MoEDAL : Search for Monopoles at LHC

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LHC's Magnificent Seventh

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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

Le 2 décembre 2009, la Commission de la recherche du CERN a approuvé la septième expérience du LHC : le détecteur MoEDAL (Monopole and Exotics Detector At the LHC). Le premier objectif de cette expérience est de rechercher la production directe du monopôle magnétique auprès du LHC. Elle s'efforcera également de découvrir des particules massives stables (ou pseudo-stables) fortement ionisantes à charge électrique conventionnelle. De dimensions modestes, par rapport aux autres détecteurs du LHC, le détecteur MoEDAL est

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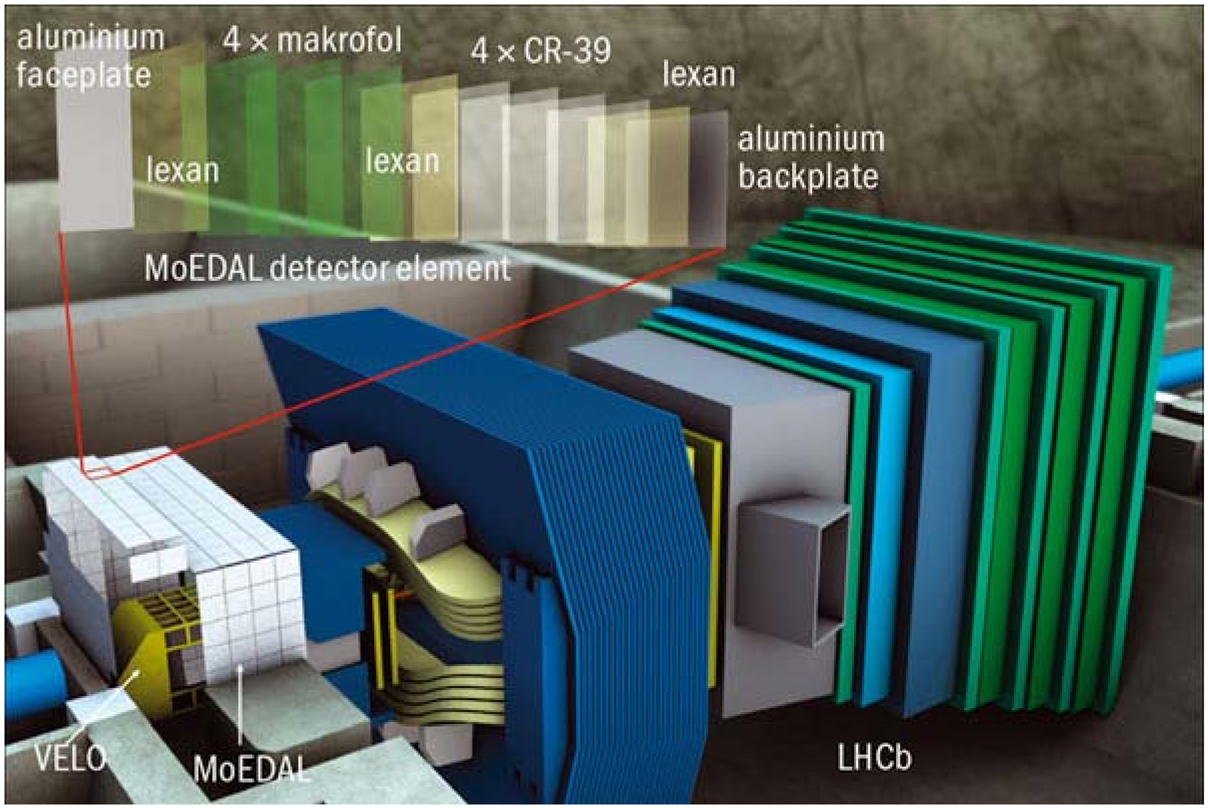
MoEDAL physics program

The goal of MoEDAL (Monopole and Exotics Detector at the LHC) is to directly search for the Magnetic Monopole and other highly ionizing Stable (or pseudo-stable) Massive Particles (SMPs) at the LHC through the deployment of an array of plastic Nuclear Track Detectors (NTDs) around the intersection region of the LHCb detector, in the VELO (VErtex LOcator) cavern.

