PMT Shield Tests for MicroBooNE

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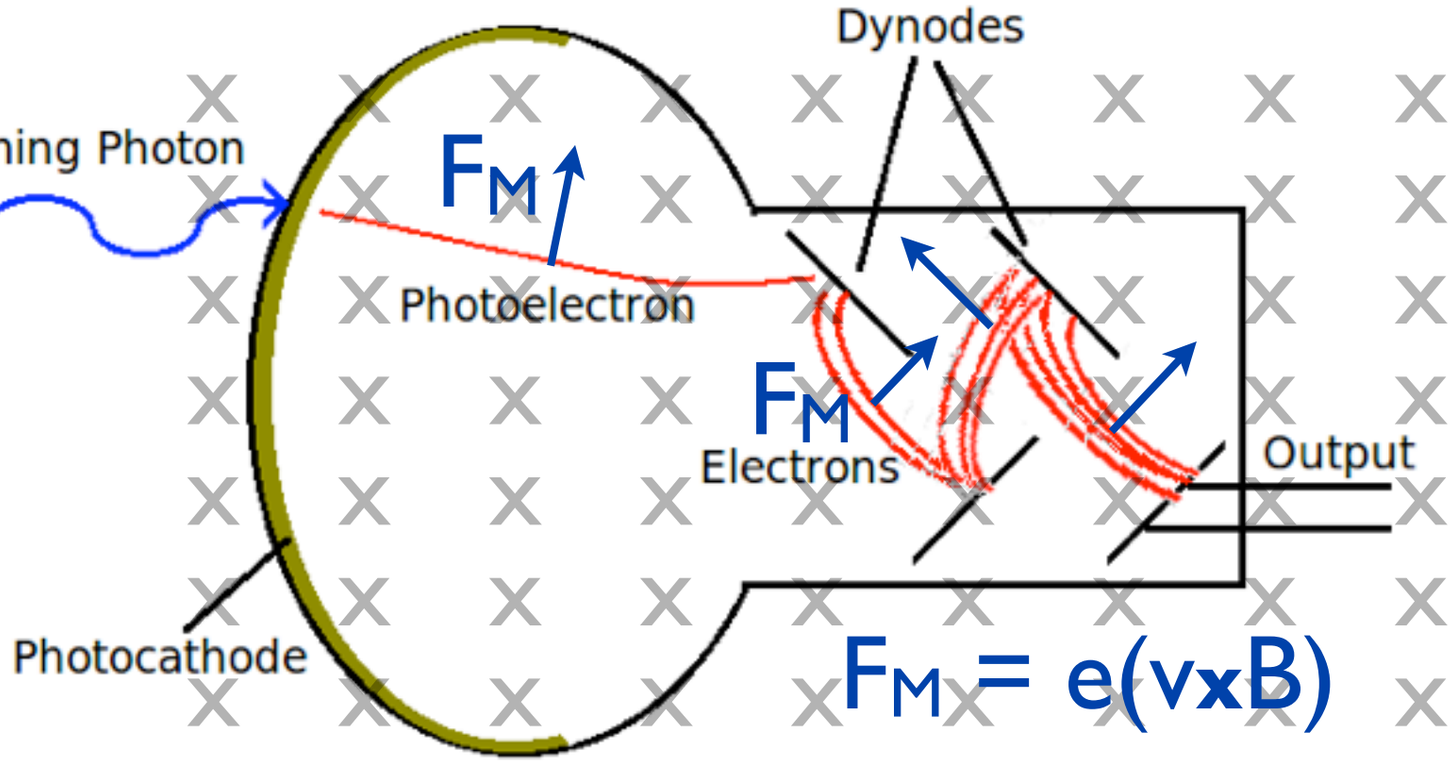
Magnetic Field Effects in PMTs

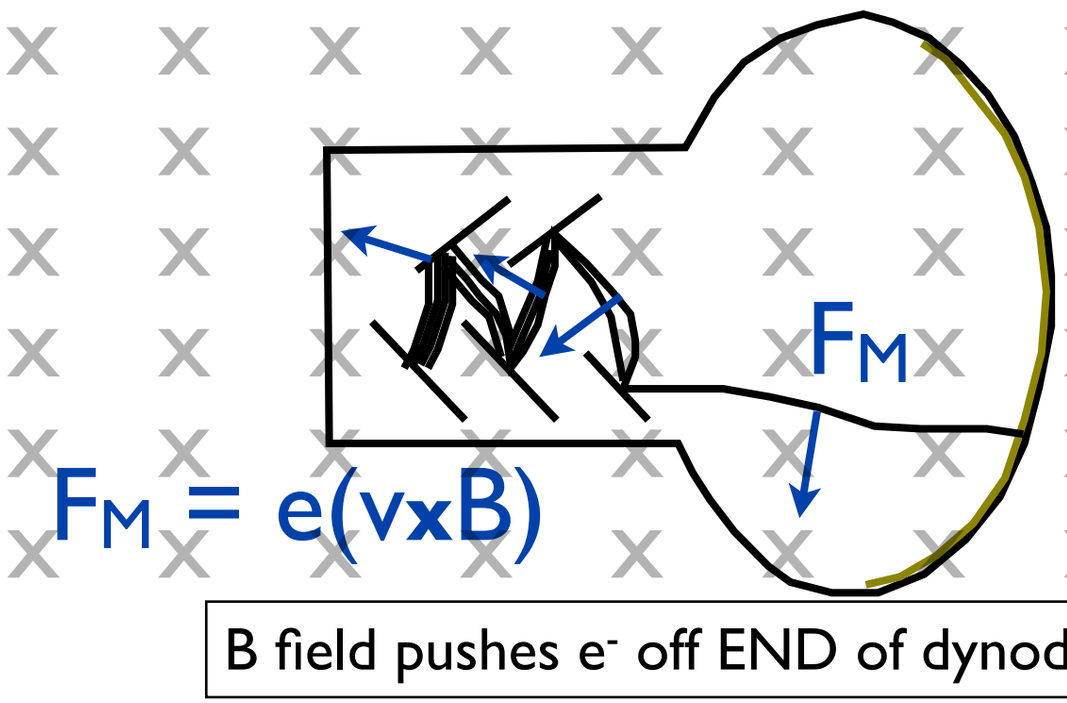
- PMT e^- trajectories can be affected by Earth's B-field:
  - Some primary photoelectrons and secondary electrions may miss their dynode, resulting in a change in charge collection, or gain



