Helium Cooling System for the Mu3e Experiment

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On behalf of the Mu3e Collaboration

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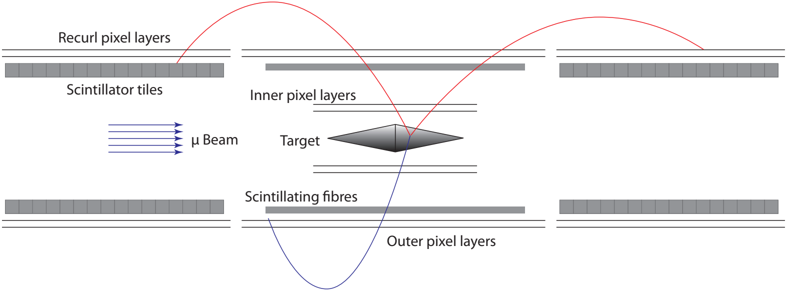
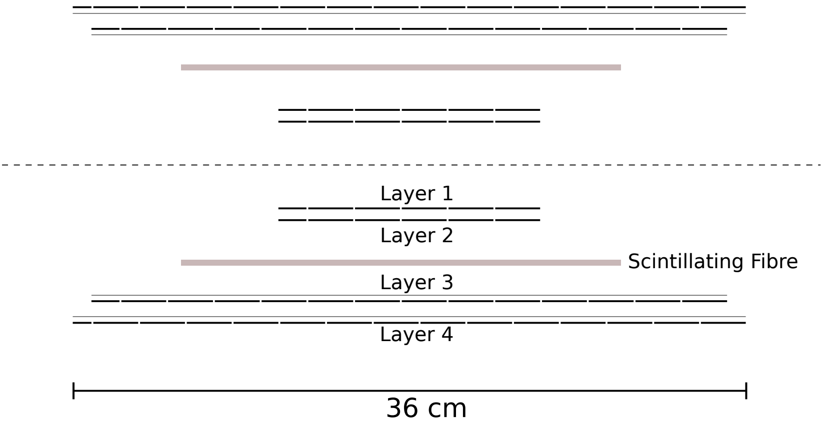
Mu3e Experiment

Search for the charged lepton flavour violating decay $\mu^+ \rightarrow e^+ e^- e^+$

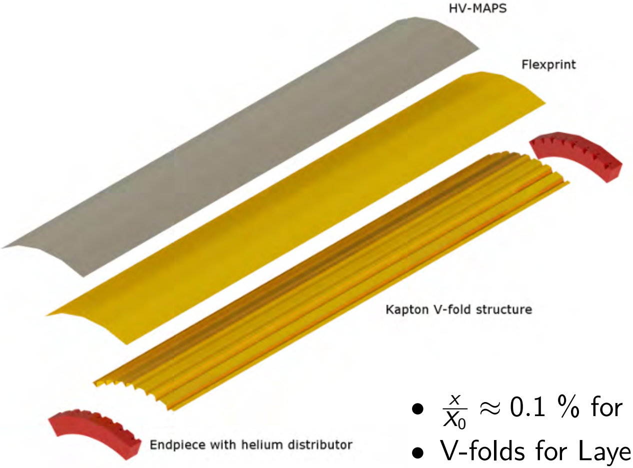


- **Stopped muons** decay in a solenoidal magnetic field of **B=1 T**
- Low momentum electrons $p_e \leq 53\,\text{MeV/c}$
  $\rightarrow$ Need low material budget to reduce multiple scattering
  $\rightarrow$ Gaseous helium cooling system for pixel detector

