pressure set at the plant and the pressure close to the detector

Test done in 2009







Observed behaviors:

1. "Good" sectors have a higher pressure drop
2. "Bad" sectors are more "sensitive" to pressure changes ...

SEM analysis

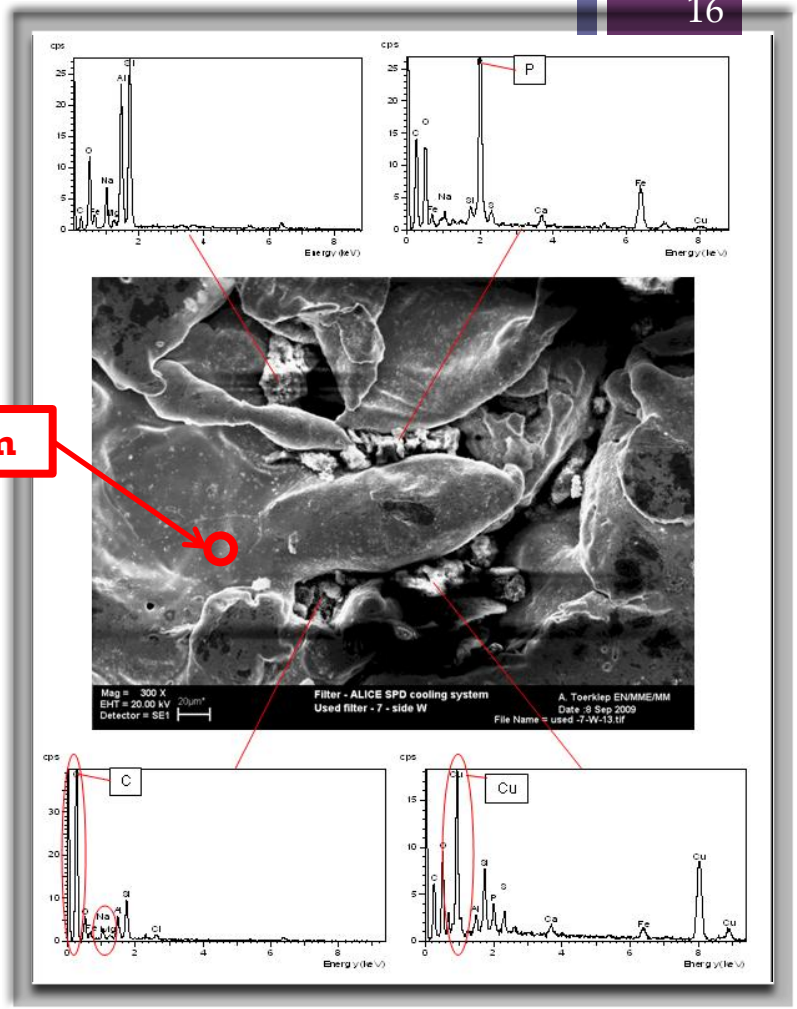
Analysis of a filter taken from PP4, in place for 1 year approx.

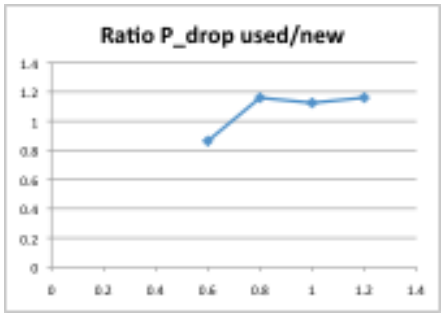
Results and conclusions: "In the used filters several exogenous fragments were located clogging the filter. There were several fragments containing different composition elements. In addition to elements from the Stainless steel, the following traces of elements were found: O, Al, K, C, Sn, Cu, P, Ca, Cu, Na, Cl and Zn."

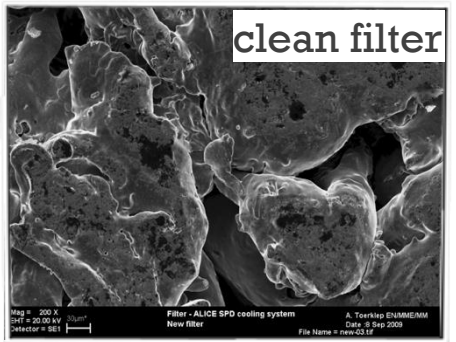
Possible origin of the fragments:

- pumps (graphite)
- hydrofilter (aluminium oxide)
- weldings (TIG weldings remnants)

NB lines: electro-cleaned s.s. pipes (Sandvik), flushed after installation with liquid freon







The picture

- Some pollution went into the lines
- It had to go through molecular sieve/hydrofilter of the plant (2 μm filter was installed after 1 year run)

  and/or

- It had to go through the first 60 μm inline filter and clog (and partly go through) the second inline filter
- The second clogged filter cannot be replaced (have to disassembly the experiment) and causes:
  - less flow
  - pressure drop
- The liquid heats up to room temperature along the path to the detector (~40 meters) – this was not a problem, if alone
- The combination of the last two causes:
  - less flow in the single line ➔ worse performance in the sector
  - bubbling before the capillaries ➔ local and occasional loss of performance

"Upgrades"

1. Installation of a 2μm at the plant (in 2008)
2. Installation of new liquid-side pipes

   dedicated path of new lines, more straight (less elbows), shorter;

   inox SS316L, 6/4 o/i diameter (same as before),

   no insulation (useless)

3. Additional heat exchangers to cool the fluid close to the detector

   10 HX's (one per line), redundat exchange factor (more than 5 times)

   use leakless system with water cooled down at 7.5 ° C

4. Flushing each line counter-flow wise

   drain particles clogging the filters outside the line

   redundant protection against overpressure: 2 safety valves (mechanical) + pressure switch (electronic)

   2 filters, stainless steel, 1 μm grid, on the "washing machine"

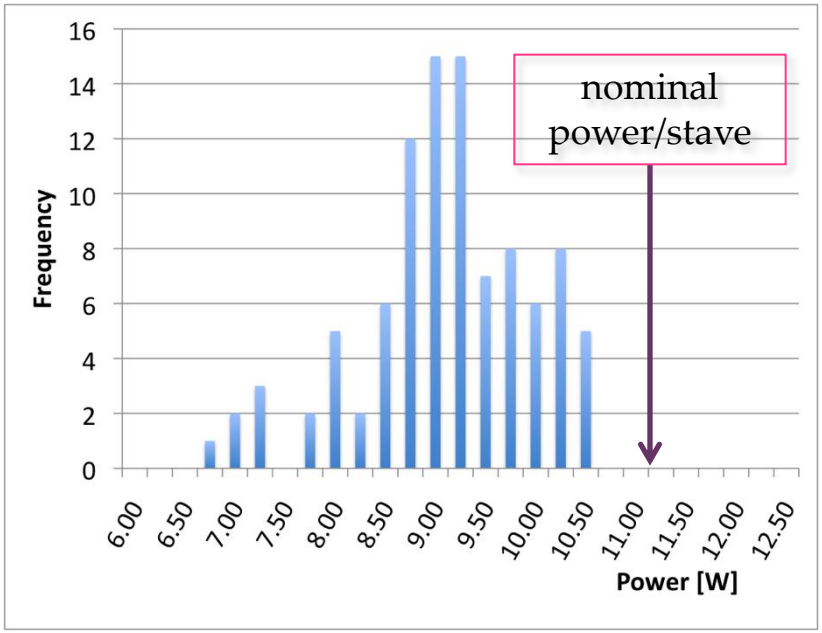
   1 to 4 days washing cycle per each sector

Optimization of power consumption

- From the lab to 'real life':
  - Three main parameters to tune:
    - thresholds
    - charge-preamplifier current
    - reference I-V

  - power consumption
    - reduced by cutting charge-preamplifier current: efficiency is conserved, a couple of "compromises" at low current

