Search for New Physics with Photons at the Tevatron

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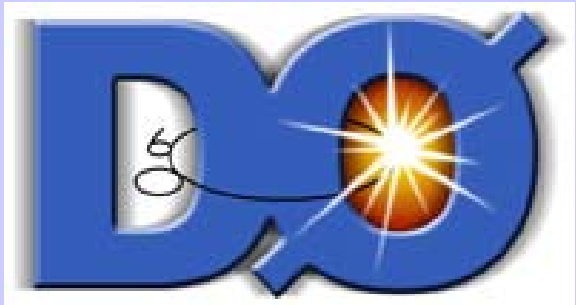
for the CDF and D0 collaborations



2007 Europhysics Conference on High Energy Physics, Manchester, England

Outline

- Motivations
- Tevatron and detectors
- How to suppress photon background
- Model-inspired search
  - Target for one particular model and optimize for sensitivity
  - Compositeness $e^*e \rightarrow ee\gamma$
  - GMSB SUSY $\gamma\gamma$MET
- Signature-based search
  - Driven by the Run I $\gamma\gamma ee$MET event and $\gamma\mu$MET excess
  - $\gamma\gamma$MET
  - $\gamma\gamma e$, $\gamma\gamma\mu$
  - $\gamma\gamma\gamma$
  - $e/\mu + \gamma + X$, X = MET, γ, or e/μ
- Conclusion

Theoretical Motivation

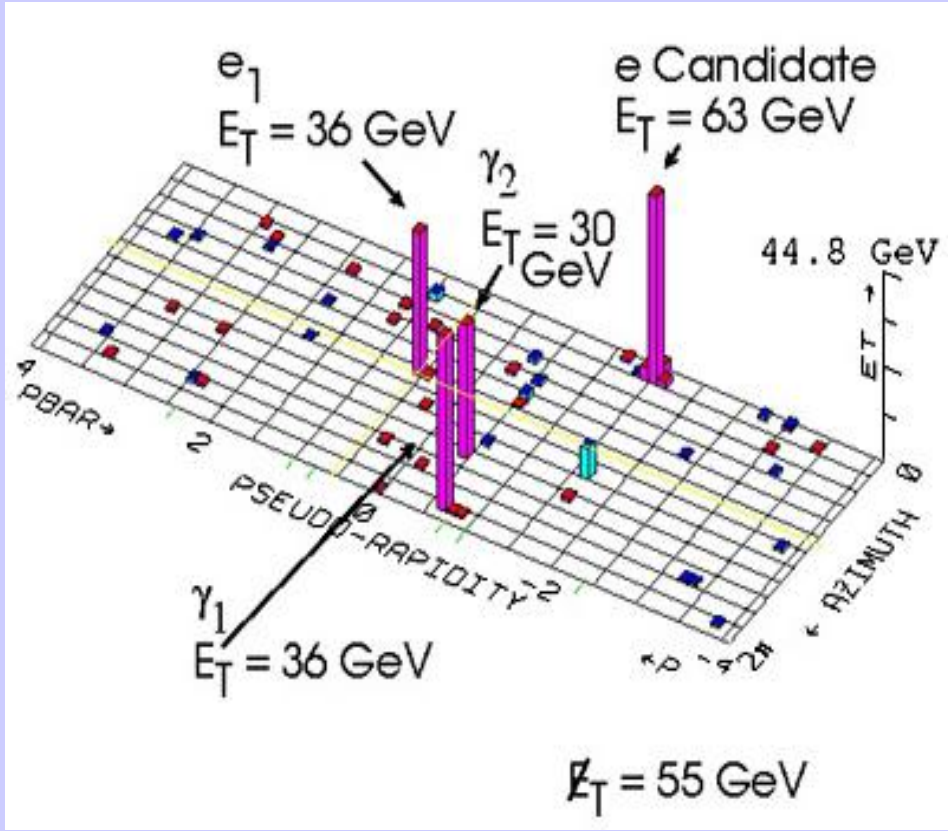
- SUSY
  - mSUGRA: $\chi^0_2 \rightarrow \gamma\chi^0_1$
    - γbcMET, $\gamma\gamma$eeMET, $\gamma\gamma\mu\mu$MET, γ MET ….
  - GMSB (Gauge-Mediated Supersymmetry Breaking): $\chi^0_1 \rightarrow \gamma$G
    - $\gamma\gamma$ **MET**, γbbMET, $\gamma\gamma$eeMET, $\gamma\gamma\mu\mu$MET, **displaced** γ**X** …
- Compositeness: X* $\rightarrow \gamma$ X
  - eeγ, $\mu\mu\gamma$
- LED Graviton: γ MET, $\gamma\gamma$ → See Smain Kermiche's talk
- Higgs: $\gamma\gamma$, $\gamma\gamma$ee, $\gamma\gamma\mu\mu$, $\gamma\gamma e\nu$, $\gamma\gamma\mu\nu$, $\gamma\gamma\gamma\gamma$ … → See Per Jonsson's talk
- Technicolor
  - $\omega_T, \rho_T \rightarrow \gamma\ \pi_T$
    - γbb, γjj, γtt, $\gamma\gamma\gamma$ …
- 4th Generation
  - b' $\rightarrow \gamma$b
    - $\gamma\gamma$bb, eeγbb, $\mu\mu\gamma$bb, jj$\gamma\gamma$bb

This talk

See Max Goncharov's talk

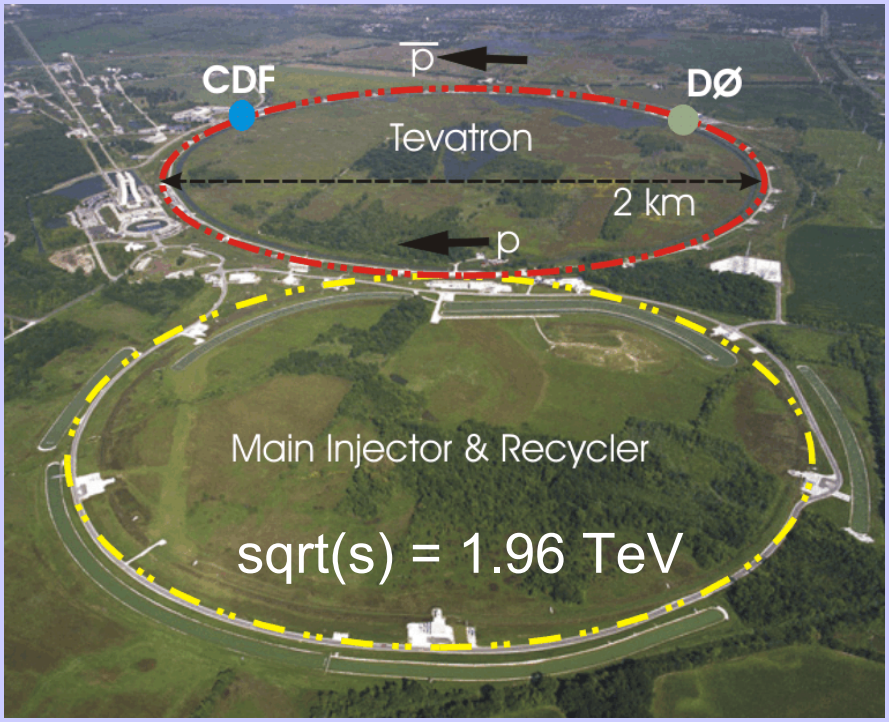
Experimental Motivation

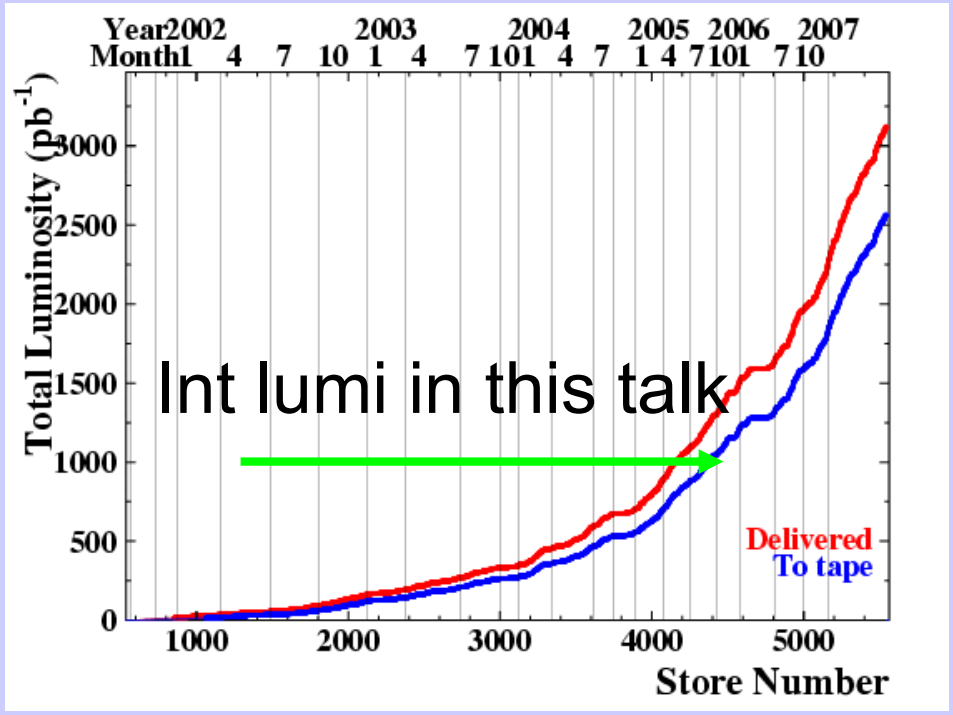
- CDF Run I ee$\gamma\gamma$+MET event
  - 86 pb^{-1}
  - Dominant SM from WW$\gamma\gamma$: 8×10^{-7} events
  - Total Bg: 10^{-6} events
  - ***PRL 81, 1791 (1998)***
- CDF Run I $\mu\gamma$+MET excess
  - 86 pb^{-1}
  - 11 observed
  - 4.2 ± 0.5 expected
  - ***PRL 89, 041802 (2002)***
- Motivate signature-based searches of $\gamma\gamma$+X and $\ell\gamma$+X at Run II
  - $\gamma\gamma$MET
  - $\gamma\gamma$e, $\gamma\gamma\mu$
  - $\gamma\gamma\gamma$
  - e/μ + γ + X, X = MET, γ, or e/μ



A hint of new physics?

