Measurement of a Lepton-Lepton Electroweak Reaction

Dr. Juliette Mammei

Measuring the electroweak couplings

The parity-violating part of the Standard Model Lagrangian is

nucleon target　　　　electron target

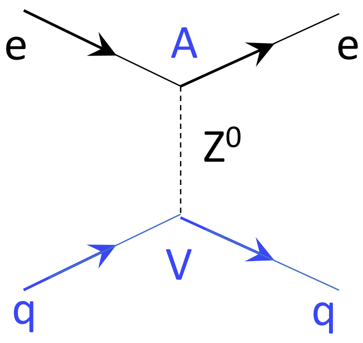
$$\mathcal{L}^{PV} = \frac{G_F}{\sqrt{2}}\left[\bar{e}\gamma^\mu\gamma_5 e\left(C_{1u}\bar{u}\gamma_\mu u + C_{1d}\bar{d}\gamma_\mu d\right) + \bar{e}\gamma^\mu e\left(C_{2u}\bar{u}\gamma_\mu\gamma_5 u + C_{2d} d\gamma_\mu\gamma_5 d\right) + C_{ee}\bar{e}\gamma^\mu\gamma_5 e\left(\bar{e}\gamma_\mu e\right)\right]$$

EM coupling: $e\gamma^\mu$ (not parity violating)

The charged current violates parity maximally: $\frac{g}{2\sqrt{2}}\gamma^\mu(1-\gamma^5)$

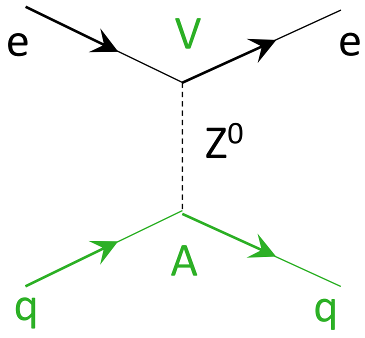
The neutral current coefficients need to be determined:

$$\frac{g}{2cos\theta_W}\left(C_V^f\gamma^\mu - C_A^f\gamma^\mu\gamma^5\right)$$



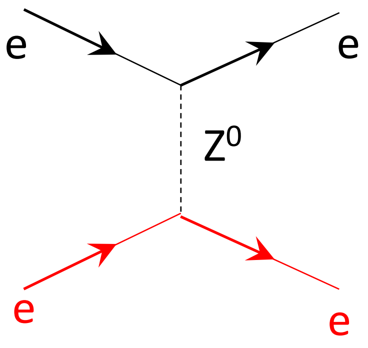
$C_{1q} = 2g_A^e g_V^q$

Small θ



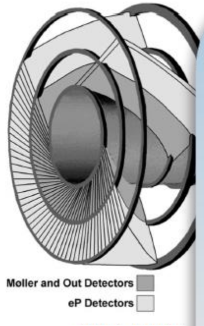
$C_{2q} = 2g_V^e g_A^q$

Large θ

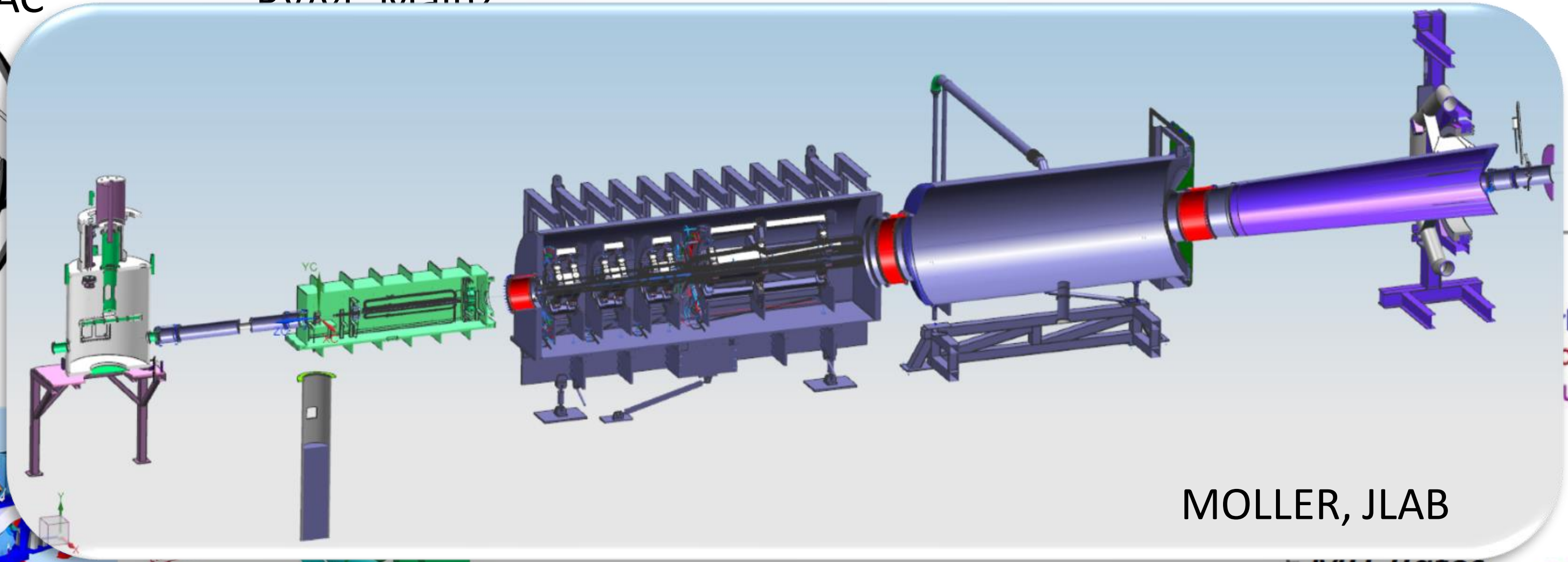


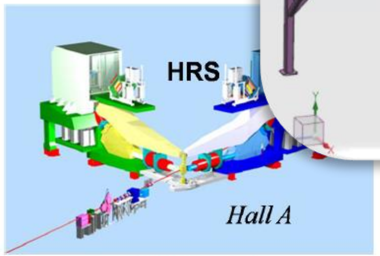
A Brief History of PVES Experiments

E158, SLAC



PVA4, Mainz





HAPPEX, JLAB

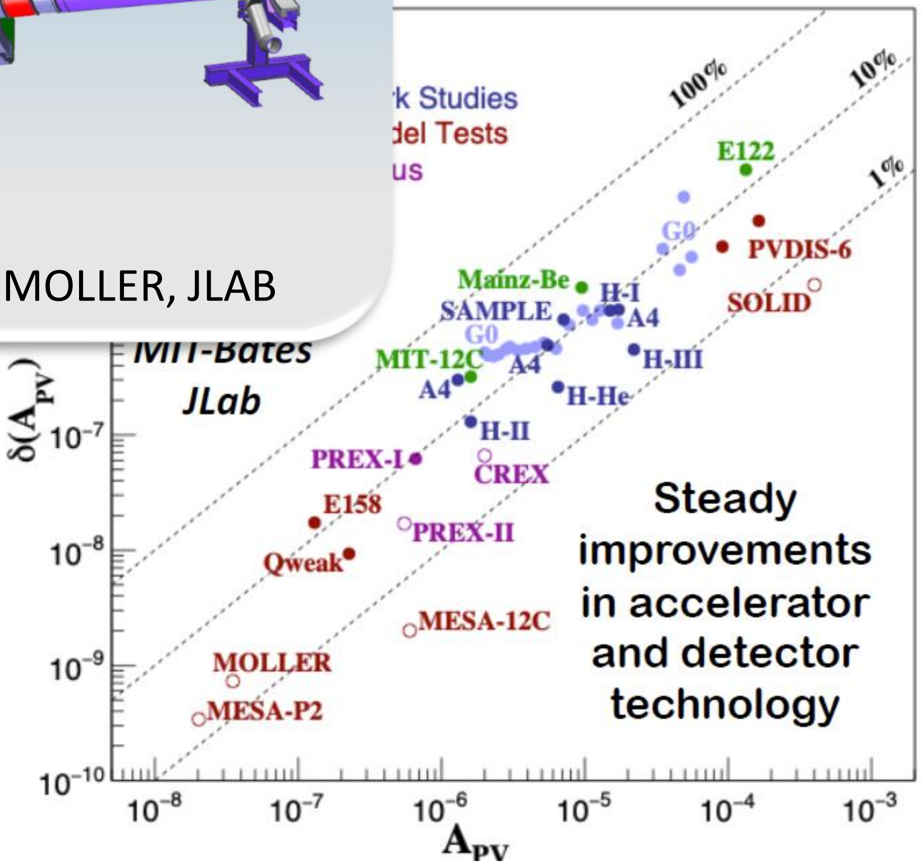
Sample, MIT-Bates

G0, JLAB

Qweak, JLAB

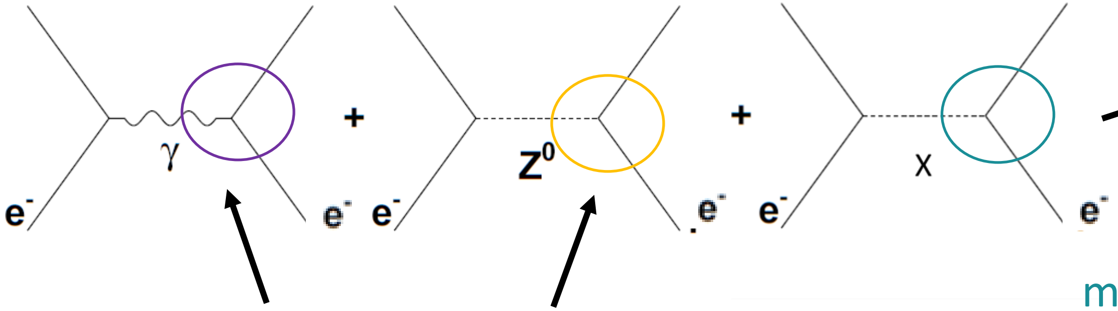
- neutral weak couplings
- strange quark content of nucleon
- neutron skin of heavy nuclei

⇒ Standard Model tests



⇒ SOLID, JLAB; P2, Mainz; EIC, BNL

Testing the Standard Model



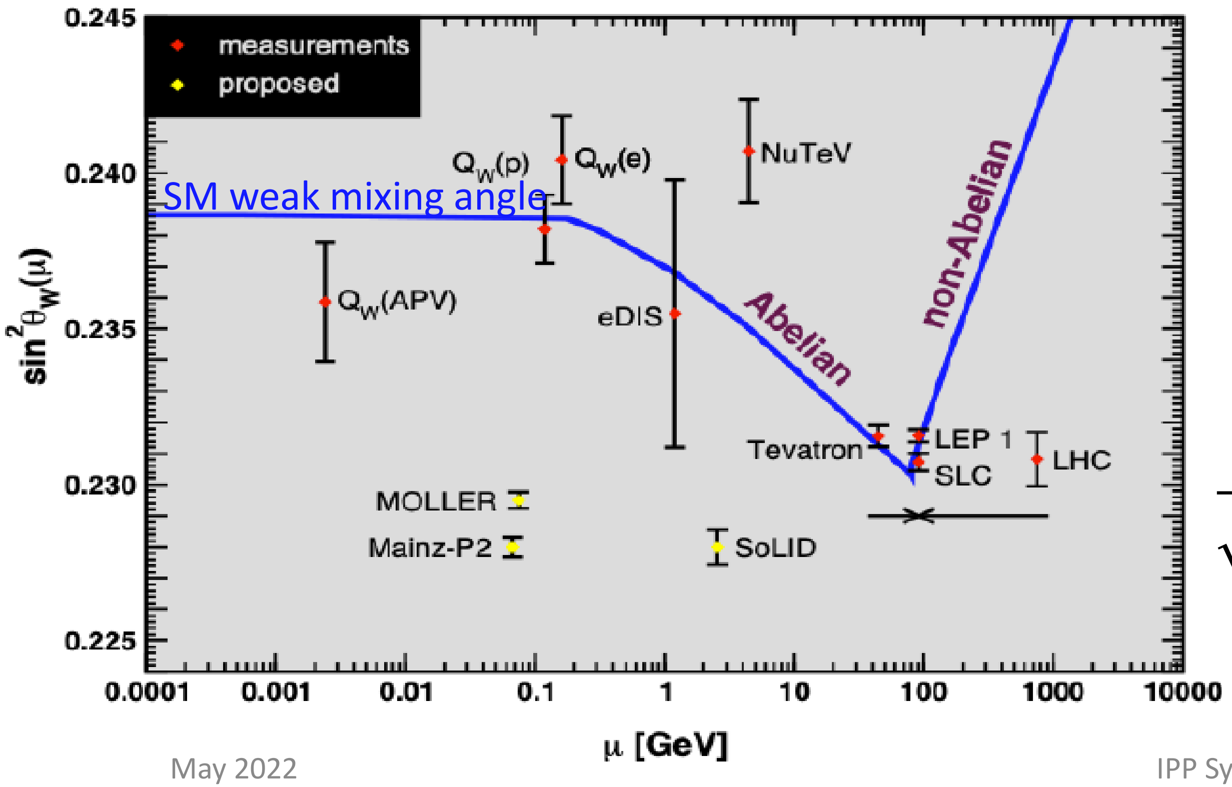
Standard Model processes

Standard Model Test
possible new exchange particle X

$Q^2 \to 0$
measure coupling of new physics to electrons

higher dimensional operators can be systematically classified…

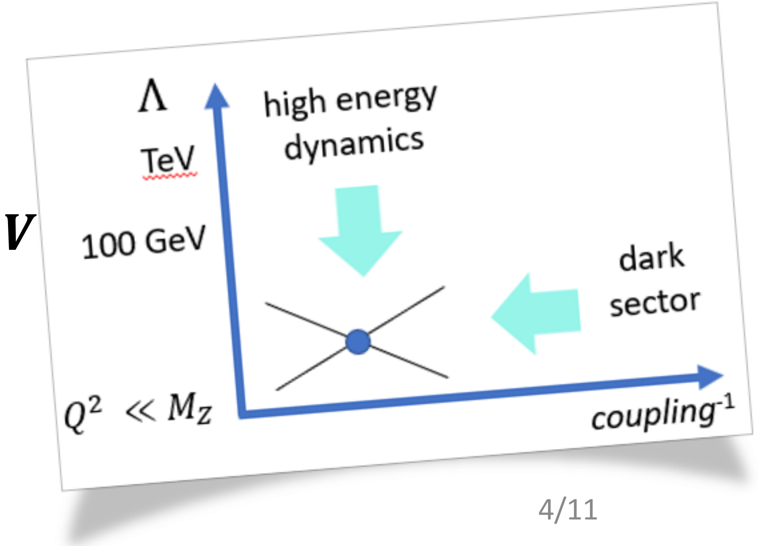
$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$



