The Polarized Target at the CBELSA/TAPS Experiment

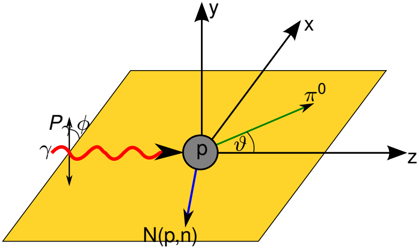
SPIN 2018 Ferrara

Stefan Runkel

on behalf of the CBELSA/TAPS collaboration

Physikalisches Institut - Universität Bonn

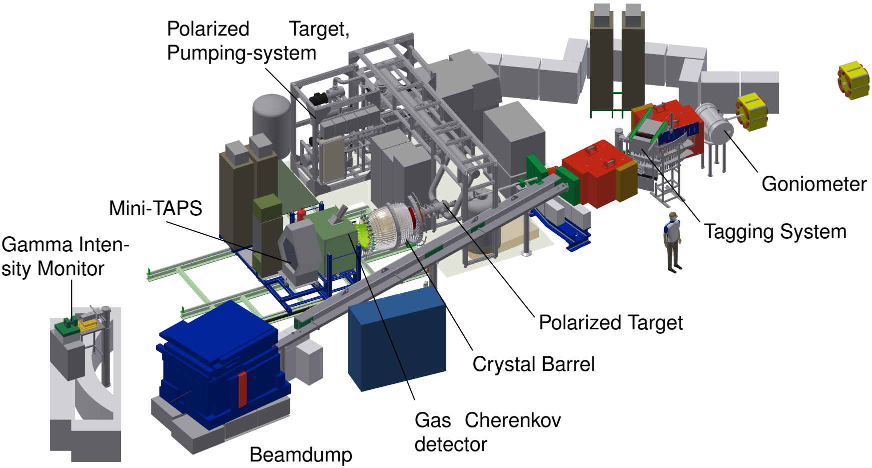
11th September, 2018



γ		Target		
		x	y	z
Unpolarised	$\boldsymbol{\sigma}$	0	**T**	0
Linear pol.	$-\boldsymbol{\Sigma}$	**H**	$-$**P**	$-$**G**
Circular pol.	0	**F**	0	$-$**E**

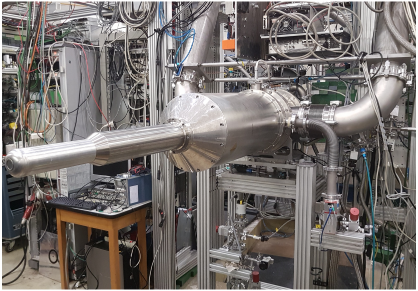
$$
\begin{aligned}
\frac{d\boldsymbol{\sigma}}{d\Omega}(\vartheta,\ \phi) = \frac{d\boldsymbol{\sigma}}{d\Omega}(\vartheta)\,[1 &- P_T\boldsymbol{\Sigma}(\vartheta)\cos(2\phi) \\
&+ P_x\left(-P_T\mathbf{H}(\vartheta)\sin(2\phi) + P_\circ\mathbf{F}(\vartheta)\right) \\
&- P_y\left(P_T\mathbf{P}(\vartheta)\cos(2\phi) - \mathbf{T}(\vartheta)\right) \\
&- P_z\left(-P_T\mathbf{G}(\vartheta)\sin(2\phi) + P_\circ\mathbf{E}(\vartheta)\right)].
\end{aligned}
$$

CBELSA/TAPS



Polarized Target, Pumping-system
Goniometer
Mini-TAPS
Tagging System
Gamma Intensity Monitor
Polarized Target
Crystal Barrel
Gas Cherenkov detector
Beamdump

CBELSA/TAPS - Polarized Target



Work in 2017

- Merging the Dubna/Mainz and Bonn Systems.

February Transport of the cryostat, the ^3He-system, temperature measurement to Bonn.

- Connecting the vacuum system.
- Leak test at room temperature.
- Change Front part of the cryostat.
- Implement the Dubna/Mainz DAQ in the Bonn system.
- ...

