Status of
Polarized Atomic Hydrogen Target

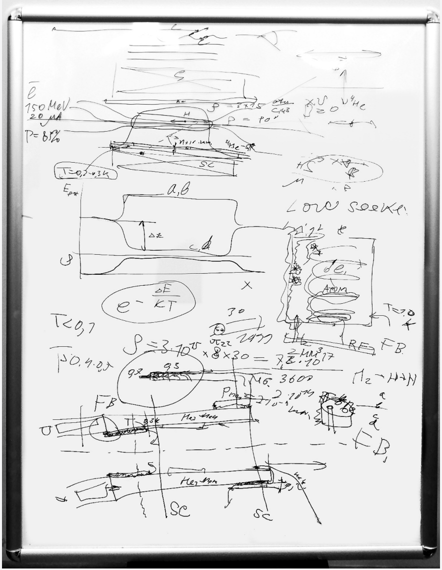
V. Tyukin[1]

[1]Inst. of Nuclear Physics
JGU Mainz, Germany

1st Workshop on New Light Physics
&
Photon Beam Experiments

Outline

1. P2 Experiment at MESA
2. Polarimetry at MAMI and MESA
   - Polarimetry status
   - Mott and Møller Scattering
   - Proposal E. Chudakov & V. Luppov
3. Actual design
   - Hardware actual design
   - Cooling power estimation
   - Hardware in fabrication
4. Summary
   - Status



Dubna, 2019

Outline

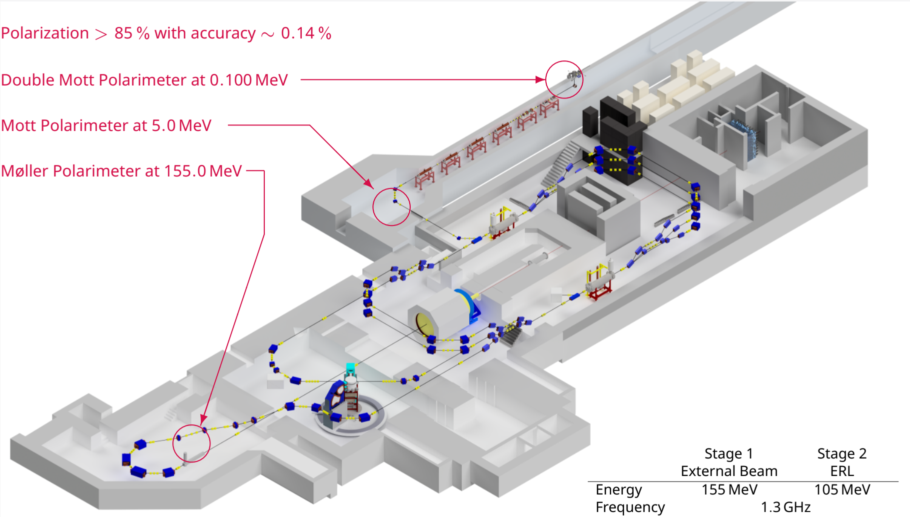
MESA accelerator

Polarization $> 85\,\%$ with accuracy $\sim 0.14\,\%$

Double Mott Polarimeter at 0.100 MeV

Mott Polarimeter at 5.0 MeV

Møller Polarimeter at 155.0 MeV



	Stage 1 External Beam	Stage 2 ERL
Energy	155 MeV	105 MeV
Frequency	1.3 GHz	
Current	150 μA / 1 mA	150 μA / 10 mA
Emittance	0.1 mm mrad	<1 mm mrad

P2 Experiment @ MESA

- MESA accelerator is being built in Mainz which will allow a next generation parity violation experiment
- CW spin polarized electron beam, polarization $\sim 85\,\%$
- Beam current $\sim 150\,\mu$A, beam energy $\sim 155\,$MeV
- Experiment collect $\sim 10^{11}\ \frac{1}{\mathrm{s}}$ for 10000 h
- High stability of position, energy and intensity of beam
- Beam polarization significantly contributes in precision
- Weak mixing angle : $\Delta\sin^2(\theta_W) = 0.14\%$

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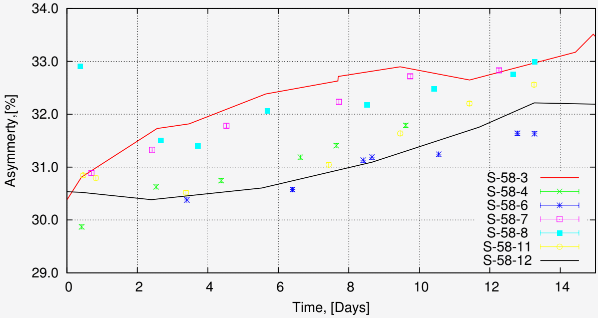
MAMI and MESA photo cathodes



- $I_{\text{MAMI}} \sim 100.0\,\mu\text{A}$
- $E_{\text{MAMI}} \sim 180.0 - 1500.0\,\text{MeV}$,
- $P_{\text{MAMI}} \sim 85\,\%$
- 7 days/24 hours

- MAMI & MESA use super lattice photo cathodes SVT Associates
- Beam polarization could vary up to 10% during run
- Red line - a new photo cathode
- Black line - a good used cathode

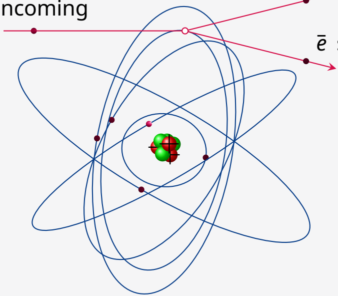
Outline

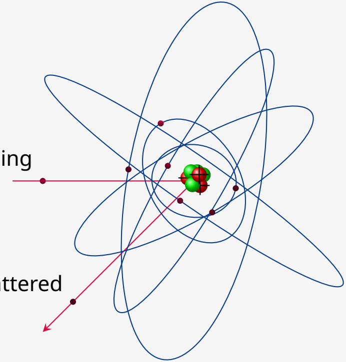
Polarimeter chain at MESA

- Double Mott polarimeter at 100.0 keV
- Mott polarimeter at 5.0 MeV
- Møller polarimeter at 55.0 – 155.0 MeV with polarized atomic hydrogen target. Proposed in 2004 and revised in 2012 Dr. E. Chudakov and Dr. V. Luppov[1]
- The goals at MESA $P_{\text{Mott, double}} = P_{\text{Mott, 5.0 MeV}} = P_{\text{Møller,H}}$
- Accuracy $\Delta P < 0.5\%$
- Online measurements only Møller polarimeter

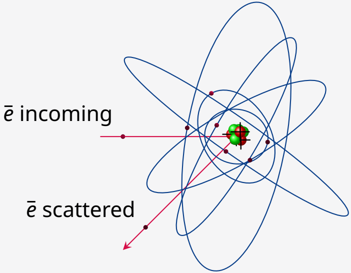
1. E. Chudakov, V. Luppov IEEE, V. 51, 2004; E. Chudakov, Nuovo Cim, V. C35, 2012

Møller and Mott scatterings



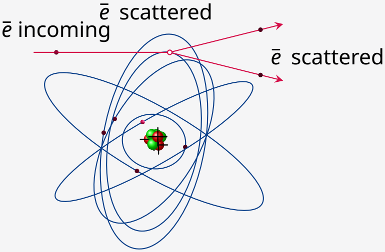


Mott polarimeters at MAMI and MESA



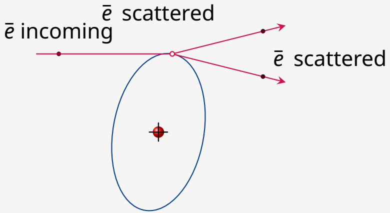
- MAMI 3.5 MeV
- MESA double 100 keV, 5.0 MeV
- Scattering on heavy nucleous
- P=$\frac{A_{exp}}{S_{eff}}$
- Target Au Z=79, A=197
- $\rho_{\mathrm{Au}} \times L_{\mathrm{Au}} = 6.0 \times 10^{18}\,\mathrm{cm}^{-2}$
- Current up to 20 μA
- Foil thickness 0.1 – 1.0 μm
- Problems: determination of S_0, radiative effects, extrapolation uncertainties of S_{eff} , target induced background reduces A_{exp}
- Overall accuracy of $\leq 1.0\%$

