# Polarized Atomic Hydrogen Target at MESA

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SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

PRISMA

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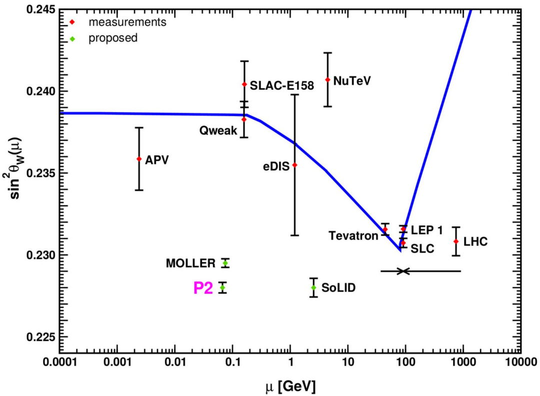
- Hardware actual design
- Hardware in fabrication
- Preliminary
- Atomic hydrogen feed system

Let us have a dream
- Møller polarimeter
- Advantage of tracking

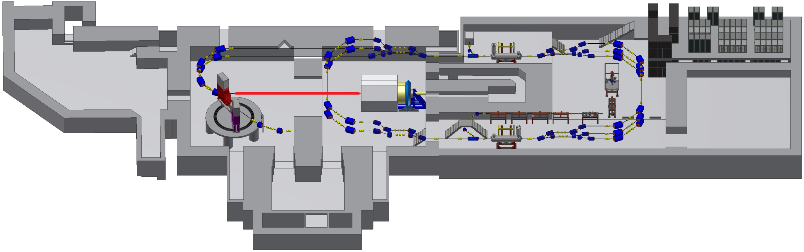
Summary
- Status

# Motivation for measuring of $\sin^2(\theta_W)$ at low $Q^2$



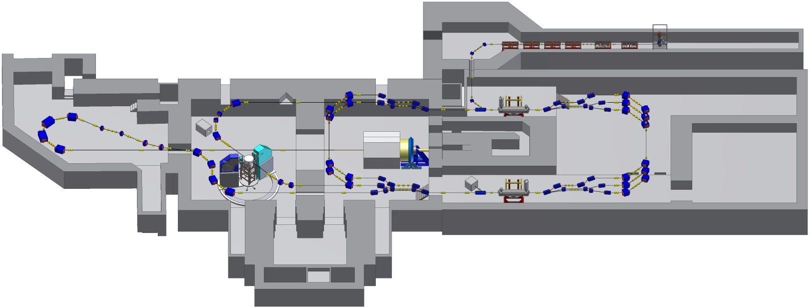

- APV
- Møller scattering
- $\nu$ - scattering
- p p collisions
- $e^+e^-$ collisions
- Deep inelastic $e^-$ scattering
- Parity violating $e^-$ scattering

# MESA
# Mainz Energy-Recovering Superconducting Accelerator



- A new accelerator is being built in Mainz which will allow a next generation parity violation experiment
- Position of Møller polarimeter at MESA - red line
- Stand 2018

# MESA
# Mainz Energy-Recovering Superconducting Accelerator



- Stand 2019

# P2 Experiment at MESA, goals

- CW spin polarized electron beam, polarization $\sim 85\,\%$
- Beam current $\sim 150\,\mu\mathrm{A}$, beam energy $\sim 150\,\mathrm{MeV}$
- Experiment collect $\sim 10^{11}\,\frac{1}{\mathrm{s}}$ for 10000 h
- Weak mixing angle : $\Delta\sin^2(\theta_W) = 0.14\%$

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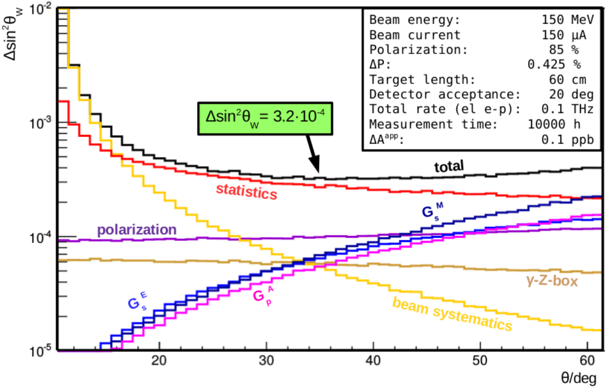
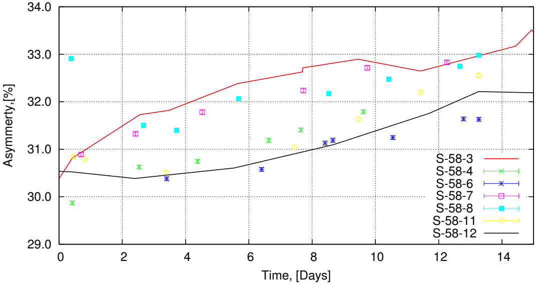
# P2 Experiment at MESA, errors budget




