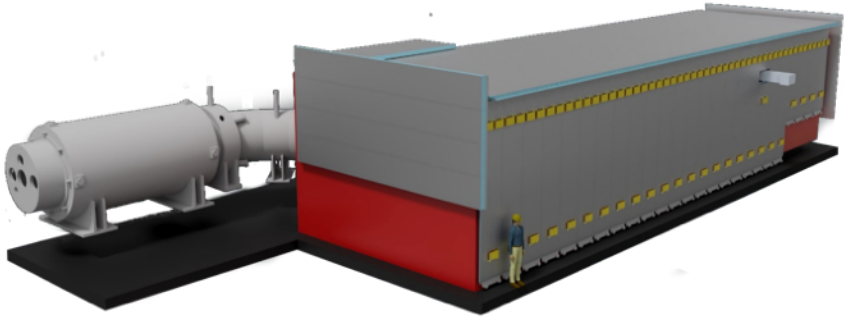
CRV AT MU2E II SUMMARY



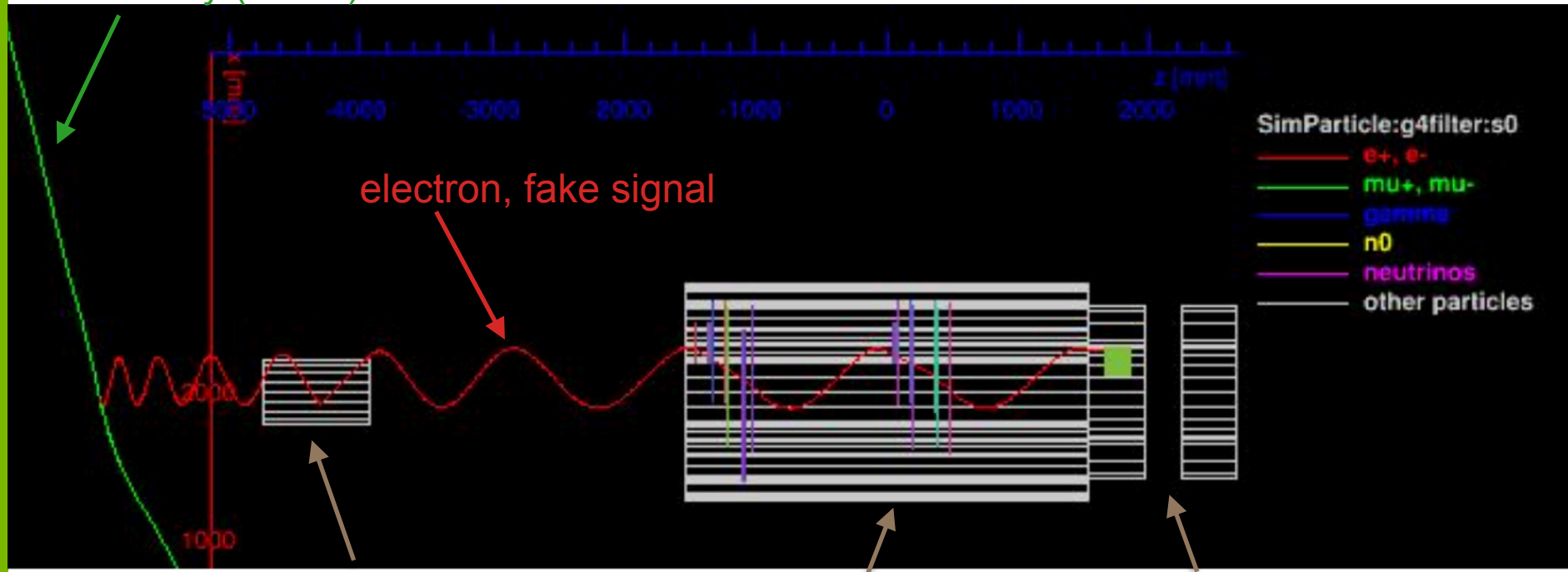
SIMON CORRODI
Argonne National Laboratory

on behalf of the Mu2e II CRV group

Workshop on the Future Muon Program at Fermilab
March 26 to 29, 2023
Caltech, Pasadena

COSMIC RAY BACKGROUND

Mu2e expects 1 signal-like event per day induced by cosmic rays
Mu2e II ~3x signal-like event (duty factor ~25% -> >90%)



CRV REQUIREMENT: A BACKGROUND FREE EXPERIMENT

Mu2e:

-> needs ~few 1000x suppression

=> needs efficiency of up to 99.99% in some areas

=> low dead time (data rates)

Expected mu2e CRV performance in 2025. -> >2 background events in mu2e II

Mu2e II challenges:

- live time for Mu2e II: 3x [5 years + duty cycle]
  -> suppression needs ~ 3x

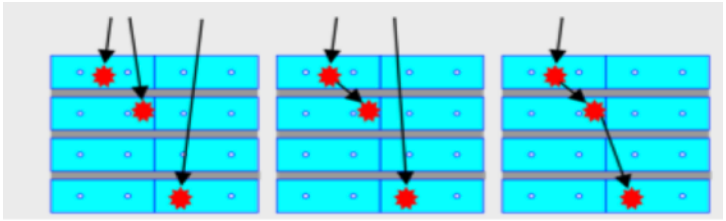
- Higher beam intensity -> higher non-cosmic ray noise (>3x)
  -> radiation, higher channel rates -> higher dead times

