

Status and Prospects of MANDATE

Monopole And Nuclear Detector At Tibetan Elevation

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- A next-generation *dedicated* search for magnetic monopoles (MMs) in cosmic rays.
- Detector: **nuclear track detectors** (NTDs) – passive, no power, no readout electronics, sensitive only to very high ionization density. $\Rightarrow$ large areas on a budget, essentially background-free.
- Phased approach: pilot now, first physics result next, full scale after.
- Site for Phase-I: **Haizi Mountain (LHAASO)**, 4400 m – high altitude opens the low-mass monopole window.
- Unique: **synergy with CR observatory** for an external trigger on high-energy cosmic rays.

Motivation: *Phys. Rev. D 111, 102004 (2025)*.

The central challenge: scalability

- The flux is tiny $\Rightarrow$ need **enormous area**.
- NTDs may be not so expensive to *deploy* – but expensive and slow to **etch**, and **scan**.
- Previous experiments reached the level of $\sim$ few hundreds to a couple of thousands m^2 active area. To go order(s) of magnitude higher is non-trivial.

Ask not “how big is the detector” – ask “how fast can we process it.”

How the previous generation did it

	MACRO	SLIM	Ohya
Stack composition	CR-39 + Lexan	CR-39 + Makrofol + Lexan	CR-39 only
Sheet size, cm ²	24.5×24.5	24.5×24.5	56×54.5
Total area, m ²	~ 1200	~400	2000
Coincidence window	??	??	10 mm
Etching, m ² /etch	<5?	<5?	80
Scanning	manual	manual	automated
CR-39 source	local	local	local

- Custom, **domestically produced CR-39** to control cost and parameters – already in both SLIM (Intercast) and Ohya (Sola Optical Japan).
- Automation appeared in Ohya decades ago.

A strategic observation

Ohya (1980s)

- 80 m² per etch
- manual stacking (scotch tape!)
- automated scanning with 1 mm coincidence window (94 candidates after ~ 4000 m²yr exposure)
- domestic Japanese CR-39

MANDATE (2020s)

- Phase-I acceptable target: 20-50 m² per *day*
- automated stacking with precision alignment (< 100 μ m coinc. window) planned
- automated scanning planned
- domestic Chinese CR-39 foreseen

The 80-x Japan's industrial power made this possible in its era.
China's industrial power of 2020x takes up the baton.

The Phase-0 etching lab

Renovated from scratch: **70 m²** of modern equipment.

Visited etching labs in Switzerland and China to gain experience.

Stacking / preparation

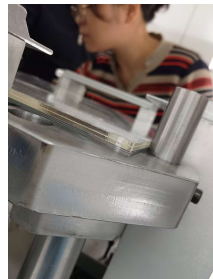
- Custom 7-head precision drill: 4 fixation + 3 alignment holes ($\varnothing 400\text{ }\mu\text{m}$ diameter)
- Semi-automated stacker with 3 pins ($\varnothing 400\text{ }\mu\text{m}$) for a precise cross-layer coordinate system $\rightarrow$ tight coincidence backgrounds
- Laser QR coding of every NTD + readers
- Database tracking every sheet end-to-end

Etching / QC

- Etch $\sim 2\text{ m}^2$ at a time
- 16-sensor thickness measurement (pneumatic plate flattens CR-39, auto-entry to database) for etch-rate determination
- Automatic precision titrator, calibrated, linearity-checked at high concentration
- 3 freezers: dosimeter-grade plastic kept free of fading/aging

Comfortably supports the **pilot** + all current and future **accelerator-based** searches. But **not** yet Phase-I MANDATE at scale.

The Phase-0 etching lab



Pilot deployment at Haizi Mountain (May 2026)

- **10 m²** active area.
- Each stack: $2 \times$ low-threshold CR-39 + $3 \times$ high-threshold Makrofol.
- 15 m² metal tables, tarpaulin cover; stacks in aluminized mylar bags.

Four goals of the pilot

- ① Gain experience with the **full chain**: prepare → deploy → accumulate → process.
- ② **Identify bottlenecks** preventing scale-up.
- ③ Verify detector performance in real high-altitude conditions.
- ④ Test the **LHAASO joint trigger**.

Pilot deployment at Haizi Mountain (May 2026)



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- **Radon concentration: very low** (α backgrounds expected to be non-issue).
- **Neutron flux and energy spectrum: measured and simulated**; higher than at sea level, as expected at 4400 m.

