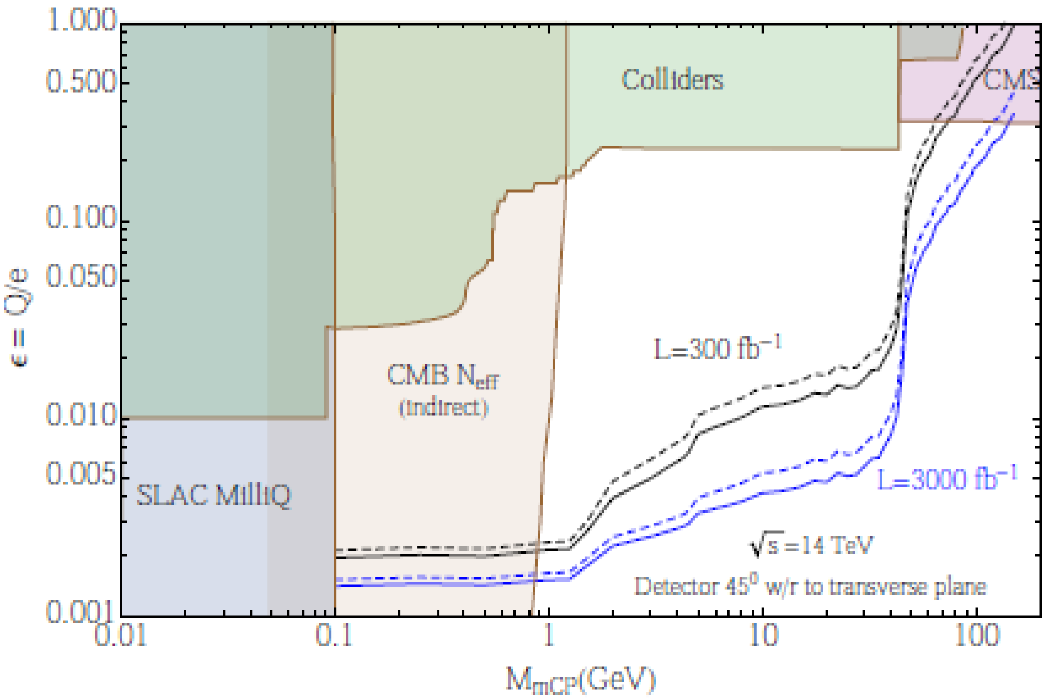
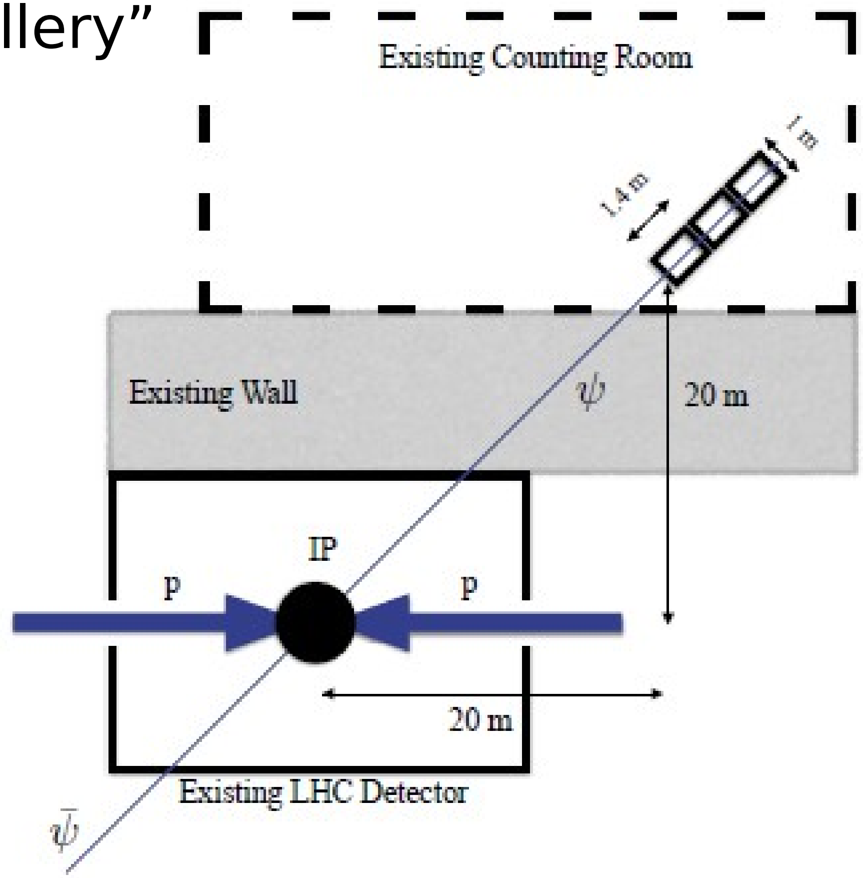
New LHC Experiment: MilliQan

