THE CONTINUING QUEST FOR THE MAGNETIC MONOPOLE

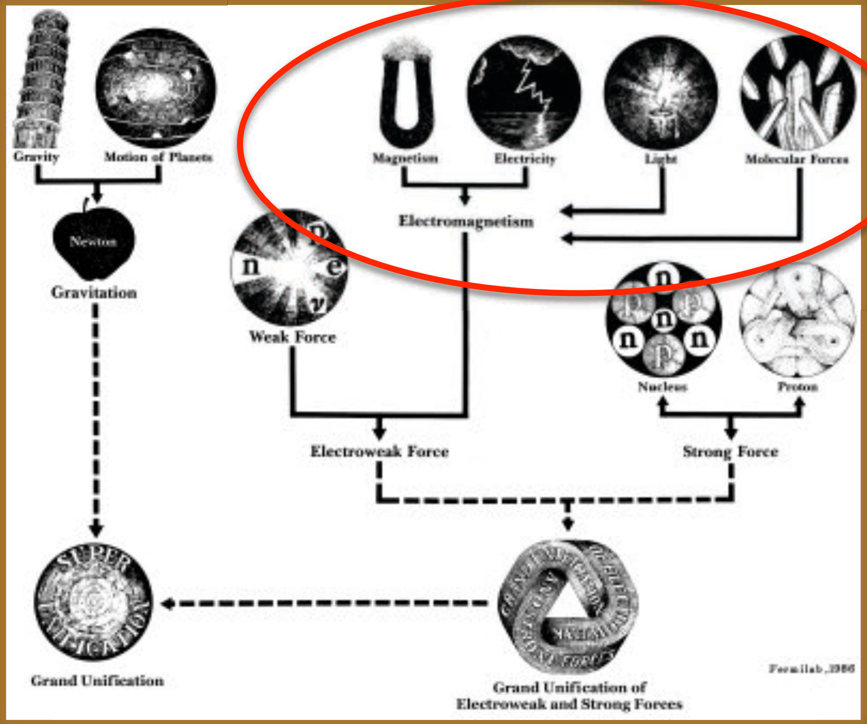
JAMES L. PINFOLD
UNIVERSITY OF ALBERTA

"INTERPLAY BETWEEN PARTICLE AND ASTROPHYSICS" QMC 2014

The Menu

- *Introduction*
  - *A brief history of the magnetic monopole*
- *Searching for monopoles at accelerators*
  - *The MoEDAL Detector*
    - *The Collaboration*
    - *The 4 sub-detectors*
- *Searching for monopoles from the cosmos*
- *Last Words*

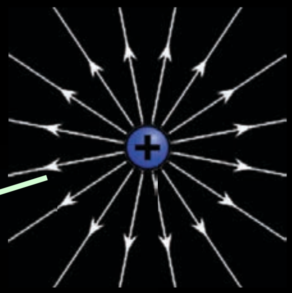
Maxwell's Grand Unification



- *Maxwell, in 1873, makes the connection between electricity & magnetism – the Victorian Grand Unified Theory!*
- *The theoretical work that led him to this unification was mostly carried out King's College London*

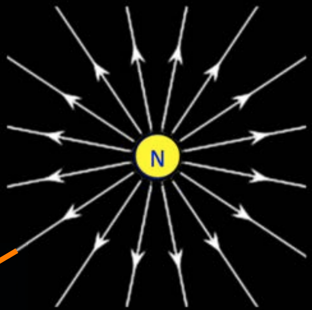
Monopoles Symmetrize Maxwell's Eqns

$$\vec{\nabla}\cdot\vec{E} = \rho_{\mathrm{E}}$$
$$\vec{\nabla}\cdot\vec{B} = 0$$
$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$
$$\vec{\nabla}\times\vec{B} = \frac{\partial\vec{E}}{\partial t} + \vec{j}_{\mathrm{E}}$$



ELECTRIC CHARGE

$$\vec{\nabla}\cdot\vec{E} = \rho_{\mathrm{E}}$$
$$\vec{\nabla}\cdot\vec{B} = \rho_{\mathrm{M}}$$
$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} - \vec{j}_{\mathrm{M}}$$
$$\vec{\nabla}\times\vec{B} = \frac{\partial\vec{E}}{\partial t} + \vec{j}_{\mathrm{E}}$$



MAGNETIC CHARGE

- *The symmetrized Maxwell's equations are invariant under rotations in the plane of the electric and magnetic field*
- *This symmetry is called Duality - the distinction between electric and magnetic charge is merely one of definition*

Oliver Heaviside's Magnetons

- *Maxwell's formulation of EM consisted of 20 equations in 20 variables!*
  - *Oliver Heaviside replaced Maxwell's EM potential by 'force fields' as the centerpiece of EM theory.*
  - *He used vector calculus to reformulate these equations into 4 equations in 4 variables (**B**, **E**, **J**, and ρ), the form we use today*
  - *Heaviside used the idea of magnetic charges called magnetons but as a construction only*
- *Dirac became familiar with Heaviside's work while he was training to be an electrical engineer*

Maxwell's Asymmetric Equations

— 76 —

Sur la possibilité d'existence de la conductibilité magnétique et du magnétisme libre;

Par M. P. Curie.

Le parallélisme des phénomènes électriques et magnétiques nous amène naturellement à nous demander si cette analogie est plus complète. Est-il absurde de supposer qu'il existe des corps conducteurs du magnétisme, des courants magnétiques (¹), du magnétisme libre?

Il convient d'examiner si des phénomènes de ce genre ne seraient pas en contradiction avec les principes de l'Énergétique ou avec les conditions de symétrie. On constate qu'il n'y aurait aucune contradiction. Un courant magnétique dégagerait de la chaleur; il aurait la symétrie du champ magnétique qui lui a donné naissance et jouirait de la curieuse propriété, pour un courant, d'être symétrique par rapport à un plan normal à sa direction. Le courant de magnétisme créerait un champ électrique comme le courant électrique crée un champ magnétique et suivant les mêmes lois.

Une sphère isolée dans l'espace et chargée de magnétisme libre serait caractérisée par le groupe sphérique (18) $\infty L\infty$, énantiomorphe, c'est-à-dire une infinité d'axes d'isotropie doublés passant par le centre de la sphère dans toutes les directions; mais pas de centre et aucun plan de symétrie. En effet, la sphère est entourée de champs magnétiques tous orientés suivant les rayons et tous dirigés vers l'extérieur, si la sphère est chargée de magnétisme austral, ou vers l'intérieur, si elle est chargée de magnétisme boréal. Il ne peut y avoir de plan de symétrie passant par un rayon, puisque l'existence d'un champ magnétique n'est pas compatible avec celle d'un plan de symétrie passant par sa direction. Au contraire, rien ne s'oppose à l'existence des axes d'isotropie, on a donc le groupe (18).

Si l'on pouvait placer une sphère chargée de magnétisme libre

(¹) M. Vaschy a déjà posé cette question (*Traité d'Électricité et de Magnétisme*).

— 77 —

dans un champ magnétique, on aurait une force, et ceci semble à première vue en contradiction avec l'existence du plan de symétrie normal au champ. La disparition du plan de symétrie est précisément due à la dissymétrie caractéristique du magnétisme libre. La symétrie du champ magnétique est (*d*) $\frac{L\infty l\infty}{P\infty}C$, celle de la sphère chargée (18) $\infty L\infty$; en superposant les dissymétries, il reste seulement $(L\infty l\infty)$ groupe (*e*), qui est un intergroupe de la symétrie d'une force groupe (*c*) $(L\infty, \infty P)$.

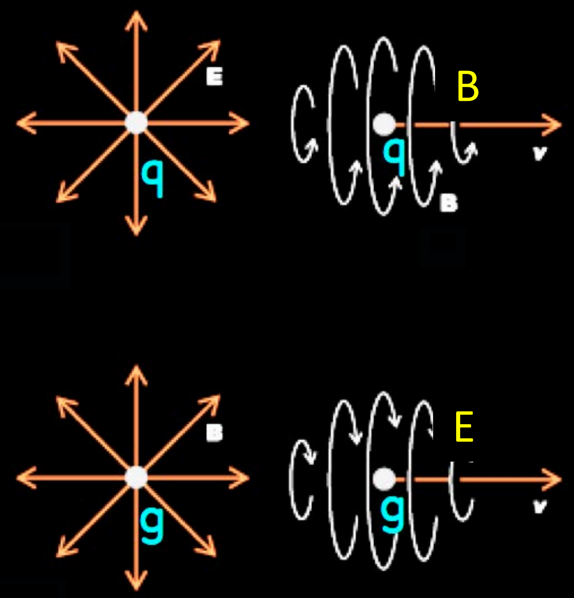
Un corps chargé de magnétisme libre serait donc nécessairement dissymétrique énantiomorphe, c'est-à-dire non superposable à son image obtenue par mirage. Deux sphères chargées respectivement de quantités égales de magnétisme austral et boréal seraient symétriques l'une de l'autre. On voit qu'il n'y aurait rien d'absurde, au point de vue de la symétrie, à supposer que les molécules dissymétriques douées de pouvoir rotatoire soient naturellement chargées de magnétisme libre (¹).

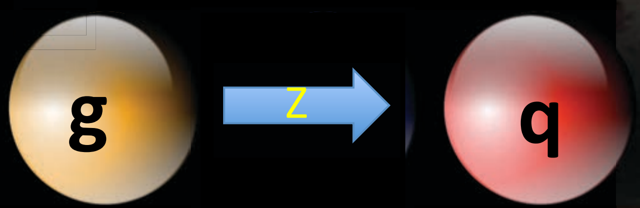
Ainsi, au point de vue de l'énergétique, au point de vue de la symétrie, on peut concevoir sans absurdité les courants de magnétisme et les charges de magnétisme libre. Il serait certes téméraire d'induire de là que ces phénomènes existent réellement. Si cependant il en était ainsi, ils devraient satisfaire aux conditions que nous avons énoncées.

