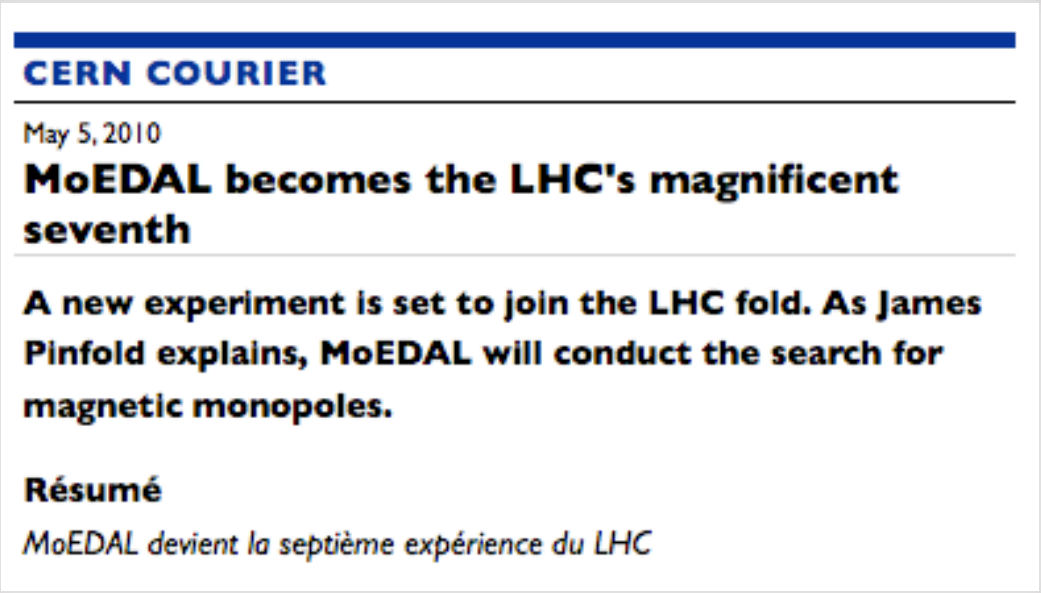
The MoEDAL Experiment – a New Light on the LHC Physics

CAP Congress 2015
James L. Pinfold
The University of Alberta

MoEDAL the 7^{th} LHC Experiment

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



CERN COURIER

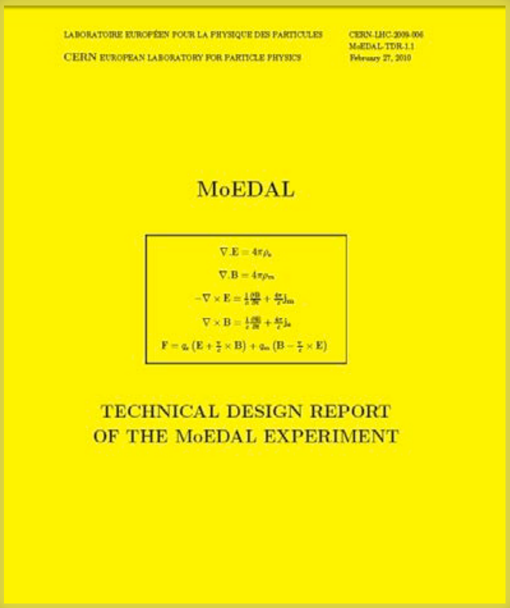
May 5, 2010

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

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

TECHNICAL DESIGN REPORT
OF THE MoEDAL EXPERIMENT

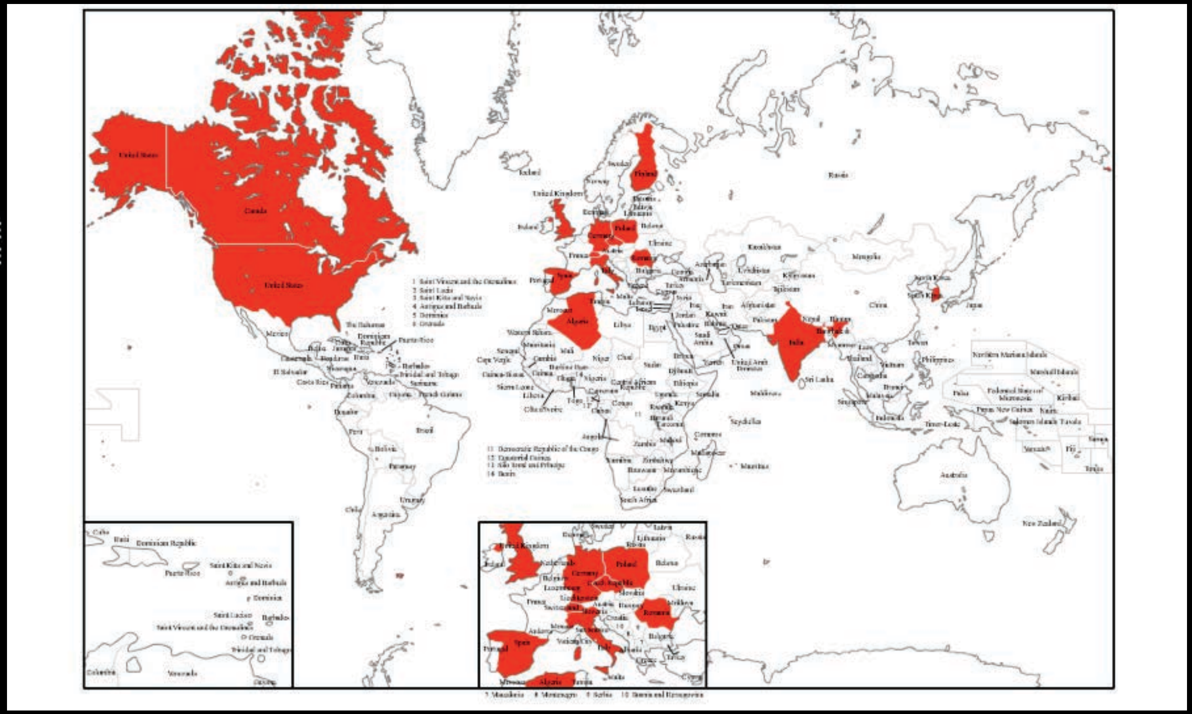
- *The CERN Research Board (CRB) unanimously approved the MoEDAL during their 190^{th} meeting on Dec. 3rd 2009 – it became official at there next meeting on March 10^{th}*
  - *This LHC experiment was proposed and is led by the UofA*

THE MAGNIFICENT SEVENTH

They fought on the high energy frontier

ATLAS		LHCb		TOTEM		MoEDAL
STEVE MCQUEEN	JAMES COBURN	HORST BUCHHOLZ	YUL BRYNNER	BRAD DEXTER	ROBERT VAUGHN	CHARLES BRONSON
	"BRITT"	"CHICO"	"CHRIS ADAMS"	"HARRY LUCK"	"LEE"	"BERNARDO O'REILLY"
	CMS		ALICE		LHCf	

The MoEDAL Collaboration

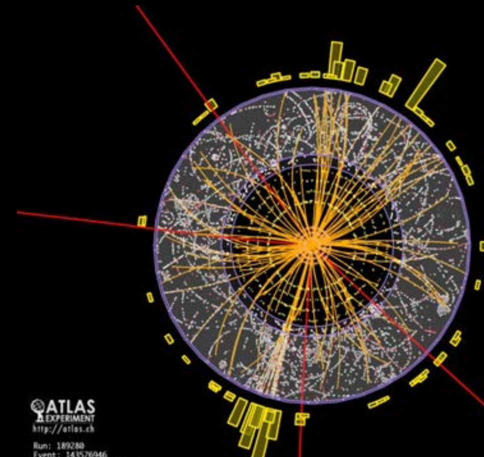


66 physicists from 14 countries & 25 institutes. on 4 continents:

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*

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

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

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

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

  - *The velocity dependence of the Lorentz force cancels 1/β^2 term*
  - *The ionization of a rel. monopole is $4700n^2$!! (n=1,2,3…) that of a MIP*

The MoEDAL Physics Program

MoEDAL's Physics Program - 34 scenarios

The search for the highly ionizing particle avatars of new physics

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. Posnisil ... akellariadou, S. Sarkar, G. Semenoff, G. Sirri, K. Sliwa, R. Soluk, M. Spurio, Y.N. Srivastava, R. Staszewski, J. Swain, M. Tenti, V. ... ykydal, A. Widom, et al. (1 additional author not shown)

(Submitted on 29 May 2014 (v1), last revis...

