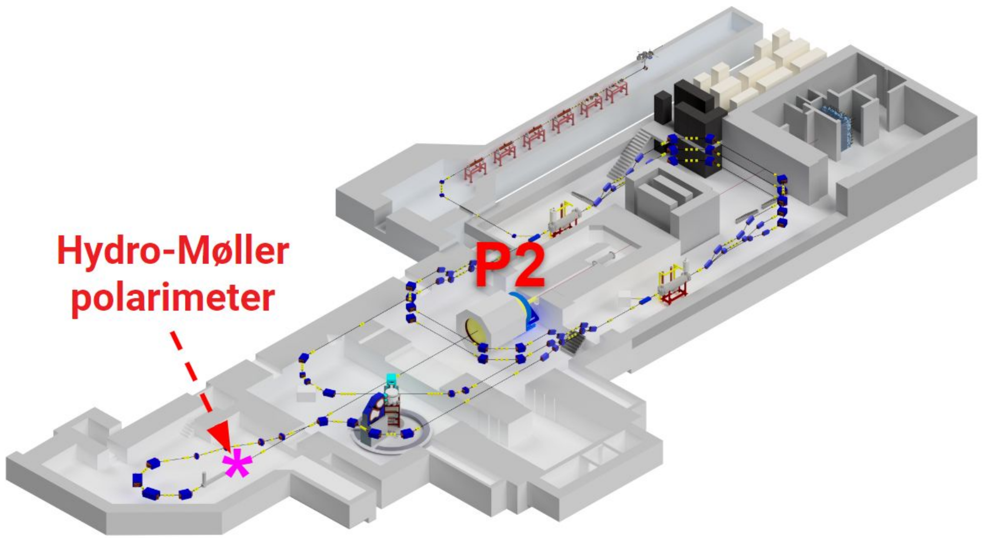
Detector system and simulation of the 155 MeV Hydro-Møller polarimeter at MESA



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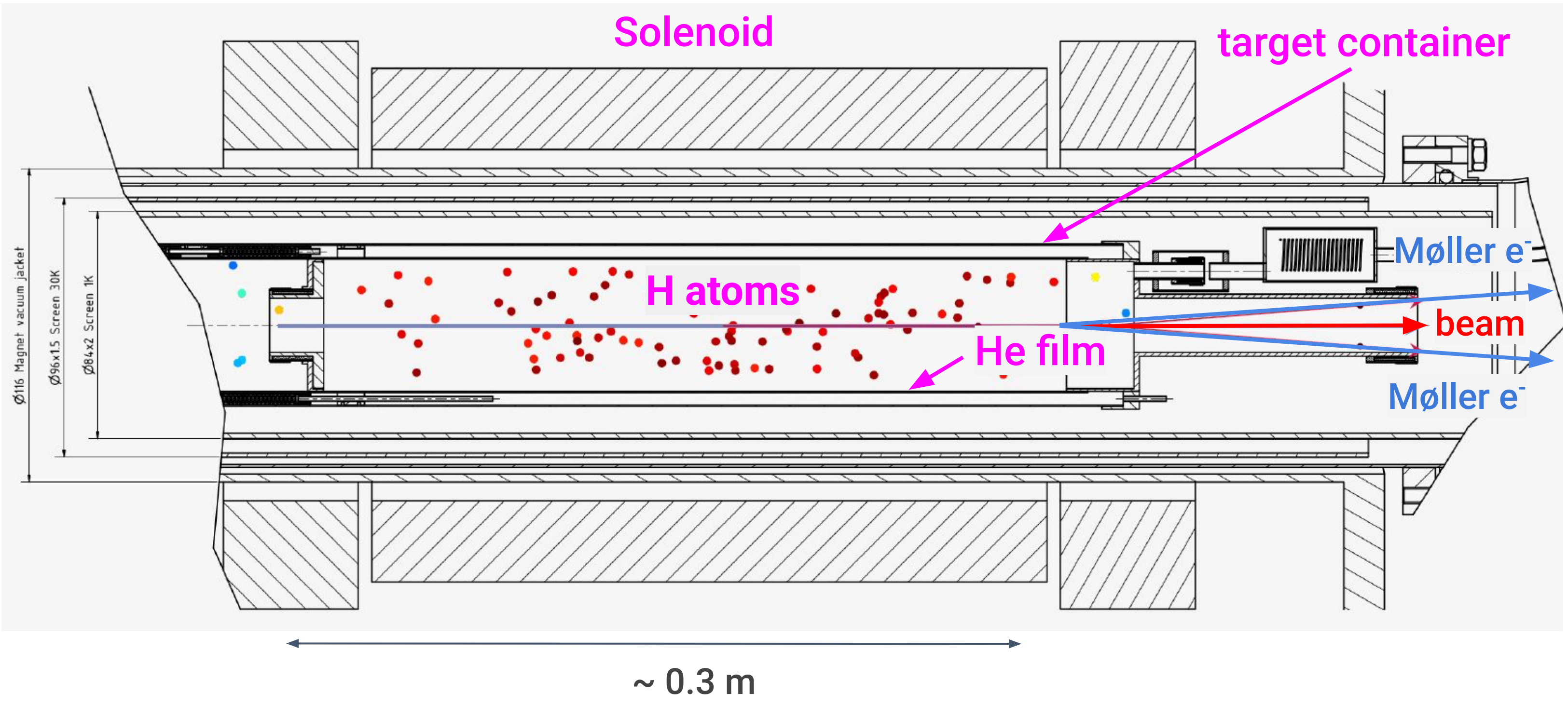
MESA-Polarimeter Workshop, 15.06.2023
Helmholtz Institute Mainz, Mainz

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**

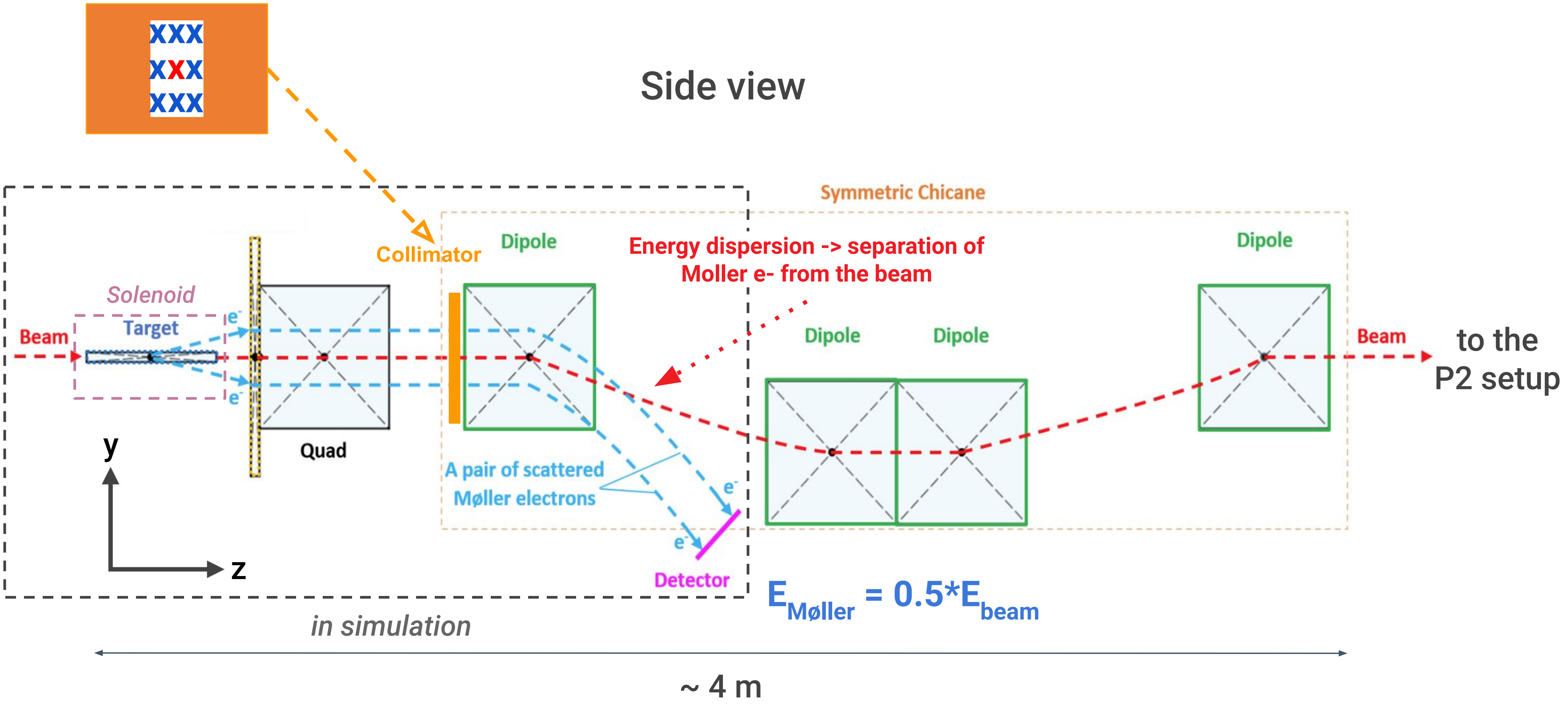
$P_{target} = 1 - \varepsilon$,
with $\underline{\varepsilon \sim 10^{-5}}$ @ $B_{Solenoid} = 8.0$ T

Atomic Hydrogen target



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

Hydro-Møller polarimeter: Chicane based design



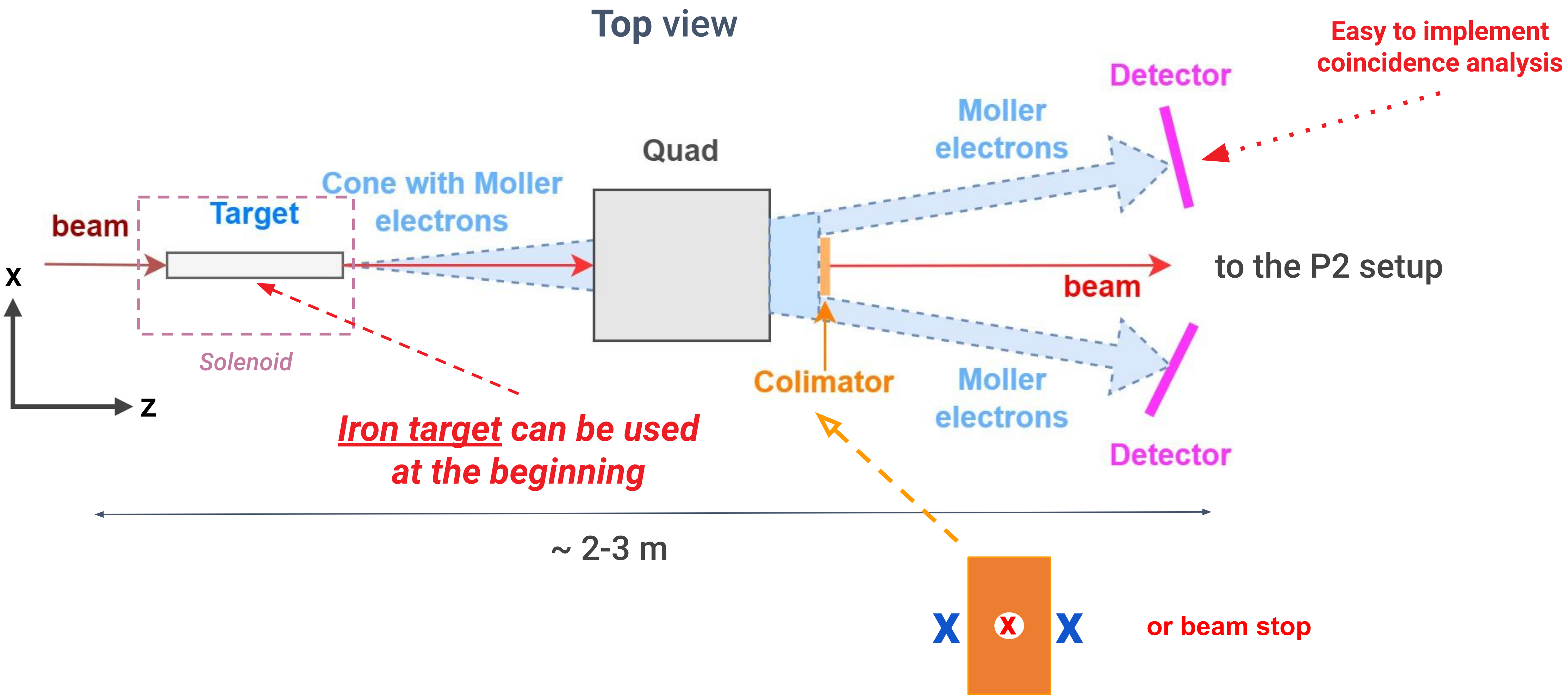
$E_{Møller} = 0.5*E_{beam}$

Hydro-Møller polarimeter: general issues

- Building of the H gas target is not available as initially planned due to the global unexpected and unavoidable circumstances
- As a result, Iron solid target option is being considering as a substitution at the beginning
- Chicane design won’t be suitable + has some unpleasant effects (will be discussed later)

=> **Polarimeter design needs to be reconsidered**

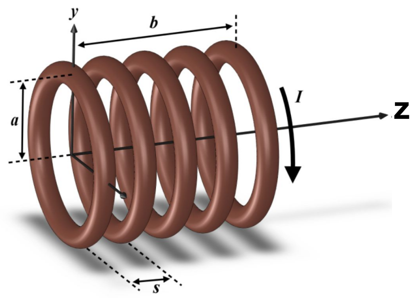
Hydro-Møller polarimeter: Quadrupole based design