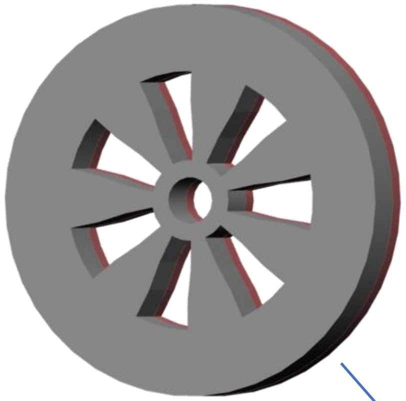
$$\mathcal{L}^{PV}_{e_1 e_2} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda_{ij}^2} \bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma^\mu e_j$$

Parameterize as a 4-fermion contact interaction

$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = \mathbf{7.5\ TeV}$$

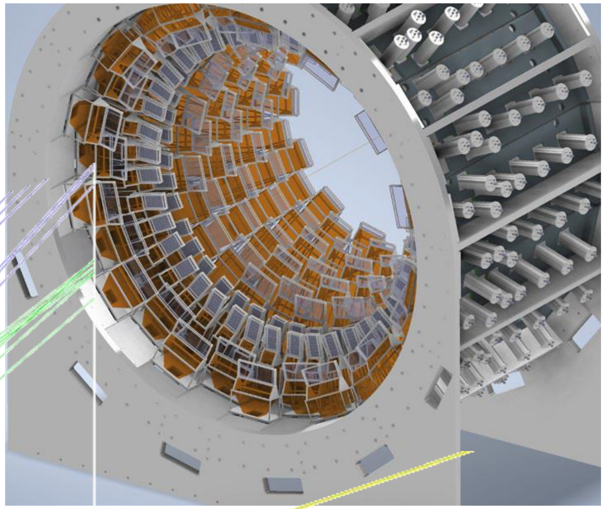


Experimental apparatus



Acceptance defining collimator

Integrating detector array
Tracking detectors
Spectrometer system
Beam monitors
Shielding
Target



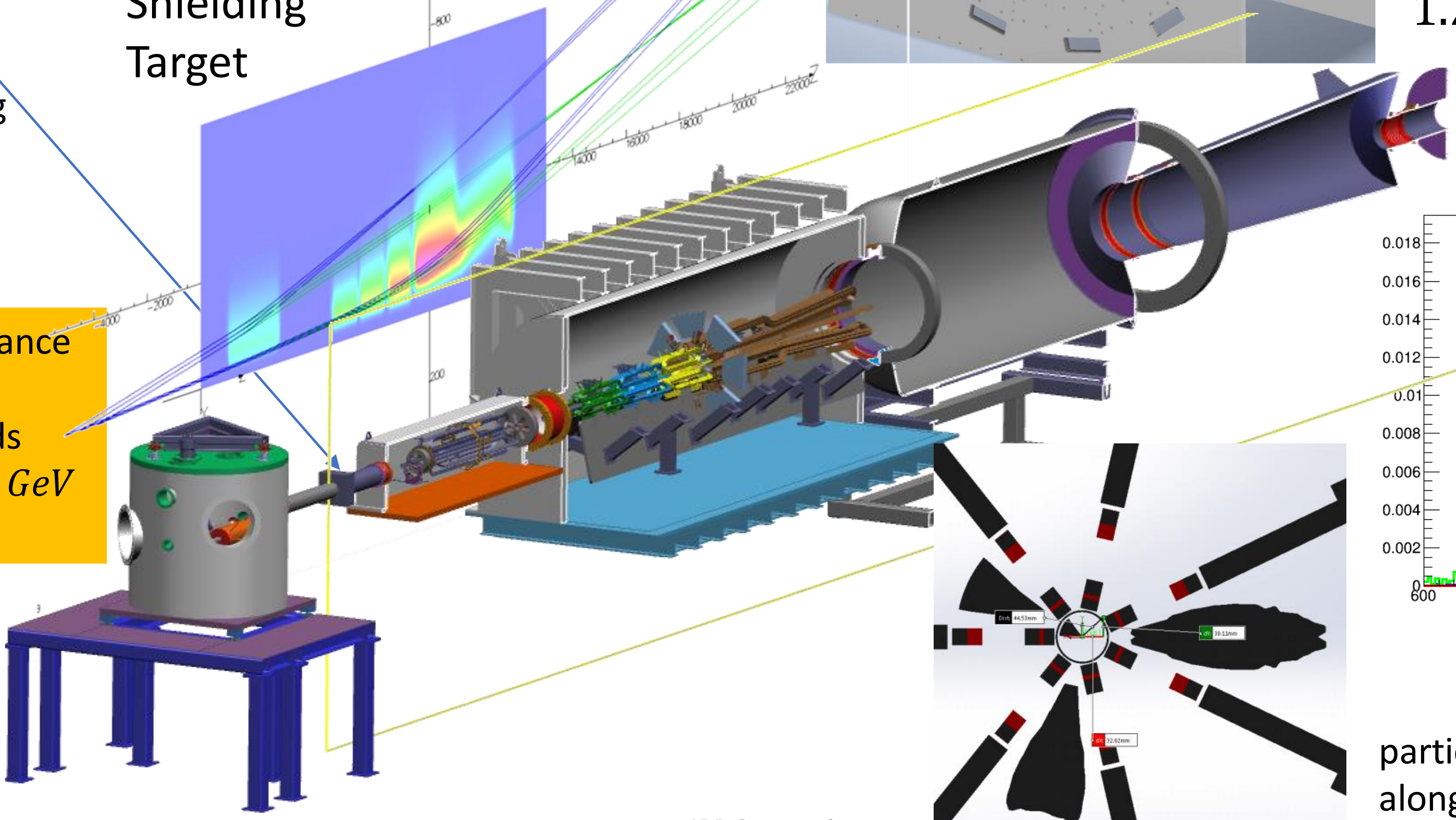
$E_{beam} = 11\ GeV$

$I_{beam} = 65\ \mu A$

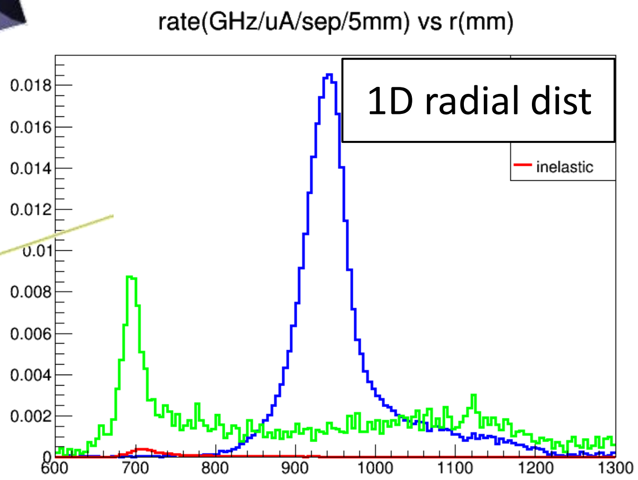
$\mathcal{L} = 3 \times 10^{39}\ cm^{-2} \cdot s^{-1}$

$P_{beam} \geq 90 \pm 0.5\ \%$

$1.25\ m$ LH_2 target



Full azimuthal acceptance for mollers from
$6 < \theta_{lab} < 20$ mrads
$2.75 \leq E_{scat} \leq 8.25\ GeV$