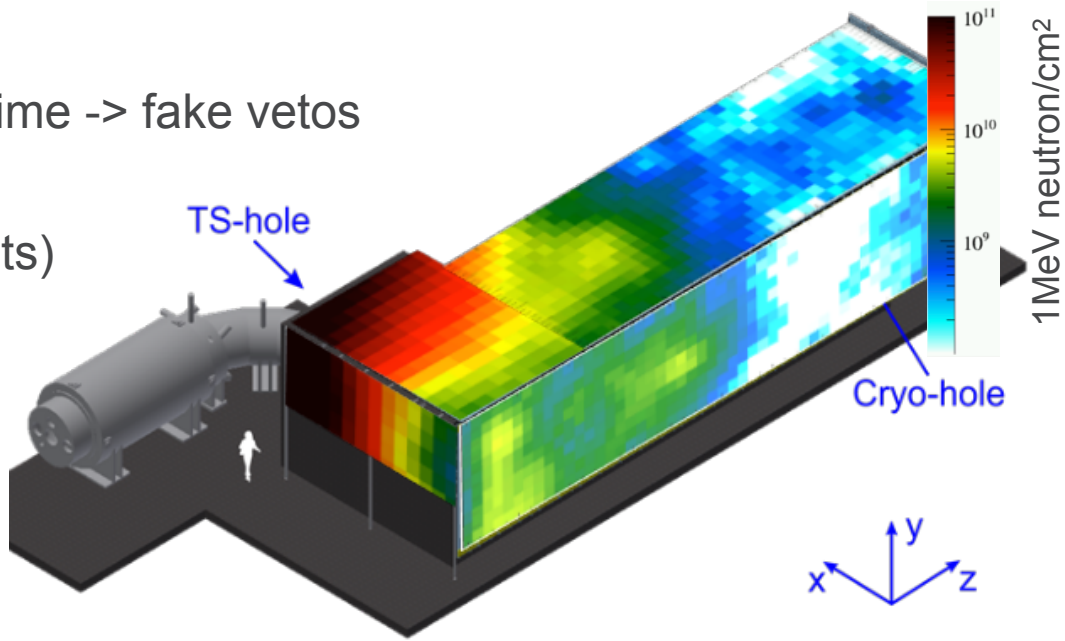
=> Balancing act between dead time and efficiencies

CHALLENGES: DEAD TIME

"Fake CR events" introduce dead time -> fake vetos

Superposition of different sources:
-> detector noise (SiPM dark counts)
-> "radiation"





Current design:
50% dead time in Mu2e II*

*improved algorithm reduce this number already

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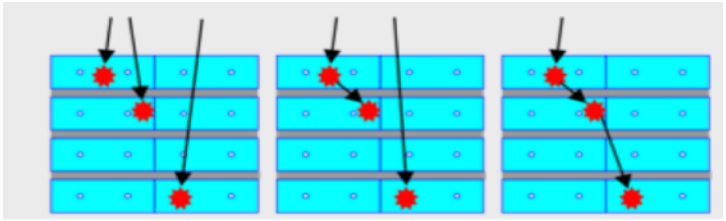
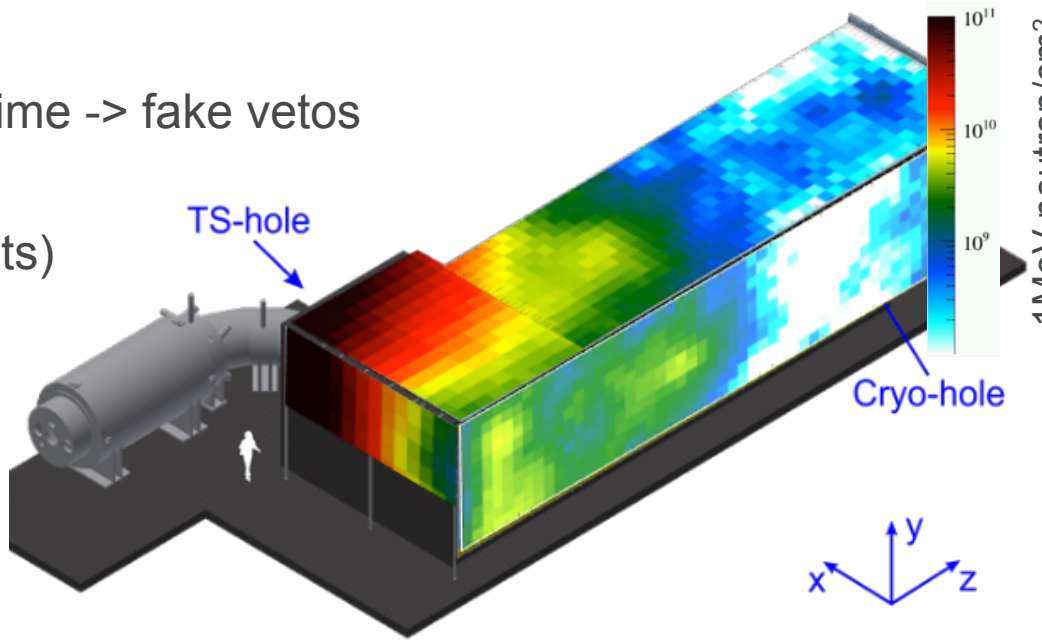




Source I: primary production beam
->Improved shielding Barite and boron loaded concrete

Source II: Stopped Muon produced secondaries
-> reducing the single channel rates
-> reducing false coincidence rates -> reducing dead time

