Searching for a Dark Matter Candidate at the Fermilab Tevatron

Paul Geffert, **Max Goncharov, Eunsin Lee, and David Toback – Texas A&M**
Slava Krutelyov – now at UCSB
Peter Wagner – now at Penn

Outline

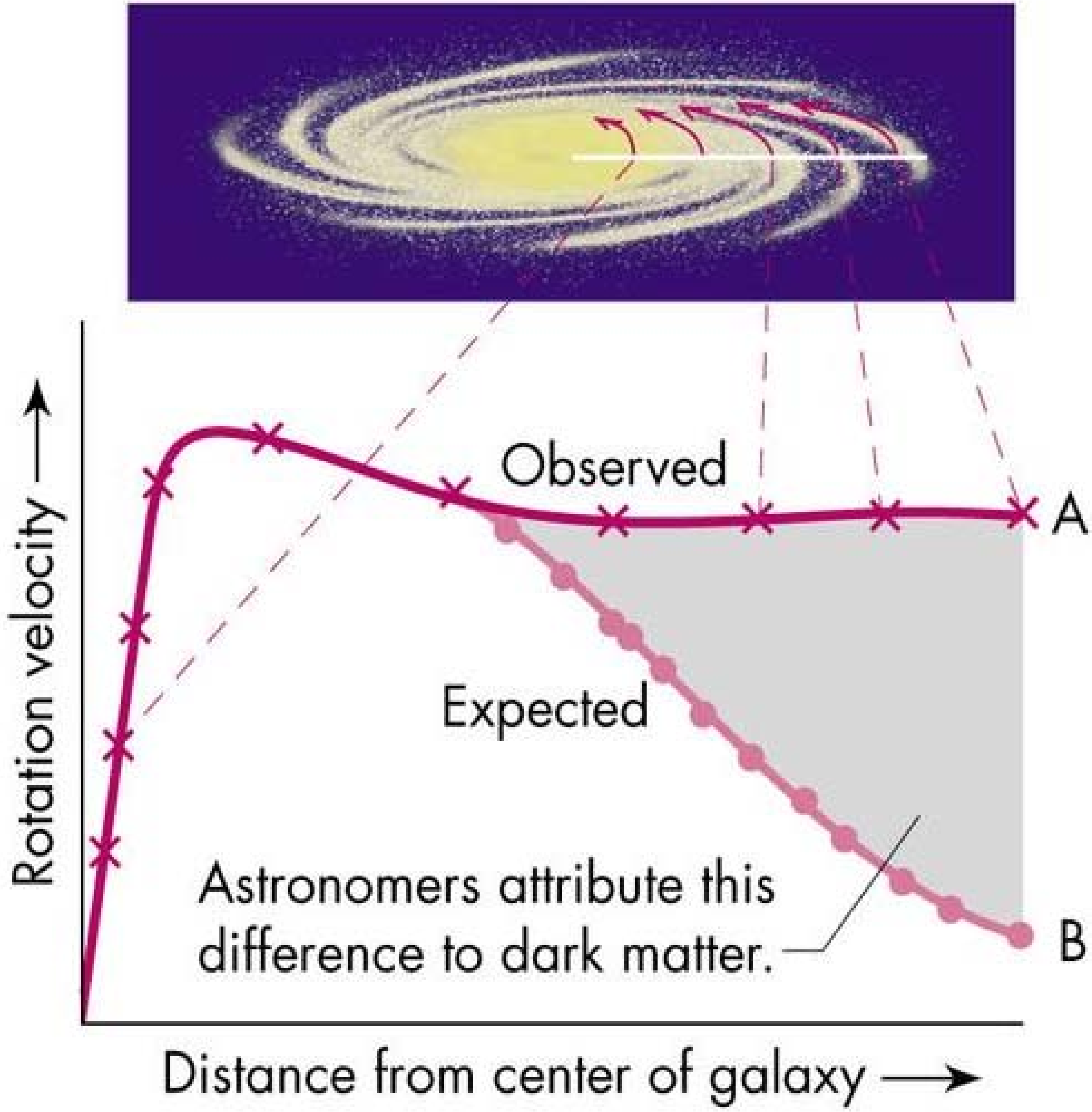
- What is dark matter?
- Supersymmetry provides a dark matter candidate
- Experimental tools: The Fermilab Tevatron and CDF
- Searching for dark matter in particle collisions
- My work this summer
- Conclusion

What is Dark Matter?

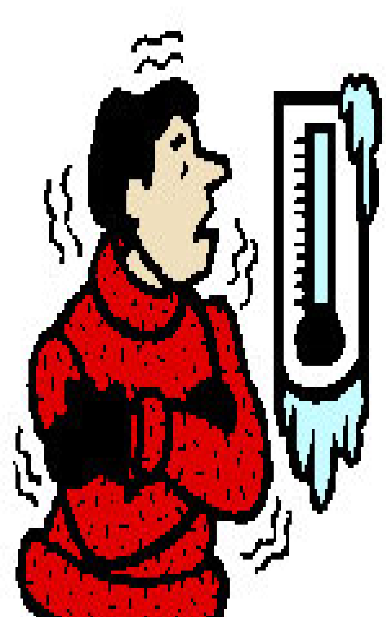
- Very little is known
- Why is it called "**dark**"?
  - Does not interact with light (hence we cannot see it)
- Has mass and attracts other objects through gravity
  - This is how we know it exists
- 23% of the energy of the universe

Some Experimental Evidence

- The rotational velocity curves in galaxies are not what we expect
- There must be additional mass (**dark matter**) spread throughout galaxies
- Other experiments agree



“Cold” Dark Matter vs. “Warm” Dark Matter



Cold

Mass ~100 GeV

Moves “slower”

- Cold Dark Matter is favored for large-scale galaxy formation
- Warm Dark Matter is favored for sub-galactic scale formation
- Most searches focus on Cold Dark Matter, but we search for Warm Dark Matter because we have a powerful new search technique

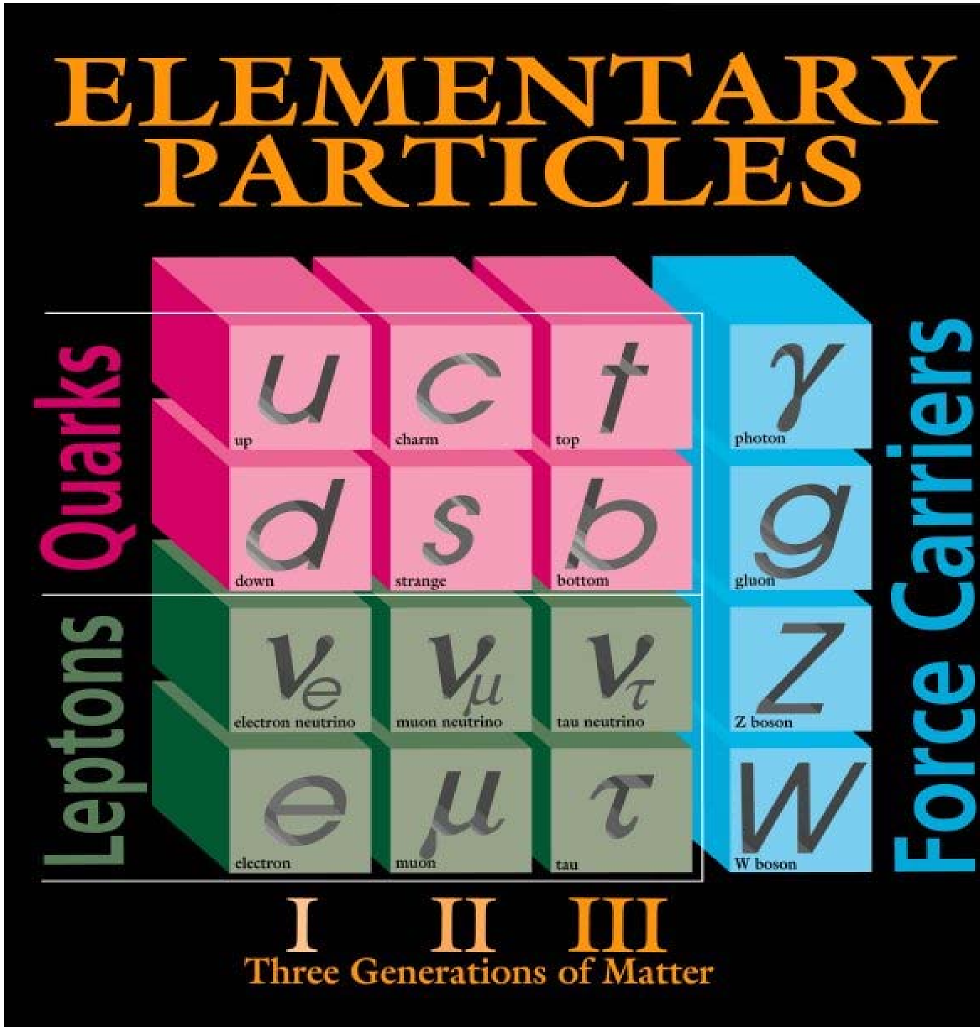
Warm

Mass ~1 keV

Moves “faster”