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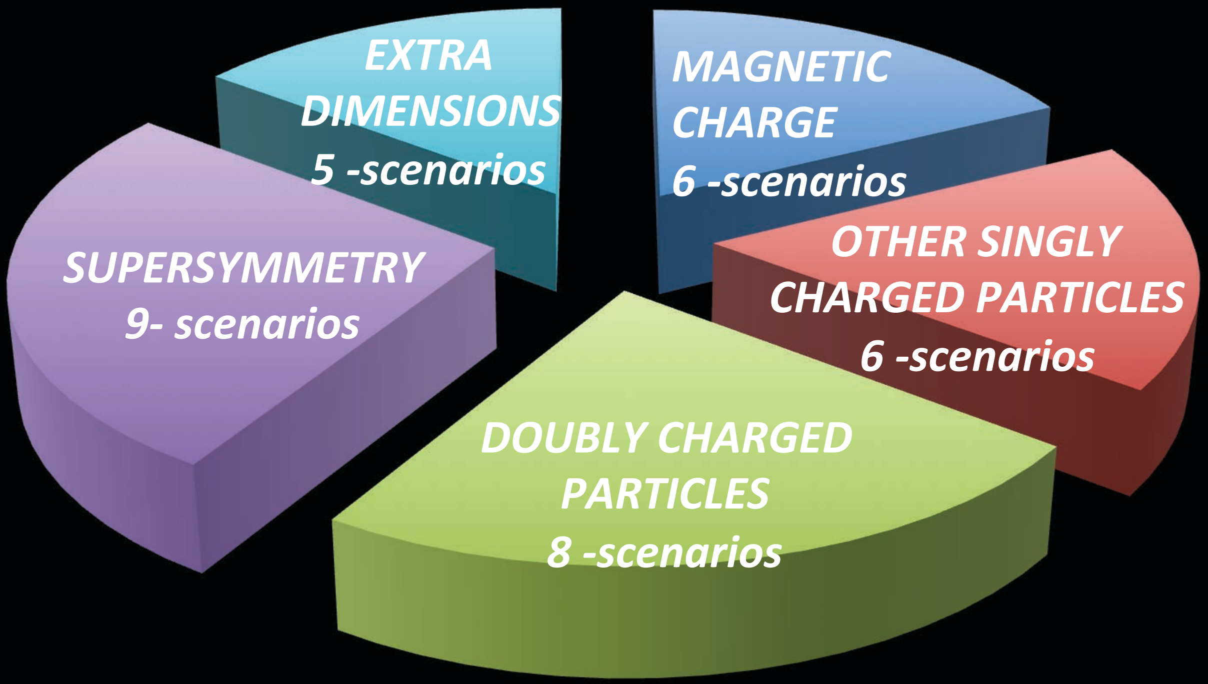
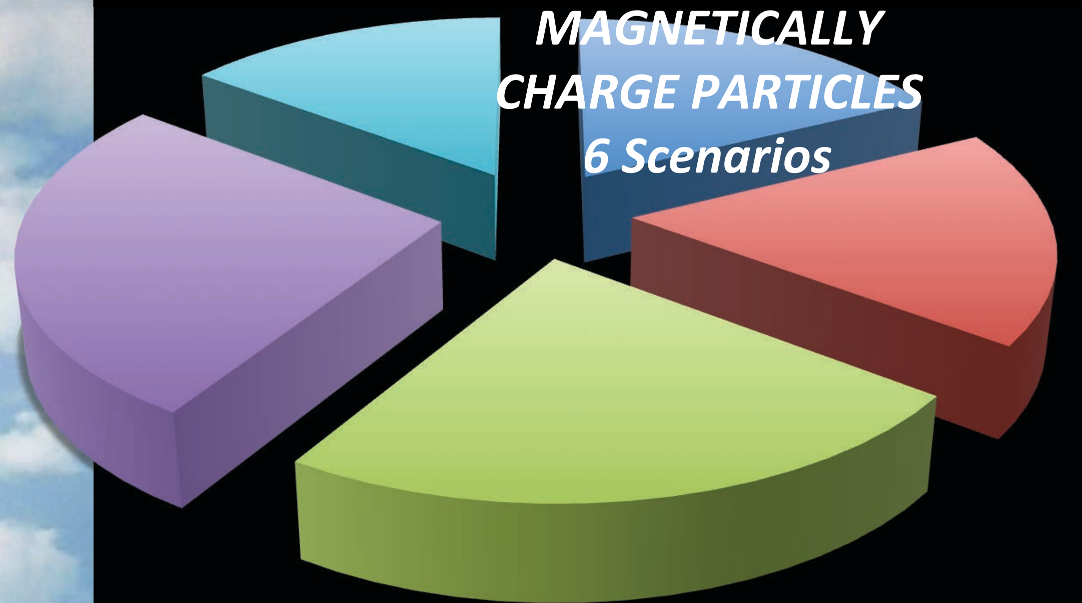
International Journal of Modern Physics A Vol. 29, No. 23 (2014) 1430050 (91pages)

The MoEDAL experiment at Point 8 o... the Standard Model, extending significantly the discovery ... AL is an unconventional and largely passive LHC detector co... 8 on the LHC ring. Another novel feature is the use of paramagne... predicted in new physics scenarios. It includes an array of TimePix pixel devices for monitoring ... detector do not require a trigger system, electronic readout, or online computerized data acquisition. The ... physics reach, which is largely complementary to the programs of the large multi-purpose LHC detectors ATLAS and CMS.



Massive Magnetically Charged Particles

6 SCENARIOS

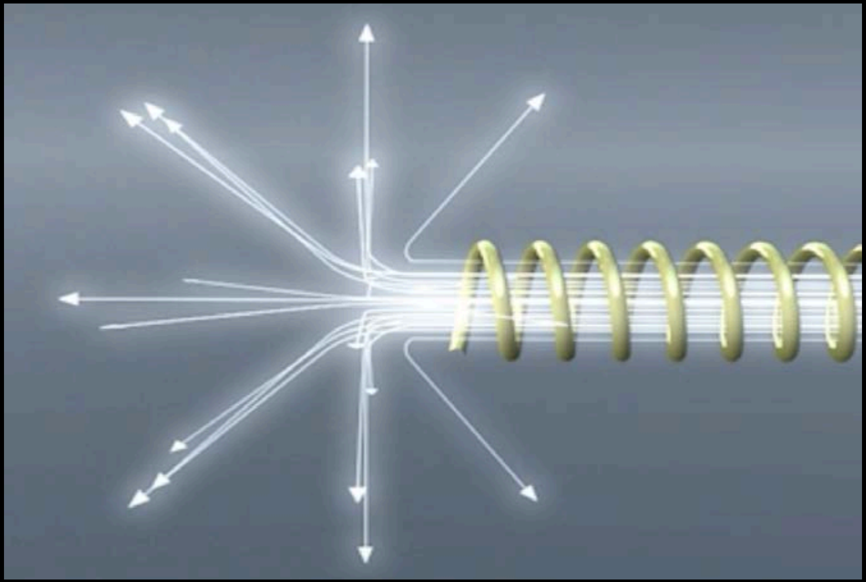


- *Dyons/Monopoles in general*
- *Electroweak Monopole*
- *Electroweak strings*
- *Light 't Hooft-Polyakov monopoles*
- *Monopolium*
- *D-particles*

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!*

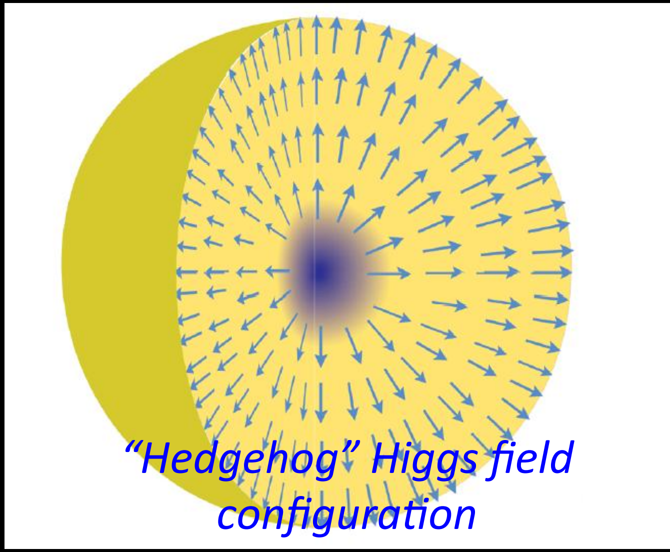
Dirac's Monopole

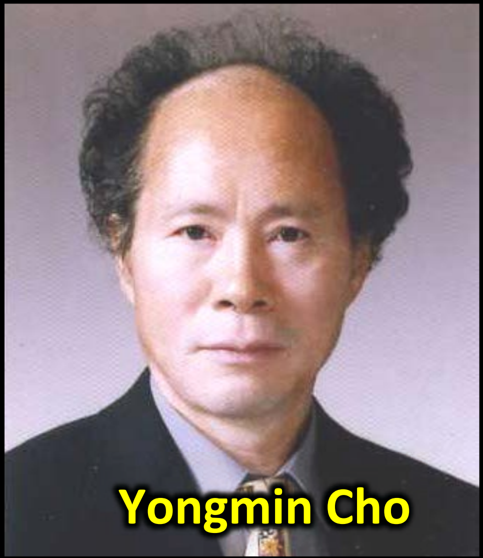


- *In 1931 Dirac hypothesized that the Monopole exists as the end of an infinitely long and thin solenoid - the "Dirac String"*
- *Requiring that the string is not seen gives us the Dirac Quantization Condition & explains the quantization of charge!*