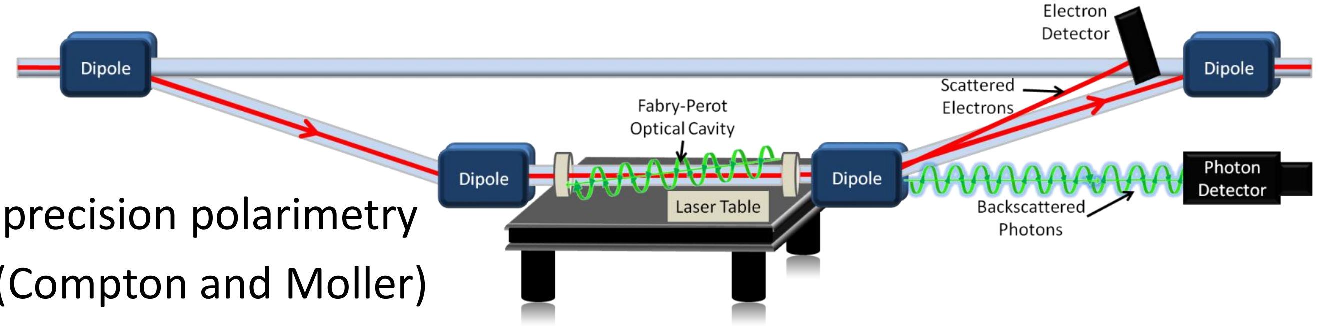


particle envelopes along beamline

Measuring A_{PV} with ES – *"step by step"*

unpolarized target

high current, highly polarized beam



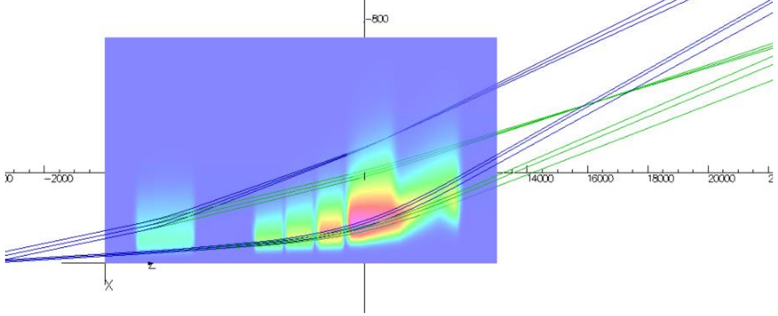
precision polarimetry

(Compton and Moller)

$$A_{PV} = \frac{A_{sig}}{P_{beam}}$$

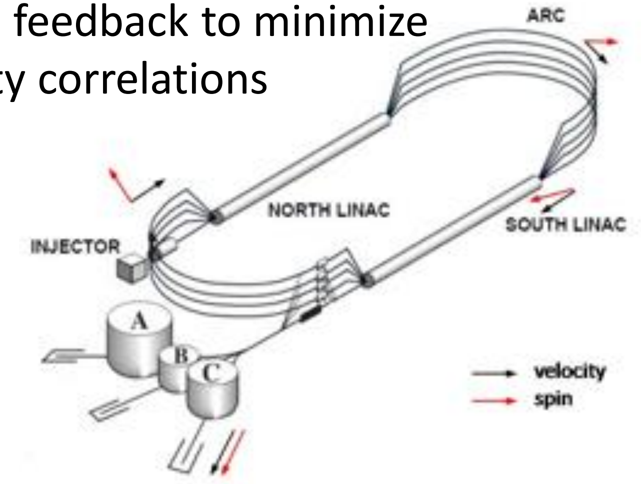
$$A_{sig} = \frac{A_{corr} - A_{back}\, f_{back}}{f_{sig}}$$

moller scattered electrons



beam property monitoring

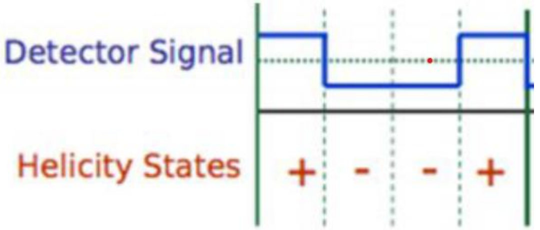
active feedback to minimize helicity correlations



$$A_{corr} = A_{meas} - \sum_{i=1}^{N} \frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

