

# The Life of a 25-year-old Physicist: Navigating High Energy Physics with My Core Values at Heart

Savanna Rae Starko

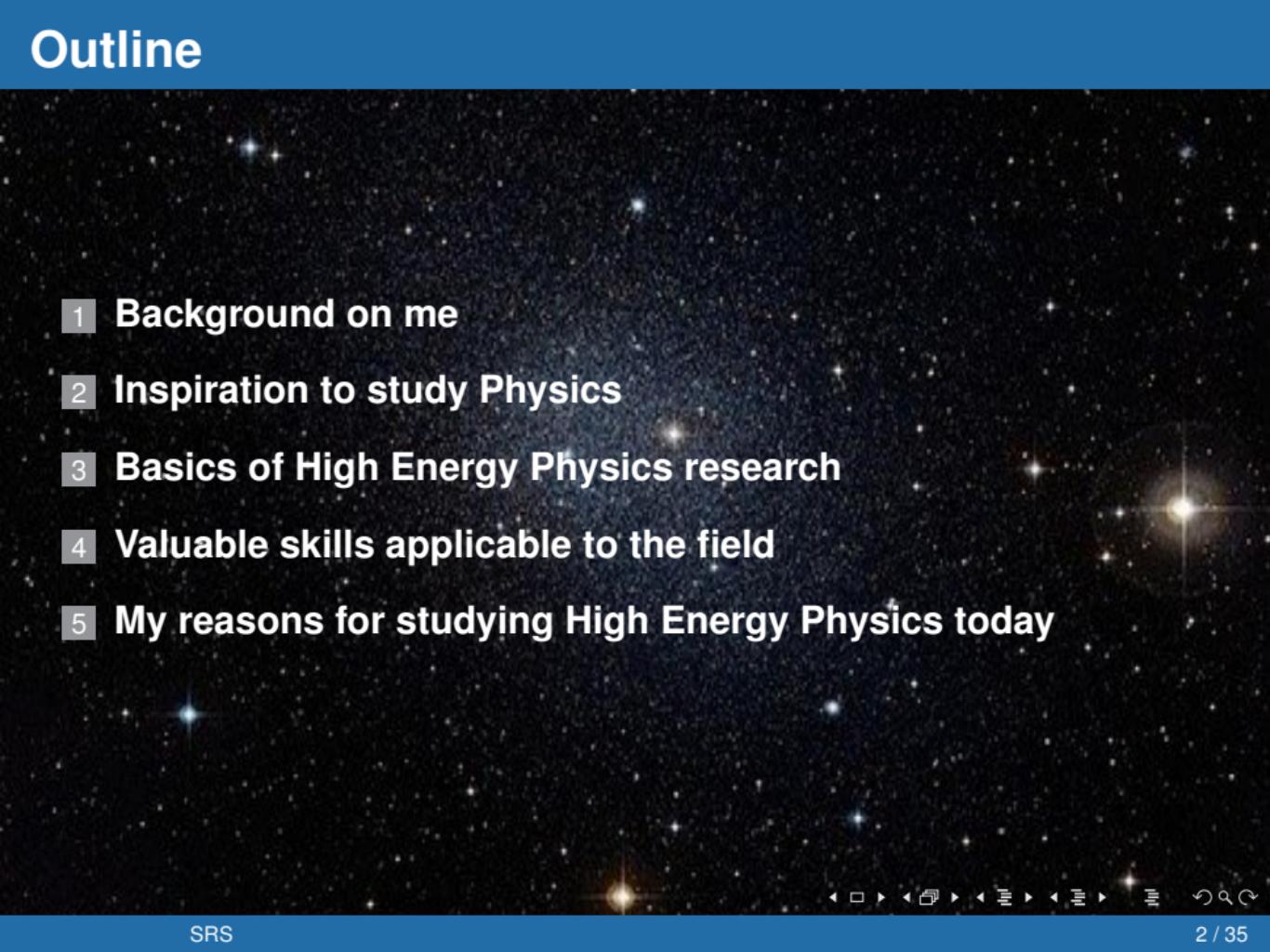
June 24, 2019



VANDERBILT  
GRADUATE SCHOOL



# Outline

- 
- 1 Background on me**
  - 2 Inspiration to study Physics**
  - 3 Basics of High Energy Physics research**
  - 4 Valuable skills applicable to the field**
  - 5 My reasons for studying High Energy Physics today**

# The House That Built Me



# About Me: Education

- Attended Moon Area High School in Moon Twp., PA
- May 2016: graduated from Washington and Jefferson College (Washington, PA) with majors in Mathematics and Physics
- August 2016: started graduate school at Vanderbilt University
- January 2017: became a Research Assistant in High Energy Physics
- April 2018: became a Graduate Research Fellow of the National Science Foundation
- May 2018: passed Vanderbilt's qualifying exam to officially become a PhD candidate
- May 2020: running away with the PhD, barring no major catastrophes

# Inspiration to Study Physics

"SCIENCE INVESTIGATES; RELIGION INTERPRETS. SCIENCE GIVES MAN KNOWLEDGE, WHICH IS POWER; RELIGION GIVES MAN WISDOM, WHICH IS CONTROL. SCIENCE DEALS MAINLY WITH FACTS; RELIGION DEALS MAINLY WITH VALUES. THE TWO ARE NOT RIVALS."

