Status Report of MoEDAL

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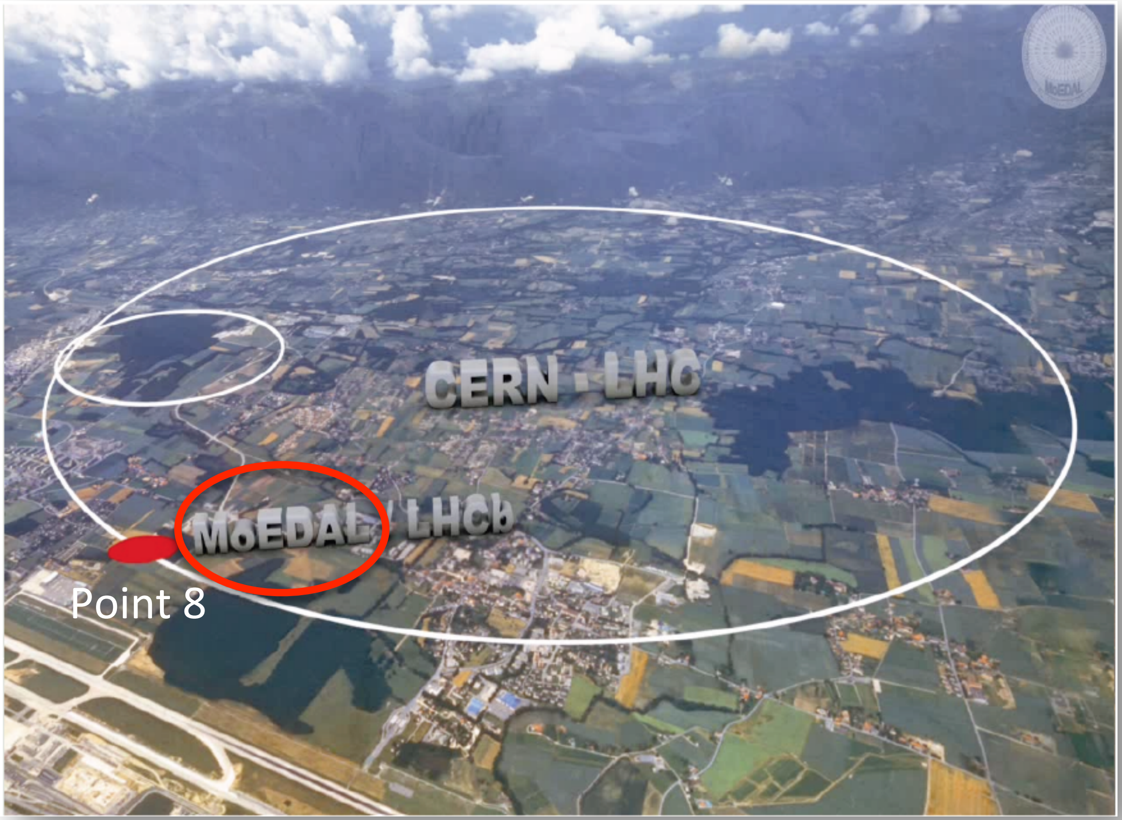
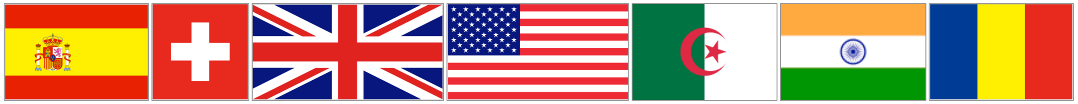
IFIC Valencia

XLIII International Meeting on Fundamental Physics
15 – 21 March 2015, Benasque, Spain

MoEDAL at LHC





International collaboration ~65 physicists from 24 participating institutions

UNIVERSITY OF ALBERTA
INFN & UNIVERSITY OF BOLOGNA
UNIVERSITY OF BRITISH COLUMBIA
CRAAG. ALGERIA
CERN
UNIVERSITY OF CINCINNATI
INPPS CRACOW
CONCORDIA UNIVERSITY
CZECH TECHNICAL
UNIVERSITY IN PRAGUE
UNIVERSITÉ DE GENÈVE
GANGNEUNG-WONJU NATIONAL UNIVERSITY
DESY
HELSINKI UNIVERSITY
IMPERIAL COLLEGE LONDON
KING'S COLLEGE LONDON
KONKUK UNIVERSITY
UNIVERSITY OF MÜNSTER
NATIONAL INSTITUTE OF TECHNOLOGY, INDIA
NORTHEASTERN UNIVERSITY
SIMON LANGTON SCHOOL, UK
INSTITUTE FOR SPACE SCIENCES, ROMANIA
TUFT'S UNIVERSITY
IFIC VALENCIA

MoEDAL timeline

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

CERN-LHC-2009-006
MoEDAL-TDR-001
June 11, 2009

MoEDAL

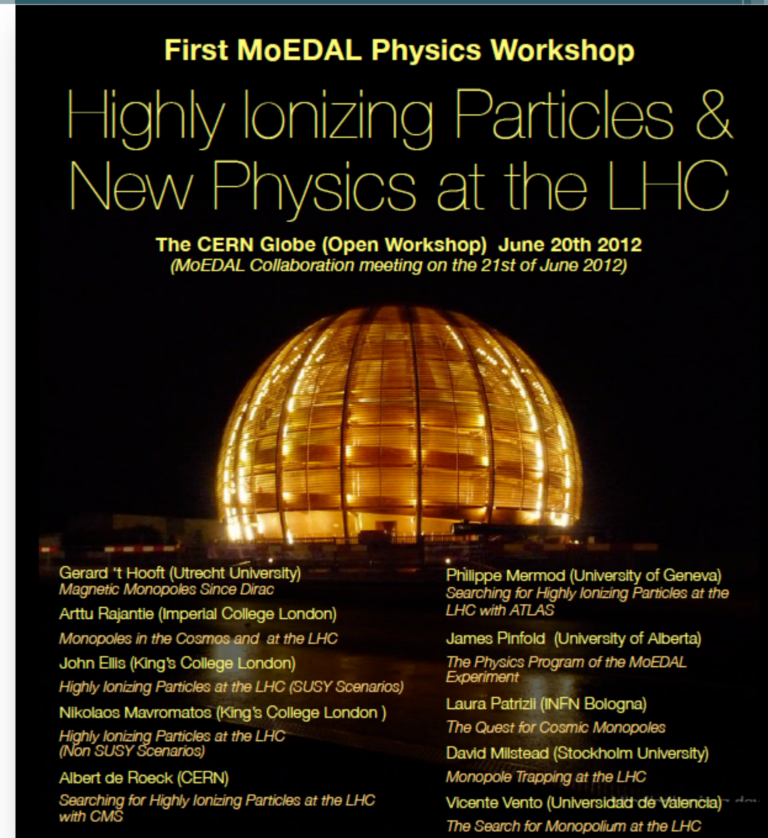
$$\nabla . \mathbf{E} = 4\pi\rho_e$$
$$\nabla . \mathbf{B} = 4\pi\rho_m$$
$$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_m$$
$$\nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_e$$
$$\mathbf{F}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

TECHNICAL DESIGN REPORT
OF THE MoEDAL EXPERIMENT

MoEDAL TDR, Jun 2009

Dec 2009: The CERN Research Board unanimously approved the MoEDAL experiment

First MoEDAL detectors deployed for 2012 run



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.

"MoEDAL prepares for new physics at LHC restart"

2nd MoEDAL Collaboration Meeting, CERN, June 2014

CERN Courier, Aug 2014

Key feature: high ionisation

$$\frac{\text{charge}}{\text{velocity: } \beta = v/c} = z/\beta$$

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

Electric charge

High ionisation possible when:

- multiple electric charge (H^{++}, Q-balls, etc.) = n × e
- very low velocity & electric charge, e.g. Stable Massive Particles (SMPs)
- magnetic charge (monopoles, dyons) = ng = n × 68.5 × e
  - a singly charged relativistic monopole has ionisation ~4700 times MIP!!
- any combination of the above

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

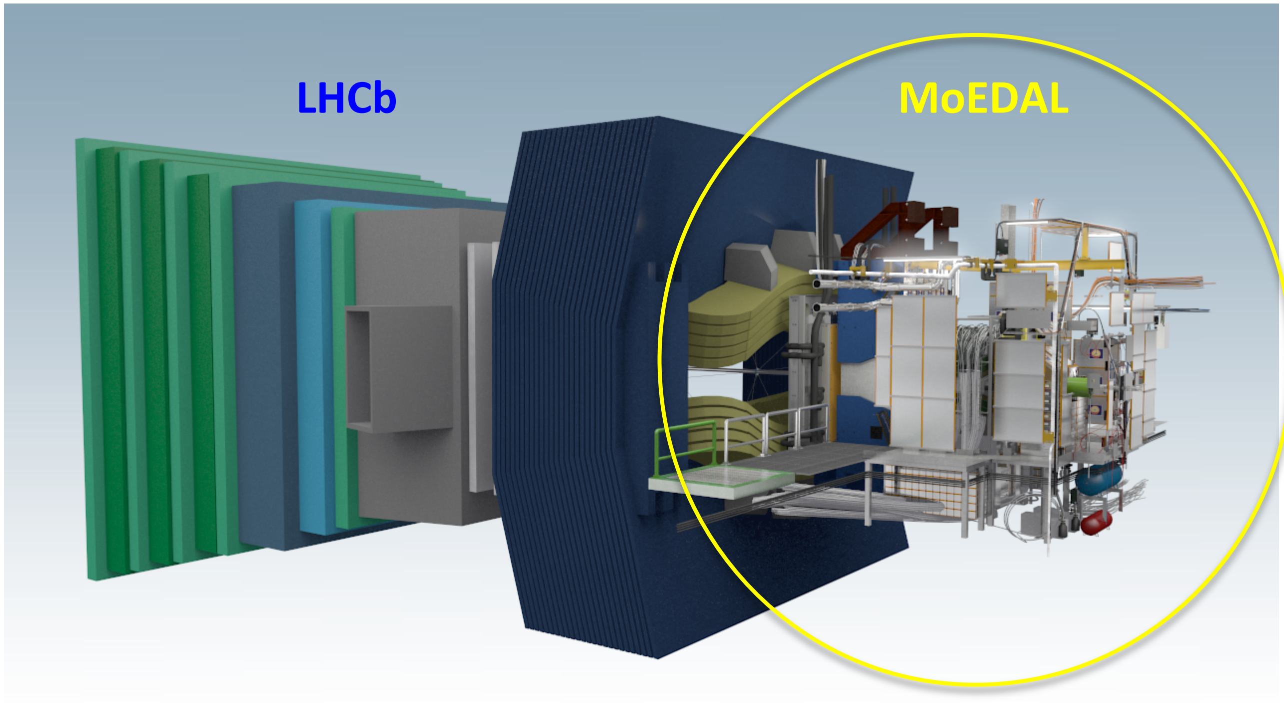
Magnetic charge

MoEDAL detectors have a threshold of **z/β ~ 5**

Particles must be *massive*, *long-lived* & *highly ionising* to be detected at *MoEDAL*

