Search for SUSY in the trilepton channel

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For the CDF Collaboration

Outline

- Motivation for searching in the trilepton SUSY signature
- Description of the SUSY signal and of its standard model backgrounds
- Description of to the trilepton analysis
- Dilepton and trilepton kinematics and control regions
- Results and limits

Search for new physics using leptons

- The use of multi-leptons for the discovery of new physics offers low hadronic and well-understood electroweak backgrounds

- This analysis is a general multi-lepton search for new physics and for SUSY in particular in the trilepton channel
  - We investigate ee+lepton, ee+track, μμ+lepton, μμ+track
  - Lepton is e, μ, or hadronic τ

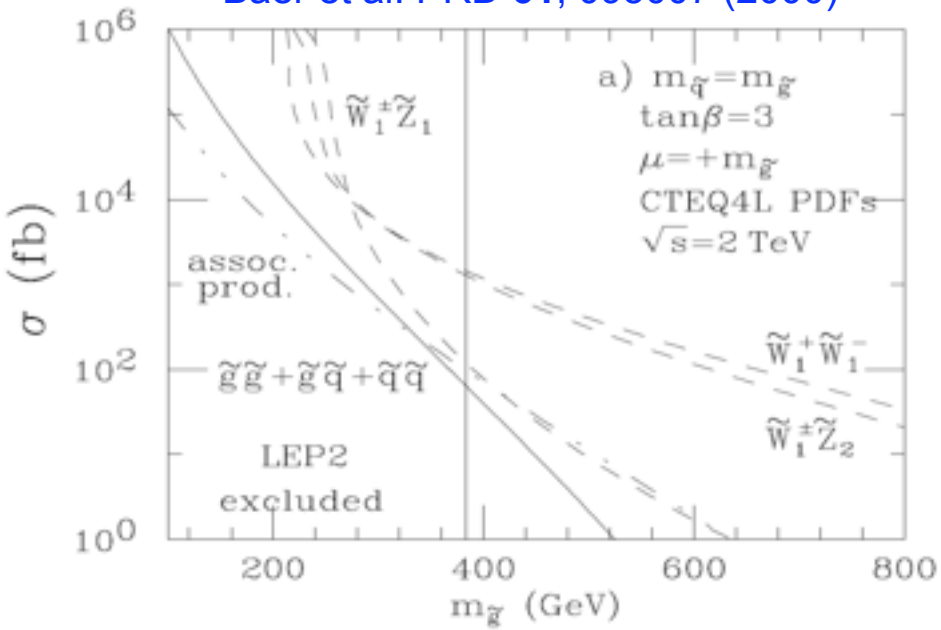
- The specific SUSY channel considered is the chargino + neutralino production and decay to three leptons + Missing E_T (MET)
  - MET is an important component of our analysis

- Although we treat the dilepton (ee, μμ) channels as control regions in the trilepton analysis, we have used them in dilepton searches for new physics.

Why chargino-neutralino, why trileptons?

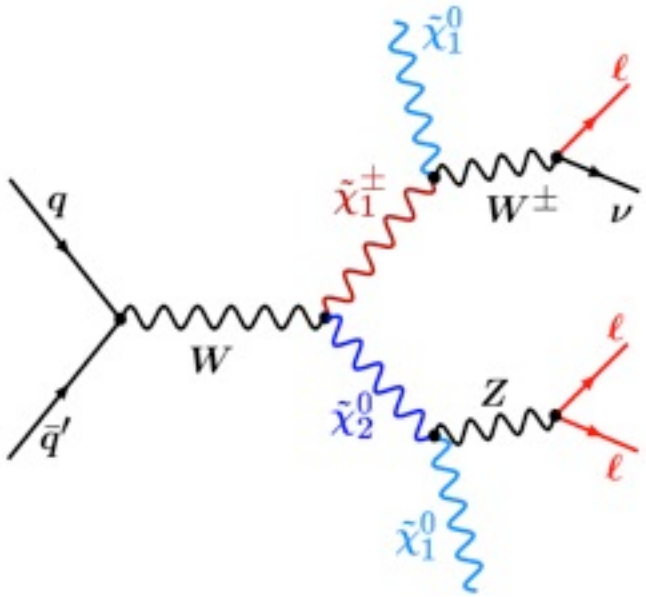
- The non-excluded chargino-neutralino production cross-section at the Tevatron is of the order of 0.1-1 pb, depending on the SUSY parameters

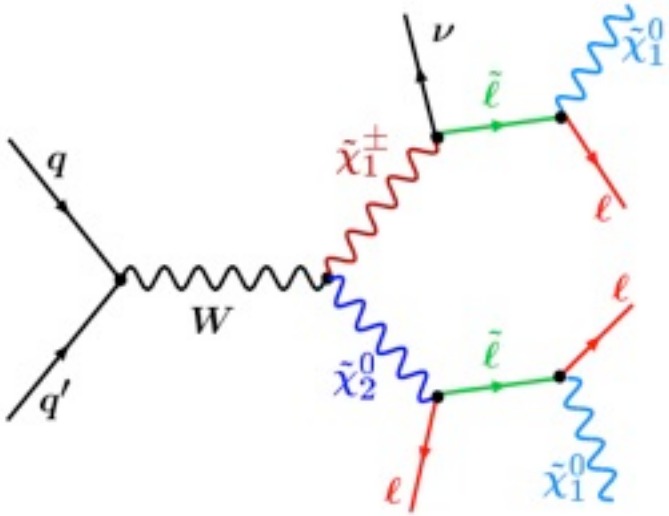
Baer et al. PRD **61**, 095007 (2000)



- The leptonic decays of the chargino and the next-to-lightest neutralino give ***3 leptons and MET***, a signature with low SM backgrounds.
- For these reasons, the trileptons are ***the golden channel for the discovery of SUSY at the Tevatron***

Trilepton chargino-neutralino signal





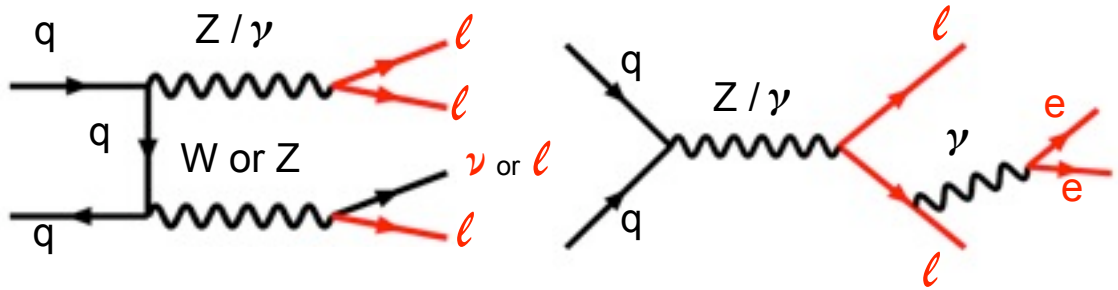
Decays through W/Z favorable for heavy sleptons, but BR to leptons low

Decays through sleptons guarantee final leptons, preferably to τ

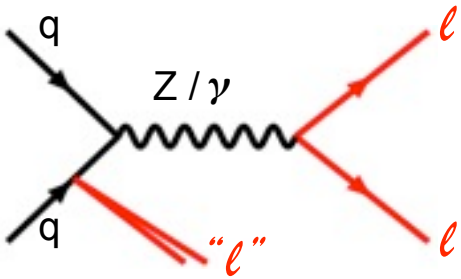
- Both cases give the signature of interest: ***Three leptons and Missing Transverse Energy*** (MET) due to undetected neutralinos (LSP in mSUGRA with R-parity conservation) and neutrinos

SM Trilepton Backgrounds

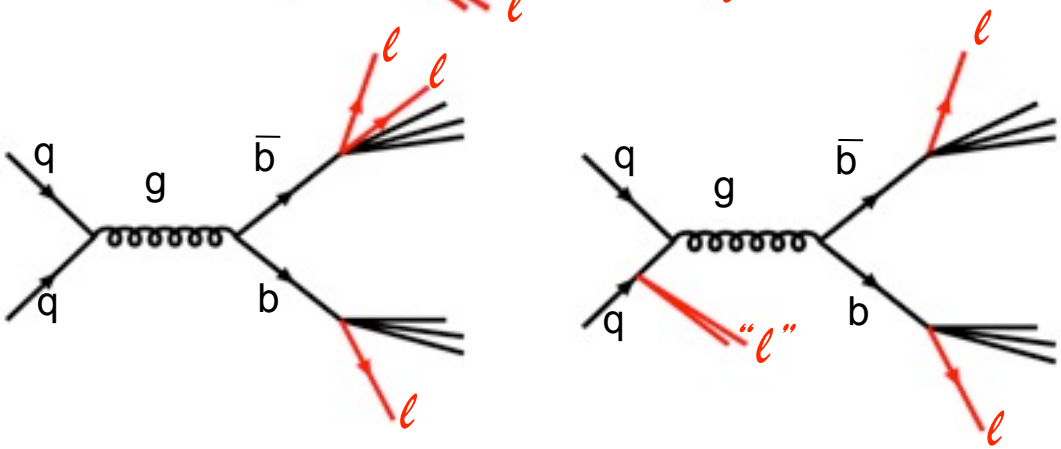
- Electroweak
  (Drell-Yan+γ and diboson)
  Measured with MC simulation



- Light-flavor QCD
  (u,d,s quark-based)
  Measured with CDF data



- Heavy-flavor QCD
  (c,b quark-based)
  Measured with CDF data

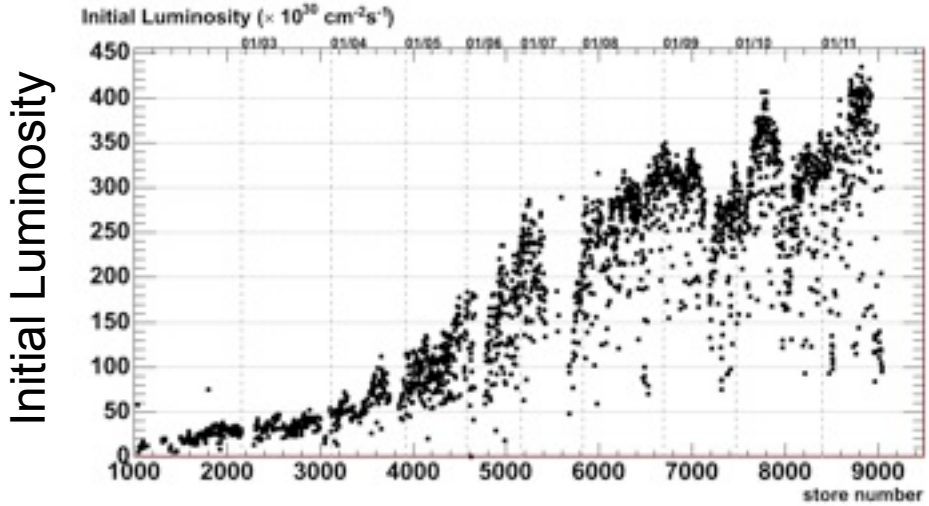


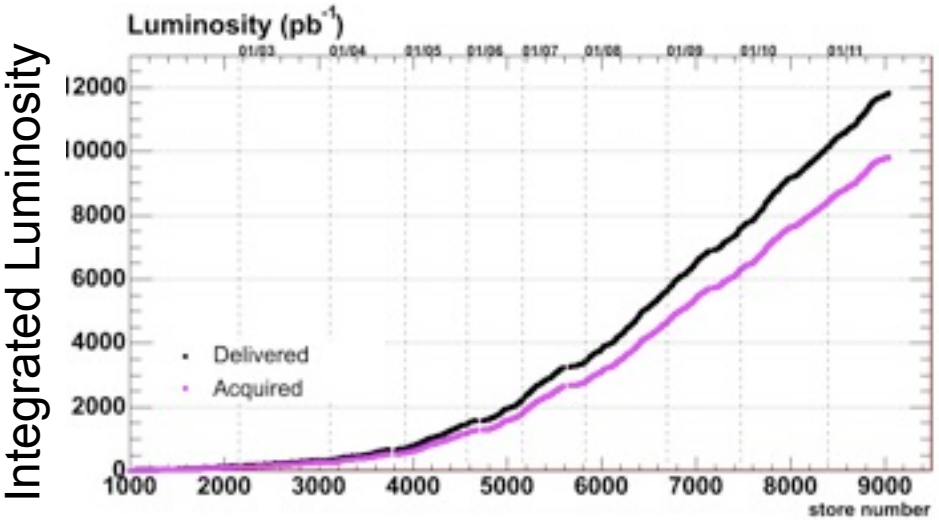
"ℓ" = fake lepton

Our trilepton analysis improvements

- We expand geometrically
  - We include forward ($|\eta|>1$) regions of the detector by including electrons and muons reconstructed in the forward sub-detectors.
- We expand kinematically
  - Low-p_T and low-M_{ll}
- We include new leptons
  - Hadronic tau leptons (as thirds)
- Compared to our (UNM) previous analysis, we also include
  - Isolated third tracks
  - Stubless central muons
- We present here results for a **luminosity 5.8 fb^{-1}** collected at CDF

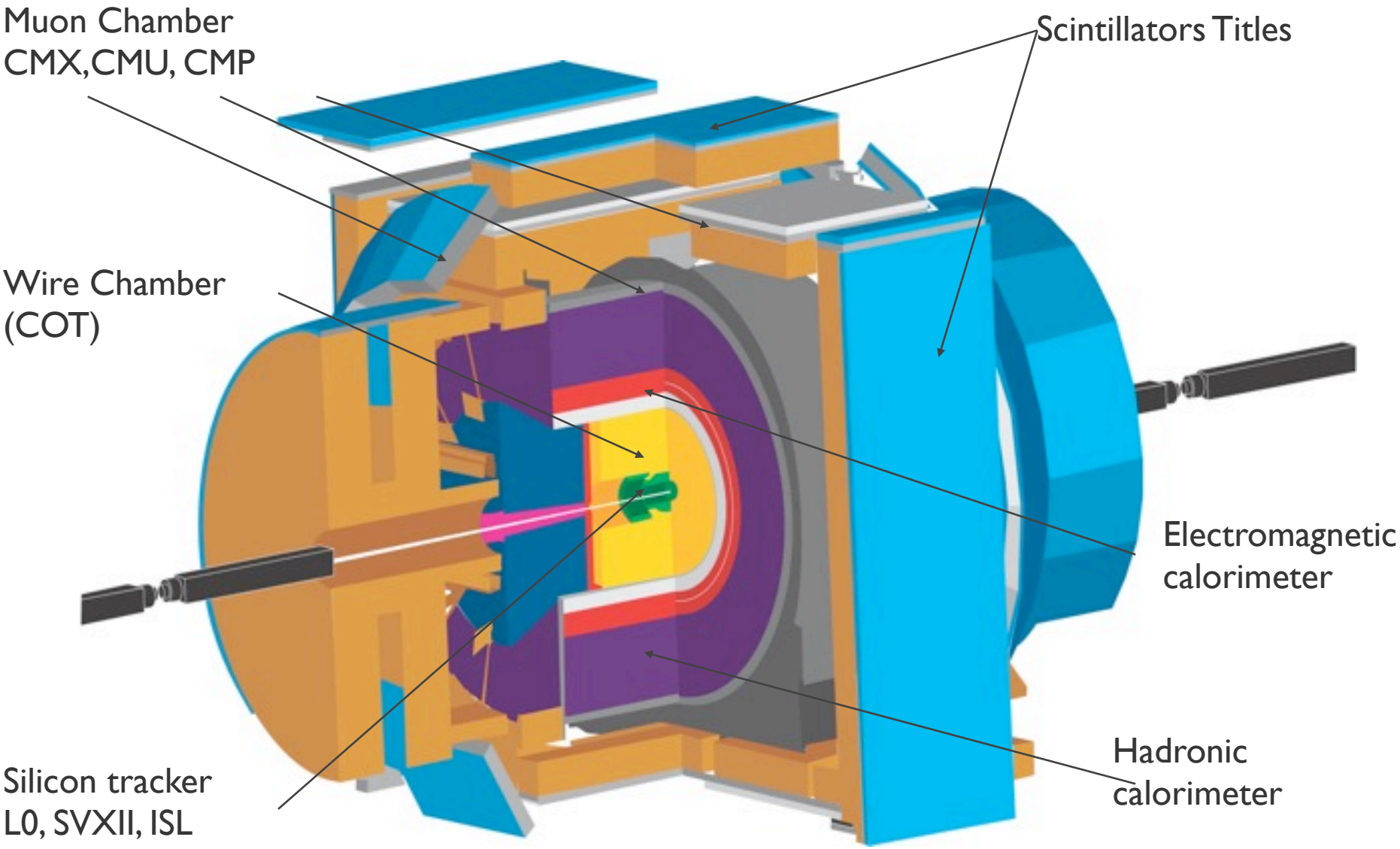
The Tevatron





- Tevatron collides protons with antiprotons at 1.96 TeV center-of-mass energy
- Instantaneous luminosity:
  $>400 \times 10^{30}\ cm^{-2}\ s^{-1}$
- Delivered luminosity ~ 12 fb^{-1}
- Recorded luminosity: ~ 10 fb^{-1}
- **Presented in this talk: 5.8 fb^{-1}**

The CDF Detector



Analysis cuts

- 2 isolated leptons, at least one central above 20 GeV/c
- A 2-d or 3-d primary vertex within 4 cm from the average Z of the two muons (the Z of the two muons within 5 cm)
- $\Delta R>0.4$ between any 2 or 3 objects
- Cosmic veto and conversions (+ trident) removal
- Good silicon when a plug electron is used (ee, eeX analysis)
- $\Delta\Phi$(MET-lep)>20 in the high-MET dilepton signal region
- $\Delta\Phi$(MET-jet)>20 in the high-MET, high-jet multiplicity dilepton control region

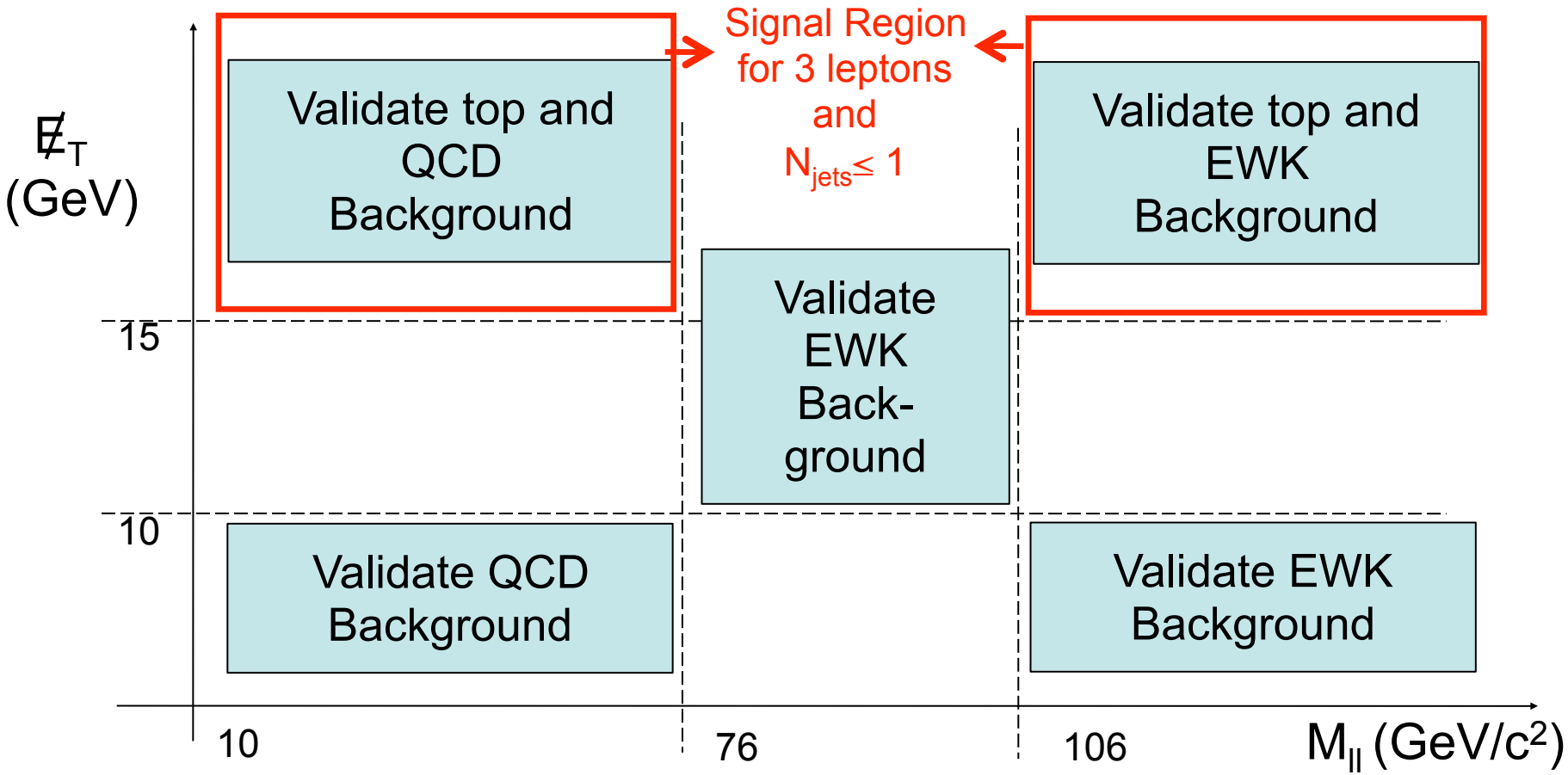
Analysis strategy

- Unbiased (blind) analysis:
  - We define control regions where we validate our SM backgrounds
  - We look at the signal region only after control-region background validation

- Control regions:
  - Investigated dilepton and trilepton control regions in MET-M_{ll}-N_{jet} three- dimensional kinematic space
    - 36 control regions overall (ll+track control regions investigated separately)

- Signal region:
  - Keep it as simple as possible (based on background minimization) and don't over-optimize until we unblind (to do both SUSY testing and generic discovery)

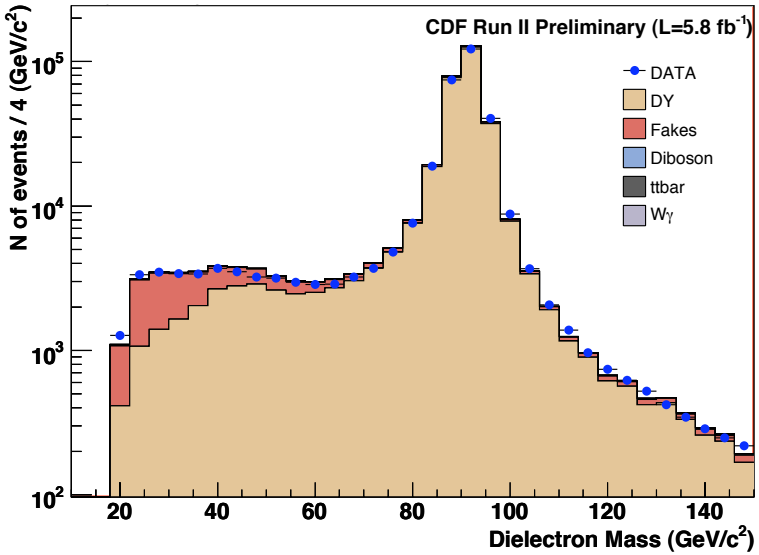
Control Regions



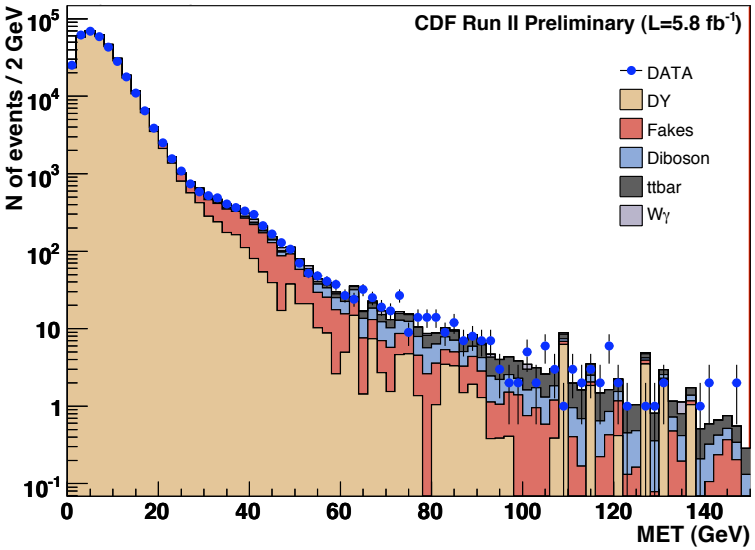
- Several control regions in the MET vs M_{ll} space are defined, with the extra requirement of low (<2) and high (>1) jet multiplicity
- All control regions are studied for both dileptons and trileptons