MoEDAL detector array



Challenges of detecting Monopoles with existing detectors

- The main LHC experiments are designed to detect conventionally charged particles produced with a velocity large enough to fall within LHC trigger window of 25 ns. But Monopoles will be slow moving. So cannot be associated with the correct branch crossing. Track reconstruction becomes very difficult.
- Very highly ionizing particles can be absorbed before they penetrate the detector fully.
- High dE/dx for highly ionizing particles will cause saturation of the electronics used in tracking detectors.
- The sampling time and reconstruction software of each sub-detector is optimized for relativistic particles. Hence, the quality of the read-out signal or reconstructed track or cluster will be degraded for an SMP, especially for sub-systems far away from the interaction point.

Advantages of NTDs in Monopole search

- NTDs do not require a trigger
- Also, track-etch detectors provide a tried and tested method to detect and accurately measure the track of a highly ionizing particle
- Heavy-ion beams provide a demonstrated calibration technique using energy depositions very similar to that of the hypothetical particles sought
- NTDs can basically eliminate all background. So the detection of even one magnetic monopole track that fully penetrated a MoEDAL NTD stack will be distinctive.

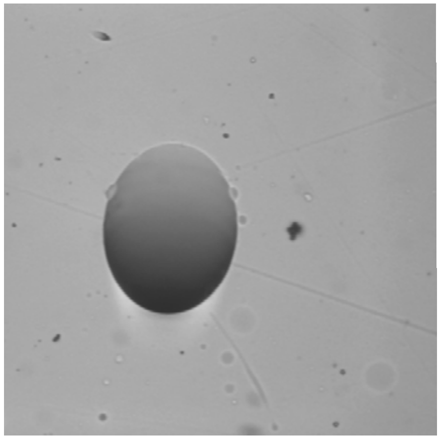
How NTDs work ?

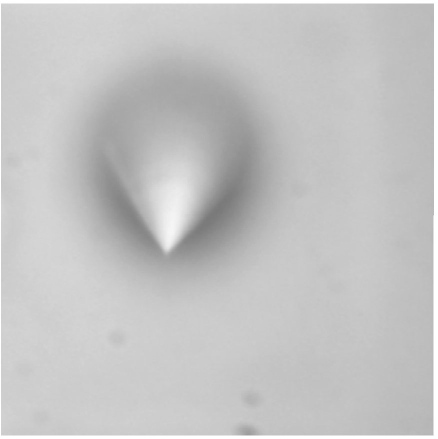
- Heavy charged particles on their passage through materials lose energy according to the Bethe formula :

$$-dE/dx=(4\pi e^4z^2/m_0v^2)NZ[\ln(2m_0v^2/I)-\ln(1-v^2/c^2)-v^2/c^2]$$

- The ionization and excitation produced by the charged particles along their path causes molecular bonds to break, thereby producing narrow(30-100Å) damage trails. Naturally the damaged portions become chemically more reactive to suitable chemical reagents (etchants) (e.g. ionic compounds like NaOH) compared to the undamaged bulk material.

- During etching, the material along the damage trails are etched out at a much higher rate V_T (Track etch rate) compared to the rate of etching V_B also called V_G (Bulk etch rate) of the undamaged surface. The etch pits so formed can be closely approximated by geometrical cones with the damage trail along its axis and is observable under an optical microscope.





Monopole Basics

- In 1931 Dirac introduced the magnetic monopole in order to explain the quantization of the electric charge, which follows from the existence of at least one free magnetic charge
- Basic relationship between the elementary electric charge e and the basic magnetic charge:

$$g = n\hbar c/2e = ng_D$$

where $n=1,2,3\ldots.$ and $g_D = \hbar c/2e = 68.5e$ called unit Dirac Charge
- There is no real prediction of the mass of classical Dirac magnetic monopole.
- One may have a rough estimate assuming that the classical monopole radius is equal to the classical electron radius:

$$r_M = g^2/(m_M c^2) = r_e = e^2/m_e c^2$$

- From which $m_M = g^2 m_e/e^2 \approx n.4700.m_e = n.2.4\ \mathrm{GeV}/c^2$
- Thus the mass should be relatively large and even larger if the basic charge is e/3 and if n > 1.

