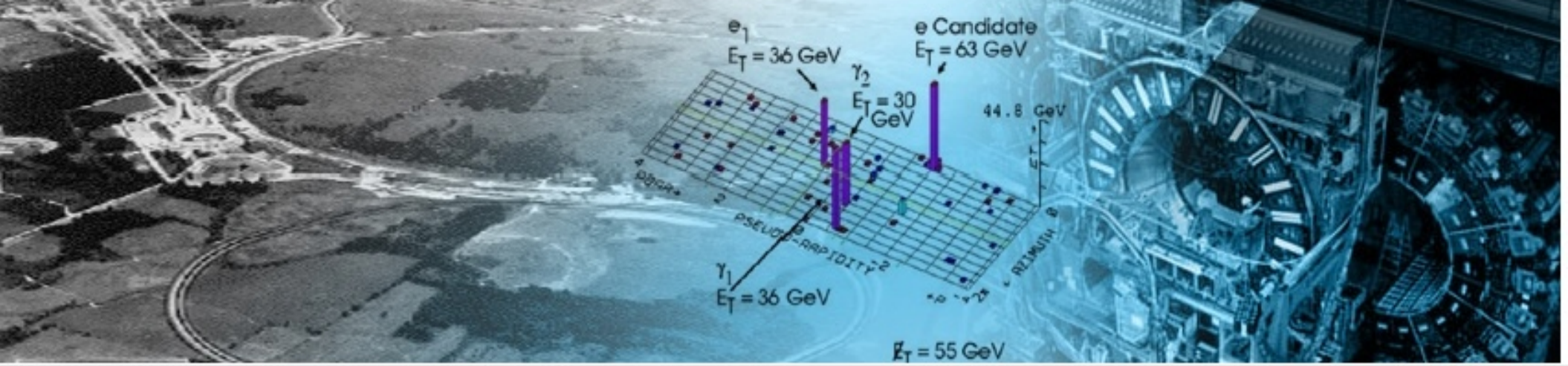


Searches for New Physics Using Photons at the Tevatron

David Toback

Texas A&M University

University of Wisconsin HEP Seminar

March, 2005

Overview

The next big discovery in particle physics may well come from looking at samples with final state photons

- This talk will cover a series of searches over the last ~10 years with final state photons
- Describe some of the important theories we've tested as well as some new model-independent methods we've developed to follow up on the interesting hints we've found

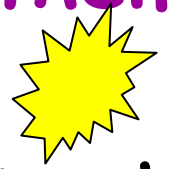
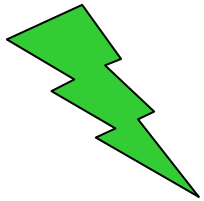
Motivation

There are two types of motivation for looking for new physics in final states with photons

1. Specific models
   - Most importantly Supersymmetry
2. Model independent searches which follow up on some of the anomalies from CDF in Run I

Color coding the recurring themes in the story…

Three recurring themes…

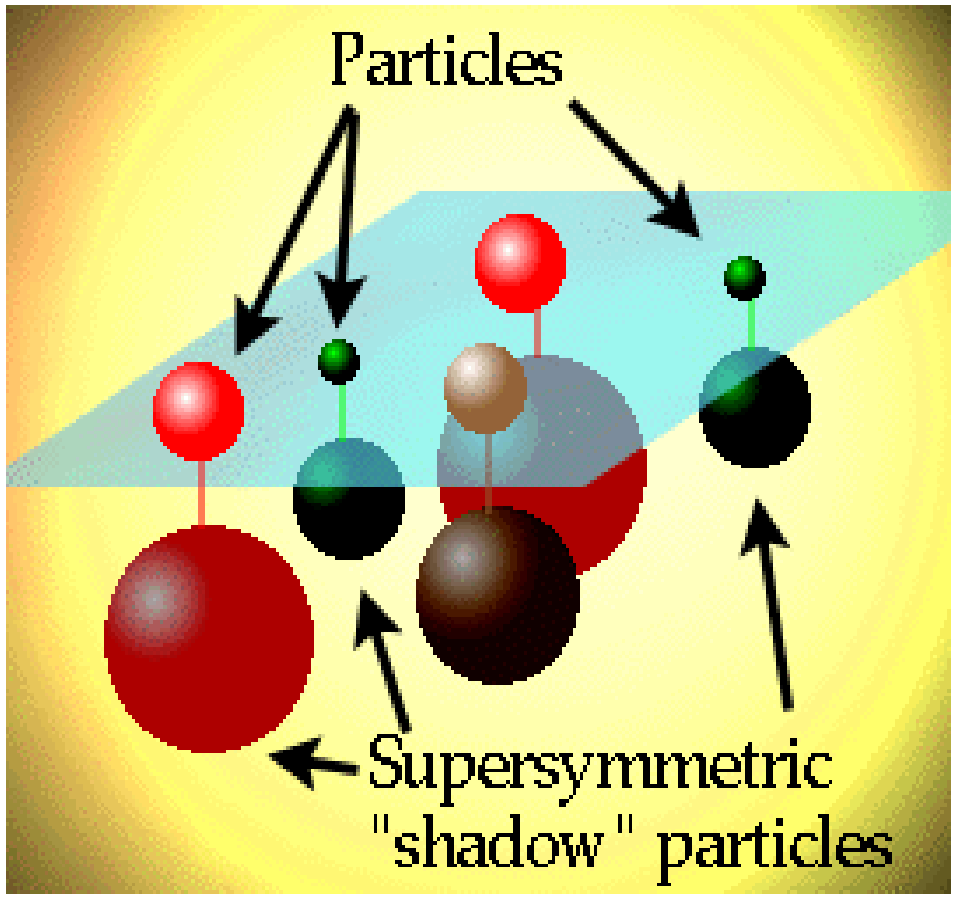
1. Golden Events 
   - Individual events which don't look SM-like and thus could be "hints" of what the new particles might look like
2. Null Results or Theory that doesn't explain the hints 
   - Mother Nature is fond of teasing those who try to understand her
   - Theories of new particles haven't helped as much as we would like
3. New ideas or new techniques 

Outline

- Supersymmetry and Photons
- Run I Results
  - The CDF $ee\gamma\gamma$ candidate event
  - Limits
  - Model-independent follow-up and other interesting hints
- Run II Results
  - New limits
  - Exciting new hints
  - Recently installed hardware
  - Prospects for the future
- Conclusions

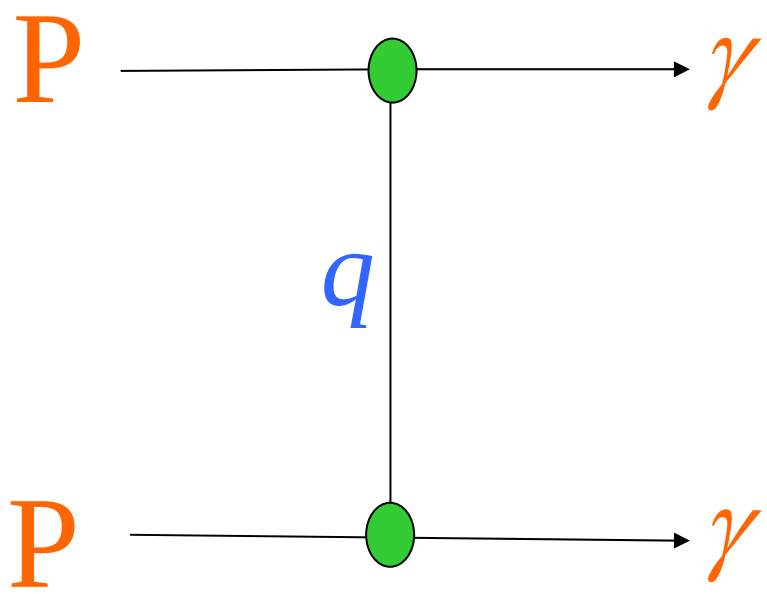
Supersymmetry

- One of the most promising theories of new particles (for MANY reasons not discussed here)
  - Well developed and motivated
  - Potential for helping with Grand Unified Theories
  - Cold Dark Matter candidate/Cosmology connections
  - Etc…
- Each Standard Model particle has a Supersymmetric partner to look for



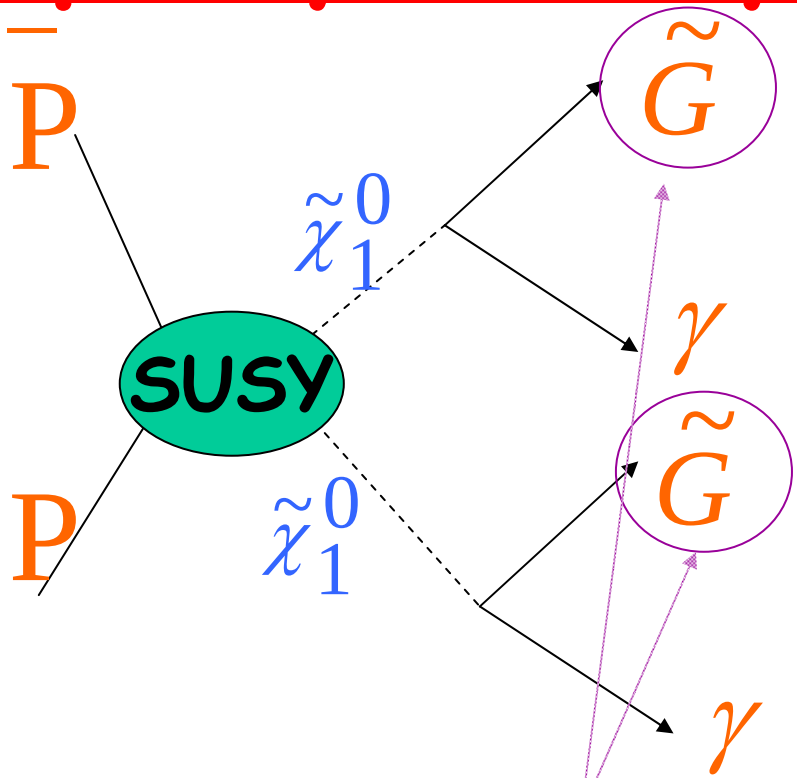
Example Final States: Two photons and Supersymmetry

Standard Model:



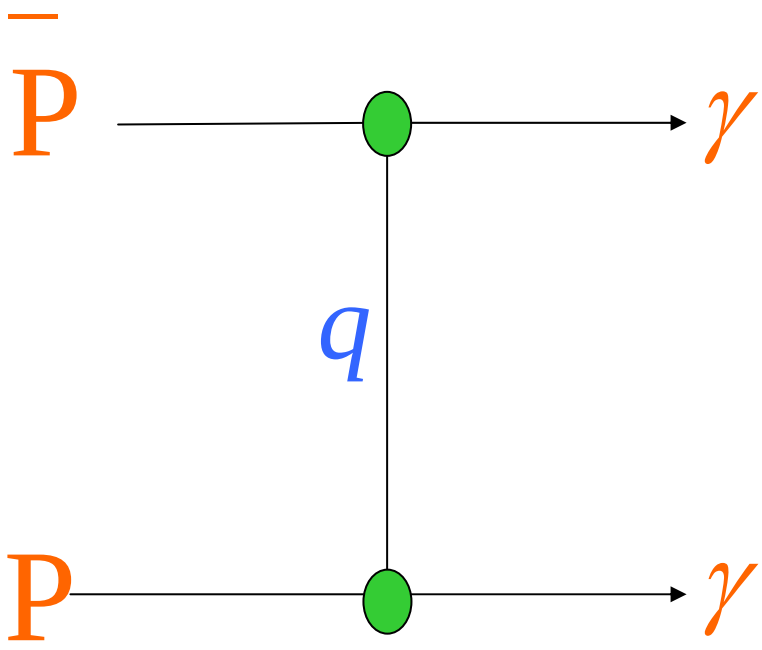
$\gamma\gamma$ +No Supersymmetric Particles in Final State

