Setting limits on the Toponium cross-section, and the direct detection of dark matter

A story of a non-traditional student

Andreas Jung (Mentor)[1] David Velasco (Mentee)[2]

[1]Purdue University

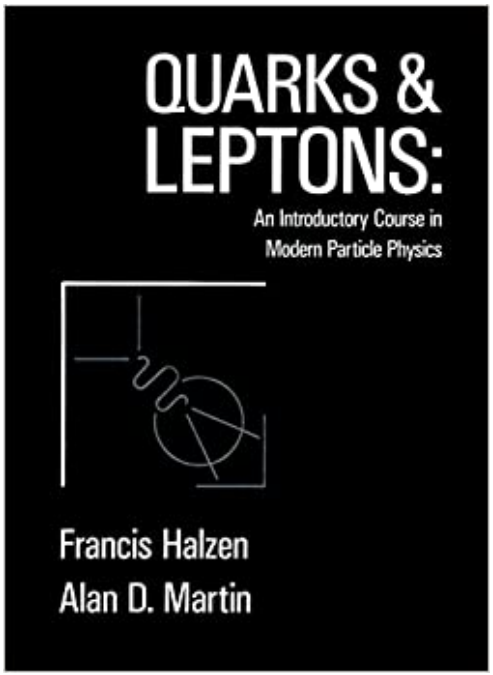
[2]DePaul University

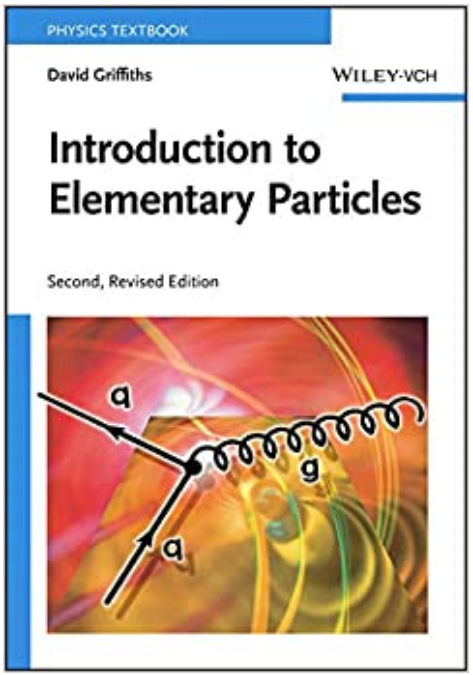
June 22, 2023

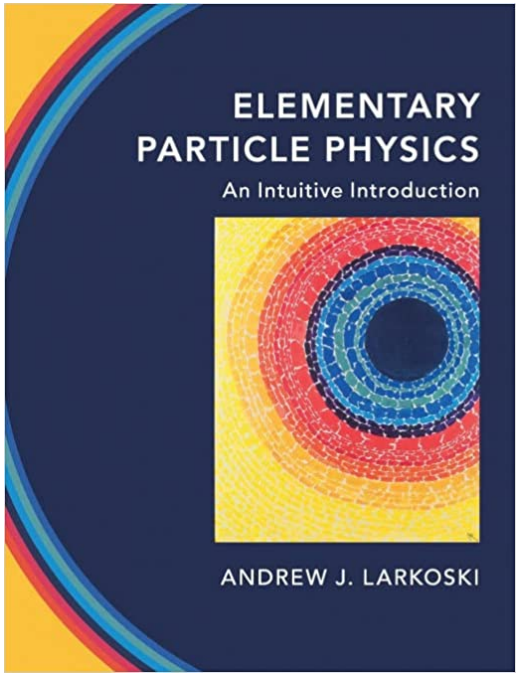
About Me

- 34 years old, single, no children
- Live with family and dog in Logan Square, Chicago
- Doing physics research since 2008: Cosmic Ray astronomy, Optical transients, Computational Linguistics, Mathematical Linguistics, worth with SiPMs, CMS internship, Dark Matter Search (SBC), Gamma Ray Burst imaging pipeline, work with CF4, work with piezos
- Worked at Fermilab before COVID furlough
- Have yet to finish my BS degree
- Run a successful tutoring business
- Live with a degenerative neuro-psychiatric disorder
- First-generation student with parents from Jalisco, Mexico