- DR. MARTIN LUTHER KING JR.



- I've always been inquisitive.
- Both science and religion leave us asking 'the big questions.'
- Personally, I don't believe we'll ever understand how the universe was divinely intended to function.
- High Energy Physics can get us closer to the answers we desire (often by exclusion).

# The Law of Conservation of Energy

Energy can neither be created nor destroyed; it can only alter forms.

LIFT UP YOUR EYES ON HIGH AND SEE:

**WHO CREATED THESE?**

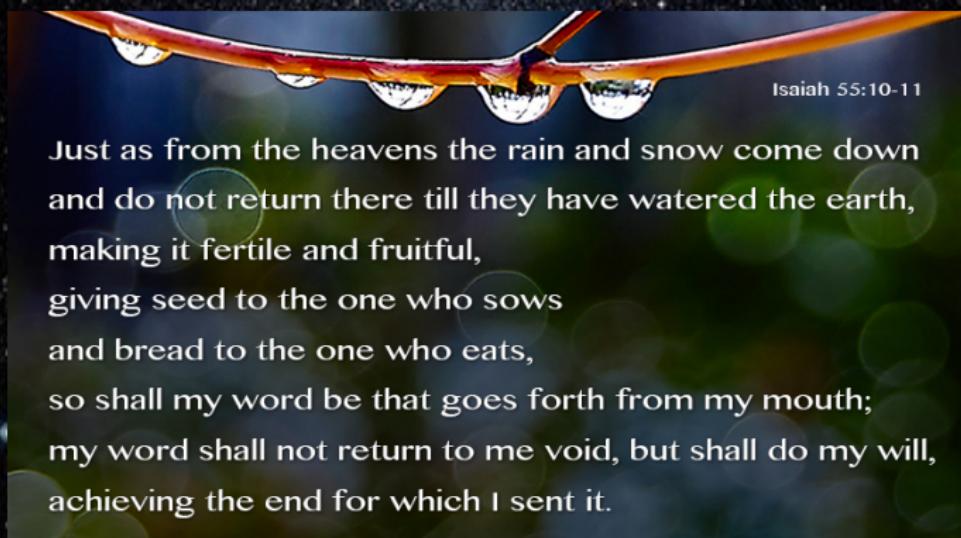
HE WHO BRINGS OUT THEIR HOST  
BY NUMBER, CALLING THEM ALL  
BY NAME, BY THE GREATNESS OF HIS  
MIGHT, AND BECAUSE HE IS STRONG  
IN POWER NOT ONE IS MISSING.

— ISAIAH 40:26 —



# Hydrology

This is the science of how the waters of the Earth are recycled.  
Until the 17th Century, people thought there were inexhaustible reservoirs of water at the center of the Earth.



# The Stars in the Sky

The Sun Has One Kind  
Of Splendor, The Moon  
Another And The Stars  
Another; And Star Differs  
From Star In Splendor.

1 Corinthians 15-41

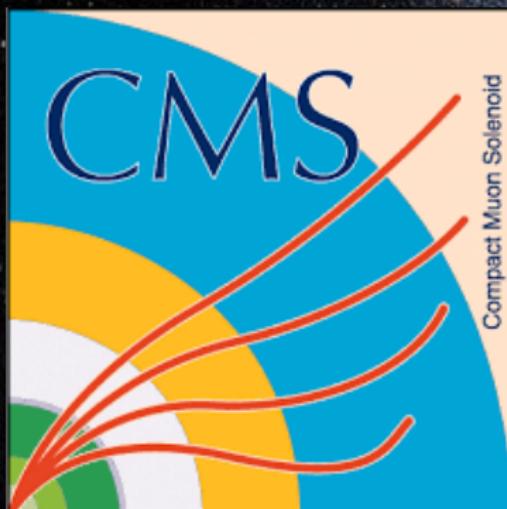
BibleWordings.com

- Astronomers today acknowledge that there are countless different types of stars.

# High Energy Physics at Vanderbilt University



## Vanderbilt **Johns / Sheldon / Webster** Elementary Particle Physics Group

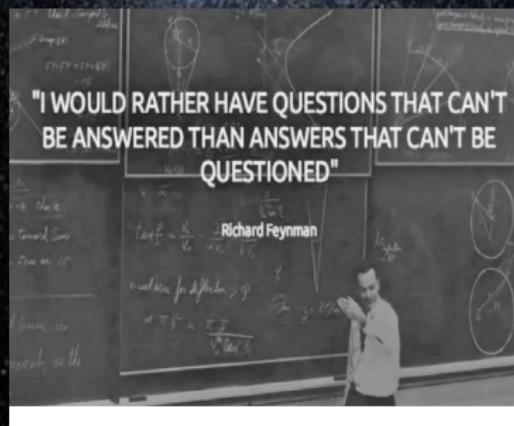


- Advisor: Dr. Alfredo Gurrola

- 3 professors
- 2 postdoctoral researchers
- 6 graduate students
- 10+ affiliated undergraduate students

# Particle Physics as a Discipline

- Particle Physics is the branch of physics that deals with the properties and interactions of subatomic particles.
- The particles of interest are fundamental in that we believe they cannot be broken down into further constituent parts.
- For me, Particle Physicists attempt to understand how this universe was divinely intended to function.

