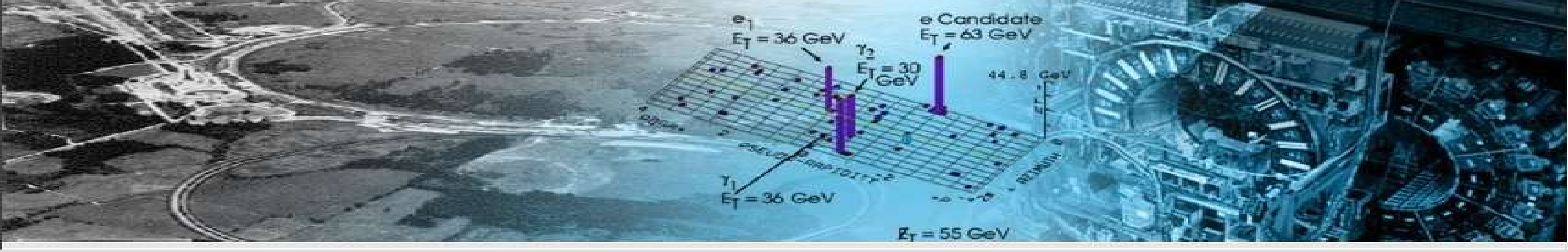

Prospects of a Search for Neutral, Long-Lived Particles Using Timing

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(July 6th 2004)

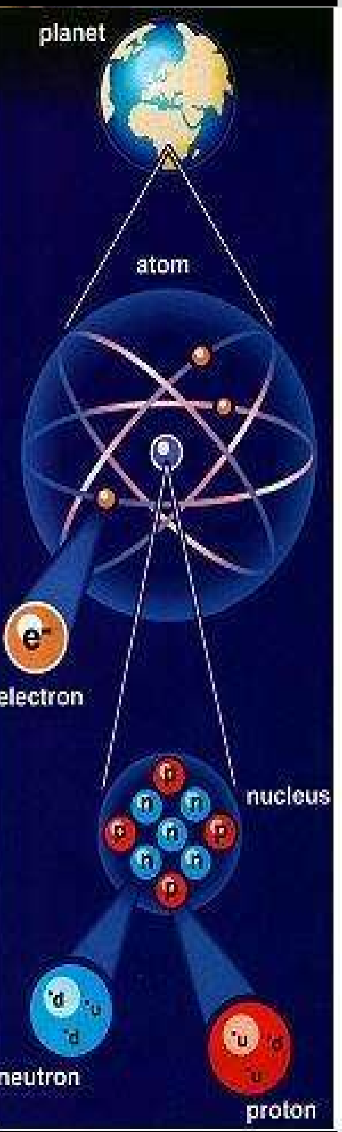
Outline

- Motivation
  - The Standard Model of Particle Physics
  - An Extension: Supersymmetry
  - A SUSY Model: GMSB
  - An Unusual Event
- Tools
  - The Tevatron Particle Collider
  - A multi-purpose Detector: CDF
  - EMTiming
- Analysis (Prospects)
  - Discriminating Variable
  - Quasi model-independent sensitivity to long-lived particles
  - Sensitivity to GMSB models
  - Factors that might change our results
- Conclusion

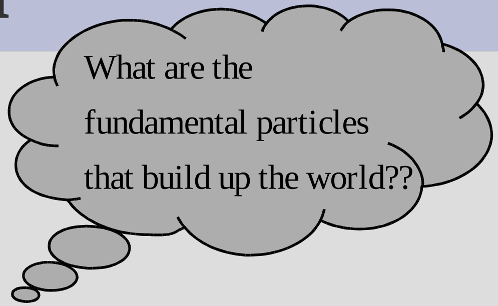
I

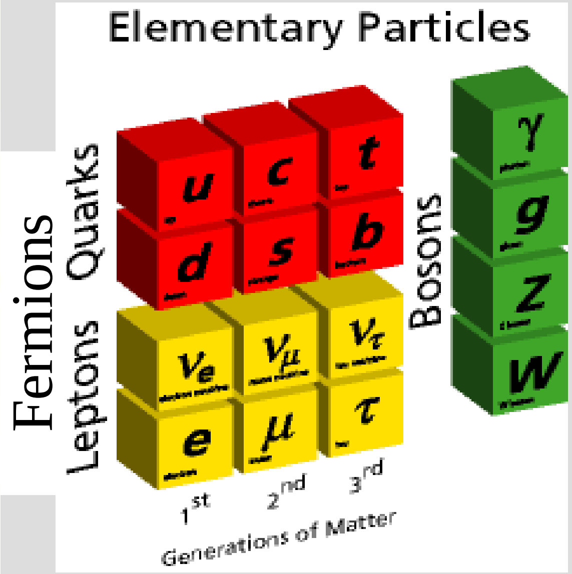
Motivation

The Standard Model



The question about the origins of matter has been raised a long time ago...





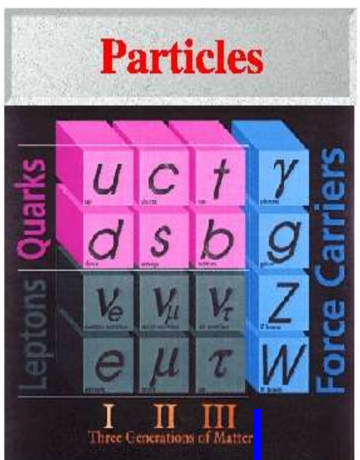
Today the "Standard Model" provides a very precise description of the properties of fundamental particles based on symmetry principles...

... but this model shows theoretical problems and is philosophically insufficient.

Supersymmetry

A solution to the problem: Modern particle theories predict a symmetry of fermions and bosons, Supersymmetry, at energies of a few TeV:

Standard Model:



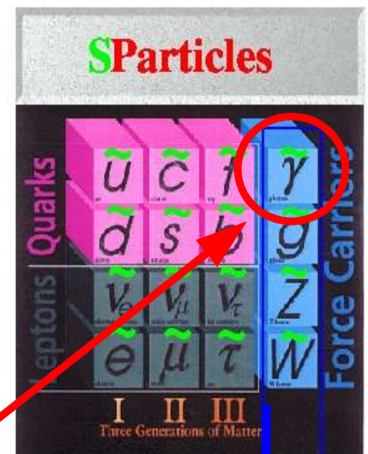
Higgs Bosons

h^0

(unobserved)

Fermions | Bosons

Supersymmetric counterparts:



Higgsinos

$\tilde{h}^0$

Bosons | Fermions

Neutralino: $\tilde{\chi}^0_1$

SUSY Models

- Since this symmetry is not observed (the particles don't have the same masses), the symmetry must be broken at higher energies (TeV) which are not accessible now.
- The way in which they are broken is model-dependent. All models predict new, heavy particles to appear at energies, which may be now observable.
- The “SUSY property” (denoted by a ~) is a conserved parameter in most models (R-Parity conservation).

MSSM

Supersymmetry is most easily realized in the MSSM (Minimal SUSY Model) but it has drawbacks:

- It does not describe gravitational interactions
- No. of free parameters: 106
- SUSY particles are lighter than their SM partners after SUSY breaking

$\Rightarrow$ SUSY must be broken through a “hidden sector”

SUSY Models

R. Arnowitt *et.al.*, Phys. Lett. B538, 121 (2002)

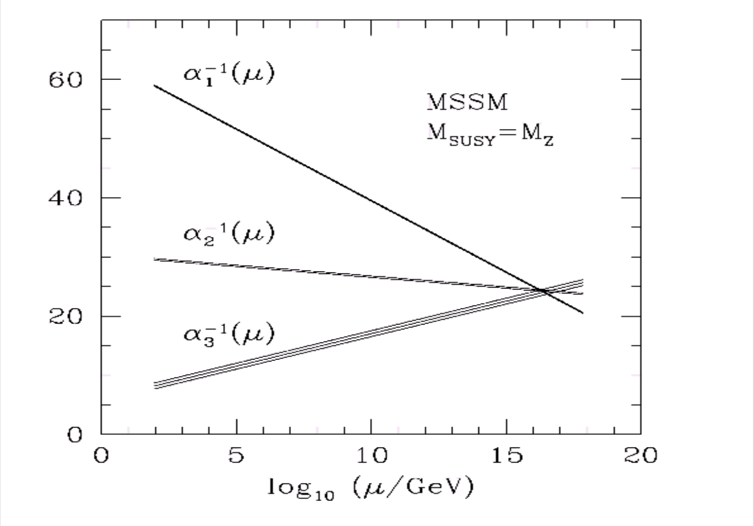
mSUGRA

"minimal Supergravity" has five free parameters:

- Common scalar mass (m_0)
- Universal gaugino mass ($m_{1/2}$)
- Universal soft breaking mass (A_0)
- $\tan(\beta)$ at the electroweak scale
- Sign of the Higgs mixing parameter ($\mathrm{sign}(\mu)$)

Phenomenology

- provides unification of gauge coupling constants
- incorporates gravitational interaction
- the lightest particle, $\tilde{\chi}^0_1$, is a candidate for Dark Matter



SUSY Models

S. Dimopoulos, *et.al.*, Nucl.Phys. B488, 39-91

GMSB

"Gauge Mediated SUSY Breaking" has six free parameters:

- SUSY breaking scale (Λ)
- Messenger mass scale (M_M)
- Number of messenger fields (N_M)
- Ratio of the Higgs vacuum expectation values ($\tan(\beta)$)
- Sign of the Higgs mixing parameter ($\text{sign}(\mu)$)
- Gravitino scale (c_{Grav})

Phenomenology

- Intrinsically suppresses FCNCs (Flavor Changing Neutral Currents)
- Breaks SUSY at low energy $\Rightarrow$ large parts of parameter space predict new particles to be accessible at today's energies
- Gravitino, $\tilde{G}$, is the lightest SUSY particle (LSP)
- Both Neutralino and Gravitino candidates for Dark Matter
- Cosmological constraints have a big effect $\rightarrow$ more on this later!

