Search for A New Particle Using ppbar Collision Events

Eunsin Lee
Department of Physics
Texas A&M University

Outline

- Analysis Process
- Hardware Tools
- Optimization
- Conclusion

Analysis Process

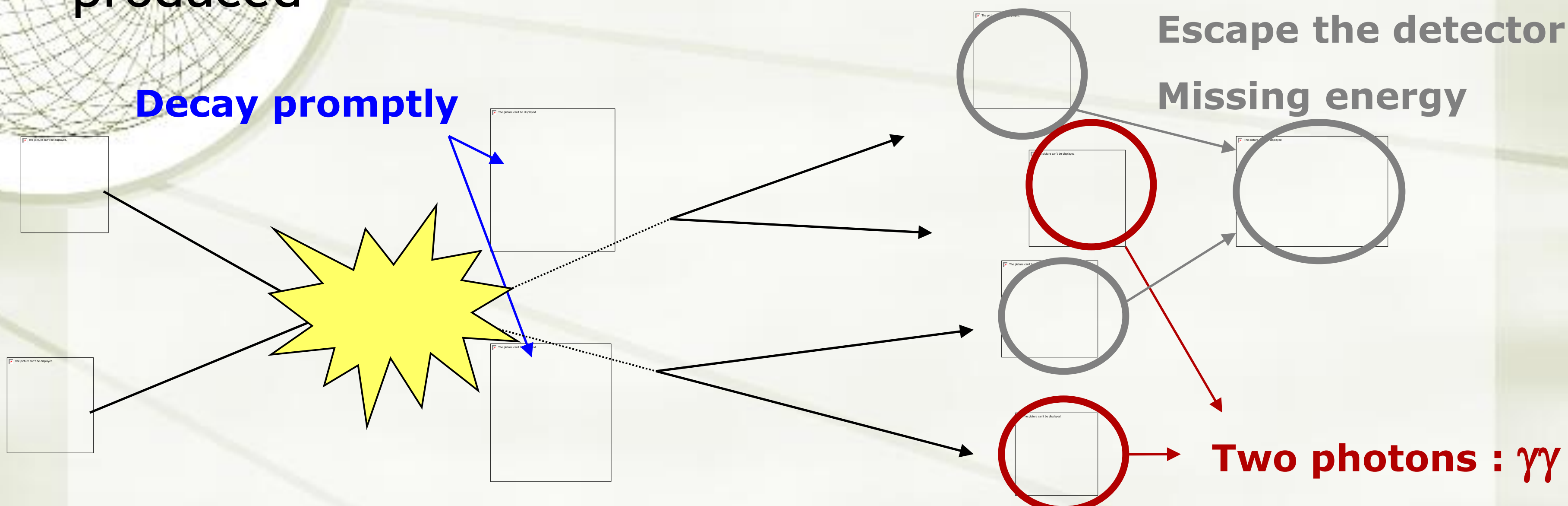
Search Experiment

- Search for a new particle in high-energy physics involves

1) Collect a large number of collisions
2) Select interesting final state objects (photons)
3) Separate events produced by a particular signal process from those produced by a set of well-known background process
4) These results in a small number of events passing our selection requirements, consistent with the expectation from a calculation of the expected backgrounds
5) Determine the search sensitivity by setting an upper limit on the signal hypothesis parameters, using optimization procedure

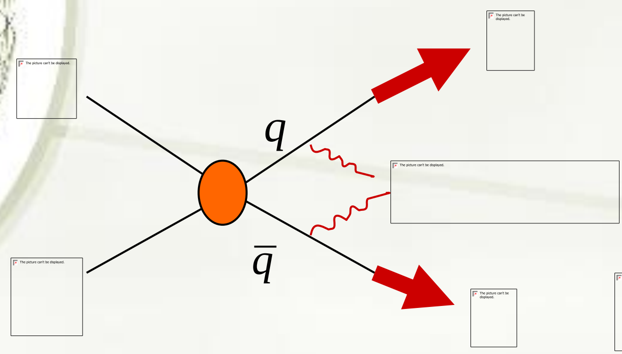
A New Physics Event Signal

- A new physics predicts that in the Tevatron (collision) a pair of new heavy neutral particles (: neutralino) produced

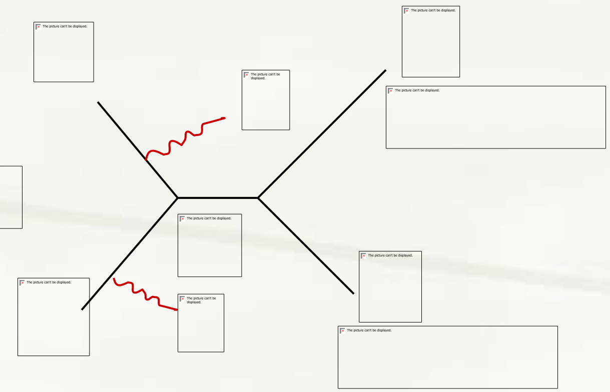


- decays into an undetectable particle (:gravitino), that gives rise to energy imbalance, missing energy ( ), and a photon
- Focus on both 's can decay in the detector:

The Well-known Backgrounds

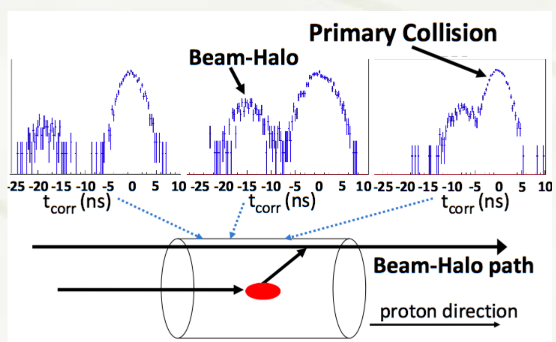


QCD Background



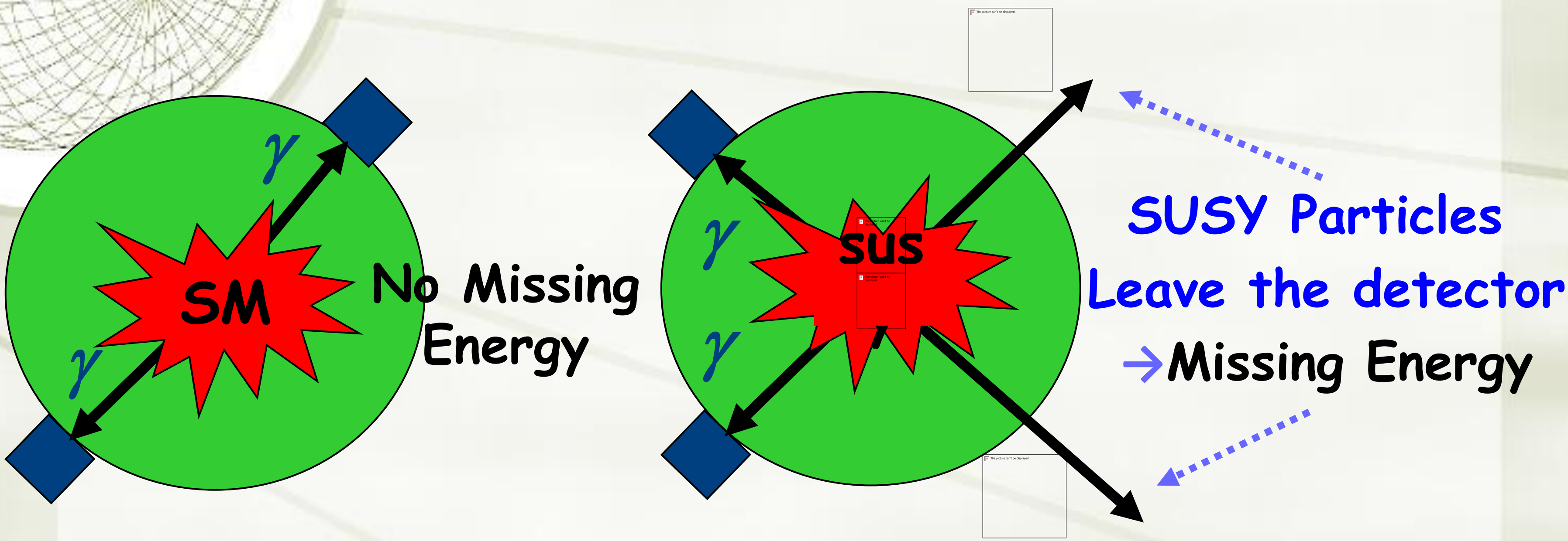
EWK Background

Non-collsion Backgrounds



Non-Collision Background
: Cosmic and Beam effects

SM Particle vs. New Particle



⇒ SM particle deposits energy, but new particle doesn't interact with the detector and leaves

Going from Collisions to Experimental Results

Look at lots of collisions (call them events) and identify the ones that pass the "New Particle Identification Requirements"

$$N_{signal} = \text{Luminosity} \cdot \sigma \cdot \text{Acceptance}$$

- N_{signal}: How many collisions (events) pass all our requirements
- Luminosity: How many proton anti-proton collisions happened
- σ: How often a proton anti-proton collision produces a SUSY event
- Acceptance: How well the detector does at detecting SUSY events

Number of background events from Standard Model Sources follows the same procedure

Analysis Overview

- An *a priori* analysis where we look at all events that have two photons
  - Use CDF detector (EM calorimeter and photon timing system)
  - Require good photon identification
- Estimate the backgrounds for this sample as a function of various requirements
- Optimize with background predictions and signal acceptance to get best sensitivity
  - Implement photon timing simulation into signal MC sample
  - Use limit calculator based on Bayesian method