Tevatron Performance

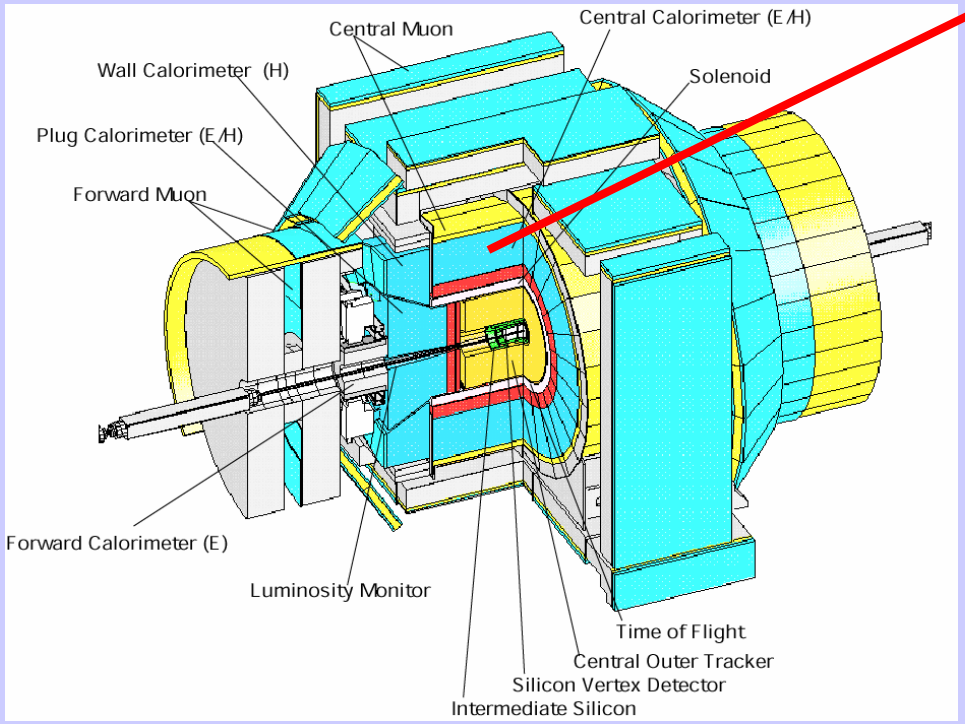


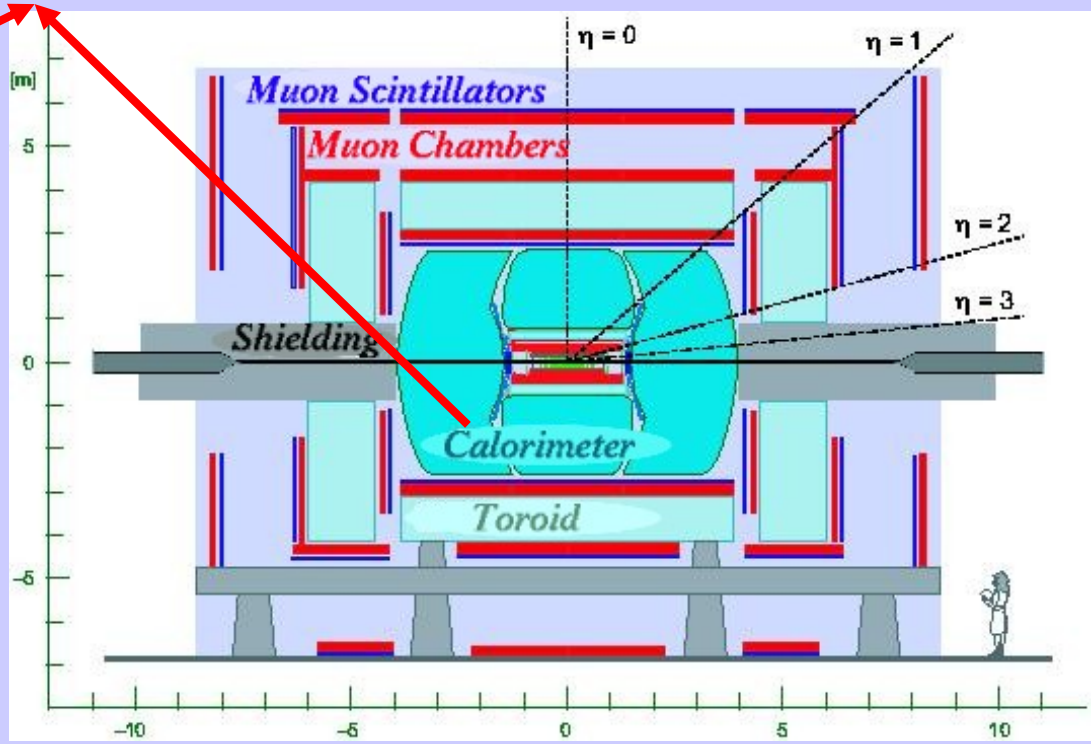


- CDF and D0 have > 2.5 fb^{-1} of data on tape (3 fb^{-1} delivered)
- Record initial luminosity: $2.9\times10^{32}\ cm^{-2}s^{-1}$
- Expect 4-8 fb^{-1} by 2009
- Will focus on ~1 fb^{-1} results in this talk

Detectors

Measure EM transverse shower profile at shower maximum

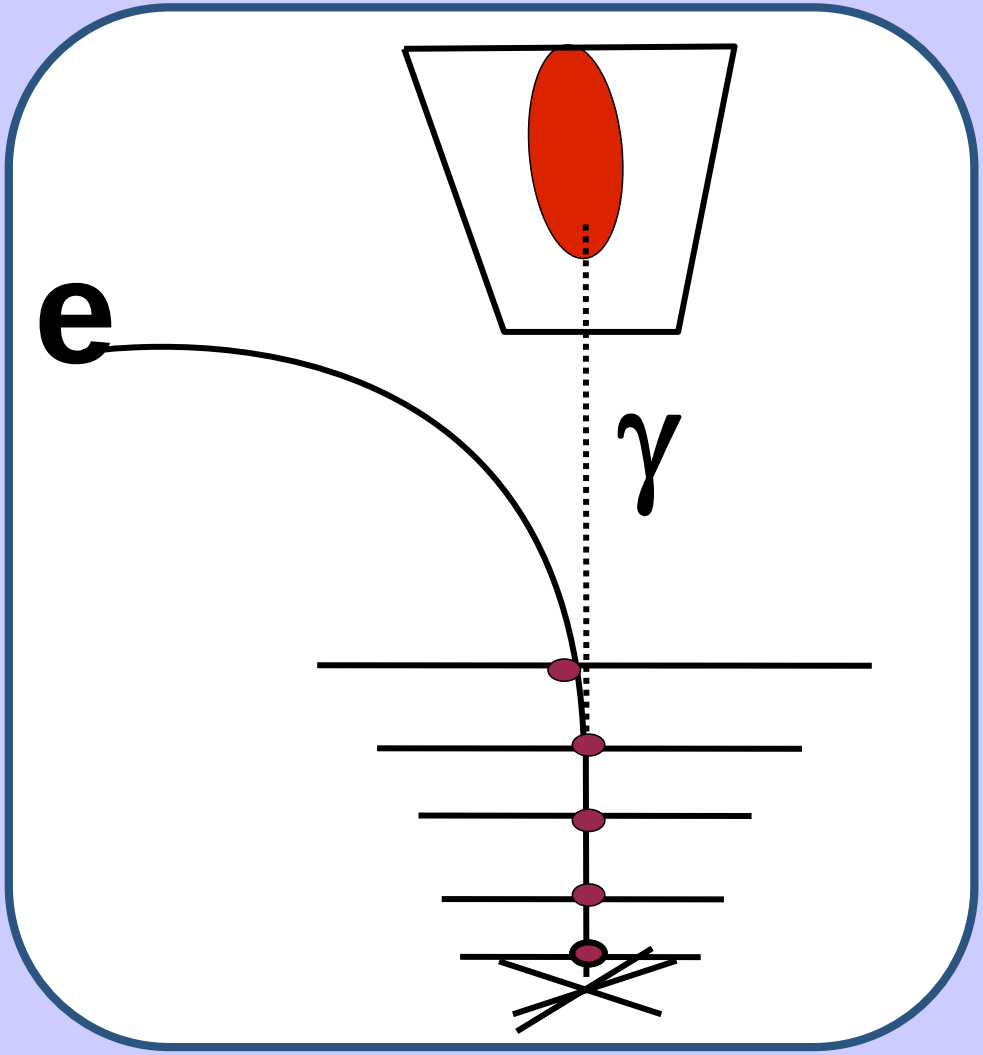




- γ: shower in the EM calorimeter with no associated track
- Multi-purpose detector: tracking chamber, EM (ECAL) and Had calorimeters (HCAL), and muon chamber

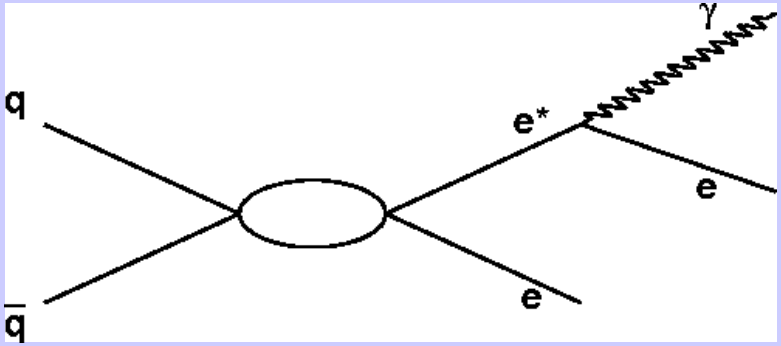
How to Suppress Photon Backgrounds

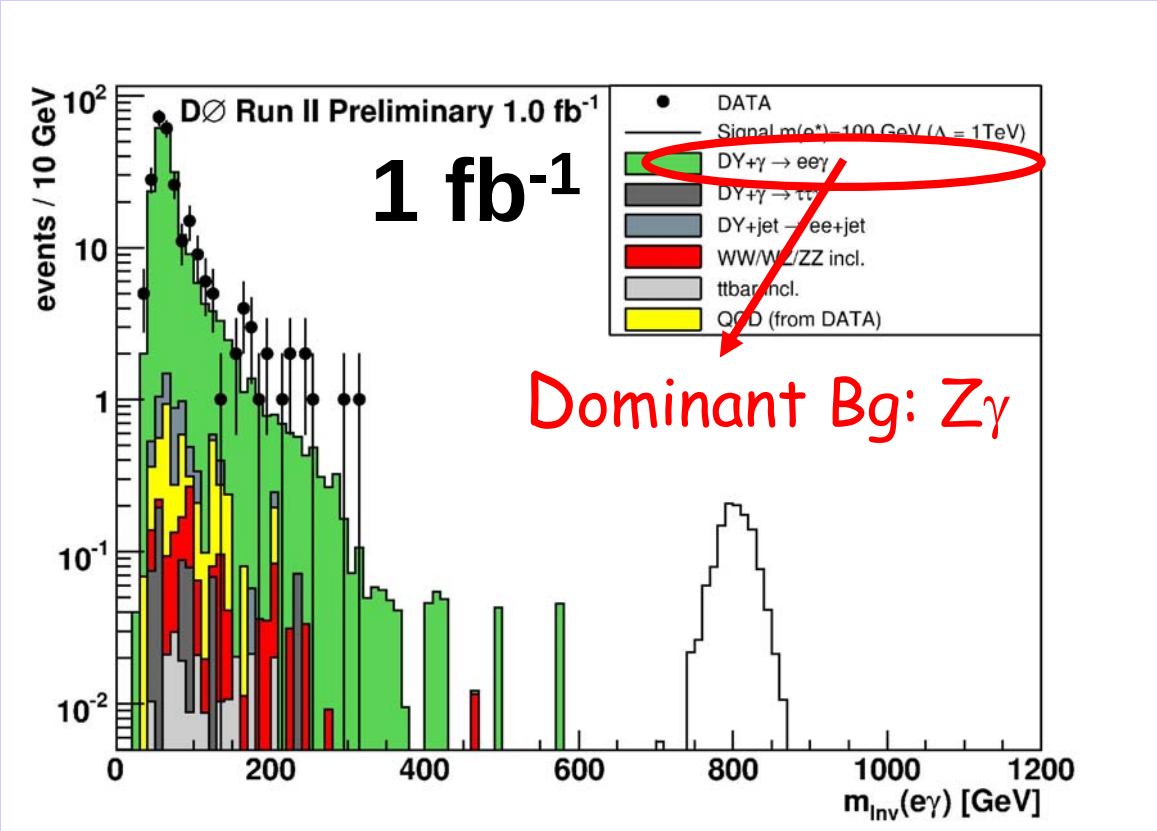
- Photons not produced in hard scattering process
- π^0, K_s, and η in jets
  - Most of the energy deposited in the EM calorimeter
  - Require isolated photons
  - EM shower profile consistent with single photon.
- Electron bremsstrahlung or tracking inefficiency
  - Road from the EM cluster to the event vertex
  - Search for hits along the road
  - Reduces electron by a factor of 3 to 7



