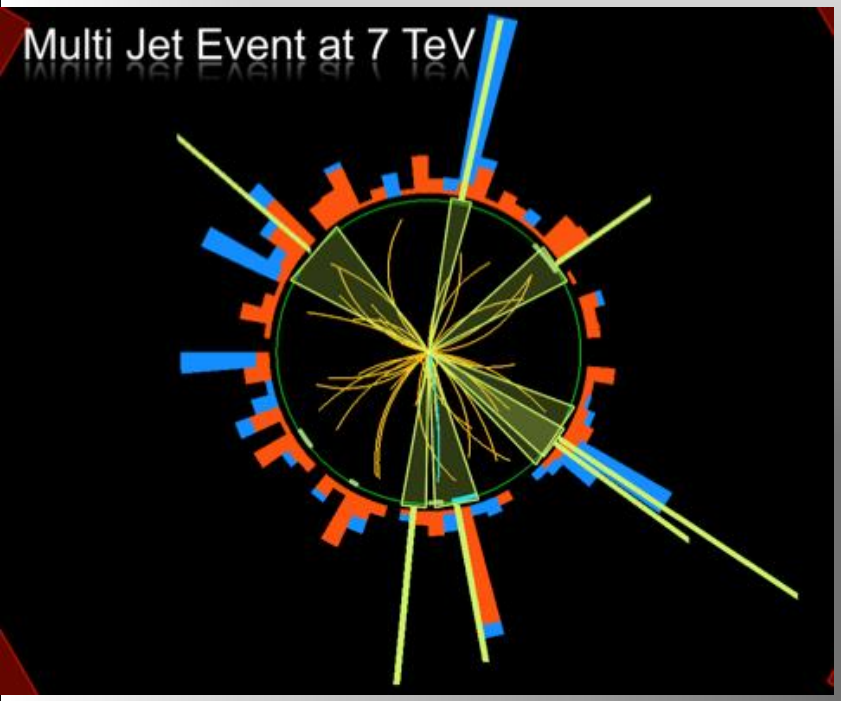
Searching for New Physics with Dedicated Experiments@ the LHC

Albert De Roeck
CERN, Geneva, Switzerland
Antwerp University Belgium
UC-Davis California USA
BUE, Cairo, Egypt
NTU, Singapore

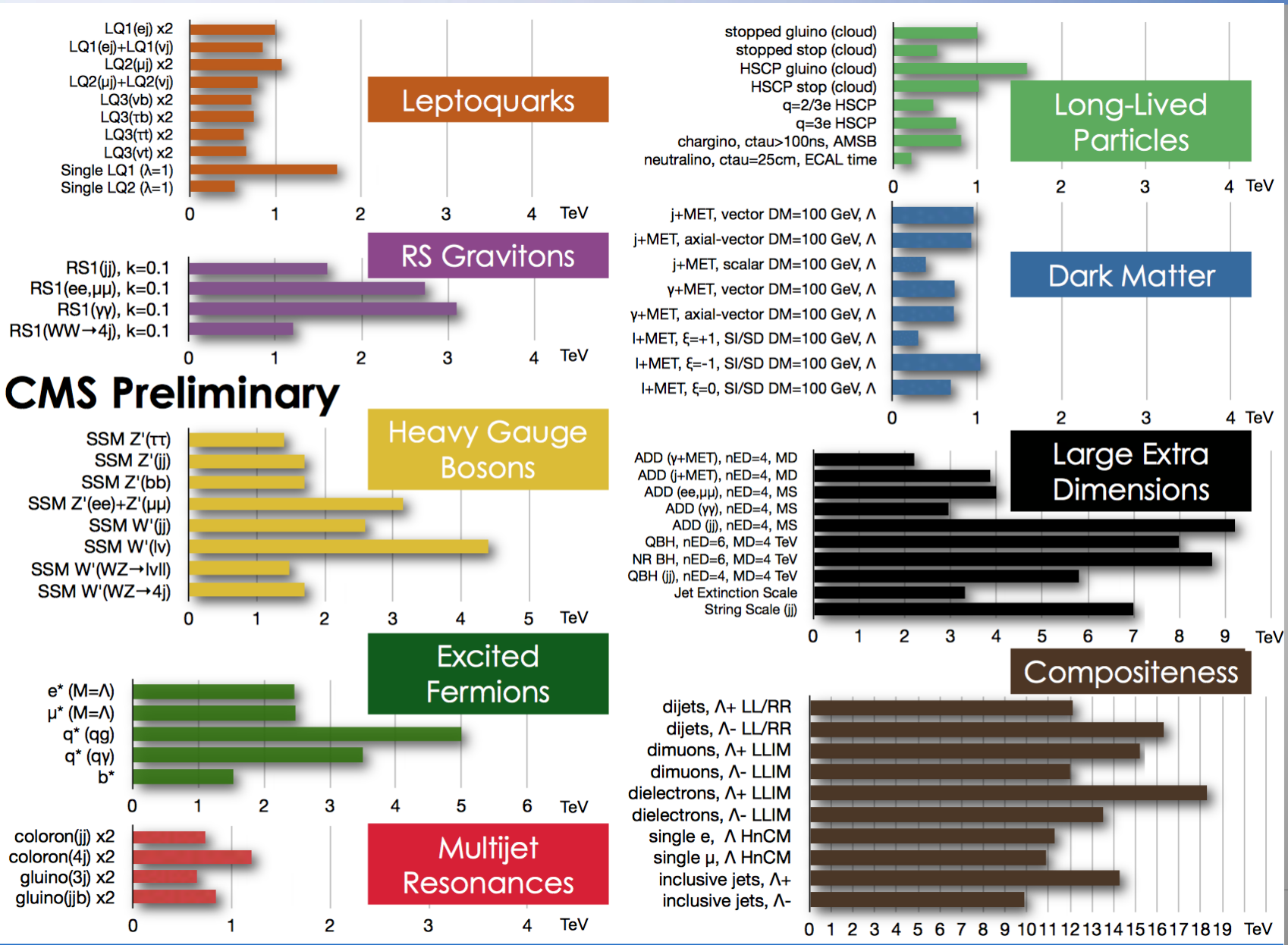
June 28th 2016
MoEDAL Meeting
Valencia, Spain



Outline

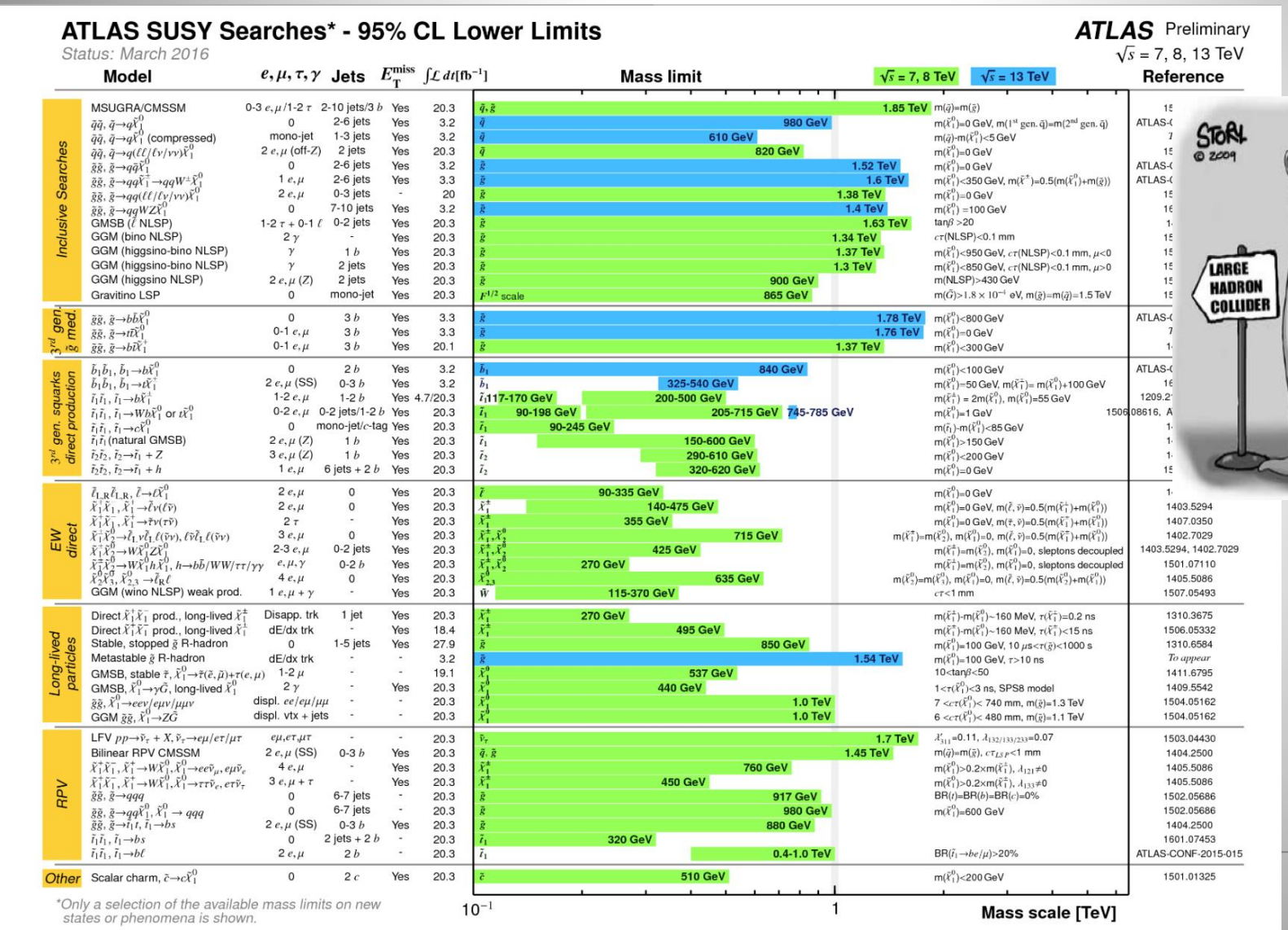
- Search for Physics Beyond the Standard Model
- The MilliQan experiment plan
- The idea for MAPP
- MATHUSLA, for long lived particles
- Summary

