Development of cryogenic silicon detectors for the TOTEM Roman pots

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RD39 Collaboration

Seminar on Solid State Detectors
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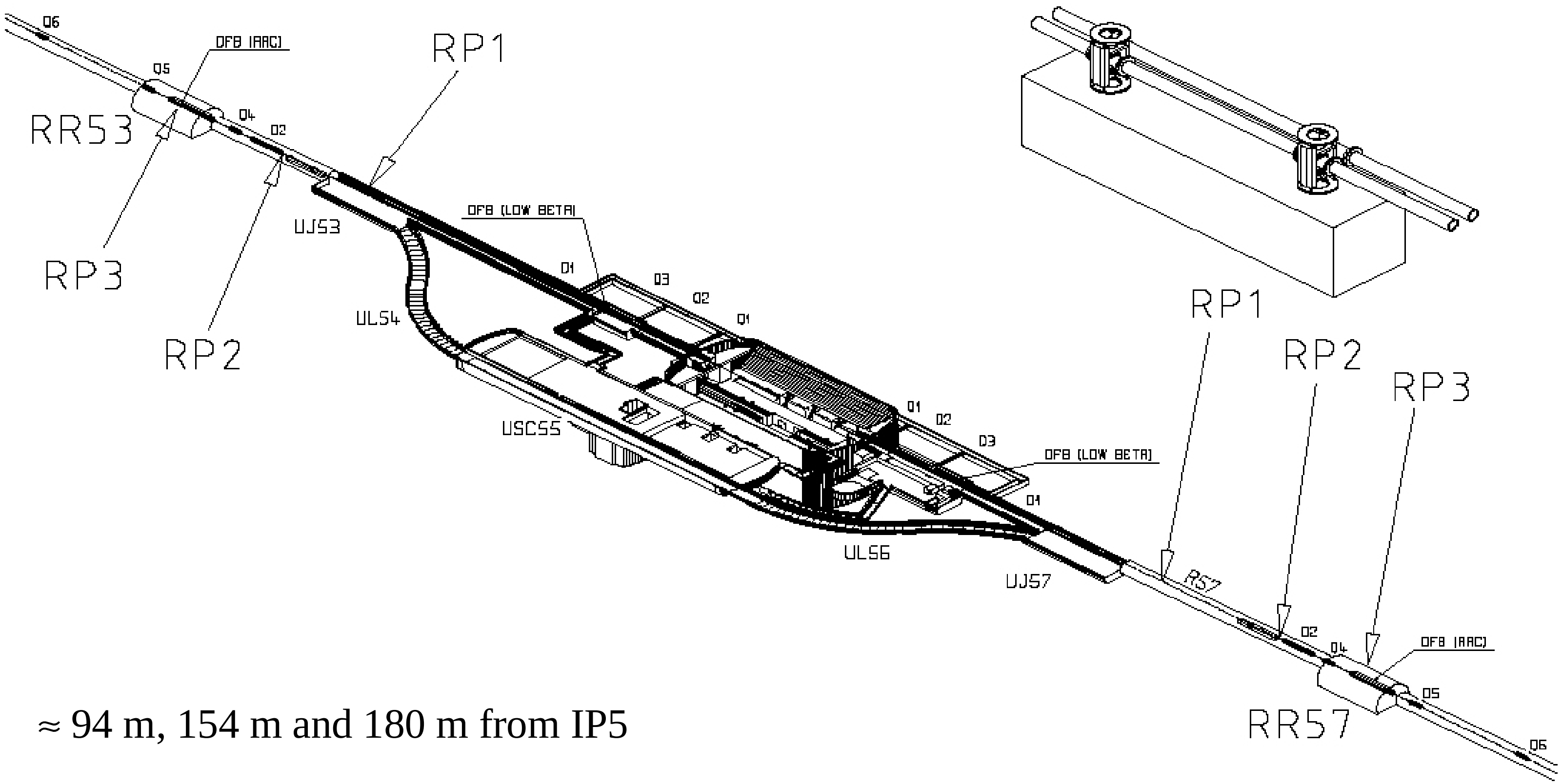
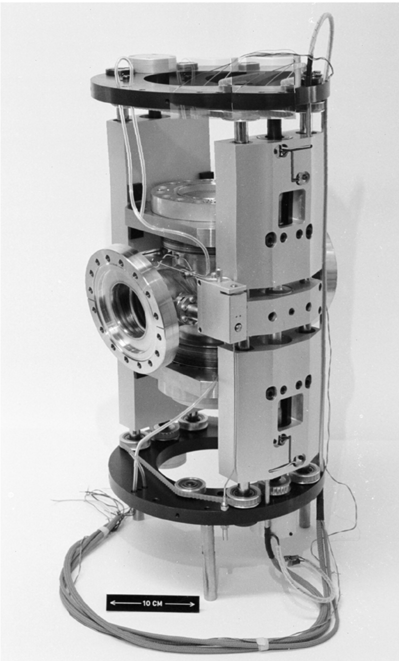
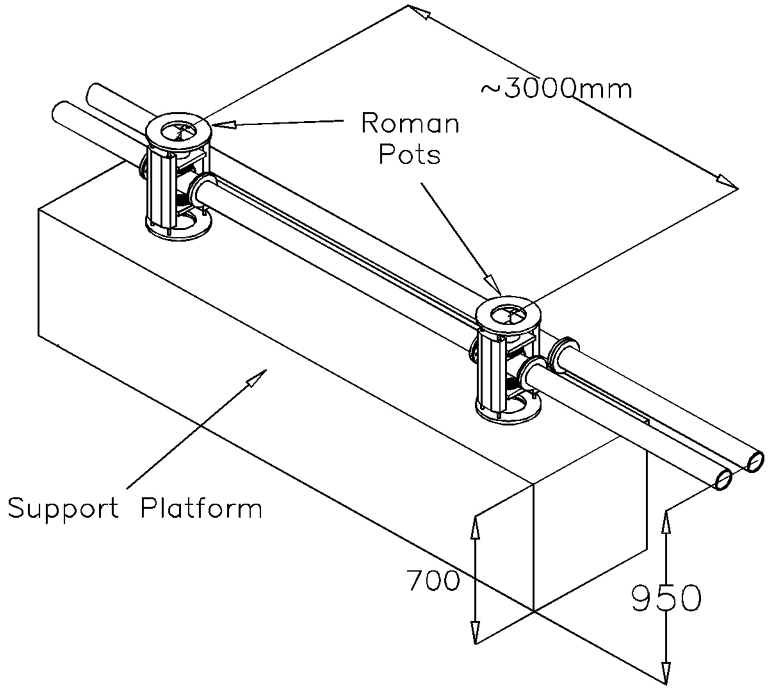
Integration of the TOTEM Roman pots in LHC