Current design:
50% dead time in Mu2e II*

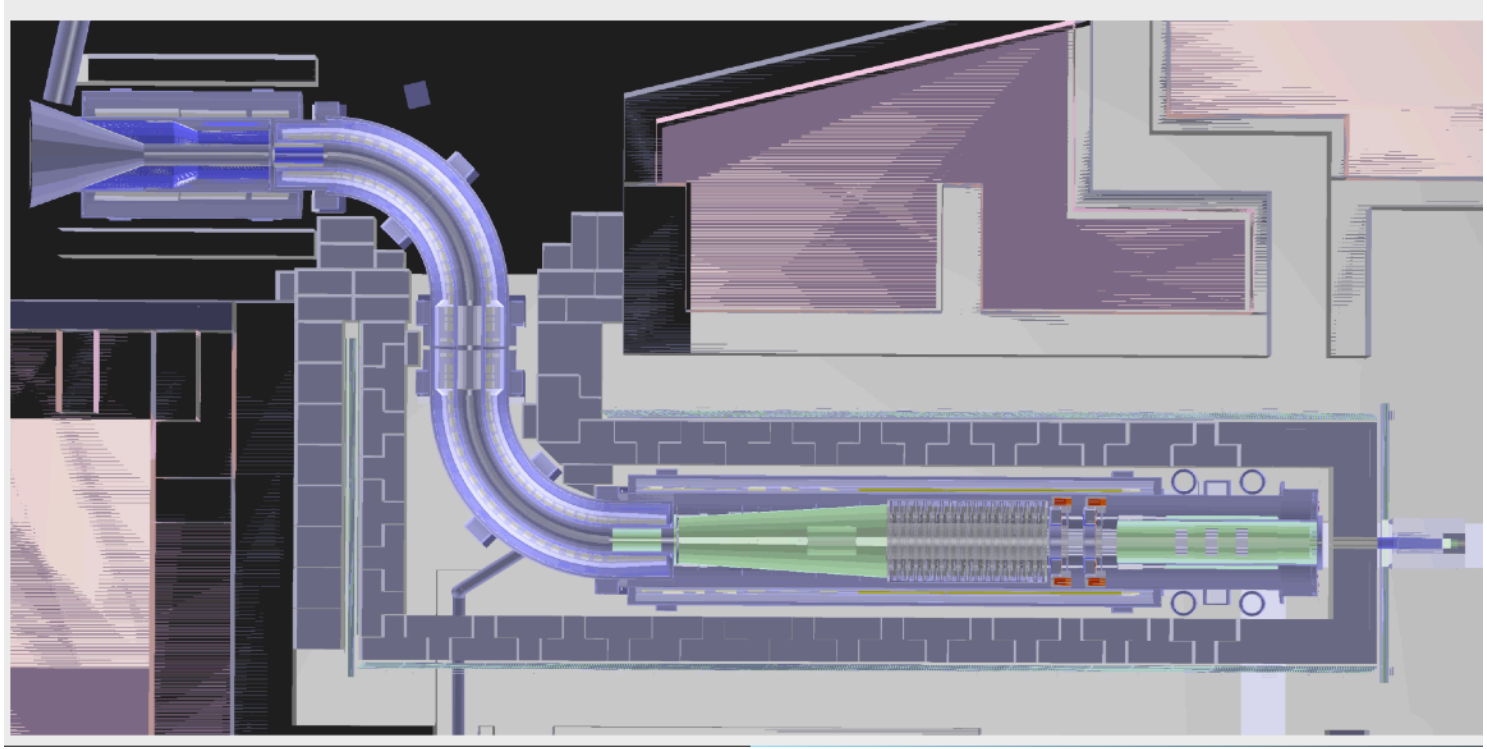
*improved algorithm reduce this number already

SOLUTIONS/ONGOING R&D: SHIELDING

Yuri simulated high-Z (Barite) enriched with 1% Boron carbide: capture neutrons

=> reduces dead time close to 0

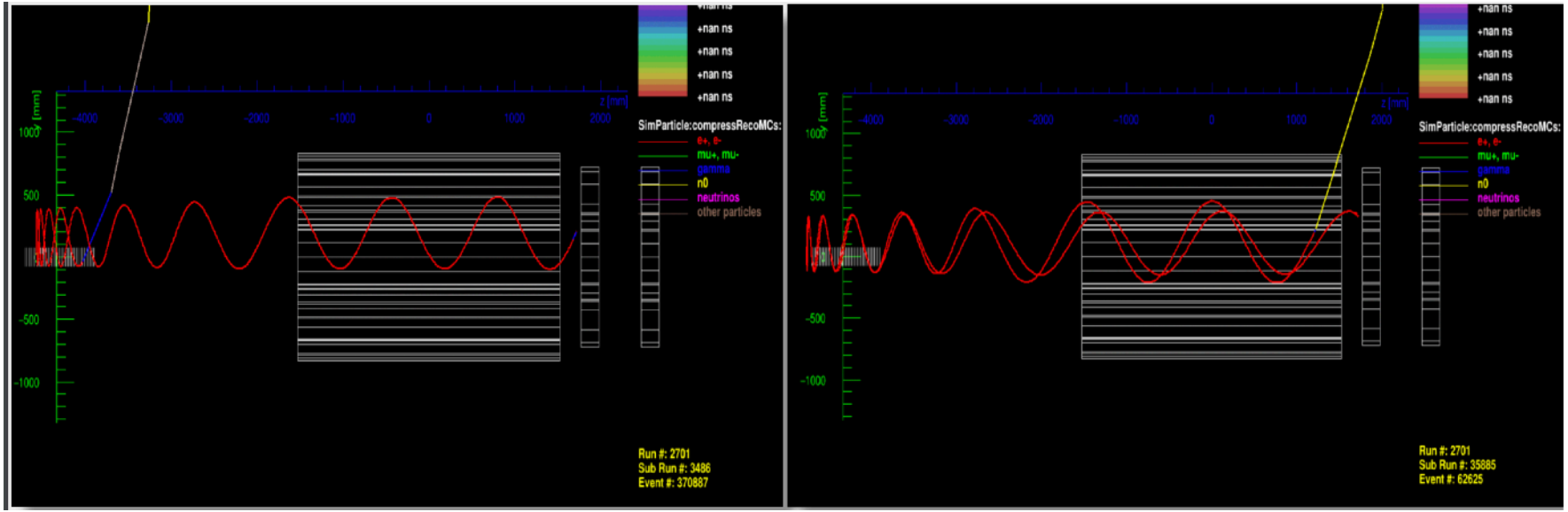
TODO: optimize improved shielding



CHALLENGES: CR BG FROM NEUTRALS

Not neglectable for mu2e II:
- estimated to be 0.007 BG events per 1M seconds
- Mu2e II (~25M seconds) -> 0.175 BG events

Solutions: more shielding



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6 feet concrete shielding above target -> 0.02±0.002