Summary of Exotica Searches (CMS)



Summary of SUSY Searches (ATLAS)

No sign of SUSY with the data collected so far (similar for CMS)



Are we leaving no stone unturned?

- The LHC BSM searches are indispensable and should be continued in the new energy regime and with increasing statistics.
- But if we still do not see more than a 2 sigma at the end of run-III, the HL-LHC will be likely mostly a precision physics machine. (Of course we await the verdict on the 750 GeV…)
- Are we looking at the right place? Time for more effort in thinking of complementary searches?

Are we looking at the right place?

Leave no stone unturned!!

Alternative Searches: Examples

- Searches at the LHC

Reflecting personal interest…

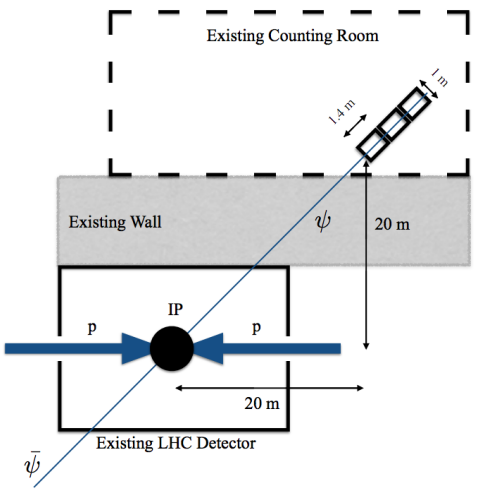
  - Explicit Search for Monopoles (and more) with MoEDAL
  - Search for Milli-charge particles: a new proposal formulated for an experiment, called MilliQan
  - In MoEDAL: MAPP (Monopole Apparatus for detecting Penetrating Phenomena). A proposal for a MoEDAL upgrade?
  - Explore the Lifetime Frontier with MATHUSLA (new!)
  - Trapping in beampipe & using the LHC ring for Monopole searches are discussed later this meeting (tomorrow)
  - Searches for new signatures in CMS/ATLAS/LHCb etc will continue of course. The 750 GeV? SUSY? Exotica? Monopoles?...

The MilliQan Experiment Proposal

Particles with Milli-Charges?

CMS search for fractional charged particle arXiv:1210.2311
Q=1/3e > 140 GeV; Q=2/3e >310 GeV (95% CL. dE/dx)

A "new" idea -> Hunting for particles with charges
~ 0.3-0.001e arXiv:1410.6816

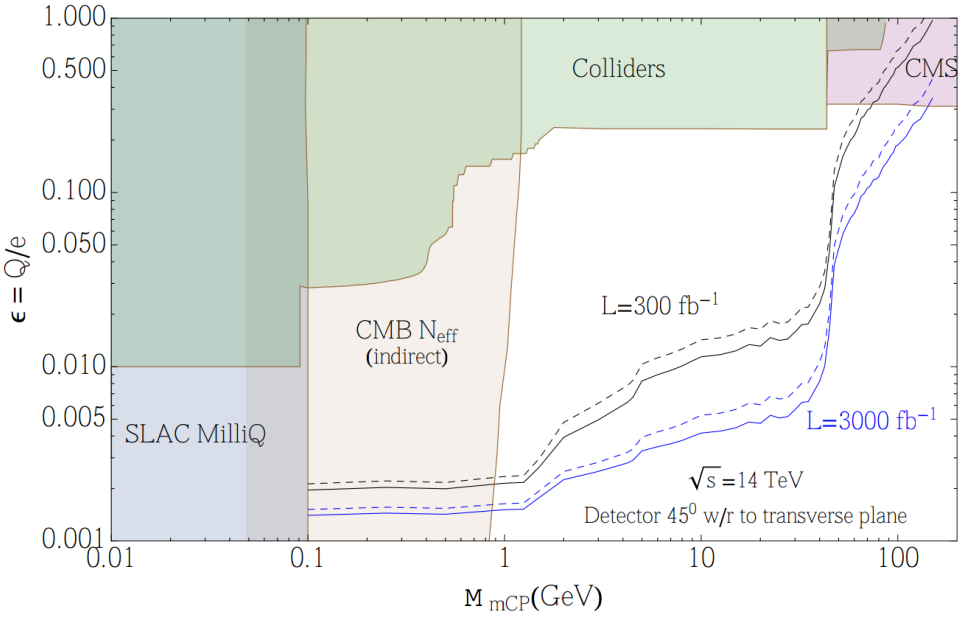


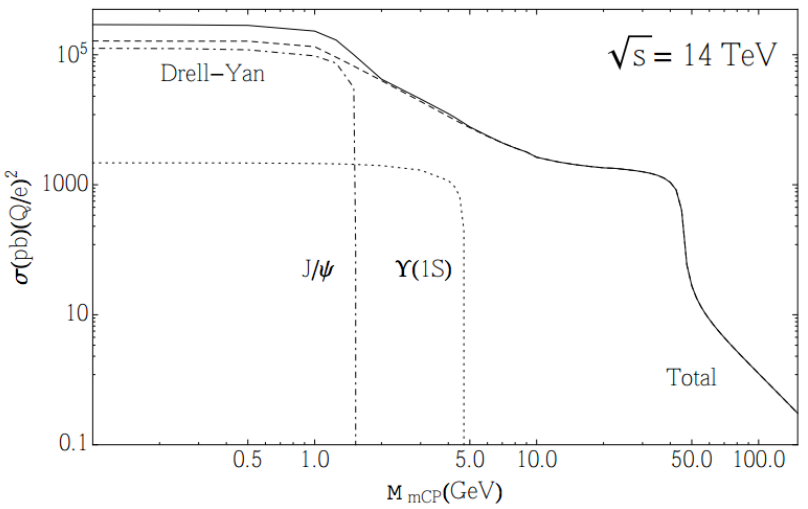
Looking for milli-charged particles with a new experiment at the LHC

Andrew Haas, Christopher S. Hill, Eder Izaguirre, Itay Yavin

(Submitted on 24 Oct 2014)

We propose a new experiment at the Large Hadron Collider (LHC) that offers a powerful and model-independent probe for milli-charged particles. This experiment could be sensitive to charges in the range $10^{-3}e - 10^{-1}e$ for masses in the range $0.1 - 100$ GeV, which is the least constrained part of the parameter space for milli-charged particles. This is a new window of opportunity for exploring physics beyond the Standard Model at the LHC.





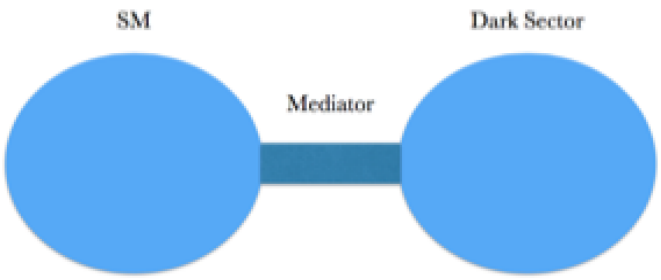
Particles with Milli-Charges?