(¹) Si la conductibilité magnétique existait, un transformateur analogue aux transformateurs à courant alternatif, mais à noyau annulaire conducteur du magnétisme, transformerait un courant continu en un autre courant continu. J'ai essayé si le fer donnait un phénomène de ce genre, mais je n'ai obtenu aucun effet. Un tore de fer doux était recouvert de quelques couches de fil qui faisait partie du circuit d'un galvanomètre très sensible. On faisait circuler un fort courant constant dans une autre série de couches de fils. Les deux circuits étaient séparés par un tube de plomb enroulé sur le premier circuit et dans lequel passait un courant d'eau, de façon à éviter l'échauffement du premier circuit par le courant du second. Tant que le fer n'est pas saturé, on a des déviations au galvanomètre dues visiblement aux trépidations inévitables qui facilitent l'aimantation du fer. Quand le courant est assez intense pour que le fer soit déjà fortement aimanté, on n'a plus rien de sensible. Il convient de remarquer que cette méthode, fondée sur l'observation d'un effet dynamique, ne permettrait pas d'apprécier une très faible conductibilité magnétique.

- *Pierre Curie was the first to suggest that Magnetic Monopoles could exist (Seances, Société Française de Physique, 1894)*
- *We are now at the 120th anniversary of the monopole search!*

Thomson's & Poincare's Monopole

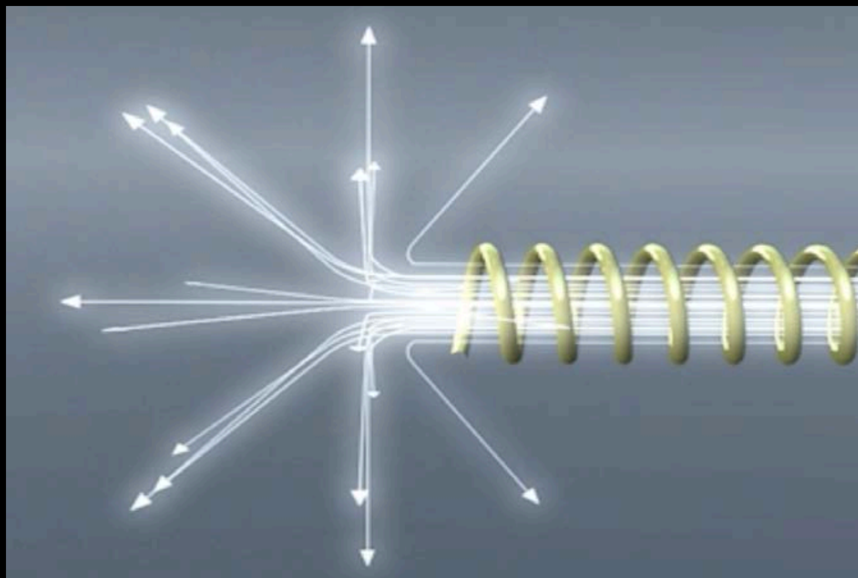




In 1904 Thomson published a paper in which he considered an electric charge (e) – magnetic monopole (g) system

- *He found the angular momentum of the EM field of this system in the direction shown $J_Z = eg/c$*
- *By invoking the quantization rule for angular momentum we can write $eg/c = n\hbar/2$ → Dirac's quantization rule!*

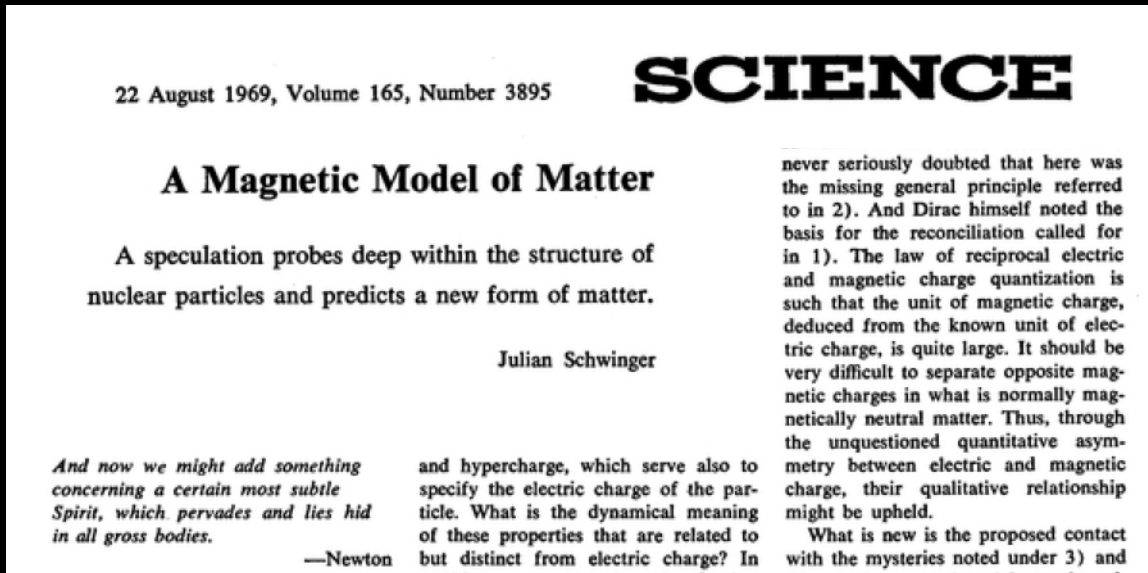
Dirac's Monopole



- *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!*

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

Schwinger's Dyon



22 August 1969, Volume 165, Number 3895 **SCIENCE**

A Magnetic Model of Matter

A speculation probes deep within the structure of nuclear particles and predicts a new form of matter.

Julian Schwinger

And now we might add something concerning a certain most subtle Spirit, which pervades and lies hid in all gross bodies.
—Newton

and hypercharge, which serve also to specify the electric charge of the particle. What is the dynamical meaning of these properties that are related to but distinct from electric charge? In

never seriously doubted that here was the missing general principle referred to in 2). And Dirac himself noted the basis for the reconciliation called for in 1). The law of reciprocal electric and magnetic charge quantization is such that the unit of magnetic charge, deduced from the known unit of electric charge, is quite large. It should be very difficult to separate opposite magnetic charges in what is normally magnetically neutral matter. Thus, through the unquestioned quantitative asymmetry between electric and magnetic charge, their qualitative relationship might be upheld.

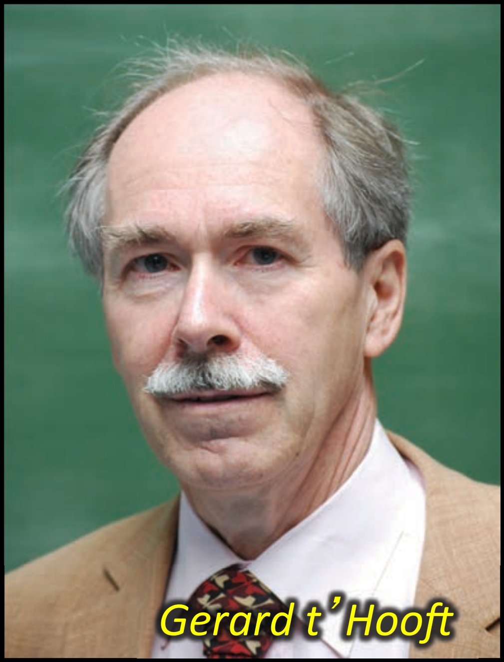
What is new is the proposed contact with the mysteries noted under 3) and

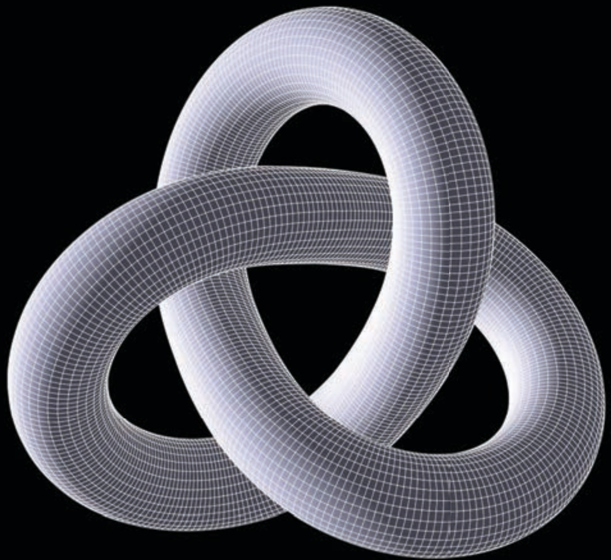
- *Postulated a "dyon" that carries electric & magnetic charge*
- *Quantisation of angular momentum with two dyons (q_{e1},q_{m1}) and (q_{e2},q_{m2}) yields*

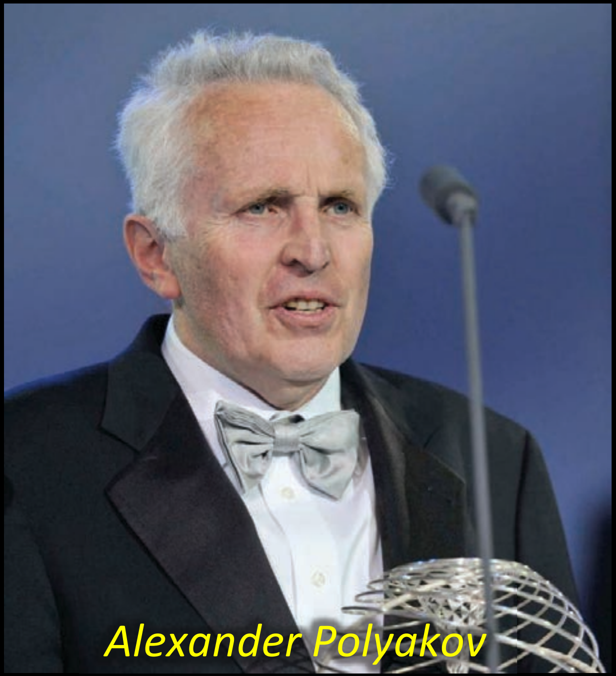
$$(q_{e1}, q_{m1}) - (q_{e2}, q_{m2}) = 2nh/m_0 \quad (\text{ n is an integer})$$

