The milliQan experiment: search for milli-charged particles at the LHC

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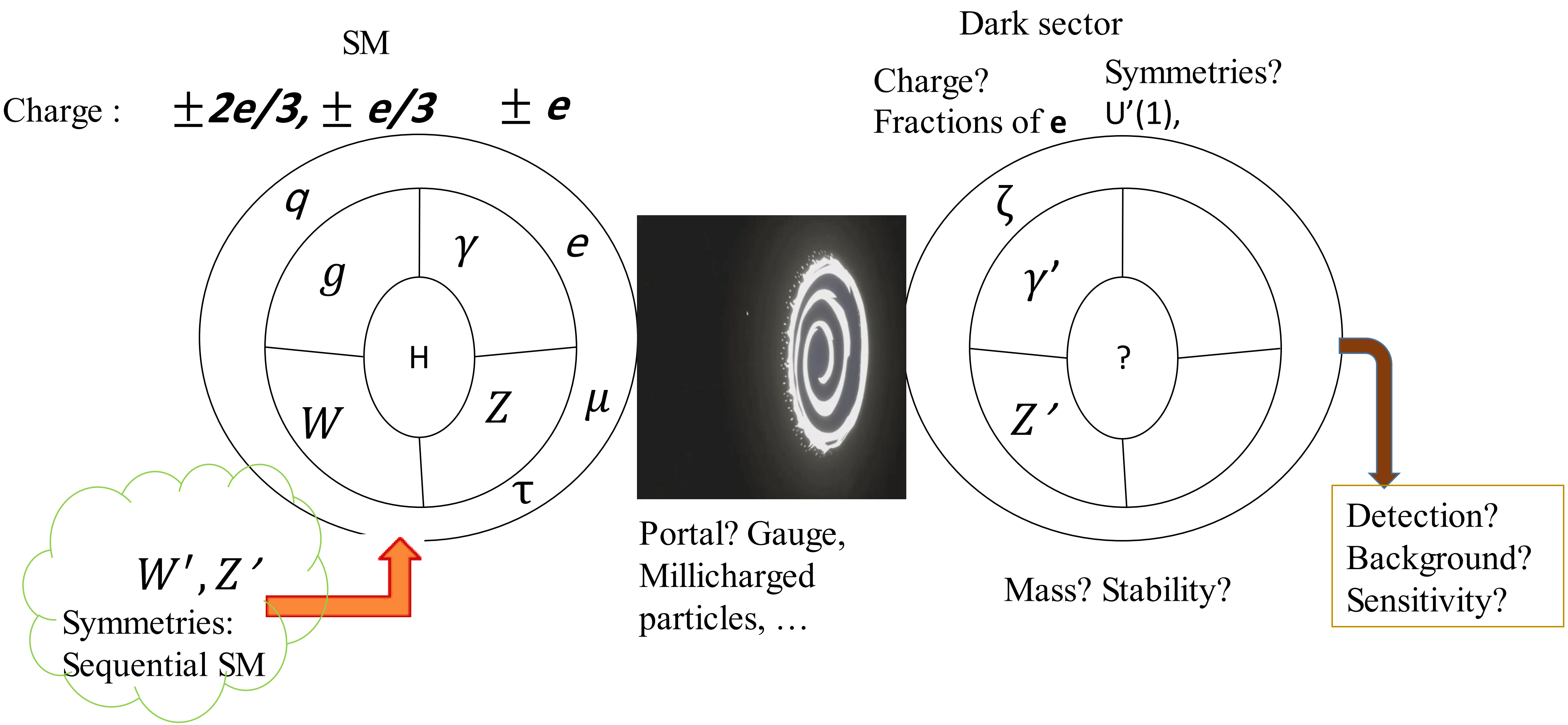
SM and BSM, Dark sector, …



Different models

Millicharged particles (mCPs) as Candidates for Dark Matter

- Holdom Phase: Massless B'
- Okun Phase: Massive B'
- Mixed Phase: Combination of massless and Massive fields as it is the case in SM for B (combination of photon and Z). Hence leading to Z' and dark photon.

Simple model of millicharged particles

- Extra abelian gauge field that couples to a massive Dirac fermion ("dark QED") and that mixes with hypercharge through the kinetic term:

$$L = L_{SM} - \frac{1}{4} A'_{\mu\nu} A'^{\mu\nu} + i\bar{\Psi}(\partial_\mu \gamma^\mu + ie' A'_\mu \gamma^\mu + iM_{mcp})\Psi - \frac{\kappa}{2} A'_{\mu\nu} B^{\mu\nu}$$

$\kappa \ll 1$ and as usual in SM $B_\mu = \cos\theta_w A_\mu - \sin\theta_w Z_\mu$

Redefinition of the new gauge boson:

$A'_\mu \rightarrow A'_\mu - \kappa B_\mu$ will get rid of gauge fields mixing/interaction

$$L = L_{SM} - \frac{1}{4} A'_{\mu\nu} A'^{\mu\nu} + i\bar{\Psi}(\partial_\mu \gamma^\mu + ie' A'_\mu \gamma^\mu + iM_{mcp} - i\kappa e' \cos\theta_w A_\mu \gamma^\mu - i\kappa \sin\theta_w Z_\mu \gamma^\mu)\Psi$$

Dark photon (massless)

millicharge

Mixed Model for millicharged Particle

In addition to SM particles : massless dark photon (A') and a massive dark Z boson (Z')

$$L = L_{SM} + L_{DM} - \frac{\kappa}{2} B'_{\mu\nu} B^{\mu\nu} \text{ with again } \kappa \ll 1 \text{ and } B'_{\mu} = \cos\theta'_w A'_\mu - \sin\theta'_w Z'_\mu$$

More parameters,

New couplings between the Dark sector fermions and SM particles.