The MoEDAL detector

The MoEDAL detector



DETECTOR SYSTEMS

① Low-threshold NTD array (Z/β > ~5)

② Very High Charge Catcher NTD array (Z/β > ~50)

③ Monopole Trapping detector

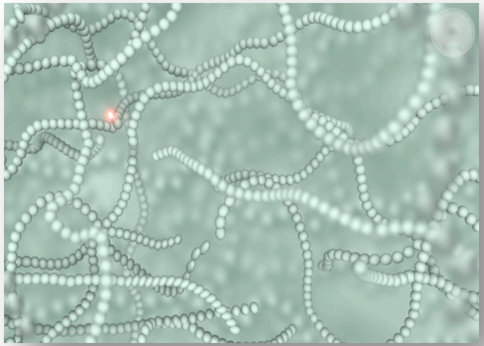
④ TimePix radiation background monitor

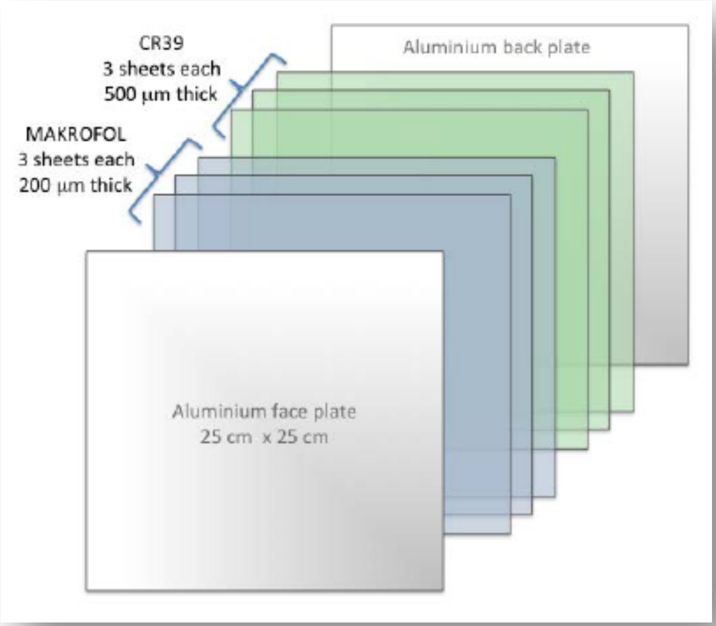
MoEDAL is unlike any other LHC experiment:

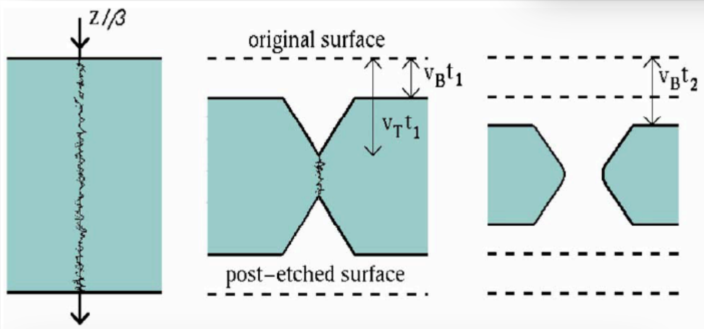
- mostly **passive detectors**; no trigger; no readout
- the largest deployment of passive **Nuclear Track Detectors (NTDs)** at an accelerator
- the 1st time **trapping detectors** are deployed as a detector

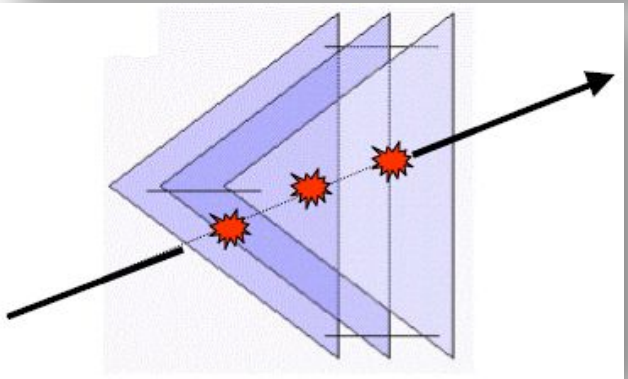
Highly-ionising particle detection in NTDs

- The passage of a highly ionising particle through the plastic track-etch detector (e.g. CR39®) is marked by an invisible damage zone ("latent track") along the trajectory
- The damage zone is revealed as a cone-shaped etch-pit when the plastic detector is etched in a controlled manner using a hot sodium hydroxide solution





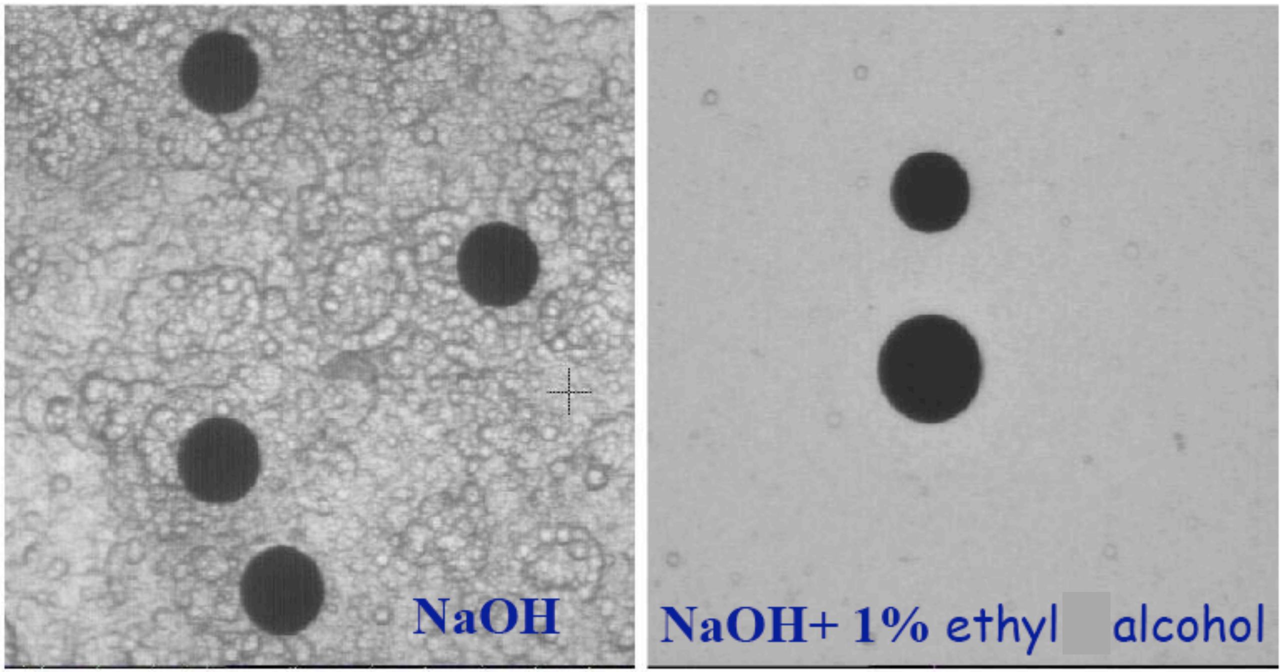




Looking for aligned etch pits in multiple sheets

Scanning results

Bologna INFN NTD laboratory

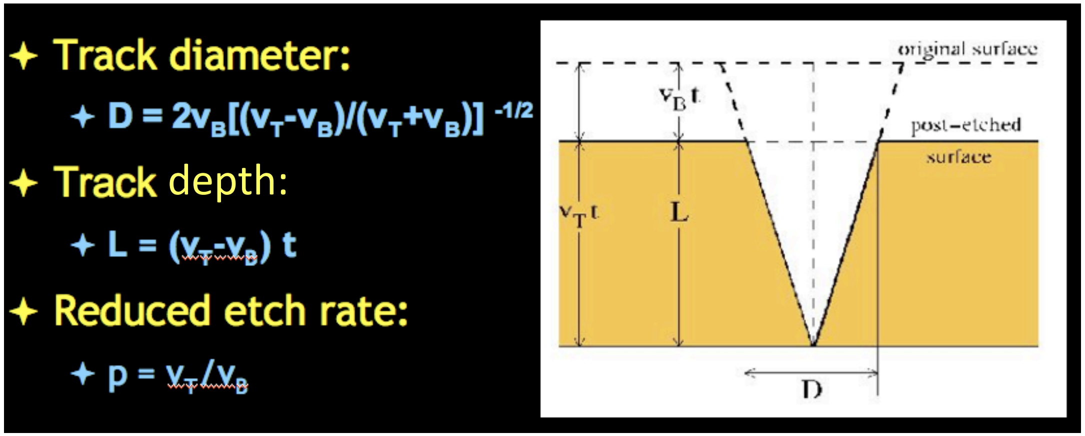


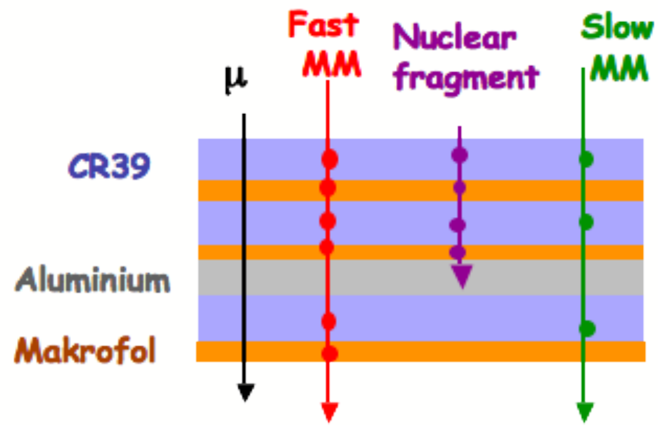
(a) Makrofol etched in 6N NaOH at 50 C for 95 hours

(b) Makrofol etched in 6N KOH with addition of 20% ethyl alcohol by volume for 8 hours

Evident that with KOH the surface defects are drastically reduced and the sheets are more transparent