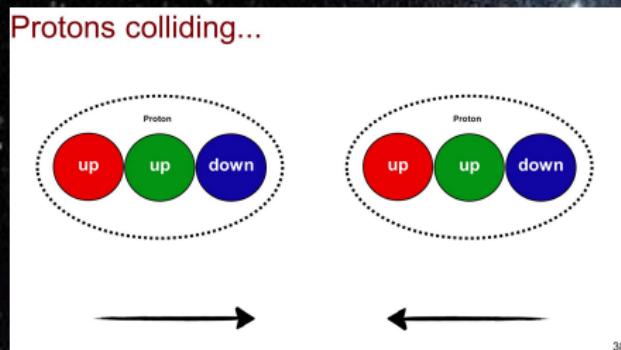


# The Status of Particle Physics

## Particle Physics...

- ...has relied on the Standard Model (SM) for the last several decades to describe particles and their interactions.
- ...connects microscopic and macroscopic scales.
- ...addresses questions of societal intrigue (ex. identity of dark matter).

Protons colliding...



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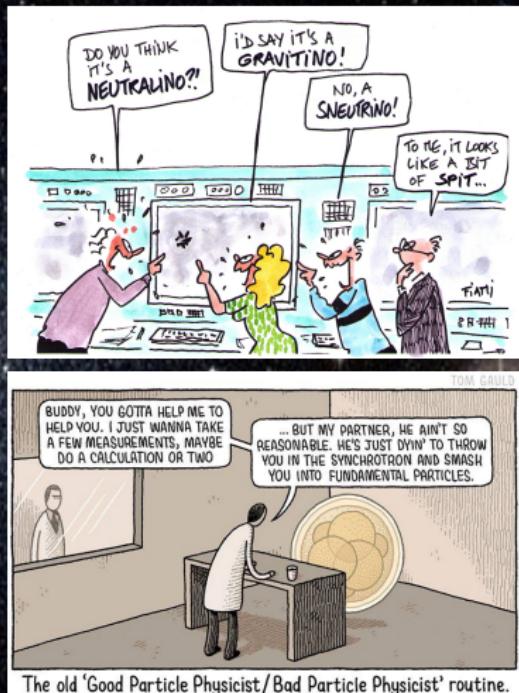
<http://slideplayer.com/slide/2720427/>

<http://bigthink.com/dr-kaku/universe-andromeda-offers-clues-into-the-formation-of-galaxies-including-our-own>

# The Shortcomings of the SM

The unresolved problems of the SM suggest its incompleteness.

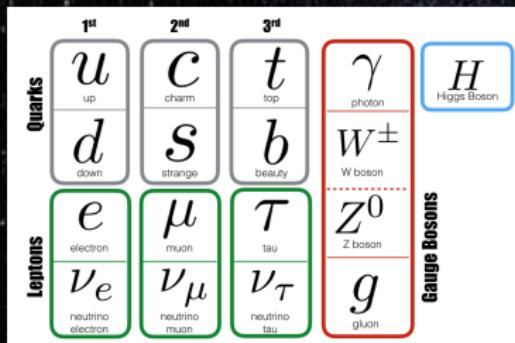
- failure to provide a dark matter (DM) particle
- failure to explain...
  - ...the matter-antimatter asymmetry in the universe
  - ...the origins of dark energy
  - ...the hierarchy problem  
(i.e. that gravity is so much weaker than the other forces)



<http://cds.cern.ch/record/1261775/files/postillonE.image.jpg>

<https://www.pinterest.com/pin/436215913894409290/?lp=true>

# The Standard Model



<http://www.physik.uzh.ch/en/researcharea/lhcb/outreach/>

- Four fundamental forces: strong, weak, electromagnetism, gravity
- Fermions: the spin- $\frac{1}{2}$  particles
  - Quarks: electric charge and color charge, electromagnetic force, and strong force
  - Leptons: electric charge ( $e, \mu, \tau$ ) and chargeless neutrinos, electromagnetic force, and weak force
- Bosons: the integer-spin particles
  - Gauge Bosons: mediators of particle interactions
  - Higgs: origins of mass
- We look at collisions at energies typical of the early universe in order to attempt to understand particles and interactions.

