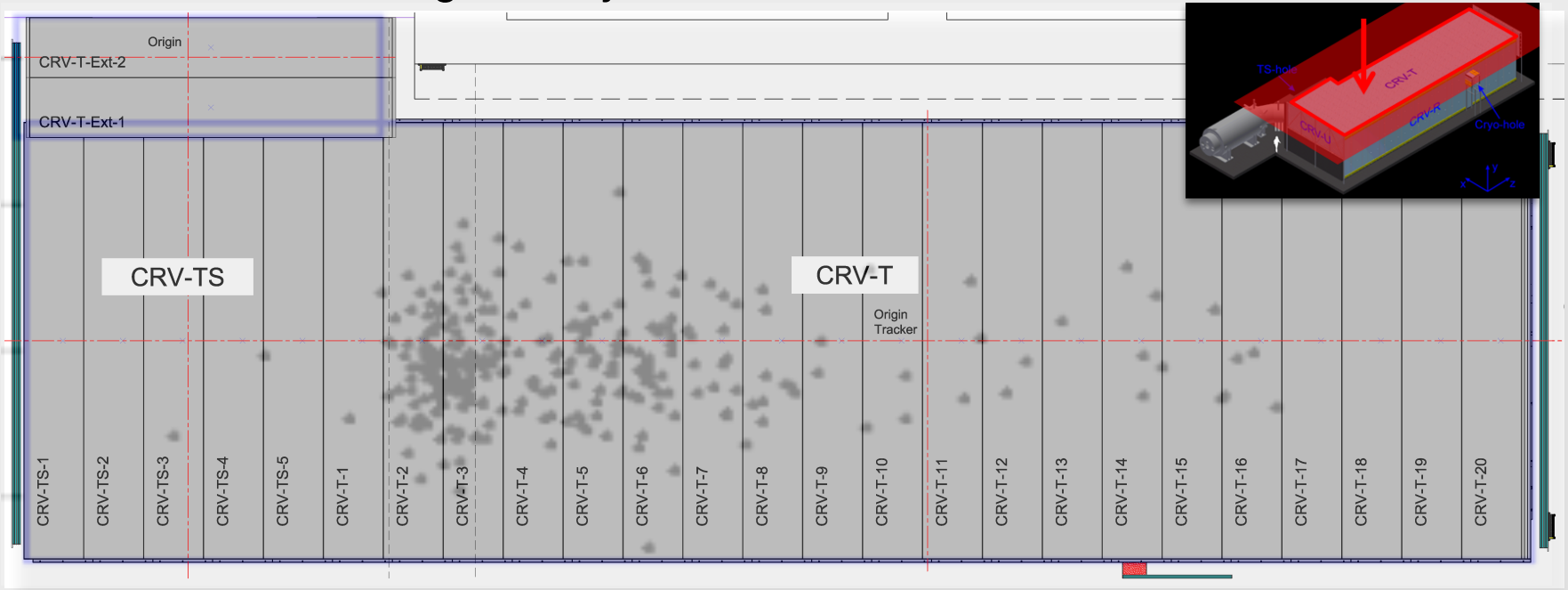
CRV at Mu2e-II

Enhancing CRV performance

- Expected live-time and therefore CR background will be ~4x higher for Mu2e-II
  - Need to enhance the CRV performance in the most critical regions
- The light yield degradation impacts the CRV performance
  - Large (all?) portion of CRV needs to be replaced for Mu2e-II
  - Rebuild the CRV and enhance the light yield in critical regions
- Gaps between di-counters and modules impact the CRV performance
  - Reduce gaps
  - Use different counter geometry



Requirements

- Suppress cosmic ray background to a fraction of an event
- Readout noise and experimental dead-time induced by beam activities are <1 MHz and < 10% respectively
- Radiation doses at the CRV readout is <1E10 neutrons[1MeV eq]/(cm2 lifetime)

