Search for GUT monopoles in the cosmic radiation with MACRO at Gran Sasso

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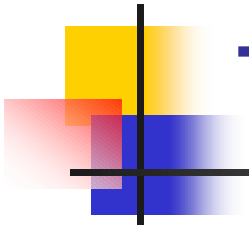


Talk overview

- Magnetic monopoles in Grand Unification Theories
- The MACRO experiment/detector at Gran Sasso
- The analysis techniques used for monopole searches
- Results of the monopole searches
- Searches for other massive exotic particles
- Conclusions

Magnetic monopoles in GUT's

- Produced as intrinsically stable topological defects during phase transitions in the Early Universe.
- Huge mass of the order of the energy scale of the symmetry breaking transitions. Unpredicted flux.
- Velocity expected around $\beta \sim 10^{-3}$ if gravitationally bound to the Galaxy. Larger velocity reached due to acceleration in magnetic fields.
- Astrophysical bounds to the monopole flux (e.g. the Parker bound)
- UHECR events above the GZK cut-off explained as due to monopole induced showers or to energy release in monopole-antimonopole annihilation.

The MACRO experiment @ GS

Collaboration: Italy-USA

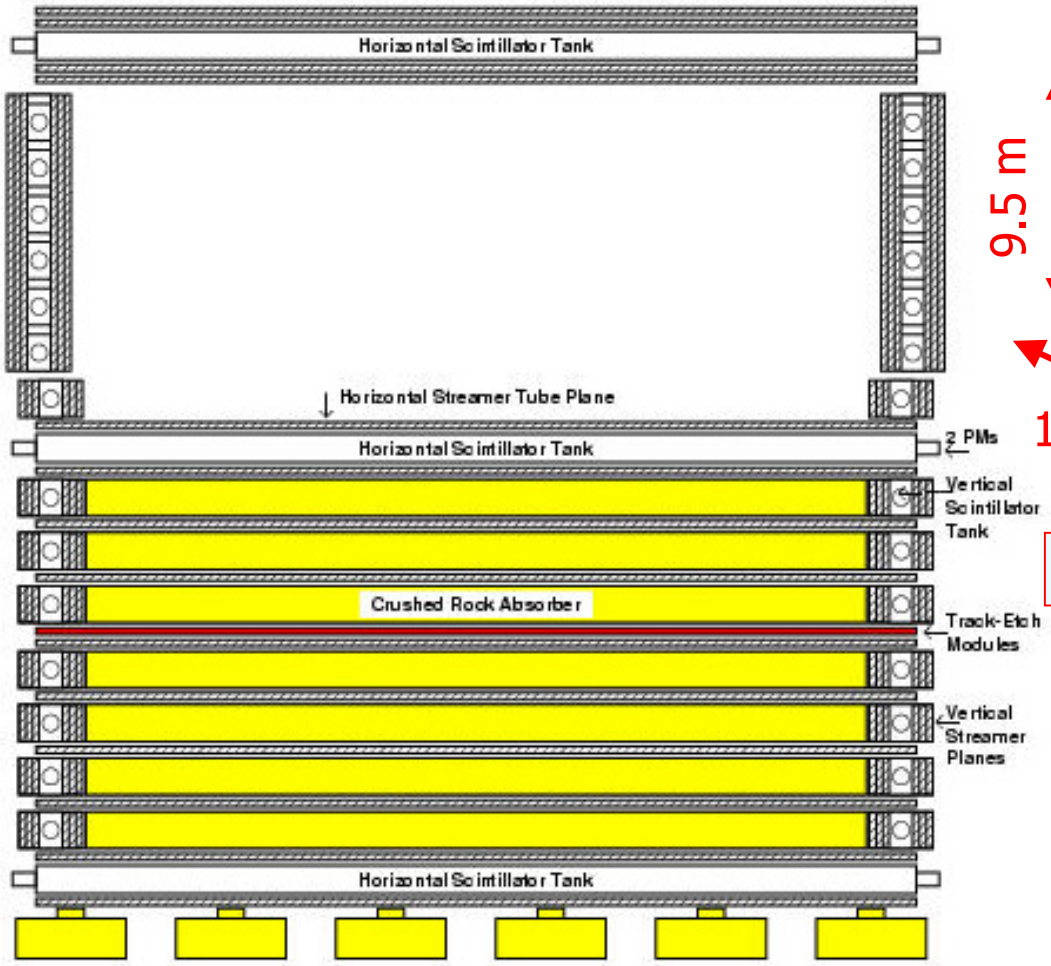
Location: Hall B @ LNGS

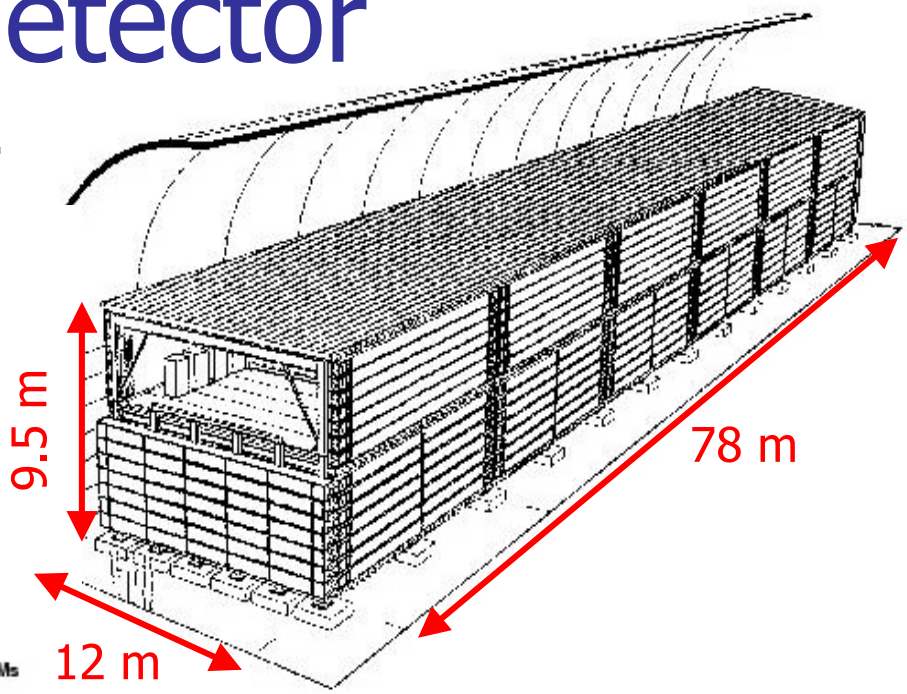
Physics goals:

- ✓ GUT monopole search
- ✓ Atmospheric ν oscillations
- ✓ High Energy Cosmic Rays
- ✓ WIMP search
- ✓ ν burst from SN explosion
- ✓ LIP search
- ✓ Nuclearites, exotica

www.lngs.infn.it

The MACRO detector

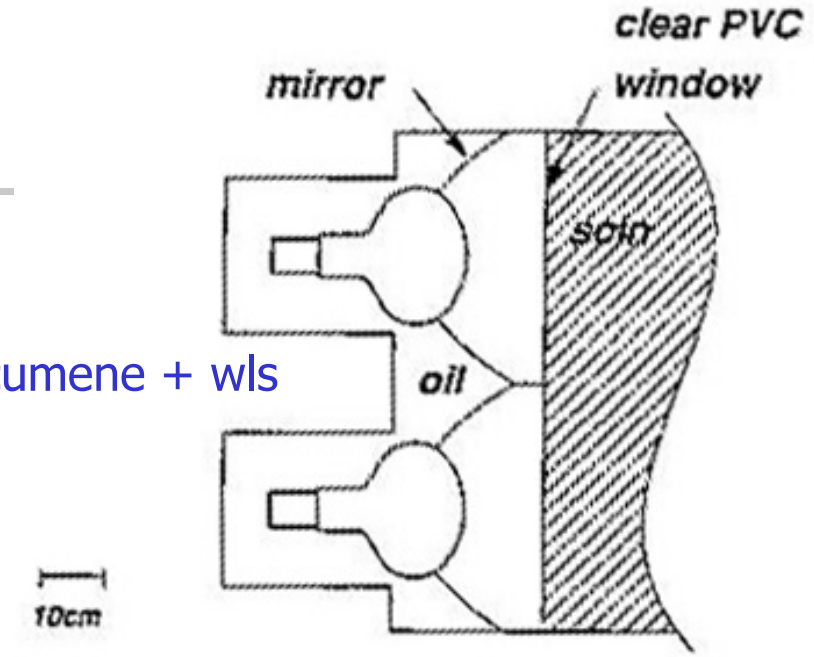




A ~ 10000 m^{2}sr <h> ~3800 mwe

- ⇨ Liquid scintillators
- ⇨ Streamer tubes
- ⇨ Nuclear track-etch

Scintillators

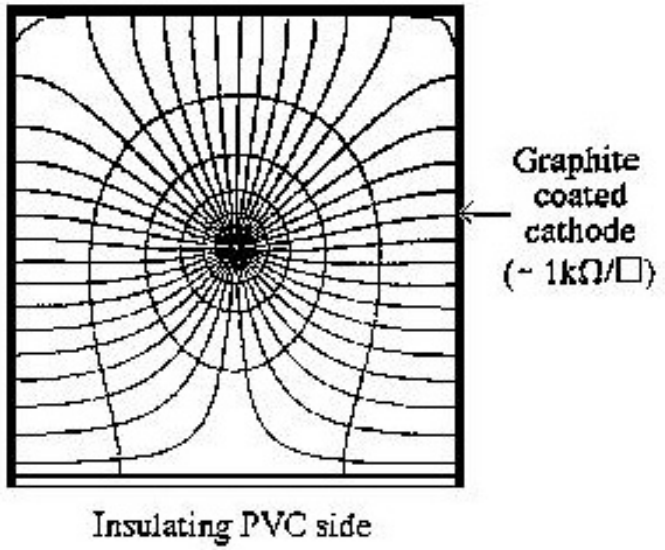


- Liquid scintillator: mineral oil+ pseudocumene + wls
- Total mass : 600 t
- Time resolution: ~750 ps
- Calibration tools: cosmic muons, LED's, UV laser

- ✓ 200 MHz WFD for pulse shape analysis
- ✓ Energy Reconstruction Processor (ERP): ADC/TDC system
- ✓ PHRASE: dedicated hardware for ν burst detection from SN

Streamer Tubes

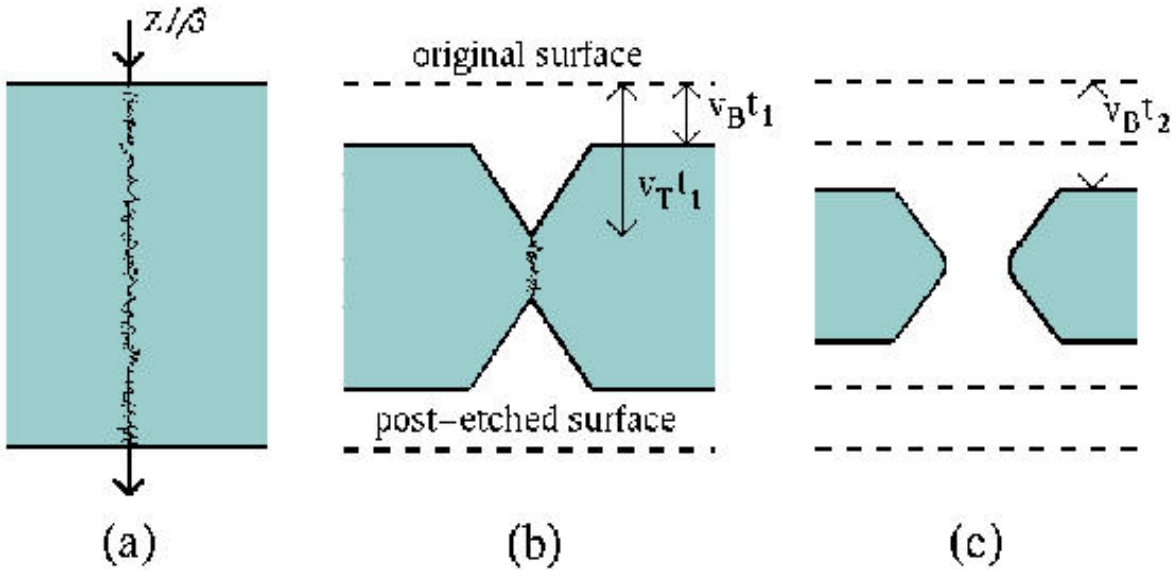
- (3 cm x 3 cm x 12 m) cell with 100μm Cu-Be wire
- Gas mixture: He (73%) + n-pentane (27%)
- Total surface : ~ 19000 m^2
- Maximum time jitter: 600 ns
- Pick-up strips for stereo track reconstruction
- Angular resolution: 0.2°



- ✓ Digital and analogic (OR of few ch's) readout
- ✓ Two temporal windows: FAST (10μs) and SLOW (500μs)
- ✓ Charge and Time Processor (QTP): ADC + 150ns sampling

Track-etch detectors

- CR39/Lexan/CR39/Lexan/Al/CR39/Lexan wagons
- (24.5 x 24.5) cm^2 wagons
- Total surface : ~ 1263.2 m^2 (~ 7100 m^2 sr)
- Calibrated with slow and fast ions