# The Large Hadron Collider (LHC)



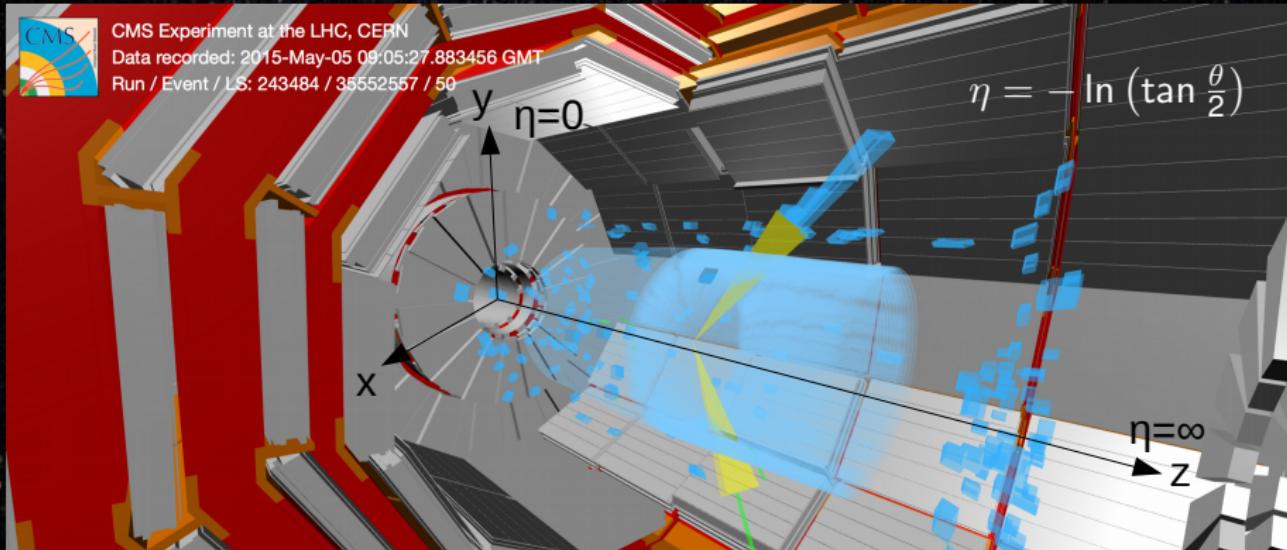
<https://sureshemre.wordpress.com/2017/06/05/updated-links-lhc-large-hadron-collider-operation/>



<http://www.extremetech.com/extreme/152326-cern-begins-lhc-upgrade-to-hopefully-change-our-understanding-of-the-universe>

- The LHC is a 27-km ring straddling France and Switzerland that accelerates protons to nearly the velocity of light prior to colliding them.
- Each proton beam has 6.5 TeV of energy.
- The beams are collided at four different locations along the ring, one of which is CMS.

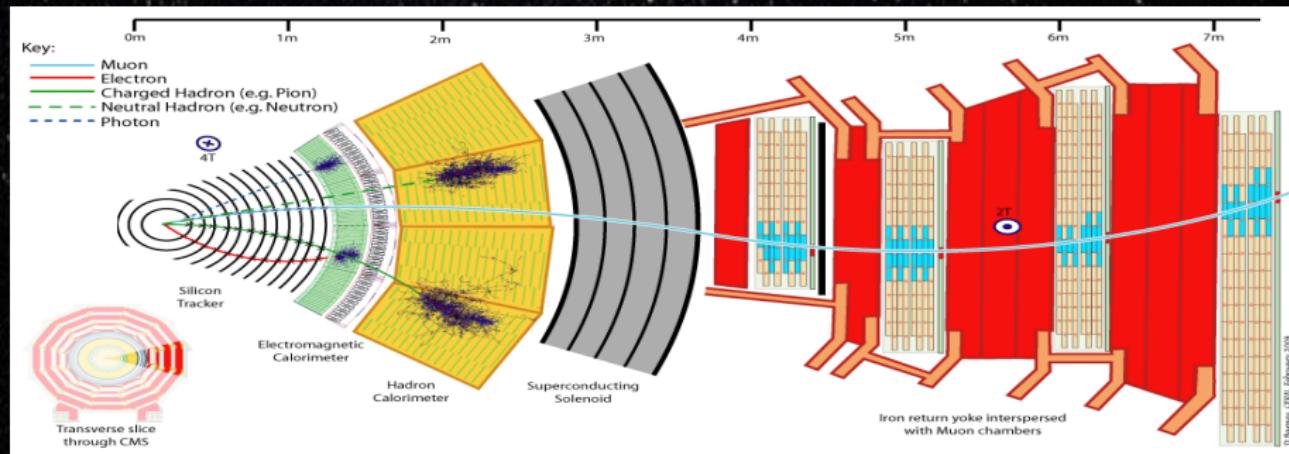
# The CMS Experiment



<http://cms.web.cern.ch/news/lhc-delivers-low-energy-collisions-cms-and-other-experiments>

- Two circulating beams of protons collide along  $z$ -axis;  $xy$ -plane is the transverse plane.
- The relativistic energy of the collision can be transferred to mass.
- CMS measures positions, momenta, and energies of resulting heavier particles.