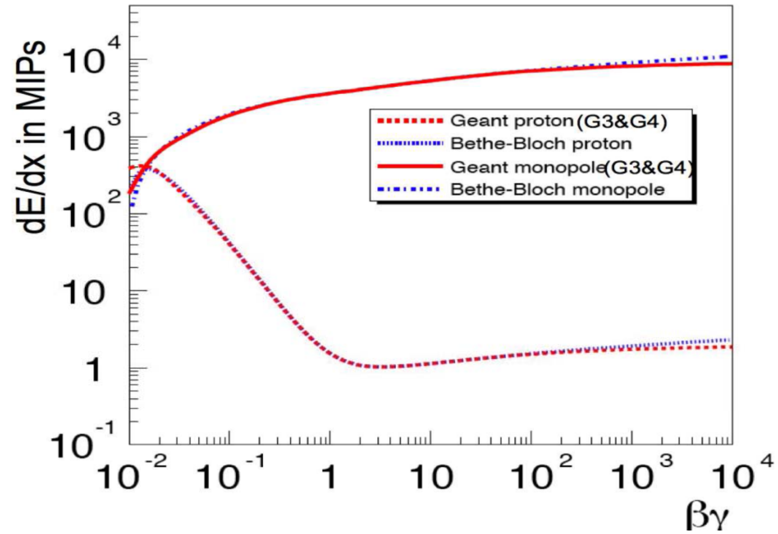
Magnetic Monopole Simulation

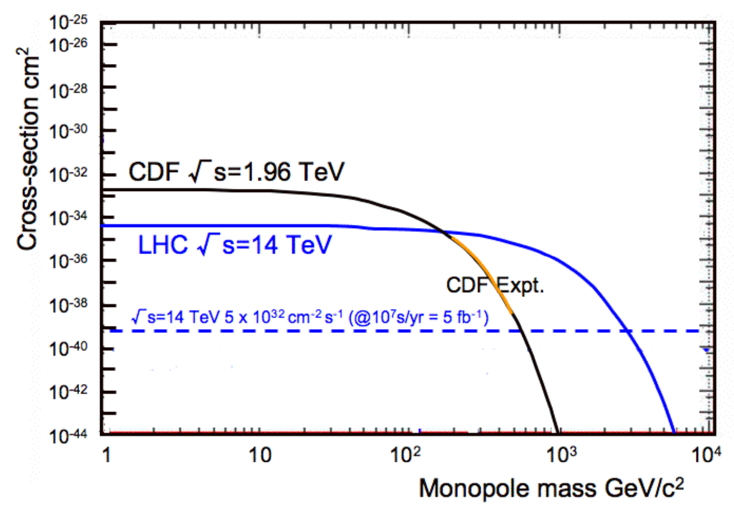
- An extension to GEANT4 implemented to allow for the tracking of Magnetic Monopoles
- dE/dx for relativistic magnetic monopoles can be calculated by replacing ze by $ng_D\beta$ in the standard Bethe Bloch formula
- For $3\times10^{-4} < \beta < 0.1$ the energy loss can be modeled by the equation:

$$dE/dx = K\beta$$

where, for example,

$K = 33n^2$ GeV/cm for plastic and $124n^2$ GeV/cm for iron.





Experimental Signature of Monopole

- The signature of a monopole in a MoEDAL NTD stack would consist of a chain of collinear etch-pit pairs in 10 successive sheets, with roughly constant, actually slowly decreasing, etch pit radius indicating the passage of a particle with ionization rate gradually decreasing as it (gradually) slows in the plastic stack.
- No known particle can produce a similar track.
- Also, the detector stack positions will be surveyed and it will be possible to point back a track formed from collinear etch pits back to the intersection point with an accuracy of 1 cm. Providing another source of background reduction.
- A single through going track will be enough to claim discovery.

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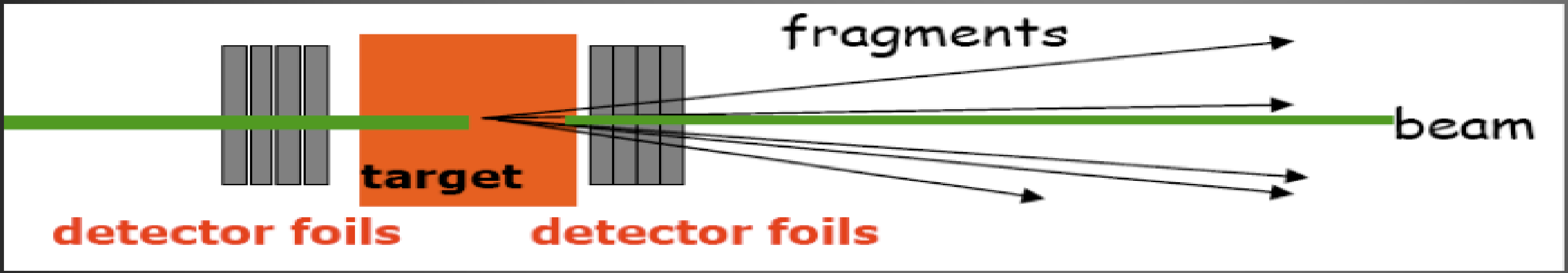
Research goals

