Title: Alumni Stories: Stefania Gori

Speakers: Stefania Gori

Collection/Series: Beyond Perimeter - Alumni 25th Anniversary Event

Date: September 24, 2025 - 7:30 PM

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Abstract:

Title: The Next Frontiers of Particle Physics: Linking Theory, Experiment, and Other Disciplines

Abstract: Particle physics stands at a pivotal moment. While high-energy colliders have long been the primary tool for discovery, new ideas and technologies are opening complementary paths. In this talk, I will survey some of the most pressing open questions in particle physics, including the nature of dark matter and the possible existence of axions. I will highlight recent developments that bridge theory with experiment, such as the DarkQuest beam-dump experiment at Fermilab (that I started developing as a postdoc at Perimeter), novel dark matter detection strategies using condensed matter systems, and the potential of quantum sensing and gravitational wave observatories to probe dark sectors. This interdisciplinary perspective reflects a broader shift in the field: breakthroughs are increasingly likely to emerge from the interplay of particle physics with other disciplines. I will also reflect on my own journey, from a postdoc at Perimeter Institute to a professor leading a research group at the University of California, Santa Cruz, emphasizing how creativity, cross-field connections, community engagement, and mentoring are shaping the next frontiers of discovery.

The Next Frontiers of Particle Physics: Linking Theory, Experiment, and Other Disciplines

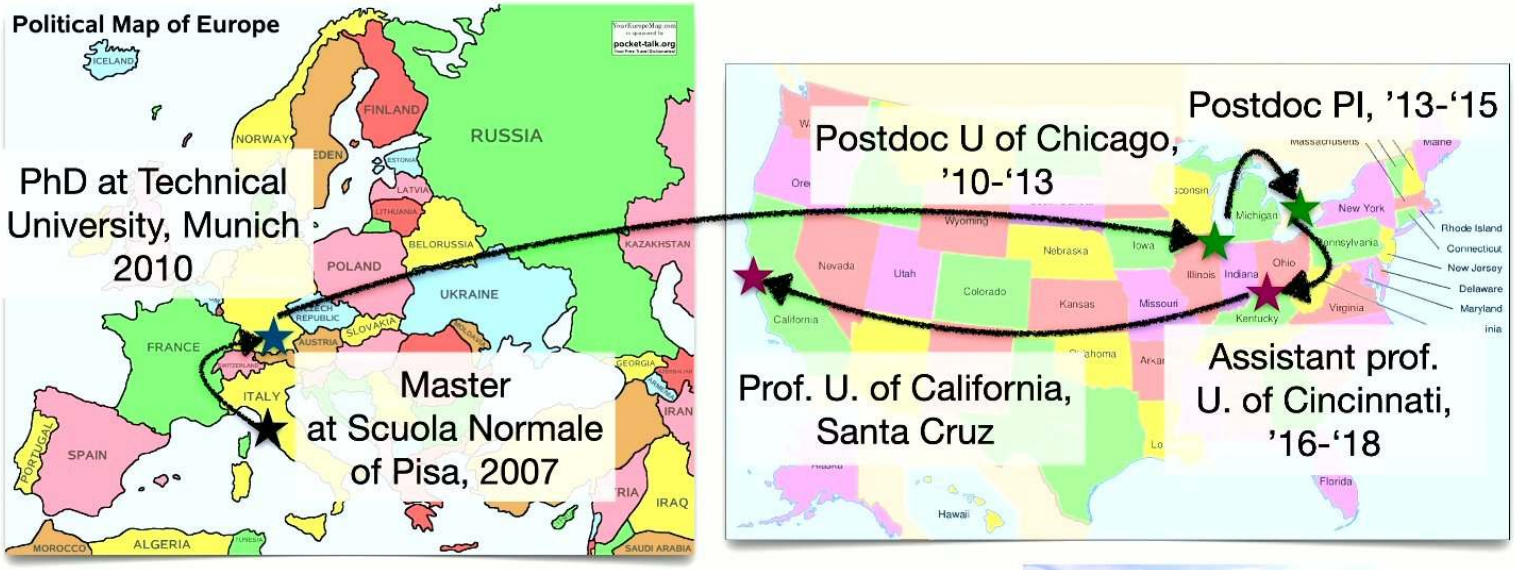
Stefania Gori
University of California, Santa Cruz