Helium Cooling System

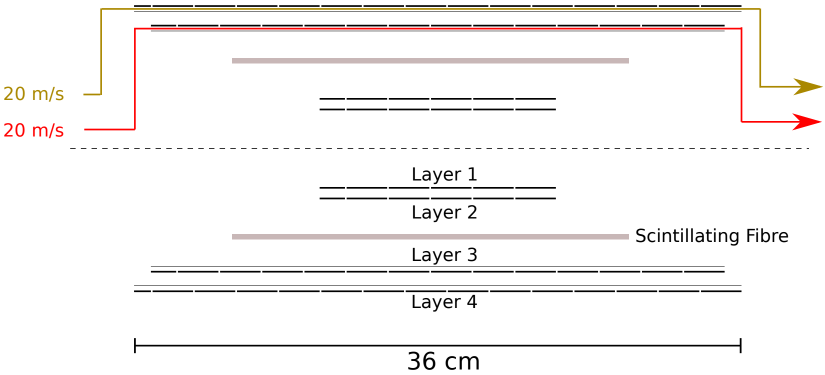


Detector modules

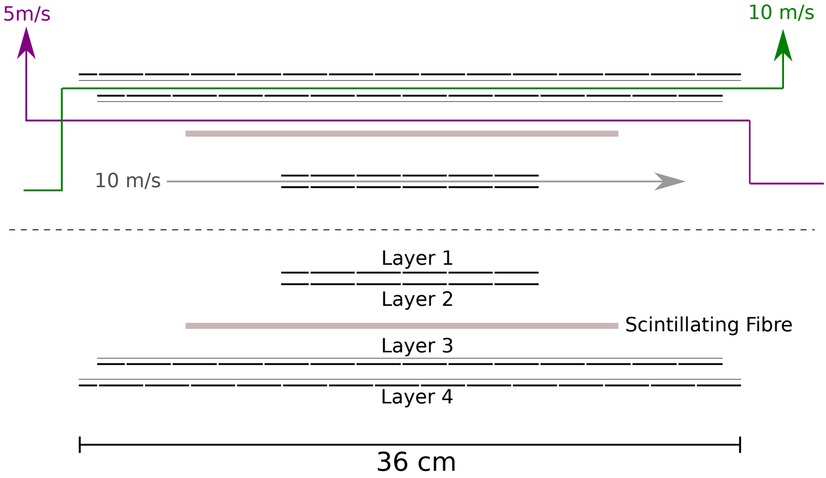


- $\frac{x}{X_0} \approx 0.1$ % for each layer
- V-folds for Layer 3 and Layer 4
  $\rightarrow$ Additional flow channel