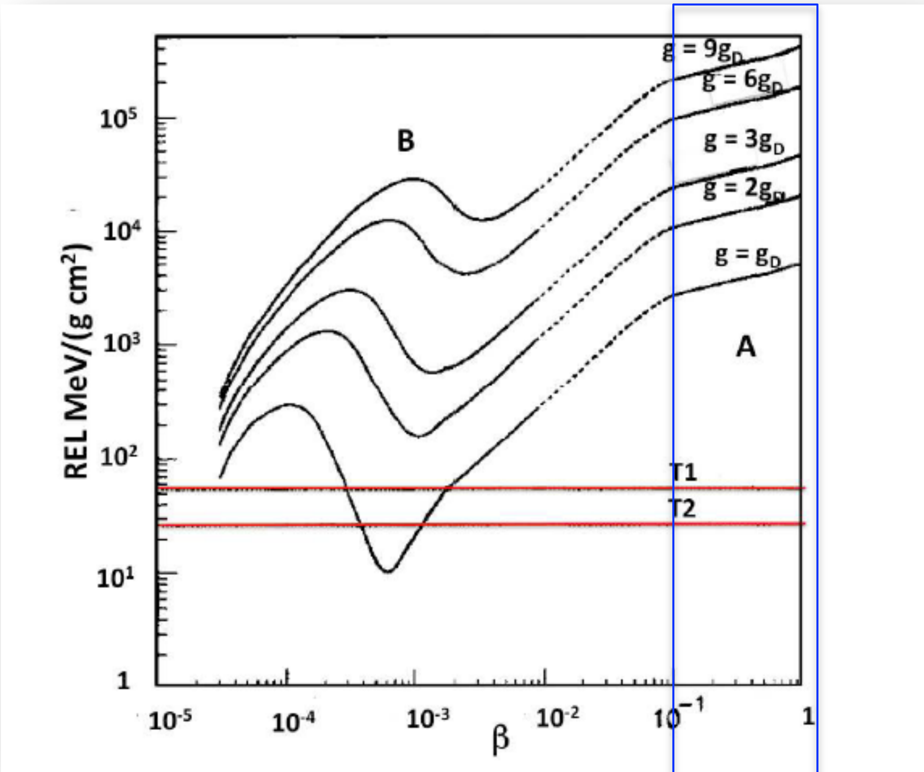
Analysis procedure

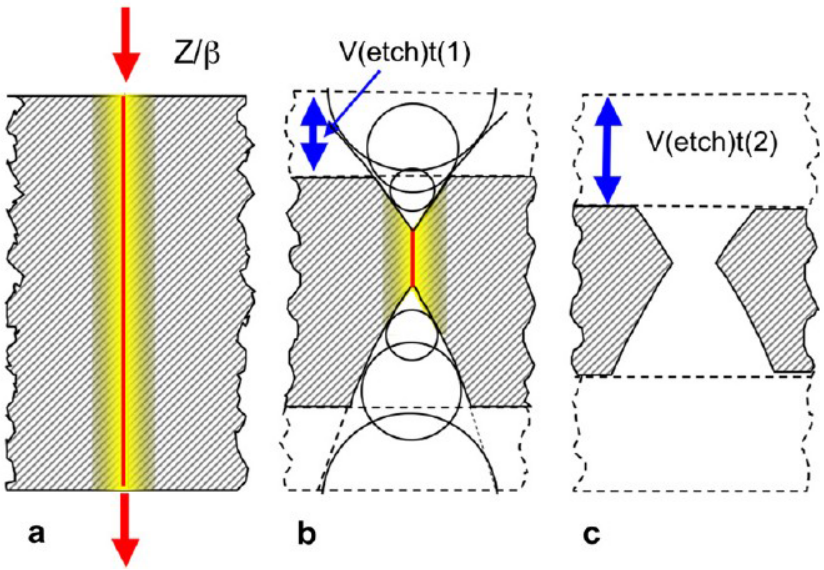




- Electrically-charged particle: $dE/dx \sim \beta^{-2}$ ➔ slows down appreciably within NTD ➔ opening angle of etch-pit cone becomes **smaller**
- Magnetic monopole: $dE/dx \sim \ln\beta$
  - slow MM: slows down within an NTD stack ➔ its ionisation falls ➔ opening angle of the etch pits would become **larger**
  - relativistic MM: dE/dx essentially constant ➔ trail of equal diameter etch-pit pairs
- The reduced etch rate is simply related to the *restricted energy loss* $REL = (dE/dx)_{\text{10nm from track}}$

Monopole energy loss in MoEDAL NTDs





T2: Z/β ≃ 5 for CR39 NTD

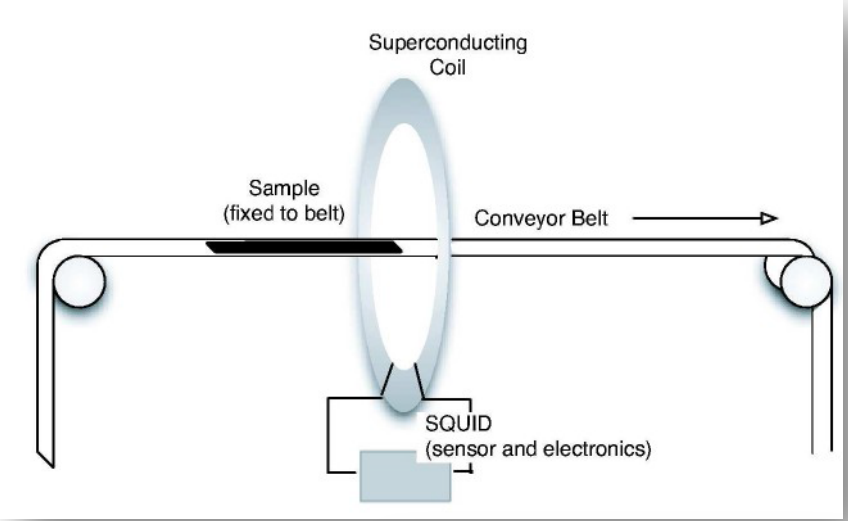
$$\left(\frac{dE}{dx}\right)_{REL} = K\frac{Z_t}{A_t}\frac{Z^2}{\beta^2}\left[\ln\left(\frac{2m_e c^2\omega\gamma^2\beta^2}{I^2}\right)-\frac{\beta^2}{2}\left(1+\frac{T_{upper}}{T_{max}}\right)-\frac{\delta}{2}-\frac{C_S}{Z_t}\right]$$

NTDs deployment in 2012 (√s = 8 TeV)

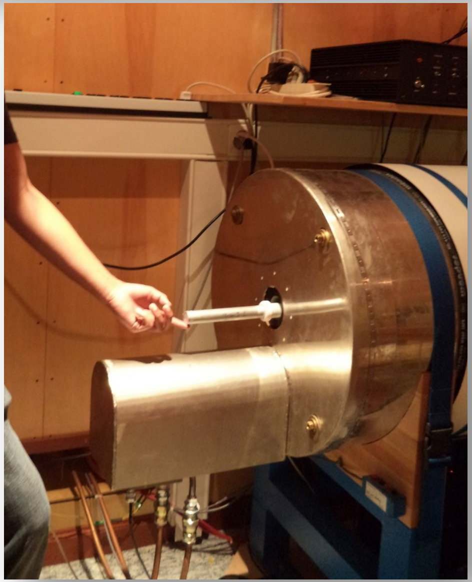
NTDs sheets kept in boxes mounted onto LHCb VELO cavern walls

TODAY: NTDs installed for 2015 run

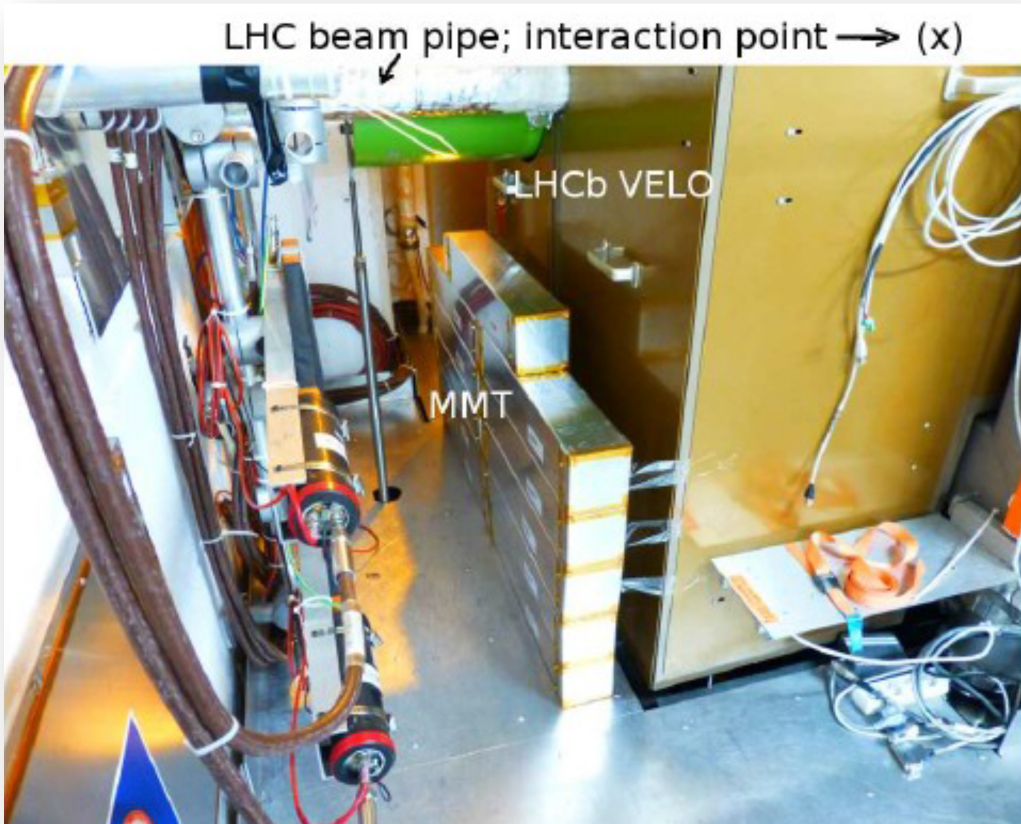
MMT: Magnetic Monopole Trapper



- Complement the MoEDAL detector with an array of trapping modules
  - the binding energies of monopoles in nuclei with finite magnetic dipole moments estimated to be hundreds of keV
- To be analysed with SQUID at ETH Zürich
- Disadvantage: rather low geometrical acceptance
- Advantages:
  - speed! Magnetometer measurements plus analysis take ~2 weeks → first monopole search at LHC
  - complementarity: a signal should be seen in both MoEDAL main detector and MMT
  - MMT can measure magnetic charges with < 5% accuracy
  - monitoring for decay products of trapped electrically-charged particles at underground laboratory