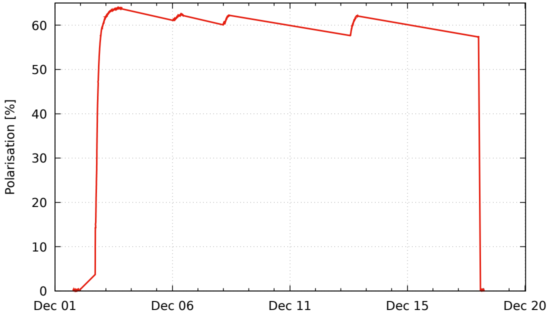
May First cooling test, $T_{min} = 60\,\mathrm{mK}$.

September Test of all components, $T_{min} < 30\,\mathrm{mK}$ $P_{\mathrm{max}} \approx 45\,\%$.

December First measurement.

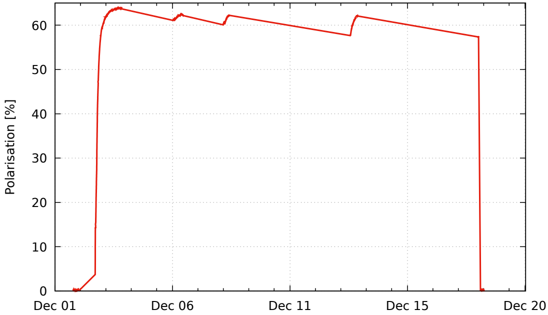
- Dubna: Y. Usov, N. Borisov, I. Gorodnov et al. Mainz: A. Thomas et al. Bochum: G. Reicherz. Bonn: S. Goertz, H. Dutz, S. Runkel et al

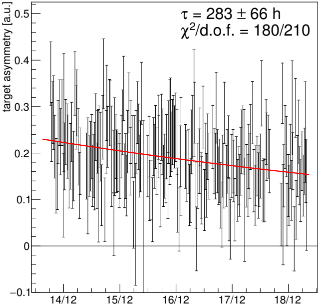
Target Polarization and Beam Heating - December 2017



- Butanol doped with 0.5 % TEMPO.
- t_{rel} =1000 h to 1500 h.
- $P_{max} \approx 63\,\%$.
- Higher concentration of TEMPO?
- Butanol doped with 1 % TEMPO reached a maximum polarization of $\approx 70\,\%$.
- Change of the radical?

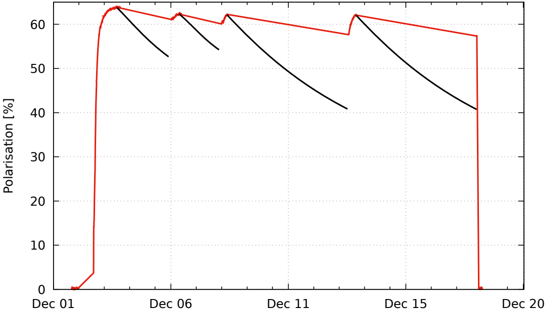
Target Polarization and Beam Heating - December 2017

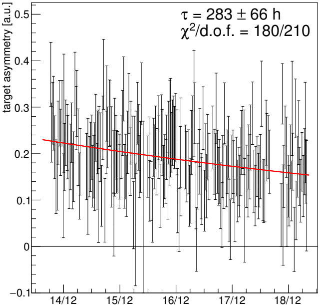




- NMR coil at the edge of the container.
- The polarization lost due to the beam was not measured with the NMR system.

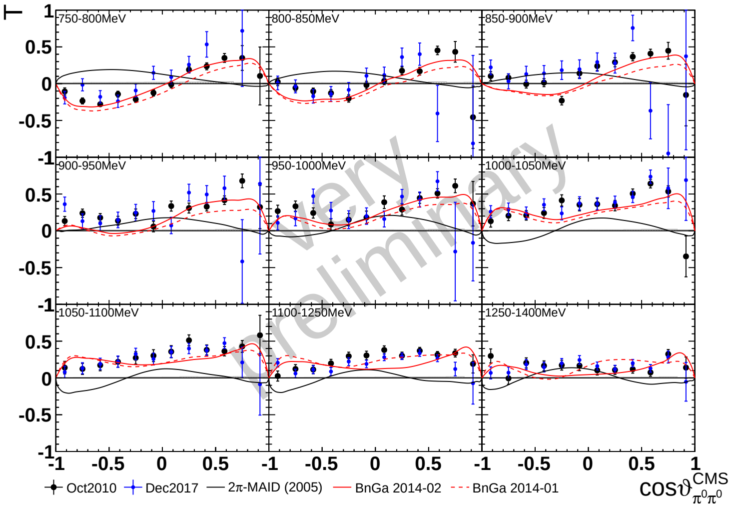
Target Polarization and Beam Heating - December 2017





- NMR coil at the edge of the container.
- The polarization lost due to the beam was not measured with the NMR system.
- Change of the geometry for the NMR coil.