Beyond Perimeter - Alumni 25th Anniversary Event
Perimeter Institute for Theoretical Physics

September 24, 2025

About me

I am an Italian theoretical particle physicist working on beyond the Standard Model (BSM) theories



★ **Hometown** (Fornacette…a ~6000 inhabitant town between Pisa and Florence)

My research at Perimeter

Before joining Perimeter in 2013,
my focus was on Higgs and LHC physics, flavor physics
This was the time of the Higgs discovery! July 2012

At Perimeter: many open questions about the Higgs boson
- is the Higgs the only source of electroweak symmetry breaking?
- does the Higgs have flavor violating couplings?
- does the Higgs have "exotic decays"?

PHYSICAL REVIEW D **90,** 075004 (2014) By now, 500+ citations

Exotic decays of the 125 GeV Higgs boson

David Curtin,[1,a] Rouven Essig,[1,b] Stefania Gori,[2,3,4,c] Prerit Jaiswal,[5,d] Andrey Katz,[6,e] Tao Liu,[7,f] Zhen Liu,[8,g] David McKeen,[9,10,h] Jessie Shelton,[6,i] Matthew Strassler,[6,j] Ze'ev Surujon,[1,k] Brock Tweedie,[8,11,l] and Yi-Ming Zhong[1,m]

New research directions while at Perimeter:
- does Dark Matter live in its own dark sectors with particles below the ~GeV scale?
- initial thoughts about the DarkQuest experiments (more later)
- do neutrinos have new beyond the Standard Model interactions?

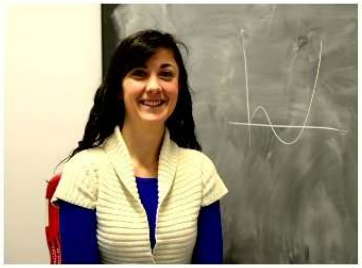
PRL **113,** 091801 (2014) PHYSICAL REVIEW LETTERS week ending 29 AUGUST 2014

Frontiers of science award
in theoretical physics, 2024

Neutrino Trident Production: A Powerful Probe of New Physics with Neutrino Beams

Wolfgang Altmannshofer,[1] Stefania Gori,[1] Maxim Pospelov,[1,2] and Itay Yavin[1,3]

My time at Perimeter
(2013-2015)



Great mentorship (M. Arvanitaki, M. Pospelov, P. Schuster, N. Toro, I. Yavin)

→ think out of the box, creativity
how to be an independent researcher

As a more senior postdoc at Perimeter, I particularly valued

What made Perimeter special

- Abundant opportunities to organize meetings and workshops
- The ability to invite collaborators
- Informal discussions with a diverse range of physicists (Perimeter bistro)
- Engaging cross-disciplinary talks and colloquia
- Social events fostering connections among theorists from different fields (Holiday parties!)
- Outreach events (talk about the Enigma Machine!)

A very stimulating intellectual environment!

My time at Perimeter
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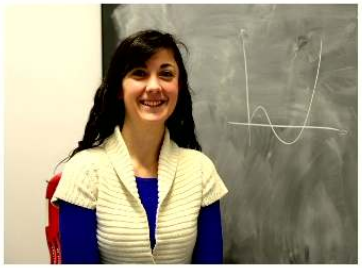

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think out of the box, creativity
how to be an independent researcher

New hobbies

New friendships

A fantastic group of postdocs
Altmannshofer, Baryakhtar, Cui,
Izaguirre, Krnjaic, Shuve, Tamarit.