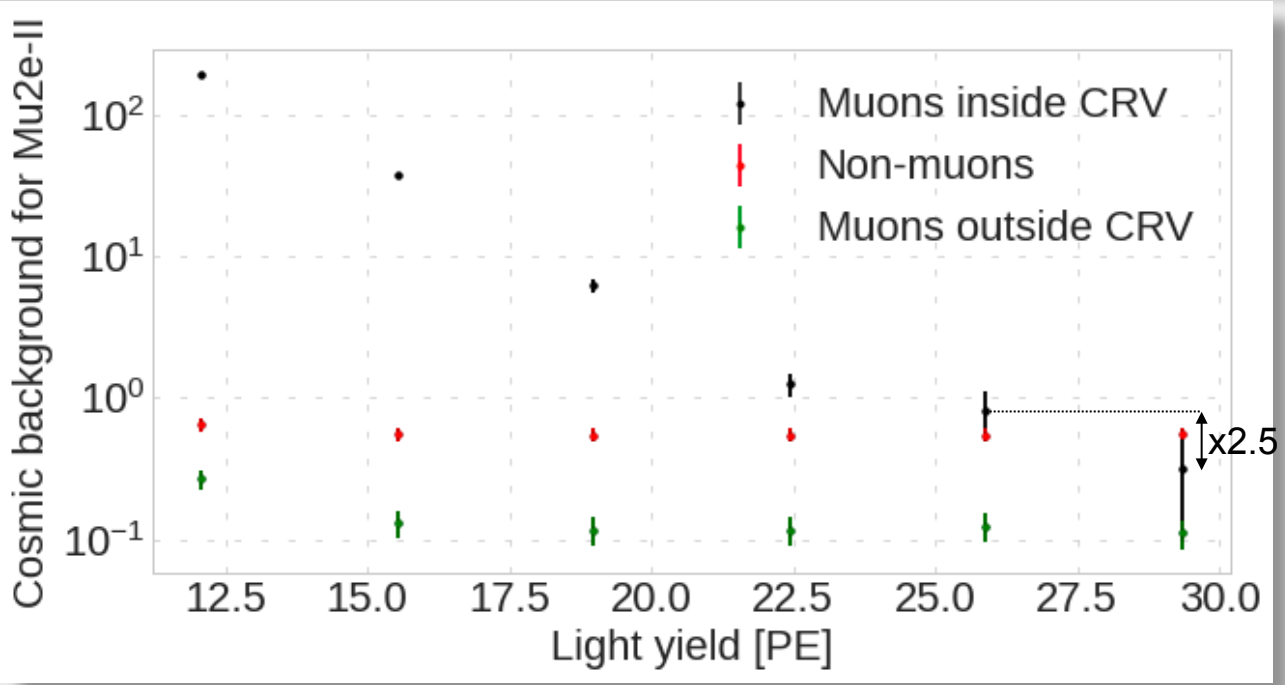
Cosmic background estimation

- I've assumed 5 year run plan: 6E22 POT, 1.4E9 POT/ubunch and [690; 1650] ns signal window. Live-time of 4.1E7 seconds
- I also assumed the same CRV design and performance as in Run-1, LY = 29 PE
- Total background, assuming Run-1 configuration: 0.98 ± 0.21 events
- Cosmic neutrons can be suppressed to a negligible level with additional shielding
  - Every 3' of concrete results in x5 reduction
  - We'll require the total of 9' of concrete in DS hatch to reduce the background to 0.02 events
- We assume the CRV efficiency can be improved by >x3
- Cosmic background component originating through the TS-opening is hard to suppress, but relatively small. It will be somewhat reduced if we use high-Z shielding.

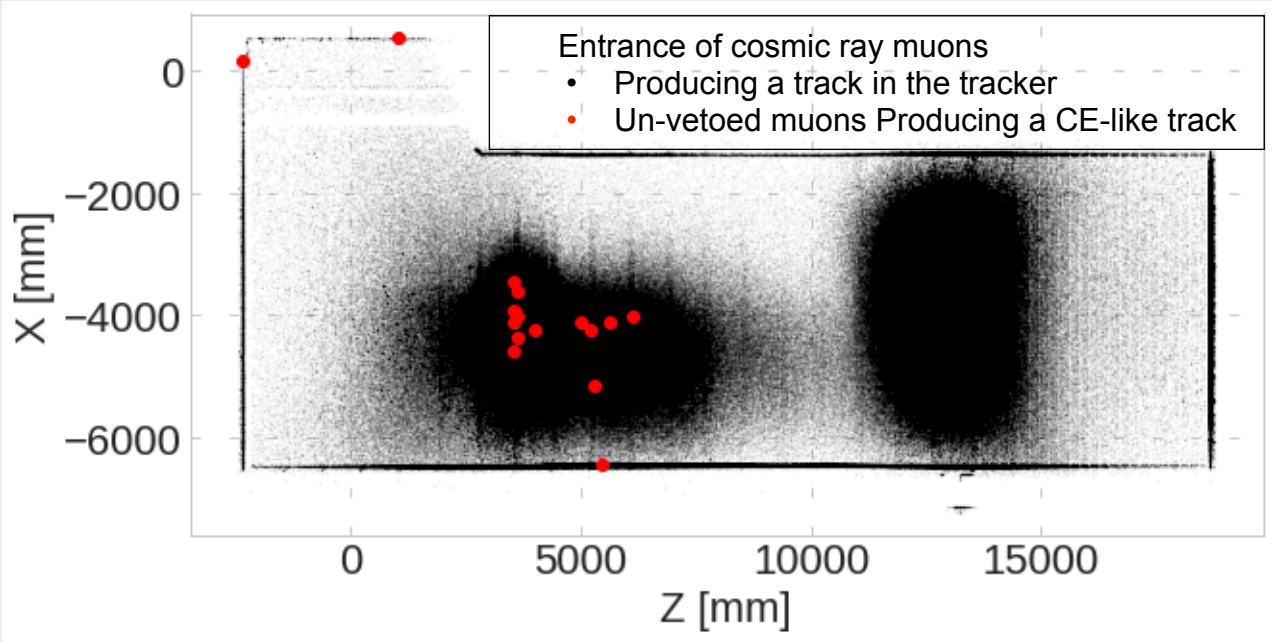
Cosmic background at Mu2e-II	Assuming Run-1 conf	With enhancemenss
Muons inside CRV	0.31 ± 0.21	0.1 ± 0.07
Muons outside CRV (TS-opening)	0.11 ± 0.03	0.11 ± 0.03
Cosmic neutrons	0.56 ± 0.05	0.02 ± 0.002
Total	0.98 ± 0.21	0.23 ± 0.08

Cosmic background estimation

- Light yield drives the CRV performance
- CRV efficiency exponentially decays up to ~22 PE
- For higher light yield gaps make a stronger impact

