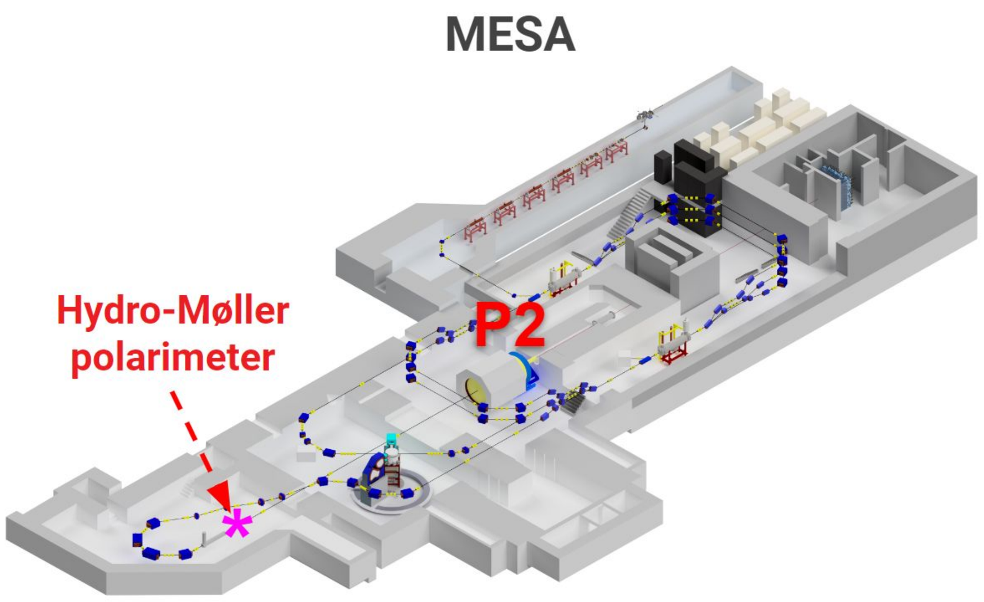
Detector system and simulation of the 155 MeV Hydro-Møller polarimeter at MESA



Michail Kravchenko

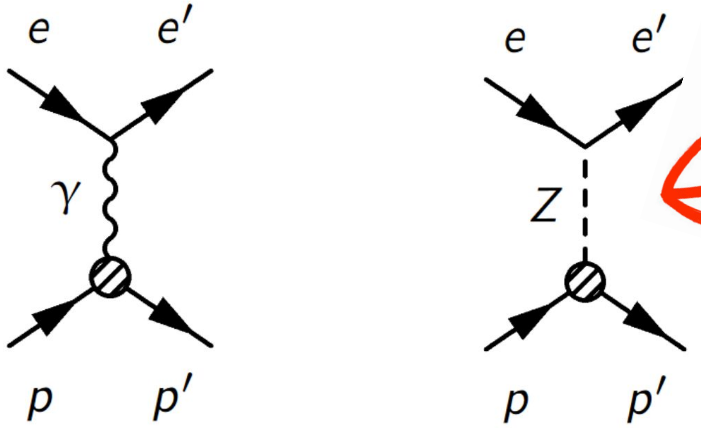
PhD student, AG Berger
PRISMA+ Cluster of Excellence/
Institute for Nuclear Physics,
Johannes Gutenberg University Mainz

DPG Spring Meeting SMuK 2023, Dresden

The P2 experiment: overview and theory

The weak mixing angle
(Weinberg-angle):

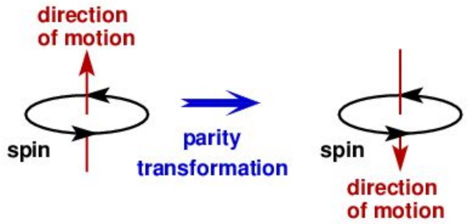
$$\sin^2\theta_W = \frac{g'^2}{g^2+g'^2}$$



Proton electric charge $+1$

Proton weak charge $1-4\sin^2\theta_W$

Violates parity!



Parity violating asymmetry

momentum transfer

Asymmetry: $$A_{PV} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(1-4\sin^2\theta_W - F(Q^2)\right)$$

proton form factor
(small @ low Q^2)

The P2 experiment: overview and theory

Measuring the parity violating asymmetry in e-p-scattering

polarization of the beam

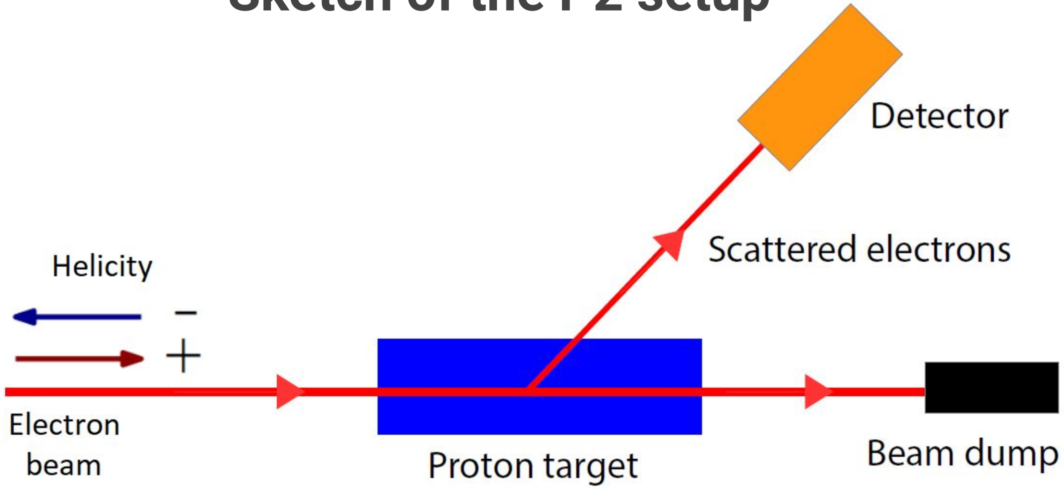
$$A_{exp} \equiv \frac{N^+ - N^-}{N^+ + N^-} = P_{beam} \cdot \langle A_{pv} \rangle + A_{app}$$

$\sim$ 30 ppb

averaged expected value

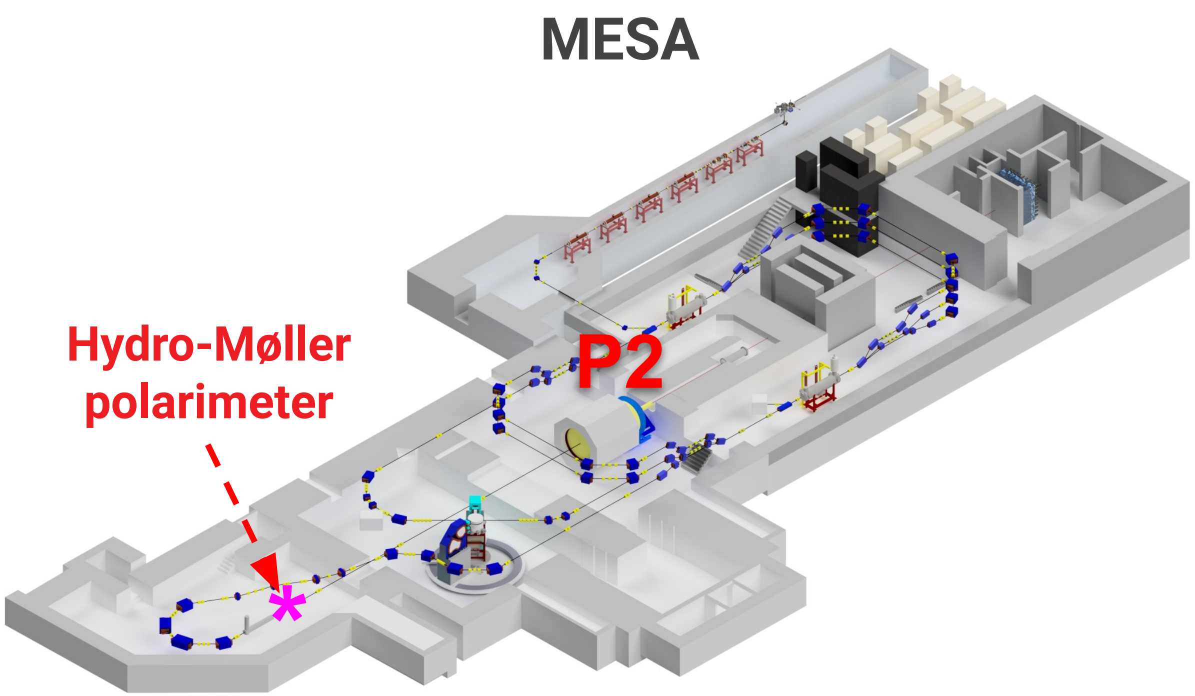
apparative asymmetry

Sketch of the P2 setup



***More about the P2 experiment**: presentation "Design and Production of Pixel Strips for the P2 Tracking Detector Modules" (T 148.3), L. Binn*

Mainz Energy-Recovery Superconducting Accelerator (MESA)



First beam is planned for 2024

Beam:

- Highly polarized (≥85%)
- Current: 150 μA = 10^{15} e^-/s
- L ≈ $2.4 \cdot 10^{39}$ $cm^{-2}s^{-1}$
- Energy: 155 MeV
- Flip helicity @ 1 kHz

Additional requirement:

- Beam polarization: $\Delta P_b / P_b \leq 0.5\%$

Goal:

$$\frac{\Delta \sin^2\theta_W}{\sin^2\theta_W} \sim 0.14\%$$

Issue: beam polarization could vary up to 10% during the run

→ need for an online polarimetry

Mainz Energy-Recovery Superconducting Accelerator (MESA)

Suitable polarimetry technique

Method	Physics	Pros	Cons
Møller	$\vec{e}^- + \vec{e}^- \rightarrow e^- + e^-$	Rapid, precise; not very high beam energy	Solid target (but concept of a **low-density gaseous target**)

Atomic Hydrogen target (proposal by E. Chudakov and V. Luppov*):

- Non-destructive → online measurement;
- Suitable for low-energies (E_{beam} = 155 MeV)
- Overall accuracy: $\Delta P \leq 0.14\%$
- Max analyzing power @ $\Theta^{CM} = 90^o$ ($E_{Møller} = 0.5 * E_{beam}$ = 77.5 MeV)
- Pioneering technology → technical challenges to solved

