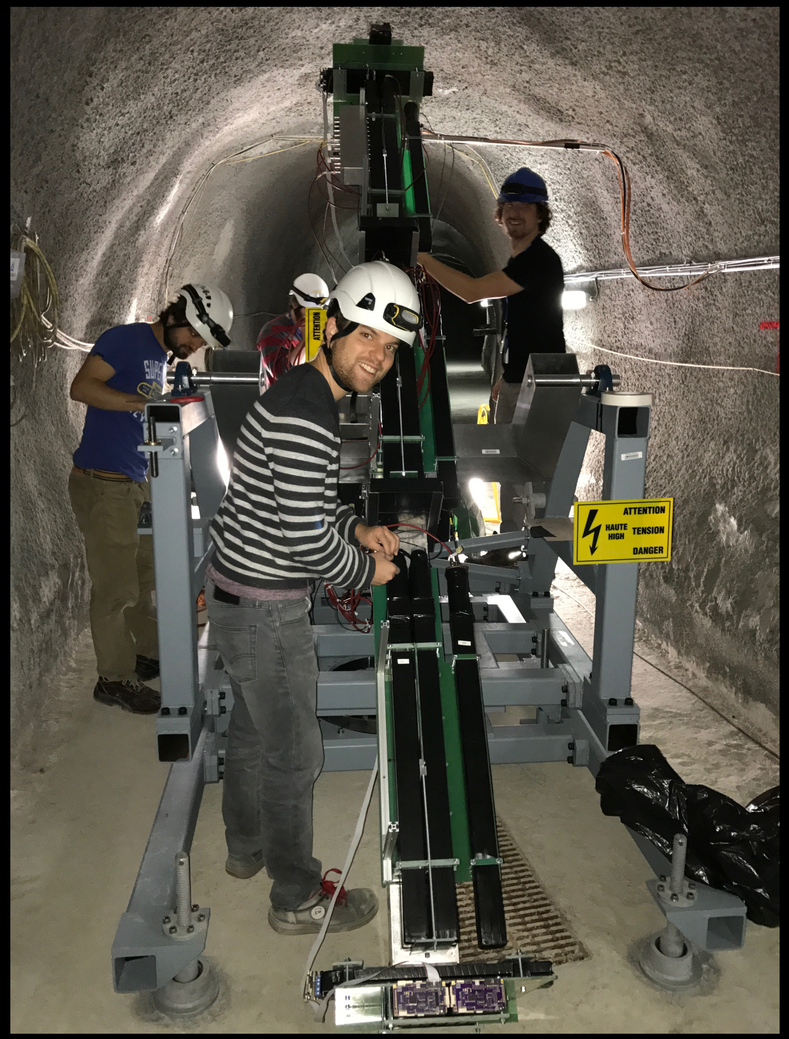
The MilliQan Experiment

David Stuart, UC Santa Barbara

HEP at the Sensitivity Frontier, KITP, 5/23/18



Funding: DOE and UCSB

Search for milli-charged particles produced at LHC

Example: A new, dark sector U(1), could give dark sector particles a small *effective* SM charge through mixing

"Dark EM" — **Mixing of dark photon and SM photon**

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} B'^{\mu\nu} B'_{\mu\nu} - \frac{\kappa}{2} B^{\mu\nu} B'_{\mu\nu}$$

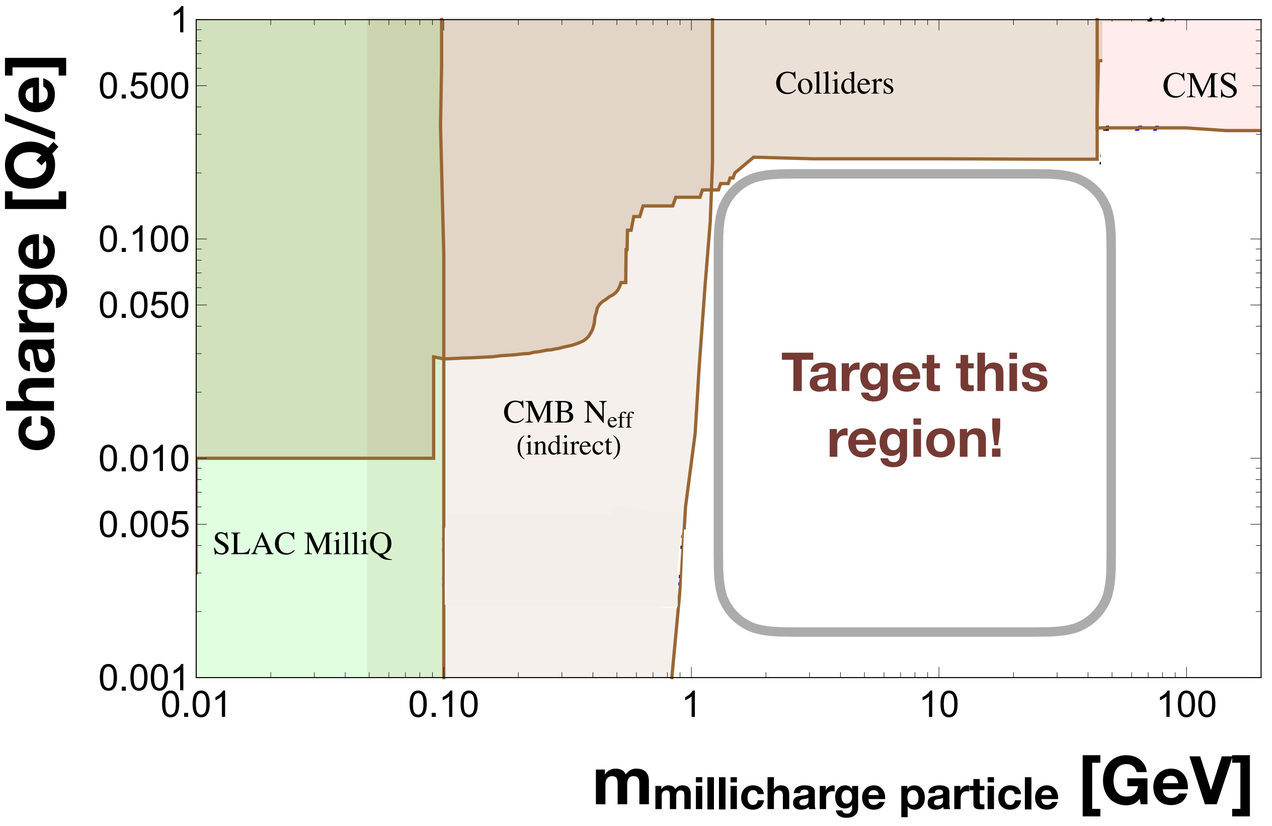
$$- \frac{1}{4} B'^{\mu\nu} B'_{\mu\nu} - \frac{\kappa}{2} B'^{\mu\nu} B_{\mu\nu} + i\bar{\psi}(\not{\partial} + i g_D \not{B}' + i M_{\rm mCP})\psi$$

$$B'_\mu \to B'_\mu + \kappa B_\mu$$

$\longrightarrow Q_{\rm eff} \propto \kappa\, g_D$

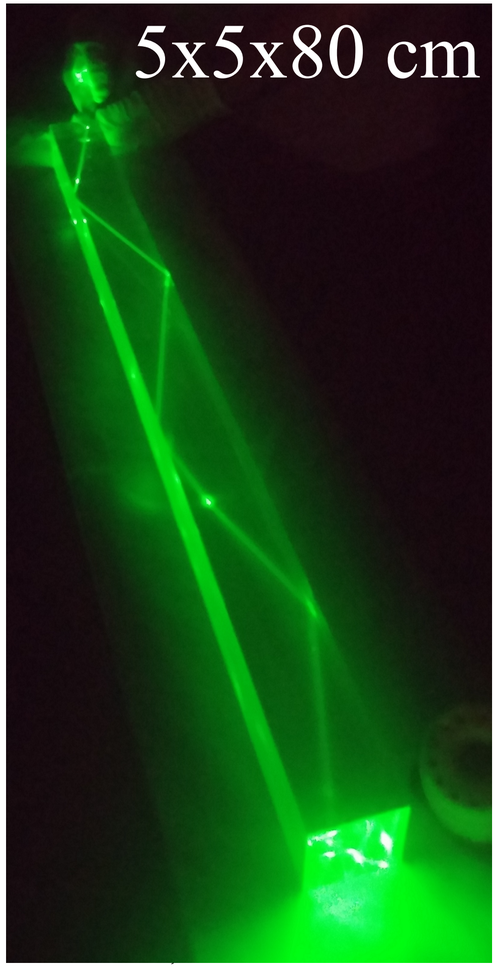
Would be produced at LHC, eg via Drell-Yan

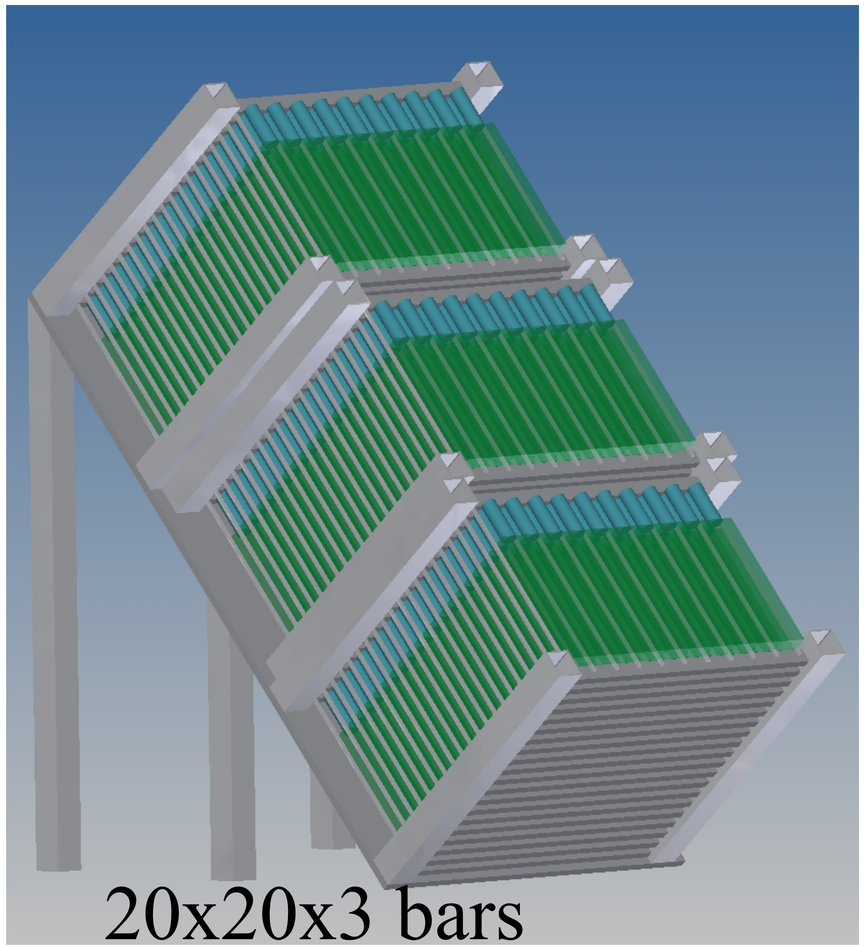
- invisible to detectors due to Q^2 suppressed ionization



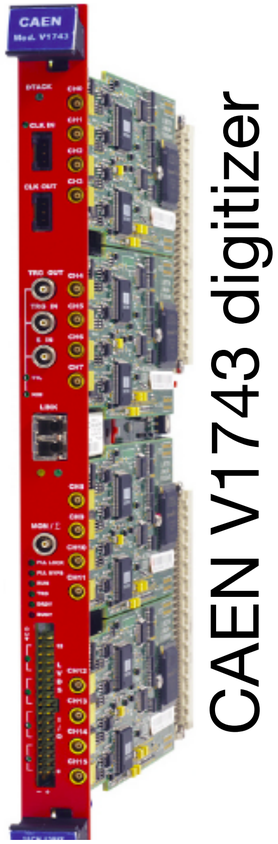
Detector design

Three layers of long scintillator bars, arranged projectively to beam spot;
Search for triple-coincidence of ≥1 photon signals, in-time and in-line.