- Milli-charged particles → massive, with electric charge ~10^{-3} e
- Easy to add to SM: "dark U(1)" (with massless dark photon) kinetic mixing → dark fermion milli-charged under SM
- Currently weak direct limits for fermion mass > 100 MeV
- ~1 photo-electron observed per 1m long scintillator
- Require triple-incidence in time window
- Moving forward in CMS "drainage gallery"





MilliQan Theory

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{DS}$$

$$\mathcal{L}_{DS} = -\frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + i\overline{\psi}'\left(\partial\!\!\!/ + ie'A\!\!\!/' + iM_{\psi'}\right)\psi' - \frac{\kappa}{2}A'_{\mu\nu}B^{\mu\nu}$$

$$\mathcal{L}_{DS} = -\frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + i\overline{\psi}'\left(\partial\!\!\!/ + ie'A\!\!\!/' + i\kappa e'B\!\!\!/' + iM_{\psi'}\right)\psi'$$

- Let us assume that the DS has at least one Abelian gauge group, $U_{DS}(1)$
  - Consisting of a massless dark boson A'_μ, and a dark fermion ψ' with charge e' and field strength $A'_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$
  - Small kinetic mixing with the SM hypercharge ($B_{\mu\nu}$) and strength $\kappa << 1$
  - A gauge transformation ($A'_\mu \to A'_\mu + \kappa B_\mu$) eliminates the kinetic mixing term, in favor of mixing between the dark fermion and the SM gauge boson
- The dark fermion, ψ', interacts with the SM $\gamma(Z)$ with **charge** $\kappa e' \cos\theta_w(\sin\theta_w)$ **and has mass** $M_{\psi'} = M_{mCP}$

