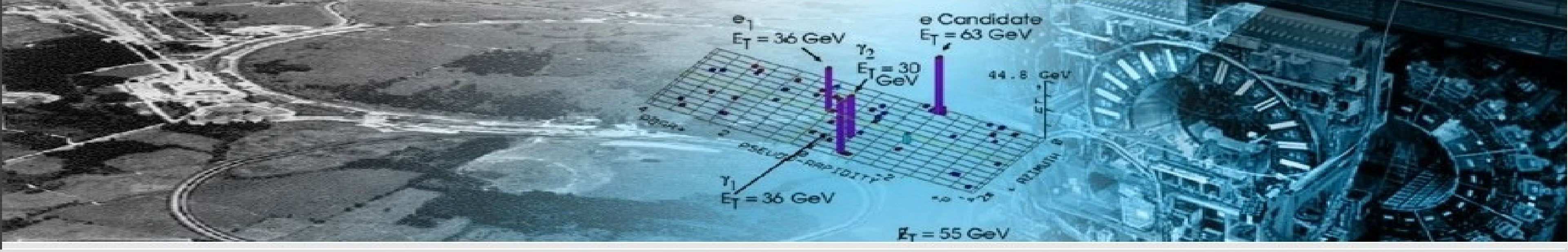


Search for Heavy, Neutral, Long-Lived Particles that Decay to Photons at CDF

Peter Wagner
Texas A&M University

Outline

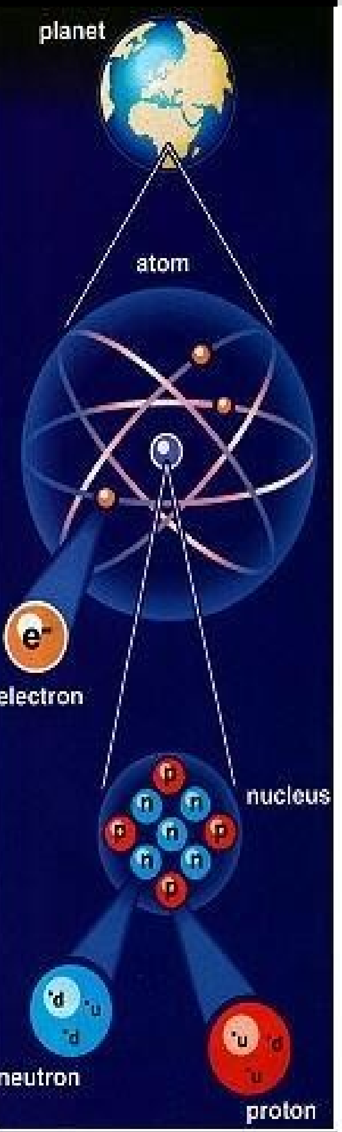
- Motivation and Theory
- The Tool: EMTiming
- Vertex Finding Algorithm
- Analysis
  - Photon Identification
  - Backgrounds
  - Event Preselection
  - Optimization
- Results and Limits
- Conclusion

Motivation and Theory

Overview: Motivation

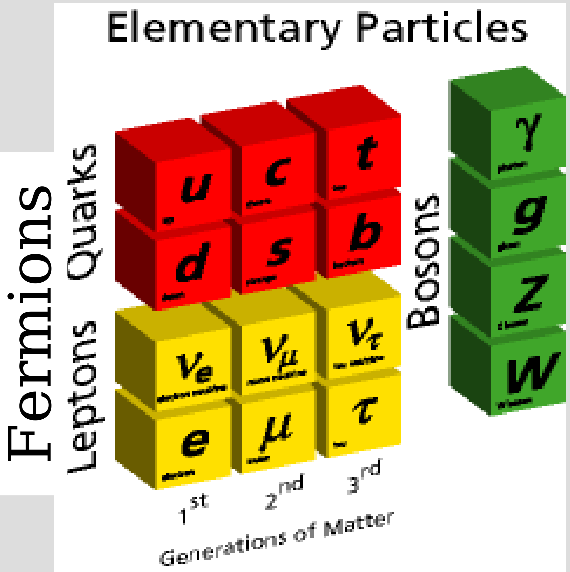
- Supersymmetric models predict heavy neutralinos that decay to photons ($\rightarrow$ next slides)
- "$ee\gamma\gamma+\not{E}_T$" candidate event at CDF in Run I
- First search for heavy, long-lived particles that decay to photons at a hadron collider

The Standard Model



What are the fundamental particles that build up the world??

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...

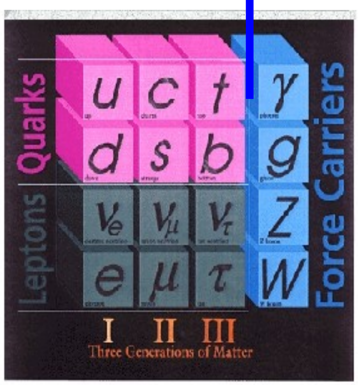
... but this model must be incomplete for theoretical ("naturalness problem") and experimental reasons (neutrino oscillations, muon anomalous magnetic moment, ...)

Supersymmetry

Modern particle theories predict a symmetry of fermions and bosons, Supersymmetry, at energies of a few TeV:

Standard Model:

Fermions | Bosons



Higgs Bosons

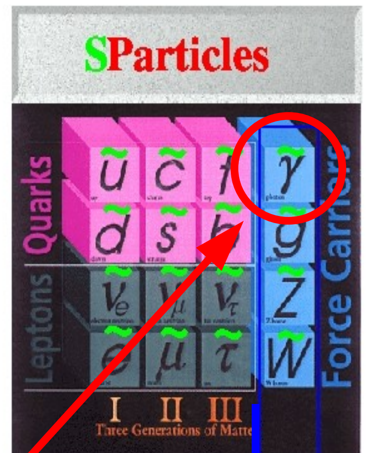
(unobserved)

h^0

H^0 A^0 $H^\pm$

predicted by SUSY

Supersymmetric counterparts:



Higgsinos

$\tilde{h}^0$

$\tilde{H}^0$ $\tilde{A}^0$ $\tilde{H}^\pm$

Bosons | Fermions ("gauginos")

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

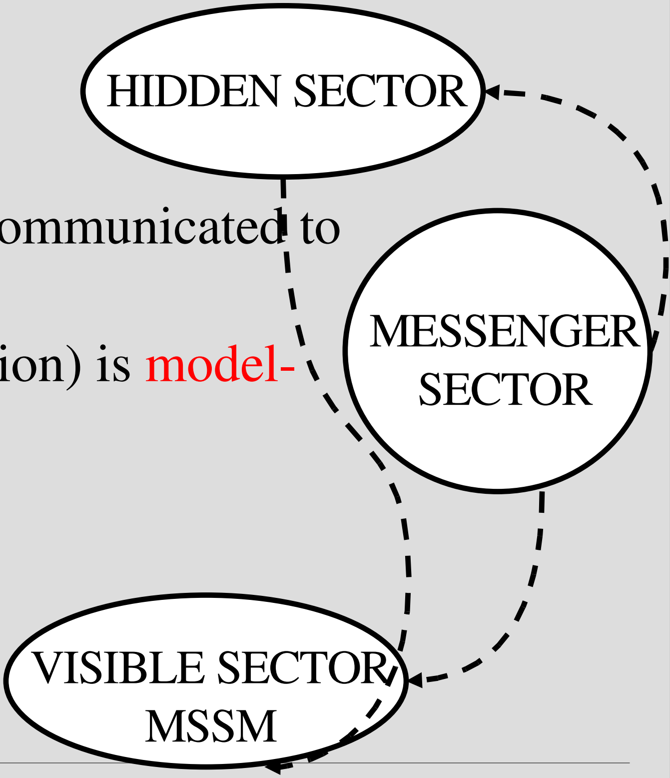
"Gauge" particle: $\tilde{G}$

The "SUSY property" (denoted by a ~) is a conserved parameter in most models (R-Parity conservation). ⇒ The lightest SUSY particle must be stable!

MSSM and SUSY Breaking

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

- It does not describe gravitational interactions
- It has 106 free parameters
- SUSY particles don't have the same mass as their SM partners
- After tree-level SUSY breaking the SUSY particles are lighter than their SM partners



⇒ SUSY must be broken in a "hidden sector" and communicated to the visible SM and SUSY particles at loop level!

- The breaking mechanism (= the mediation interaction) is model-dependent

Why GMSB Models?

- SUSY breaking can occur at any energy between SM and the Planck mass
- If it occurs at low energy then it is likely that the messenger group has the same symmetries as the SM interactions as gauginos only couple through gauge interactions
- Messenger interactions are flavor independent and intrinsically suppress 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

GMSB Models

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

"Gauge Mediated SUSY Breaking" has six free parameters:

- SUSY breaking scale ($\sqrt{F}$ ~10 TeV)
- Messenger mass scale (M_{Mess} ~100 TeV)
- Number of messenger fields (N_{mess} ~ 1-5)
- Ratio of the Higgs vacuum expectation values ($\tan(\beta)$~5-40)
- Sign of the Higgs mixing parameter ($\mathrm{sign}(\mu)$)
- Gravitino scale (c_{Grav})

- c_{Grav} varies the $\tilde{\chi}_1^0$ lifetime, M_{Mess} and $\sqrt{F}$ its mass

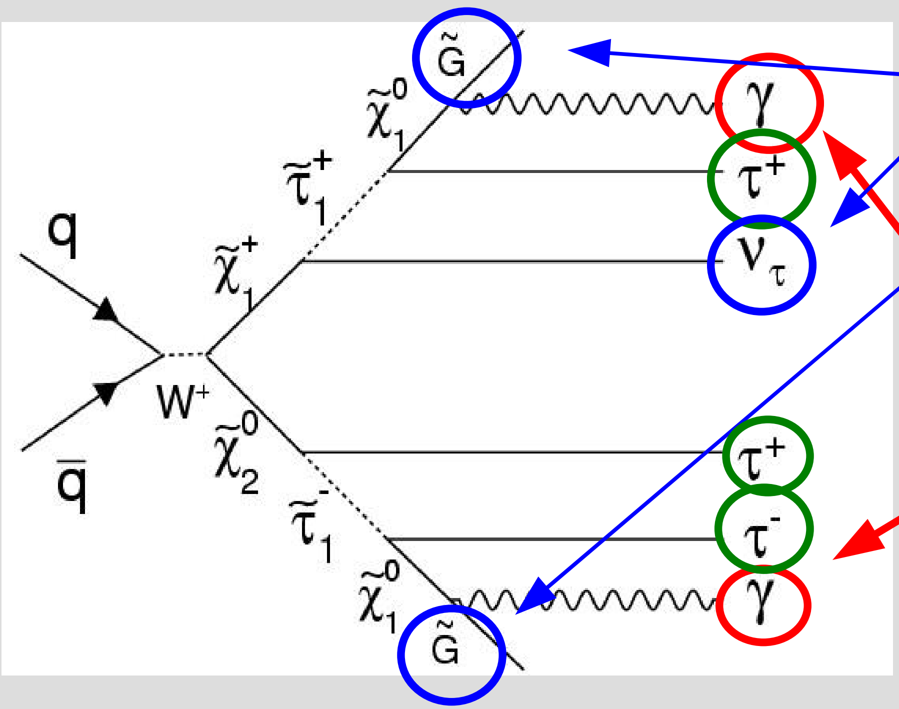
Some Striking Features

- The superpartners receive masses that are mostly ordered according to their gauge coupling strength: $m(\tilde{q},\tilde{g})>m(\text{gauginos})$
- The mass of the goldstone particle Gravitino ($\tilde{G}$) is determined from the SUSY breaking scale $\Rightarrow$ it is the lightest SUSY particle (LSP) in GMSB

GMSB Phenomenology

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

- For N_{Mess}=1 the lightest neutralino is NLSP and decays as $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$
- For much of the parameter space the $\tilde{\chi}_1^0$ decay time can be ~ns
- At the Tevatron neutralinos are pair-produced from $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ or $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$



Signature:

$\Rightarrow \not{E}_T$

Jets

$\Rightarrow \gamma\gamma$ or γ

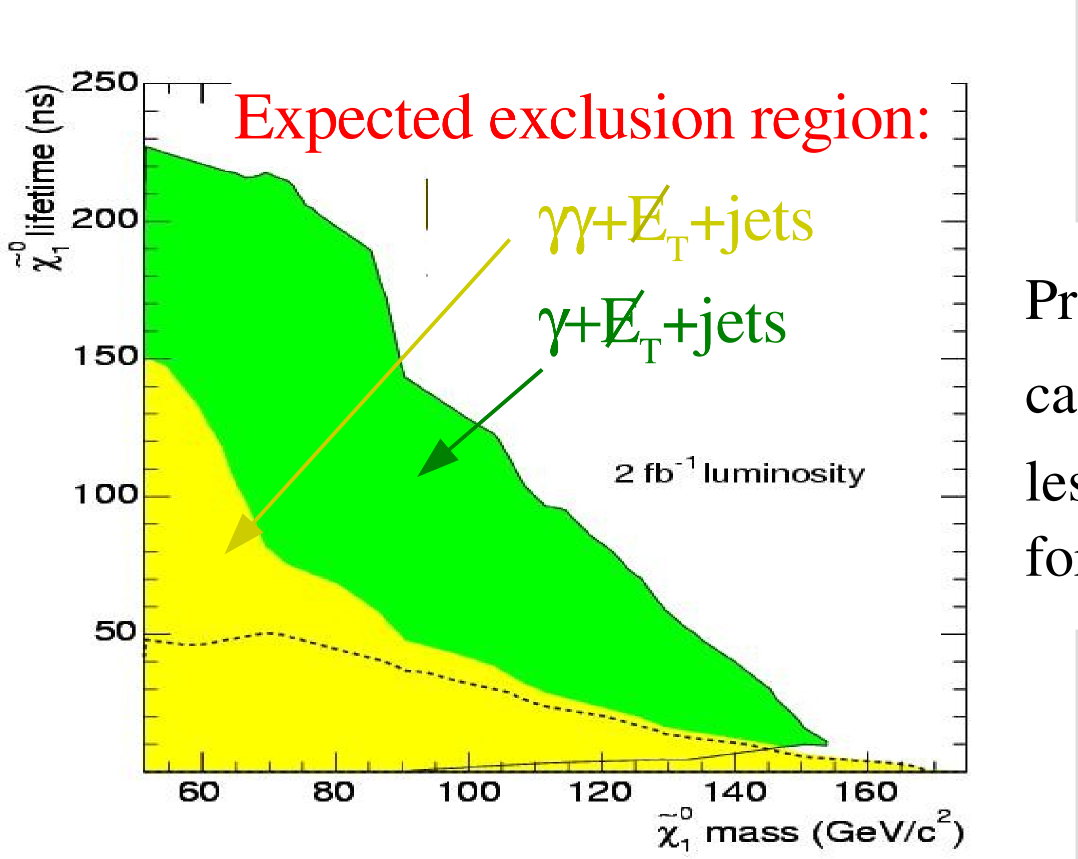
if both or only 1 $\tilde{\chi}_1^0$ decay in the detector due to large decay lengths

- Use this model to estimate our sensitivity

Sensitivity: $\gamma\gamma+\not{E}_T \Leftrightarrow \gamma+\not{E}_T$

A $\gamma+\not{E}_T$+jets analysis has sensitivity to longer $\tilde{\chi}_1^0$ lifetimes compared to a $\gamma\gamma+\not{E}_T$+jets analysis!

D. Toback and P. Wagner, Phys Rev D70, 114032 (2004)

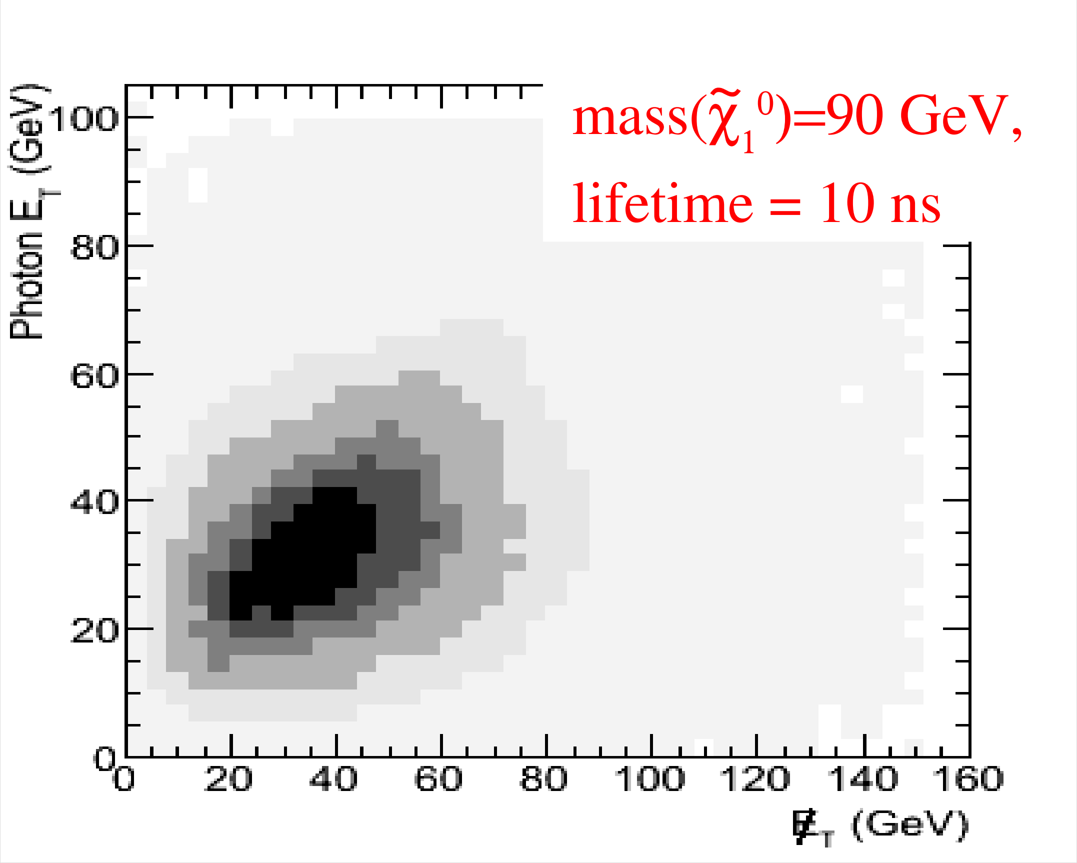


Previous $\gamma\gamma+\not{E}_T$ searches can exclude $\tilde{\chi}_1^0$ masses less than 120 GeV for prompt lifetimes

$\Rightarrow$ Will do a $\gamma+\not{E}_T$+jets analysis!

Kinematics of $\gamma + \not{E}_T$

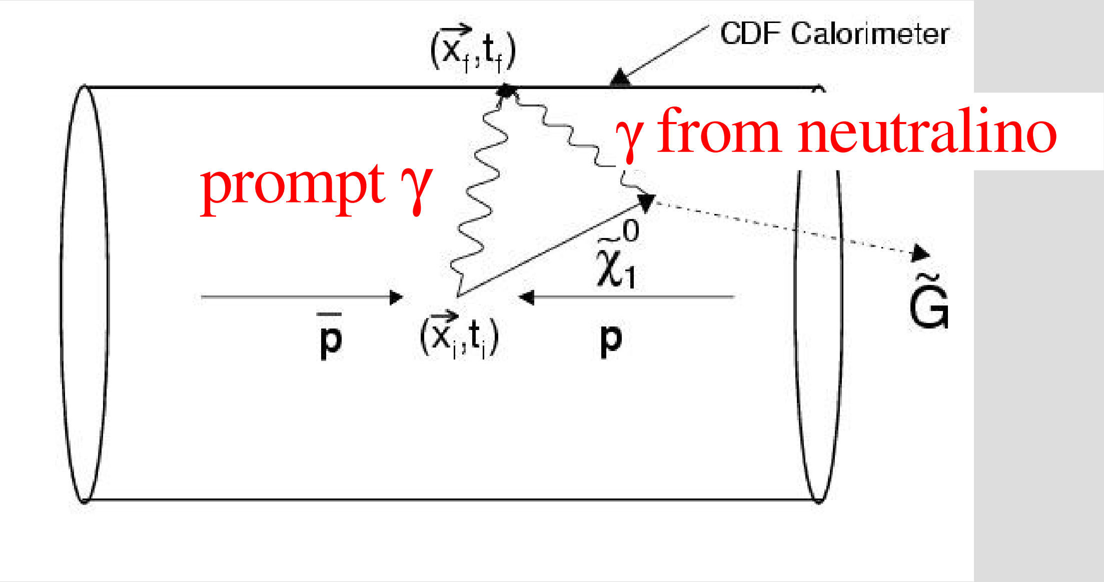
In a $\gamma + \not{E}_T$+jets analysis we expect events with a $\not{E}_T$ of ~40 GeV and a high-energy photon with an E_T of ~30 GeV



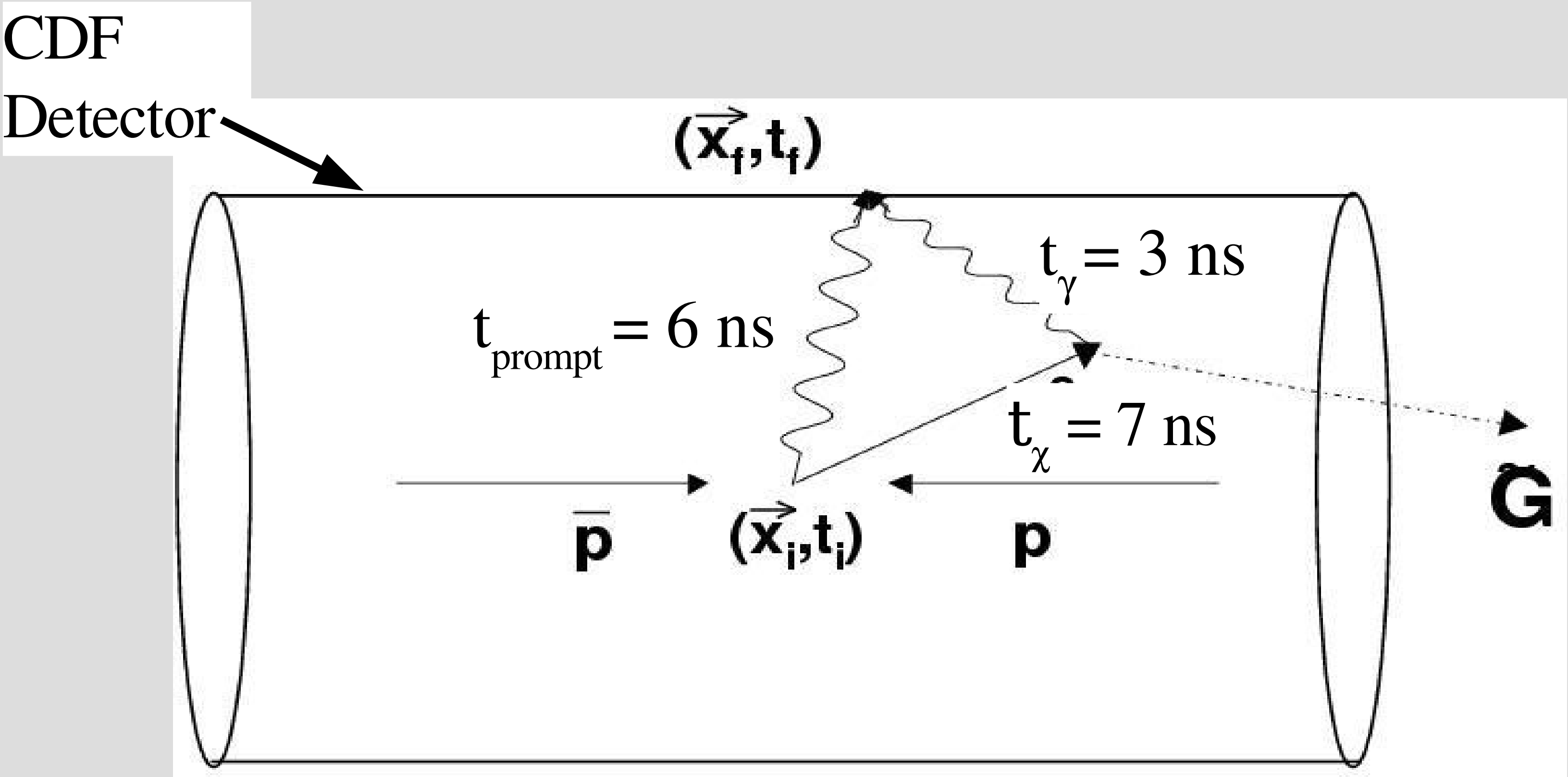
Delayed Photons

Photons from long-lived neutralinos can arrive at the calorimeter delayed compared to photons from the collision! ⇒

The idea: Look at the difference between the time of arrival of the photon and the time a prompt photon would need to reach the same position:



Example:



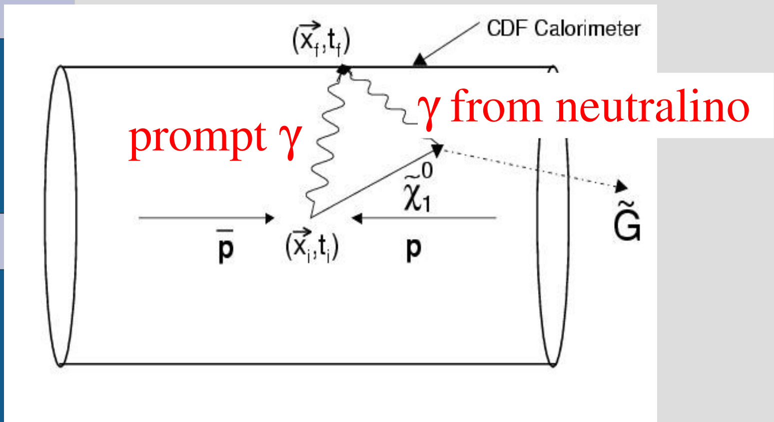
⇒ Time delay relative to the collision:

$\Delta t = (3 + 7) - 6 = 4$ ns

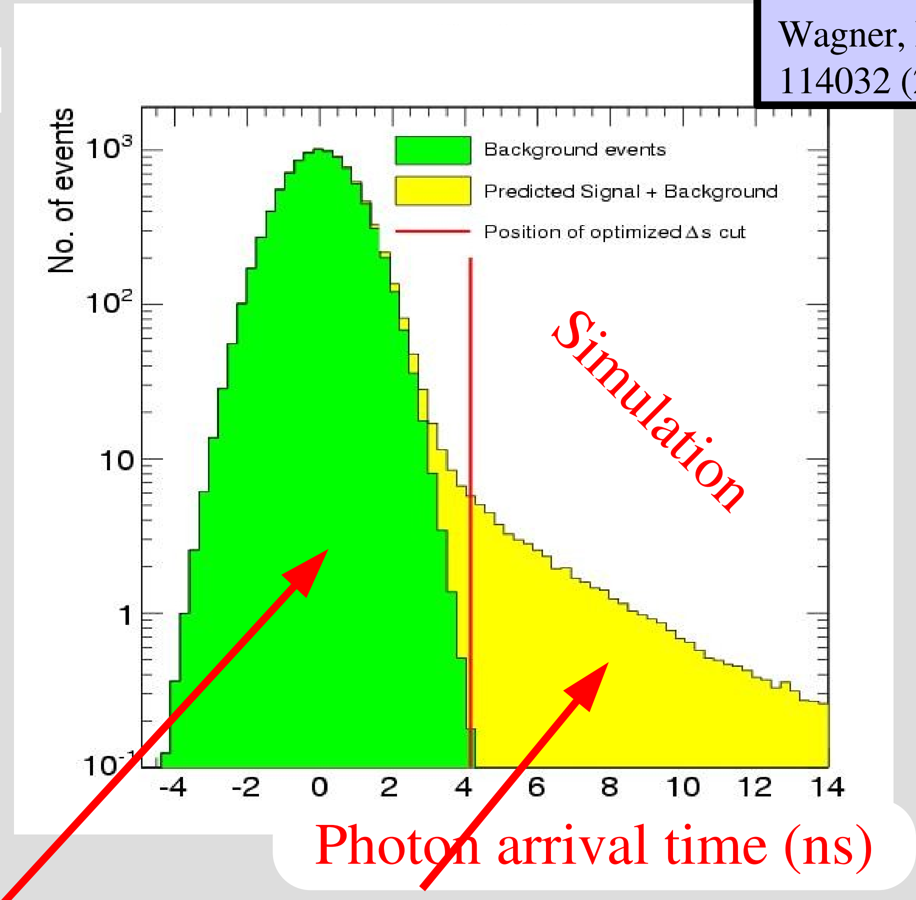
Prompt photons (SM): $\Delta t \equiv 0$ ns

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

Discriminating Search Variable



D. Toback and P. Wagner, Phys Rev D70, 114032 (2004)

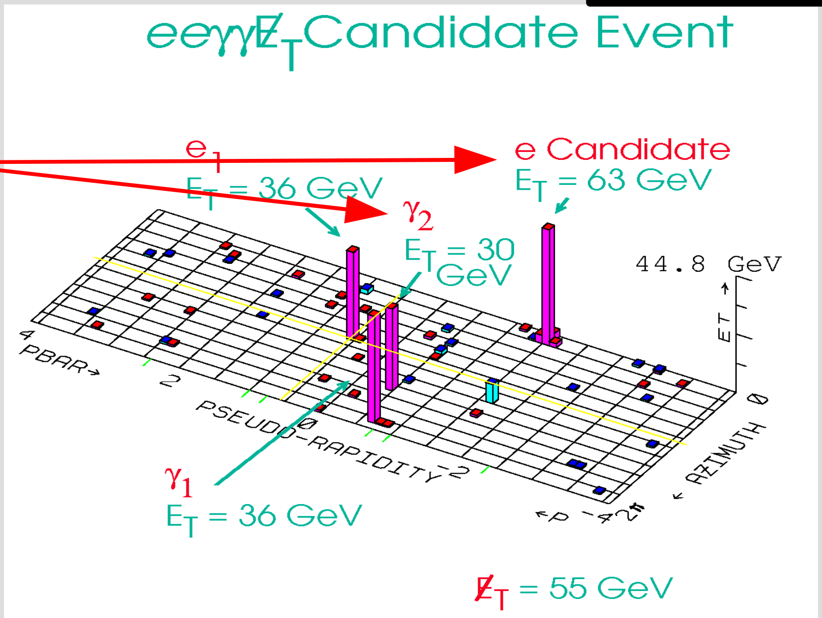


- Separate SM Background from GMSB Signal using the arrival time of the photon from the EMTiming system
- Low SM background at non-prompt arrival times

Experimental Hints for SUSY at the Tevatron?

CDF Coll., Phys. Rev. D59, 092002 (1999)

- "$ee\gamma\gamma+\not{E}_T$ candidate" event at CDF in Run I: One of the photons and the plug electron candidate had no time information. The SM prediction for this event was $1\pm1\times10^{-6}$ events

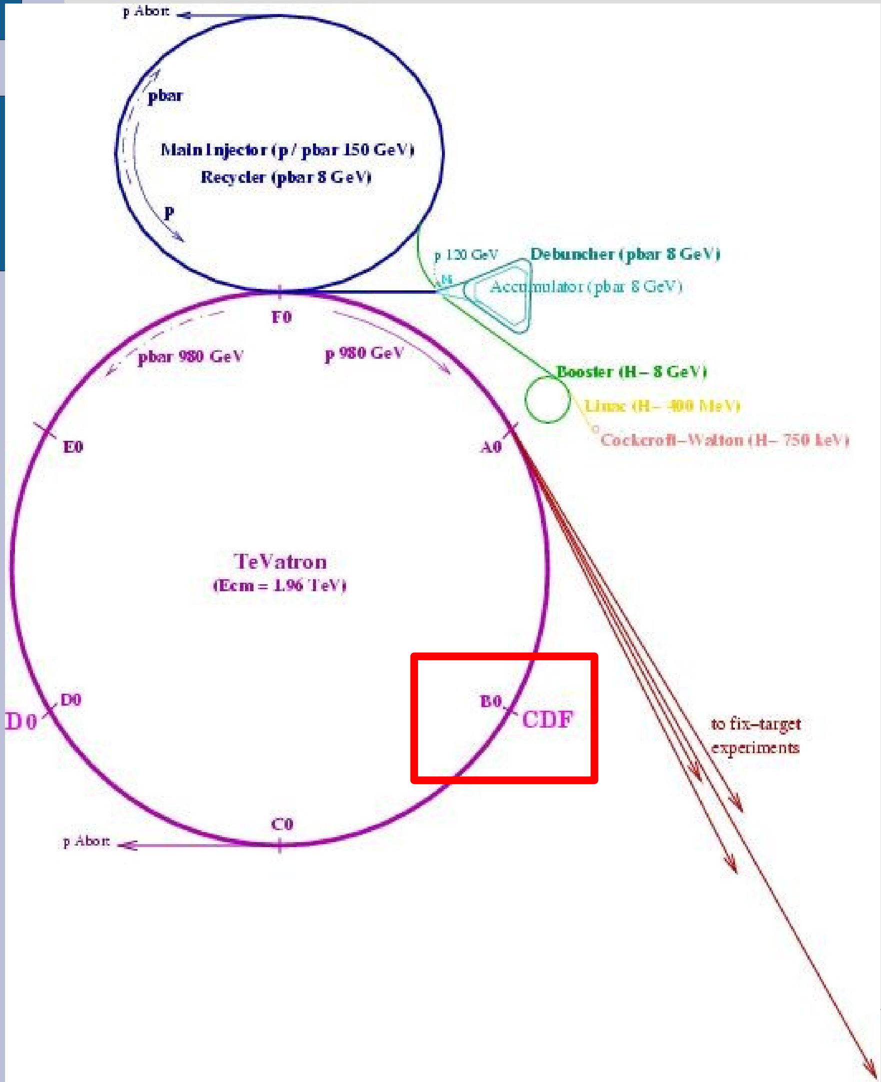


- Hypotheses: Some objects were not from the collision? Or from neutral, long-lived particles?
- A timing system in the EM calorimeter could help verify that future such events are from the collision or find these long-lived particles
- GMSB models are the favored explanation for this event

EMTiming at CDF

Fermilab Tevatron

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



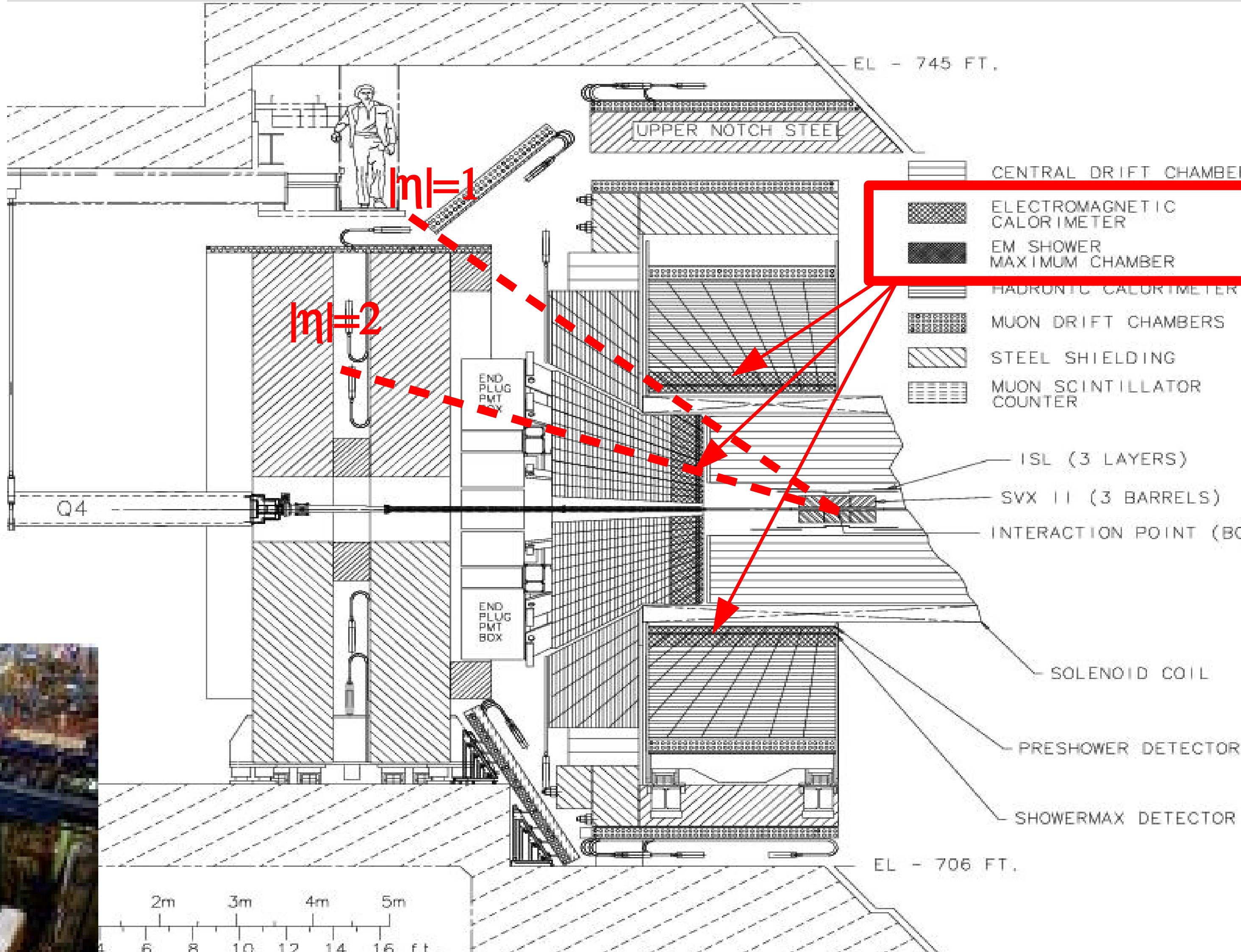
Specifications:

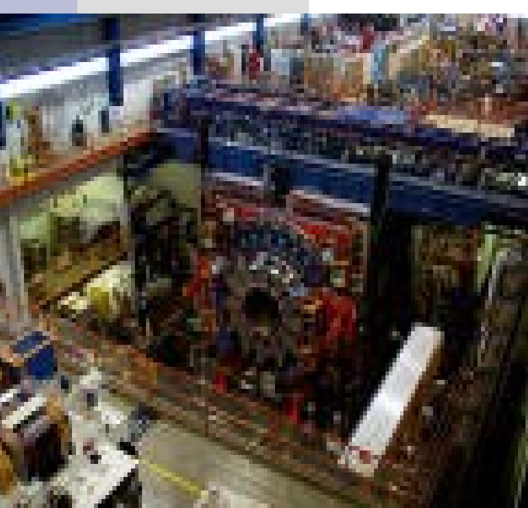
- World highest energy synchrotron: $p\bar{p}$ collisions with CM-energy 1.96 TeV
- A bunch crossing every 396 ns
- Serves two multi-purpose detectors: D0 and CDF

CDF II Detector

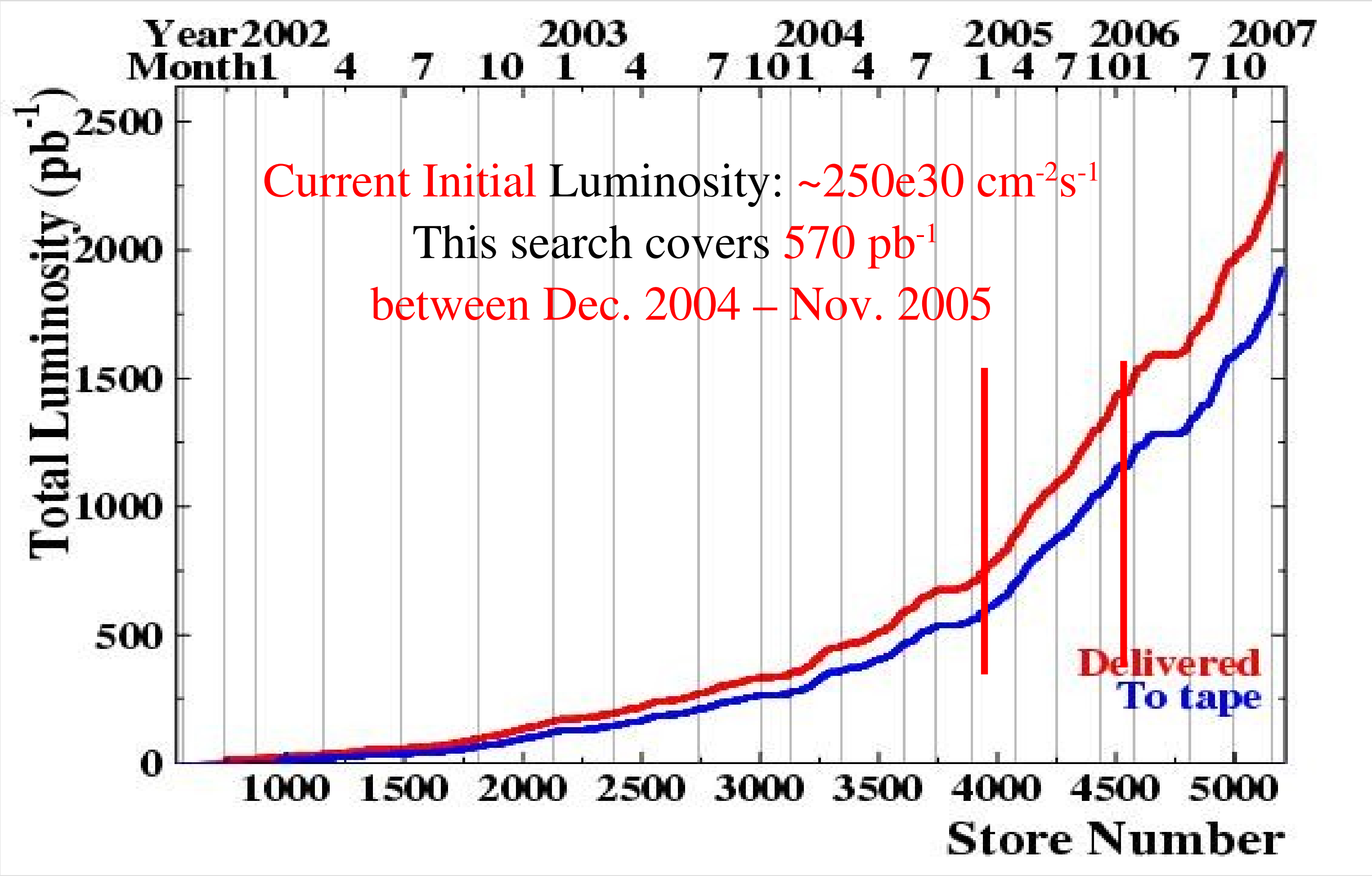
Specifications for Run II:

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





CDF II Detector Performance



Data currently recorded at CDF: ~2 fb^{-1}

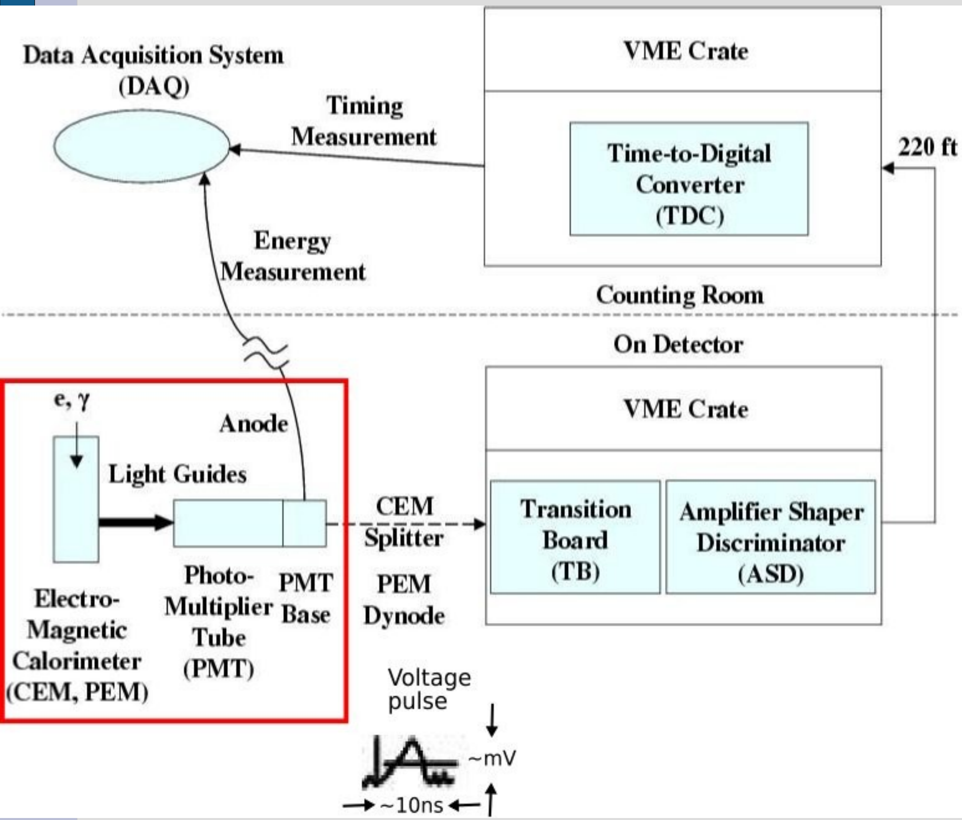
Why Timing?

3 Motivations:

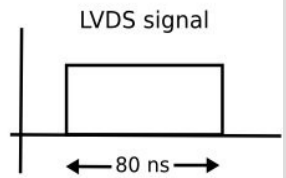
- To provide an additional handle for unusual events like $ee\gamma\gamma\not{E}_T$
- To reject cosmic ray background
- To search for neutral long-lived particles like the GMSB neutralino

New at CDF: Timing in the EM calorimeter - EMTiming

M. Goncharov, D. Toback, P. Wagner et.al., Nucl. Instr. Meth. A565, 543 (2006)

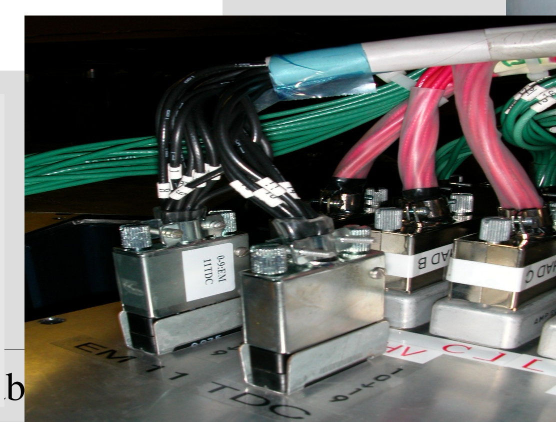


- Hardware similar to Timing system in the Hadronic Calorimeter (HAD)
- The installation was finished in Fall 2004



- Covers most of the EM calorimeter ($|\eta| < 2.1$)

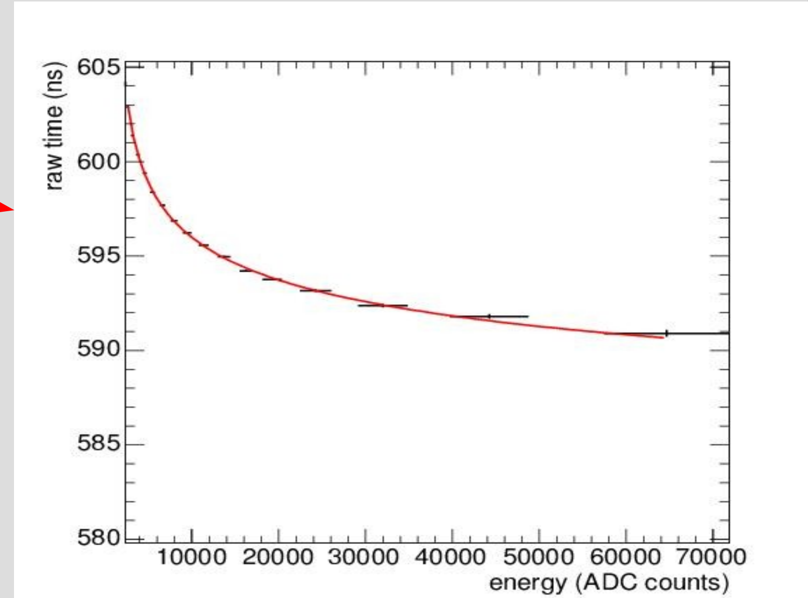
- 100 % efficient for photons with >3.5 GeV (CEM)
- 1 channel failure in 40000 PMT months

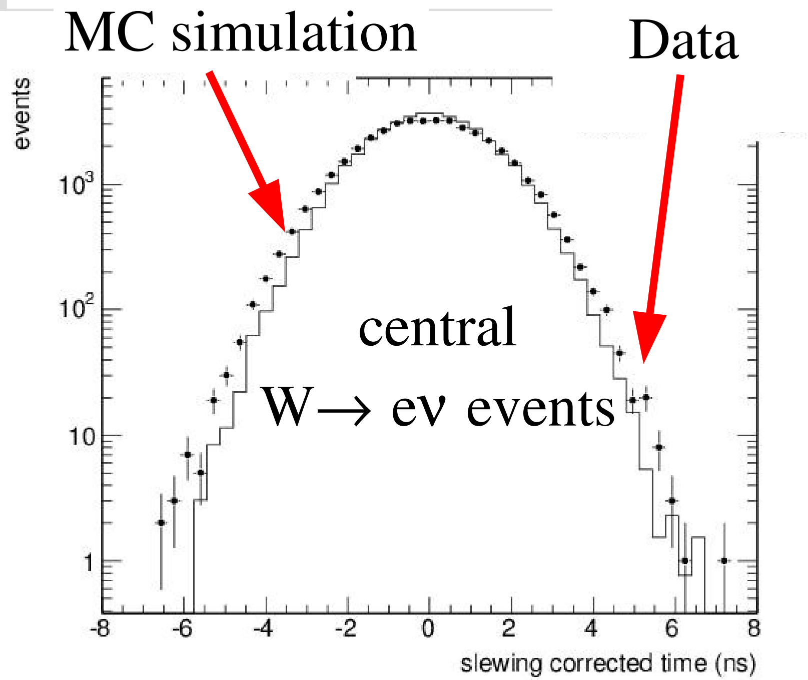


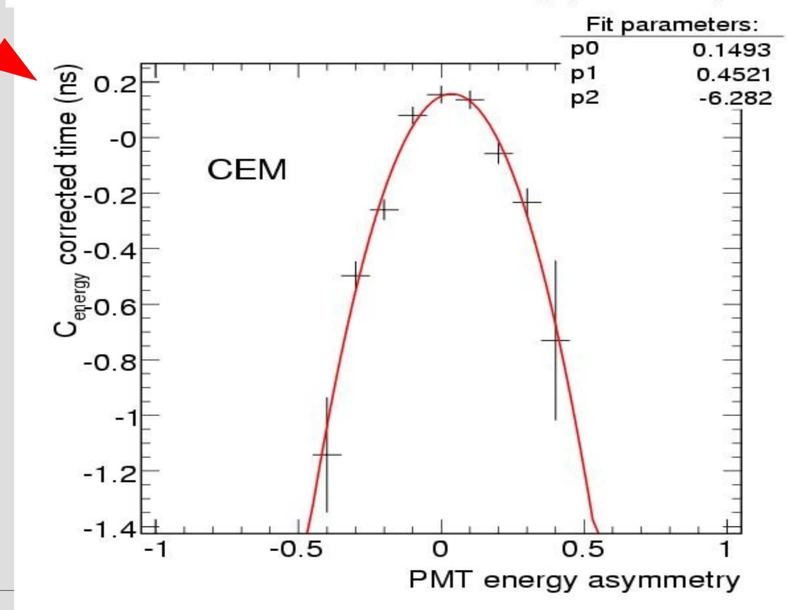
Some Details about the EMTiming Calibrations