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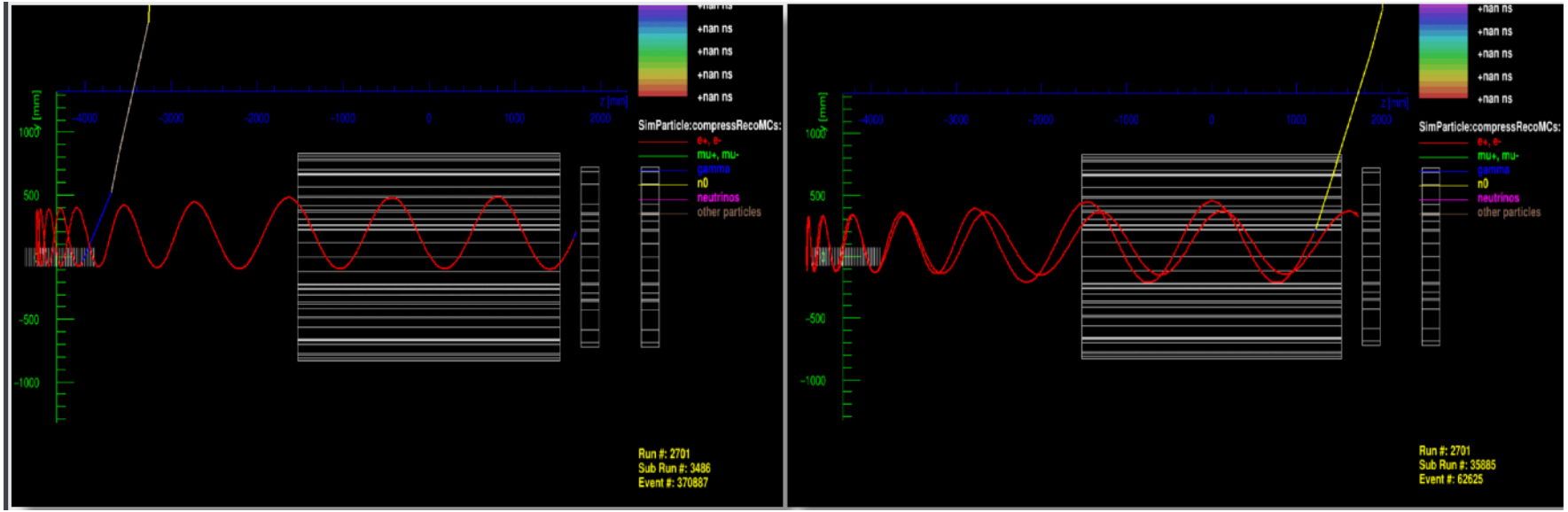
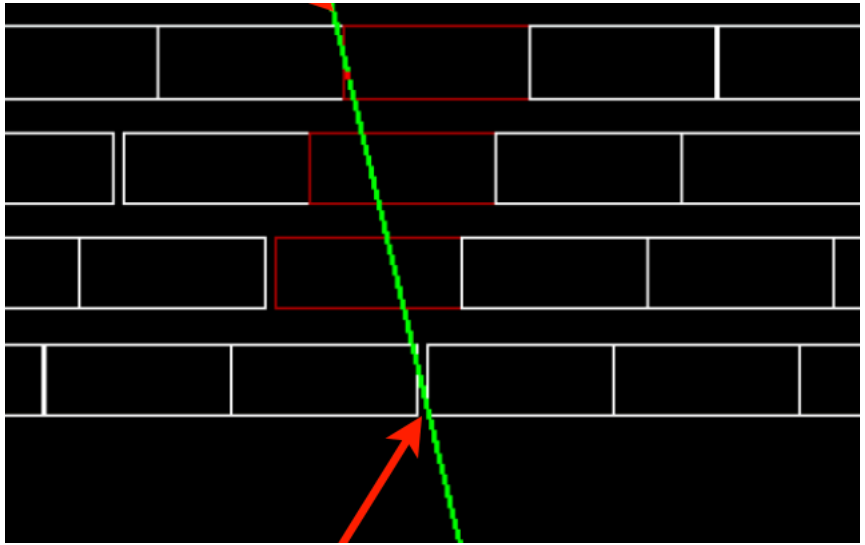


CHALLENGES: INEFFICIENCIES I: HOLES AND EDGE EFFECTS

Geometry/Edge Effects



already a staggered design
to minimize gaps

CR moun background estimate from “gaps”: 0.22 ± 0.15

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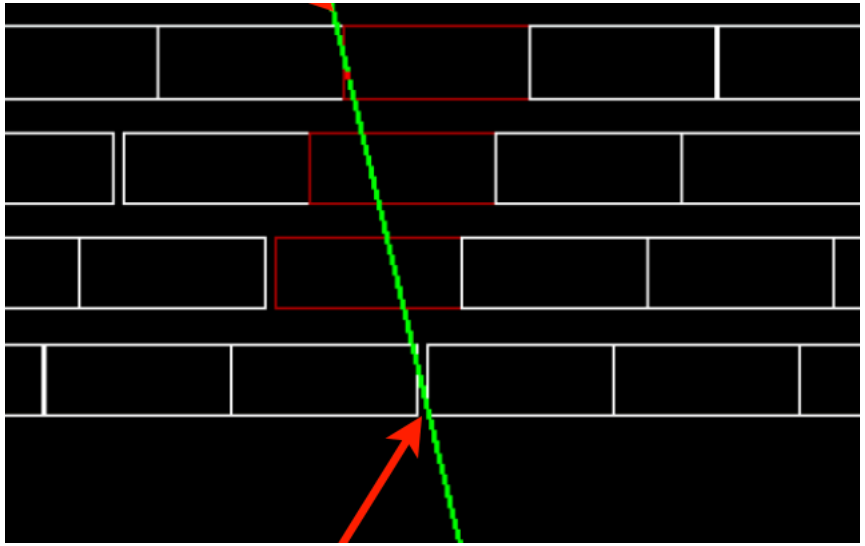

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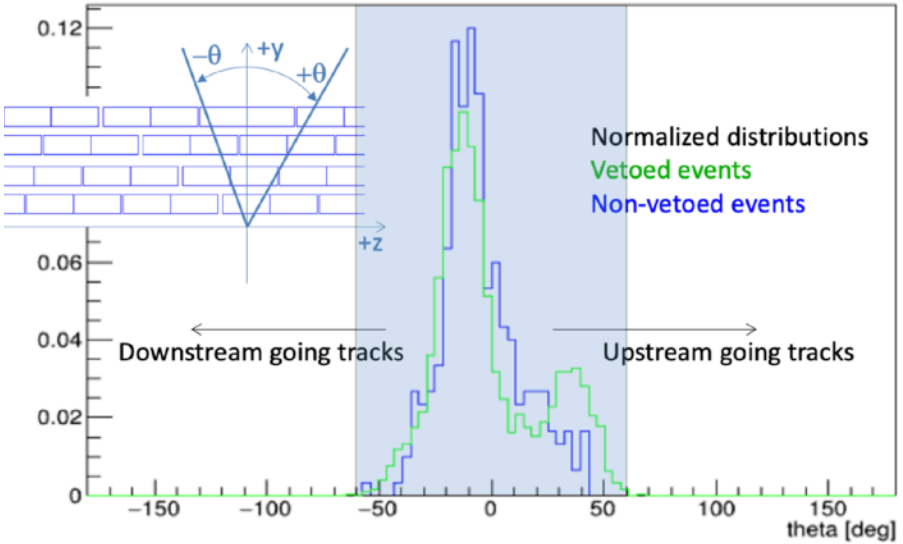
most of the CR come from “above”



