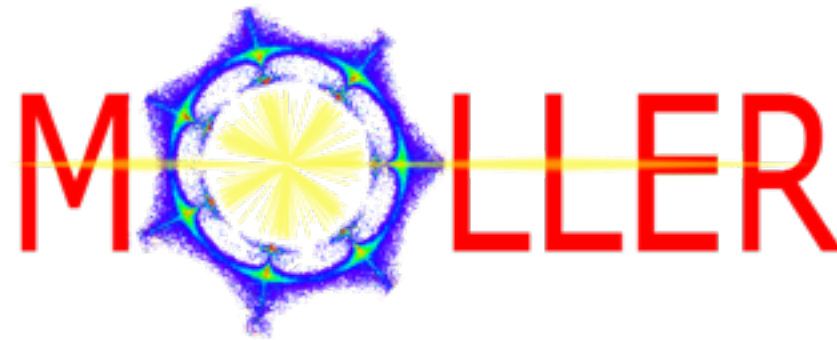


Measurement of Lepton-Lepton Electroweak Reaction



Status Report



Overview and Recent Activities

Krishna Kumar

Stony Brook University

Amherst Center for Fundamental Interactions &
the University of Massachusetts, Amherst

Hall A Collaboration Meeting, Jefferson Laboratory, January 31, 2019

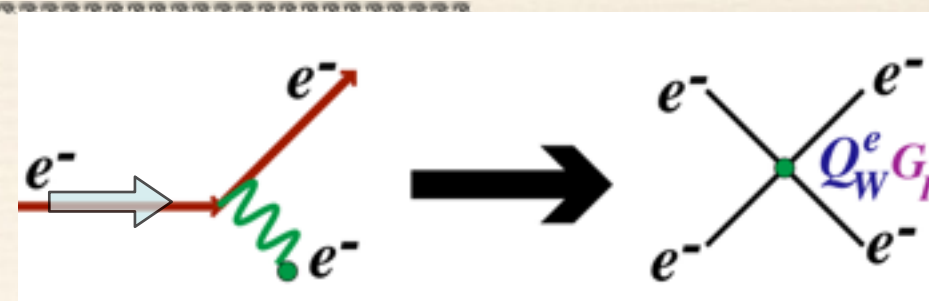
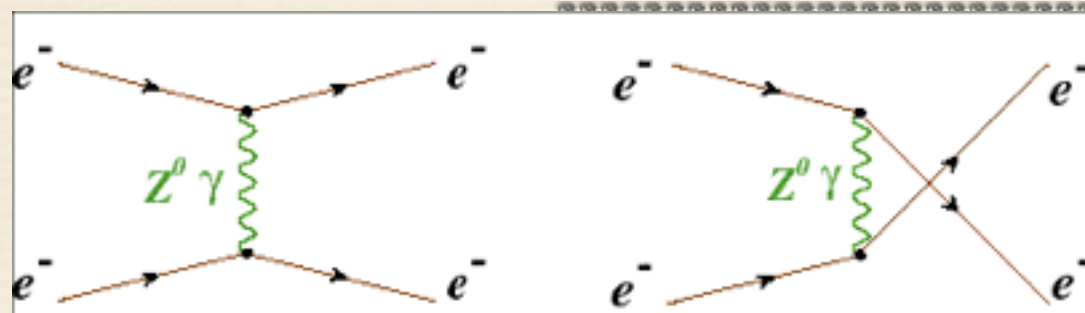


Outline

- ◆ **Physics Motivation and Experiment Goal**
- ◆ **MOLLER Chronology**
- ◆ **Some Details of Recent Activities**
 - ★ Review Outcomes
 - ★ Examples of Technical Progress
- ◆ **Towards a Construction Project**
 - ★ Ongoing activities
 - ★ Near-term Plans
- ◆ **Conclusions and Outlook**

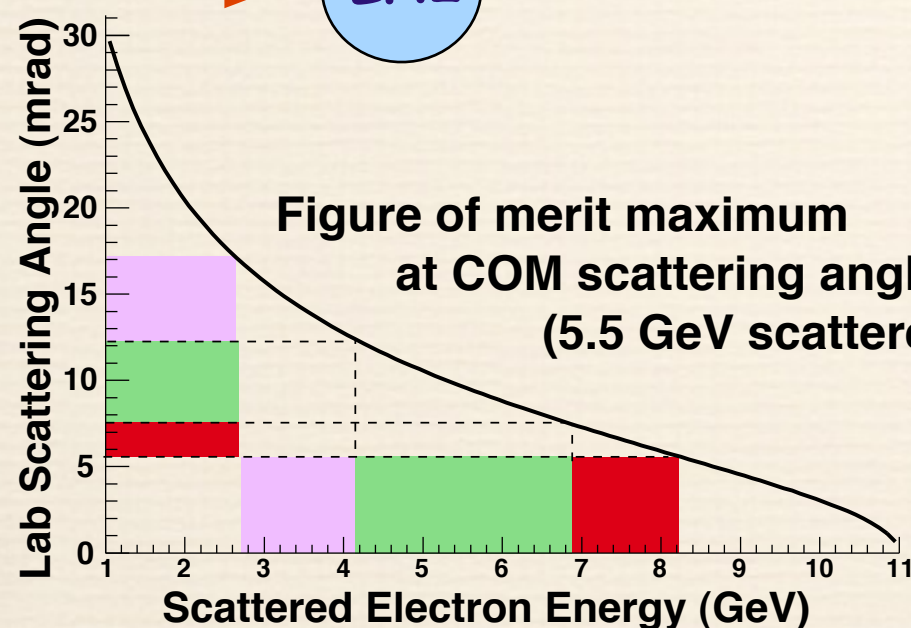
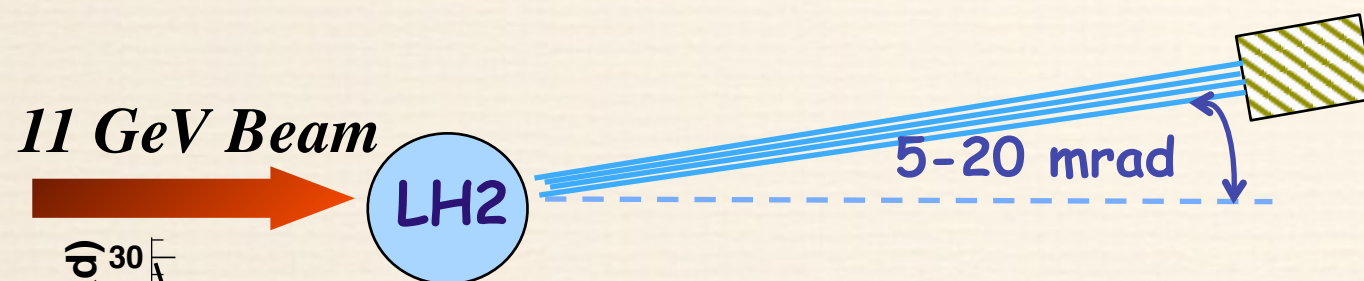
Measurement Goal

A_{PV} in Møller Scattering



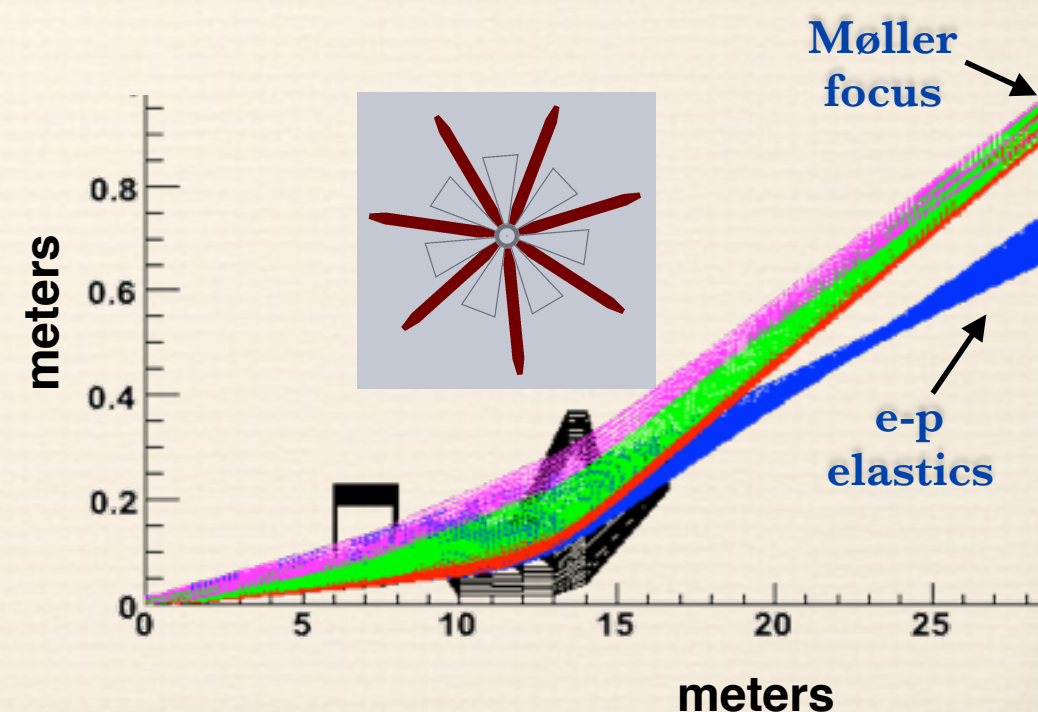
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16 \sin^2 \Theta}{(3 + \cos^2 \Theta)^2} Q_W^e$$

$$Q_W^e = 1 - 4 \sin^2 \theta_W \sim 0.075$$



measure 3 to 5.5 GeV OR 5.5 to 8 GeV

100% azimuthal acceptance:
3 to 8 GeV with an odd number of coils



Projected Uncertainty

$$A_{PV} = 35 \text{ ppb}$$

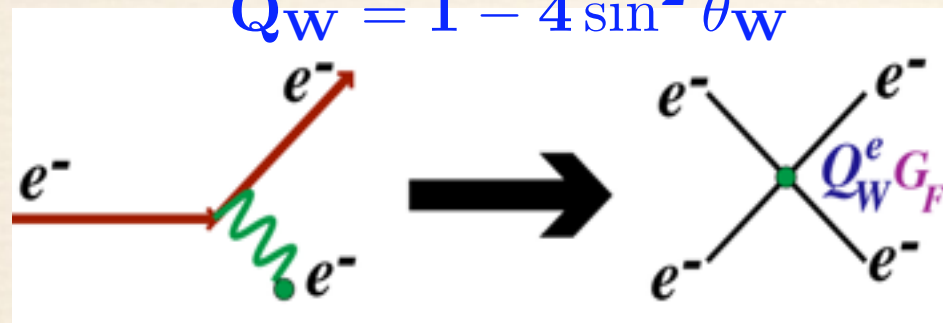
$$\delta(A_{PV}) = 0.74 \text{ parts per billion}$$

$$\text{Luminosity: } 3 \times 10^{39} \text{ /cm}^2/\text{s}$$

$$75 \mu\text{A} \quad 80\% \text{ polarized}$$

$$\delta(Q_W^e) = \pm 2.1 \% \text{ (stat.)} \pm 1.1 \% \text{ (syst.)}$$

$$\delta(\sin^2 \theta_W) = \pm 0.00023 \text{ (stat.)} \pm 0.00012 \text{ (syst.)} \longrightarrow \sim 0.1\%$$