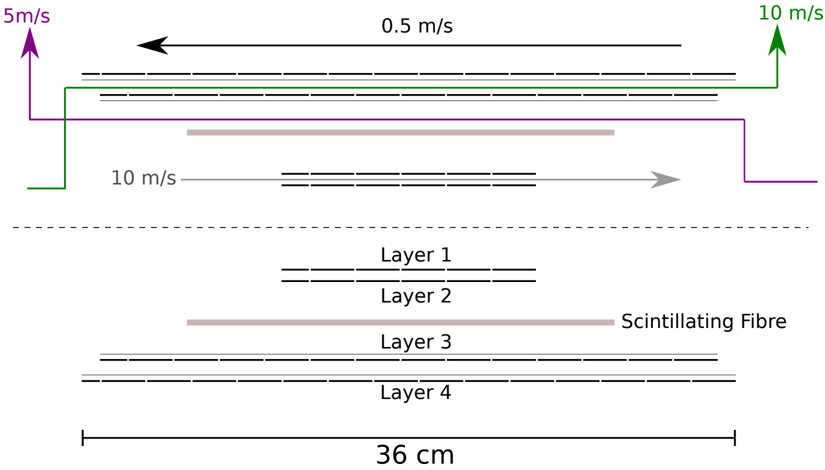
Helium Cooling System



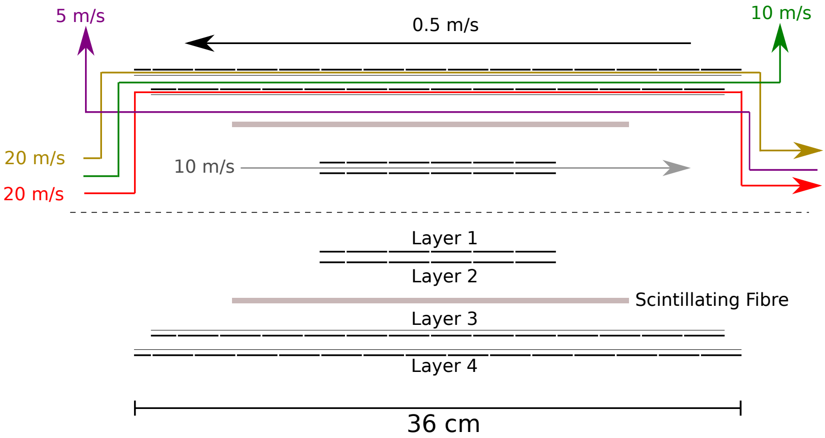
Helium Cooling System



Helium Cooling System



Helium Cooling System



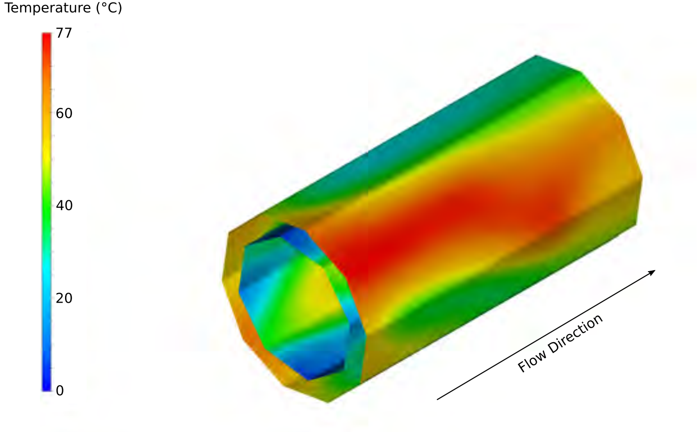
Simulations for Cooling System

- Expected power consumption per chip area $P/A = 250\,\mathrm{mW/cm^2}$
  $\rightarrow$ Test more conservative scenario with $P/A = 400\,\mathrm{mW/cm^2}$
- Temperatures should not exceed $70\,^\circ\mathrm{C}$
- Helium enters detector with slightly above $0\,^\circ\mathrm{C}$

Testing cooling system using Computational Fluid Dynamics Simulations.
Inner and Outer double layer are presented separately.