- Possible extensions of the standard model of elementary particle physics suggest the existence of particles with small, un-quantized electric charge... Milli-charged have been searched for in some dedicated experiments eg at SLAC.
- Eg. New sub-GeV gauge forces ("dark/hidden photons") that kinetically mix with the photon can provide a promising scenario for MeV-GeV dark matter.
- Formalism used for the study is ‘dark QED’ (Holdom 1986), ie an extra abelian gauge boson that is kinematically mixed with the SM hypercharge. Charged fermions in the additional U(1) can interact with SM particles as though they have reduced electric charge

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} A'_{\mu\nu} A'^{\mu\nu} + i\bar{\psi}\left(\not{\partial} + ie'\not{A}' + iM_{\rm mCP}\right)\psi - \frac{\kappa}{2} A'_{\mu\nu} B^{\mu\nu}. \quad (1)$$

- Direct DM via milli-charged particles: eg arXiv:0809.1953

Massless Dark Photons!

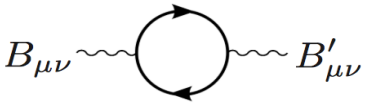


One organizing principle for probing it: focus on lowest-dimension allowed interactions: vector portal, Higgs portal, neutrino portal

$\epsilon_\gamma B^{\mu\nu} B'_{\mu\nu}$ $\quad \epsilon_h |h|^2 |\phi|^2 \quad$ $\epsilon_\nu L h \psi$

- Run 2 program covers Higgs portal (and neutrino portal not directly accessible), but what about vector portal?
  - Massive dark photons (~covered)
  - Massless dark photons, **not covered**

- 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)**
  - *Typically 10^{-2} to 10^{-3} e, so they are called "millicharged particles"*
- Due to small EM charge interact very weekly with typical, ionization based, particle detectors
  - *Need dedicated experiment to search for these*



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

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

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

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

Gets rid of "mixing term" and generates an apparent milli-hypercharge for the new fermions

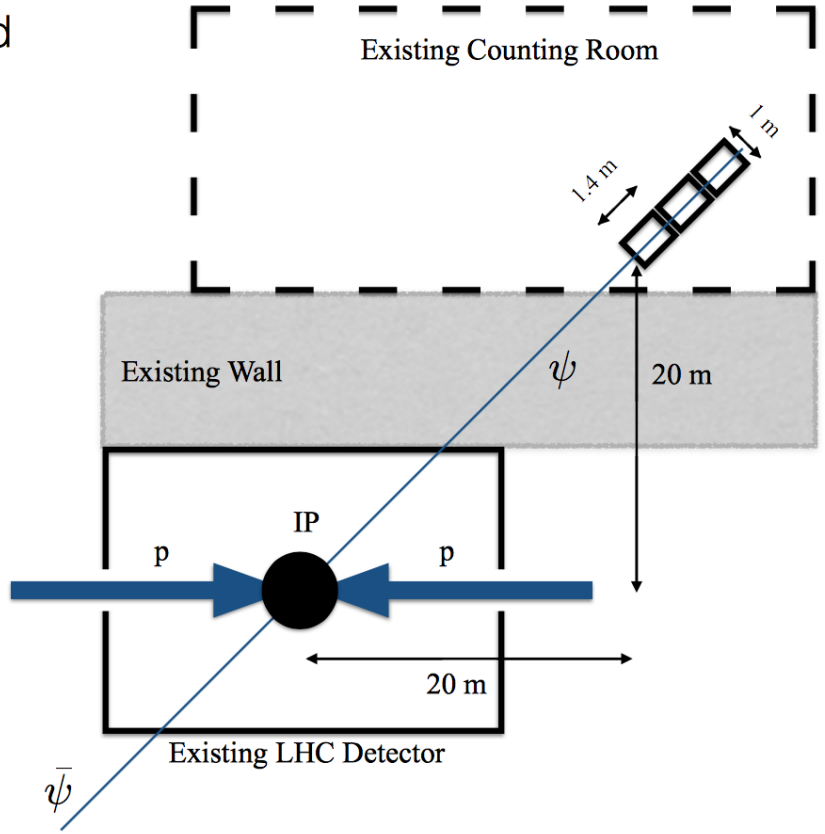
After electro-weak symmetry breaking DS fermions acquire an EM charge

$$Q = \kappa g_D \cos\theta_W$$

(normalized to charge of electron)

Idea for the MilliQan Experiment

- Proposal to add detector that would be sensitive to milli-charged particles produced in LHC collisions
- 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



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]

[1] *Department of Physics, New York University, New York, NY, USA*
[2] *Department of Physics, The Ohio State University, Columbus, OH, USA*
[3] *Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada*
[4] *Department of Physics, McMaster University, Hamilton, ON, Canada*

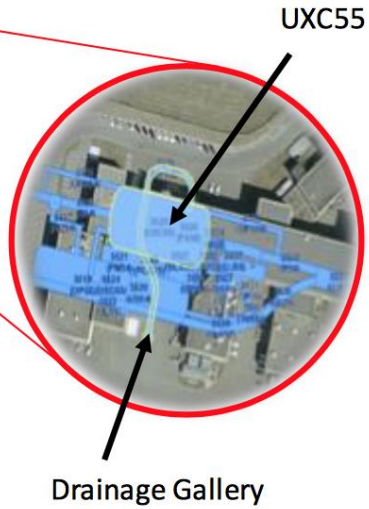
We propose a new experiment at the Large Hadron Collider (LHC) that offers a powerful and model-independent probe for milli-charged particles. This experiment could be sensitive to charges in the range $10^{-3}e - 10^{-1}e$ for masses in the range $0.1 - 100$ GeV, which is the least constrained part of the parameter space for milli-charged particles. This is a new window of opportunity for exploring physics beyond the Standard Model at the LHC.

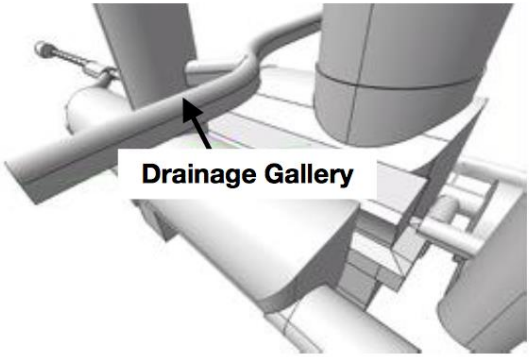
arXiv:1410.6816v1 [hep-ph] 24 Oct 2014

Few slides taken from C. Hill

Contacts: drandyhaas@gmail.com and Christopher.Hill@cern.ch

The PX56 Observation and Drainage Gallery

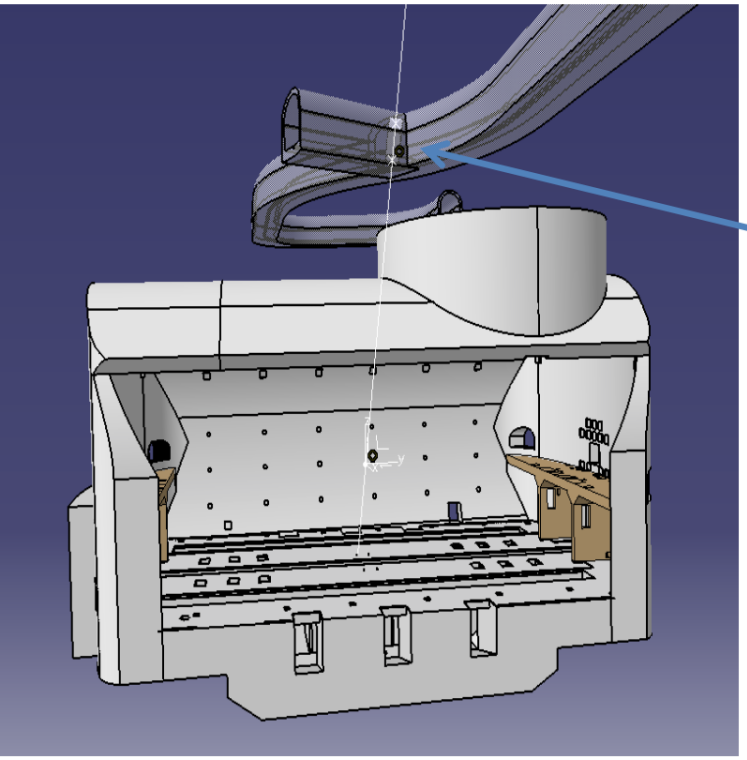




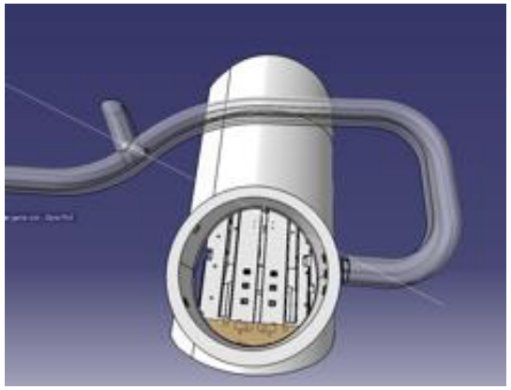
- The PX56 drainage gallery was used during the excavation phase of the CMS experimental area.
- It links the 2 CMS shafts PM54 and PX56 together