MMTs deployment in 2012 ($\sqrt{s}$ = 8 TeV)

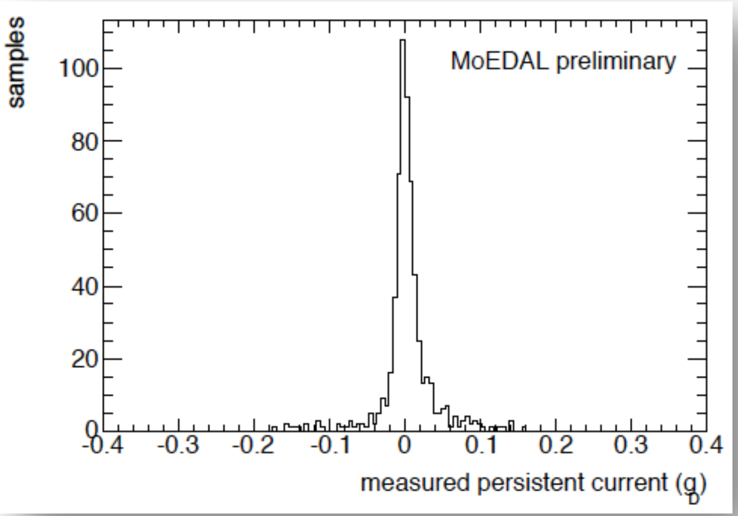


11 boxes each containing 18 aluminium rods of 60 cm length and 2.54 cm diameter

TODAY: MMTs installed for 2015 run

MMT 2012 analysis

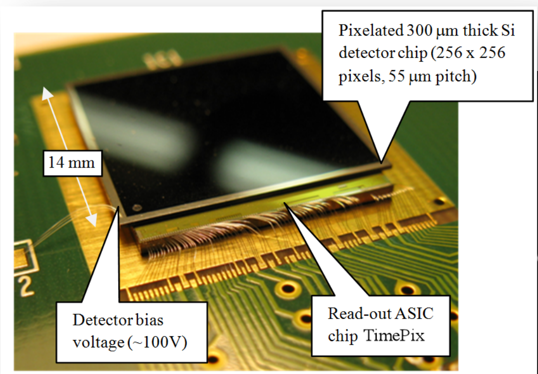
- Material: Aluminium
  - large nuclear dipole moment → likely to bind to monopoles with binding energy several 100's of keV
  - cheap
- Persistent current after first passage for all samples
- Excellent charge resolution (< 0.1 g_D) except for outliers
  - small occasional (2%) offset jumps are expected for large samples
- **No monopole with charge > 0.5 g_D observed in MMT**
- Detailed material map of the cavern necessary to set limits on monopole charges
  - work in progress



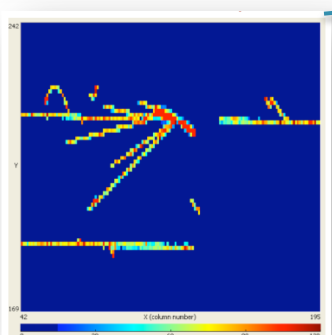
Bendtz, Katre, Lacarrère, Mermod, Milstead, Pinfold, Soluk, arXiv:1311.6940

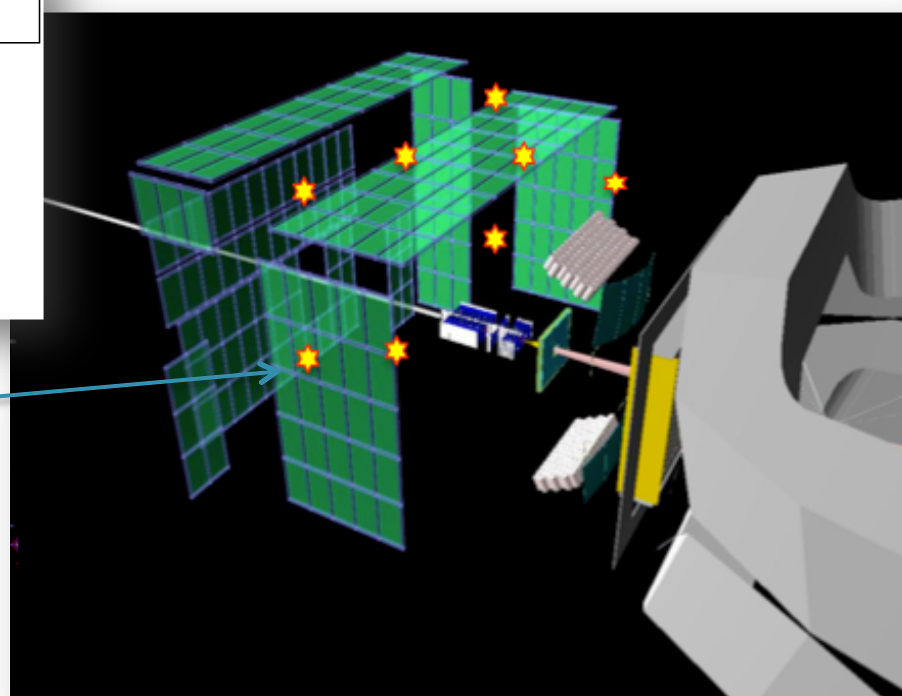
The TimePix radiation monitor

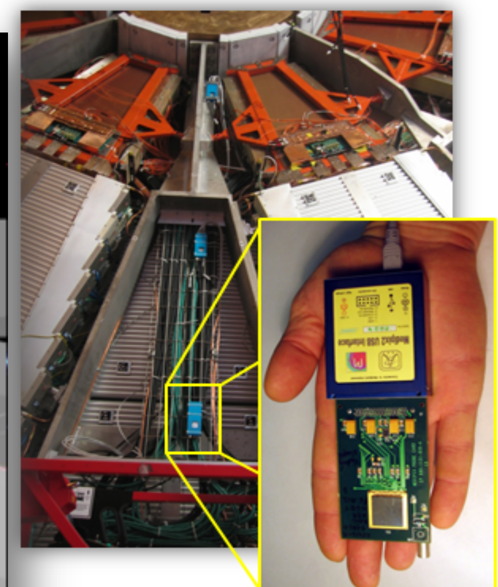
- Timepix (MediPix) chips are used to measure online the radiation field + measure the spallation product background
- The Timepix chip pixels are instrumented with an amplifier + comparator + counter + timer (allows time-over-threshold energy measurement)



Timepix chip







Deployment of MediPix chips in ATLAS

Complementarity of MoEDAL & other LHC exps

ATLAS+CMS

- The main LHC detectors are optimised for the detection of singly (electrically) charged (or neutral) particles ($Z/\beta \sim 1$) moving near to the speed of light ($\beta > 0.5$)
- Typically a largish statistical sample is needed to establish a signal

MoEDAL

- MoEDAL is designed to detect charged particles, with effective or actual $Z/\beta > 5$
- As it has no trigger/electronics slowly moving ($\beta <\sim 0.5$) particles are no problem
- One candidate event should be enough to establish the signal (no Standard Model backgrounds)

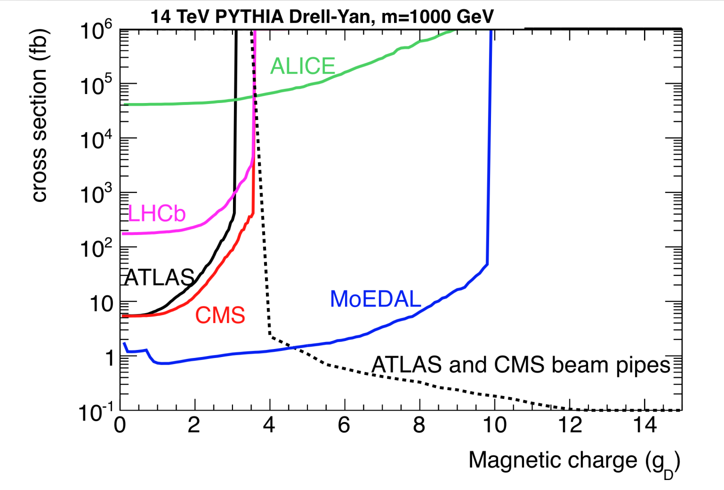
MoEDAL strengthens & expands the physics reach of LHC

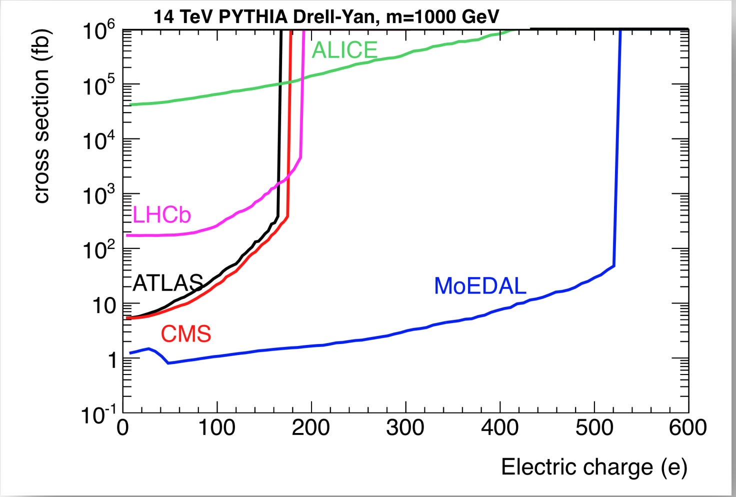
MoEDAL sensitivity

Cross-section limits for magnetic and electric charge assuming that:

- ~one MoEDAL event is required for discovery and ~100 events in the other LHC detectors
- integrated luminosities correspond to about two years of 14 TeV run

