CAST: CERN Axion Solar Telescope

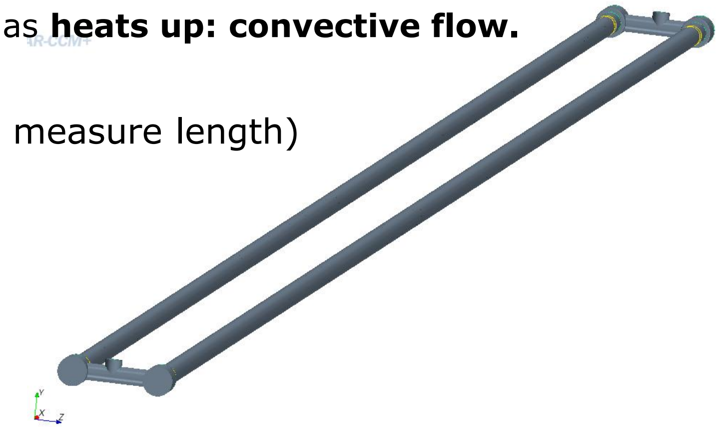
^{3}He Gas System CFD simulations

1. Technical Specifications: Gas System.
2. Problem Description.
3. Results.
4. Model Revision.
   - Validation
5. Summary.

Technical specifications: Gas System

CAST: detects **solar axions** → **LHC Magnet** Magnetic field**:** Conversion from **axions into X-Rays** occurs in **closed volume** filled with **^{3}He gas at low T (~1.8K) and low P (~10-100 mbar)**

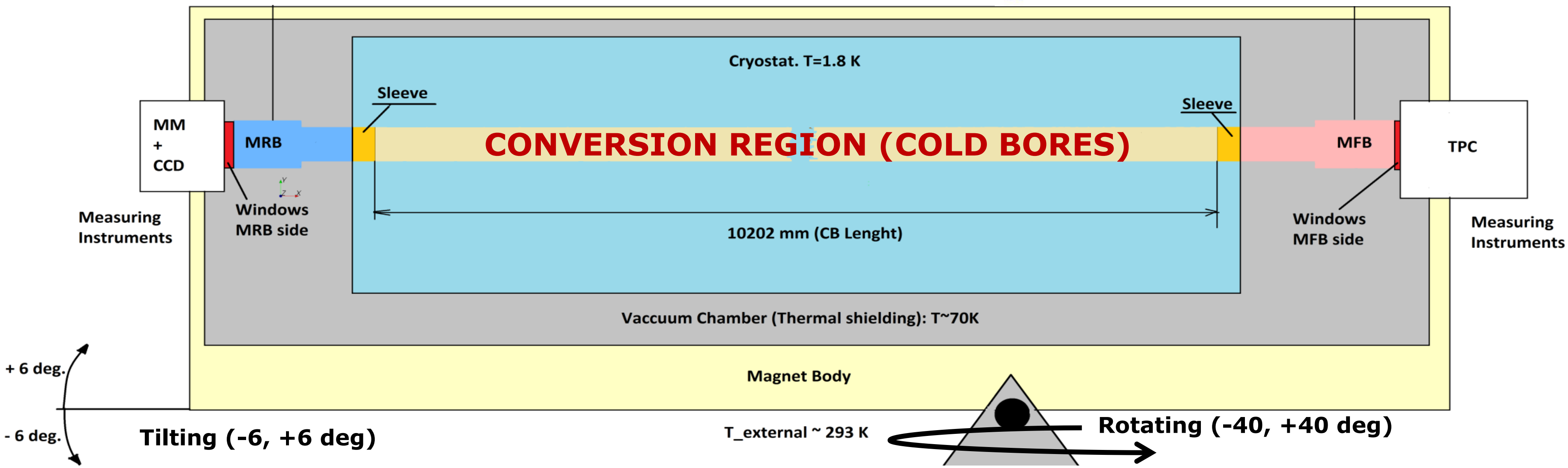
- Parts outside cryostat receive heat from environment → **^{3}He** gas **heats up: convective flow.**



REQUIREMENTS: uniform density field along CB's (Effective measure length)

TARGETS:

- Provide **^{3}He** density plots in CB's.
- Verify validity of existing CFD studies.
- Study model's movement: **tilting and rotation.**



Problem description: characteristics

- **Boundary conditions (BC's) not** known everywhere in the volume.
- **Uncertainty** of sensors

ASSUMPTIONS →

Choice of BC's determine the **accuracy** of the computed solution **compared** to the **real situation**

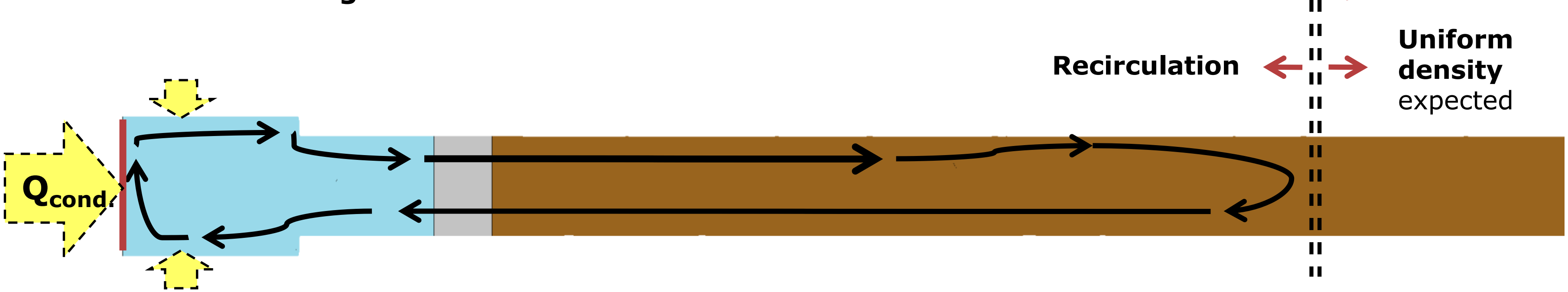
- Gas density **NOT ACTUALLY MEASURABLE** →