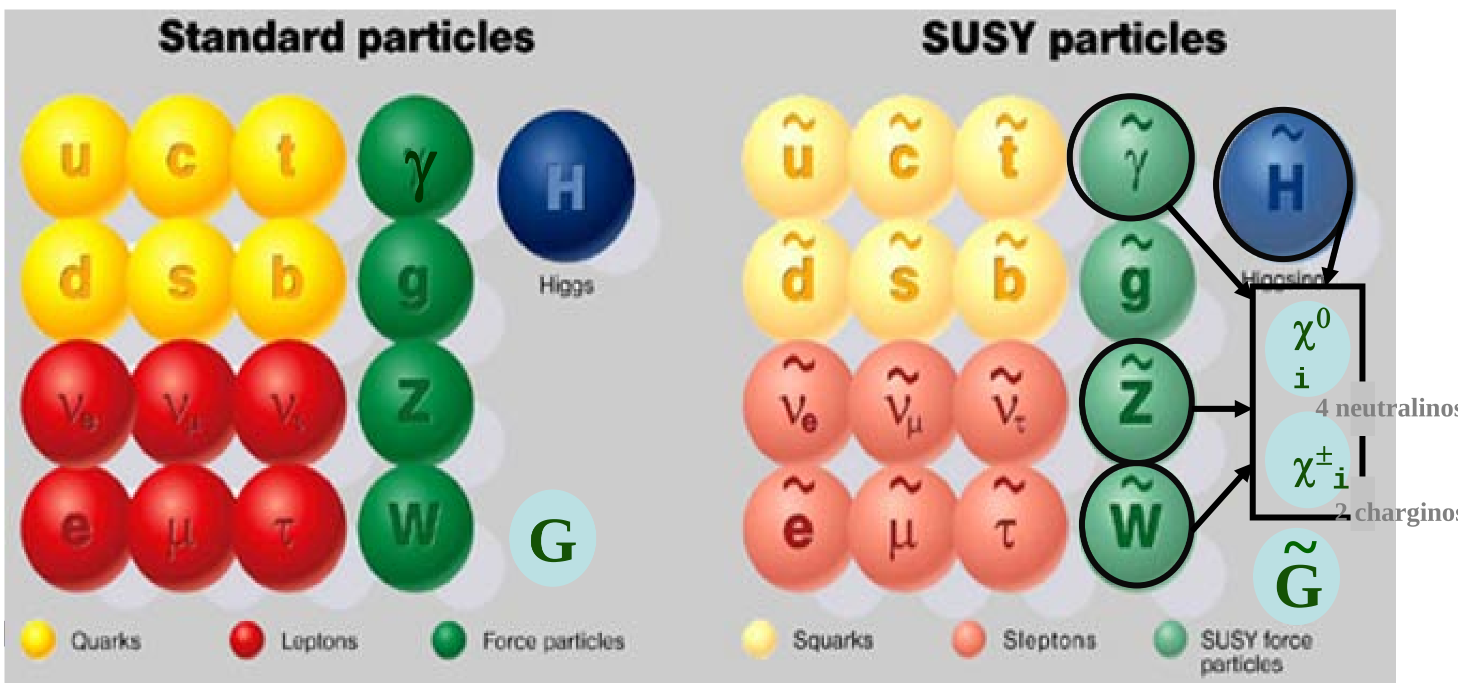
The Standard Model and Dark Matter

- The standard model is a description of the currently known elementary particles
- None of the known particles fits the bill as a dark matter candidate
- Therefore, we must consider new models of physics to find a dark matter candidate



Supersymmetry to the Rescue?

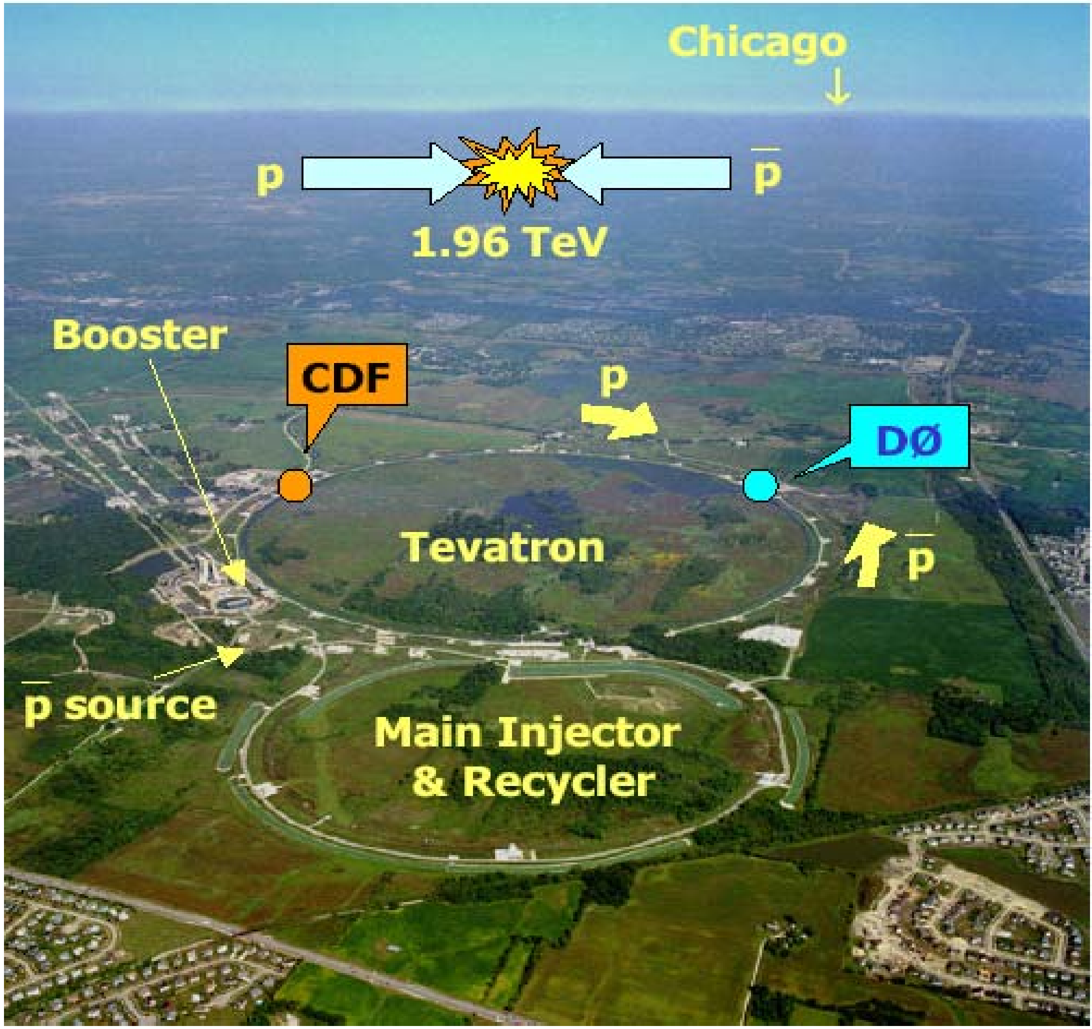
- Supersymmetry is a model of particle physics that predicts new particles
- If this theory is correct, one of these new particles could be the dark matter
- Our warm dark matter candidate is a gravitino, $\tilde{G}$, the supersymmetric partner of the yet undiscovered graviton



