Cosmology Inspired Models of Supersymmetry that can be Searched for in Collider Experiments

Sean Yeager
Rutgers University
Department of
Physics and Astronomy

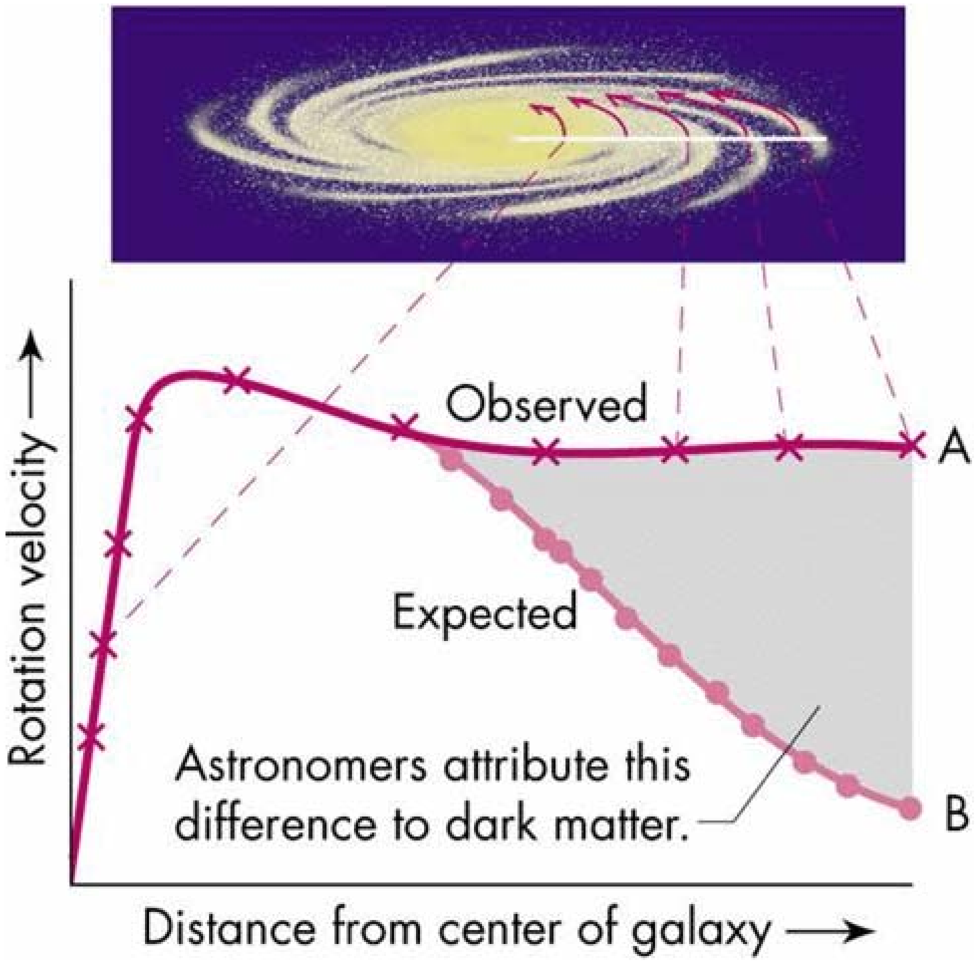
Advisor: Dr. David Toback

Overview

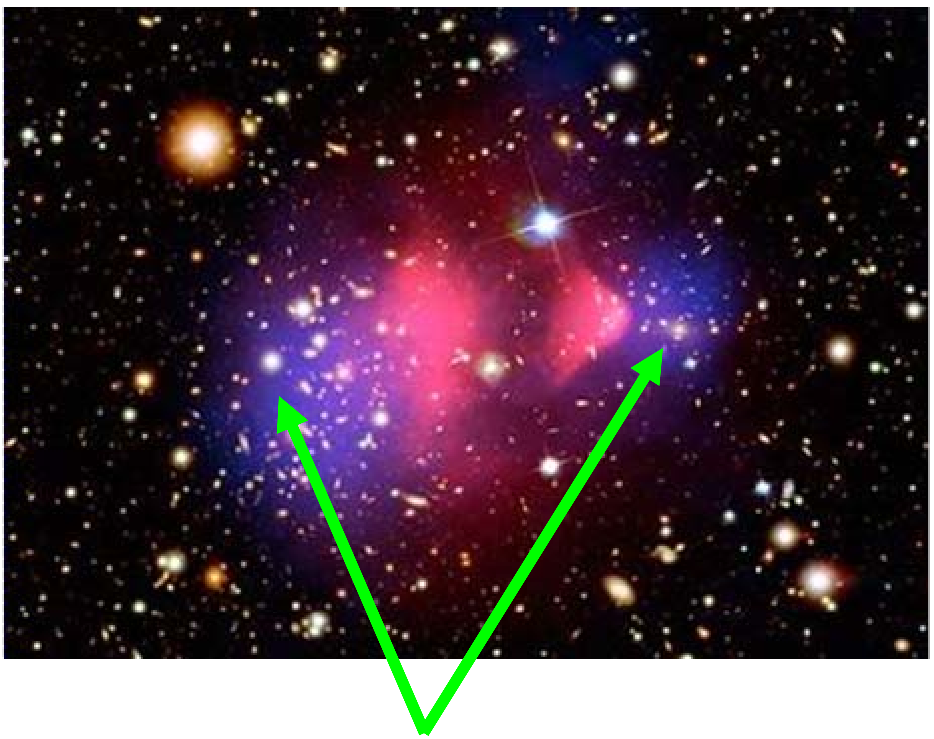
- The Dark Matter Problem
- What is Supersymmetry (SUSY)?
  - Problems it solves
- Searching for SUSY
- Models of SUSY
  - Minimal Supergravity
  - Charged Massive Particles
  - Gauge Mediated Supersymmetry Breaking
- Current State of Affairs