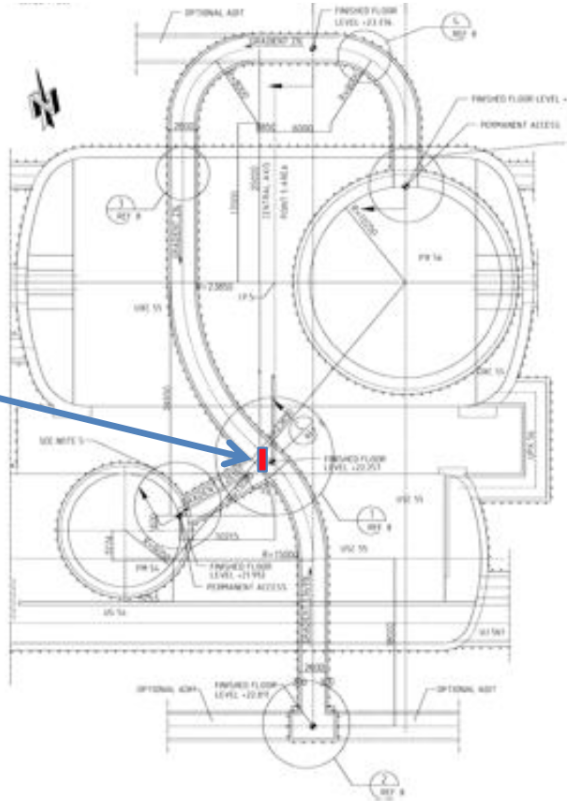
Location in the Drainage Gallery

- Sensitivity of experiment ∝ length of scintillator
  - *want to maximize what can fit in dimensions*
- Sensitivity of experiment ∝ 1/(distance from IP)^2,
  - *want to minimize this distance, while satisfying above*



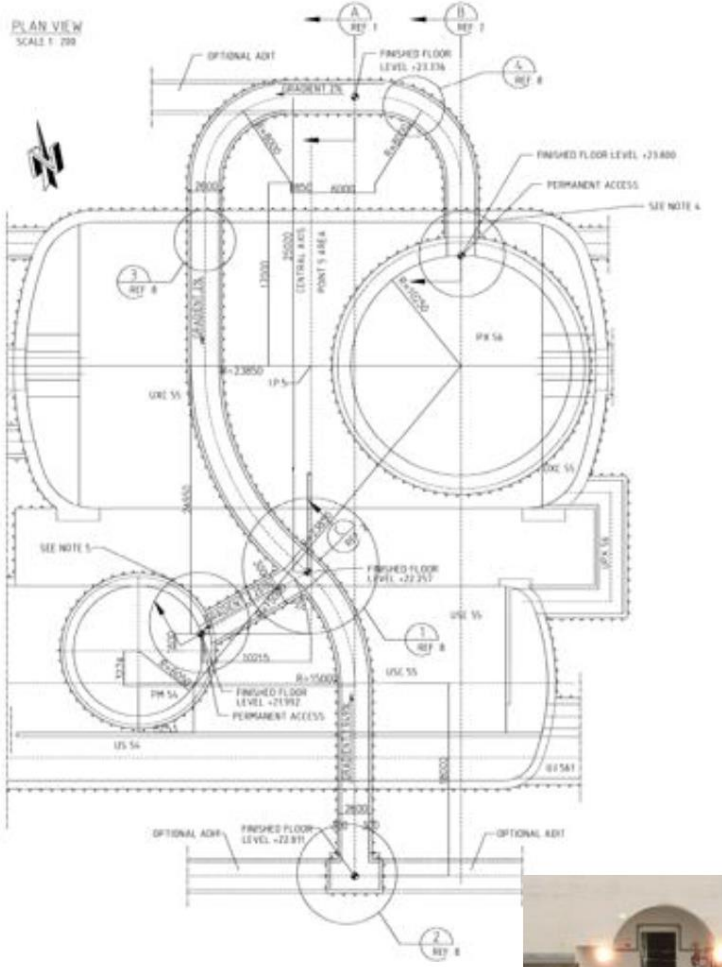
Optimum location in red





The PX56 Observation and Drainage Gallery

- The gallery has a basic shotcrete finish

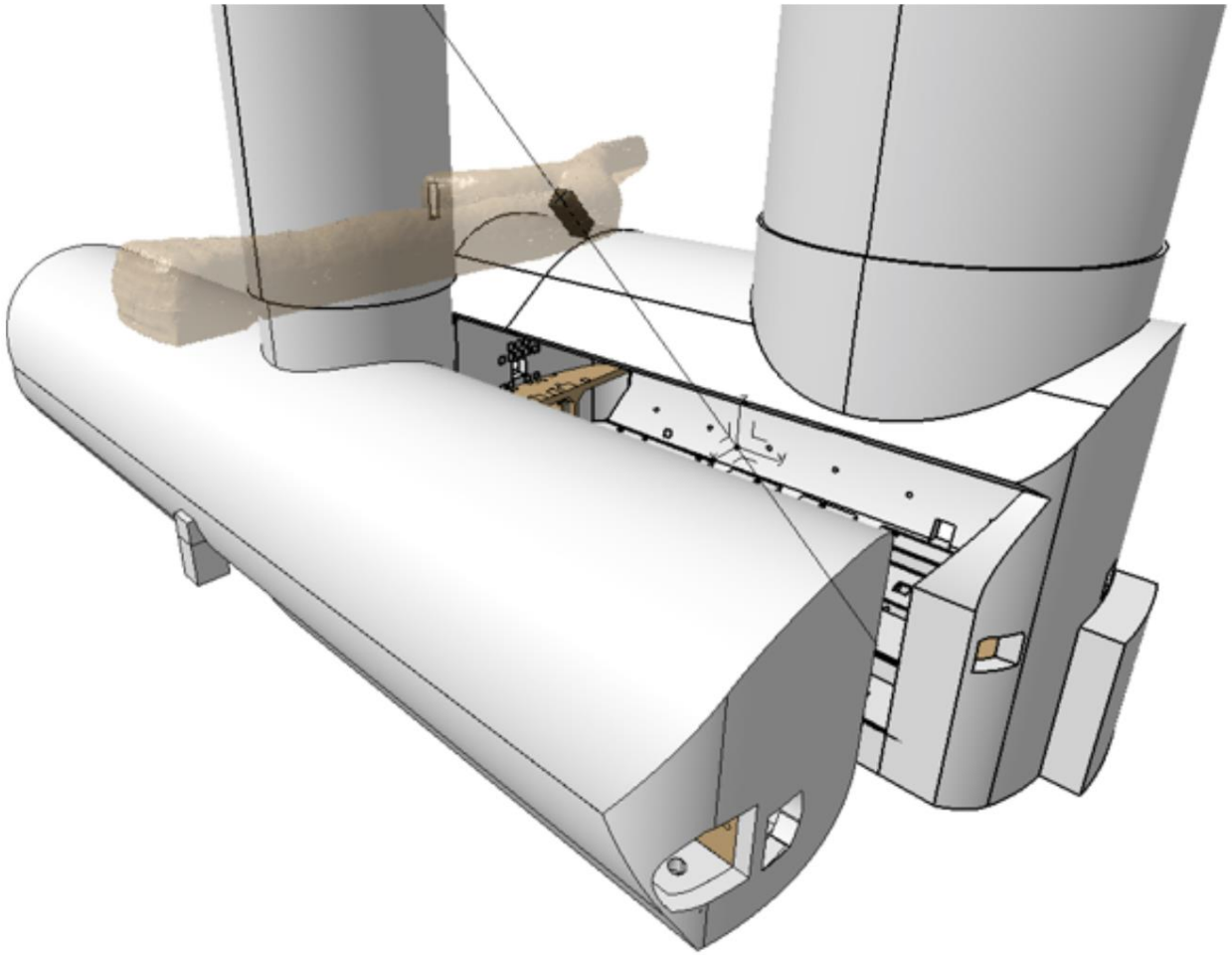


- Dimensions are 2.78 m in height, 2.73 m in width
- Basic power, lighting, drainage available

Only existing use is for infrequent transit to PX56 platform (interlocked during LHC operation)