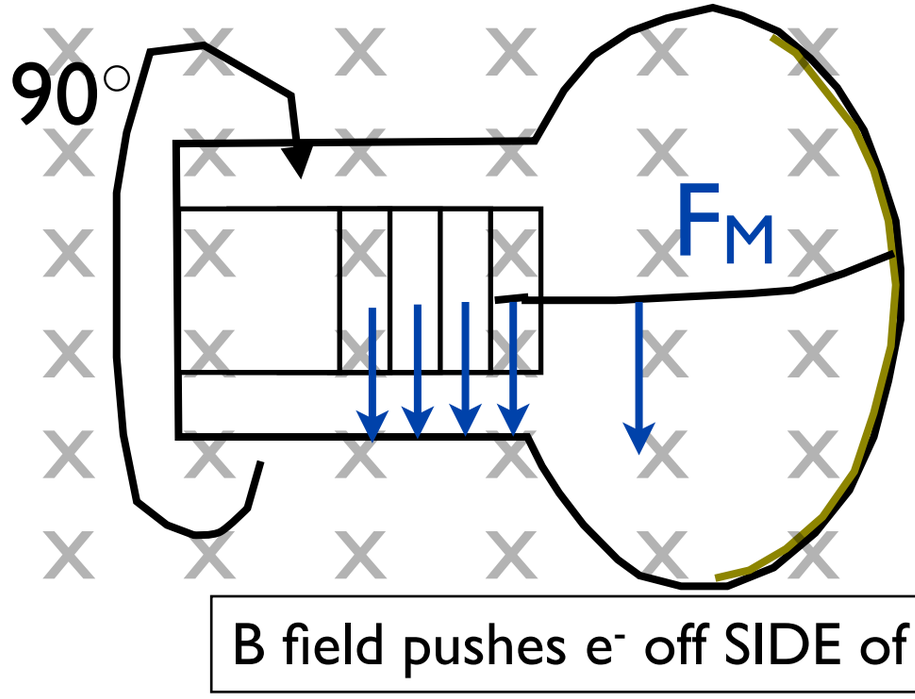
- Effect demonstrated for uB PMTs: DocDB 2119
  - Also demonstrated for other PMT experiments like:
    - Double Chooz: http://arxiv.org/abs/0905.3246v1
    - Daya Bay: http://arxiv.org/abs/1109.4666 - using Hamamastu R5912

Magnetic Field Effects on uB PMTs

- In MicroBooNE, all PMTs face the same direction, but can have different rotations:



B field pushes e^- off END of dynodes

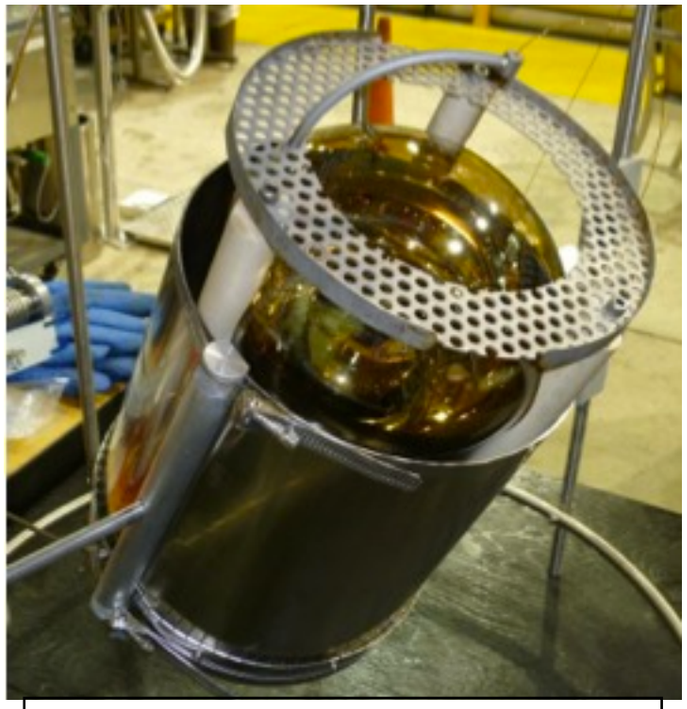


B field pushes e^- off SIDE of dynodes

- Net results:
  - Overall gain reduction for all PMTs - Easily remedied by raising baseline HV
  - **Different B-field effects for different PMTs**
- Possibility of wider overall PMT gain distribution
  - Not optimal for a scintillation detector: want a sharp SPE peak distribution for each PMT channel over time, and summed over all channels

Magnetic Shields on uB PMTs

- Effect can be reduced or removed by surrounding PMT with metal of low magnetic permeability
- Positively demonstrated in DocDB 2119 for:
  - uB PMTs at room temperature
  - uB PMTs in liquid nitrogen
  - Magnetic shields of various materials, heights



