Search for New Physics in the Exclusive Delayed Photon + MET Final State at CDF

Adam Aurisano
Texas A&M University

Fermilab
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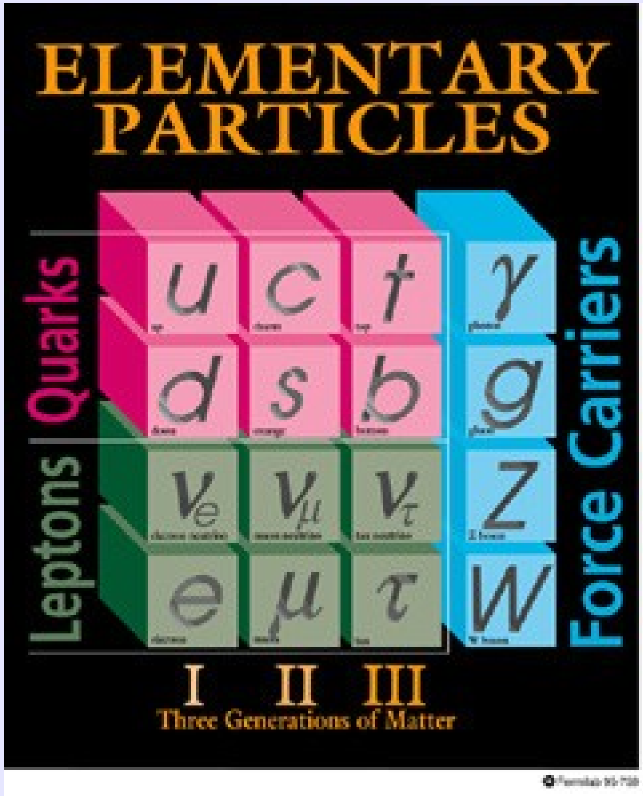
Outline

- Introduction
- Motivation
- Tools
- Overview of the Delayed Photon Analysis
- Backgrounds with Large Times and Cuts to Get Rid of Them
- Background Estimation
- Results
- Conclusions

Standard Model

- The Standard Model (SM) describes all currently known particles and interactions
- Decades of experimental verification have confirmed many of its predictions
- Despite extraordinary success, the Standard Model has problems
  - The “hierarchy problem” - the Higgs mass has divergences that must be canceled with fine tuning
  - Dark matter and dark energy make up a substantial portion of the universe



Supersymmetry

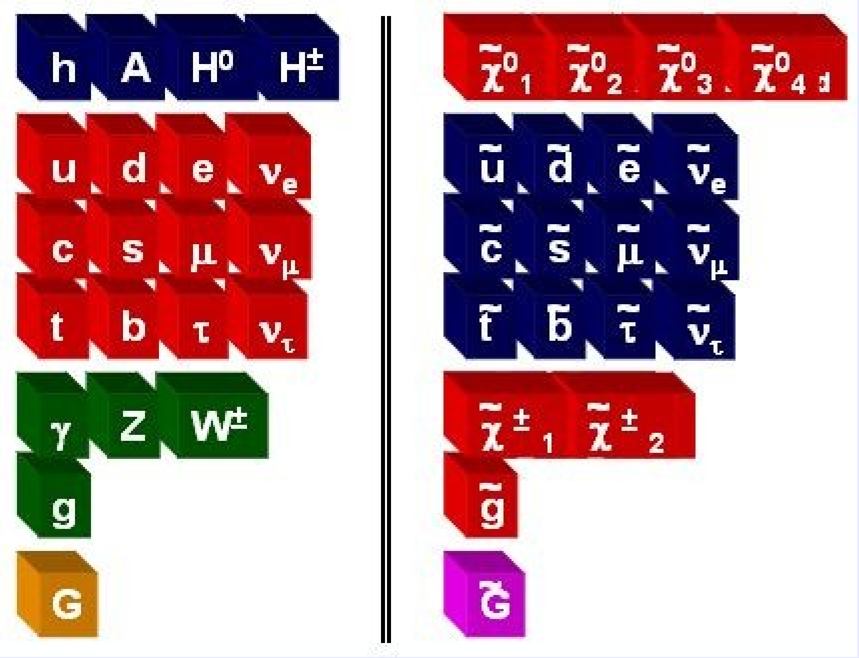
Supersymmetry (SUSY) proposes a symmetry between fermions and bosons – roughly doubles the particle count

The new particles cancel the divergence in the Higgs mass

If “R-parity” is conserved, SUSY could provide a dark matter candidate

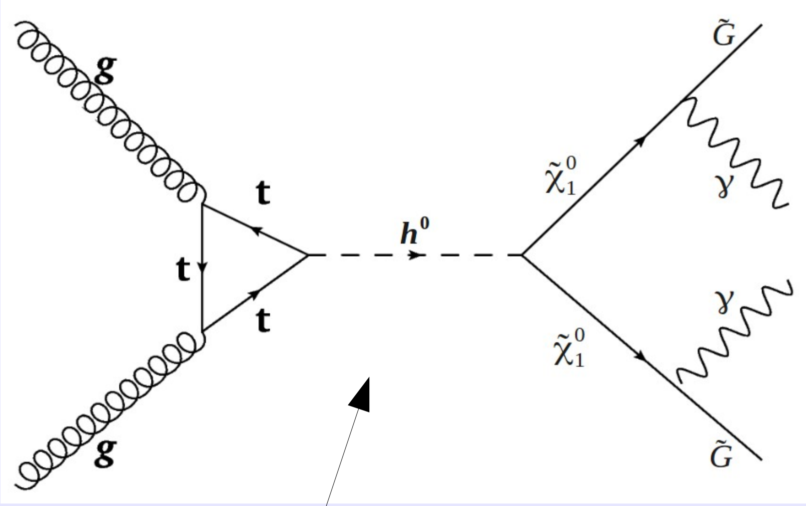
This isn't an exact symmetry → SUSY particles must be heavy

Various breaking mechanisms lead to different phenomenology



Gauge Mediated Supersymmetry Breaking (GMSB)

In GMSB, the $\widetilde{G}$, the SUSY partner of the graviton, is typically the lightest supersymmetric particle (LSP)



In general GMSB models, it is possible that only the $\widetilde{\chi}_1^0$ and $\widetilde{G}$ are accessible at the Tevatron

These models are not constrained by current limits → worth going after!

The NLSP, $\widetilde{\chi}_1^0$ is often long-lived. We look at cases where it has a lifetime of a few nanoseconds

Often, only one $\widetilde{\chi}_1^0$ decays in the detector, leading to the exclusive $\gamma + \not{E}_T$ final state

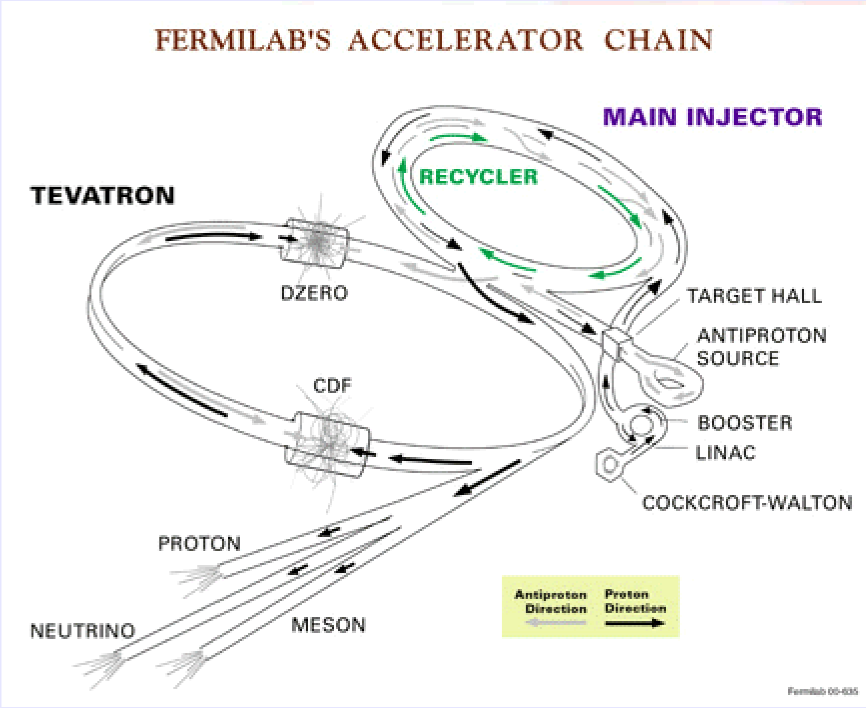
Production via the Higgs, rather than direct pair-production, dominates

References:
Toback and Wagner
Phys. Rev. D 70, 114032 (2004) and
Mason and Toback
Phys. Lett. B 702, 377 (2011)

Tevatron

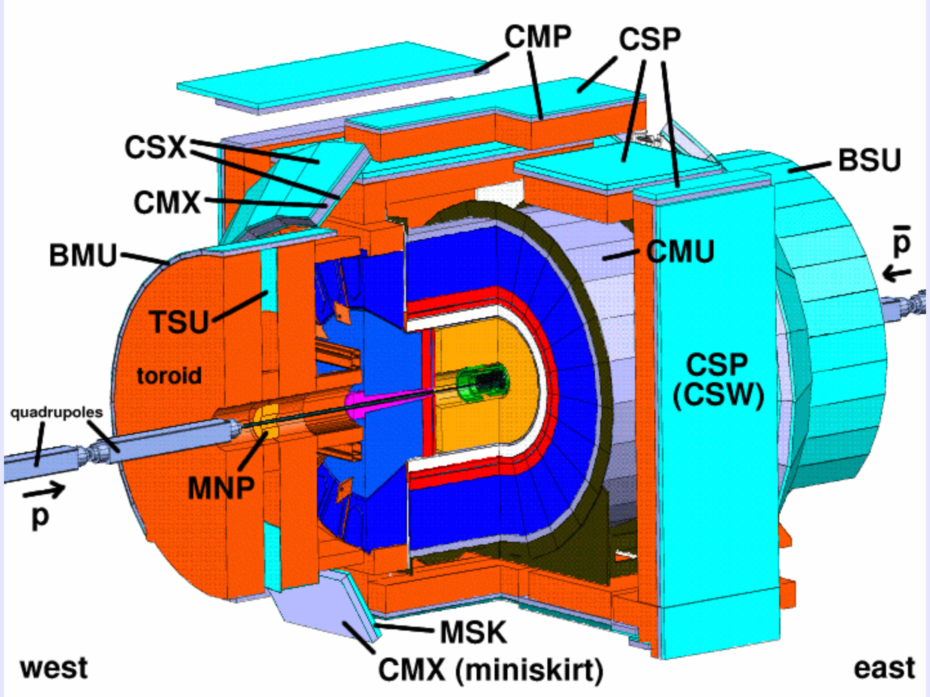
The Tevatron, with a center of mass energy of 1.96 TeV, was the most powerful accelerator in the world. It collided protons with anti-protons every 396 ns.

Even though the LHC is much more powerful, the Tevatron has accumulated nearly 10 fb^{-1} of data. In certain final states, the Tevatron is still more sensitive.



Collider Detector at Fermilab (CDF)

CDF is one of two multi-purpose detectors built to study collisions at the Tevatron.



<u>Components heavily used in this analysis:</u>

Central outer tracker – records the path taken by charged particles.

Electromagnetic calorimeter - records energy deposits from particles that interact electromagnetically

EMTiming system – converts output of the EM calorimeter into the time of arrival of the incident particle. In the central region, it is fully efficient for energies > 6 GeV (resolution ~ 0.6 ns)

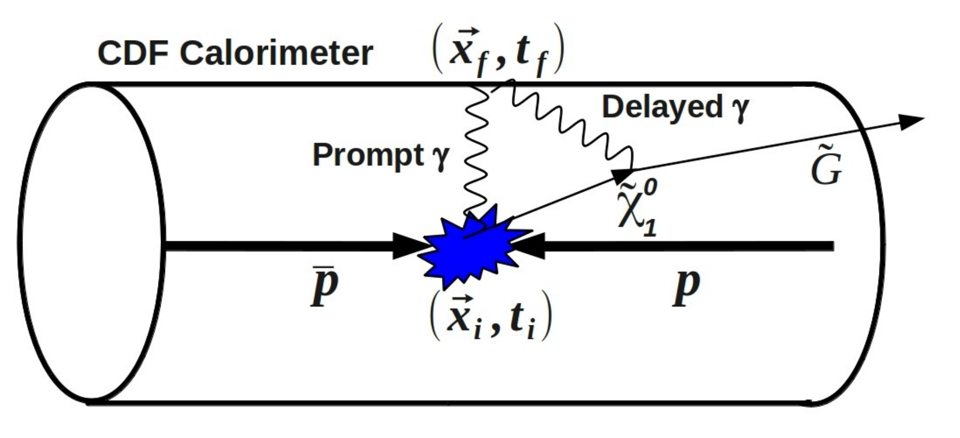
Delayed Photons

Photons from long-lived $\widetilde{\chi}_1^0$ arrive at the calorimeter late compared to expectations from prompt photons ("delayed photons").

This gives provides a distinct search signature.

Our primary analysis variable is the time of arrival of the photon at the EM calorimeter minus the expected time of arrival.

$$t_{corr} = t_f - t_i - \frac{|\vec{x}_f - \vec{x}_i|}{c}$$



General timing methods:
Nucl.Instrum.Meth.A563, 543 (2006)

Previous searches:
P. Geffert, M. Goncharov, V. Krutelyov, E. Lee, D. Toback, and P. Wagner
Phys. Rev. Lett. 99 (2007) 121801
Phys. Rev. D 78 (2008) 032015

Overview of the Delayed Photon Analysis: Final State

Exclusive delayed photon + MET final state:

Require:

(all E_T relative to Z = 0)

-Photon with E_T > 45 GeV

-MET > 45 GeV

-At least one space-time vertex
with |Z| < 60 cm

Veto:

-Extra calorimeter clusters with E_T > 15 GeV

-Tracks with P_T > 10 GeV

-Tracks geometrically close to the photon

-Standard Vertices with at least 3 tracks and |Z| > 60 cm

-Additional cosmics and beam halo cuts

Overview of the Delayed Photon Analysis: Backgrounds

As in published analyses, background estimation is data-driven.

Standard Model Collision Sources

$$W \rightarrow e\nu \rightarrow \gamma_{fake} + \not\!\!E_T$$

$$\gamma + jet \rightarrow \gamma + jet_{lost} \rightarrow \gamma + \not\!\!E_{T\,fake}$$

$$W \rightarrow \tau\nu \rightarrow \gamma_{fake} + \not\!\!E_T$$

$$W\gamma \rightarrow l\nu\gamma \rightarrow \gamma + l_{lost} + \not\!\!E_T$$

$$Z\gamma \rightarrow \nu\nu\gamma \rightarrow \gamma + \not\!\!E_T$$

Non-Collision

- Cosmics
- Beam Halo

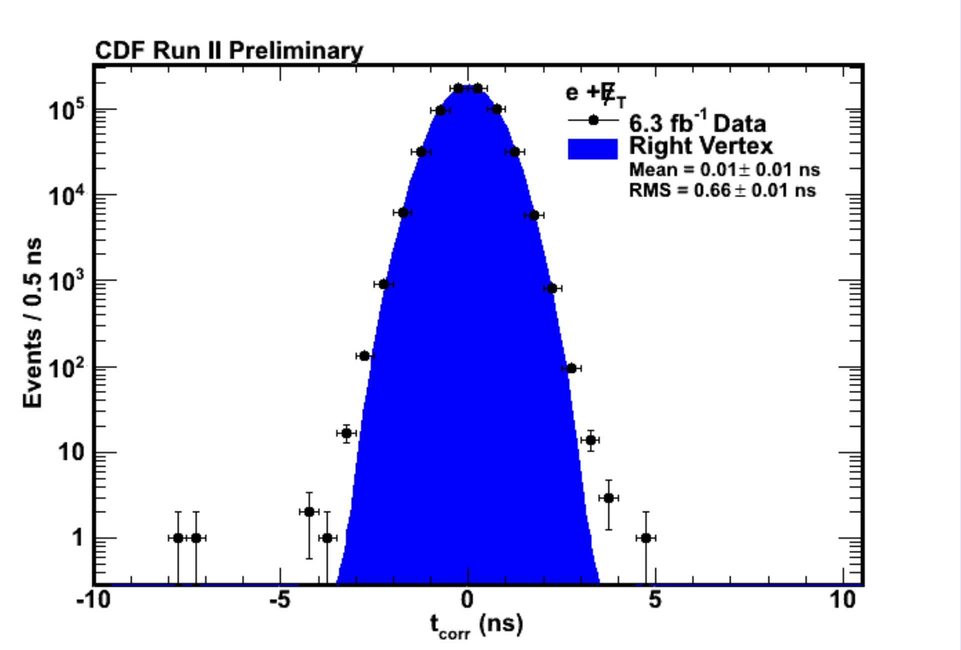
Standard Model sources have different characteristics depending on whether we select a right or wrong vertex

Overview of the Delayed Photon Analysis: Right Vertex Distribution

To construct the corrected time, we pick the highest ΣP_T vertex.

If this vertex is the origin of the particle that created the deposit in the calorimeter, it is a **Right Vertex** event.

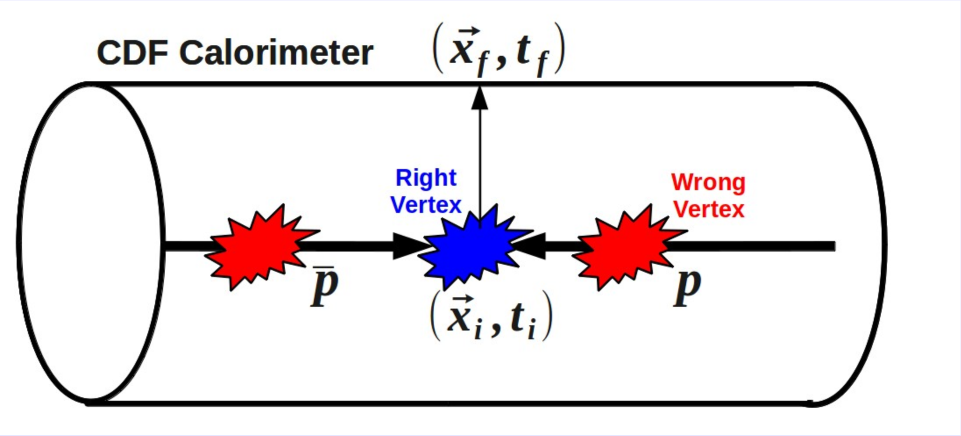
In a perfect detector, the corrected time would be exactly zero. In our detector, it has a mean of zero with an RMS of ~0.64 ns.



See:
P. Geffert, et al.
Phys. Rev. Lett. 99 (2007) 121801
Phys. Rev. D 78 (2008) 032015

M. Goncharov, et al.
Nucl.Instrum.Meth. A563, 543 (2006)

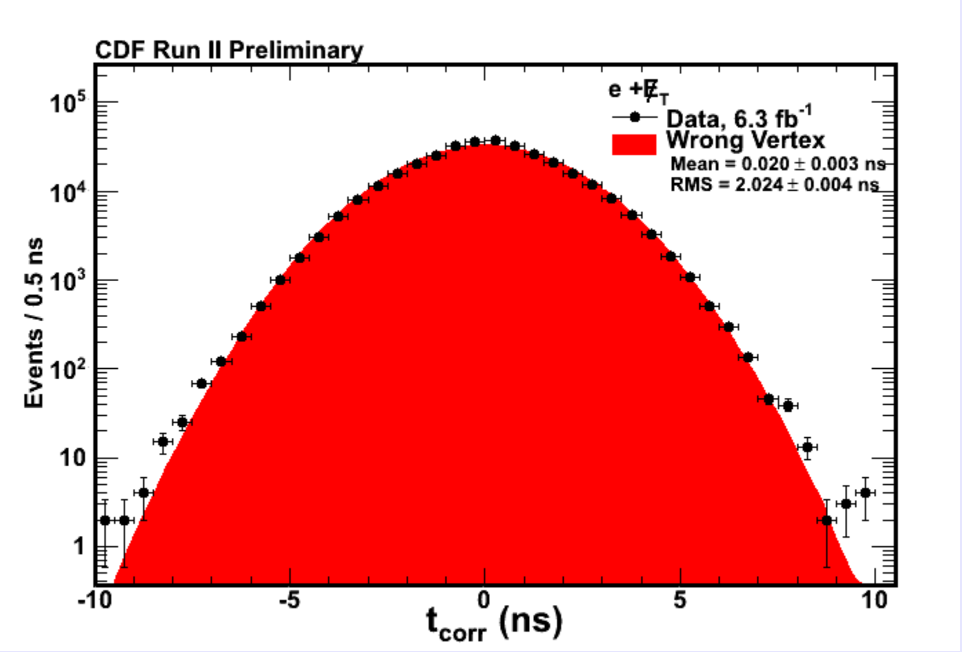
Overview of the Delayed Photon Analysis: Wrong Vertex Distribution



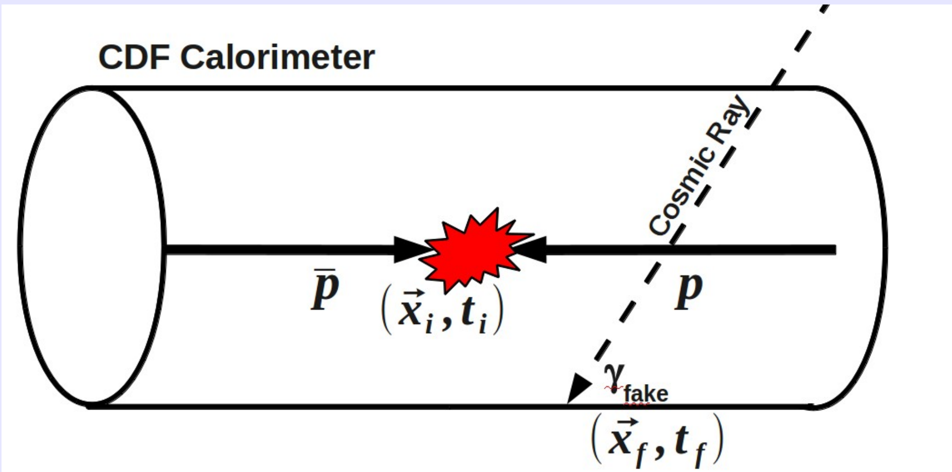
There often multiple vertices per event. Sometimes the wrong vertex has a higher ΣP_T than the right vertex, and sometimes the right vertex is not reconstructed at all.

The wrong vertex distribution has an RMS ~ 2.0 ns, mostly due to the time profile of the beam spot.

The mean of the distribution is generally not zero (contrary to previous assumptions).

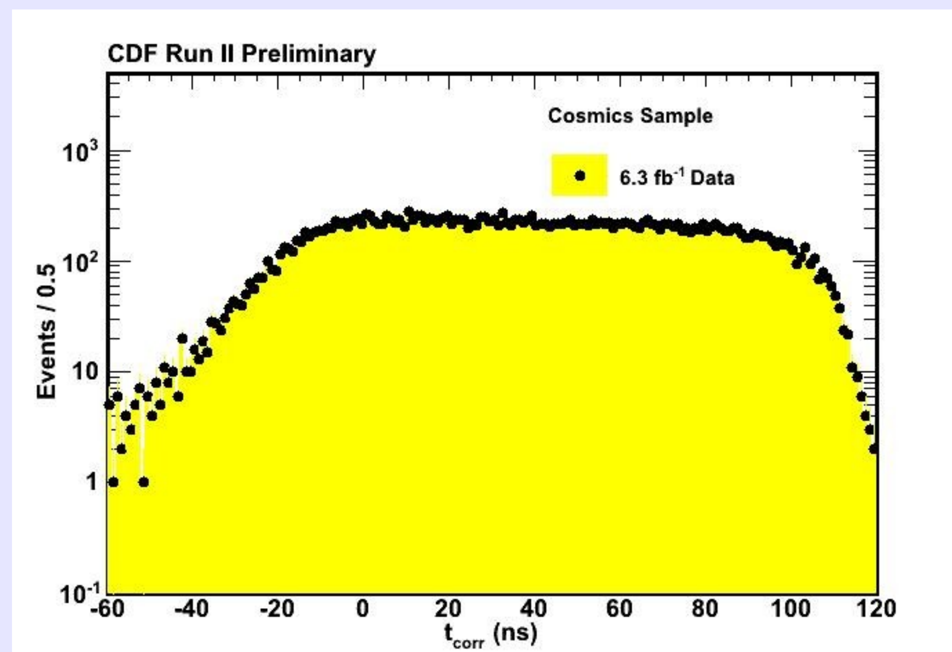


Overview of the Delayed Photon Analysis: Cosmics

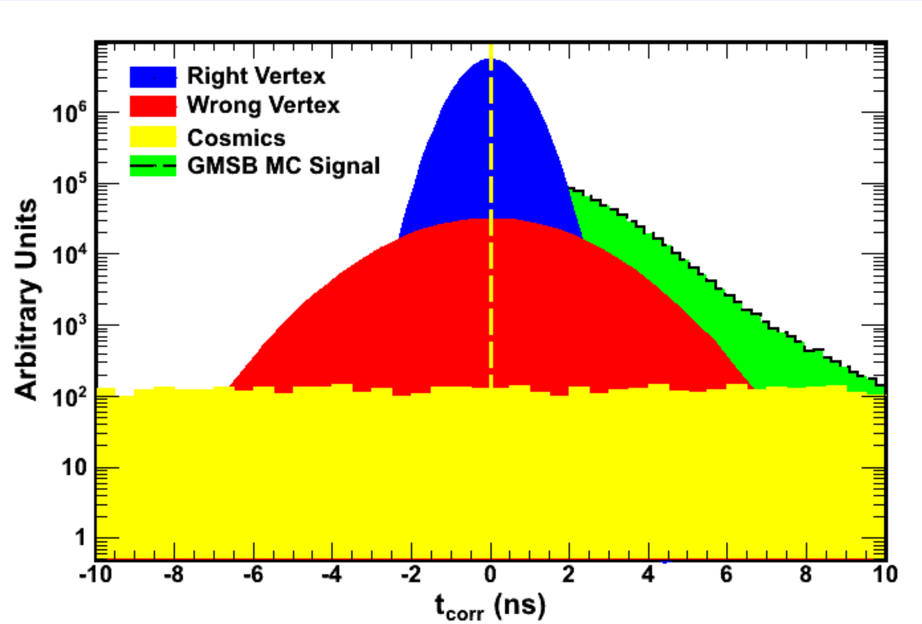


Cosmic rays occasionally reach the detector and leave an energy deposit which is reconstructed as a photon

This is uncorrelated with the bunch structure of the beam, so the rate of recording such events is flat in time, except near the opening and closing of the energy integration window

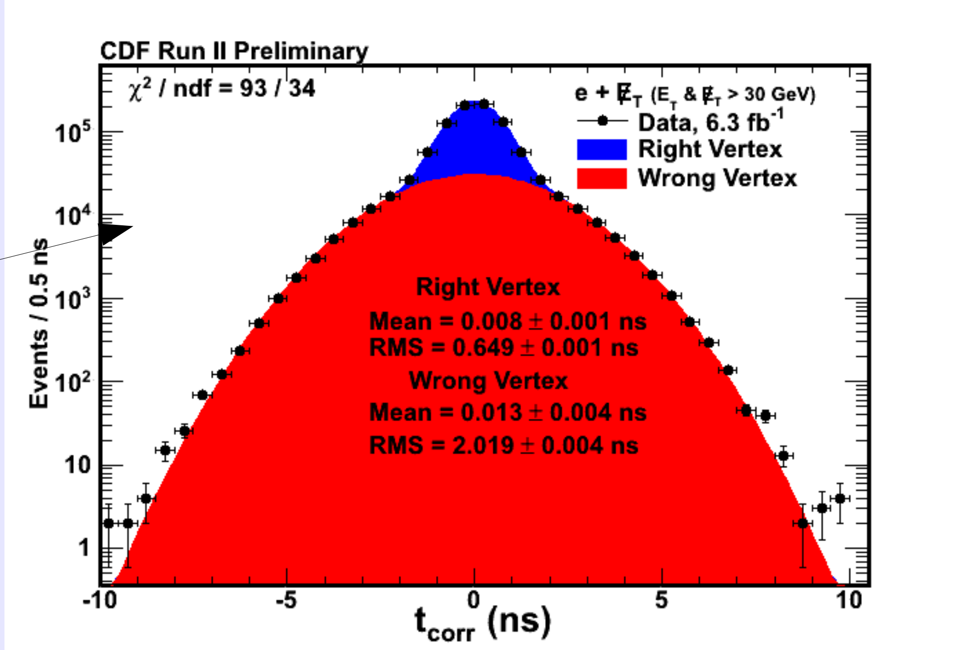


Overview of the Analysis: Timing Distributions



The distribution of photons from GMSB decays are expected to be a decaying exponential smeared by the detector resolution

W → eν where we ignore the track for the purposes of selecting a vertex acts as a control region for $\gamma + \not\!\!E_T$



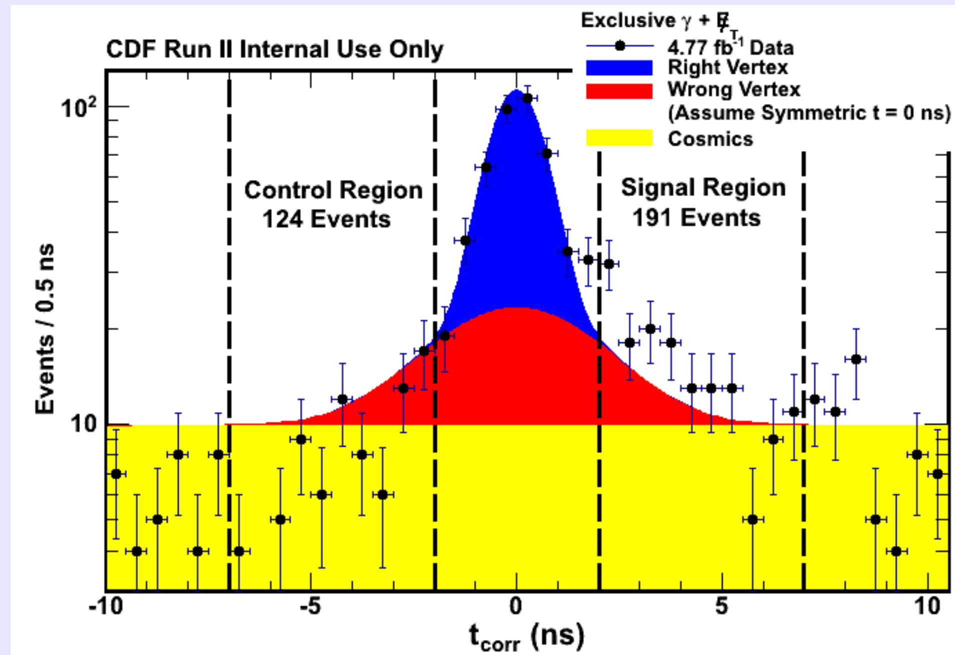
Real collision data with electrons is well modeled by a double Gaussian description

Overview of the Delayed Photon Analysis: Preliminary 4.8 fb^{-1} Result

A preliminary study uncovered a large excess in the exclusive $\gamma + \not{E}_T$ final state

Extraordinary claims require extraordinary evidence: examine the assumptions in the background model and look for any previously unknown biases

N.B. This result is confidential and will not be published!



Rather than treat this as a focused Higgs search, we treat this as a model independent search to determine whether or not this excess is real

Understanding the Preliminary Result

- We have found that initial assumption that the wrong-vertex mean = 0 is not correct
- To develop a correct background estimate, we need to do three things
  - Identify effects which could lead to large times
  - Develop new requirements which reduce any biases
  - Develop a method to measure any remaining bias

Understanding Non-Zero Wrong-Vertex Means

The corrected time when we choose a wrong vertex:

$$t_{corr}^{WV} = t_{arrival} - TOF_{WV} - t_{WV}$$

Substituting the definition of the time of arrival:

$$t_{corr}^{WV} = t_{RV} + TOF_{RV} - TOF_{WV} - t_{WV}$$

Rearranging:

$$t_{corr}^{WV} = (t_{RV} - t_{WV}) + (TOF_{RV} - TOF_{WV})$$

Mean = 0, RMS = $\sqrt{2} * 1.28$ ns due to the beam profile in T

Physics dependent geometrical term – can have a non-zero mean.

Next, we will show three effects which cause this term to be biased.

Sources of Large Times from SM Backgrounds

The following effects can cause the bias term to have a non-zero mean:

1) **E_T Threshold Effect**:

A distortion caused by events entering or leaving our sample due mis-measured E_T near the cut.

Topology Biases:

2) Fake photons: Fake photons tend to be biased to larger times due to being more likely at large path lengths.

3) Lost jets: Losing an object tends to happen at more extreme vertex Z positions (to allow the object to point out of the detector).

Next: examine these effect and show how to mitigate them

Sources of Large Time Events: 1) E_T Threshold Effect

Promotion Effect

Wrong vertex gives shorter apparent path length

→ Longer apparent time

→ Larger measured E_T

Events below the E_T threshold enter the sample and **increase** the positive time bias.

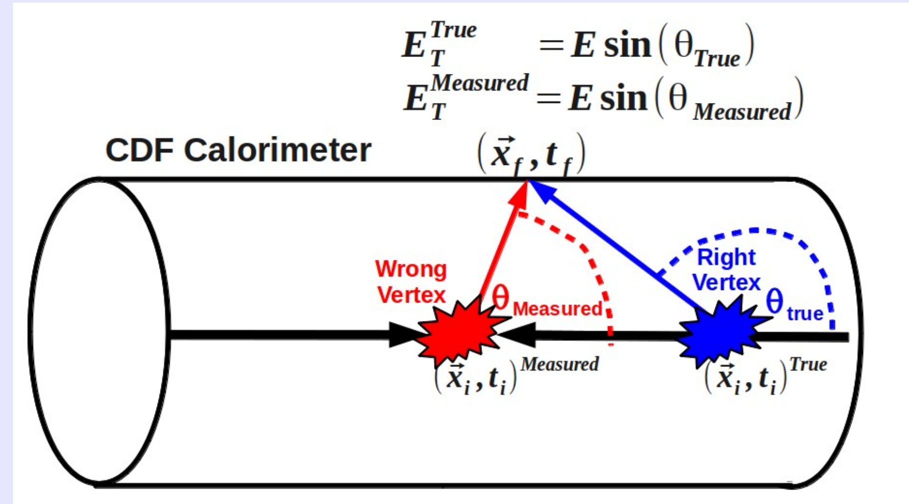
Demotion Effect

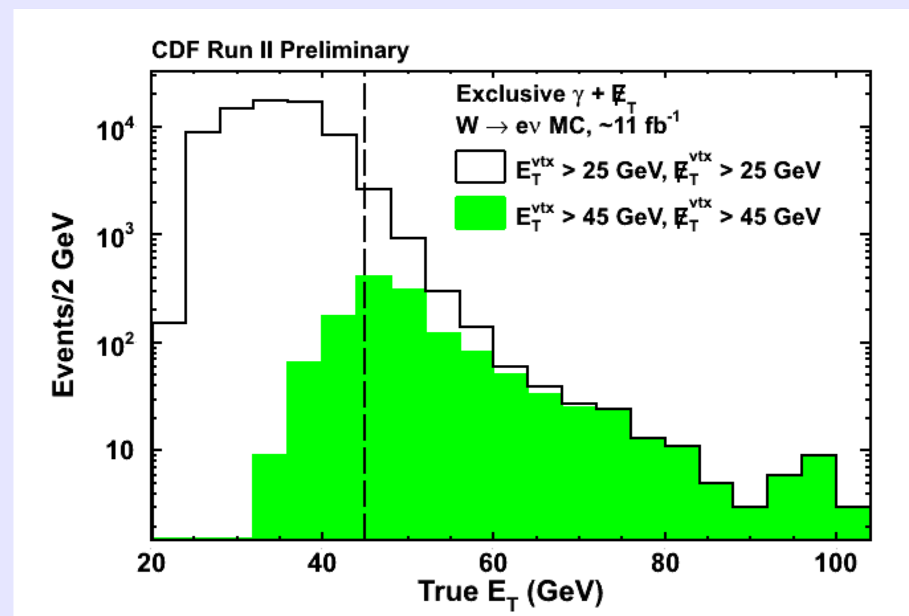
Wrong vertex gives larger apparent path length

→ Shorter apparent time

→ Smaller measured E_T

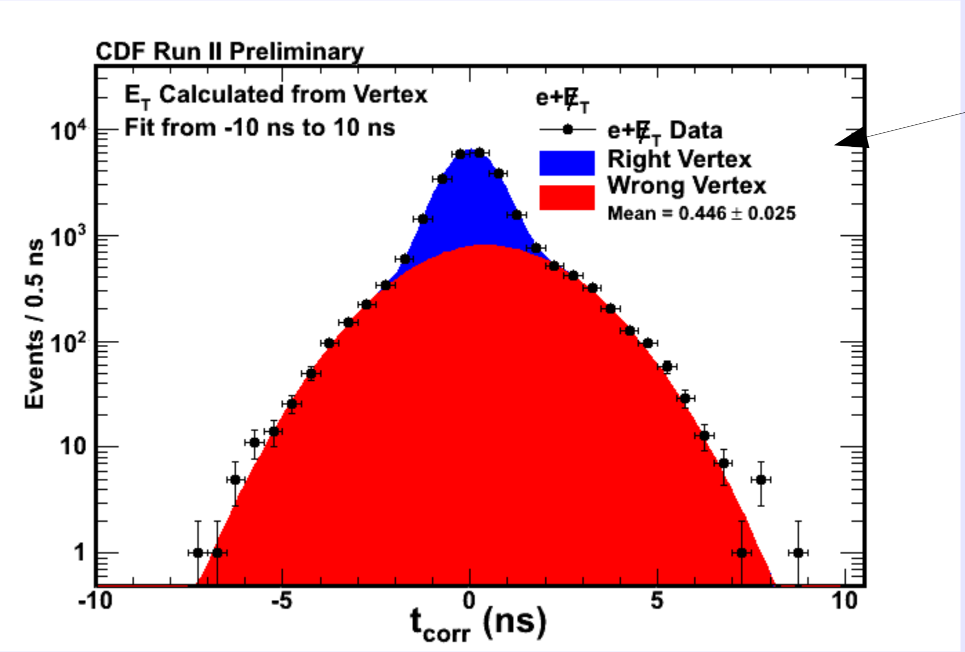
Events above the E_T threshold exit the sample and **decrease** the negative time bias.





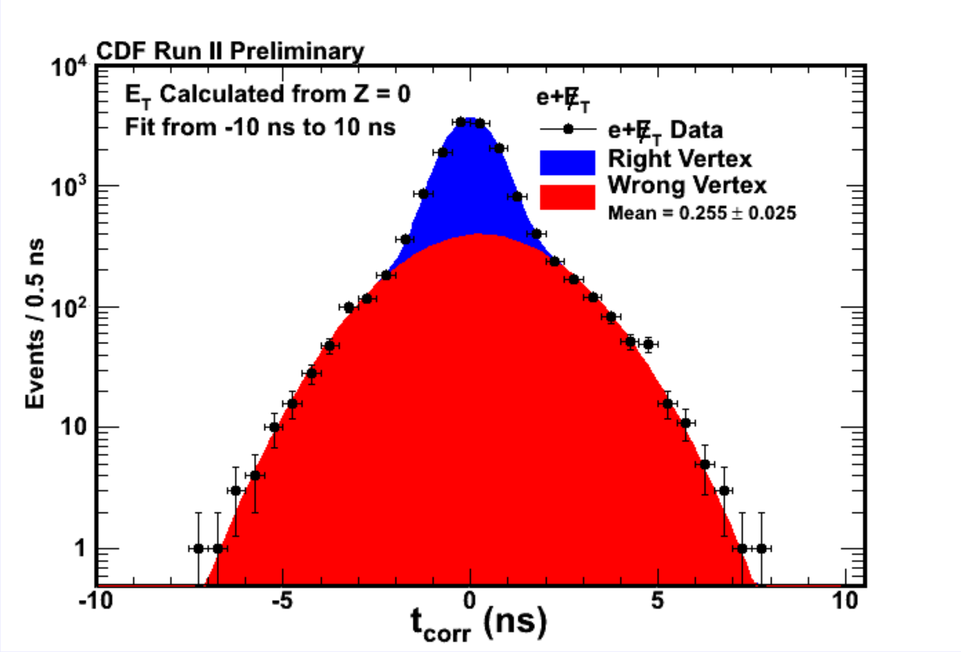
1) Solution: E_T^0 Cut

Decouple the timing measurement from the E_T measurement by calculating E_T relative to Z = 0

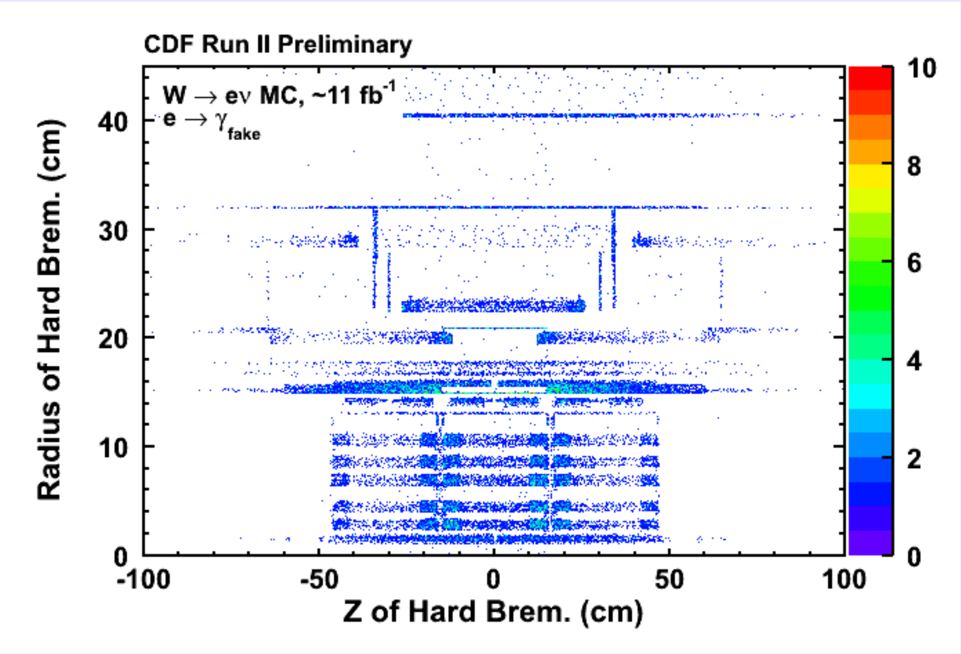


Real data with electrons using E_T relative to the selected vertex

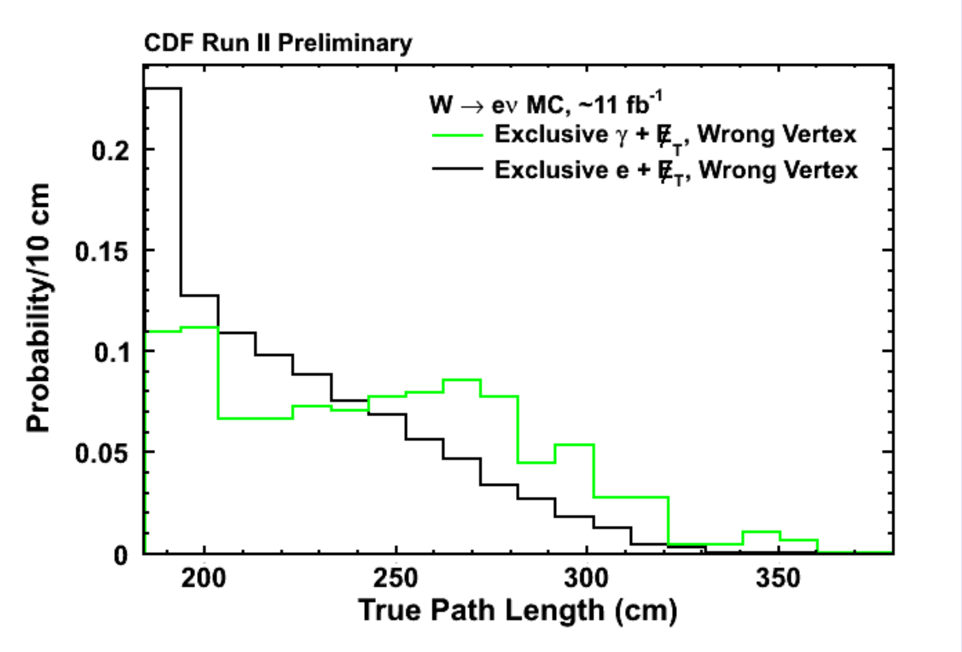
The same data using E_T^0 → the wrong-vertex mean decreases by ~half!