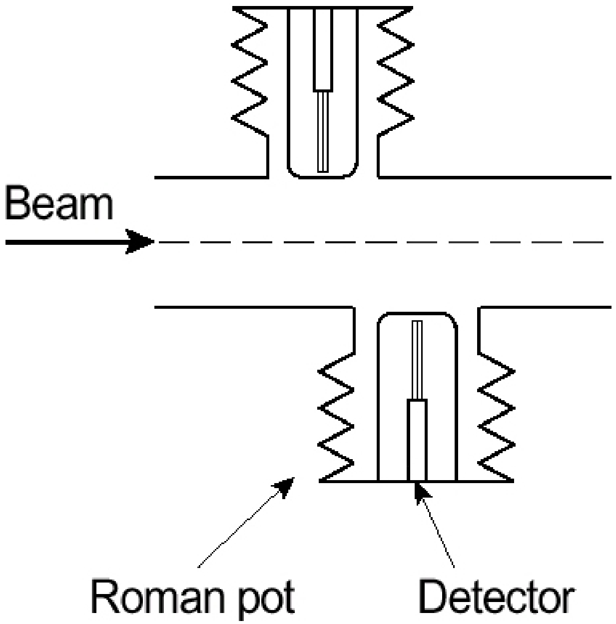
≈ 94 m, 154 m and 180 m from IP5

Layout of a Roman pot station



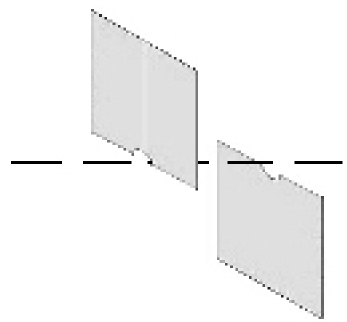


Cryogenic silicon detectors in the Roman pots



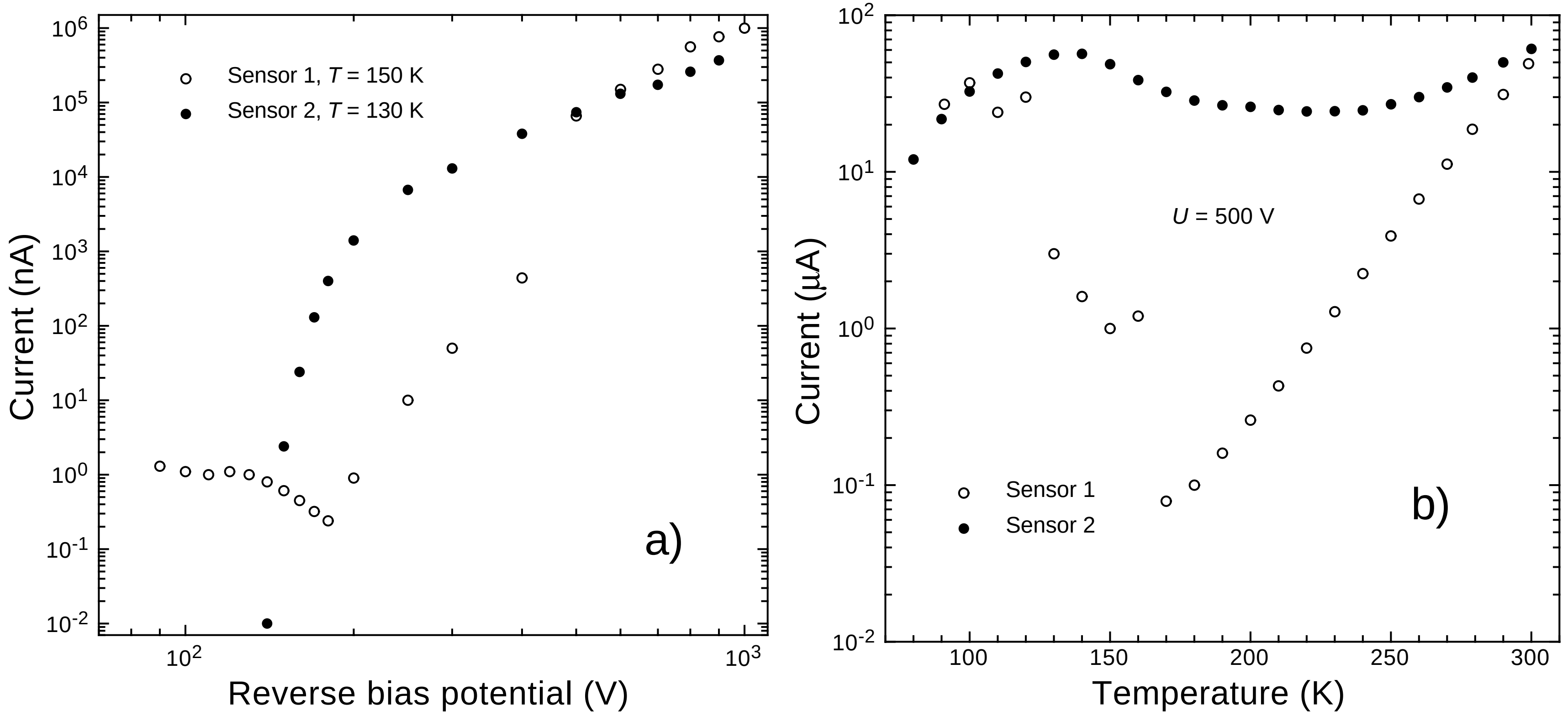
Detectors:

- x-y strips
  (10 μm spatial resolution)
- edgeless (min. distance to the beam 20 σ_y)
- circular dent
- overlapped
  (relative alignment)
- vacuum insulation

