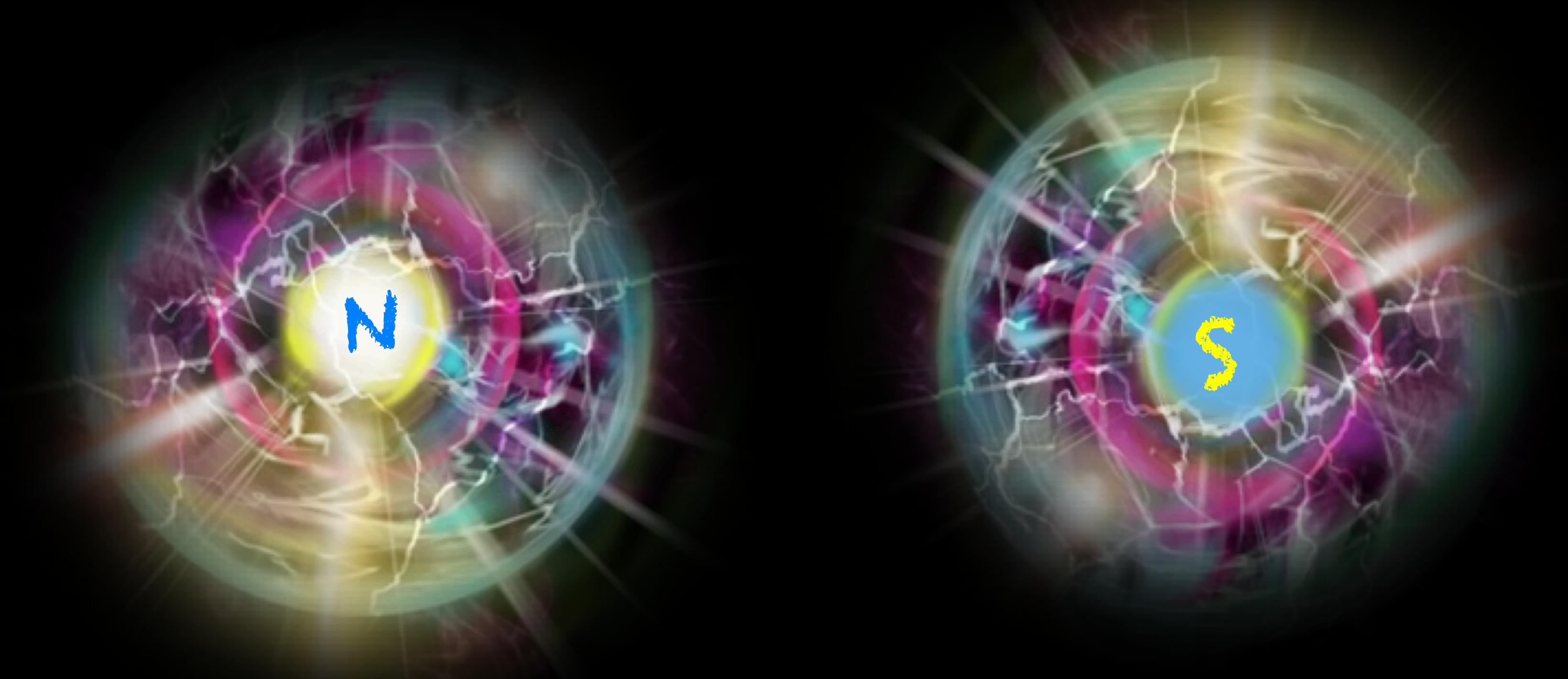
SEARCHING FOR THE MAGNETIC MONOPOLE & OTHER HIGHLY IONIZING PARTICLES) AT THE LHC WITH MOEDAL



James Pinfold (for the MoEDAL Collaboration)
University of Alberta

See Nikolaos Mavromatos’ upcoming talk on MoEDAL ‘s Physics Program

and

Vasiliki Mitsou’s talk on MoEDAL’s search for highly ionizing electrically charged particles

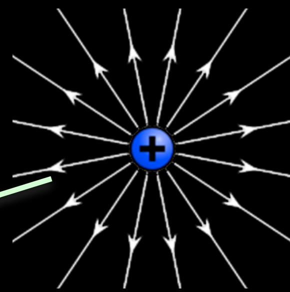
for more details

The Monopole is MoEDAL's Higgs

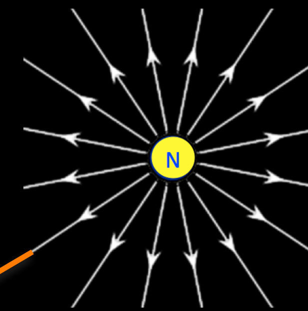
- *Just as the general purpose experiments ATLAS & CMS have as their prime physics purpose the discovery and elucidation of the Higgs……*
- *….Then the equivalent "benchmark" physics physics process for MoEDAL is the magnetic monopole production – thus we shall concentrate on this topic due to time constraints*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

Monopoles Symmetrize Maxwell's Eqns

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

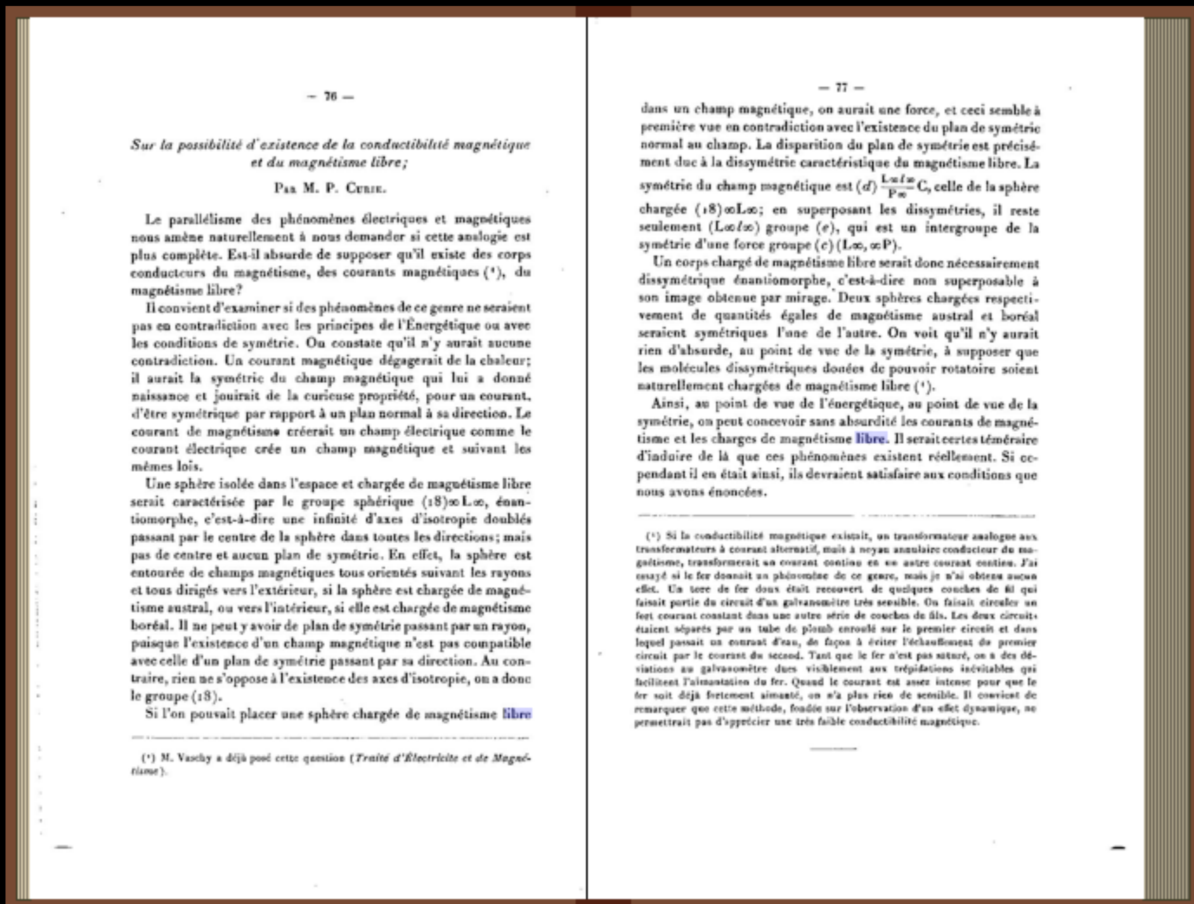


$$\begin{aligned}
\vec{\nabla} \cdot \vec{E} &= \rho_{\mathrm{E}} \\
\vec{\nabla} \cdot \vec{B} &= \rho_{\mathrm{M}} \\
\vec{\nabla} \times \vec{E} &= -\frac{\partial \vec{B}}{\partial t} - \vec{j}_{\mathrm{M}} \\
\vec{\nabla} \times \vec{B} &= \frac{\partial \vec{E}}{\partial t} + \vec{j}_{\mathrm{E}}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



- *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*

Pierre Curie's Challenge



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*).

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).

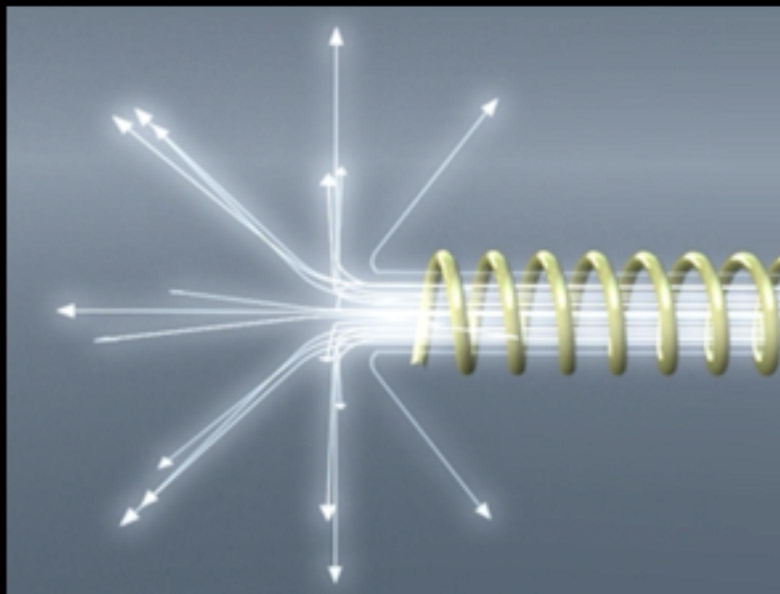
Ainsi, au point de vue de l'énergétique, au point de vue de la symétrie, on peut concevoir sans absurdité les courants de magnétisme et les charges de magnétisme libre. Il serait certes téméraire d'induire de là que ces phénomènes existent réellement. Si cependant il en était ainsi, ils devraient satisfaire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