The Dark Matter Problem: Galaxy Rotations

- Matter in galaxies that is far from the center is observed to have rotational velocities far faster than predicted



The Dark Matter Problem: Bullet Galaxies



Astronomers attribute this to dark matter

- The remnants of a galaxy collision
- Red is observed baryonic matter, blue is additional unseen matter measured by gravitational lensing

SUSY and How It can Help

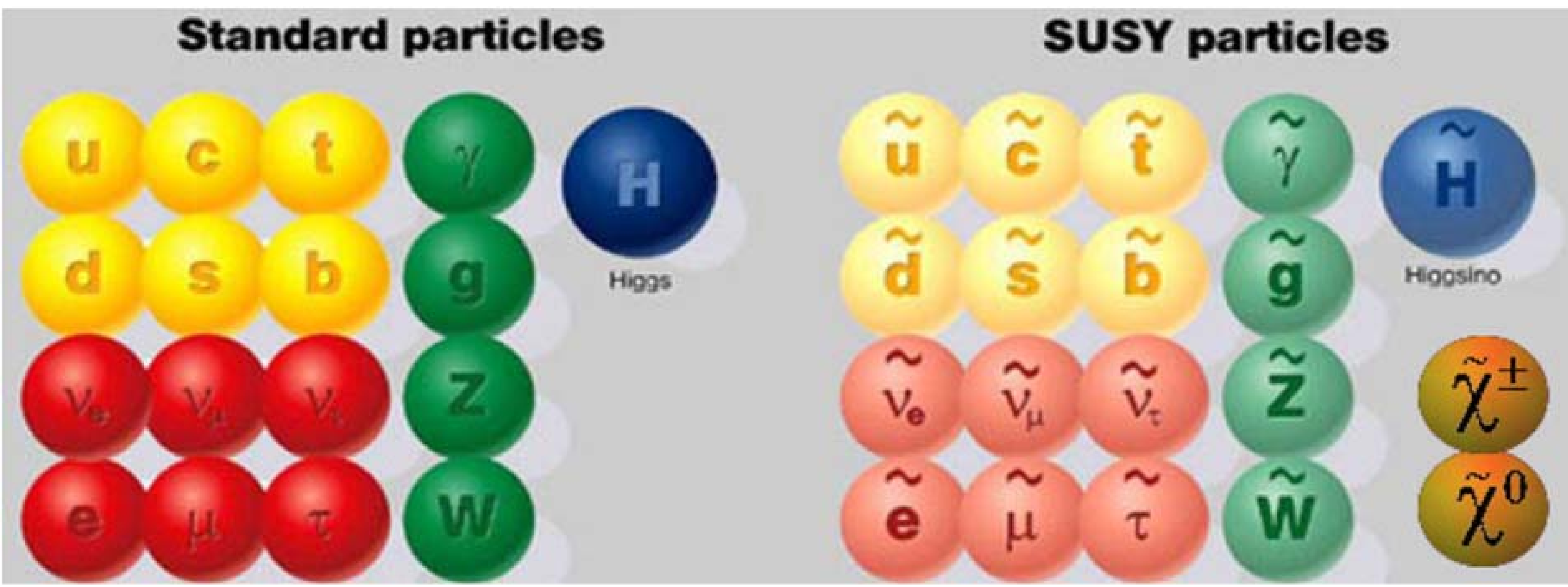
- Minimal Supersymmetric Standard Model
- New particles have spins that are reversed
  - A particle with a half integer spin will have a partner with a whole integer and vice versa
- Can predict a particle that is
  - Massive
  - Stable
  - Weakly interacting
  - Charge neutral

This is a dark matter candidate!

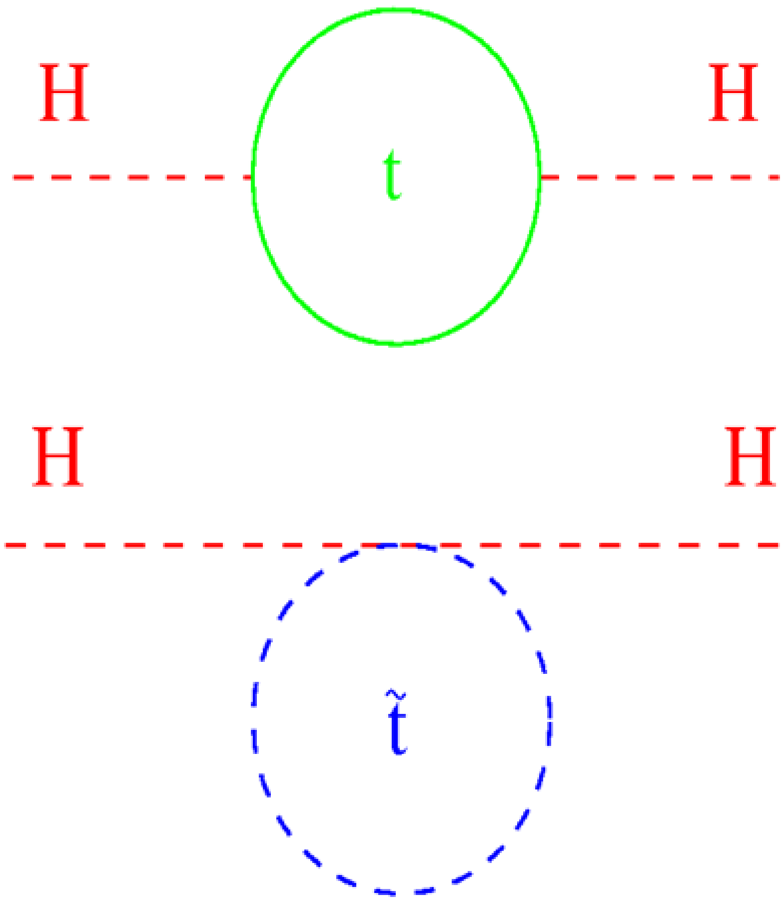
- These are the basics of SUSY; we are going to explore several versions