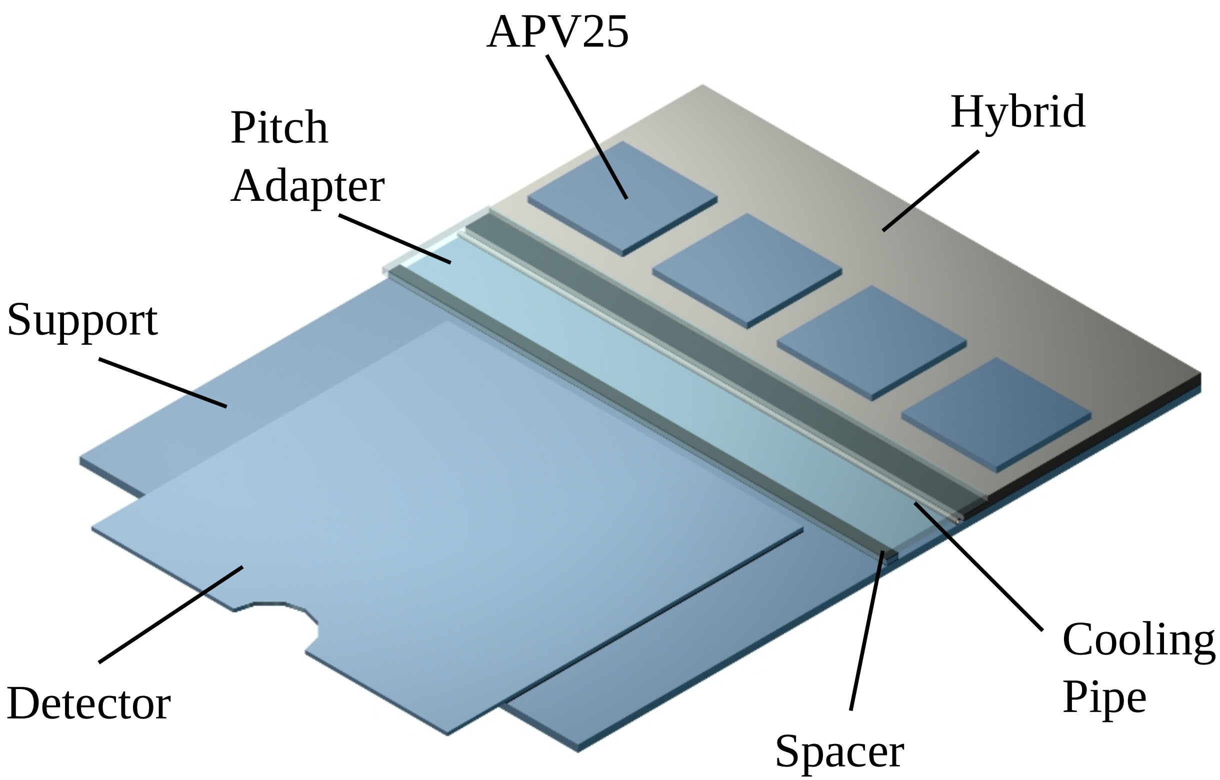


Edge current vs. bias potential and temperature

- Preliminary results -



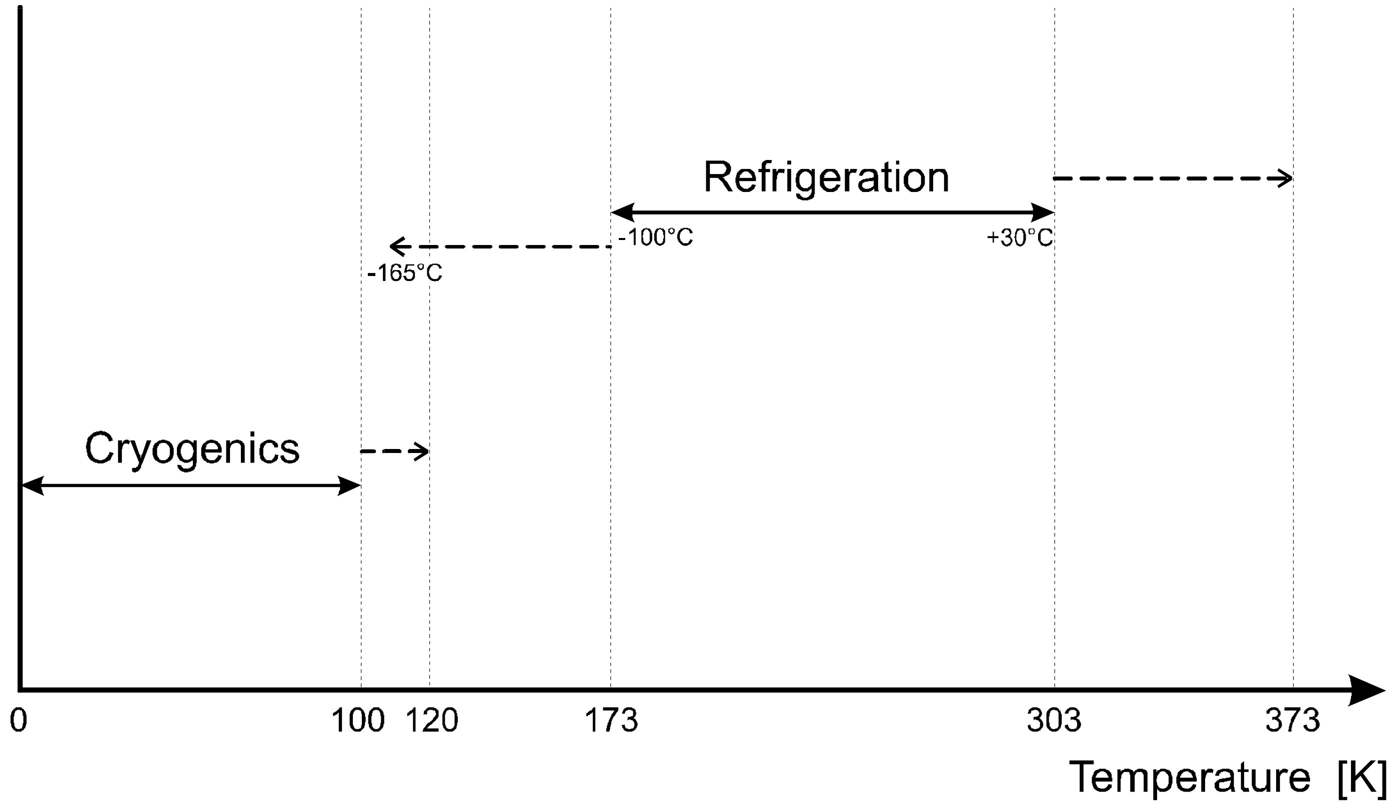
Module design



Summary of heat loads

Module power dissipation		Total Capacity per Station	
Module		Module	
Surface:	30 x 30 mm	Total power:	3 W
Segmentation:	$\approx 50\ \mu m$	Number of modules:	4
Number of channels:	1280	Roman pot	
APV25 readout electronics		Radiation heat load:	1 W
Power dissipation per channel:	2.31 mW	Interface thermal losses	
Channels per chip:	128	Heat sink / fluid circuit:	2 W
Number of chips:	10	Transfer lines:	5 W
Power dissipation per module:	3.0 W	Total:	20 W