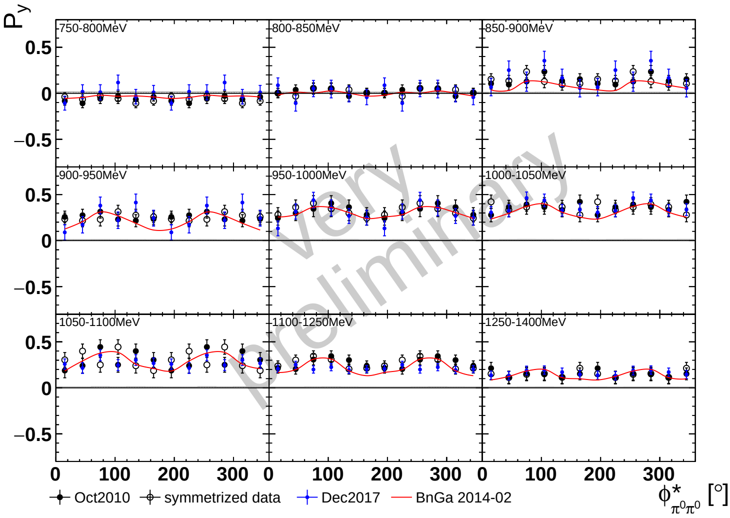
A First Look into the $2\pi^0$ Channel



- Less than two weeks of beamtime.
- No dilution factor.
- Preliminary calibration.

T. Seifen et al.

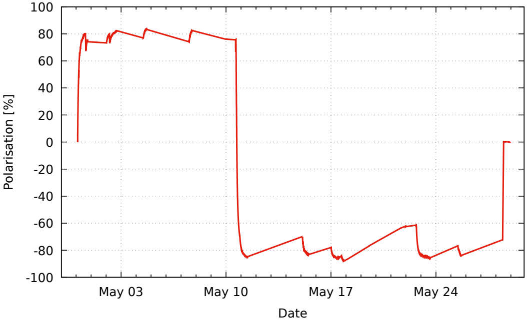
A First Look into the $2\pi^0$ Channel



- Less than two weeks of beamtime.
- No dilution factor.
- Preliminary calibration.

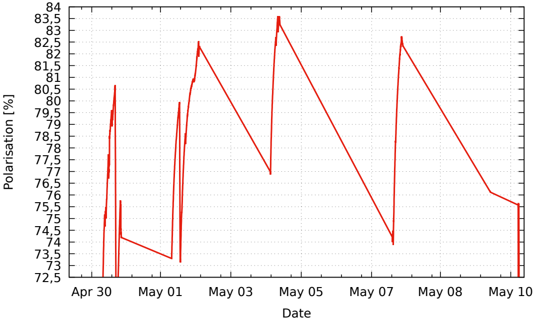
T. Seifen et al.

Target Polarization and Beam Heating - May 2018



- Butanol doped with 0.45 % Porphyrexide.
- $P_{\text{max}\,+} \approx 83\,\%$,
  $P_{\text{max}\,-} \approx 86\,\%$,
  $\tau_{\text{rel, without beam}} \approx 1800\,\text{h}$,
  $\tau_{\text{rel, with beam}} \approx 500\,\text{h}$.
- Coil wound through the Target container and the beam axis.
- Difference in the relaxation time with and without beam can be seen directly.