Problem aimed to **predict** the density field

- **Lack of experimental data**

Expected phenomena:

- Strong **buoyancy-driven flow** in **CB ends: $T_{windows}$, T_{Metal} >$T^{3}He$.**
- **Transitional regime.**



Problem description: gas physics

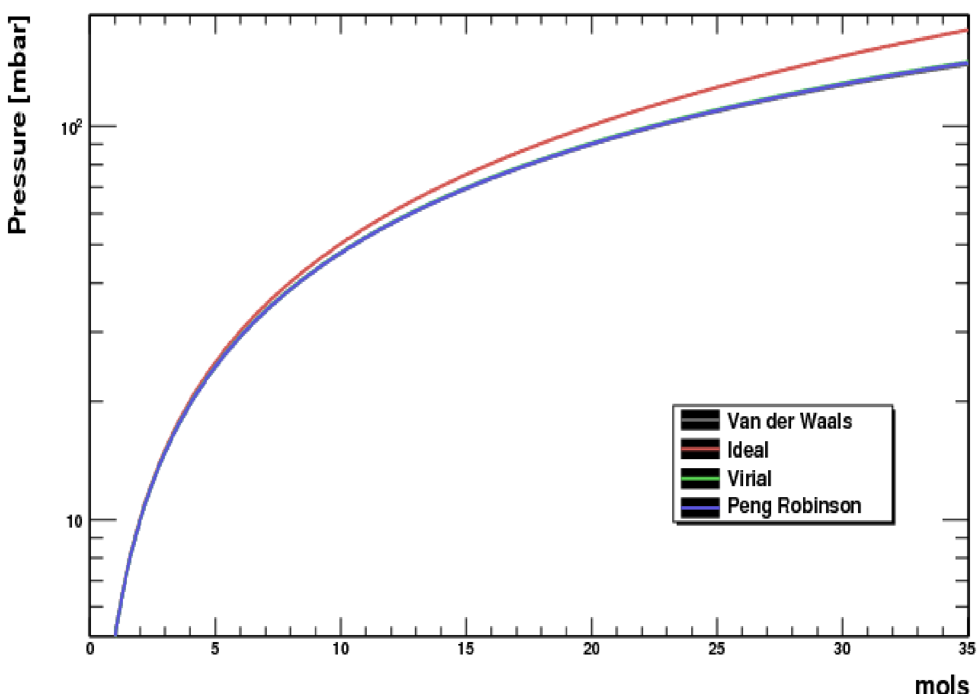
Reference ^{3}He conditions:

- **P_{Ref} <140 mbar**
- Static **T_{3He}** ~ 1.8 K

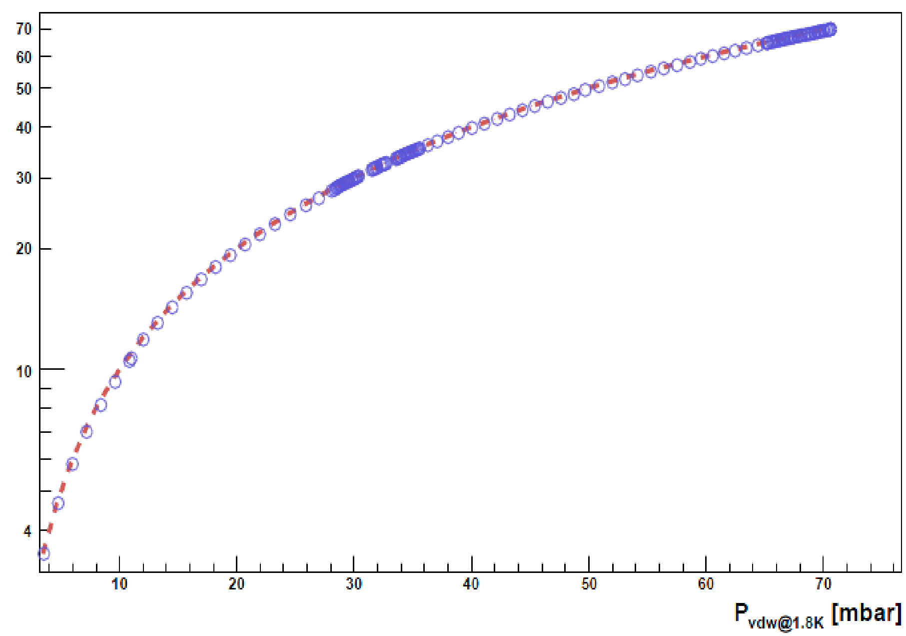
P, T far **from Ideal Gas range of applicability.**

Real Gas vs. **Ideal Gas**: eq. of state

- Virial Equation (physical description)
- Peng-Robinson.
- Van der Waals Model.



Comparing the four gas models.