Temperature ranges for cryogenics and refrigeration



“Conventional” way of sensor cooling at cryogenic temperatures

- **sensor directly attached to a cold finger (stirling or puls-tube)**
  - ***vibrations, space***

or

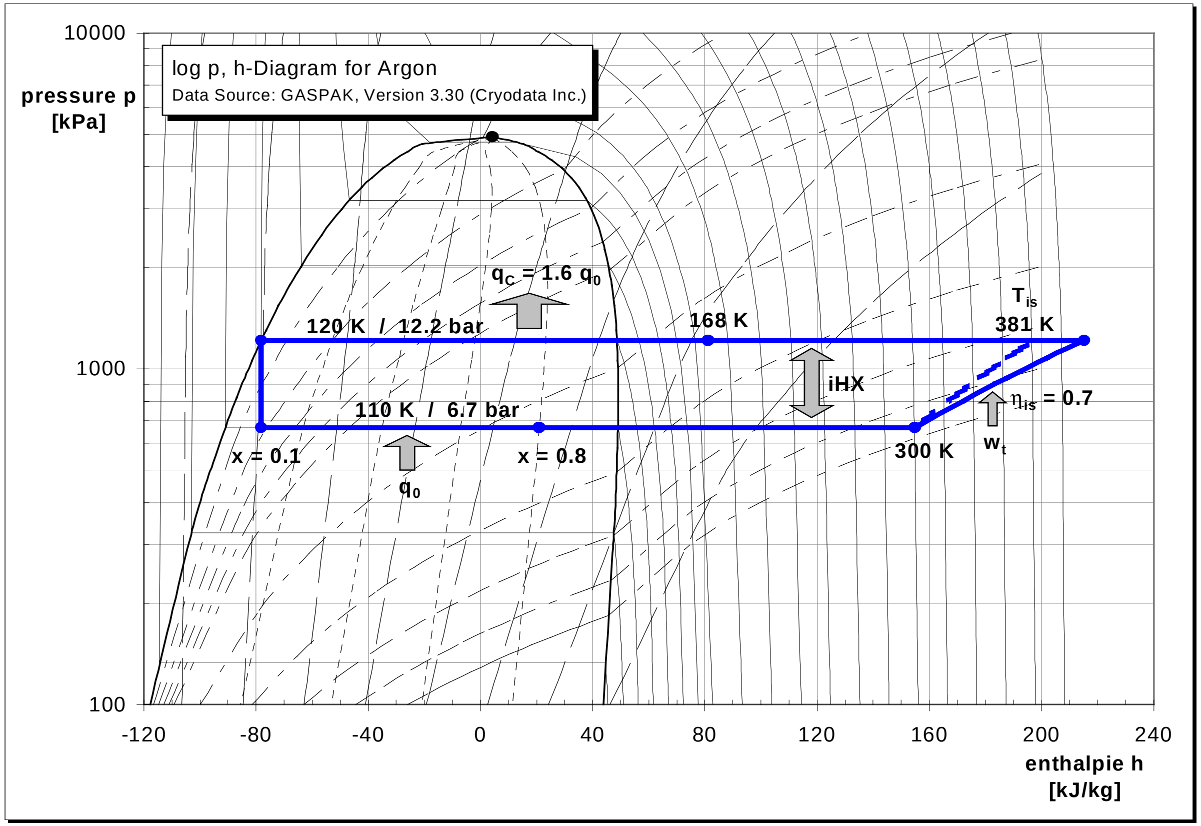
- **separation via copper braid**
  - ***small distance, mass***

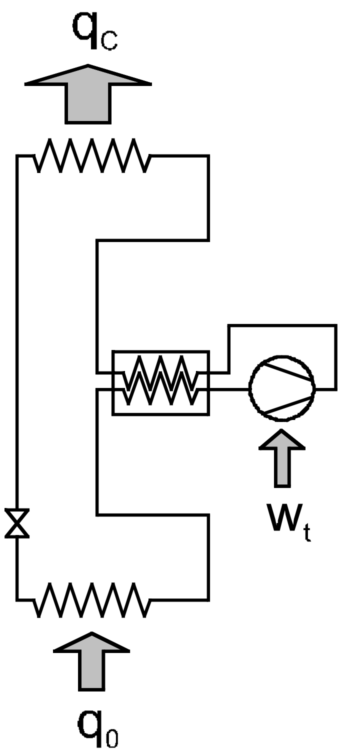
☞ **fluid circuit with direct evaporation to fulfill requirements in TOTEM**

Working fluids for evaporative cooling at 120 K

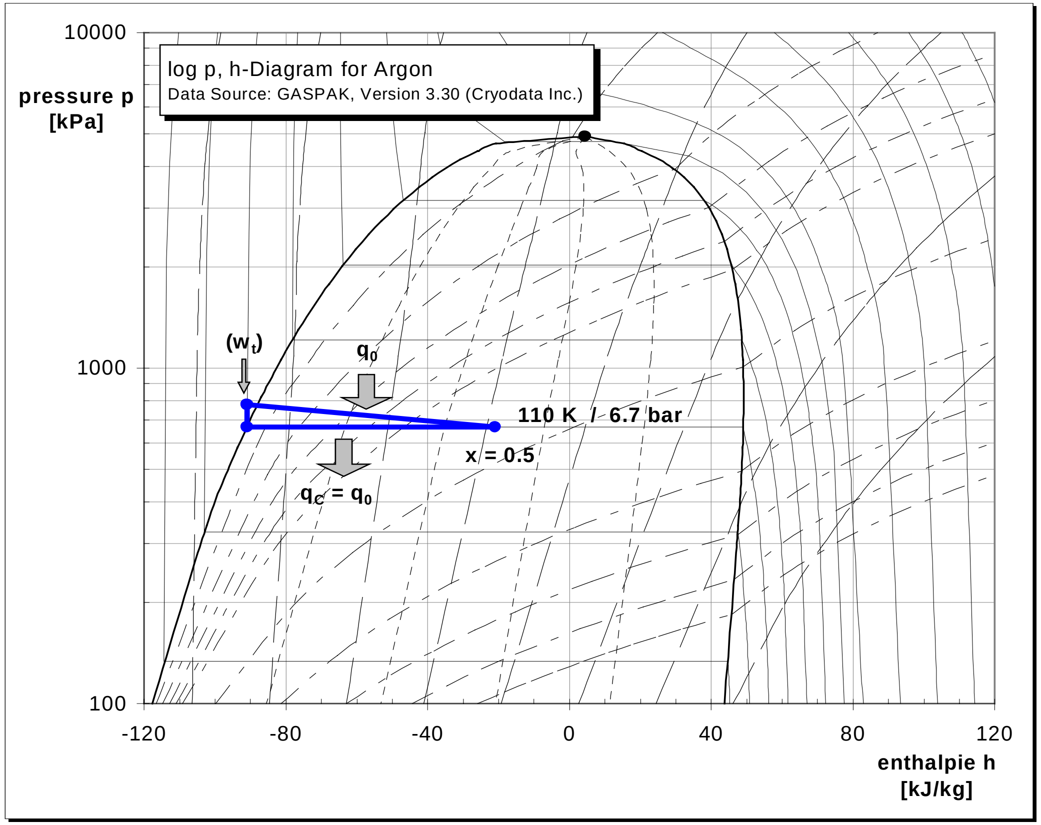
Fluid name	$M[g/mol]$	$T_{tr}[K]$	$T_{crit}[K]$	$T_{nb}[K]$	$p_{120K}[bar]$
Perfluoromethane (CF_4)	88.01	98.9	227.5	145.1	0.11
Krypton (Kr)	83.80	115.8	209.4	119.8	1.03
Methane (CH_4)	16.04	90.7	190.6	111.7	1.91
Oxygen (O_2)	32.00	54.4	154.8	90.2	10.2
Argon (Ar)	39.95	83.8	150.7	87.3	12.2
Nitrogen (N_2)	28.01	63.2	126.0	77.4	25.3