PMT shielded to equator

PMT shielded to photocathode zenith

Study Goals

- Study goals are to answer two main design questions:
- **Will shields be useful for MicroBooNE?**
  - Check reduction of B-field effect on uB PMTs in their true operational orientation
- **How tall should the shields be?**
  - Check reduction of B-field effect in operation orientation for various shield heights
- With these 2 questions answered, magnetic shield design can be finalized so that overall PMT designs can be finalized and orders can be made.
  - Preferred shielding material already identified in DocDB 2119
  - Effectiveness of shields at low temperature already demonstrated in DocDB 2119

Test Setup

- Insulating dark box with in which PMT and LED-connected fiber can be rotated together 360◦ about one axis
- Entire apparatus can be rotated on dolly to achieve uB alignment

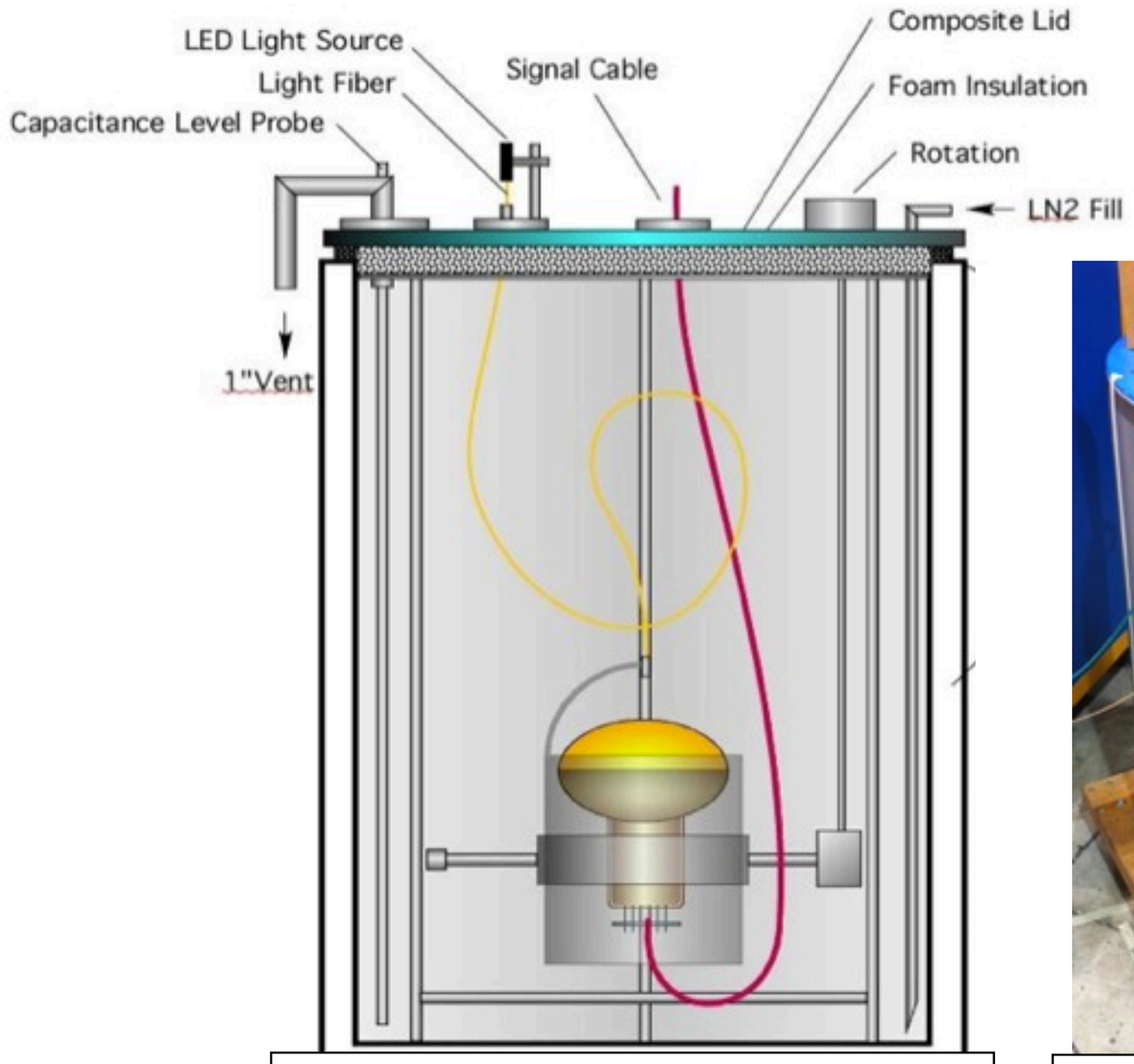
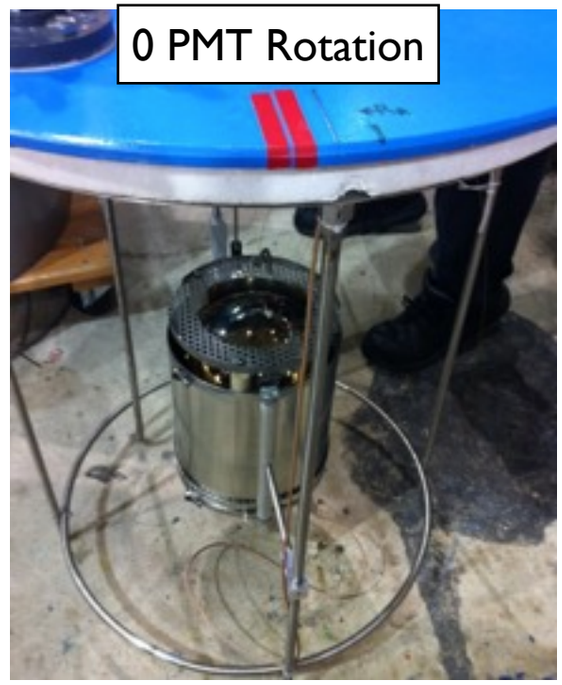