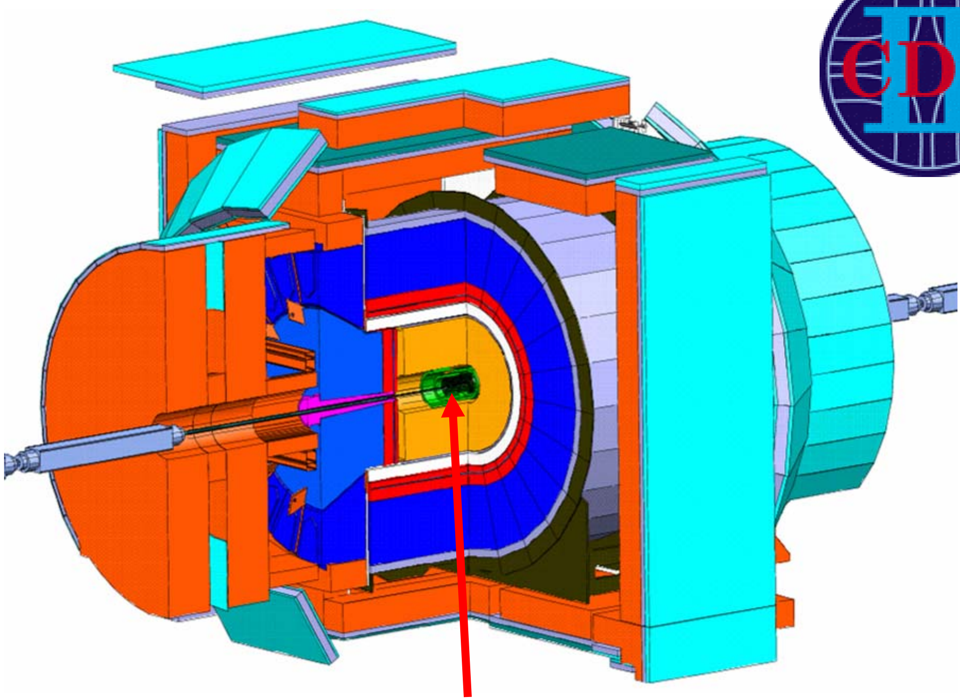
Now that we have a specific dark matter candidate, how might we experimentally search for it?

The Fermilab Tevatron

- The Fermilab Tevatron collides protons and anti-protons moving at more than 0.99999c.
- This amount of energy may be great enough to produce supersymmetric particles that decay to dark matter

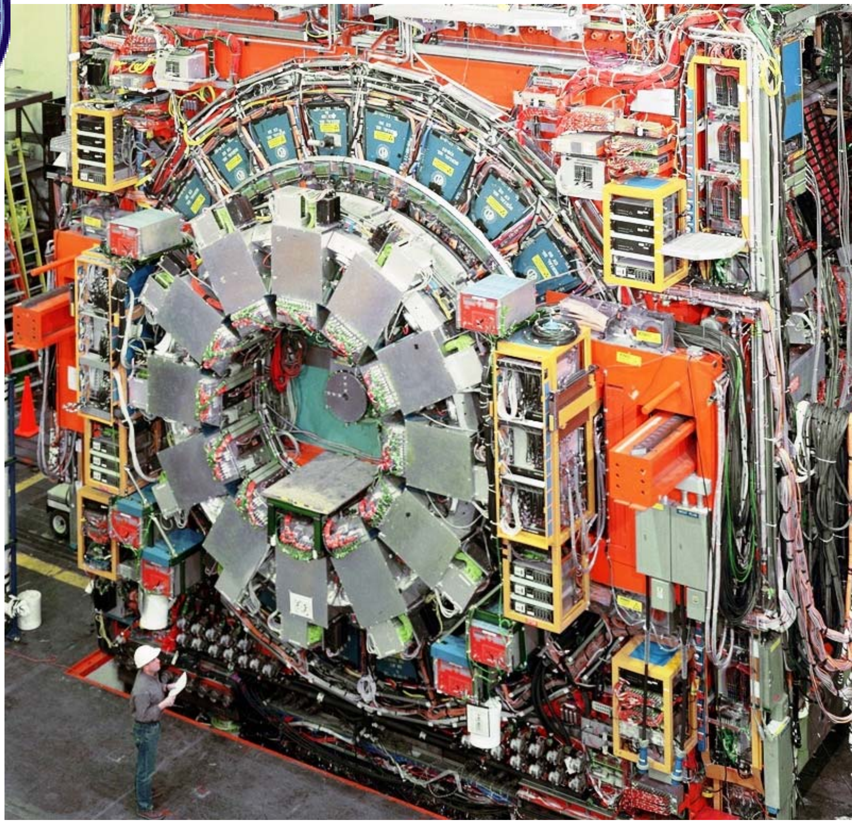


Collider Detector at Fermilab (CDF)



Surround the collision point with a huge detector

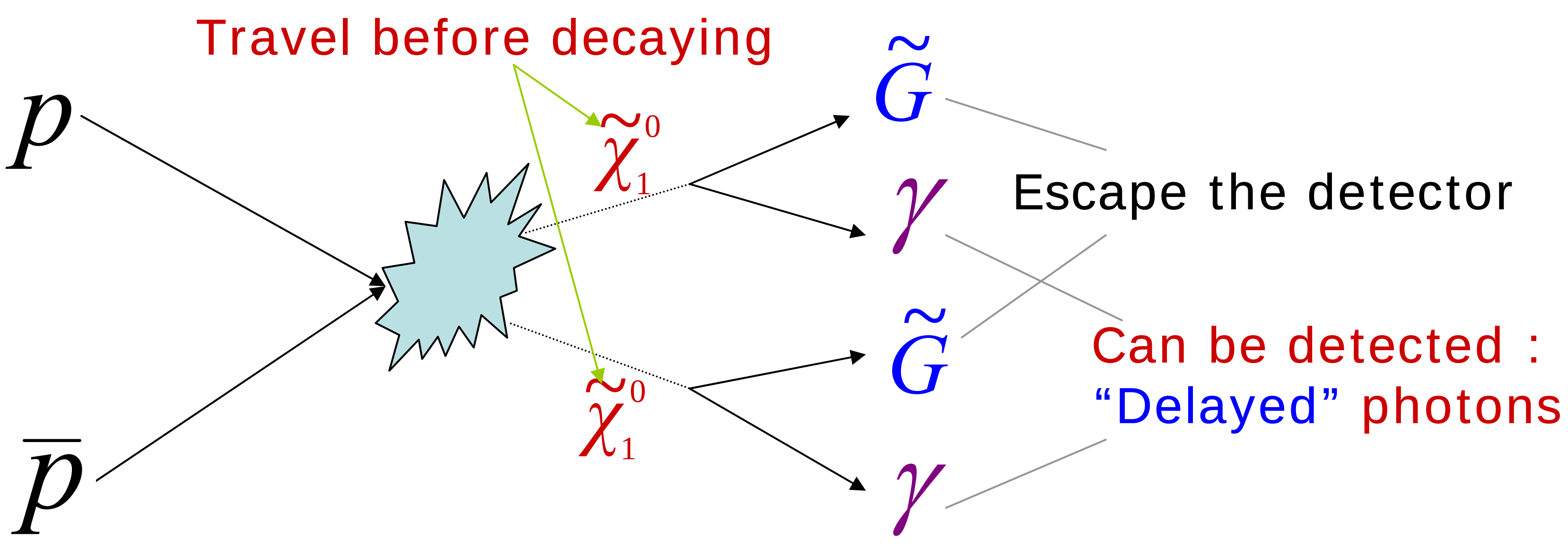
A Photograph



The detector gives us lots of information about the particles produced in the collision. We can use this information to determine if new physics has occurred.