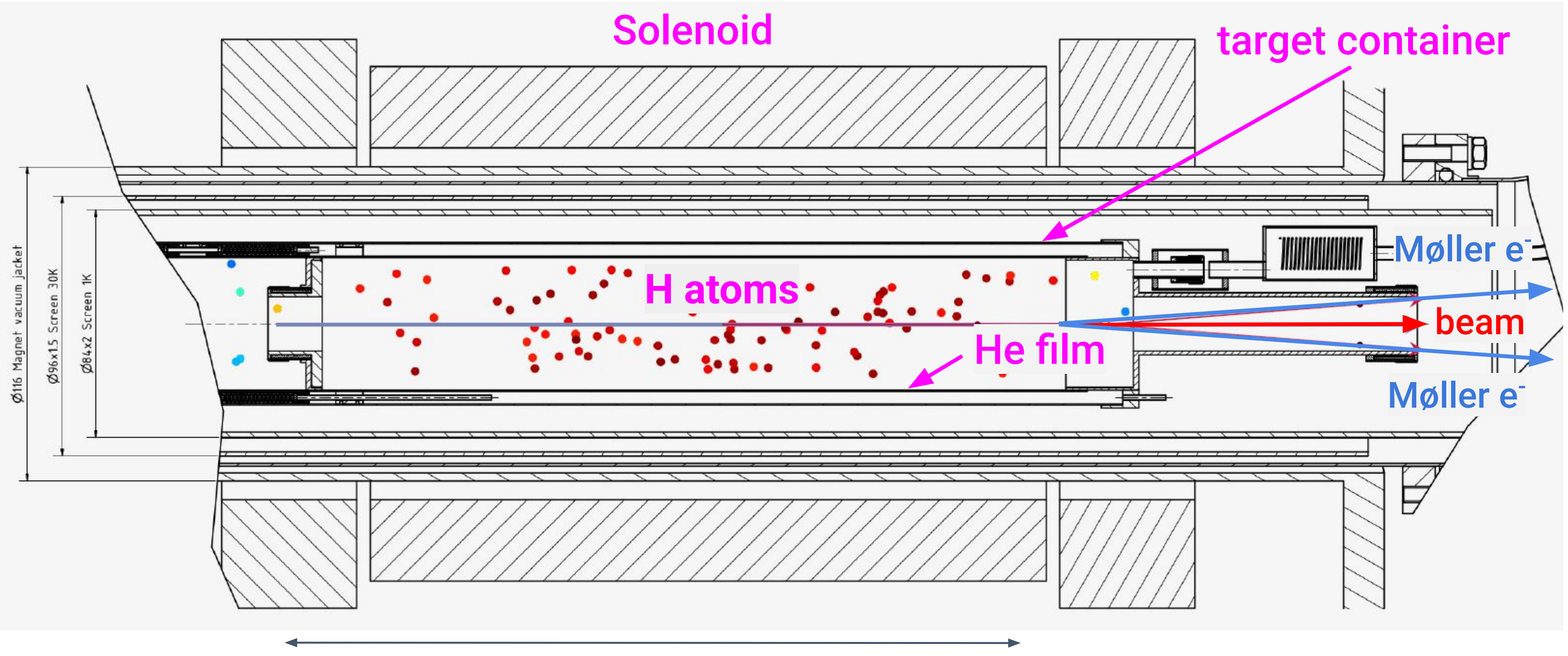
*E. Chudakov, V. Luppov IEEE, V. 51, 2004; E. Chudakov, Nuovo Cim, V. C35, 2012

Hydro-Møller polarimeter: target

- **Target**:
  - L_T = 30 cm
  - $\rho_T = 3.0 \times 10^{15}$ cm^{-3}
- **non-destructive**
  => **online measurement**
- Atomic **magnet trap** and **superfluid thin He film** for **suppressing recombination**

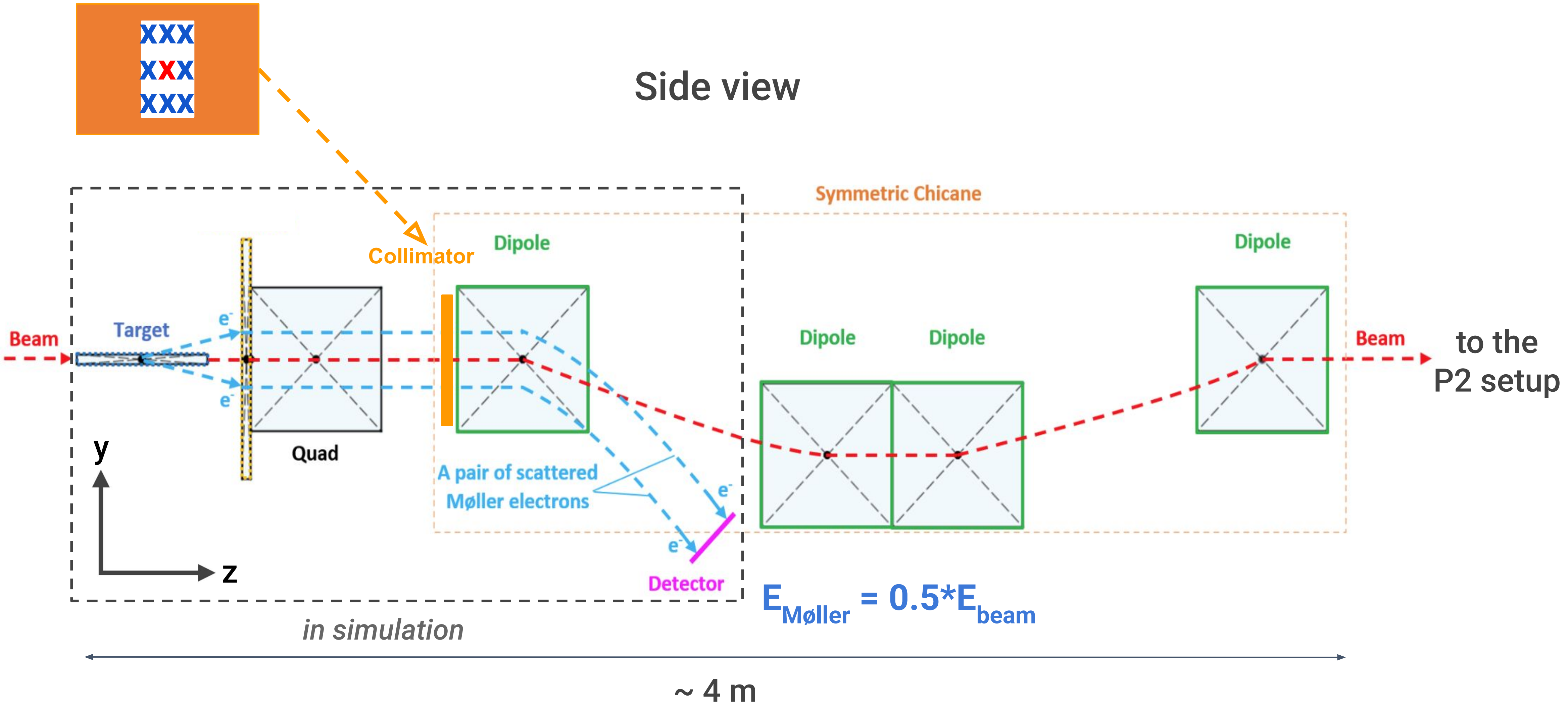
P_{target} = 1 - ε,
with ε ~ 10^{-5} @ $B_{Solenoid}$ = 8.0 T

Atomic Hydrogen target



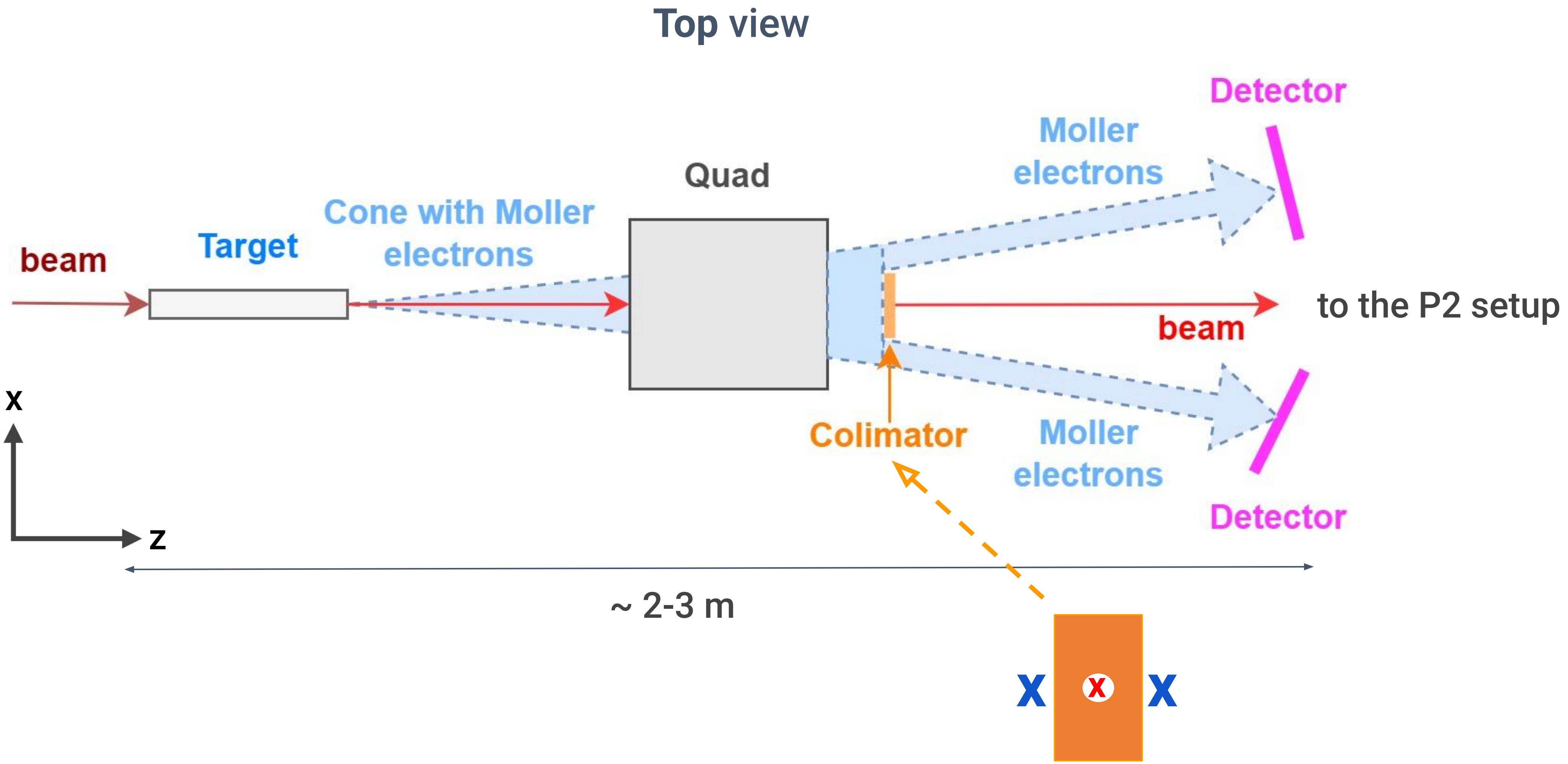
Courtesy of V. Tyukin (KPH, JGU), V. Fimushkin and R. Kusaykin (JINR, Dubna)

Hydro-Møller polarimeter: Chicane design



$$E_{Møller} = 0.5*E_{beam}$$

Hydro-Møller polarimeter: Double-arm design



Geant4 simulation: model

Particle generators (original + PRAD*):

- Moller:

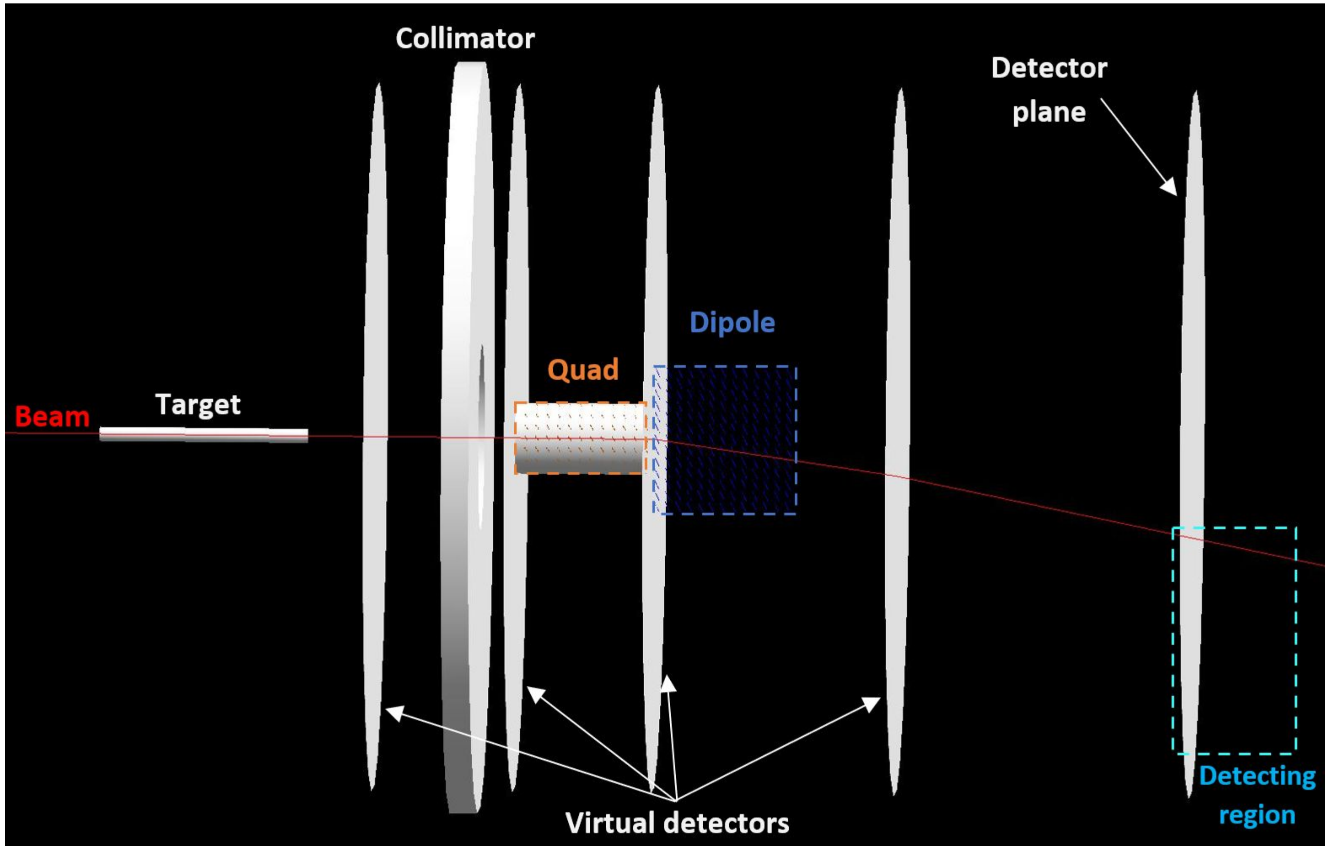
  only $\vec{e}^- + \vec{e}^- \rightarrow e^- + e^-$ => signal

- Elastic e⁻-p (Mott , **e-p**):

  only $\vec{e}^- + Z \rightarrow e^-$ => background

code of generators was kindly provided by PRAD collaboration
(based on Eur. Phys. J. A 51(2015)1)

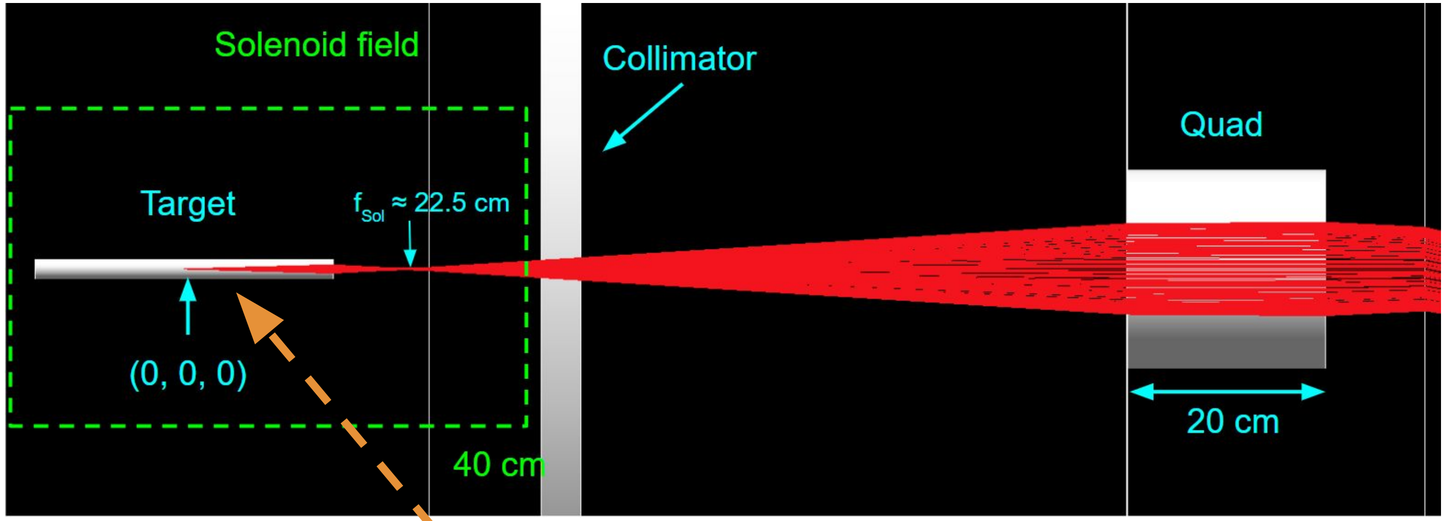
Geant4 model

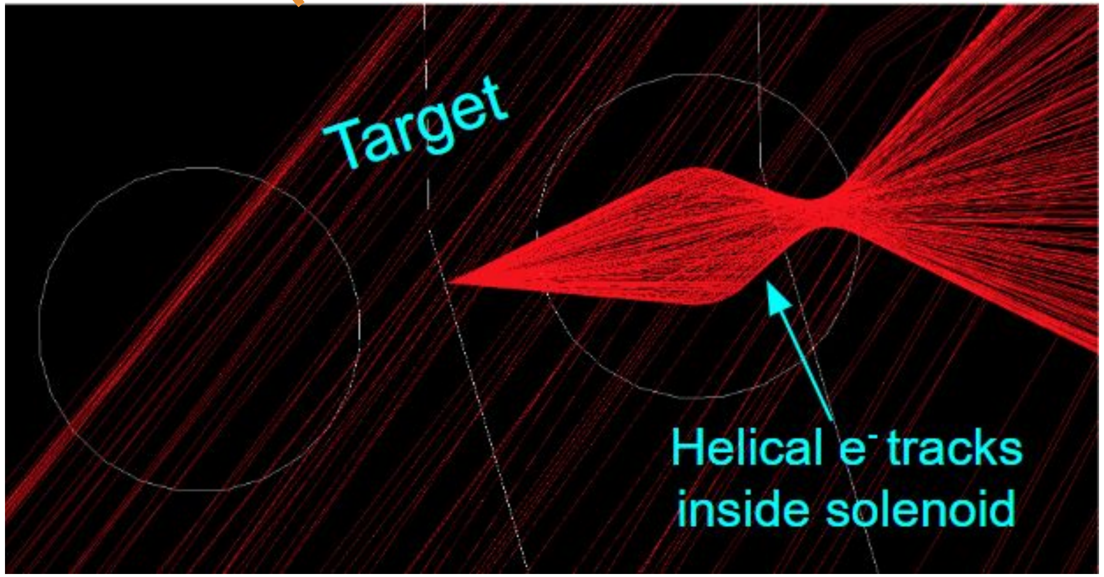


Geant4 simulation: model

Simulation parameters:

- E_{beam} = 155 MeV
- Beam current = 150 μA = 10^{15} e^-/s
- $B_{solenoid}$ = 8 T
- Moller generator:
  - $E_{electrons} \in [75, 80]$ MeV
- E-p generator:
  - $\theta_{scat} \in [0.01, 90]$ deg





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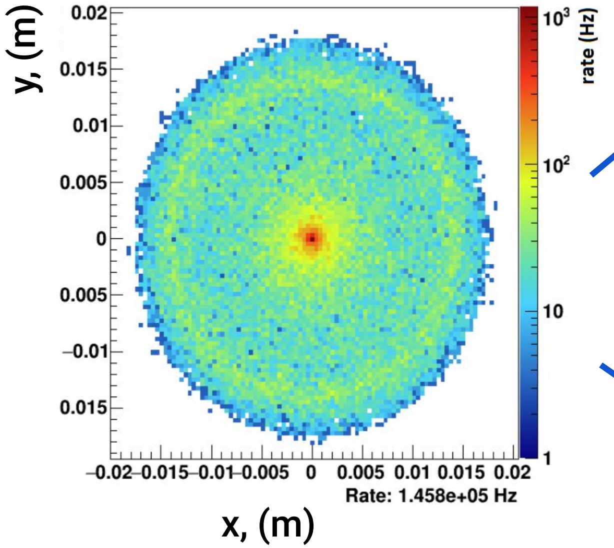
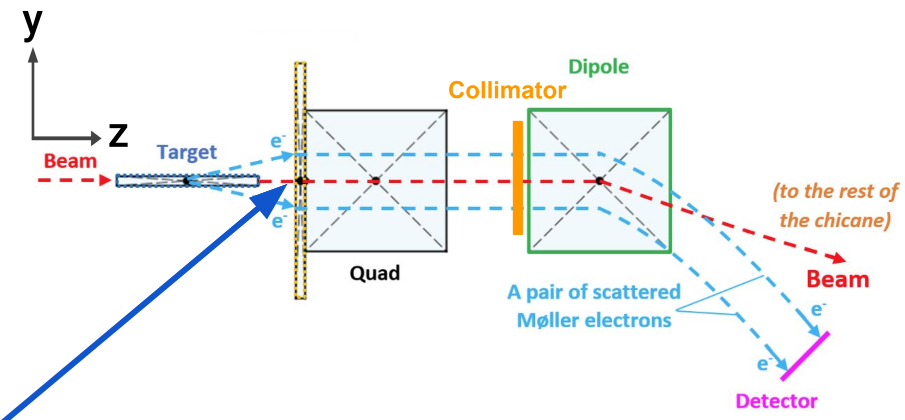
Geant4 simulation: current results

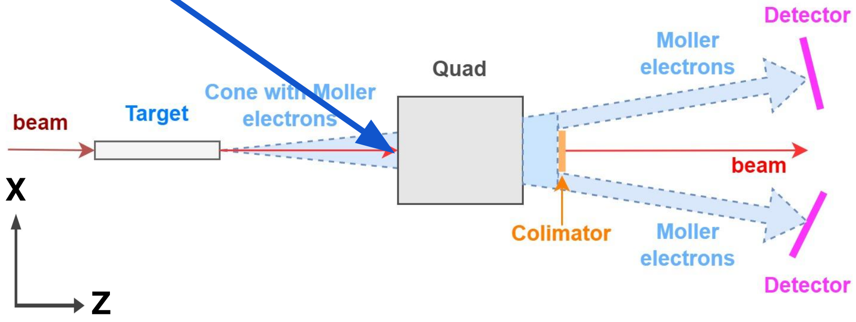
Only Moller events (signal)



