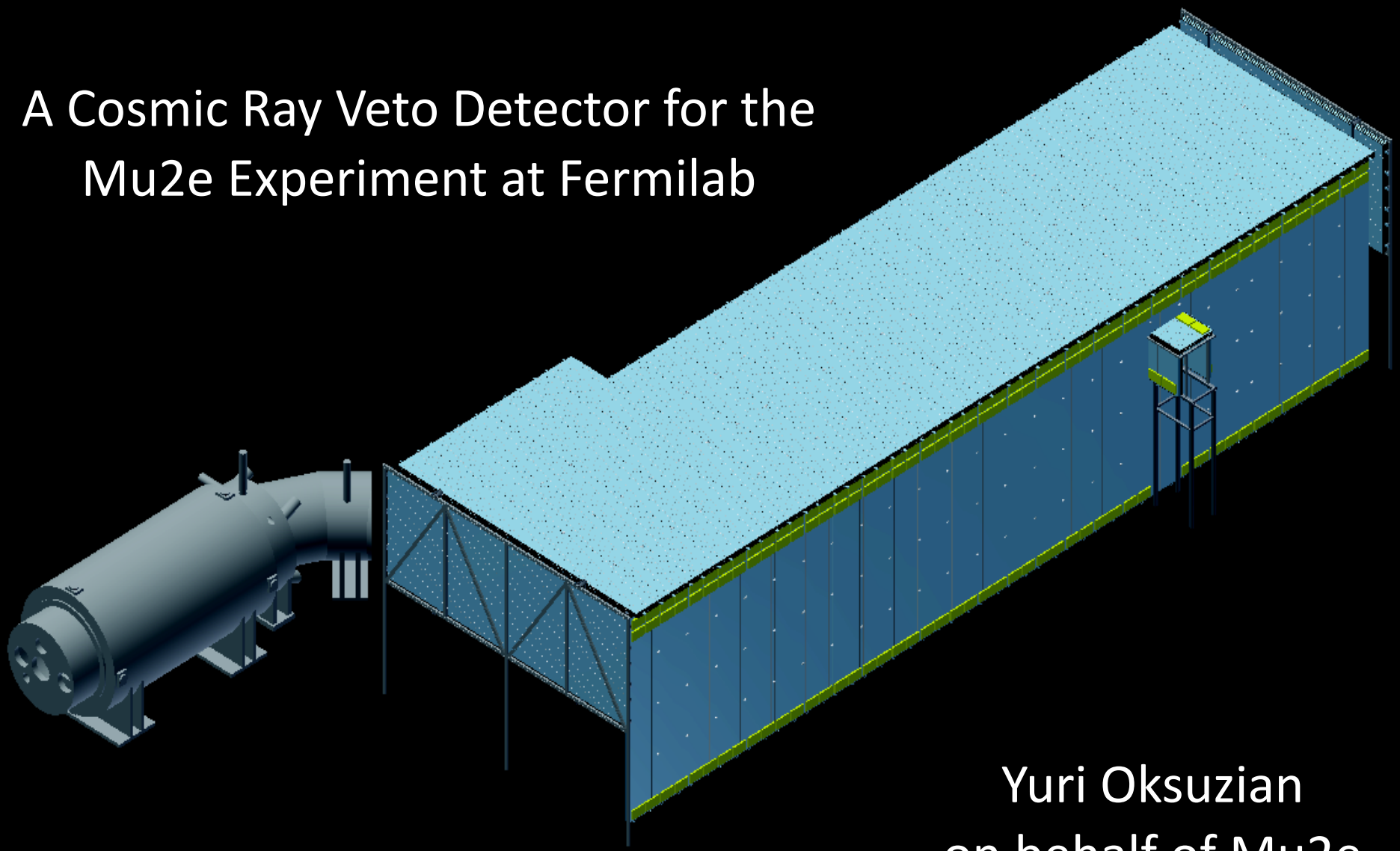
A Cosmic Ray Veto Detector for the Mu2e Experiment at Fermilab



Yuri Oksuzian
on behalf of Mu2e

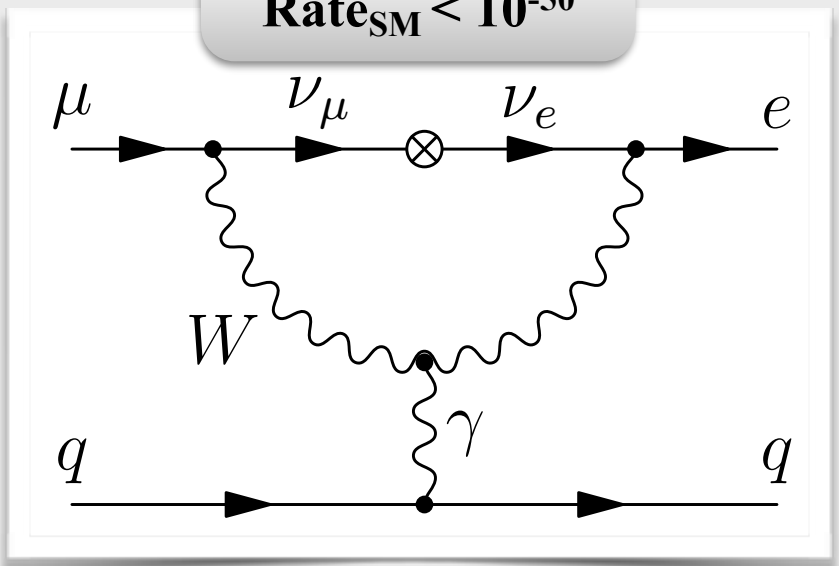
Mu2e

- Fermilab is actively pursuing the searches with high intensity beams: NOvA, Short-baseline neutrino, DUNE, Muon g-2, Mu2e…
- Mu2e will search for neutrino-less, coherent muon conversion into an electron

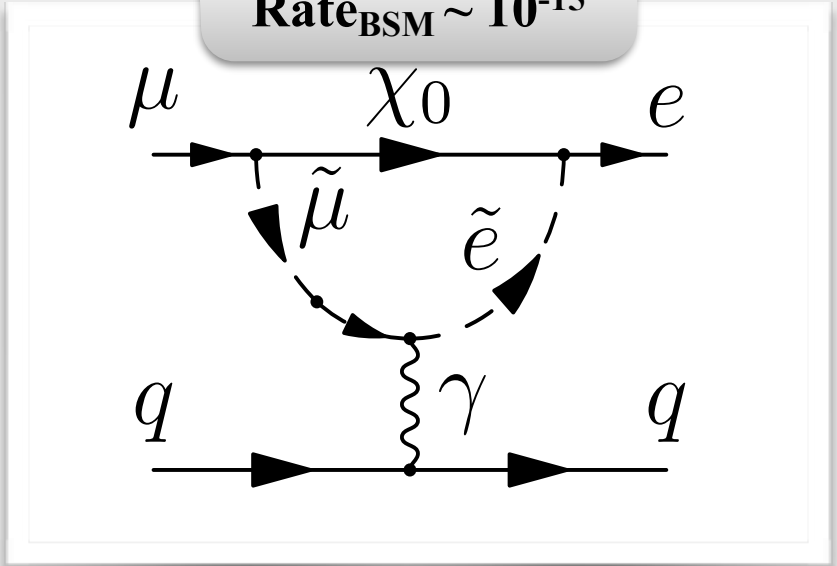
$$\mu^- + N \rightarrow e^- + N$$

- In the SM, $\mu \rightarrow e$ occurs at the rate of $<10^{-50}$
  - Signal observation at Mu2e is unambiguous sign of new physics
  - Indirectly probing high mass scales ($>10^4$ TeV)