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SOLUTIONS/ONGOING R&D: ALTERNATIVE CRV DESIGN

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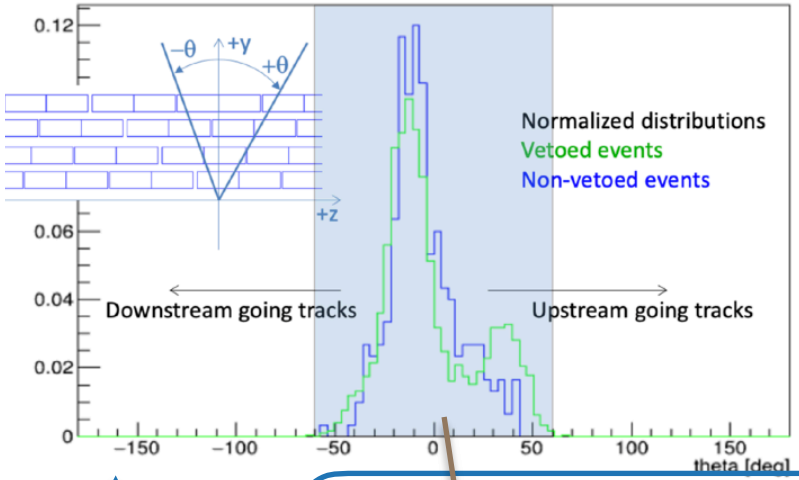
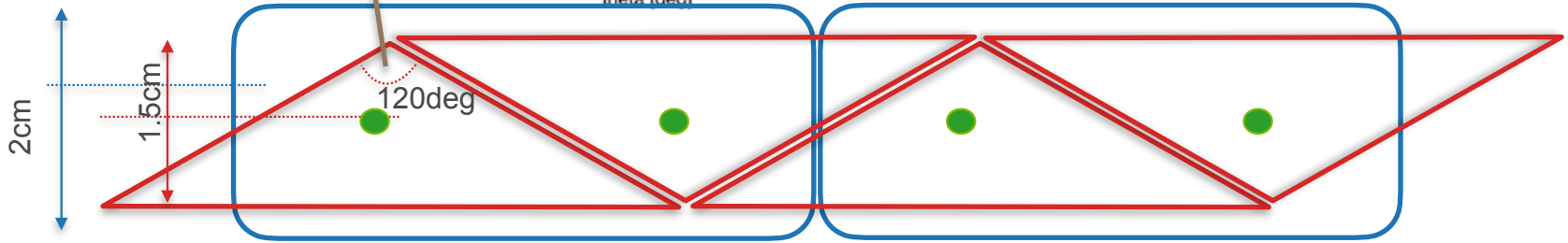


- improved **efficiency** due to reduced gaps
- **finer granularity**, 3x resolution

-> lower rate per channel

- simplifies design of future modules

- ~45deg particles that “hit a gap" deposit more energy in the other layers



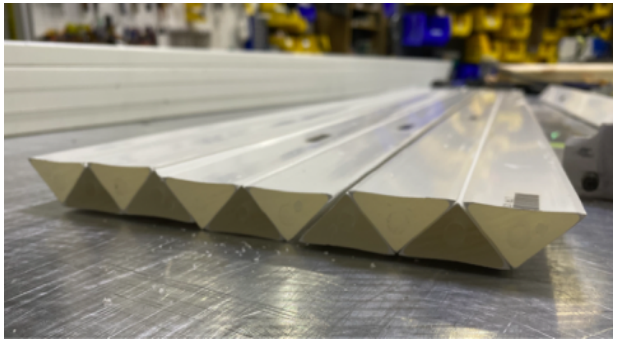
CR background estimate from “gaps”: 0.22 ± 0.15 -> below 0.1

ALTERNATIVE CRV DESIGN: SYNERGIES

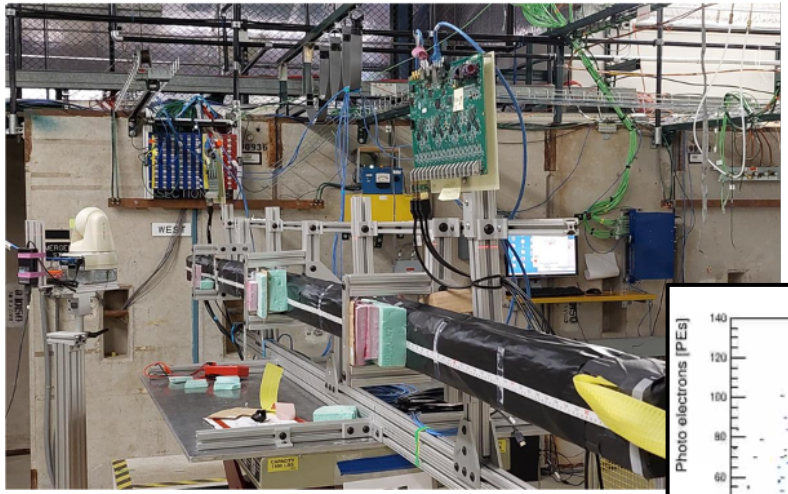
Ralf's slides

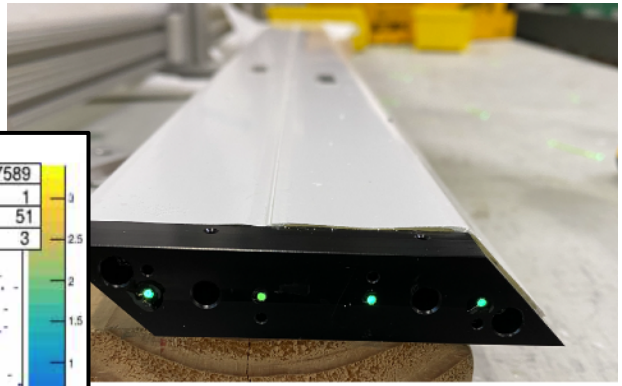
Very similar counters will be use for muography projects to scan the interior of pyramids using cosmic ray muons (UVa)