Sources of Large Time Events: 2) Fake Photons



Most electrons that fake photons are due to hard interactions with detector material

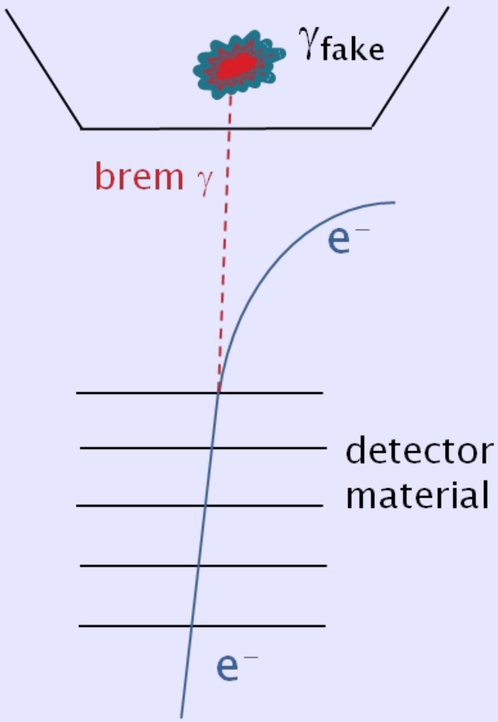


This make makes them have longer path lengths on average → larger apparent times with a wrong vertex

2) Solution: ΔR_{pull} Cut

Develop a new fake rejection technique:

Electrons faking photons start off pointing towards the calorimeter deposit, but due to the hard interaction, the path has a “kink” that ruins track extrapolation



Create a ΔR between the track and the calorimeter deposit based on standardized versions of the initial η and ϕ of the track

~73% rejection of fake photons
~90% efficiency

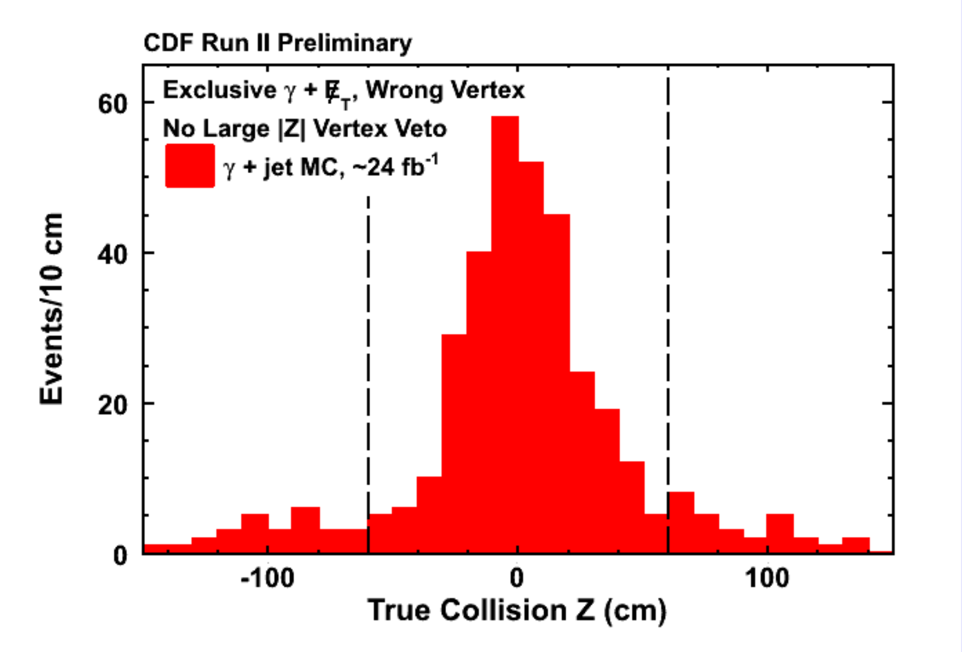
Sources of Large Time Events: 3) Large |Z| Production

γ+jet events tend to occur unusually often at large |Z| positions

Jets are messy objects – to lose one, it usually has to be pointed into an uninstrumented region

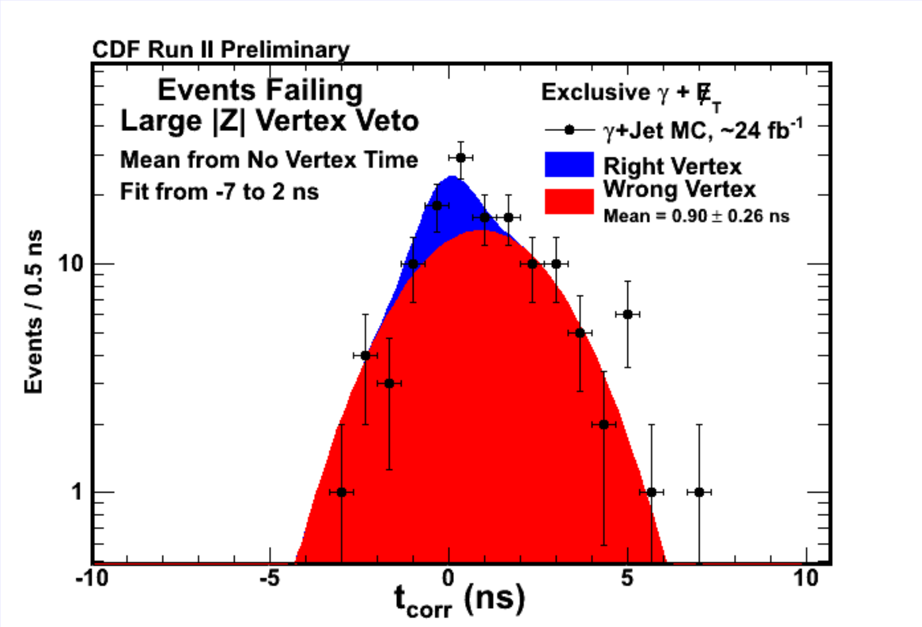
Events with large |Z| are more likely to lose a jet due to it being oriented out of detector

Large |Z| events have large times → the true time-of-flight is large compared to any possible time-of-flight correction



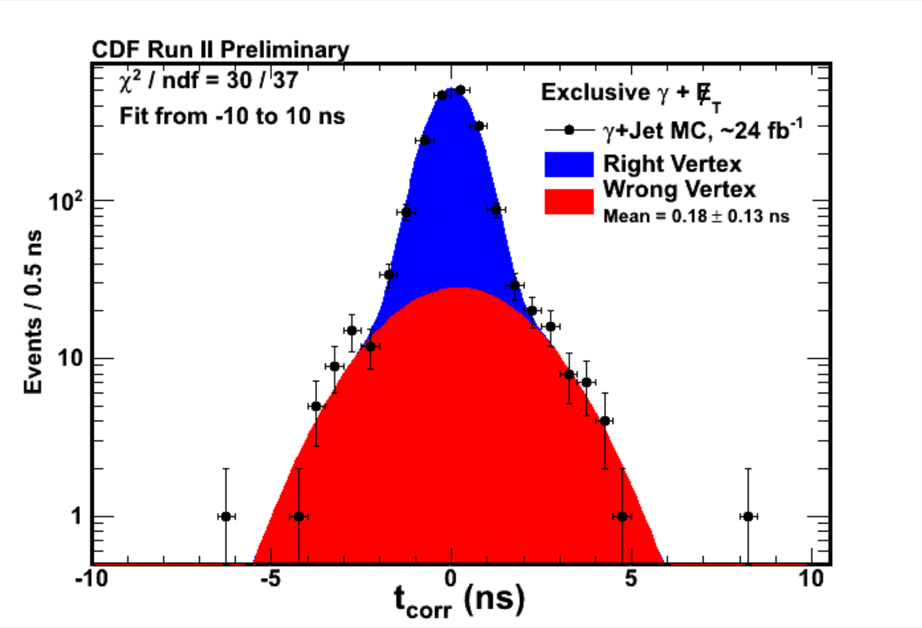
3) Solution: Large |Z| Veto

Reject any event with a vertex with 3 or more tracks and |Z| > 60 cm (~95% efficient for right vertex events)

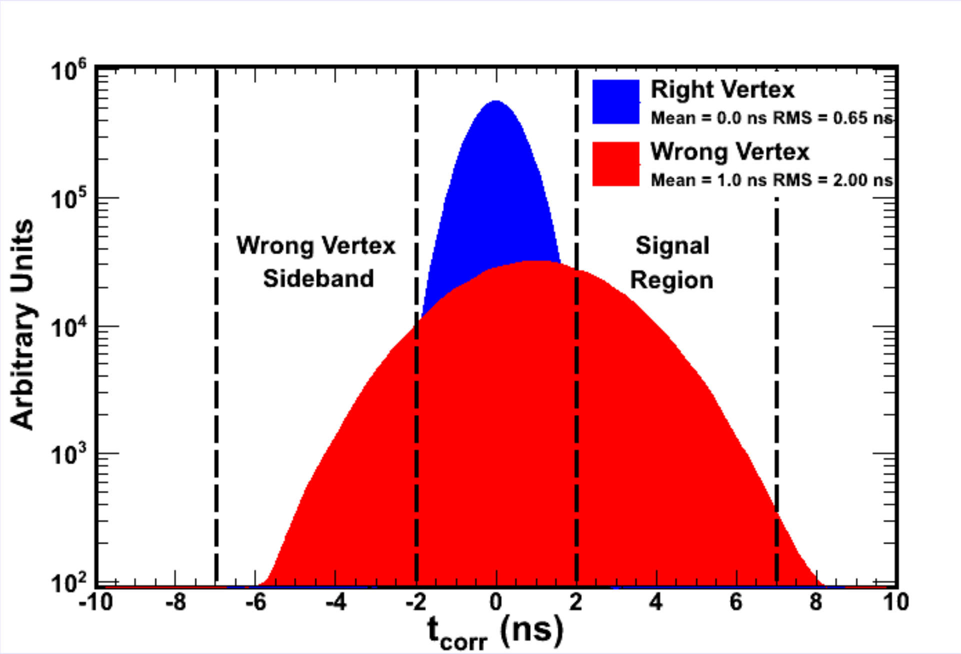


γ+jet events failing the large |Z| veto are highly shifted

After the veto, the distribution is well behaved with a small wrong-vertex mean



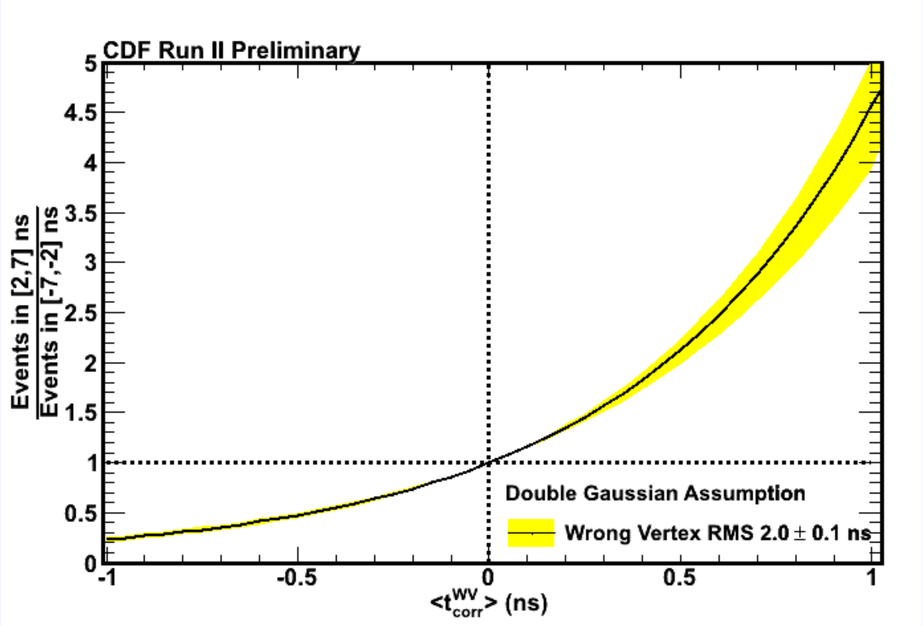
Predicting Background Events in the Signal Region From the Wrong-Vertex Mean



We want to be able to predicted the number of background events in (2,7) ns using a data-driven method

Note: right-vertex events are largely irrelevant in the signal region

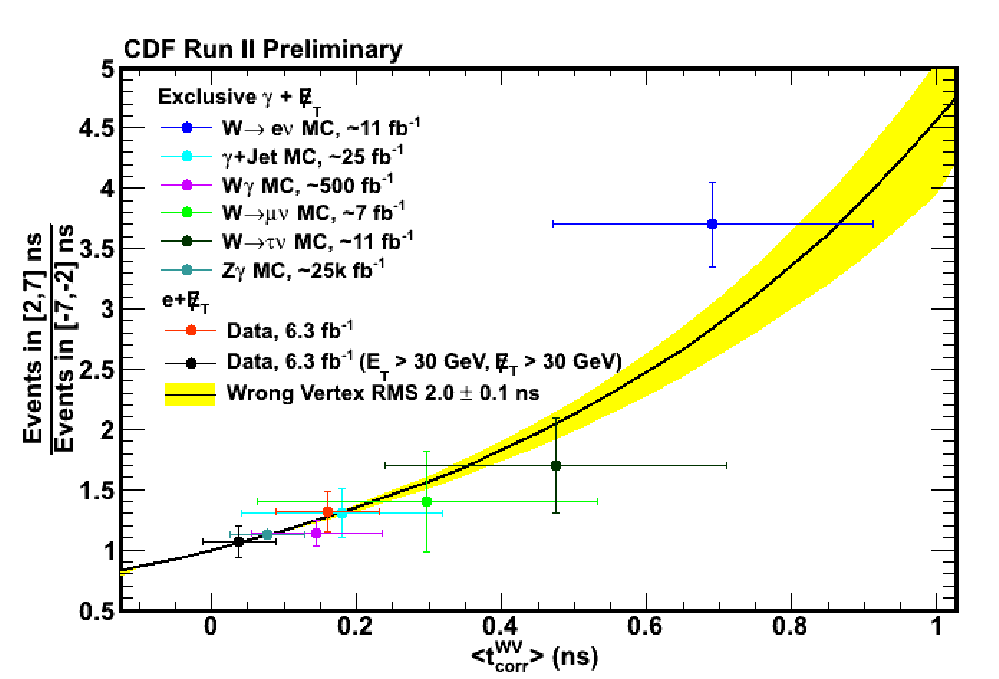
The number of wrong-vertex background events in the signal region depends directly on its normalization which we can get from (-7,-2) ns, and the wrong-vertex mean which we get from a second sample



Checking the Double Gaussian Approximation with Lots of Datasets

We isolate wrong vertex events in Monte Carlo and fit to find the wrong-vertex mean and RMS

For real data, we use electrons so we can use the electron track to identify wrong vertex events



Our data after all cuts is at ~0.2 ns

The ratio of events in (2,7) ns to events in (-7,-2) ns follows our predictions according to the double Gaussian approximation. (Not a fit!)

Estimating the Wrong Vertex Mean

- We want to be able to predict the number of events in the signal region only using various sideband region
- If we know the wrong-vertex mean, we have enough information in (-7, -2) ns to make the estimation
- How can we find the wrong-vertex mean?
- Fitting in (-7, 2) ns does not have enough information → we need an additional handle
- We find an addition handle in the no-vertex timing distribution.

Estimating the Wrong-Vertex Mean From the No-Vertex Sample

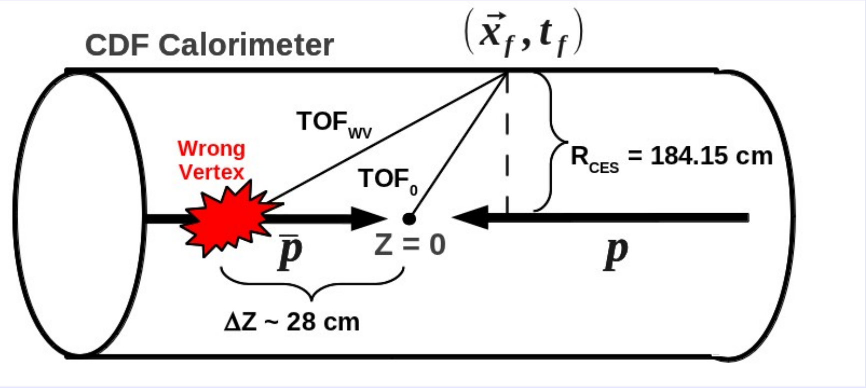
Create an orthogonal sample consisting of events passing all cuts except the good vertex requirement. Create the corrected time relative to the center of the detector:

$$t^{0}_{corr} = t_{arrival} - 0 - TOF_0$$

Substituting this into the wrong-vertex time:

$$t^{WV}_{corr} = t^{0}_{corr} - t_{WV} + (TOF_0 - TOF_{WV})$$

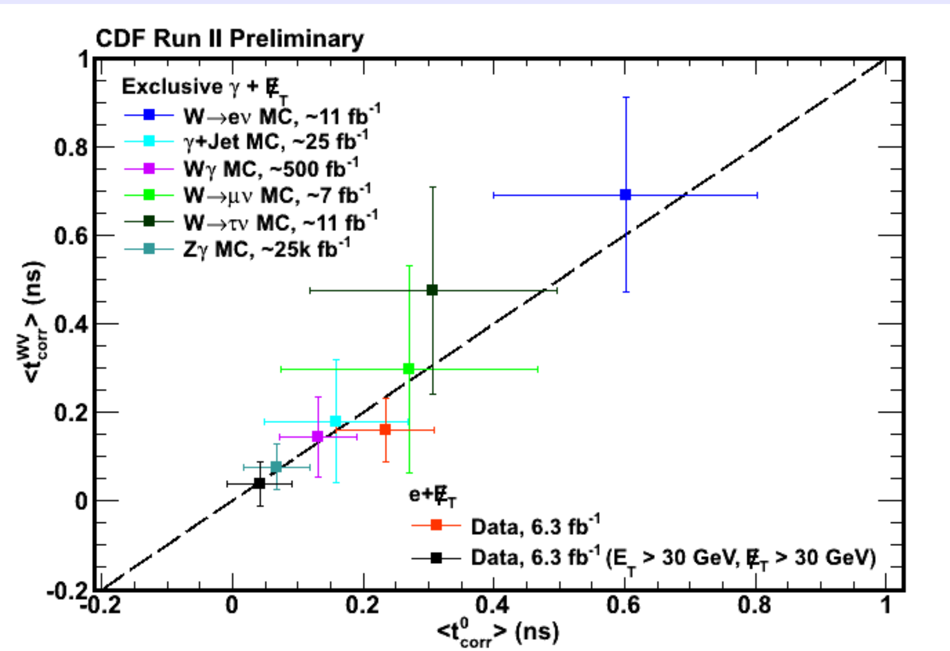
On average, this is zero.



Since the typical ΔZ is much smaller than the radius of the detector, this term contributes little.

The mean no-vertex time is approximately equal to the mean wrong-vertex time.

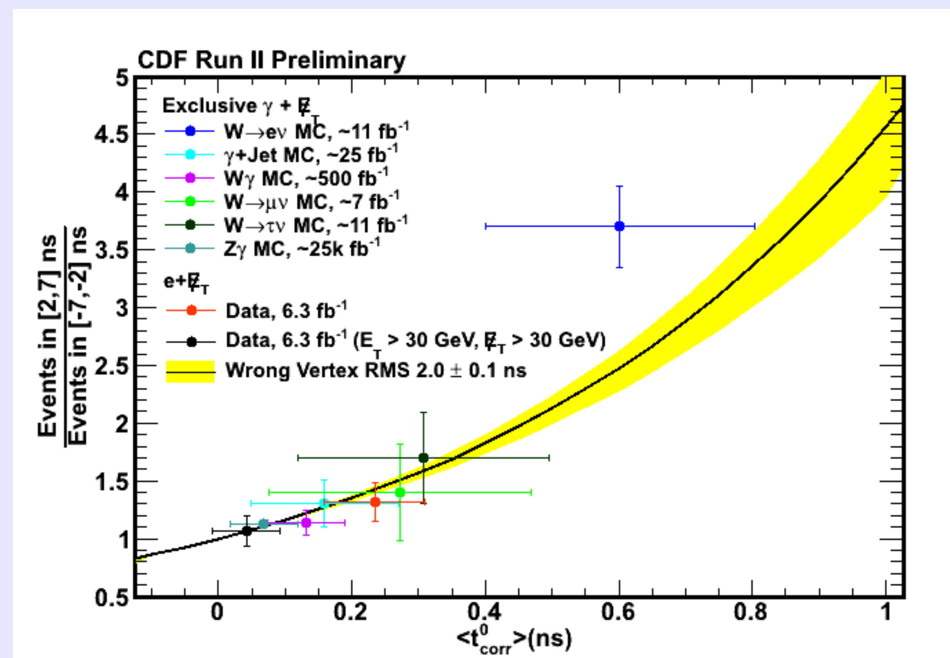
Does This Assumption Work?



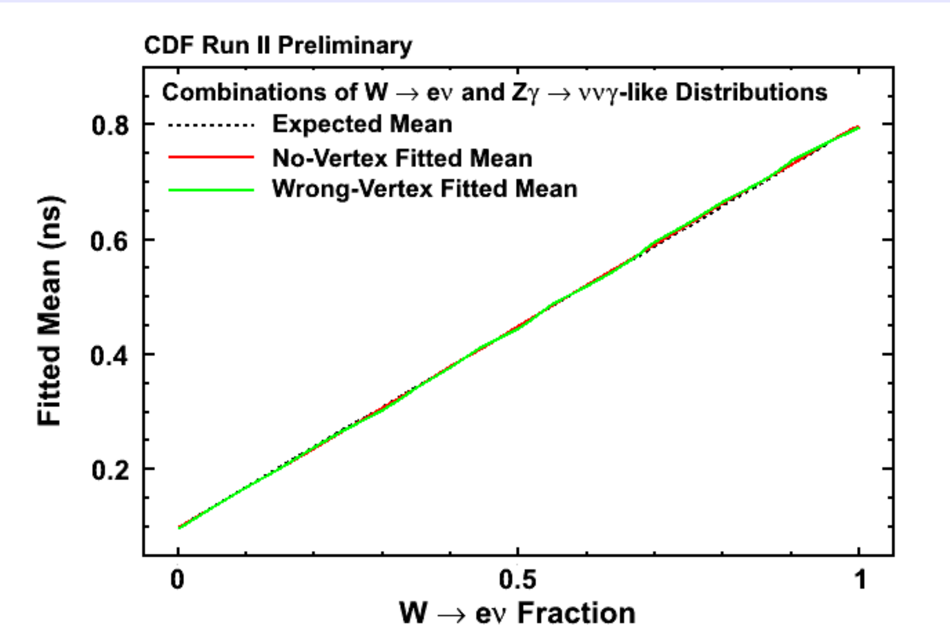
Check with both Monte Carlo and electrons in real data.

All samples show good agreement between the fitted no-vertex and wrong-vertex means

The no-vertex mean well predicts the number of events in the signal region for all control samples



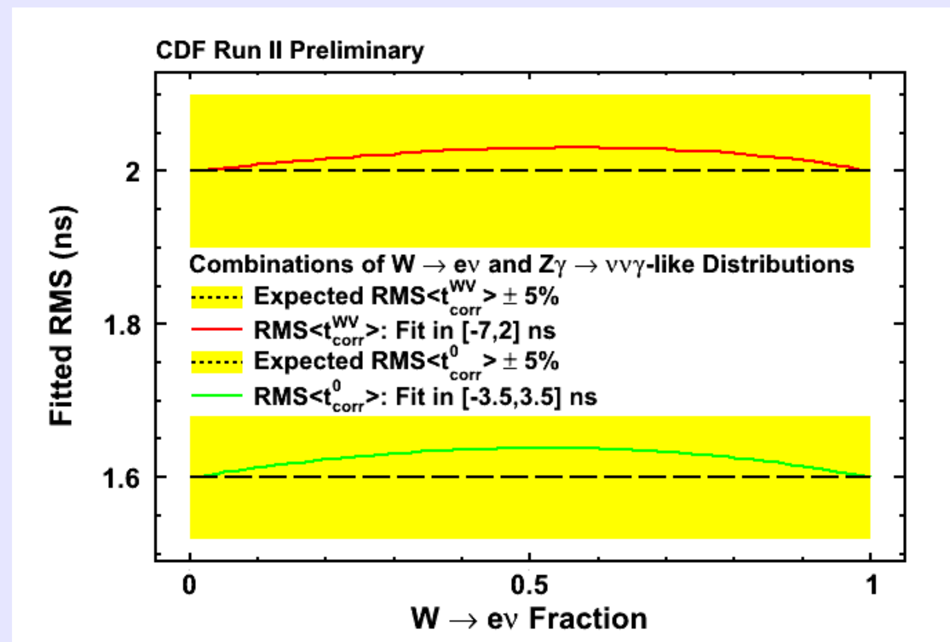
Effect of Combining Collision Background Sources



Up to this point, we considered single Standard Model sources. Does the double Gaussian description apply with combinations of sources?

We generate Gaussians with means of 0.1 ns and 0.7 ns. We combine them in various fractions.

The fitted RMS increases slightly as we approach a 50% combination. We cover this with a 5% systematic.