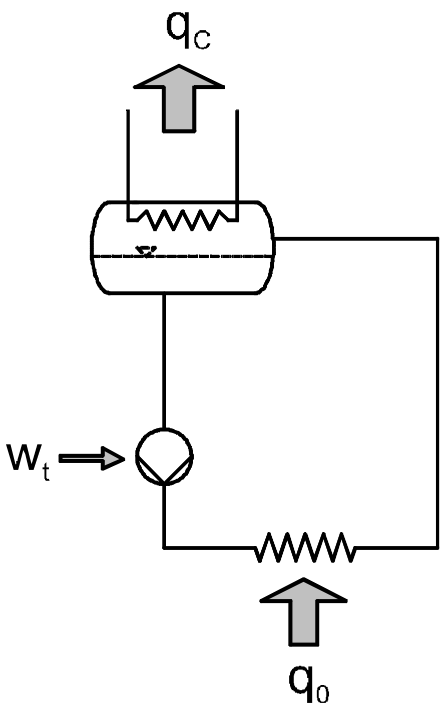
Cooling Methods
Joule-Thomson Process



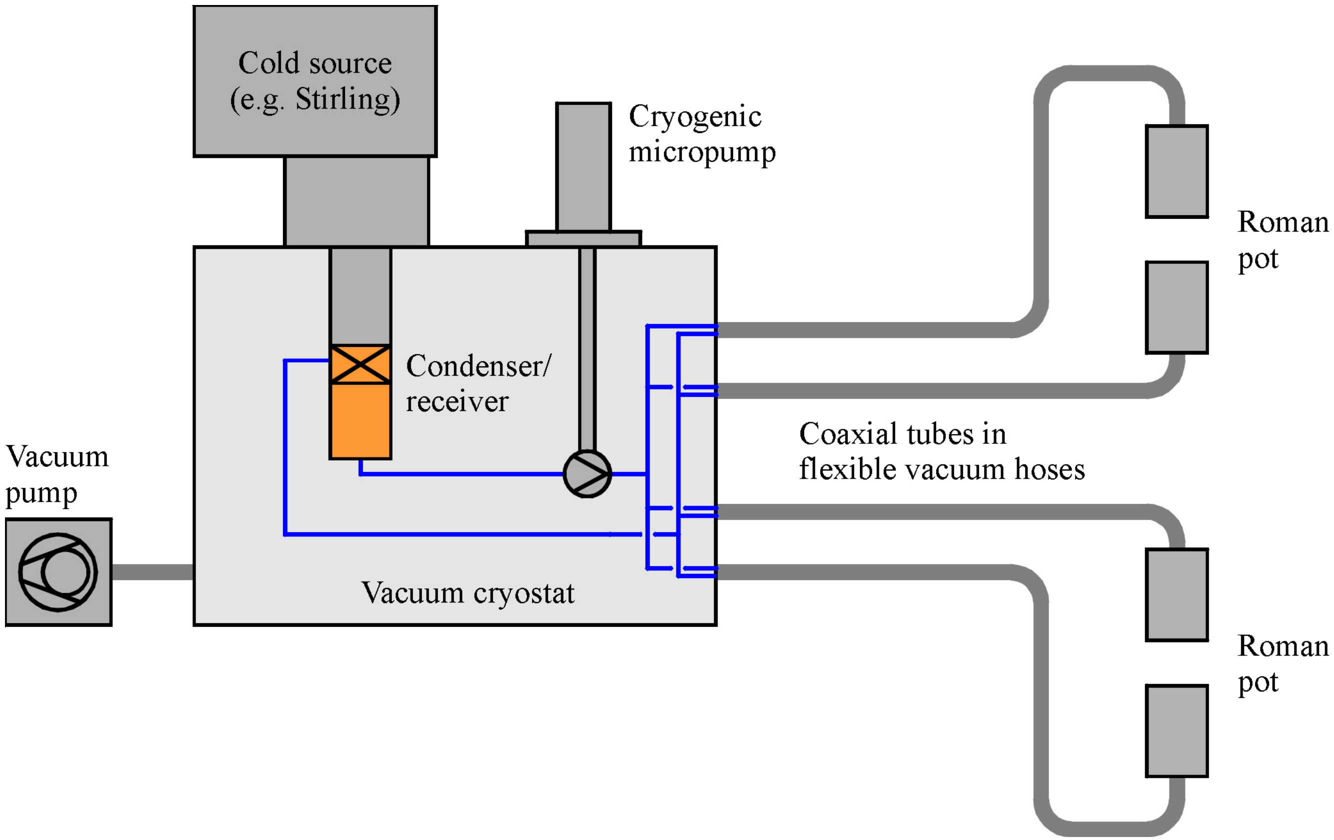


Cooling Methods
Flooded System





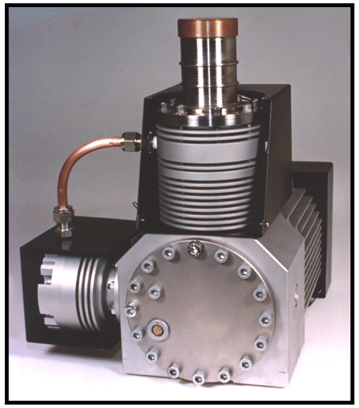
Principle of cooling



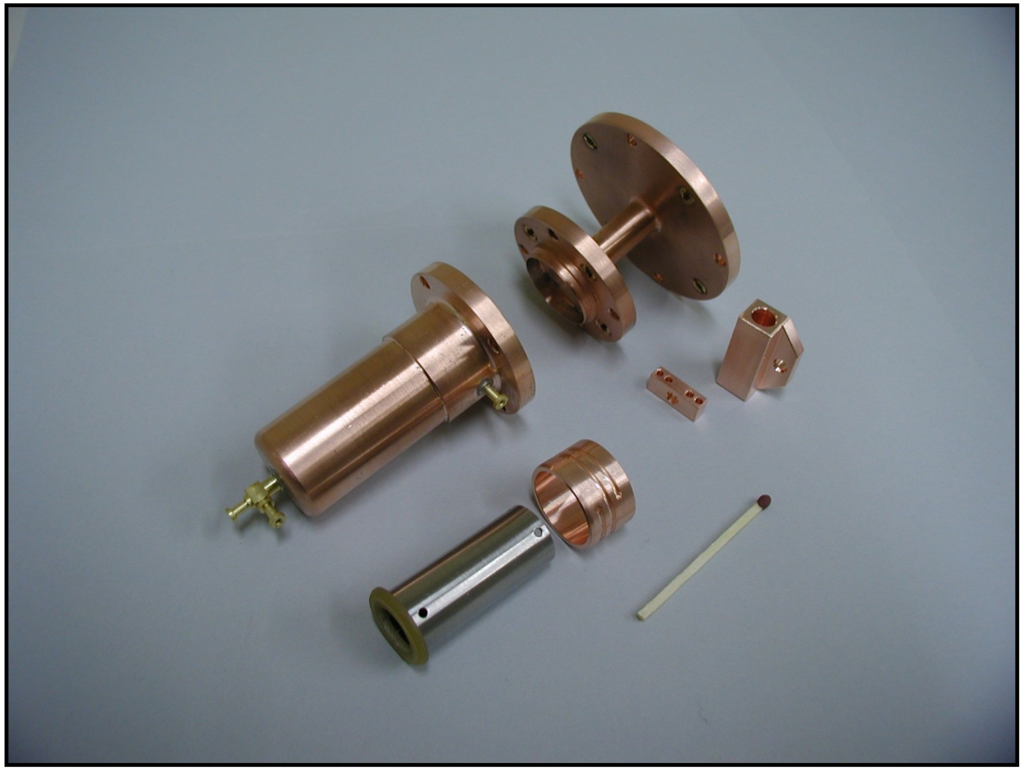
Heat Sink

Gifford-McMahon Cryocooler

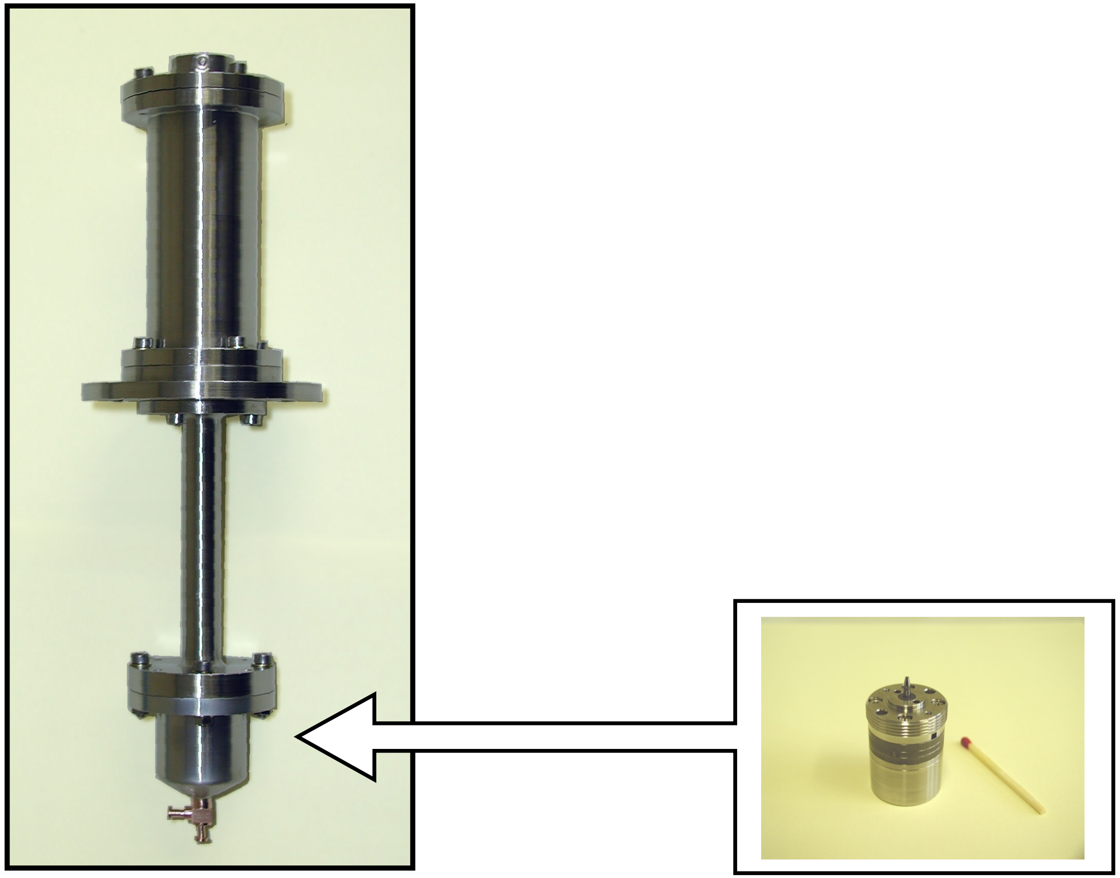
Integral Stirling



Thermal interface
condenser / receiver