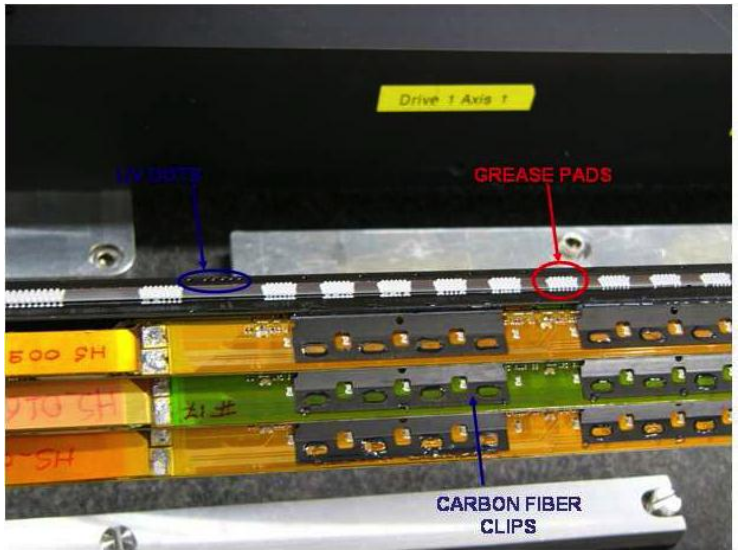
Typical distribution during run

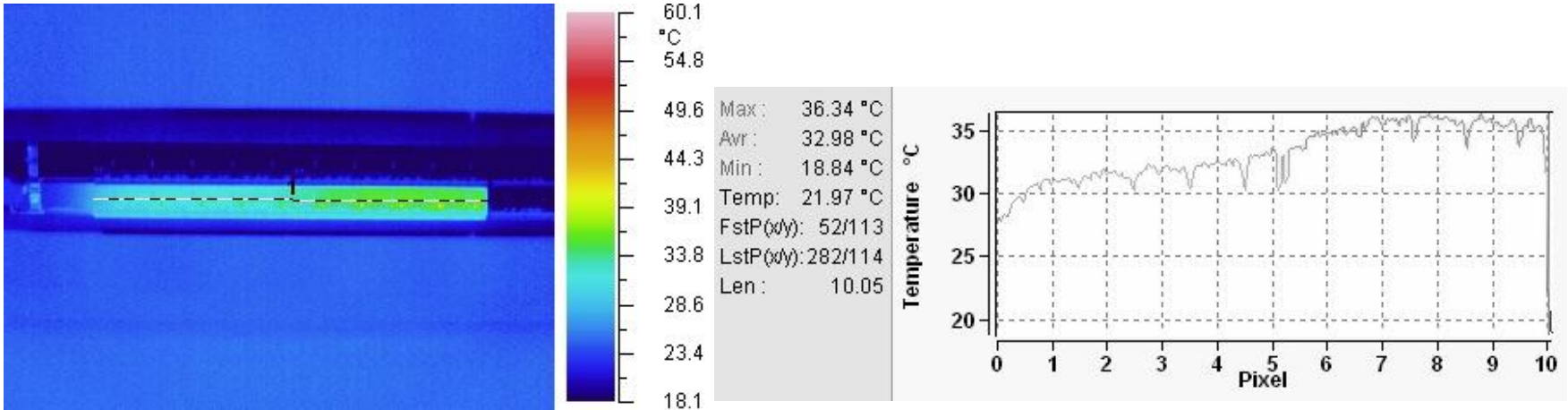


Thermal contact

Could thermal contact be another issue?

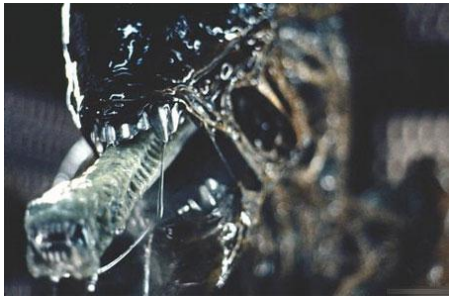
- Performed with AOS 52029 thermal grease
  - real K measured (slightly less than promised)
  - mechanical stress tested
- Long term performance?
- Thermal/mechanical stress?
- It is a minor issue (by now): well cooled sectors do not show a worse performance

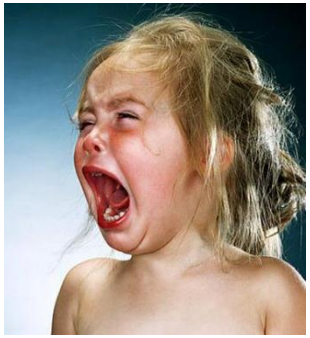




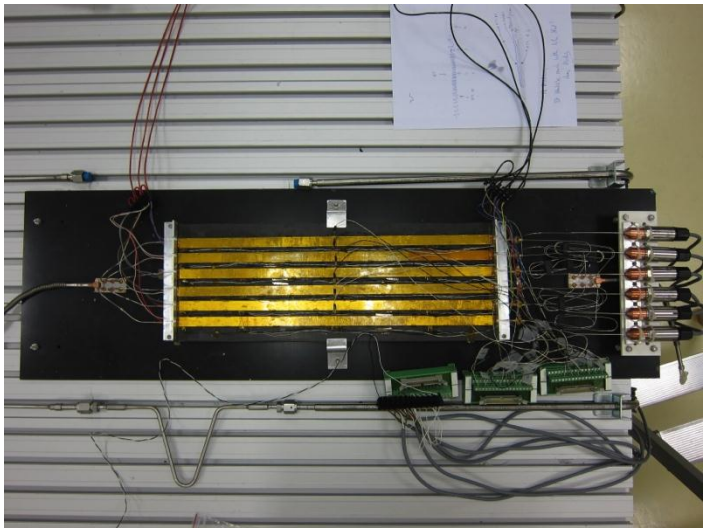
Possible solutions?

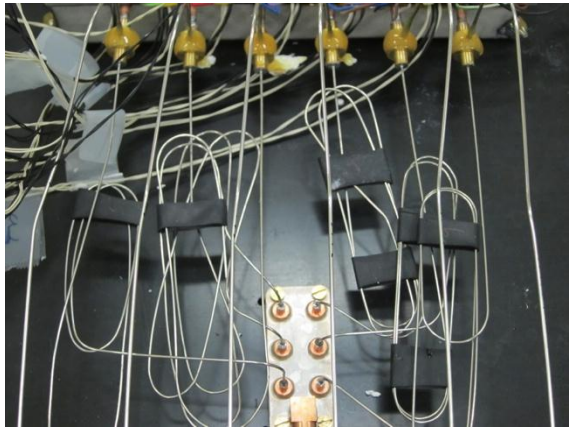
- Essential for any intervention of this kind: first, try in the lab!
  - We build a test bench to reproduce the issue and test any possible of solution
  - We have a spare sector for most critical tests and two dummies (same hydraulics but fake detectors) to play with.
- Be open-minded: solution can come from whatever technology, e.g.





Test bench: plant + dummy





Evidences from the test bench

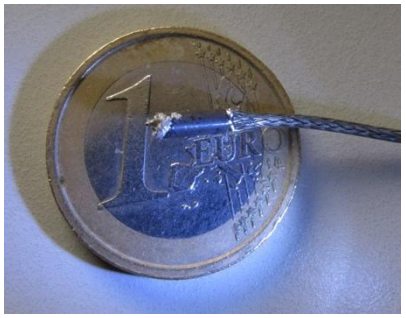
- A test bench has been installed in DSF
  - same fluid and pressure/flow conditions as in the system installed in ALICE
  - plant build by EN/CV/DC, test section by INFN-Padova + CERN-ALICE
- Two lines feed a dummy sector (same hydraulics as real detector, dummy heat load) and a test hydraulics
- Thermal bath and real pipe length (~40 m) to reproduce different liquid input conditions
- Many pressure/temperature pick-up points and transparent pipe sections for visual inspection

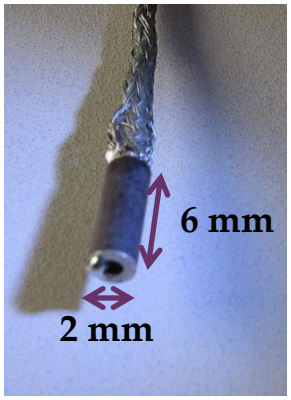
- Loss of flow-rate due to filter clogging
- Local inefficiencies due to impedance non-perfect equalization
- Bubbling in the pipe section before the detector
  - caused by a combination of pressure drop (due to filter clogging) and heating of the fluid (thermal contact with environment and slow translation)

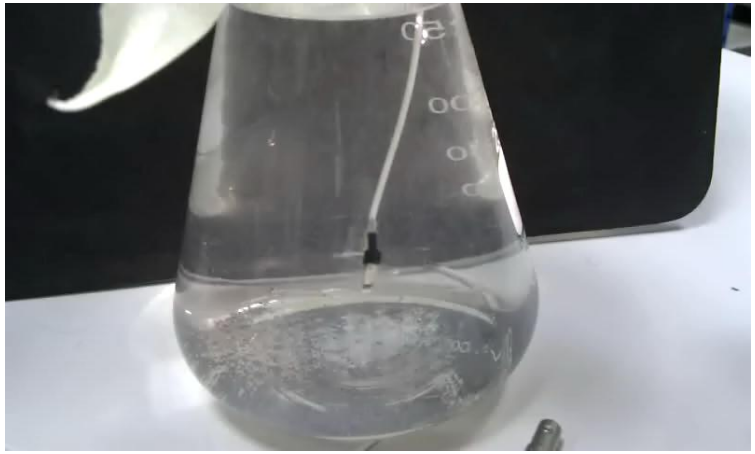
Failed attempts…

- Counterflow flushing with solvents
  - used METKLENE C3 (''SUPERFLUSH'') for ~1 h
  - no clear effect – flow changed <10%