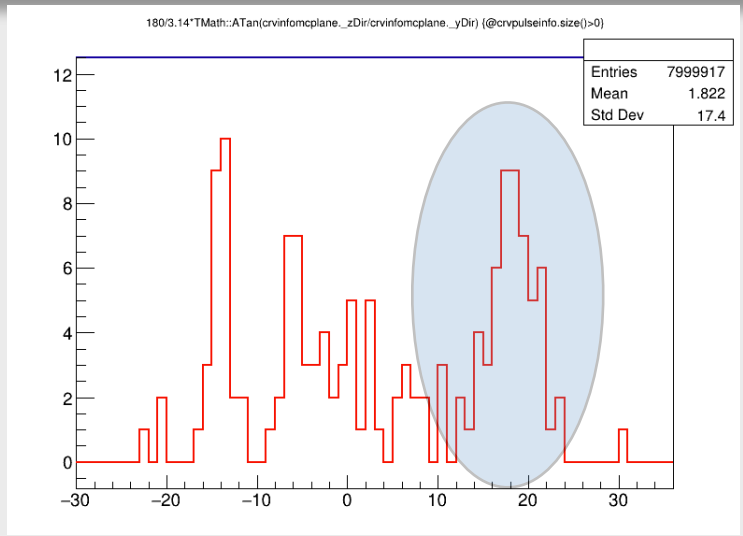


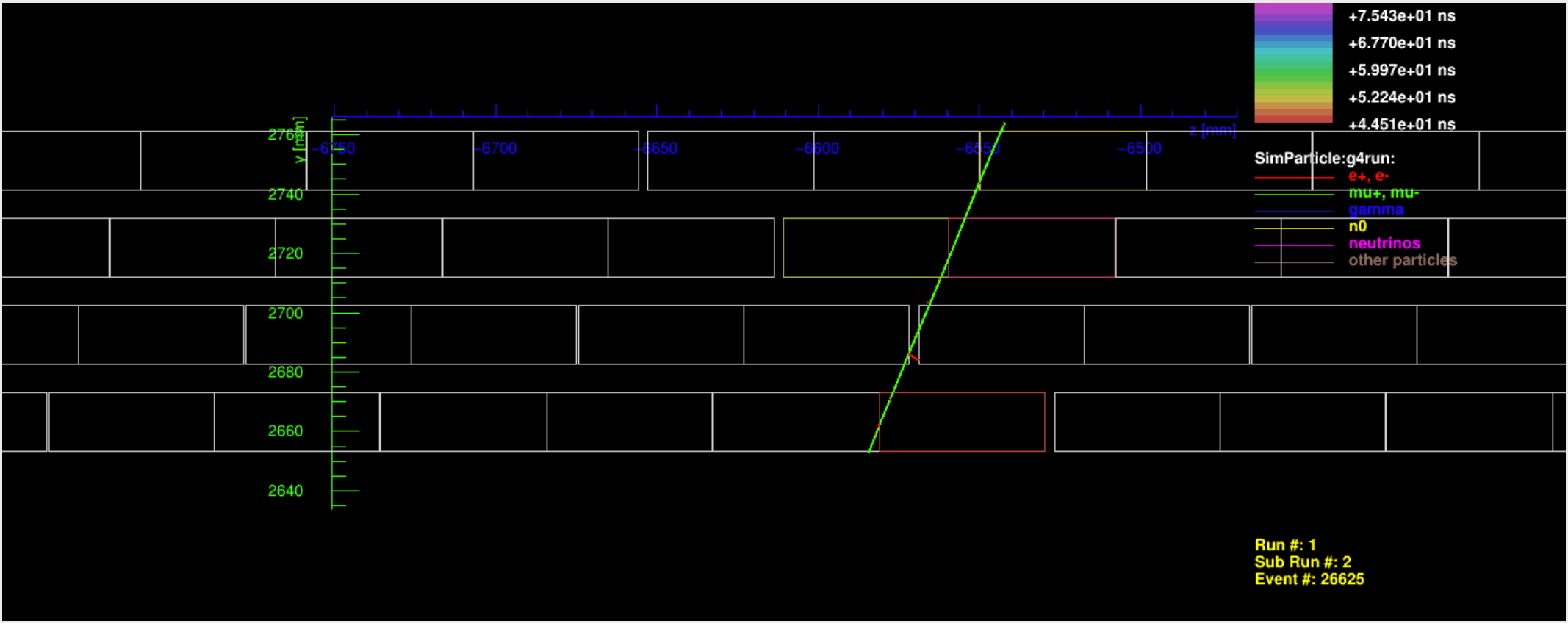
- Entrance of cosmic ray muons that create CE-like events
- The dominant fraction of un-vetoed muons enter through the gaps



