MoEDAL at the LHC
A very different collider detector

James L. Pinfold
University of Alberta

Vienna Conference on Instrumentation 2016

The Menu

CAFE BIERBEISL
einstein
DAS GENIALE LOKAL

- *Introduction – anomalously ionizing particles as as avatars of new physics*
- *The MoEDAL detector's triune nature:*
  - *The "Giant Box Camera" – the nuclear track detector array*
  - *Capturing new physics (literally) – the trapping detector system*
  - *The "Digital Energy Camera" array – the TimePix radmon system*
- *PHASE-II model upgrade plans:*
  - *A millicharged particle detector*
  - *A very low cost electronic detector for highly charged particles*
- *Summary and Conclusion*

THE MAGNIFICENT SEVENTH

They fought on the high energy frontier

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

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

UPGRADE AIM: to continue the search for HIPS and start the search for minimally charged particles (MCP) at the LHC as well a initiate a search for Cosmic HIPS at high altitude

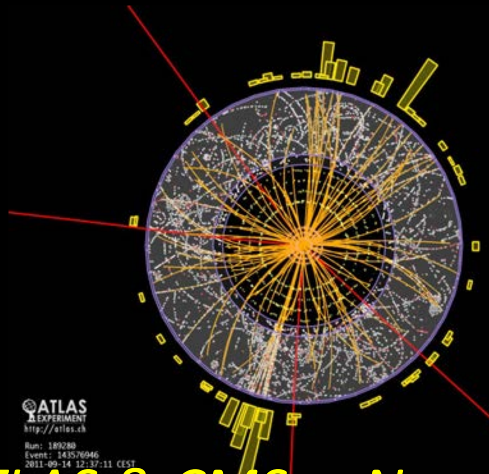
The MoEDAL Collaboration

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 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*

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

  - *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*

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

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

Physics Program (34 Scenarios)

arXiv.org > hep-ph > arXiv:1405.7662

Search or Article-id

High Energy Physics – Phenomenology

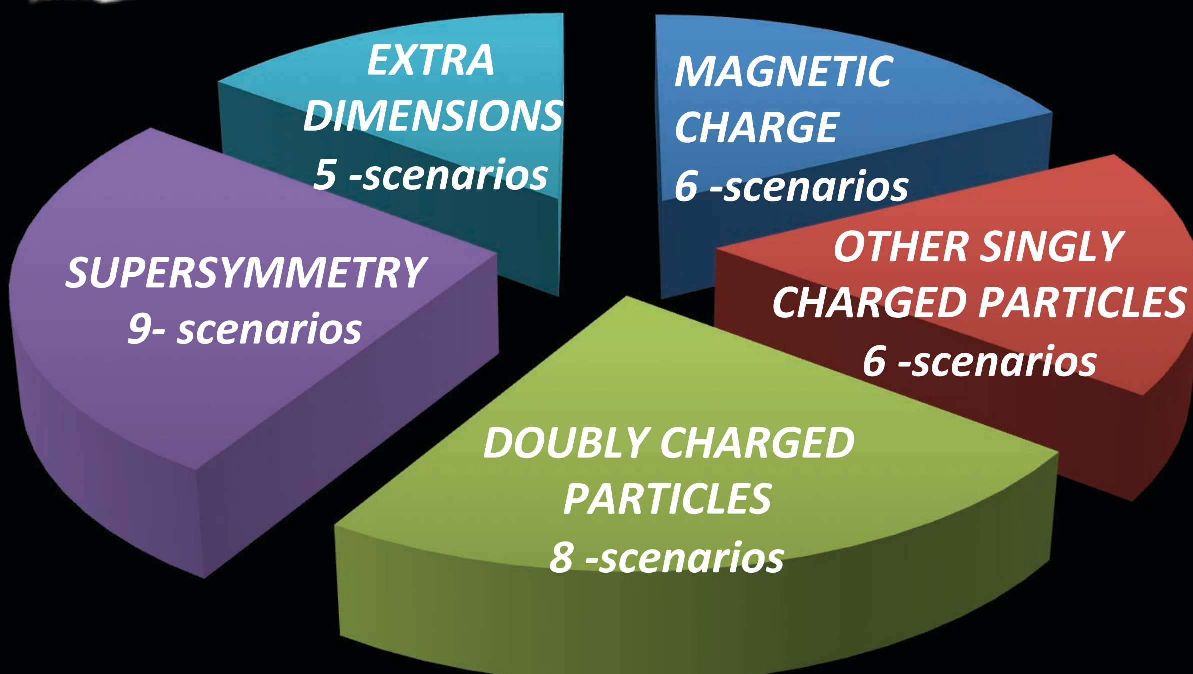
The Physics Programme Of The MoEDAL Experiment At The LHC

B. Acharya, J. Alexandre, J. Bernabéu, M. Campbell, S. Cecchini, J. Chwastowski, M. De Montigny, D. Derendarz, A. De Roeck, J. R. Ellis, M. Fairbairn, D. Felea, M. Frank, D. Frekers, C. Garcia, G. Giacomelli, M. Giorgini, D. HaŞegan, T. Hott, J. Jakůbek, A. Katre, D-W Kim, M.G.L. King, K. Kinoshita, D. Lacarrere, S. C. Lee, C. Leroy, A. Margiotta, N. Mauri, N. E. Mavromatos, P. Mermod, V. A. Mitsou, R. Orava, L. Pasqualini, L. Patrizii, G. E. Păvălaş, J. L. Pinfold, M. Platkevč, V. Popa, M. Pozzato, S. Pospisil, A. Rajantie, Z. ... M. Sakellariadou, S. Sarkar, G. Semenoff, G. Sirri, K. Sliwa, R. Soluk, M. Spurio, Y.N. Srivastava, R. Staszewski, J. Swain, M. Tenti, V. Togo, M. Trzebi... Vykydal, A. Widom, et al. (1 additional author not shown)

(Submitted on 29 May 2014 (v1), last revised 15 Jul 201...)

