# QTOR Mapping and Main Detector for the Qweak Experiment

Peiqing Wang
University of Manitoba

For the Qweak Collaboration

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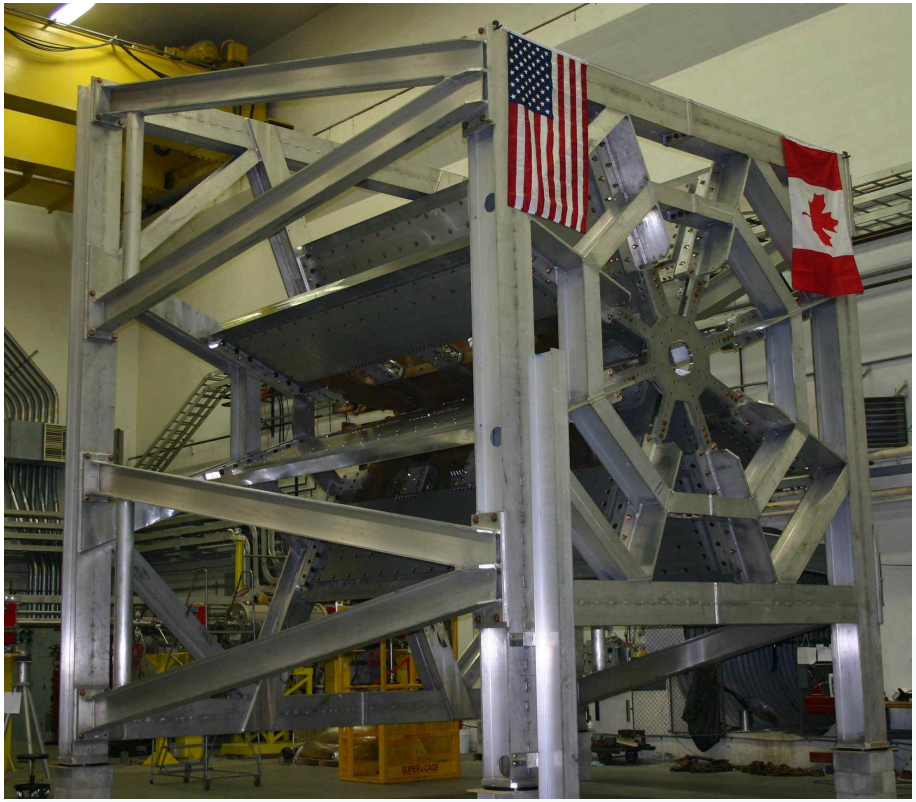
# Qweak Toroidal Magnetic Spectrometer (QTOR)

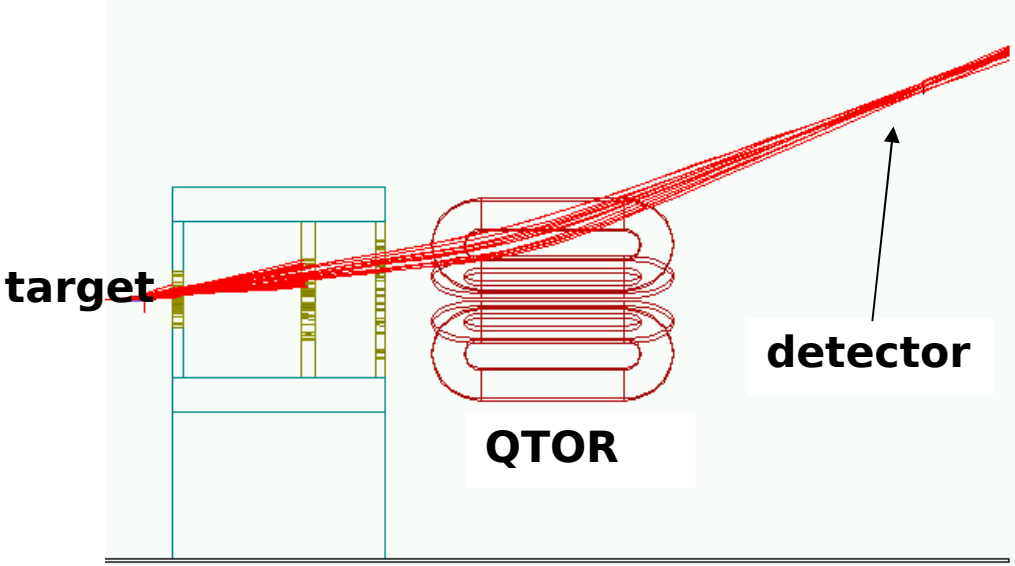
- **Resistive, iron-free toroidal magnet**
- **Symmetric 8 fold coil packages**
- **Hollow, water-cooled copper conductor**
- **Field integral ~ 0.67 T m**
- **DC current ~ 9 kA**



The Qweak experiment requires:

- large acceptance
- good focusing, high symmetry
- clean separation for elastic and inelastic events

The field integral along the central electron trajectories need to be measured to <0.4% level



# Zero-crossings of Toroidal Magnetic Field

• QTOR mapping is using the zero-crossing measurement technique, rather than a full 3D field measurement (huge mapping cost, many grid points are not accessible)

• The magnetic field of an iron-free toroidal magnetic spectrometer can be characterized by the zero crossing points in its fringe area, which are determined by the current distribution in the magnet.

• The current distribution can be described by means of the shape and location of individual current-carrying coils.

• A precision determination of the locations of zero crossing points enables us to infer the locations of the coils, leading to a complete determination of the toroidal magnetic field.

*(Zero crossing points: the locations where individual magnetic field components change sign in a 3D magnetic field)*

# Zero-crossing Analysis

Zero-crossing positions ( Z ) are determined by coil locations ( C ), thus the 1st order approximation gives:

$$\Delta Z = \sum_n \left(\frac{\partial Z}{\partial C}\right) \Delta C$$

ΔZ: zero-crossing displacements (known from simulations and measurements)

∂Z/∂C: derivatives (sensitivities, known from simulations)

ΔC: coil misalignments (unknown)

n: the degrees of coil freedom

The unknown ΔC then can be obtained from solving the above linear equations:

- More unknowns can be involved in the linear equations (such as the misalignment of mapping device),

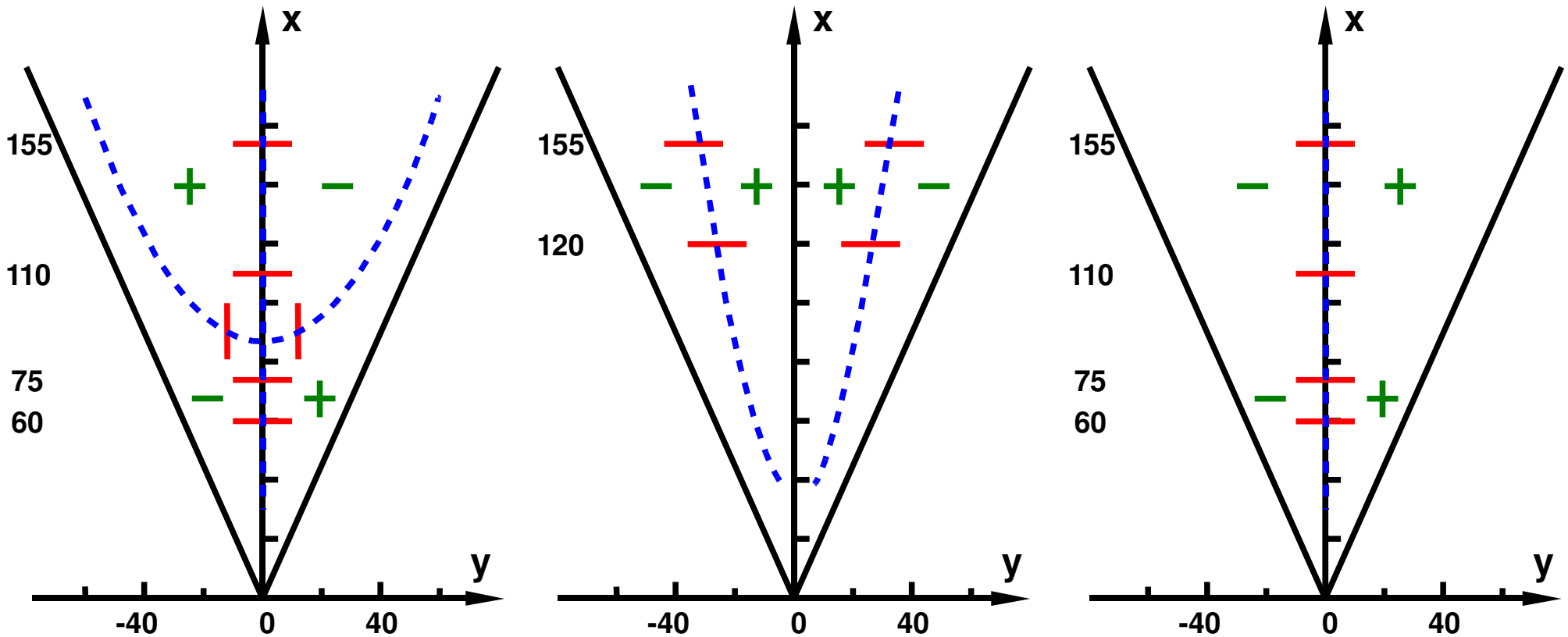
- Measure more zero-crossings than unknowns to minimize the uncertainty through least squares fit

# QTOR Zero-crossing Points

- Qweak magnet model: each as-build coil is characterized in detail
- Model gives zero-crossing points for normal and displaced coil positions
- Zero-crossing points are sensitive to coil positions
- Measure zero-crossing points ==>> complete determination of the magnetic field