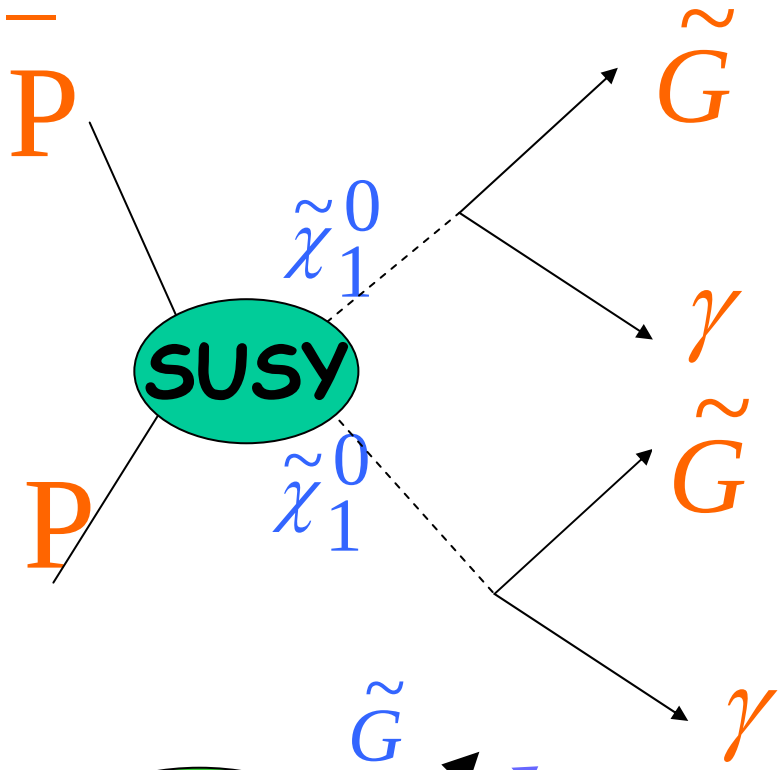
Supersymmetry:

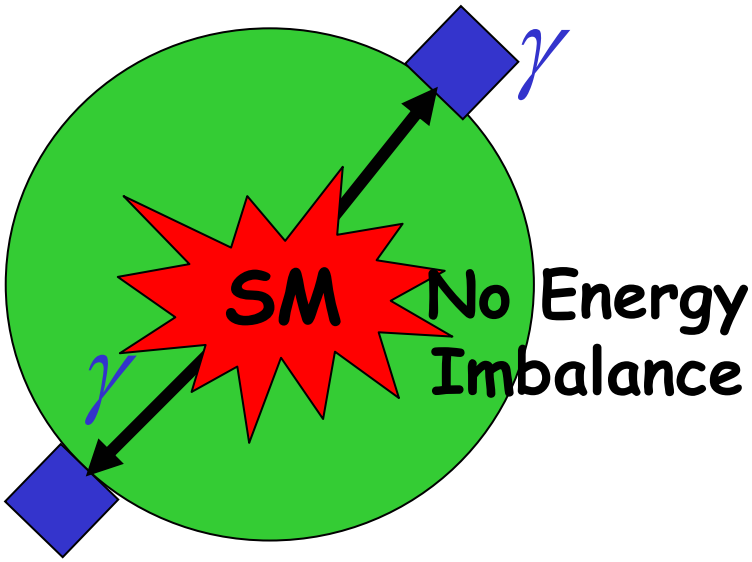


$\gamma\gamma$+Supersymmetric Particles in Final State

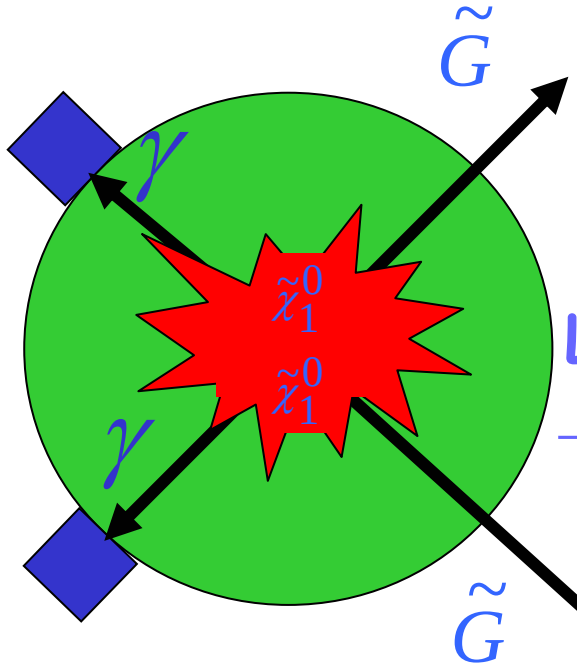
Standard Model: Supersymmetry:







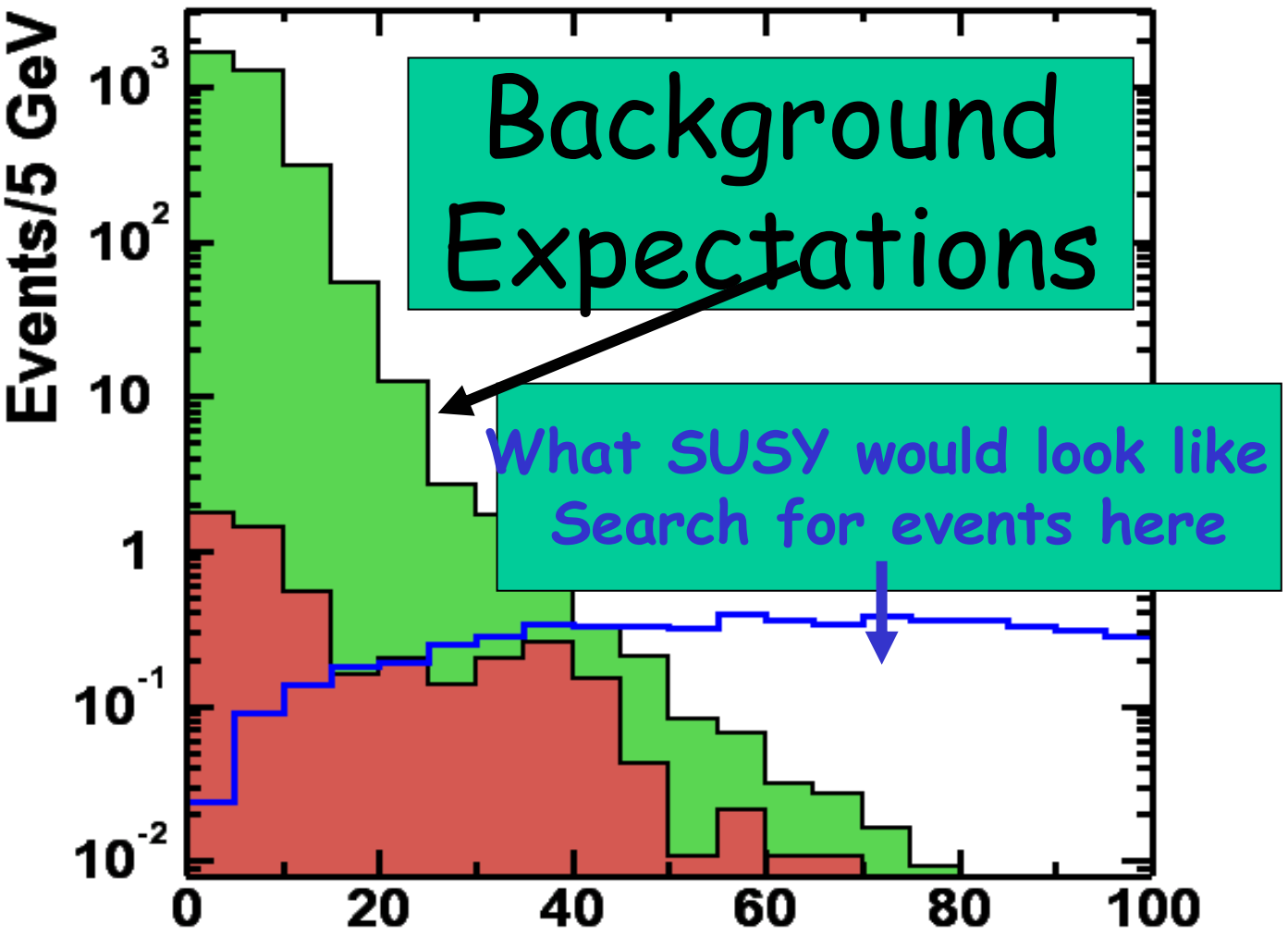
No Energy Imbalance



SUSY Particles Leave the detector

→Energy Imbalance

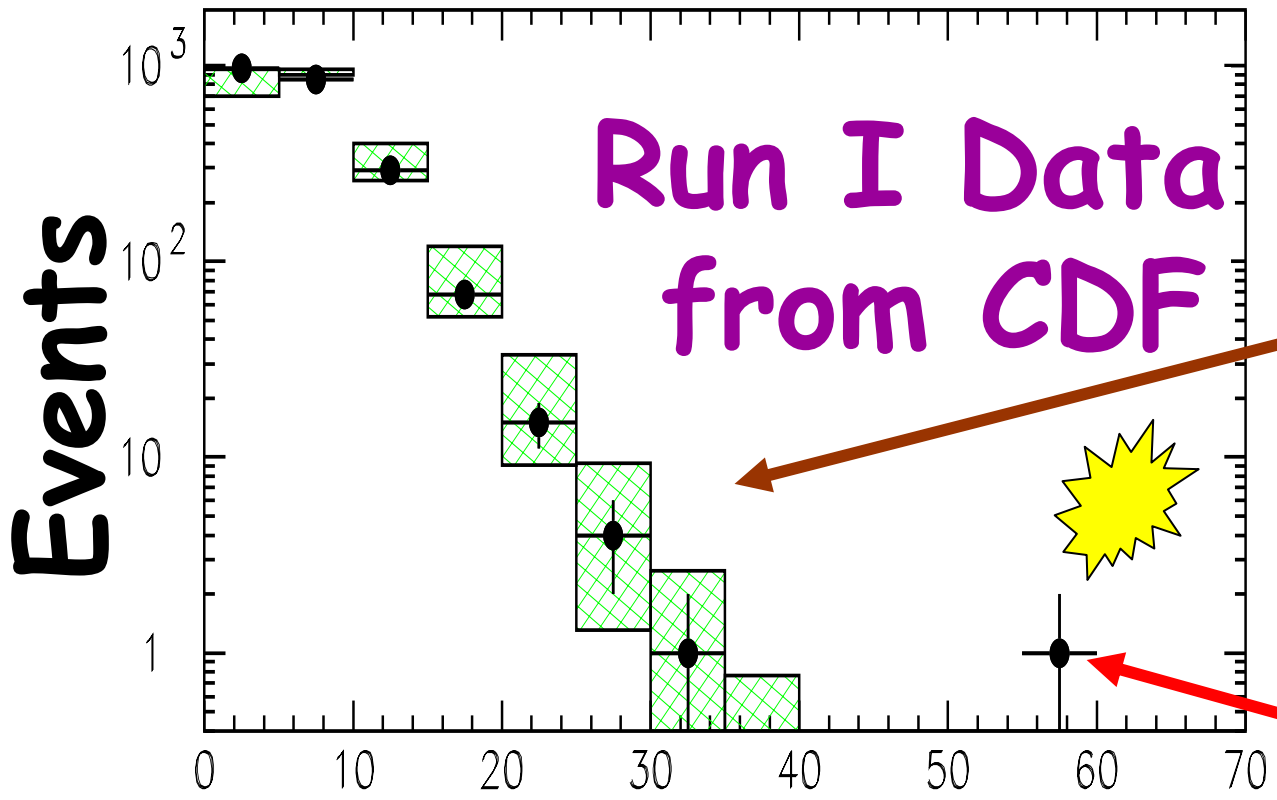
Signal Vs. Background



- Look at each $\gamma\gamma$ event
- Put its Energy Imbalance in a histogram
- Compare the expected predictions from Standard Model and from SUSY

