The MoEDAL-LHC Experiment – a New Light on Terascale Physics

Dark Matter – Cairo Workshop

James L. Pinfold
The University of Alberta

MoEDAL the 7th 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

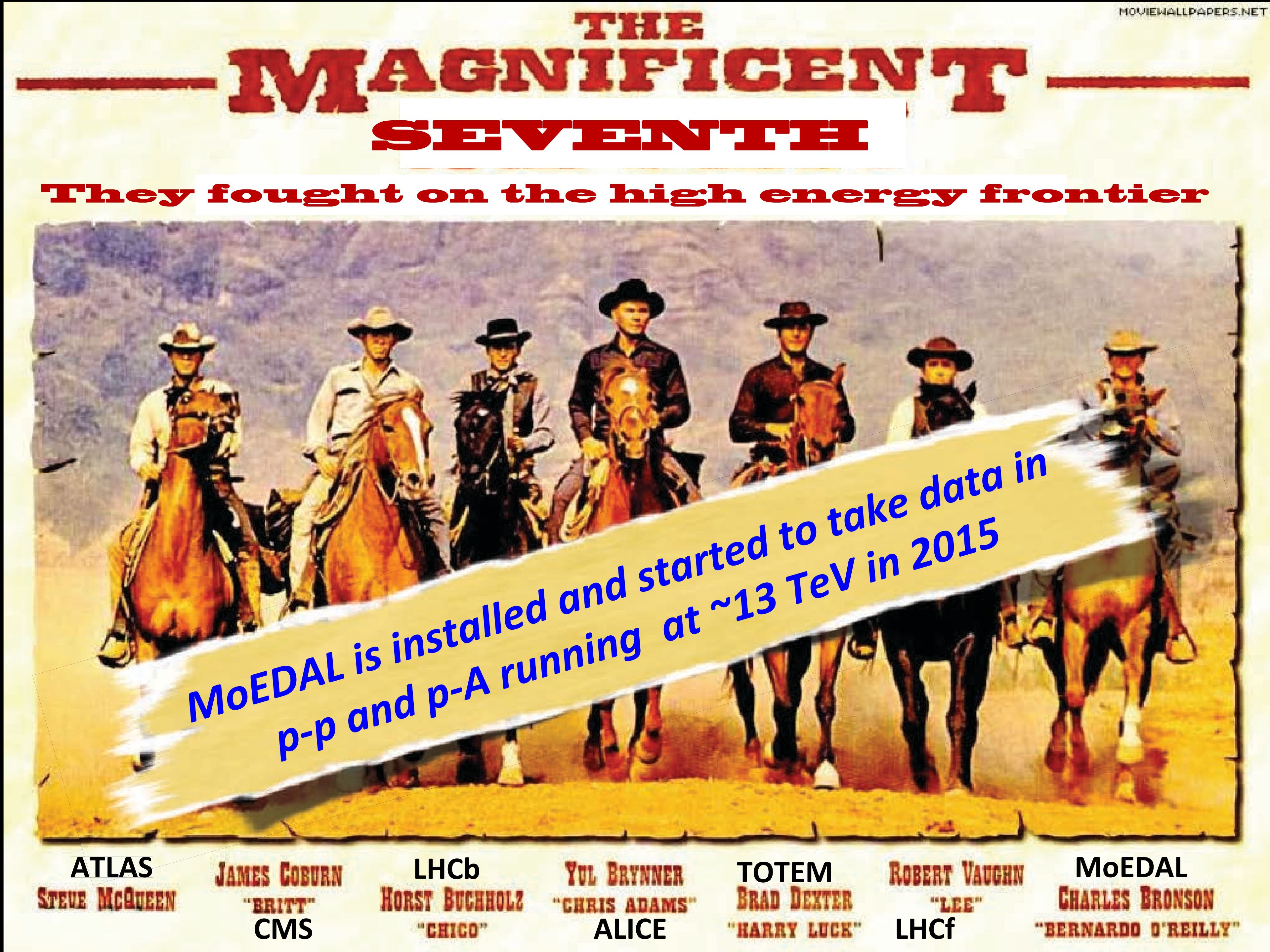
CERN-LHC-2009-006
MoEDAL-TDR-1.1
February 27, 2010

MoEDAL

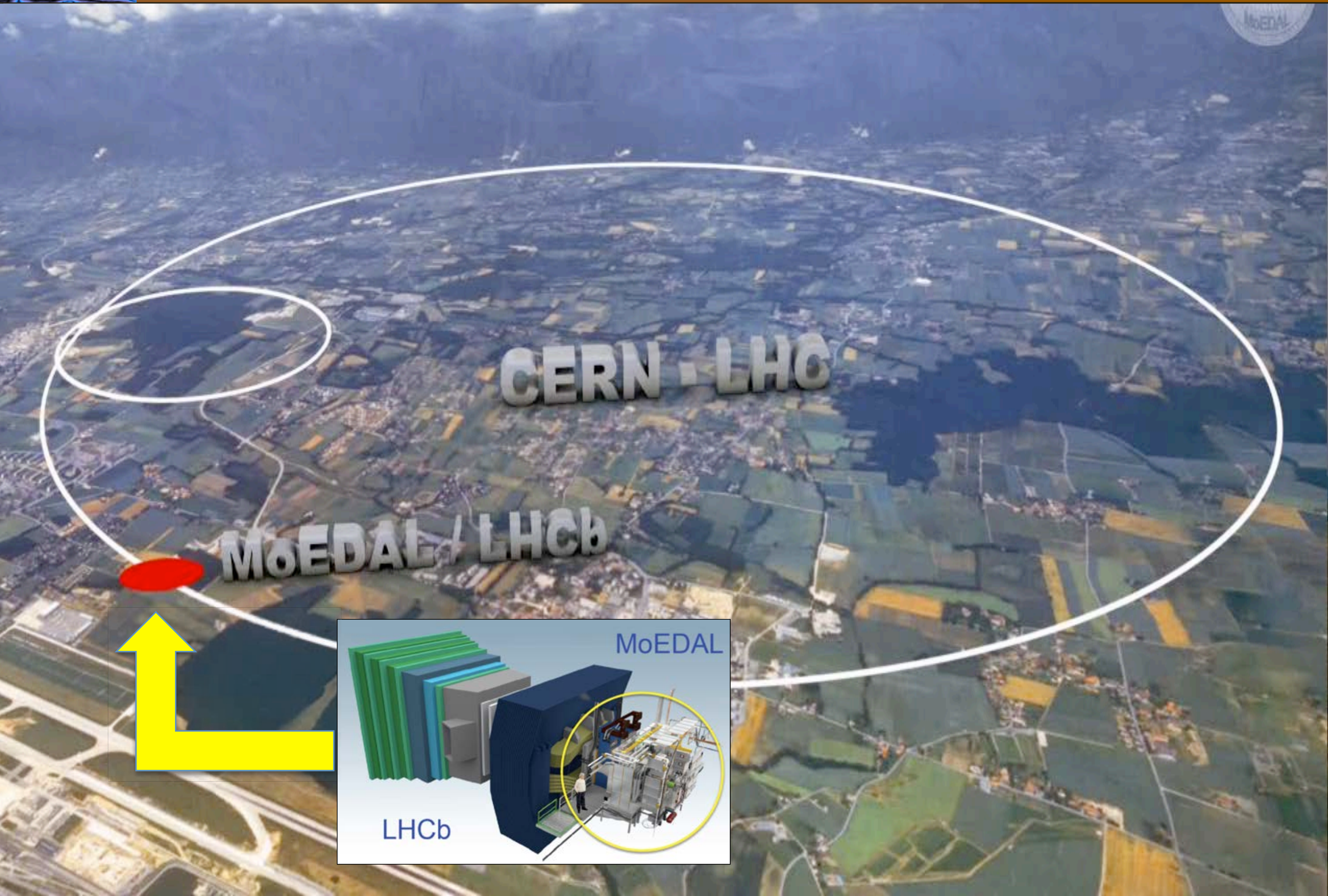
$$\nabla \cdot \mathbf{E} = 4\pi\rho_e$$
$$\nabla \cdot \mathbf{B} = 4\pi\rho_m$$
$$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_m$$
$$\nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_e$$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