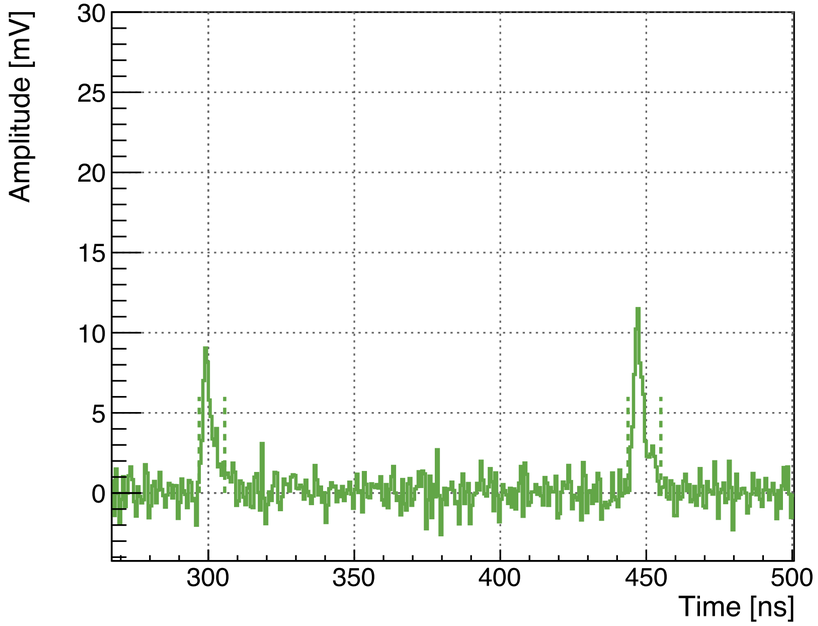




16 chan
1.6 GS/s

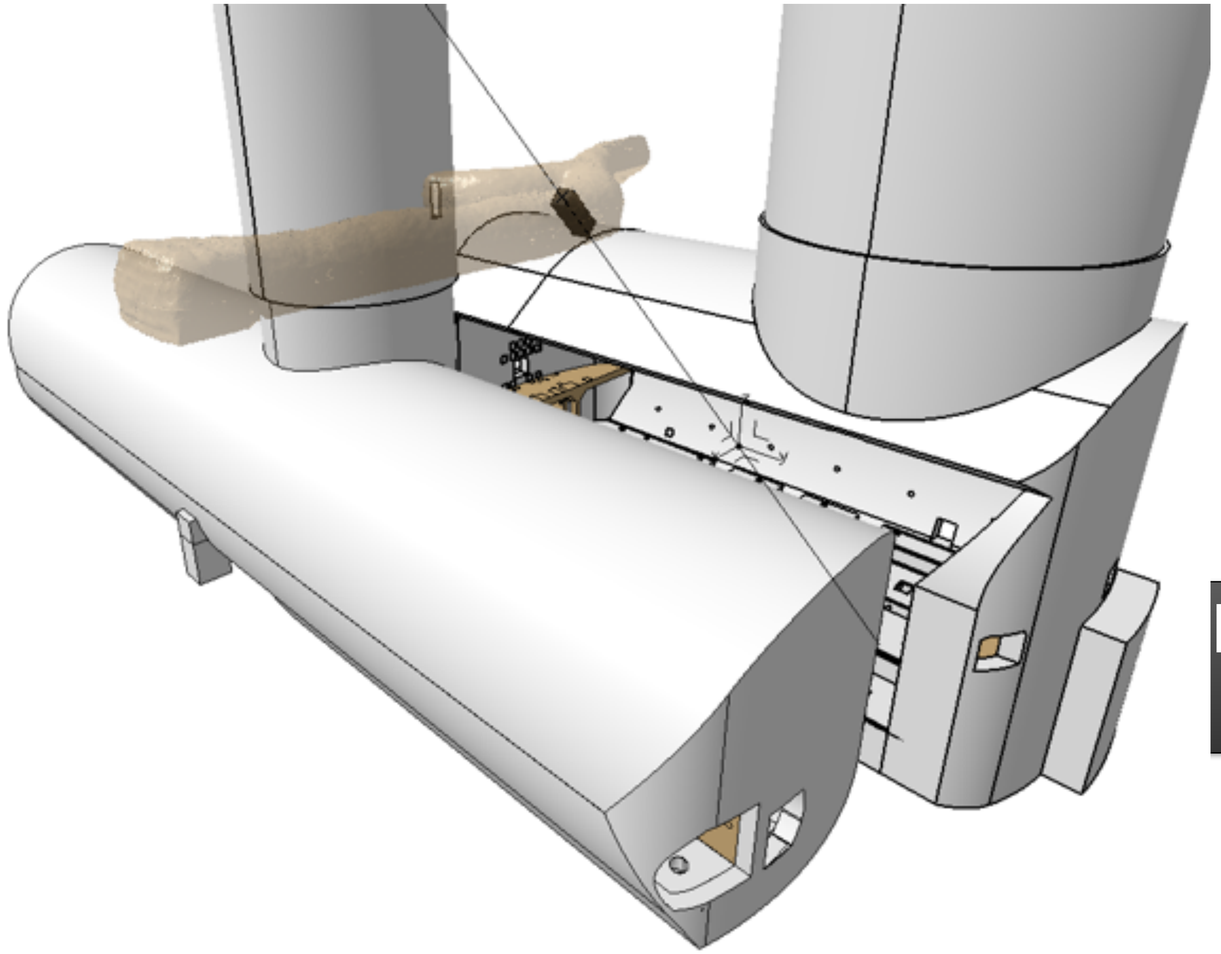


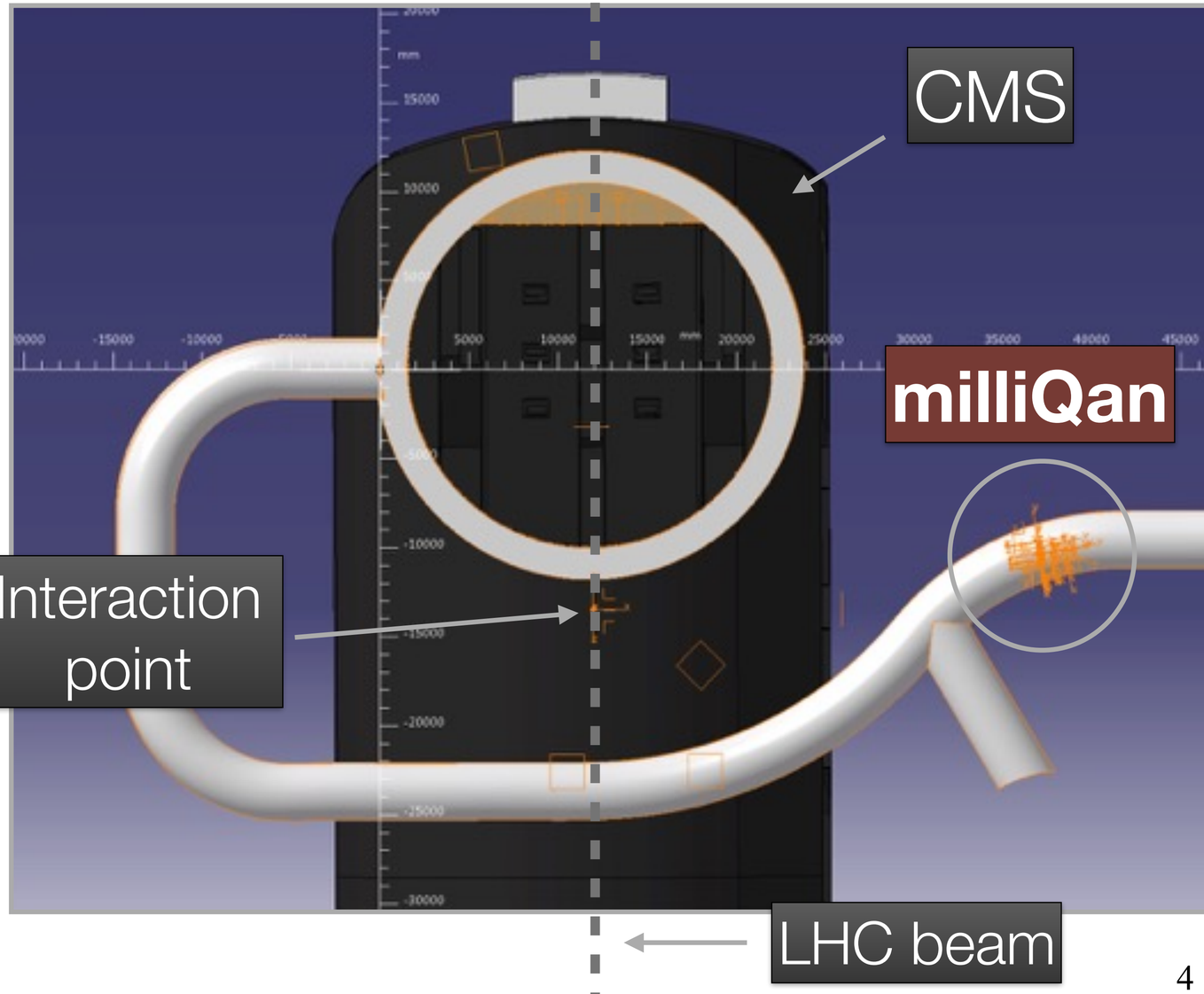
CAEN V1743 digitizer



Detector location

Situate near LHC collision point, with ~15 m of rock shielding

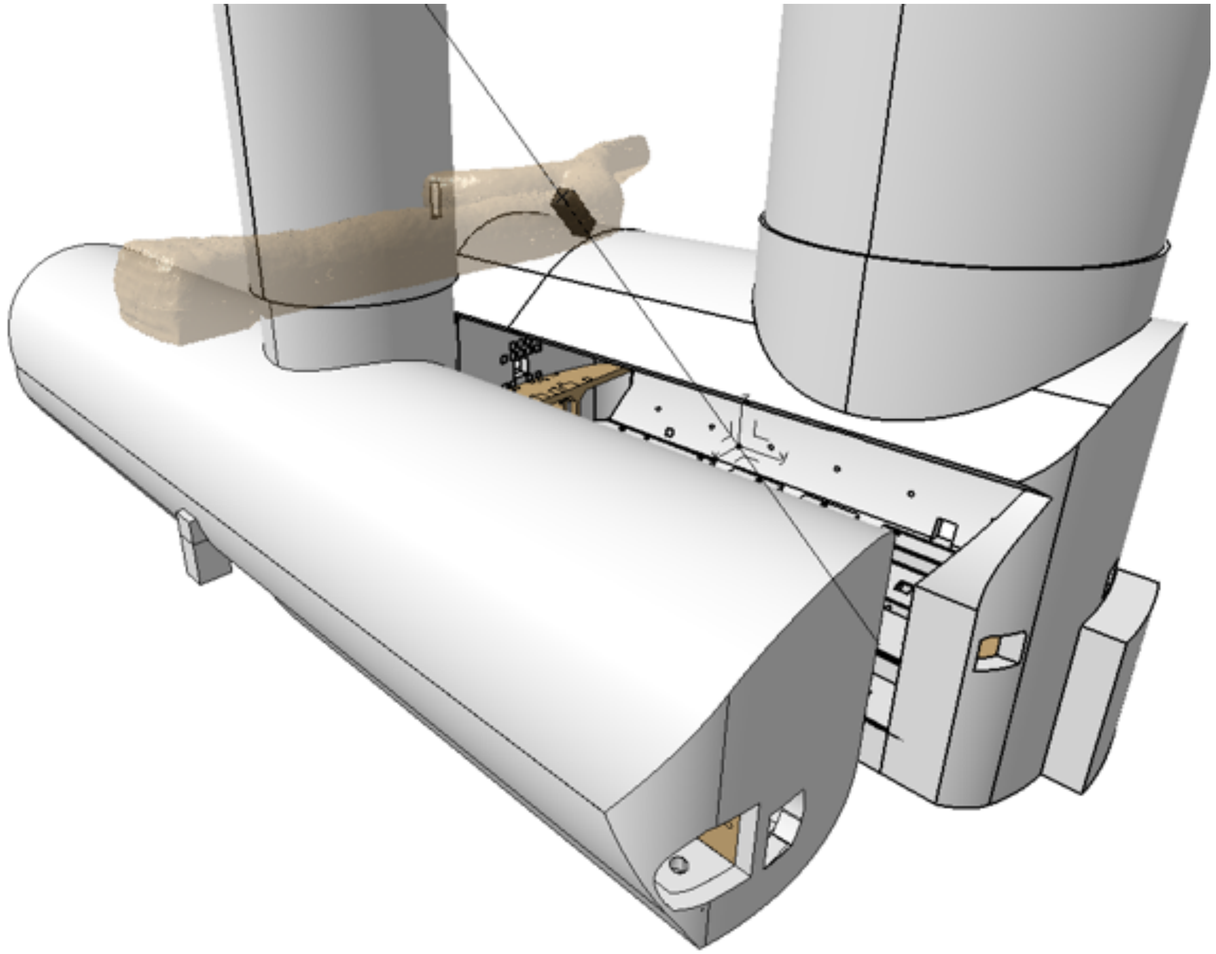




Detector location

"spelunking toward the dark sector"

Situate near LHC collision point, with ~15 m of rock shielding

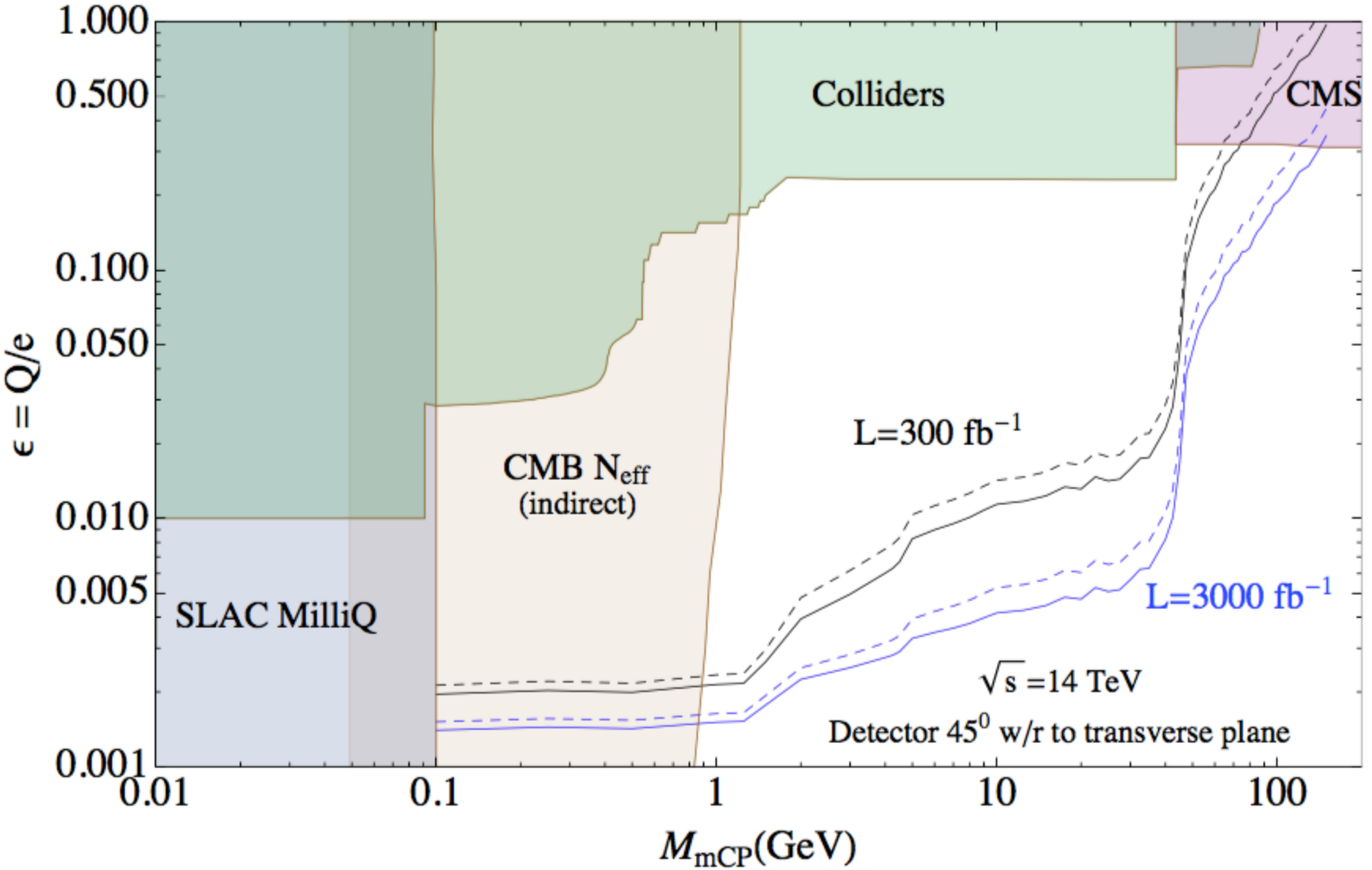


Expected sensitivity

Original paper: **Looking for milli-charged particles with a new experiment at the LHC**

Andrew Haas,[1] Christopher S. Hill,[2] Eder Izaguirre,[3] and Itay Yavin[3,4]

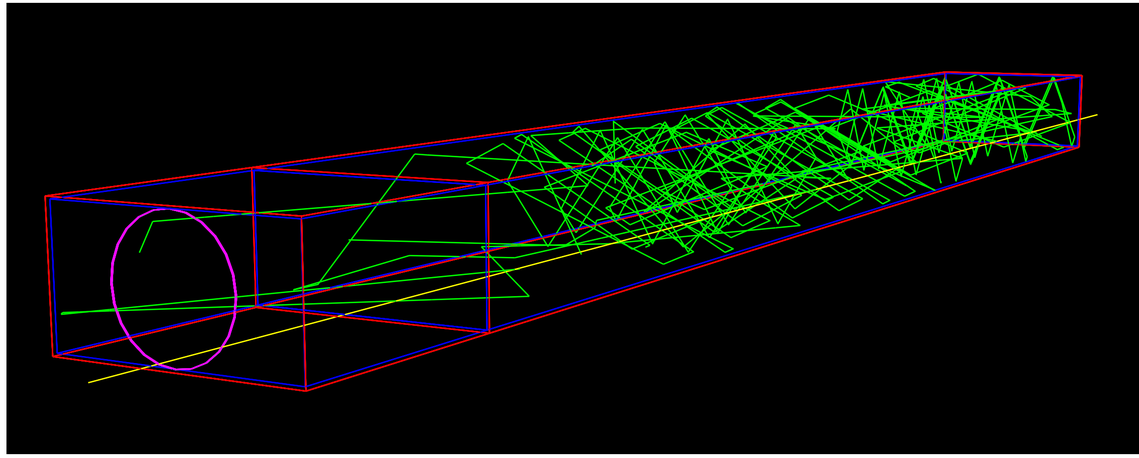
Phys.Lett. B746 (2015) 117

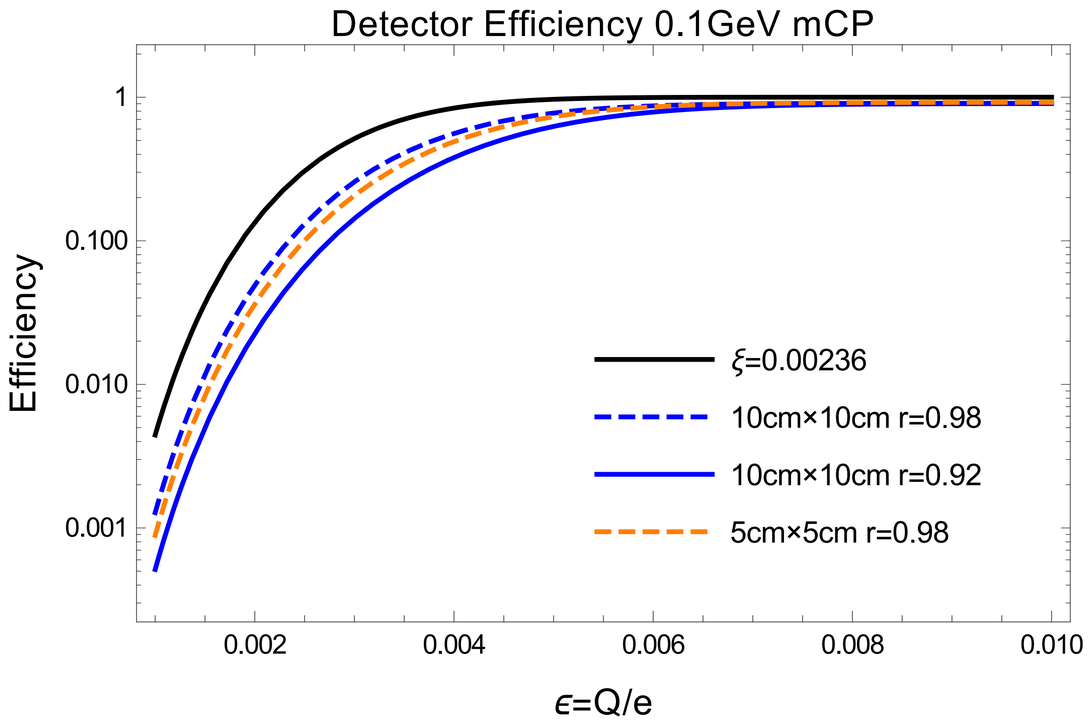


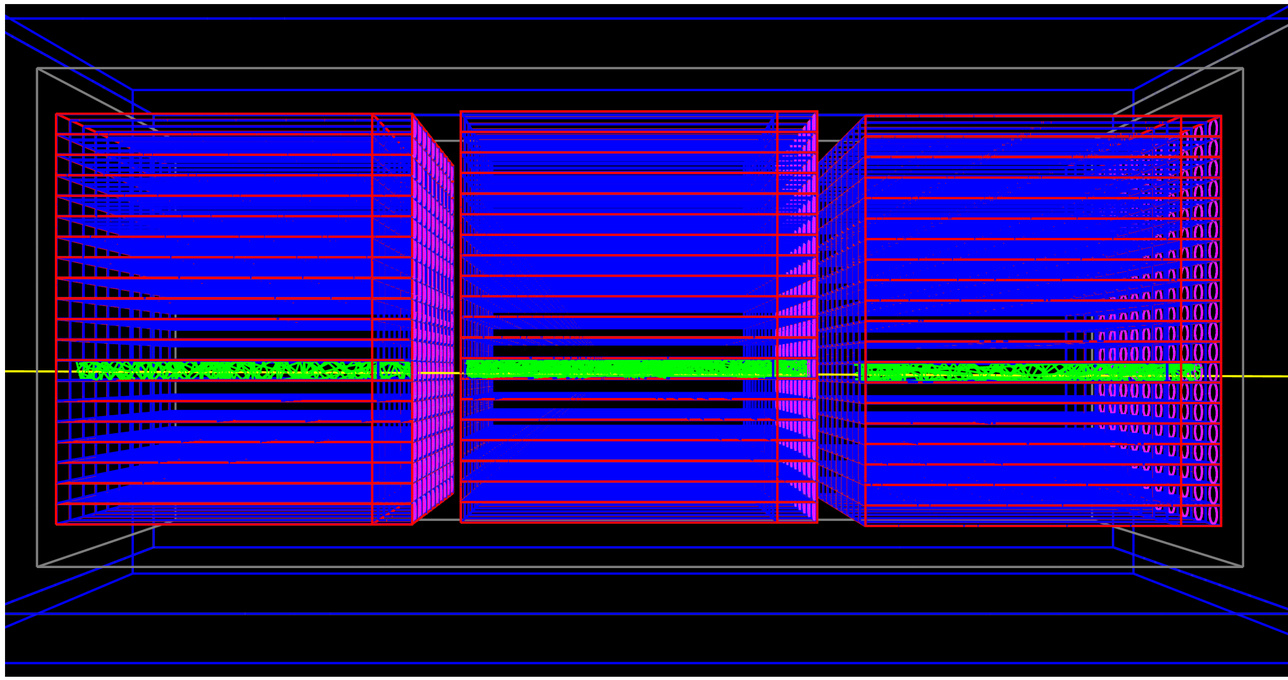
Expected sensitivity: estimated with GEANT

