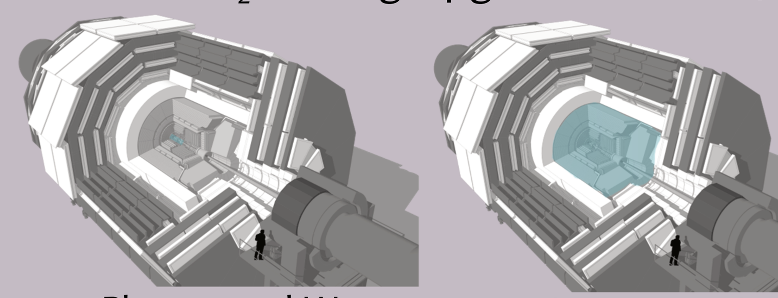
Performance measurements of a co-axial transfer line for 2-phase CO_2 HEP detector cooling

T. Pakulski CERN EP-CMX, CH-1211 Geneva 23, Switzerland

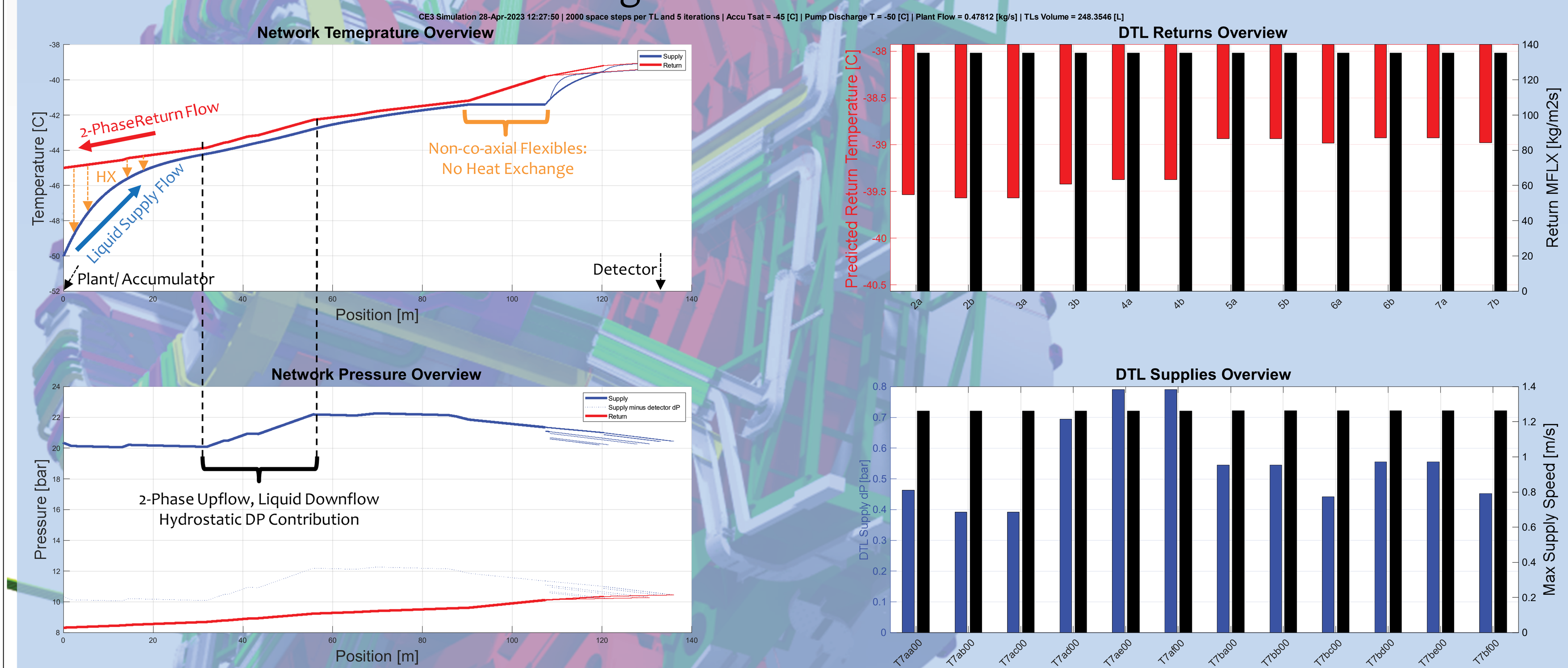
CMS CO_2 Cooling Upgrade for Run 4



Background – Phase-2 CO_2 Cooling Transfer Lines

Phase-2 CMS detectors require an order-of-magnitude increase in 2PACL (2-Phase Accumulator-Controlled Loop) CO_2 cooling capacity while operating roughly 20°C colder than legacy systems [1]. The 2-phase pressure drop and supply-return heat transfer through the co-axial transfer lines that will route CO_2 to the new detectors has a direct impact on cooling performance. A tool was therefore developed to simulate the performance of these transfer lines, as shown below, based on the