The 122nd Birthday of the Monopole Quest

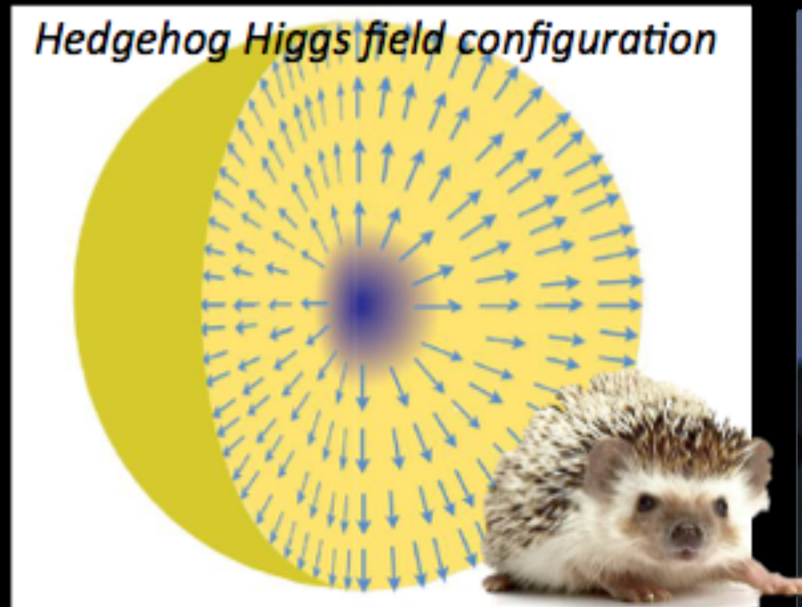
Dirac's Monopole



- *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!*

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

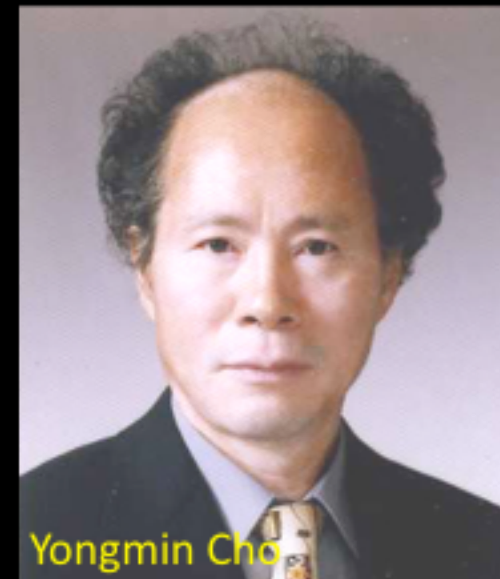
The 't Hooft-Polyakov Monopole



- *In 1974 't Hooft and Polyakov showed that monopoles must exist with the framework the SU(5) GUT with mass around 10^{16} GeV (10 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*

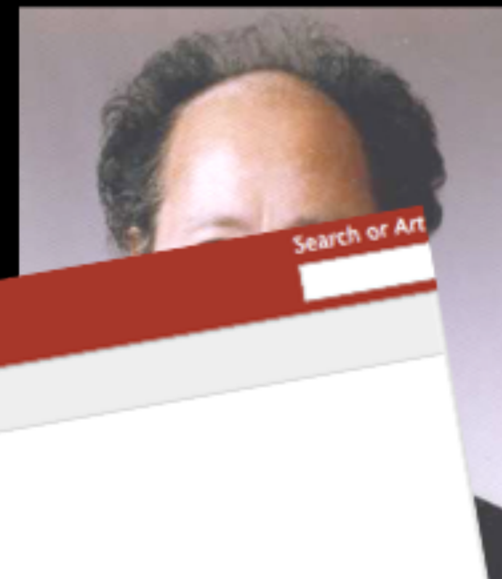
As Usual the Greeks Were There First

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 Dirac monopole & the 't Hooft-Polyakov monopole*
  - *His monopole arises from the framework of the Standard Model*
- *The Cho-Maison monopole could be detectable by MoEDAL*

The Cho-Maison Magnetic Monopole



arXiv.org > hep-ph > arXiv:1602.01745

Search or Art

High Energy Physics – Phenomenology

The Price of an Electroweak Monopole

John Ellis, Nick E. Mavromatos, Tevong You

(Submitted on 4 Feb 2016 (v1), last revised 10 Feb 2016 (this version, v2))

In a recent paper, Cho, Kim and Yoon (CKY) have proposed a version of the SU(2) × U(1) Standard Model with finite-energy monopole and dyon solutions. The CKY model postulates that the effective U(1) gauge coupling → ∞ very rapidly as the Englert-Brout-Higgs vacuum expectation value → 0, but in a way that is incompatible with LHC measurements of the Higgs boson $H \to \gamma\gamma$ decay rate. We construct generalizations of the CKY model that are compatible with the $H \to \gamma\gamma$ constraint, and calculate the corresponding values of the monopole and dyon masses. We find that the monopole mass could be < 5.5 TeV, so that it could be pair-produced at the LHC and accessible to the MoEDAL experiment.

- ... Dirac ... pole
  - ... the Standard Model (Weinberg-Salam)
- Th... Maison monopole could be detectable by MoEDAL

Magnetic Monopole Properties

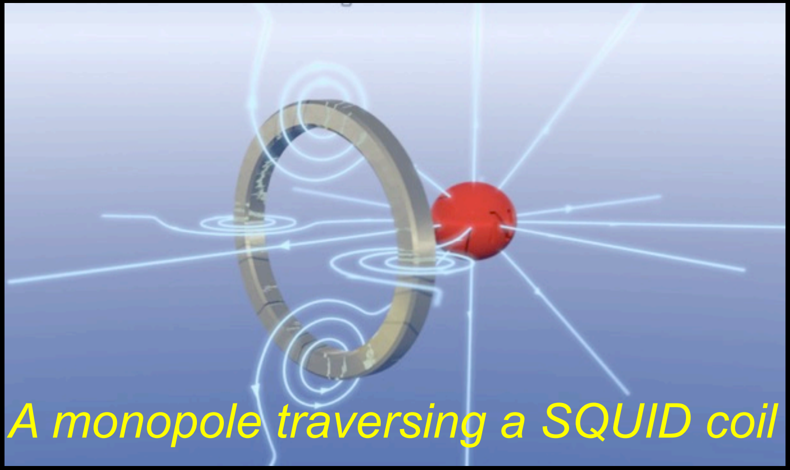
Magnetic charge
= ng = n68.5e
(if e→1/3e; g→3g)
HIGHLY IONIZING

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?



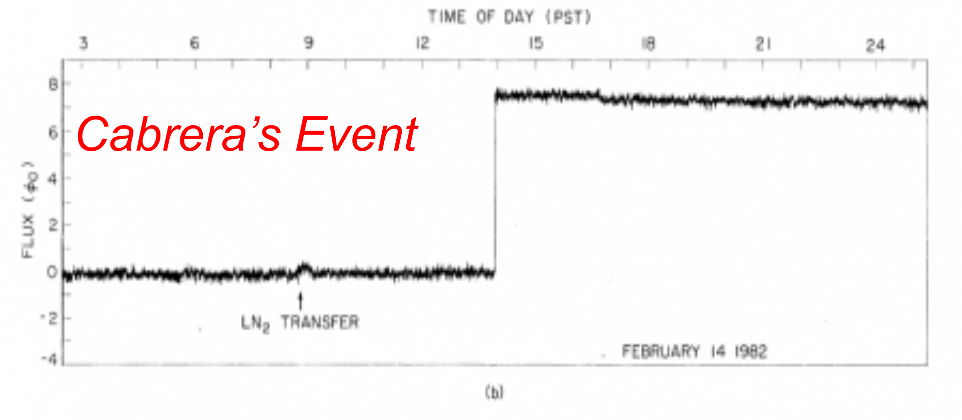
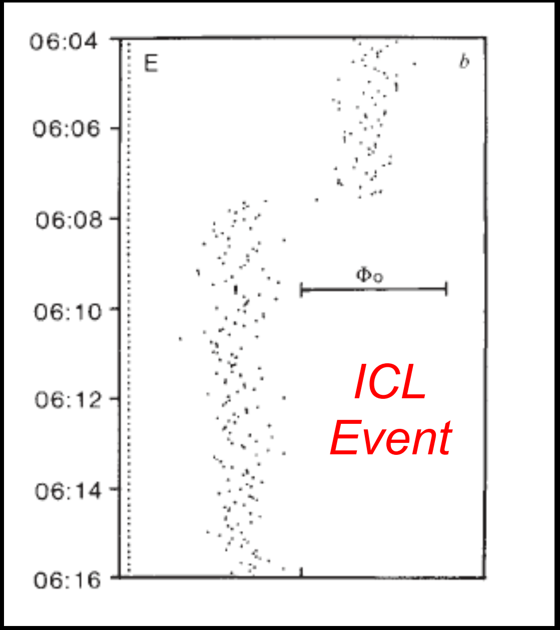
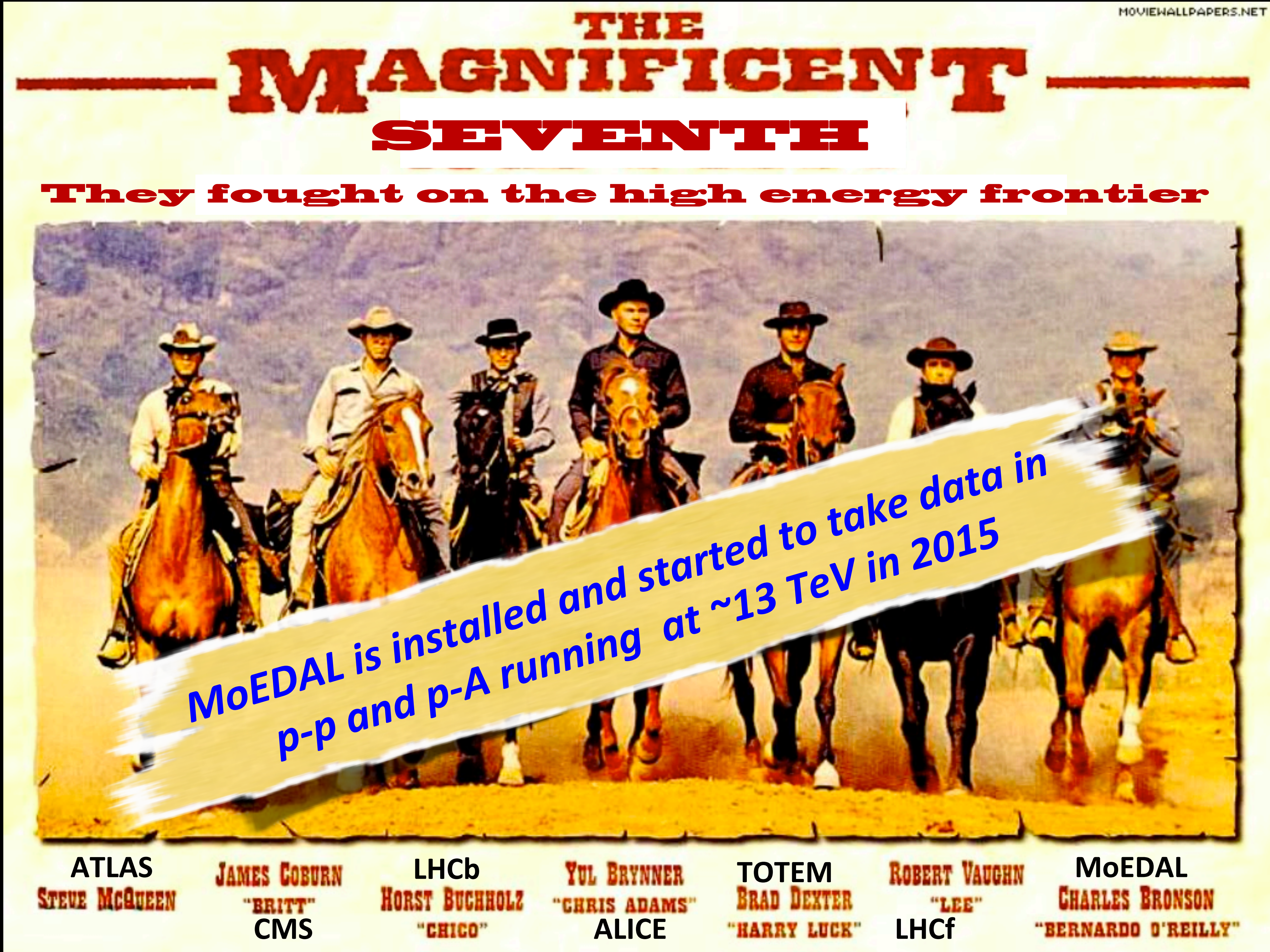


FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.