Naming

- Fermions → Sfermions
  - Quarks → Squarks
  - Electrons → Selectrons
- Gauge Bosons → Gauginos
  - Electroweak gauginos states mix
    - Charginos
    - Neutralinos



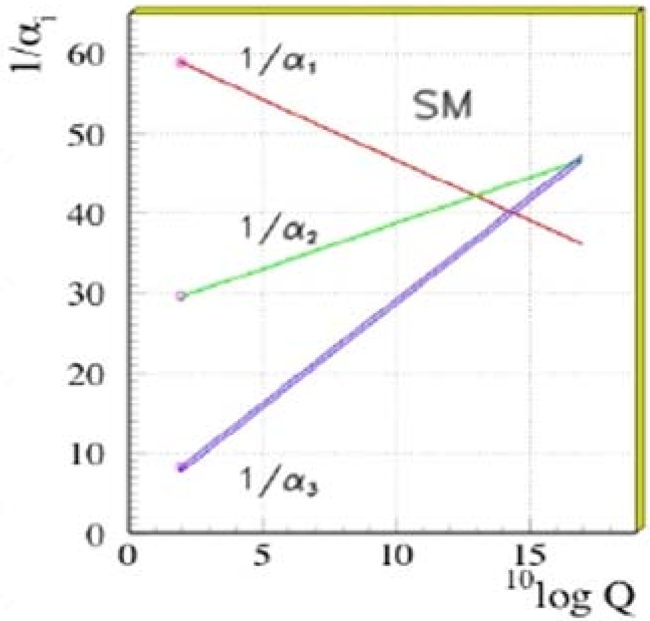
Reasons for SUSY: Corrections to the Higgs Boson

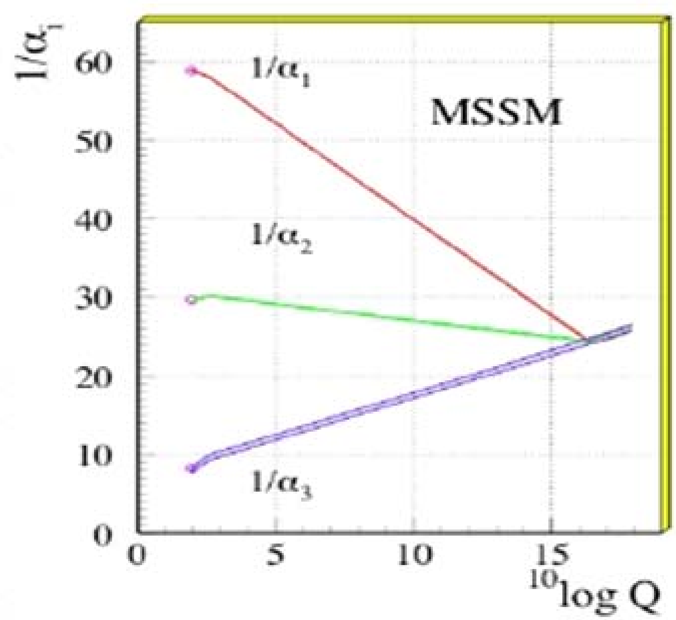


- Standard Model corrections to the Higgs boson's mass diverge
- When sparticles are included in loops, the corrections converge to a finite value

Reasons for SUSY: Convergence of the Coupling Constants

- Allows coupling constants for the Electroweak and Strong forces to converge at high energies
- No *a priori* reason for this, but Electroweak unification is suggestive