CoBra library [2] of empirical correlations. But future systems' low saturation temperatures (<-35°C), large-diameter co-axial design, and long routings – including about 20 m of vertical 2-phase up-flow – entail significant modelling uncertainties when relying on empirical correlations with limited validation in these ranges.

TK2 (Tracker) 2PACL System
4" MTL : ~20 m Vertical



Example Transfer Line Network Performance Simulation – CE3 2PACL System

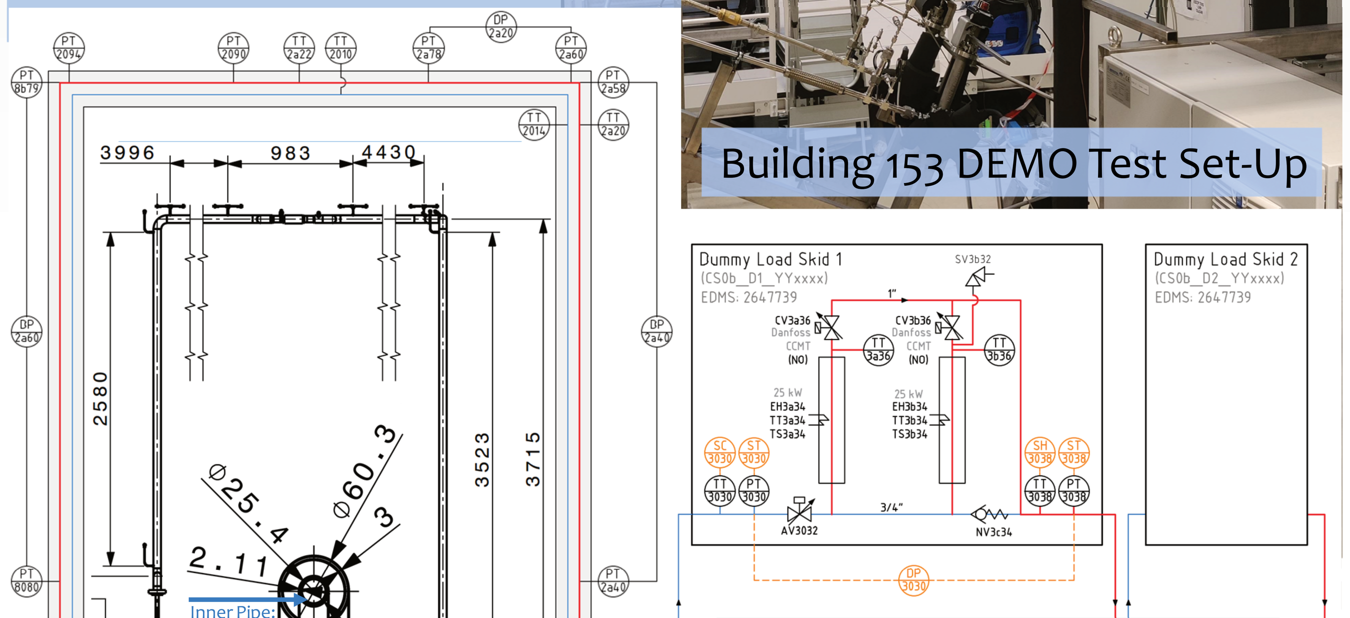
This poster summarizes preliminary performance measurements of a prototype Phase-2 CMS Main Transfer Line (MTL) connected to DEMO, a prototype Phase-2 2PACL system [1]. It then evaluates the performance of various adiabatic 2-phase DP models that are critical for correct sizing of future CMS transfer lines.