*Drift between **Van der Waals** model **(red)** and **experimental data (blue)***

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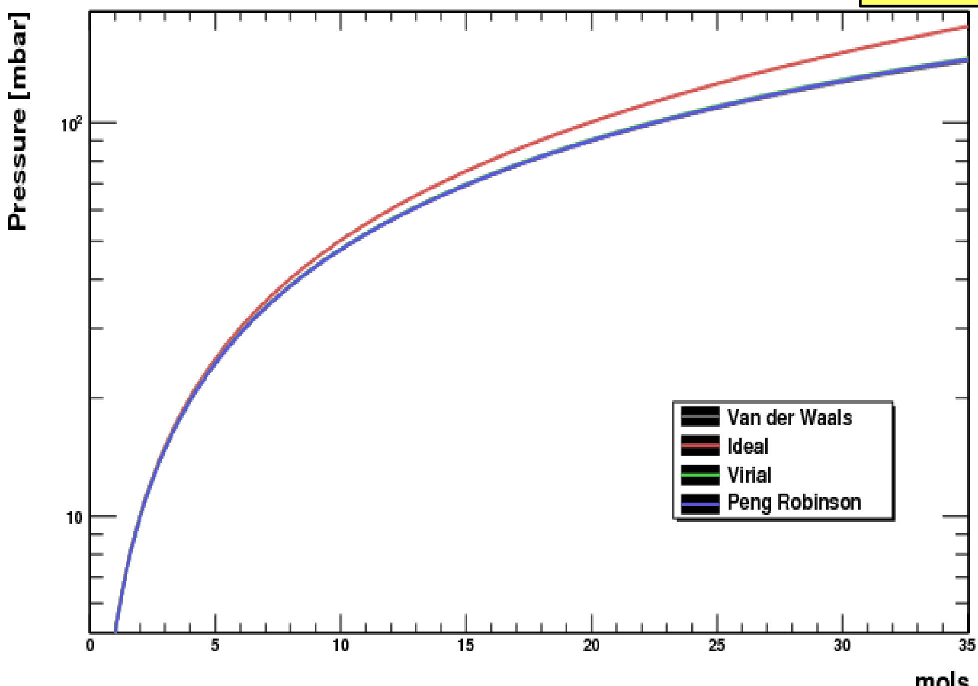
P, T far **from Ideal Gas range of applicability.**

Real Gas vs. **Ideal Gas**: eq. of state

- Virial Equation (physical description)
- Peng-Robinson.
- **Van der Waals Model.**

<1% drift between them.

Included in Star CCM+



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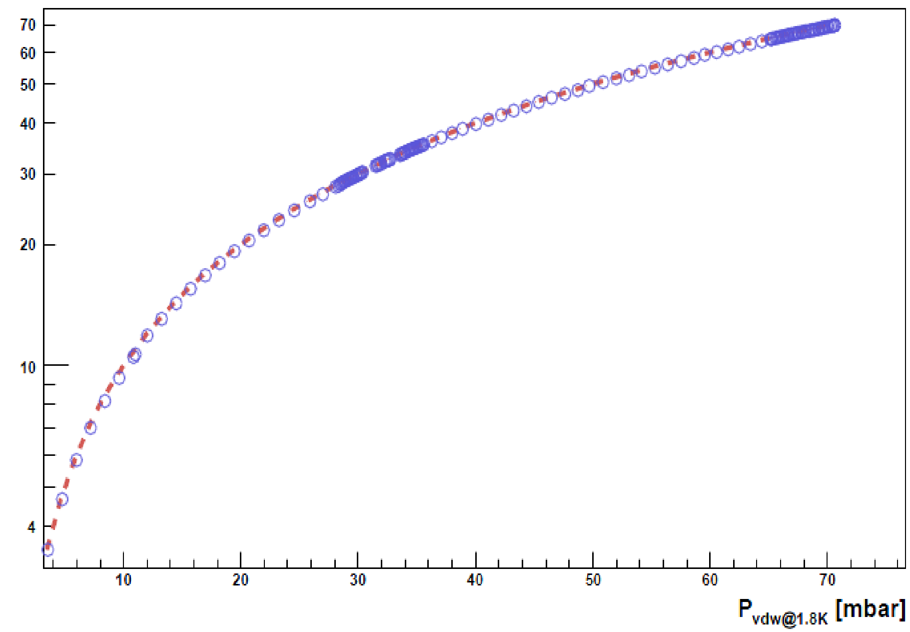
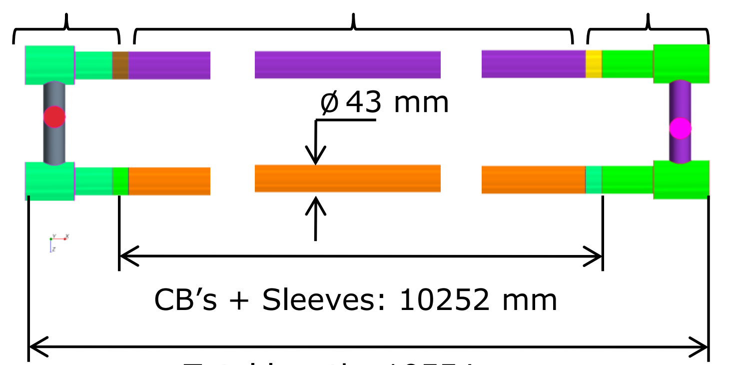
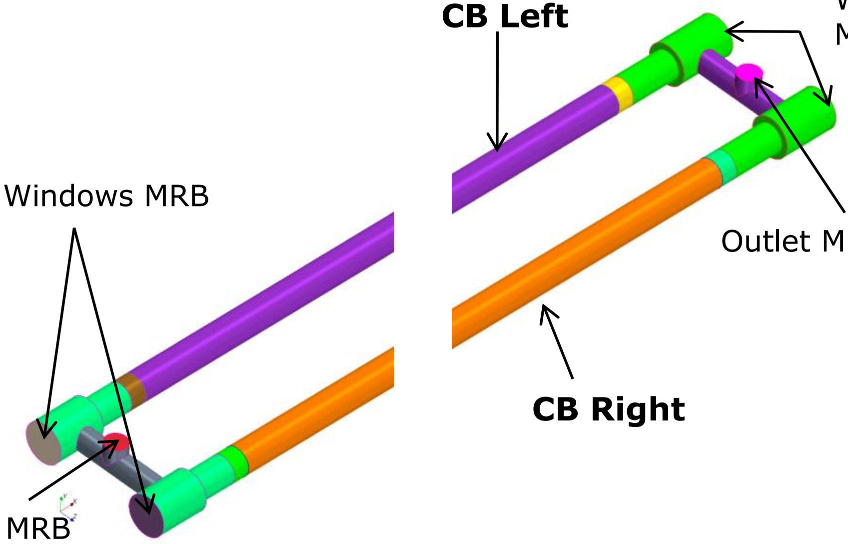