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

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*
  - *His monopole arises from the Weinberg Salam model*
- *Such monopoles are topological solitons like a knot in the Standard Model Higgs field configuration*
- *The Cho-Maison monopole could be detected at the LHC*

Magnetic Monopole Properties

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

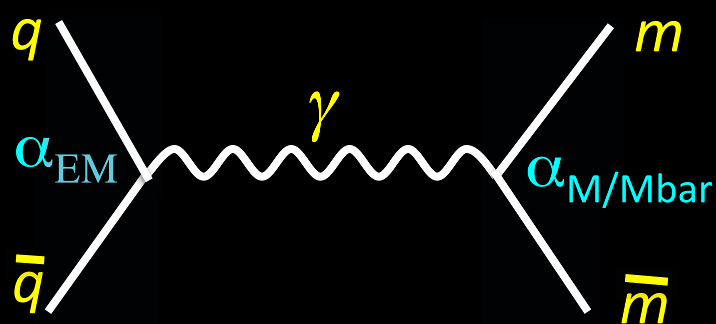
Coupling constant = g/ħc ~ 34. Spin ½?

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

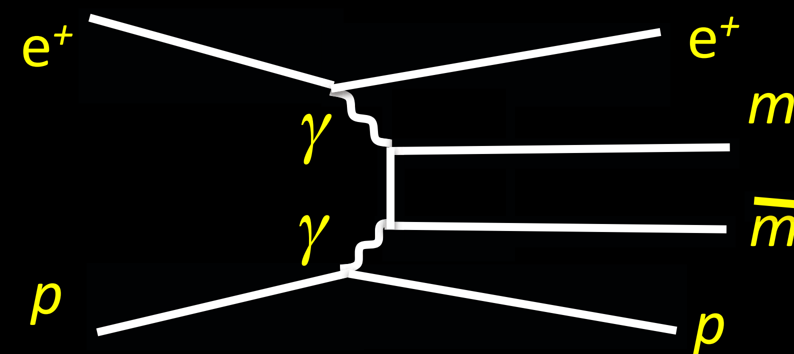
The monopole mass is not predicted within the Dirac's theory, ~ 4-7 TeV EW monopole