Møller polarimeter at MAMI 180.0-1500.0 MeV



- Scattering on heavy or ligth nucleous
- Target Fe Z=26, A=59
- $\rho_{\mathrm{Fe}} \times L_{\mathrm{Fe}} = 6.0 \times 10^{19}\,\mathrm{cm}^{-2}$
- Energy range $0.15 - 12.0\,\mathrm{GeV}$
- Current up to $1\,\mu\mathrm{A}$
- Foil thickness $5.0 - 10.0\,\mu\mathrm{m}$
- Problems: target saturation, Levchuk effect
- Overall accuracy of $\leq 1.0\%$

Hydrogen target for Møller polarimeters



- Scattering on hydrogen nucleous
- Target H, Z=1, A=1
- Ionization energy = 13.6 eV
- $\rho_{\mathrm{H}} \times L_{\mathrm{H}} = 6.0 \times 10^{16}\,\mathrm{cm}^{-2}$
- Energy range 0.15 – 12.0 GeV
- Current up to 1000.0 μA
- No Levchuk effect
- Overall accuracy of $\leq$ 0.14%

The main idea of Polarized Atomic Hydrogen Target

Møller scattering of electron beam

$$\left(\frac{d\sigma}{d\Omega}\right)_{CM} = \left(\frac{d\sigma^0}{d\Omega}\right)_{CM} \times \left(1 + \sum_{i,j=x,y,z} a_{ij} P_i^B P_j^T\right) \quad (1)$$

where: P_j^T , P_i^B target and beam polarizations,
z - beam direction, x, y - scattering directions

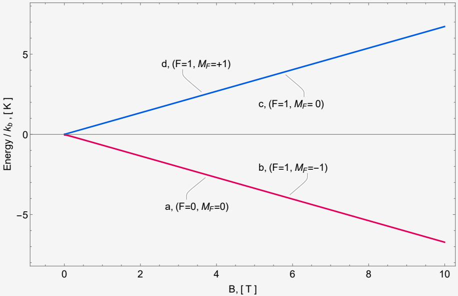
$$A_{exp} = \frac{N^{\uparrow p \uparrow} - N^{\uparrow p \downarrow p}}{N^{\uparrow p \uparrow} + N^{\uparrow p \downarrow p}} = a_{zz} P^B P^T. \quad (2)$$

it would be more convenient with: $a_{zz}^{max} = -\frac{7}{9}$, $P^T = 1.00$

$$A_{exp} = -\frac{7}{9} P^B \quad (3)$$

Complication from hyperfine splitting

Molecular hydrogen H_2 opposite electron spin
Atomic hydrogen H : $\vec{\mu} \approx \vec{\mu}_e$ in magnetic field

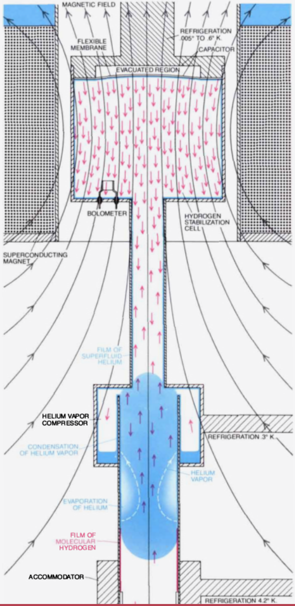


High field seekers:
$|a\rangle \; \left|\downarrow_e\uparrow_p\right\rangle \cos(\theta) - \left|\uparrow_e\downarrow_p\right\rangle \sin(\theta)$
$|b\rangle \; \left|\downarrow_e\downarrow_p\right\rangle$
Low field seekers:
$|c\rangle \; \left|\downarrow_e\uparrow_p\right\rangle \sin(\theta) + \left|\uparrow_e\downarrow_p\right\rangle \cos(\theta)$
$|d\rangle \; \left|\uparrow_e\uparrow_p\right\rangle$
$\tan(2\theta) \approx \frac{0.05}{B}$, $\sin(\theta) = 0.0035$

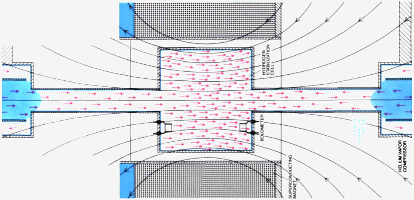
- gas: parallel electron spins 2-body kinematic suppression
- gas: 3-body density suppression
- surface: strong unless coated $\sim$ 50 nm film of superfluid $^4\mathrm{He}$

Polarization of hydrogen target $P^T \sim (1 - 10^{-4}) \sim 0.9999$

Storage cell in 1980

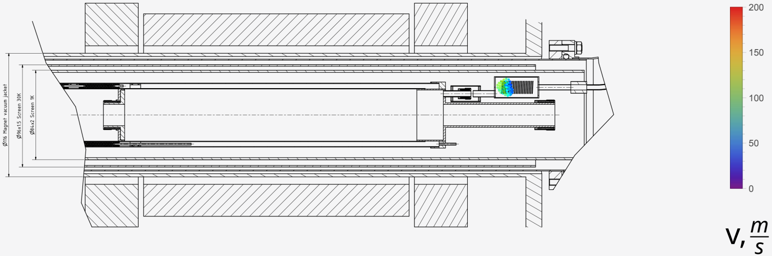


- $\rho_{\mathrm{H}} \sim 3.0 \times 10^{18}\,\mathrm{cm}^{-3}$
  gas lifetime of several minutes
- $\rho_{\mathrm{H}} \sim 3.0 \times 10^{14}\,\mathrm{cm}^{-3}$
  gas lifetime of hours
- I. F. Silvera and J. T. M. Walraven. Phys. Rev. Lett. V.44, N.3 (1980)
- Tools: cut, copy, rotate, align



Pirture: Scientific American V.246, N.1 1982 and JSTOR

Moving of LFS hydrogen atoms in magnetic field



- Force in the field gradient $-\vec{\nabla}\left(\vec{\mu}_H \times \vec{B}\right)$
- H in $|c\rangle$ and $|d\rangle$ states are repelled towards the low-field region
- B_{sole}=8.0 T, L_{sole}=400 mm, D_{sole}=130 mm
- Wall of storage cell is coated $\sim$ 50 nm film of superfluid ^{4}He at $T_{\text{wall}} = 0.25 - 0.30\,\text{K}$

Courtesy V. Fimushkin, R. Kusaykin, JINR, Dubna

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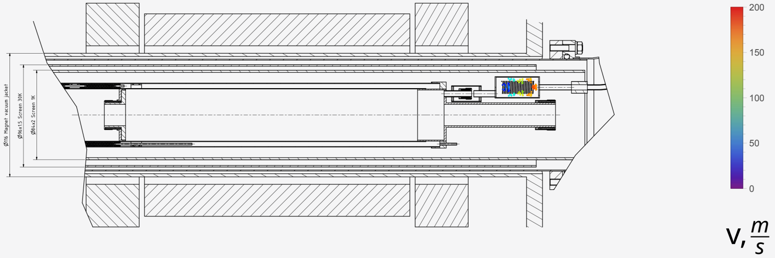

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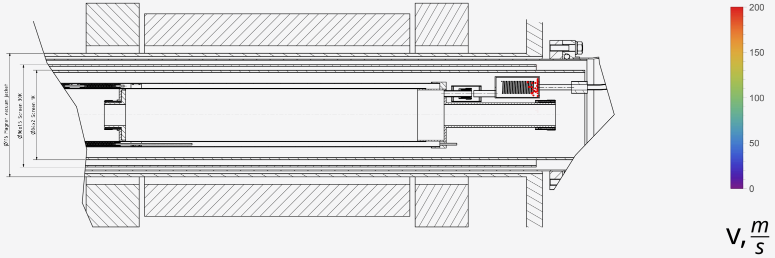

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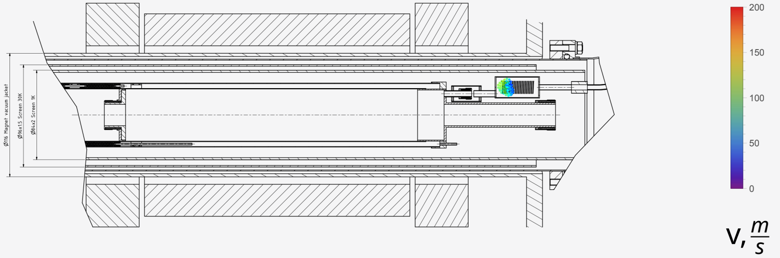