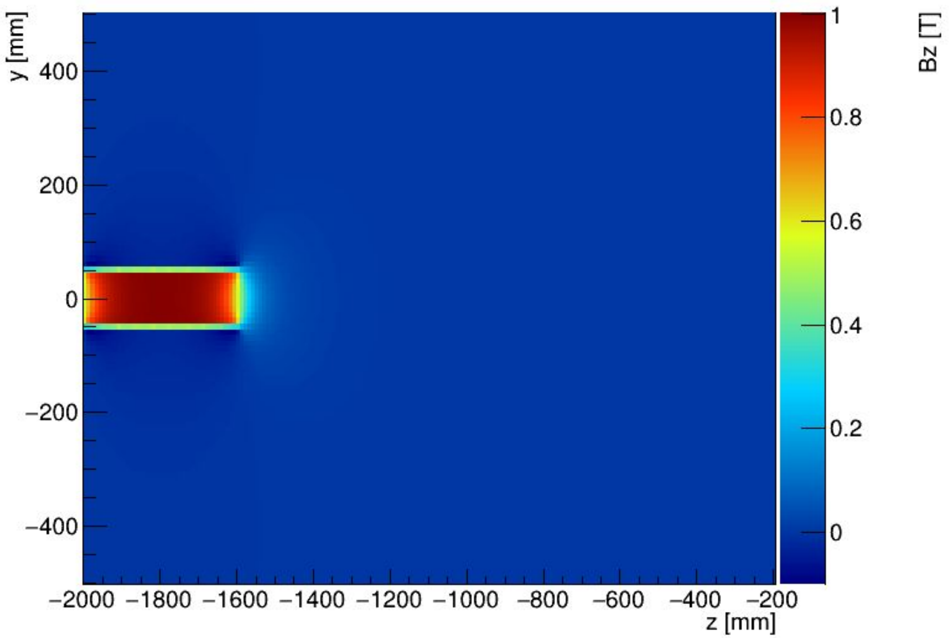


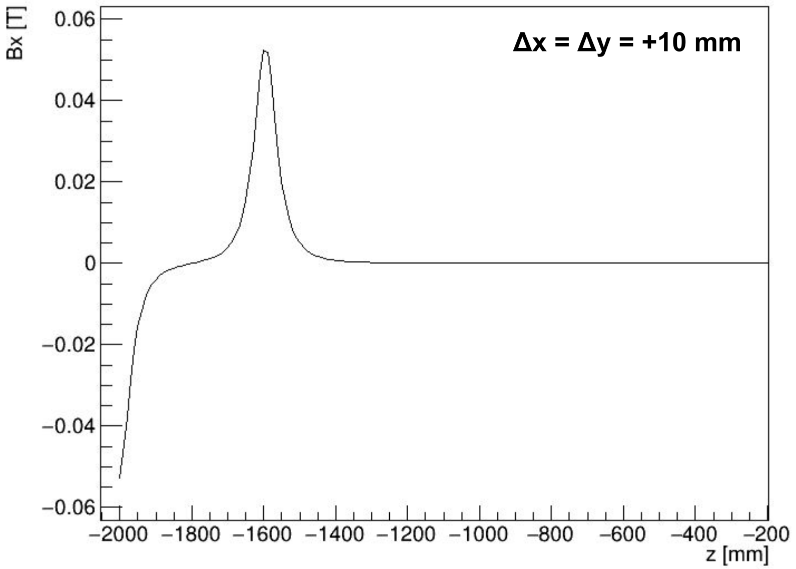
Geant4 simulation: magnets

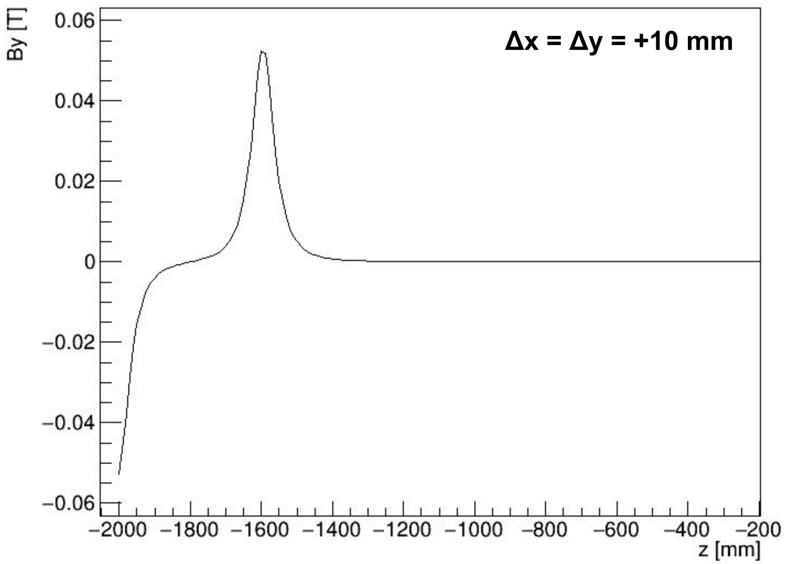
Solenoid:

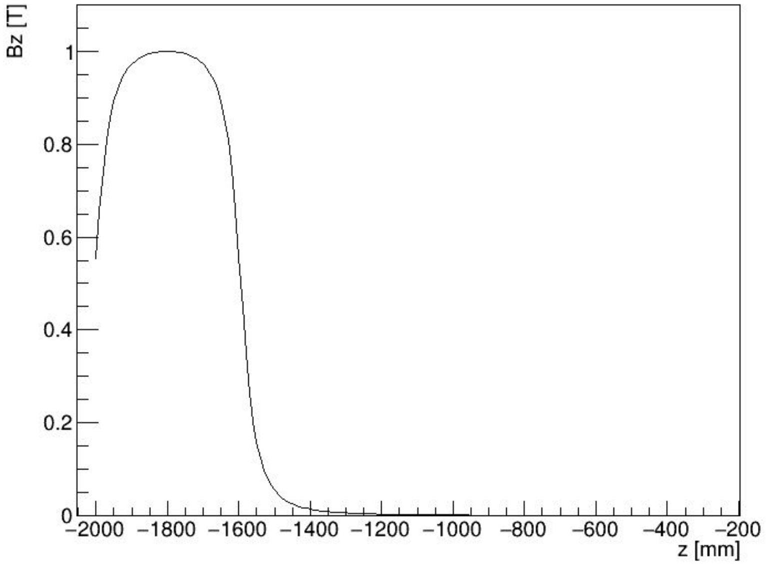
- Biot-Savart summation approach: thin air core solenoid formed by current loops







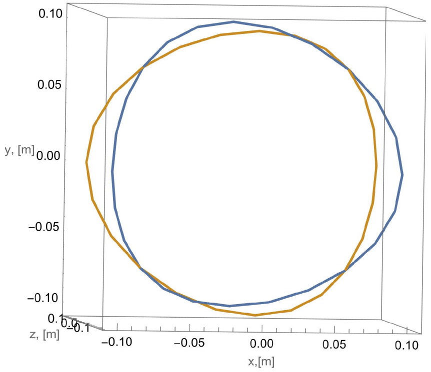


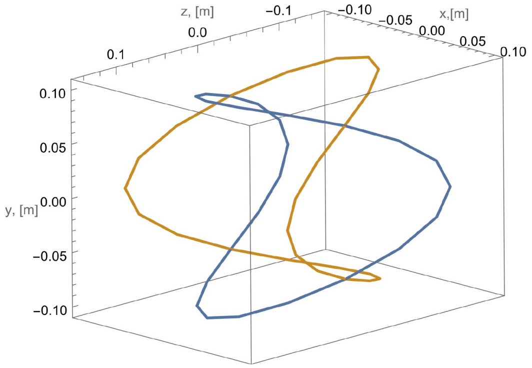


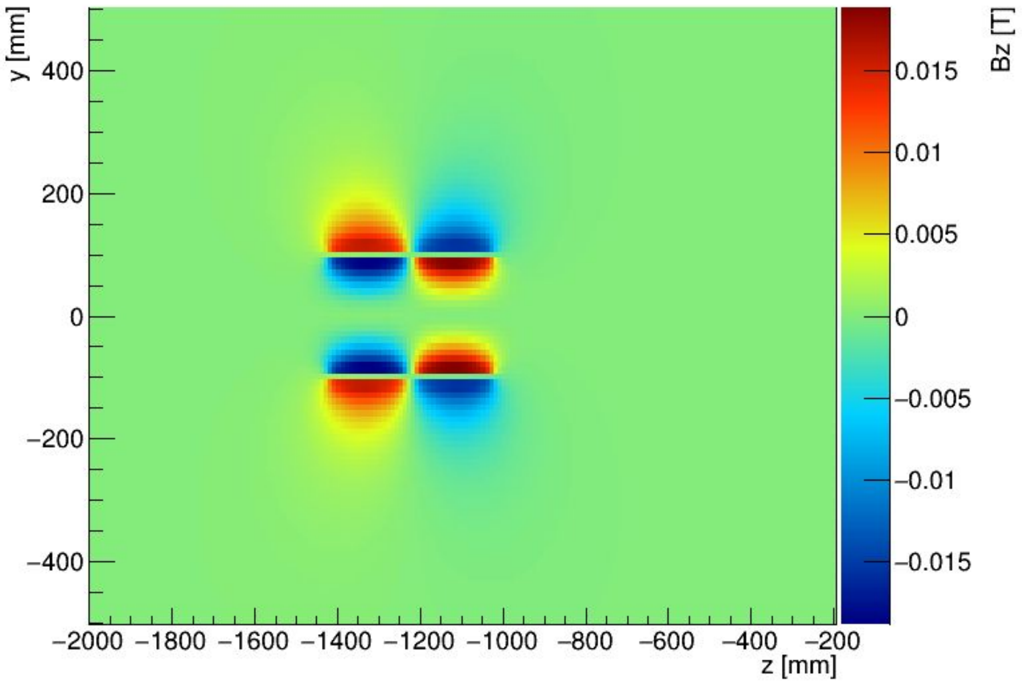
Geant4 simulation: magnets

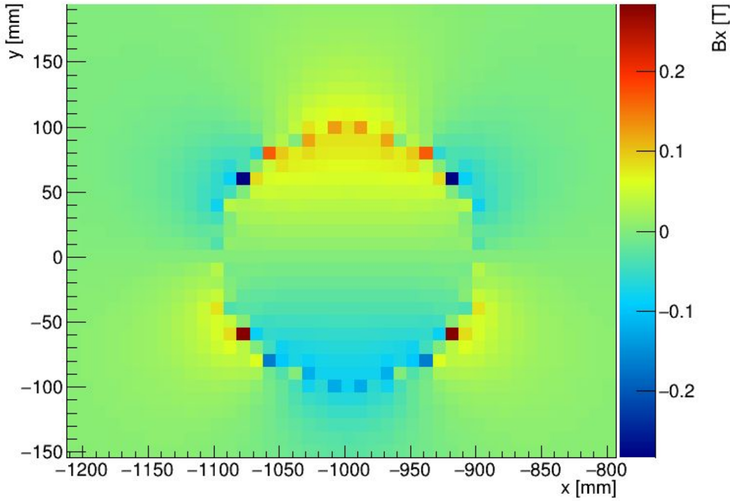
Quadrupole:

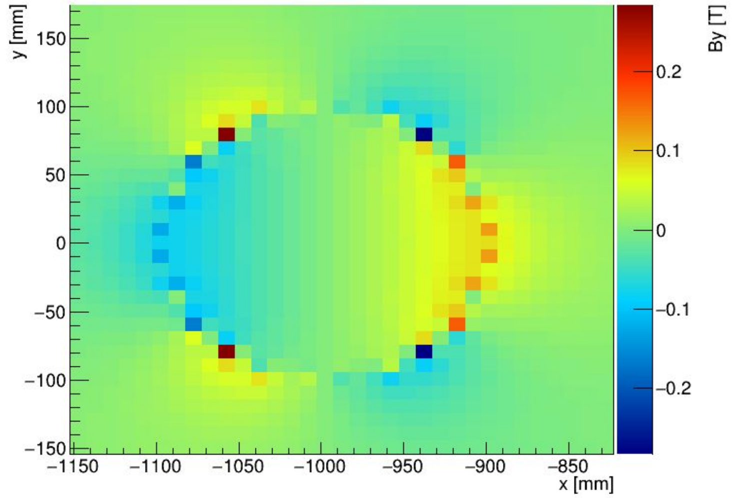
- Analytical solution (from Wolfram Mathematica) for magnetic field components of an air core quadrupole formed by a set of pairs of loops with opposite currents