Cryogenic Micro Pump



Two-phase flow pressure drop in microchannels

In general:

- frictional, accelerational and hydro-static term
- correlations for homogeneous and separated flow models ($d_h \geq 5$ mm)
- *Storek and Brauer:*

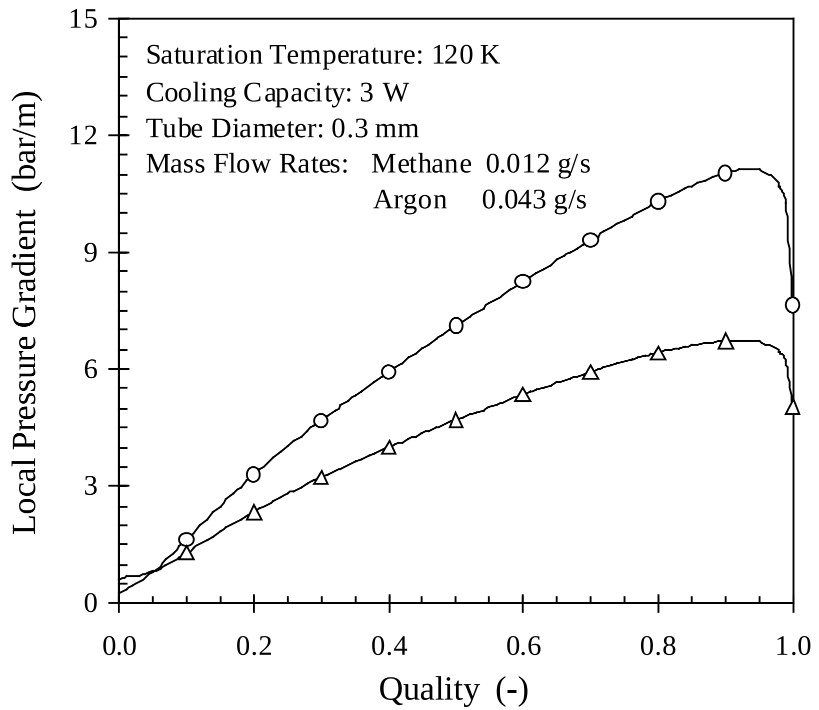
$$\frac{1}{\rho_h} = \frac{x}{\rho_g} + \frac{1-x}{\rho_l} \qquad \frac{1}{\eta_h} = \frac{x}{\eta_g} + \frac{1-x}{\eta_l}$$