TECHNICAL DESIGN REPORT
OF THE MoEDAL EXPERIMENT

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


MOVIEWALLPAPERS.NET
THE
MAGNIFICENT
SEVENTH
They fought on the high energy frontier
MoEDAL is installed and started 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



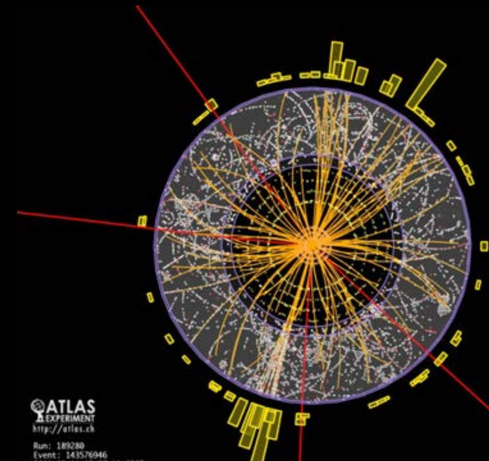
The MoEDAL Collaboration

66 physicists from 14 countries & 24 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, ISS Bucharest, King's College London, Konkuk U., U. Montréal, MISis Moscow, 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:



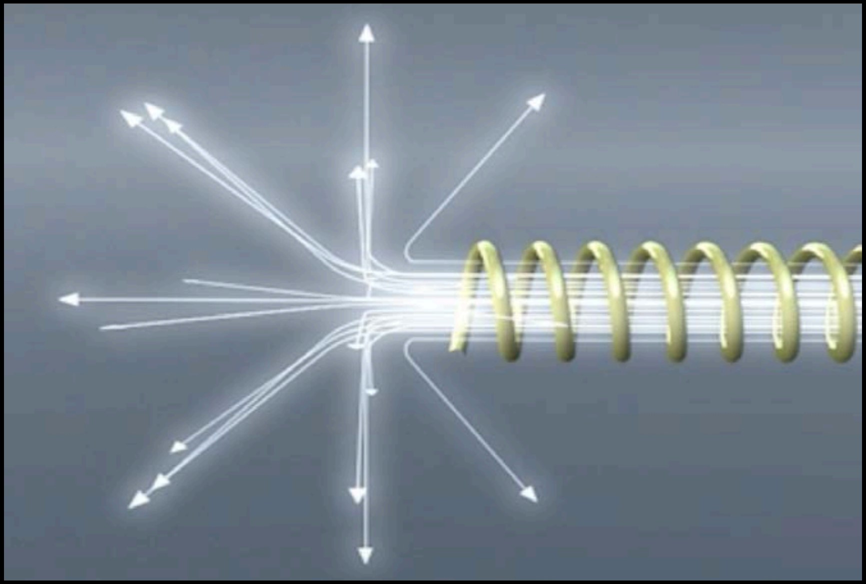
MoEDAL – Highly Ionizing Particles directly detected as messengers of new physics – no SM backgrounds

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

The 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!*

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

Magnetic Monopole Properties

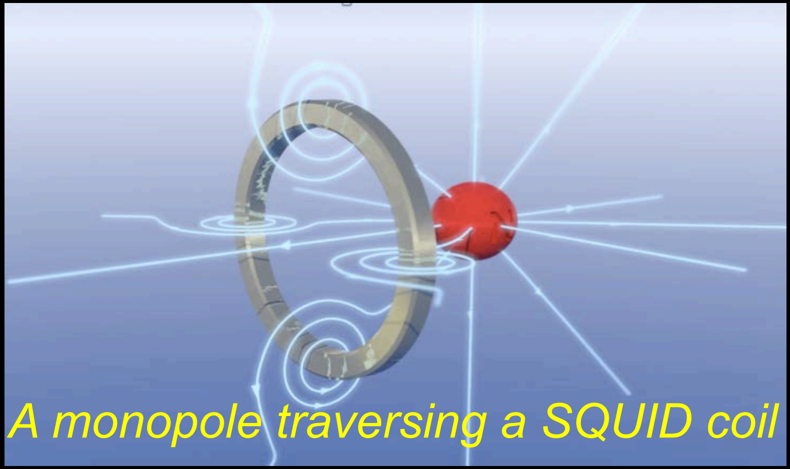
Magnetic charge
= ng = n68.5e
(if e→1/3e; g→3g)
HIGHLY IONIZING

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

Induction Experiments - Evidence?



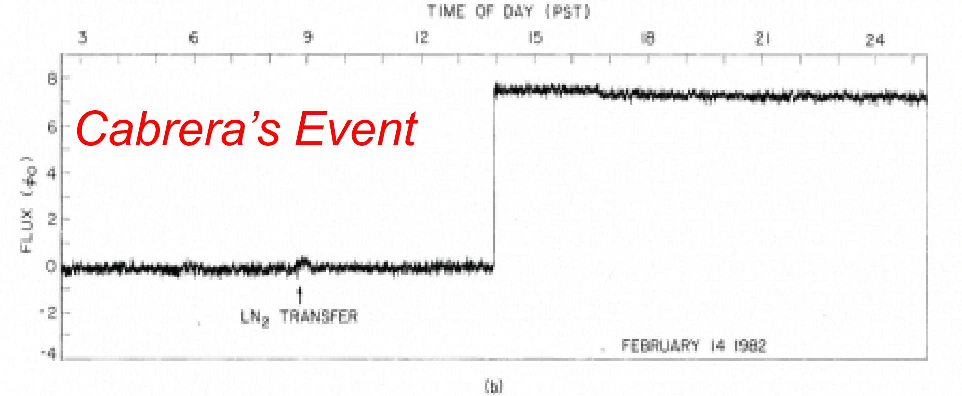
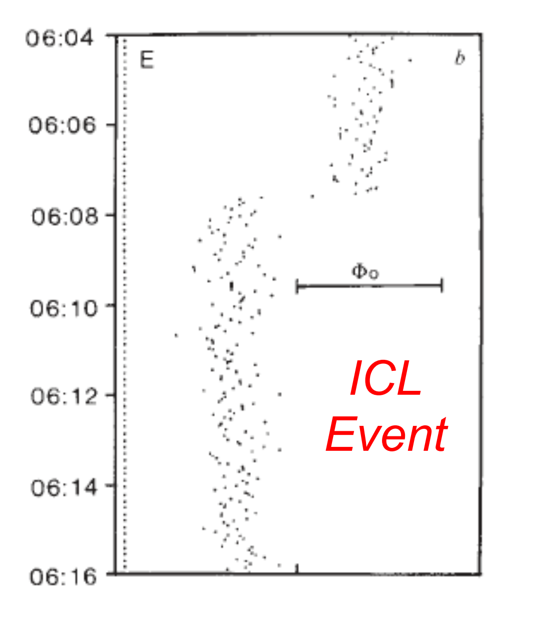


FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.

- *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*



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!