Location in the Drainage Gallery

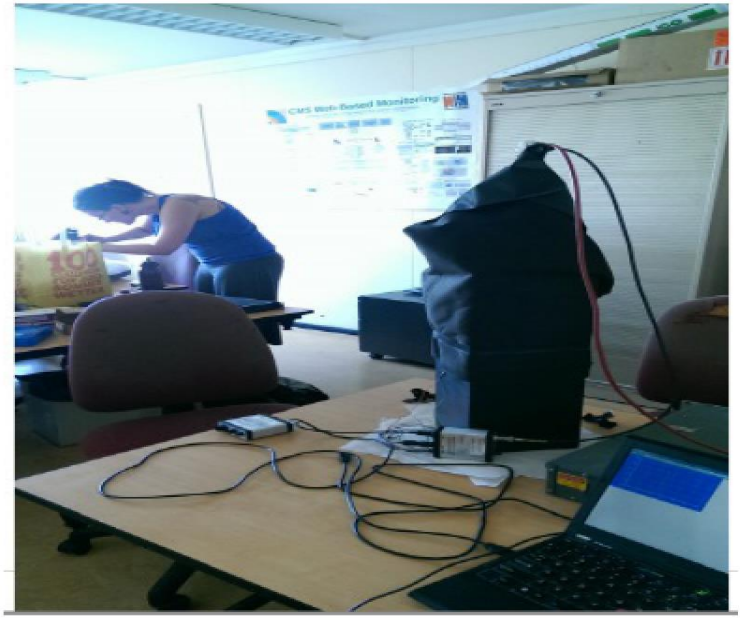
- Martin Gastal (and his team) have been particularly helpful
  - *3D drawings, surveys, B-field measurements, pictures, etc.*
- Now have precise details of location:
  - *33 m from IP*
  - *17 m through rock*
  - *Angle from horizontal plane is 43.1 deg*
  - *Clearance to gallery boundaries is ~30 mm*



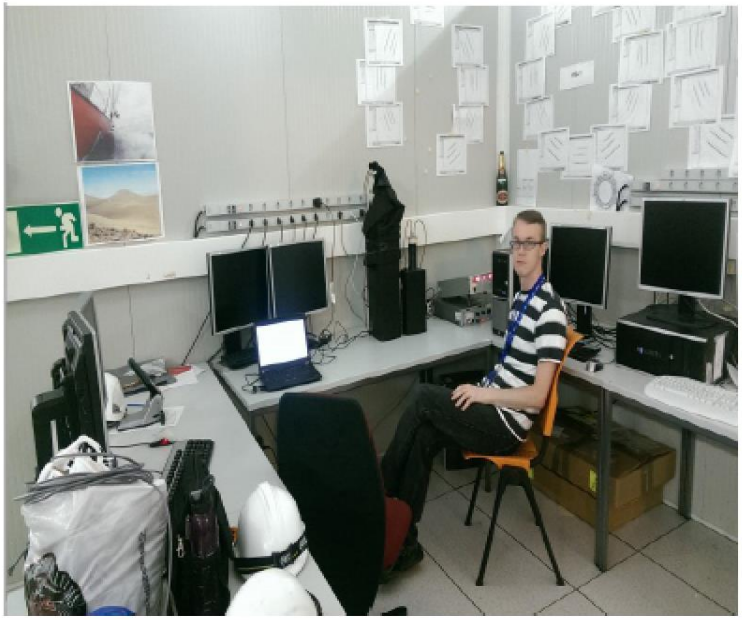
Testing Background Levels

MilliQan will look for signals down to a few photo-electrons produced.
(A minimum ionizing particle leaves ~2×10^6 photons/meter)
Shielding is key. Test background and effect of collisions in IP5 in underground counting room at IP5 with scintillators during summer '15

Surface Test,Bldg.10

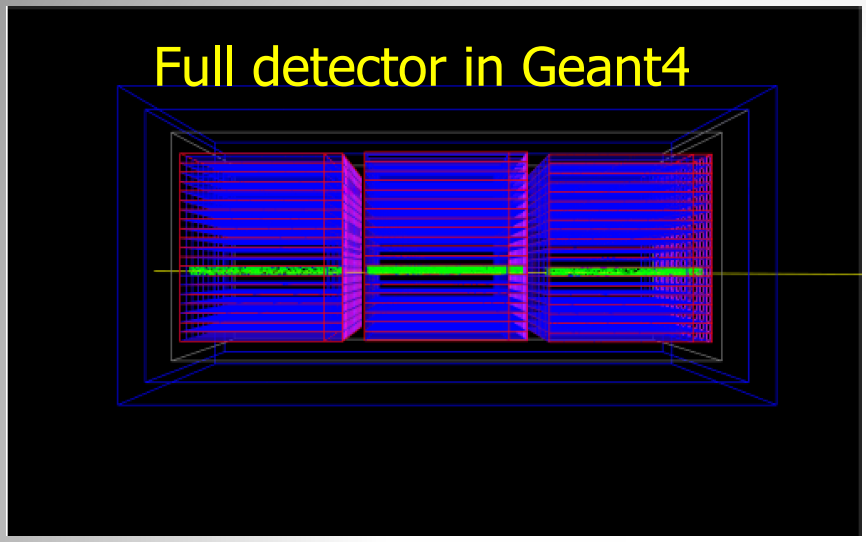


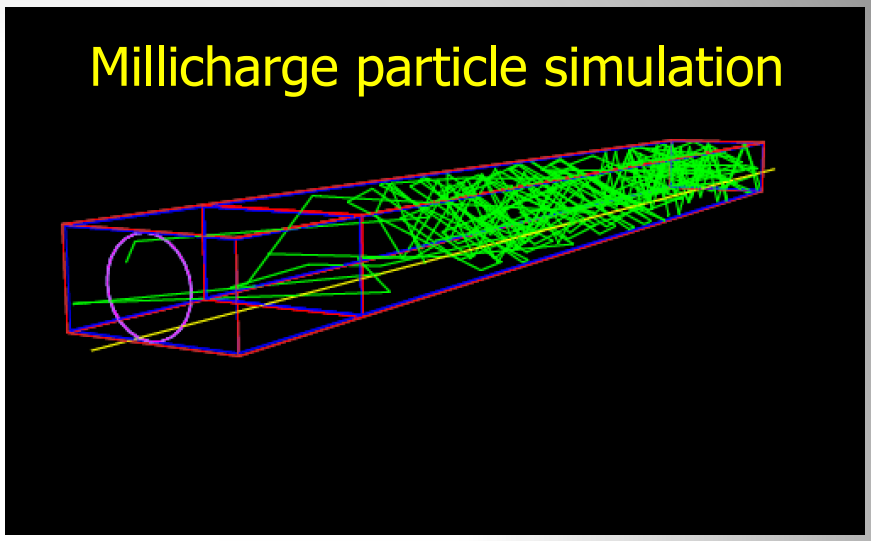
Counting Room, P5

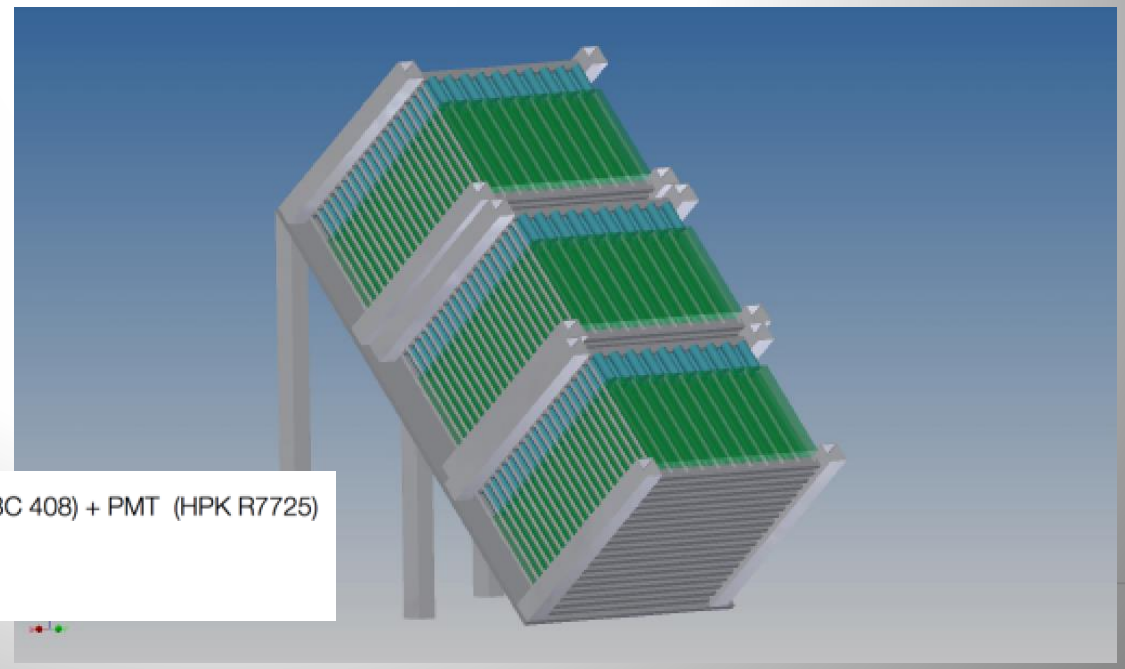


Backgrounds are low. Effect of collisions in IP seen (linear dep. on Lumi)
New measurements on the muon background from CMS ongoing this week