Monopole Production at Colliders

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

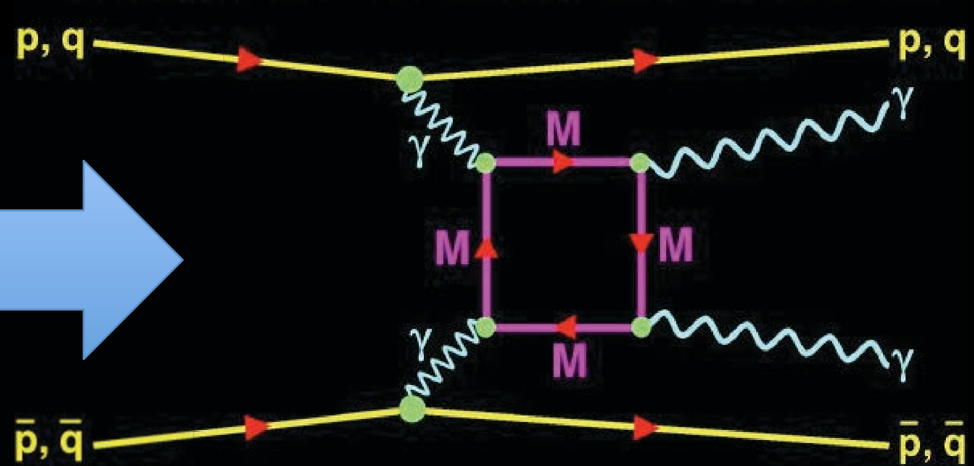


Drell-Yan Production



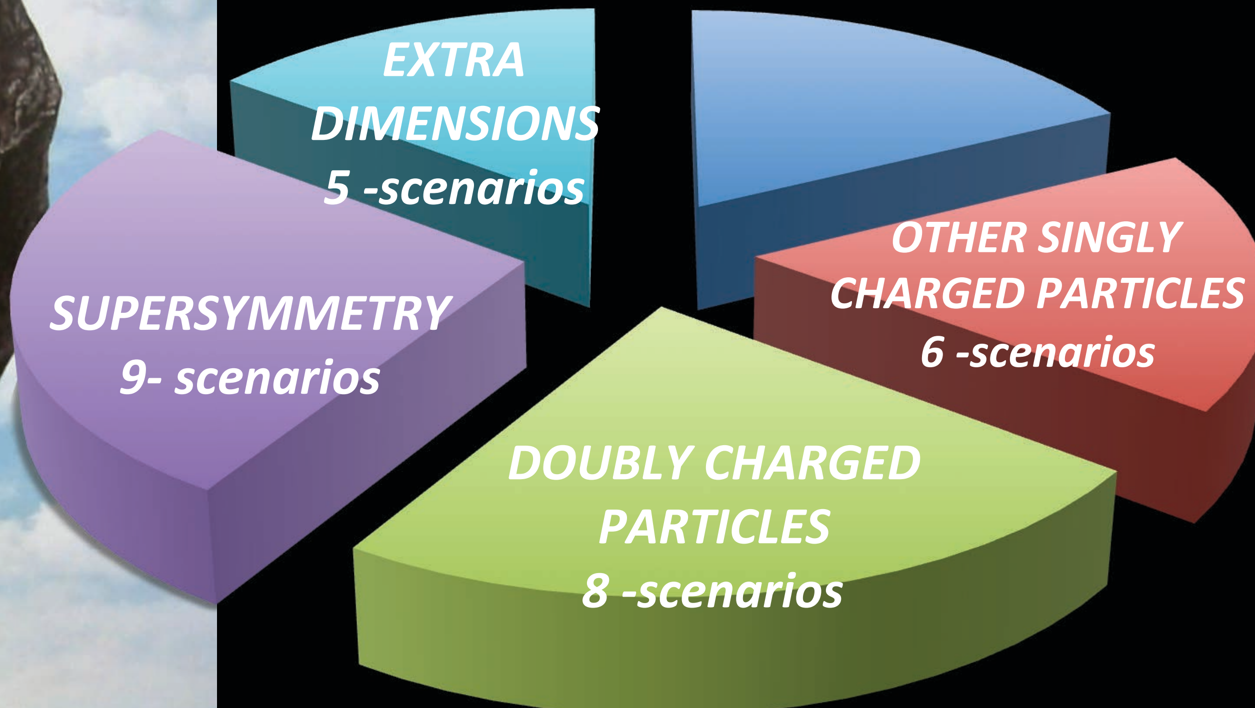
Two-photon production

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



Massive “Stable” Electrically Charged Particles

~30 SCENARIOS

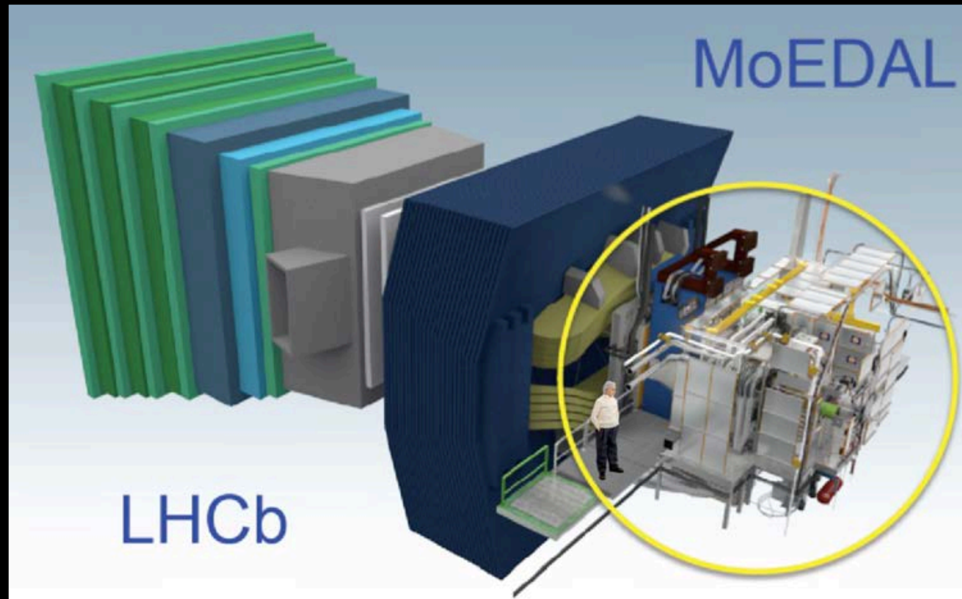


Examples: Massive “Stable” Charged Particles

The MOEDAL Detector

MoEDAL – a Unique Collider Detector

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

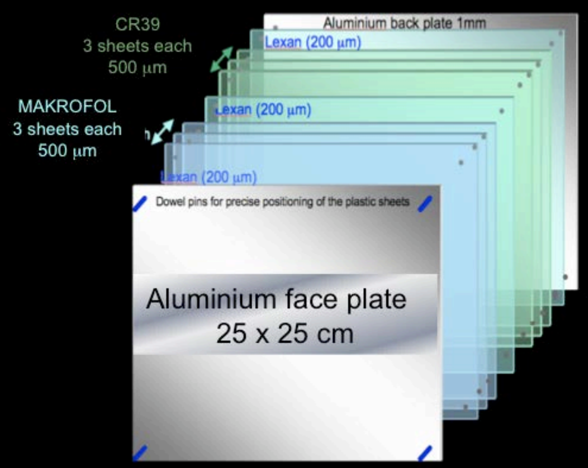
MoEDAL is largely passive made up of three detector system.

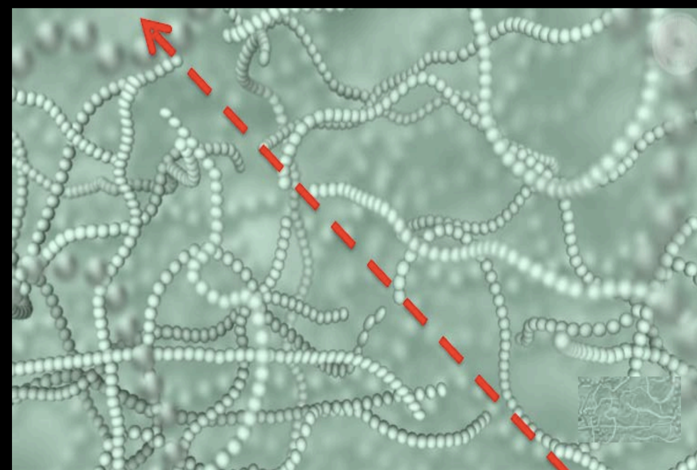
NUCLEAR TRACK DETECTOR
Plastic array (~200 sqm)
– Like a Giant Camera