Note that ψ' is not, itself, a candidate for THE dark matter

MilliQan Collaboration

- Members of CMS, ATLAS, and “theorists”
- Currently 6 PIs

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*

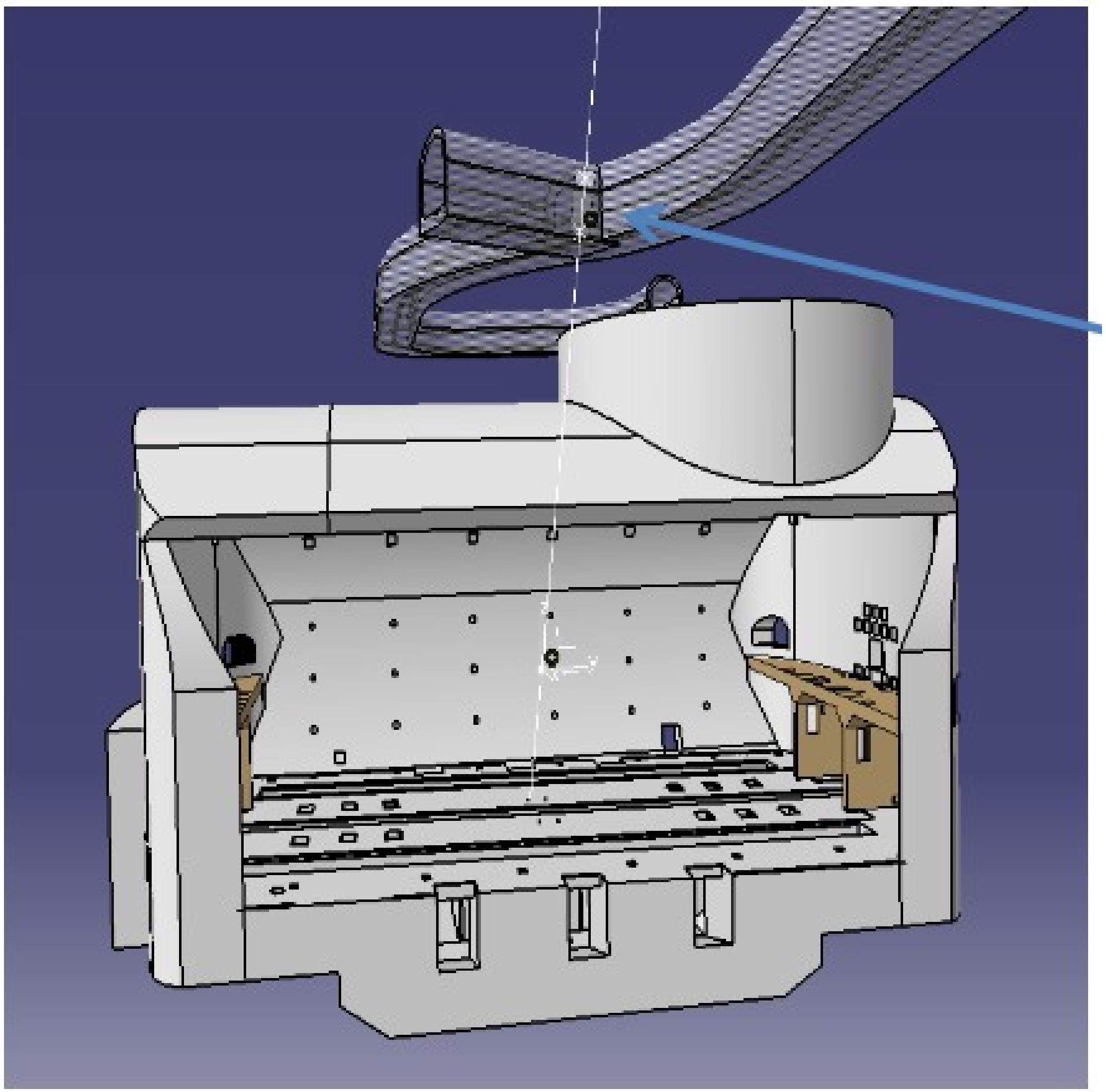
[6]*Perimeter Institute for Theoretical Physics*

[7]*McMaster University*

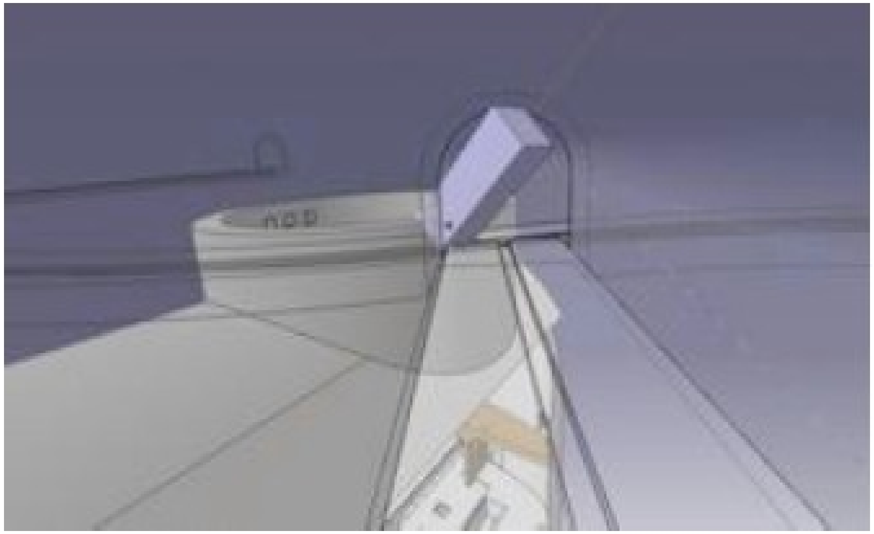
[8]*University of Chicago*

MilliQan Site

- “Drainage Gallery” - an interlocked tunnel above CMS Point 5



Beam backgrounds shielded by 14m of rock



30m from interaction point

Small angle from vertical

MilliQan Detector

- Array of plastics scintillators and PMTs, see single photo-electrons from traversing mCPs