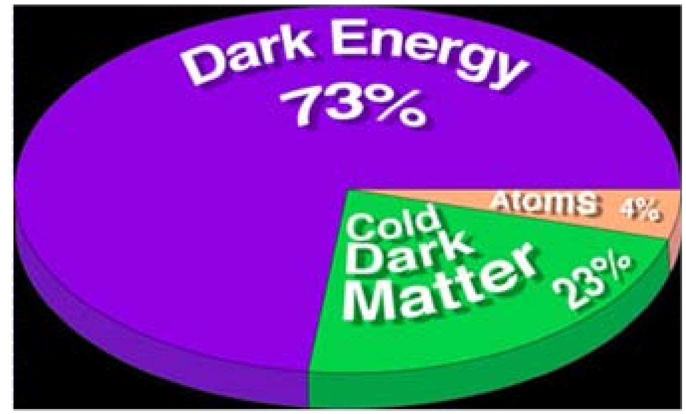


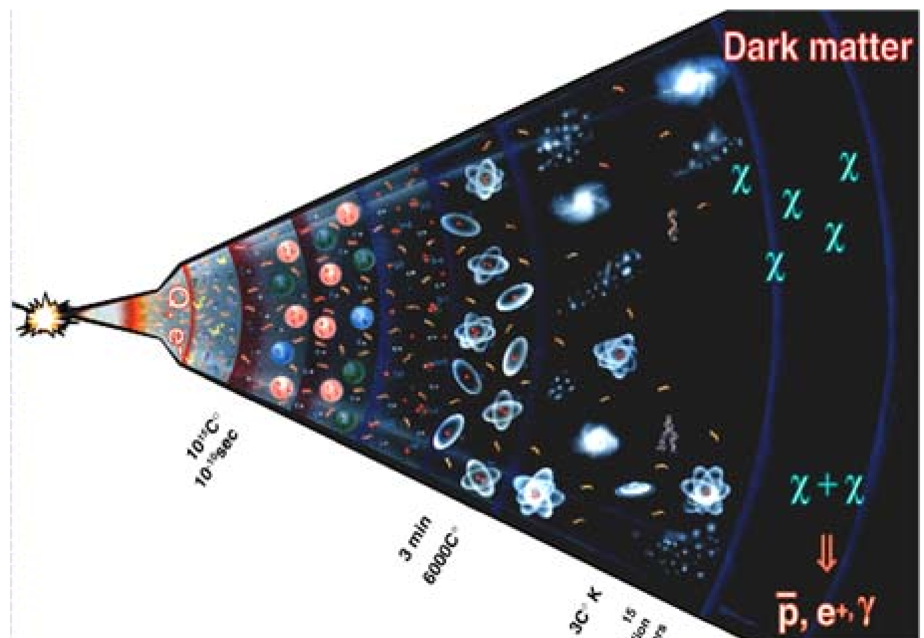
Constraints

- Broken symmetry → Sparticles must be much more massive (otherwise they would have been found long ago)
- Proton lifetime must be > 10^{36} years
- Define R-Parity as $(-1)^{3(B-L)+2S}$ and assert its conservation
- R-Parity will be 1 for SM particles, and -1 for sparticles
- This leaves nothing for the proton to decay to

Bridging the Gap

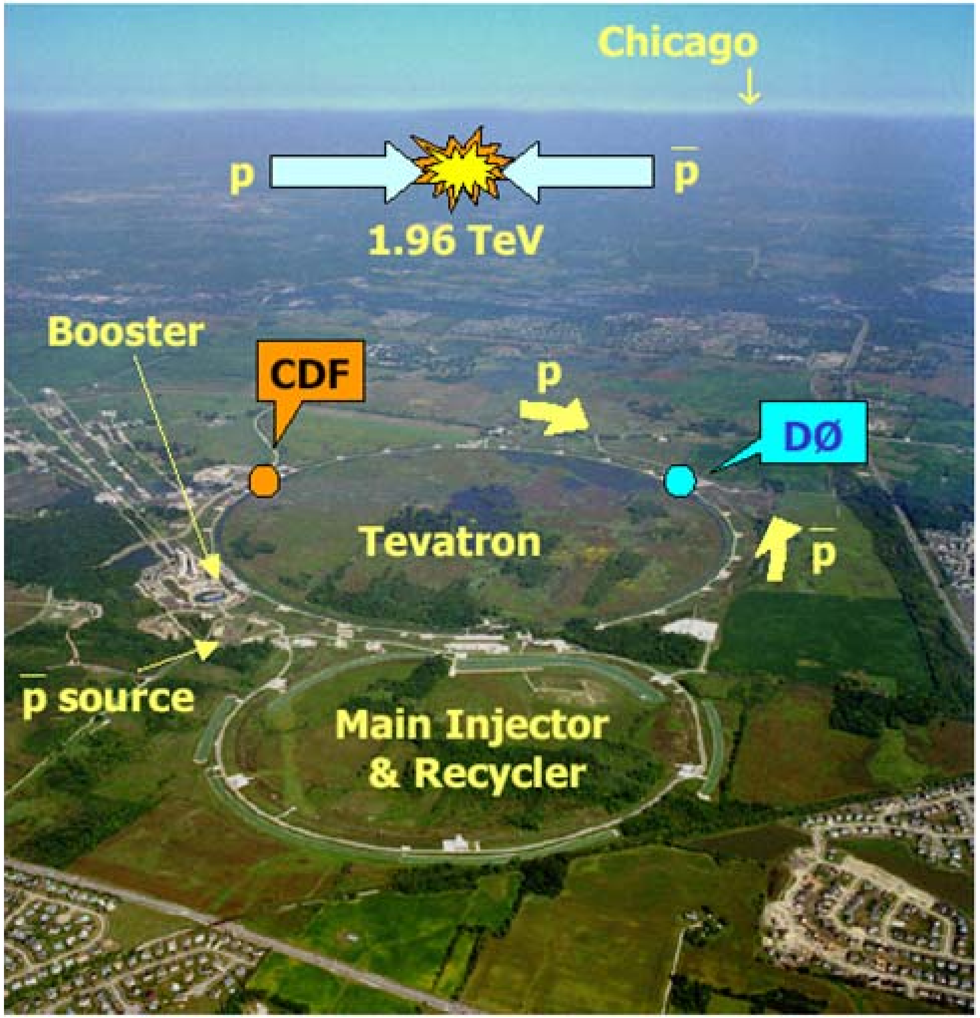
- Likewise, the Lightest SUSY Particle (LSP) would also be stable
- If neutral, it is a dark matter candidate
- Possibly provides a link between cosmology, astronomy, and particle physics