*Drift between **Van der Waals** model **(red)** and **experimental data** **(blue)***

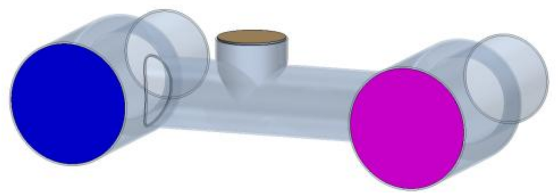
Problem description: pre-processing

Geometry:

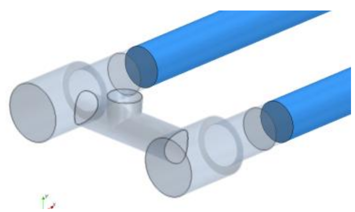




Boundary Conditions:

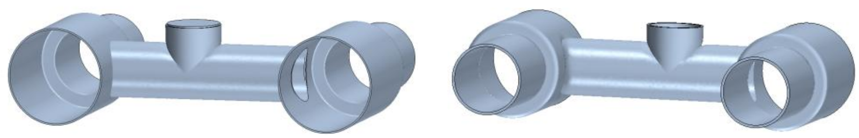


Windows: MRB=11.16 K; MFB=17.77 K



CB's (pipes): T=1.74 K

- As **a first approach** to the problem
- Check validity of previous **CFD studies**
- Achieve a **solution** for further simulations.

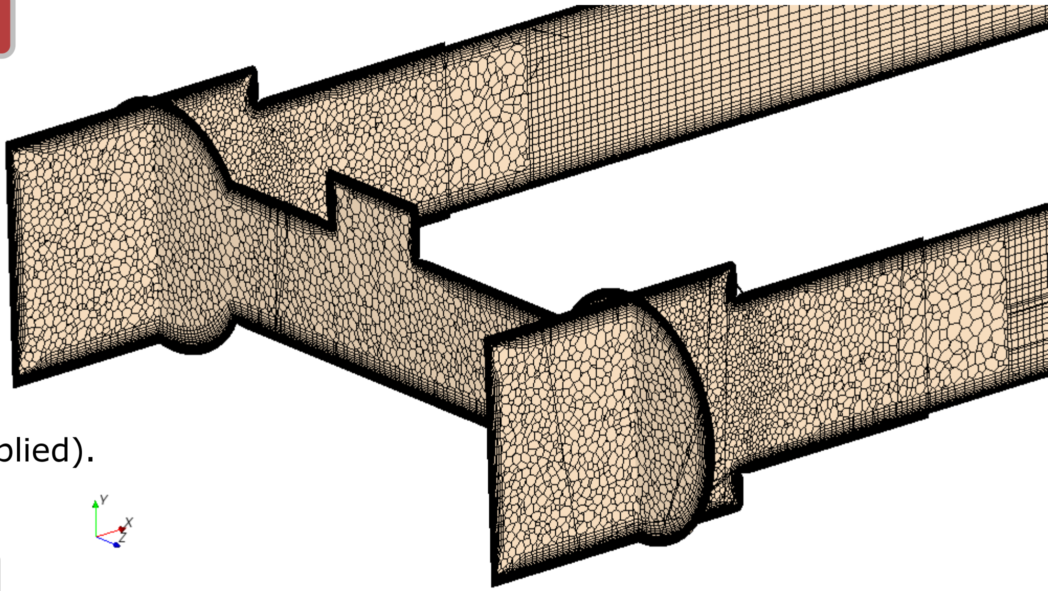


Metal thicknesses: *MRB:* 4.00 K *MFB:* 6.00 K

Problem description: pre-processing

Physics:

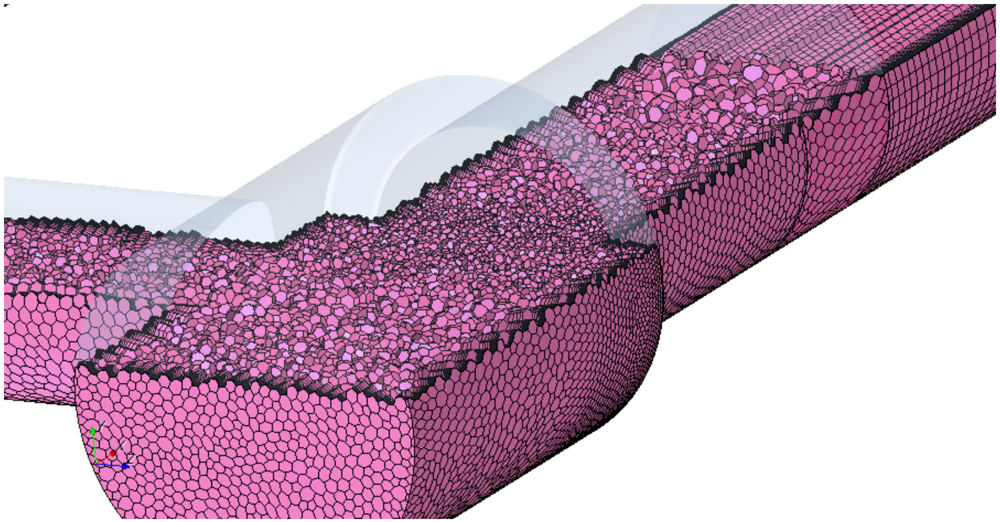
- Material properties = **f(T)**
- **Steady-state**.
- SST – K-omega turbulence model.
  - ➢ **Low-Re** approach
- Gravity (Natural Convection).
- **Coupled Solver.**
- Boundary layer solved (**no wall functions** applied).



