UNIVERSITY OF MANITOBA

CINP ICPN
Canadian Institute of Nuclear Physics
Institut canadien de physique nucléaire

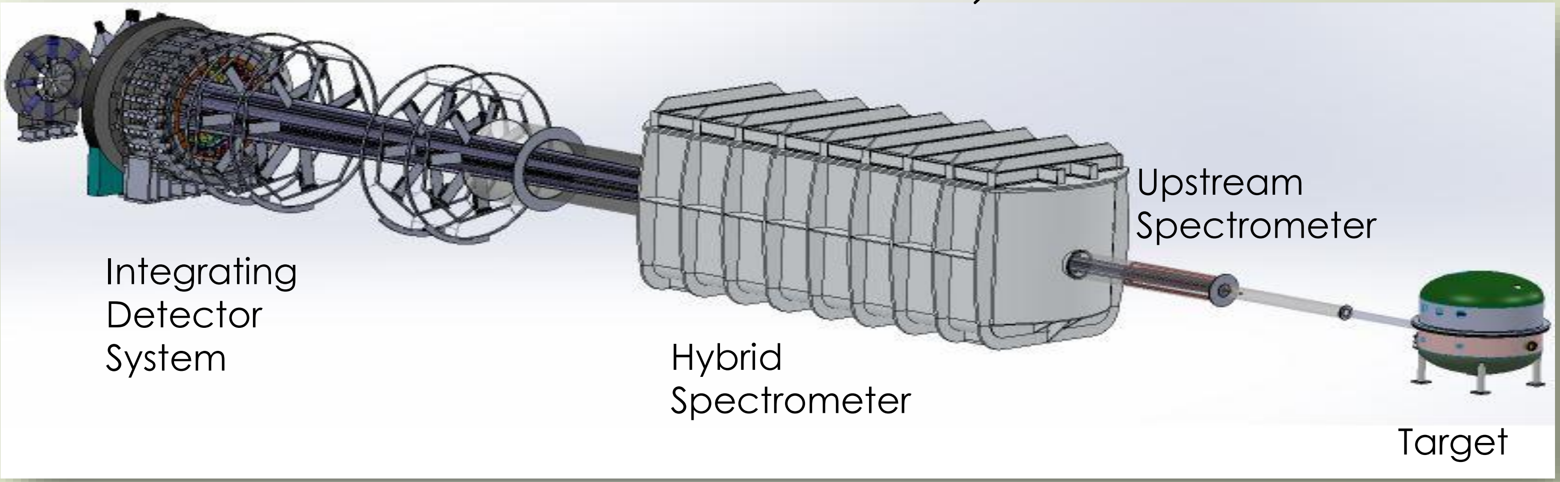
Spectrometer and Detector Simulations for the MOLLER Experiment

Sakib Rahman

Introduction

- Parity-violating asymmetry (A_{PV}) in electron-electron scattering.
- Measurement of weak charge of electron up to 2.4% accuracy.
- Highest precision on weak mixing angle measurement till date.
- Spectrometer and detector systems need to be optimized with regards to sensitivity to coil offsets and background contributions.