Diagram of dark box and inner components

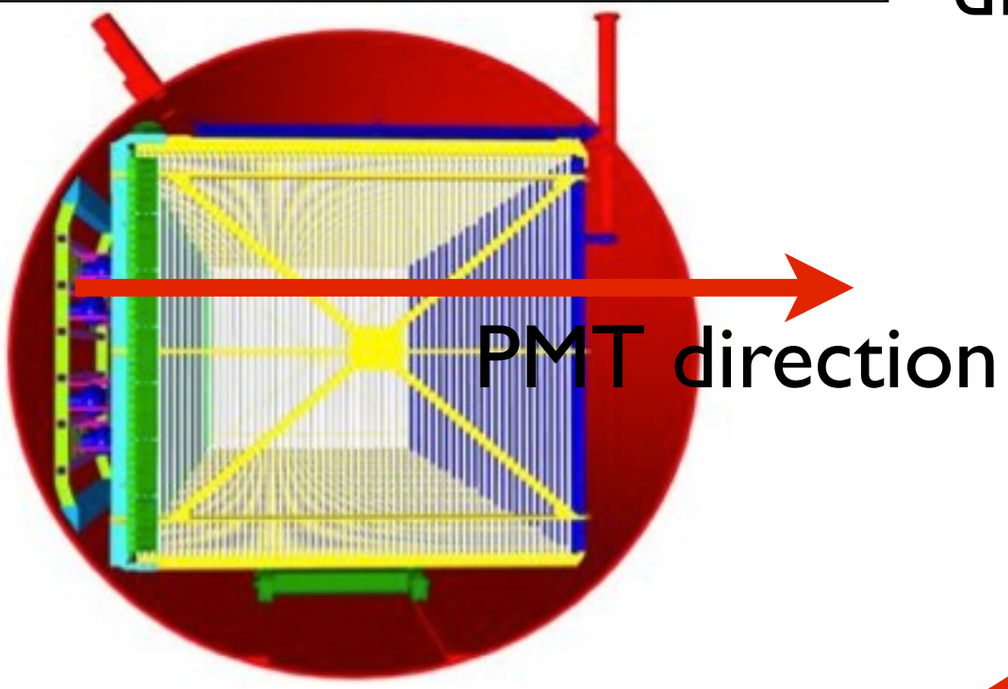
Outer view of dark box and dolly



Achieving uB PMT Alignment

- Get uB PMT direction WRT beamline
- Get beamline direction WRT Proton Assembly Building wall
- Get test PMT direction WRT dark box and dolly references
- Set dark box rotation WRT PAB wall to properly align test PMT and uB PMT direction

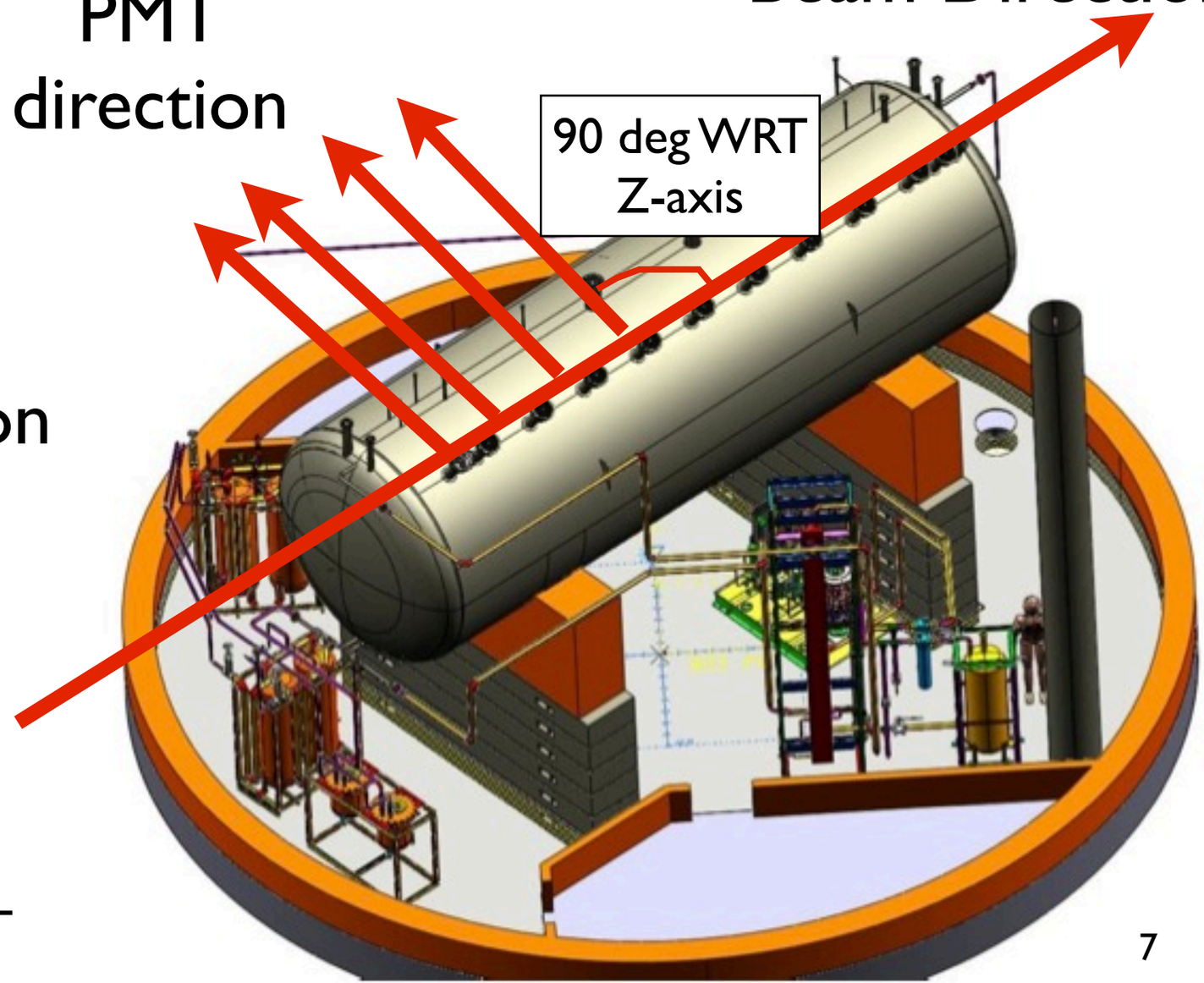
PMT Direction parallel to ground, rotated 90 degrees WRT beam from a bird's eye view