Mesh:

- **Polyhedral mesh** in both ends.
- **CB's:** cylindrical extrusion.
- Windows and metal thicknesses: **extrusion**
- **Prism layer mesh** near walls in fluid domain:
  - 16-20 layers, 1,2 stretching factor.

➢ **Number of cells: 6.6M**

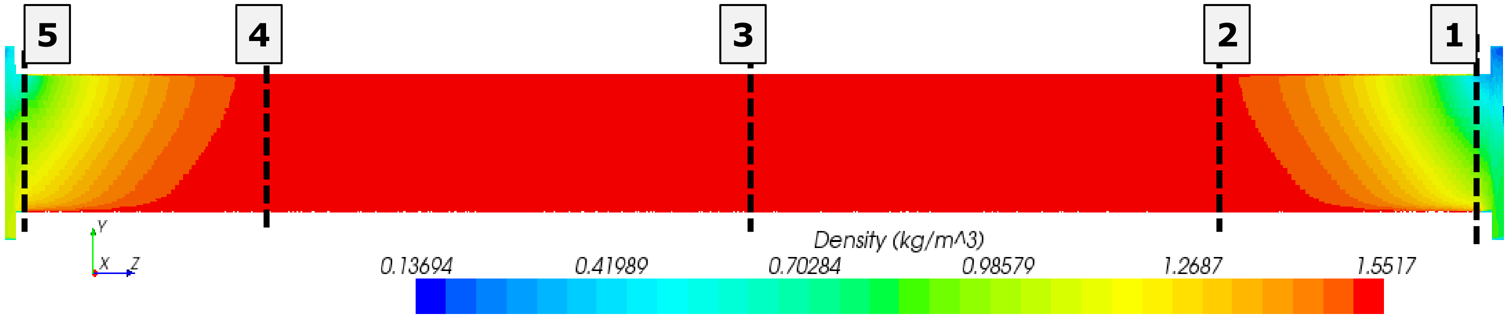


Results: density field

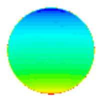
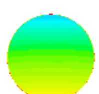
67 mbar

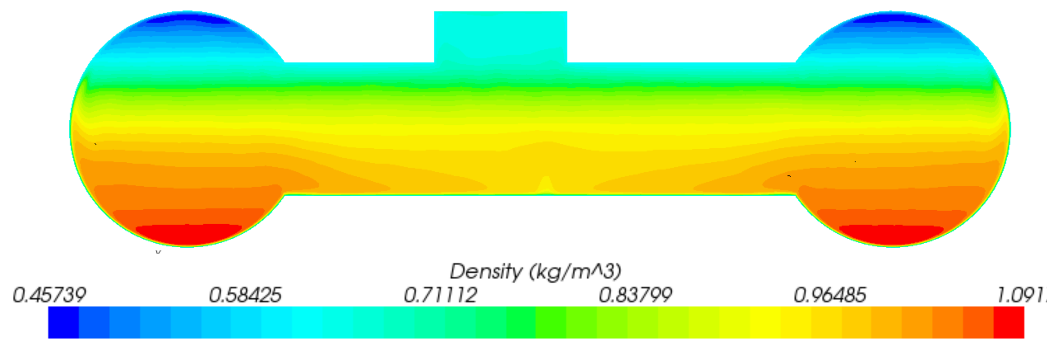
0 deg

(Horizontal)



Section along right CB (scaled in axial direction 1:30)

X (m)	Place	CB section ρ
10.362	CB end MFB	**1** 
8.362	CB @2m from MFB	**2** 
5.262	CB Center	**3** 
2.16	CB @2m from MRB	**4** 
0.16	CB end MRB	**5** 



Transversal Section in MRB volume.

