MilliQan : A new detector for milli-charged particles at the LHC

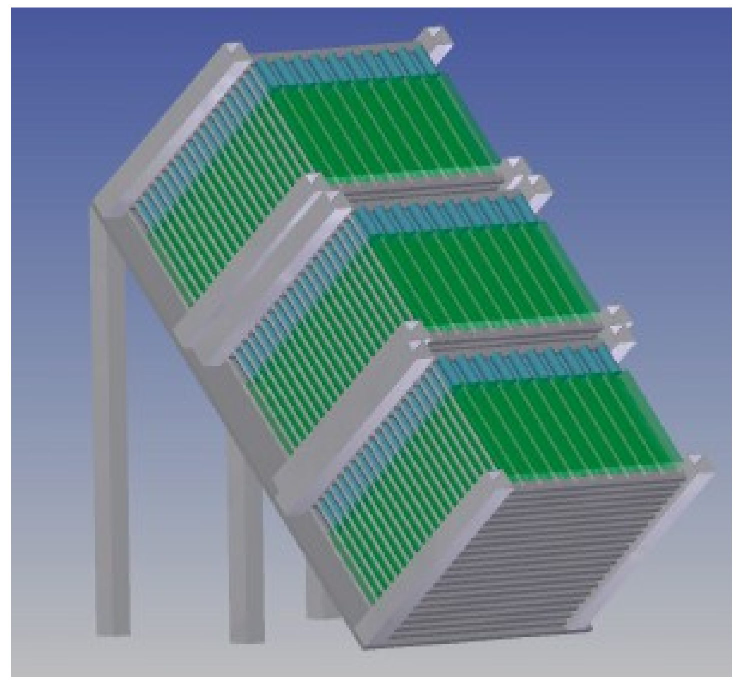
Andy Haas (NYU)
on behalf of the milliQan collaboration

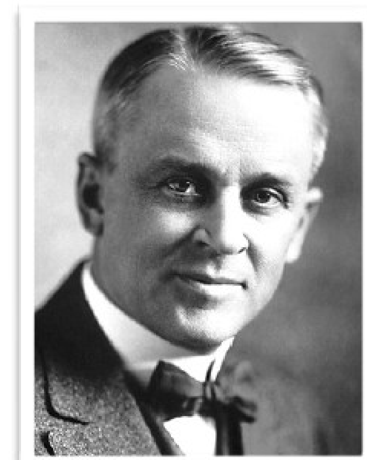
Future of collider searches for Dark Matter at the LPC

Fermilab

July 27-28, 2017

https://indico.cern.ch/event/632708/





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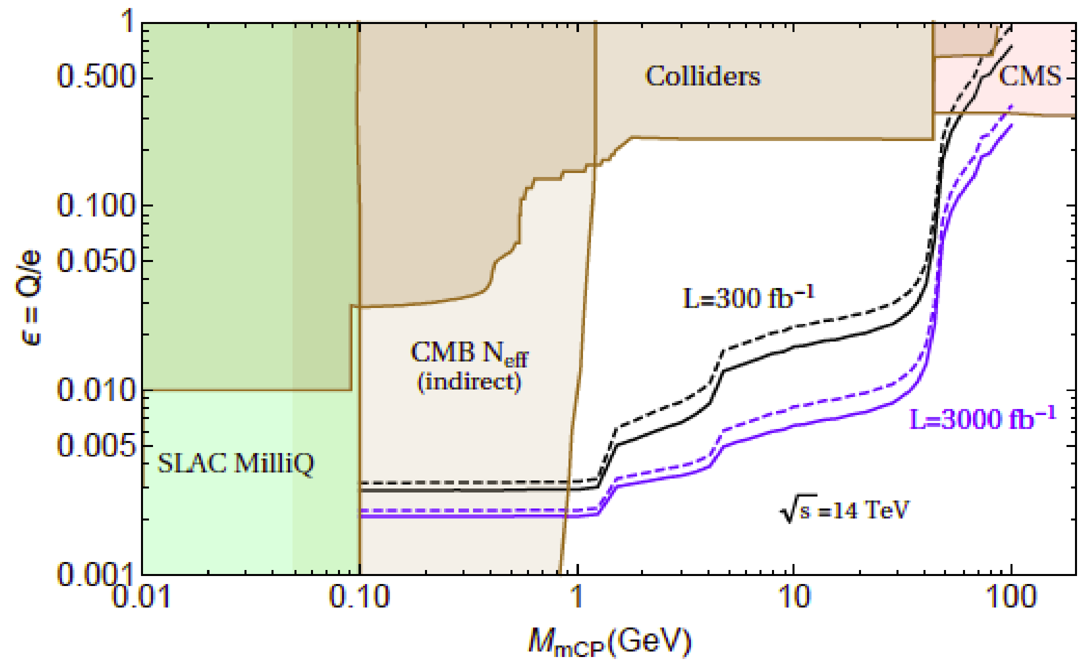
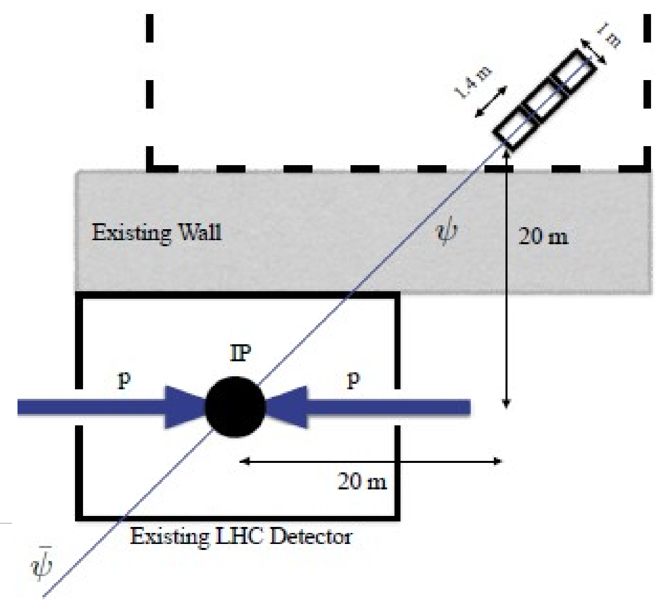
Introduction