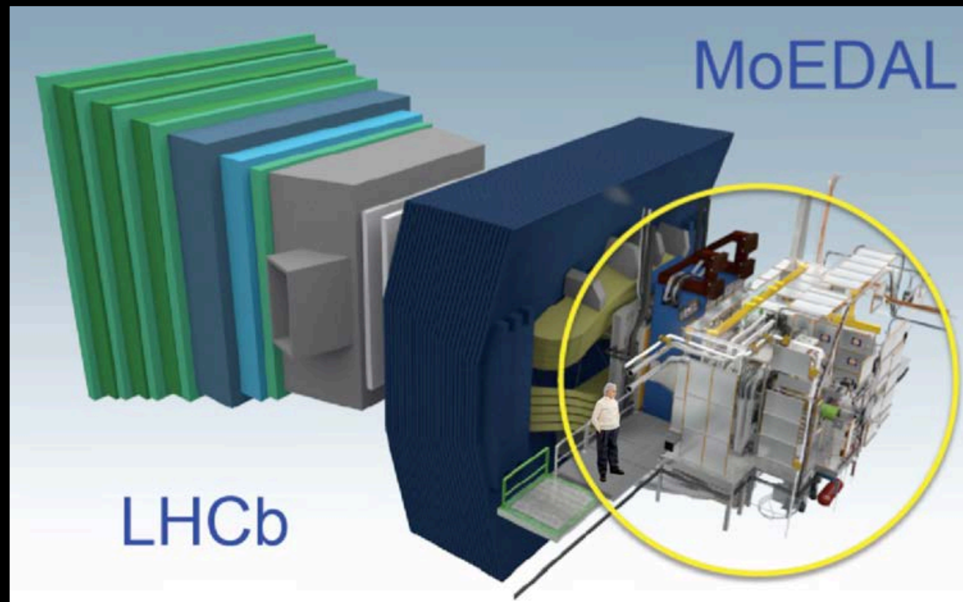
The MoEDAL experiment at ... the Standard Model, extending significantly the d... DAL is an unconventional and largely passive LHC dete... on the LHC ring. Another novel feature is the use of p... includes an array of TimePix pixel devices for mo... trigger system, electronic readout, or online computerized data acquisiti... complementary to the programs of the large multi-purpose LHC detectors ATLAS and CMS.

JUST PUBLISHED (September 9th 2014)
International Journal of Modern Physics A Vol. 29, No. 23 (2014) 1430050 (91pages)



MoEDAL – a Unique Collider Detector

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

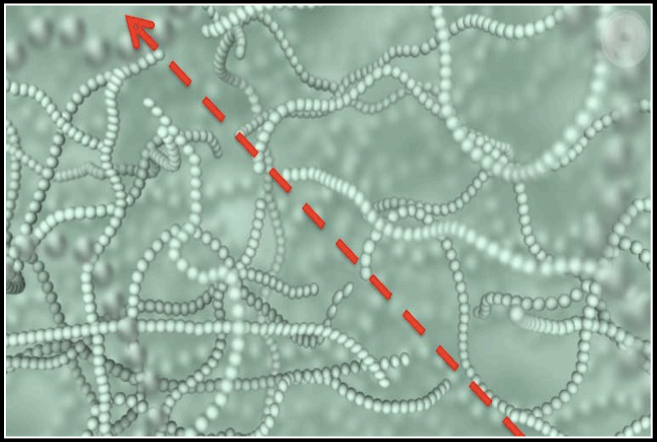
MoEDAL is largely passive made up of three detector system.

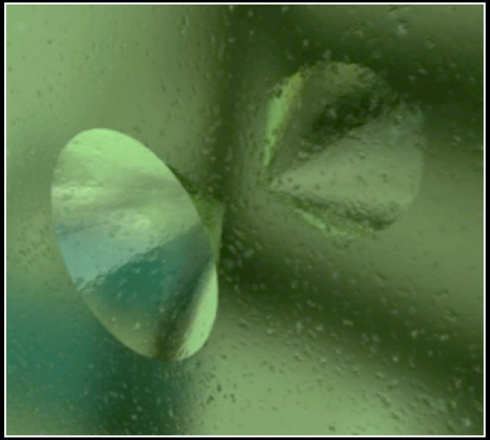
NUCLEAR TRACK DETECTOR
Plastic array (~200 sqm)
– Like a Giant Camera

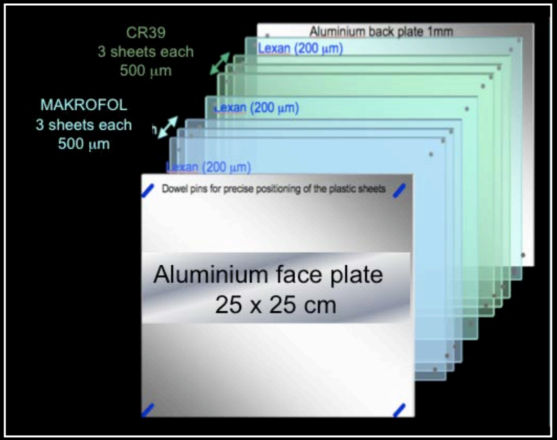
TRAPPING DETECTOR ARRAY
A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