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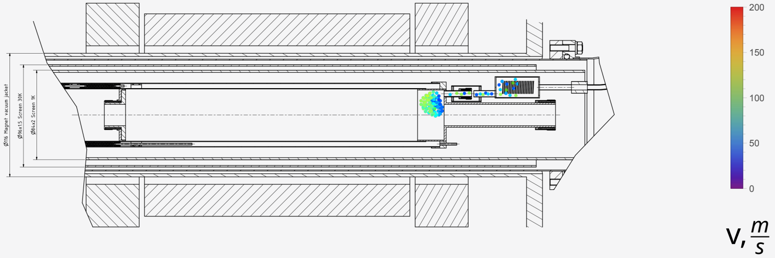

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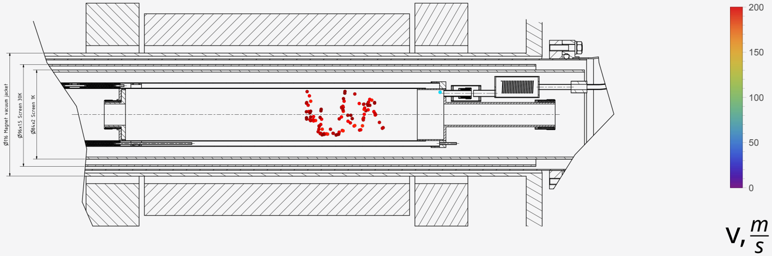

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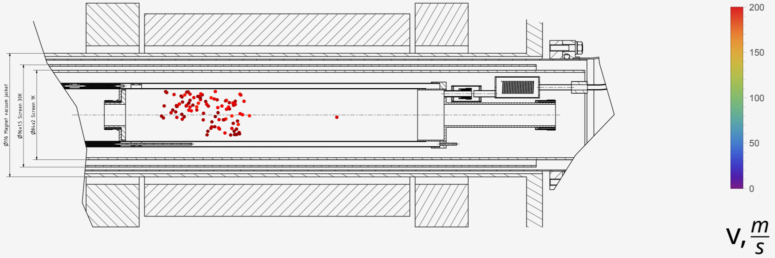

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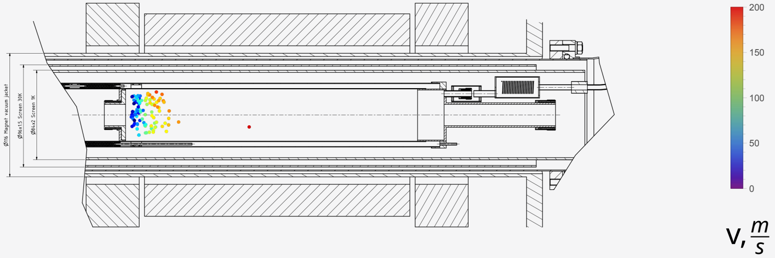

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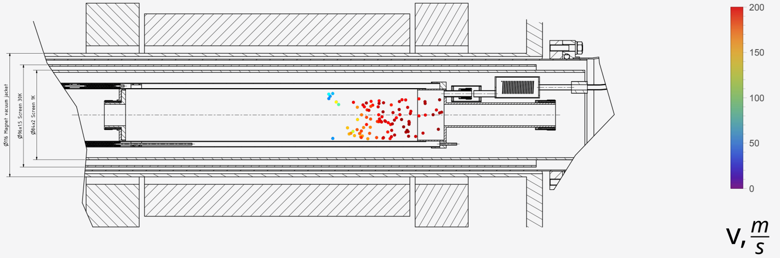

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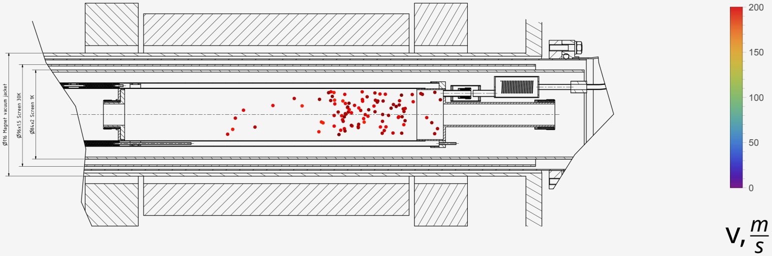

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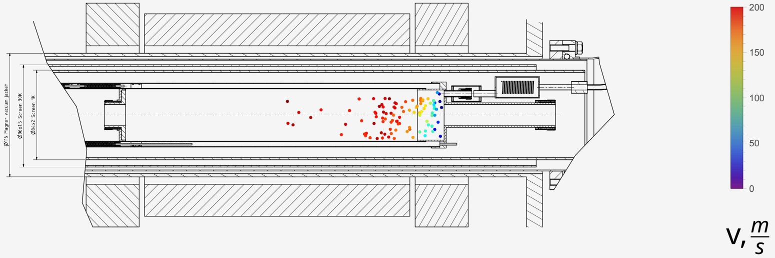

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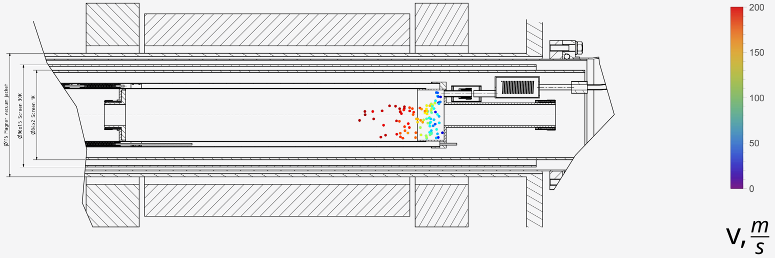

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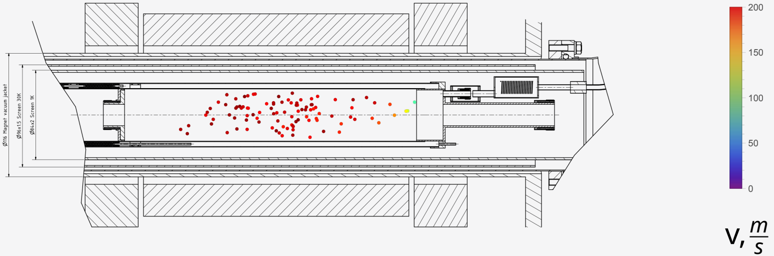

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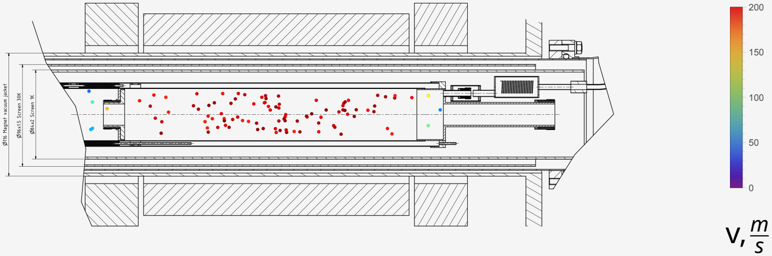

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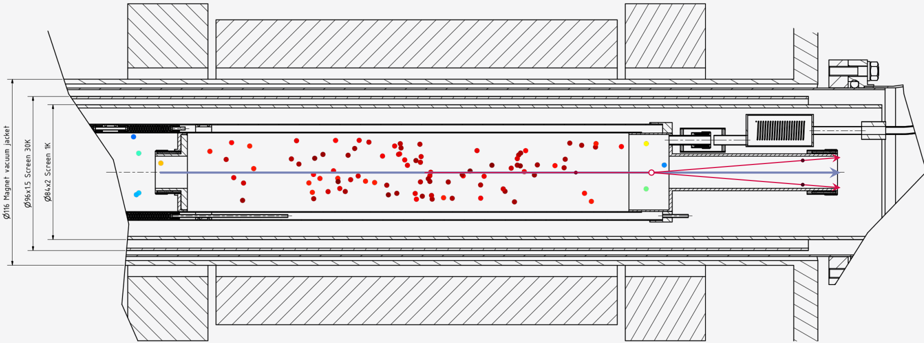
Polarized Atomic Hydrogen Target



- $L_{\mathrm{H}} = 0.20\,\mathrm{m}$, $D_{\mathrm{H}} = 0.02\,\mathrm{m}$, $\rho_{\mathrm{H}} = 3.0 \times 10^{15}\,\mathrm{cm}^{-3}$
- $\rho_{\mathrm{H}} \times L_{\mathrm{H}} = 6.0 \times 10^{16}\,\mathrm{cm}^{-2}$, $P^{T} \sim 0.9999$
- Gas lifetime $\sim 1.0\,\mathrm{h}$