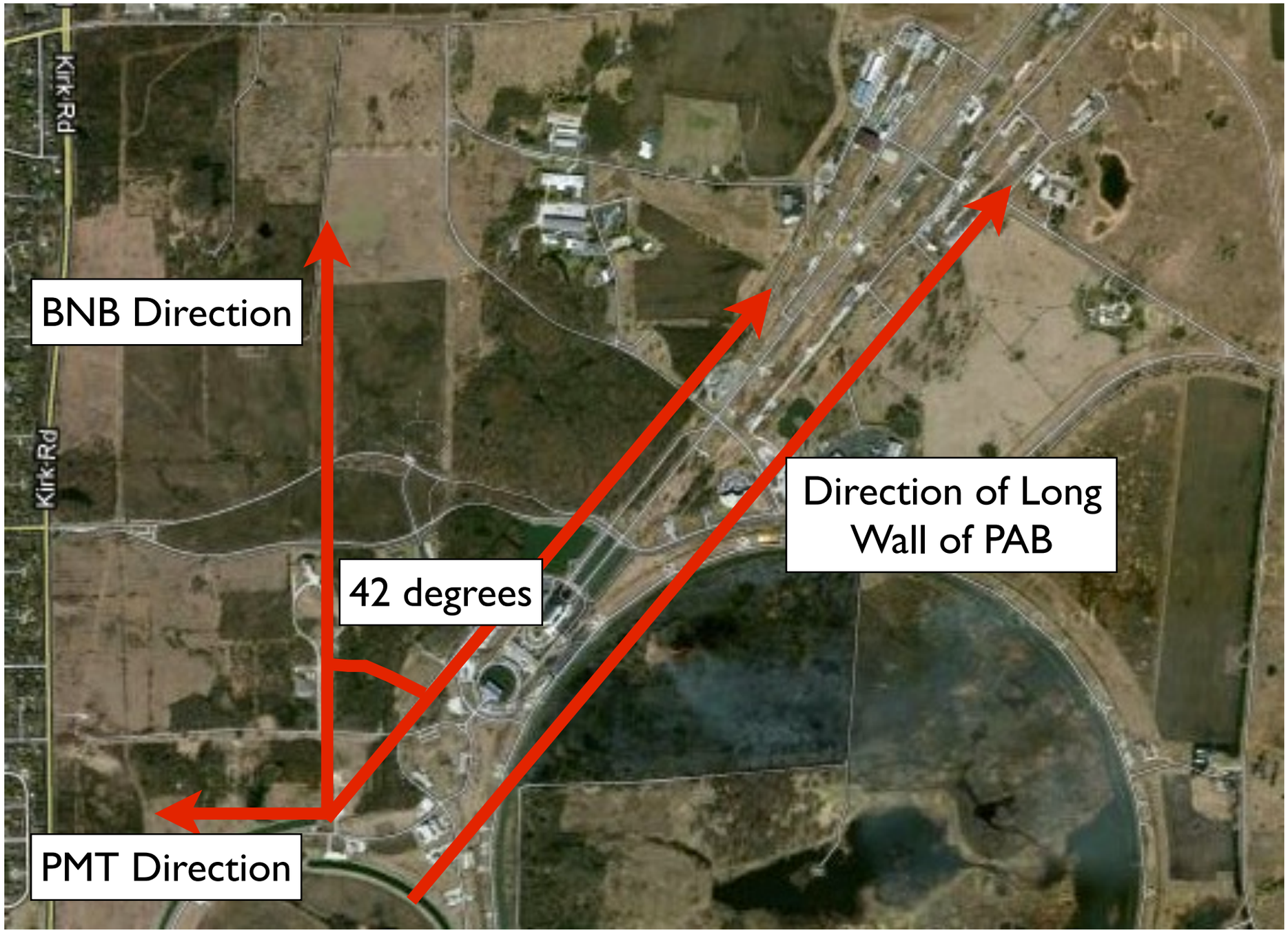
Beam Direction out of page

PMT direction

Beam Direction

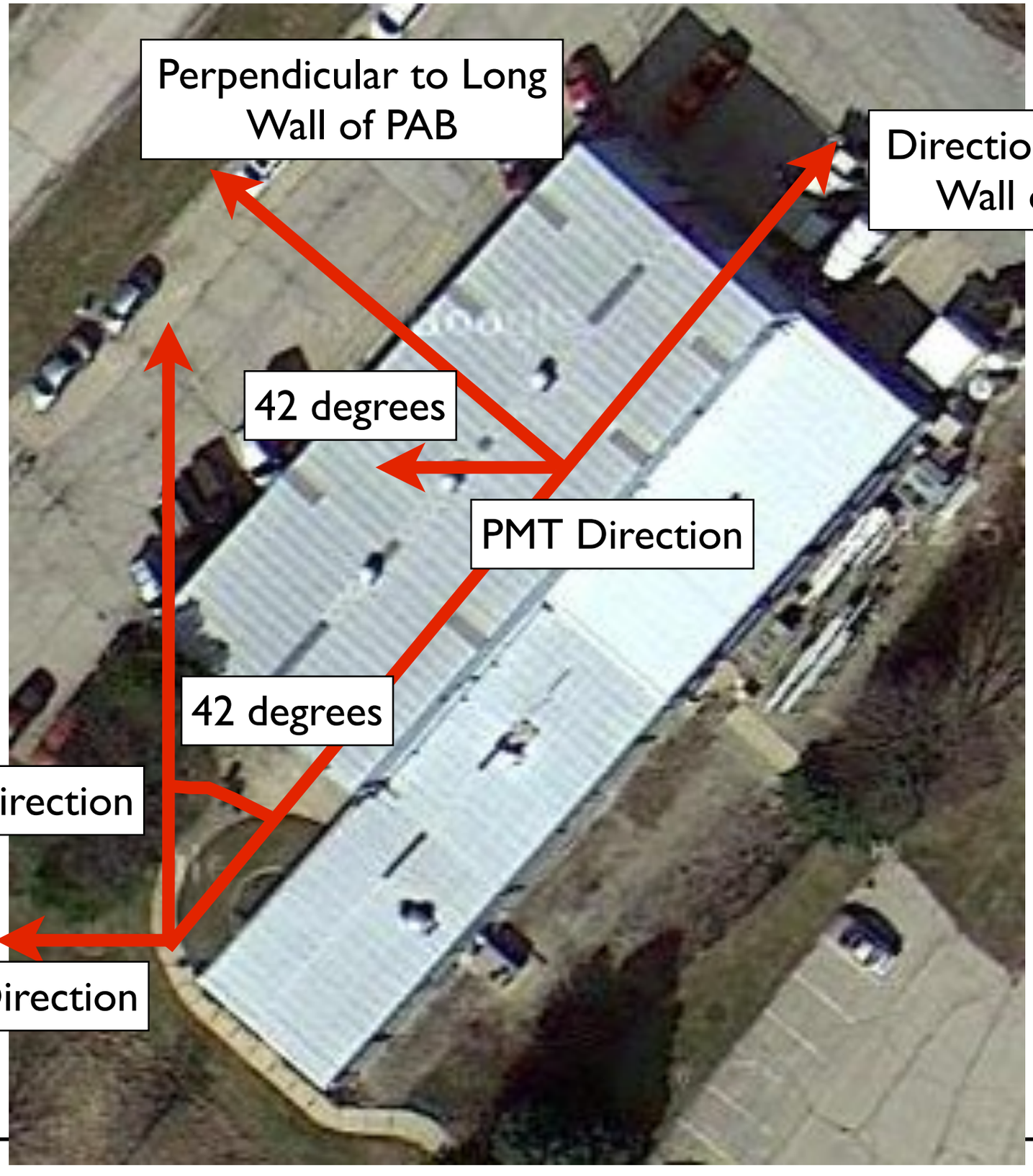


Achieving uB PMT Alignment

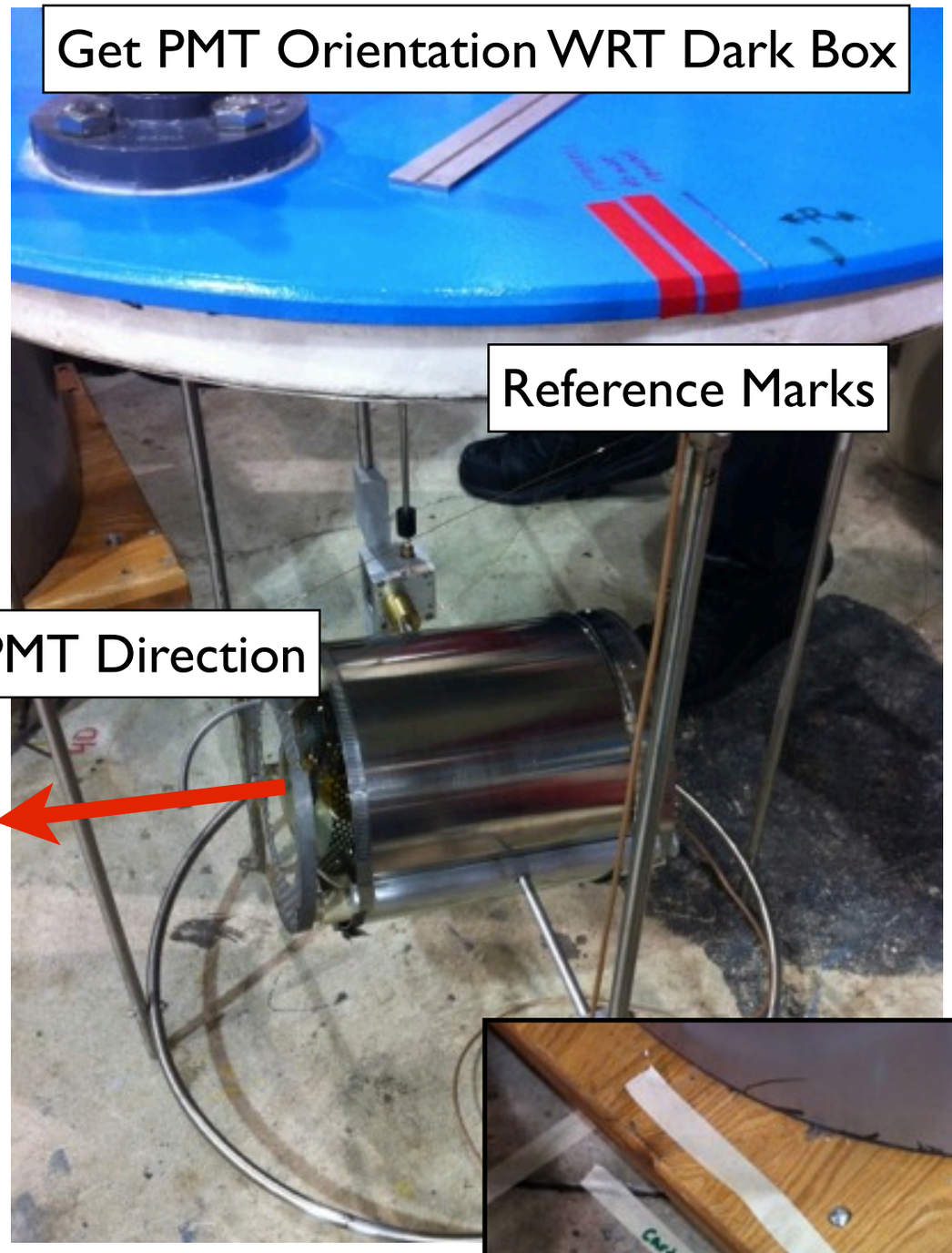


Achieving uB PMT Alignment

Test PMT should be oriented at a 42 degree angle WRT the PAB