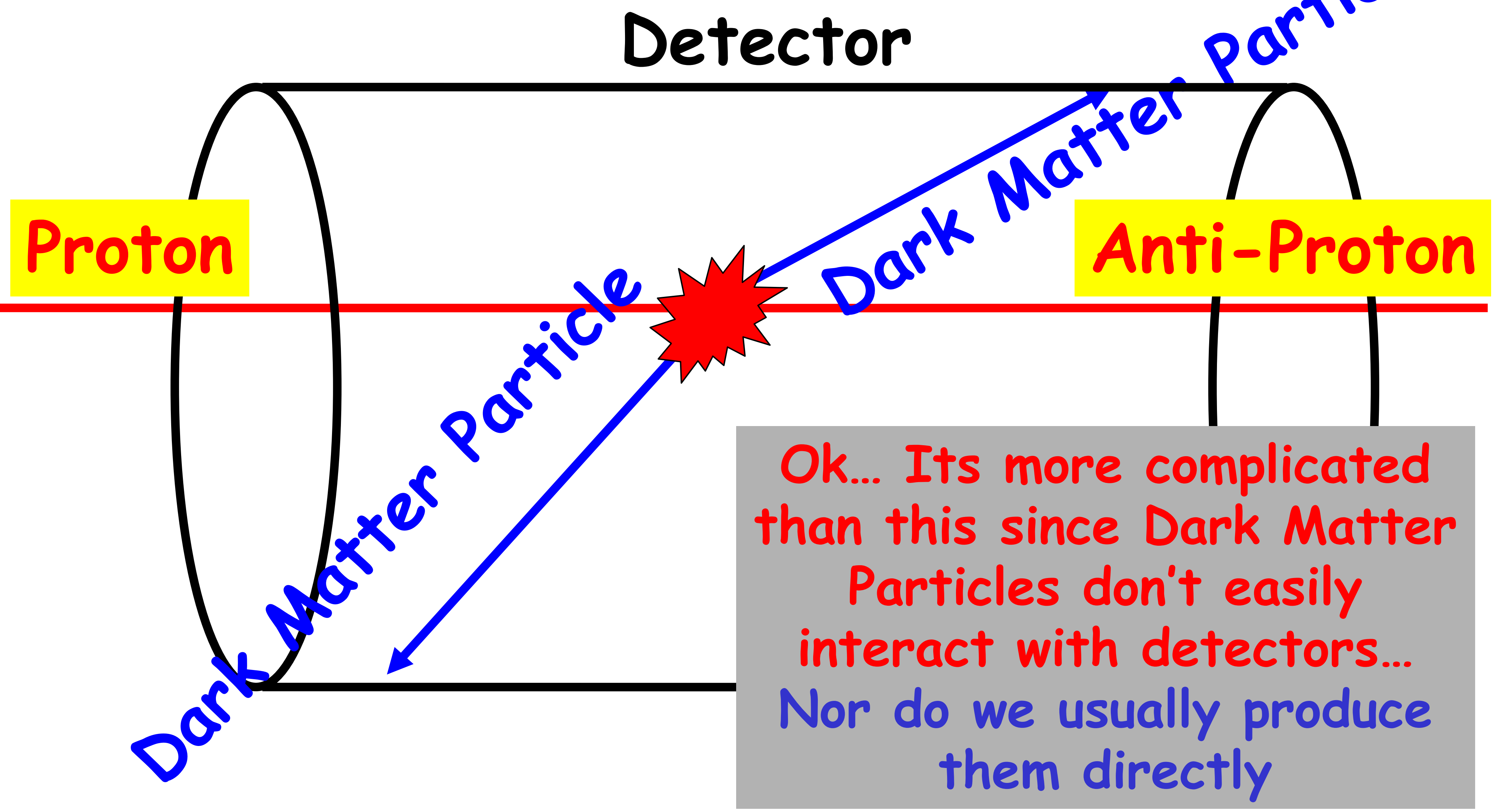


Desperately Seeking SUSY: The Tevatron at Fermilab

- Collide protons and antiprotons in the middle of detectors like the CDF and DØ every 396 ns
- Recreates conditions of the early universe
  - Energies of 2 TeV
  - About 10 ps after the big bang