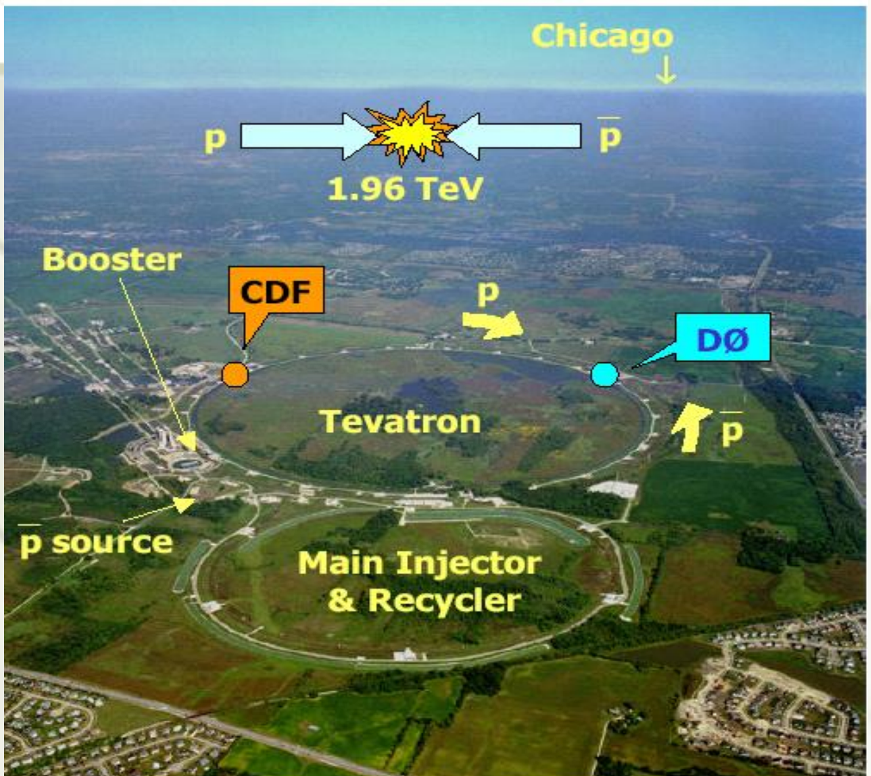
Hardware Tools to Identify Photons

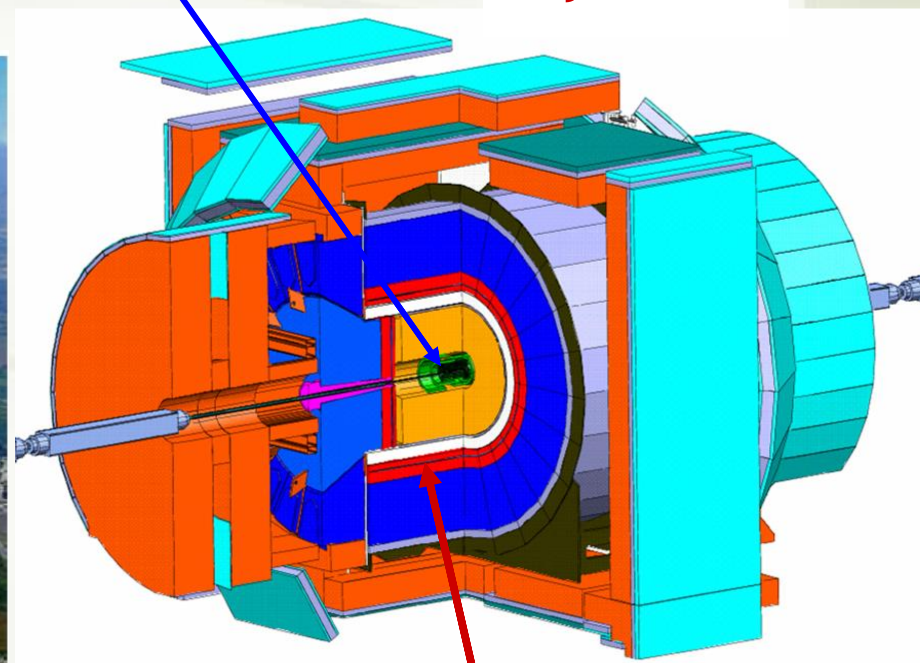
Tevatron Particle Collider at Fermilab: Collider Detector at Fermilab (CDF)