- Generate the ultrasounds close to the filter with piezoceramics:
  - tubes with size 6 × 2.2x1.0 (LxODxID), transversal oscillation, ν_R~3.8 MHz
    Material is PIC 181, a modified lead zirconate-titanate







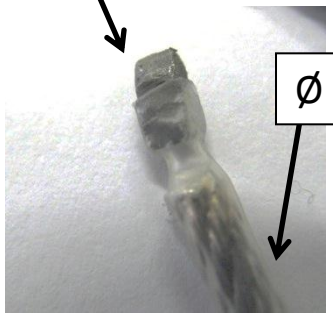
The hard way: drilling

Tools used:

- drilling:
  - tungsten carbide tip welded on twisted ss cable
  - drill to operate the rotation
  - counter-flow at 200 mbar w/manometer to detect the presence of the hole
- cleaning:
  - rilsan pipe connected to a rotary vane vacuum pump
  - magnet tip on twisted ss cable
  - cleaning machine to force counter-flow wise a cleaning fluid

Edwards RV3 rotary vane 2-stage pump

magnet

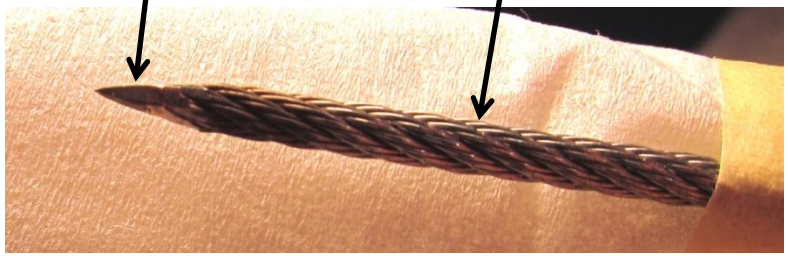


Ø 2.5 mm ss twisted cable

cleaning machine

tungsten carbide 5-faces tip

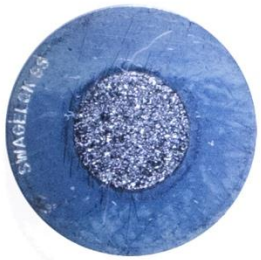
Ø 2.5 mm ss twisted cable

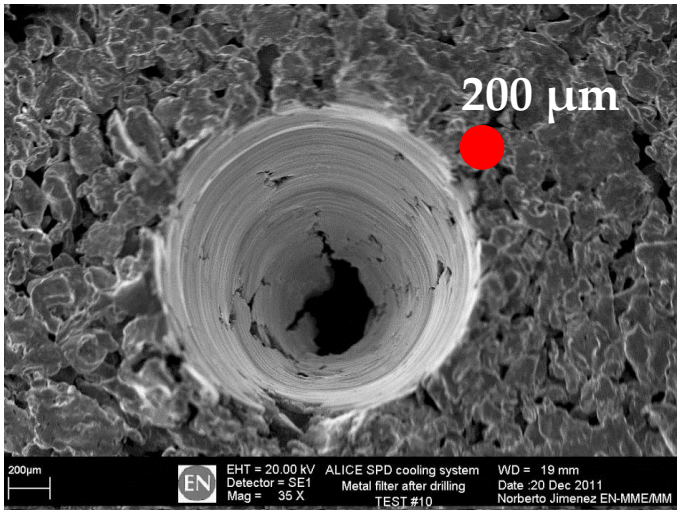


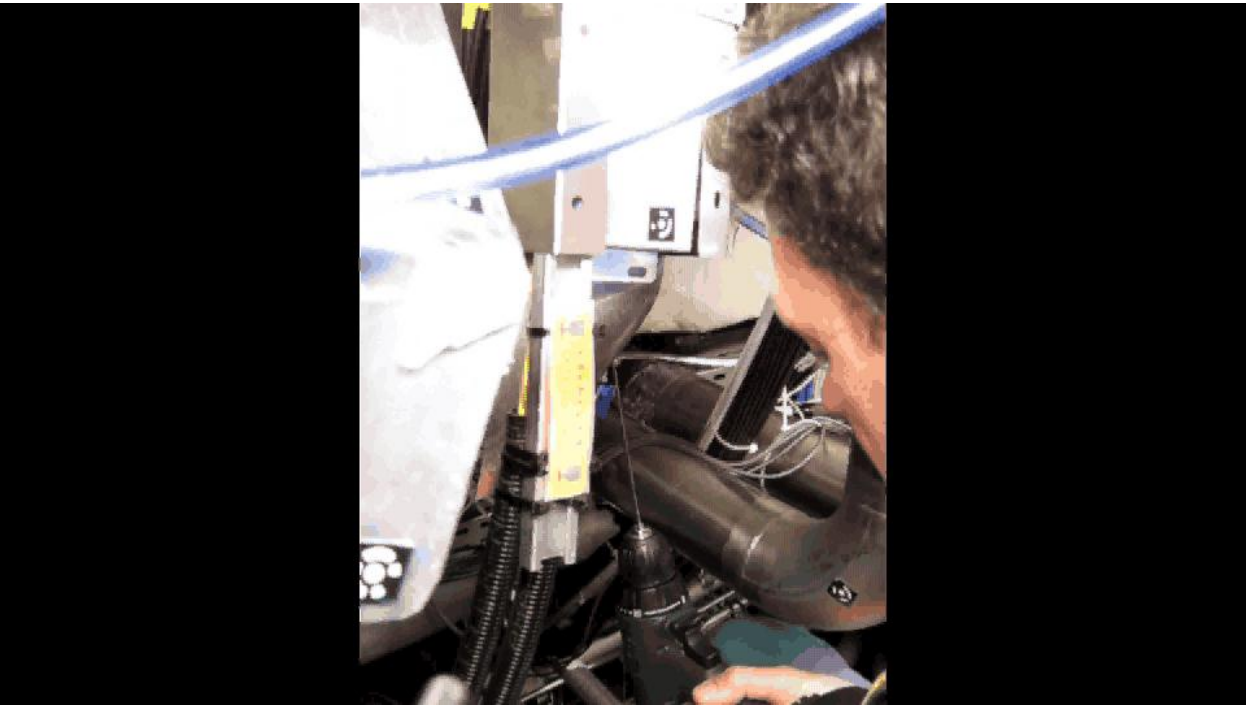
Procedure

- Drilling:
  - rotation of the tool inside the pipe by the drill
  - pressure drop (~20-50 mbar) on a manometer with specific trend when hole done
- Cleaning:
  1. suction of drilling remains with small pipe inside the stainless steel pipe (down to the filter) and vacuum pump
  2. ‘’walk” with magnet inside the pipe
     1. the steel of the filter is slightly magnetic
  3. counter-flow with C_6F_{14} for 30’ @ 1.5 bar
  4. pipe drying with Ar flow @ 1.5 bar
  5. repeat 1-4 4 more times (5 cycles total)
  6. last counter-flow with fluid lasts 12 h

A few pictures…







First application

- First sector treated: #9
- It never worked properly
- First one to be turned on for some time: 12/12/2007, h 15:13, for 41'
- Pre-cleaning:
  - 4 cycles
  - vacuum cleaning + 3 magnet sweeps + vacuum cleaning + counterflow
  - last counterflow left running overnight
  - flow: from 0.27 to 0.46 g/s
- Cleaning: 5 cycles (overnight counterflow between cycle 3 and 4)
- Results:

Was: 0.27 g/s @ 6 bar

Flow= 2.0 g/s @ 4.75 bar

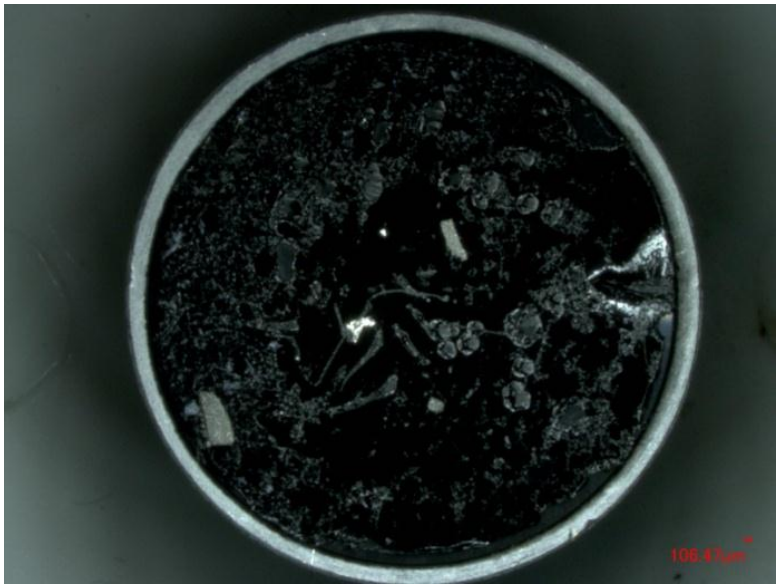
Was: 0%

Modules on= 100%

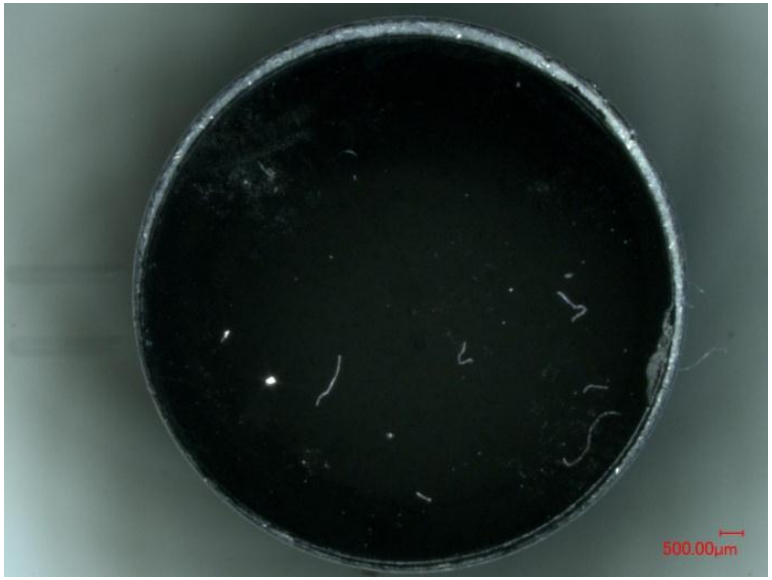
Materials analyses – Optical images

Residuals collected

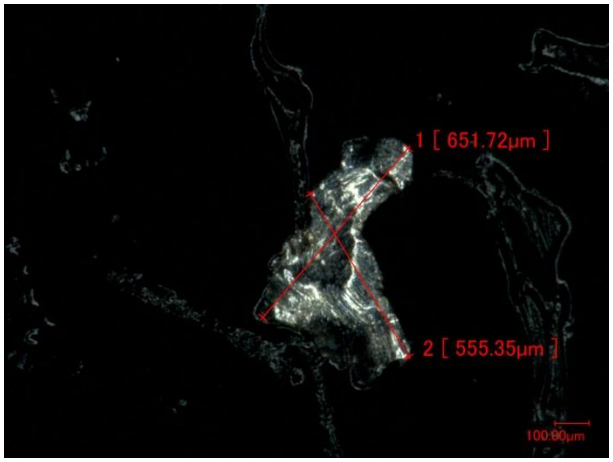
before…

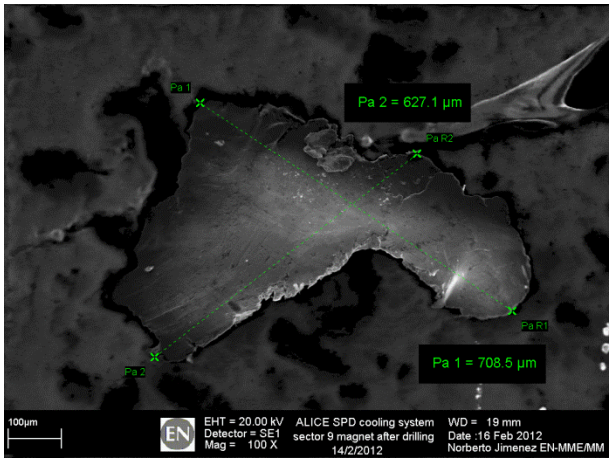


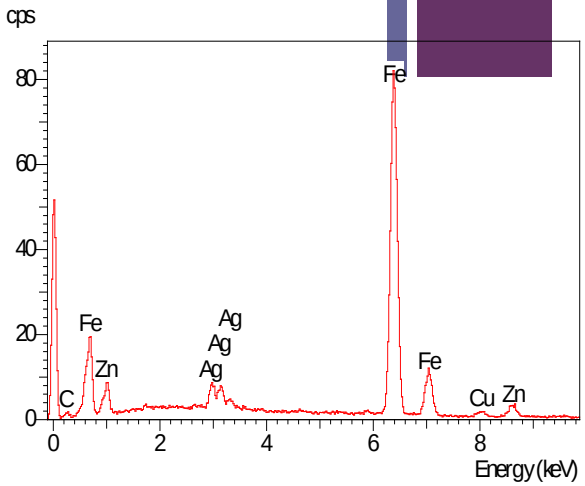
…and after the cleaning!

