Recent Results in High p_T Physics from CDF

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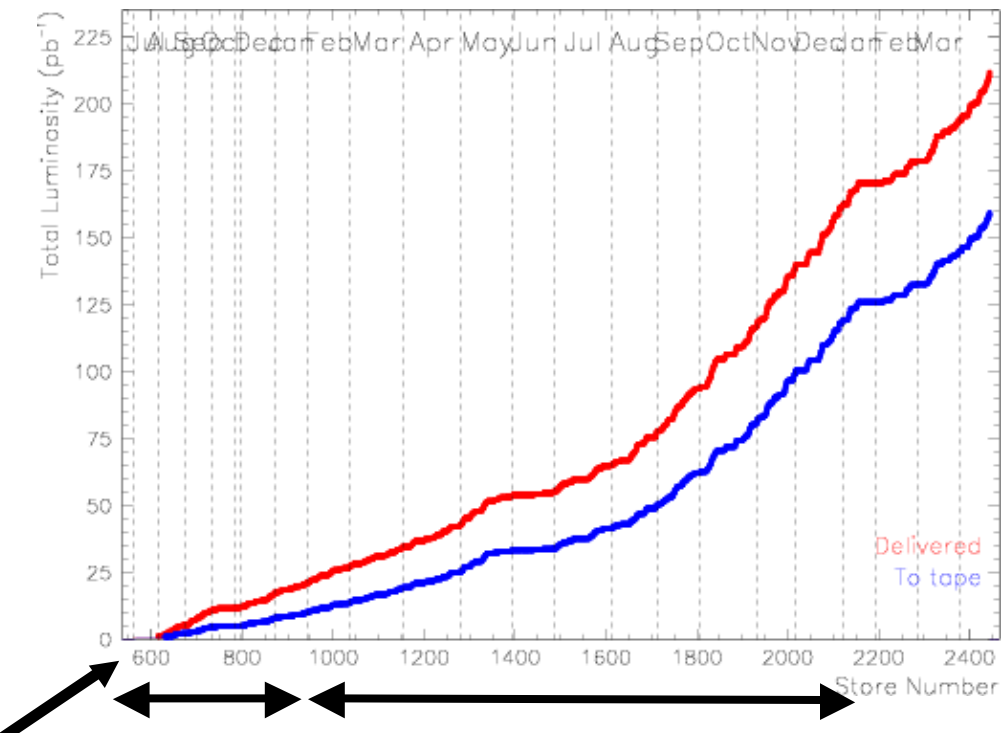
(For the CDF Collaboration)

- **Introduction: Data taking and CDF II upgrade**
- **Electroweak Results**
- **Top Results**
- **Searches for new Physics**

CDF data taking

- Running stably since Feb. '02
  - ➤ **Silicon sensitive to beam conditions**
- >150 pb^{-1} to tape
- 5-8 pb^{-1}/week
- ~82% efficiency

- 53-91 pb^{-1} used in current "winter" analyses



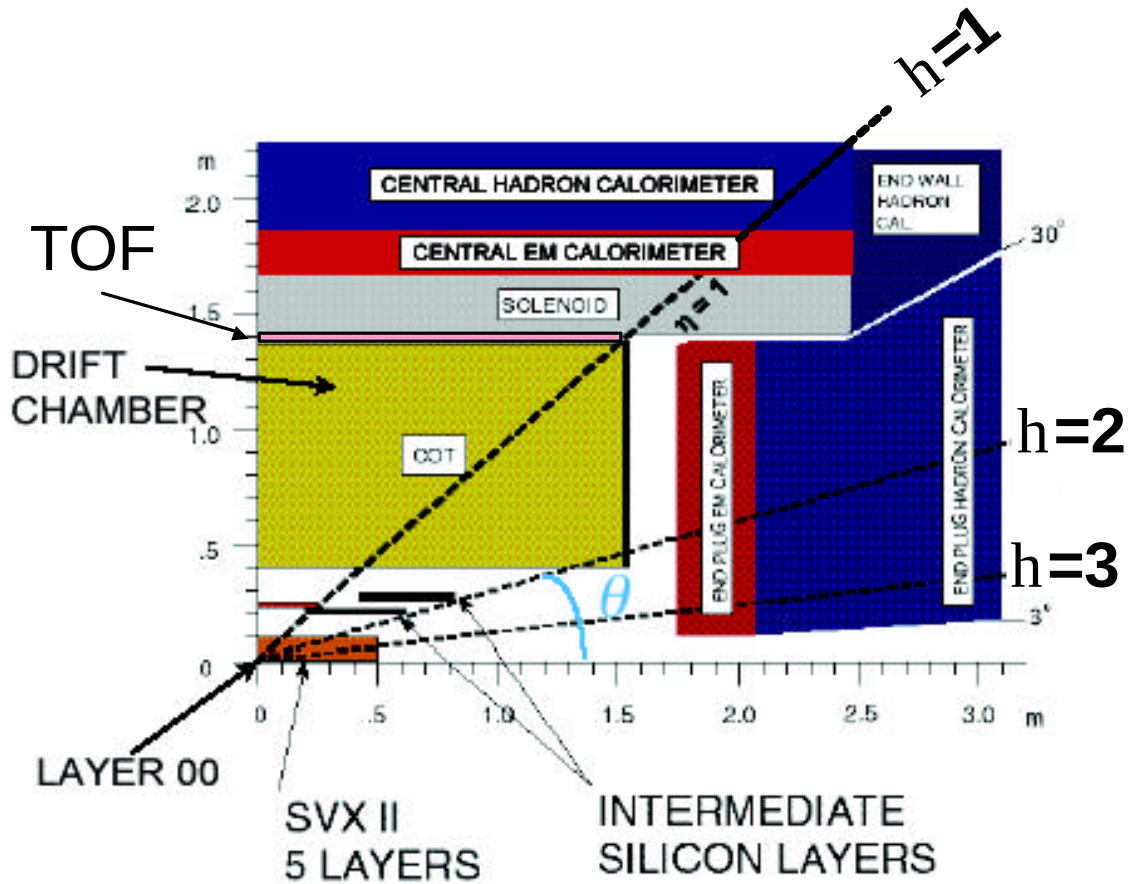
July 2001

Commissioning

Approved for analysis

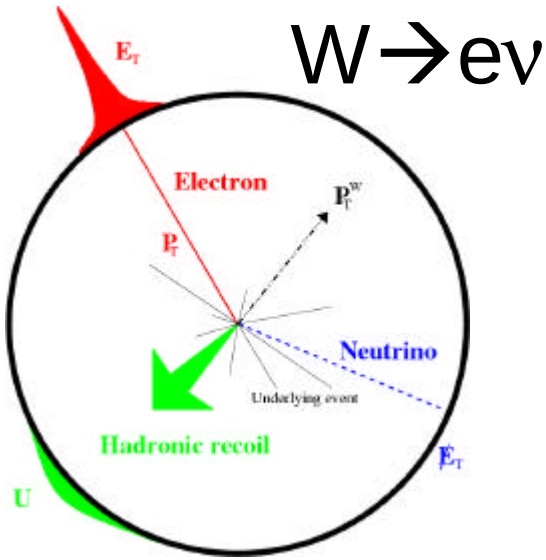
CDF Run II Upgrade

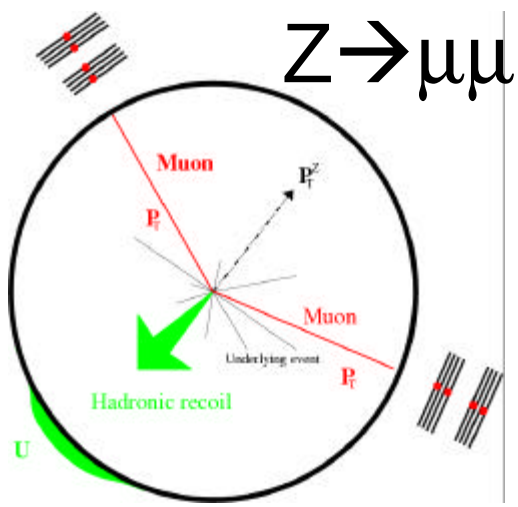
- Improved Si coverage
  - |h| < 2
  - 8 layers
- Central Drift Chamber
  - 96 layers
- Time of Flight
- Expanded μ coverage
- Forward Calorimeter
- Trigger
  - COT tracks at L1
  - Silicon tracks at L2



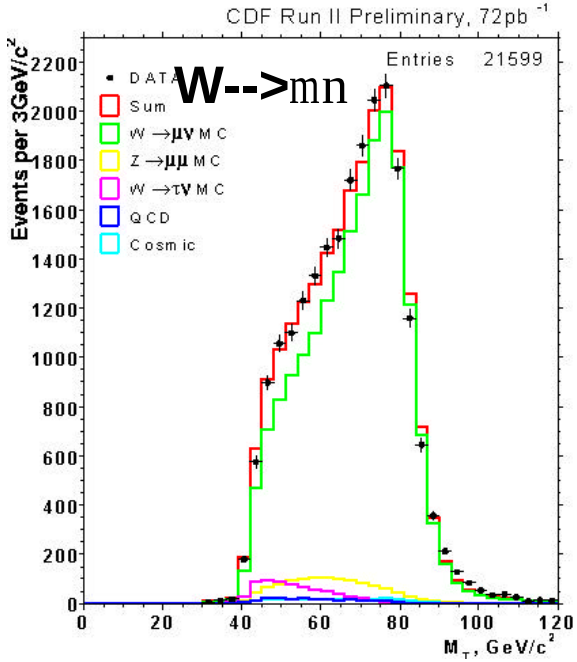
Electroweak Program

- Baseline Measurements
  - **W/Z cross sections**
  - **Ratio of W/Z cross section**
  - **Lepton Universality**
  - **Forward-Backward Asymmetry**
- Improve EWK parameters
  - **W Charge Asymmetry**
    - Constrains on PDFs
  - **Diboson Production**
    - Look for Anomalous couplings
  - ***W Mass Measurement***
    - **Dominated by Systematics**

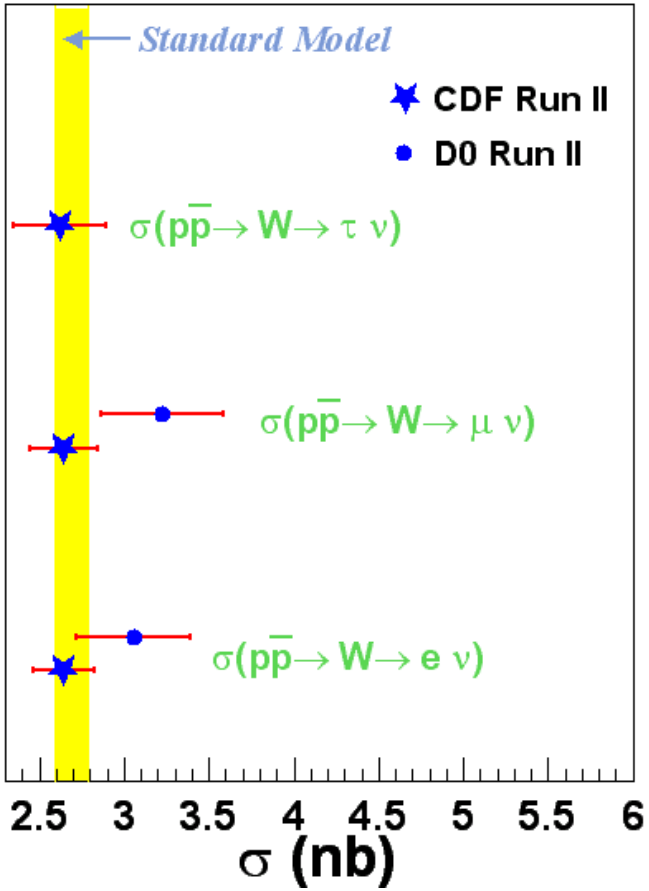




$\sigma \bullet B(W \to l\nu_l)$



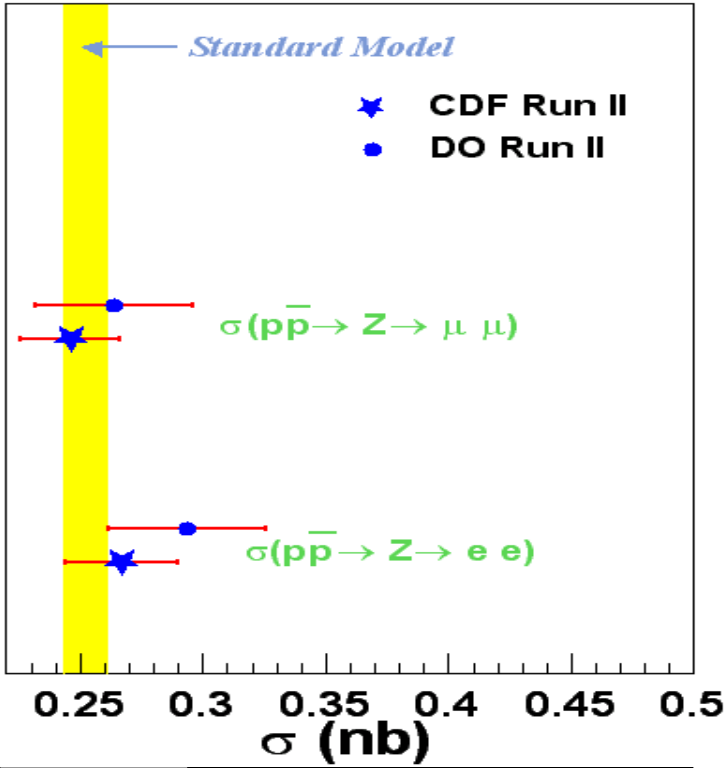
- Clean Signature
  - ➤ **Isolated lepton**
  - ➤ **Missing E_T**
- High σ & S/B
- 72 pb^{-1}

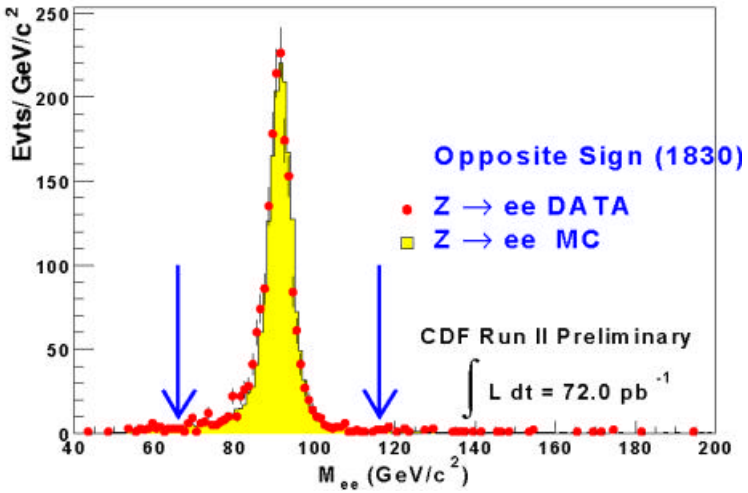


	Sample	Back.	$\sigma \bullet B(W \to l\nu_l)$ (nb)
e	38625	6%	**2.64**$\pm 0.01_{stat} \pm 0.09_{sys} \pm 0.16_{lum}$
μ	21599	11%	**2.64**$\pm 0.02_{stat} \pm 0.12_{sys} \pm 0.16_{lum}$
τ	2346	26%	**2.62**$\pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}$

σ•B(Z-->ll)

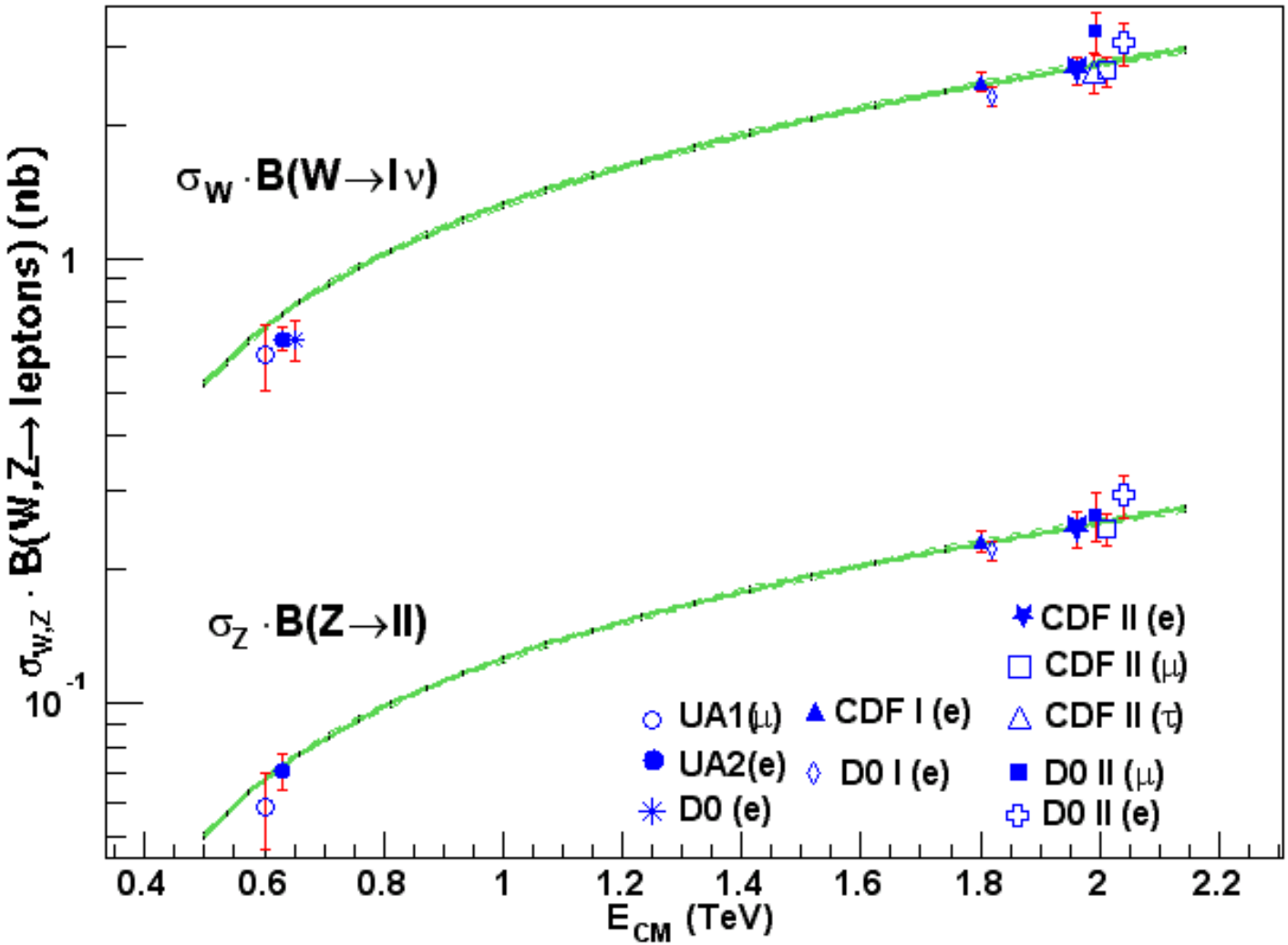
- Require two isolated leptons
  - ➤ **Negligible backgrounds**
- 72 pb^{-1}
- Essential for Detector Calibrations
  - ➤ **Energy scale and resolution**
  - ➤ **ID efficiency**