The Tevatron (accelerator) : to produce high energy proton-antiproton collisions

Surround the collision point with a huge detector

CDF : To study the collisions





EM Calorimeter: Photon timing + 4-momentum

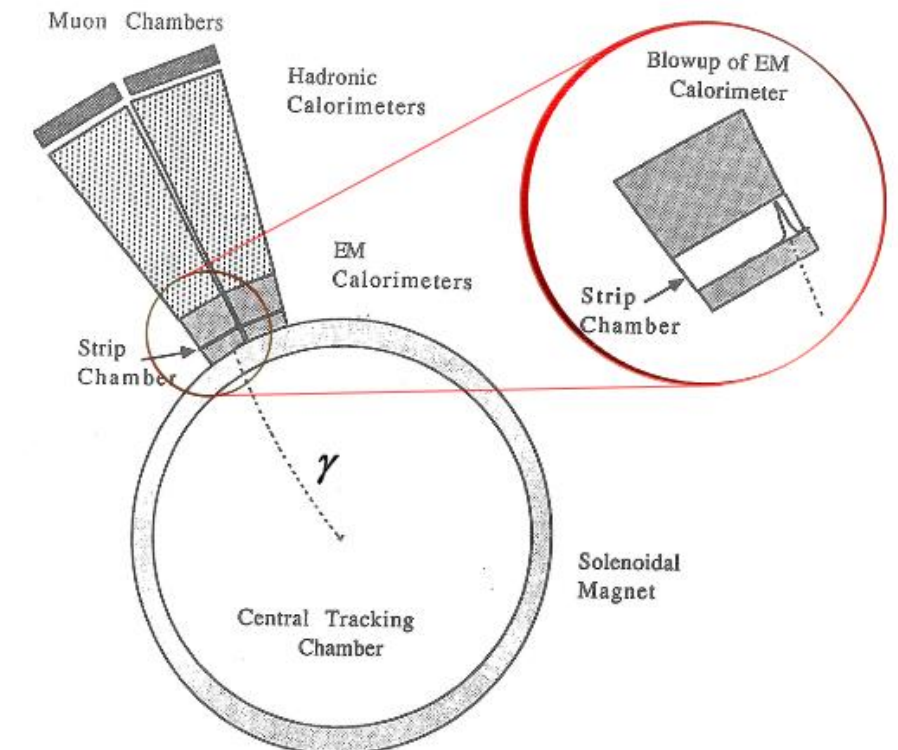
Inside the Accelerator

- Proton-antiproton bunches are counter-rotated in the Tevatron accelerator and collide every 400 ns

EM Calorimeter

- CDF uses a scintillator based sampling calorimeter detector: measure the energy deposition of particles
- When photon interacts with heavy material in the calorimeter it creates a cascade (“shower”) of electron, positron, and photon with light emission
- The light is readout by PMT with output being proportional to the total energy
- Energy resolution:

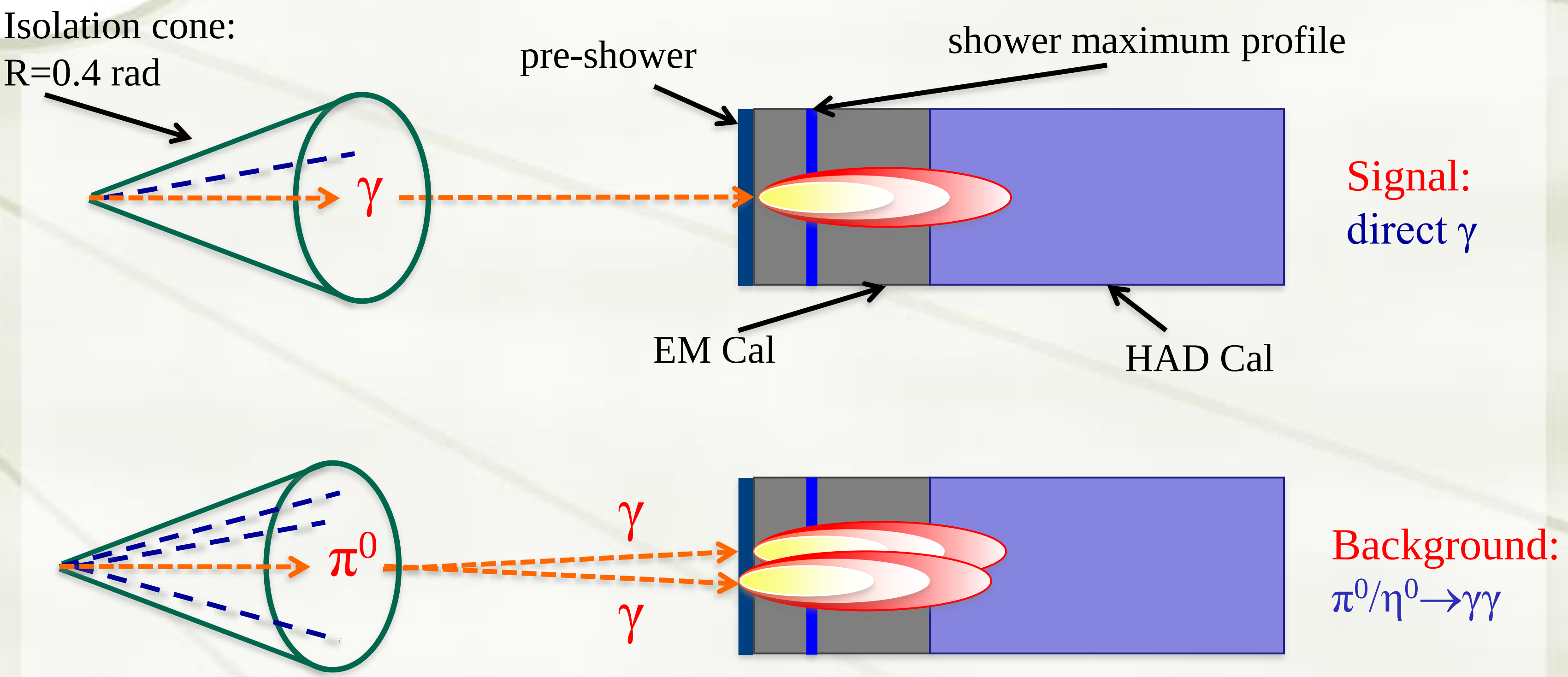
  $\sigma(E)/E = 13.5\%/\sqrt{E_T}$



- Strip/Wire Gas Chamber used to refine the position of a photon, located where the EM shower has its maximum, using its shower profile
- Position resolution: 2 mm