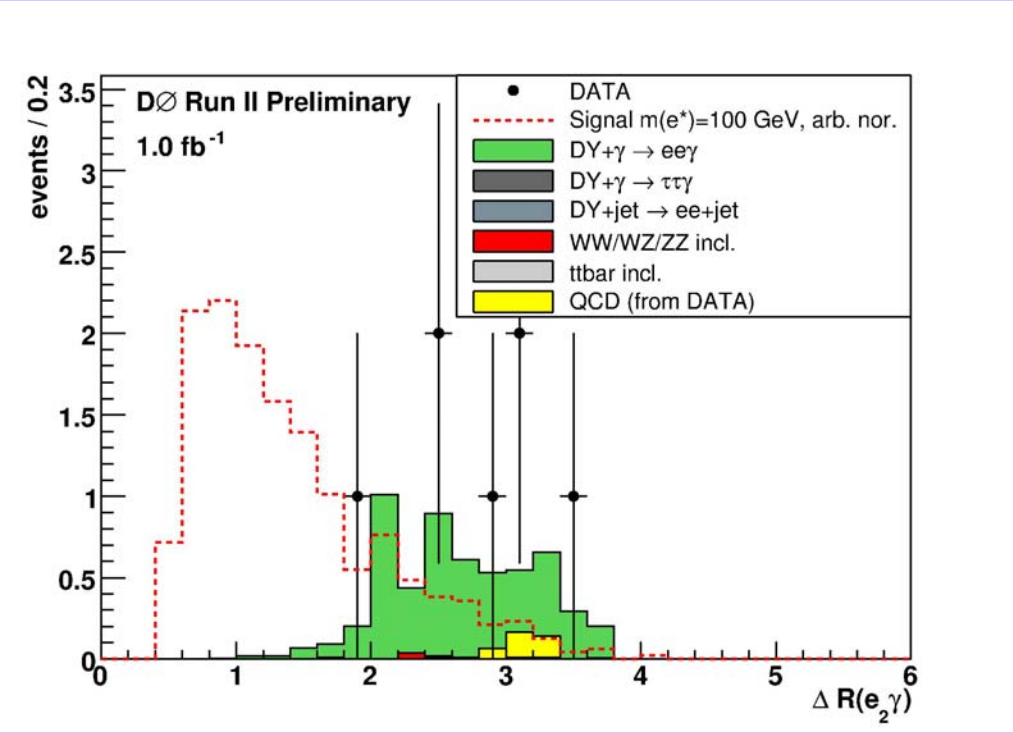
Search for Excited Electrons e*→eγ

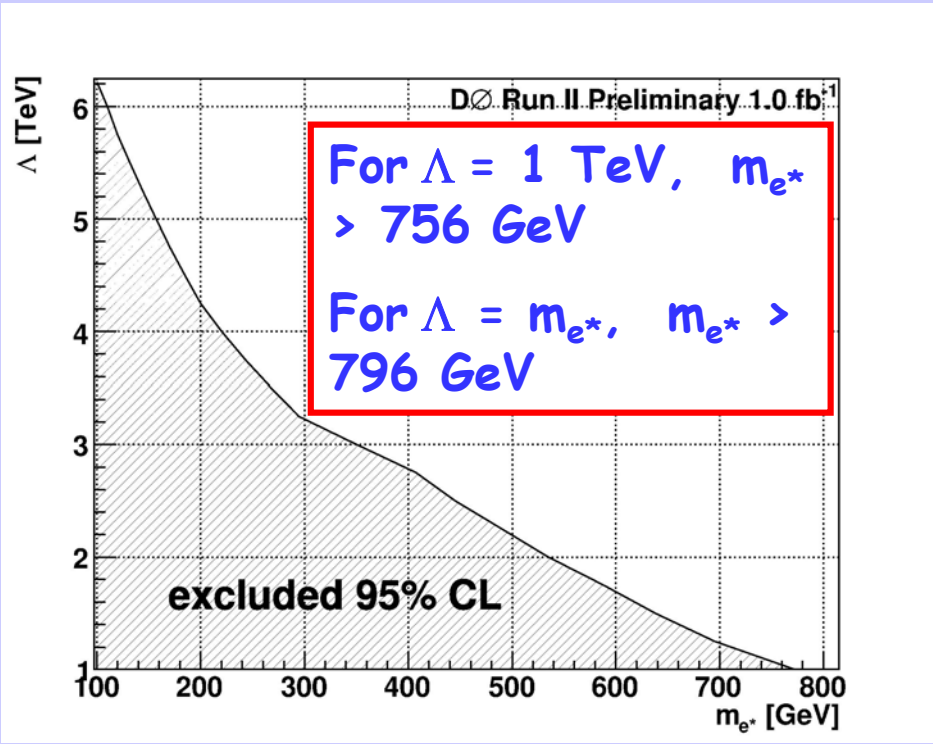
- Possible sign of compositeness
  - m(f*) and compositeness scale Λ
- Look in Contact Interaction channel qq→ee*→eeγ
  - Single EM or di-EM triggers
  - 2 isolated electrons (E_T^1 > 25 GeV, E_T^1 > 15 GeV), 1 isolated photon (E_T > 15 GeV), $|\eta_{det}|$ < 1.1 or 1.5 < $|\eta_{det}|$ < 2.5
  - ee control sample
  - Dominant bg: Zγ
    - Pythia MC and corrected to NNLO cross-section (Hamberg, van Neerven, Matsuura)





Search for Excited Electrons e*



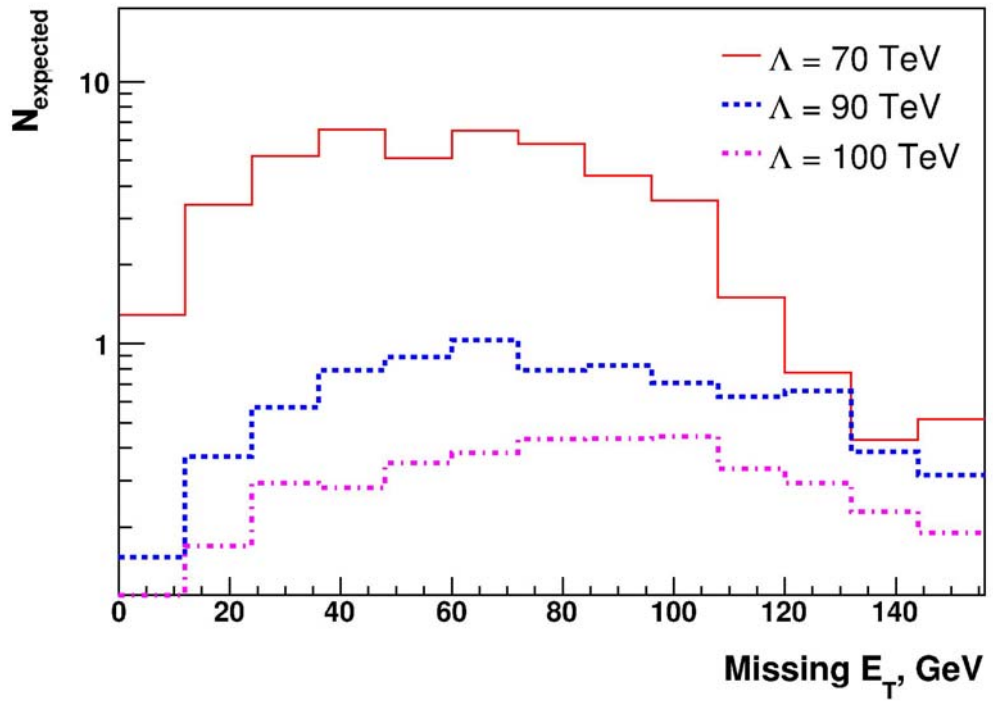


- Optimize minimum requirement on m(eγ)
  - Use second leading electron for m(e*) ≤ 200 GeV
  - Use electron which give m(eγ) closer to the search regon for m(e*) > 200 GeV
- For m(e*) < 300 GeV, optimize cuts on the $\Delta R(e_2,\gamma)$
- No excess, 95% CL limit for compositeness scale Λ = 1 TeV, m(e*)> 756 GeV