A Letter of Intent to Install a Milli-charged Particle Detector at LHC P5 arXiv:1607.04669

Austin Ball,[1] Jim Brooke,[2] Claudio Campagnari,[3] Albert De Roeck,[1] Brian Francis,[4] Martin Gastal,[1] Frank Golf,[3] Joel Goldstein,[2] Andy Haas,[5] Christopher S. Hill,[4] Eder Izaguirre,[6] Benjamin Kaplan,[5] Gabriel Magill,[7,6] Bennett Marsh,[3] David Miller,[8] Theo Prins,[1] Harry Shakeshaft,[1] David Stuart,[3] Max Swiatlowski,[8] and Itay Yavin[7,6]







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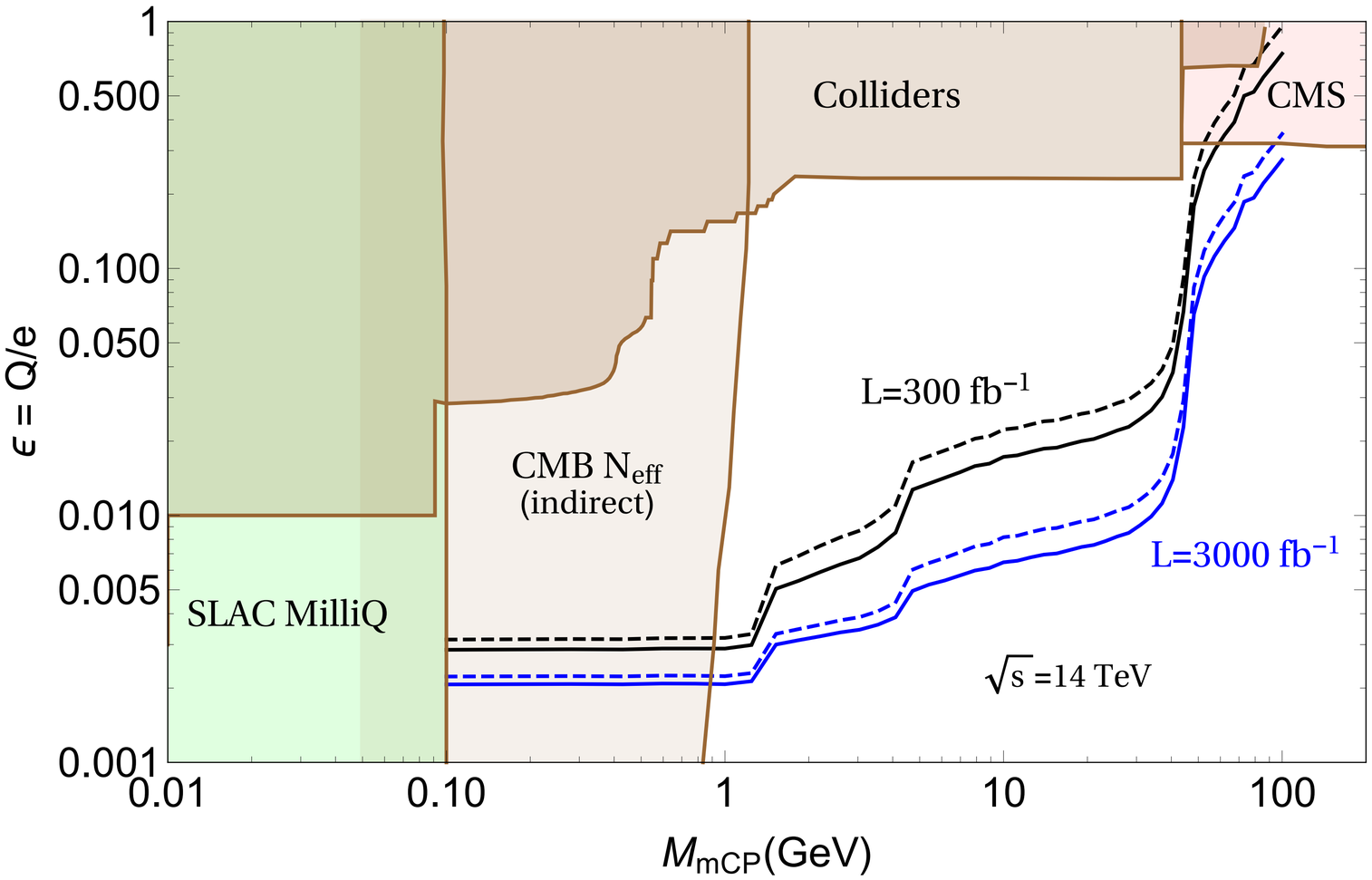
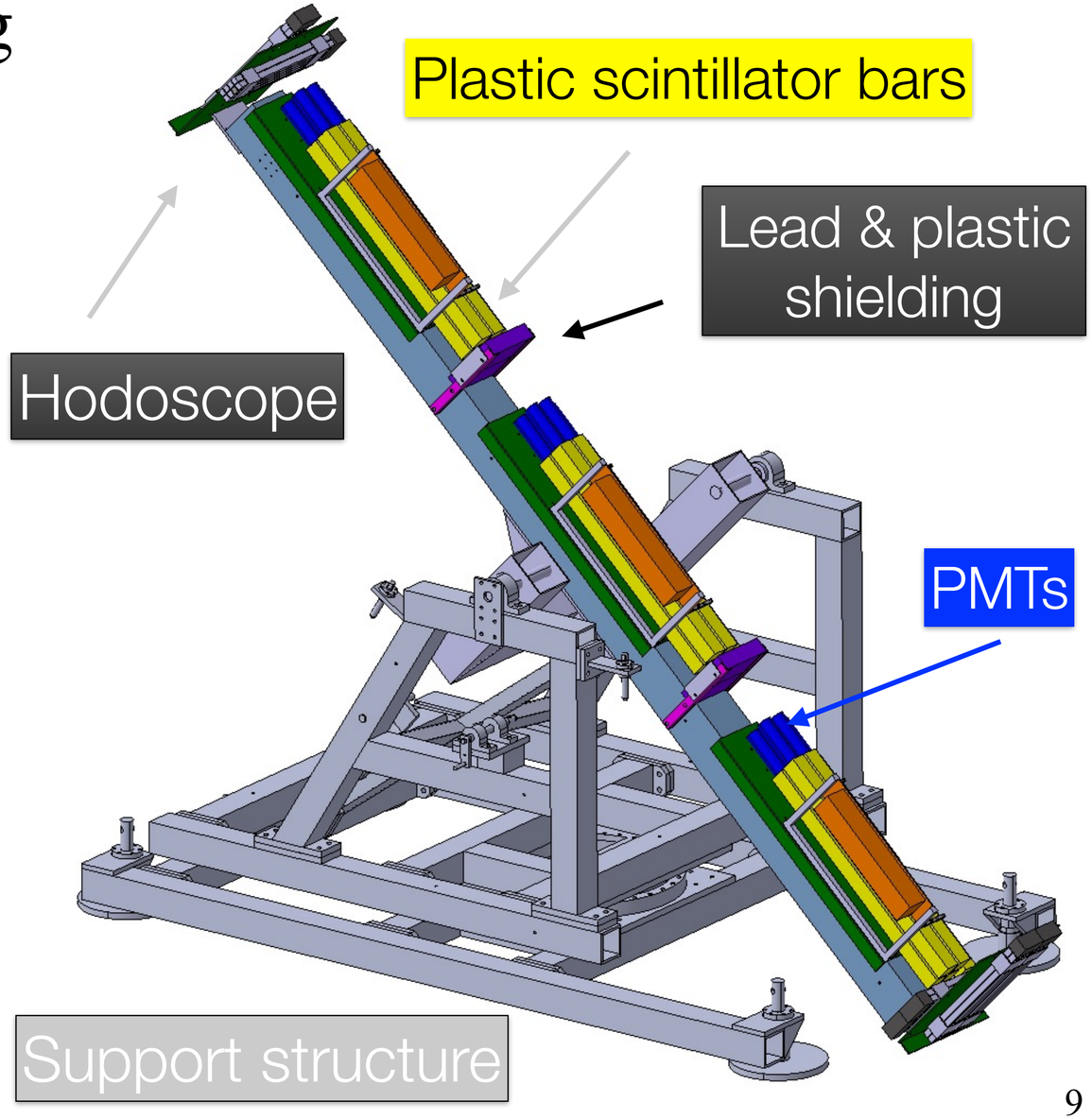


A key assumption is that background is dominated by dark rate.

MilliQan Demonstrator: running with 1% of full detector

To measure the backgrounds and optimize the design, we installed a 1% scale demonstrator for 2017-18 running



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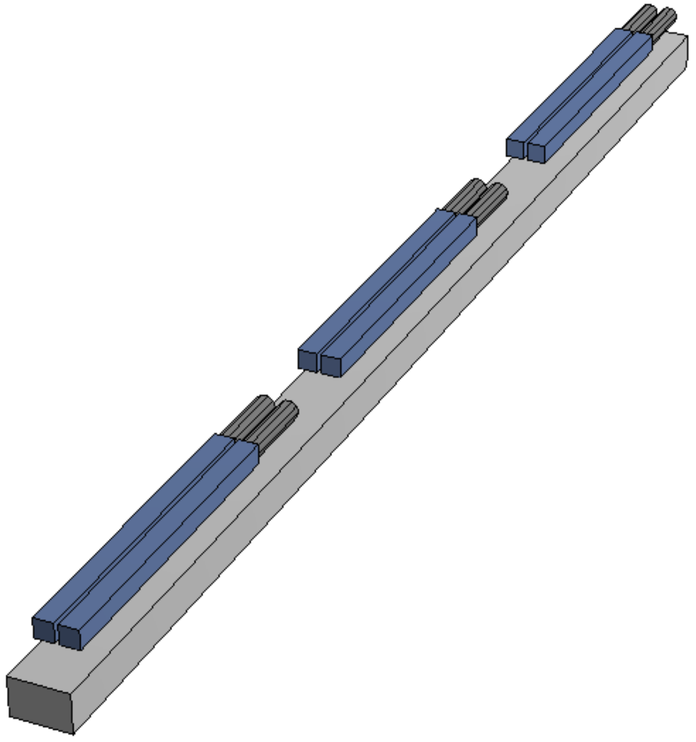

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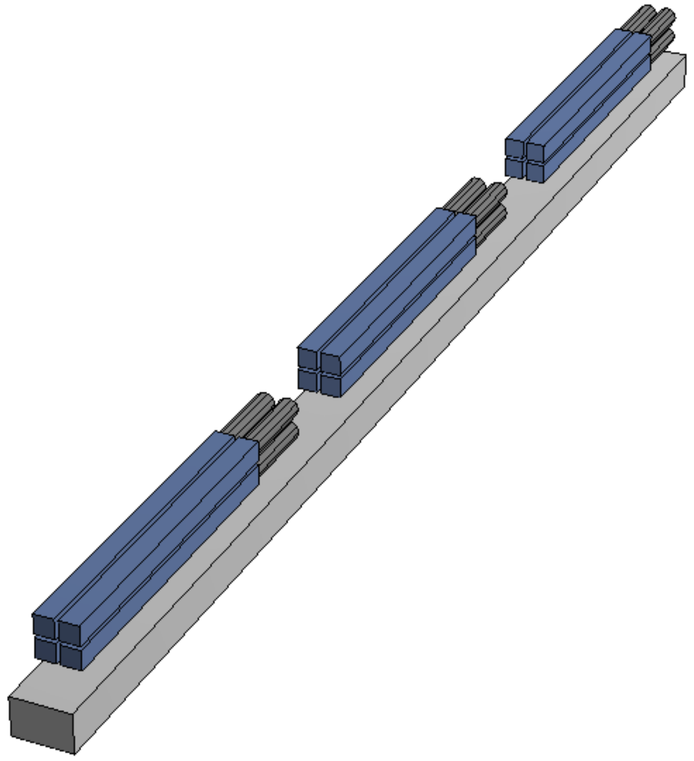

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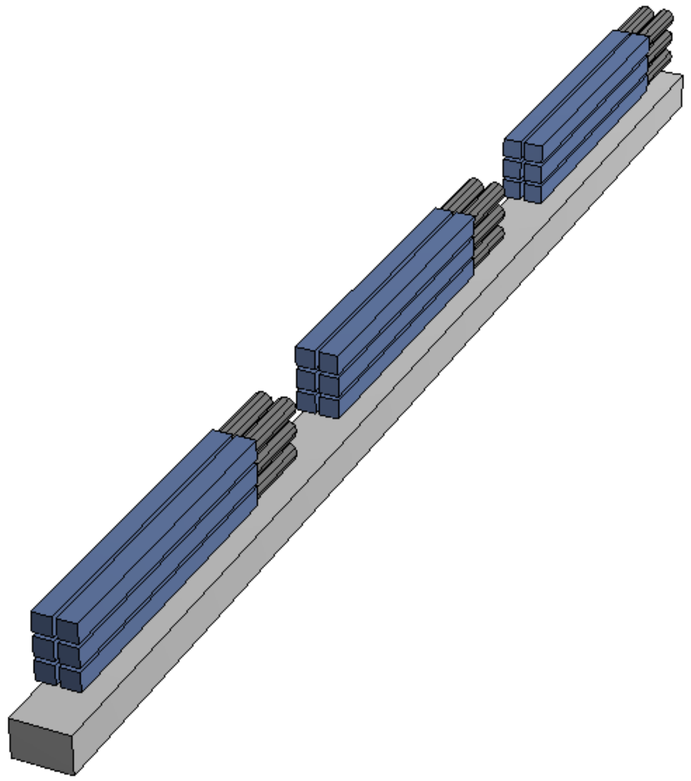

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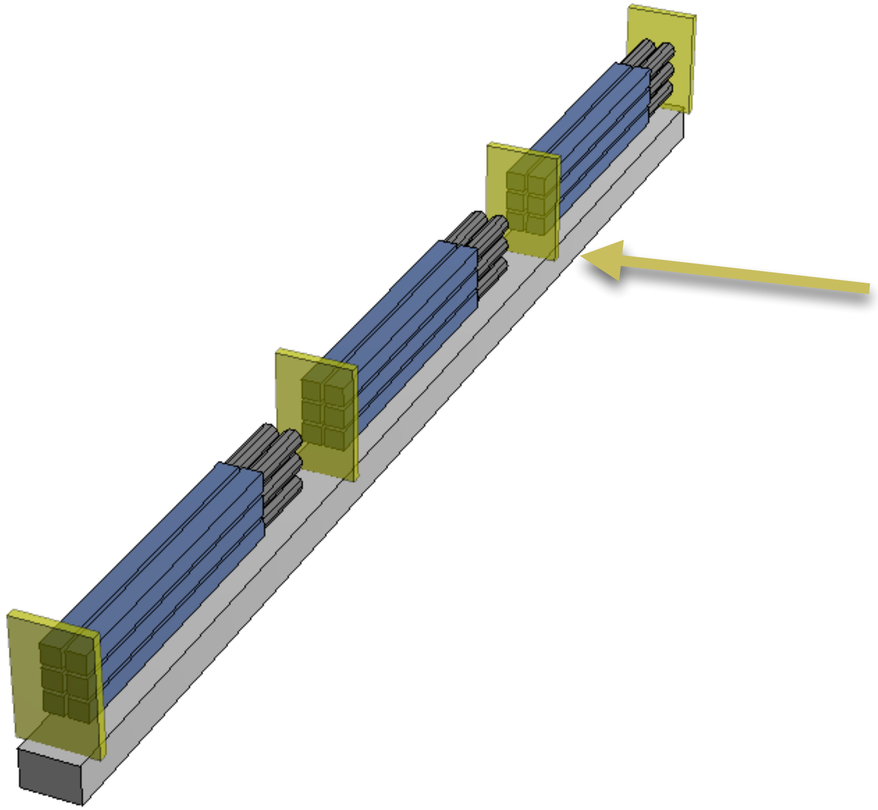

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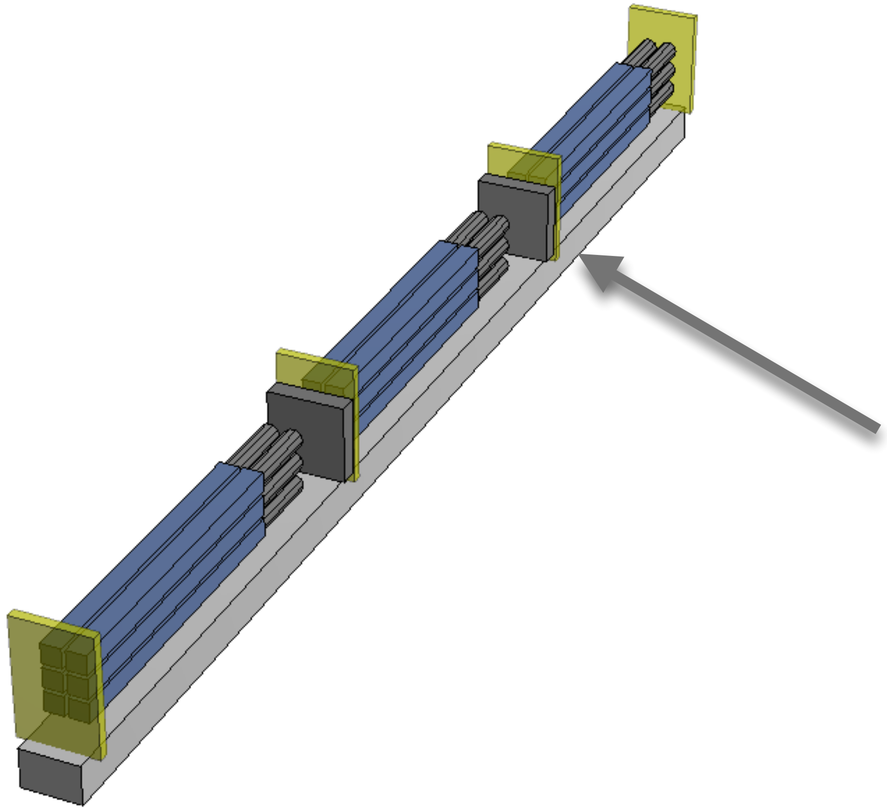