- *Fundamental magnetic charge is now $2g_D$*
  - *If the fundamental charge is 1/3 (d-quark) as the fundamental electric charge then the fundamental magnetic charge becomes $6g_D$*

The 't Hooft-Polyakov Monopole

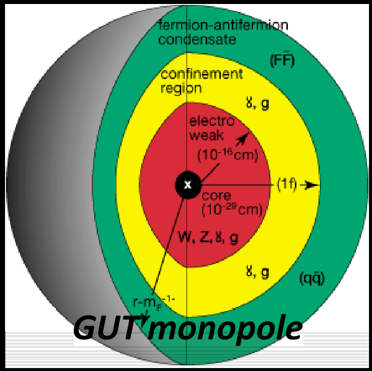



Topological soliton



- *In 1974 't Hooft and Polyakov showed that monopoles exist with the framework of Grand Unified Theories*
  - *Such monopoles are topological solitons (stable, non dissipative, finite energy solutions) with a topological charge*
  - *The topology of the soliton's field configuration gives stability EG like a trefoil knot*

The GUT Monopole



- *A symmetry-breaking phase transition caused the creation of topological defects as the universe froze out at the GUT trans.*
  - *The GUM is a tiny replica of the Big Bang with mass ~ 0.2 μg (10^{17} GeV*
  - *GUT monopoles should comprise 10^{11} x $\rho_{critical}$ of the Universe !!*
  - *Guth introduced the inflationary scenario to dilute the monopoles to an acceptable level and also solve the horizon and flatness problems.*
- *Lighter "Intermediate Mass Monopoles" can be produced at later Phase Transitions – mass 10^{10} GeV or lower*

$$SO(10) \xrightarrow[10^{-35}s]{10^{15}\ GeV} SU(4) \times SU(2) \times SU(2) \xrightarrow[10^{-23}s]{10^{9}\ GeV} SU(3) \times SU(2) \times U(1)$$

GUT Monopole Catalysis of p-Decay

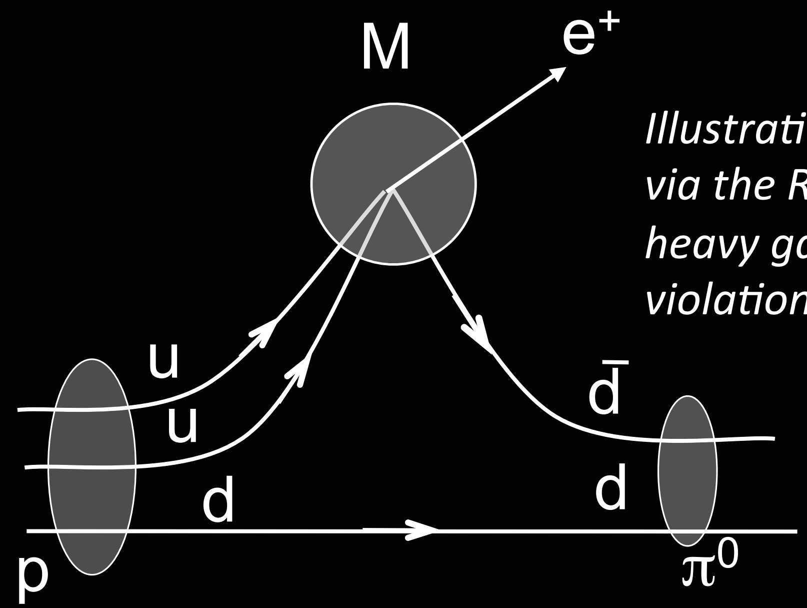
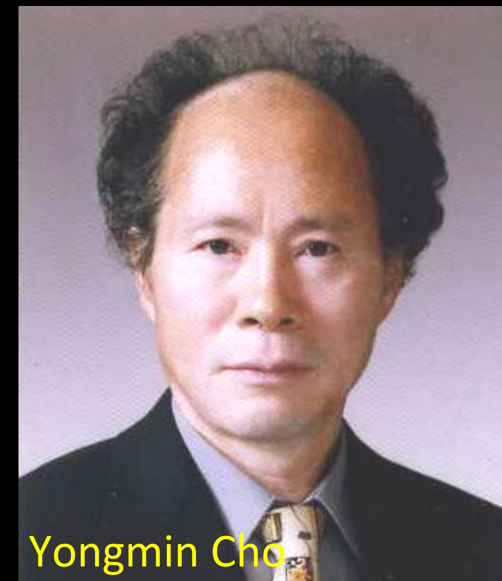


Illustration of monopole catalysis of proton decay via the Rubakov-Callan Mechanism via super heavy gauge bosons that mediate baryon number violation

- *The central core of the GUT retains the original symmetry containing the field of the superheavy "X" all quarks and leptons are here essentially indistinguishable*
  - *Protons can be induced to decay with x-section ofo $\sigma_B\beta \sim 10^{-27}$ cm^2- giving a line of catalyzed proton decays on the trail of the monopole*
- *One can search for non relativistic monopoles at water/ice detectors (IceCube, KamioKande, etc.) using catalysis*

The Cho-Maison Magnetic Monopole



- *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 abelian Dirac monopole & the non-abelian 't Hooft-Polyakov monopole*
- *The Cho-Maison monopole would be detectable by MoEDAL*

Magnetic Monopole Properties

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

Coupling constant =
$g/\hbar c$ ~ 34. Spin ½?

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

GUT monopoles ~10^{17} GeV
IMM monopoles mass as
low as 10^{7} GeV
4-7 TeV EW monopole

The Ways to get High Ionization

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

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

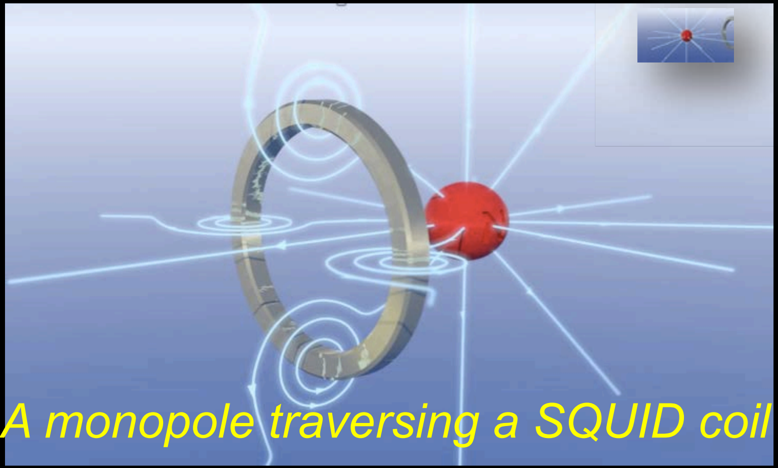
- ***Magnetic charge** - ionization increases with magnetic charge and decreases with velocity β – a unique signature*

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

  - *The velocity dependence of the Lorentz force cancels $1/\beta^2$ term*

- *The ionization of a relativistic monopole is $(ng)^2$ times that of a relativistic proton i.e $4700n^2$!! (n=1,2,3…)*

Induction Experiments - Evidence?



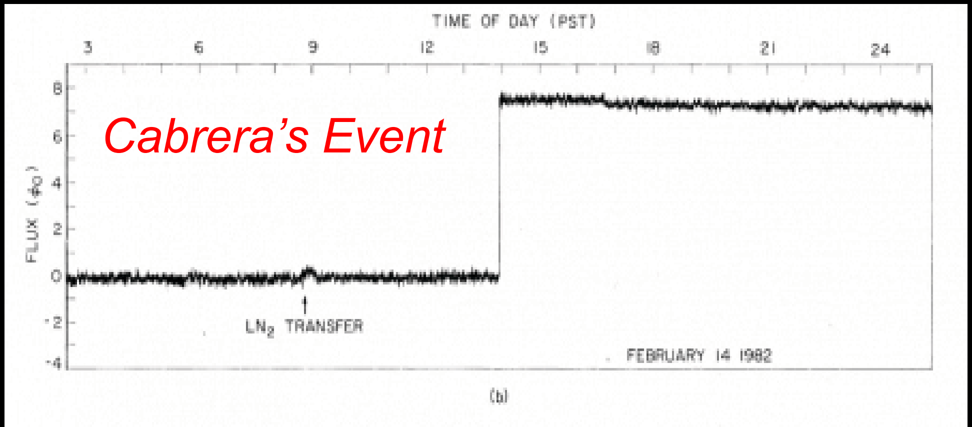
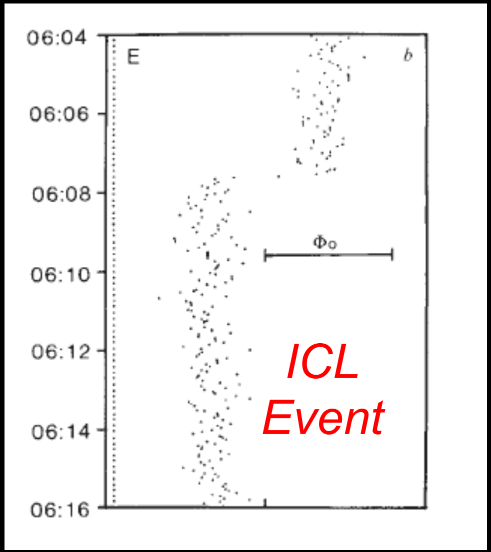


FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.