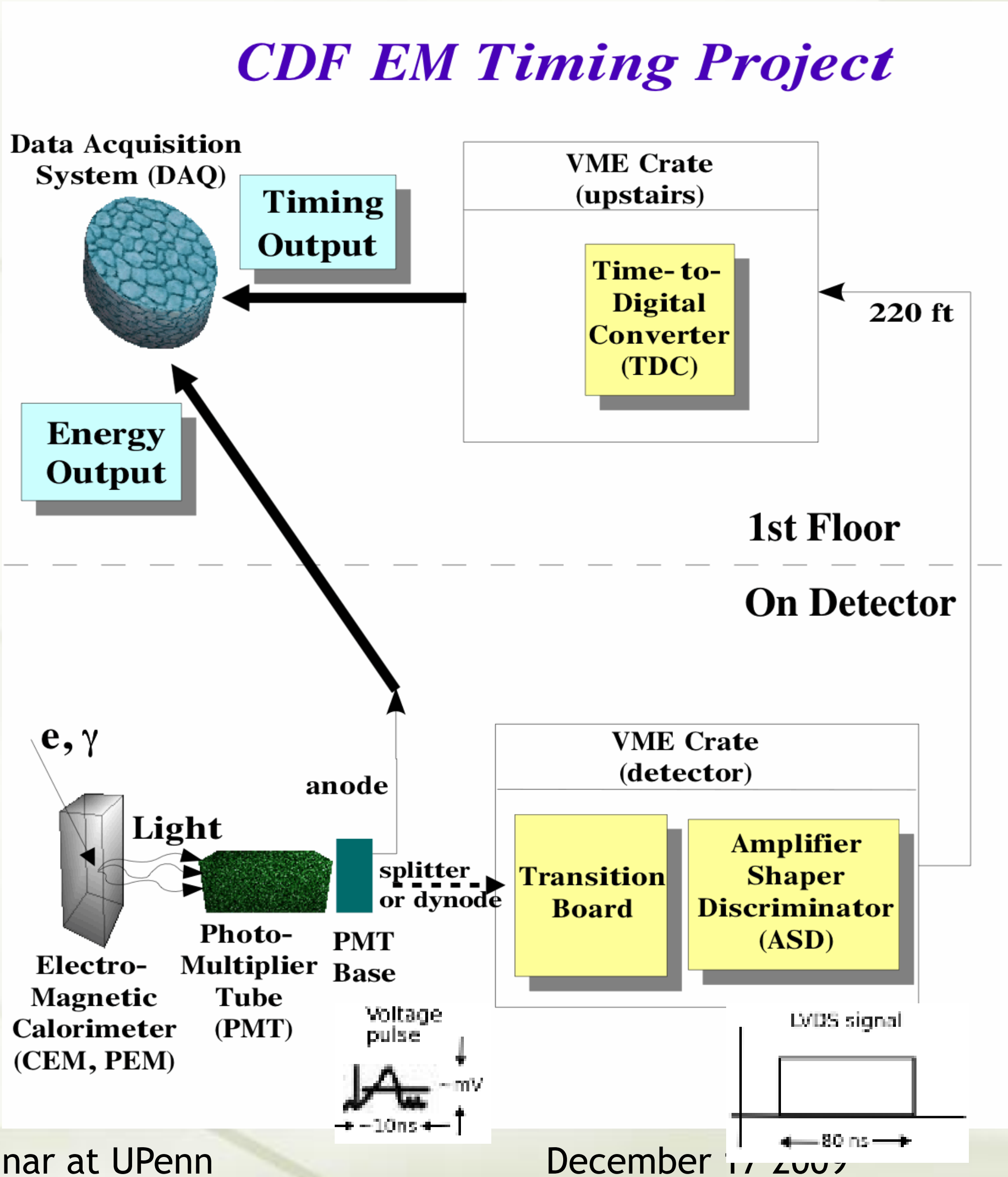
Concept of Photon ID

- Photon signature
  - "Compact" EM cluster: shower contained in EM calorimeter
  - No electric charge: no track (unlike electron)
  - No color charge: unlike π^0, photon is isolated object



The EMTiming System

- Provides time of arrival of photons at calorimeter
- Timing resolution: ~0.5 ns
- 100% efficient for photons with E_T>13 GeV



Photon Timing (EMTiming) Simulation

- EMTiming System is simulated using MC that is run, independently, after event generation (PYTHIA) and detector simulation (GEANT based)
- Goal is to reproduce the arrival time of single particles and handle with all MC particle types as in real data
- Takes into account physics effects like vertex position and event time
- Correct for energy slewing effects as well as channel-by-channel energy threshold

MC Generation and Reconstruction

- 6 steps of the process of turning MC events into TDC readout

- 1. Calculate the true arrival time and correct for the time of flight(TOF) and vertex time

For example, for neutralino decaying into a photon and a gravitino, t_{vert} is the time the neutralino decays

- 2. Check to see if it hits an EMTiming-instrumented part of the detector
- 3. Smear the corrected arrival time for the intrinsic resolution
- 4. Check to see if it has energy to create a hit
- 5. Convert the generated arrival time to a raw time using the ASD (Amplifier Shaper Discriminator) slewing curve
- 6. Truncate the raw time to an integer to simulate the TDC