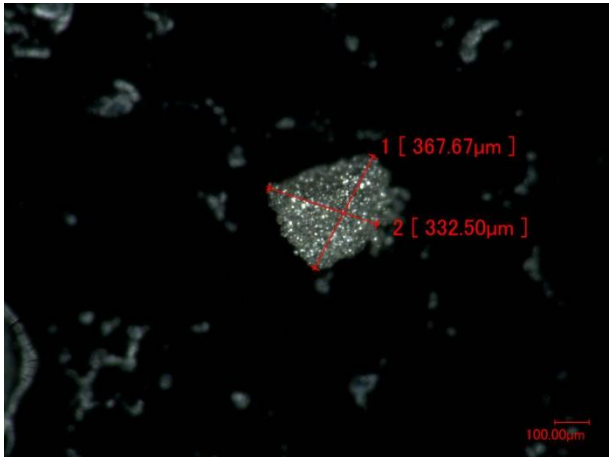


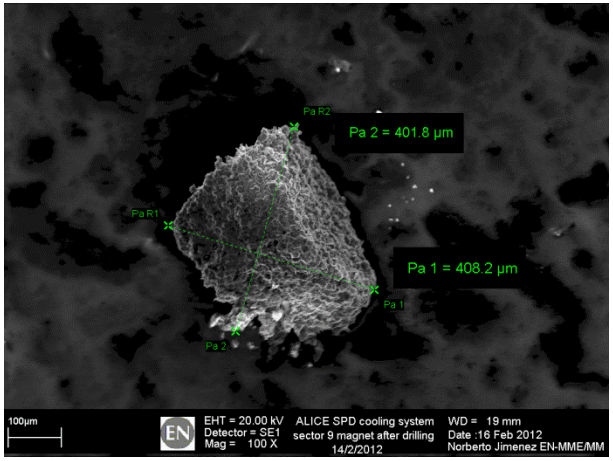
Materials analyses – SEM images 1

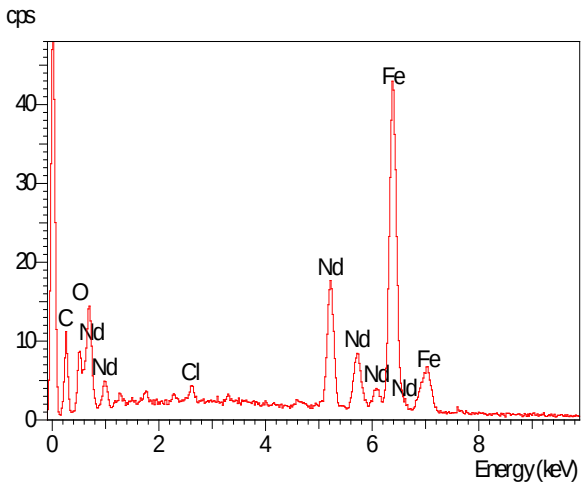




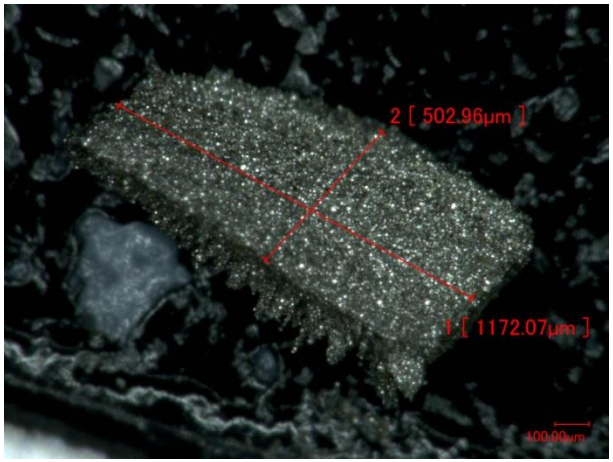


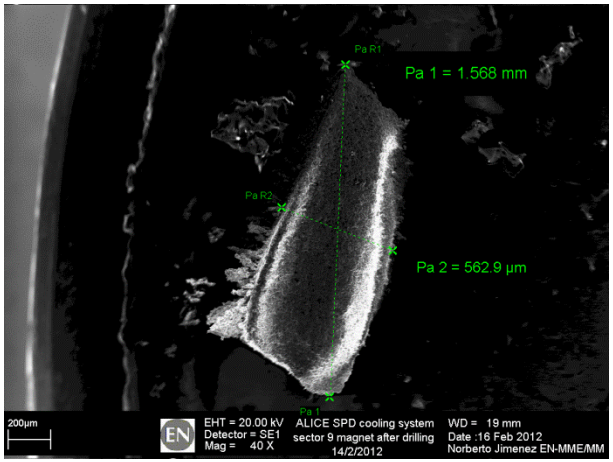


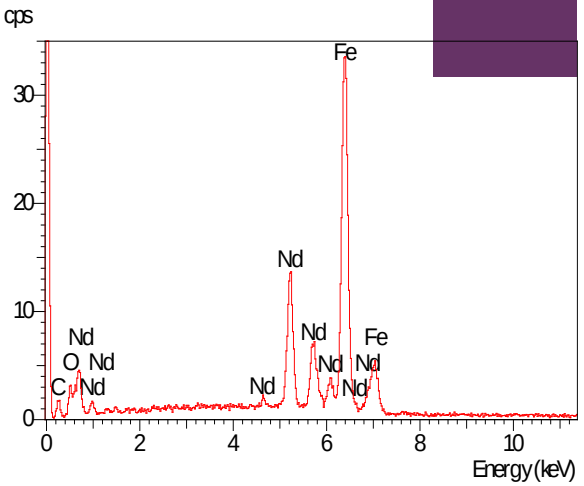


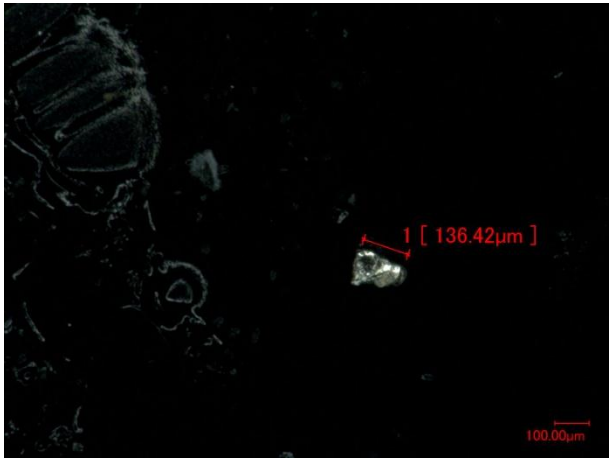


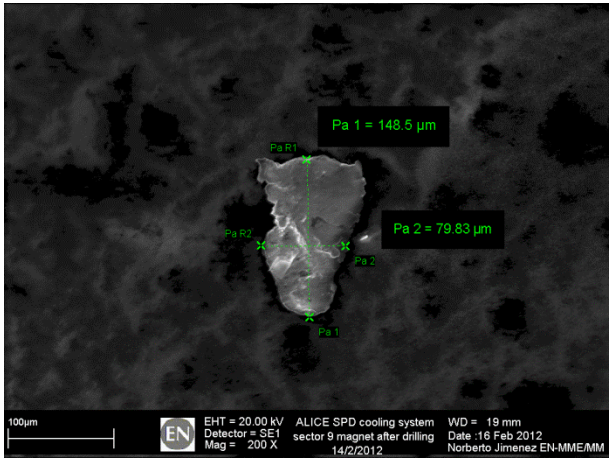
Materials analyses – SEM images 2

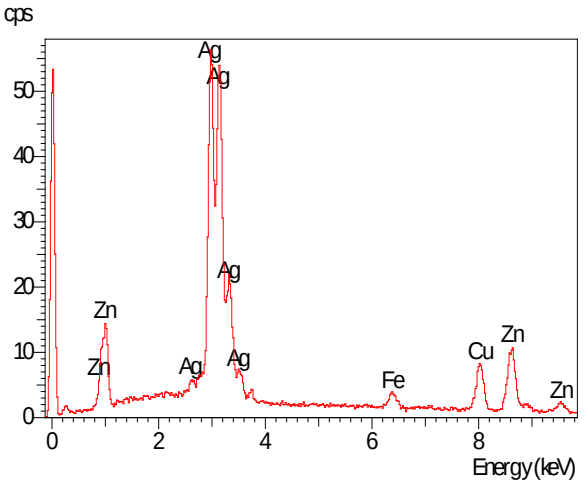








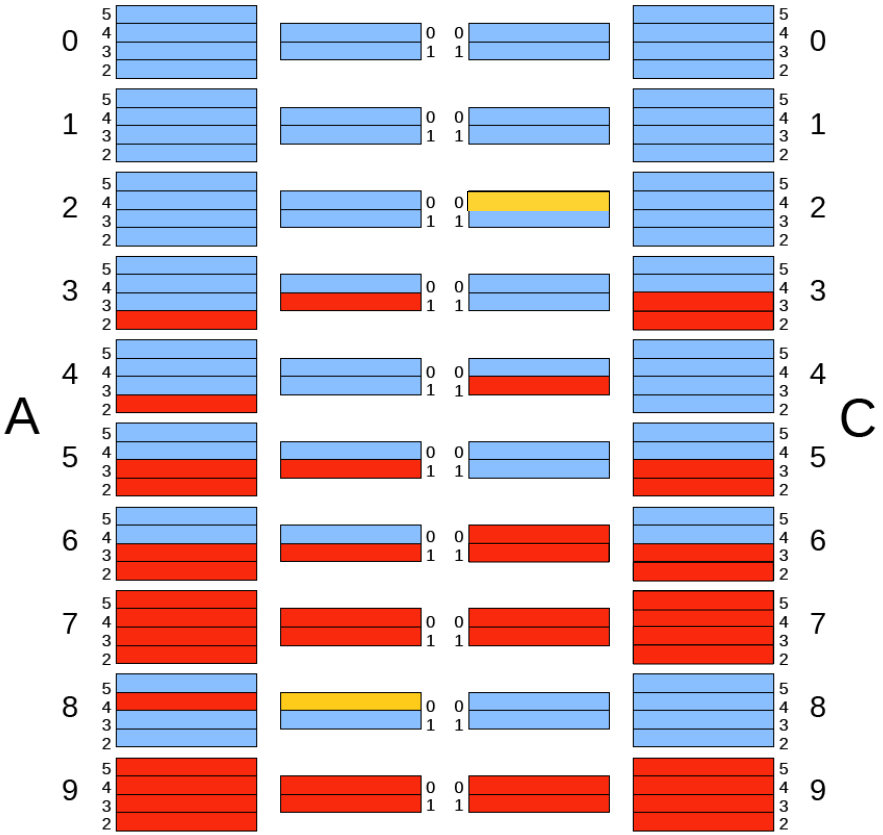




Current performance

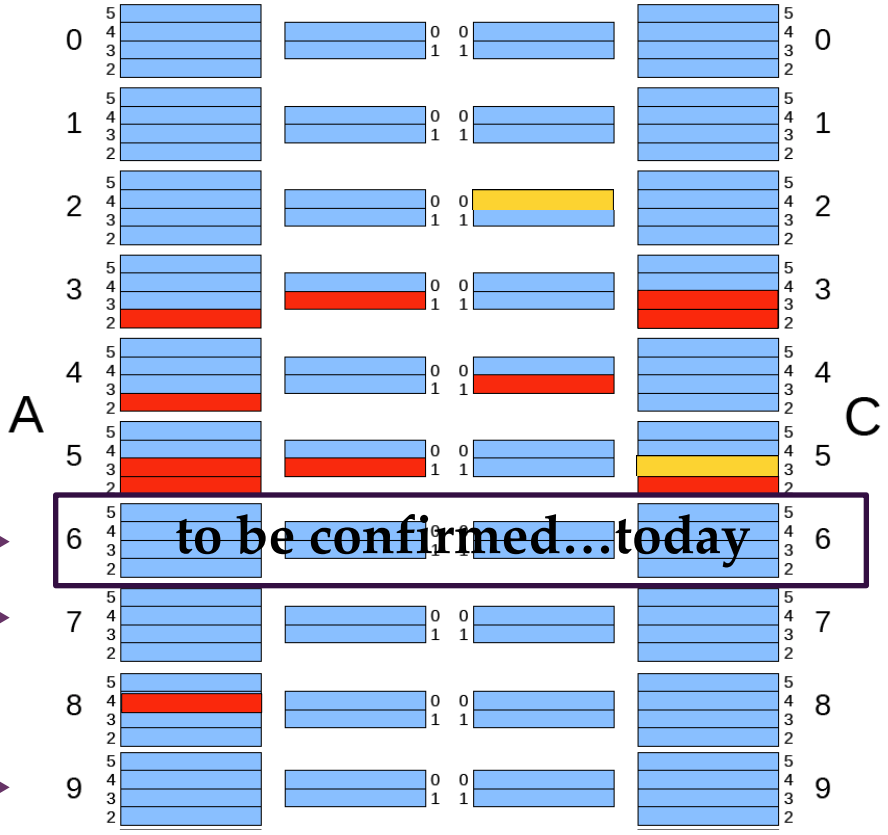
Efficiency changed from this…

62.5% (75/120 on) - Nov, 30 2011



to this! (and more to come!)