Density in the centre of CB´s: 1.55 kg/m³

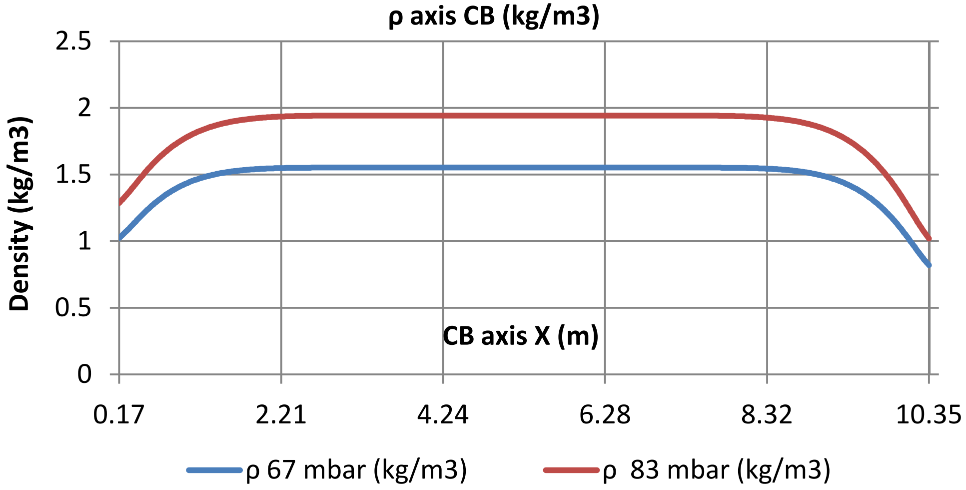
- **(P_{ref} = 83 mbar): 1.94 kg/m³**

$\rho = f(P_{ref})$

Results: validation

AXIAL DENSITY distribution

Desired ρ homogeneity: **$\Delta\rho = 10^{-3}$ kg/m³**

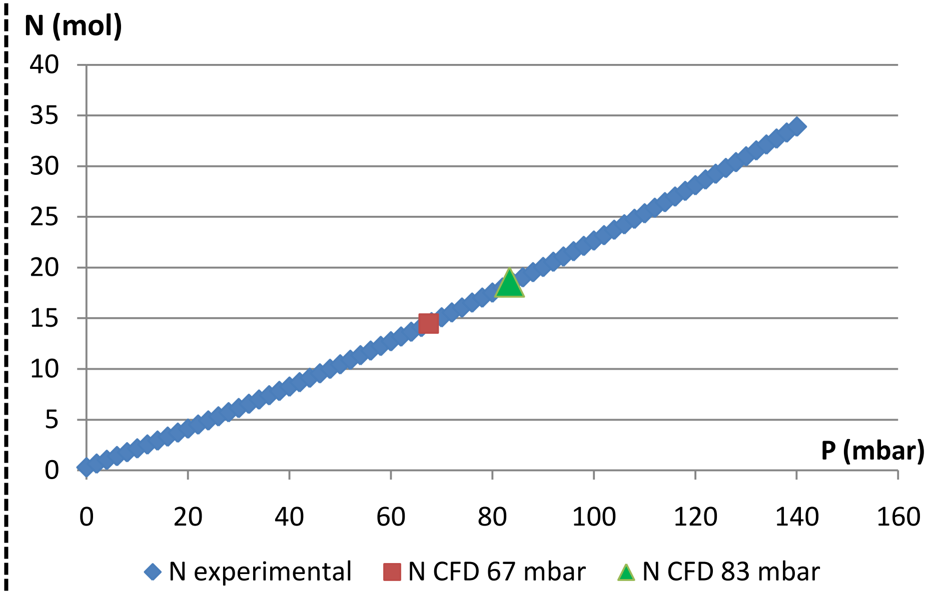


Ref P	L where < Δρ (m)	L(eff) (m)	|ΔL| (m)
67 mbar	**5,23**	6,87	**1,64**
83 mbar	**4,81**	6,67	**1,86**

$$L_{eff}(cm) = 778.6 - 1.33 * P_{VdV@1.8K}$$

Length where **$\Delta\rho = 10^{-3}$ kg/m³ SHORTER than expected using CAST's L_{eff} formula.**

MASS VALIDATION



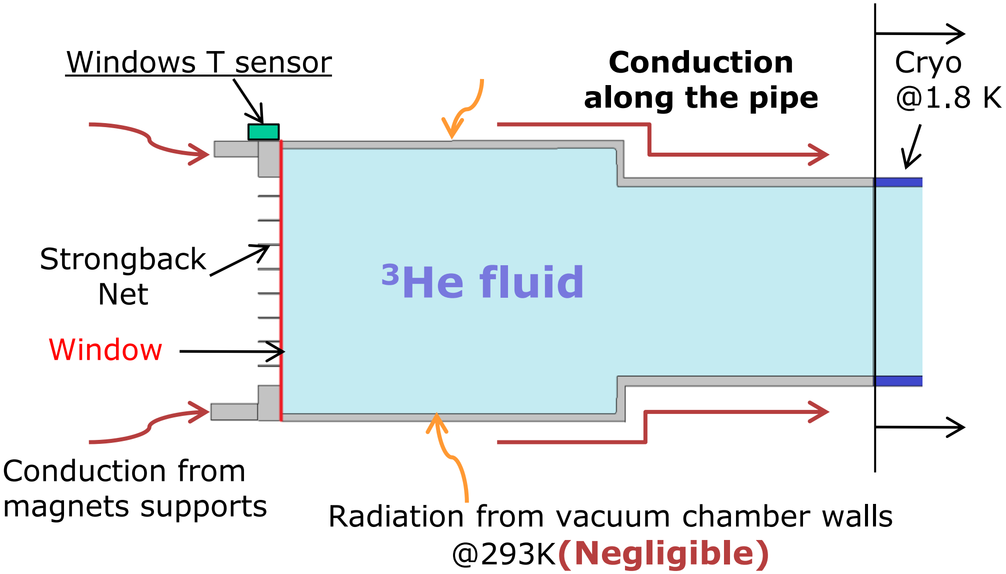
- **SOLUTION VALIDITY:**
  - **N (mols) experimentally** measured **vs. CFD** value.
  - **Error < 3%** for both reference Pressures
    - ACCURATE SOLUTION

Model Revision

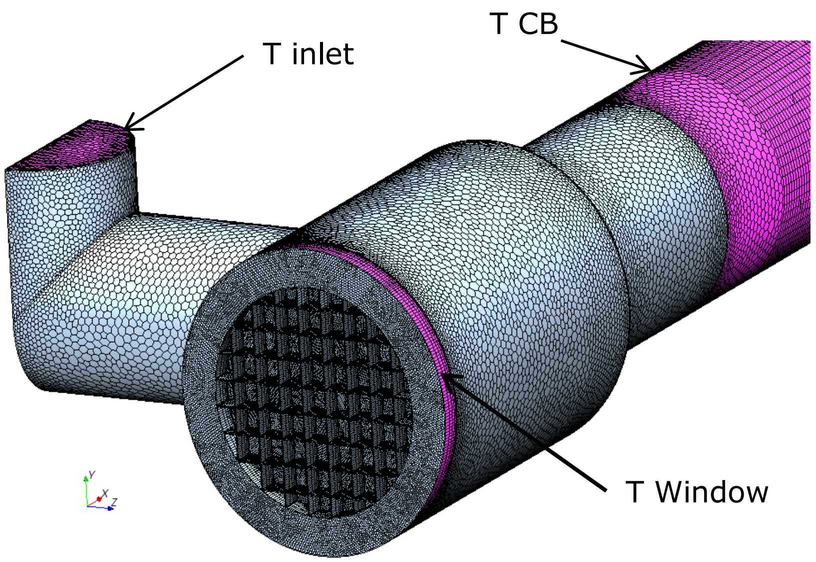
- **WHY?**
  - ➢ **Converged solution ≠ Accurate solution (depends on how the problem is defined)**
- **CONSIDERED MODEL REVISIONS:**