Optimization

Optimization Strategy

- Take the diphoton data sample and then do an optimization
- Consider various requirements, choose the one that gives the best sensitivity
- Find these optimal requirements by calculating the 95% C.L. expected upper cross section limit (Bayesian method)

Upper Limits (Bayesian method)

- In counting experiment, given the number of observed event, n_0, the probability P for observing *that number* depends on the mean number of events expected, μ, according to the Poisson distribution

- The sensitivity is estimated in the form of expected 95% C.L. upper cross section limits, σ_{95}(exp), using a Bayesian calculation with a constant cross section prior
- The Limit is calculated from the 95% C.L. upper cross section limits, $\sigma_{95}(N_{obs})$, based on the number of events N_{obs} "observed" in a pseudo-experiment, assuming no signal exists, using background and signal expectations

- The $\sigma_{95}(N_{obs})$ is determined from:

$$0.95 = \int_0^{\sigma_{95}(N_{obs},\mathrm{cut})} d\sigma \;\; \mathrm{Poisson}(N_{obs}, \mu_{exp}(\sigma, \mathrm{cut})) \qquad (7.1)$$

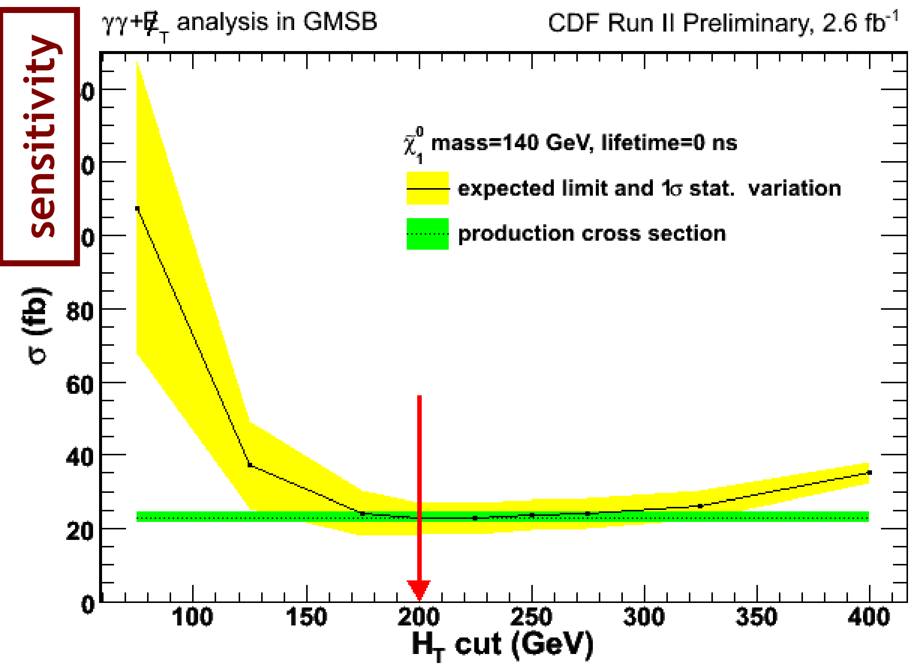
$$\text{where} \quad \mu_{exp}(\sigma, \mathrm{cut}) = N_{exp}(\mathrm{cut}) + \sigma \cdot \mathcal{L} \cdot (A \cdot \epsilon)(\mathrm{cut})$$

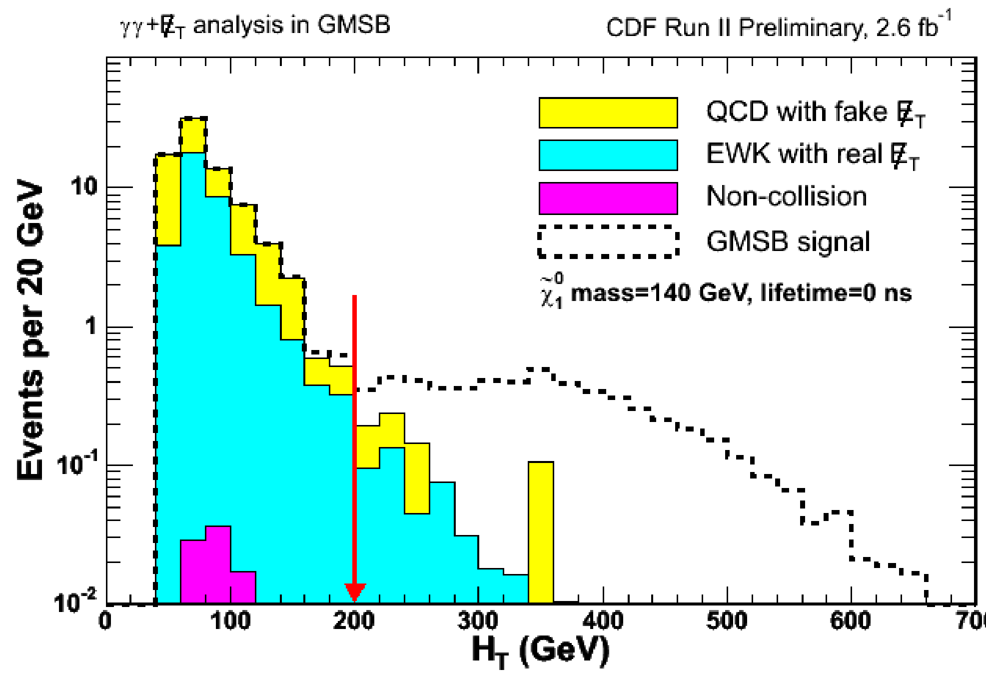
is the sum of the number of expected background (N_{exp}) and expected signal events, and Poisson(N_{obs},μ_{exp}) is the normalized Poisson distribution of N_{obs} with mean μ_{exp}.