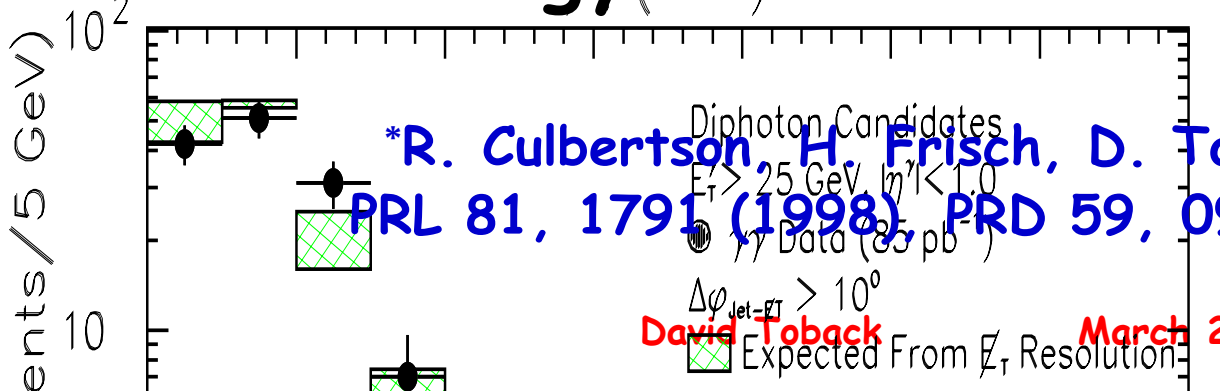
Energy Imbalance Per Event

Search for anomalous $\gamma\gamma$ events at CDF



Data is consistent with background expectations (gives us confidence we got that part right)

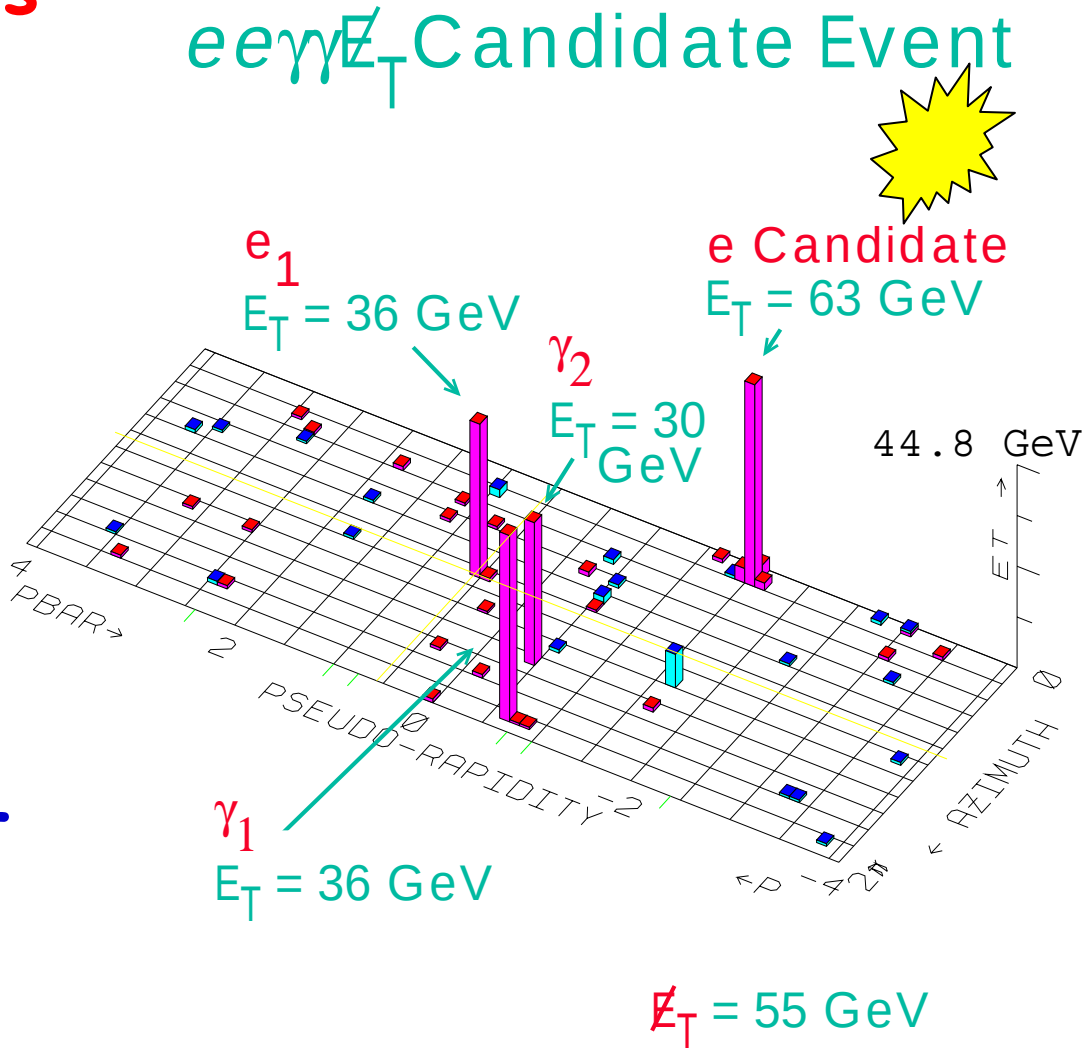
One possible exception



*R. Culbertson, H. Frisch, D. Toback + CDF
PRL 81, 1791 (1998), PRD 59, 092002 (1999)

The interesting event on the tail

- In addition to $\gamma\gamma$+ Energy Imbalance this (famous) event has two high energy electron candidates
  - *Both are unexpected*
- Very unusual
- Good example of getting an answer which is far more interesting than what you asked for
- How unusual?



Predicted by the Standard Model?

- Dominant Standard Model Source for this type of event: $WW\gamma\gamma$
  - $WW\gamma\gamma \rightarrow (e\nu)(e\nu)\gamma\gamma \rightarrow ee\gamma\gamma$+Energy Imbalance:

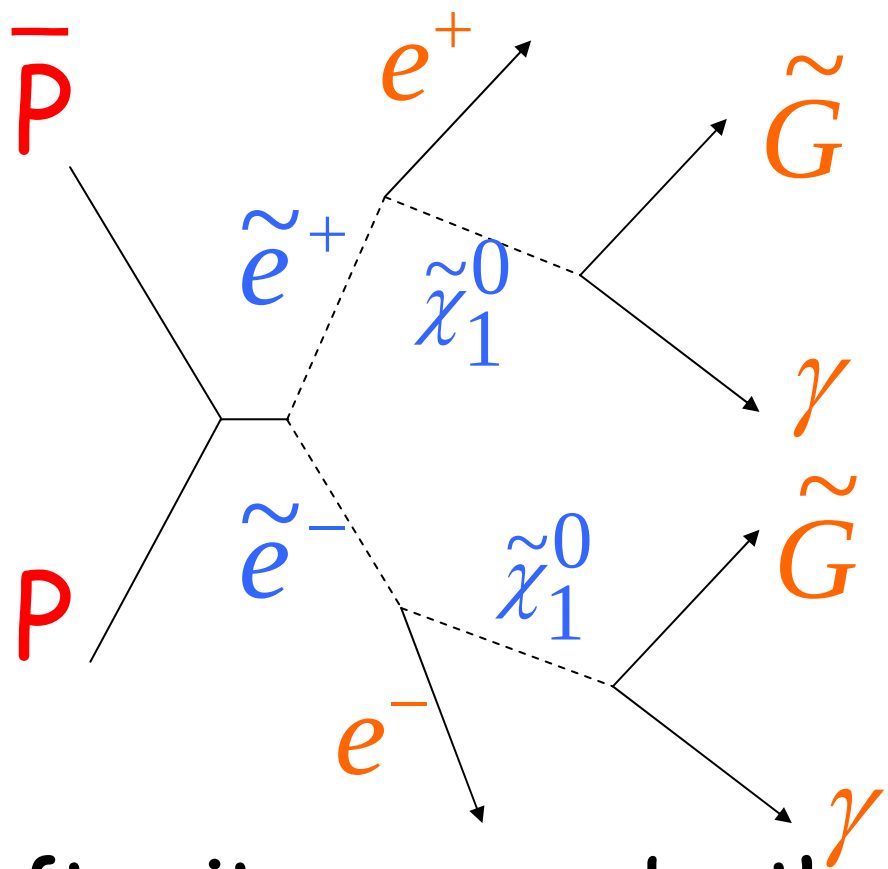
    $\rightarrow 8\times10^{-7}$ Events
- All other sources (mostly detector mis-identification): 5×10^{-7} Events
- Total: $(1 \pm 1) \times 10^{-6}$ Events

Perspective: Look at 5 trillion collisions, expect 10^{-6} events with two electrons, two photons and an energy imbalance; observe 1

(expect one like this in 5 quintrillion collisions)

Predicted by Supersymmetry?

This event looks like a natural prediction of Supersymmetry



(Well…this was pointed out <u>after</u> it was seen by the theory community… Gauge Mediated Supersymmetry has since been revived and become an important theme in the field)

Supersymmetry?

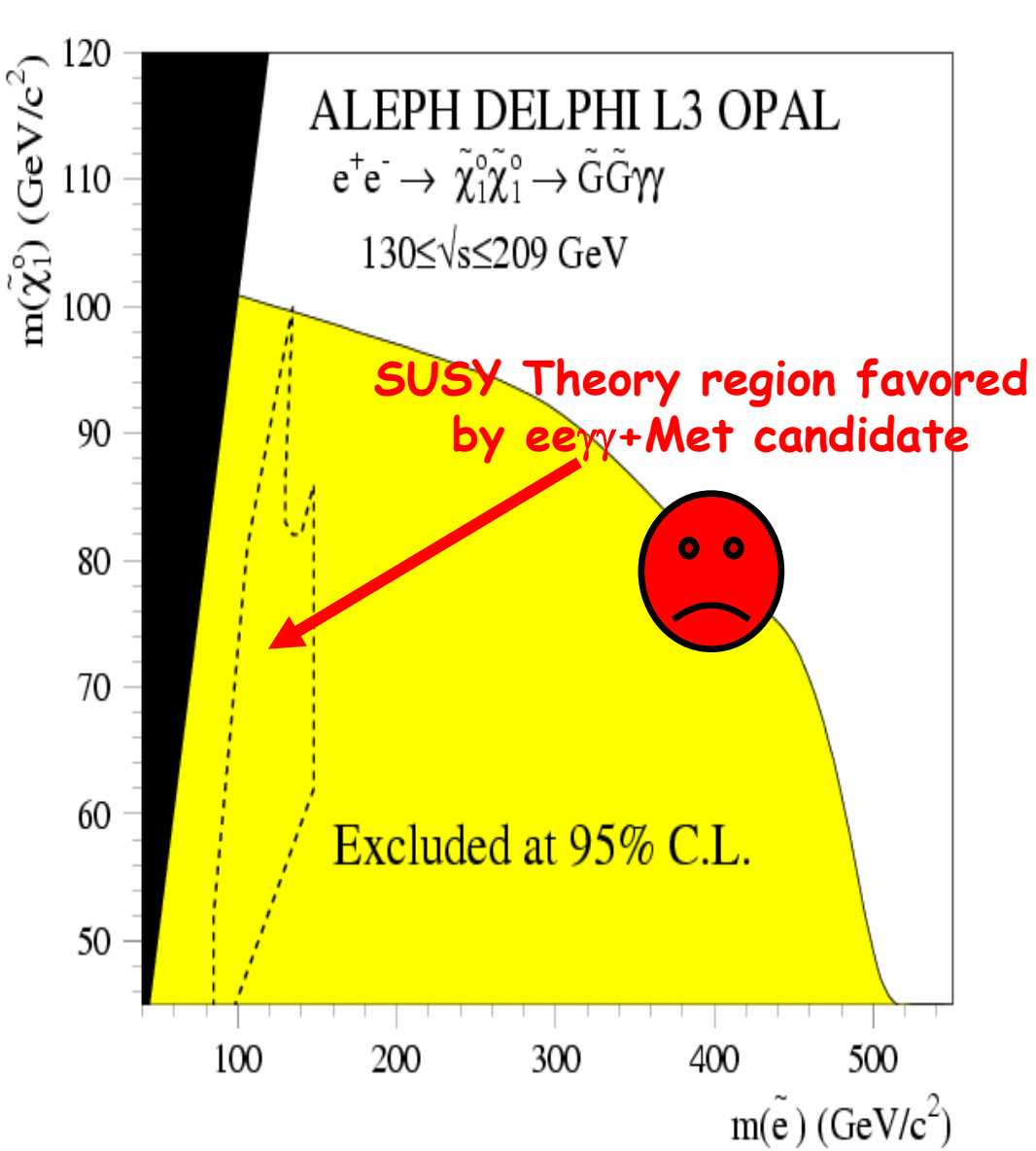
Other evidence for this type of Supersymmetry?