Everybody got faculty jobs!

New food

New weather

April 2014

Interesting times: faculty job application period

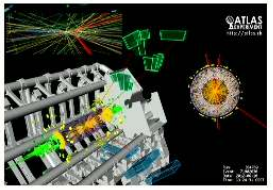
After 10 years…

I am now a full professor at the University of California, Santa Cruz

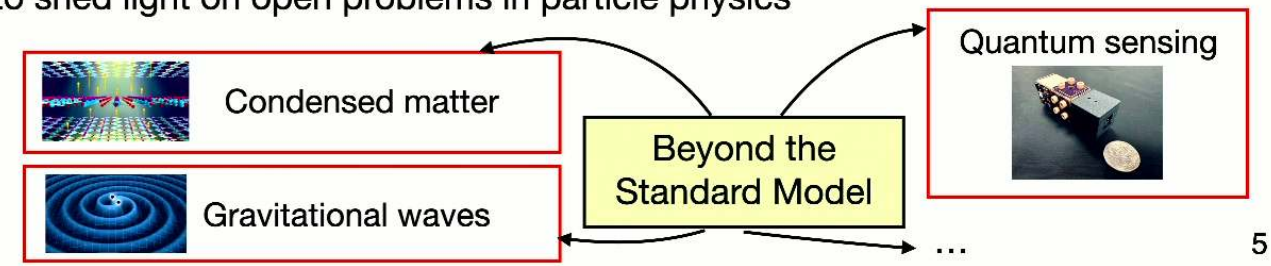
Questions that keep me up at night:

- What is the nature and origin of Dark Matter (DM)?
- Why the CP symmetry is such a good symmetry of QCD? Axions?
- Is the Higgs the only source of electroweak symmetry breaking?
- What is the origin of the baryon-antibaryon asymmetry of the Universe?

My research has been always very connected to experiments and data
(LHC, flavor factories, fixed target experiments, cosmological data, …)



Recently, I've been exploring how tools from other branches of physics
(condensed matter, quantum sensing, gravitational waves, …) can be
harnessed to shed light on open problems in particle physics



DM: past present and future

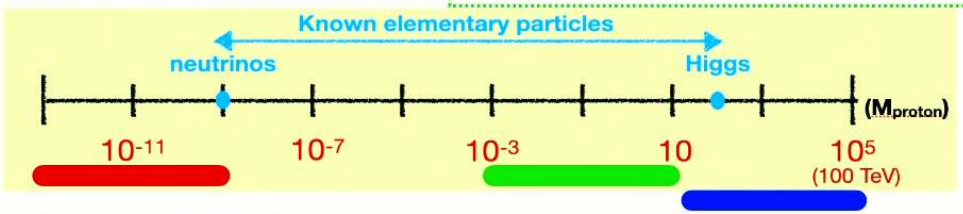
Does it have interactions with us other than gravity?

Many DM cosmological histories do require additional interactions (freeze-out, freeze-in …)

We do not know what the DM energy scale is:

Light DM in its own dark sectors

Future: Probing thermal targets?



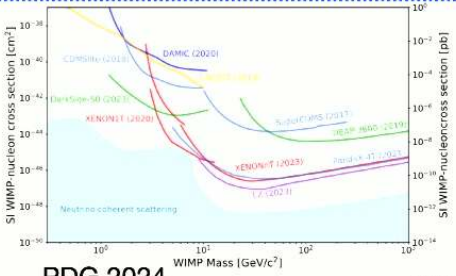
Primordial blackholes

Axions

(behave as a classical field)

Future:

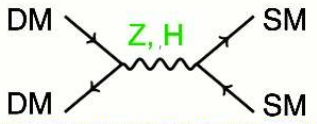
Probing extensively the QCD axion?



PDG 2024

Weakly interacting massive particles (WIMPs)

Future: Reaching the neutrino floor?



