The MilliQan Experiment and More Searches for Millicharges

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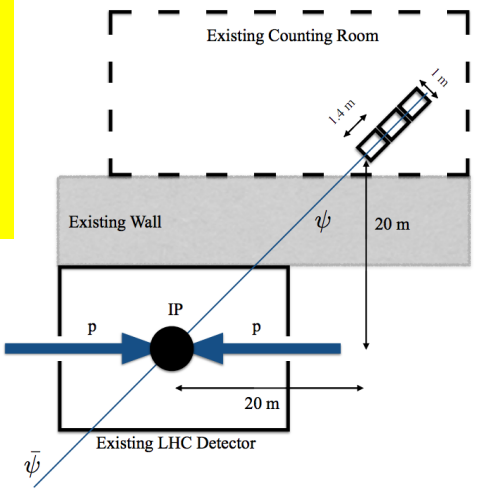
Particles with Milli-Charges?

"New" idea -> Hunting for particles with charges ~ 0.3-0.001e
Baseline paper: arXiv:1410.6816
Proposal for a new experiment/CMS subdetector.
Demonstrator (1%) taking data since mid-2017

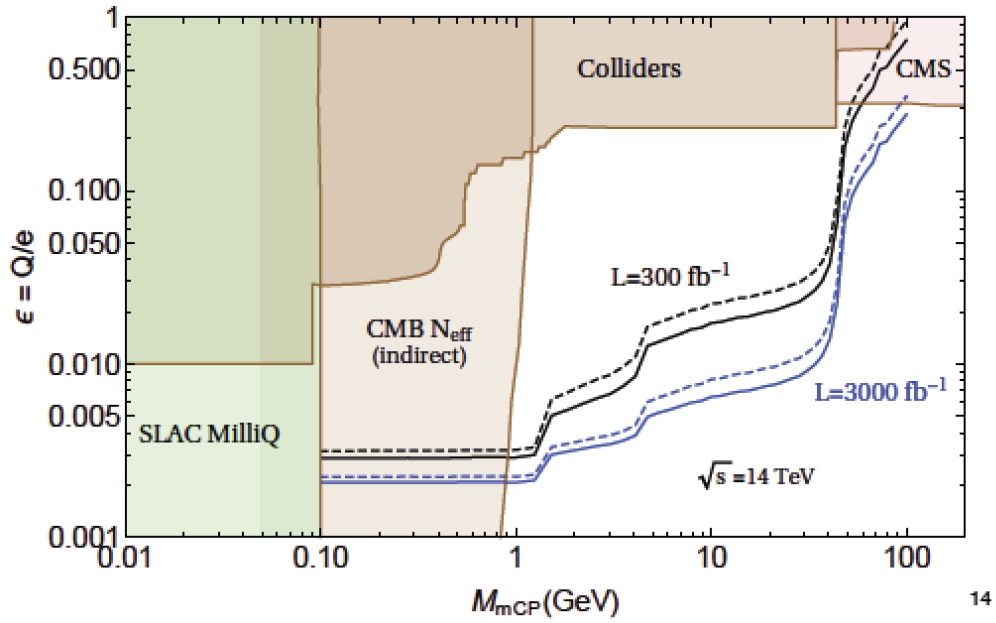


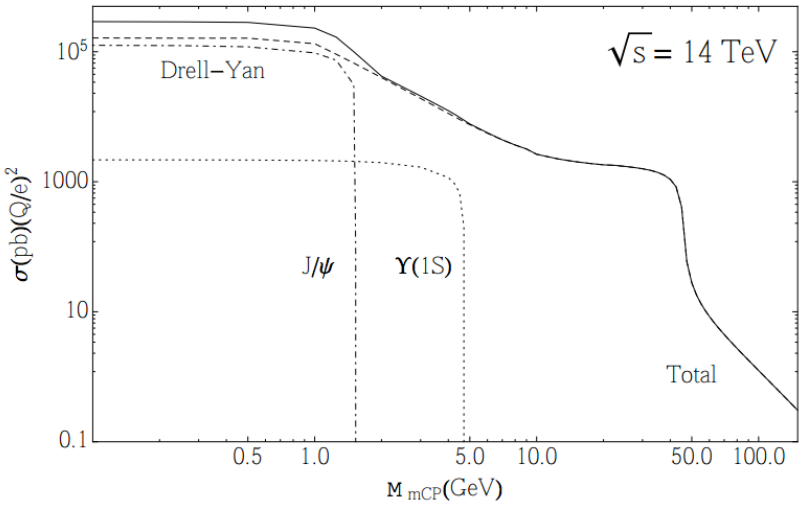
A Letter of Intent to Install a Milli-charged Particle Detector at LHC P5

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]

MilliQan Experiment





Milli-Charges

Fractionally charged particles

Posit the existence of a new hidden $U(1)$ with **massless** field A'_μ:

$$\begin{aligned}
\mathcal{L} &= \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm dark-sector} \\
\mathcal{L}_{\rm dark-sector} &= -\frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} - \frac{\kappa}{2}A'_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{A'}(A'_\mu)^2 \\
&\quad + i\bar{\psi}\left(\partial\!\!\!/ + ie'A\!\!\!/' + iM_{\rm mCP}\right)\psi
\end{aligned}$$

- ψ is a Dirac particle of mass $M_{\rm mCP}$, charged under a new $U(1)$ with charge e', and field-strength $A'_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$
- ψ is charged under hypercharge with charge $\kappa e'$, **a milli-charge**
- ψ couples to γ and Z^0 with $\kappa e' \cos\theta_W$ & $-\kappa e' \sin\theta_W$, respectively.
- Fractional charge is therefore $\epsilon \equiv \kappa e' \cos\theta_W / e$, where $\epsilon << 1$

$\rightarrow$milli-charged particles (mCP) are a natural consequence of extra $U(1)$