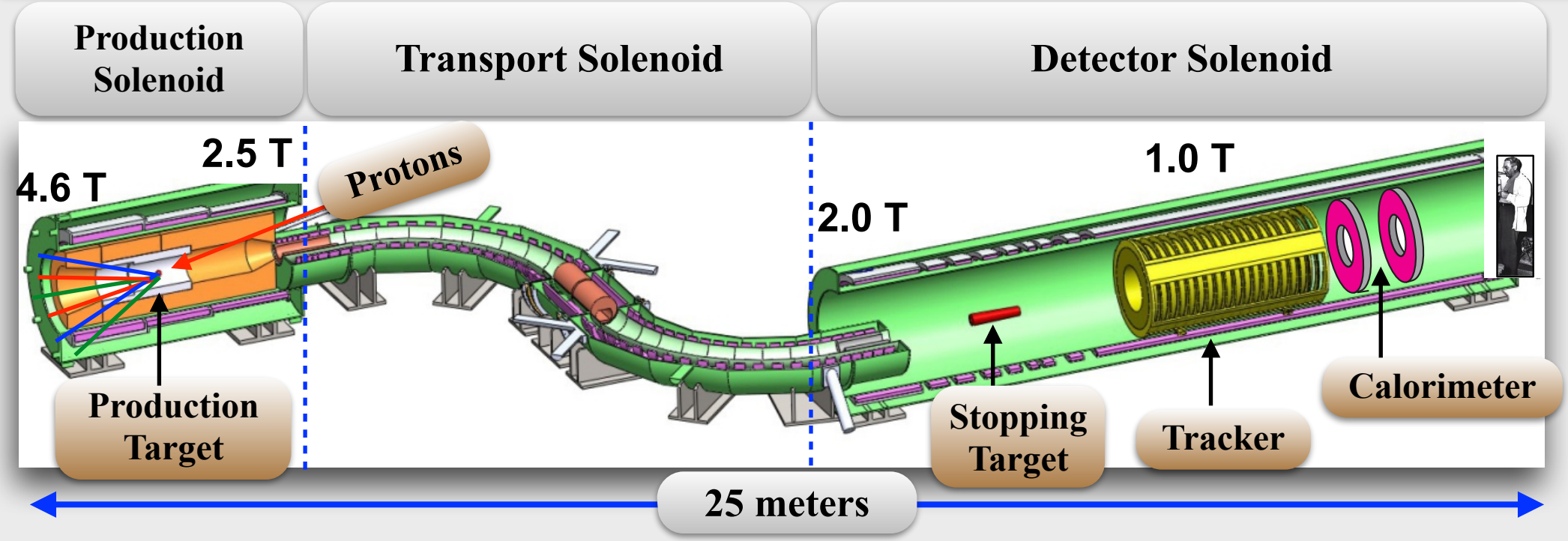
$\text{Rate}_{\text{SM}} < 10^{-50}$



$\text{Rate}_{\text{BSM}} \sim 10^{-15}$



Mu2e apparatus



(1) Pulsed 8 GeV proton beam strikes production target to produce π^-
  – Graded B-field reflects pions toward the transport solenoid
(2) Trasport solenoid:
  – Transports π^-/μ^- , selects particle's momentum and charge, avoids direct line of sight
(3) Muons stop on Al stopping target
  – Conversion electron momentum and energy are measured in the tracker and calorimeter

See Marc BUEHLER talk

Mu2e@DPF

- Various components of Mu2e are covered at DPF
- Four talks and two poster on Cosmic Ray Veto

Tue 16:45	A Cosmic Ray Veto Detector for the Mu2e Experiment at Fermilab (Yuri OKSUZIAN, University of Virginia)
Tue 17:00	Performance of Scintillation Counters with Silicon Photomultiplier Readout (Yongyi WU, University of Virginia)
Tue 17:15	Radiation Damage Testing of Silicon Photomultipliers for the Mu2e Experiment (Vishnu ZUTSHI, Northern Illinois University)
Tue 17:40	The Mu2e Experiment at Fermilab (Marc BUEHLER, Fermi National Accelerator Laboratory)
Wed 15:54	Beam Extinction and Monitoring at the Upcoming Mu2e Experiment (Ryan HOOPER, Lewis University)
Wed 16:45	A Straw Tube Tracker for the Mu2e Experiment (Daniel AMBROSE, University of Minnesota)
Fri 14:30	The Mu2e electromagnetic calorimeter (Tomonari MIYASHITA)
Fri 14:45	Studies of Beam Induced Radiation Backgrounds at the Mu2e Experiment and Implications for the Cosmic Ray Veto Detector Operations (Yuri OKSUZIAN, University of Virginia)

Mu2e Sensitivity

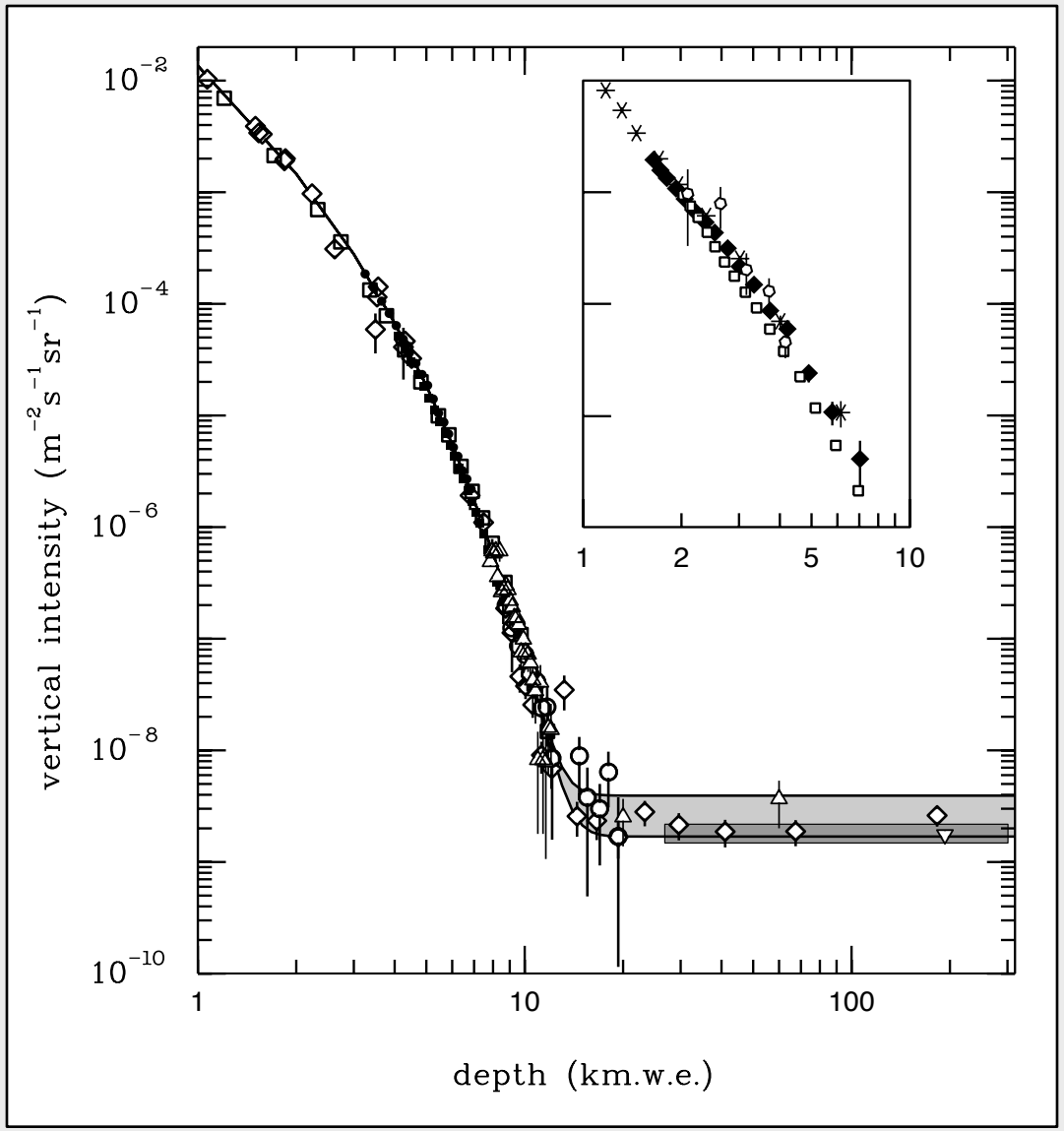
Mu2e will measure the ratio of $\mu \rightarrow e^-$ conversions to the number of muon captures by Al nuclei:

$$R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)}$$

- Mu2e single event sensitivity: $R_{\mu e}$ = 2.5×10^{-17}
  - Almost 4 orders of magnitude improvement to the current best limit
  - Expect 40 events at $R_{\mu e}$ = 10^{-15}
- Need to keep background small and well understood
  - Total expected background 0.4 events
  - Total expected background from cosmic rays 0.08 events

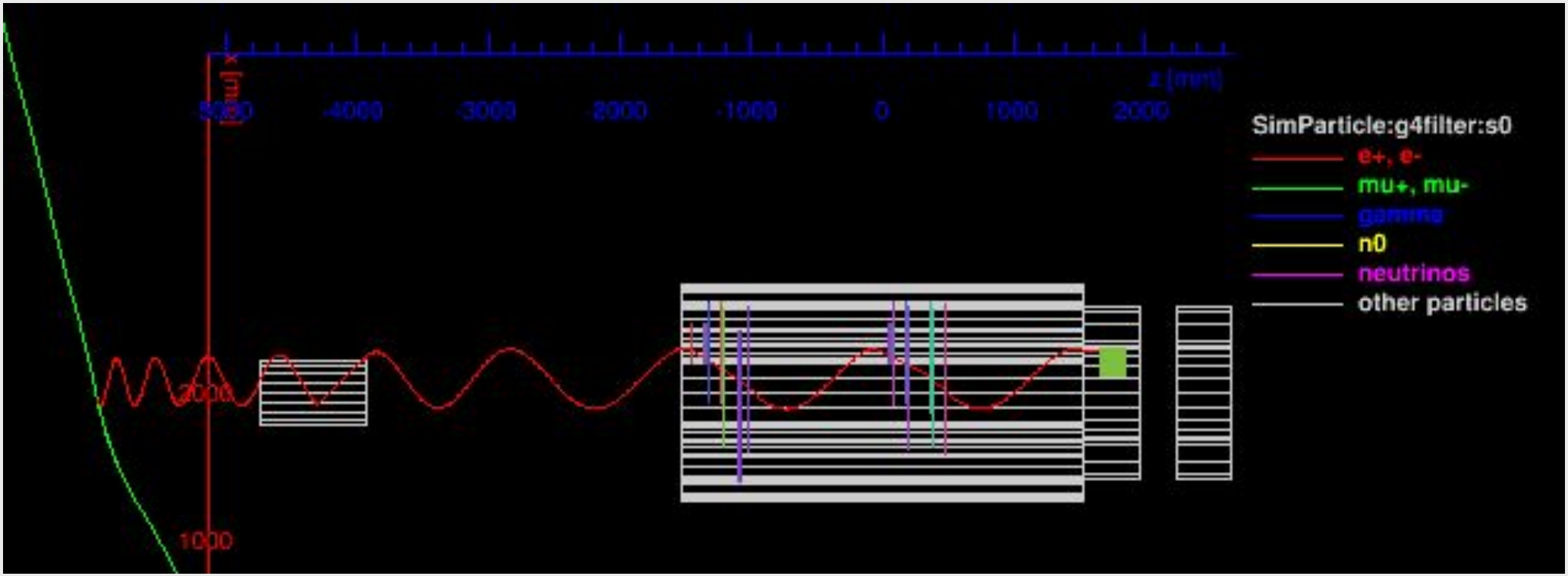
Cosmic Ray Background

- Mu2e expects 1 signal-like event per day induced by cosmic rays
- Need to build the detector several km under the ground
- …or cover Mu2e detector solenoid with an active shielding