The Nuclear Track Detector System





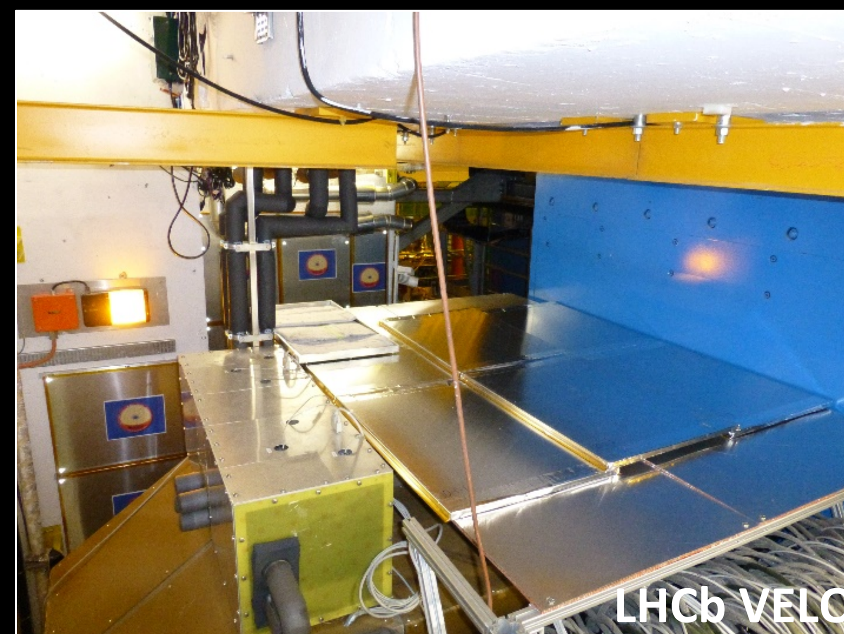


- *Largest array (150m²)of NTDs every deployed at an accelerator*
  - *Plastic NTD stacks consist of CR39 (threshold 5 MiPs) and Makrofol (50 MiPs) – that are "damaged" by the highly ionizing particle*
  - *The damage is revealed by controlled etching in a hot Sodium Hydroxide solution – etch pits are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

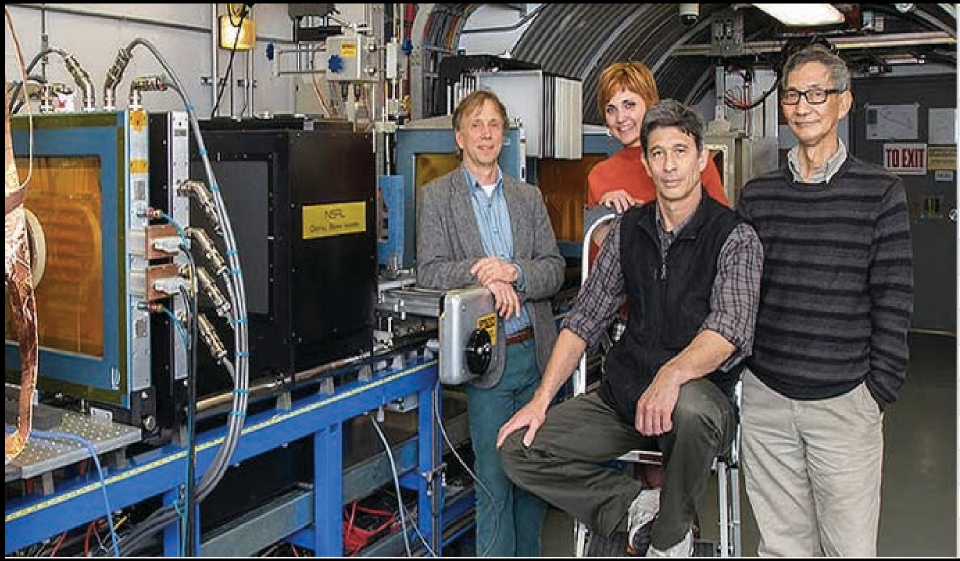
The NTD Instal 2015

HIGH CHARGE CATCHER
(E_{th} >50 mips)

LOW THRESHOLD
(E_{th} > 5 mips)