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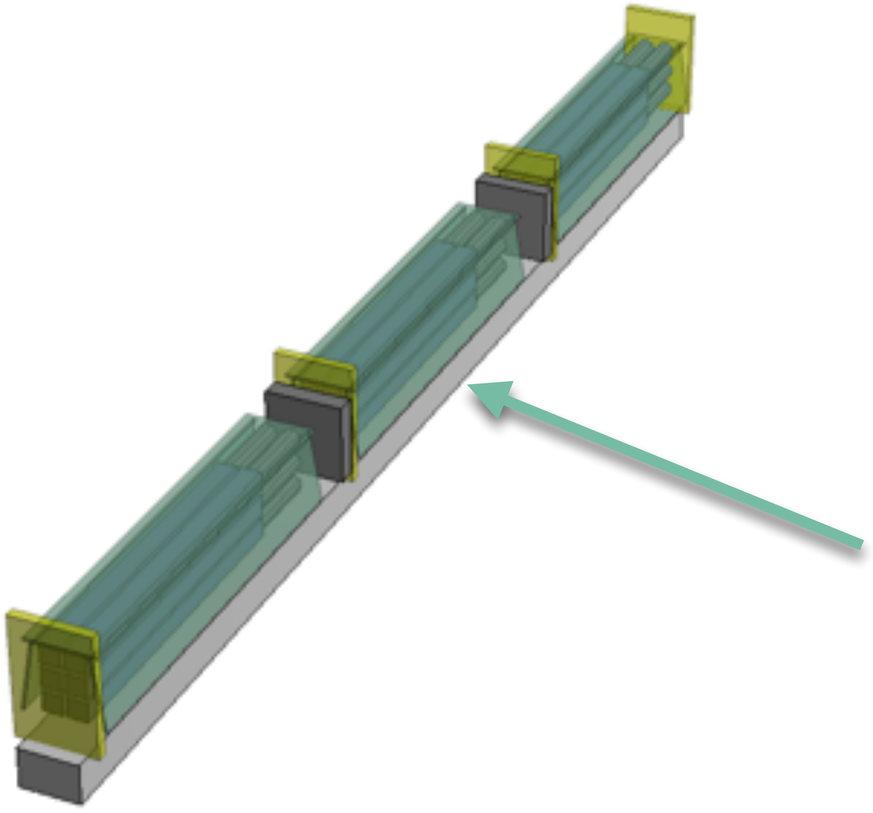

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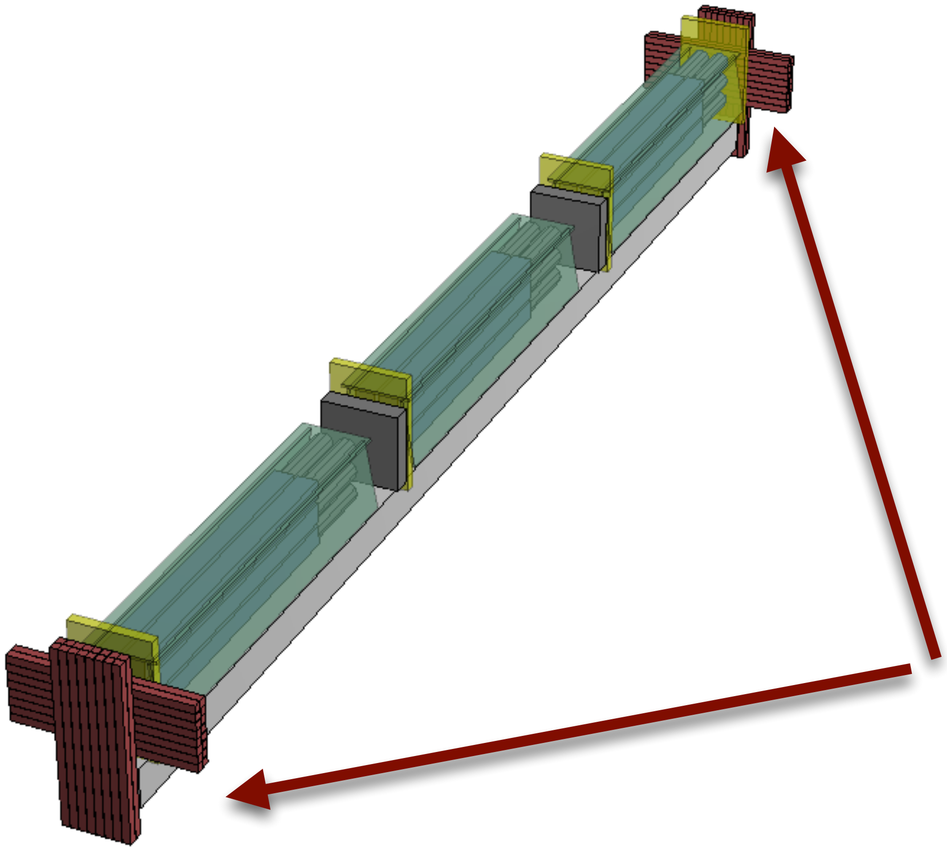

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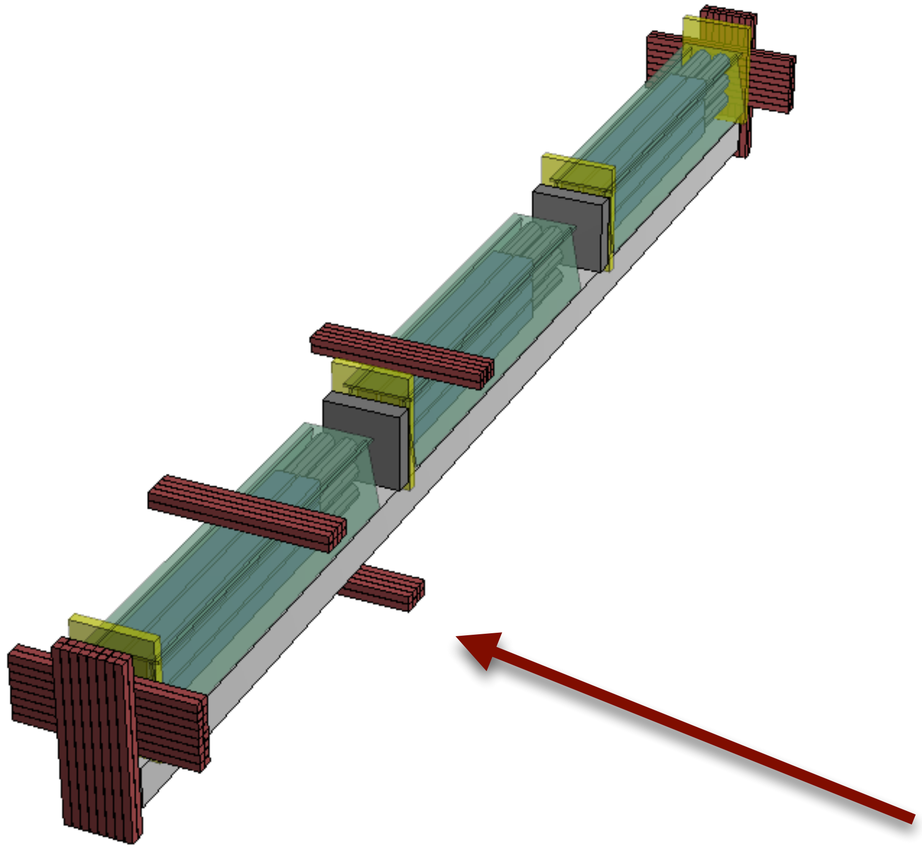

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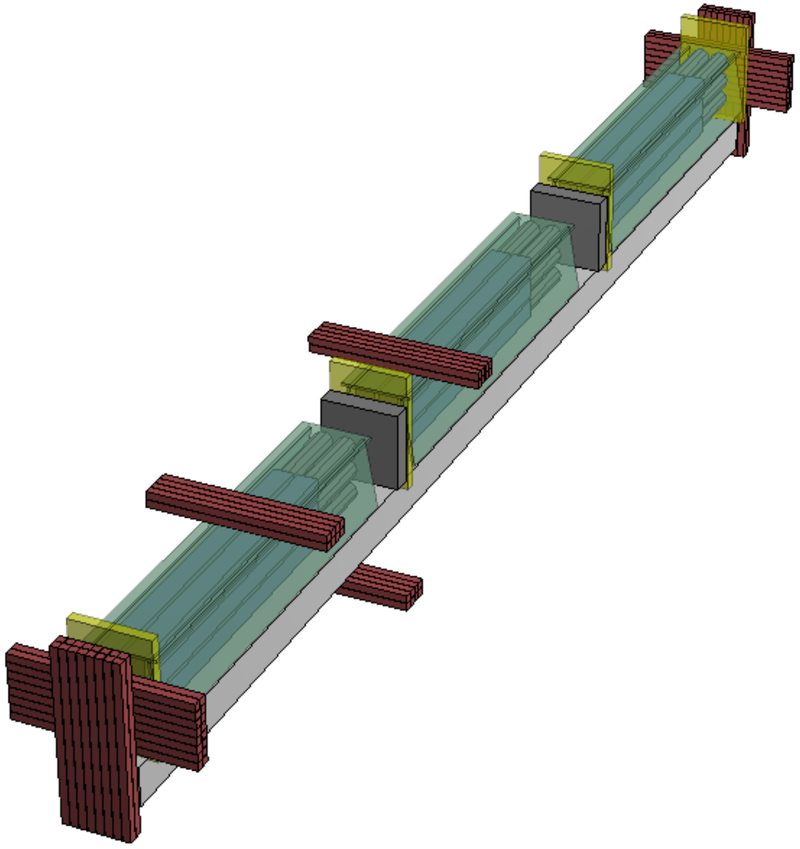

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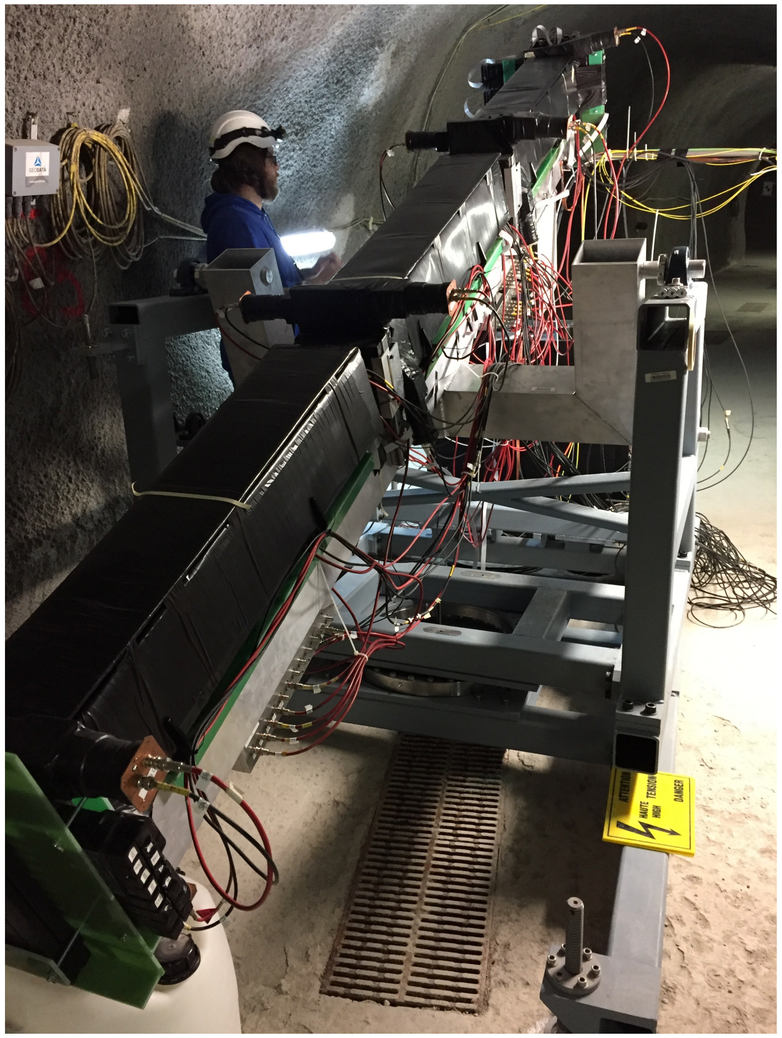

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Learning a lot about operations and backgrounds.

E.g.,: muons from collisions

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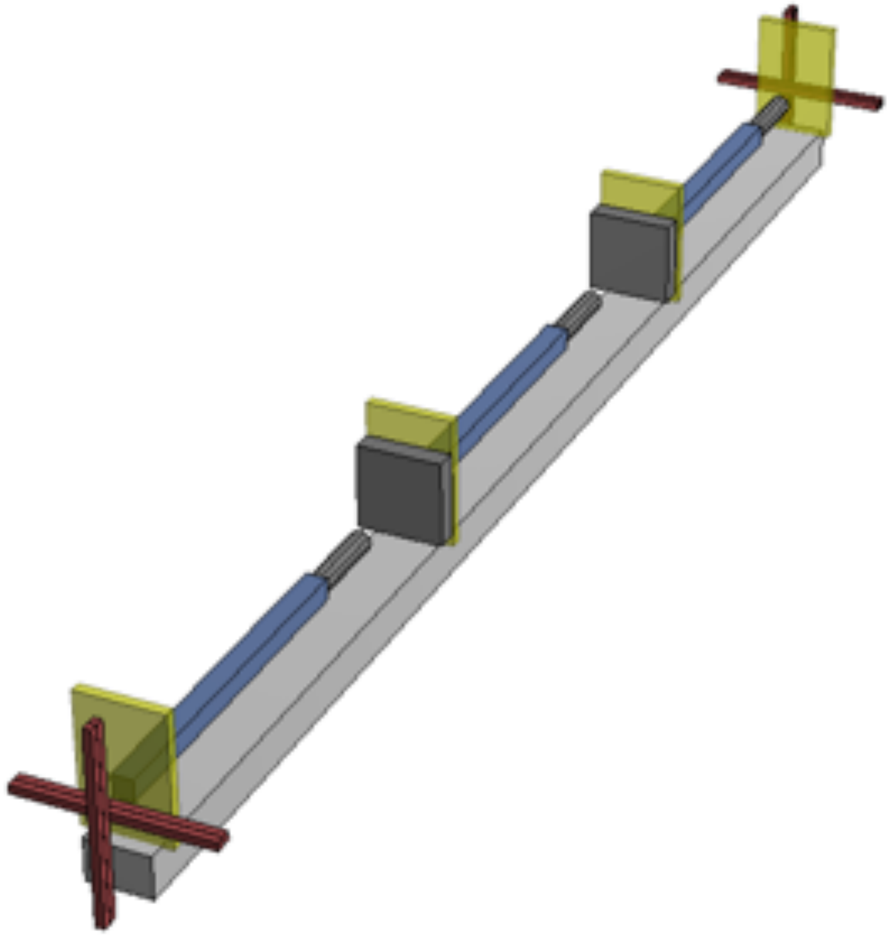

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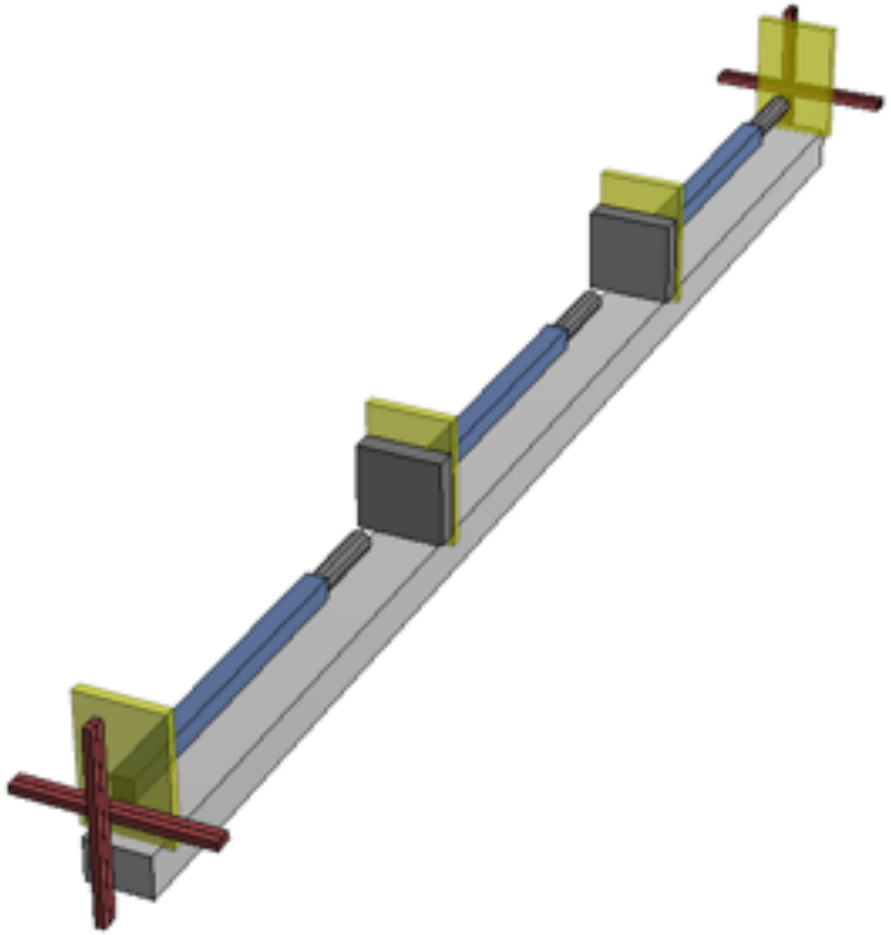