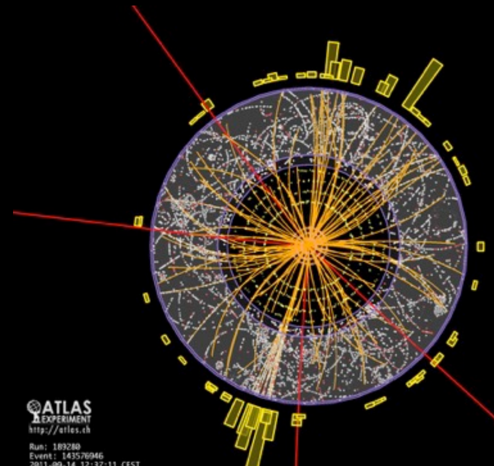
- *Data from Cabrera's apparatus taken on St Valentine's day in 1982 (A=20 cm^2).*
  - *The trace shows a jump – just before 2pm - that one would expect from a monopole traversing the coil.*
- *In August 1985 a groups at ICL reported the:"observation of an unexplained event" compatible with a monopole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




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"

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 $g = ng_d$ 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*
  - *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!*

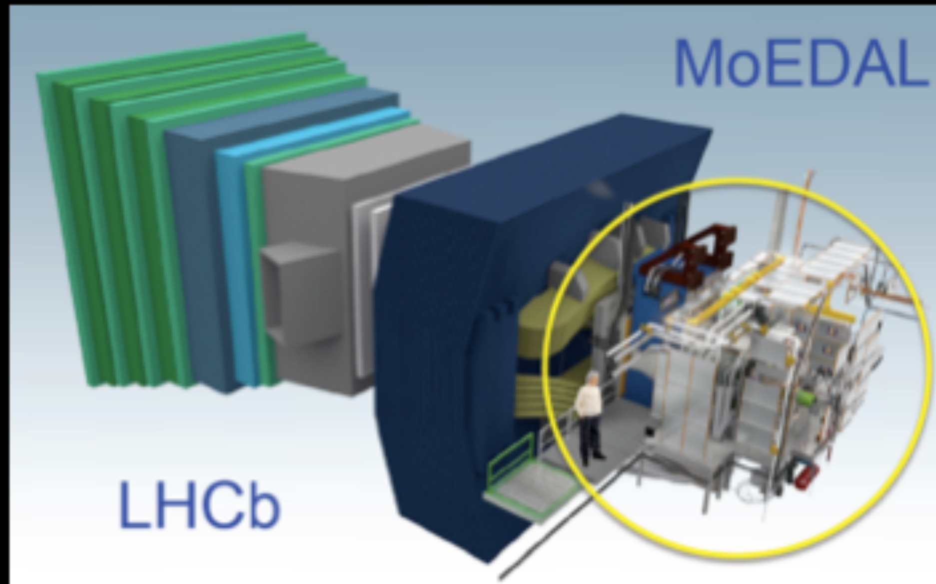
The MoEDAL Collaboration

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.

MoEDAL – a Unique Collider Detector

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

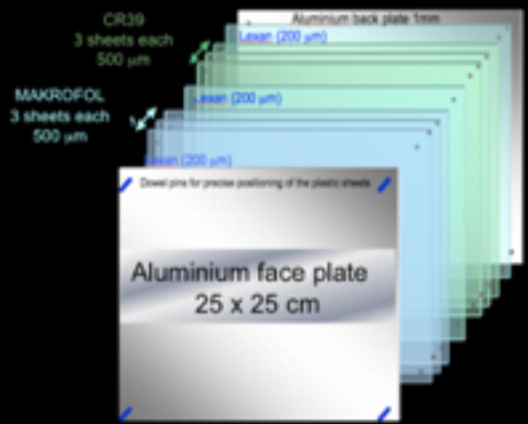
MoEDAL is largely passive made up of three detector system.

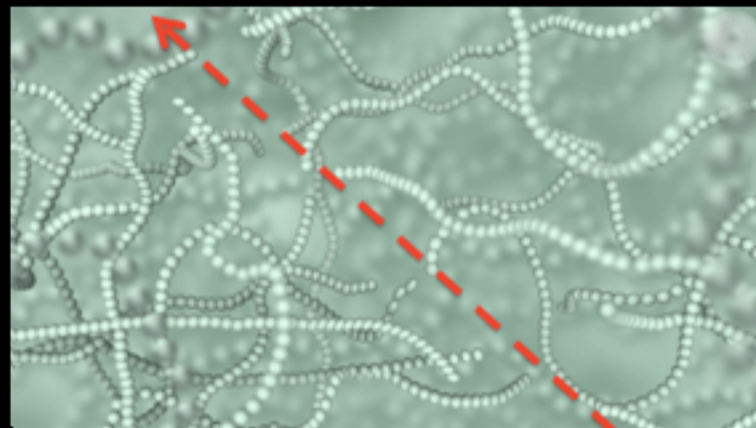
NUCLEAR TRACK DETECTOR Plastic array (~200 sqm) – Like a Giant Camera (with film)

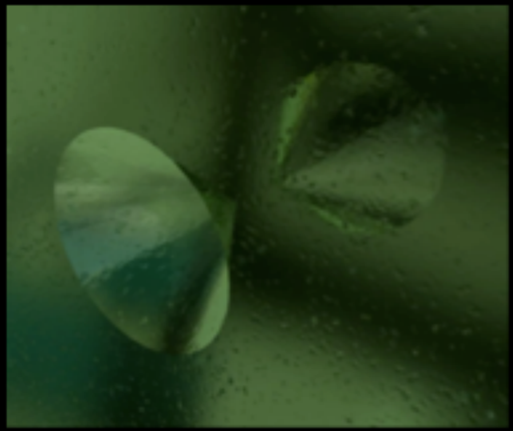
TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

The Nuclear Track Detector System

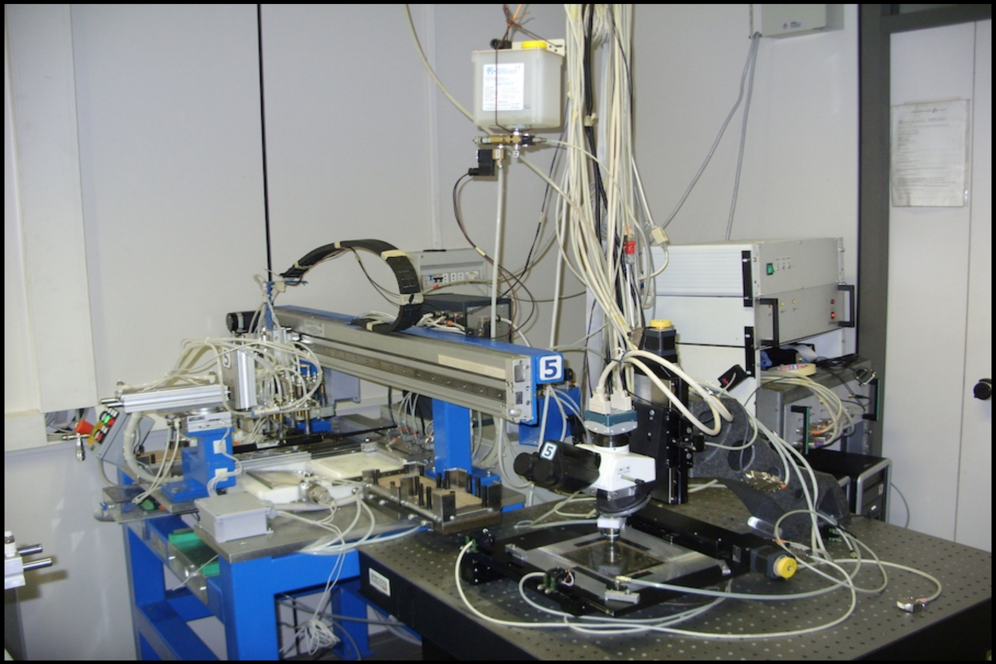






- *Largest array (150 m^2 of NTDs every deployed at an accelerator*
  - *Plastic NTD stacks consist of CR39 (threshold 5 MiPs) and Makrofol (50 MiPs) – that are "damaged" by the highly ionizing particle*
  - *The damage is revealed by controlled etching in a hot Sodium Hydroxide solution – etch pits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

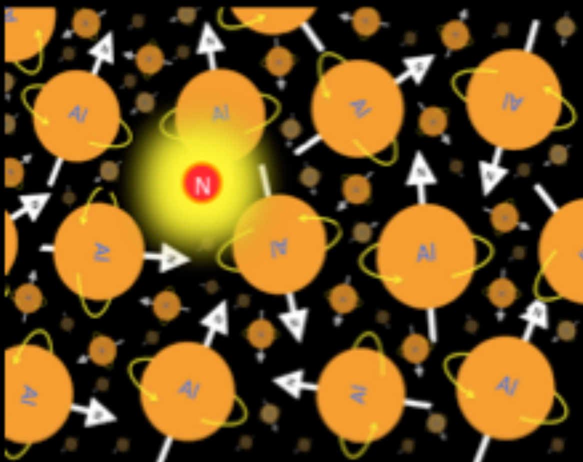
Scanning for New Physics



- *Exposed NTDs are being used to test automated high-rate optical CCD based scanning microscopes developed by MoEDAL groups at INFN Bologna and the Univ. of Muenster.*
  - *Very high scan rate 60-100 frames /sec → 100 cm^2 in 40 minutes*
  - *Specialized image enhancement/pattern recognition software*