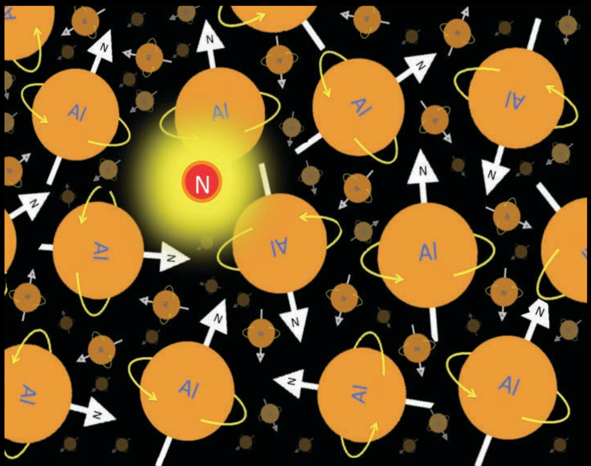
Calibrating the Plastic NTDs



Ion Species [1]	Energy [2] (MeV/nucleon)	Maximum Intensity [3] (ions per spill)	LET [4] (keV/micron) in water
H-1	50 - 2500	2.2×10^{11}	1.26 - 0.21
He-4	50 - 1000	0.88×10^{10}	5.01 - 0.89
C-12	65 - 1000	1.2×10^{10}	36.79 - 8.01
O-16	50 - 1000	0.4×10^{10}	80.50 - 14.24
Ne-20	70 - 1000	0.10×10^{10}	96.42 - 22.25
Si-28	93 - 1000	0.3×10^{10}	151 - 44
Cl-35	500 - 1000	0.2×10^{10}	80 - 64
Ar-40	350	0.02×10^{10}	105.8
Ti-48	150 - 1000	0.08×10^{10}	265 - 108
Fe-56	50 - 1000	0.2×10^{10}	832 - 150
Kr-84	383	2.0×10^{7}	403
Xe-131	228	5.0×10^{7}	1204
Ta-181	292 - 342	3.0×10^{8}	1827 - 1896
Au-197	76 - 165	1×10^{8}	4828 - 3066

- *Calibration of NTDs and HCC plastic performed mainly at the BNL NASA Space Radiation Laboratory*
  - *Large choice of species and easy energy adjustment with energies up to 1 GeV/nucleon.*
  - *Can achieve very low intensities (as low as 1000/sq cm)*
- *MoEDAL is the only LHC detector that can be directly calibrated for highly ionzing particles*

The Trapping Detector System



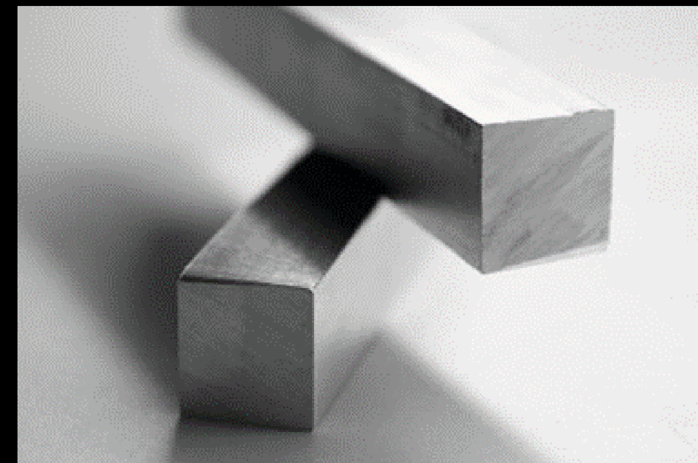
Trapped monopole

SQUID magnetometer (ETH Zurich)

Search for trapped quasi-stable decays at SNOLAB

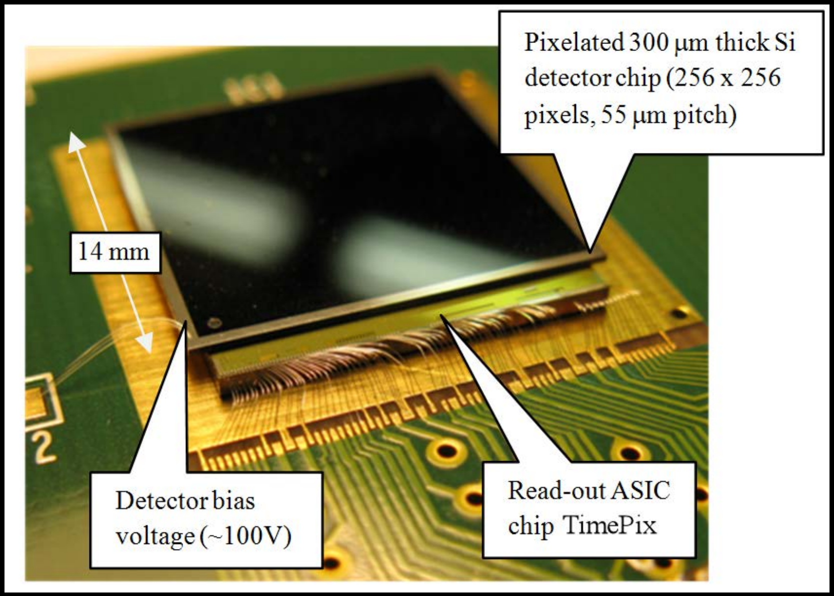
- *We will deploy trapping volumes (~1 tonne – 2400 bars) in the MoEDAL/VELO Cavern to trap highly ionizing particles*
  - *The binding energies of monopoles in nuclei with finite magnetic dipole moments are estimated to be hundreds of keV*
- *After exposure the traps are removed and sent to:*
  - *The SQUID magnetometer at ETH Zurich for Monopole detection*
  - *Underground lab (SNOLAB) to detect decays of electrically charged MSPs*