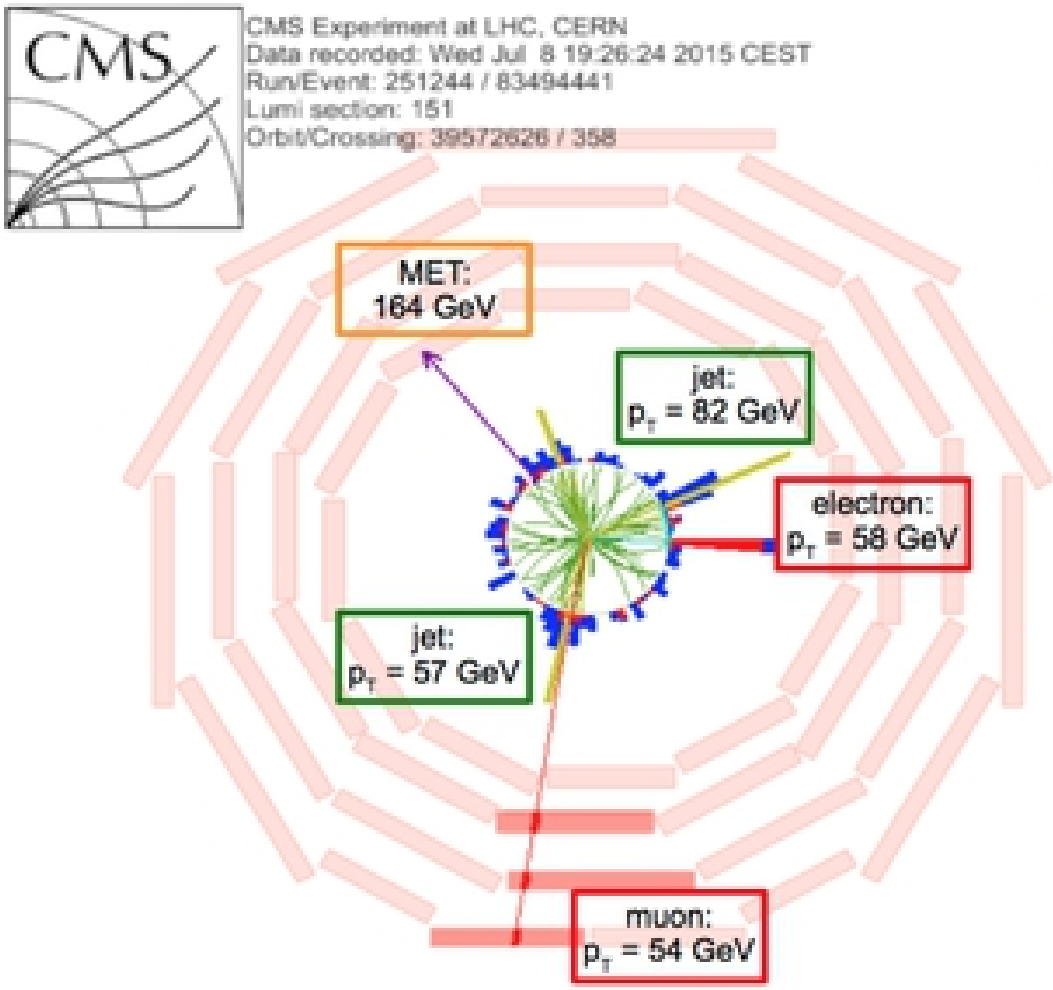
Elementary Intros: 1984 to Post-Higgs Era