Simulation of MilliQan (Geant4)







- 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*

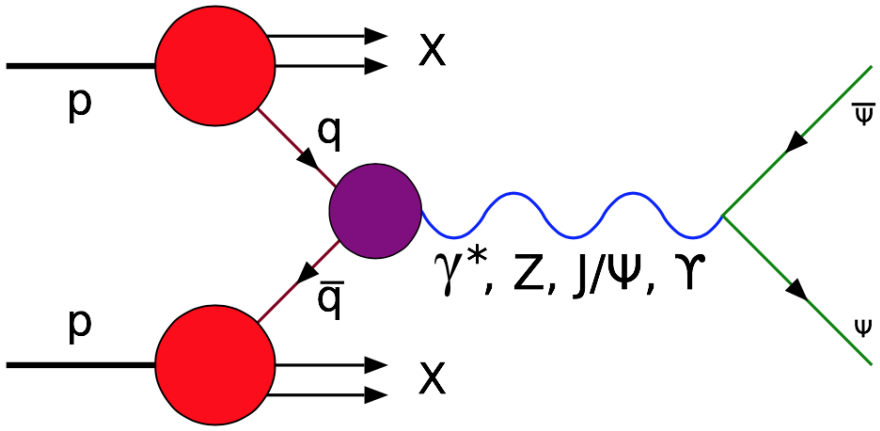
Basic Readout and Trigger

- 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**

Expected Backgrounds

- Expect 17 m of rock will shield particles form pp collision (except muons) to negligible levels
- Muons (from LHC or cosmics) not actually a background since will be very bright (~1M photons in scintillator)
  - *They will be a small source of dead time though*
- Expect irreducible background to be from dark current pulses in PMTs
  - *Assuming dark rate of ~1kHz, triple-incidence in 15 ns window reduces this to ~10^{-6} Hz*
    - **$\mathcal{O}$(50) bkg events in 3000 fb^{-1}**
- Expect additional sub-dominant, reducible, backgrounds from activity in the scintillator, background radiation, and photo-multiplier after pulsing
- Actual background rate will ultimately be measured *in situ* during beam-off periods
  - *Can also measure backgrounds from non-pointing coincidence during beam on periods.*

Expected # of MCPs in MilliQan



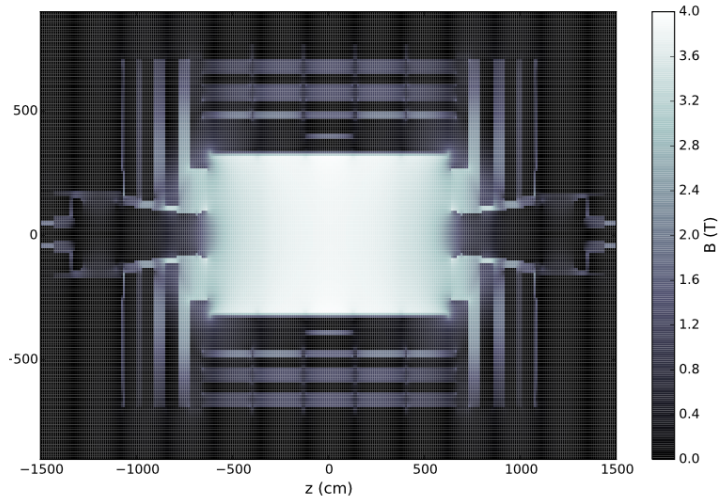
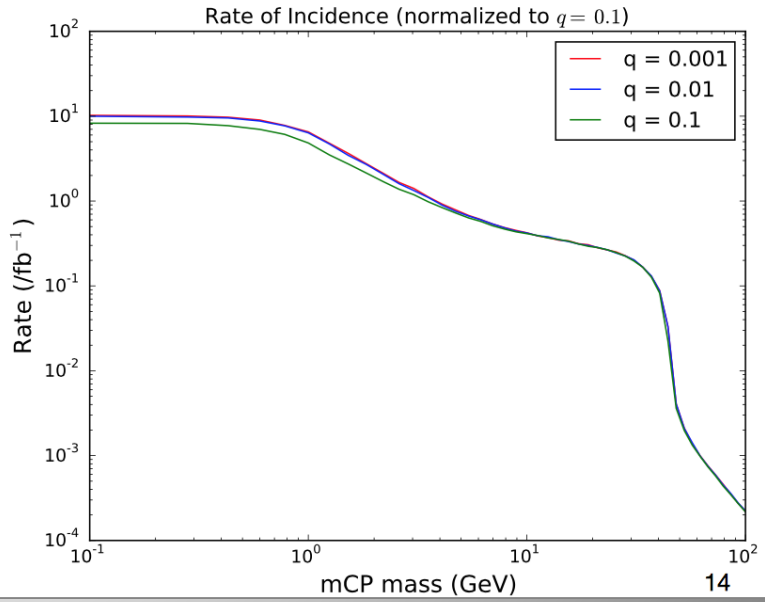
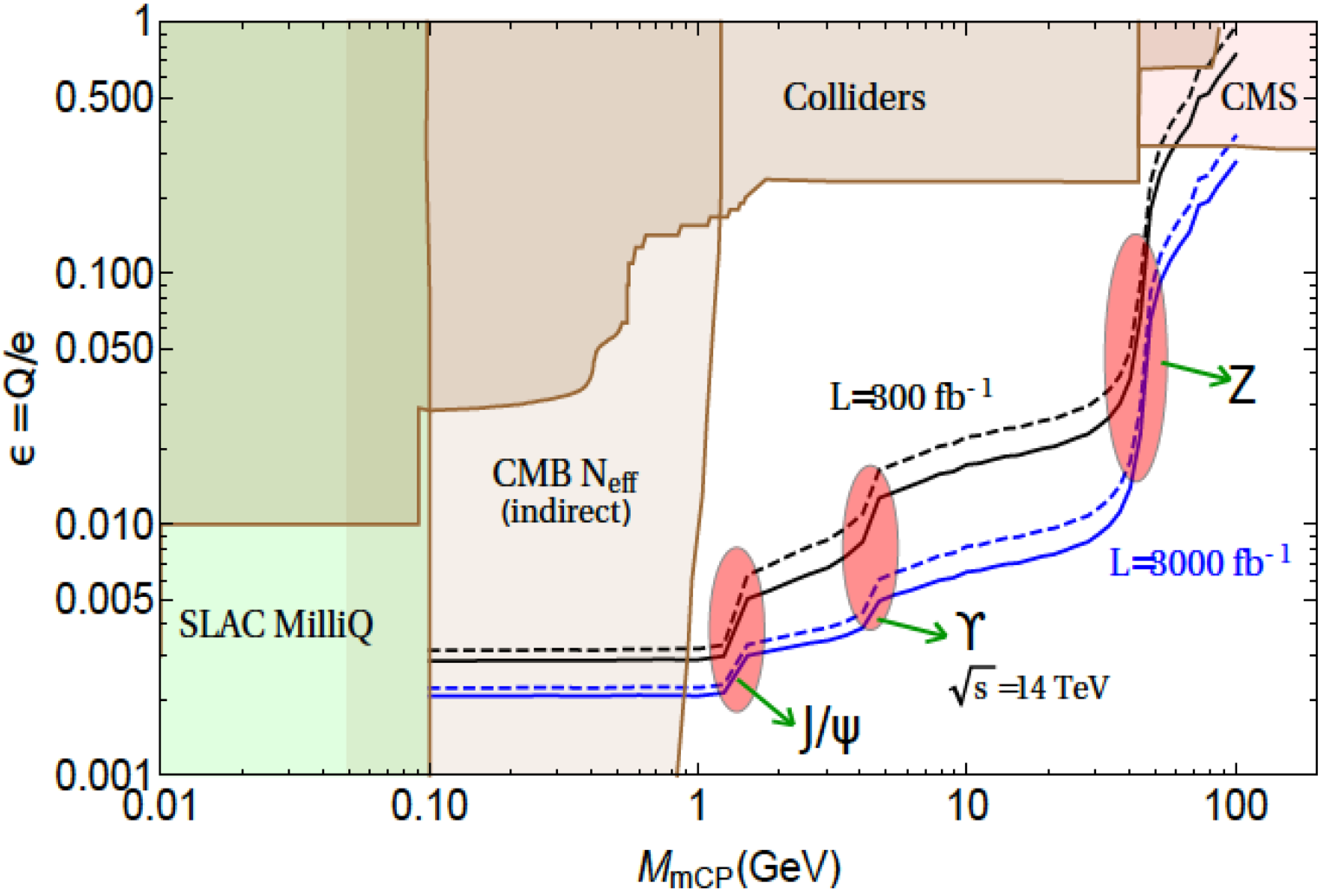


FIG. 2: Map of the CMS magnetic field in the r–z plane.