Dilepton control regions

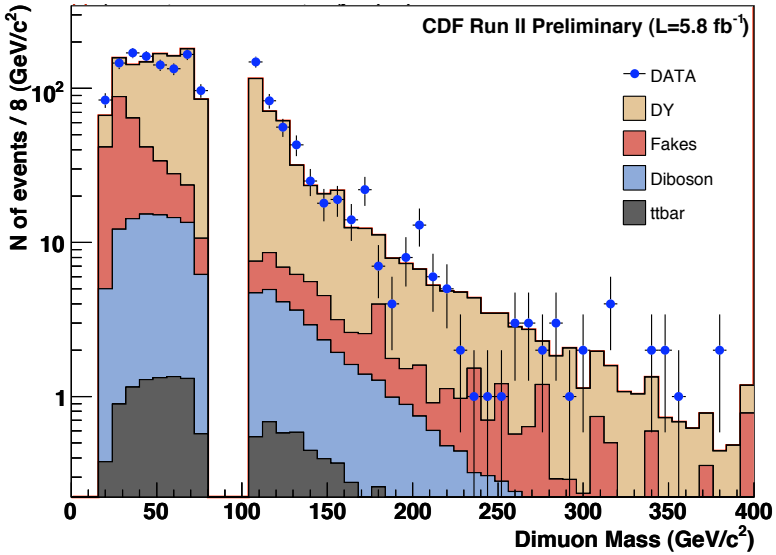
ee (inclusive)



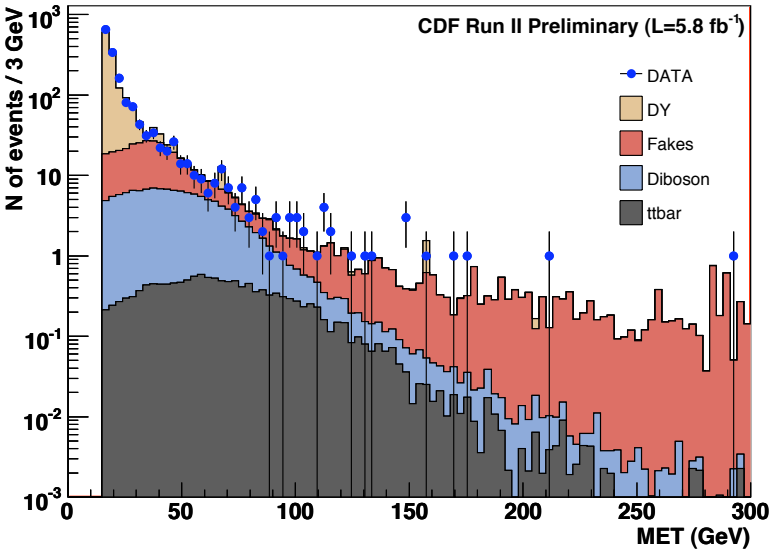
ee (inclusive)



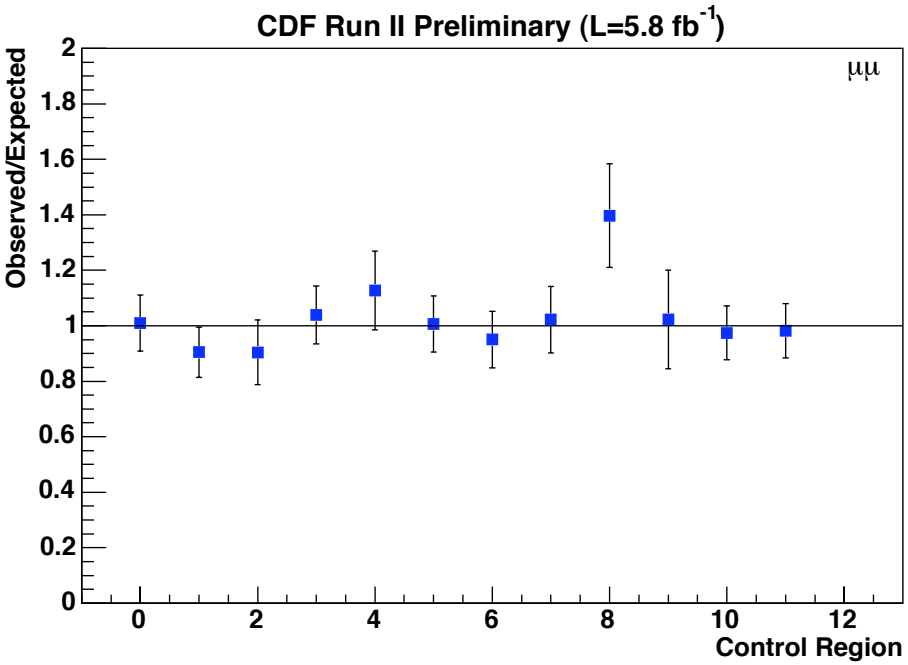
μμ, Z veto, Met >15 GeV, N(jets) < 2

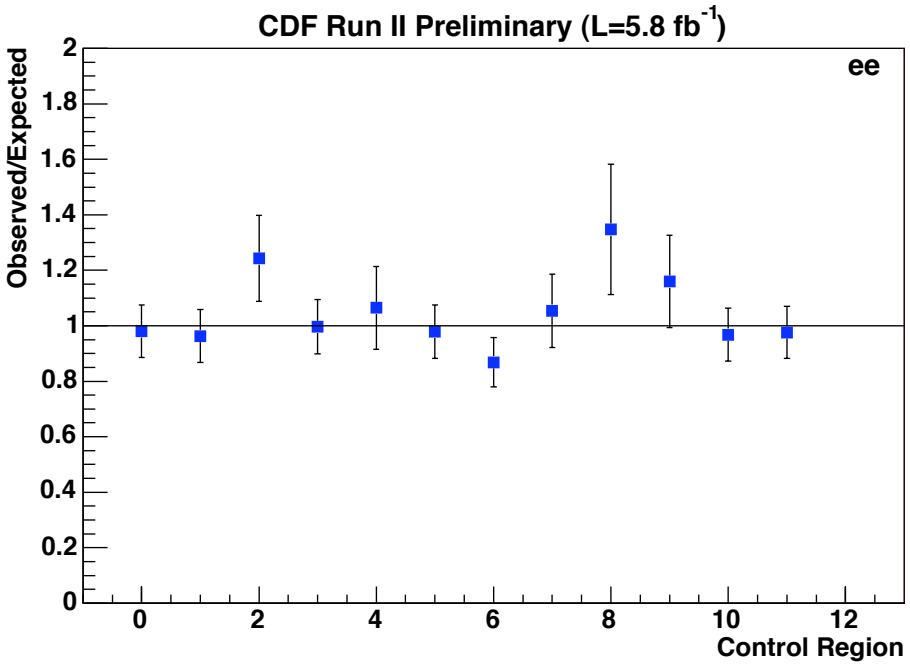


μμ, Z veto, Met >15 GeV, N(jets) < 2



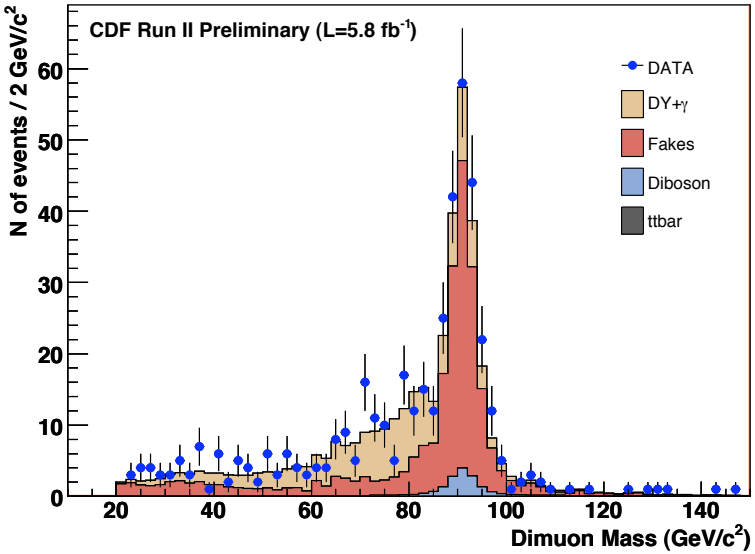
Summary of dilepton control regions



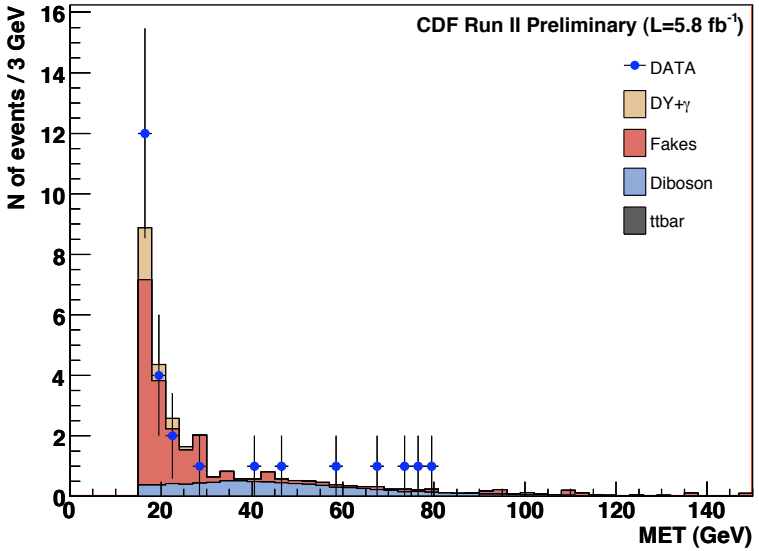


Trilepton control regions

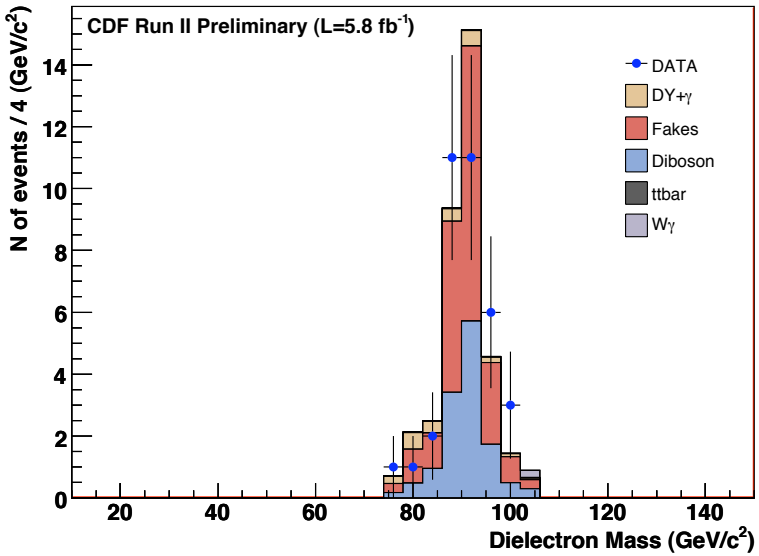
μμ+lepton (inclusive)



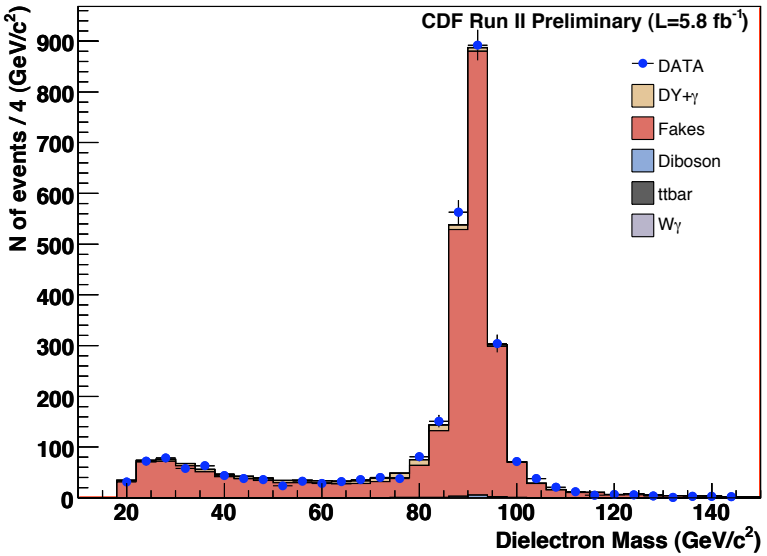
μμ+lepton, Z region, Met >15 GeV, N(jets) < 2



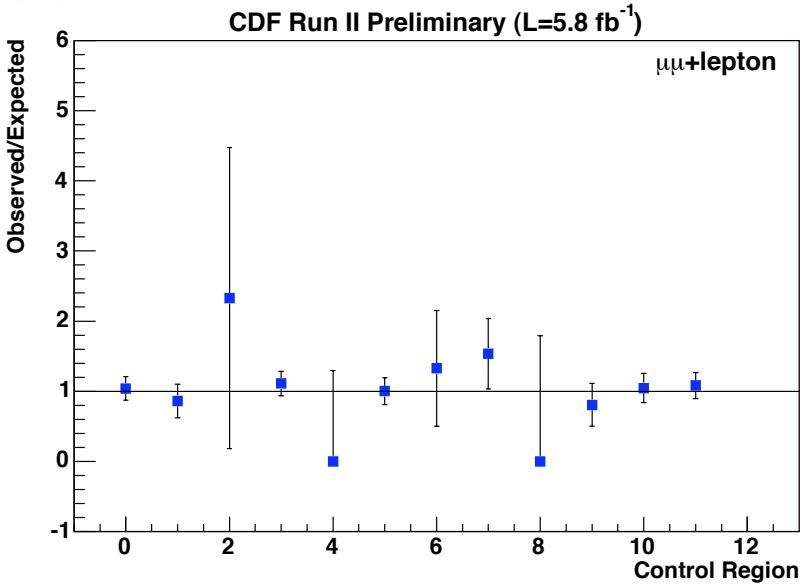
ee+lepton, Z region, Met >15 GeV, N(jets) < 2

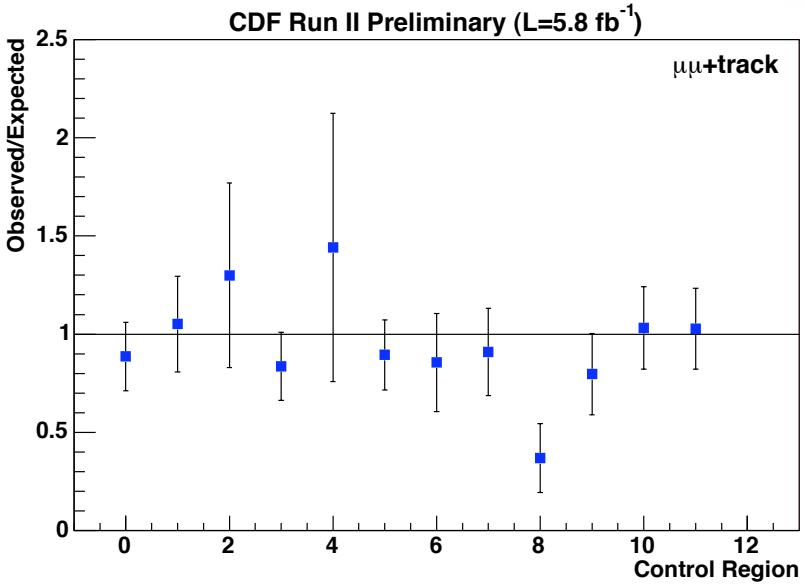


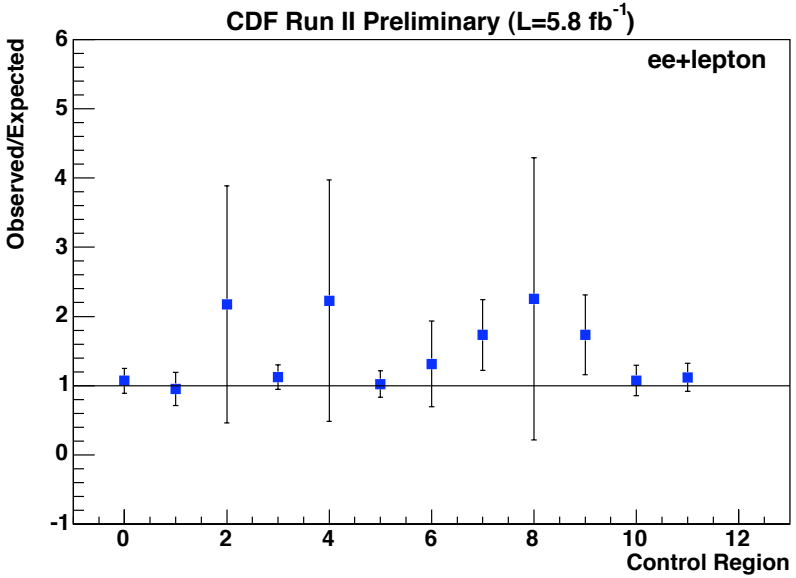
ee+track (inclusive)

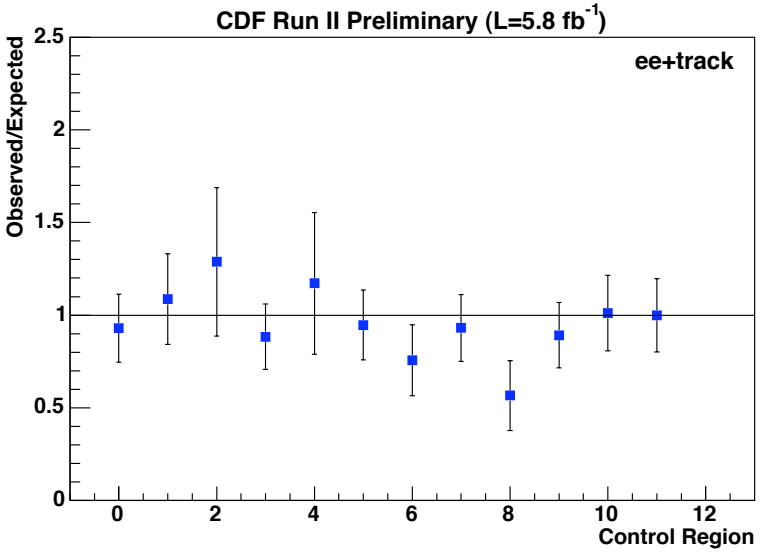


Summary of trilepton control regions





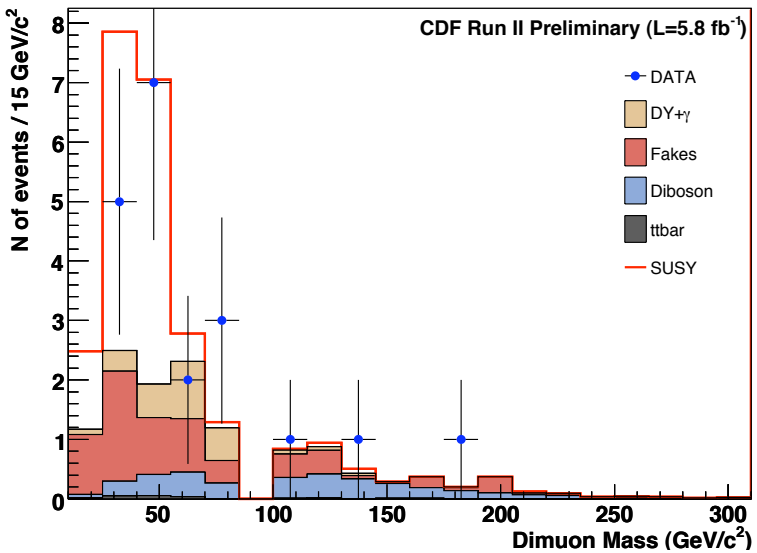




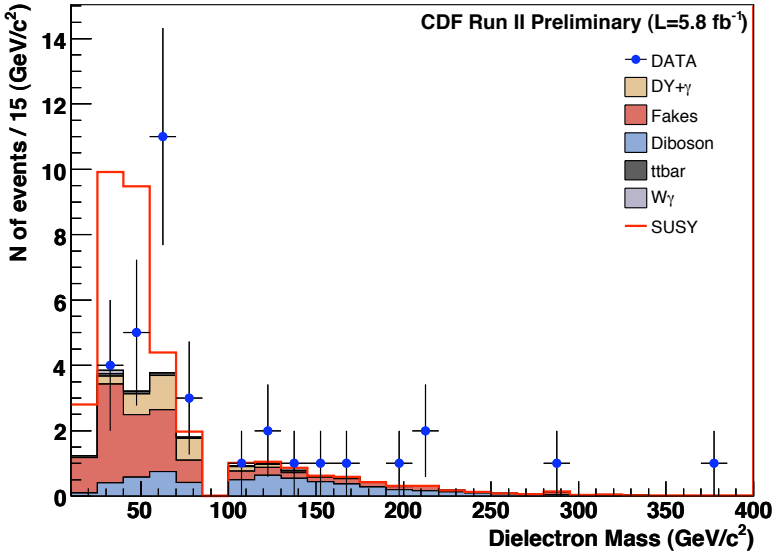
Trilepton results in the signal region

mSugra: m_0=60, $m_{1/2}$=160, tanβ=3,A_0=0, μ>0

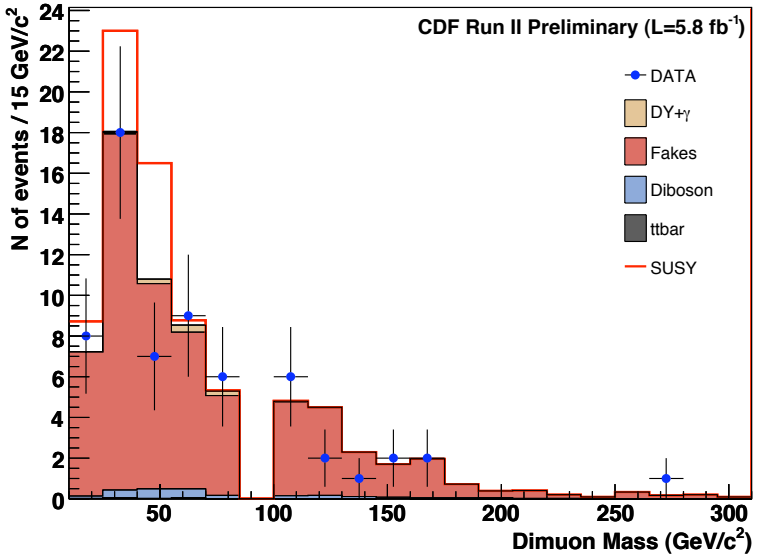
μμ+lepton, Z veto, Met >15 GeV, N(jets) < 2



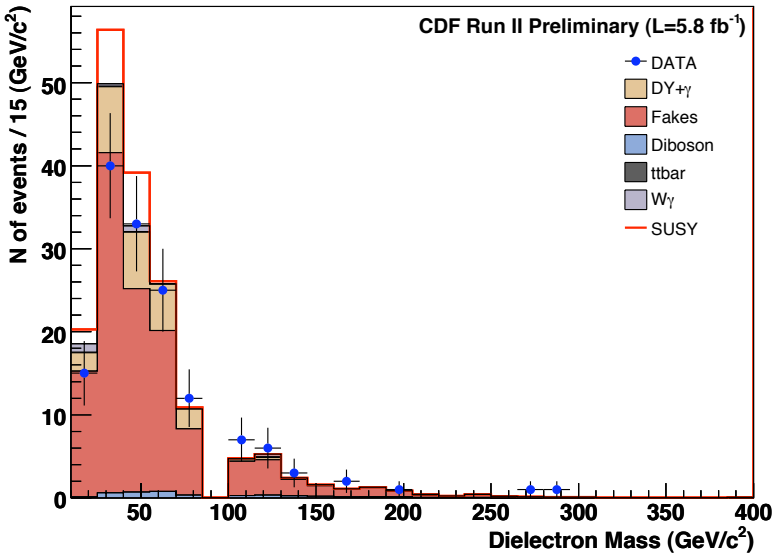
ee+lepton, Z veto, Met >15 GeV, N(jets) < 2



μμ+track, Z veto, Met >15 GeV, N(jets) < 2



ee+track, Z veto, Met >15 GeV, N(jets) < 2



Signal optimization and limits

- Our trilepton signal results are interpreted in the mSUGRA model.