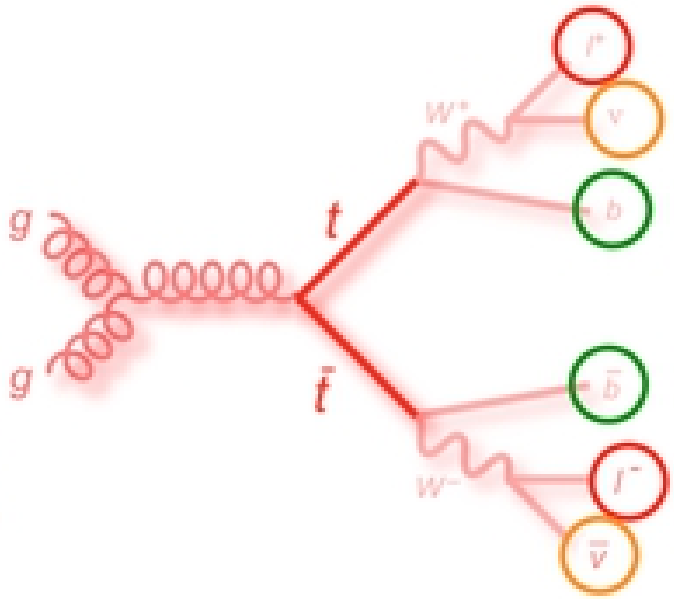






Top Quark Physics





In short

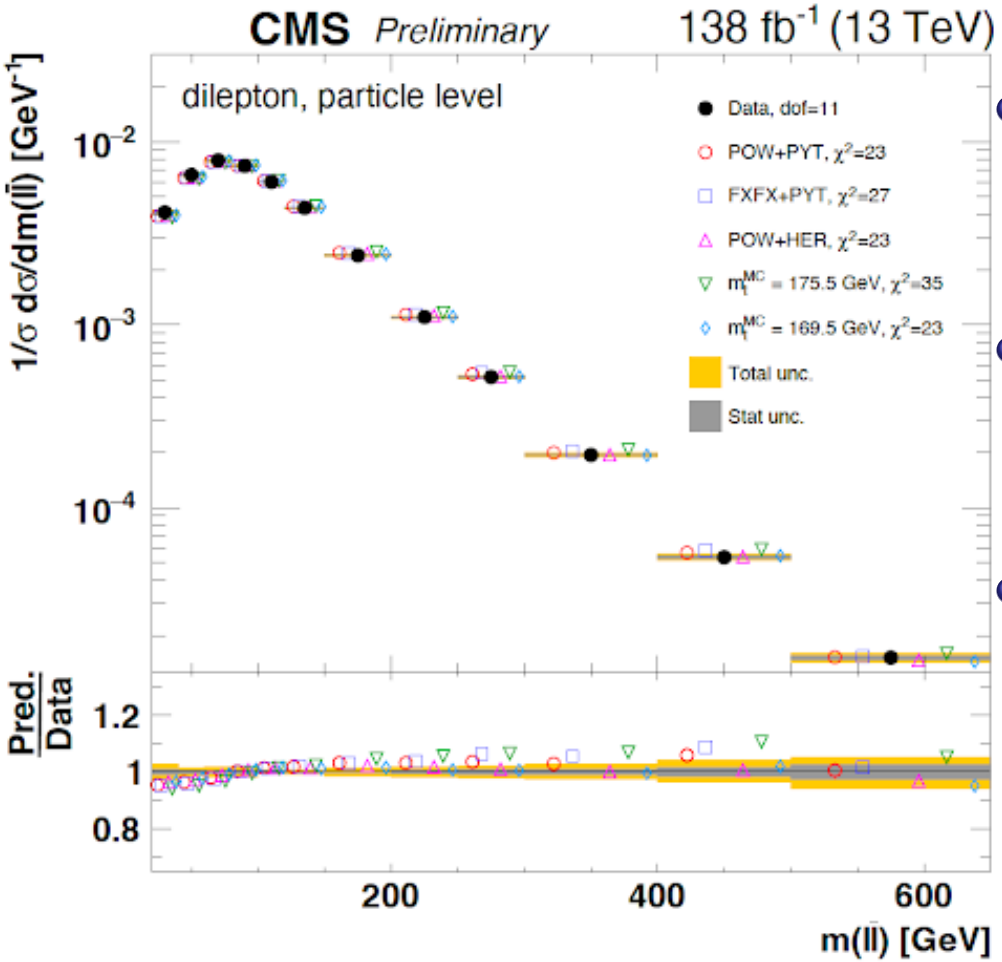
According to a particle theory book from 2015:

> The t-quark has, due to its large mass, only a fleeting lifetime. Thus no pronounced $t\bar{t}$ states *(toponium)* are expected.

This may be wrong.

Moral: Work with the end goal in mind. Always do a literature search. Is an incomplete product a bad product? Is bad the right word to use in this context?

Evidence for Toponium?



- ATLAS [arxiv:1910.08819] and CMS see an excess of low $m_{\ell\bar{\ell}}$ events (dilepton events)
- Fuks et. al. showed that this can be explained via a $t\bar{t}$ scalar resonance [arxiv:2102.11281]
- Using an event selection procedure biased for toponium production Fuks et. al. achieved a S/N ratio of 7% when considering only $t\bar{t}$ events

Goal of Toponium analysis

A lot of work done so far:

- MadGraph
- PYTHIA
- delphes
- BiLSTMs
- transformers??

Goal: Put a limit on the cross section for Toponium using Higgs PAG - combine and machine learning tools.

Moral: You will need to climb a steep learning curve to get anything done that may be useful to your mentor. Just focus on the goal of learning. You are starting something that may mature into a full career. Also, there are plenty of physicists who have never and will probably never understand quantum field theories. There is room for everyone in physics work.

Method

- Techniques used to identify final state particles and their evaluation: neural network methods are used.
- Event Selection Criteria: TBD. Maybe use the same as Fuks et al?
- Background determination: Comes from NN classifier.
- Uncertainties: 20 known of in analysis thus far.
- Expected Results: Make a plug-and-play limit setting procedure that can be used with any Monte Carlo data and hopefully with real data in the near future

Comment: Machine learning methods are the future whether or not we like that fact. Take solace that the math is starting to justify many of the ad hoc approaches taken by certain groups in using the latest tool du jour. Look up the Universal Approximation Theorem.

Statement of Classifier Problem in n = 7

From this we want to map this vector:

$$\mathbf{v} =< p_t, \eta_t, \phi_t, p_{\bar{t}}, \eta_{\bar{t}}, \phi_{\bar{t}}, m_{t\bar{t}} > \tag{1}$$