- Beam polarization significantly contributes in precision

# MAMI and MESA Photo cathodes




- $I_{\mathrm{MAMI}} \sim 100.0\,\mu\mathrm{A}$
- $E_{\mathrm{MAMI}} \sim 180.0 - 1500.0\,\mathrm{MeV}$,
- $P_{\mathrm{MAMI}} \sim 85\,\%$
- 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

# Polarimeters chain at MESA

- Double Mott polarimeter at $100.0\,\mathrm{keV}$
- Mott polarimeter at $5.0\,\mathrm{MeV}$
- Møller polarimeter at $50.0 - 150.0\,\mathrm{MeV}$ with Polarised Atomic Hydrogen Target. Proposed in 2004 and revised in 2012 Dr. E. Chudakov and Dr. V. Luppov
- 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

# The main idea of Polarized Atomic Hydrogen Target

Møller scattering of electron beam

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

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

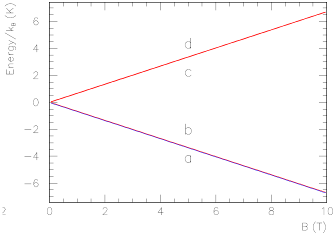
$$A_{exp} = \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow}} = a_{zz} P^B P^T. \qquad (2)$$

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

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

# Complication from hyperfine splitting

Molecular hydrogen $H_2$ opposite electron spin
Atomic hydrogen $H_1$ : $\vec{\mu} \approx \vec{\mu}_e$ in magnetic field

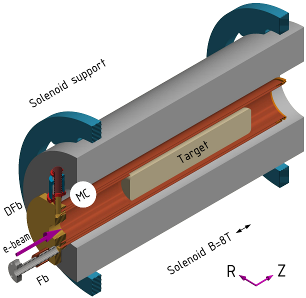



Low energy seekers:
$|a\rangle \; |\uparrow\Downarrow\rangle \cos(\theta) - |\downarrow\Uparrow\rangle \sin(\theta)$
$|b\rangle \; |\downarrow\Downarrow\rangle$
High energy seekers:
$|c\rangle \; |\downarrow\Uparrow\rangle \cos(\theta) + |\uparrow\Downarrow\rangle \sin(\theta)$
$|d\rangle \; |\uparrow\Uparrow\rangle$
$\tan(2\theta) \approx \frac{0.05}{B}$, $\sin(\theta) = 0.0035$

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

Target Polarization $P^T \sim (1 - 10^{-5}) \sim 0.99999$

# How to keep the target in Z and R-directions




On figure:
R and Z - coordinates
Fb - film burner
MC - mixing chamber

.

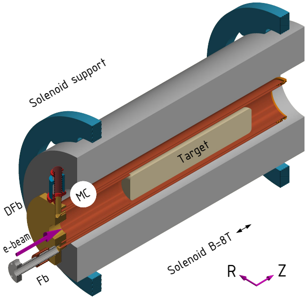
Trapping in Z-direction

- Superconducting magnet $B = 8.0\,\mathrm{T}$
- force in the field gradient $-\vec{\nabla}\left(\vec{\mu}_H \times \vec{B}\right)$
- $|a\rangle$ and $|b\rangle$ are pulled into strong field
- $|c\rangle$ and $|d\rangle$ are repelled out of field

Trapping in R-direction

- Wall of storage cell is coated $\sim 50\,\mathrm{nm}$ film of superfluid $^4$He
- $T_{\mathrm{wall}} = 0.25 - 0.30\,\mathrm{K}$

# Storage cell, established




- $L_H = 0.20\,\mathrm{m}$,
- $D_H = 0.02\,\mathrm{m}$,
- $\rho_H = 3.0 \times 10^{15}\,\mathrm{cm}^{-3}$
- $\rho_H \times L_H = 6.0 \times 10^{16}\,\mathrm{cm}^{-2}$
- Gas lifetime $\sim 1.0\,\mathrm{hour}$