**Zero-crossings distribution in an octant at fringe area**

**Upstream, z = -185 cm**




**Bx = 0** **By = 0** **Bz = 0**

# Displacement of Zero-crossing Points

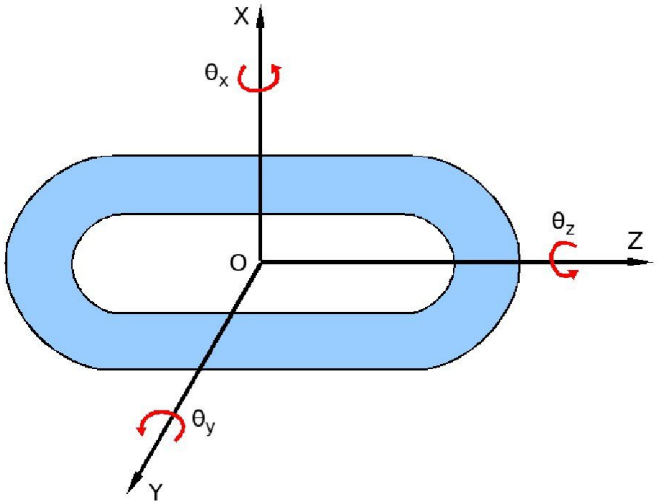
There are many sources leading to the displacement of zero-crossing points:

1. Displacement and rotation of coils

$$\Delta X_{coil}, \Delta Y_{coil}, \Delta Z_{coil}$$

$$\Delta\theta_X, \Delta\theta_Y, \Delta\theta_Z$$

==>> 6 x 8 = 48 unknowns

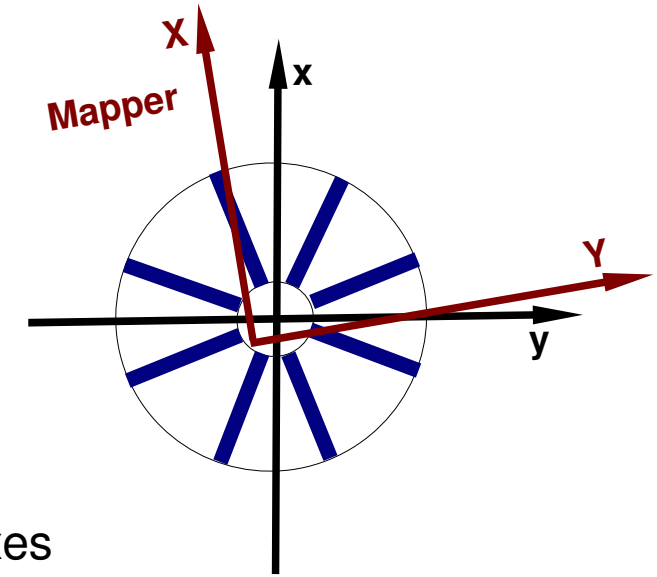



2. Displacement and rotation of field mapping gantry with respect totoroid

$$\Delta X_0, \Delta Y_0, \Delta\Phi_0$$

seperate setup at each end of toroid:

==>> 2 x 3 = 6 unknowns



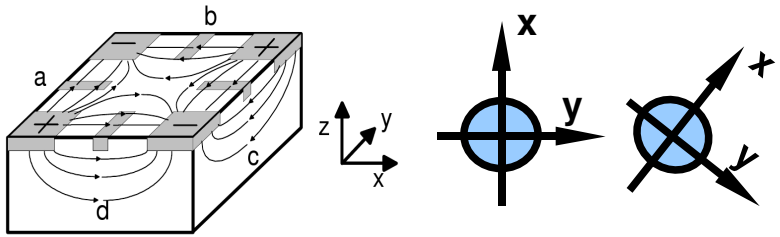

- **Each zc point where a component, say Bx, changes sign, another component (By) is large**
- **Probe alignment critical**
- **Mapper alignment critical**

3. Misalignments of 3-D Hall probe axes

$$\Delta\theta_X, \Delta\phi_X, \Delta\theta_Y, \Delta\phi_Y, \Delta\theta_Z, \Delta\phi_Z,$$

Two seperate 3-D Hall probes:

==>> 2 x 6 = 12 unknowns

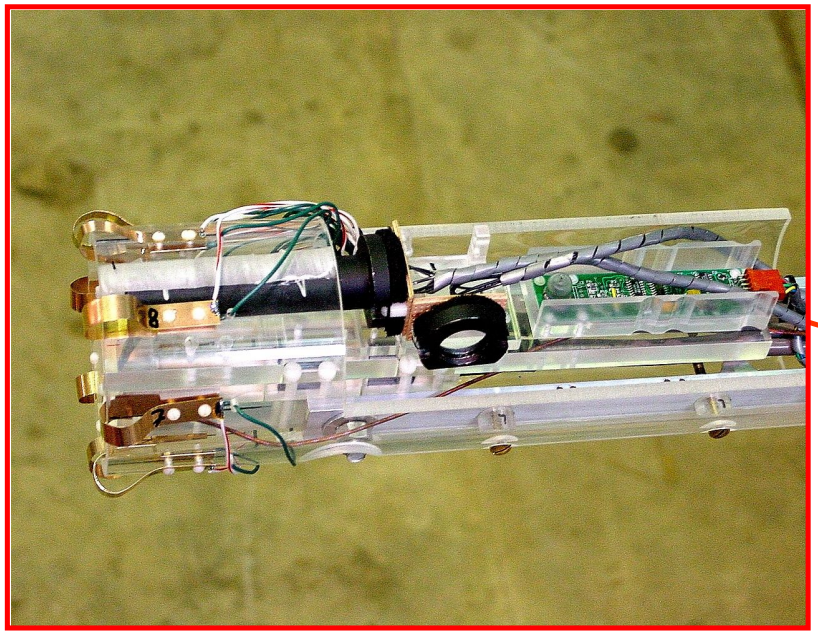


# Magnetic Field Mapping Device

Precise, 3D automated field mapping device was used to determine the location of zero-crossings

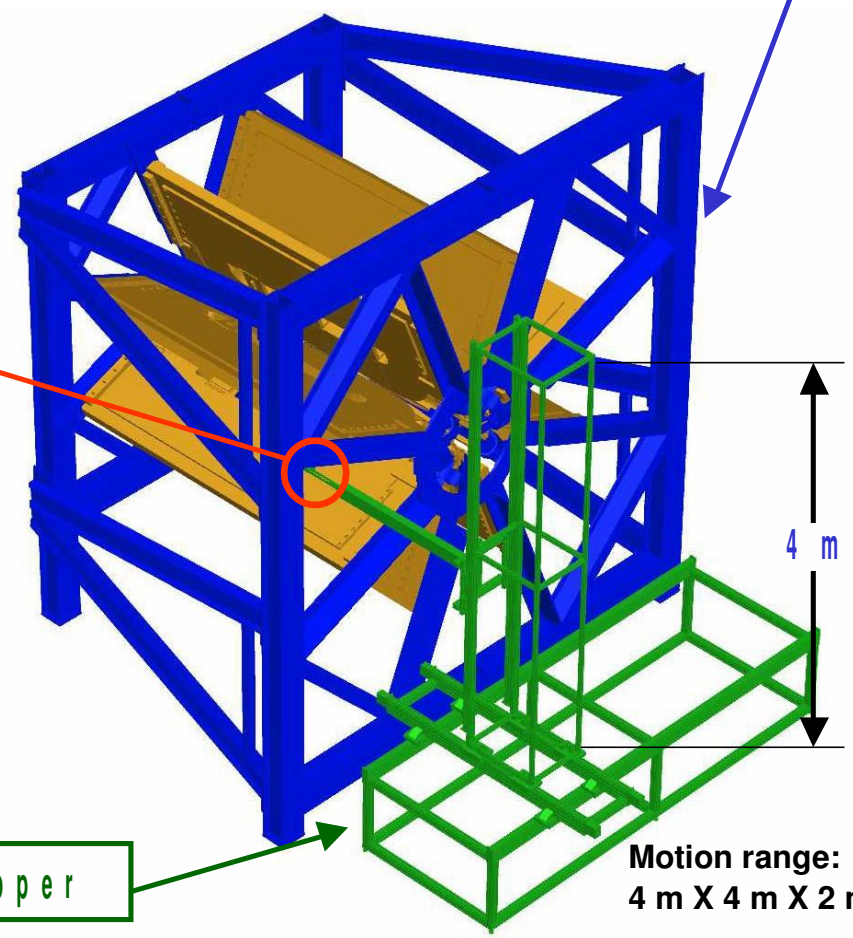
(position determination: ±0.2 mm, magnetic field determination: ±0.2 Gauss)