D. Miller LHCP (last week)

Collaboration

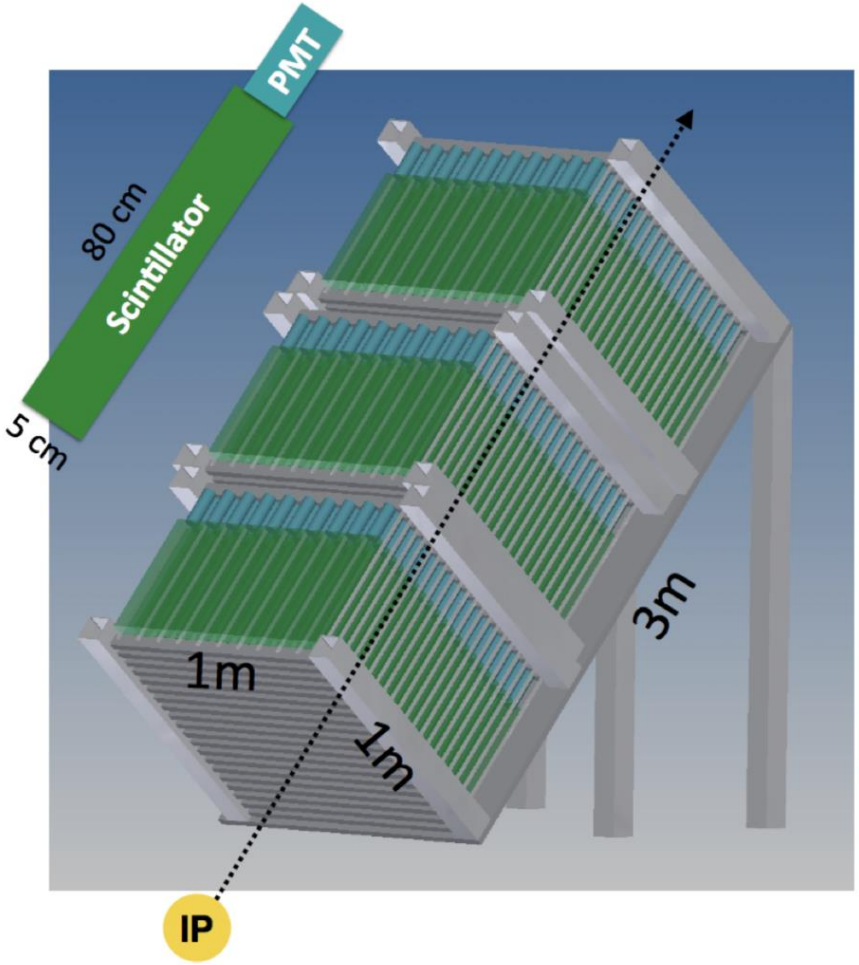
- **~20 people, 12 institutes, 6 countries**
- 9 "CMS" groups
  - *The Ohio State University (**C. Hill***, B. Francis)*
  - *University of California, Santa Barbara (**D. Stuart, C. Campagnari**)*
  - *The University of Nebraska (**F. Golf**)*
  - *CERN (**A. Ball, A. De Roeck, M. Gastal**)*
  - *The University of Bristol (**J. Brooke, J. Goldstein**)*
  - *Karlsruhe Institute of Technology (**R. Ulrich**)*
  - *Lebanese University (**H. Zaraket**)*
  - *University of Virginia (C. Neu)*
  - *FNAL (J. Hirschauer)*
- 2 "ATLAS" groups
  - *New York University (**A. Haas***, B. Kaplan)*
  - *University of Chicago (**D. Miller,** M. Swiatlowski)*

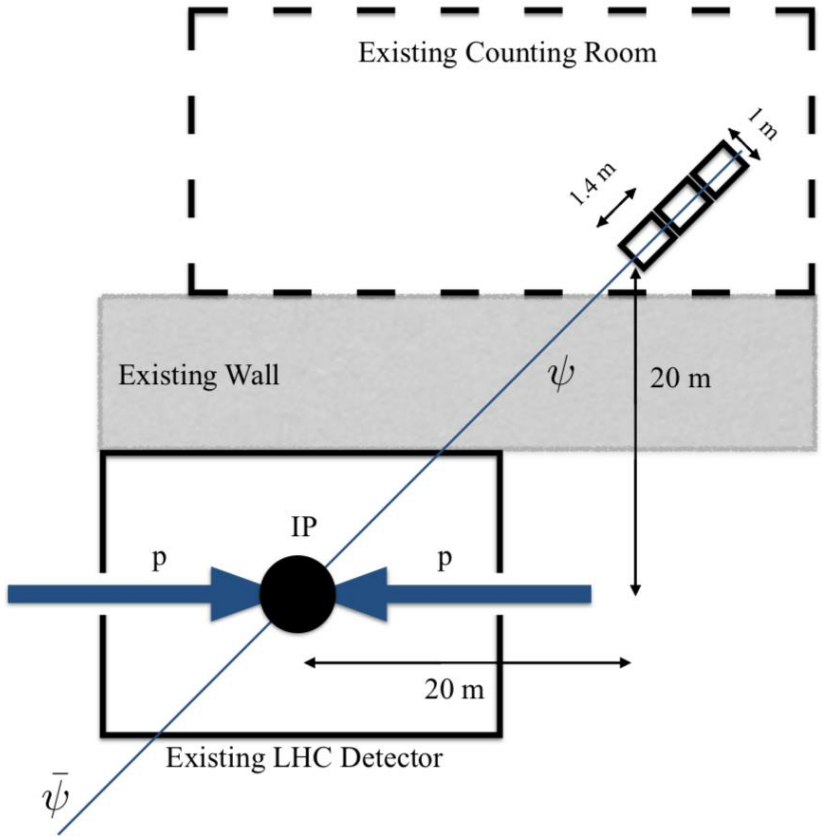
+VUB, Brussels (S. Lowette)