Nobody has put the target in a high power beam

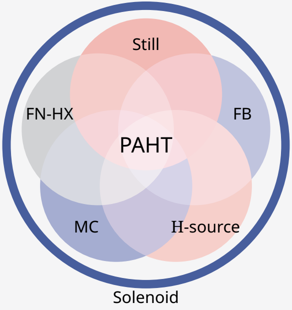
Outline

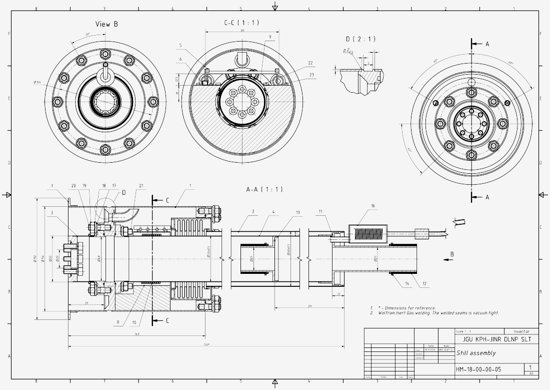
Requirements to cryostat: heat load, cooling power

- Wall is coated by super fluid ^{4}He film at $T_{wall} = 0.25 - 0.30\,\mathrm{K}$
- $P_{rec} = 10.0\,\mathrm{mW}$, – H-pair recombination energy, depends on feed rate of atomic hydrogen
- P_{fb}=$10.0\,\mathrm{mW}$, – film burners and transition unit
- P_{bb}=$25.0\,\mathrm{mW}$, – estimated black body radiation to mixing chamber from warm parts of beam line.
- $P_{cooling}$=$P_{rec} + P_{fb} + P_{bb} = 45.0\,\mathrm{mW}$
- In an ideal case:
  $P_{cooling} \sim 45.0\,\mathrm{mW}$ at $T_{mc} = 0.25\,\mathrm{K}$ and $\dot{n}_{He3} = 16.5\,\frac{\mathrm{mmol}}{\mathrm{s}}$
- In a real case:
  $P_{cooling} \sim 60.0\,\mathrm{mW}$ at $T_{mc} = 0.25\,\mathrm{K}$ and $\dot{n}_{He3} = 40.0\,\frac{\mathrm{mmol}}{\mathrm{s}}$

Special thanks N. Borisov JINR, Dr. T. Niinikoski, Dr. N. Doshita CERN

Dilution unit, FN-HX, still, MC, H-source, FB





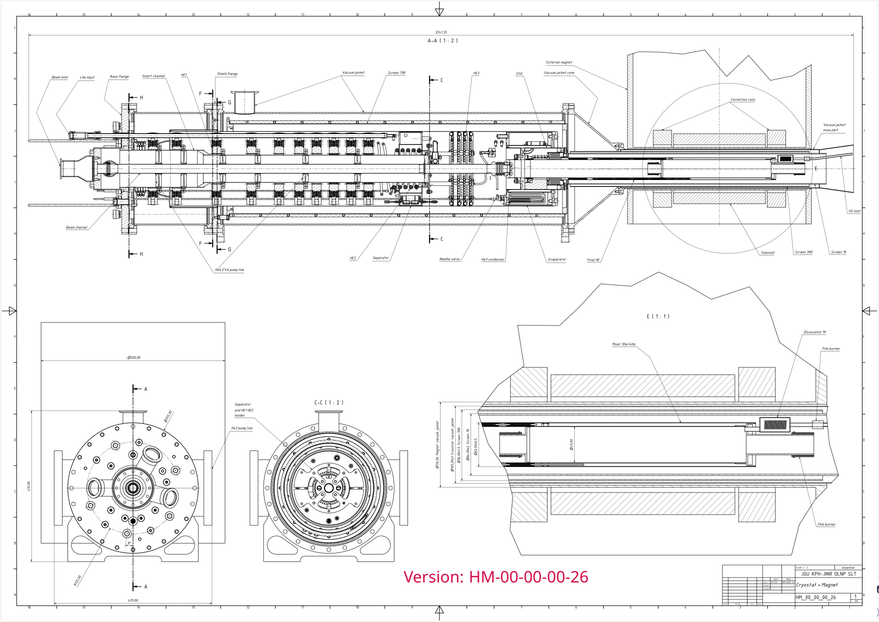
1) Still, 12) FB, 16) H-source at 1K, 2,4) MC, 2,4,10) FN-HX, Sole not show

- The star of success
- All elements are highly interconnected

- The key unit of cryostat
- Discussed in JINR 2019, 2020

Original technical drawing by N. Borisov, I.Gorodnov, JINR

Under construction, ready in 2022



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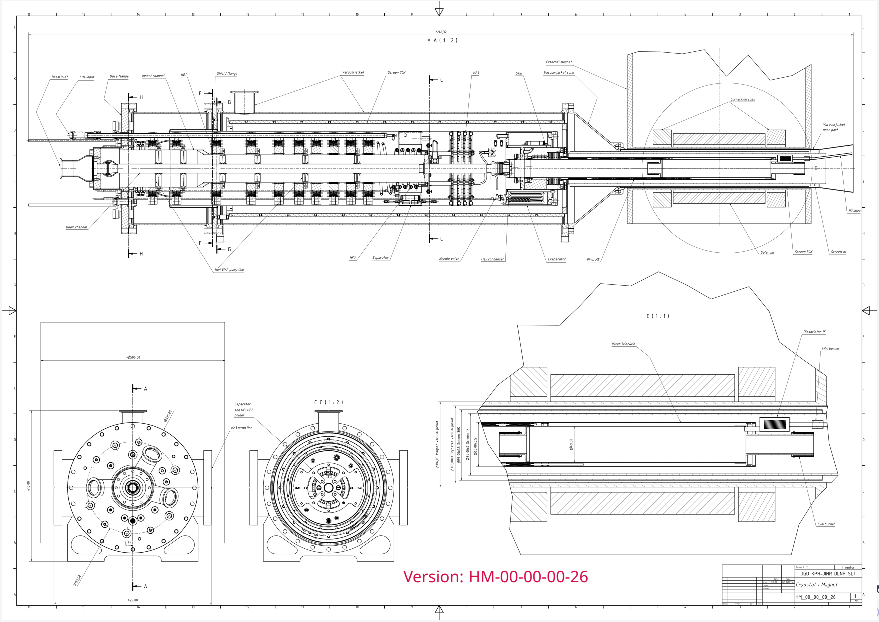

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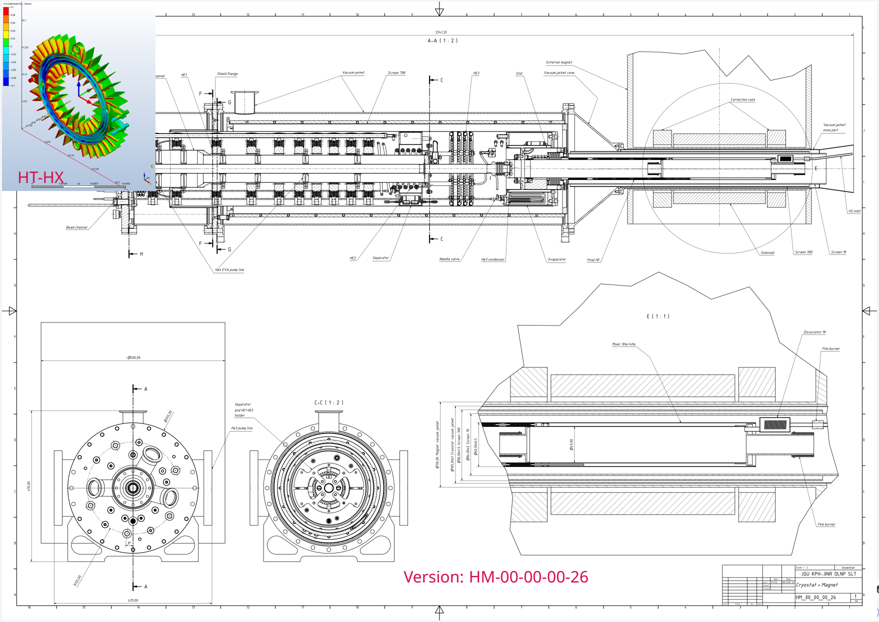