The MoEDAL Physics Program

34 New Physics 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. To... ...ykydal, A. Widom, et al. (1 additional author not shown)

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

The MoEDAL experiment at Point 8 o... the Standard Model, extending significantly the discovery ... AL is an unconventional and largely passive LHC detector co... ...oint 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.

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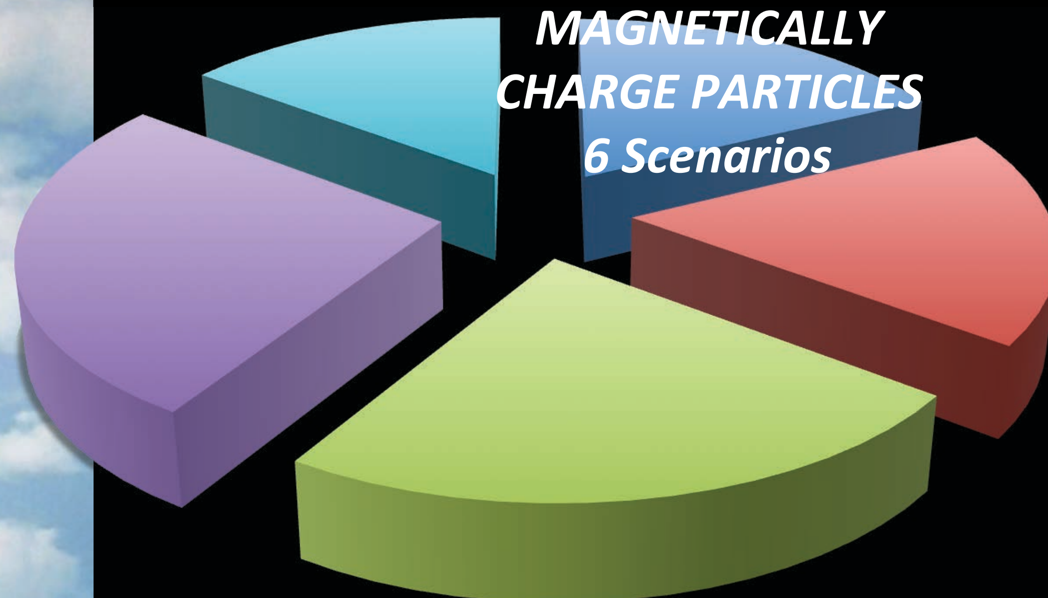
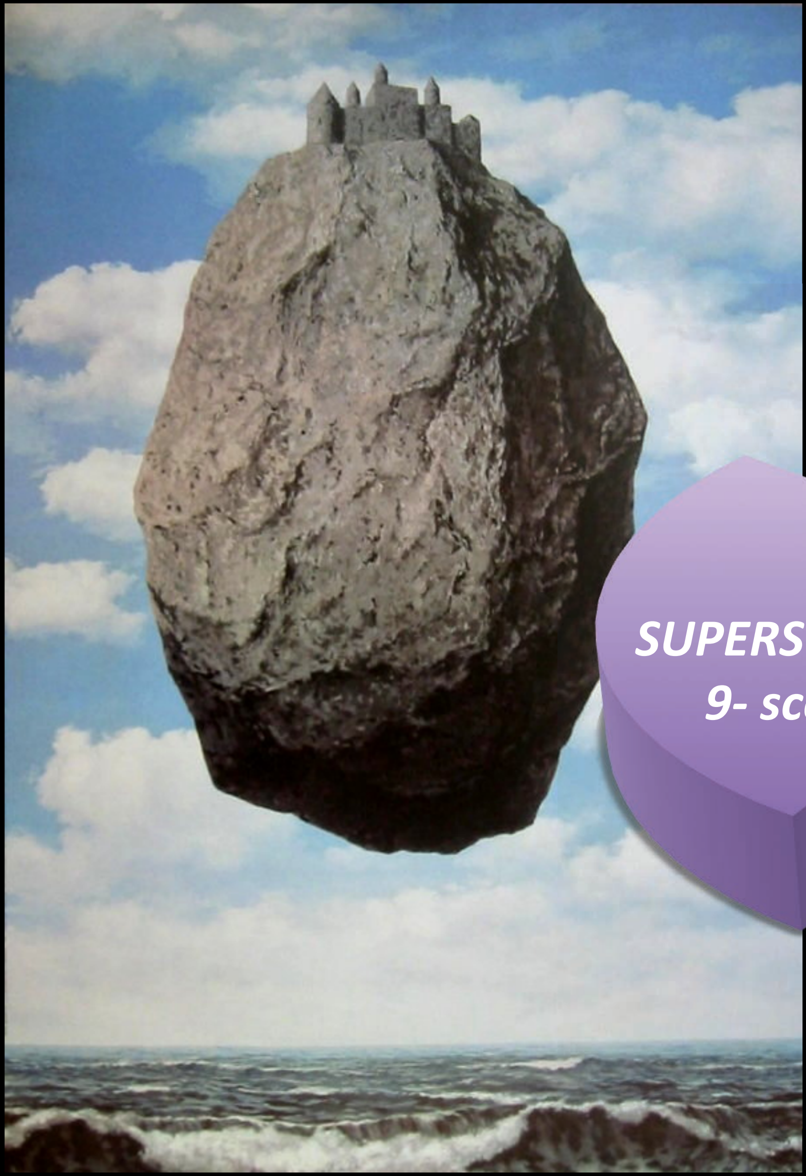
Massive Magnetically Charged Particles

6 SCENARIOS

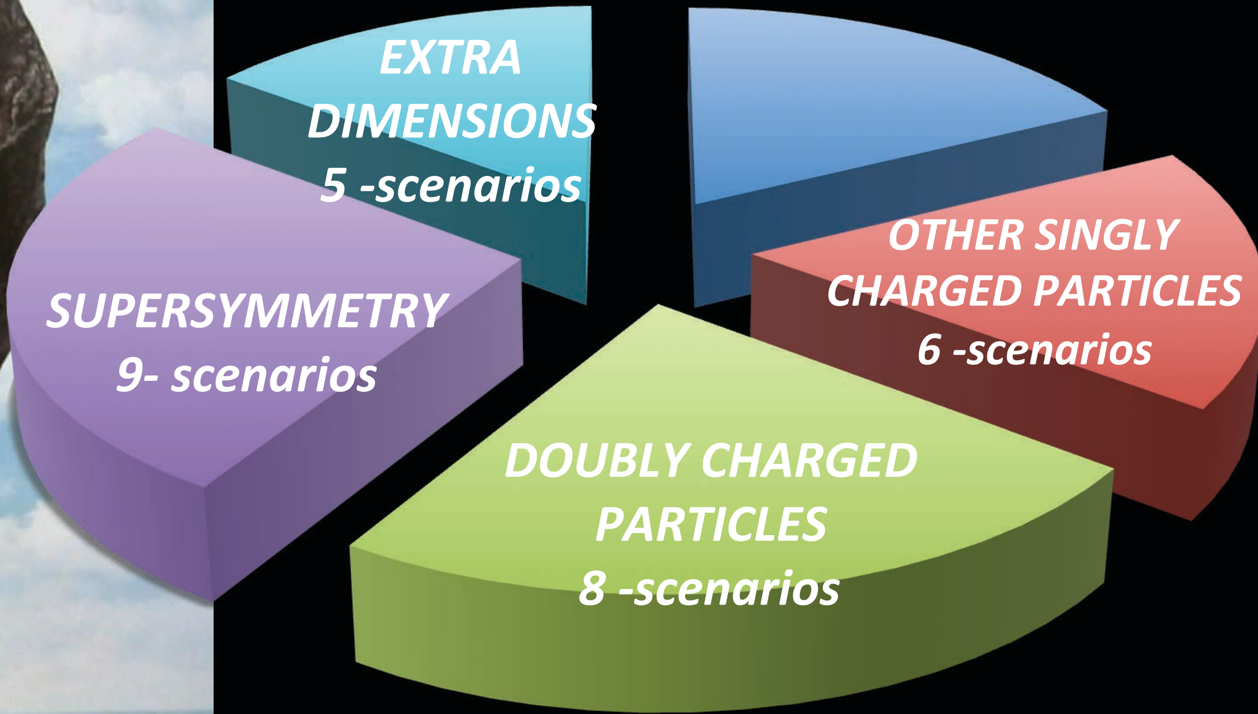


- *Magnetic Dyons/Monopoles*
- *Electroweak Monopole*
- *Electroweak strings*
- *Light 't Hooft-Polyakov monopoles*
- *Monopolium*
- *D-particles*