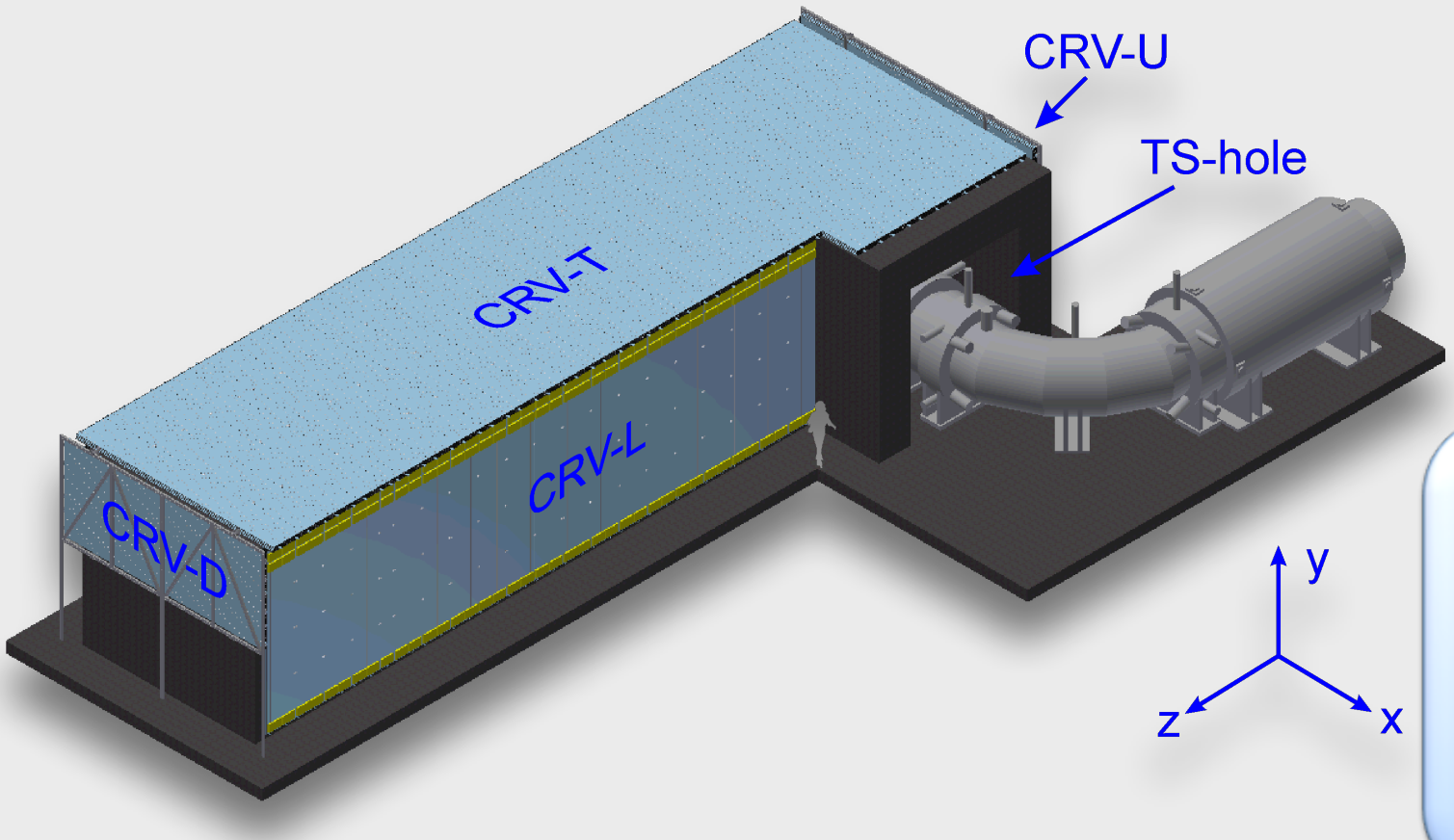
Cosmic Ray Background Event

- Cosmic rays can interact with detector components producing 105 MeV electron, faking a conversion signal
- We simulated 28 billion cosmic ray muons, only 2% of total number expected over experiment lifetime
- In addition we simulated the full experiment lifetime for the region with poor CRV coverage
- To achieve experiment's designed sensitivity, cosmic ray veto inefficiency is required to be no worse than 10^{-4}



Cosmic Ray Veto

- Cosmic Ray Veto(CRV) consists of 4-layer scintillating counters
- We require hit coincidence in at least 3 out of 4 layers localized in time and space for a cosmic ray muon track
- We veto 125 ns from the signal window after each coincidence in the CRV

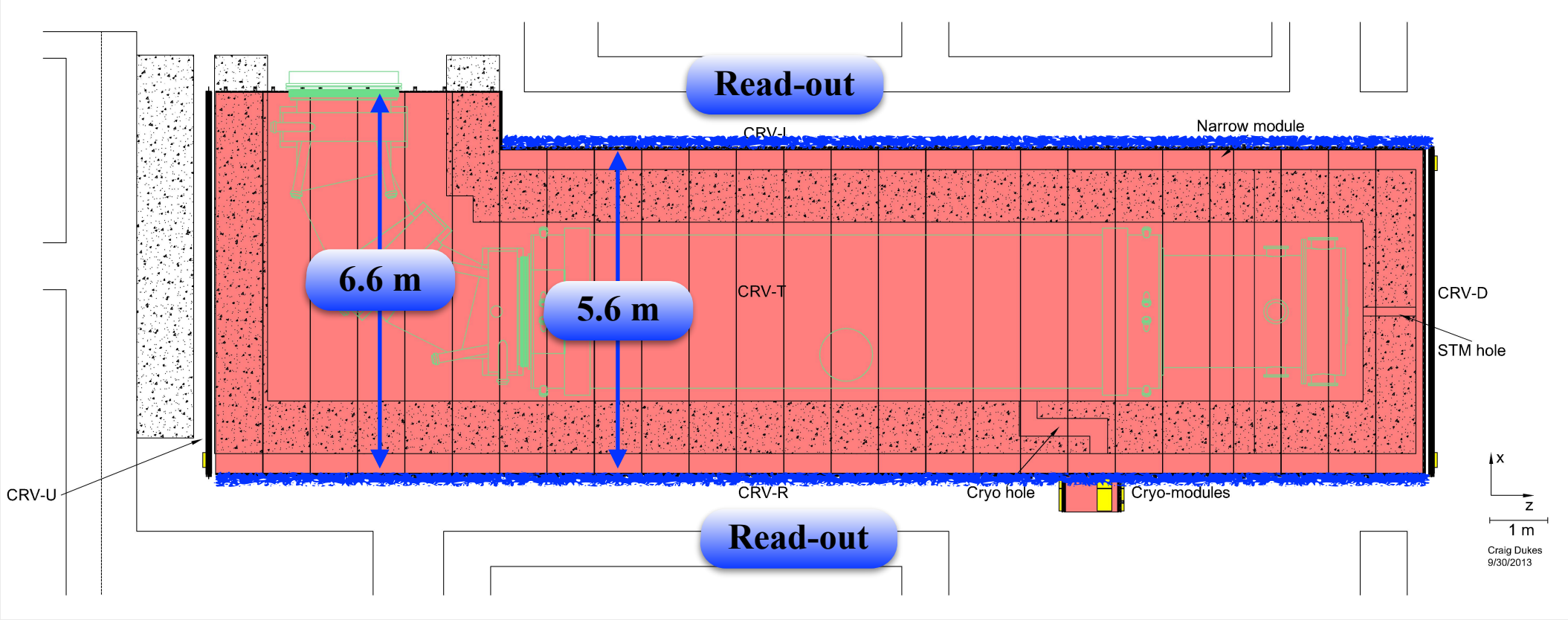


CRV details:

- Area: 323 m^2
- 82 modules
- 55 tons of counters
- 50 km of fibers
- 18,944 SiPMs

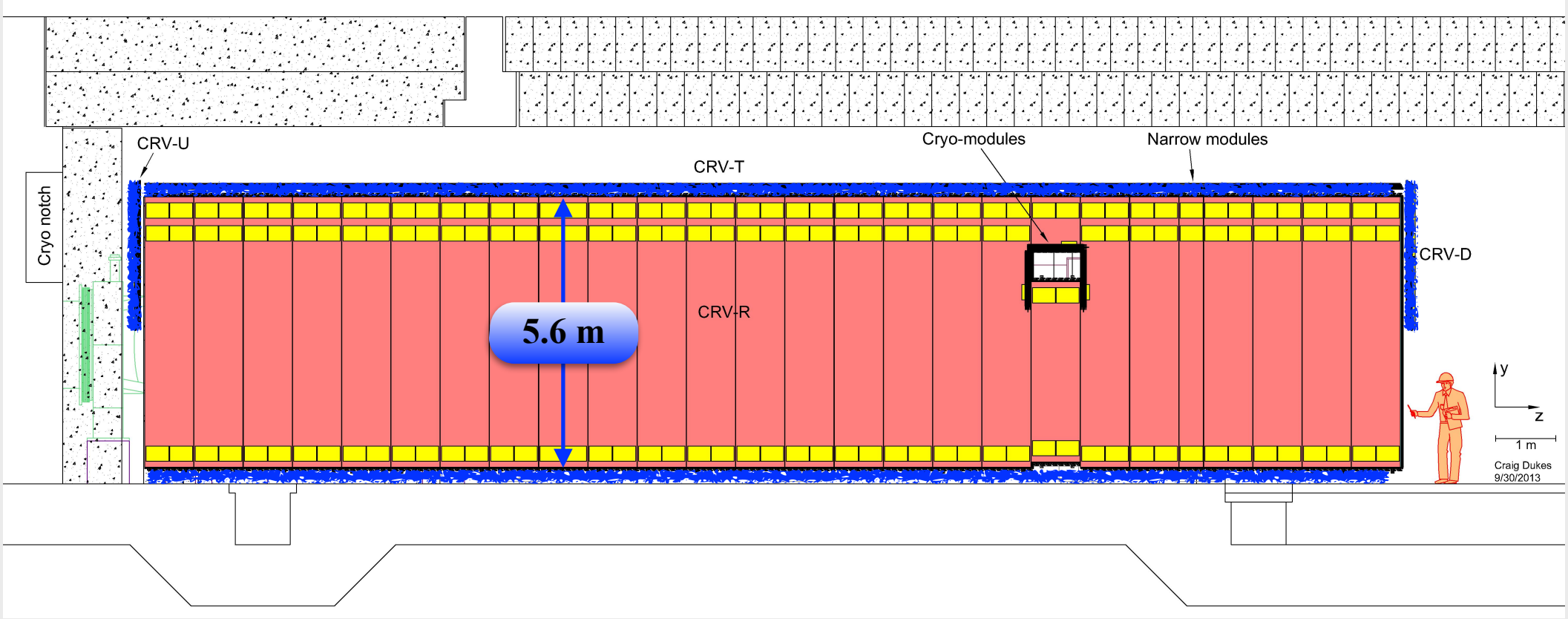
CRV design (top-view)