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

TIMEPIX Array a digital Camera for real time radiation monitoring

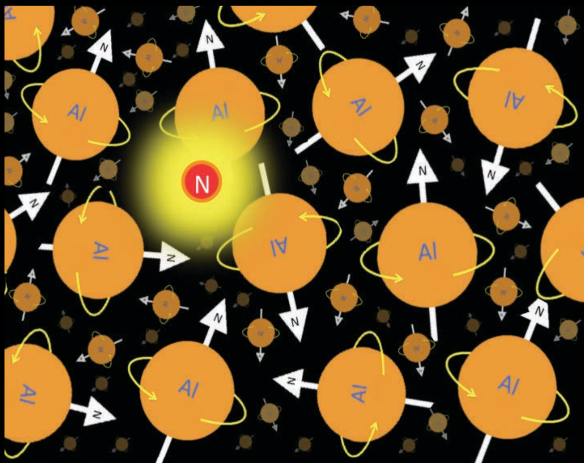
The Nuclear Track Detector System





- *Largest array (150 m^2 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

MoEDAL's Complementarity

Designed & Optimized for highly ionizing particles

Insensitive to SM particles

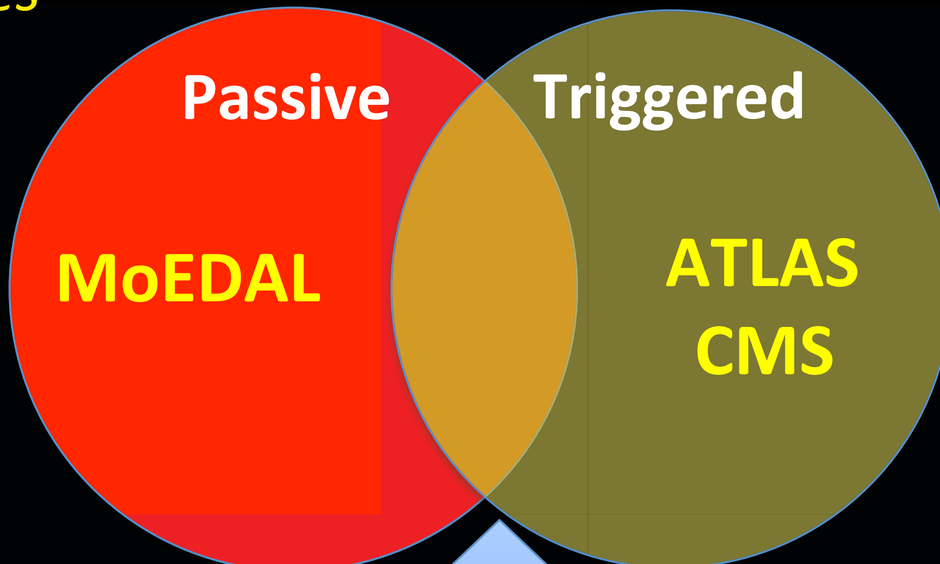
Mass ~ 1 ton

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

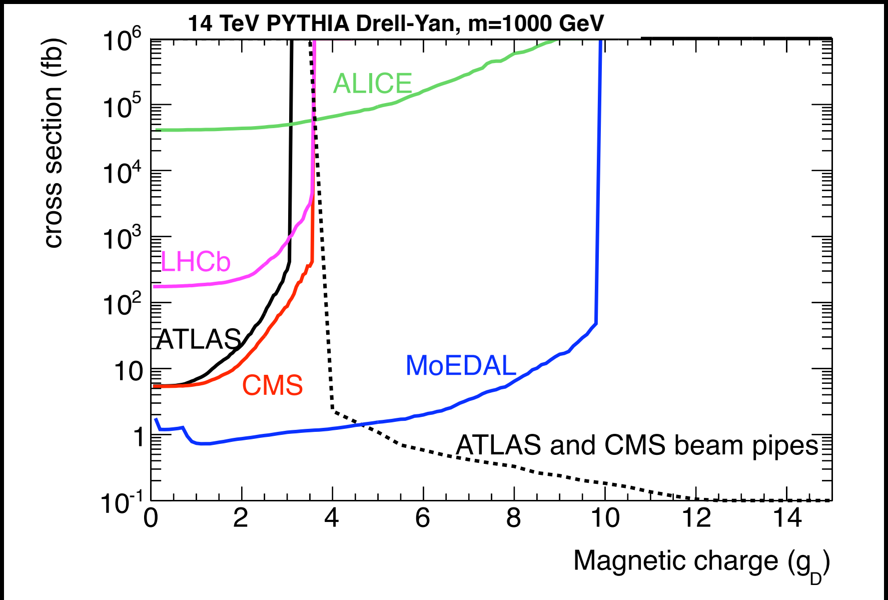
Cannot detect magnetic charge

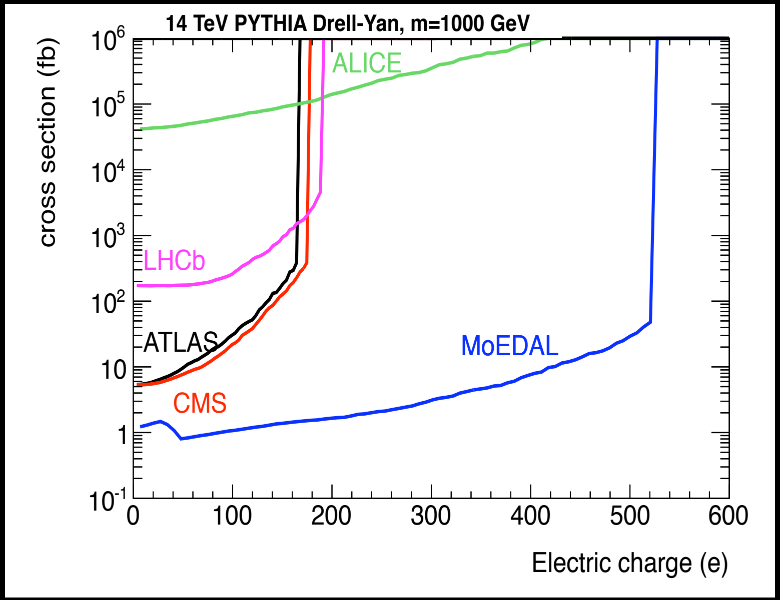
Cannot be directly calibrated for HIPs

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 Sensitivity

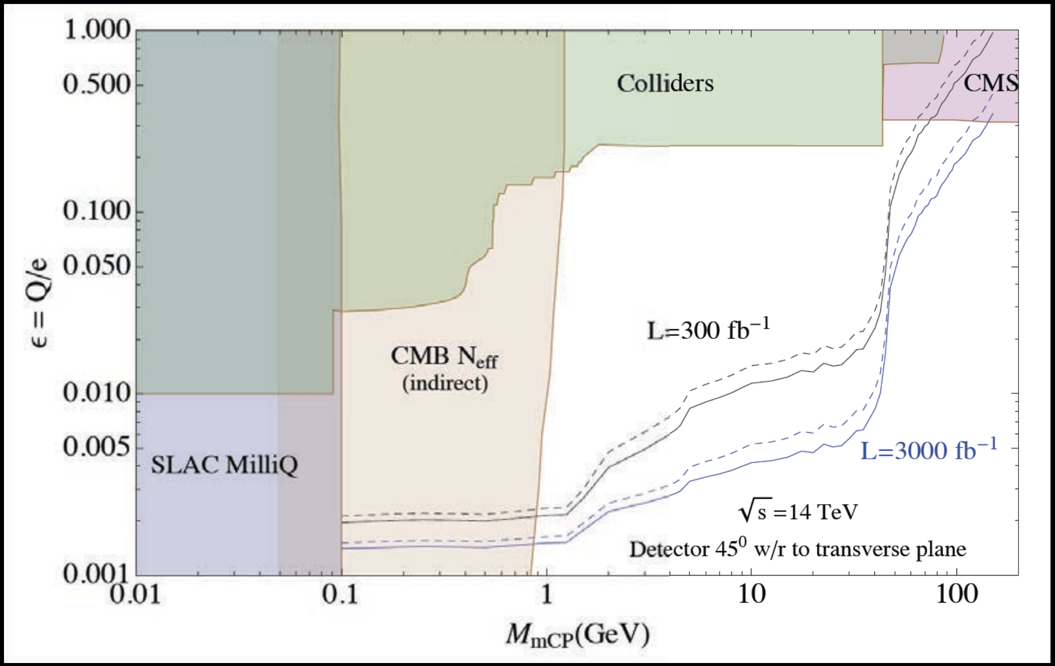
detector	energy threshold	angular coverage	luminosity	robust against timing	robust efficiency
ATLAS	medium	central	high	no	no
CMS	relatively low	central	high	no	no
ALICE	very low	very central	low	yes	no
LHCb	medium ✔	forward	medium	no	no
MoEDAL	low	full ✔	medium ✔	yes ✔	yes ✔





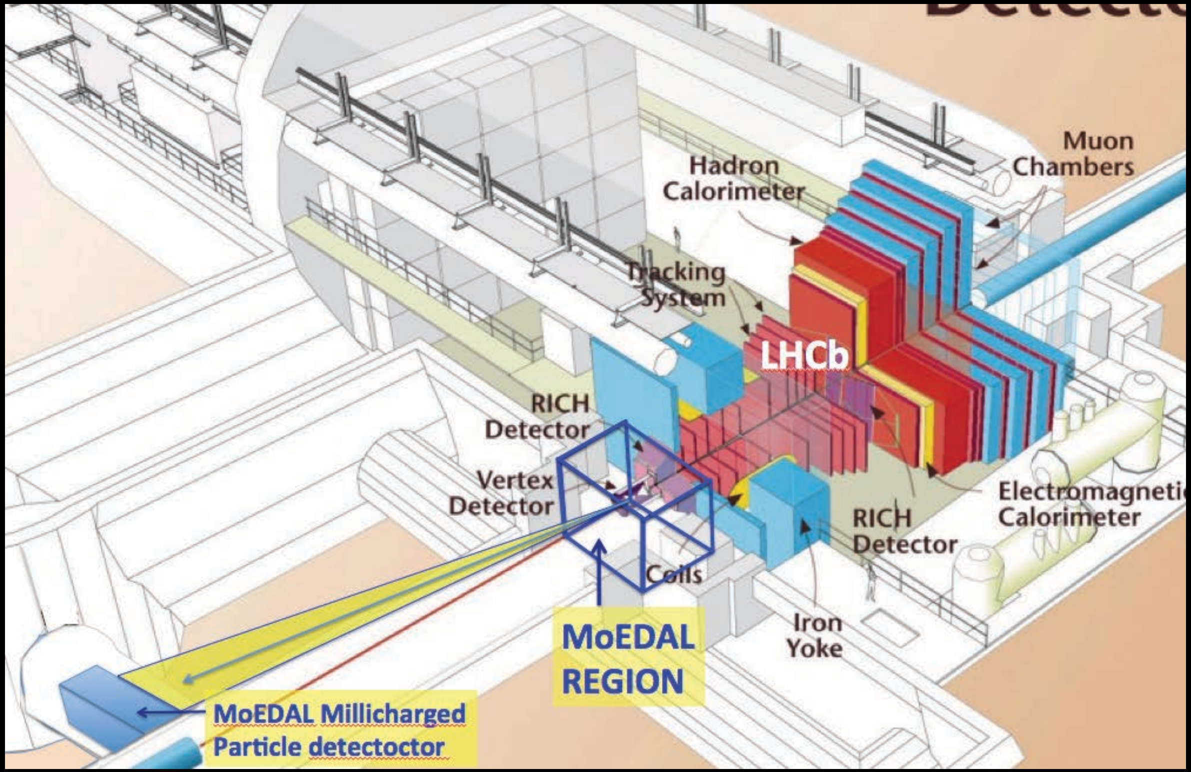
- *Cross-section limits for magnetic (LEFT) and electric charge (RIGHT) (from* ***arXiv:1112.2999V2*** *[hep-ph])*
- *MoEDAL COMPLEMENTS the physics reach of the existing LHC experiments*

MoEDAL's Phase-II Physics Challenge?



- *Search for millicharged particles 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

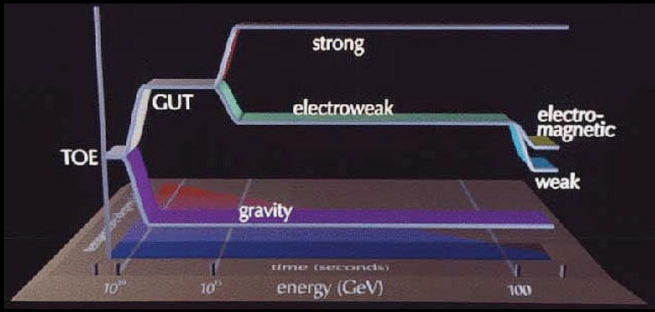


- *MoEDAL is now working on a new sub-detector to search for millicharged particles (mQP) as low as 10^{-3}e*
  - *A location near to IP8 adjacent to the MoEDAL detector has been ID'ed*
  - *Fine segmentation, deep detectors, precise timing and triple layer coincidence will be used to get single photo-electron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

Closing Remarks

On the Existence of the Monopole (1)

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

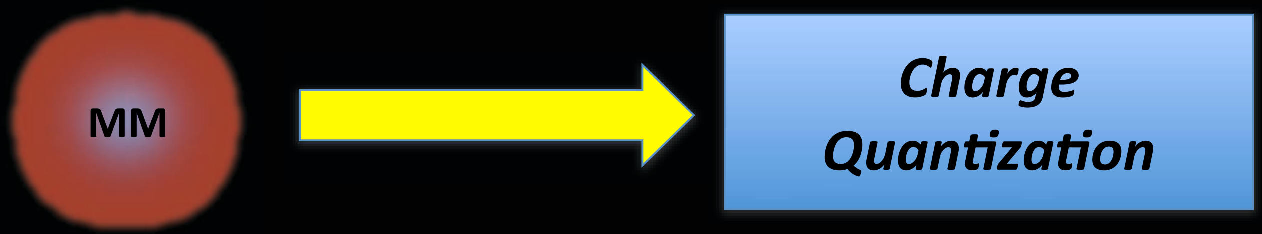


- ***Dirac** felt that he "would be surprised if Nature had made no use of it". It, being the Magnetic Monopole.*