Magnetic field probes



3-axis Hall effect transducer can measure 3 orthogonal magnetic field components

Toroidal magnet and support structure

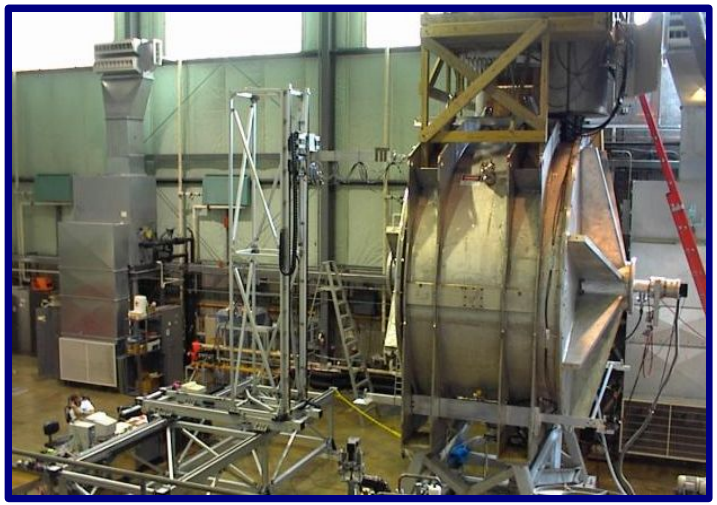



Field Mapper

Motion range:
4 m X 4 m X 2 m

Designed & assembled by TRIUMF

# Magnetic Field Mapping



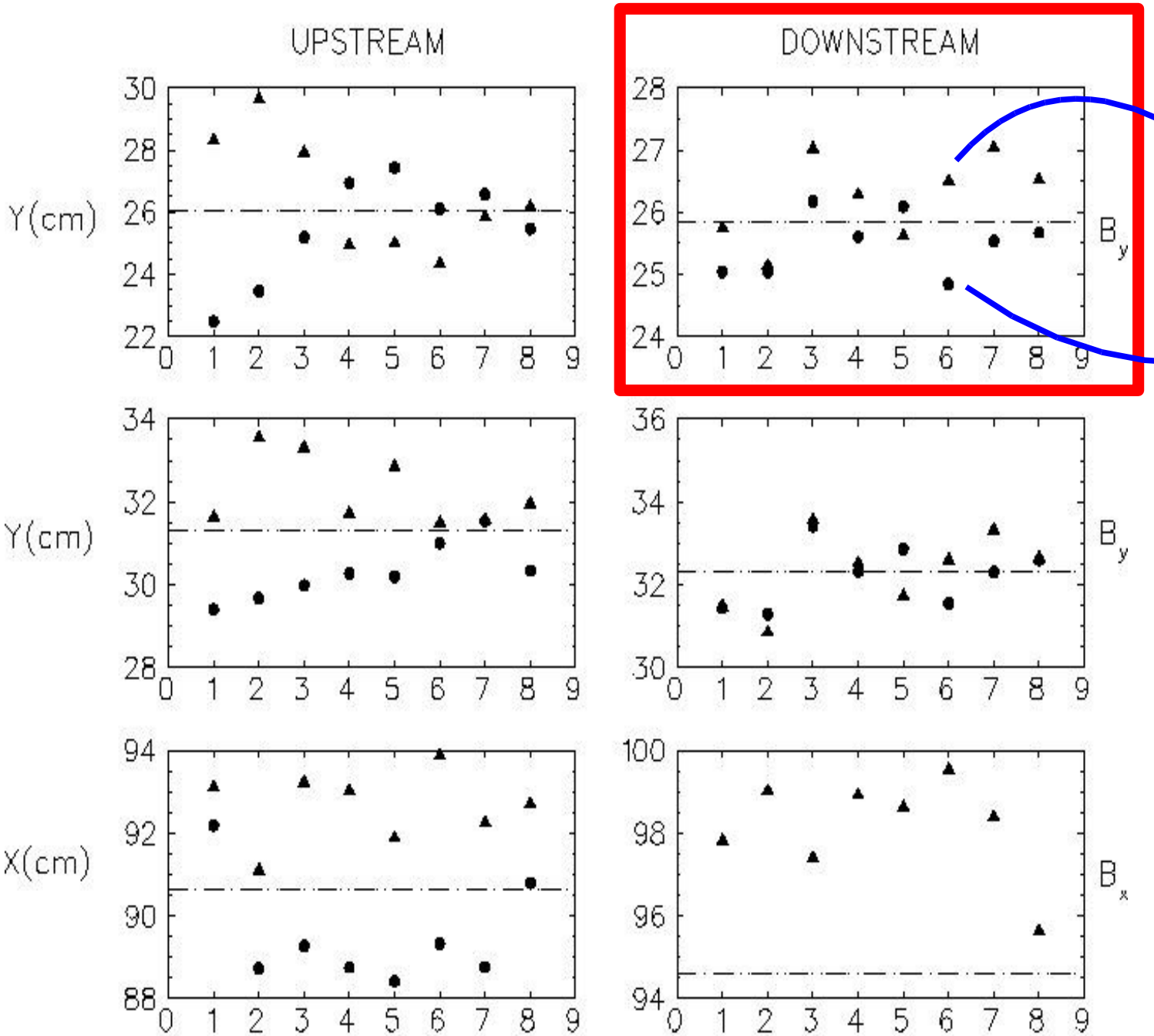
(G0 field mapping at Univ. of Illinois)

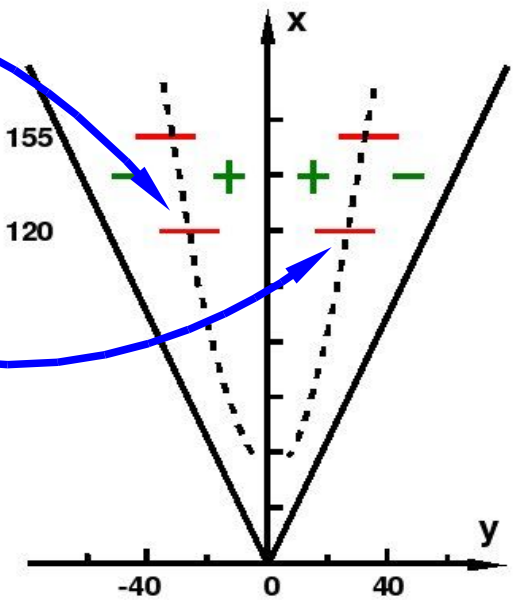
Zero-crossing technique has been validated in the G0 magnetic field determination

Zero-crossing measurement for the Qweak toroidal magnetic spectrometer at the MIT-Bates Laboratory

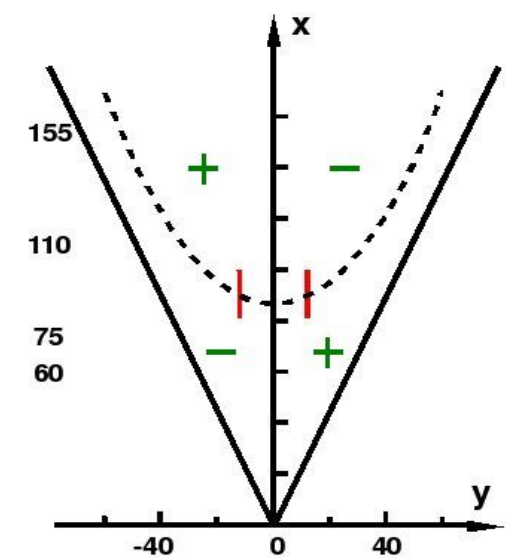
# Experimental Zero-crossing Points

Zero-crossings are off few cm wrt model expection




By = 0




Bx = 0

# Coil Misalignments from Fitting

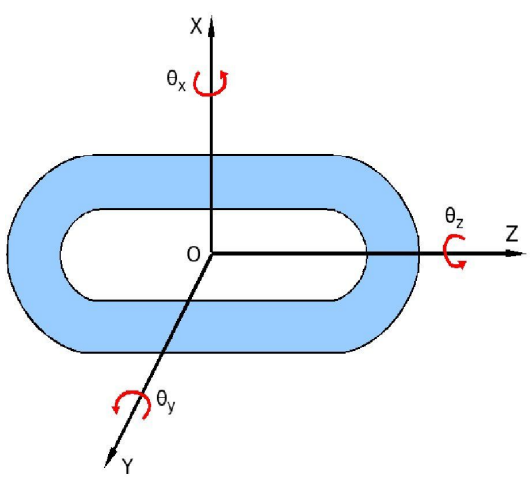
Zero-crossing analysis gave the misalignment of individual coil:

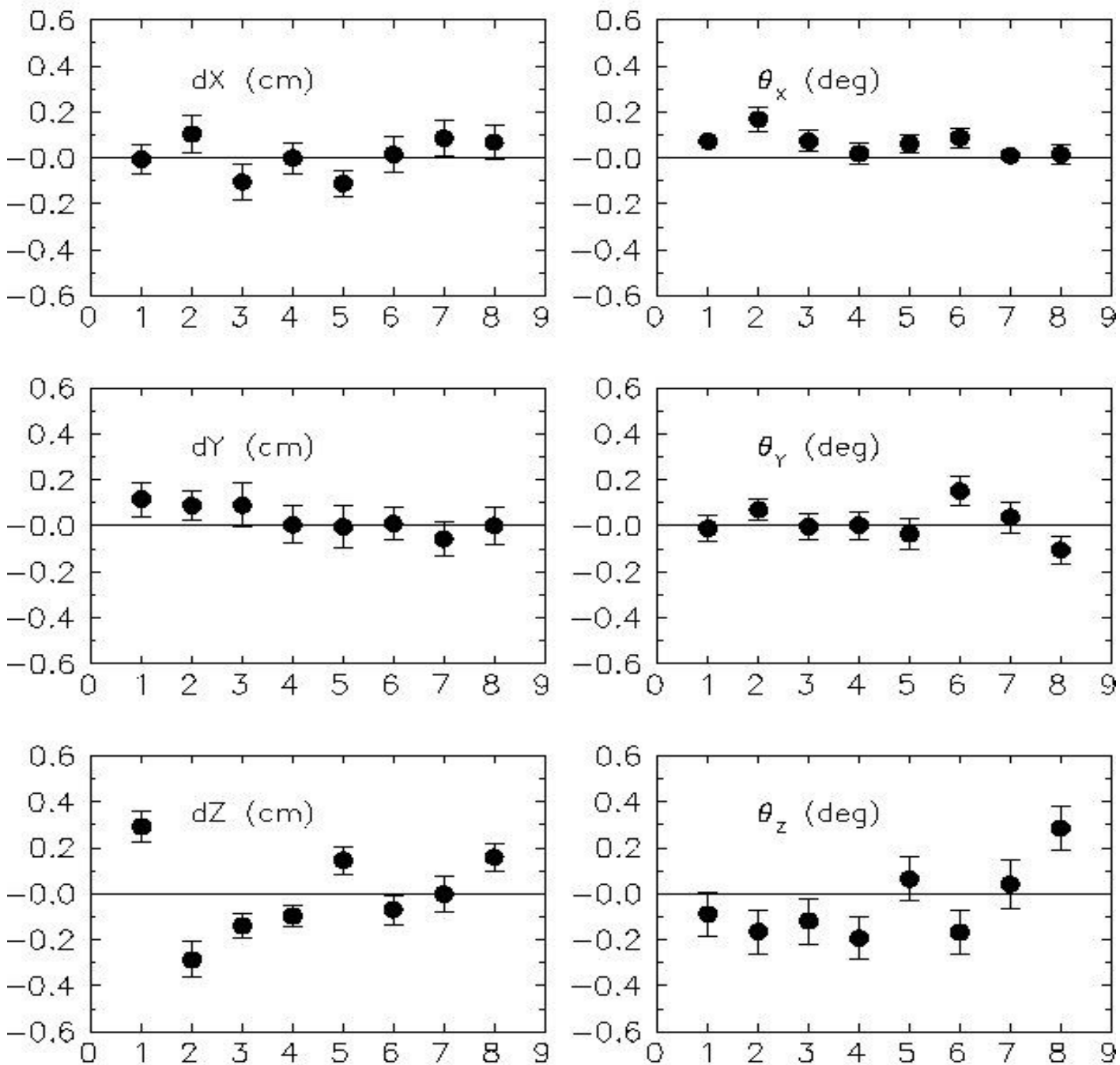
± 0.2 cm, ± 0.1 deg

All quantities in cm and degrees

Number of unknown = 66

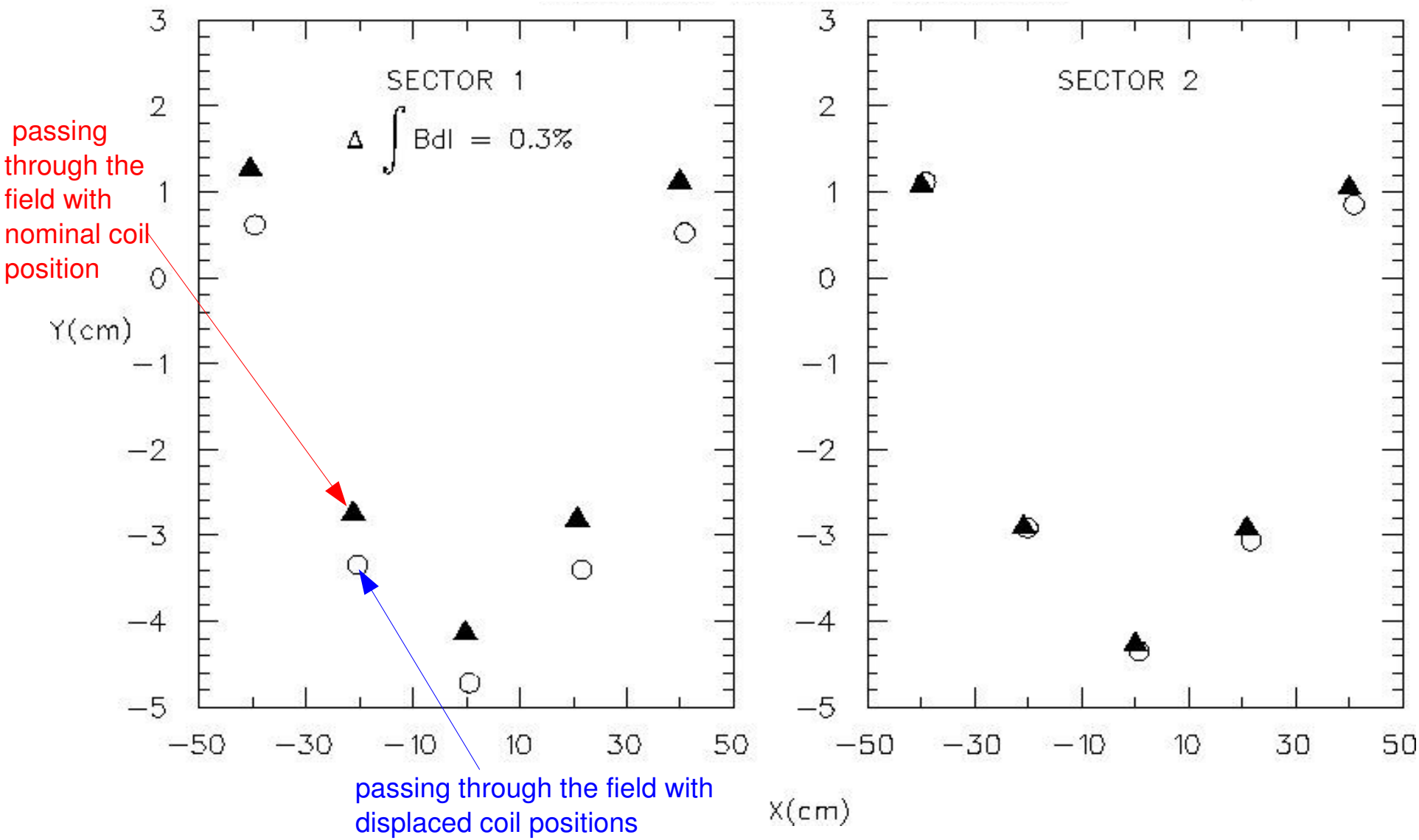
zero-crossing points per sector = 12



# Impact of Misalignments on Field Integral

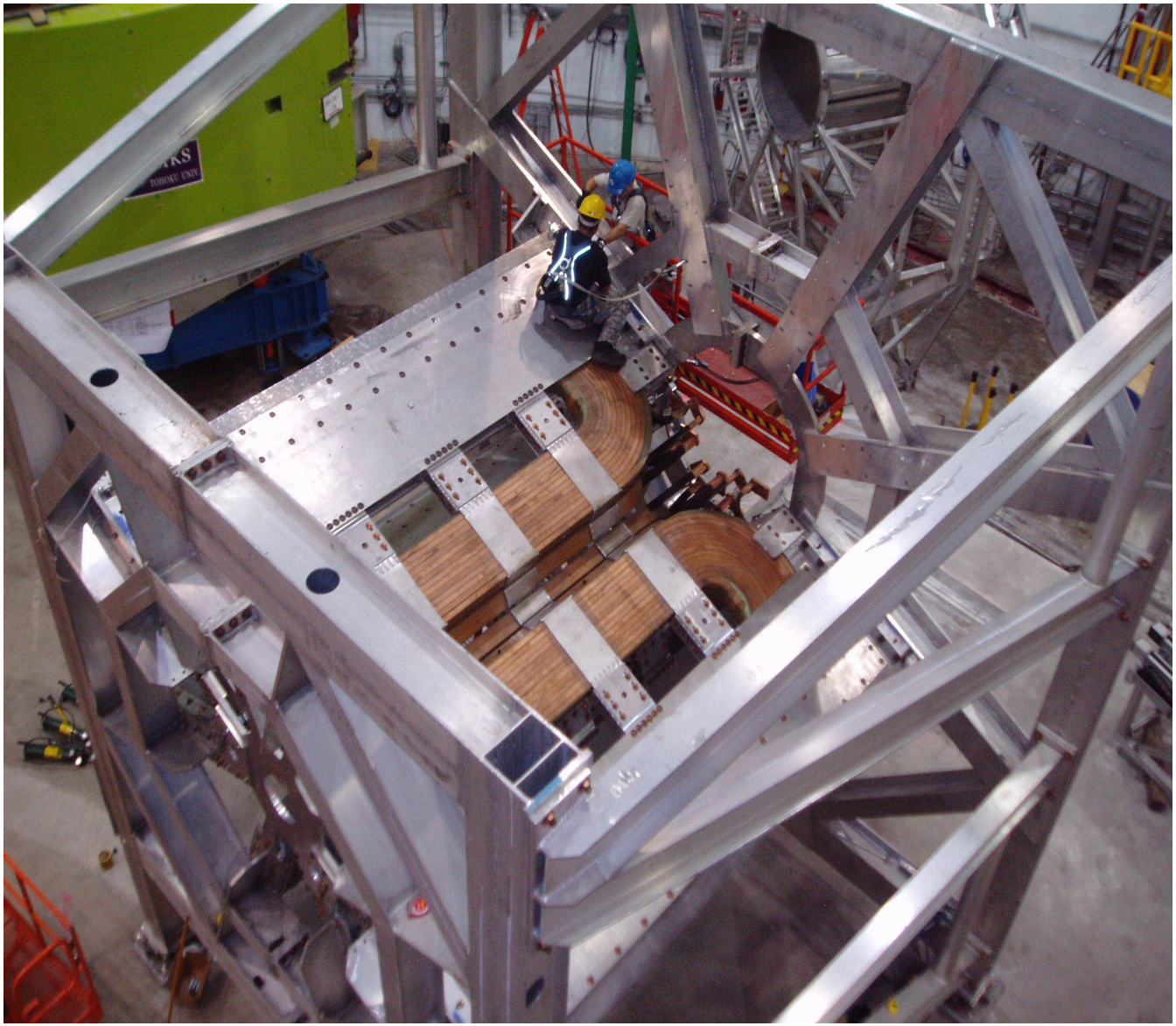
- send a family of scattered electrons, alternatively, through the fields (the field with nominal coil positions and the field with displaced coil positions)
- calculate the field integral along the trajectories and make a comparison: $\Delta \int B\, dl = 0.3\%$




The electron hit positions on the detector

# QTOR Installation in Hall C

- Present results of QTOR mapping at MIT-Bates provide a good description of coil positions