C. Hill 2018:
not quite complete
person list

Experimental Set-up

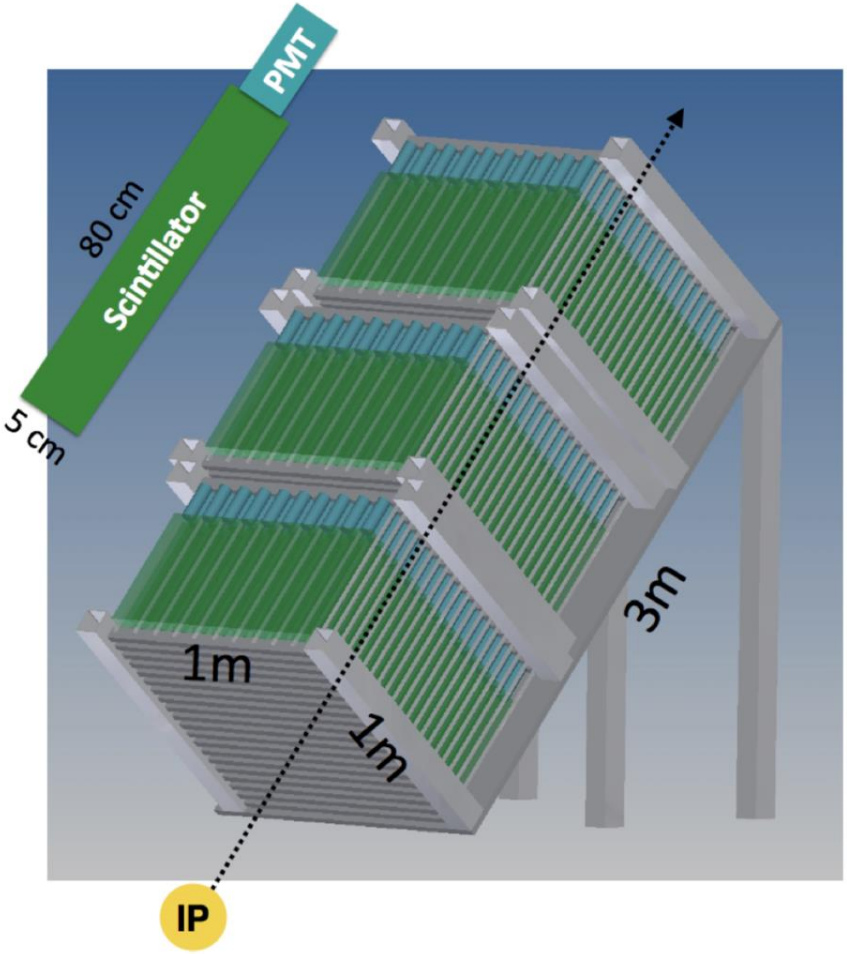
- Basic element is a 5 cm² x 80 cm bar pf plastic scintillator (BC 408) + PMT (HPK R7725)



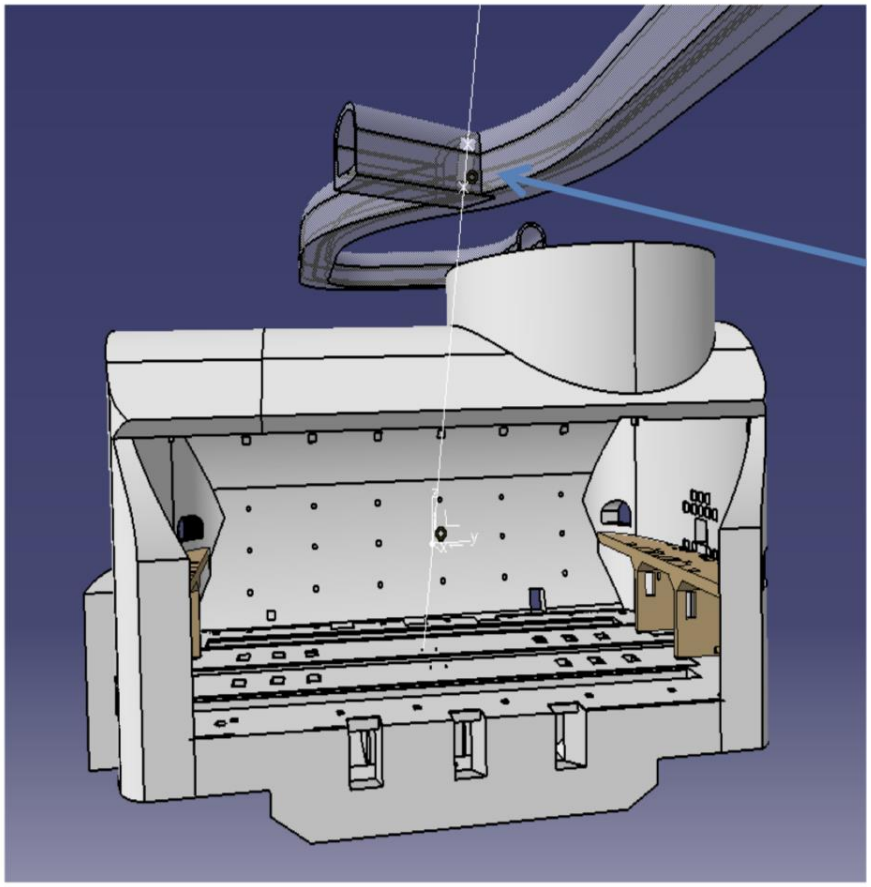


- Projective scintillator array requiring **multi-layer coincidence and ToF**
- Located in tunnel above CMS experiment (33m, $\phi \sim 43^\circ$, $\eta \sim 0.7$)

Experimental Set-up



Drainage gallery



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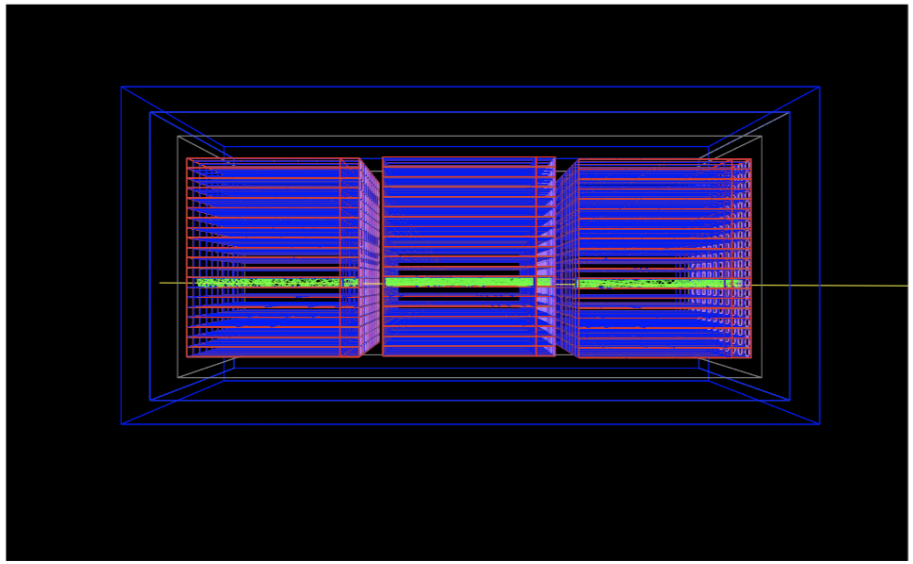
Experimental Set-up

Detector must simultaneously operate as a very low background experiment, while also functioning as a sort of "beam telescope."

