The MoEDAL Experiment at the LHC

Searching Beyond the Standard Model

ICNFP 2015

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University of Alberta

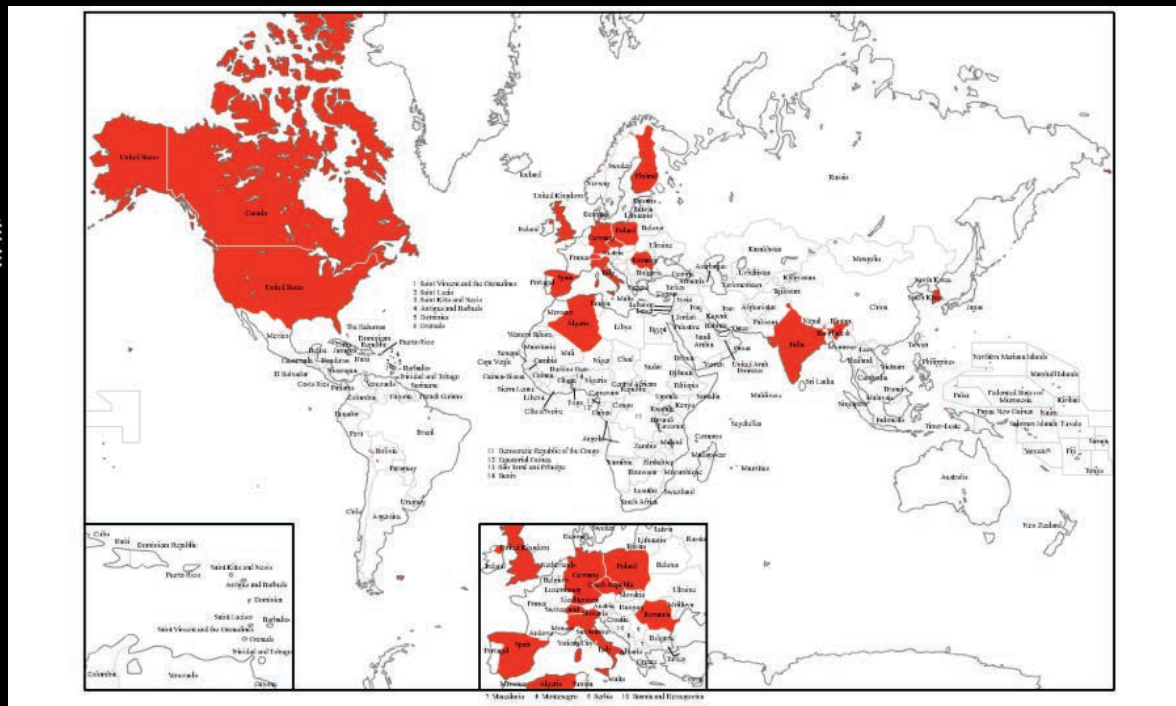

MOVIEWALLPAPERS.NET
THE
MAGNIFICENT
SEVENTH
They fought on the high energy frontier
APPROVED BY THE CERN RB IN 2010
MoEDAL is installed and starts to take data in
p-p and p-A running at ~13 TeV in 2015
ATLAS
STEVE McQUEEN
JAMES COBURN
"BRITT"
CMS
LHCb
HORST BUCHHOLZ
"CHICO"
YUL BRYNNER
"CHRIS ADAMS"
ALICE
TOTEM
BRAD DEXTER
"HARRY LUCK"
ROBERT VAUGHN
"LEE"
LHCf
MoEDAL
CHARLES BRONSON
"BERNARDO O'REILLY"

MoEDAL's Location

AIM: The search for the highly ionizing particle (HIP) avatars of New Physics with magnetic and/or electric charge

UPGRADE AIM: to continue the search for HIPS and start the search for minimally charged particles (MCP) at the LHC as well a initiate a search for Cosmic HIPS at high altitude

The MoEDAL Collaboration

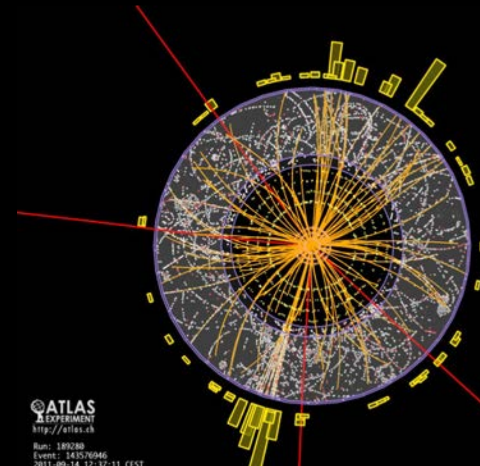


66 physicists from 14 countries & 25 institutes. on 4 continents:

U. Alberta, UBC, INFN Bologna, U. Bologna, CAAG-Algeria, U. Cincinatti, Concordia U., CSIC Valencia, Gangneung-Wonju Nat. U., U. Geneva, U. Helsinki, IEAP/CTU Prague, IFIC Valencia, Imperial College London, INP/PAS Cracow, ISS Bucharest, King's College London, Konkuk U., U. Montréal, Muenster U., National Inst. Tec. (india),Northeastern U., Simon Langton School UK, Stanford University [is the latest (associate) member of MoEDAL], Tuft's.

Highly Ionizing Particles – Avatars of New Physics

Avatar [av-uh-tahr]: An incarnation, embodiment, or manifestation of a person or idea:



MoEDAL – Highly Ionizing Particles directly detected as messengers of new physics – no SM backgrounds

ATLAS & CMS – New physics largely reconstructed from SM particles – large SM backgrounds

The Ways to Get Anomalous Ionization

- **Electric charge** - *ionization increases with increasing charge & falling velocity β (β=v/c) – use Z/β as an indicator of ionization*

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

  - *If Z ~ 0.001e (millicharged) we get anomalously low ionization*

- **Magnetic charge** - *ionization increases with magnetic charge $g = ng_d$ and decreases with velocity β – a unique signature*

$$-\frac{dE}{dx} = K\frac{Z}{A}g^2\left[\ln\frac{2m_ec^2\beta^2\gamma^2}{I_m} + \frac{K|g|}{2} - \frac{1}{2} - B(g)\right]$$

  - *The velocity dependence of the Lorentz force cancels $1/\beta^2$ term*
  - *As g = 137e/2 = 68.5e the ionization of a rel. monopole is $4700n^2$!! (n=1) that of a MIP. But n could be larger!*

