



# BeamScan

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

**Los Topos Cósmicos** · Instituto San Francisco de Asís  
Santa Rosa de Calamuchita, Córdoba, Argentina 🇦🇷

*BL4S 2026 · Project Briefing for Teachers*

# What is BeamScan?

## The Idea

Shoot a beam of particles (protons, pions, electrons) through a thin slab of material.

**Measure how much the beam spreads out** — Multiple Coulomb Scattering (MCS).

Different materials scatter differently → each gets a unique "fingerprint."

● **Non-destructive:** the sample is untouched.

## Two Real-World Applications

### **Recycling**

Detect PVC contamination in mixed plastic waste — a critical quality-control problem for cooperatives in Córdoba.

### **Heritage Science**

Classify geological materials in Comechingón *morteros* — 2,000-year-old stone tools that cannot be destroyed for analysis.

# The Physics — Multiple Coulomb Scattering

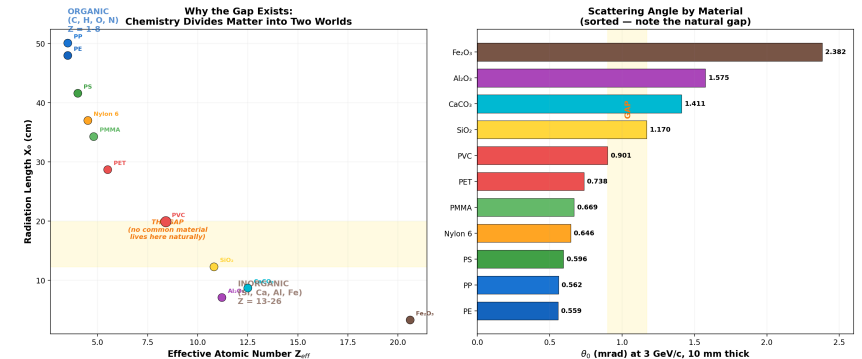
When a fast particle passes through matter, it bounces off atomic nuclei many times.

**Heavier atoms (higher  $Z$ ) → more scattering → wider beam spread.**

The Highland formula gives the expected spread:

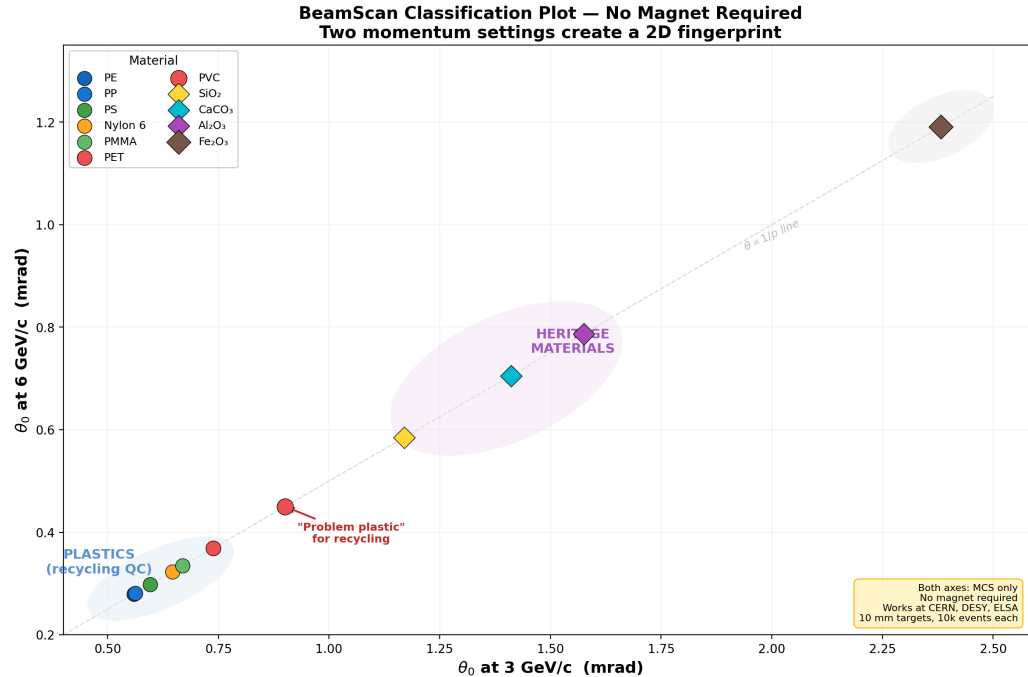
$$\theta_0 = \frac{13.6 \text{ MeV}}{p\beta c} \sqrt{\frac{x}{X_0}} \left[ 1 + 0.038 \ln \frac{x}{X_0} \right]$$

Where:  $x$  = thickness,  $X_0$  = radiation length (material property),  $p$  = momentum.



*The natural gap between plastics (C,H,O) and minerals (Si,Ca,Al,Fe) is the scientific result.*

# The BeamScan Atlas — 11 Materials, 2 Momenta



## Key Results

- ✓ 7 plastics + 4 minerals fully separable
- ✓ PVC detection needs only ~50 events (seconds of beam time)
- ✓ Full atlas in under 1 hour
- ✓ No magnet required — works at CERN, DESY, ELSA
- ✓ Two momenta provide built-in consistency check ( $1/p$  scaling)

**Geant4 validated:** G4/Highland = **1.12**  
 **$\pm 0.03$**  across all light materials

# Geant4 Validates Highland — And Reveals Nuclear Scattering

Material	3 GeV/c	6 GeV/c	Note
PET	1.097	1.090	Closest to Highland
PVC	1.101	1.108	
Nylon	1.105	1.113	
PMMA	1.112	1.111	
PP	1.120	1.122	
CaCO <sub>3</sub>	1.136	1.135	
SiO <sub>2</sub>	1.147	1.152	
Al <sub>2</sub> O <sub>3</sub>	1.168	1.168	
<b>Fe<sub>2</sub>O<sub>3</sub></b>	<b>1.397</b>	<b>1.493</b>	⚠ Nuclear scattering

## What this means

**Highland underestimates by a consistent 12%** — because it only models electromagnetic scattering.

Geant4 adds nuclear elastic + inelastic scattering, which grows with Z.