	Sample	Back.	σ•B(Z-->ll) (pb)
e	1830	0.6%	$267 \pm 6_{stat} \pm 15_{sys} \pm 16_{lum}$
μ	1631	0.9%	$246 \pm 6_{stat} \pm 12_{sys} \pm 15_{lum}$

W and Z cross sections



R and Γ_W

Measure

Theoretical prediction

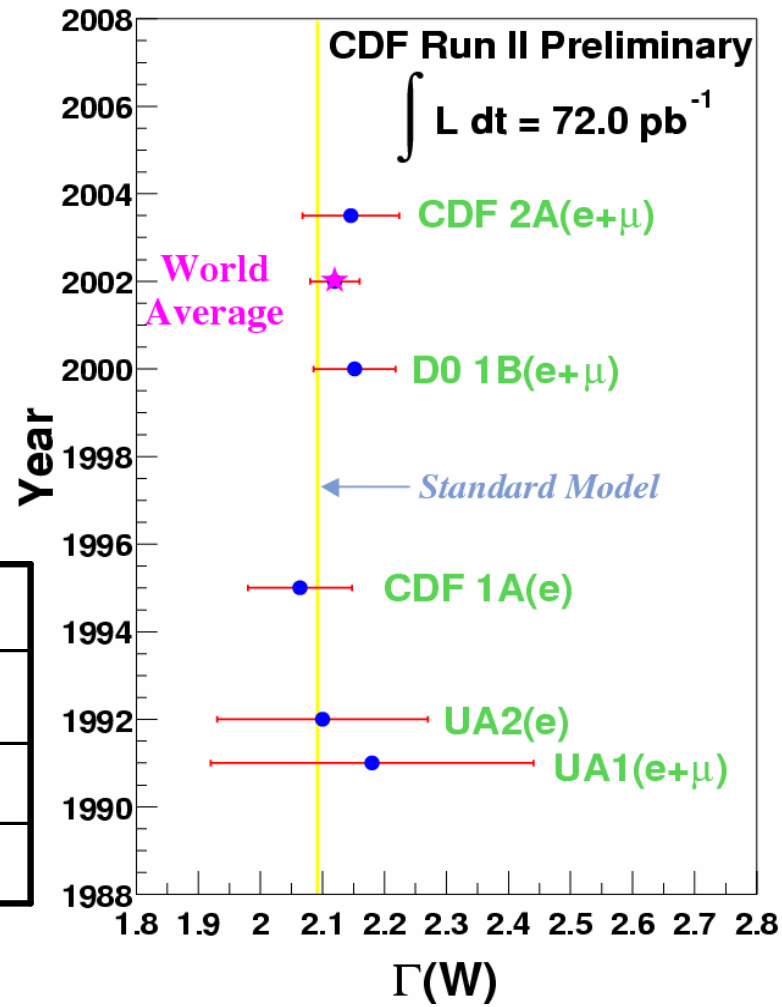
PDG SM

PDG combined Exp

$$R = \frac{s(pp \to W)\, G(W \to en)\, G(Z)}{s(pp \to Z)\, G(W)\, G(Z \to ee)}$$

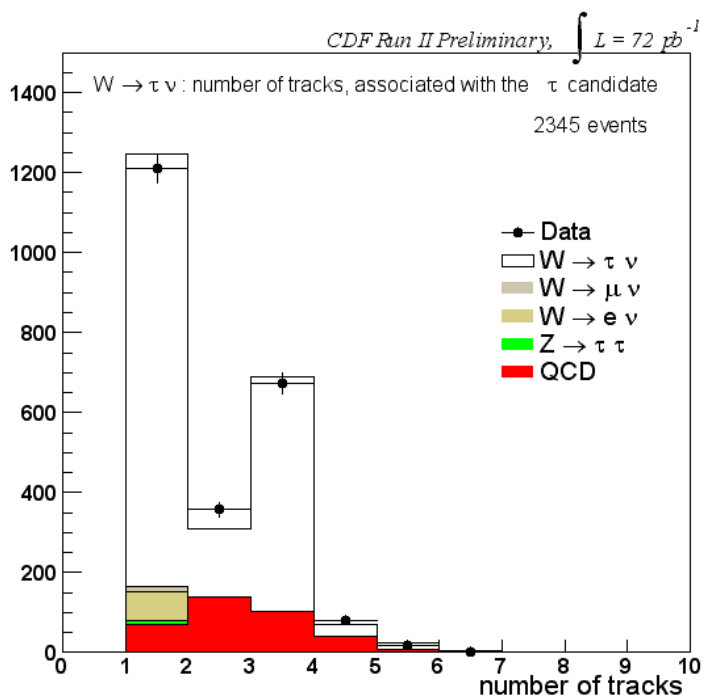
Extract

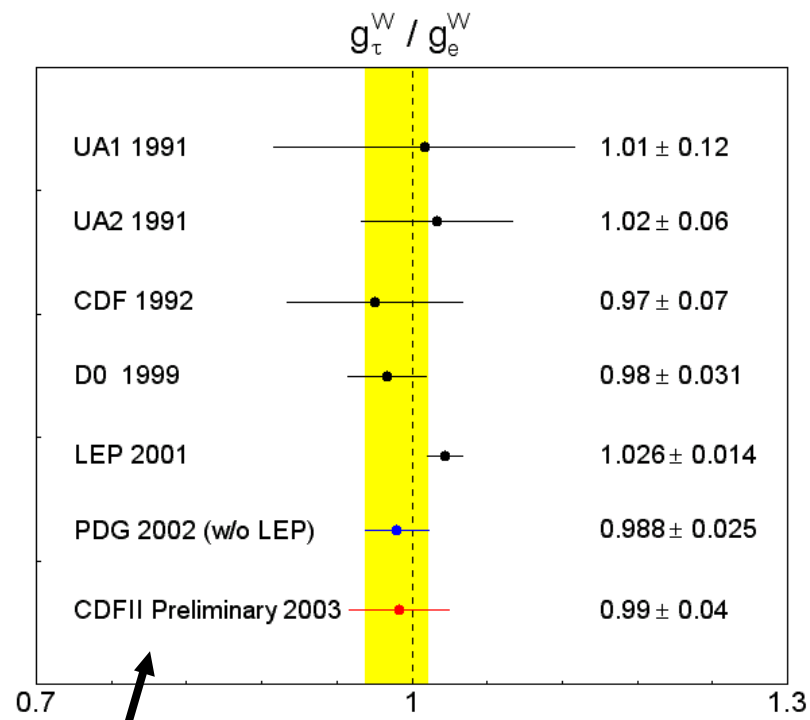
	R		G	
e	±	±	±	±
m	±	±	±	±
e+m	±	±	±	±



W→τν and Lepton Universality

- Clean W→τν decays
- Baseline for analyses using τ's





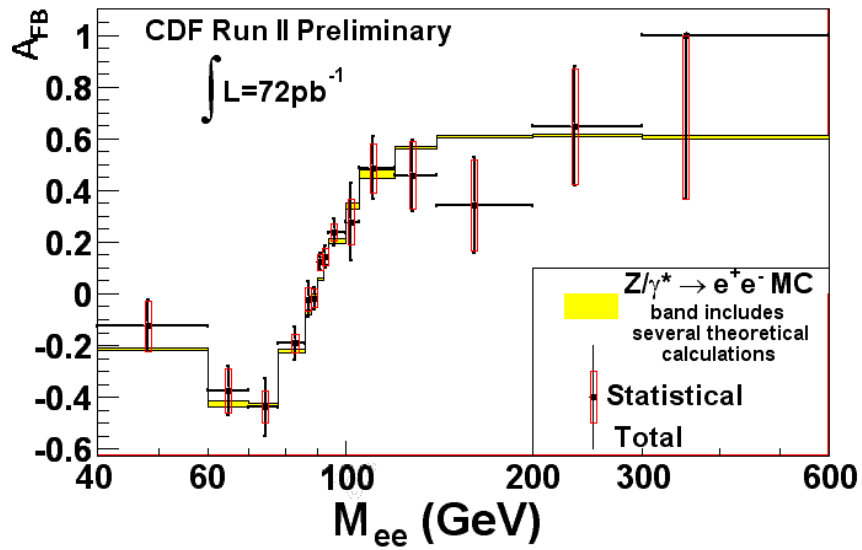
$$\frac{s \cdot BR(W \to tn)}{s \cdot BR(W \to en)} = 0.99 \pm 0.04_{stat} \pm 0.07_{sys}$$

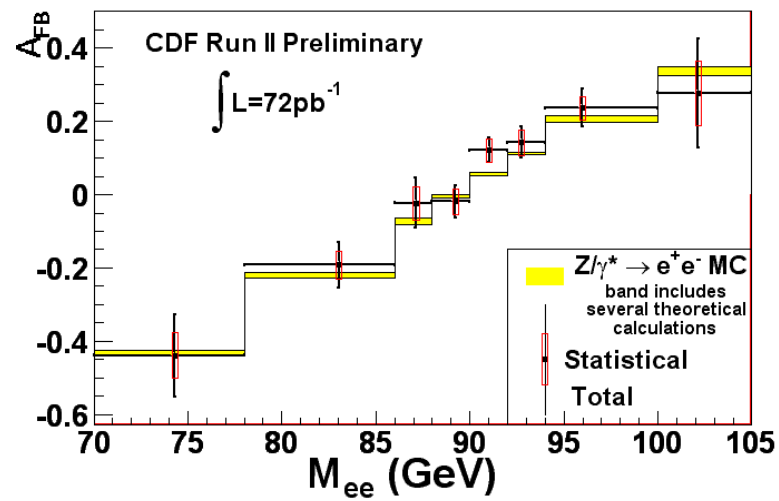
A_{FB} using Dielectrons

- Forward-Backward Asymmetry

$$A_{FB} = \frac{ds\,(\cos q > 0) - ds\,(\cos q < 0)}{ds\,(\cos q > 0) + ds\,(\cos q < 0)}$$

- Exploits forward coverage of electrons
  - **|h|<3**
- Direct probe of γ,Z couplings
  - **Sensitive to interference from new physics**
- High mass reach is unique to Tevatron
- Results consistent with SM



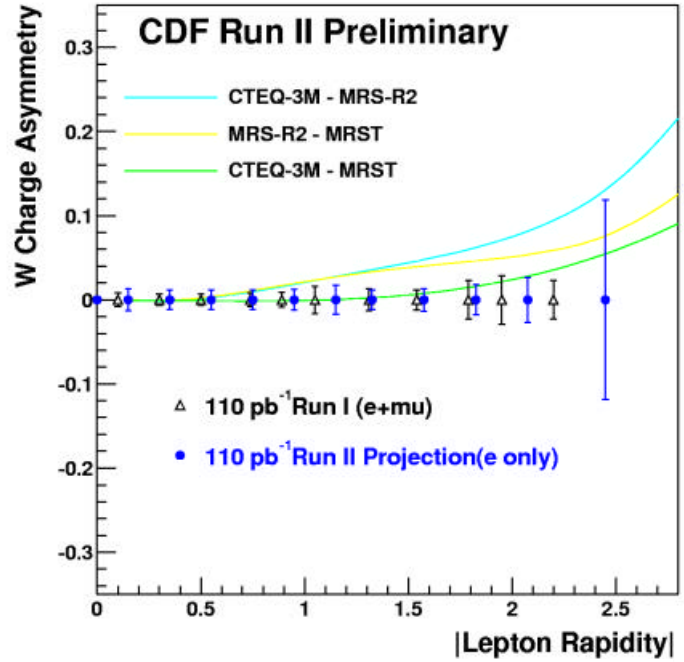


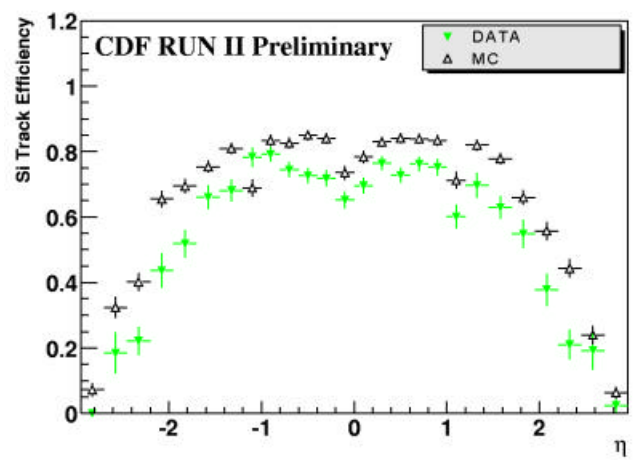
W→eν Charge Asymmetry

- A_l constrains PDF's

$$A_l(h) = \frac{ds(e^+)/dh - ds(e^-)/dh}{ds(e^+)/dh + ds(e^-)/dh}$$

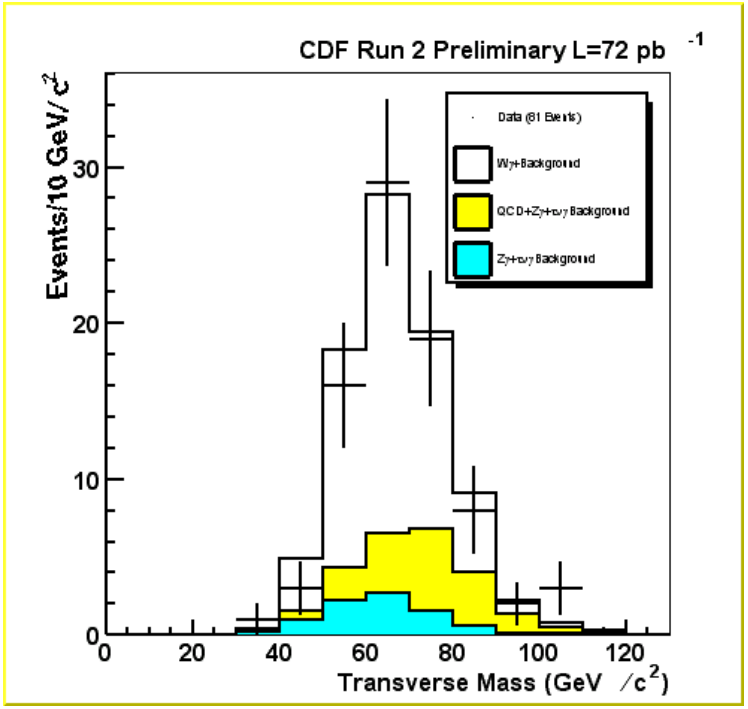
- Charge ID and polar coverage essential
- Uses new Calorimeter seeded Silicon tracking
  - **Consistent tracking: |h|<2**
  - **Improvement on Run I**
- Blind Analysis
  - **Results: Summer**

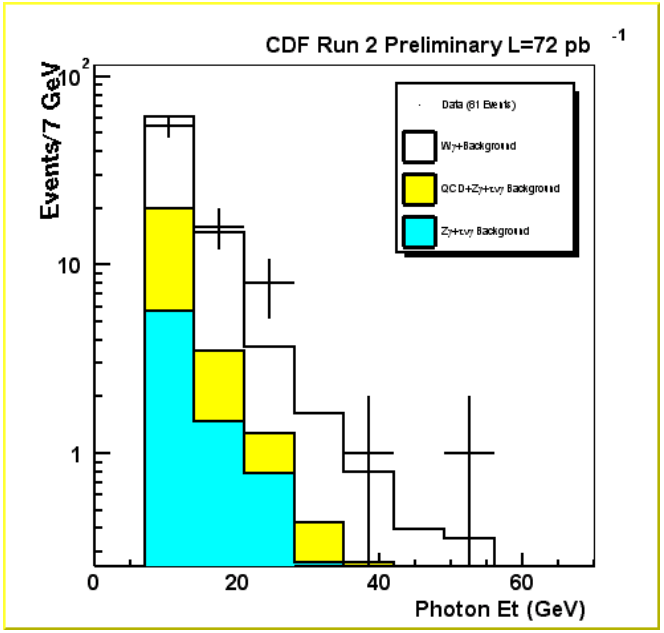




Diboson Couplings:Wγ

- Signature
  - **One high p_T lepton**
  - **One photon (DR(g-l)>0.7)**
  - **$\not{E}_T$**
- Results consistent with SM
  - **SM: s•B(Wg-->lng) = 18.7 ±1.3 pb**

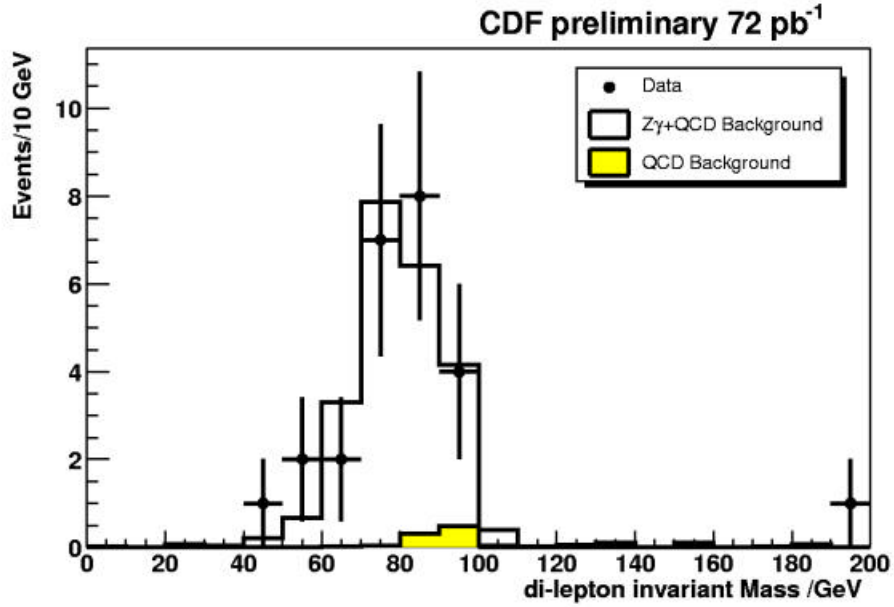


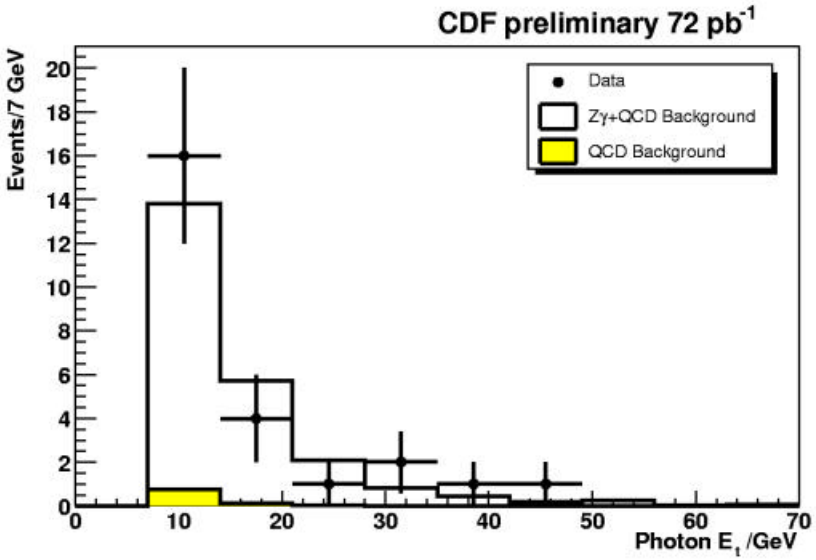


	Sample	Back.	σ•B(Wγ-->lνγ) (pb)
e	43	33%	**17.2**$\pm 3.8_{stat} \pm 2.8_{sys} \pm 1.0_{lum}$
μ	38	29%	**19.8**$\pm 4.5_{stat} \pm 2.4_{sys} \pm 1.2_{lum}$