# The CMS Detectors

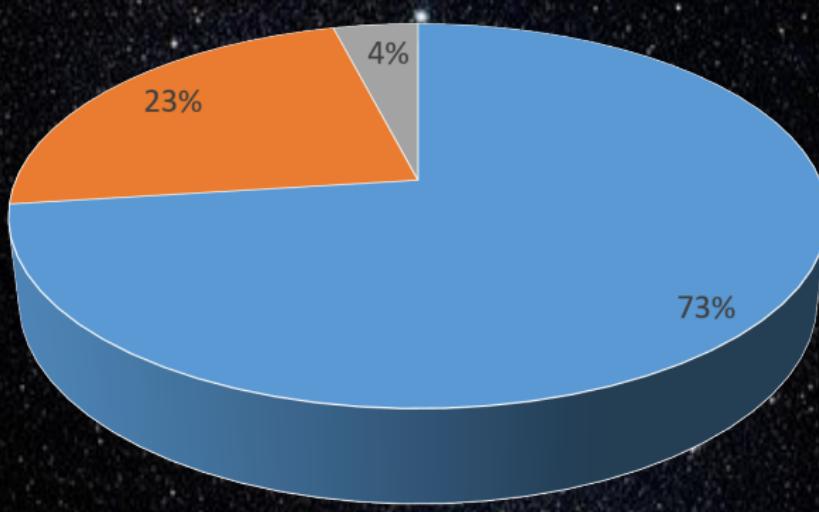


<https://cds.cern.ch/record/2205172>

- **Tracker:** trajectories from position measurements
- **Electromagnetic Calorimeter (ECAL):** energy deposits of charged particles like electrons and photons
- **Hadronic Calorimeter (HCAL):** energy deposits of hadrons (things made of quarks)
- **Muon Chambers:** signals from muons

# The Composition of the Universe

Energy Density of the Universe

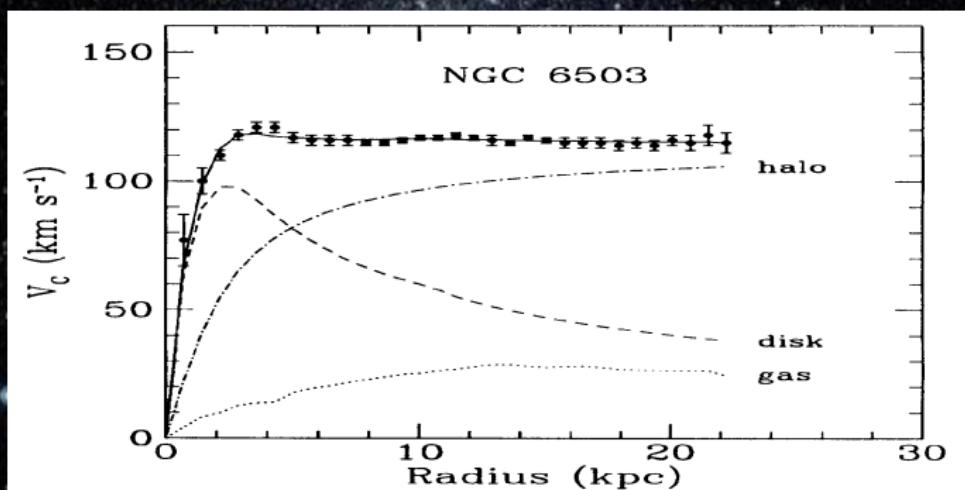


■ Dark Energy ■ Dark Matter ■ Baryonic Matter

- Baryonic matter comprises only a small fraction of our universe!
- Why don't we have a better understanding of dark matter & dark energy?

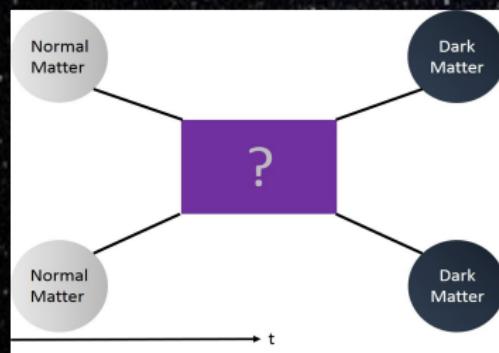
# The Necessity of Dark Matter Searches

- DM binds the stars to the galaxies and the galaxies to the universe.
- DM is crucial to our understanding of the structure and evolution of the universe.
- DM is an essential part of Big Bang Cosmology.