X

The Trapping Detector System



Trapped monopole

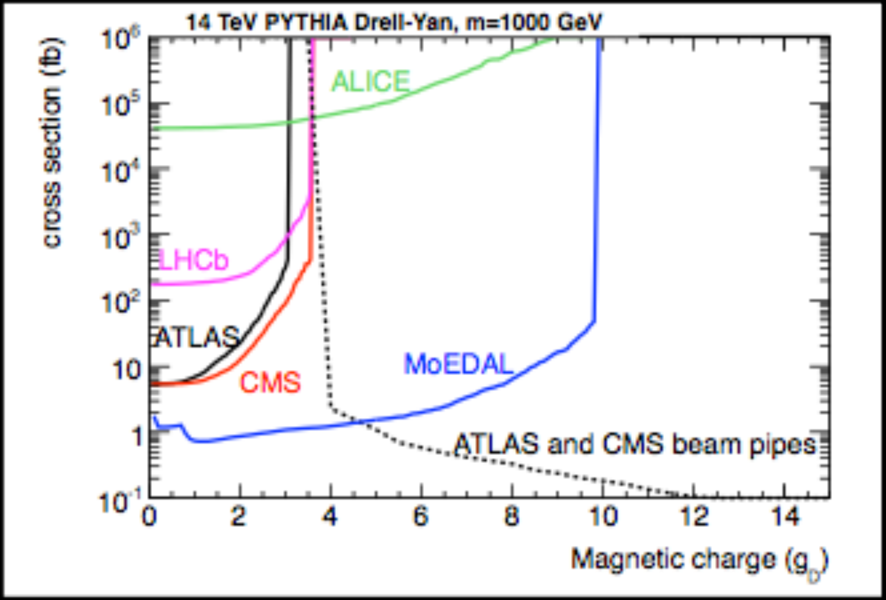
SQUID magnetometer (ETH Zurich)

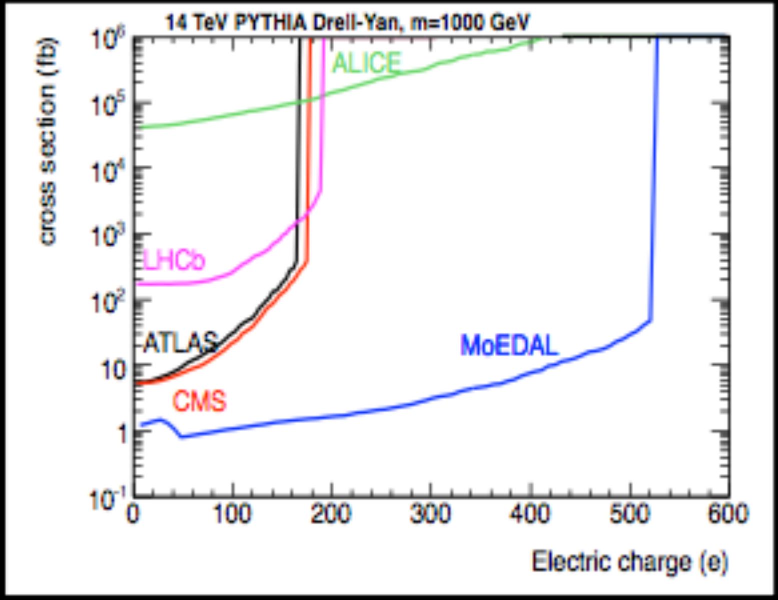
Search for trapped quasi-stable decays at SNOLAB

- 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 to detect decays of MSPs

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 Complementarity

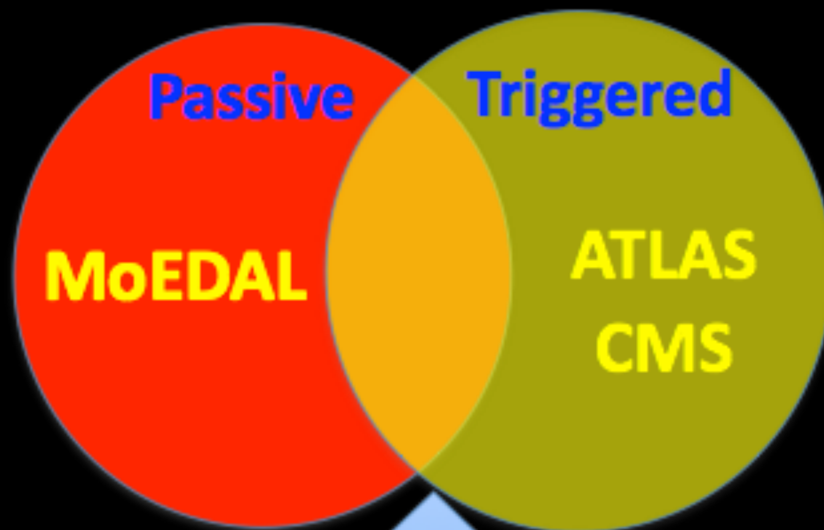
Optimized for highly ionizing particles

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

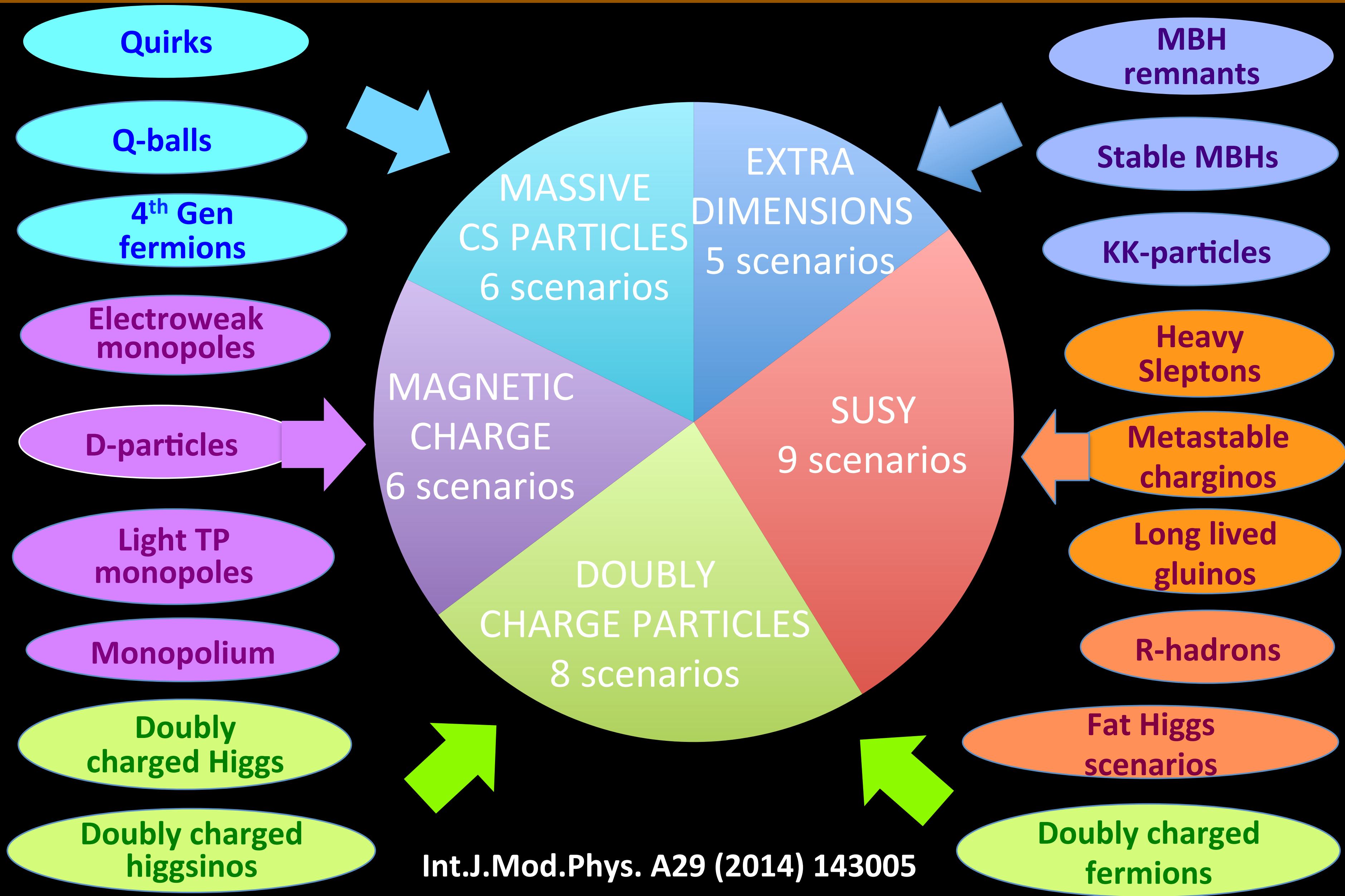
Difficult to measure very slow decays

Cannot detect magnetic charge

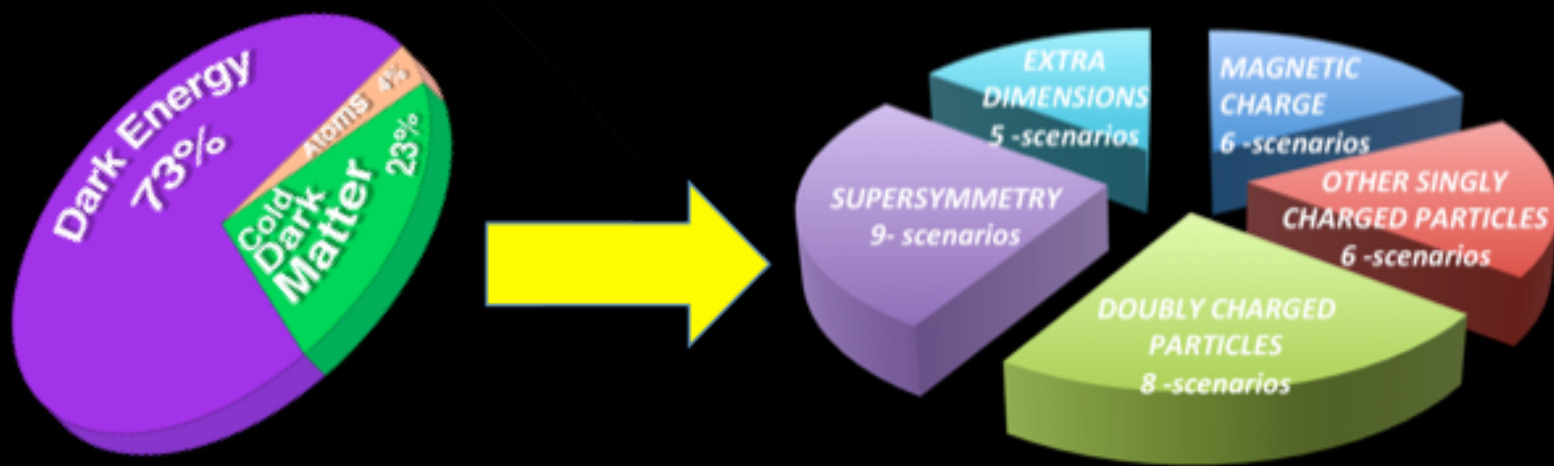
Cannot be directly calibrated for highly ionizing particles

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

MoEDAL – Physics Scenarios (34+)