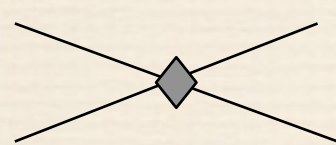
$$Q_W = 1 - 4 \sin^2 \theta_W$$


$$+ \text{New Physics}$$

$$\mathcal{L}_{e_1 e_2} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda^2} \bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma^\mu e_j \longrightarrow \frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = 7.5 \text{ TeV}$$

Carefully chosen low energy experiments complement direct searches

Comparison with Colliders

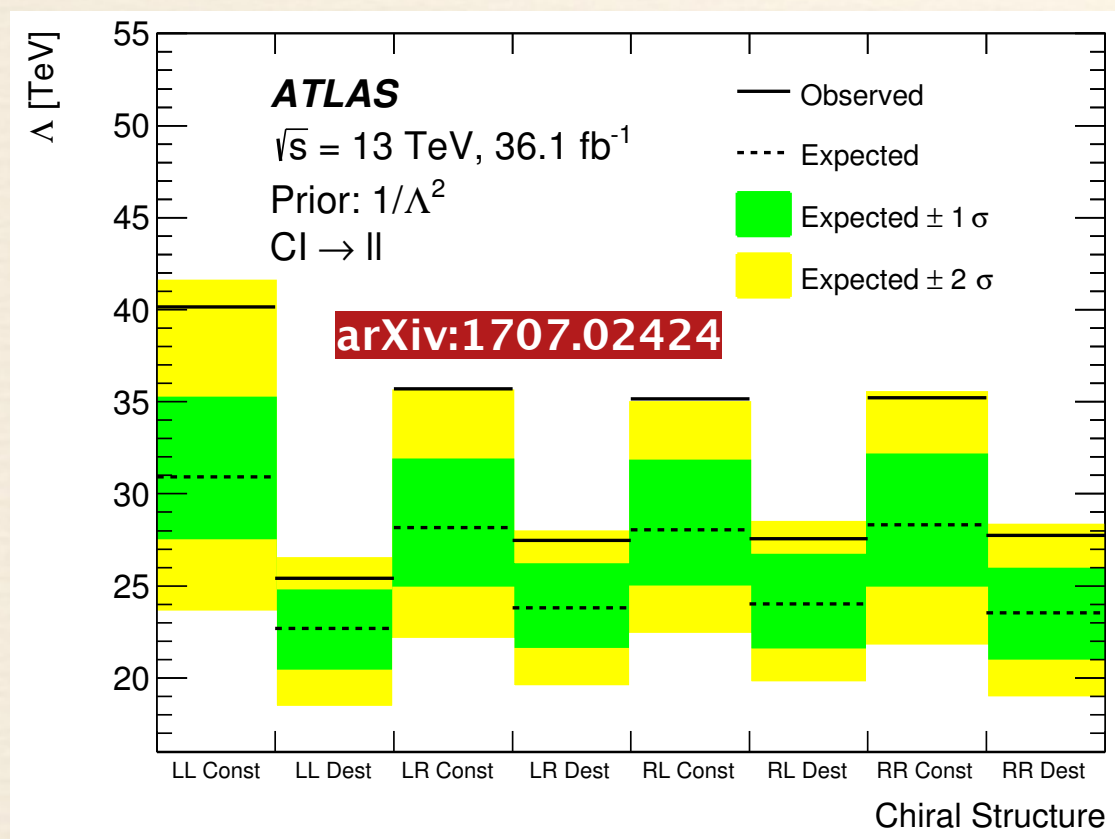


$$\frac{1}{\Lambda^2} \mathcal{L}_6$$

Lacking any direct evidence for new particles besides the Higgs, both colliders and fixed target experiments search for new physics by looking for deviations from Standard Model predictions