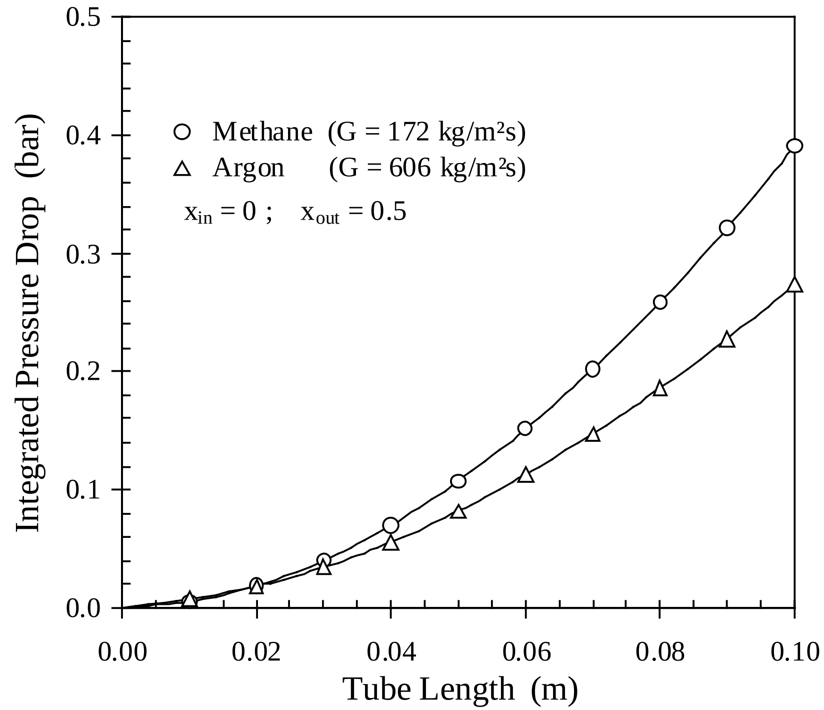
correction factor for $w_v > w_l$

In microchannels:

- tube dimensions are in the same order of magnitude as the thermal and hydrodyna-mic boundary layers
- Reynolds analogy is no longer valid (Re_{crit} = 200-900)
- no correlation
- few data for single-phase flow published

Calculated pressure drop in the Roman pot detector modules





Flow boiling in microchannels

In general:

- heat transfer depending on:
  - operating conditions
  - fluid properties
  - heating-wall properties
  - phase distribution
  - fluid quality
- nucleate boiling: $\alpha = f(\dot{q})$
- algorithms only for macroscale tubes with $d_h \geq 5$ mm
- *Steiner* reference quantities: $d_0 = 10$ mm; $m_0 = 100$ kg/m²s

In microchannels:

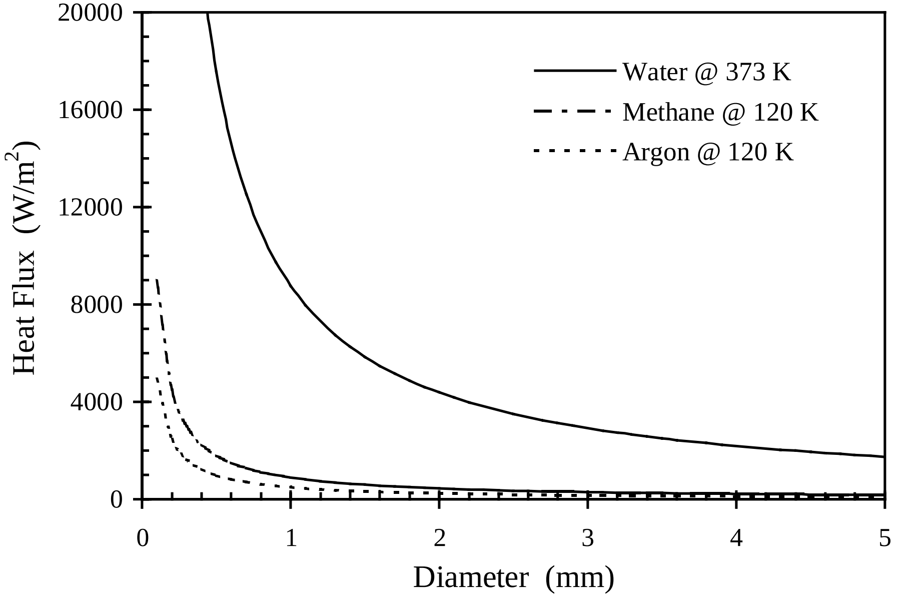
- ‘simple’ scaling to our dimensions increases the HTC by factor 10
- different flow profiles due to relatively large boundary layers
- concept of ‘evaporating space’ and ‘fictitious boiling’ introduced by *Peng*
- few data published