Theory Prediction: Models which predict this event predict additional events with $\gamma\gamma$+Energy Imbalance

- We don't see any other candidates like that
- No others seen by CDF or DØ in Run I, or in the high energy data taking at LEP

Set limits on the models

- These null results have been combined
- They constrain or exclude most SUSY models which predict the event



What to do?

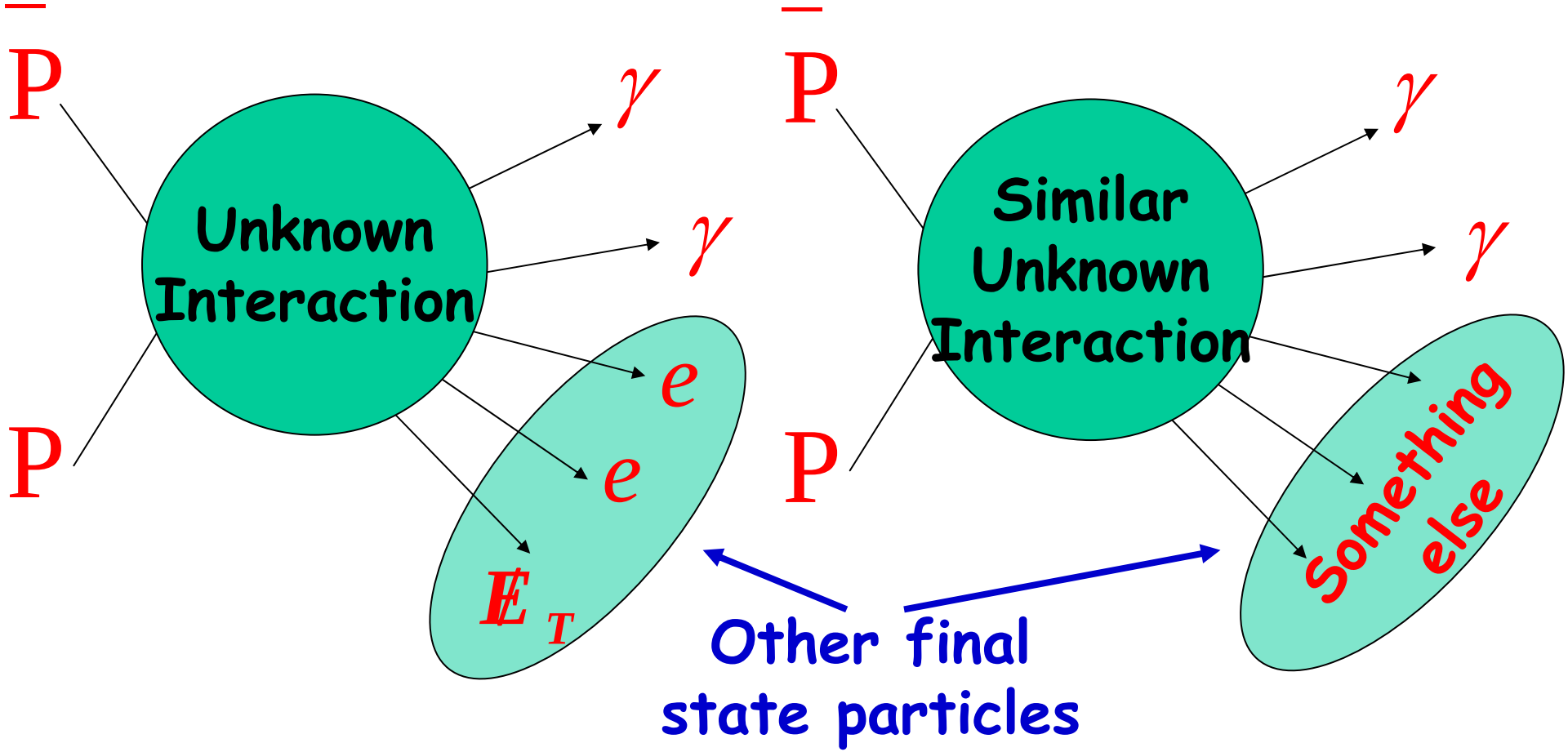
- Our anomaly doesn't look like the currently favored models of Supersymmetry
- While there are other models which predict this event, most have long since fallen by the wayside
- Perhaps there is something far more interesting and unpredicted going on! But what? Need more experimental hints… and new ways of doing things…

Model Independent Searches

New Systematic Method: Use properties of the event to suggest a more *model independent* search

- Look for "cousins" of our events
  - Others with "similar" properties
  - Others of this "type"
- To corrupt a famous quote: *"I don't know exactly what I'm looking for, but I'd know it if I saw it."*

Unknown Interactions: Example



These two events would be "cousins"

Example "cousins" Search

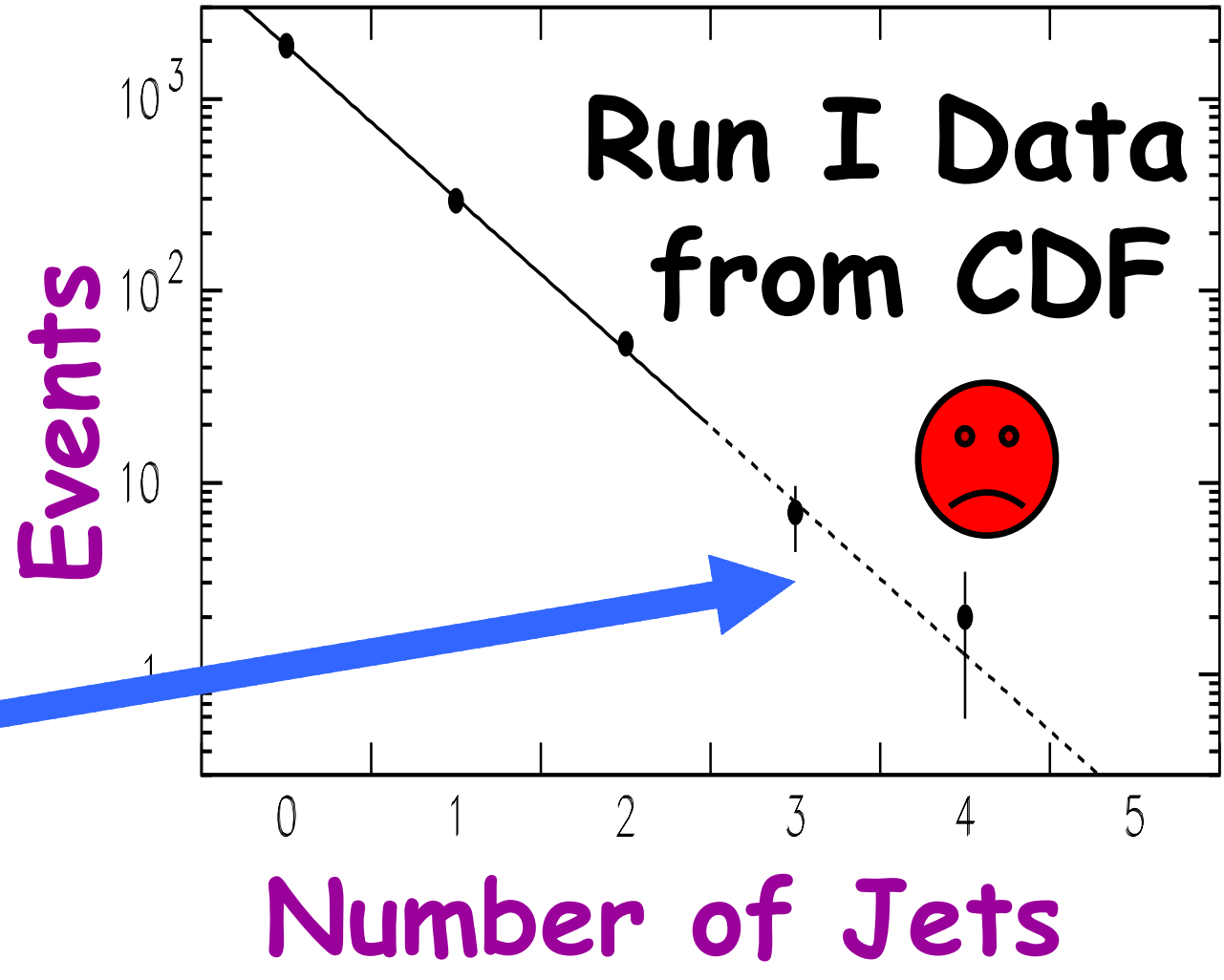
- *A priori* the ee$\gamma\gamma$+Energy Imbalance event is unlikely to be Standard Model WW$\gamma\gamma$ production
  - (~10^{-6} Events)
- Guess that the unknown interaction is "Anomalous" WW$\gamma\gamma$ production and decay
- Look for similar unknown interaction with
  - WW → (qq)(qq) → jjjj
  - Br(WW → jjjj)>>Br(WW → ee+EnergyImb)

By branching ratio arguments: Given 1 $\gamma\gamma$+*ll*+Energy Imbalance event

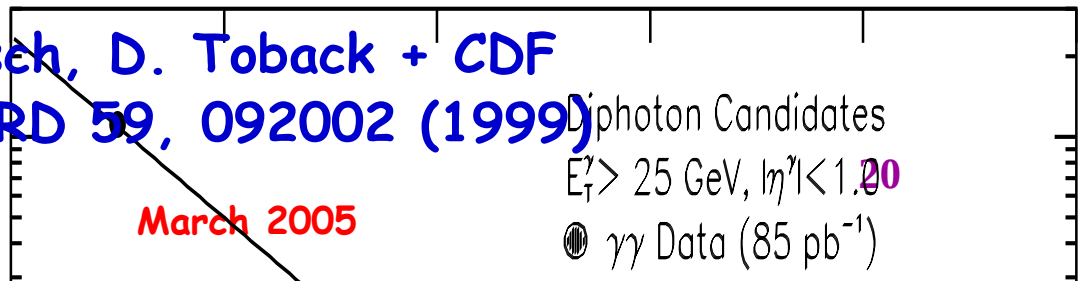
→Expect ~30 $\gamma\gamma$+jjj "cousin" events

γγ + Jets Search at CDF

- Look in γγ data for anomalous production of associated jets from quark decays of W's
- ~30 Event excess would show up here



*R. Culbertson, H. Frisch, D. Toback + CDF
PRL 81, 1791 (1998), PRD 59, 092002 (1999)



Repeat many times for γγ+"Something"

CDF Run I

All results are consistent with the Standard Model background expectations with no other exceptions