Physics Program (34 Scenarios)

arXiv.org > hep-ph > arXiv:1405.7662

Search or Article-id

High Energy Physics – Phenomenology

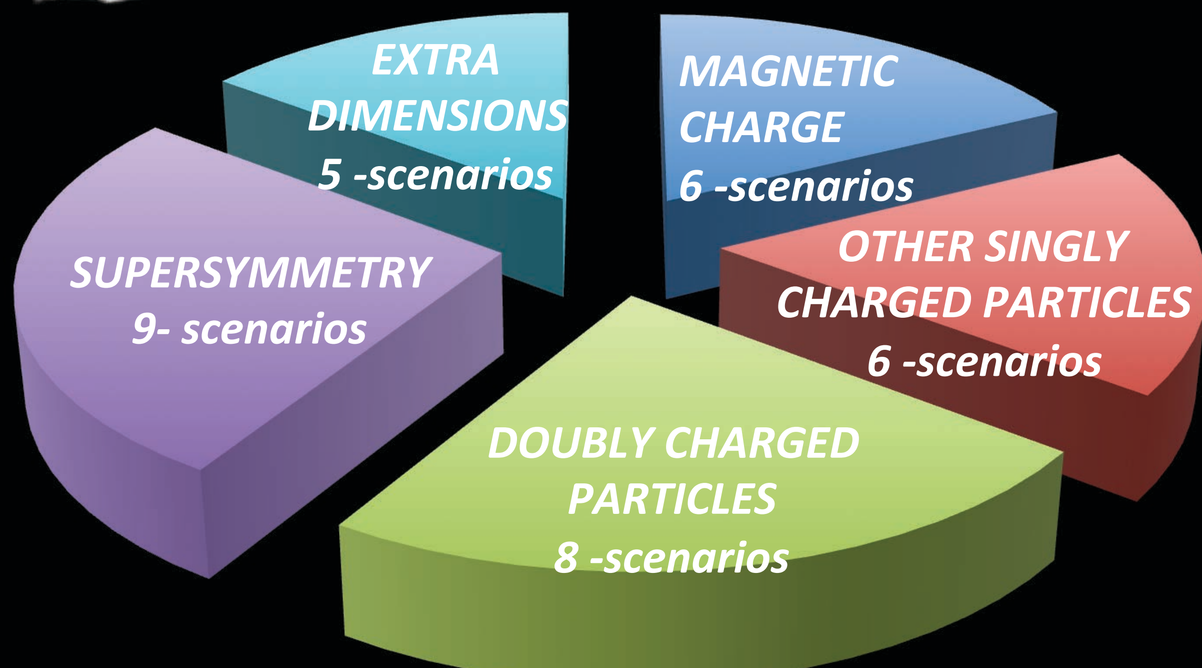
The Physics Programme Of The MoEDAL Experiment At The LHC

B. Acharya, J. Alexandre, J. Bernabéu, M. Campbell, S. Cecchini, J. Chwastowski, M. De Montigny, D. Derendarz, A. De Roeck, J. R. Ellis, M. Fairbairn, D. Felea, M. Frank, D. Frekers, C. Garcia, G. Giacomelli, M. Giorgini, D. HaŞegan, T. Hott, J. Jakůbek, A. Katre, D-W Kim, M.G.L. King, K. Kinoshita, D. Lacarrere, S. C. Lee, C. Leroy, A. Margiotta, N. Mauri, N. E. Mavromatos, P. Mermod, V. A. Mitsou, R. Orava, L. Pasqualini, L. Patrizii, G. E. Păvălaş, J. L. Pinfold, M. Platkevč, V. Popa, M. Pozzato, S. Pospisil, A. Rajantie, Z. ... M. Sakellariadou, S. Sarkar, G. Semenoff, G. Sirri, K. Sliwa, R. Soluk, M. Spurio, Y.N. Srivastava, R. Staszewski, J. Swain, M. Tenti, V. Togo, M. Trzebinski ... Vykydal, A. Widom, et al. (1 additional author not shown)

(Submitted on 29 May 2014 (v1), last revised 15 Jul 2014 ...)

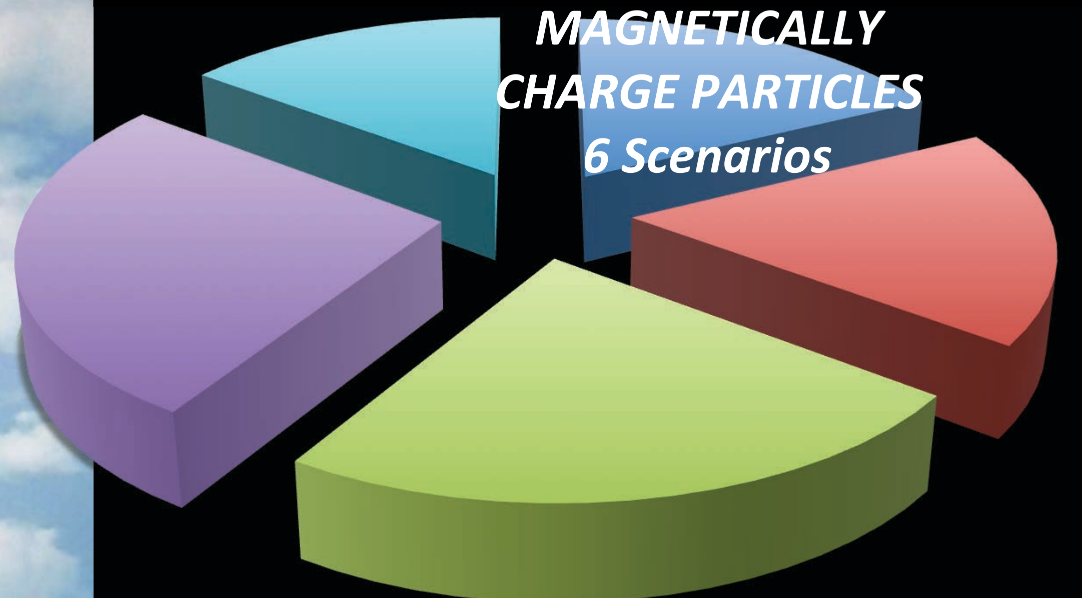
The MoEDAL experiment at ... the Standard Model, extending significantly the d... DAL is an unconventional and largely passive LHC dete... on the LHC ring. Another novel feature is the use of p... includes an array of TimePix pixel devices for mo... trigger system, electronic readout, or online computerized data acquisitio... complementary to the programs of the large multi-purpose LHC detectors ATLAS and CMS.