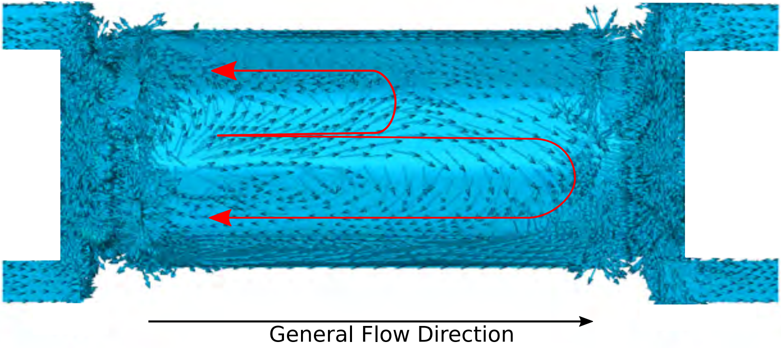
Inner Double Layer

Temperature of silicon parts with $P/A = 400\,\mathrm{mW/cm^2}$



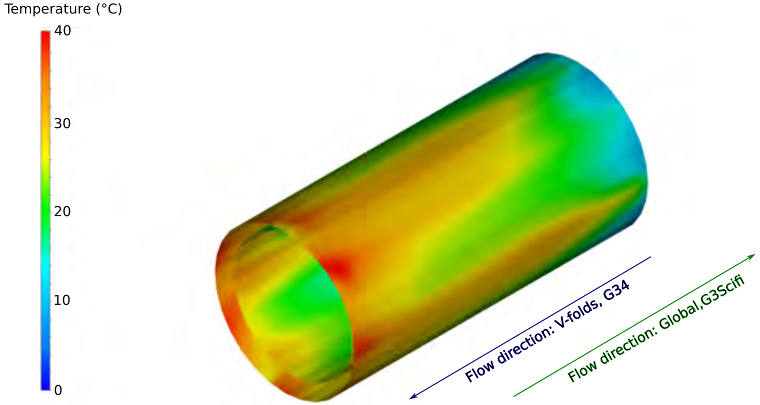
Inner Double Layer

Flow directions in the inner double layers



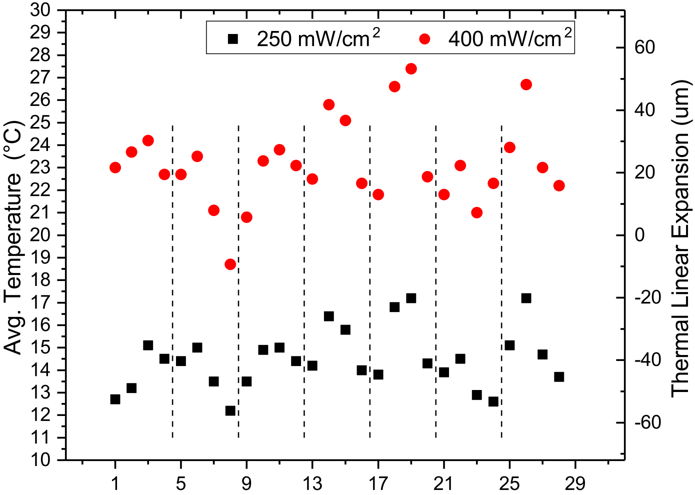
Outer Double Layers

Temperature of silicon parts with $P/A = 400\,\mathrm{mW/cm^2}$



Thermal Expansion

Thermal linear expansion $\Delta L = \alpha L_0 \Delta T$
Layer 4: $L_0 = 36\,\mathrm{cm}$ and $\alpha_{\mathrm{polyimide}} = 2 \times 10^{-5}\,^{\circ}\mathrm{C}^{-1}$

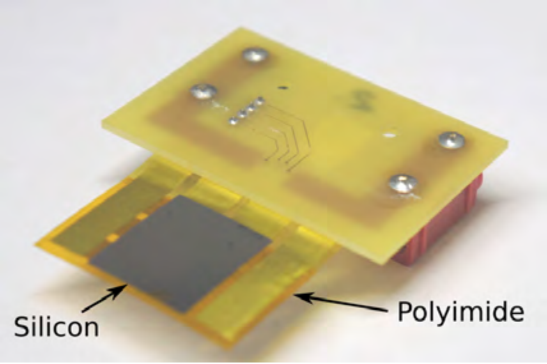


Thermal-Mechanical Chip Prototype

First thermal-mechanical prototype of pixel sensor:

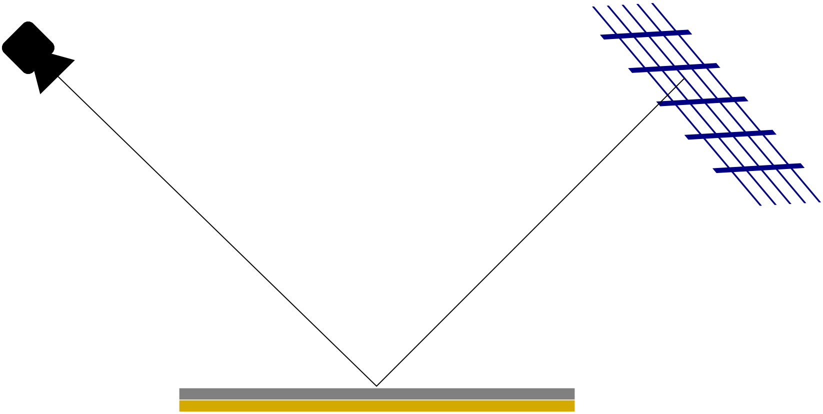
- 50 µm thick silicon layer
- 50 µm aluminium-polyimide flexprint

$\alpha_{\text{polyimide}} \approx 8 \cdot \alpha_{\text{silicon}}$
$\rightarrow$ Study deformation