- Long history of searches for milli-charged particles (MCP)
- MilliQan will probe for heavier MCP, 0.1 – 100 GeV, using a new detector at the LHC
- Produced via Drell-Yan and interact with detector via Bethe-Bloch
  - Simple and model-independent



Andrew Haas,[1] Christopher S. Hill,[2] Eder Izaguirre,[3] and Itay Yavin[3,4]
arXiv:1410.6816v1 [hep-ph] 24 Oct 2014

- With Q down to ~10^{-3}e, dE/dx is 10^{-6} MIP -> need large, sensitive, active area to see signal, $\mathcal{O}(1)$ PE.
- Install ~1 m x 1 m x 3 m scintillator array, pointing back to IP, in well shielded area of Point 5
- With triple coincidence, random background is controlled



Milli-charged particles

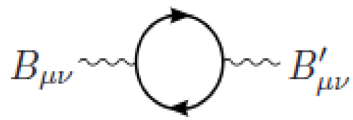
- Huh? I thought charge was quantized. Dirac or GUT or something?
  - Maybe... we still don't understand charge quantization!

- Also, plenty of ways get something that *appears* milli-charged

massless dark-photon and massive dark-fermion

If you add a new U(1), get mixing with SM U(1)

- *Generically, charge carriers of new U(1) will have small EM charge, proportional to the mixing*
  - **Holdom PLB 196-198 (1986)**



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

If there are new fermions charged under the new U`(1)

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}B'^{\mu\nu}B'_{\mu\nu} - \frac{\kappa}{2}B'^{\mu\nu}B_{\mu\nu} + i\bar{\psi}(\partial\!\!\!/ + ig_D B\!\!\!/' + iM_{\rm mCP})\psi$$

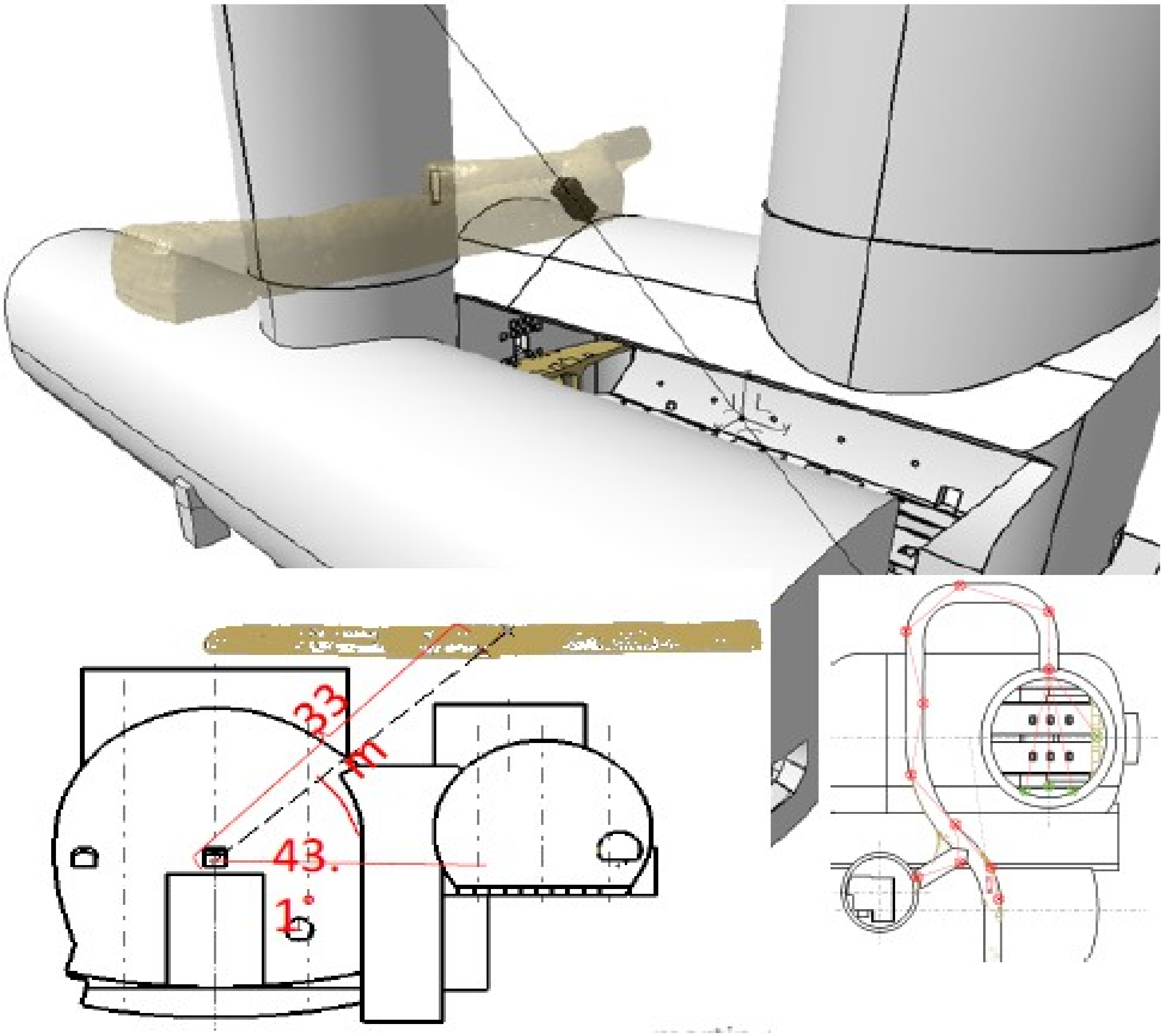
$$B'_\mu \to B'_\mu + \kappa B_\mu$$

- Could also be a neutral bound state of charge ± 1 objects with a magnetic dipole...