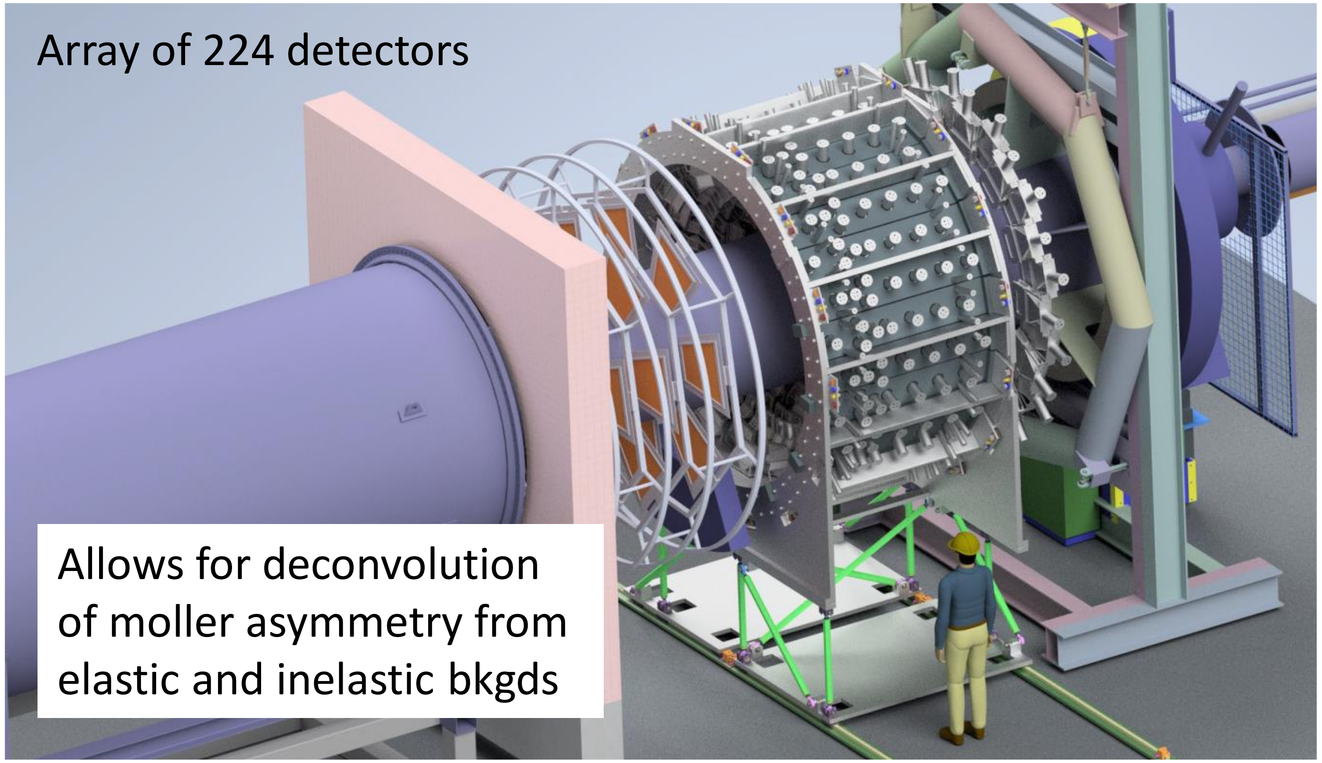
where $\Delta P_i = P_+ - P_-$

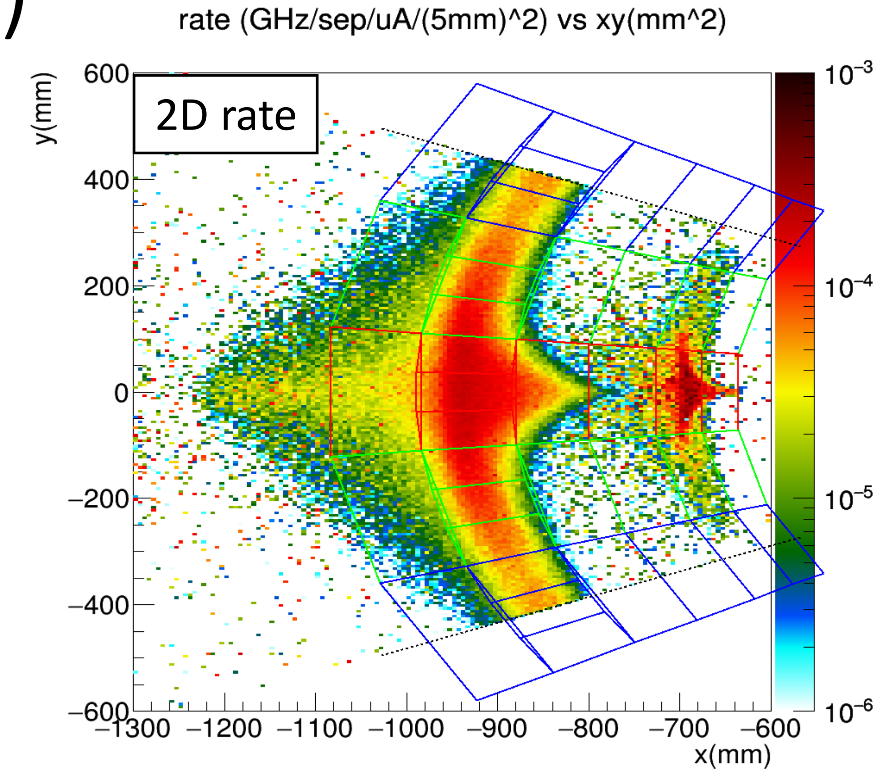
both slow and rapid helicity reversals

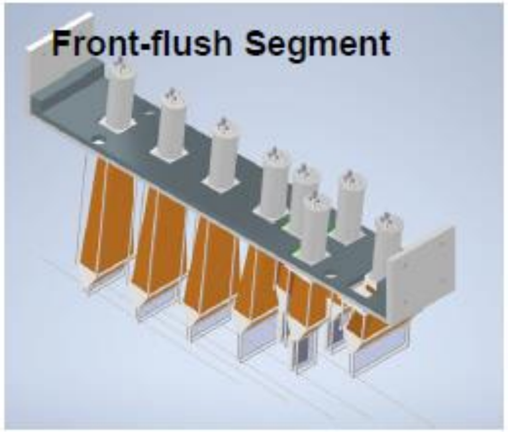


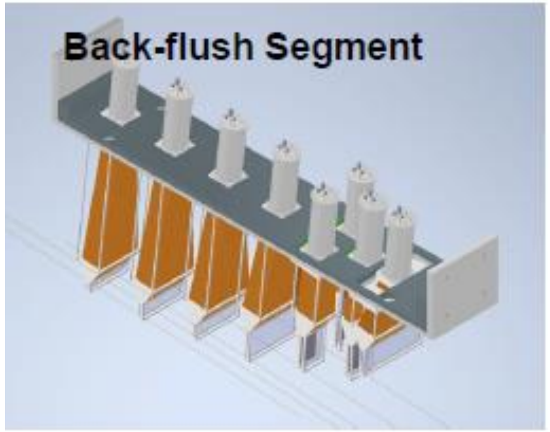
$$A_{meas} = \frac{Y_+ - Y_-}{Y_+ + Y_-}$$

Main detector array (CFI funded)





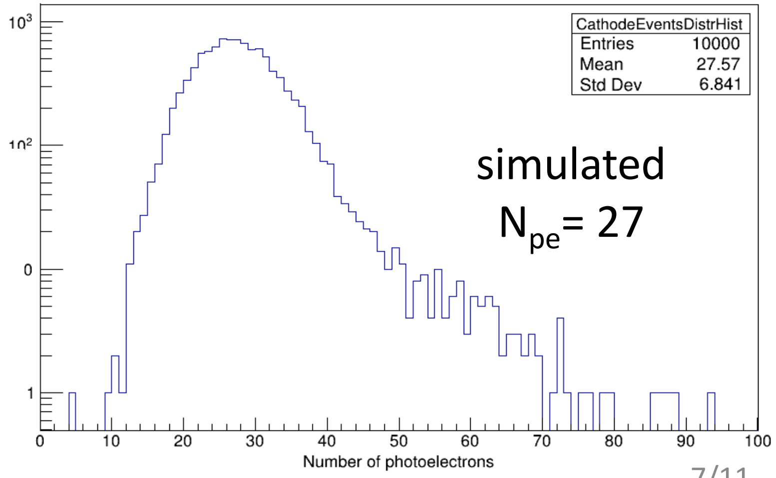




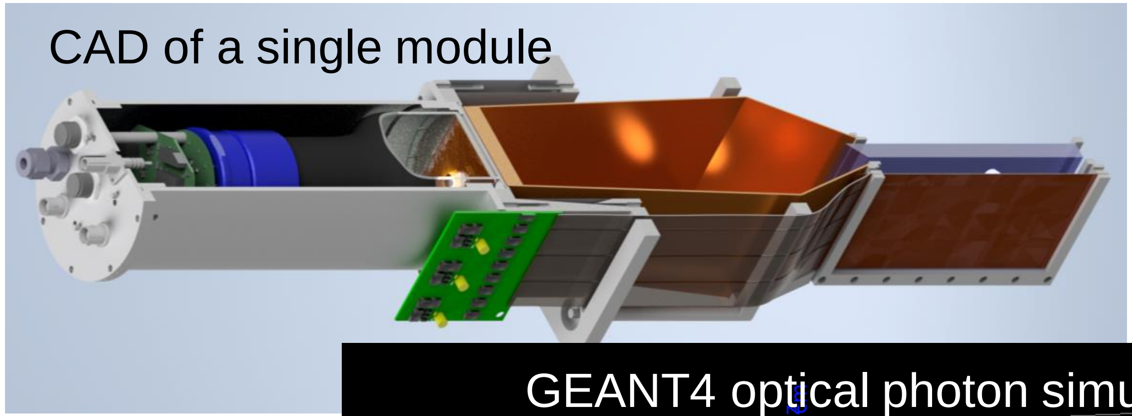
Assembled in segments

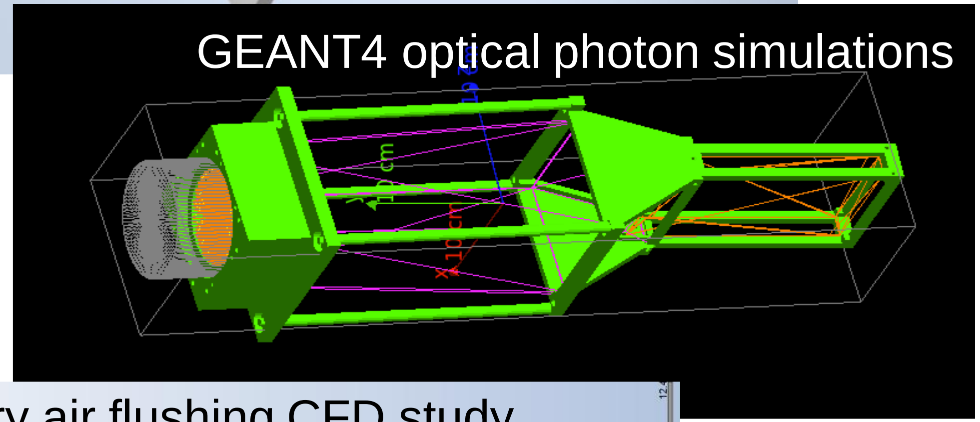
Red – "open"
Blue – closed
Green – transition