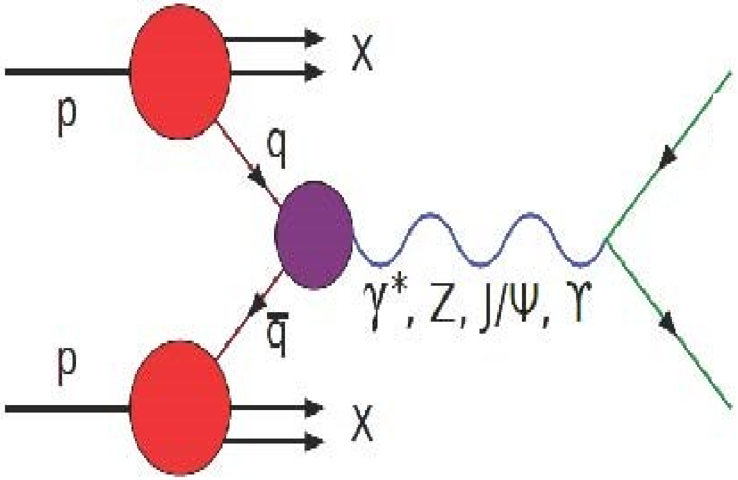
Keeping only terms to the first order of κ

$$L \sim e' A' J'_{EM} \oplus A.(eJ_{EM} - \kappa_{cc} e' J'_{EM}) \oplus Z.\left[\frac{g_2}{\cos\theta_w} J_Z + e' \kappa_{sc} J'_{EM} - \frac{g'_2}{\cos\theta'_w} \kappa_{ss} \frac{M_Z^2}{M_Z^2 - M_{Z'}^2}\right]$$

More models, Massive A', …….

Choose the model first simple model, less free parameters

Production mechanisms (proton-proton, LHC):



ζ^+

ζ^-

QCD inspired, just multiplying by Q^2

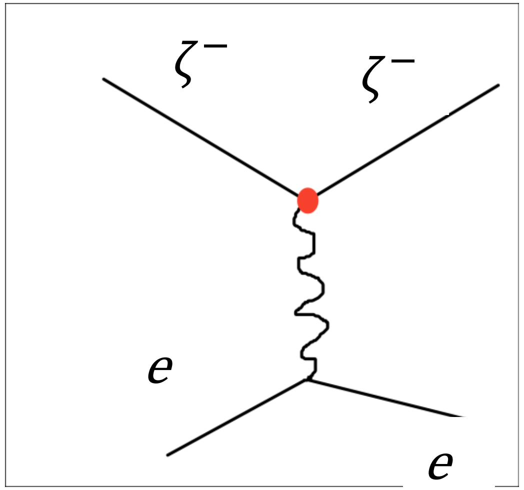
$\eta, \eta', \pi^o \rightarrow \zeta^-\zeta^+\gamma; \rho \rightarrow \zeta^-\zeta^+; \phi, \frac{J}{\psi}, \ldots. \rightarrow \zeta^-\zeta^+;$

Important below few GeV

Plus Drell-Yan, Modified MADGraph

Detection? Small charge? Not too heavy?

mCP can decay but can travel to detector and scatter on detector particles



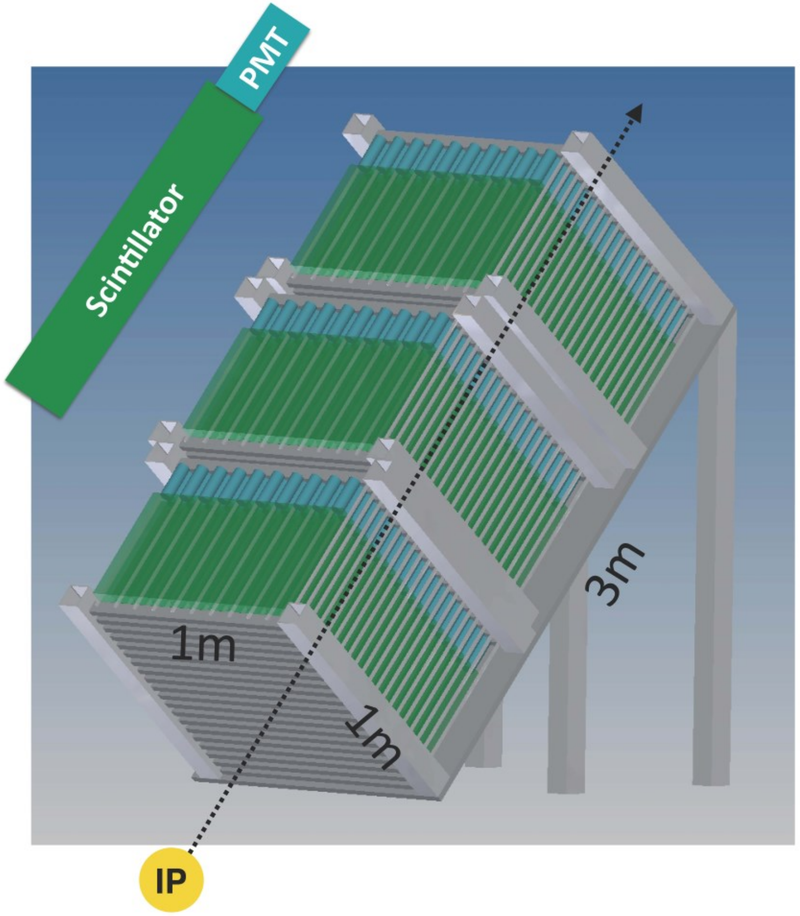
Energy loss: $\frac{dE}{dx} \sim Q^2$ ….. Charge $Q \sim 10^{-3}e \rightarrow 10^6$ higher sensitivity is needed compared to e-charged particles, need for abundant source $\rightarrow$ LHC, screened from background, Rock barrier, still cosmic particles as background

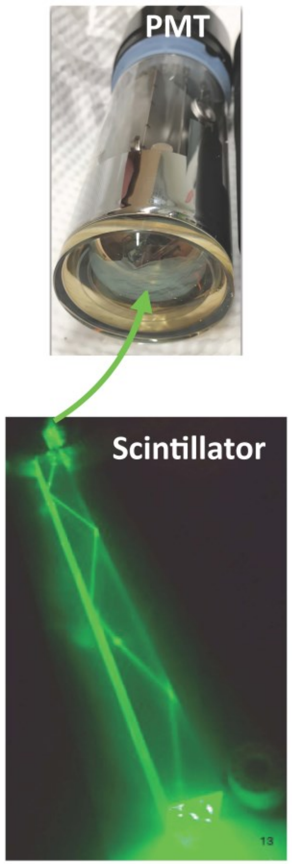
THE MILLIQAN EXPERIMENT design requirements

- Long active material,
- Several aligned scintillators, three, then four
- Well isolated from main background, calibration & Triple coincidence (15 ns)
- High sensitivity, single photo-electron
- Not affecting existing LHC experiments
- Low cost
- Modular design as an option, future extension is possible