- First to determine an ideal etching condition for the large scale etching and scanning of detector films (CR-39, Makrofol, Lexan) by etching them under different conditions and measuring the background radiation, bulk etch rates etc.
- Next to look for any through going track in NTD stacks exposed at LHC as part of pilot study (Area ~ 8 m^2). This will enable the setting of limits on Monopole production.
- The search strategy called for etching one layer from the NTD stacks under a strong etching condition so that if a passing track is present, a hole large enough to be seen under low magnification/naked eye will be formed. This is to enable quick initial scanning.
- Only if a through going track is found in one layer, other layers from that stack will be etched and scanned.

Calibration

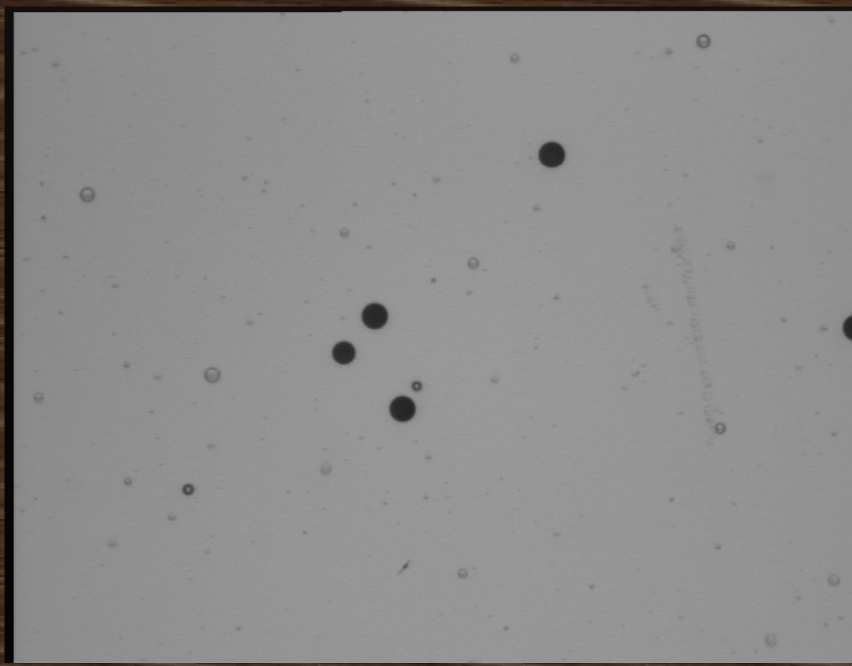


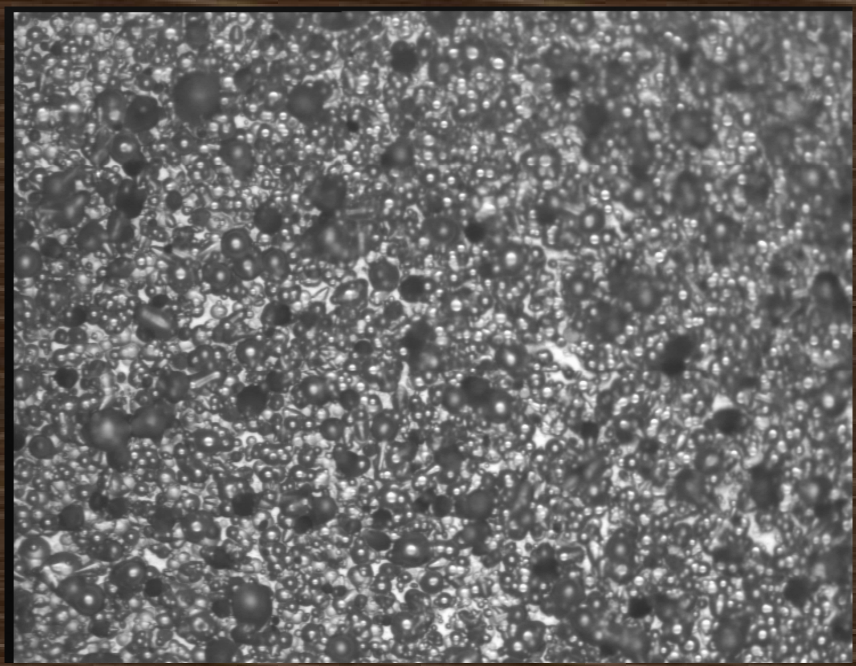
- A typical calibration set-up at an ion beam accelerator includes a fragmentation target and nuclear track detector foils in front of and behind a target. The ion beam passes through some detector foils, interacts in the target (typically 10 mm thick Cu or Al plates) and then traverses downstream detector foils which record the survived fraction of original projectiles, as well as their fragments. The projectile fragments carry on in the approximately the same direction of the incident ion. The Z of each resolved peak is identified via the base area spectrum
- CR-39, Makrofol and Lexan Nuclear Track Detectors (NTDs) exposed at the LHCb cavern at CERN as part of the MoEDAL experiment as well as some new ones were exposed to 1 GeV/n ^{26}Fe – ion beams at BNL.