GMSB Neutralino

- For low tan(β) and a simple $N_M = 1$ GMSB predicts the lightest Neutralino to be the NLSP with the Gravitino as LSP
- The electroweak eigenstate of the Neutralino is mostly photino $\Rightarrow$ it decays preferable via:

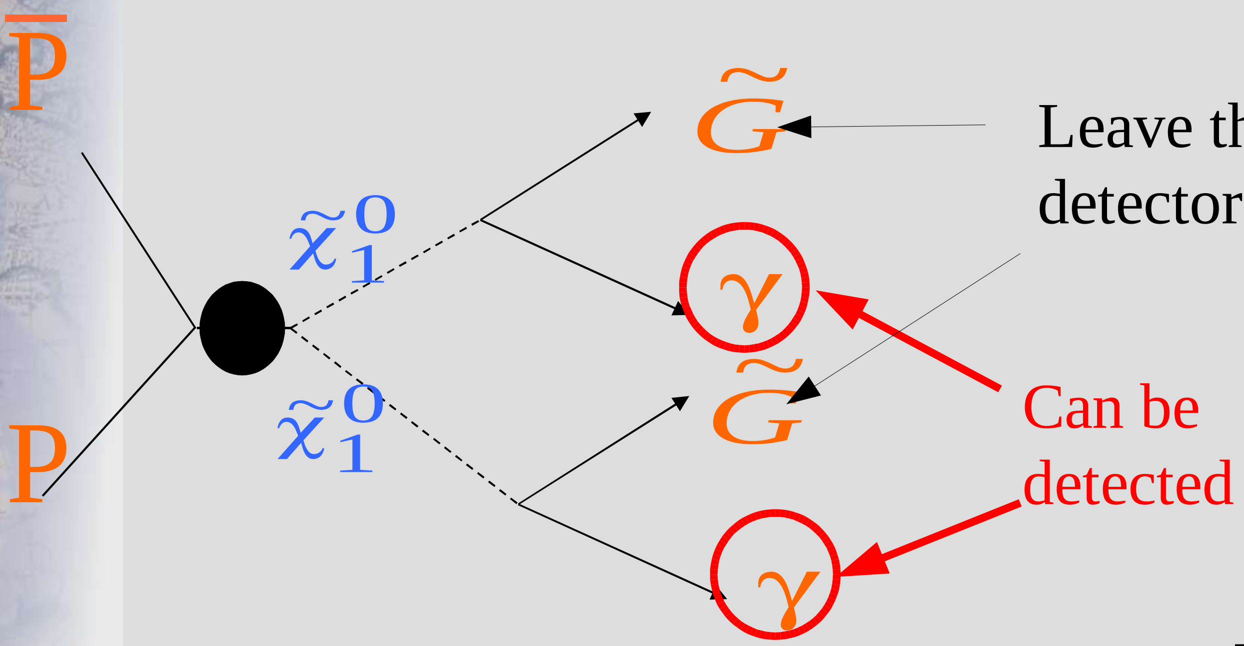
$$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$$

- For much of the parameter space the Neutralino decay time (length) can be macroscopic (ns (meters))

$\Rightarrow$ Measure the arrival time of the photon

Event Signature

In proton-antiproton collisions the Tevatron produces Neutralino pairs and they decay preferably via:



Signature:

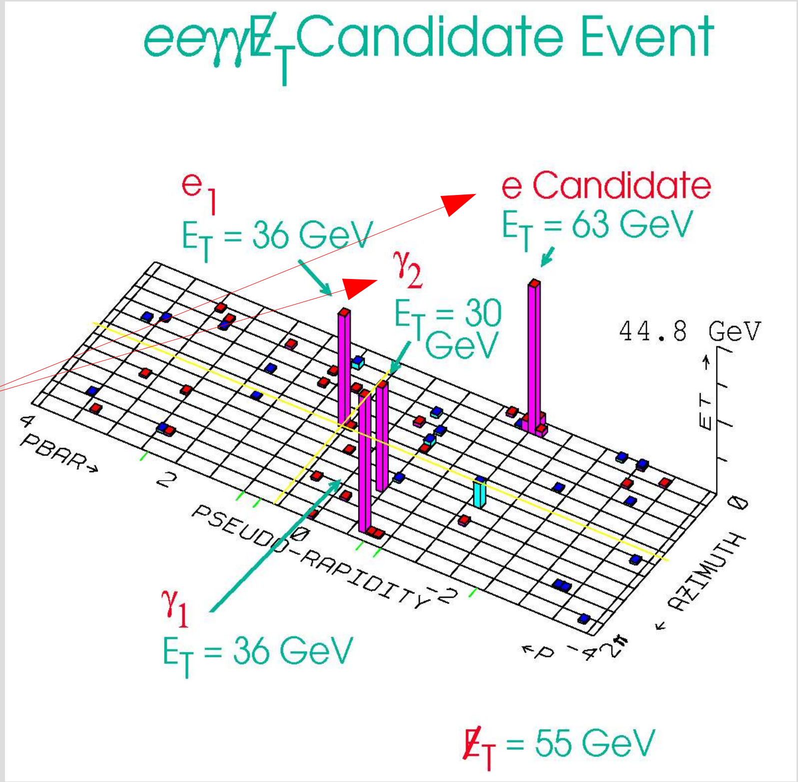
$\Rightarrow \not{E}_T$

$\Rightarrow \gamma\gamma$ or γ

if both or only 1 $\tilde{\chi}_1^0$ decay in the detector due to large decay lengths

Experimental Hints for SUSY?

- In the late 90's an unusual $ee\gamma\gamma\not{E}_T$ cand. event was recorded in the CDF detector at Fermilab (SM-Bkg prediction: $1\pm1\text{x}10^{-6}$ evts.)
- *Problem:* Part of the event might be from cosmic background – no timing information available



⇒ Timing can help confirm/reject unusual events

Note that the GMSB model is already ruled out as an explanation of this event.

... *but* we also do a quasi-model-independent analysis.

Why Timing?

3 Motivations:

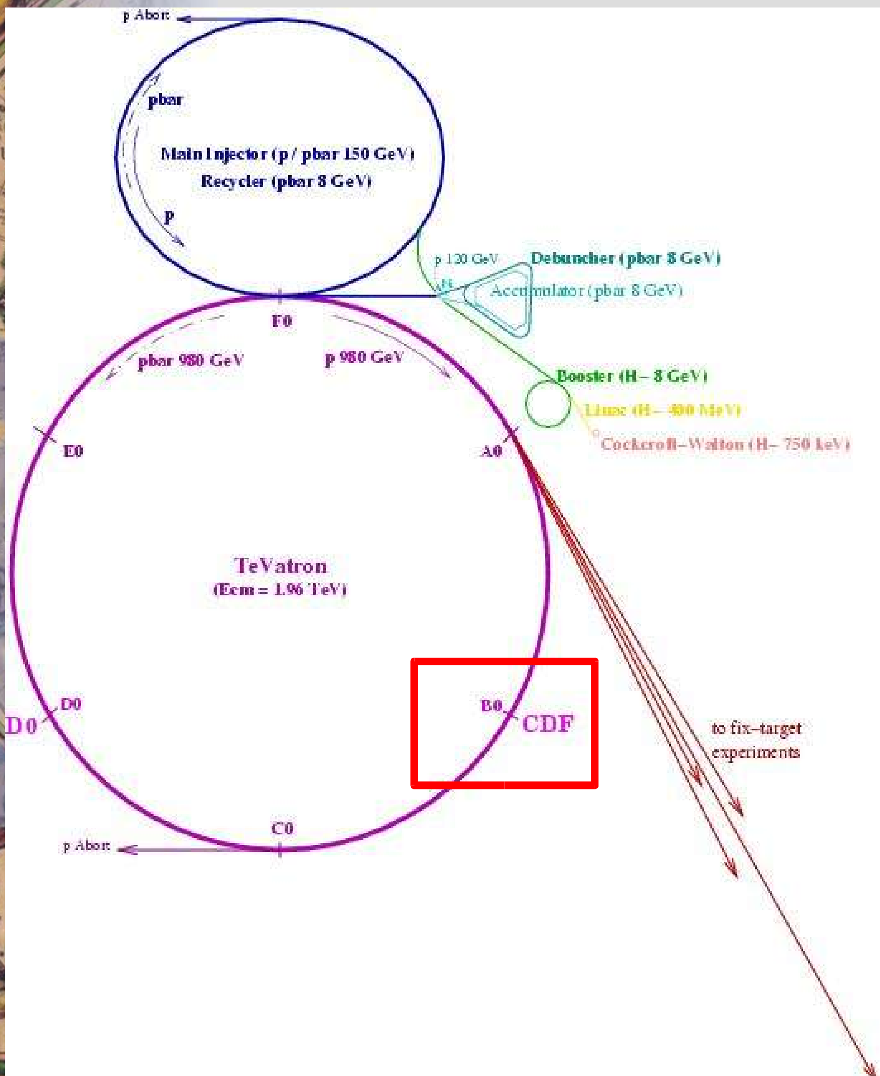
- To provide an additional handle for unusual events like $ee\gamma\gamma \not{E}_T$
- To reject cosmic background radiation
- To search for neutral long-lived particles like the GMSB neutralino

II

Tools

Particle Colliders

One way to search for new, heavy particles is to use particle colliders like the Tevatron at Fermilab.