High Acceptance, Large # of Background Events

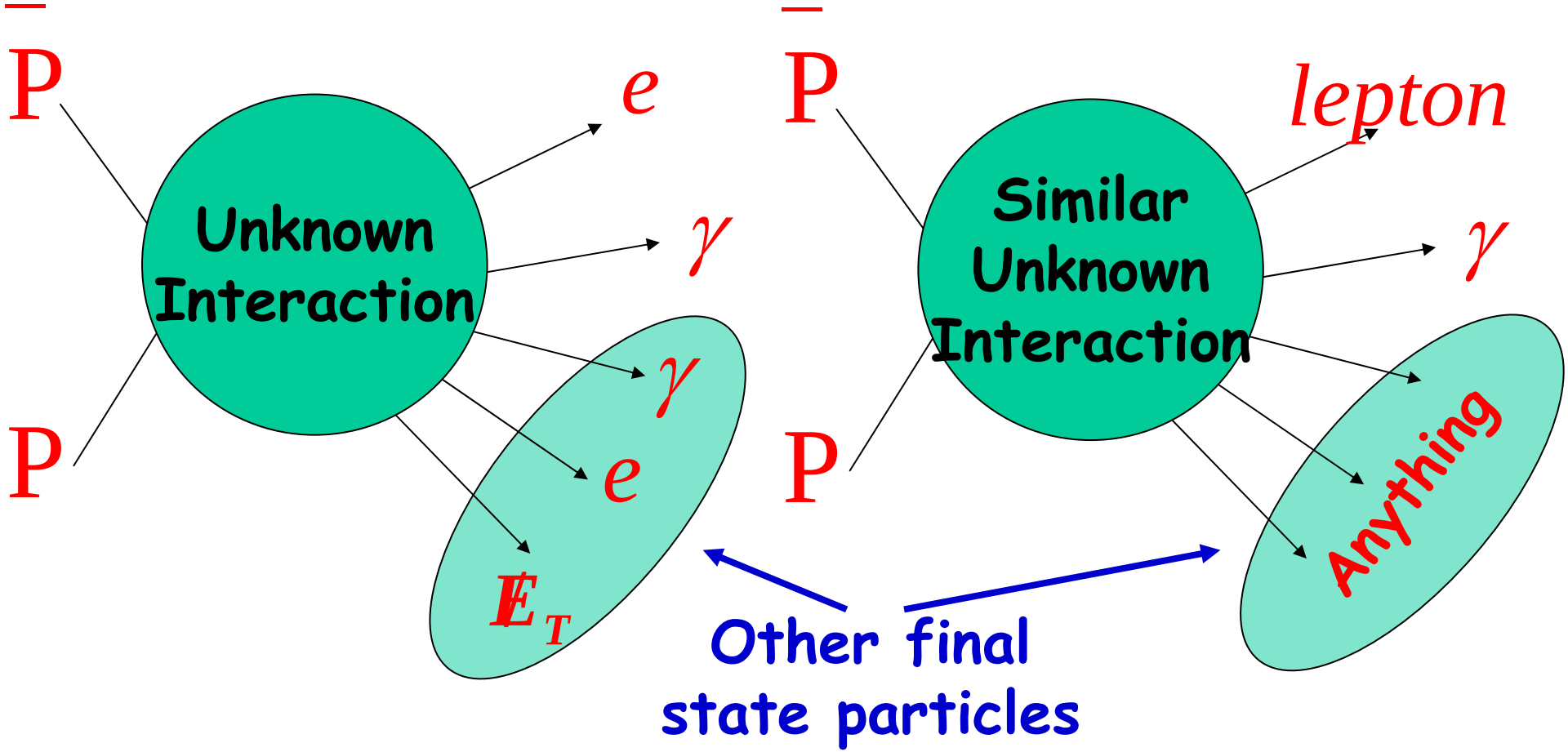
Signature (Object)	Obs.	Expected
$\not\!\!E_T > 35$ GeV, $\lvert\Delta\phi_{\not\!\!E_T-\text{jet}}\rvert > 10°$	1	0.5 ± 0.1
$N_{jet} \geq 4$, $E_T^{jet} > 10$ GeV, $\lvert\eta^{jet}\rvert < 2.0$	2	1.6 ± 0.4
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	3	0.3 ± 0.1
Central τ, $E_T^{\tau} > 25$ GeV	1	0.2 ± 0.1
b-tag, $E_T^{b} > 25$ GeV	2	1.3 ± 0.7
Central γ, $E_T^{\gamma 3} > 25$ GeV	0	0.1 ± 0.1

Lower Acceptance, Smaller # of Background Events

Object	Obs.	Exp.
$\not\!\!E_T > 25$ GeV, $\lvert\Delta\phi_{\not\!\!E_T-\text{jet}}\rvert > 10°$	2	0.5 ± 0.1
$N_{Jet} \geq 3$, $E_T^{Jet} > 10$ GeV, $\lvert\eta^{Jet}\rvert < 2.0$	0	1.7 ± 1.5
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	1	0.1 ± 0.1
Central τ, $E_T^{\tau} > 25$ GeV	0	0.03 ± 0.03
b-tag, $E_T^{b} > 25$ GeV	0	0.1 ± 0.1
Central γ, $E_T^{\gamma 3} > 25$ GeV	0	0.01 ± 0.01

*R. Culbertson, H. Frisch, D. Toback + CDF
PRL 81, 1791 (1998), PRD 59, 092002 (1999)

Another Cousins Search



Instead of two photons try a photon and a lepton

Lepton+Photon Cousin Search Results

In general data agrees with expectations. But:

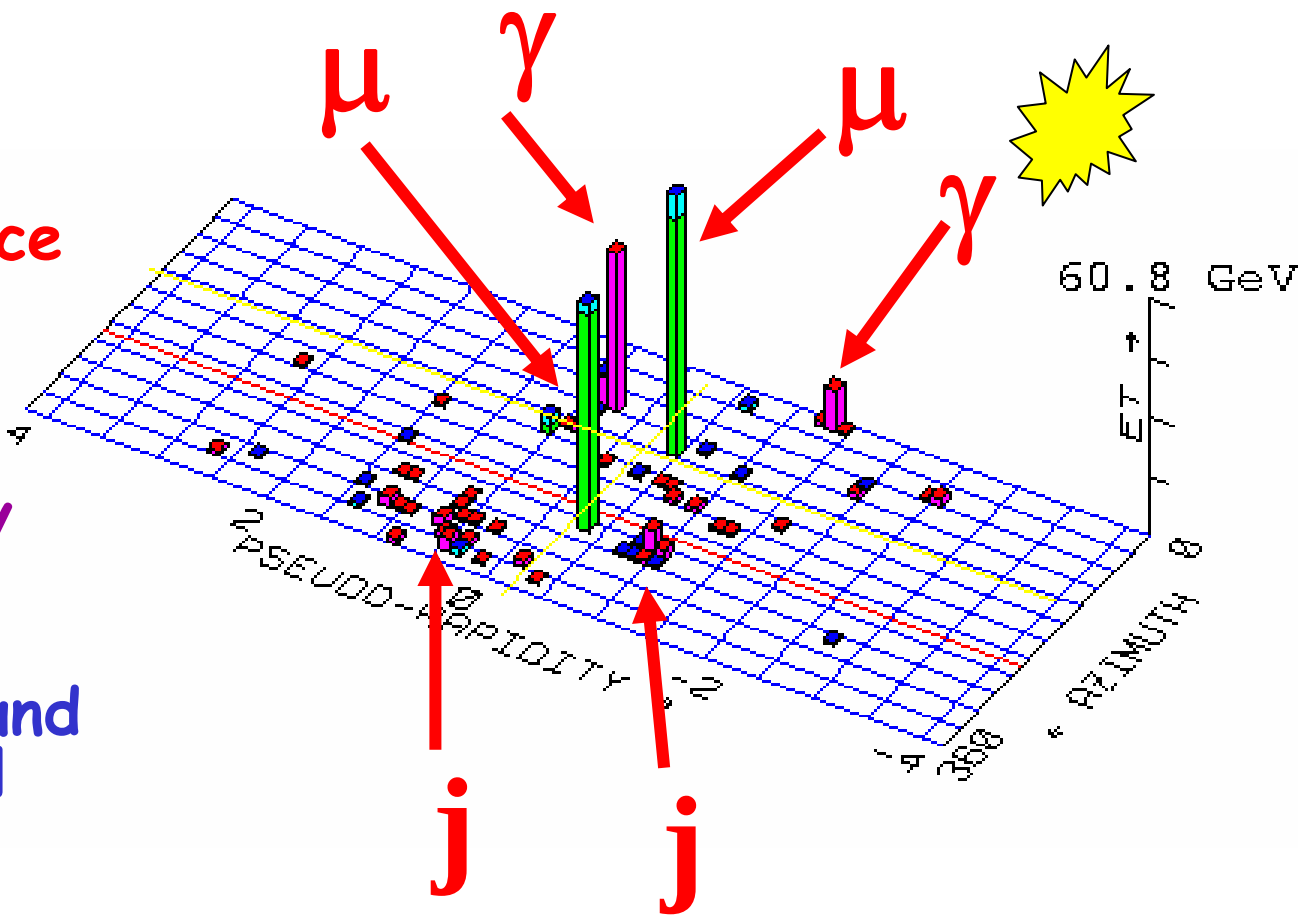
- 11 μγ+Met events on a background of 4.2±0.5 expected
  - Not statistically significant enough to be a discovery, but interesting
- No excess in eγ+Met!?! 5 on a background of 3.4±0.3
- Not clear what to make of this… In general SM particles have roughly the same branching ratio for all leptons
- However, we are encouraged that this new model independent method gave us a new hint

*J. Berryhill, H. Frisch, D. Toback + CDF
PRL 89, 041802 (2002), PRD 66, 012004 (2002)

Hmmm…Another hint? μμγγjj

- Another event in the data with properties "similar" to the eeγγ+Energy Imbalance candidate
- Not part of the "official" γγ dataset
- No significant energy imbalance
- Not <u>quite</u> as interesting. Background only at the 10^{-4} level
  - 1 in 10 quadrillion
- Again, no good Standard Model explanation

  Need to keep looking…



Unpublished confidential result

M. Contreras, H. Frisch and D. Toback
(CDF Internal 1996)

Half-Way Point Summary

- Theory not confirmed by experiment
- "cousins" model provides interesting hints, but doesn't point to a theory
- The logical next steps are:
  1. Look in many more places using new systematic model-independent search methods
     - "Sleuth" Method
       - B. Knuteson, D. Toback + DØ, PRD 62, 092004 (2000)
     - Whole separate talk… bottom line: no new hints in DØ photon data or otherwise
       - B. Knuteson, D. Toback + DØ, PRL 86, 3712 (2001) & PRD 64, 012004 (2001)
  2. Improve the detectors and take more data

Fermilab Run II

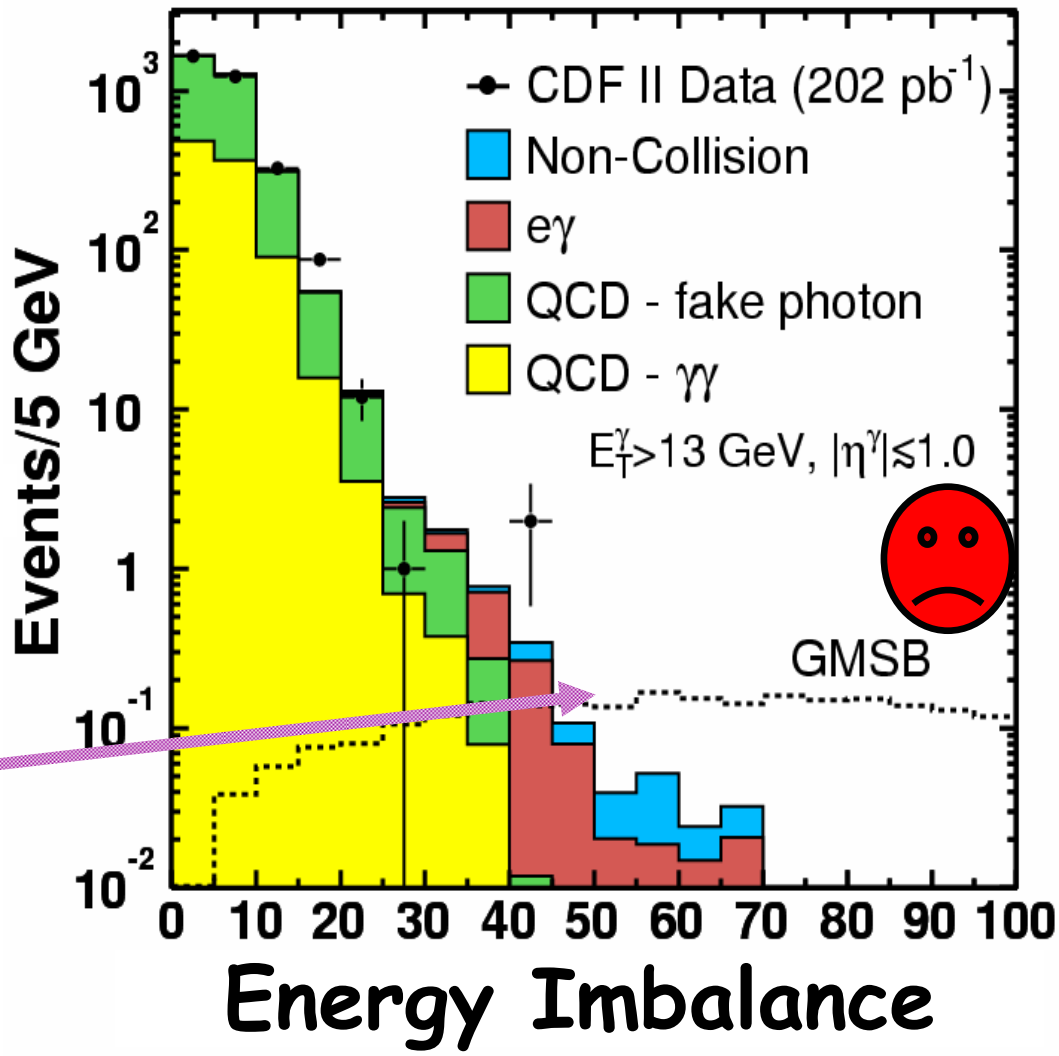
Take more data!