Jefferson Lab

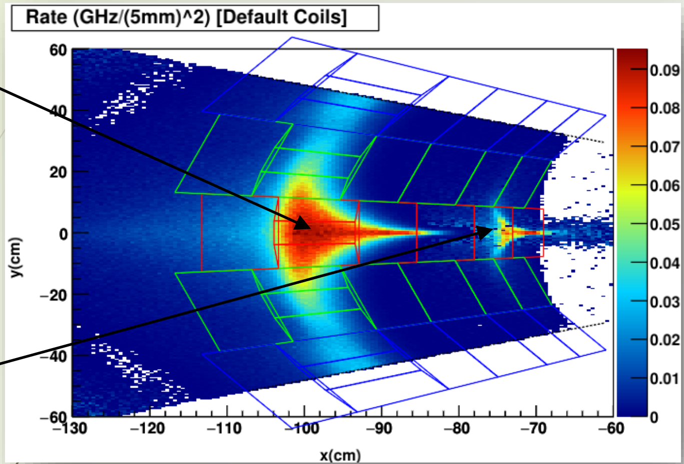


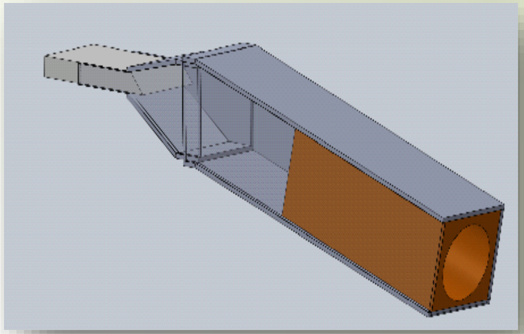
Cameron Clarke and Tyler Kutz

Detector Studies

Møller Ring

Elastic ep Ring

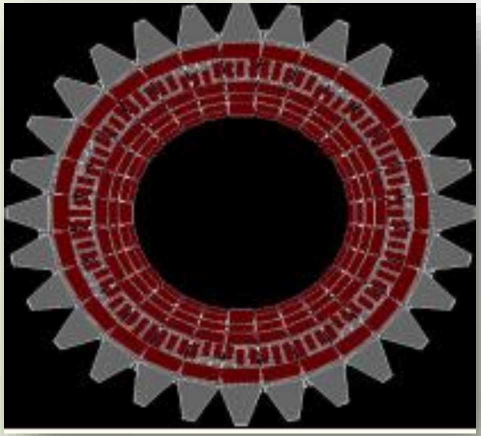


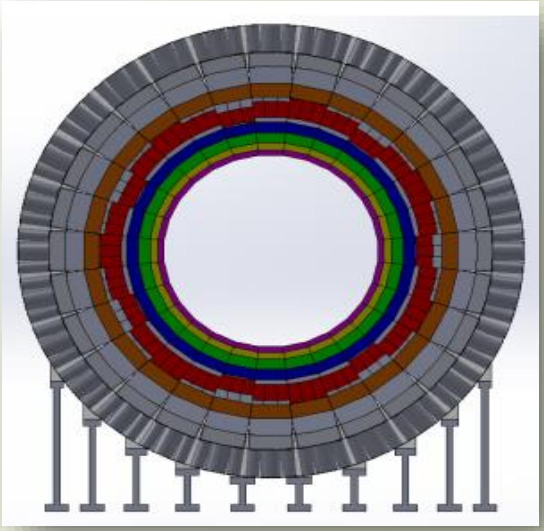


Beam tests & standalone optical simulations

Redo background studies with master simulation

Background studies with simple plane detector





Translate CAD model to GEANT4 readable format (GDML)

Yuxiang Zhao

Extracting the Physical Asymmetries

Dilution= $\frac{N_i}{N_{total}}$ Asymmetry

- $A_{meas} = \sum f_i A_i$
  i = ee, ep-el, ep-in, eAl-el, eAl-qel, eAl-in, pim etc. in each quartz tile of a ring.
- Minimize $\chi^2 = \sum \frac{(A^j_{meas} - \sum f^j_i A^j_i)^2}{\sigma^2_{A^j_{meas}}}$ to extract the physical asymmetries and their uncertainties from different sources in all the tiles.
- Combine the results from the tiles for each individual ring.

Ring No.	$\frac{\sigma_{A_{meas}}}{A_{meas}}$ (%)	A_{meas} (ppb)	$\frac{f_{ee}A_{ee}}{A_{meas}}$ (%)	$\frac{f_{ep-el}A_{ep-el}}{A_{meas}}$ (%)	$\frac{f_{ep-in}A_{ep-in}}{A_{meas}}$ (%)	$\frac{f_{eAl-el}A_{eAL-el}}{A_{meas}}$ (%)	$\frac{f_{eAl-in}A_{eAL-in}}{A_{meas}}$ (%)	$\frac{f_{pim}A_{pim}}{A_{meas}}$ (%)
1	3.05%	-78.69	0	79.9	28.6	-9.66	1.12	0
2	1.09%	-103.1	0	65.3	44.1	-11.3	1.83	0.05
3	1.68%	-91.15	1.12	50.3	54.3	-8.25	1.34	1.13
4	3.06%	-44.73	33.5	37.8	28.3	-7.33	0.63	7.04
5	1.61%	-34.26	88.2	6.61	3.56	-1.47	0.09	2.98
6	7.24%	-13.28	57.5	25.3	8.40	-7.47	0.30	15.9

Systematic Uncertainties in Møller Ring

- $A_{ee} = \frac{1}{f_{ee}} A_{meas} - \sum_{i \neq ee} \frac{f_i}{f_{ee}} A_i.$
- Systematic uncertainty from each source assuming negligible uncertainty on dilution:

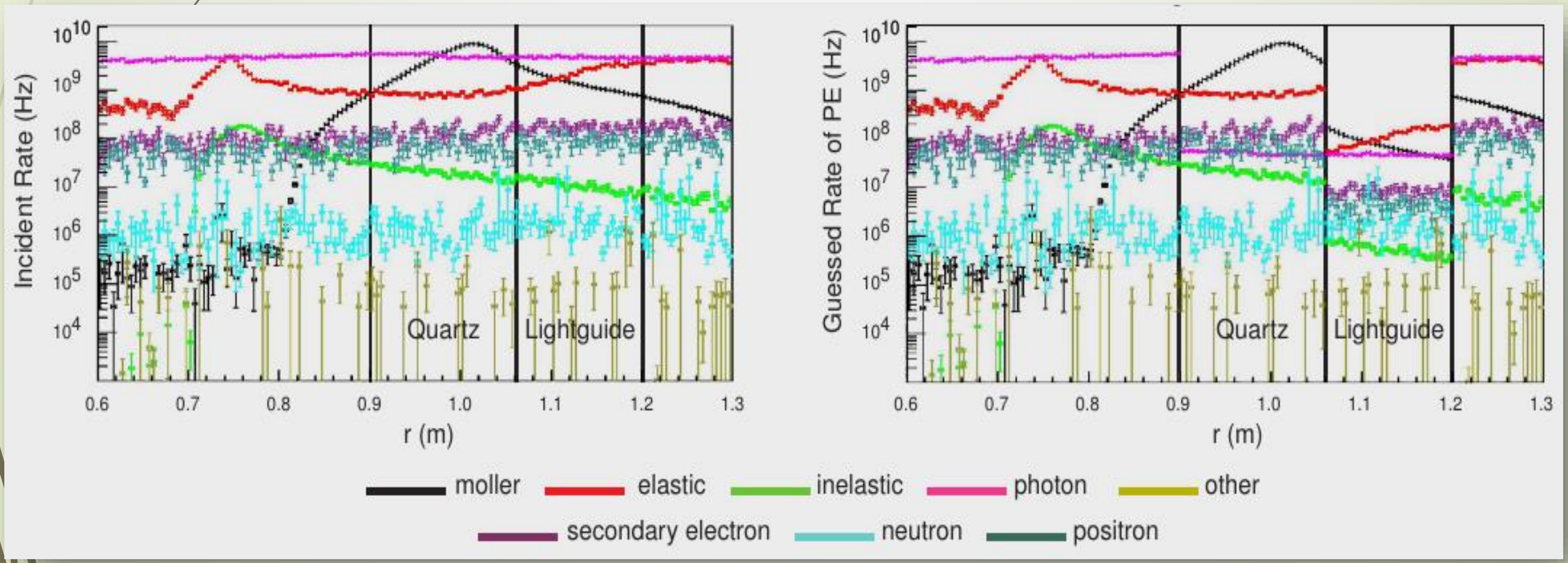
$$\frac{f_i}{f_{ee}} \sigma_{A_i}$$

Processes	Uncertainties normalized to 33 ppb (%)
ee (stat)	1.88
ep-el	0.37(0.036)
ep-in	0.16
eAl-el	0.36(0.1)
eAl-qel	0
eAl-in	0.09
pim	0.33

Can be reduced by further inputs From QWEAK (arrows point to ep-el and eAl-el)

Taking the Lightguides into Account

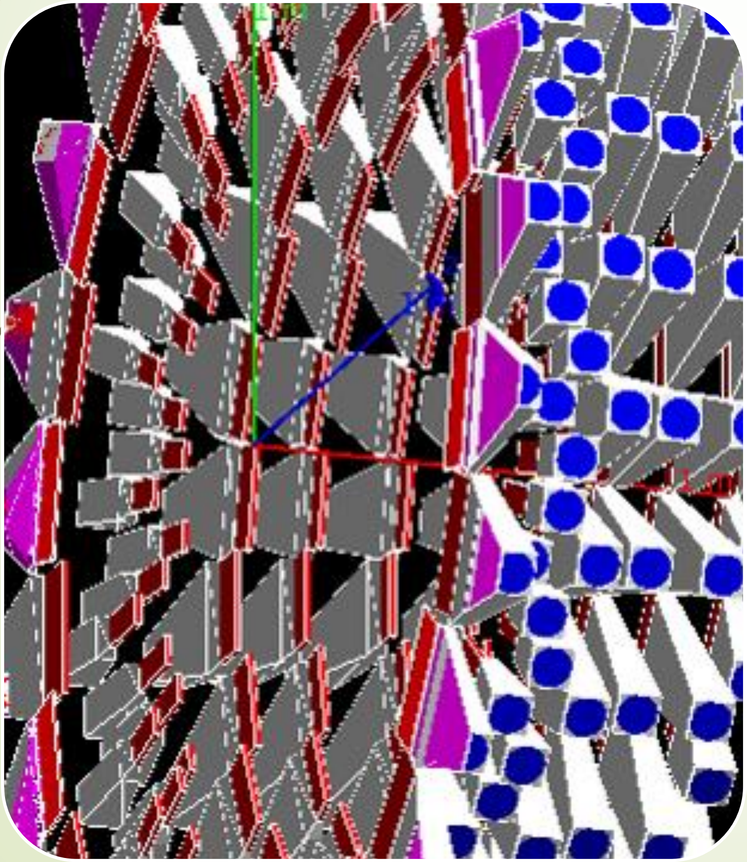
- The photoelectrons recorded at a single detector has contributions from incidences on the quartz and the light guide.
- The quartz and light guide have different response factors to incident rates.
- Use an educated guess for the response factors to determine what the expected contributions are from incidences on either segments.



Photoelectrons generated from different sources in Møller Ring

Initial Parametrization In GDML

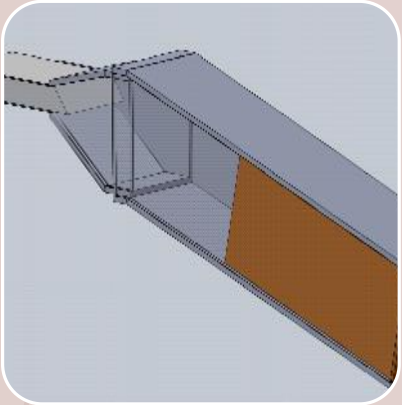
- Quickly change geometry with the modification of a few parameters.



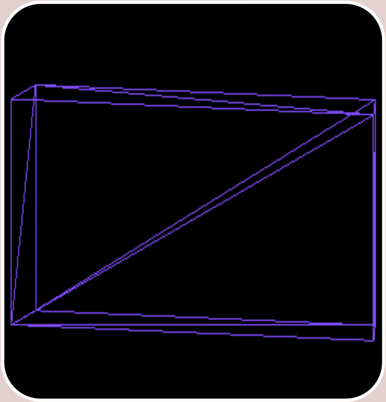
- Rad Pos: 18 parameters
- Z Pos: 18 parameters
- Rad Extent : 18 parameters
- Z Extent : 18 parameters
- Φ Extent : 18 parameters
- Quartz Cut Angle: 18 parameters
- Reflector Angle: 18 parameters
- Angle of Lightguide wrt Quartz : 18 parameters
- Reflector Lengths: 18 parameters
- LG Lengths: 18 parameters

Alternate Parametrization With CADMesh

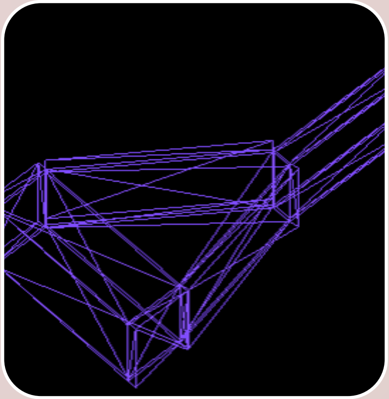
- Go directly from CAD to GEANT 4 instead of having intermediate GDML.
- Reduces the number of parameters on the GEANT 4 side.