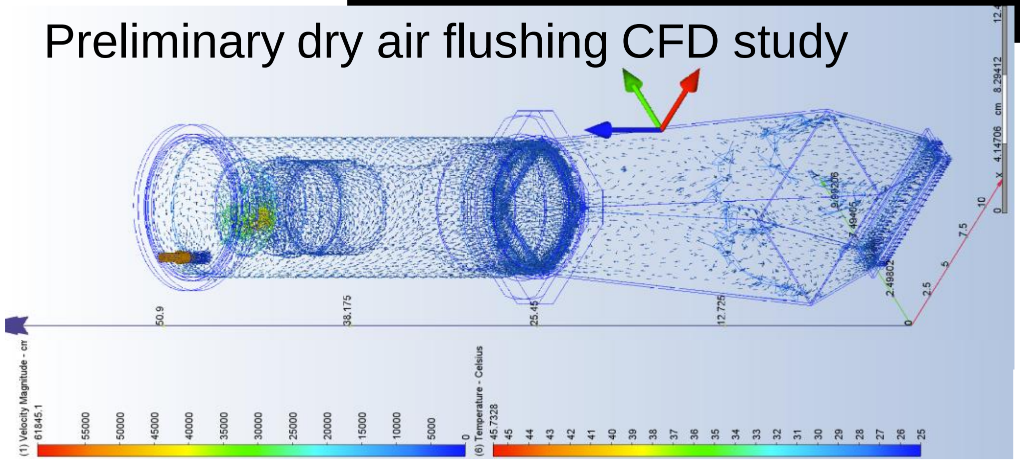
overlap azimuthally

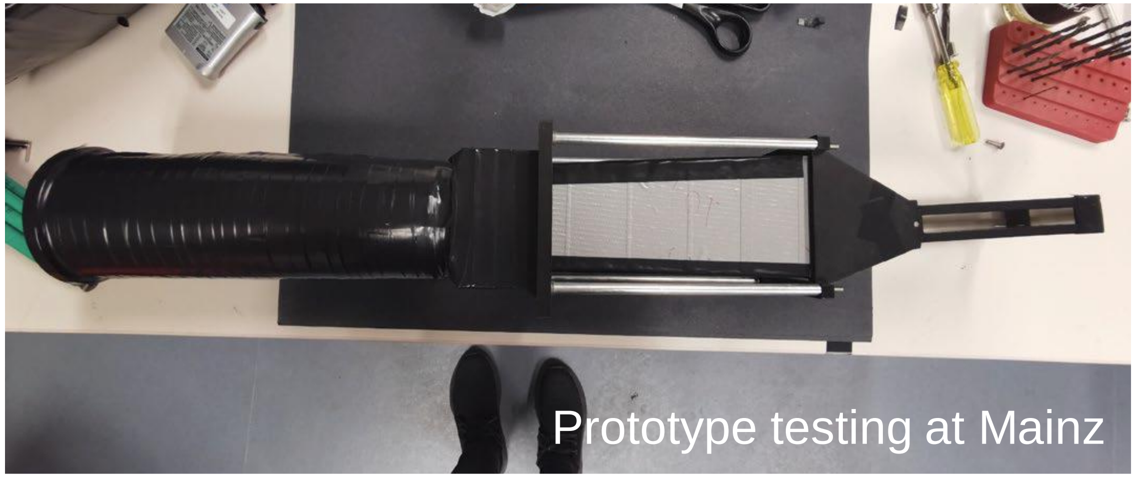


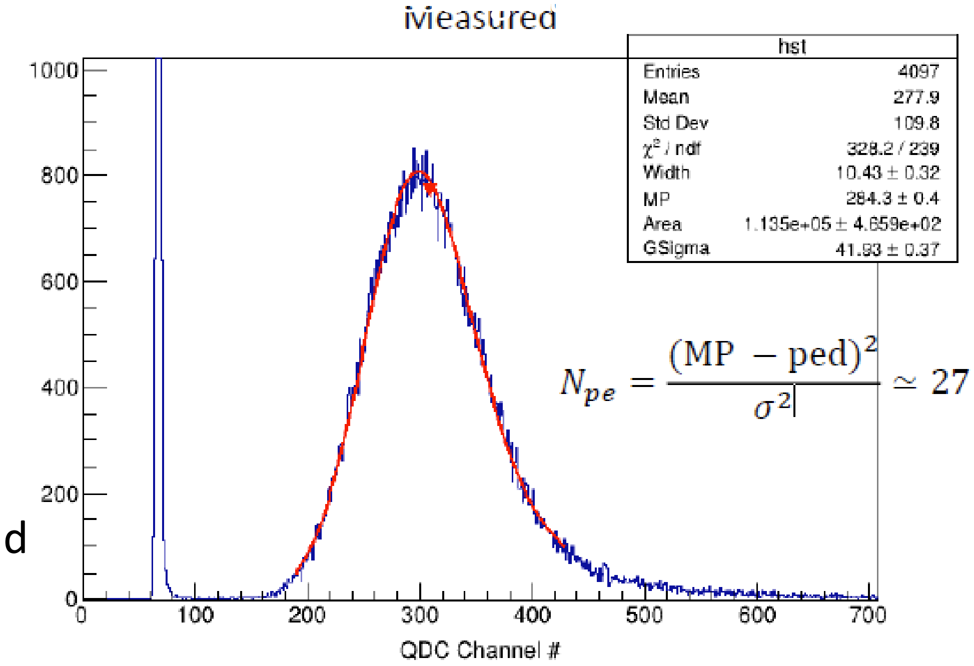
Detector prototyping











$$N_{pe} = \frac{(\mathrm{MP} - \mathrm{ped})^2}{\sigma^2} \simeq 27$$

Front-end electronics design is nearly final

PMT and preamp noise and bandwidth meet goals

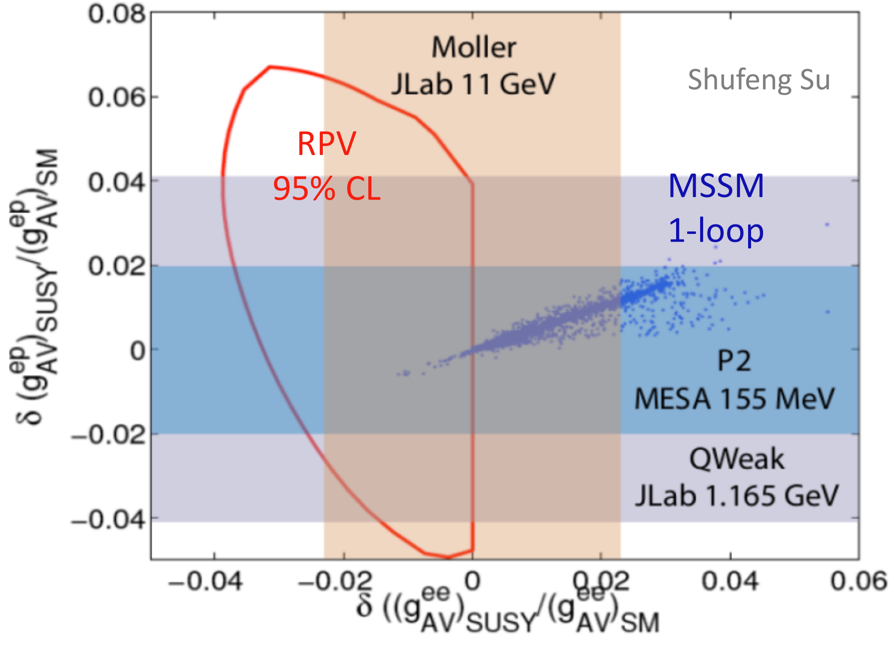
Precision provides physics reach

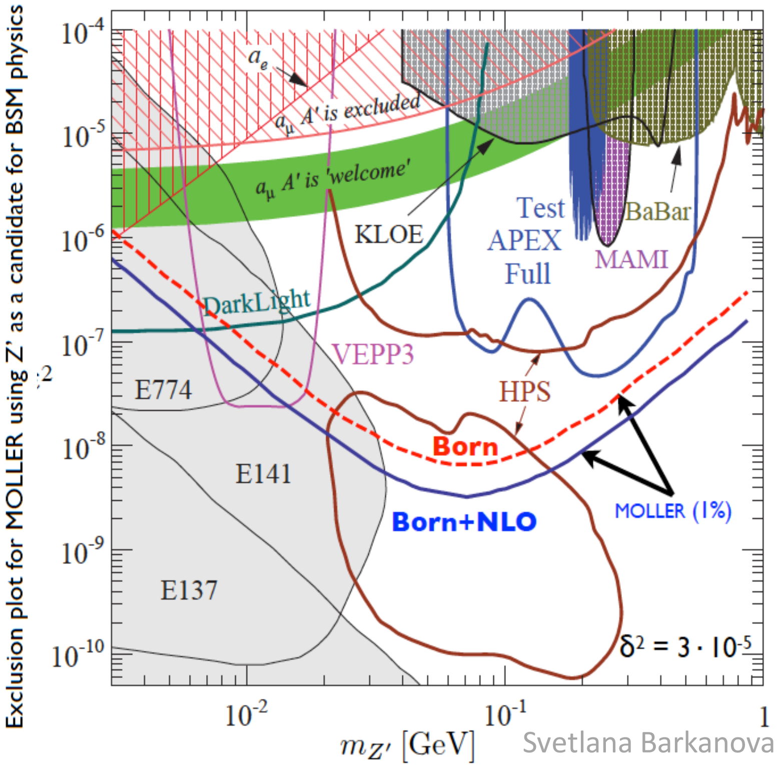