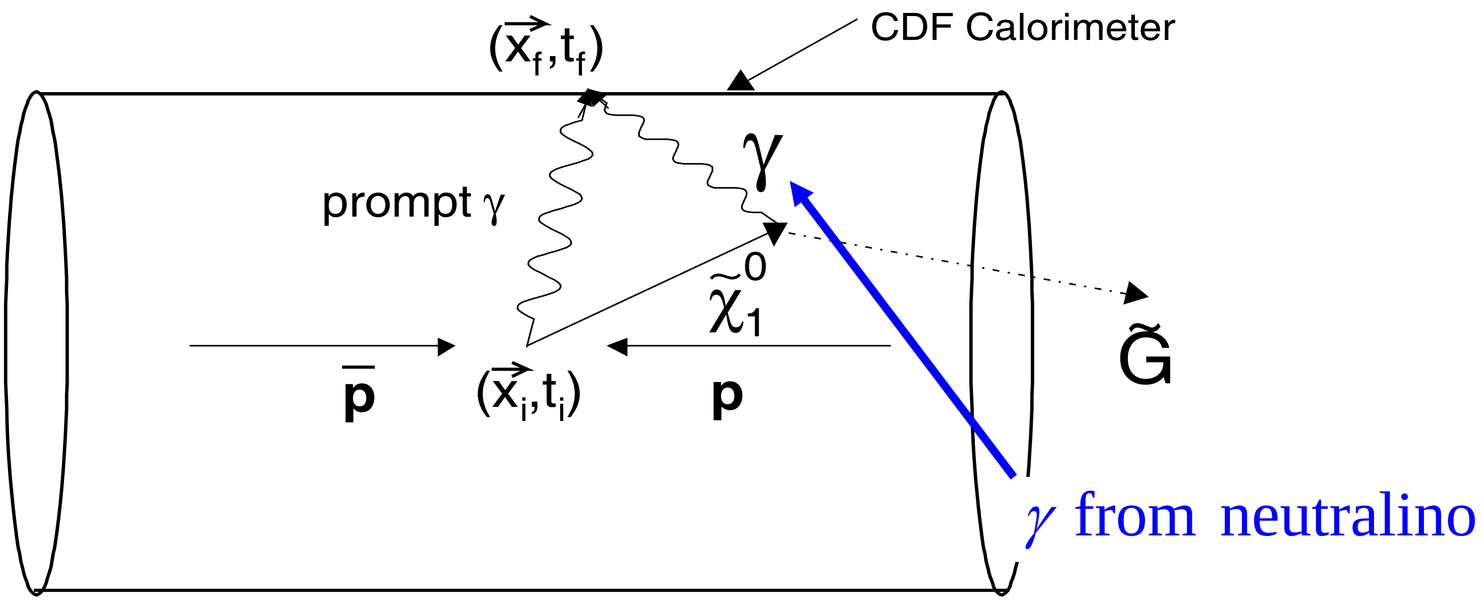
Dark Matter Production

- The neutralino, $\tilde{\chi}_1^0$, (another supersymmetric particle) may be produced in pairs at Fermilab and decay via $\tilde{\chi}_1^0 \rightarrow \gamma \, \tilde{G}$
- The $\tilde{G}$ is our dark matter candidate
- The γ is a photon- CDF is very good at detecting these



“Delayed” Photons

- In the current theory of particles, photons always travel directly from the collision point to the detector
- Neutralinos can travel away from the collision point and then decay
  - The photon arrives at the detector later than expected, in other words “delayed”



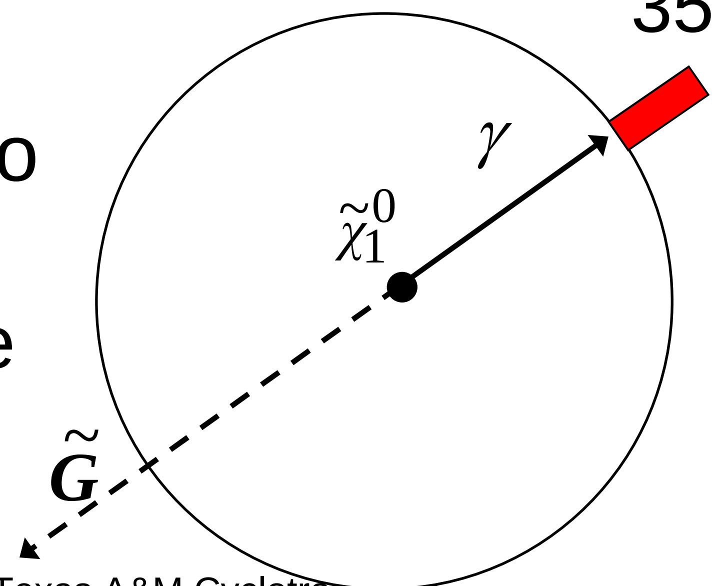
Conservation of Momentum

- The energy deposited in the calorimeter should be balanced around the collision
- Gravitinos and neutralinos leave the detector without depositing energy (they are weakly interacting), resulting in "missing energy"

Example: A neutralino decay in the detector

The gravitino escapes the detector while the photon does not.

The result is 35 GeV of missing energy.



Backgrounds

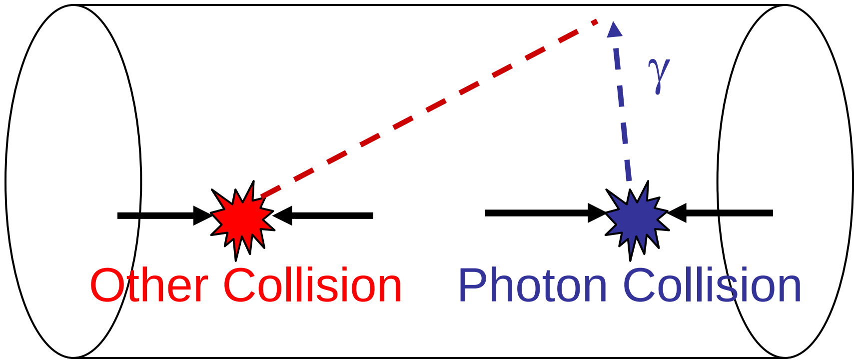
- There are three types of backgrounds that can fake our dark matter signal:

1. Standard Model events
2. Cosmic-ray events
3. Beam related events

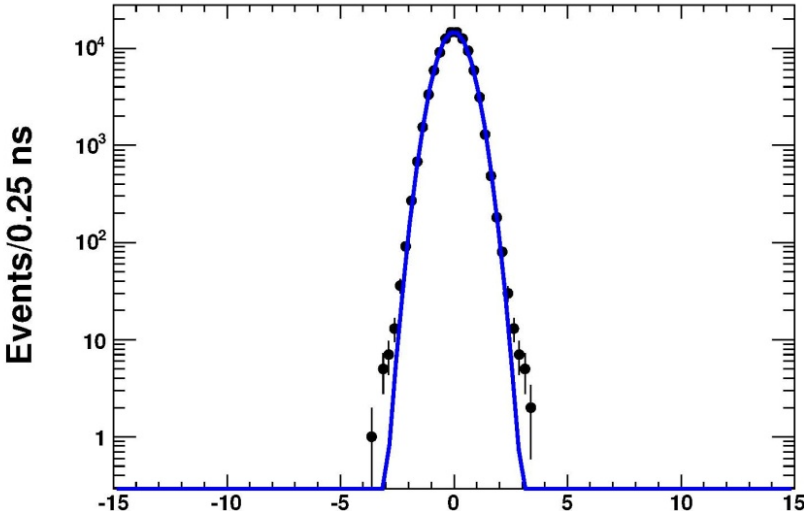
- We can separate them using their unique photon time distributions