JUST PUBLISHED (September 9th 2014)
International Journal of Modern Physics A Vol. 29, No. 23 (2014) 1430050 (91pages)



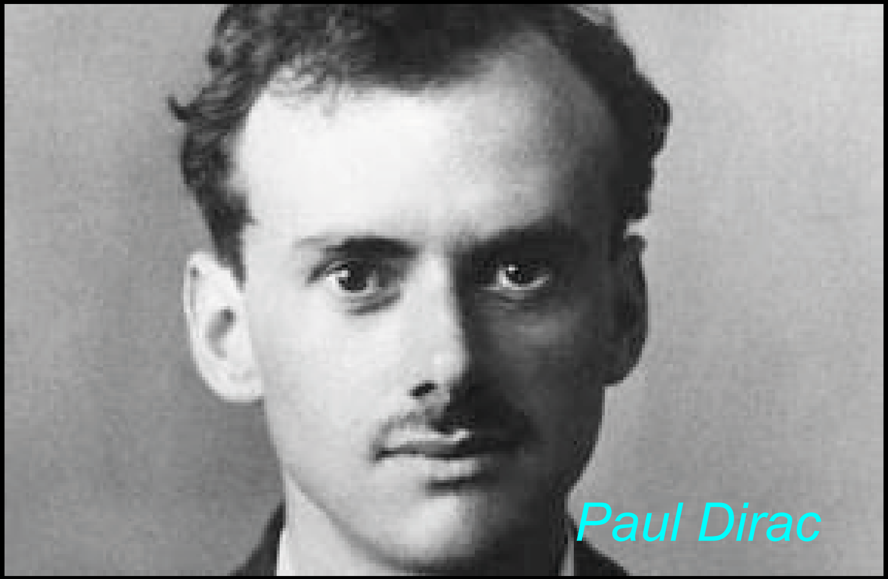
Massive Magnetically Charged Particles

6 SCENARIOS



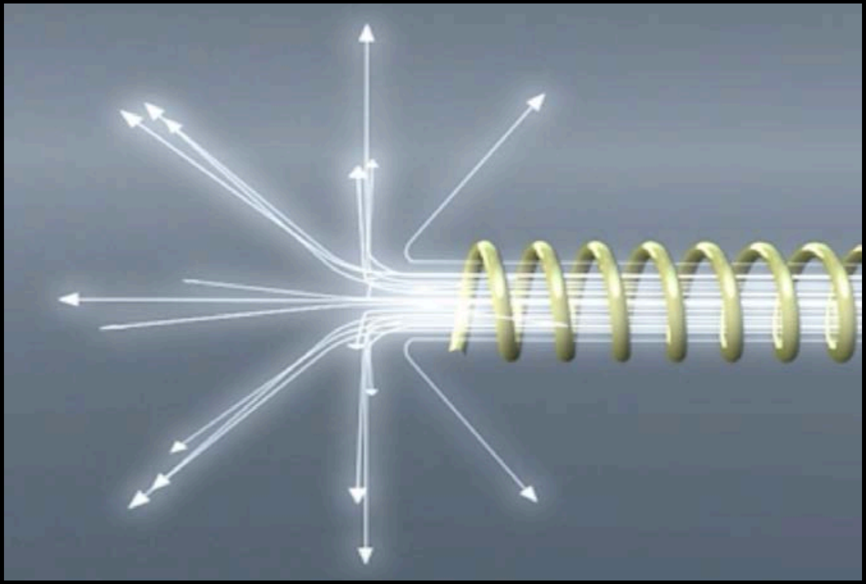
- *Magnetic Dyons/Monopoles*
- *Electroweak Monopole*
- *Electroweak strings*
- *Light Hooft-Polyakov monopoles*
- *Monopolium*
- *D-particles*

The Monopole is MoEDAL's Higgs



- *Just as the general purpose experiments ATLAS & CMS have as their prime physics purpose the discovery and elucidation of the Higgs……*
- *….Then the equivalent "benchmark" physics process for MoEDAL is the magnetic monopole production – thus we shall concentrate more on this topic due to time constraints*
- *But ATLAS, CMS and MoEDAL can do much more!*

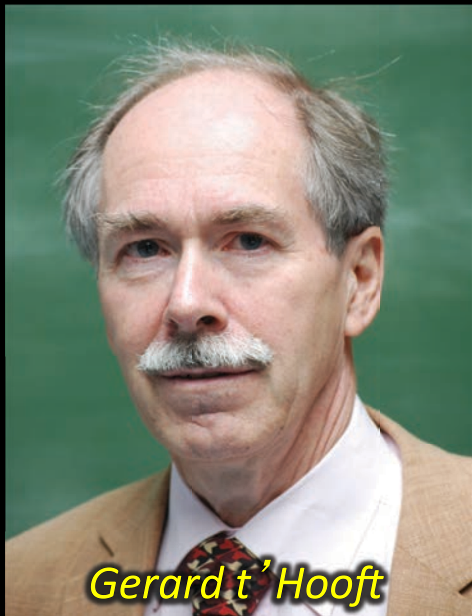
Dirac's Monopole

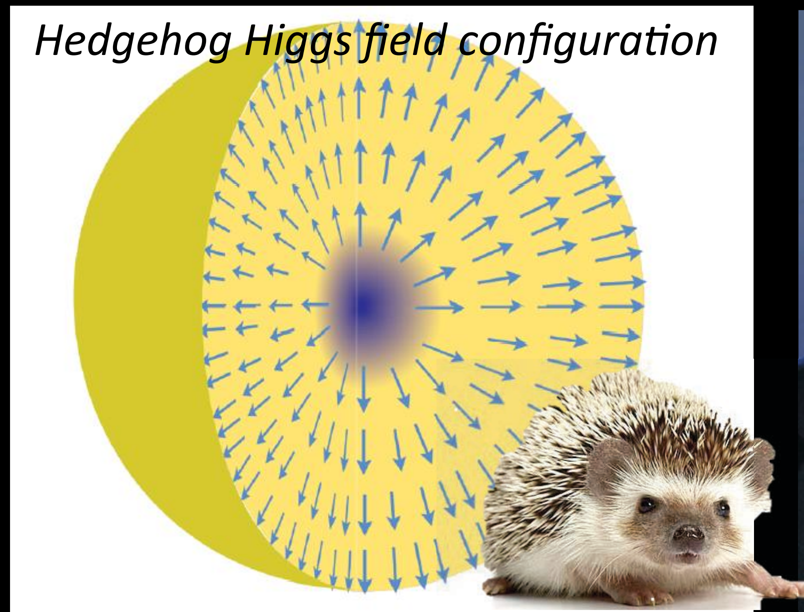


- *In 1931 Dirac hypothesized that the Monopole exists as the end of an infinitely long and thin solenoid - the "Dirac String"*
- *Requiring that the string is not seen gives us the Dirac Quantization Condition & explains the quantization of charge!*

$$ge = \left[\frac{\hbar c}{2}\right] n \quad OR \quad g = \frac{n}{2\alpha} e \quad \left(from \ \frac{4\pi e g}{\hbar c} = 2\pi n \quad n = 1,2,3..\right)$$