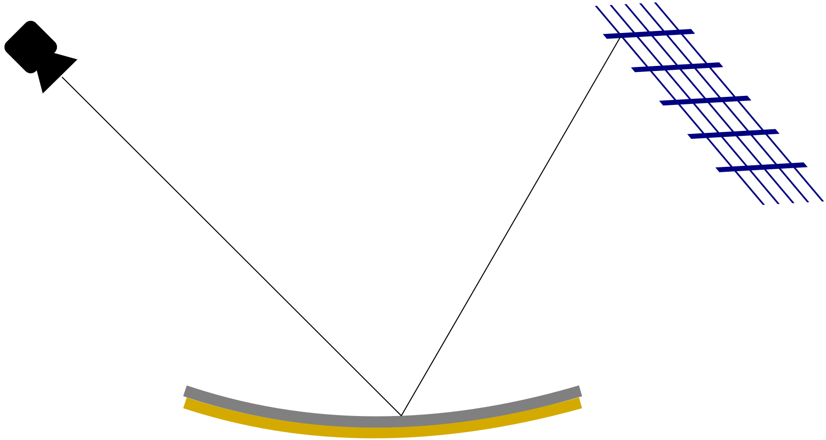
Experimental Concept

Initial Temperature

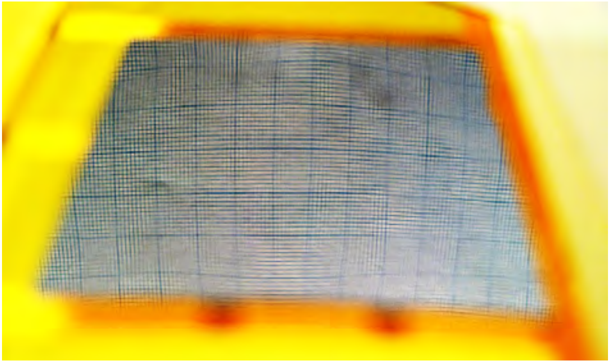


Experimental Concept

Increased Temperature

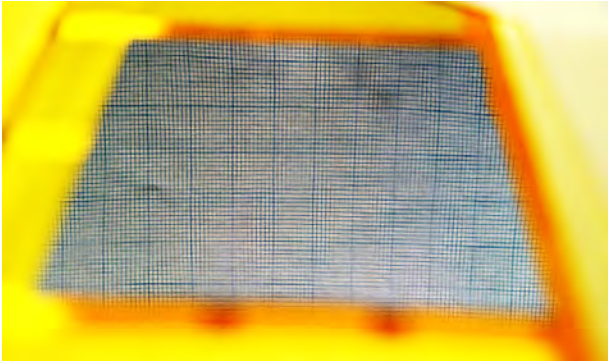


Chip Deformation



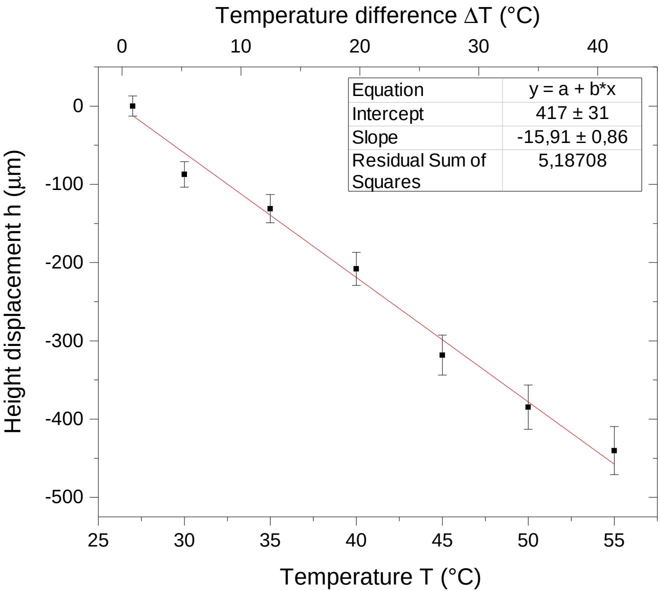
$T = 30\,^{\circ}\mathrm{C}$

Chip Deformation



$T = 50\,^{\circ}\mathrm{C}$

Deformation



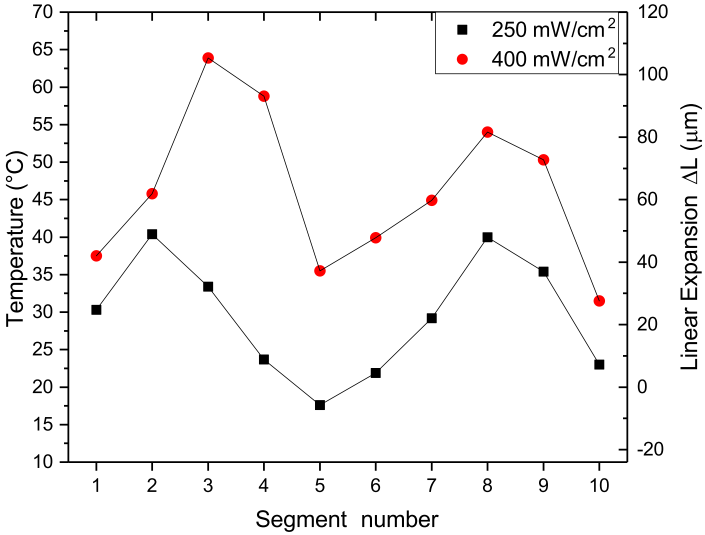
Summary & Outlook