- Are milli-charged particles dark matter?
  - No, in fact need an annihilation mechanism to reduce density from BB
  - But, they could be related to DM – part of a dark sector

MilliQan location

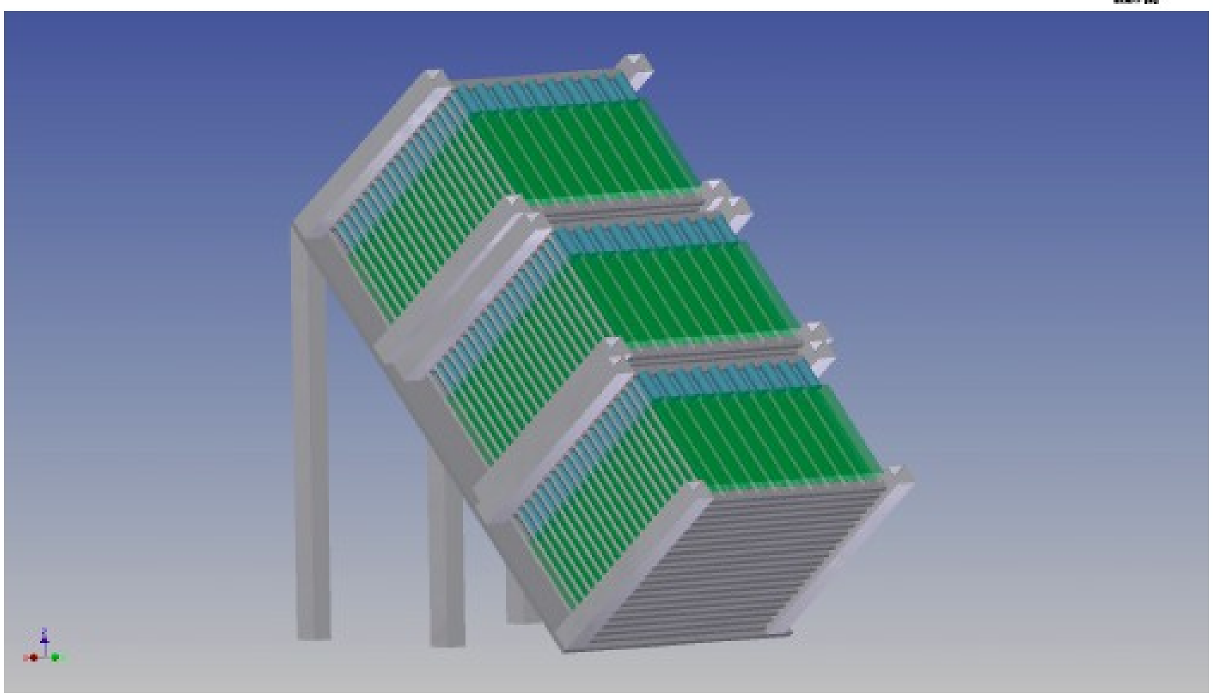
- **"Drainage Gallery" - an existing tunnel just above CMS**
  - Martin Gastal (CERN), and his team, have been particularly helpful
    - *3D drawings, surveys, B-field measurements, pictures, etc.*
  - Now have precise details of location:
    - *33 m from IP*
    - *17 m through rock*
    - *Angle from horizontal plane is 43.1 deg*
    - *Clearance to gallery boundaries is ~30 mm!*

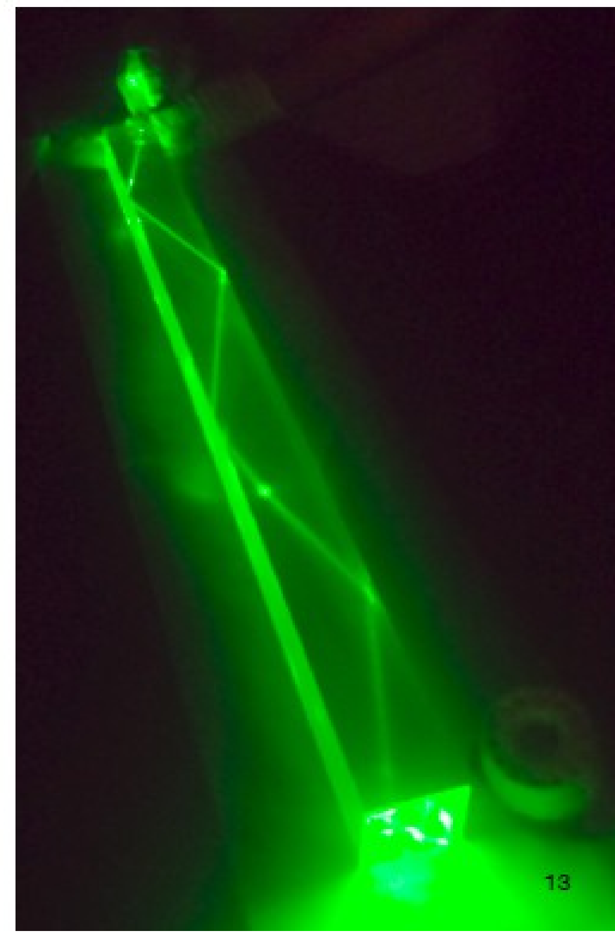


Detector idea

- **Aim to detect single photons in 3 adjacent large scintillators pointing back to IP, within a small time window (15 ns)**