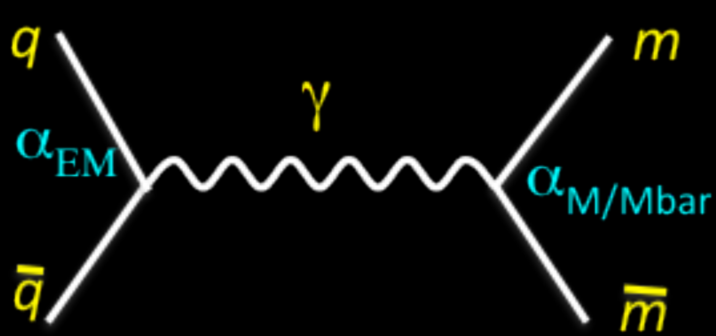
MoEDAL's Dark Matter Scenarios



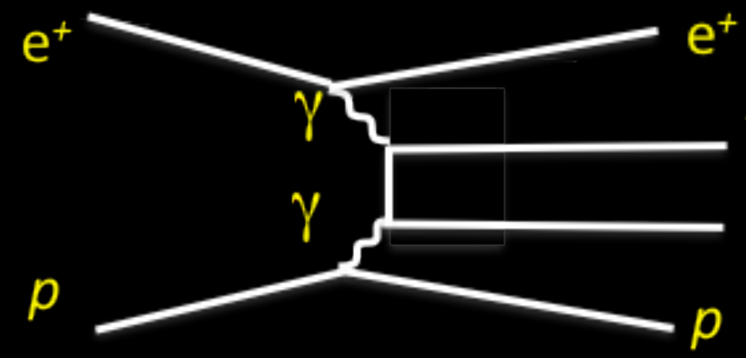
- *Most of MoEDAL's 34 physics scenarios involve new physics with well motivated dark matter scenarios (SUSY, extra dimensions)*
- *Several scenarios directly involve the detection of particles that could contribute to the dark matter of the universe:*
  - *Magnetic monopoles and monopolium*
  - *Stable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

Monopole Production at Colliders

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

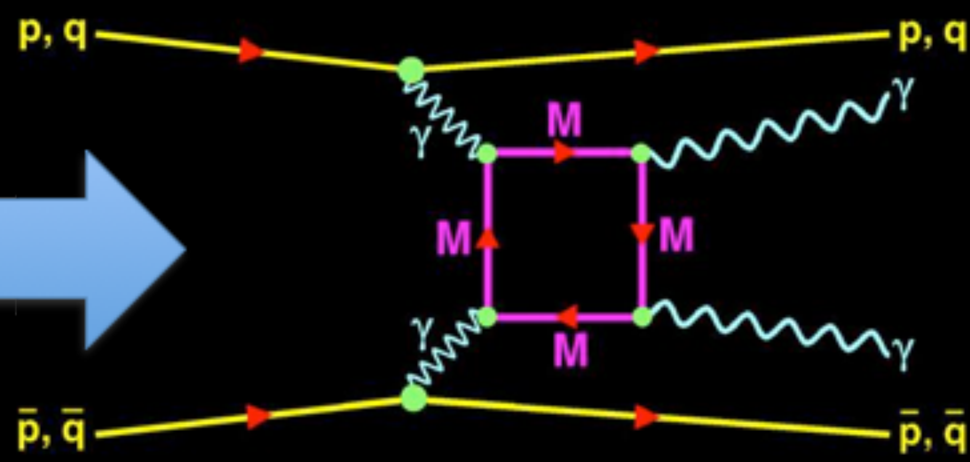


Drell-Yan Production



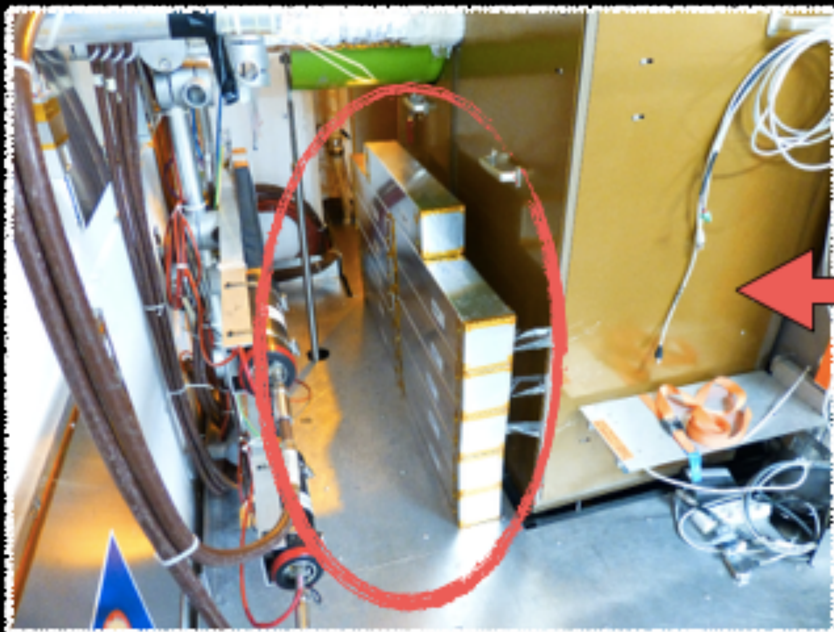
Two-photon production

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

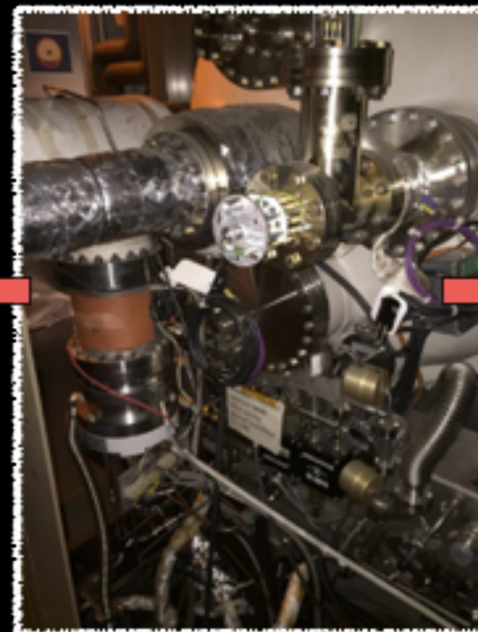


The First MoEDAL Physics Result Paper

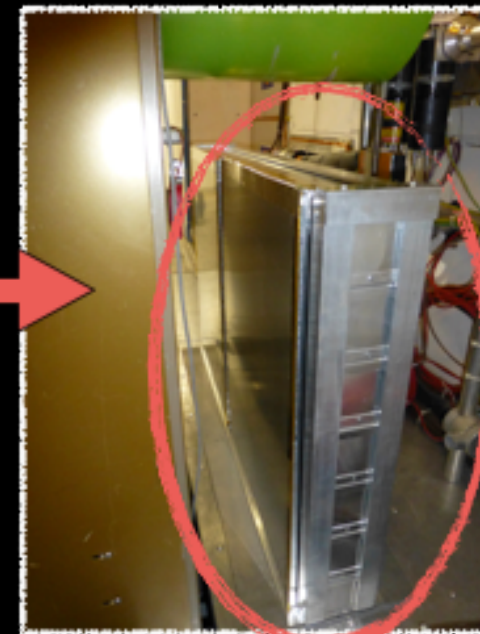
The 1st Result - Breaking News



Prototype trapping detector
160 kg



The challenge



Current deployment
270 kg /800 kg

- *The MoEDAL trapping detector is the first of its kind (a purpose built detector for trapping highly ionizing particles*
- *Our first result is on the search for trapped magnetic charge using a SQUID to monitor for magnetic charge - future results also on trapped electric charge are in the pipeline.*

The Results - Breaking News

Cornell University Library

arXiv.org > hep-ex > arXiv:1604.06645

Search

High Energy Physics - Experiment

Search for magnetic monopoles with the MoEDAL ... detector in 8 TeV proton-proton collisi...

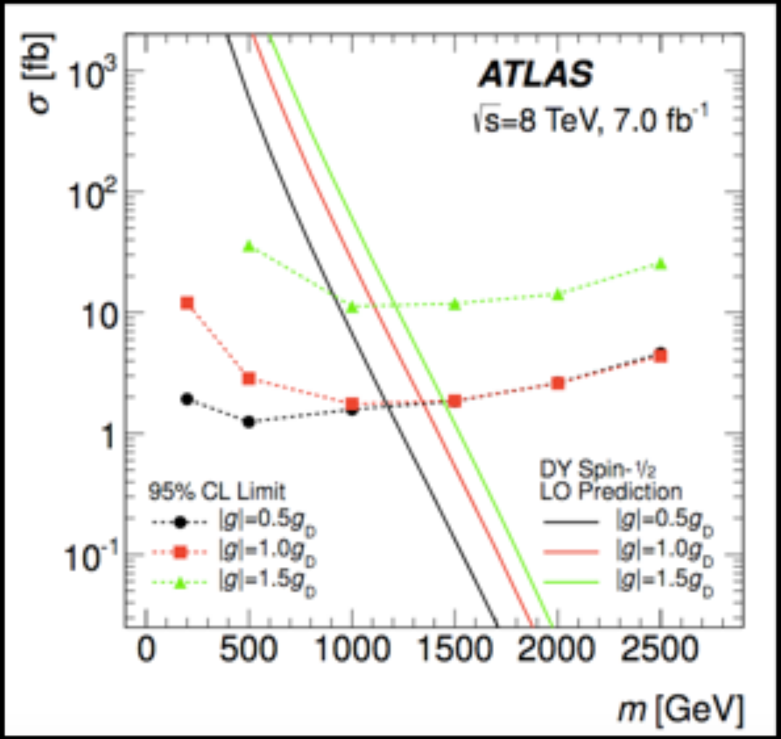
MoEDAL Collaboration

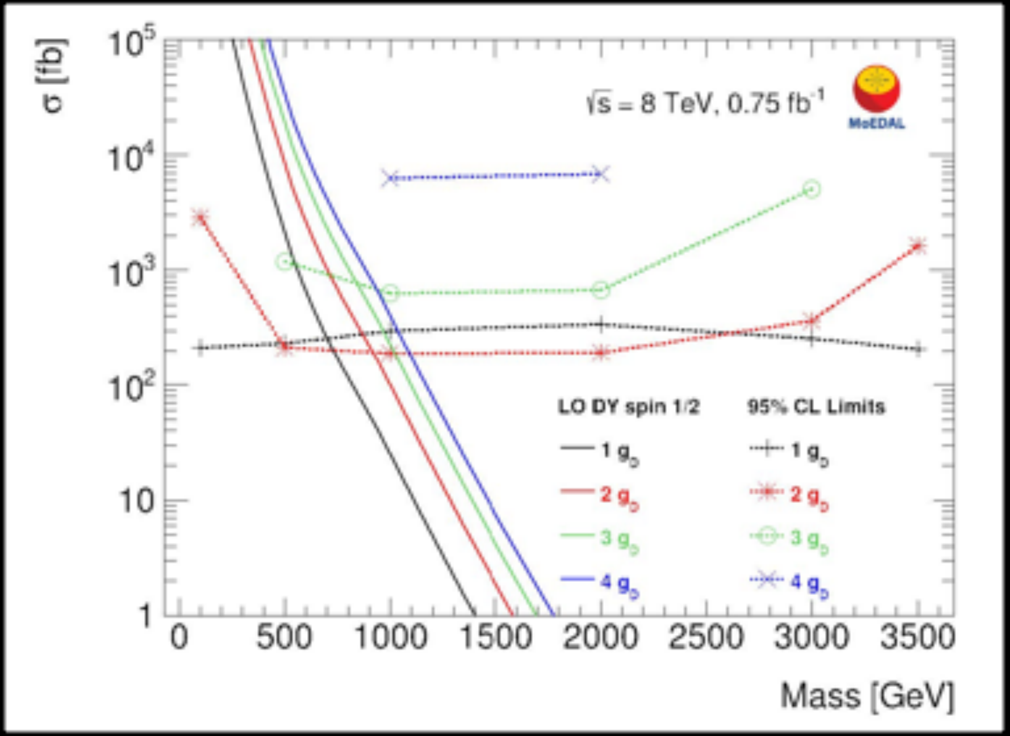
(Submitted on 22 Apr 20...

