🔬 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.
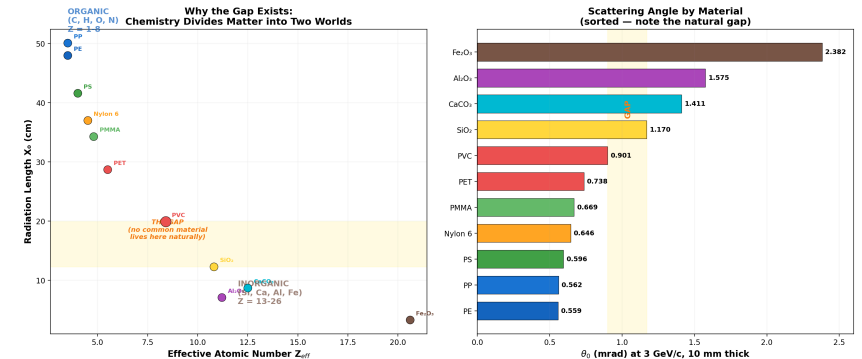
The Physics — Multiple Coulomb Scattering

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

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

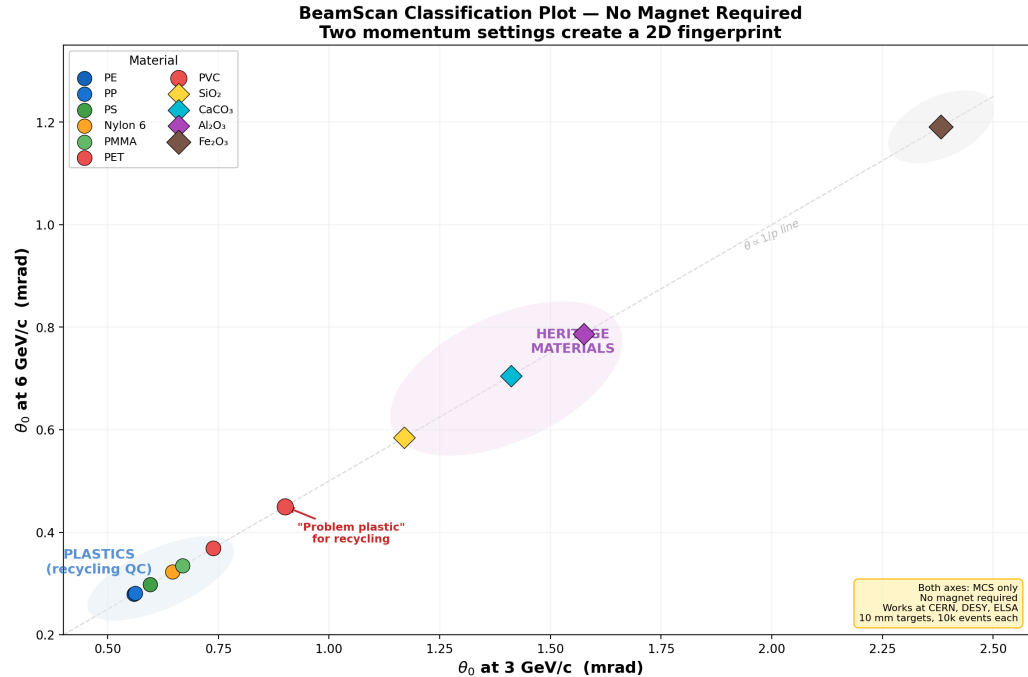The Highland formula gives the expected spread:

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

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

BeamScan Classification Plot — No Magnet Required
Two momentum settings create a 2D fingerprint

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 ± 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	
$CaCO_3$	1.136	1.135	
SiO_2	1.147	1.152	
Al_2O_3	1.168	1.168	
Fe_2O_3	**1.397**	**1.493**	⚠️ 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_2O_3 is the proof: iron nuclei (Z=26) have much larger hadronic cross-sections → 40–50% excess.

This deviation is itself a publishable result

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

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How Students Participate

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

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

What a Student Request Looks Like

```yaml
# 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

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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`

🔵 **If Selected (summer/fall)**

- Prepare physical target samples

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** — Public GitHub repo, CI/CD pipelines, automated

🔗 Ready to Explore

🌐 **Website**	los-topos-cosmicos.github.io/beam4school-proposal
📁 **Repository**	github.com/los-topos-cosmicos/beam4school-proposal
📄 **Proposal**	`PROPOSAL.md`
🤝 **Contributing**	`CONTRIBUTING.md`
📖 **Student Guide**	`docs/guides/STUDENT_GUIDE.md`

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¡La física fundamental es para todos!