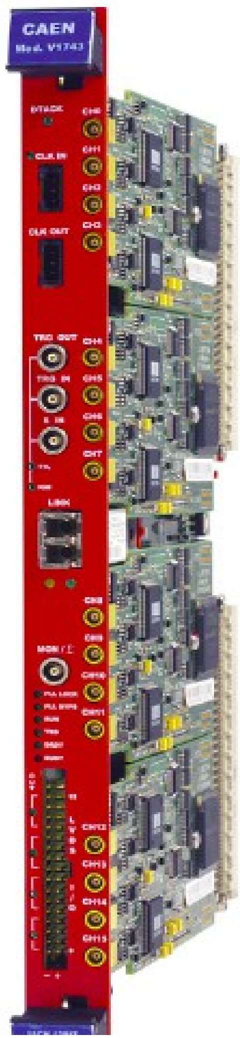
  - Basic element is a 5 cm^2 x 80 cm bar pf plastic scintillator (BC 408) + PMT (HPK R7725)
  - Arranged in a 20 x 20 x 3 array
    - *Supported by movable mechanical structure*
      - **Alignment to IP + retraction to allow passage through gallery**





Readout and trigger

- Fantastic detail of each pulse from a triggered event
- ~1 ns timing resolution, even for tiny (single PE) pulses



- Readout via CAEN V1743 12 bit digitizer
- 16 channels
  - *Sampled at 3.2 GS/s (a sample each 312.5 ps)*
  - *1024 analog buffer ring (320 ns long).*
  - *Analog noise is about 0.75 mV per channel, allowing good identification of and triggering on single PE signals*
- Trigger
  - *If 2 of 3 bars coincident in 15 ns window, self-triggers to read out whole detector*
    - **Completely separate from CMS trigger**
  - *Data will be read out via CAEN CONET 2 over 80 Mbps optical fiber to a PCI card in dedicated DAQ*
    - **Completely separate from CMS DAQ**