- Increased the Collision Energy
- Increased the rate at which we take data
- Upgraded the detectors

CDF Run II Data

4 years of work in one slide

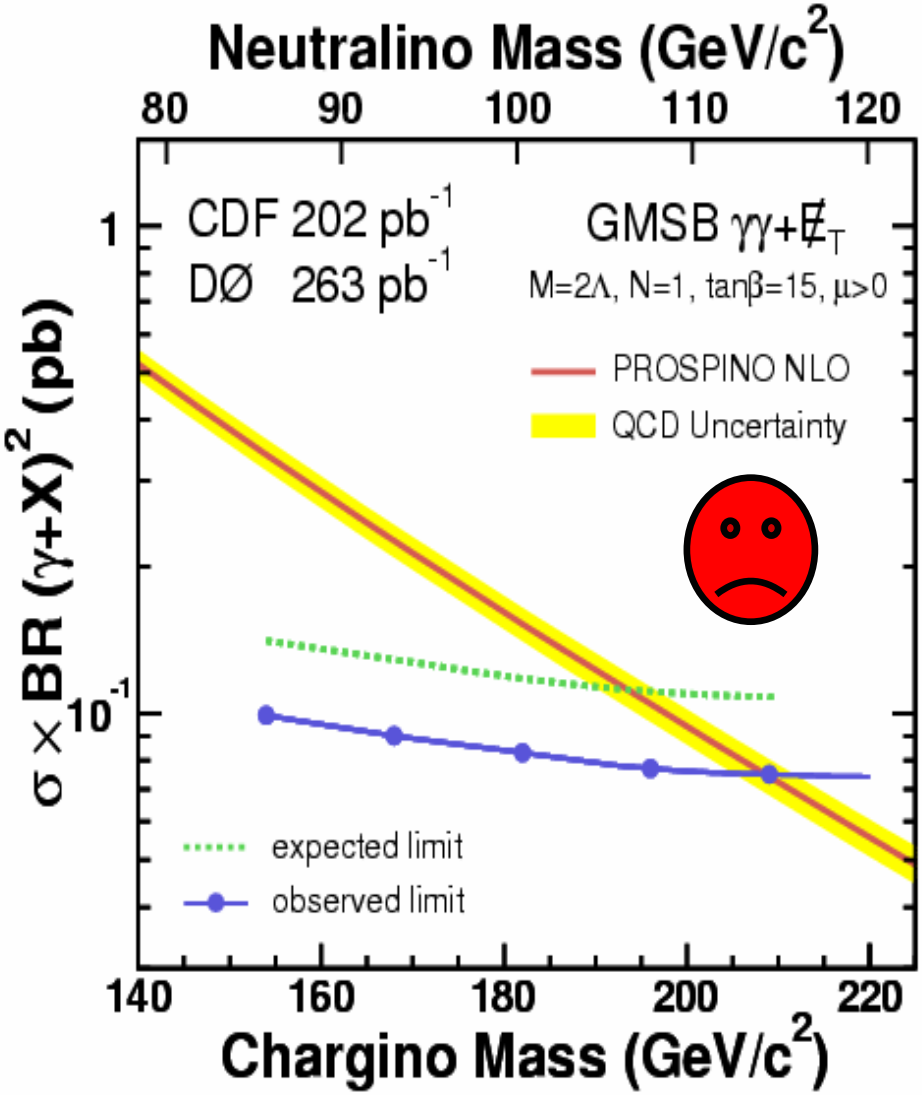
- Any new excess in two photons + energy imbalance?
- No new official events out here!



*R. Culbertson, D.H. Kim, M.S. Kim, S.W. Lee, D. Toback + CDF PRD 71, 031104 (2005). First CDF II direct SUSY Result

Combined Limits

- DØ has a similar null result
- CDF and DØ have combined their results to create the worlds most stringent limits on GMSB SUSY



A New CDF Run IIa Event Candidate

But…

Another unofficial interesting event!!

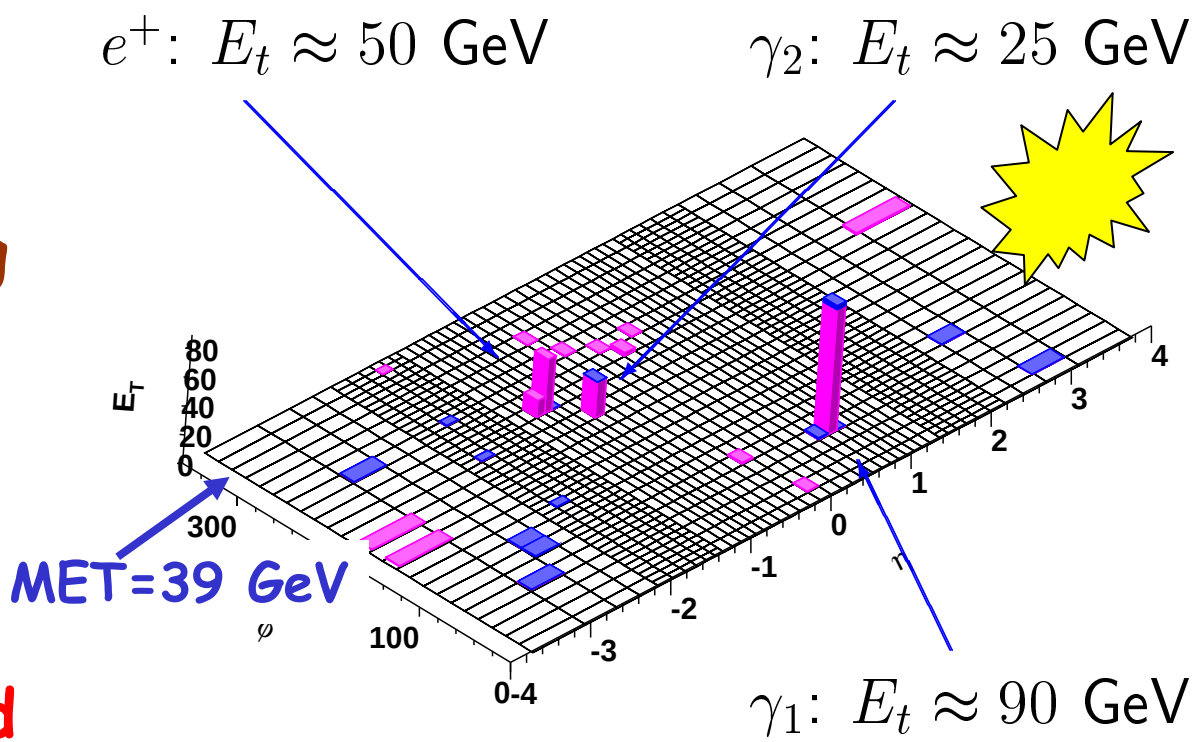
Came in before the "official" data taking period started (will never become public)

Two photons, one electron and energy imbalance

Preliminary background estimate at the 3×10^{-3} level from $W\gamma\gamma$

Clearly similar to the other CDF anomalies

An $e\gamma\gamma\not{E}_t$ Event



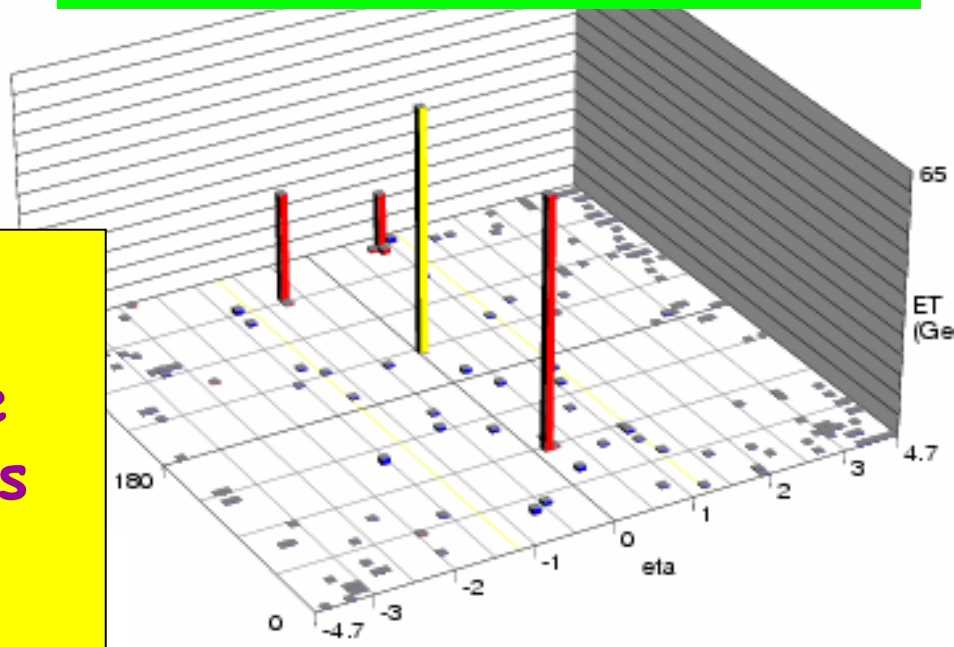
Unpublished confidential result

R. Culbertson, H. Frisch, B. Heinemann, P. Merkel & D. Toback
(CDF Internal 2002)

Yet Another Event…

- DØ finally has an event like this
- Wγγ? Same background level
- Cousin of CDF events?

eγγ+Energy Imbalance Candidate



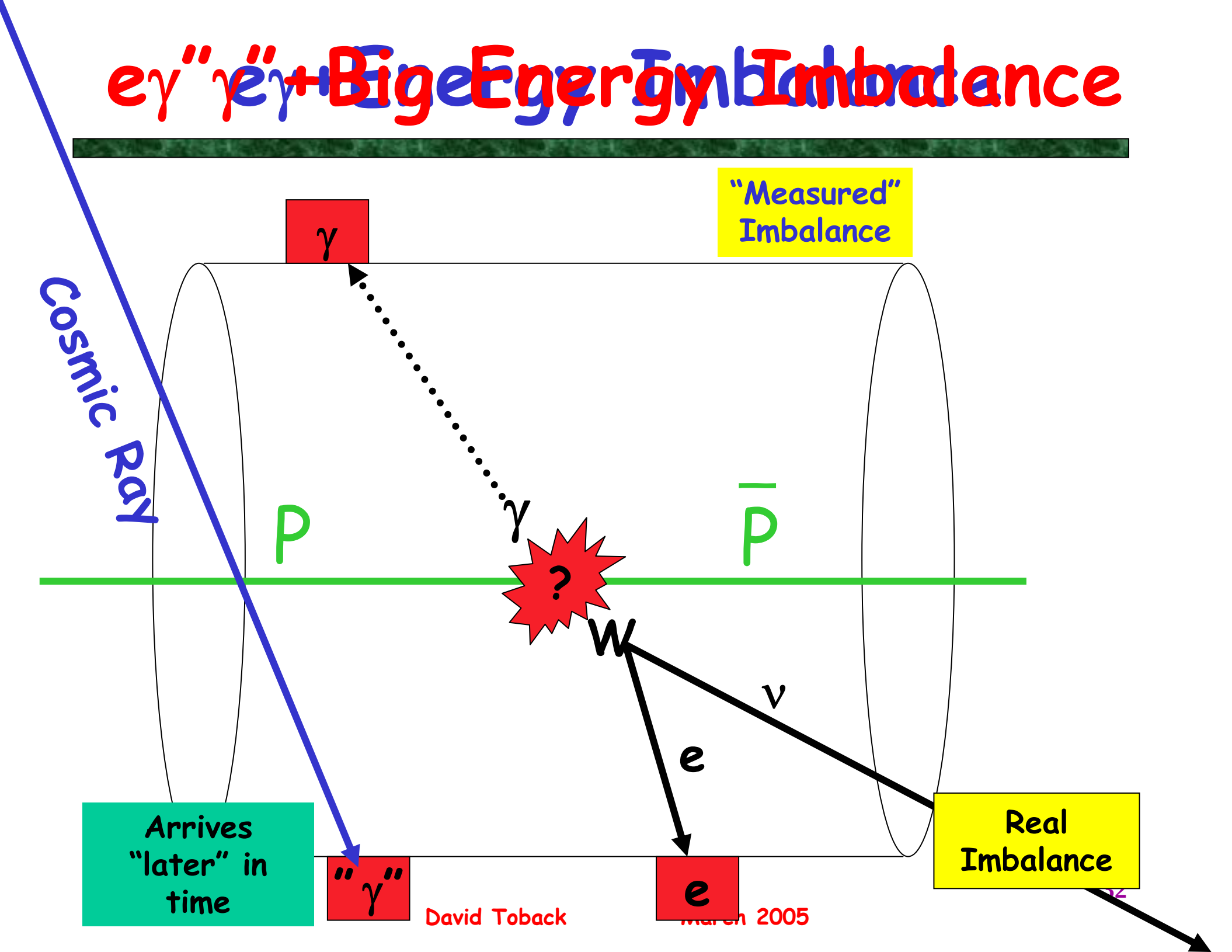
If all "eeγγ+Energy Imbalance" favored SUSY parameter space is nearly excluded, then what is it? Why do we keep getting these events?