Search for GMSB SUSY in $\gamma\gamma$MET

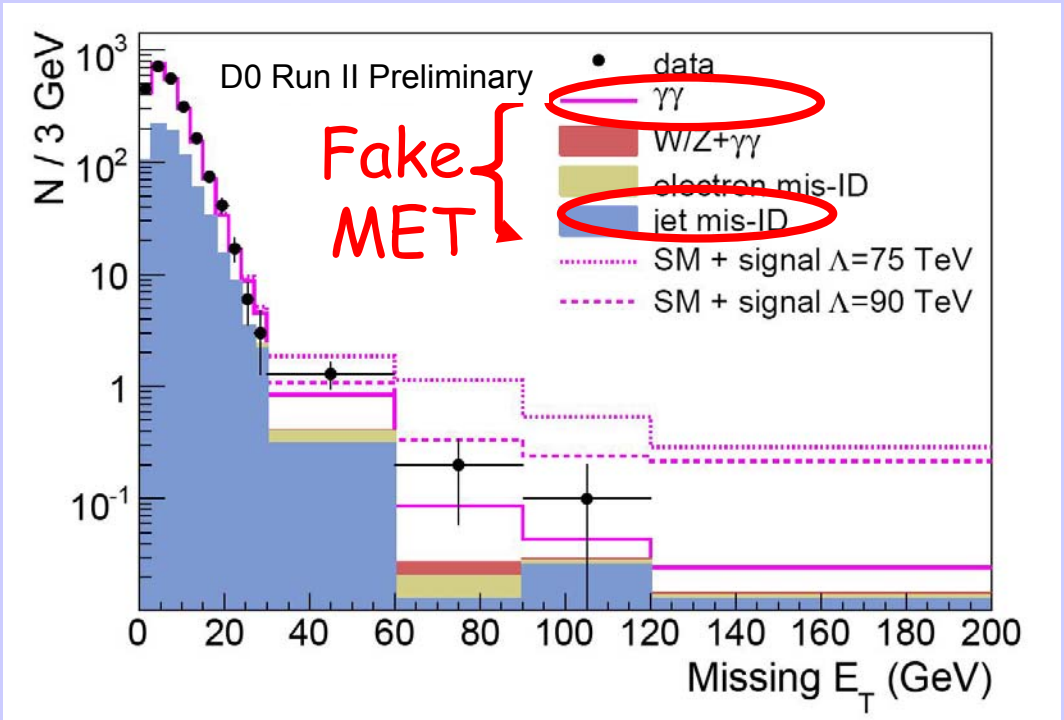
- SUSY breaking mediated by gauge interactions $\chi_1^0 \rightarrow \gamma\tilde{G}$
  - LSP is gravitino
  - Snowmass Slope SPS 8 model
  - Single parameter Λ determines the effective scale of SUSY breaking
- Single-EM trigger
- Require two isolated central photons with $E_T > 25$ GeV
  - Photon vertex consistent with primary: $\varepsilon = (95.8 \pm 0.1)\%$
  - Photon vertex: line along pre-shower detector and 4 layers of ECAL, $\sigma = 2.3 \pm 0.3$ cm

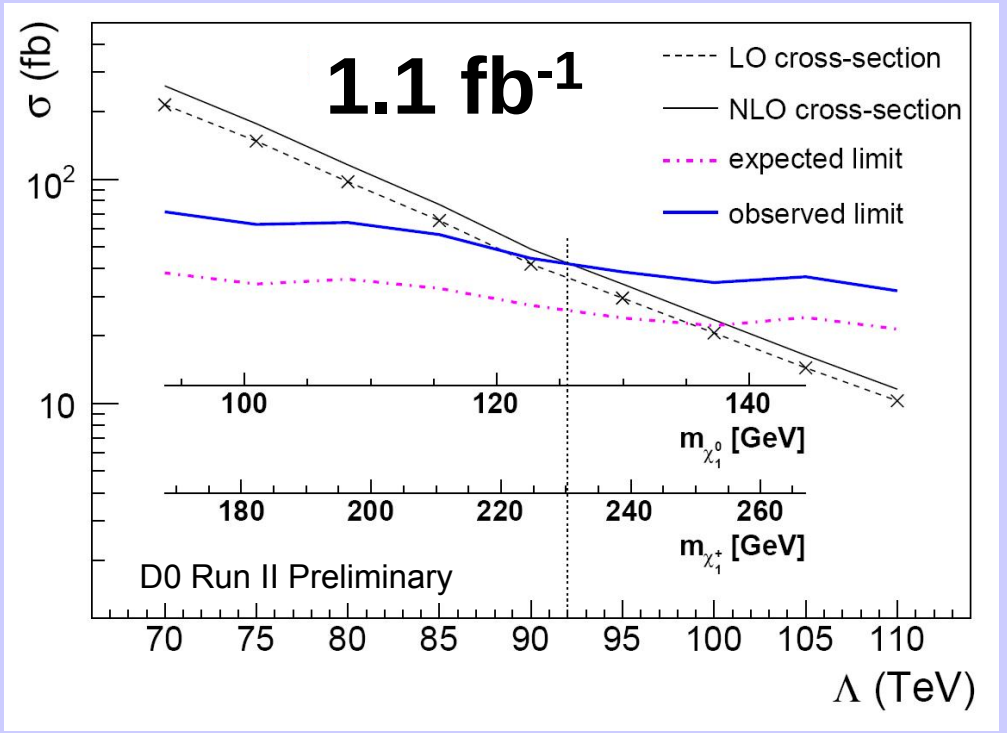
Expected MET from GMSB



- MET
  - Jets: midcone, size 0.5
  - Uses CAL $|\eta| < 4.0$
  - $\Delta\phi$ (leading jet, MET) < 2.5 radians

Search for GMSB SUSY in γγMET

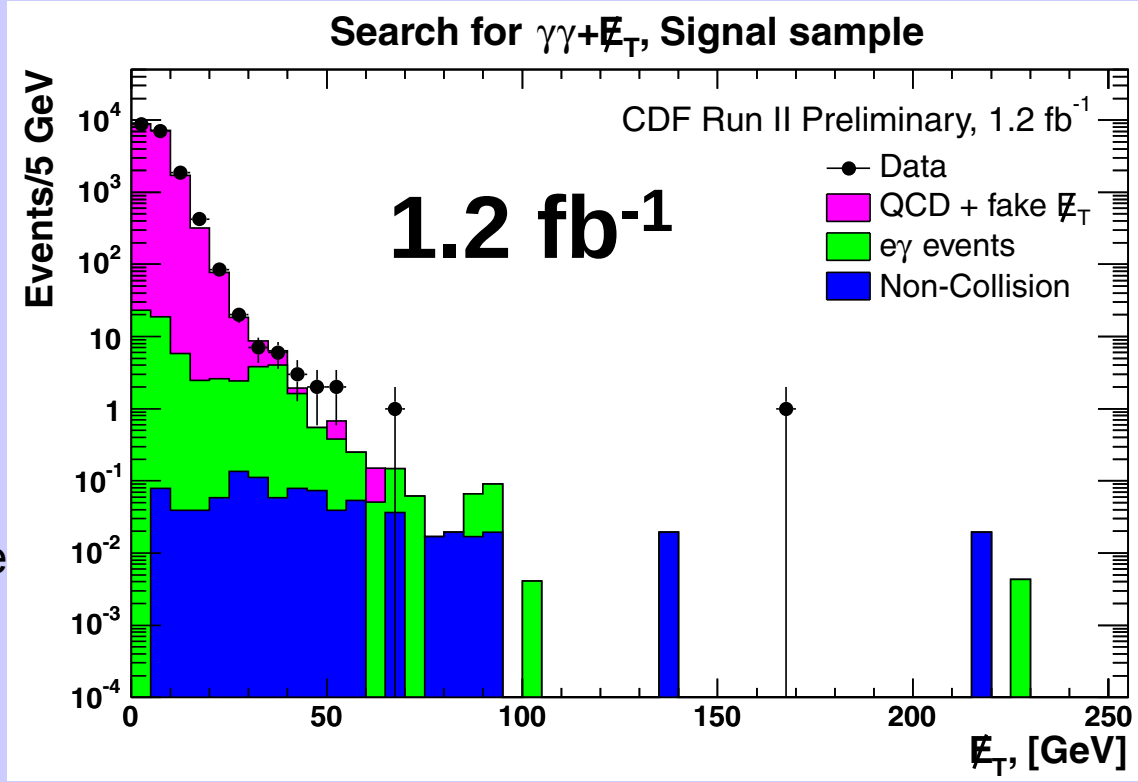




- Backgrounds
  - Fake MET from jets: MET shapes from Z->ee and multi-jet samples, normalized to the low MET region in the γγ sample
  - Real MET from Wγ, Wj: apply e->γ rate rate (~1.4%) to the MET in eγ events
  - Zγγ, Wγγ: CompHep MC (x-check with Madgraph)
- No excess, use binned MET distributions to set 95% CL limit:
  $\Lambda > 88.5$ TeV, $m\chi_1^0 > 120$ GeV, $m\chi_1^+ > 220$ GeV

Search for Anomalous $\gamma\gamma$MET Events

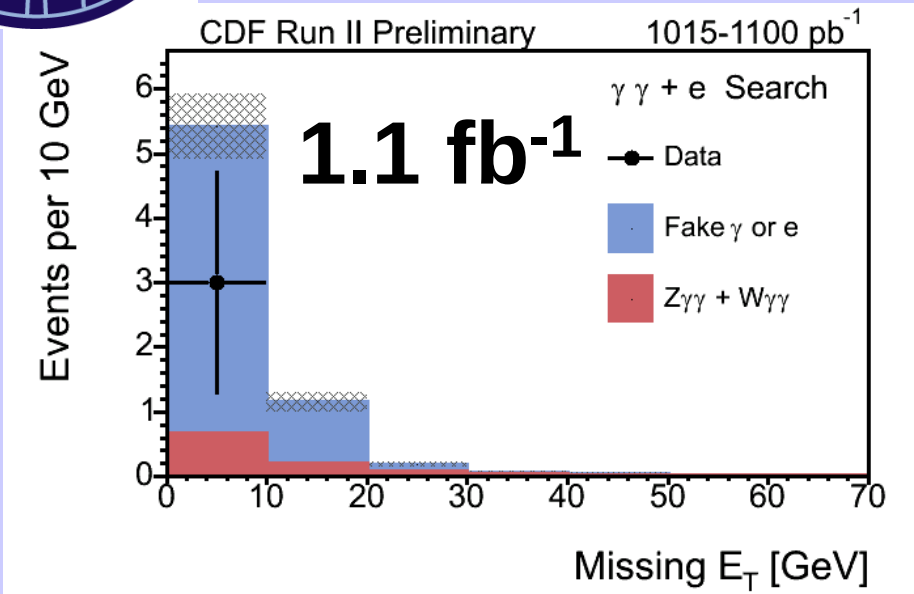
- Diphoton trigger
- Central photons with Et > 13 GeV
- All backgrounds estimated from data
- Fake MET
  - parameterize fake MET
  - dijet sample for jet energy resolution
  - 0-jet events in loose photon and Z->ee samples for UE and MI
- Real MET
  - Apply e->γ rate (0.4-2%) to eγ events
- Beam Halo, Cosmic
  - Remove photons with beam halo topology
  - Require EM timing consistent with collision time or remove photons close to trackless muon hits
  - Extrapolate from out of time events