Will also interface with LHC clock to time-stamp events with bunch-crossing info

Readout and trigger

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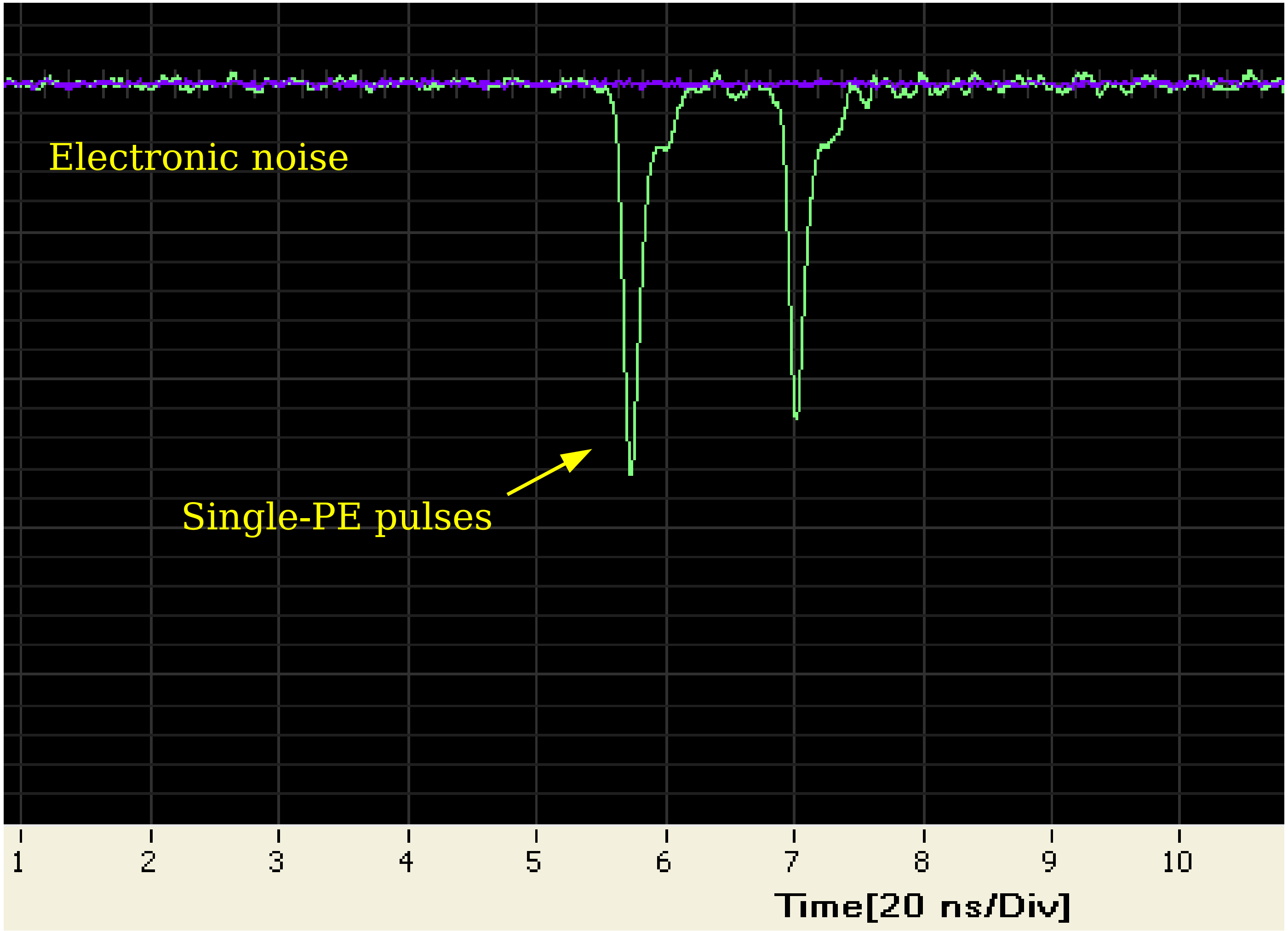
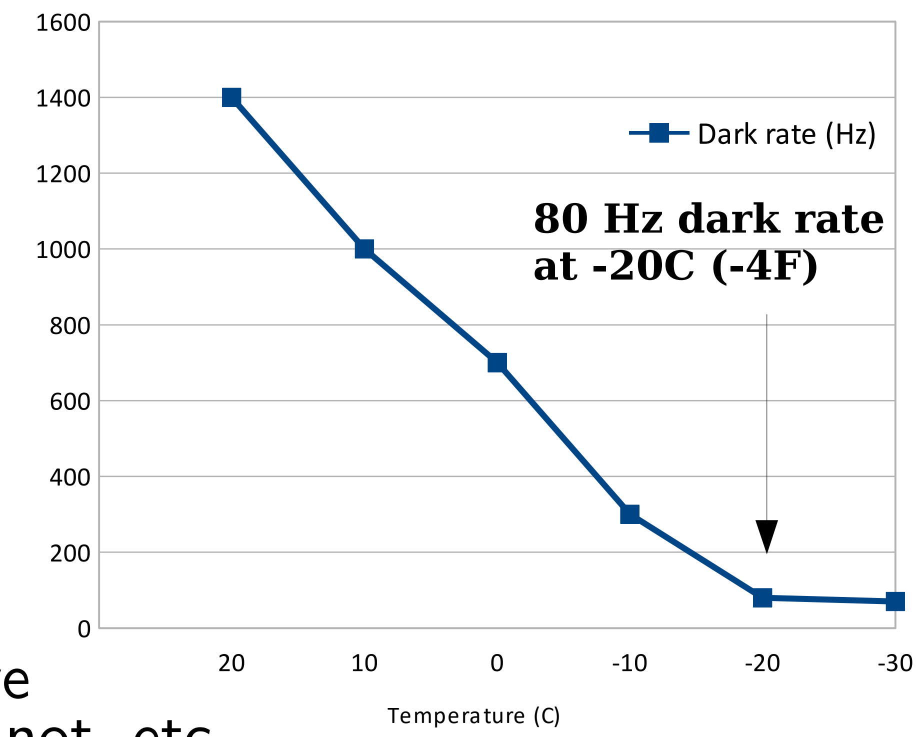


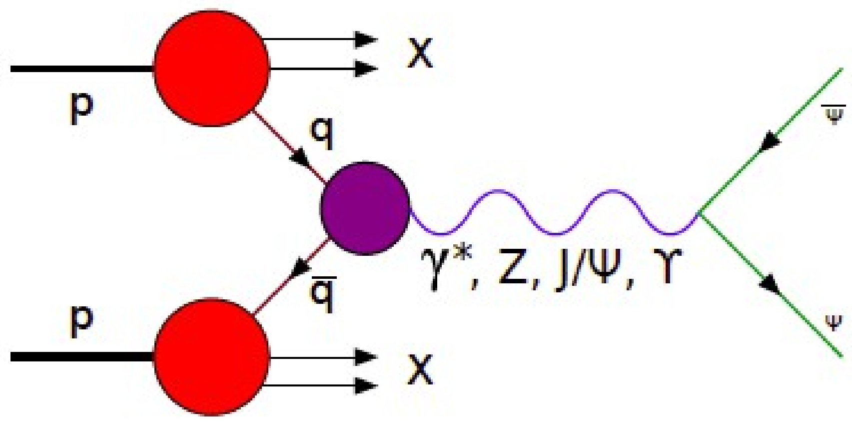
Backgrounds

- 17m of rock removes all SM background from LHC collisions
  - Few muons per minute, p>20 GeV makes it through the rock, but clearly not milli-charged (~1M PE actually saturates detector)
    - Can be used for rough check of alignment
  - Middle layer offset to protect against glancing muons on edge of 3 bars
- Cosmic rate ~100x smaller in tunnel than on surface
  - Comparable to collider muon rate
  - Worry about showers in rock with n, γ, etc. but will have active vetos and self-shielding from outer layer
- Random dark-pulse background
  - Need 3 coincident pulses
  - ~50 events per year at room temp
  - Greatly reduced by cooling to -20C
- Backgrounds will be studied in situ from data: beam on/off, time relative to bunch crossing, pointing to IP or not, etc.