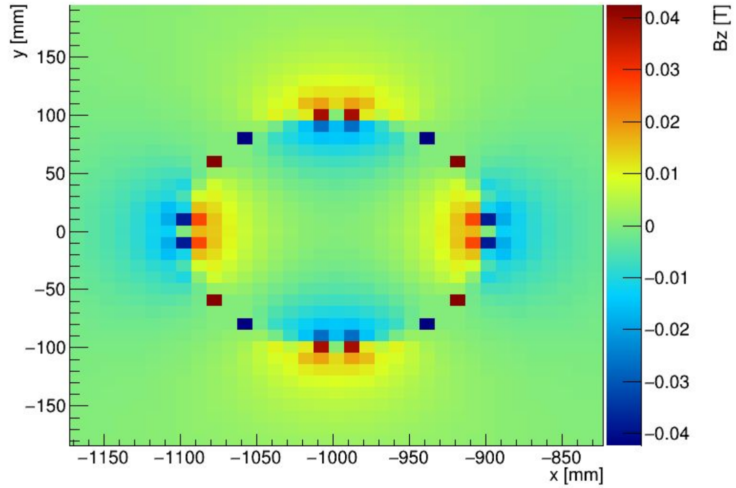








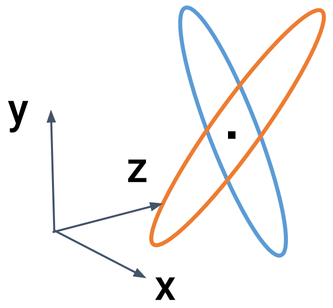


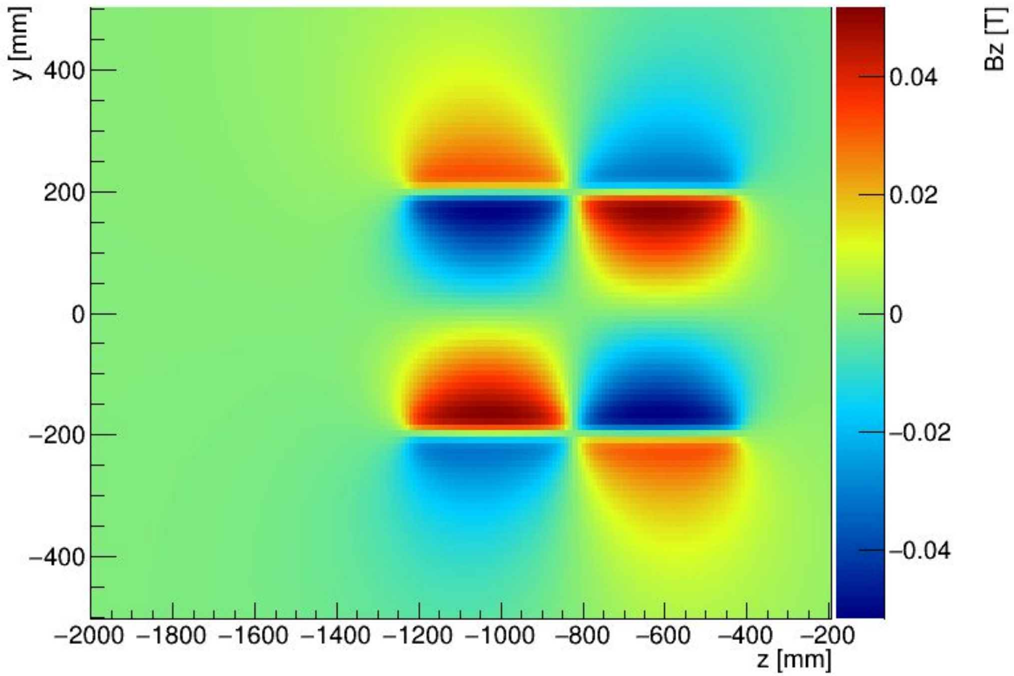


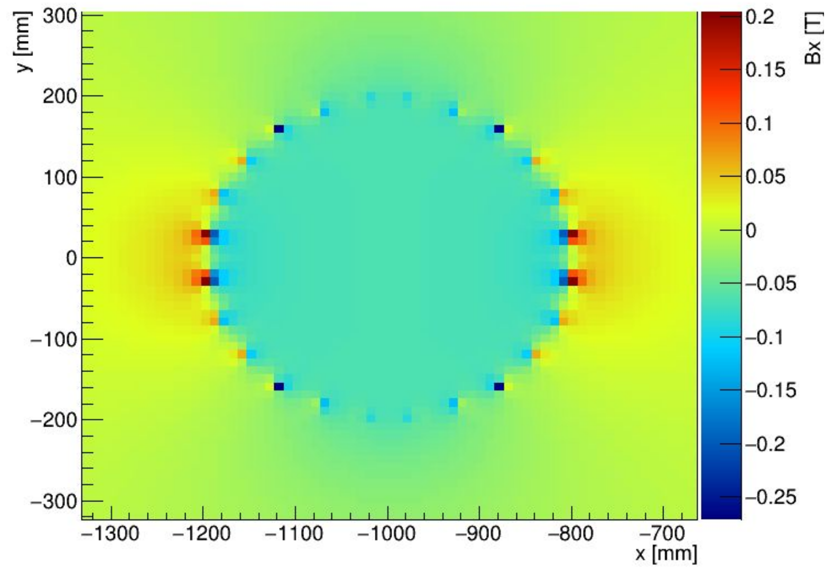
Geant4 simulation: magnets

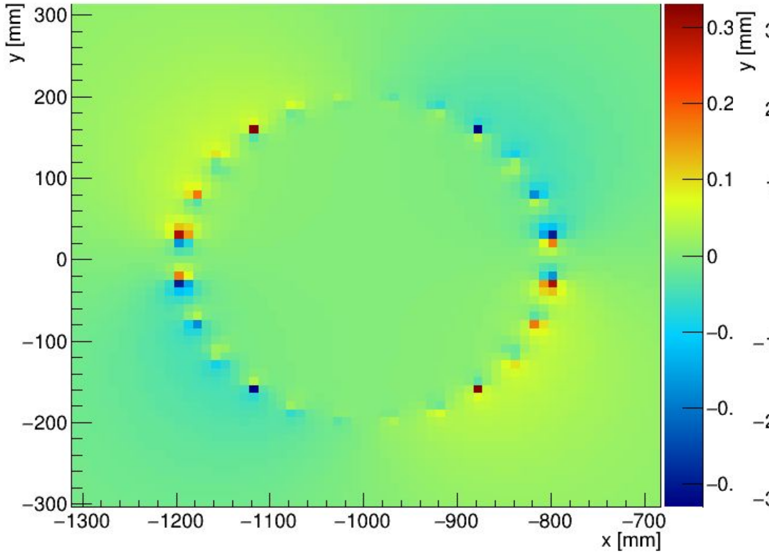
Dipole:

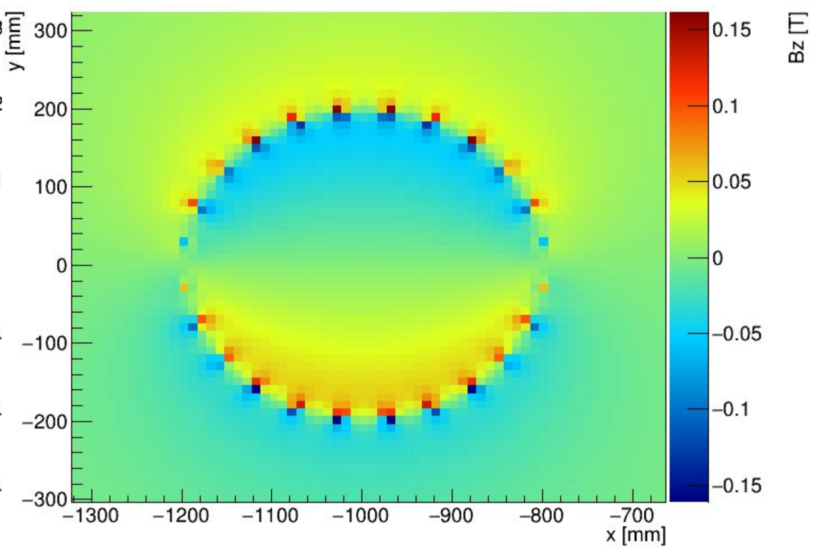
- Analytical solution (from Wolfram Mathematica) for magnetic field components of an air core dipole formed by a set of pairs of loops with opposite currents
- Biot-Savart summation approach is possible, but more complicated



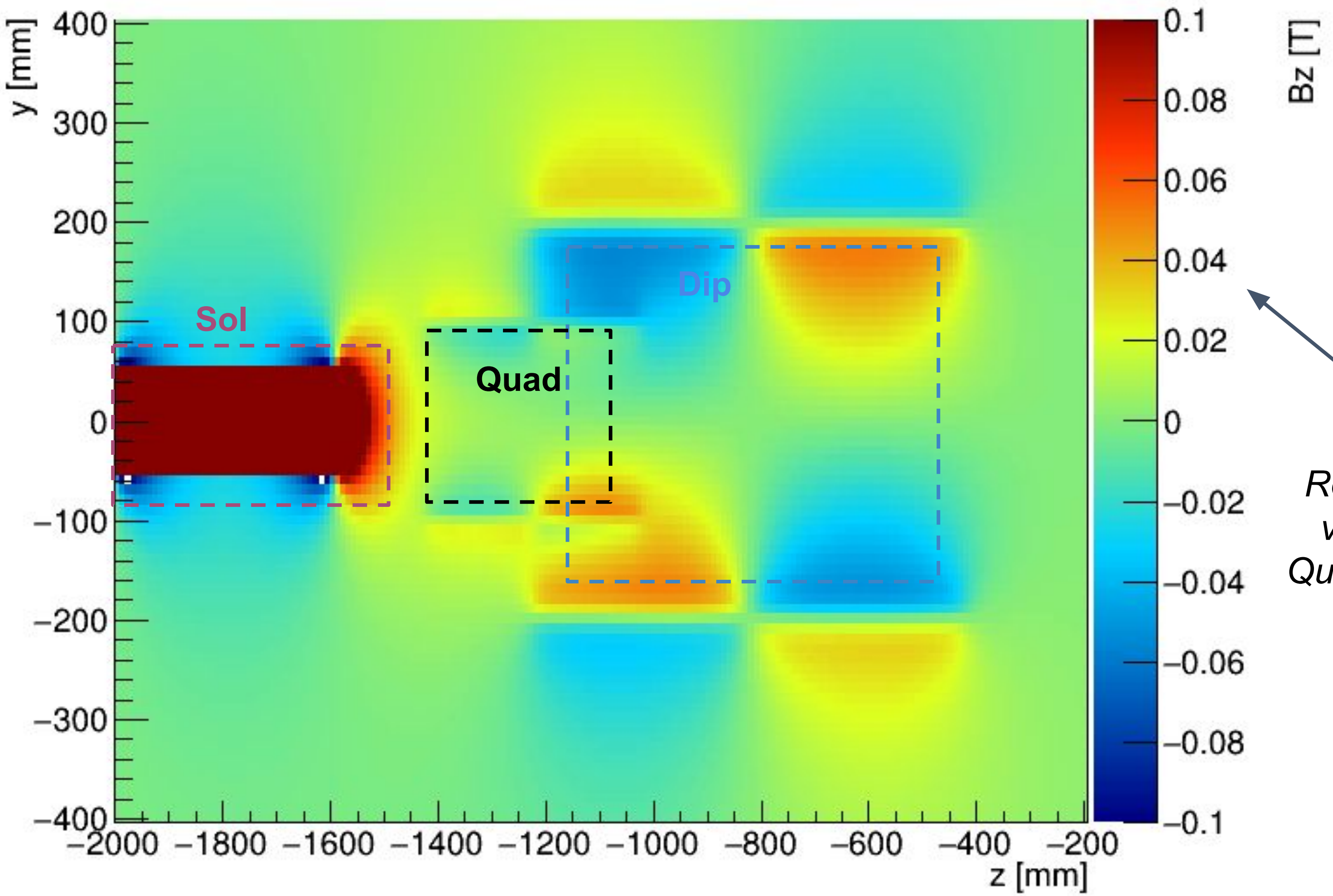








Geant4 simulation: global total magnetic field map



Reduced z-range for visualization of the Quad and Dipole fields

Geant4 simulation: model

Particle generators (original + **<u>PRad</u>***):

- Moller **(original + PRad*)**:

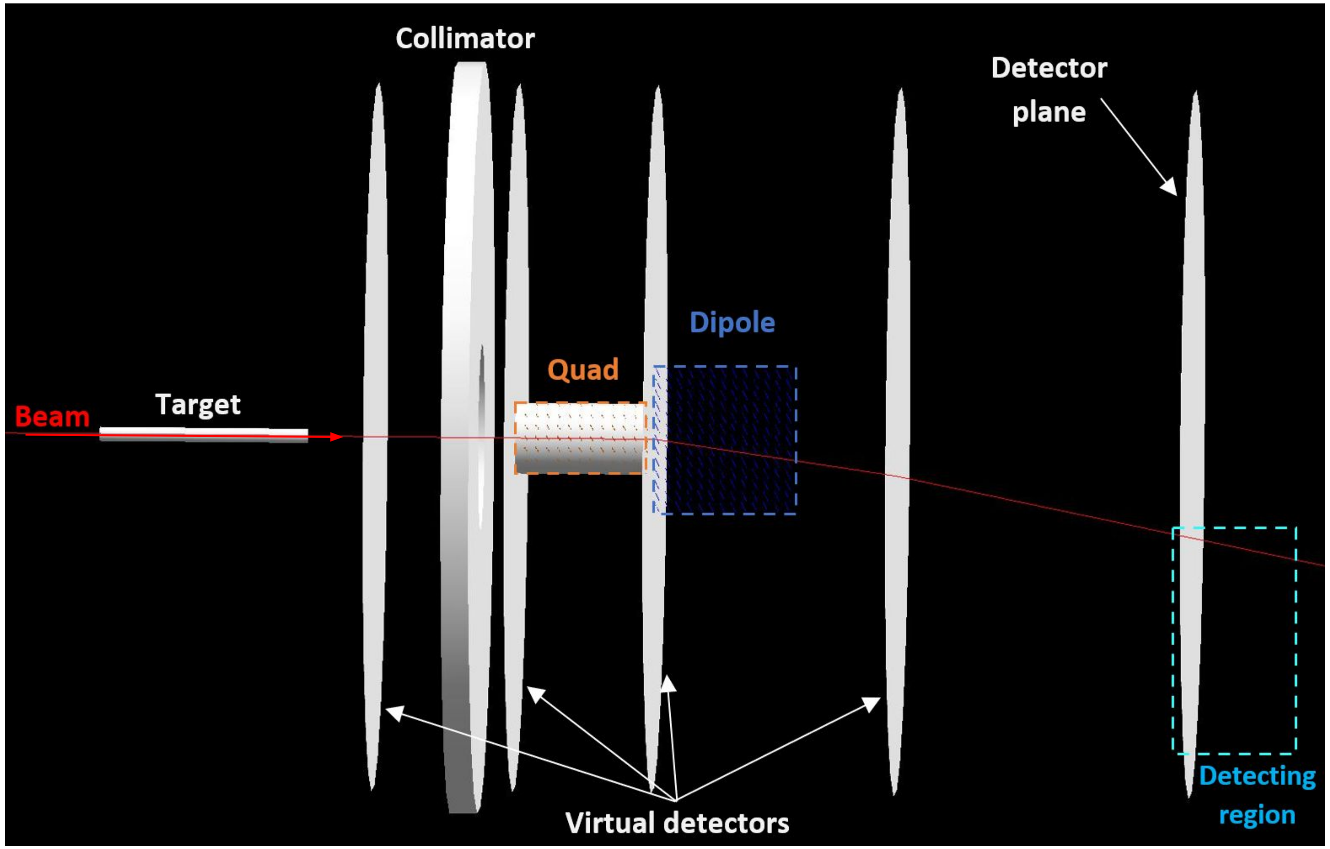
  only $\vec{e}^- + \vec{e}^- \rightarrow e^- + e^-$ => **signal**

- Elastic e^--p (Mott; **PRad* only**):

  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)*
<u>GitHub repository:</u>
https://github.com/JeffersonLab/PRadSim