Plans for the next 6 months:

- **Take back** stacks after 6 months exposure:
 - open mylar bags vs. sealed mylar bags $\rightarrow$ disentangle α (radon/air) from **neutron** backgrounds
- Practice interaction with LHAASO (**trigger test**).
- **Deploy new stacks** with the neutron-shielding holder.

The LHAASO joint trigger

- LHAASO flags high-energy showers whose reconstructed **core lands within the MANDATE footprint**; MANDATE scans only the tagged region.
- Pilot thresholds for testing purposes:
 - **3.7 PeV** ($\sim$ first knee) heavy-nucleus (Fe) $\rightarrow \sim 20$ triggers in 6 months: don't actually expect to see anything, as survival probability of a detectable ($Z \gtrsim 5-7$) remnant, even at 4.4 km asl, is much smaller. But a first practice of LHAASO-MANDATE interaction
- Plan a detailed CORSIKA study of various remnants' survival probabilities as potential backgrounds for full-scale deployment, as well symmetric return to CR community.

Why the trigger is a potentially big scalability advantage

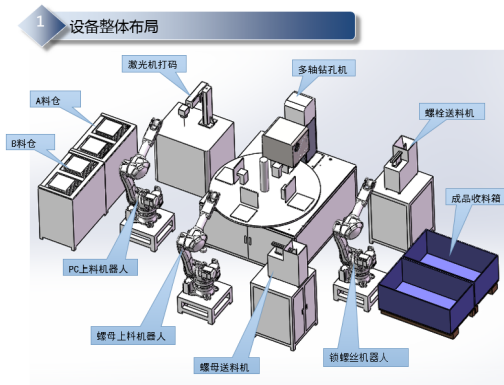
The key idea

With the observatory localising a shower core to a few meters, MANDATE needs to etch and scan **only the triggered spots** – not the whole array.

- Turns a brute-force scan into a **targeted** scan.
- Pilot is *exercising this now*.
- **Validation plan:** Phase-I will still brute-force etch/scan the whole exposure, and **cross-check** against triggered spots – before trusting the trigger-only mode for Phase-II.

Scalability axis 1 – stacking

- Design of the automated stacking setup (company-produced): **500 stacks/day/setup**, *no person intervention in normal mode*.
- $2\text{--}5\text{ k m}^2 \Rightarrow$ **2–5 months with one setup**.
- Cost target: **50–60 wan** per setup.



Scalability axis 2 – etching

- Custom-designed etching tank **on order**.
 - Target for Phase-I etching facility: **$\sim 20\text{-}50 \text{ m}^2/\text{day}$ at $\sim 15 \text{ wan total}$.**
 - Context: Bologna $\sim 3 \text{ m}^2/\text{day}$; Ohya $80 \text{ m}^2/\text{etch}$.
- $50 \text{ m}^2/\text{day}$ at that cost is the difference between feasible and science-fiction for Phase-I.**

Scalability axis 3 – scanning

- First, commercial **automated scanner** already in operation.
- Working with the designer of hardware&software for **OPERA** and **SND** scanners on a custom solution.
- Using **domestic Chinese components** (stages, controllers, optics, CCD, assembly) to cut cost.
- Target: $\sim 500 \text{ cm}^2/\text{hr}$ per unit, $< 10 \text{ wan}$ per scanner as acceptable for brute-forcing Phase-I. (cf. TASLimage claims $3600 \text{ cm}^2/\text{hr}$.)



Dedicated talk on scanning later today.

A hard decision: what goes in the stack

What the history teaches

Keeping multiple redundant NTD types per stack is **costly and hard to scale**.

- **Decision:** 3-layer Makrofol-only stacks by default for Phase-I.
- **Limited 2-layer CR-39** added at TBD scale *depending* on the local-supplier effort.
- Status: **domestic samples already exposed at the CERN SPS Pb-ion beam (August 2026)**
– evaluating supplier CR-39 quality now.

Rationale: one material, one high-throughput chain $\gg$ redundancy is a luxury we can't yet afford at scale.

Roadmap: Phase-I (physics deployment)

Exposure goal

- 10 000 m²yr Makrofol, 3 layers
- ~4000 m²yr CR-39, 2 layers (conditional)

Expected physics

- Substantially improve on SLIM.
- Open genuinely **unexplored** parameter space (low-mass, high- γ).