**Nobody has put the target in a high power beam**

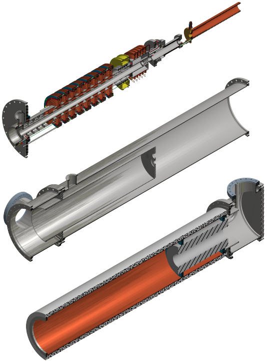
I. F. Silvera and J. T. M. Walraven. Phys. Rev. Lett. V.44, N.3 (1980), M. Mertig et al. Rev. Sci. Inst. 62.1 (1991), E. Chudakov Nuovo Cim, V. C35, N.4 (2012)

# Requirements to cryostat: heat load, cooling power

- Super fluid $^4$He film coated wall 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 $\dot{n}_{He3} = 40.0\,\frac{\mathrm{mmol}}{\mathrm{s}}$

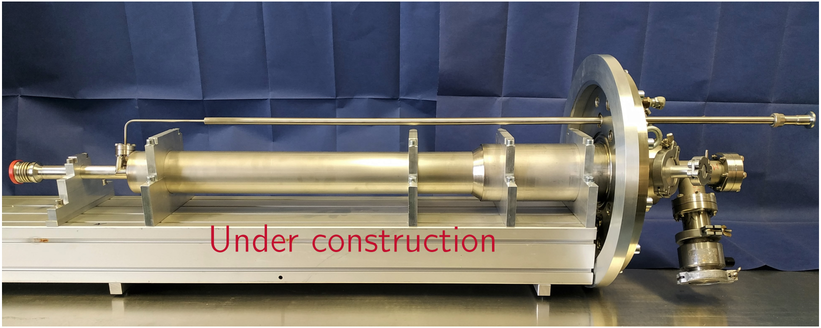
Special thanks N. Borisov JINR, Dr. T. Niinikoski, Dr. N. Doshita CERN

# Polarimeter components = Dilution cryostat + Storage cell + Møller polarimeter

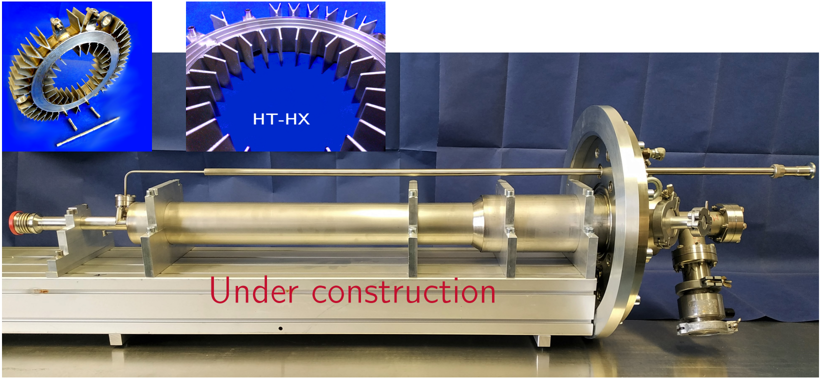


- Horizontal oriented dilution cryostat – mixing $^3$He in $^4$He
- Cryostat insert (up)
- Cryostat housing (middle)
- Superconductive magnet, thermal shield and atomic hydrogen feed system (down)
- Møller polarimeter (not shown) $\rightarrow$ JLAB, W&M, JGU, Lous. Uni
- Dimensions: $L \sim 2.5 + 2.0\,\mathrm{m}$, $D \sim 0.50\,\mathrm{m}$
- **Funding secure**
- Under construction: JGU Mainz

# Farbrication



# Farbrication



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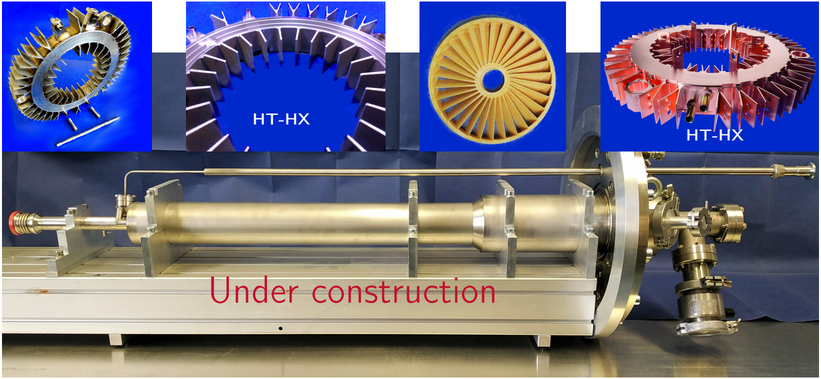