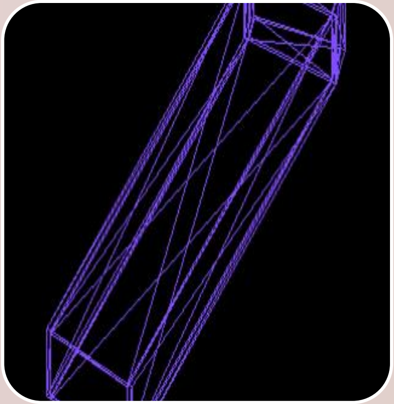
Detector in CAD



Quartz Piece in GEANT



Reflector in GEANT

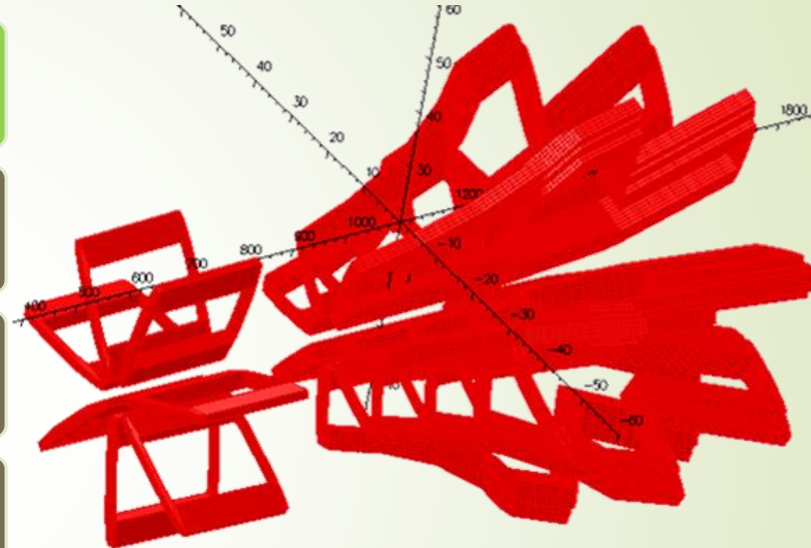


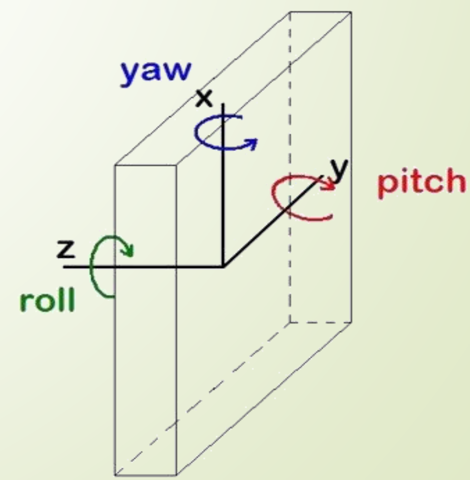
Lightguide in GEANT

Spectrometer Studies

Use allowed uncertainty in **rate, asymmetry, θ_{lab} and θ_{com}** to estimate how much spectrometer coils can deviate from their default position.

- Sensitivity Studies
  - Single Coil Offset
    - r
    - θ
    - z
    - roll
    - pitch
    - yaw
  - Multiple Coil Offset





Juliette Mammei

Sensitivity Studies

$$Q^2 = 4EE'\sin^2\frac{\theta_{lab}}{2}$$

$$\delta Q^2 = \left(\frac{\partial Q^2}{\partial E}\right)^2 (\delta E)^2 + \left(\frac{\partial Q^2}{\partial E'}\right)^2 (\delta E')^2 + \left(\frac{\partial Q^2}{\partial \theta_{lab}}\right)^2 (\delta\theta_{lab})^2$$

$$\frac{\partial Q^2}{\partial E} = 4E'\sin^2\frac{\theta_{lab}}{2} \sim 0.001 \text{ GeV}$$

$$\frac{\partial Q^2}{\partial E'} = 4E\sin^2\frac{\theta_{lab}}{2} \sim 0.001 \text{ GeV}$$

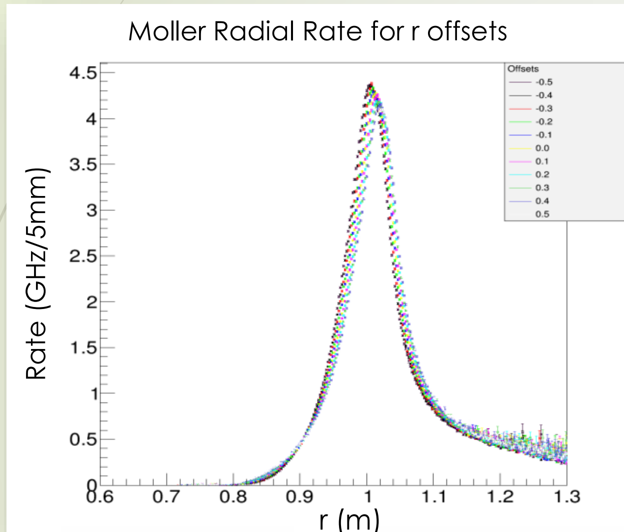
$$\frac{\partial Q^2}{\partial \theta_{lab}} = 4EE'\sin\frac{\theta_{lab}}{2}\cos\frac{\theta_{lab}}{2} \sim 1.33 \text{ GeV}^2/\text{rad}$$