Diboson Couplings: $Z\gamma$

- Signature
  - **Two high p_T leptons**
  - **One photon ($\Delta R(\gamma\text{-}l)>0.7$)**
- Results consistent with SM
  - **SM: $\sigma \cdot B(Z\gamma \to ll\gamma) = 5.4 \pm 0.4$ pb**

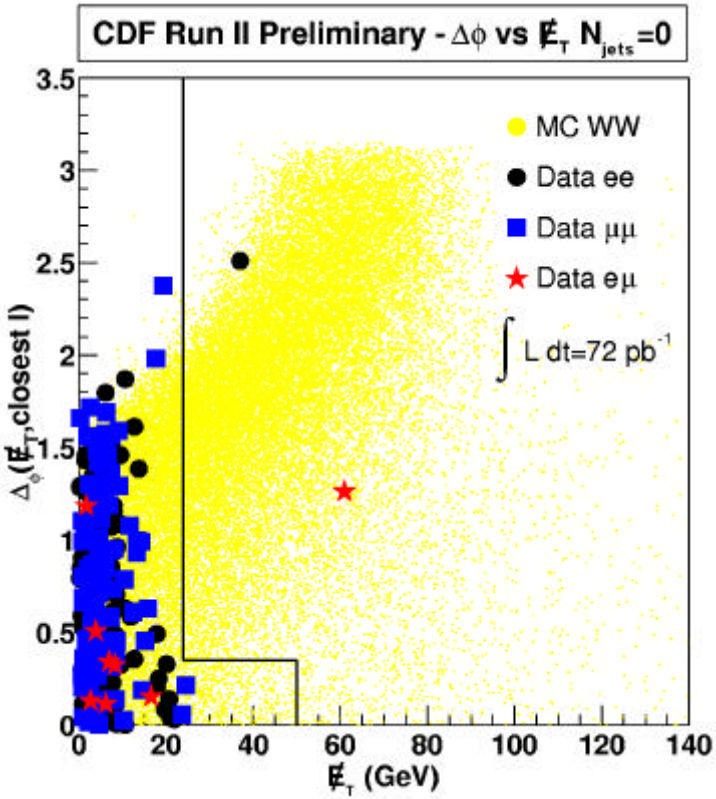




	Sample	Back.	$\sigma \cdot B(Z\gamma \to ll\gamma)$ (pb)
e	11	4.6%	**5.5**$\pm 1.7_{stat} \pm 0.6_{sys} \pm 0.3_{lum}$
μ	14	4.0%	**6.0**$\pm 1.6_{stat} \pm 0.7_{sys} \pm 0.4_{lum}$

Diboson:WW

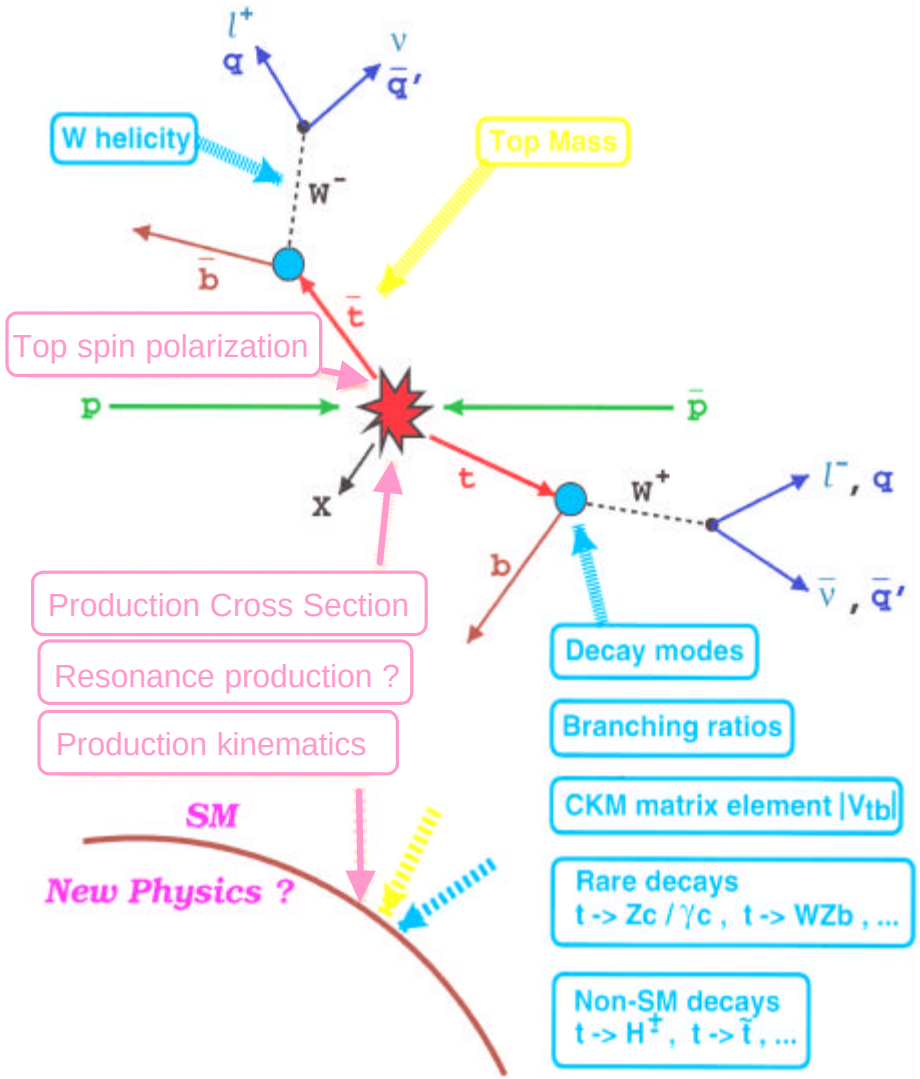
- Search for W W production
  - ➤ **Dilepton + $\not\!\!E_T$ search**
- Consistent with SM
  - ➤ **Wait for more statistics**
- Precursor to SM Higgs Search



		mm	m	
	±	±	±	±
→ νν	±	±	±	±

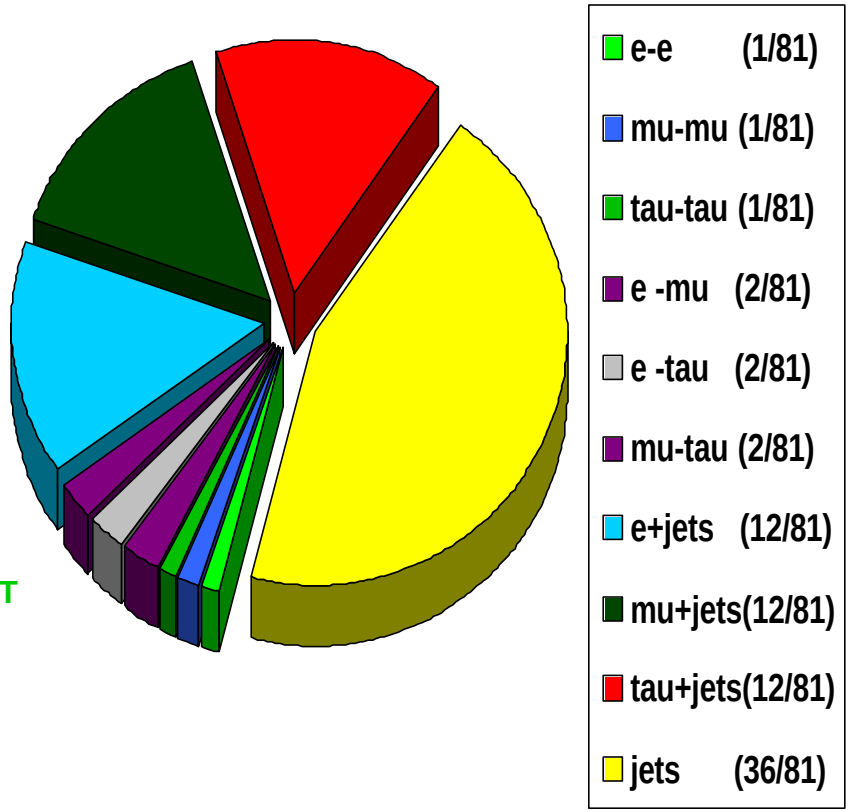
Top Program

- Establish Baseline Measurements from Run I
- Top cross section
  - **Precision test of QCD**
  - **Probe for non-SM Production**
- Top Mass
  - **Preliminary Result**
  - **Getting machinery warmed up!**
- Many precision tests of top to come with more data



Production and Decay of Top

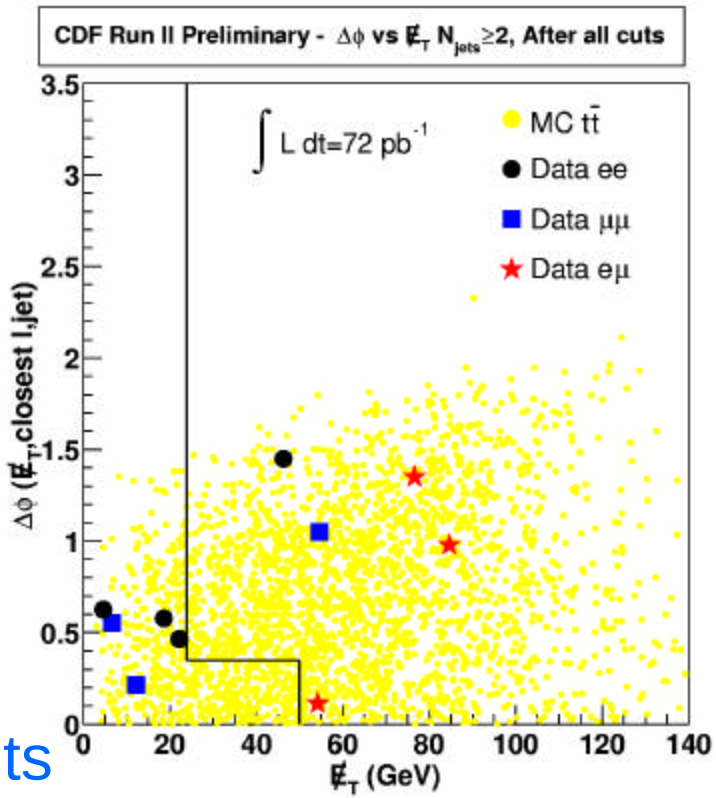
- Top decays as a free quark
  - t_{top} ~ 4×10^{-25}s
  - BR(t->Wb) ~100%
- 3 classes of signals
  - Dilepton
    - 2 high-p_T leptons, 2 b jets, $\not{E}_T$
    - BR ~ 1/9 (e,m : ~5%)
  - Lepton + Jets
    - 1 high-p_T lepton, 4 jets (2 b's), $\not{E}_T$
    - BR ~ 4/9 (e,m: ~30%)
  - All-hadronic:
    - 6 jets (2 b's)



$$s_{t\bar{t}}(\sqrt{s}=1.96\,\mathrm{TeV})\approx1.30\times s_{t\bar{t}}(\sqrt{s}=1.8\,\mathrm{TeV})$$

Dilepton Cross Section

- Signature
  - Two high p_T Isolated leptons
  - Veto Z, cosmic, conversion
  - DF($\not{E}_T$,l/j)>20º, or $\not{E}_T$>50 GeV
  - $\not{E}_T$ > 25
  - Two jets with E_T>10 GeV
  - Total transverse energy > 200 GeV
- Expect S/B ~ 9, S~2.5
- Find 5 candidate events in 72 pb^{-1}
- Expect 0.3 ± 0.12 background events

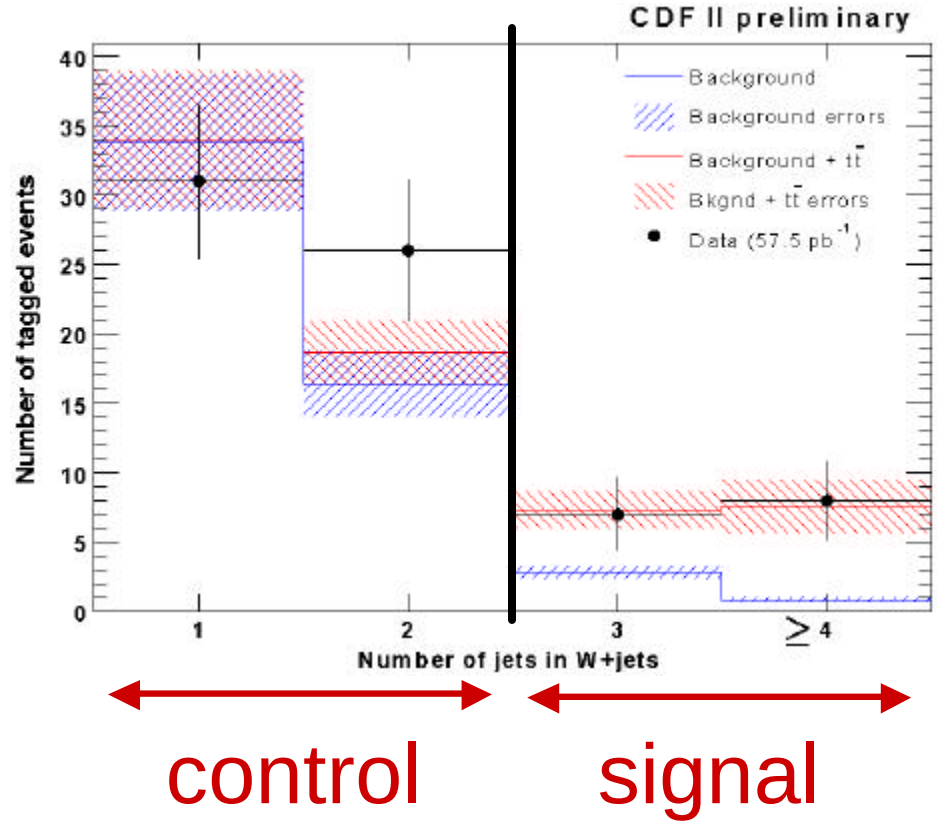


$$\sigma_{tt}=13.2 \pm 5.0_{stat} \pm 1.5_{sys} pb$$

NLO:$\sigma_{tt}(\sqrt{s}=1.96\ TeV)=6.70^{+0.71}_{-0.88}$ pb
(hep-ph/0303085(ML Mangano et al))

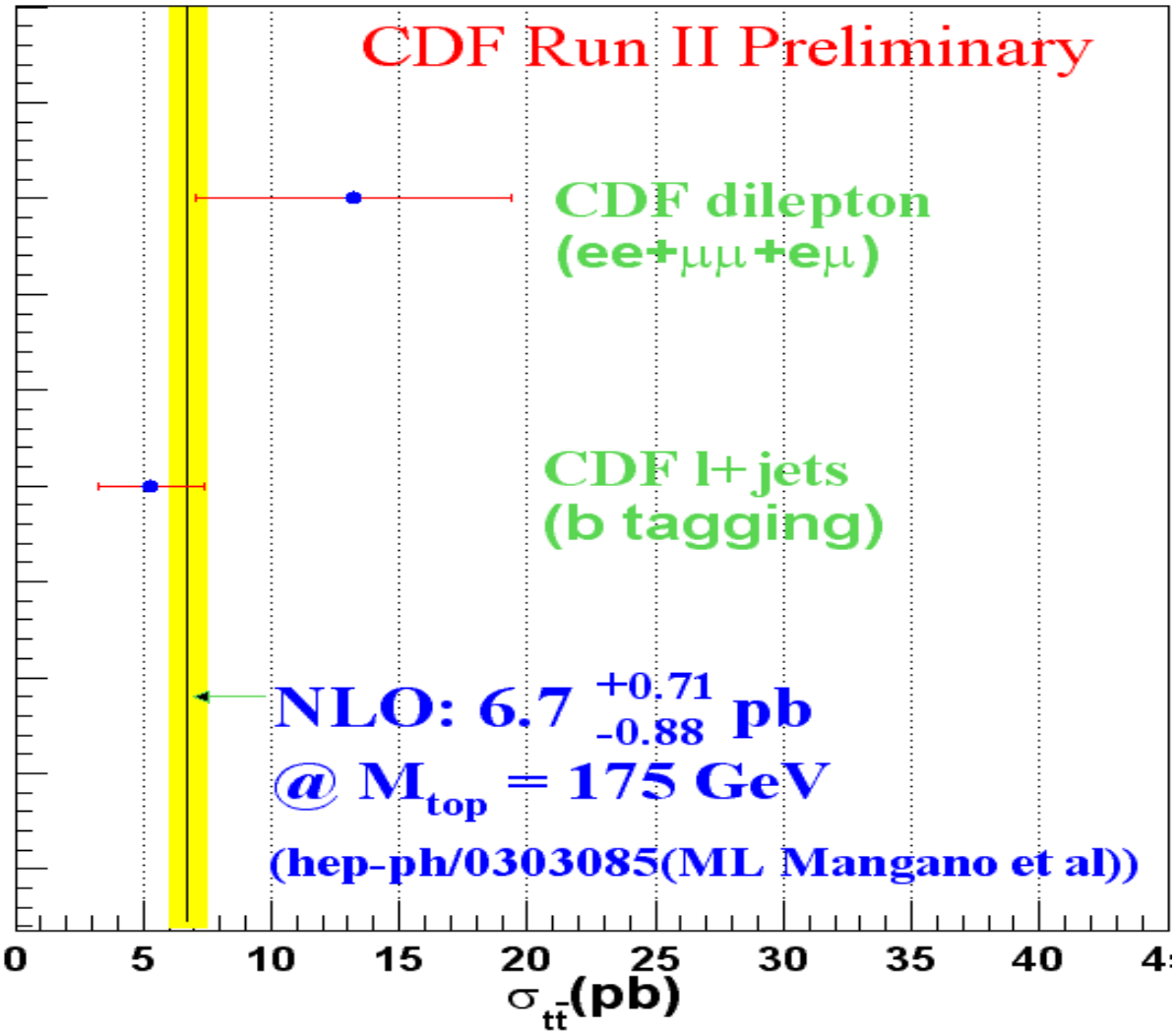
Lepton + jet Cross Section

- Signature
  - **One high p_T Isolated lepton**
  - **Veto Z, cosmic, conversion**
  - **$\not{E}_T$ > 20 GeV**
  - **3 or more jets with E_T>15 GeV**
  - **1 jet with secondary vertex tag**
- B tag improves S/B 1/6 →3/1
- Find 15 candidate events in 57.5 pb^{-1}
- Expect 3.8 ± 0.5 background events