LHC searching for lepton-hadron interactions

LEP200: lepton-lepton interactions



e^+e^- Collisions

LEP200 Reach

$$\Lambda_{LL}^{ee} \sim 8.3 \text{ TeV}$$

Fixed Target

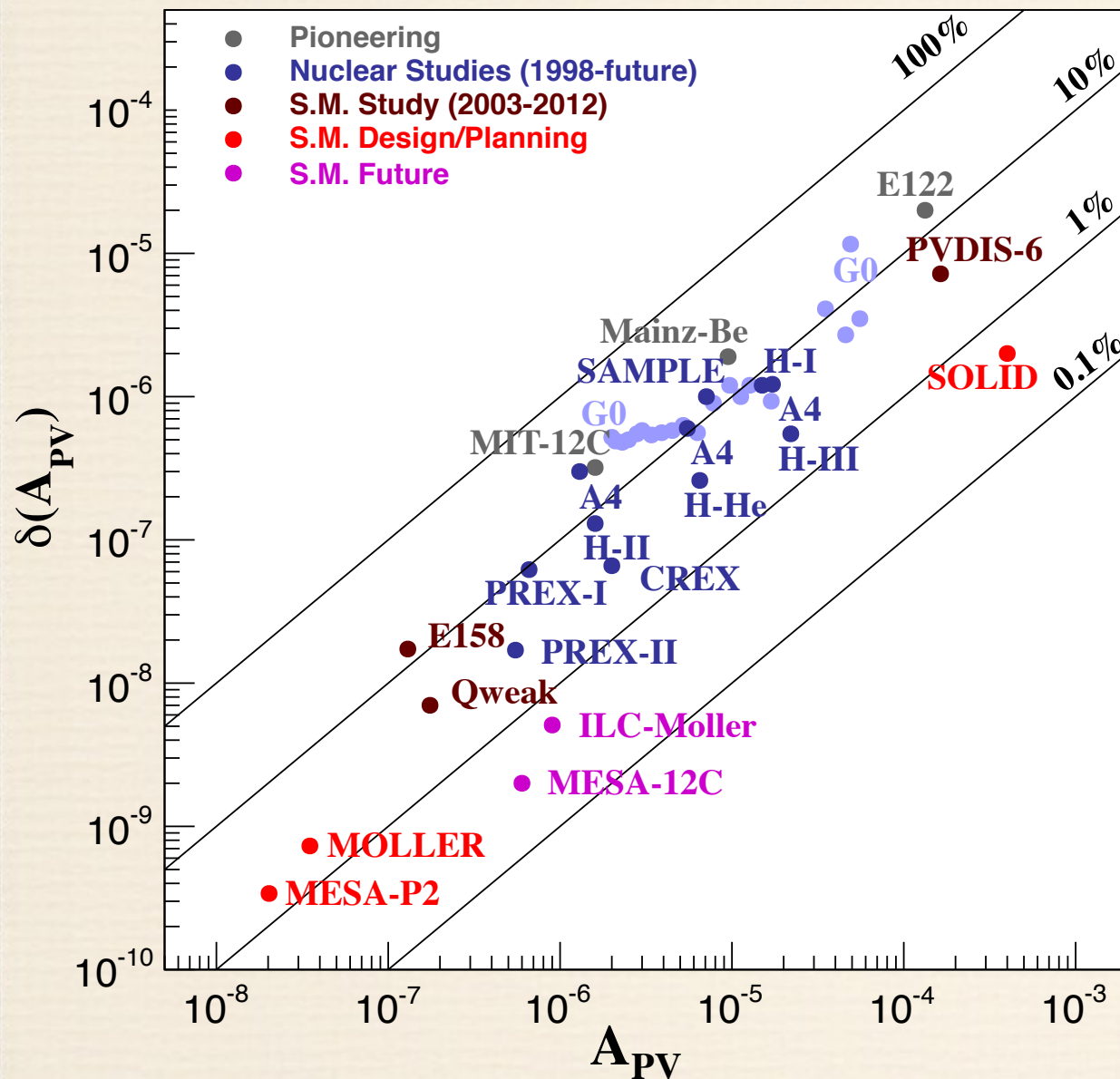
E158 Reach

$$\Lambda_{LL}^{ee} \sim 12 \text{ TeV}$$

MOLLER Reach $\Lambda_{LL}^{ee} \sim 27 \text{ TeV}$

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

4th Generation PVES at JLab

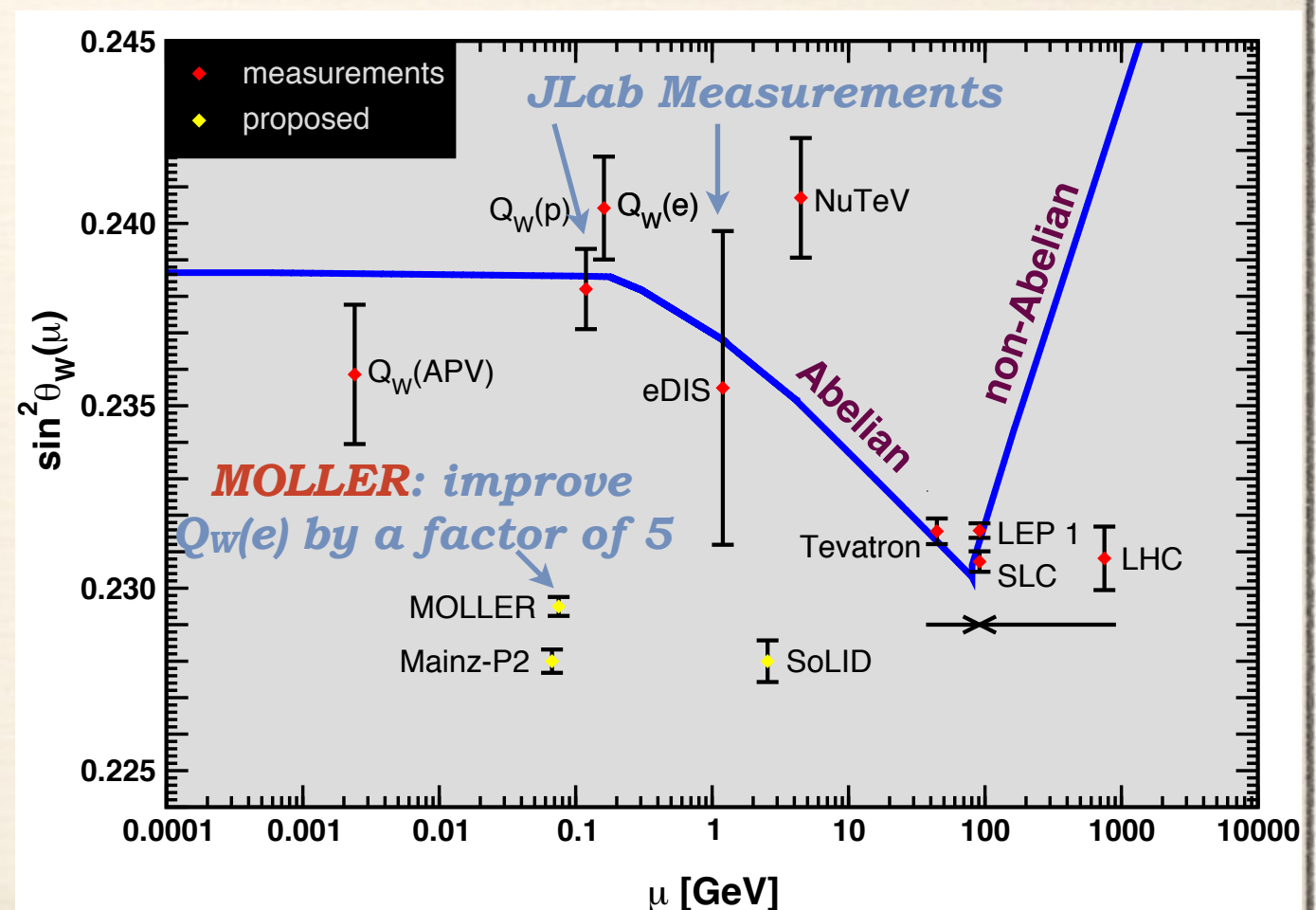


State of the Art

- sub-part per billion statistical reach and systematic control
- sub-1% normalization control

Variety of Physics Topics:
continuous interplay between
hadron physics and electroweak physics

*Steady improvements in accelerator
and detector technology*



MOLLER Chronology

MOLLER Evolution

◆ MOLLER 100% Acceptance Concept Conceived ~ 2007

★ JLab PAC approval in 2009

- *"...outstanding physics reach....", "...potential JLab flagship experiment..."*

★ JLab PAC Ranking and Beamtime allocation in 2011

- *enthusiastic endorsement, "...flagship...", full request (344 PAC days) allocated*

◆ First Director's Review took place in January 2010

★ C. Prescott, chair, members: Doug Beck, David Hertzog, Bob Kephart, Bill Marciano, Matt Poelker, Michael Schmitt, Glenn Young, John Weisend

- *strongly endorsed physics case and commended experimental team and approach*
- *series of recommendations helpful as a blueprint for pre-conceptual design development*

◆ Pre-Conceptual Design and Pre-R&D phase since 2010

◆ Support since 2012 from DOE NP MEP Research, JLab and NSF

◆ Consistent Community Endorsement

★ Tribble Subcommittee Report in 2012 (LRP Implementation)

★ DOE NP Science Review in September 2014; report issued July 2015

★ 2015 Long Range Plan Document

2014 MOLLER Review

◆ Science Review run by DOE NP Office

- ★ September 2014 at UMass, Amherst, Chair: Tim Hallman
- ★ Members: W. Donnelly, D. Hertzog, C. Horowitz, Z-T. Lu, M. Perelstein, T. Rizzo

◆ Theoretical Uncertainty

- ★ Report submitted to DOE on September 15, 2016

◆ Background Analysis

- ★ Report submitted to DOE on December 2, 2015

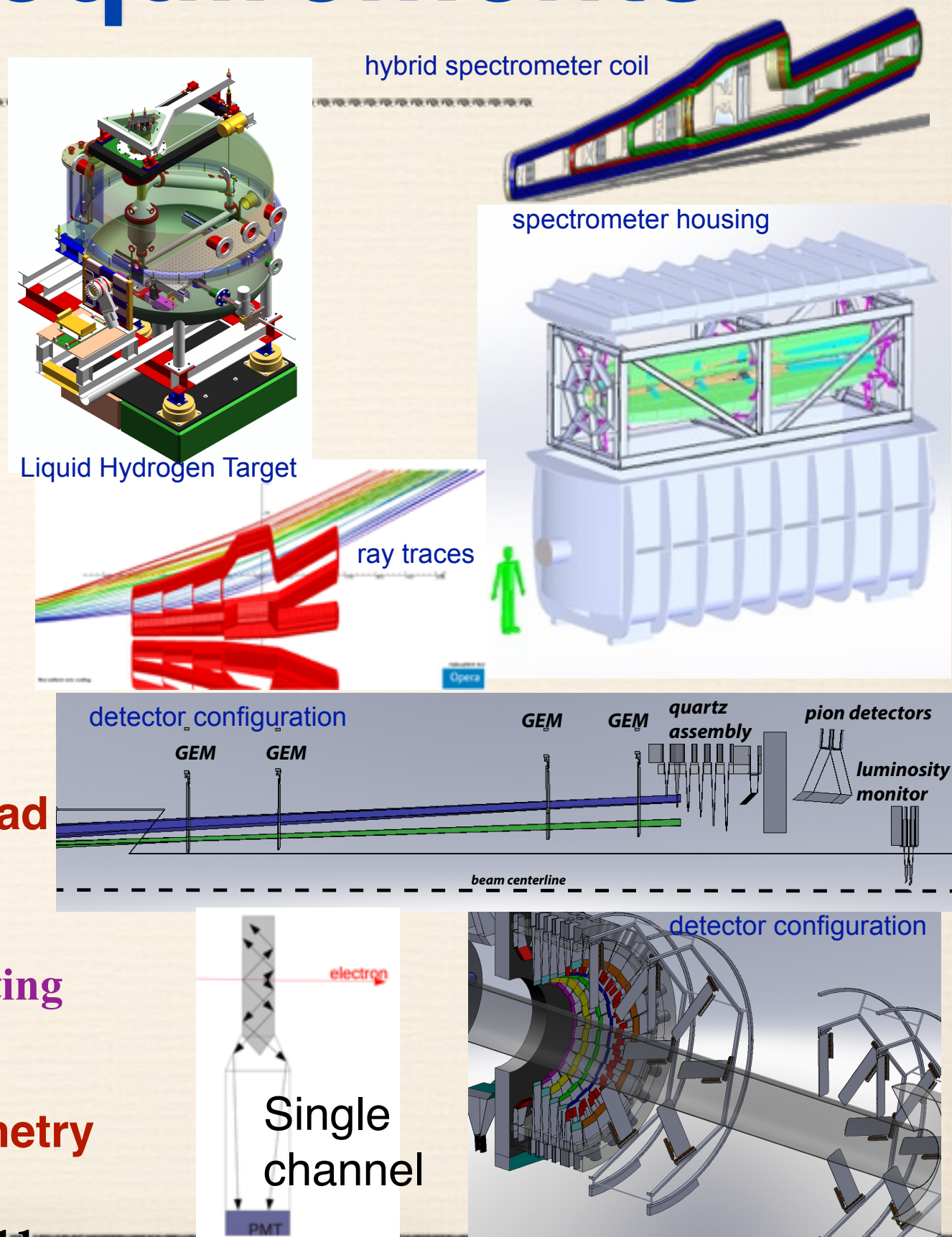
◆ Technical Feasibility

- ★ Review report emphasized importance of achieving proposed statistical and systematic uncertainties: no technical showstoppers identified; Pre-R&D tasks have addressed high risk items

Technical Requirements

Evolutionary Improvements from Technology of Third Generation Experiments

- ~ 150 GHz scattered electron rate
- 1 nm control of beam centroid on target
- > 10 gm/cm² liquid hydrogen target
 - 1.5 m: ~ 5 kW @ 85 μ A
- Full Azimuthal acceptance w/ $\theta_{\text{lab}} \sim 5$ mrad
 - novel toroidal spectrometer assemblies
 - radiation hard, highly segmented integrating detectors
- Robust & Redundant 0.4% beam polarimetry



Pre-Conceptual Design: Examples of Progress

◆ **Liquid Hydrogen Target**

- ★ QWeak performance: conservative extrapolation to MOLLER requirements

◆ **Spectrometer/Collimation Concept**

- ★ Successful SLAC E158 and JLab Qweak designs pave the way
- ★ Novel toroid concept vetted and deemed feasible by outside experts
- ★ Hybrid coil prototype tests validate a number of assumptions

◆ **Concept for a Comprehensive Detector Package**

- ★ Successful test beam results validate novel integrating detector designs
- ★ Report articulates analysis for control of all physics backgrounds

◆ **Polarimetry**

- ★ Excellent Qweak/PREX-I performance and successful 11 GeV beam tests

◆ **Polarized Beam**

- ★ Qweak, PREX performance met challenging requirements
- ★ 12 GeV beam parasitic measurements reveal no showstoppers

Recent Activities

Dec. 2016 Director's Review

◆ Committee: Physics, Technical and Project experts

- ★ Chair: Doug Beck, Other Members: V. Cirigliano, W. Edwards, P. Ghoshal, X. Guo, M. Jones, C. Keith, C-Y. Liu, D. Mack, S. Prestemon, E. Sichtermann, W. Wisniewski

◆ Intensive 1.5 Days

- ★ Plenary and breakout sessions vetted subsystems, scrutinized progress in demonstrating technical feasibility and reviewed preliminary cost range

◆ Quotes from Committee Report: Overview Section

- ★ “Scientific case as strong as ever...”
- ★ “...noteworthy progress in virtually all areas...”, “...ready to move to next stage...”
- ★ “...encouraged by small Qweak beam asymmetries...”
- ★ “...notable agreement at 0.7% between two Hall C polarimeters...”
- ★ “...outstanding understanding of high power liquid hydrogen targets...”
- ★ “...spectrometer has progressed substantially...”
- ★ “...focal region has a range of detectors... critical to experiment success...”, “...outstanding report on analysis of backgrounds...”