Etching conditions employed

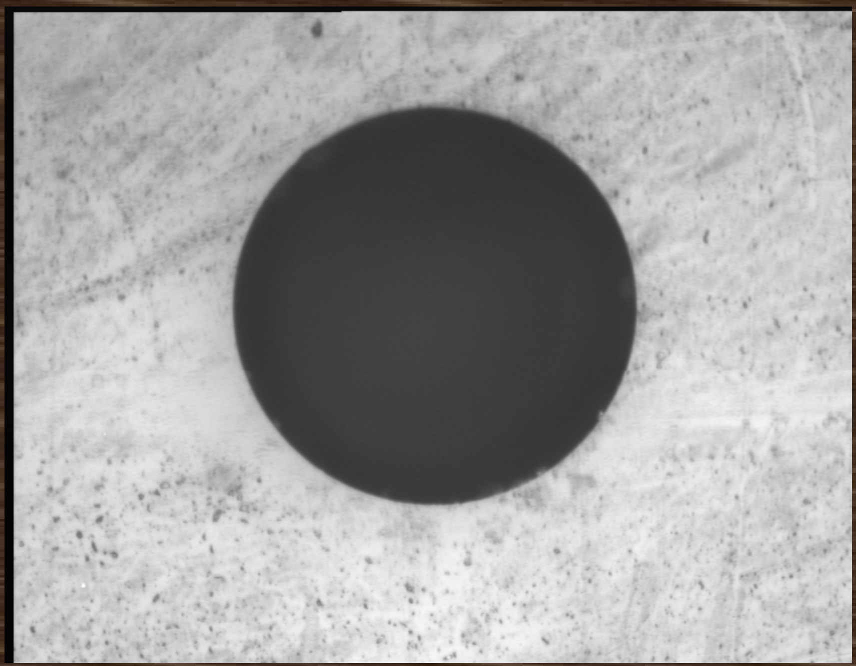
Sl. No.	Etchant	Temperature (°C)	Remarks
1	6 N NaOH + 1% Ethyl Alcohol	70	
2	6 N KOH + 20% Ethyl Alcohol	50	Weak etching condition
3	6 N KOH + 20% Ethyl Alcohol	65	Strong etching condition
4	6 N KOH + 20% Ethyl Alcohol	55	
5	6 N KOH	65	Etching without alcohol

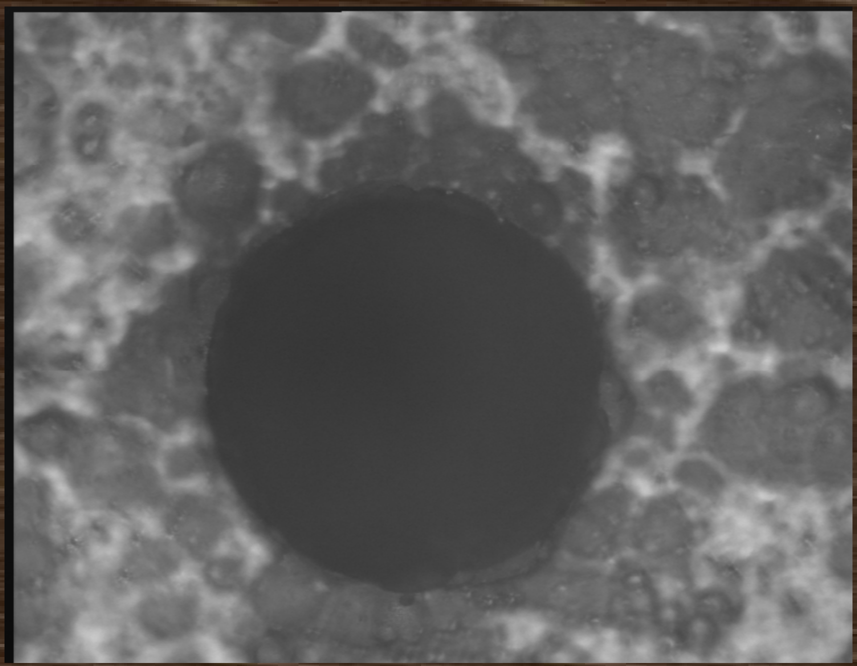
Some results
CR-39: NaOH+1% Alcohol: 70°C: 8h