S.Gori

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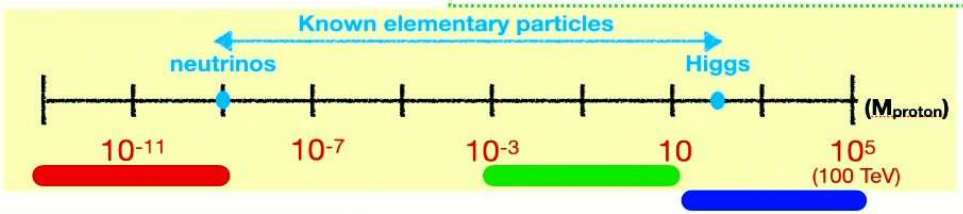

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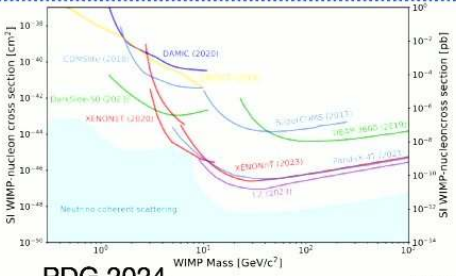

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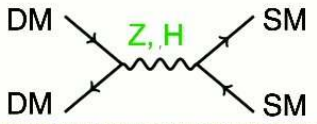
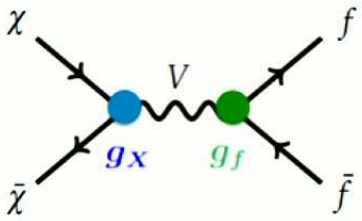


S.Gori

Theories & experiments for light dark sectors

Dark Matter in the mass range ~ (MeV - 10 GeV) can be a thermal freeze-out relic



Minimum annihilation cross section needed for a thermal relic DM candidate (to avoid overabundance):

$$\langle \sigma v \rangle^{\min} \simeq \frac{1}{10^9 \mathrm{GeV}^2}$$

Similar to WIMPs

$$\langle \sigma v \rangle \simeq \frac{16\pi \alpha_X \alpha_f m_X^2}{m_V^4}$$

$m_V \sim m_Z$, $\alpha_f \sim \alpha_w$ ⇒ $\langle \sigma v \rangle < \langle \sigma v \rangle^{\min}$ for $m_X \lesssim 1\mathrm{GeV}$

"Lee-Weinberg bound"

⇒ Light Dark Matter generically needs additional particles.

These particles need to be around the same mass as DM.

They cannot posses a charge under the Standard Model gauge symmetries (dark sector particles)

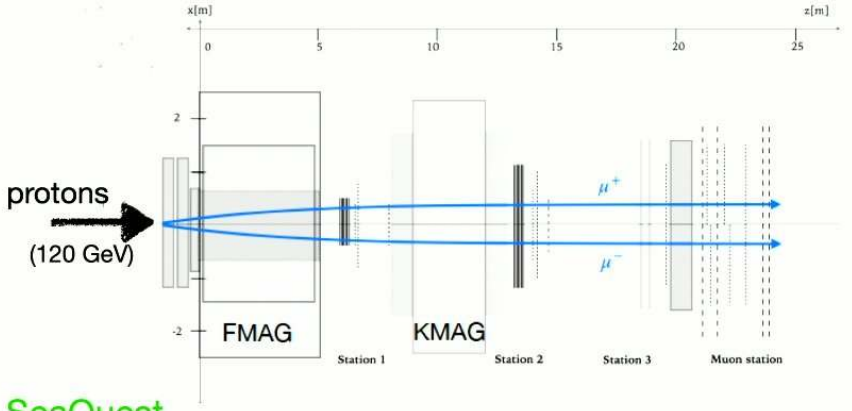
Several opportunities to discover such theories:

* indirect detection (DM annihilation products)
* direct detection (DM scattering with detectors) **2.**
* production of DM or of the dark sector particle(s) in our labs **1.**

1. The DarkQuest experiment

This is an experiment I first began thinking about during my postdoc here at PI.