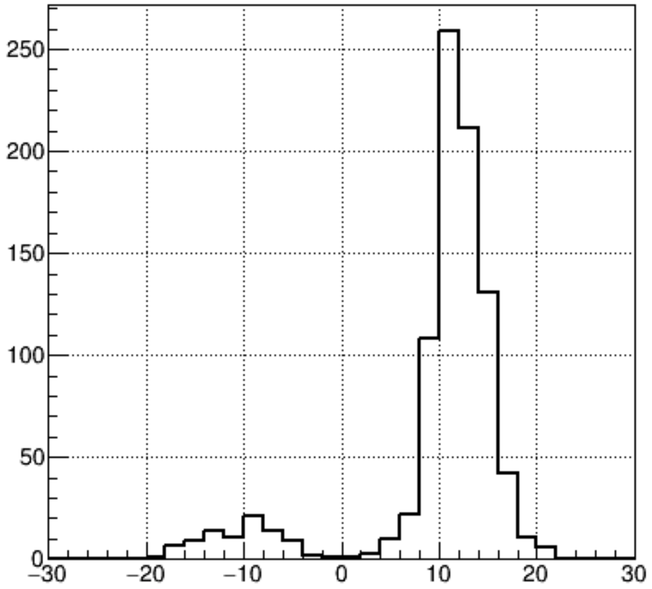

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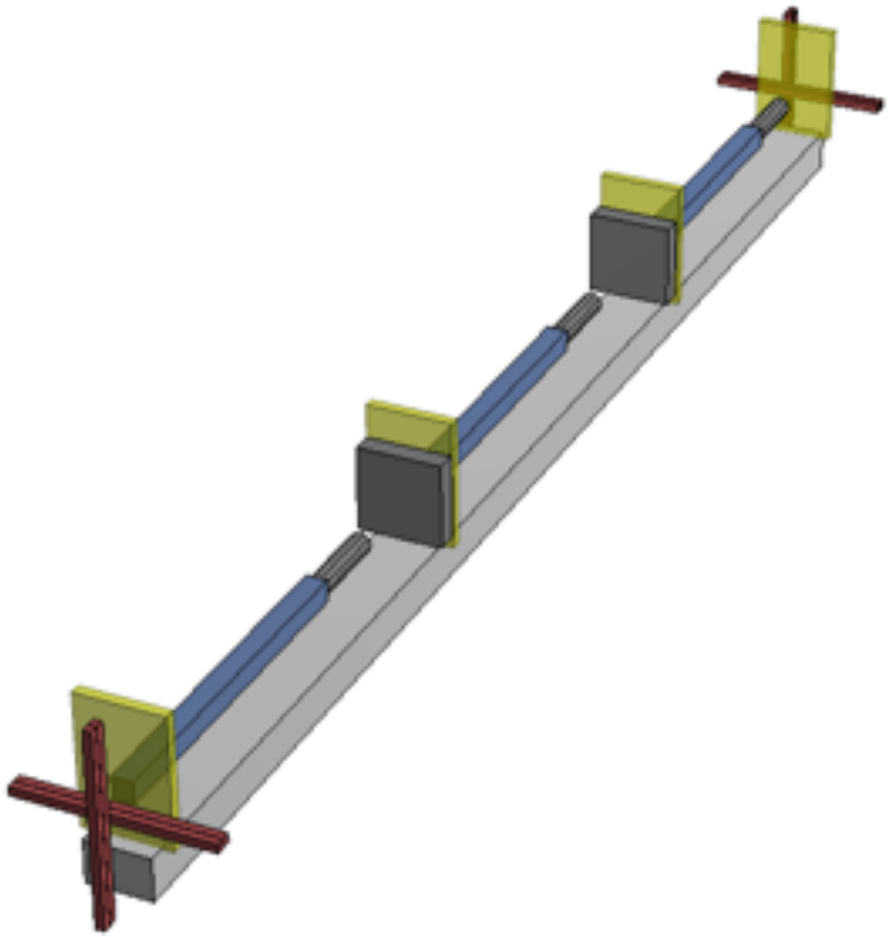

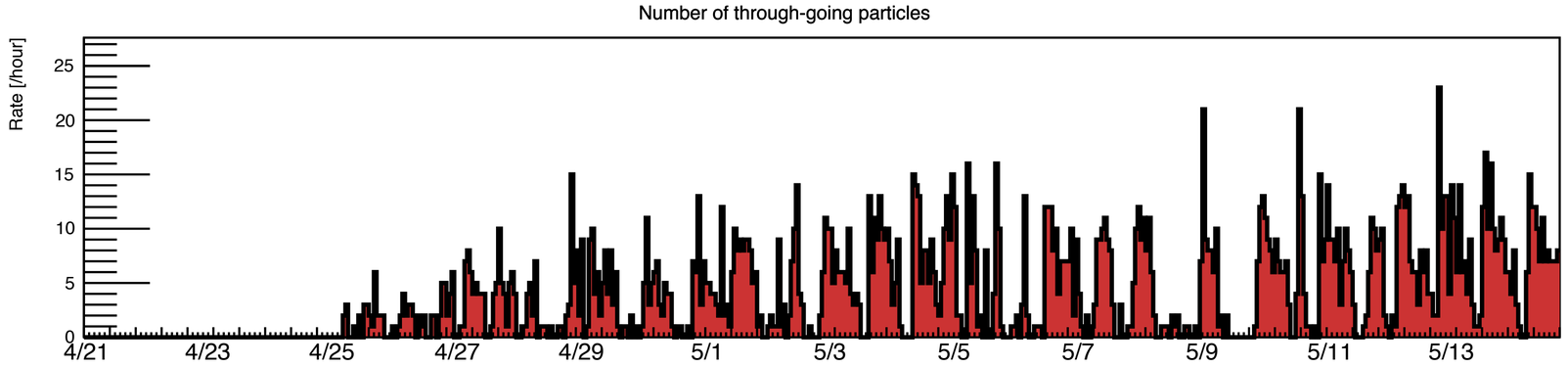

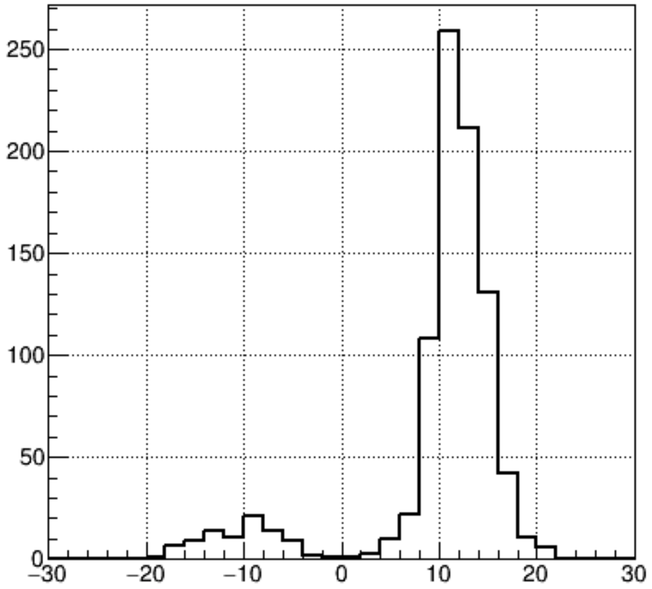

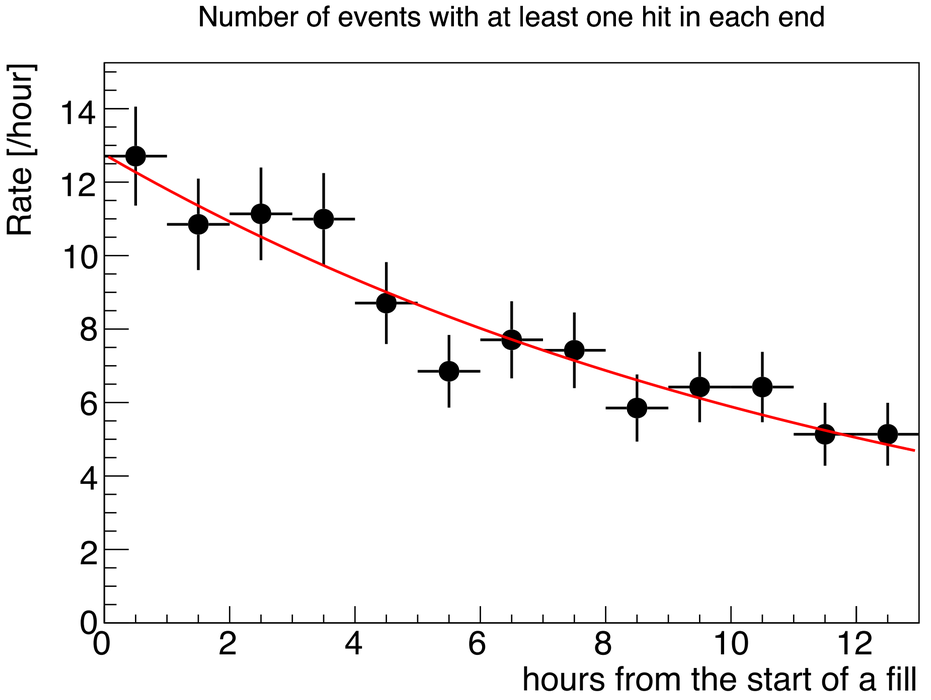

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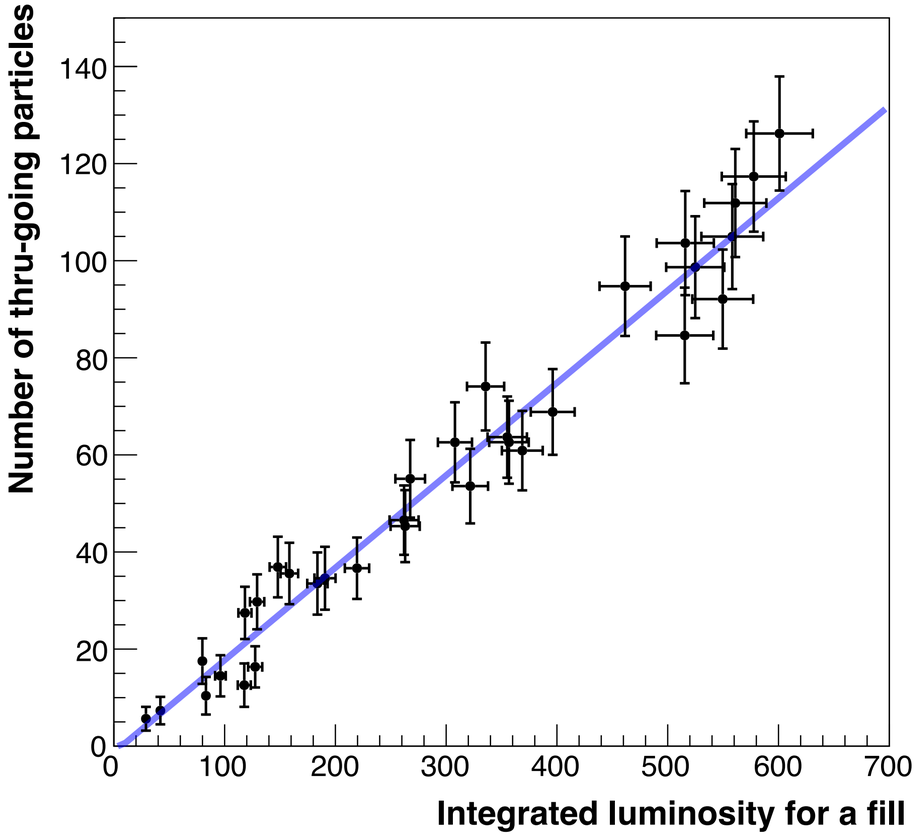
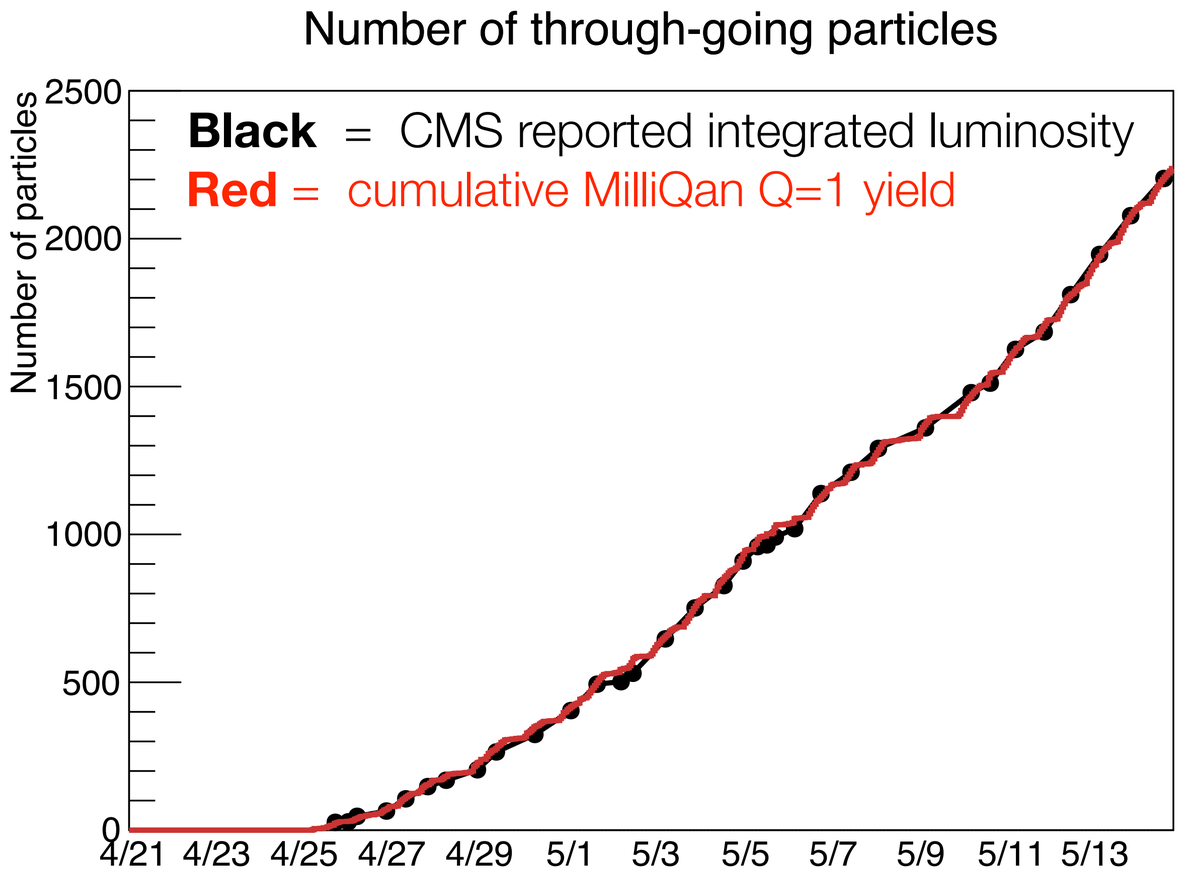




Measured Rate of 180 per fb^{-1} is consistent with expected rate from simulation of 220 per fb^{-1}

Summary and Outlook

Have design with new sensitivity over a large range of charge and mass

Engineering & mechanics at an advanced stage
 Final support structure already in place, module designs becoming mature

Have installed 1% scale demonstrator in tunnel taking data since Sept. 2017

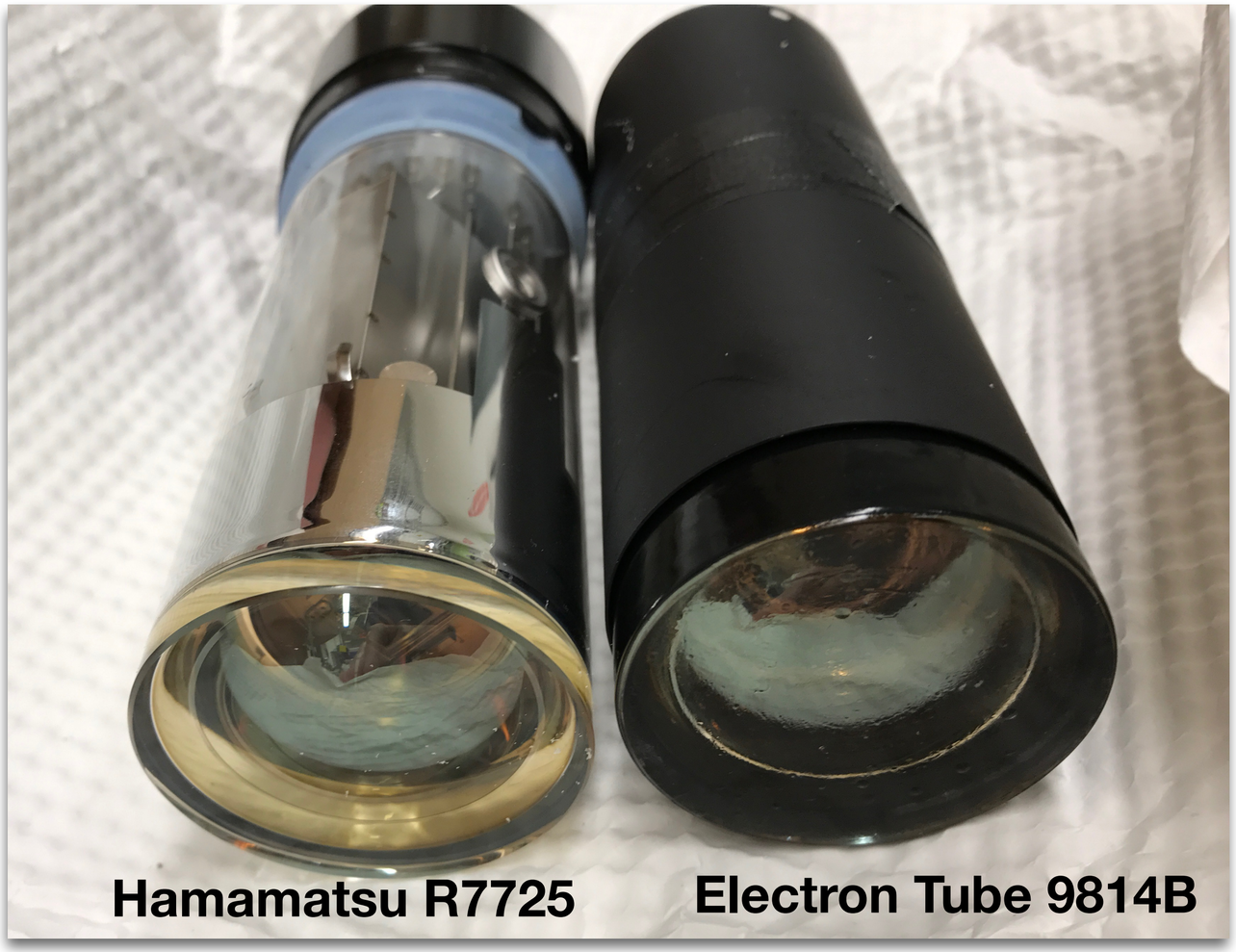
Plan is to have experiment ready for physics before Run 3 (2020)
 Construction/Installation during LS2