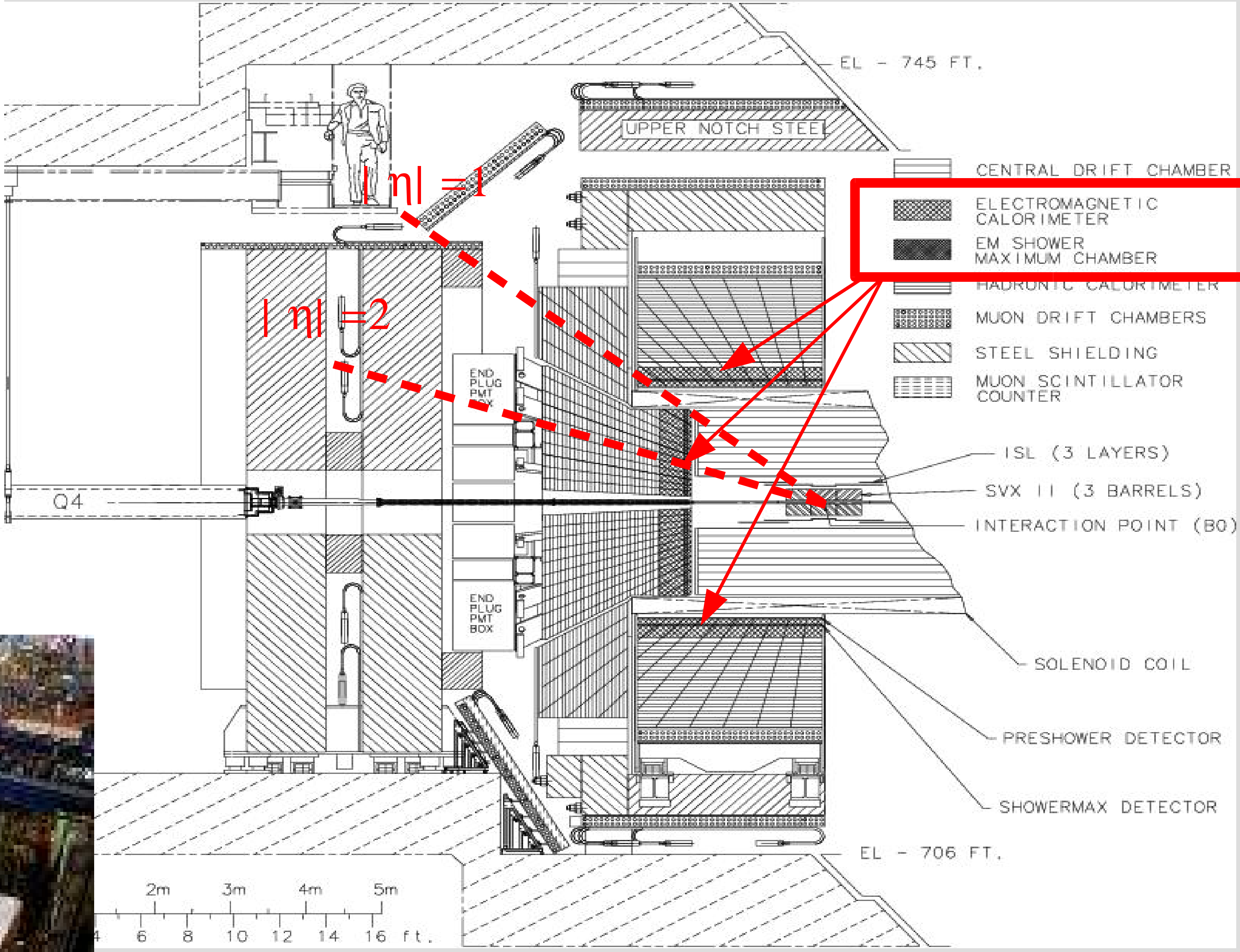
<u>Specifications:</u>

- World highest energy synchrotron: CM-energy 1.96 TeV
- A bunch crossing every 396 ns
- Serves two multi-purpose detectors: D0 and CDF
- Integrated luminosity for the current Run II now: 550 pb^{-1}, with a total of 4-8 fb^{-1} expected

CDF Detector

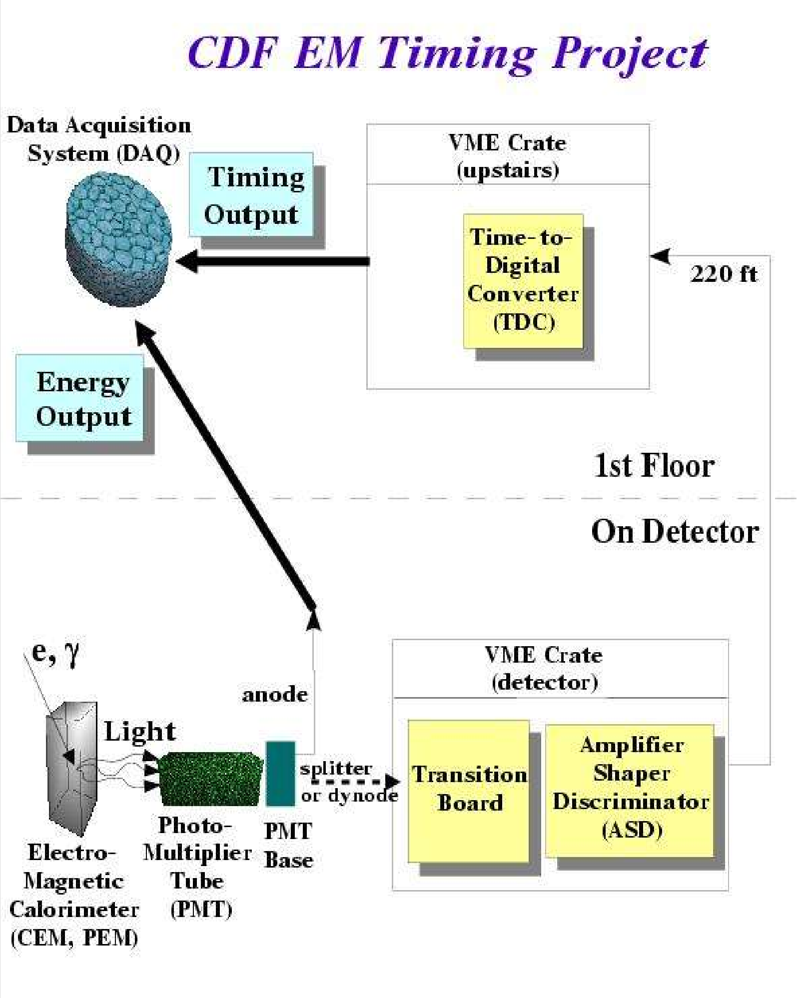
Specifications for Run II:

- 3-Level trigger system (20 kHz → 70 Hz)
- SVX ($|\eta| < 2.0$)
- COT ($|\eta| < 1.0$)
- CEM, CHA ($|\eta| < 1.0$)
- PEM ($1.0 < |\eta| < 3.6$)