Unpublished Result

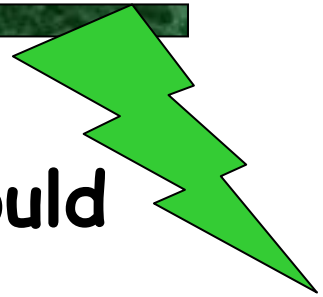
Last Couple Years → Next Couple Years

- There continue to be interesting events with photons and no good theory to explain them
- Perhaps they are from Cosmic Rays?
- Our studies show that these backgrounds are VERY small
  - For the $ee\gamma\gamma$+Energy Imbalance candidate expect about 10^{-9} events of this type

eγ"γ"+Big Energy Imbalance



A new CDF upgrade: EMTiming



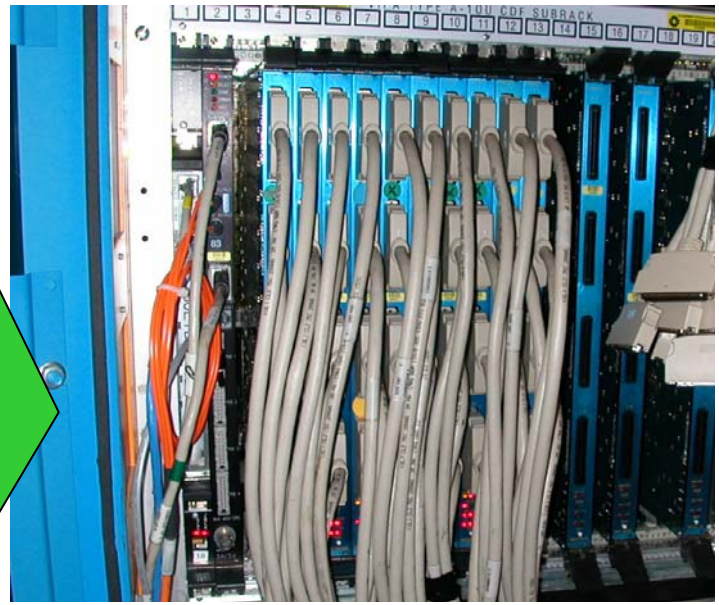
Add "photon" timing:

1. Provides a vitally important handle that could confirm or deny that all the photons in unusual events are from the primary collision
2. Reduces cosmic ray background sources
   - Further improves the sensitivity to important models such as SUSY, Large Extra Dimensions, Anomalous Couplings etc. which produce γ+Energy Imbalance in the detector
3. Allows for direct searches for long-lived particles (A few words on this in a moment)

Hardware for EMTiming Project

~2000 Phototubes

- Large system to add to existing (very large) detector
- Effectively put a TDC onto about 2000 phototubes at CDF
- International collaboration led by Texas A&M
  - INFN-Frascati*
  - Michigan*
  - Chicago*,**
  - Fermilab**
- ~$1M Run IIb project (parts and labor)
  - Project jointly funded by DOE and the INFN

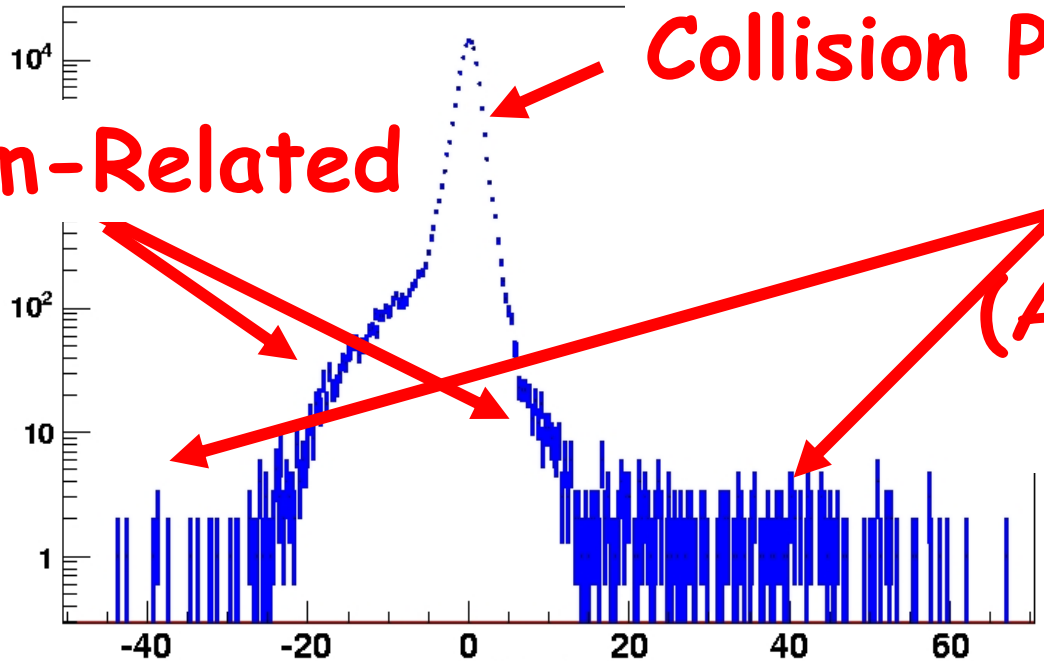


* Engineering support

** Technician support

Preliminary System Sensitivity

- ~100% Efficient for all high P_T photons
- System resolution of ~800 psec
- Finished full installation this October (2 years ahead of original Run IIb schedule)
- Started taking data in January 2005

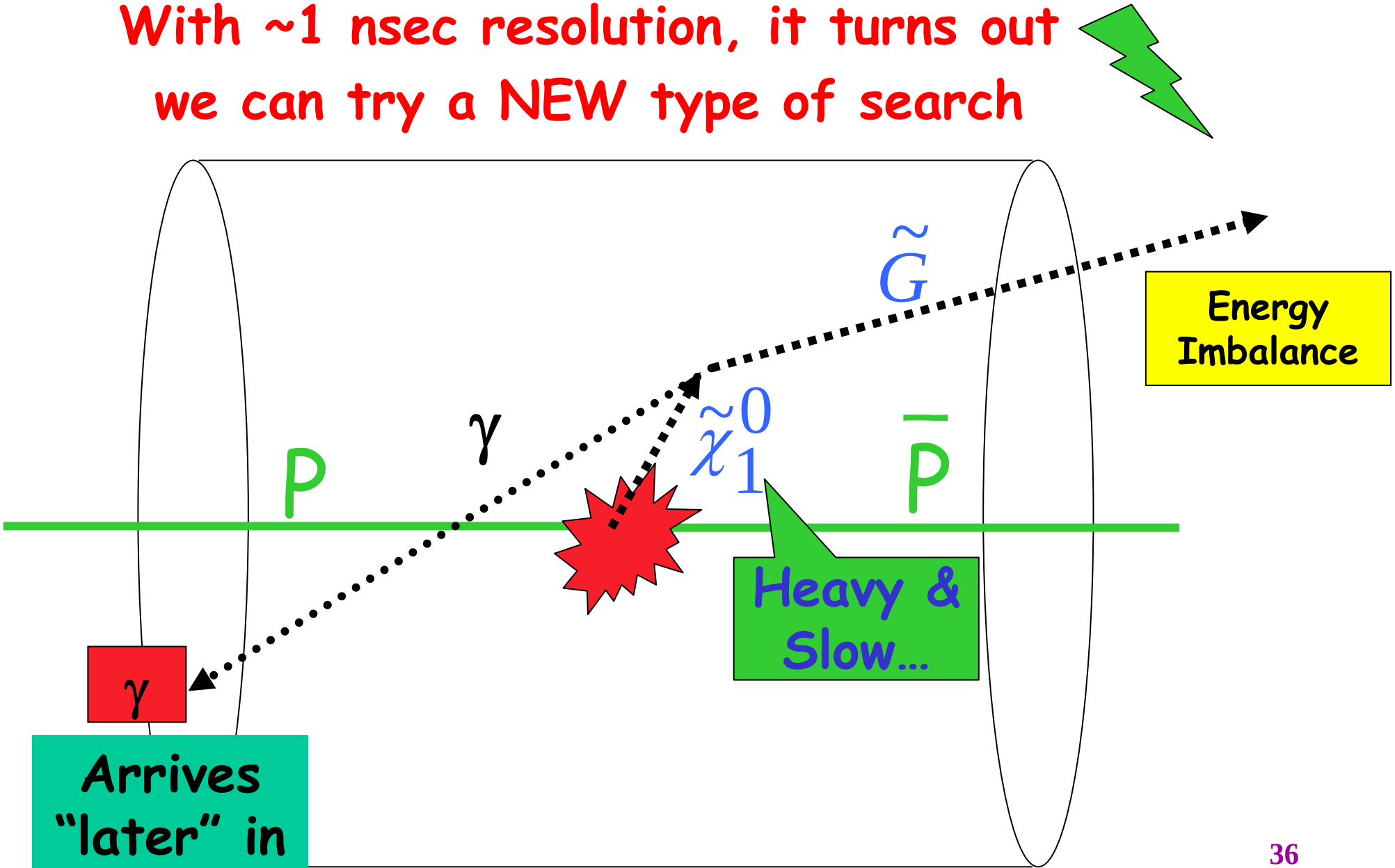


M. Goncharov, D. Toback *et al*, to be submitted to NIM (June 2005)

2005

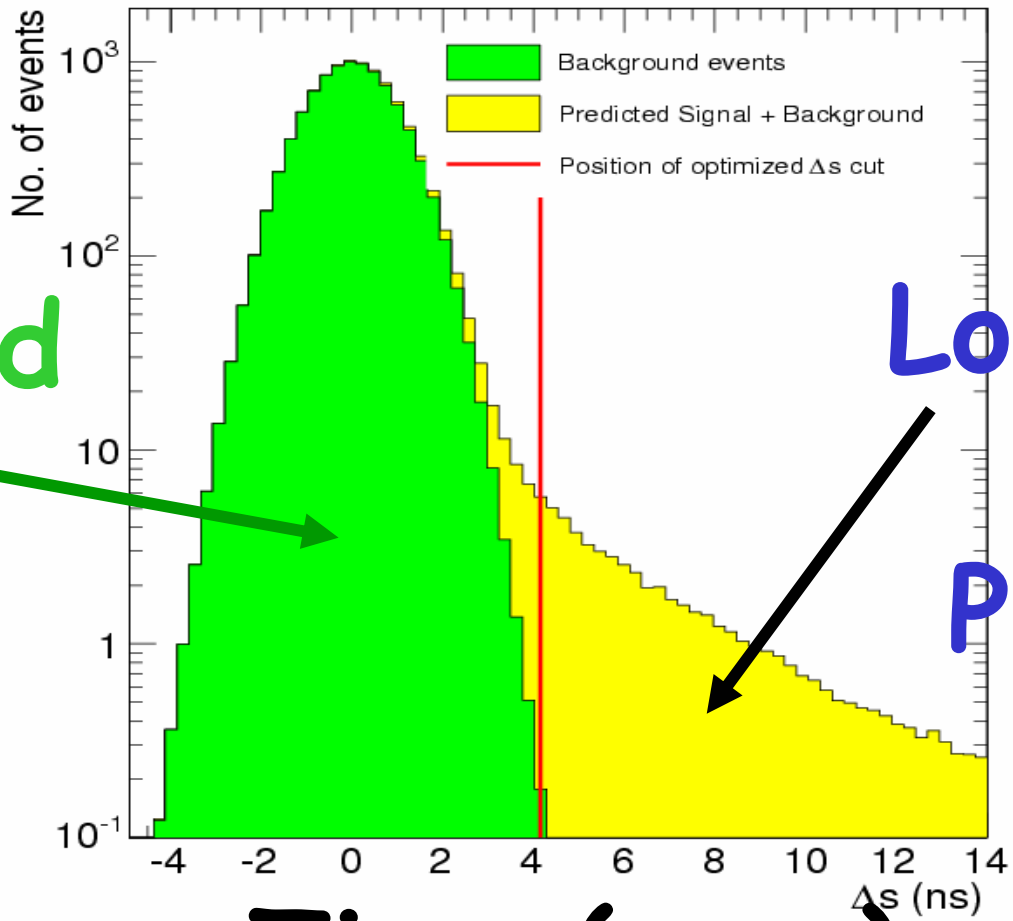
Can we Search for Long-Lived Particles that decay to photons?