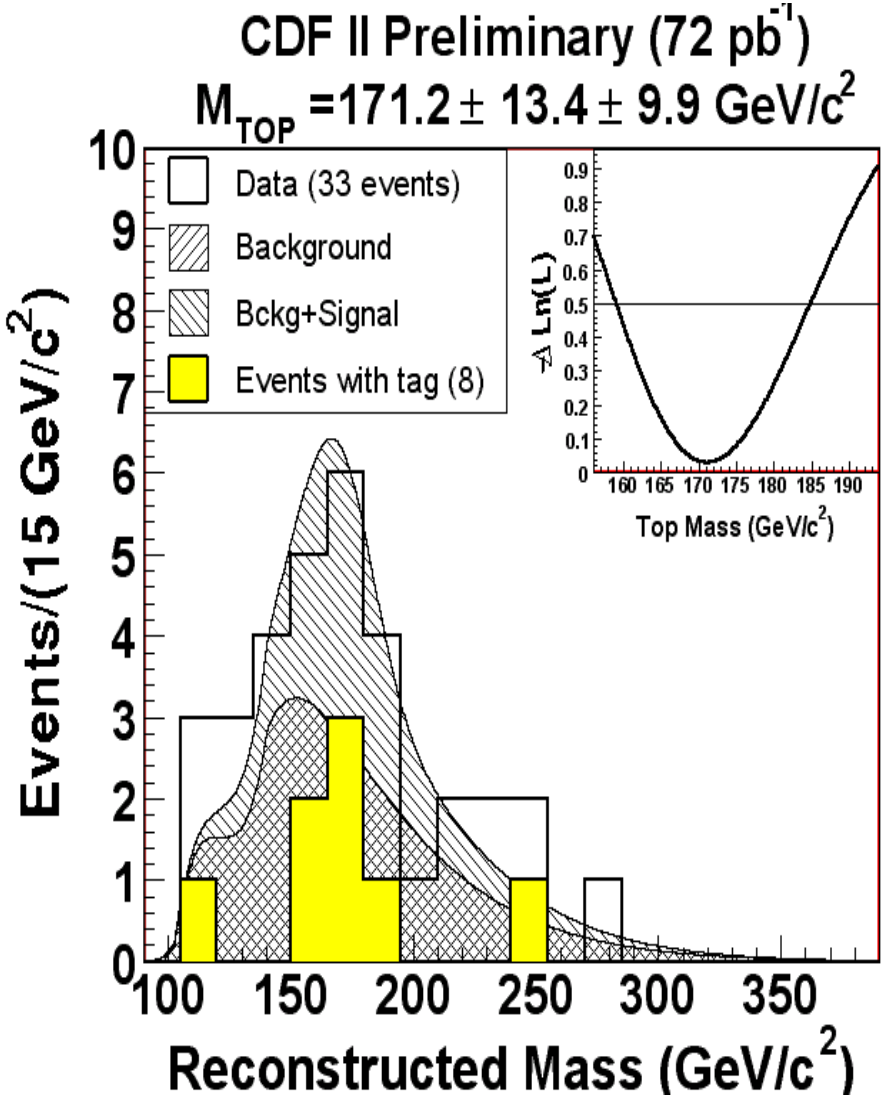
$$\sigma_{tt}=5.3 \pm 1.9_{stat} \pm 0.8_{sys} pb$$

Top production cross sections



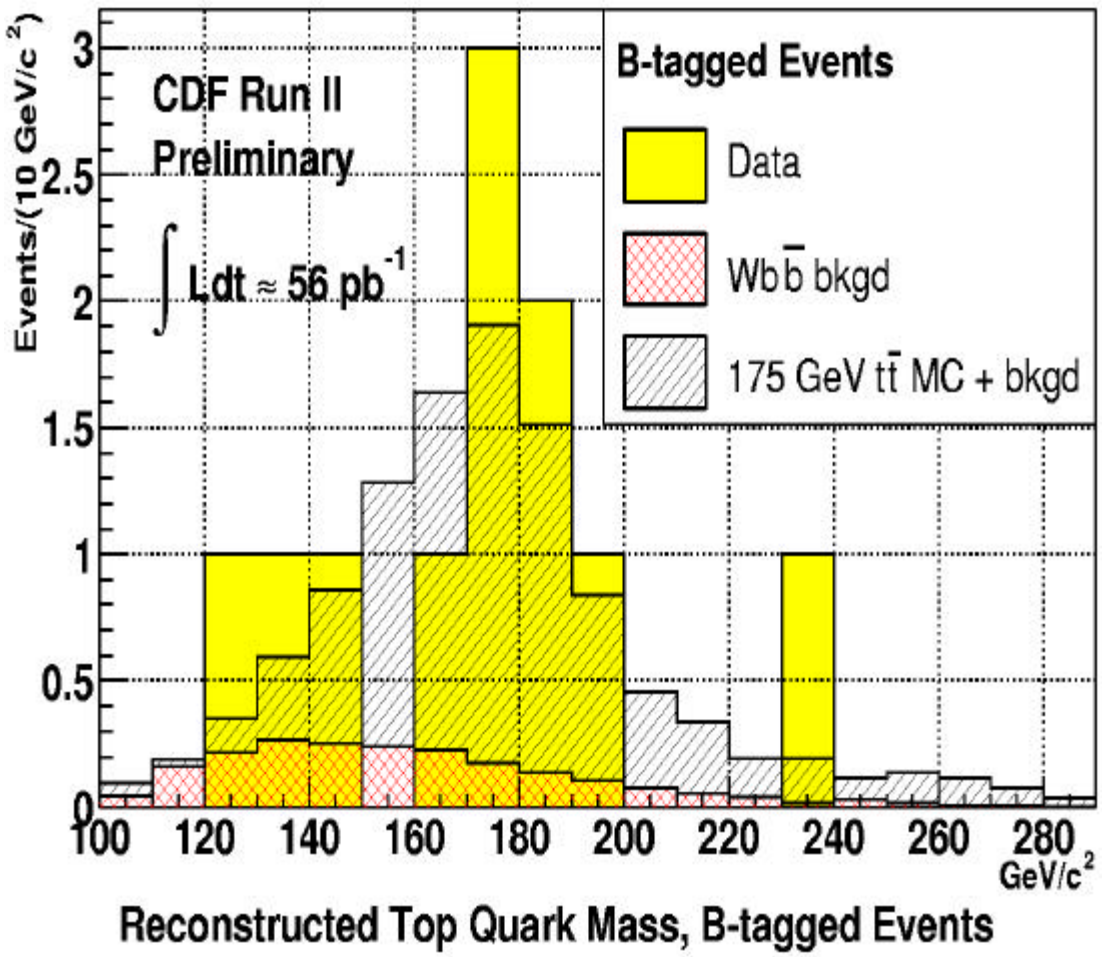
Top Mass

- Select l +4 jet events
  - **Same as cross section, but no b tags**
- 33 candidate events
- Method
  - **24 combinations in an event**
  - **2-C fit applied, lowest c^2 is chosen to get mass for each event**
  - **A continuous likelihood method is used with parameterized mass templates**
  - **M_{top} is the minimum of log-likelihood distribution**
- Systematic uncertainty to improve with understanding of detector



Top mass with b tag

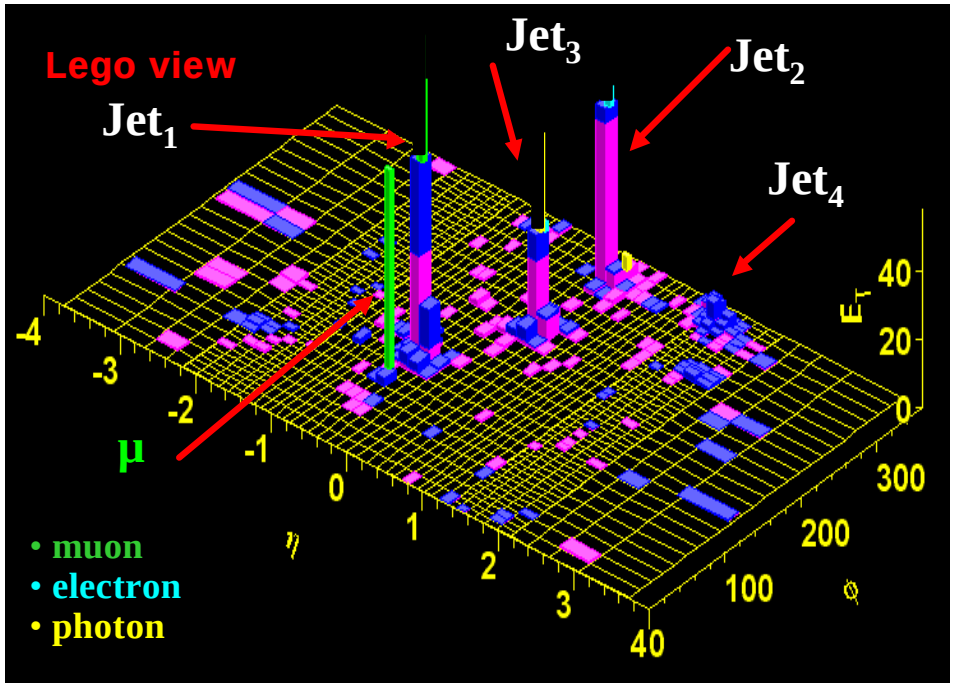
- B tag
  - Lower backgrounds
  - Improves mass resolution
- Same selection
  - Relaxed 4th jet requirement
  - 11 candidates
- Work in Progress
  - Results by Summer

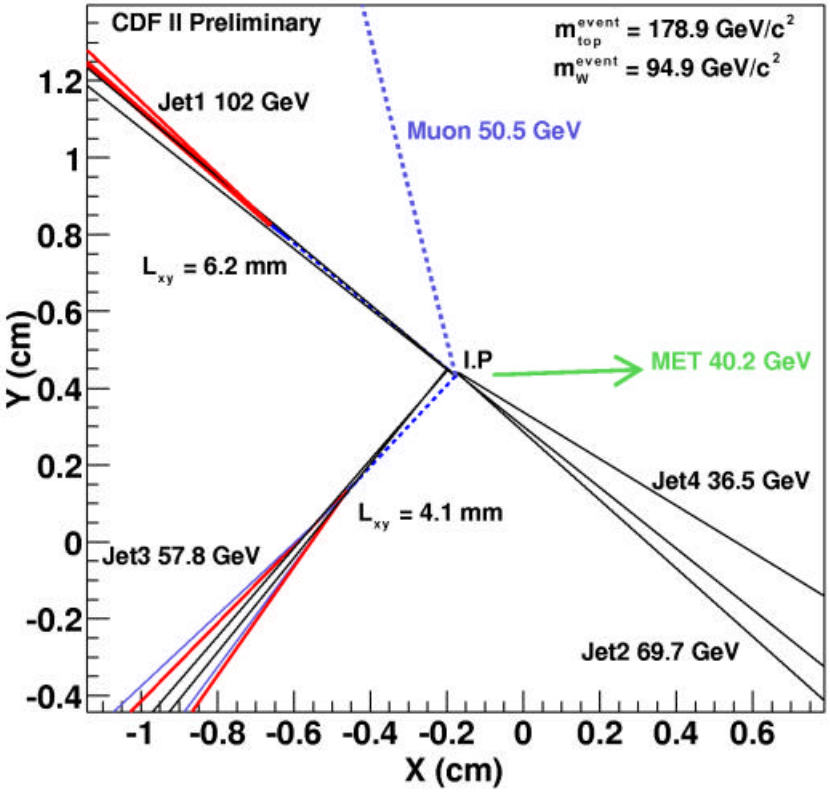


Lepton + Jets Candidate Events

tt l + jet candidate:
Nov 02 2002 run: 153693 event: 799494
μ (CMUP) + 4 jets

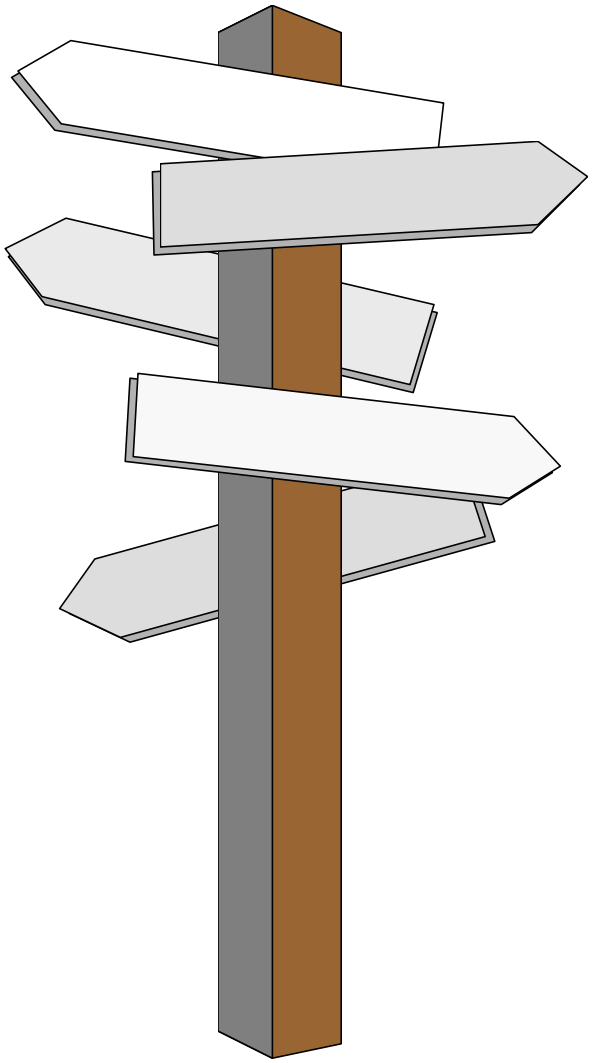
$p_T(m)$ = 54.4 GeV
E_T^j = 96.7, 65,8, 54.8, 33.8 GeV
$\not{E}_T$ = 40.8 GeV





New Physics??

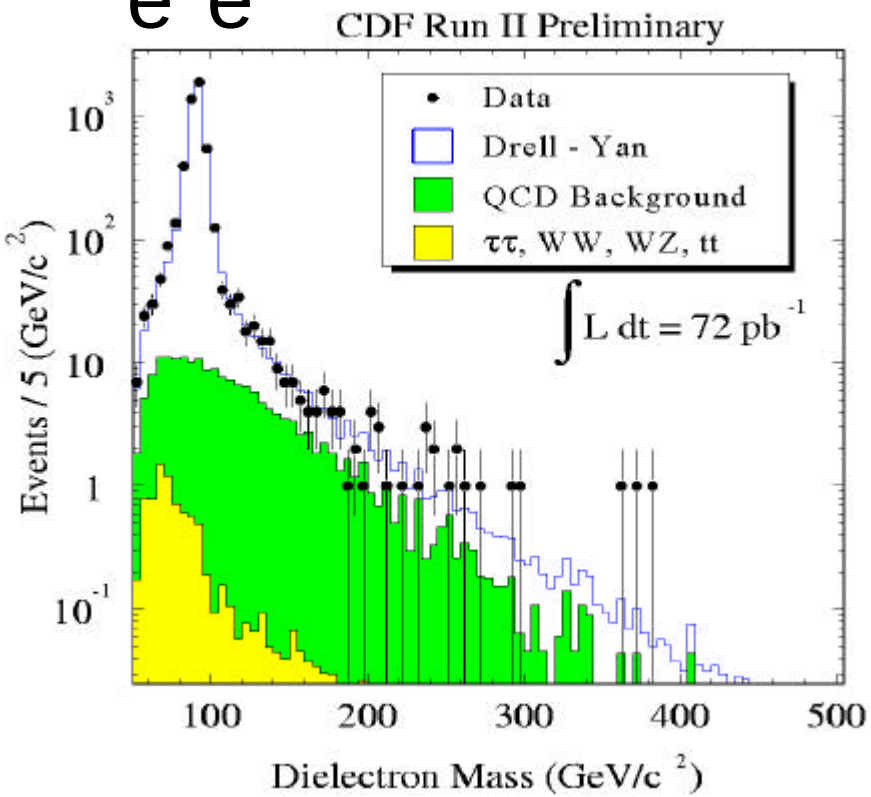
- Where to look?
- Two Approaches at CDF
- Model driven searches
  - **Drell-Yan spectrum search**
  - **Leptoquarks**
  - **Doubly charged Higgs**
  - **SUSY**
- Signature driven searches
  - **Dijet spectrum**
  - **CHArged Massive Particles**
  - **Photon final states**



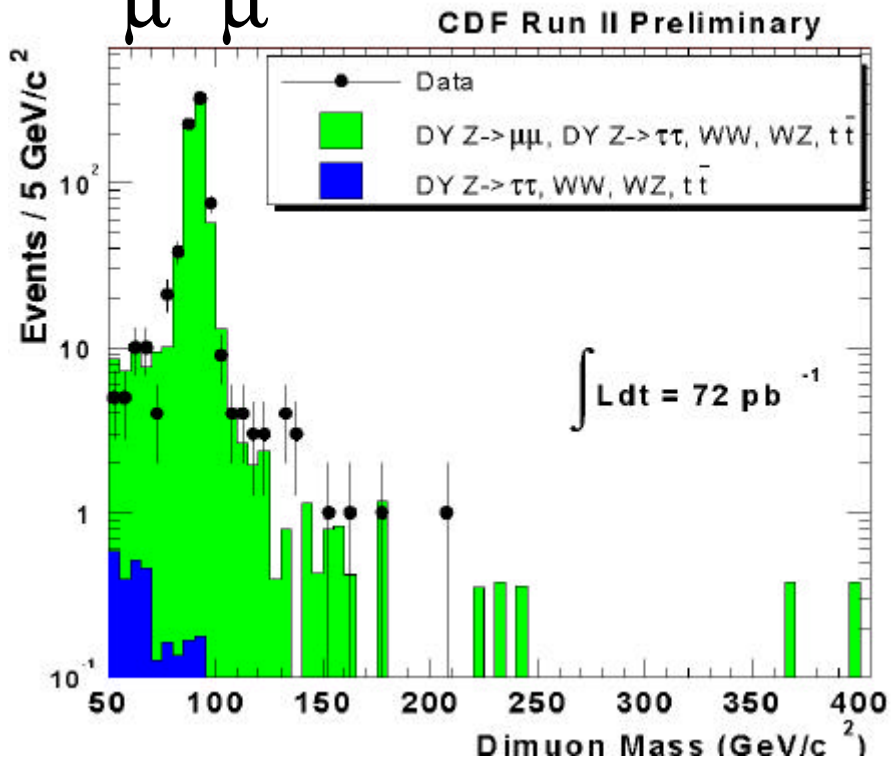
Search in Drell-Yan Spectrum

- High Mass Dileptons
  - electrons & muons used
- Sensitive to Z' and Randall-Sundrum Graviton
- No excess observed