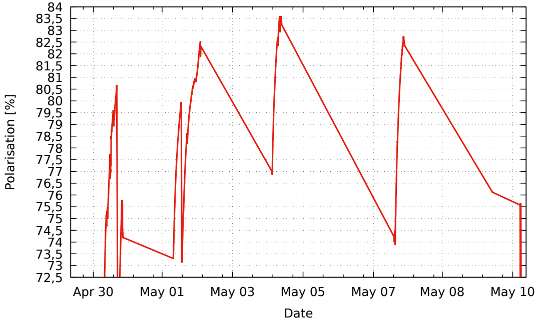
Target Polarization and Beam Heating - May 2018



- Butanol doped with 0.45 % Porphyrexide.
- $P_{\text{max}\,+} \approx 83\,\%$,
  $P_{\text{max}\,-} \approx 86\,\%$,
  $\tau_{\text{rel, without beam}} \approx 1800\,\text{h}$,
  $\tau_{\text{rel, with beam}} \approx 500\,\text{h}$.
- Coil wound through the Target container and the beam axis.
- Difference in the relaxation time with and without beam can be seen directly.
- Two possibilities:
  - Reduce the beam intensity,
  - Increase the temperature.

Target Polarization and Beam Heating - May 2018

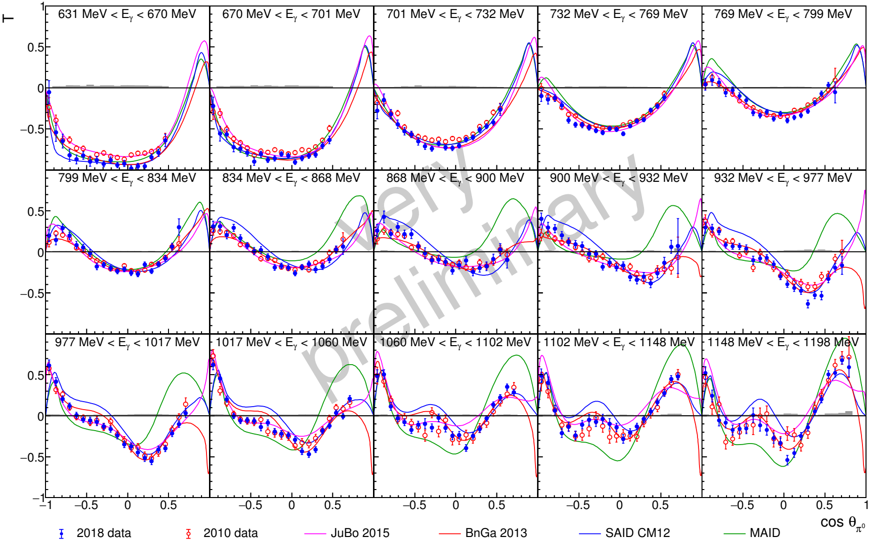
UNIVERSITÄT BONN



- Butanol doped with 0.45 % Porphyrexide.
- $P_{\text{max}\,+} \approx 83\,\%$,
  $P_{\text{max}\,-} \approx 86\,\%$,
  $\tau_{\text{rel, without beam}} \approx 1800\,\text{h}$,
  $\tau_{\text{rel, with beam}} \approx 500\,\text{h}$.
- Coil wound through the Target container and the beam axis.
- Difference in the relaxation time with and without beam can be seen directly.

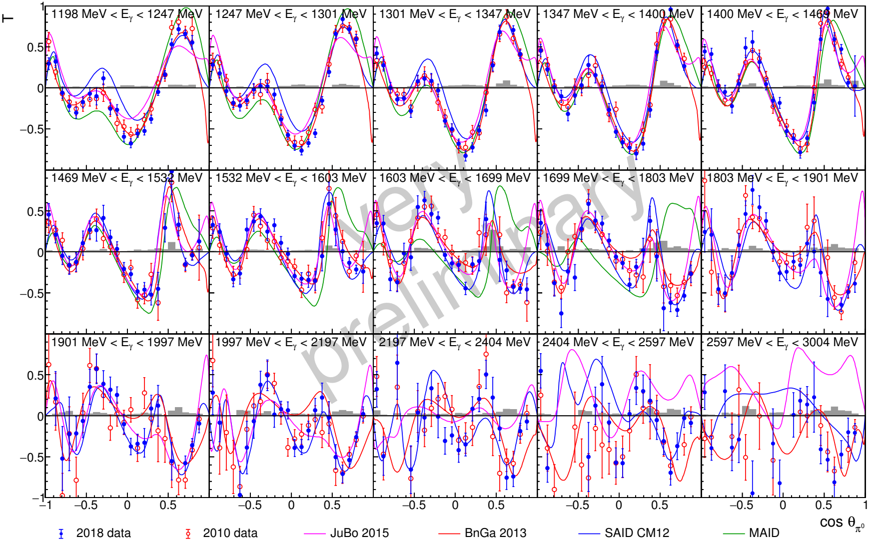
- To minimize the beam heating effect, the temperature of the helium bath in the mixing chamber was increased to 27 mK.
- Next measurement with D-Butanol start in October. Two production runs planned in 2019.