The Trapping Detector Instal 2015

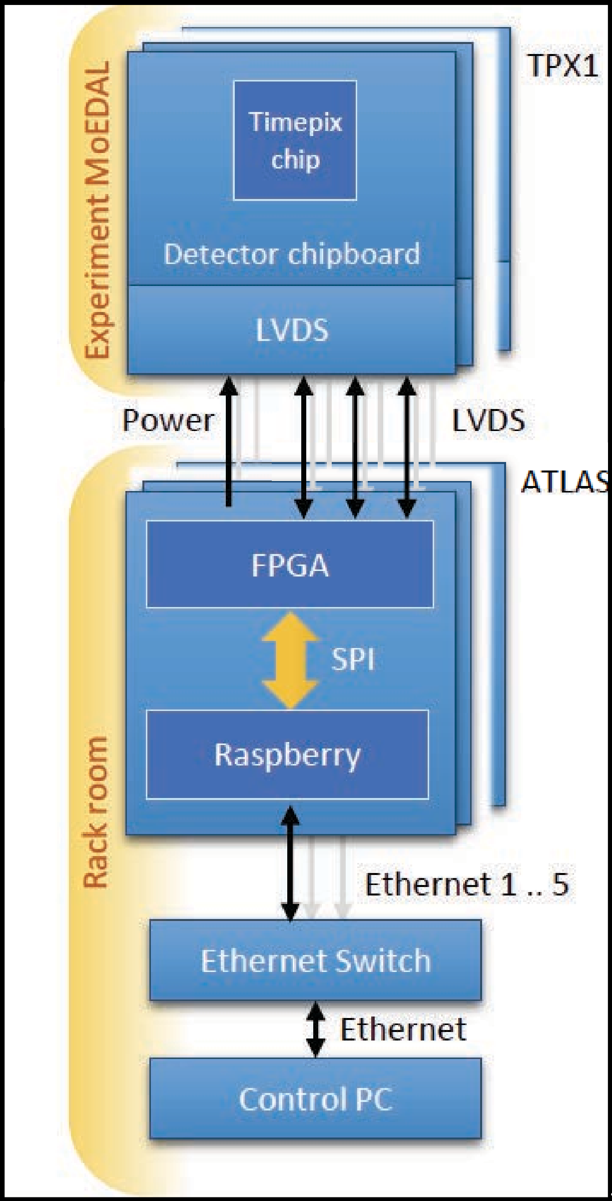


- *Total mass ~ 1 ton of trapping detectors*
  - *2400 aluminum bars - 2.5 x 2.5 x 19 cm each*
- *MoEDAL is the only LHC experiment that can reliably directly detect magnetic charge*

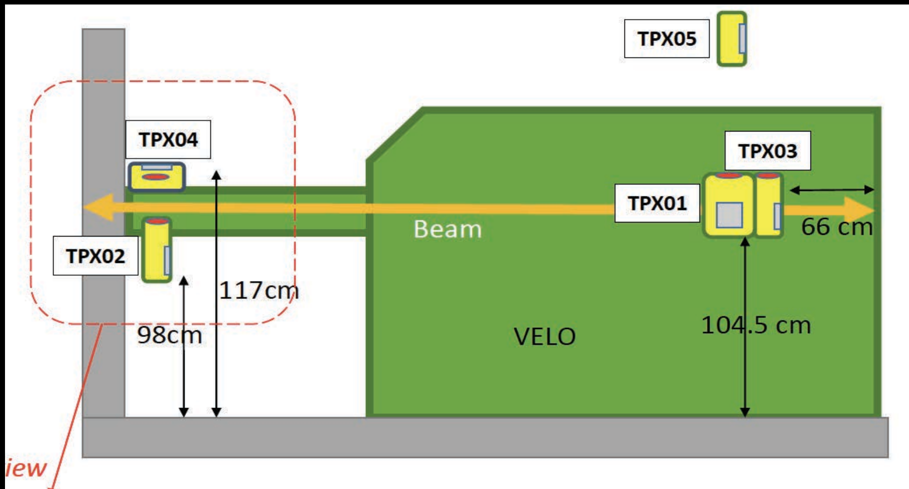
The TimePix Array – Radiation Monitor



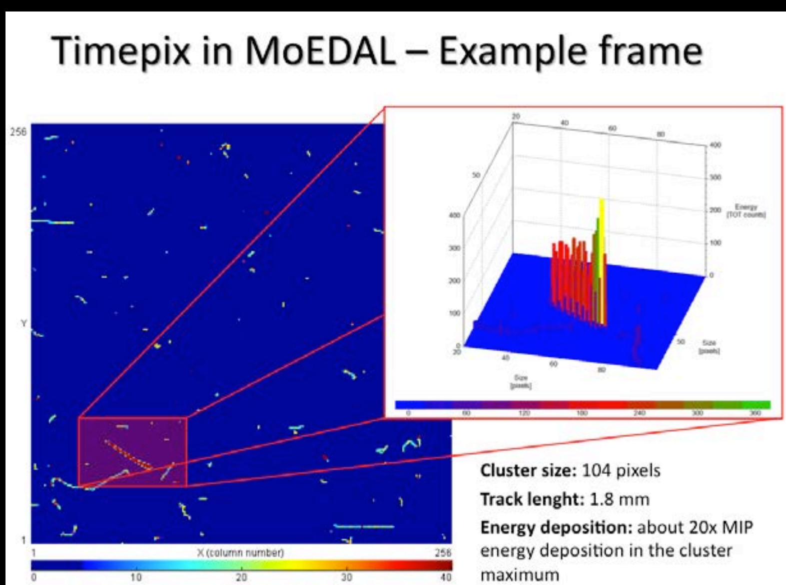
- *Timepix (MediPix) chips measure online the radiation field + measure the spallation product background*
  - *The Timepix chip pixels are instrumented with an amplifier + comparator + counter + TOT energy measurement)*