$$\frac{\delta \sin^2 \theta_W}{\sin^2 \theta_W} \simeq .05 \frac{\delta A_{PV}}{A_{PV}} \Rightarrow \quad \delta Q_W^e$$

$$= 2.3\%, \sim 5 \times \mathit{smaller\ than\ E158}$$

2.3% MOLLER uncertainty → mass reach $\mathbf{7.5}$ to $\mathbf{27\ TeV}$

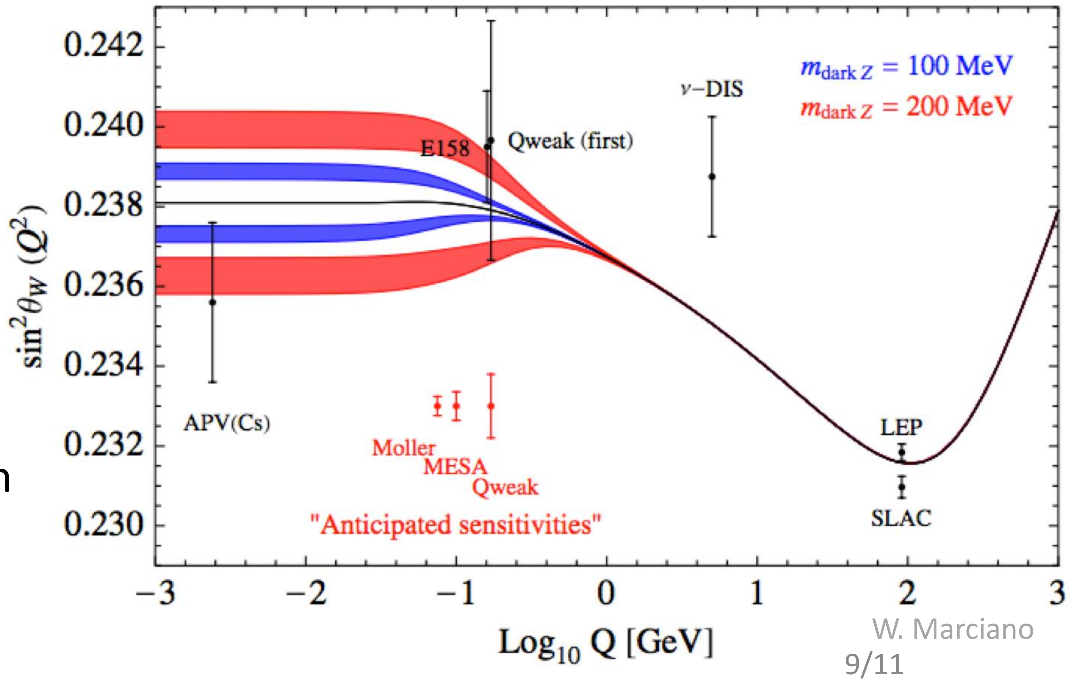
(depending on the model of new physics)



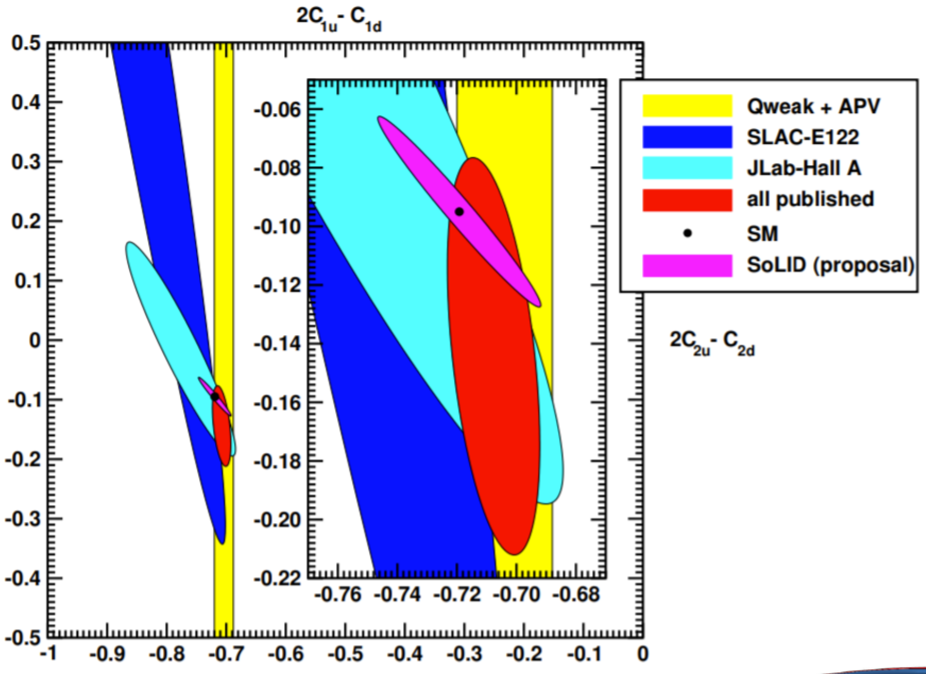


	95% conf. level
LEP200	$\Lambda_{LL}^{ee} \sim 8.3\ TeV$
E158	$\Lambda_{LL}^{ee} \sim 12\ TeV$
MOLLER	$\Lambda_{LL}^{ee} \sim 27\ TeV$