Massive "Stable" Electrically Charged Particles

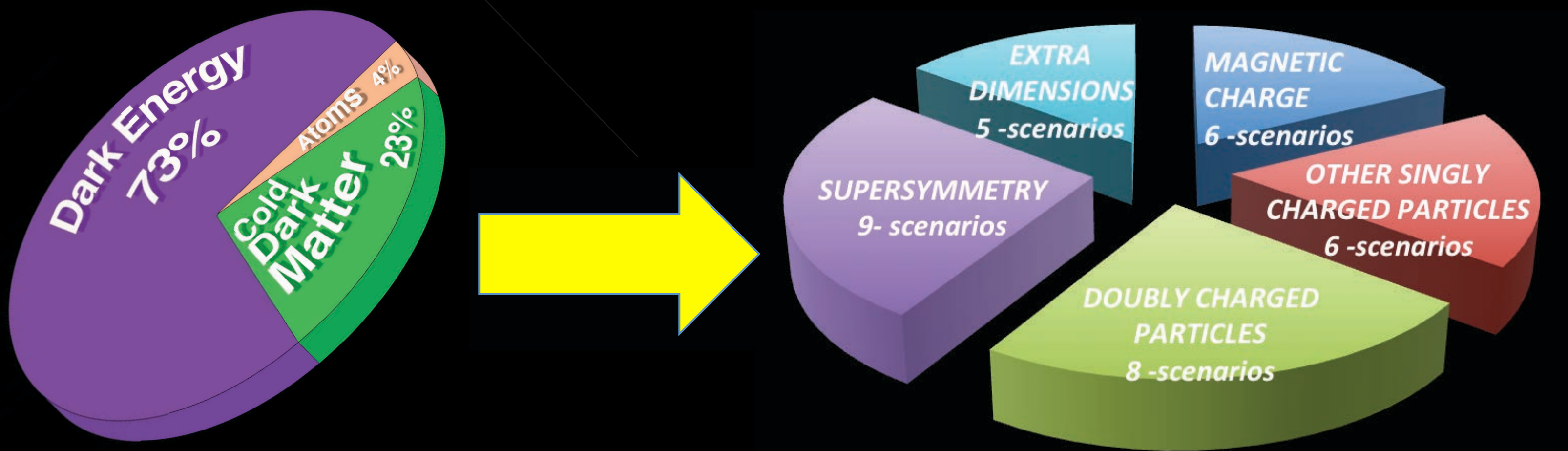


~30 SCENARIOS



Eg: Massive “Stable” Charged Particles

MoEDAL's Dark Matter Scenarios

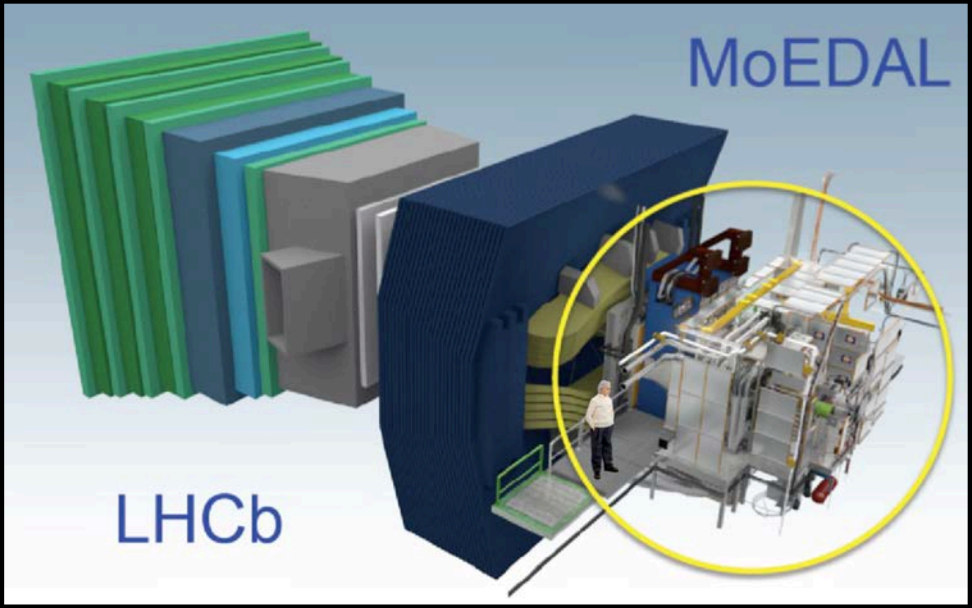


- *Most of MoEDAL's 34 physics scenarios involve new physics with well motivated dark matter scenarios (SUSY, extra dimensions)*
- *Several scenarios directly involve the detection of particles that could contribute to the dark matter of the universe:*
  - *Magnetic monopoles and monopolium*
  - *Stable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

The MOEDAL Detector

MoEDAL – a Unique Collider Detector

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

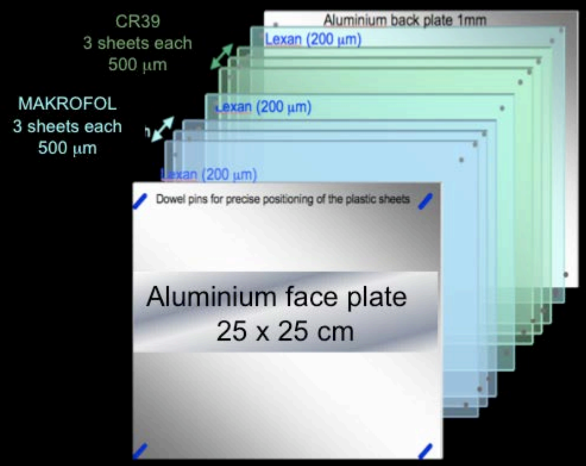
MoEDAL is largely passive made up of three detector system.