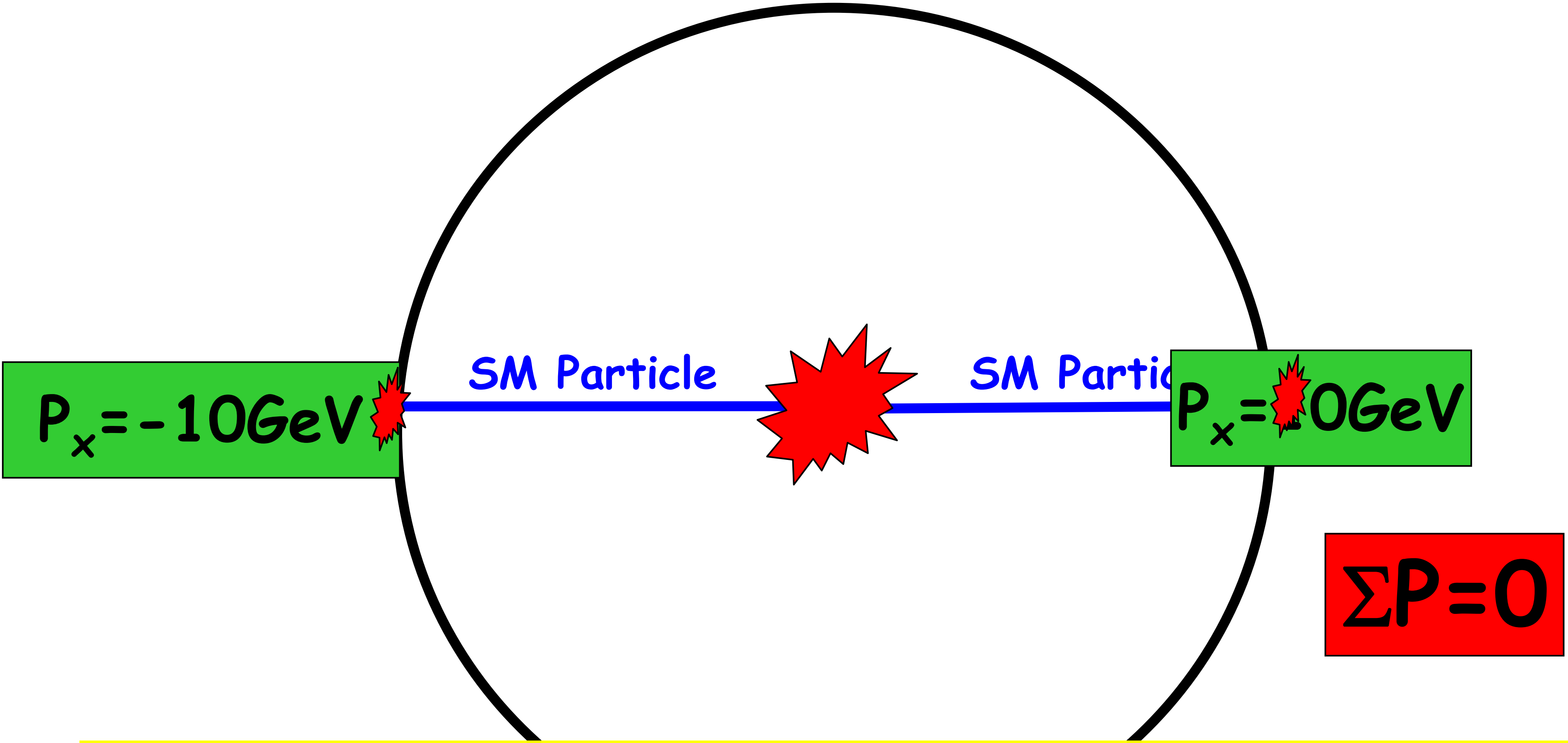


Particle Physics = High Energy Collisions



Now look at the head-on view of particles coming out

Detector End-View



Proton and Anti-Proton Collide in the middle and produce SM particles

Particle momenta measured by detector

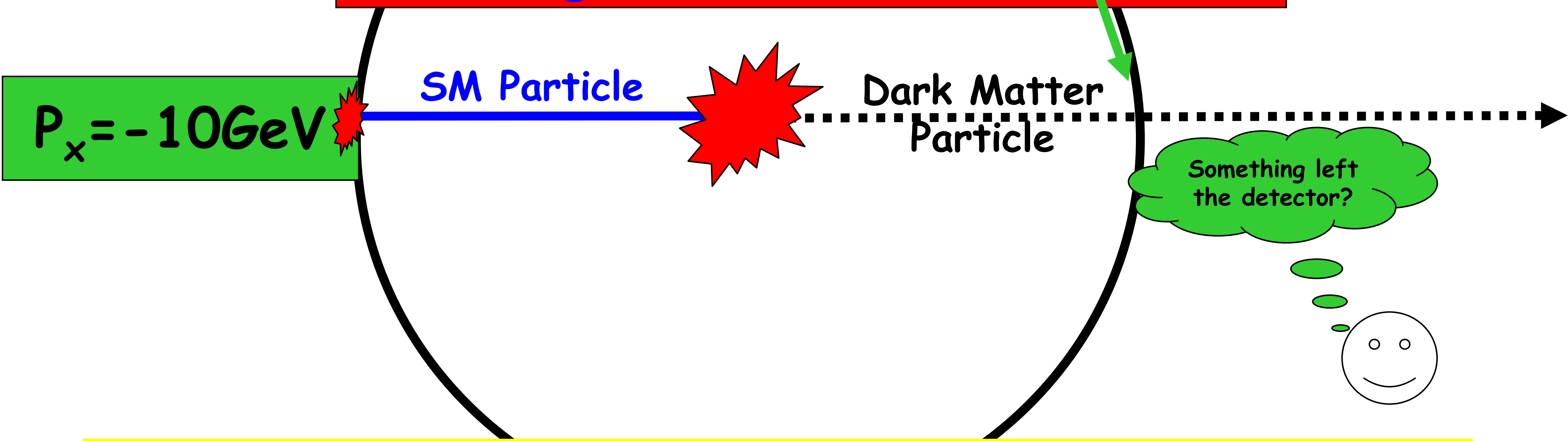
A Dark Matter and a SM particle at the same time?