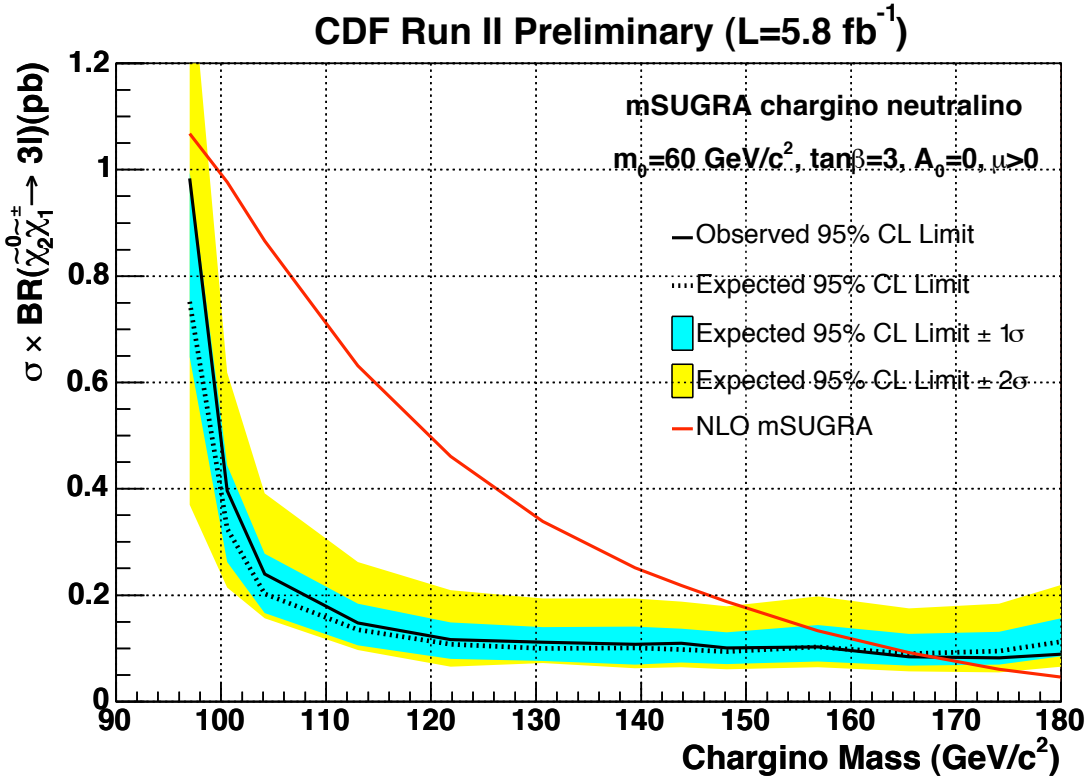
- We generated a total of 14 different signal points for the mSUGRA parameters m_0 = 60 GeV/c^2, tan β = 3, A_0 = 0, and $M_{1/2}$ = 162 to 280 GeV/c^2, which correspond to lightest chargino masses $M_{\chi_1^\pm}$ = 97 to 200 GeV/c^2.

- We optimize our selection based on signal sensitivity, using the following variables dilepton masses, 3 lepton p_T , MET.

- The limit is determined using a modified frequentist approach (CLs method) and by treating all the channels independently.

Signal optimization and limits

- We are searching for new-physics trilepton signal motivated by the chargino-neutralino analysis, using 5.8 fb^{-1} of CDF data



Optimization cuts	
$M_{\ell_1\ell_2}$	$> M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$
$M_{\ell_1\ell_3}$	< 75 GeV/c^2
$M_{\ell_2\ell_3}$	< 75 GeV/c^2
$\not{E}_T$	> 25 GeV
$p_{T,2}$	$(> 8$ and $< 36-65)$ GeV/c
$p_{T,3}$	> 8 GeV/c

CDF10636
http://www-cdf.fnal.gov/physics/exotic/r2a/20110826.trilepton_6fb/

Conclusions

- We performed a 5.8 fb^{-1} trilepton + MET search for new physics, the golden Tevatron channel for SUSY searches.
- Although inspired by SUSY, the goal of this analysis was a general search for new physics.
- We expanded our leptonic acceptance geometrically, kinematically and included new objects.
- We observe signal-region results with a slight excess not incompatible with expectation.
- We set a limit in the chargino-neutralino production cross-section with subsequent decay to trileptons.
  - At 95% CL, we exclude $\sigma(\chi_1^{\pm}\chi_2^0)$xBR(lll) above 0.1 pb and chargino masses below 168 GeV/c^2.

Backup

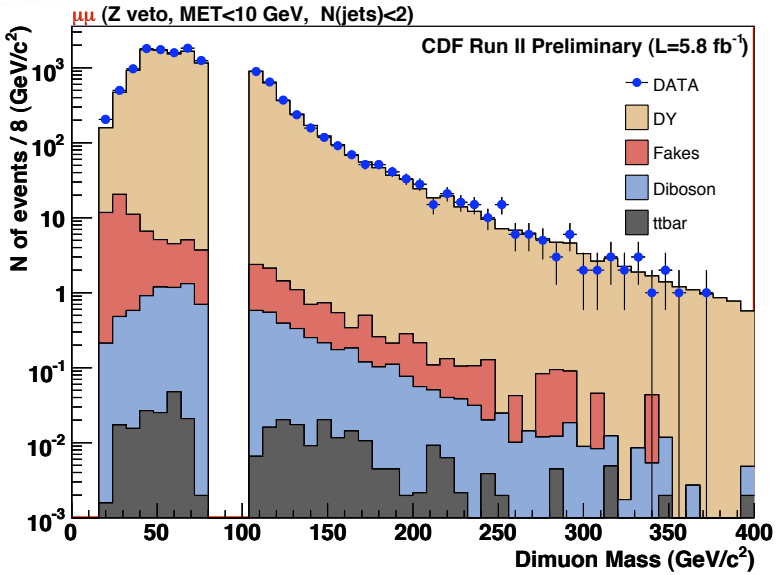
CDF Datasets

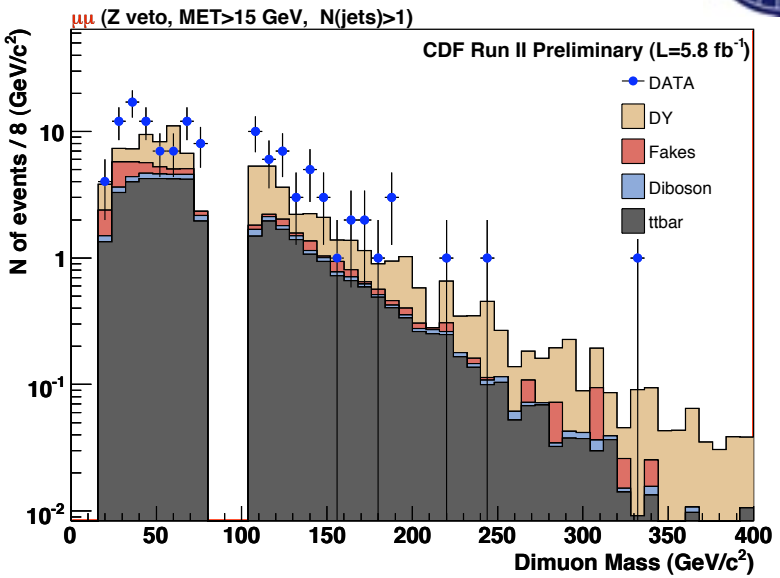
- High-p_T single-muon triggers (bhmucd,h,i,j and bhmubk,m) and high-p_T single-electron triggers (bhelbd,h,l,j,k,m)
  - ELECTRON_CENTRAL_18
  - MUON_CMUP18
  - MUON_CMX18
  - MUON_CMUP18_L2_LOOSE_LUMI_260
  - MUON_CMUP18_L2_LOOSE_LUMI_240
  - MUON_CMUP18_L2_LOOSE_DPS
  - MUON_CMUP18_L2_PT15
  - MUON_CMX18_L2_PT15
  - MUON_CMX18_L2_PT15_LUMI_200
  - MUON_CMX18_L2_LOOSE_LUMI_200
  - MUON_CMX18_L2_LOOSE_DPS
  - MUON_CMX18_LUMI_250
  - MUON_CMX18_DPS
- The bhmuc* stntuples were created especially for us (we needed some quality tracking variables)
- Because many muon triggers are dynamically pre-scaled, we carefully consider the trigger lifetime (luminosity per trigger per run)
- Data up to period 28 (**Luminosity 5.8 fb^{-1}**)
- Good run list: goodrun_em_mu_nosi_cmxignored_bmu_v34
- Same datasets used for fakes determination
- The use of high-p_T triggers kills the heavy-flavor background which is thus not considered here.

Our lepton objects

- Central Electrons (**CEMtight, CEMloose**)
- Forward Electrons (**PEM, Phoenix**)
- Central Muons (**CMU, CMUP, CMX, CMIO**)
- Forward muons (**BMU**)
- Standard selection, isolated, impact parameter applied (cuts in backup)
- The third objects can also be hadronic **Taus** or isolated tracks **(IsoTracks)**

μμ


μμ (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY
Fakes
Diboson
ttbar
N of events / 8 (GeV/c^2)
Dimuon Mass (GeV/c^2)


μμ (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
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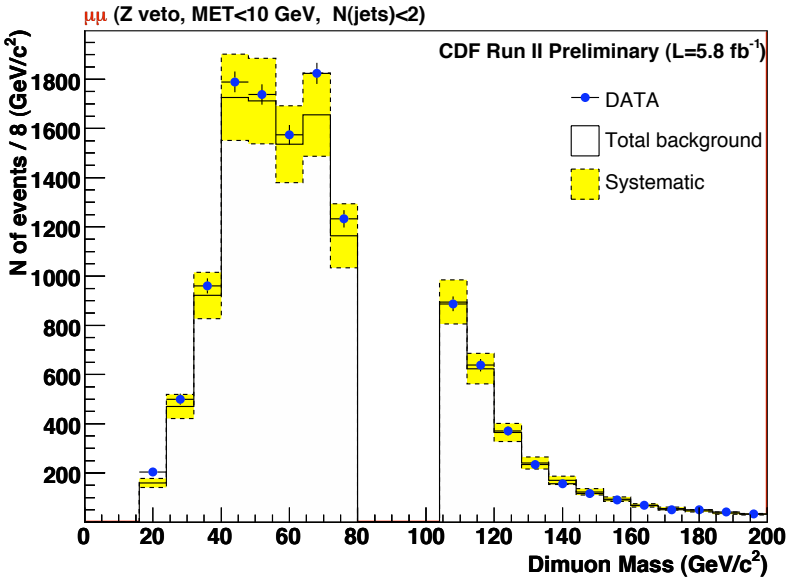
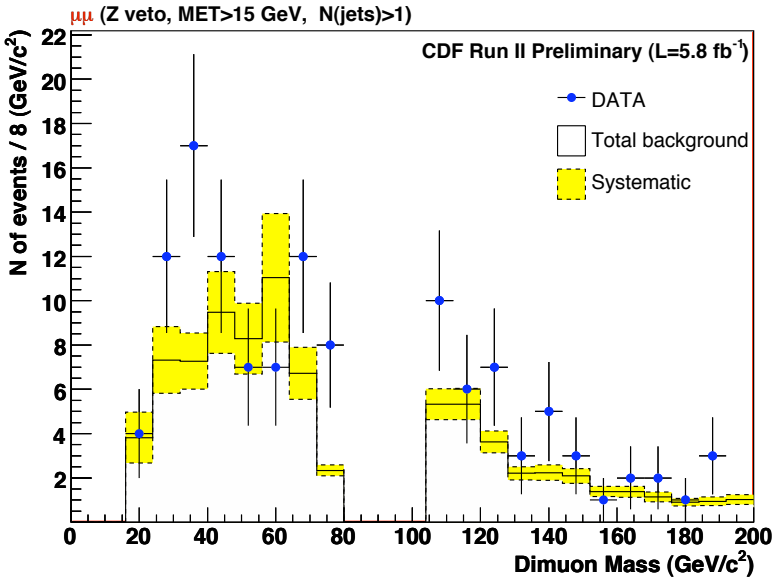
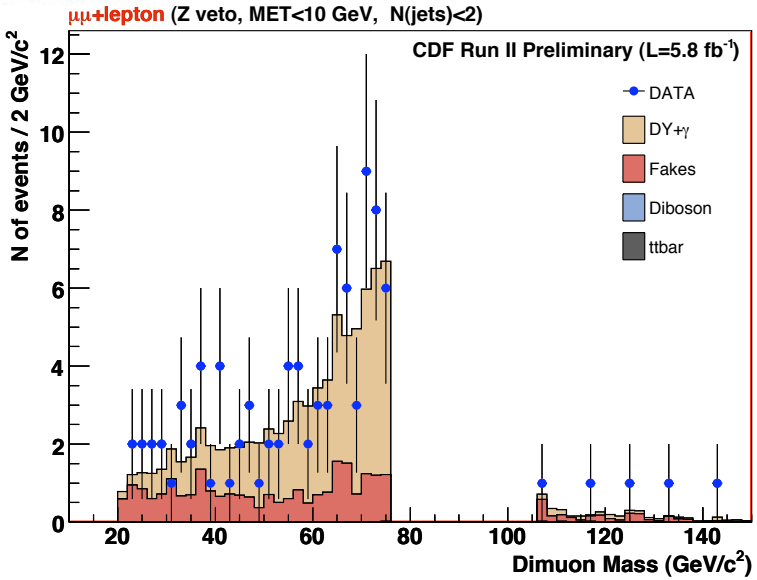
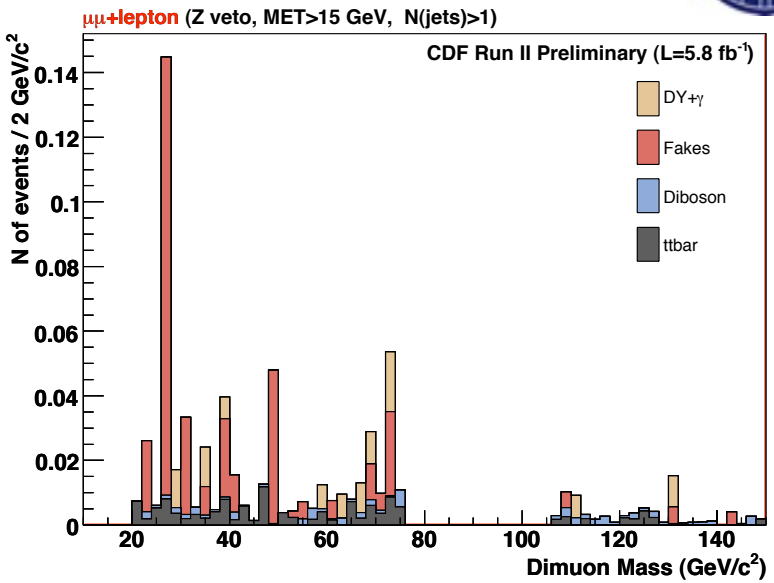

μμ (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
Total background
Systematic
N of events / 8 (GeV/c^2)
Dimuon Mass (GeV/c^2)


μμ (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
Total background
Systematic
N of events / 8 (GeV/c^2)
Dimuon Mass (GeV/c^2)

μμ+lepton


μμ+lepton (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)


μμ+lepton (Z veto, MET>15 GeV, N(jets)>1)
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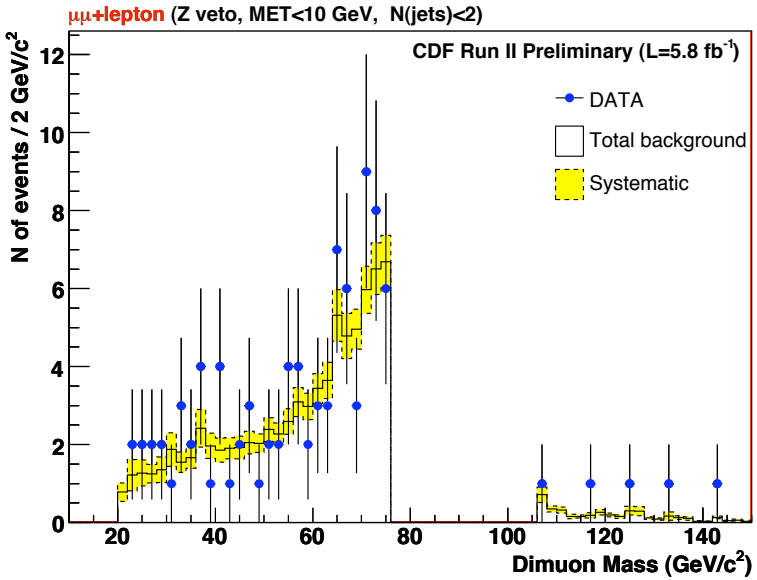
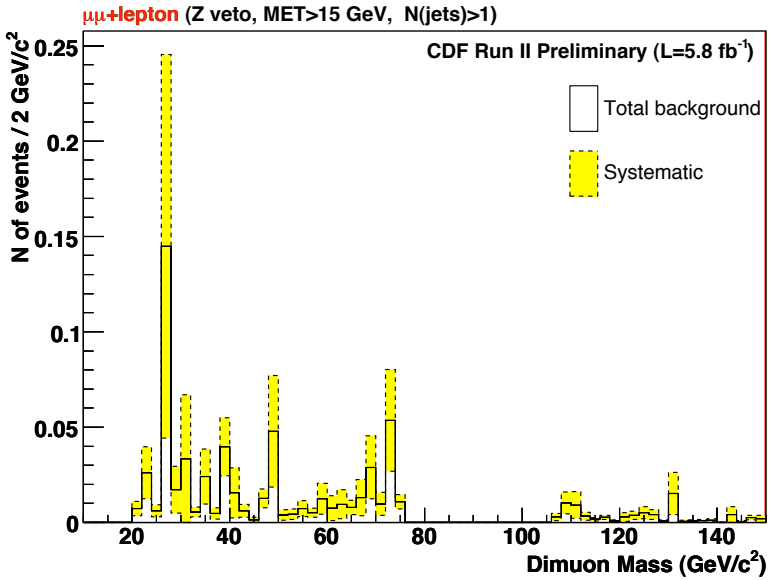
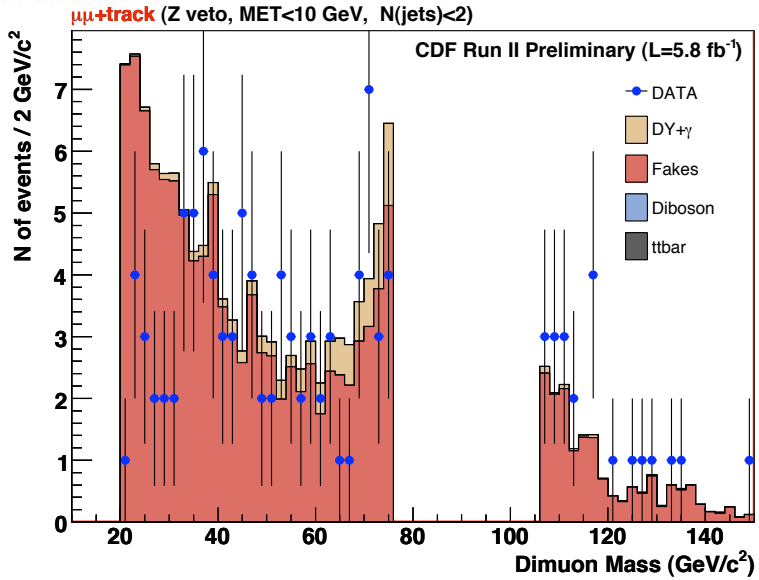
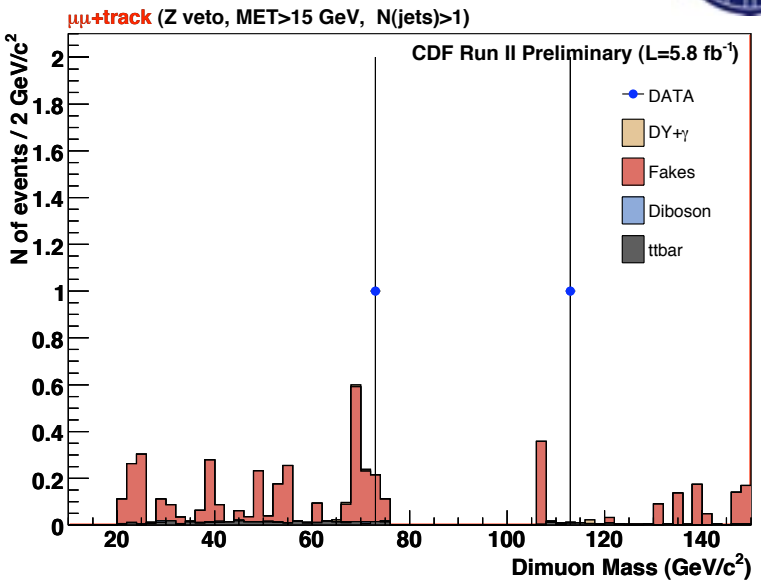
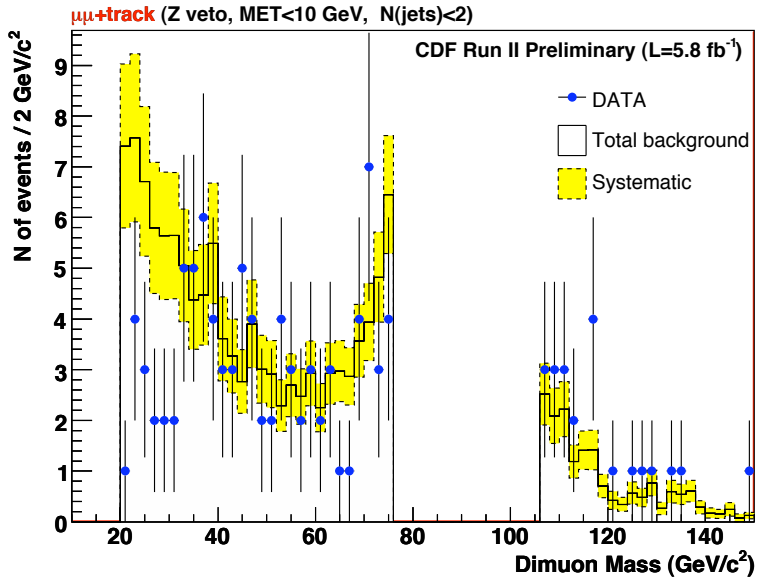