Signal simulation

Detailed simulation, including CMS mag field (small effect)



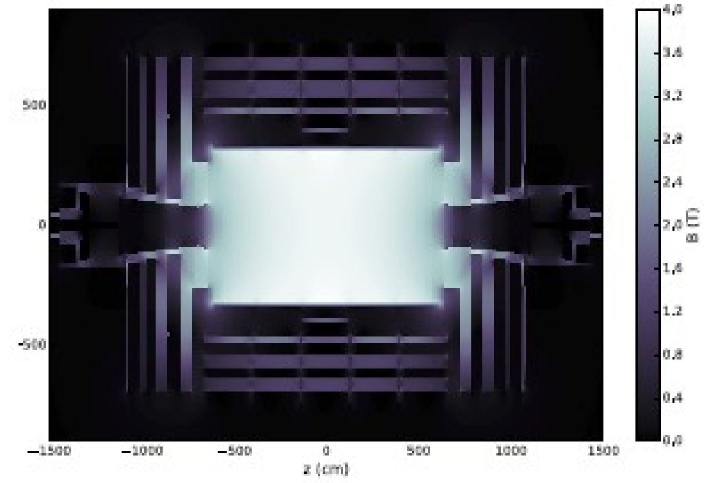
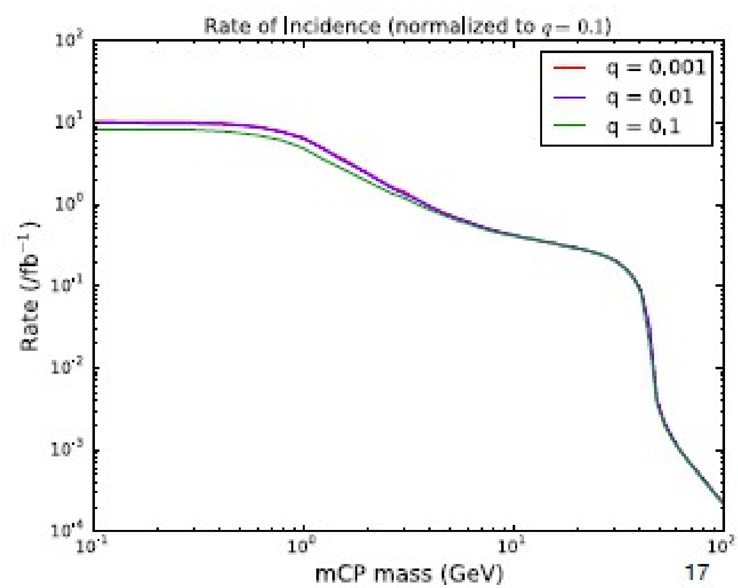


FIG. 2: Map of the CMS magnetic field in the r–z plane.

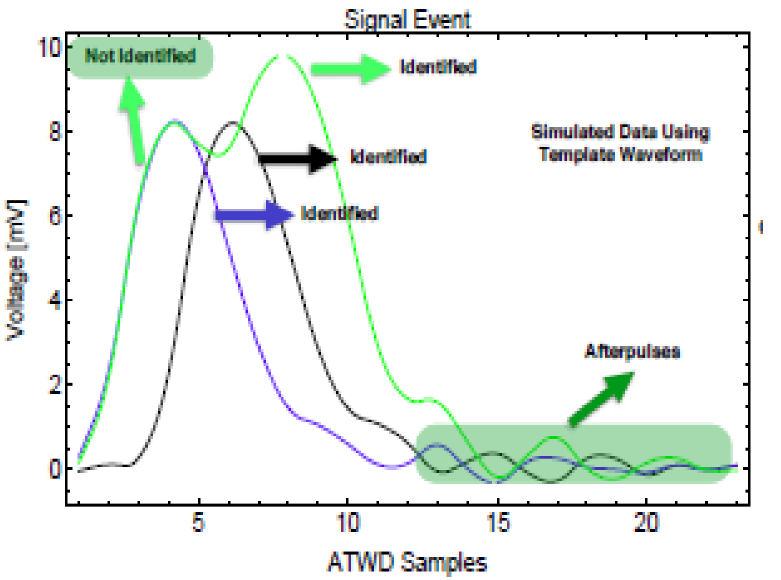


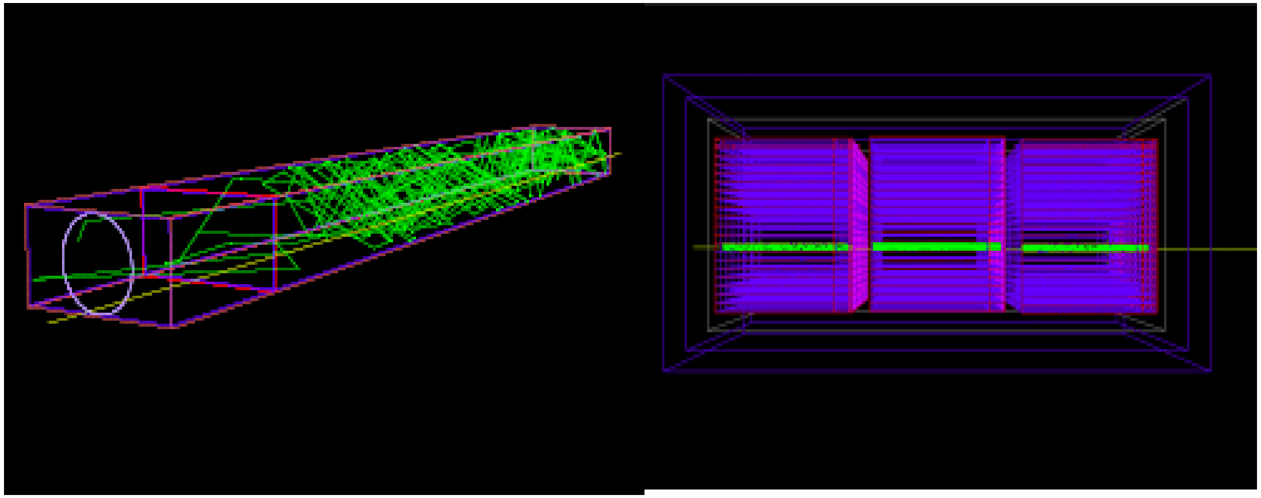
- Use madGraph + madOnia to simulate production via modified Drell-Yan
- Then propagate particles through parameterized simulation of material interactions with CMS & rock (full CMS simulation overkill)
  - *Used actual CMS B-field map though*
- Count rate of incidence on 1 m^2 face of milliQan detector