Timeline

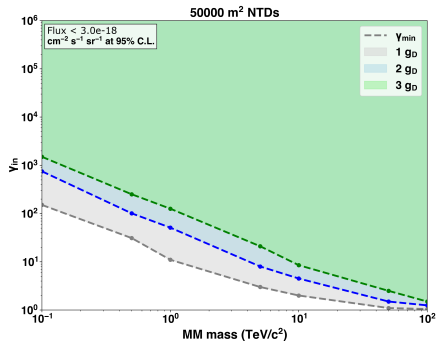
- Start ~2 years
- 2–5k m² collects ~5–2 years
- ~1 year analysis

Roadmap: Phase-II (full scale)

- Target exposure: $500\,000\text{ m}^2\text{ yr}$, both Makrofol and CR-39.
- **Trigger becomes essential**: at $500\text{ k m}^2\text{ yr}$ expect **several coincidences with multi-EeV cosmic rays** (*PRD 111, 102004*, Section IV.B.3).
- *Site question*: LHAASO is adequate for Phase-I; for Phase-II we may consider an observatory sensitive to **higher energies** – unless LHAASO upgrades.

Phase-II is where the observatory-trigger becomes **essential**, may enable **further scale-up**.

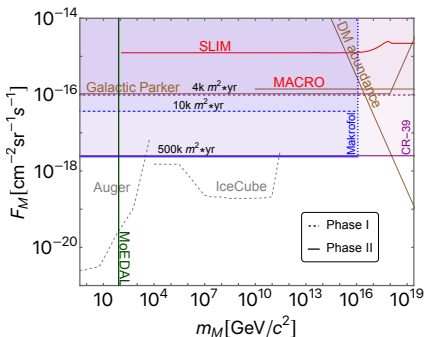
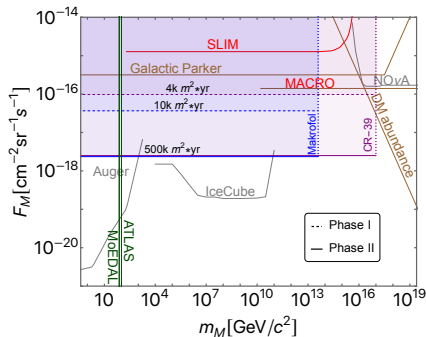
Sensitivity reach, acceleration-agnostic. $1g_D - 3g_D$



Notes on the plot:

- Detailed Geant4 simulation (*PRD 111, 102004*)
- However, E&M losses only (excludes interesting composite MMs models)
- Surpasses current results (Auger, IceCube?, others) for $\gamma_{in} \sim 12 - 10^{7-9}$, depending on the mass

Sensitivity reach, acceleration-model dependent. $1g_D$ vs. $3g_D$



Notes on the plots:

- E&M losses only (excludes interesting composite MM models)
- For $g > 1g_D$, ATLAS is out, IceCube/NOvA shorten low-mass reach, MANDATE reaches high masses even with Makrofol
- Understood cosmic acceleration history (may be orders of magnitude off)

Collaboration – all levels welcome

- **Endorse the CDR** – every attendee is welcome to sign.
- **Contribute to writing** – reach out offline.
- **Theorists** – help address the open issues (Discussion I).
- **Research groups** – join at the level that fits:
 - adopt our engineering solutions (1–2 scanners to share the scanning load; etching or stacking machines; simulation);
 - join with alternative technologies;
 - anything is on the table at this point.

Funding

- **Phase-I:** in principle IHEP can handle it alone on existing talent funding (contributors still welcome).
- **Phase-II:** plan to pursue **CAS** and **MOST** infrastructure grants on the IHEP side (beyond single-PI NSFC research grants);
- **Joint opportunities:**
 - open to ICFCRT with Chinese colleagues;
 - **JINR** is very welcome – special funding channels exist there, with positive experience in the JUNO context.

- ① **Pilot is running** at Haizi Mountain (10 m^2).
 - **November:** retrieval for backgrounds + Fe-remnant search + shielded re-deployment.
- ② **Scalability** attacked on three axes: stacking, etching, scanning, with cost/throughput targets defined.
- ③ **Hard decision made:** Makrofol-only by default (+limited CR-39 if the domestic supply matures).
- ④ **Phase-I** ($10^4 \text{ m}^2 \text{ yr}$): improve on SLIM, open new parameter space, while validating the brute-force vs. triggered comparison.
- ⑤ **Phase-II** ($5 \times 10^5 \text{ m}^2 \text{ yr}$): trigger-driven processing becomes essential; possible higher-energy observatory partner.