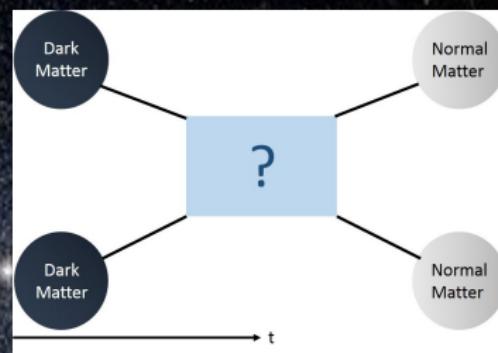


Source: [1]

# Creation & Annihilation of DM in the Early Universe



Dark Matter Creation

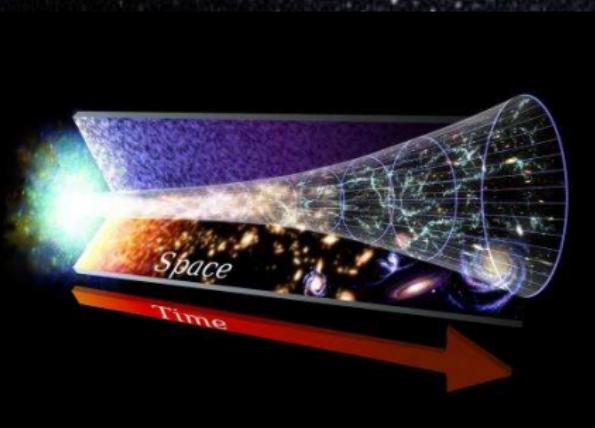


Dark Matter Annihilation

- A common theory dictates that in the early universe, dark matter could be both created and destroyed via processes above.
- Dark matter was both created and destroyed at equal rates. That is,

$$\Gamma_{\text{creation}} \approx \Gamma_{\text{reduction}}$$

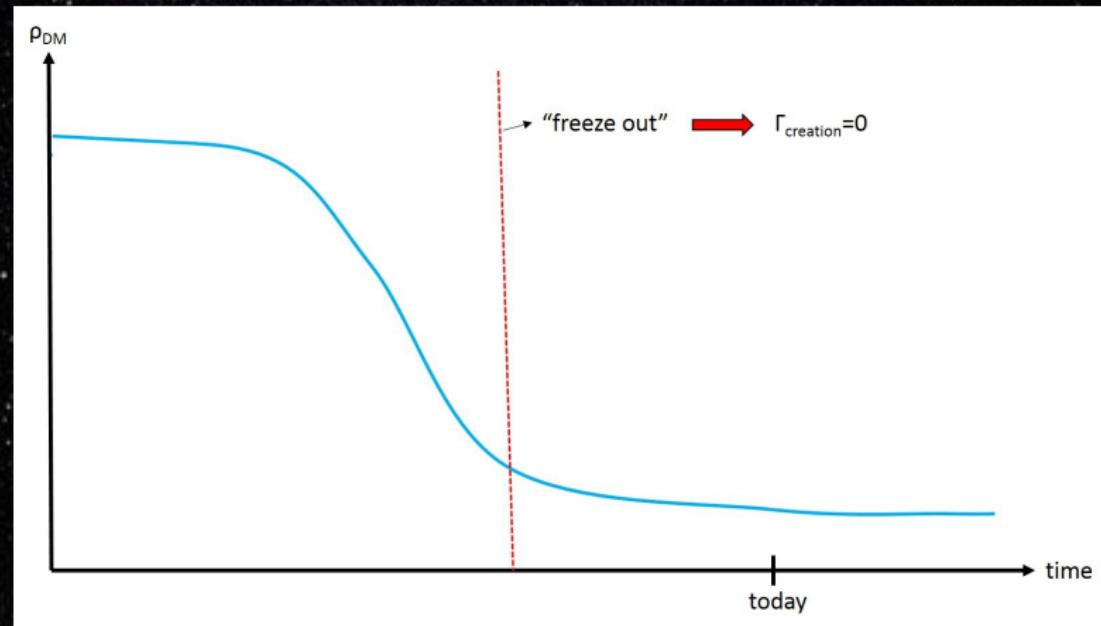
# Expansion and Cooling of the Universe



Source: [2]

- Normal matter loses kinetic energy.
- The density of dark matter ( $\rho_{\text{DM}}$ ) decreases since it is inversely proportional to  $R_{\text{universe}}^3$ .
- Eventually, the normal matter particles do not have enough total energy for dark matter creation;  
 $\Gamma_{\text{creation}} \rightarrow 0$ .
- The dark matter particles are too spread out for reduction to occur;  
 $\Gamma_{\text{reduction}} \approx 0$ .

# Dark Matter Relic Density



DM Density vs. Time

- The number of dark matter particles in the universe is roughly constant.