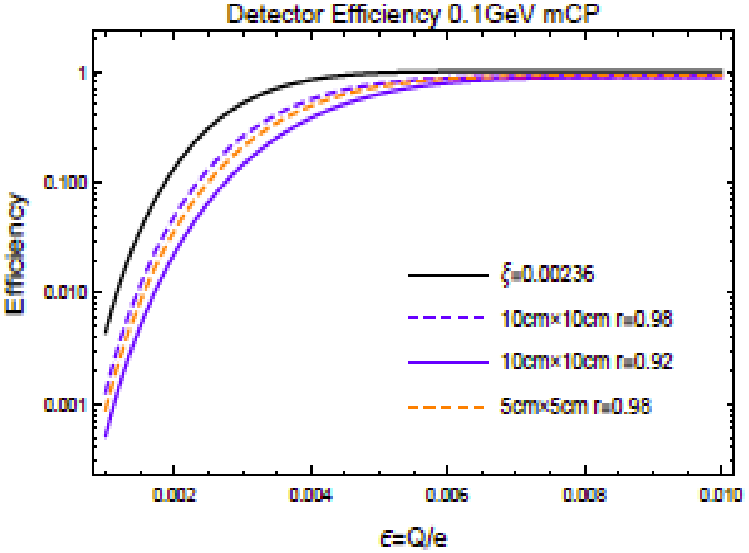
Signal simulation

Full Geant4 detector simulation

- Models reflectivity, the light attenuation length, and the shape of the scintillator. We input the PMT quantum efficiency, scintillator light emission spectrum, time constants, and digitized waveforms







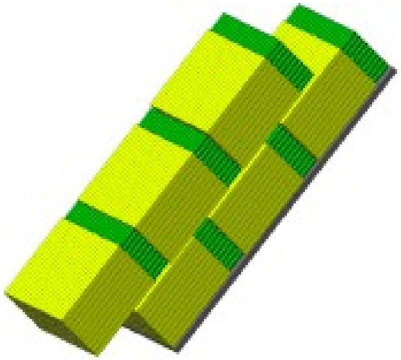
Put milliQan here!

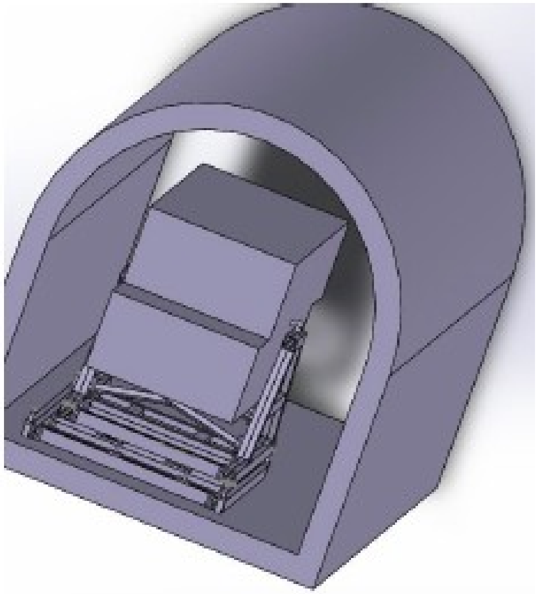
Alignment

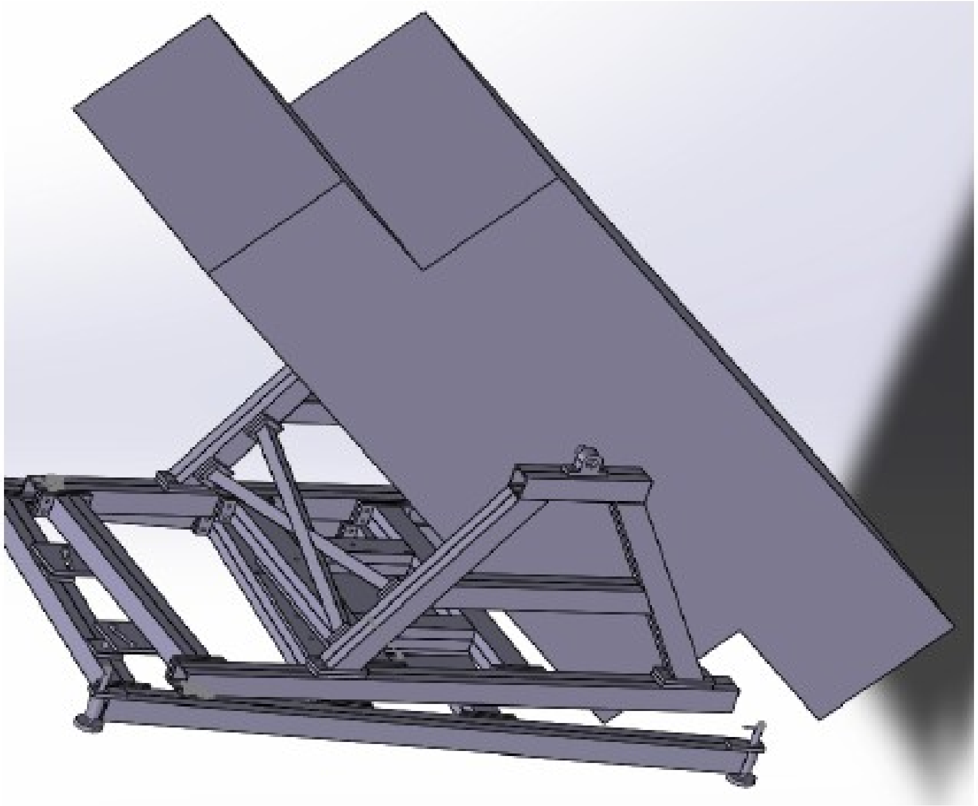
- Special challenge, since far from IP with no line-of-sight!
- CERN team heroically extended the CMS coordinate system into the tunnel, with ~mm precision