- Shielding from beam particles from LHC
- Long (0.6m – 0.8m) active material: $\frac{dE}{dx} \propto Q^2$
- Multi-layer coincidence in 15 ns to mitigate random tracks



Dominant background: dark current pulses in the PMTs in coincidence with environmental radioactivity.
New design under study: 3 x 80cm → 4 x 60cm scintillator bars

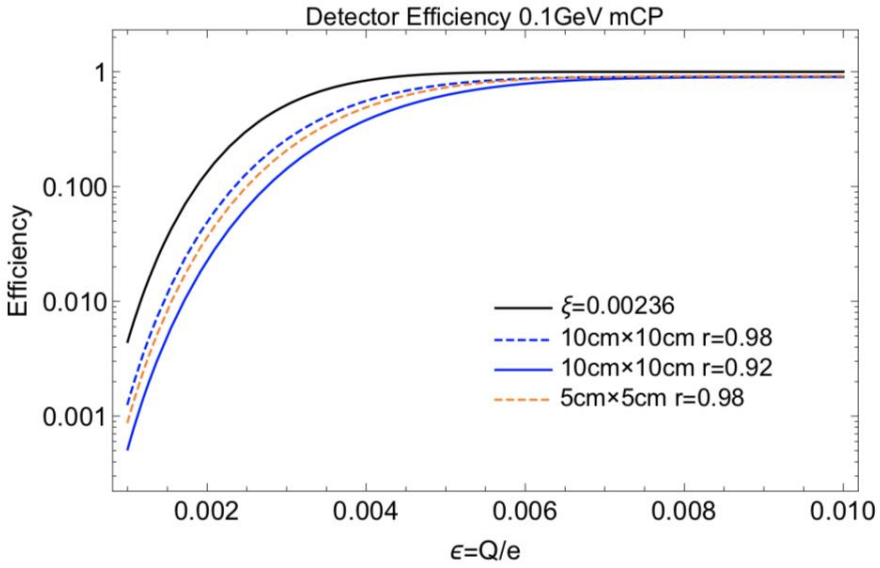
Sensitivity

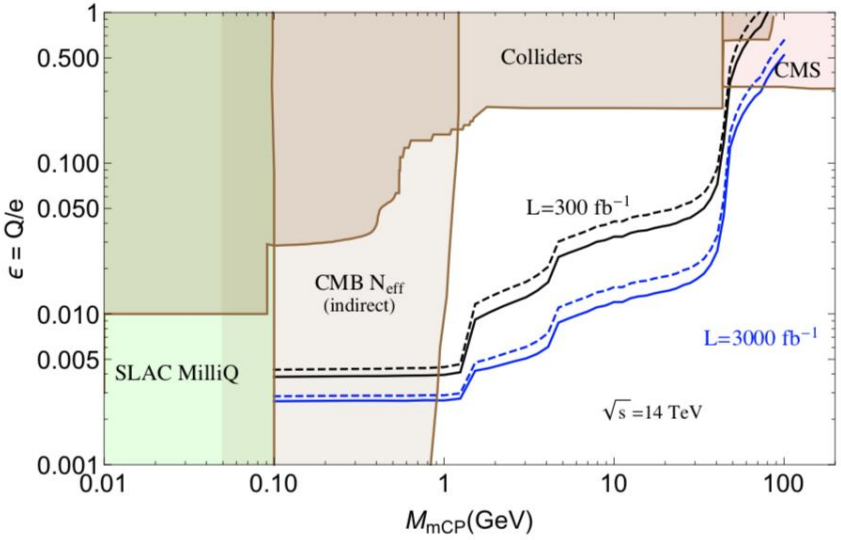
Sensitivity with full detector simulation, incl. Geant4 model of the 3-layer detector.

- Production of mCP particles via Drell-Yan, J/Ψ, $\Upsilon(1,2,3S)$
- Detection efficiency in single scintillator bar
- Overall detection efficiency in the detector, incl. 15 ns triple coincidence

Expect low mass (~0.1-1 GeV) sensitivity to mCP with $Q = 3 \times 10^{-3} e$!