Acknowledgments
Thanks to B. Verlaat, V. Bhanot, J. Noite, and other CERN EP-DT colleagues for the CoBra library and access to DEMO data.
Transfer line routing 3D model in background courtesy of C. Penadés CERN EP-CMX.

DEMO Transfer Line

DEMO is connected to a dummy load by a foam-insulated prototype 4" Phase-2 CMS MTL. It includes horizontal, vertical upflow and downflow sections, and is instrumented for temperature, absolute & differential pressures. DEMO enables measurements at Phase-2 temperatures, flow rates and vapor qualities.

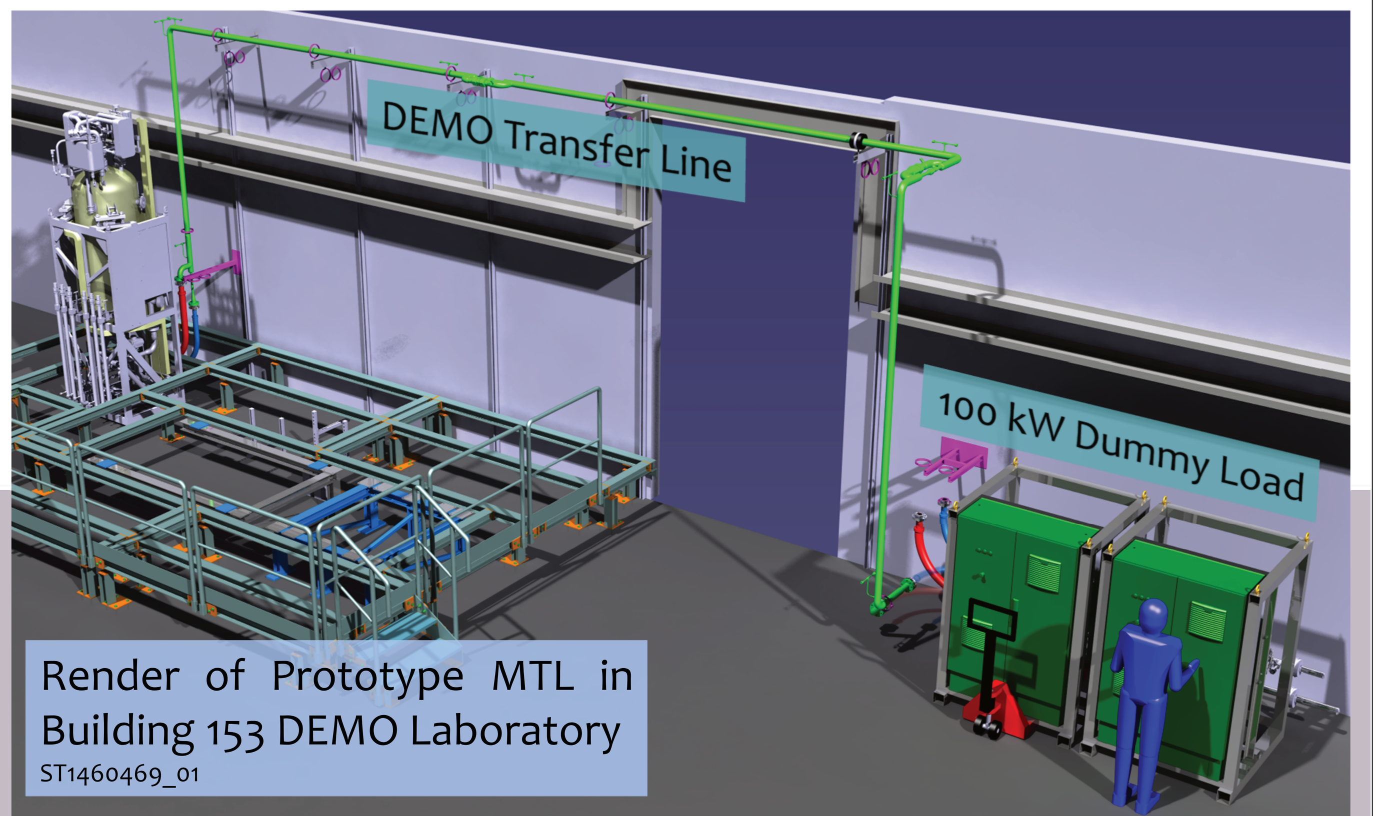
Building 153 DEMO Test Set-Up



P&ID: EDMS 234140
V. Bhanot CERN EP-DT

DEMO MTL Return Line Test Parameter Ranges

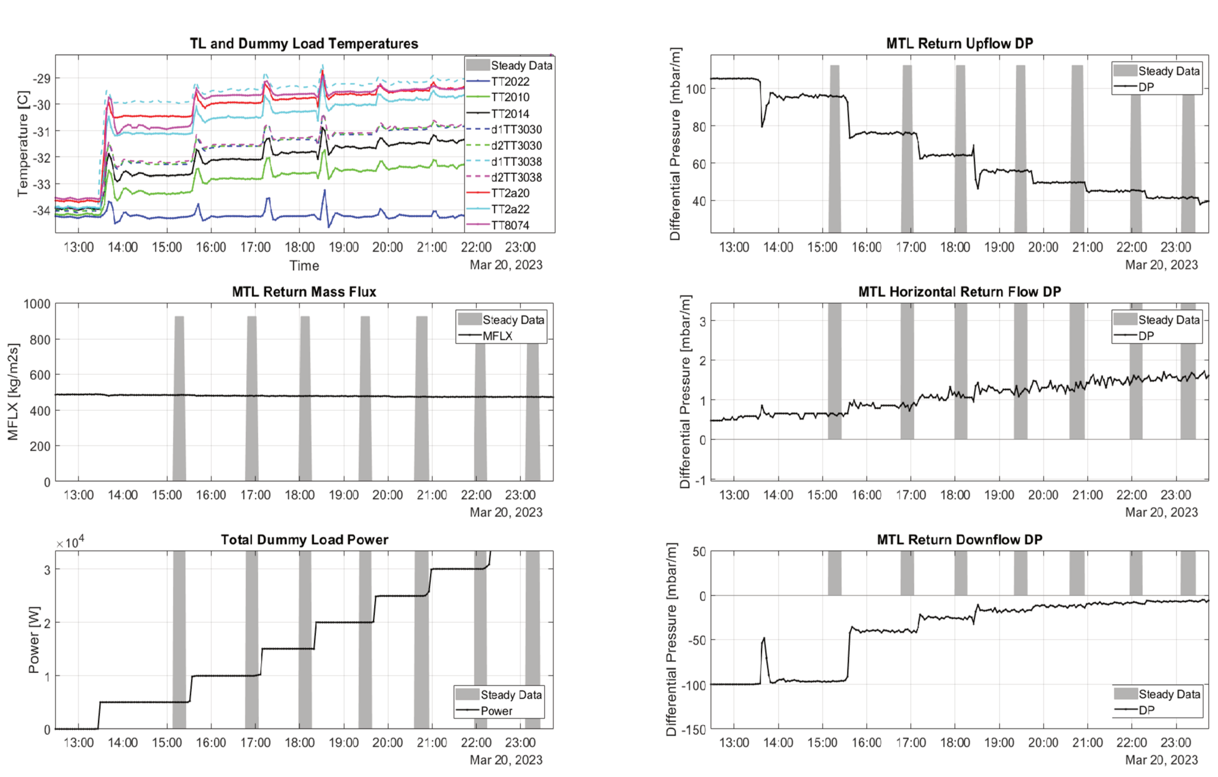
Temperature	-50°C to +6°C
Mass Flux	220 – 640 kg/m²s
Vapor Quality	0 – 96 %