$\Sigma P = -10$ GeV

in the *x*-direction

→Missing Energy!

Smoking Gun for Dark Matter



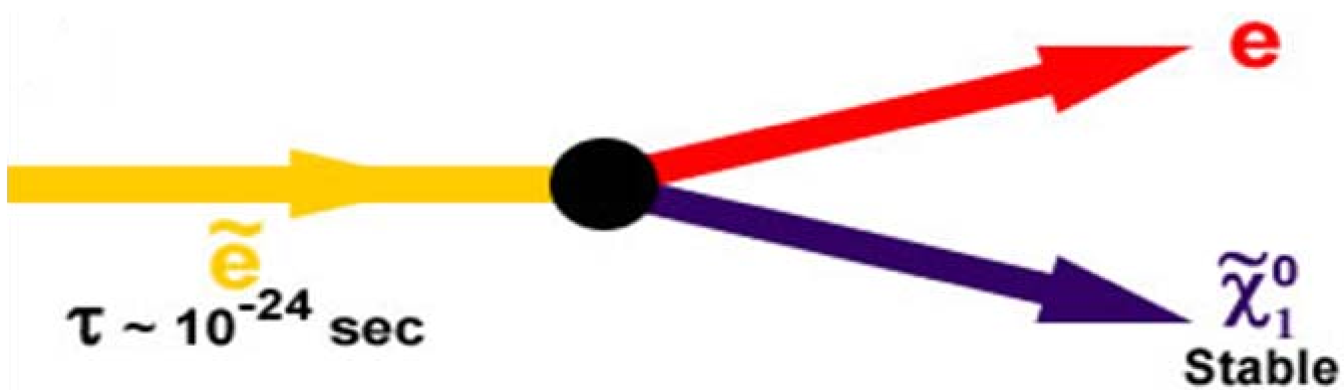
SM Particle Deposits energy, but Dark Matter particle doesn't interact with the detector and leaves

A Smoking Gun...

- Missing transverse energy is a key signal of sparticle production
- Weakly interacting: rarely interacts with baryonic matter
- Hard to produce: Harder to detect
- Worse problem than neutrino detectors face

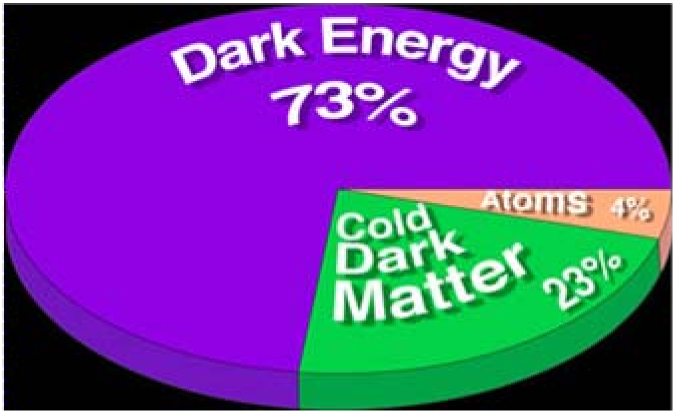
Minimal Supergravity: mSUGRA

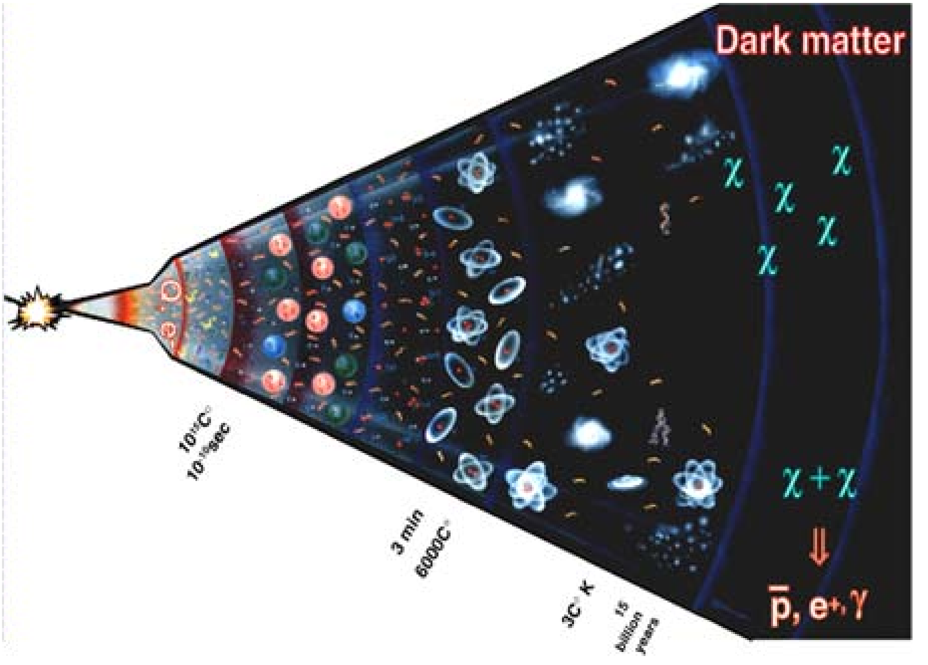
- Simplest model of SUSY that includes potential unification with gravity
- All other sparticles quickly (10^{-24} s after the big bang) decayed into the LSP
- LSP is usually the lightest neutralino and its mass is predicted to be around 100 GeV
- Would still be around today and make up all of dark matter
  - Is a favored dark matter candidate



But...