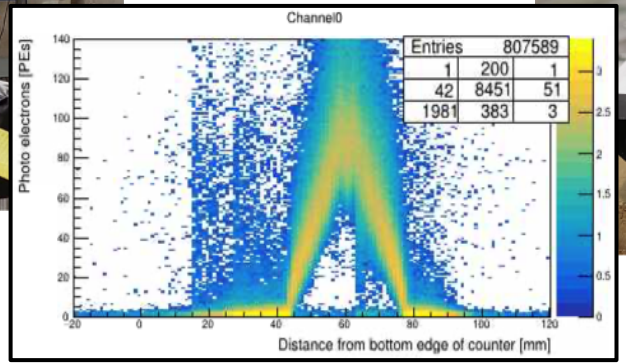
4cm x 2cm, 90deg bars



Testbeam at FNAL



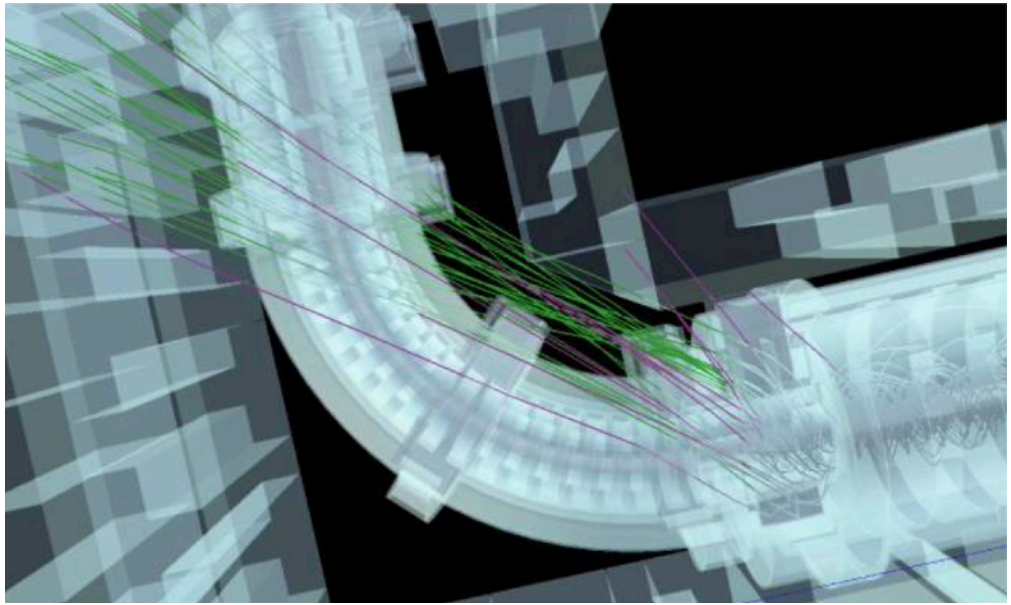


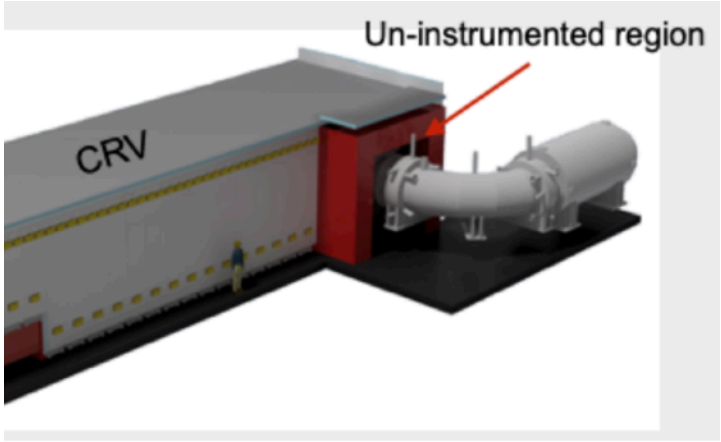


TODO: prototyping

CHALLENGES: INEFFICIENCIES II: UNINSTRUMENTED

Example: No shielding at the TS opening





=> mitigation with passive absorbers,
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background estimate 0.08 ± 0.02 (dominant CR)

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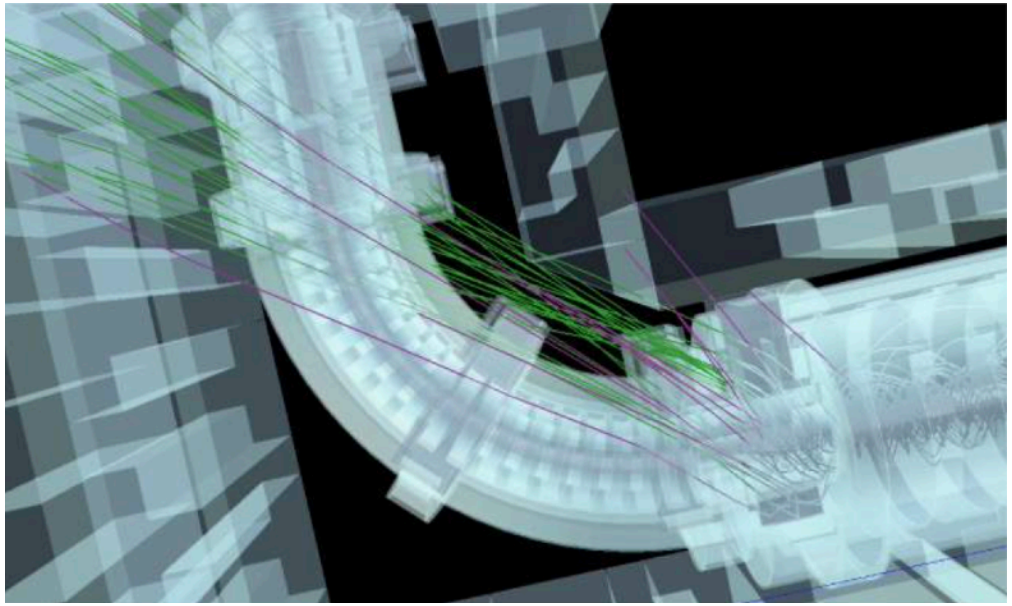