With ~1 nsec resolution, it turns out we can try a NEW type of search



Compare Supersymmetry vs. SM

Standard Model



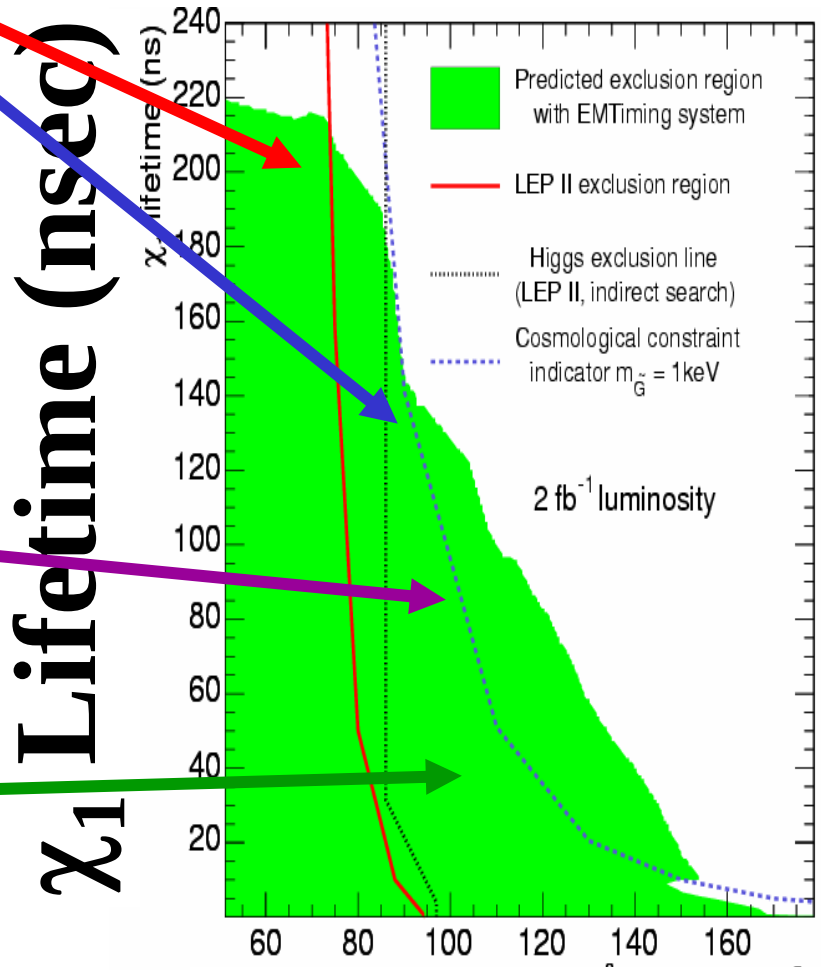
Long-Lived SUSY Particles

Time (nsec)

Signal can be well separated from SM

Comparing the sensitivity

- Exclusions from LEP experiments
- Favored theory region due to cosmological constraints
  - Line is Gravitino mass=1keV
- Our prospects for ~3 years of data taking



D. Toback and P. Wagner
PRD 70, 114032 (2004)

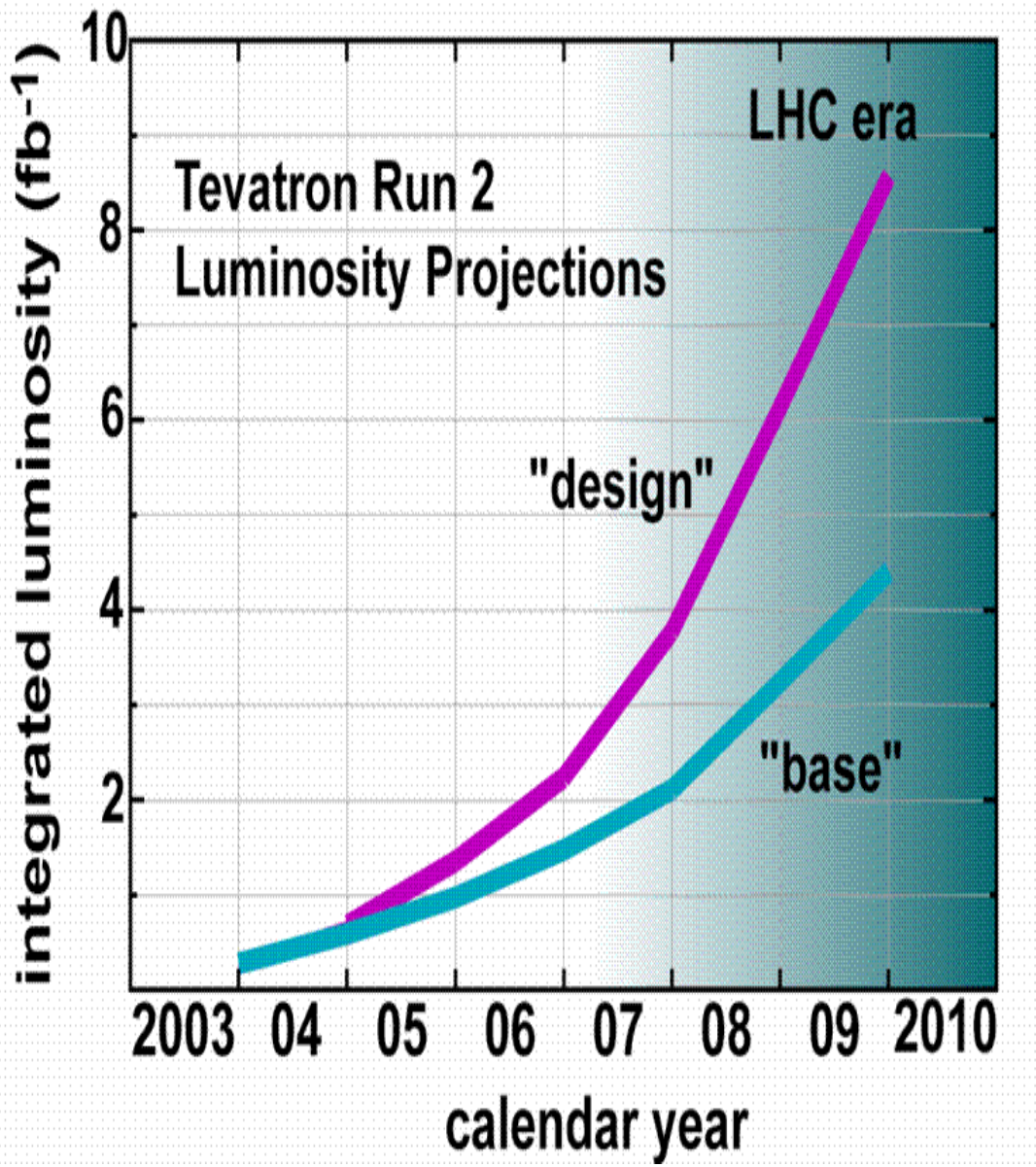
The plan for the next couple years at the Tevatron

Next two years:

- Dedicated SUSY searches
- Model-Independent Searche
- Use our new timing system f both

Next five years:

- Pursue new hints from Run I
- Full Sleuth searches
- Search for long-lived particles
- Higgs Bosons? Supersymmetry? Twenty eeγγ+Energy Imbalance events?
- Some other completely unexpected events?

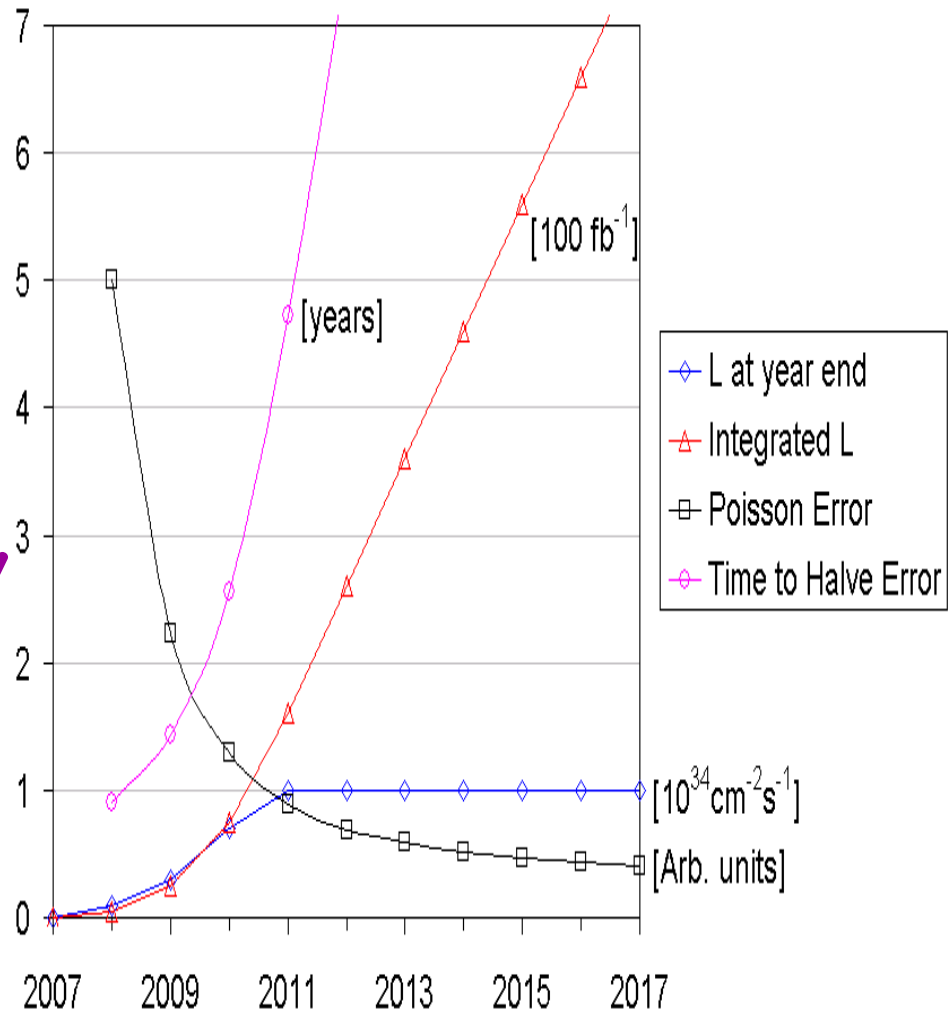


The LHC Era

The LHC era is rapidly approaching

Start taking data in 2007

- 2007-2013(?) Discovery of Supersymmetry?
- Model-independent searches will be especially excited at the new energy frontier
- 2013?-2017? Precision measurements of the properties of our new physics



Conclusions

The next big discovery in particle physics may well come from looking at samples with final state photons

- Many interesting hints in the data with photons; may well point the way
- Model Independent search techniques (*Sleuth*) may enable a major discovery even if the current theories that predict them are wrong
- New results from the Tevatron have a significant sensitivity improvement and there are new hints!
- New instrumentation at CDF and the immanent turn-on of LHC gives us new and exciting sensitivity for the next many years
- The prospects are excellent and this should be fun for many years…