long wall to replicate PMT orientation in MicroBooNE



Get PMT Orientation WRT Dark Box



Reference Marks

PMT Direction

Set Dark Box/Dolly Orientation WRT PAB Wall

Direction of Long Wall of PAB - along concrete seam

Necessary dolly orientation for PMT alignment

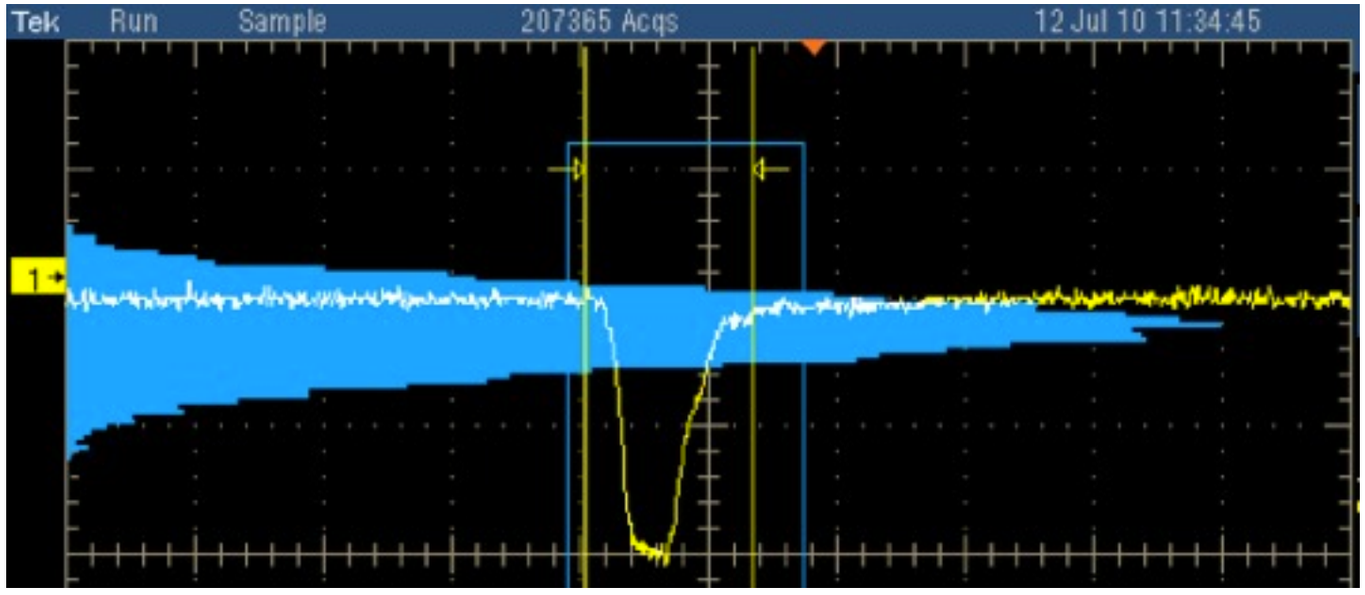
Perpendicular to Long Wall of PAB

PMT Direction

BNB Direction

Data Acquisition and Analysis

- Determine average gain for 0-180 degree PMT orientation
  - PMT output is sent to a scope triggered on the LED pulse
  - Scope integrates PMT pulse (yellow) and stores total charge in histogram (blue)