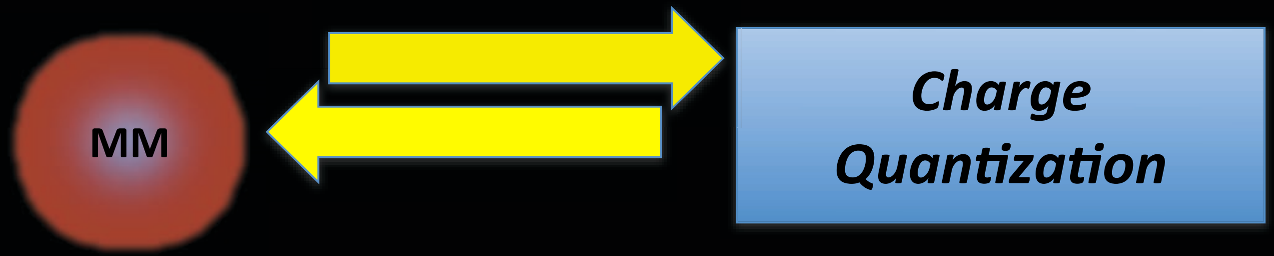
- ***Ed Witten** once asserted in his Loeb Lecture at Harvard, "almost all theoretical physicists believe in the existence of magnetic monopoles, or at least hope that there is one."*

The Polchinski Conjecture

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

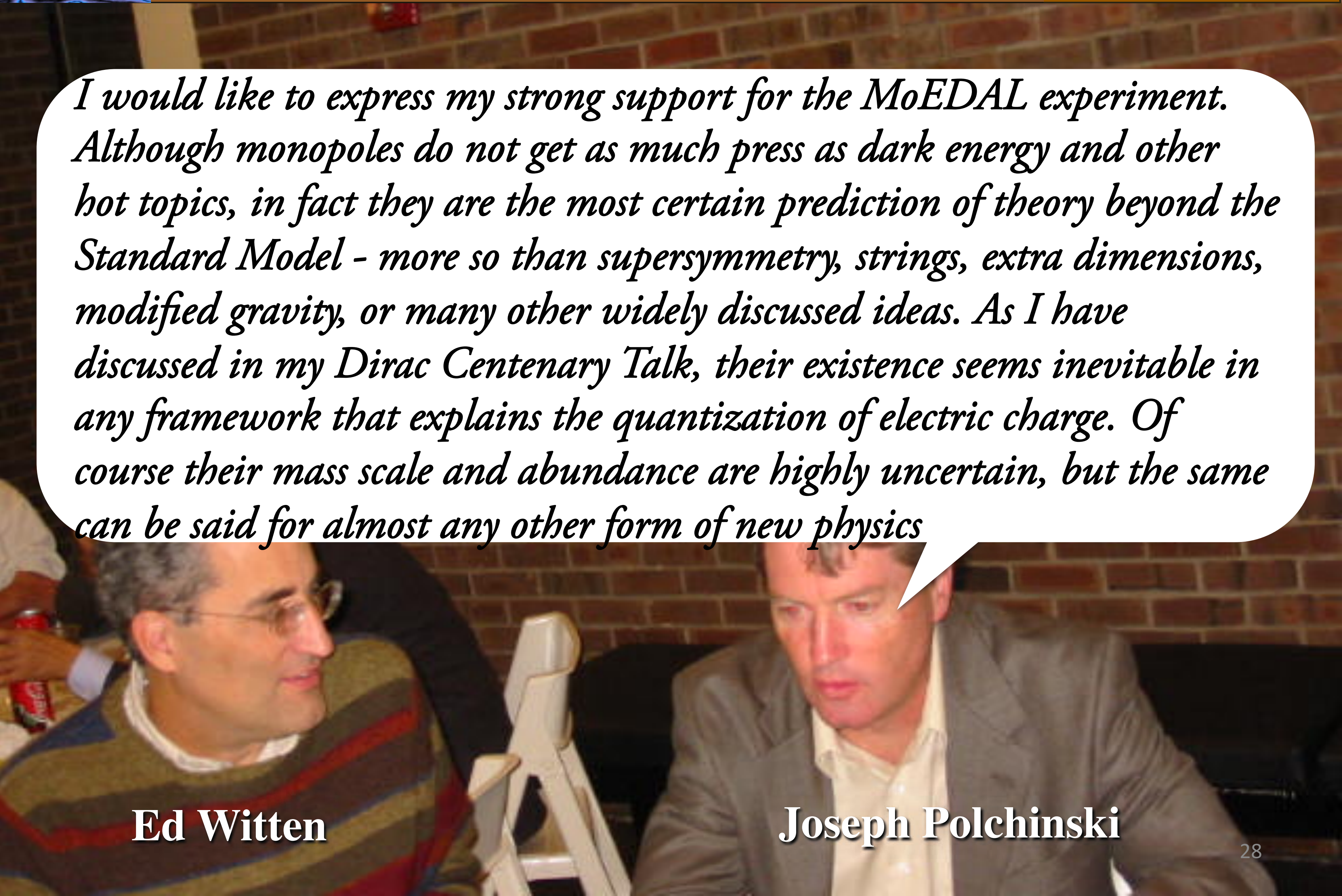


- *Thus, Polchinski conjectured, any theory requiring charge quantization must have a monopole*



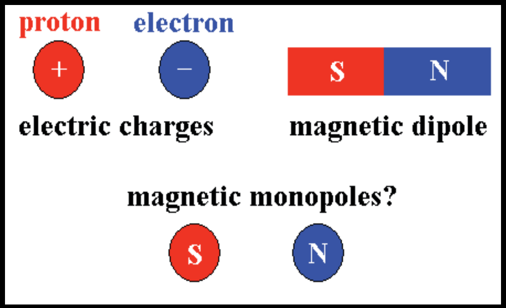
- *He also maintains that in any fully unified theory, for every gauge field there will exist electric and magnetic sources.*

Polchinski on MoEDAL



MoEDAL Addresses Fundamental Questions:

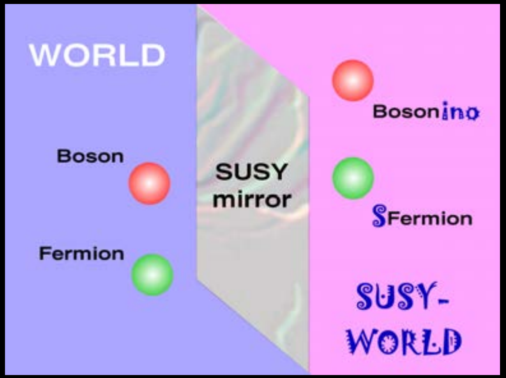
Are there extra dimensions?



Does magnetic charge exist?

What is the nature of Dark matter?

What happened just after the big bang?

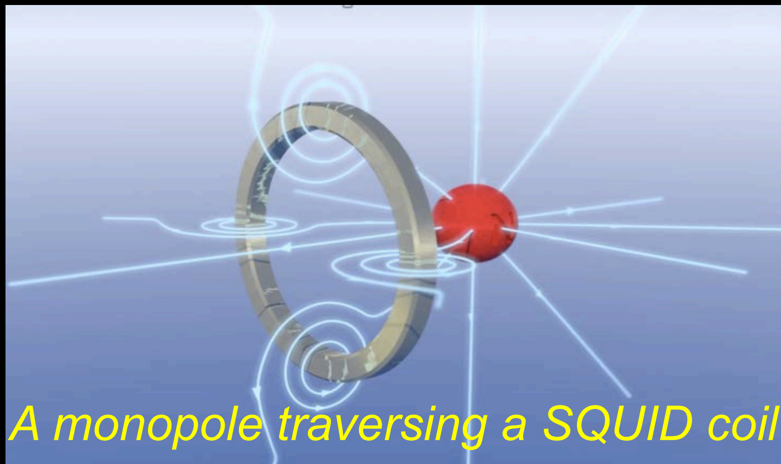


Are there new symmetries of nature?

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 (or join us)

EXTRA SLIDES

Induction Experiments - Evidence?