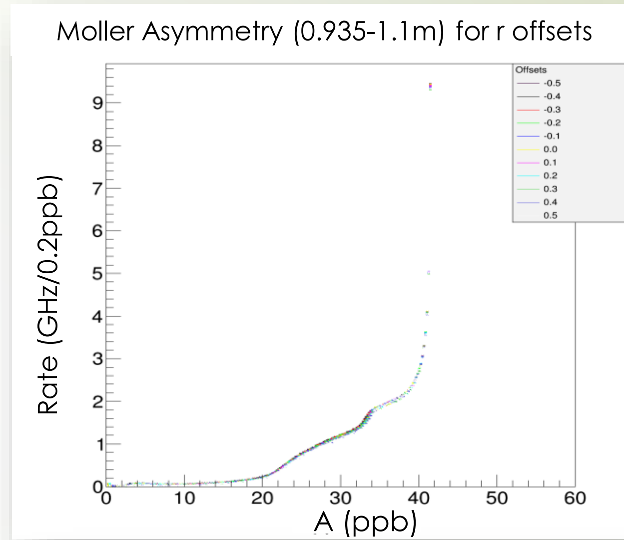
$$\frac{\delta Q^2}{1.33\text{GeV}^2/\text{rad}} = \delta\theta_{lab} = \frac{(0.005)(0.0058\text{GeV}^2)}{1.33\text{GeV}^2/\text{rad}} = 2 \times 10^{-5}\text{rad}$$

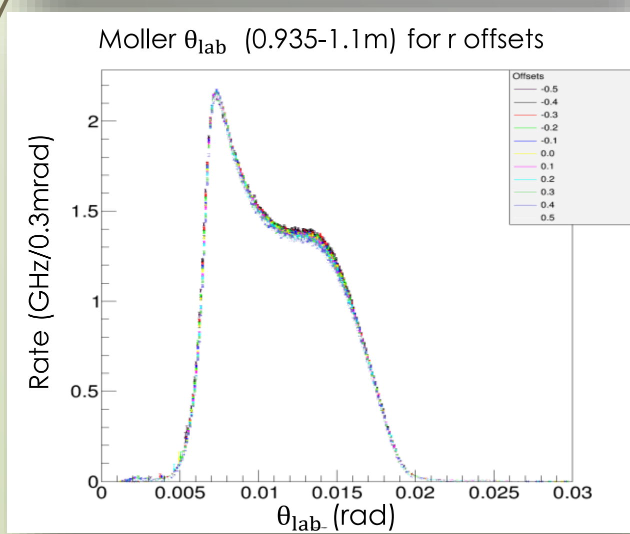
Then $\delta\theta_{lab}\left(\frac{\partial\theta_{lab}}{\partial r}\right)^{-1} = \delta r$, the deviation in r allowed.
Repeat calculation for different types of offsets.
Do similar calculations with allowed δR=10%*R, δA=0.60 ppb and $\delta\theta_{com} = 1$ deg.