On track to meet schedule if funded. M&S ~$1M

Collaboration meeting photo

Additional slides

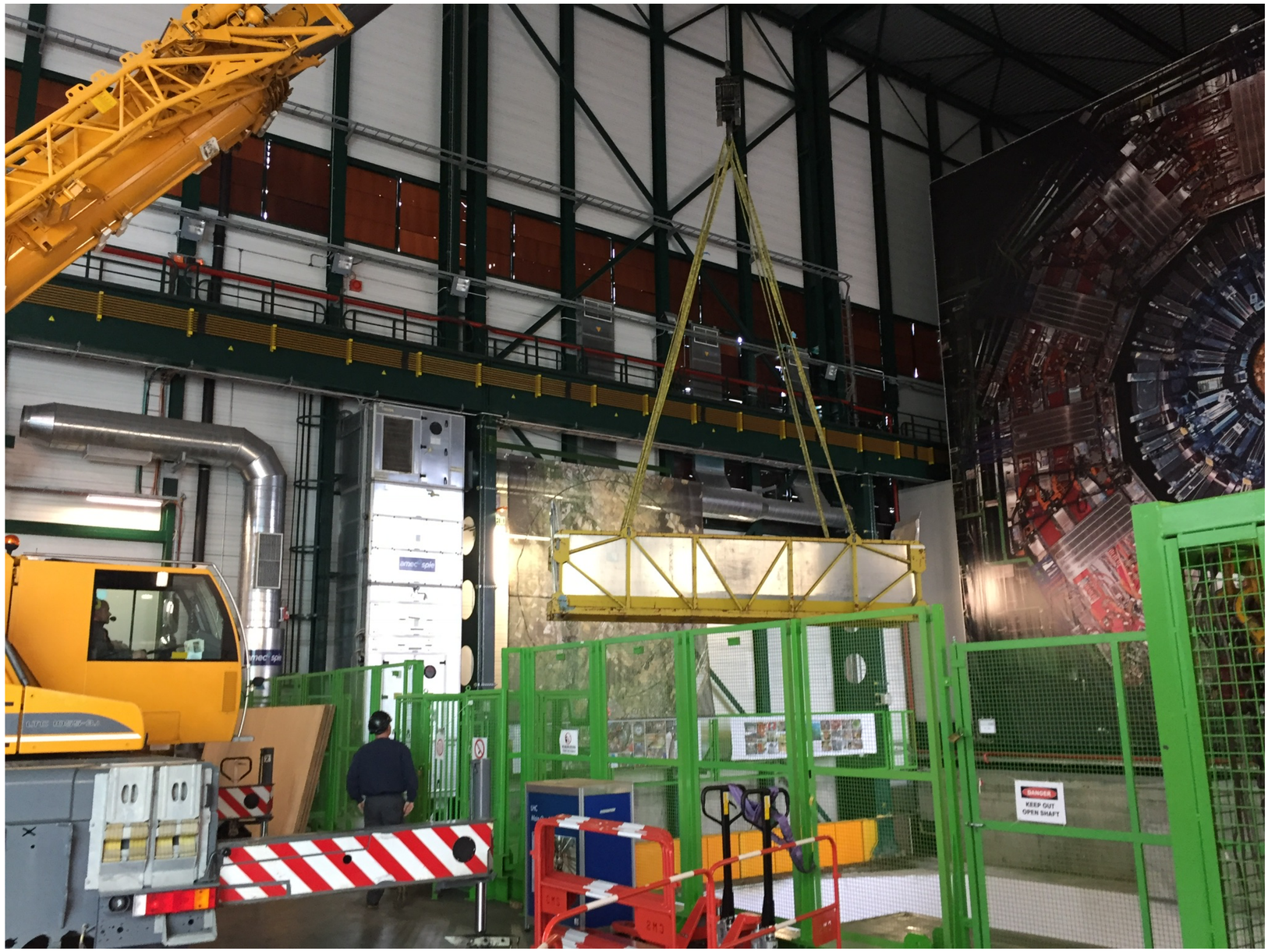
High gain, fast PMTs
($$)

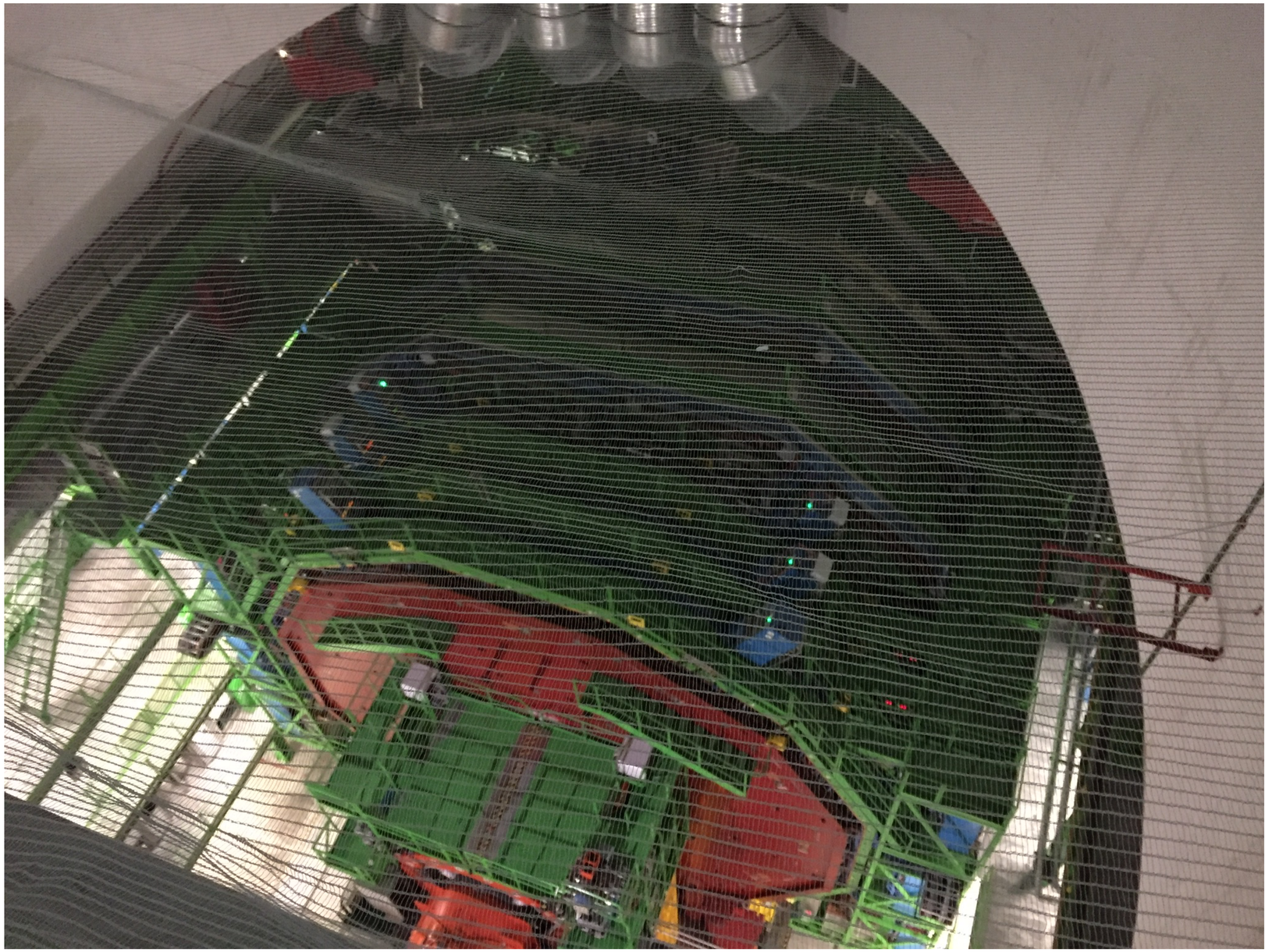


Hamamatsu R7725 **Electron Tube 9814B**

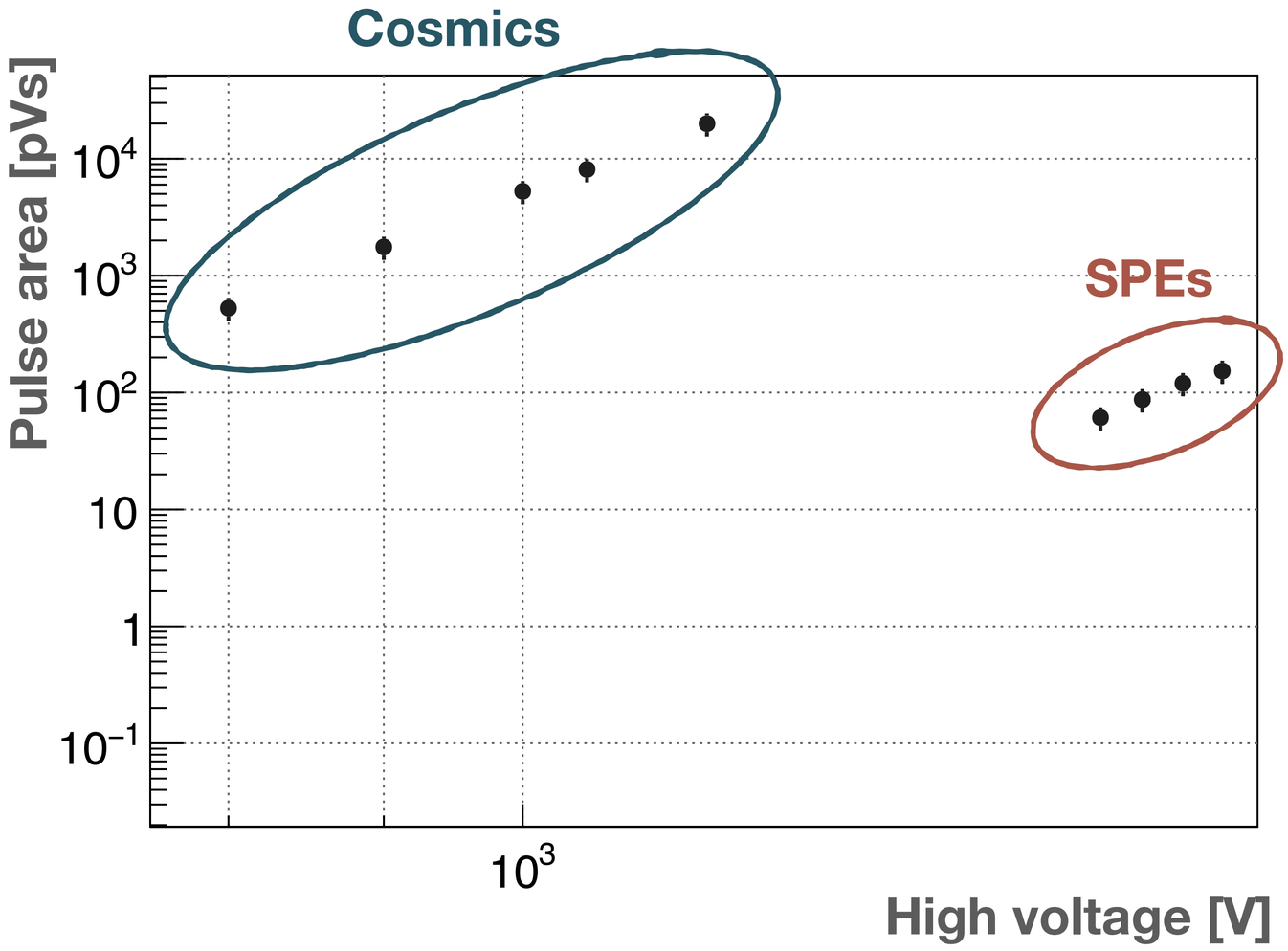
Older, slower PMTs
(effectively free!)

Hamamatsu R878


DANGER
KEEP OUT
OPEN SHAFT



Extracting cosmic light yield



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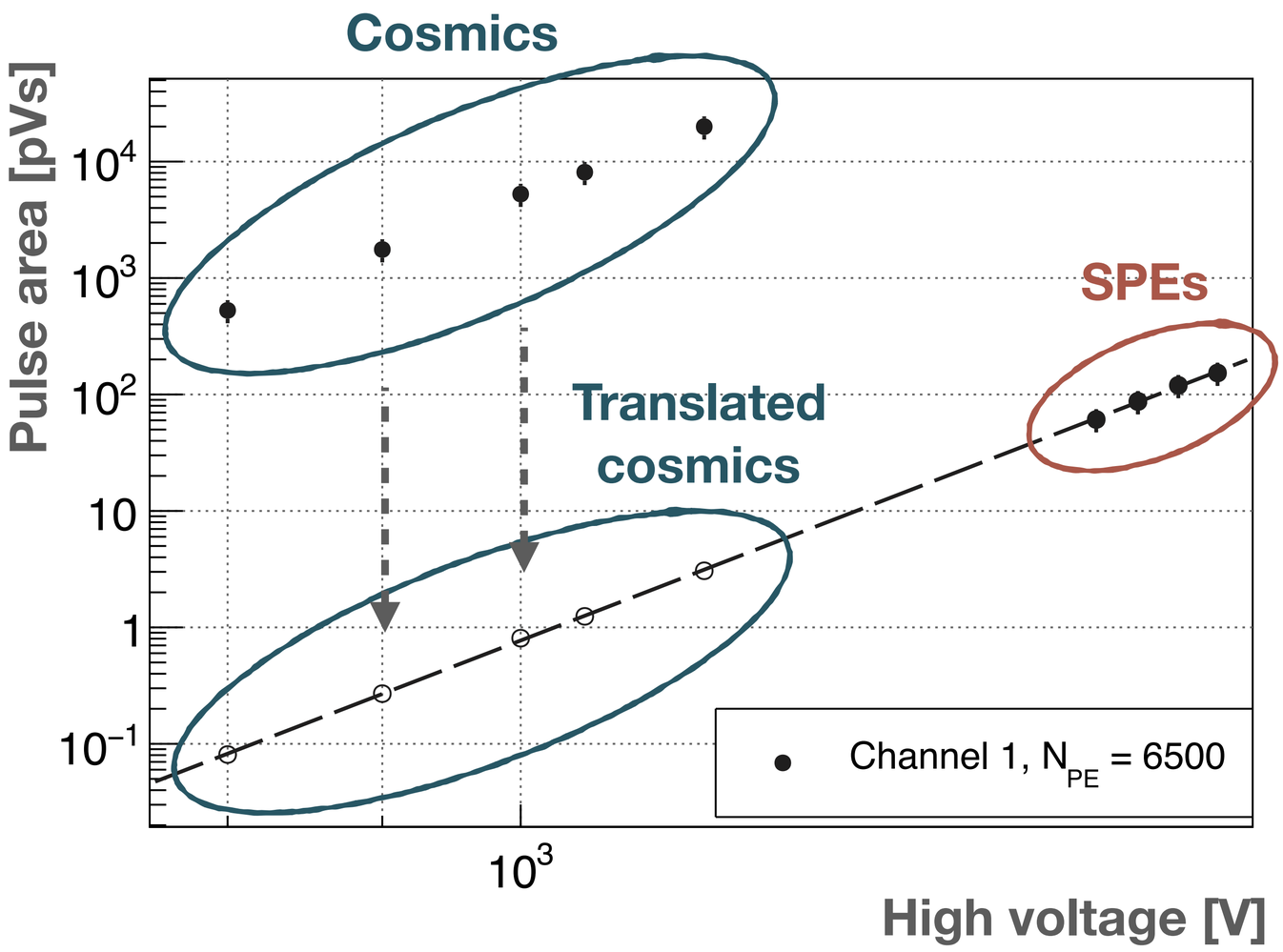
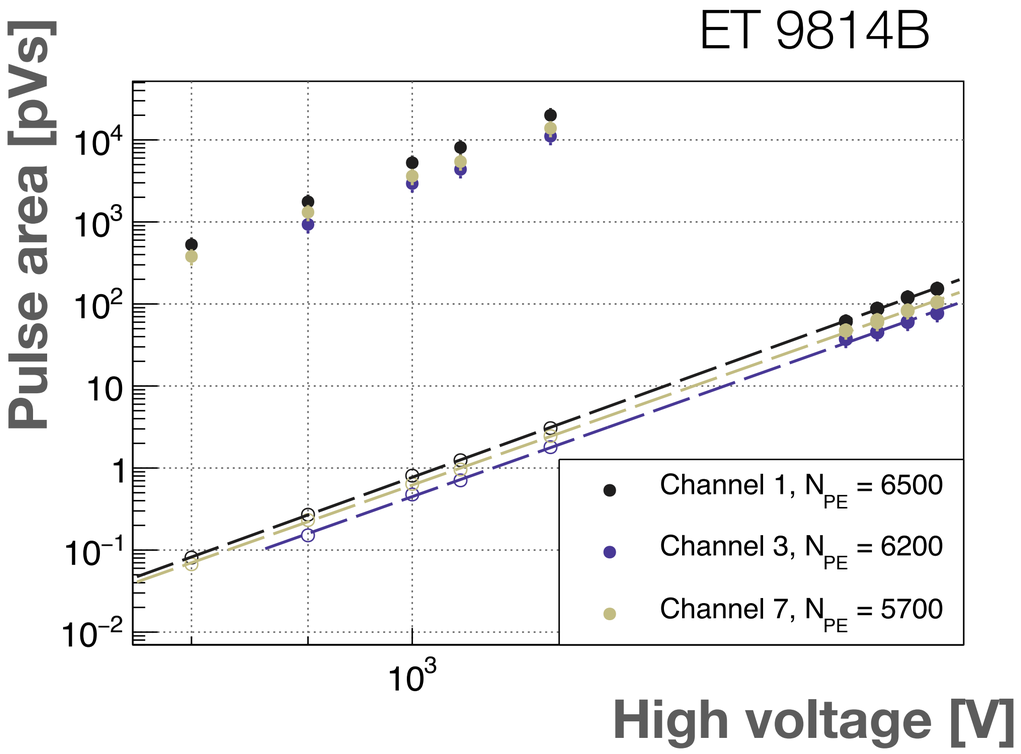
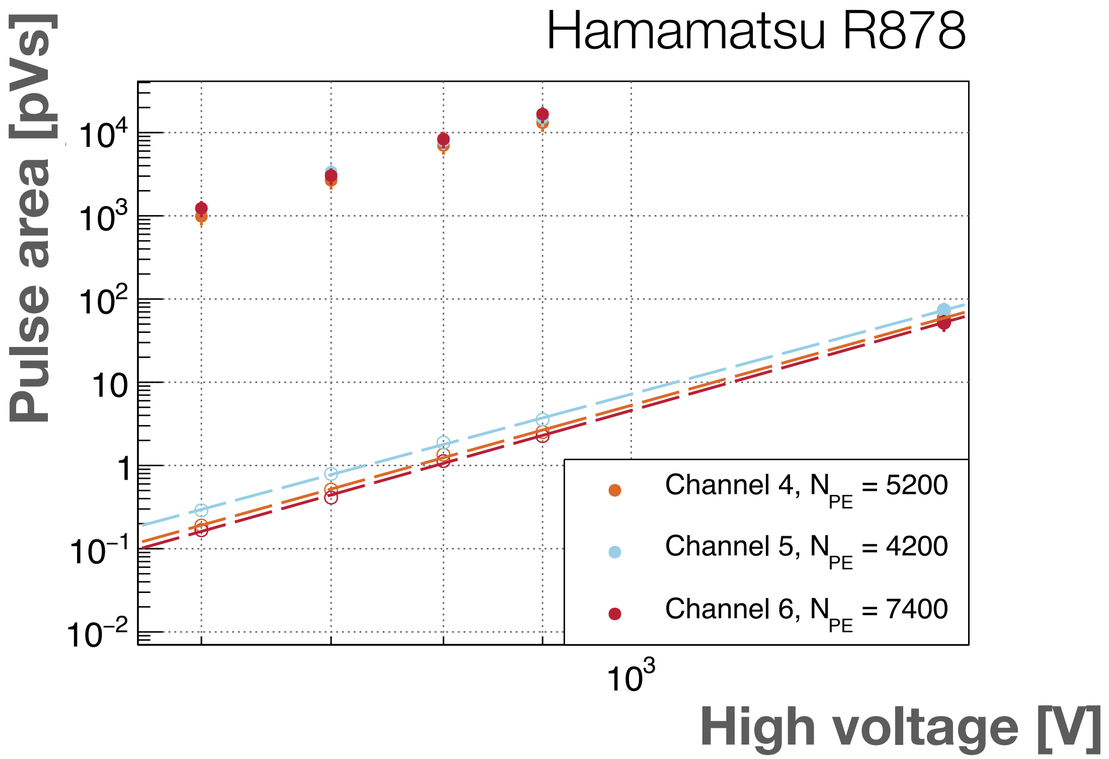