THE MILLIQAN EXPERIMENT design

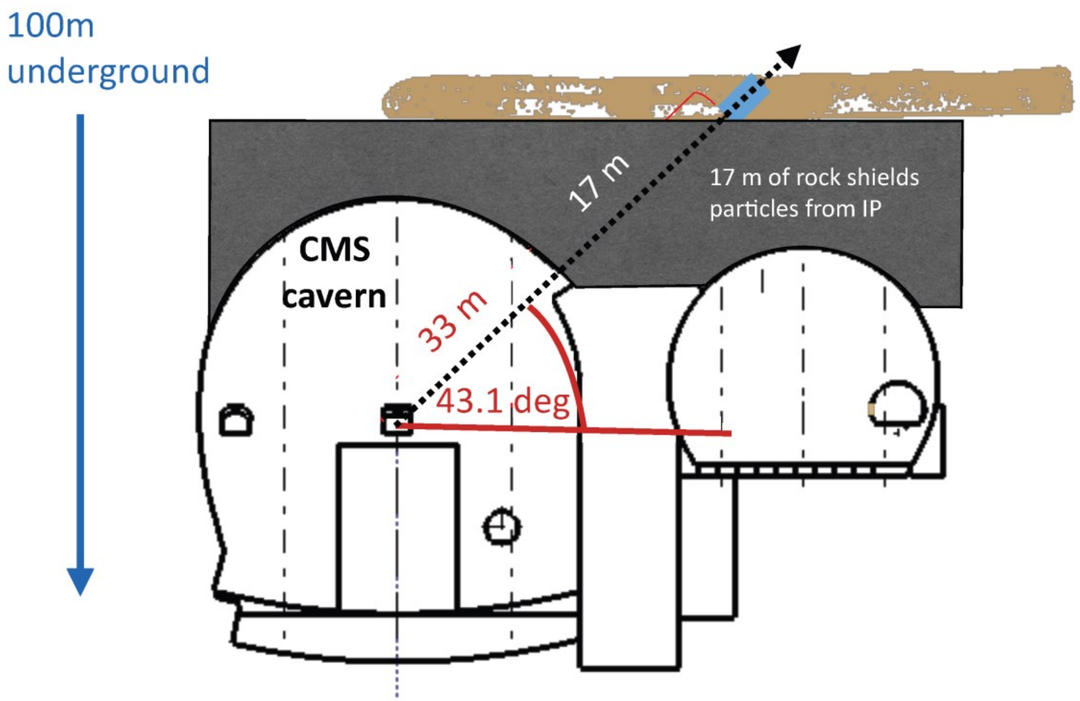
- Detection concept:

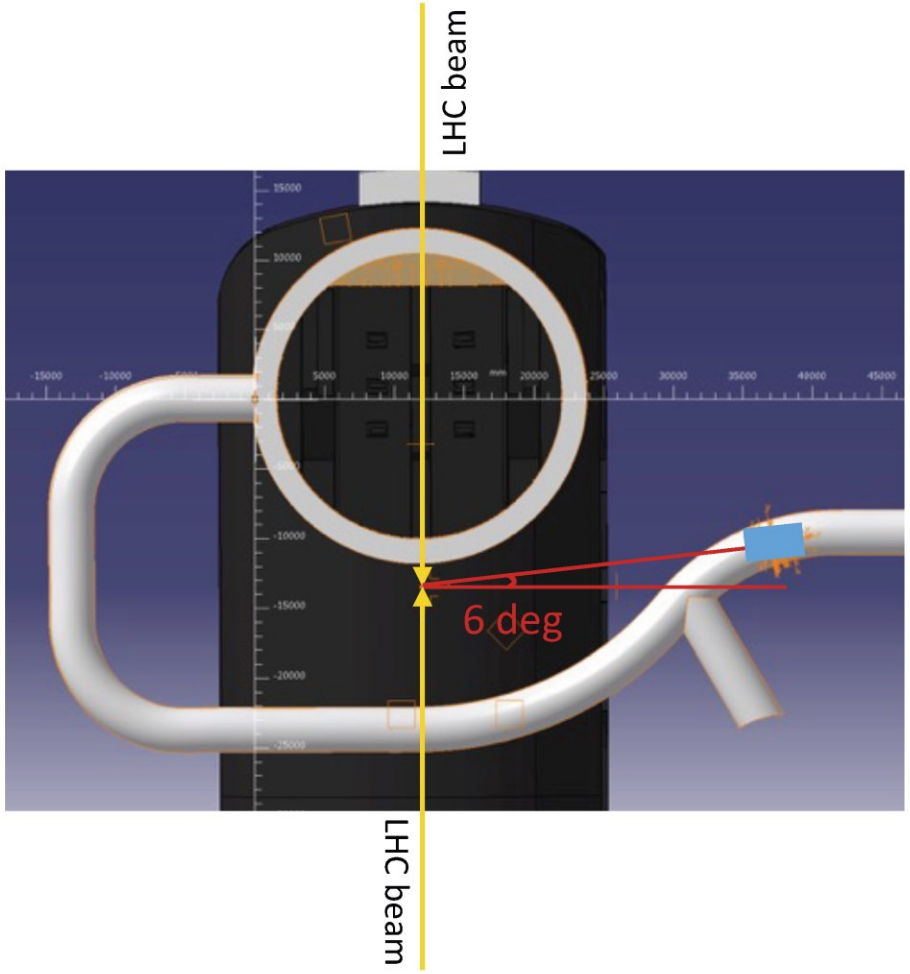




- 1m x 1m x 3m structure
- 3 layers 80cm x 5cm x 5cm Scintillators
- Particles produced from IP will traverse the three layers
- Coincidence is a key factor
- Straight line trajectories, with B-effect
- Time of flight (TOF)