- EMTiming TDC time is energy dependent due to fixed-height discriminators
- Arrival time depends also on where the photon showers into the tower (PMT asymmetry)

→ After calibrations: RMS=1.6ns



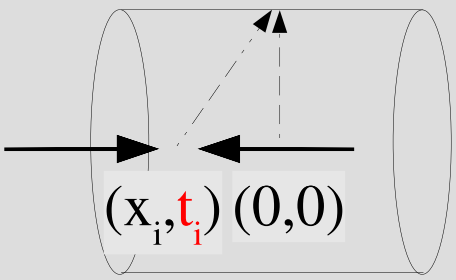




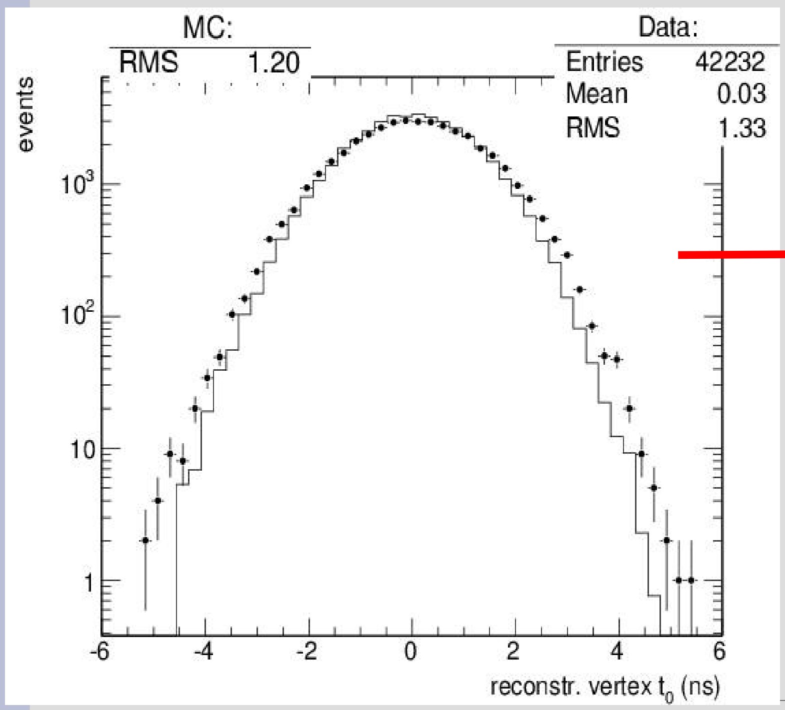
EMTiming Event-by-Event Corrections

After calibrations successively apply event-by-event corrections:

1) Collision time:

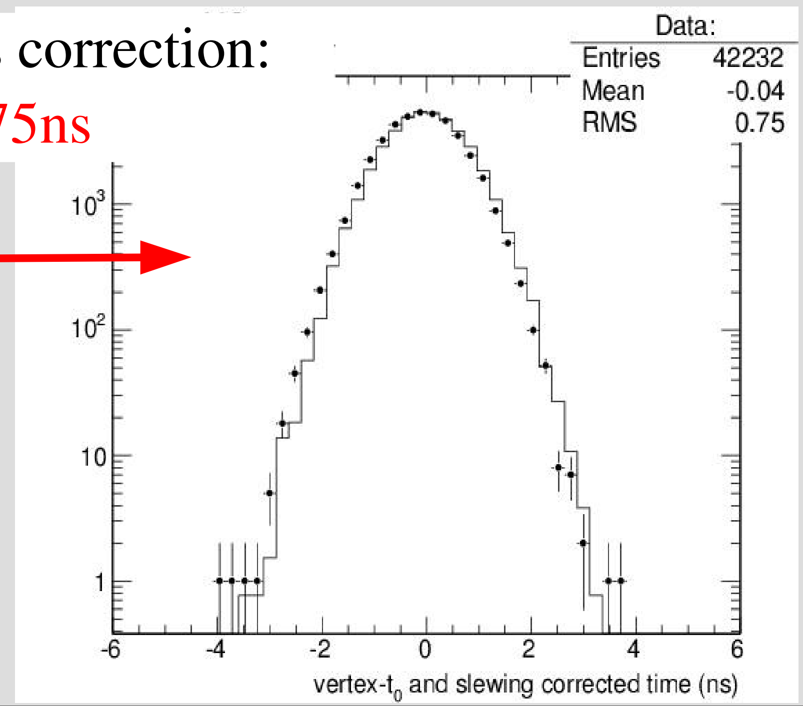


- Need vertex reconstruction in space and time → later!
- RMS=1.3ns
- Measurement resolution = 0.2 ns



After this correction:

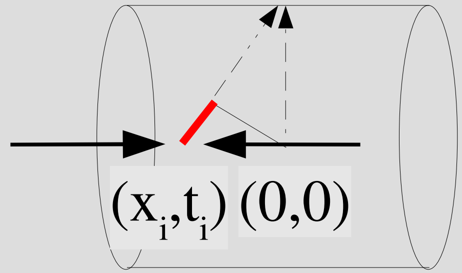
RMS=0.75ns



EMTiming Event-by-Event Corrections

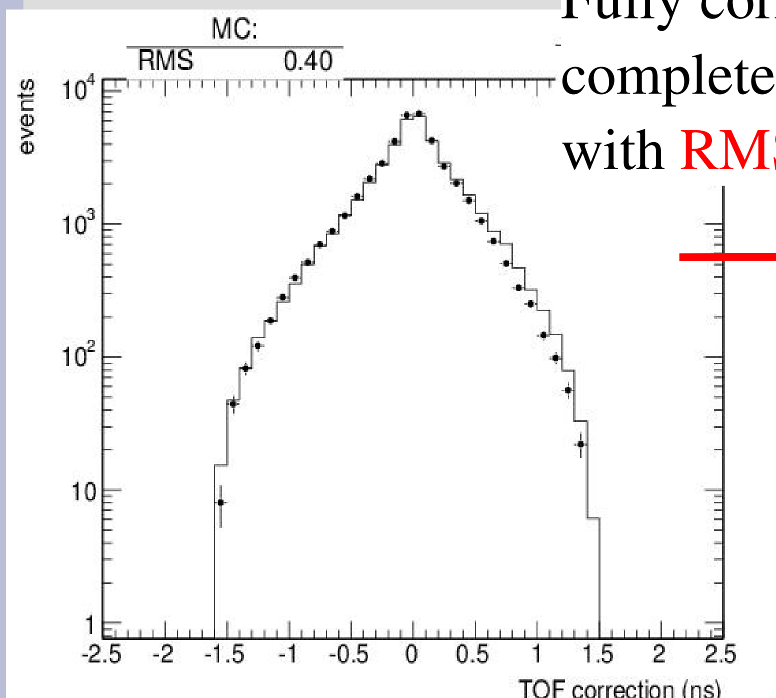
2) Time of flight:

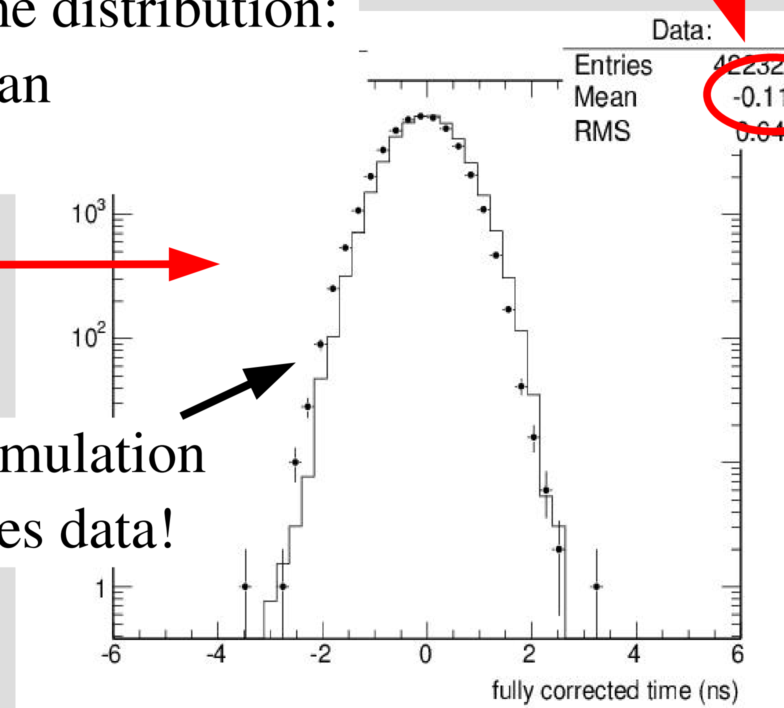
- RMS=0.4ns
- Measurement resolution: negligible



Data is shifted by 0.11ns: taken into account by systematics

Fully corrected time distribution: completely Gaussian with RMS=0.64ns



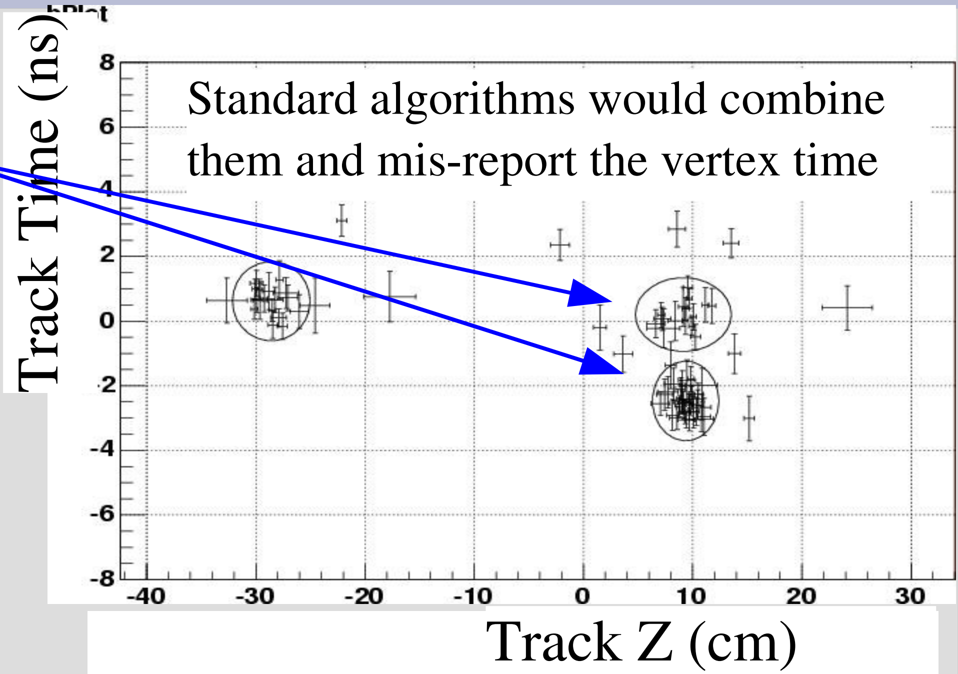


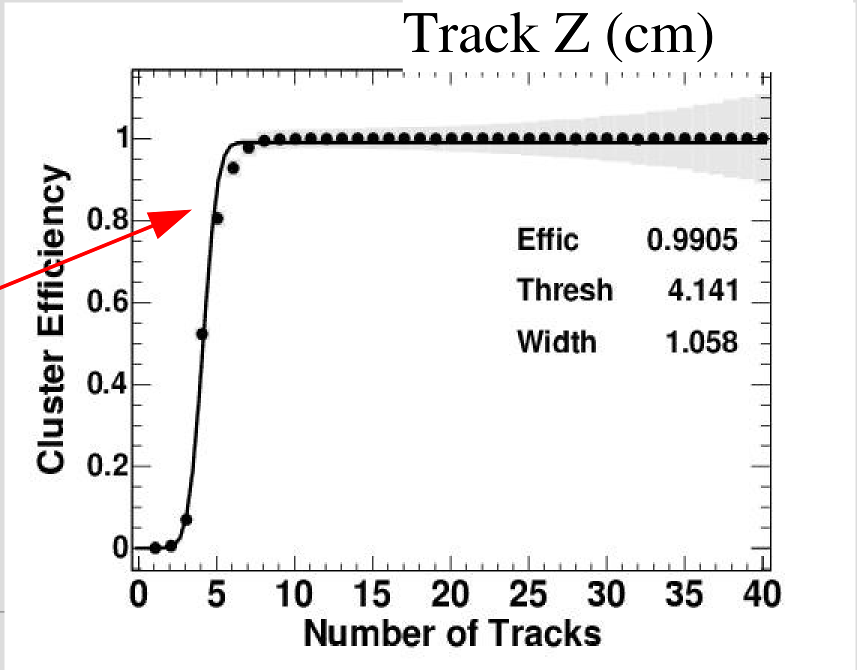
MC simulation matches data!

Vertex Finding Algorithm

NEW Vertexing in Space and Time

- At high instantaneous luminosity two or more collisions can occur
- To correct the photon arrival time for the right collision time it is important to separate vertices that lie close in space but have different times
- Track resolution is $(t_0, z_0) \approx (0.3$ ns, 0.2 cm$)$, vertex RMS is of the same order
- 98% of collision events have a fiducial vertex
- It is fully efficient with >4 tracks

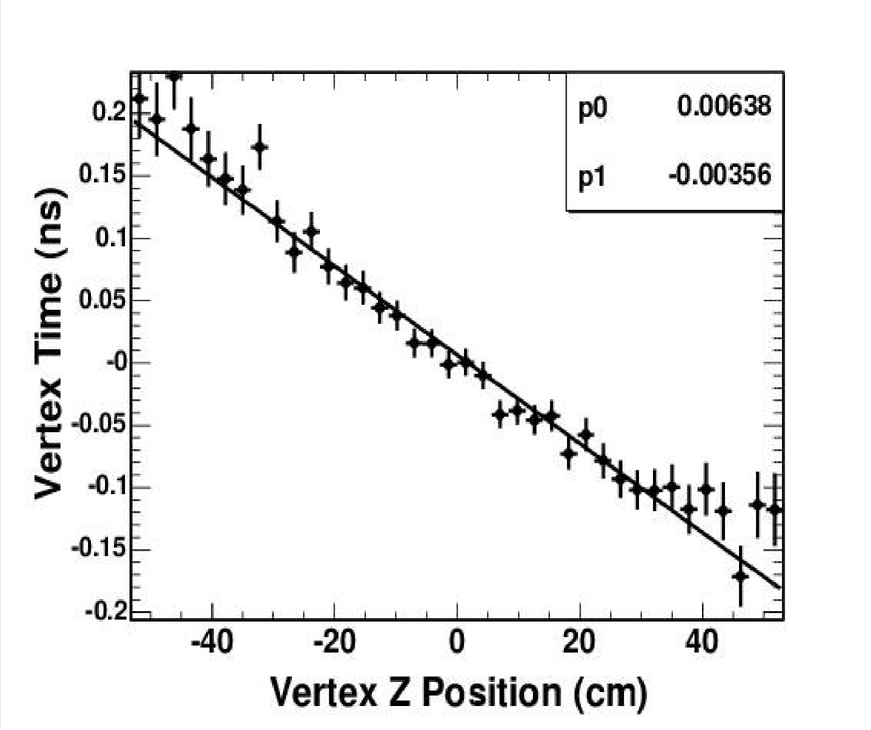




Sidenote: Correlation between Collision x and t

Interesting feature: This vertexing allows us to measure the correlation between the collision position and time!

This is a real effect that can be described by the bunch sizes of proton and antiproton bunches being different



From the slope parameters can calculate the bunch sizes:

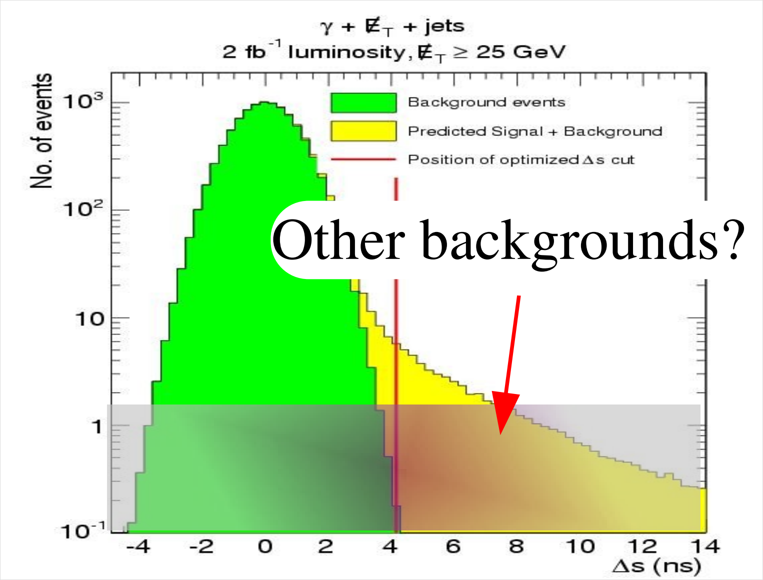
σ(proton)=55 cm

σ(antiproton)=60 cm

The Analysis

Overview

- Can we use standard identification criteria to identify photons from long-lived particles?
- As the GMSB signal is expected to show up at arrival times inconsistent with the collision time we will have to estimate the contribution from non-collision sources



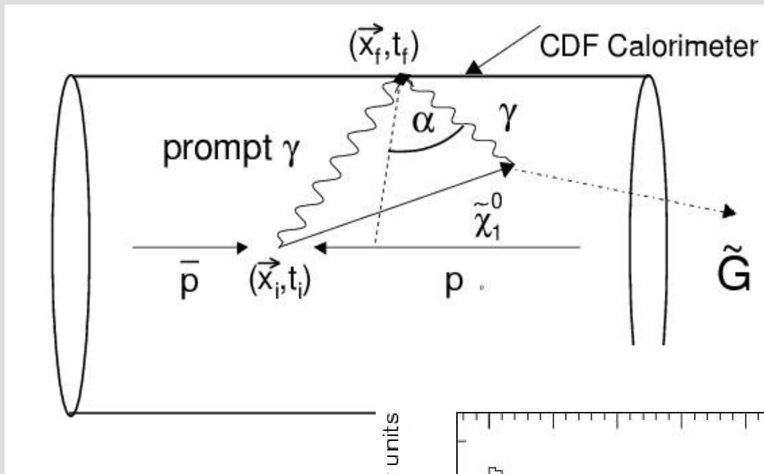
- Make a loose event selection such that we are sensitive to any model with a similar final state, then optimize our event selection requirements using a GMSB model for several $\tilde{\chi}_1^0$ masses and lifetimes
- Open the blinded signal region and set limits

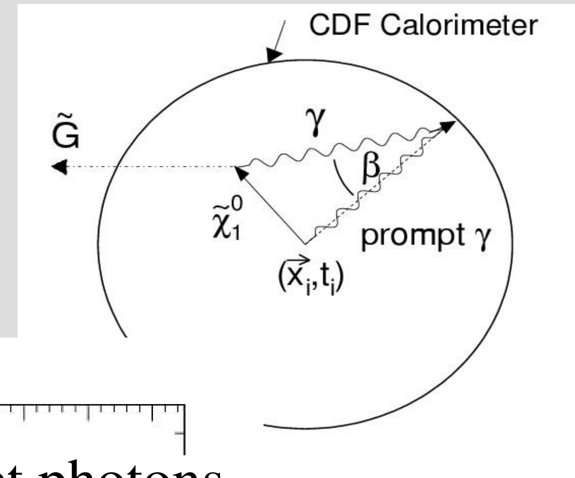
Outline

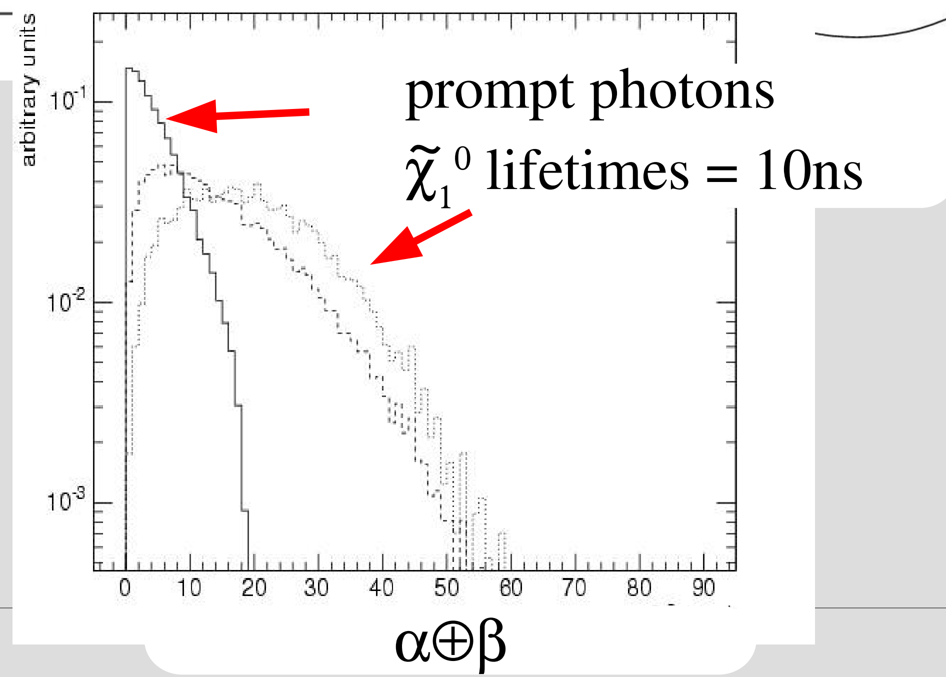
- Identification of photons from long-lived particles
- Backgrounds
- Event Preselection
- Optimization
- Results

Photon Identification – Incident Angle

Photons from long-lived particles are different from “standard” photons: their incident angle at the calorimeter can be much higher



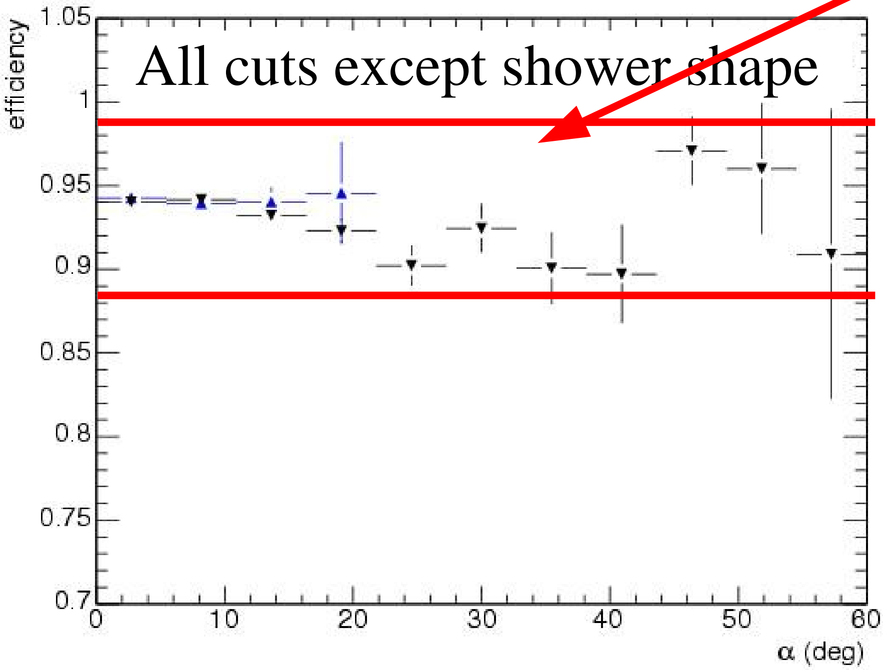


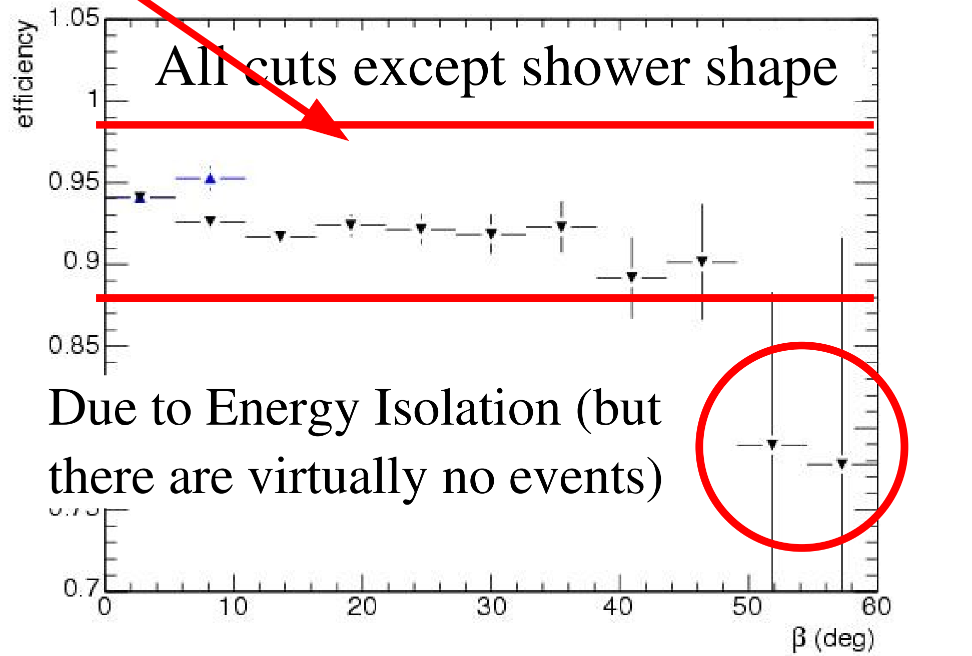


→ investigate ID criteria as a function of angle!