EMTiming

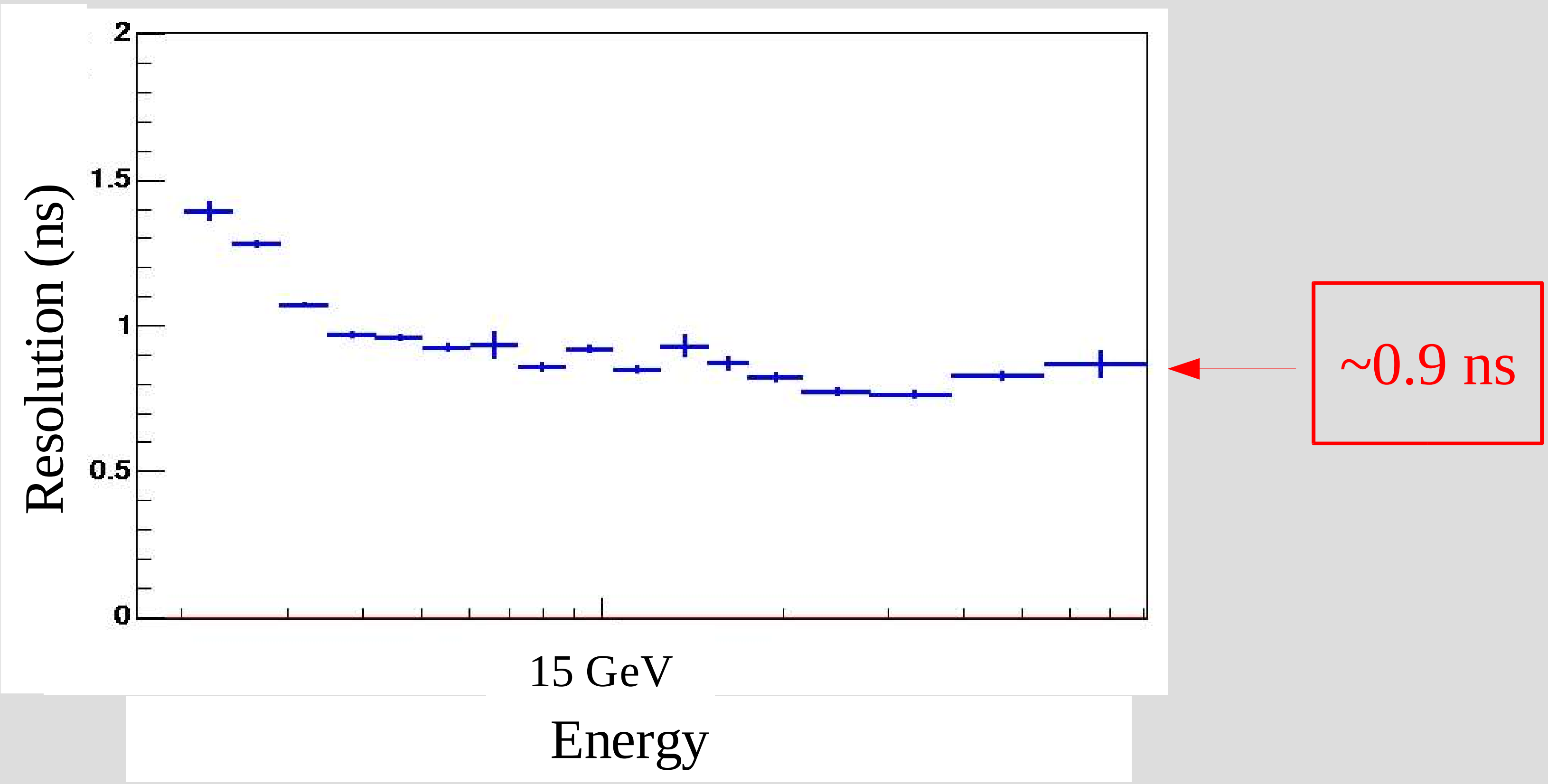
- Hardware similar to Timing system in the Hadronic Calorimeter (HAD)
- The installation of the plug part was finished in Fall 2003
- Especially efficient for particles which leave only little energy in the HAD (e.g. photons)



First Measurements

M. Goncharov, priv. comm.

... and it has been shown to have a resolution of < 1.0 ns:



III

Analysis (Prospects)

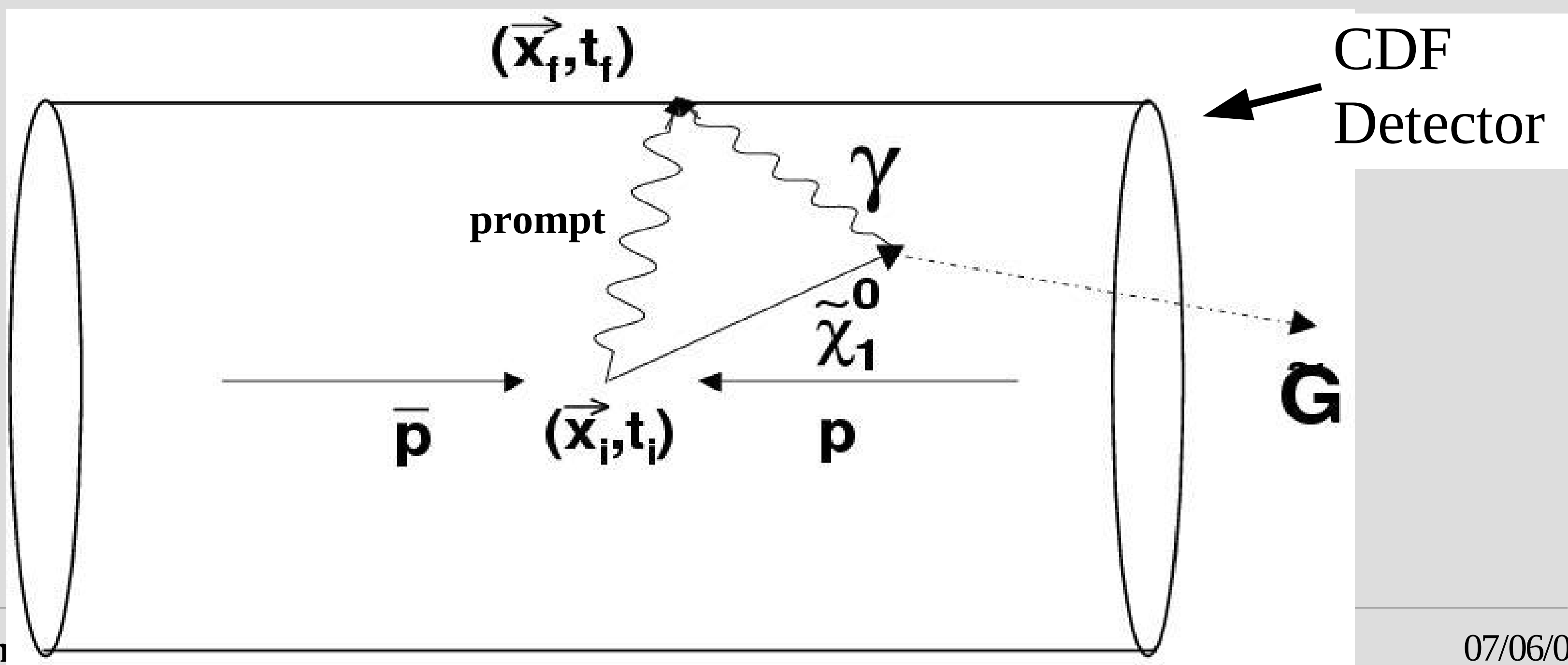
Discriminating Variable

(1) Measure the photon's final position x_f in the EM calorimeter and the time of arrival of the photon with the EMTiming system $\Rightarrow$ Time of Flight Δt

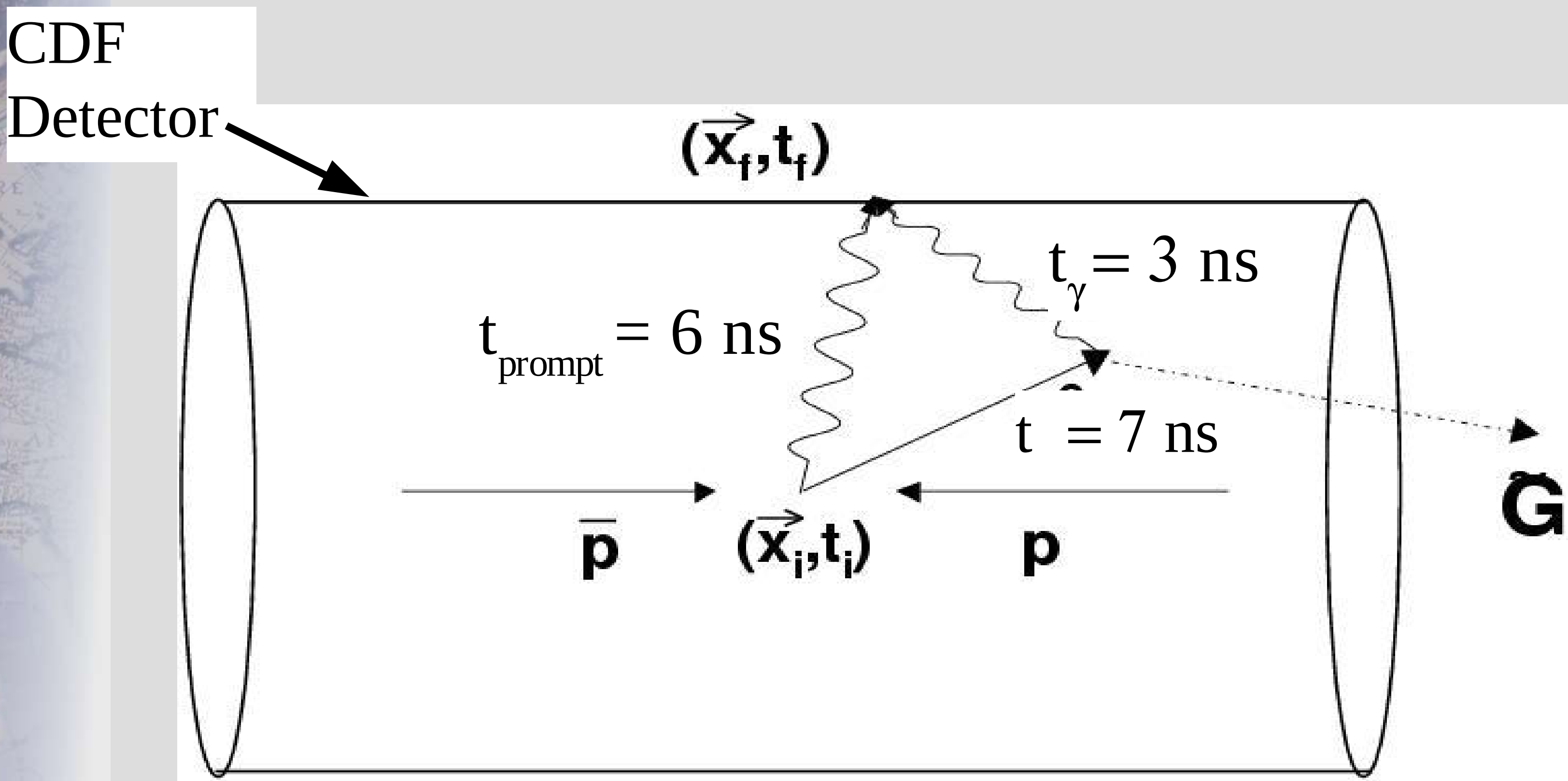
(2) Calculate the time at which a prompt (Standard Model) photon would arrive at the same position