μμ+lepton (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
Total background
Systematic
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)


μμ+lepton (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
Total background
Systematic
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)

μμ+isoTrack


μμ+track (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)


μμ+track (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)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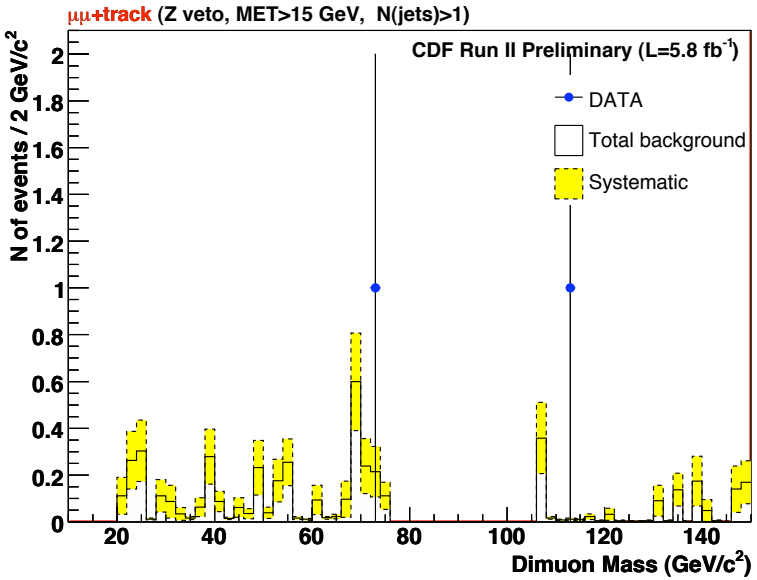
DATA
Total background
Systematic
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)


μμ+track (Z veto, MET>15 GeV, N(jets)>1)
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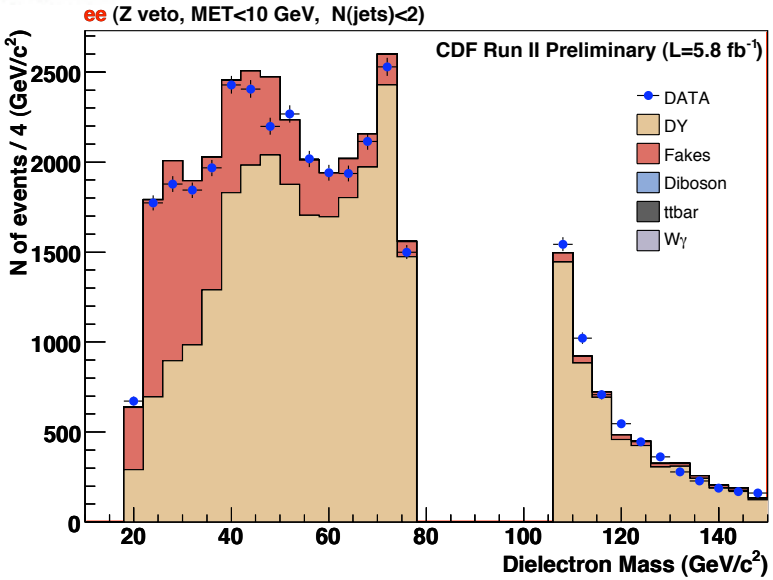
DATA
Total background
Systematic
N of events / 2 GeV/c^2
Dimuon Mass (GeV/c^2)

ee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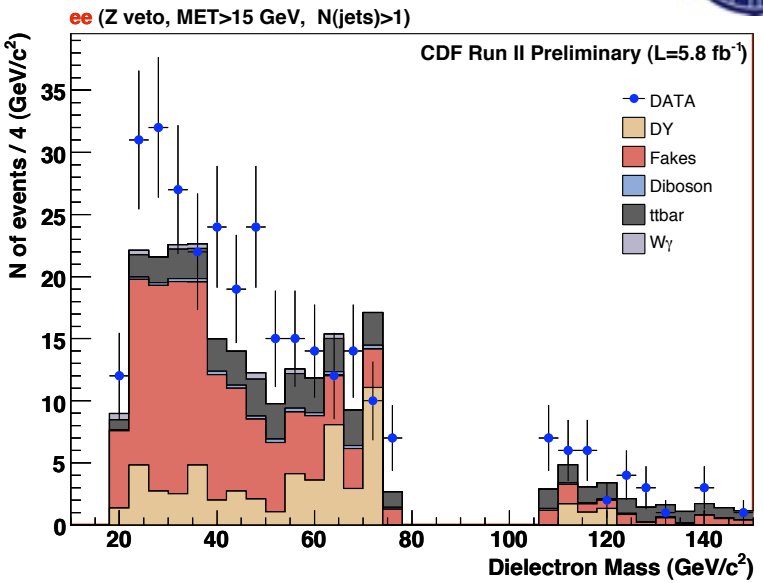
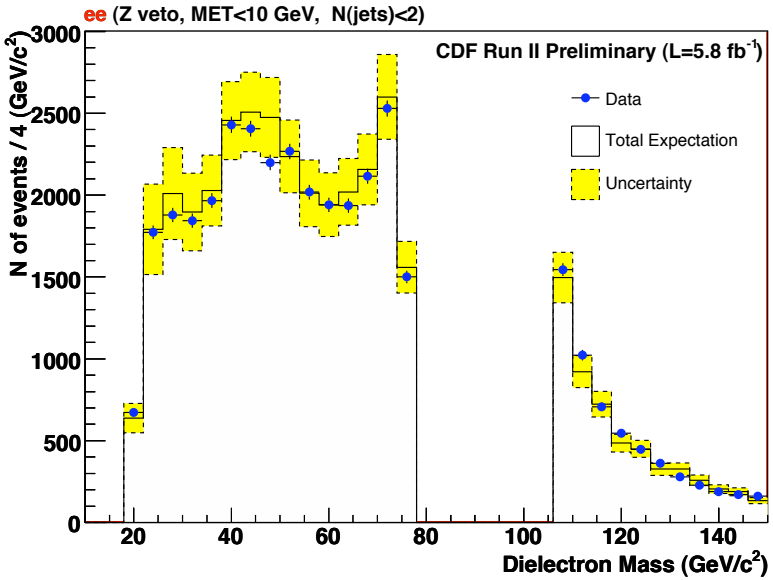
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY
Fakes
Diboson
ttbar
Wγ
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY
Fakes
Diboson
ttbar
Wγ
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee (Z veto, MET<10 GeV, N(jets)<2)
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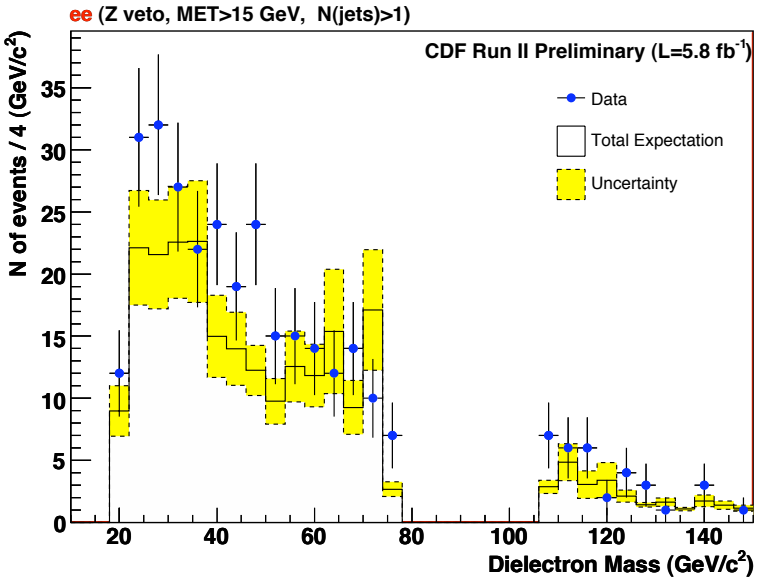
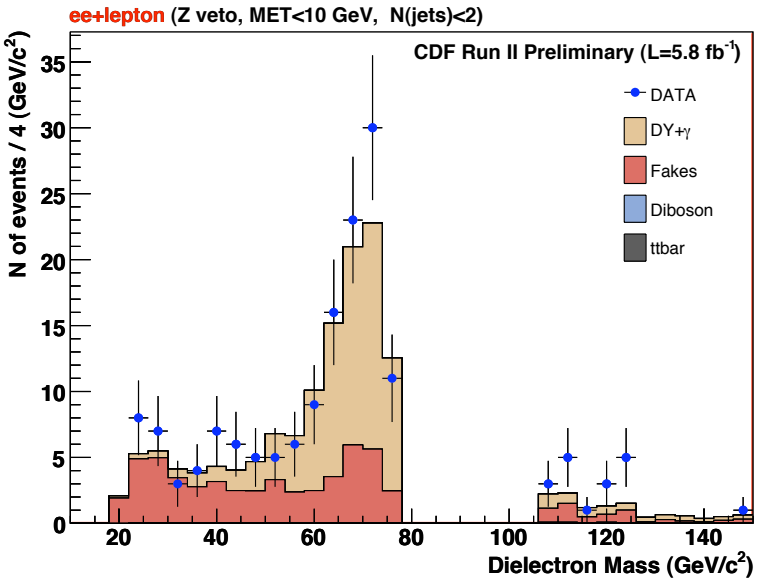
Data
Total Expectation
Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
Data
Total Expectation
Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)

ee+lepton


ee+lepton (Z veto, MET<10 GeV, N(jets)<2)
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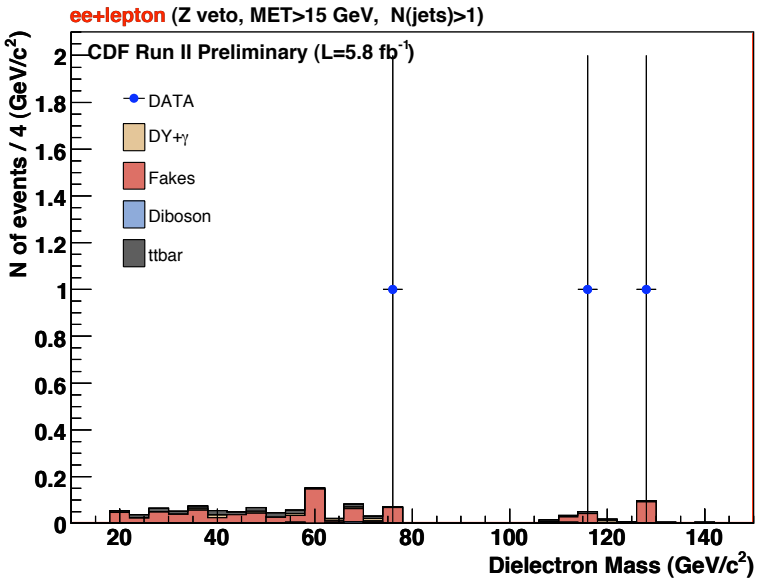
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)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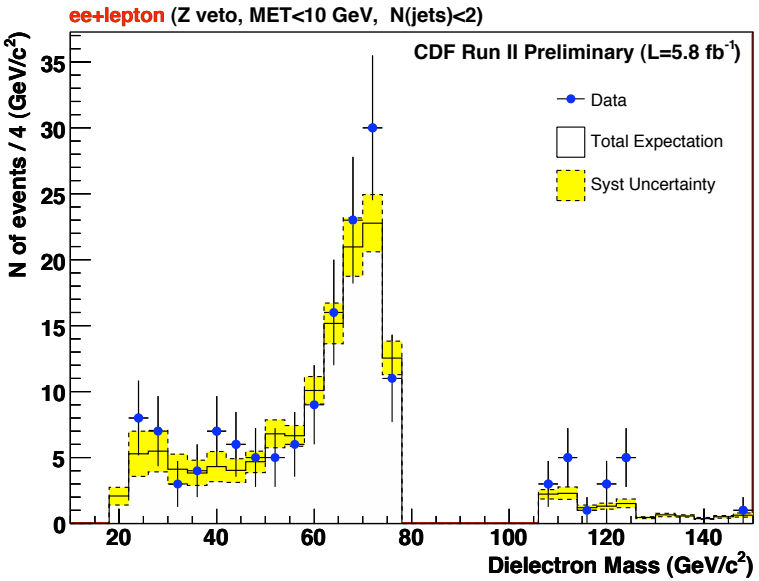
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee+lepton (Z veto, MET<10 GeV, N(jets)<2)
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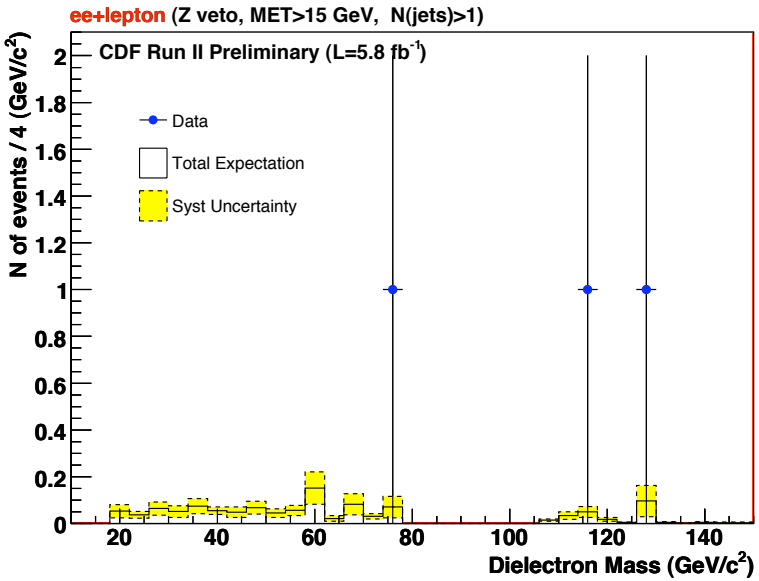
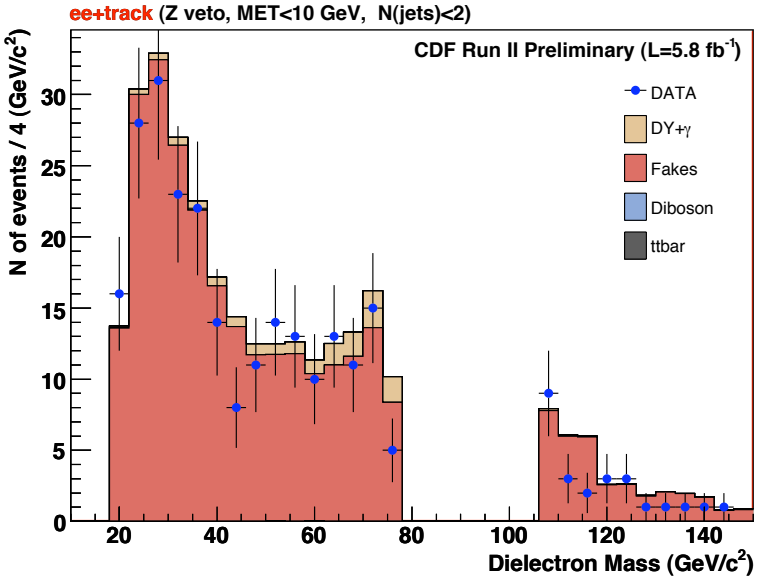
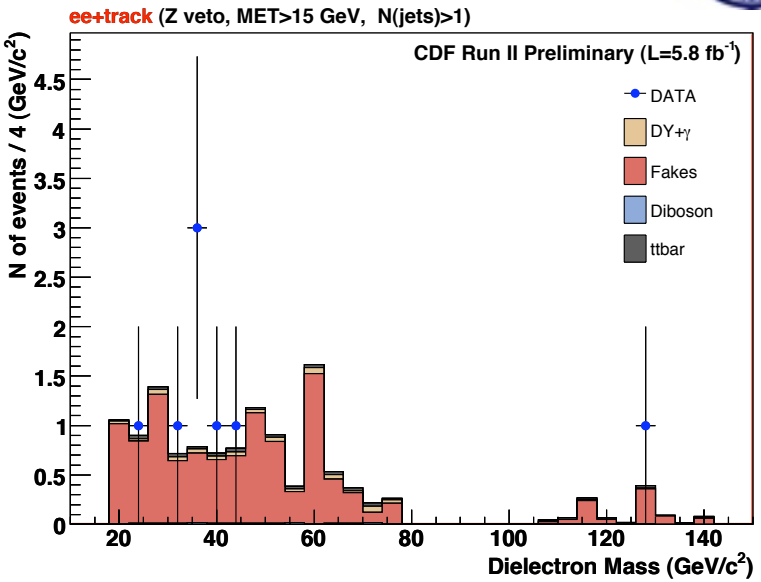
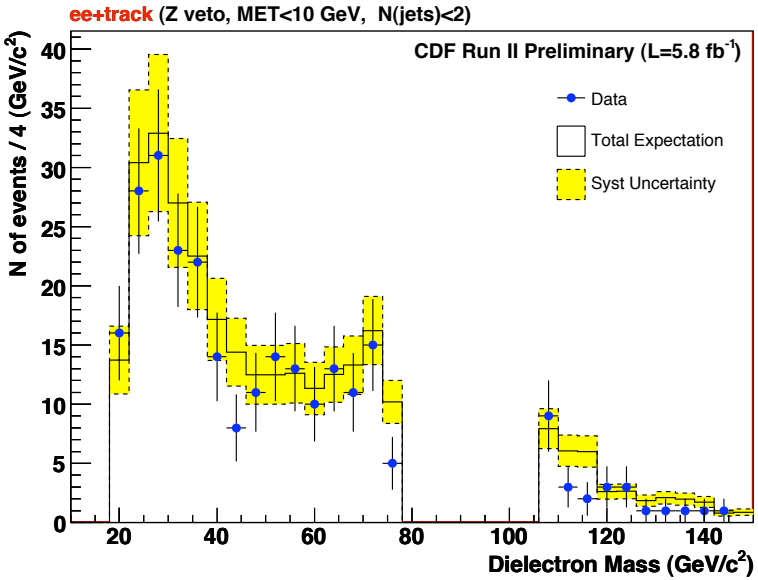
Data
Total Expectation
Syst Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee+lepton (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
Data
Total Expectation
Syst Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)

ee+isoTrack


ee+track (Z veto, MET<10 GeV, N(jets)<2)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee+track (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
DATA
DY+γ
Fakes
Diboson
ttbar
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)


ee+track (Z veto, MET<10 GeV, N(jets)<2)
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Data
Total Expectation
Syst Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)

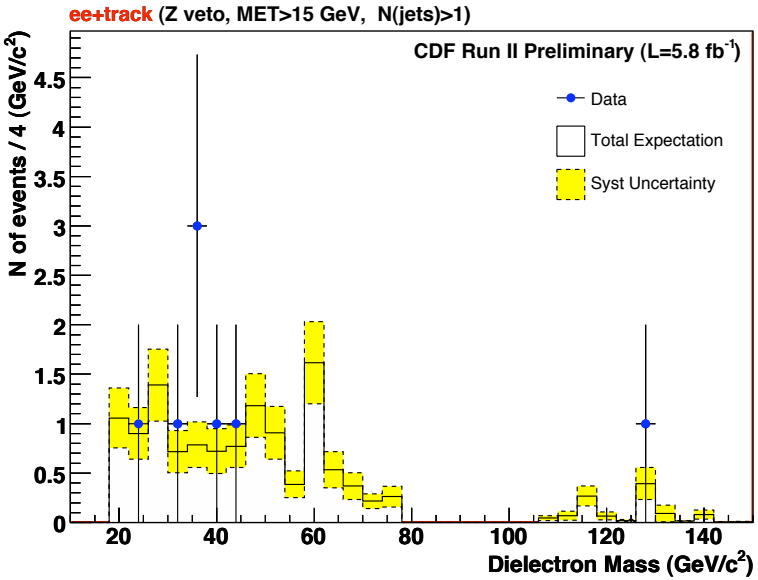

ee+track (Z veto, MET>15 GeV, N(jets)>1)
CDF Run II Preliminary (L=5.8 fb^{-1})
Data
Total Expectation
Syst Uncertainty
N of events / 4 (GeV/c^2)
Dielectron Mass (GeV/c^2)

Table of dimuon yields

Table of dimuon yields (CDF Run II Preliminary, L=5.8 fb^{-1})						
	Drell-Yan	Fakes	Diboson	Top	Total SM	Observed
Region0	114498 ± 11454	226 ± 113	75 ± 8	1.8 ± 0.2	114802 ± 11455	**115884**
Region1	7926 ± 802	38 ± 19	72 ± 7	3.6 ± 0.4	8039 ± 802	**7272**
Region2	319 ± 40	1.6 ± 0.8	8.8 ± 0.9	12 ± 1	341 ± 40	**308**
Region3	12171 ± 1218	70 ± 35	9.7 ± 1	0.33 ± 0.04	12251 ± 1218	**12729**
Region4	170 ± 18	2 ± 1	3.4 ± 0.3	1.1 ± 0.1	177 ± 18	**199**
Region5	100913 ± 10100	152 ± 76	30 ± 3	0.08 ± 0.01	101095 ± 10100	**101740**
Region6	1244 ± 132	3 ± 1	32 ± 3	0.31 ± 0.04	1279 ± 132	**1216**
Region7	1170 ± 118	273 ± 136	118 ± 12	14 ± 1	1575 ± 181	**1610**
Region8	36 ± 4	9 ± 5	3.7 ± 0.4	41 ± 4	89 ± 7	**125**
Region9	366 ± 37	258 ± 129	113 ± 11	53 ± 5	790 ± 135	**808**
Region10	145635 ± 14572	245 ± 123	202 ± 20	21 ± 2	146103 ± 14573	**142386**
Region11	163932 ± 16397	728 ± 364	364 ± 36	98 ± 10	165122 ± 16401	**162127**

Table of μμ+lepton yields

Table of $\mu\mu$+lepton yields (CDF Run II Preliminary, L=5.8 fb^{-1})						
	Drell-Yan	Fakes	Diboson	Top	Total SM	Observed
Region0	115 ± 12	126 ± 35	3.1 ± 0.3	0.019 ± 0.007	244 ± 37	254
Region1	2.8 ± 0.3	19 ± 6	8.8 ± 0.9	0.043 ± 0.01	30 ± 6	26
Region2	0.08 ± 0.02	1 ± 0.4	0.18 ± 0.02	0.035 ± 0.009	1.3 ± 0.4	3
Region3	58 ± 6	26 ± 8	0.64 ± 0.07	0.015 ± 0.006	85 ± 10	94
Region4	0.37 ± 0.07	0.5 ± 0.2	0.027 ± 0.004	0.004 ± 0.003	0.9 ± 0.2	0
Region5	56 ± 6	98 ± 26	2.4 ± 0.2	0 ± 0	156 ± 27	156
Region6	0.56 ± 0.09	2.3 ± 0.7	0.11 ± 0.01	0 ± 0	3 ± 0.7	4
Region7	2.8 ± 0.3	7 ± 2	3.4 ± 0.3	0.24 ± 0.03	13 ± 2	20
Region8	0.1 ± 0.03	0.4 ± 0.1	0.08 ± 0.01	0.14 ± 0.02	0.7 ± 0.1	0
Region9	0.7 ± 0.1	4 ± 1	3.2 ± 0.3	0.37 ± 0.05	9 ± 1	7
Region10	77 ± 8	170 ± 49	15 ± 2	0.09 ± 0.02	262 ± 49	274
Region11	156 ± 16	224 ± 65	22 ± 2	0.66 ± 0.07	402 ± 67	435