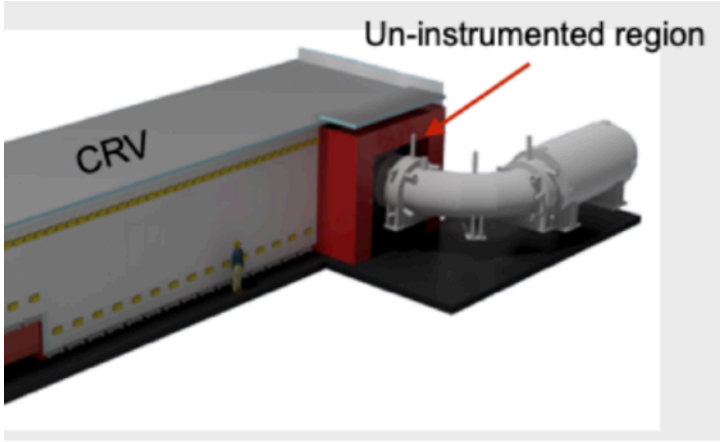

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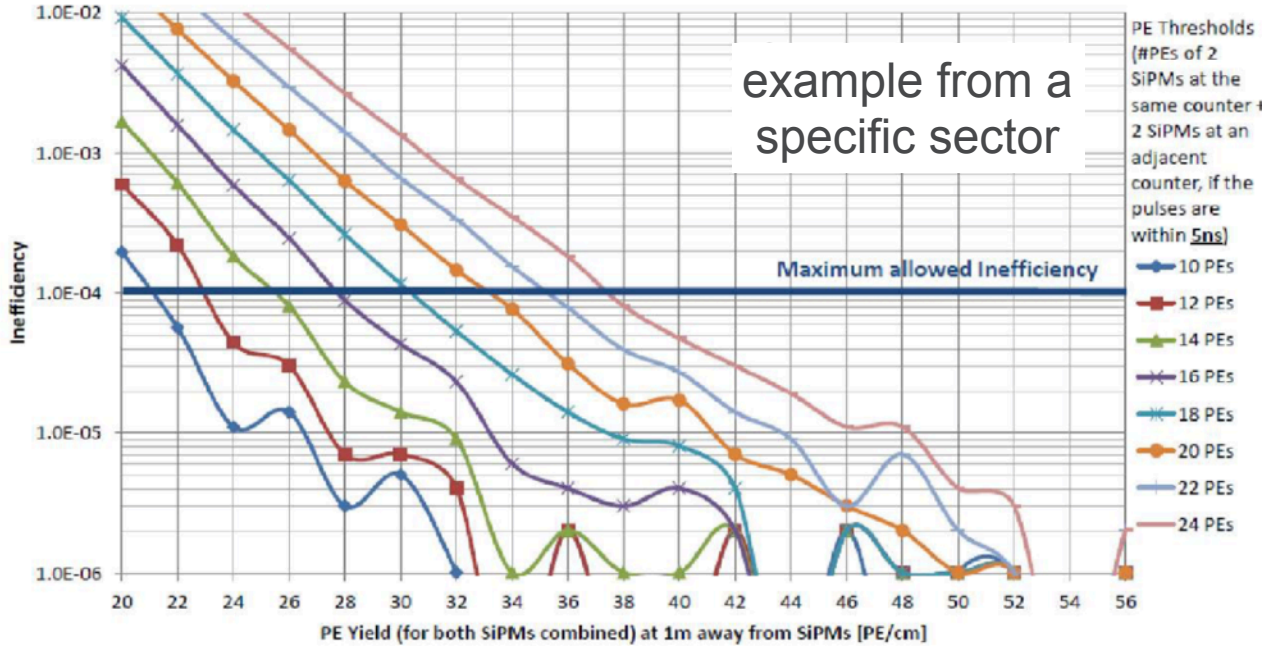
Ray Culbertson (docdb 8322): explored more shielding
-> a factor 2 reduction seems possible

Argonne NATIONAL LABORATORY

CHALLENGES: INEFFICIENCIES III: LIGHT YIELD

efficiency scales with light (photo electron) yield



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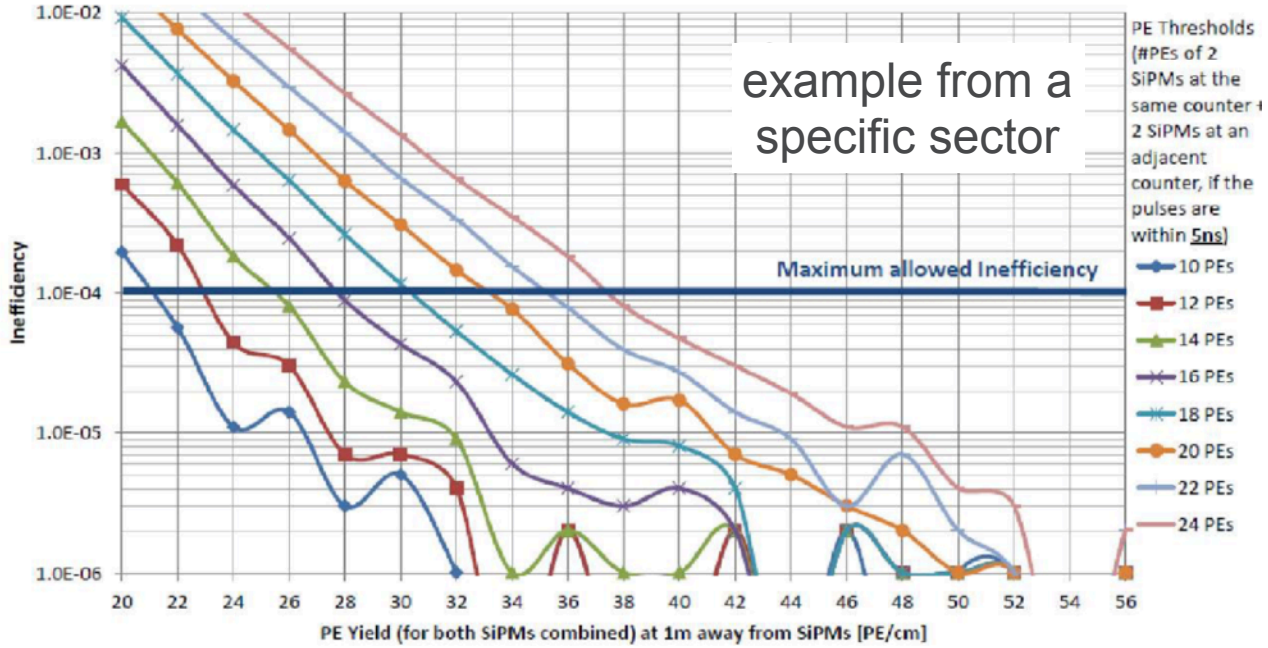