- The uncertainties on the signal acceptance and background are treated as nuisance parameters with Gaussian priors (Bayesian)
- The expected cross section limit is given by averaging over Poisson probability

$$\sigma_{95}^{exp}(\mathrm{cut}) = \sum_{N_{obs}=0}^{\infty} \sigma_{95}(N_{obs}, \mathrm{cut}) \; \mathrm{Poisson}(N_{obs}, \mu_{exp} = N_{exp}(\mathrm{cut})) \qquad (7.2)$$

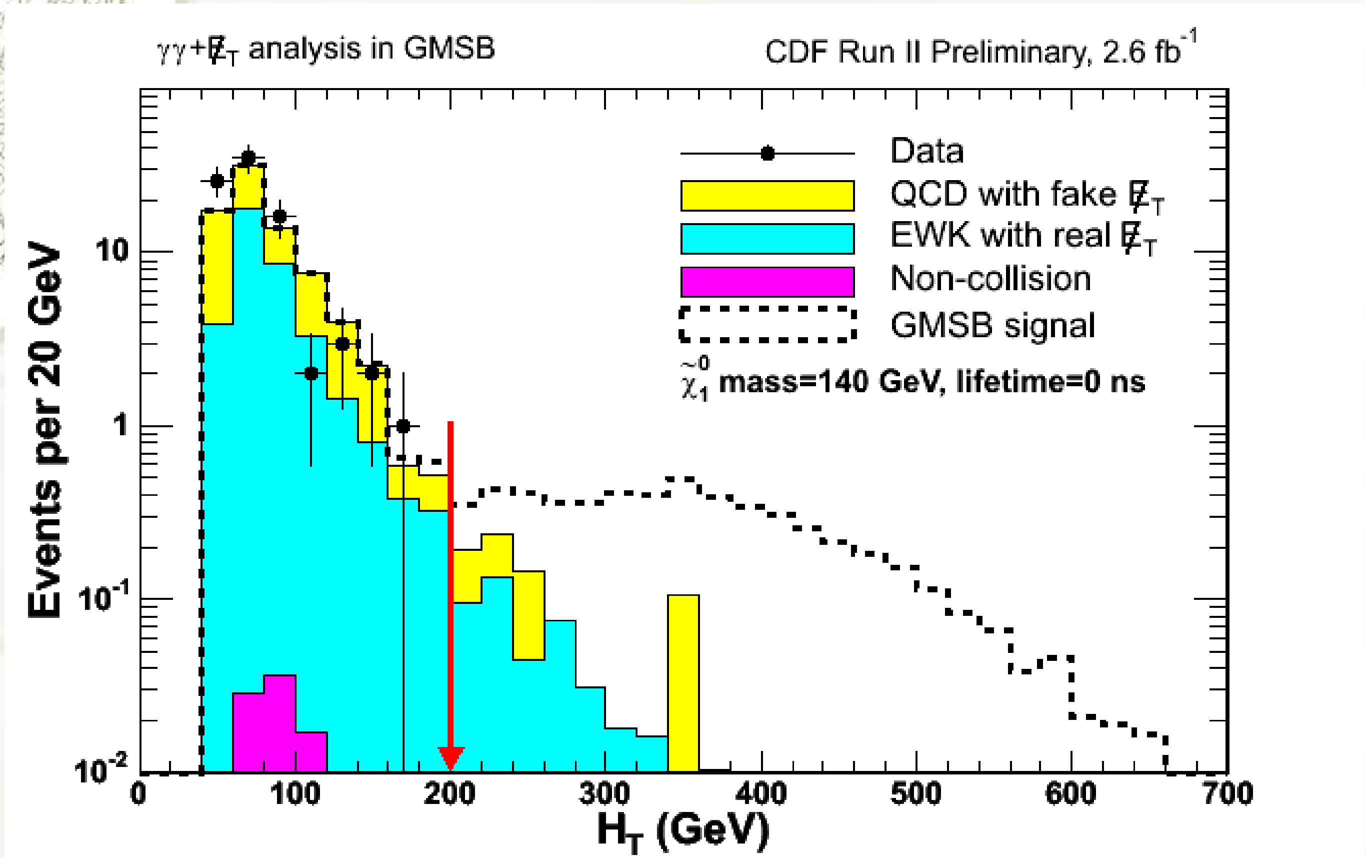
95% C.L. Cross Section Limits and Plot of H_T





- Optimization Result : Minimal at H_T=200 GeV
- H_T Plot for background distributions along with new physics signal: Good separation!