Standard Model Backgrounds

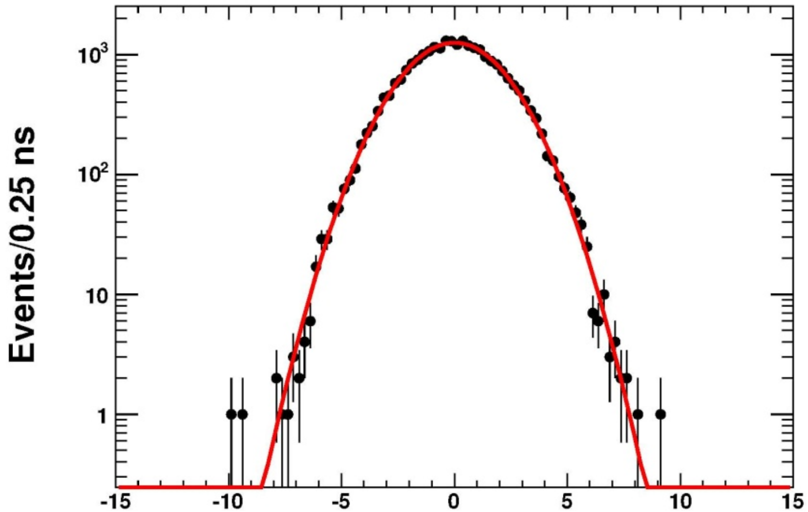
- Standard Model events produce photons directly from the collision point with corrected times, on average, of zero
- However, if the photon is matched to the wrong collision, it can appear delayed



Correct Match

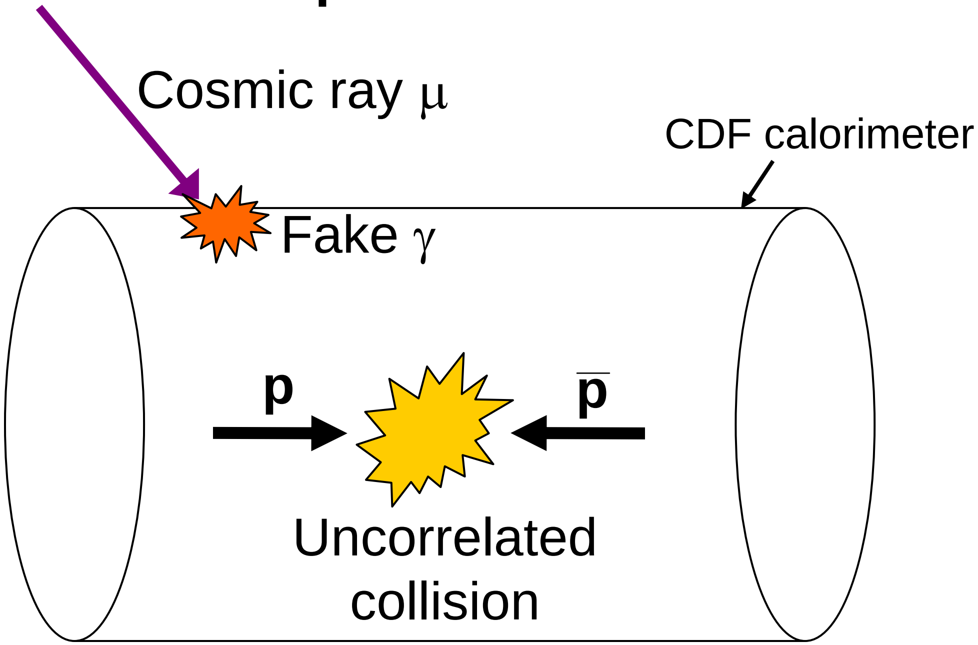


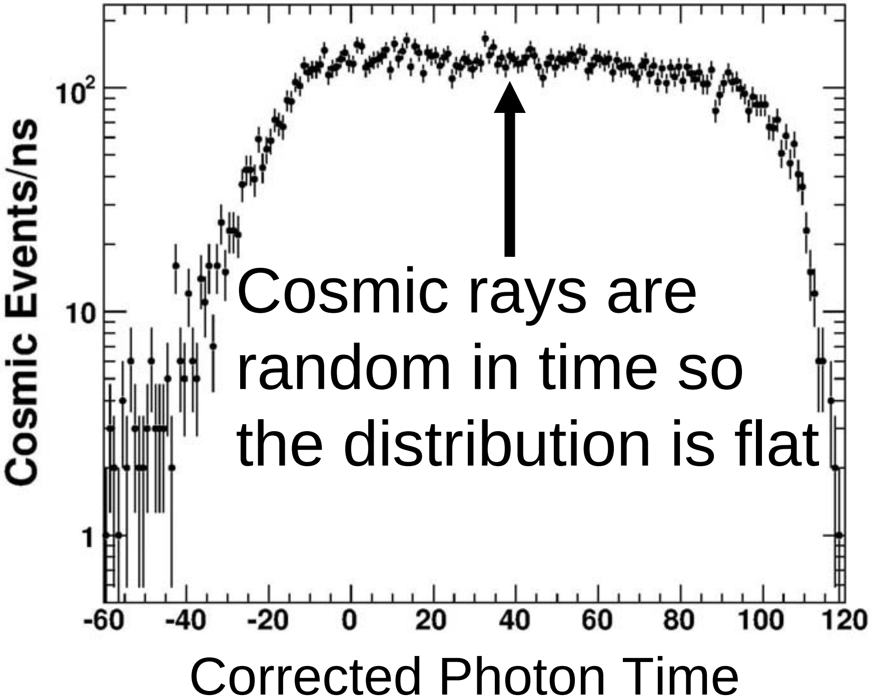
Incorrect Match



Cosmic Ray Events

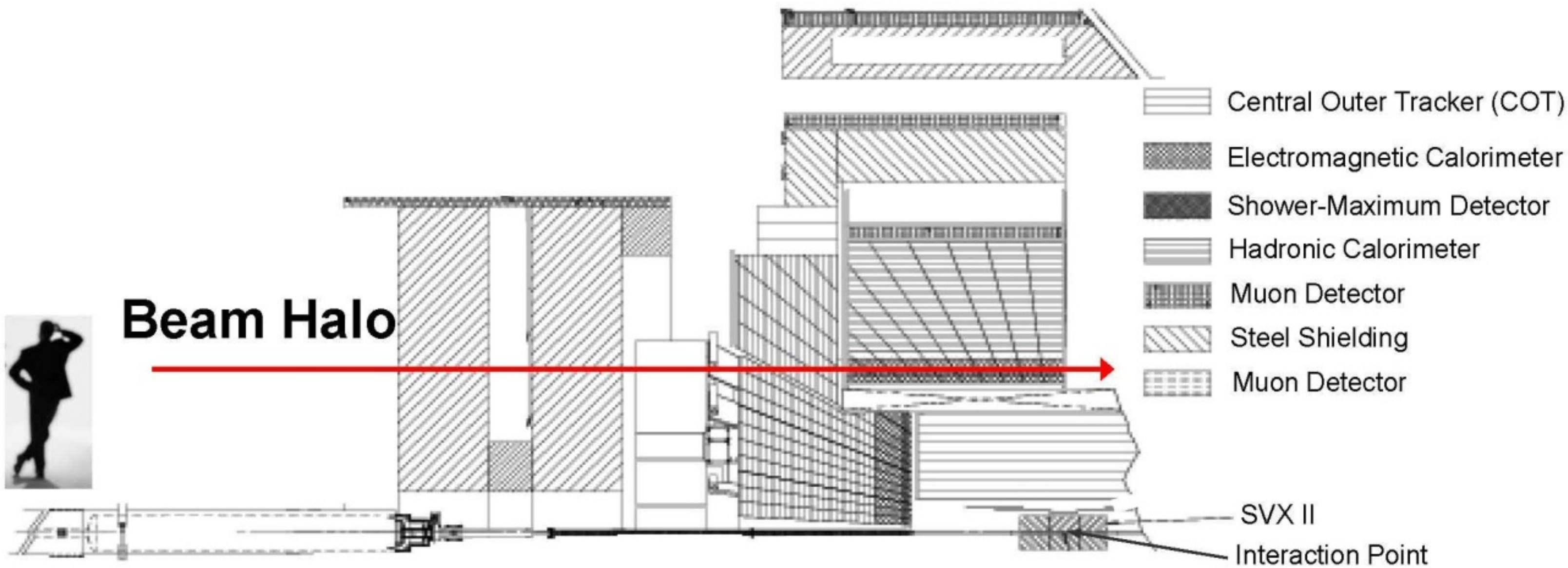
- A cosmic ray muon can deposit energy in the calorimeter that can seem like a photon
- If a collision occurs at a similar time, the fake photon can look delayed.