Combined Identification Efficiencies vs α and β

- Drop the CES Shower Shape requirement
- Assign a systematic uncertainty of 5% to the identification efficiency





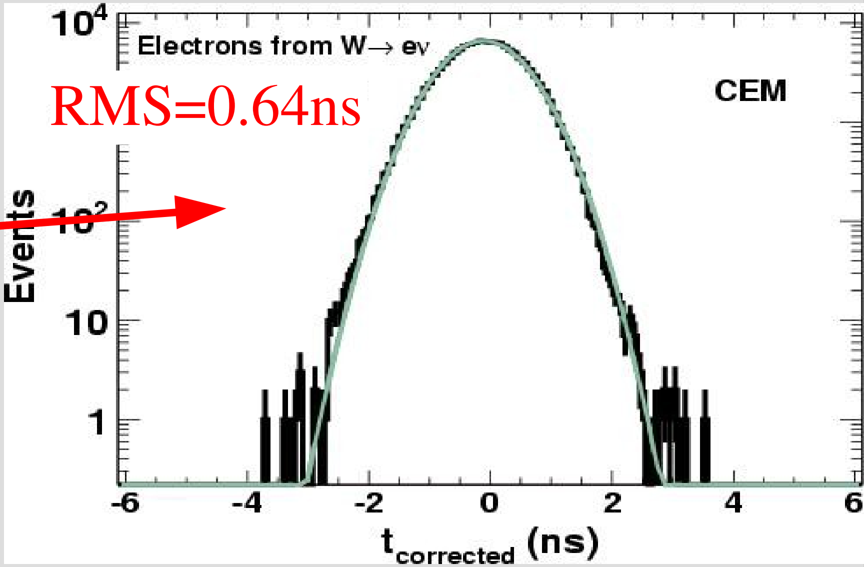
Backgrounds

Backgrounds - Outline

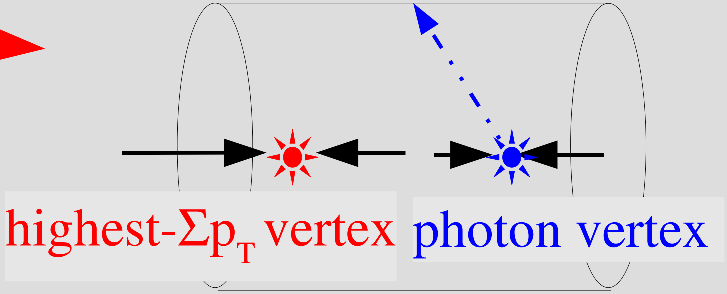
- Background Description:
  1) Collision: Standard Model photon candidates
     - Right vertex
     - Wrong vertex
  2) Non-collision photon candidates
     - Beam Halo
     - Cosmics
- Background Prediction, Methods and Results

Collision Backgrounds

At high beam luminosity there may be multiple interactions for each bunch crossing ⇒ there is more than one event vertex reconstructed with a different position in space and time



- As I showed, this is the time distribution of electrons from W enu – if we apply the right corrections, in particular, if the selected vertex is the one that produced the electron
- This is easy for electrons – but non-trivial for photons as there is no track that points to the vertex!



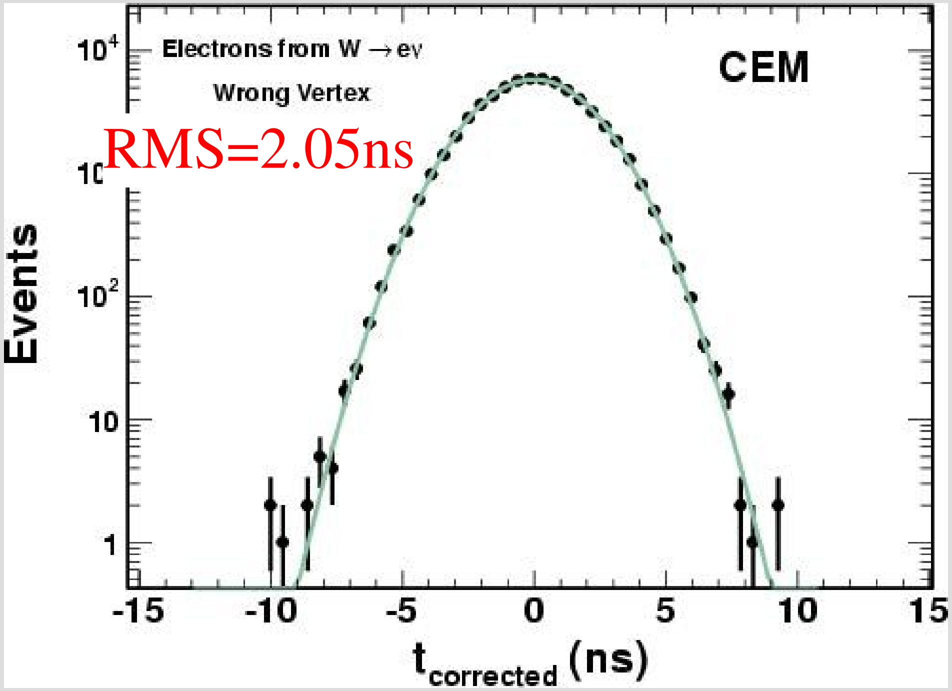
Wrong Vertex Selection

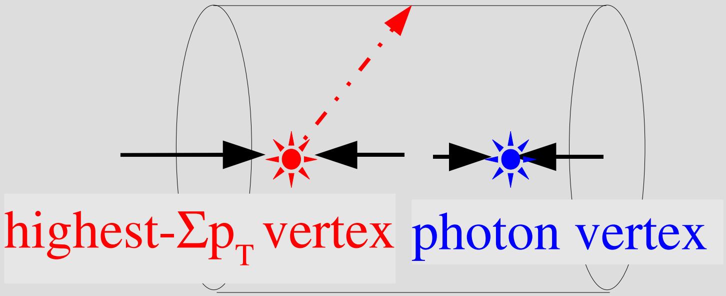
- If we purposely choose the wrong vertex for $W \to e\nu$ electrons (their tracks are not used in the vertex reco) then their time distribution has an RMS=2.05 ns.

$\Rightarrow$ Have to separate between cases where highest-Σp_T vertex is and where it is not the photon vertex

$|Z_{e\ track} - Z_{Vertex}| > 2$ cm

Wrong Vertex:





Systematic Error on Collision Bkgs.

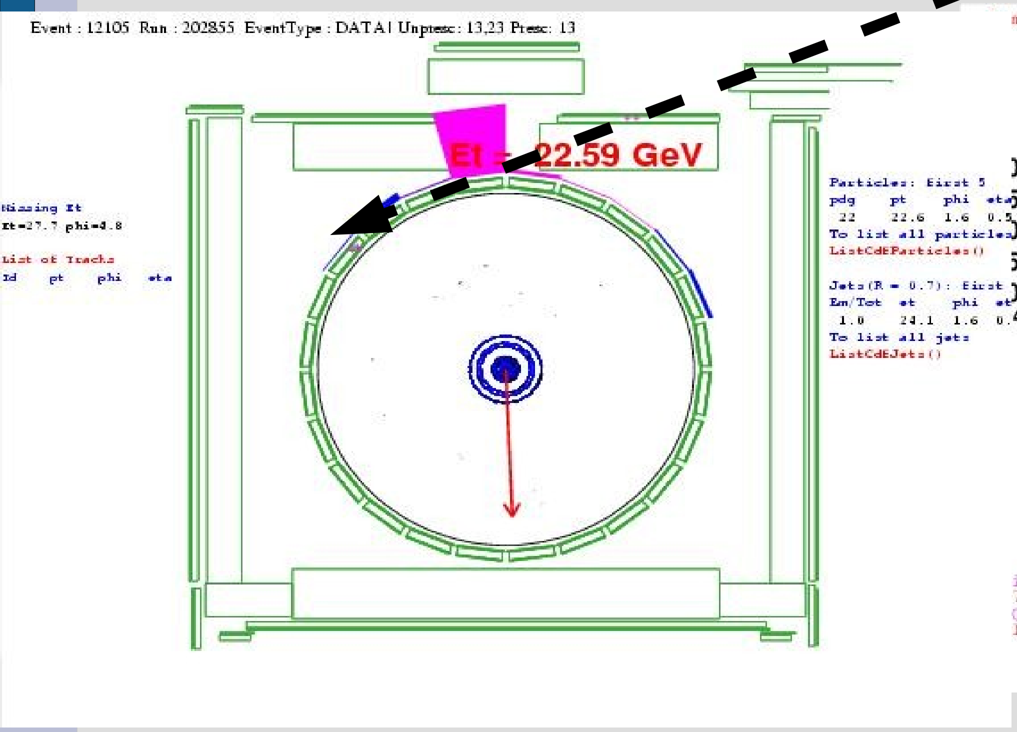
- While the system is well calibrated for an inclusive data sample the mean time may be off for subsamples $\Rightarrow$ assign a conservative systematic error on the mean of 0.2 ns on the right vertex distribution
- This is the main source of systematic uncertainties
- We also assign a systematic error of 0.33 ns on mean and 0.28 ns on RMS of the wrong vertex distribution

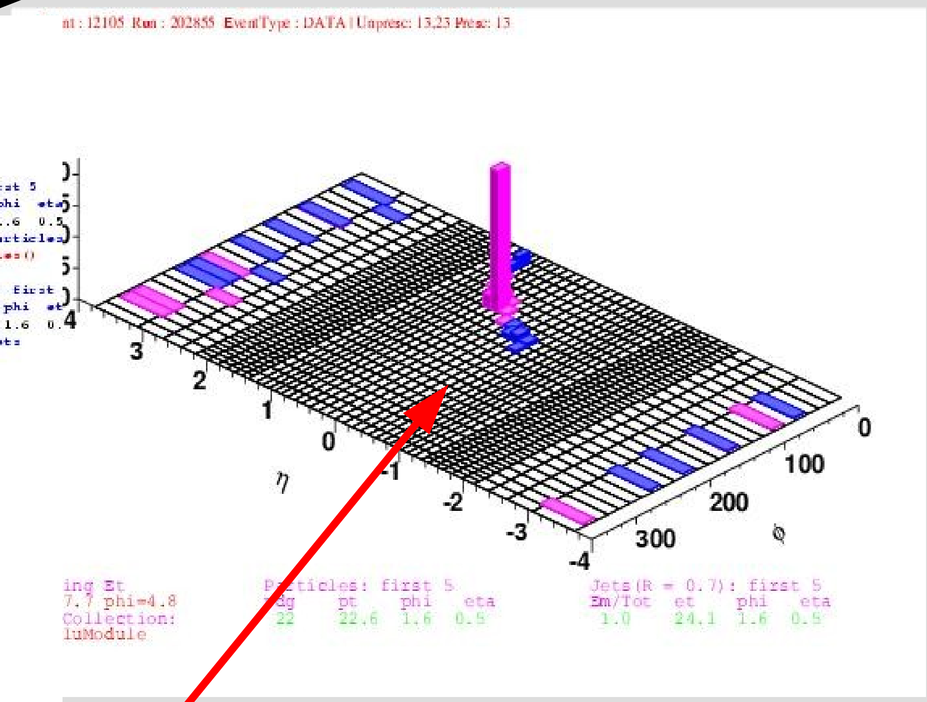
Non-Collision Backgrounds

- Non-collision backgrounds that fake $\gamma+\not{E}_T$ events are:
  - Beam Halo
  - Cosmics
- As they come from different sources with different rates we have to separate them for the background estimate to our signal region
- We investigate each case separately using a $\gamma+\not{E}_T$ sample without vertices (or with vertex $\Sigma p_T < 1$ GeV)

Non-Collision Backgrounds – Cosmics

- A cosmic ray shower that brems in the calorimeter can produce a fake $\gamma + \not{E}_T$ event
- The photon is mostly ~30^0 away from hits in the muon chambers
- These “photons” are random in time

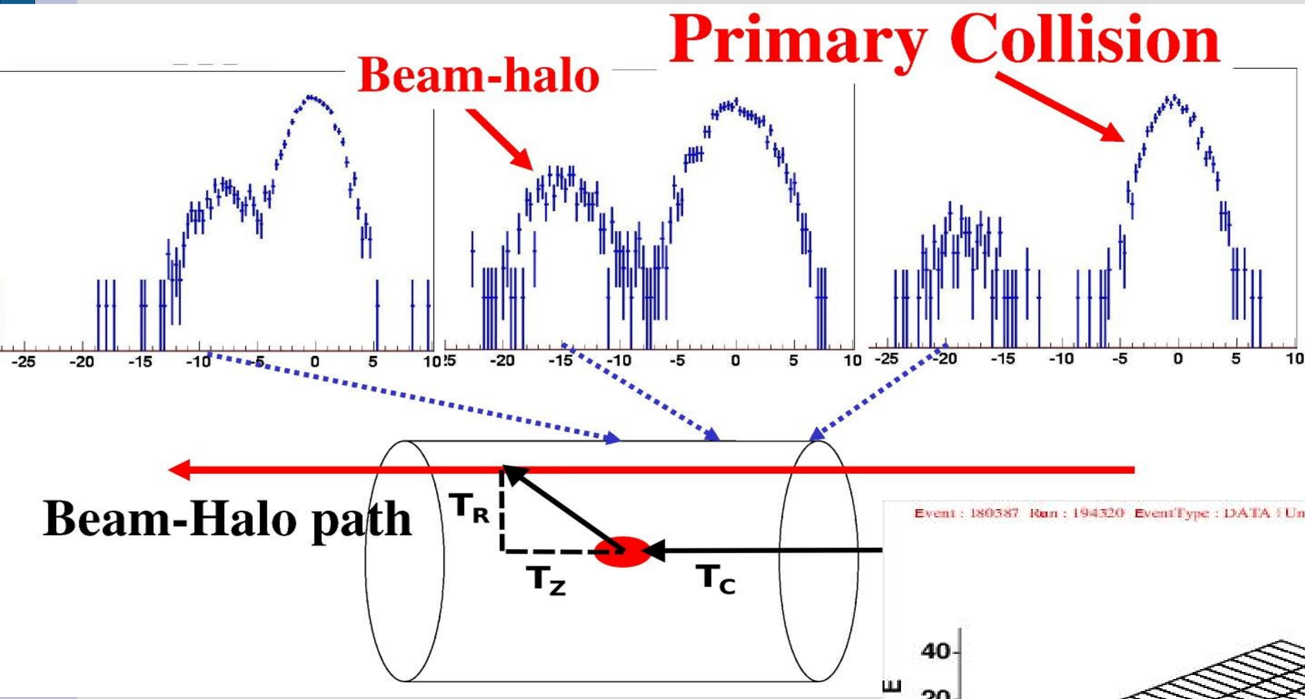




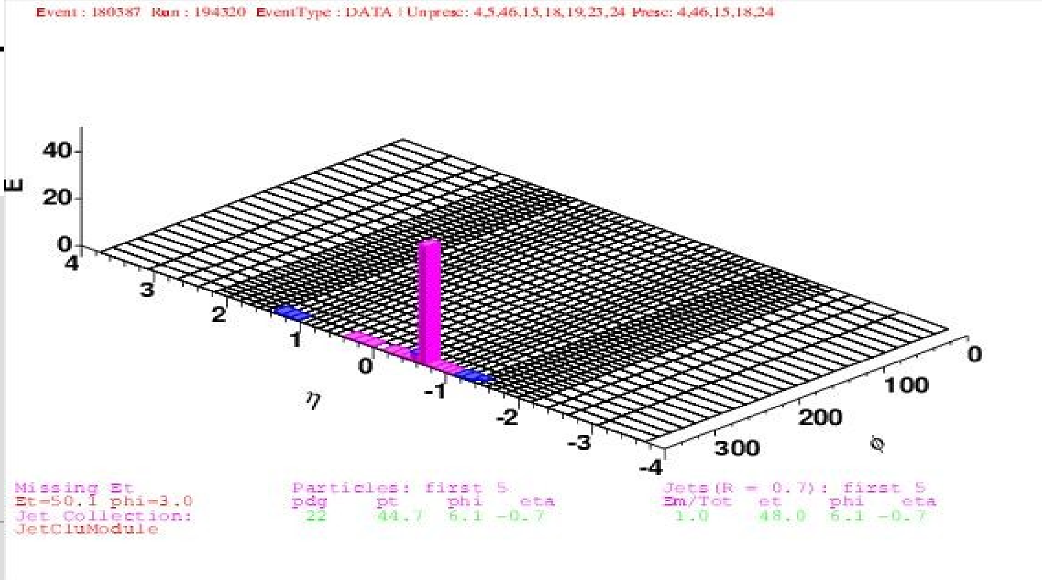
This photon looks very much like from the collision!

Non-Collision Backgrounds – Beam Halo

- Beam Halo (BH) is produced by proton-bunch interactions with the beam pipe that scatter off muons that can traverse the calorimeter



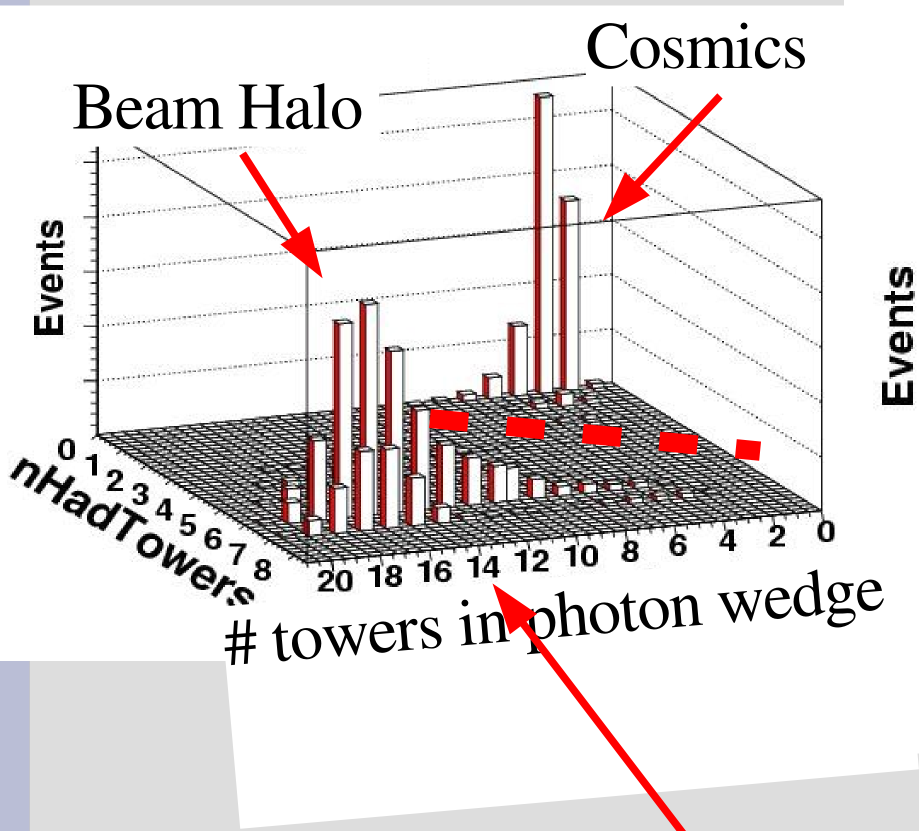
1) These photons mostly have negative arrival times for geometrical reasons if the beam halo muon came from the primary collision bunch

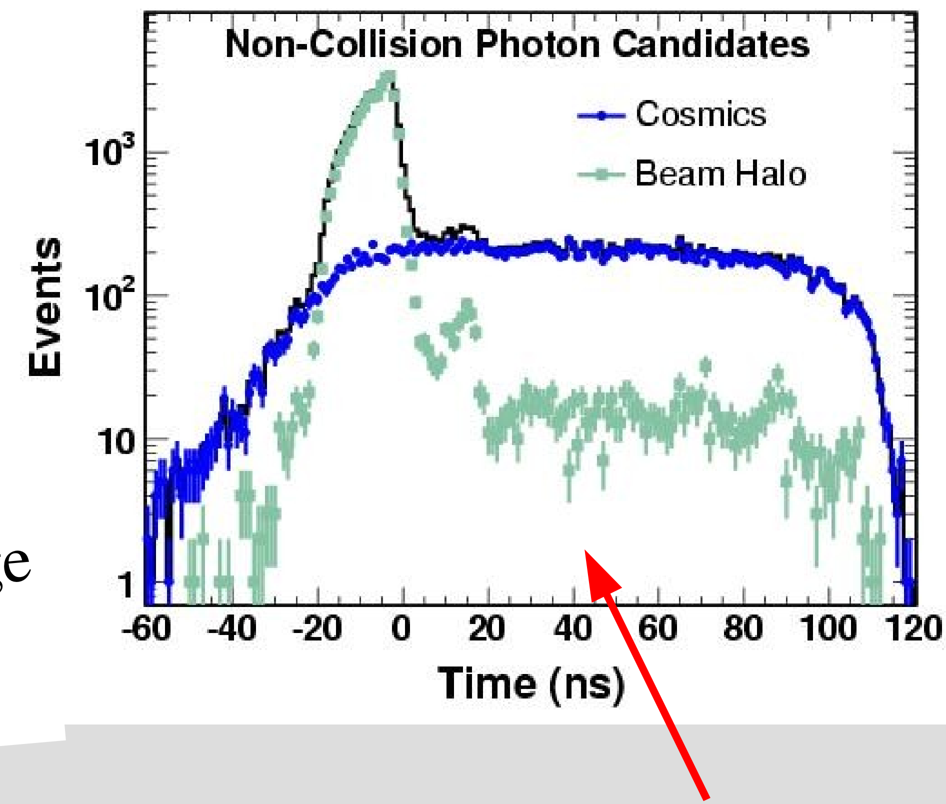


2) They mostly occupy multiple towers in the same wedge

Non-Collision Time Distribution

- We have to estimate the non-collision contribution to our $\gamma+\not{E}_T$+jet data sample

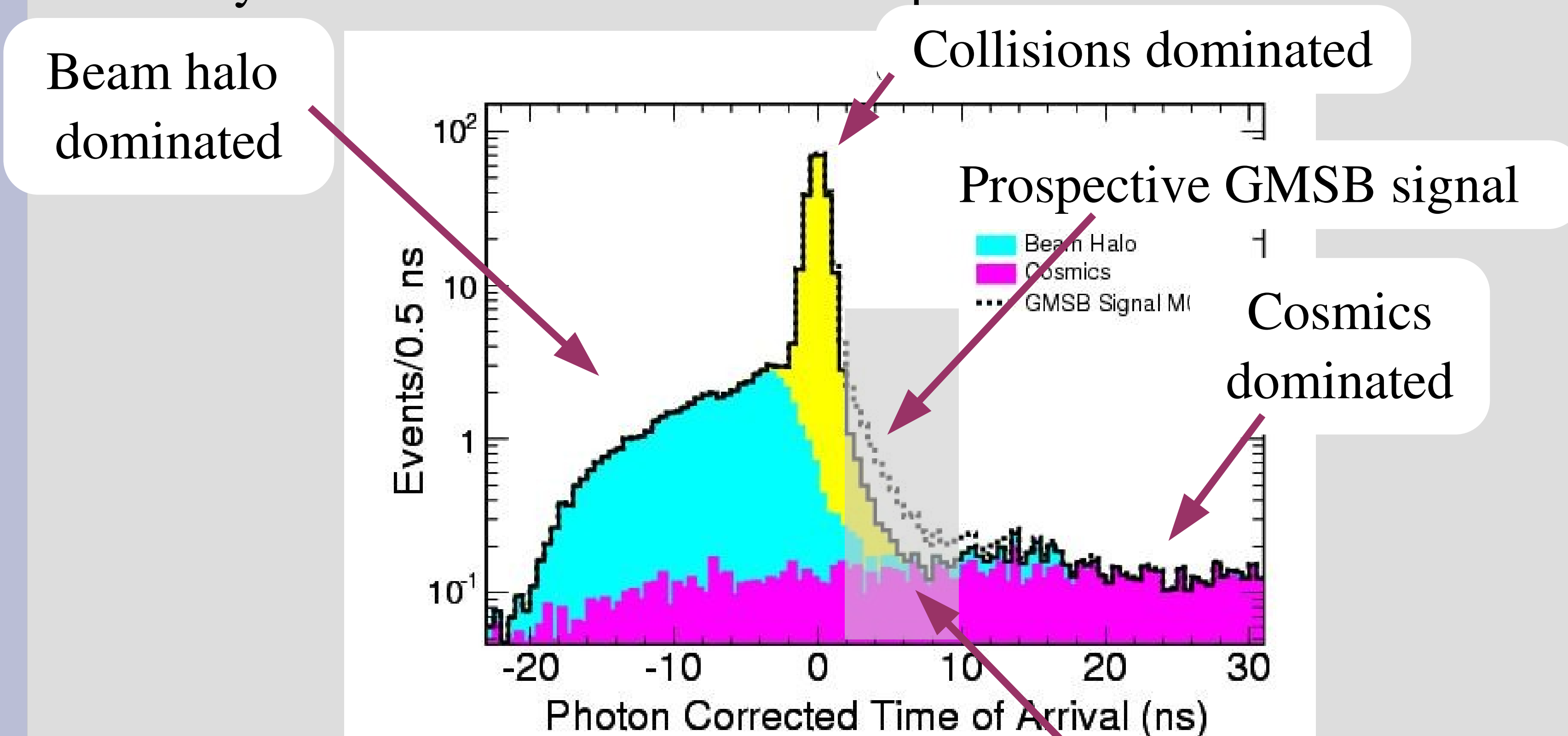




⇒ Using the BH's properties we can separate their time distributions

Background Prediction

- Take the collision time shape from $W \rightarrow e\nu$ sample, the non-collision shape from the no-track sample
- Fit each background shape to a time window in the $\gamma + \not\!\!E_T$+jet data where the respective background dominates
- Vary the normalization of each shape:



- Predict the number of events in the blinded signal region

Summary: Event Preselection

- Not GMSB specific!
- Require a central high-E_T photon, $\not{E}_T$ and at least one high-E_T jet
- The only trigger that doesn't require the photon to pass the shower shape requirement: "W_NOTRACK"
  - EM cluster E_T > 25 GeV and $\not{E}_T$ > 25 GeV
- Trigger fully efficient at photon E_T > 30 GeV and $\not{E}_T$ > 30 GeV — 39%
- Good vertex in space and time with >4 tracks that have a total p_T of >15 GeV to reduce non-collision backgrounds — 31%
- Require a jet with E_T > 30 GeV to reduce non-collision backgrounds — 24%
- No potential muon within 30^{o} to reduce cosmics — 23%

Efficiencies for a signal with m_χ = 100 GeV and τ_χ = 5 ns

Optimization and Expected Limits

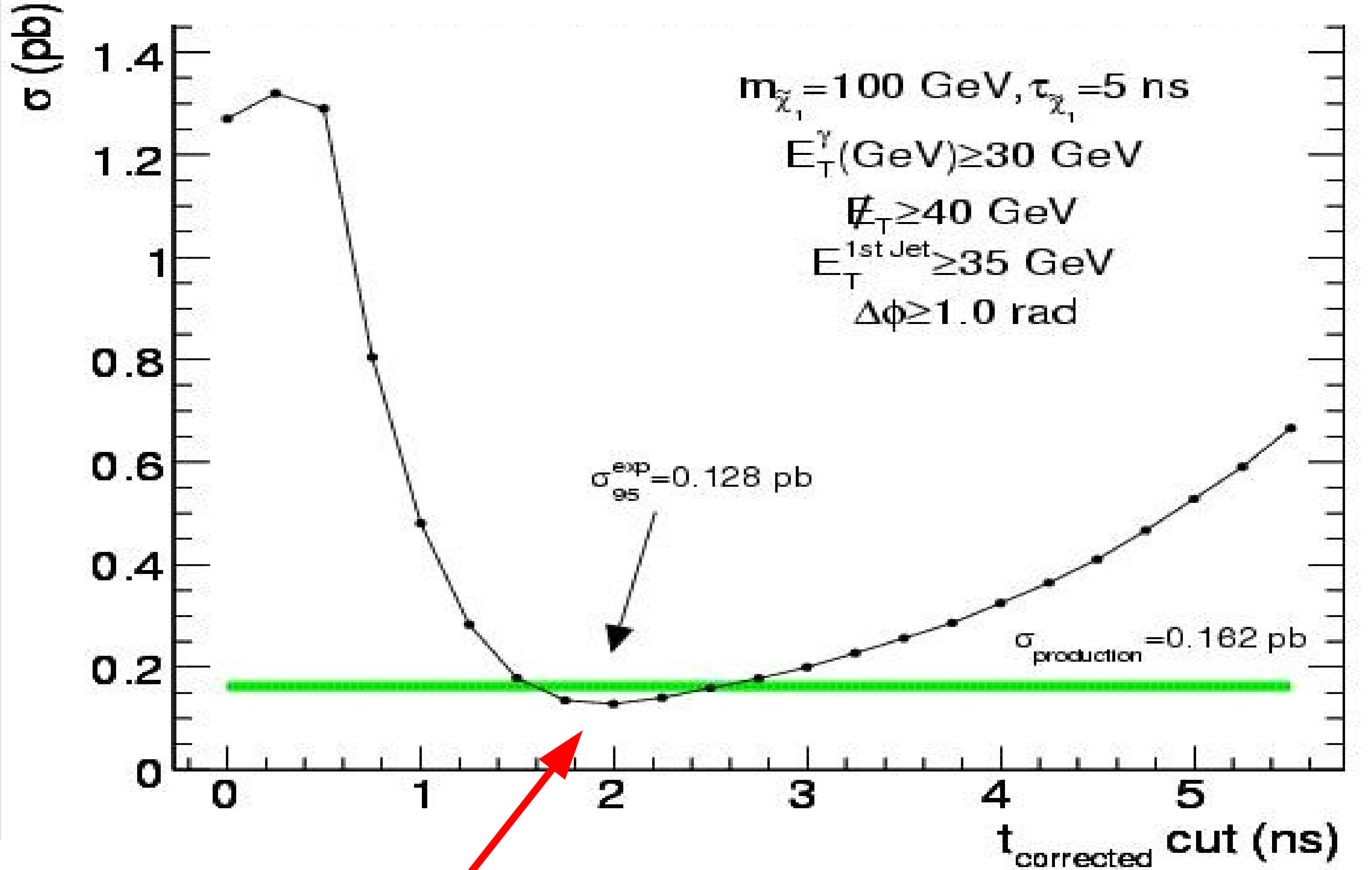
Optimization

- Idea: Find a fixed set of *a-priori* event selection cuts before unblinding the signal region
- Method: We calculate the 95% C.L. expected cross section limit, taking into account the expected no. of background events, luminosity, GMSB acceptance and their errors
- The result is a function of the event selection cuts: Photon E_T, jet E_T, $\not{E}_T$, $\Delta\phi(\not{E}_T,\text{jet})$ and time window
- Pick the lowest limit
- Map it out as a function of the $\tilde{\chi}_1^0$ mass and lifetime

Comparison of Signal and Bkg

$m_\chi = 100$ GeV and $\tau_\chi = 5$ ns

Prod. cross section: 0.162pb



Choose optimal cut at 2ns

Optimization Result

Final cuts:

- Photon E_T: 30 GeV
- $\not{E}_T$: 40 GeV
- Jet E_T: 35 GeV
- $\Delta\phi(\not{E}_T, \text{jet})$: 1.0 rad
- t_{min}: 2.0 ns

Expected Background: 1.3 ± 0.7

(SM 0.7 ± 0.6; Cosmics 0.5 ± 0.3; BH 0.1 ± 0.1)

Dominant systematics:

- mean and RMS of the collision time distribution (7%)
- ID efficiency (5%)
- stat. uncertainty on the fit of the time shapes (determined by the fit)

⇒ open the box with these cuts

Example point: $m_\chi = 100$ GeV and $\tau_\chi = 5$ ns

- Acceptance: 6.3%±0.6%
- $\sigma^{exp} = 0.128$ pb
- $\sigma_{prod} = 0.162$ pb

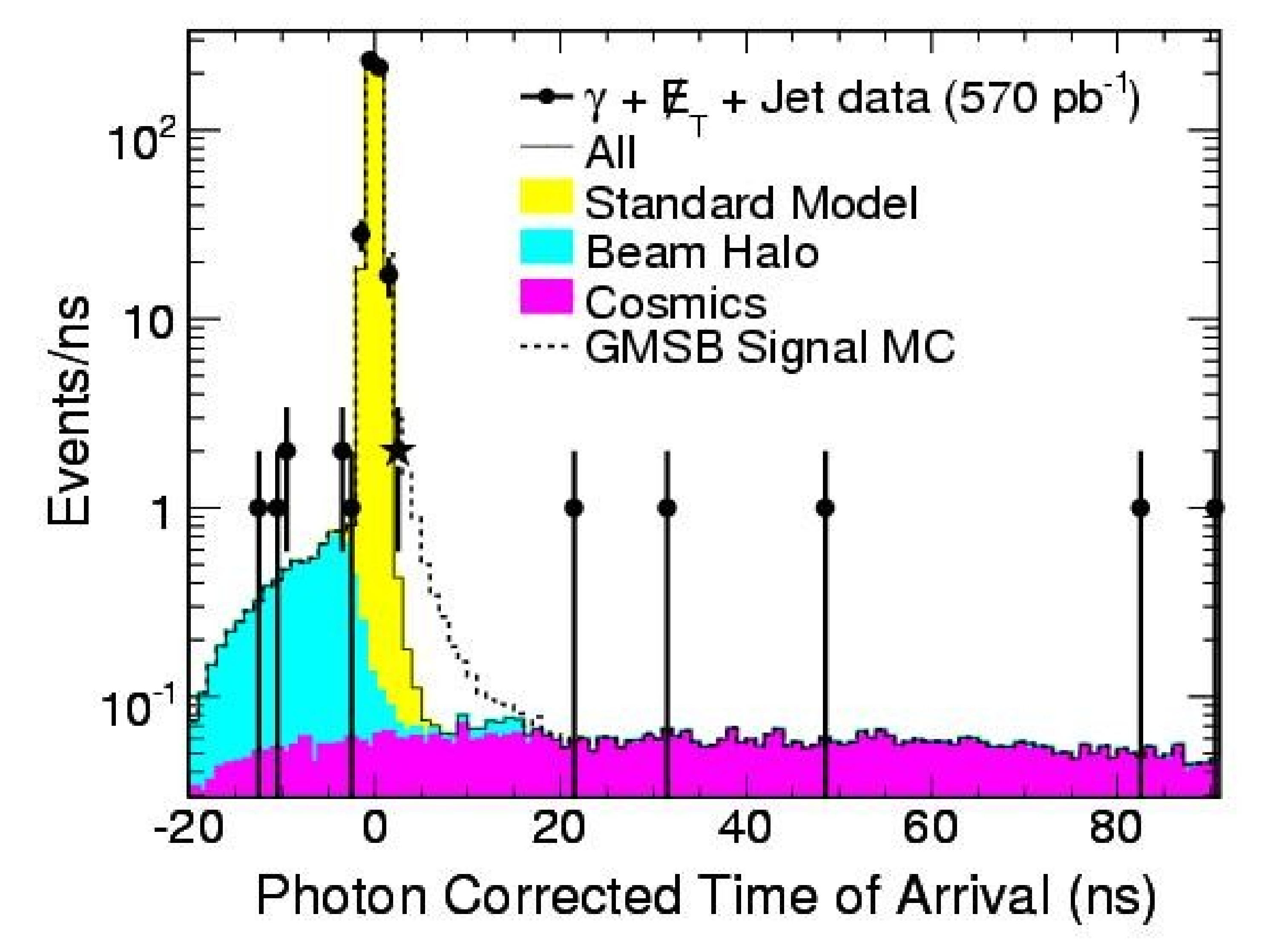
⇒ we are sensitive to this GMSB point

Results and Limits

Overview

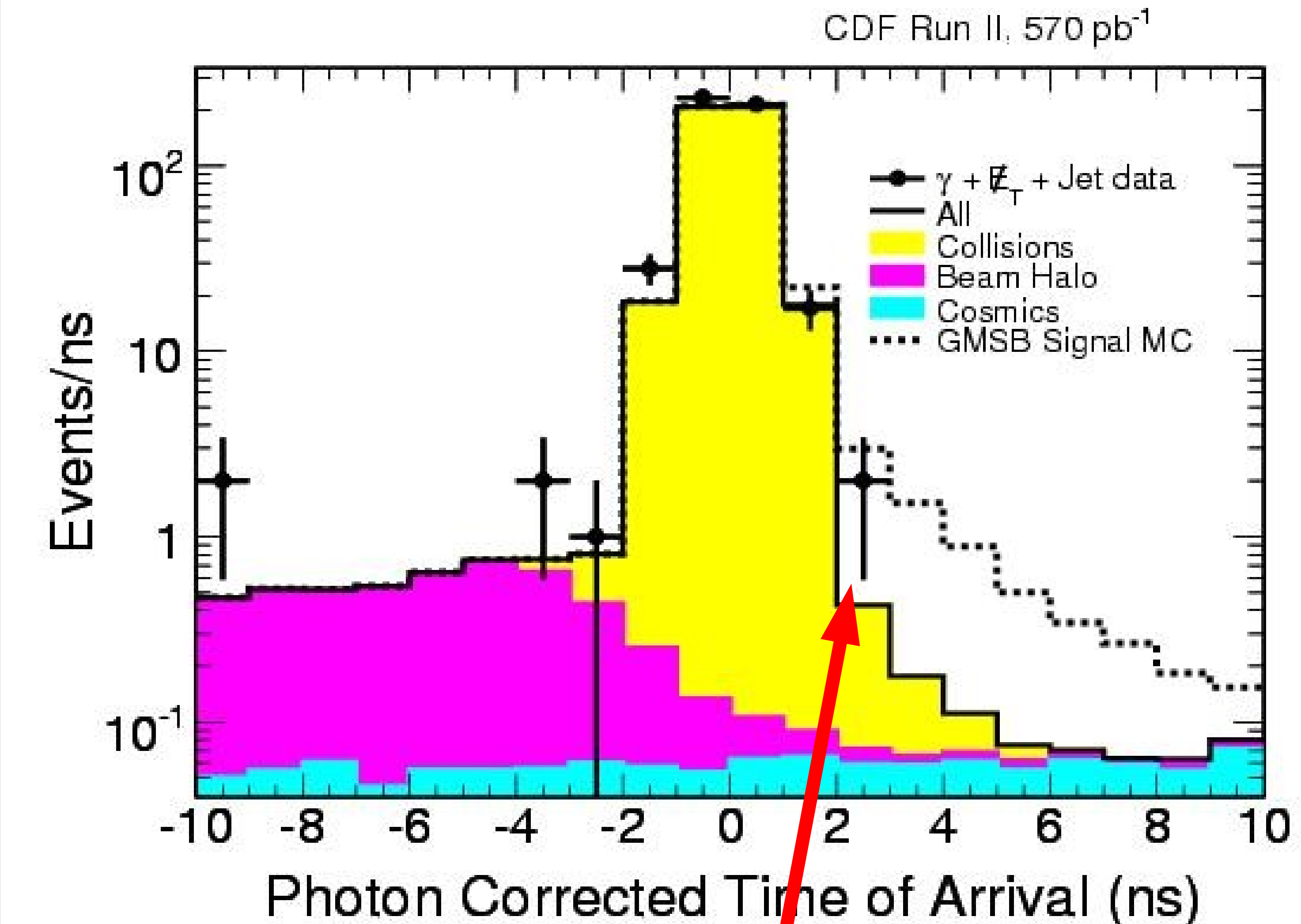
- Unblind the signal region
- Parametrize the acceptance for a model-independent description
- Set cross section limits an set exclusion region

Unblinding the Signal Region – Overview



The predicted shapes for the total time window

The Data



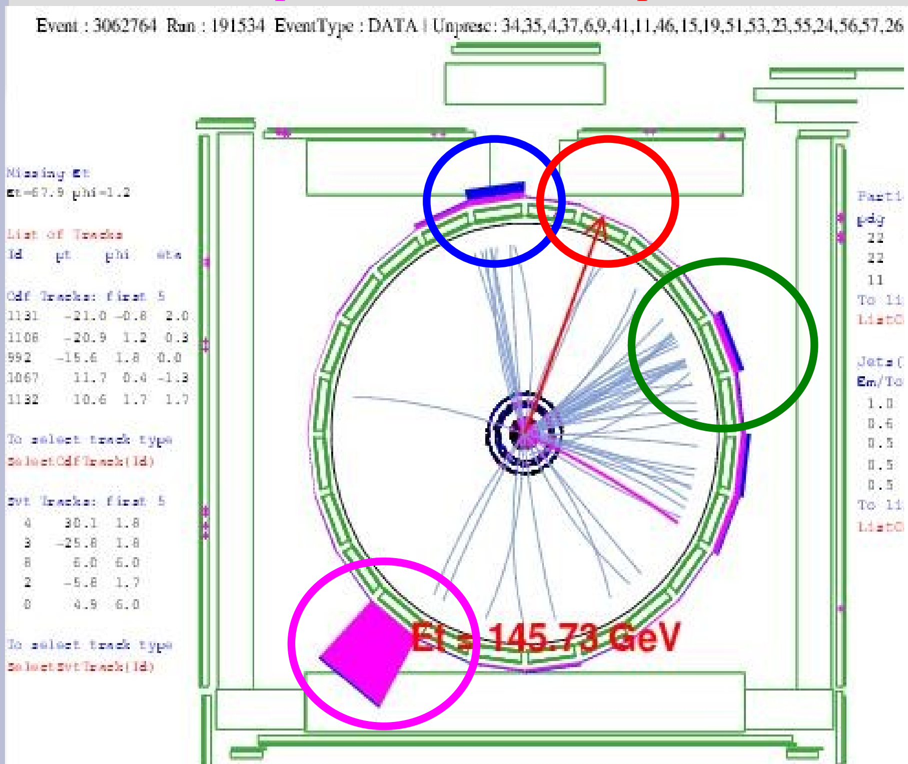
We observe 2 events in the signal region (predicted 1.3±0.7)

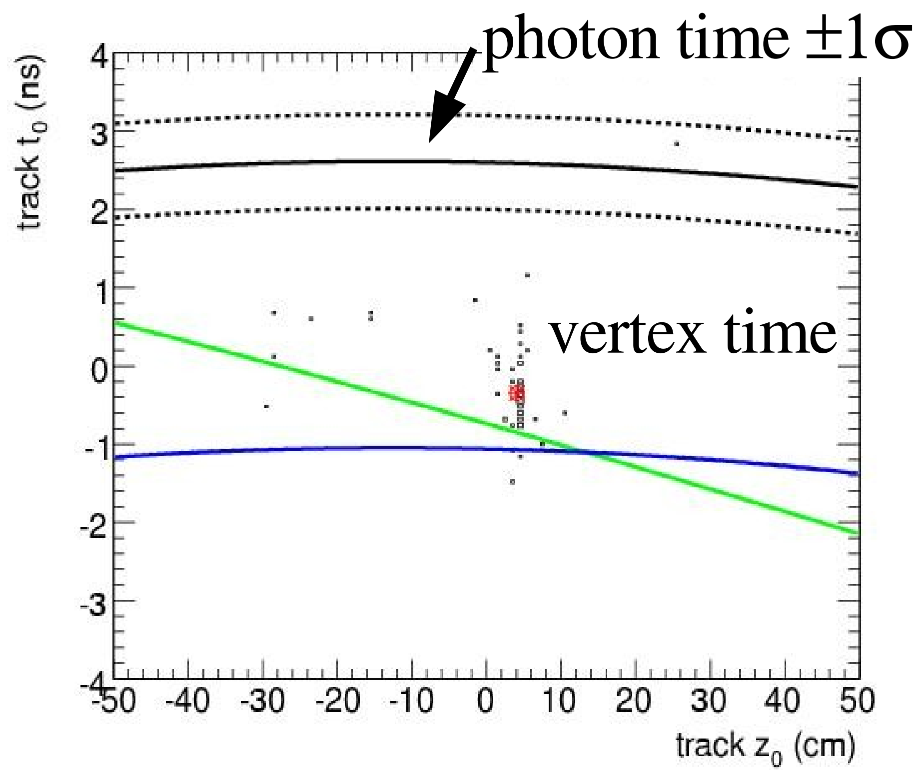
What are those 2 events?

Both look like collision events:

Event 191534, 3062764

photon E_T = 135 GeV, $\not\!\!E_T$ = 68 GeV, jet1 E_T = 125 GeV, jet2 E_T = 61 GeV





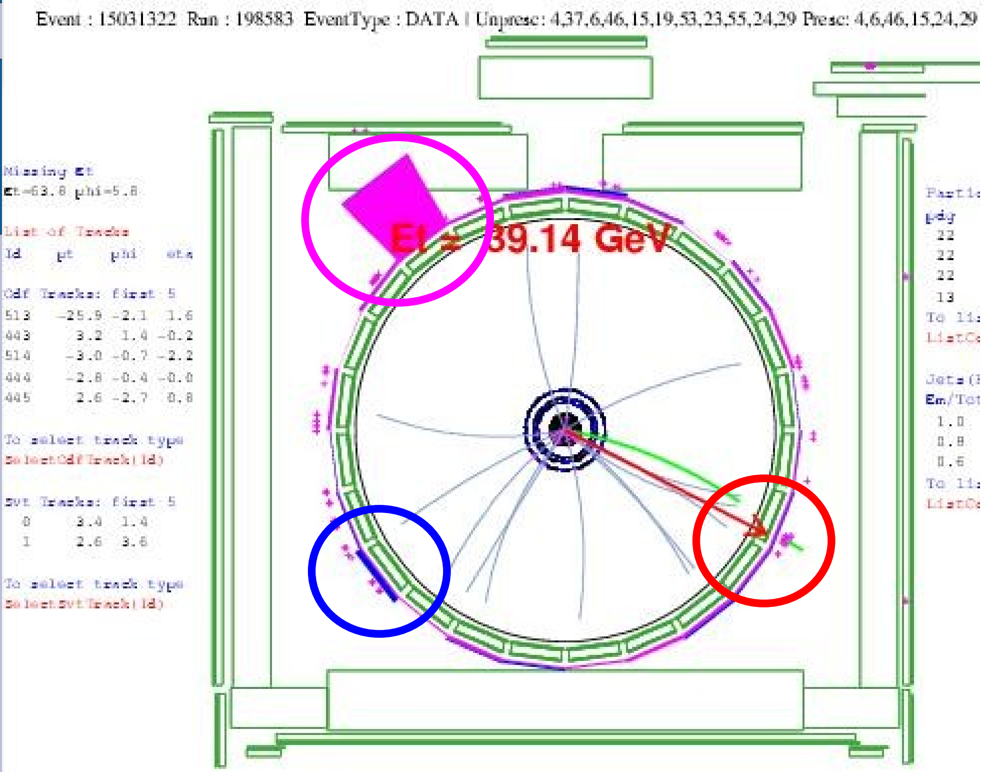
⇒ looks like a QCD event where both $\not\!\!E_T$ and photon time are mis-measured by a combined deviation of 5.6σ.

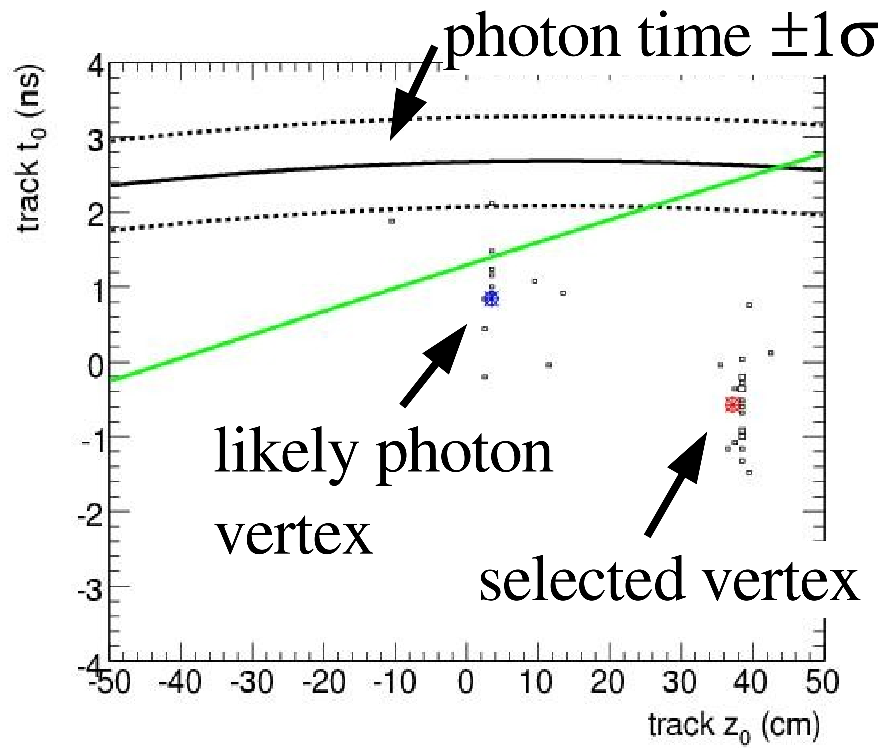
What are those 2 events?

Event 198583, 15031322

photon E_T = 38 GeV, $\not{E}_T$ = 64 GeV, jet E_T = 43 GeV

inv. mass of photon and $\not{E}_T$ is 102 GeV/c^2





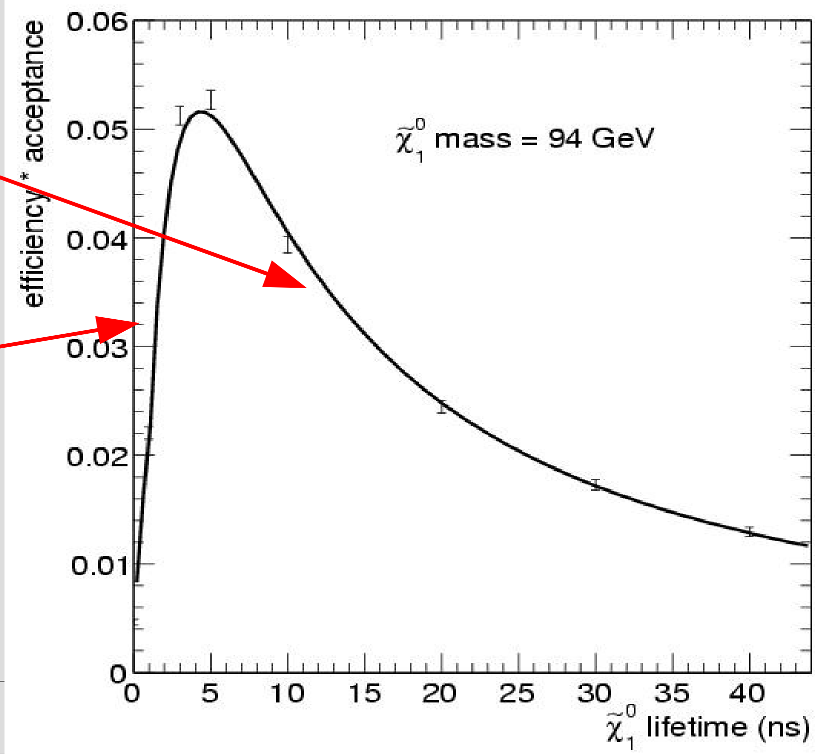
⇒ W→eν+jet event where the electron brem'd early in the tracking chambers and where the wrong vertex has been selected.

Acceptance Parametrization

A parametrization of the acceptance allows for a comparison to the production cross sections from any model that predicts long-lived particles with $\gamma+\not{E}_T$+jet final states

The fit function implements the dominant effects:

- the probability that at least one $\tilde{\chi}_1^0$ decays in the detector (goes down with higher $\tilde{\chi}_1^0$ lifetime)
- the photon arrival time lies in the signal time window (goes up with higher $\tilde{\chi}_1^0$ lifetime)

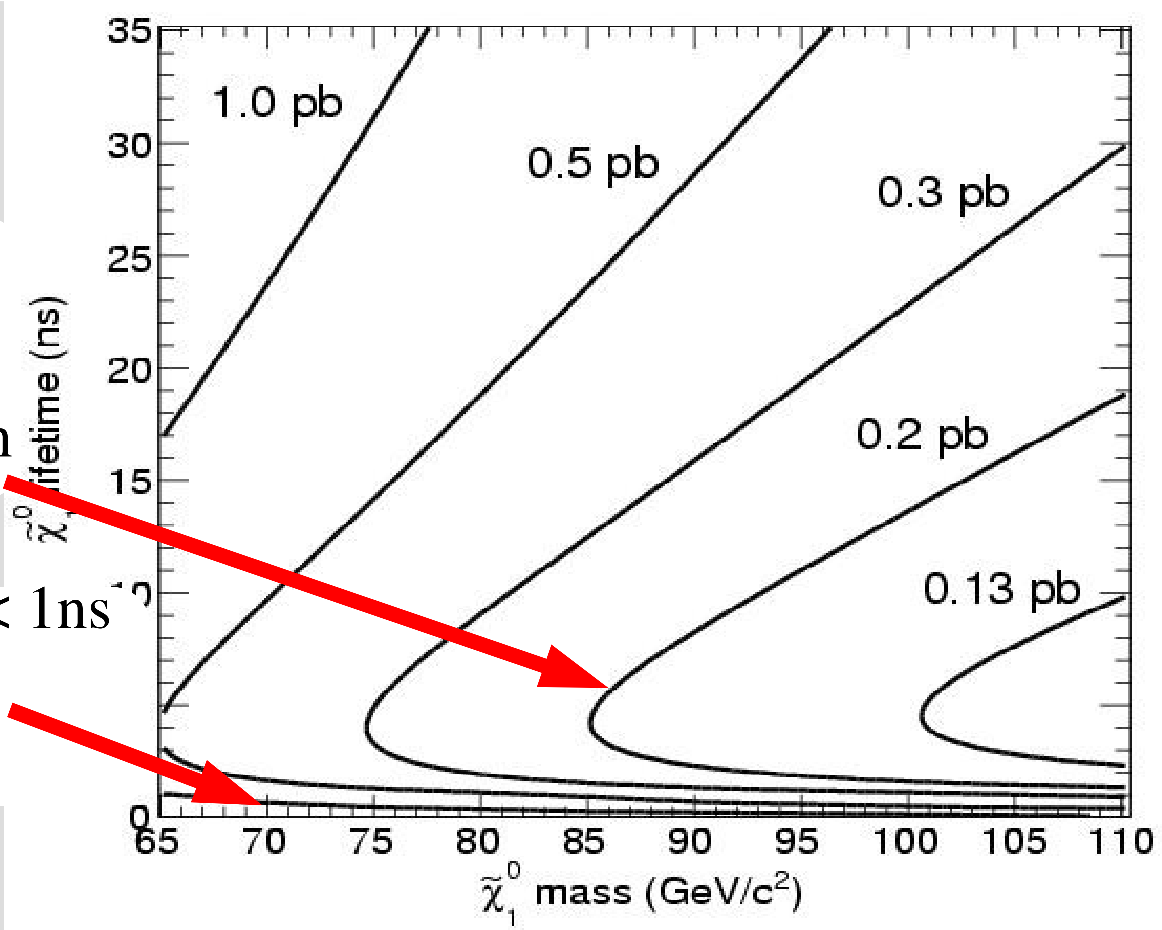


Observed Cross Section Limits in 2-D

What is our sensitivity in the GMSB parameter space?

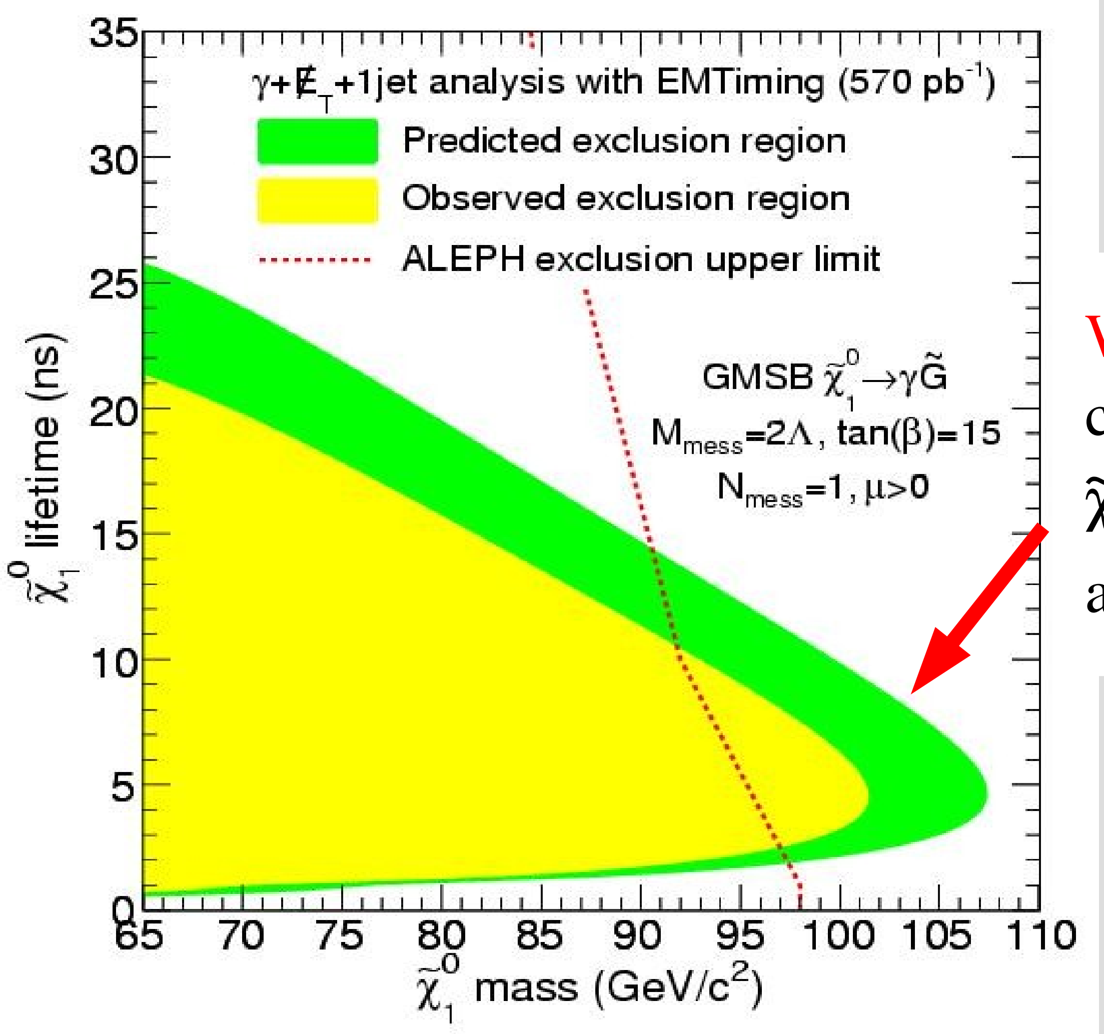
Highest sensitivity at
high mass & lifetime ~5ns
BUT low prod cross section

No sensitivity at lifetime < 1ns
BUT $\gamma\gamma+\not{E}_T$ analyses are
sensitive there



I am working with the new grad student E. Lee to get the limits for the next generation analysis...

Exclusion Region



World best observed cross section limit on the $\tilde{\chi}_1^0$ mass of 101 GeV at a lifetime of 5ns

Conclusion

I have presented the first search for heavy long lived particles decaying to photons at a hadron collider

- First result using the newly installed EMTiming system (640ps resolution)
- Background predictions are entirely from data
- Final cuts are chosen to be most sensitive to the GMSB model
- We observe 2 events which is consistent with the background estimate of 1.3 ± 0.7
- With 570 pb^{-1} we set the world-best exclusion limits beyond the final LEP limits on GMSB models and exclude all models that produce more than 5.5 events
- Just submitted to PRL (FNAL PUB-07-075-E)

BACKUP

Gravitino Dark Matter

- All SUSY particles decay to the $\tilde{G}$ but they are too weakly interacting to annihilate
- Light (~eV) $\tilde{G}$ can destroy nuclei produced during Big Bang Nucleosynthesis and can alter the structure formation of the universe in contrast to cosmic microwave background observations

Solution:

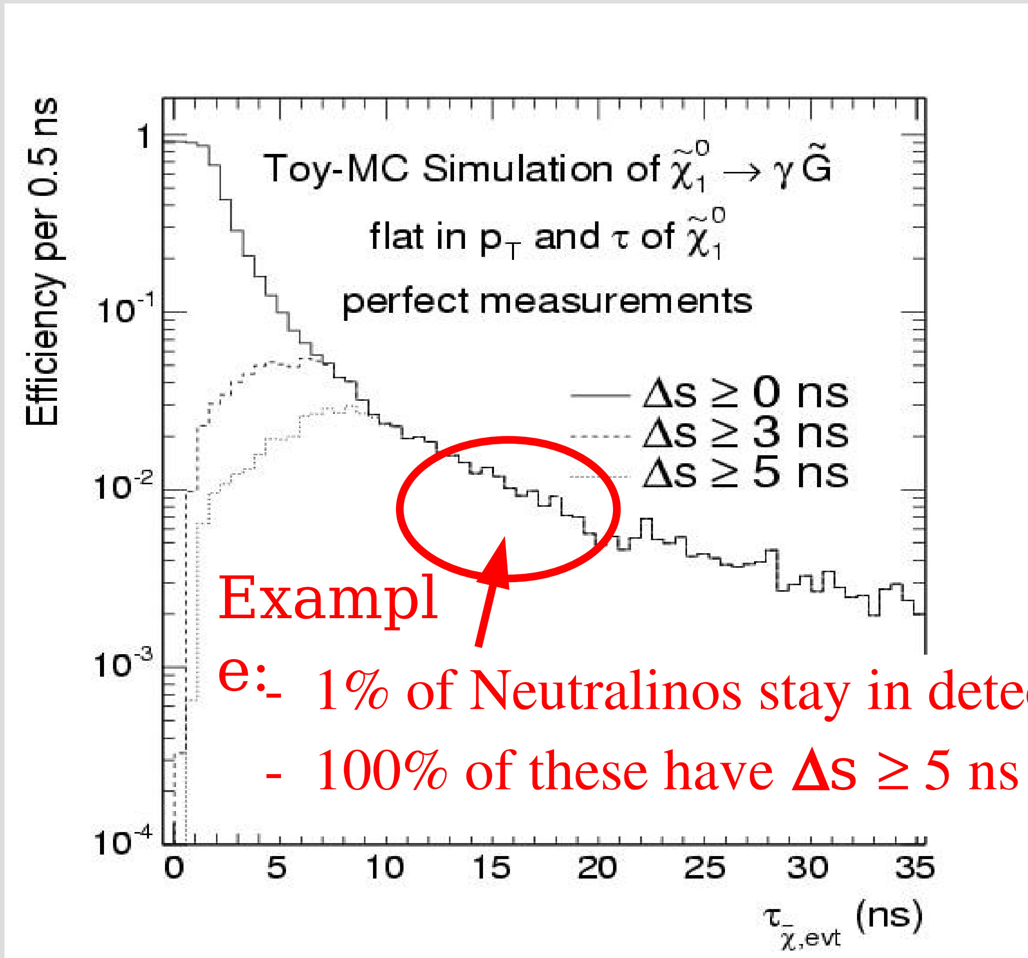
1. $\tilde{G}$ mass is ~GeV $\rightarrow$ it is a Cold Dark Matter candidate as in SUGRA models
2. $\tilde{G}$ is ~1 keV $\rightarrow$ it is a Warm Dark Matter candidate that is favored to explain clustering on sub-galactic scales
3. Axino is Warm Dark Matter candidate

In our searches the $\tilde{G}$ mass is ~0.5-1 keV

Selection of Long-lived Particles

Long lifetime ⇔ Long time delay relative to collision (Δs)

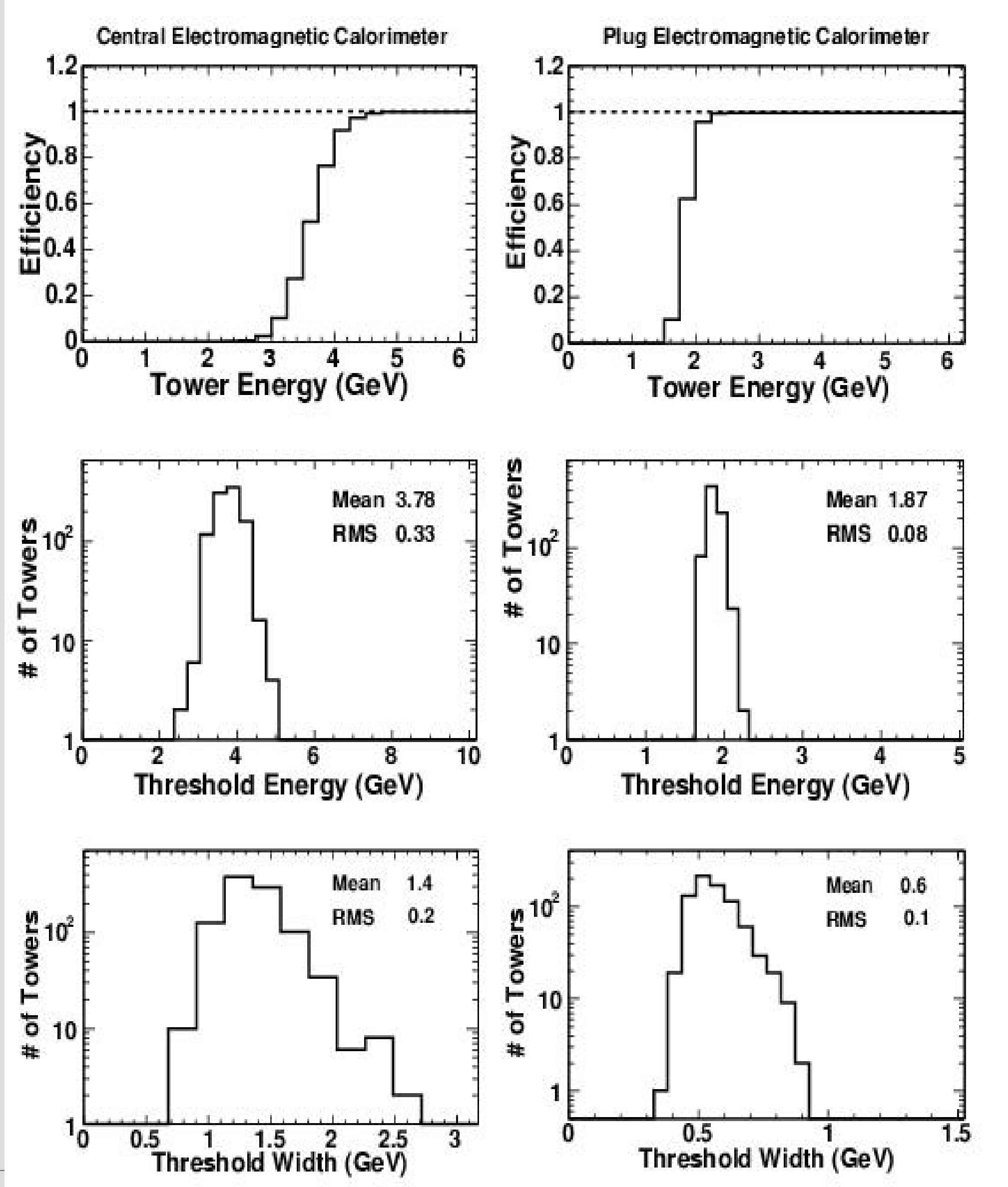
Phys. Rev. **D**70, 114032



Exampl
e:
- 1% of Neutralinos stay in detector
- 100% of these have **Δs** ≥ 5 ns

EMTiming Performance

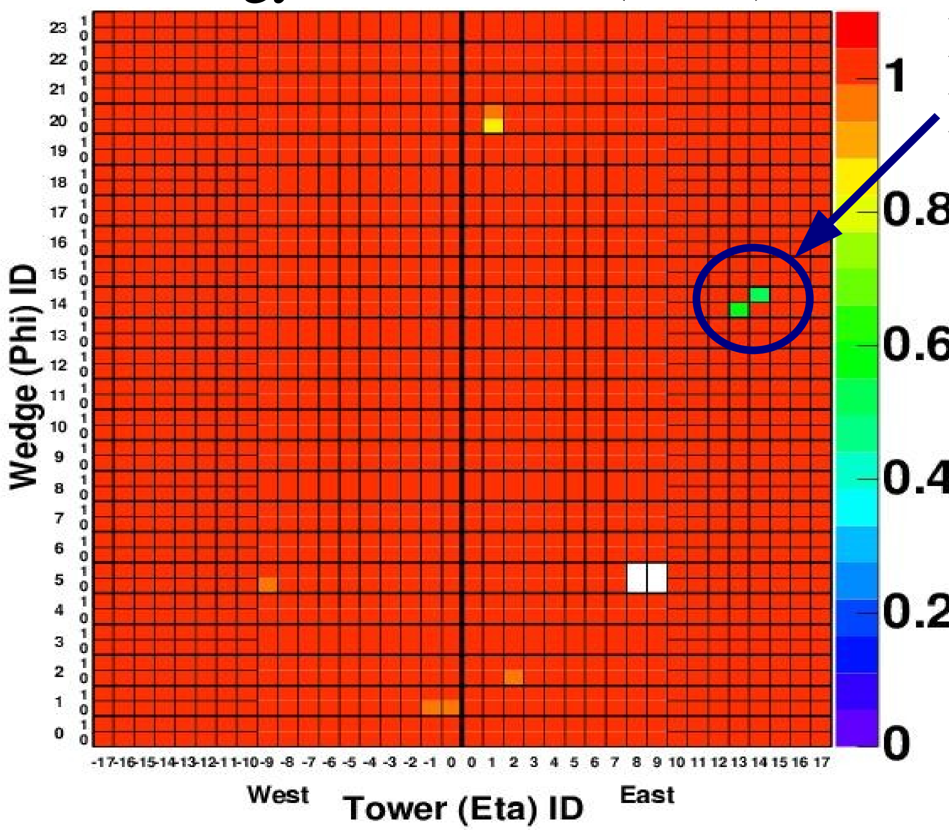
- Coverage: |η| < 2.1
- Energy threshold:
  2-5 GeV per tower
- There is one time measurement for each tower (each tower comprises two PMTs for the energy measurement)



EMTiming Performance

- Online Monitoring using ObjectMon
- The few pathologies are easily captured
- During the data taking period of this analysis 1 channel was marked bad!

Events with time recorded / all events
with tower energy > 6.25 GeV (CEM) or > 3 GeV (PEM)

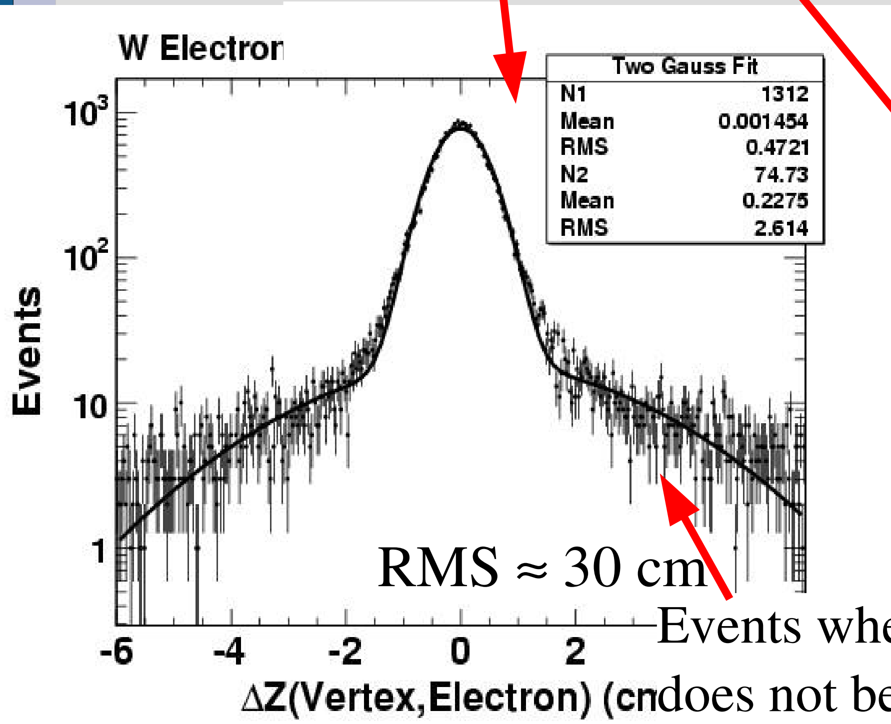


Example run with a LEMO cable swap

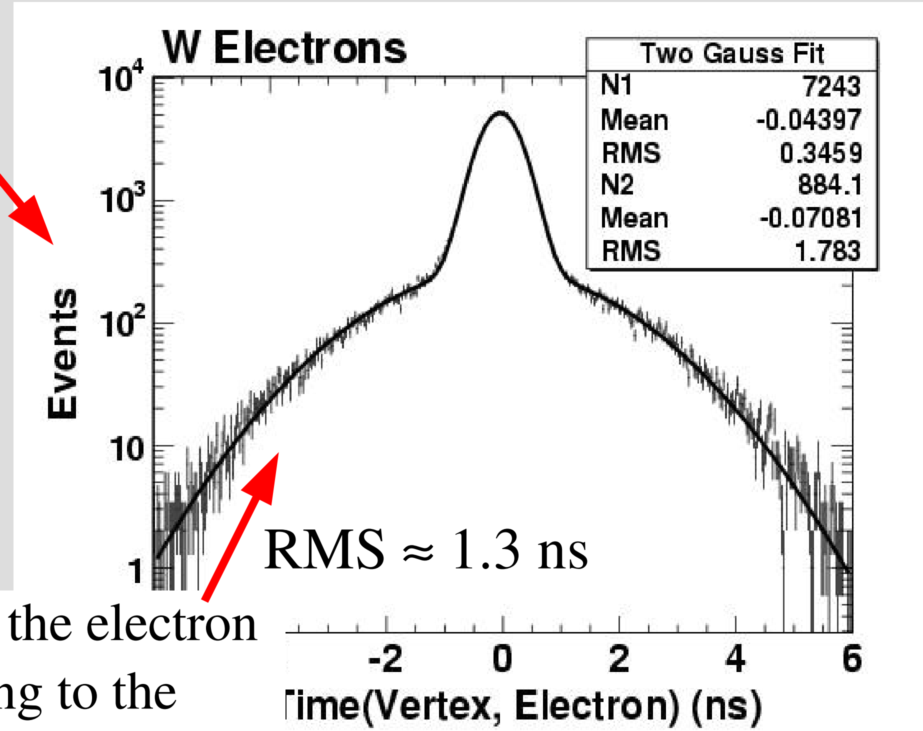
Vertexing – Make Sure It Works!