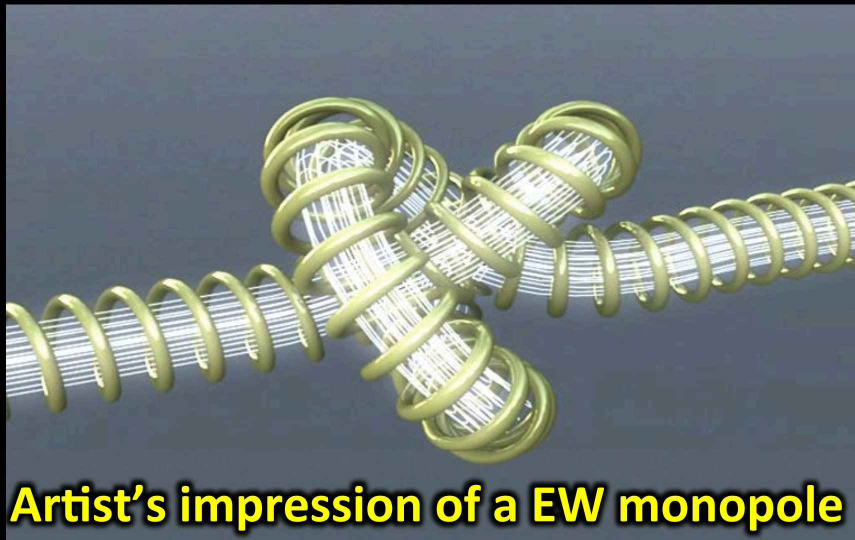
The ‘t Hooft-Polyakov Monopole



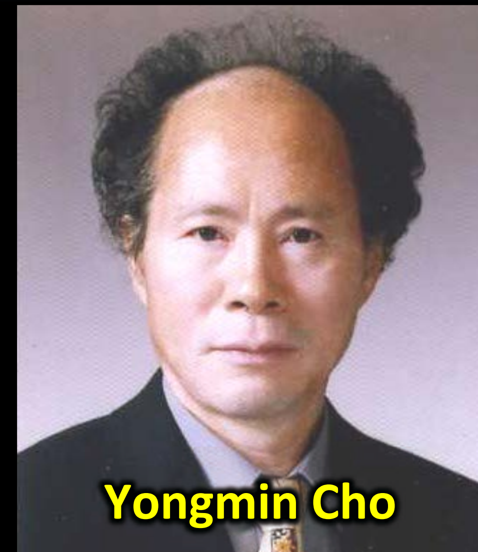


- *In 1974 ‘t Hooft & Polyakov showed that monopoles must exist with the framework of Georgi-Glashow “Standard mode” & also in GUT models with mass ~10^{17} GeV ofo 100 ng in SI units*
  - *The 't Hooft and Polyakov monopole arises when the Higgs field vector points away from the origin everywhere - the “hedgehog” configuration*
  - *Such monopoles are topological solitons (stable, non dissipative, finite energy solutions) - Like a knot in the Higgs field configuration*

The Cho-Maison Magnetic Monopole



Artist's impression of a EW monopole



Yongmin Cho

- *Yongmin Cho's pioneering paper in 1986 envisioned a spherically symmetric Electroweak Monopole, with:*
  - *Magnetic charge $2g_D$ & mass potentially in the range 4→7 GeV/c^2*
- *The Cho monopole is a non-trivial hybrid between the Dirac monopole & the 't Hooft-Polyakov monopole*
  - *His monopole arises from the Weinberg Salam model*
- *The Cho-Maison monopole could be detectable by MoEDAL*

As Usual the Greeks Were There First

The fox knows many things – the hedgehog knows one great thing

(Archilocus)

Magnetic Monopole Properties

Magnetic charge = ng = n68.5e (if e→1/3e; g→3g) HIGHLY IONIZING

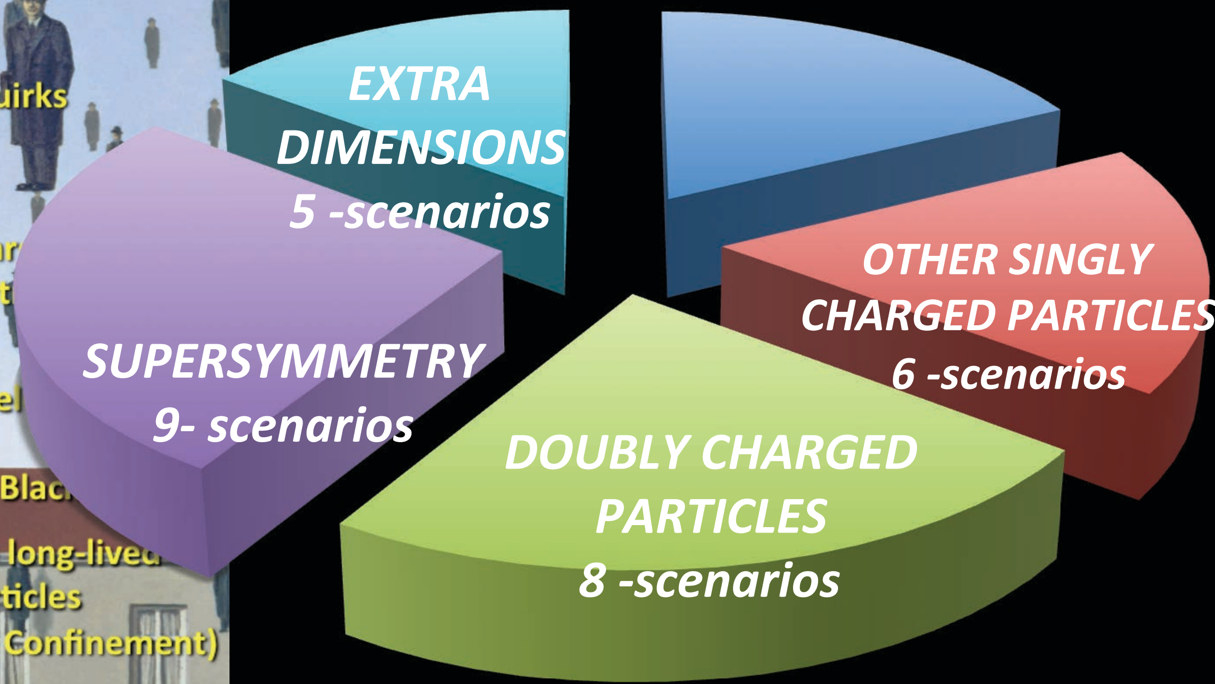
Coupling constant = g/ħc ~ 34. Spin ½?