- *Data from Cabrera's apparatus taken on St Valentine's day in 1982 (A=20 cm^2).*
  - *The trace shows a jump – just before 2pm - that one would expect from a monopole traversing the coil.*
- *In August 1985 a groups at ICL reported the:"observation of an unexplained event" compatible with a monopole traversing the detector (A= 0.18 m^2*
- *SAME TECHNOLOGY IS UTILIZED BY MoEDAL*



Looking for Monopoles at the LHC

MoEDAL the 7th LHC Experiment

CERN COURIER

May 5, 2010

MoEDAL becomes the LHC's magnificent seventh

A new experiment is set to join the LHC fold. As James Pinfold explains, MoEDAL will conduct the search for magnetic monopoles.

Résumé

MoEDAL devient la septième expérience du LHC

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN-LHC-2009-006
MoEDAL-TDR-1.1
February 27, 2010

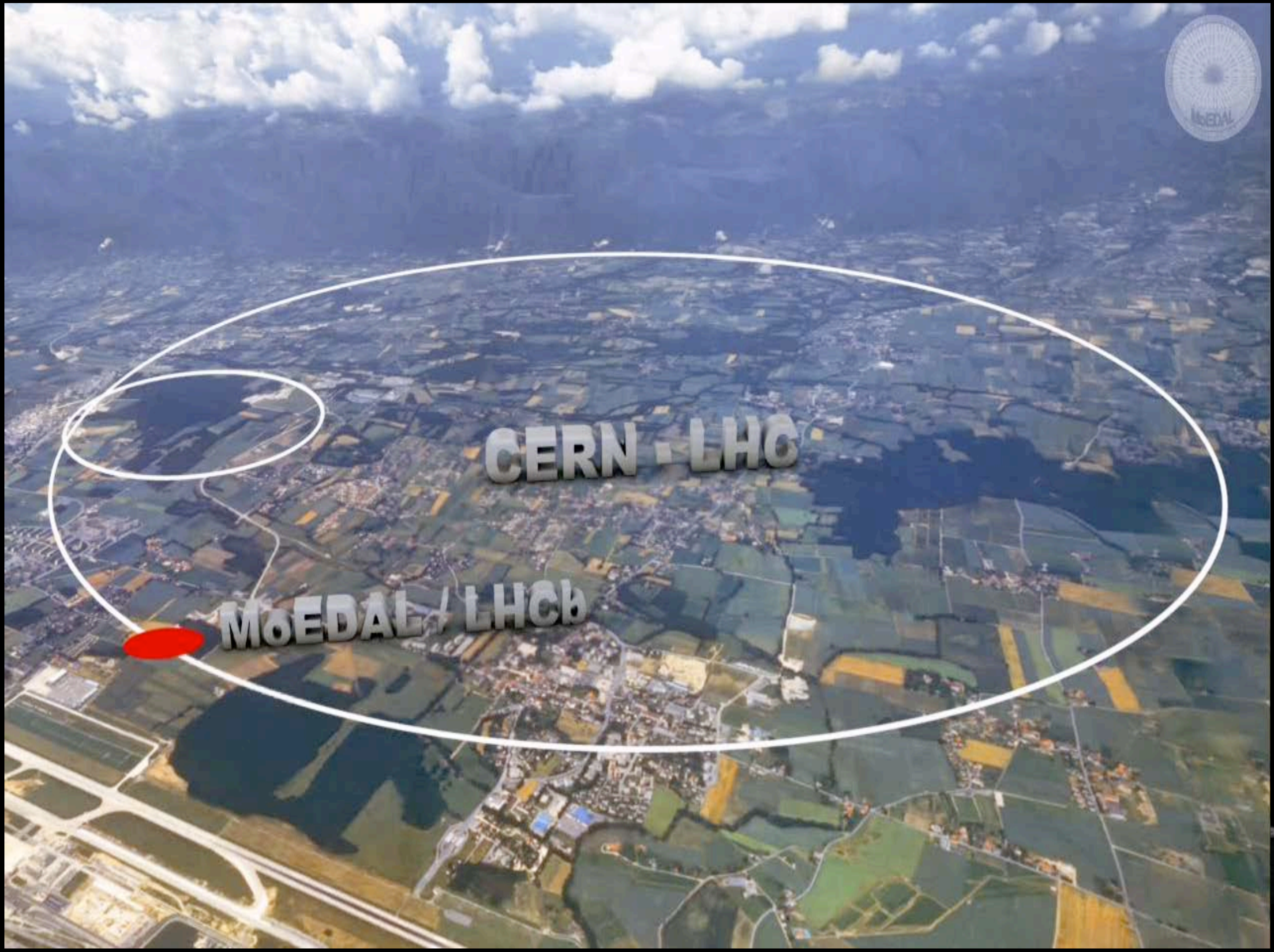
MoEDAL

$$\nabla \cdot \mathbf{E} = 4\pi\rho_e$$
$$\nabla \cdot \mathbf{B} = 4\pi\rho_m$$
$$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_m$$
$$\nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_e$$
$$\mathbf{F} = q_e\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right) + q_m\left(\mathbf{B} - \frac{\mathbf{v}}{c} \times \mathbf{E}\right)$$

TECHNICAL DESIGN REPORT
OF THE MoEDAL EXPERIMENT

- *The MoEDAL experiment the 7th LHC experiment was officially approved by the CERN Research Board on March 3rd 2010*
- *MoEDAL shares the 8th LHC IP with the LHCb experiment*
- *MoEDAL is an array of passive Nuclear Track-Etch Detectors & Trapping Detectors - with a MediPix chip online radiation monitor system*
- *MoEDAL will start taking data at the LHC in the Spring 2015*

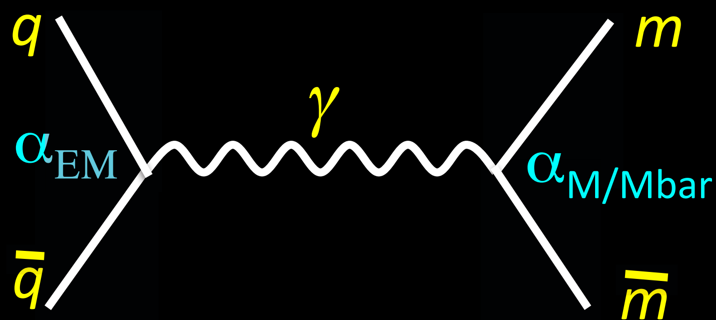
Where is the MoEDAL Experiment?



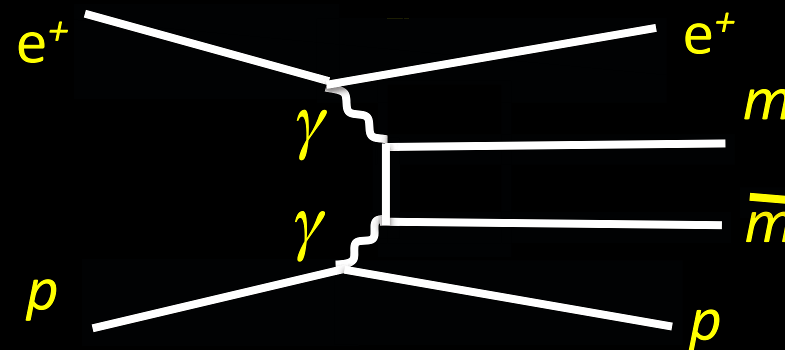
MoEDAL shares intersection point 8 on the LHC ring with LHCb

Monopole Production at Colliders

$$e^+e^- \rightarrow M\bar{M},\ pp \rightarrow M\bar{M},\ e^+p \rightarrow e^+pM\bar{M},\ \text{etc,}$$

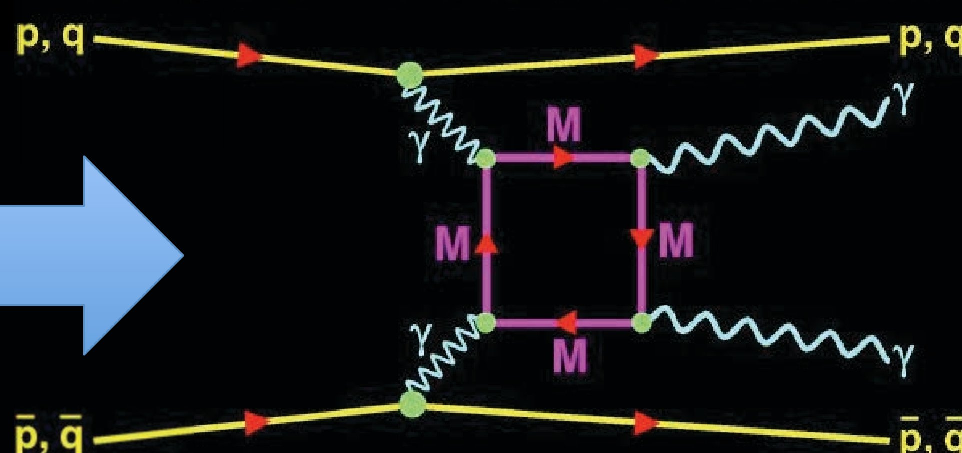


Drell-Yan Production



Two-photon production

Indirect search using virtual monopole box diagrams allow – observable two high energy gammas.