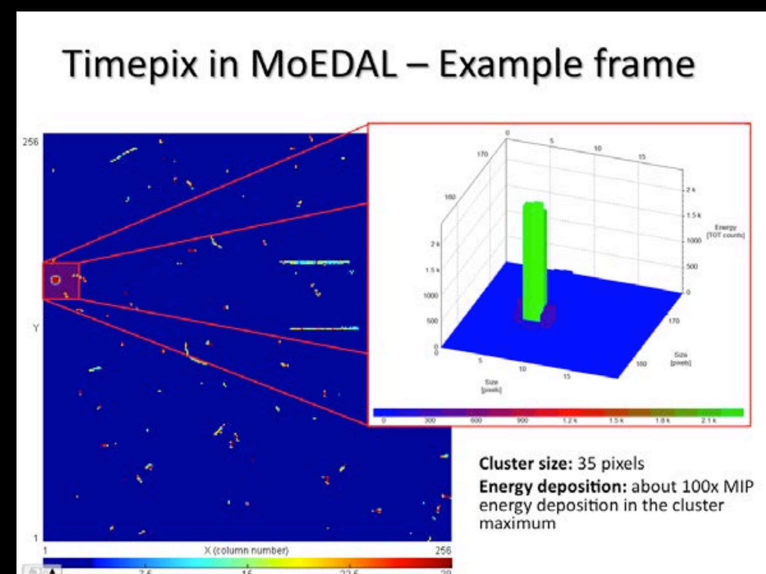


TimePix Deployment and Pictures



The TimePix chip is essentially an electronic bubble chamber

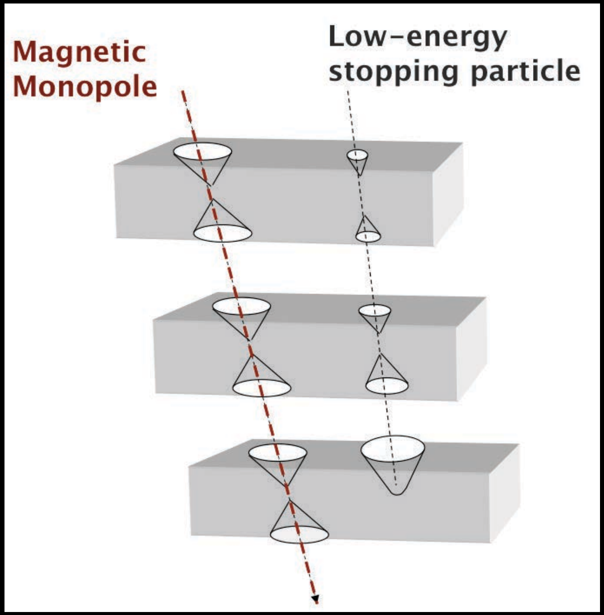




Detector Resolution

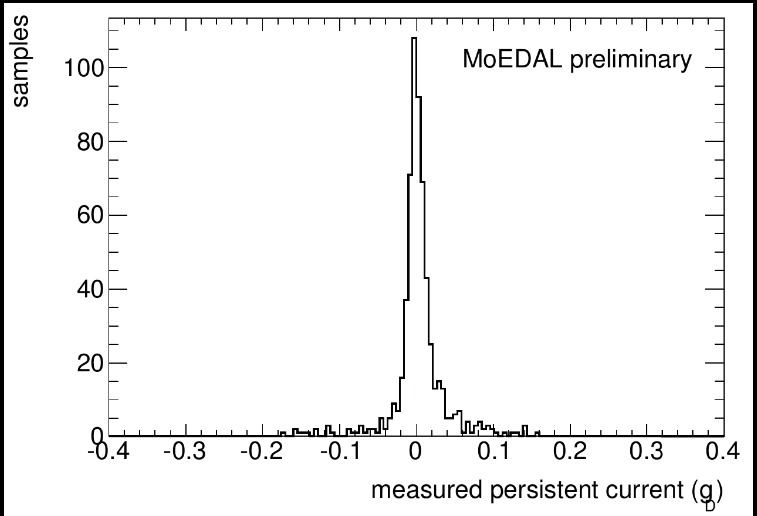
Nuclear Track Detectors

Tracking resolution: 10μm/pit (~10 pits)
Pointing resolution (to the IP): ~1 cm
Charge resolution: 0.1e