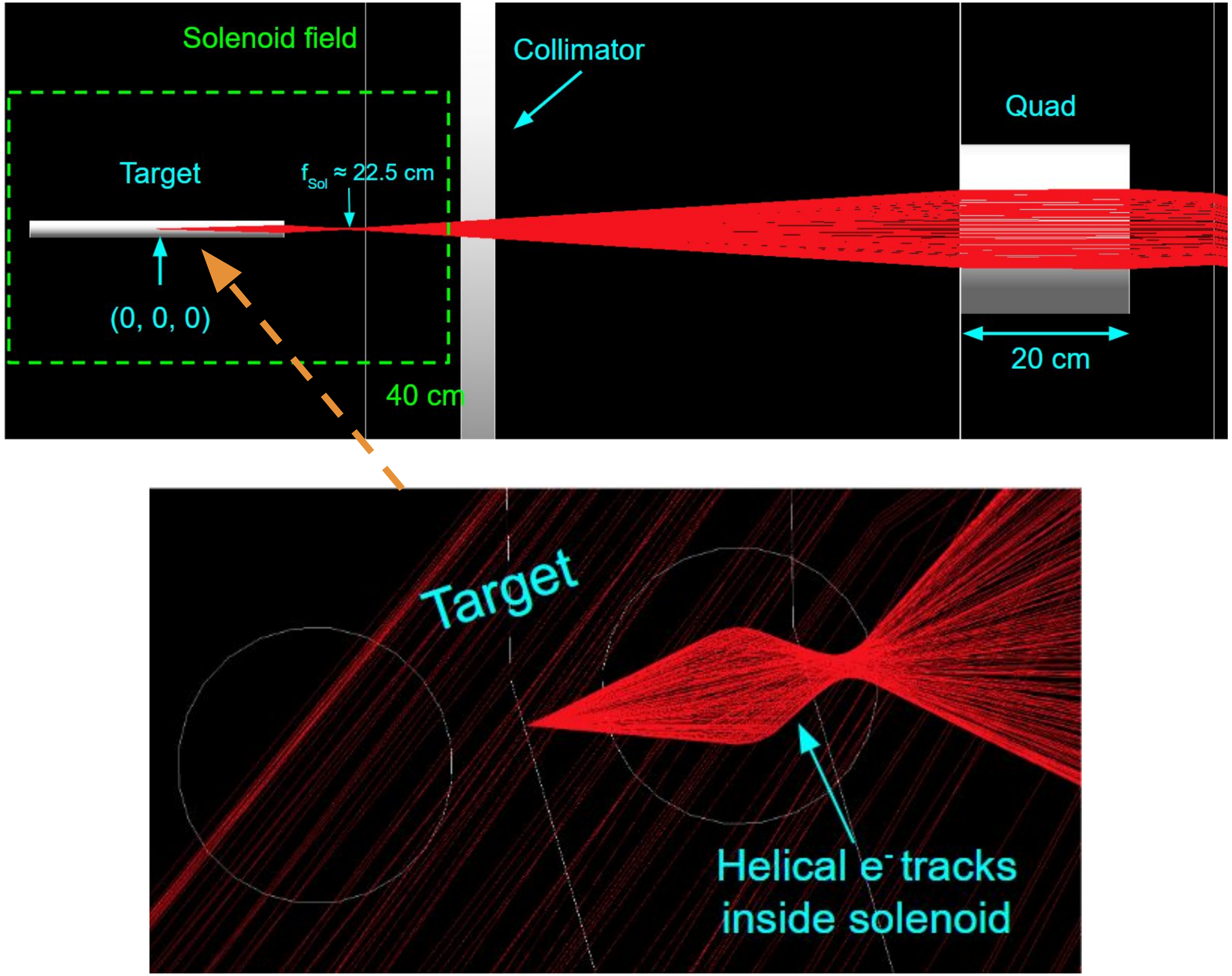
Geant4 model



Geant4 simulation: model

Simulation parameters:

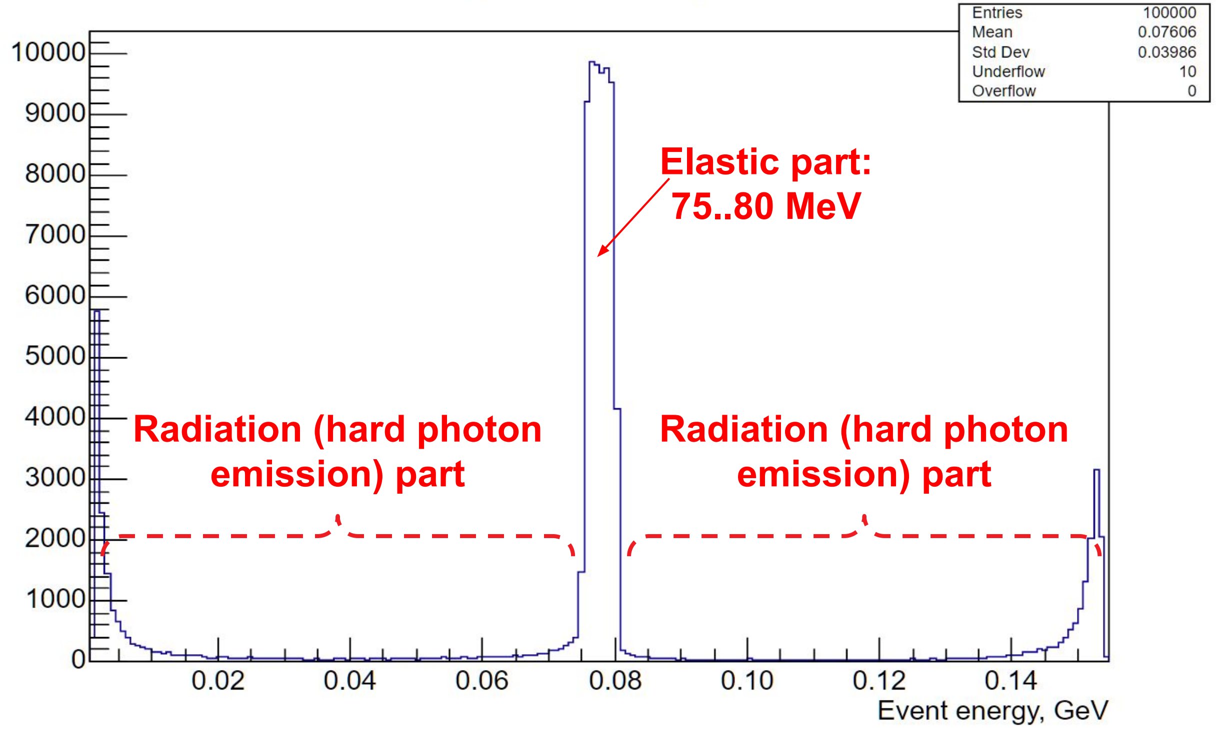
- E_{beam} = 155 MeV
- Target length:
  - **H: 30 cm**
  - **Fe: 20 µm**
- Beam current = 150 µA = 10^{15} e^{-}/s (***Hydrogen target***)
- $B_{solenoid}$ = 8 T
- Moller generator:
  - **$E_{electrons}$ ∈ [75, 80] MeV**
- E-p generator:
  - **θ_{scat} ∈ [0.01, 90] deg**



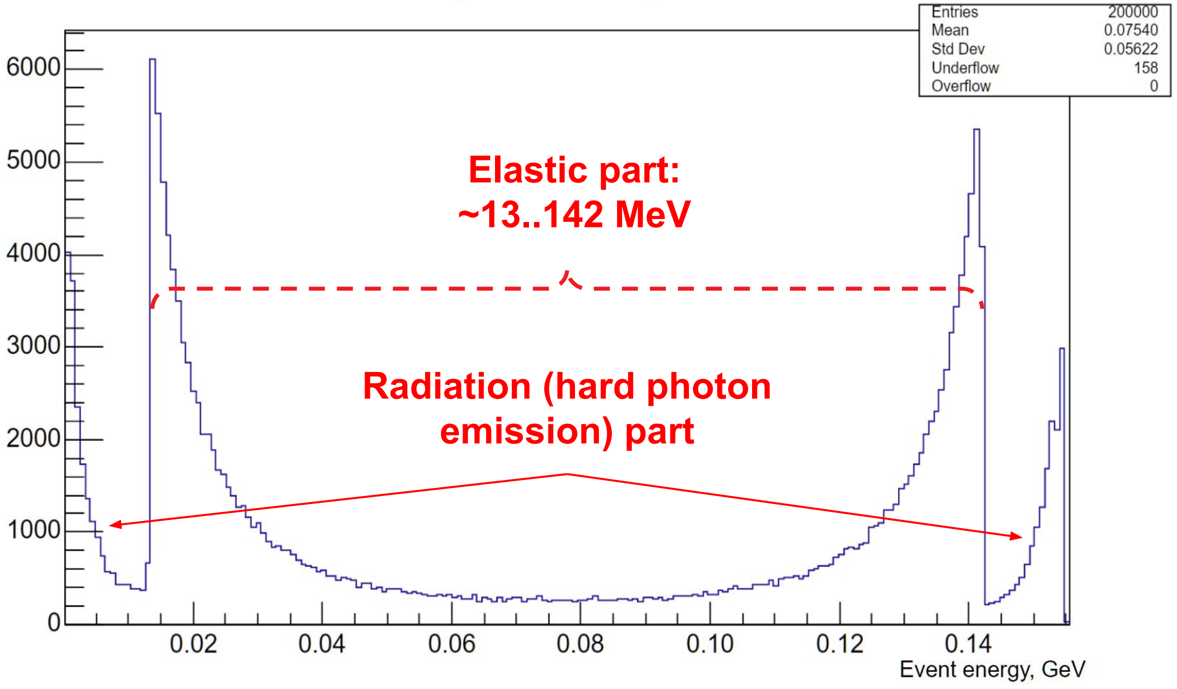
Geant4 simulation: PRad generators

- E_{beam} = 155 MeV => E_{Moller_symm} = 77.5 MeV

Moller PRad generator: $E_{Moller} \in$ [75, 80] MeV



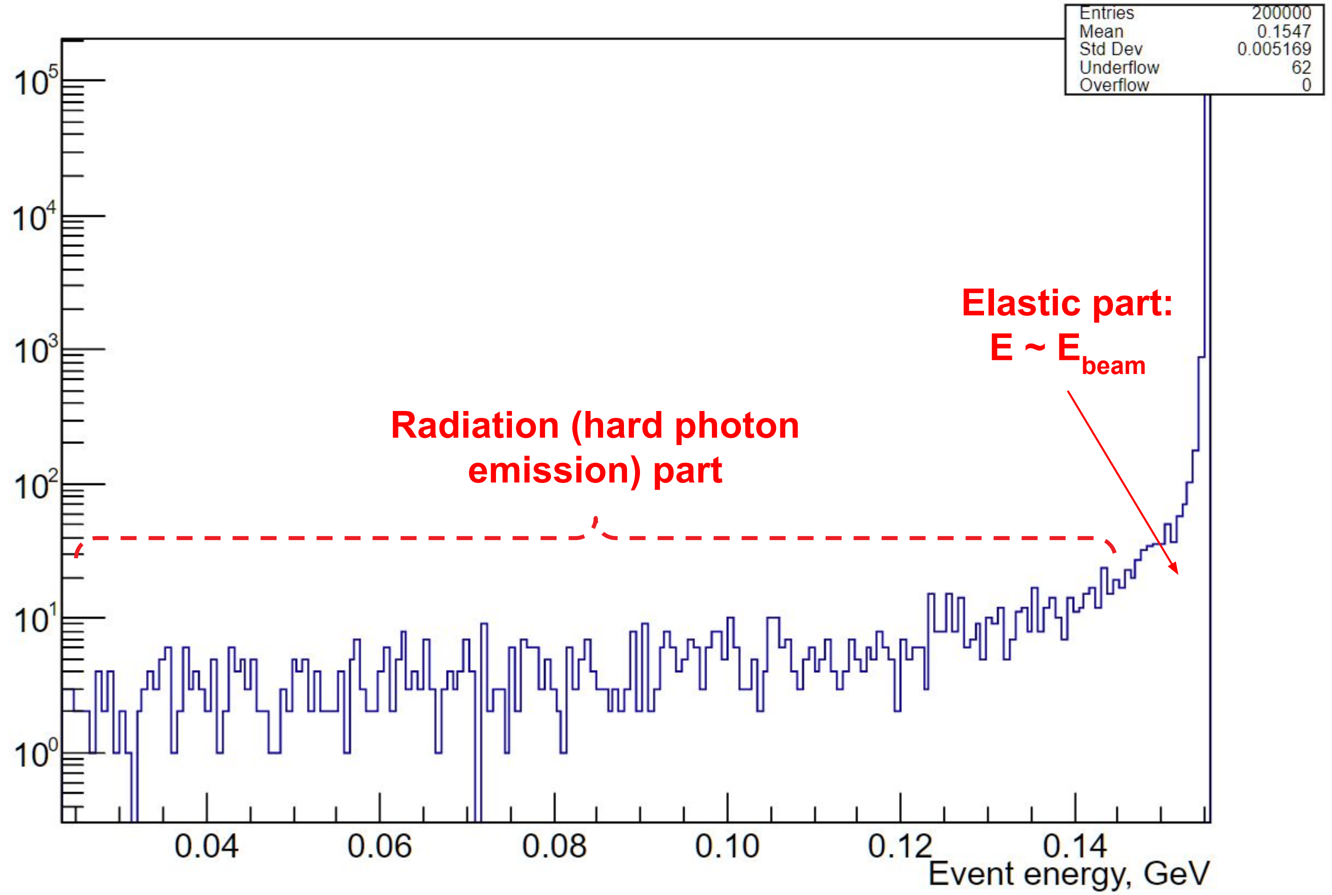
Moller PRad generator: $E_{Moller} \in$ ~[13, 142] MeV