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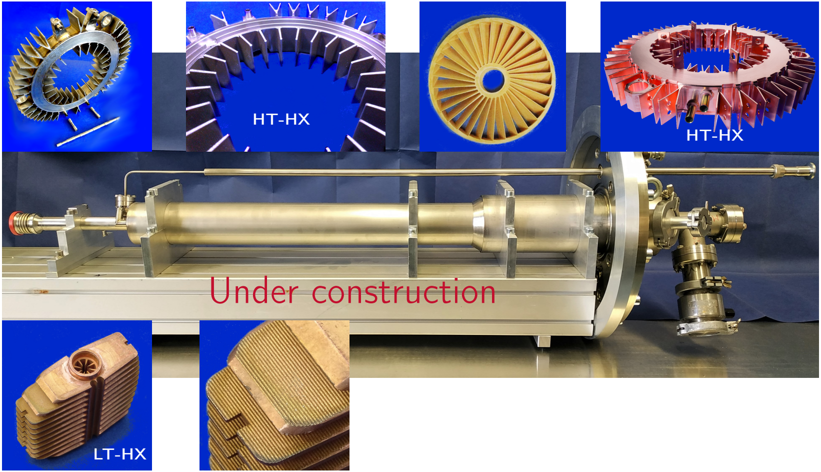

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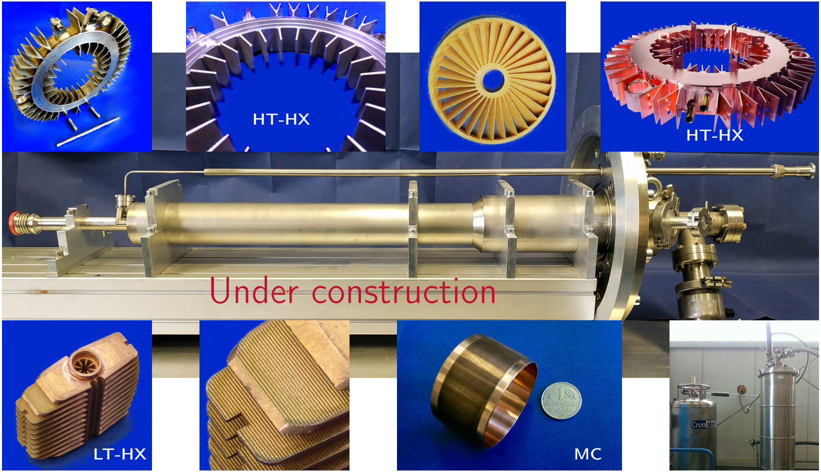
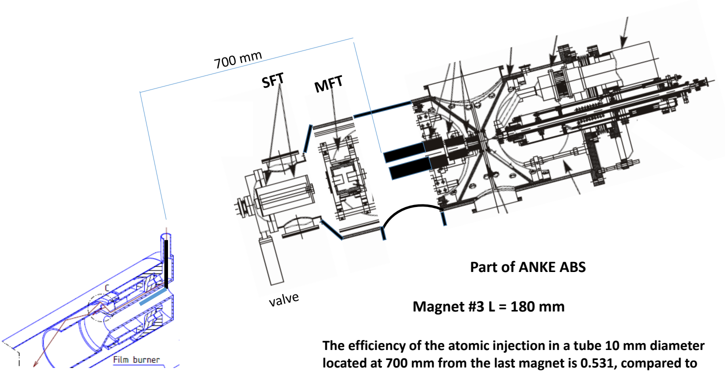



Status: Under construction, cooling down 2020, ready in 2021

# Operating with atomic hydrogen

- Atomic hydrogen losses $\sim 1.0 \times 10^{14}\,\frac{\mathrm{atom}}{\mathrm{s}}$
- Dissociator at room temperature, filling time $\sim 1\,\mathrm{hours}$, Baffles of feed system blocked due to frozen hydrogen, not available continuously on line
- Classic atomic hydrogen beam sourse
  - Suppress flux of $H_2$ and $H_1$ in states $|c\rangle$ and $|d\rangle$
  - Inlet only $H_1$ in states $|a\rangle$ and $|b\rangle$
  - It seems continuous operation possible
- Cryogenics atomic hydrogen source at 1K