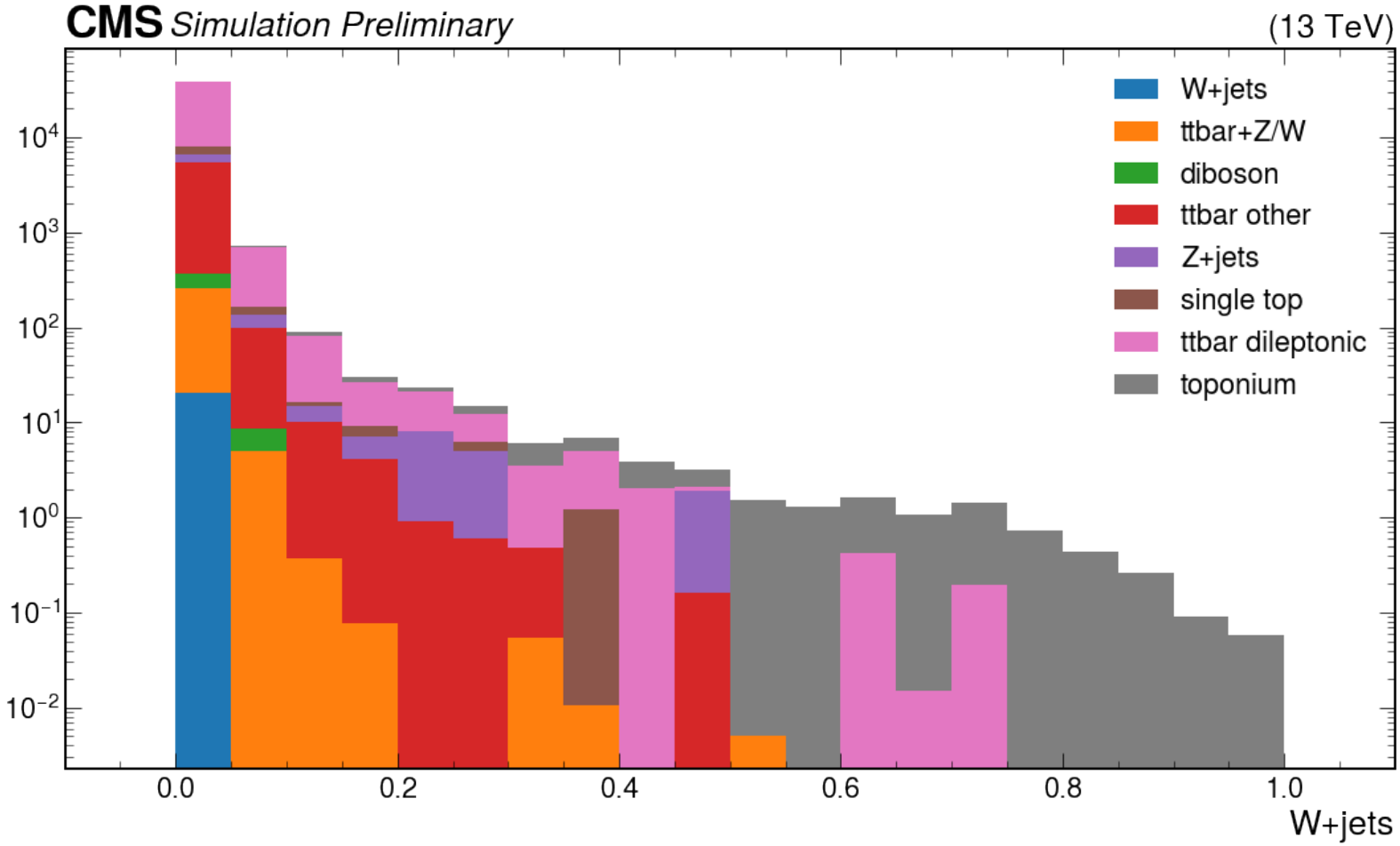
under

$$\Gamma : \mathbb{E}^7 \longrightarrow [0, 1]$$

where Γ is a kernel map determined by the choice of classifier architecture. The output of $\Gamma(\mathbf{v})$ is a probability that that $\mathbf{v}$ is a signal event as determined by the classifier.

Note: We have never seen a quark. We infer the existence of a $q\bar{q}$ by looking at a relevant variable or kinematic discriminator among decay products.

Results



How would you use this plot to look for the toponium out of all events produced at the HL-LHC?

Dark Matter Physics

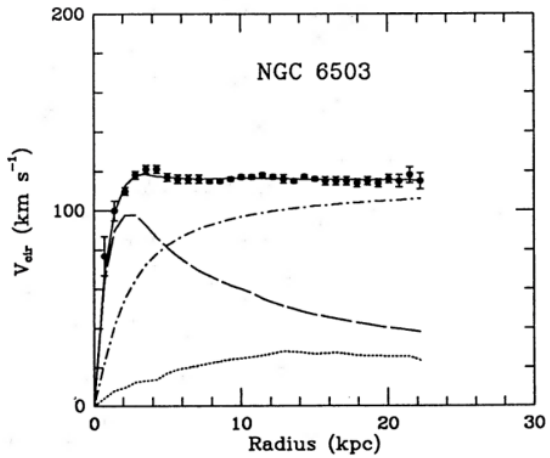


Figure 1.1. An example rotation curve for NGC 6503. The observed velocities are shown by the points and error bars. A multicomponent fit (solid line) was done to determine the contributions from gas (dotted line), stars (dashed line), and a dark matter halo (dot-dashed). Published as Figure 1, in [**5**].