Chicane design

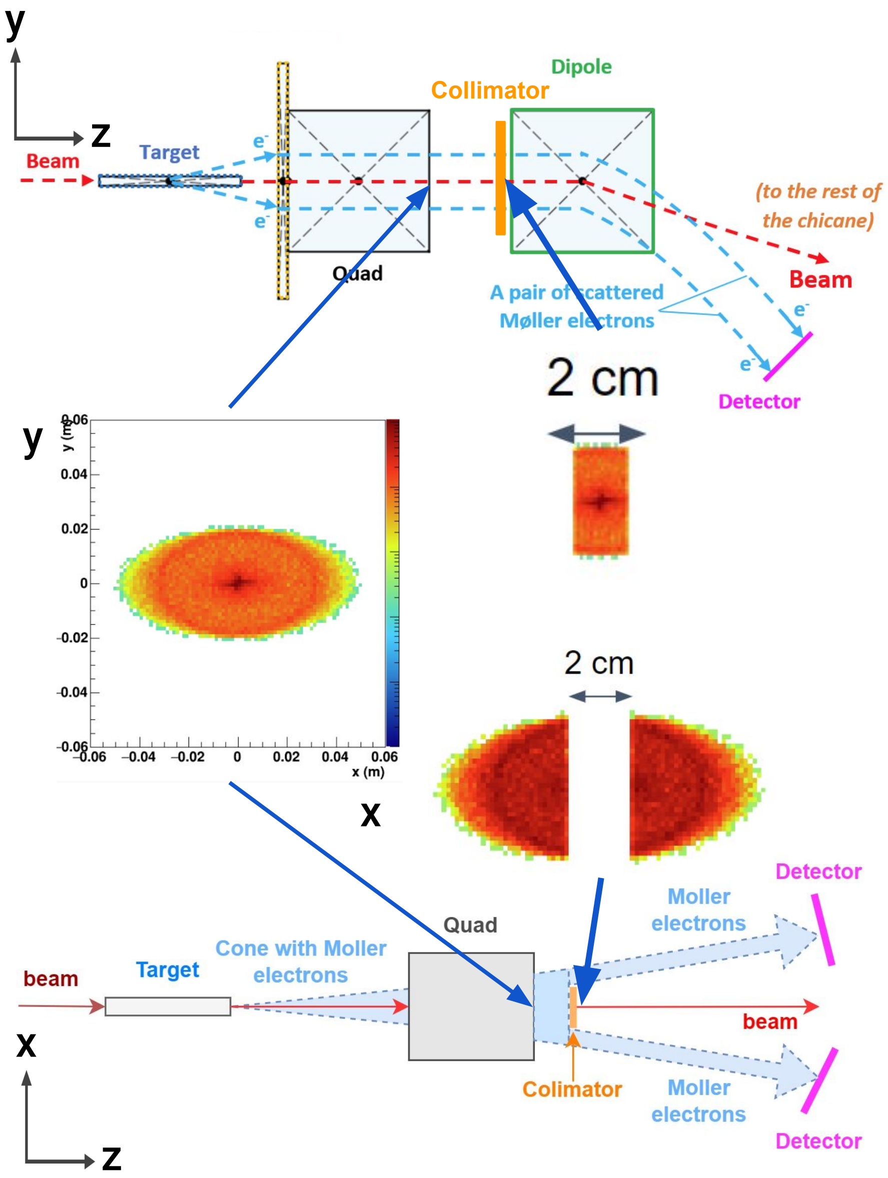


Double-arm design



Geant4 simulation: current results

Chicane design

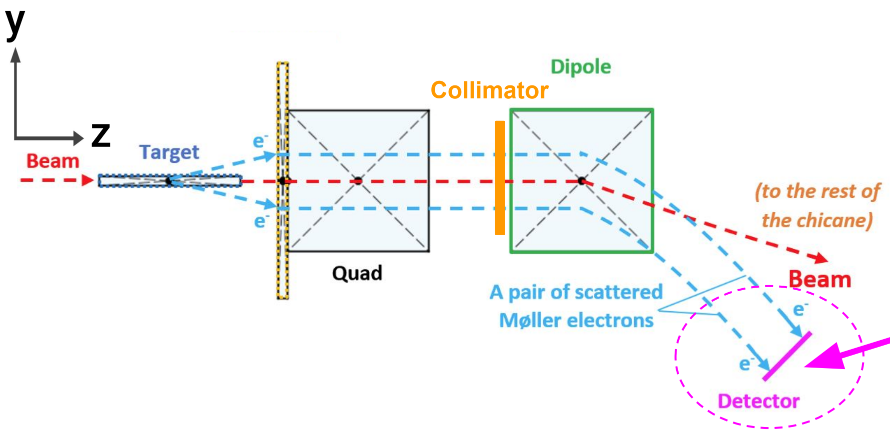


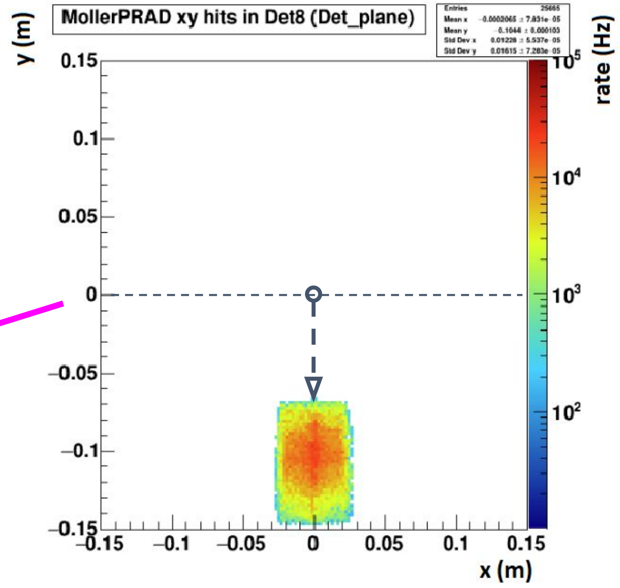
Only Moller events (signal)

Double-arm design

Geant4 simulation: current results

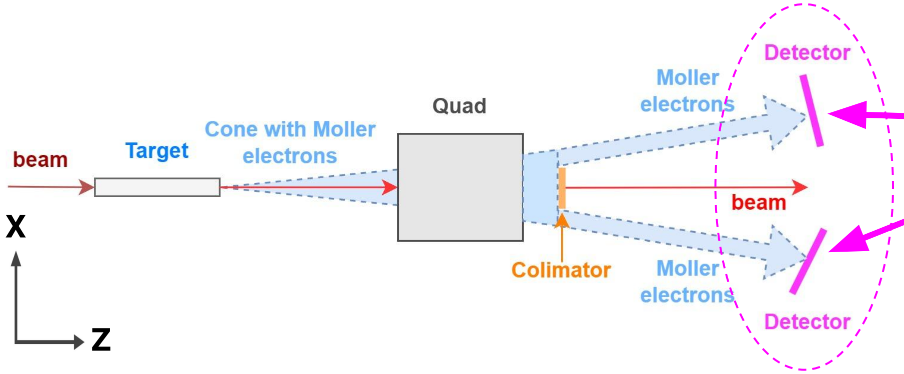
Chicane design

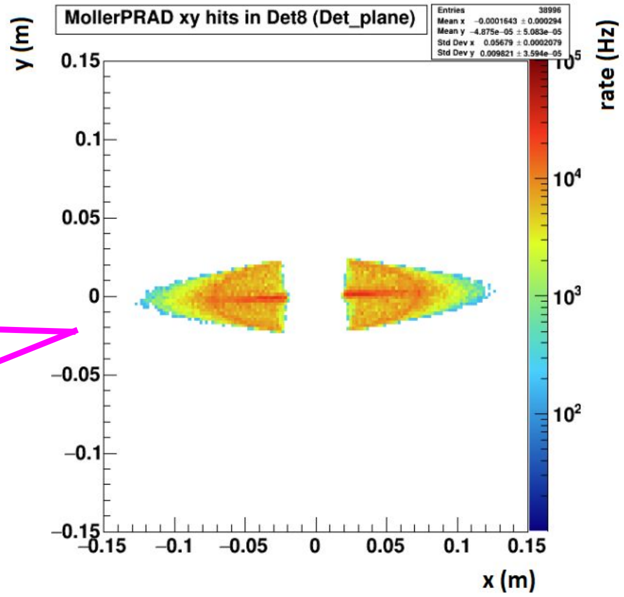




Only Moller events (signal)

Double-arm design



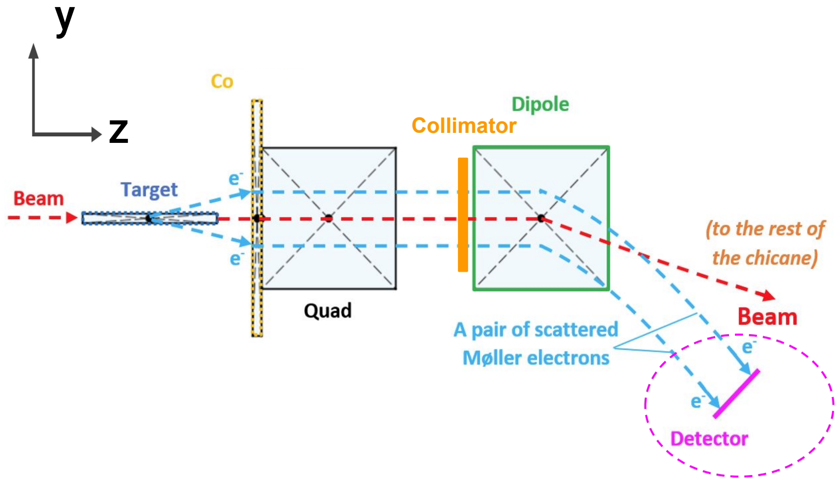


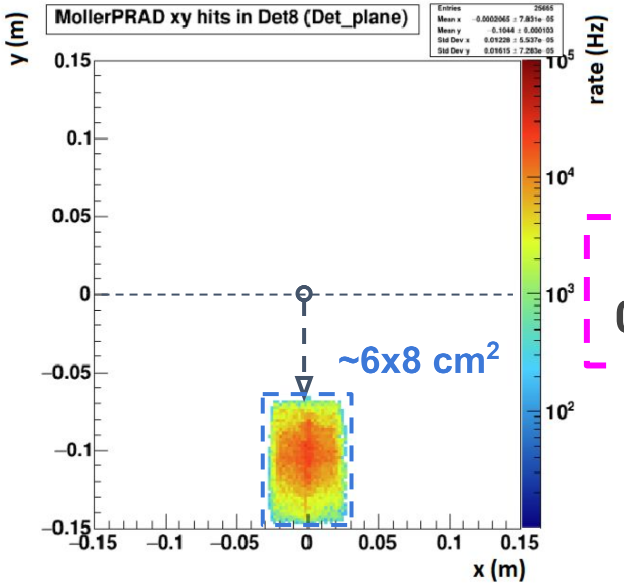
Geant4 simulation: current results

Moller events (**signal**)

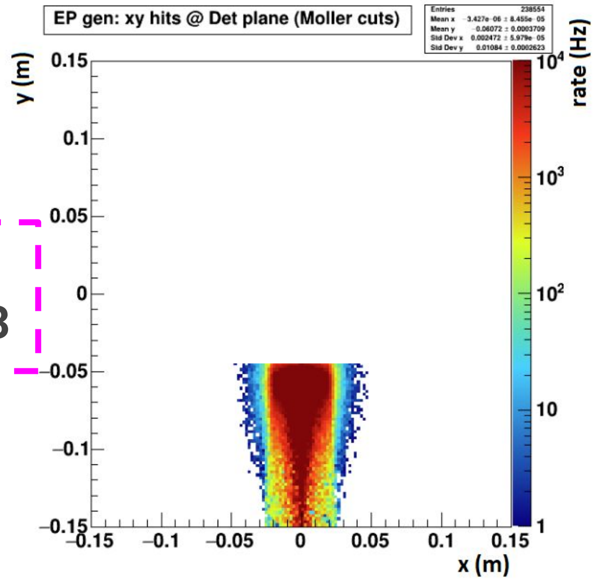
EP events (**background**)