# Conventional atomic hydrogen source



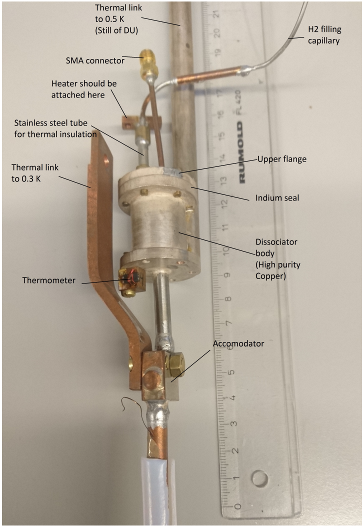

**Part of ANKE ABS**

**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

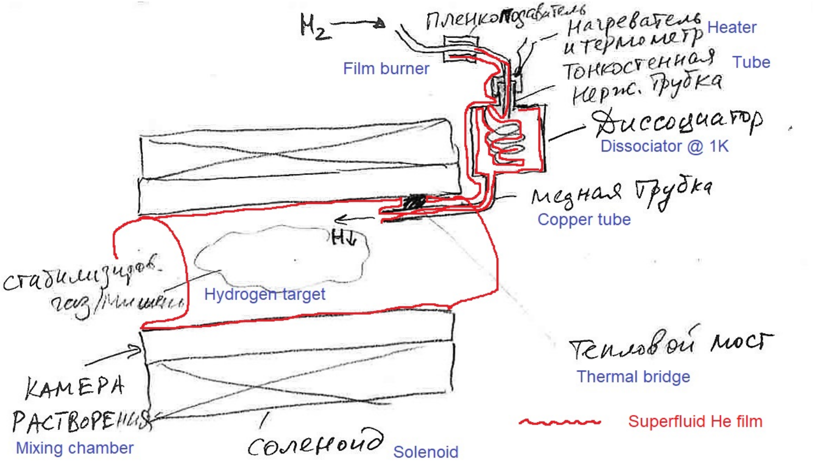
# Cryogenic atomic hydrogen source




- atomic fluxes $10^{14} \frac{\text{atoms}}{\text{sec}}$
- flux $H_1$ in $|c\rangle$ and $|d\rangle$ states is supressed
- inlet only $H_1$ in $|a\rangle$ and $|b\rangle$ states
- long time operation

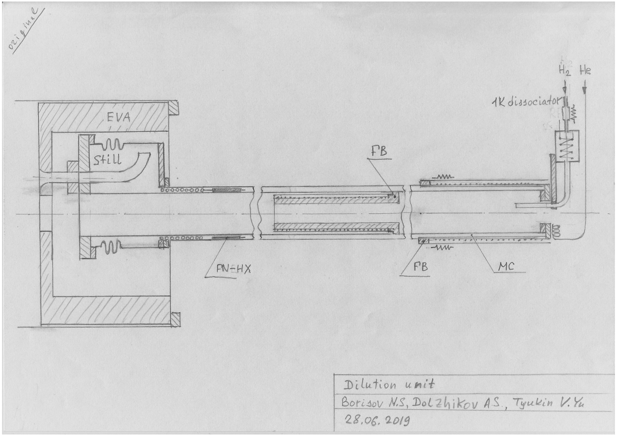
Thanks Dr. S. Vasiliev, UTU, Finland

# Cryogenic source of atomic hydrogen




Drawing by Dr. S. Vasiliev, UTU, Finland

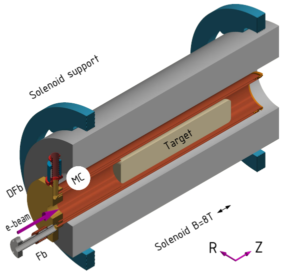
# Still, mixing chamber, film burners, H inlet and target unit