These results have just been submitted to JHEP

T... ...ly-ionising particles produced in hi... ...ployed at Interaction Point 8 on the LHC ring, relies on tw... ...is based on stacks of nuclear-track detectors with surface area ~18 m... ...gh threshold. These detectors are analysed offline by optical scanning mic... ...ique is based on the trapping of charged particles in an array of roughly 800 kg of aluminium sa... ...amples are monitored offline for the presence of trapped magnetic charge at a remote superconducting magnetometer facility. We present here the results of a search for magnetic monopoles using a 160 kg prototype MoEDAL trapping detector exposed to 8 TeV proton-proton collisions at the LHC, for an integrated luminosity of 0.75 fb^{-1}. No magnetic charge exceeding $0.5g_D$ (where g_D is the Dirac magnetic charge) is measured in any of the exposed samples, allowing limits to be placed on monopole production in the mass range 100 GeV$\leq m \leq$ 3500 GeV. Model-independent cross-section limits are presented in fiducial regions of monopole energy and direction for $1g_D \leq |g| \leq 6g_D$, and model-dependent cross-section limits are obtained for Drell-Yan pair production of spin-1/2 and spin-0 monopoles for $1g_D \leq |g| \leq 4g_D$. Under the assumption of Drell-Yan cross sections, mass limits are derived for $|g| = 2g_D$ and $|g| = 3g_D$ for the first time at the LHC, surpassing the results from previous collider experiments.

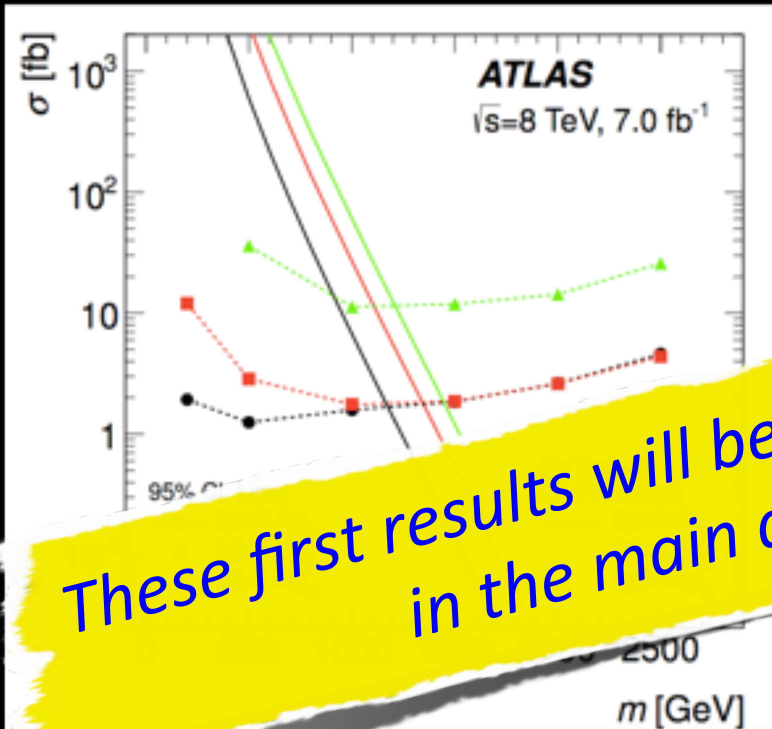
The Results - Some numbers

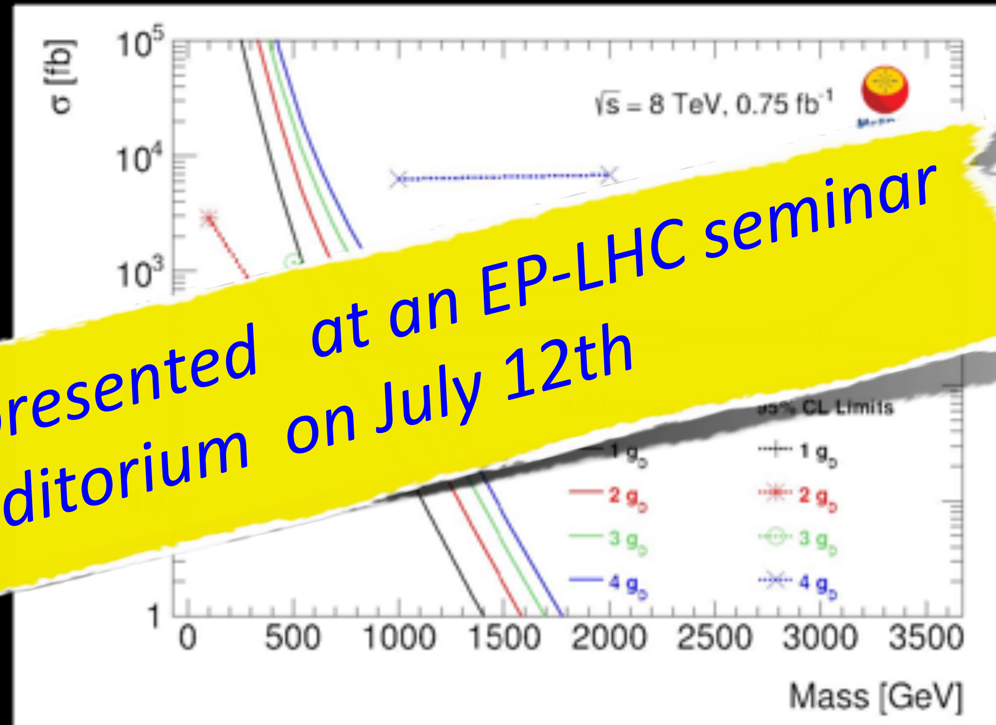




- *Even with this prototype & low lumi MoEDAL probed multiple magnetic charges which other LHC detectors find challenging*
- *Greater mass range probed by MoEDAL - 3.5 TeV (M) 2.5 Tev (A)*

The Results - Some numbers

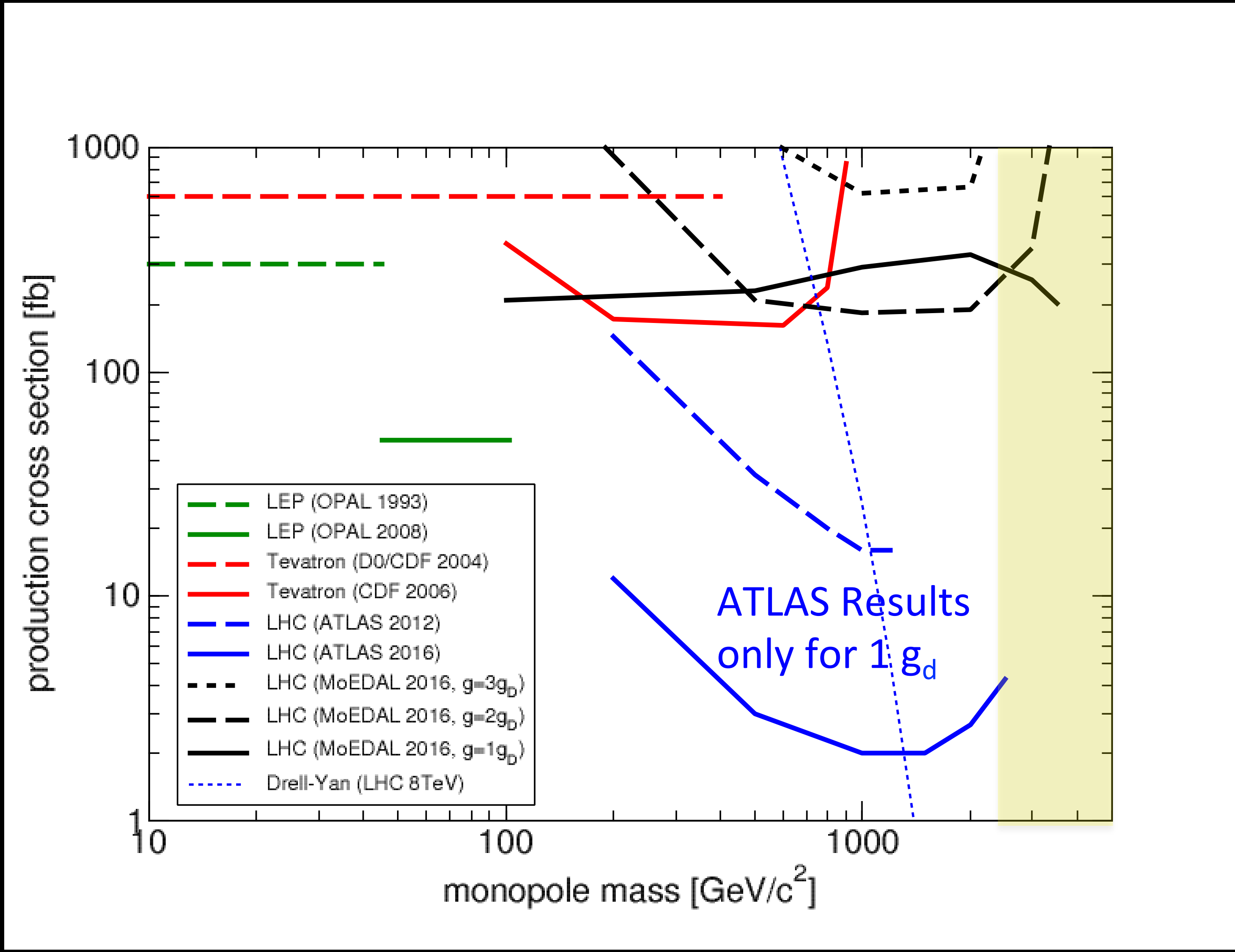




These first results will be presented at an EP-LHC seminar in the main auditorium on July 12th