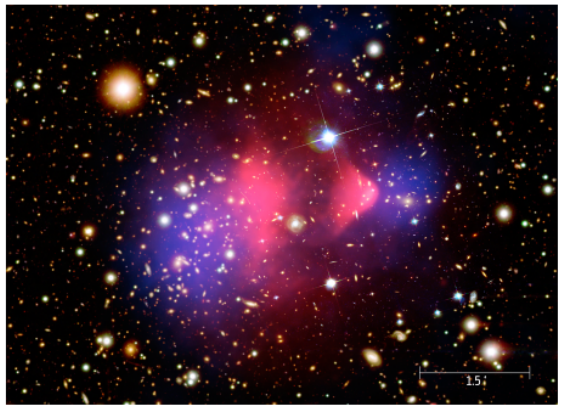


Figure 1.2. The bullet cluster in the optical wavelengths. Overlaid are the distribution of hot gas, as determined by x-ray observations (pink), and the distribution of gravitating mass (dark matter), as determined by weak

u can now record yourself and your screen at the same time

lensing). By NASA/CXC/M. Weiss - Chandra X-Ray Observatory. 1E 0657-56, Public Domain.

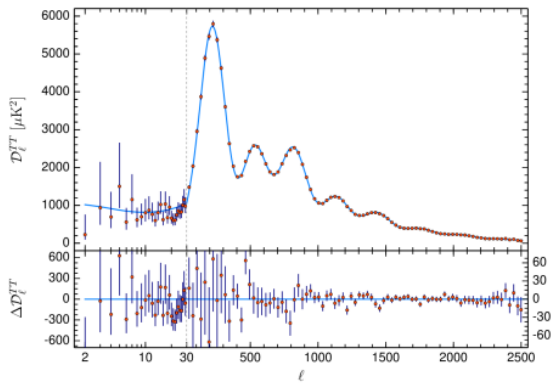


Figure 1.4. The power spectrum of the temperature anisotropies of the CMB, as observed by Planck (red points). A fit to the ΛCDM model is shown by the blue line. The bottom panel shows the residuals. Published as Figure 1, in [**13**].