Sources of CRV inefficiencies

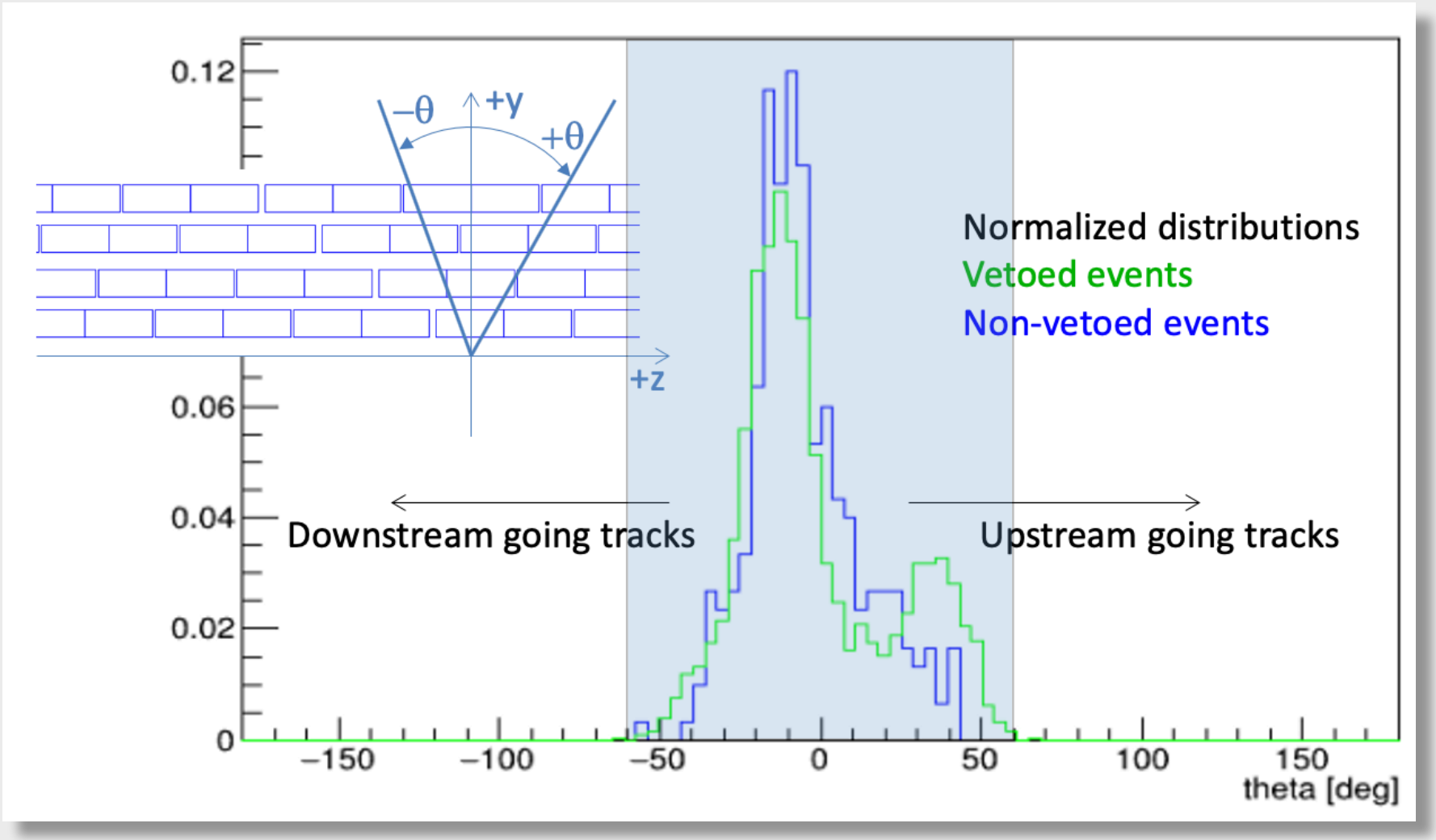
- Total energy deposited: 13.4 MeV
- Min path length per layer: 12.8 mm
- Angle: 20.9





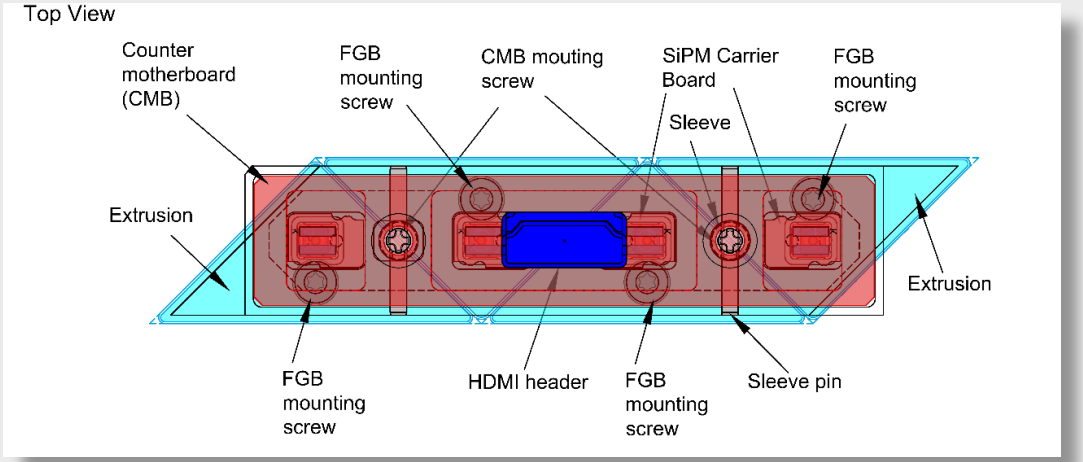
Cosmic ray angles of incidence

- The dominant fraction of the background inducing CR muons impact CRV at an angle <60^0