The Collaboration

- *Now 64 physicists from 12 countries and 21 institutions:*

U. Alberta, UBC, INFN Bologna, U. Bologna, U. Cincinatti, Concordia U., CSIC Valencia, DESY, Gangneung-Wonju Nat. U., U. Geneva, U. Helsinki, ICTP Trieste, IEAP/CTU Prague, IFIC Valencia, Imperial College London, INP/PAS Cracow, ISS Bucharest, King's College London, Konkuk U., Muenster U., Northeastern U., Simon Langton School UK, Tuft's.

Physics Program (34 Scenarios)

arXiv.org > hep-ph > arXiv:1405.7662

Search or Article-id

High Energy Physics – Phenomenology

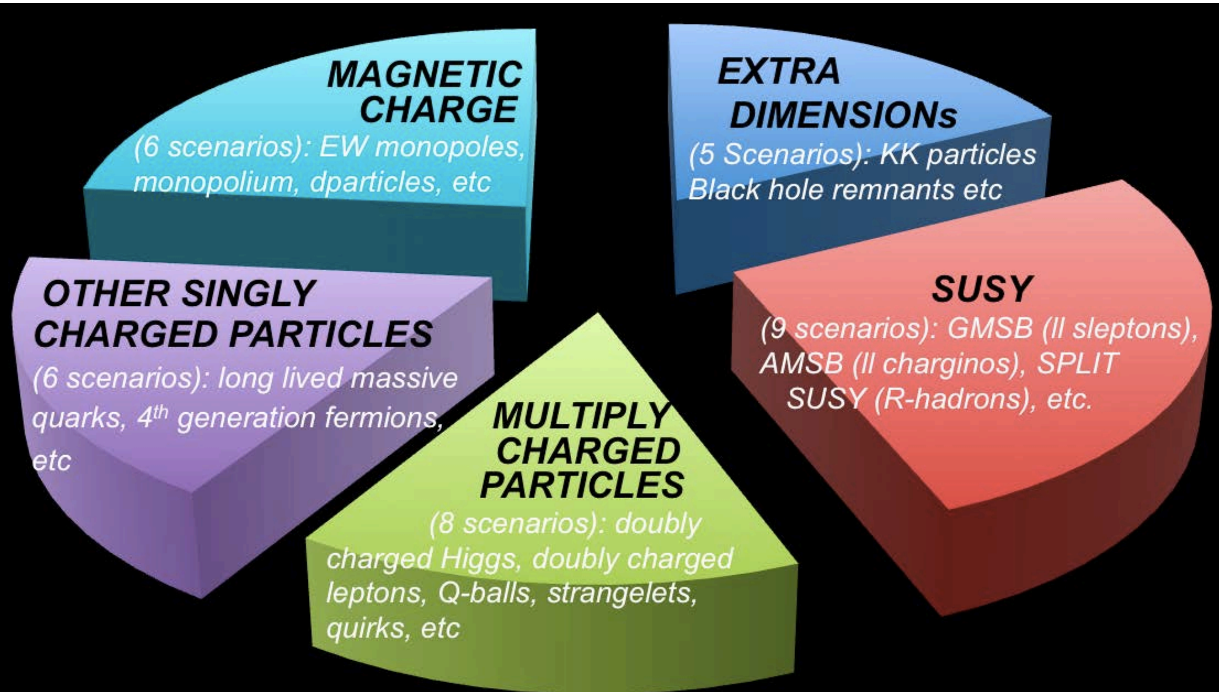
The Physics Programme Of The MoEDAL Experiment At The LHC

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. Sahnoun, 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, J. A. Tuszyński, V. Vento, O. Vives, Z. Vykydal, A. Widom, et al. (1 additional author not shown)

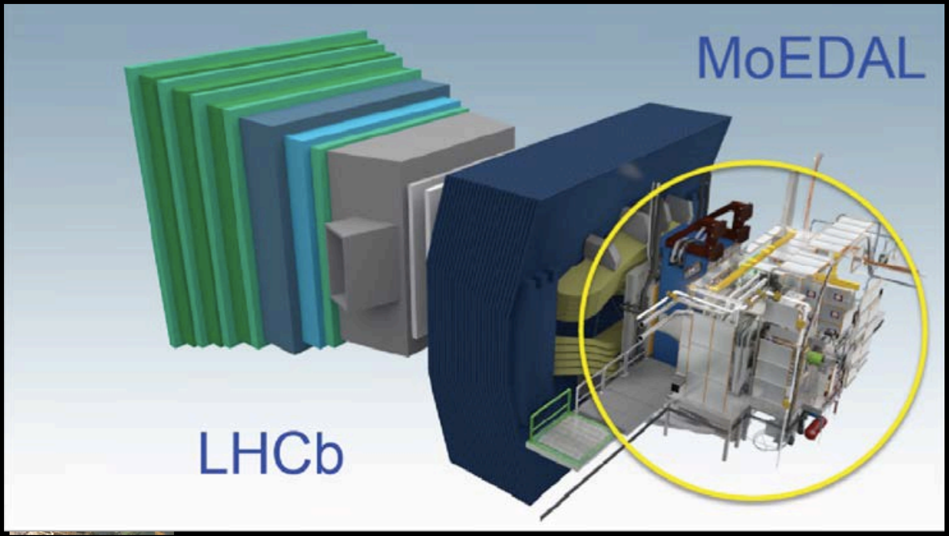
(Submitted on 29 May 2014 (v1), last revised 15 Jul 2014 (this version, v2))

To be published in IJMPA

The MoEDAL experiment at Point 8 of the LHC ring is the seventh and newest LHC experiment. It is dedicated to the search for highly ionizing particle avatars of physics beyond the Standard Model, extending significantly the discovery horizon of the LHC. A MoEDAL discovery would have revolutionary implications for our fundamental understanding of the Microcosm. MoEDAL is an unconventional and largely passive LHC detector comprised of the largest array of Nuclear Track Detector stacks ever deployed at an accelerator, surrounding the intersection region at Point 8 on the LHC ring. Another novel feature is the use of paramagnetic trapping volumes to capture both electrically and magnetically charged highly-ionizing particles predicted in new physics scenarios. It includes an array of TimePix pixel devices for monitoring highly-ionizing particle backgrounds. The main passive elements of the MoEDAL detector do not require a trigger system, electronic readout, or online computerized data acquisition. The aim of this paper is to give an overview of the MoEDAL physics reach, which is largely complementary to the programs of the large multi-purpose LHC detectors ATLAS and CMS.



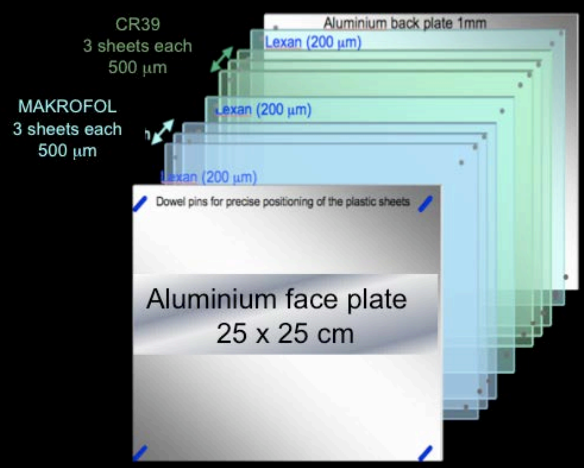
The MoEDAL Experiment

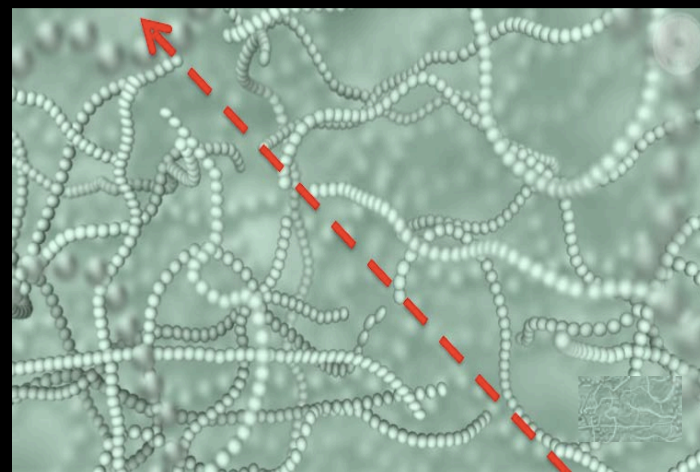


- *The MoEDAL detector design consists of 4 subdetectors, the:*
  - *Low Threshold (≥ 5xMIP) Nuclear Track Detector (LT-NTD) system*
  - *High Charge Catcher (HCC) NTD array (≥ 50 xMIP)*
  - *Magnetic Monopole/Exotics Trapper (MMT) Al trapping volumes*
  - *TimePix pixel device (TMPX) array online radiation monitoring system*

23

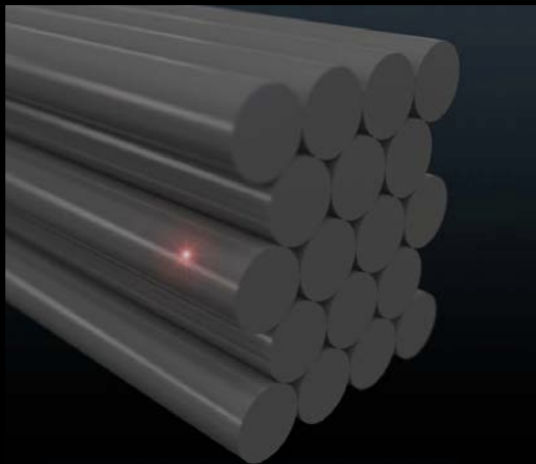
The Nuclear Track Detector System





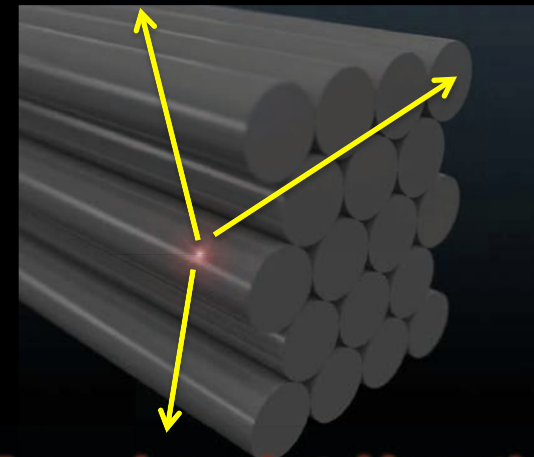
- *Largest array (150 m² of NTDs every deployed at an accelerator*
  - *Plastic NTD stacks consist of CR39 (threshold 5 MiPs) and Makrofol (50 MiPs) – that are "damaged" by the highly ionizing particle*
  - *The damage is revealed by controlled etching in a hot Sodium Hydroxide solution – etch pits are 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)