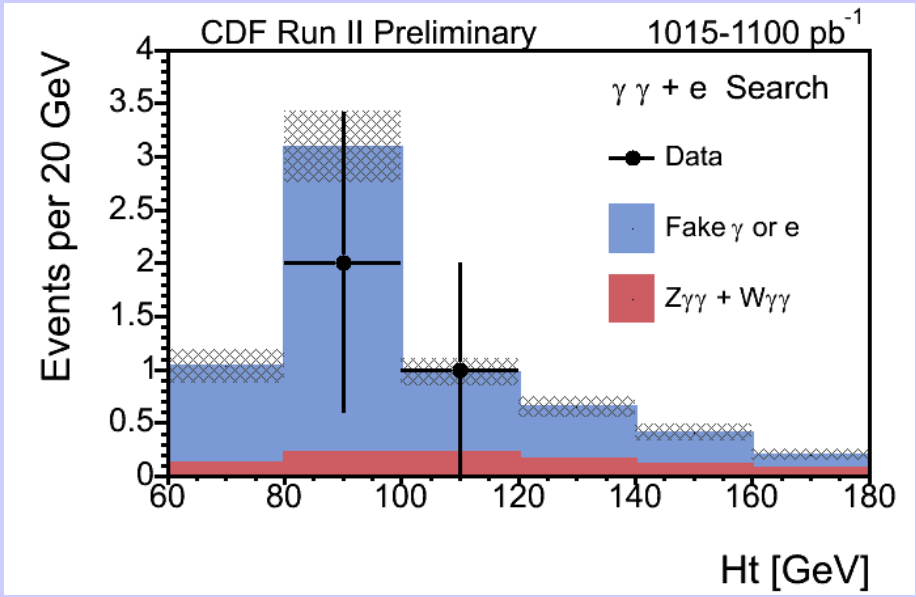


- For MET > 50 GeV. 4 observed, 1.6 ± 0.3 expected

See Max Goncharov's talk

Search for Anomalous γγe,μ Events





- Diphoton trigger
- 2 central photons with Et > 13 GeV and 1 lepton Et > 20 GeV
- *Wγγ* and Zγγ (MadGraph)

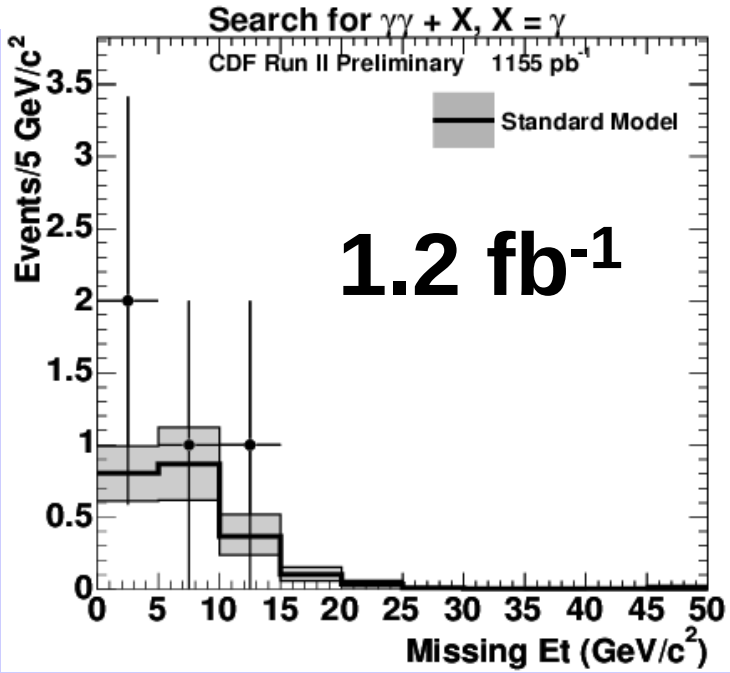
Ht = scalar sum of Et from photons, leptons, jets, and MET

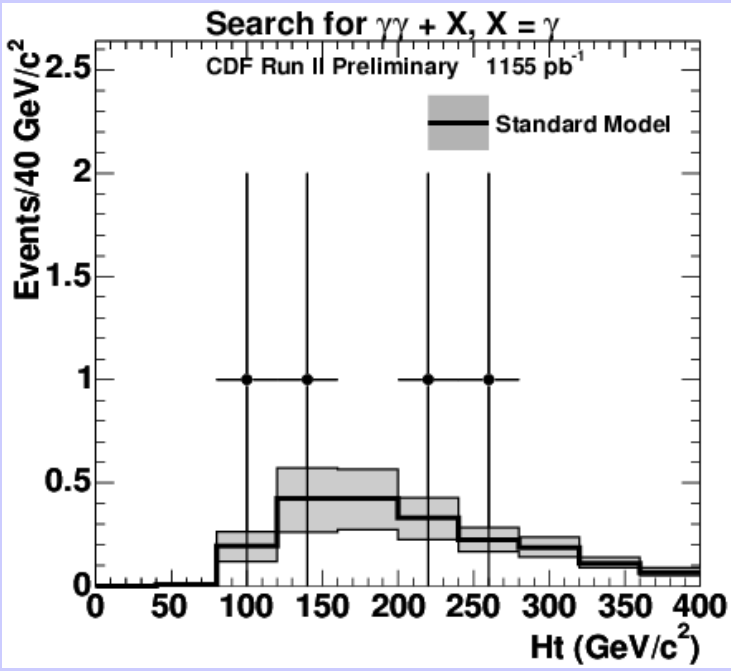
- A denominator times fake rate for:
  - jets faking leptons: γγ jet
  - jets faking photons: W(Z)γ+jet, W(Z)+2jets
  - electrons faking photons: Zγ, Z+jet

γγe	6.82±0.75	3
γγμ	0.79±0.11	0

Dominant Bg { Zγ, Zγγ

Search for Anomalous γγγ Events



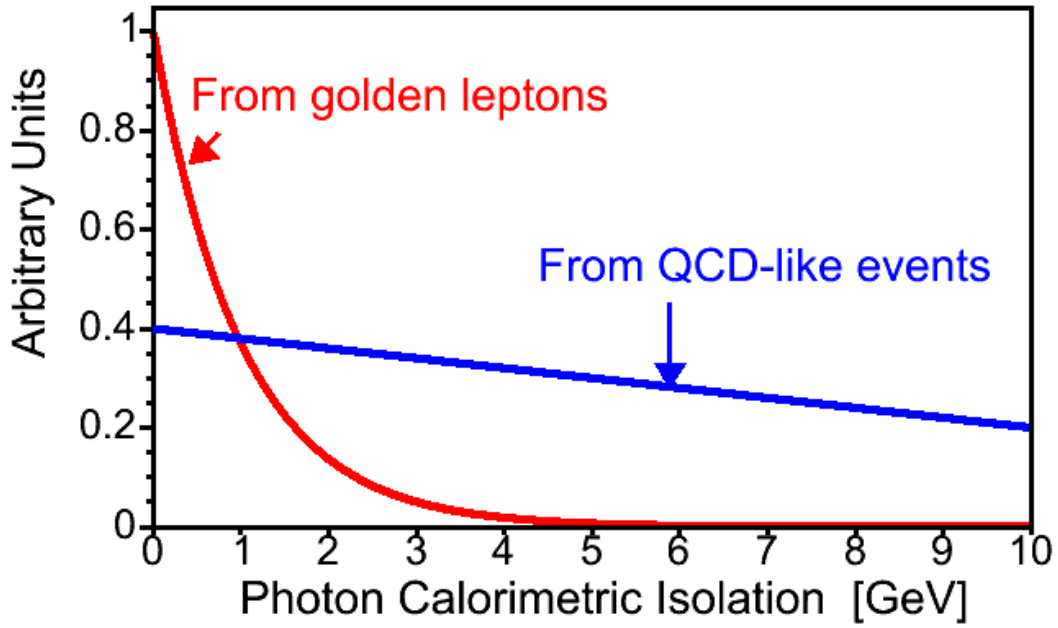


- Diphoton trigger
- 3 central photons with Et > 13 GeV
- SM tri-photon production estimated from Madgraph with K-factor 1.5±0.2

SM tri-photon	0.80 ± 0.15
Fake from jets	1.4 ± 0.6
Total	2.2± 0.6
Observed	4

Search for Anomalous $\ell\gamma$+X Events

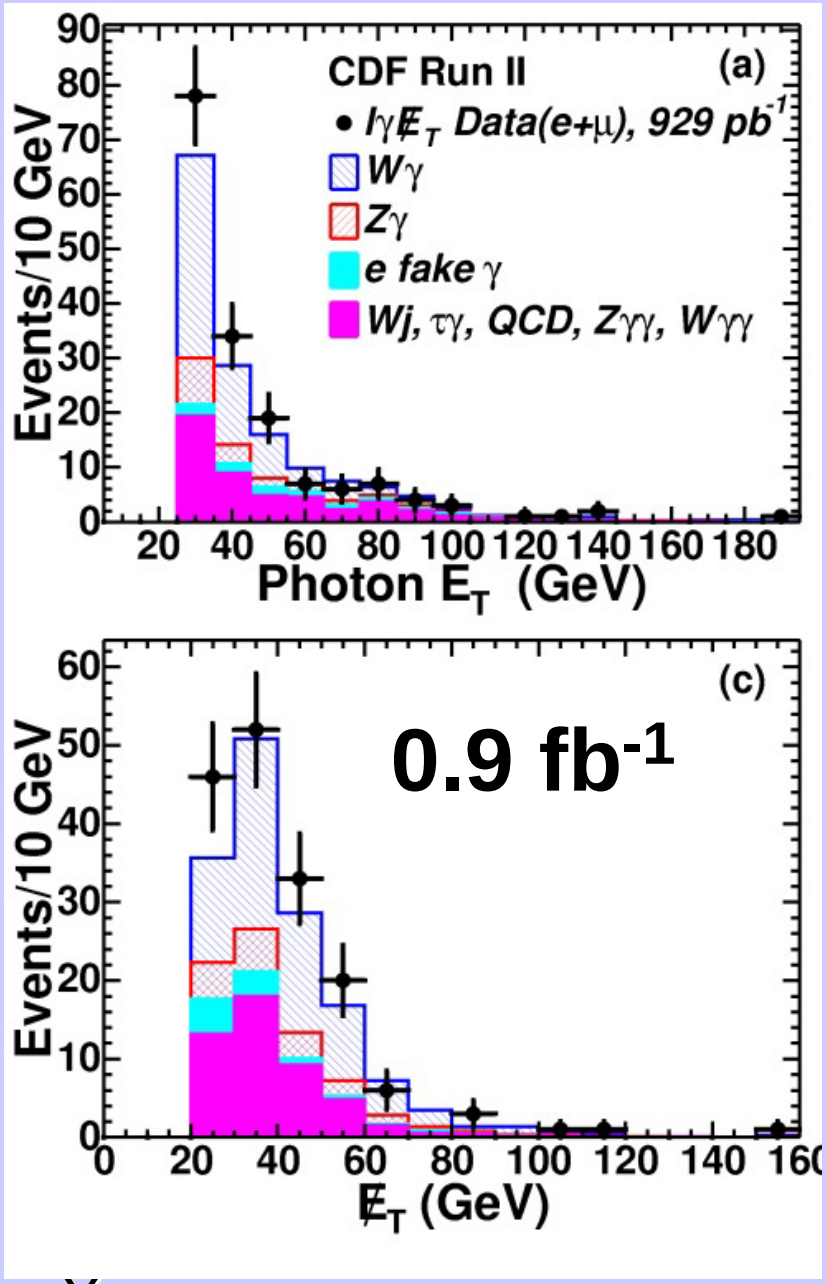
- Motivated by the CDF I $\gamma\mu$ MET excess
- Repeat the same kinematic requirements
- Inclusive lepton or photon triggers
- Basic objects:
  - Central lepton (e,μ) > 25 GeV, central photon > 25 GeV
- X = MET, lepton, or photon
  - MET > 25 GeV
  - Photon > 25 GeV
  - Loose central electron Et > 20 GeV, forward electron > 15 GeV, central muon Pt > 20 GeV