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

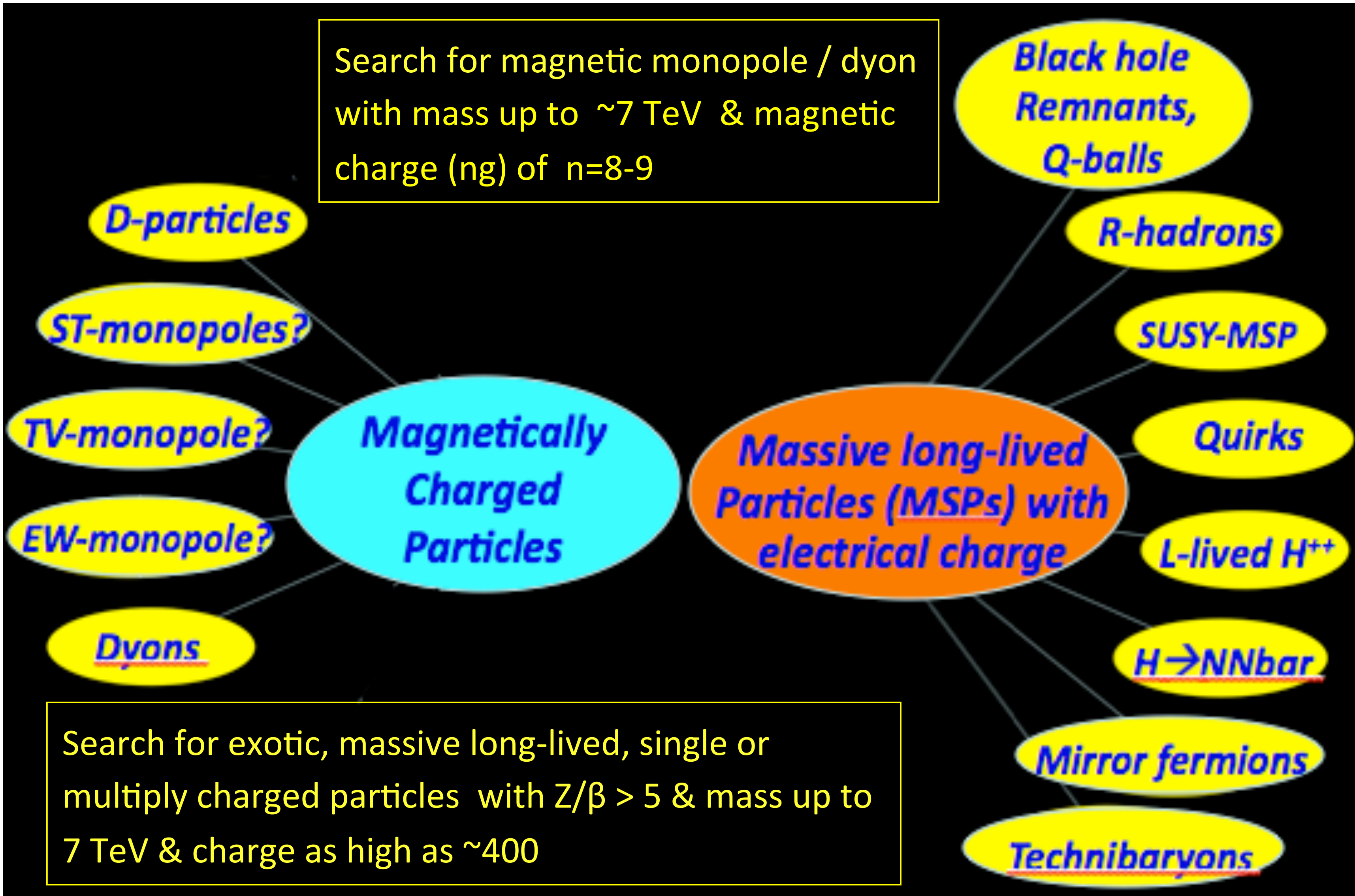




De Roeck, Katre, Mermod, Milstead, Sloan, EPJC72 (2012) 1985 [arXiv:1112.2999 [hep-ph]]

The MoEDAL physics program

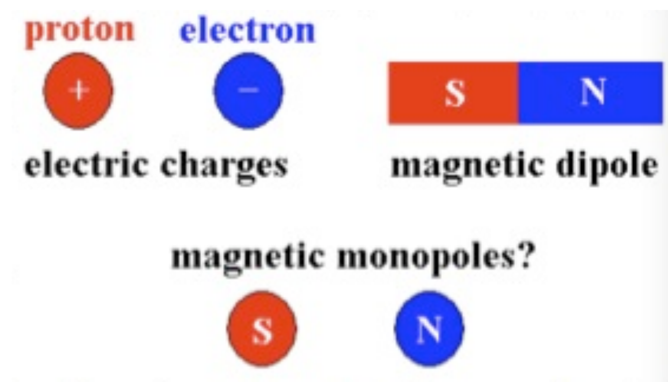
The MoEDAL Physics Program



Magnetic monopoles: Symmetrising Maxwell

- Maxwell, in 1873, makes the connection between electricity and magnetism - the first Grand Unified Theory!
- As no magnetic monopole had ever been seen Maxwell cut isolated magnetic charges from his equations - making them asymmetric
- A magnetic monopole restores the symmetry to Maxwell's equations

Name	Without Magnetic Monopoles	With Magnetic Monopoles
Gauss's law:	$\vec{\nabla} \cdot \vec{E} = 4\pi \rho_e$	$\vec{\nabla} \cdot \vec{E} = 4\pi \rho_e$
Gauss' law for magnetism:	$\vec{\nabla} \cdot \vec{B} = 0$	$\vec{\nabla} \cdot \vec{B} = 4\pi \rho_m$
Faraday's law of induction:	$-\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t}$	$-\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t} + 4\pi \vec{J}_m$
Ampère's law (with Maxwell's extension):	$\vec{\nabla} \times \vec{B} = \frac{\partial \vec{E}}{\partial t} + 4\pi \vec{J}_e$	$\vec{\nabla} \times \vec{B} = \frac{\partial \vec{E}}{\partial t} + 4\pi \vec{J}_e$



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

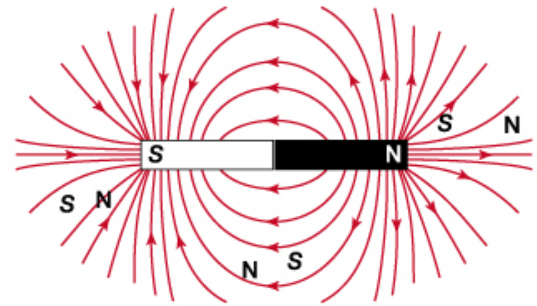
Dirac's Monopole

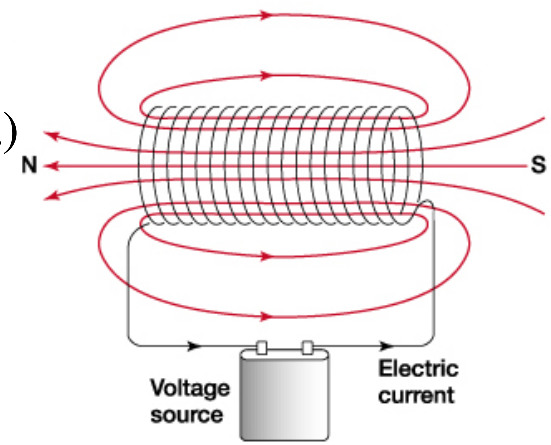
- Paul Dirac in 1931 hypothesized that the magnetic monopole exists
- In his conception the monopole was the end of an infinitely long and infinitely thin solenoid
- Dirac's quantisation condition:

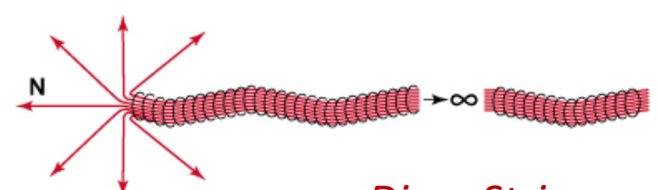
$$ge = \left[\frac{\hbar c}{2}\right] n \quad OR \quad g = \frac{n}{2\alpha} e \quad \left(from \quad \frac{4\pi e g}{\hbar c} = 2\pi n \quad n = 1,2,3..\right)$$

- Where g is the "magnetic charge" and α is the fine structure constant 1/137
- This means that **g = 68.5e** (when n=1)!
- The other way around: IF there is a magnetic monopole then charge is quantised:

$$e = \left[\frac{\hbar c}{2g}\right] n$$







Dirac String

Magnetic monopole properties

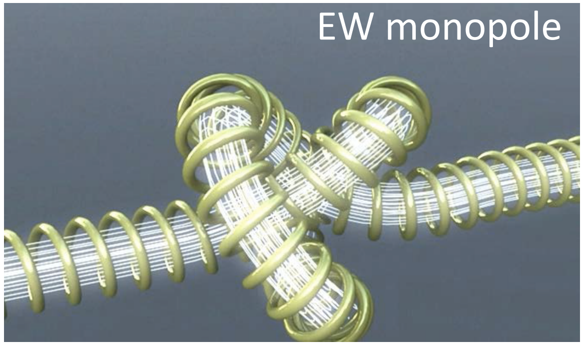
- Single magnetic charge: g = 68.5e and no electric charge
  - if the fundamental unit of charge is e/3 then g → 3g
  - if electric charge as well, called Dyon
- Coupling constant = g/ℏc ~ 34
- Energy acquired in a magnetic field: 2.06 MeV/gauss.m
  - with a 10 m × 10 T LHC magnet we can accelerate monopoles to ~2 TeV!
- Monopoles will accelerate along field lines and not curve in a normal manner in a magnetic field - according to the Lorentz equation:

$$\vec{F} = g\vec{E} + e\vec{p} \times \vec{B} / \gamma m_0$$

- Also, monopoles would have anomalously high ionisation, Cerenkov radiation, transition radiation and multiple scattering
- The monopole mass is not predicted within the Dirac's theory *(see next slide)*
- The Dirac monopole is a point-like particle