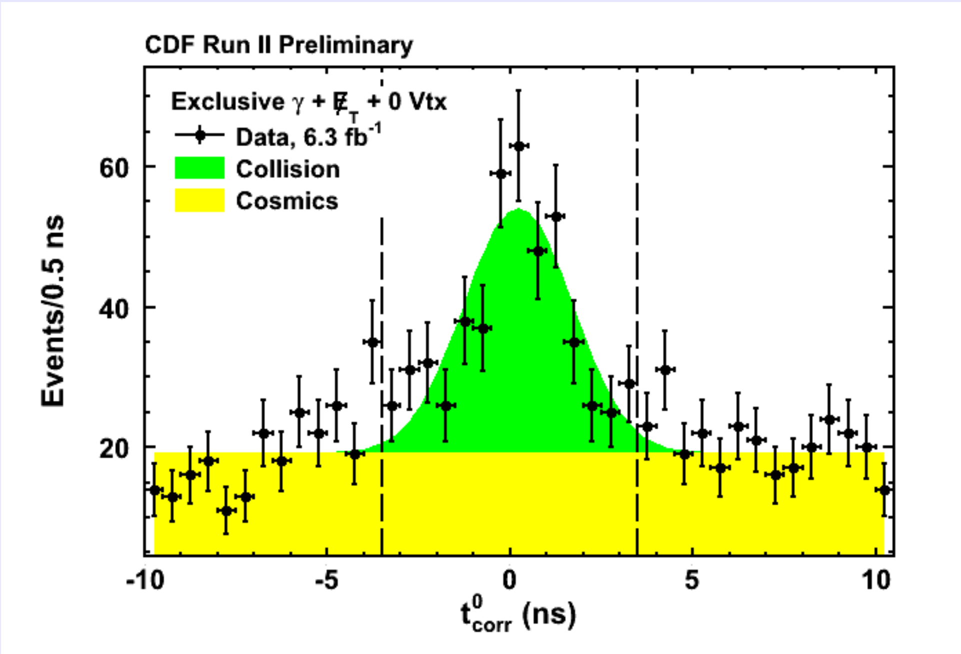
Putting It All Together: Likelihood Fit

- Estimate the number of background events in the signal region using a combined likelihood fit to the sideband regions extrapolated to the signal region
  - Good vertex: (-7,2) ns and (20,80) ns
  - No vertex: (-3.5, 3.5) ns and (20,80) ns
- Include systematic uncertainties as constraint terms:
  - Right-vertex mean = 0.0 ± 0.05 ns
  - Right-vertex RMS = 0.64 ± 0.05 ns
  - Wrong-vertex mean = No-vertex mean ± 0.08 ns
  - Wrong-vertex RMS = 2.0 ± 0.1 ns

Event Reduction Table for 6.3 fb^{-1}

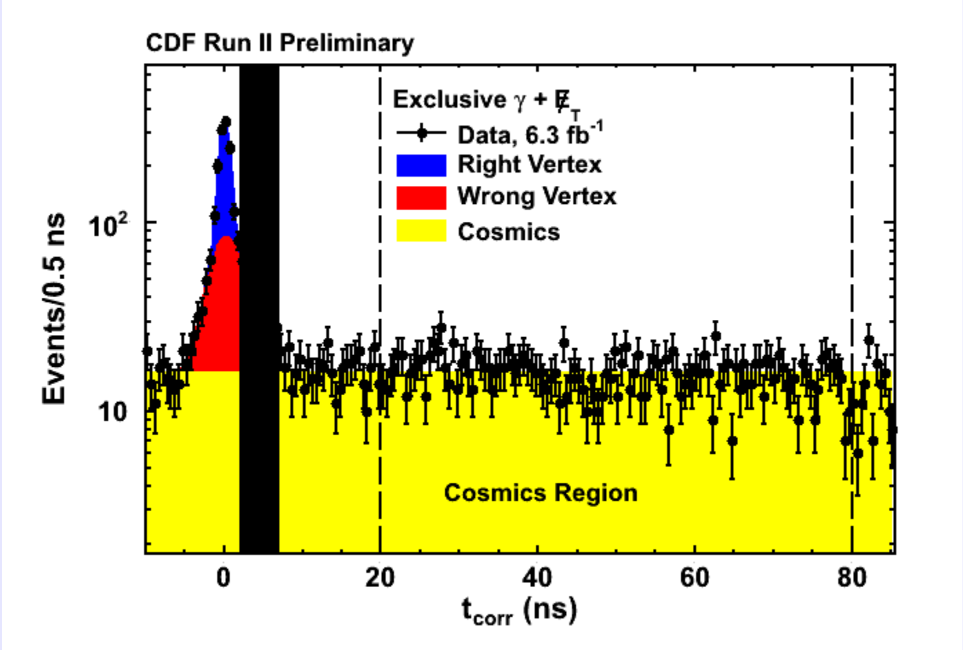
Cut	# of Events
Preselect a sample with a Photon w/ E_T > 45 GeV & MET > 45 GeV	38,291
Reject Beam Halo Events	36,764
Reject Cosmic Events	24,462
Track Veto	16,831
Jet Veto	12,708
Large |Z| Vertex Veto	11,702
$e \rightarrow \gamma_{fake}$ Rejection	10,363
Good Vertex Events/No Vertex Events	5,421/4,942

Sideband Regions



No Vertex:
Collision Events = 260 $\pm$ 30
Collision Mean = 0.2 $\pm$ 0.1
Cosmics/ns = 38.1 $\pm$ 0.8

Good Vertex:
Right-Vertex Events = 870 $\pm$ 70
Wrong-Vertex Events = 680 $\pm$ 80
Cosmics/ns = 31.9 $\pm$ 0.7

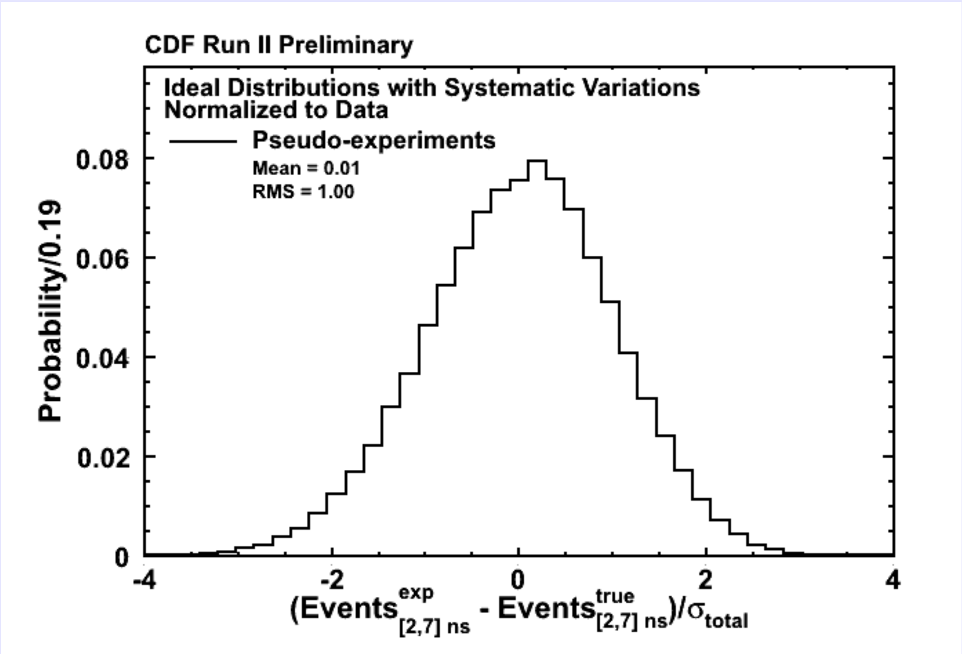


Next: use the numbers to validate the fit

Validating the Likelihood Fit

- Generate ideal pseudo-experiments varying parameters within their systematic uncertainties
- Generate more realistic pseudo-experiments from full MC of the three largest SM backgrounds
- Sample at the statistics level seen in data
- Add the expected level of cosmics to the good and no vertex distributions

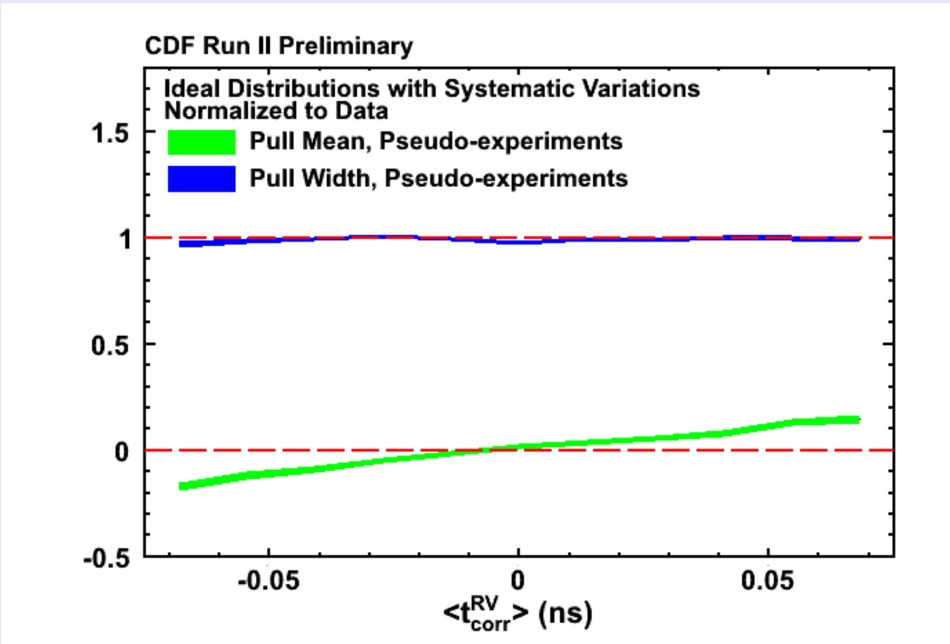
Ideal Distributions: How Well Do We Do?



All parameters with systematic uncertainties are allowed to vary within those uncertainties.

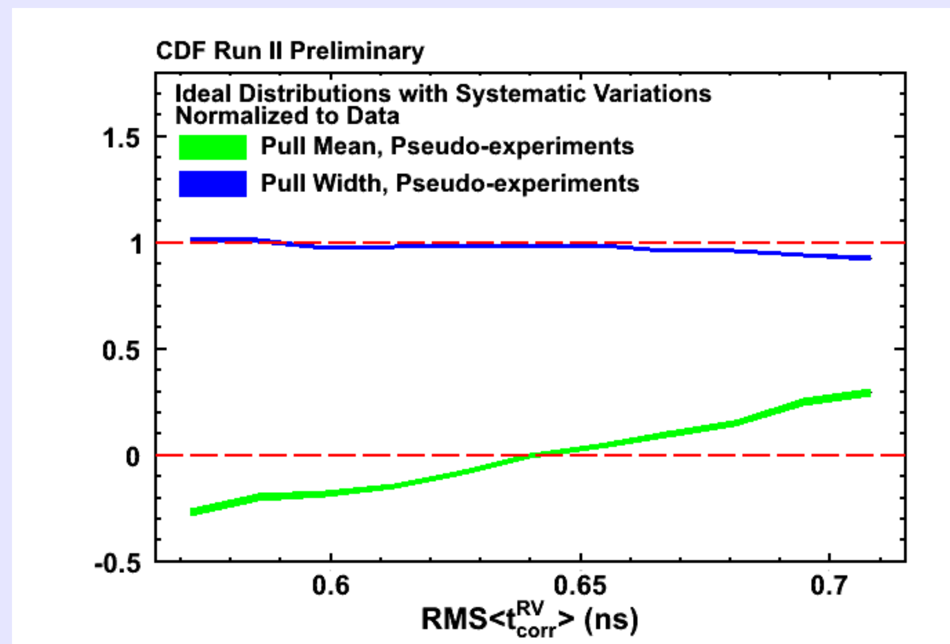
The pull distribution shows that with full variation of the systematics, the fit is unbiased (mean ~ 0) and the errors are well estimated (RMS ~ 1).

Ideal Distributions: Pulls vs. Systematic parameters



Figures range from -1.5σ to 1.5σ in systematic uncertainty

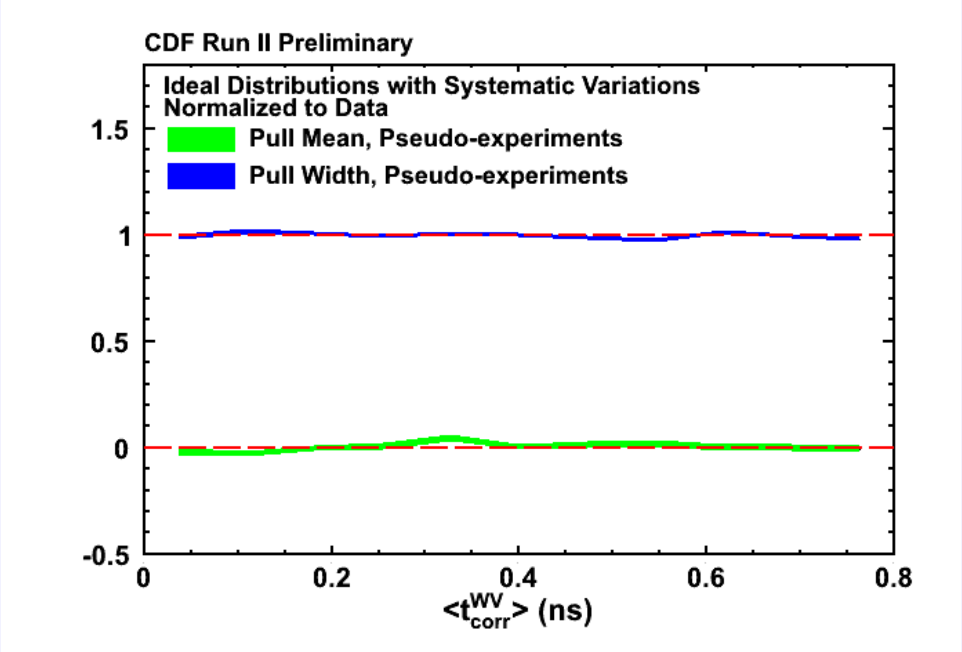
The fit remains largely unbiased over this range



In both cases, the pull width indicates that the uncertainties are well estimated over the entire range

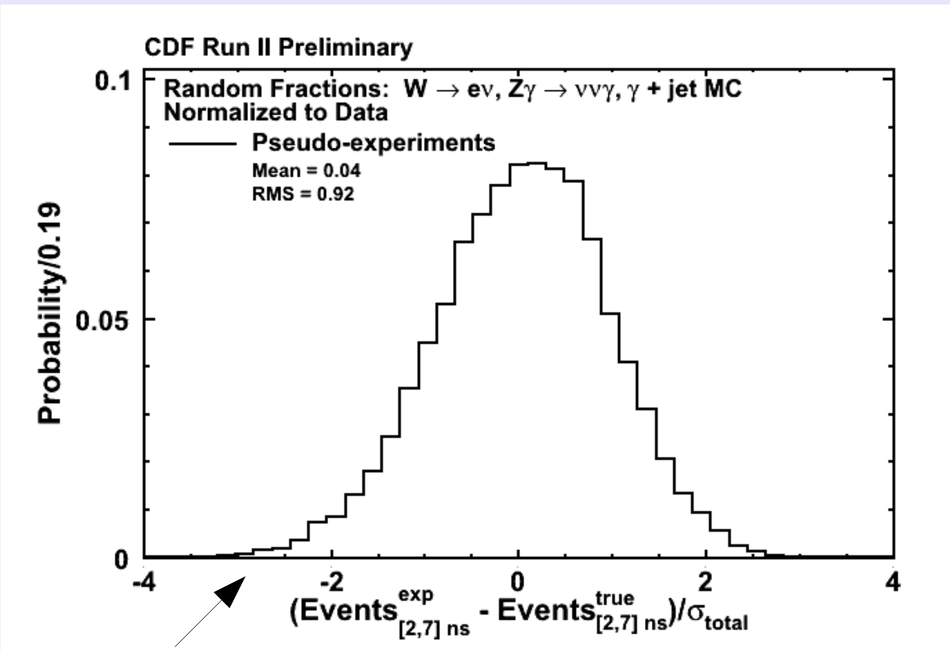
How well does the fitter do for different wrong vertex means?

The wrong-vertex mean is not known a priori.
We vary wrong-vertex mean between 0.0 ns and 0.8 ns to see how well the fitter responds.

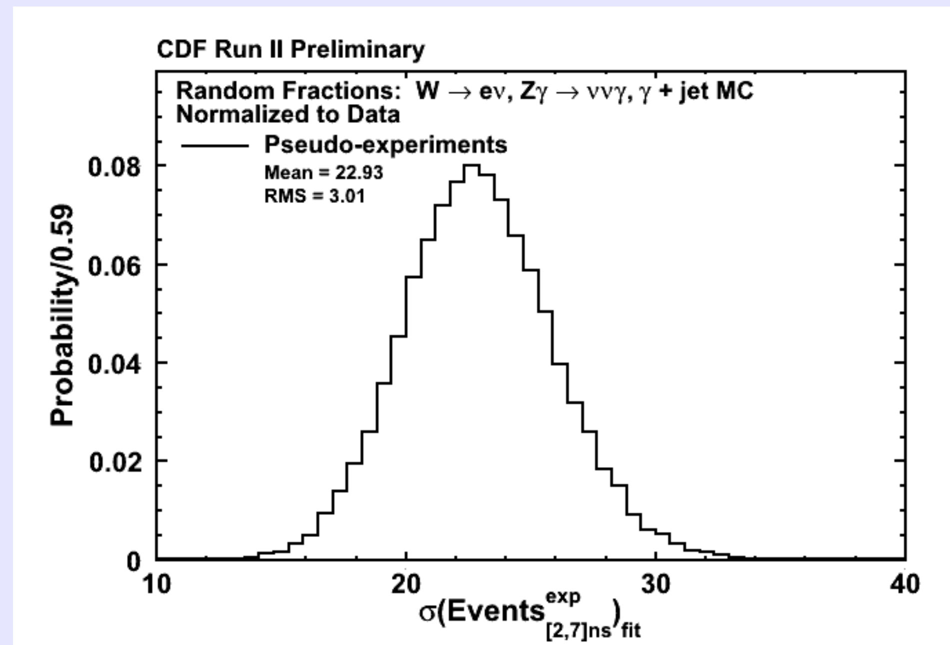


The quality of the estimation of number of events in the signal region is largely not affected by the particular wrong vertex mean chosen.

How well do we do when we combine fully simulated MC samples?



We take Zγ, W → eν, and γ+jet MC in random fractions.

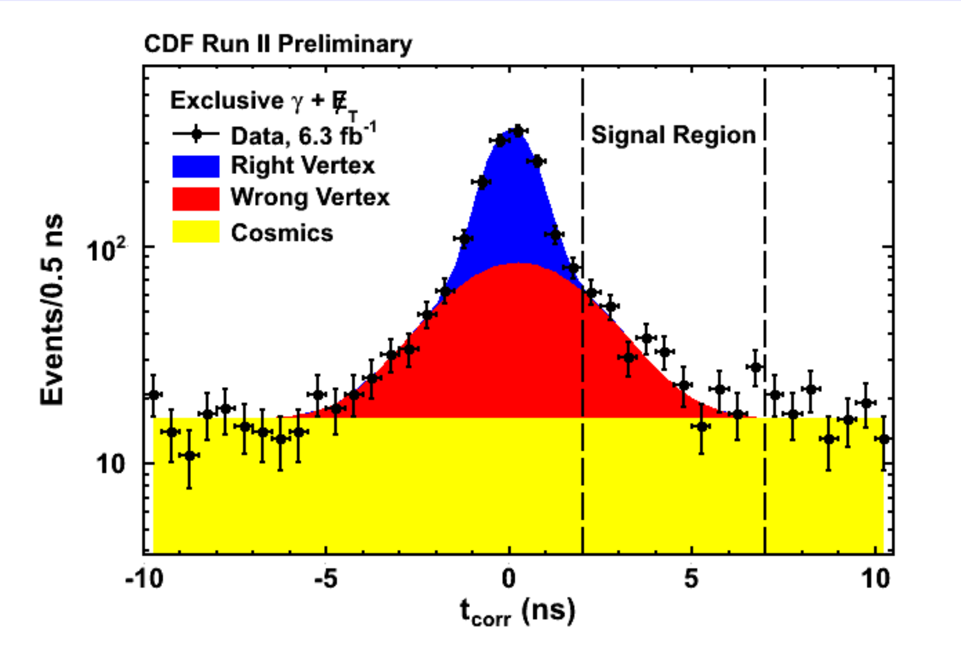


Pull distribution: largely unbiased and the errors well estimated.

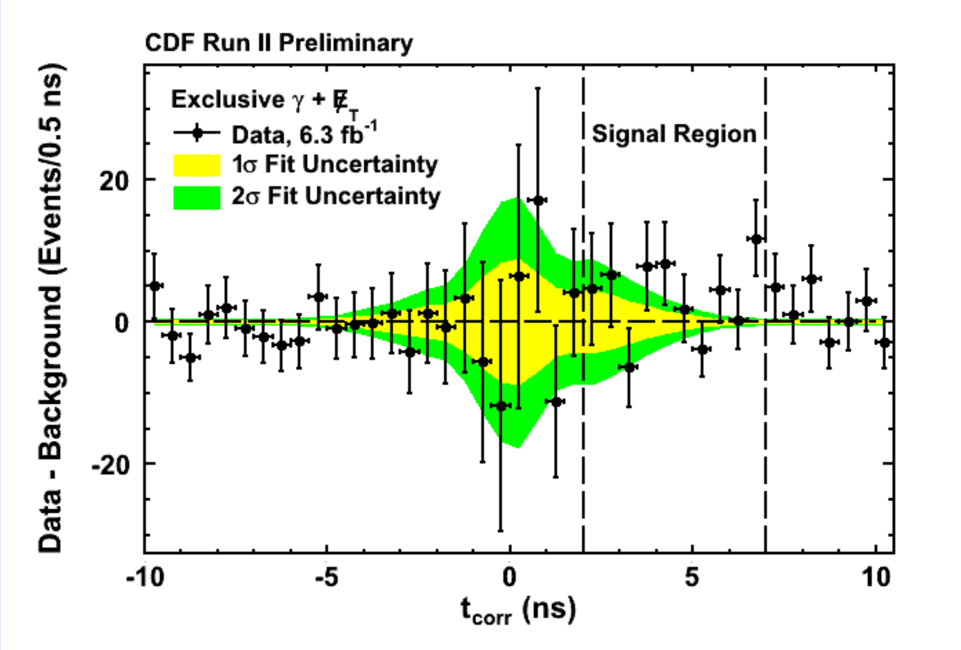
Double Gaussian approximation is very successful, even under worse case combinations.

Fit uncertainty ~23 counts.

Results



N(SR) expected = 286 $\pm$ 24
N(SR) observed = 322



The excess is interesting because almost all bins are high, but the counting experiment significance is only 1.2σ.

What made the excess get so much smaller?

What Happened to the Excess?

- Our new requirements decreased the worst biases
  - $W \rightarrow e\nu$ MC had the worst wrong-vertex mean (~0.8 ns), and it was originally the dominant background. After the ΔR_{pull} cut, it is much less important
- Our background estimation techniques are much better now
  - The wrong-vertex mean in the 4.8 fb^{-1} sample was very large and our previous method assumed it was zero
  - With our old cuts, this method would not have worked

Conclusions

- Studied a previous excess in delayed photons and uncovered a number of previously unknown biases
- Used new requirements to minimize those biases in a way that is very efficient for any signal
- Developed a data driven method to estimate background contributions
- A modest excess remains
- Now on to publication!

Backups

Overview of the Delayed Photon Analysis: Photon Timing

$$t_{corr} = t_f - t_i - \frac{|\vec{x}_f - \vec{x}_i|}{c}$$

t_f = Arrival time measured by the EMTiming system

t_i = Initial time measured by the space-time vertexing

$\vec{x}_f$ = Final position measured in the CES

$\vec{x}_i$ = Initial position measured by the space-time vertexing

Our primary analysis variable is the time of arrival of the photon at the EM calorimeter minus the expected time of arrival.

We calculate the expected time of arrival assuming the photon originated at the event vertex and is prompt.

Space-time vertexing described in: Nucl.Instrum.Meth.A563, 543 (2006)

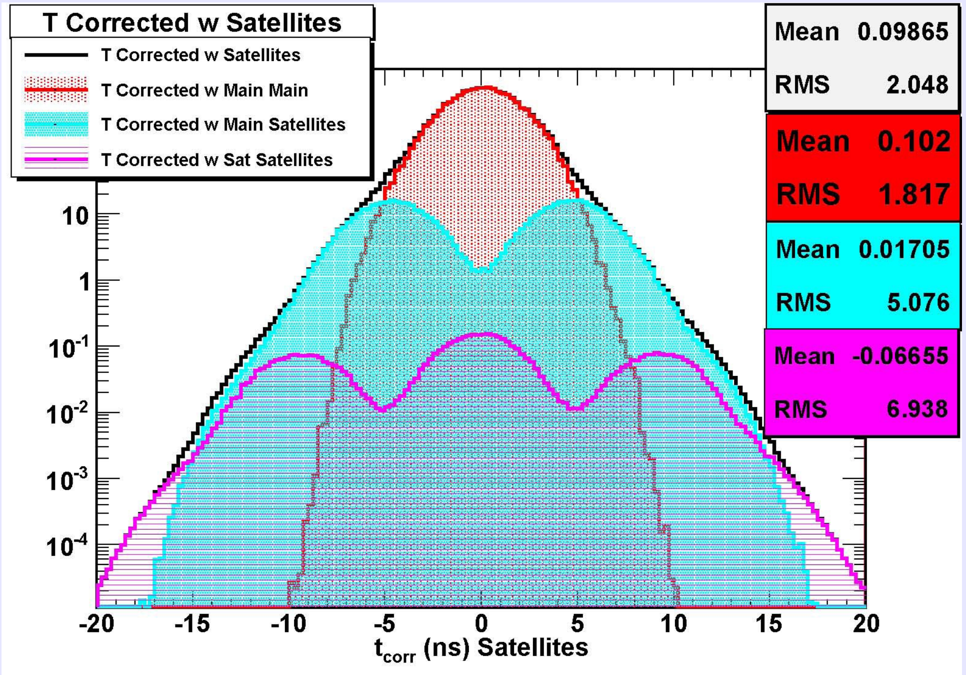
Overview of the Delayed Photon Analysis: Satellite Bunches

Satellite bunches occur 18.8 ns before and after the primary bunches

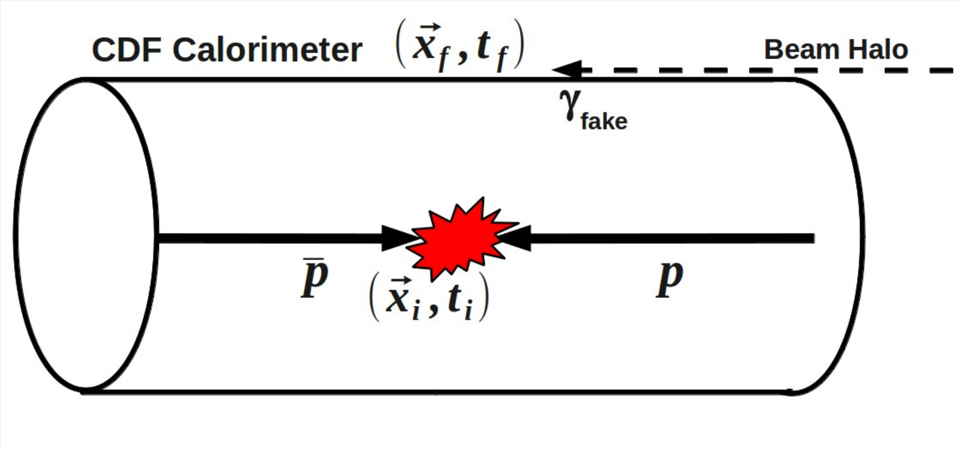
Satellite bunches contain ~1% as many particles as the main bunches do

Satellite-satellite and satellite-main collisions contribute heavily suppressed peaks to the corrected time distribution

These contributions are negligible in this analysis



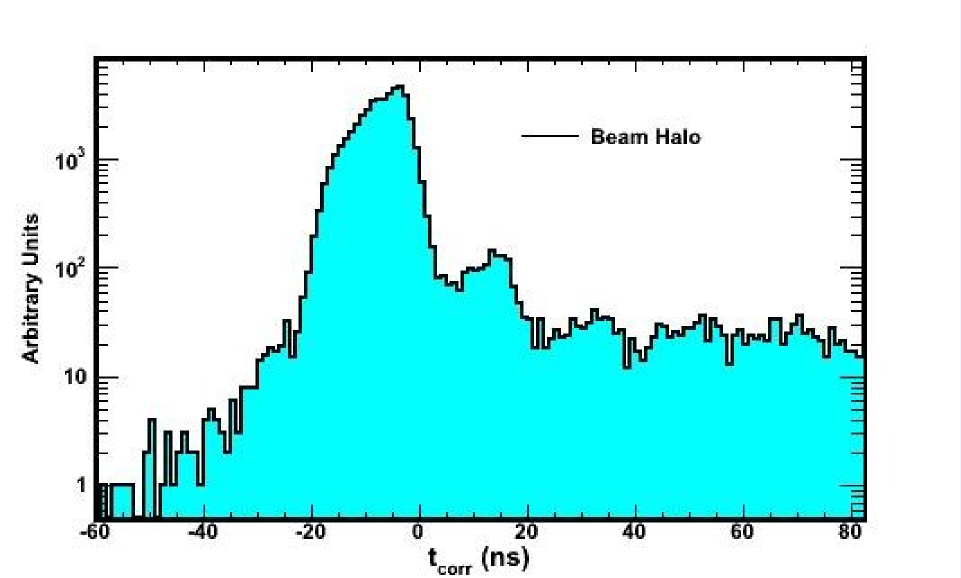
Overview of the Delayed Photon Analysis: Beam Halo



Beam halo particles are typically muons produced beam interactions upstream of the detector

These particles travel parallel to the beam. If they interact in the calorimeter, they predominantly appear as photons arriving earlier than expected.

Our cuts are efficient at removing beam halo

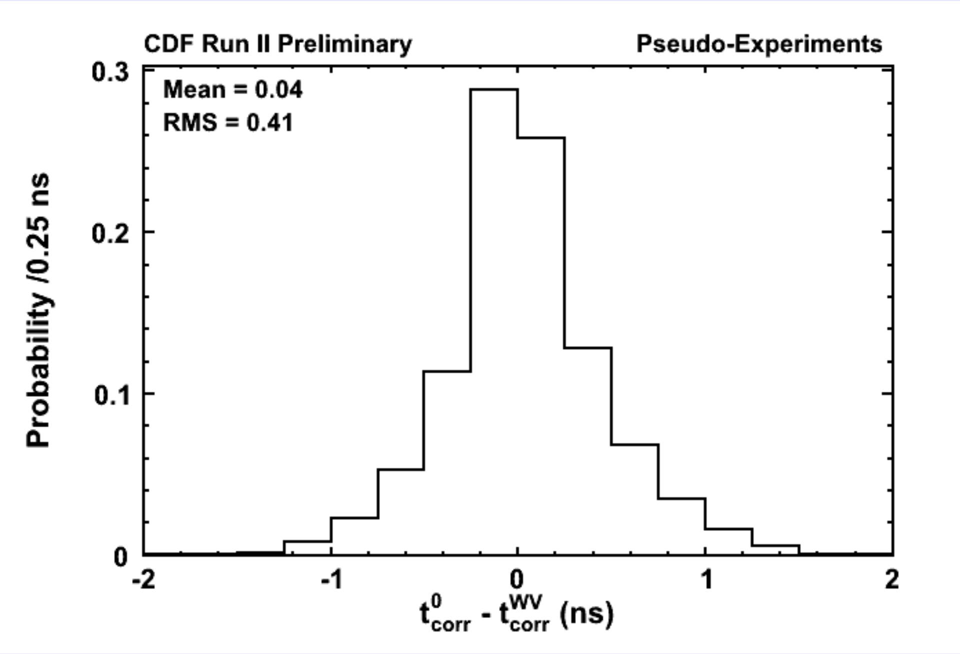


No-Vertex Time and Wrong-Vertex Time Toy MC

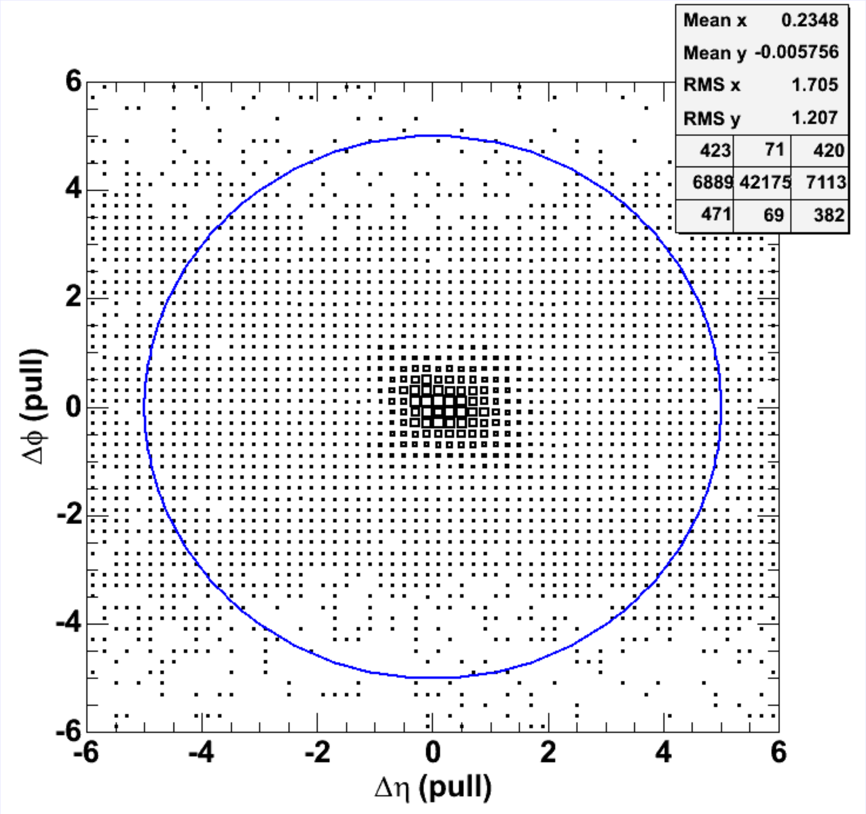
Consider pseudo-experiments where vertices are generated according to the Z and T profiles of the beam spot (Z RMS ~ 28 cm, T RMS ~ 1.28 ns).

Assume spherically symmetric production to determine CES Z.

Shows that if the process dependent geometric time of flight difference is the same for no-vertex and wrong-vertex events, the means of the two distributions will be very close.

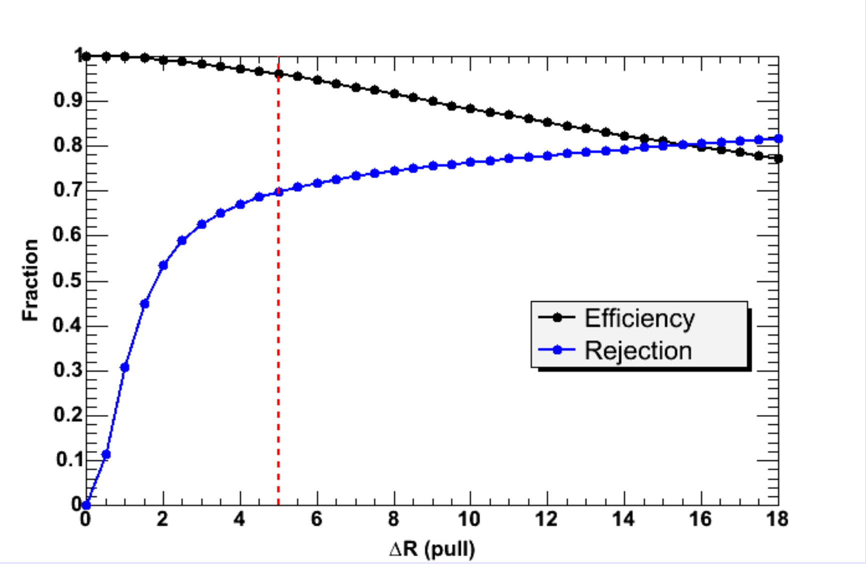


ΔR(pull)



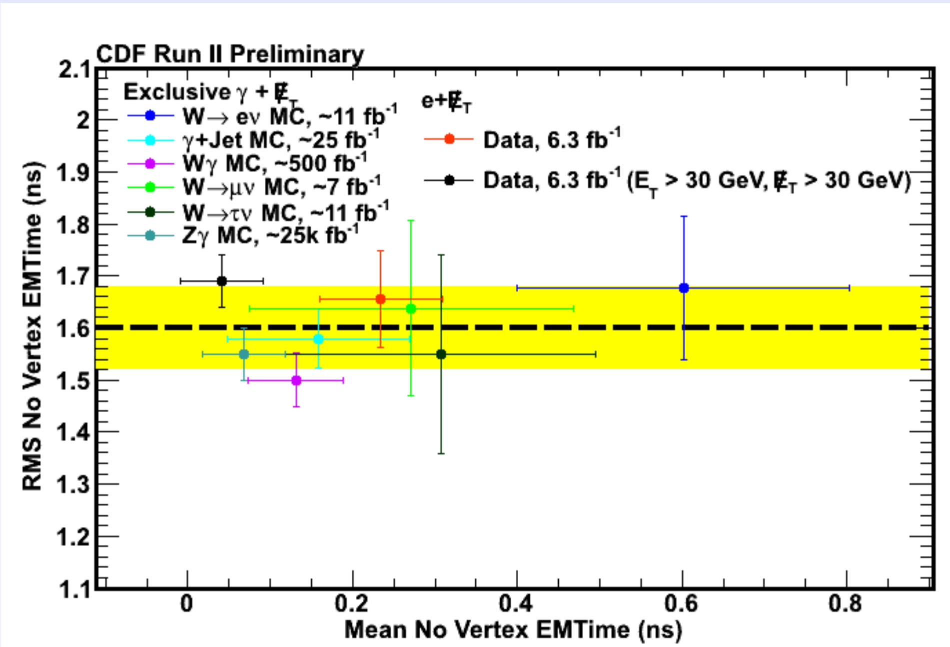
-Find the track with Φ_o and η closest to the reconstructed photon.

-Standardize the variables to account for worse resolution in Φ_0 due to the "kink" in the track from the hard interaction.



Vetoing reconstructed photons with a track with ΔR(pull) < 5 removes 73% of fake photons while accepting 95% of real photons.

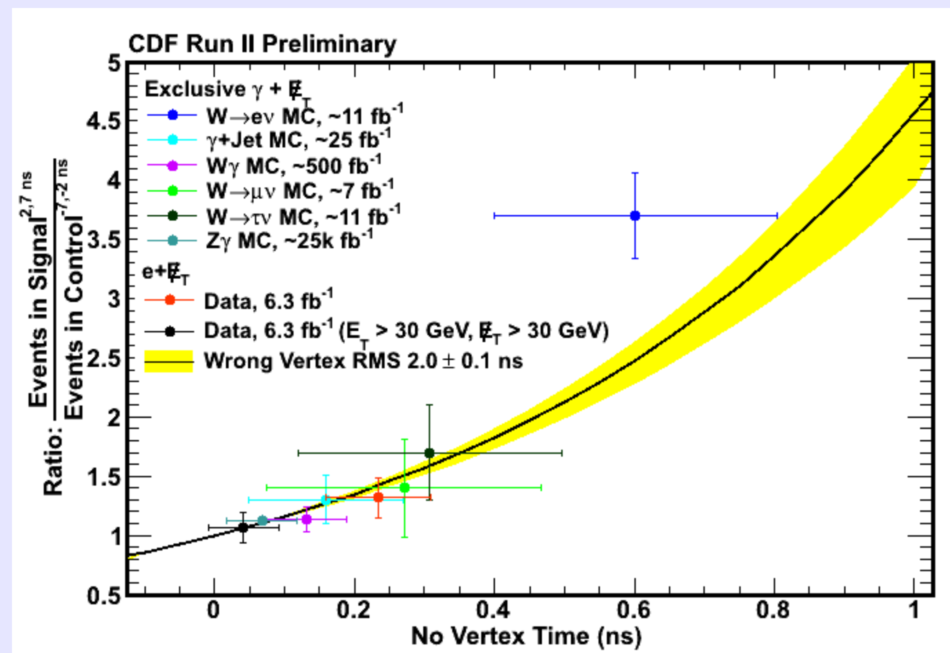
Predicting N(SR)/N(CR) From No Vertex Mean



N(SR)/N(CR) follows the prediction from the no-vertex mean as well as for the wrong-vertex mean → we can use the no-vertex mean as proxy for the wrong-vertex mean.

We isolate no vertex events in Monte Carlo and electron data and fit to find the no vertex mean.

The RMS of the no-vertex distribution does not depend on the mean of the distribution.



Combined Likelihood Function

$$-\ln L = \sum_{i}^{Nbins(GV)} \nu_i^{GV} - n_i^{GV} \ln \nu_i^{GV} + \sum_{j}^{Nbins(NV)} \nu_j^{NV} - n_j^{NV} \ln \nu_j^{NV} + \sum_{k}^{Nconstraints} \frac{(\theta_k - \theta_k^0)^2}{2\sigma_k^2}$$

Good vertex portion includes bins between (-7,2) ns and (20,80) ns

No vertex portion includes bins between (-3.5, 3.5) ns and (20,80) ns

ν is the number of expected events in a bin

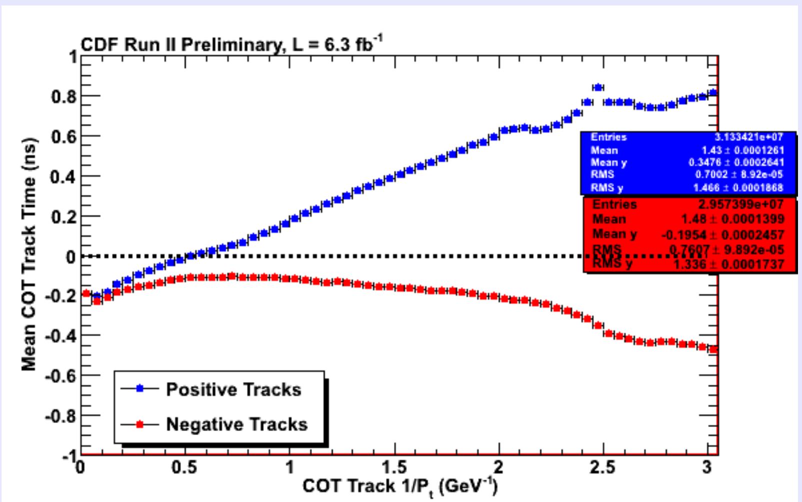
n is the number of observed events in a bin

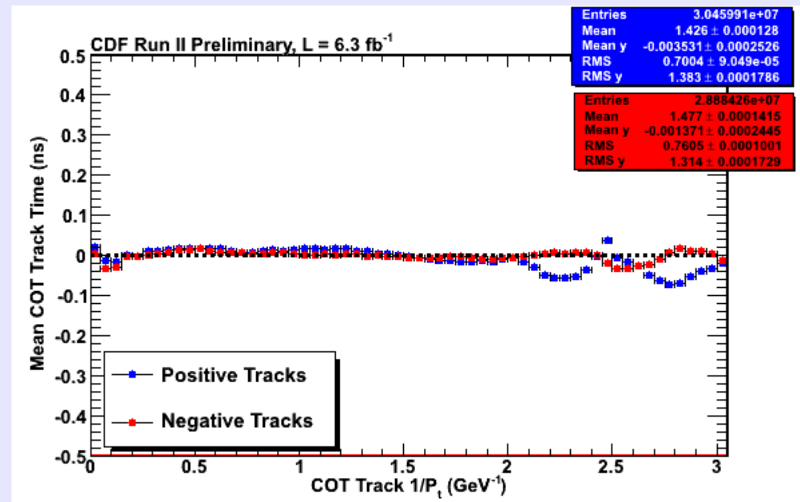
θ_k is the parameter being constrained

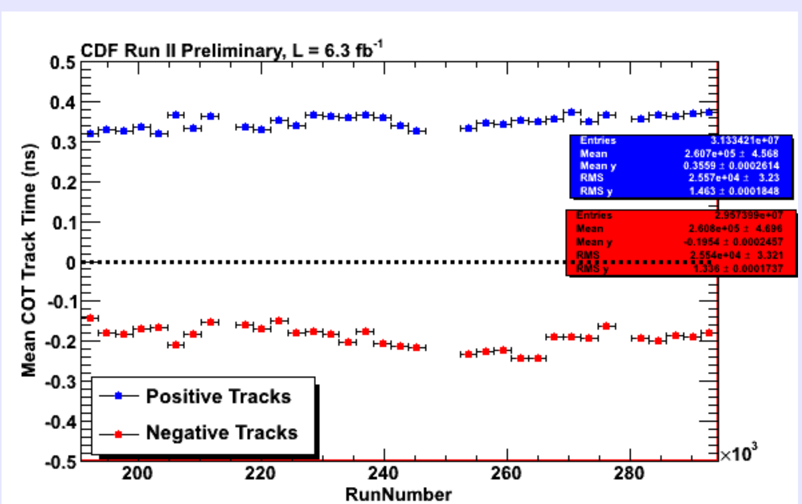
θ_k^0 is the nominal value of the constrained parameter

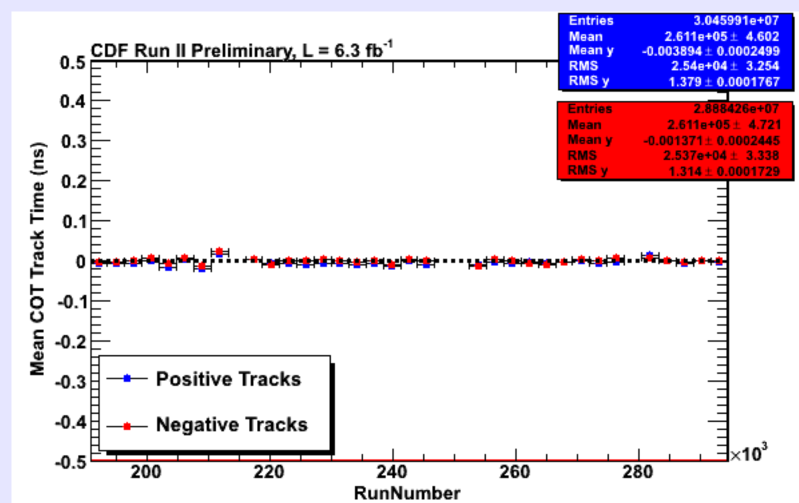
σ_k is the systematic uncertainty on θ_k

COT Track t_0 Corrections

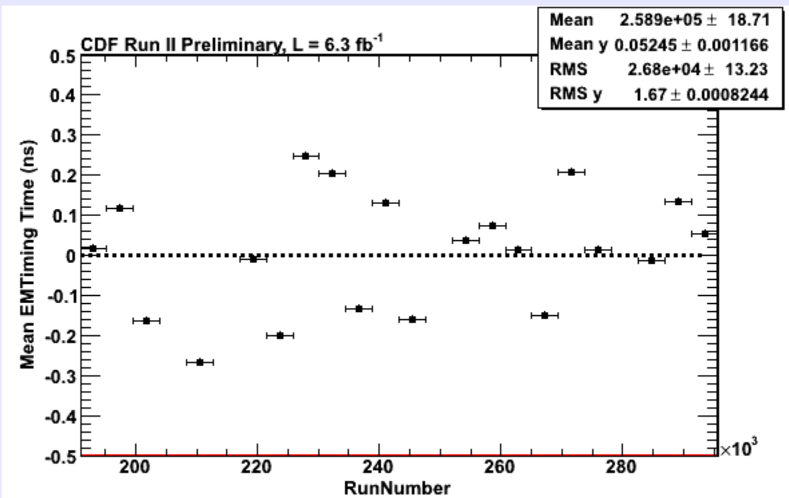


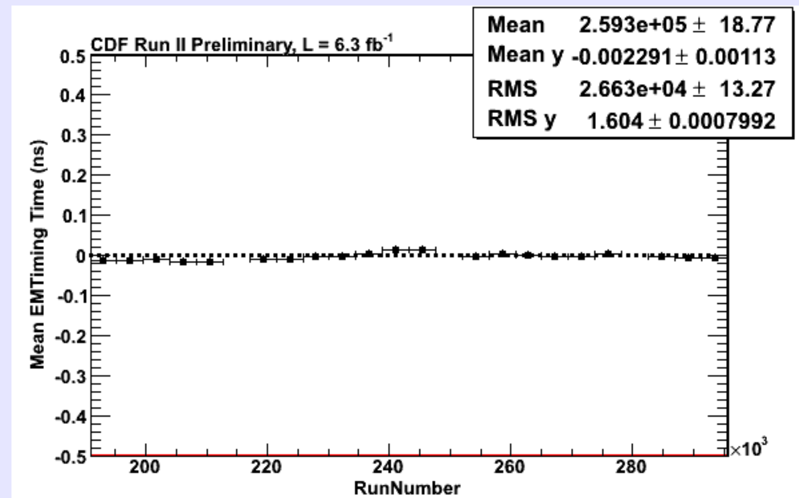


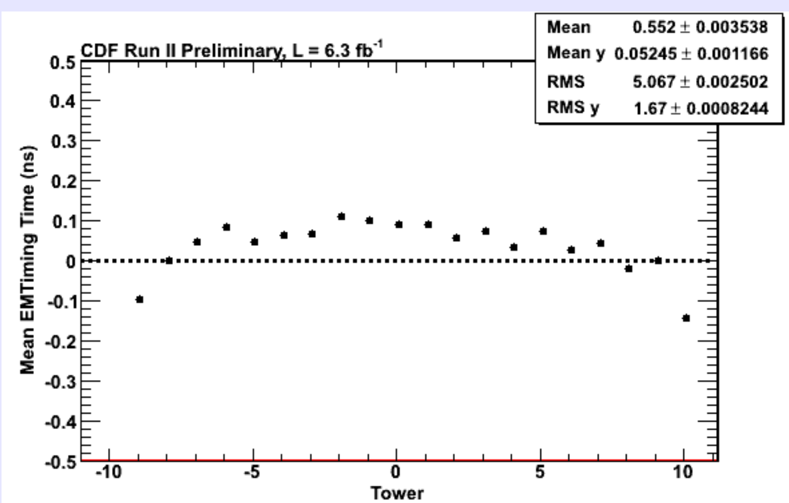


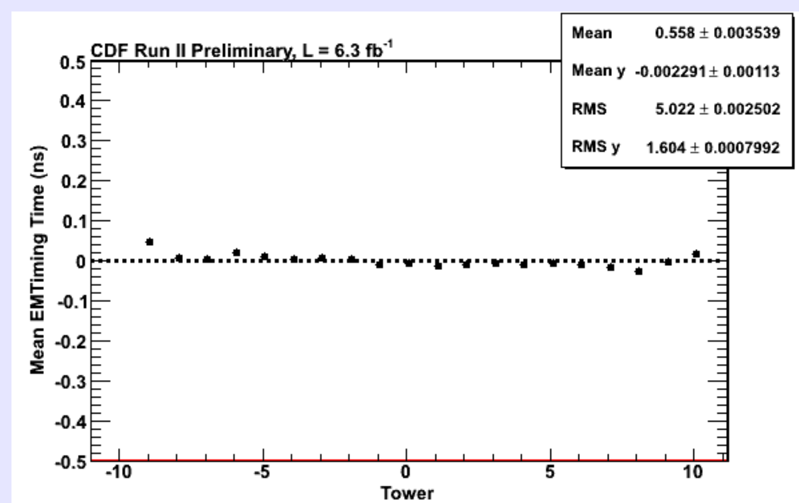


EMTiming Corrections









Overview of the Delayed Photon Analysis: Timing Regions

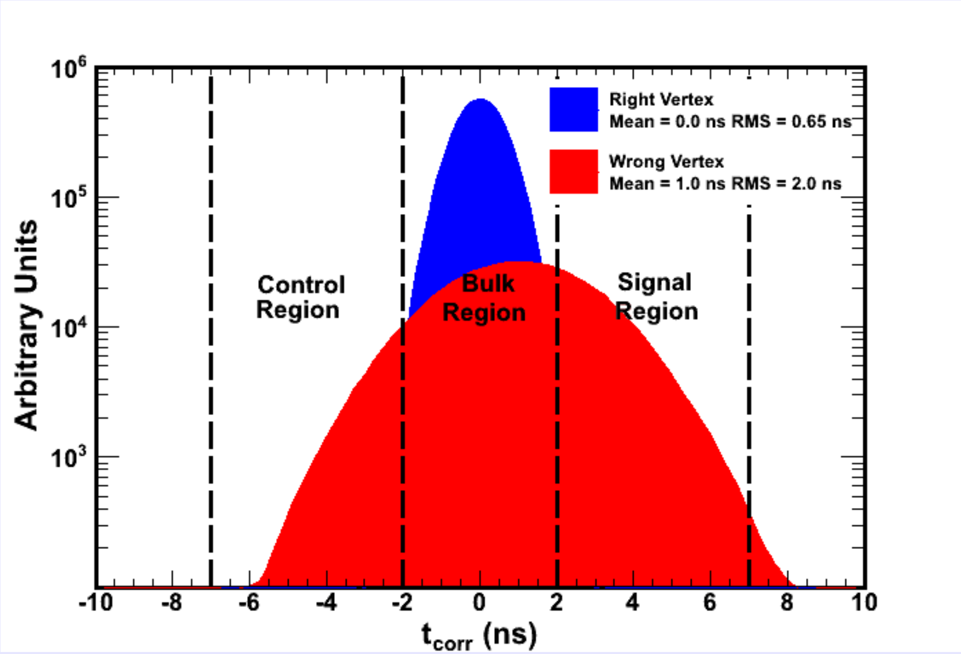
Timing Regions:

Wrong Vertex Sideband
-7 ns < t_{corr} < -2 ns

Right Vertex Sideband
-2 ns < t_{corr} < 2 ns

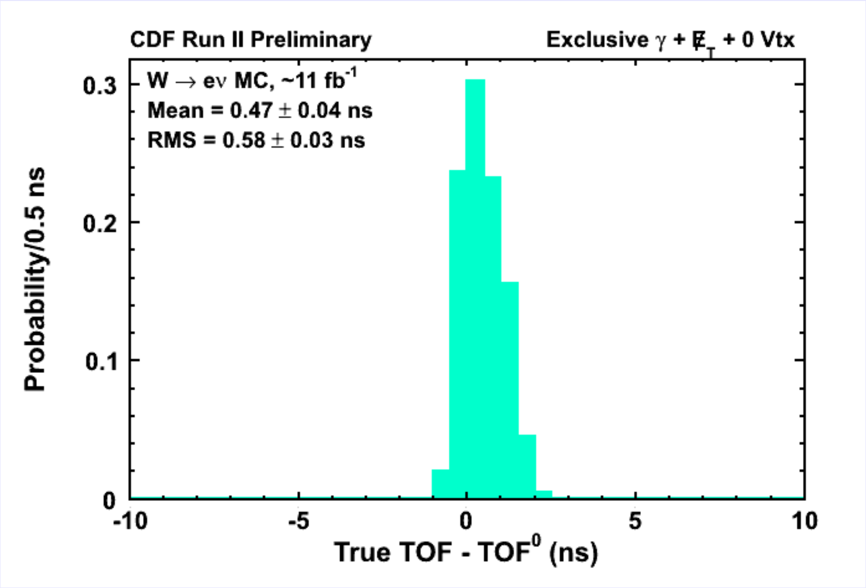
Cosmics Sideband
20 ns < t_{corr} < 80 ns

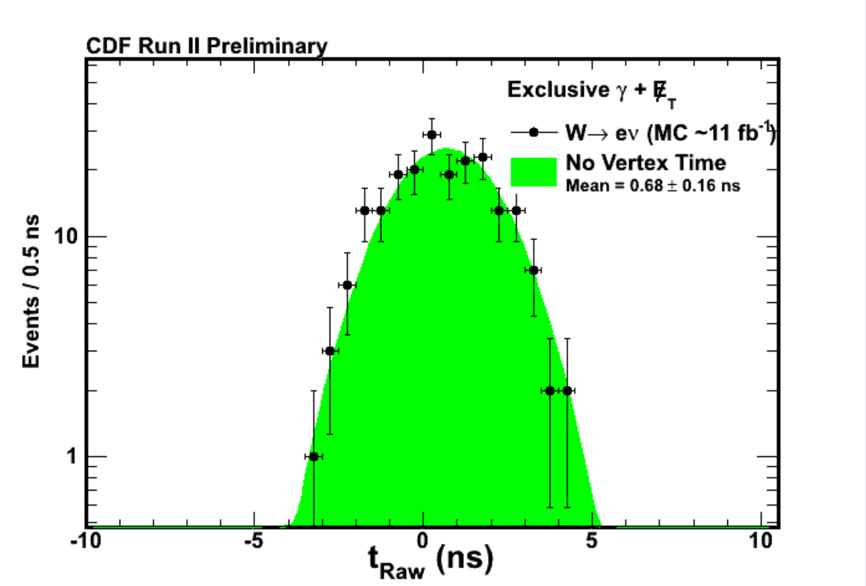
Signal Region
2 ns < t_{corr} < 7 ns

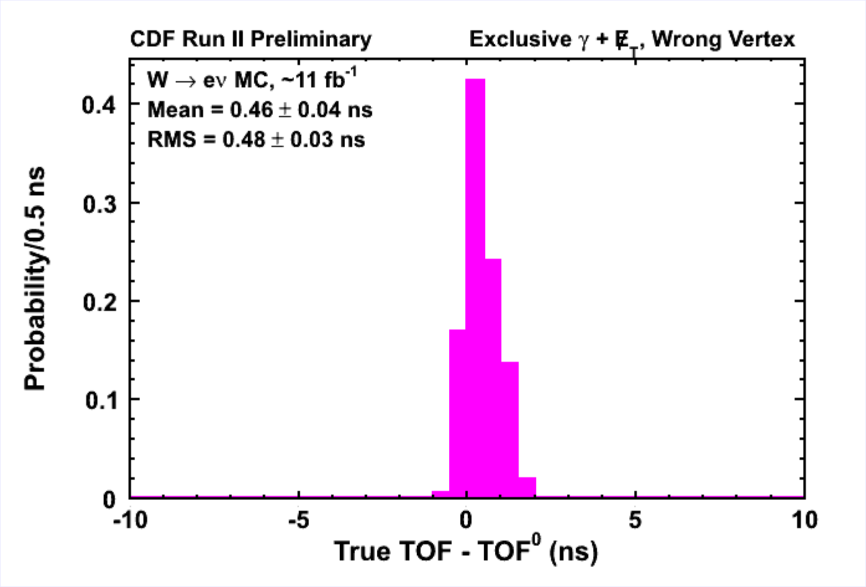


The number of events in the signal region and the wrong vertex sideband directly depend on the wrong-vertex mean.

No-Vertex: $W \rightarrow e\nu$

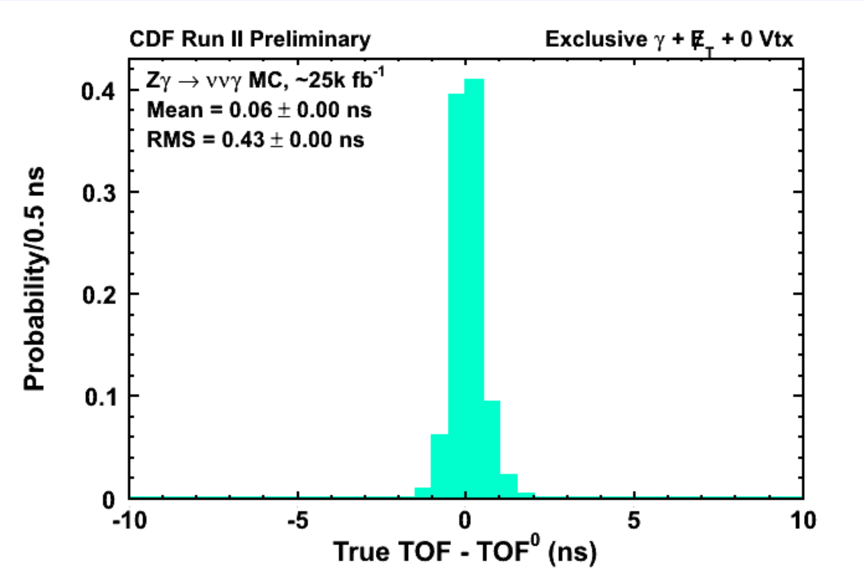


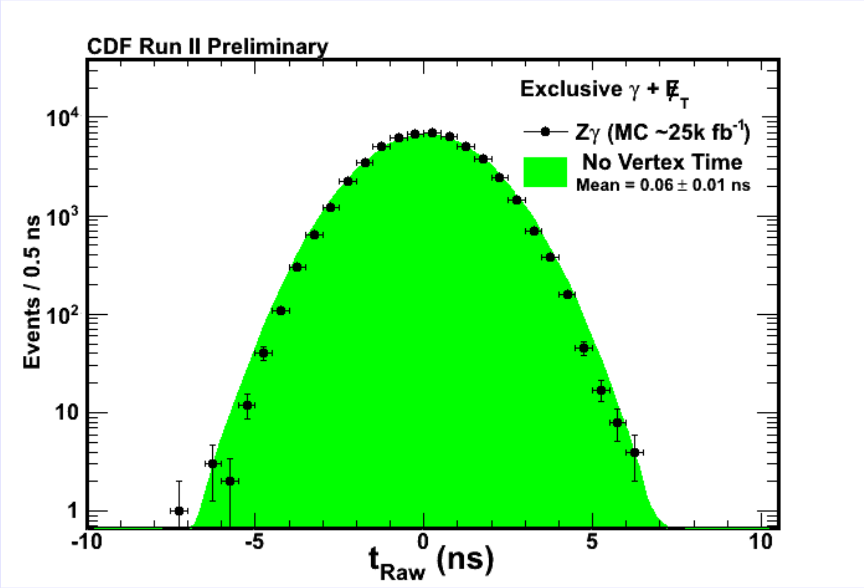


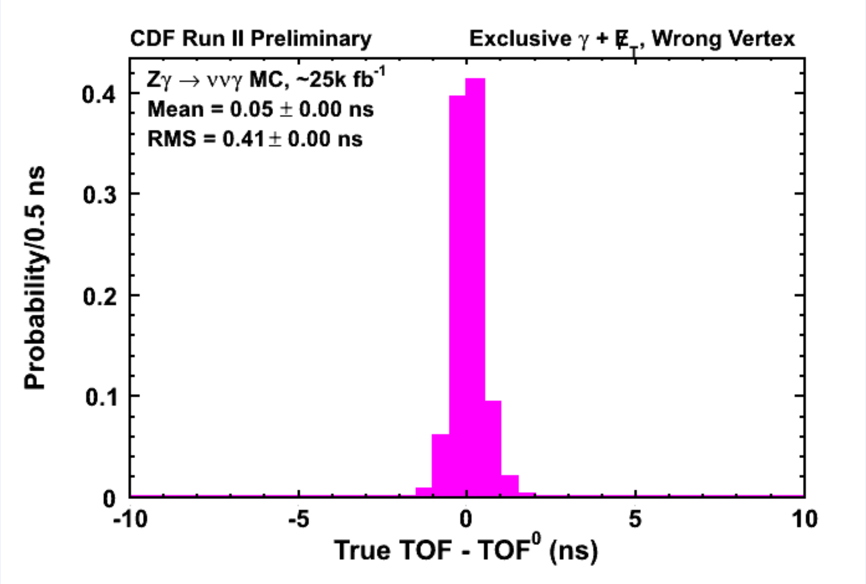


The means for wrong-vertex events and no-vertex events are very close. The smearings due to the distribution of vertices only smooth out any non-Gaussian behavior.

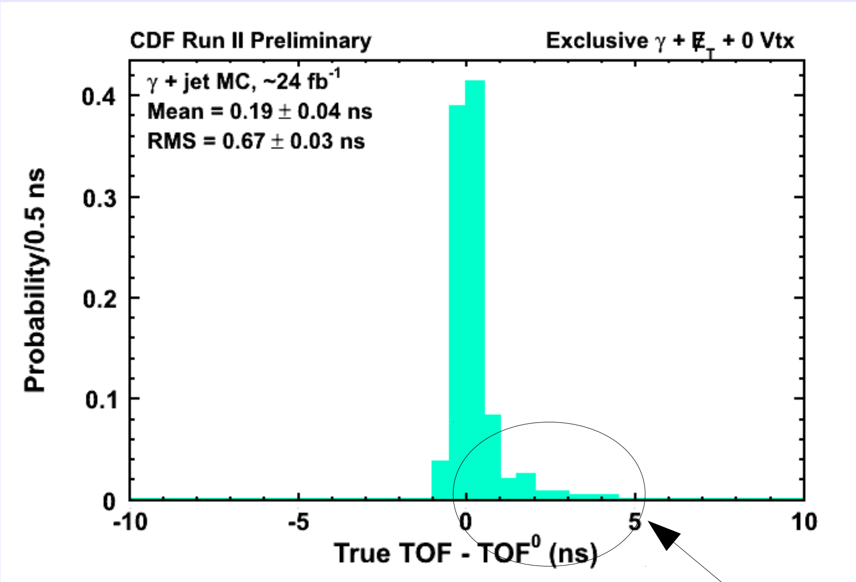
No-Vertex: $Z\gamma \rightarrow \nu\nu\gamma$

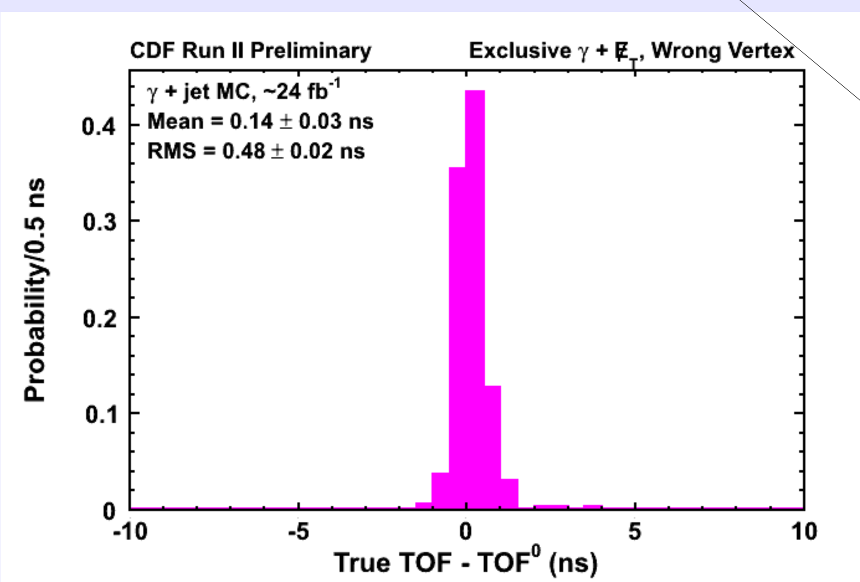


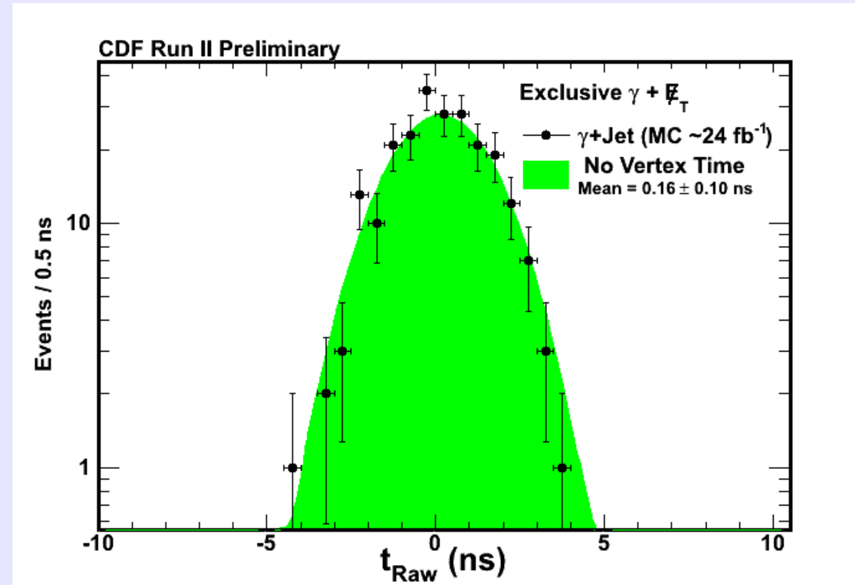




No-Vertex: γ+jet







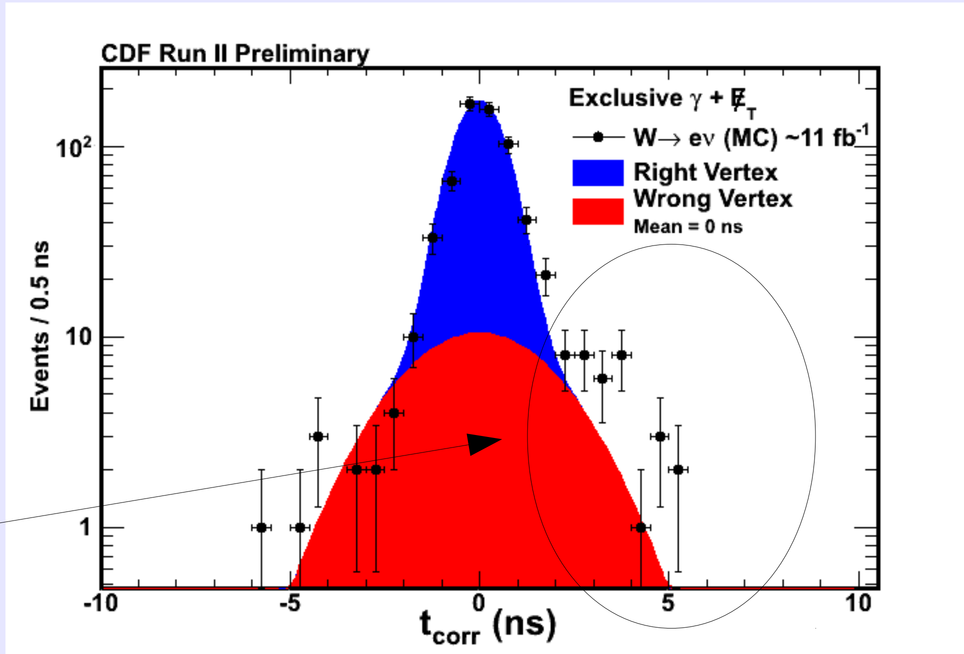
This tail is due to a small number of remaining events with very large |Z| production that escape the large |Z| veto. We see in our fit testing that this does not disrupt our fitting method.

Overview of the Delayed Photon Analysis: Wrong Vertex Mean

Is taking the wrong vertex mean = 0 a good assumption?

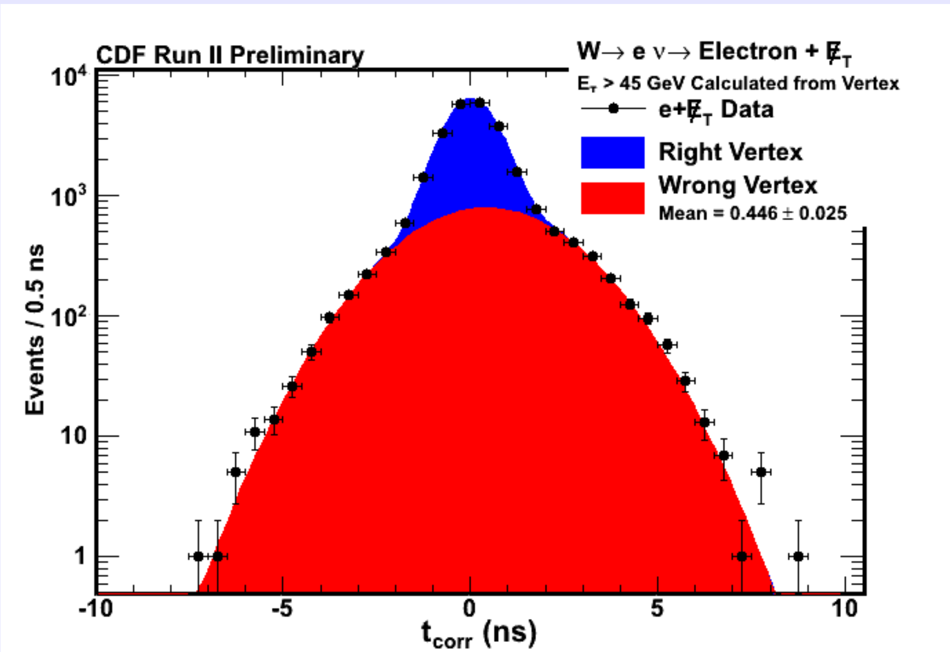
Fit W → eν from (-7,2) ns assuming the wrong vertex mean is zero.

Very bad assumption!



We need a method that can handle a non-zero wrong vertex mean.

E_T Threshold Effect (cont.)

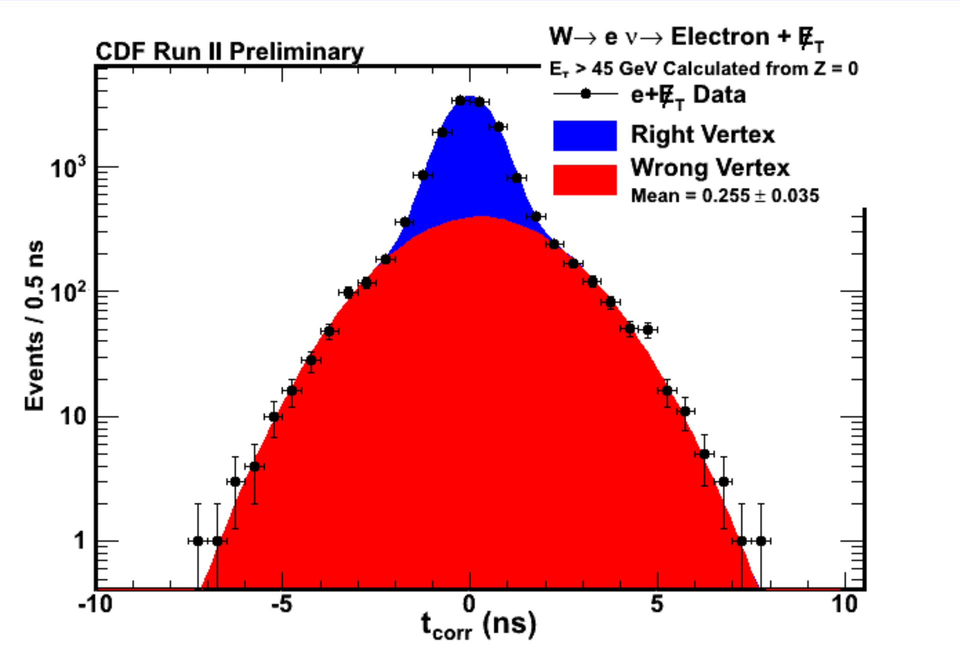


We fit W → eν data and Monte Carlo with the wrong vertex mean allowed to float.

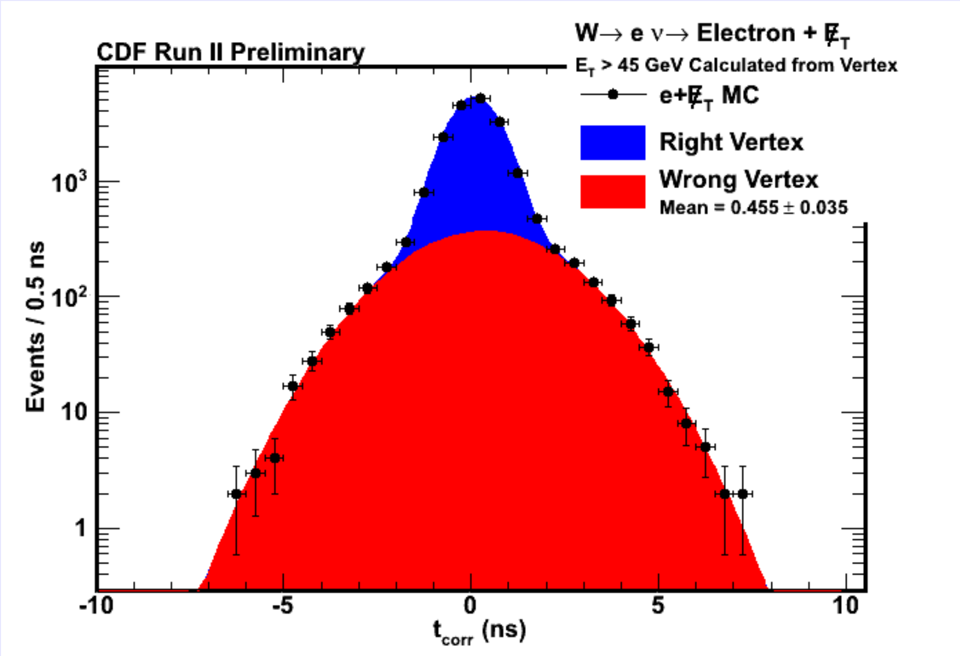
We see similar wrong vertex means in both data and MC.

How can we decouple the measured time from the measured E_T?

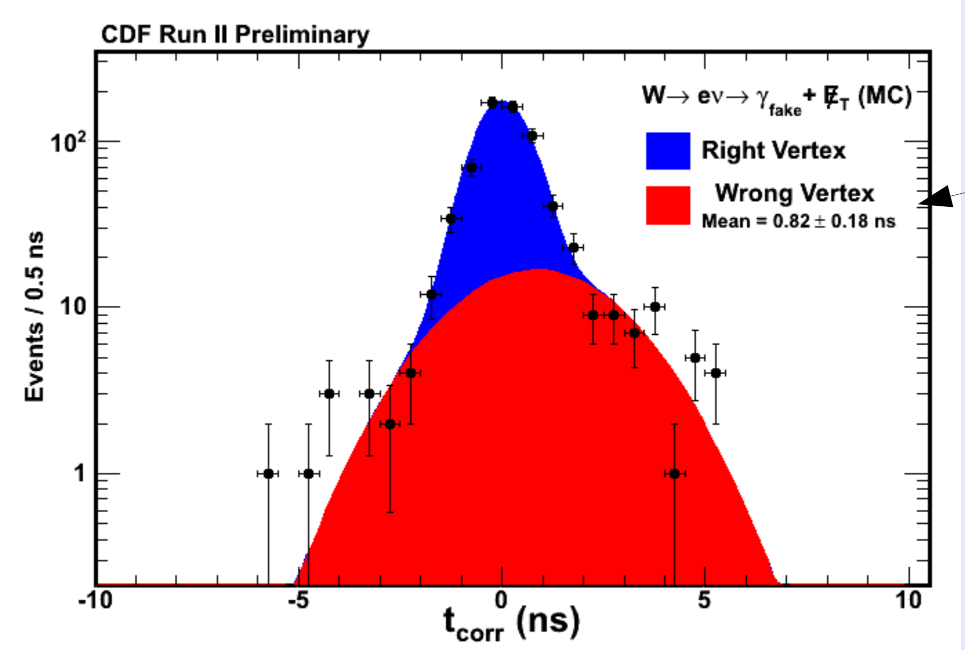
E_T^0 Cut



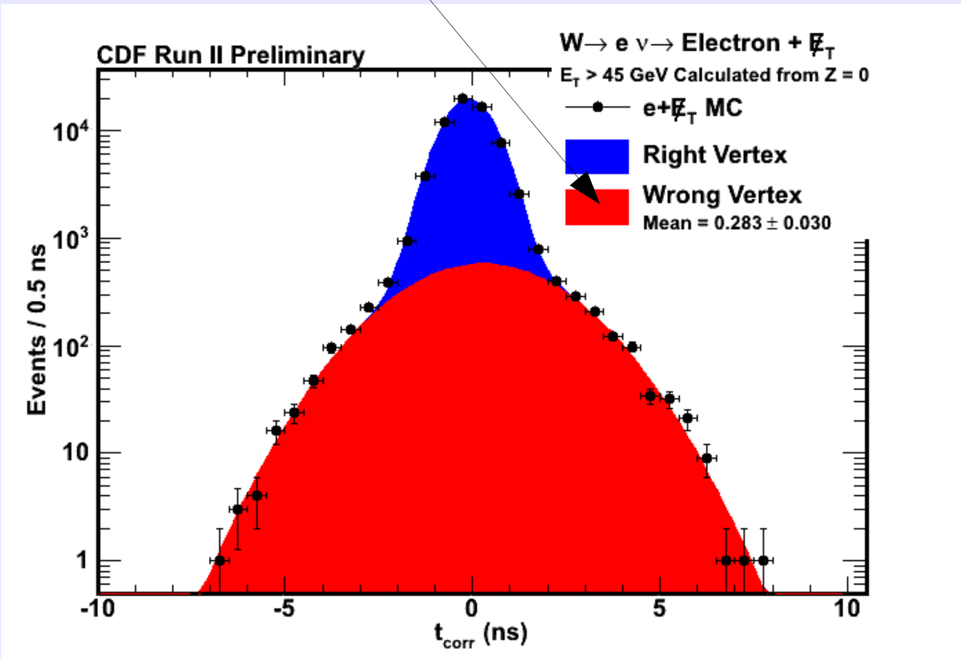
If we cut on E_T calculated relative to Z = 0, we limit how wrong we can be. The measured time and E_T are no longer completely coupled, and the mean shift is halved!



Effect 2: Fake Photons



Even after the E^0_T cut, $W \rightarrow e\nu \rightarrow \gamma_{fake}$ + MET still has a larger mean shift & much larger than W-> eν → e + MET has.

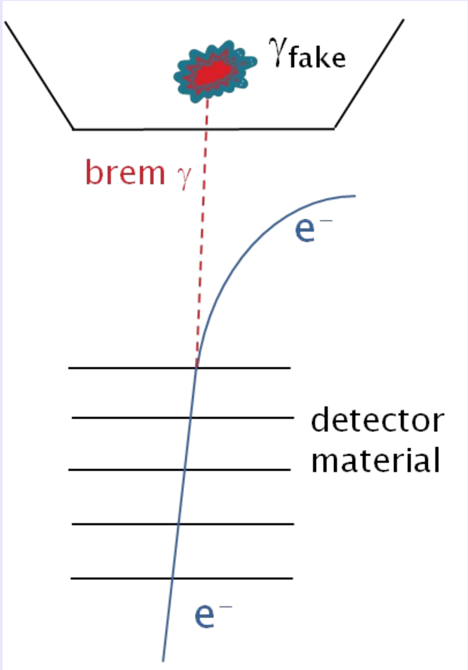


The difference is due to how electrons lose their tracks to look like photons.

This is our largest single background, so it's important to try to reduce it.

Fake Reduction

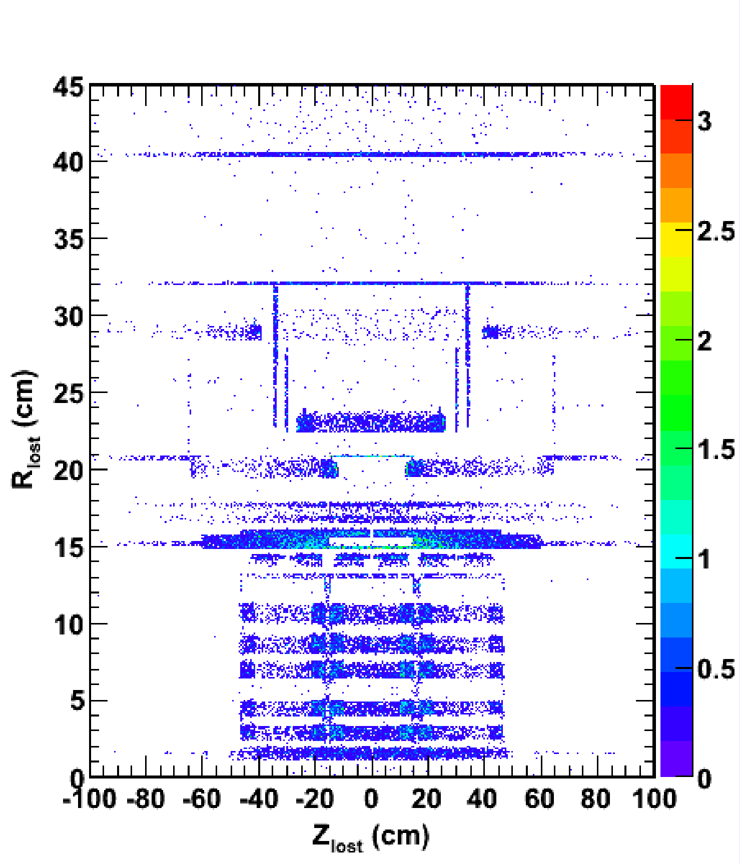
How can we reduce the number of fake photons?



-Fakes are overwhelmingly due to hard interactions.

-Hard interactions are most likely in dense regions (SVX, bulkheads, port cards, etc)

-The electron that gave rise to the fake photon should have started life pointing towards the calorimeter deposit.

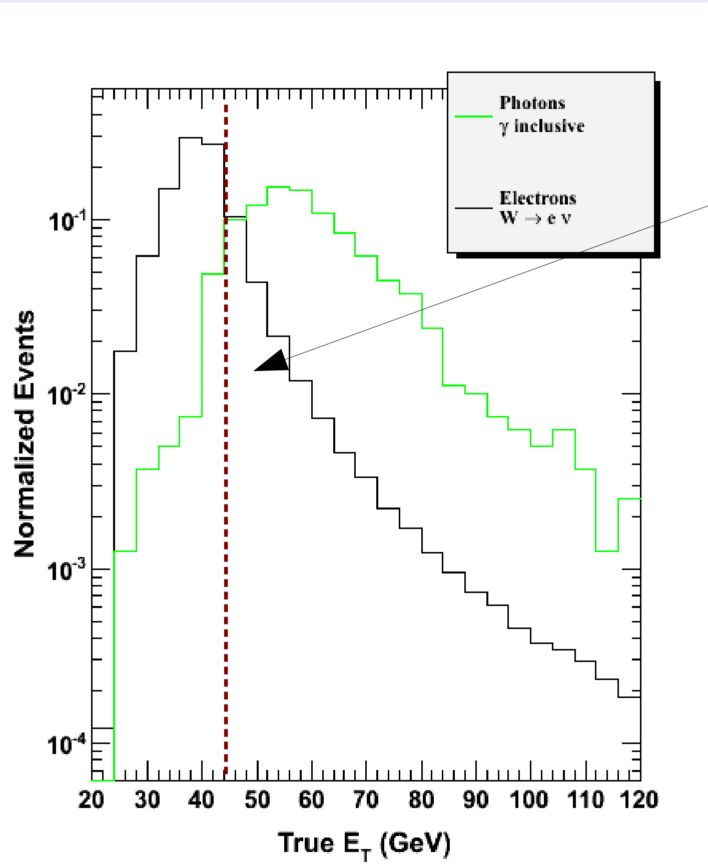


Look for tracks with initial direction close to the reconstructed photon.

See CDFnote 8308

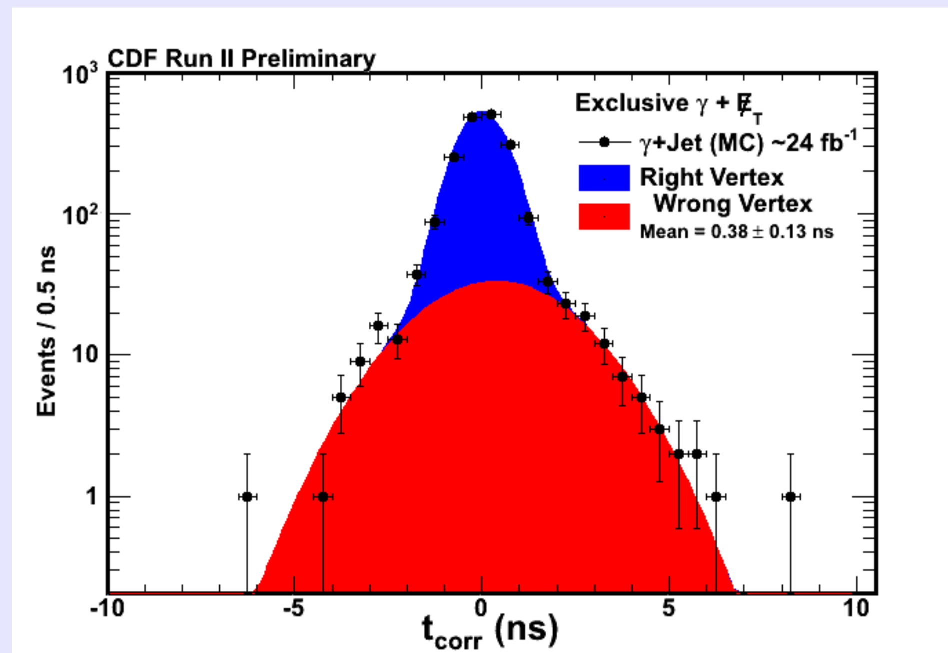
W → eν MC "xray" of where hard interactions tend to happen.

Effect 3: Lost Objects



γ+j → γ + MET does not have many event to promote over threshold like W → eν.

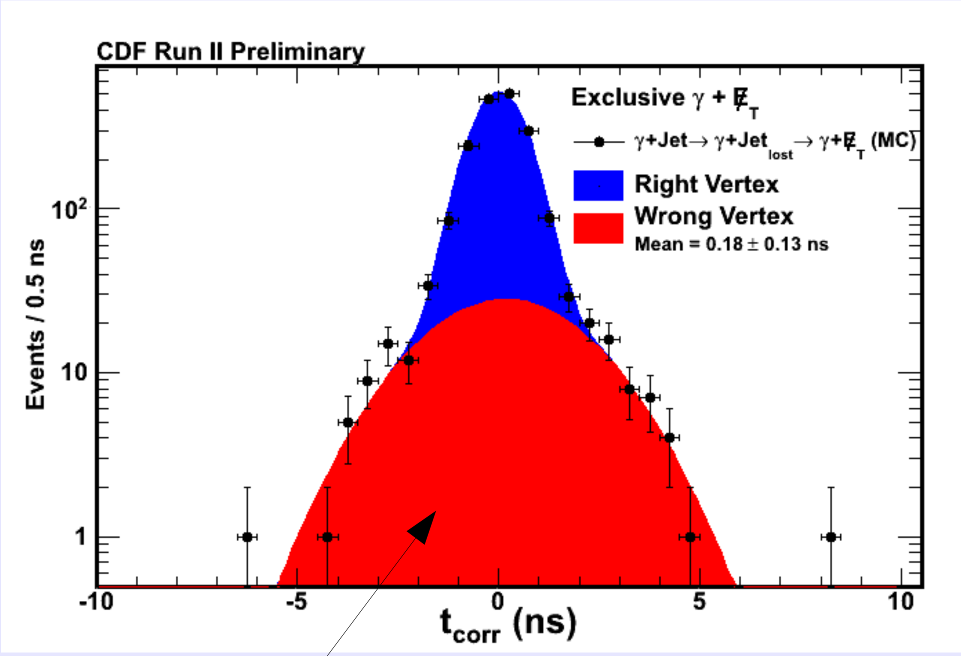
Virtually all reconstructed photons here are real photons, not fakes.



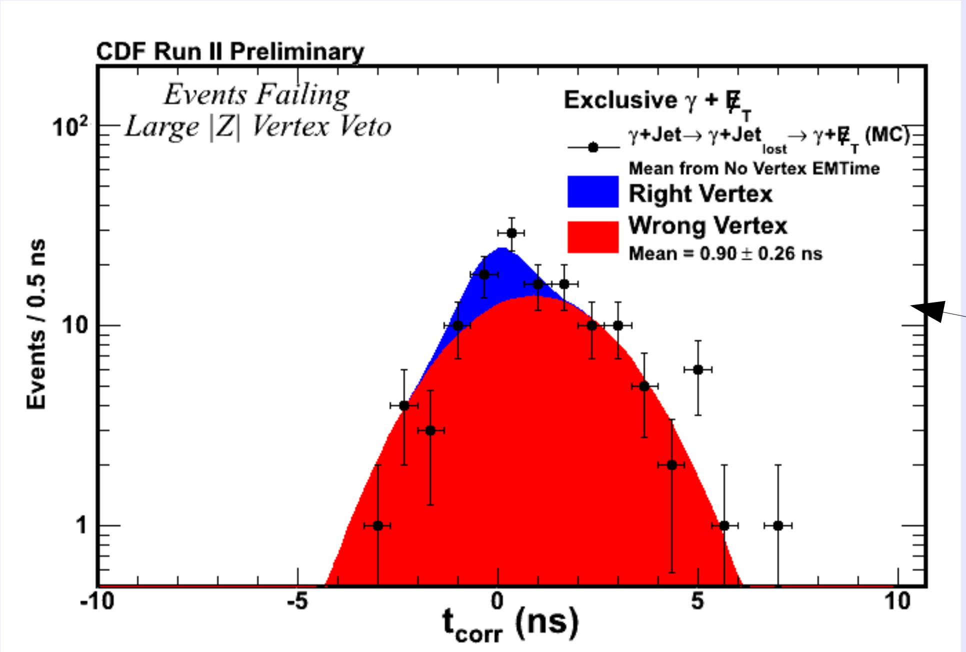
Why is the mean still so shifted?

Large |Z| Veto

- Veto any event with a standard vertex with |Z| > 60 cm if it contains at least 3 tracks.
- This almost halves the γ+j wrong vertex mean.
- Using cosmics, we find this cut 96% efficient.

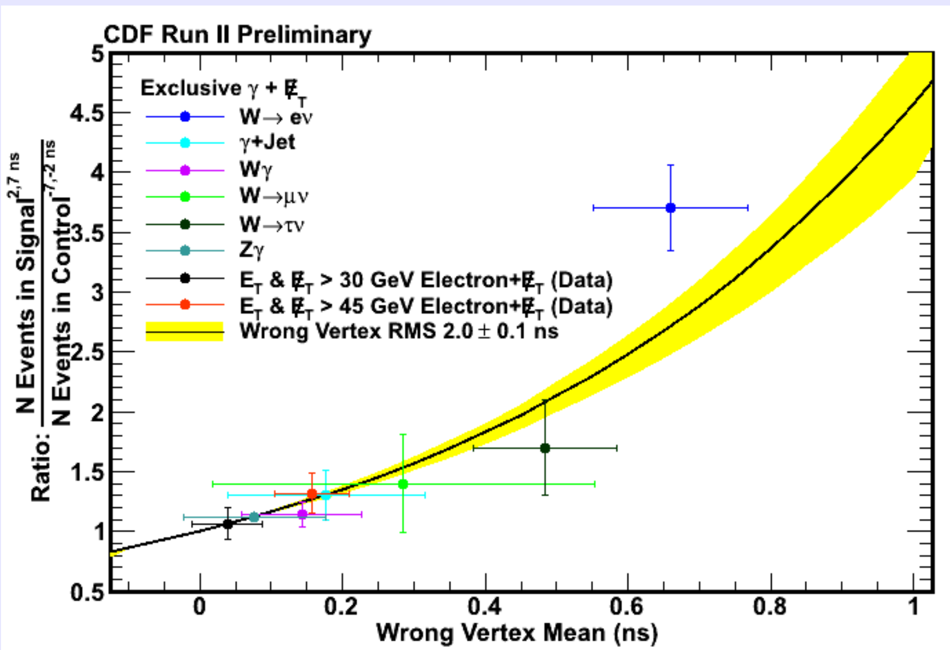


Passing Z Veto



Failing Z Veto
Rejected wrong vertex events are very highly shifted.

N(SR)/N(CR) vs. Wrong Vertex Mean

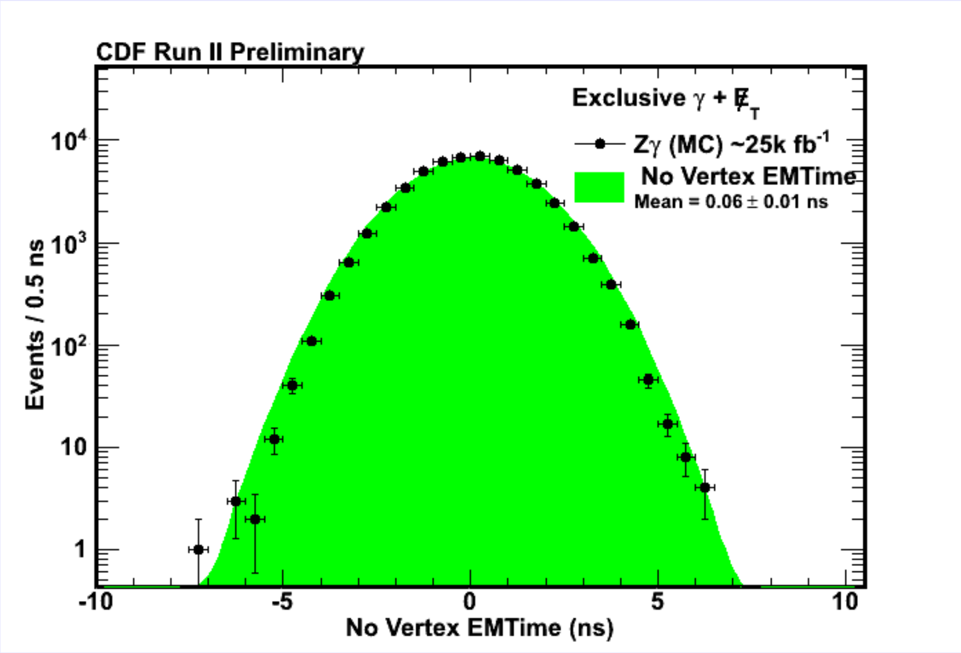


If the double Gaussian approximation holds, we can predict the ratio N(SR)/N(CR) using just the wrong vertex mean.

We isolate wrong vertex events in Monte Carlo and fit to find the wrong vertex mean.

N(SR)/N(CR) follows the prediction from the wrong vertex mean well → the double Gaussian approximation holds.

No Vertex Distribution

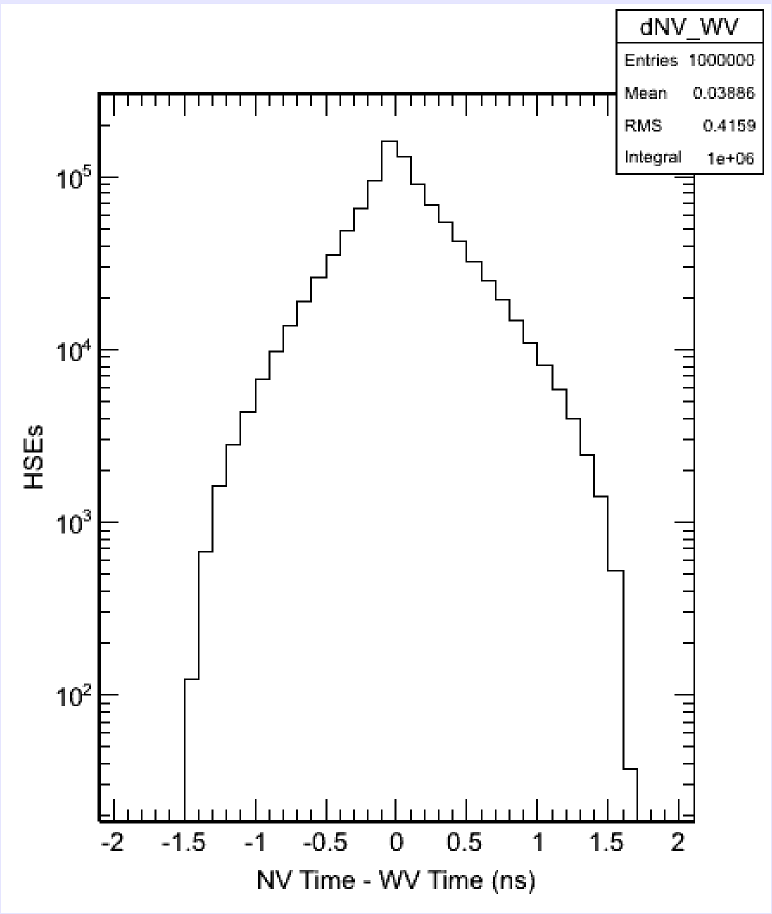


If no good vertex reconstructed, we can still construct the raw time variable: the corrected time, around a vertex with Z = 0 and T = 0.

The raw time distribution is Gaussian with RMS ~1.6 ns.

We will show that the mean of the no vertex distribution is always close to that of the wrong vertex distribution.

No Vertex Time – Wrong Vertex Time: Toy MC



Wrong vertices are distributed according the the beam profile. In Z, they are Gaussian distributed with a mean of ~0 cm and an RMS of ~ 28 cm. In T, they are Gaussian distributed with a mean of ~0 ns and an RMS ~1.28 ns.

Toy MC:

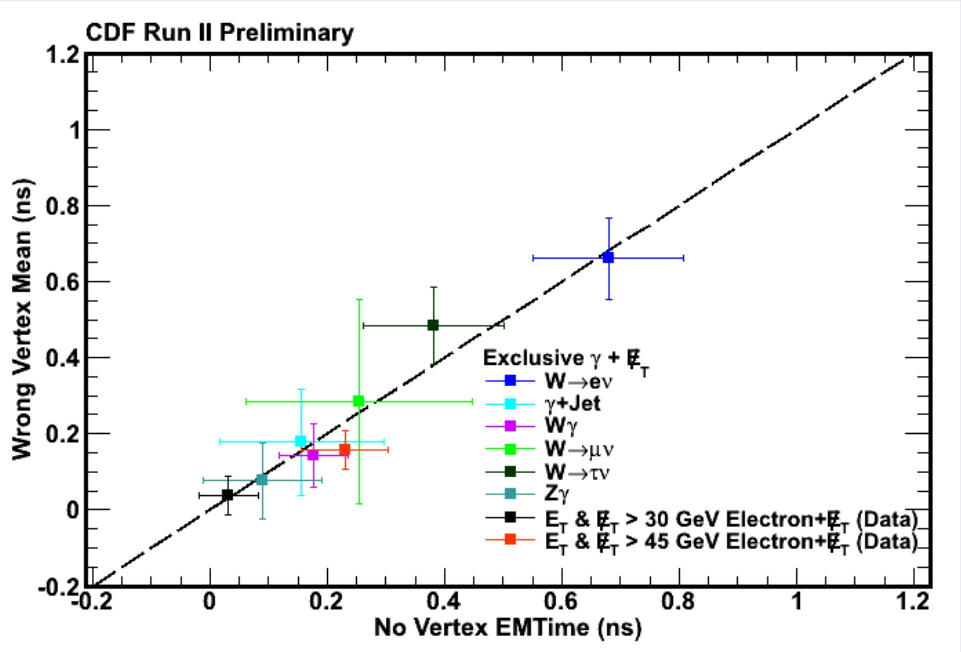
-Generate wrong vertices following the beam parameters.

-Determine Z_{CES} assuming a spherically symmetric decay.

-Calculate the corrected time and raw time.

On average, the corrected time and raw time are very close.

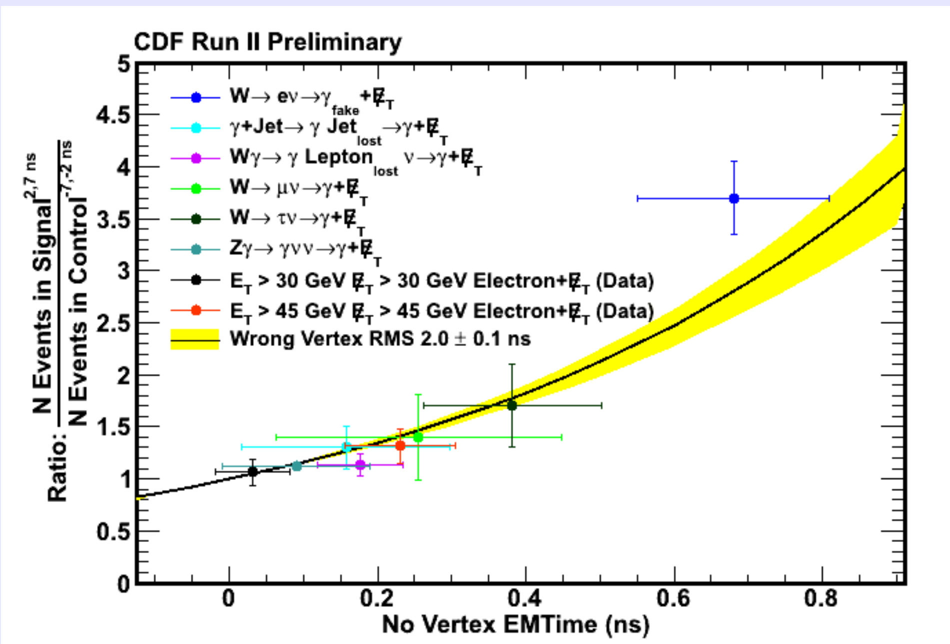
Comparing No Vertex and Wrong Vertex



Both Monte Carlo samples and electron data show good agreement between the fitted no vertex and wrong vertex means.

We take a 100 ps systematic uncertainty to cover the variation.

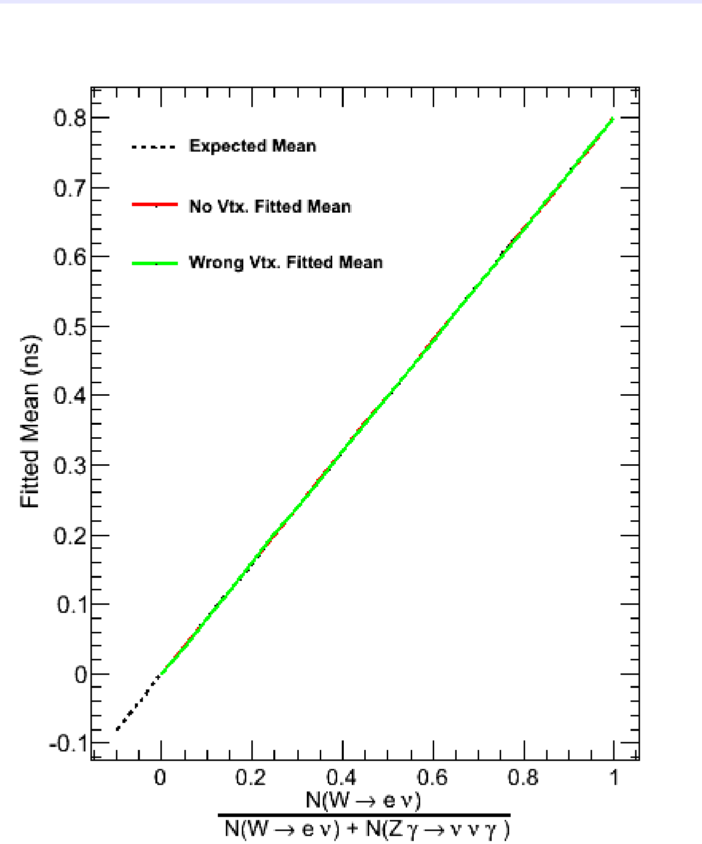
Predicting N(SR)/N(CR) From No Vertex Mean



We isolate no vertex events in Monte Carlo and electron data and fit to find the no vertex mean.

N(SR)/N(CR) follows the prediction from the no vertex mean as well as for the wrong vertex mean.

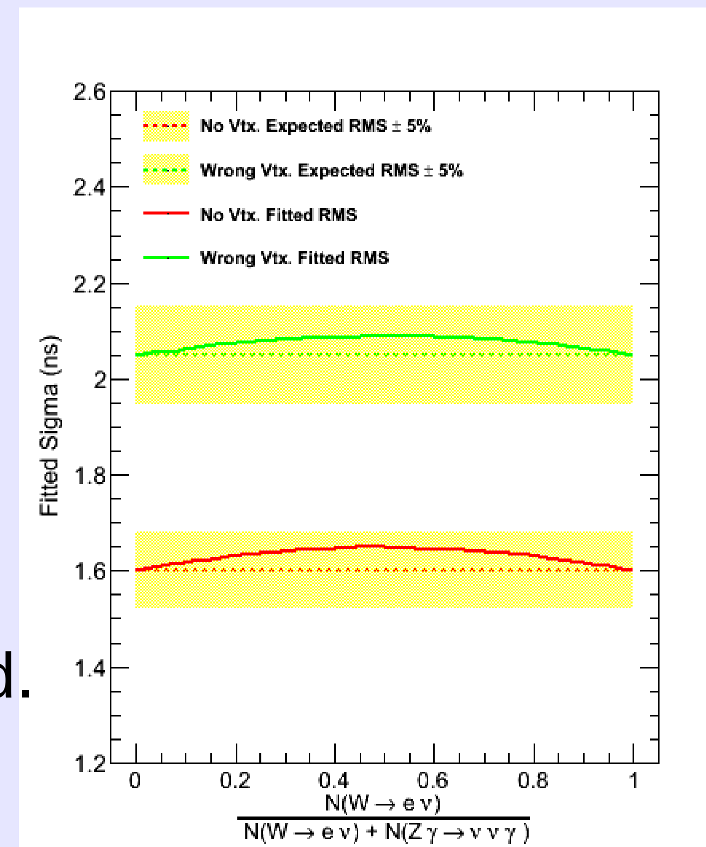
Combining Multiple Standard Model Backgrounds



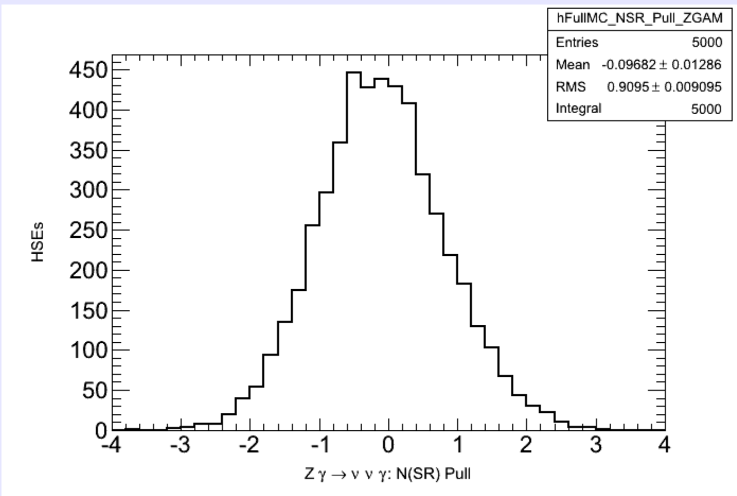
To estimate the effect of treating multiple, combined Standard Model backgrounds as a double Gaussian, we fit combinations of Gaussians in various fractions with very different means.

Fitted mean: a Weighted average of means of the combined samples

Take a 5% systematic uncertainty in the wrong vertex and no vertex distribution RMSs to cover the variation due to treating combinations as a single background.

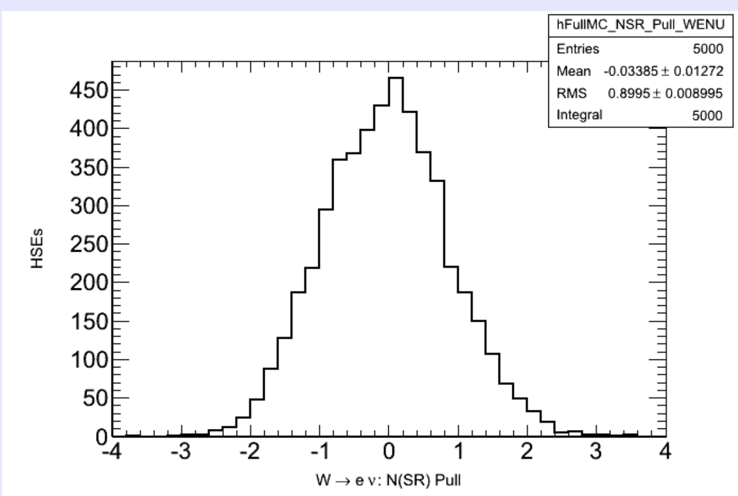


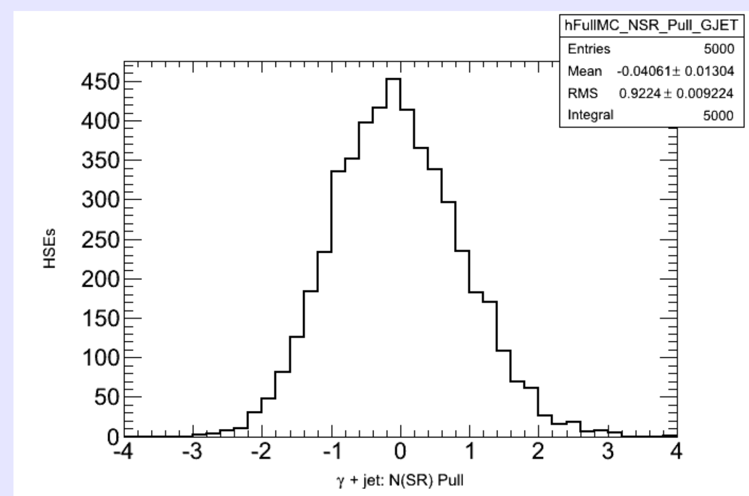
How well do we do with fully simulated MC samples?



Draw pseudo-experiments from fully simulated MC samples (Zγ, γ+jet, and W → eν).

For all three, the means are ~ 0 and the RMSs are < 1.





No-Vertex Time

If no good vertex is reconstructed, we construct the corrected time assuming a vertex with Z = 0 and T = 0. The mean of the no-vertex distribution is always close to that of the wrong-vertex distribution.

Can think of the corrected time having three parts:

1) Geometric time of flight difference relative to the center of the detector (process dependent)

2) Geometric time of flight difference relative to the chosen vertex. This is the same for all processes: it only depends on beam parameters.

3)Time of collision variation for the true collision and a possible wrong vertex is 1.28 ns (from beam profile). Leads to a no-vertex RMS ~ 1.6 ns and a wrong-vertex RMS ~ 2.0 ns.

Estimating Background Contributions

- We have successfully reduced events which tend to produce large wrong vertex mean times.
- We still can't count on the wrong vertex mean time being zero.
- How can we estimate the background contributions in these circumstances?

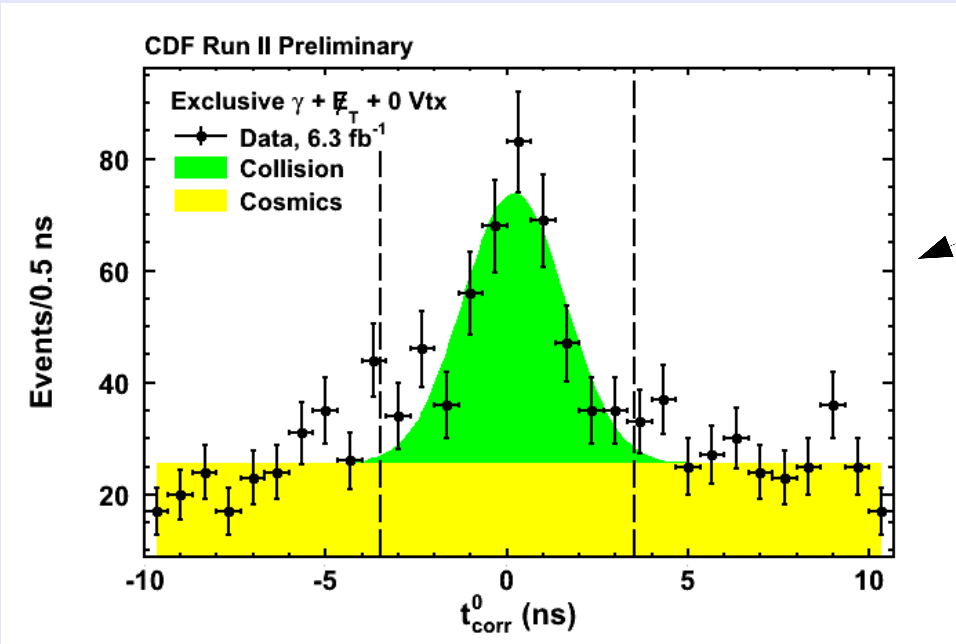
Double Gaussian Approximation

- First, we will determine how to estimate the background contribution if there were only one Standard Model background.
- Now that the most pathological cases have been removed, Standard Model backgrounds can be described by a double Gaussian
  - Right vertex: Mean = 0.0 ns, RMS = 0.64 ns
  - Wrong vertex: Mean = ?, RMS = 2.0 ns

Sources of Large Time Events

- We have found that the wrong-vertex mean can be larger than zero
- Also found three effects that cause events with large times
  - E_T threshold effect
  - Fake photon effect
  - Lost jet effect
- New cuts are designed to mitigate these effects
  - A brief description of each follows
- Will need to measure the amount of bias remaining in the wrong-vertex mean → this is the

Opening the Box



Fit in the no-vertex sample to assist in estimating the wrong-vertex mean.

Fit in the good-vertex sample. Showing full cosmics estimation range