Table of μμ+isoTrack yields

Table of $\mu\mu$+isoTrack yields (CDF Run II Preliminary, L=5.8 fb^{-1})						
	Drell-Yan	Fakes	Diboson	Top	Total SM	Observed
Region0	27 ± 3	695 ± 140	1.5 ± 0.1	0.016 ± 0.006	723 ± 140	641
Region1	1.6 ± 0.2	169 ± 38	3.3 ± 0.3	0.033 ± 0.009	174 ± 38	183
Region2	0.03 ± 0.01	12 ± 3	0.28 ± 0.03	0.14 ± 0.02	12 ± 3	16
Region3	10 ± 1	128 ± 26	0.16 ± 0.02	0.005 ± 0.003	139 ± 26	116
Region4	0.17 ± 0.04	5 ± 1	0.059 ± 0.008	0.009 ± 0.004	6 ± 1	8
Region5	17 ± 2	540 ± 109	0.68 ± 0.07	0 ± 0	557 ± 109	498
Region6	0.32 ± 0.06	21 ± 4	0.55 ± 0.06	0.002 ± 0.002	22 ± 4	19
Region7	1 ± 0.1	65 ± 15	2.2 ± 0.2	0.19 ± 0.03	68 ± 15	62
Region8	0.06 ± 0.02	5 ± 1	0.1 ± 0.01	0.47 ± 0.06	5 ± 1	2
Region9	0.36 ± 0.06	45 ± 10	2.2 ± 0.2	0.64 ± 0.07	48 ± 10	38
Region10	25 ± 3	1151 ± 238	7.3 ± 0.7	0.24 ± 0.03	1184 ± 238	1221
Region11	43 ± 4	1463 ± 303	12 ± 1	1.2 ± 0.1	1518 ± 303	1560

Table of dielectron yields

Table of dielectron yields (CDF Run II Preliminary, L=5.8 fb^{-1})							
	Drell-Yan	Fakes	Diboson	$W+\gamma$	Top	Total SM	Observed
Region0	250500 ± 25056	12261 ± 4234	124 ± 12	12 ± 2	2.6 ± 0.3	262900 ± 25425	257588
Region1	9937 ± 1004	387 ± 172	103 ± 10	35 ± 5	5.2 ± 0.5	10468 ± 1032	10077
Region2	359 ± 43	22 ± 9	11 ± 1	0.7 ± 0.5	16 ± 2	407 ± 46	506
Region3	28941 ± 2896	7711 ± 2139	16 ± 2	11 ± 2	0.49 ± 0.06	36679 ± 3603	36538
Region4	390 ± 44	285 ± 80	5.5 ± 0.5	0 ± 0	1.5 ± 0.2	683 ± 92	727
Region5	218443 ± 21852	4191 ± 1985	49 ± 5	0.9 ± 0.5	0.13 ± 0.02	222684 ± 21947	217846
Region6	2725 ± 280	74 ± 30	54 ± 5	0 ± 0	0.45 ± 0.05	2854 ± 287	2477
Region7	1963 ± 201	2152 ± 524	165 ± 16	360 ± 37	19 ± 2	4658 ± 583	4909
Region8	51 ± 9	136 ± 38	4.9 ± 0.5	3.2 ± 0.9	56 ± 6	251 ± 41	338
Region9	632 ± 69	1620 ± 382	157 ± 16	339 ± 35	72 ± 7	2820 ± 402	3270
Region10	263381 ± 26346	4891 ± 2309	282 ± 28	20 ± 3	28 ± 3	268603 ± 26480	260010
Region11	321856 ± 32192	20218 ± 6638	527 ± 53	472 ± 48	134 ± 13	343206 ± 32980	334968

Table of ee+lepton yields

Table of ee+lepton yields (CDF Run II Preliminary, L=5.8 fb^{-1})							
	Drell-Yan	Fakes	Diboson	$W+\gamma$	Top	Total SM	Observed
Region0	174 ± 17	226 ± 63	5.2 ± 0.5	0 ± 0	0.041 ± 0.009	406 ± 65	434
Region1	2.4 ± 0.3	21 ± 7	13 ± 1	0.2 ± 0.2	0.13 ± 0.02	37 ± 7	35
Region2	0.13 ± 0.03	1.4 ± 0.5	0.26 ± 0.03	0 ± 0	0.06 ± 0.01	1.8 ± 0.5	4
Region3	86 ± 9	59 ± 18	1.9 ± 0.2	0 ± 0	0.026 ± 0.007	147 ± 20	165
Region4	0.51 ± 0.07	1.2 ± 0.4	0.075 ± 0.009	0 ± 0	0.008 ± 0.004	1.8 ± 0.4	4
Region5	87 ± 9	161 ± 43	3.1 ± 0.3	0 ± 0	0.002 ± 0.002	251 ± 44	257
Region6	0.77 ± 0.1	5 ± 1	0.15 ± 0.02	0 ± 0	0.005 ± 0.003	6 ± 1	8
Region7	3.1 ± 0.3	10 ± 4	5.9 ± 0.6	0.1 ± 0.1	0.44 ± 0.05	20 ± 4	34
Region8	0.09 ± 0.02	0.9 ± 0.3	0.12 ± 0.01	0 ± 0	0.25 ± 0.03	1.3 ± 0.3	3
Region9	0.9 ± 0.1	7 ± 3	5.5 ± 0.6	0.1 ± 0.1	0.66 ± 0.07	14 ± 3	24
Region10	94 ± 9	243 ± 69	20 ± 2	0.2 ± 0.2	0.21 ± 0.03	358 ± 70	385
Region11	215 ± 22	363 ± 106	34 ± 3	0.7 ± 0.4	1.3 ± 0.1	614 ± 109	687

Table of ee+isoTrack yields

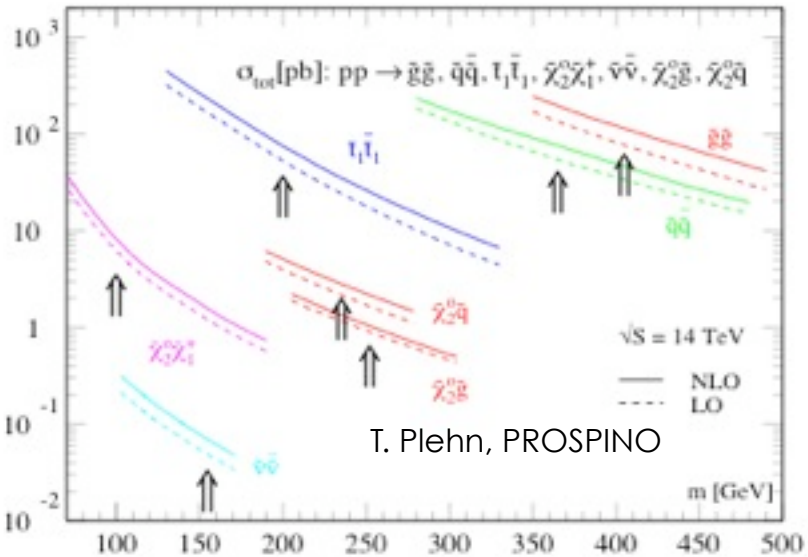
Table of ee+isoTrack yields (CDF Run II Preliminary, L=5.8 fb^{-1})							
	Drell-Yan	Fakes	Diboson	$W+\gamma$	Top	Total SM	Observed
Region0	39 ± 4	1380 ± 277	1.7 ± 0.2	0 ± 0	0.019 ± 0.006	1420 ± 277	1321
Region1	6.6 ± 0.7	249 ± 57	5.8 ± 0.6	0.4 ± 0.2	0.08 ± 0.01	262 ± 57	285
Region2	0.25 ± 0.04	18 ± 4	0.59 ± 0.06	0 ± 0	0.2 ± 0.03	19 ± 4	25
Region3	15 ± 2	290 ± 58	0.27 ± 0.03	0 ± 0	0.004 ± 0.003	306 ± 58	270
Region4	0.28 ± 0.05	15 ± 3	0.065 ± 0.008	0 ± 0	0.013 ± 0.005	15 ± 3	18
Region5	23 ± 2	1035 ± 208	0.77 ± 0.08	0 ± 0	0.002 ± 0.002	1058 ± 208	1002
Region6	0.35 ± 0.06	40 ± 8	0.59 ± 0.06	0 ± 0	0 ± 0	41 ± 8	31
Region7	26 ± 3	124 ± 27	4 ± 0.4	2.4 ± 0.7	0.27 ± 0.04	157 ± 28	146
Region8	0.62 ± 0.08	13 ± 3	0.24 ± 0.03	0 ± 0	0.65 ± 0.07	14 ± 3	8
Region9	21 ± 2	83 ± 19	4 ± 0.4	2.4 ± 0.7	0.91 ± 0.1	111 ± 19	99
Region10	42 ± 4	1890 ± 390	11 ± 1	0 ± 0	0.36 ± 0.04	1942 ± 390	1964
Region11	114 ± 11	2707 ± 560	18 ± 2	4 ± 0.9	1.9 ± 0.2	2845 ± 560	2843

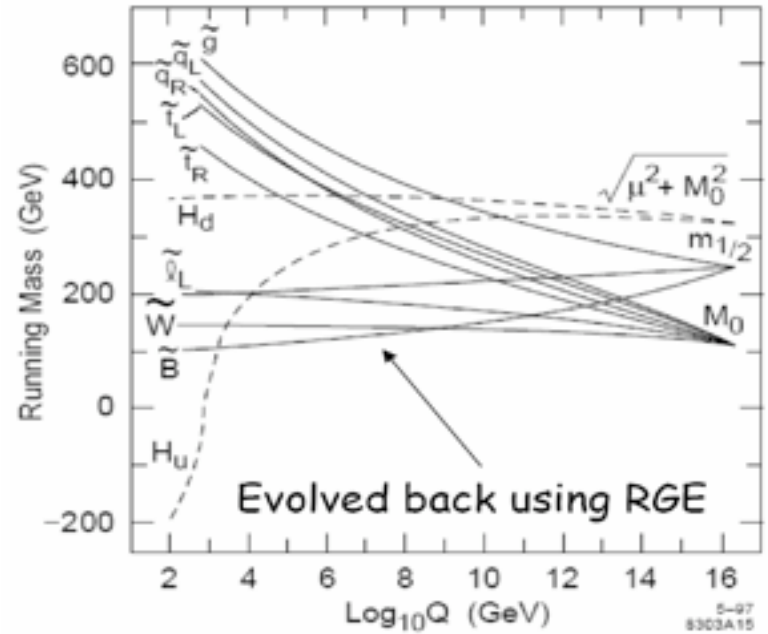
Monte Carlo samples

- DY:
  - For the entire DY spectrum (for dielectrons): electroweak group sample **ze0sdd**
  - For Z resonance: our own **dexo5m** DY MC ($Z \rightarrow \mu\mu$, 70<mass<100 GeV/c^2)
  - For low and intermediate mass: Our own **dexo6m** ($Z \rightarrow \mu\mu$, 5<mass<70 GeV/c^2)
  - Our high-mass DY: Our own samples **dexo4m** ($Z \rightarrow \mu\mu$, 100<mass<300 GeV/c^2)
  - Our high-mass DY: Our own samples **dexo3m** ($Z \rightarrow \mu\mu$, mass>300 GeV/c^2)
  - For intermediate mass: electroweak group sample **ze0sbt** ($Z \rightarrow \tau\tau$)
- DY+γ:
  - Electroweak group samples **re0s33** (DY+γ → ee+γ), **re0s34** (DY+γ → μμ+γ), **re0s37** (DY+γ → ττ+γ),
- W+γ:
  - Electroweak group samples **re0s28** (W+γ → eν+γ), **re0s1a** (W+γ → τν+γ)
- Diboson:
  - Electroweak group samples **we0sbd** (WW), **we0scd** (WZ), **we0sdd** (ZZ)
- t-tbar:
  - Electroweak group sample **te0s2z** (top pairs to dileptons)

mSUGRA

mSUGRA a LHC





- The free parameters are
  - m_0, the common sfermion mass
  - $M_{1/2}$, the common gaugino mass
  - tanβ, the ration of higgs vacuum expecation values
  - A, the trilear sfermion-sfermion-higgs coupling
  - Sign of μ, the higgs parameter scale

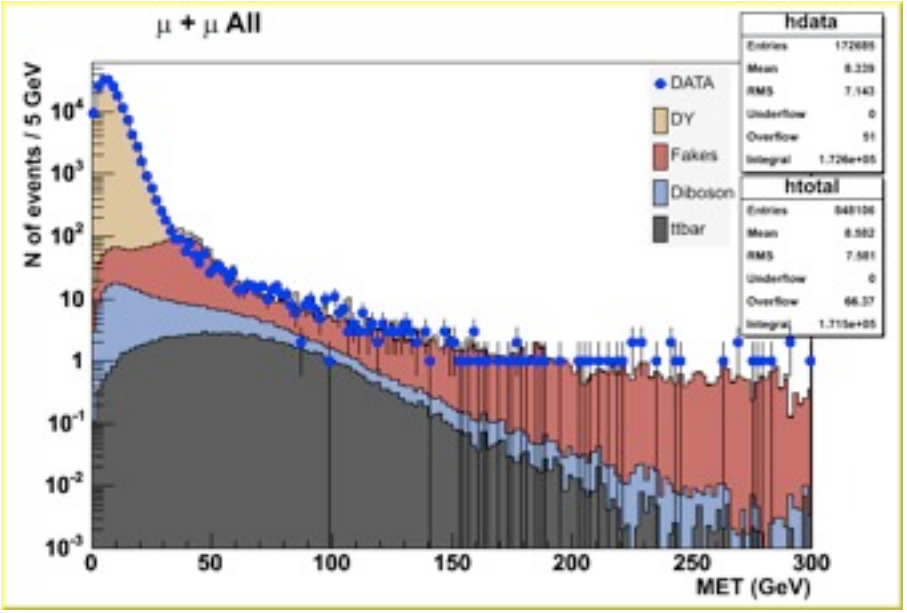
Checking one SUSY benchmark point

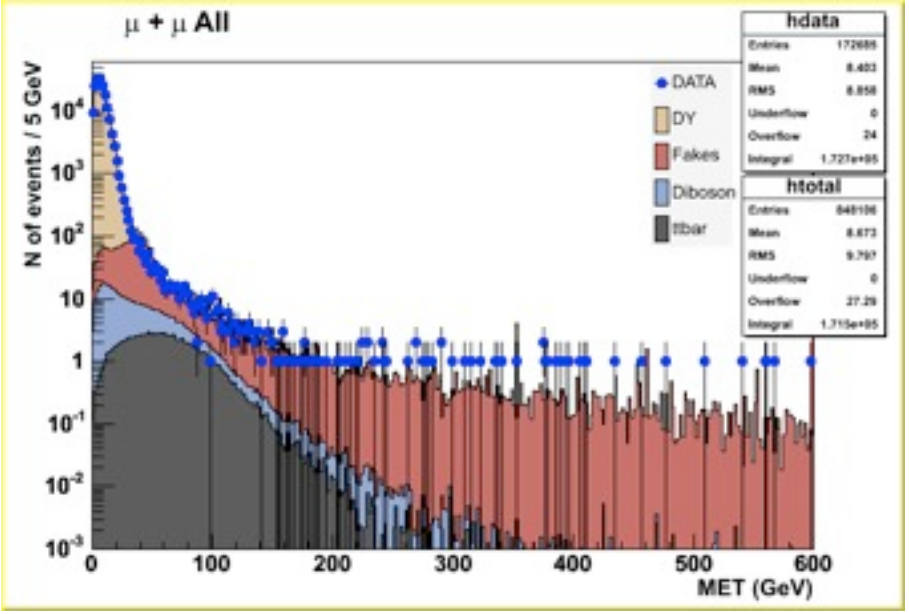
- This is point m_0=60 GeV/c^2, $m_{1/2}$=190 GeV/c^2, tanβ=3, A_0=0, μ>0
  - Benchmark used in CDF, Phys. Rev. Lett. 101, 251801 (2008)
- Spectrum created with Isajet 7.79
- The decay to leptons is really good and our acceptance even better
  - Neutralino goes 30% to selectron, 30% to smuon, 40% to stau
  - Chargino goes 2% to electron, 2% to muon, 2 % to tau, 92% to stau
- Cross section (prospino) equals to 0.47 pb.
- Masses:
  - Lightest chargino ~ 122 GeV/c^2
  - Next to-lightest chargino ~ 325 GeV/c^2
  - Lightest neutralino ~ 67 GeV/c^2
  - Next-to-lightest chargino ~ 125 GeV/c^2
  - Lightest higgsion ~ 100 GeV/c^2
  - Heavy higgsinos ~ 350 GeV/c^2

Hadronic Tau reconstruction

- $|\eta|<1$
- $E>20$ GeV
- $M<1.8$ GeV/c^2
- N_{tracks} (inner cone)=1 or 3
- N_{tracks} (between inner and outer cone)=0
- $N_{towers}\leq 6$
- good tracking for seed track
- d0 cut on seed track
- track-EMcalorimeter matching with seed track

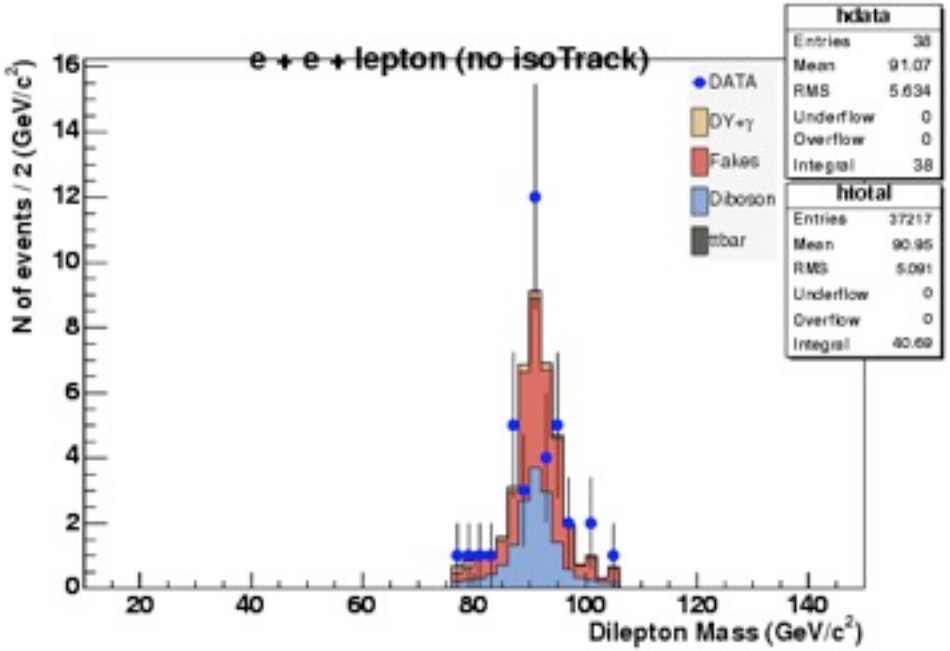
MET for the inclusive case (region 11) (no MET or jet multiplicity cuts)

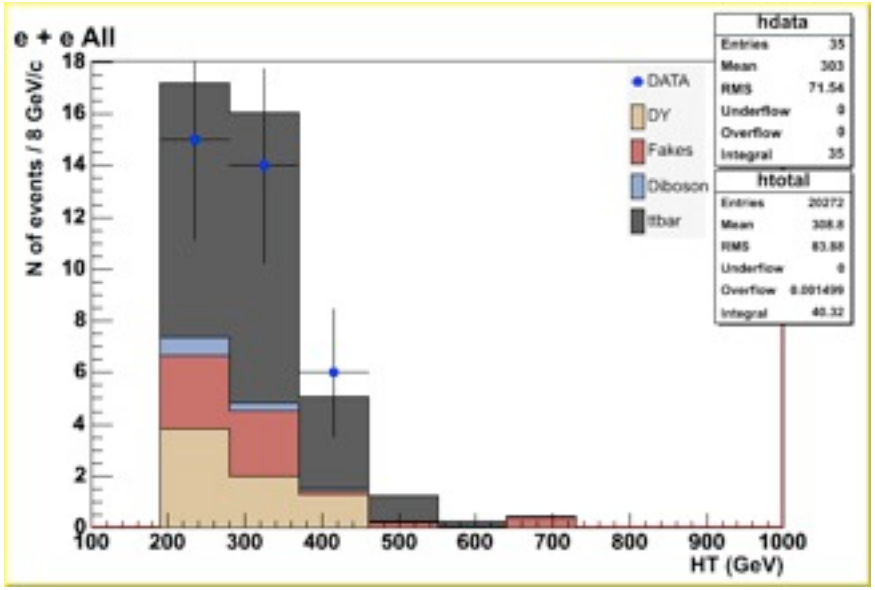




- MET looks good up to very large value

Validation of diboson, top, fakes



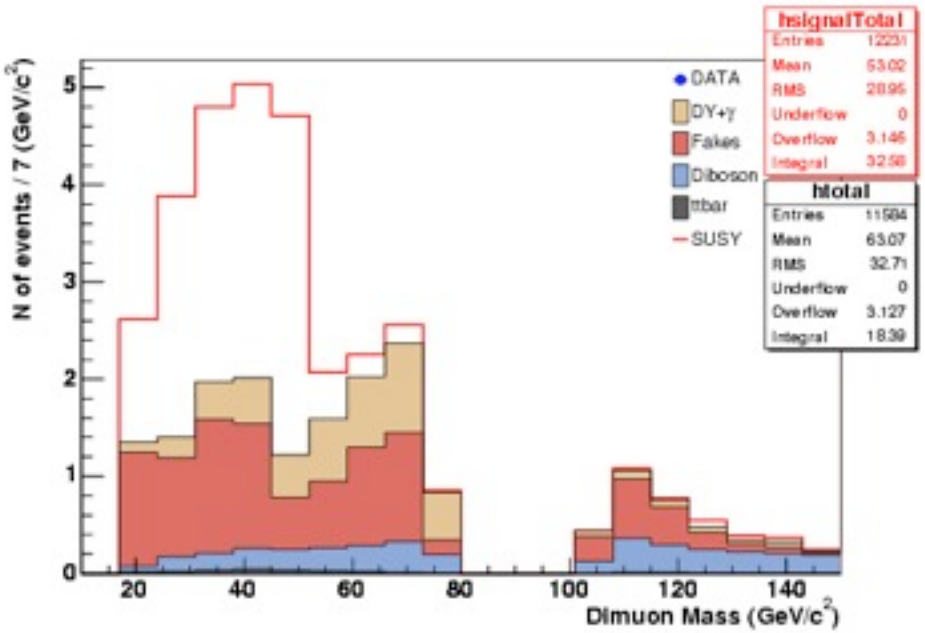


- Diboson enhanced region: trileptons with MET>15 GeV, $N_j \leq 1$
- Top enhanced region: dielectrons with HT>200, MET>20 GeV, $N_j \geq 2$

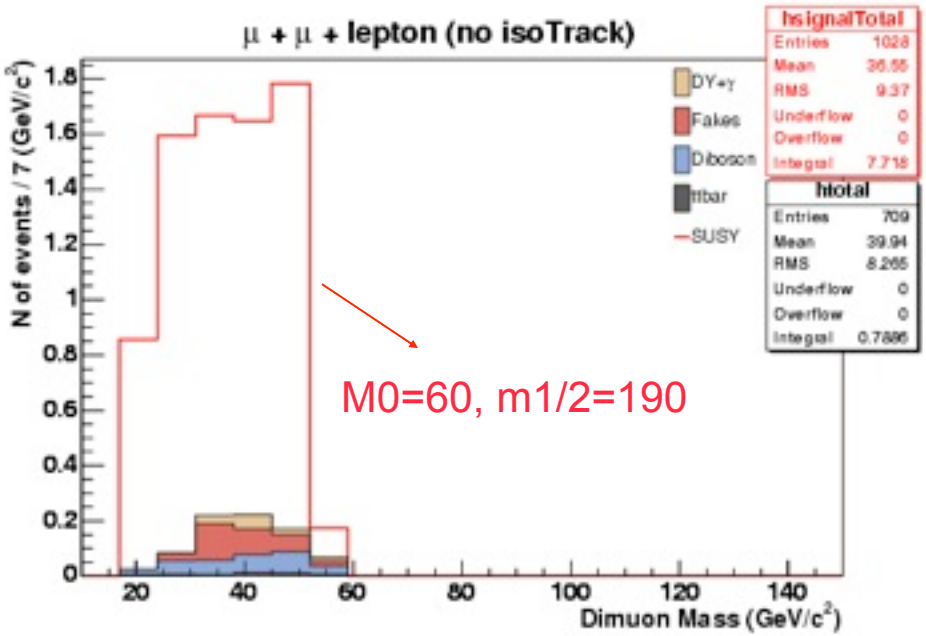
Region 7 (!Z, MET>15 GeV, $N_j \leq 1$)