Magnetic monopole mass

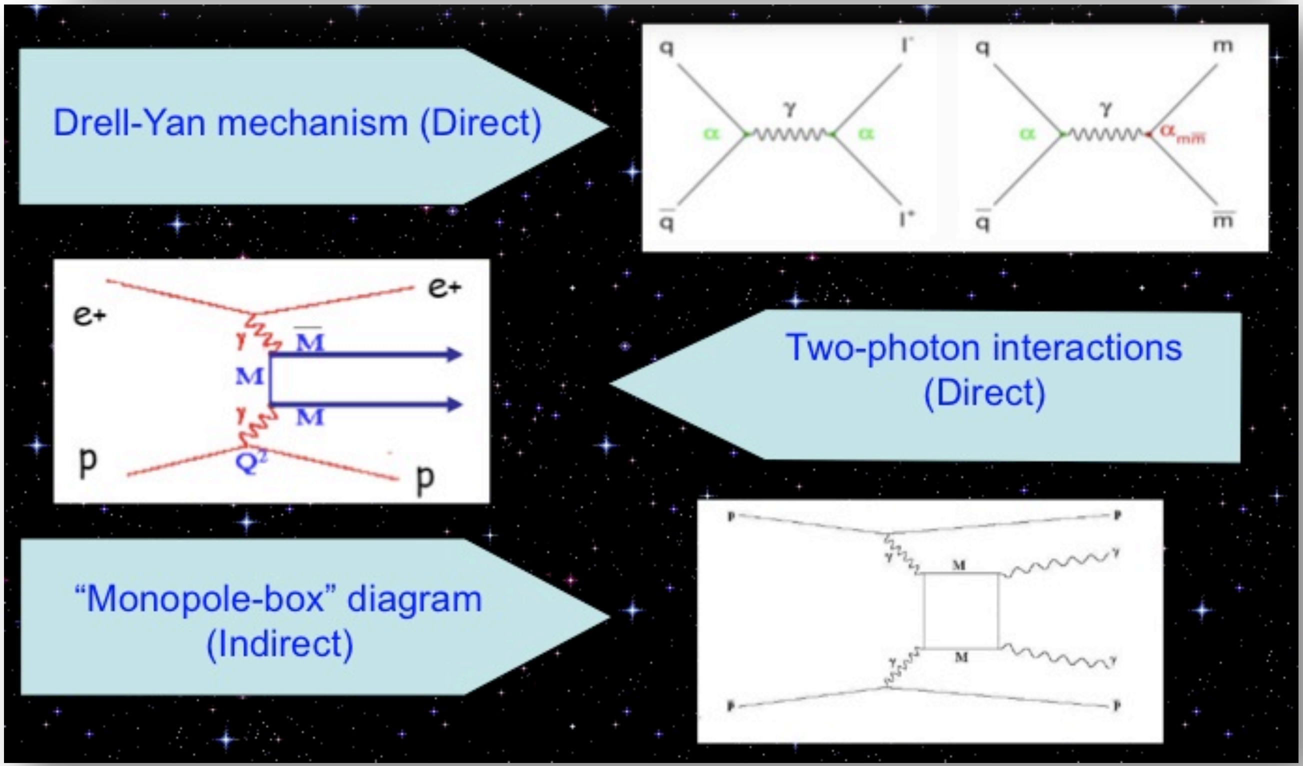
- No real prediction for classical Dirac monopole mass
  - if monopole radius ~ electron radius ⇒ $m_{monopole} \approx n \times (2.4\ \text{GeV})$
- There are other models where monopoles could appear in a mass range accessible to the LHC. e.g.:
  - the electroweak Cho-Maison monopole [PLB 391 (1997) 360]
  - the Troost-Vinciarelli monopole had a matter field: 50-100 GeV [PLB 63 (1976) 453]



- GUT monopoles
  - 't Hooft and Polyakov (1974) showed that monopoles are fundamental solutions to non-Abelian gauge "GUT" theories – in any theory with an unbroken U(1) factor embedded
  - $m(M_{GUT}) \geq m_X/G > 10^{16}$ GeV $\rightarrow 10^{17}$ GeV ~ 0.02 μg - not producible by particle accelerators
- We consider the magnetic monopole mass a free parameter

Monopole production at colliders

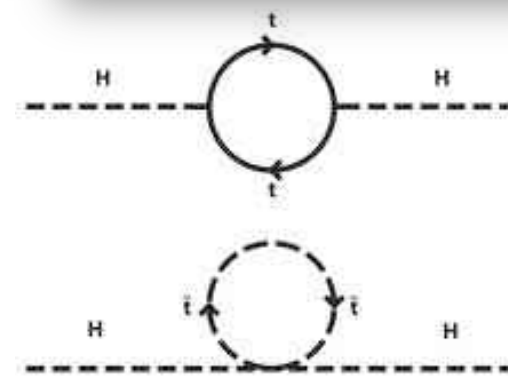
$$e^+e^- \rightarrow M\,M\,, \quad \overline{p}p \rightarrow M\,\overline{M}\,, \quad pp \rightarrow pp\,M\,\overline{M}$$



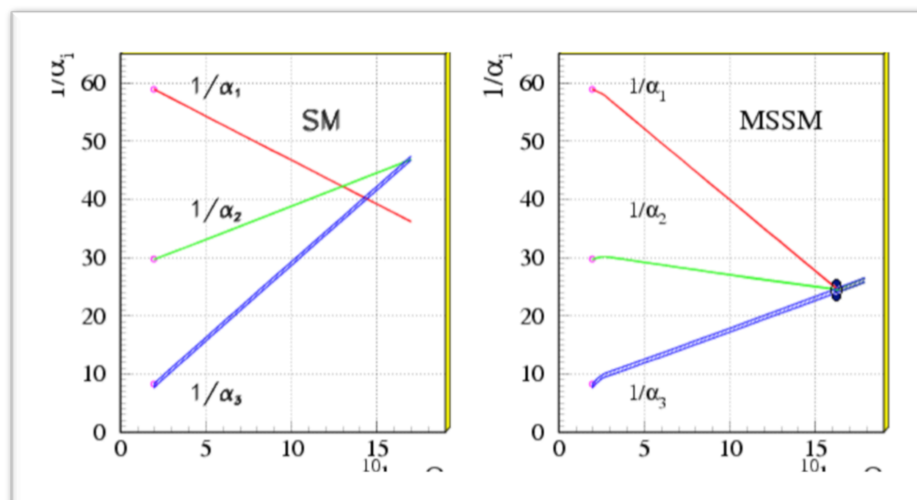
- CDF excluded MM pair production at the 95% CL for cross-section < 0.2 pb and monopole masses 200 < m_M < 700 GeV
- ATLAS set upper cross-section limits set for Dirac monopoles of mass of **200 – 1200 GeV**

Supersymmetry (SUSY)

- What it is?
  - SUSY = global symmetry between fermions & bosons
- Why is it attractive?
  - Higgs mass stabilisation against loop corrections (**fine-tuning** problem)
  - **unification** of gauge couplings at single scale
  - **dark matter** candidate

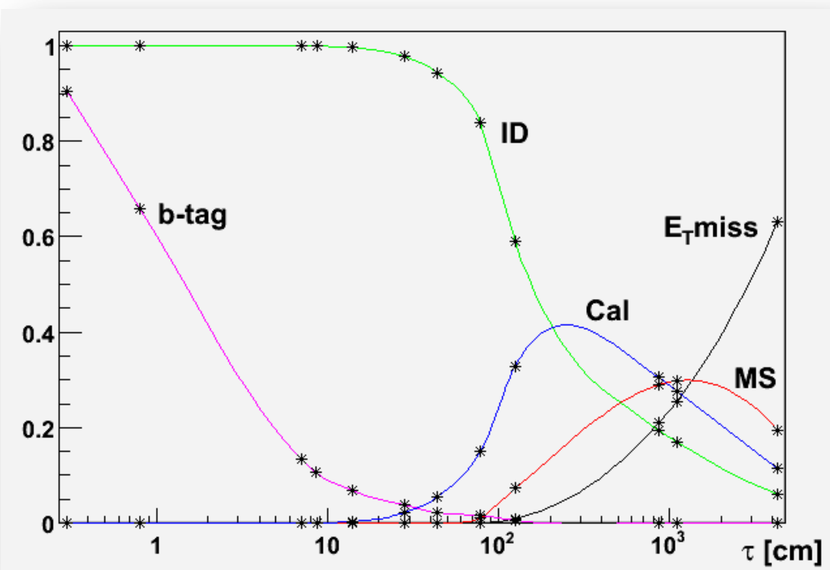


- Particle stability mechanisms
  a) lightest state (LSP) carrying a conserved quantum number:
     R-parity: $R = (-1)^{3(B-L)+2s}$
  b) suppressed (effective) coupling
  c) lack of phase space for decay, e.g. mass degeneracies



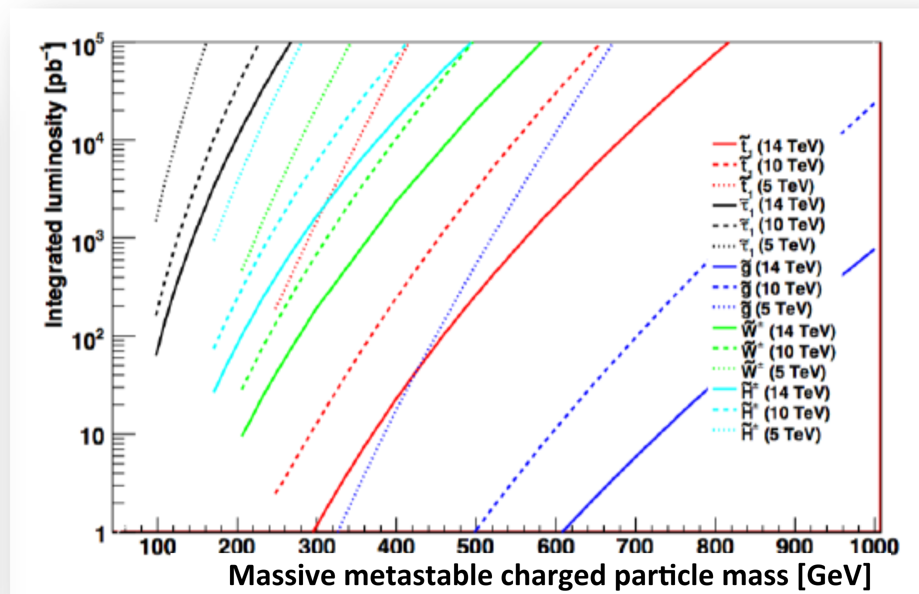
LHC sensitivity to sparticle direct production

- Metastable particles ≡ they live long enough to pass through detector
- Detection at LHC
  - large ionisation energy loss dE/dx, e.g. time-over-threshold in ATLAS Transition Radiation Tracker
  - nuclear interactions (R-hadron) in calorimeters
  - delay (time of flight) reconstructed in muon chambers



Integrated luminosities needed for discovery at LHC at 14 TeV (solid), 10 TeV (dashed) and 5 TeV (dotted)

- signal efficiency of 20% (5%) for electrically charged (strongly interacting) MMCPs
- 1 bkg event for 100 pb^{-1}



Raklev, Mod.Phys.Lett. A24 (2009) 1955

Long-lived particles in SUSY scenarios

- **GMSB**: NLSP decays to gravitino LSP only via (small) gravitational coupling
  - $N_{mes} = 1$: non-pointing photons

$$\tilde{\chi}_1^0 \to \tilde{G} + \gamma$$

  - $N_{mes} > 1$: **penetrating sleptons**

$$\boxed{\tilde{\ell} \xrightarrow{\text{long}} \tilde{G} + \ell}$$

- **Split SUSY**: squarks heavy, suppressing gluino decays ➞ colored heavy particles

R-hadrons $\boxed{R = \tilde{g}q\bar{q},\ \tilde{g}qqq,\ \tilde{g}g}$

- **AMSB:** $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ are mass degenerate
  - long-lived chargino (→ kink track)

$$\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + \pi^{\pm}$$

SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [20].
		SUGRA	Supergravity with a gravitino LSP, see [21].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg \lvert\mu\rvert$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll \lvert\mu\rvert$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m_{\tilde{q}}^2 \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [22–24].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{GS} = -3$.
		GMSB	SUSY GUT extensions [22–26].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m_{\tilde{q}}^2$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m_{\tilde{q}}^2$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