Chicane design:

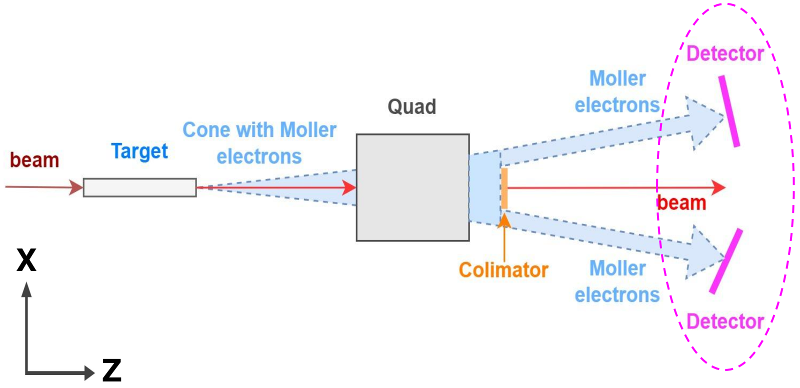


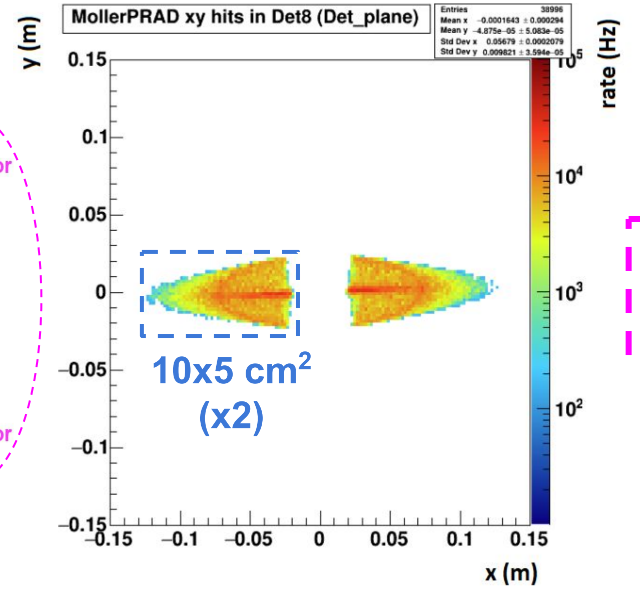


S/B: 0.1-0.03

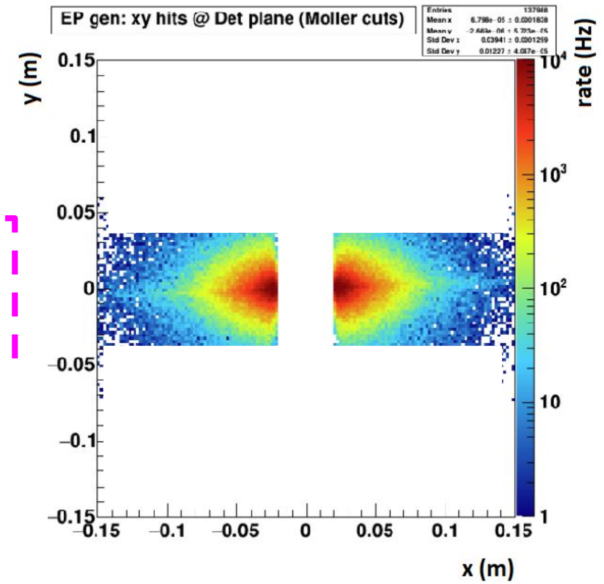


Double-arm design:





S/B: ~5



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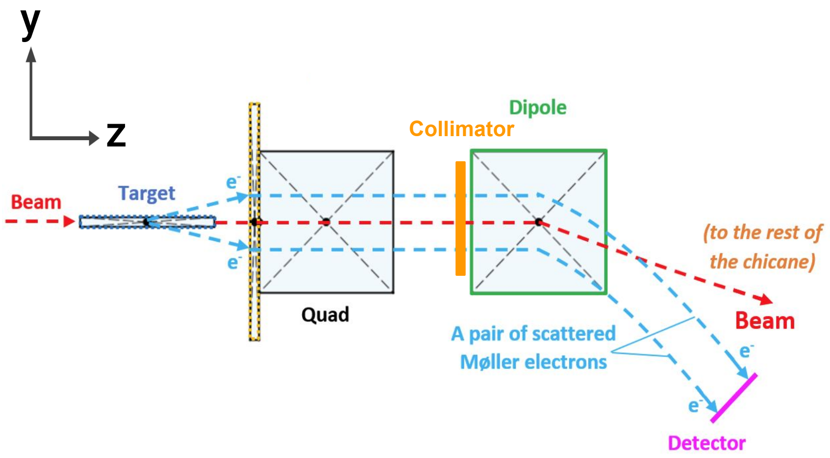
Summary

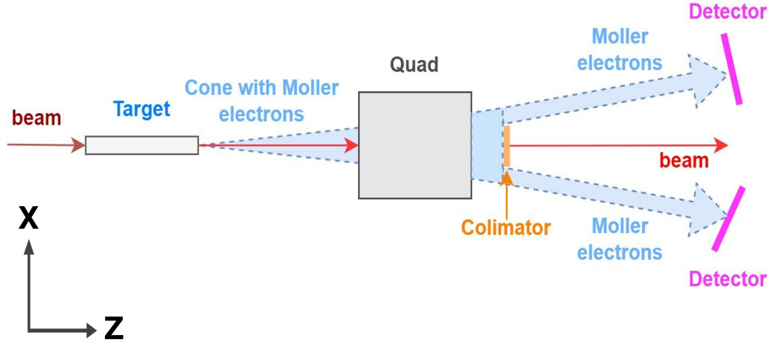
- Precise measurement of the weak mixing angle in the P2 experiment can test the SM or provide a sign of the new physics

- Need of online polarimetry → Hydro-Møller polarimeter

- Pioneering technology → lot of technical and practical issues to be solved

- Further simulation and studies to choose the most optimal design for polarimeter and detecting system





Thank you for your attention!
Questions/comments?

Special thanks to V. Tyukin (KPH, JGU) and R. Beminiwattha (Louisiana Tech University)!

Backup

The P2 experiment: overview and theory

Measuring the parity violating asymmetry in e-p-scattering

polarization of the beam

$$A_{exp} \equiv \frac{N^+ - N^-}{N^+ + N^-} = P_{beam} \cdot \langle A_{pv} \rangle + A_{app}$$

averaged expected value

apparative asymmetry

- $\langle A_{pv} \rangle$- expected value after averaging over the target length L and the detector acceptance
- A_{app} - apparative asymmetry induced by helicity-correlated fluctuations of the electron beam properties