$\gamma p \rightarrow \pi^0 p$, Target Asymmetry



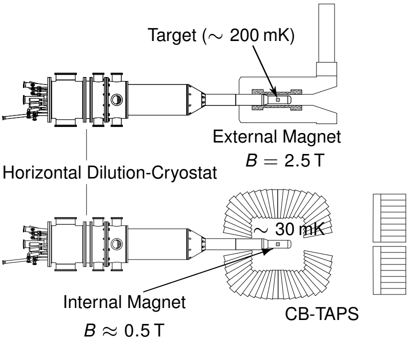
J. Hartmann et al.

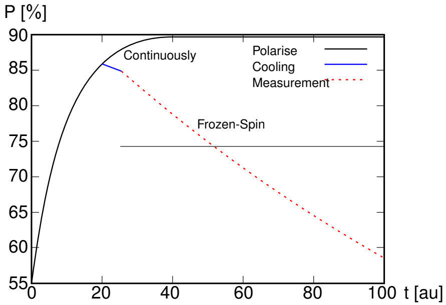
$\gamma p \rightarrow \pi^0 p$, Target Asymmetry



J. Hartmann et al.

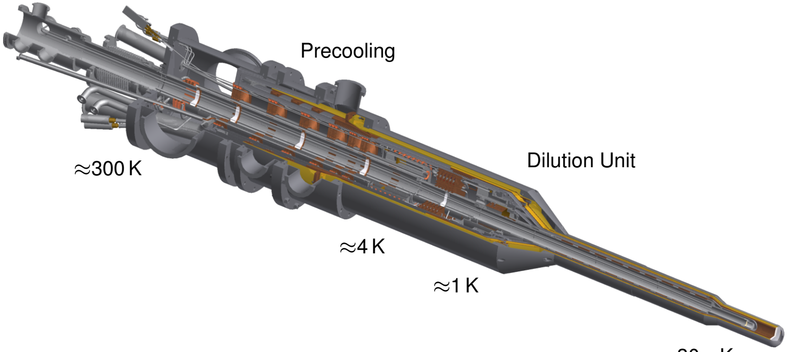
Continuous and Frozen-Spin Target





- 2018/2019: Measurements in Bonn with the Dubna/Mainz frozen-spin target.
- A new frozen-spin cryostat is under construction by Dubna and will be finished in the end of 2018.
- A continuous mode target is under construction by Bonn.