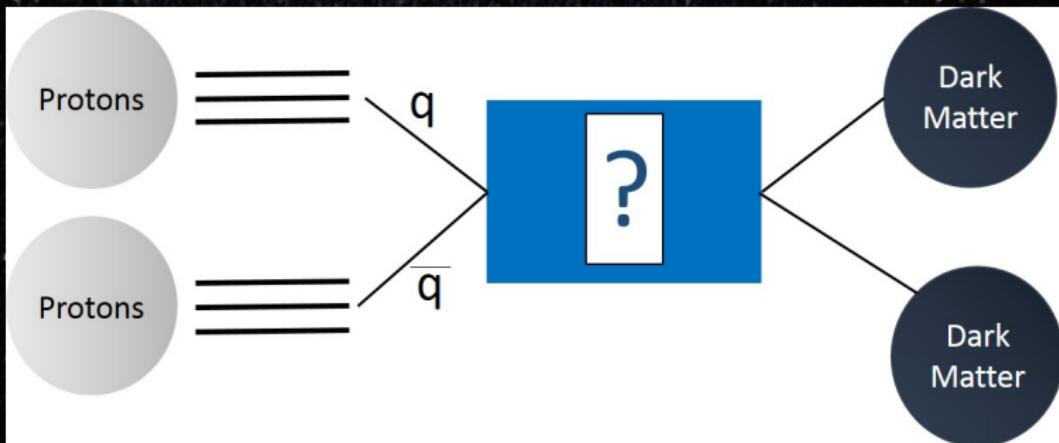
# Dark Matter Searches at the LHC



<https://www.tibco.com/blog/2016/11/16/finding-a-needle-in-a-data-haystack/>

- **dark matter particle: the needle**
- **particles produced via processes of which we already have some understanding: the hay**
- **We must firmly establish our understanding of what “hay” is and firm logic on the “needle’s” appearance. We accomplish this via simulation.**
- **Then, we will touch the real data: the real haystack.**

# Dark Matter Searches at the LHC



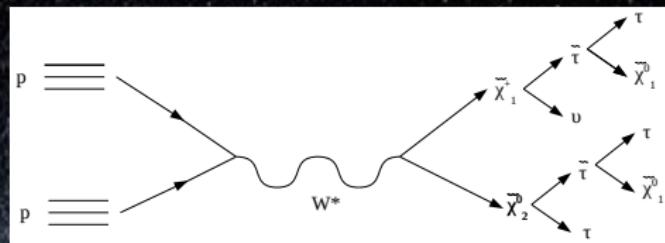
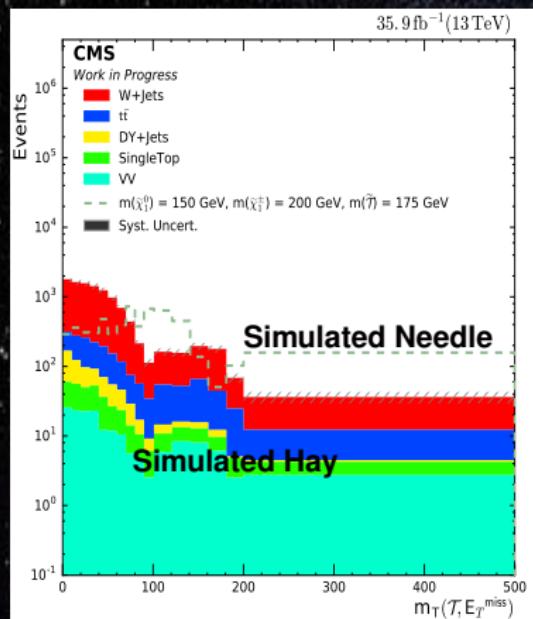
DM Production from Quark ( $q$ ) and Antiquark ( $\bar{q}$ )

- **Advantage:** This collision will produce dark matter in high abundance.
- **Disadvantage:** There are high rates of background processes.

# Example Dark Matter Search

Pheno. paper: \*DOI:<https://doi.org/10.1103/PhysRevD.94.073007>

“ISR + stau”



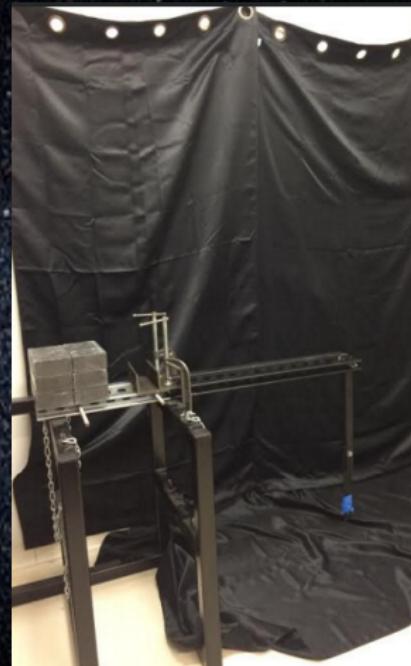
- We seek out a signal process and must differentiate it from background processes that mimic the signal.
- Primary backgrounds are in red, blue, yellow, green, and cyan: the “hay.”
- Signal cross-section is scaled by a factor of 10 for clarity: “the needle.”
- Though this analysis shows no evidence of new physics, it sets the most sensitive bounds on the mass of the  $\tilde{\chi}_1^\pm$  to date.