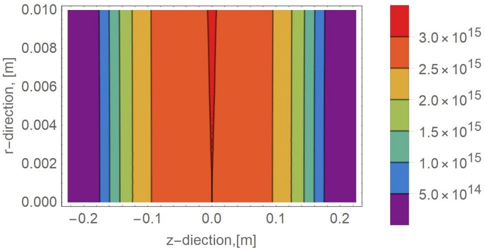



Status: Under conversations, ready in 2021

Original drawing by N. Borisov, JINR

# Assumption: target is ready

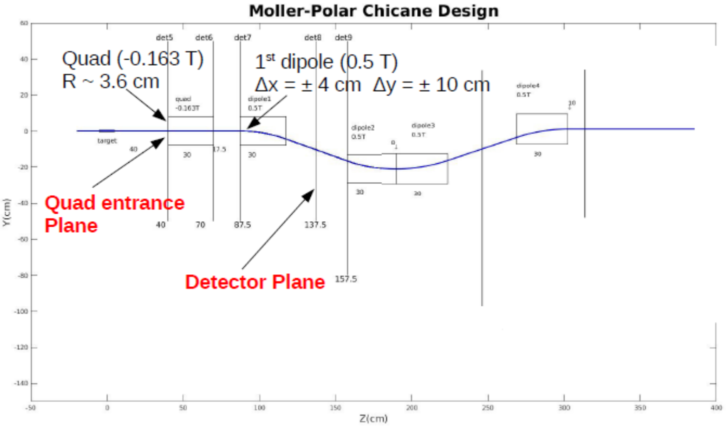



- The hydrogen density varies along the target length $L_H = \pm 0.20\,\mathrm{m}$ according to the field strength. With $B_{\max} = 8\,T$ reachs $\rho_{maxH} = 3.0 \times 10^{15}\,\mathrm{cm}^{-3}$
- $\theta_{cm}$ =90°, $\theta_{scat1}$ =4.70°, $\theta_{scat2}$ =−4.70°, $E_{1,2} = 75\,\mathrm{MeV}$

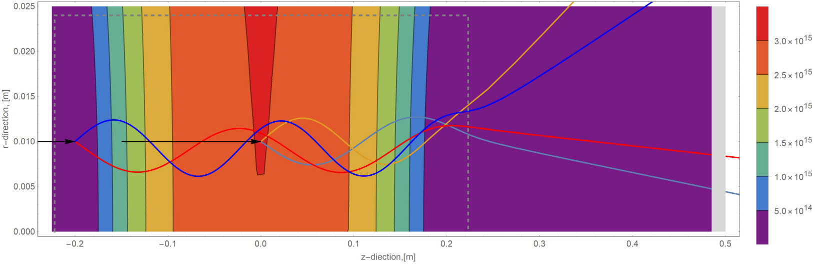
# Møller polarimeter

Chicane Dispersion in vertical axis and quad focus on horizontal axis




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

# Target and detector




- Target at $z = -0.2.. + 0.2\,\mathrm{m}$ 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 advantage
- If the tracker can operate at the full beam intensity $\sim 583\,\frac{\mathrm{electron}}{\mu\mathrm{A}}$, then the polarization measurement could be performed with the tracker itself

# Measurement 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 He4 and film of super fluid He4 on wall over time.

# 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")
- Hardware in fabrication
- Cooling down precooler 2020 , full test 2022, on beam 2023

# Thank for support

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PRISMA

Thank you for your attention!

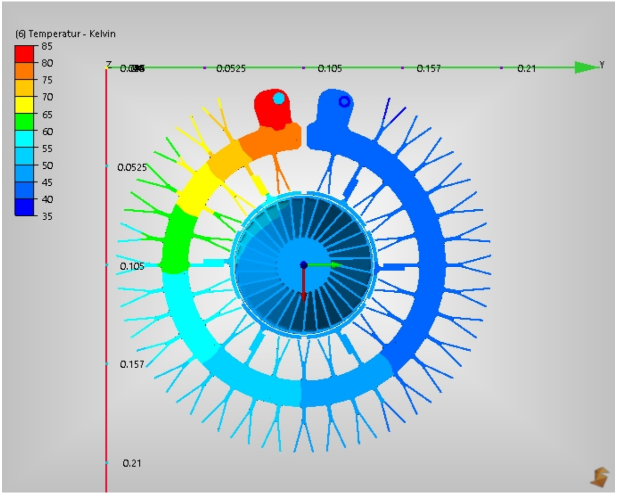
# Backup slides

Backup

# Abstract

One aim for the new electron accelerator MESA is to measure the weak mixing angle in electron proton scattering to a precision of 0.14%. The beam polarization significantly contributes to this measurement. The Møller polarimeter proposed by V. Luppov and E. Chudakov opens the way to reach a sufficiently accurate determination of polarization. At the moment the polarized atomic hydrogen target is under construction. The current status and atomic hydrogen feed system is presented.

# Thermal simulation using CFD 2015 of HT-HX



# P2 Spectrometer

- Magnetic field of solenoid bends electrons around a lead shield which protects the counting detector from background: