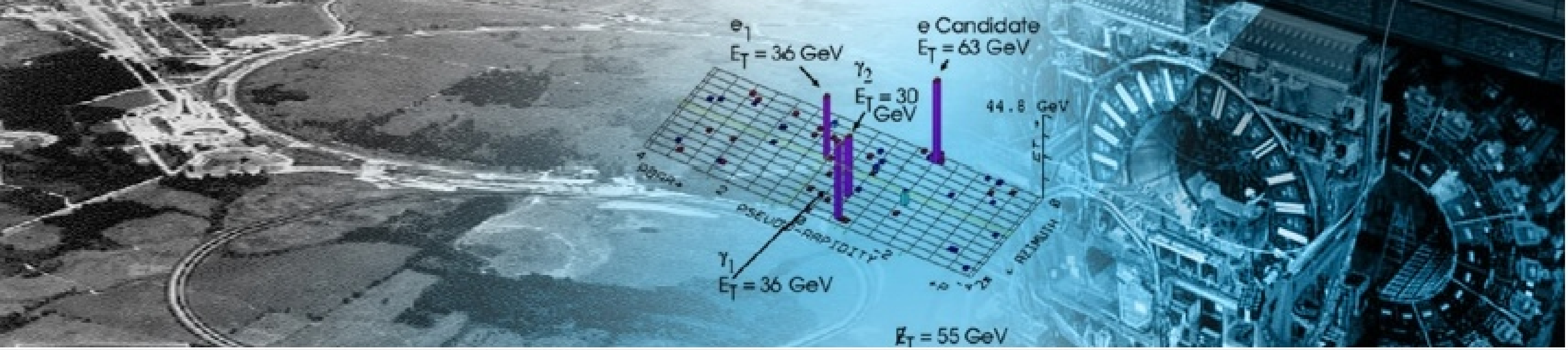

Searching for New Physics with Photons and Missing Energy at CDF:

Recent Results, Upgrades and Prospects

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Texas A&M University

May 2004

University of Chicago

HEP Seminar

Outline

- Motivation for searching for new physics in the photon+Met final state
- New $\gamma\gamma$+Met results at CDF II
- Why we need the EMTiming system at CDF
- Status of the system & preliminary performance results
- Prospects of searching for long lived-particles which decay to photons

Motivation

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

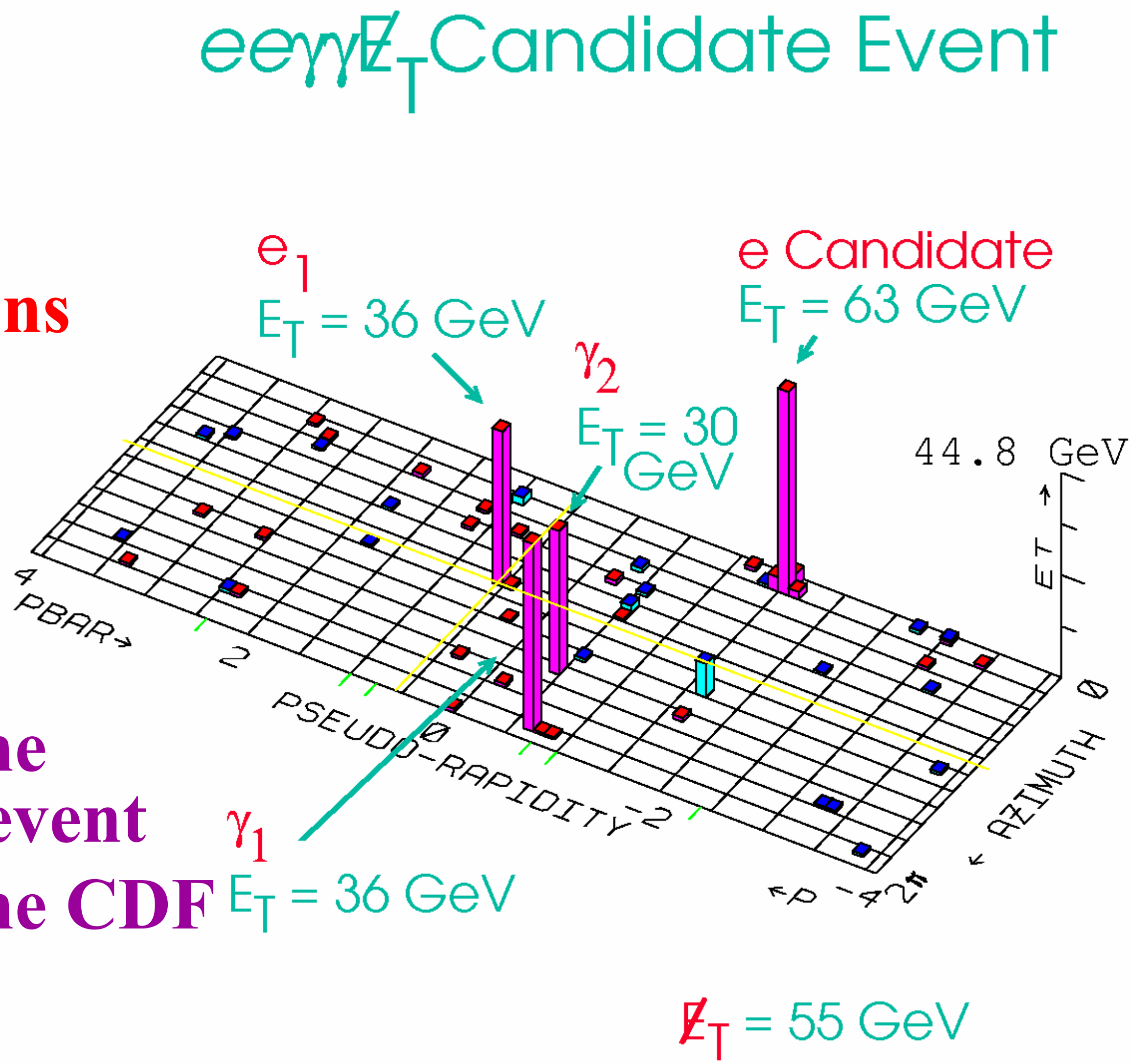
1. Specific models
   – Most importantly Supersymmetry
2. Model independent searches which follow up on some of the anomalies from CDF in Run I

I'll concentrate on the former, but much of what I'll say (except for limits) are equally applicable to Sleuth-like analyses.

Models with Photons

Types of high P_T physics with photons and/or MET

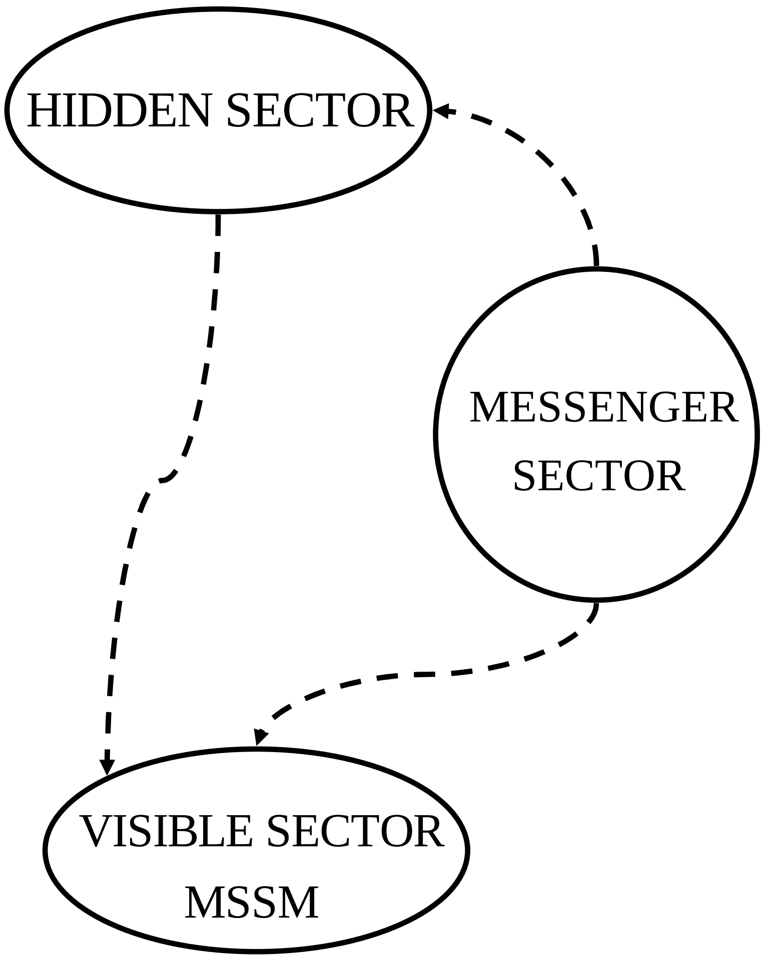
- SUSY with $\chi_1 \rightarrow \gamma G$
- SUSY with $\chi_2 \rightarrow \gamma N_1$
- Large Extra Dimensions
- Excited leptons
- New dynamics
- V+Higgs $\rightarrow$ V+$\gamma\gamma$
- W/Z+γ production
- Whatever produced the ee$\gamma\gamma$+MET candidate event
- Whatever produced the CDF Run I $\mu\gamma$+Met excess



Standard Model background estimate of 10^{-6}

Gauge Mediated SUSY Breaking

SUSY Breaking Mechanism



Phenomenology :

- Gravitino is the LSP (< 1 keV)
- NLSP is the Neutralino (or slepton)

$$\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$$

– Gaugino Pair - Production and decay Dominates at the Tevatron

$$p\bar{p} \rightarrow \tilde{\chi}\tilde{\chi} \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 + X \rightarrow (\gamma\tilde{G})(\gamma\tilde{G}) + X$$

– Final State Signature : $\gamma\gamma$ + Met + X

Previous Searches

- CDF has found an interesting event; $ee\gamma\gamma \not{E}_T$ candidate
- In GMSB framework CDF set lower limits:

$\Rightarrow$ $M_{\tilde{\chi}_1^\pm} > 120$ GeV/c^2 and $M_{\tilde{\chi}_1^0} > 65$ GeV/c^2

- DØ found no $\gamma\gamma \not{E}_T$ events and set lower limits:

$\Rightarrow$ $M_{\tilde{\chi}_1^\pm} > 150$ GeV/c^2 and $M_{\tilde{\chi}_1^0} > 77$ GeV/c^2

- LEPII recently set lower limits on $M_{\tilde{\chi}_1^0}$ of about 99 GeV

at 95% C.L. ($\sqrt{s} = 189 \sim 208$ GeV)

– ALEPH: $M_{\tilde{\chi}_1^0} \geq 90$ GeV/c^2 for Neutralino pair production

– DELPHI and L3: $M_{\tilde{\chi}_1^0} \geq 96$ GeV/c^2 for $M_{\tilde{e}_R} = 2.0 M_{\tilde{\chi}_1^0} \approx M_{\tilde{e}_L}$

$M_{\tilde{\chi}_1^0} \geq 99$ GeV/c^2 for $M_{\tilde{e}_R} = 1.1 M_{\tilde{\chi}_1^0} \approx M_{\tilde{e}_L}$

CDF Run II Analysis*

- Second generation analysis
- 202 pb^{-1} of data (March 2002-Sept 2003)
- Two isolated photons in the central part of the detector ($|\eta|<1$) with $E_T>13$ GeV and passing standard identification criteria
- Cuts to remove cosmics, beam-halo and other machine related backgrounds
- Require no jets pointing either directly towards or away from the Met for good Met resolution measurement

*Minsuk Kim, Sungwon Lee, Ray Culbertson, DongHee Kim & DT.

Backgrounds

Three main backgrounds

1. **QCD + Fake Met**
2. **$e\gamma$ events with real Met**
3. **Non-Collision backgrounds**

QCD with Fake Missing Energy

Dominant Background

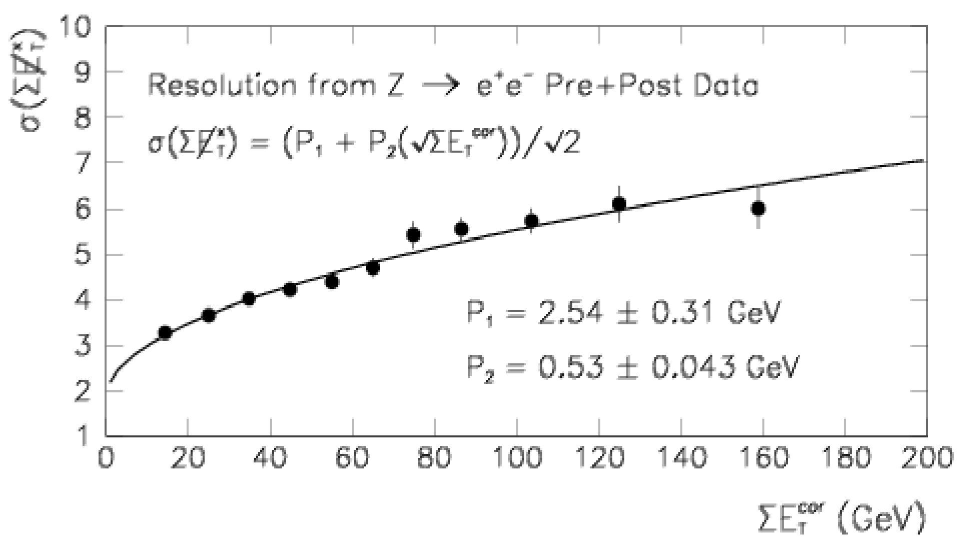
- Events from γγ, γ+jet and jet-jet
  - High production rates *x* low fake rates
  - Jets fakes photons
  - Met is from mis-measurement
- Estimate using Run I style techniques:
  - Control sample of events with similar event topologies

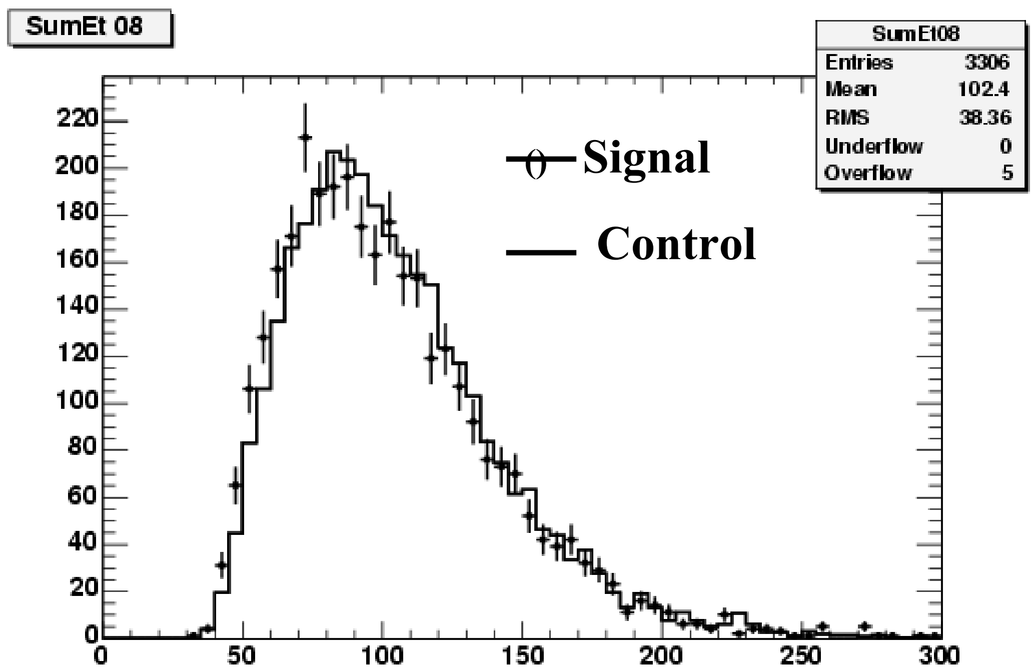
QCD Background Estimate

- Correct the distribution for small differences between the control sample and the signal region sample
- Normalize control sample to low values of Met and extrapolate to very high vales of Met
- Check with sample of Z's

Correcting for differences between samples

- Resolution is a function of the total energy in the event
- Total energy in signal and control samples differ by 6%





Small correction

Checking the methods

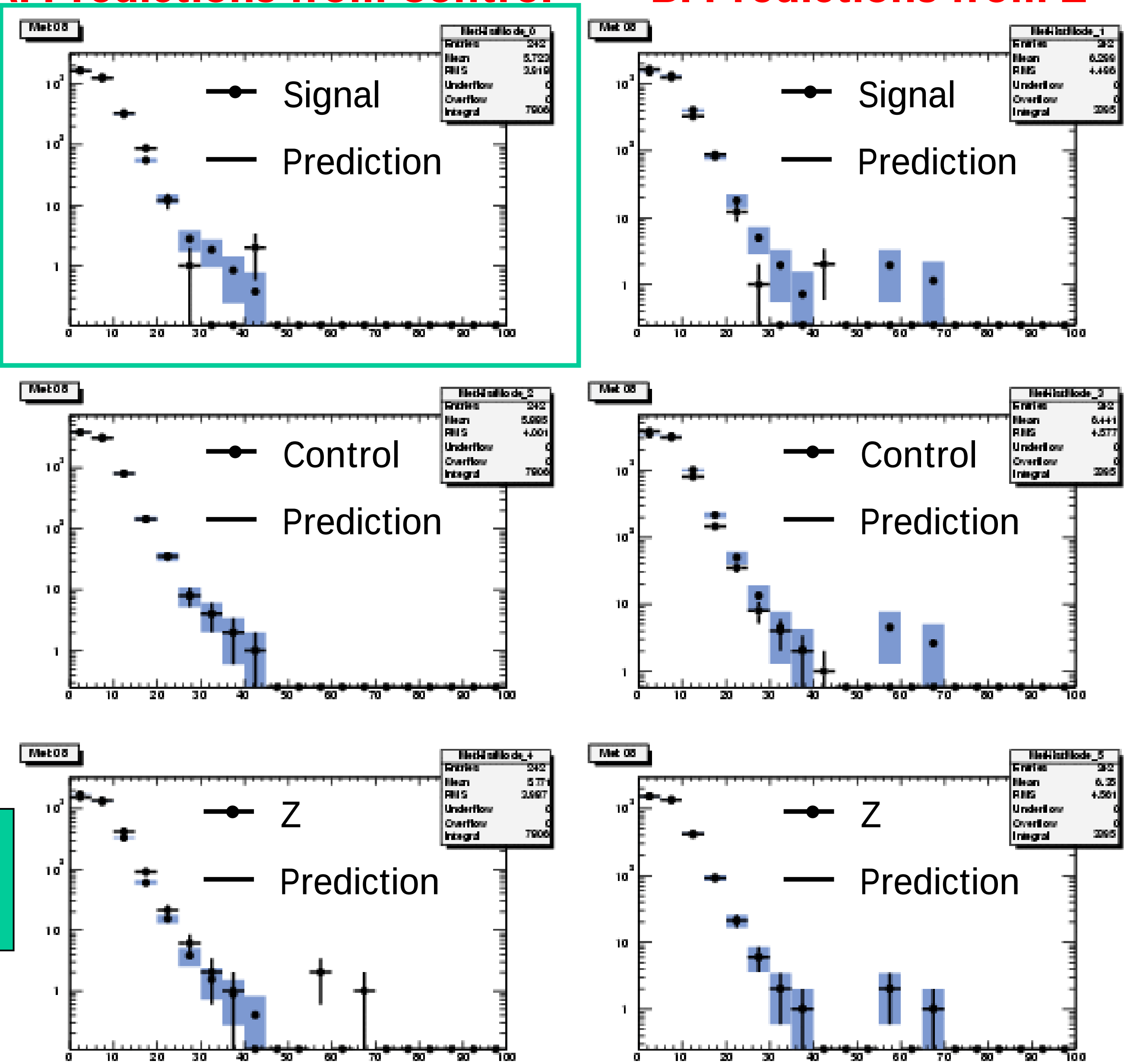
Checks:

Use control sample to predict Met distribution in Z->ee events

Compare:

1. Z
2. Control Sample
3. Signal Region

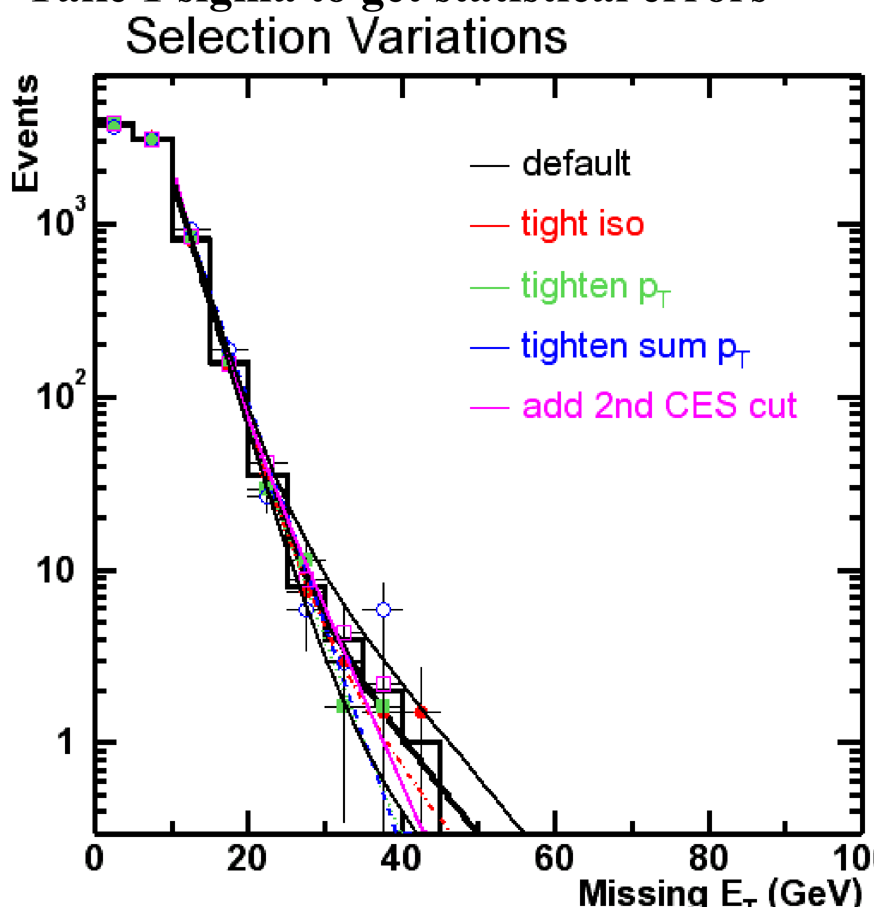
A. Predictions from Control **B. Predictions from Z**

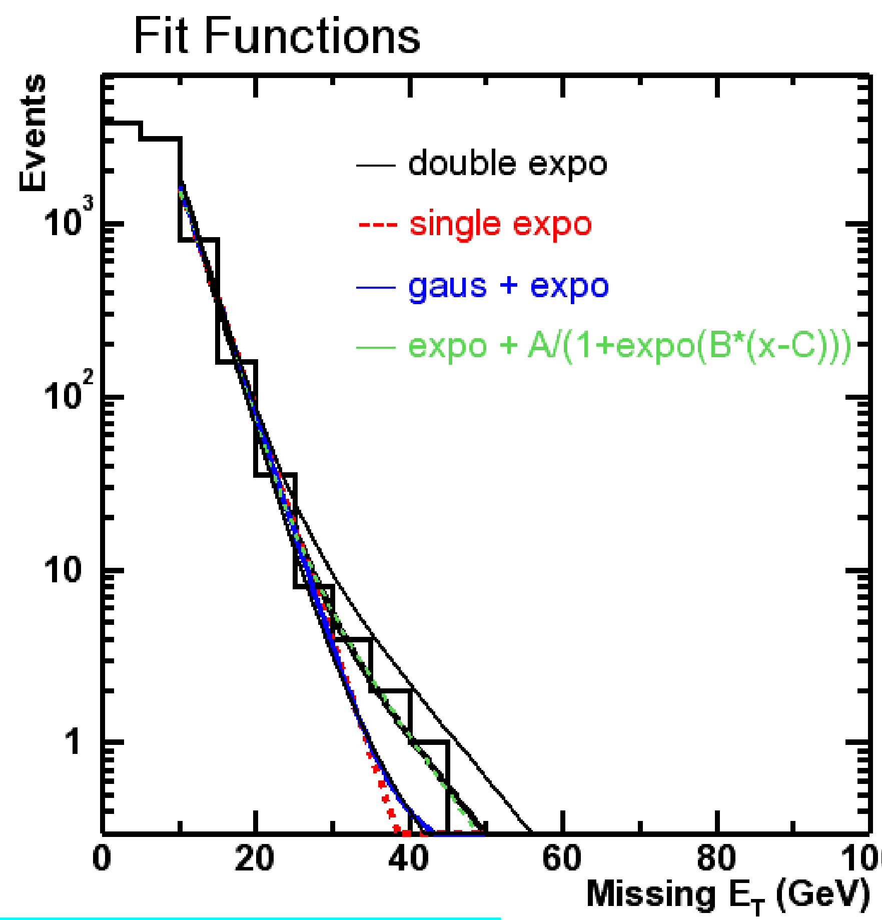


Method does a good job of predicting Met shapes

Extrapolate to large Met

- **Use a double exponential fit to extrapolate to the large MET region**
- **Use variation on the control sample selection as a source of systematic uncertainty**
- **Use various fit functions to get systematic error on prediction**
- **Take 1 sigma to get statistical errors**



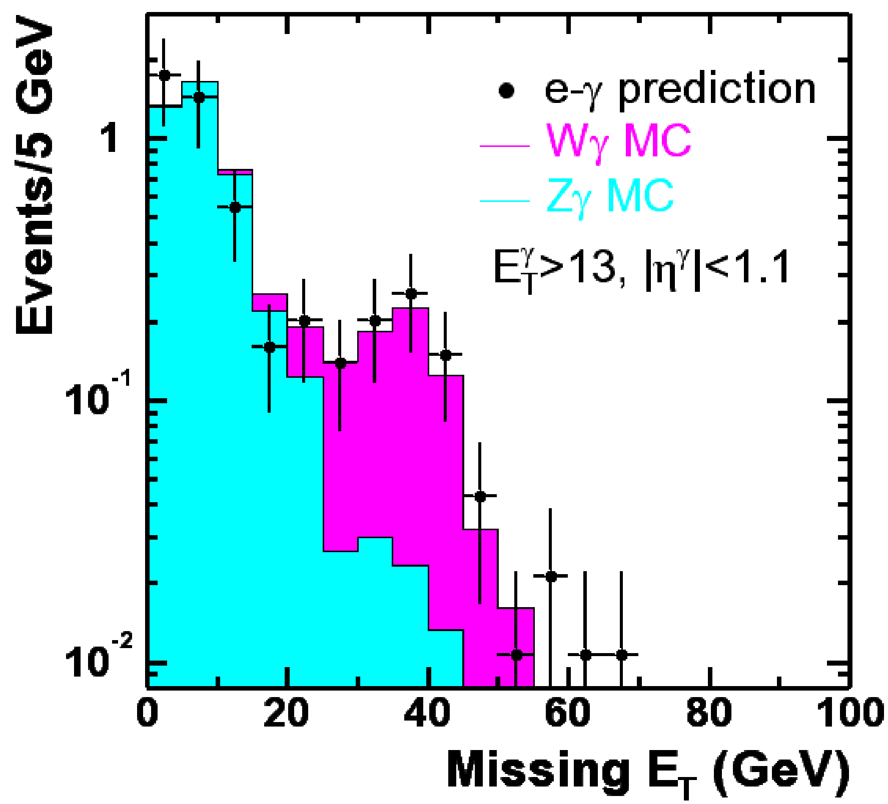


$\Rightarrow$ Systematic error = 90%

Electrons with a lost track can fake a γ

- Events with electrons can have real Met
  - Wγ
  - Zγ
  - Top pairs etc.
- Estimate all sources together using data
- Use a sample of eγ events and the rate at which electrons fake photons (~1%)

Check: eγ data well modeled by Wγ-type (real Met) and Zγ-type production (no Met)

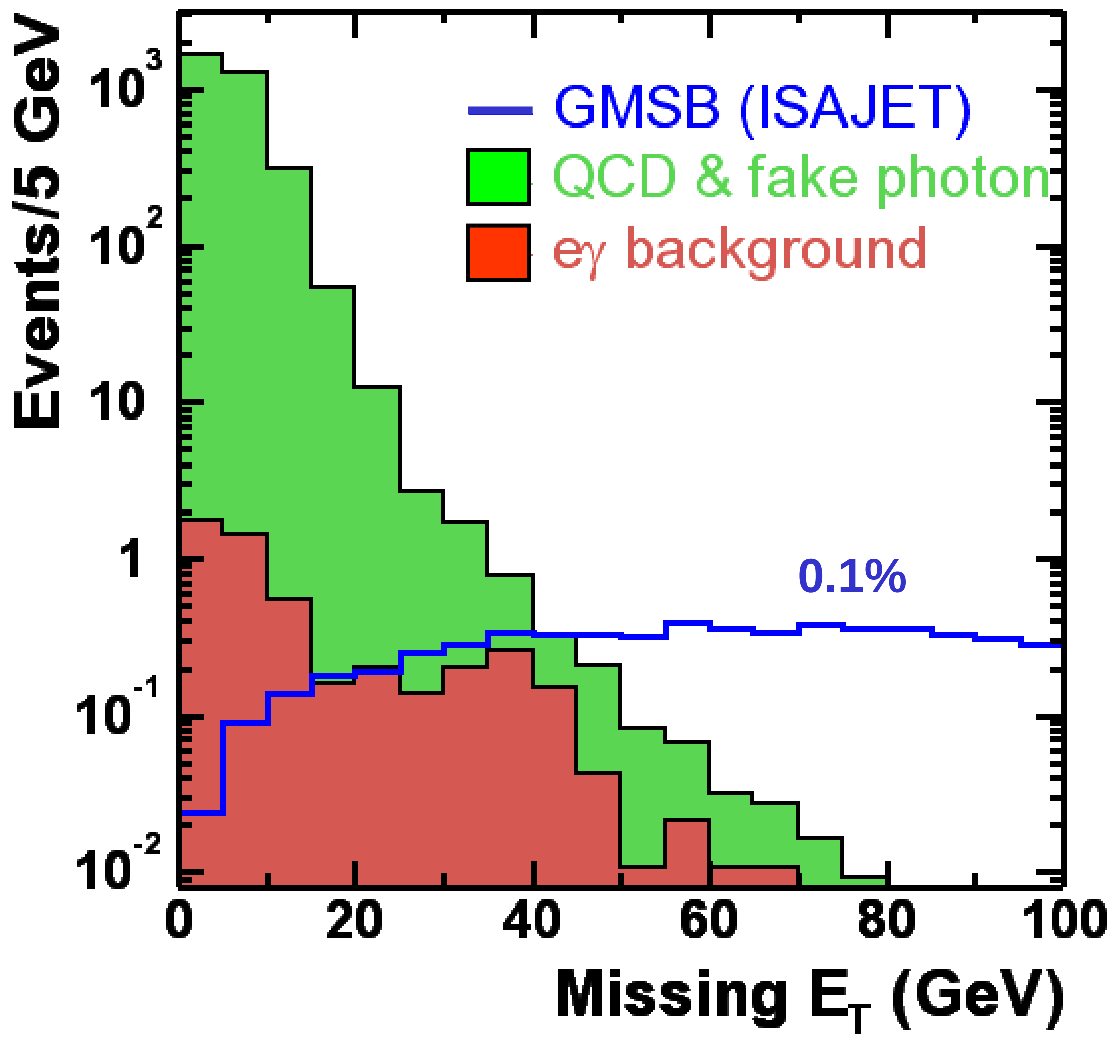


Non-Collision Backgrounds

- Cosmic rays, Beam-halo and Beam-gas type backgrounds can produce photons and/or Met which is not from the primary collision
- Reject events with:
  - Photon(s) equal and opposite Met
  - Muon Stubs with no tracks near them
  - Evidence of beam-halo deposits
  - Out-Of-Time energy from Hadron TDC (HADTDC)
- Most of these are crude and indirect, but can be efficient for this particular analysis. More on this later

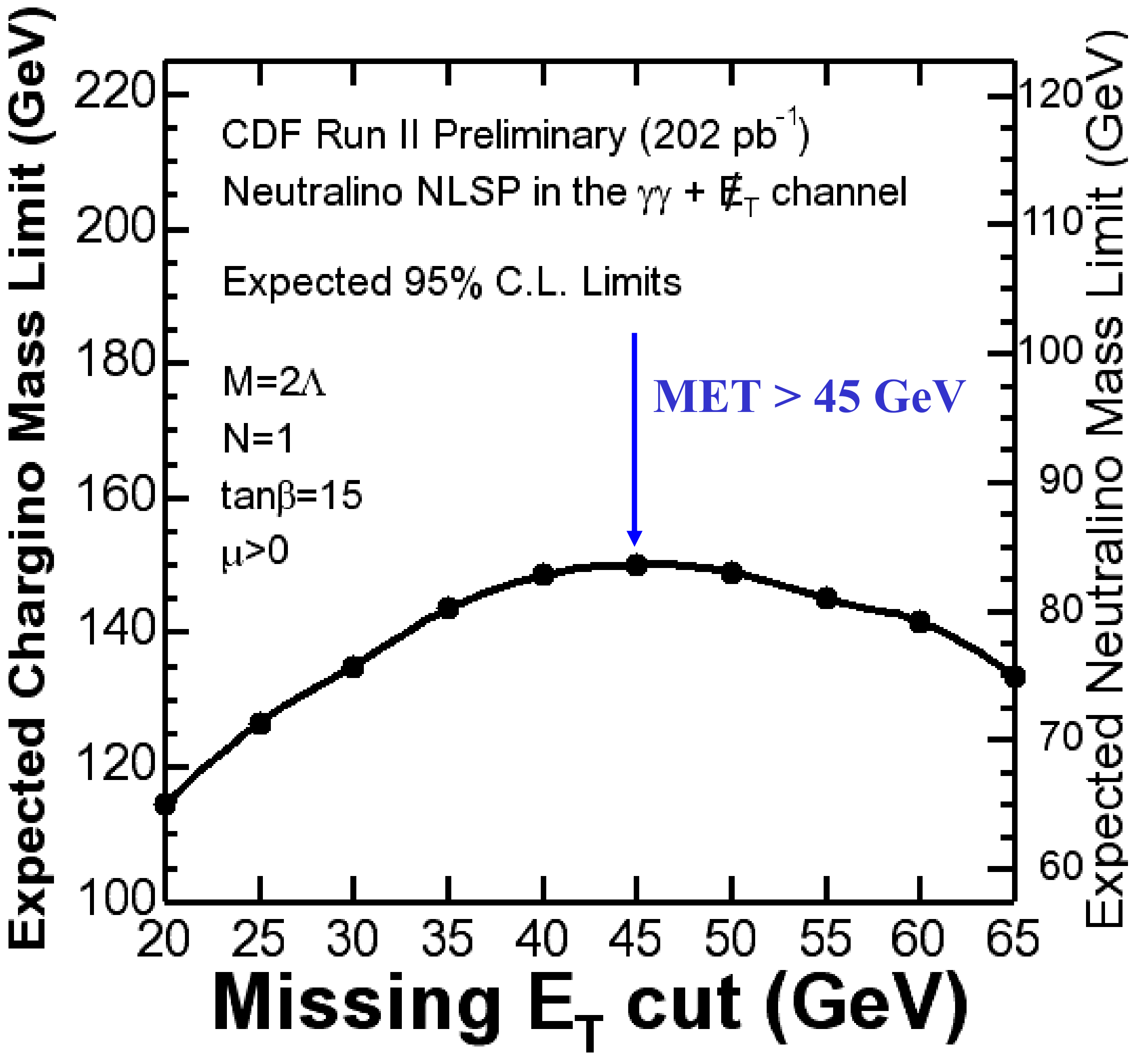
Signal Vs. Background

- **Estimate Acceptance with ISAJET and Detector simulation**
- **Correct for differences between Monte Carlo and detector performance**

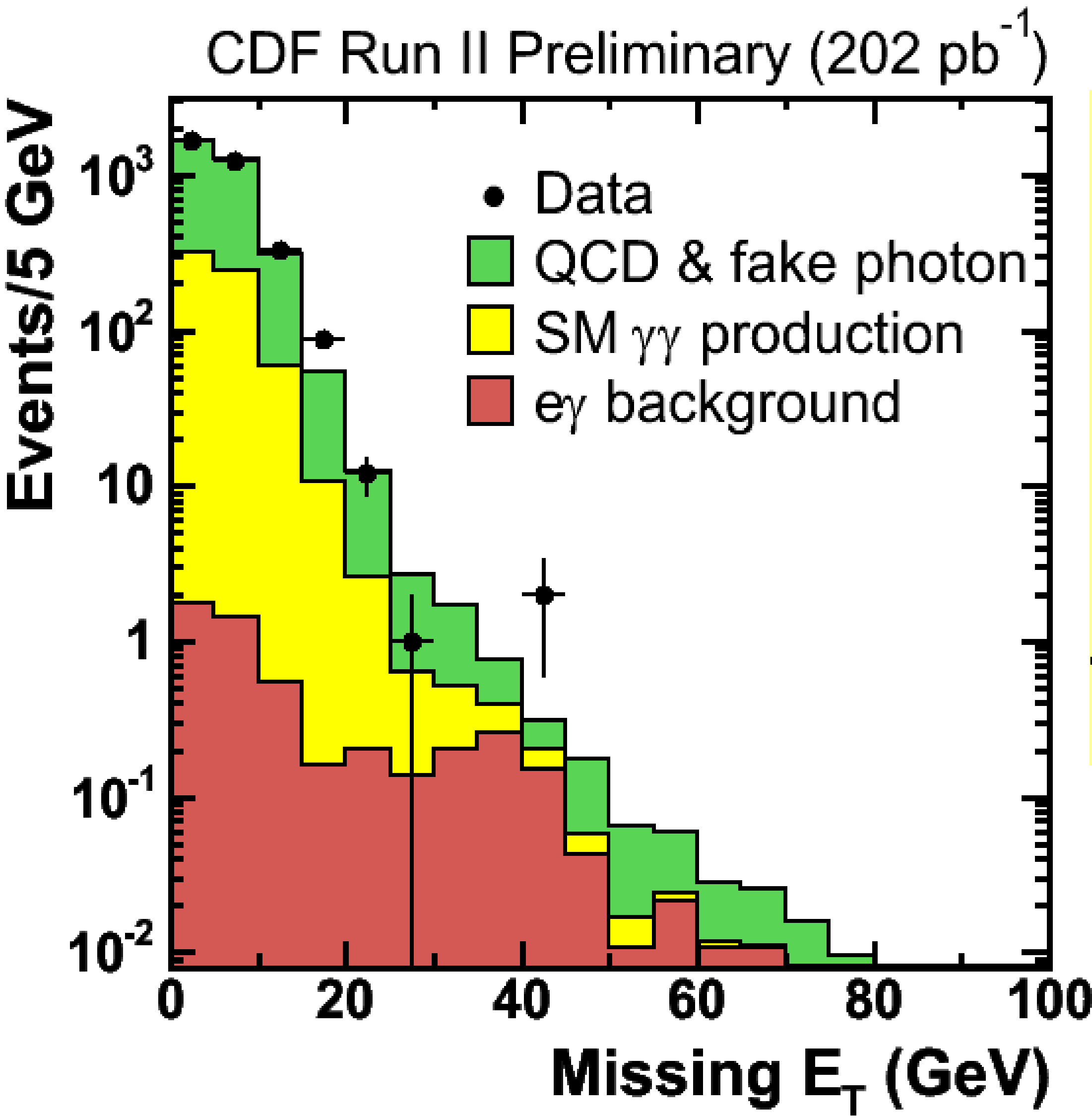


Optimization

Find the expected cross section limit as a function of the final Met cut to optimize the sensitivity



Comparing Data vs. Backgrounds



For $\not{E}_T > 45$ GeV,

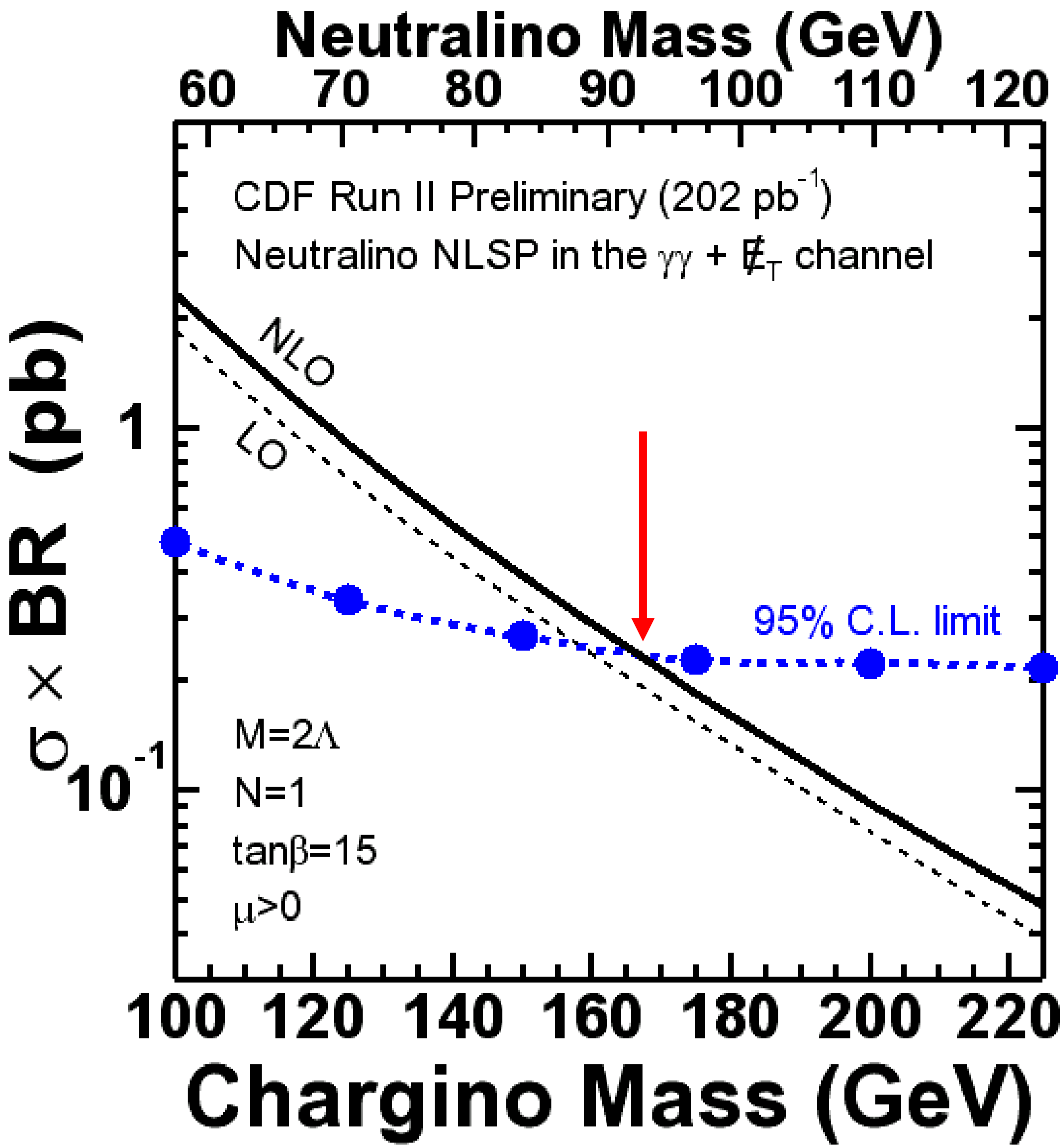
the expected # of backgrounds:

- QCD $= 0.27^{+0.50}_{-0.25} \pm 0.24$
- SM $\gamma\gamma$ $= 0.02^{+0.03}_{-0.01} \pm 0.02$
- $e-\gamma$ $= 0.10 \pm 0.05 \pm 0.03$
- Non-Collision $= 0.21 \pm 0.05 \pm 0.14$

Total $= 0.60^{+0.50}_{-0.26} \pm 0.28$

0 events observed with MET > 45 GeV

Cross section limit @95% C.L.



- 0 events observed with $\not{E}_T > 45$ GeV
- $0.60\ ^{+0.50}_{-0.26}(stat.) \pm 0.28(syst.)$ expected
- 18% systematic uncertainty on $\varepsilon \times \mathcal{L}$

$\Rightarrow$ $N_{95\%\ C.L.}$ limit of 3.3 events

NLO Limit at 95% C.L.

$m(\tilde{\chi}_1^{\pm}) > 168$ GeV/c^2

$m(\tilde{\chi}_1^{0}) > 93$ GeV/c^2

Some issues of Non-Collision Backgrounds

1. **Fake photon+Met from non-collision backgrounds still a worry**
   – Is that what produced the CDF eeγγ+Met event in the Run I γγ+Met search? Unlikely, but we'll never know…
   – Currently no good handle to indicate that the photon is from the collision →Only Hadronic portion of calorimeter component has timing
2. **Looking at a control of sample of fake γ+Met shows:**
   - Photons are real
   - Only small amounts of hadronic energy which are out-of-time
   - Out-of-time hadronic energy not always near photon
3. **A direct handle, such as timing, now requires looking for hadronic leakage and often no hadronic energy is associated with the photon at all**

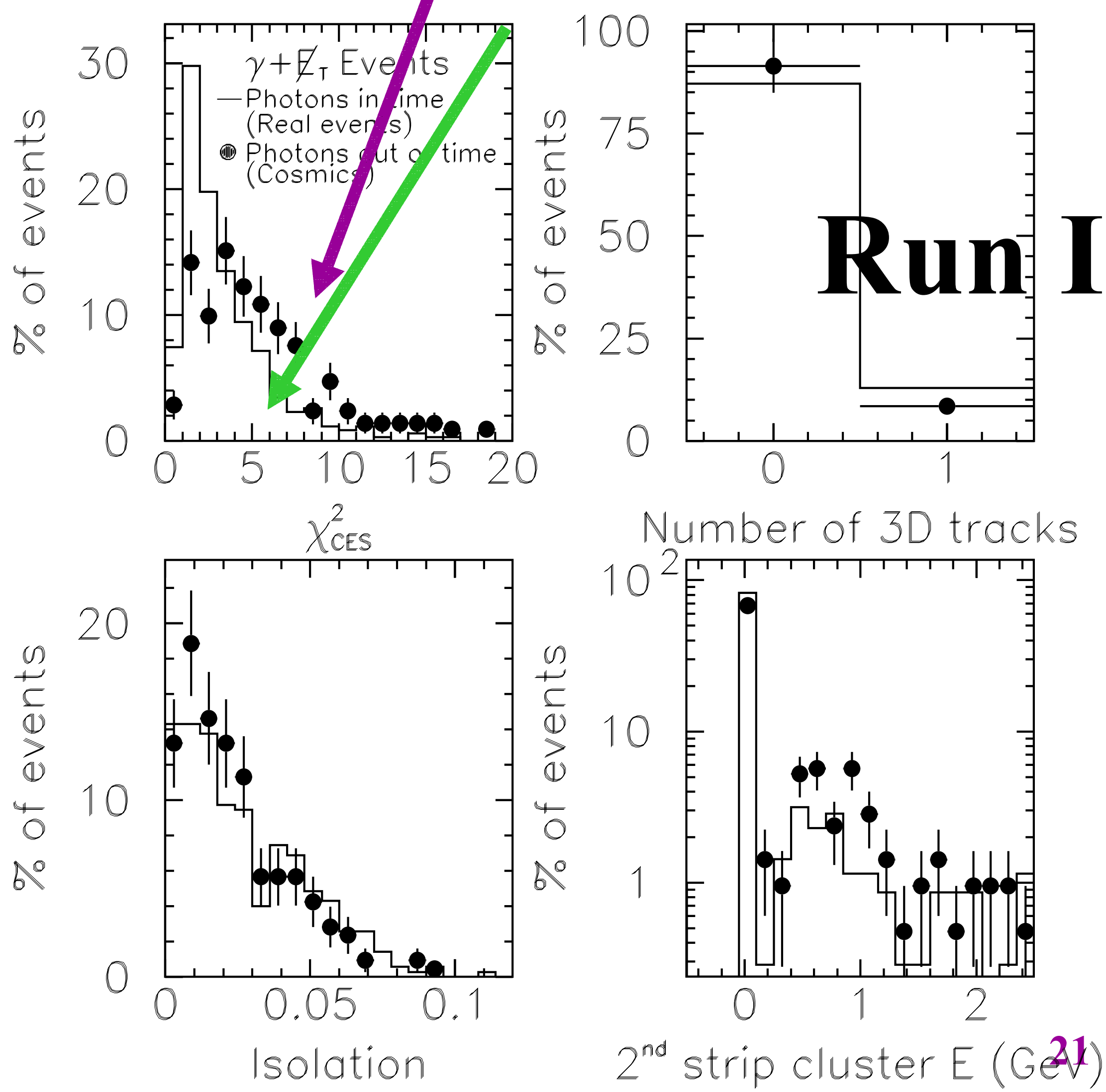
Real photons vs. Cosmics

Problem: **Cosmic rays enter the detector and fake a photon (+Met)**

- **<u>Question:</u>** **Can't you just make ID cuts and get rid of the cosmic ray backgrounds?**
- **<u>Answer:</u>** **Photons from the primary event, and photons from cosmic rays look very similar in the CDF calorimeter. Many are real photons.**

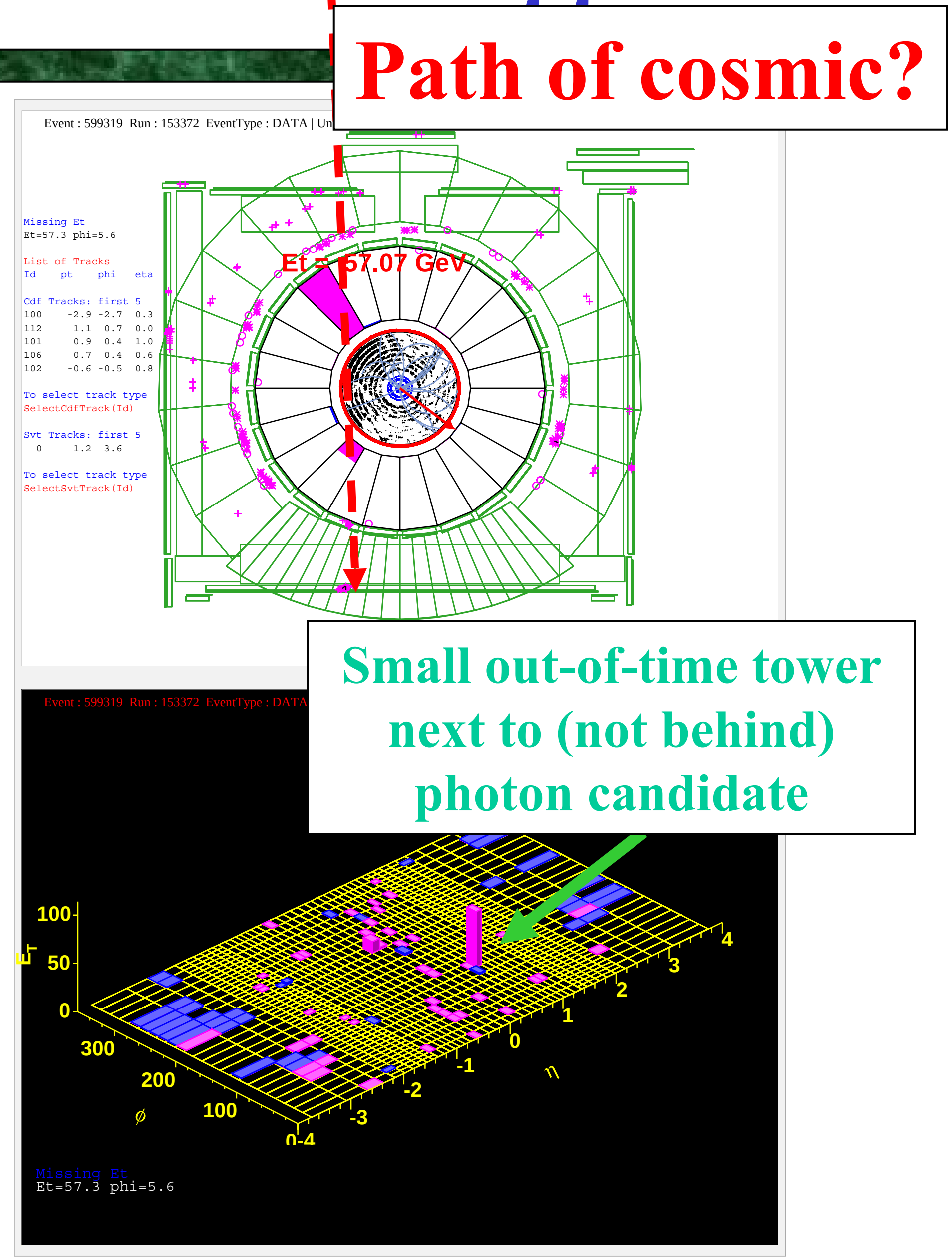
Points: Photons from Cosmics

Solid: Photons from collisions



Example of a rejected event in $\gamma\gamma$+Met

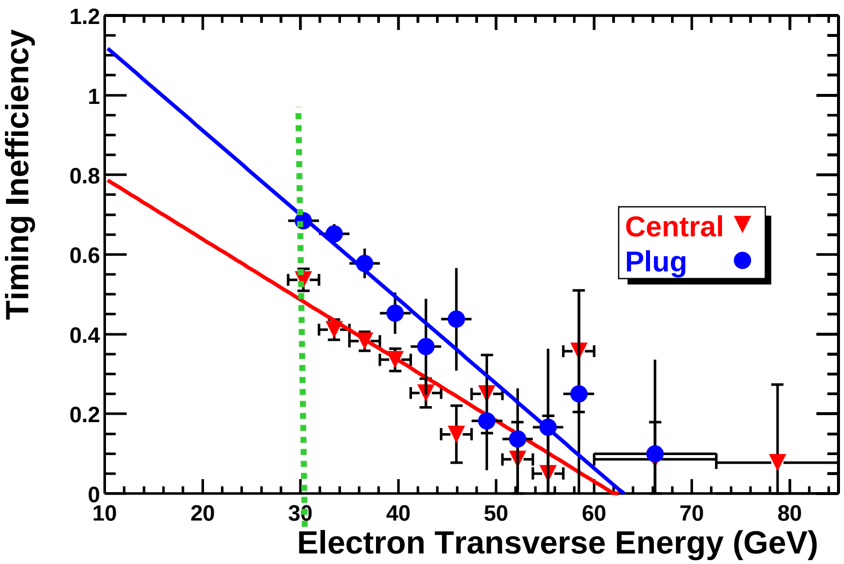
- **This event has one tower (E=1.5 GeV) “near the photon” which is 85 ns out of time. No timing info for 75 & 14 GeV photons.**
- **Can’t tell if photons are in time, can’t tell if Met is reliable**
- **We reject this event, based on the small, poorly measured HAD energy rather than the well measured dominant part of the event**



HADTDC & Timing for photons

An photon shower needs to leak into the hadronic calorimeter to have timing

- HADTDC system is very inefficient for low E_T photons
- Requiring timing for a photon gives a bias toward fake photons from jets



Run II γ +MET
Trigger threshold

In Run I: Expected ~1.4 of the 4 EM objects in eeγγ+Met to have timing. Only 2 did (both were in time)

In Run IIa: Only ~5% of eeγγ+Met events would have timing for all objects.

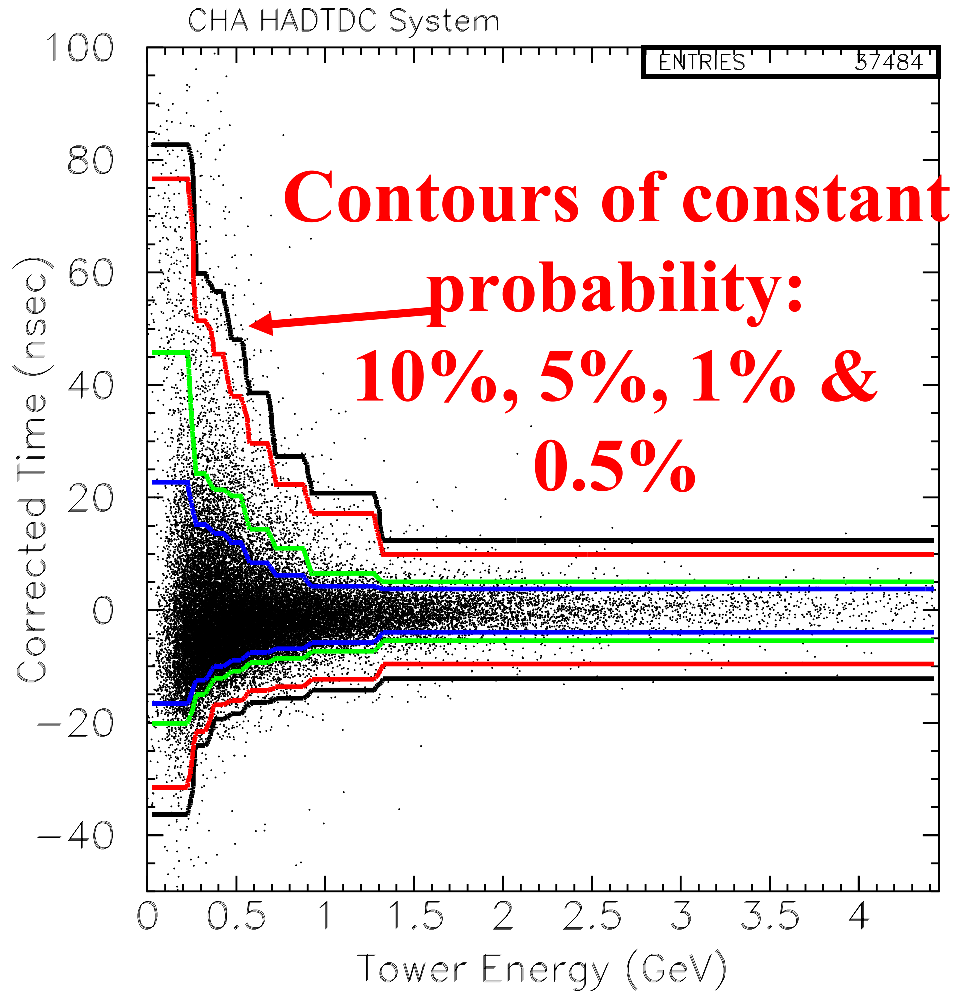
To be fully efficient requires a 55 GeV photon (Peter Onyisi's γ+Met analysis)

More problems at low HAD energy

The leakage energy of a photon into the hadronic compartment is small which is why it has low efficiency

It gets worse: As the energy goes down:

1. Timing resolution gets worse
2. Distribution becomes asymmetric



EMTiming

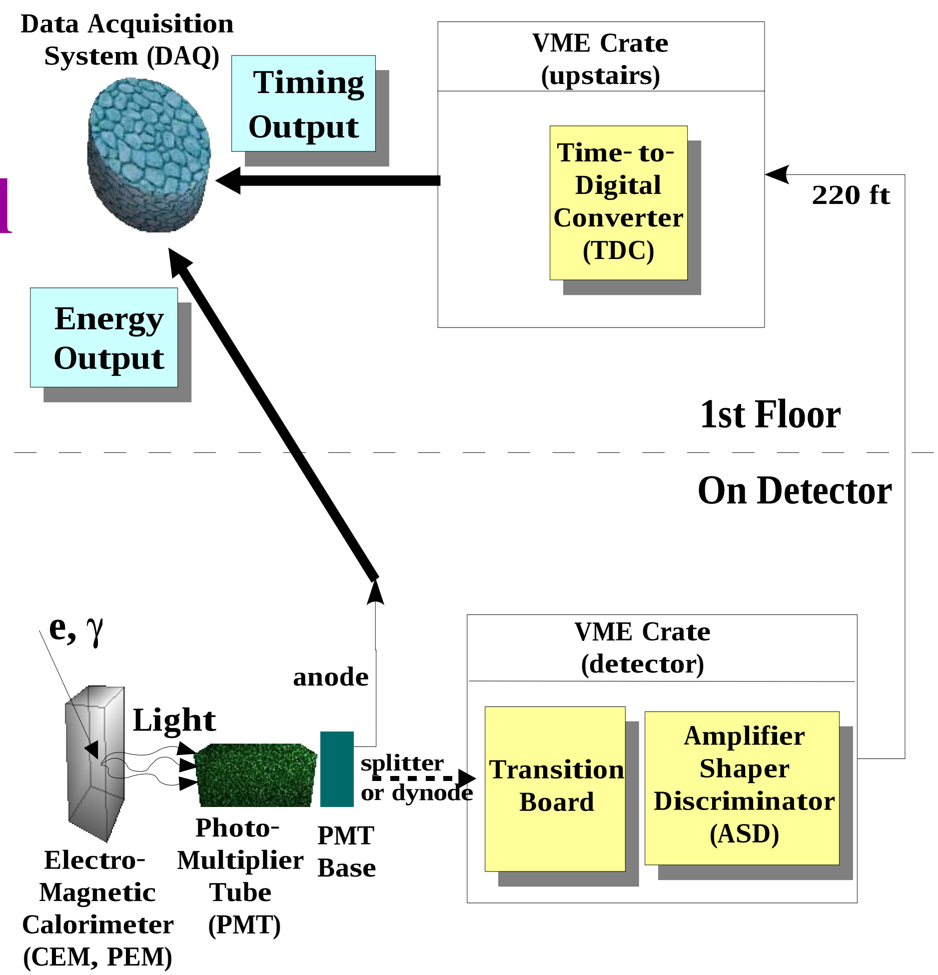
Adding timing on EM Calorimeter would help

- **Photon handle:** Would provide a vitally important handle that could confirm or deny that all the photons in unusual events (e.g. $ee\gamma\gamma$+Met candidate events) are from the primary collision.
- **Met handle:** For events with large EM energy, full calorimeter coverage reduces the cosmic ray and beam halo background sources and improves the sensitivity for high-P_T physics such as SUSY, LED, Anomalous Couplings etc.
- **Search for long-live particles** (More on this later)

EMTiming Overview

- Run IIb proposal in 2000
  - TAMU-INFN-UC-Argonne-Michigan
- Hardware virtually identical to existing HADTDC system except for the CEM
- Final project design was approved by CDF/DOE/INFN
- Production of all components completed in Fall of 2003, well ahead of schedule

CDF EM Timing Project



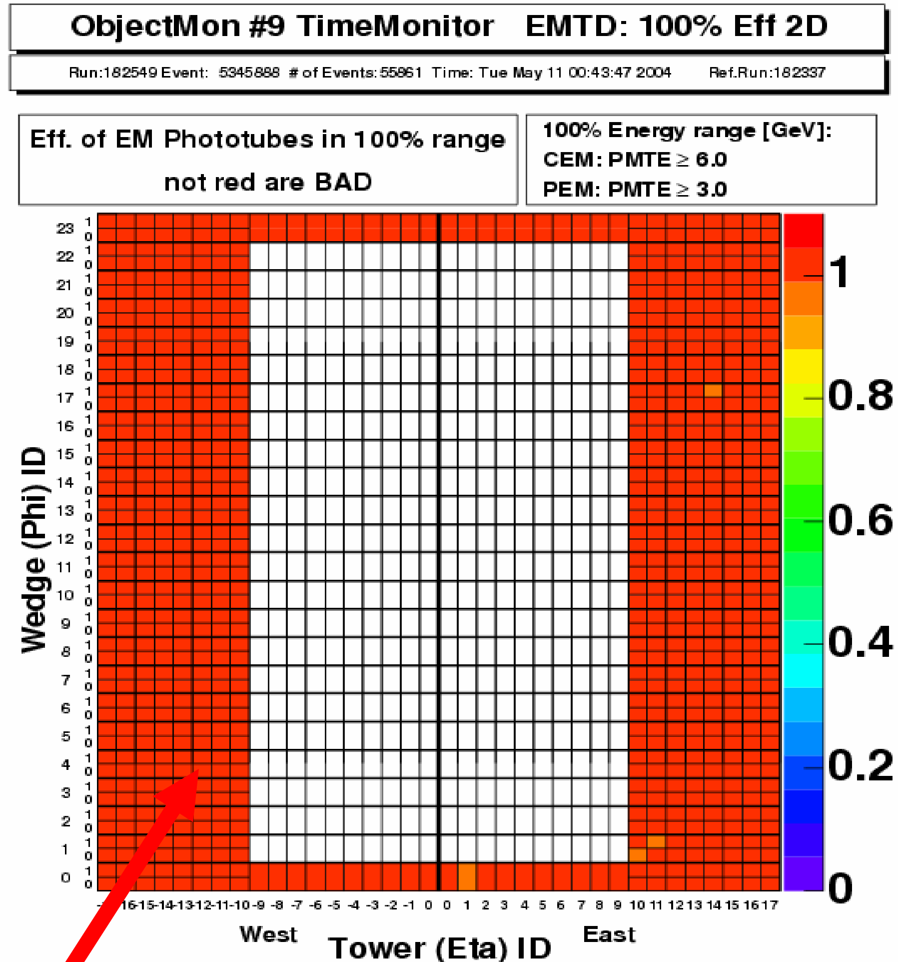
EMTiming Status

Partial installation completed Fall 2003*

EMTiming now covers:
- Entire PEM
- Two wedges in the CEM

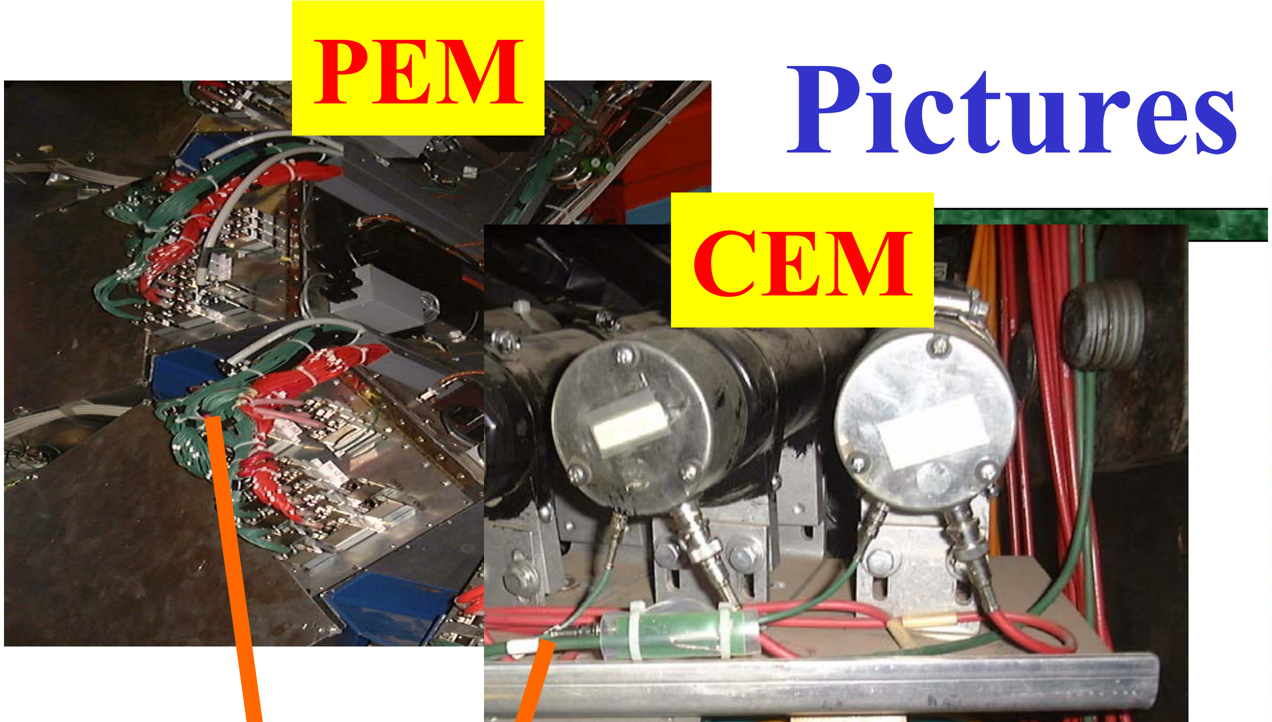
The rest is ready to be installed: Fall 2004

*M. Goncharov, S. Krutelyov, S. Lee, D. Allen, P. Wagner, V. Khotilovich & D.T.

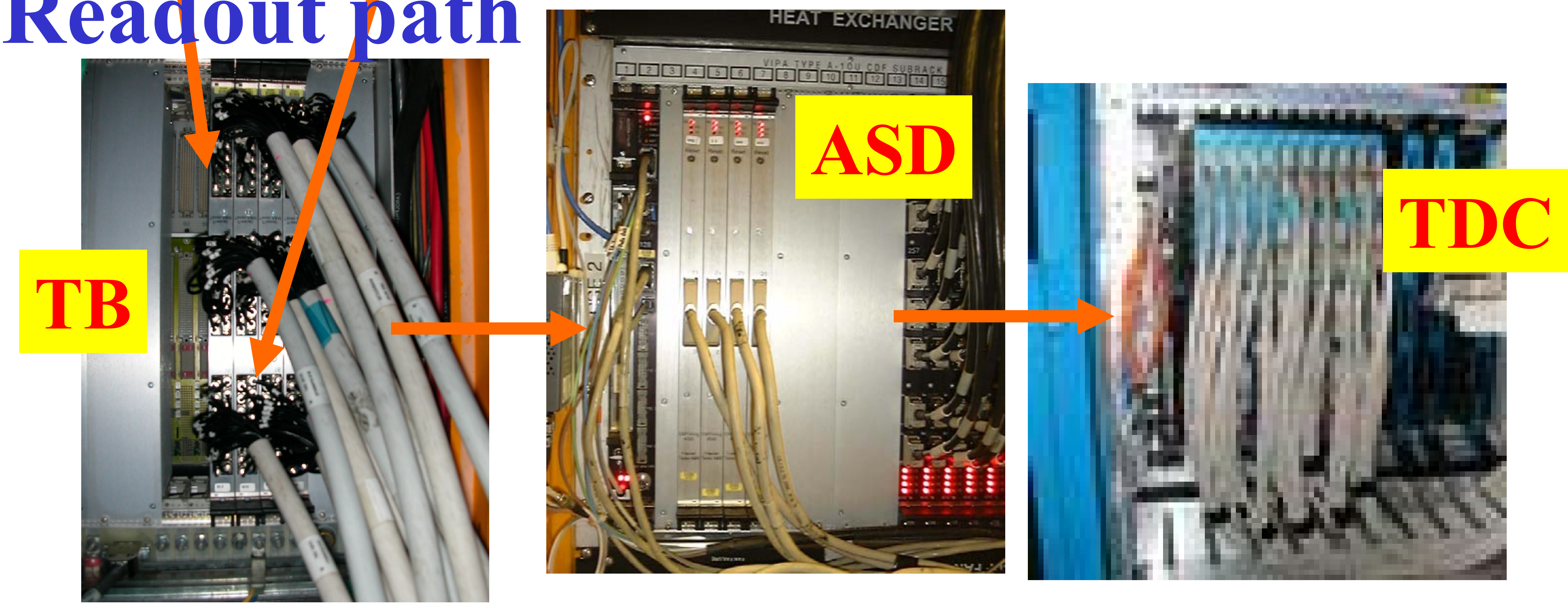


Red towers are fully functional

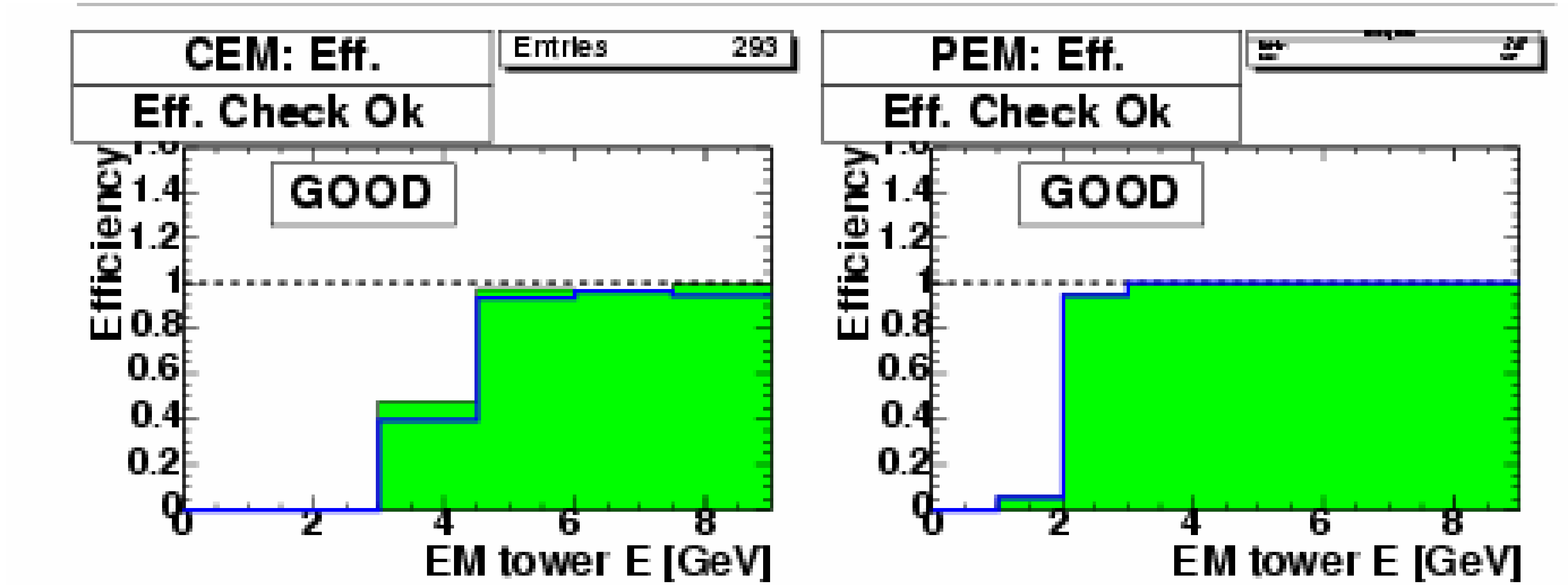
Pictures



Readout path



Efficiency from Online Monitoring



CEM: E*>~5 GeV　　**PEM: E*>~2GeV**

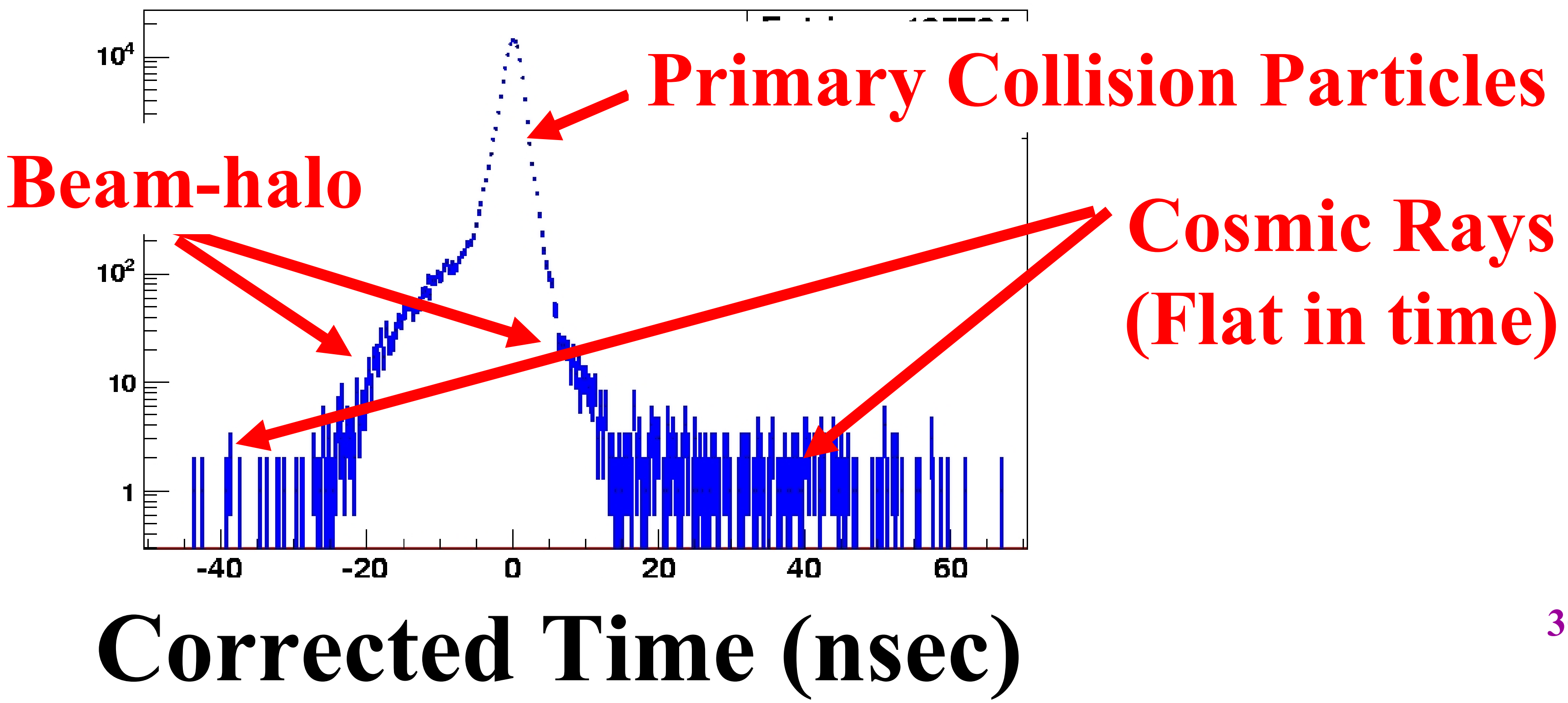
For all towers the system becomes fully efficient for all useful photon energies

***Energy not E_T**　　**Negligible fake rates**

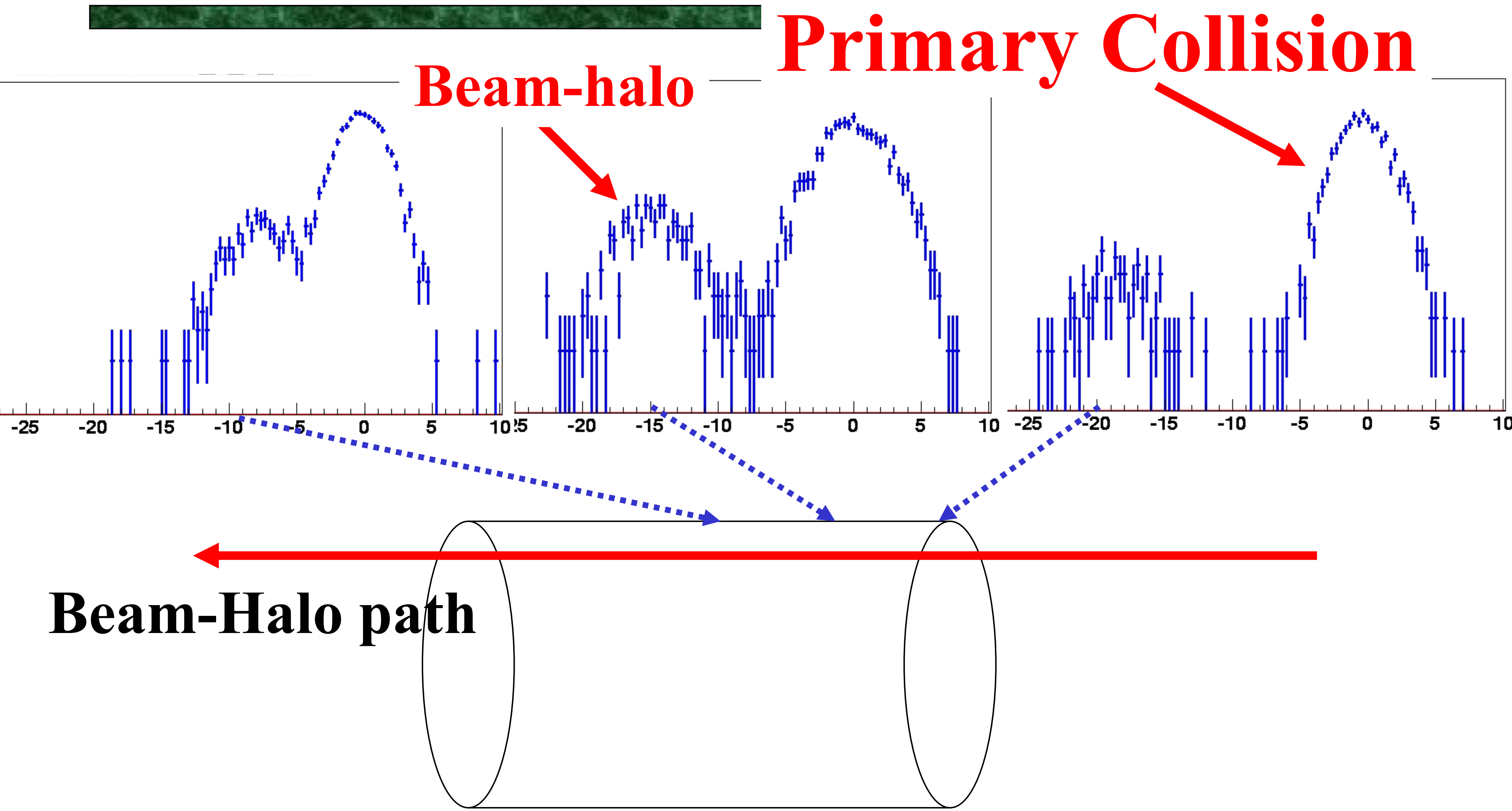
Timing distributions

Do timing corrections for

- Fixed Threshold Discriminator energy slewing corrections applied
- Collision time and vertex corrections (new ideas for CDF)

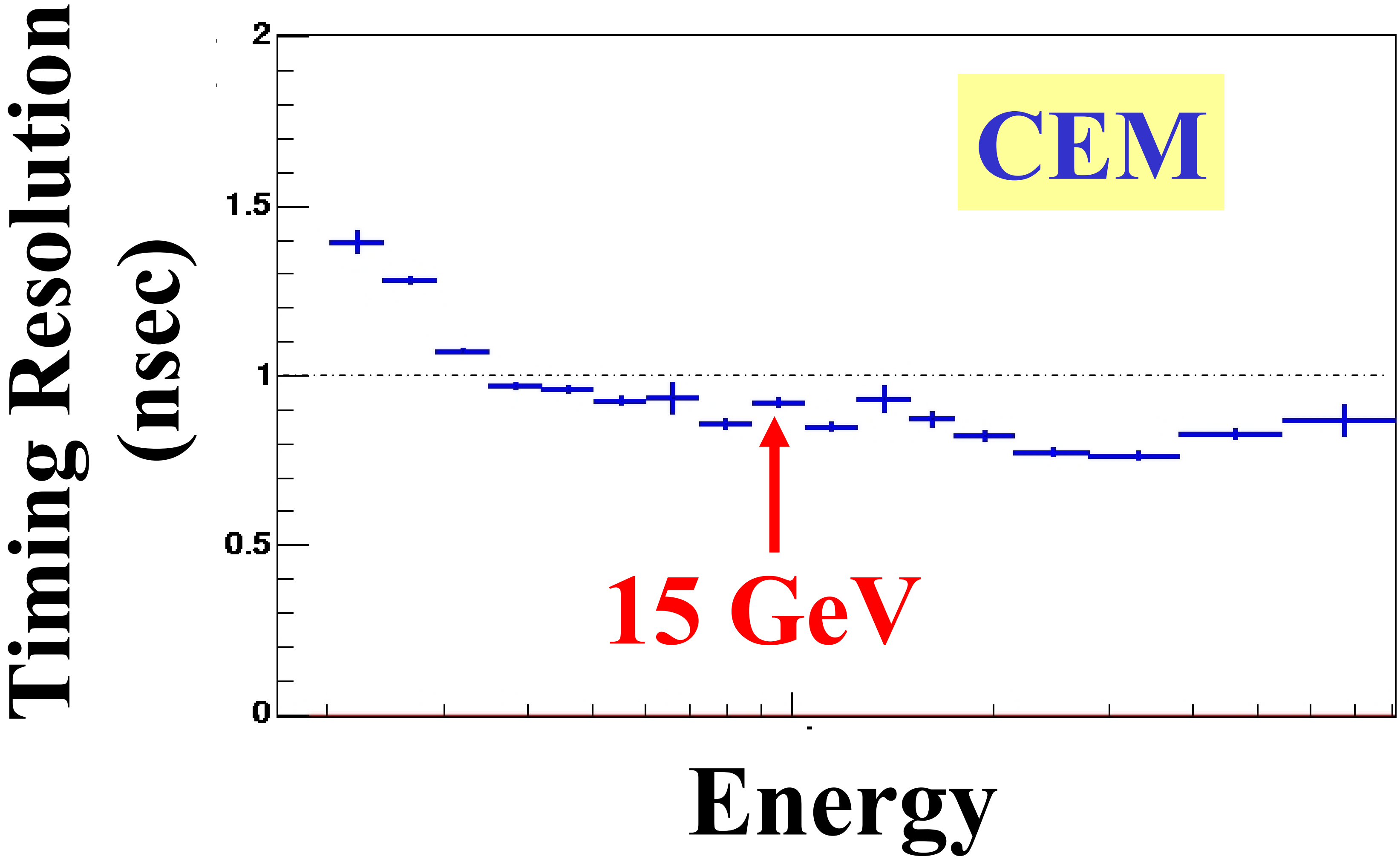


Time of arrival of Beam-Halo vs. Position



Measure speed of beam-halo to be $2*10^8$ m/s

Timing Resolution vs. Tower Energy



At high energies get a resolution of ~800 psec

Search for Long-Lived Particles?*

- **With 1 nsec resolution, we can consider looking for long-lived particles which decay to photons**
- **GMSB-SUSY predicts $\chi_1 \rightarrow \gamma G$ with nsec lifetimes**
  - **All Tevatron searches assume ~0 lifetimes**
- **Photons would arrive delayed in time relative to SM backgrounds**

What are the prospects?*

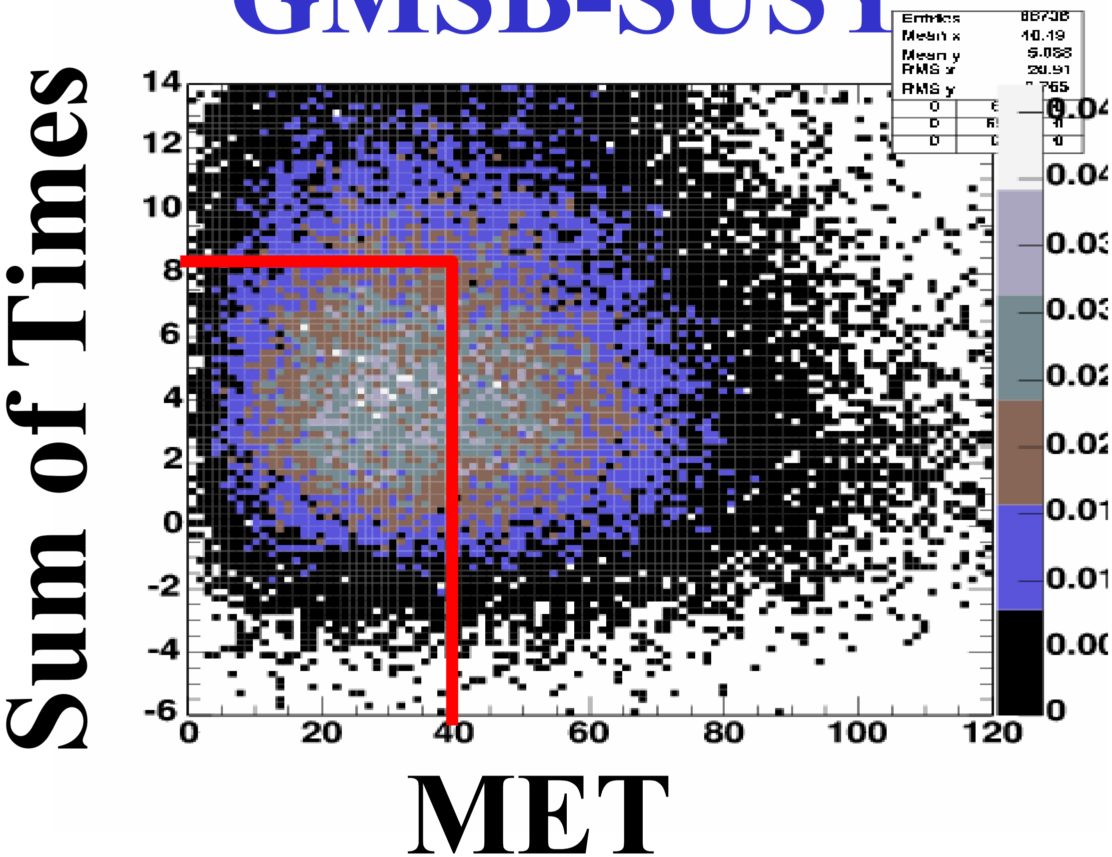
- Two neutralinos in the detector with $\chi_1 \rightarrow \gamma G$
- With nsec lifetimes it is possible one will leave the detector
- Do two complementary searches:
  1. $\gamma\gamma$+Met
  2. γ+Met+jets

  Follow previous analyses and re-optimize for addition of timing

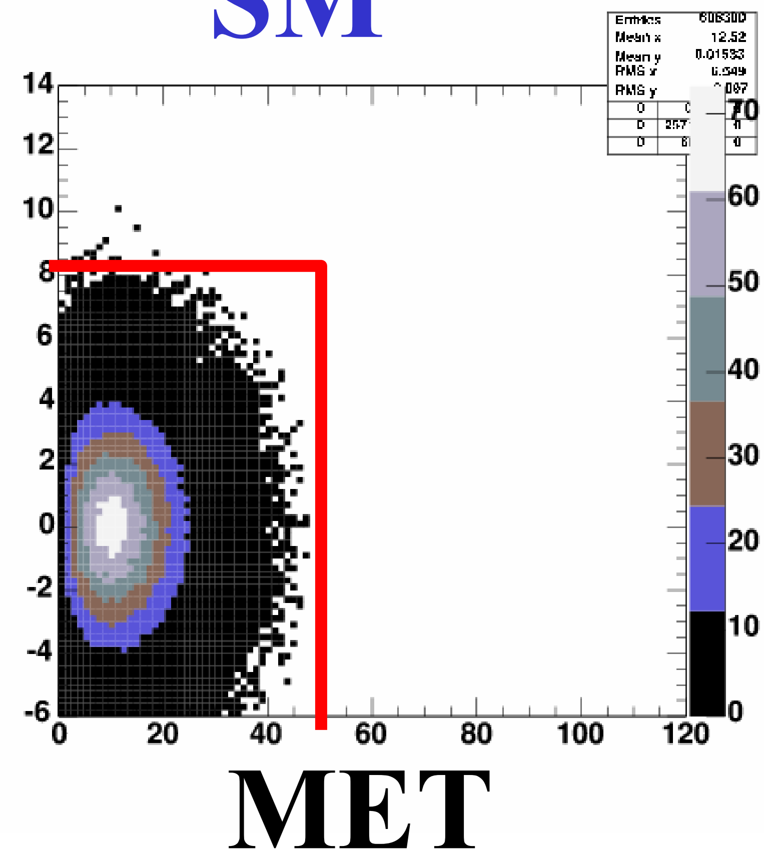
*Peter Wagner & D.T.

Compare GMSB vs. SM in γγ+Met

GMSB-SUSY

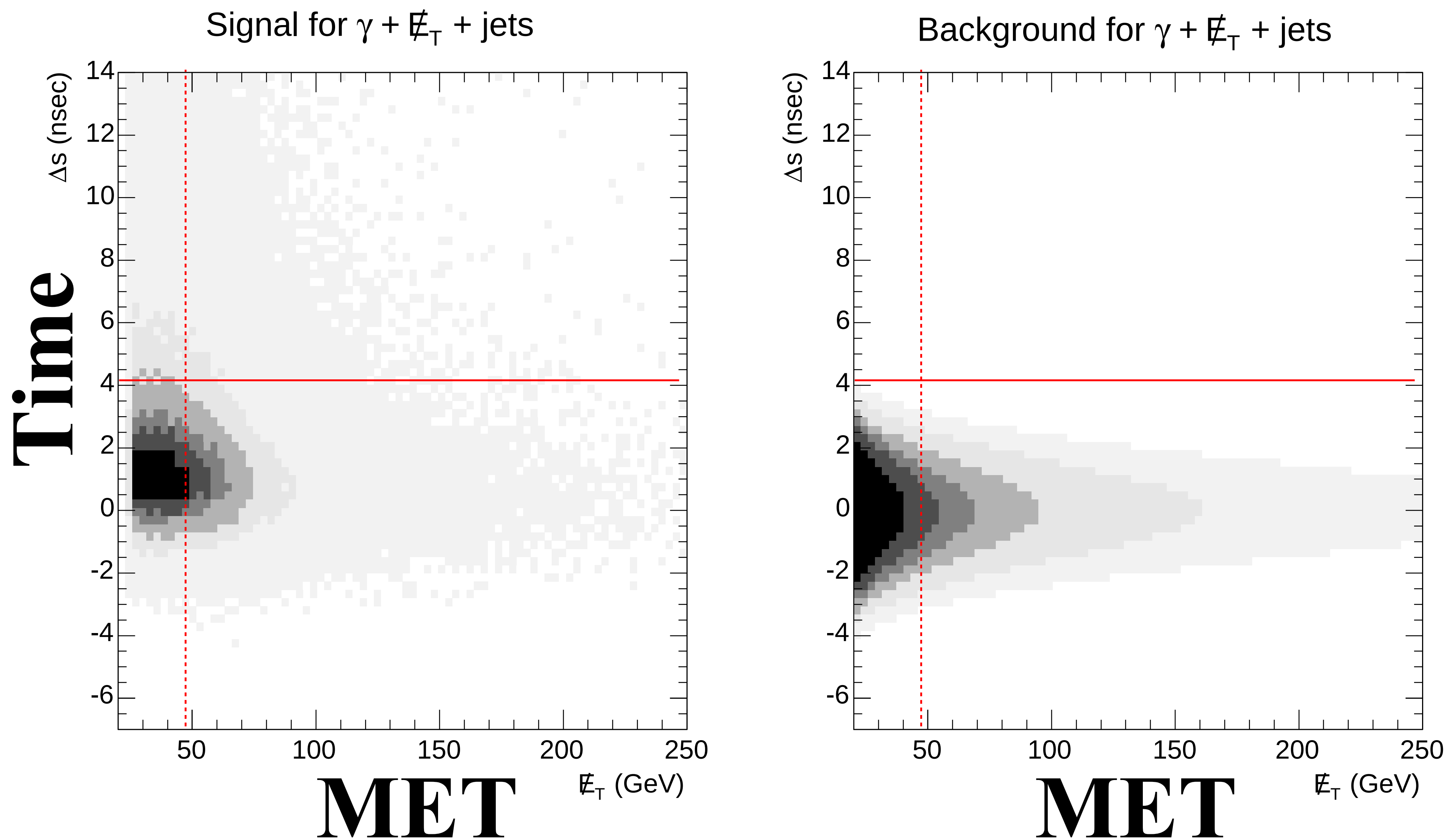


SM



Signal can be well separated from SM
(backgrounds estimate from CDF γγ+Met analysis)

Compare γ+Met+jets



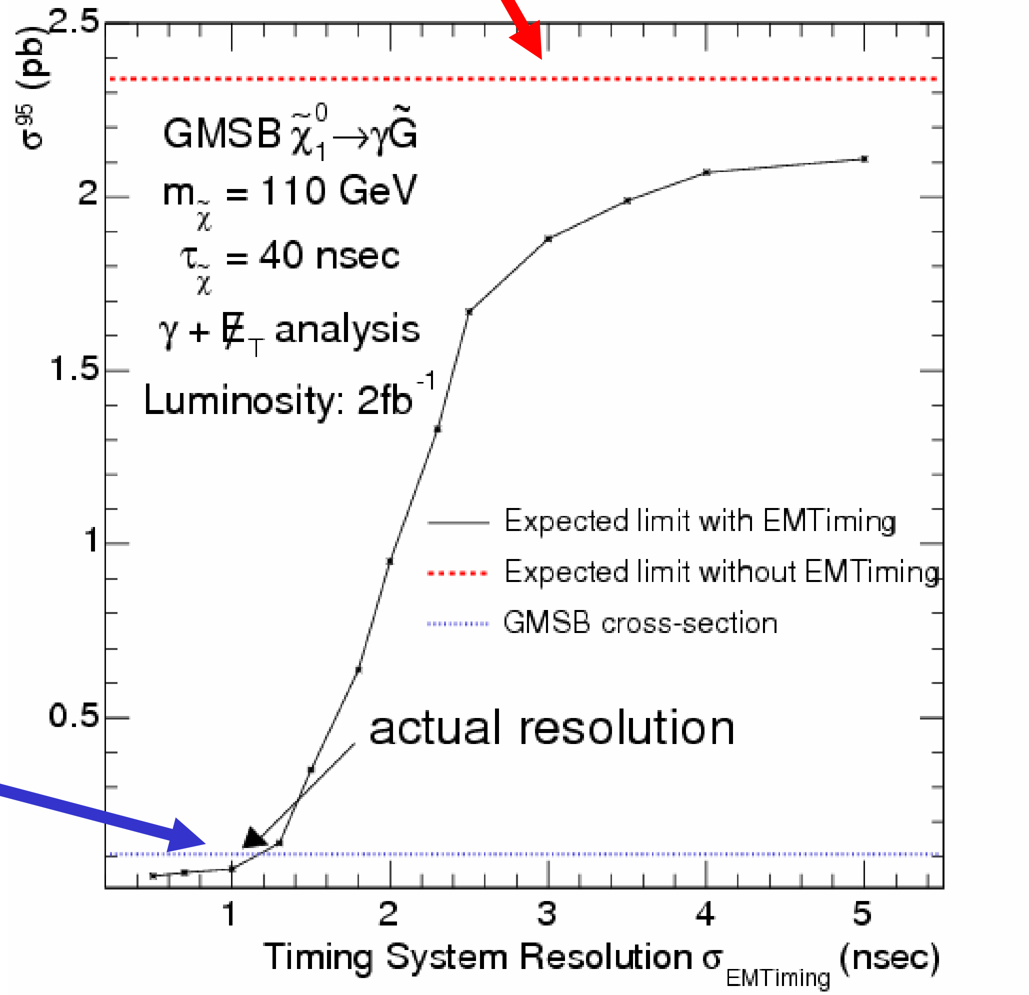
Background estimate from DZero γ+Met+2 Jet analysis

Sensitivity vs. Timing Resolution

Consider expected cross section limits as a function of timing resolution

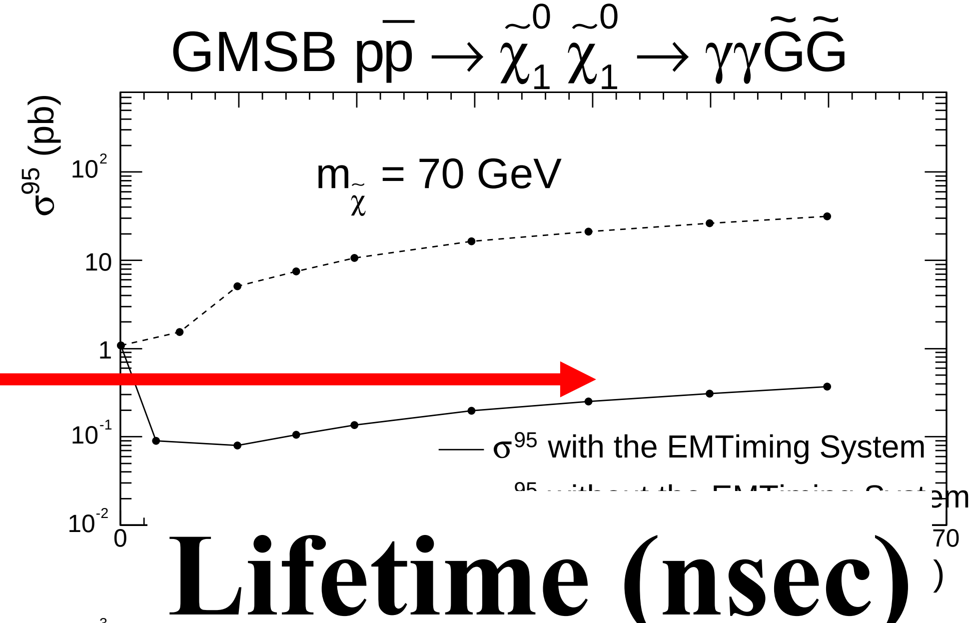
Excellent prospects for 1 nsec resolution

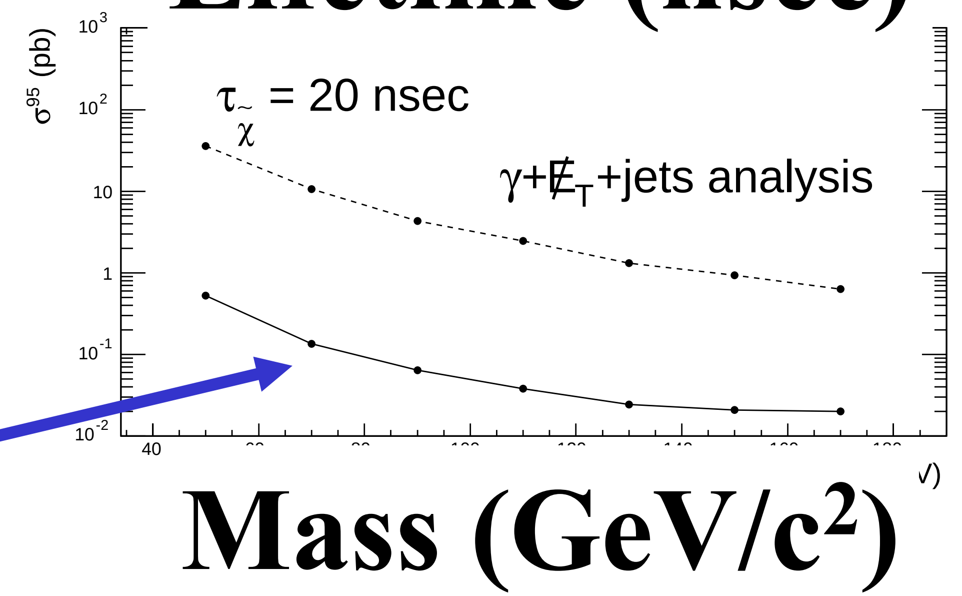
Kinematics only limit



Expected cross section limits

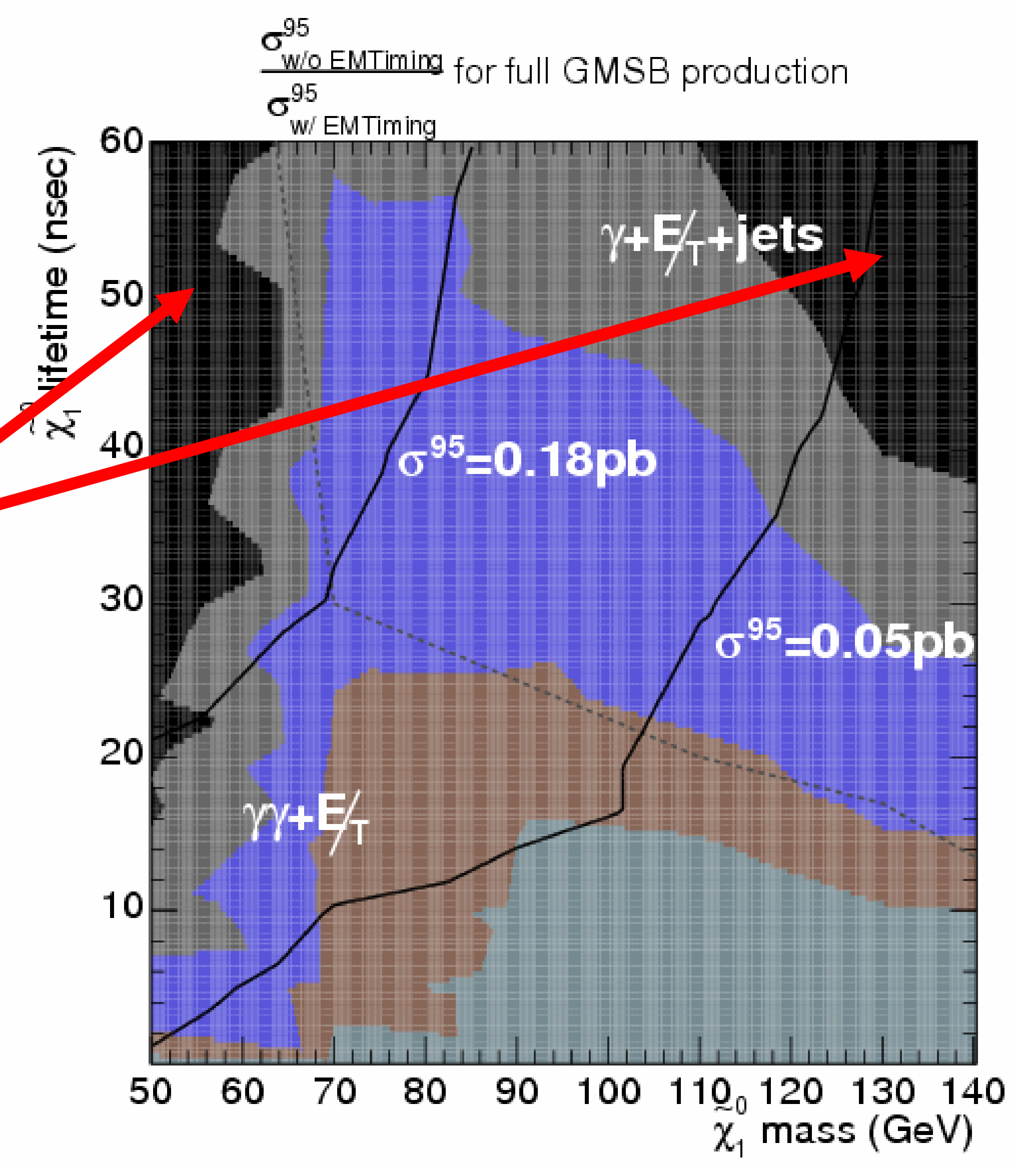
- Limits get worse as lifetime goes up, but EMTiming helps more and more relative to kinematics alone
- Limits get better as mass goes up due to kinematic effects





Where does EMTiming help most?

EMTiming gives the most improvement relative to kinematics alone at high lifetimes even though the limits get worse there

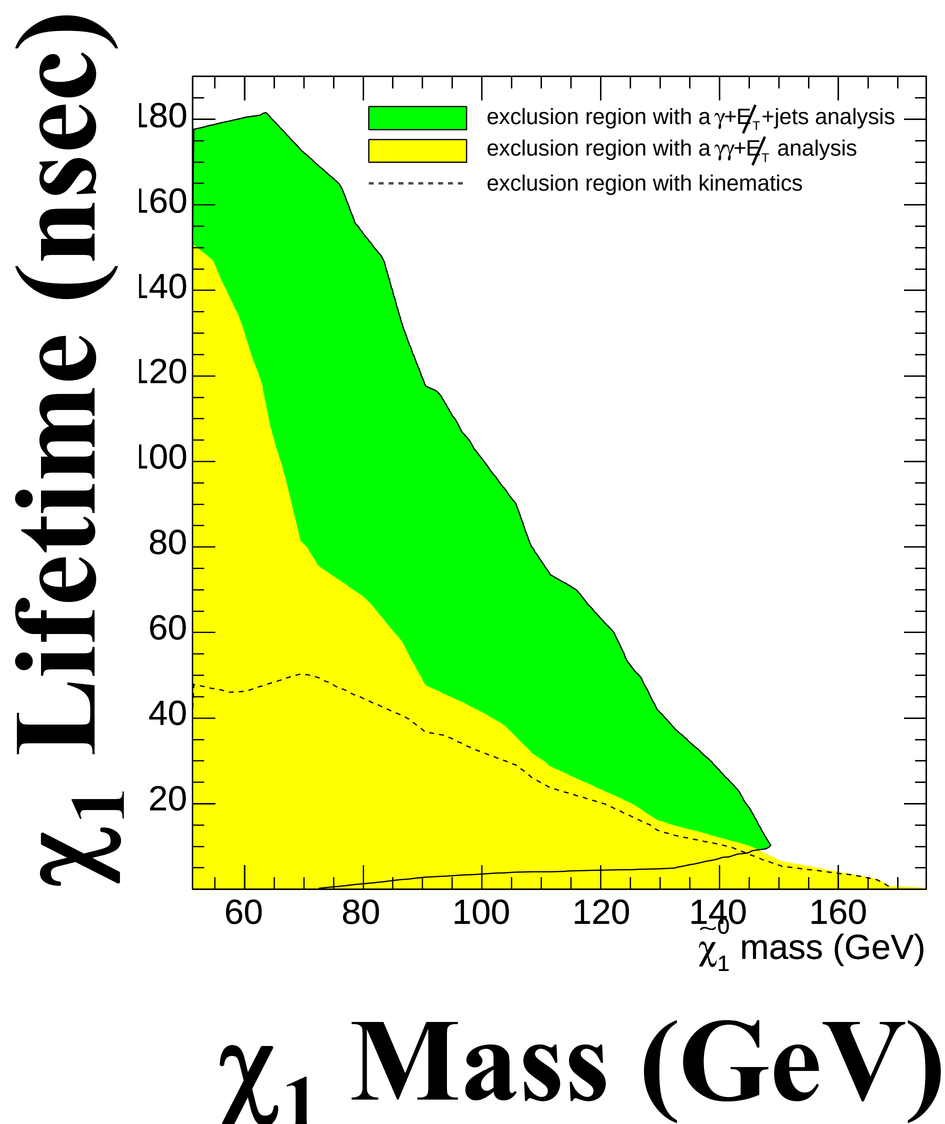


Sensitivity for the analyses for $2fb^{-1}$

Yellow region is the expected exclusion region from γγ+Met

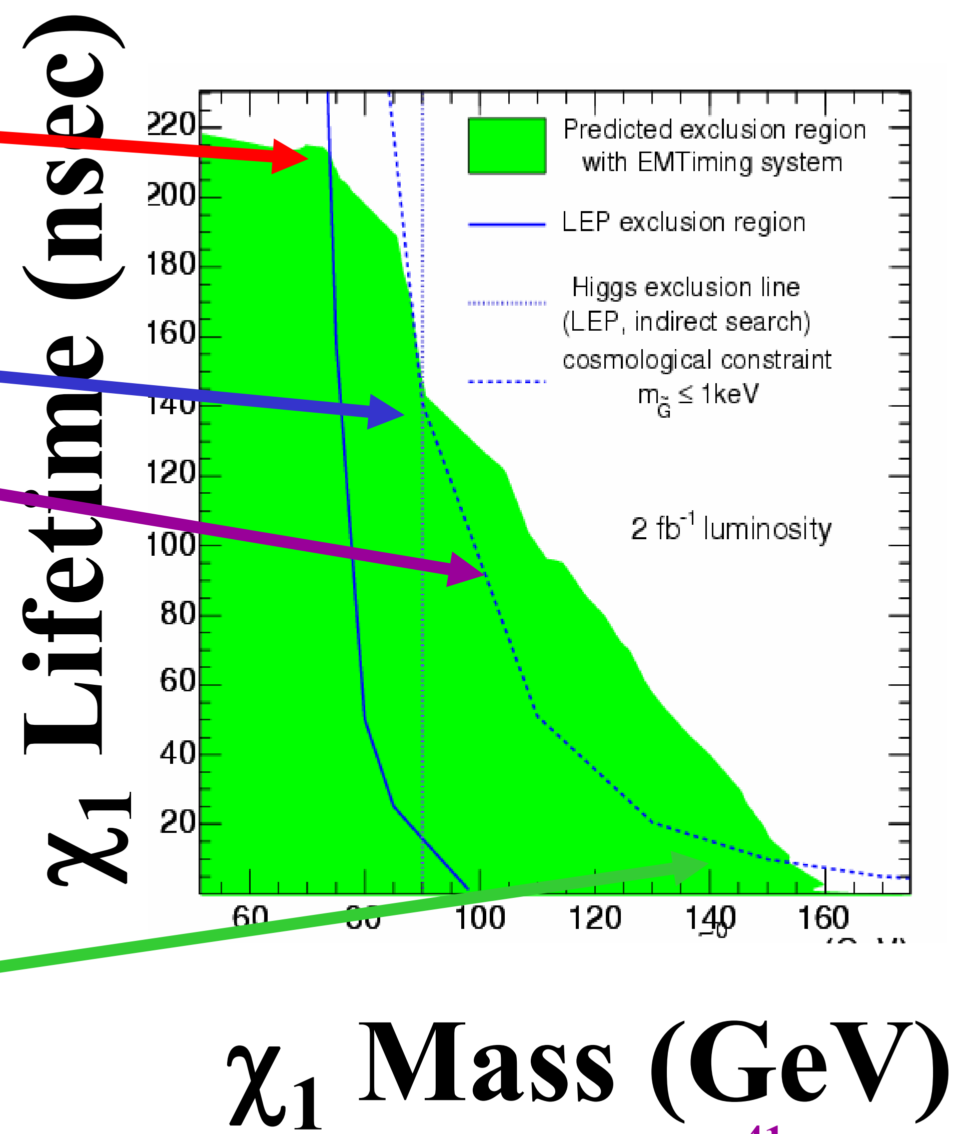
Green Region is exclusion from γ+Met+Jets

Dashed line is from kinematics only



Comparing the sensitivity

- Direct SUSY limits from LEP
- Indirect Higgs limits from LEP
- Favored region due to cosmological constraints
  - Gravitino mass<1keV
- The combined limits would cover most of the important parameter space below 150 GeV.



Conclusions

- **New γγ+Met results from CDF II are a significant improvement over Run I results**
- **New EMTiming system is functioning better than expected and when fully installed (Fall 2004) will really help answer the question "*Are all the photons in unusual events from the primary collision?*"**
- **With more data and the EMTiming system in Run II we have excellent prospects for discovery of SUSY in GMSB-light Gravitino scenarios even at long lifetimes**