Back then, the Fermilab SeaQuest beam-dump experiment was actively measuring di-muon Drell-Yan production.



SeaQuest

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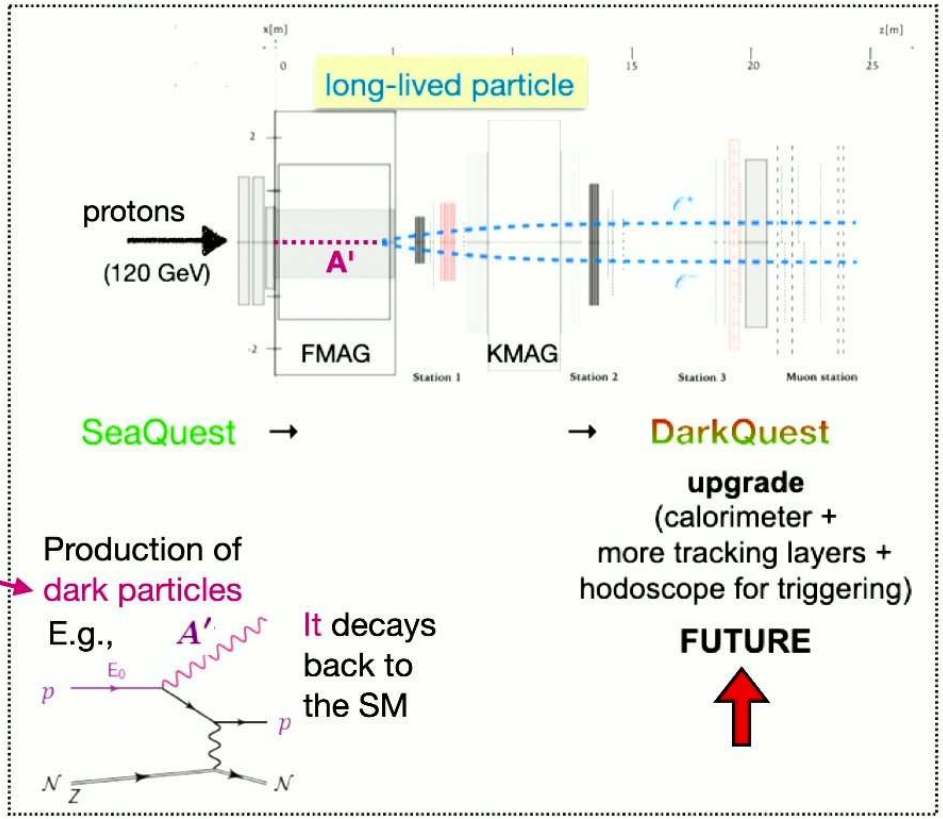
Idea: What about adding calorimetry + displaced trigger to detect displaced (and prompt) electromagnetic objects from a long-lived dark sector particle? **DarkQuest**