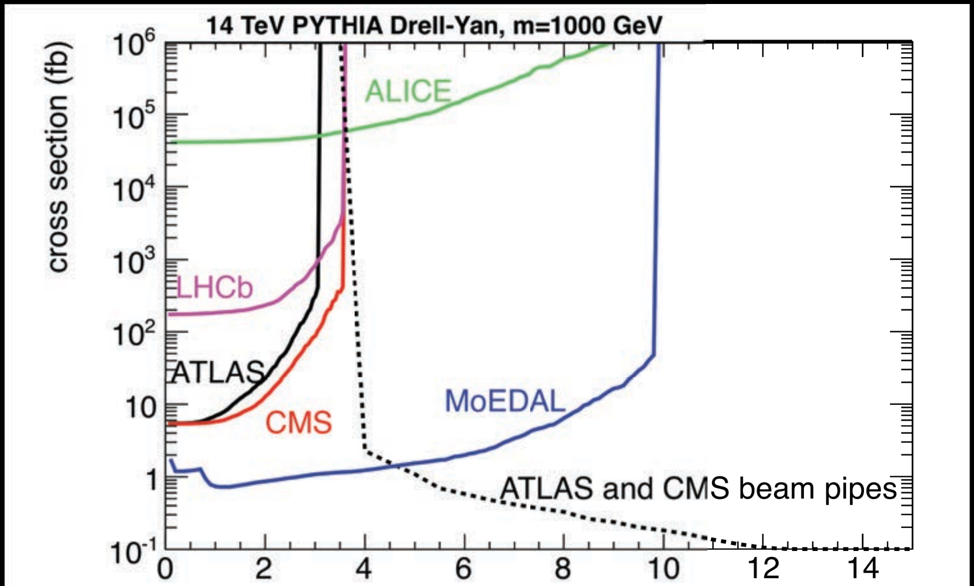


Trapped pseudostable particle decaying to charged particles

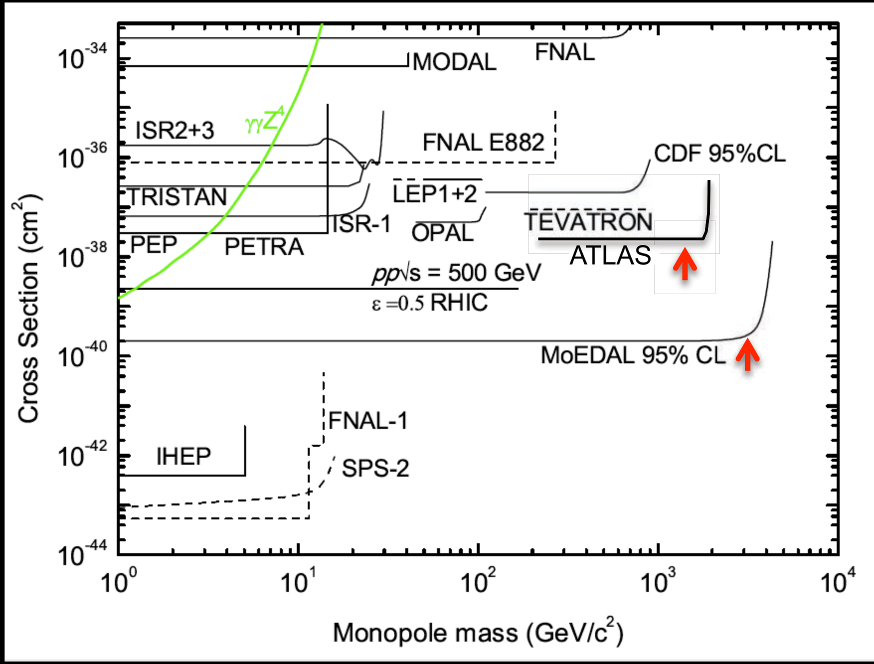
- *We will deploy trapping volumes (~1 tonne) in the MoEDAL/VELO Cavern to trap highly ionizing particles*
  - *The binding energies of monopoles in nuclei with finite magnetic dipole moments are estimated to be hundreds of keV*
- *After exposure the traps are removed and sent to:*
  - *The SQUID magnetometer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

MoEDAL Sensitivity

detector	energy threshold	angular coverage	luminosity	robust against timing	robust efficiency
ATLAS	medium	central	high	no	no
CMS	relatively low	central	high	no	no
ALICE	very low	very central	low	yes	no
LHCb	medium	forward	medium	no	no
MoEDAL	low ✔	full ✔	medium ✔	yes ✔	yes ✔



arXiv:1112.2999V2 [hep-ph]



MoEDAL's Complementarity

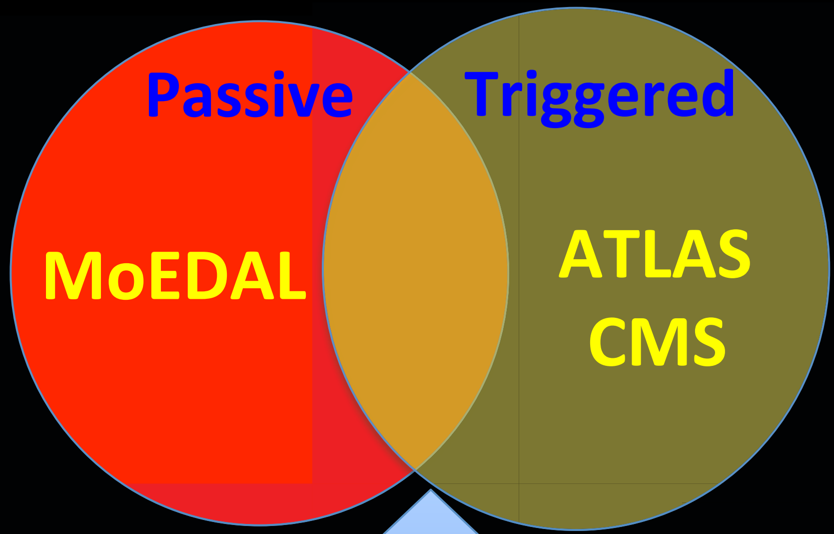
Optimized for highly ionizing particles

Insensitive to SM particles

Sensitive to very long-lived particles

Can directly detect & trap magnetic charge

Calibrated by heavy-ions



Optimized for SM relativistic MIPs & photons

Difficult to measure evry slow decays

Cannot detect magnetic charge

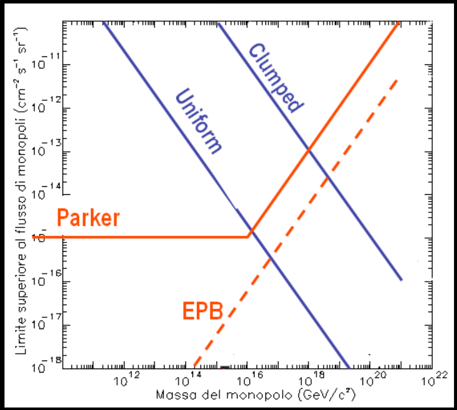
Cannot be directly calibrated for highly ionizing particles

The totally different systematics and mode of detection of MoEDAL compared to the ATLAS/CMS experiments will yield important validation of and insights into a joint observation of new physics that we hope to see starting in 2015

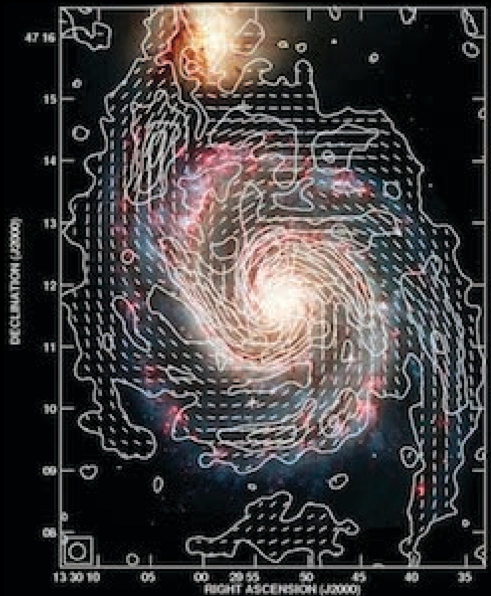
Searching for Primordial Magnetic monopoles

Primordial Monopoles

- *Primordial Monopoles:*
  - *GUT monopoles - m~10^{17} GeV*
  - *IM Monopoles– made in later phase transitions of early universe m ~ 10^9 GeV*
- *Monopoles accelerate to relativistic speeds in galactic B-fields → ~10^{20} eV*
- *Parker Bound is an upper limit on the density of magnetic monopoles based on the existence of a galactic B- field.*
  - *This bound can be evaded if monopole anti-monopoles pairs are bound*
- *Extended Parker Bound - a more stringent limit.*
  - *Based on the survival of the small seed field of the protogalaxy*