Geant4 simulation: PRad generators

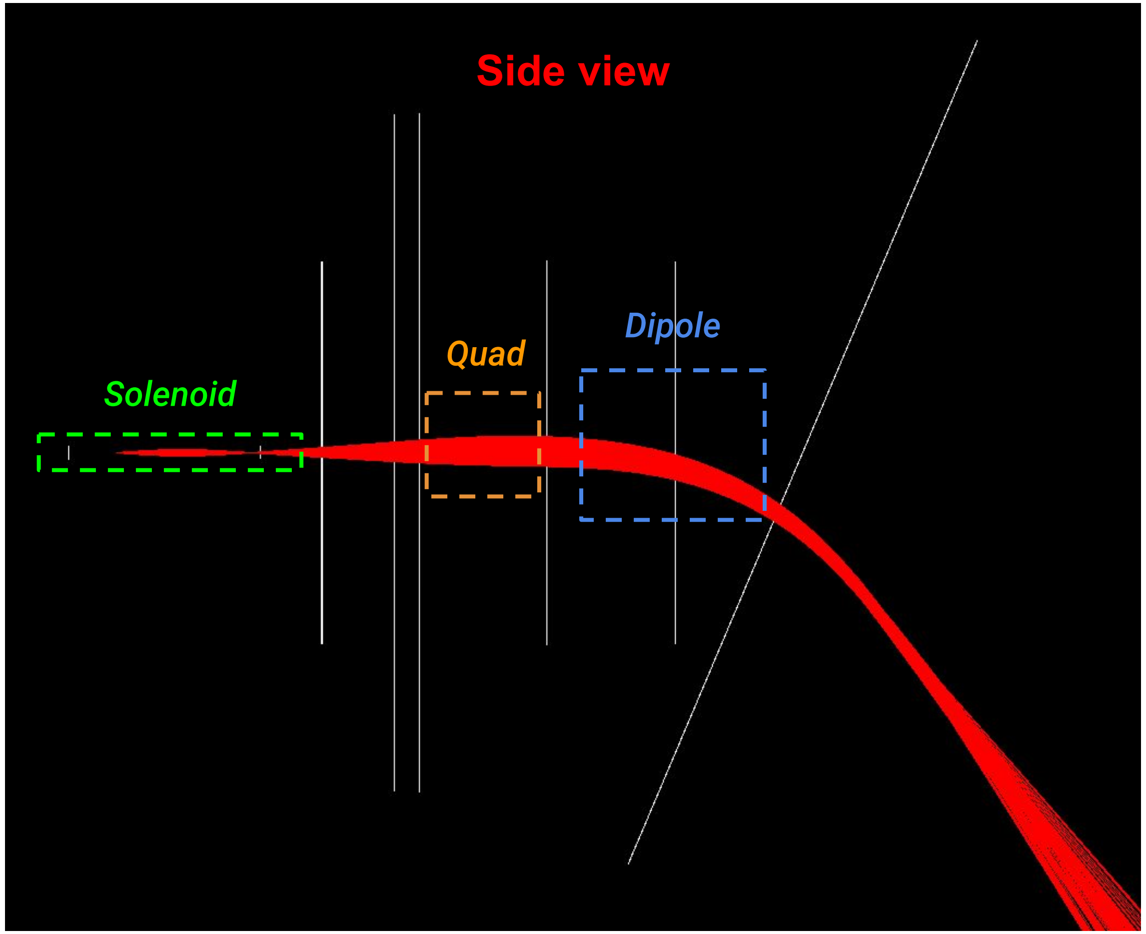
- E_{beam} = 155 MeV

Mott (ep) PRad generator: $E_{Moller} \in$ [75, 80] MeV



Geant4 simulation: current results

Point-like target

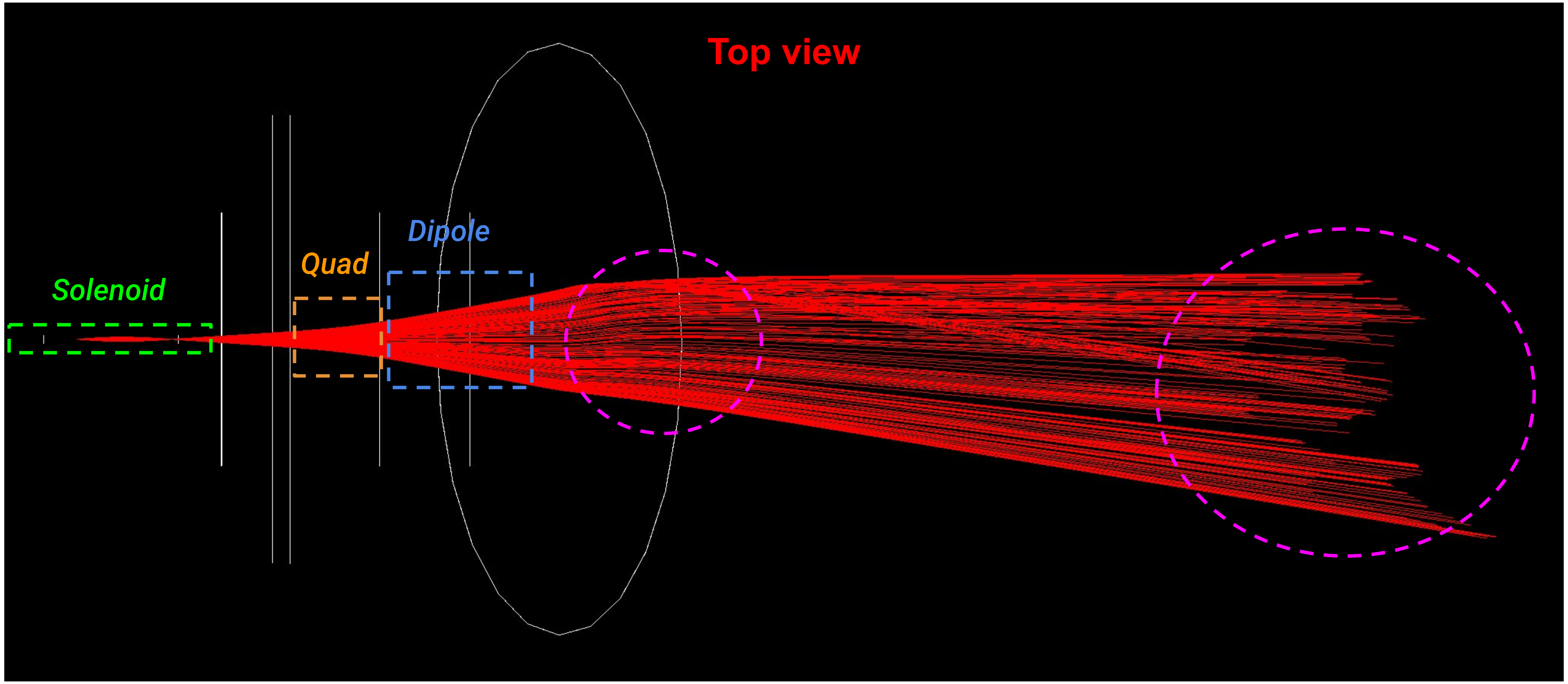


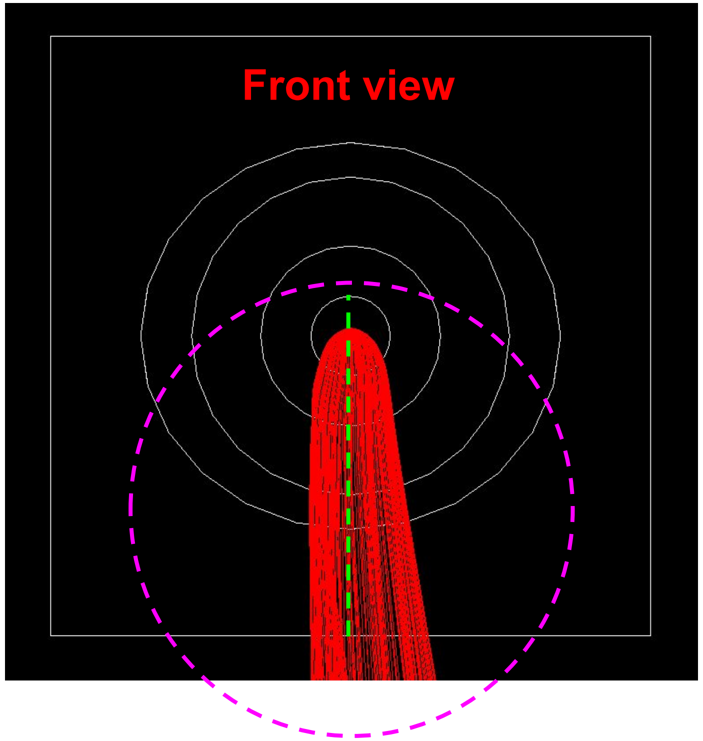
Solenoid:
- l = 40 cm
- r = 5 cm
- B = 8 T
- n_loops = 100

Quad:
- r = 10 cm
- l = 20 cm
- G = 5 T/m
- n_loops = 20 (pairs)

Dipole:
- r = 20 cm
- l = 40 cm
- B = -0.5 T
- n_loops = 30

Geant4 simulation: effect of the Dipole fringe field



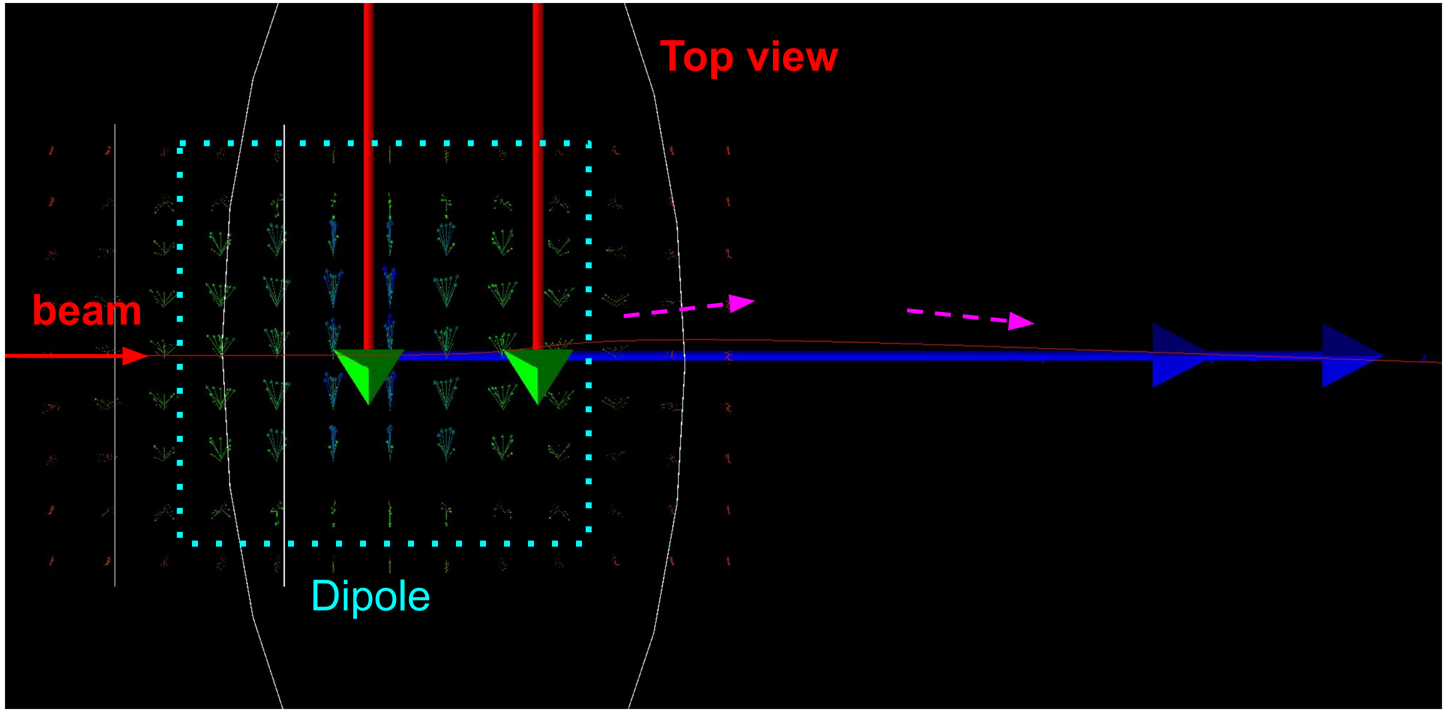


The most likely cause:

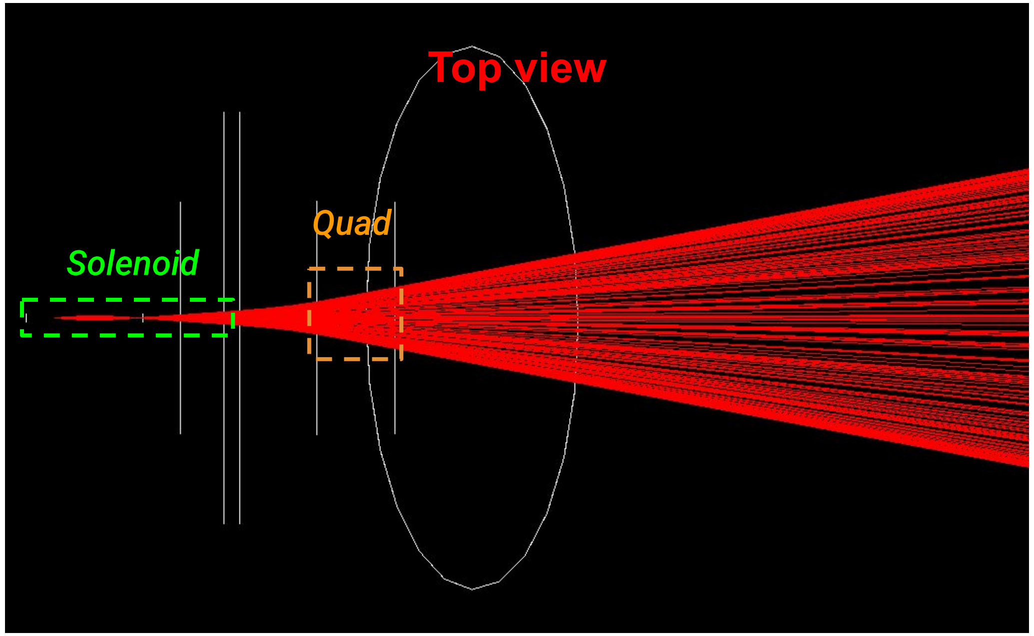
- Fringe field of the Dipole

Geant4 simulation: effect of the Dipole fringe field

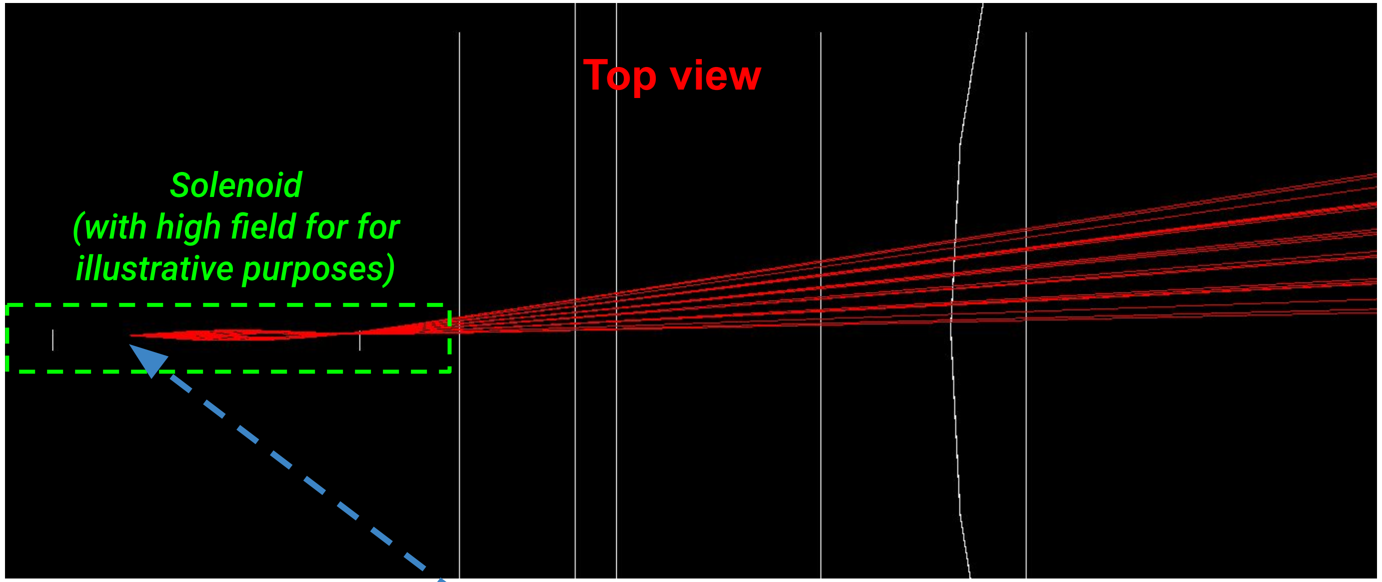
Dipole only

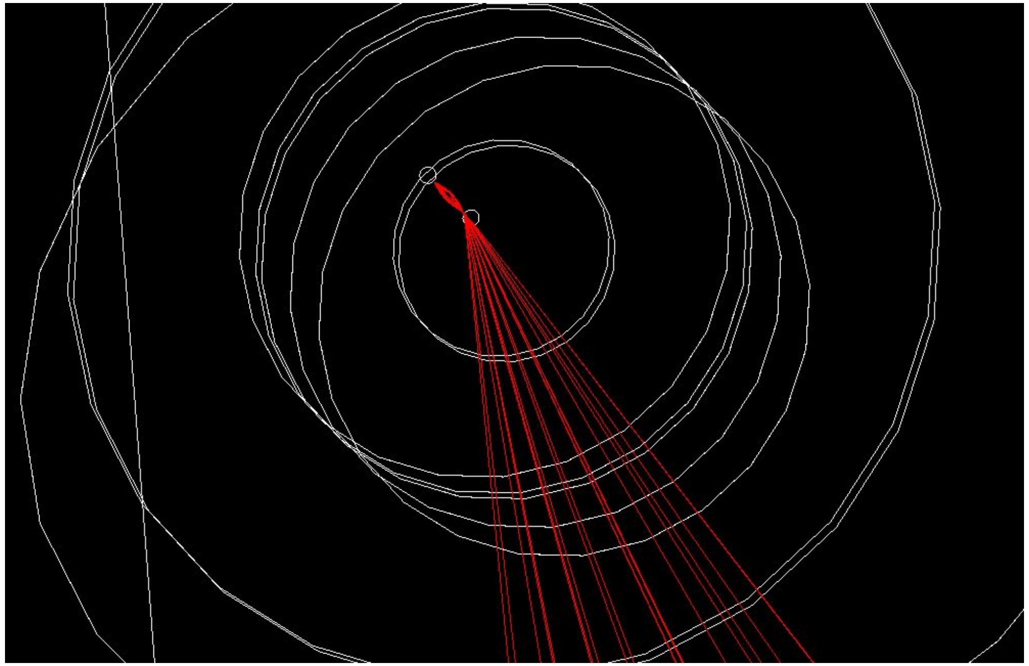


Sol + Quad only



Geant4 simulation: solenoid alignment





Example

Beam displacement (= solenoid misalignment):