- Background
  - Wγ, Zγ, W$\gamma\gamma$, Z$\gamma\gamma$: Madgraph MC
  - Fake photons from electrons
  - Fake photons or leptons from jets: study isolation shapes in QCD events and golden leptons

Search for Anomalous $\ell\gamma$+X Events

	Exp.	Obs.
eγMET	94.8±8.1	96
$\mu\gamma$MET	55.7±7.1	67
eeγ	39.0±4.8	53
$\mu\mu\gamma$	26.1±3.1	21
$\gamma\gamma$e	0.53±0.13	0
$\gamma\gamma\mu$	0.10±0.06	0
$\gamma\mu$e	1.0±0.3	0



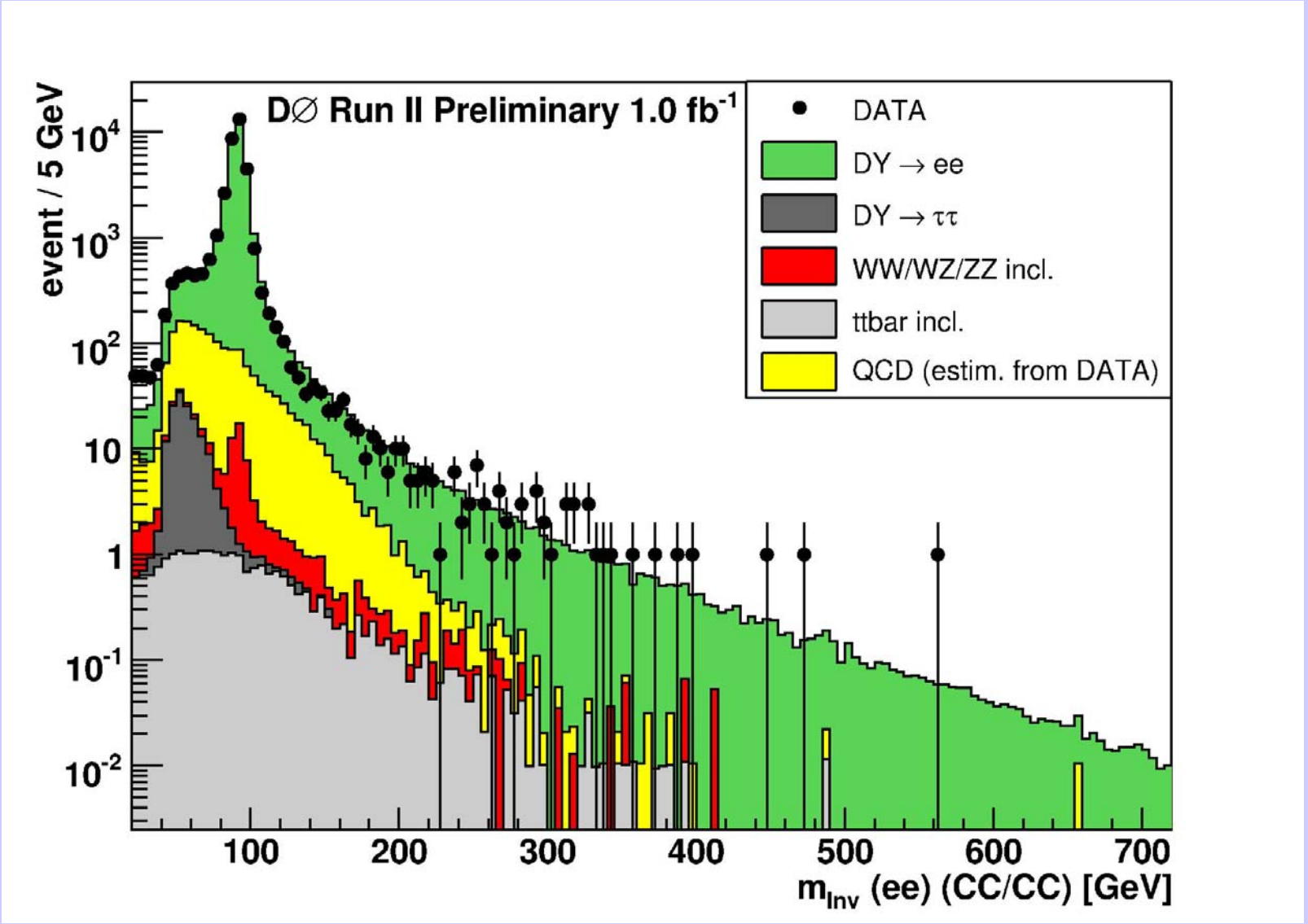
Conclusion

- Both CDF and D0 have performed extensive model-dependent and signature-based searches with photon final states
- No hint of new physics in 1 fb^{-1} of Run II data
  - CDF I excess can not be confirmed.
- Improve analysis techniques
- Results from other photon final states and with 2-8 times more data will come out in the future
  - $\gamma\gamma\tau$, $\gamma\gamma$b, $\gamma\gamma$j and more
- Keep looking. Something unexpected before LHC?


NP

Backup Slides

Control Sample of Search for e*



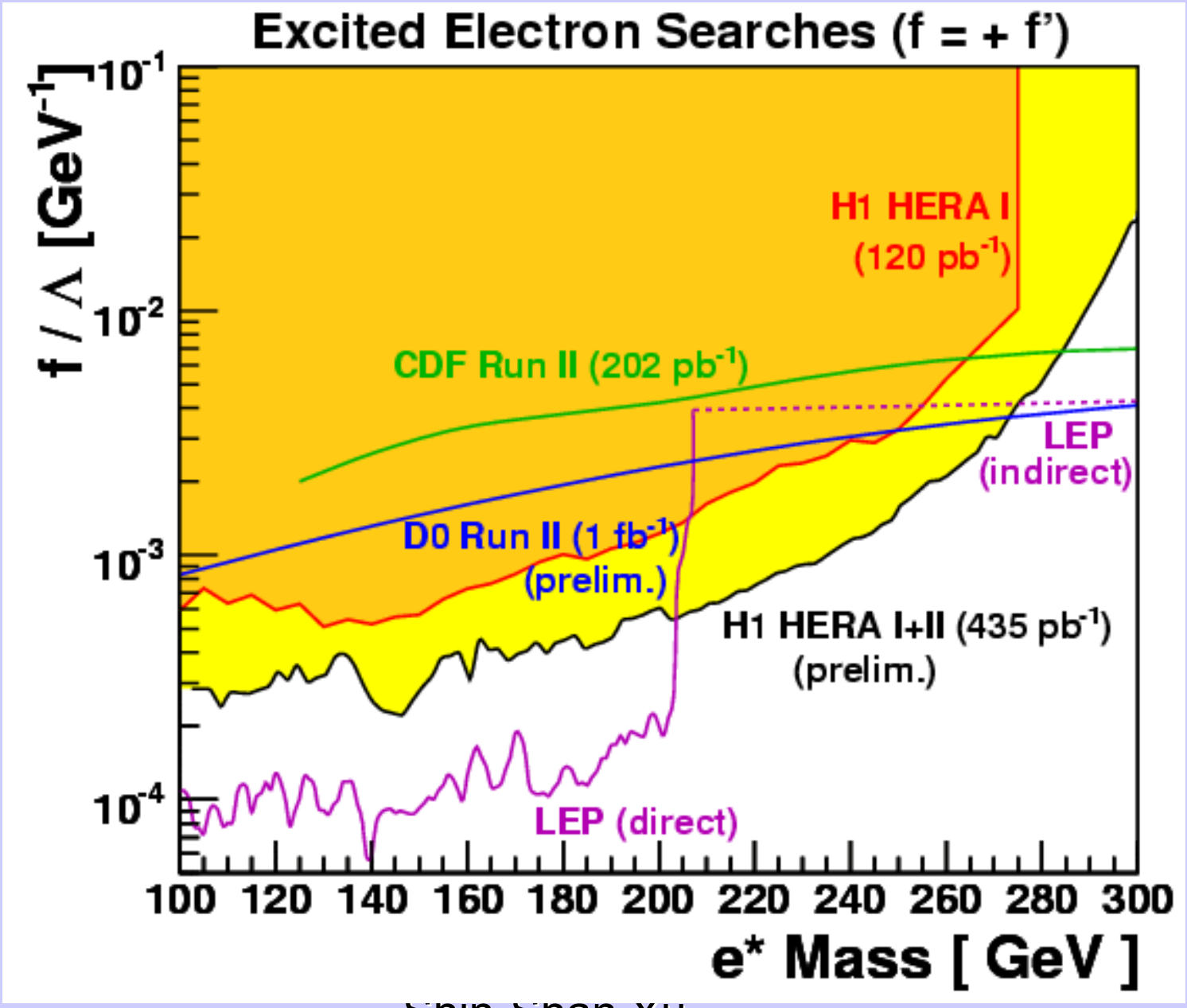
Optimize Cuts for the Search of e*

m_{e^*} [GeV]	$m(e_2,\gamma)$ [GeV]	$m(e\gamma)$ [GeV] (closest to m_{e^*})	EC/EC	EC γ	$\Delta R(e_2,\gamma)$
100	>90	–	no	no	<1.8
200	>165	–	no	no	<2.8
300	–	>290	no	no	all
400	–	>370	yes	yes	all
500	–	>445	yes	yes	all
600	–	>515	yes	yes	all
700	–	>600	yes	yes	all
800	–	>705	yes	yes	all
900	–	>800	yes	yes	all
1000	–	>900	yes	yes	all

BR e* -> e γ when Λ = 1 TeV

(me*)	BR(e*->eγ)	S (NNLO) X BR (pb)
100	0.27	35
200	0.21	7.3
300	0.15	2.2
400	0.11	0.67
500	0.08	0.23
600	0.06	0.08
700	0.05	0.02
800	0.04	0.006
900	0.03	0.002
1000	0.03	0.0004