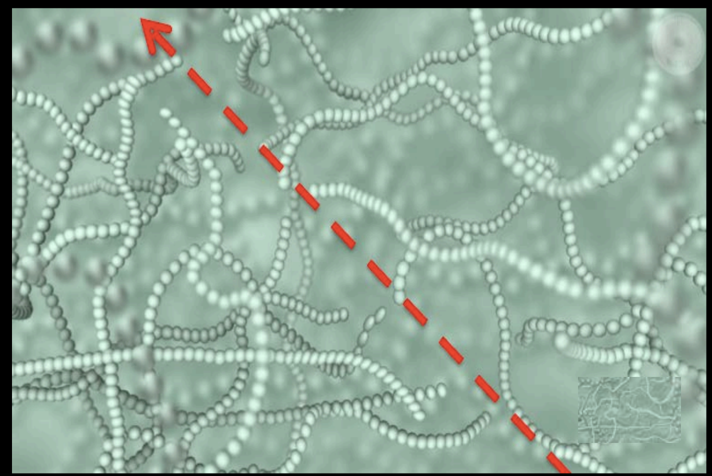
NUCLEAR TRACK DETECTOR
Plastic array (~200 sqm)
– Like a Giant Camera

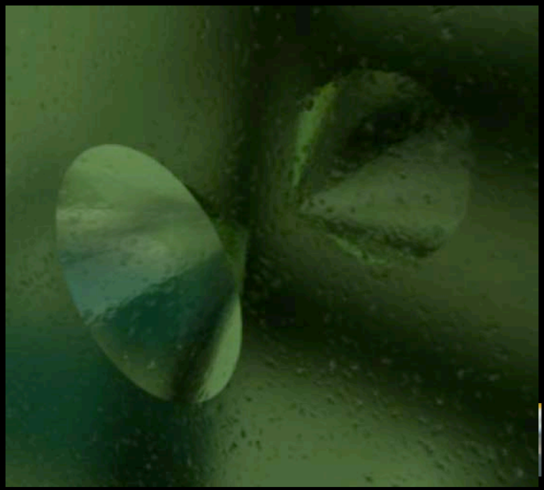
TRAPPING DETECTOR ARRAY
A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

The Nuclear Track Detector System

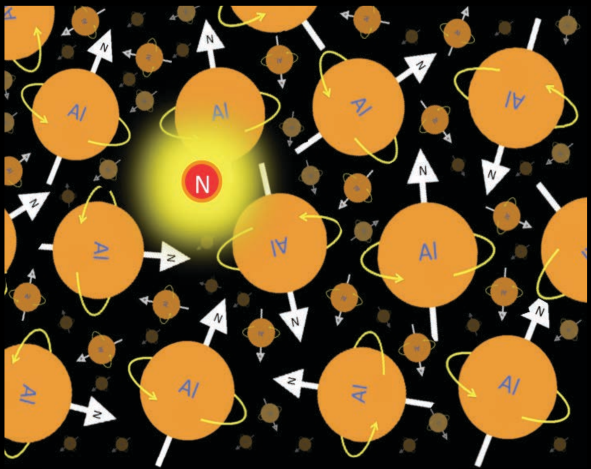






- *Largest array (150 m^2 of NTDs every deployed at an accelerator*
  - *Plastic NTD stacks consist of CR39 (threshold 5 MiPs) and Makrofol (50 MiPs) – that are "damaged" by the highly ionizing particle*
  - *The damage is revealed by controlled etching in a hot Sodium Hydroxide solution – etch pits 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

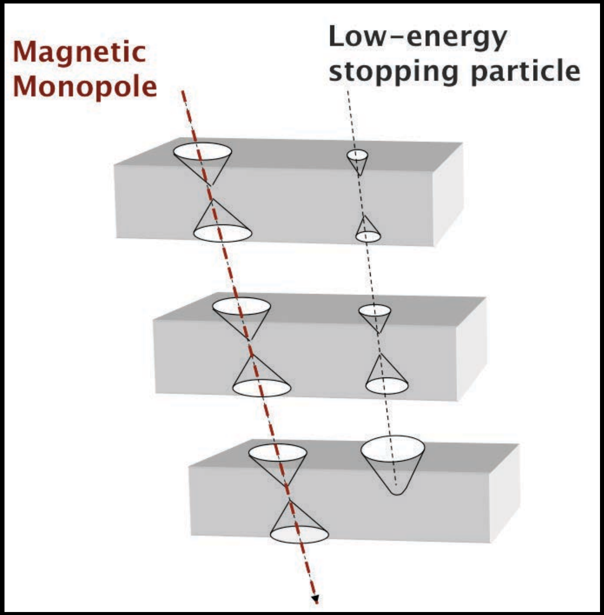
Detector Resolution

Nuclear Track Detectors

Tracking resolution: 10μm/pit (~10 pits)

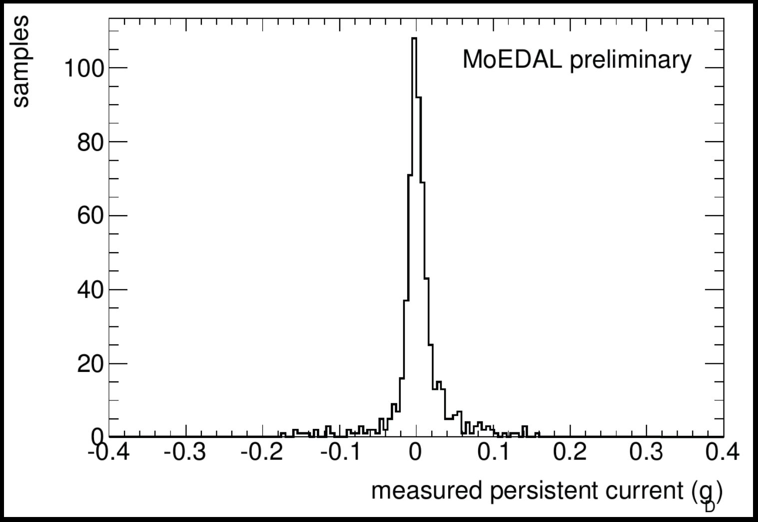
Pointing resolution (to the IP): ~1 cm

Charge resolution: 0.1e



Trapping Detector SQUID

Magnetic charge resolution < $0.1g_D$



TimePix Chips (2cm x 2cm)

