2025/06/25

How might we establish a meaningful, manageable secondary school research program at SNOLAB?

Stephen Sekula (he/him/his)

Research Group Manager at SNOLAB

Professor of Physics at Queen’s University

My personal inspiration

“Jim Gates gives back”

Symmetry Magazine. Feb. 8, 2022

After **developing a mathematical toolbox during the month-long residency program**, students have the option to **work remotely in groups on long-term theoretical problems** that Gates has carved out of his own research. **“It’s authentic research,” he says. “We’re answering questions nobody in the world has answered previously.”**

Over the next several months, the students organize group meetings, fine-tune each other’s equations and check in with Gates or his colleagues if they get stuck. “But they’re the ones driving the solution to the problem,” he says, noting that **the length of the calculations they’re solving is typically what postgraduate researchers would tackle.**

Once the students finish the calculations, Gates and his research team make sure the math checks out, and then he analyzes the work—picking out the narrative theoretical threads and weaving them into publishable manuscripts. **When he publishes the papers, which he says happens about 30% of the time, he always includes his young collaborators as co-authors.**

“I wound up publishing papers with high school students—on string theory, of all things,” he says.

SMU Electron Ion Collider theory/experiment study group, summer 2021

In total, I worked with 5 high school students at SMU. Some snapshots.

- **Sahil J.:** supervised his research project on computational astrophysics for the Frisco Independent School District Integrated Study and Mentorship Program. Now an AI engineer at Sony AI.
- **Jackie B-R:** shadowed me for a day at SMU to see what academic life is like. BSc at University of Texas-Arlington, research with NEXT/Ben Jones. Now a PhD candidate at Yale University on SIMPLE and QuIPS w/ David Moore.
- **Justine C:** developed reconstruction strategy for Muon-Ion Collider (MuIC) project using event display and simulations. Now studying Anthropology and Linguistics at Columbia University.
- **Pavan A.:** was in 8th grade when he started working with me. Developed missing energy approach on EIC study. Has since conducted research at Rice University while in high school.
- **Michelle B:** sat in on my Honours Physics class, including working on team project. Studying mechanical engineering at University of Texas.

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Higgs Production and $H^0 \to c\bar{c}$ at a Future Muon-Ion Collider

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We investigate the production of Higgs bosons in neutral- and charged-current interactions at a future Muon-Ion Collider (MuIC) with emphasis on $H^0 \to c\bar{c}$ decay. In particular, we focus on the leading production mechanisms and explore the impact of a range of Parton Distribution Function (PDF) scenarios, with emphasis on the role of heavy intrinsic quark flavor. We emphasize estimates of non-resonant di-charm background production and explore the impact of this background on a possible future measurement of $H^0 \to c\bar{c}$ at a future Muon-Ion Collider facility.

I. INTRODUCTION

The Electron-Ion Collider at Brookhaven National Laboratory [1, 2] will open an entirely new window on hadron structure through the use of high-intensity, high-energy electron and ion collisions. A recent proposal for later upgrading the EIC to a Muon-Ion Collider (MuIC) has been presented [3] and a case is being built within the community for such an upgrade path beyond the nominal EIC program [4]. A MuIC would not only provide a useful step forward toward the eventual idea of a dedicated muon collider, but itself would facilitate a novel physics program that complements the High-Luminosity Large Hadron Collider (HL-LHC) and other future accelerator complexes (c.f. Ref. [5]). In particular, the center-of-mass energy possible in such a machine would facilitate a program that includes Higgs physics.

In this note, we explore in additional detail the production of Higgs particles at such a collider. We focus specifically on $H^0 \to c\bar{c}$ and di-charm production that would serve as a background to the Higgs reconstruction. The decay $H^0 \to c\bar{c}$ is a key part of the ongoing LHC program (c.f. Refs [6, 7]) but poses a challenge in the LHC proton-collider environment. Mechanisms for production of the Higgs boson at a lepton-hadron collider are well-understood in the context of past such collider studies. A MuIC operated at, for example, a reasonable center-of-mass energy ($E_\mu = 960$ GeV, $E_p = 275$ GeV, $\sqrt{s} \approx 1000$ GeV, achievable without a complete overhaul of the EIC complex) would allow for single-Higgs production dominated by charged-current (CC) and neutral-current (NC) deep-inelastic scattering (DIS) involving light-flavor quarks. This is illustrated in Fig. 1.