- Temperatures in the detector exceed 70 °C for conservative scenario of $P/A = 400\,\mathrm{mW/cm^2}$.
- Uneven temperature distribution induces mechanical stress.

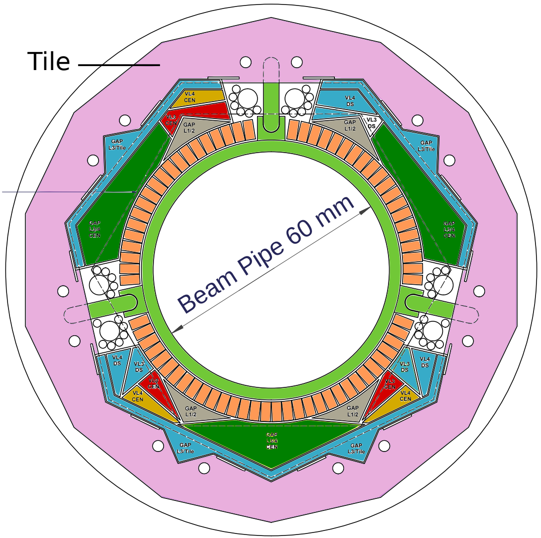
$\rightarrow$ Improve cooling system

- Building thermal-mechanical mock-up for future testing of the cooling system.
  - $\rightarrow$ Validate simulation results
  - $\rightarrow$ Study deformations of detector
  - $\rightarrow$ Study vibrations induced by the helium flow