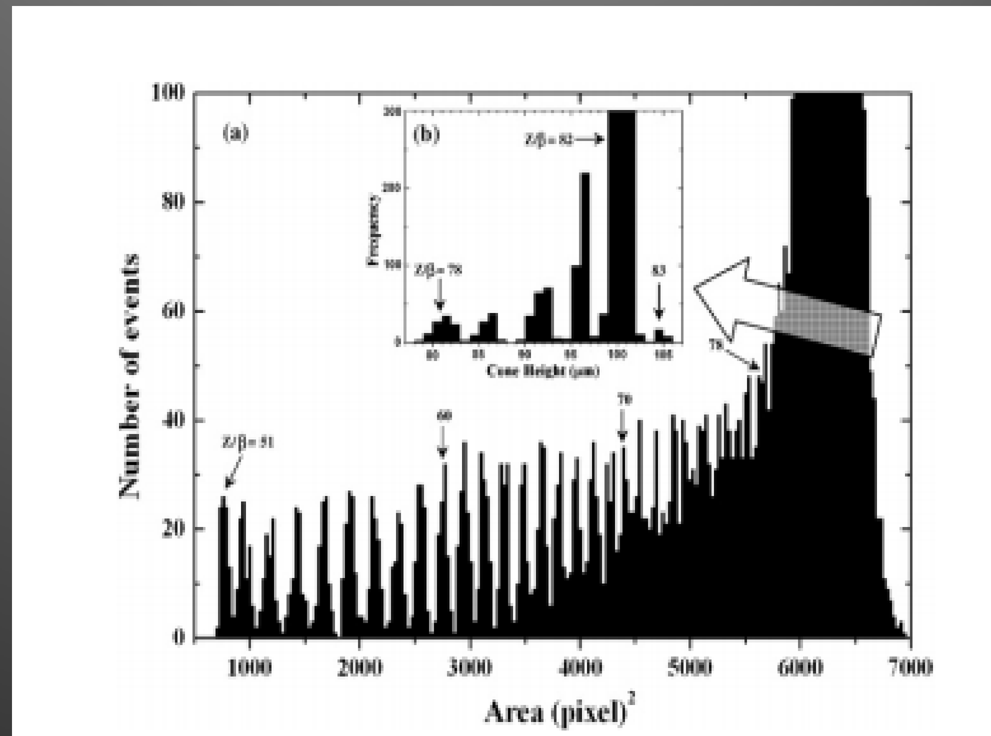
Makrofol: KOH+20 % Alcohol: 65°C: 6h





Ideal etching condition

So use of the etching condition 6 N KOH + 20 % Ethyl alcohol at 65 C was judged to be the best condition for large scale etching of Makrofol detector foils exposed at MoEDAL. Under this condition the surface quality was good, the bulk etching rate high (~20 micron/hr) and any holes due to through going particles large enough to be easily detectable under low magnification even after 6 hr etching. Also from past studies with Makrofol we know that the Z/β threshold under this etching condition is ~ 51



Large scale scanning of Makrofol from MoEDAL

Exposure duration at MoEDAL	Number of detector foils scanned (each 24 cm X 24 cm)	Area Scanned (m^2)
Dec 2009 – Aug 2012	1	0.0576
Dec 2009- Dec 2012	11	0.6336
Dec 2010 – Aug 2012	15	0.8640
Dec 2010 – Dec 2012	96	5.5296
Jun2012 – Dec 2012	12	0.6912
Total	**135**	**7.776**

Results

- No through going tracks were found in any of the 135 Makrofol films scanned
- Detailed Monte Carlo simulations are currently in progress in order to determine the detector acceptance and to set limits on Monopole production cross-section.

Future goals of MoEDAL

- Further studies are to be carried out in order to determine the ideal etching conditions for CR-39 and Lexan detectors exposed to the high radiation environment of the VELO cavern.
- Development of an automated scanning system to speed up the scanning process
- Full deployment is expected to be completed before the LHC starts running at its maximum design energy in 2015.

Thank you