- **Δx = Δy ~ 1 *mm, @ 8T**
- Beam deflection at Quad entrance: **Δx = Δy ~ 1 *cm**

Geant4 simulation: Moller event rate

E = 155 Mev	Z = 1	curr = 150 uA		
Moller generators (rate, Hz)				
	Moller_VT (Mathematica)	Moller_PRad (elastic)	Moller_PRad (elastic + rad)	Moller_init
th_lab: ~4.67...4.63 deg (~77.5MeV)	**1.24E+02**	1.10E+02	-	1.26E+02
th_lab: ~4.48...4.78 deg (75-80 MeV)	**3.99E+04**	3.53E+04	2.98E+04	4.01E+04
th_lab: ~3.68...5.81 deg (60-95 MeV)	**2.92E+05**	2.87E+05	2.36E+05	2.94E+05

E = 155 Mev	Z = 26	curr = 150 uA ← *for benchmarking evaluation*		
Moller generators (rate, Hz)				
	Moller_VT (Mathematica)	Moller_PRad (elastic)	Moller_PRad (elastic + rad)	Moller_init
th_lab: ~4.67...4.63 deg (~77.5MeV)	**6.13E+06**	5.42E+06	-	6.21E+06
th_lab: ~4.48...4.78 deg (75-80 MeV)	**1.97E+09**	1.74E+09	1.48E+09	1.98E+09
th_lab: ~3.68...5.81 deg (60-95 MeV)	**1.44E+10**	1.42E+10	1.17E+10	1.45E+10

Geant4 simulation: Mott event rate issues

E = 155 Mev	Z = 1	curr = 150 uA		
Mott (ep) generators (rate, Hz)				
	Mott_VT (Mathematica)	Mott_PRad (elastic)	Mott_PRad (elastic + rad)	*Mott_PRad (elastic + rad) + energy cut*
~0.1-75 deg (0.07-155 MeV)	2.96E+08	-	7.36E+13	3.68e+10 (75-80MeV)
th_lab: ~4.67...4.63 deg	5.53E+01	4.70E+01	4.45E+03	-
th_lab: ~4.48...4.78 deg	1.78E+04	1.52E+04	1.44E+06	-
th_lab: ~3.68...5.81 deg	1.31E+05	1.54E+05	1.85E+07	-

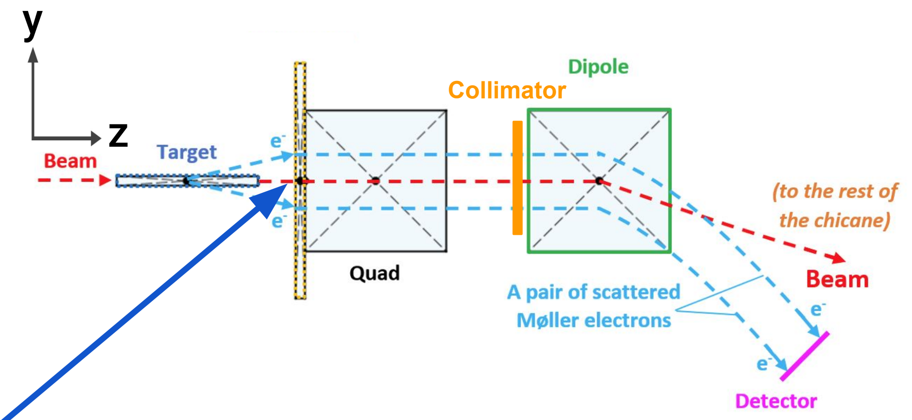
Moller 75..80 MeV rate: 2.98E+04

E = 155 Mev	Z = 26	curr = 150 uA ← *for benchmarking evaluation*		
Mott (ep) generators (rate, Hz)				
	Mott_VT (Mathematica)	Mott_PRad (elastic)	Mott_PRad (elastic + rad)	*Mott_PRad (elastic + rad) + energy cut*
~0.1-75 deg (0.07-155 MeV)	3.80E+14	-	9.39E+19	*1.04e+17 (75-80MeV)*
th_lab: ~4.67...4.63 deg	7.09E+07	6.02E+07	5.77E+09	-
th_lab: ~4.48...4.78 deg	2.28E+10	1.90E+10	2.78E+12	-
th_lab: ~3.68...5.81 deg	1.68E+11	1.99E+11	2.34E+13	-