Need to check:

✔ No bias in position or time



RMS ≈ 30 cm



RMS ≈ 1.3 ns

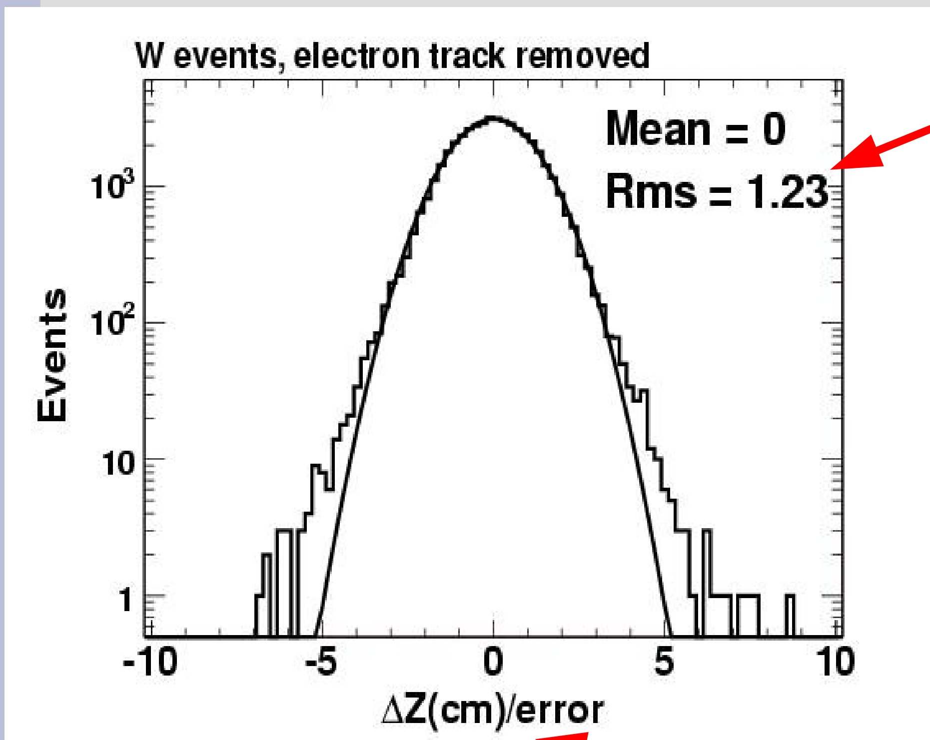
Events where the electron does not belong to the reconstr. vertex

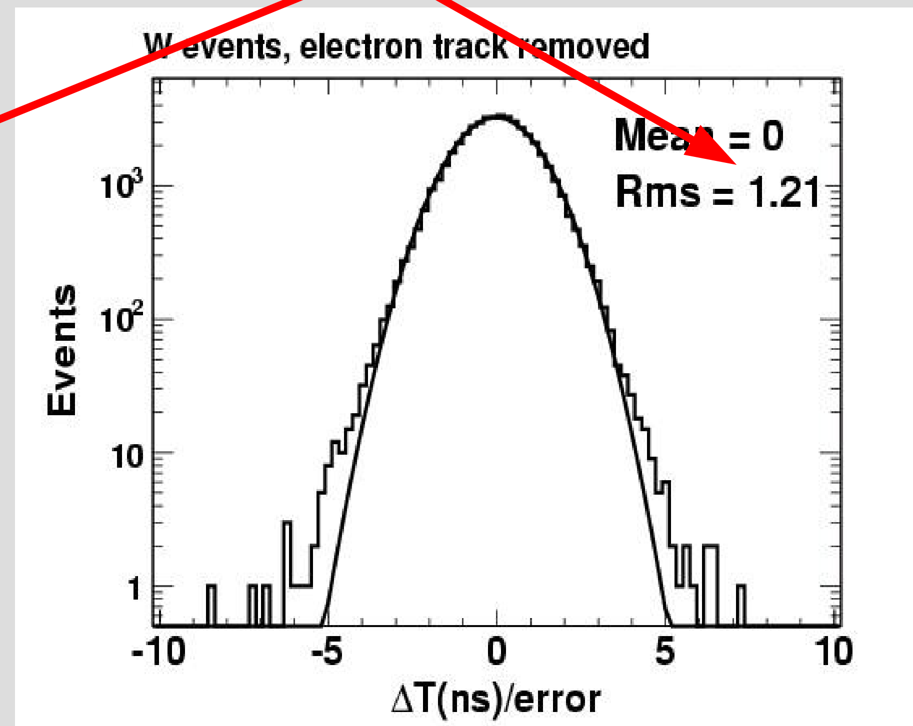
Method: Plot the difference of the position and time of the vertex (reconstr. w/o the electron track) with the position and time of the electron track

Vertexing – Make Sure It Works!

Need to check:

✔ Each vertex estimates its own size correctly (to ~20%)

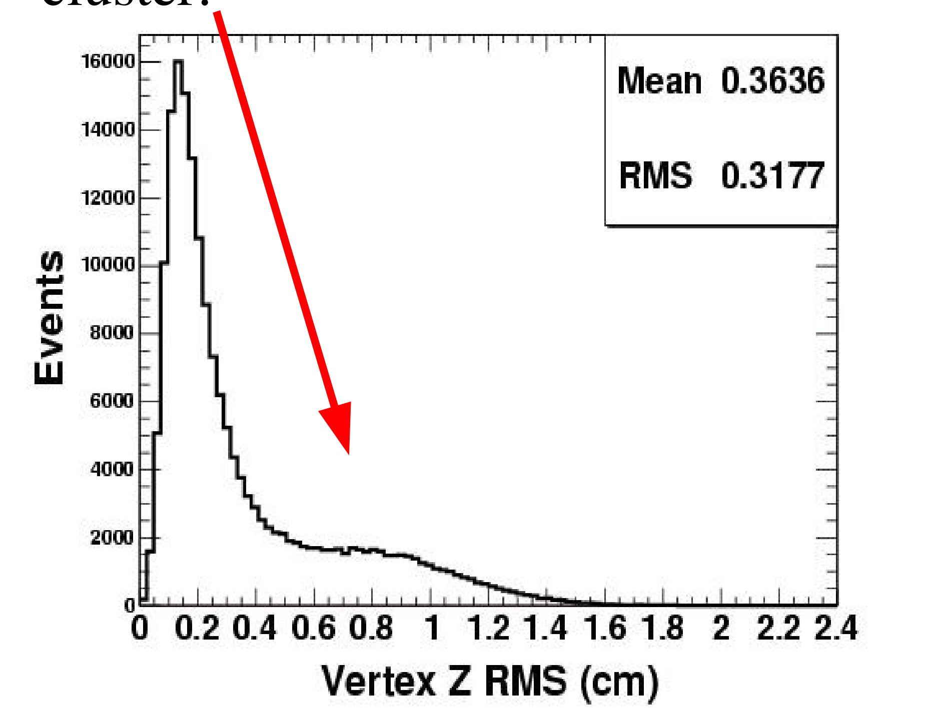




Method: Plot the difference of the position and time of two subsets of tracks from a known vertex divided by the vertex width from the algorithm

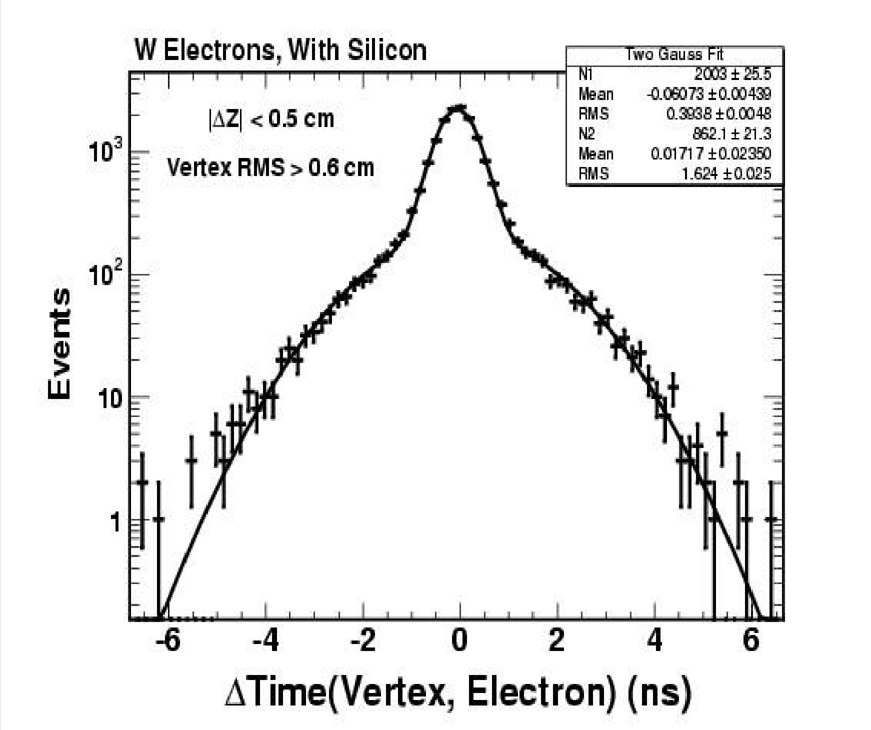
Vertexing – Make Sure It Works!

There are cases where two vertices close in space are reconstructed in one cluster:



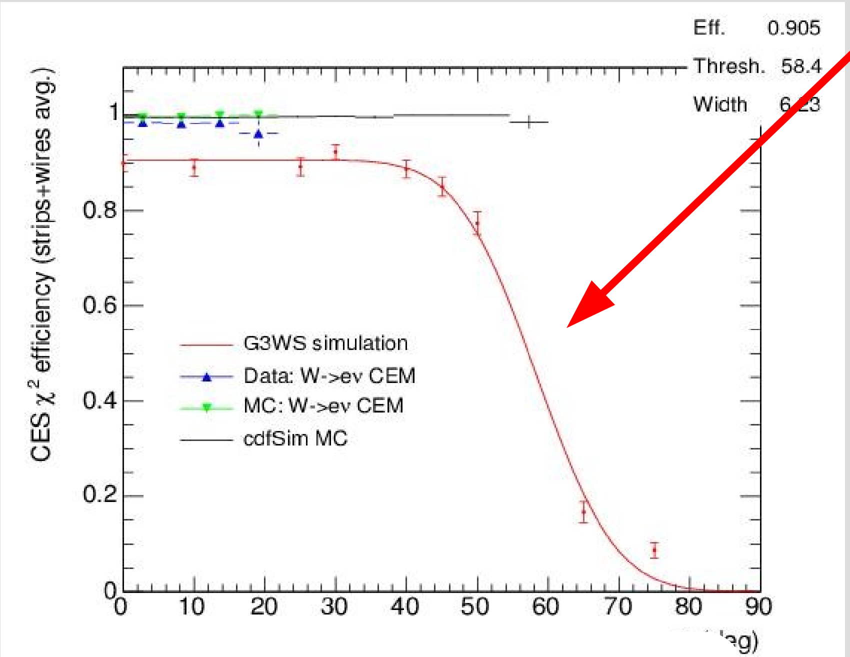
→ Need to check their time distribution:

✔ Looks the same as for the normal cases

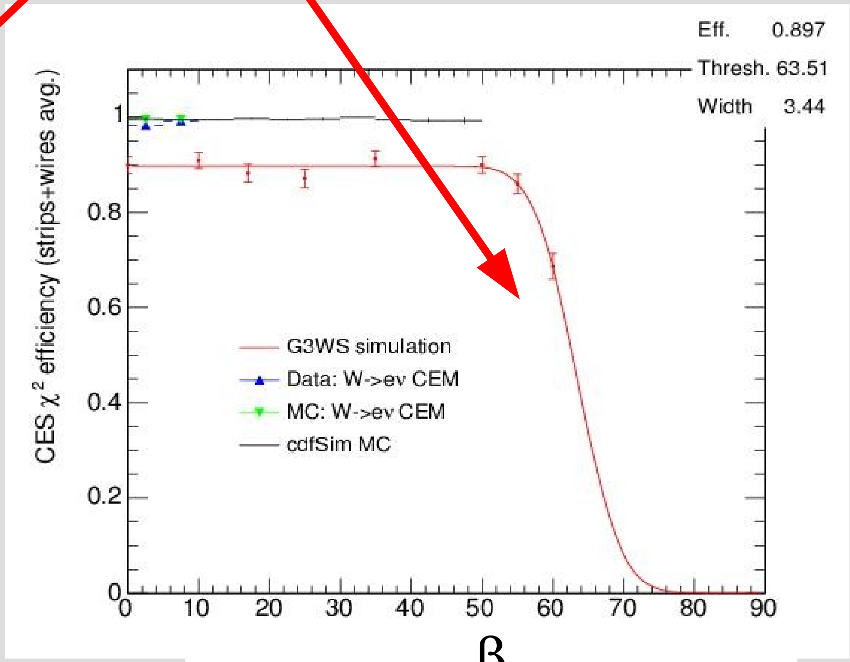


Sidenote: Efficiency of Shower Shape Requirement

- Requirement: transverse shower shape has to match the shape expected from a photon from the beamline
- The efficiency drops sharply for $\alpha > 40^o$ or $\beta > 50^o$



α



β

⇒ Drop this requirement!

Background Prediction Methods

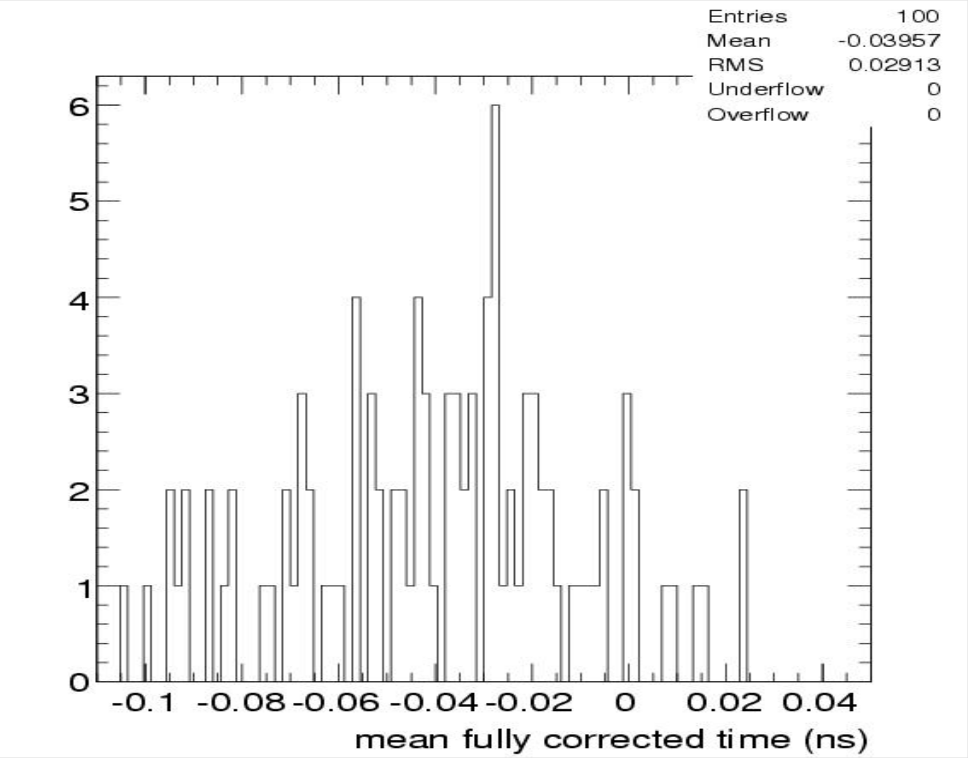
We fit for the normalization of both classes of backgrounds as follows:

1) Scale non-collision time shapes to match events in [-20, -6] ns (BH dominated) and [25, 90] ns (cosmics dominated) windows simultaneously
2) Use the result to predict non-collision events between [-10, 10] ns
3) Fit the data in [-10, 1.2] ns window (collision dominated) to right and wrong vertex shapes using the known BH and cosmics shapes.

After that we have a prediction of the total background from the SM and non-collision photon candidates into the time region [1.2,10].

Systematic Error on Collision Bkgs.

While the system is well calibrated for an inclusive data sample the mean time may be off for subsamples:



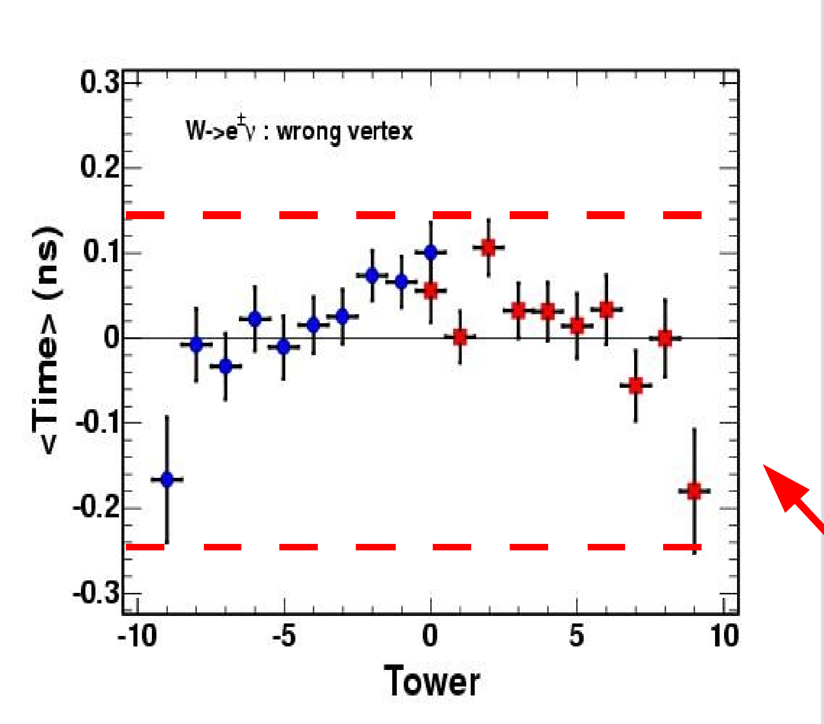
- ⇒ assign a conservative systematic error on the mean of 0.2 ns
- This is the main source of systematic uncertainties

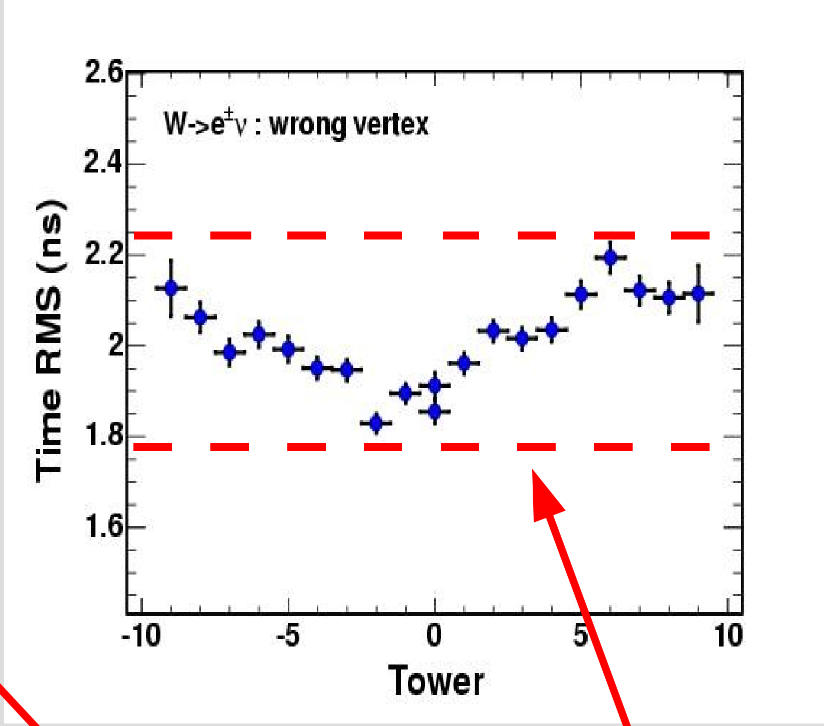
Systematic Error on Collision Bkgs.

If we select the wrong vertex then we apply to the time corrections

(a) the wrong vertex t_0 ⇒ larger time distribution RMS (constant ~1.3 ns)

(b) the wrong TOF correction – both its mean and its RMS depend on the calorimeter tower position of the measured photon/electron:



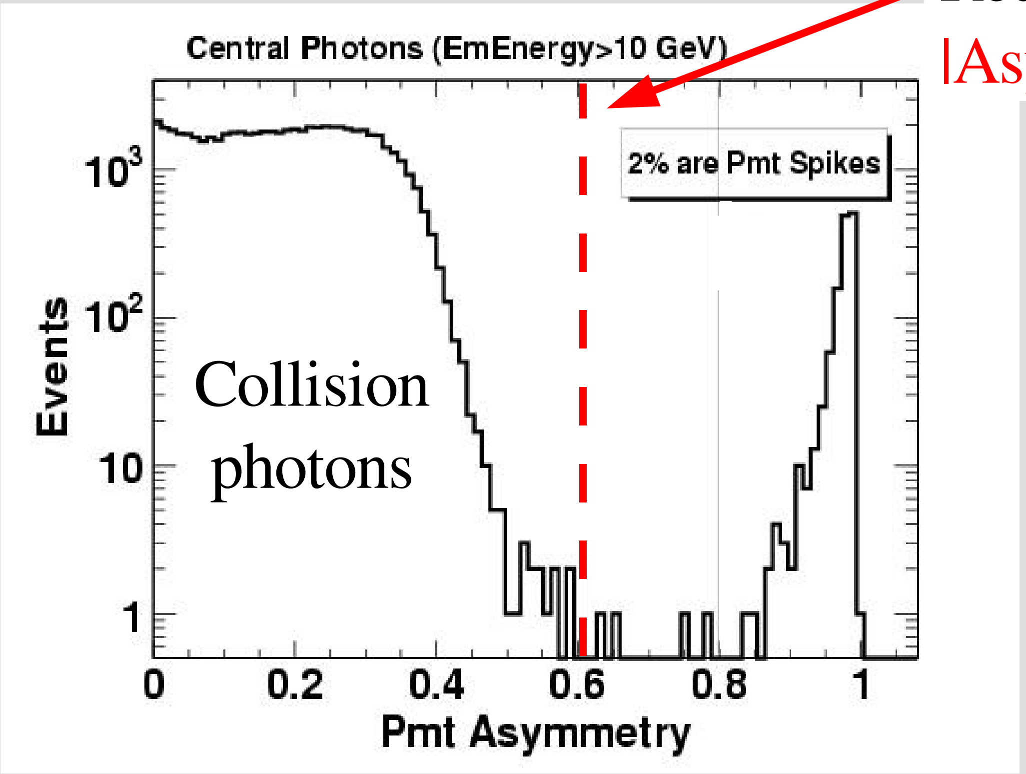


⇒ assign a systematic error of 0.33 ns on mean and 0.28 ns on RMS

Sidenote "PMT spikes"

- The central EM calorimeter has two PMTs per tower that collect light from the scintillators
- In a small fraction of events one of the PMTs can experience a high voltage discharge (spike) which fakes energy deposited
- These events have a strong PMT asymmetry:

Require |Asymmetry| < 0.6



Summary: Systematic Uncertainties

- Signal Acceptance: ~8% with major contributions from
  - uncertainty on the mean and RMS of the time distribution (7%)
  - ID efficiency (5%)
  - minor contributions from PDFs, jet energy scale/resolution, ISR/FSR,...
- Production cross section (theory): ~6%
- Luminosity measurement: 6%
- Background:
  - Non-collision errors are statistically dominated and are determined by the fit
  - SM background statistical errors are determined by the fit. Systematic errors mostly from the uncertainty on the time distribution

Standard Photon Identification

We require a photon with E_T>30 GeV in the central (|η|<1.0) calorimeter part where the EMTiming system is fully understood and many ID variables are available

Goal: Separation of real photons from

- $\pi^0 \rightarrow \gamma\gamma$ conversions
- jets
- electrons
- Non-collision particles (see later!)