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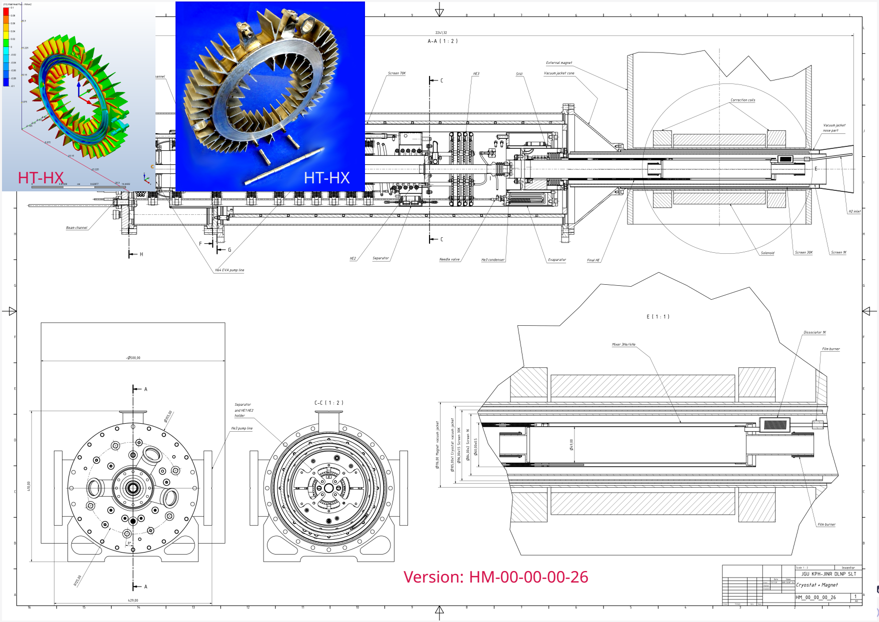
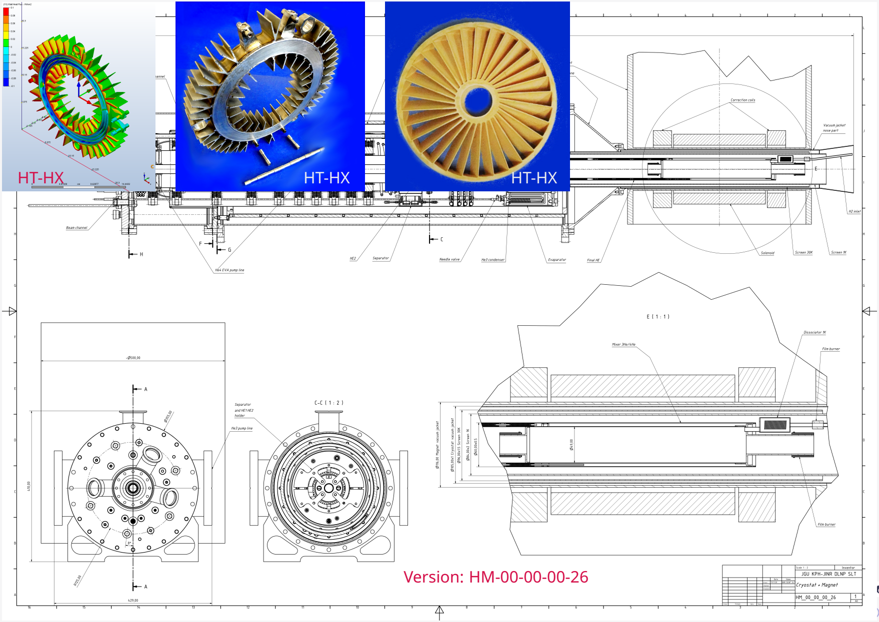


Under construction, ready in 2022



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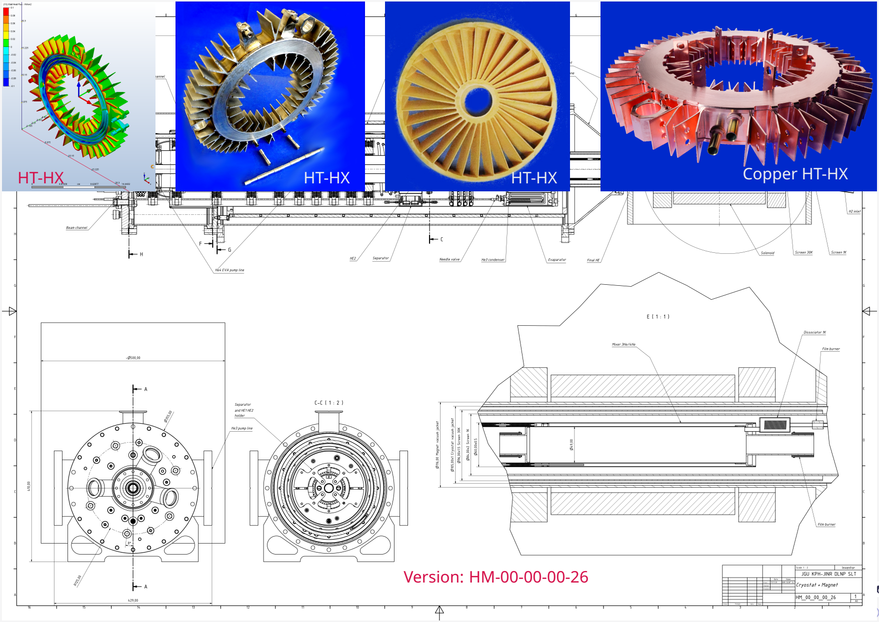

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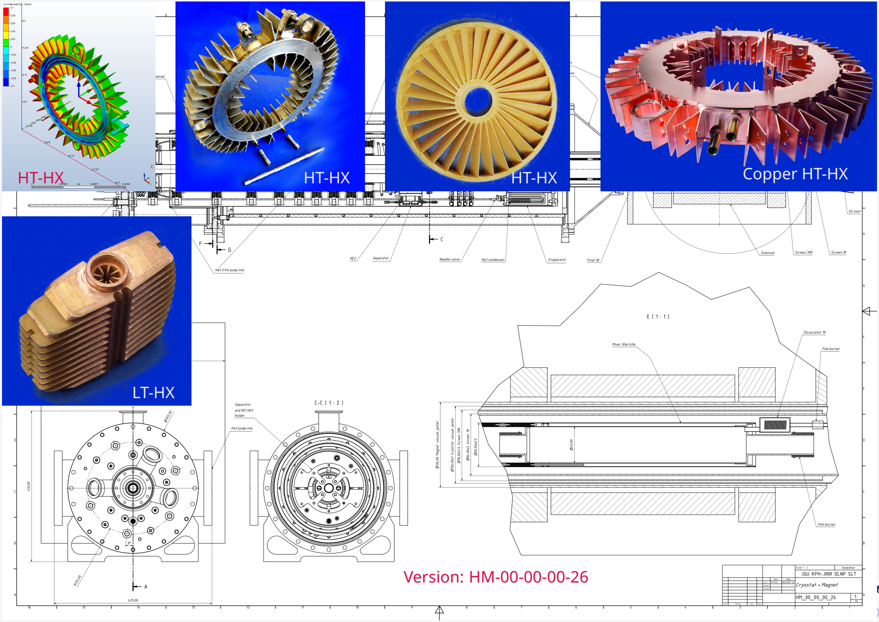

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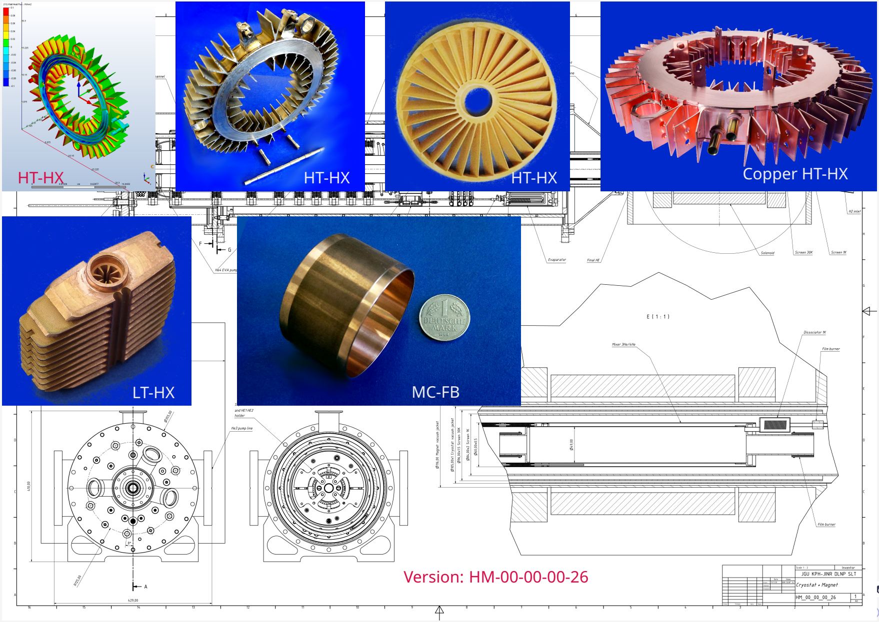