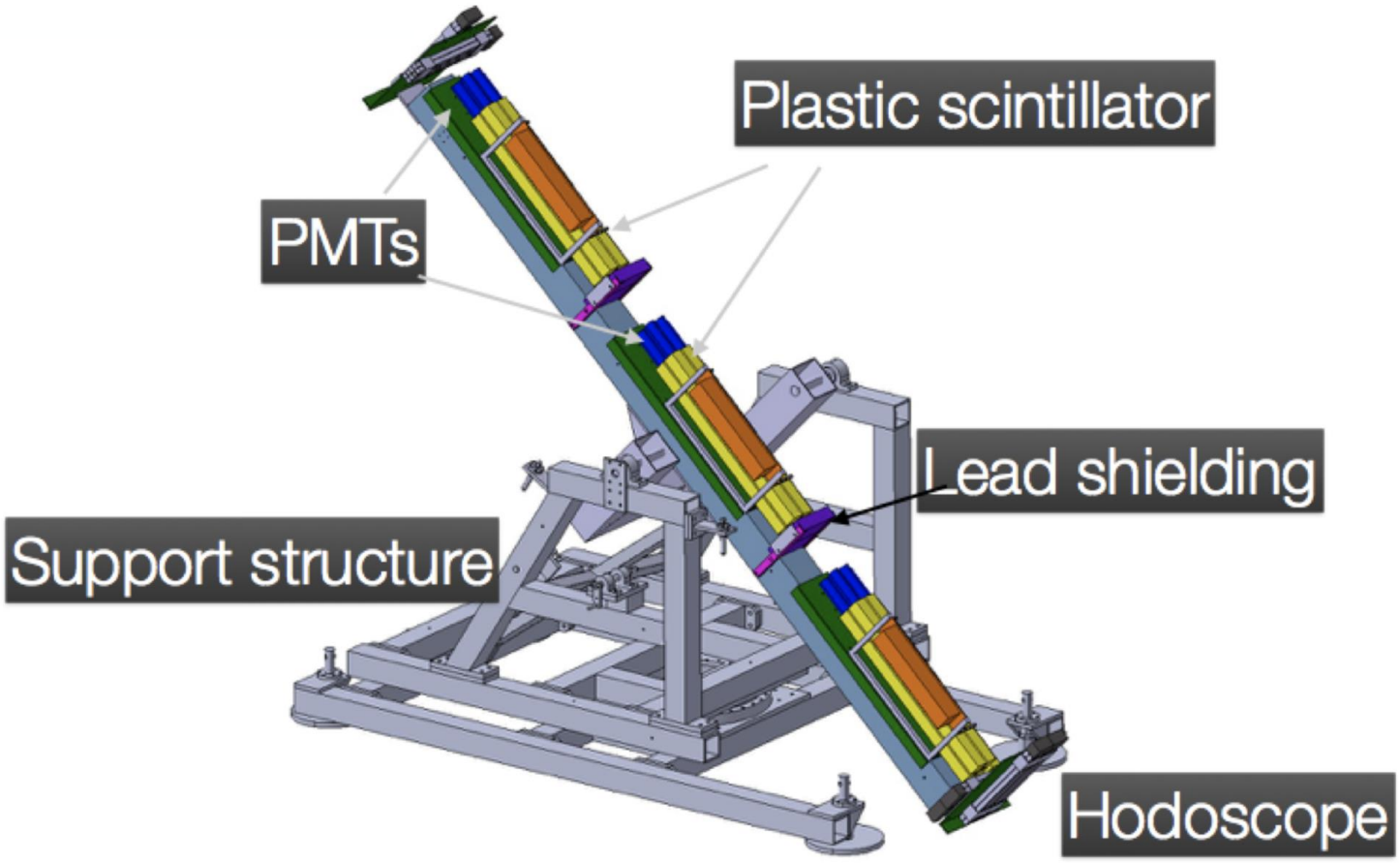
If backgrounds understood!





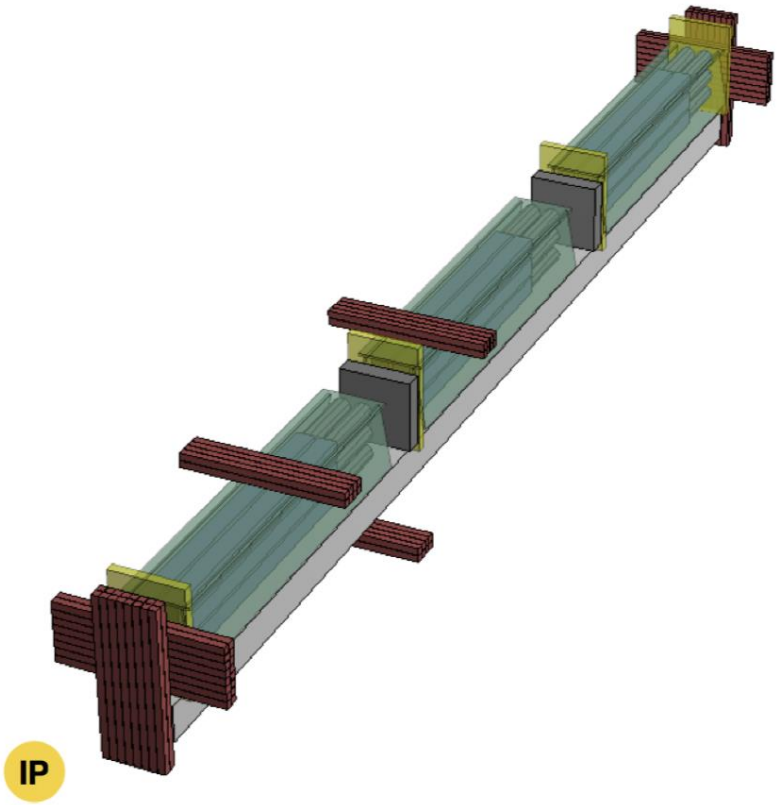
Installed Demonstrator (2017)

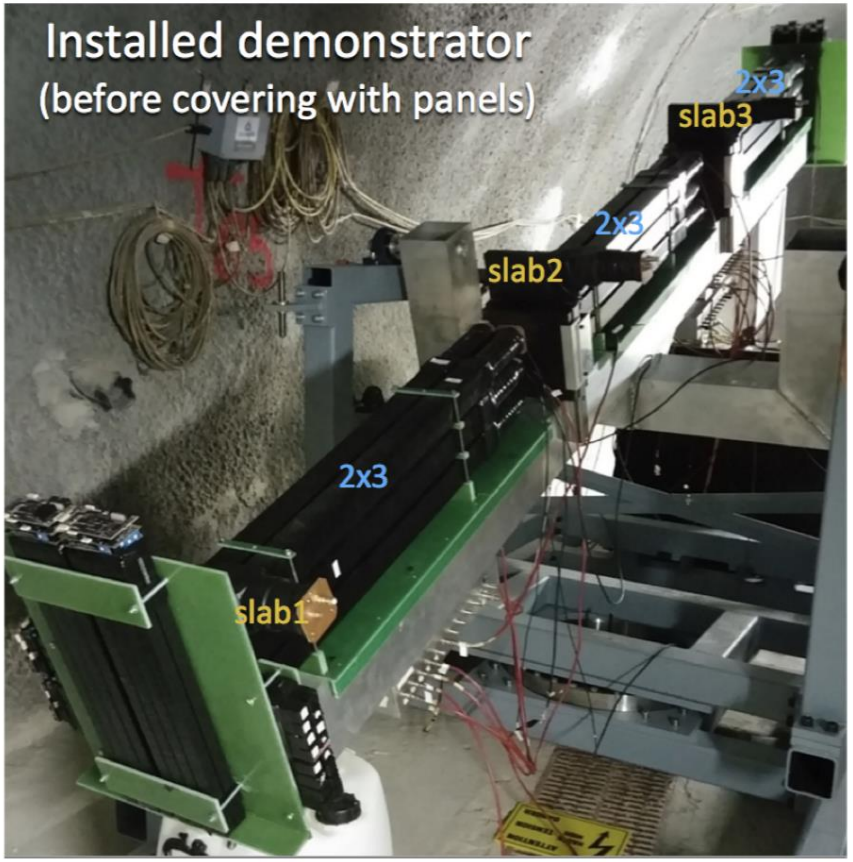
- In order to verify the feasibility and optimize the design of the experiment thoroughly, ~1% of the detector is installed as a "demonstrator"
- 3 layers of 2x3 scintillator+PMT