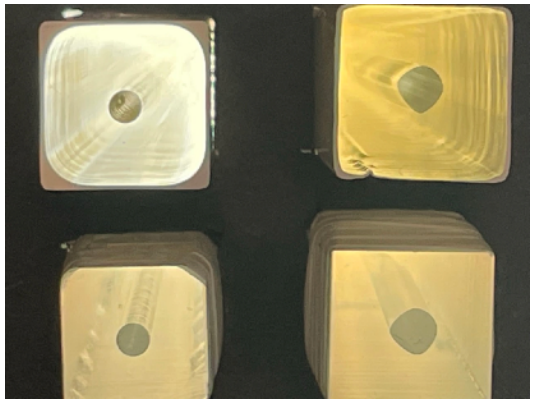
-> mu2e CRV can not be used for mu2e II due to aging/radiation damage

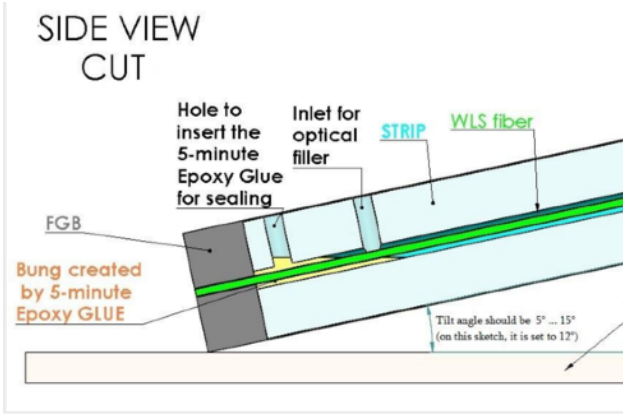
SOLUTIONS/ONGOING R&D

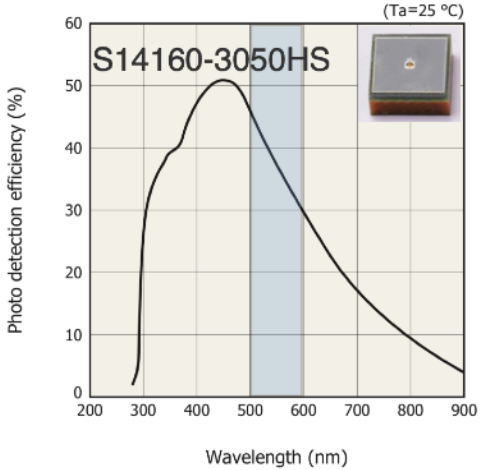
Light yield increase of 24% by switching from 1.4 to 1.8 mm fibers

Mu2e CRV uses “old” SiPMS, new SiPMs have significant higher PDE ~15%

Potting channels with silicon resin increases the light yield on a 40% level, or optimize channel shapes







TODO: R&D program refining details

SUMMARY

CR backgrounds:

from “gaps”: below 0.1

uninstrumented 0.08 ± 0.02

neutrals 0.02 ± 0.002

total: 0.20 ± 0.08

+ optimized momentum cuts:
=> 0.17

Mu2e: 103.85 < p < 104.90 MeV/c
700 < t < 1697ns

Mu2e II: 104.05 < p < 104.90 MeV/c
690 < t < 1650ns

Results	Mu2e	Mu2e-II (5-year)
Backgrounds		
DIO	0.144	0.263
Cosmics	0.209	0.171
RPC (in-time)	0.009	0.033
RPC (out-of-time)	0.016	< 0.0057
RMC	< 0.004	< 0.02
Antiprotons	0.040	0.000
Decays in flight	< 0.004	< 0.011
Beam electrons	0.0002	< 0.006
Total	0.41	0.47
N(muon stops)	6.7×10^{18}	5.5×10^{19}
SES	3.01×10^{-17}	3.25×10^{-18}
$R_{\mu e}$(discovery)	1.89×10^{-16}	2.34×10^{-17}
$R_{\mu e}$(90% CL)	6.01×10^{-17}	6.39×10^{-18}

Large uncertainty in background radiation estimates
Example: trust in CRV rates from PS opening only on a factor of 2
=> turning on mu2e will help significantly -> refine Mu2e II CRV design

SUMMARY - NO SHOW STOPPERS, WHAT'S NEEDED?

Mu2e CRV can not be used
- detector degradation, high noise rate

can parts be used?

CRV design with a finer granularity
- reduce high rates, dead time, while improving efficiency (triangular shaped)
- most critical regions can be enhanced with additional layers if needed

Light output can be enhanced
- new SiPMs with higher PDE, potting thicker fibers, improved reflectivity

Additional Shielding will be needed
- reduce readout noise, suppress background from TS-opening and neutrons

Comment: with additional effort higher (>100kW) very likely possible

“WELL DEFINED” R&D PROGRAM

Improved counters: - R&D to improve the profile of counter extrusions
- R&D to improve coating reflectivity
- R&D to fill fiber holes -> potting
- aging studies

CRV prototype: to be installed during shutdown

Shielding Prototypes: - Procure high-Z shielding:
few small blocks to be installed in mu2e
- optimize the shielding design

DAQ: - demonstrate mu2e-II feasibility

…. …..

Mu2e not only a great proofing ground for mu2e II CRV, the proposed R&D likely to improve mu2e along the way, some very general topics (fiber coupling, shielding,…)