The cross-sections for the above processes were estimated in Ref. [4] for a 960 GeV × 275 GeV muon-proton collider. Estimates were made at leading order (LO) in the matrix element and next-to-leading order (NLO) in the parton distribution function (PDF). The matrix element was computed using MadGraph 3.3.1 and the `sm-no_b_mass` model (a "five-flavor scheme" in which the quarks contributing to the proton are assumed to all be massless except the top quark). The PDF set used was `PDF4LHC15_nlo_mc_pdfas`. A number of kinematic selections are set implicitly by MadGraph; these are disabled (e.g. the minimum jet p_T is set to 0 instead of 20 GeV, etc.). For certain processes (c.f. Section II C) we do employ generator-level kinematic criteria.

For zero beam polarization, the authors of Ref. [4] determined the CC (NC) DIS cross-section to be 65 fb (12 fb). In addition, the authors did a dedicated simulation of a top-associated Higgs production channel that is strongly influenced by the bottom quark content in the proton and the modeling of the proton's gluon content (which can lead to $g^* \to b\bar{b}$ splitting). They estimated the cross-section for this process (Fig. 2) to be 0.0158 fb (also at zero polarization).

The authors of the study also estimated the uncertainties associated with these production mechanisms owing to the scale and the combined PDF and α_s uncertainties. They estimated the scale uncertainty in the CC and NC DIS processes to be at the level of 6% and the combined PDF and α_s uncertainty to be at the level of 1%. For the top-Higgs associated production mechanism, these were estimated to be at the level of $1-2\%$ and 14%, respectively.

In this note, we reproduce some of the key results in

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A Solid-State Cloud Chamber for Science and Outreach

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Abstract:

This document presents a comprehensive overview of the steps to build a Solid-State Cloud Chamber, also known as a Peltier Thermocooler Cloud Chamber originally developed at Siena College. The following includes the step by step guide including our modifications, suggested modifications, ideas for future enhancements, development, and build notes, for the build of this specific cloud chamber.

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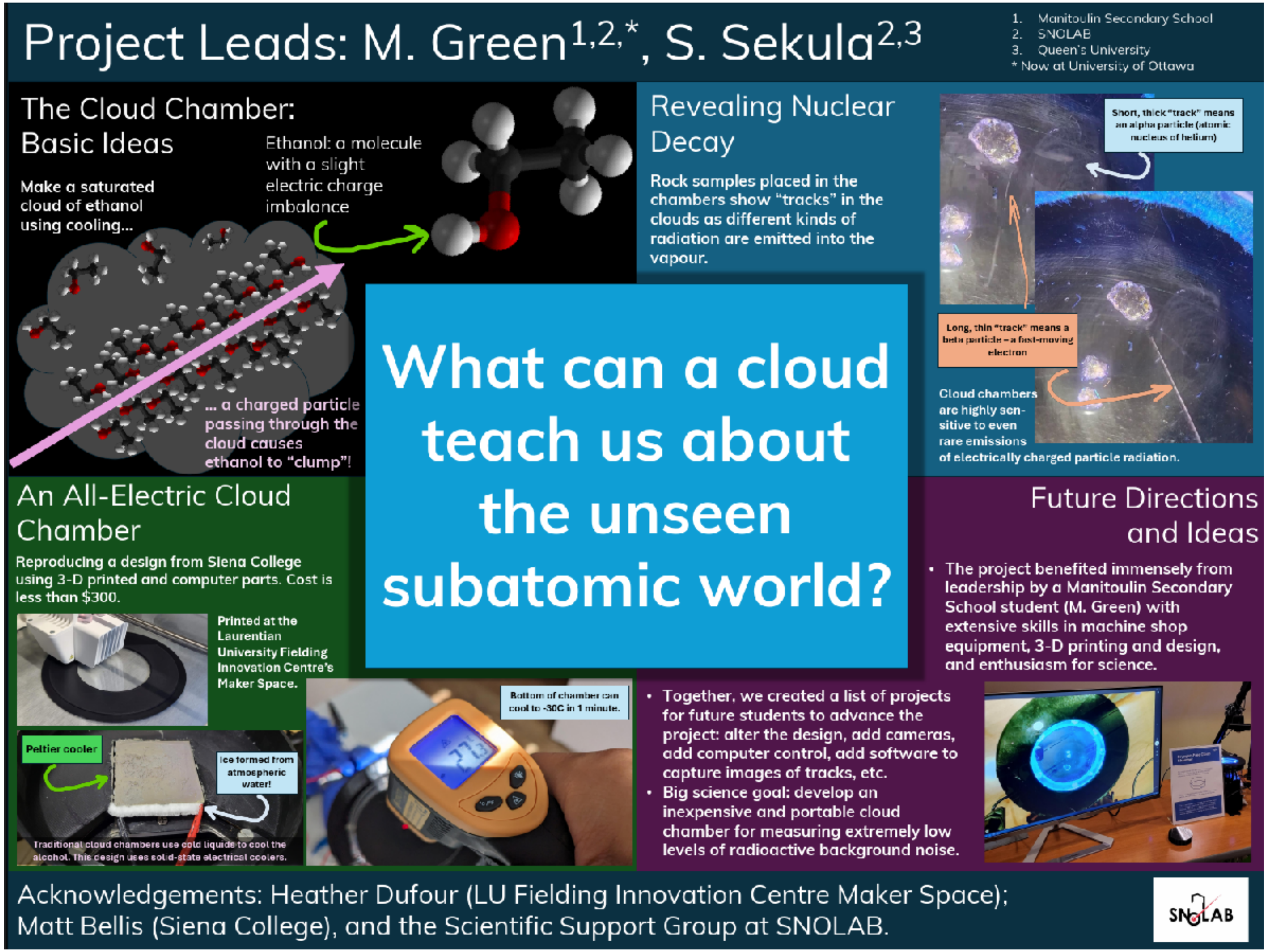