THE MILLIQAN EXPERIMENT location

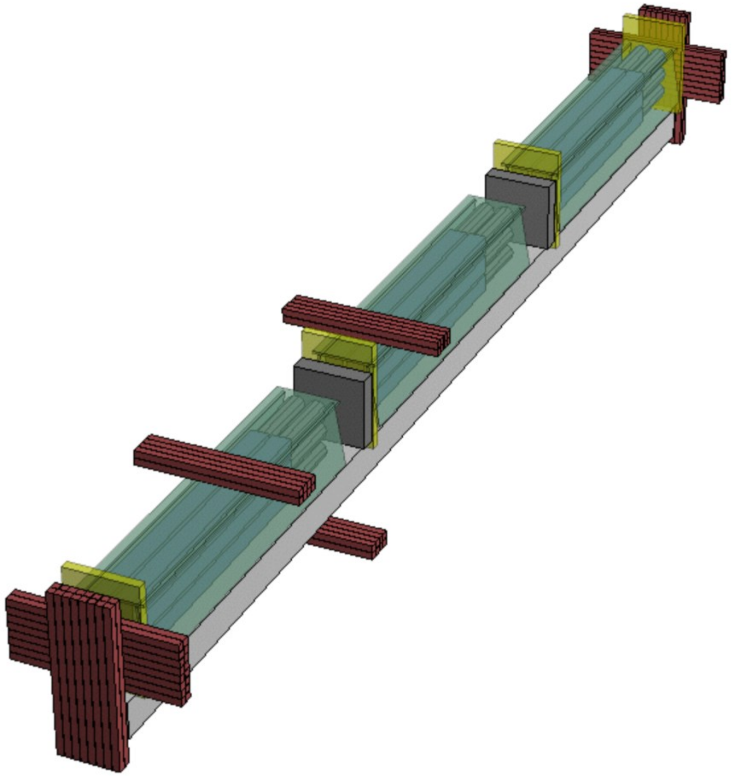




Located in tunnel above CMS experiment
$(33\ \mathrm{m}, \phi \sim 43^{o}, \eta \sim 0.7)$

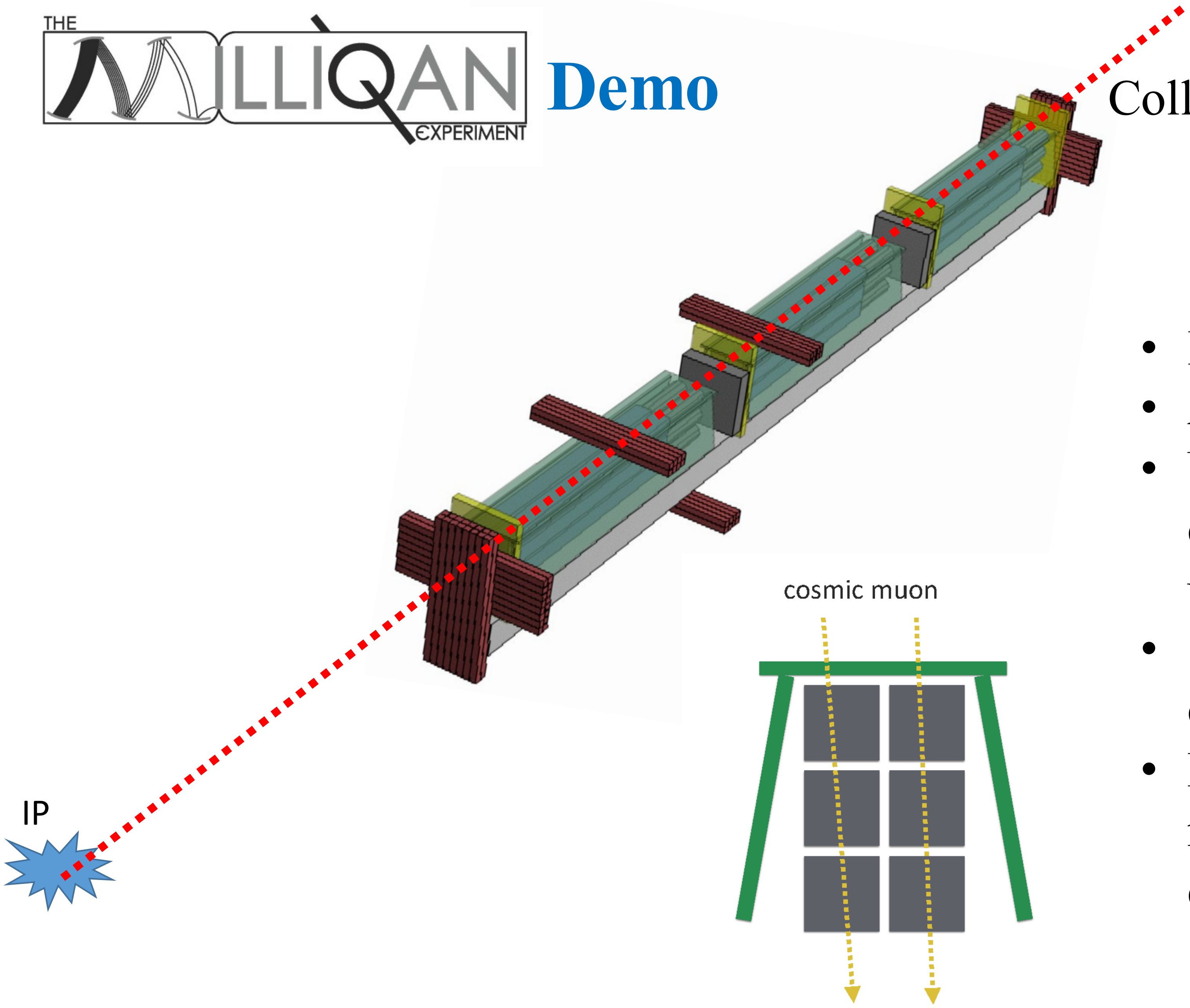
MILLIQAN /100 a Demo

Milliqan milestones: Paper, LOI, then a 1% version, looking for full detector



- Installed Fall 2017
- 3 layers of 2x3 scintillator+PMT
- Scintillator slabs and lead bricks Tag thru-going particles
- Scintillator panels to cover top and side, cosmic muons reject
- Hodoscope, Get tracks of beam