(3) Subtract:

$$\Delta s \equiv \Delta t - \frac{|\vec{x}_f - \vec{x}_i|}{c}$$



Example:



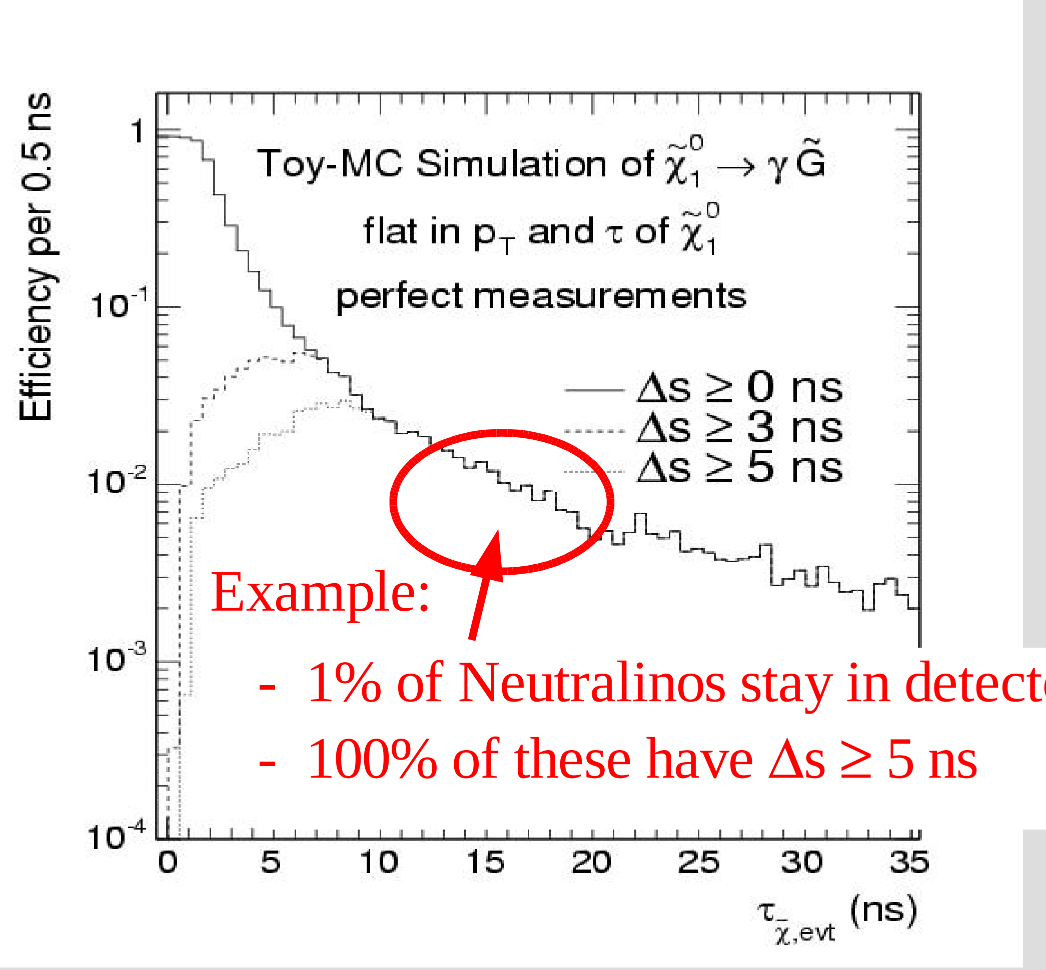
$\Rightarrow \quad s = (3 + 7) - 6 = 4$ ns

Prompt photons (SM): $\Delta s \equiv 0$ ns

Long-lived particles (SUSY): $\Delta s > 0$ ns

Selection of long-lived particles

Long lifetime ⇔ High Δs



Example:

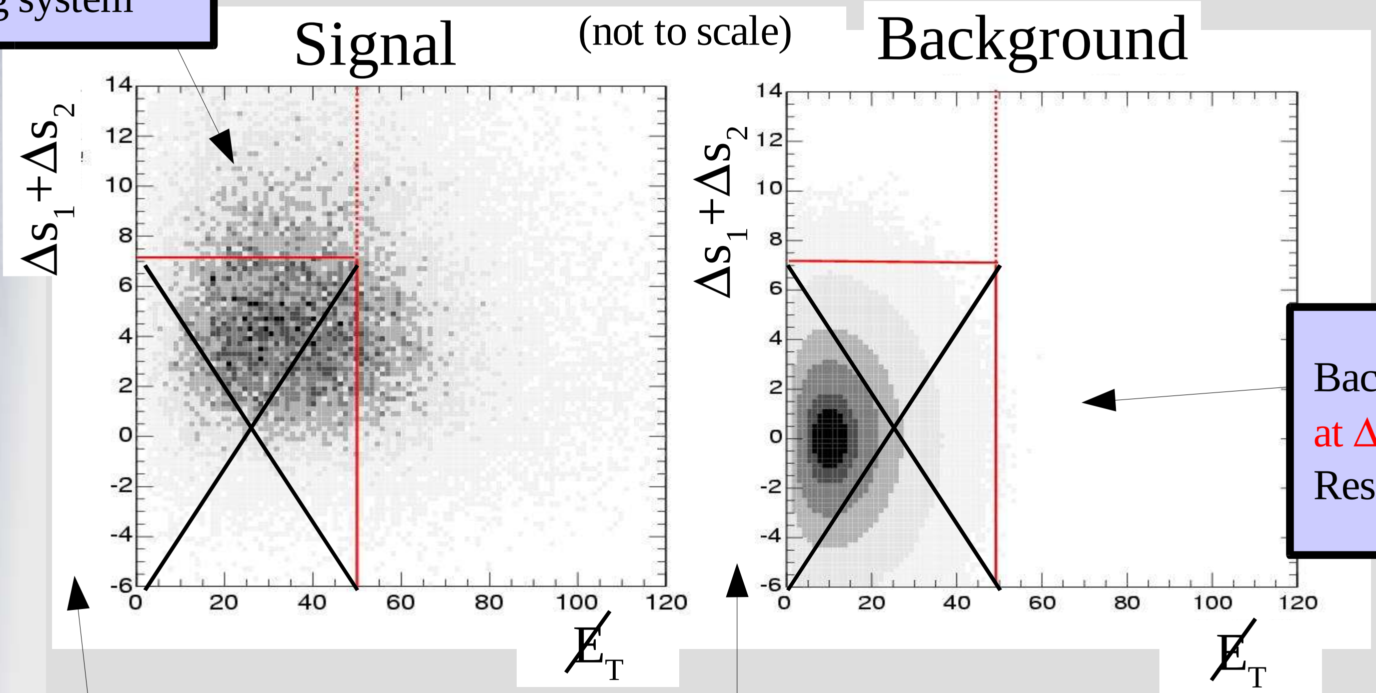
- 1% of Neutralinos stay in detector
- 100% of these have $\Delta s \geq 5$ ns

Event Selection for Quasi-Model-Independent Analyses

To optimize the sensitivity for the largest possible neutralino lifetime range, we use 2 analyses: a $\gamma\gamma + \not{E}_T$ analysis (for low lifetimes)...