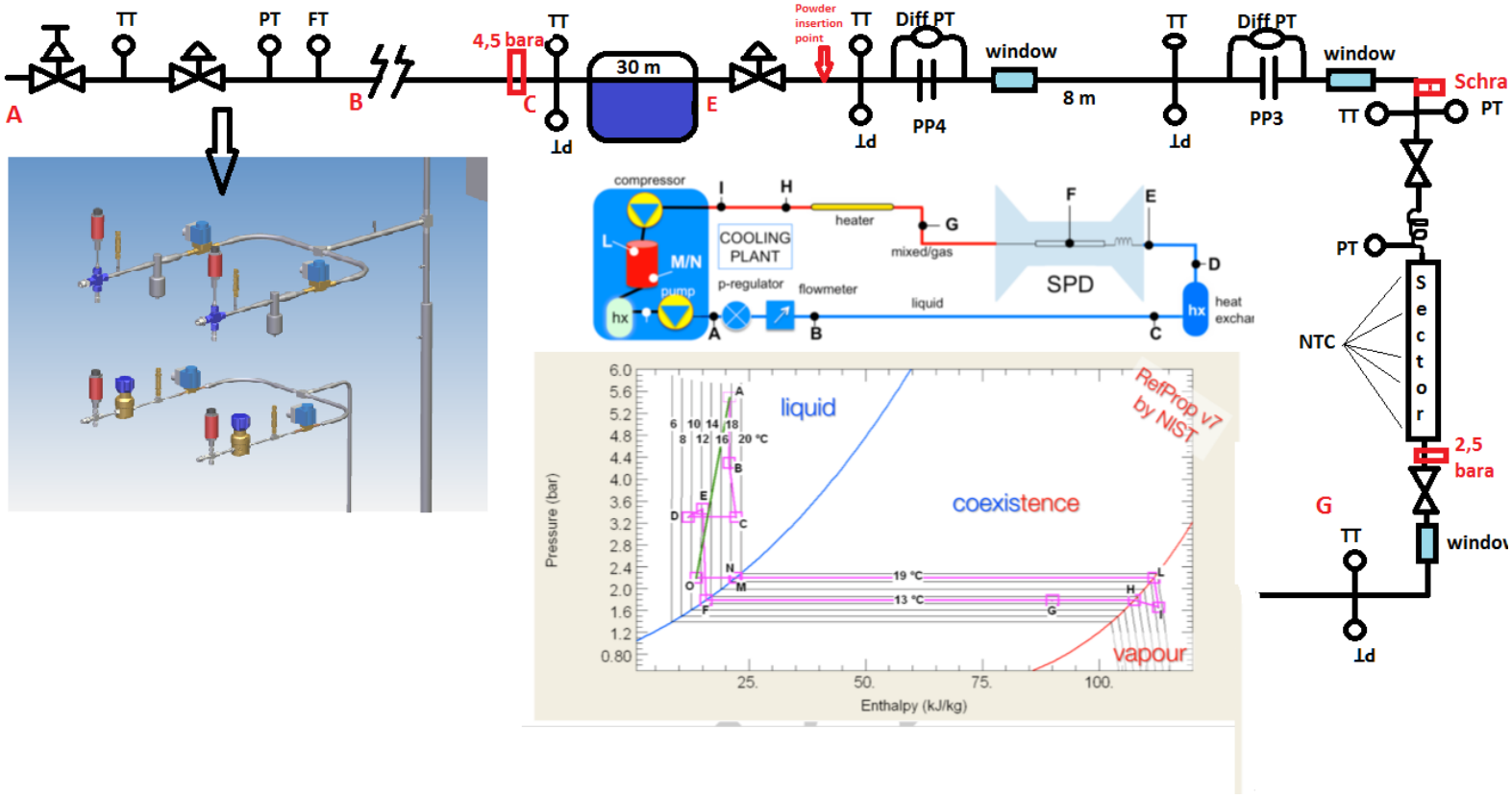
89.2% (107/120 on) - Mar, 8 2012

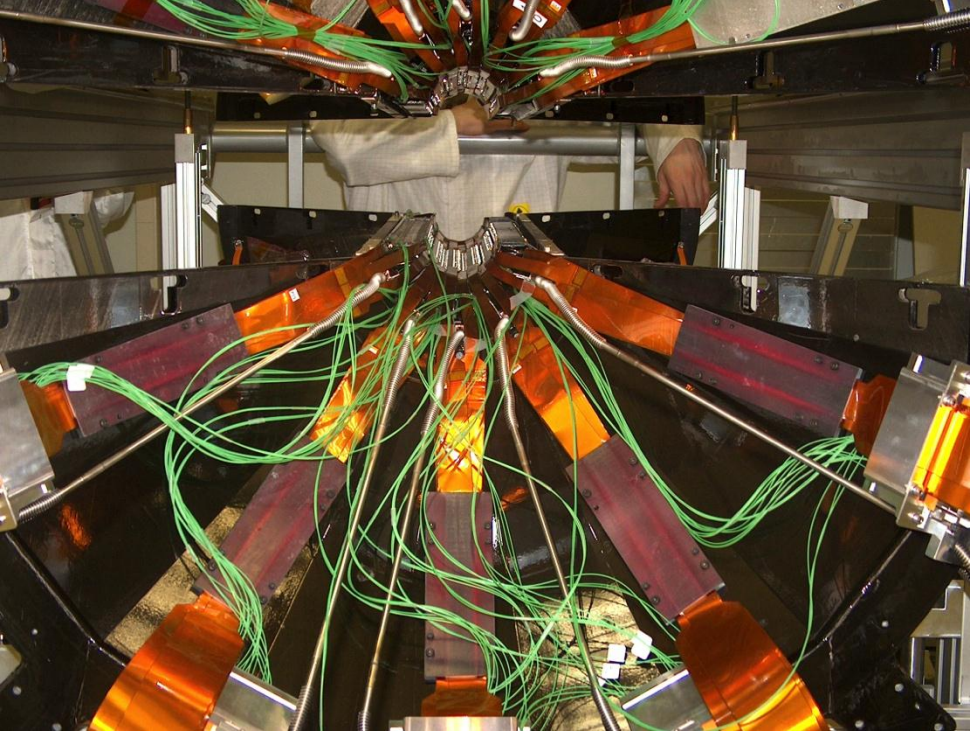


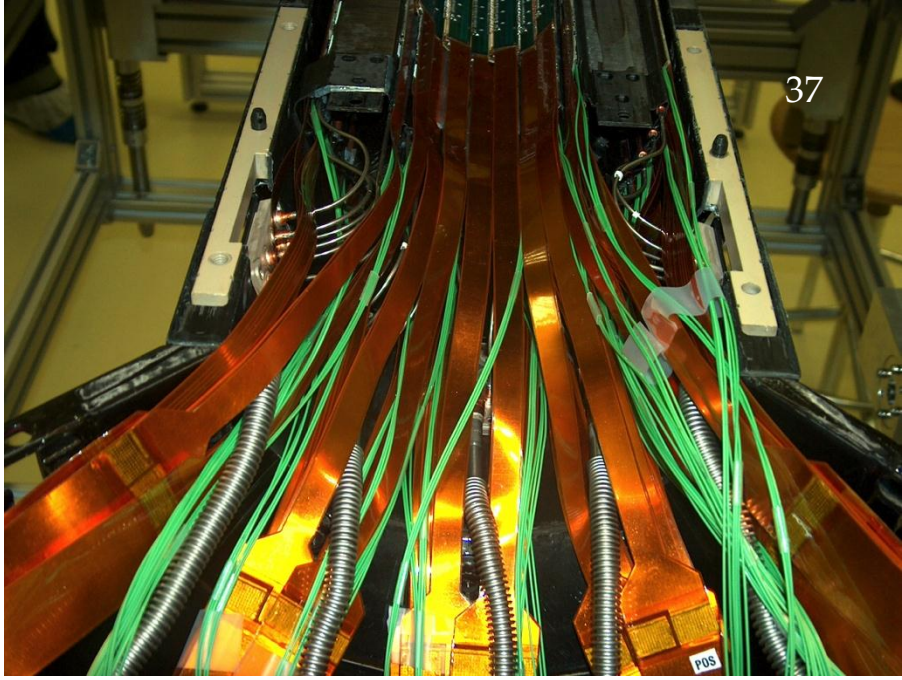
Thanks for the attention!