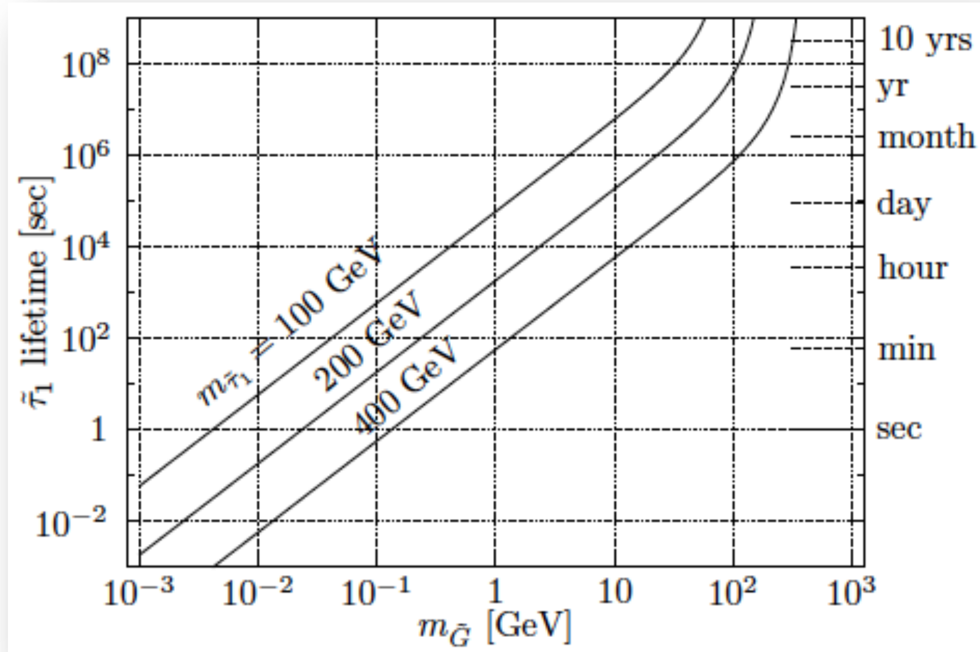
Several SUSY-model signatures accessible to MoEDAL

Fairbairn *et al*, Phys Rept 438 (2007) 1

Long-lived sleptons

$$\Gamma(\tilde{l} \to l\tilde{G}) = \frac{1}{48\pi M_*^2} \frac{m_{\tilde{l}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{l}}^2}\right]^4$$

- Gauge-mediated Supersymmetry-Breaking (GMSB)
- Stau NLSP decays via gravitational interaction to gravitino LSP
  ➜ naturally long lifetime
  ➜ LSP dark matter candidate
- Long-lived staus
  - also in coannihilation region with Lepton Flavour Violation
  - may be slow-moving when produced at LHC
  - ➜ high ionisation



Hamaguchi, Nojiri, De Roeck,
JHEP 0703 (2007) 046 [hep-ph/0612060]

average distance travelled

$$L = \frac{1}{\kappa_\gamma}\left(\frac{100\mathrm{GeV}}{m}\right)^5 \left(\frac{\sqrt{F/k}}{100\mathrm{TeV}}\right)^4 \sqrt{\frac{E^2}{m^2} - 1} \times 10^{-2} cm \quad \sqrt{F} \gtrsim 10^6 \text{ GeV}$$

R-hadrons

- Gluinos in Split Supersymmetry
  - long-lived because squarks very heavy
  - possible gluino hadrons: $R = \tilde{g}q\bar{q}, \tilde{g}qqq, \tilde{g}g$
  - gluino hadrons may flip charge as they pass through matter
    - e.g., $\tilde{g}u\bar{u}$ + uud → $\tilde{g}$ud + $u\bar{u}$
    - ☛ may be missed by ATLAS and CMS

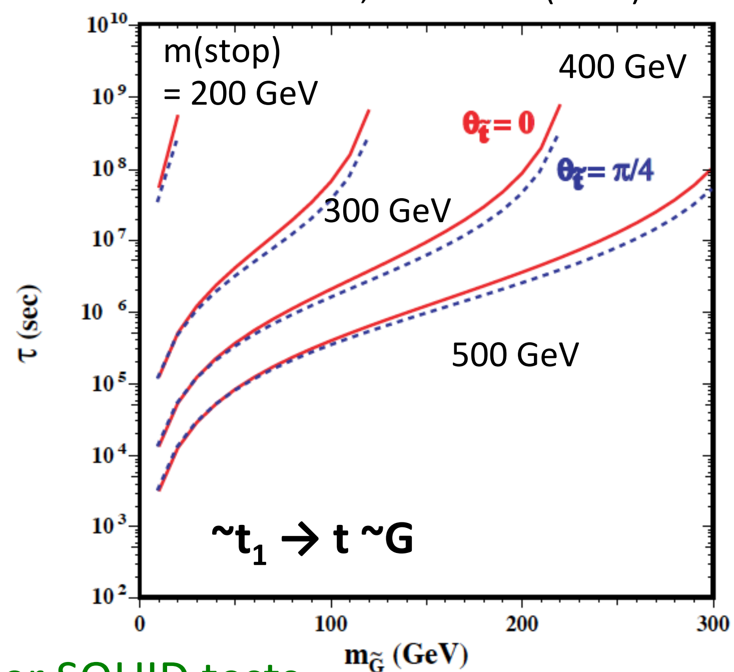
$$\tau \simeq 8 \left(\frac{m_S}{10^9\ \mathrm{GeV}}\right)^4 \left(\frac{1\ \mathrm{TeV}}{m_{\tilde{g}}}\right)^5 \mathrm{s}$$

- *R*-parity violating SUSY

$$W_{RV} = \lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \lambda_{ijk}L_iL_j\bar{E}_k + \mu_iL_iH_2$$

  - if λ' or λ''≠0, stop NLSP case → stop R-hadron → metastable charged particle in material → detection in MoEDAL, if sufficiently slow

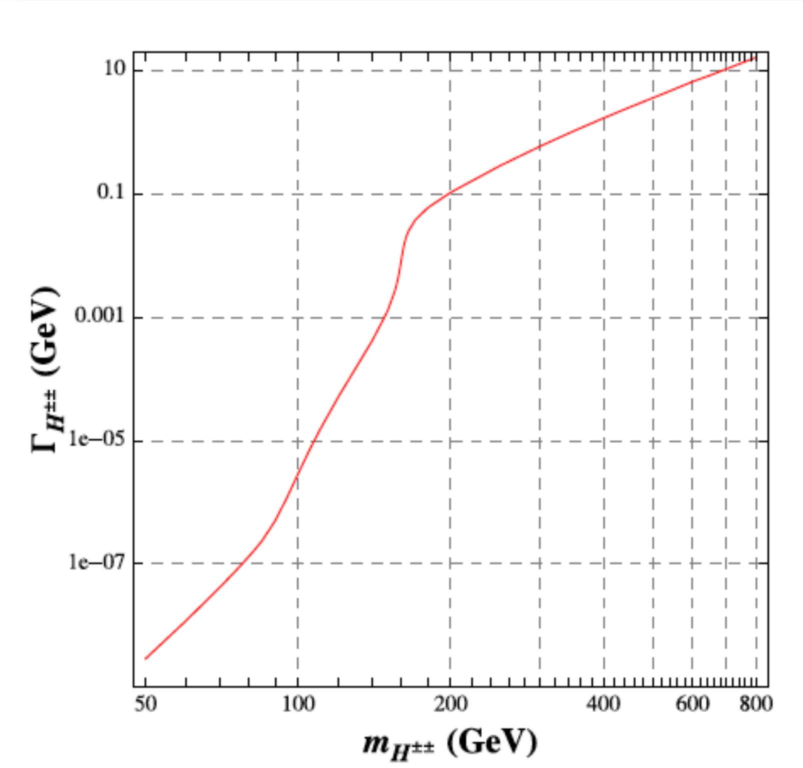
Diaz-Cruz et al, JHEP 0705 (2007) 003



- Moreover R-hadrons may be "trapped" in MMTs and decay at later times ➔ monitoring of MMTs after SQUID tests

Doubly-charged Higgs

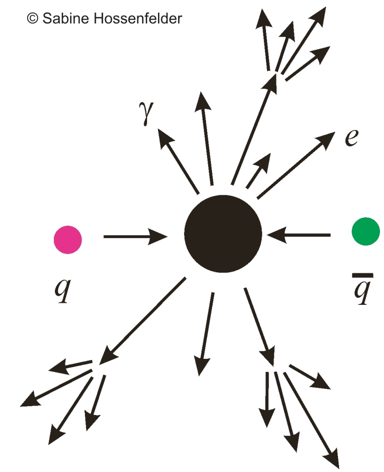
- Extended Higgs sector in BSM models: $SU_L(2) \times SU_R(2) \times U_{B-L}(1)$ P-violating model
- Higgs triplet model with massive left-handed neutrinos but not right-handed ones
- Common feature: **doubly charged Higgs bosons $H^{\pm\pm}$** as parts of a Higgs triplet
- Lifetime
  - depends on many parameters: Yukawa h_{ij} (long if $< 10^{-8}$), $H^{\pm\pm}$ mass, ...
  - essentially there are no constraints on its lifetime ➜ relevant for MoEDAL



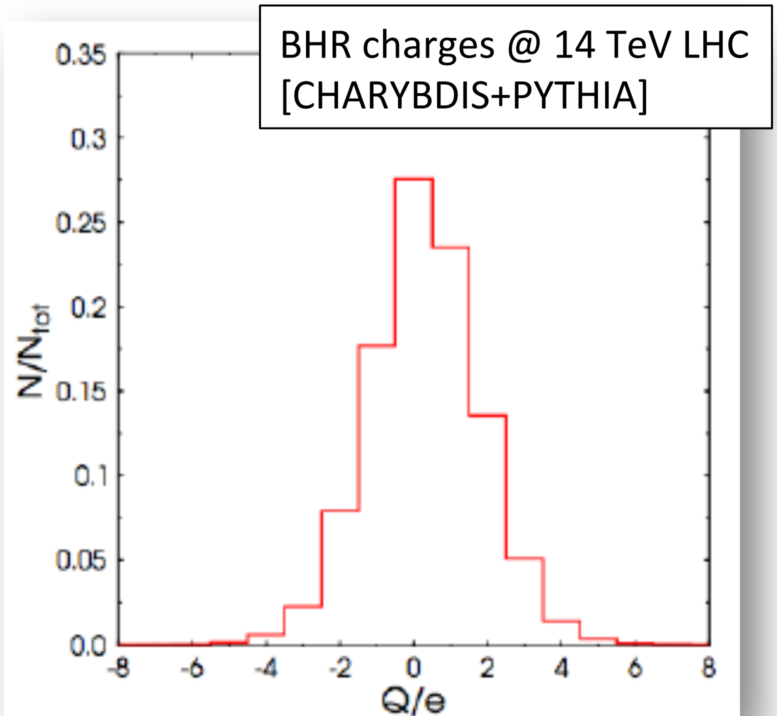
Partial decay width of $H^{\pm\pm} \to W^{\pm}W^{\pm}$