Response to Director's Review

◆ 2016 Director's Review Recommendations

- ★ Technical: Collaboration actively working on these
- ★ Project: teamed with JLab staff for pre-project planning

◆ Task List Developed

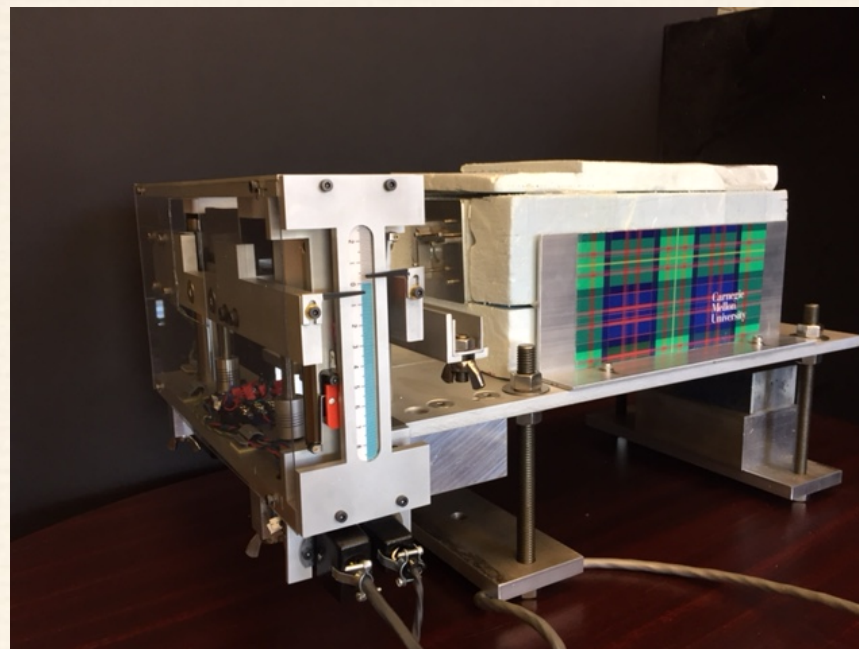
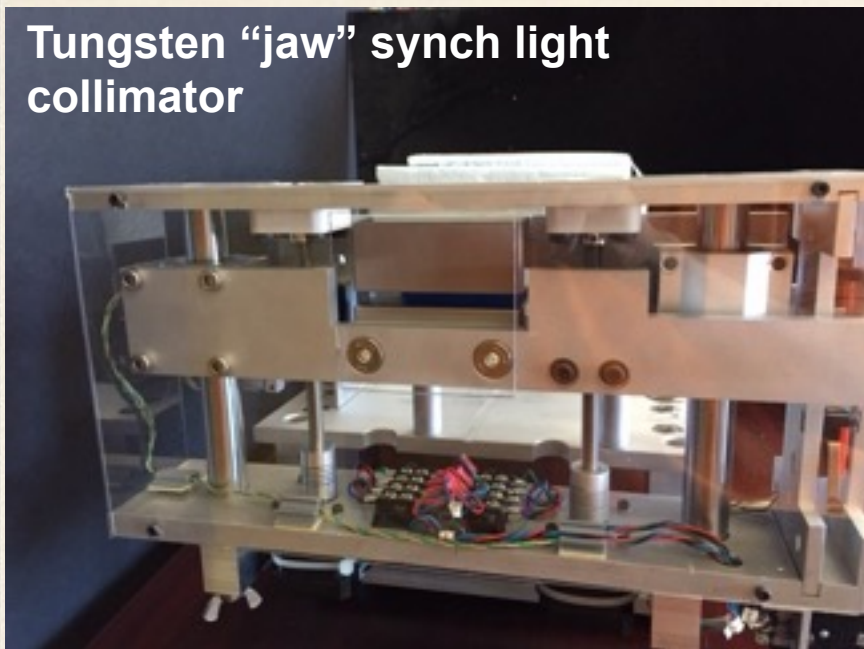
- ★ Started with technical recommendations from review
- ★ Collaboration and JLab management added a few more
- ★ Responsibilities assigned and progress tracked

Project stage	Number of tasks
Between CD0 and CD1	10
Post CD1 approval	30
Post CD2 approval	10

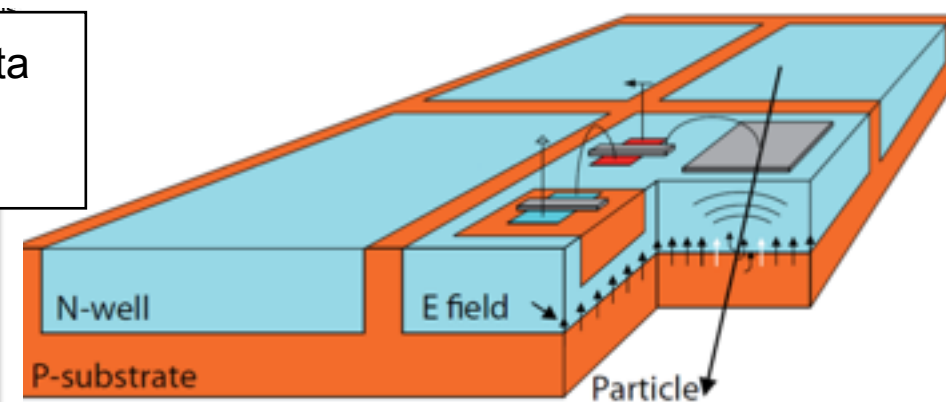
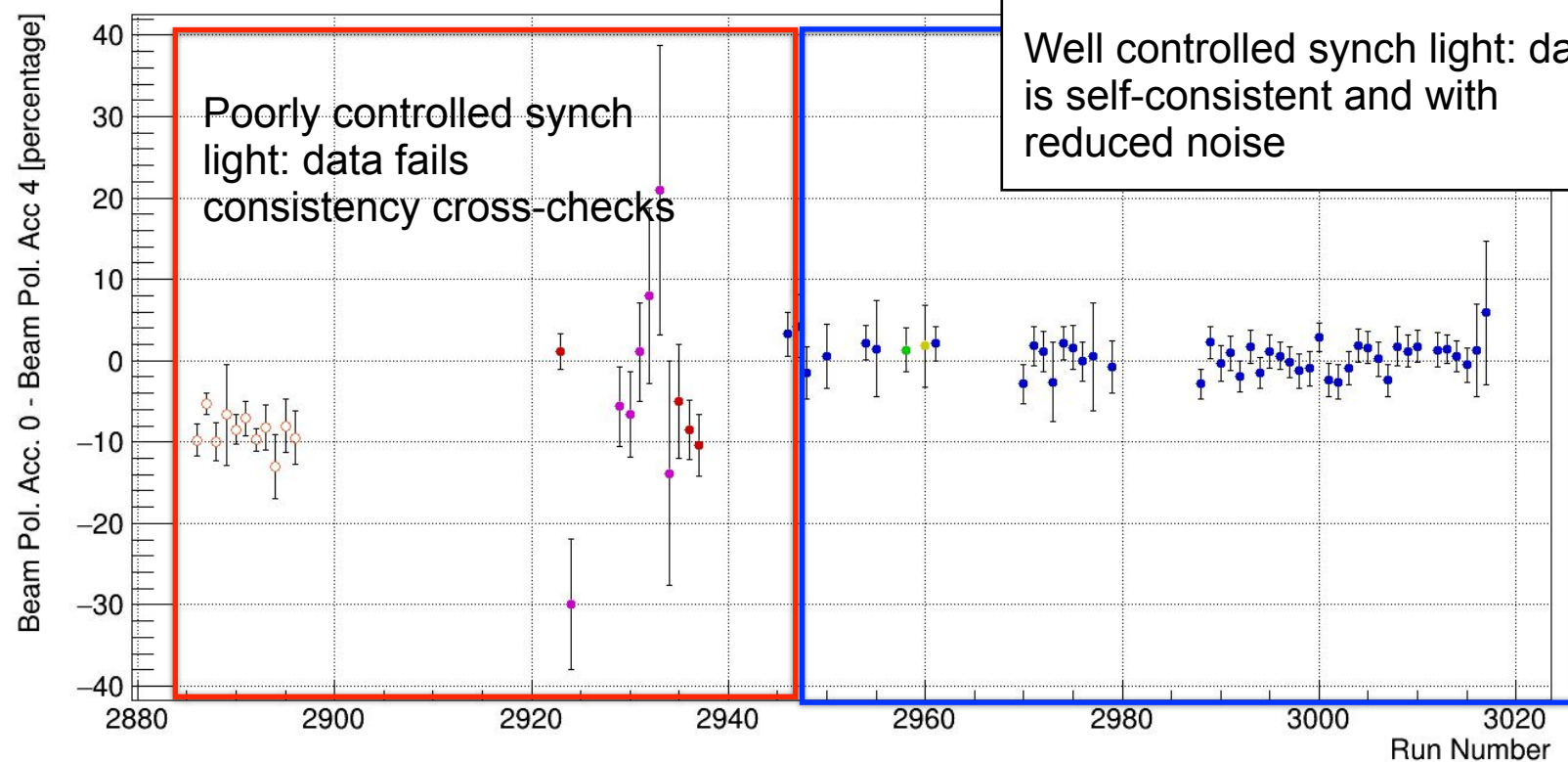
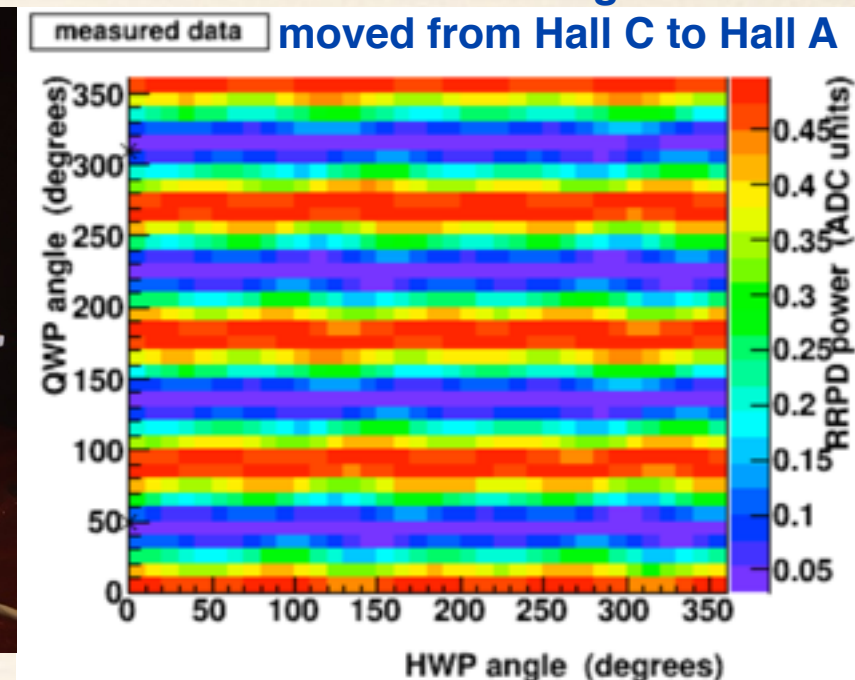
Compton Polarimetry