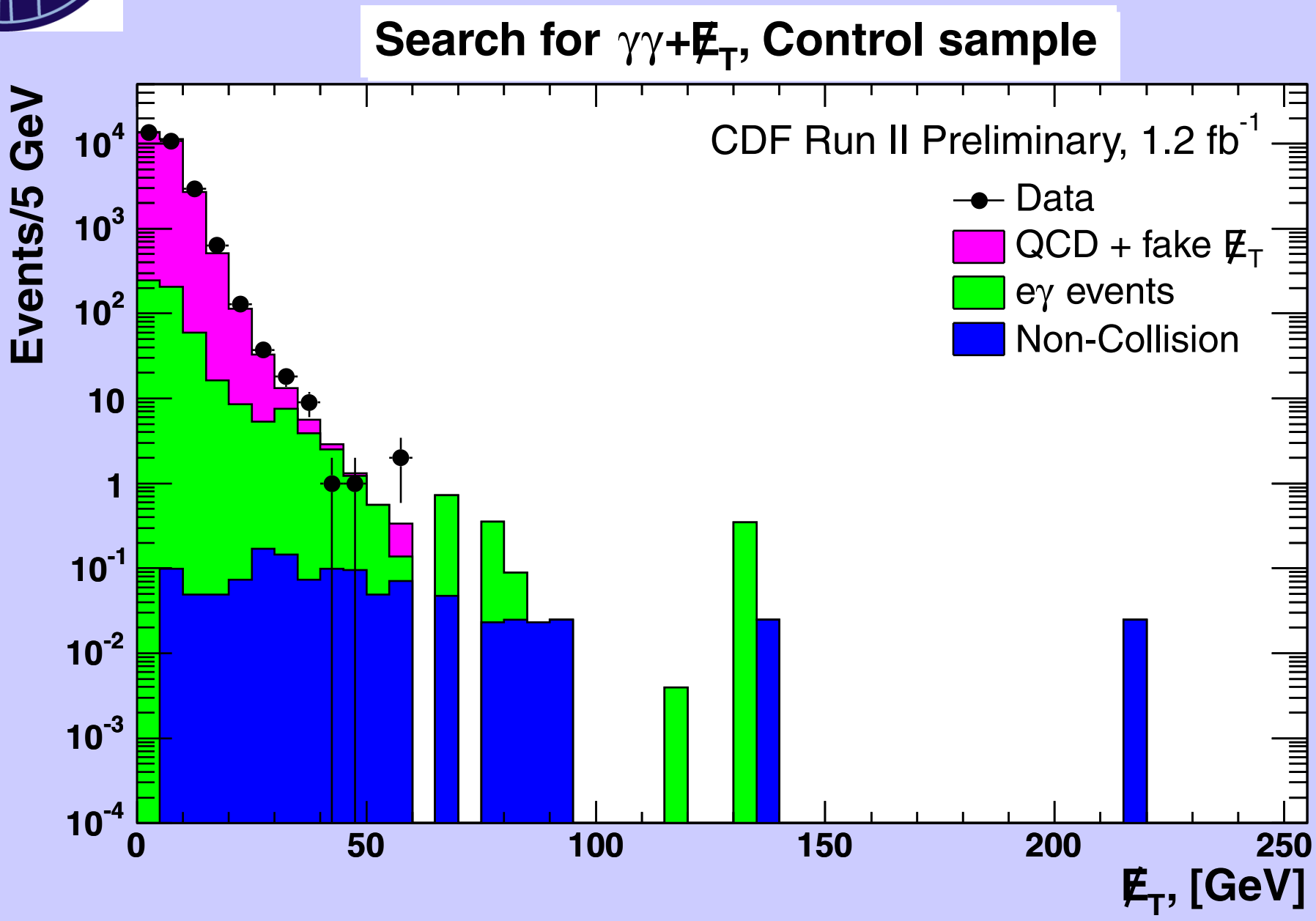
Gauge-mediated interaction



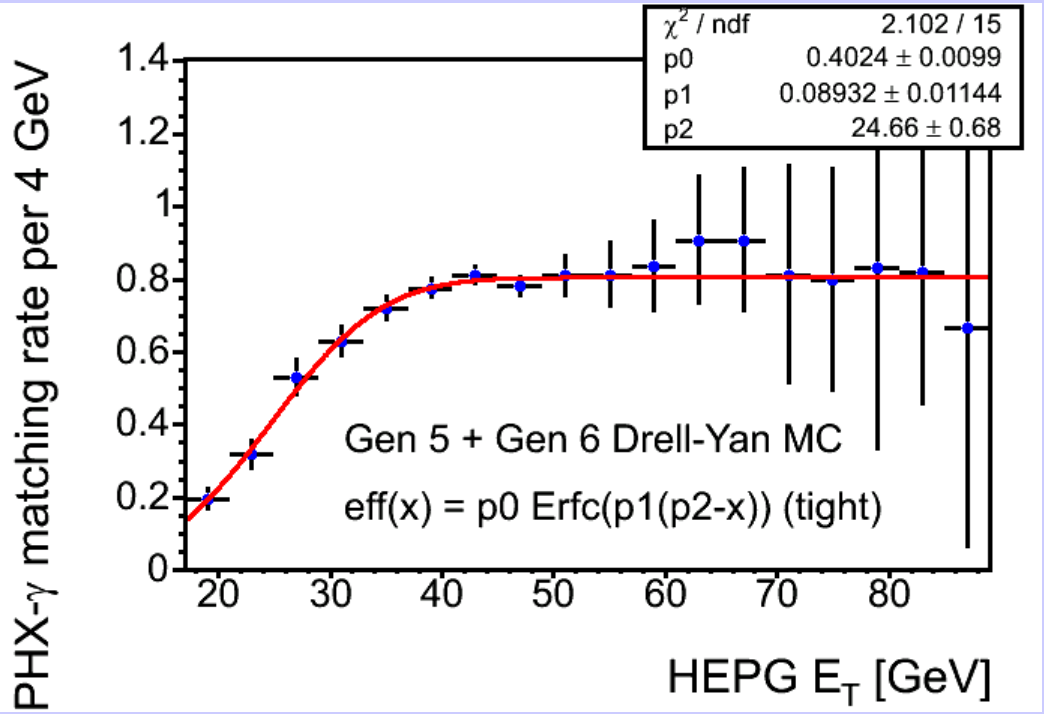
Search for GMSB in $\gamma\gamma$MET

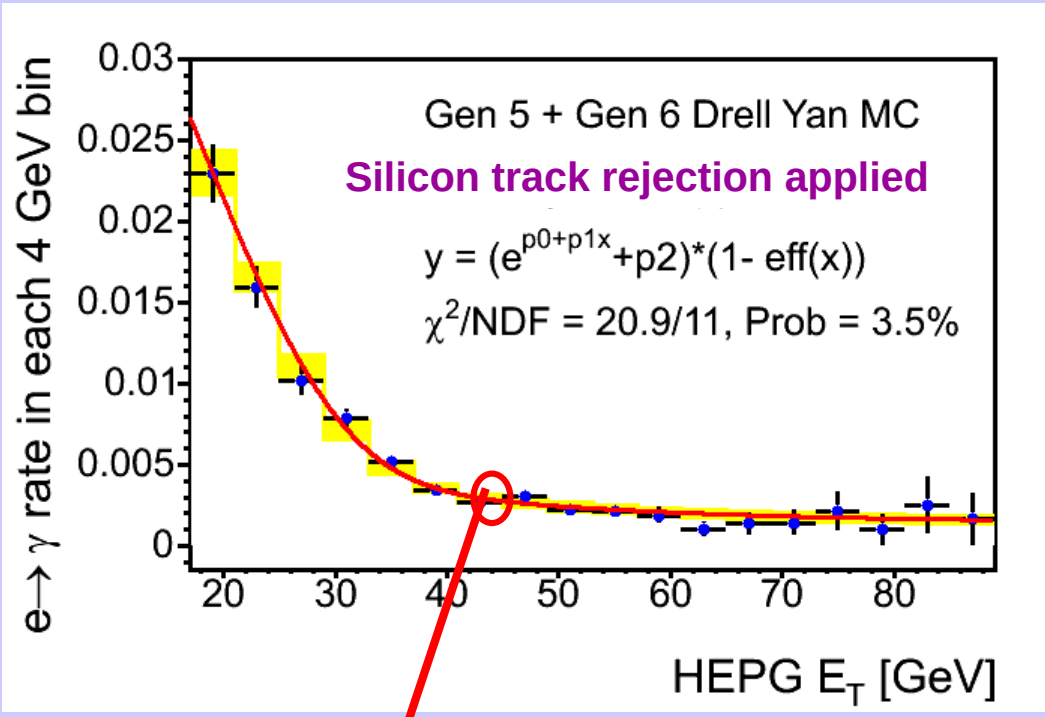
- Basic Snowmass Slope SPS 8 Model
  - Number of messenger = 1
  - Messenger mass = 2 * Λ
  - tan β = 15
  - Sign of the Higgsino mass μ > 0
- Hits on the road
  - Recover electron efficiency from 93% to 98,6%
  - Photon anti-track efficiency still 91%
- Require preshower hits from at least one of the photons
  - E = 1-0.2*2 = 96%
- MET > 30 GeV, expected 9.8±1.1, observed 16 events
- MET > 60 GeV, expected 1.5±0.4, observed 3 events

MET Distributions in the Control Sample of $\gamma\gamma$MET



Electron Mis-identified as Photons





- Compare Z peak from ee and eγ
- Get Et dependence from MC
- Normalize to data
- Silicon-track rejections reduce the fake rate by a factor of 3-4

0.36% at 45 GeV

SM Production Cross-section

Process	(pb)
$W\gamma$ ($\Delta R > 0.2$)	27.20
$Z\gamma$ ($\Delta R > 0.2$)	6.86
$W\gamma\gamma$ ($\Delta R > 0.2$)	0.13
$Z\gamma\gamma$ ($\Delta R > 0.2$)	0.09
$\gamma\gamma\gamma$ (Et>10 GeV, η < 1.2)	0.008