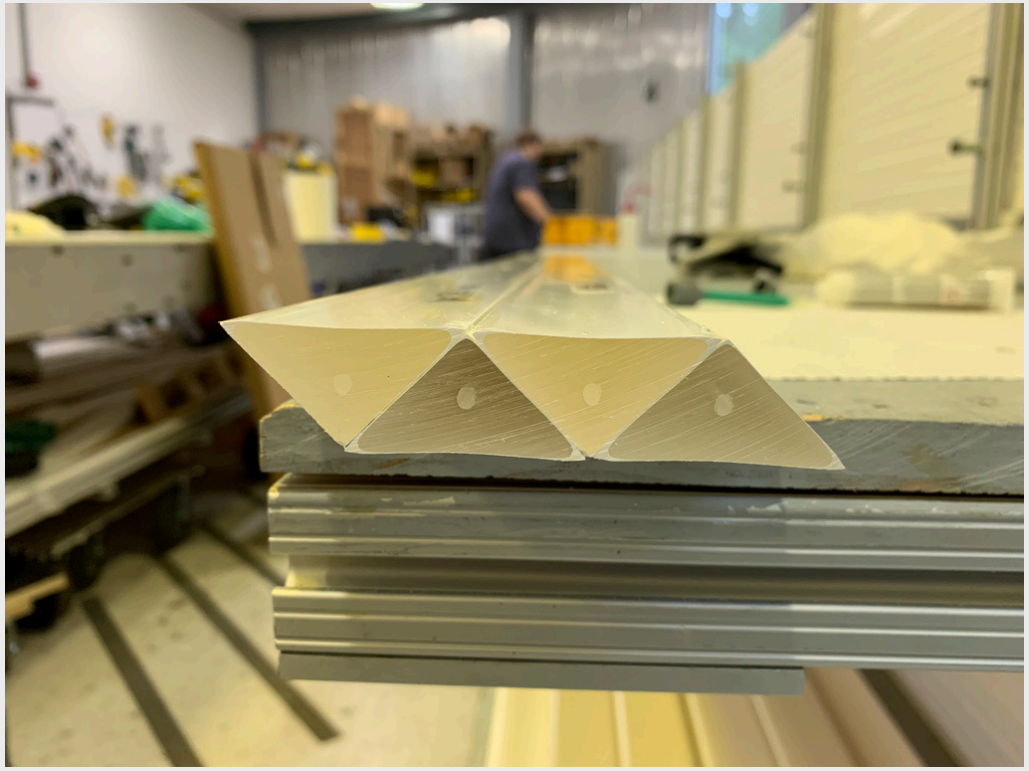
Proposed counter design

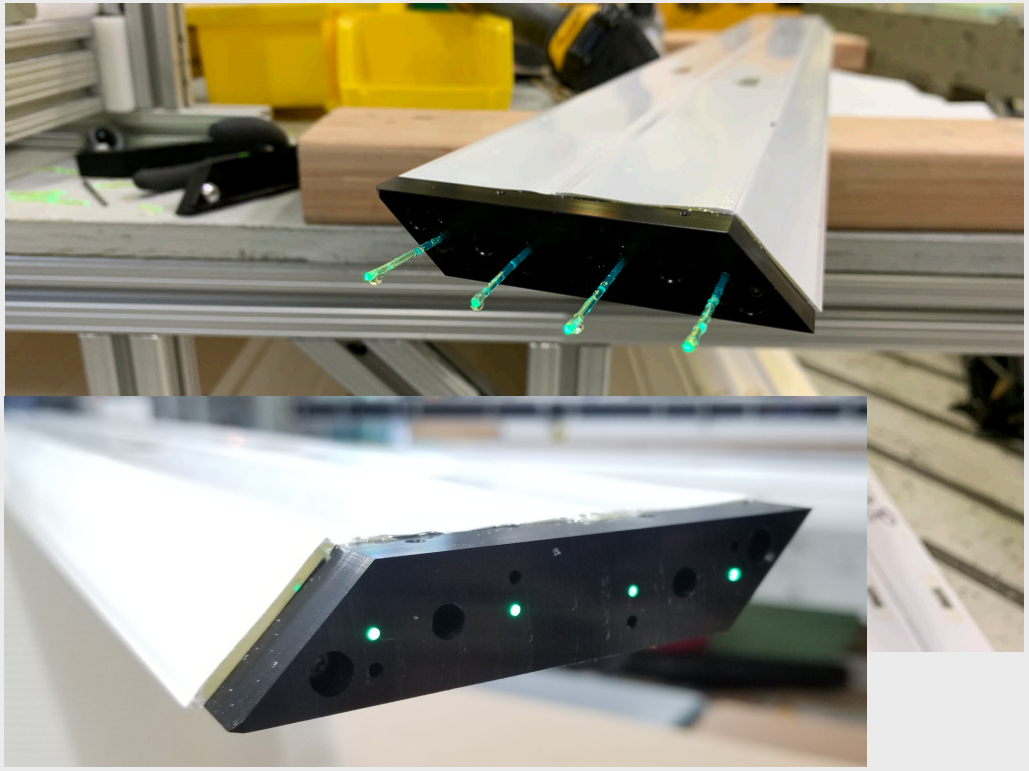
- An impact from gaps can be reduced in triangular-shaped counter design
- Benefits of proposed design:
  - Improved efficiency due to reduced gaps
  - Lower dead-time: improved positional resolution due to finer granularity and charge-sharing
  - Lower (~x2) per-channel rate
  - Lower (?) aging rate due to smaller profile
  - Simplified design of future modules



CRV prototype for Mu2e-II

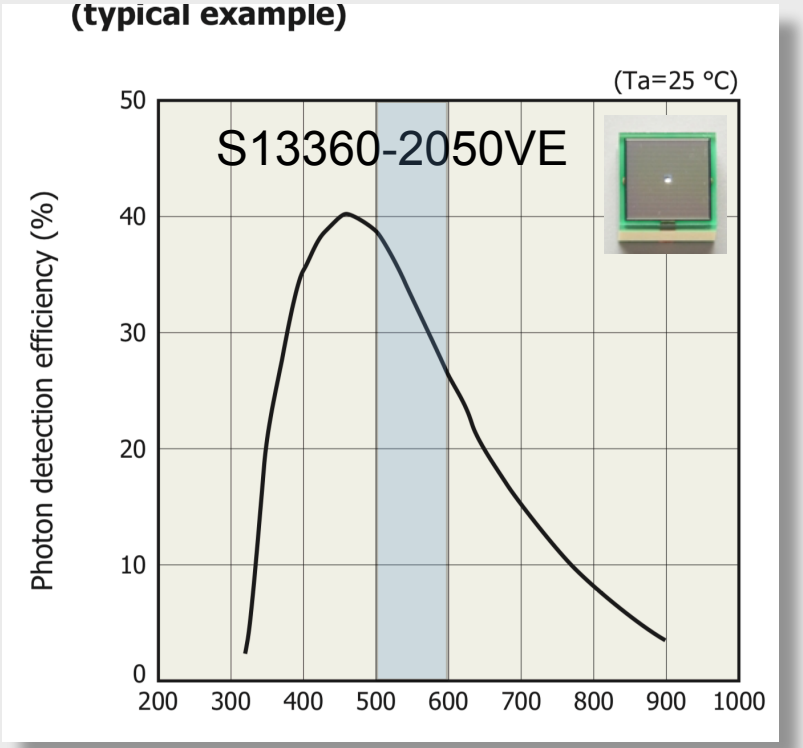
- We have recently assembled a quad-counter prototype
- Plan to measure the properties in May
- Preliminary cosmic data suggests a triangular counter delivers an improved light yield collection relative to a rectangular counter.