MOLLER requires high precision polarimetry at 11 GeV

Tungsten “jaw” synch light collimator



Polarization diagnostic moved from Hall C to Hall A



New electron detector options being investigated



Polarized Source

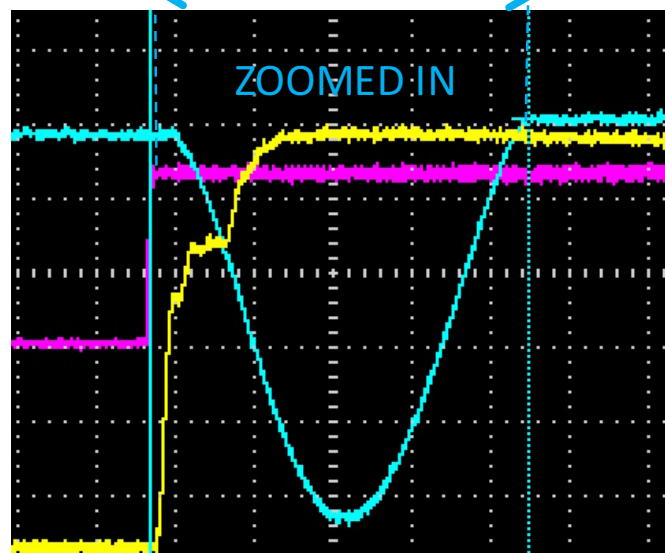
Fast helicity flips, small beam asymmetries



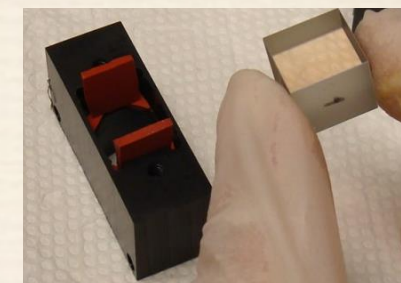
RTP Cell Mechanical Holding Structure

RTP Cell

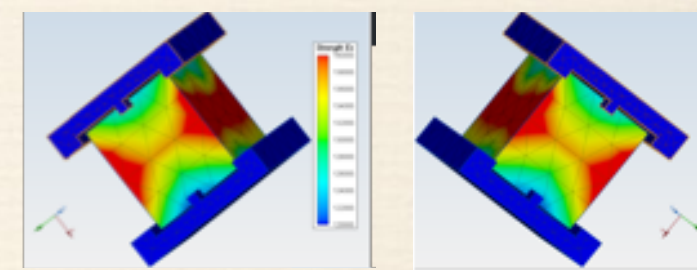
transition $\sim 12\mu s$



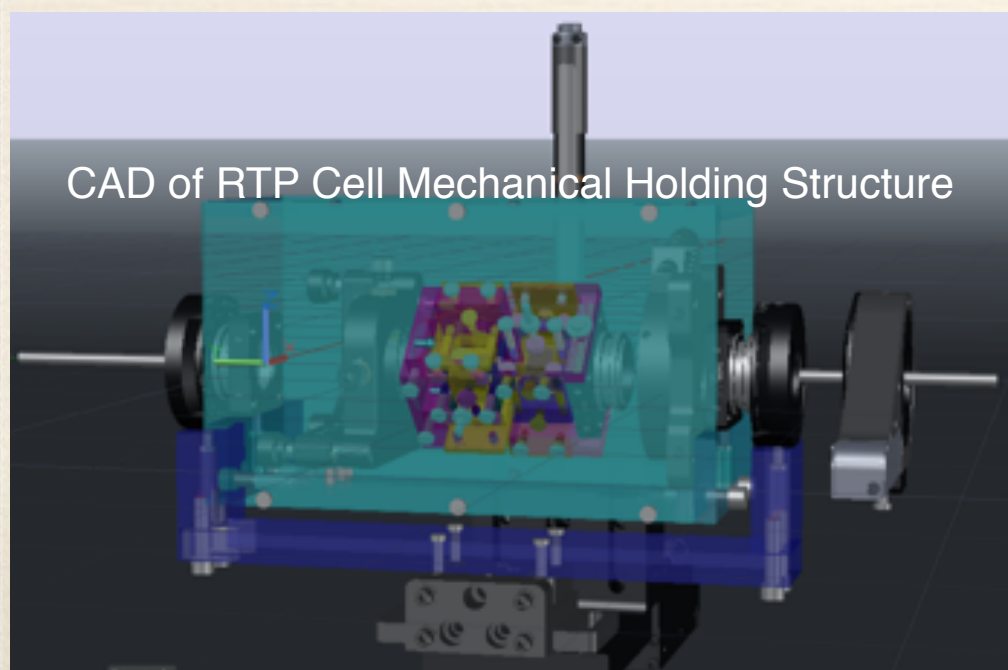
One of two bare RTP cells



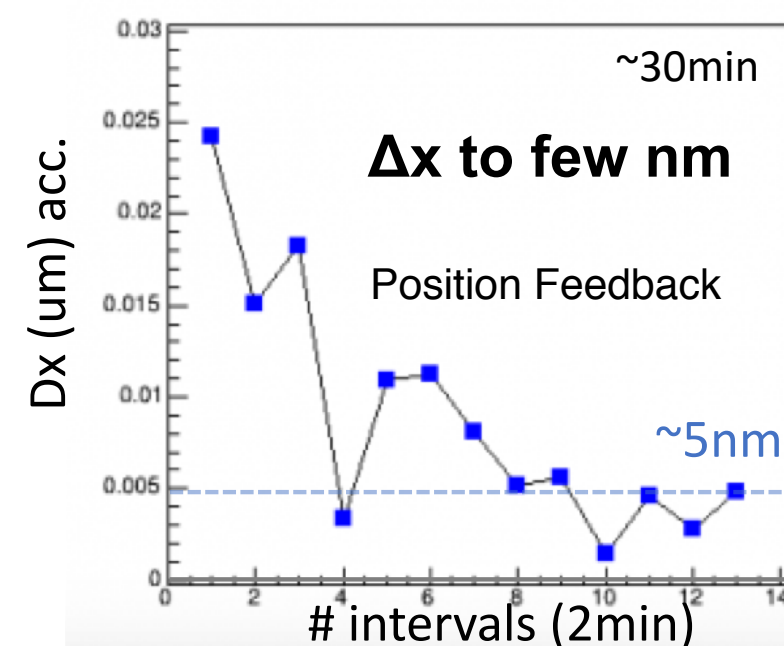
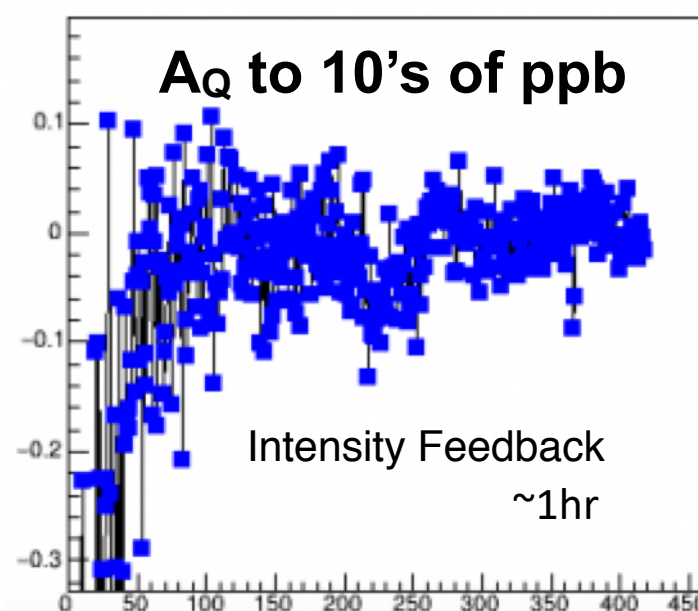
Electric Field Simulation