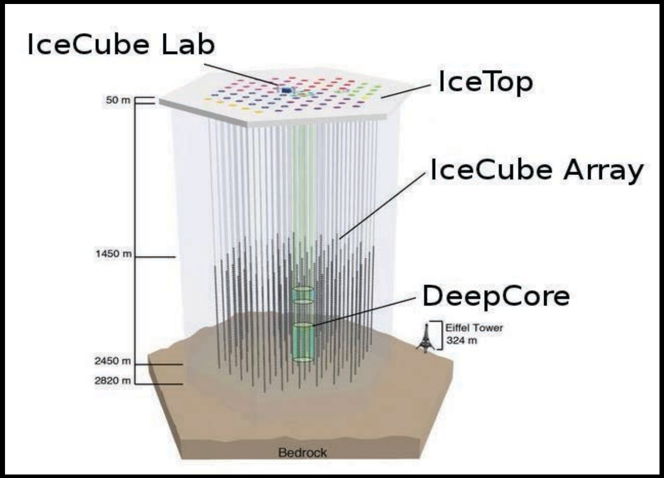


F< 10^{-15} cm^{-2} s^{-1} sr^{-1} for $\beta<3 \times 10^{-3}$



B-field in spiral galaxies is ofo 10 μG (microGauss) (Earth's field ofo 0.1G)

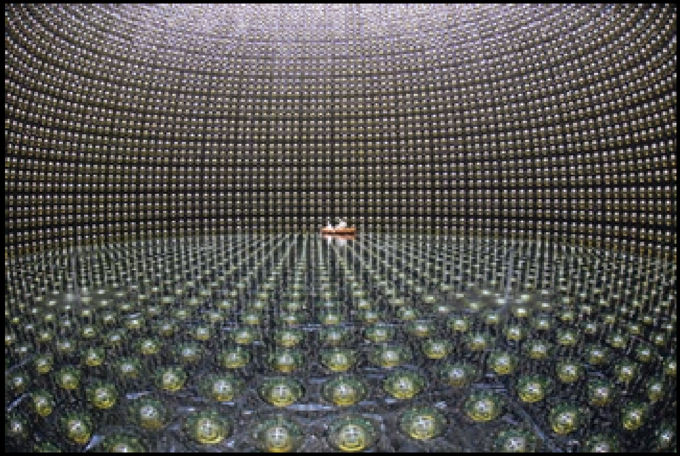
Major Cosmic Monopole Searches



IceCube (Antarctica: -2.4km) - Cerenkov emission& catalyzed p-decay

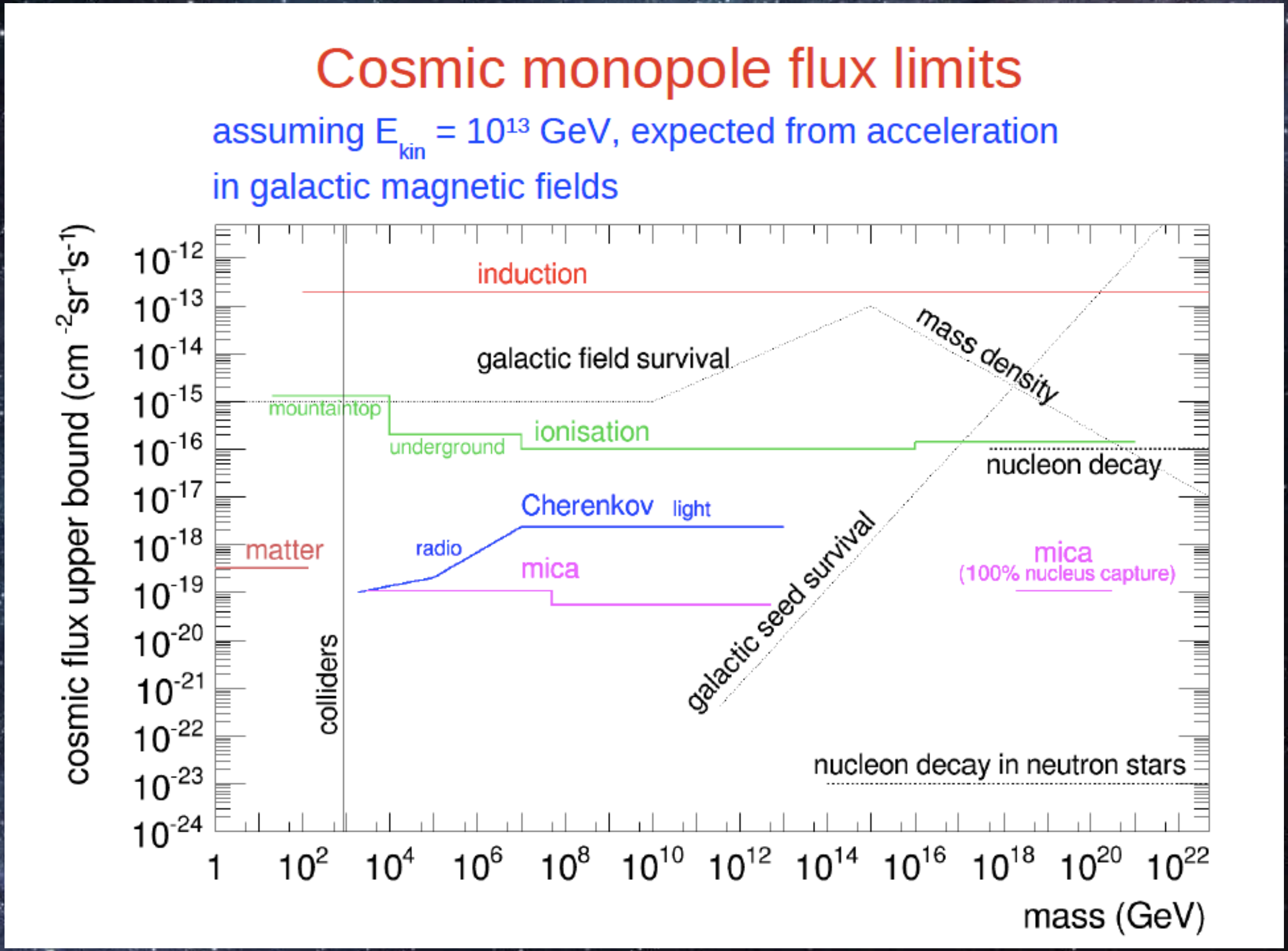
MACRO (Gran Sasso: -1400m) – high ionization