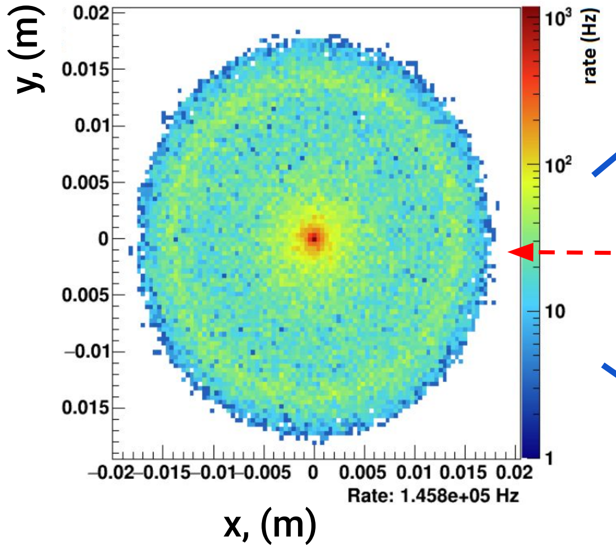
Moller 75..80 MeV rate: 1.48E+09

Geant4 simulation: current results

Chicane design

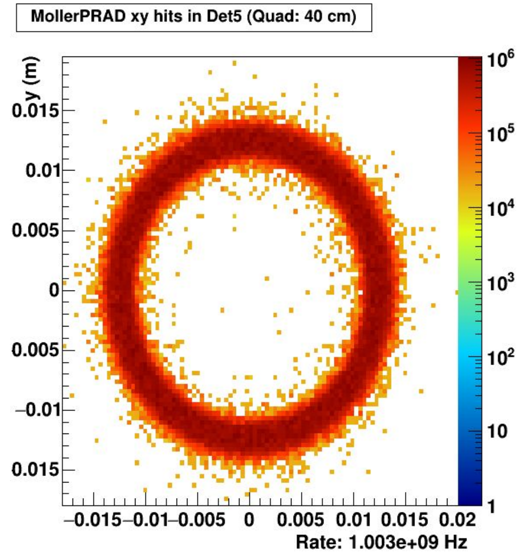


Only **Moller** events, **H target**

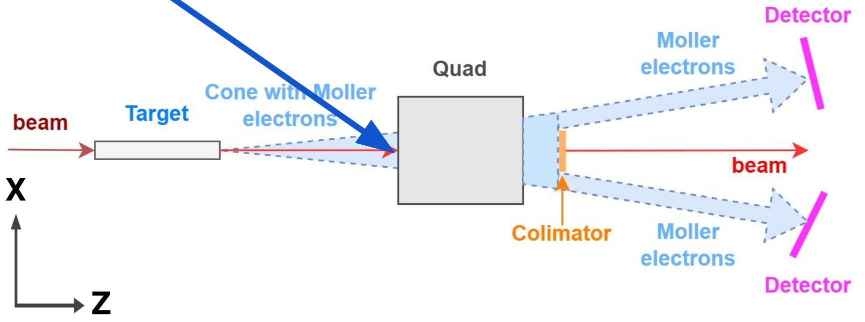


Long target + solenoid effect

Moller events w/o rad part, **Fe target**



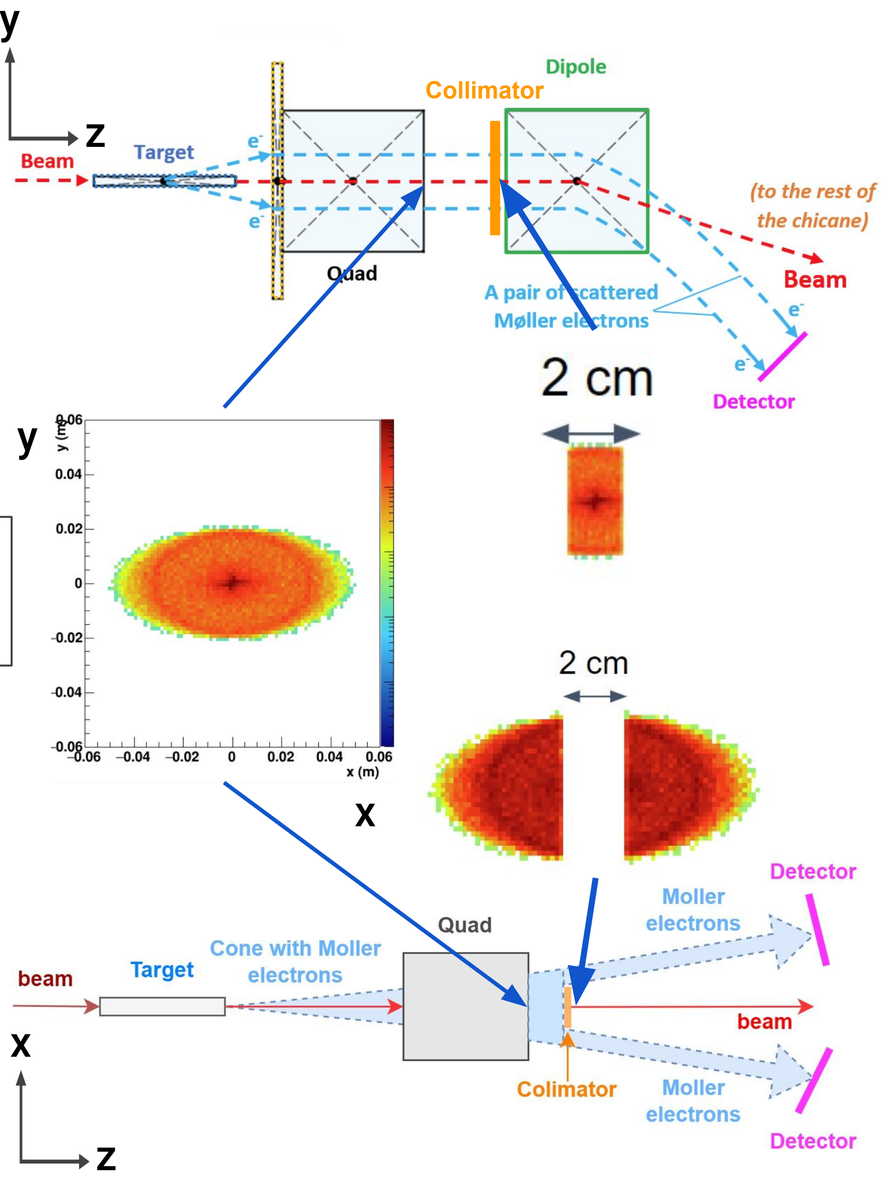
Double-arm design



Geant4 simulation: current results

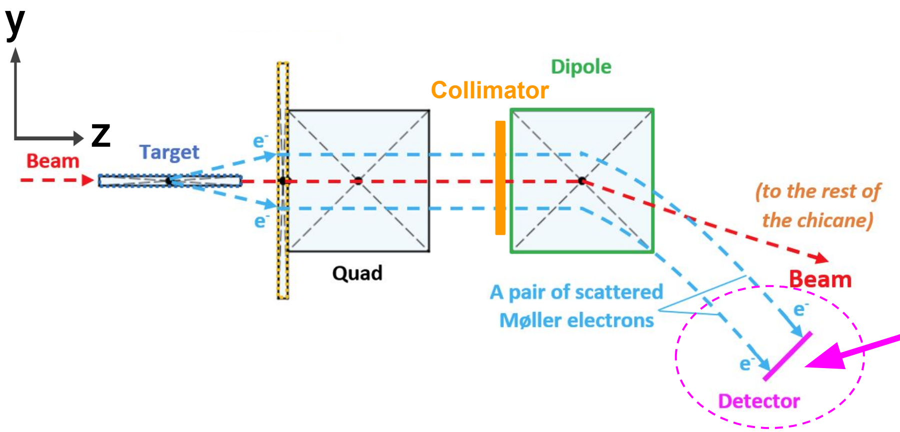
Chicane design

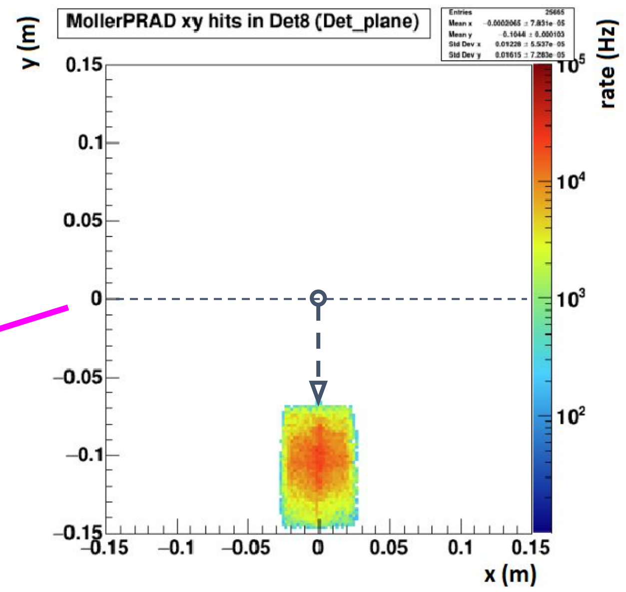
Only **Moller** events,
H target



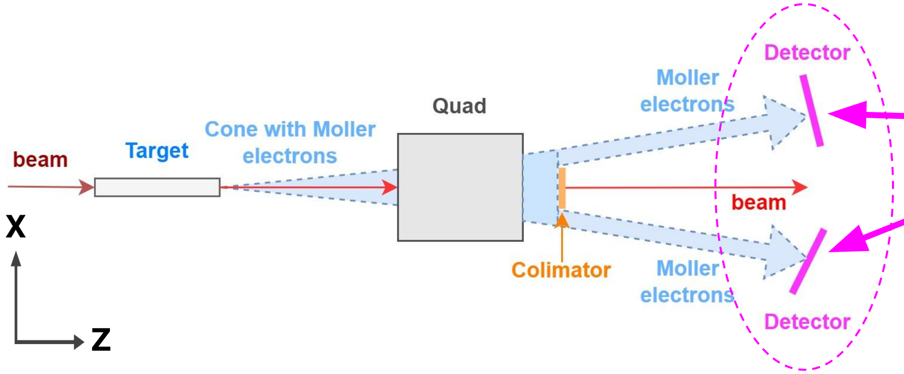
Double-arm design

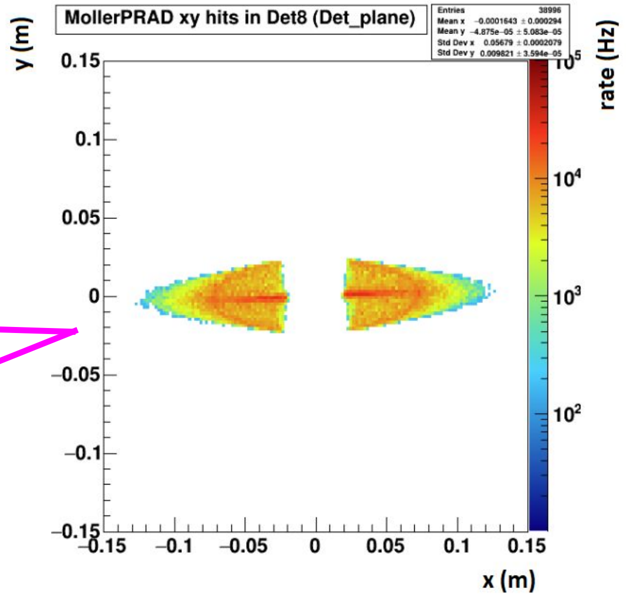
Geant4 simulation: current results





Only **Moller** events,
H target



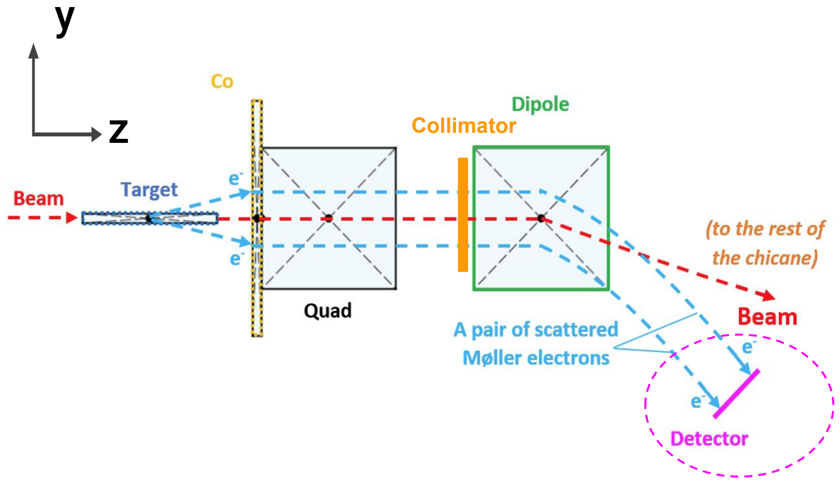


Geant4 simulation: current results

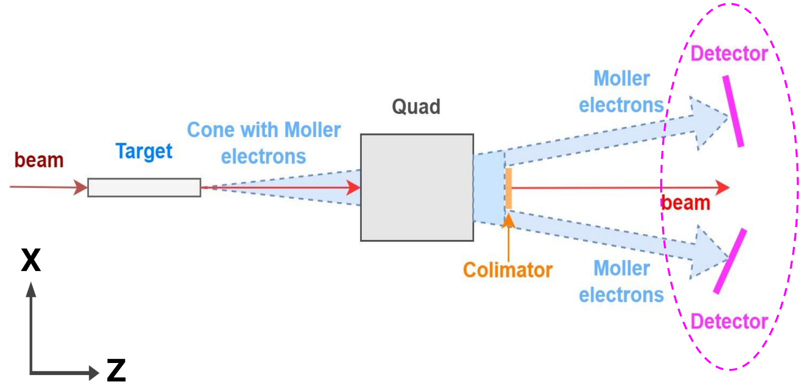
Moller events (**signal**)

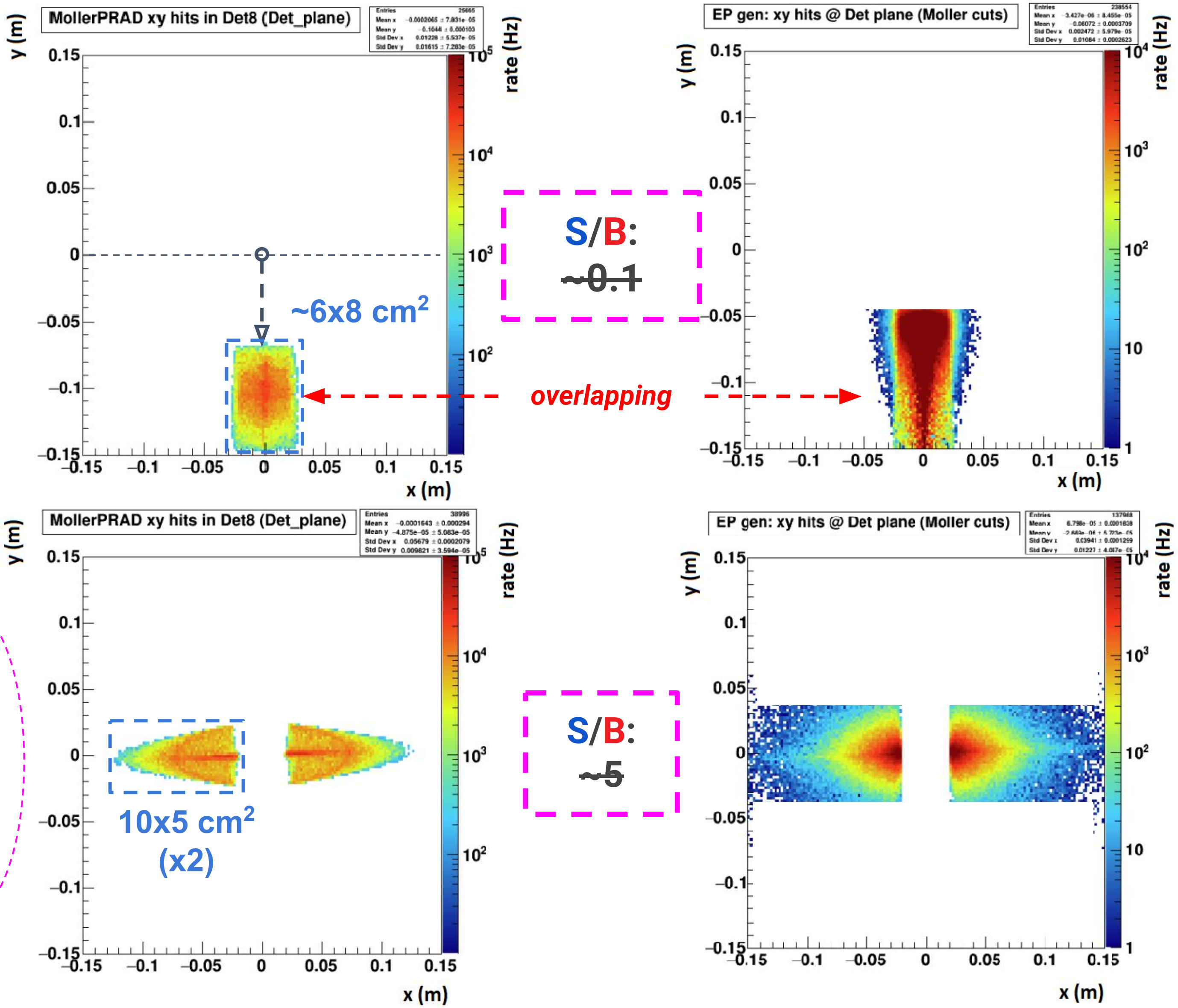
EP events (**background**)

Chicane design:



Double-arm design:



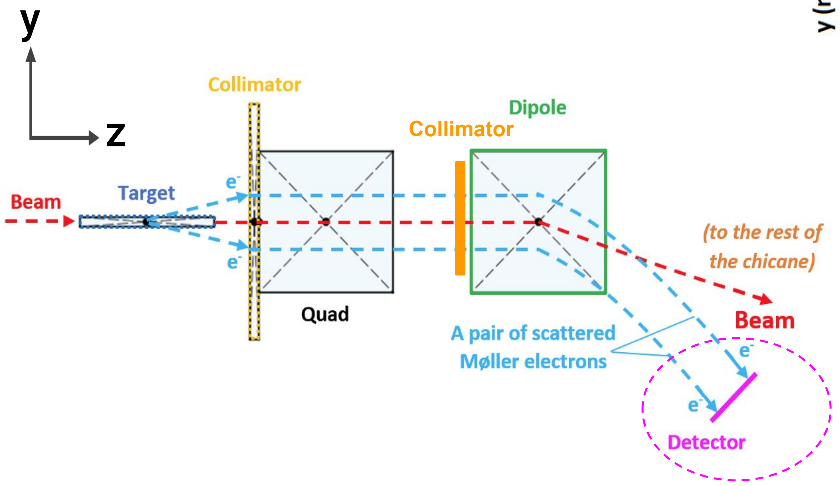


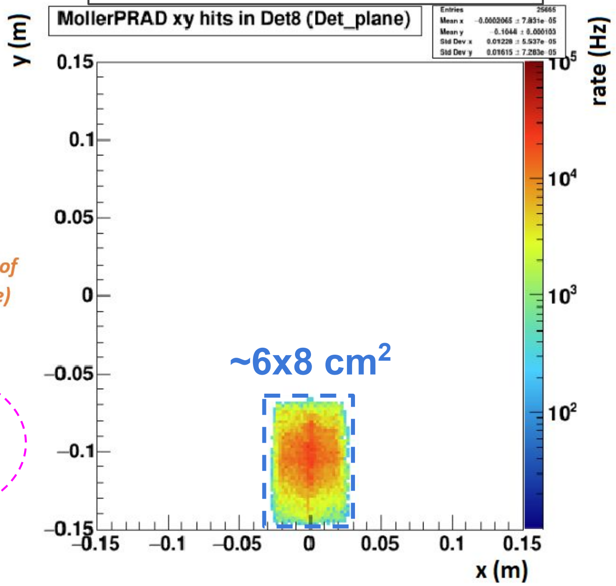
Geant4 simulation: current results

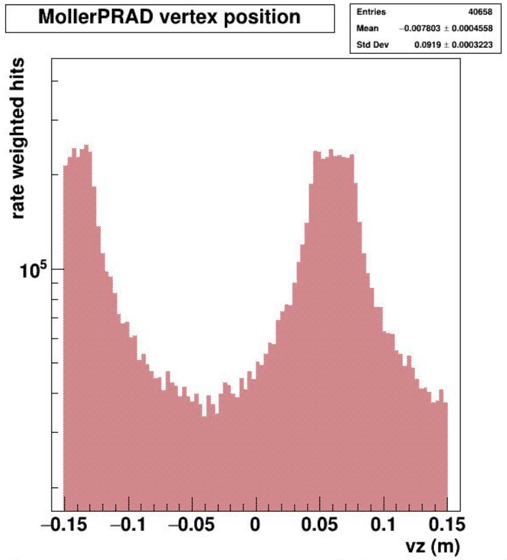
Only **Moller** events, H target

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

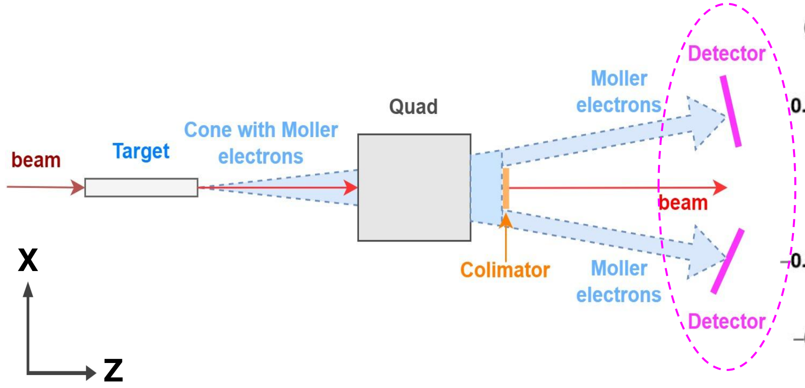
Chicane option:

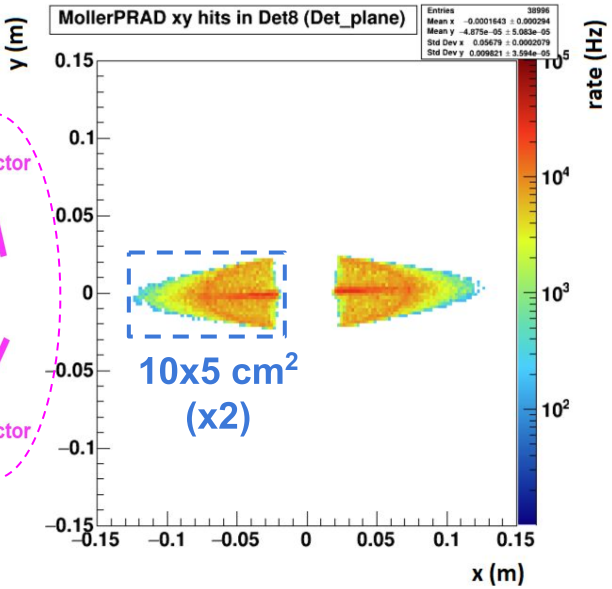


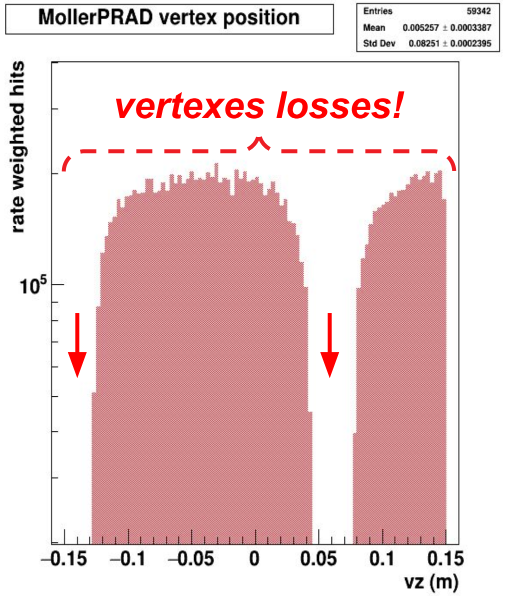




"Double-arm option:







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Summary

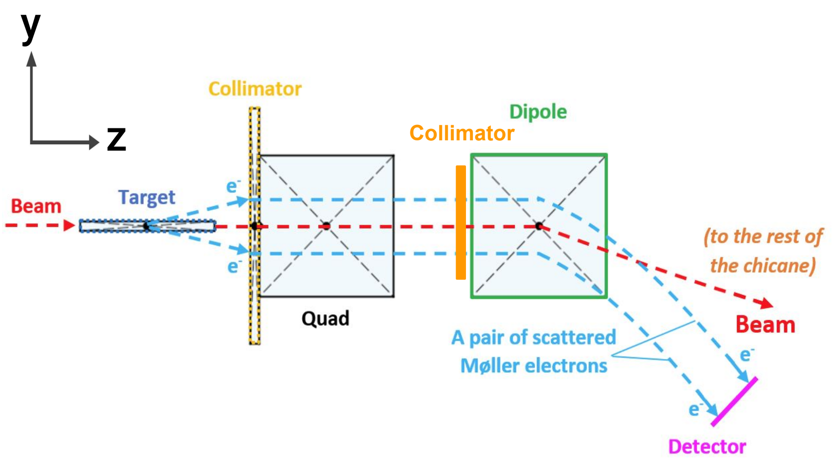
- Developed framework for the simulation of the Moller polarimeter with optional designs and different type of targets

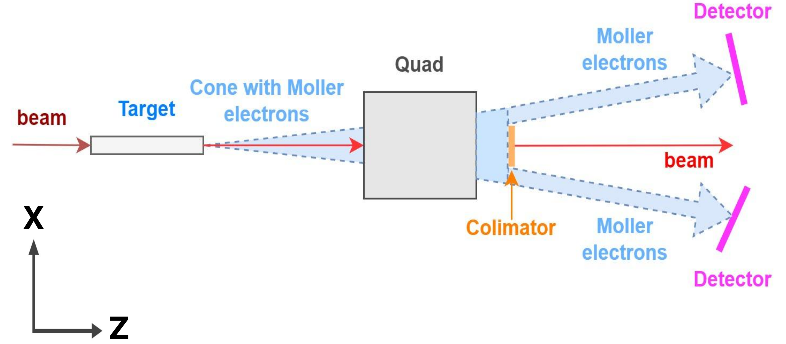
- Verified and benchmarked Moller generators (including one from the PRad collaboration)

- Implemented realistic field maps for all types of the magnetic elements that are used in the simulation -> no non-physical discontinuities

- <u>Current goal</u>: to build a spectrometer that can utilize Iron target for low beam current polarimetry with an option to install H gas target later on

- <u>Further steps</u>:
  - ☐ Fixing and benchmarking evaluation of the Mott generator
  - ☐ Further simulation for detailed comparison of the design options
  - ☐ Optimizations for magnetic elements (positions and specs, etc.) and detector design

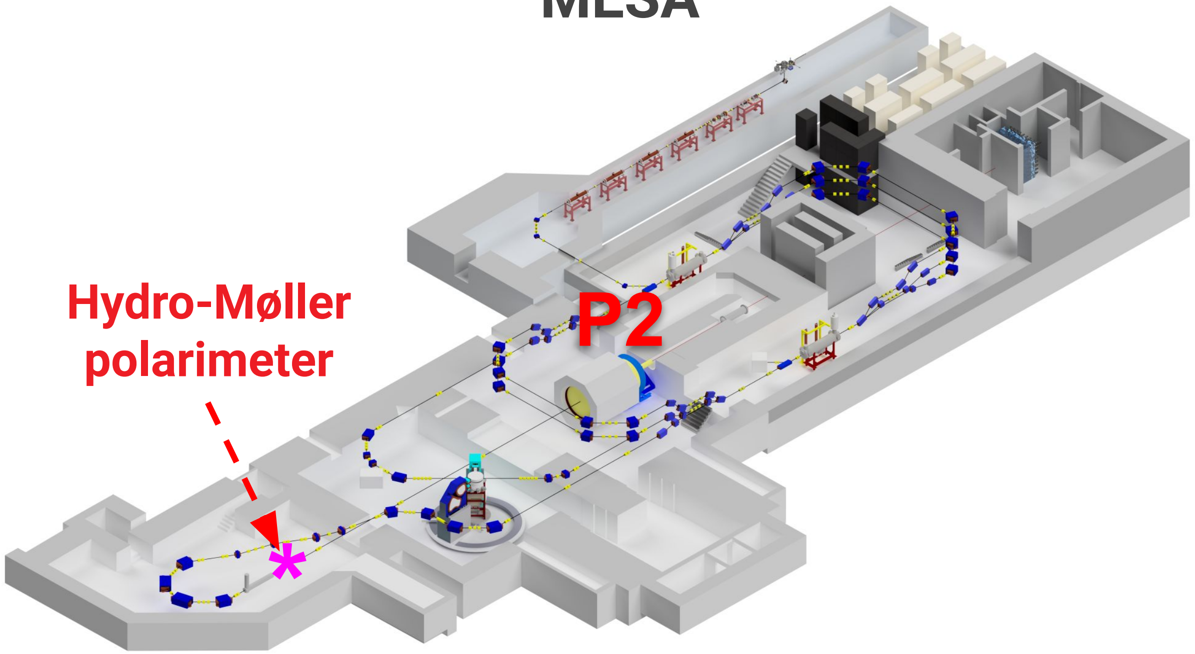




Thank you for your attention!
Questions/comments?

Backup

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)

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

Mainz Energy-Recovery Superconducting Accelerator (MESA)

Polarimetry techniques

Method	Physics	Pros	Cons
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Møller	$\vec{e}^- + \vec{e}^- \to e^- + e^-$	Rapid, precise	Solid target + concept for a **low-density gaseous target**

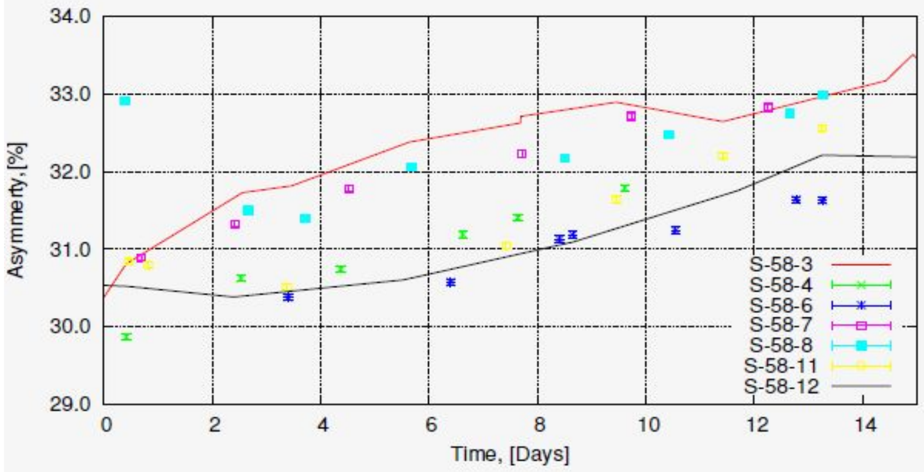
Atomic Hydrogen target (proposal by E. Chudakov and V. Luppov*):

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

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

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Polarimetry techniques

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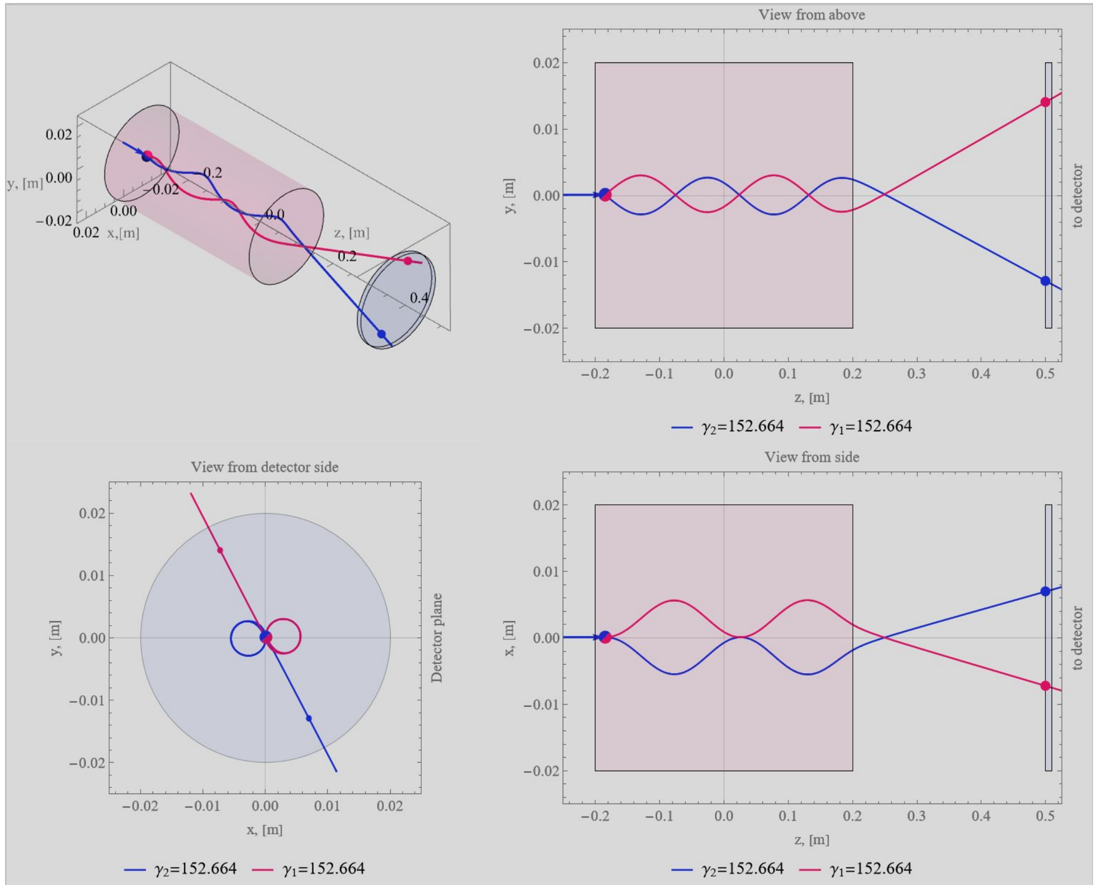
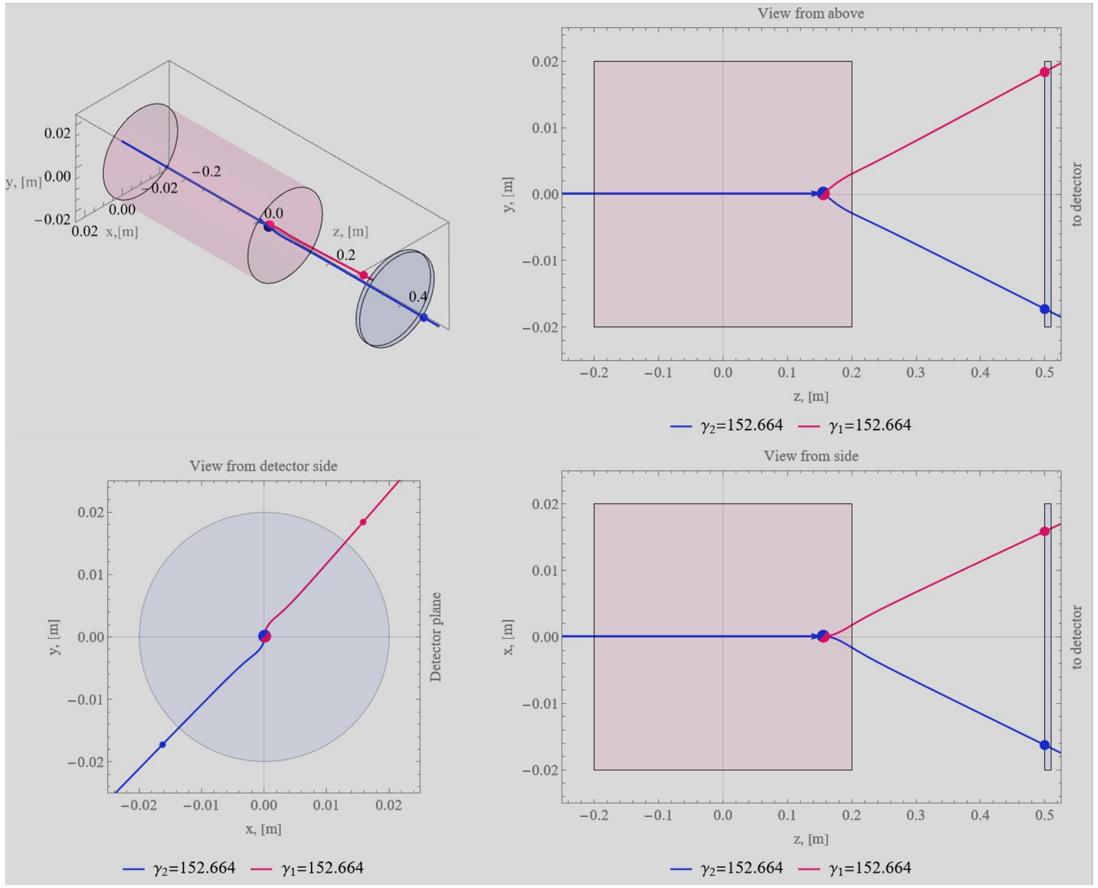
Hydro-Moller polarimeter: effect of the long target

Effect of solenoid magnetic field and long target





V. Tyukin, KPH