- Can't measure cosmic and SPE at single HV
- Scale cosmic yields by N_{PE}
- 3-parameter fit:
  slope, intercept, N_{PE}

Cosmic light yields

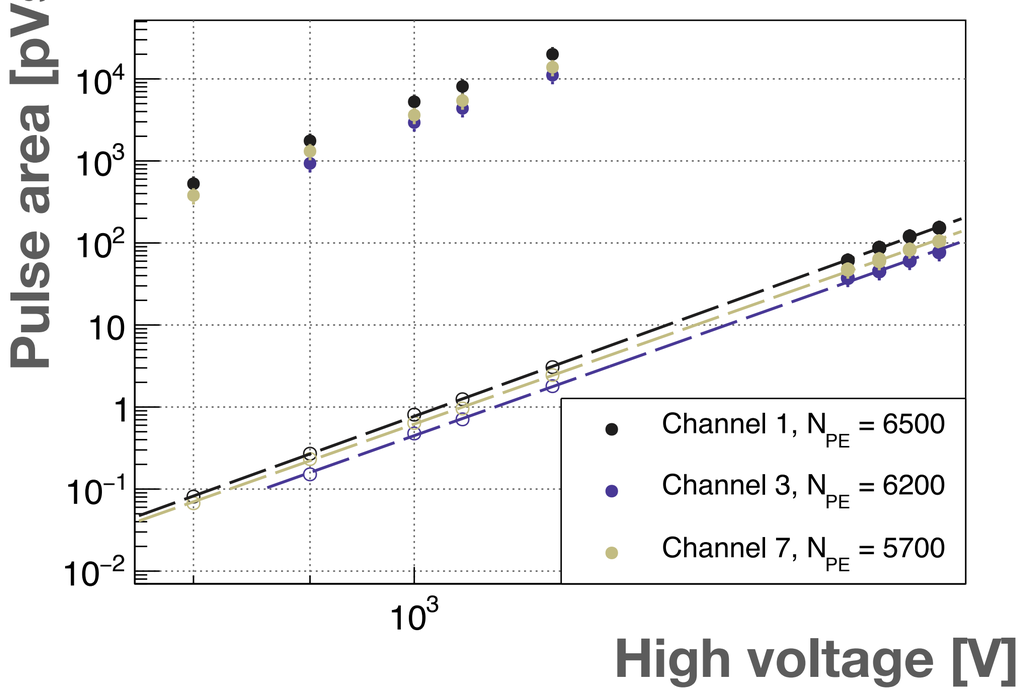




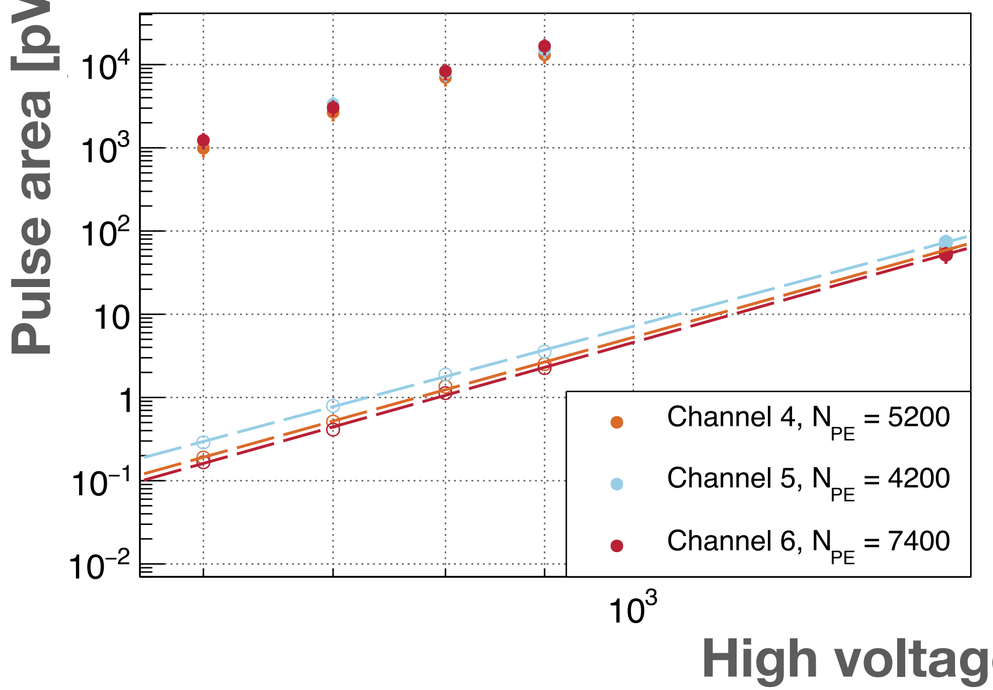
O(5000) photons for vertical muon

Cosmic light yields

ET 9814B

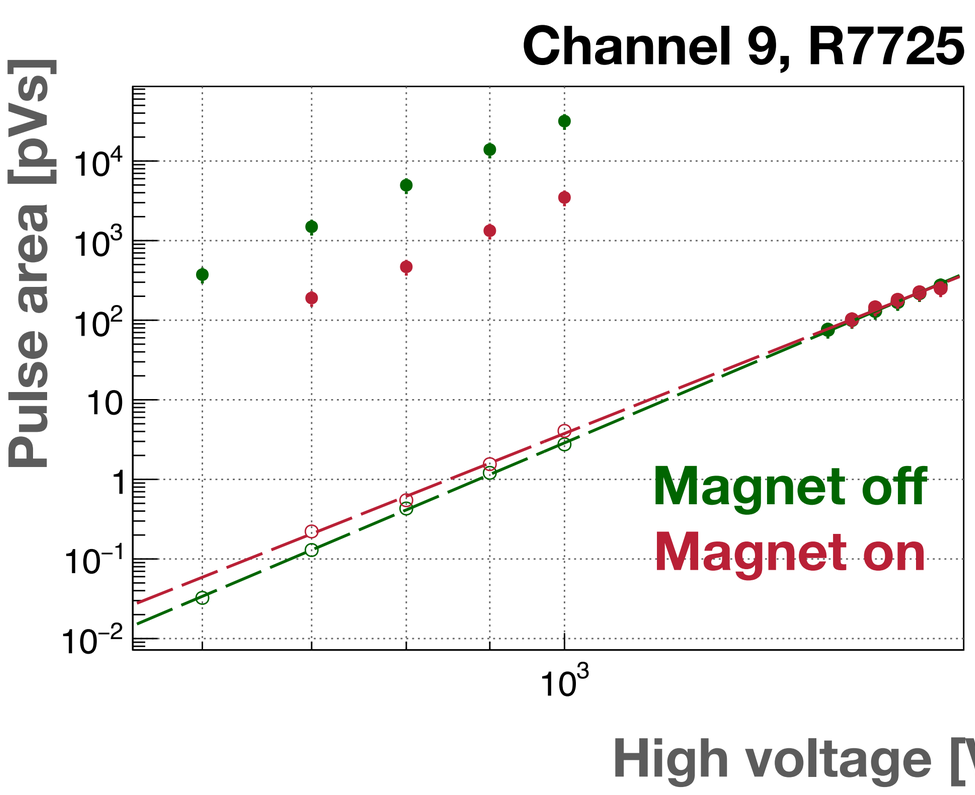


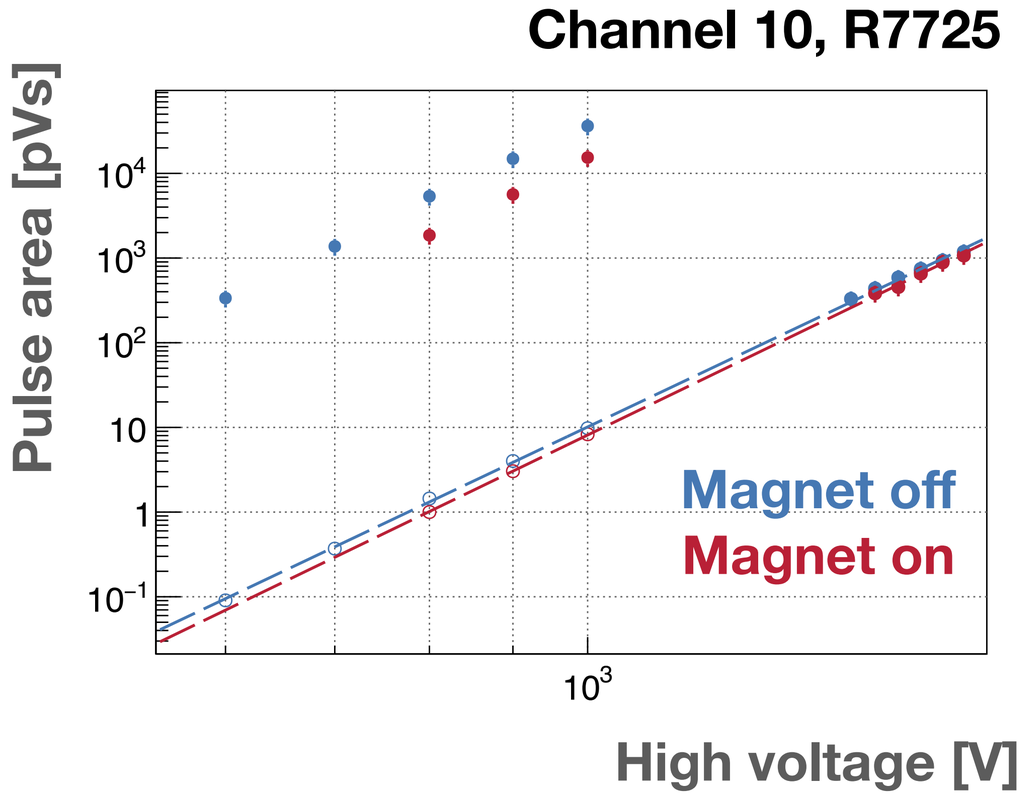
Hamamatsu R878



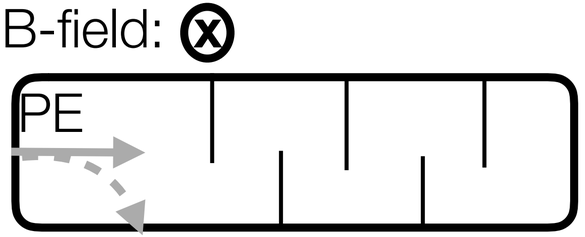
O(5000) photons for vertical muon → **Q=0.01**: ~5 photons
Q=0.005: ~1 photon