Berlin, SG, Schuster, Toro, 1804.00661

Now the **DarkQuest** collaboration has ~50 members

Snowmass white paper: 2203.08322
Test beam studies: 2502.20590



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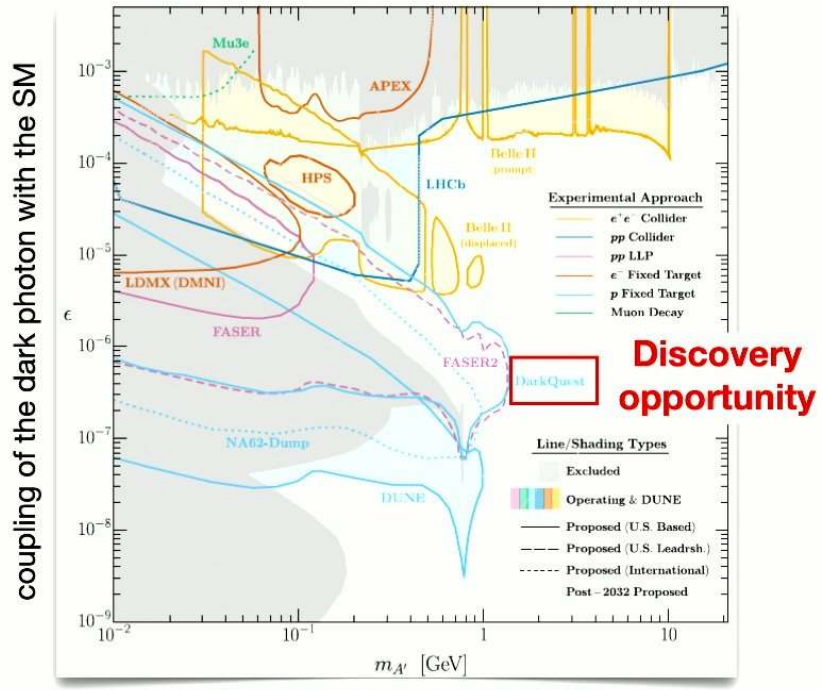
Long-lived dark photons:



Discovery opportunity

Gori, Williams et al., 2209.04671

2. DM and condensed matter

Cosmological DM comes to earth and can scatter in our detectors

This is the principle of DM direct detection experiments

Search for nuclear recoils

This experimental strategy is particularly good to search for WIMPs

$$v_{\rm DM} \sim 10^{-3} \;\Rightarrow\; E^{\rm max}_{\rm Recoil} \sim \frac{m^2_{\rm DM} v^2_{\rm DM}}{m_N} \sim 10^{-8}\, m_{\rm DM} \left(\frac{m_{\rm DM}}{\rm GeV}\right)$$

$E_{Recoil} \geq$ O(keV) in most experiments

This gives a ~lower bound on the DM masses we can probe.

Challenging to probe $m_{DM} <$ O(GeV)

Challenge

Towards a resolution…

Several novel techniques have been developed in the past few years to fill this gap (electron recoil, Migdal effect, low energy threshold detectors, …)

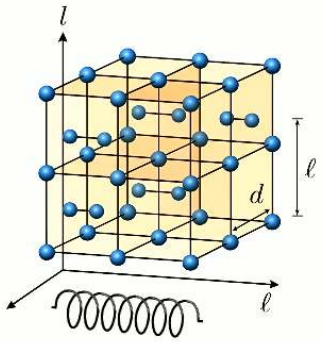
For light DM, the deBroglie wavelength > interatomic spacing

→ "Billiard ball" nuclear recoil not applicable

The DM sees more than one atom at a time

Phonon excitations

(many coupled harmonic oscillators)



Discovering DM in crystals

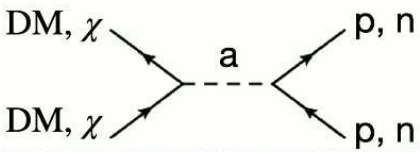
Theories where DM interacts with the Standard Model through the exchange of an axion are particularly interesting and well-motivated Dror, SG, Munbodh, 2306.03145

How to compute the DM-detector scattering rate? SG, Knapen, Lin, Munbodh, Suter, 2506.11191

$$\mathcal{L} \supset c_{GG}\frac{\alpha_s}{4\pi}\frac{a}{f_a}G^a_{\mu\nu}\tilde{G}^{a,\mu\nu}$$

axion interaction with gluons

$$\mathcal{L}_a = a\left[g_\chi \bar{\chi}\chi + g_q \bar{p}\gamma^5 p + g_n \bar{n}\gamma^5 n\right]$$



Particle physics

$$\mathcal{H}^N = -\frac{g_\chi g_N}{q_0^2 + m_{\rm med}^2} F_{\rm med}(\mathrm{q})\, \mathcal{O}\,(\mathrm{J}_\chi, \mathrm{q}) \cdot \mathrm{J}\, e^{i\mathrm{q}\cdot\mathrm{r}} \qquad g_N \equiv g_p f_p + g_n f_n$$