Dark Matter Candidates

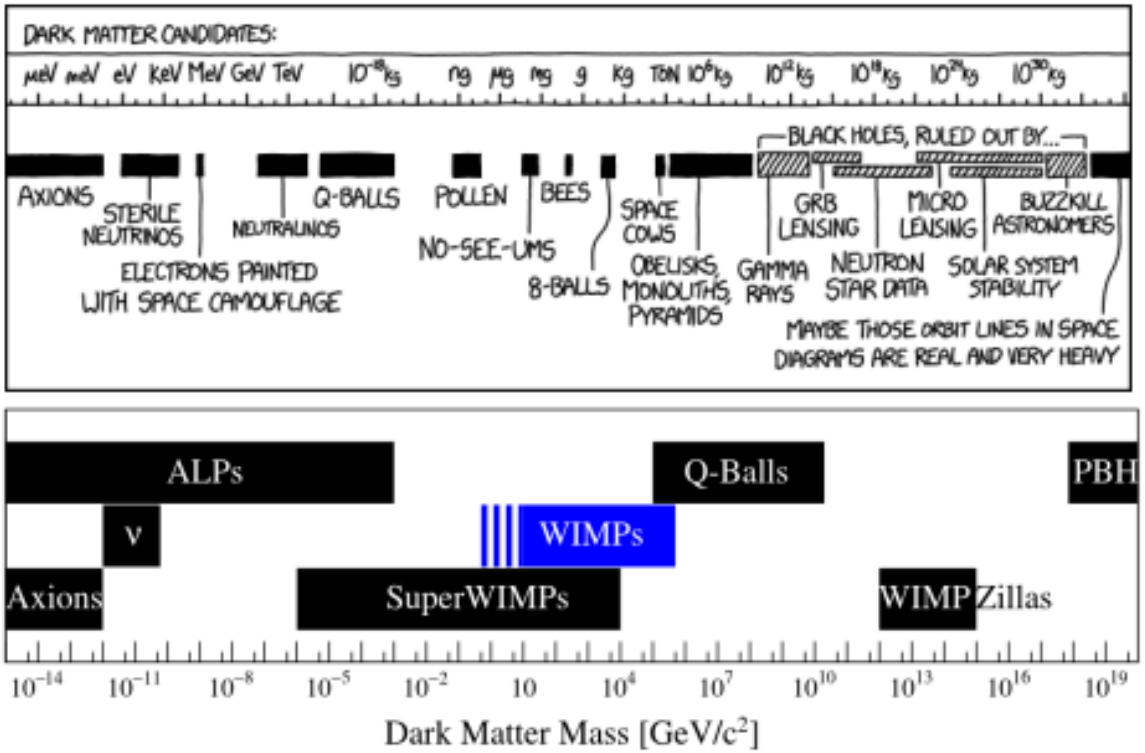


Figure 1.7. (Top) A cartoon of the viable parameter space for dark matter. This includes real models of DM (axions, neutralinos, black holes, etc) as well as currently un-studied models such as space cows and electrons painted with space camouflage. Reproduced from XKCD [**26**]. (Bottom) A perhaps more informative scale for the mass-space of various dark matter model. Published as Fig. 2, in [**27**].