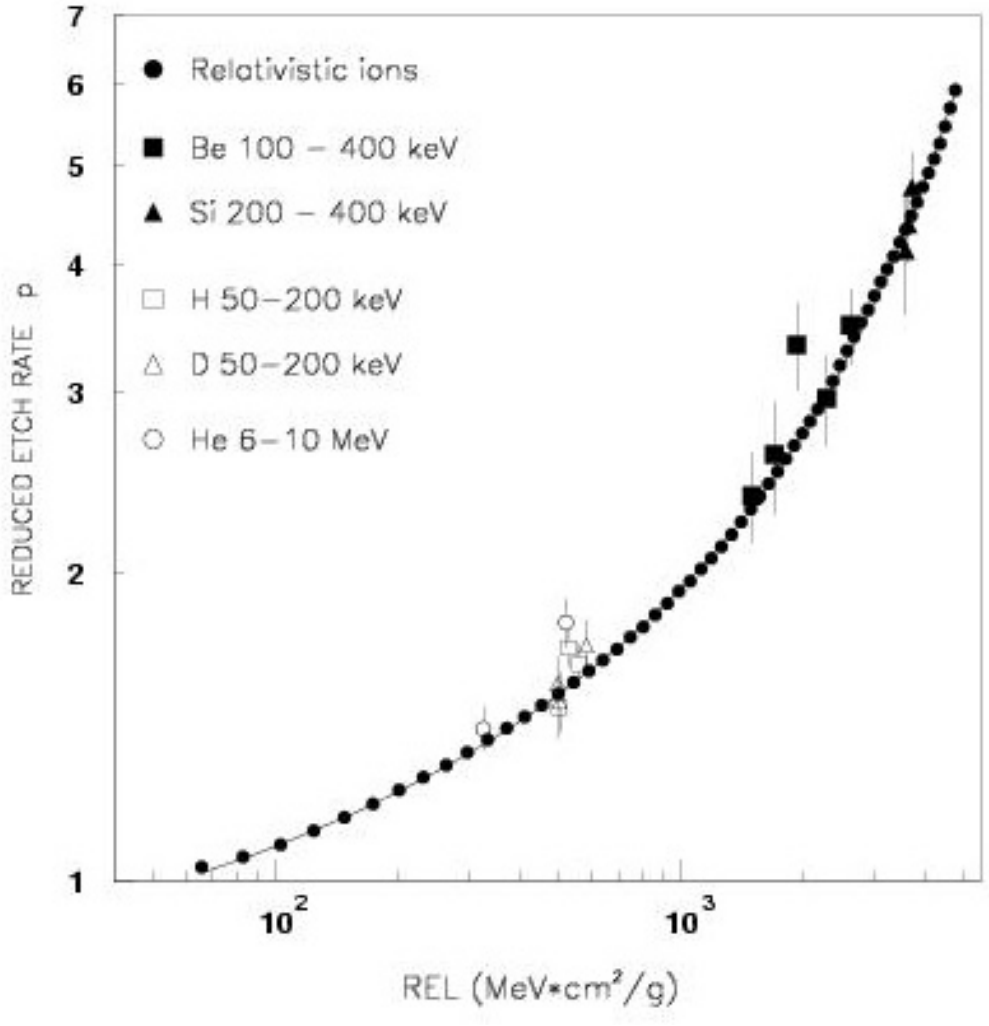
The reduced etch rate

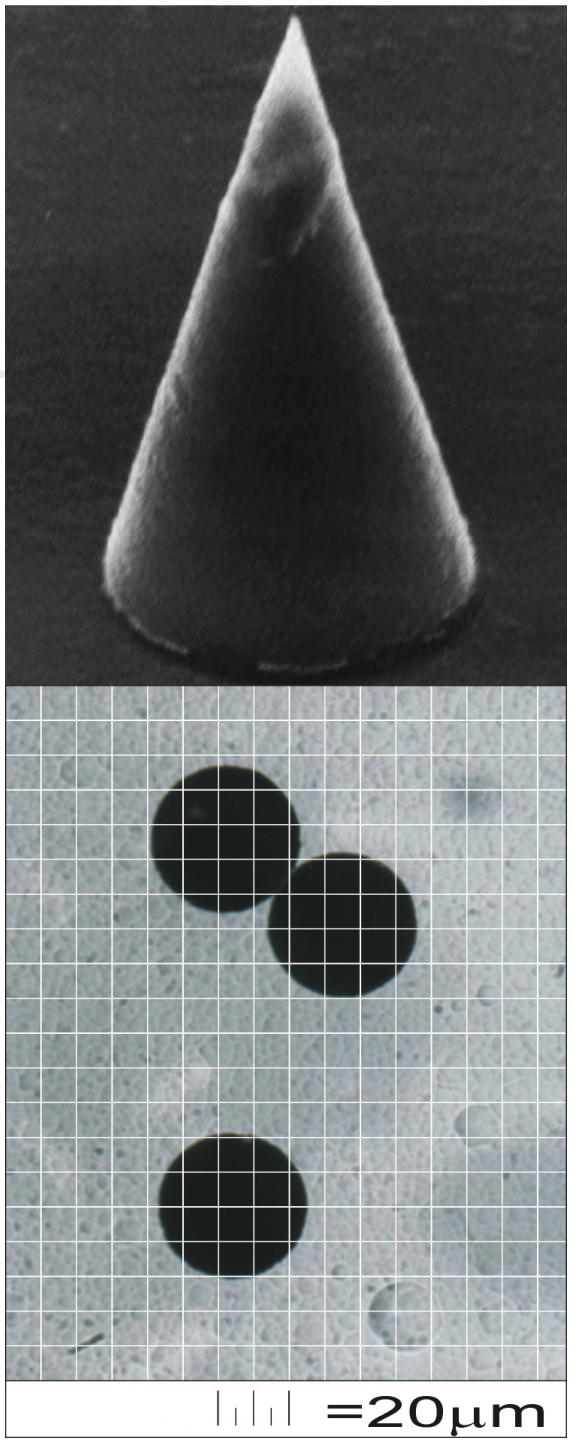
$p = V_T/V_B$

is simply related to the Restricted Energy Loss (REL)

$REL = (dE/dX)_{E<Emax}$

CR39 calibrations

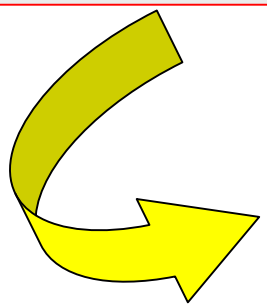




Magnetic monopole searches in MACRO

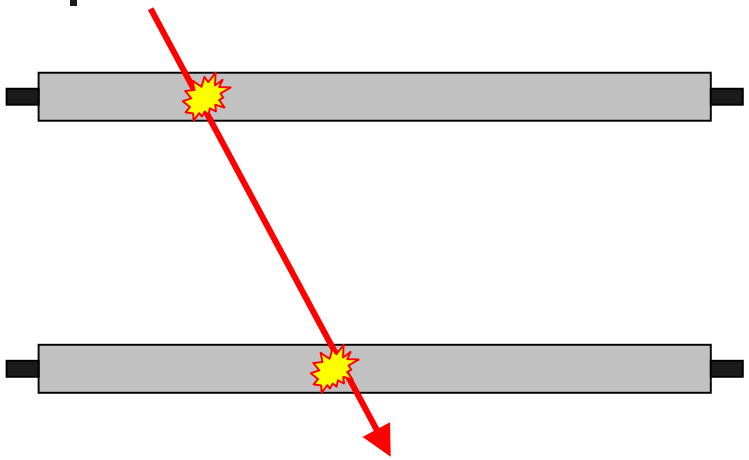
Different analysis techniques are used in different β ranges:

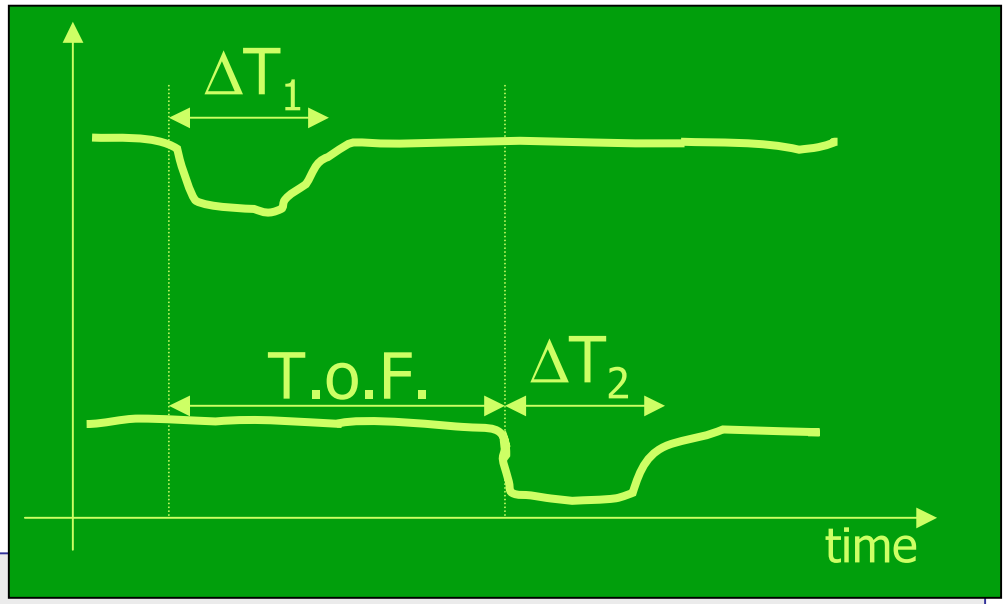
- ✓ searches with scintillators alone
- ✓ searches with streamer tubes alone
- ✓ searches with nuclear track-etch
- ✓ combined searches



Redundancy & Complementarity

Search with scintillators alone





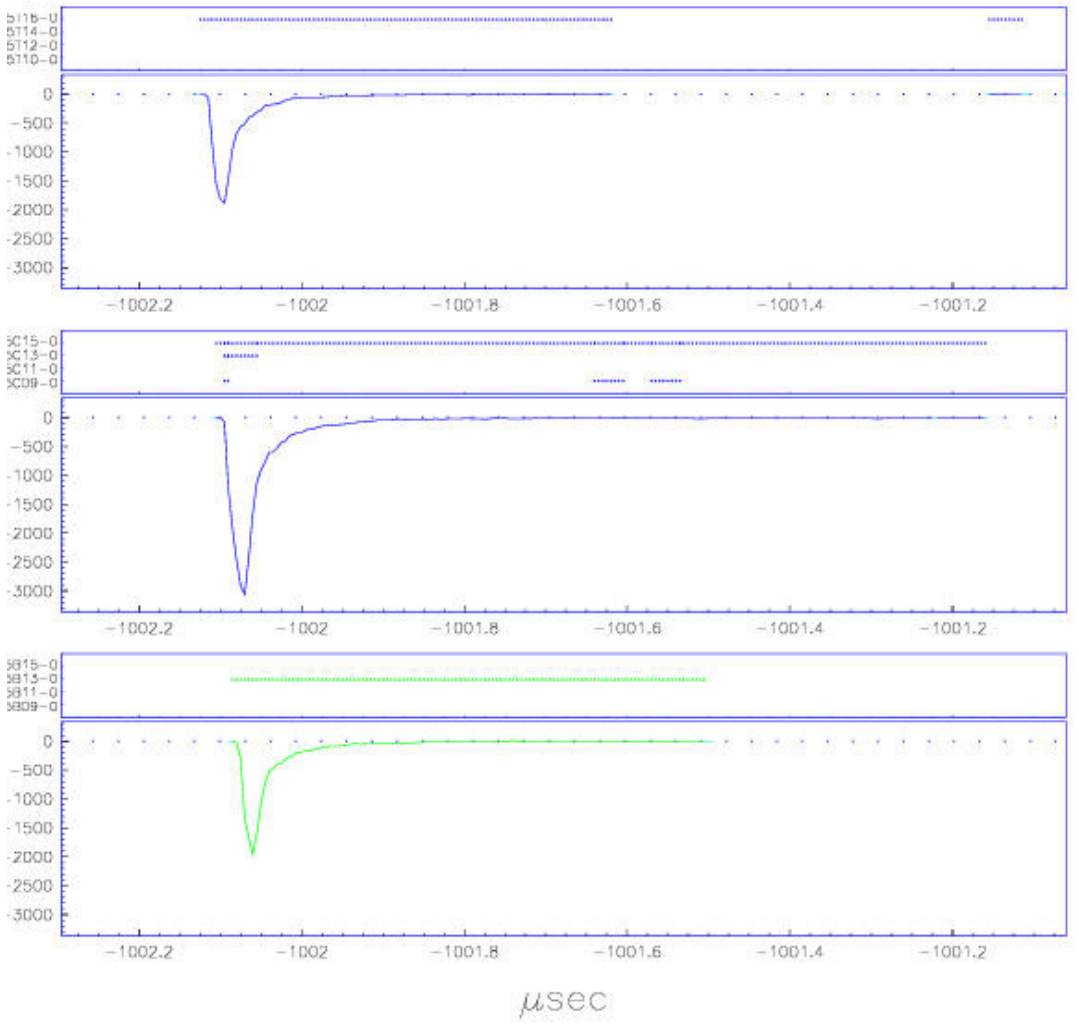
- ✓ Study of the PMT pulse
- ✓ Measurement of the light yield
- ✓ Consistency check between the box crossing time and the ToF across MACRO

For slow monopoles the PMT pulse might reduce to a train of single photoelectrons.

Dedicated hardware: trigger + WFD

A cosmic muon in the 200 MHz WFD system

- 200 MHz clockspeed
- Memory depth: 1ms
- Hardware zero suppression
- 4:1 multiplexing
- Non-linear front-end amplifier
- In ACQ from Aug'95 to May'00



Search with scintillators alone

Low velocity

Velocity range: $10^{-4} \leq \beta \leq 10^{-3}$

- Sensitivity down to $\beta \sim 10^{-4}$ ensured by the low threshold for scintillation light production
- Sensitivity for $\beta > 10^{-3}$ forbidden by the muon background

Analysis strategy:

- Scan of the PMT wave form with dedicated 200 MHz WFD
- Consistency check of the box crossing time with T.o.F. across MACRO

Background:

- Natural radioactivity + Electronic noise

Search with scintillators alone

Medium velocity

Velocity range: $10^{-3} \leq \beta \leq 10^{-1}$

- Sensitivity below $\beta \sim 10^{-3}$ forbidden by PHRASE threshold
- Sensitivity for $\beta > 10^{-1}$ forbidden by the huge muon background

Analysis strategy:

- Consistency check of the box crossing time with T.o.F. across MACRO
- Comparison with the expected monopole light yield at a given β

Background:

- Stopping muons with delayed electron emission
- Natural radioactivity + Electronic noise

Search with scintillators alone

High velocity

Velocity range: $\beta \geq 10^{-1}$

- Sensitivity above $\beta \sim 10^{-1}$ ensured by the large monopole light yield with respect to that of atmospheric muons

Analysis strategy:

- Cut on the energy deposit in N > 1 scintillator counters
- Comparison with the expected monopole light yield at a given β

Background:

- Showering atmospheric muons
- Natural radioactivity + Electronic noise

Search with streamer tubes alone

Velocity range: $10^{-4} \leq \beta \leq 5 \cdot 10^{-3}$

- Sensitivity down to $\beta \sim 10^{-4}$ allowed by the Drell effect on He
- Sensitivity for $\beta > 5 \cdot 10^{-3}$ forbidden by the huge muon background

Analysis strategy:

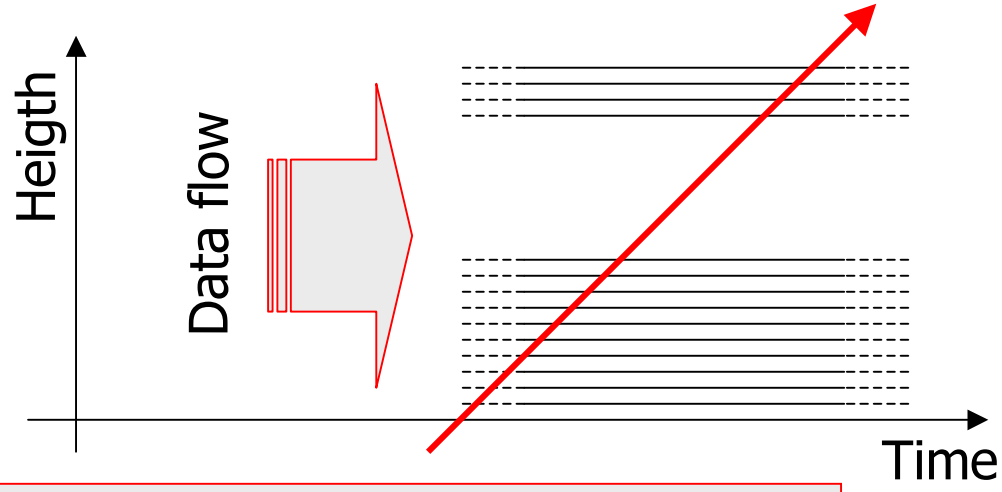
- look for slow particles crossing MACRO with constant β

Background:

- Accidental coincidences of radioactivity background hits (~40Hz/m^2)
- Electronic noise, pick-up, cross-talk

ST analysis scheme

Look for temporal alignments in a ~500μs window with 150ns resolution



Require single track in wire, strip and time view

Time of Flight measurement

Integrated live time from 1992 to 1999: $6.6 \cdot 10^4$ hours

Combined search for fast monopoles

ERP + Streamer + Track-etch

Velocity range: $\beta \geq 5 \cdot 10^{-3}$

- Sensitivity above $\beta > 5 \cdot 10^{-3}$ ensured by the large energy loss of mm's (at least 30 m.i.p) and by the combined use of ST and SC data

Analysis strategy:

- large energy deposit in scintillators + use of ST tracking information
- large primary ionization in streamer tubes
- Comparison with the expected mm light yield vs β (if ToF available)
- Scan of the track-etch wagons for the few selected candidates / year

Background:

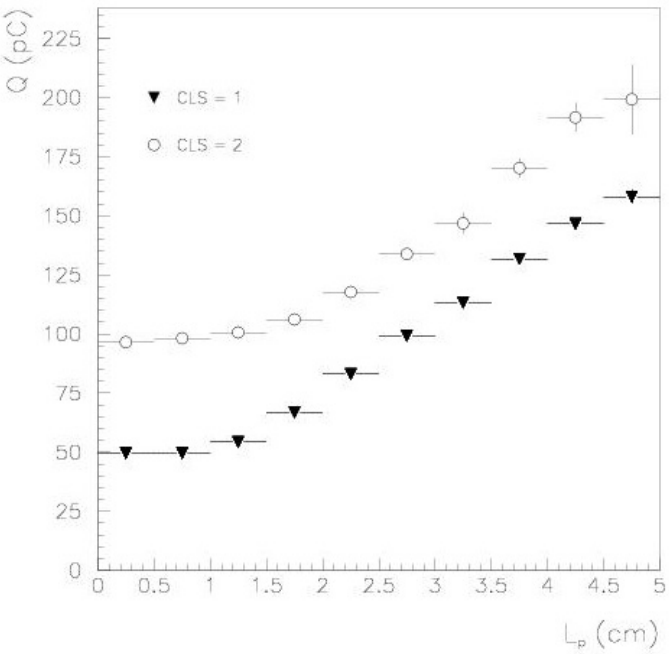
- High energy single muons

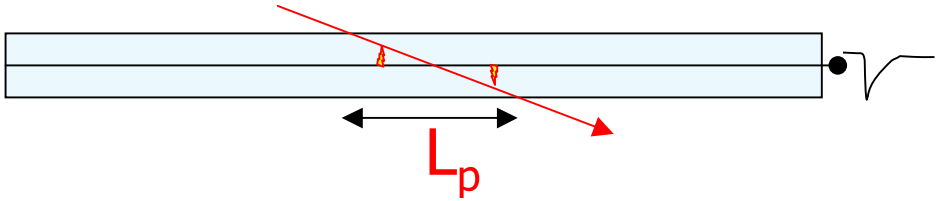
Combined search for fast monopoles

ERP + Streamer + Track-etch

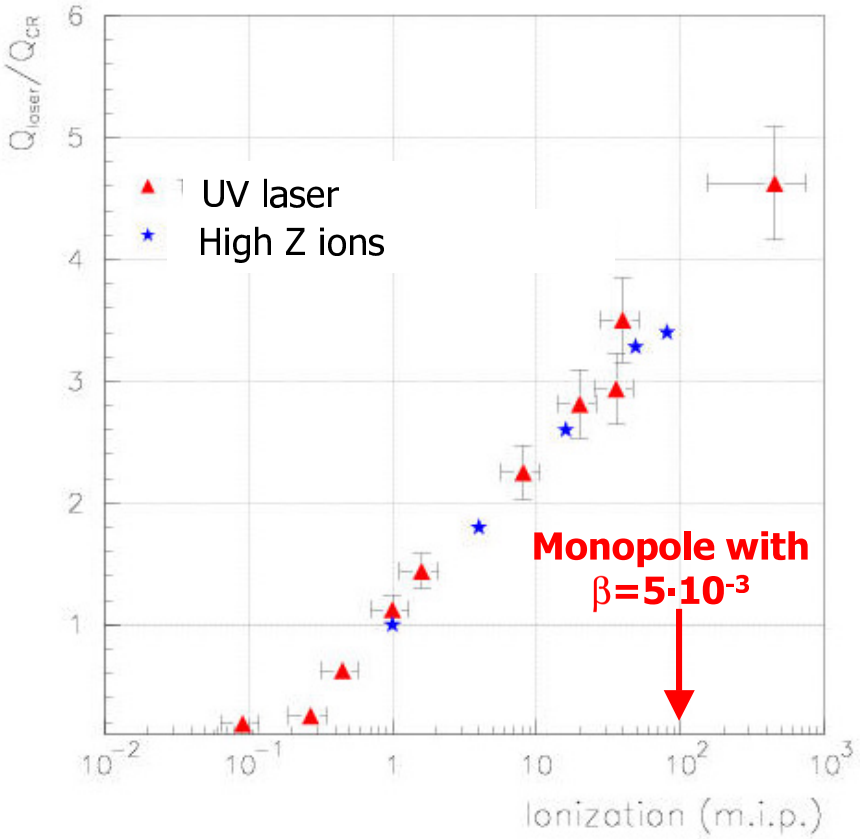
Study of the streamer tube response vs ...