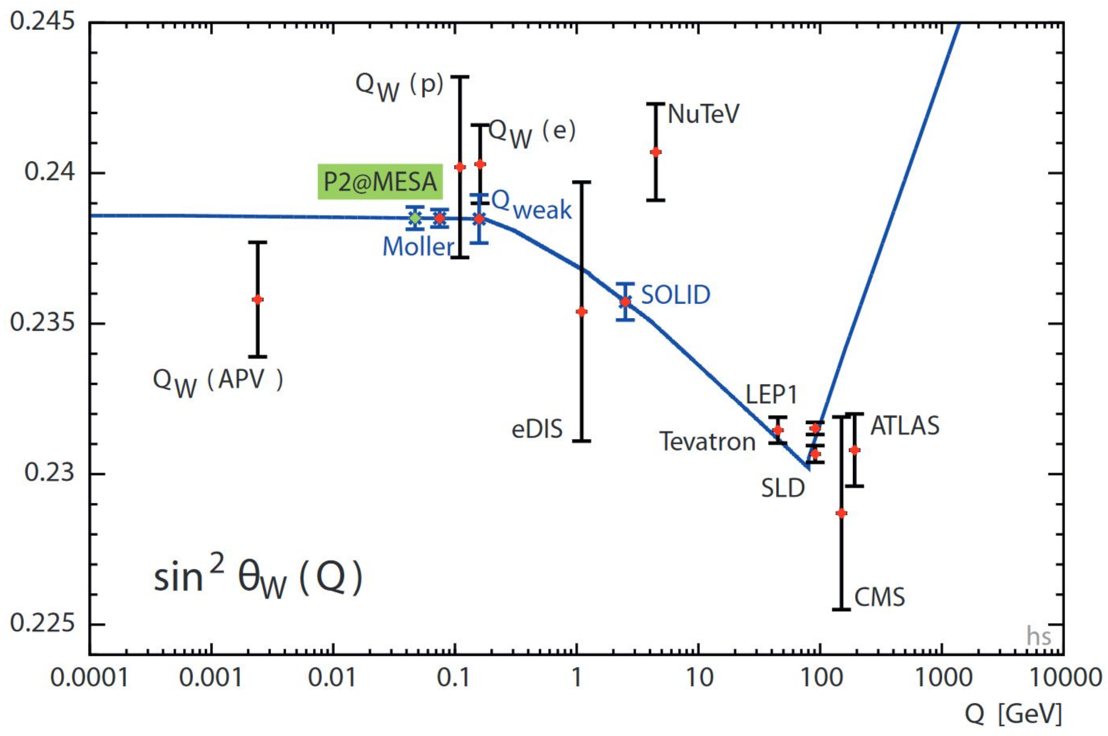
The P2 experiment

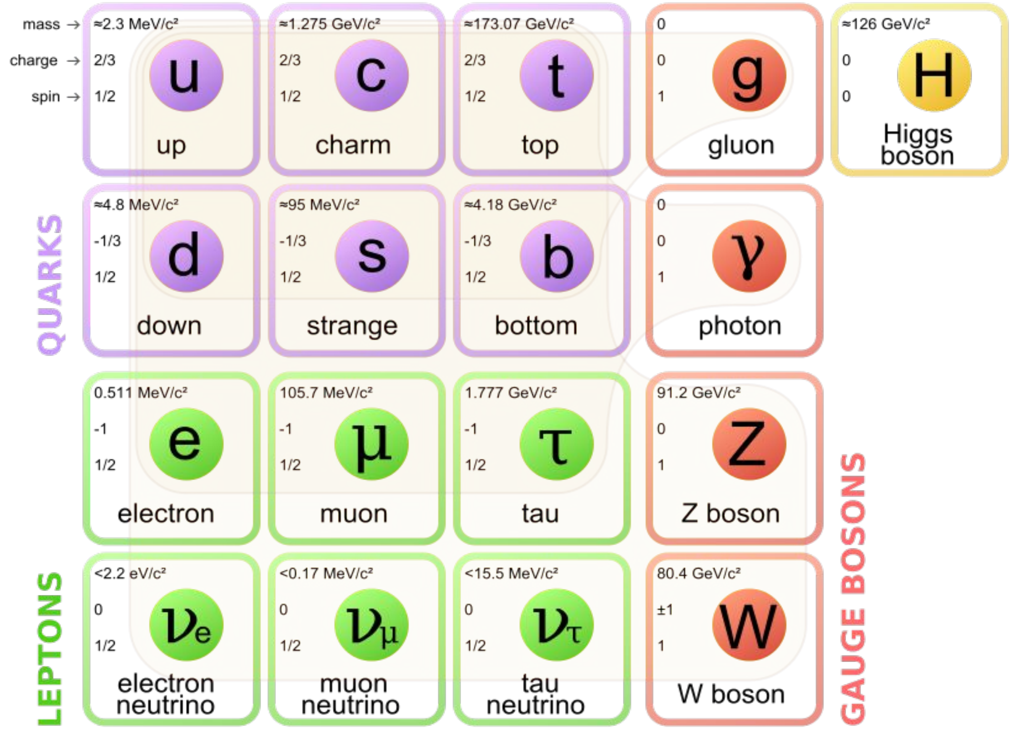
The idea

Precise measurement of the weak mixing angle $\sin^2\theta_W$ at low Q^2

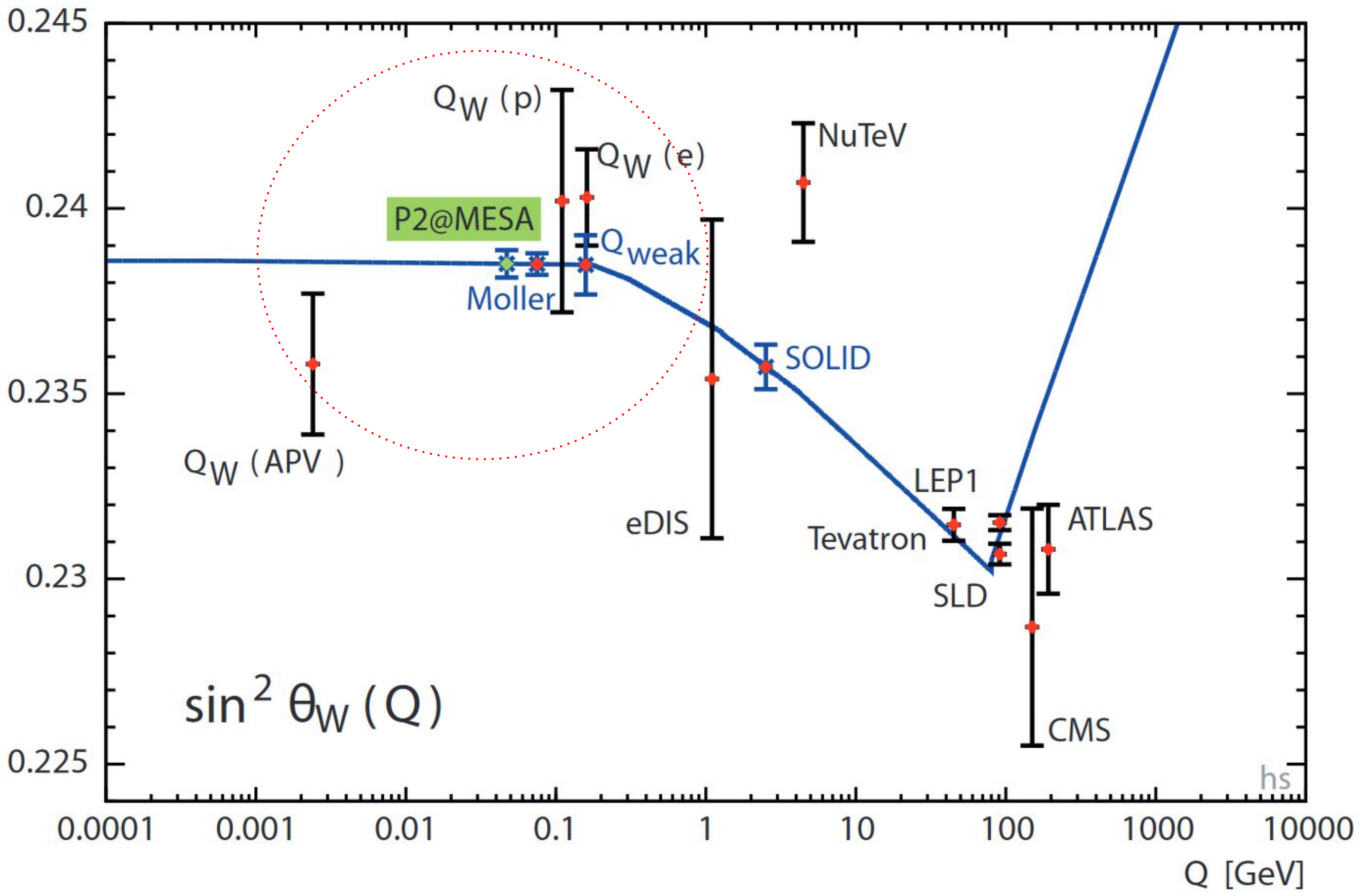
Motivation

- $\sin^2\theta_W$ is a fundamental quantity of the SM and a parameter in the electroweak unification theory;
- accurate testing the SM or providing the new physics;

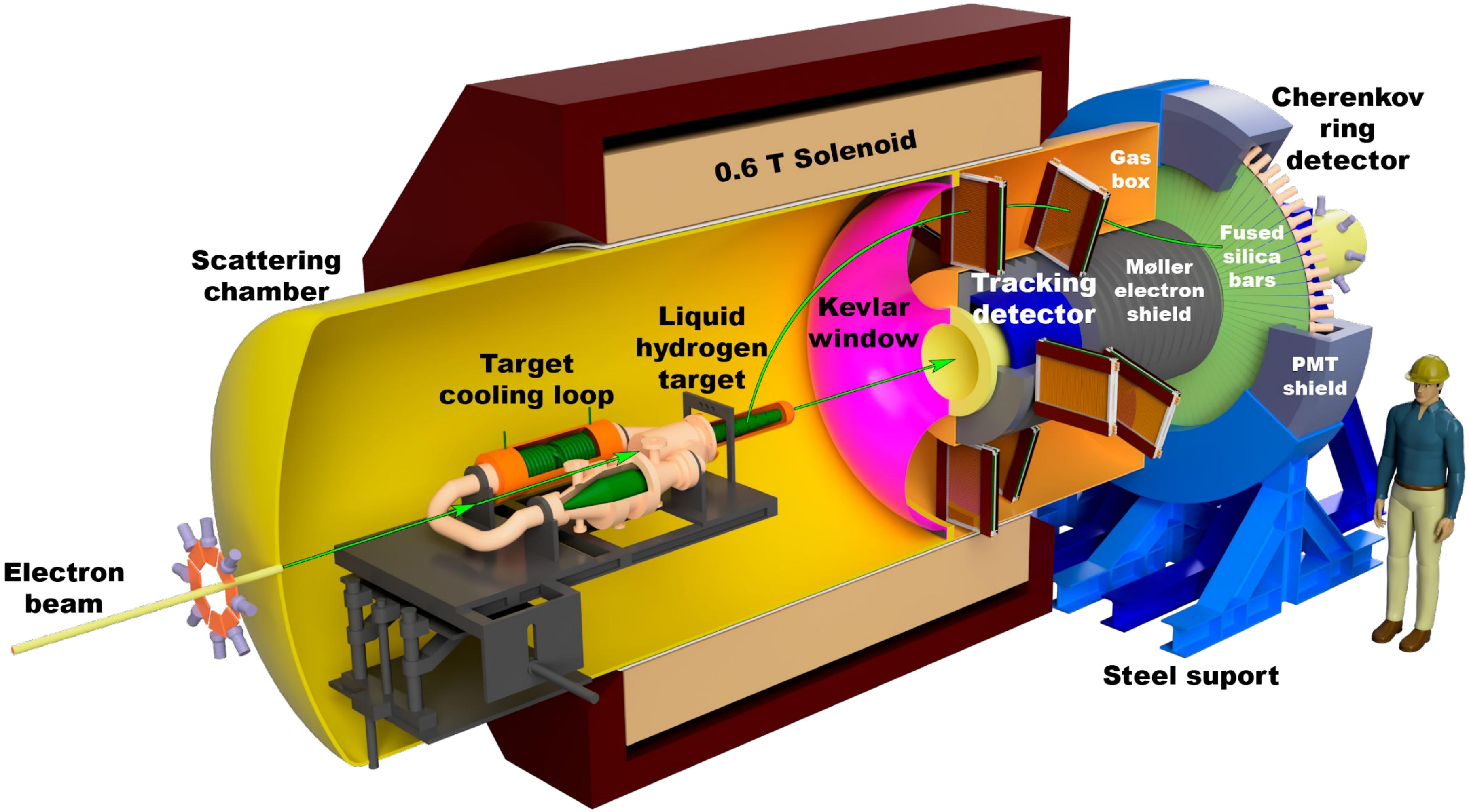




Scale dependence (running) of $\sin^2\theta_W(Q^2)$

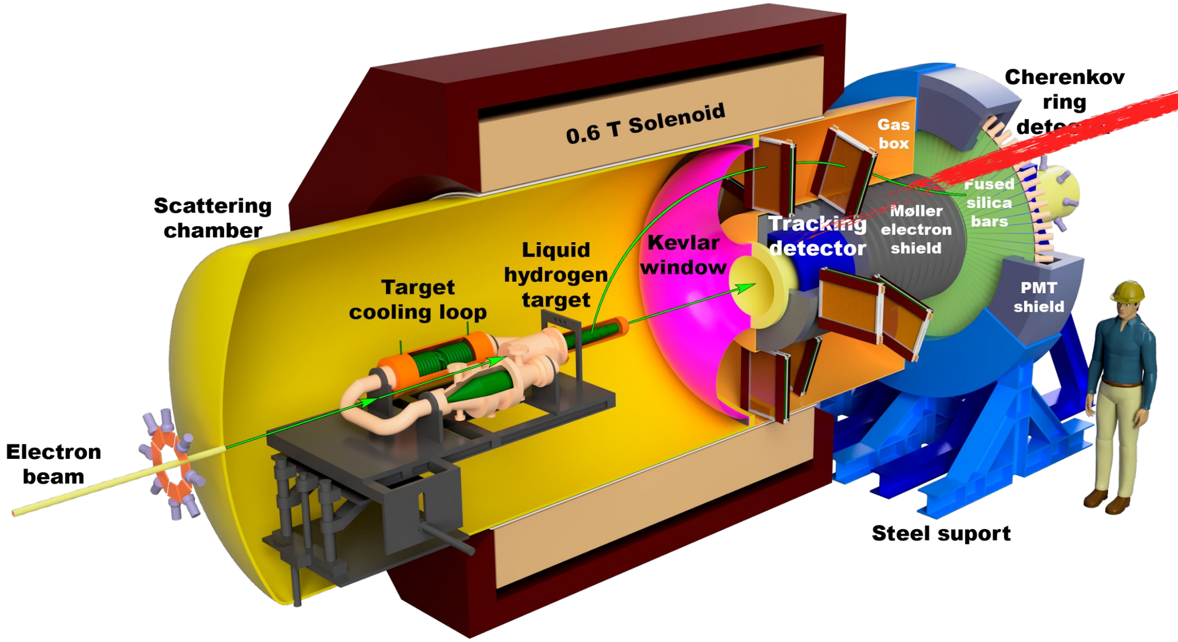


P2 setup



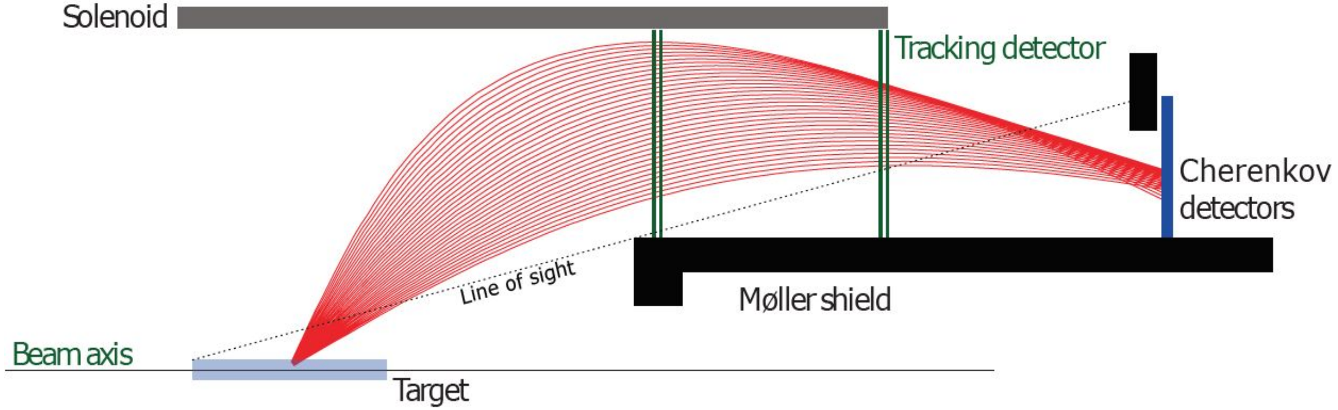
- 60 cm LH_2 target
- Magnetic field along the beam axis
- Tracking detector will determine Q^2
- Integrating Cherenkov detector will measure the asymmetry