The QTOR magnet was

- fiducialized at MIT-Bates
- transported to Jlab
- reinstalled in Hall-C

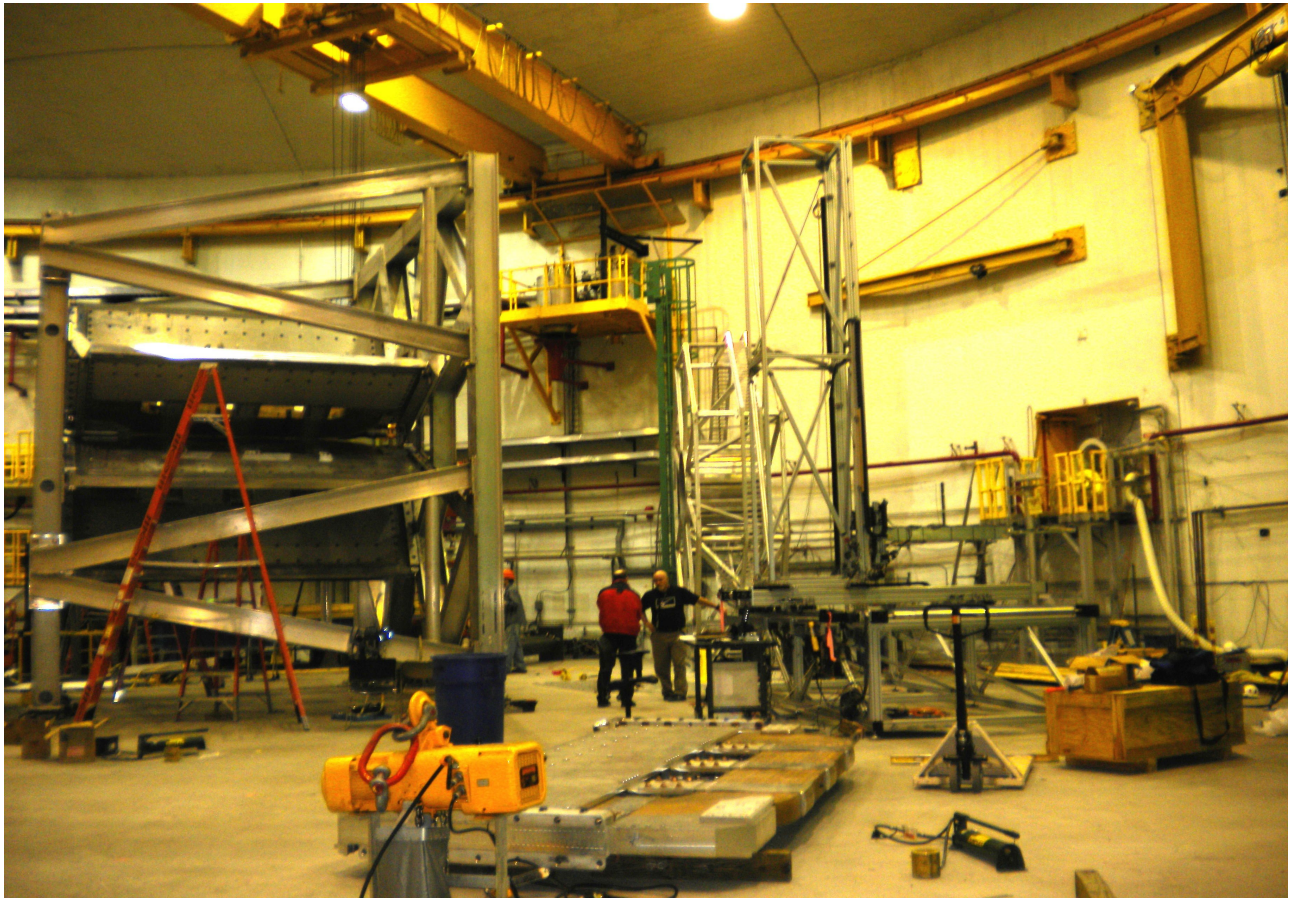
The preliminary analyzed survey results indicate displacements of the coils of ~ 1.5 mm

# QTOR Mapping Status

- The QTOR mapper was transported from the Bates Accelerator Facility to Jefferson Lab in early January, and arrived in Hall-C on January 5.

- Since then, Q-weak collaborators from Canada traveled to JLab to reassemble and calibrate the QTOR mapper.

- The field mapper has been reassembled, briefly tested, and had its motion recalibrated using the JLab survey group's laser-tracker.



- At this time, it is located near the QTOR magnet and ready to be craned into position

- The field mapping is scheduled for early February 2010.

# Qweak Main Focal Plane Detectors

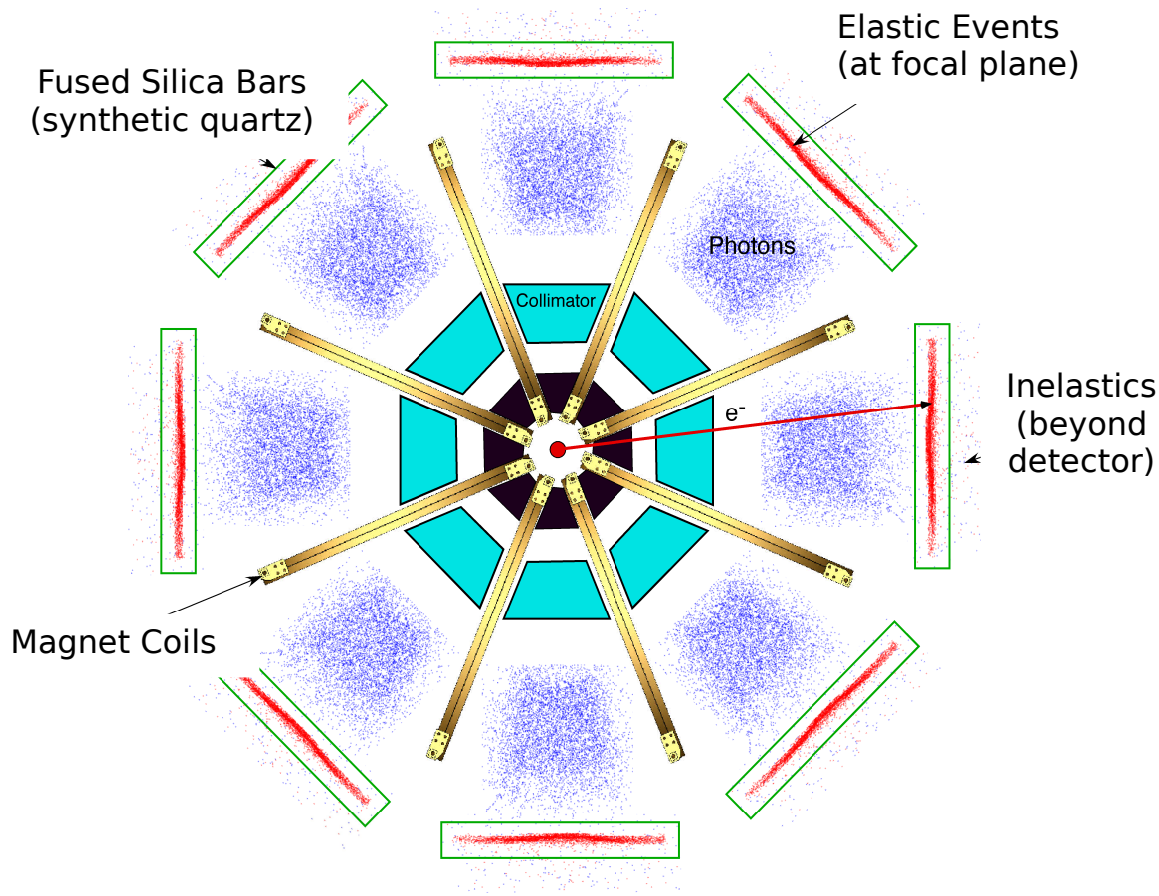
- Qweak spectrometer has 8 octants, providing a clean seperation of elastic and inelastic events on the focal plane

- The eleastic events rate: 800 MHz/octant

- The detectors need to cover elastic area, run in current mode

- Detector design considerations: Radiation hardness (~ 300 kRad), Background (photon, neutron)

**End View at focal plane (with GEANT simulated Events)**




- **Detector solid angle ~45 msr, $\phi$ acceptance ~ 53% of 2 $\pi$**

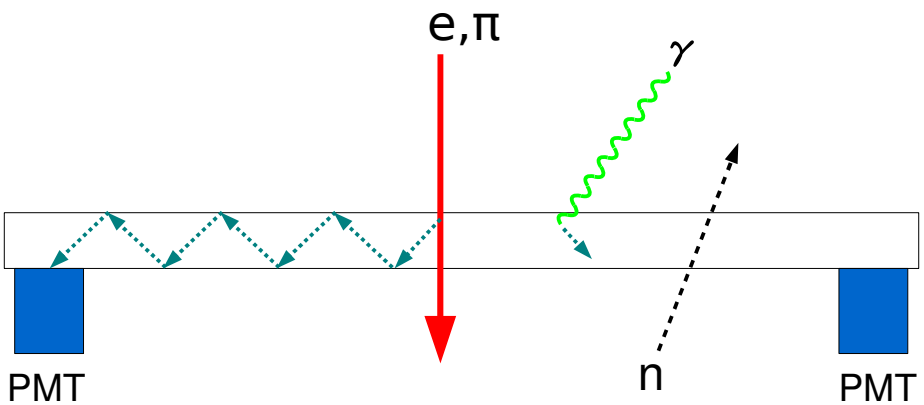
# Synthetic Quartz Čerenkov Detectors

- Radiation hard (>300 kRad)
- Insensitivity to background

Specifications:

- 200 cm x 18 cm x 1.25 cm synthetic quartz bars
- 5” PMT's attached
- Operation at counting and current mode ( current mode readout $I_a$ = 6 μA)

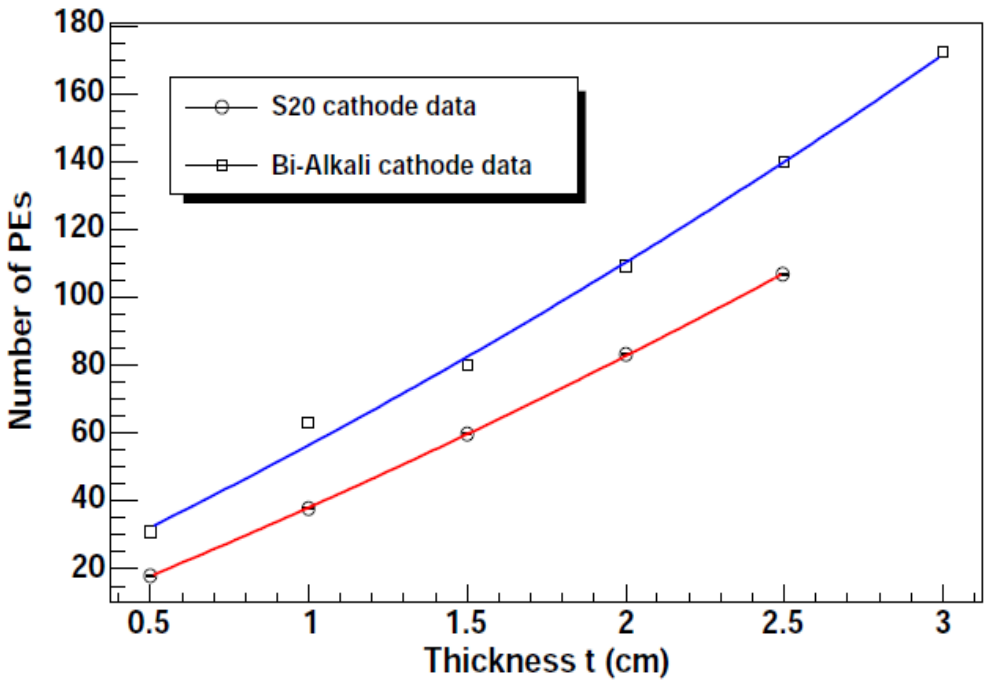
Spectrosil 2000 Synthetic Quartz Bar
(an artificial fused silica by St. Gobain)