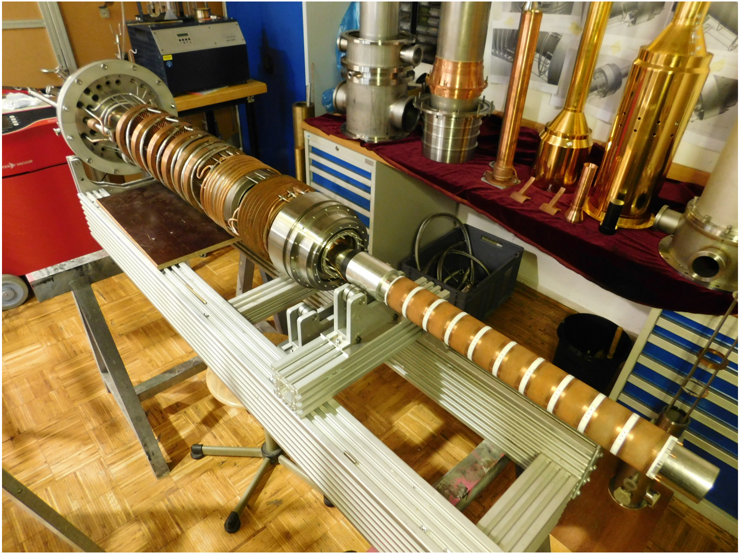
4π-Continuous Target



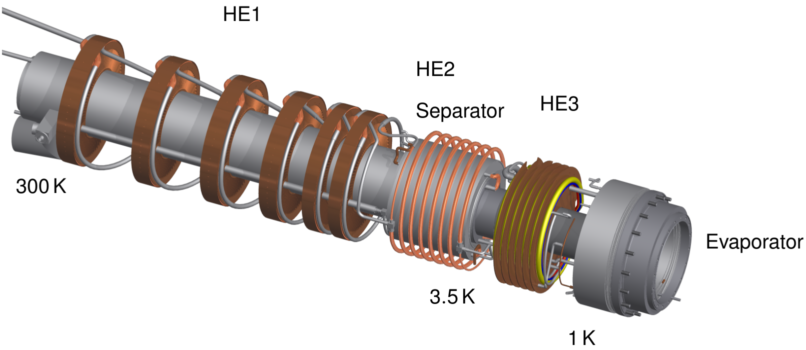
Design conditions:

- Current of 90 A for internal, longitudinal polarization-magnet.
- Cooling power of 100 mW at 200 mK for DNP.
- Minimal temperature 30 mK for transverse polarized targets.

4π-Continuous Target



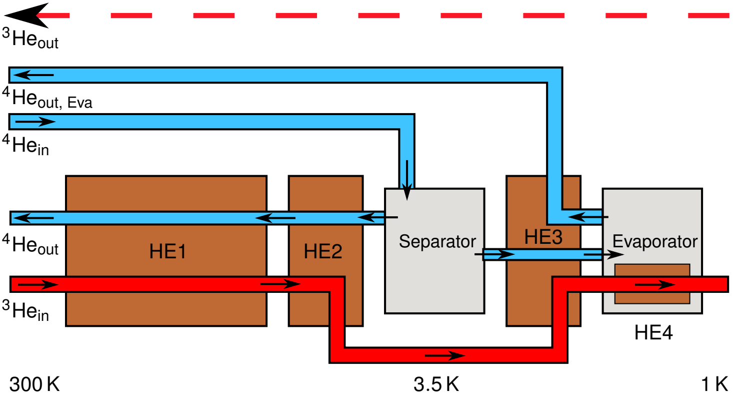
Precooling



- Four heat exchangers and two heat sinks to cool and liquefy the circulating mixture.
- HE4 inside the evaporator to ensure 1 K after the precooling stages.
- Circulating ^{3}He-^{4}He-mixture cooled by ^{4}He from the heat sinks and by evaporating mixture from the dilution unit.

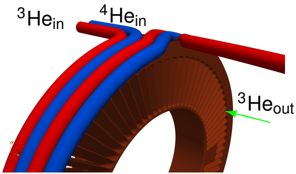
Precooling

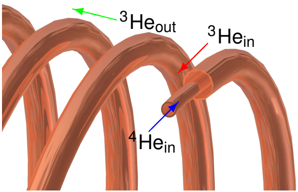
UNIVERSITÄT BONN

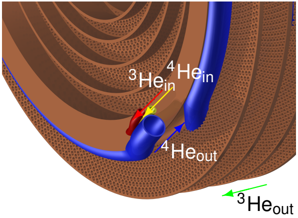


- HE1 - HE3 counterflow heat exchangers with more than two streams.
- Calculations of the precooling stages only with simple models for two stream heat exchangers.

Precooling







- The heat exchange between the different streams and the solid is given by:

$$\dot{Q}_{\text{solid}}(\Delta T_{\text{m}}) = \alpha \cdot A \Delta T_{\text{m}} \quad \text{mit} \quad \alpha \propto \text{Nu}(\text{Re}, \text{Pr}) \cdot \frac{\lambda}{L}.$$

- NUSSELT-, PRANDLT- and REYNOLDS-Number are characteristic flow parameter depending on the geometry.
- Characteristic flow parameter given by the dimensionless NAVIER-STOKES equations.
- Idea: Solve the NAVIER-STOKES equations with a finite-volume-method.