The Scintillator

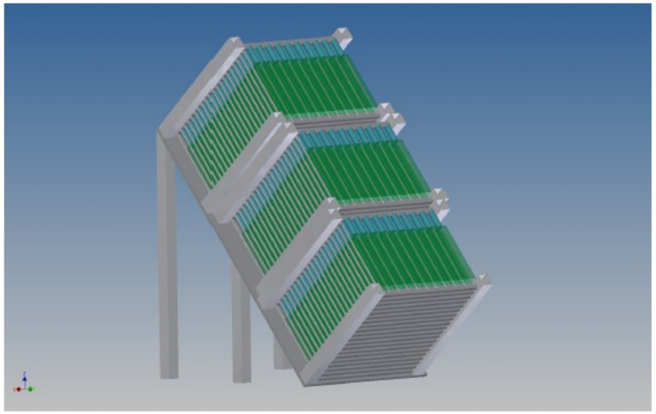
- A MIP with $Q = 1e$ deposits $\sim$ 2 MeV/cm in a material with a density of 1 g/cm^3
- For a plastic scintillator, energy deposits result in $\sim 10^4$ photons / MeV
- Putting it together, 2×10^6 photons would be liberated in a 1m long bar

The PMT

- On average 1/3 of photons successfully hit the PMT
- The quantum efficiency of the PMT is $\sim$25%
- Thus, the overall efficiency is 10%,
  i.e. one photo electron (PE) for every 10 liberated photons

mCP's

- The deposited energy is proportional to Q^2
- For a mCP with $Q = 2.2 \times 10^{-3}e$, we expect 1 PE per bar