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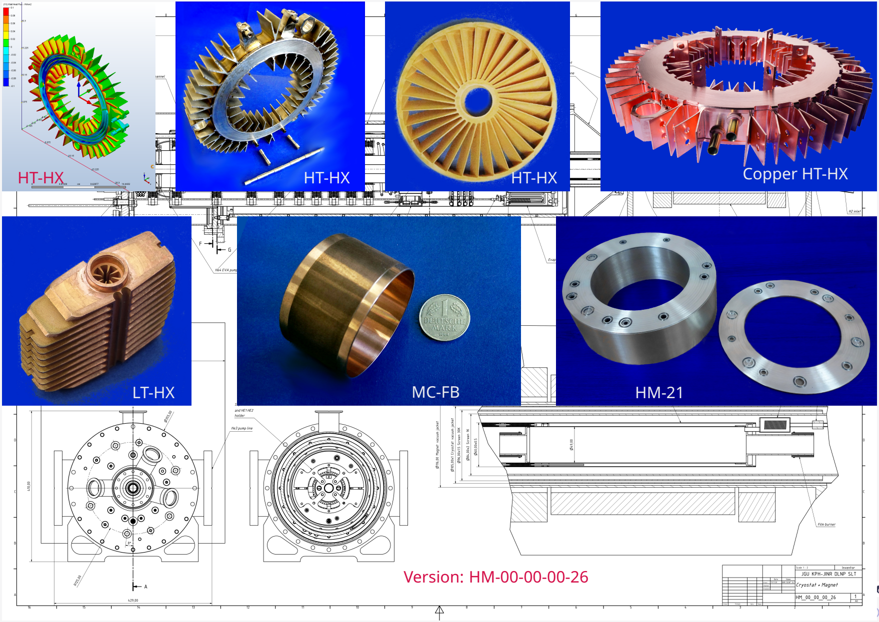
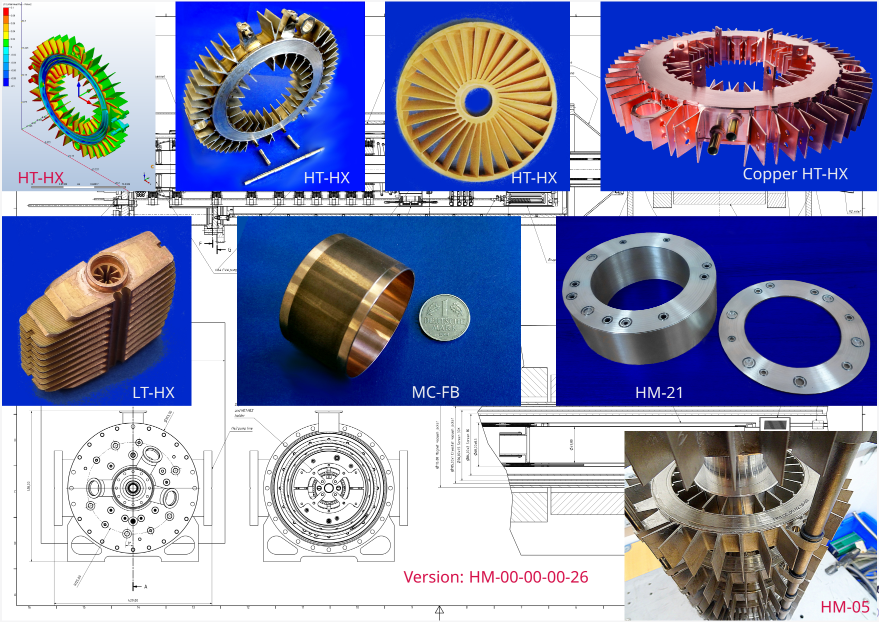


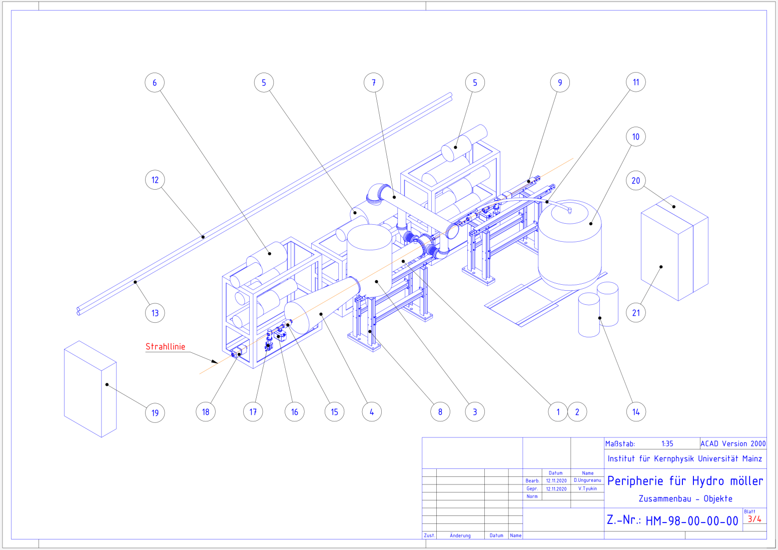
Under construction, ready in 2022



Under construction, ready in 2022

Under construction, ready in 2022

View of the PAHT in ExH4 (preliminary)



1,2) ^{3}He-^{4}He refrigerator; 3) Super cond. sole., 4) Møller detector, 5,6,7,19) Root pumps & lines, 8,9) Supports, 10,11) Dewar& line, 12,13) He& N lines, 14) Purifiers, 15) BMP, 16) BL pump, 17) Valves, 18) Quad, 20,21) Mixing system

Outline

Summary and outlook

- The Møller polarimeter for MESA
- Collaboration or technology transfer necessary
  - Film burners - experience with superfluid helium films
  - Møller polarimeter - discussions
  - Some technological efforts
  - Some design challenges still have to be solved (e.g. FX-HX, Target ”clearing”)
- Horizontal oriented dilution cryostat – mixing ^{3}He in ^{4}He
- Superconductive magnet ist separated from cryostat
- Detector of Møller electrons JLAB, W&M, JGU, Lous. Uni
- Funding secure
- Under construction: JGU Mainz, JINR Dubna
- Cooling down precooler 2020 , full test 2022, on beam 2023

Thank for support

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

MAINZER MIKROTRON

SFB 1044

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

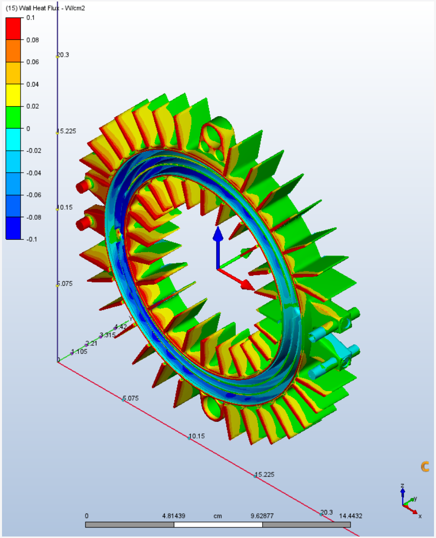
PRISMA

Thank you for your attention!

Abstract

One aim for the new electron accelerator MESA is to measure the weak mixing angle in electron proton scattering with high precision. This results in a requirement for beam polarization measurement of $\Delta P/P \approx 0.5\%$. The Møller polarimeter proposed in 2004 opens the way to reach a sufficiently accurate measurement. The polarized atomic hydrogen target is under construction. The current status including recent modifications is presented.