- Top-view at the CRV
- Top region of the CRV consists of
  - Extra-long (6.6 m) counters in transport solenoid region read out from one side
  - Long counters (5.6 m) counters in detector solenoid region readout from both sides



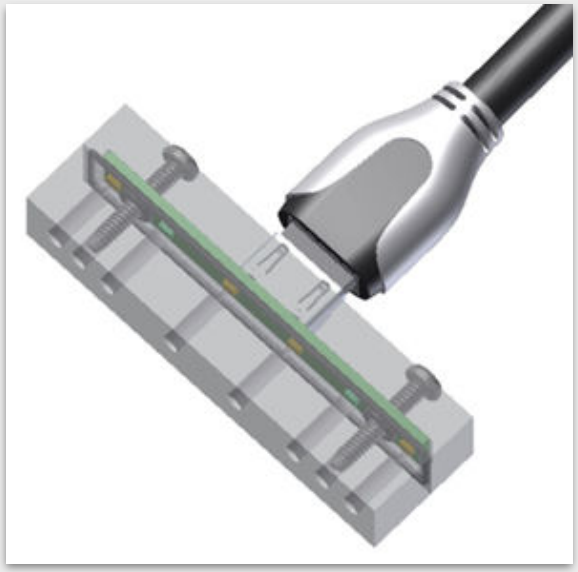
CRV design (side-view)

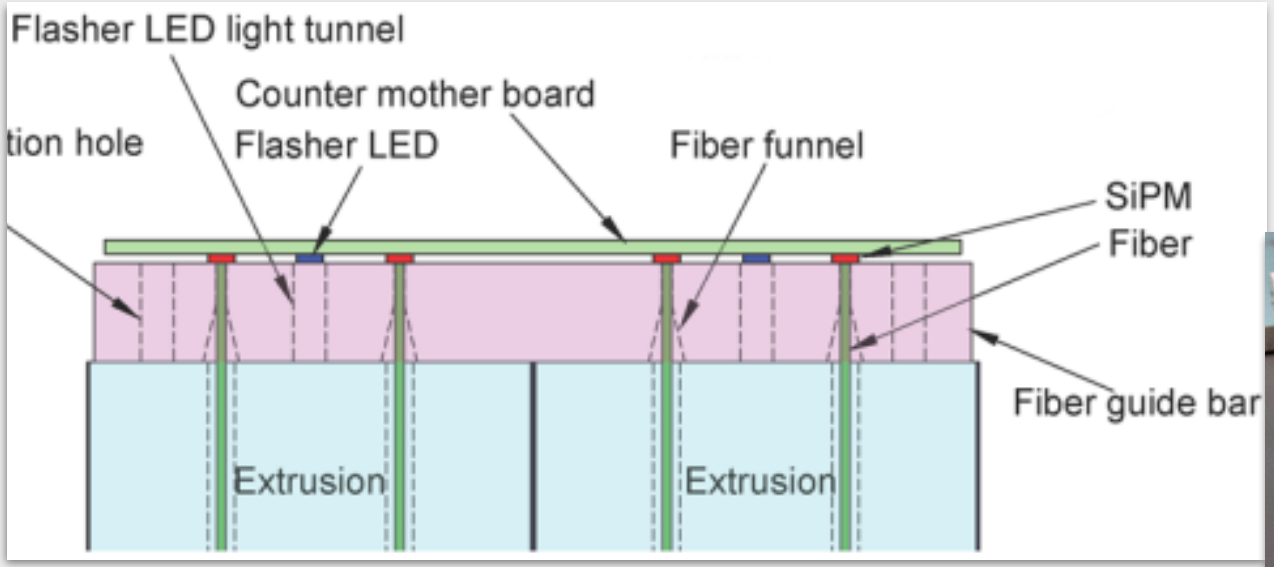
- Side-view at the right region of CRV
- Right region of the CRV consists of
  - Medium (4.5 m) counters
  - Special size counter modules are designed for cryo penetration region



CRV counter

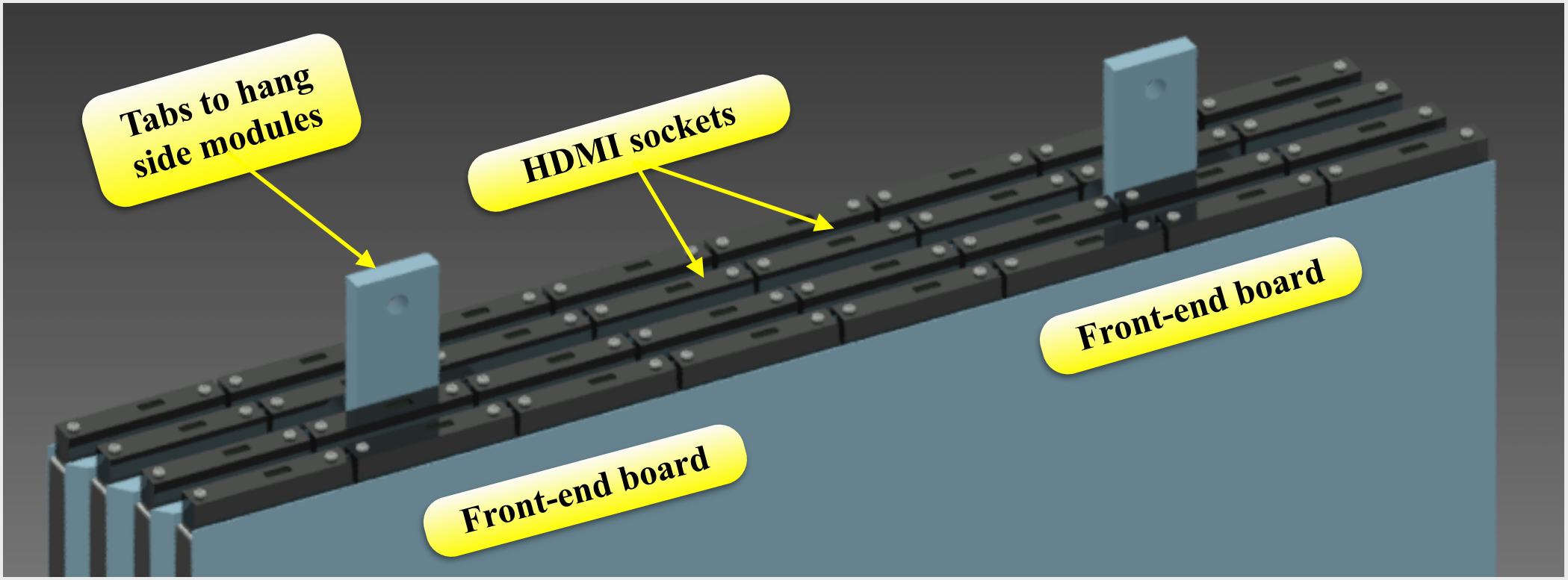
- Extruded polystyrene scintillator counters: 50 x 20 x 900-6600 mm^3
- Two Kuraray Y11 non-S type, 1.4-mm diameter wavelength shifting fibers
- Readout: 2x2 mm^2 SiPMs on each fiber end
  - Two fibers per extrusion, up to four SiPMs for readout
  - Each counter (except TS region) read out on both ends
- Glue two extrusions together to form di-counters
  - Each di-counter is read out by one counter motherboard