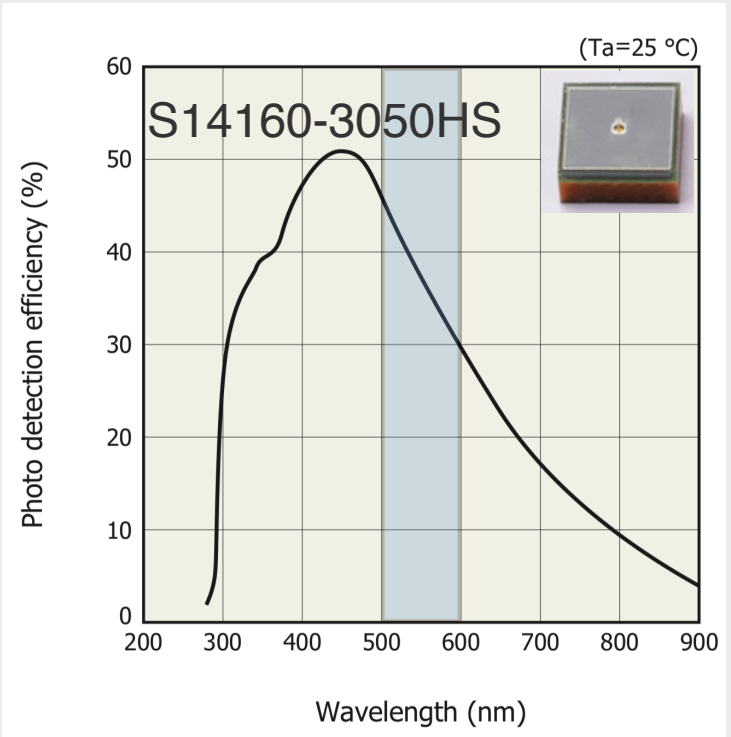




SiPM with improved PDE

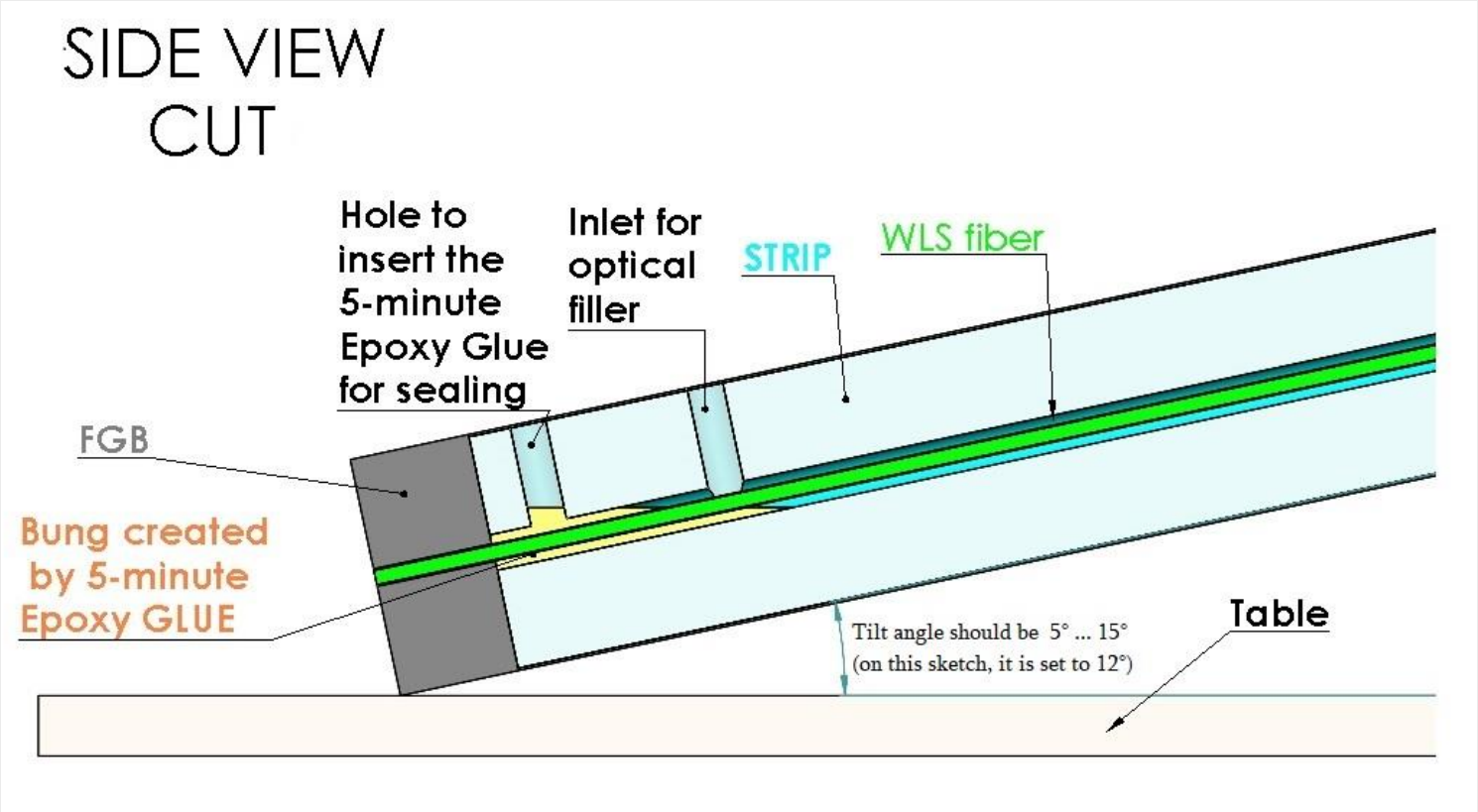
- Light yield is improved by 24% by switching from 1.4 to 1.8 mm fiber
- SiPM technology has advanced since the CRV was designed
- We can consider SiPMs with:
  - PDE peaked in green-yellow spectrum
  - Enhanced (20%) PDE overall