- 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



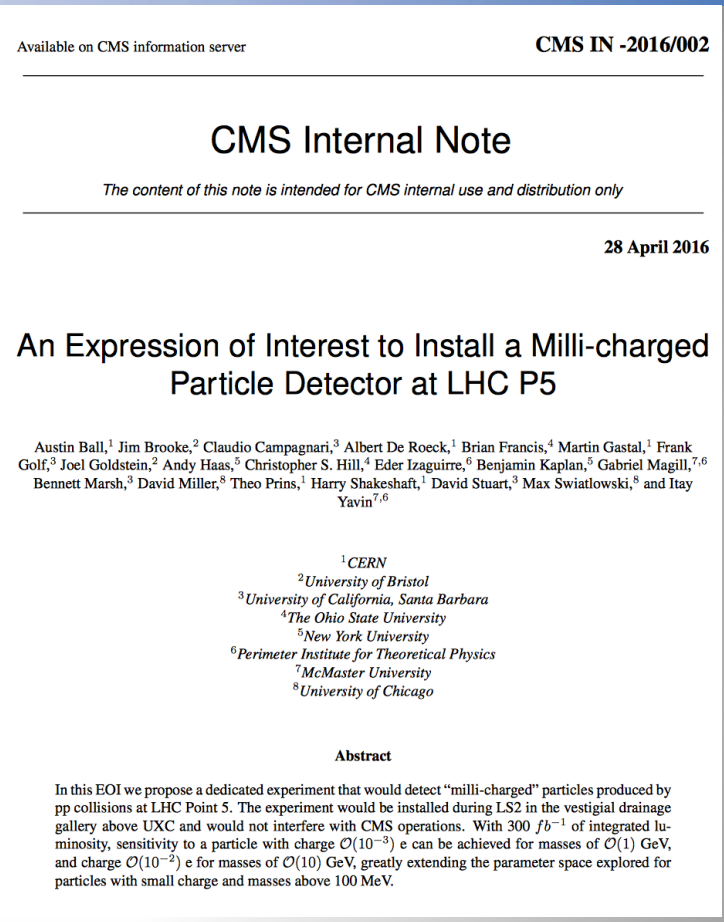
Expected Sensitivity



With Geant4, CMS B-field and Bethe-Bloch energy loss!

Next Steps/Schedule

- The experiment is proposed to be associated with CMS, ie use the cavern have and some support and interaction (ie lumi) but be open to non-CMS members
- Membership to date:
  - -5 CMS groups (+ 2 being considered)
  - -2 ATLAS groups and 1 Theory group
- Request being evaluated in CMS based on the submitted EOI (April 2016)
- Funding request being organized O(1)MCHF
- Further studies/developments:'
  - -Scintillator and PMT tests
  - -Electronics tests/firmware development
  - -Online-offline software organization
  - -Analysis framework set-up
  - -Real size mechanical model test(?)
  - -Measurements in situ of the background
  - -New simulations being conducted with 'final' set-up…



Available on CMS information server **CMS IN -2016/002**

CMS Internal Note

The content of this note is intended for CMS internal use and distribution only

28 April 2016

An Expression of Interest to Install a Milli-charged Particle Detector at LHC P5

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]

[1]*CERN*
[2]*University of Bristol*
[3]*University of California, Santa Barbara*
[4]*The Ohio State University*
[5]*New York University*
[6]*Perimeter Institute for Theoretical Physics*
[7]*McMaster University*
[8]*University of Chicago*

Abstract

In this EOI we propose a dedicated experiment that would detect "milli-charged" particles produced by pp collisions at LHC Point 5. The experiment would be installed during LS2 in the vestigial drainage gallery above UXC and would not interfere with CMS operations. With 300 fb^{-1} of integrated luminosity, sensitivity to a particle with charge $\mathcal{O}(10^{-3})$ e can be achieved for masses of $\mathcal{O}(1)$ GeV, and charge $\mathcal{O}(10^{-2})$ e for masses of $\mathcal{O}(10)$ GeV, greatly extending the parameter space explored for particles with small charge and masses above 100 MeV.

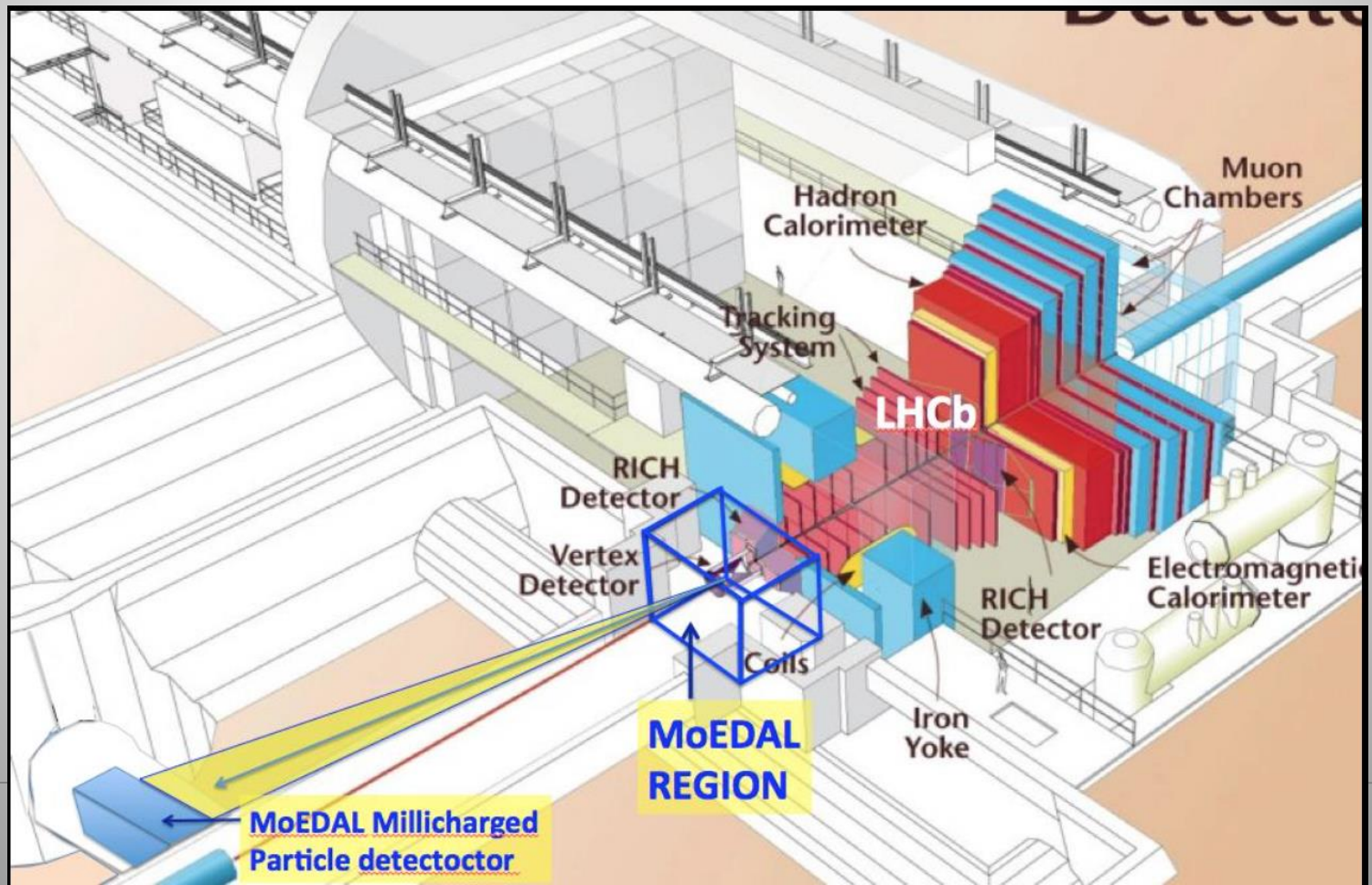
Still an open collaboration

Expect to install prototype in Run-2 but full detector in Run-3

MAPP
Monopole Apparatus for detecting Penetrating Phenomena

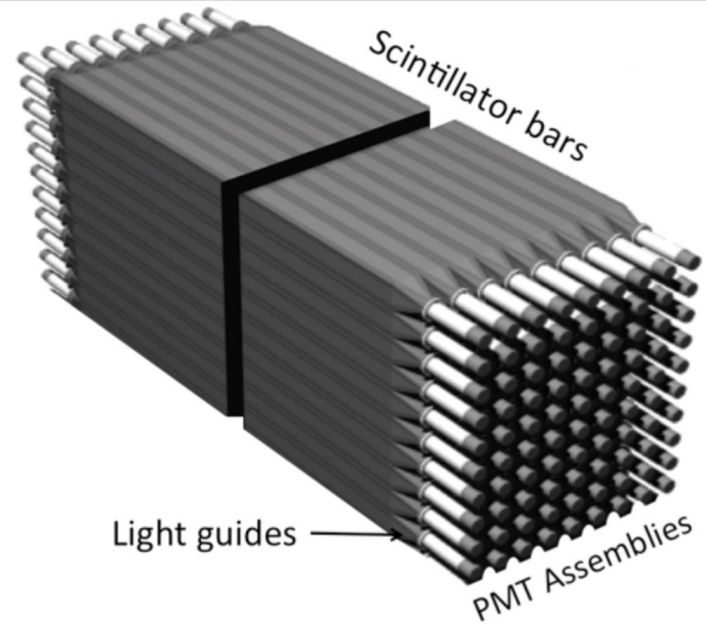
MAPP: For MoEDAL Upgrade?