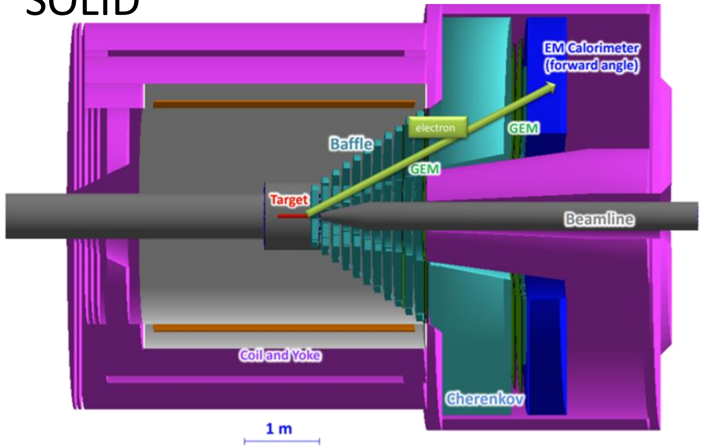
MOLLER is accessing discovery space that cannot be reached until the advent of a new lepton collider or neutrino factory

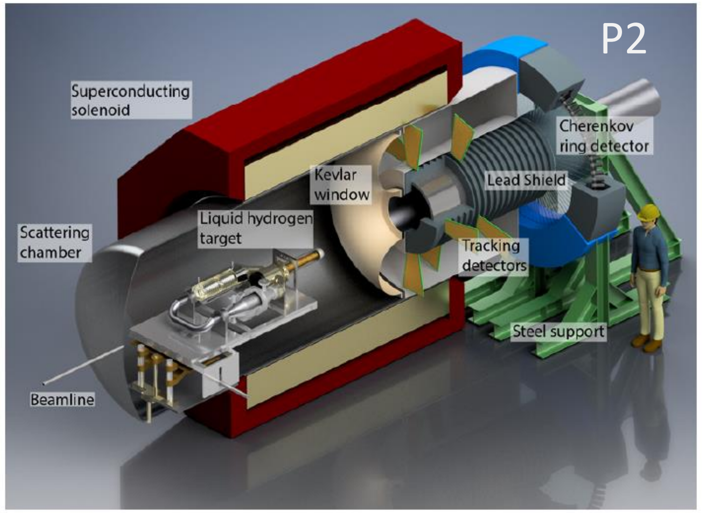


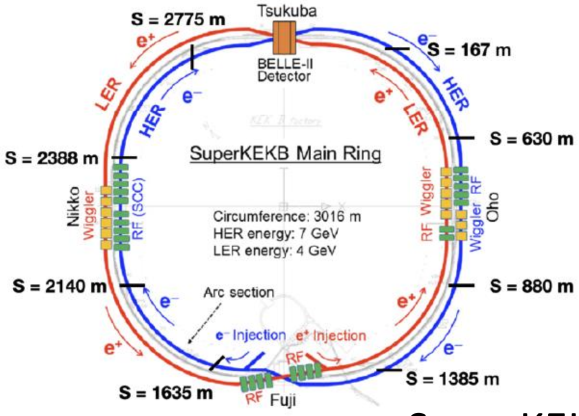
Future – couplings and SM Tests



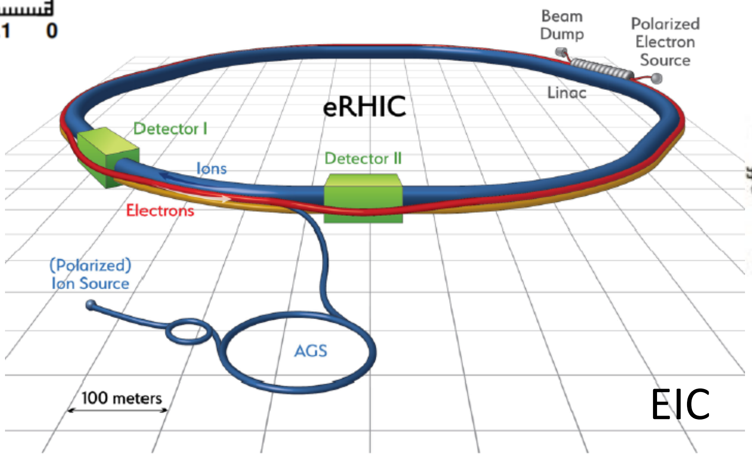
SOLID



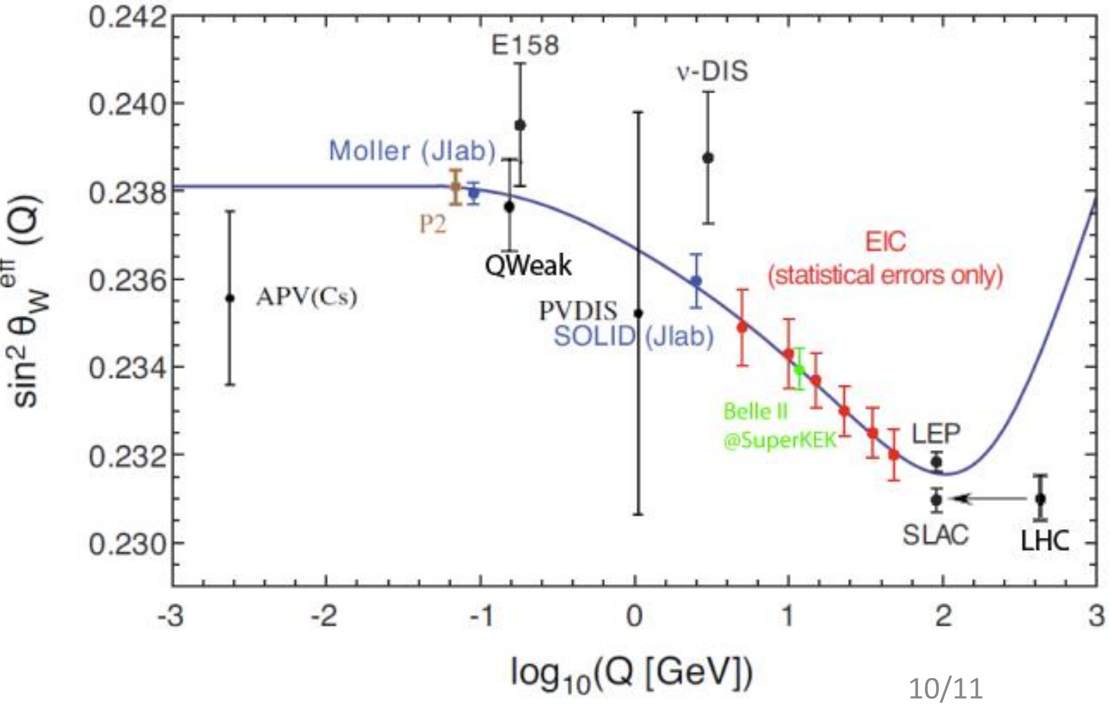




SuperKEKB



EIC



Summary

- MOLLER has about 140 collaborators from the US, Canada, Germany, Italy, France, and Mexico

- Obtained CD0 in 2017, CD1 in 2020
- Detector PDR January 2022
- Spectrometer PDR last Monday

} 60% design reviews

- TDR November 2022 – 90% design completion
- Planned CD2/3 Review in early 2023

- First physics in 2025

USD 65M Project (approximate breakdown)

6M NSF (partial In-Kind from here)
4M CFI ($2.4M CFI, $1.6M Research MB)
55M DOE (partial In-Kind from here)
TRIUMF (and others) support for electronics development

Current Canadian Group

9 faculty from U. Manitoba, U. Winnipeg, U. Memorial, UNBC
2 postdocs and 7 students

New U. Manitoba faculty member starts in July!