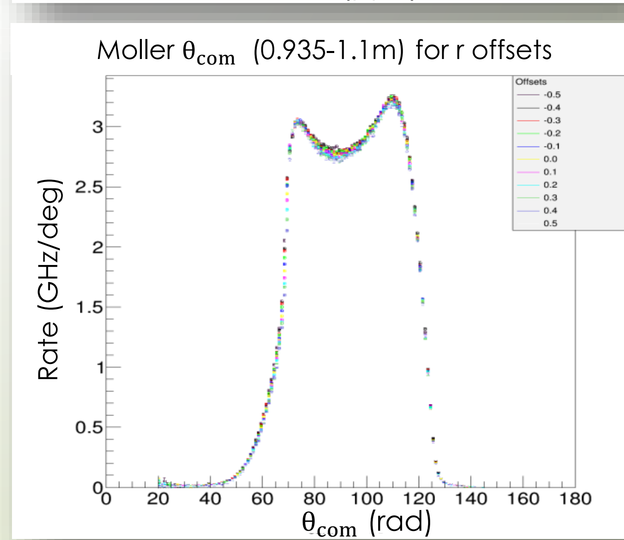
Hybrid Spectrometer

Single Coil Sensitivity to Radial Offset



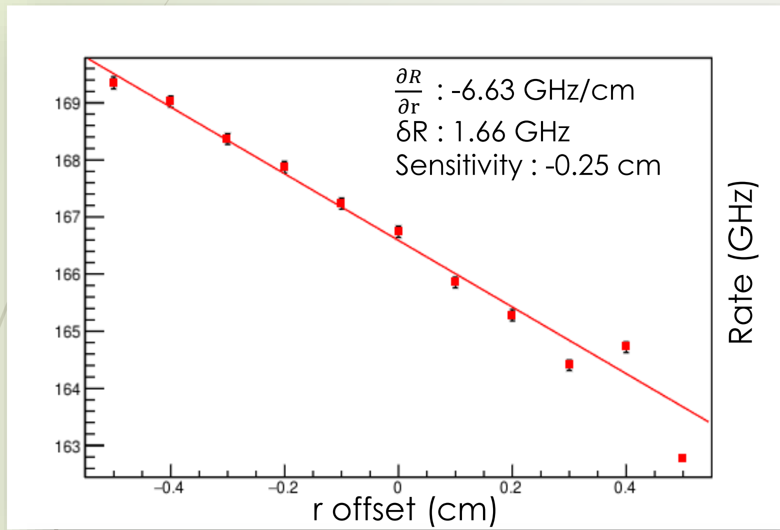


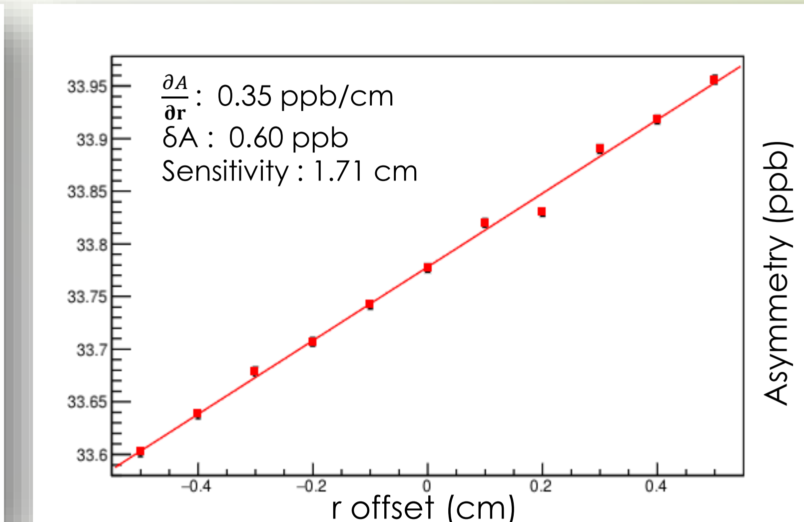


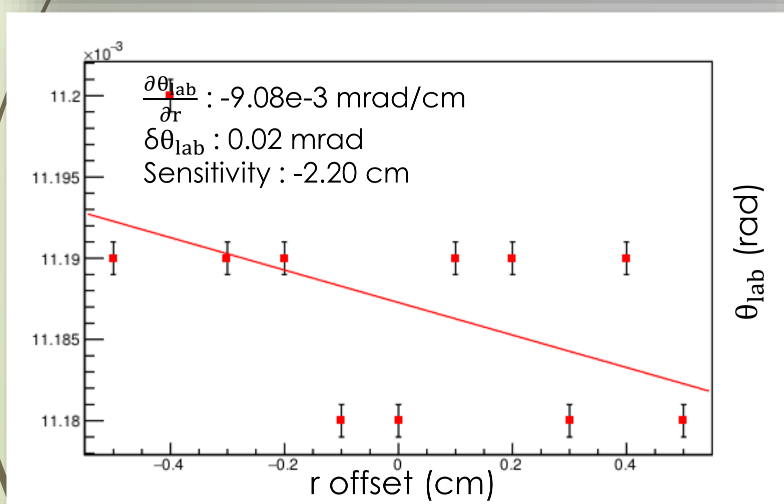


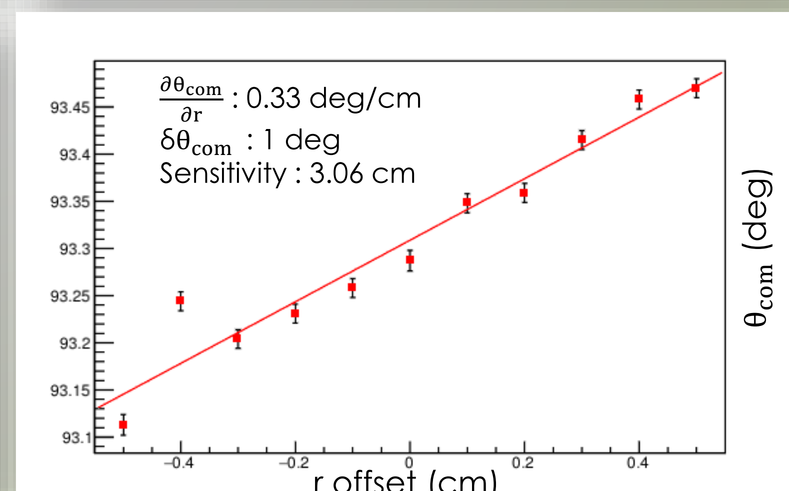
Hybrid Spectrometer

Single Coil Sensitivity to Radial Offset



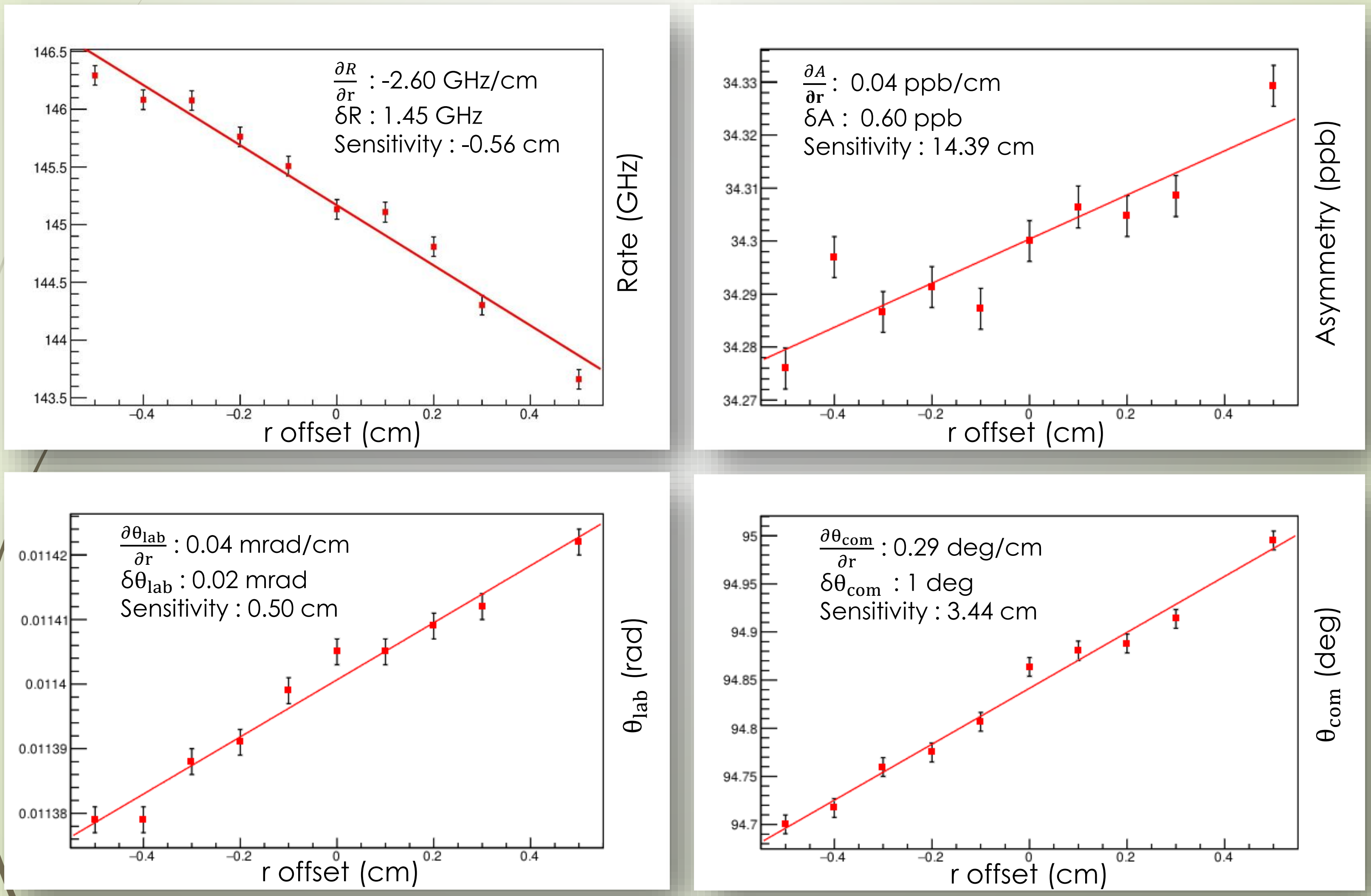






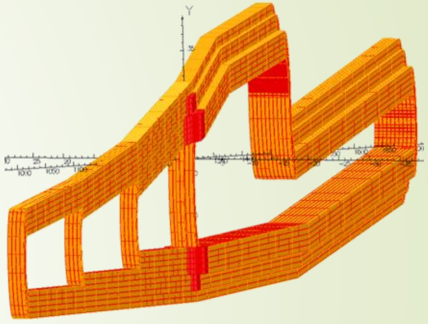
Upstream Spectrometer

Single Coil Sensitivity to Radial Offset



Ongoing and Future Work

- Spectrometer System
  - Beam steering studies.
  - Sensitivity studies with multiple coil offset.
  - Hybrid Segmentation studies.



- Integrating Detector System
  - Implement a flexible and easily transferable geometry in simulation.
  - Background study with complete detector geometry incorporating errors in both dilution and asymmetry in our analysis.

Acknowledgements

- Cameron Clarke and Tyler Kutz - CAD model.
- Yuxiang Zhao - Asymmetry calculations.
- Dr. Juliette Mammei and Iris Halilovic – TOSCA field maps for spectrometer simulations.
- This work was supported by NSERC, US Department of Energy and JSA.
- Thanks to CINP for the travel funding.