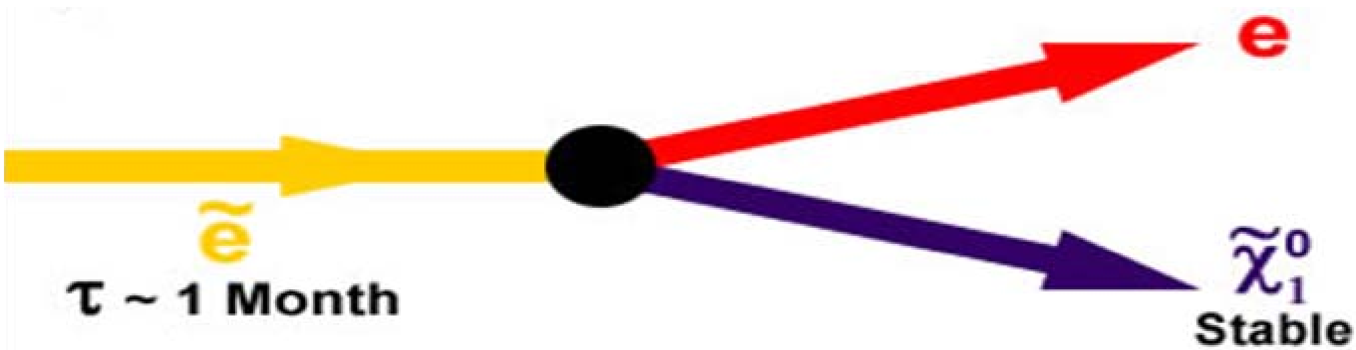
- In this model all dark matter has been the same particle since about 10^{-24} s after the big bang
- There's no reason why nature needs to be this simple
- Compare to role of quarks and atoms in the early universe





Charged Massive Particles: (CHAMPS)

- Once again, dark matter today is made of LSP
- Add more sparticles to affect the physics of the early universe
  - Stable on the time scale the early universe, but decay to the LSP shortly afterwards
- After the temperature of the universe fell below a certain level, sparticles stopped being produced in collisions

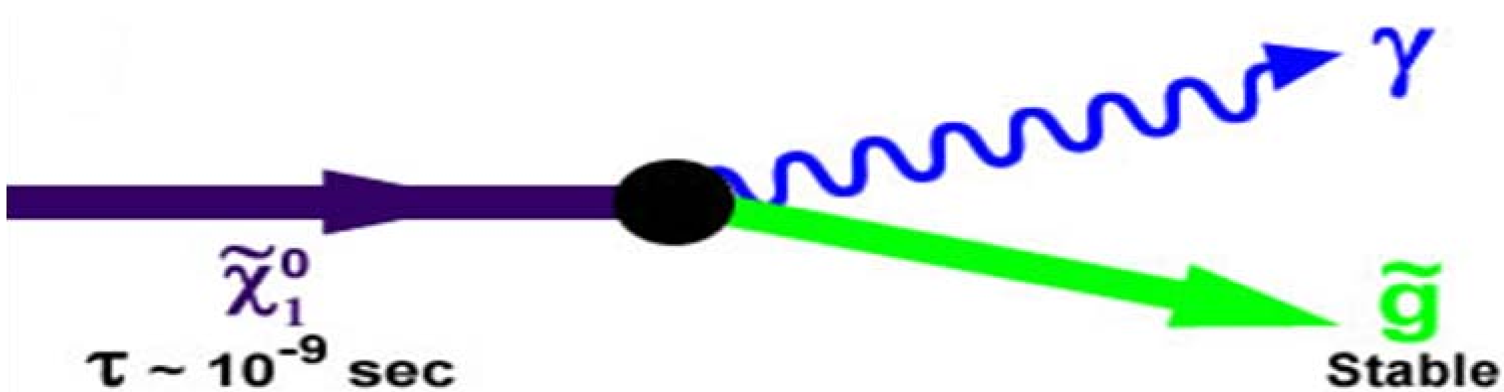


Other Parameters

- The lifetime of the LSP is an important parameter, but clearly not the only one of consequence
- The LSP's mass is another crucial parameter

Gauge Mediated Supersymmetry Breaking: (GMSB)

- The graviton is assumed to exist and its sparticle, the gravitino, is the LSP
- May have a heavy mass, although still much lighter than in Supergravity models
- Here, the lightest neutralino is stable during the early universe, but decays to the gravitino



Nothing in Common?

- Perhaps SUSY is a correct description of nature, but is completely separate from dark matter
- Experimentally this makes figuring out where to look
  - Whimsical side note: Axions
  - Named after a detergent because they “clean up” the situation

The Current State of Affairs

- So far there is no evidence for SUSY
- The Large Hadron Collider is not running yet
- The Tevatron keeps delivering more and better data
- The Large Hadron Collider will be running soon
  - (knock on wood)
- A plethora of exciting new physics is waiting to be explored

Acknowledgments

- Dr. Toback
- Dr. Yennello
- REU Program
- Department of Energy
- National Science Foundation