Each pixel instrumented (TOT/Cnt /Arr.Time

Pixel size: 55mm x 55mm

Silicon thickness 300 μm → 1mm

MoEDAL's Complementarity

Designed & Optimized for highly ionizing particles

Insensitive to SM particles

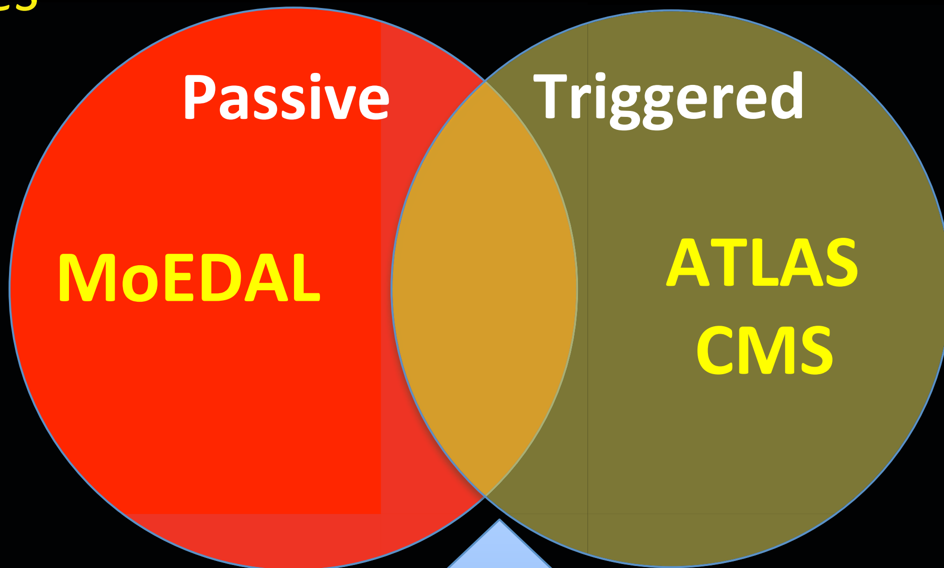
Mass ~ 1 ton

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

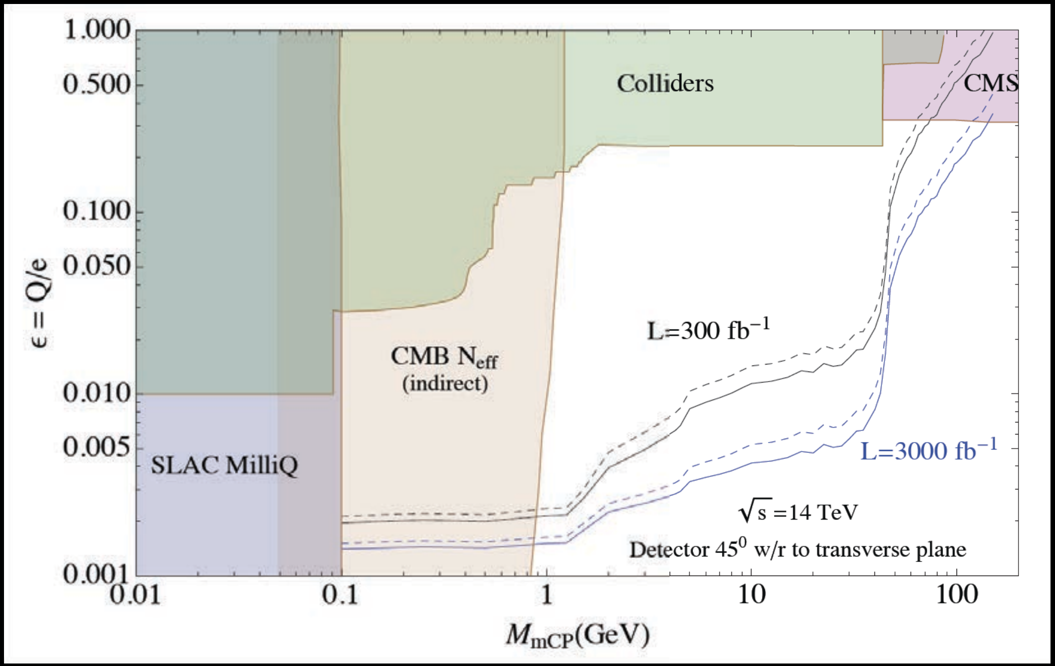
Cannot be directly calibrated for HIPs

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

From HIP to MMIP

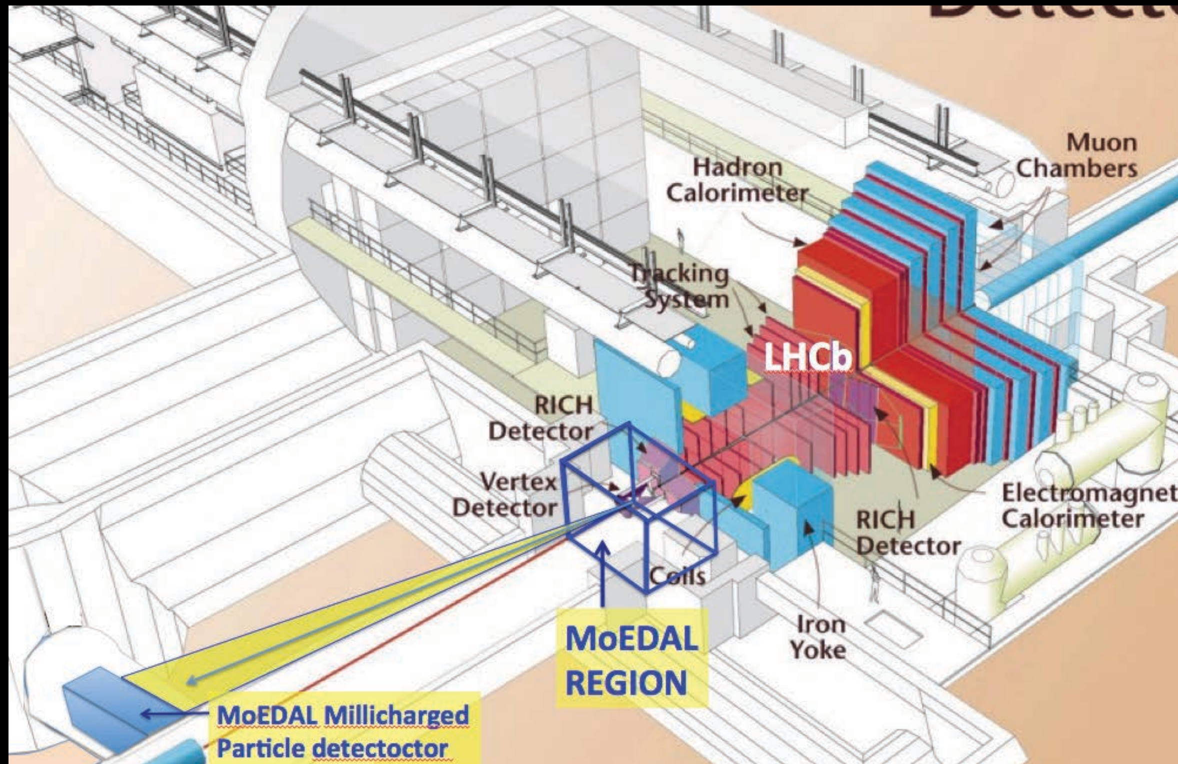
- *Highly Ionizing Particles (HIPs) are the basic entity sought by MoEDAL Phase-I and Phase-II*
  - *Phase-II would start after the Phase-I objectives have been reached – 10 fb^{-1} of integrated Lumi or a discovery*
- *A MMIP is a Massive Minimally Ionizing Particle – with charge in the range $10^{-1}e$ to $10^{-3}e$.*
- *The MMIP is an extension of the MoEDAL program (for Phase-II) that is consistent with MoEDAL's modus operandi:*
  - *Significant expansion of the physics reach of the LHC in a way that is complementary to the existing LHC effort involving anomalously charged particles*

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***

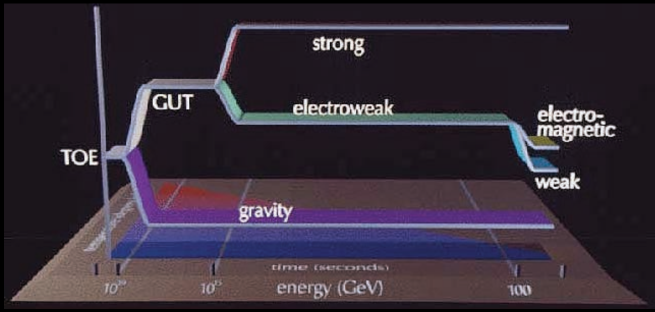
A Phase-II MoEDAL mQP Detector



- *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*

Closing Remarks

On the Existence of the Monopole (1)

