BeamScan

A Particle-Beam Material Classifier: From Recycling to Heritage Science

1. Motivation to Participate

We are a team of high-school students from Córdoba, Argentina. In our country, plastic waste clogs rivers from the Pampas to Patagonia, and pre-Columbian obsidian tools still emerge from Andean soil. These challenges, sorting plastic for recycling and identifying archaeological materials, share a surprising connection: both can be addressed by measuring how a particle beam scatters inside matter. We want to show that the same physics that probes the structure of the universe can also serve society. Participating in BL4S would let us test this idea with a real accelerator beam and bring the results home to our communities.

2. Experiment Idea

The Question

Can we build a "BeamScan Atlas", a classification chart that identifies materials by measuring how charged particles scatter through them? We aim to demonstrate this across two real-world domains in a single experiment: identifying plastics for **recycling quality control** and classifying geological reference materials relevant to **heritage science**.

The Physics

When a GeV-scale charged particle traverses matter, it undergoes many small deflections from atomic nuclei, multiple Coulomb scattering (MCS). The resulting angular spread θ_0 depends on the material's radiation length X_0, a fundamental property set by elemental composition. From the Highland formula, $\theta_0 \propto \sqrt{x/X_0} / p$, where x is the target thickness, and p is the beam momentum. Materials with heavier atoms scatter the beam more.

Predicted Separation

Using the Highland formula with PDG radiation lengths, we calculated expected scattering angles at 3 GeV/c through 10 mm targets:

Polyolefins PE and PP ($\theta_0 \approx 0.56$ mrad): pure carbon–hydrogen baseline. **Oxygen-containing plastics** PS, PMMA, PET (θ_0 = 0.60–0.74 mrad): progressively heavier effective composition. **PVC** ($\theta_0 \approx 1.04$ mrad): the chlorine atom (Z = 17) dramatically increases scattering, enabling detection of PVC contamination in recycling streams, which is our primary industrial application. **Geological materials:** obsidian, quartz, calcite, alumina, iron oxide (θ_0 = 1.17–1.81 mrad): minerals built from silicon, calcium, aluminium, and iron scatter even more.

A natural gap separates the plastics cluster from the minerals cluster, reflecting a fundamental divide in chemistry: organic matter (C, H, O, N) versus inorganic matter (Si, Ca, Al, Fe). This gap is itself a scientific result that proves MCS naturally sorts materials into compositional families. Our Geant4 simulations confirm that even the closest useful pairs (PS vs PMMA) require fewer than 2,000 events to be distinguished at 3σ with 1 second of beam time. PVC versus PE needs only ~50 events. The full atlas requires under one hour of data.

Experimental Setup (facility-agnostic)

Our core measurement requires only tracking detectors and trigger scintillators, standard equipment at all BL4S facilities:

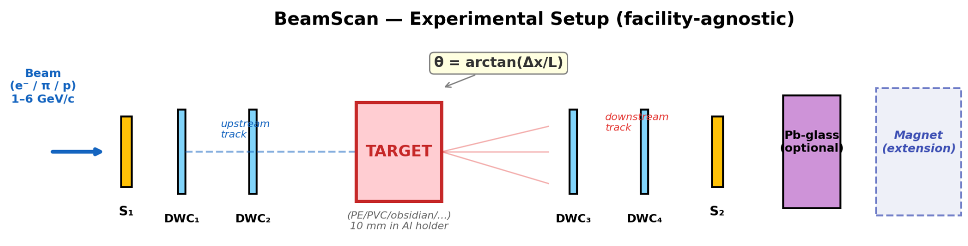

Figure 1: Facility-agnostic BeamScan layout. Magnet and calorimeter are optional extensions.

Two trackers upstream record the incoming direction; two downstream record the direction after the target. We subtract the no-target angular width in quadrature to extract the material scattering signal. This layout works at CERN T9 (Delay Wire Chambers), at DESY (beam telescope), and at ELSA.

Targets and Facility Considerations

CERN and DESY accept only non-combustible targets; ELSA also permits combustible materials. Our plan adapts accordingly: **at ELSA,** we run the full set of plastics (PE, PP, PS, PMMA, PET, Nylon, PVC) plus geological references (obsidian, quartz, calcite, alumina, iron oxide), including the PVC "hero result." **At CERN or DESY,** we run the non-combustible set of geological references, plus graphite and metal foils as low-Z anchors, to span a wide X_0 range and demonstrate the full classifier concept. All targets are solid samples in an aluminium holder. We will provide safety data sheets and coordinate with facility safety officers.