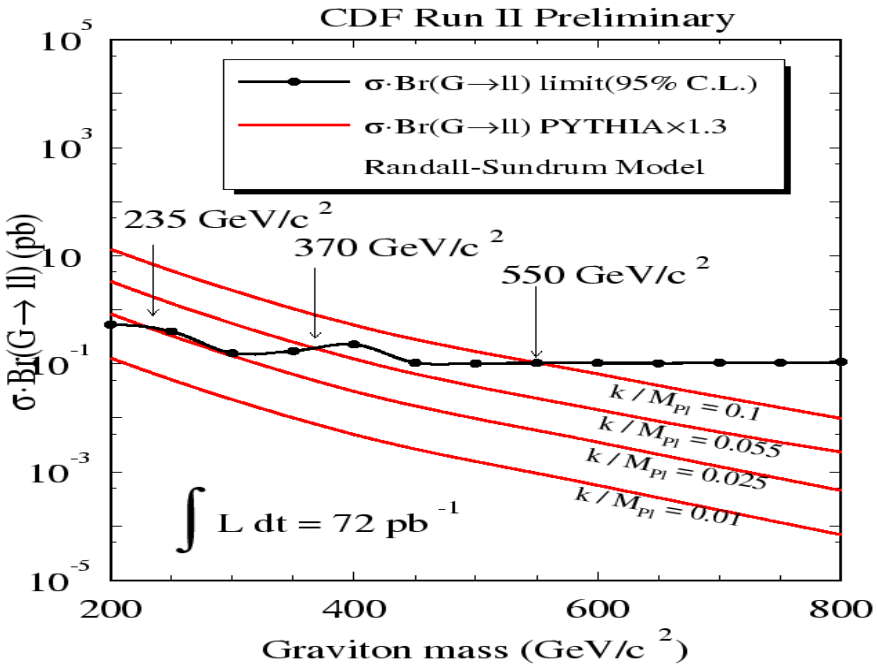
e^+e^-

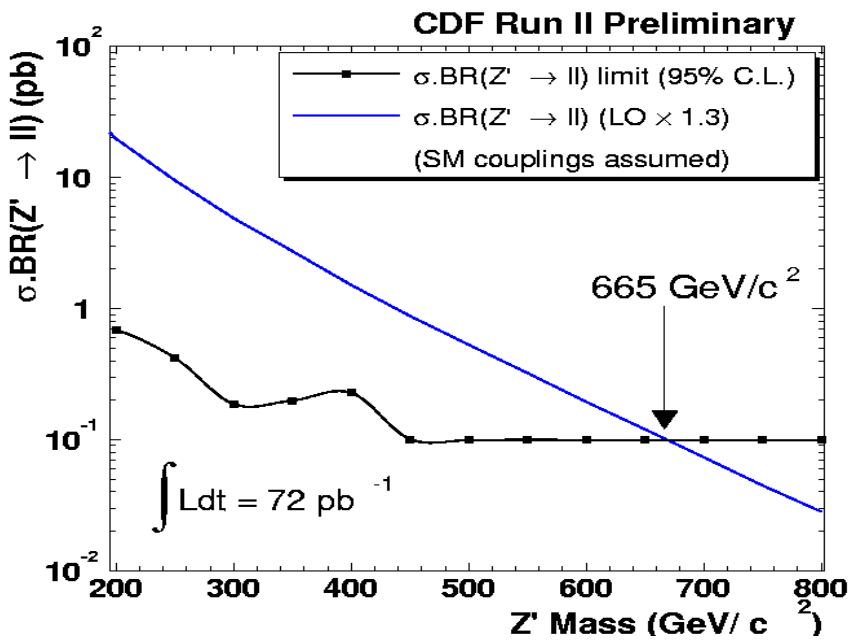


$\mu^+\mu^-$



Search in Drell-Yan Spectrum





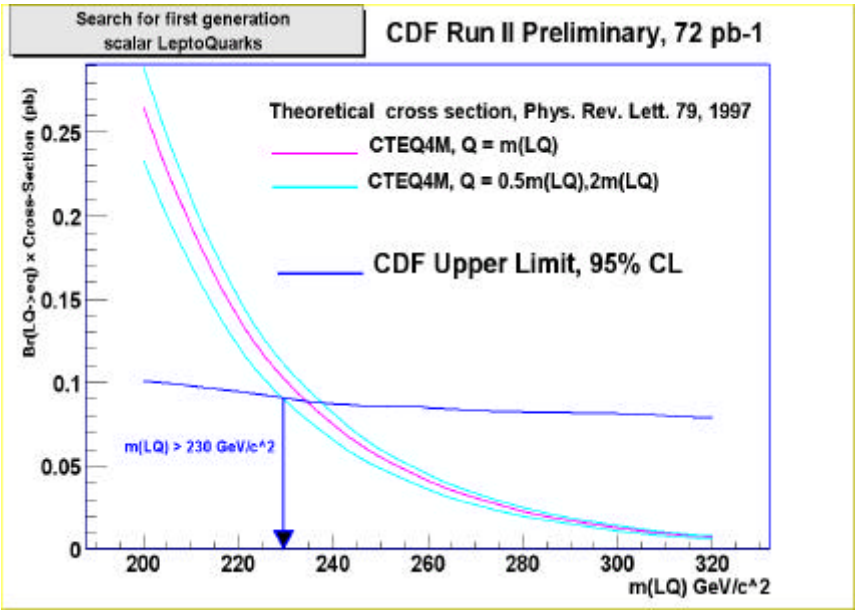
Already Improving on Run I!! →

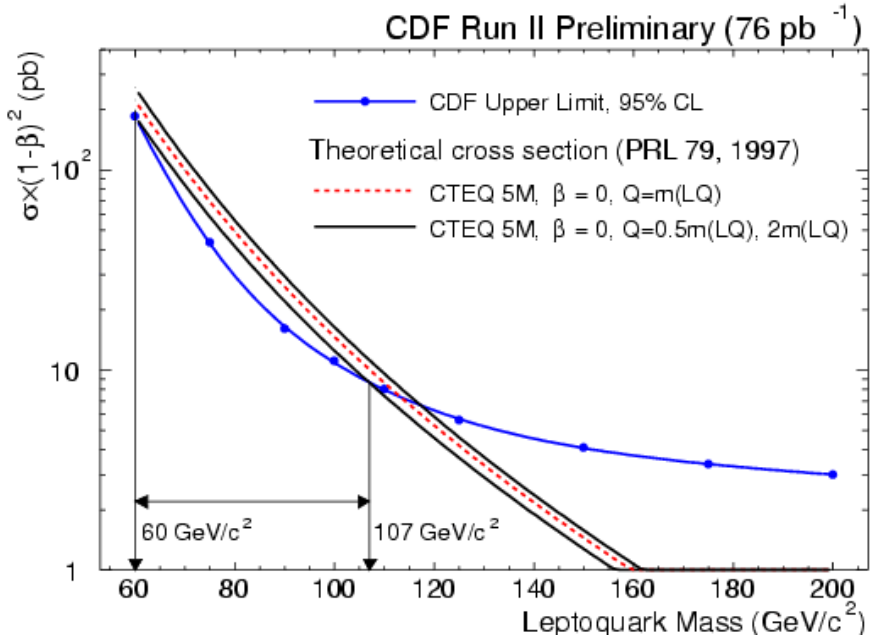
Run	Lum.(pb^{-1})	Mass Limit (95% CL) (GeV/c^2)
Run1a (1.8TeV)	19.7	505
Run1b (1.8TeV)	90	640
Run2(1.96TeV)	**72**	**665**

1st Generation Scalar LeptoQuarks

- LQLQ → e^+e^-qq
  - ➤ **2 high E_T electrons, 2 jets**
- 0 events observed
  - ➤ **Background: 3.4±3 events**
- M(LQ)>230GeV/c^2 (R1:>220)

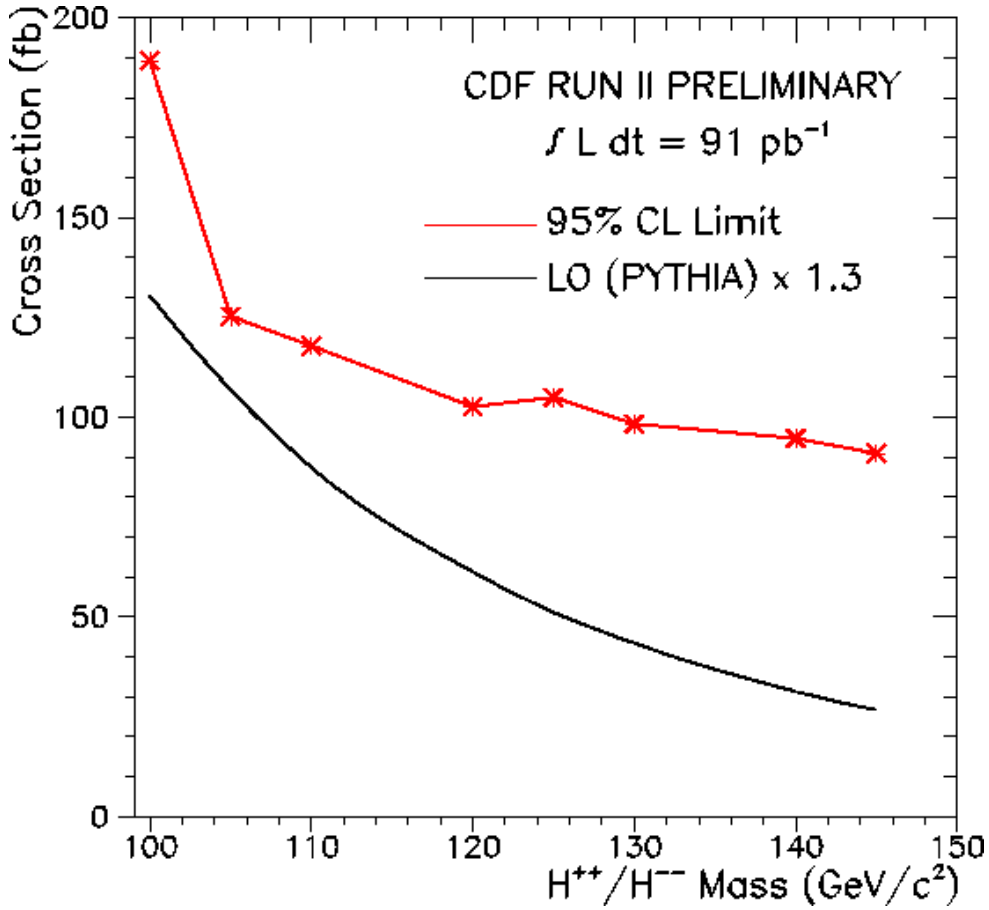
- LQLQ →$\nu\nu qq$
  - ➤ **2 high E_T jets, large $\not{E}_T$**
- 42 events observed
  - ➤ **Background: 43±11 events**
- 60<M(LQ)<107GeV excl.





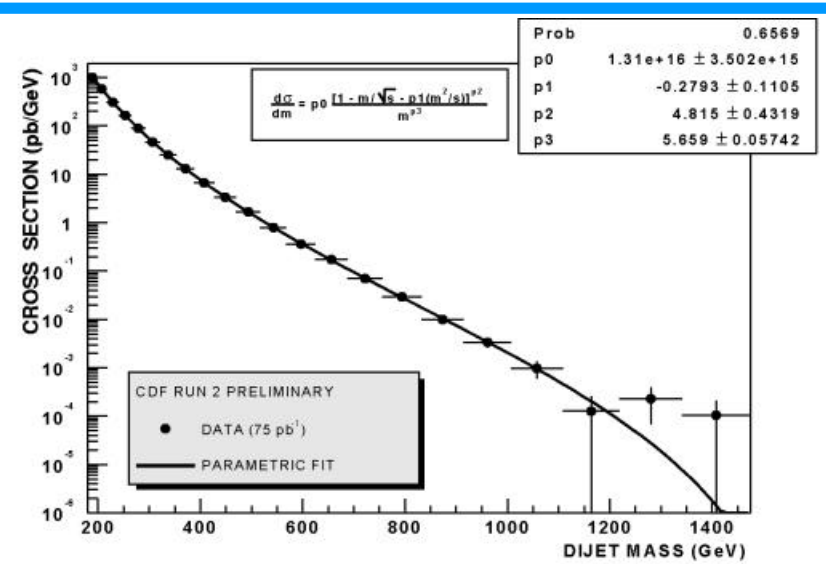
H^{++} Search

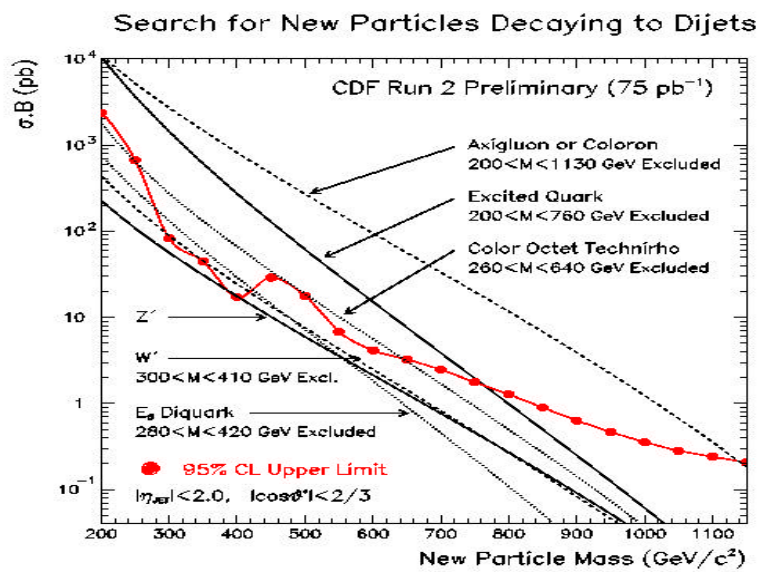
- Arises in extensions of SM (L-R symmetric)
- Same sign leptons
  - **Low backgrounds**
  - **Study with less integrated luminosity**
- Dielectron channel
  - **Signal above Z pole**
  - **Low mass used as control**
    - 0 events observed
    - Background: 0.6±0.5
- Binned Search: 0 events



DiJet Search

- **Consistent with SM**
- **Set limits on New Physics**
- **Axigluons or flavor universal colorons:**
  - **200 < m < 1130 GeV/c^2**
- **Excited quarks:**
  - **200 < m < 760 GeV/c^2**
- **Color octet techni-r's:**
  - **260 < m < 640 GeV/c^2**
- **E6 diquarks:**
  - **280 < m < 420 GeV/c^2**
- **W' :**
  - **300 < m < 410 GeV/c^2**





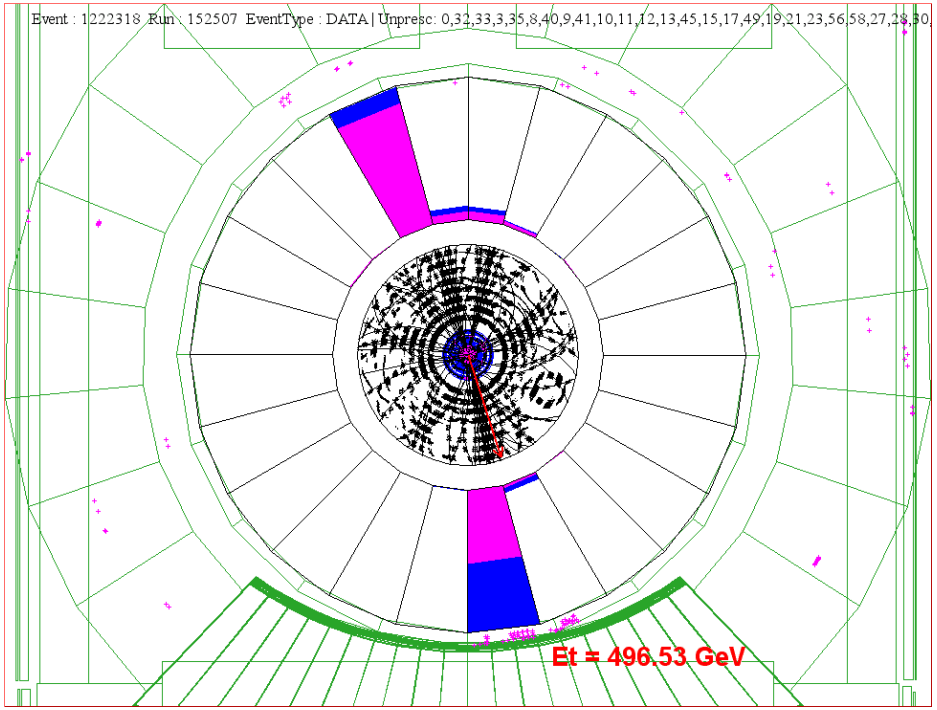
Highest Dijet mass event

Run 152507 event 1222318

Dijet Mass = 1364 GeV (corr)

cos θ* = 0.30

z vertex = -25 cm

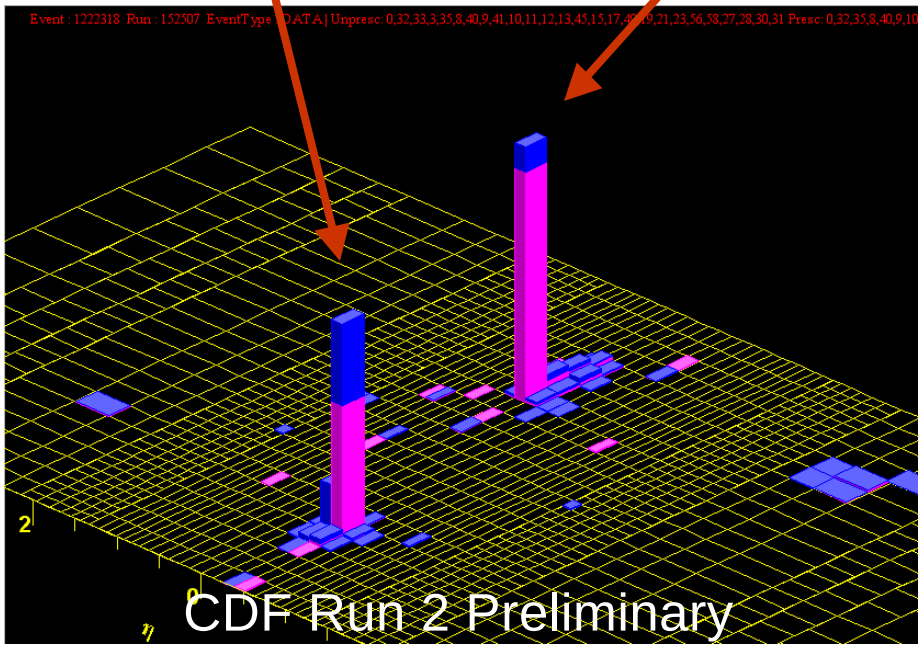


J2 E_T = 633 GeV (corr)
546 GeV (raw)

J2 η = -0.30 (detector)
= -0.19 (correct z)

J1 E_T = 666 GeV (corr)
583 GeV (raw)