<u>Trialing high school student research at SNOLAB in 2024-2025:</u>

- Morgan Green (2024): reproduce a solid-state cloud chamber build. Now at University of Ottawa.
- 2025 (starting soon): Xavi Mara (Manitoulin) and Zoe Shipp-Wiedersprecher (Kingston)

My Personal Framework

- High school students should be given real research opportunities with the strong potential of a meaningful deliverable (e.g. paper, report, publication)
- We should aim to recruit from schools where students are interested in science, technology, engineering, and mathematics **<u>but do not have enough opportunities</u>** to pursue the subject (e.g. are significantly under-served or underrepresented in STEM in some/all ways)

DISCUSSION

Challenges

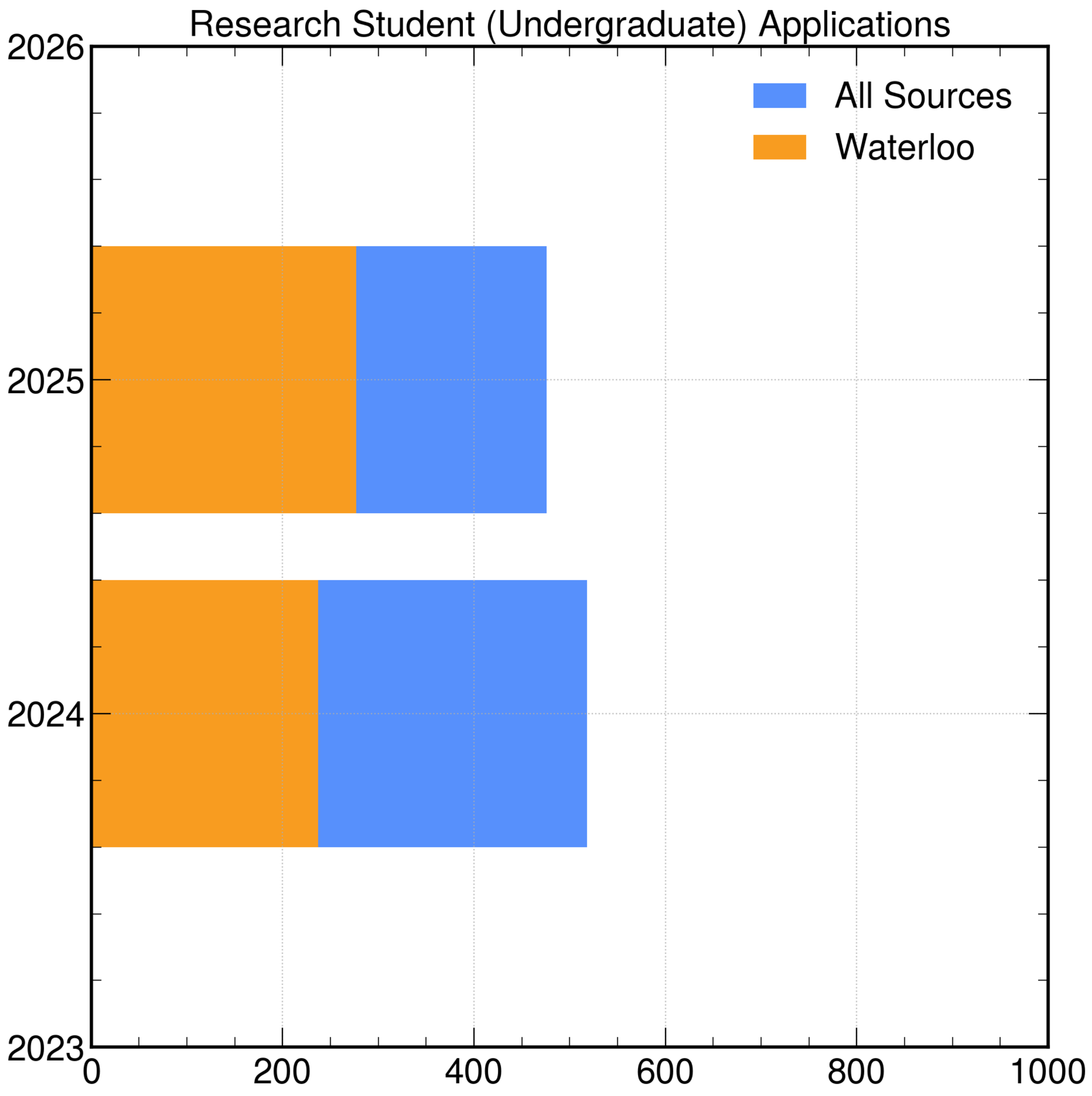
- Site access
  - Must be 18+ to work at Creighton Mine site.
  - We must be honest with students who will not be 18 in summer term that they will be based at Laurentian University, with *perhaps* only a tour opportunity at the lab (must be carefully pre-arranged through Corporate Services)
- Duration of Appointment
  - Early July – Late August: 2 months maximum, typically.
  - Must have a well-thought-out project
- Volume of Applications
  - We need to shape the program to avoid being overwhelmed with applications we are not really interested in and/or capable of processing.

Opportunities

- Impact
  - The SEEDLING program recognized as its foundation that major losses in future STEM leaders occur at the grade 4-8 level. This program could help provide an additional positive “kick” forward in the next stage (9-12)
