Search for Excited and Exotic Electrons at CDF in Run II

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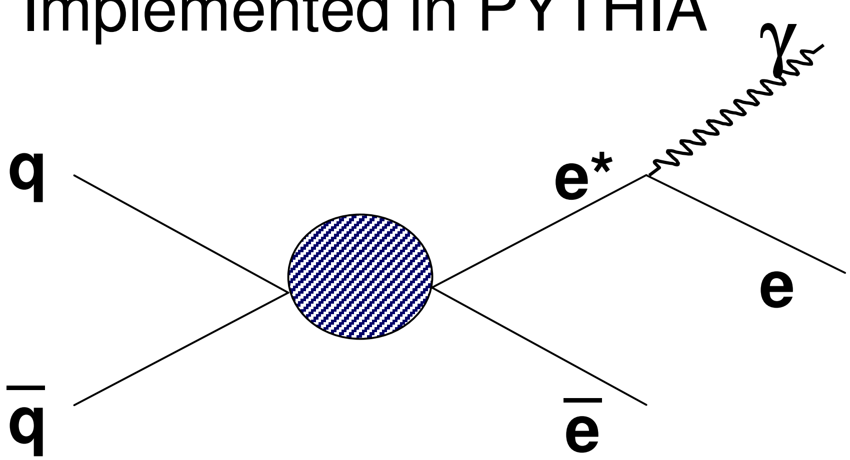
- Introduction/Motivation
- Excited/Exotic Electron Models
- Acceptance
- Backgrounds
- Data
- Results

Introduction/Motivation

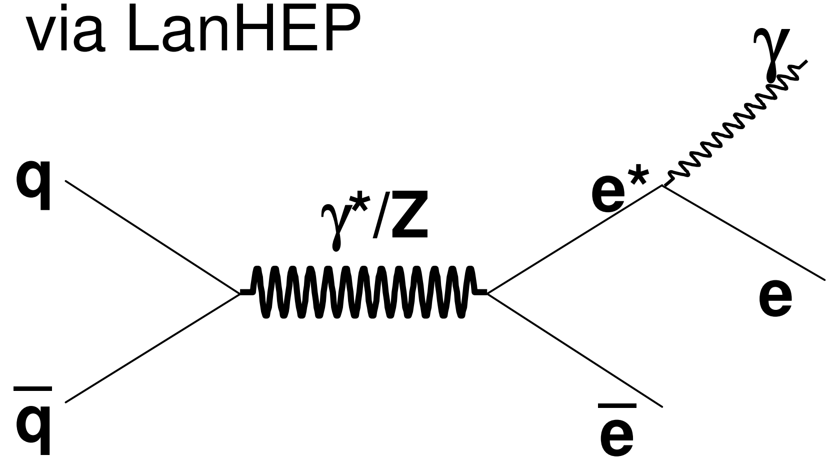
- The hierarchical structure of the standard model families could be indication of quark and lepton substructure
- The **observation of excited states of leptons or quarks** would be a first indication of their **compositeness**
- We search for singly produced excited/exotic electrons in association with an additional (oppositely charged) electron, where the excited electron decays in the electron + photon channel
- $p\bar{p} \rightarrow e^{*} + e \rightarrow e\gamma + e$

e* Models

- Contact Interaction Model
- (U. Baur, et.al., Phys Rev D. V42,3)
- Effective four-fermion Lagrangian
- Model depends on M_{e^*} and Λ (Compositeness Scale)
- Implemented in PYTHIA

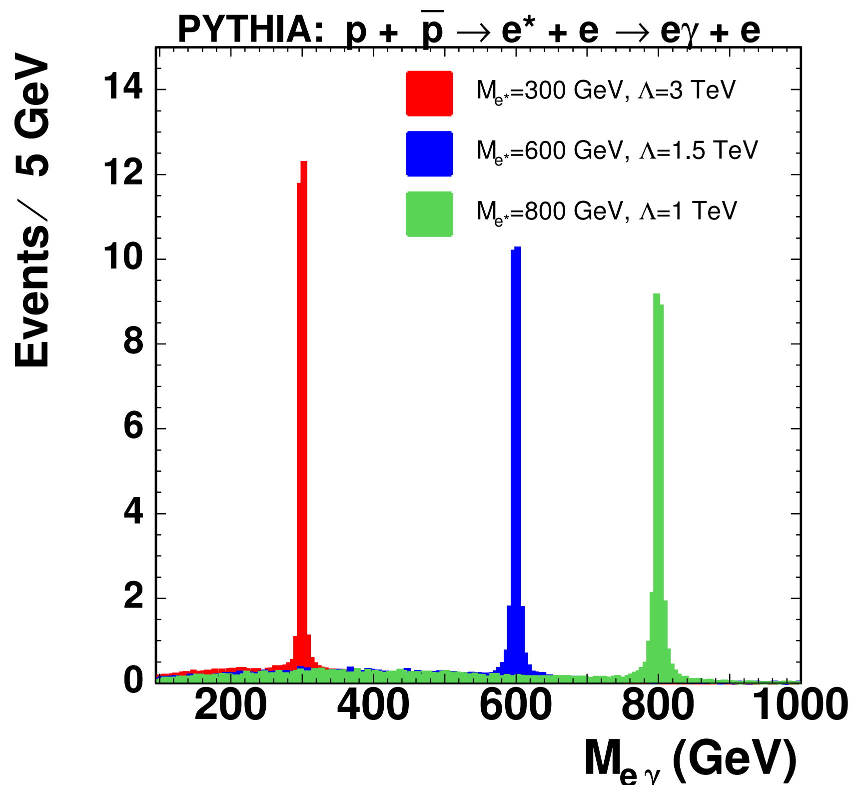


- Gauge Mediated Model
- (K. Hagiwara, et. al., Z.Phys. C29:115, 1985)
- Model depends on M_{e^*} and f/Λ
- Implemented in CompHEP via LanHEP

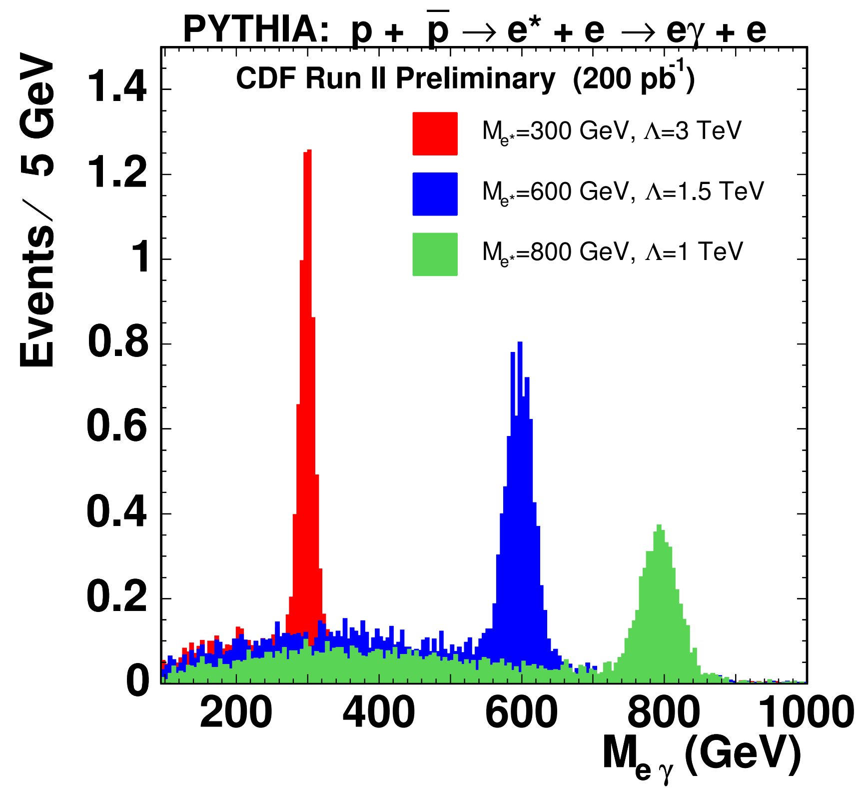


e*→eγ Decay Channel

- $\Gamma_{th} \propto M_{e*}^3/\Lambda^2$: for $M_{e*} < \Lambda$, an e* signal would manifest itself as a narrow resonance peak in the eγ invariant mass
- Each event has at least 2 e - γ combinations
- The width is dominated by detector energy resolution

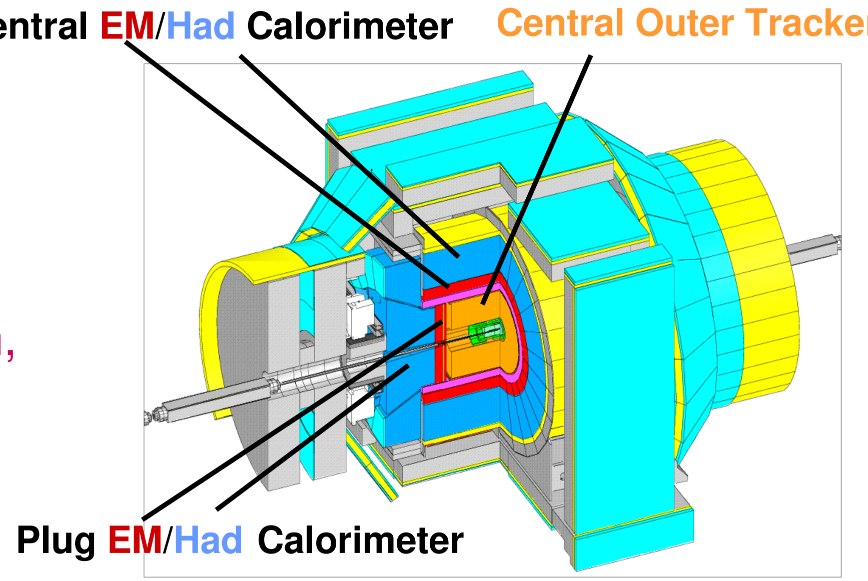


- Parton Level

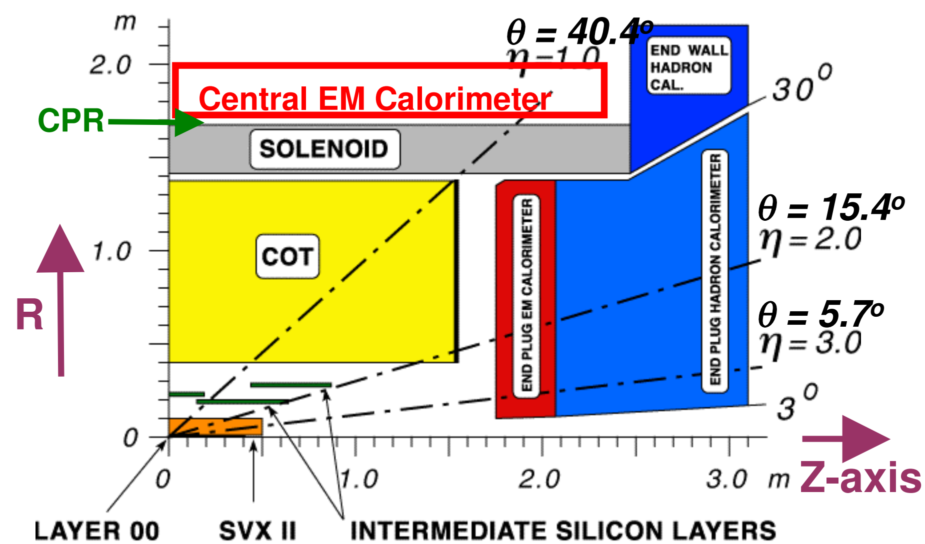


- After CDF Simulation

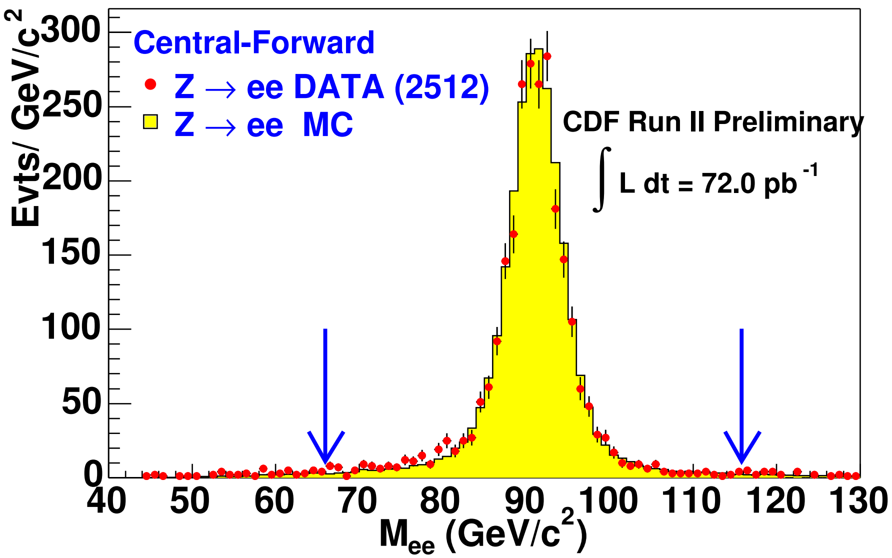
CDF Detector and Event Selection



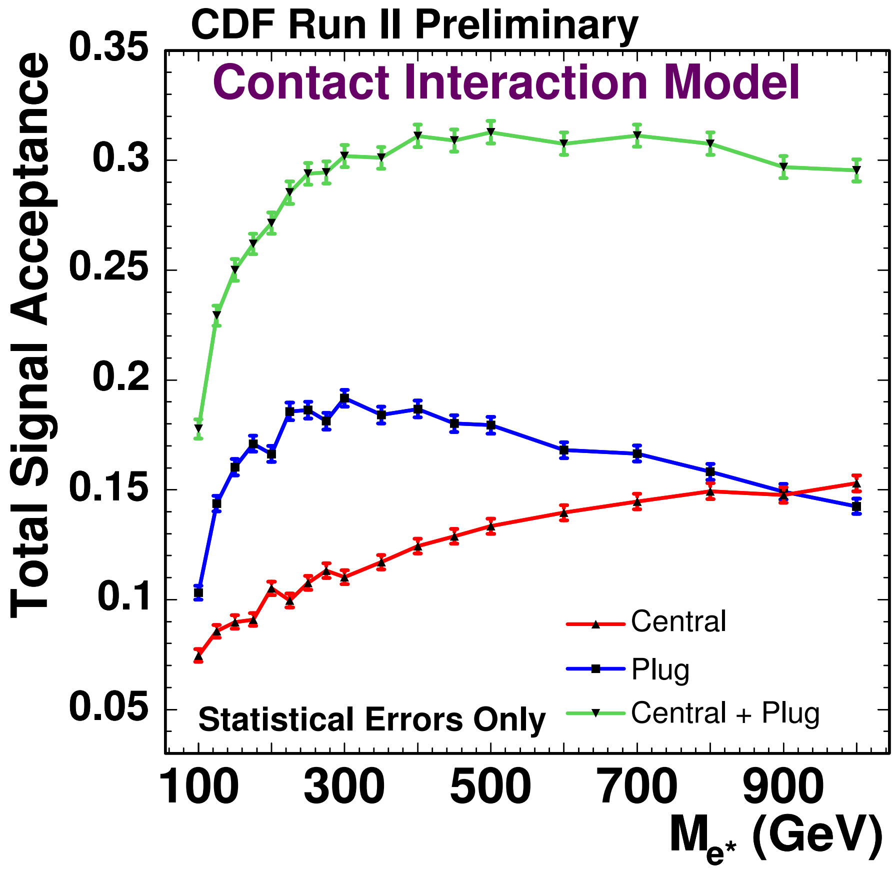
- $\int L \cdot dt = 200\ pb^{-1}$
- High E_T central electron trigger
- Search for two electrons and one photon, where one electron must be central
- **Central** region has **track** and **calorimeter** requirements
- **Plug** region has **calorimeter** requirements **only**
  - Electrons and photons are collectively called plug EM objects
- To reduce background due to Z+γ and Z+jet, events with dielectron invariant mass in the Z mass region (81-101 GeV) are rejected



Simulation Validation and Acceptance Studies



- Z→ee events provide a clean sample with high statistics and good energy resolution and are used to:
  - Measure the calorimeter energy scale and resolution
  - Validate simulation of central electron, central photon, and plug EM object identification variables



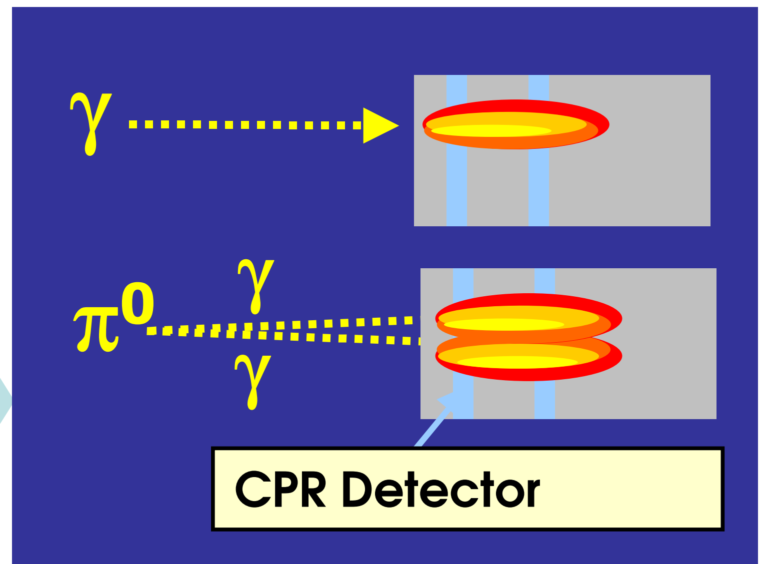
- The new Run II plug calorimeter increases the acceptance by more than a factor of 2

Dielectron + Photon Expectations

- **Pure Standard Model:**
  - $Z/\gamma^{*}+\gamma \rightarrow ee+\gamma$
- **Electron misidentification:**
  - $W(\rightarrow e\nu)Z(\rightarrow ee)$ (where electron is misidentified as a photon)
  - $Z(\rightarrow ee)Z(\rightarrow ee)$ (where electron is misidentified as a photon)
- $t\bar{t} \rightarrow e^{+}\nu b + e\bar{\nu}\bar{b}$
- **Jet Misidentification Backgrounds:**
  - $Z(\rightarrow ee)$ + jet
  - Multijet
  - $\gamma\gamma$ + jet
  - $W(\rightarrow e\nu) + \geq 2$ jets

Raw Central jet → γ Fake Rate

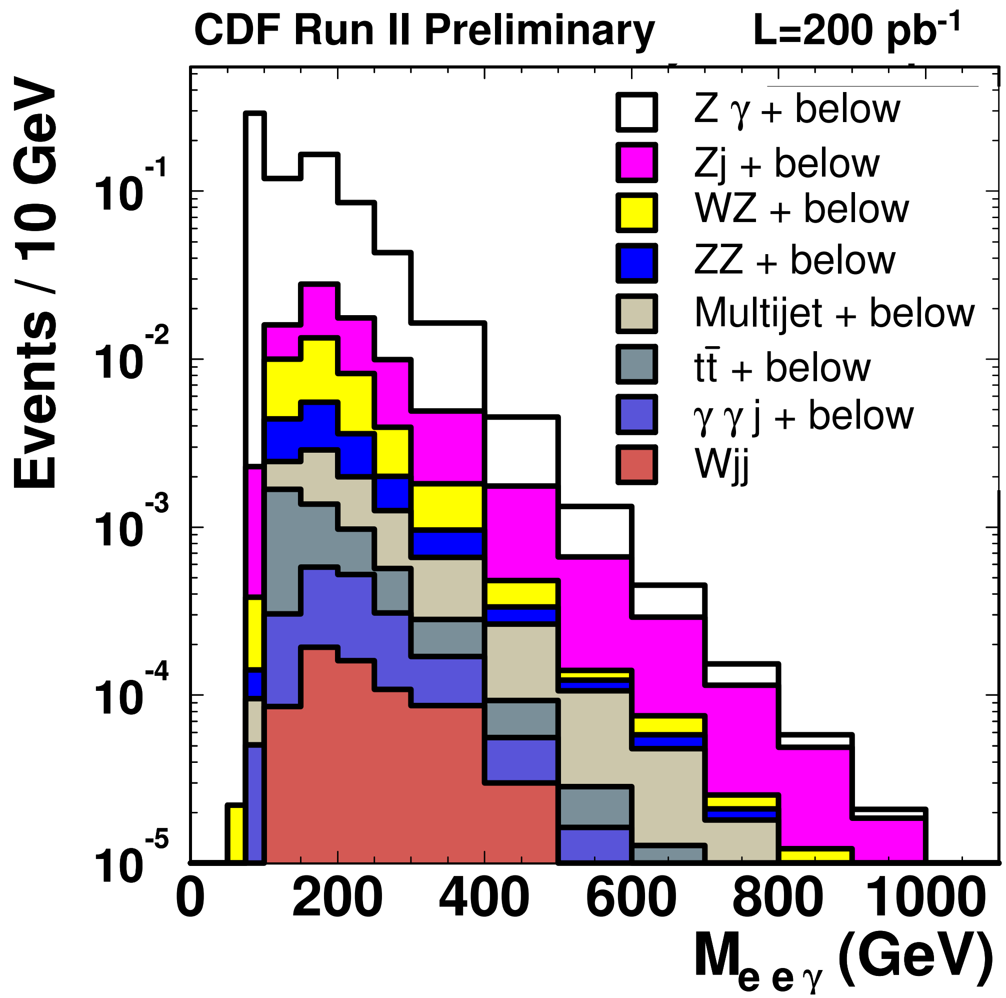
Subtract true, prompt γ contribution



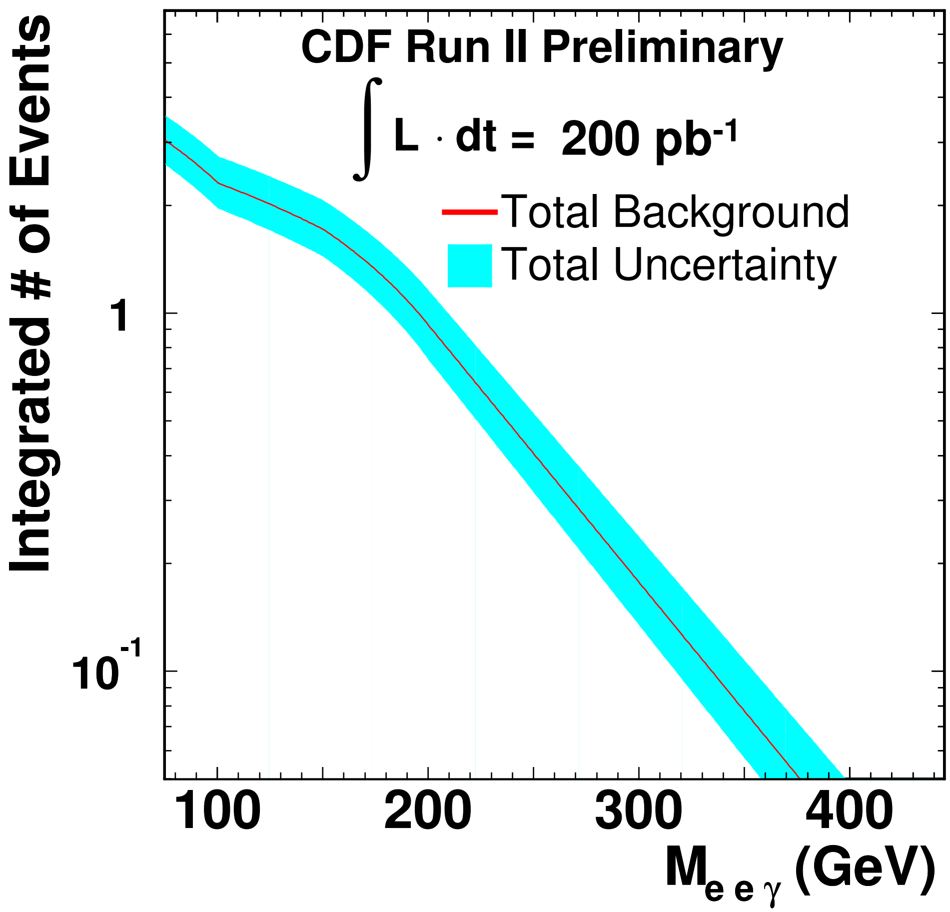
Corrected Central jet → γ Fake Rate

$M_{ee\gamma}$ Expected Distribution

Source	Events
$Z(\rightarrow ee)\gamma$	2.56 ± 0.24
$Z(\rightarrow ee)$+jet	$0.24^{+0.24}_{-0.07}$
$W(\rightarrow e\nu)Z(\rightarrow ee)$	0.11 ± 0.01
$Z(\rightarrow ee)Z(\rightarrow ee)$	0.038 ± 0.004
Multi-jet	$0.03^{+0.03}_{-0.01}$
$t\bar{t}$	0.015 ± 0.005
$\gamma\gamma$+jet	$0.008^{+0.005}_{-0.003}$
$W(\rightarrow e\nu)$+jet	$0.004^{+0.005}_{-0.002}$
Total	$3.01^{+0.39}_{-0.28}$

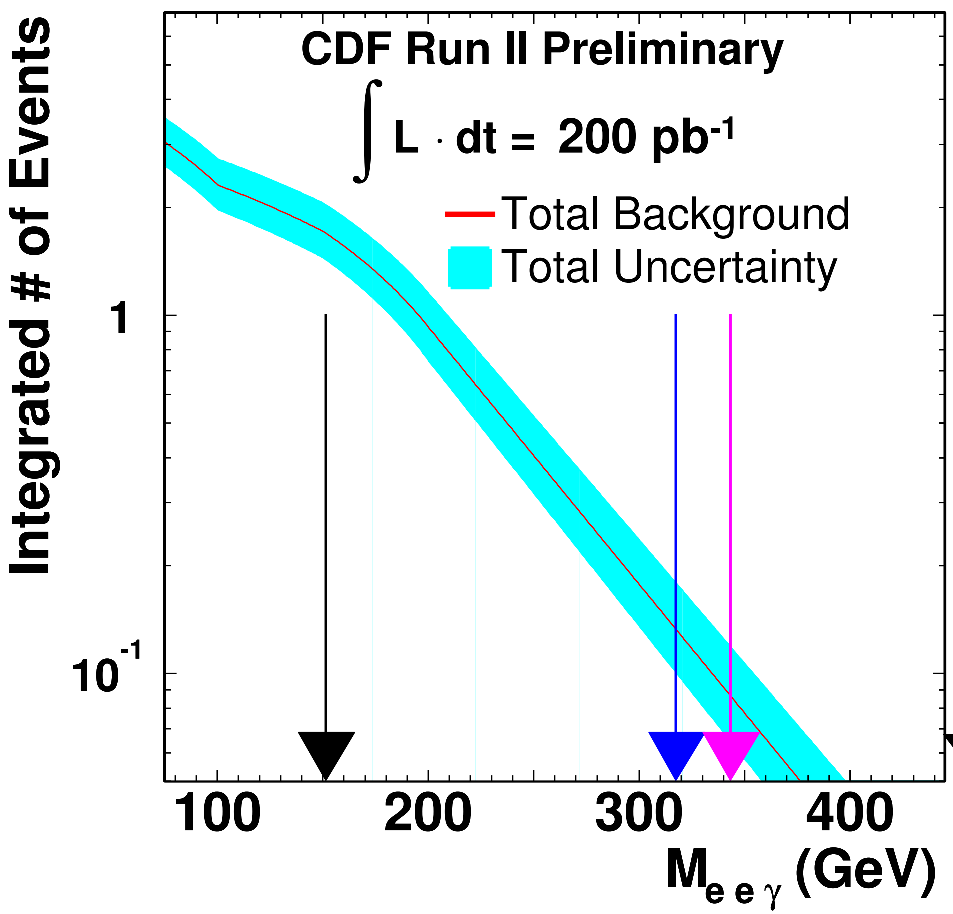


Integrated $M_{ee\gamma}$ Expected Distribution



$M_{ee\gamma}$ (GeV)	Background
>0	$3.0^{+0.4}_{-0.3}$
>100	$2.2^{+0.4}_{-0.3}$
>150	1.7 ± 0.3
>200	0.9 ± 0.2
>250	0.4 ± 0.1
>300	$0.17^{+0.06}_{-0.04}$
>350	$0.07^{+0.03}_{-0.02}$

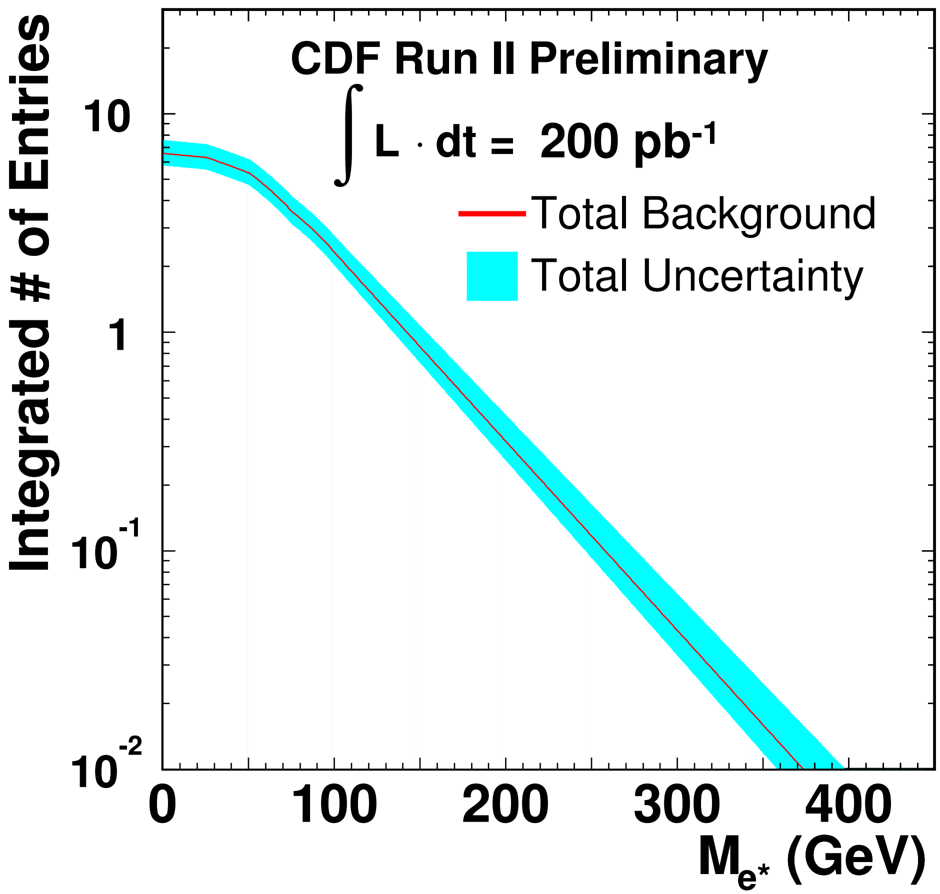
Results, $M_{ee\gamma}$ Distribution



$M_{ee\gamma}$ (GeV)	Background	N_{obs}
>0	$3.0^{+0.4}_{-0.3}$	3
>100	$2.2^{+0.4}_{-0.3}$	3
>150	1.7 ± 0.3	3
>200	0.9 ± 0.2	2
>250	0.4 ± 0.1	2
>300	$0.17^{+0.06}_{-0.04}$	2
>350	$0.07^{+0.03}_{-0.02}$	0

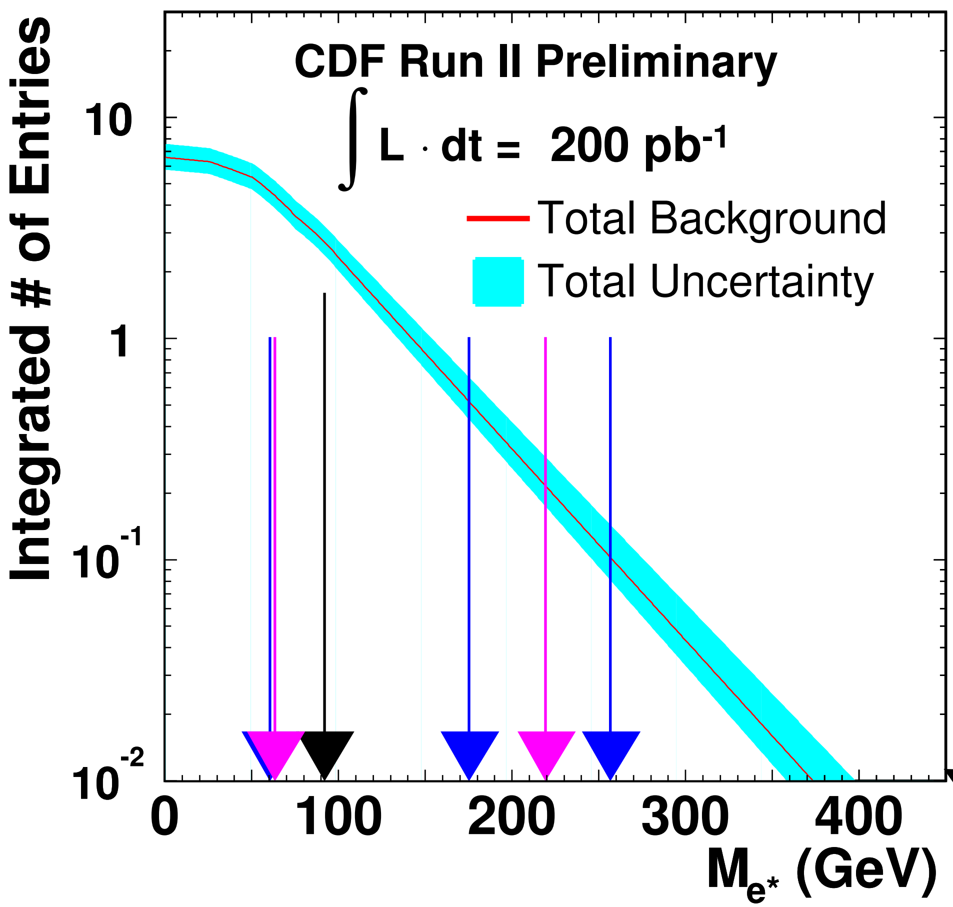
- Blue for Event 1
- Black for Event 2
- Pink for Event 3

Integrated $M_{e\gamma}$ Expected Distribution



$M_{e\gamma}$ (GeV)	Background
>0	$6.5^{+0.9}_{-0.6}$
>50	$5.2^{+0.8}_{-0.6}$
>100	$2.2^{+0.4}_{-0.3}$
>150	$0.8^{+0.2}_{-0.1}$
>200	$0.31^{+0.10}_{-0.05}$
>250	$0.11^{+0.04}_{-0.02}$
>300	$0.04^{+0.02}_{-0.01}$

Results, $M_{e\gamma}$ Distribution

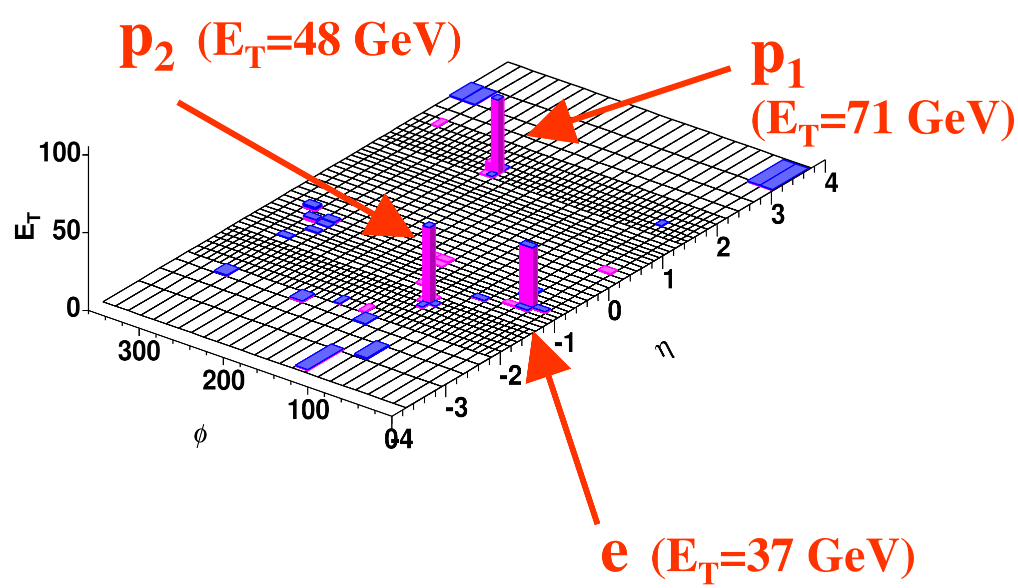


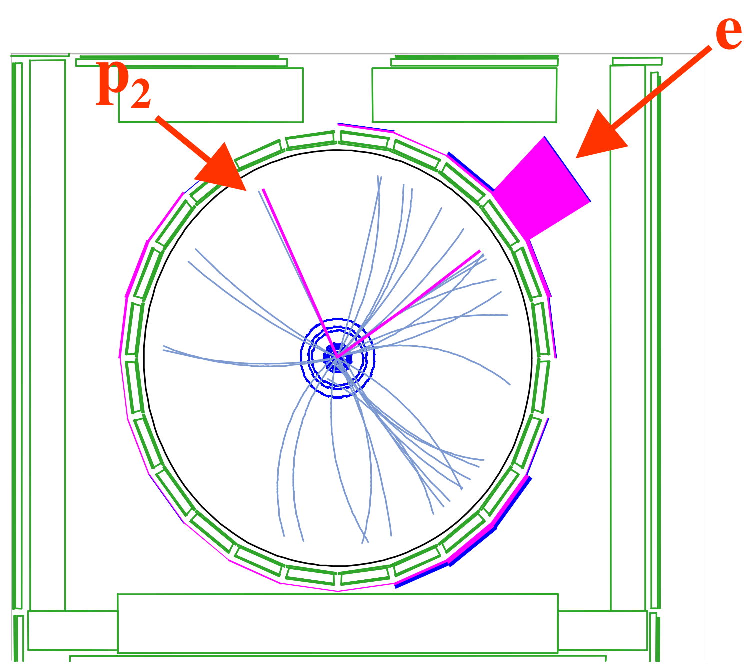
$M_{e\gamma}$ (GeV)	Background	N_{obs}
>0	$6.5^{+0.9}_{-0.6}$	7
>50	$5.2^{+0.8}_{-0.6}$	7
>100	$2.2^{+0.4}_{-0.3}$	3
>150	$0.8^{+0.2}_{-0.1}$	3
>200	$0.31^{+0.10}_{-0.05}$	2
>250	$0.11^{+0.04}_{-0.02}$	1
>300	$0.04^{+0.02}_{-0.01}$	0

- Blue for Event 1
- Black for Event 2
- Pink for Event 3

Event 1

- One central electron (e), two plug EM objects (p_1 and p_2)

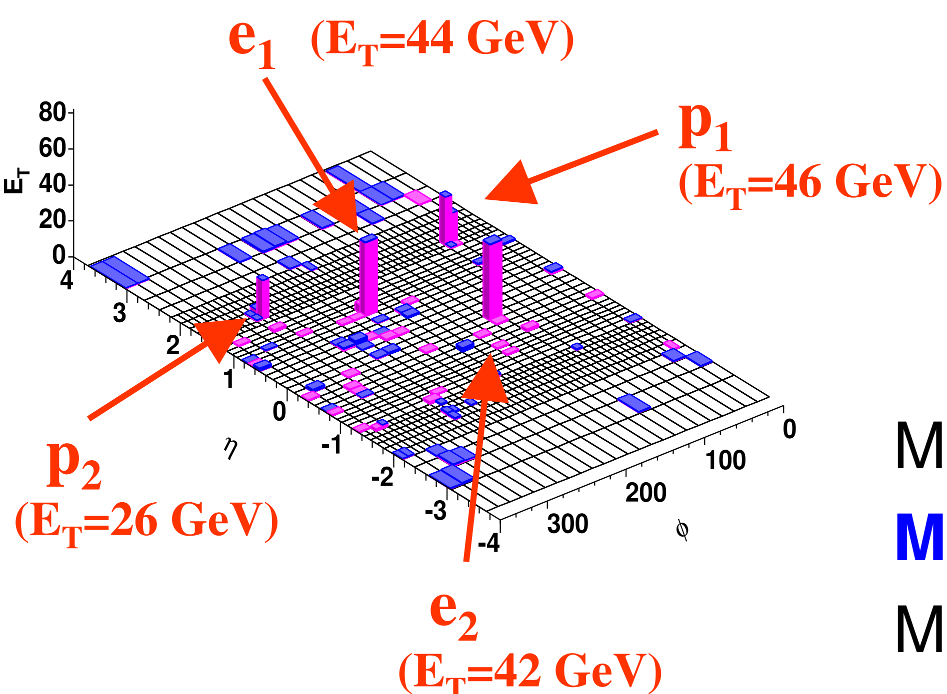


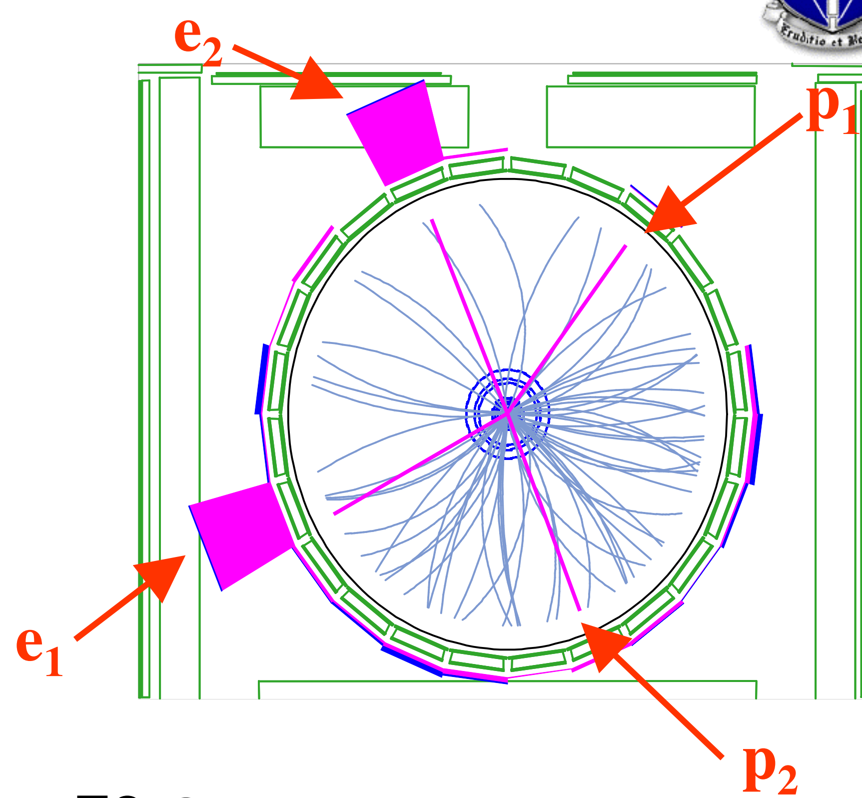


- M_{ep_1} = 176 GeV
- M_{ep_2} = 61 GeV
- $M_{p_1p_2}$ = 257 GeV
- **$M_{ep_1p_2}$=318 GeV**

Event 2

- 2 Central Electrons (e_1 and e_2), 2 Plug EM Objects (p_1 and p_2)
- ZZ Candidate Event





$M_{e_1e_2}$ = 78 GeV

$M_{e_1p_1}$ = 92 GeV

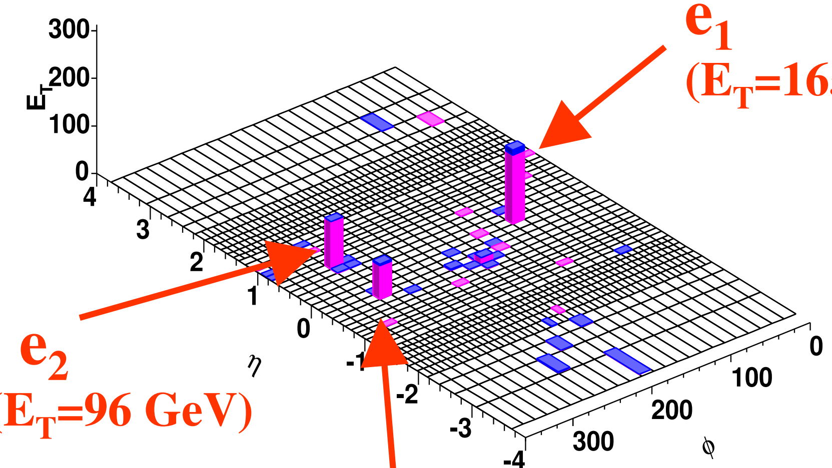
$M_{e_2p_1}$ = 91 GeV

- $M_{e_1e_2p_1}$ = 152 GeV
- **$M_{e_2p_2}$ = 91 GeV**
- $M_{e_1e_1p_1p_2}$=194 GeV

Event 3

- 2 Central Electrons (e_1 and e_2), 1 Central Photon (γ)

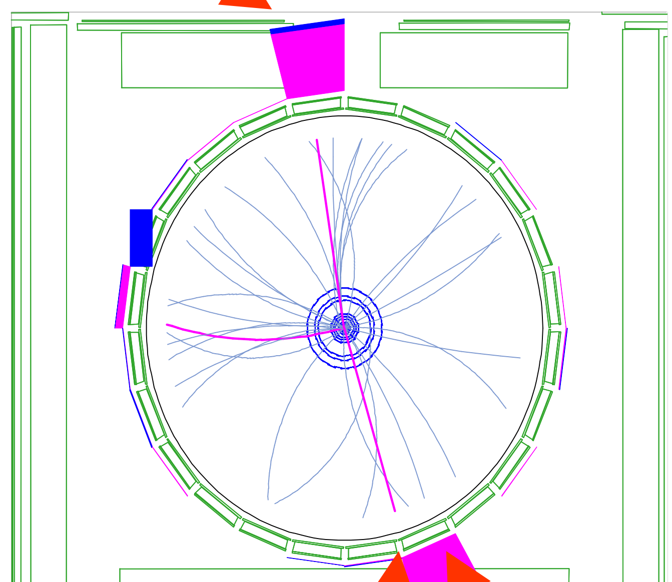
e_1



e_1 (E_T=165 GeV)

e_2 (E_T=96 GeV)

γ (E_T=73 GeV)

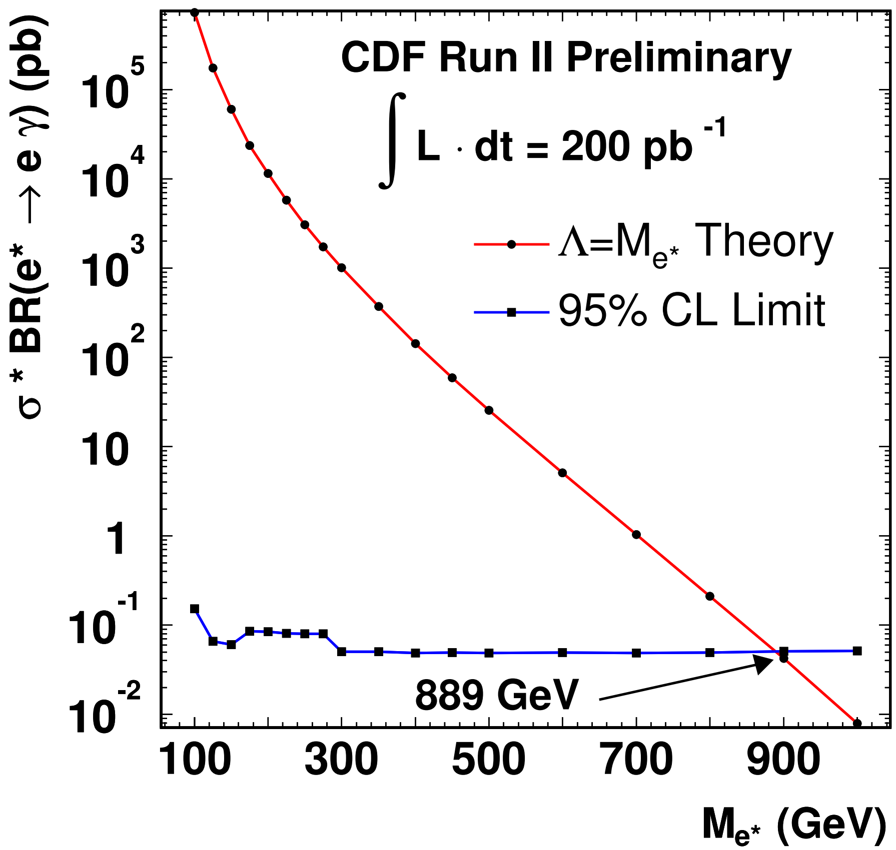


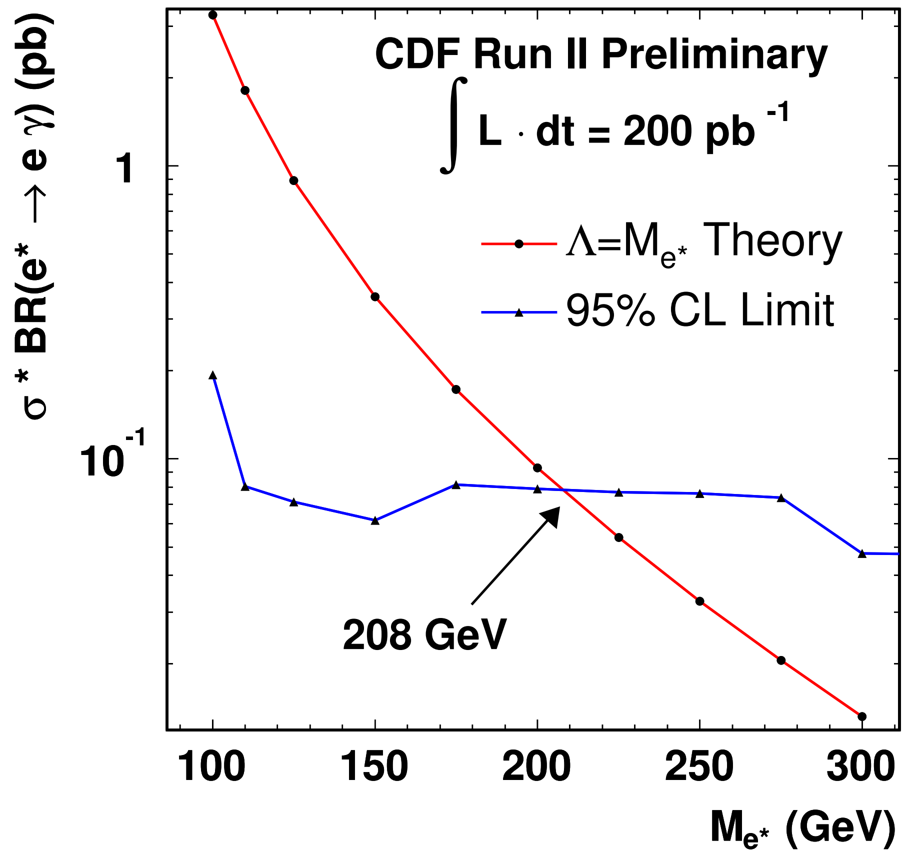
e_2 γ

- **$M_{e_1e_2}$ = 256 GeV**
- $M_{e_1\gamma}$ = 220 GeV
- $M_{e_2\gamma}$ = 64 GeV
- **$M_{e_1e_2\gamma}$= 344 GeV**

Experimental Limits for $M_{e^*} = \Lambda$

- Using a Bayesian approach, we obtain upper limits on the experimental cross-section and lower limits on the e* mass

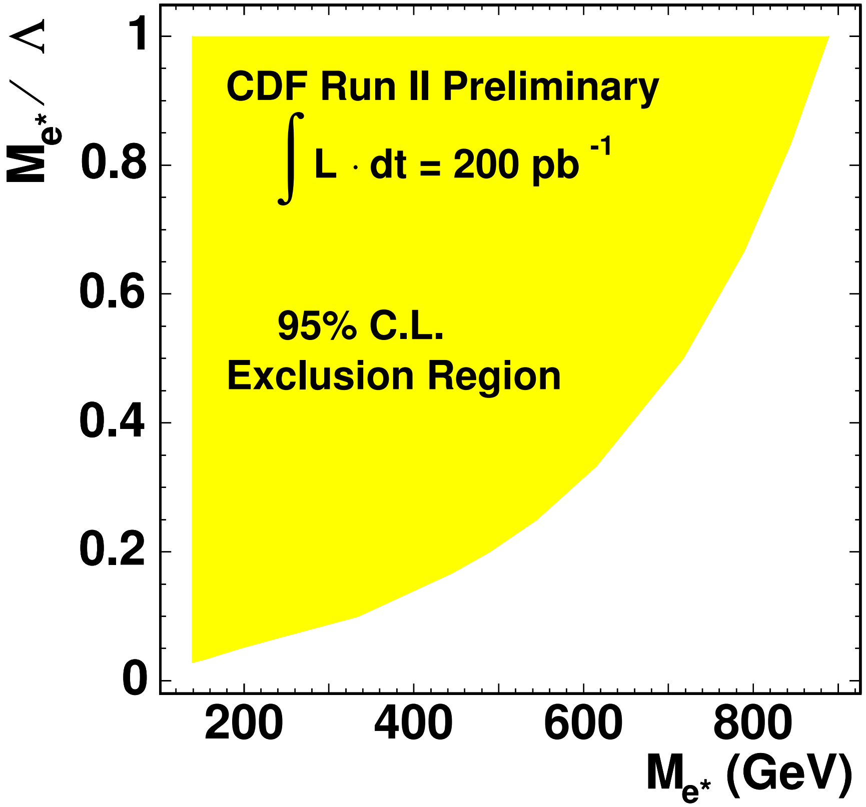




- Contact Interaction Model
- Gauge Mediated Model

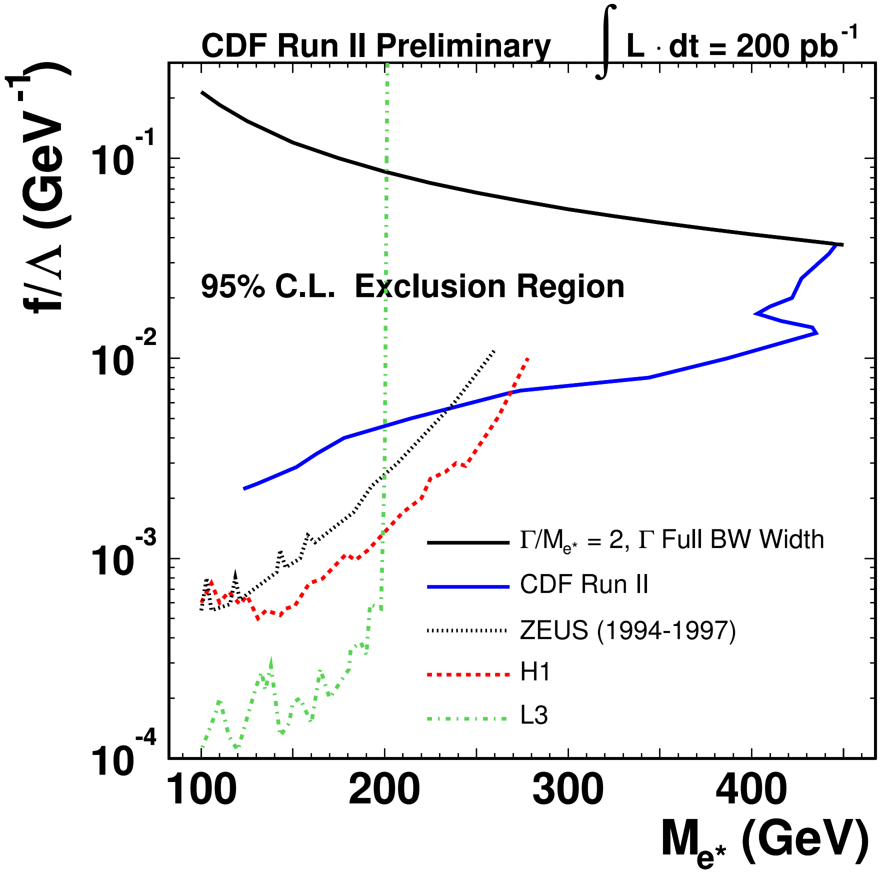
2-D Experiment Limits

- **Contact Interaction Model**
  depends on M_{e^*} and Λ
- **$M_{e^*} < \Lambda$**



- No published limits

- **Gauge mediated model**
  depends on M_{e^*} and f / Λ



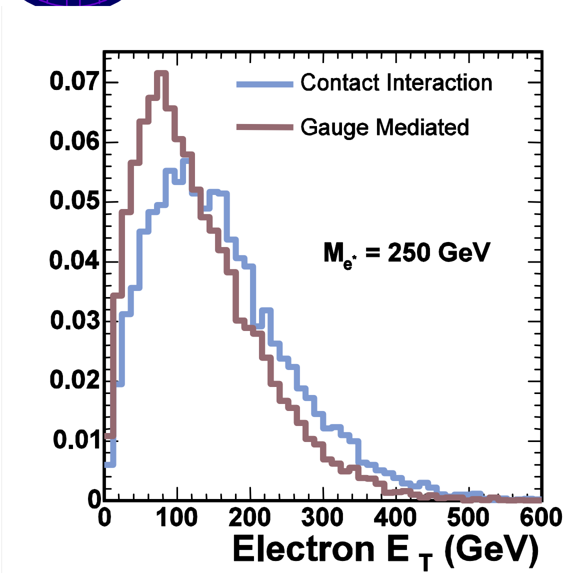
- L3: hep-ex/0306016, Zeus: hep-ex/0109018, H1: hep-ex/0207038

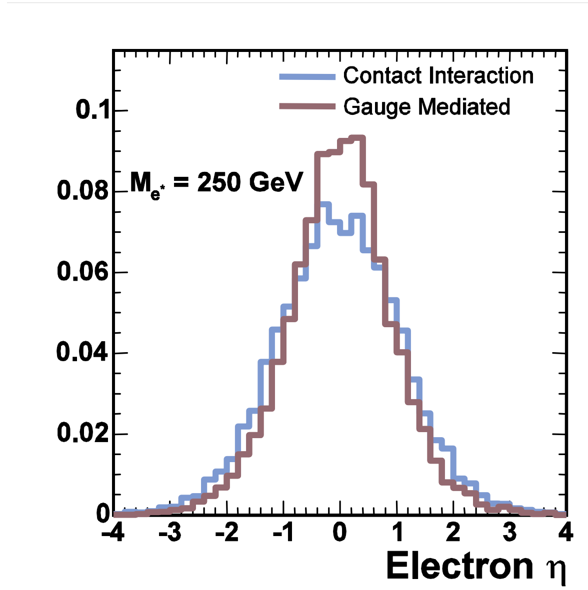
Summary

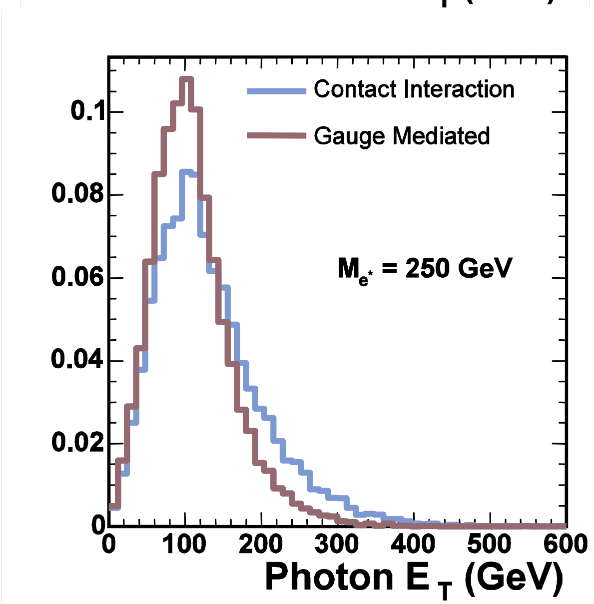
- Three high mass $ee\gamma$ candidates were found in 200 pb^{-1}, while the total background prediction was ~ 3 events
  - One event could be a ZZ candidate
  - Other two events have interesting characteristics
- For $M_{e^*} = \Lambda$:
  - Contact Interaction Model, $M_{e^*} > 889$ GeV
  - Gauge Mediated Model, $M_{e^*} > 208$ GeV
- Established 2-D exclusion region in $M_{e^*} / \Lambda - M_{e^*}$ plane for contact interaction model
- CDF results extend sensitivity in $f / \Lambda - M_{e^*}$ plane for $M_{e^*} >$ 280 GeV for gauge mediated model
- Now have recorded another ~200 pb^{-1} which we are eager to look at to extend these searches

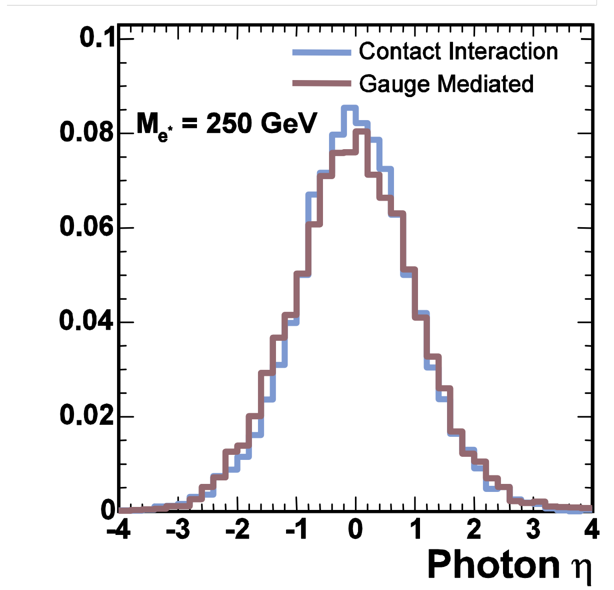
BACKUP SLIDES

E_T and η Distributions





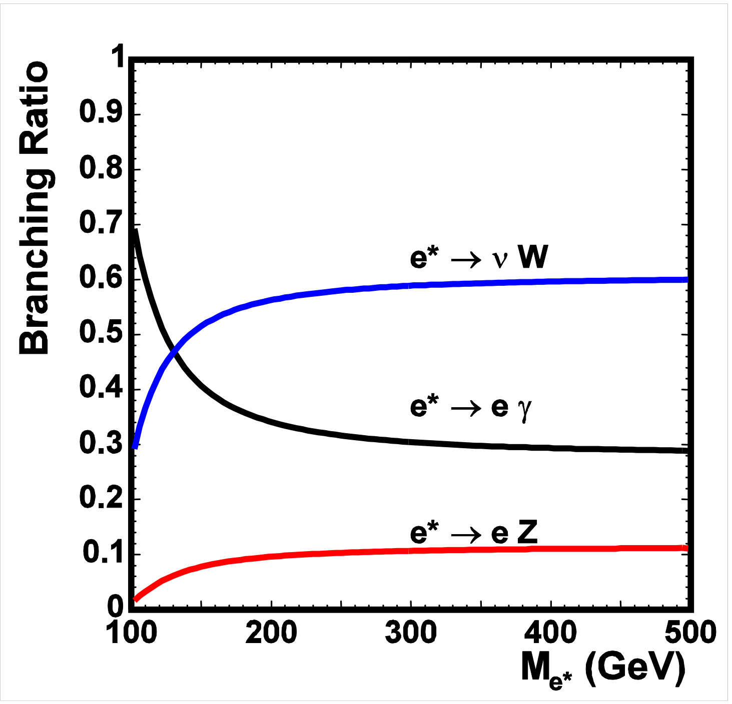




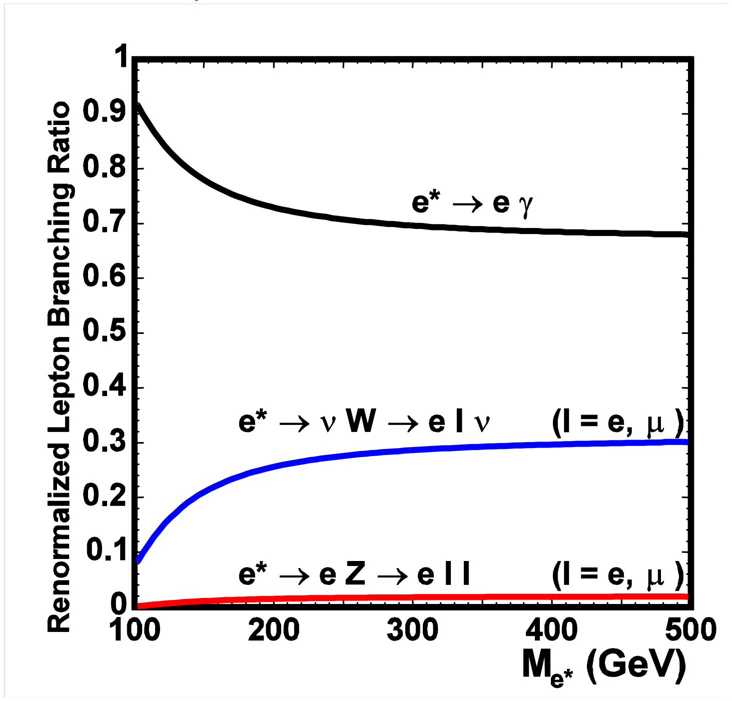
- Parton level E_T and η distributions for the electron produced in association with the excited electron and the photon from the excited electron decay for M_{e^*}=250 GeV
- Kinematics are different so we measure acceptances for both models
- Areas normalized to 1

e* Decay Channels

- There are three decay channels:
  - e* → eγ
  - e* → e Z
  - e* → νW

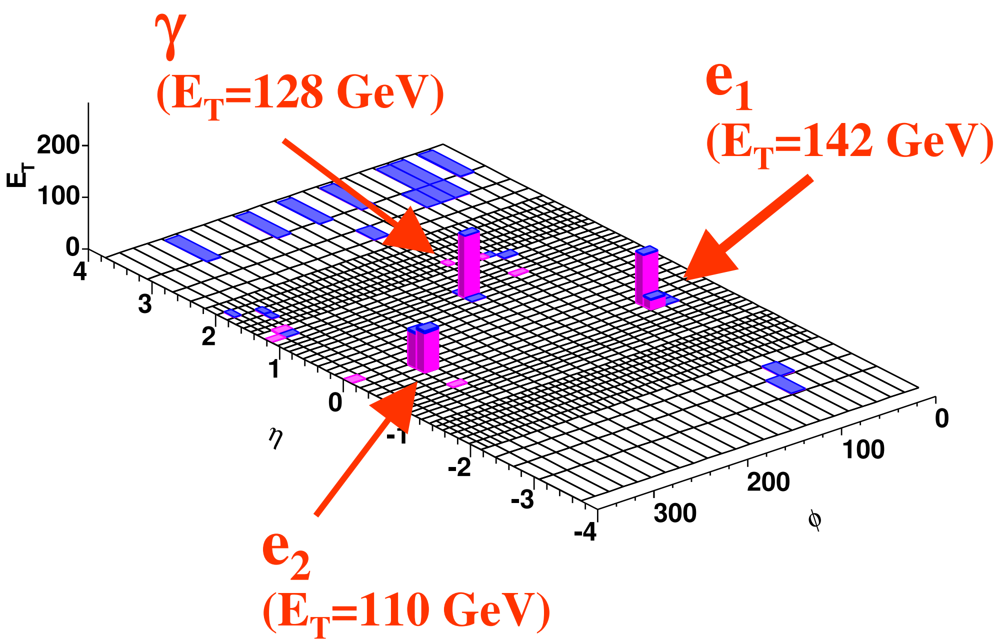


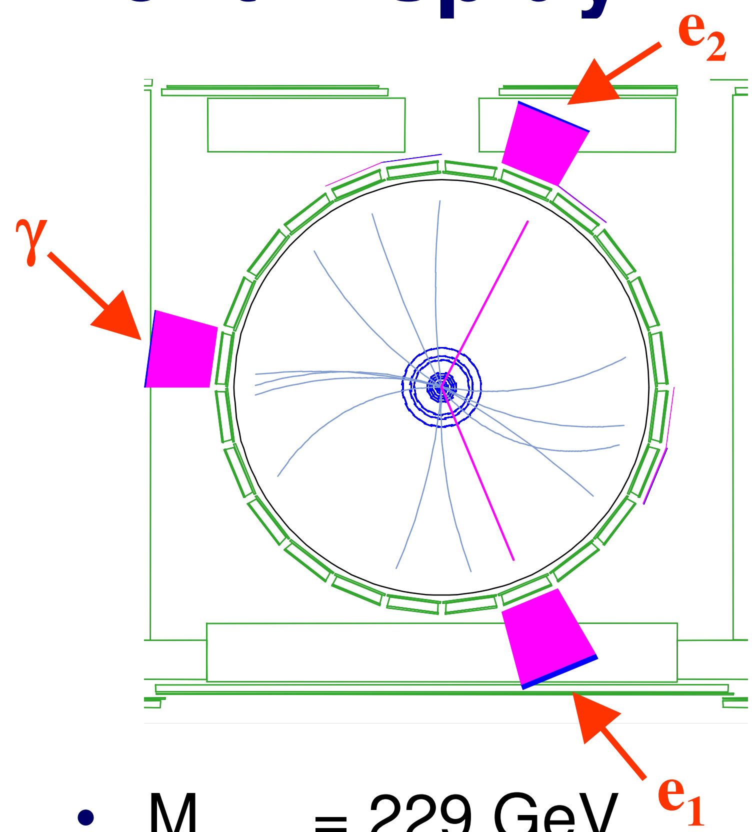
- Consider only leptonic Z and W decays
  - Very Clean Signal
  - Low Background
  - Good Energy Resolution
- Renormalized Branching Ratio
- e* → eγ is the chosen channel



Simulated e* Event Display

- e* mass = 250 GeV
- Clean signal
- Good energy resolution

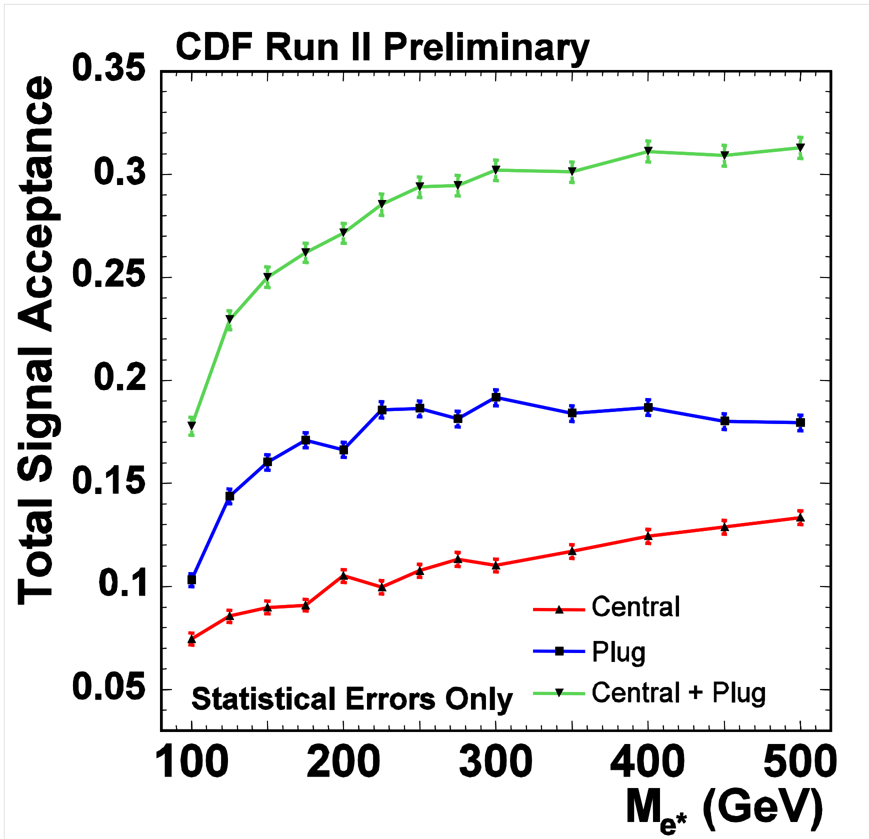


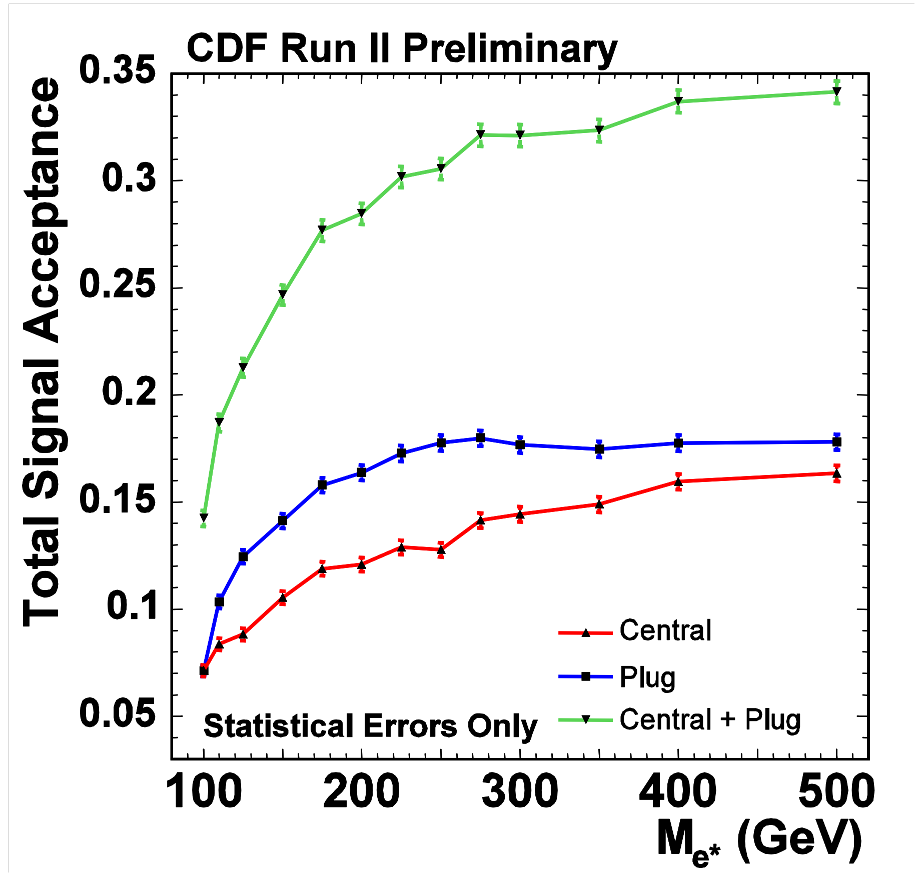


- $M_{e_1e_2}$ = 229 GeV
- $M_{e_1\gamma}$ = 282 GeV
- **$M_{e_2\gamma}$ = 251 GeV**
- $M_{e_1e_2\gamma}$ = 442 GeV

Total Signal Acceptance

- Contact Interaction Model
- Gauge Mediated Model





$M_{e\gamma}$ Background Distribution

Source	$e\gamma$ Entries
$Z(\rightarrow ee)\gamma$	5.52 ± 0.53
$Z(\rightarrow ee)$+jet	$0.48^{+0.47}_{-0.12}$
$W(\rightarrow e\nu)Z(\rightarrow ee)$	0.25 ± 0.03
$Z(\rightarrow ee)Z(\rightarrow ee)$	0.08 ± 0.01
Multi-jet	$0.07^{+0.09}_{-0.03}$
$t\bar{t}$	0.03 ± 0.01
$\gamma\gamma$+jet	$0.022^{+0.024}_{-0.004}$
$W(\rightarrow e\nu)$+jet	$0.010^{+0.015}_{-0.004}$
Total	$6.47^{+0.83}_{-0.58}$