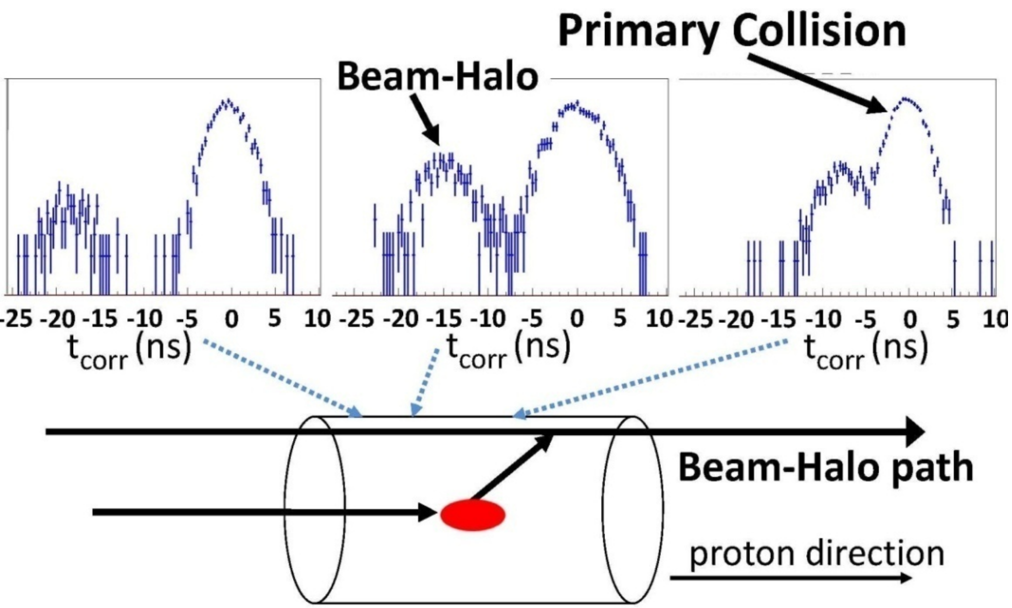
Beam Related Events

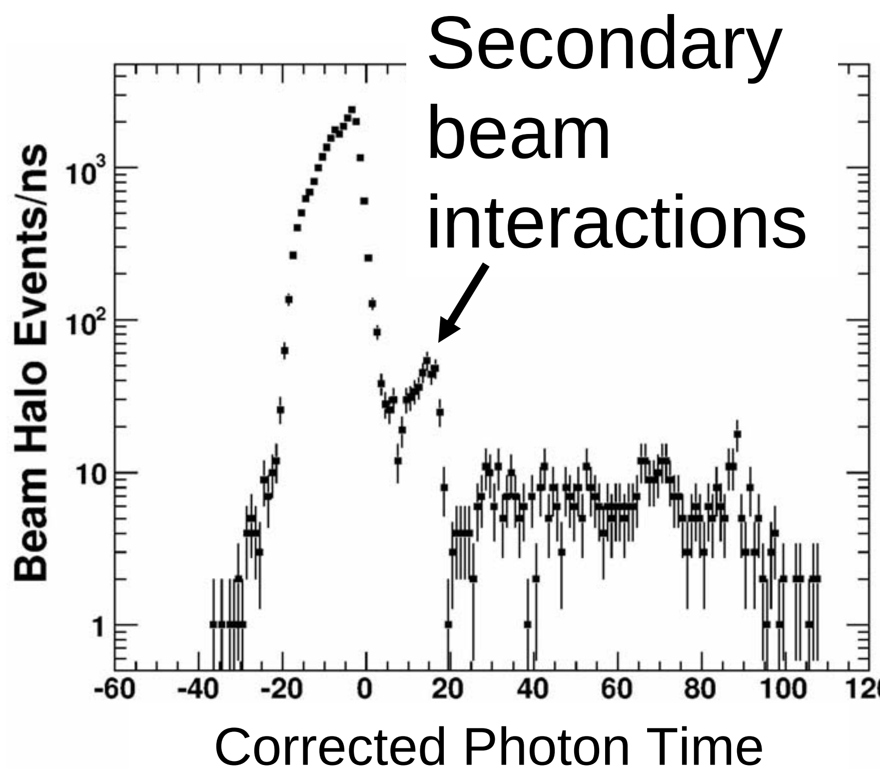
- Protons can hit the beam pipe and produce energetic muons
- These muons can interact with the detector to produce a fake photon



Beam Related Events

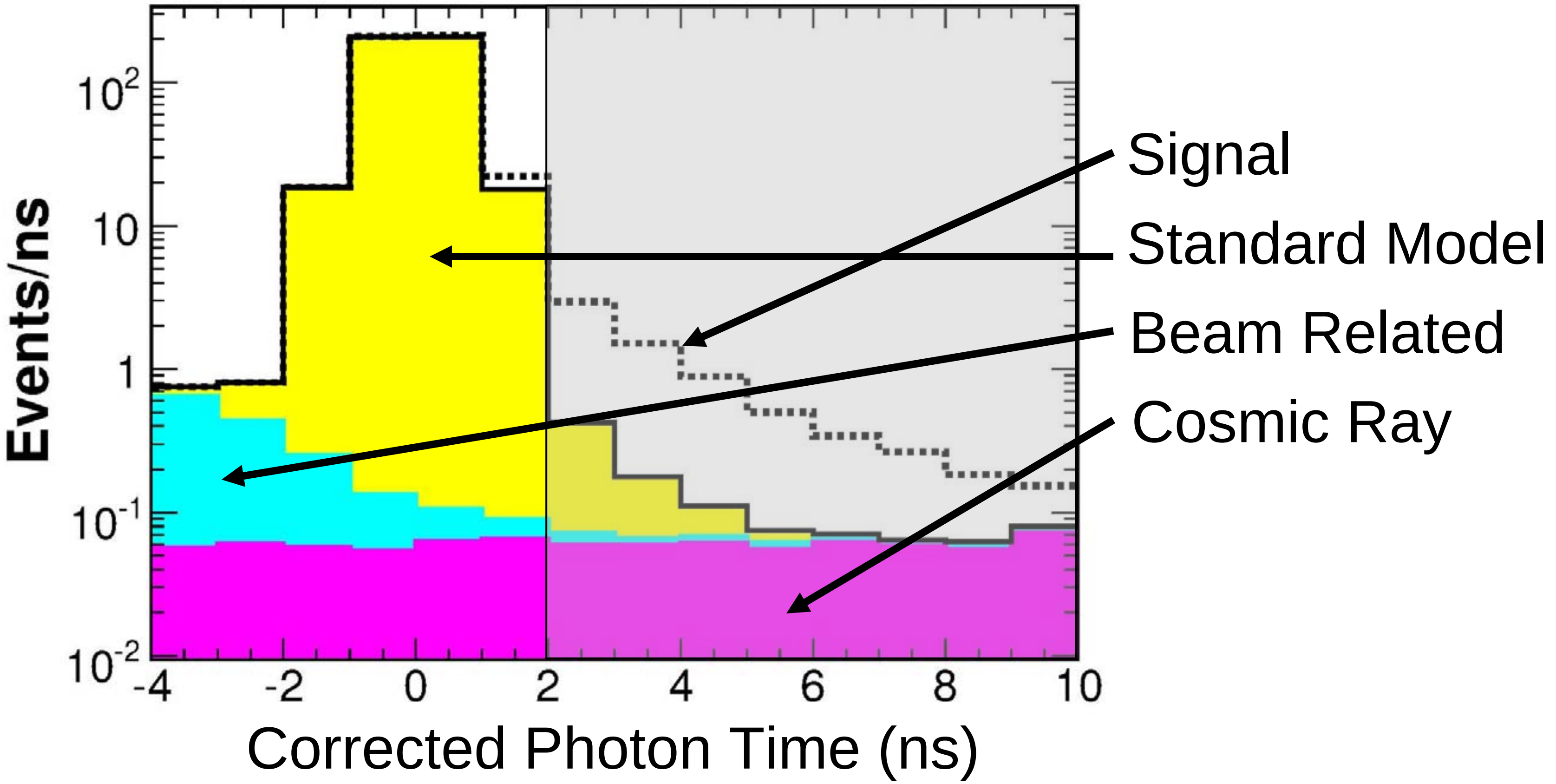
- The beam produced muons arrive earlier at the detector than collision particles
- Their fake photons should have negative corrected times





Signal

- We use the photon timing distributions of the backgrounds to estimate them
- We predict much more signal than background for 2<Photon Time<10 ns.