Encouraging test beam data supports installation during PREX-II

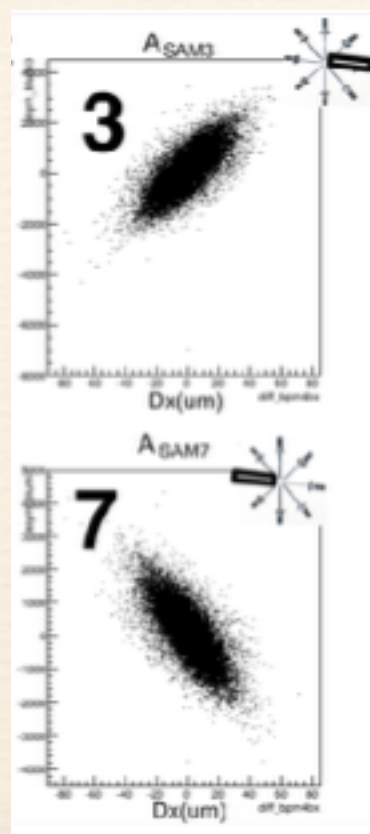
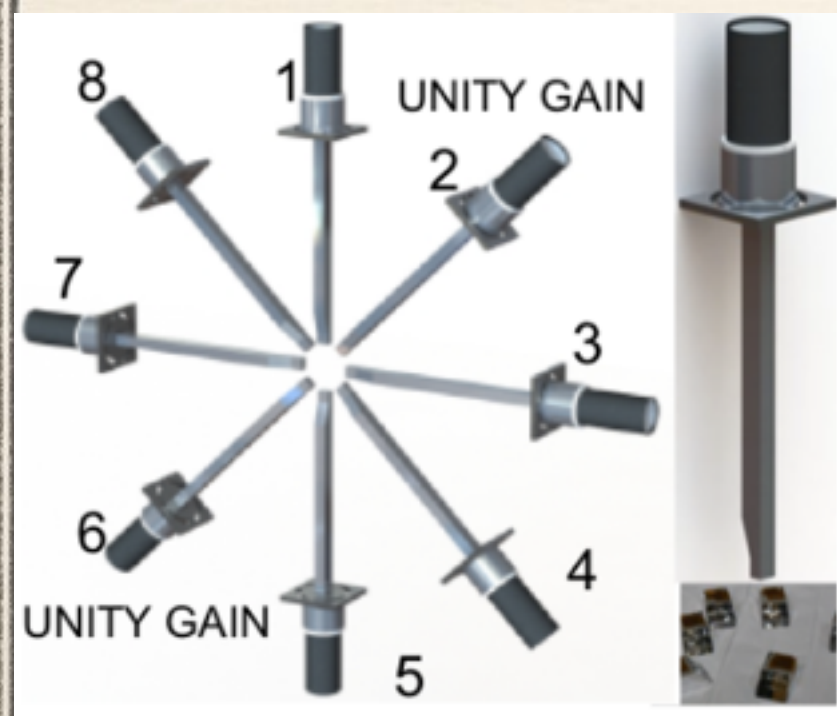
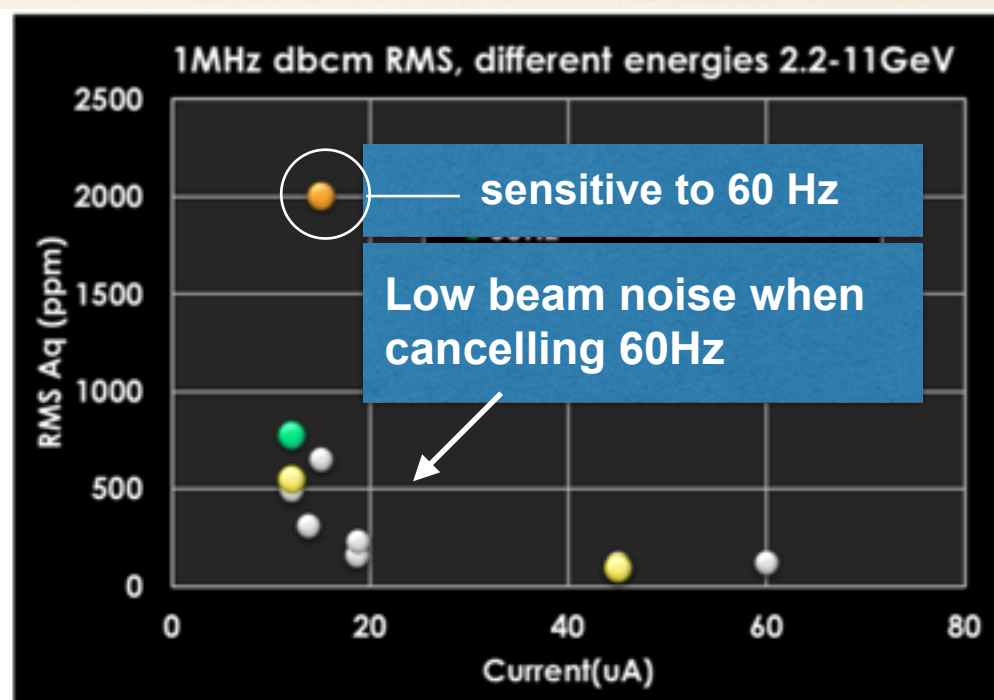
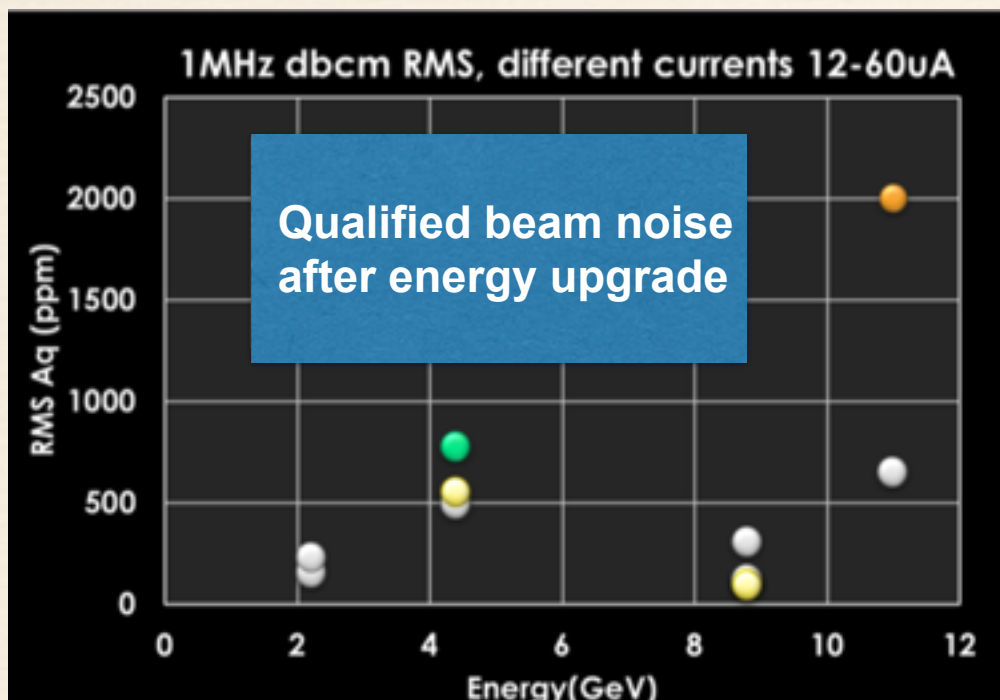


CAD of RTP Cell Mechanical Holding Structure

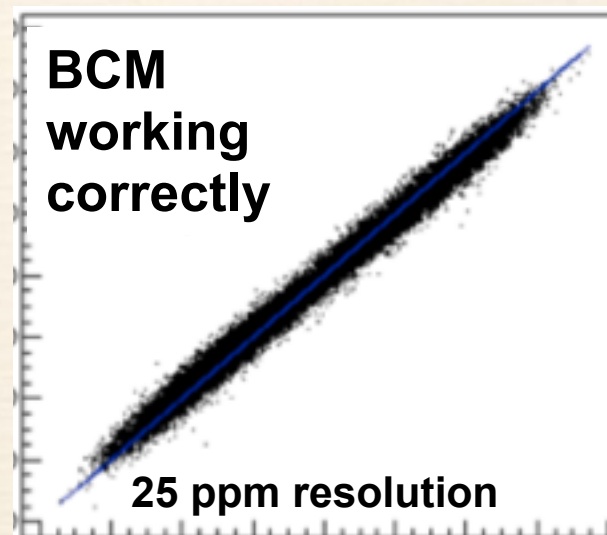


11 GeV Beam Measurements

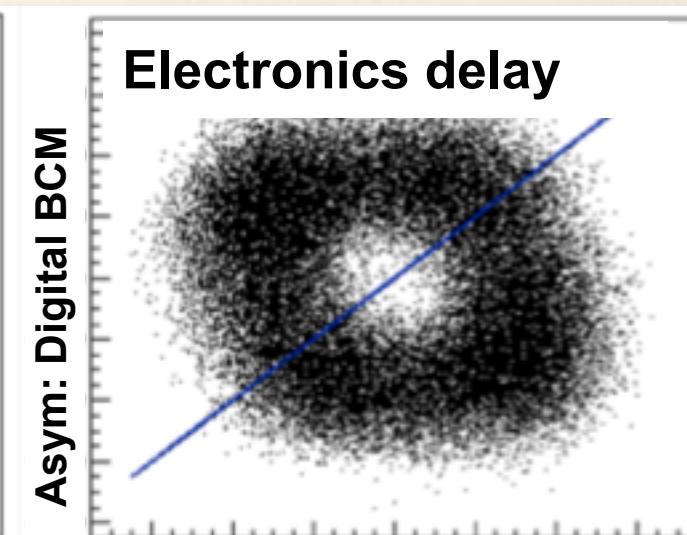
Beam studies after energy upgrade demonstrate beam properties, test beam monitors