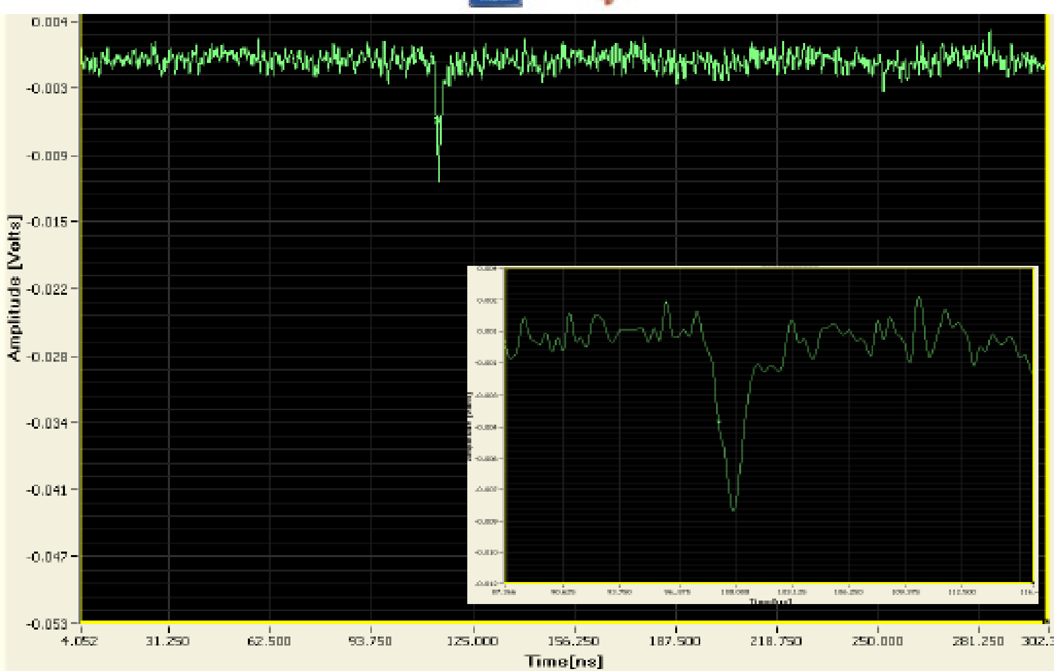


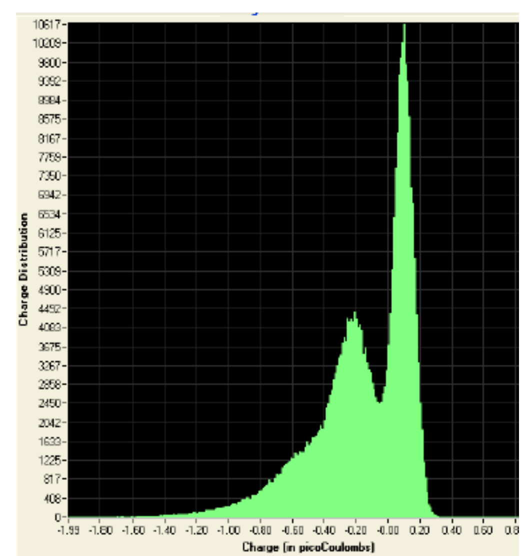
MilliQan Trigger and Readout

- Low noise (~0.7 mV RMS)
- Full pulse shape
- Easily observe single PE's
- Good time resolution (~few ns)

Hardware Overview (CAEN V1743):

- 16 analog read-out channels, continuously sampled at 3.2 GS/s into a 1024 cell ring
- Programmable trigger logic, including an external trigger
- Both and internal clock and an external one (for sync-ing multiple boards to the same clock)
- Equipped with both VME and Optical Link interfaces
- Cost per channel is about $400