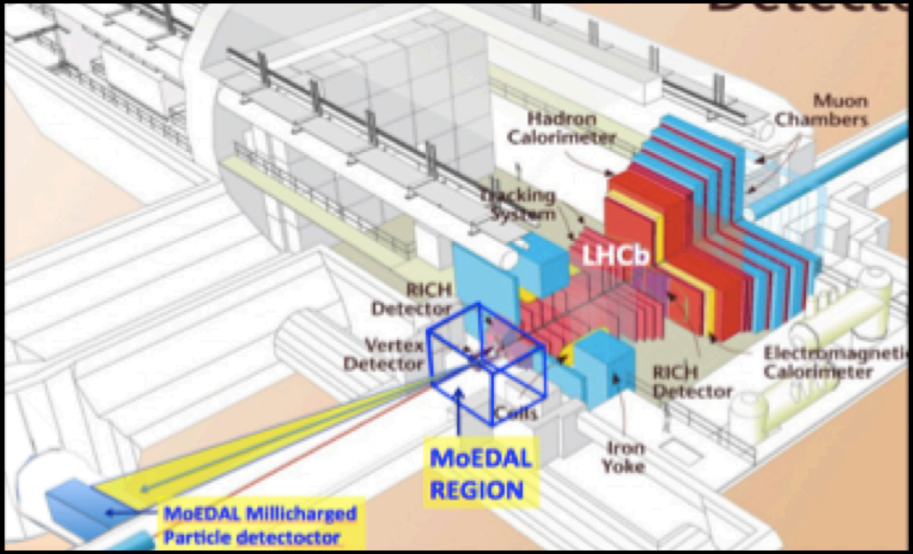
- *Even with this prototype & low lumi MoEDAL probed multiple magnetic charges which other LHC detectors find challenging*
- *Greater mass range probed by MoEDAL - 3.5 TeV (M) 2.5 Tev (A)*

Comparing with Previous Collider Results



- *NB MoEDAL results are from a small test detector deployed for a short period – more results with full detector to come.*

MoEDAL Apparatus for Penetrating Particles (MAPP



- *MAPP will be able to take data in p-p, p-A,A-A and also fixed target interactions using SMOG (an internal gas target in LHCb)*
- *MAPP has three motivations*
  - *To search for particles with charge ~0.1 (beyond the reach of the other LHC detectors)*
  - *To search for new pseudostable neutrals.*
  - *To search for anomalously pentrating particles*

Example Physics Rationale for MAPP

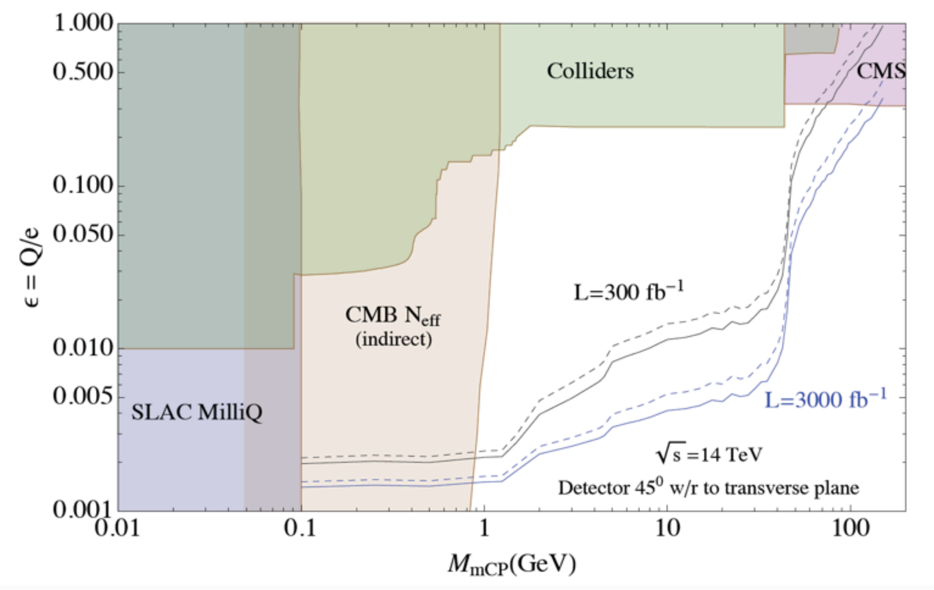


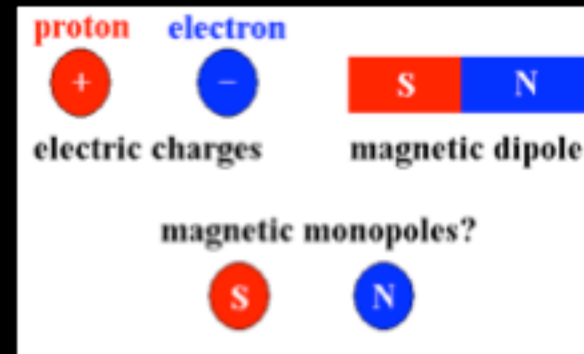
FIGURE TAKEN FROM: "Looking for milli-charged particles with a new experiment at the LHC Andrew Haas, Christopher S. Hill, Eder Izaguirre, Itay Yavin, . Oct 24, 2014. 4 pp. Phys.Lett. B746 (2015) 117-120 – Experiment is planning to run at the CMS IP.

300 fb^{-1} is the data expected to be gained in the first 10-12 years of LHC running

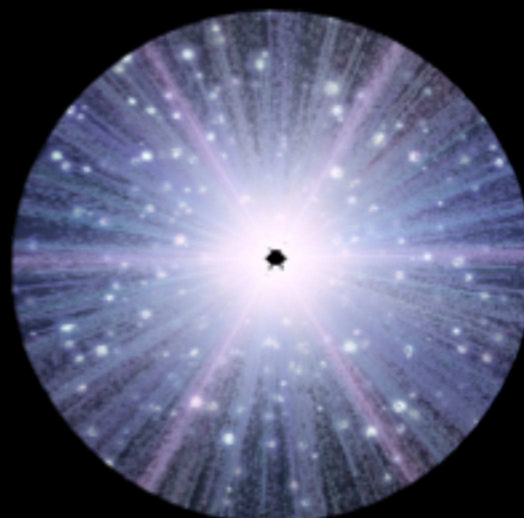
- *Search for millicharged particles – a dark matter candidate - to which the standard LHC detectors are not sensitive*
  - *New dark sectors can have new particles which appear with small fractional charge wrt the Standard Model sector*
  - *Charges typically in the range 10^{-1} to 10^{-3} e*
  - *No direct constraints above 100 MeV and Q/e <0.01*
- ***A MoEDAL millicharged detector could probe up to 100 GeV***

MoEDAL Addresses Fundamental Questions:

Are there extra dimensions?



Does magnetic charge exist?



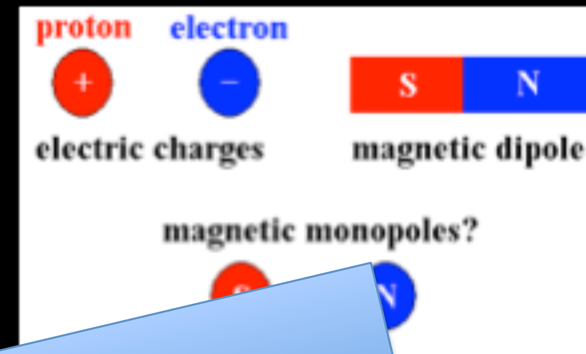
What happened just after the big bang?

What is the nature of *Dark matter?*

Are there new symmetries of nature?

MoEDAL Addresses Fundamental Questions:

Are there extra di...

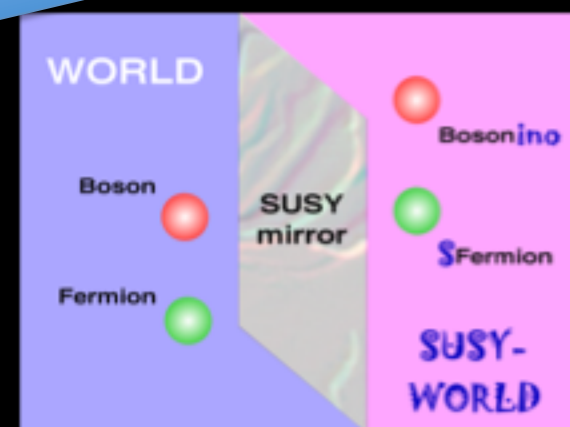


...arge exist?

We are just starting, potentially revolutionary MoEDAL results to come

What is the nature of Dark matter?

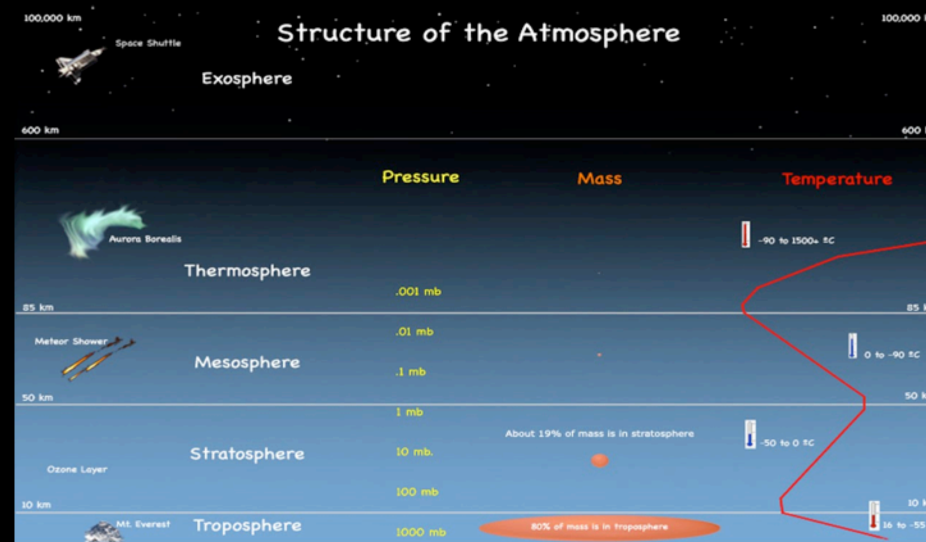
What happened just after the big bang?



Are there new symmetries of nature?

EXTRA SLIDES

The Future - Cosmic-MoEDAL?