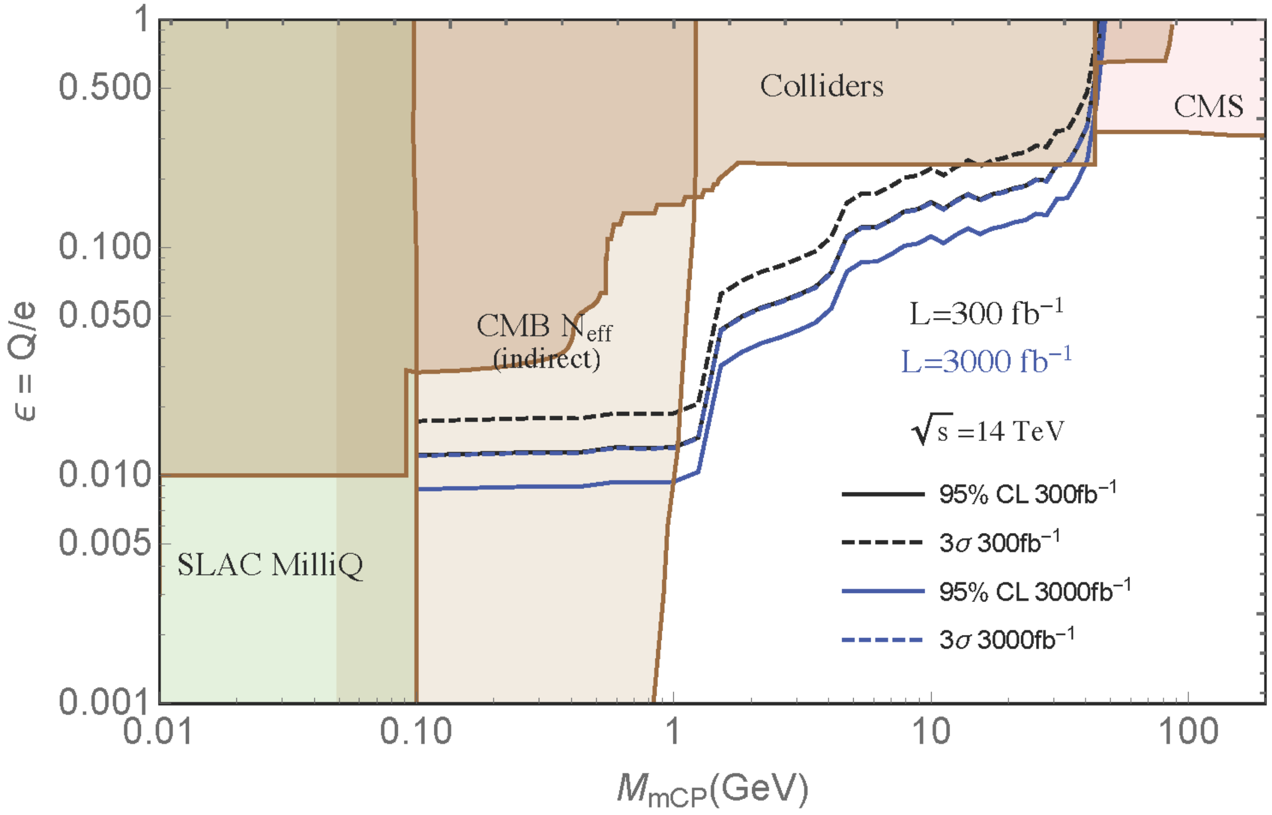
THE MILLIQAN EXPERIMENT Demo

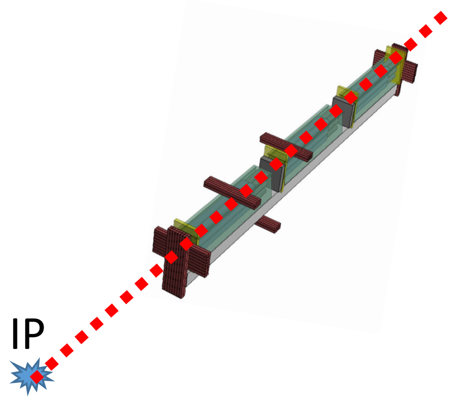


- In situ charge calibration
- Alignment with CMS IP
- Understanding tracking, coincidence, triggering, timing using muons from collision
- Byproduct, realistic sensitivity curves for full Milliqan detector.
- Byproduct, continuous monitoring of CMS beam as a check.