HM-05 Simulation



- Efficiency $\epsilon = 1 - e^{-\text{ntu}}$
- Area outside ^{3}He : $S = 873\,\text{cm}^2$, $V \sim 14000\,\text{cm}^3$
- Area inside ^{3}He, ^{4}He: $S = 526\,\text{cm}^2$, $V = 37.7\,\text{cm}^3$

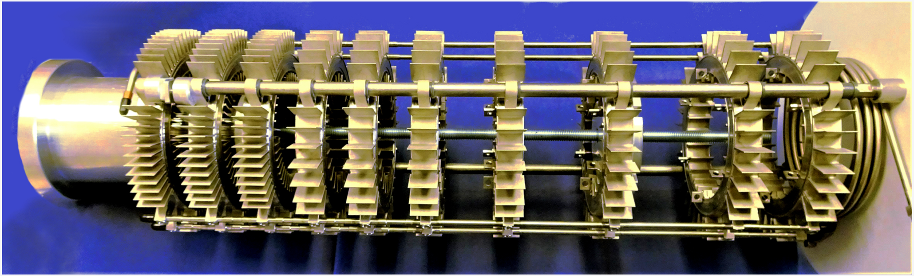
HM-05 Calculation

15,95RPS
0,42cRPS

	Nu_He3_cold	Nu_He3_warm	Nu_He4_evap	Nu_He4_sepr	Nu_He4_warm	ntu_He3_cold	ntu_He3_warm	ntu_He4_evap	ntu_He4_sepr	ntu_He4_warm	temp_He3_cold	temp_He3_warm	temp_He4_evap	temp_He4_sepr	temp_He4_warm	temp_Metal
HT-HX(1)	3.67	3.67	3.66	3.67	3.66	30.2	47	0.0	49	0.0	199.57	199.57	3.5	199.57	4.25	199.57
HT-HX(2)	3.68	3.67	3.66	3.67	3.66	24.5	36.	0.0	39.	0.0	146.5	146.5	3.5	146.5	4.25	146.5
HT-HX(3)	3.68	3.67	3.66	3.67	3.66	19.7	29.4	0.0	31.	0.0	106.23	106.23	3.5	106.23	4.25	106.23
HT-HX(4)	3.69	3.68	3.66	3.68	3.66	15.7	23.8	0.0	25.1	0.0	76.18	76.18	3.5	76.18	4.25	76.18
HT-HX(5)	3.69	3.68	3.66	3.68	3.66	12.5	19.1	0.0	19.9	0.0	54.16	54.16	3.5	54.16	4.25	54.16
HT-HX(6)	3.7	3.69	3.66	3.69	3.66	10.0	15.3	0.0	15.7	0.0	38.28	38.28	3.5	38.28	4.25	38.28
HT-HX(7)	3.72	3.69	3.66	3.69	3.66	8.01	12.2	0.0	12.4	0.0	26.99	26.99	3.5	26.99	4.25	26.99
HT-HX(8)	3.75	3.71	3.66	3.7	3.66	5.73	9.75	0.0	11.6	0.0	19.05	19.08	3.5	19.08	4.25	19.08
IM-HX-M2(9)	6.43	3.95	3.66	4.07	3.66	0.13	2.43	0.0	1.86	0.0	11.31	17.58	3.5	17.2	4.25	17.44
IM-HX-M2(10)	6.58	3.97	3.66	4.1	3.66	0.12	2.32	0.0	1.77	0.0	10.48	16.25	3.5	15.86	4.25	16.11
IM-HX-M2(11)	6.73	3.99	3.66	4.12	3.66	0.12	2.21	0.0	1.7	0.0	9.75	15.06	3.5	14.67	4.25	14.91
IM-HX-M2(12)	6.88	4.01	3.66	4.15	3.66	0.12	2.11	0.0	1.63	0.0	9.09	13.98	3.5	13.6	4.25	13.83
IM-HX-M2(13)	7.03	4.03	3.66	4.17	3.66	0.12	2.02	0.0	1.56	0.0	8.49	13.01	3.5	12.64	4.25	12.87
IM-HX-M2(14)	7.17	4.05	3.66	4.2	3.66	0.11	1.94	0.0	1.5	0.0	7.96	12.14	3.5	11.77	4.25	11.99
IM-HX-M2(15)	7.32	4.07	3.66	4.23	3.66	0.11	1.86	0.0	1.44	0.0	7.48	11.35	3.5	10.98	4.25	11.2
IM-HX-M2(16)	7.46	4.09	3.66	4.25	3.66	0.11	1.79	0.0	1.39	0.0	7.04	10.63	3.5	10.28	4.25	10.49
IM-HX-M2(17)	7.59	4.11	3.66	4.28	3.66	0.11	1.72	0.0	1.34	0.0	6.65	9.98	3.5	9.63	4.25	9.84
IM-HX-M2(18)	7.73	4.14	3.66	4.31	3.66	0.1	1.66	0.0	1.29	0.0	6.29	9.39	3.5	9.05	4.25	9.25
IM-HX-M2(19)	7.86	4.16	3.66	4.34	3.66	0.1	1.6	0.0	1.25	0.0	5.96	8.85	3.5	8.52	4.25	8.71
IM-HX-M2(20)	7.99	4.18	3.66	4.36	3.66	0.1	1.55	0.0	1.21	0.0	5.66	8.35	3.5	8.03	4.25	8.22
IM-HX-M2(21)	8.11	4.2	3.66	4.39	3.66	0.1	1.5	0.0	1.17	0.0	5.39	7.9	3.5	7.59	4.25	7.77
IM-HX-M2(22)	8.24	4.22	3.66	4.42	3.66	0.1	1.45	0.0	1.14	0.0	5.14	7.48	3.5	7.18	4.25	7.36
IM-HX-M2(23)	8.36	4.24	3.66	4.44	3.66	0.1	1.41	0.0	1.11	0.0	4.91	7.1	3.5	6.81	4.25	6.98
IM-HX-M2(24)	8.47	4.27	3.66	4.47	3.66	0.1	1.37	0.0	1.08	0.0	4.7	6.75	3.5	6.46	4.25	6.63
IM-HX-M2(25)	8.59	4.29	3.66	4.5	3.66	0.09	1.33	0.0	1.05	0.0	4.51	6.42	3.5	6.14	4.25	6.3
IM-HX-M2(26)	8.7	4.31	3.66	4.53	3.66	0.09	1.29	0.0	1.02	0.0	4.33	6.11	3.5	5.84	4.25	6.0
IM-HX-M2(27)	8.8	4.33	3.66	4.56	3.66	0.09	1.26	0.0	0.99	0.0	4.17	5.83	3.5	5.55	4.25	5.71
IM-HX-M2(28)	8.9	4.35	3.66	4.59	3.66	0.09	1.23	0.0	0.96	0.0	4.02	5.56	3.5	5.28	4.25	5.44
IM-HX-M2(29)	8.99	4.37	3.66	7.51	3.66	0.09	1.19	0.0	1.49	0.0	3.88	5.25	3.5	5.01	4.25	5.12
IM-HX-M2(30)	9.07	4.4	3.66	8.29	3.66	0.09	1.16	0.0	1.53	0.0	3.76	4.91	3.5	4.63	4.25	4.76
IM-HX-M2(31)	9.12	4.44	3.66	9.59	3.66	0.09	1.12	0.0	1.57	0.0	3.67	4.52	3.5	4.14	4.25	4.32
IM-HX-M2(32)	9.13	7.66	3.66	13.1	3.66	0.09	1.83	0.0	1.6	0.0	3.61	3.89	3.5	3.47	4.25	3.77
LT-HX(33)	3.88	92.03	25.54	3.66	88.79	3.08	3.04	1.51	0.0	6.65	3.6	3.63	3.5	2.25	3.62	3.62
LT-HX(34)	3.9	95.36	27.62	3.66	88.79	2.83	3.01	1.48	0.0	6.65	3.17	3.22	3.08	2.25	3.2	3.2
LT-HX(35)	3.93	101.3	30.16	3.66	88.79	2.56	2.96	1.45	0.0	6.65	2.76	2.81	2.67	2.25	2.79	2.79
LT-HX(36)	3.98	108.4	33.3	3.66	88.79	2.28	2.9	1.42	0.0	6.65	2.35	2.42	2.27	2.25	2.39	2.39
LT-HX(37)	4.04	117.2	37.05	3.66	88.79	1.97	2.83	1.38	0.0	6.65	1.94	2.03	1.89	2.25	2.0	2.0
LT-HX(38)	4.18	128.1	41.42	3.66	88.79	1.55	2.76	1.33	0.0	6.65	1.51	1.67	1.54	2.25	1.65	1.65

Courtesy A. Tyukin

HM-05 Photo



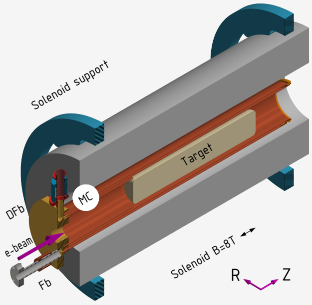
- Fully welded out of stainless steel
- Four-way heat exchanger ^{3}He, ^{4}He vs ^{3}He, ^{4}He