P2 setup

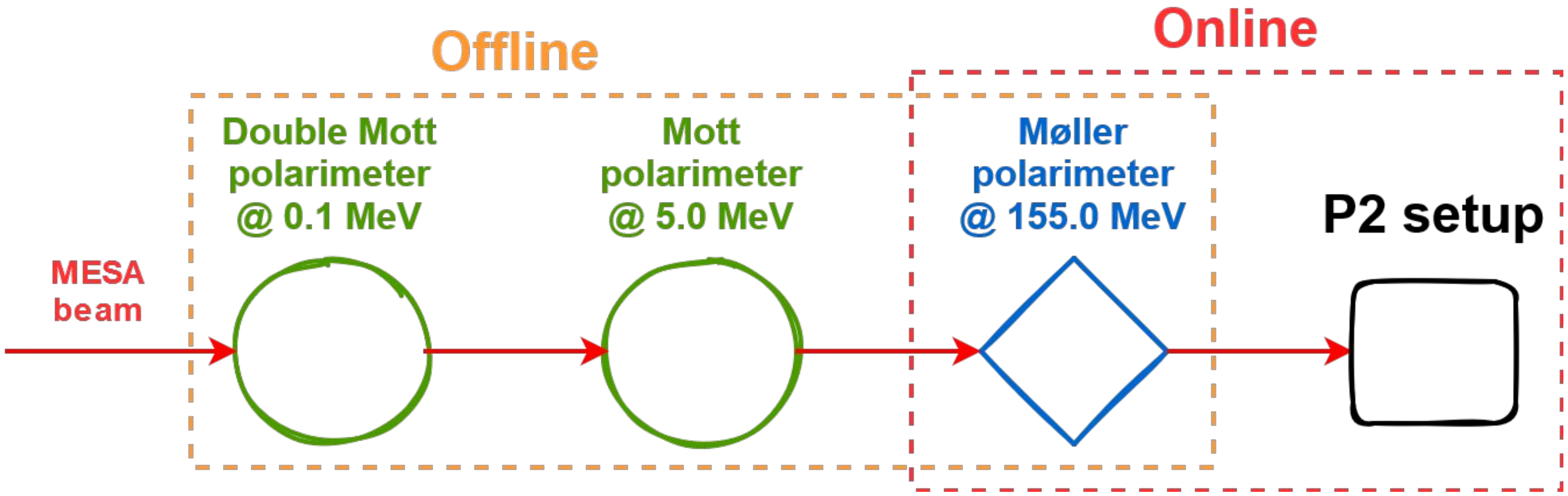


Tracking detector:

- 2 planes with 4 modules/plane;
- Helium inside gas box;
- ~15° azimuthal coverage per module;
- measure average Q^2;
- reconstruct individual electron tracks;



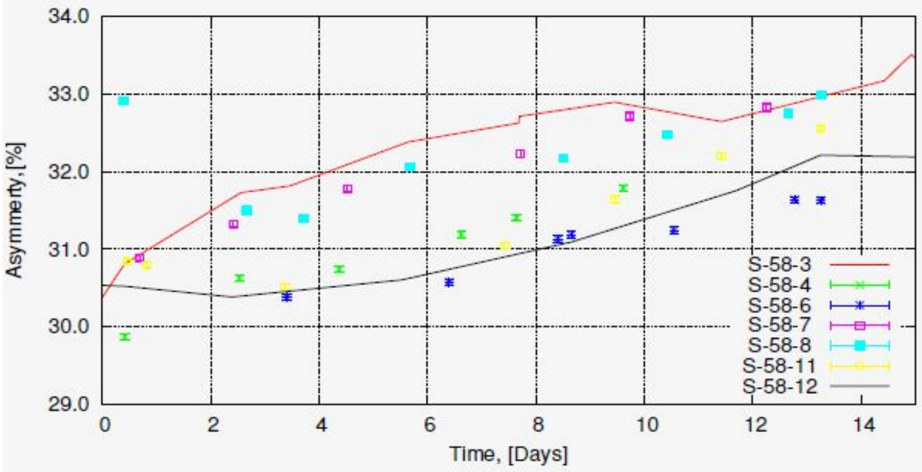
Polarimetry chain @ MESA



- Polarimeter chain for cross checking
- Goal: $P_{\text{Mott, Double}} = P_{\text{Mott, 5.0 MeV}} = P_{\text{Møller, H}}$
- Online measurements => correction for changes in P_{beam}
- Overall accuracy: $\Delta P < 0.5\%$

Polarimetry chain @ MESA

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

Main problem for P2 => online polarimeter

Polarimetry techniques

Issue: beam polarization could vary up to 10% during the run

→ need for an online polarimetry

Polarimetry techniques

Method	Physics	Pros	Cons
Mott	$\vec{e}^- + Z \rightarrow e^-$	Rapid, precise	Solid target => destructive
Compton	$\vec{e}^- + \vec{\gamma} \rightarrow e^-$	Non-destructive	Suitable only for high E_{beam}
Møller	$\vec{e}^- + \vec{e}^- \rightarrow e^- + e^-$	Rapid, precise	Solid target + concept for a **low-density gaseous target**

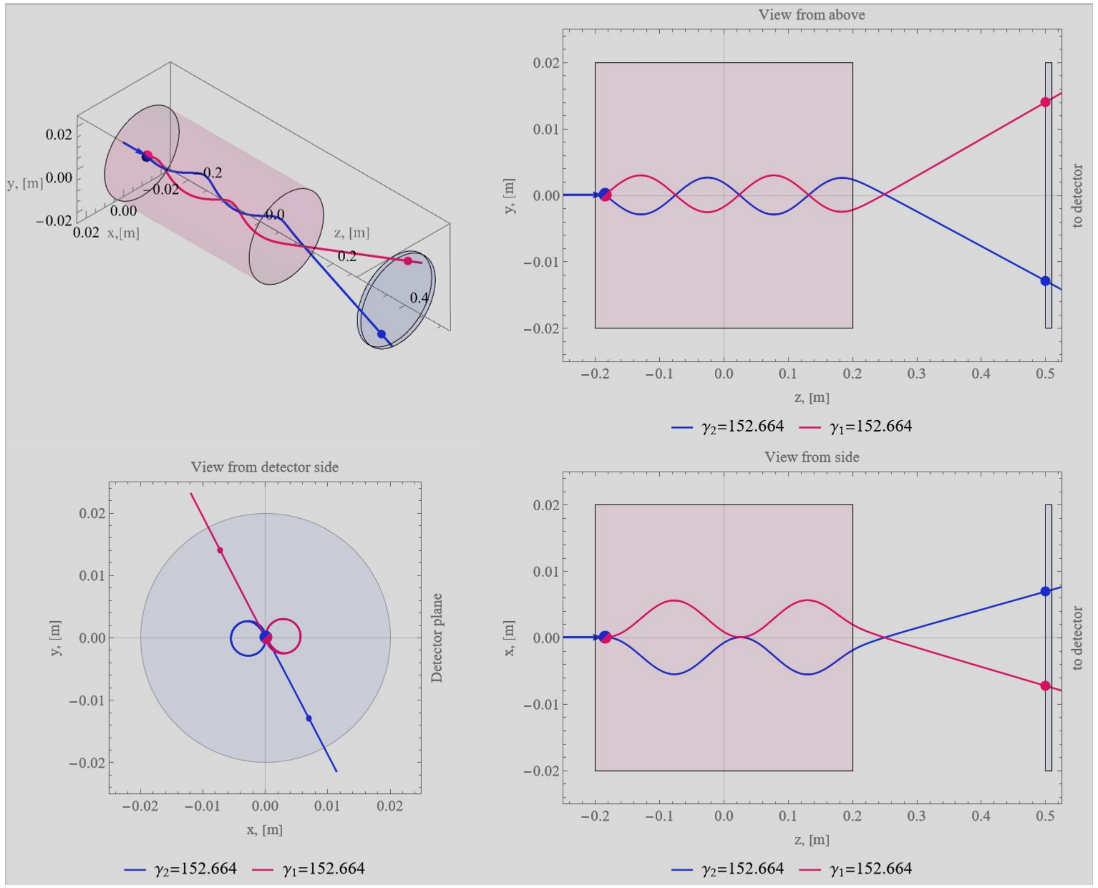
Atomic Hydrogen target (proposal by E. Chudakov and V. Luppov*):