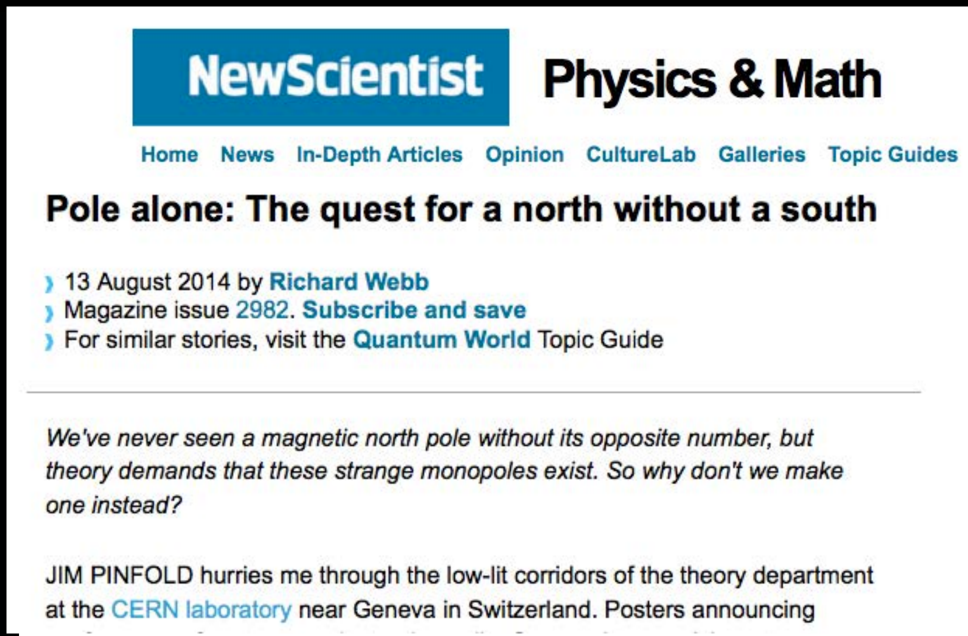


- *The existence of magnetic monopoles is suggested by Electromagnetic theory. But, Grand unified and superstring theories, predict the existence of the monopole.*

- ***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."*

On the Existence of the Monopole (2)



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Pole alone: The quest for a north without a south

- 13 August 2014 by Richard Webb
- Magazine issue 2982. Subscribe and save
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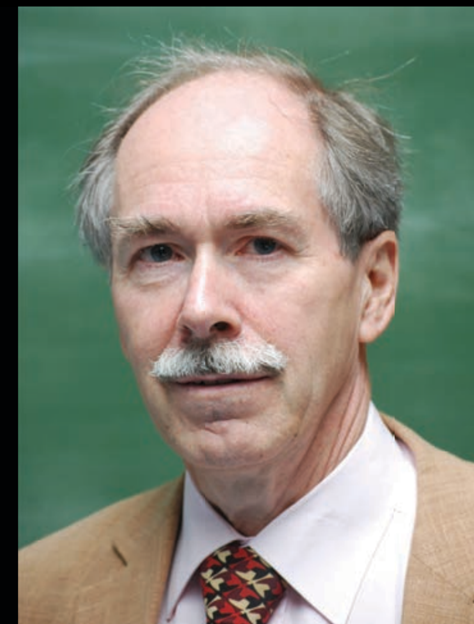
We've never seen a magnetic north pole without its opposite number, but theory demands that these strange monopoles exist. So why don't we make one instead?

JIM PINFOLD hurries me through the low-lit corridors of the theory department at the CERN laboratory near Geneva in Switzerland. Posters announcing

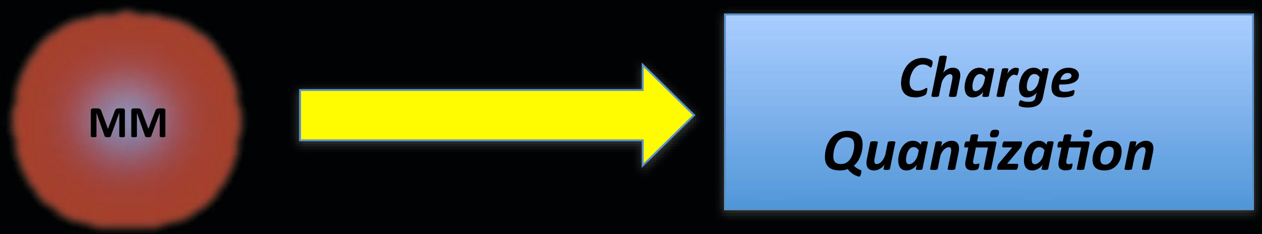


- *Gerard 't Hooft a father of the GUT was quoted in the recent New Scientist article on MoEDAL:*

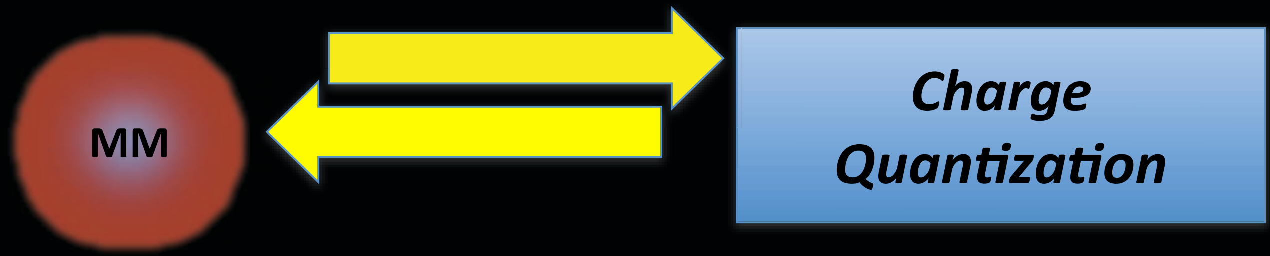
  "Many attempts to improve on the standard model have emerged in recent years. Some of these exotic theories, such as ones that predict the existence of extra dimensions, predict a significantly lighter monopole too….Their energy would be much closer to where the LHC or its future descendants can reach, so the prospects look brighter".