Optimization Example

before



after



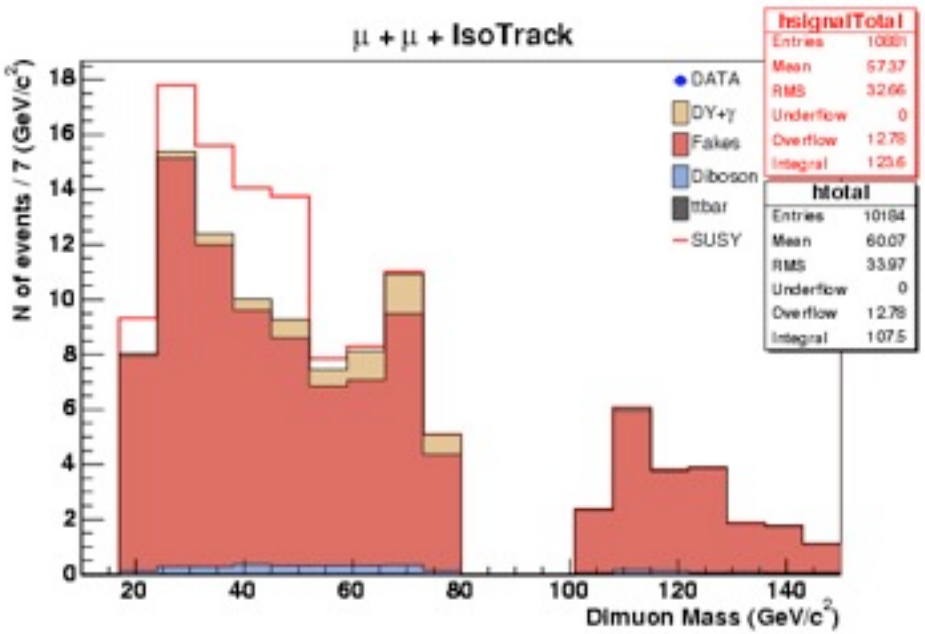
Our signal region

- With trivial "optimization", no ΔΦ(MET-closest muon)

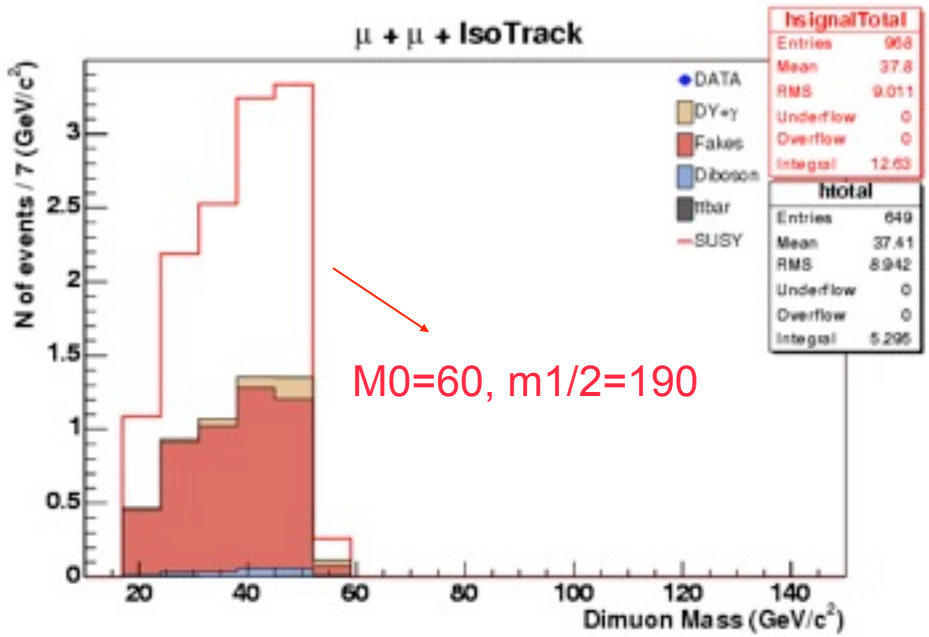
Region 7 (!Z, MET>15 GeV, $N_j \leq 1$)

Optimization Example

before



after



Our signal region

- With trivial "optimization", no ΔΦ(MET-closest muon)

Systematics breakdown

- Parton Distribution Functions and energy scale
  - 3%
- Theoretical cross sections
  - 8%
- ID Scale factors
  - 2 %
- Trigger efficiency
  - 0.5 %
- Fake rates
  - 20 % (for p_T<20 GeV/c), 50% (for p_T>20 GeV/c)
- Luminosity
  - 6%

Fakes

Due to the imperfect simulation of QCD processes (generation rates, isolation in hadronic environment etc.) we use CDF data for the determination of the QCD-induced background (Fake dimuons)

- Fake electrons and taus are jets that are reconstructed as electrons and taus that pass all the identification cuts of these leptons. Fake muons are decays-in-flight or punch-through kaons and pions

- The contribution of fakes is estimated through the measurement of fake rates, or the probability that jets and tracks will fake ID leptons

- Fake rates are applied to data by treating fakeable objects in data as real leptons and assigning the fake rate as the weight of the event.

Fake rates

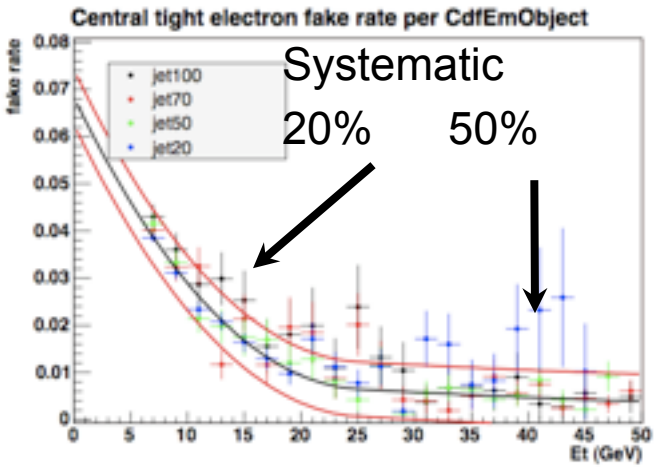
- Measurement is done using jet data: jet20, jet50, jet70, jet100
- Sample is cleaned up of real leptons: Met < 15, no dileptons events
- Trigger bias is removed by identifying trigger jets

Trigger Jet Requirements					
	Jet sample	Jet 20	Jet 50	Jet 70	Jet 100
L1	One calorimeter tower with	> 5 GeV	> 5 GeV	> 10 GeV	> 10 GeV
L2	One calorimeter cluster with	> 15 GeV	> 40 GeV	> 60 GeV	> 90 GeV
		$\lvert\eta\rvert < 3.6$	$\lvert\eta\rvert < 3.6$	$\lvert\eta\rvert < 3.6$	$\lvert\eta\rvert < 3.6$
L3	One cone 0.7 jet with	$E_T > 20$ GeV	$E_T > 50$ GeV	$E_T > 70$ GeV	$E_T > 100$ GeV

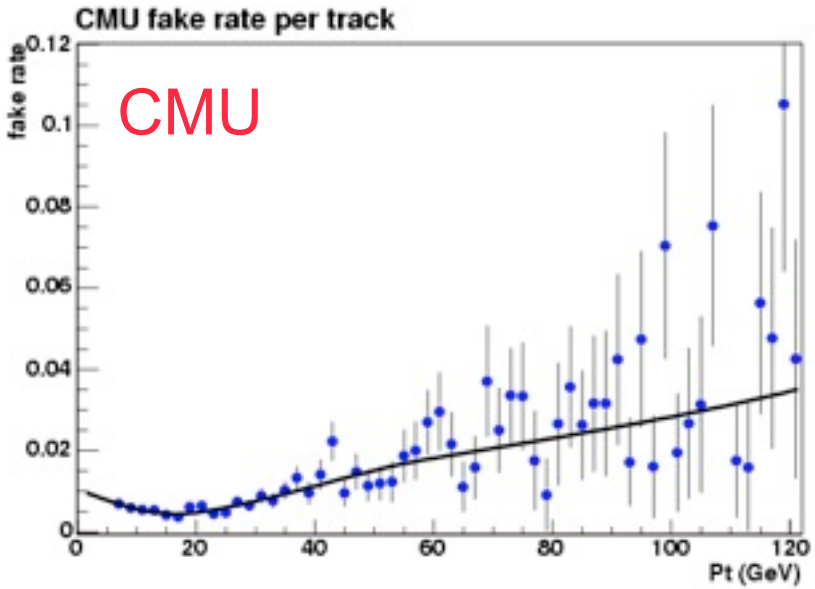
Combined fake rate

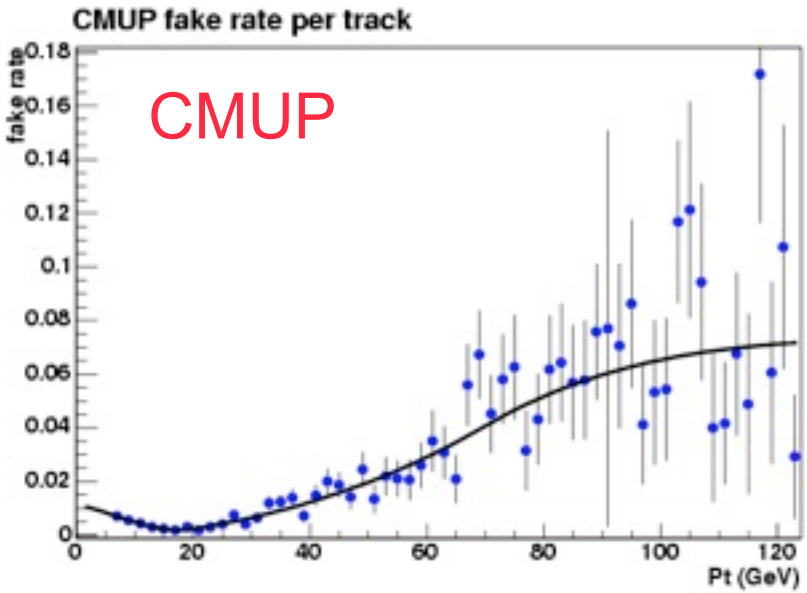
$$\bar{x} = \frac{\sum x_i/\sigma_i^2}{\sum 1/\sigma_i^2}$$

$$\sigma_x^{-2} = \sum 1/\sigma_i^2$$



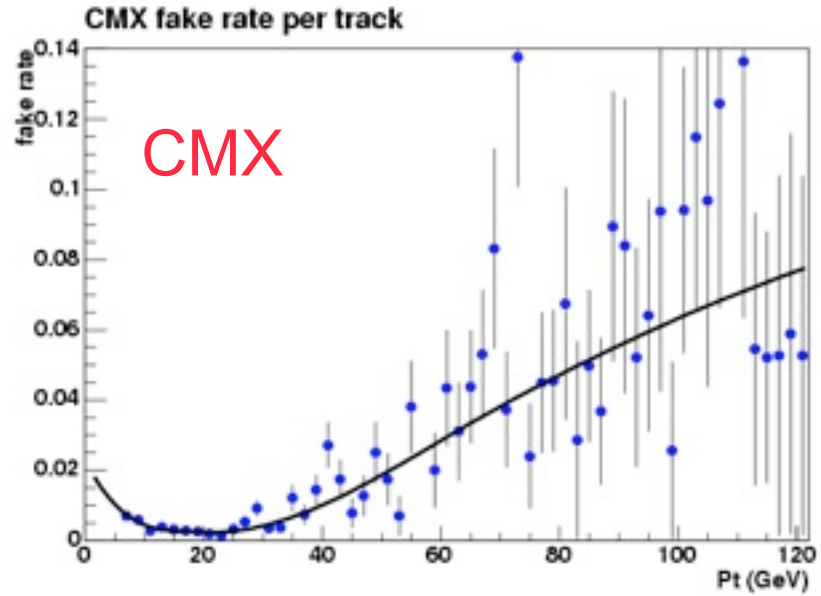
Measurement of fake-rates (CMU and CMUP)

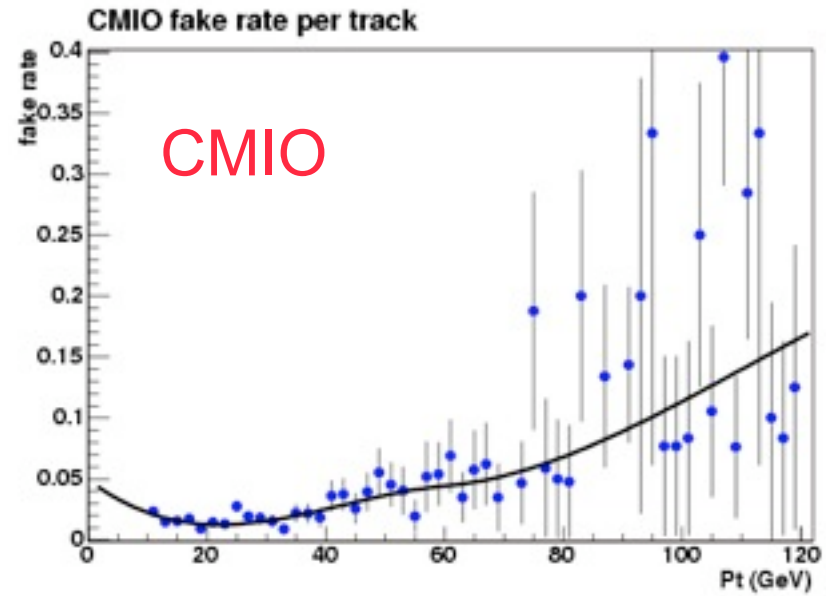


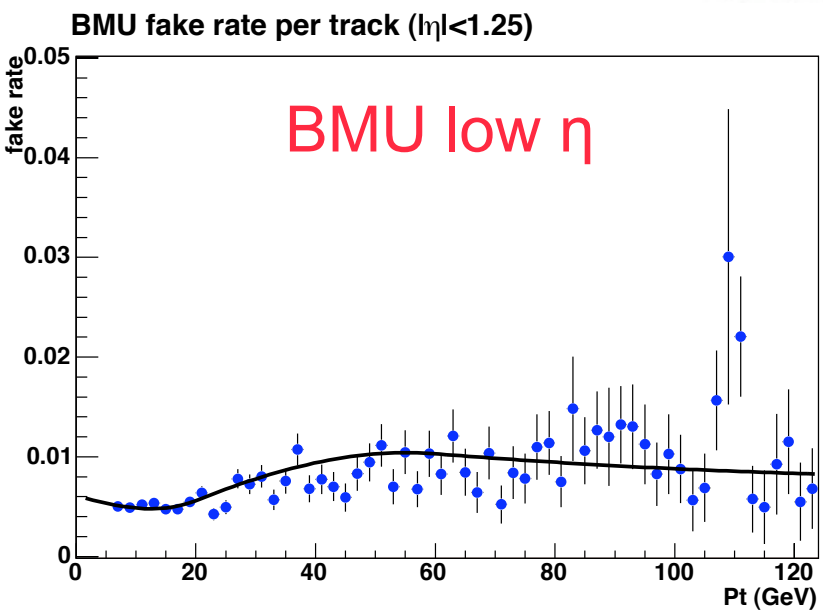


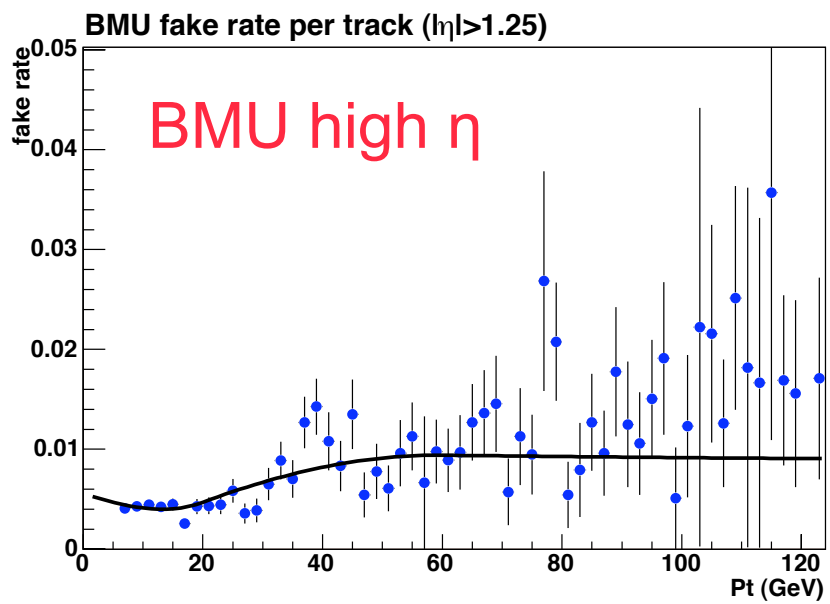
- Low p_T rise: due to looser isolation definition
- High-p_T rise: due to high momentum

Measurement of fake-rates (CMX, CMIO, BMU)

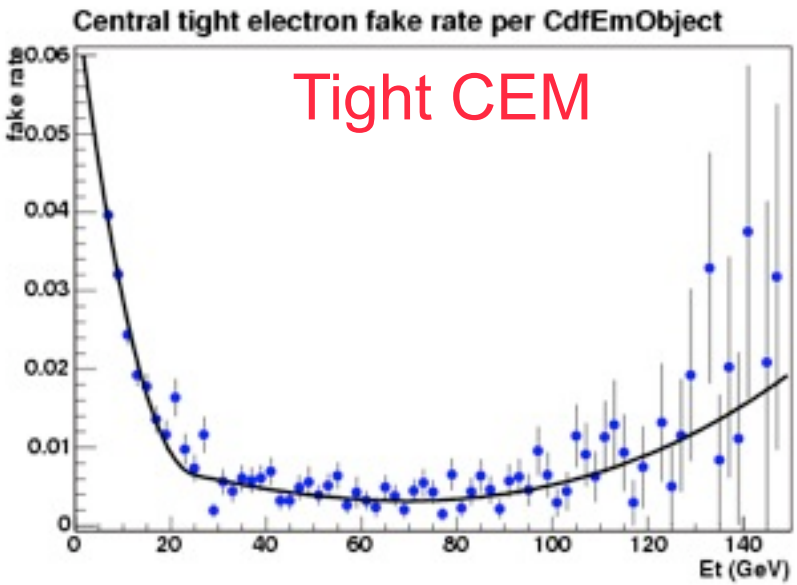


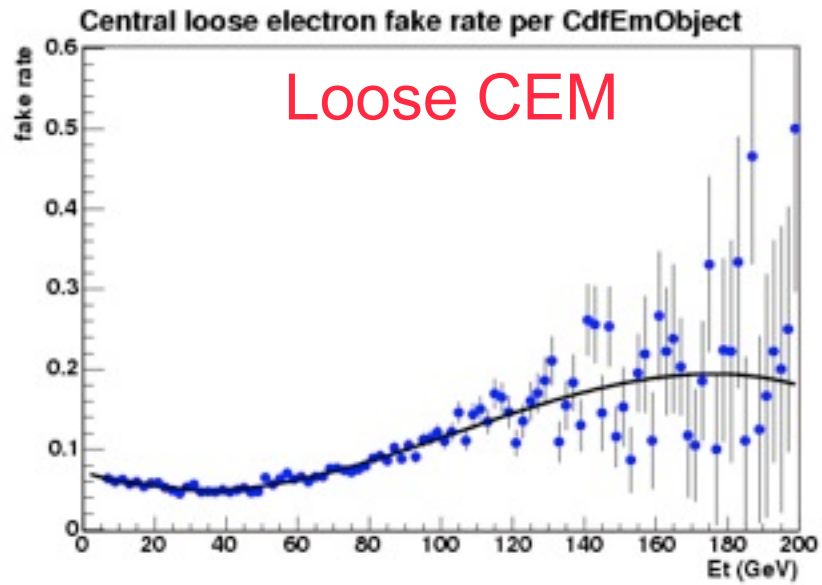






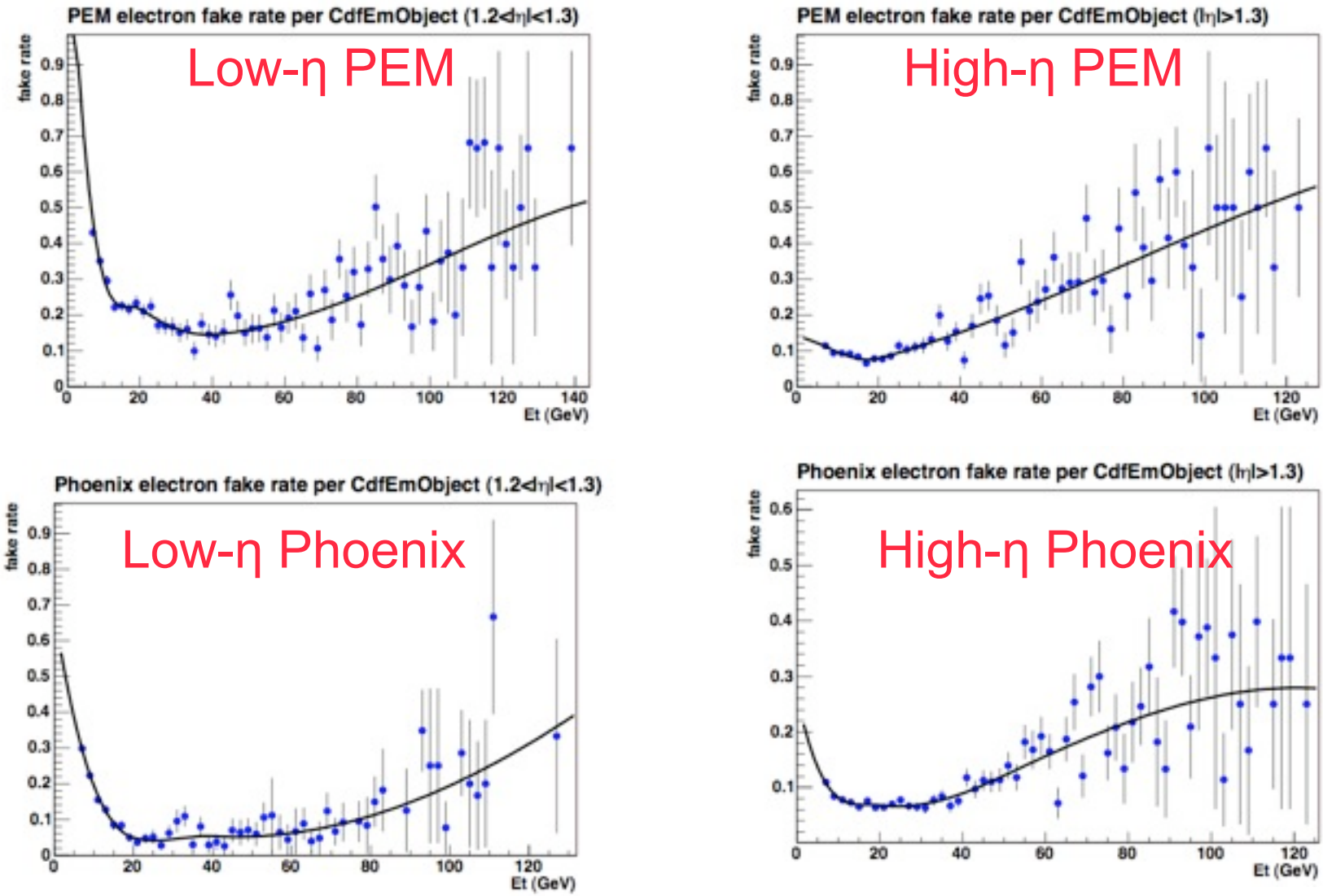
Measurement of fake-rates (central)