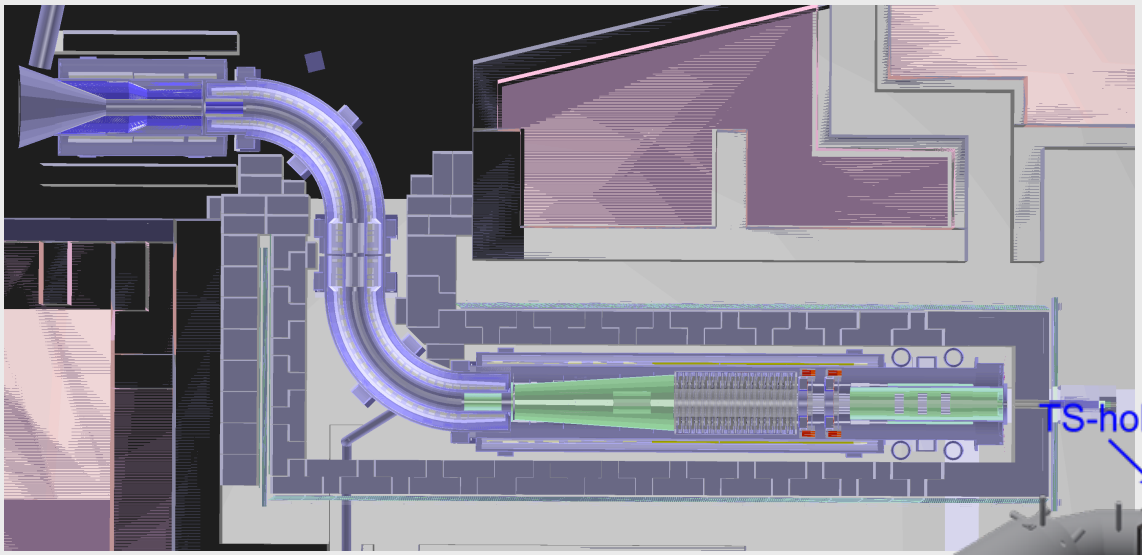
Potting fiber channels

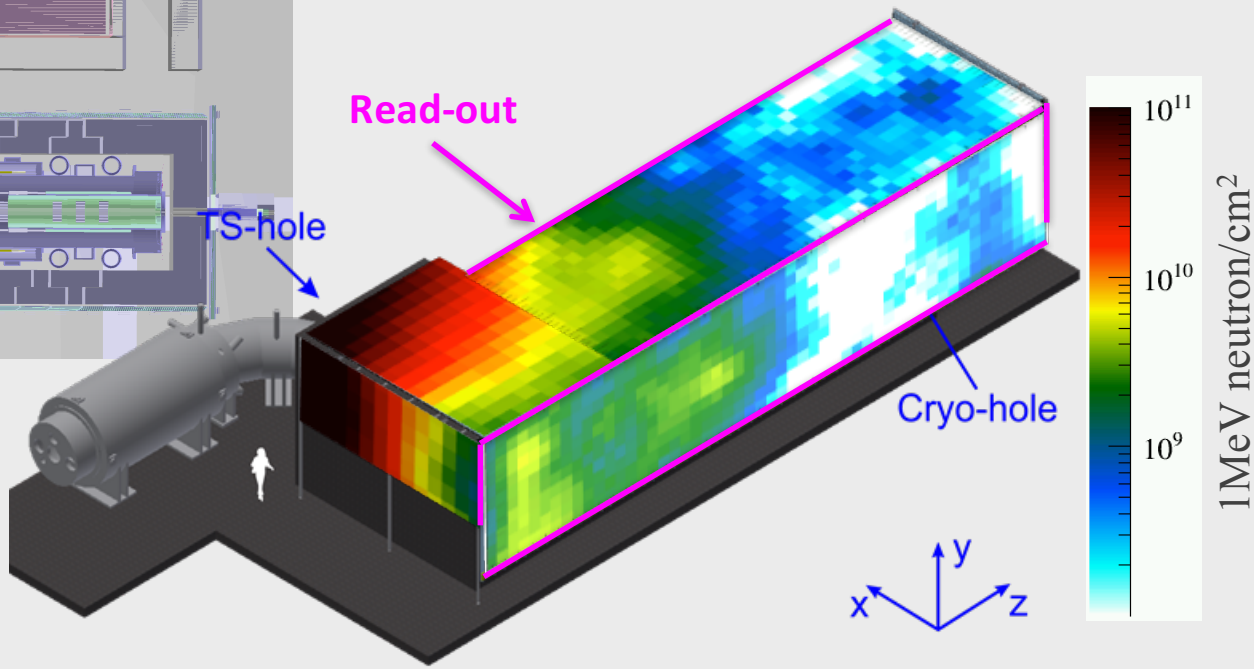
- Light collection can be improved by 40%, if fiber channels are filled with silicone resin
- Concern: silicone resin might leak damaging read-out
- Dubna team has been investigating an improved procedure to pot fibers
- We need to find resources to finalize this procedure