Asym: Analog BCM



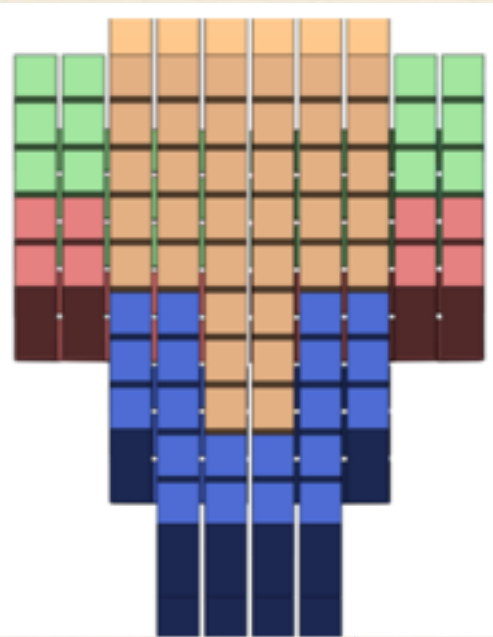
Asym: Small Angle Monitor



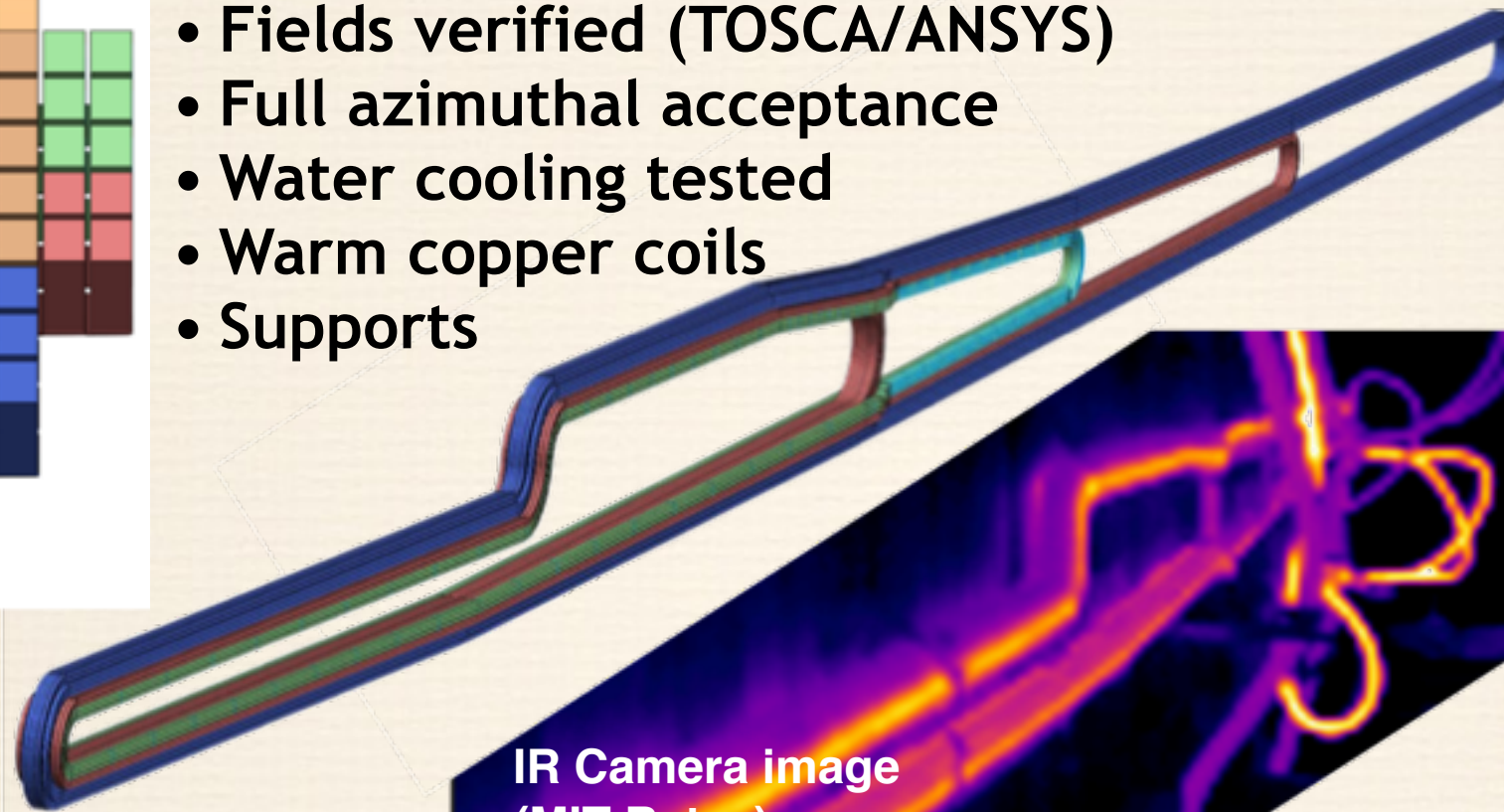
Asym: Small Angle Monitor

Spectrometer Concept

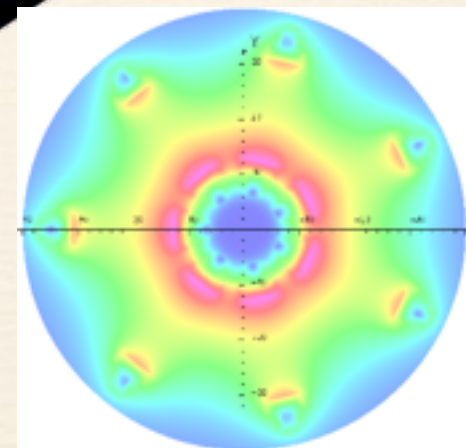
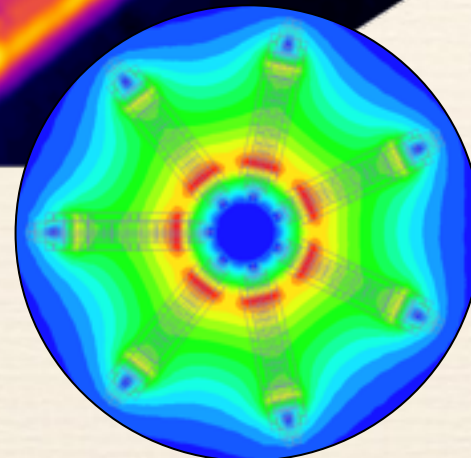
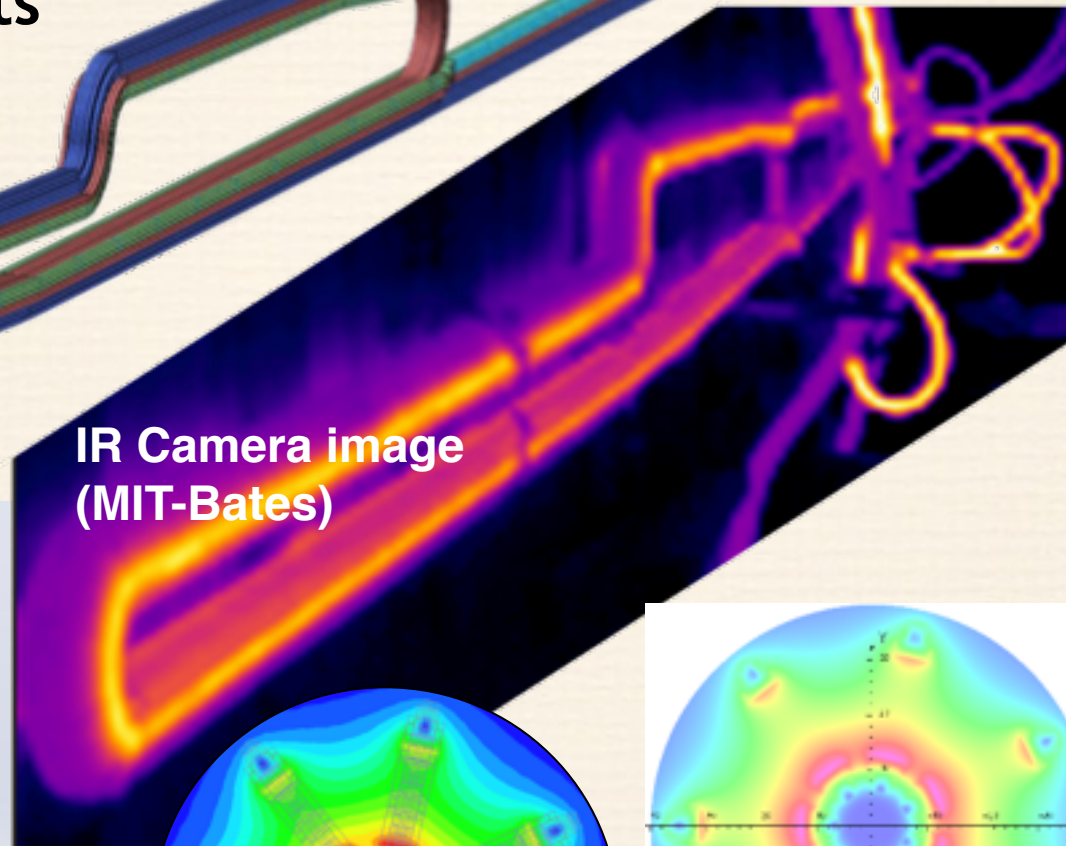
Funding from DOE NP MEP Research, Canada



- Fields verified (TOSCA/ANSYS)
- Full azimuthal acceptance
- Water cooling tested
- Warm copper coils
- Supports

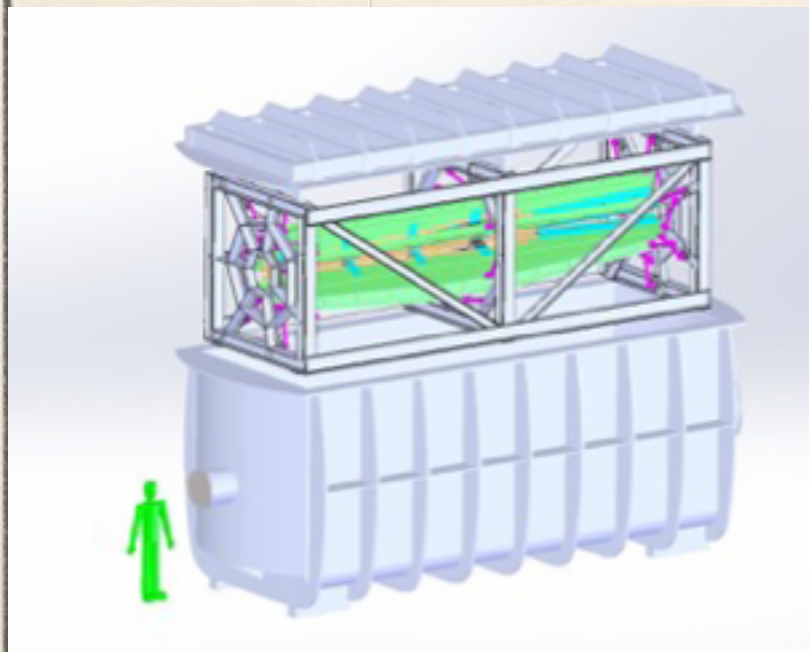


IR Camera image
(MIT-Bates)