Additional gain with the timing system

$\gamma\gamma + \not{E}_T$ analysis from CDF Phys. Rev. D59 092002 (1999)



Background centered at $\Delta s = 0$ ns
Resolution: 1.41 ns

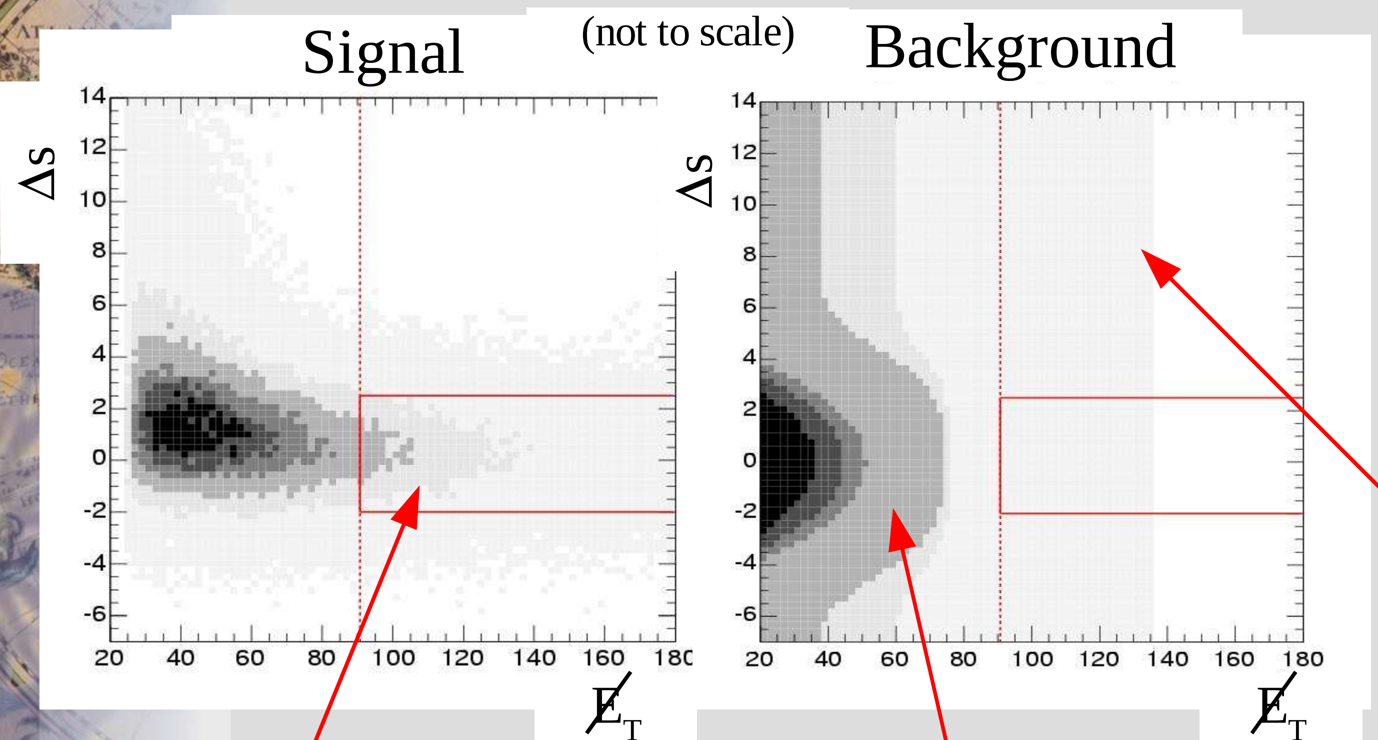
Add up the Δs values of the 2 photons

...and a $\gamma + \not{E}_T$ + 0jet analysis (for high lifetimes).

$\gamma + \not{E}_T$ + 0 jet analysis from CDF

Background: $Z\gamma$, $W\gamma$, $W \rightarrow e\nu$, QCD and cosmics

Phys.Rev.Lett. 89, 281801 (2002)



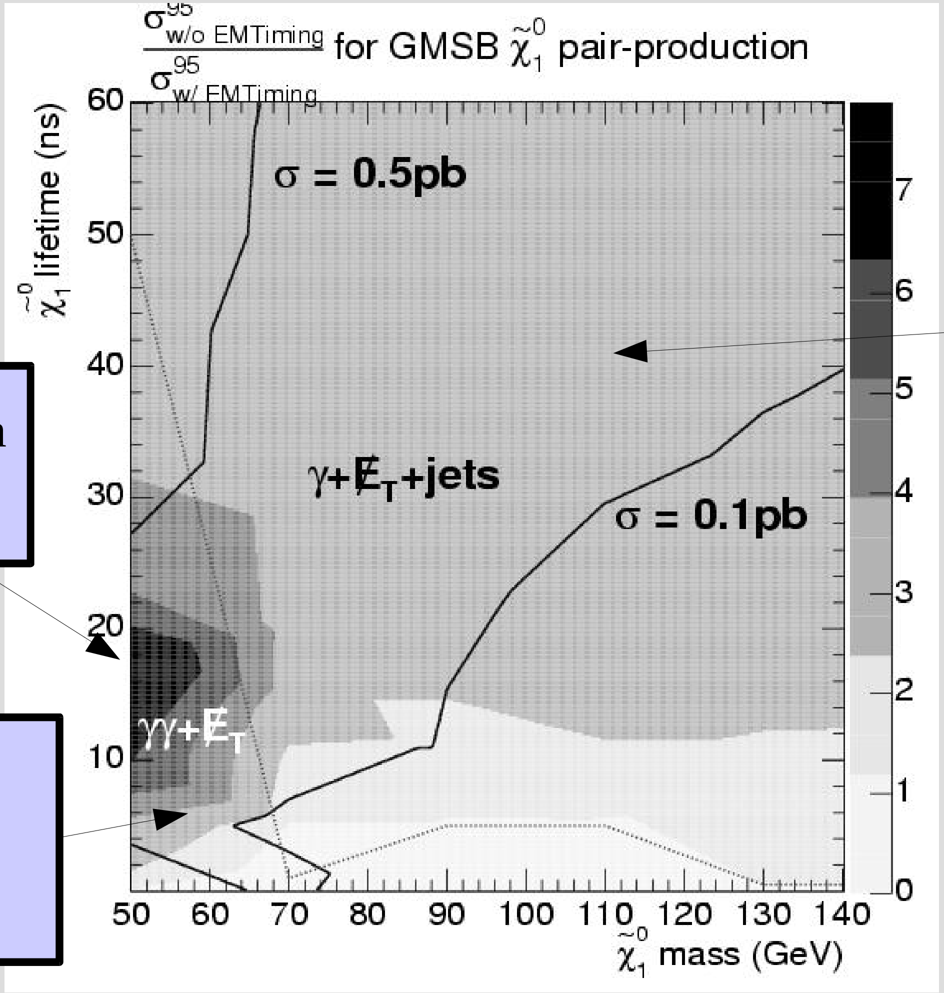
Accepted events

QCD background: centered at $\Delta s = 0$ ns

Cosmics background: randomly in Δs

Sensitivity in a Quasi-Model-Independent Search

Compare the cross section limits of with EMTiming and kinematics-only at each ($\tau_{\tilde{\chi}}$,$m_{\tilde{\chi}}$) point:



The EMTiming system is most effective here

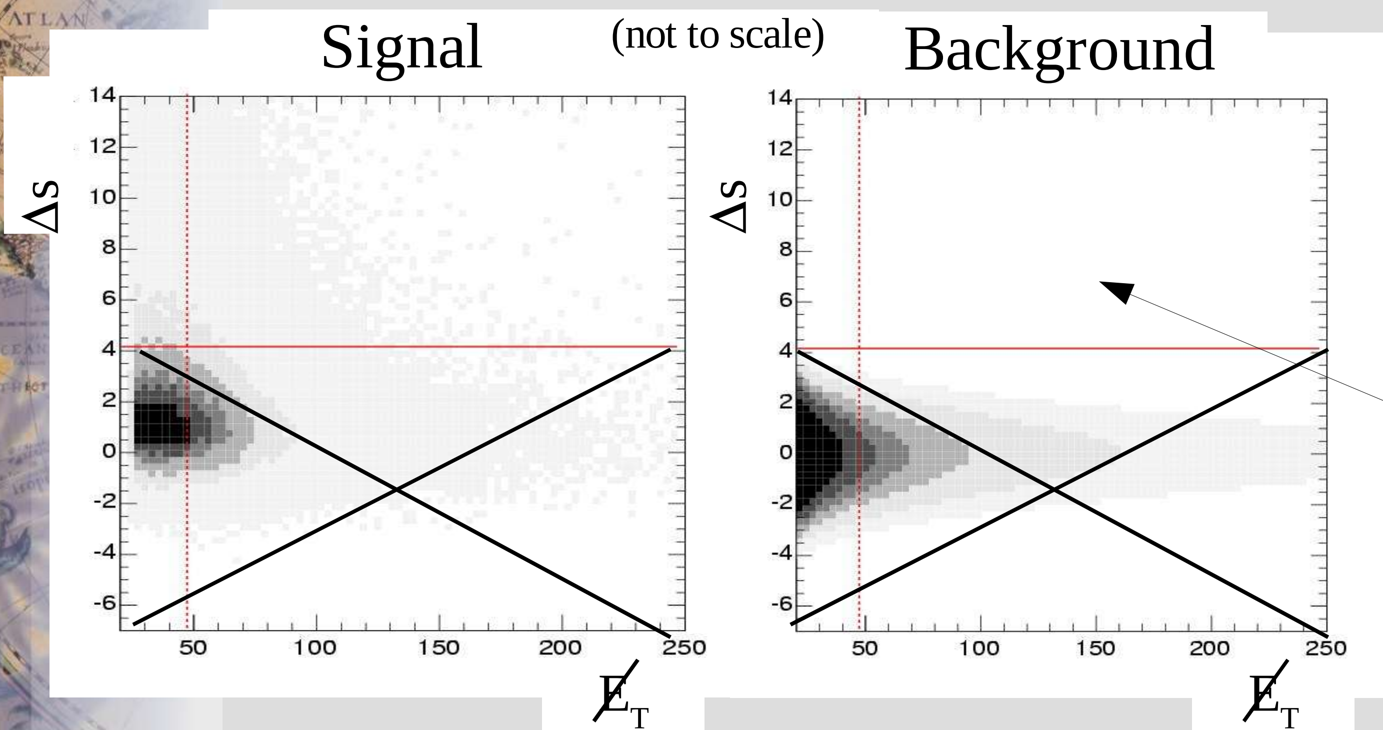
$\gamma\gamma + \not{E}_T$ analysis better at low lifetimes and low masses

– $\gamma + \not{E}_T$ analysis dominates

– remains effective up to high lifetimes

Event Selection for GMSB Analyses

To optimize the sensitivity for the largest possible neutralino lifetime range, we use 2 analyses:



$\gamma + \not\!E_T$ + jets analysis from D0
Background: QCD, W+jets
Phys.Rev.Lett. 82, 29 (1999)

Good background rejection with the timing system

The $\gamma\gamma + \not\!E_T$ analysis is the same as in the quasi-model-independent search .