... track geometry





... primary ionization



Combined search for fast monopoles

PHRASE + Streamer (tracking alone)

Velocity range: $\beta \geq 10^{-2}$

- Sensitivity above $\beta > 10^{-2}$ ensured by the large monopole light yield

Analysis strategy:

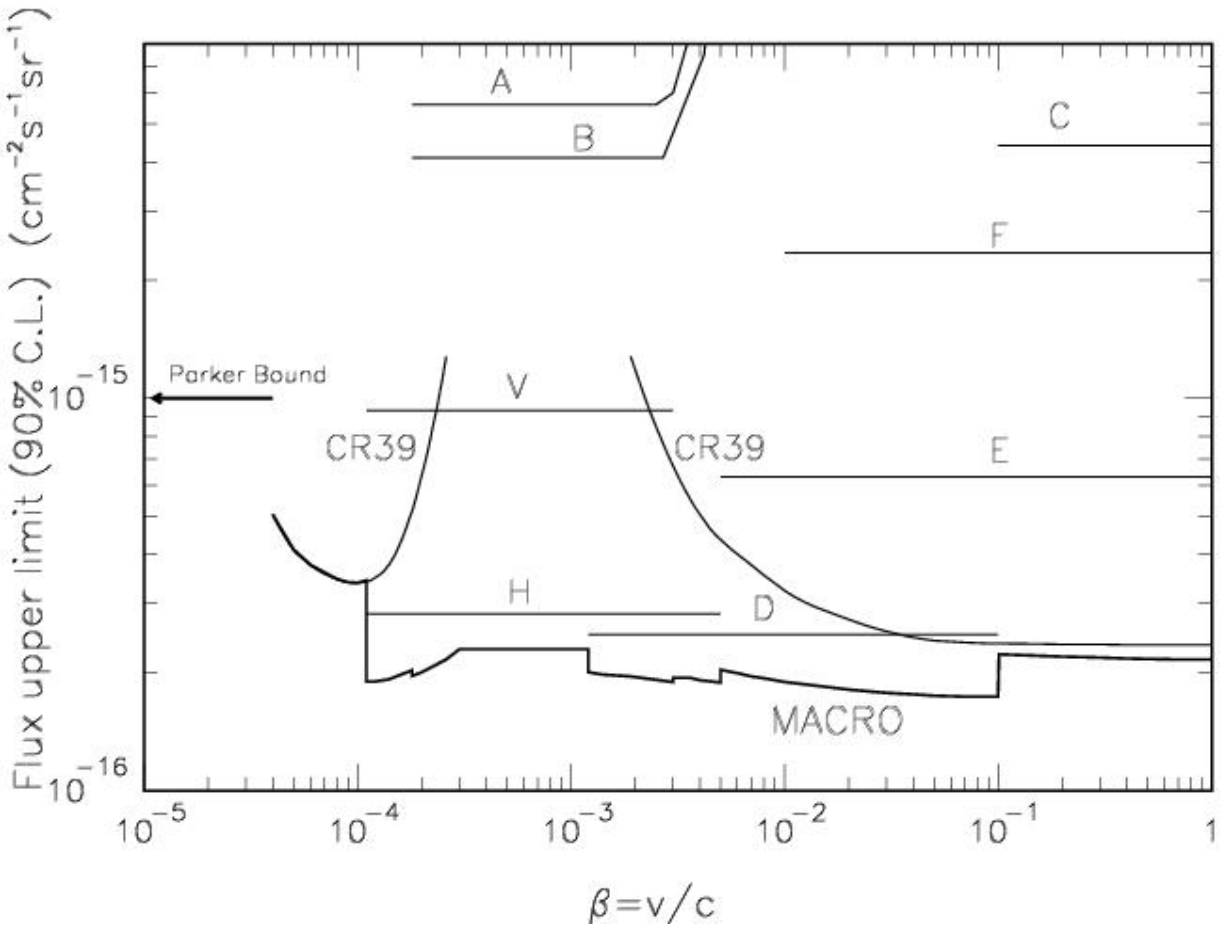
- Large energy deposit in scintillators + use of ST tracking information
- Comparison with the expected mm light yield vs β

Background:

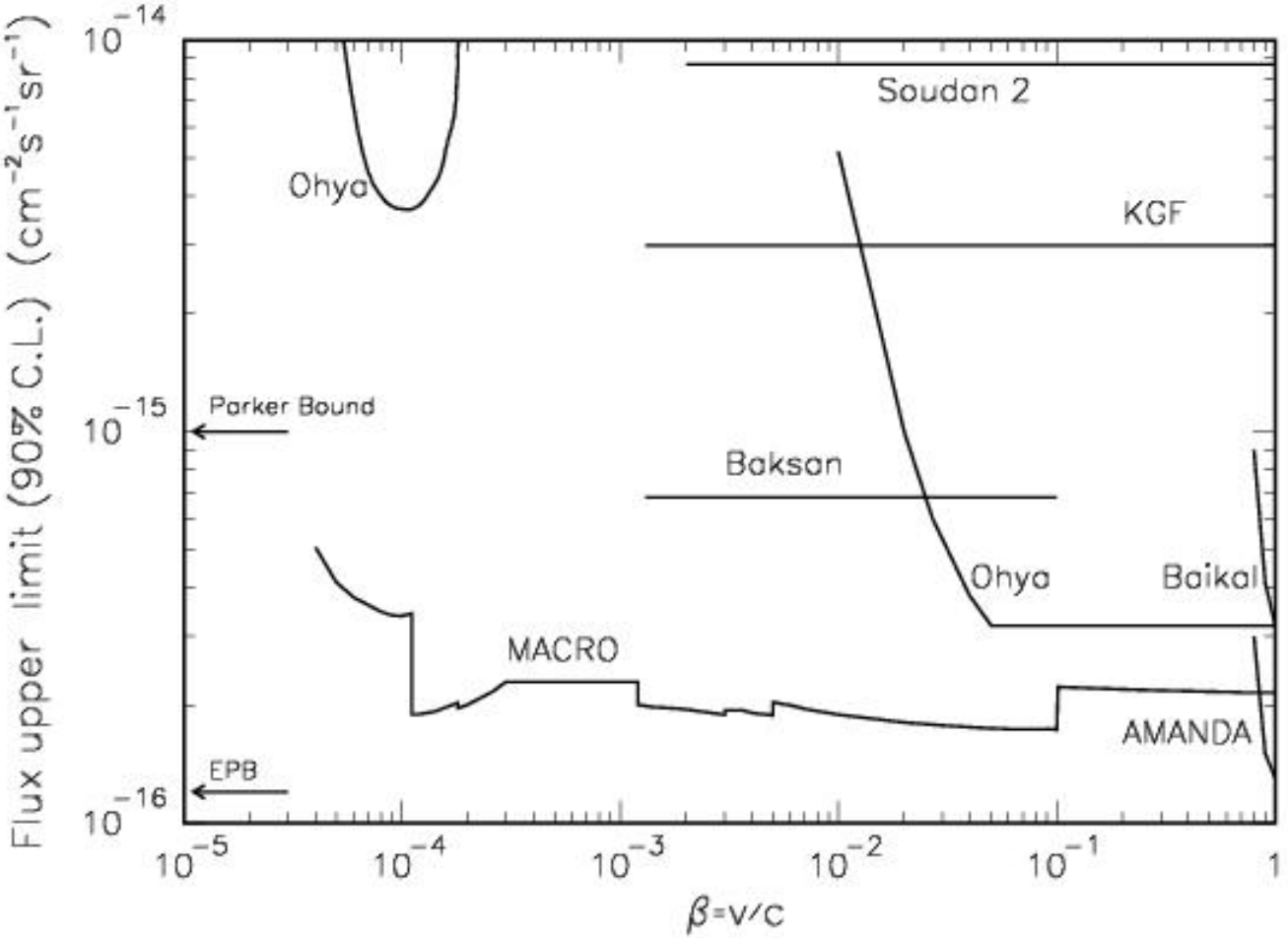
- High energy single muons

MACRO limits to monopoles

- $g=g_D$
- $\sigma_{catalysis} < 1$ mb
- Isotropic flux



Limits to the monopole flux

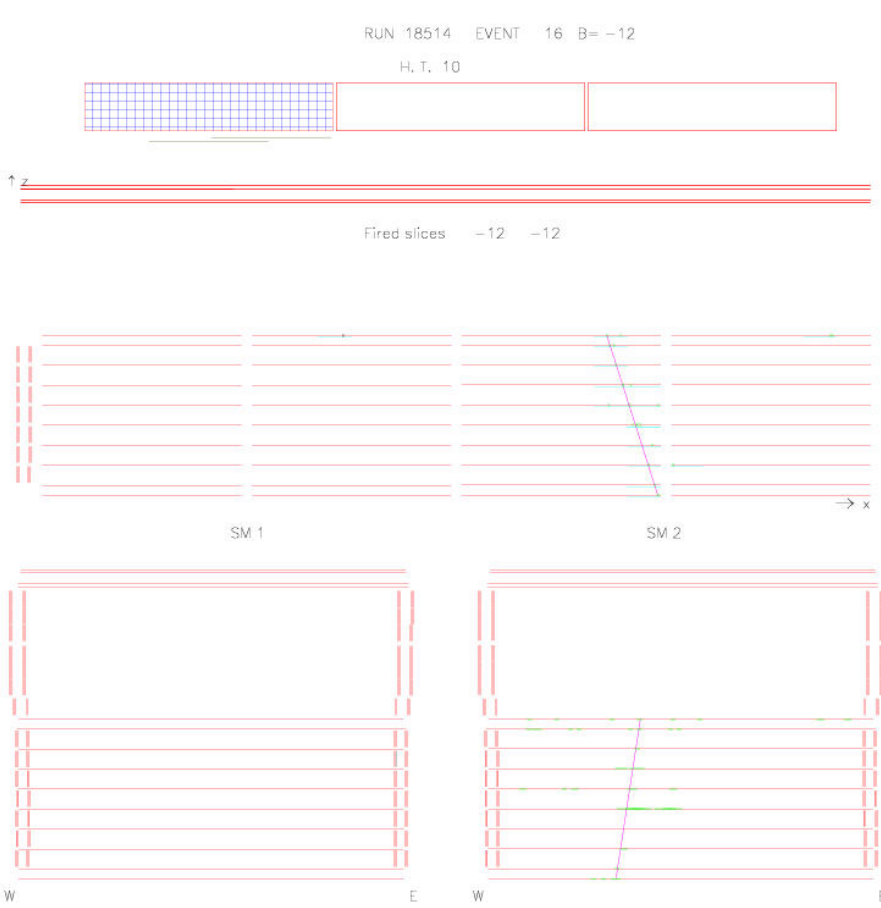


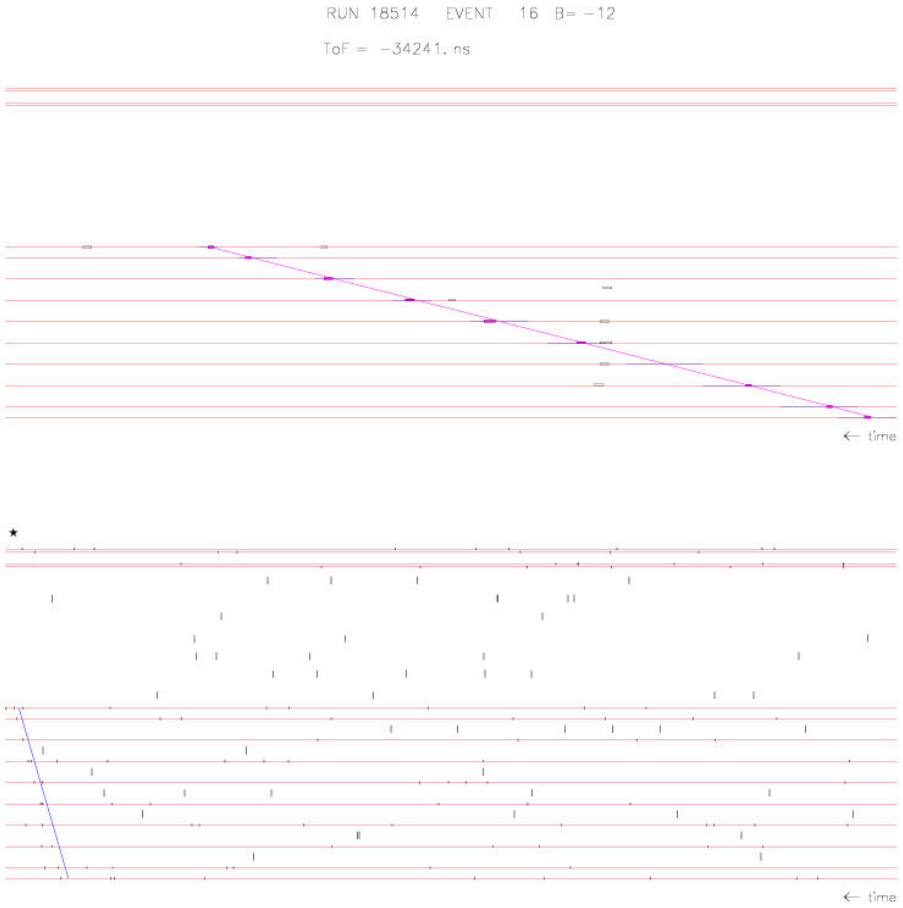
Monopole induced nucleon decay

If the catalysis cross section is larger than ~1 mb monopole induced nucleon decay in the apparatus might change the efficiency of the various searches.

- ✓ A detailed simulation of the physical processes, the detector response and the analysis procedures has been applied to the case of the search for slow monopoles with the streamer tubes. A similar work is being done for the other searches.
- ✓ Also in progress is the setting up of an analysis technique dedicated to GUT magnetic monopoles with nucleon decay catalysis along their trajectory.