(interaction with nuclei)

$$F_{\rm med}(\mathrm{q}) = \frac{q_0^2 + m_{\rm med}^2}{q^2 + m_{\rm med}^2}$$

$q_0 = m_\chi v_0$, $v_0 = 220$ km/s

$$f_{p/n} = \frac{\langle JJ|S^{\rm tot,z}_{p/n}|JJ\rangle}{J}$$

nuclear form factors

Nuclear physics

$$\Gamma = \frac{g_\chi^2 g_p^2}{(q_0^2 + m_{\rm med}^2)^2}\frac{N}{V}\int\frac{d^3\mathrm{q}}{(2\pi)^3}|F_{\rm med}(\mathrm{q})|^2 G(\mathrm{q})S(\mathrm{q},\omega)$$

Crystal response function

$$G(\mathrm{q}) \equiv \frac{1}{3}\sum_{i_\chi} w_{i_\chi}\langle i_\chi|\mathcal{O}\,(\mathrm{J}_\chi, \mathrm{q}) \cdot \mathcal{O}\,(\mathrm{J}_\chi, \mathrm{q})\,|i_\chi\rangle$$

DM part of the rate

$$S(\mathrm{q},\omega) = \sum_d \overline{\lambda_d^2 J_d(J_d+1)} C_{\ell,d}(\mathrm{q},\omega), \quad C_{\ell,d}(\mathrm{q},\omega) \equiv \int_{-\infty}^{+\infty} dt\, e^{i\omega t}\langle 0|e^{-i\mathrm{q}\cdot r_{\ell,d}(0)} e^{i\mathrm{q}\cdot r_{\ell,d}(t)}|0\rangle$$

Condensed matter physics

Beyond research: community impact

Engaging with the broader community is essential, and it is a privilege to help shape the future directions of particle physics and beyond.

Belle-II advisory committee
(this is a e^+ e^- collider experiment at KEK, Japan)

Fermilab physics advisory committee

General Member of the Aspen Center for Physics

Beyond research: mentoring

Throughout my career, I have been fortunate to learn from outstanding mentors (R. Barbieri at Scuola Normale in Pisa, C. Wagner at the University of Chicago, and here at Perimeter: M. Arvanitaki, M. Pospelov, P. Schuster, N. Toro, I. Yavin)

Their guidance has profoundly shaped my scientific thinking and development.

Mentoring more junior scientists is deeply rewarding

on the job market this year :)

Undergraduates (K. Bartel, O. Jackson, K. Luong, …), Ph.D. students (D. Tuckler, N. Hamer, P. Munbodh, …), & postdocs (B. Shakya, D. Robinson, J. Dror, R. Balkin, P. Asadi, …) now thriving in academia & industry. faculty at DESY; faculty at Berkeley; faculty at U. of Florida

Teaching at UCSC, summer schools (TASI, SLAC, ICTP, TRISEP, …), and **Perimeter PSI master's program** has enriched my experience in mentoring. Thanks to online recordings (many available on YouTube) these lectures have reached a remarkably broad and global audience.

As scientists, we have the opportunity to serve as role models and to contribute, even in small ways, to improving the society we live in.

Concluding remarks

Particle physics is entering an era where interdisciplinary approaches are more and more important. Complementary with present and future high energy colliders.

The most exciting discoveries may come from unexpected directions by connecting theory, experiment, and other physics disciplines.

Mentorship, collaboration, and community engagement are as important as the research itself for shaping the future.

The journey is as rewarding as the breakthroughs: passion, resilience, and curiosity are the keys.

Since my time as a postdoc at Perimeter, particle physics has been characterized by a decade of remarkable advances.

I am excited to uncover and advance the discoveries that lie ahead in the decade to come.

Past decade

New decade