My Work this Summer

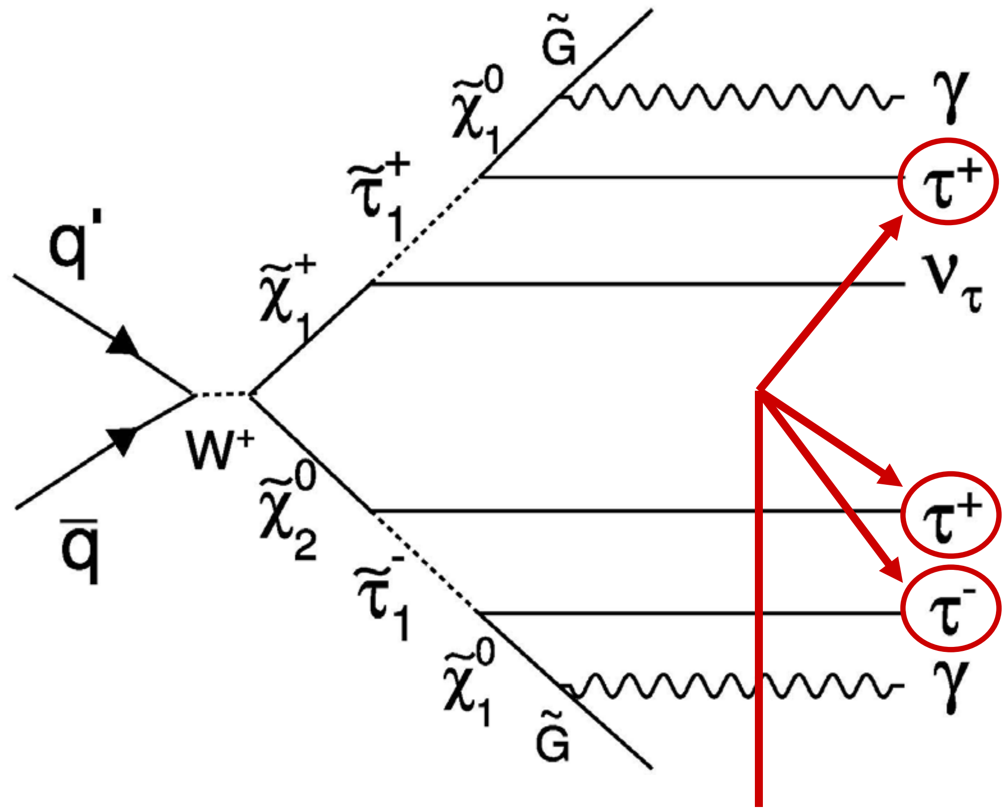
- An analysis looking for delayed photons and missing energy has already been published (no discovery)
  – Phys. Rev. Lett. **99** 121801 (2007)

- My work this summer has been towards improving this previous analysis…

Determining the Collision

- The old analysis used a complicated collision reconstruction algorithm to determine what collision produced the photon
- To greatly simplify the analysis, I am working on using a single high momentum track to indicate where the collision occurred

Dominant Production Diagram



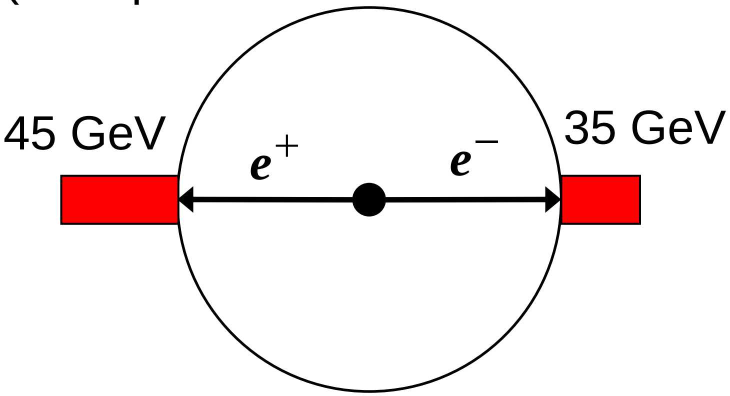
Can show up as high momentum tracks originating from the collision

Missing Energy Significance

- Missing energy can arise in multiple ways…
- We determine the "significance" of missing energy to tell whether it is from real physics

Calorimeter Mismeasurement

(Both particles should have 40 GeV.)

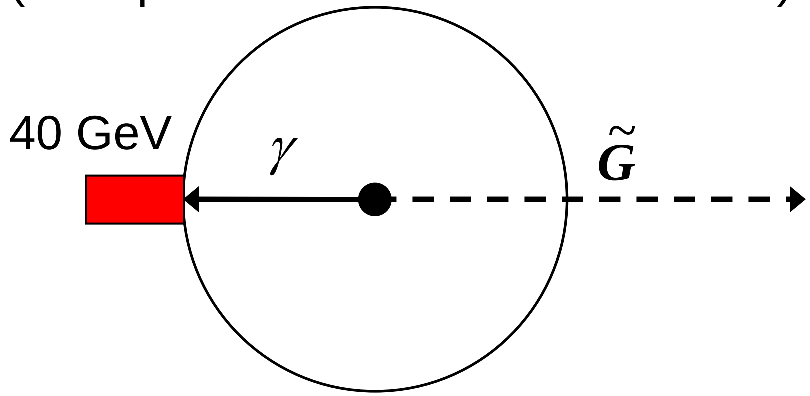


There is 10 GeV of missing energy.

This occurs commonly so the missing energy is <u>not significant</u>.

Real Physics

(Both particles should have 40 GeV.)