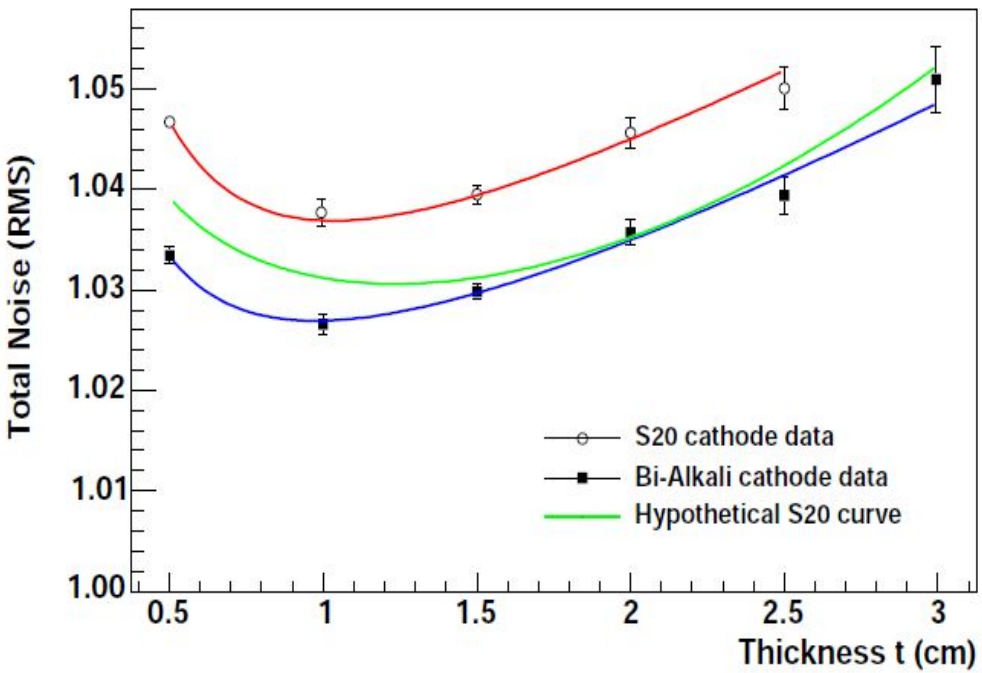
# Optimize Quartz Bar Thickness

- Light yield in the quartz bar directly relates to the asymmetry measurement
- Geant4 simulation for light production and collection optimized the detector design

**A thicker quartz bar produces more light, but shower effects in the thicker quartz bar will generate excess noise, leading to a longer experimental time.**