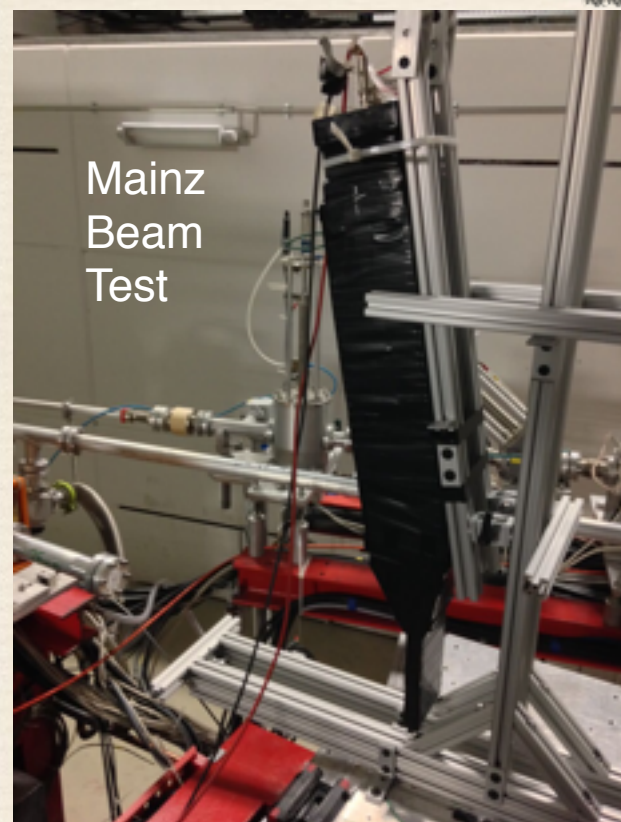
Prototype coil at
Everson Tesla

Funding from
DOE NP MEP
via SBU

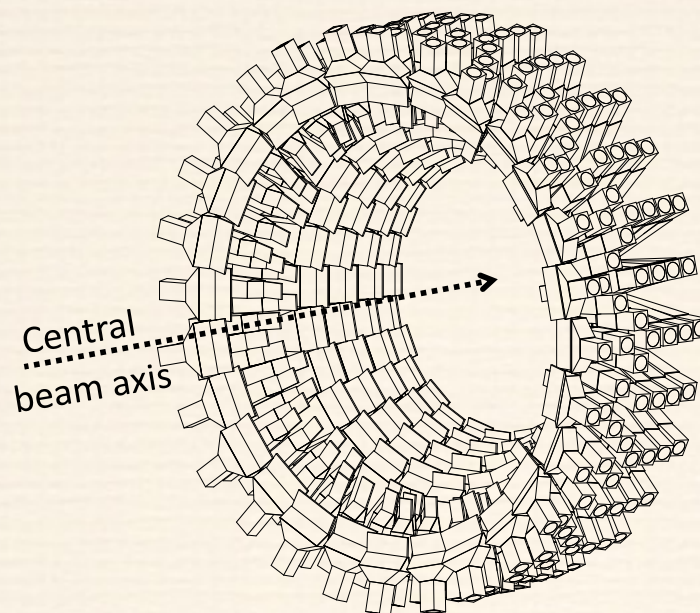


Detector Concept Validation

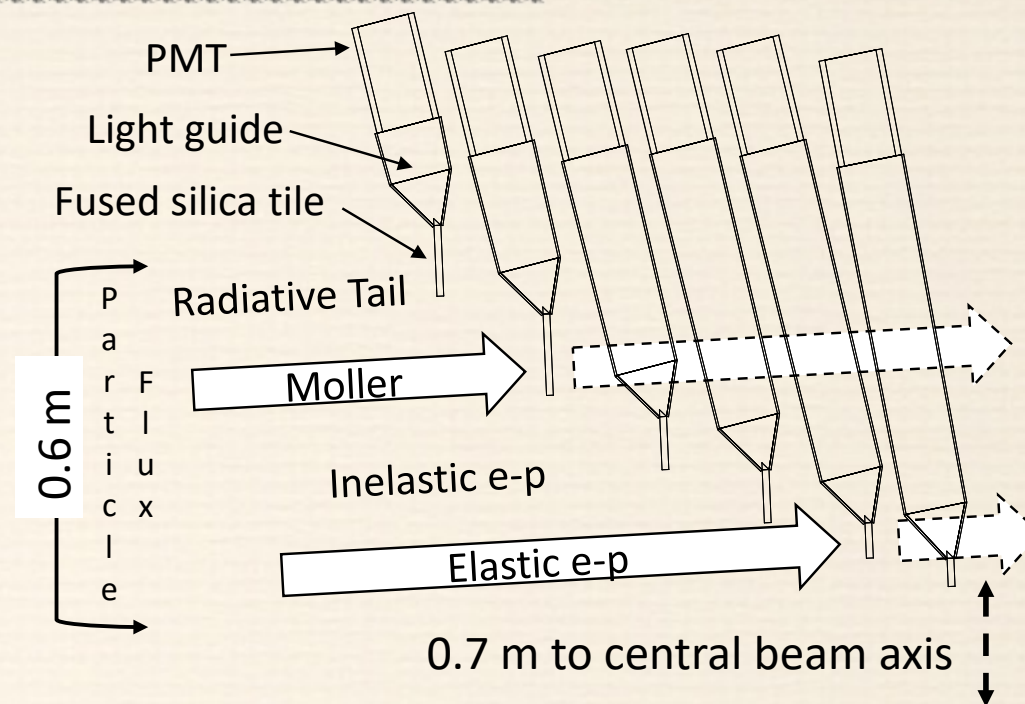
Funding from DOE NP MEP Research, NSF NP, Canada



Mainz
Beam
Test



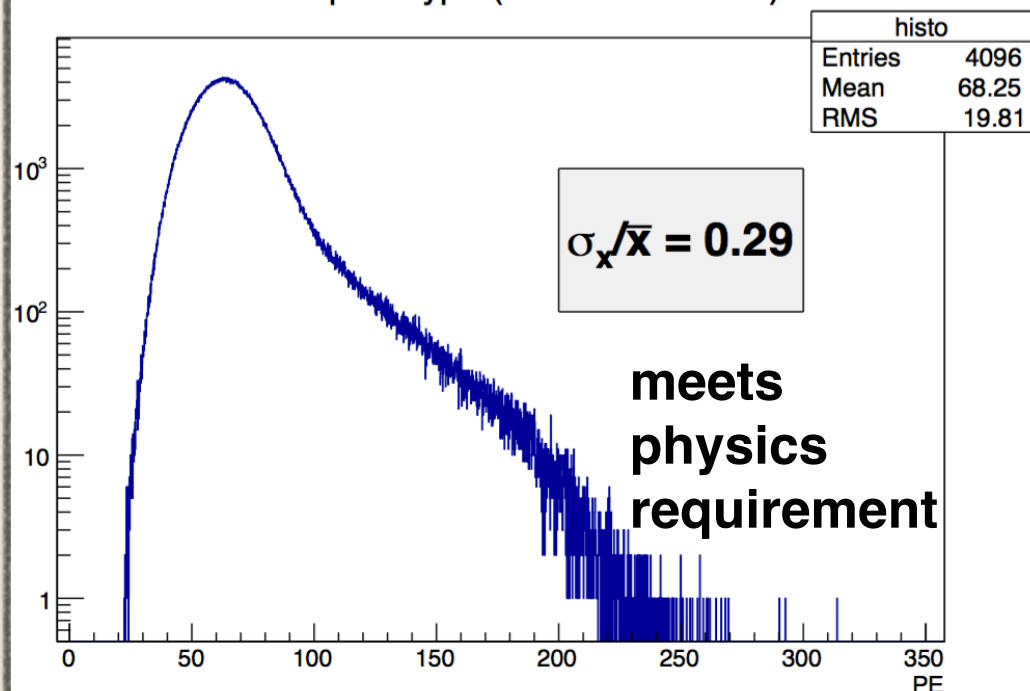
Detector assembly



N2 scintillation concern addressed: CO2 in air provides sufficient quenching

First MOLLER publication! NIM A 896 (2018) 96–102

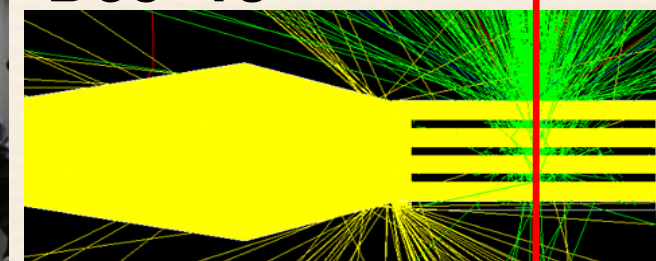
Moller prototype (MAMI test beam)



SLAC End Station A



**Successful beam test
Dec '18**

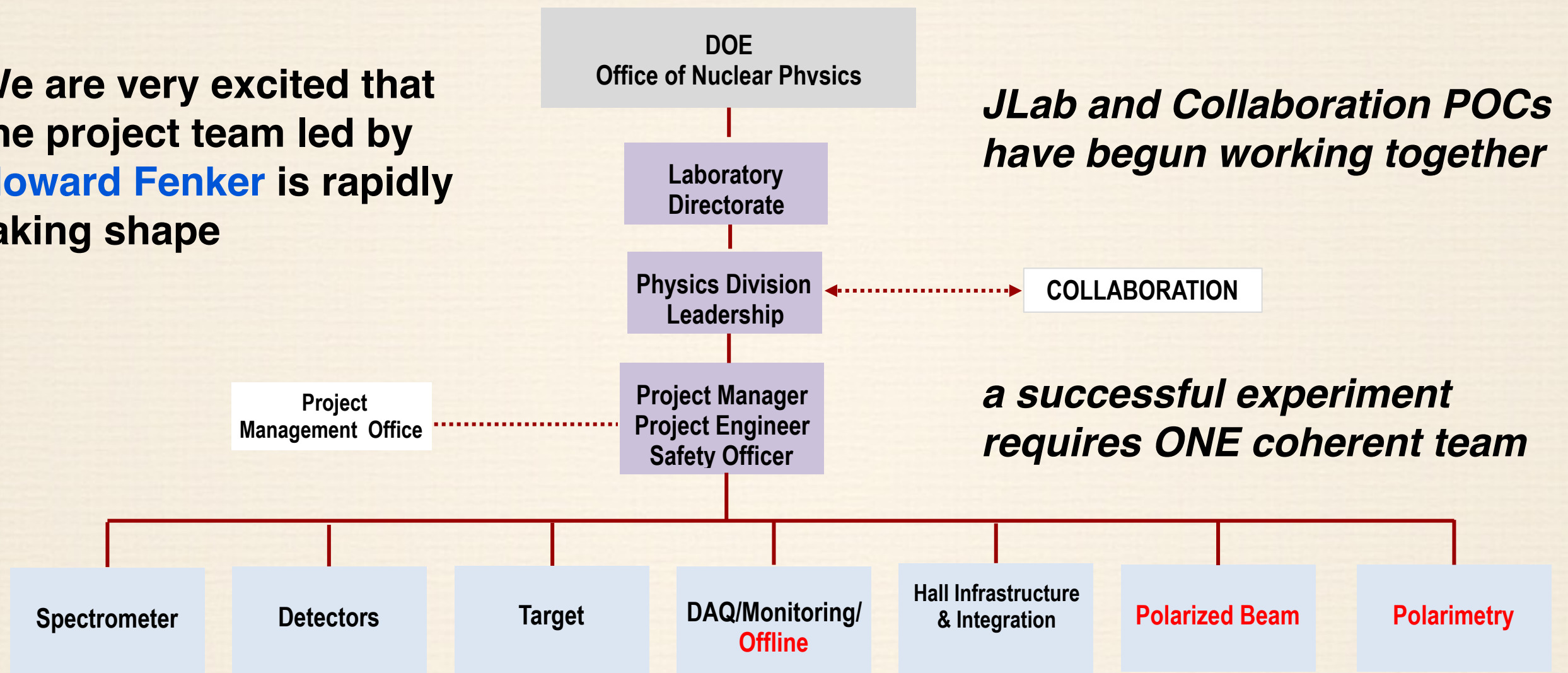


“shower-max” simulation
green: gammas
yellow: optical photons

Towards a Construction Project

Possible Project Structure (under development)

We are very excited that the project team led by **Howard Fenker** is rapidly taking shape



- Level 2 are assigned a JLab CAM, Collaboration POC(s), and a JLab Reviewer
- Level 3 (if not a dependency) are assigned a JLab POC, Collaboration POC(s), and a JLab Reviewer
- Red font indicates dependencies
- A Change Control Board and a Technical Board will be formed

Tasks in Preparation for CD-1

◆ High priority tasks in progress

- ★ Shielding: optimization of weight, volume, cost
- ★ Parity Quality Beam: refining Qweak/PREX beam specifications in the context of 11 GeV MOLLER
- ★ Tolerances: ensure most critical components specified
- ★ Hybrid coil prototype testing
- ★ Investigate alternate concepts for spectrometer coil arrangement and vacuum configuration
- ★ Shower-max detector concept validation

◆ Working towards a Director's Review

- ★ Validate cost/schedule estimates
- ★ Ensure risks to feasibility and performance are being addressed

2019 JLab Priorities

(Subject to DOE NP approval and funding)

- ◆ **Advance conceptual design of spectrometer magnets and evaluate optional design approaches**
- ◆ **Define requisite parameters for ESR2 transfer line to reduce risk in determination of scope & costs**
- ◆ **Carry out Hall radiation and beamline activation studies to reduce risk in determination of scope & cost**
- ◆ **Evaluate Hall infrastructure per MOLLER power requirements**
- ◆ **Develop conceptual design for fast raster system**

Conclusions and Outlook

- ◆ **MOLLER is a compelling opportunity to search for new physics beyond the Standard Model**
 - ★ Leverages unique 12 GeV beam and past operational experience
 - ★ Cannot be done elsewhere in the world
 - ★ Discovery space untouched until a new lepton collider is built
- ◆ **After many years of conceptual development, we are poised to start a construction project**
 - ★ The MOLLER collaboration and especially the project team look forward to working together to successfully execute the project plan
- ◆ **Exciting times ahead for Hall A!**