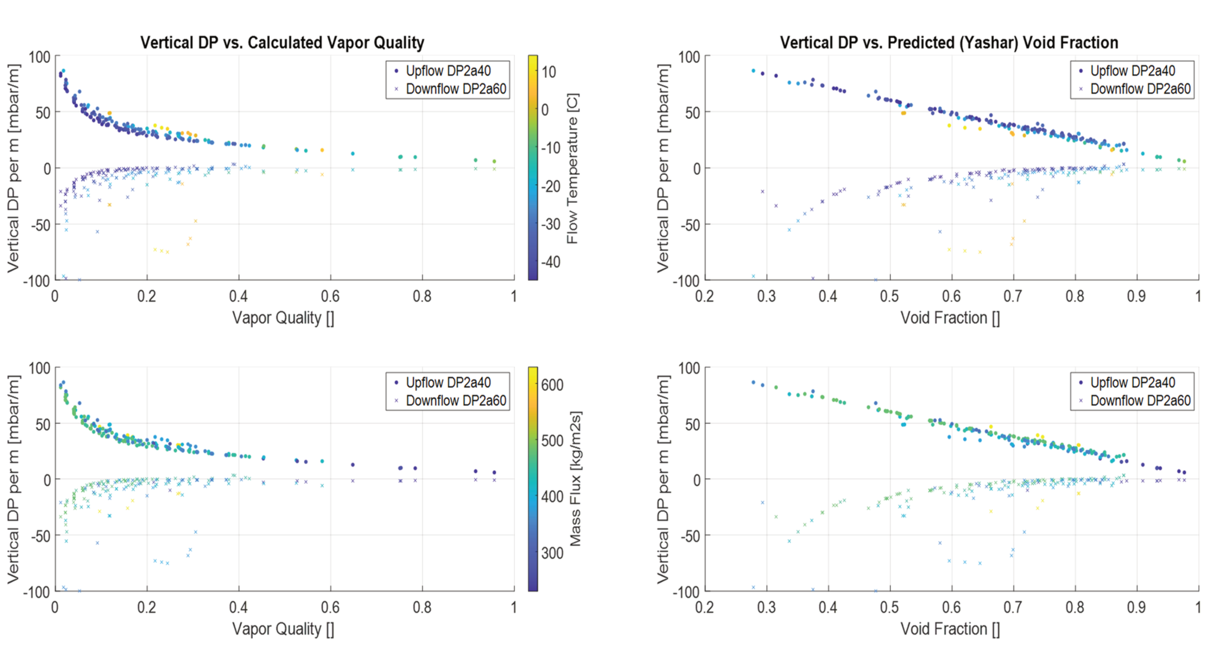
Render of Prototype MTL in Building 153 DEMO Laboratory
ST1460469_01

Overview of Measurements

Steady-state data (marked in grey below) was retroactively identified within long-term DEMO performance data. High-sampling-rate data was extracted from each of about 200 steady-state intervals and averaged to yield unique system states for analysis. Typical steady-state interval lasted 15 minutes

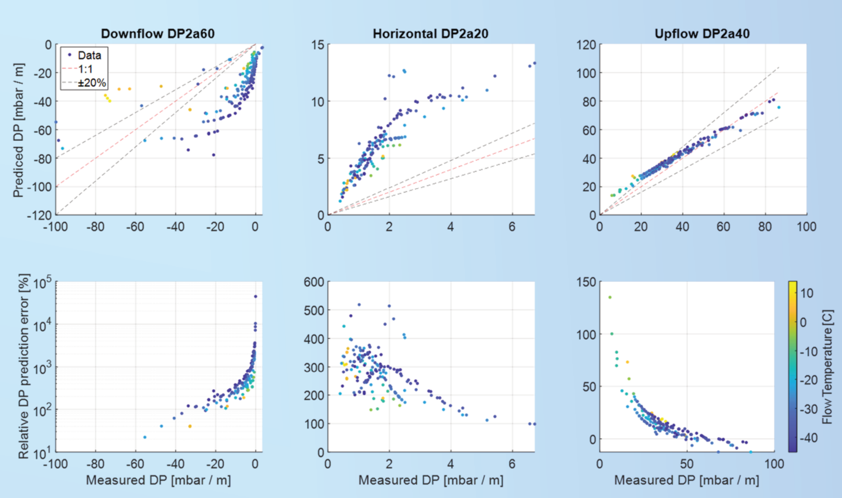


The overview of steady-state vertical DP measurements 2-phase density driving the hydrostatic DP, as indicated by previous research. [3] The 2-phase upflow DP is linear with predicted void fraction, due to the relatively low frictional component in the present mass flux range.
2-Phase downflow is more difficult to predict, in line with previous attempts [3]. Associated pressure recovery has therefore been neglected so far in transfer line performance simulations.