Demo, Sensitivity

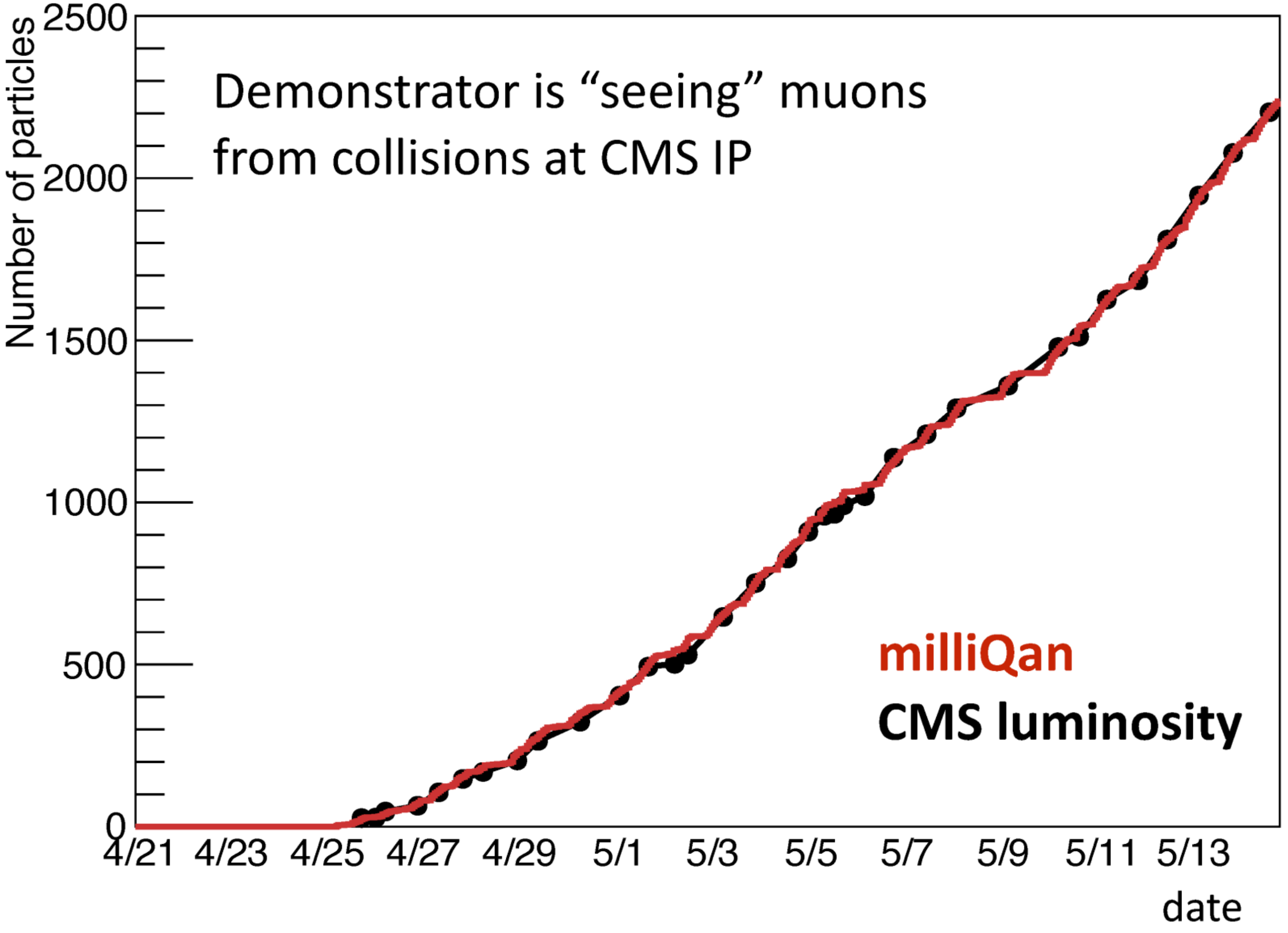
15 ns, coincidence

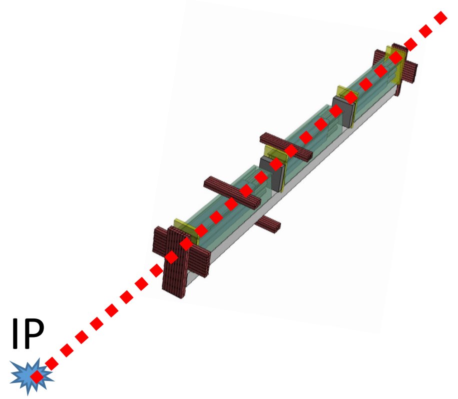




Low mass (0.1-1 GeV) sensitivity to mCP with $Q \sim 10^{-3}e$

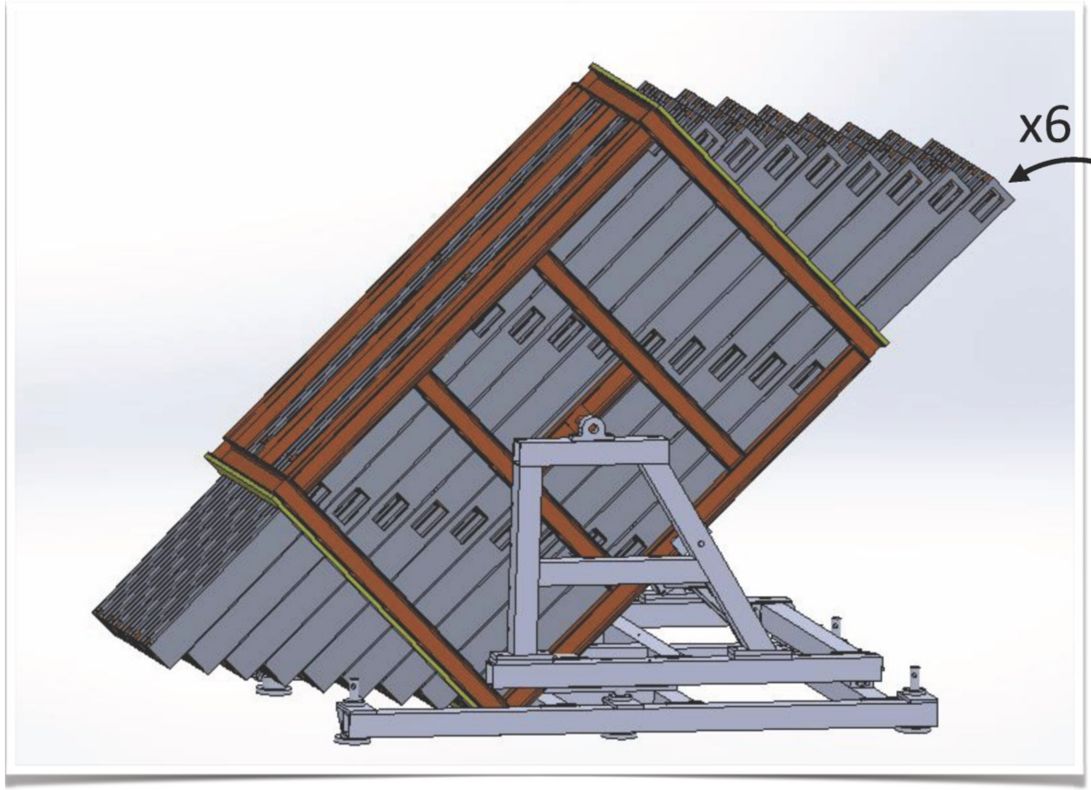
Demo, Luminosity,

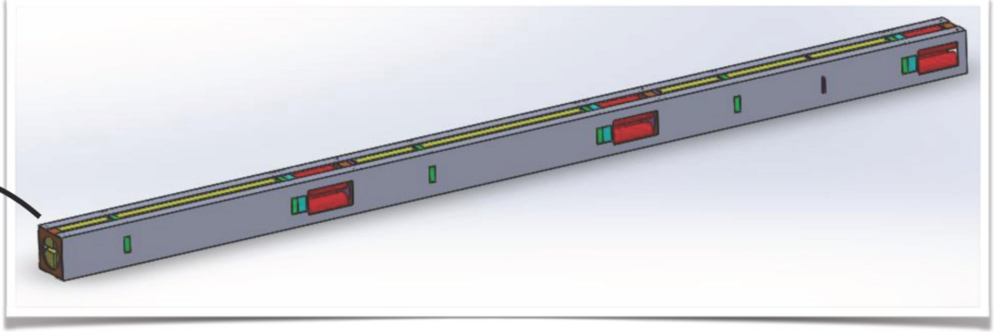


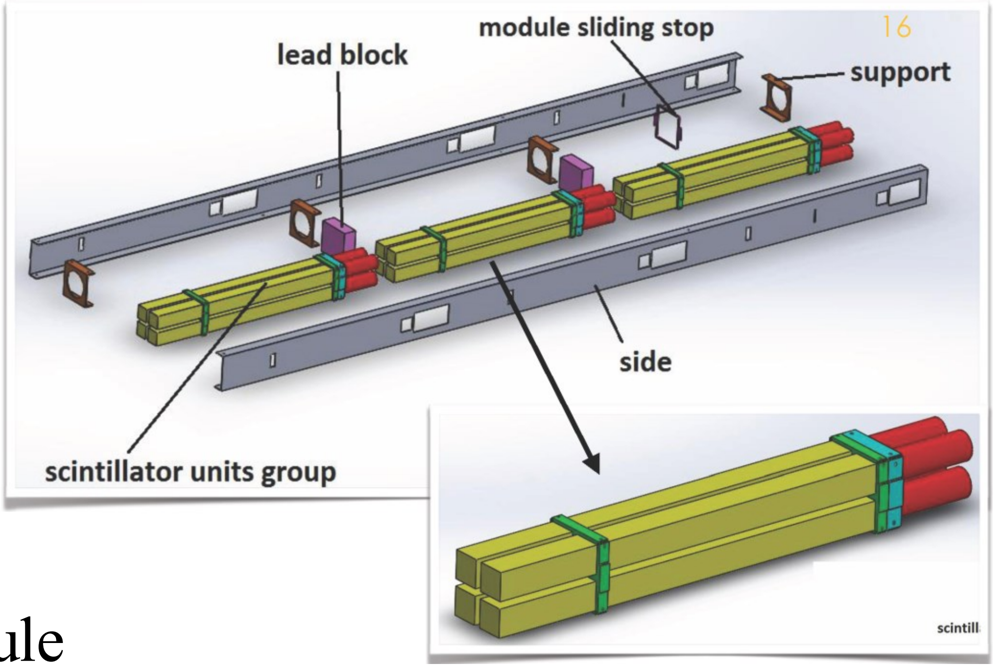


Current agenda:
- Analyzing collected data
- Full simulation updated
- Grant awaiting for full construction.

Upgrading, mechanical







- Easy to upgrade
- Possibility to replace any defected module

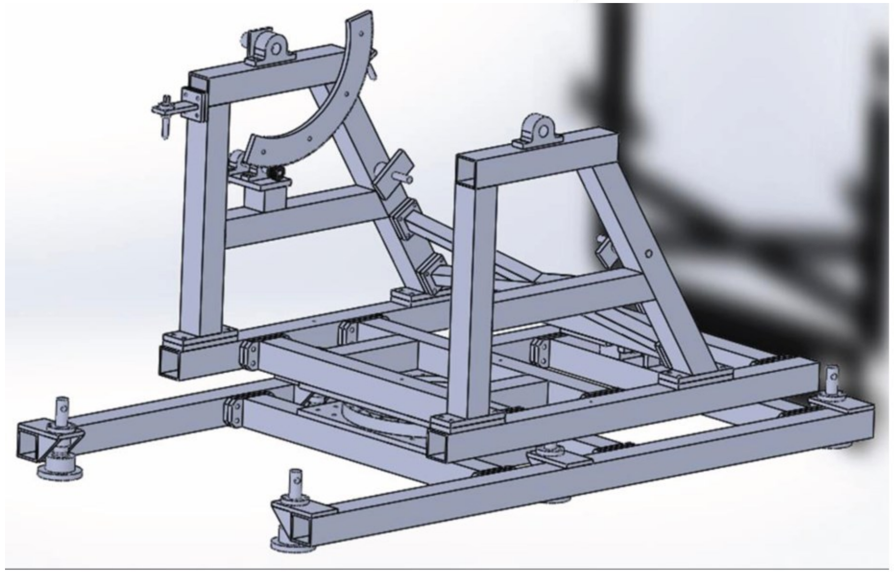
Conclusions and results

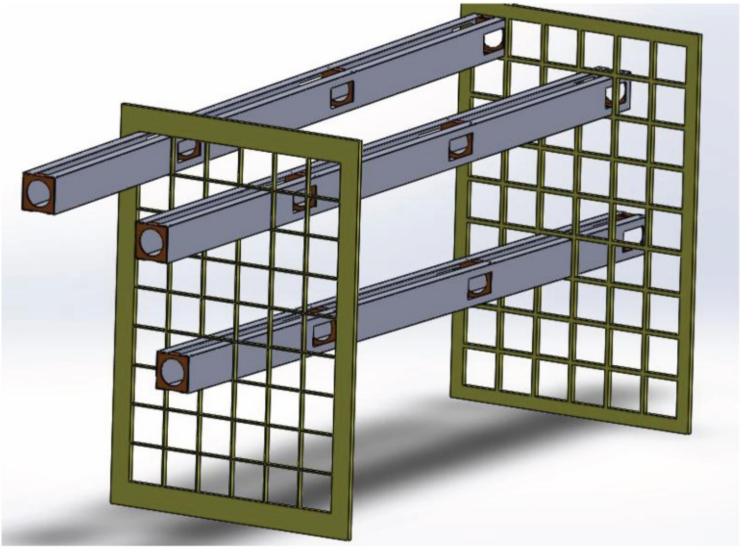
- Millicharge particle as an interesting candidate could be spotted with existing particle physics colliders, CMS, explored parameters: low mass (0.1-few GeV) sensitivity to mCP with $Q \sim 10^{-3}e$.