In the Gallery

Installed Demonstrator (2017)

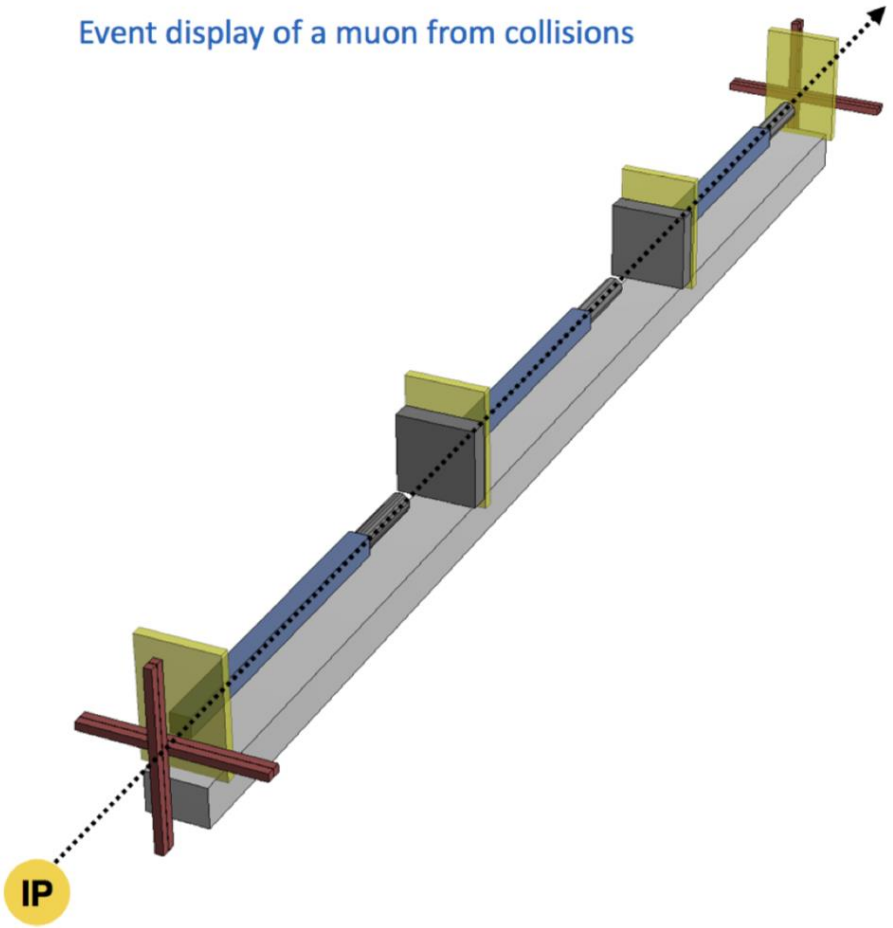




Demonstrator Analysis

Have performed multiple *in situ* measurements important to inform the full detector design and operation.

- Charge calibration using ratio of cosmic muon pulse to single photo-electrons
- Angular resolution and timing using LHC *pp* muons
- Beam muon occupancy and luminosity dependence



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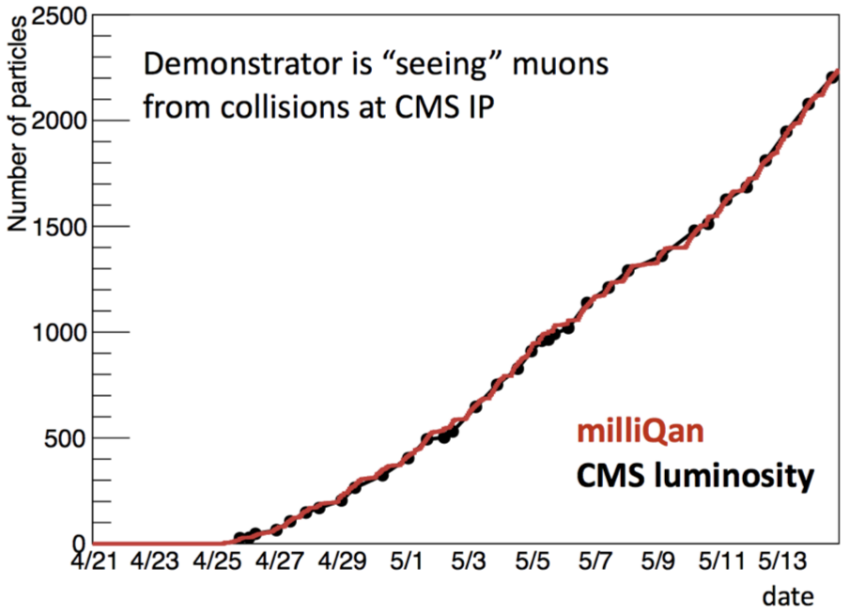