High gain R7725s in B-field

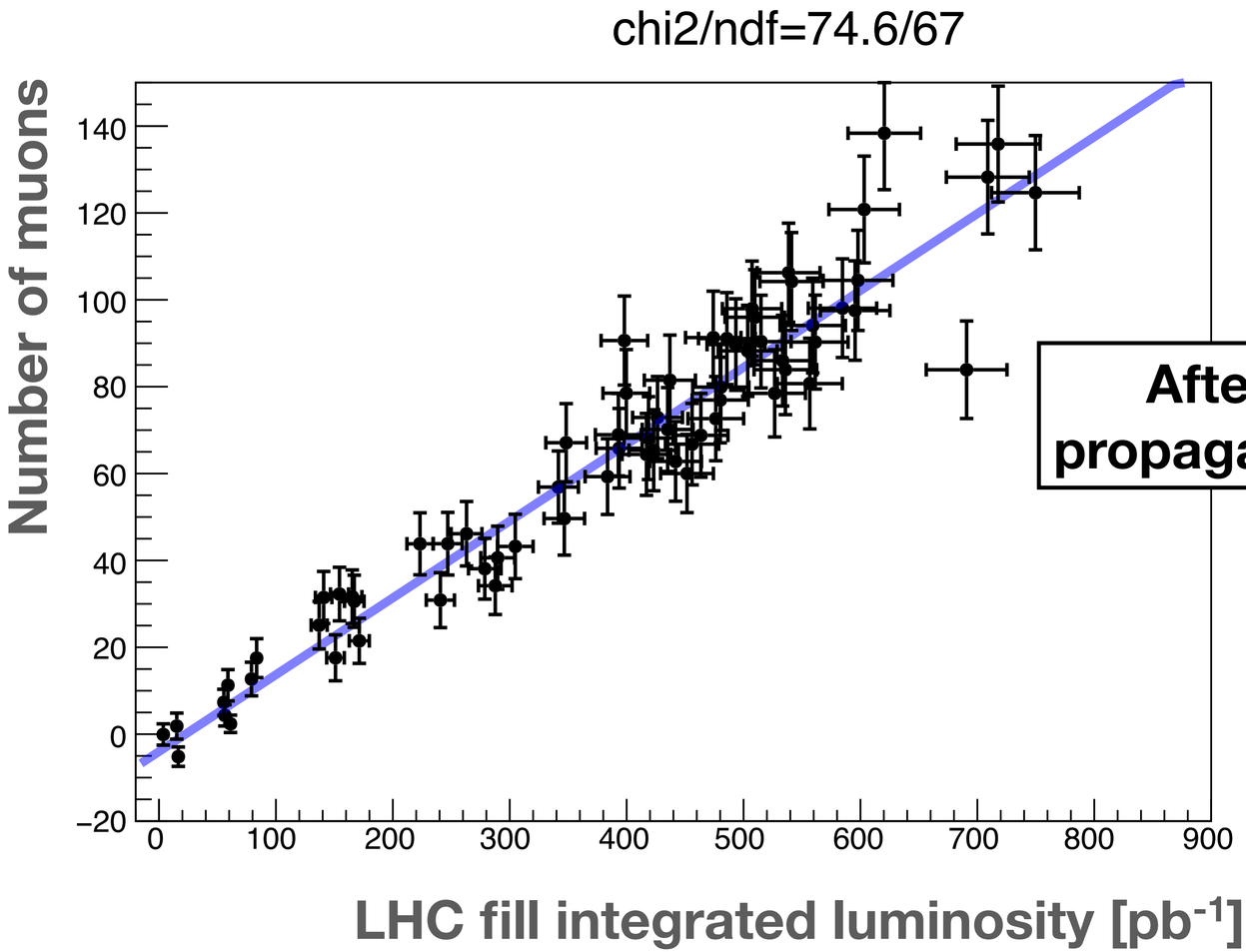




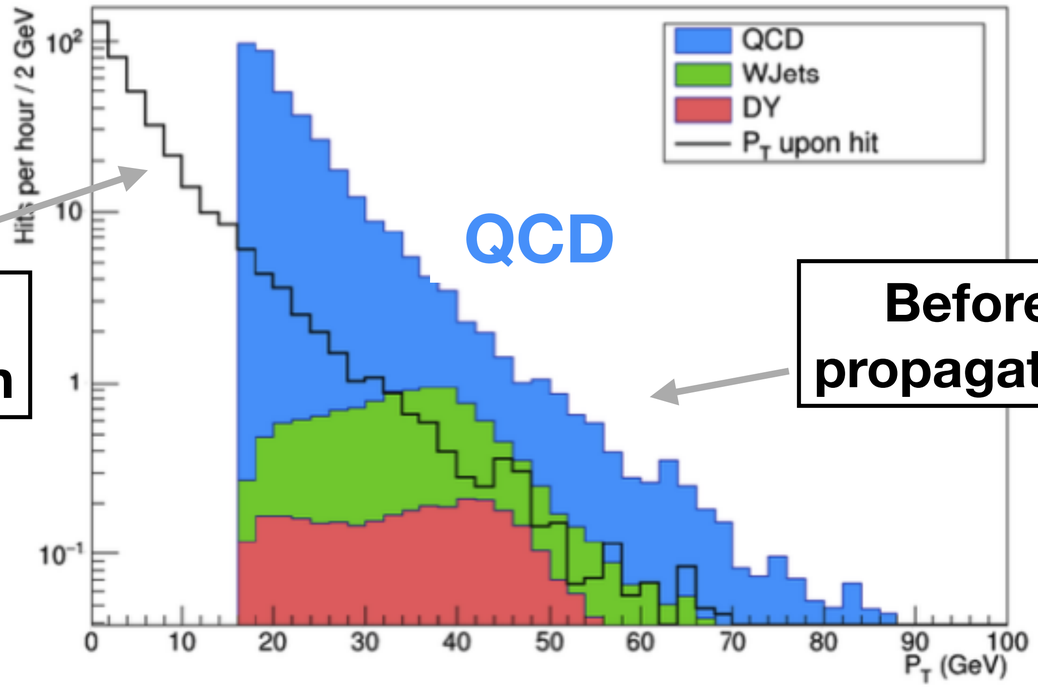
Much more dramatic effect in R7725s



Simulate propagation of muons from CMS

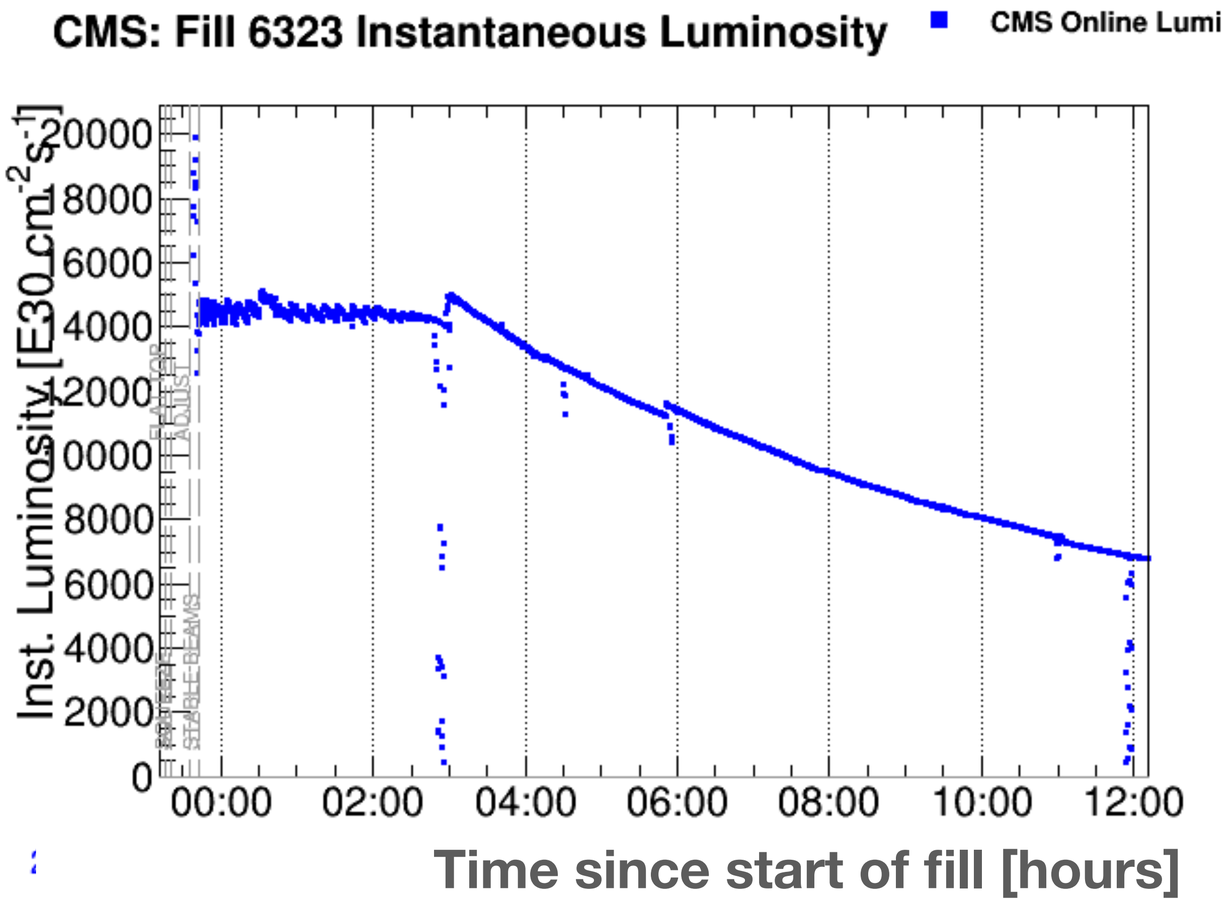


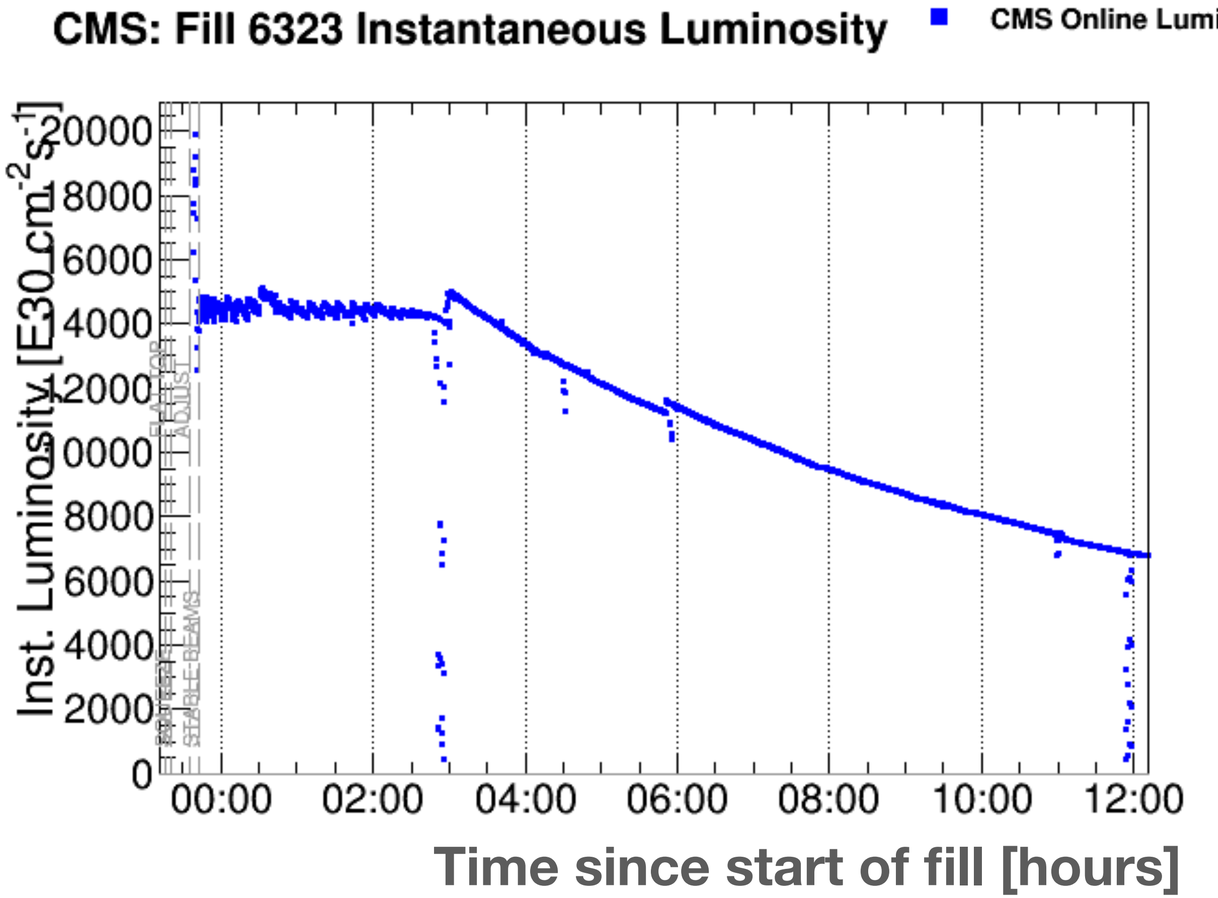
After propagation

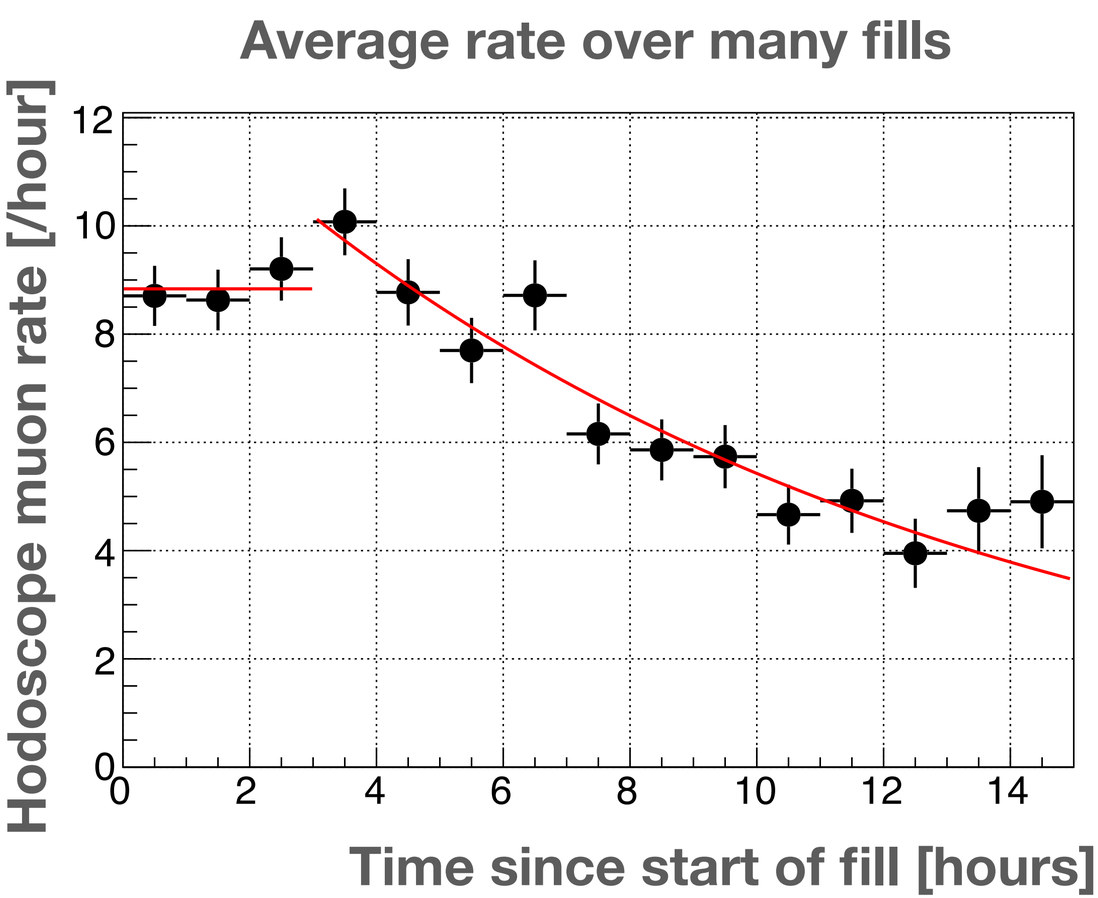


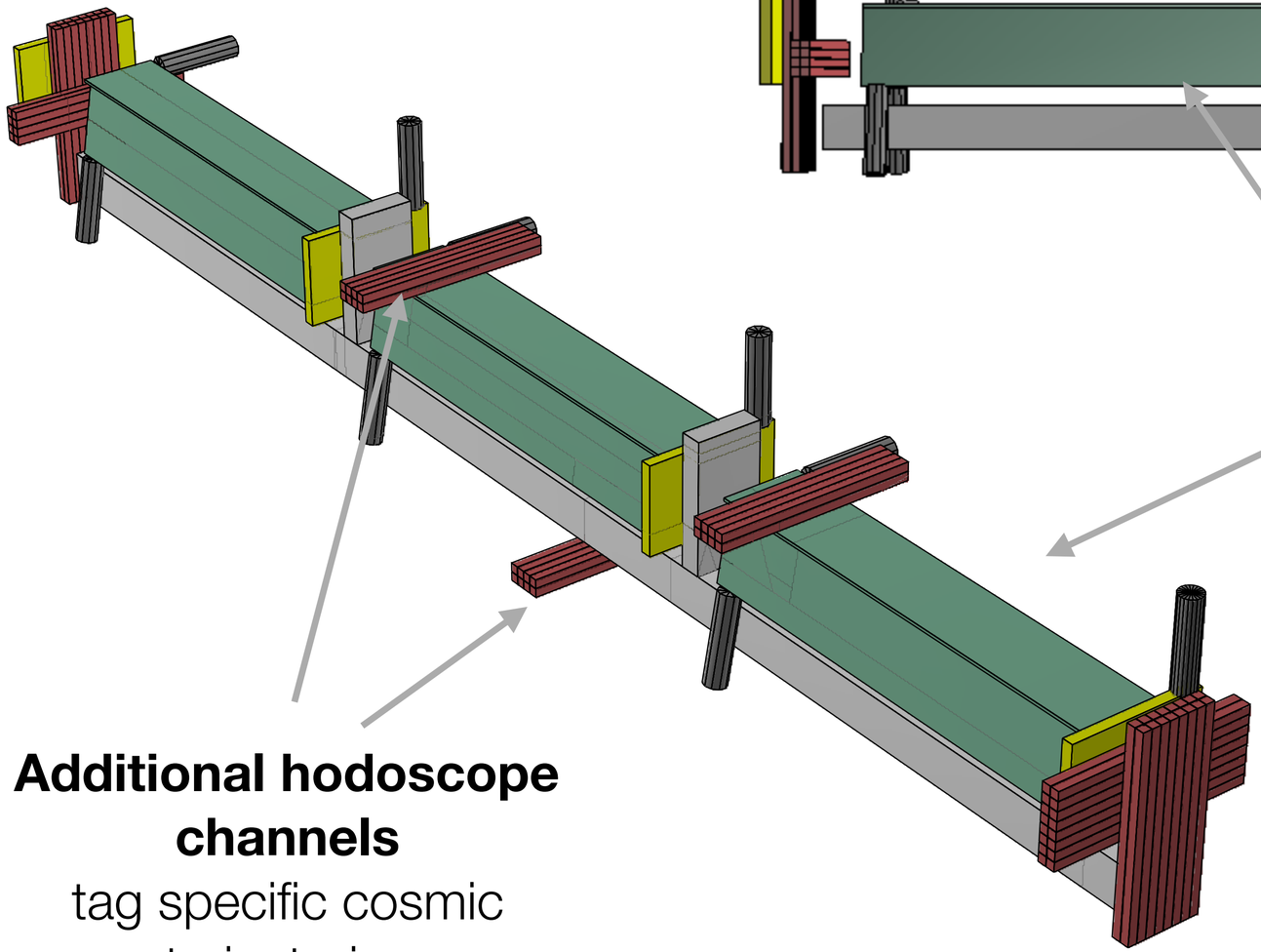
Before propagation

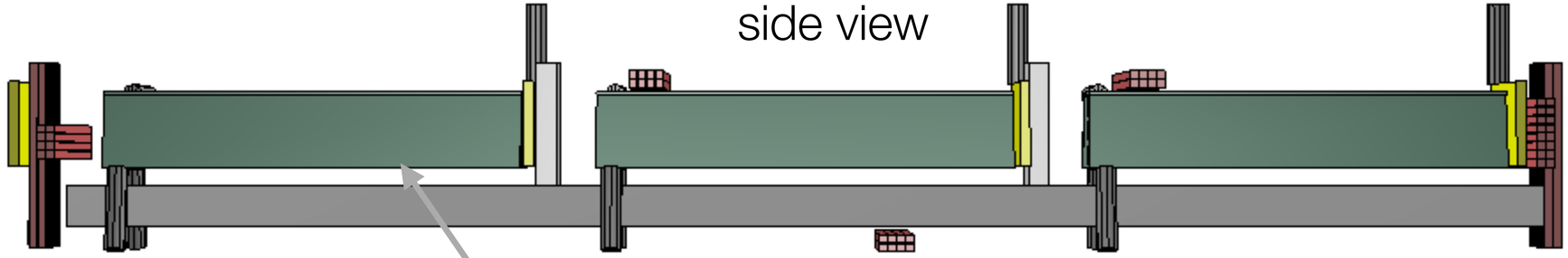
- Measured rate: **0.18 / pb^{-1}**
- Expected rate: **0.22 / pb^{-1}**


CMS: Fill 6323 Instantaneous Luminosity
CMS Online Lumi
Inst. Luminosity [E30 cm-2 s-1]
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
Time since start of fill [hours]


CMS: Fill 6323 Instantaneous Luminosity
CMS Online Lumi
Inst. Luminosity [E30 cm-2s-1]
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
Time since start of fill [hours]


Average rate over many fills
Hodoscope muon rate [/hour]
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
Time since start of fill [hours]





Hermetic veto panels
tag cosmic showers

Improved magnetic shielding and monitoring

Additional hodoscope channels
tag specific cosmic trajectories