Trapping Detector SQUID

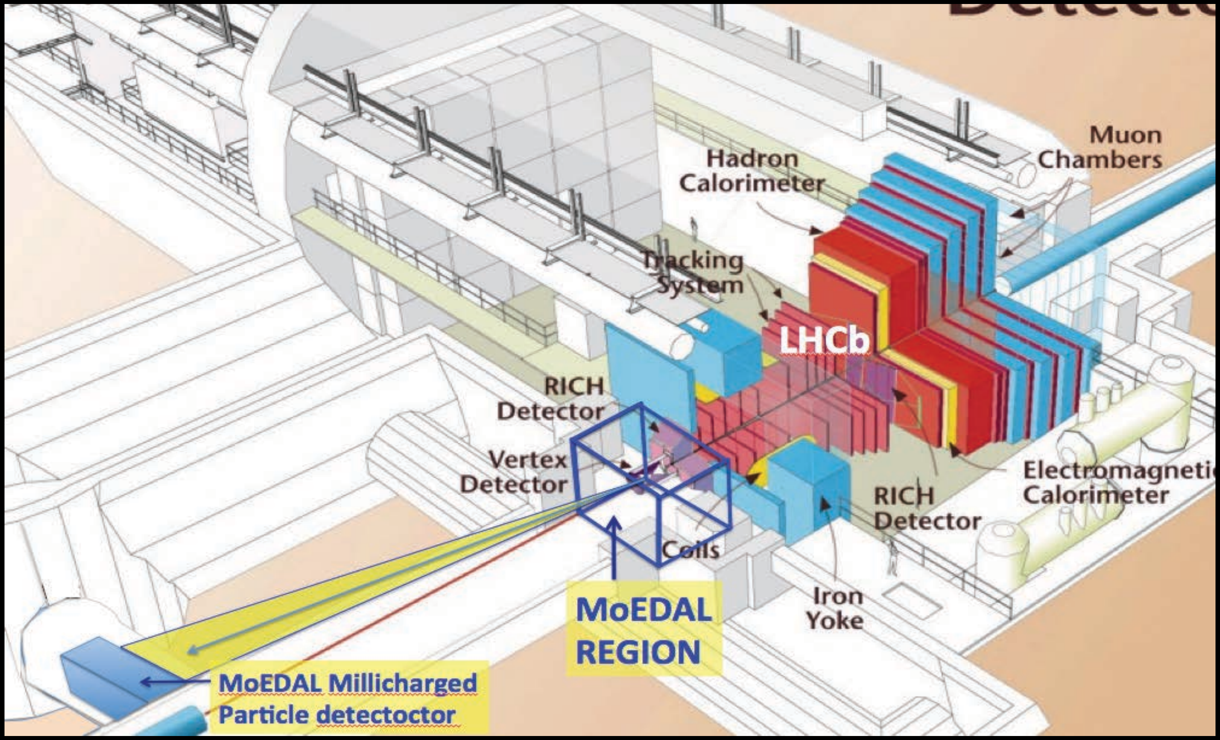
Magnetic charge resolution < $0.1g_D$



TimePix Chips (2cm x 2cm)

Each pixel instrumented (TOT/Cnt /Arr.Time
Pixel size: 55μm x 55μm
Silicon thickness 300 μm → 1mm

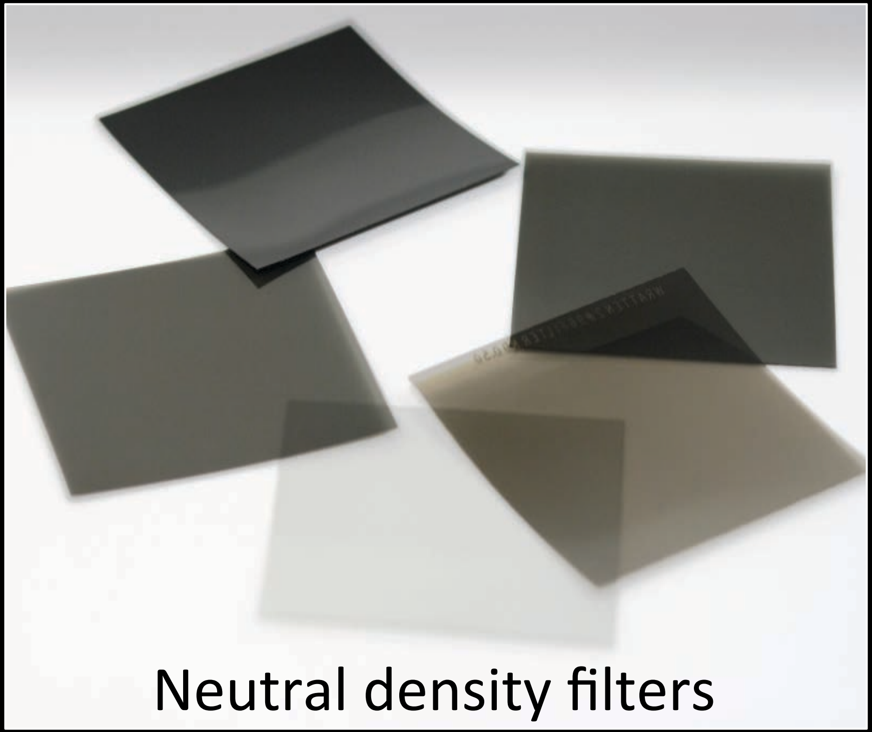
A Phase-II MoEDAL mQP Detector



- *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*
- *The standard LHC detectors are not sensitive to Charge < ~0.1e*

The mQP Prototype

Plastic scintillator bars



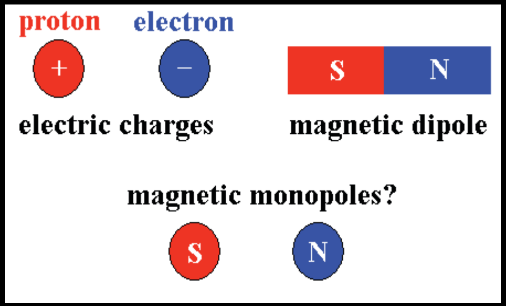
Neutral density filters

- *6 (5" x 5" x-sec) of these very long bar sets arranged to detect cosmic muons*
  - *Basic unit: three collinear 1m plastic bars read out the PMTs:*
- *We turn muons in milli-charged particles using a variable filter that goes to 1000 time reduction in the transmitted light*

MoEDAL Addresses Fundamental Questions:

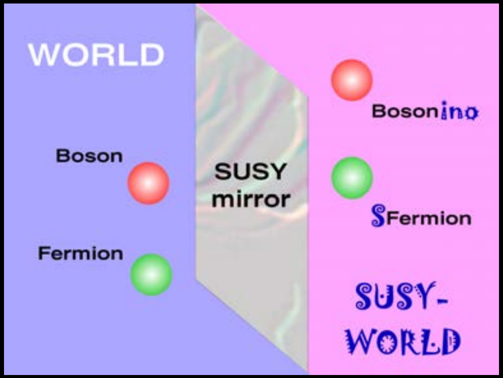
Are there extra dimensions?