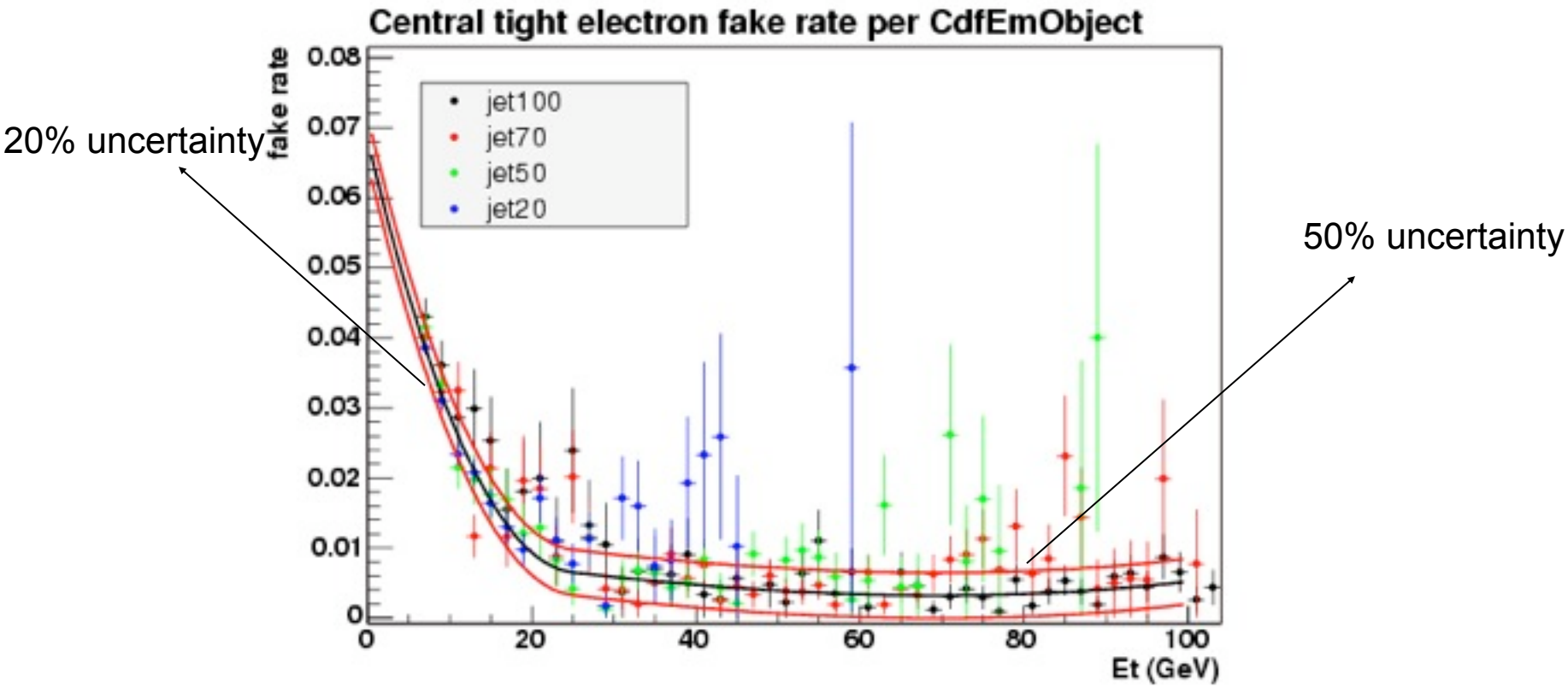
- Low E_T rise: due to looser isolation definition
- High-E_T rise: due to high energy

Measurement of fake-rates (forward)



Fakes systematics

- Example for fakes-systematic uncertainty



Electron Selection

Cut	CEMTIGHT	CEMLOOSE
Track P_T	> 4	
E_T	> 5	
Fiduciality	FidEleSmx()=1	
HAD/EM	$< 0.055 + 0.00045 \times E$	
Tracking	NStereoSegments(5) ≥ 2 NAxialSegments(5) ≥ 3	
Scaled CES χ^2_s	< 10	< 20
Lshr	< 0.2	—
ΔX	$-3.0 < \Delta X \times Q < 1.5$	—
ΔZ	$\lvert\Delta Z\rvert < 3.0$	—
E/P	< 2, for $P_T < 50$	—
Impact Parameter	$\lvert D0_{cor}\rvert < 0.02$, for nSvxHits$> 2$ $\lvert D0_{cor}\rvert < 0.2$, for nSvxHits$\leq 2$	
Vertex	$\lvert Z0\rvert < 60$	
Isolation	$ISO_{frac} < 0.1$, for $E_T > 20$ $ISO < 2$, for $E_T < 20$	
Conversion Veto	$\Delta xy < 0.1$ AND $\Delta cot\theta < 0.02$	

Cut	PEM	PHOENIX
E_T	> 5	
PesEta	$1.13 \leq \lvert\eta_{PES}\rvert \leq 2.8$	
HAD/EM	< 0.055, for $E^{EM} < 100$ $< 0.055 + 0.0026{*}\log(E^{EM})$, for $E^{EM} >= 100$	
χ^2_{PEM}	< 10	
Pes5x9	> 0.65	
Isolation	ISO< 4.0	
Track	stand-alone	Phoenix
Silicon Hits	—	≥ 3
Vertex	$\lvert Z0\rvert < 60$	
Impact Parameter	$\lvert D0_{cor}\rvert < 0.02$, for nSvxHits$> 2$ $\lvert D0_{cor}\rvert < 0.2$, for nSvxHits$\leq 2$	
Conversion Veto	$\Delta xy < 0.1$ AND $\Delta cot\theta < 0.02$	—

Central-Muon Selection

Cut	CMU	CMUP	CMX	CMIO
P_T	> 5			> 10
Fiduciality	CMU	CMU and CMP	CMX	non-finducial
Stub	CMU	CMU and CMP	CMX	—
Track-Stub $P_T > 20$	$\lvert\Delta X_{\mathrm{CMU}}\rvert < 7$	$\lvert\Delta X_{\mathrm{CMP}}\rvert < 5$	$\lvert\Delta X_{\mathrm{CMX}}\rvert < 6$	—
Track-Stub $P_T < 20$	$\chi^2_{\mathrm{CMU}} < 9$ or $\lvert\Delta X_{\mathrm{CMU}}\rvert < 7$	$\chi^2_{\mathrm{CMU}} < 9$ and $\chi^2_{\mathrm{CMP}} < 9$ or $\lvert\Delta X_{\mathrm{CMP}}\rvert < 5$	$\chi^2_{\mathrm{CMX}} < 9$ or $\lvert\Delta X_{\mathrm{CMX}}\rvert < 6$	—
EM	$< 2 + Max(0, 0.0115 \times (P - 100))$, for $P_T > 20$ < 2, for $P_T < 20$			
HAD	$< 6.0 + Max(0, 0.028 \times (P - 100))$, for $P_T > 20$ $< 3.5 + P_T/8$, for $P_T < 20$			
Tracking	NStereoSegments(5) ≥ 2 and NAxialSegments(5) ≥ 3			
Impact Parameter	$\lvert D0_{cor}\rvert < 0.02$, for nSvxHits$> 2$ $\lvert D0_{cor}\rvert < 0.2$, for nSvxHits$\leq 2$			
Vertex	$\lvert Z0\rvert < 60$			
Isolation	$\mathrm{ISO}_{frac} < 0.1$, for $E_T > 20$ $\mathrm{ISO} < 2$, for $E_T < 20$			

BMU selection

Cut	BMU
	BMU
Fiduciality	BmuFidX()< 0
	BmuFidZ()< -13, for $\lvert\eta_{det}\rvert < 1.25$
	BmuFidZ()< -3, for $\lvert\eta_{det}\rvert \geq 1.25$
Stub	BMU Stub
Track-Stub $P_T > 20$	$\lvert\Delta X_{\mathrm{BMU}}\rvert < 9$
Track-Stub $P_T < 20$	$\lvert\Delta X_{\mathrm{BMU}}\rvert < 9$ or $\chi^2_{\mathrm{BMU}} < 9$
EM	$< 2 + Max(0, 0.0115 \times (P - 100))$, for $P_T > 20$
	< 2, for $P_T < 20$
HAD	$< 6.0 + Max(0, 0.028 \times (P - 100))$, for $P_T > 20$
	$< 3.5 + P_T/8$, for $P_T < 20$
Tracking	NStereoSegments(5) ≥ 2
	NAxialSegments(5) ≥ 3
Impact Parameter	$\lvert D0_{cor}\rvert < 0.02$, for nSvxHits$> 2$
	$\lvert D0_{cor}\rvert < 0.2$, for nSvxHits$\leq 2$
Vertex	$\lvert Z0\rvert < 60$
Isolation	$\mathrm{ISO}_{frac} < 0.1$, for $E_T > 20$
	ISO < 2, for $E_T < 20$

Tau selection

Cut	TAU
Visible E_T	> 20
Tower E_T	> 10
Seed Track P_T	> 10
$\lvert\eta_{det}\rvert$	< 1
Cluster mass	< 4
Visible mass	< 1.8
ISO_{frac}	< 0.1
Tracking	NStereoSegments(5) ≥ 3 NAxialSegments(5) ≥ 3
Seed Track $D0$	< 1
Vertex	$\lvert Z0\rvert < 60$
Seed Track $\lvert X_{CES}\rvert$	< 21.5, for 1-prong tracks only
Seed Track $\lvert Z_{CES}\rvert$	$9 < \lvert Z_{CES}\rvert < 230$
$\chi^2(COT)/N_{DOF}$	< 3
Charge	$=1$
Standard electron rejection	yes
Number of tracks in cone ($< 10^0$)	1 or 3
Number of tracks in annulus ($10^0 - 30^0$)	0 with $P_T > 1$
Number of associated cal. towers	≤ 6

Tevatron

- Proton anti-proton beam can reach a center of mass energy $s^{1/2}$ = 1.96TeV
- Collisions occur every 396ns (bunch spacing)

Tevatron accelerates protons and antiprotons to 980 GeV

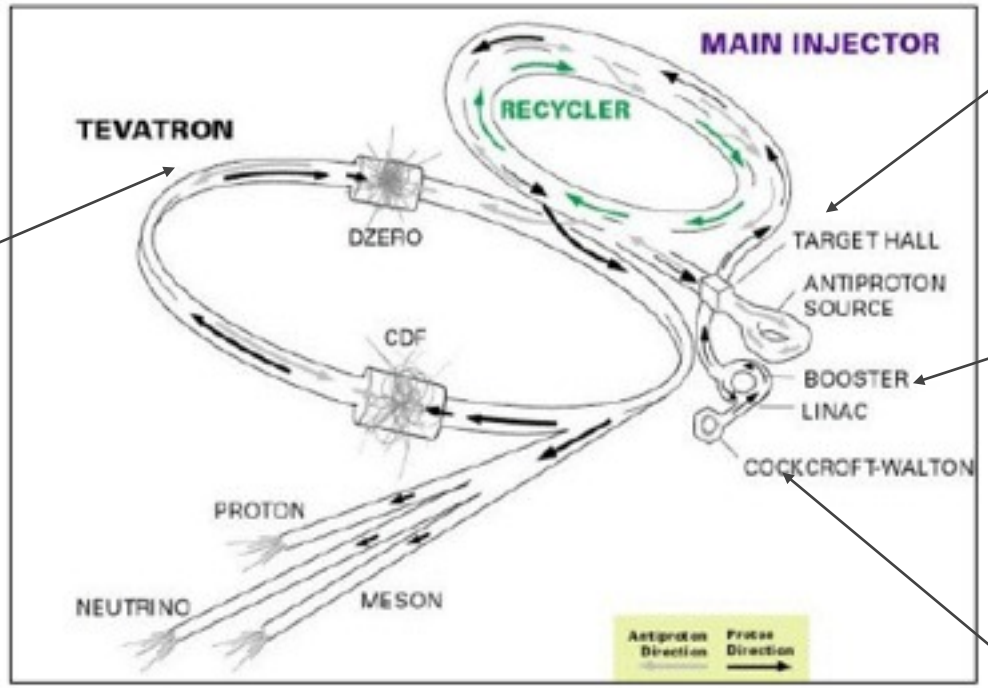


Figure 1. Fermilab's Accelerator Chain

120GeV protons are used to make antiprotons

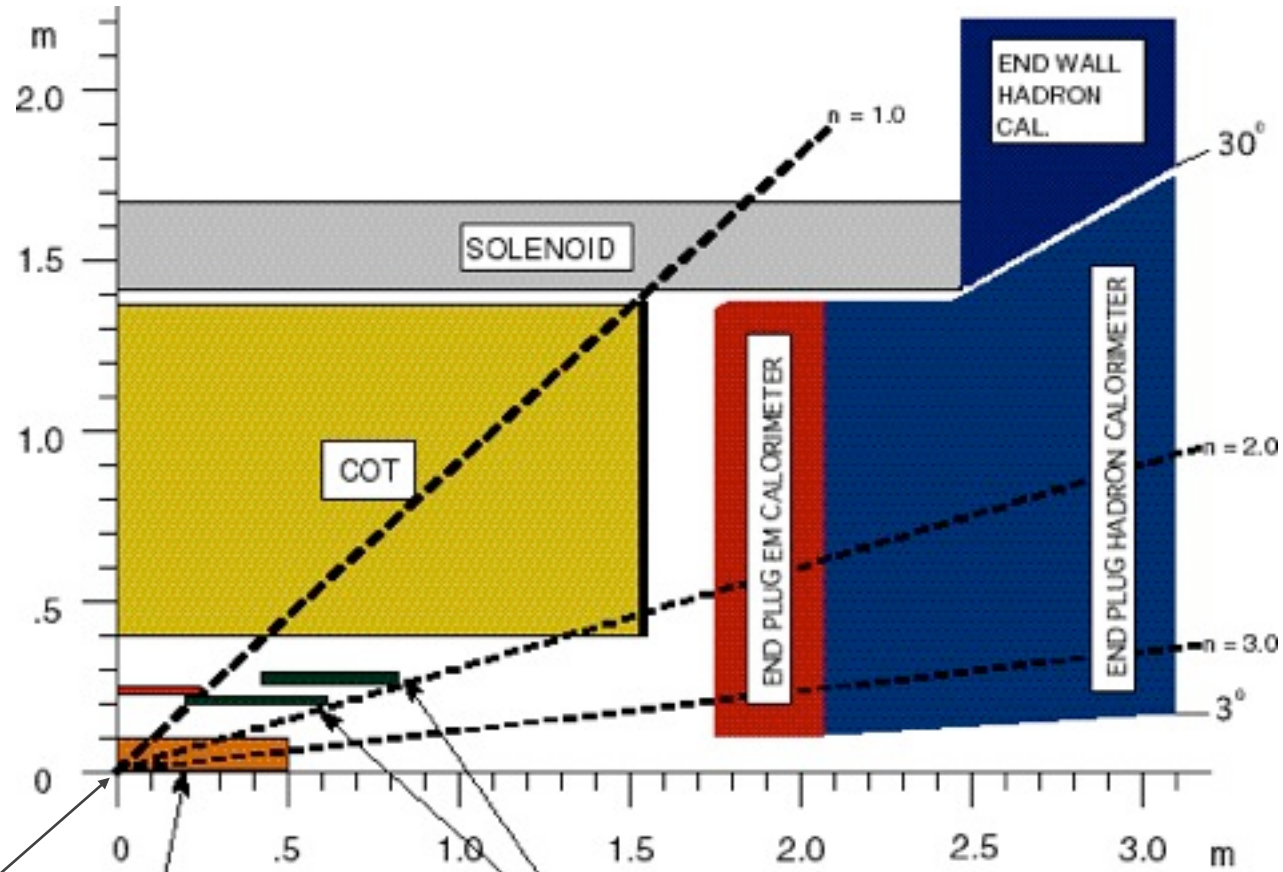
H^- are stripped of electrons by passing through a thin carbon foil.

Source of H^- ions

The CDF Detector Components

- Tracking:
  - Silicon layers: L00, SVX, ISL
  - COT: Central Outer Tracker
- Calorimeters:
  - Electromagnetic calorimeter
  - Hadronic calorimeter
- Muon chambers

CDF Detector

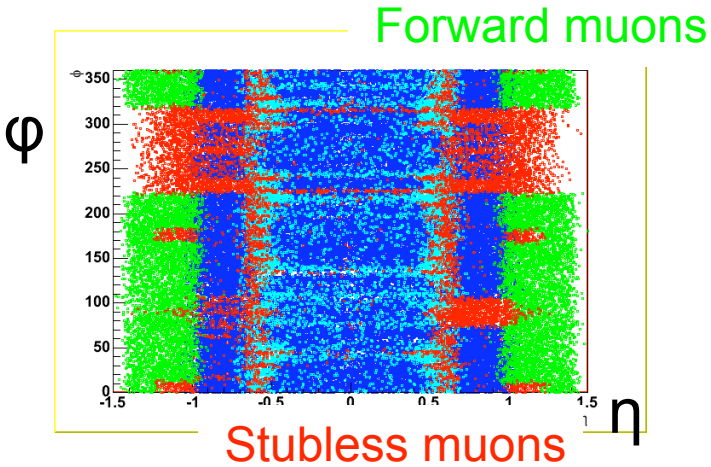


LAYER 00

SVX II
5 LAYERS

INTERMEDIATE
SILICON LAYERS

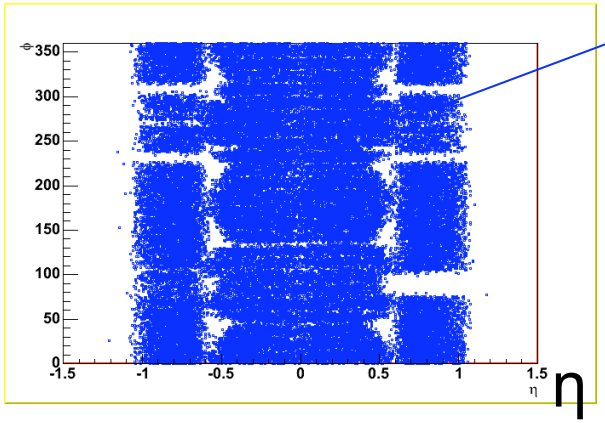
Increase coverage for muons and electrons



Increase coverage for muons and electrons

central muons

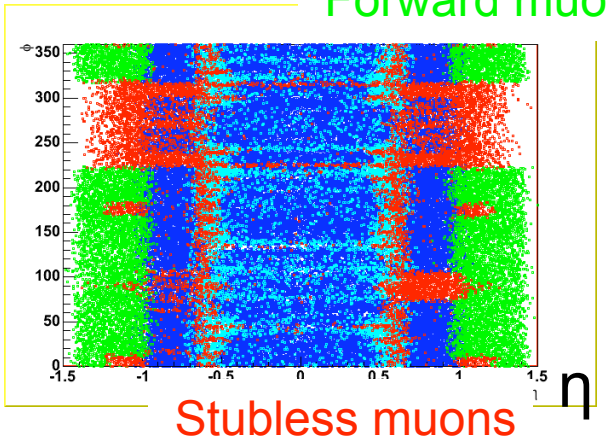
φ



η

Forward muons

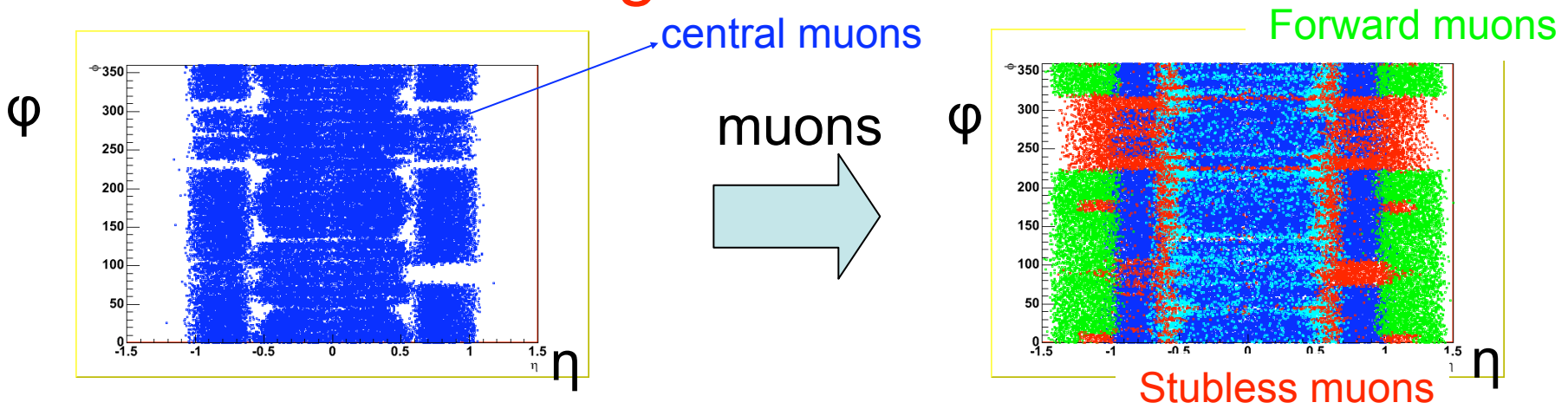
φ



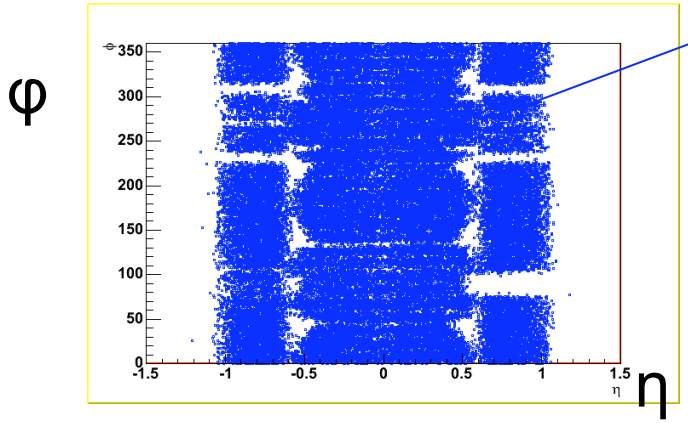
η

Stubless muons

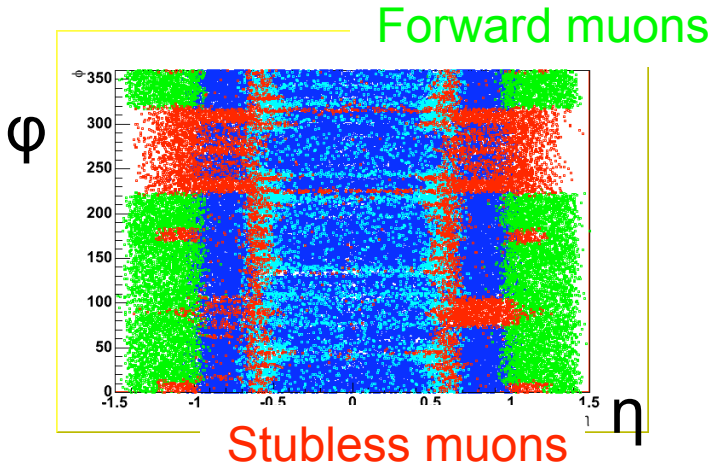
Increase coverage for muons and electrons