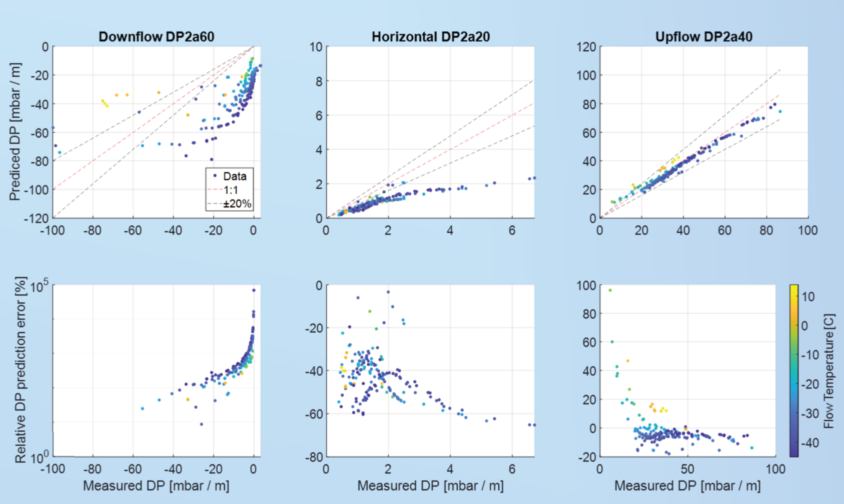


DP Model Performance

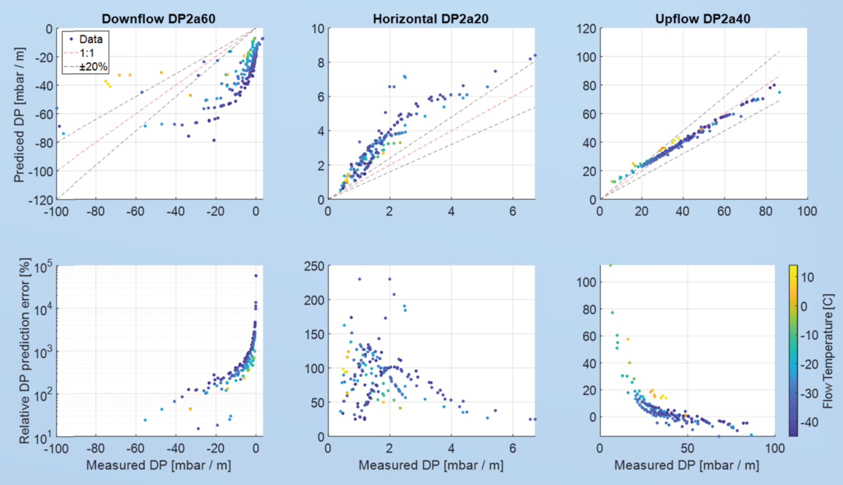
Frictional DP: Friedel Correlation [5] with correction factor 1.5 [4]
Static DP: Yashar Void Fraction Correlation [8]
Model now used for transfer line simulations, neglecting downflow DP



Frictional DP: Müller-Steinhagen & Heck Correlation [6]
Static DP: Yashar Void Fraction Correlation [8]



Frictional DP: Owens Correlation [7]
Static DP: Yashar Void Fraction Correlation [8]



Discussion

2-phase DP prediction models used for Phase-2 transfer lines design perform well in upflow, but significantly overpredict horizontal flow and are of little use for modelling downflow. The resulting DP error yields conservative detector saturation temperature estimates.

The Müller-Steinhagen & Heck model with good recent performance in horizontal flow [3] underpredicted DP on the present set-up, possibly due to the pipes' co-axial configuration. Owens' correlation [5] for frictional DP looks like a promising option for modelling the co-axial line, but requires further evaluation.

Outlook

While the test set-up has yielded unique opportunistic data on 2-phase co-axial DP, dedicated tests will be needed to validate these findings in real phase-2 detector conditions. Horizontal 2-phase DP models have significant room for improvement, though they appear conservative so far. Several potential factors in prediction errors, notably flow patterns and co-axial configuration, remain to be examined. A separate analysis evaluating heat exchange models will also need to be conducted.

References *Analysis code available at https://gitlab.cern.ch/CO2/153_co-ax*

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2. Verlaat, B., Noite, J. , *Design Considerations of Long Length Evaporative CO_2 Cooling Lines.* 10th IRR Gustav Lorentzen Conference on Natural Refrigerants, GL-209, 2012
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Forum on Tracking Detector Mechanics 2023 Indico 1228295
May 31-June 2 –Eberhard Karls Universität Tübingen

Tym.Pakulski@cern.ch
https://ep-dep.web.cern.ch/organisation/cms