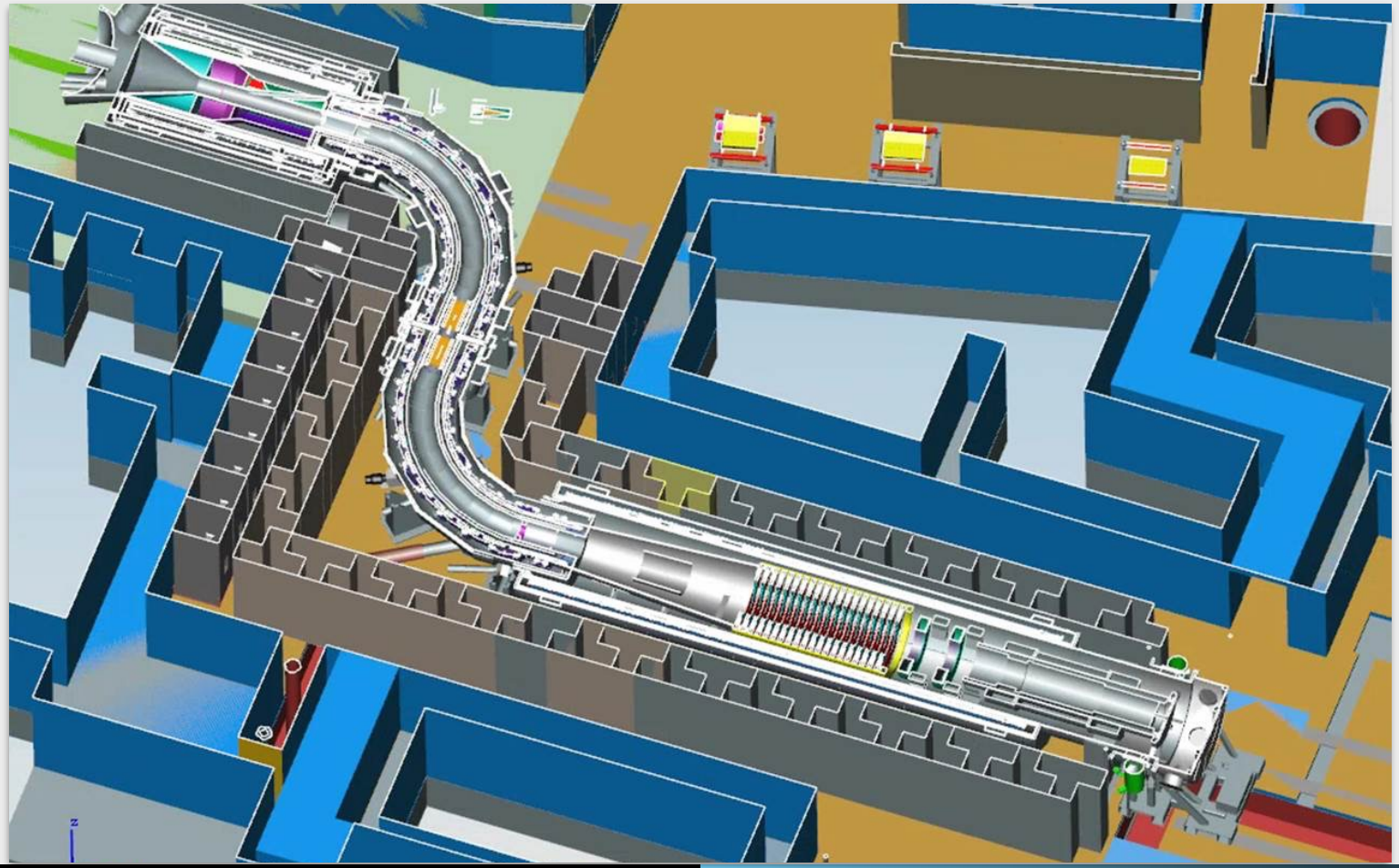
CRV module

- Four layers of counters with 3 layers of Al absorbers sandwiched between them: 16 counters/layer
- Layers are offset to avoid projective gaps between layers
- Total: 82 modules; two widths, five different lengths



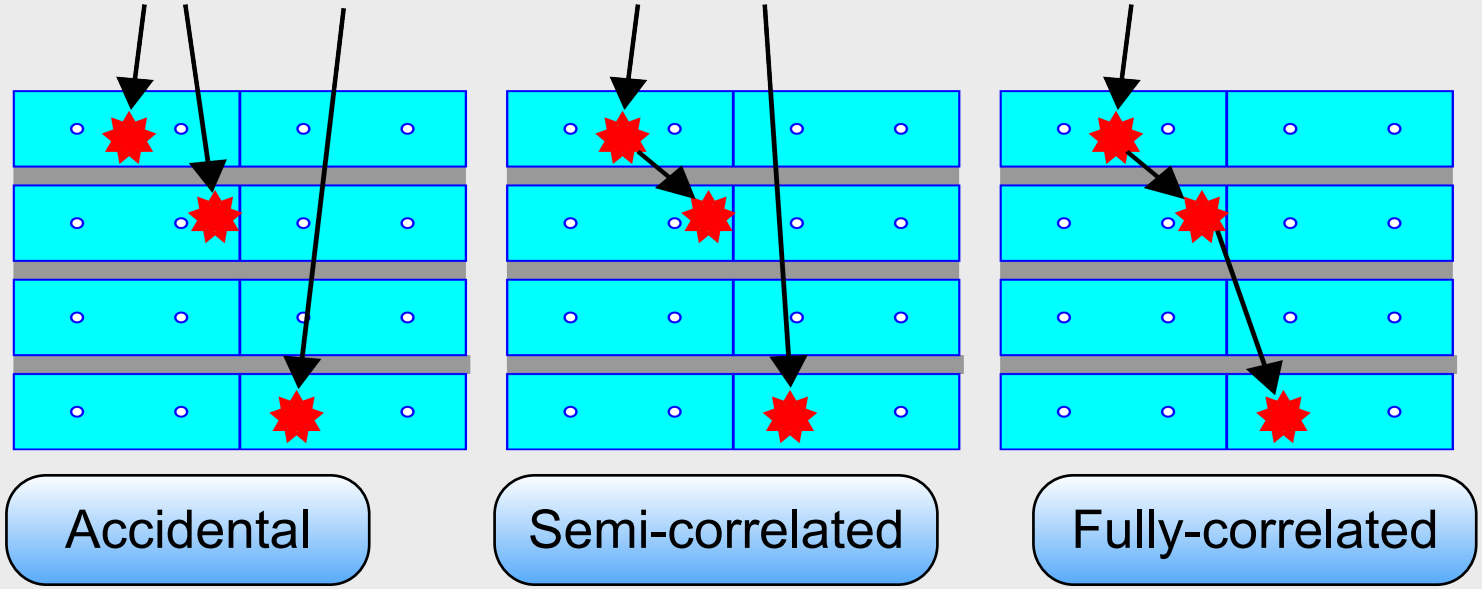
CRV shielding

- CRV needs to be shielded from the beam induced radiation backgrounds
- CRV is mounted on 1 yd of concrete wall
- T-shaped concrete blocks are designed to avoid direct cracks
- Region close to PS/TS is enhanced with heavy barite enriched concrete