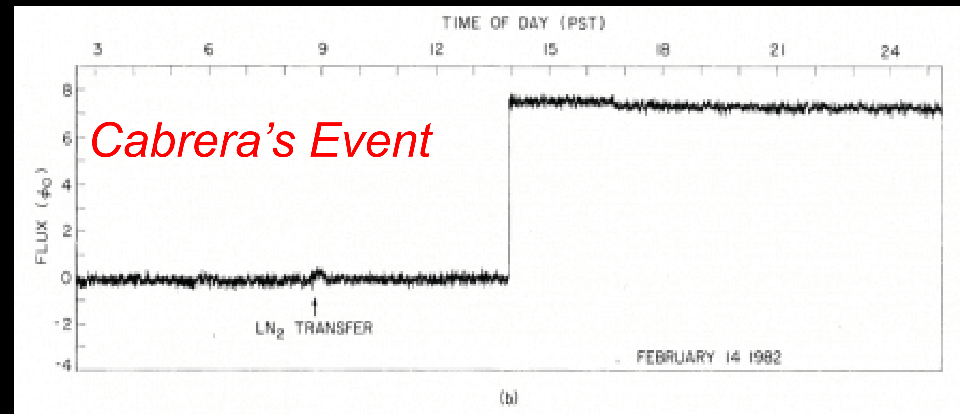
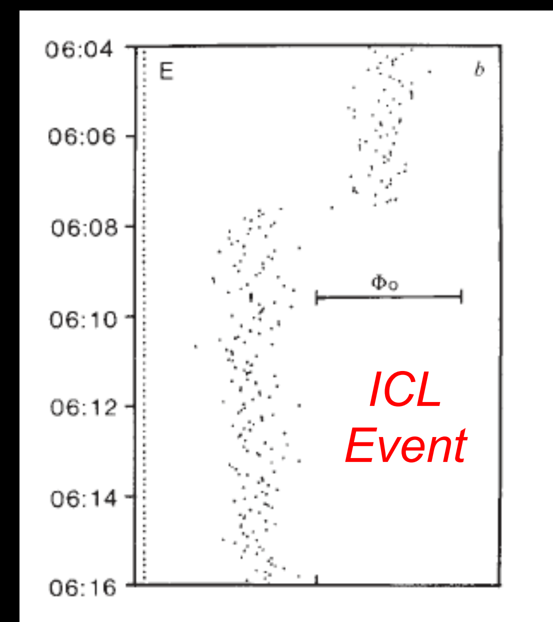


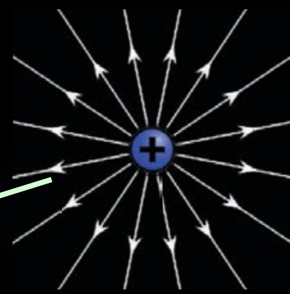
FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.

- *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*

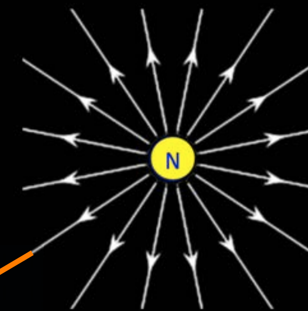


150th Anniversary of Maxwell's Equations

Monopoles Symmetrize Maxwell's Eqns



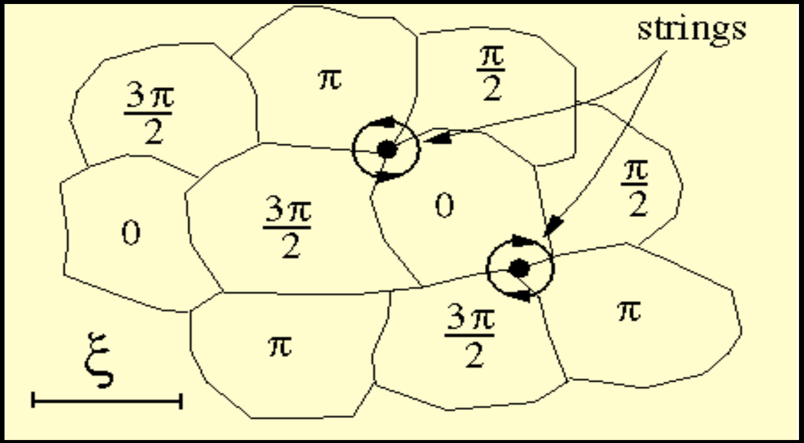
$$\vec{\nabla}\cdot\vec{E} = \rho_{\mathrm{E}}$$
$$\vec{\nabla}\cdot\vec{B} = 0$$
$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$
$$\vec{\nabla}\times\vec{B} = \frac{\partial\vec{E}}{\partial t} + \vec{j}_{\mathrm{E}}$$

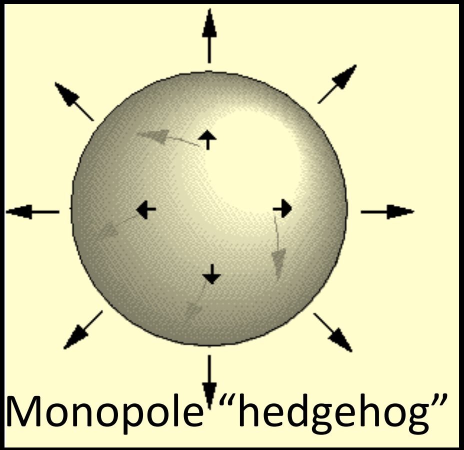


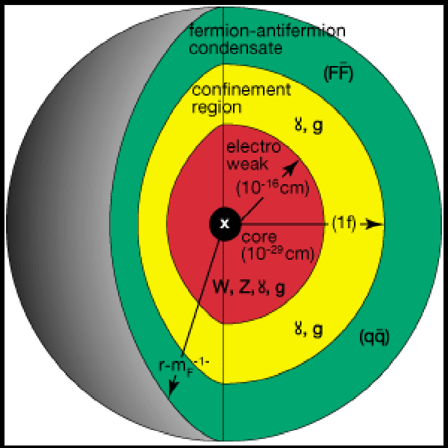
$$\vec{\nabla}\cdot\vec{E} = \rho_{\mathrm{E}}$$
$$\vec{\nabla}\cdot\vec{B} = \rho_{\mathrm{M}}$$
$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} - \vec{j}_{\mathrm{M}}$$
$$\vec{\nabla}\times\vec{B} = \frac{\partial\vec{E}}{\partial t} + \vec{j}_{\mathrm{E}}$$

- *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*
- *SEE VERY NICE TALK BY ARTTU RAJANTIE ON THE FIELD THEORY OF MAGNETIC MONOPOLES (Thursday parallel-9)*