Chiang, Nomura, Tsumura, Phys.Rev. D85 (2012) 095023 [arXiv:1202.2014]

Black-hole remnants



- Large Extra dimension models proposed to address the hierarchy problem:
  - electroweak scale $\mathcal{O}(100\text{ GeV})$
  - gravitational (Planck) scale $M_{Pl} = \mathcal{O}(10^{16}\text{ TeV})$
- Formation of TeV Black Holes (BH) by high energy SM particle collisions
  - BH average charge 4/3
  - slowly moving ($\beta \lesssim 0.3$)
- Charged Hawking BH evaporate but not completely
  ➜ certain fraction of final BH remnants carry **multiple charges ($BH^{\pm}$)**
  ➜ highly ionising, relevant to MoEDAL



Hossenfelder, Koch, Bleicher
hep-ph/0507140

D-matter

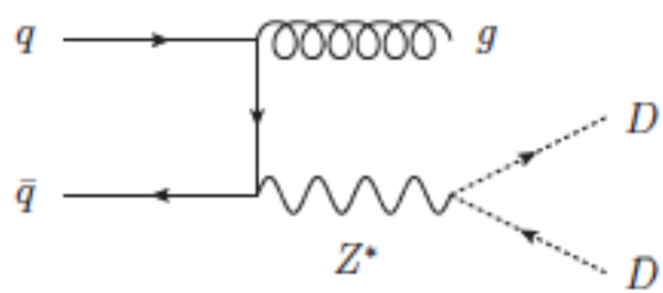
J Ellis, Mavromatos, Wesmuckett

- Brane worlds with D-particle (point-like brane) **D**efects
  - can play the role of a kind of dark matter/dark energy fluid
  - perturbative couplings
  - they have masses $M_D = M_s/g_s$,
    - M_S = string mass scale (≥ TeV)
    - $g_s < 1$ = (weak) string coupling
- D-matter/SM matter interactions
  - via exchange of open strings stretched between D-particle and p' (D-brane) world
  - excited states can be electrically (or magnetically) charged ➜ can be highly ionising ➜ relevant to MoEDAL

D-matter Mass spectrum

$$M^2_{D^*} = M^2_D + n\, M^2_s \qquad n \in \mathbf{Z}^+$$

$$M_D \sim M_s/g_s$$ Lightest D-matter (stable, play role of DM)



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The physics programme of the MoEDAL experiment at the LHC

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Many more interesting theoretical scenarios relevant and accessible to MoEDAL not presented here:

- quirks
- Q-balls
- CHAMPS
- ....

Complete and detailed review on MoEDAL impact on searches for exotic models

MoEDAL physics program:

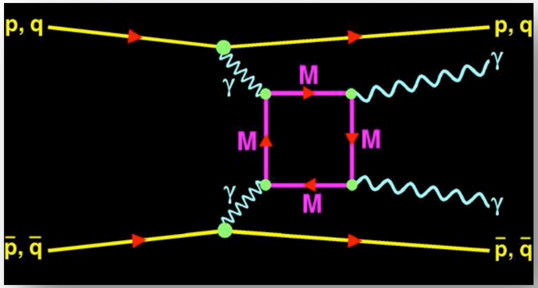
IJMP A29 (2014) 1430050
arXiv:1405.7662

MoEDAL web page:

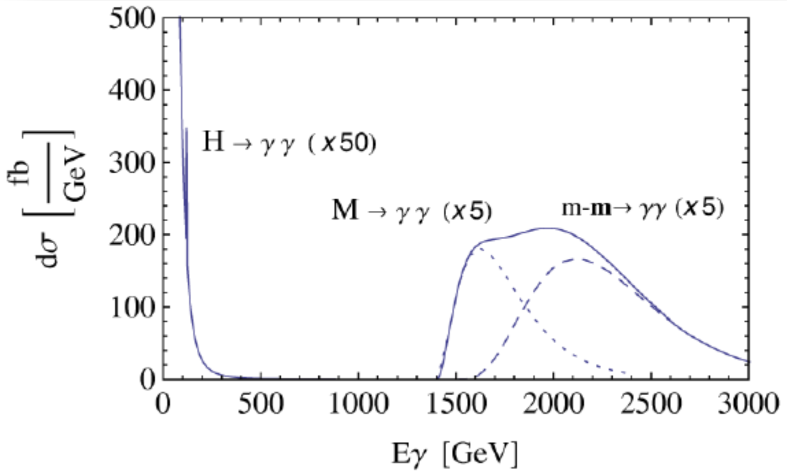
http://moedal.web.cern.ch/

Spanish involvement in MoEDAL

- Members of IFIC Valencia Team
  - J. Bernabeu, M. King, VAM (leader), V. Vento, O. Vives
- IFIC Team responsibilities
  - Geant4 detector simulation & particle propagation
  - simulation of monopole, monopolium & slepton production – acceptance studies
- Management positions
  - VAM: Chairperson of the Collaboration Board



LHC results on h→ γγ can be used to explore monopole production through box-diagram



Epele, Fanchiotti, Garcia Canal, VAM, Vento, Eur.Phys.J.Plus 127 (2012) 60

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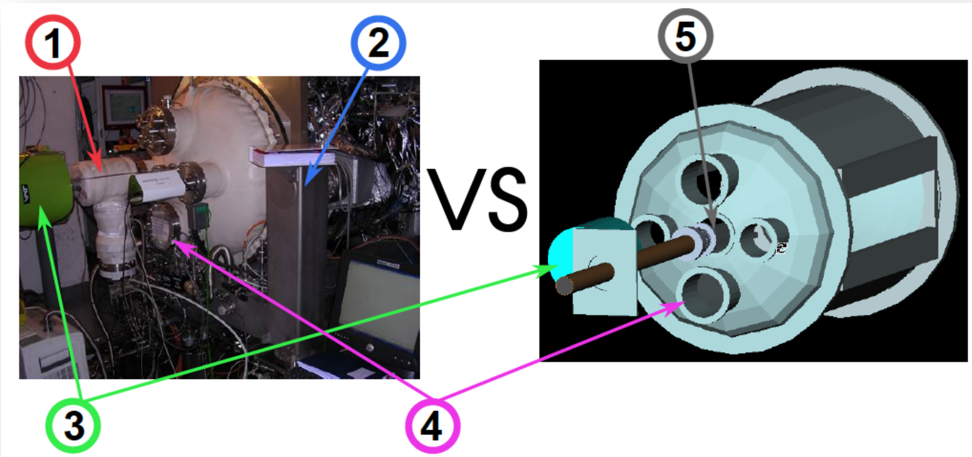
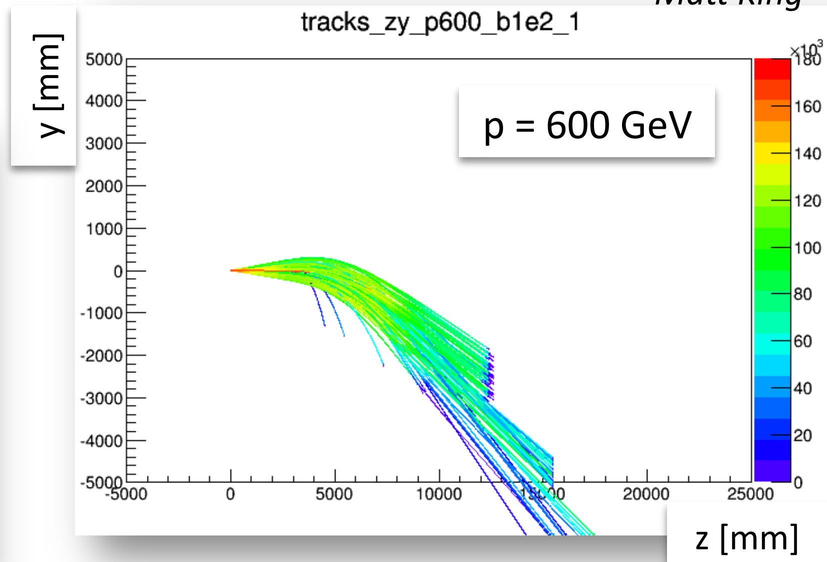
MoEDAL simulation



Material in front of MoEDAL detectors mapped into Geant4 simulation

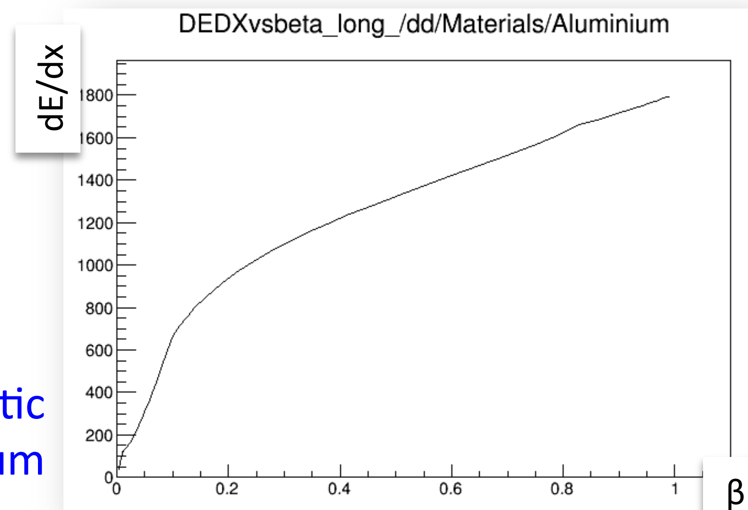
Matt King



Magnetic monopole stopping position

King, VAM *et al, Simulation of the MoEDAL experiment,* ICHEP2014, Valencia

dE/dx versus β for magnetic monopoles in aluminium



Summary & outlook

- MoEDAL is going to extend considerably the LHC reach in the search for **(meta)stable highly ionising particles**
  - predicted in variety of theoretical models
  - design optimised for such searches (unlike other exps)
  - combining various detector technologies
- Physics results with Run-I data to be published soon
- MoEDAL experiment is ready for LHC Run-II … … looking for the least explored signals of New Physics