Energy acquired in a magnetic field =2.06MeV/gauss.m = 2TeV in a 10m, 10T solenidal field

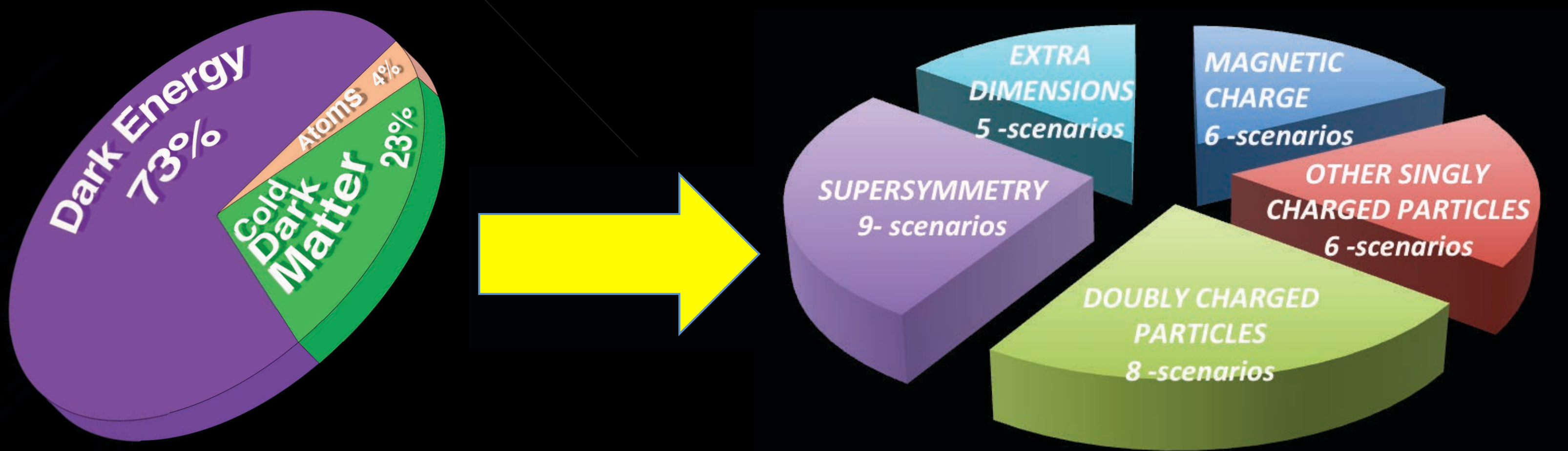
The monopole mass is not predicted within the Dirac's theory, ~ 4-7 TeV EW monopole

Massive "Stable" Electrically Charged Particles

~30 SCENARIOS



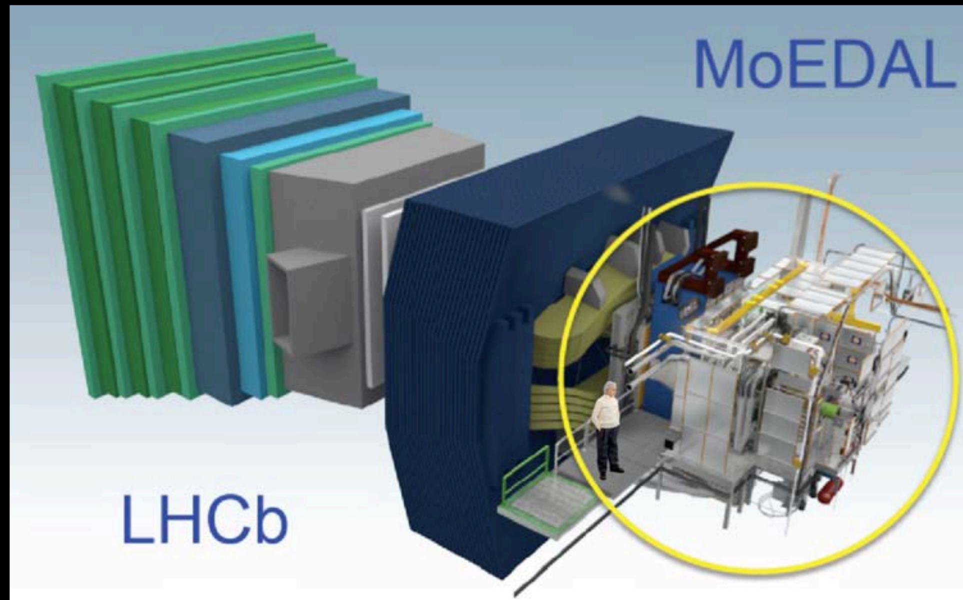
MoEDAL's Dark Matter Scenarios



- *Most of MoEDAL's 34 physics scenarios involve new physics with well motivated dark matter scenarios (SUSY, extra dimensions)*
- *Several scenarios directly involve the detection of particles that could contribute to the dark matter of the universe:*
  - *Magnetic monopoles and monopolium*
  - *Stable microscopic black holes and black hole remnants*
  - *D-particles and Quirks.*
  - *Q-balls and strangelets*
  - *Fractionally charged CHAMPs*
  - *Millicharged particles (Phase-II MoEDAL)*

MoEDAL – a Unique Collider Detector

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

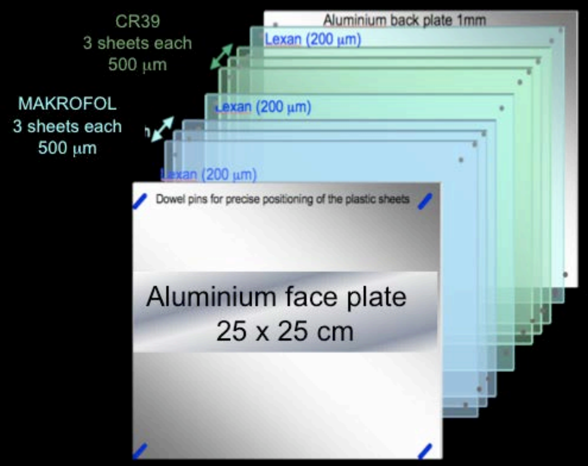
MoEDAL is largely passive made up of three detector system.

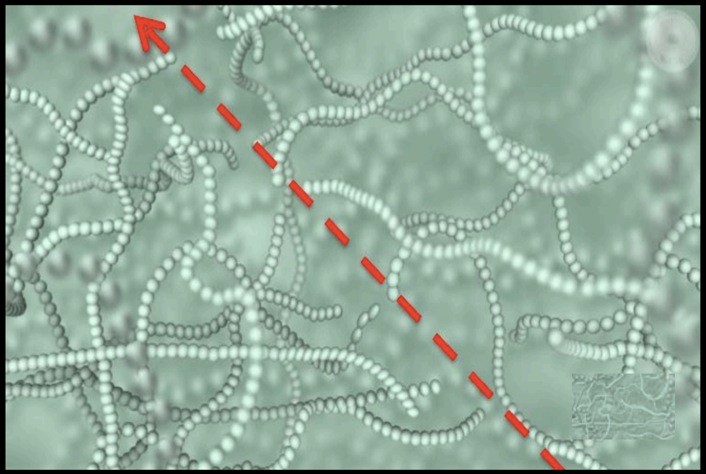
NUCLEAR TRACK DETECTOR Plastic array (~200 sqm) – Like a Giant Camera

TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

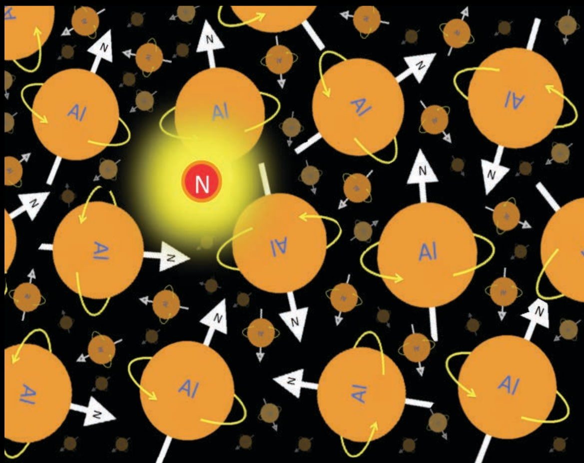
The Nuclear Track Detector System





- *Largest array (150 m² of NTDs every deployed at an accelerator*
  - *Plastic NTD stacks consist of CR39 (threshold 5 MiPs) and Makrofol (50 MiPs) – that are "damaged" by the highly ionizing particle*
  - *The damage is revealed by controlled etching in a hot Sodium Hydroxide solution – etch pits are formed*
  - *Charge resolution is ~0.1|e|, where |e|is the electron charge*
- *NTD system acts like a giant camera that is only sensitive to new physics - no known SM backgrounds*

The Trapping Detector System



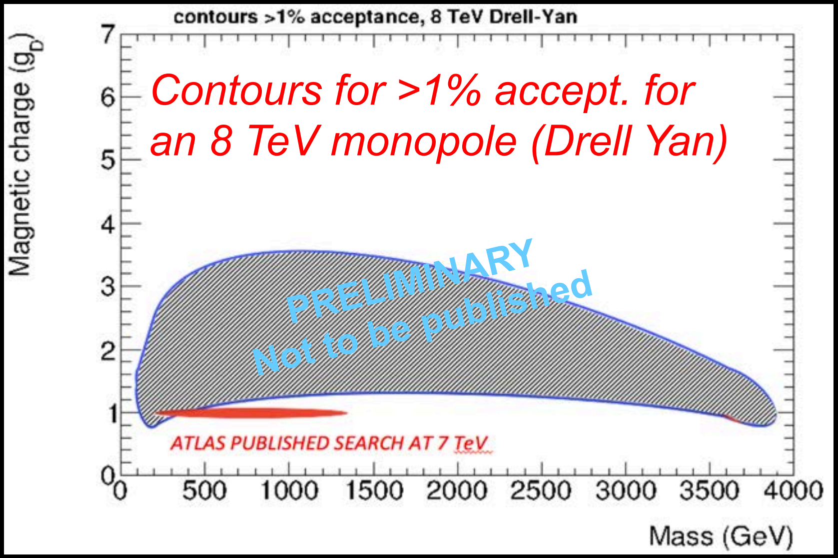
Trapped monopole

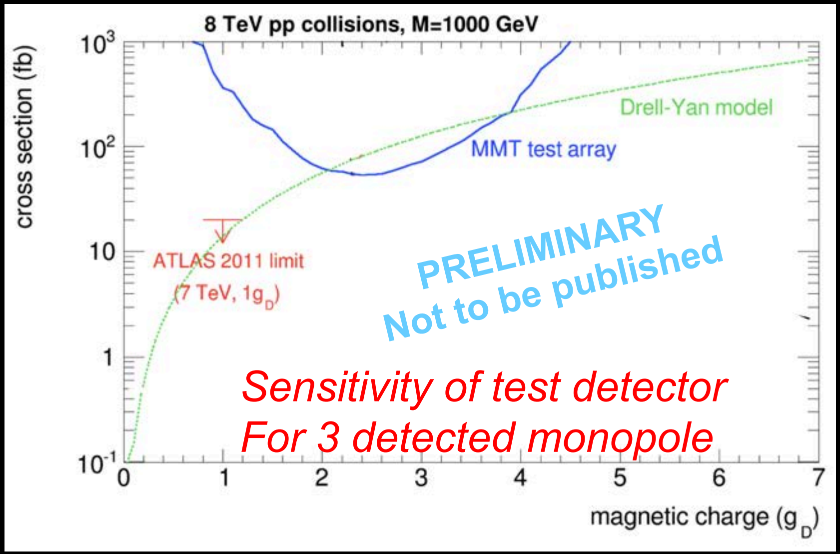
SQUID magnetometer (ETH Zurich)

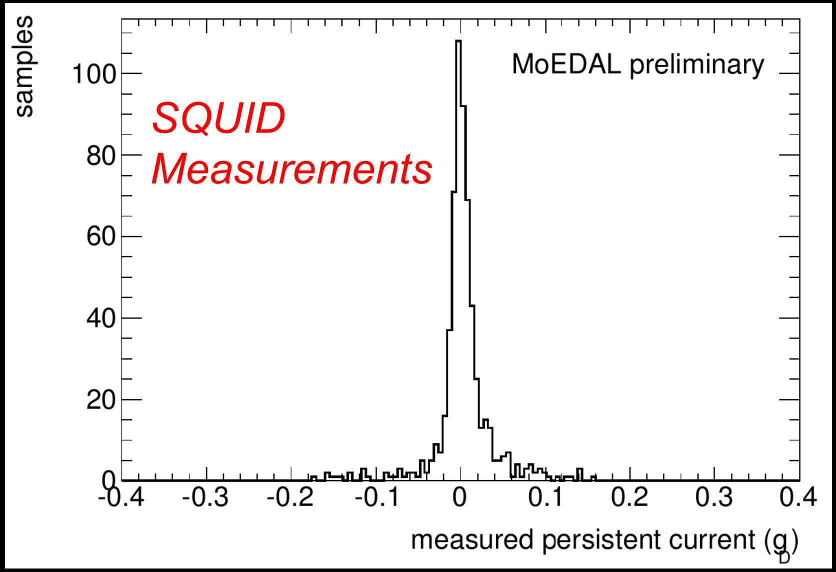
Search for trapped quasi-stable decays at SNOLAB

- *We will deploy trapping volumes (~1 tonne) in the MoEDAL/VELO Cavern to trap highly ionizing particles*
  - *The binding energies of monopoles in nuclei with finite magnetic dipole moments are estimated to be hundreds of keV*
- *After exposure the traps are removed and sent to:*
  - *The SQUID magnetometer at ETH Zurich for Monopole detection*
  - *Underground lab (SNOLAB) to detect decays of electrically charged MSPs*

Results from MMT Test Deployment







- *MoEDAL is the only LHC experiment that can observe magnetic charge*
  - *No monopole seen with > 0.1 g_D*
  - *Monopole with charge > 1g_D and mass > 1500 GeV constrained for the 1st time at the LHC*