- Enthusiasm
  - Secondary school students seeking these opportunities are generally extraordinarily enthusiastic about the chance to do meaningful work at SNOLAB, a major institution.
- Future Impacts
  - Cultivates a new population of students who might recommend SNOLAB to peers or apply later in university, work in graduate school (etc.), and/or work her as post-graduate professionals

Undergraduate Application Statistics

- Note: hiring cycles for 2025 (fall) are NOT complete.
  - 2025 already at nearly same levels as 2024 before fall hiring cycle closes.
  - 2025 fall data NOT included.
- The student hiring team has done an excellent job of managing a difficult and growing process.
  - Still working to identify the best process that manages application load to a world-class lab with time commitments of hiring staff.



Possible Scopes for Recruitment

- SEEDLING (Science and Engineering Experiments at Depth – LearnING) at SNOLAB Program
  - Aimed at grades 4-8, led by Education and Outreach (funded through NSERC PromoScience program)
  - Target encouragement to apply for SNOLAB program to the 8th graders, who will be 9th graders next year!
- McDonald Institute and other Partner Institutions
  - They have pre-existing relationships with many under-served schools and communities
- Leverage our own connections
  - Through Morgan and Xavi, I am personally aiming to develop a relationship with Manitoulin Secondary School, but one-offs are risky. Whatever we do, establish sustainable pathways.