What is the nature of Dark Matter?



Does magnetic charge exist?

What happened just after the big bang?



Are there new symmetries of nature?

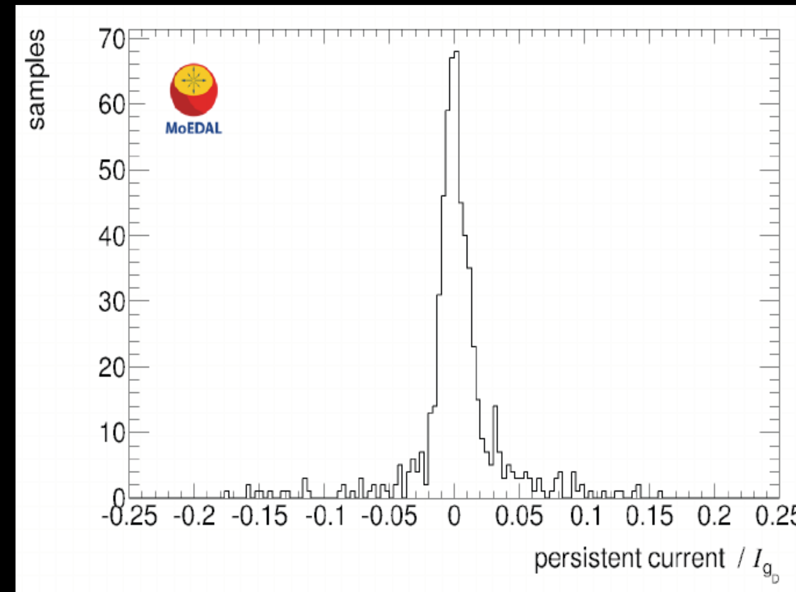
The MoEDAL experiment has just set sail on a voyage of discovery with the opening of a new LHC high energy frontier 13-14TeV in 2015 - stay tuned

EXTRA SLIDES

The High Threshold NTD Instal 2015

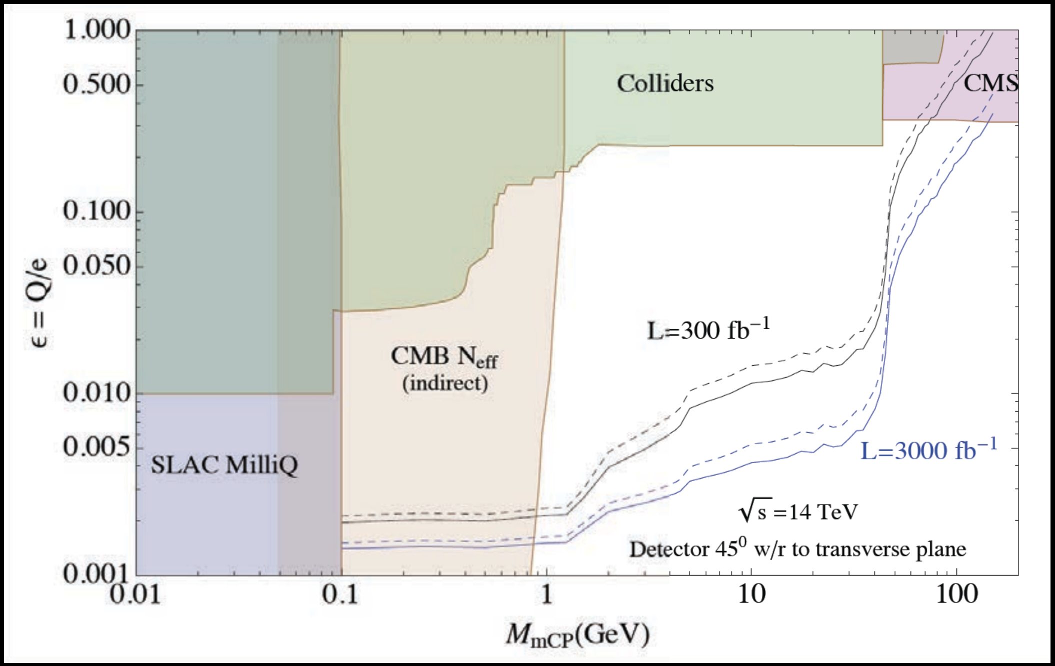
- *Inside LHCb acceptance bteween the RICH and the 1st LHCb tracking detector (TT)*
  - *2 layers of 250μm Makrofol inside a 25μm aluminum foil bag*
  - *0.19% of a radiation length thickness*
  - *"Shower curtain design"*

The SQUID Magnetometer



- *2G Long Core magnetometer newly installed at Lab. for Natural Magnetism at ETHZ*
  - *Coveyer belt → very convenient for monopole search, can scan a large numberof samples in a short time*
  - *Resolution is ~1/100 of a Dirac charge*
- *The SQUID readout makes MoEDAL the only LHC experiment that can reliably directly detect magnetic charge*

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***