SLIM (Chacaltaya: +5200m) – high ionization

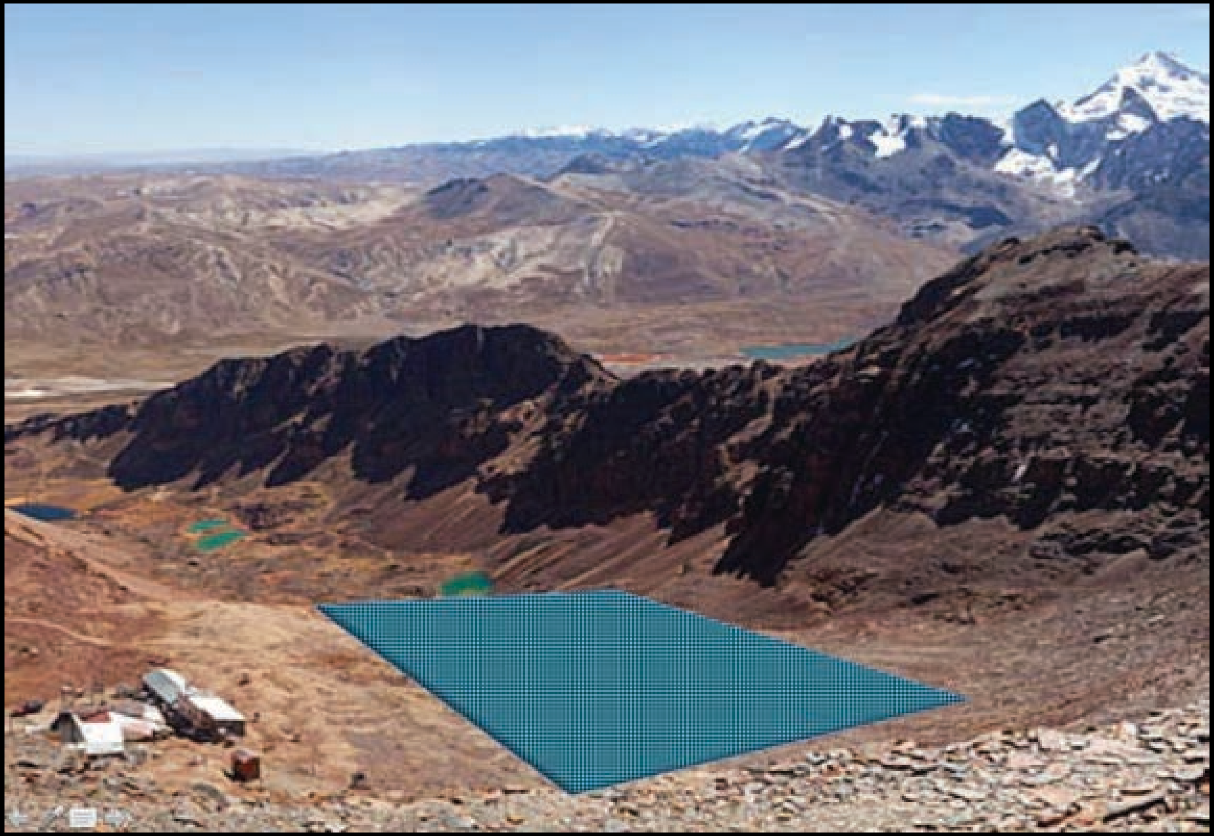


Super-K (Kamioka: -1000m) – catalyzed p-decay

Cosmic Monopole Flux Limits

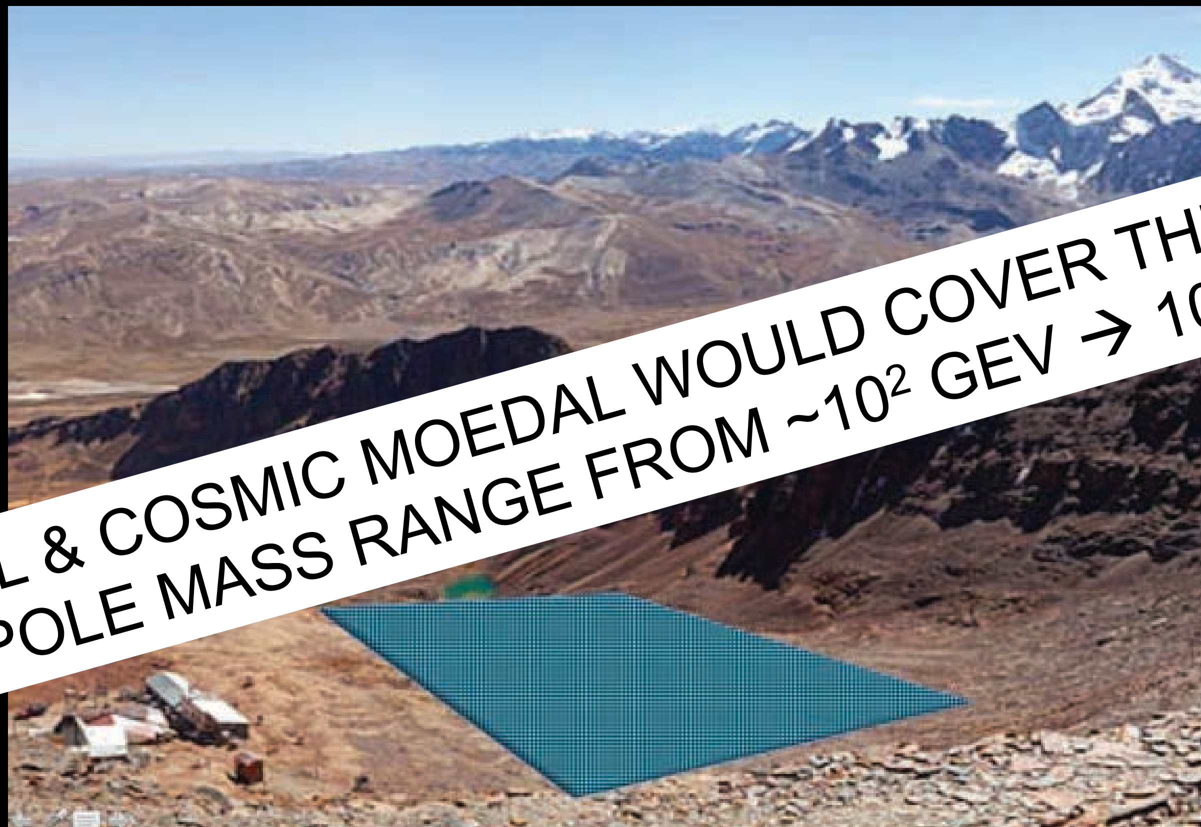


The Future – Cosmic-MoEDAL



- *Cosmic-MoEDAL would deploy 10K-50K m^2 of NTDs at Mount Chacaltaya (5385m) - 50/100 times larger than MACRO/SLIM*
  - *To detect monopoles from late phase transition & GUT scenarios with mass from ~$10^5 \rightarrow 10^{18}$ GeV with fluxes below the Parker Bound*

The Future – Cosmic-MoEDAL



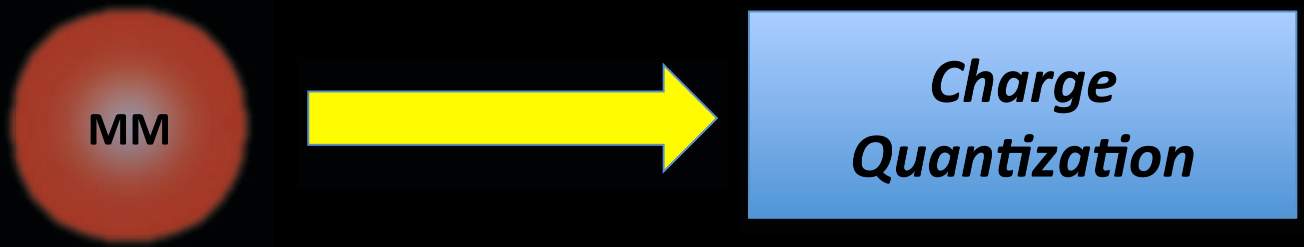
MOEDAL & COSMIC MOEDAL WOULD COVER THE MONOPOLE MASS RANGE FROM ~10^2 GEV → 10^{18} GEV

- *Cosmic-MoEDAL would deploy 10K-50K m^2 of NTDs at Mount Chacaltaya (5385m) - 50/100 times larger than MACRO/SLIM*
  - *To detect monopoles from late phase transition & GUT scenarios with mass from ~10^5 → 10^{18} GeV with fluxes below the Parker Bound*

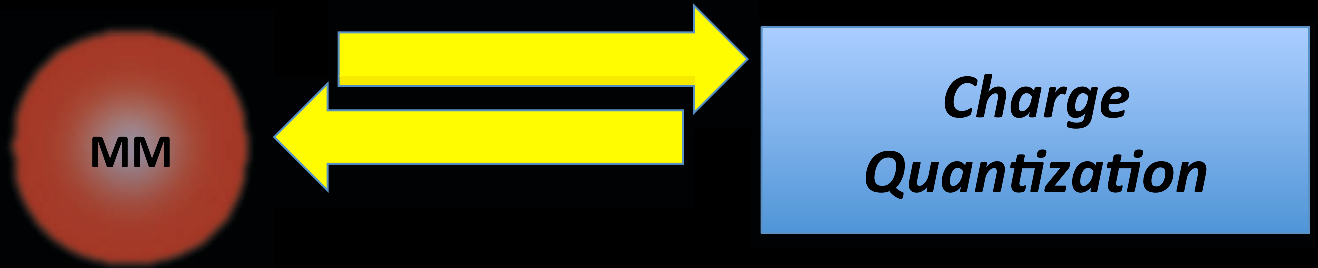
Last Words

The Polchinski Conjecture

- *Dirac showed that the existence of at least one magnetic monopole would explain charge quantization*

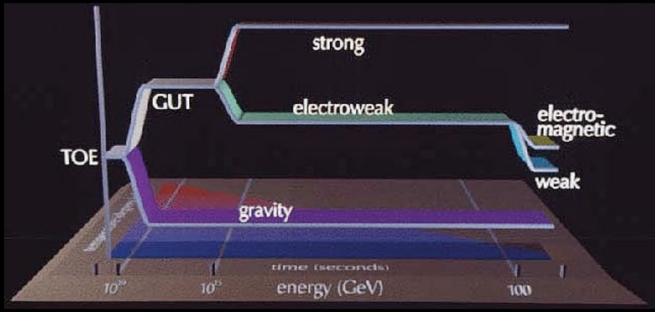


- *Thus, the leading string theorist Joseph Polchinski conjectured, any theory requiring charge quantization must have a monopole*



- *He also maintains that in any fully unified theory, for every gauge field there will exist electric and magnetic sources.*

On the Existence of the Monopole



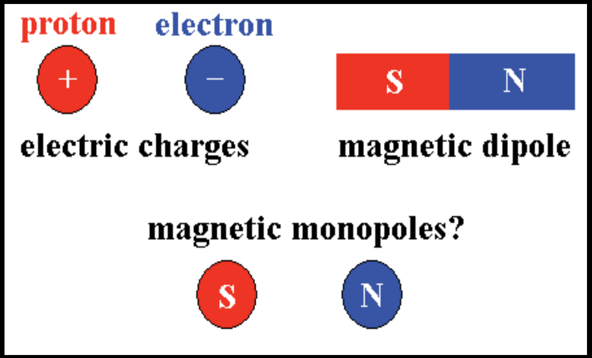
- *The existence of magnetic monopoles is suggested by Electromagnetic theory. But, Grand unified and superstring theories, predict the existence of the monopole.*

- ***Dirac** felt that he "would be surprised if Nature had made no use of it". It, being the Magnetic Monopole.*

- ***Ed Witten** once asserted in his Loeb Lecture at Harvard, "almost all theoretical physicists believe in the existence of magnetic monopoles, or at least hope that there is one."*

MoEDAL Addresses Fundamental Questions:

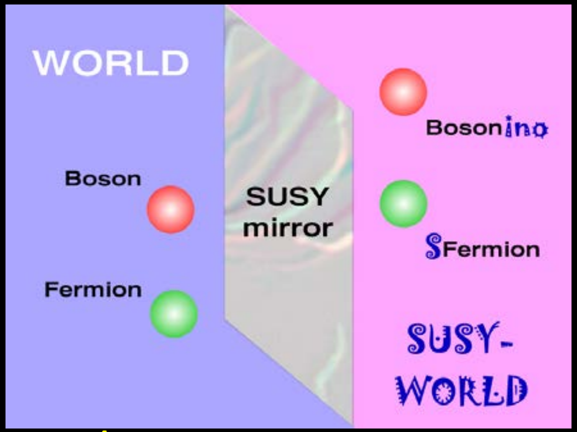
Are there extra dimensions?



Does magnetic charge exist?

What is the nature of Dark matter?

What happened just after the big bang?



Are there new symmetries of nature?

A new LHC discovery frontier will open at 13-14TeV in 2015 - stay tuned