$\Rightarrow$ CFD-Simulation

Computational Fluid Dynamics

The basis of almost all CFD simulations is

$$\frac{\partial}{\partial t}(\rho\phi) + \underbrace{\nabla \cdot (\rho \underline{u} \phi)}_{F_\phi} = D_\phi + Q_\phi .$$

- ρ: density
- ϕ: fluid dynamic parameter (e.g. fluid velocity $\underline{u}$, enthalpy h)

Gl.	ϕ	D_ϕ	Q_ϕ
1. KON	1	0	0
2. IMP	$\underline{u}$	$\nabla \cdot \underline{\sigma}$	$-\nabla \cdot p + \rho \underline{g}$
3. ENG	h	$\nabla (k \nabla T)$	$\frac{\partial p}{\partial t} + \underline{u} \cdot \nabla p + \nabla \cdot \left(\underline{\tau} \cdot \underline{u}\right)$

- F_ϕ: convective flow, describes the transport of the stream given by ϕ
- D_ϕ: diffusive flow, describes the changes in space given by ϕ
- Q_ϕ: all other distributions given by ϕ

$\Rightarrow$ Using openFOAM with snappyHexMesh for the simulation and the creation of the mesh.

Computational Fluid Dynamics

Compressible fluid:

1. Mass:
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \underline{u}) = 0$$

2. Motion:
$$\frac{\partial}{\partial t}(\rho \underline{u}) + \nabla \cdot (\rho \underline{u}\underline{u}) = \nabla \cdot \underline{\underline{\sigma}} - \nabla p + \rho \underline{g}$$

3. Enthalpy:
$$\frac{\partial \rho h}{\partial t} + \nabla \cdot (\rho \underline{u} h) = \frac{\partial p}{\partial t} + \underline{u} \cdot \nabla p + \nabla (k \nabla T) + \nabla \cdot \left(\underline{\underline{\tau}} \cdot \underline{u} \right)$$

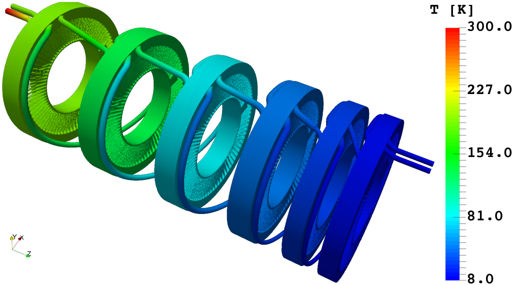
- Equations of state (e. g. ideal gas):
$$p = \rho R T$$
$$dh = c_p dT$$

- Specific material equations:
$$\dot{Q} = -k \nabla T$$

- Stress-tensor:
$$\underline{\underline{\sigma}} = \eta \left[2\underline{\underline{S}} - \frac{2}{3} (\nabla \cdot \underline{u}) \underline{\underline{\delta}} \right]$$
$$\underline{\underline{S}} = \frac{1}{2} \left[\nabla \underline{u} + (\nabla \underline{u})^T \right]$$
$$\underline{\underline{\tau}} = \underline{\underline{\sigma}} + p \mathbb{1}$$

Heat Exchanger 1

UNIVERSITÄT BONN

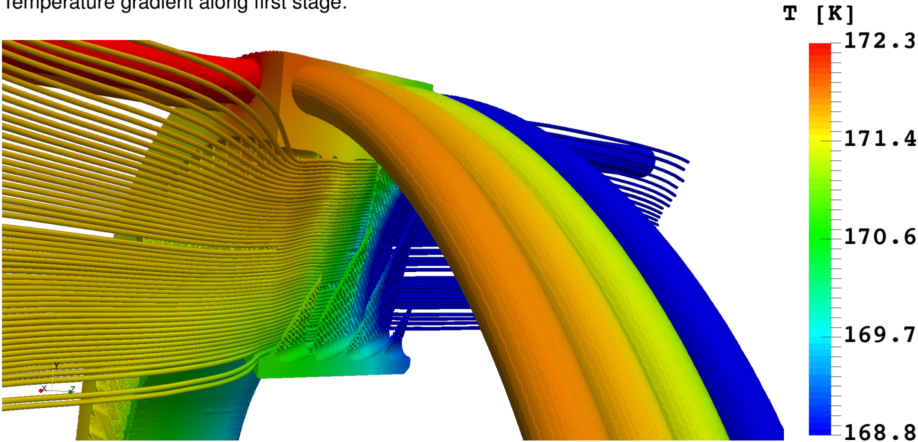


- Data for $\dot{n}_{^3\mathrm{He}} = 1\,\mathrm{mmol\,s^{-1}}$.
- Well defined temperature gradient along the heat exchanger.
- Temperature after the last stage of 8 K is reached.
- Simulation performed for all heat exchangers and a circulation rate of 1 to 20 mmol $\mathrm{s^{-1}}$