# Valuable Skill: Communication

- Written communication
  - Typesetting for papers
    - Learned in my 3rd semester at W&J
    - Used in my first semester of graduate school coursework
    - Use to give updates at group meetings and for publications
  - E-mail
    - Learned that e-mail sets a tone in a professional relationship
    - Consider format daily when communicating with fellow graduate students, postdocs, advisors, and international collaborators
- Oral Communication
  - Dialogue that is open and unrestricted by the fear of being wrong in conversation, class, and presentation settings

# Valuable Skill: Collaboration

- Encouragement to work together on problem sets
  - Exposes various learning styles
  - Increases efficiency
  - Teaches humble success and graceful failure
- Guidance to work together on long-term projects
  - Exposes diversity in ideas
  - Increases patience
  - Teaches division of labor



My Senior capstone at W&J: a double pendulum

# Valuable Skill: Ingenuity

UNQUOTE.li

“

We build too many walls and not enough bridges.

— Isaac Newton

IMAGE FROM UNSPLASH

<https://unquote.li/en/quotes/isaac-newton/>

## ■ Programming

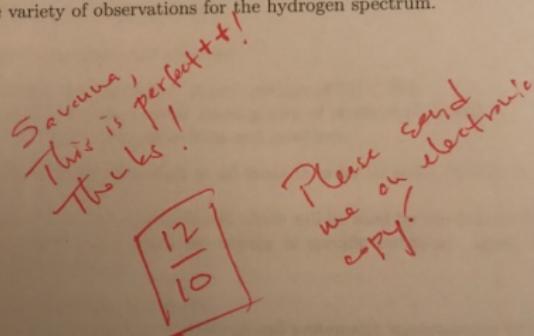
- Create faster & more efficient ways to accomplish a task
- Explore ways to visualize data
- Learn to debug errors

## ■ Problem solving in general

- Learn as you go
- Craft solutions that incorporate evolving data and a diversity of viewpoints

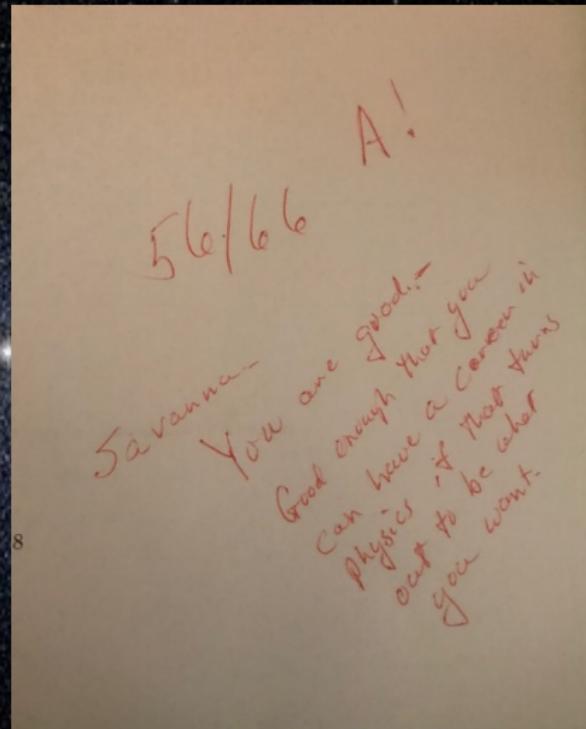
# Valuable Skill: Constant Hard Work

readings on the spectrometer for our measured angles. This was compensated for in that we took measurements in both the first and orders of the spectrum; our values were more precise when we found wavelengths for each color, as in equation 4.3. To improve this experiment could shut out all light surrounding the apparatus. This experiment was successful because we learned how Rydberg's simple formula could explain the variety of observations for the hydrogen spectrum.



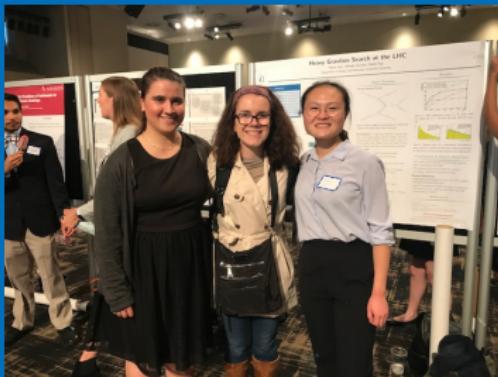
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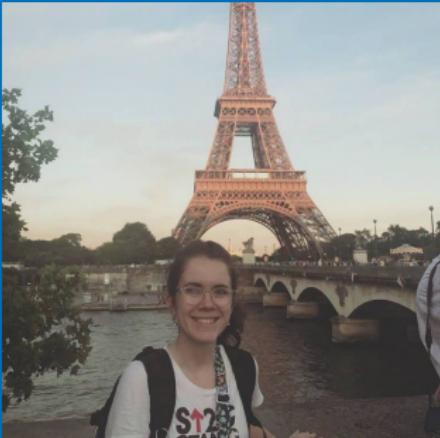


“Best of skill...” ~ my dad

*I've gotten opportunities to mentor and share my knowledge.*



*I've had many chances to travel.*



*I've acquired a wonderful extended family.*



*I still have time to be me!*



**“And though she be but little, she is fierce.”** ~ William Shakespeare

# Contact Information

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- Vanderbilt University Physics and Astronomy
  - <https://as.vanderbilt.edu/physics/graduate/degrees.php>

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