CRV noise rates at Mu2e II

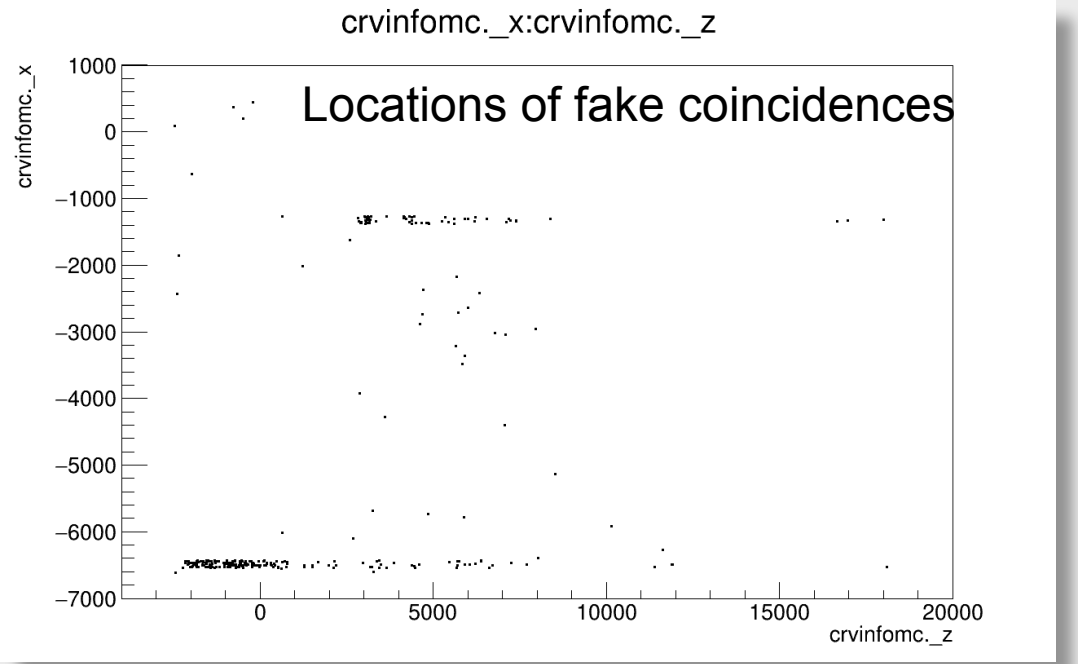
- Higher (x2-3) noise rates impose challenges: higher DAQ rates, rad damage to electronics and induced dead-time by CRV
- We've simulated high-Z (Barite) enriched with 5% Boron carbide to estimate the rates in CRV

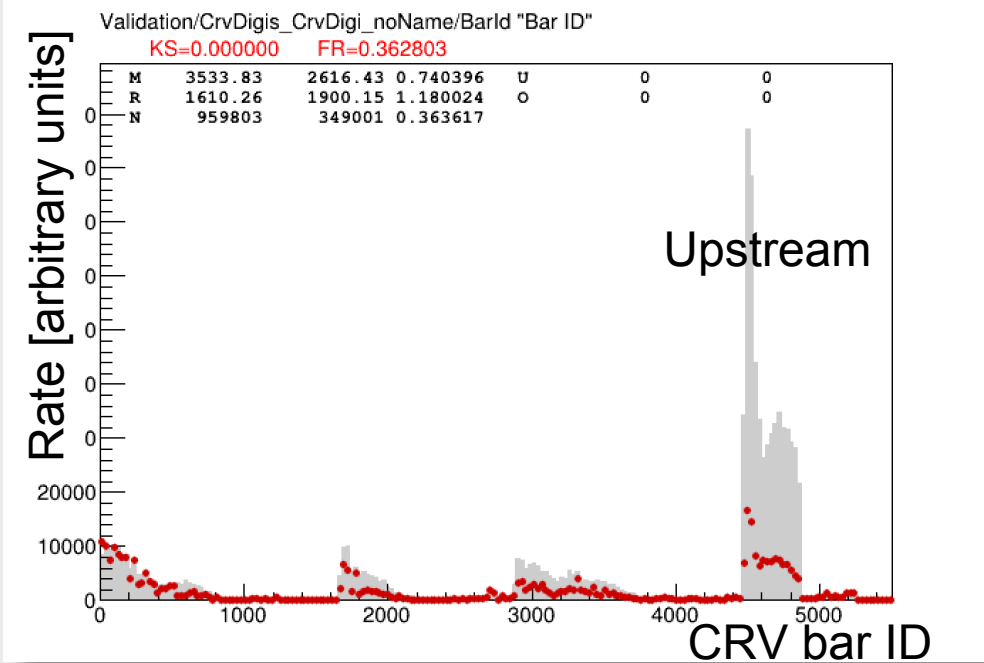




Dead-time and rates

- Enhanced shielding makes a significant impact on CRV rates and dead-time
  - Rates in the hottest region are reduced by up to a factor of 5 *relative to a single batch mode*
  - Dead-time is negligible. Hot spots at CRV-R and CRV-L are not critical, but can be addressed if needed





Summary

- The CRV operations at Mu2e-II are challenging, but feasible
- Current CRV and shielding design can't be reused:
  - Detector degradation
  - High noise rate
- We propose to explore finer granular CRV
  - Triangular shaped design seems promising
  - Light output can be enhanced by using higher PDE SiPMs, thicker fibers, potting fiber channels
- Shielding needs to be enhanced to suppress: (a) read-out noise and (b) background induced by cosmic neutrons and TS-opening muons
  - Very promising results using high-Z boron doped concrete
- Total background can suppressed to a fraction of an event at Mu2e-II

Backup

CRV efficiency vs light yield

- The CRV detection efficiency improves by a couple orders of magnitude, if we improve the light yield by a factor of 2
  - This would veto muons impacting CRV to a negligible fraction
- The dominant background contribution (~0.3 events) will be induced by TS-opening events