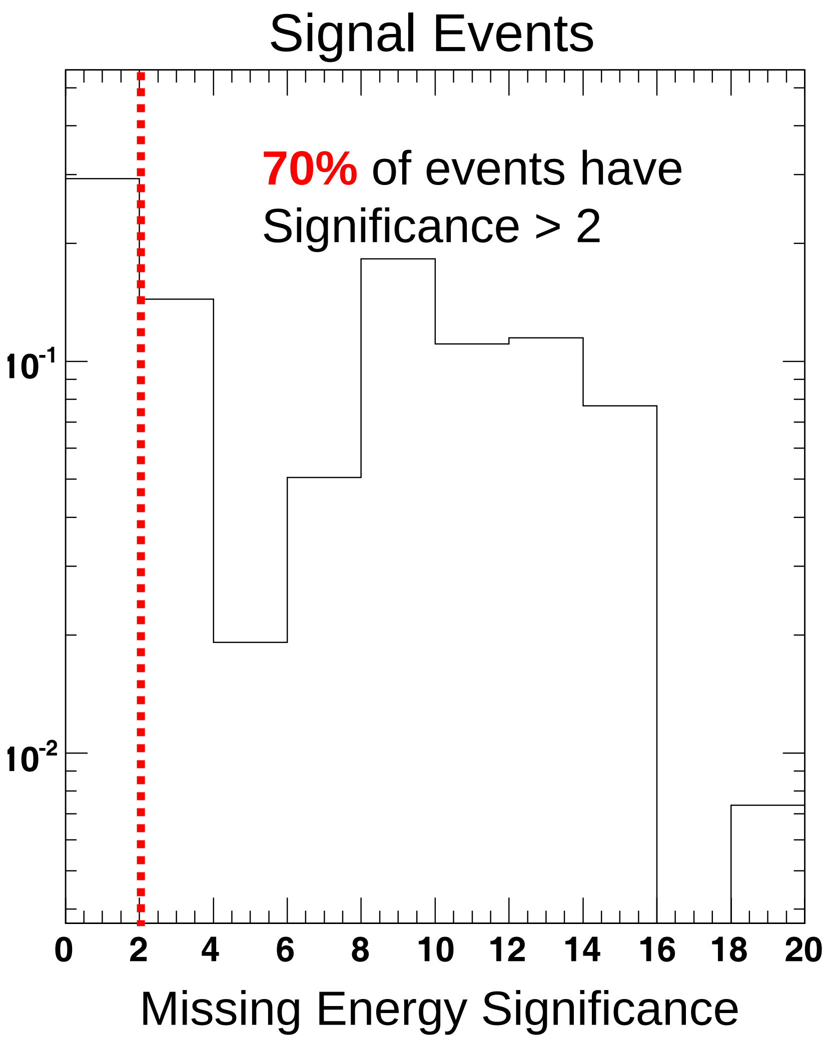


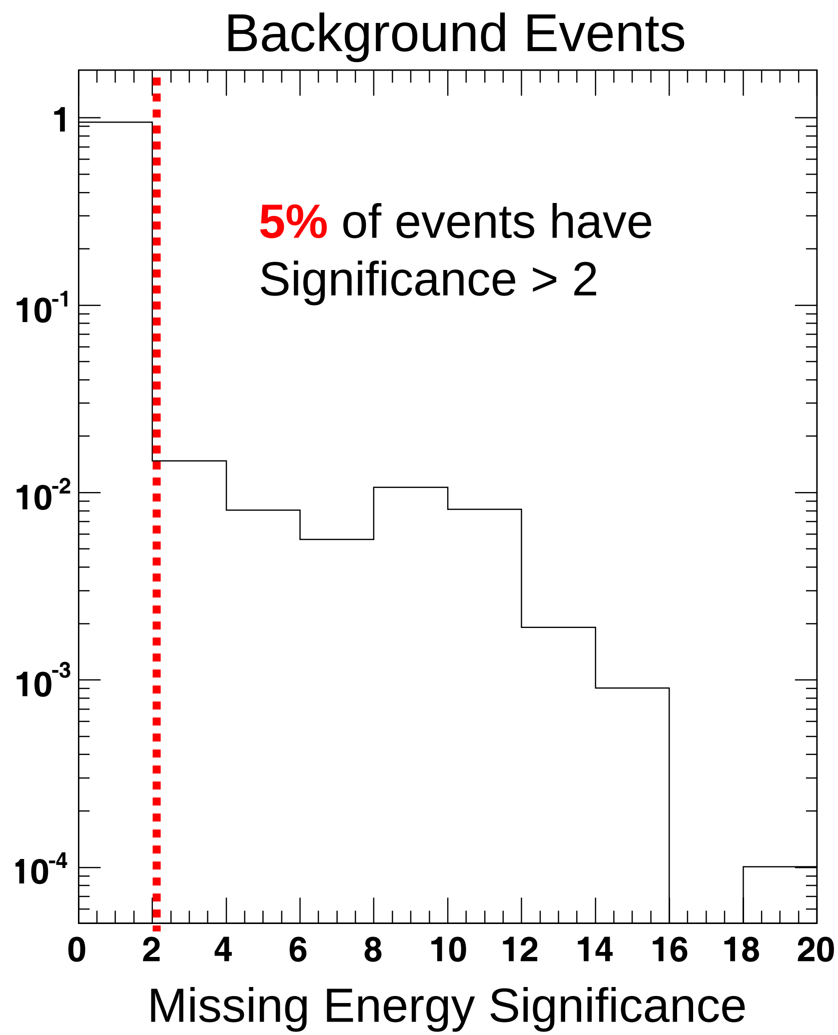
There is 40 GeV of missing energy.

The missing energy is <u>significant</u>.

Missing Energy Plots

- Standard model events should have lower missing energy significance than our signal events



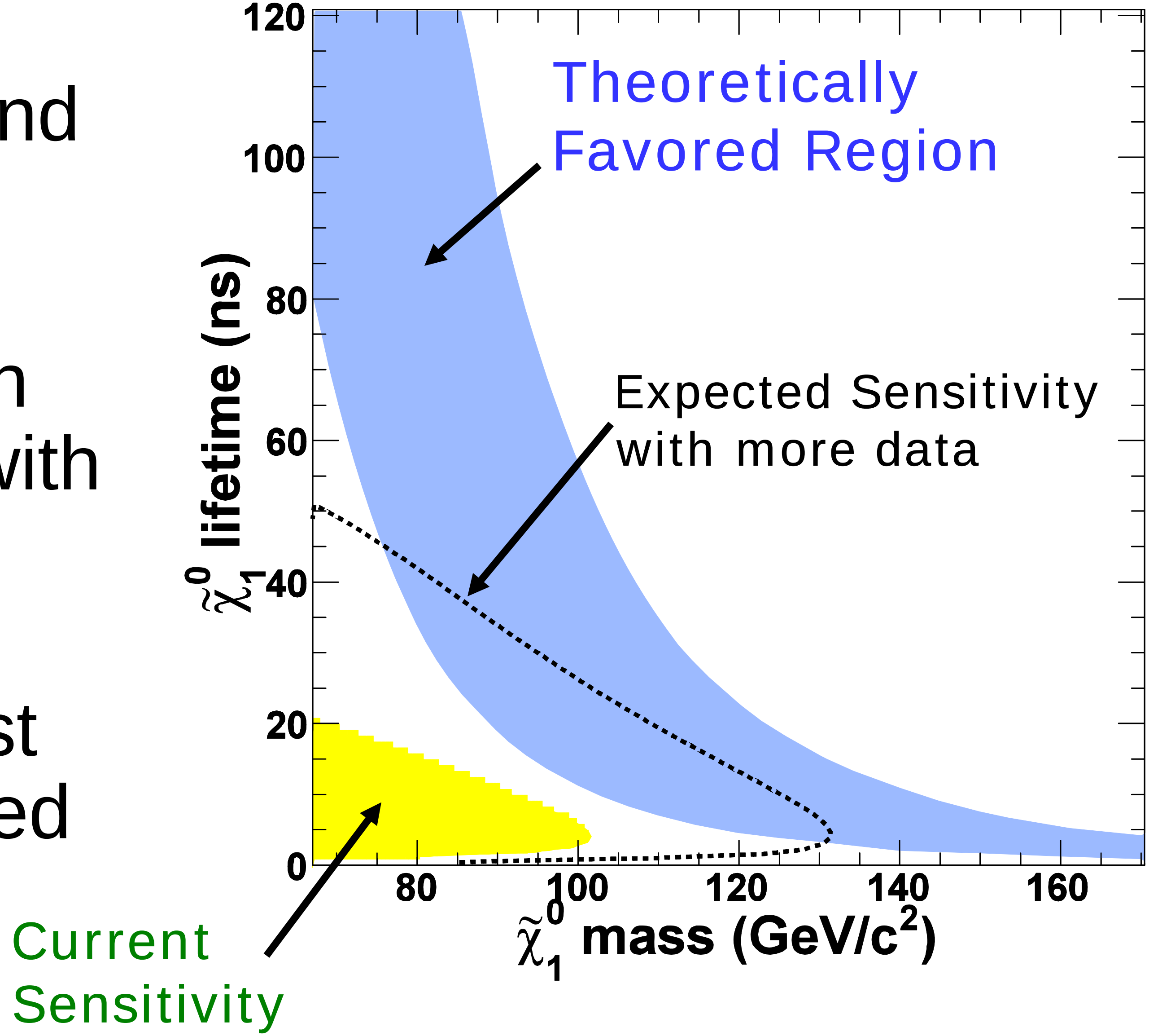


Adding More Data

- The amount of data available for the analysis is now over 4 times as much as was used in the original analysis
- This alone will greatly increase the sensitivity of the search

Results/Predictions

- Our current and predicted sensitivities
- The prediction will improve with better search techniques
- We are almost into the favored region



Conclusion

- With additional data and the improvements I have described, our prospects for discovery are promising

- With luck, we may be able to solve the cosmological mystery of dark matter