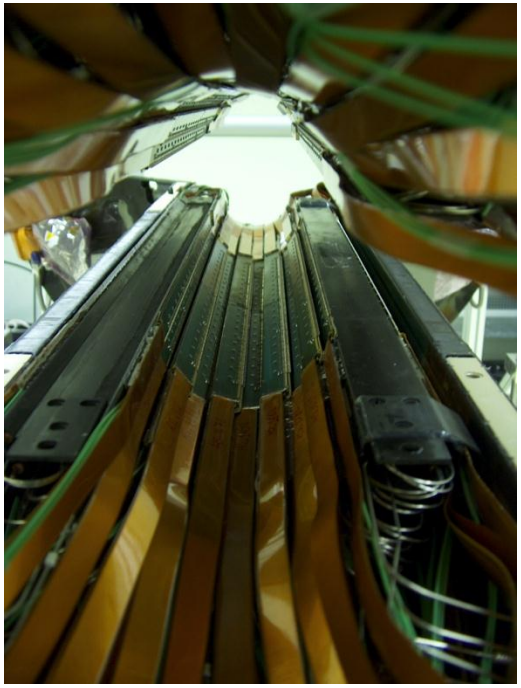
Backups

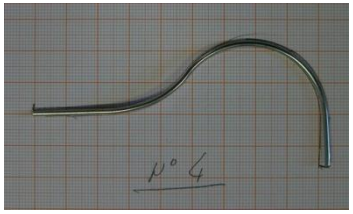
Test bench scheme

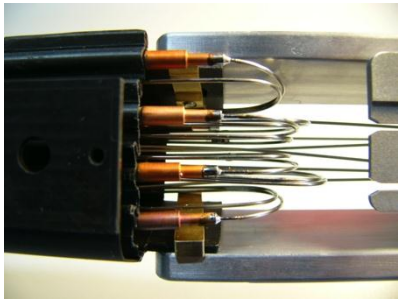


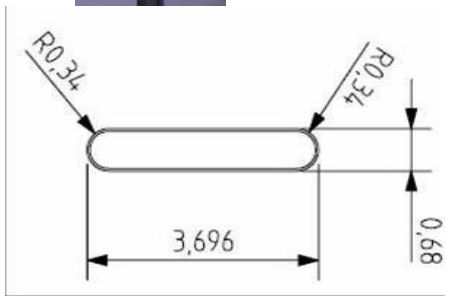




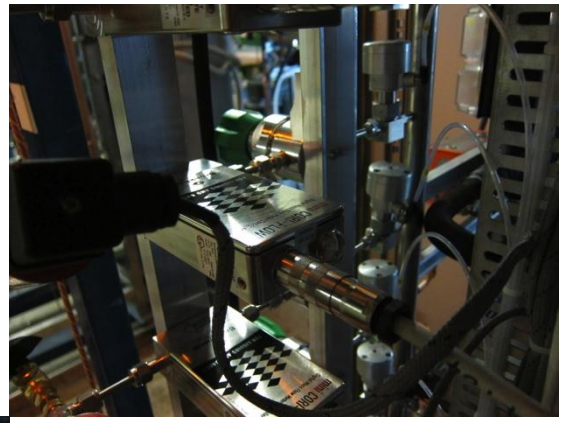


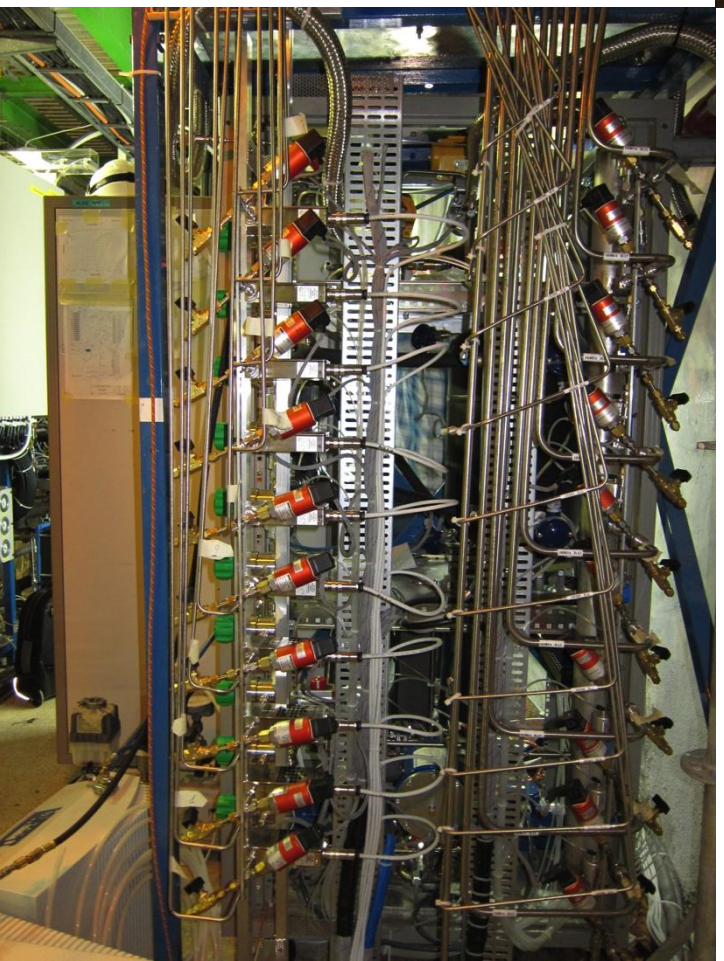

n° 4




R0,34
R0,34
3,696
0,68

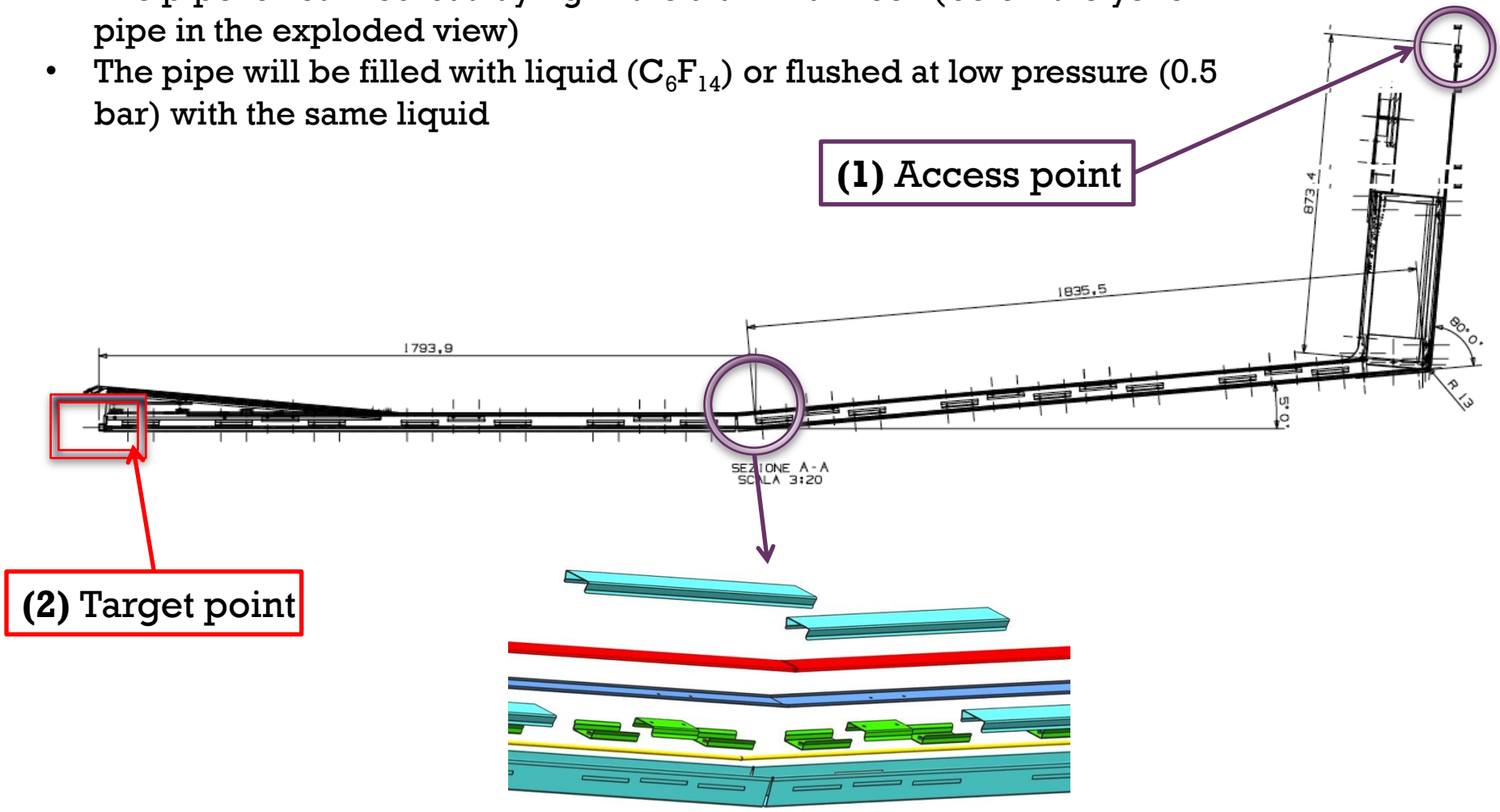

LEAK
OK





Layout of the circuit

- The pipe is in yellow
- The access point (1) is ~4.5 m away from the target point (2).
- The pipe is not fixed but laying in the aluminium box (below the yellow pipe in the exploded view)
- The pipe will be filled with liquid (C_6F_{14}) or flushed at low pressure (0.5 bar) with the same liquid