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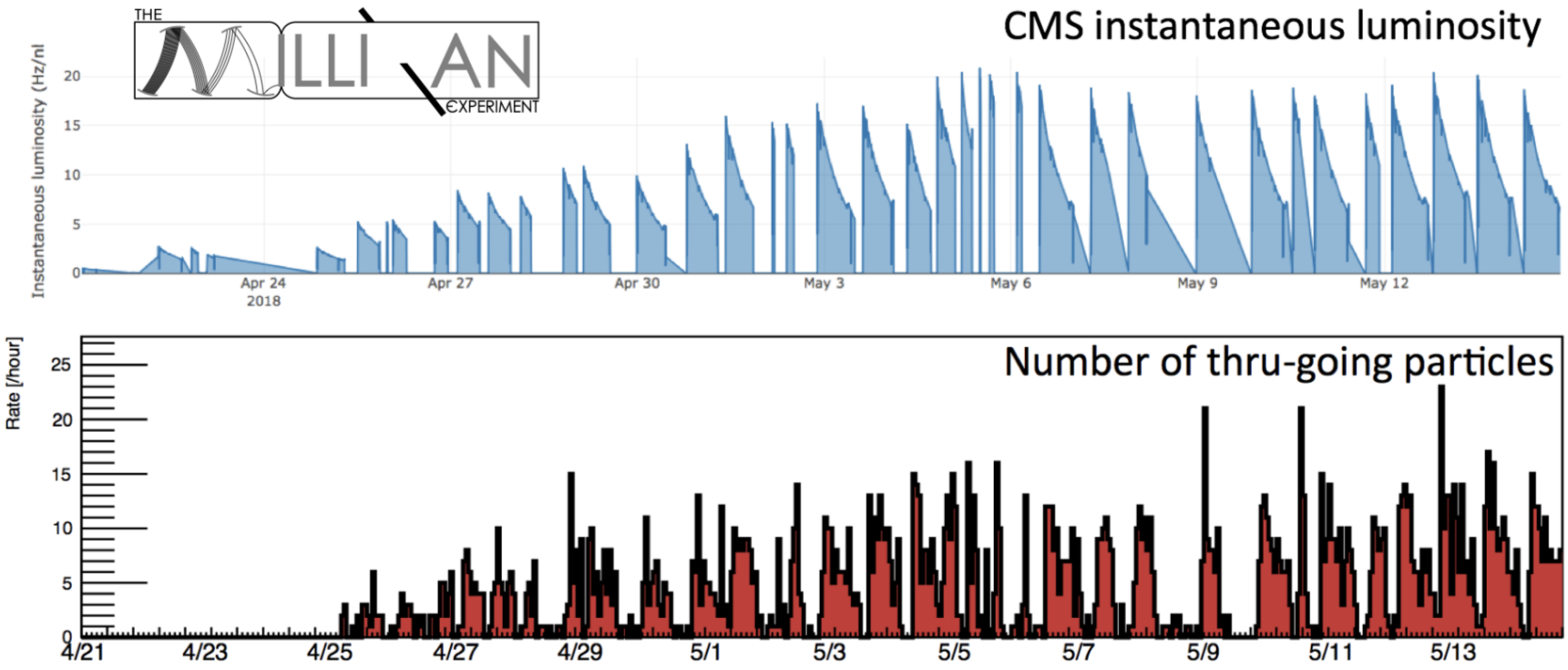


Directly verified milli*Q*an capabilities as a charged particle telescope for particles produced in the CMS IP. Next stop, fractionally charged particles!

More Milli-Charge Hunting

A proposal for milli-charges at FNAL @ MINOS near detector

FerMINI: Fermilab Search for Milicharged Particle

J. F. Hirschauer, (Principle Investigator) and Y.-D. Tsai (Co-Investigator)

Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

A. Haas (Co-Investigator)

New York University, New York, NY 10003, USA

C. Hill (Co-Investigator)

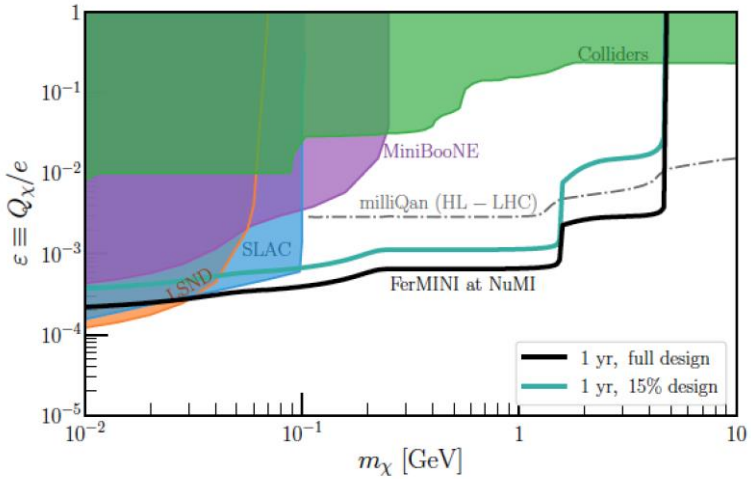
Ohio State University, Columbus, OH 43210, USA

D. Miller (Co-Investigator)

University of Chicago, Chicago, IL 60637, USA

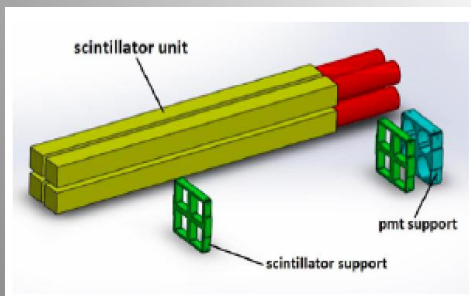
D. Stuart (Co-Investigator)

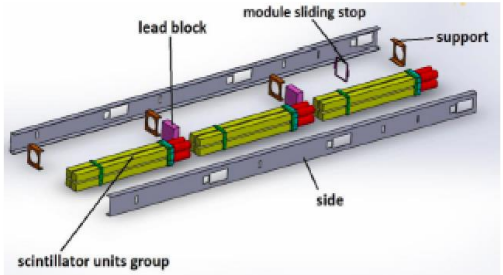
University of California, Santa Barbara, CA 93106-9530, USA