Peng's nucleation criterion for microtubes

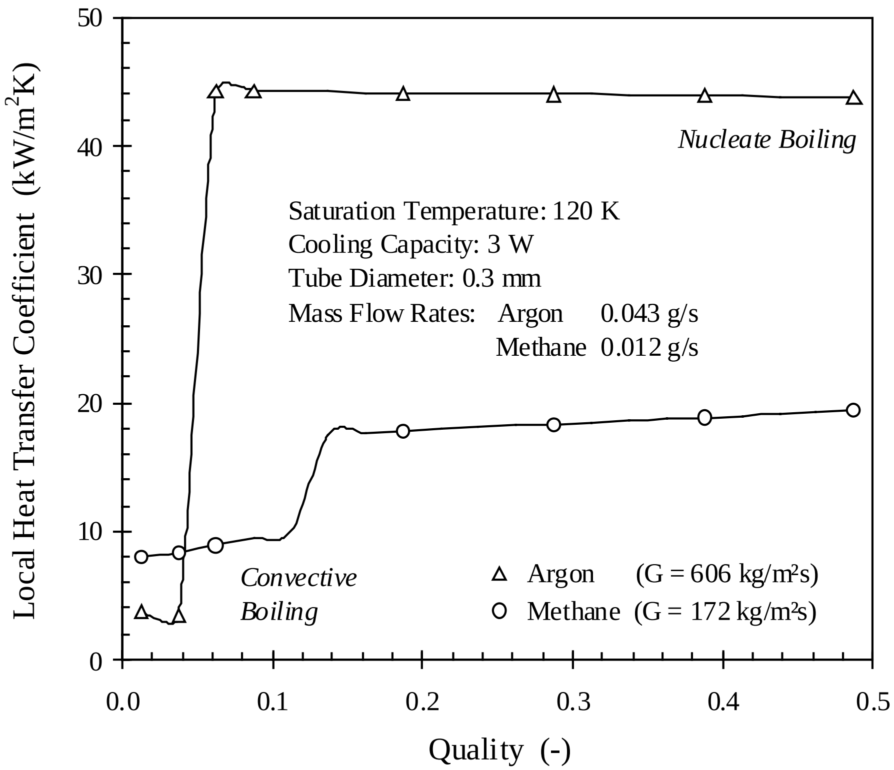
$$N_{mb} = \frac{h_{lv} \cdot a_v}{c \cdot \pi \cdot (v'' - v') \cdot \dot{q} \cdot D_h}$$

with

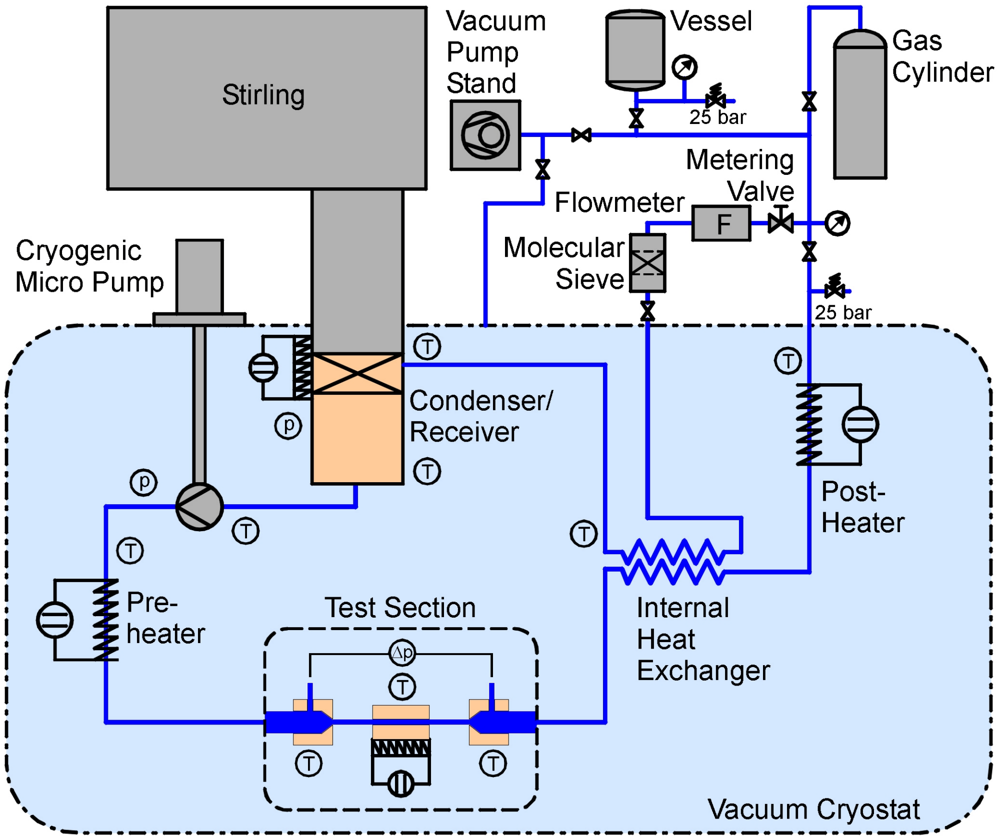
$$N_{mb} \leq 1$$



Calculated HTC in the Roman pot detector modules

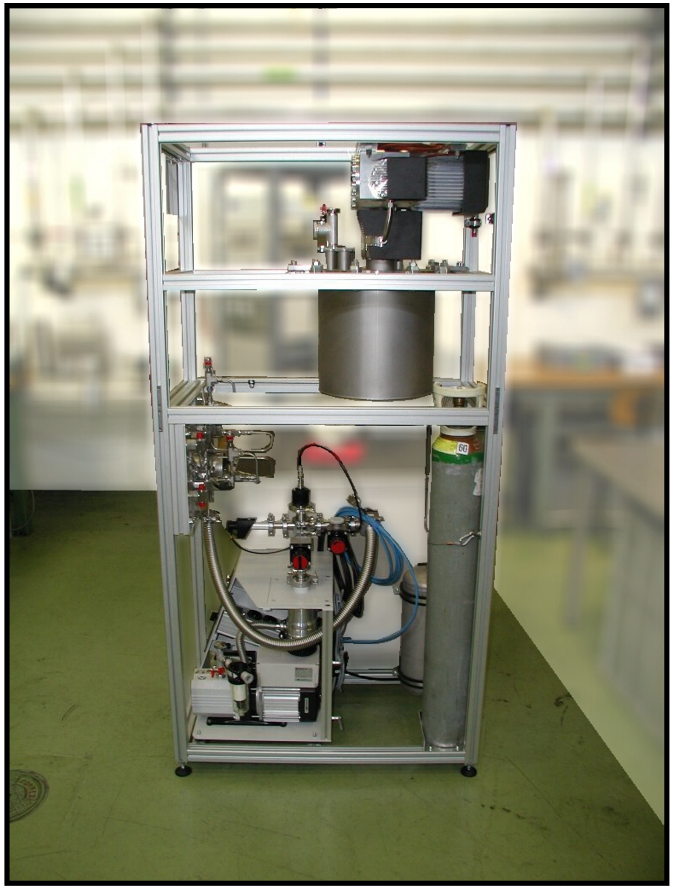


Test circuit layout



Test Stand - Total View

Test Stand - Cooling Rack



Conclusion

- Edgeless silicon microstrip detectors are being designed for the TOTEM Roman pots with their sensitive area as close as 20 σ_y to the beam.
- Spatial resolution of 10 μm is obtained with a pitch of about 50 μm.
- A circular dent and the detector overlapping allow relative alignment of the sensors using the measuring data.
- Detectors are cooled by direct evaporation in integrated microtubes, which provides minimum mass contribution, constant temperature profiles and extremely high heat transfer rates, and effective decoupling of vibrations.
- Experiments are under way to study two-phase flow pressure drop and heat transfer in microchannels and to test the new circuit components.