- *Cosmic-MoEDAL envisage deployment of ~50K m² of NTDs at high altitude - 50/125 times larger than MACRO/SLIM*
  - *To detect remnants from the early universe: EW monopoles and monopoles from late phase transition & GUT scenarios with mass from ~10^4 to 10^{18} GeV, as well as strangelets, nuclearites, etc*
  - *We can also look for monopoles and massive (pseudo)-stable charged particles particles produced in very high energy air showers.*
- *Sites under consideration: Chacaltaya (5km); Tenerife -Tiede (3km); IceCube (3km); Jeju Island (2km)*

The Royal Society Test Bed

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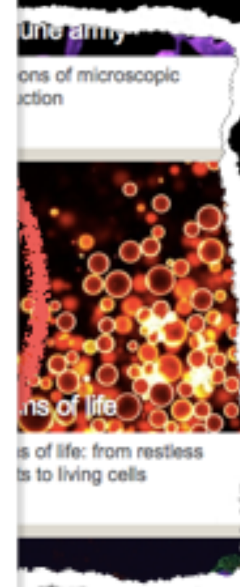
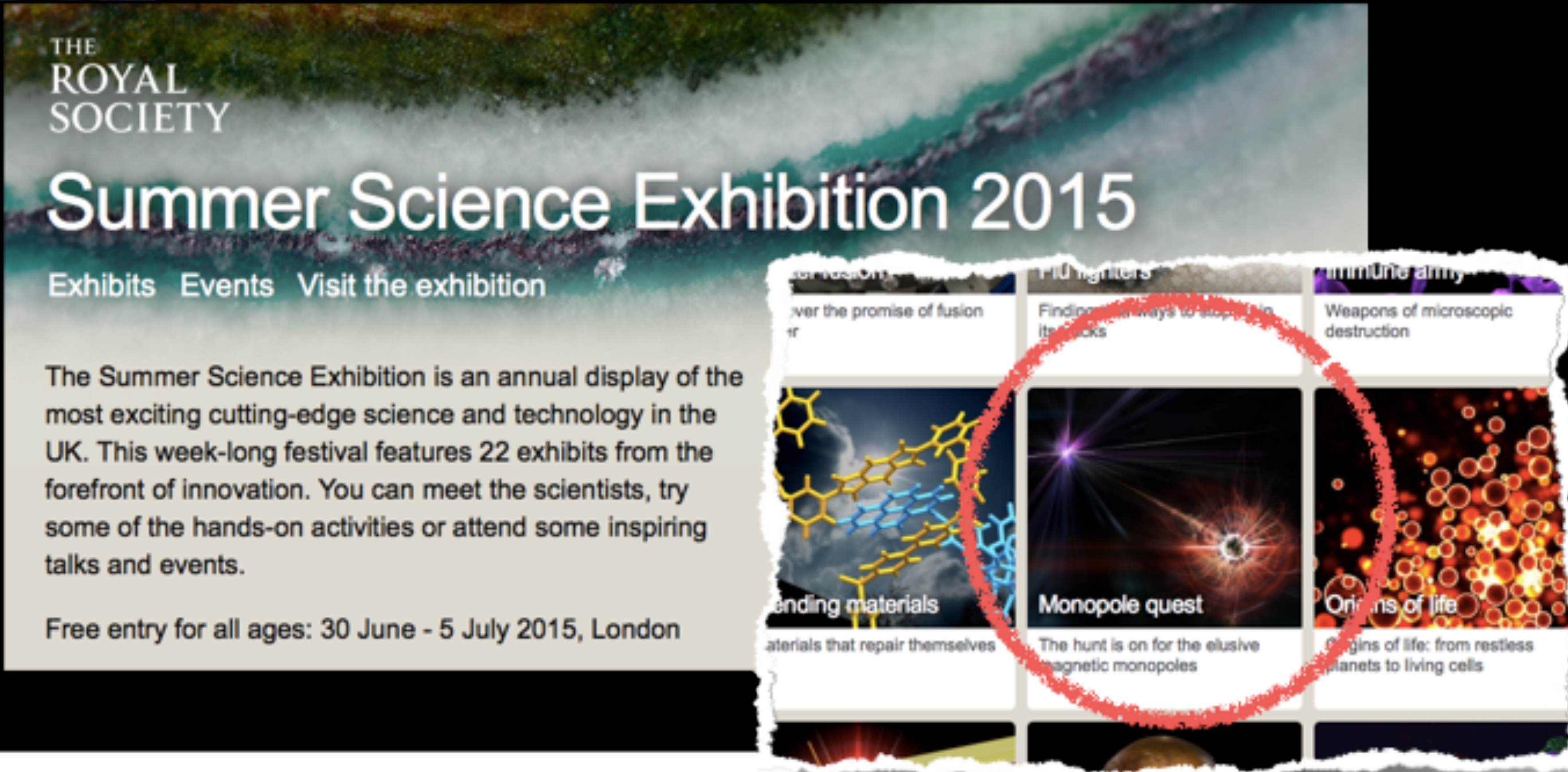
Nuclear Track Detector analysis for the MoEDAL experiment utilising mass-participation methodologies

B. Acharya[a,b], J. Alexandre[a], K. Bendtz[c], P. Benes[d], J. Bernabéu[e], M. Campbell[f], S. Cecchini[g], Y. M. Cho[h], J. Chwastowski[i], A. Chaterjee[j], C. Cooke[k], M. de Montigny[l], D. Derendarz[i], A. de Roeck[f], J. R. Ellis[a,m], A. Evans[k], M. Fairbairn[a], D. Felea[n], M. Frank[o], D. Frekers[p], C. Garcia[e], G. Giacomelli[q,1], O. Gorecan[k], D. Haşegan[o], E. Ireland[k], S. Jamieson Bibb[k], M. Kalliokoski[r], A. Katre[j], D.-W. Kim[s], M. G. L. King[e], K. Kinoshita[t], D.H. Lacarrère[f], S. C. Lee[s], C. Leroy[d], A. Lionti[j], A. Margiotta[q], N. Mauri[g], N. Mavromatos[a], P. Mermod[j], V. A. Mitsou[e], D. Milstead[c], R. Orava[u], B. ,Parker[k], L. Pasqualini[q], L. Patrizii[g], G. E. Păvălaş[n], J. L. Pinfold[l], M. Platkevič[d], V. Popa[n], F. Pomeroy[k], M. Pozzato[g], S. Pospisil[d], A. Rajantie[v], Z. Sahnoun[g,w], M. Sakellariadou[a], S. Sarkar[a], G. Semenoff[x], G. Sirri[g], K. Sliwa[y], R. Soluk[l], M. Spurio[q], Y. N. Srivastava[z], R. Staszewski[i], M. Suk[d], J. Swain[z], M. Tenti[aa], V. Togo[g], M. Trzebinski[i], J. A. Tuszyński[l], V. Vento[e], O. Vives[e], V. Vykydal[d], T. Whyntie[ab,k], and A. Widom[z]



Test o ... nverse
pro ... bit
at the Royal Society Summer Show in2015

The Royal Society Test Bed

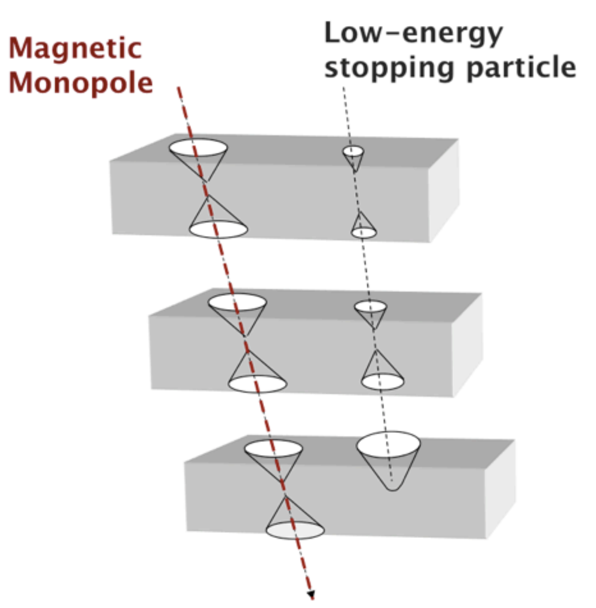


Test data was obtained for MoEDAL's Zooinverse project New Physics Quest" at their exhibit at the Royal Society Summer Show in2015

Detector Resolution

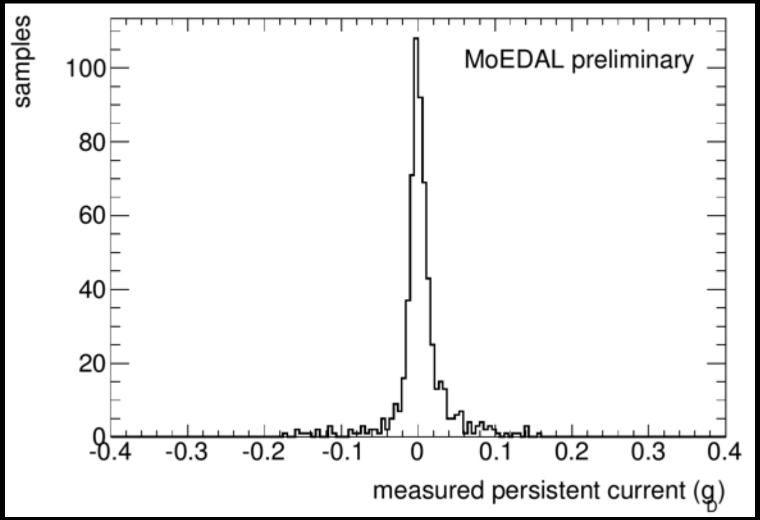
Nuclear Track Detectors

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

Examples of Refereed MoEDAL Publications

- *B. Acharya et al., "The Physics Programme Of The MoEDAL Experiment At The LHC", MoEDAL Collaboration May 29, 2014. Int.J.Mod.Phys. A29 (2014) 1430050*
- *J. Ellis, N. E. Mavromatos, T. You. "The Price of an Electroweak Monopole" Feb 4, 2016. Phys .Lett. B756 (2016) 29-35*
- *M. Fairbairn and J. L. Pinfold, "MoEDAL – A New Light on the High Energy Frontier". To be published in Contemporary Physics.*
- ***B. Acharya et al., "Search for magnetic monopoles with the MoEDAL prototype trapping detector in 8 TeV proton-proton collisions at the LHC", MoEDAL Collaboration. CERN-EP-2016-101 e-Print: arXiv:1604.06645 [hep-ex]. To be published in JHEP***
- *B. Acharya et al., "Search for magnetic monopoles with the MoEDAL trapping detector in 13 TeV proton-proton collisions at the LHC", MoEDAL Collaboration. In preparation.*
- *B. Acharya et al., "The MoEDAL LHC Detector". In preparation.*

Milestones Since the Last LHCC Report

- *Data taken in p-p & HI running in 2015. Data taking continues in 2016 after fresh detectors elements were deployed etc.*
  - *Initial plan is to carry on until 10 fb^{-1} of data is taken*
- *Two Collaboration Meetings held June 2015, December 2015 .*
  - *Upcoming collaboration meeting in Valencia June 27th - 28th.*
- *MoEDALwas invited to present at the Royal Society Summer Exhibition in July 2015 and "Behind the Scenes at the Royal Society" exhibition in March 2016*
- *15 International presentations given to date.*
  - *Upcoming talks include: a presentation at LHCP in Lund in June **, the EP-LHC seminar at CERN in July**; and, SUSY 2016 in Melbourne in June/July*
- *National University of Science and Technology(MISiS) in Moscow was admitted in December 2015*
  - *The University of Alabama applied to join MoEDAL in June 2016.*

The MoEDAL "Zooinverse" Project

- *Uniquely the Institute for Research in Schools (IRIS) (Simon Langton School) Canterbury, UK is a full member of MoEDAL*
- *MoEDAL & IRIS are working on the citizen science Zooniverse interface "New Physics Quest" to involve school students and undergraduates in the analyis of NTD data online*