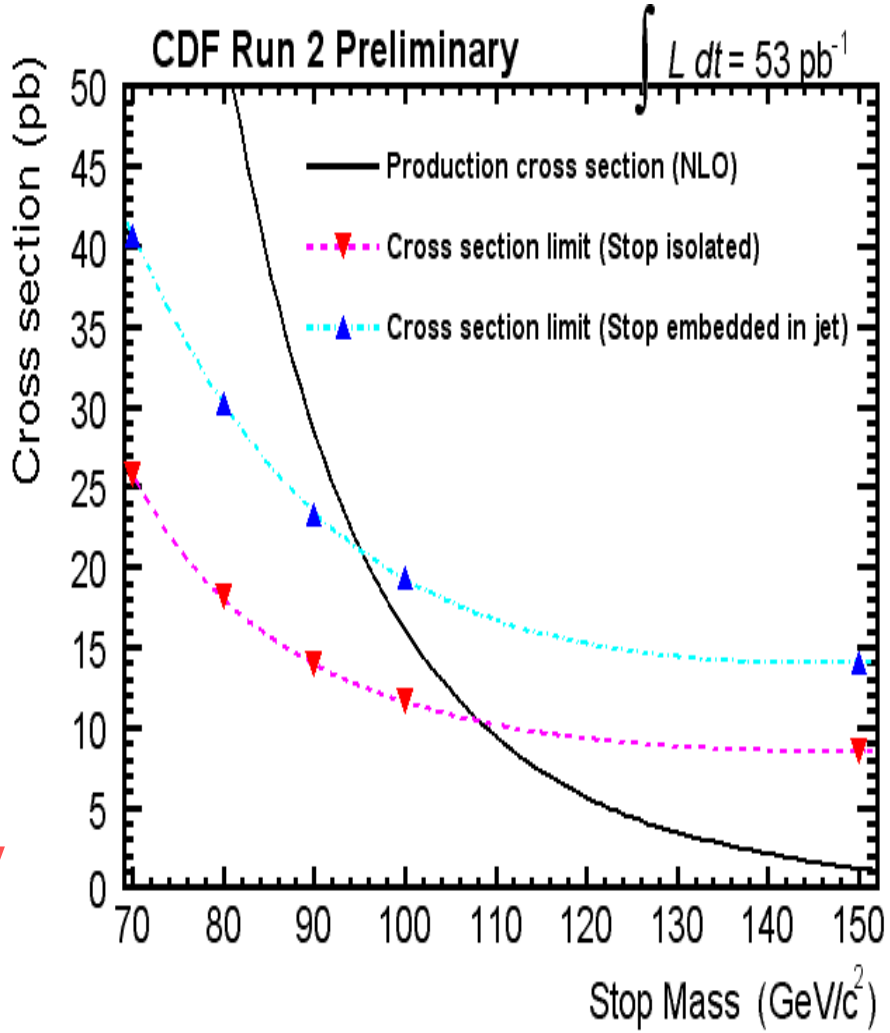
J1 η = 0.31 (detector)
= 0.43 (correct z)



Run I max: 1040 GeV

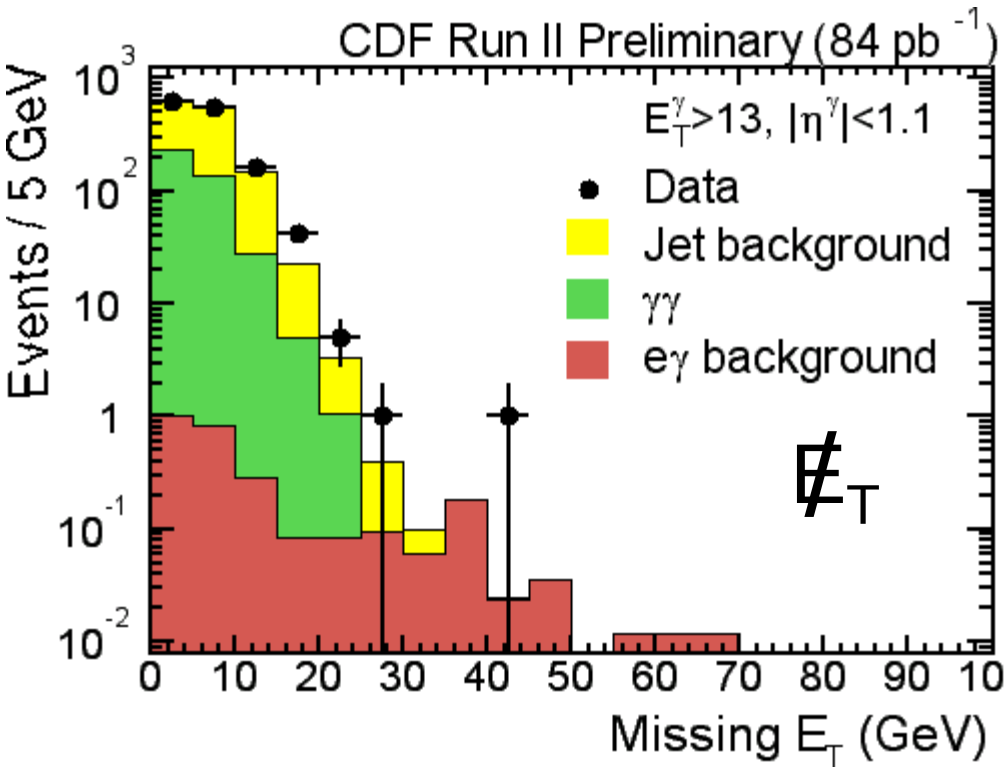
CHArged Massive ParticleS

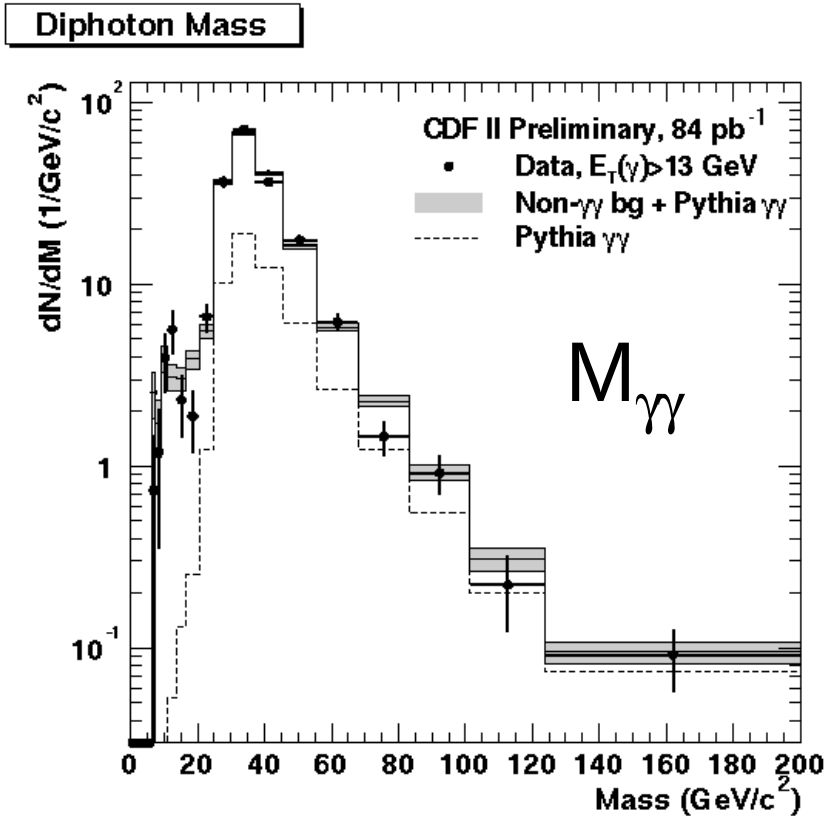
- Stable charged particle that escapes detector
- Massive → Slow moving
  - **Use TOF detector**
- 7 events observed
  - **Background: 2.9±3.2 events**
- Candidate: stop
  - **NLSP in GMSB**
- Isolated: M(stop) > 108 GeV
  - **non-isolated M(stop) > 95 GeV**
  - **LEP: M(stop)>95 GeV**



DiPhoton Search

- 2 central photons E_T>13 GeV
- Cosmic and beam halo rejection
- Good agreement with SM
- 0 Diphoton + Lepton Events observed



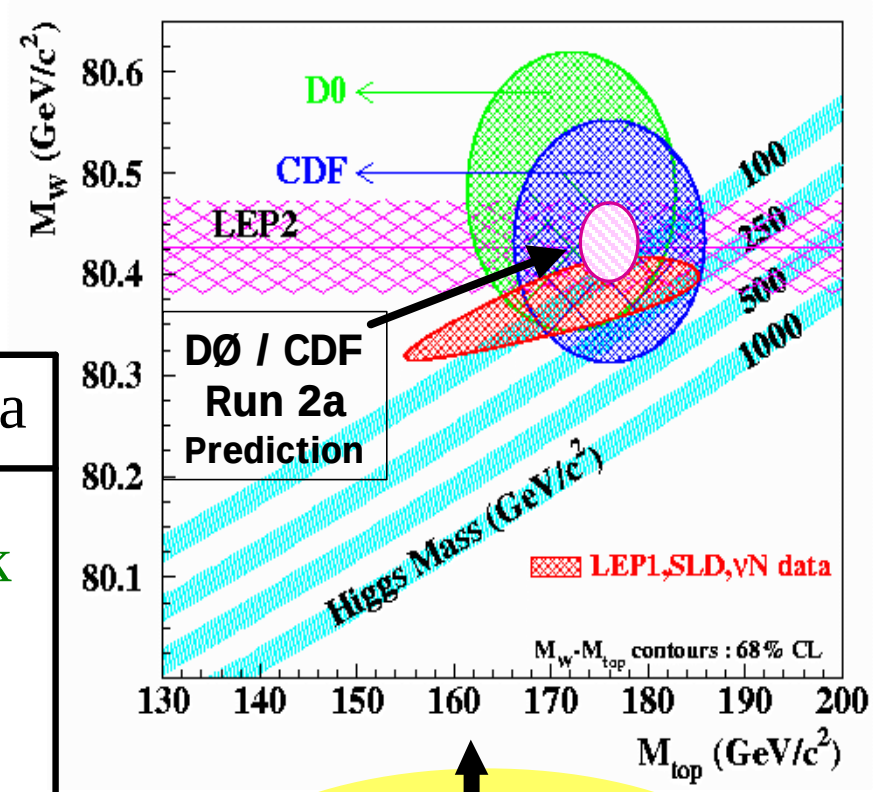


Run Iia Prospects

- Towards the next few years:

Event yields per experiment (2 fb^{-1})

Sample	Run I	Run IIa
$W \rightarrow l\nu$	77k	2300k
$Z \rightarrow ll$	10k	202k
WV ($W \rightarrow l\nu$, V=W,γ,Z)	90	1800
ZV ($Z \rightarrow ll$, V=W,γ,Z)	30	500
tt (mass sample, ≥1 b-tag)	20	800



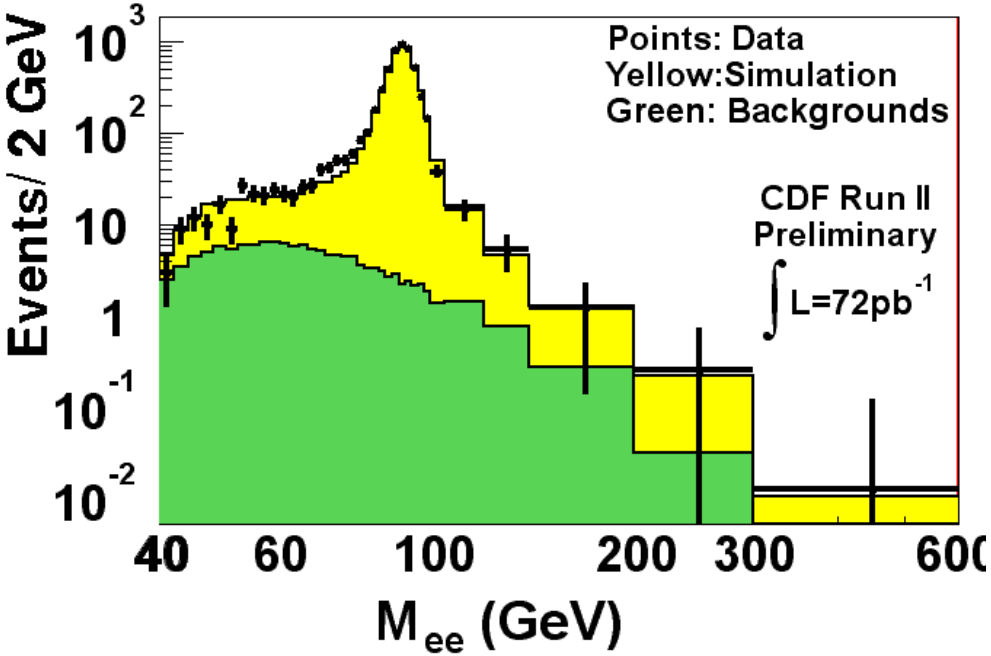
$\delta M_W \sim 40$ MeV
$\delta M_t \sim 3$ GeV

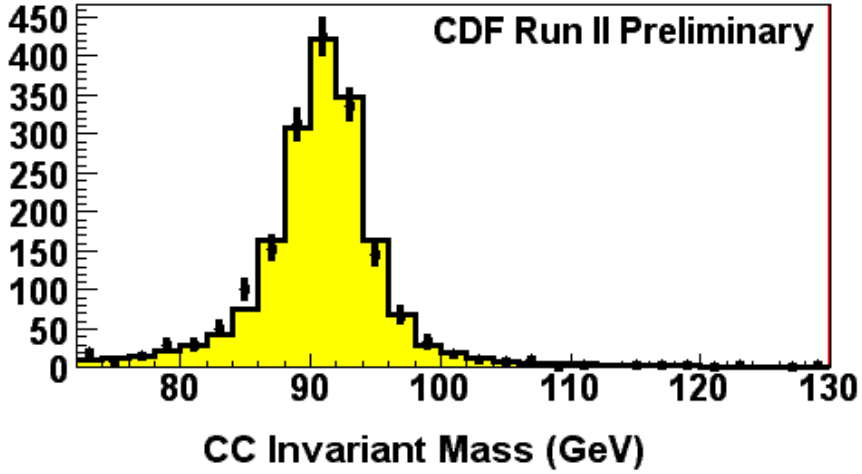
Summary

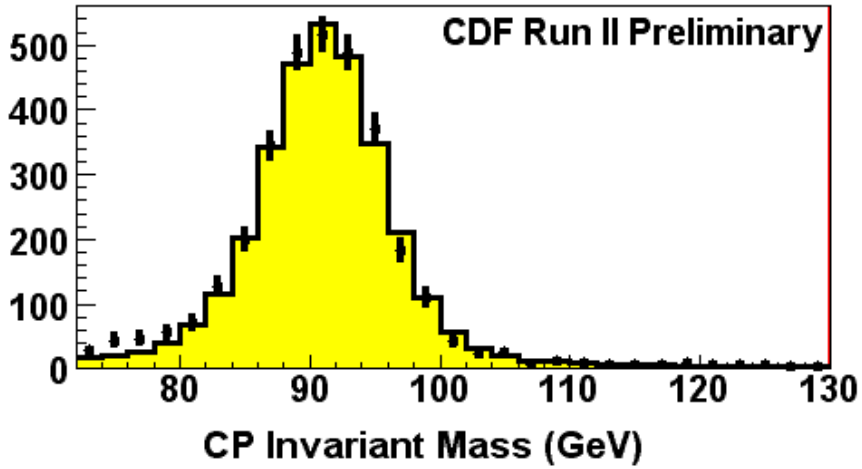
- Run 2a is well underway!
  - **Re-established baseline electroweak measurements**
  - **Top program has been launched!**
  - **Many exotics measurements improve on Run I results!**
- We look forward to larger datasets and testing the Standard Model to even greater precision

Backup Slides

A_{FB} backup


Points: Data
Yellow:Simulation
Green: Backgrounds
CDF Run II
Preliminary
∫L=72pb-1
Events/ 2 GeV
Mee (GeV)


CDF Run II Preliminary
CC Invariant Mass (GeV)


CDF Run II Preliminary
CP Invariant Mass (GeV)

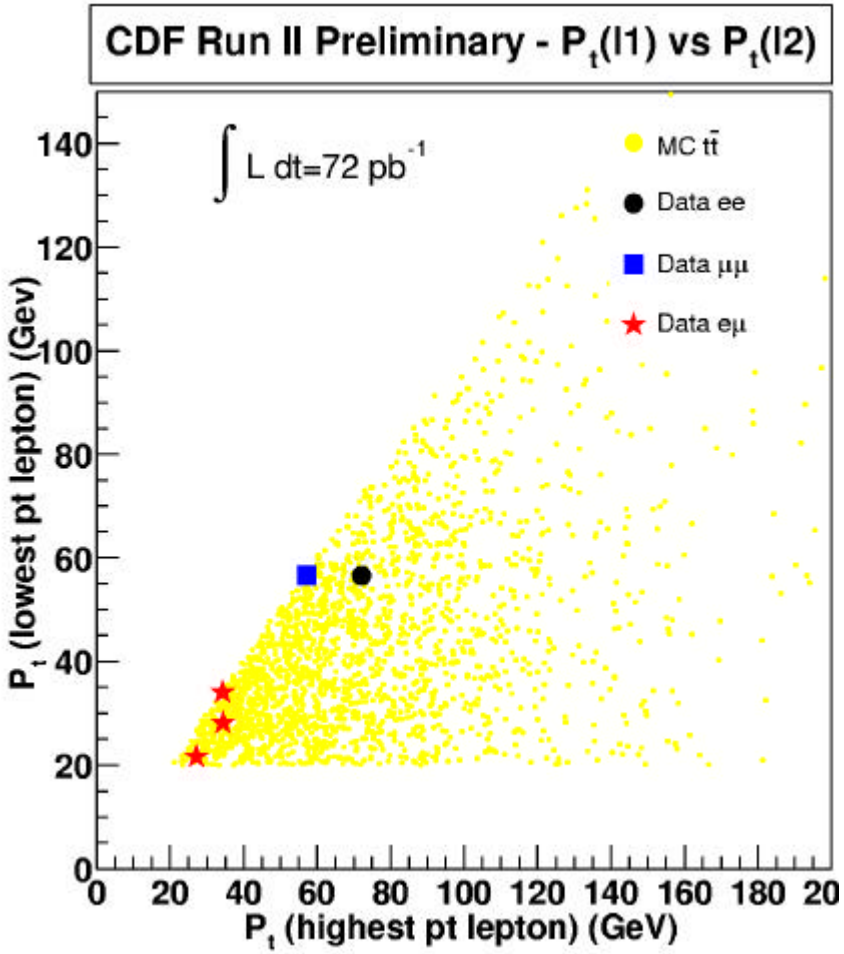
WW cross section backup

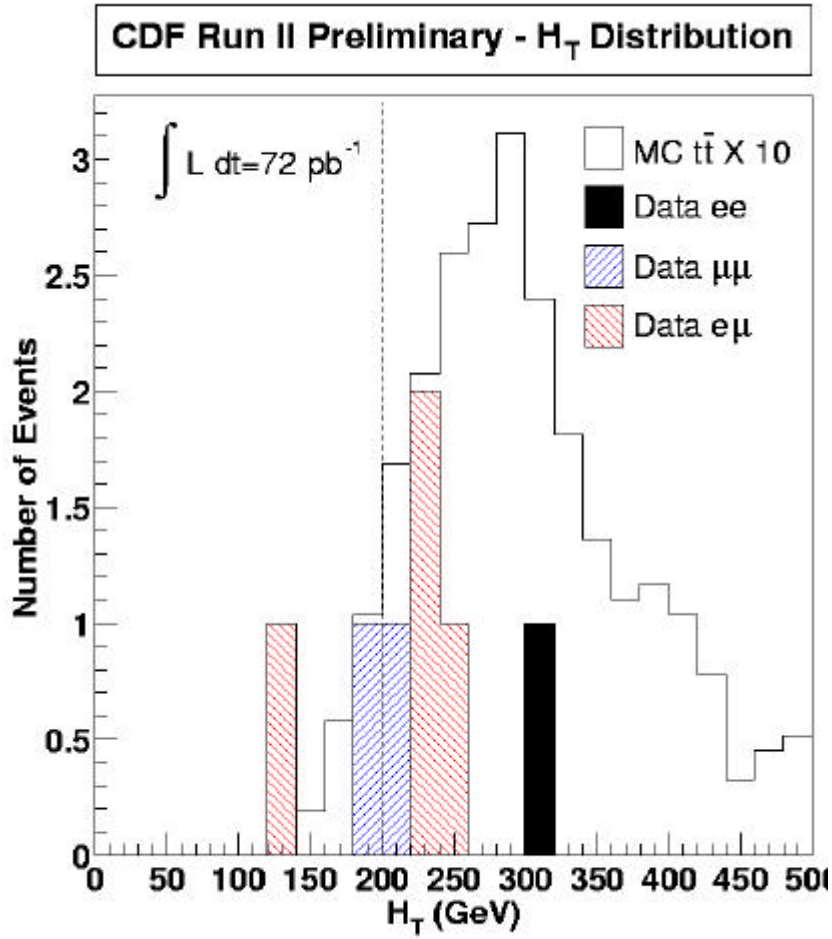
	CDF Run II Preliminary			
Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Drell-Yan e^+e^-	0.16 ± 0.09	0	0	0.16 ± 0.09
Drell-Yan $\mu^+\mu^-$	0	0.34 ± 0.15	0.16 ± 0.09	0.50 ± 0.18
Drell-Yan $\tau^+\tau^-$	0.011 ± 0.004	0.012 ± 0.005	0.034 ± 0.013	0.056 ± 0.015
WZ	0.010 ± 0.001	0.017 ± 0.002	0.029 ± 0.003	0.057 ± 0.005
Fake	0.11 ± 0.10	0.095 ± 0.111	0.54 ± 0.59	0.74 ± 0.61
$t\bar{t}$	0.0039 ± 0.0025	0.0033 ± 0.0022	0.015 ± 0.006	0.022 ± 0.007
Total Background	0.29 ± 0.13	0.47 ± 0.19	0.77 ± 0.60	1.53 ± 0.64
$WW \rightarrow$ dileptons	0.55 ± 0.13	0.66 ± 0.15	1.58 ± 0.36	2.79 ± 0.62
Run 2 Data	1	0	1	2