Monopole induced nucleon decay

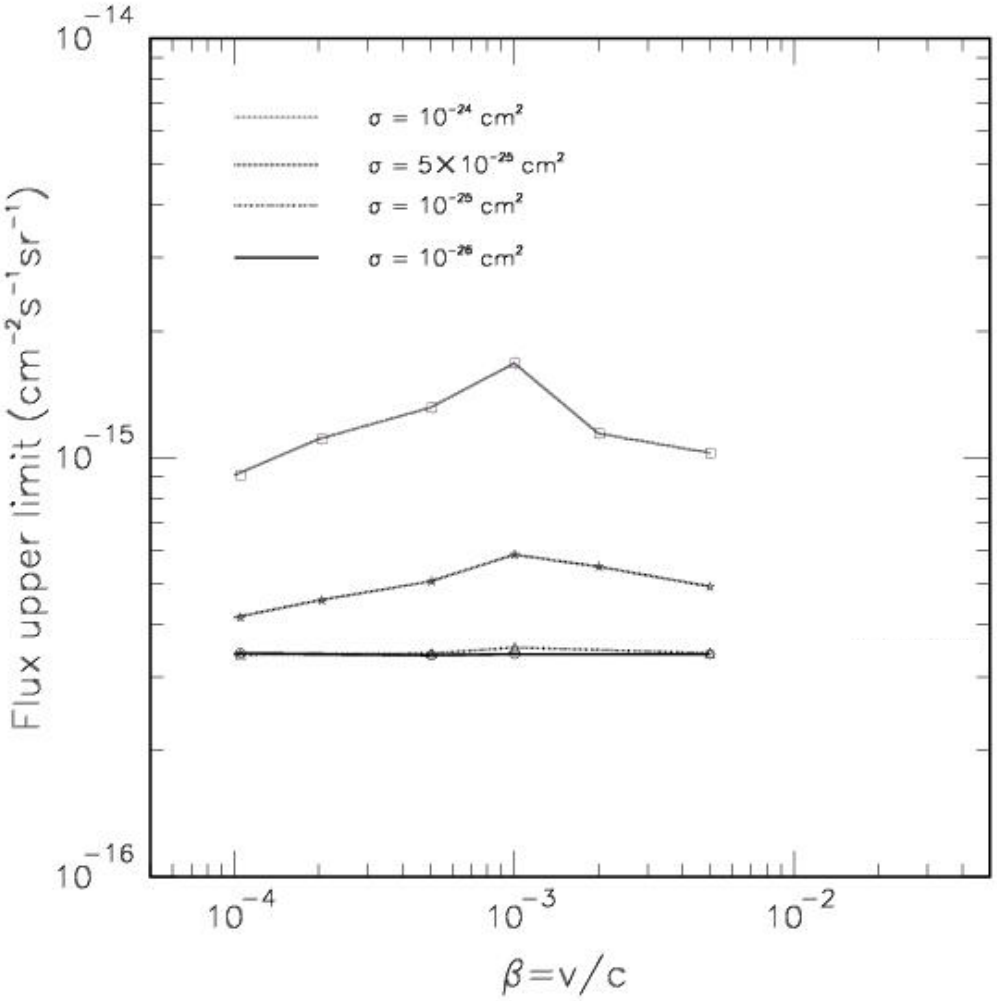




Monopole induced nucleon decay

Different limits for the slow monopole search with streamer tube

as a function of the catalysis cross section



Search for other massive exotic particles

NUCLEARITES: aggregates of SQM (Strange Quark Matter)

(E.Witten PRD30 (1984) 272 - A.De Rujula and S.L.Glashow Nature 312 (1984) 734)

Look for signatures (large energy release) in Scintillators and Track-etch.

Acceptance depends on SQM mass and velocity.

Q-balls: aggregates of squarks, sleptons and Higgs fields

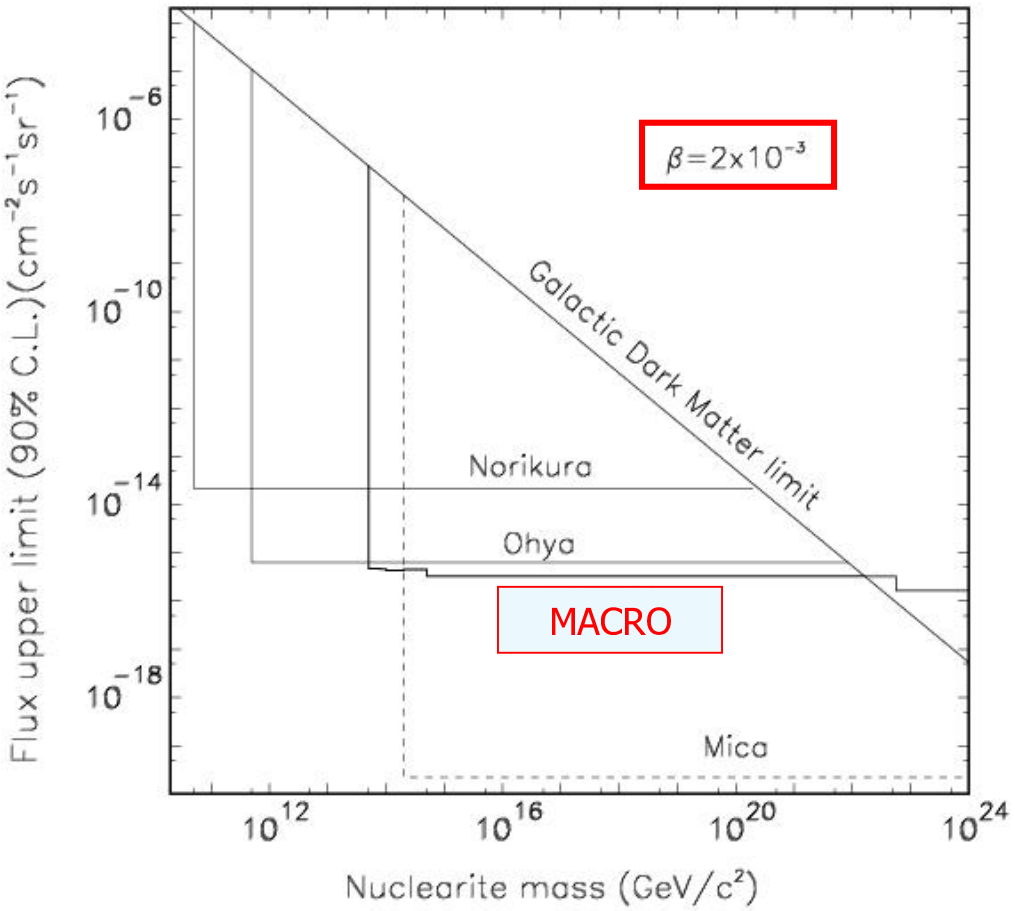
(S.Coleman NPB262 (1985) 293 – A.Kusenko & M.Shaposhnikov PLB417 (1998) 99)

Search for electrically charged Q-balls by means of their substantial energy release along a straight track with no attenuation throughout the detector.

Data analysis in progress.

Limits to the nuclearite flux

- Limit almost flat as a function of β in the range (β~10^{-4}-1), assuming an isotropic flux
- Flux isotropy depends on nuclearite mass



Conclusions

- MACRO: active since 1992. Completed in 1995. Ended in December 2000.
- Several analyses performed for magnetic monopole search. Redundancy and complementarity ensured by the use of different detection techniques.
- No monopole candidate found. Flux limit well below the Parker bound in a large velocity range (i.e. $\beta \geq 10^{-4}$). Data analysis not yet complete.
- Search for nuclearites also performed.

Have a look at

www.df.unibo.it/macro/