Measurement Program

Phase 1, Calibration: No-target runs at both momenta to measure beam divergence and angular resolution. **Phase 2, Core atlas:** Measure θ_0 for all permitted materials at two momenta (e.g. 3 and 6 GeV/c), 10 mm thickness, $\geq 10^4$ events each. The second momentum validates the expected 1/p scaling and controls systematics, since alignment shifts that affect both settings similarly, providing a built-in consistency check. **Phase 3, Systematics:** Vary thickness (5, 10, 20 mm) for selected materials to validate $\sqrt{(x/X_0)}$ dependence and extract X_0. **Phase 4, Extensions:** Contaminant sensitivity (thin metal foil inside a sample), composite materials, and if the facility offers additional observables such as dE/dx or calorimeter response, a genuinely independent second classification axis.

The Deliverable: BeamScan Atlas

A classification table and plot of measured θ_0 (and extracted X_0) for each target. The two-momentum data cross-check Highland scaling. Where the facility offers additional observables, we add a second axis (e.g. dE/dx from a TPC, or energy deposit in Pb-glass). The atlas is simultaneously a scientific result, a practical lookup table, and a memorable visualisation.

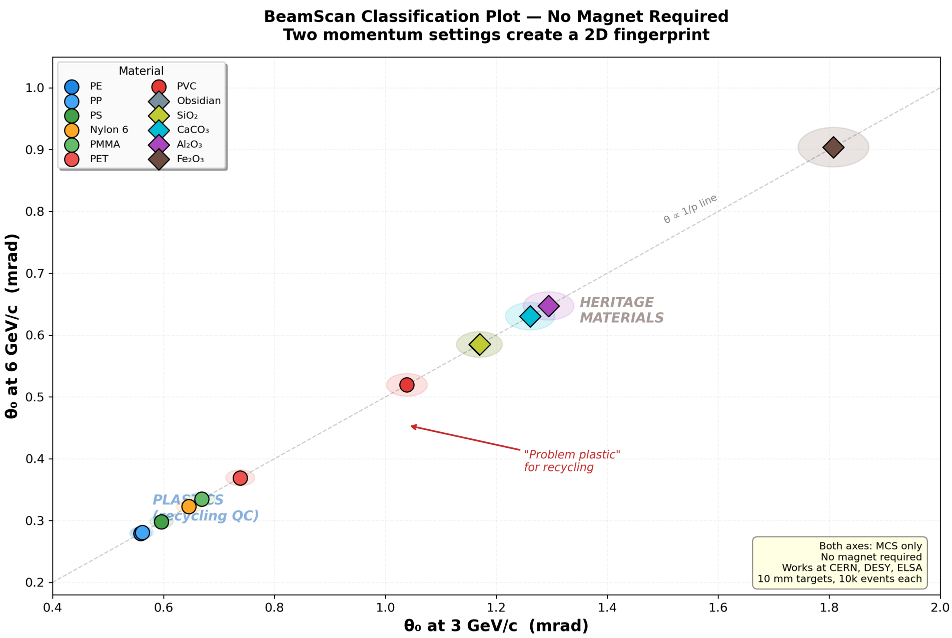

Figure 2: Predicted BeamScan Atlas (Highland formula). The two-momentum plot validates 1/p scaling; classification is based on the extracted X_0.

Simulation and Open Science

We have built a Geant4 Monte Carlo simulation of the full experiment and published it in a public GitHub repository with automated CI workflows. Students contribute by adding materials via pull requests and instantly seeing updated predictions, no C++ or Geant4 installation needed. Every figure in this proposal can be reproduced from the repository.

3. What We Hope to Take Away

We want to return to Córdoba with three things: a validated BeamScan Atlas proving that particle beams can classify materials non-destructively; the experience of designing, running, and analysing a real experiment at a world-class facility; and a story to share. If students from Argentina can use a CERN beamline to help solve recycling challenges and study their country's archaeological heritage, it shows that fundamental physics belongs to everyone. We will share our results with local recycling cooperatives, schools, and museums and publish everything openly so others can build on our work.

Outreach Activity

Before submitting this proposal, our team organised a “Physics Meets the Street” event at a recycling cooperative in Córdoba. We brought samples of different plastics and demonstrated, using simple density sorting and light-transmission tests, how difficult it is to distinguish PE from PP or to detect PVC contamination by eye. We explained our BL4S idea: that accelerator particles can “see” the atoms inside a material, not just its surface. Workers were fascinated that CERN science could connect to their daily sorting challenges.

If selected, we will expand this into a bilingual workshop series: “Del acelerador al reciclaje” (From the Accelerator to Recycling). We will bring our BeamScan Atlas to schools and cooperatives across Córdoba, explaining the physics behind each data point. We will publish the Geant4 simulation and Spanish-language tutorials so students across Latin America can run their own predictions and extend the atlas with new materials.