University of Manitoba

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Hybrid Spectrometer

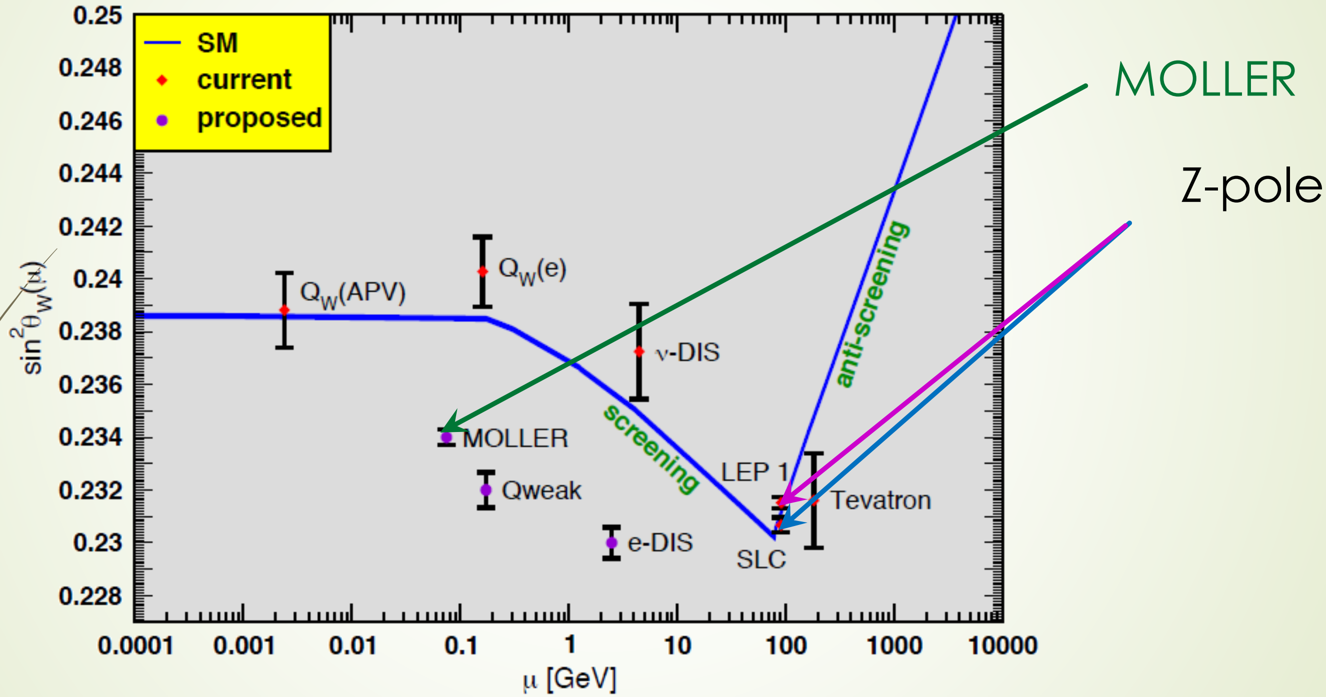
Single Coil Sensitivity to All Offsets

Position offsets (r, z) range from -0.5 cm to 0.5 cm and angular offsets (θ , roll, pitch, yaw) range from -0.05 deg to 0.05 deg.

	Rate (GHz)		Asymmetry (ppb)		θ_{lab} (rad)		θ_{com} (deg)	
	Slope	Sensitivity	Slope	Sensitivity	Slope	Sensitivity	Slope	Sensitivity
z (cm)	2.89E-03	573.68	-1.12E-02	-53.35	2.22E-06	9.02	4.70E-03	212.87
r (cm)	-6.63E+00	-0.25	3.50E-01	1.71	-9.08E-06	-2.20	3.27E-01	3.06
θ (deg)	-1.79E+00	-0.93	3.92E-03	153.19	2.71E-05	0.74	1.39E-01	7.21
roll (deg)	1.48E+00	1.12	-2.56E-02	-23.43	-7.22E-05	-0.28	-4.20E-01	-2.38
yaw (deg)	-2.81E+00	-0.59	2.11E-01	2.84	2.36E-05	0.85	4.13E-01	2.42
pitch (deg)	1.27E+01	0.13	-1.86E-01	-3.23	-1.18E-04	-0.17	-8.19E-01	-1.22

Juliette Mammei

Measurement of $\sin^2\theta_W$

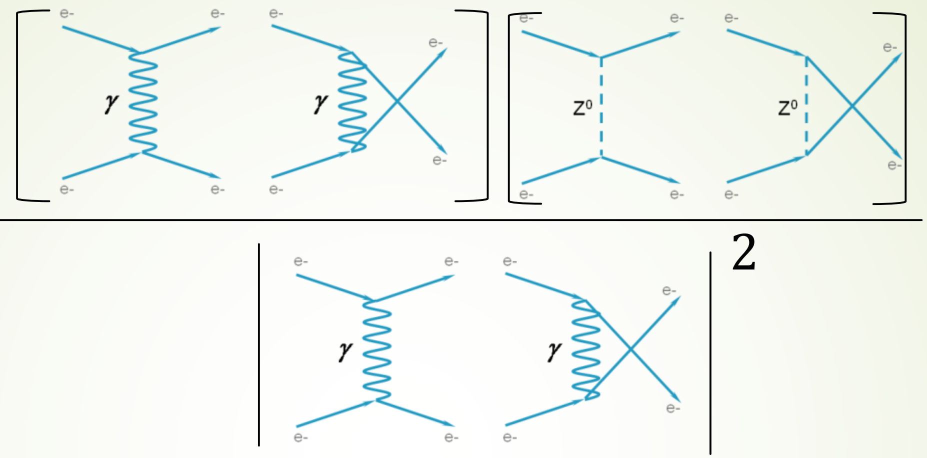


$\Delta\alpha_{had}^{(5)} = 0.02758 \pm 0.00035$
$m_t = 172.7 \pm 2.9\ GeV$

Erler, Kurylov, Ramsey-Musolf

THE PHYSICS

$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx$

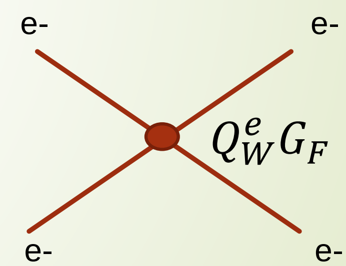


$\approx 1 \times 10^{-8}$

$\propto m_e \, E_{lab}(1 - 4sin^2\theta_W)$

$A_{PV} = 35.6 \pm 0.73$ ppb

$$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W} \simeq .05 \frac{\delta A_{PV}}{A_{PV}}$$



$\delta Q_W^e = 2.3\%, \sim 5 \times smaller$ $than\ E158\ (\delta Q_W^e = 10.9\%)$

$$\mathcal{L}^{PV}_{e_1 e_2} = \mathcal{L}^{PV}_{SM} + \mathcal{L}^{PV}_{NEW}$$