MoEDAL's Complementarity

Designed & Optimized for highly ionizing particles

Insensitive to SM particles

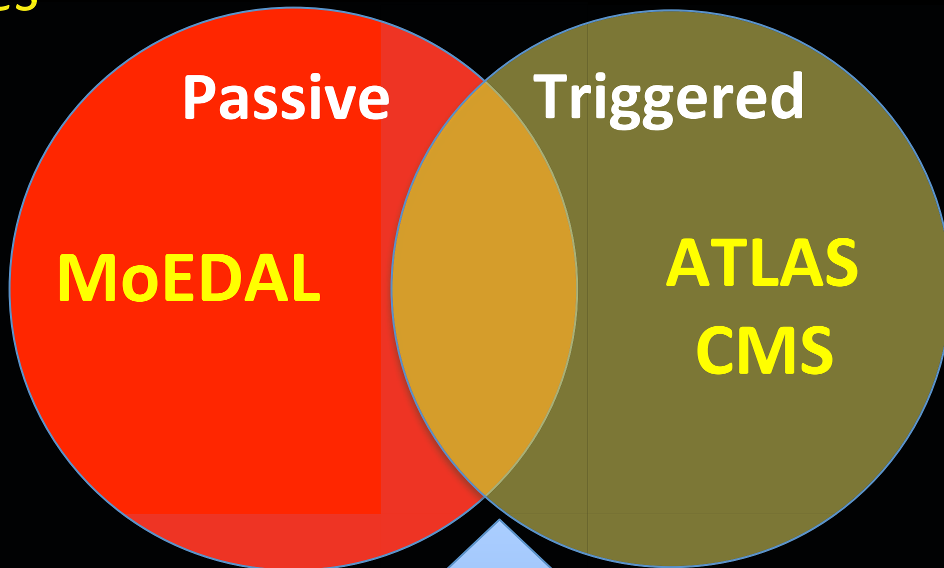
Mass ~ 1 ton

Size ~ 5 m^3

Thickness in RL ~ 0.002 X_0

Can directly detect & trap magnetic charge

Calibrated by heavy-ions



Designed & optimized for SM relativistic MIPs & photons

Mass ~10K tons

Size ~ 25m diam. x 46 m length

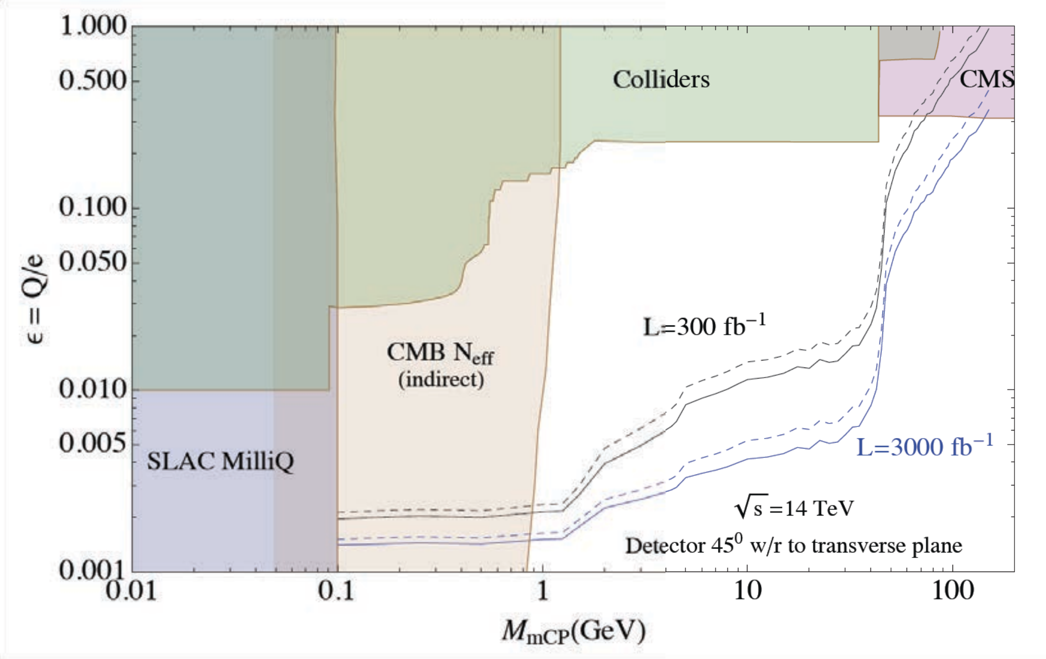
Thickness in RL ~ 25 X_0

Cannot detect magnetic charge

Cannot be directly calibrated for HIPs

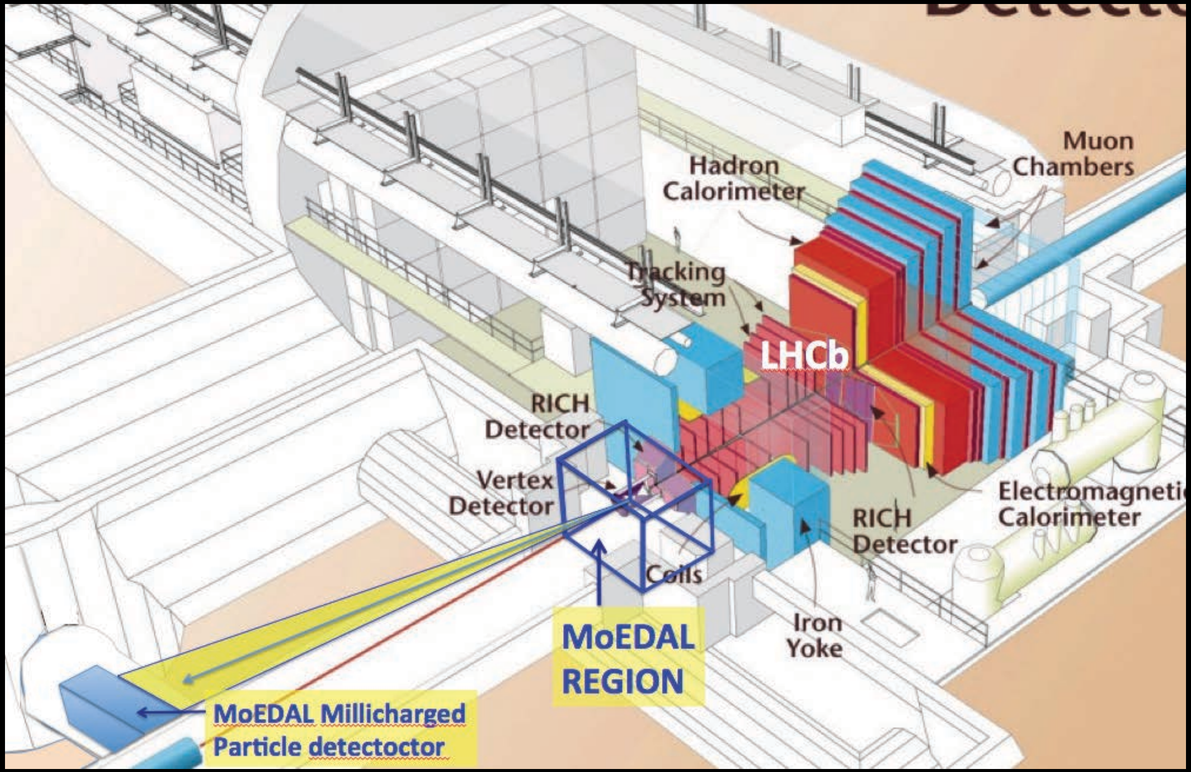
The totally different systematics and mode of detection of MoEDAL compared to the ATLAS/CMS experiments → important validation of and insights into a joint observations