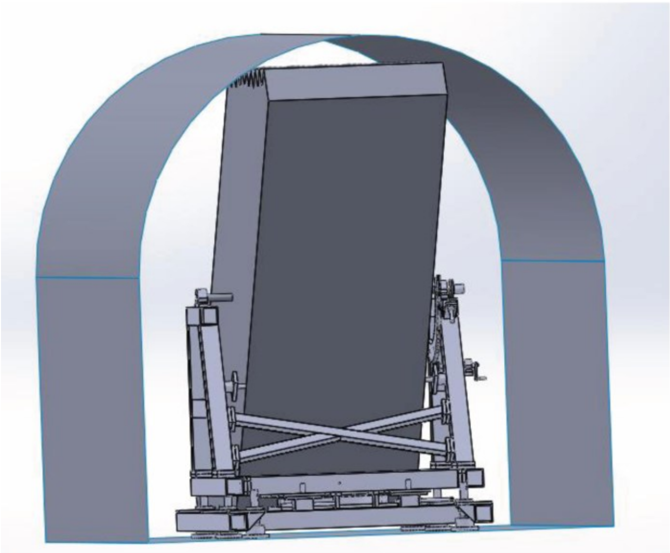
- A demonstrator is already installed, fall 2017, data was taken, now analyzed, calibration was also made
- In situ calibration was possible
- Triggering-rechecked and background understanding ongoing
- Full detector mechanical structure design done
- Full GEANT simulation of detector
- We are ready to go, however …
- Unfortunately haven't successfully secured funding – despite (well reviewed) proposals to various agencies & foundations different sources
- Without funding soon, the opportunity to carry out this interesting (and relatively cheap) extension of the LHC physics program will be put in jeopardy