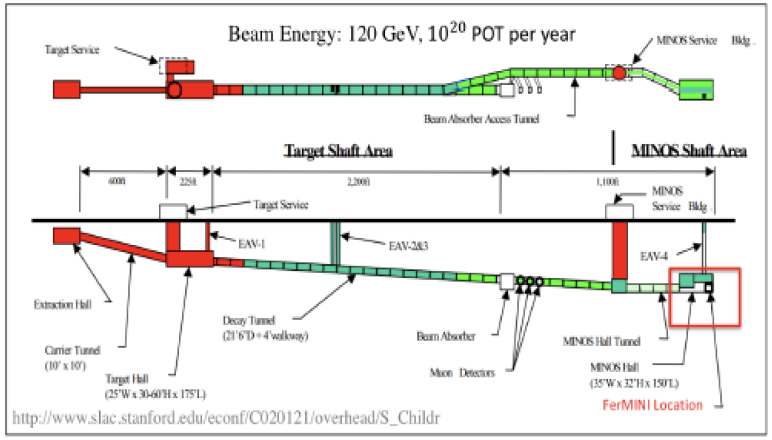


See also: arXiv:1806.03310

Based on the MilliQan design







See also MoEDAL talk for another proposal

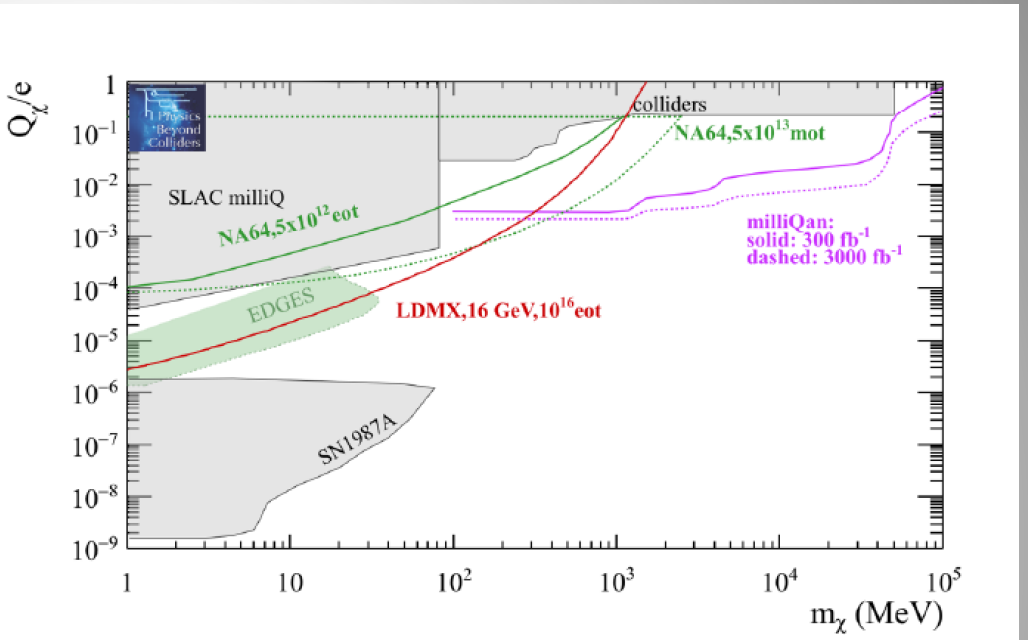
More Milli-charge Activities

Physics Beyond Collider Study

arXiv:1901.09966

Physics Beyond Colliders at CERN
Beyond the Standard Model Working Group Report

J. Beacham[1], C. Burrage[2,*], D. Curtin[3], A. De Roeck[4], J. Evans[5], J. L. Feng[6], C. Gatto[7], S. Gninenko[8], A. Hartin[9], I. Irastorza[10], J. Jaeckel[11], K. Jungmann[12,*], K. Kirch[13,*], F. Kling[6], S. Knapen[14], M. Lamont[4], G. Lanfranchi[4,15,*,**], C. Lazzeroni[16], A. Lindner[17], F. Martinez-Vidal[18], M. Moulson[19], N. Neri[19], M. Papucci[4,20], I. Pedraza[21], K. Petridis[22], M. Pospelov[23,*], A. Rozanov[24,*], G. Ruoso[25,*], P. Schuster[26], Y. Semertzidis[27], T. Spadaro[19], C. Vallée[24], and G. Wilkinson[28].

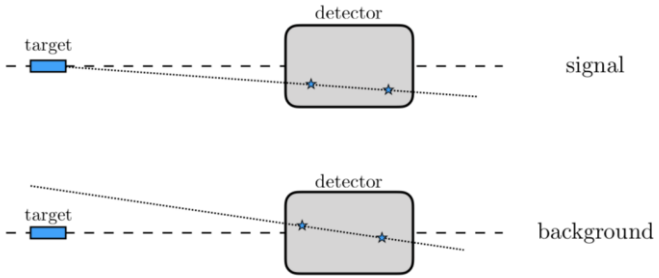


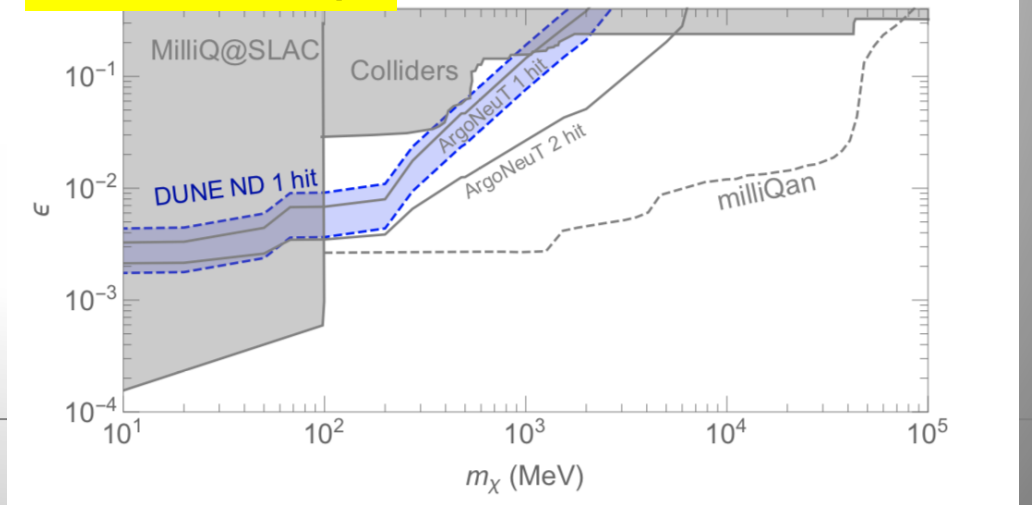
LArTPC study

Millicharged Particles in Liquid Argon Neutrino Experiments

Roni Harnik[1], Zhen Liu[2], and Ornella Palamara[1]
[1] *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[2] *Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, MD 20742-4111 USA*

arXiv:1902.03246





Summary

- MilliQan aims to search for milli-charges in the regime $0.1 < Q < 0.003$
- MilliQan demonstrator installed in mid-2017 and taking data since (1% of a full module)
- Funding requests under evaluation (NSF, European requests). Expect outcome soon
- Detector ready to be constructed, as soon as funding becomes available, for run-III
- More initiatives for milli-charge searches, at CERN and FNAL in progress