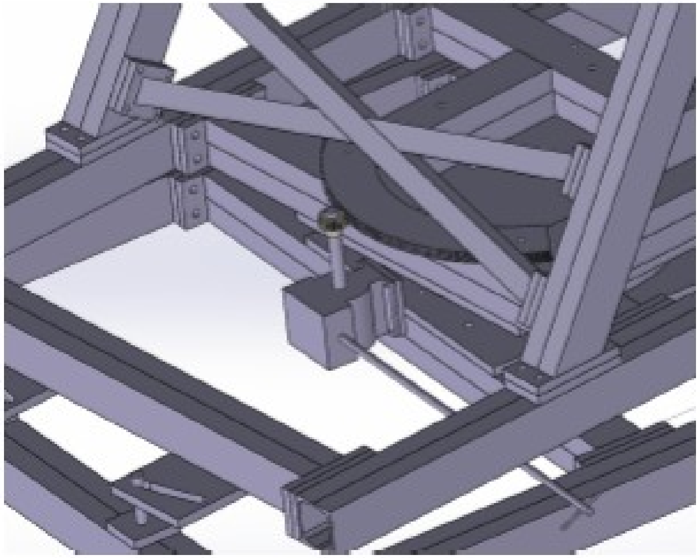
Support structure

- M. Gastal, R. Loos (CERN) working with engineers from Lebanese University on support structure
    - *Splitting in 2 gives much more clearance*







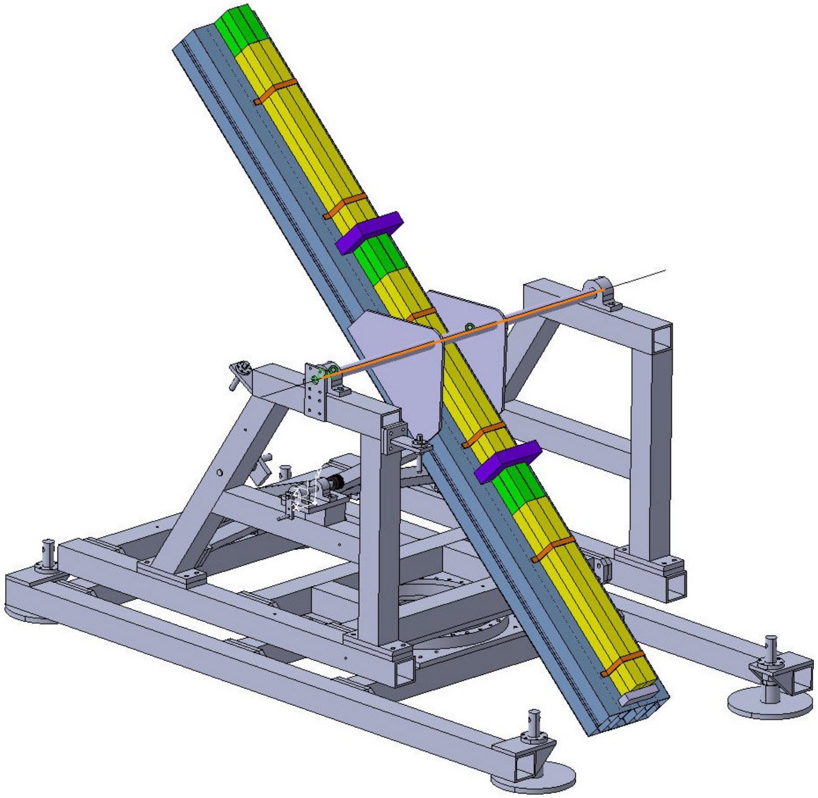


Support structure

- **A few weeks ago, in TS1, installed support structure in tunnel!**
  - Can support, rotate, tilt, and align full 6-ton detector

Next steps

- **Fall 2017:**
  1% test of milliQan in tunnel, with 12 full scintillators+PMTs
  - May get some collision data this year and should have plenty in 2018
  - Learn about operating experiment in the tunnel
  - Measure backgrounds
  - New heavy MCP sensitivity?



- **Aim to complete full detector in time for Run3 (2020-22) and collect ~300/fb of pp data**

Summary

- MilliQan is a new detector at the LHC for milli-charged particles
- Aim to cover m = 0.1 – 100 GeV for q = 0.002 – 0.3 by 2022

- More generally, milliQan is the first detector sensitive to small ionization (single PE's) at the LHC (or any collider?)
  - Potentially sensitive to other signals as well…

- Detector design basically complete, and components tested in the lab
- Thanks to strong support from CMS and CERN technical staff, milliQan is actually "on-shell"
  - Support structure installed in the underground tunnel
  - Infrastructure (power, safety, etc.) being installed
  - 1% milliQan test to be installed during TS2 (Sept. 2017)

- Personal note: small collaboration and building a new experiment "from scratch" has been super fun and educational!