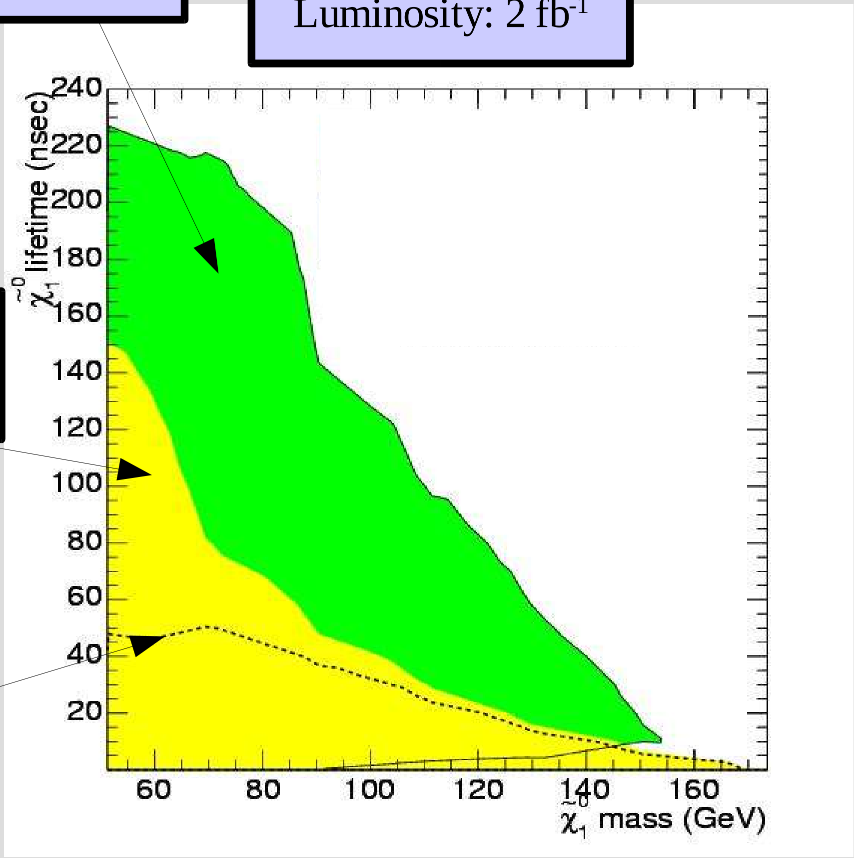
Exp. Exclusion Region for GMSB models

$\gamma + \not{E}_T$ + jets analysis

Luminosity: 2 fb^{-1}

$\gamma\gamma + \not{E}_T$ analysis

Limit with kinematical cuts only ($\not{E}_T$)



⇒ EMTiming is expected to extend the exclusion region compared to kinematics-only cuts especially at low masses

Digression: Cosmology

H. Pagels and J. Primack, Phys.Rev.Lett. 48, 223 (1982)

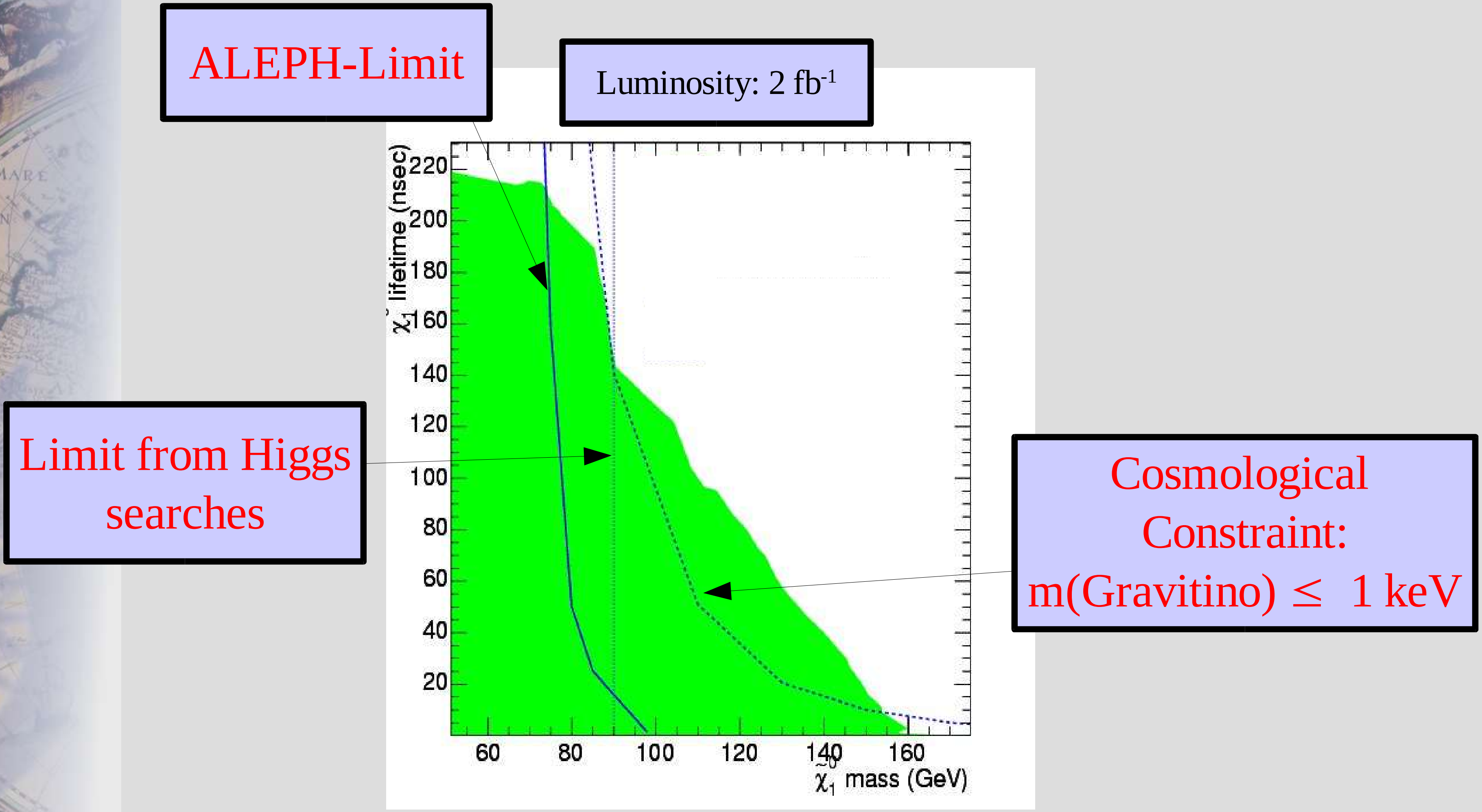
As already mentioned, cosmological constraints have a big impact on the GMSB model since the relatively massive gravitinos are too weakly interacting to effectively annihilate each other.