1. Check **Geometry & Boundary conditions**

❖ **Phenomena in real experiment:**



❖ **Applied BC's:**



2. Apply **SYMMETRY?**

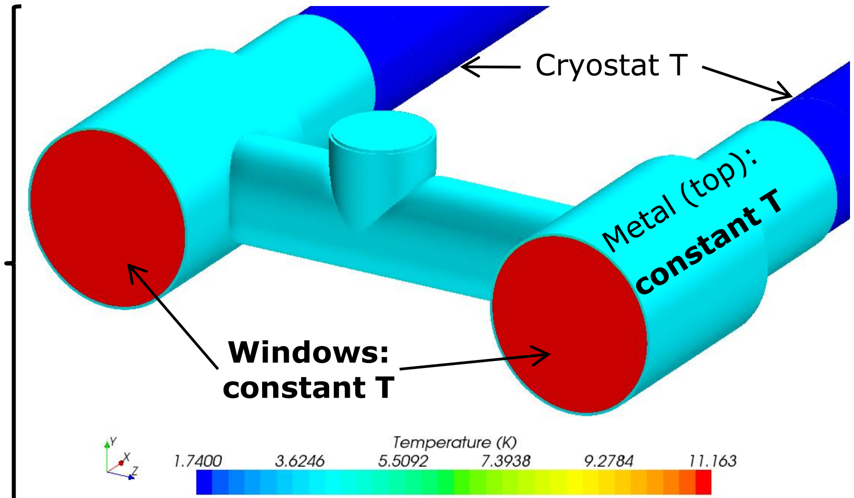
❖ **Symmetric BC's &** symmetry observed in previous simulations

❖ Slow **rotation (0.3 deg/min)** → Does not affect the gas **(CHECKED)**

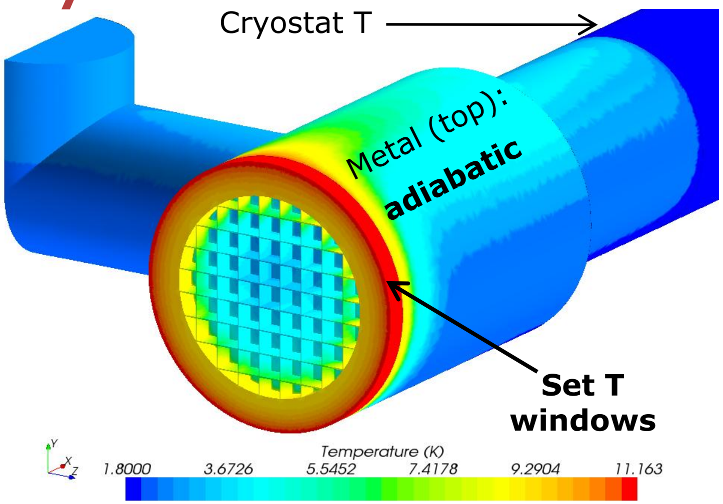
Save computation time

Model revision: boundary conditions

T map in Metal & Windows:



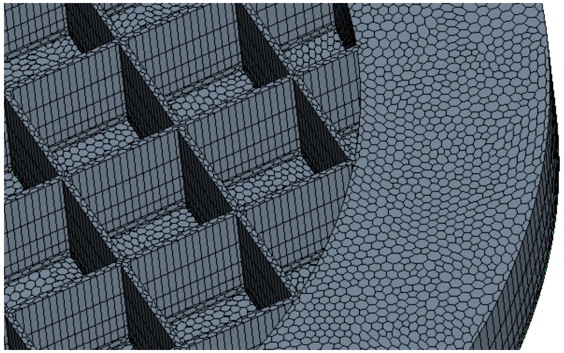
First model



Revised model

- **Computed solution = f(BC's): values and locations.**
  - **Same numbers, different assumptions → DIFFERENT SOLUTION**

- **MESH:**
  - Added metal Nets + coupling with Window foils
  - Improved where needed
  - **Number of cells: 6.85 M (~ N_{cells} 1st approach)**



Net mesh details.

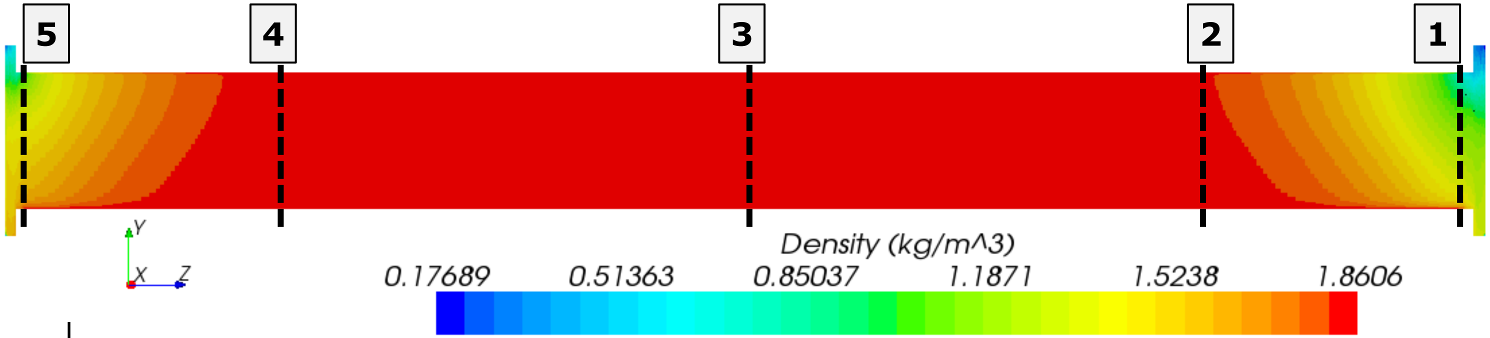
- Av. Running speed: **30s/it. @Cluster, NP: 32** for **~8300 its.**