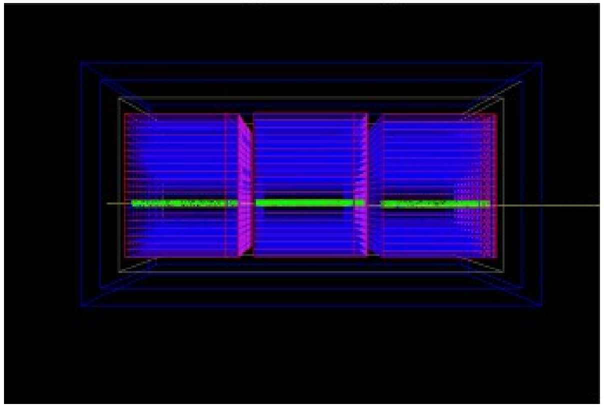


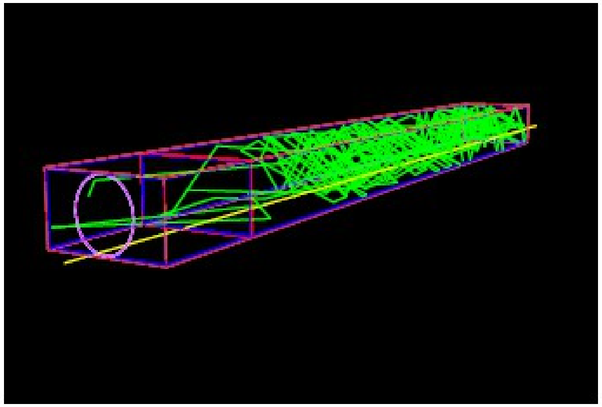


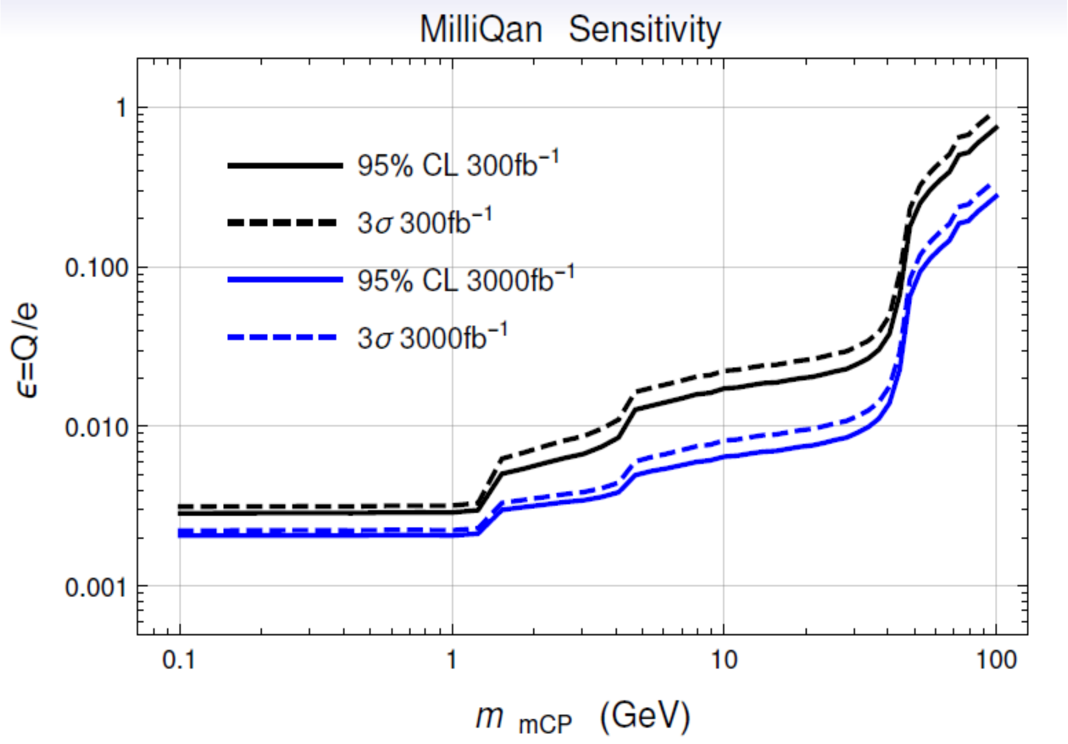
MilliQan Simulation and Sensitivity

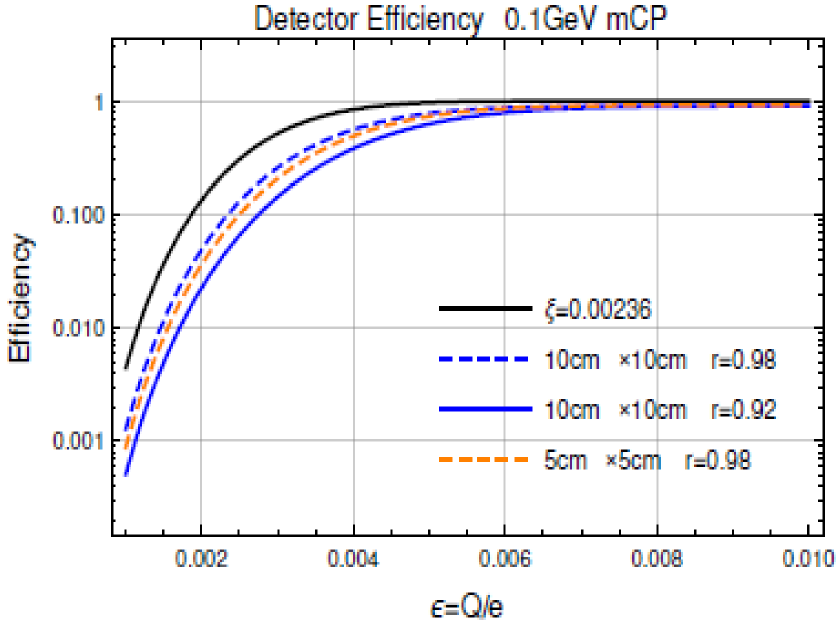
- Full G4 simulation, including magnetic field of CMS
- Sensitivity agrees with earlier estimates

Our detector geometry has been implemented in Geant4!









Background is random dark pulses: O(10) events/year

MilliQan Plan / Schedule

- Initial studies / simulations / sensitivity estimates
- Arrangements with CMS and site studies
- Expression of Interest drafted, collaboration formed

- Aim to commission a test slice at the P5 site during 2016 end-of-year shutdown
- Take test data during 2017-18

- Build full detector in 2018
- Install full detector at P5 site in 2020-22 shutdown

- Take 300/fb of data during RunIII in 2022-25
- Discover mCP :)