Dilepton backup

Source	Events per $72\,\mathrm{pb}^{-1}$ after all cuts			
	ee	$\mu\mu$	$e\mu$	$\ell\ell$
WW/WZ	0.019 ± 0.012	0.022 ± 0.014	0.050 ± 0.025	0.091 ± 0.046
Drell-Yan	0.05 ± 0.05	0.05 ± 0.05	–	0.10 ± 0.07
$Z \to \tau\tau$	0.014 ± 0.008	0.021 ± 0.013	0.030 ± 0.018	0.065 ± 0.040
Fake	0.02 ± 0.02	0	0.02 ± 0.02	0.04 ± 0.03
Total Background, B	0.103 ± 0.056	0.093 ± 0.054	0.100 ± 0.037	0.30 ± 0.12
$t\bar{t} \to dileptons$	0.47 ± 0.05	0.59 ± 0.07	1.44 ± 0.16	2.5 ± 0.3
Total SM expectation	0.57 ± 0.08	0.68 ± 0.09	1.5 ± 0.2	2.8 ± 0.3
Run 2 data, N	**1**	**1**	**3**	**5**

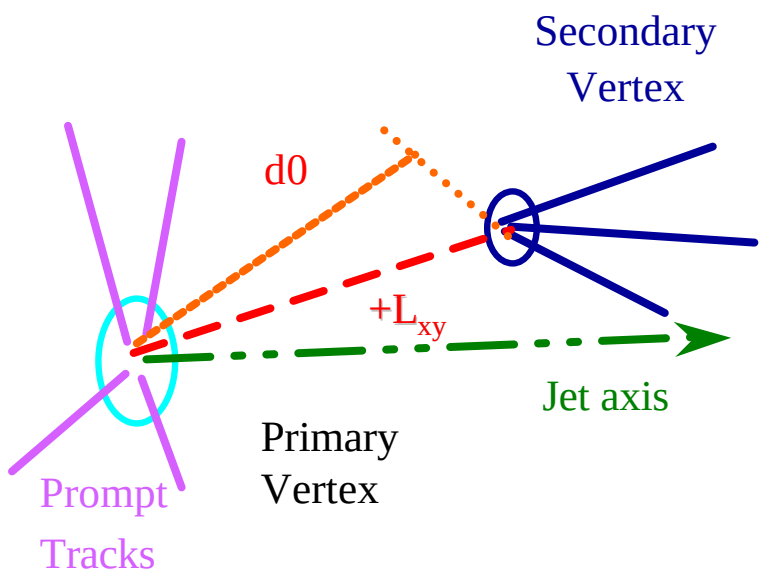
Dilepton backup

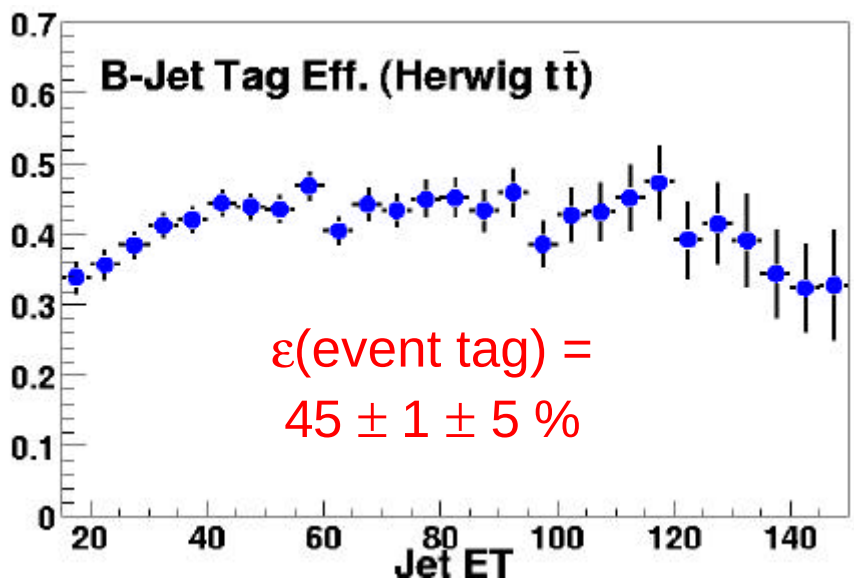




Secondary Vertex Tagging

- Signature of a b decay is a displaced vertex:
  - Long lifetime of b/c hadrons ($c\tau \sim 450\ \mu m$)
  - B hadrons travel L_{xy}~3mm before decay with large charged track multiplicity.
- Algorithm:
  - Look for displaced vertices: all combination of at least 2 tracks
  - Jet is tagged as b-jet if $L_{xy}/\sigma_{xy} > 3$ (typical σ_{xy}~150μm)





L+jets backup

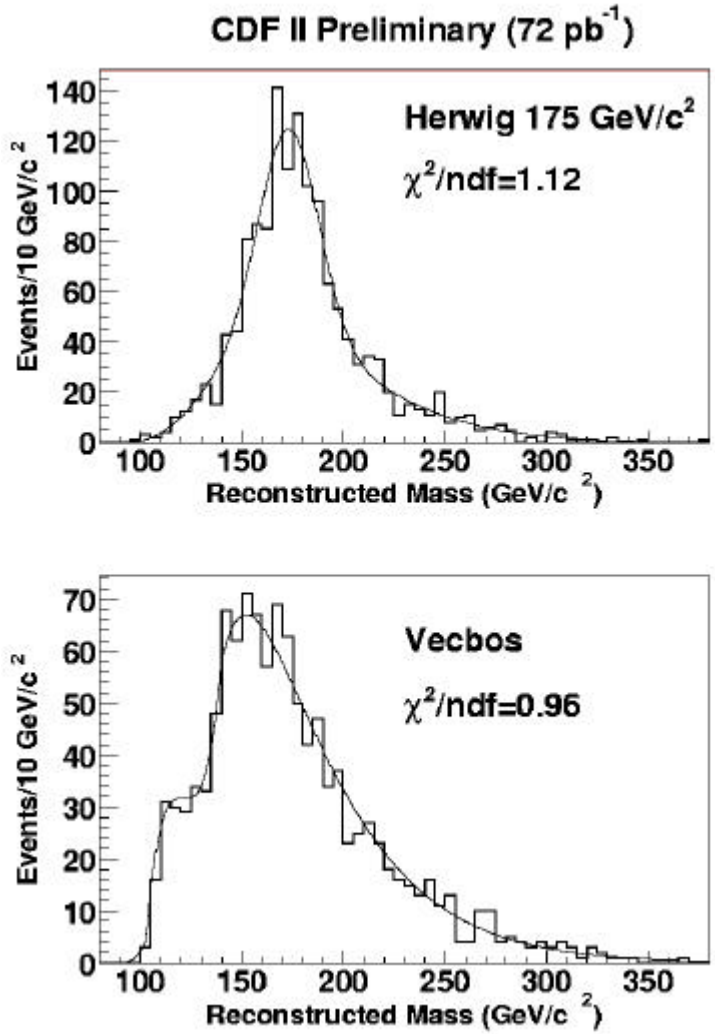
Background	$W+1$ jet	$W+2$ jets	$W+3$ jets	$W+\geq 4$jets
Events before tagging	4913	768	99	26
$Wb\bar{b}$, $Wc\bar{c}$, mistags (Method I)	35.1 ± 3.6	12.4 ± 1.4	2.9 ± 0.4	1.0 ± 0.2
$-L_{xy}$	7.4 ± 0.77	2.9 ± 0.33	0.7 ± 0.1	0.25 ± 0.046
$Wb\bar{b}$	6.3 ± 2.3	3.9 ± 1.3	0.8 ± 0.3	0.30 ± 0.11
$Wc\bar{c}$	2.3 ± 1.0	1.5 ± 0.7	0.2 ± 0.1	0.07 ± 0.03
$Wb\bar{b}$, $Wc\bar{c}$, mistags (Method II)	16.0 ± 3.4	8.4 ± 2.0	1.7 ± 0.4	0.6 ± 0.2
Wc	11.0 ± 3.1	3.4 ± 0.9	0.3 ± 0.1	0.08 ± 0.03
WW/WZ, $Z \to \tau\tau$	0.8 ± 0.2	0.8 ± 0.2	0.16 ± 0.05	0.04 ± 0.01
non-W	5.1 ± 1.1	2.4 ± 0.6	0.8 ± 0.3	0.2 ± 0.07
single top	0.9 ± 0.1	1.5 ± 0.2	0.4 ± 0.1	0.06 ± 0.01
extra $Z + b\bar{b}$ correction	0.2 ± 0.1	0.08 ± 0.03	0.02 ± 0.01	0
Total (method I)	53.1 ± 4.9	20.6 ± 1.8	4.6 ± 0.5	1.4 ± 0.2
Total (method II)	33.8 ± 5.0	16.4 ± 2.4	3.3 ± 0.5	1.0 ± 0.2
Corrected Total (method I)	53.1 ± 4.9	20.6 ± 1.8	5.2 ± 0.5	
Corrected Total (method II)	33.8 ± 5.0	16.4 ± 2.4	3.8 ± 0.5	
Observed positive tags	31	26	7	8

Top Mass backup

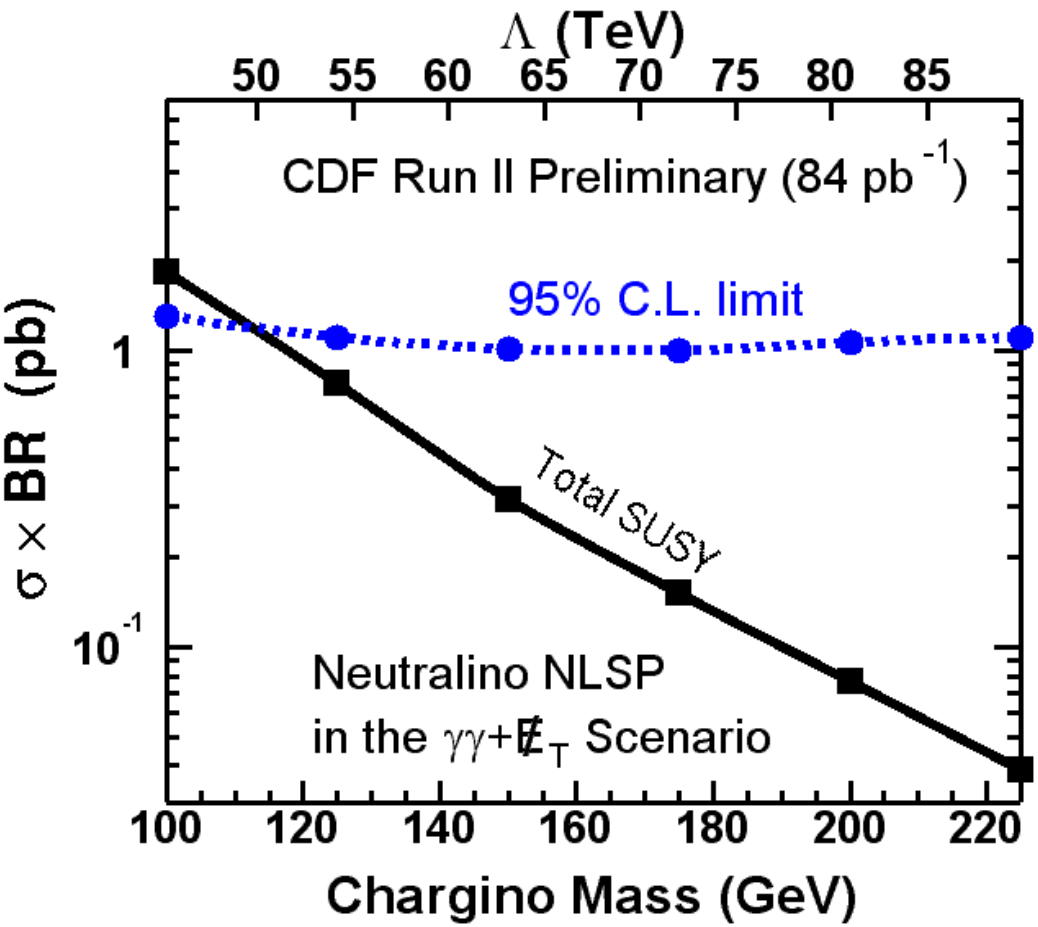
CDF Preliminary (72 pb^{-1})

Summary of Systematic Uncertainties

Source	Uncertainty (GeV/c^2)
Jet Energy Measurement	9.3
Initial and Final State Radiation	2.4
Background Shape	0.3
Parton Distribution Functions	1.8
Monte-Carlo Generators	1.8
Total	9.9

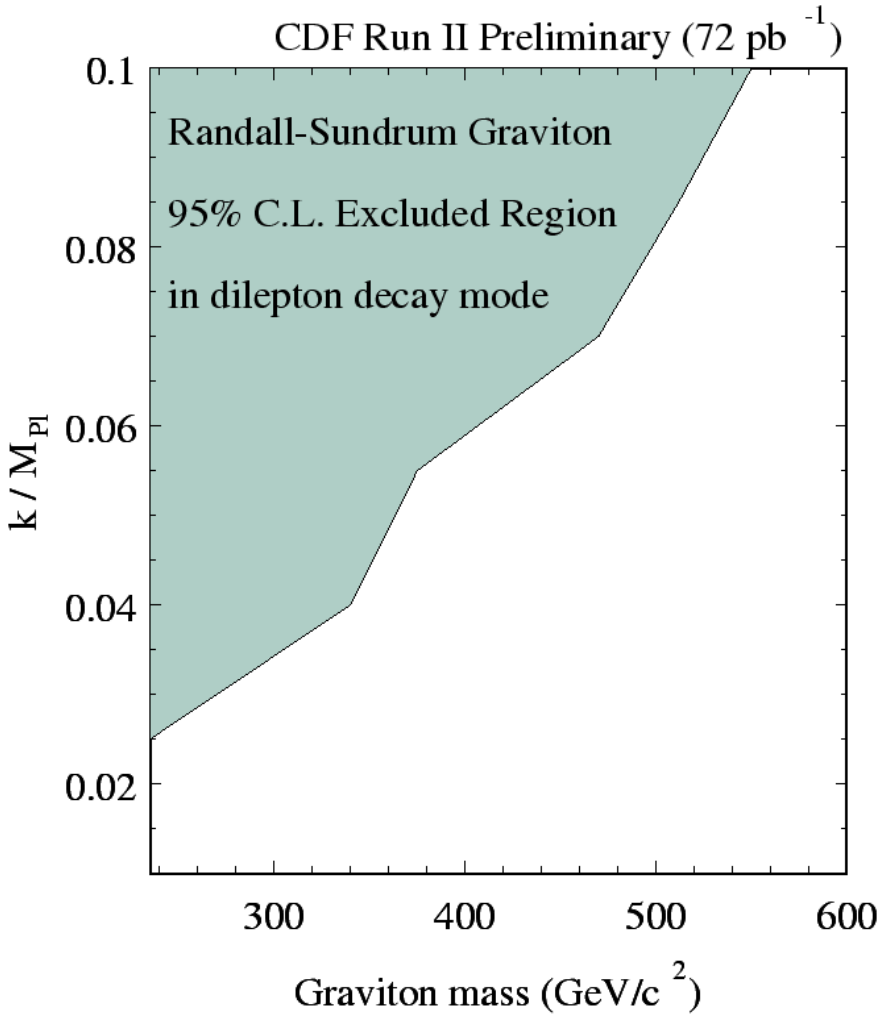


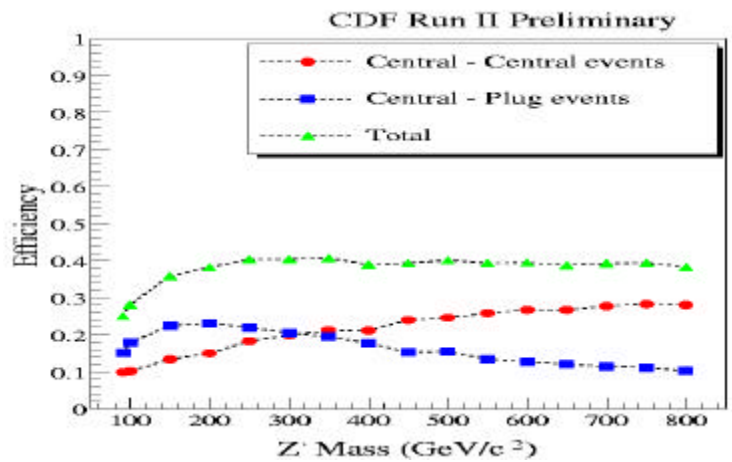
Diphoton Backup

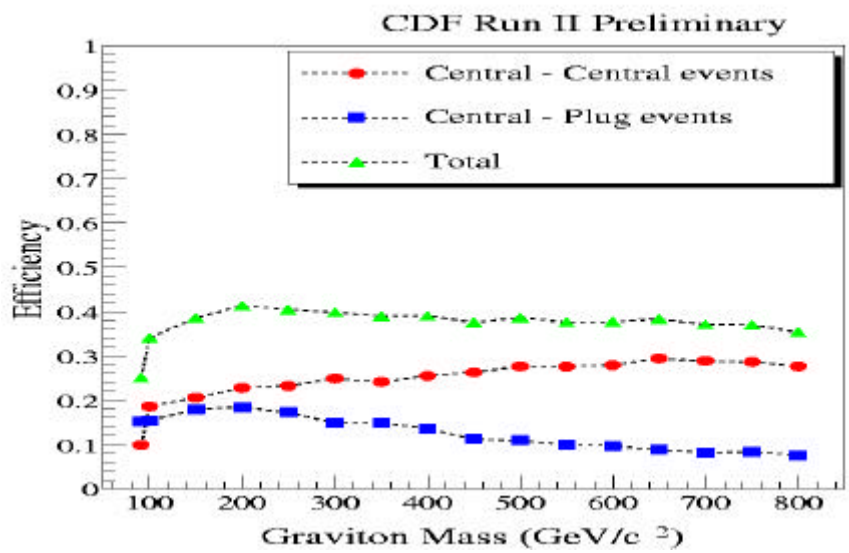


- Backgrounds in lγγ
  - **Wgg**
  - **Zgg**
  - **Zg**
  - **eg+jet**
- P(e fake γ)=2%
- Limit Set:
  - **M_c>113 GeV**