Results: density field

83 mbar

0 deg

(Horizontal)



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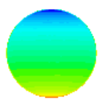
10.362	CB end MFB	1 
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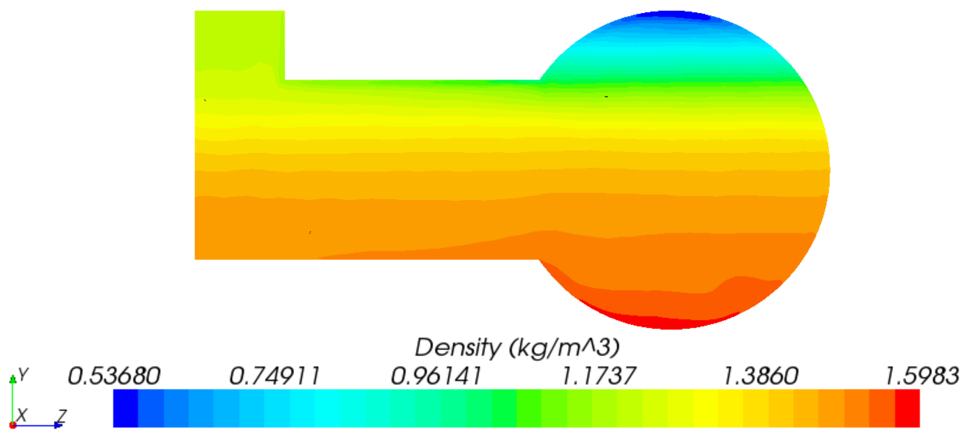


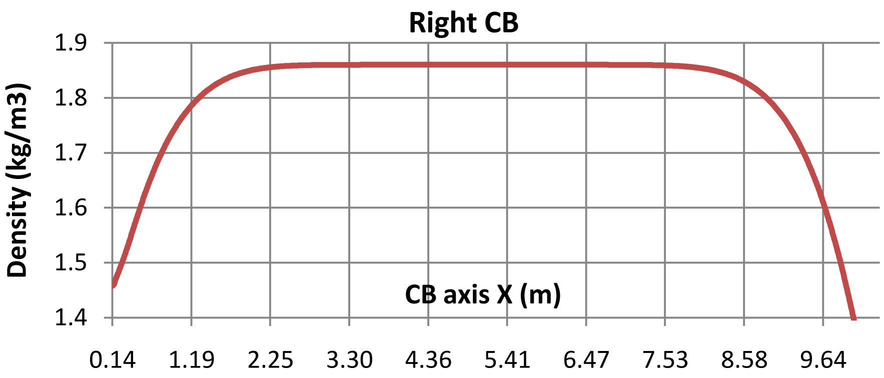
Transversal Section in MRB volume.

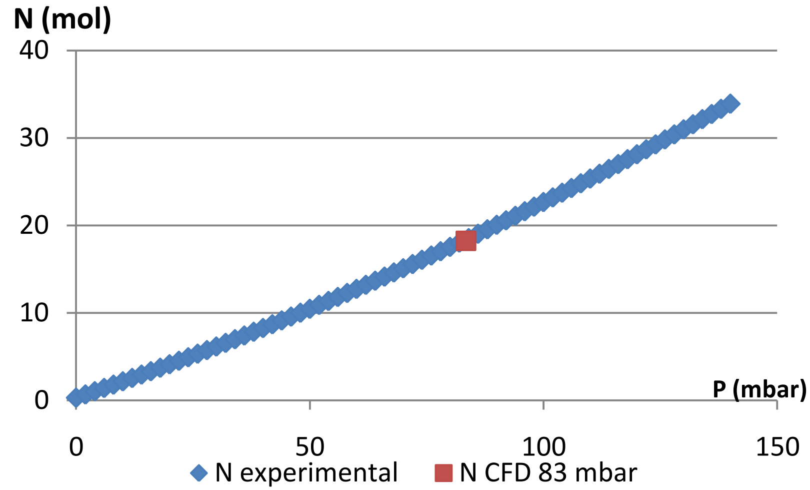
Density in the centre of CB´s: 1.86 kg/m³

- **Previous model @83 mbar: 1.94 kg/m³**

DIFFERENT!

Results: validation





- **DENSITY FIELD: SAME TREND**
  - $\rho_{CB\ centre}$ is **different** from first model!
- **SOLUTION VALIDITY: OK!**
  - **N (mols) experimental vs. CFD**

Model	Ref P	L where < Δρ (m)	L(eff) (m)	|ΔL| (m)
First	83 mbar	**4,81**	6.67	**1,86**
Revised		**4.80**		**1.87**

- **Error < 0.7%** **(FIRST MODEL < 3%)** → **Closer to real situation**

SUMMARY

- Better comprehension on the problem → Realistic approach to real system.
- **NEXT** → Perform requested **steady simulations** for tilted positions of the system (-6 to +6 deg).
- **Continuous improvement and revision on the model.**

CAST: CERN Axion Solar Telescope

^{3}He Gas System CFD simulations

THANK YOU FOR YOUR ATTENTION!