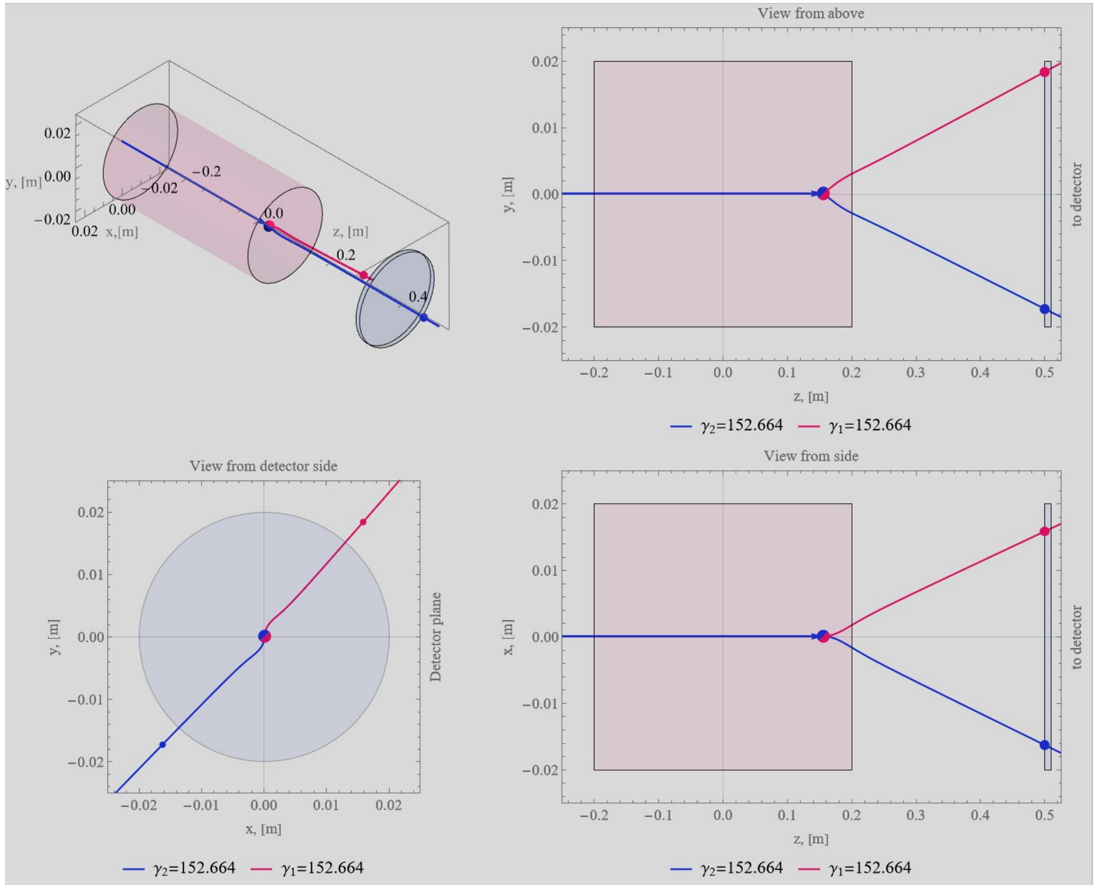
- Non-destructive → online measurement;
- Suitable for low-energies (E_{beam} = 155 MeV)
- Overall accuracy: $\Delta P \leq 0.14\%$
- Pioneering technology → technical challenges to solved

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

Hydro-Moller polarimeter: effect of the long target

Effect of solenoid magnetic field and long target





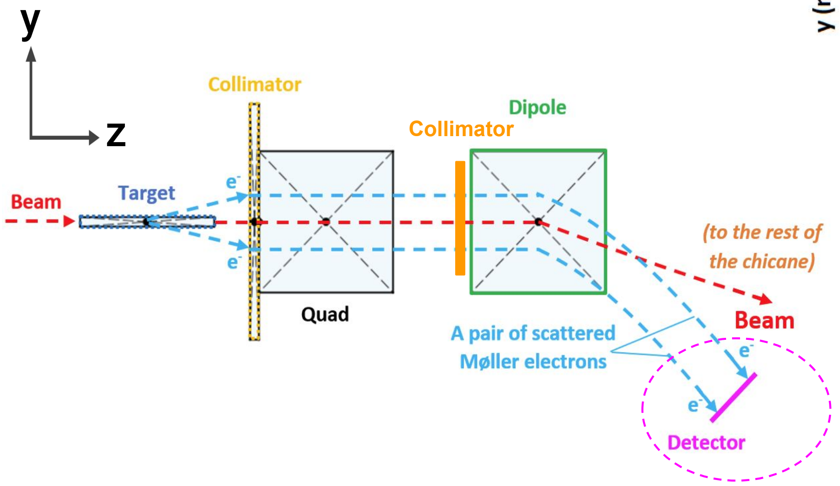
V. Tyukin, KPH

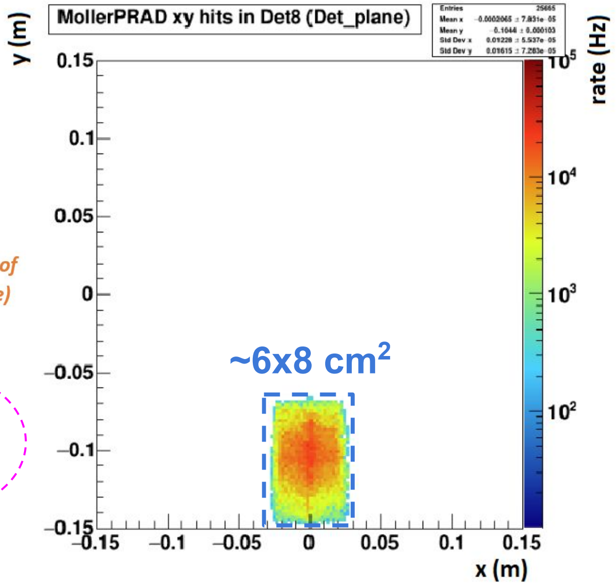
Geant4 simulation: current results

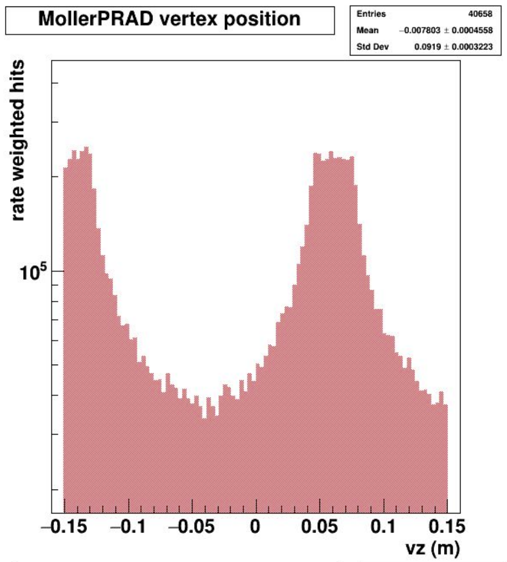
Moller events (signal)

Vertex position (z) for symmetric Mollers (77.5 MeV)

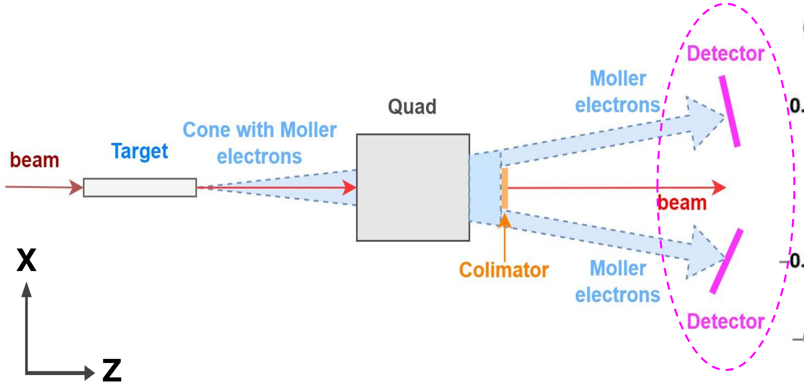
Chicane option:

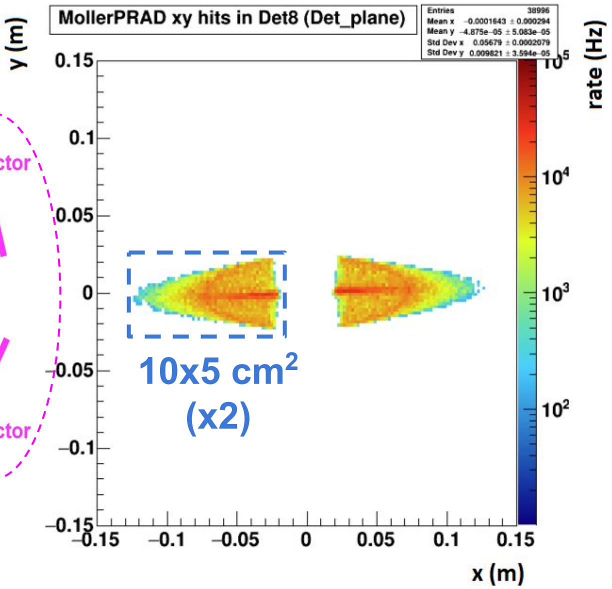


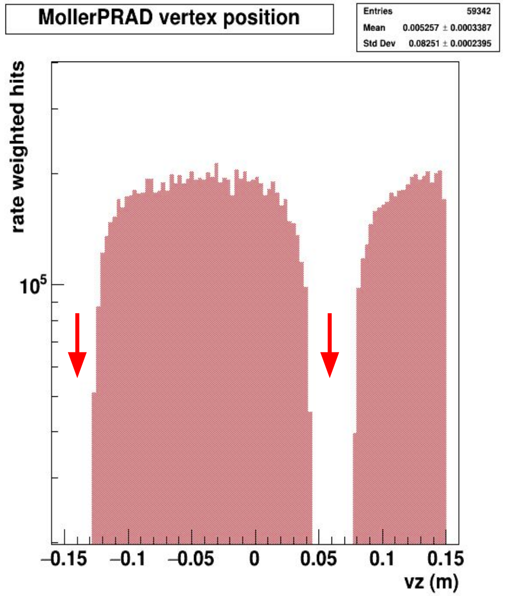




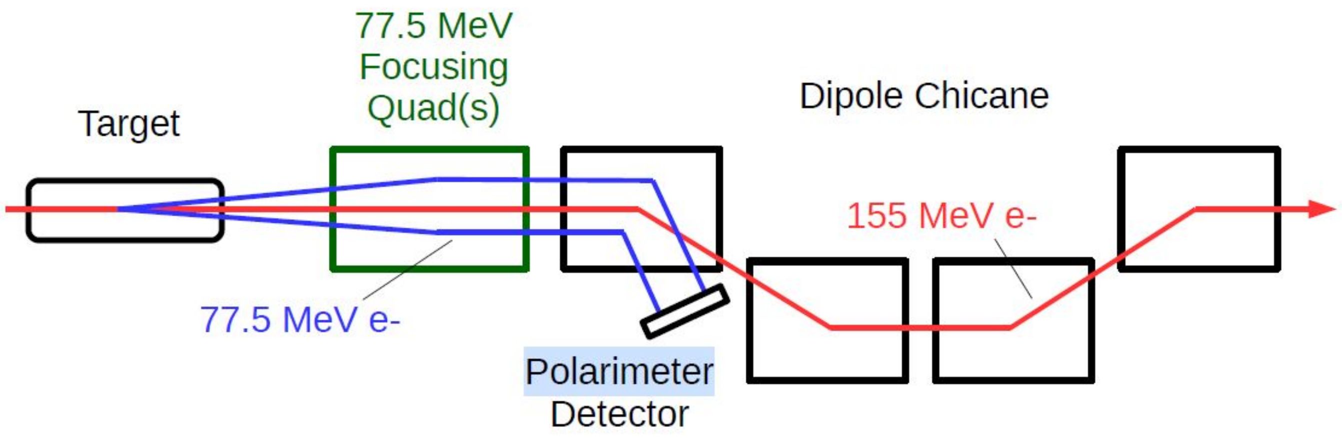
"Double-arm option:







Detector system



$$A_m = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} = P_T P_B \frac{\sin^2\theta(7+\cos^2\theta)}{(3+\cos^2(\theta))^2}$$

- σ is rate of scattered electrons,
- θ - scattered angle.

Energy + time detector system:

- Detectors: GEM or HV-MAPS
- Calorimeter: PbF_2/LYSO crystals based
- Energy resolution: ~ 1% /√E(GeV)

Thank you for your attention!

Questions/comments?

Special thanks to V. Tyukin (KPH, JGU) and
R. Beminiwattha, (Louisiana Tech University)!

Michail Kravchenko

PhD student, AG Berger
PRISMA+ Cluster of Excellence/
Institute for Nuclear Physics, Johannes
Gutenberg University Mainz

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Content

- The P2 experiment
- Mainz Energy-Recovery Superconducting Accelerator (MESA)
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