MoEDAL's Phase-II Physics Challenge?



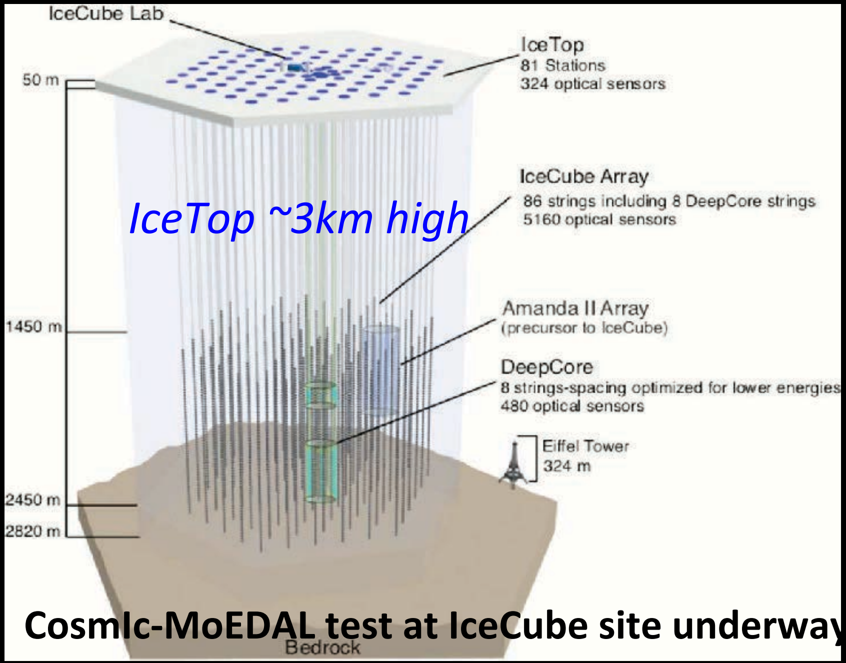
- *Search for millicharged particles – a dark matter candidate - to which the standard LHC detectors are not sensitive*
  - *New dark sectors can have new particles which appear "milli-charged" to the Standard Model*
  - *Charges typically in the range 10^{-1} to 10^{-3} e*
  - *No direct constraints above 100 MeV*
- ***A MoEDAL millicharged detector could probe up to 100 GeV***

A Phase-II MoEDAL mQP Detector



- *MoEDAL is now working on a new sub-detector to search for millicharged particles (mQP) as low as 10^{-3}e*
  - *A location near to IP8 adjacent to the MoEDAL detector has been ID'ed*
  - *Fine segmentation, deep detectors, precise timing and triple layer coincidence will be used to get single photo-electron sensitivity*

The Future – Cosmic-MoEDAL



- *Cosmic-MoEDAL would deploy 10K-100K m^2 of NTDs at high altitude - 10/25 times larger than MACRO/SLIM*
  - *To detect monopoles from late phase transition & GUT scenarios with mass from ~10^4 → 10^{18} GeV.*
- *Possible sites are Mt Chacaltaya in Bolivia (5.3km), IceTop Antarctica (~3km)), the Pryamid Lab in Nepal (5.1km) and Muna Kea, Hawaii (4.2 km)*

Why Search for Monopoles?

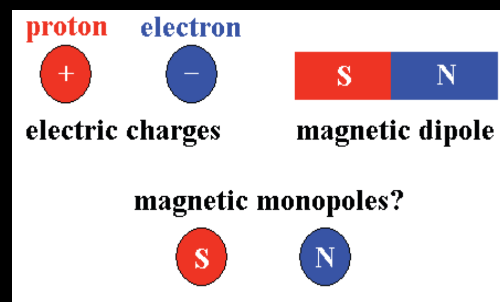
- *The existence of magnetic monopoles is suggested EM theory. But, Grand unified and superstring theories, predict the existence of the monopole.*
  - **PAUL DIRAC:** *"I would be surprised if Nature had made no use of it", (the magnetic monopole***.**
  - **ED WITTEN:** *"almost all theoretical physicists believe in the existence of magnetic monopoles, or at least hope that there is one."*
  - **WEINBERG & YI:** *The magnetic monopole may be the most interesting, and perhaps the most important, particle to be never found. It was quite natural to conjecture the existence of….magnetic poles….(to) complete the electric–magnetic duality*
  - **JOSEPH POLCHINSKI: "***…they (monopoles) are the most certain prediction of theory beyond the Standard Model - more so than supersymmetry, strings, extra dimensions, modified gravity…***"**
  - **GERARDUS 't HOOFT:** *"…Some… theories…..of extra dimensions, predict a significantly lighter monopole too……where the LHC or its future descendants can reach, so the prospects look brighter".*
  - **YONGMIN CHO: "***….Only the electroweak, monopole is consistent with the theoretical framework of the standard model…."*

MoEDAL Addresses Fundamental Questions:

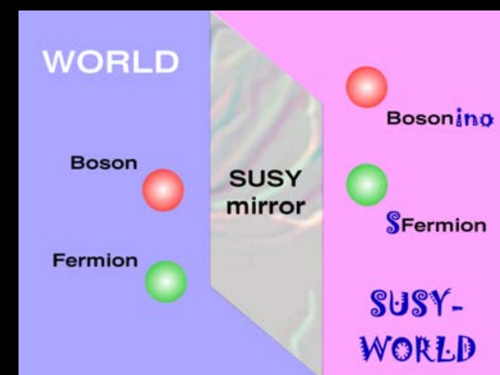
Are there extra dimensions?

What is the nature of Dark Matter?

What happened just after the big bang?



Does magnetic charge exist?



Are there new symmetries of nature?

The MoEDAL experiment as just set sail on a voyage of discovery with the opening of a new LHC high energy frontier 13-14TeV in 2015 - stay tuned