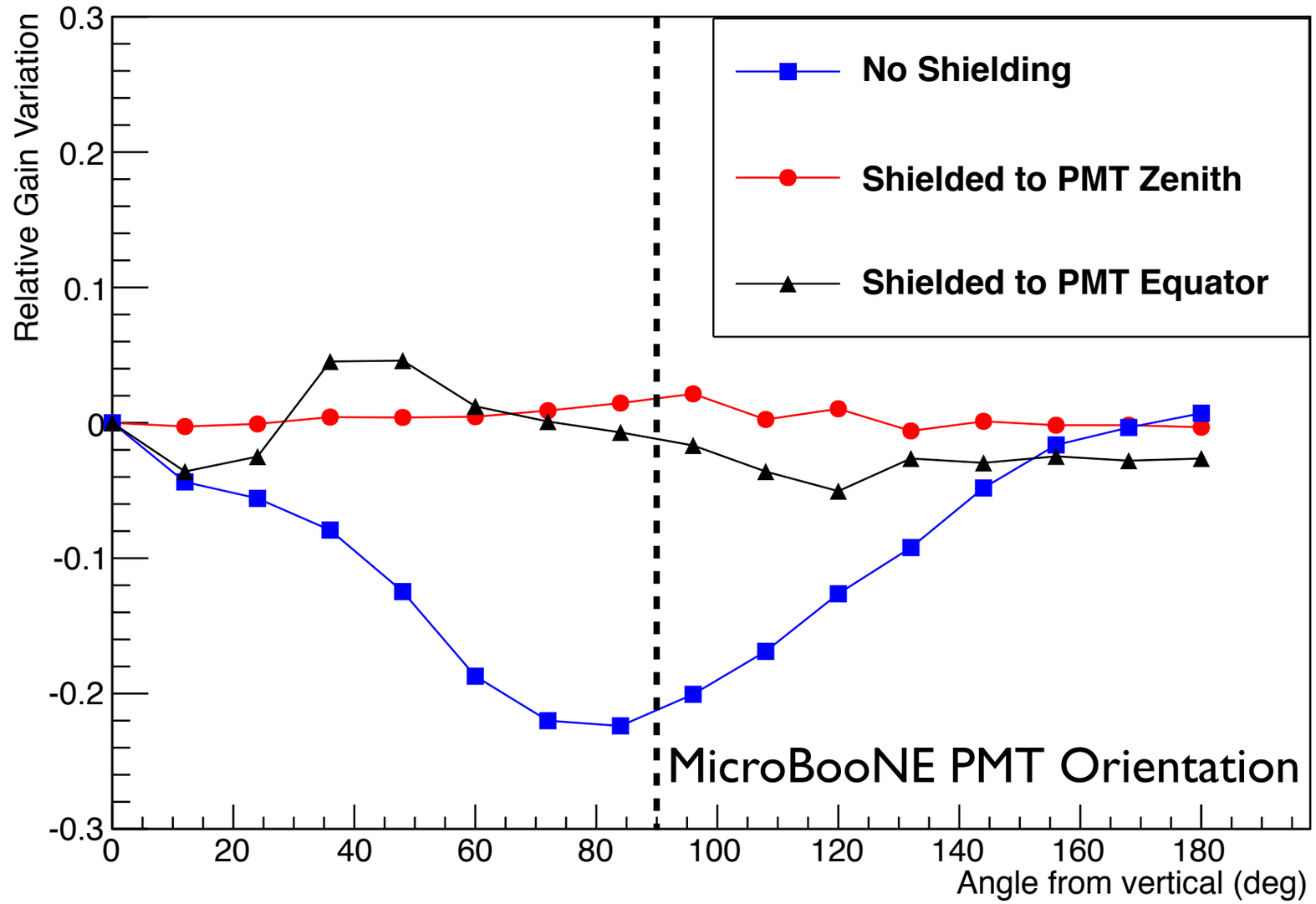
  - Record mean and sigma of resulting histogram: 2-20 min per data point
  - Change PMT direction by 12 degrees and repeat
- Note: characterizes changes in PMT direction, not rotation
  - Our thinking: if shield removes gain variations with changes in direction, it must necessarily also remove changes in rotation

Main Sources of Uncertainty

- Statistics:
  - 1e6 - 10e6 LED pulses per data point give <<1% stat. error on mean
- Systematics:
  - Temperature variations in PAB cause 5% drift in collected charge over 24 hours
    - If runs are completed over a few hours or during stable temperatures, ~1% rel. uncertainty within a run
  - Touchy cabling connections
    - Can cause 1-10% jump in collected charge from one data point to another in a run
    - Try to avoid this by being very careful with cabling
  - Large offsets in gain after opening dark box, adjusting PMT/fiber/magnetic shield
    - Large and not fully characterized absolute uncertainty between runs
    - Will not affect relative trends within one run

Results

- Effect of Earth's B-field on MicroBooNE PMT gains is clearly substantial
- Stability increases significantly with magnetic shields installed
- Both the 'zenith' and 'equator' positions appear to provide an equal amount of shielding



  - Cannot resolve any residual gain variations lower than 5% because of measurement systematics

Conclusions

- Magnetic shields should be included in MicroBooNE PMT design
  - Will help ensure a more even gain distribution regardless of PMT rotations
- Magnetic shields at PMT equator and zenith heights both remove PMT gain variations equally well
  - Conclusion supported by DocDB 2119
  - This criterion is now neutralized in determining which magnetic shield height is best
  - Absolute change in gain with shield height not measured
- Previous study has answered other design questions:
  - Shields still work at low-temperatures
  - A4K shielding material is best: effective and cheap
- Any remaining barriers to finalizing uB shield design?