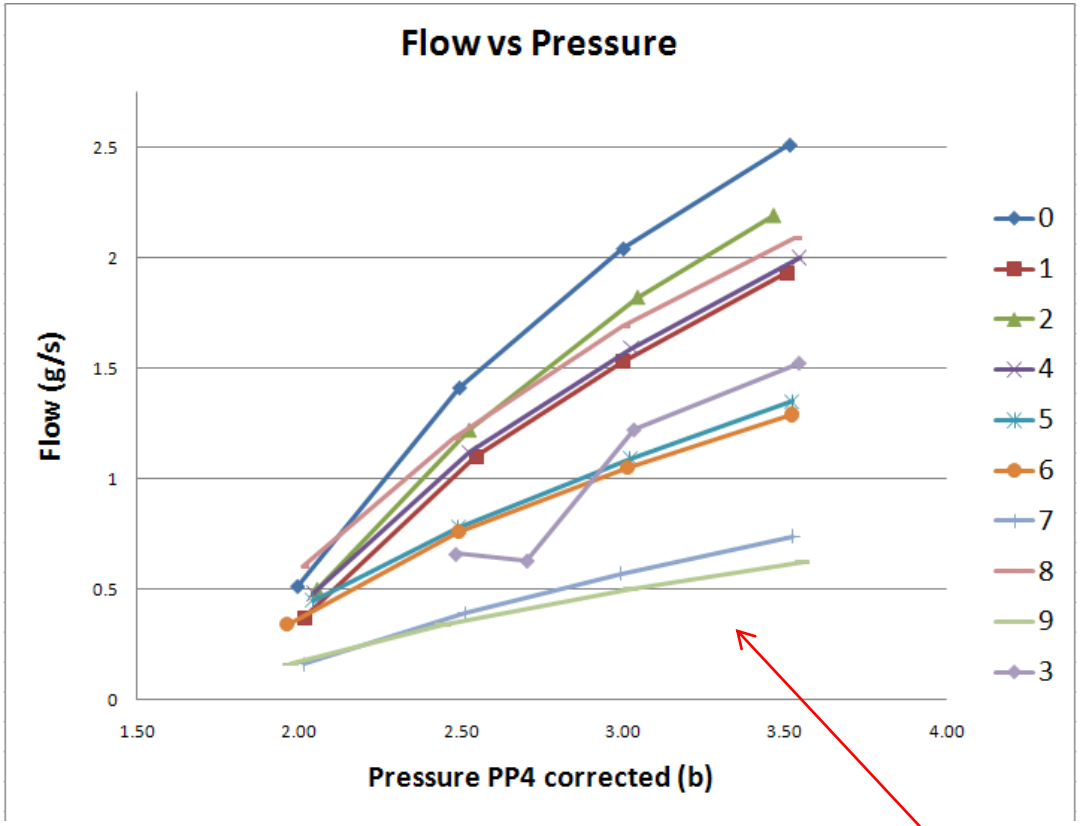
‘Ice age’ test

We installed an ‘intercooler’ on the freon line in PP4 (close to SPD)

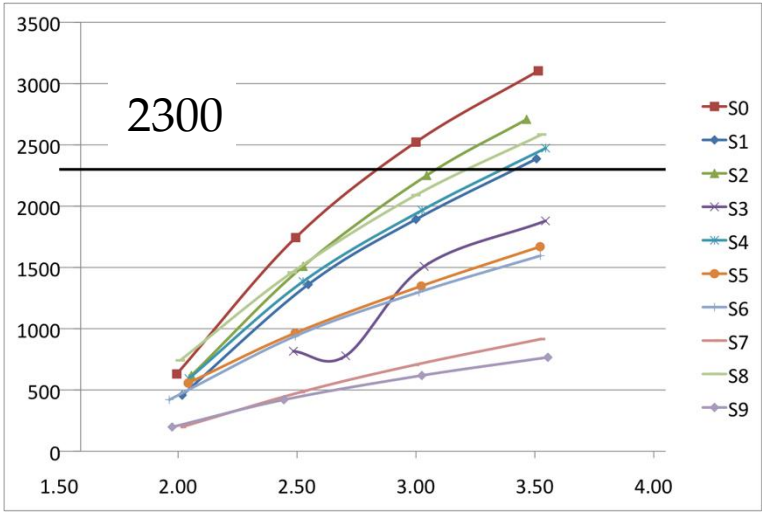
- 8 m of plastic pipe in a bucket filled with ice (many thanks to CERN Restaurant #1!)
- freon reached ~8 ° C in PP4
- Test done on 2 sectors (#6 and #5)

- Observed:
  - increase of flow in one case (~50%)
  - clear improvement of performance
  - in both cases 6/7 half-staves recovered !

Measurement of flow

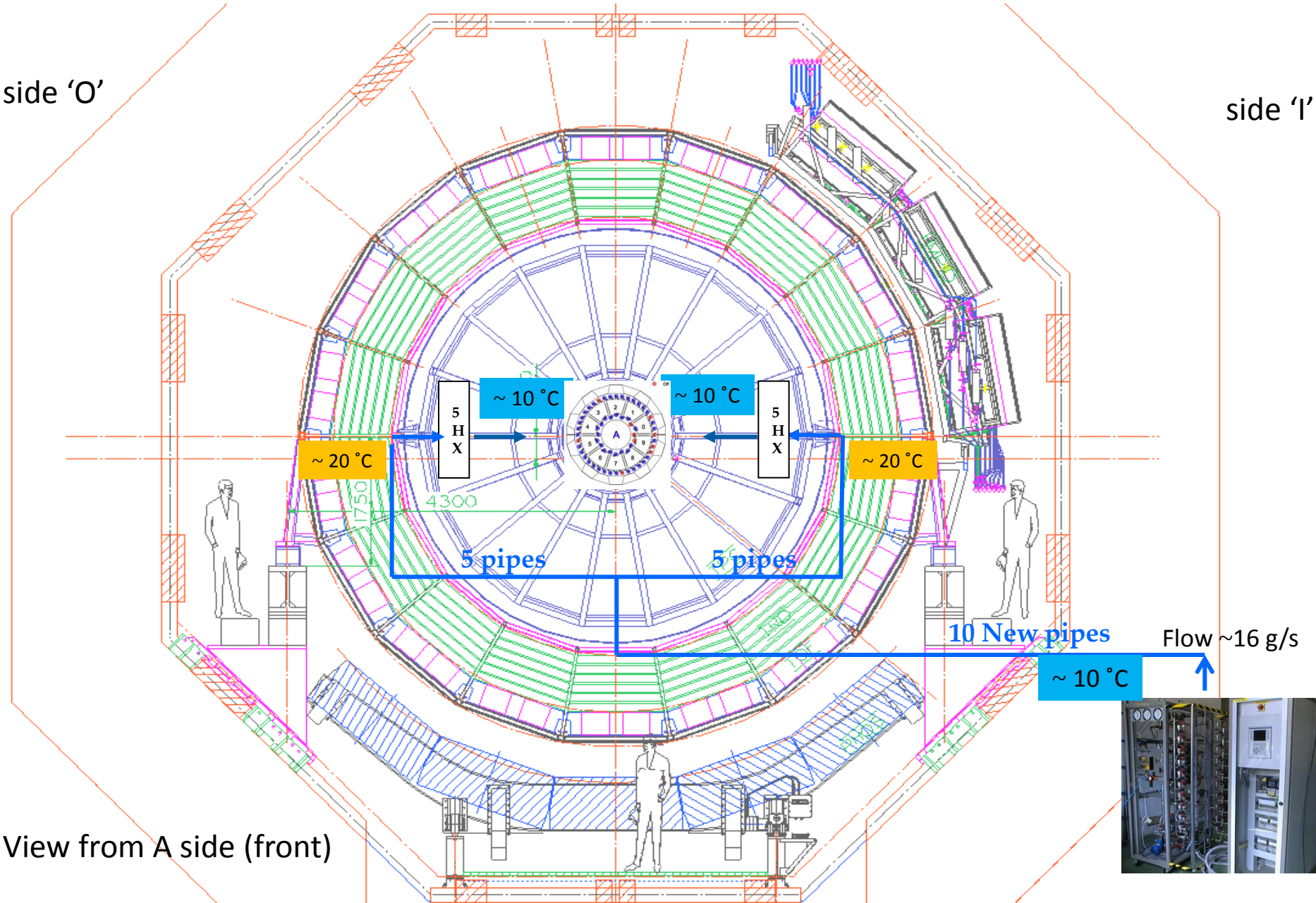


Reynold's number vs. pressure



Very low flow rate in sectors 7 and 9;

Pipes New routing (Symmetric inlet)



Flow/power correlation

- Slowly decreasing trend of flow
- The flow doesn't tell the whole story – stable # of modules must depend on local thermodynamical conditions (not monitored)