The GUT Monopole



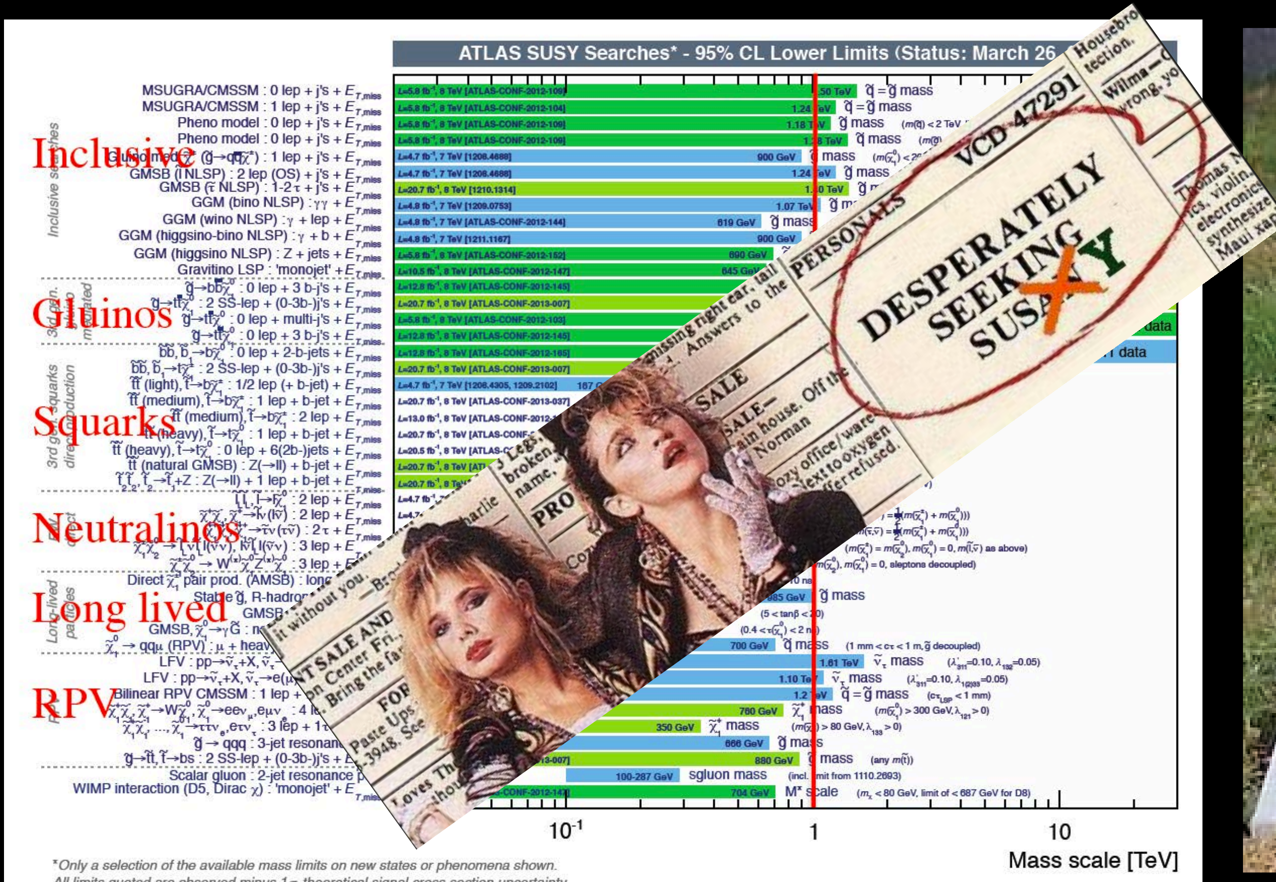




- *The structure of the SU(5) GUT is similar to the Georgi-Glashow EW theory – thus it also predicted 't Hooft-Polyakov with mass around 10^{16} GeV (or 10 ng in SI units).*
- *A symmetry-breaking GUT phase transition triggered the creation of topological defects (domain walls cosmic strings, monopoles) when the universe froze out at the GUT transition (Kibble-Zurek mechanism)*
- *GUTS+ standard cosmology leads to a monopole glut that enouraged Guth to introduce inflation to dilute their density*
- *They are obviously much too heavy to be produced on Earth*

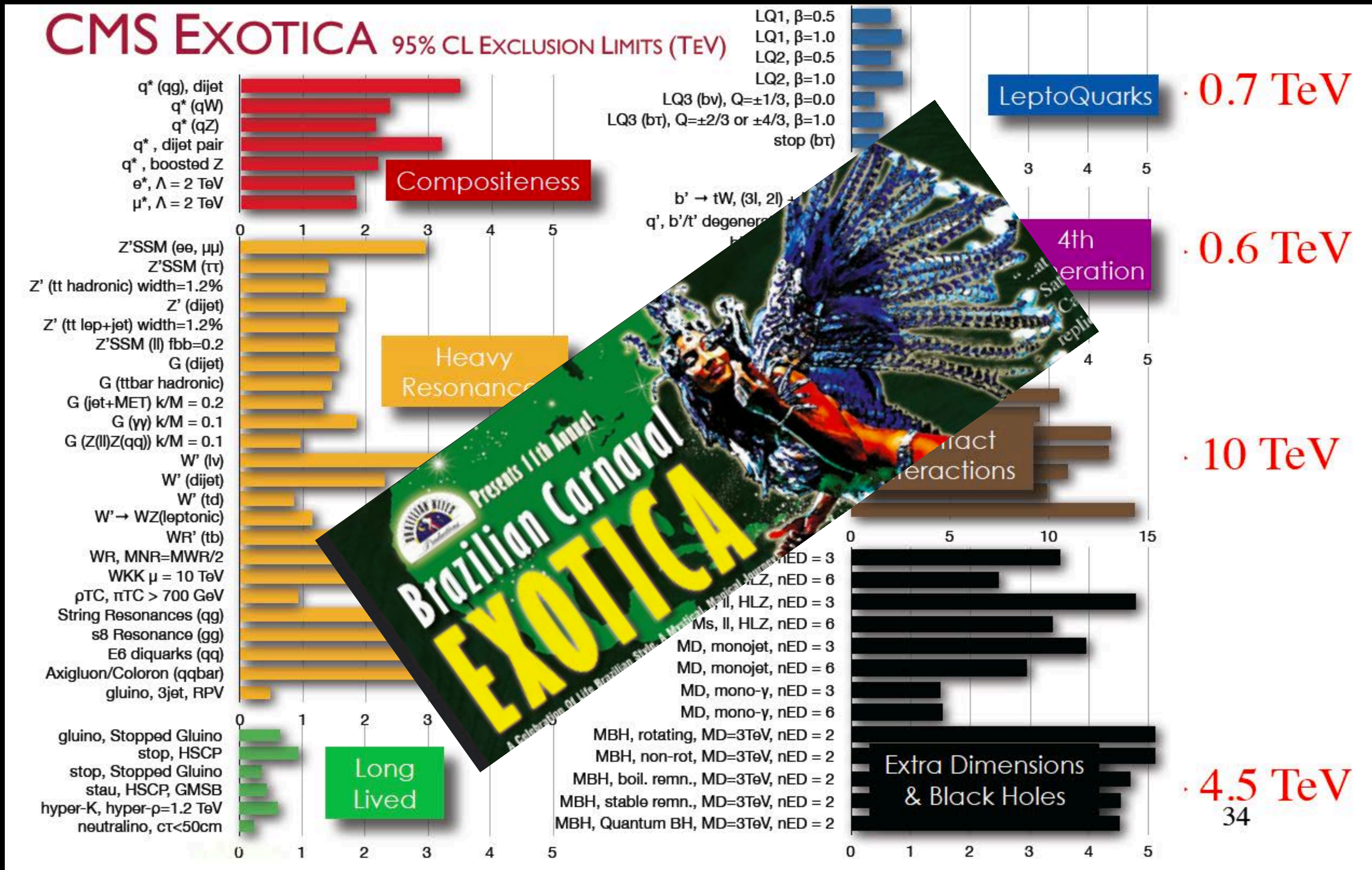
Talk is Not Specifically About Discrete Sym.

Seeking Supersymmetry



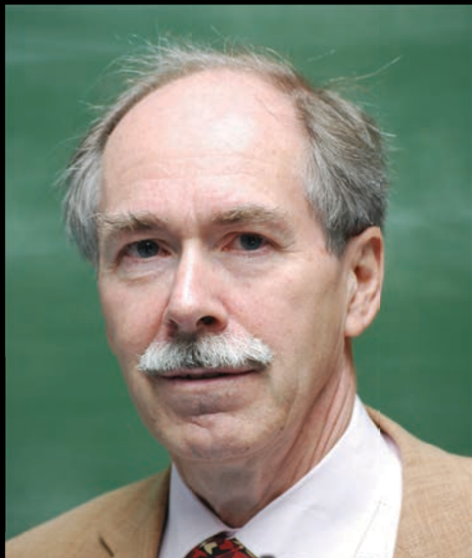
- *No evidence for SUSY at the LHC as yet but we should not despair - the search will continue in 2015 at 13.8 TeV and higher luminosity. MoEDAL will throw a new light on this search*

Other Searches Beyond the Standard Model

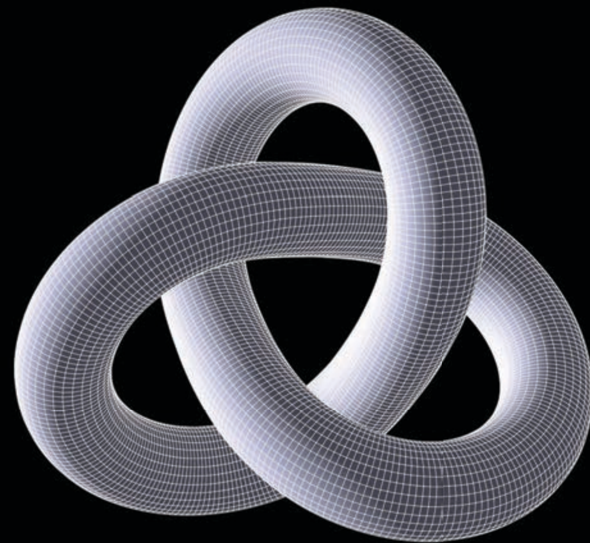


- *The search for physics beyond the Standard Model will continue at the LHC – MoEDAL expands this discovery horizon*

The ‘t Hooft-Polyakov Monopole



Gerard t’Hooft



Topological soliton

Alexander Polyakov

- *In 1974 ‘t Hooft and Polyakov showed that monopoles exist with the framework of Georgi-Glashow with an SO(3) GS broken to the U(1) of electromagnetism – with charge $2g_d$*
  - *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 with a topological charge*
  - ***Like a knot in the Higgs field configuration***

‘t Hooft’s & Polyakov’s Monopole 40th Birthday