	Simulation	Measurement
$\mathrm{HE1_{in}}$	170 K	170(5) K
$\mathrm{HE1_{middle}}$	43 K	43(3) K
$\mathrm{HE1_{out}}$	8 K	8(1) K
$p_{^3\mathrm{He_{in}}}$	100 mbar	105(10) mbar
$p_{^3\mathrm{He_{out}}}$	2.1×10^{-2} mbar	$2.2(2)\times 10^{-2}$ mbar
$p_{^4\mathrm{He_{out}}}$	15 mbar	15(3) mbar

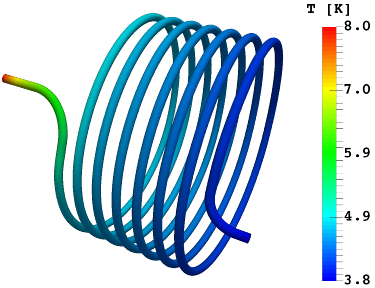
Heat Exchanger 1

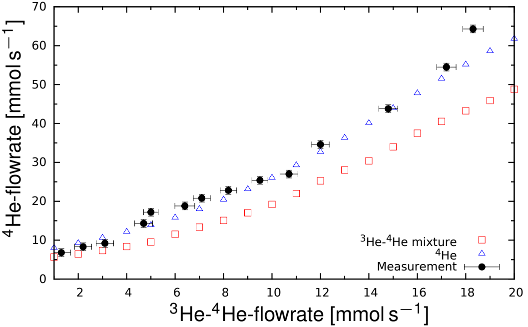
Temperature gradient along first stage:



⇒ Laminar flow through turbine stage.

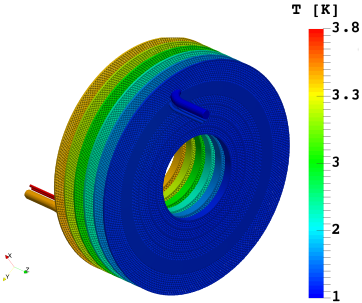
Heat Exchanger 1 & 2

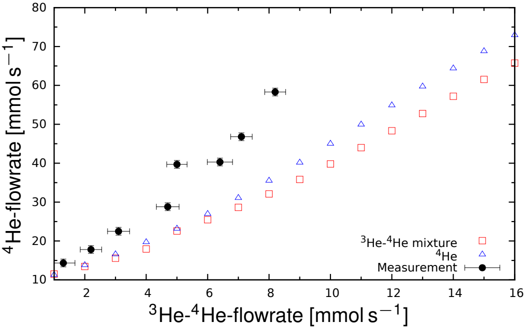




- Heat exchanger 1 & 2 are in series. Thus, they can be seen as one unit.
- ^{4}He-flowrate necessary to cool the circulating ^{3}He-^{4}He-mixture to the temperature of the separator.
- First tests done with ^{4}He, simulation performed up to 15 % ^{4}He in circulating ^{3}He.

Heat Exchanger 3





- Condenser: phase-boundary between liquid and gas not included in the mesh.
- ^{4}He$_{\text{in}}$, gets superfluid.
    - Only the change in the heat capacity is included.
    - Heat conductivity and viscosity have to be implemented. (ongoing work)
- ^{4}He from the evaporator at a higher temperature as calculated.

Summary & Outlook

UNIVERSITÄT BONN

- 2017, the Dubna/Mainz dilution cryostat was sent to Bonn and integrated in the Bonn control system.
- Production run in December 2017 and May 2018.
- First results are promising and the analysis is ongoing.
- A new frozen-spin dilution cryostat for Bonn is under construction by DIJN.
- First tests of the new continuous mode dilution cryostat were performed and compared to the existing simulation.
- The data of the precooling stages are in agreement with the simulation. (Excluding HE3, where some deviations were expected.)

- For 2019, measurements at CBELSA/TAPS are planned with the existing setup.
- Test of the Dubna/Bonn frozen-spin target.
- Tests of the new frozen-spin target and optimizing the operation parameter.
- Including the superfluid behaviour of helium in the simulation model.
- Preparing the next tests of the continuous dilution refrigerator in Bonn.