Radiation background noise

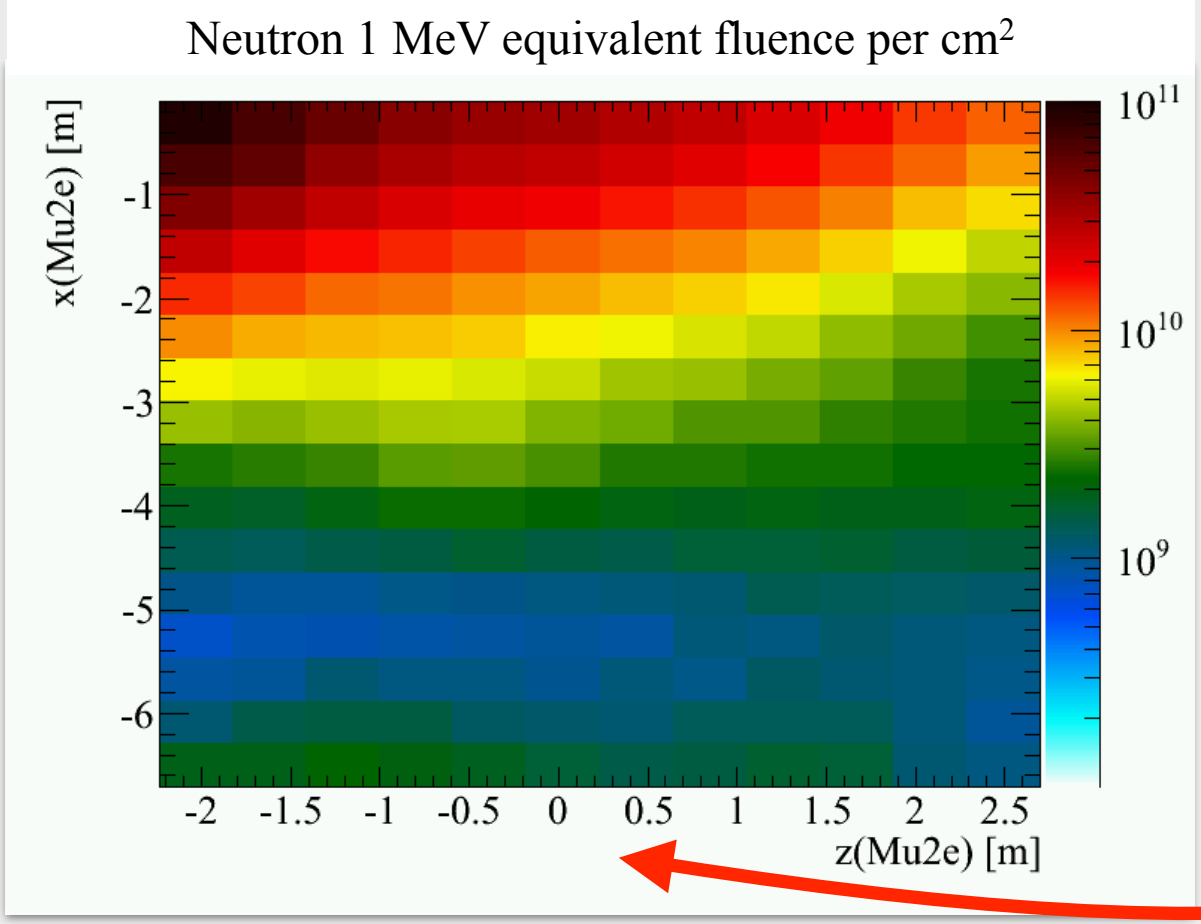
- Neutron and gamma fluxes from beam interactions cause problems to CRV operations
  - Produce hits at the CRV, faking cosmic ray muons, increasing the dead-time

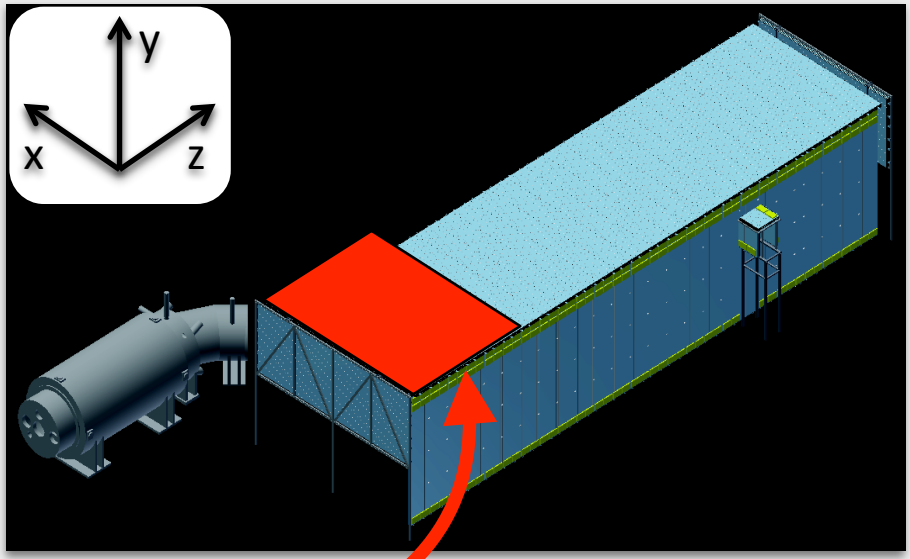


- The first detailed simulation results show the expected CRV dead-time is 12% (Y. Oksuzian)

Radiation damage

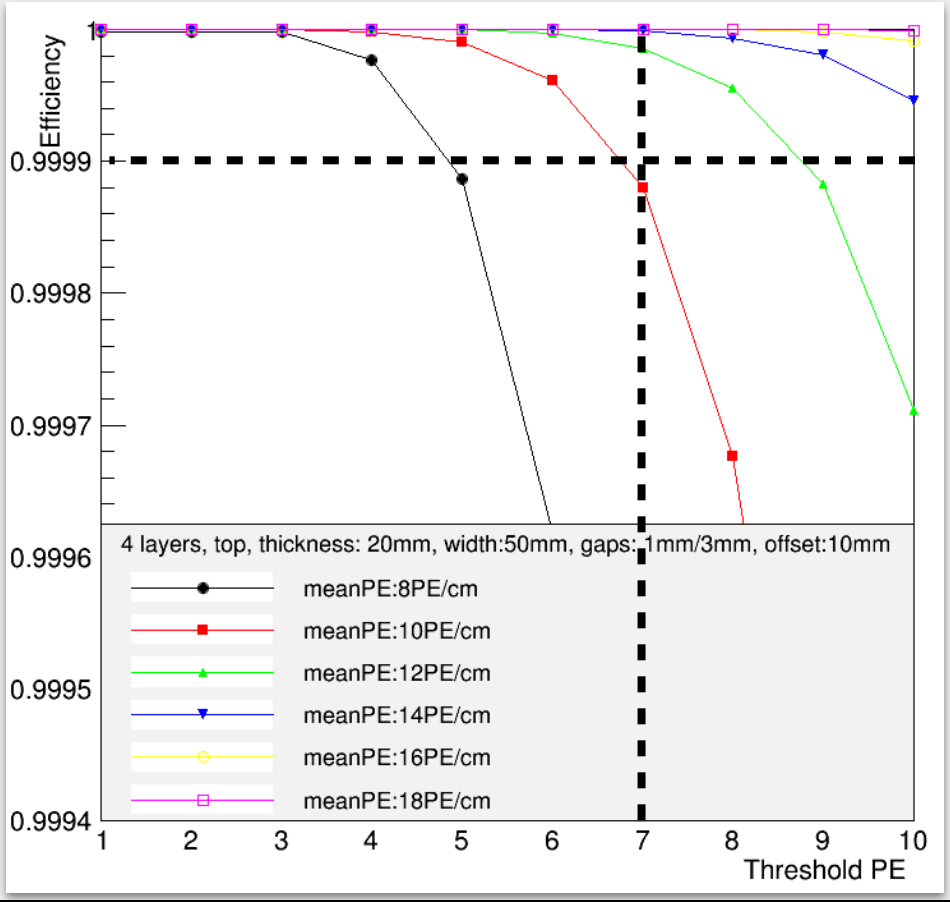
- Neutrons damage the CRV read-out components
- The modules in the hottest region are read-out only from one side
- The radiation level at the CRV readout is > 5E9 n/cm^2
- No significant impact to read-out components at this level (V. Zutshi)