- Same basic idea for millicharges, based on arXiv:1410.6816
  But also aim for more general exotica phenomena
- Location in the LHCb cavern (Lumi versus acceptance trade-off?)
- Different set-up. Different timescale?



MAPP

Possible set-up



Bonus of the LHCb area:
SMOG: gas fixed target project
Data exchange with LHCb?

To search for penetrating phenomena including (but not limited to) those that are generated by the SMOG fixed target program at LHCb
SMOG: for m < 50 GeV and O(pb) cross sections

gas type	K factor
air (N2, O2, CO)	1.0
Xe	0.4
Kr	0.5
Ar	0.8
H2	2.4
Ne	4.1
He	5.9

Studies required:
-Acceptance/sensitivity (simulation)
-Background measurements
-Dark current limit to detect small charge
-Detector performance estimates
-…

For discussion as a possible Upgrade in MoEDAL

Contact: J. Pinfold

MATHUSLA
Massive Timing Hodoscope for Ultra Stable neutraL pArticles

Methuselah is the man reported to have lived the longest at the age of 969 in the Hebrew Bible. Extra-biblical tradition maintains that he died on the 11th of Cheshvan of the year 1656AM, seven days before the beginning of the Great Flood. Wikipedia

MATHUSLA

New Detectors to Explore the Lifetime Frontier

John Paul Chou*
Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854

David Curtin†
Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, MD 20742 USA

H. J. Lubatti‡
Department of Physics, University of Washington, Seattle, WA 98195

(Dated: June 22, 2016)

contacts

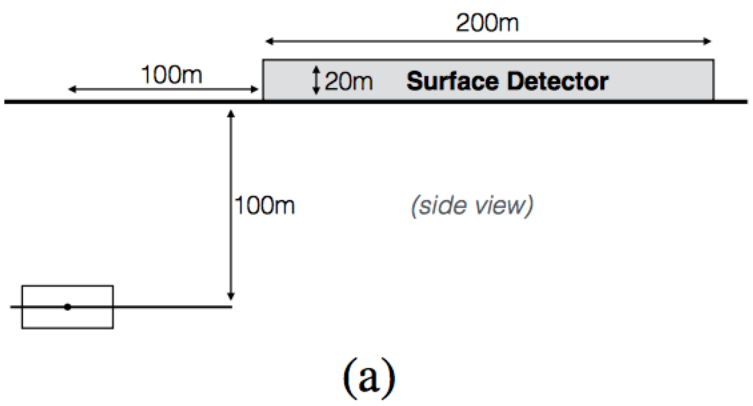
arXiv:1606.06298

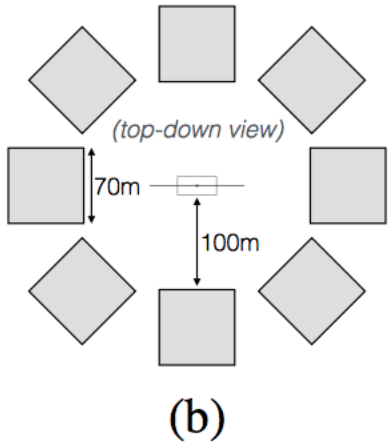
A new paper last week:
A proposal for a large area surface array to detect ultra long lived particles coming from the pp collisions

Aim to cover the range

$$c\tau \lesssim 10^7 - 10^8 \text{ m}$$

~ BBN constrained inspired

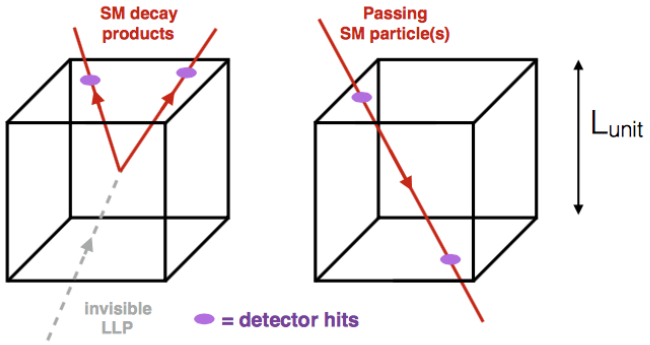




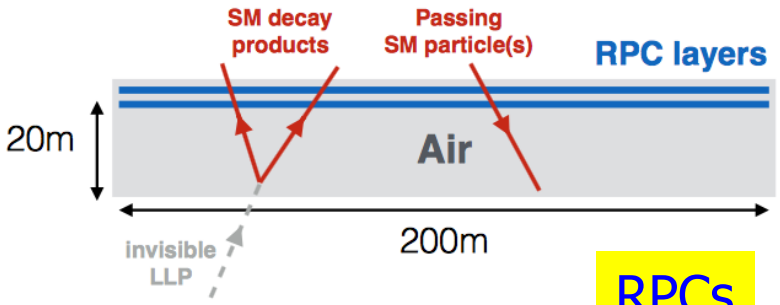
Possible detector surface array eg above ATLAS or CMS:
- $(200\text{m})^2$
- $8 \times (70\text{m})^2$

MATHUSLA

Possible technologies for the detector



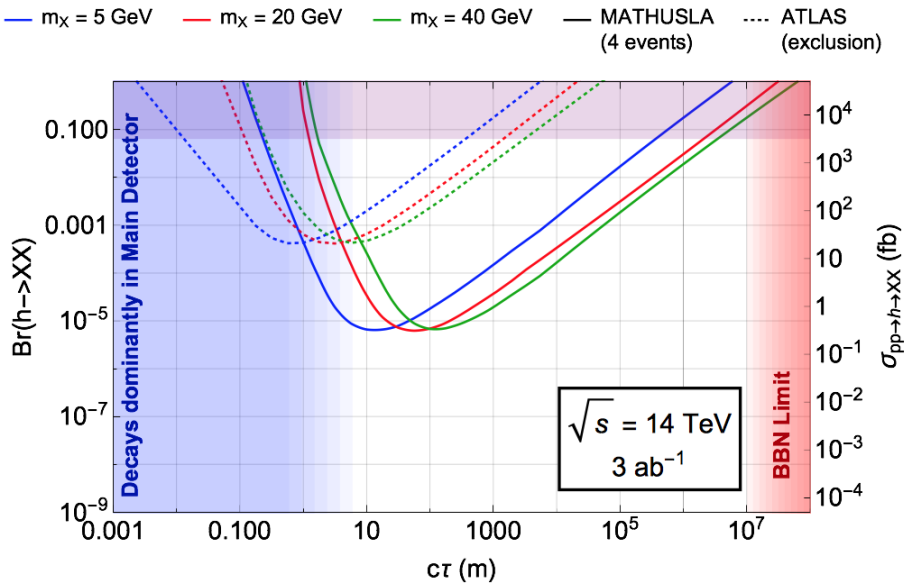
scintillators



RPCs

Sensitivity

Benchmark: exotic Higgs decay in long lived neutrals



No detailed design yet. Guestimate for the cost ~ O(20) MUSD

Summary: Exotica Searches

- The LHC has entered a new territory. The ATLAS and CMS experiments are heavily engaged in searches for new physics. No clear sign of new physics yet in the first 20 fb^{-1} at 8 TeV. The ultimate test start now with 13 TeV and higher lumi. By mid summer we will know the fate of the 750 GeV bump
- Of course we (also) want to see signals in MoEDAL, monopoles or other
- It is certainly useful to prepare for alternative searches with dedicated "smaller" experiments. A few examples
  - MilliQan: dedicated search for particles with
  - MAPP: discussion for an upgrade for MoED
  - MATHUSLA: Ultra-long lived particles
  - Using Beampipes/ LHC ring discussed later
- Maybe one day soon:

Backup