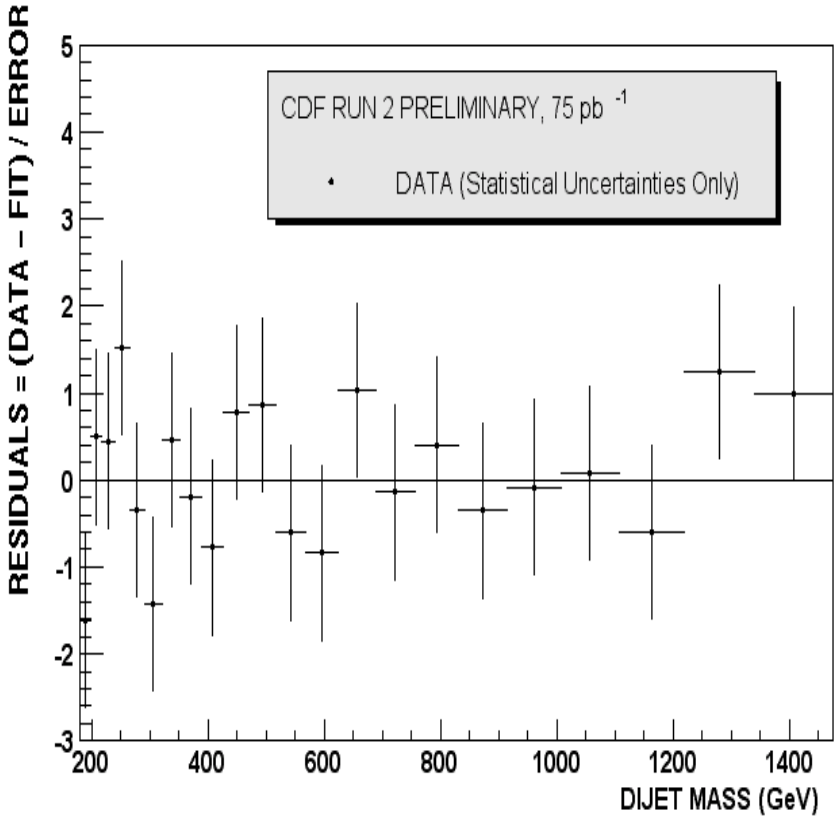
DY search backup







Dijet mass backup



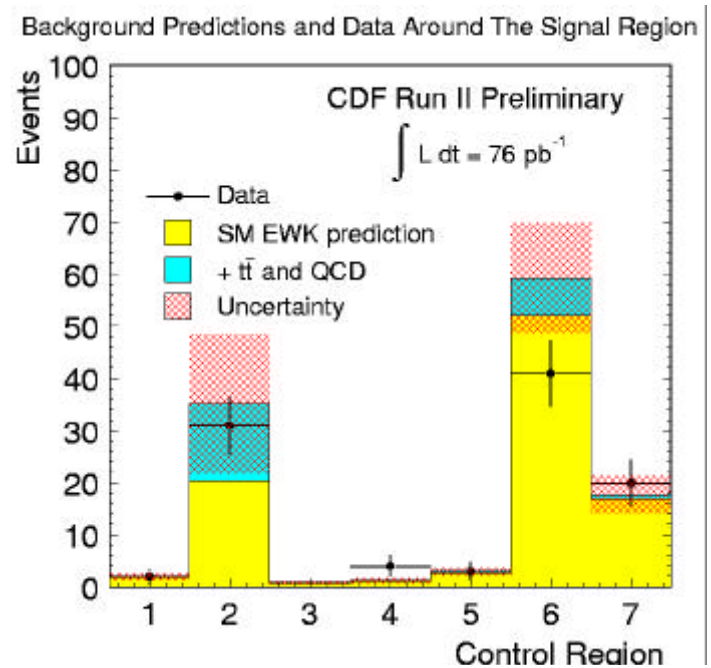
- **Axigluons or Colorons:**
  - **200 < m < 1130 GeV/c2**
  - **Run I:200<m< 980GeV/c2**
- **Excited quarks:**
  - **200 < m < 760 GeV/c2**
  - **Run I:200<m< 570&580 <m< 760**
- **Color octet techni-r's:**
  - **260 < m < 640 GeV/c2**
  - **Run I:260<m< 480 GeV/c2**
- **E6 diquarks:**
  - **280 < m < 420 GeV/c2**
  - **Run I:290<m< 420 GeV/c2**
- **W' :**
  - **300 < m < 410 GeV/c2**
  - **Run I:300<m< 420 GeV/c2**

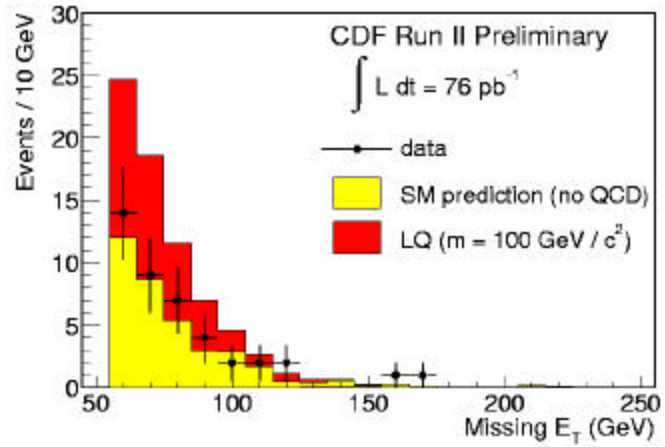
Leptoquark search backup

eeνν search:

CDF Run II Preliminary

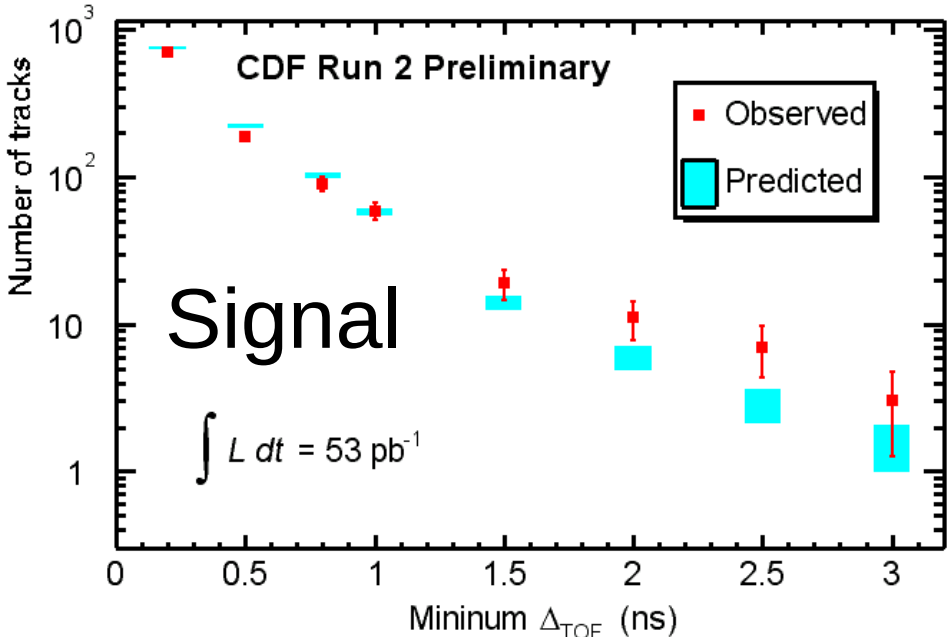
	Events
QCD	7.3
$W \to e\nu + 2$ jets	1.7
$W \to \mu\nu + 2$ jets	8.3
$W \to \tau\nu + 2$ jets	10.3
$Z \to \mu\mu + 2$ jets	0.5
$Z \to \tau\tau + 2$ jets	0.2
$Z \to \nu\nu + 2$ jets	13.4
$t\bar{t}$	0.7
All	$42.5 \pm 7.6(\text{stat}) \pm 7.5(\text{syst})$
Data	42

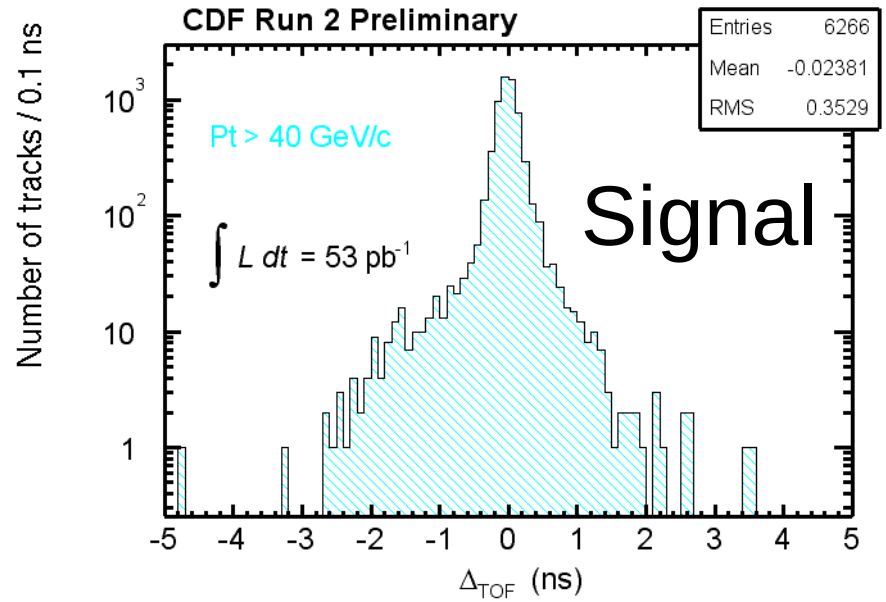




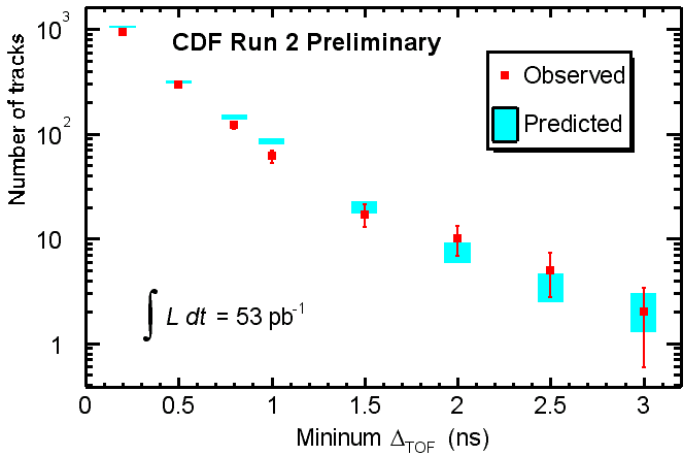
- eeqq search
  - ➤ **Dominant Back.**
    - Drell-Yan, top

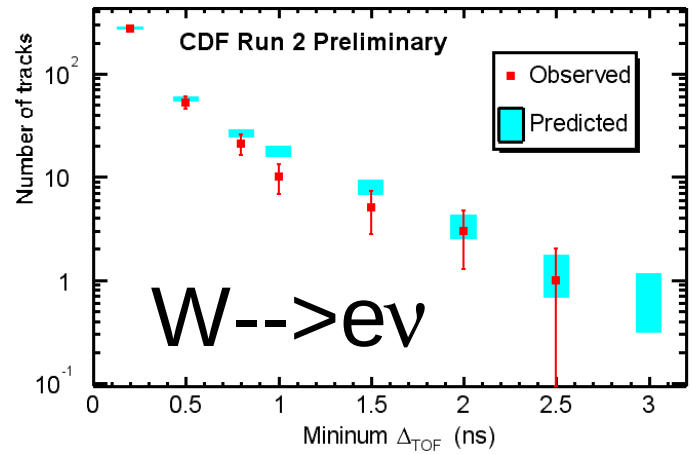
CHAMP backup



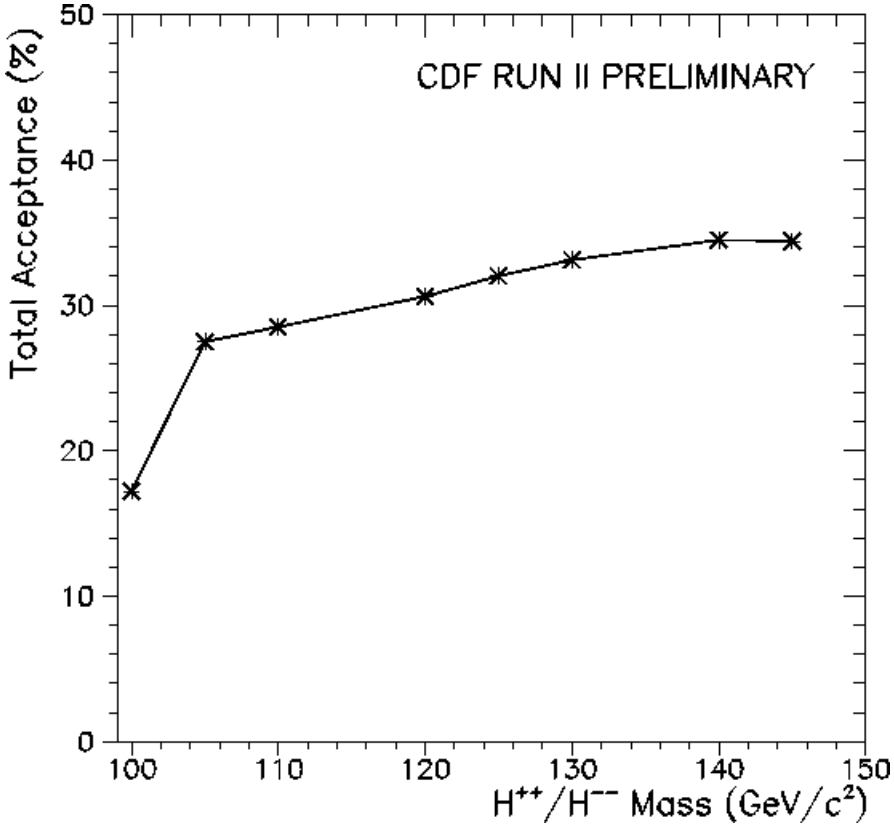


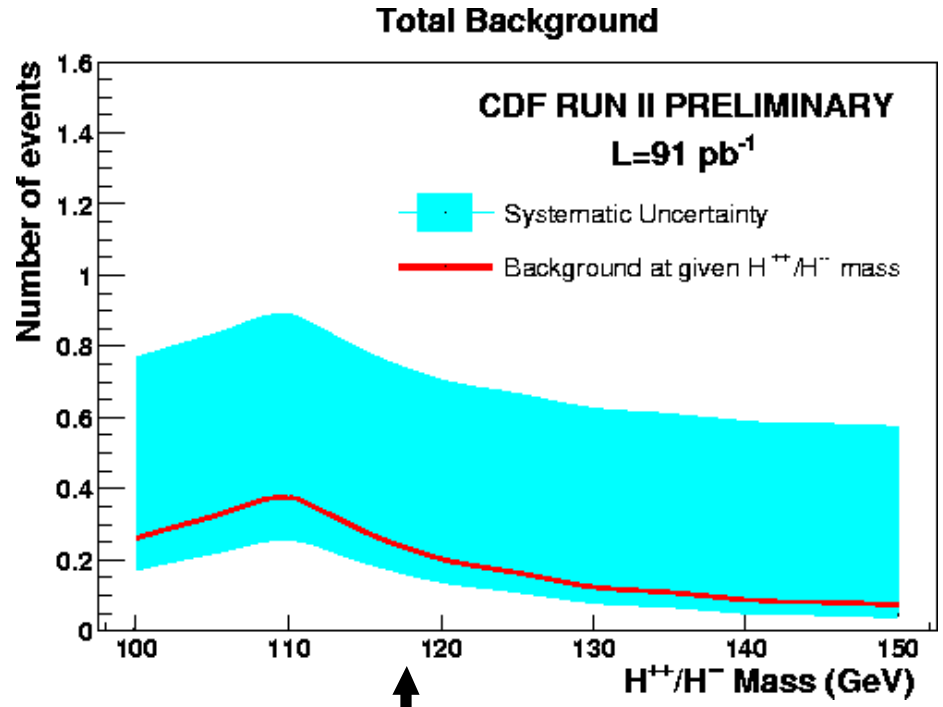
Control:





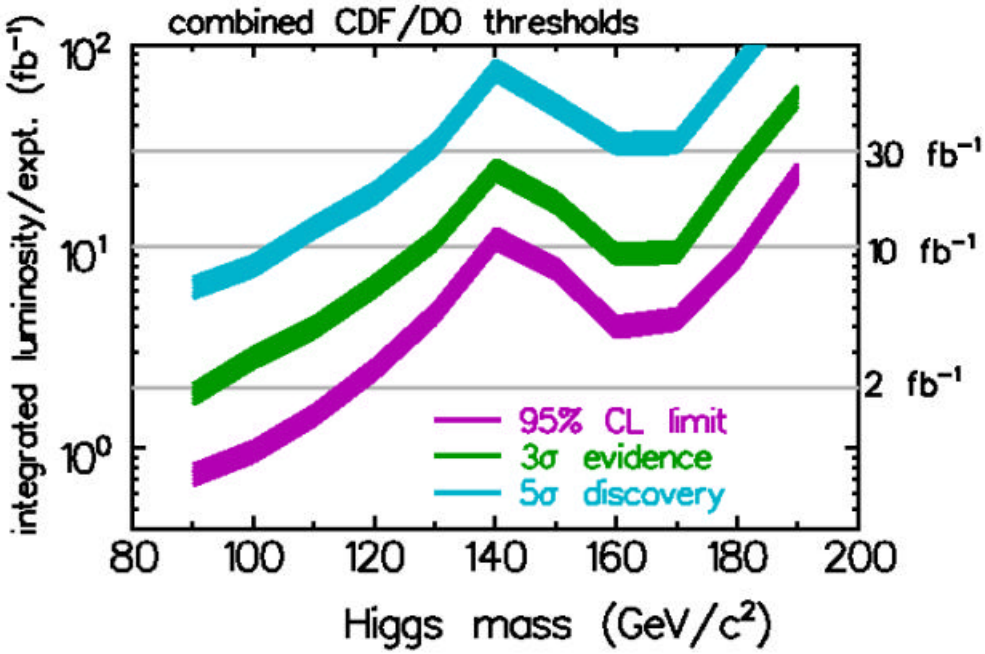
H^{++} Search





Dominated by DY

OPAL Limit: m>98.5-100.5 depending on coupling

Higgs Sensitivity

- Status as of 2000 →
- Studies with Run II ongoing
  - ➤ **Run II simulation**
  - ➤ **Run II Efficiencies**
- New report expected in June '03