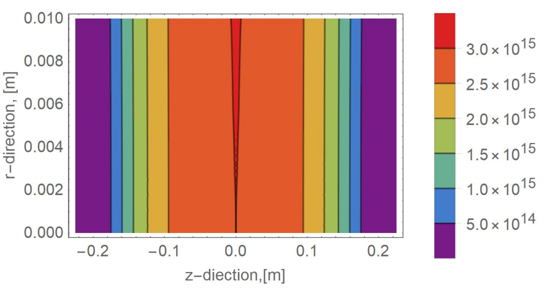
Courtesy: staff Inst. of Nucl. Phys. JGU, staff Swagelok Ltd,

Outline

5 Let us have a dream
- Møller polarimeter
- Advantage of tracking
- Atomic hydrogen feed system

Assumption: target is ready

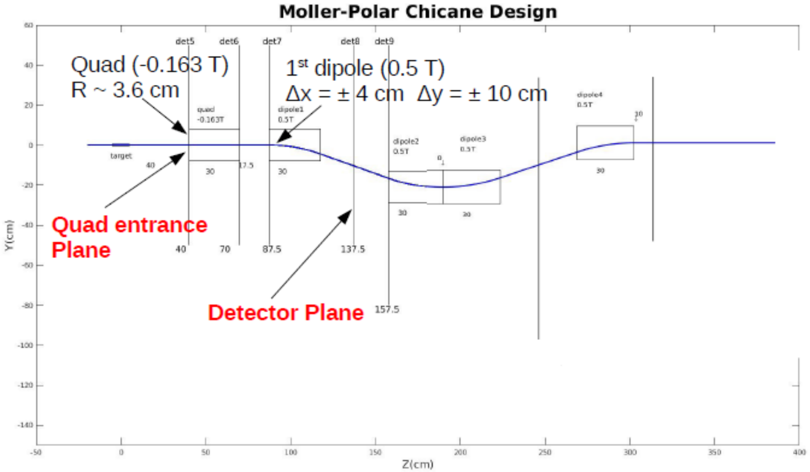




- The hydrogen density varies along the target length $L_H = \pm 0.20\,\mathrm{m}$ according to the field strength. With $B_{\max} = 8T$ reaches $\rho_{maxH} = 3.0 \times 10^{15}\,\mathrm{cm}^{-3}$
- θ_{cm} =90°, θ_{scat1} =4.70°, θ_{scat2} =−4.70°, $E_{1,2} = 75\,\mathrm{MeV}$

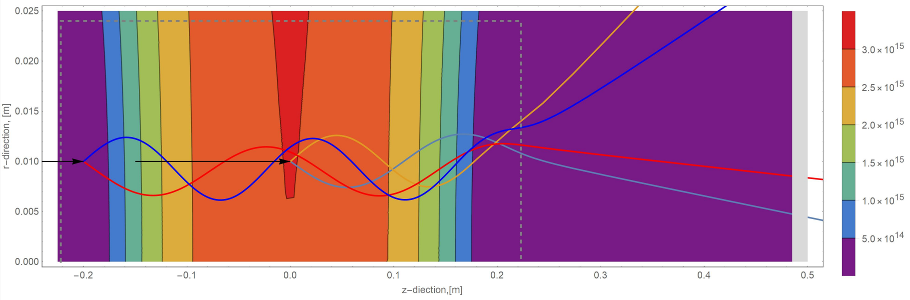
Møller polarimeter

Chicane Dispersion in vertical axis and quad focus on horizontal axis



Courtesy Prof. K.Kumar, Ass. Prof. R. Beminiwattha

Target and detector



- Target at $z = -0.2 \ldots +0.2\,\mathrm{m}$ and detector at $z = +0.5\,\mathrm{m}$
- Scattering inside of solenoid on atoms of hydrogen
- Scattering on atoms of residual gases outside of magnetic field
- Vertex reconstruction in Møller detector is advantageous
- The tracker should operate with full beam intensity at $\sim 583\,\frac{\mathrm{electron}}{\mu\mathrm{A}}$
- The polarization measurement could be performed by the tracker

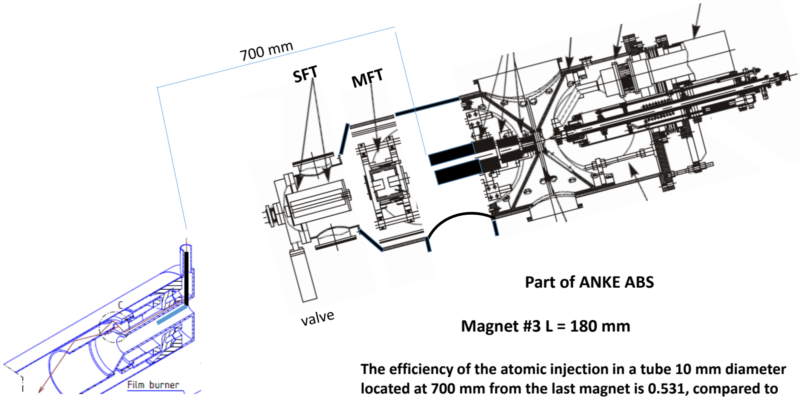
Measurement of hydrogen density inside the target

- Full reconstruction of the Møller event using a tracker would mean full reconstruction of its kinematics
- Tracks of pairs of Møller electrons bend inside the magnetic field and then fly outwards in straight lines
- If one would track these pairs in coincidence, reconstructing their trajectories backwards would allow for a precise 3D vertex reconstruction, because one could make the condition of the tracks intersecting.
- Knowledge of the beam profile finally would allow for even a 3D density distribution.
- One could track the electrons with 3-4 layers of Mupix chips, similar to how it will be done in the P2 tracker.
- In addition, information about the pressure of ^{4}He and film of super fluid ^{4}He on wall over time.

Operating with atomic hydrogen

- Atomic hydrogen losses $\sim 1.0 \times 10^{14}\,\frac{\mathrm{atom}}{\mathrm{s}}$
- Dissociator at room temperature, filling time $\sim 1.0\,\mathrm{h}$, Baffles of feed system blocked due to frozen hydrogen, not available continuously
- Classic atomic hydrogen beam source
  - Suppress flux of $\mathrm{H_2}$ and H in states $|c\rangle$ and $|d\rangle$
  - Inlet only H in states $|a\rangle$ and $|b\rangle$
  - It seems continuous operation possible
- Cryogenic atomic hydrogen source at 1 K

Conventional atomic hydrogen source



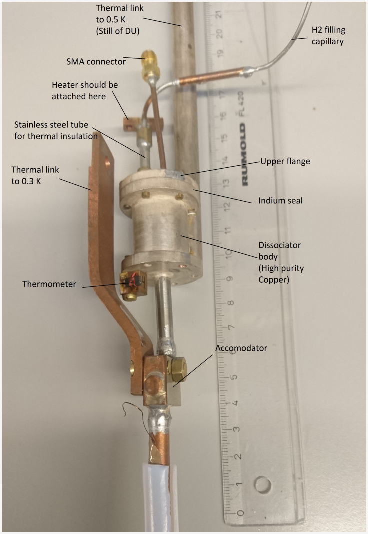
Part of ANKE ABS

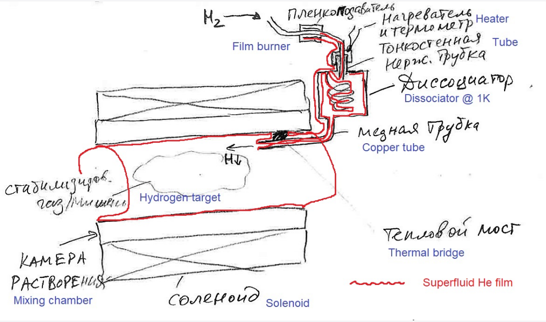
Magnet #3 L = 180 mm

The efficiency of the atomic injection in a tube 10 mm diameter located at 700 mm from the last magnet is 0.531, compared to ANKE ABS. That means that intensity of the atomic beam of $3.98 \cdot 10^{16}$ at/s in two substates is achievable.

Thanks Dr. D. Toporkov, INP, Russia, Dr. F. Rathmann, Dr. Ralf W. Engels, FZ Jülich

Cryogenic atomic hydrogen source





- atomic fluxes $10^{14}\ \frac{\text{atoms}}{\text{sec}}$
- flux H in $|c\rangle$ and $|d\rangle$ states is supressed
- inlet only H in $|a\rangle$ and $|b\rangle$ states
- long time operation

Original photo and sketch by Dr. S. Vasiliev, UTU, Finland