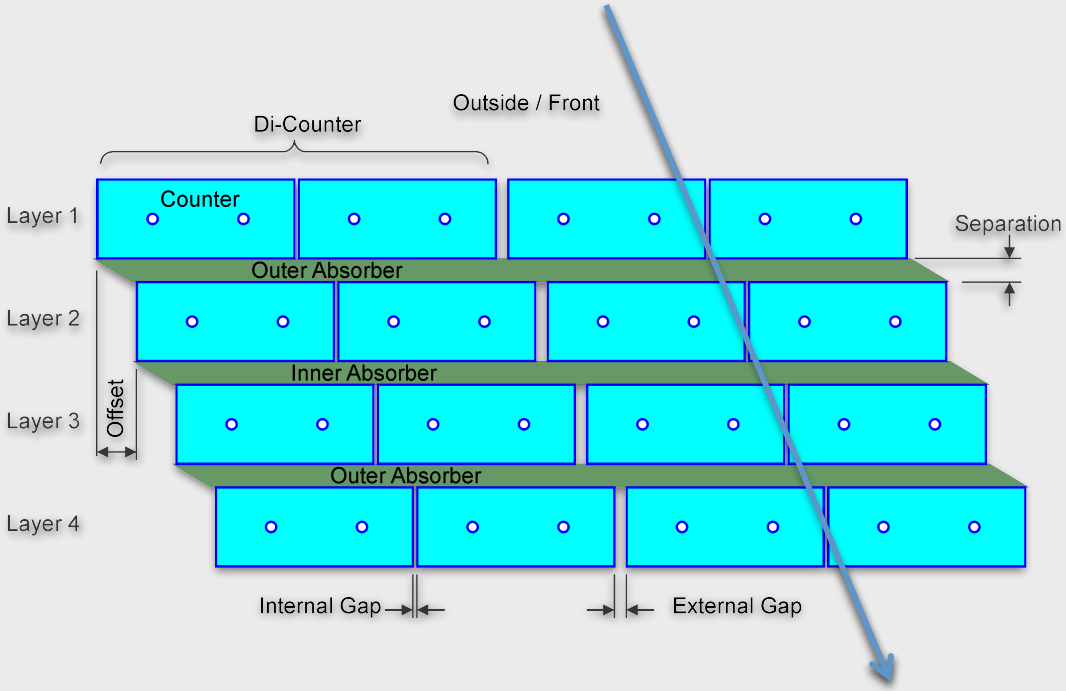




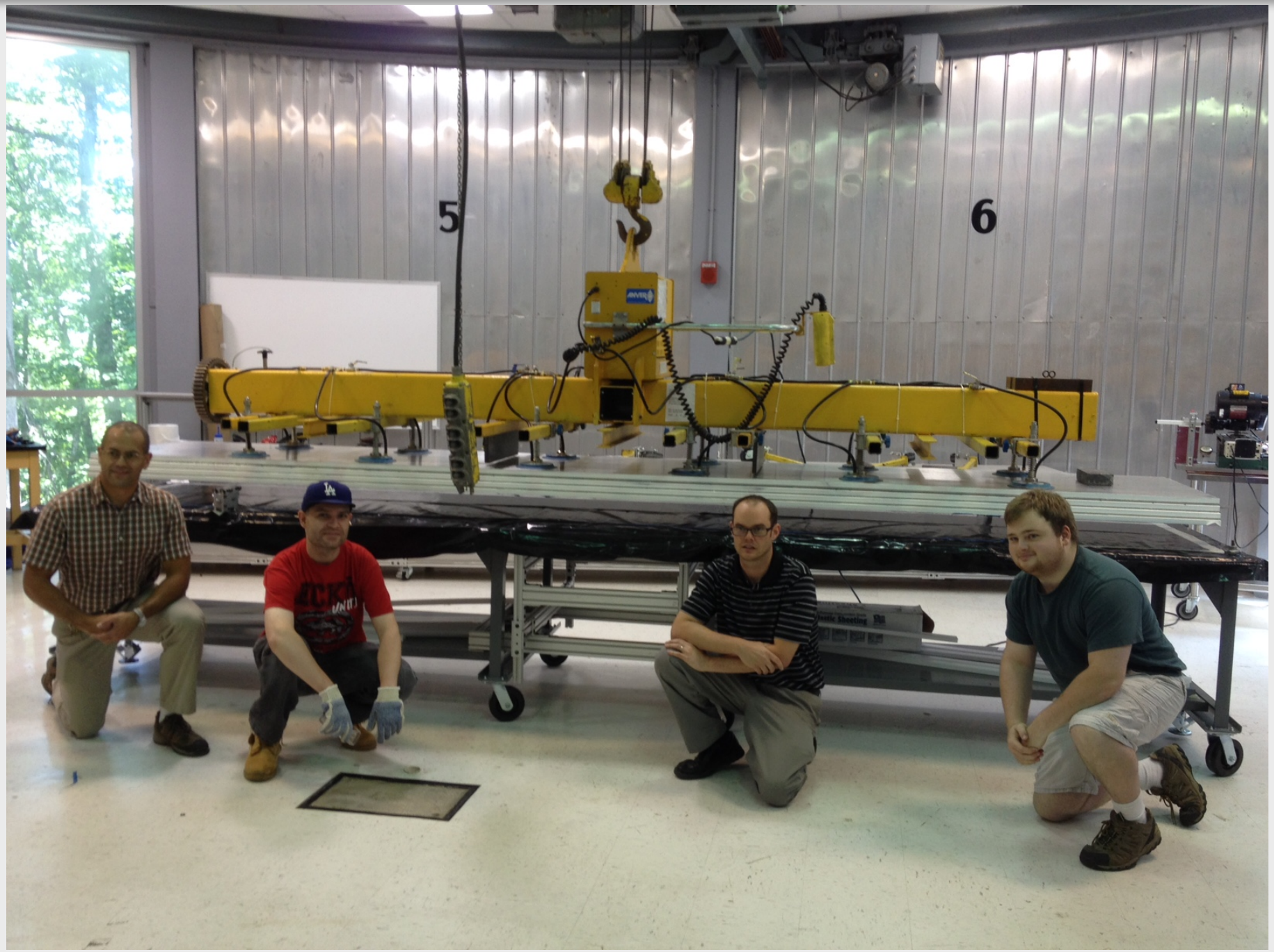
CRV efficiency

- Using MC, estimate the required light for the CRV efficiency of 99.99%
  - Vary the light yield, gaps and offsets between the counters
- The light yield of 14/SiPM from far end is required in order set a threshold at 7 PE
  - The thresholds and coincidence reconstruction is applied offline
- The test beam results suggest that we get adequate light yield (Y. Wu)





Vacuum lift test of CRV prototype



Summary

- Mu2e has a great discovery potential and can reveal New Physics
- Mu2e will improve over previous conversion experiments by 4 orders of magnitude
- Cosmic ray veto is an essential component for the Mu2e experiment by suppressing the backgrounds by 4 orders of magnitude
- CRV design is challenging, but mature and advanced
- Exciting R&D time of prototyping, test beams, simulations
- Plan to start the production in 2016
- Further details in Mu2e TDR