- In its early stage at a temperature of about $T_0 = m_e$ the universe is reheated due to e^+e^- annihilation
- Since the number of generated photons is related to their temperature, which is related to the number of gravitinos over their cross section, one can calculate the gravitino's mass density and compare it to the average mass density of the universe

$\Rightarrow$ Upper "overclosure" bound on the gravitino mass:

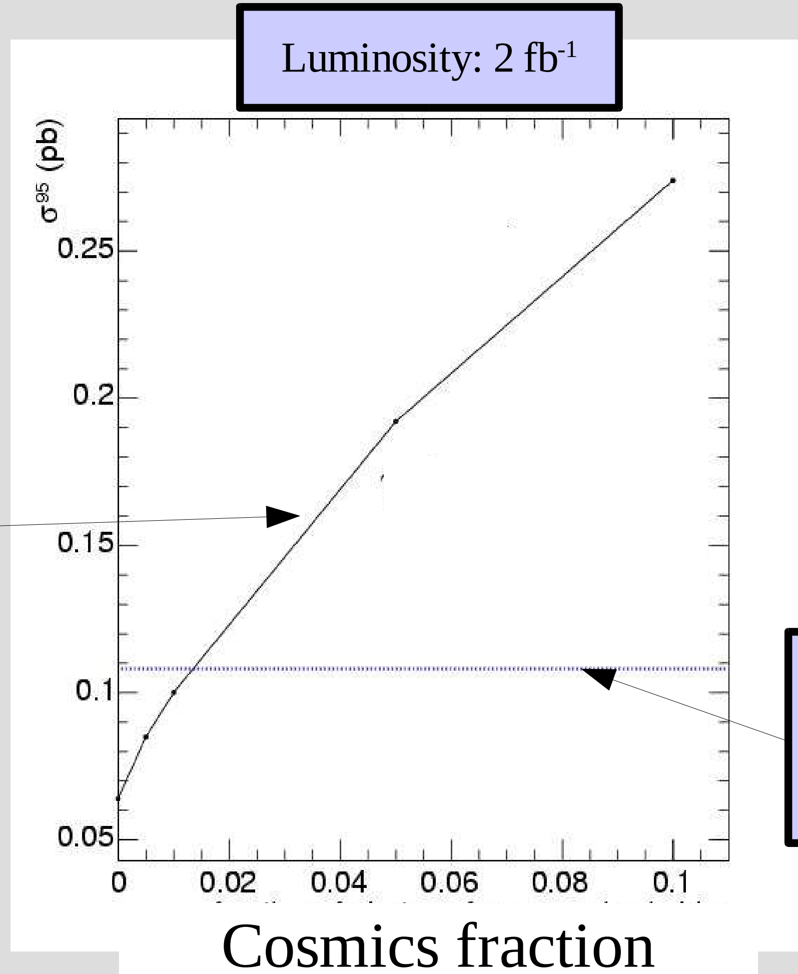
M (gravitino) = 1 keV

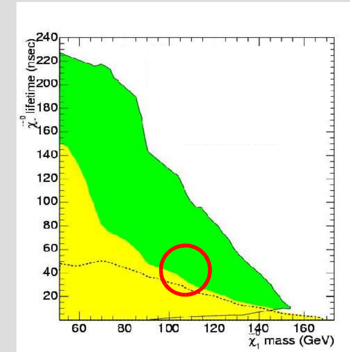
Comparison to other Constraints



⇒ **EMTiming covers the entire region between LEP and the cosmological bound for masses below 150 GeV**

Factors That Might Change the Exclusion Region





95% C.L. cross section limit

Prod. cross section at $m_{\tilde{\chi}} = 110$ GeV $\tau_{\tilde{\chi}} = 40$ ns

$\Rightarrow$ Good cosmics rejection is valuable

Conclusion

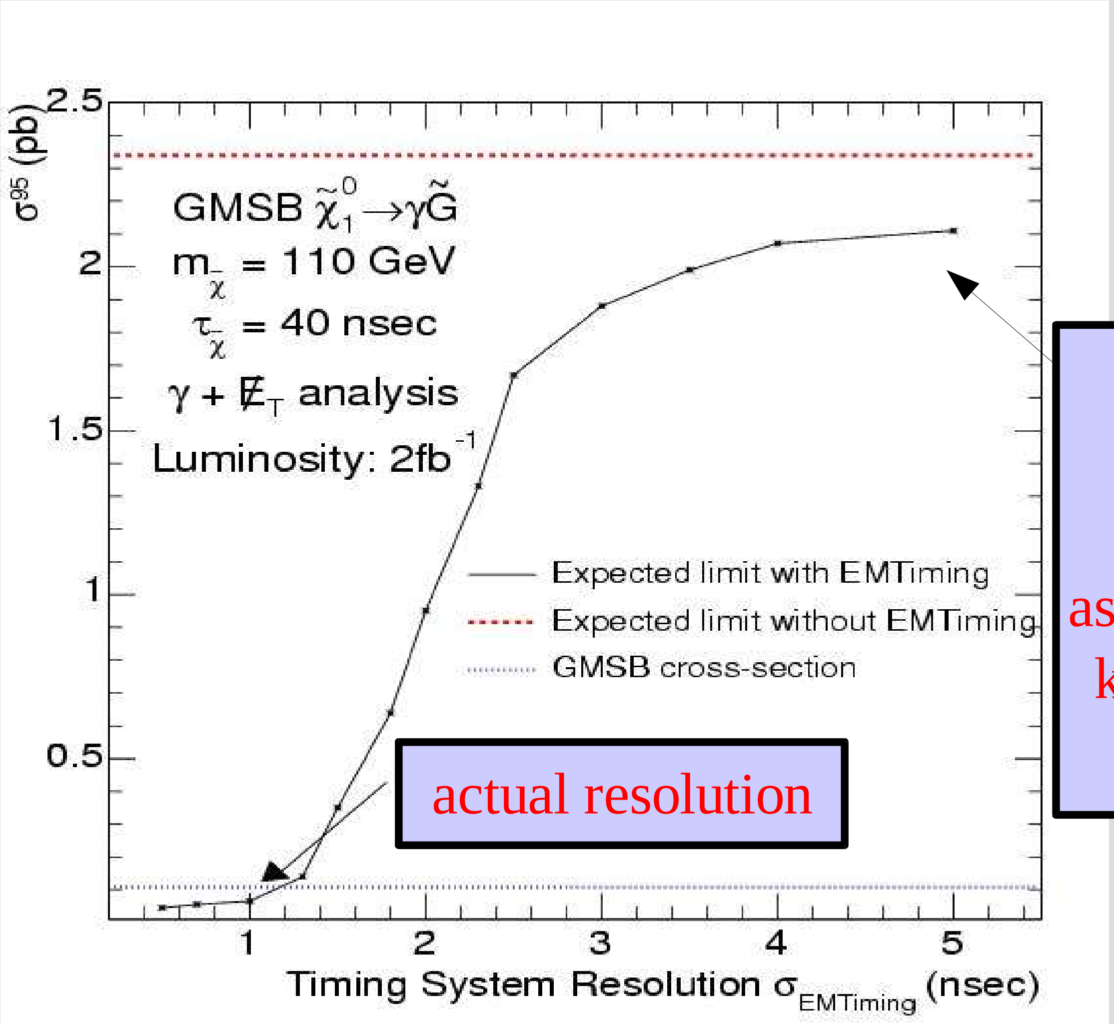
- The installation of the Timing System at CDF is lead by the Texas A&M Group - and will be finished in Fall 2004
- While timing has never been used to search for new particles the EMTiming system is sensitive to yet unexplored regions...

...and as for me:

In the next years I will assist debugging, maintenance and optimization of the EMTiming system.

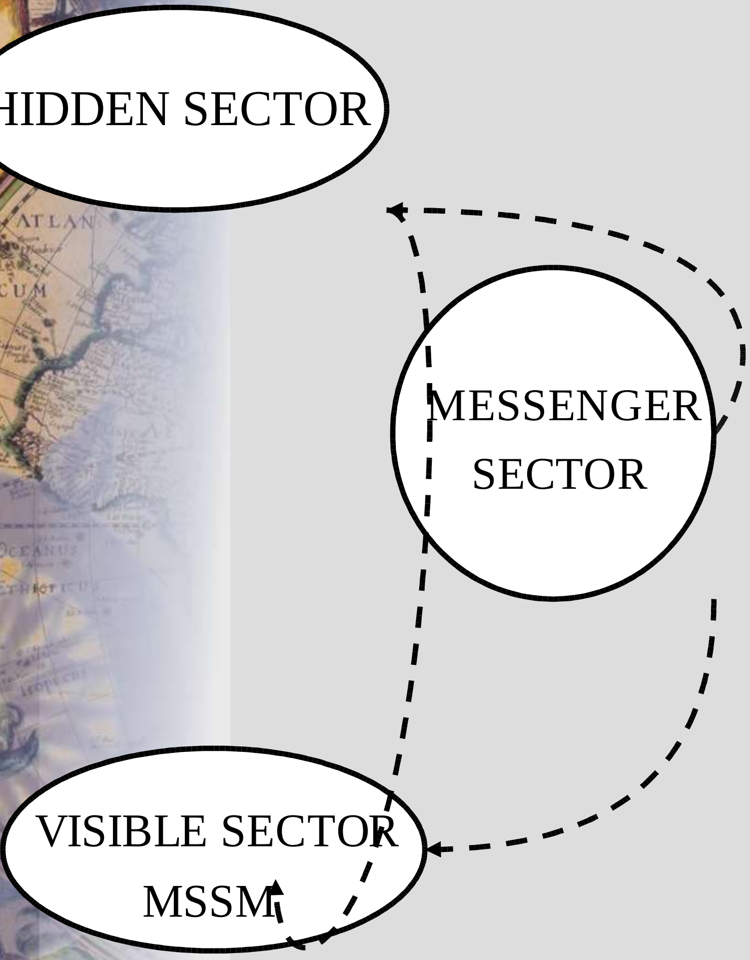
... and discover SUSY with it.

Effect of Timing resolution



actual resolution

EMTiming cross section limit reaches asymptotically the kinematics-only limit


HIDDEN SECTOR
MESSENGER
SECTOR
VISIBLE SECTOR
MSSM