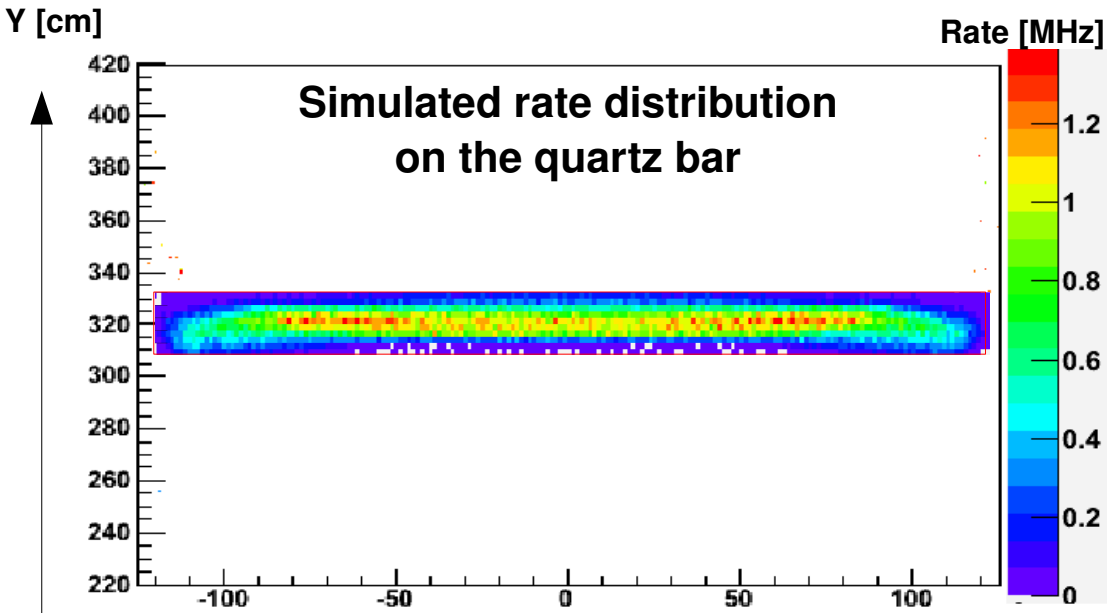

Number of photo-electron as a function of detector thickness

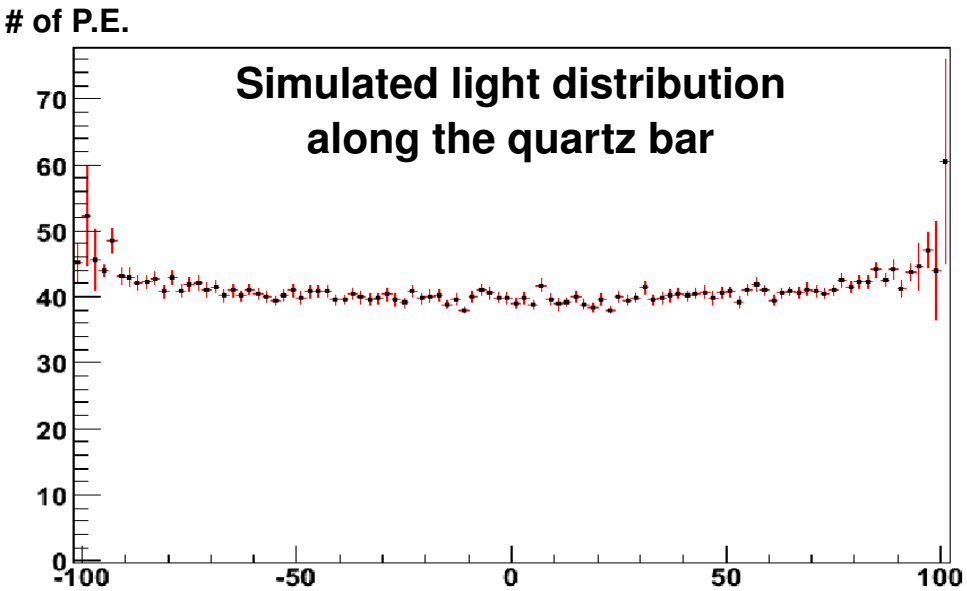


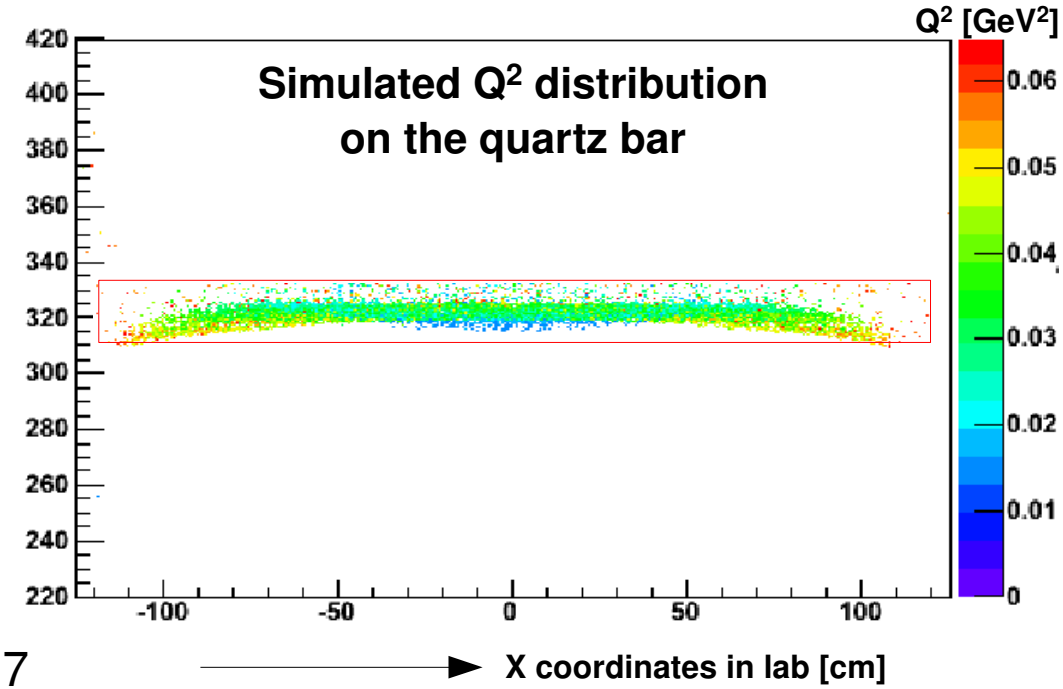

Total excess noise as a function of detector thickness

**The optimized detector thickness is 1.25 cm**

# Rate, light distribution and $Q^2$ Bias



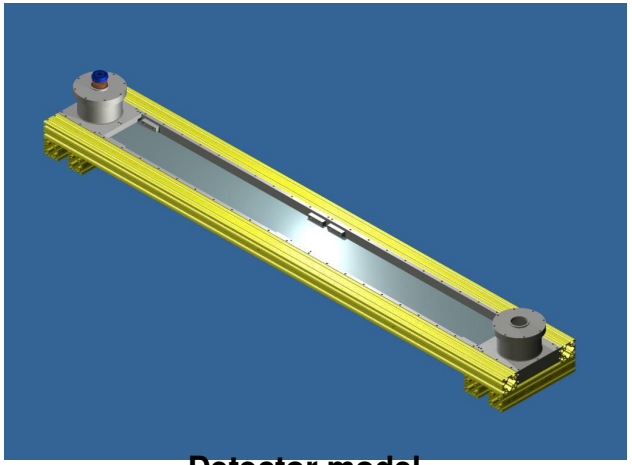



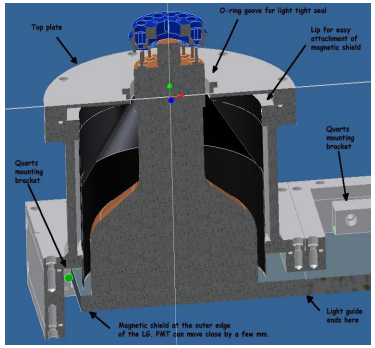

- The rate, $Q^2$ and light yield distributions on the quartz bar are not uniform
- Reality is worse
- We need correct light-weighted $Q^2$.
- Simulation and careful low beam current mapping/calibration using the tracking system are needed for providing the knowledge on weighting and correction.

# Detector Assembly

- Quartz bar and quartz light guide
- PMTs and bases
- Mounting frame/brackets and PMT housing
- Detector windows
- accessaries (diagnostic LEDs, position adjustment mechanics, etc.)

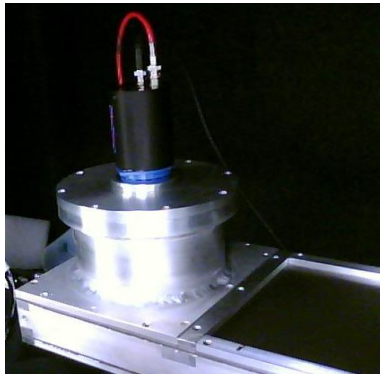


Detector model

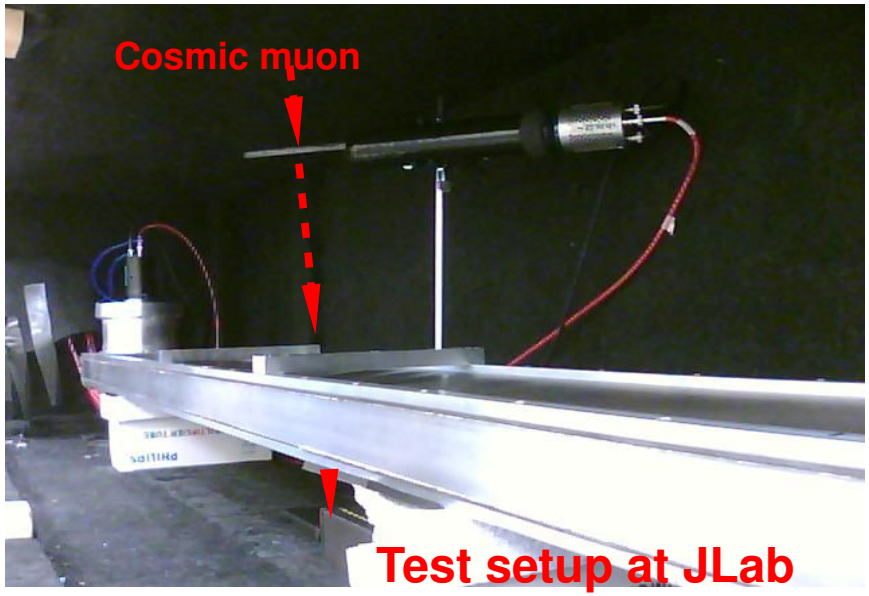


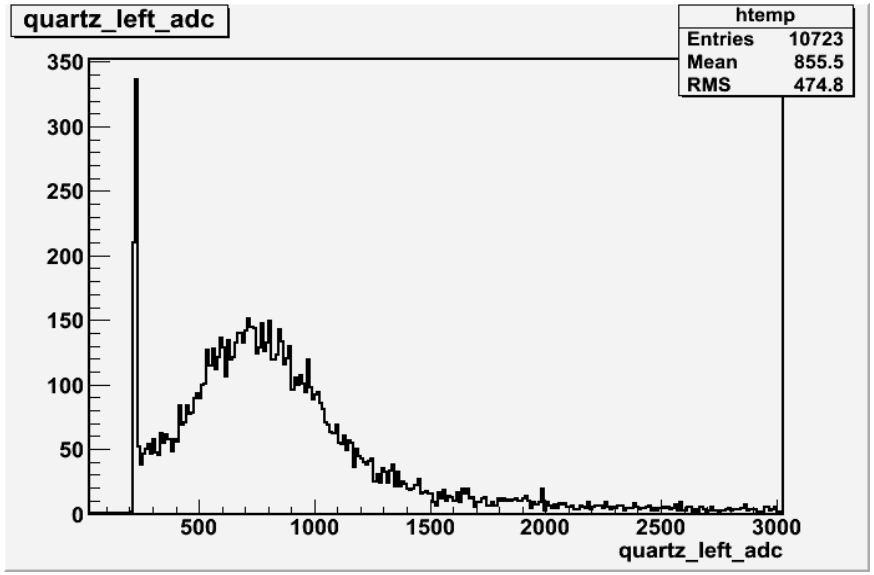

**Design constrains for the detector module:**

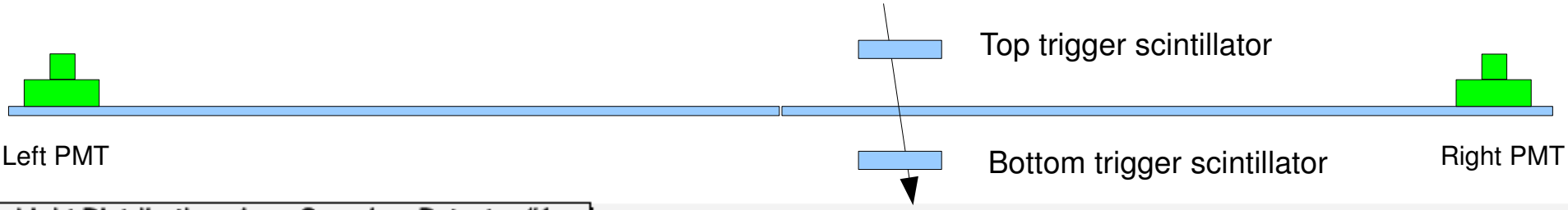
- Light tightness
- Strain and stress free mounting of the quartz
- use minimum amount of low Z material around the detector
- Allow easy access to service the PMTs
- Minimize surface contact of housing material with the quartz bar
- Thin entrance and exit windows
- Allow for possible lining of the housing inside with reflective material
- Switch between event/current mode operation easily