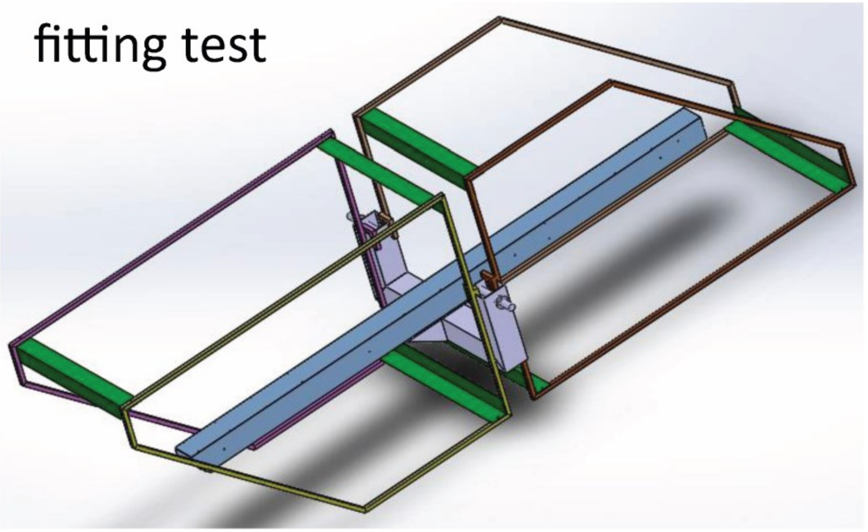
Backup

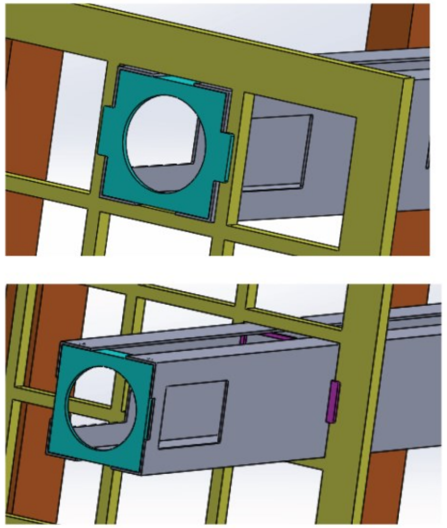
Upgrading, attaching parts



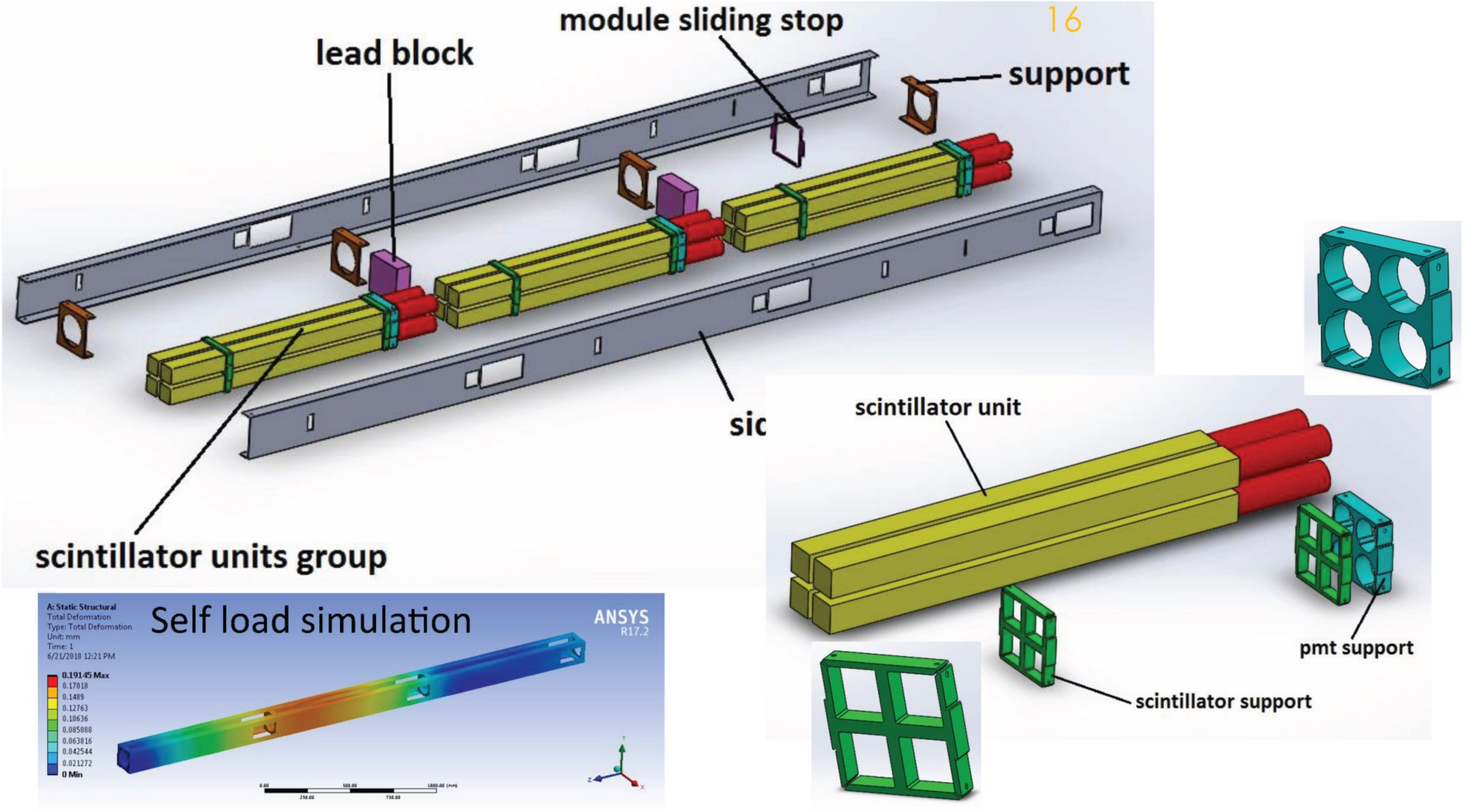








Upgrading, safety



The cage design

- Here is the photos of the cage conceptual design after calculation and simulation.
- The detailed assembly and installation procedure is still under study