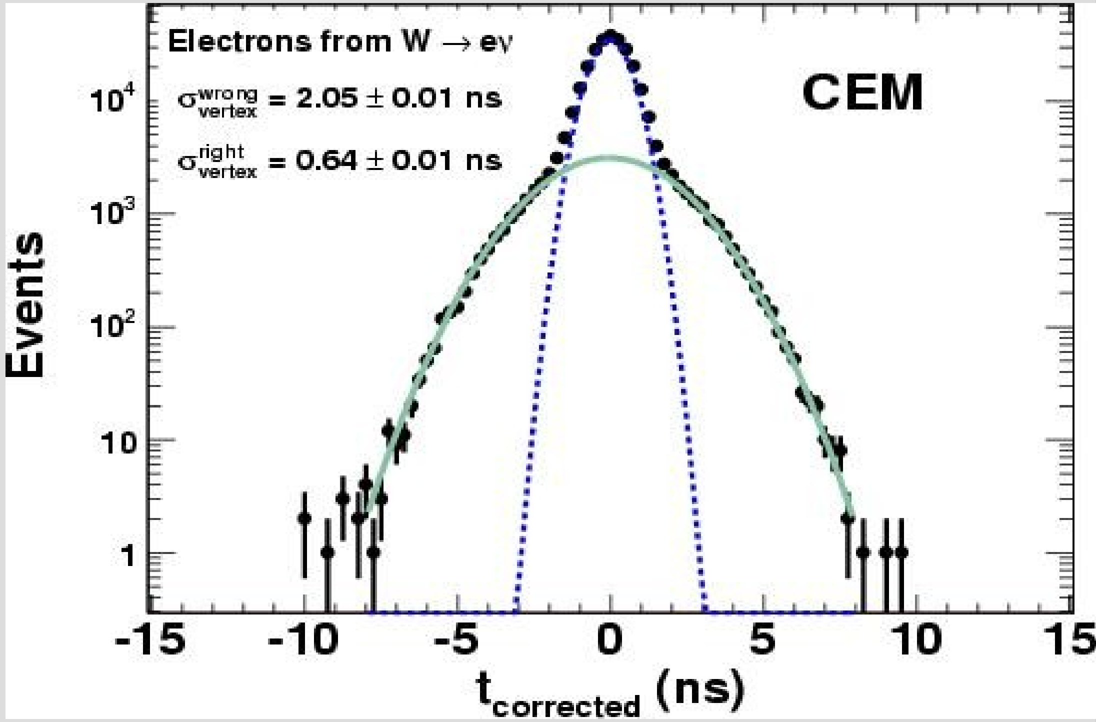
- Small Fraction of hadronic energy
- Small transverse energy spread in the calorimeter (Cal. Isolation)
- Little track activity around photon (Track Isolation)
- Only one high-energy shower close to the photon
- Shower shape consistent with coming from one photon

Background Prediction

We want to estimate the contributions of collision and non-collision backgrounds to the signal time window → use different approaches:

Collision Bkg:

- parametrize the time distribution for right and wrong vertex selections separately using $W \to e\nu$ (keep the mean fixed at 0ns)
- vary the normalization and the fraction of wrong vertex events in the fit to the final data sample



Non-Collision Bkg:

- fit for the normalization directly from the shape templates obtained from the no-vertex samples

Efficiencies

- Number of GMSB Signal events after the baseline event selection cuts for an example GMSB point:

Total Events: 120000

Central photon,

MET > 30 GeV & $E_T(\gamma)$> 30: 64303

Photon fiducial & ID cuts: 46730

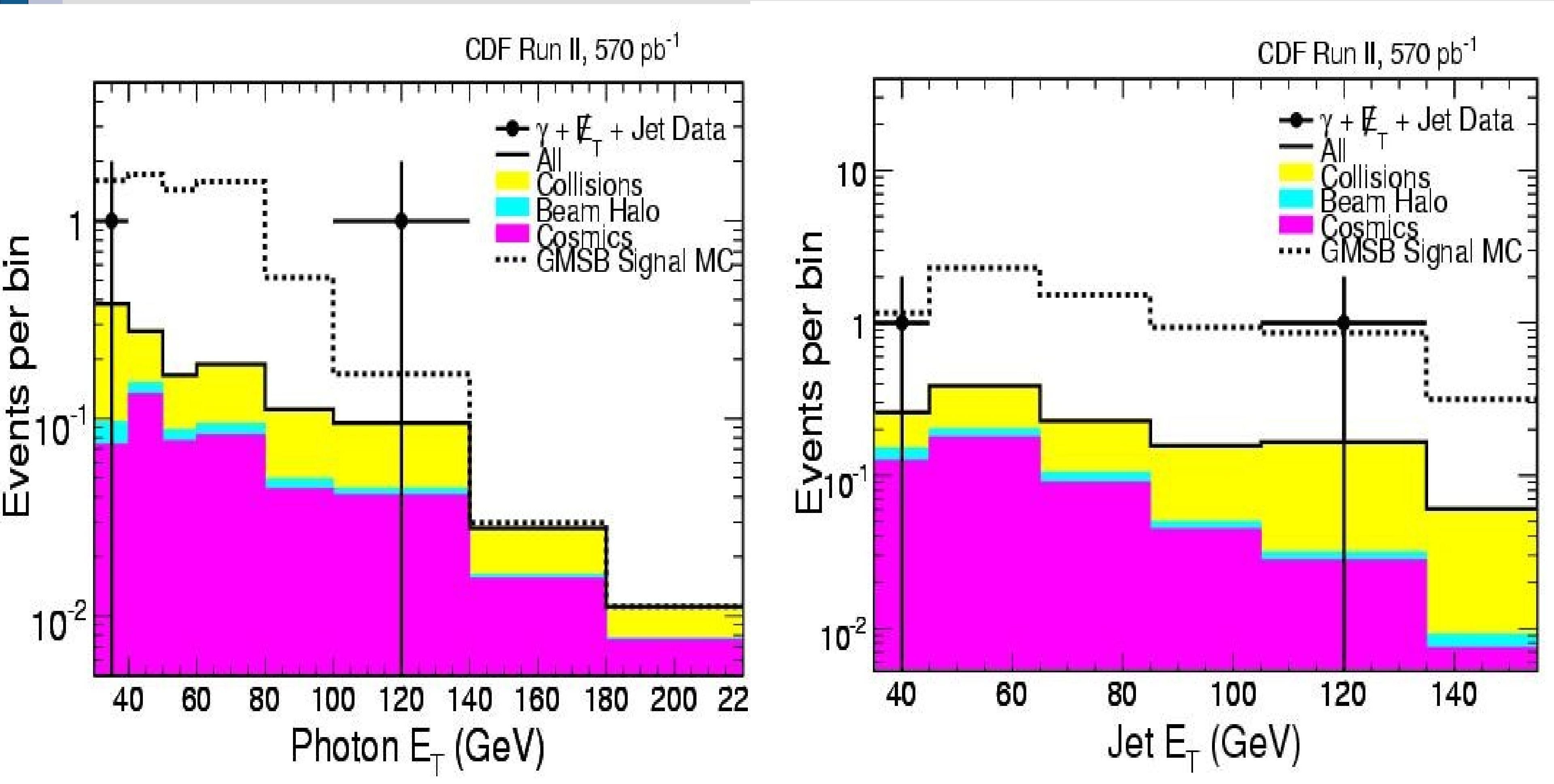
Good vertex: 42779

≥1 jet with E_T > 30 GeV and $|\eta|<2.0$: 38971

Muon co-stub cut: 38971 x 98.2%

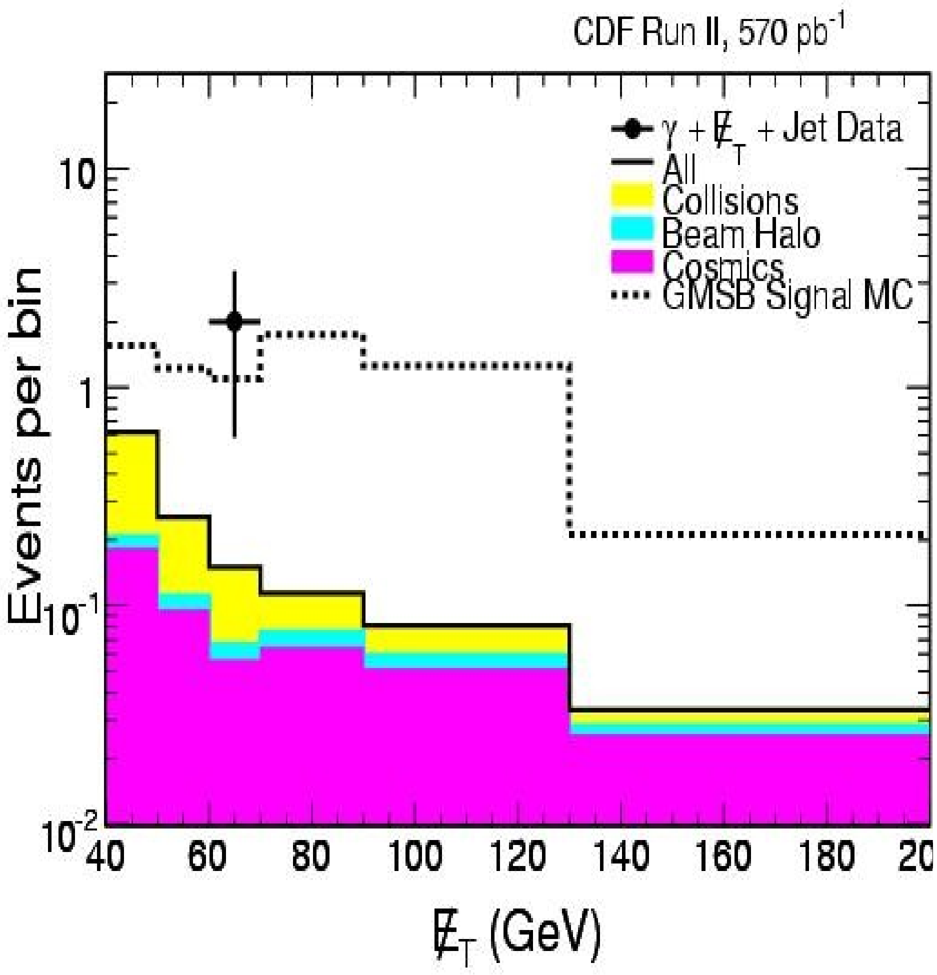
Comparison of Signal and Bkg

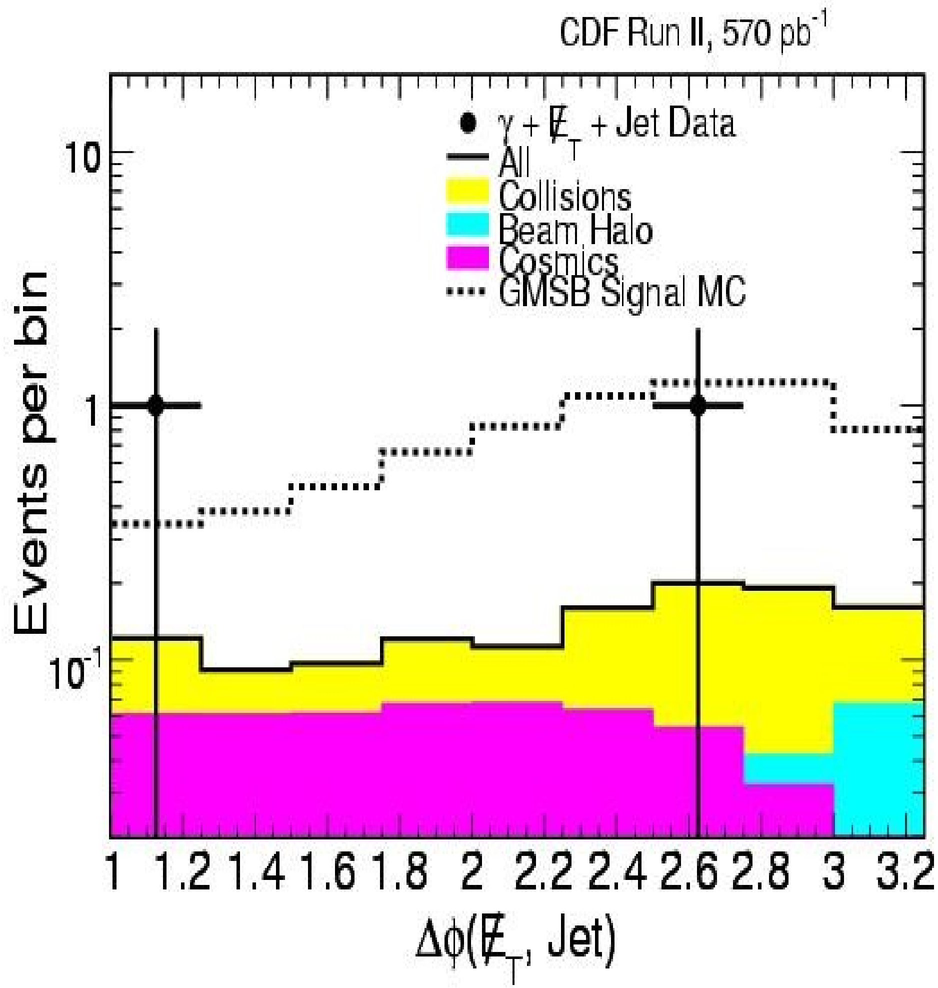
Data matches the background expectations well – no hint at GMSB



Comparison of Signal and Bkg

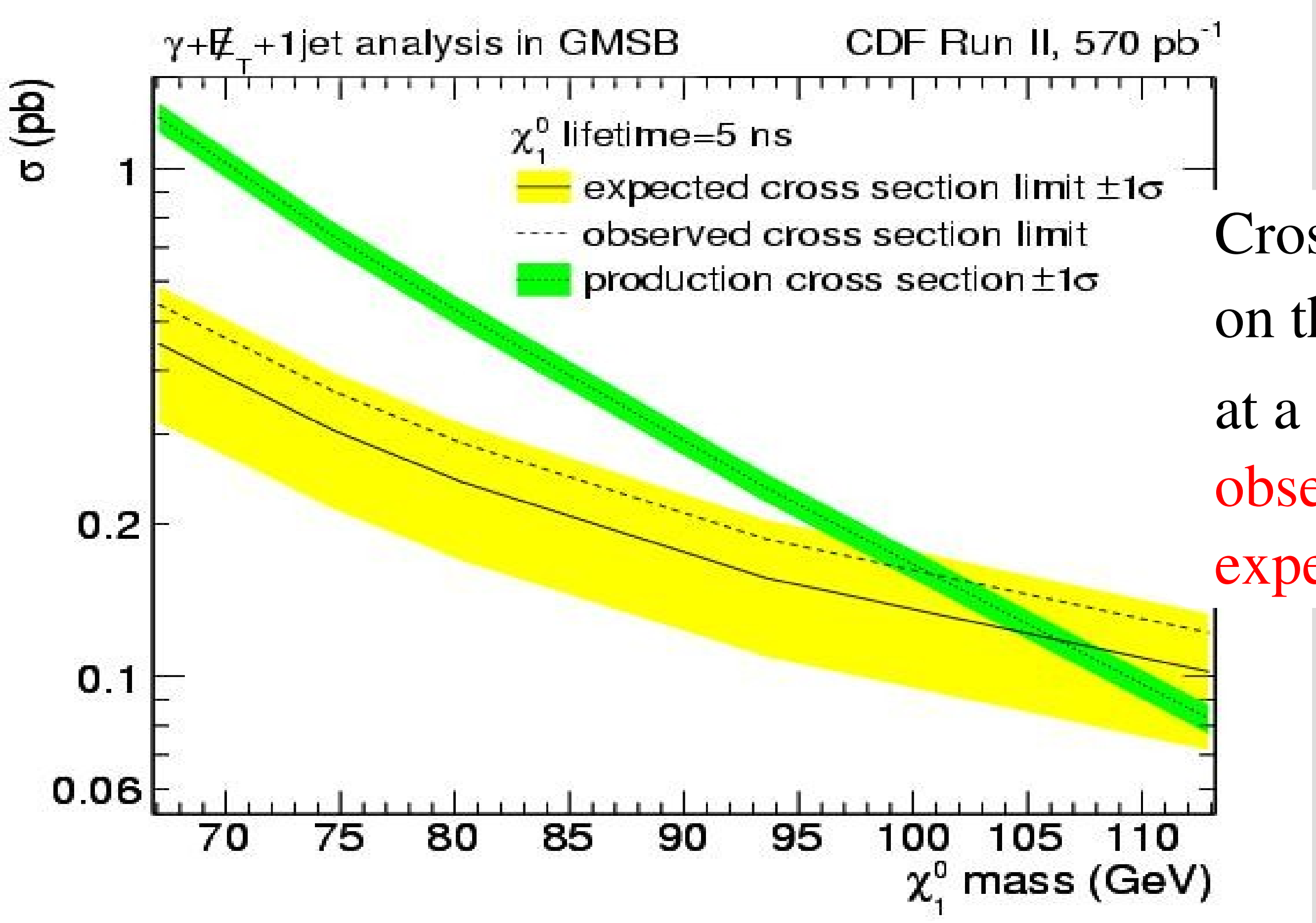
Data matches the background expectations well – no hint at GMSB





Cross Section Limits vs. Mass

Can set limits with the fixed set of cuts:

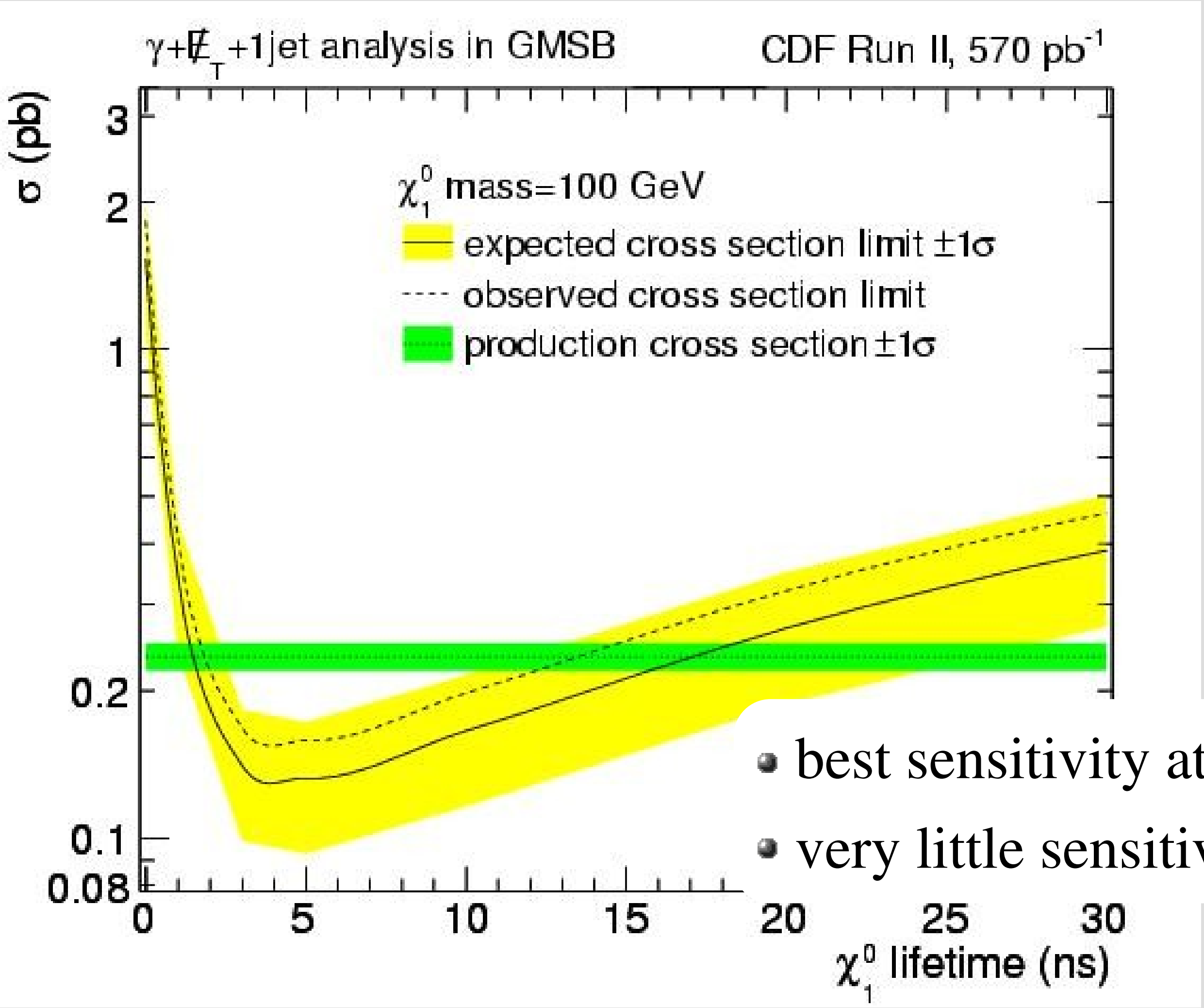


Cross section limits on the $\tilde{\chi}_1^0$ mass at a lifetime of 5ns:

observed: 101 GeV

expected: 106 GeV

Cross Section Limits vs. Lifetime



- best sensitivity at a $\tilde{\chi}_1^0$ lifetime of 5ns
- very little sensitivity at low lifetimes

Main GMSB Production Channels

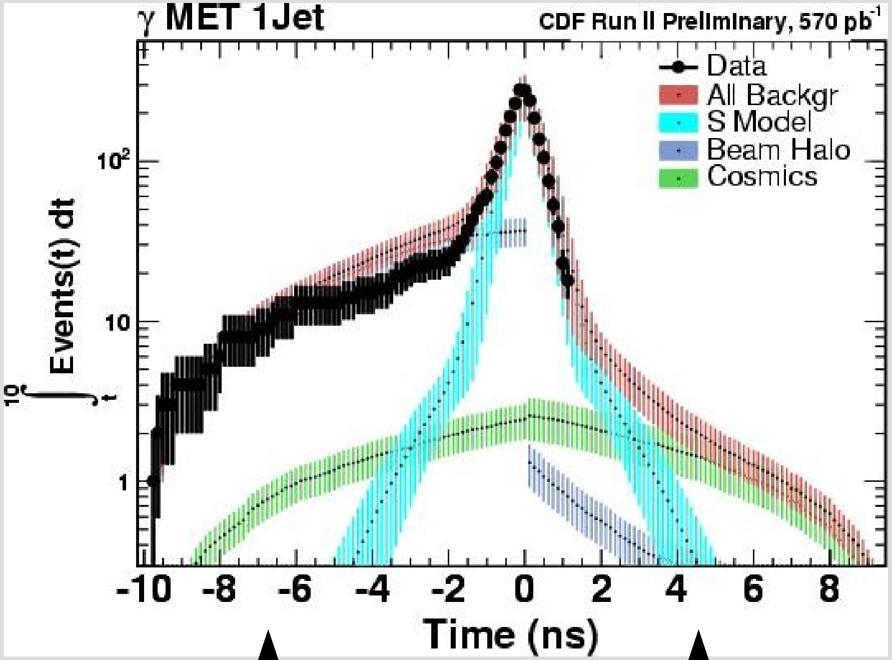
$m_{Neutralino}$ = 100 GeV and $\tau_{Neutralino}$ = 5 ns

Production channel:	σ (0.1 pb)	Fraction of total
q + qbar' -> ~chi2 + ~chi+-1	8.3898	43.0%
f+fbar -> ~chi+-1 + ~chi-+1	4.8677	25.0%
f+fbar -> ~tau_1 + ~tau_1bar	1.6833	8.6%
f + fbar -> ~e_R + ~e_Rbar	1.3435	6.9%
f + fbar -> ~mu_R + ~mu_Rbar	1.3435	6.9%
q + qbar' -> ~chi1 + ~chi+-1	2.3578	1.2%

GMSB vs. Neutralino/Chargino production

- Neutralino/Chargino production makes our limits worse by 13%

Gamma Met 1Jet

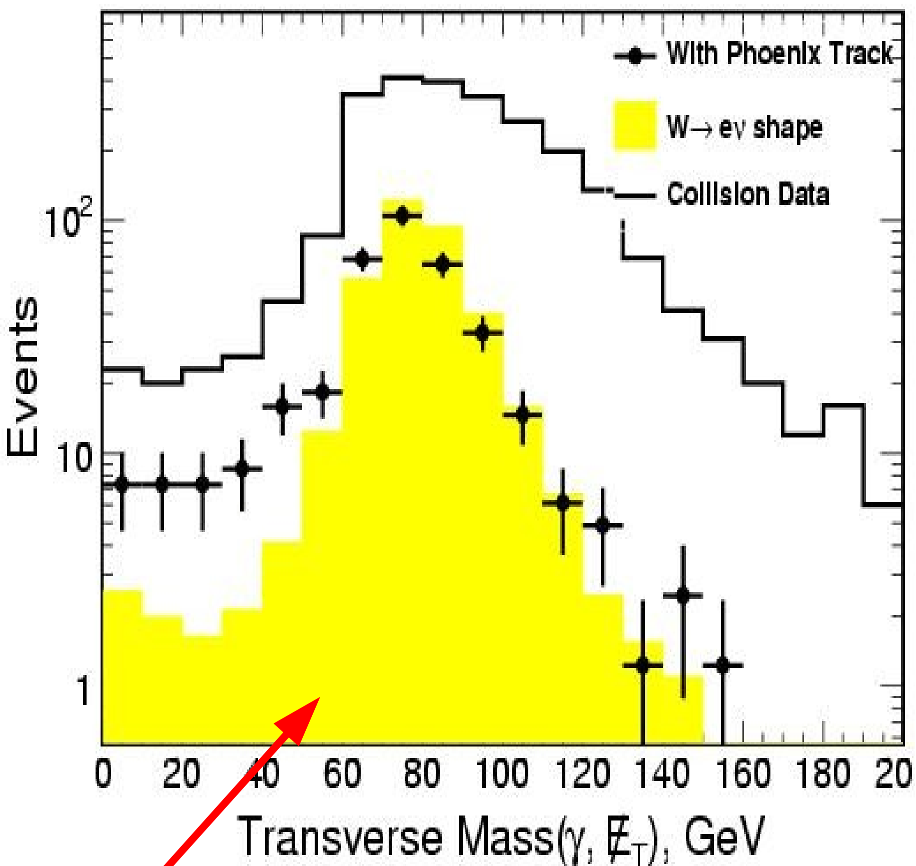


$$\int_{-t}^{-10} N(t)\,dt \qquad \int_{t}^{10} N(t)\,dt$$

Cosmic background dominates at large time. Negative side is dominated by Beam Halo.

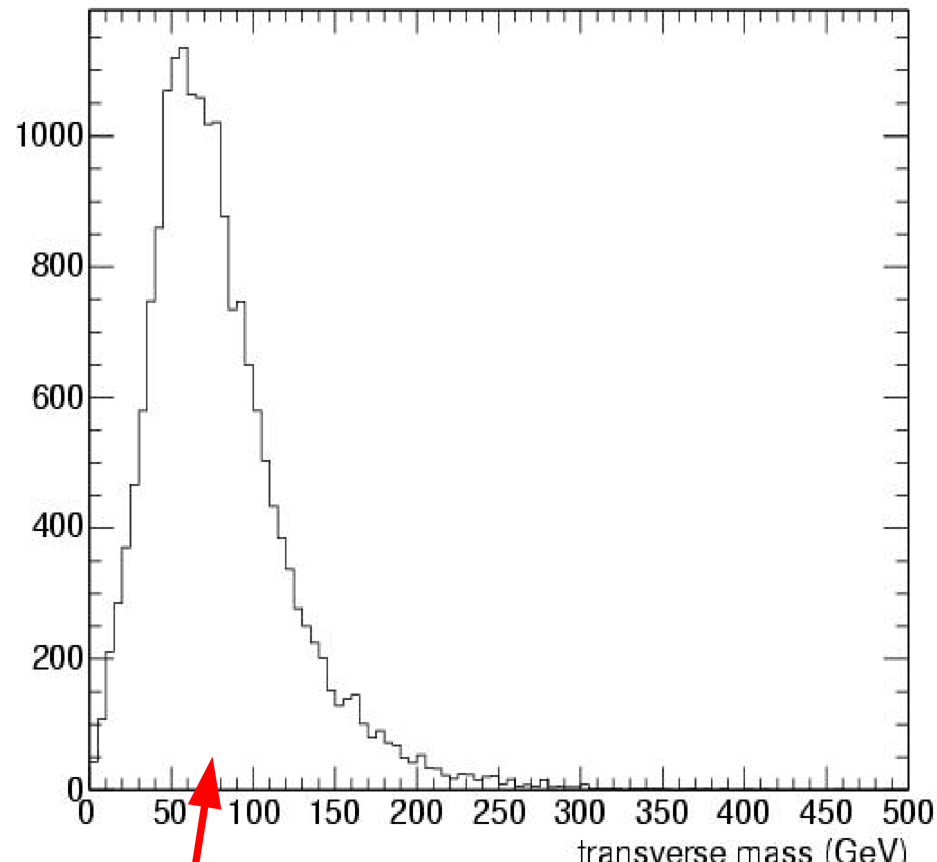
Transverse Mass of Signal and Bkg

Background
after baseline cuts



W-like peak; ~15%

GMSB Signal after baseline cuts
($m_{Neutralino}$=94GeV and $\tau_{Neutralino}$=10ns)



also peaks at
around 60-100 GeV

Events in the Signal Region

See webpage:
http://txpc1.fnal.gov/wagnp/EMTiming_analysis/index_.html

- 2 lool like collision events (expected: 1.3)

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