H_T plot along with Data



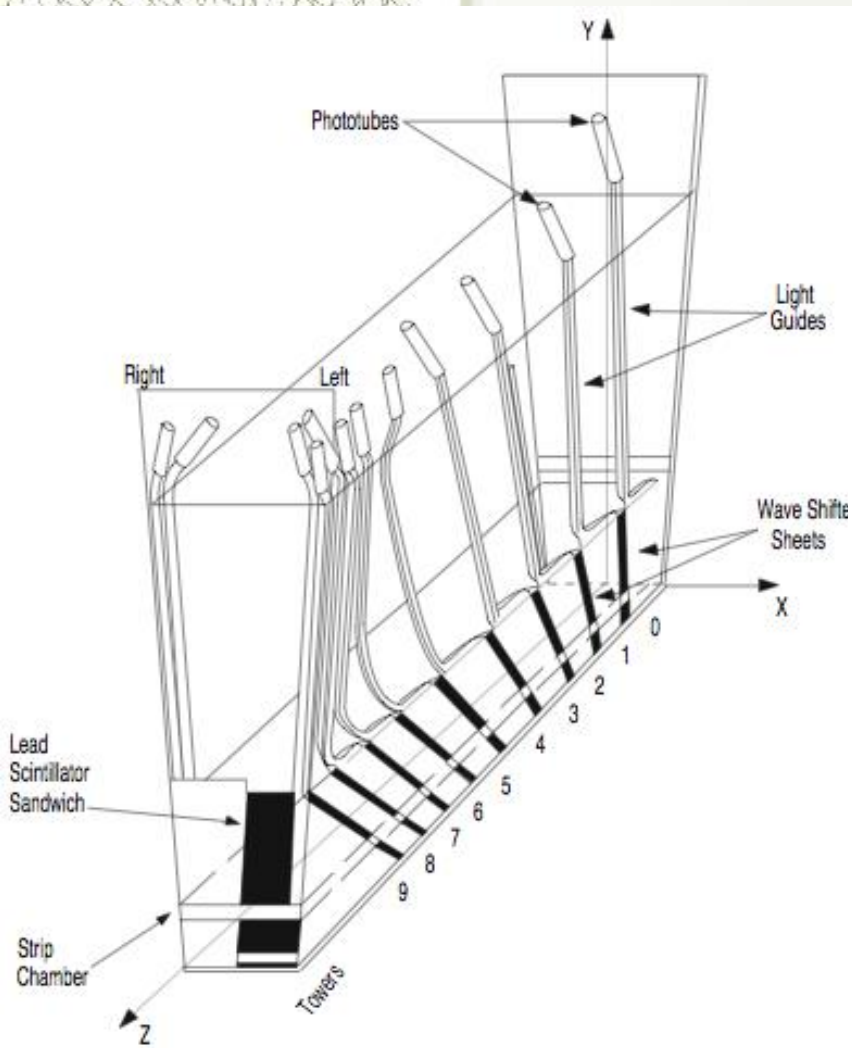
- Background estimations are well modeled
- After the H_T > 200 GeV no data event observed
  ⇒ "No new particle found"

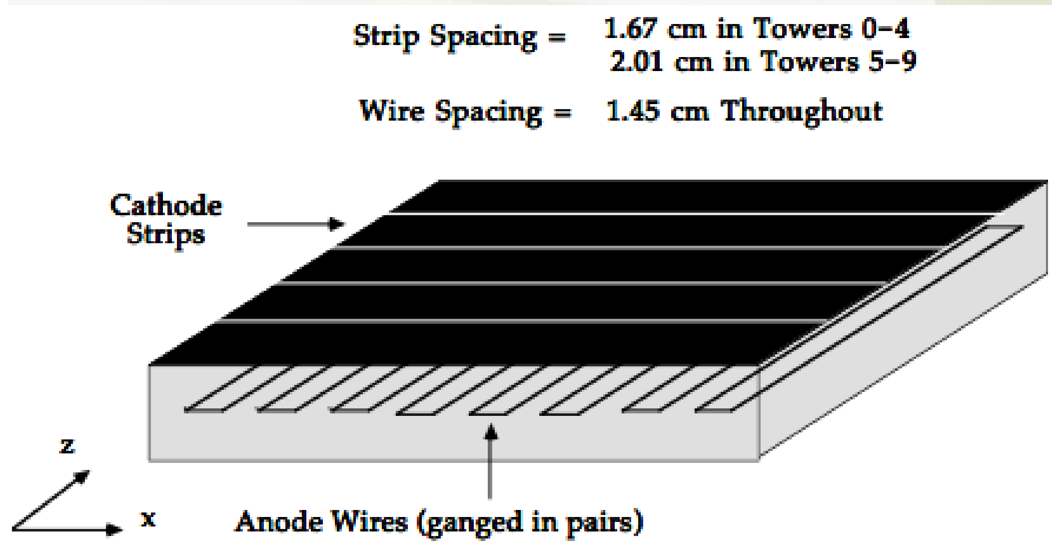
Conclusions

- We search for new particles using photon final states from high-energy proton-antiproton collisions collected by the CDF detector
- No such an event found so we set the world's best limits on this type of search sensitivity
- Expertise on photon identification using well understood detector and optimization techniques based Bayesian statistics will contribute the PET imaging project

Back Up

EM Calorimeter at CDF





Slewing Effects