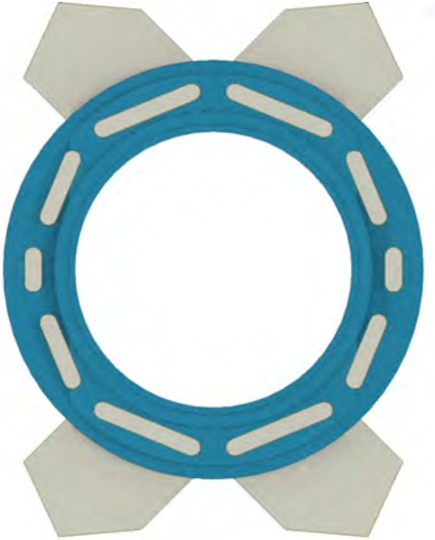
Deformation Inner Layer



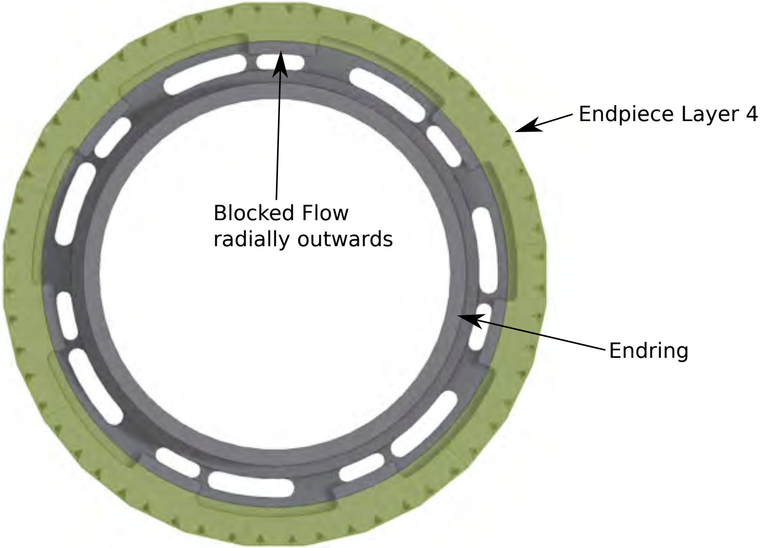
Tubing system



Inlet Inner Double Layer



Inlet Outer Double Layer



Pressure Drops

Circuit	Duct IN	Flange	Detector	Flange	Duct OUT
Gap L1/L2	25	7	<1	9	24
Gap L3/Scifi	6	<1	3	28	-
V-Folds L3	25-50	80-90	25	10-20	25-35
Gap L3/L4	8	25	<1	11	-
V-folds L4	30-50	60-70	10-20	50-70	20

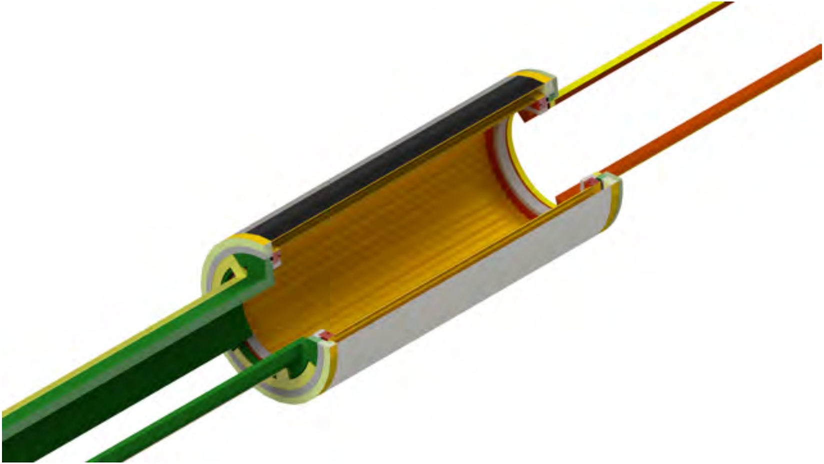
Pressures in millibar. Some flows vent into global volume.

Volumetric Flows

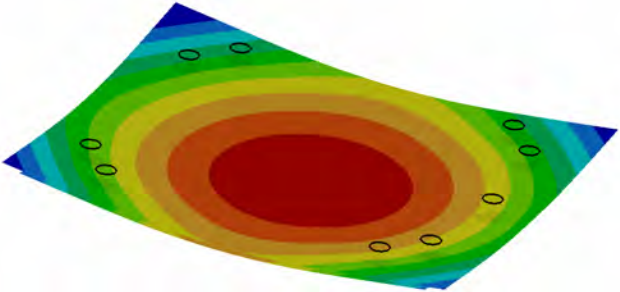
Flow channel	He flow speed $\mathrm{m\,s^{-1}}$	Cross-section $\mathrm{cm^2}$	Volumetric Flow $10^{-3}\,\mathrm{m^3\,s^{-1}}$
Gap L1/L2	10	12	12
Gap SciFi/L3	5	105	53
V-folds L3	20	$0.7 \times 24 \times 2$	20
Gap L3/L4	10	60	60
V-folds L3	20	$0.7 \times 28 \times 2$	23
Total		238	168

Inlet Outer Double Layer

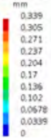
Inlet Outer Double Layer



Inlet Outer Double Layer



Height displacent



At border

by Thomas Mittelstaedt