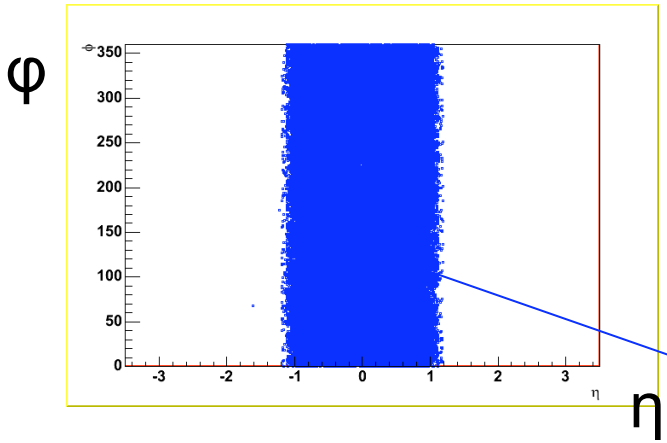


Increase coverage for muons and electrons

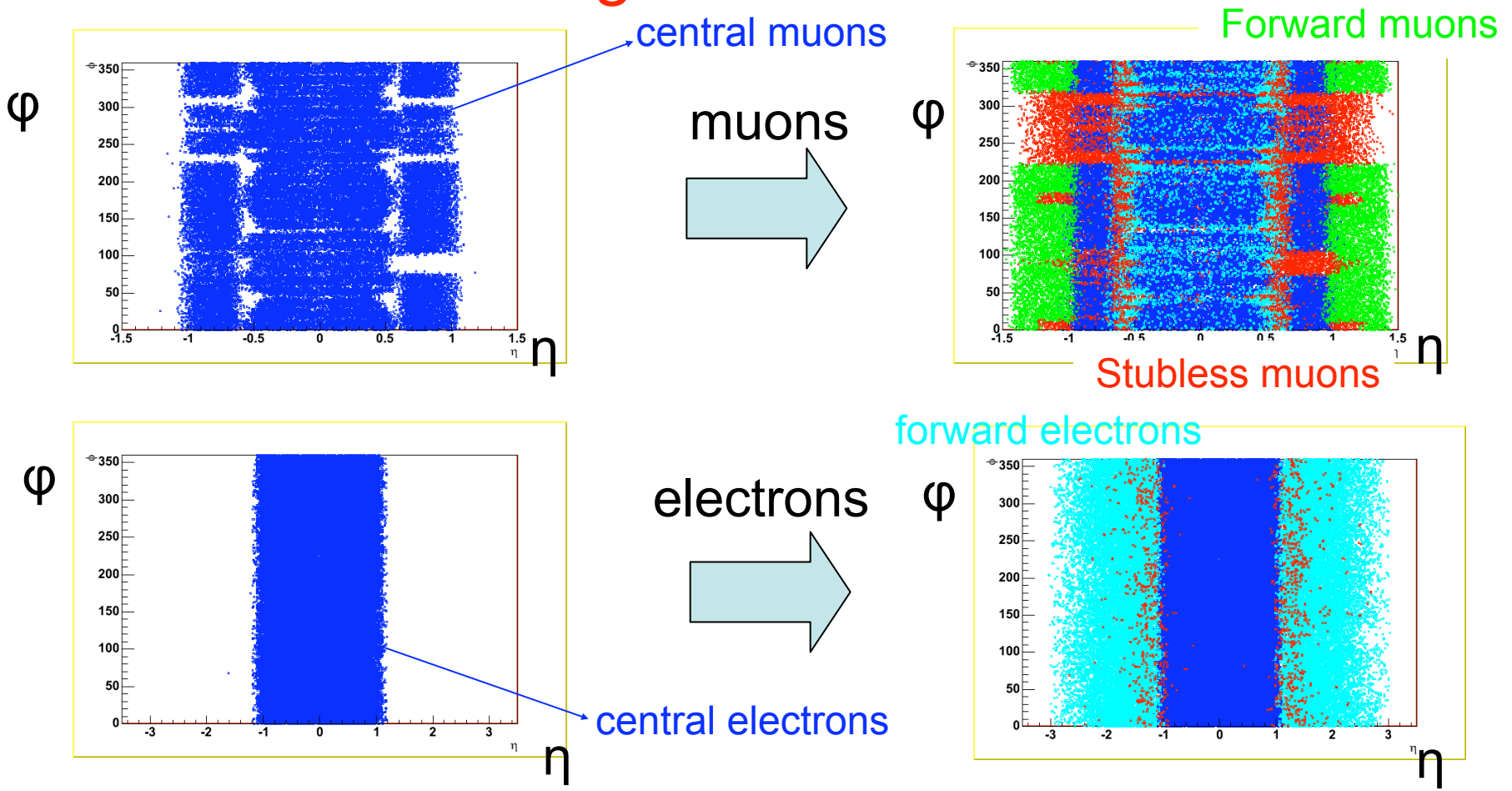


muons

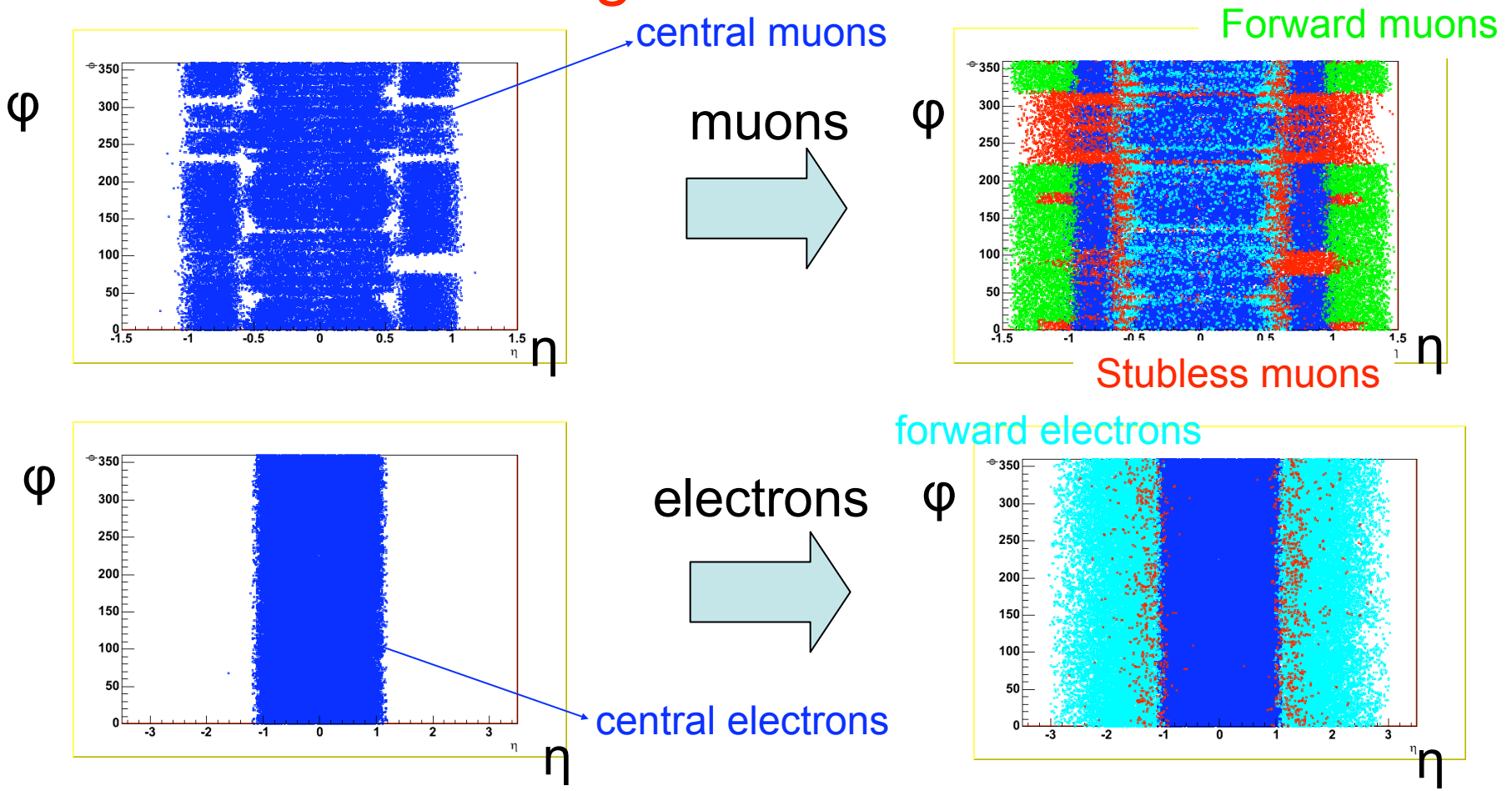




Increase coverage for muons and electrons

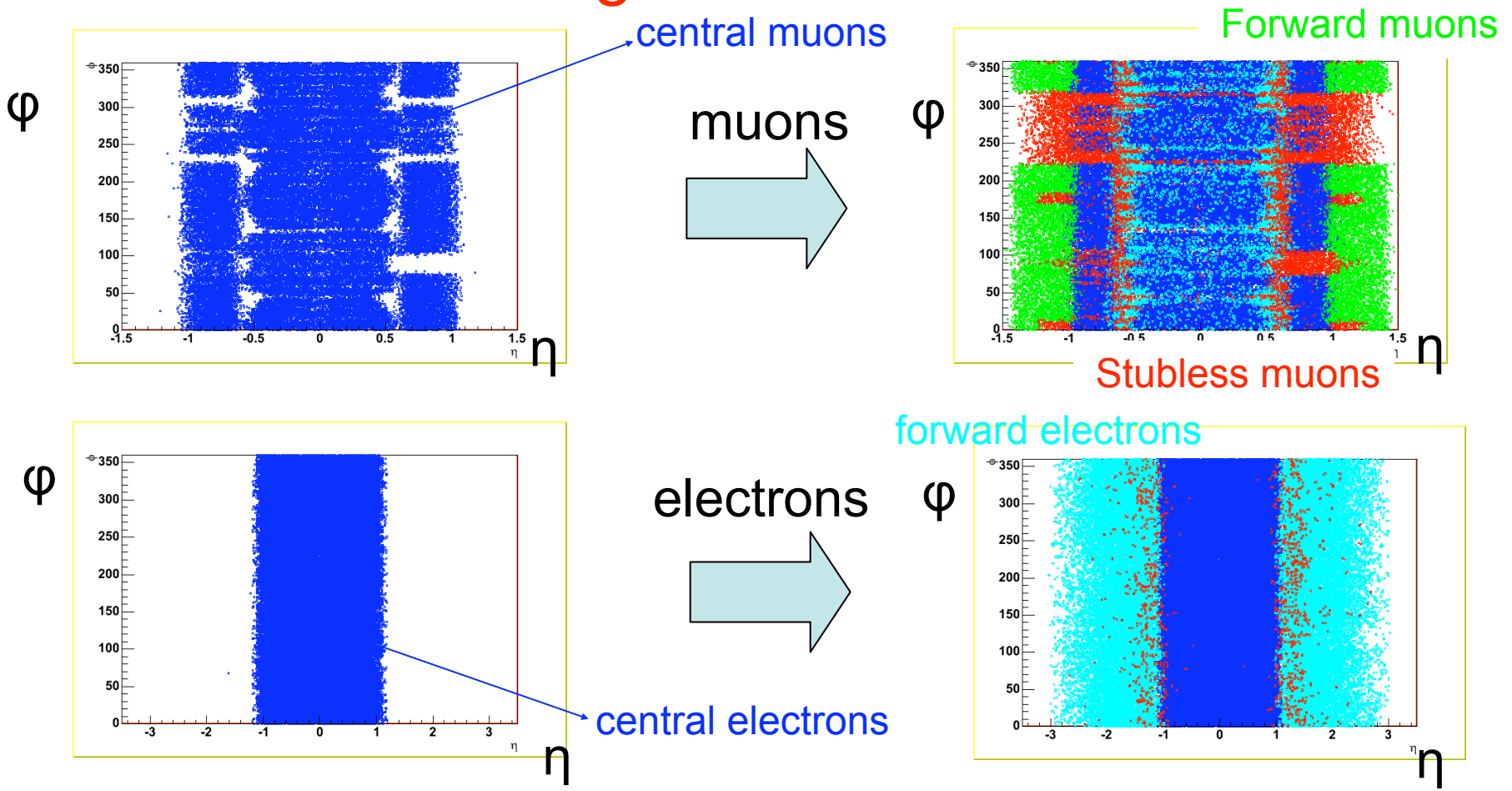


Increase coverage for muons and electrons



- We will use the full CDF detector, including the forward calorimeters and muon systems.

Increase coverage for muons and electrons



- We will use the full CDF detector, including the forward calorimeters and muon systems.
- The forward objects roughly double (triple) our dilepton (trilepton) overall acceptance

Supersymmetry

- Each particle of the SM has a supersymmetric partner that shares all its quantum numbers except for spin which differs by half a unit.
- Leptons and quarks are partnered by spin 0 sleptons and squarks
- The photon, gluon, W's and Z have spin-1/2 photino, gluino, wino and zino
- Supersymmetry must be a broken symmetry because we have never seen a supersymmetric particle
- In a supersymmetric extension of the standar model, each of the known fundamental particles is in a chiral or gauge supermultiplet

mSUGRA

- MSSM more than doubles number of particles and increases free parameters to over 100
- mSUGRA, or minimal Super Gravity, is a constrained MSSM which includes Gravitation
- Supersymmetry is broken in the hidden sector, giving rise to a massive gravitino which communicates the SB to the visible sector
- The SB generates soft SUSY breaking terms in the visible sector, among them terms which brake EW symmetry at the EW scale.
- All couplings and masses are determined by only 5 free parameters at the GUT scale
  - m_0, $m_{1/2}$, A_0, $\tan\beta = v_1/v_2$ and sign(μ)

mSugra Parameters at GUT Scale

- m_0: common scalar mass (Higgs, sleptons, squarks)
- $m_{1/2}$: common gaugino mass (bino, wino, gluino)
- $\tan\beta = \langle H_2 \rangle / \langle H_1 \rangle$: ratio of Higgs vacuum expectation values. Determines higgisino vs gaugino content of charginos and neutralinos.
- μ: un-mixed Higgisino mass
- A_0: common trilinear scalar couplings (determines sfermion mixing)

Search for Chargino-Neutralino Production

- With masses still at the reach of the Tevatron ~100 GeV for neutralino ($M\chi_0$>59 GeV, LEP II) ~250 GeV for

$$\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^{0}$$

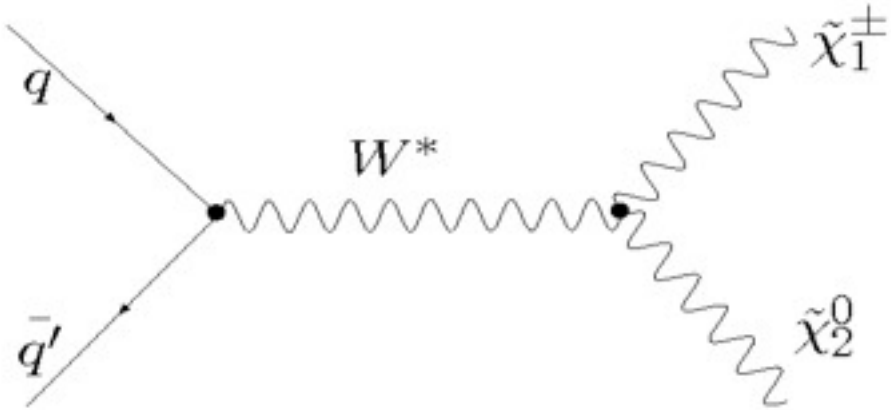
$$\widetilde{W}^{\pm}, \tilde{H}_1^{+}, \tilde{H}_2^{-} \Longrightarrow \tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$$

$$\widetilde{W}^{3}, \tilde{B}, \tilde{H}_1^{0}, \tilde{H}_2^{0} \Longrightarrow \tilde{\chi}_1^{0}, \tilde{\chi}_2^{0}, \tilde{\chi}_3^{0}, \tilde{\chi}_4^{0}$$

Lightest Supersymmetric Particle
Stable if R_P is conserved → relic density (dark matter candidate)

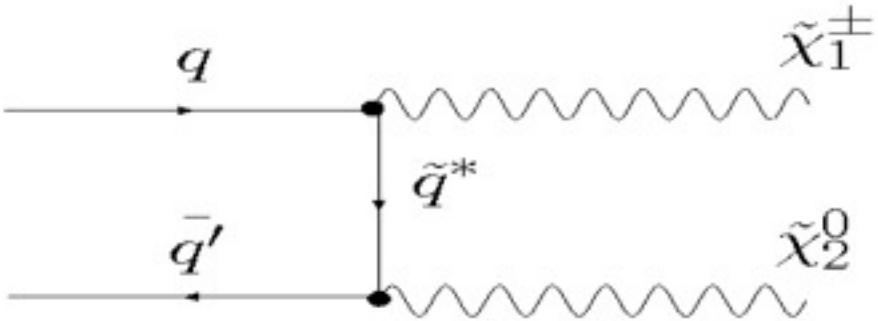
Signal:Production channels

S-channel
via virtual W



T-channel

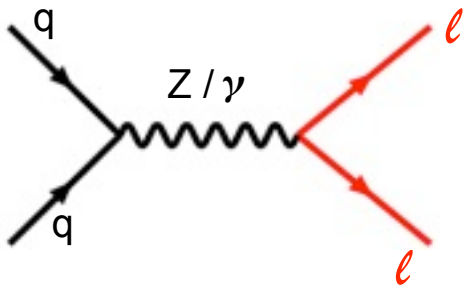
via virtual squark



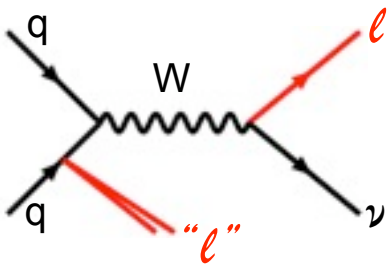
Supressed if there is no unification of scalar masses

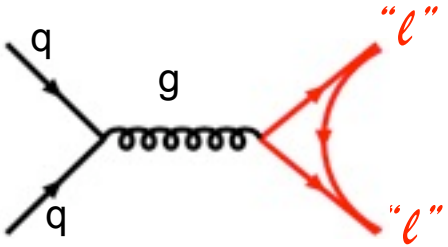
SM Dilepton Backgrounds

- Electroweak
  (Drell-Yan, W+γ)
  Measured with MC simulation

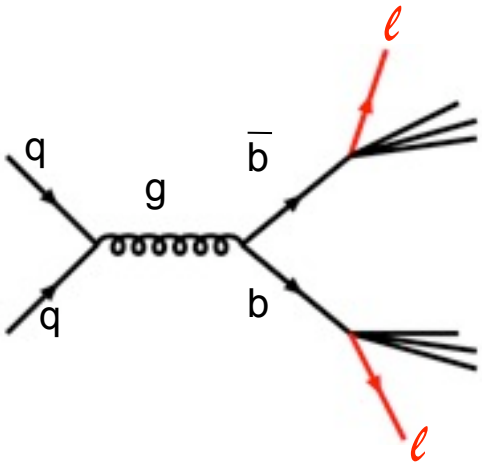


- Light-flavor QCD
  (u,d,s quark-based)
  Measured with CDF data





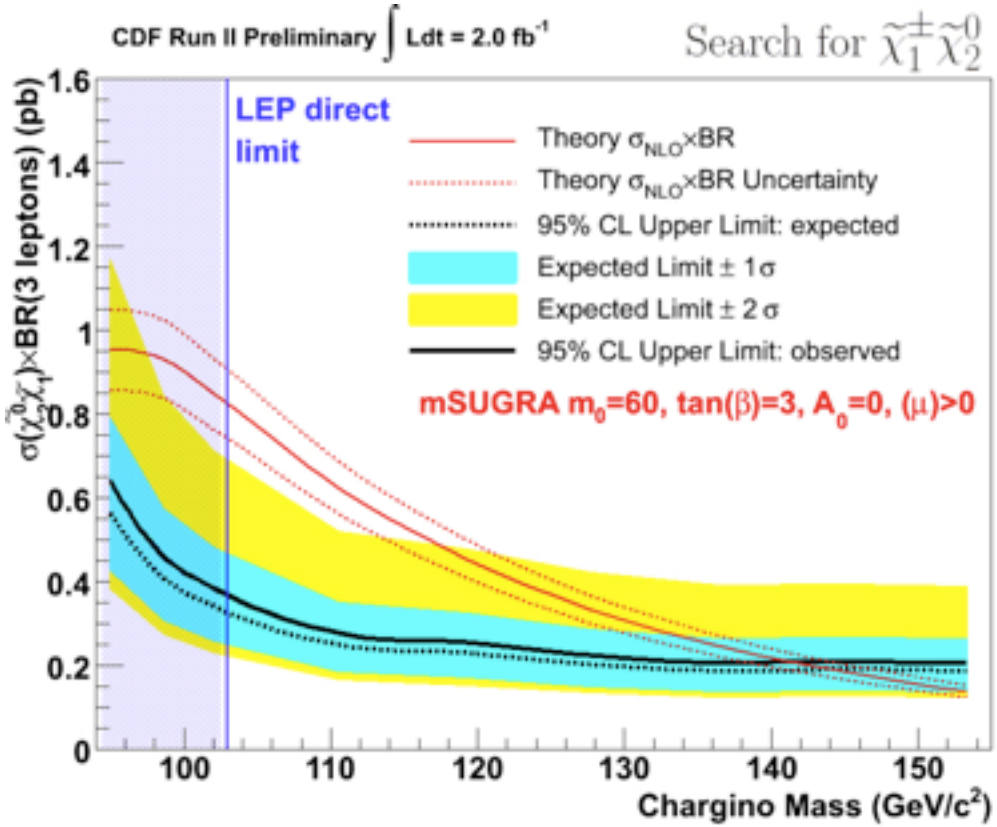
- Heavy-flavor QCD
  (c,b quark-based)
  Measured with CDF data



"ℓ" = fake lepton

Latest 2 fb^{-1} analysis

- Same analysis without forward electrons but with more data and the use of a third isolated-track resulted to a pure mSUGRA result
  - Expect 6.4 and see 7
  - $M_{chargino}$>140 GeV @ 95% CL
  - σ*BR <0.25 pb @ 95% CL



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Control regions

Definition of Control and Signal Regions			
Region	$M_{\ell\ell}$ cut (Gev/c^2)	($\not\!\!E_T$) cut (GeV)	N_{jet} cut
Region0	$M_{\ell\ell} > 20$	$\not\!\!E_T < 10$	–
Region1	$76 < M_{\ell\ell} < 106$	$\not\!\!E_T > 15$	$N_{jet} \leq 1$
Region2	$76 < M_{\ell\ell} < 106$	$\not\!\!E_T > 15$	$N_{jet} \geq 2$
Region3	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not\!\!E_T < 10$	$N_{jet} \leq 1$
Region4	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not\!\!E_T < 10$	$N_{jet} \geq 2$
Region5	$76 < M_{\ell\ell} < 106$	$\not\!\!E_T < 10$	$N_{jet} \leq 1$
Region6	$76 < M_{\ell\ell} < 106$	$\not\!\!E_T < 10$	$N_{jet} \geq 2$
Region7	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not\!\!E_T > 15$	$N_{jet} \leq 1$
Region8	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not\!\!E_T > 15$	$N_{jet} \geq 2$
Region9	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not\!\!E_T > 20$	$N_{jet} \leq 1$
Region10	$76 < M_{\ell\ell} < 106$	–	–
Region11	$M_{\ell\ell} > 20$	–	–