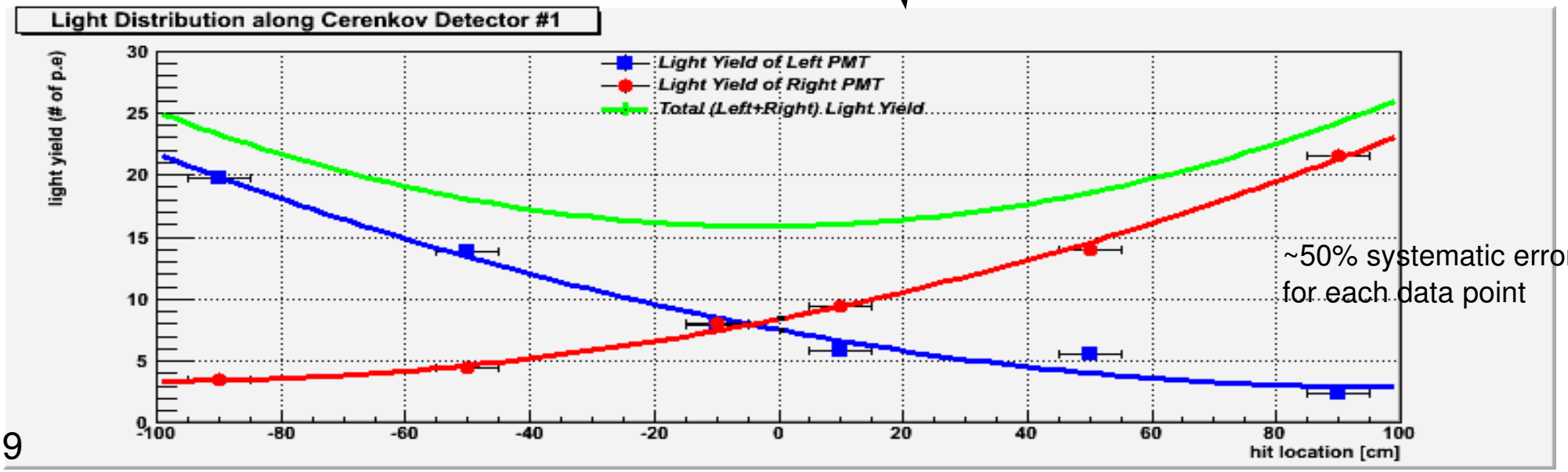


# Light Yield and Distribution Test



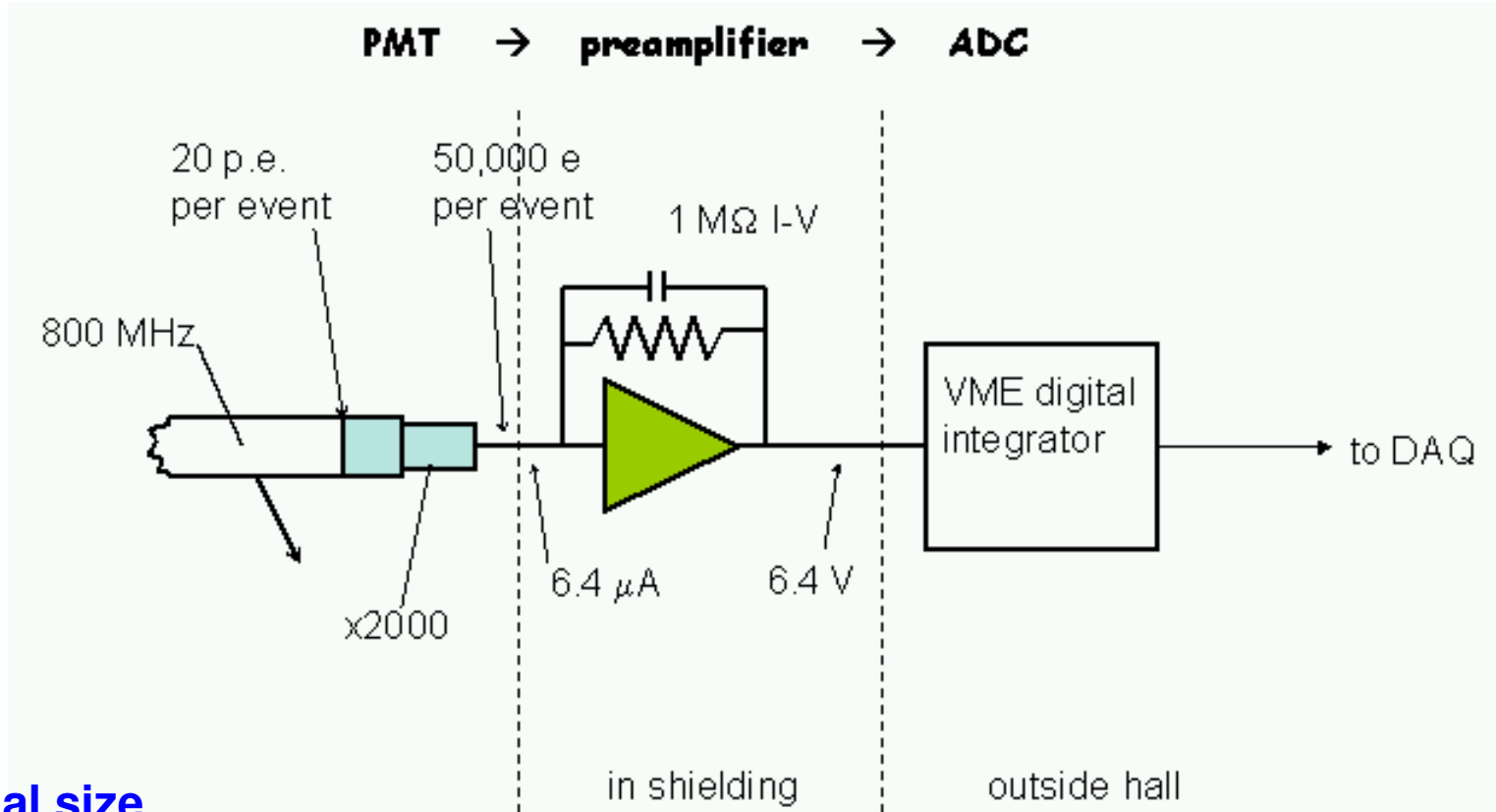




~50% systematic error for each data point

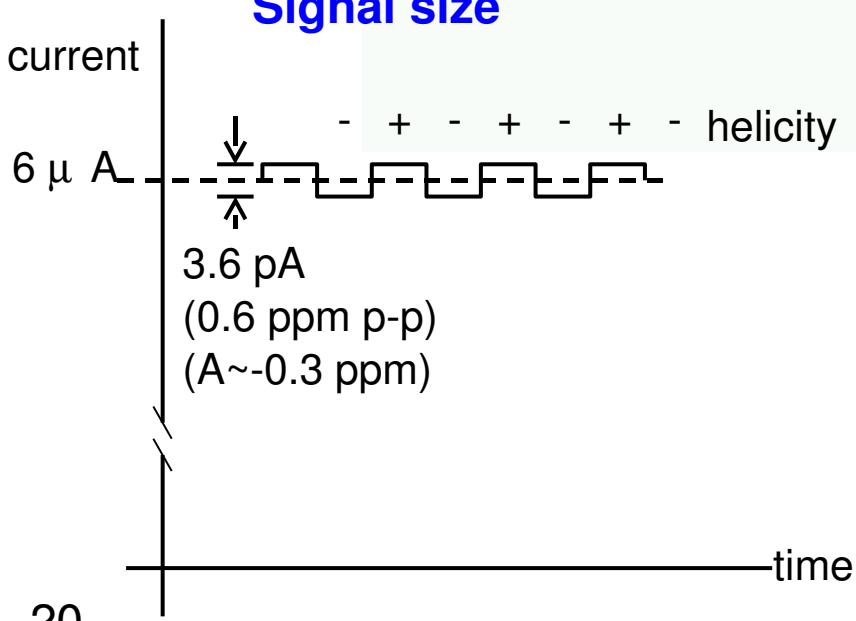
# Signal Path and Front-end Electronics

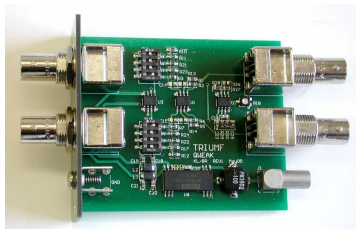


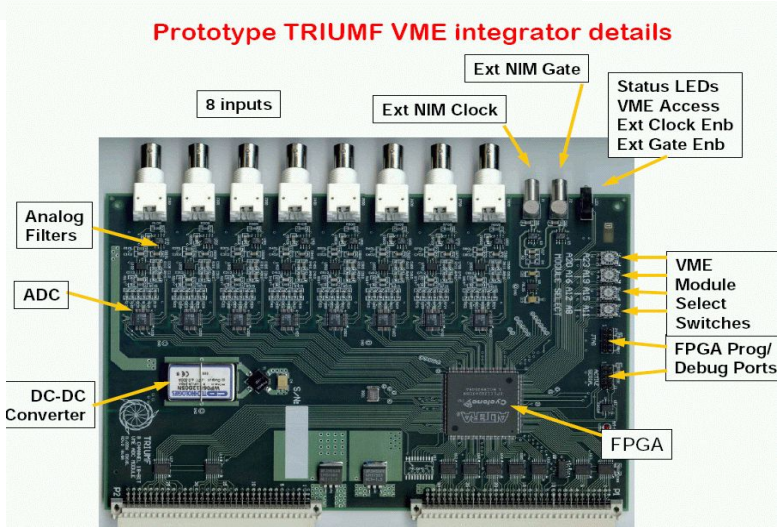

Low noise I-to-V trans-impedance amplifiers (nominal gain: 1 MOhm)

On-board FPGA sums samples during a spin state,

## Signal size





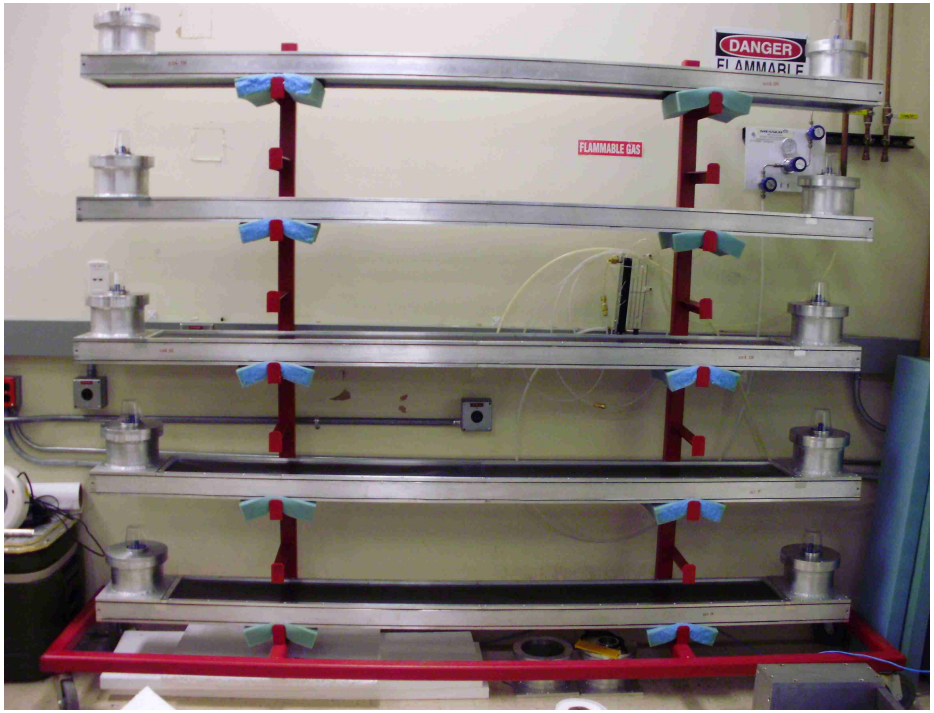
# Main Detector Status and Schedule

- Preliminary tests (radiation hardness, magnetic field sensitivity, transparence, optical glue properties, scintillation and neutron background, light yield ... ) are complete

- Custom designed main preamplifiers, VME integrator (ADC's) and PMT bases were built and tested

- 8 detectors were assembled, ready for installation

- More tests with full detector assembly are underway.




- Installation of the detectors in the Qweak experiment is scheduled

  (3 by end of February, another 5 in early April, 2010)