**Fe<sub>2</sub>O<sub>3</sub> is the proof:** iron nuclei (Z=26) have much larger hadronic cross-sections → 40–50% excess.

# How It's Built — Technical Architecture



## Student Input

Students write YAML request files: materials, momenta, thickness.  
No code needed — just a text editor.



## Highland CI











GitHub Actions runs Highland predictions in ~30 seconds.  
Produces plots + CSV + PR comment.  
Triggered automatically on PR.



## Geant4 CI

Full Monte Carlo simulation.

# Repository — 66 files, 100% open source

Directory	Contents	Who uses it
<code>requests/</code>	Student YAML files — material choices	 Students
<code>requests/examples/</code>	4 named examples (Lucía, Valentina, Tomás, Sofía)	 Students
<code>analysis/</code>	<code>highland_calculator.py</code> , <code>analyze_geant4.py</code>	 CI / Teachers
<code>simulation/</code>	Geant4 C++ ( <code>beamsan.cc</code> , 6 source files)	 CI
<code>scripts/</code>	<code>validate_requests.py</code> , <code>generate_macros.py</code> , <code>pseudo_mc.py</code>	 CI
<code>docs/</code>	GitHub Pages site, Physics Deep Dive, Student Guide	 Everyone
<code>results/</code>	Committed predictions, plots, G4 comparison	 Everyone
<code>.github/workflows/</code>	2 CI pipelines (Highland + Geant4)	 CI
<code>materials/</code>	<code>materials.yaml</code> — 11 materials + Graphite fallback	 Reference
<code>schemas/</code>	<code>request.schema.json</code> — validates YAML structure	 CI

# How Students Participate

Step	Action	Details
1	<b>Choose Materials</b>	Pick materials to study. <i>"I want to see if BeamScan can tell PVC apart from PE at 3 GeV."</i>
2	<b>Write a YAML File</b>	Copy a template, change materials, momenta, thickness. No programming — it's a structured text file.
3	<b>Open a Pull Request</b>	Push to a branch → open PR → GitHub Actions runs Highland predictions in 30 seconds.
4	<b>Interpret Results</b>	CI comments with plots + CSV. The student analyzes: <i>can these materials be distinguished? How many events are needed?</i>

● **Key:** Students never need to install Geant4, C++, or Python. Just a GitHub account and a text editor.

# What a Student Request Looks Like

```
# valentina_pvc_detection.yaml
author: "Valentina García"
description: >
  Can BeamScan detect PVC contamination
  in a mixed plastic recycling stream?

materials:
  - name: PE
    geant4_name: G4_POLYETHYLENE
    thickness_mm: 10
  - name: PVC
    geant4_name: G4_POLYVINYL_CHLORIDE
    thickness_mm: 10

beam:
  particle: e-
  momenta_GeV: [3.0, 6.0]

num_events: 10000
```

## What happens next

1. Student commits this file
2. Opens a Pull Request
3. CI validates the YAML
4. Highland runs in **30 seconds**
5. Bot comments with plots:
  - `distributions.png`
  - `classification.png`
  - `predictions.csv`
  - `SUMMARY.md`
6. **Student writes analysis** in their PR description

# What's Missing — Next Steps

## ● Before Submission (March deadline)

- Video (1 min): required by BL4S — team intro + experiment explanation
- Cost estimate: target materials, shipping to facility
- Team photo + teacher signatures on application form

## ● Student Activities (can start now)

- Each student picks a research question → writes YAML → opens PR
- 4 named examples already exist: Valentina, Tomás, Lucía, Sofía
- Students write analysis in PR descriptions — builds proposal portfolio

## ● Technical Hardening

- Schema caps: limit `num_events` moments, materials per request

## ● If Selected (summer/fall)

- Prepare physical target samples (deadline: 5/10/22, optional)

# Why This Proposal Stands Out



**Real Science** — Not a textbook repeat. Original classification method with validated predictions. The G4/Highland ratio analysis is genuinely publishable.



**Student-First Design** — Students participate without installing C++ or Geant4. YAML → PR → results in 30 seconds. The barrier to entry is a text editor.



**Social Impact** — Connects CERN physics to recycling cooperatives and indigenous heritage in Córdoba. Reviewers love proposals that matter beyond the lab.




**Facility-Agnostic** — Works at CERN T9, DESY, or ELSA. Adapts target list to safety rules. No magnet needed. Easy for BL4S organizers to schedule.



**Professional Infrastructure** — Los Topos Cósmicos · BL4S 2026 Public GitHub repo, CI/CD pipelines, automated

# Ready to Explore

 <b>Website</b>	<a href="https://los-topos-cosmicos.github.io/beam4school-proposal">los-topos-cosmicos.github.io/beam4school-proposal</a>
 <b>Repository</b>	<a href="https://github.com/los-topos-cosmicos/beam4school-proposal">github.com/los-topos-cosmicos/beam4school-proposal</a>
 <b>Proposal</b>	<code>PROPOSAL.md</code>
 <b>Contributing</b>	<code>CONTRIBUTING.md</code>
 <b>Student Guide</b>	<code>docs/guides/STUDENT_GUIDE.md</code>

Los Topos Cósmicos · Instituto San Francisco de Asís  
Santa Rosa de Calamuchita, Córdoba, Argentina 

*¡La física fundamental es para todos!*