The Polchinski Conjecture

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

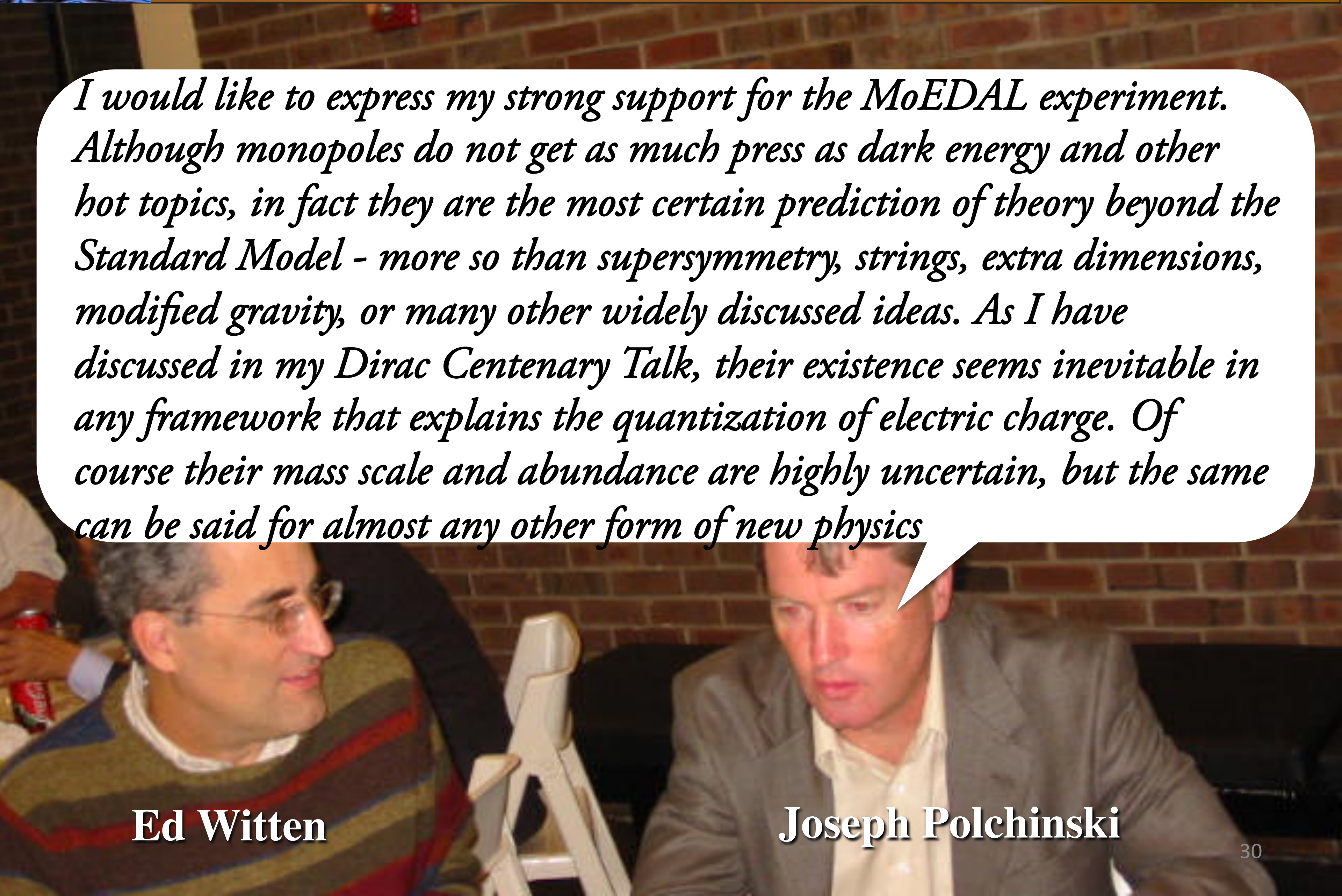


- *Thus, Polchinski conjectured, any theory requiring charge quantization must have a monopole*



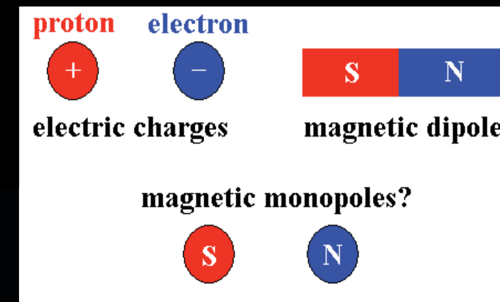
- *He also maintains that in any fully unified theory, for every gauge field there will exist electric and magnetic sources.*

Polchinski on MoEDAL



MoEDAL Addresses Fundamental Questions:

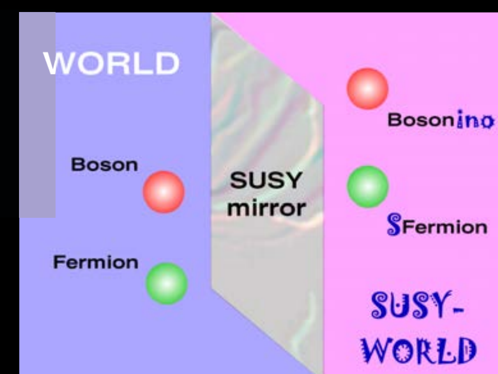
Are there extra dimensions?



Does magnetic charge exist?

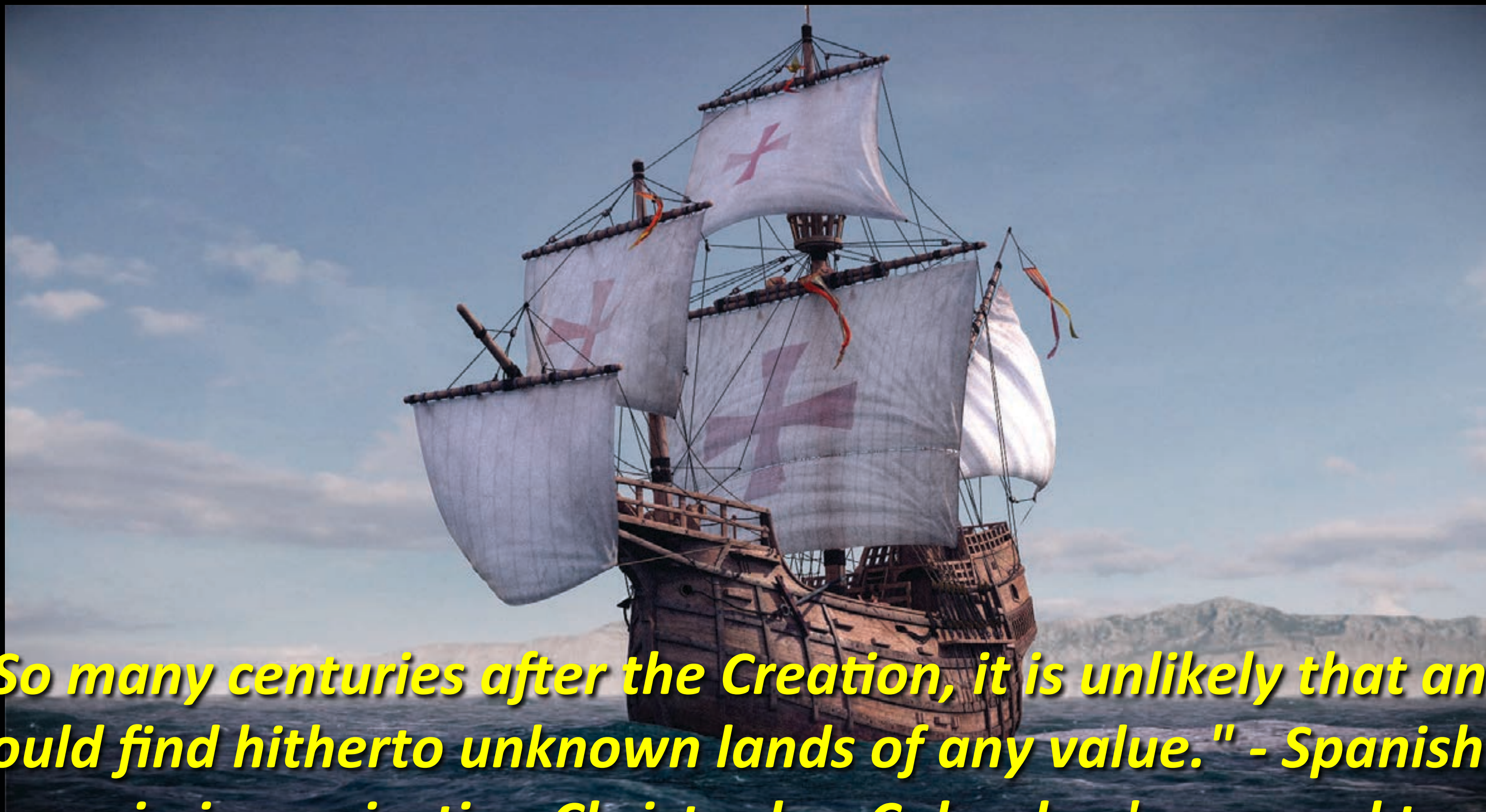
What is the nature of Dark Matter?

What happened just after the big bang?



Are there new symmetries of nature?

The Continuing Quest for Dark Matter



"So many centuries after the Creation, it is unlikely that anyone could find hitherto unknown lands of any value." - Spanish Royal Commission, rejecting Christopher Columbus' proposal to sail west.

In 2015 the LHC experiments – now including MoEDAL - set sail out on a voyage of discovery at the new LHC high energy frontier of 13TeV - ***stay tuned for the report of new worlds***