Make it, break it, or shake it

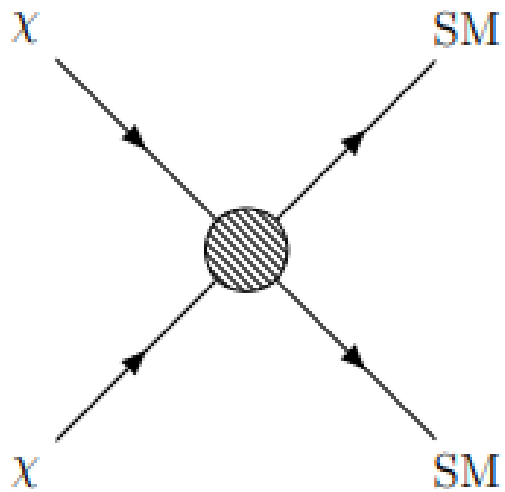
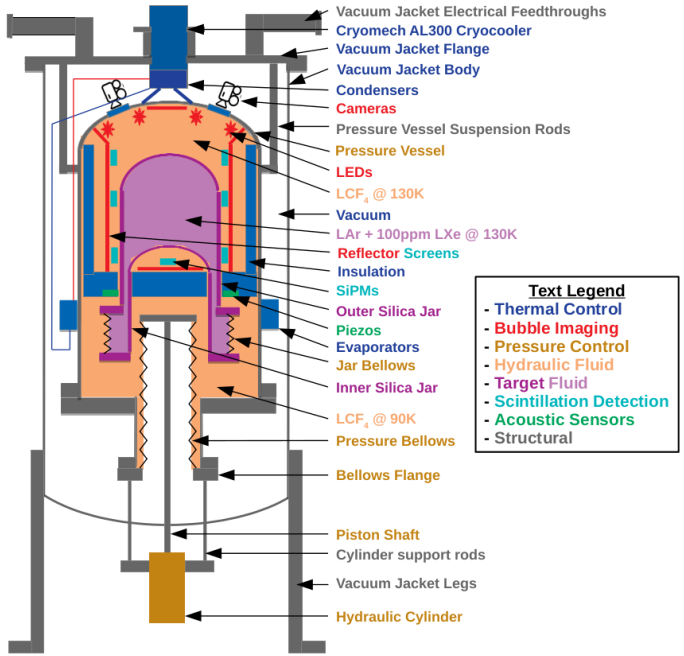
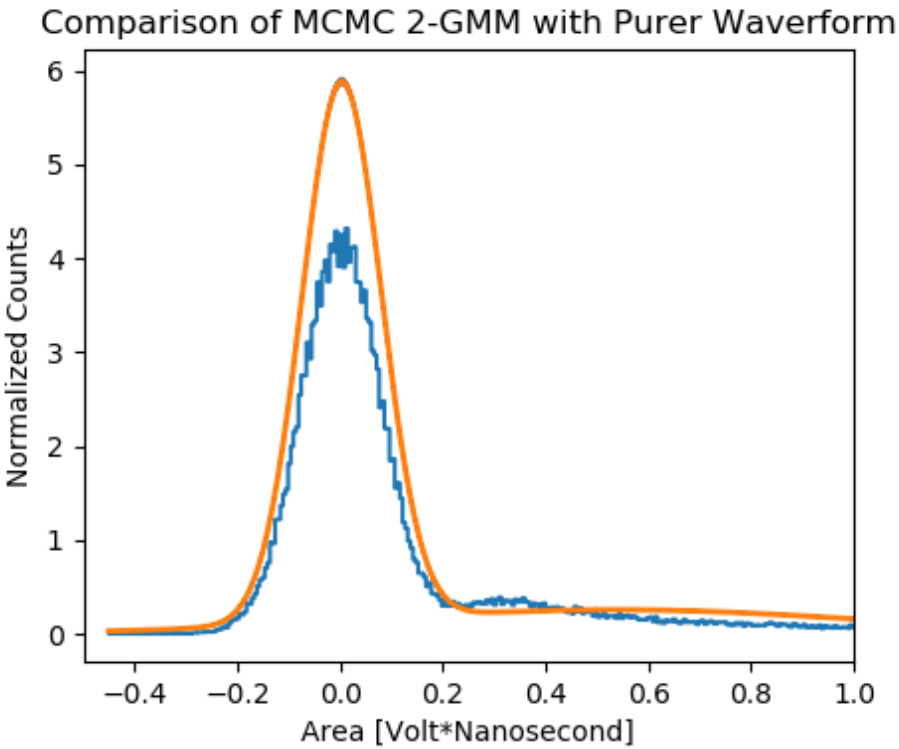


Figure 1.12. A Feynman diagram depicting the three paradigms of dark matter searches. (Left-to-right) An annihilation diagram corresponding to indirect detection. (Right-to-left) A production diagram corresponding to collider searches. (Vertically) A scattering diagram corresponding to direct detection. The particle lines were chosen to be fermions for no reason.

SBC


Vacuum Jacket Electrical Feedthroughs
Cryomech AL300 Cryocooler
Vacuum Jacket Flange
Vacuum Jacket Body
Condensers
Cameras
Pressure Vessel Suspension Rods
Pressure Vessel
LEDs
LCF4 @ 130K
Vacuum
LAr + 100ppm LXe @ 130K
Reflector Screens
Insulation
SiPMs
Outer Silica Jar
Piezos
Evaporators
Jar Bellows
Inner Silica Jar
LCF4 @ 90K
Pressure Bellows
Bellows Flange
Piston Shaft
Cylinder support rods
Vacuum Jacket Legs
Hydraulic Cylinder
Text Legend
- Thermal Control
- Bubble Imaging
- Pressure Control
- Hydraulic Fluid
- Target Fluid
- Scintillation Detection
- Acoustic Sensors
- Structural

Future



A good idea will keep your seat at the table, but where do the good ideas come from?

Thank you!

Thank you for your time. Special thanks to Guillermo and Dr. Malik for setting this up. My email is velascodavid00 at gmail; Feel free also to contact me via Slack or LinkedIn if you wish. Questions?