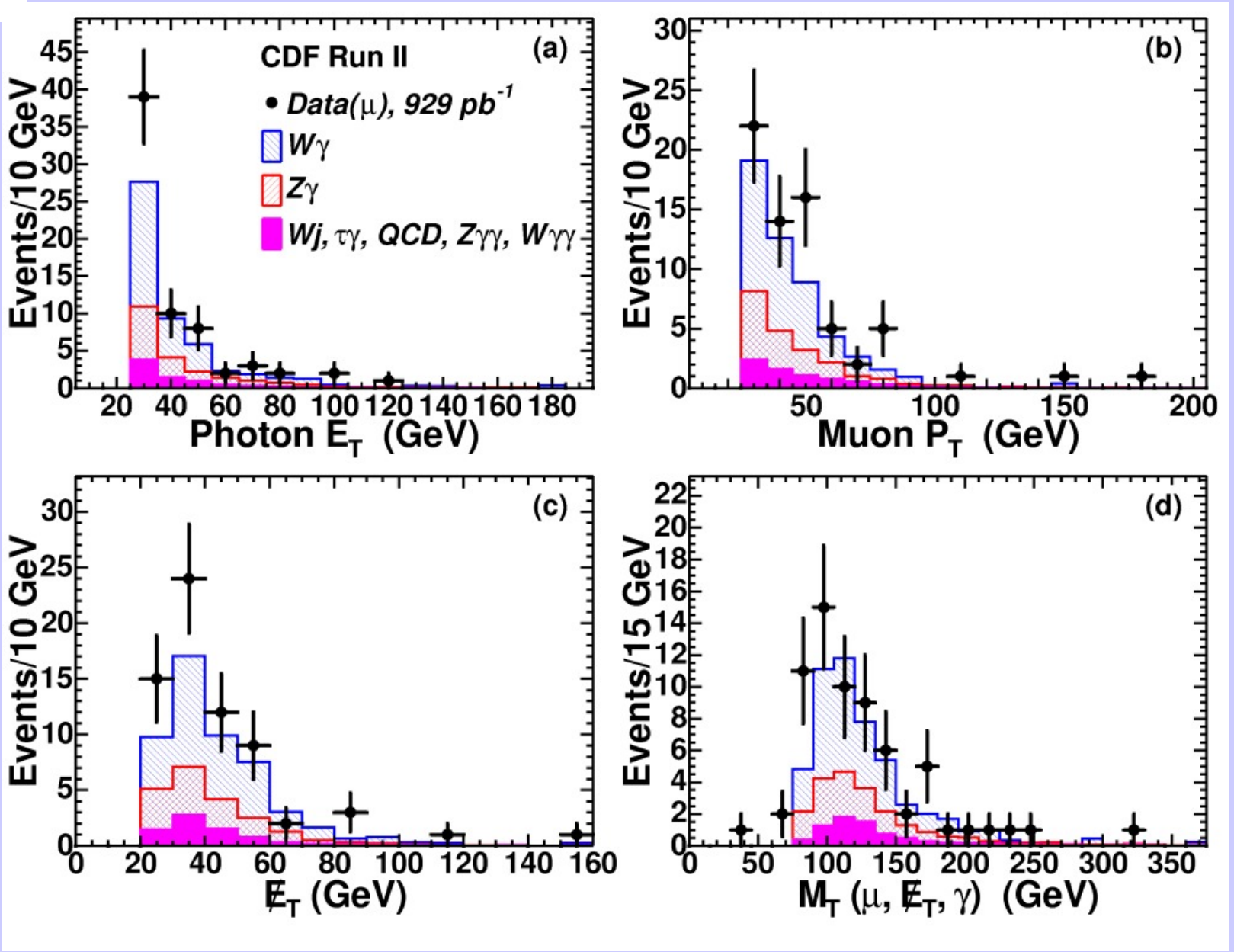
Search for Anomalous γγe,μ Events

Before applying Phoenix rejection		
Source	electron	muon
$Z\gamma\gamma$	$0.904 \pm 0.023 \pm 0.083$	$0.552 \pm 0.017 \pm 0.050$
$W\gamma\gamma$	$0.170 \pm 0.012 \pm 0.016$	$0.086 \pm 0.008 \pm 0.008$
Fake $l+\gamma\gamma$	$0.131 \pm 0.004 \pm 0.053$	$0.004 \pm 0.003 \pm 0.002$
$l\gamma + \text{jet} \to \gamma$	$0.475 \pm 0.025 \pm 0.312$	$0.133 \pm 0.013 \pm 0.090$
$l\gamma + e \to \gamma$	$5.140 \pm 0.340 \pm 0.584$	$0.017 \pm 0.017 \pm 0.002$
Total	6.82 ± 0.75	0.79 ± 0.11
Data	3	0

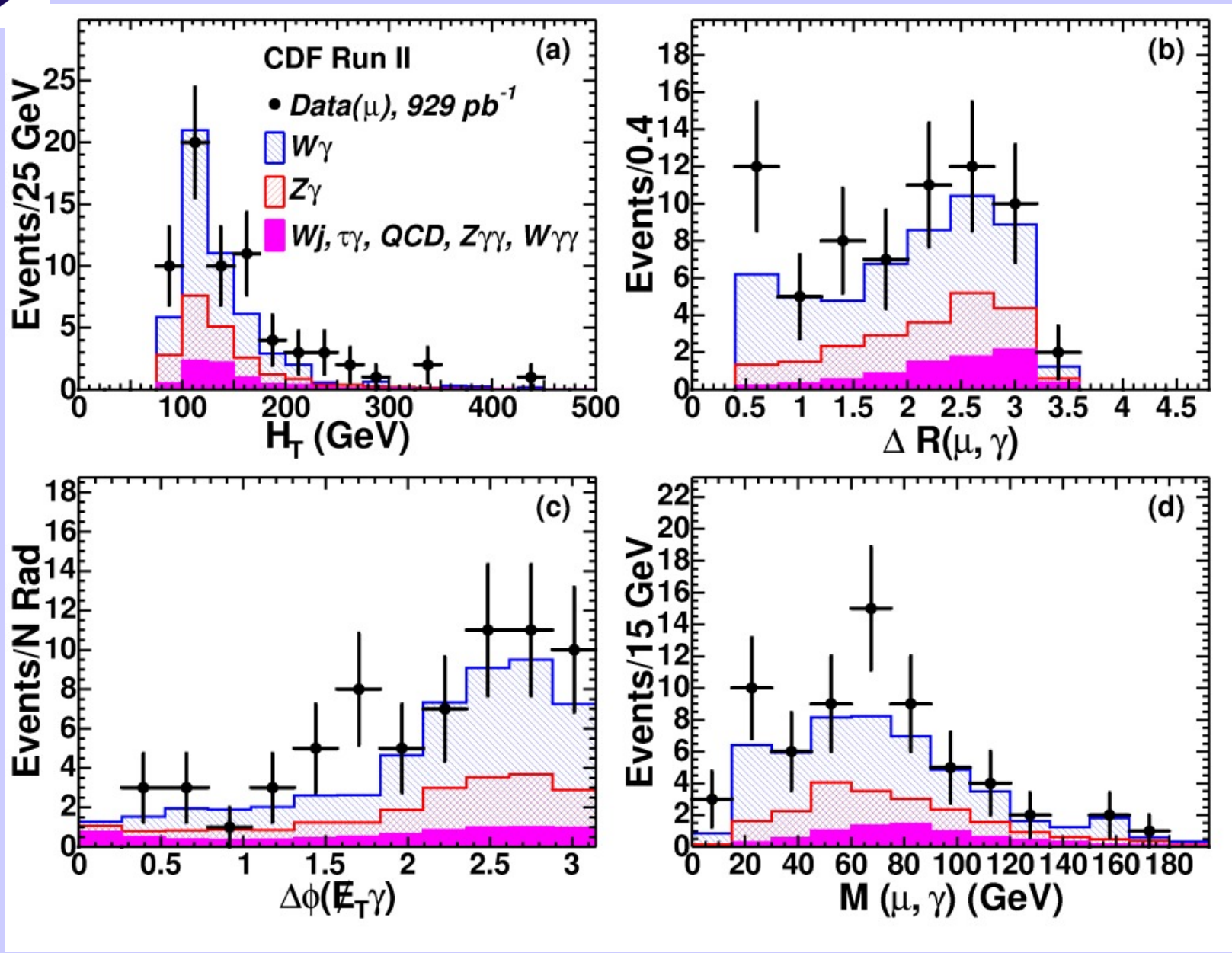
Search for Anomalous $\ell\gamma$+X Events

	Dominant Background
$\ell\gamma$MET	Wγ
$\ell\ell\gamma$	Zγ
$\gamma\gamma$e	Zγ
$\gamma\gamma\mu$	Fakes from jets
$\gamma\mu$e	Zγ

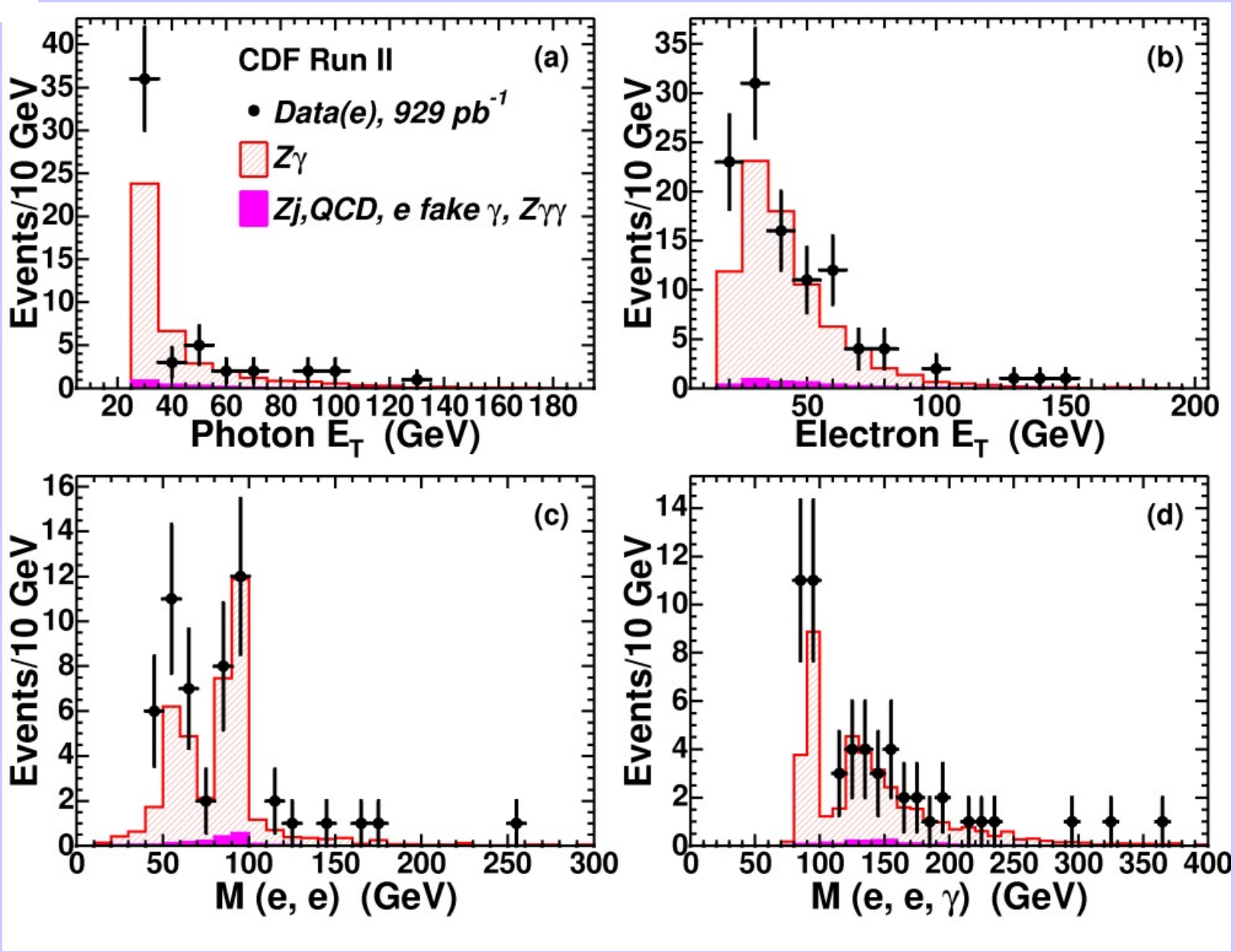
μγ MET Kinematical Distributions 1



μγ MET Kinematical Distributions 2



The eeγ Kinematical Distributions 1



The eeγ Kinematical Distributions 2