Recent results on searches for new physics at CDF II

Simona Rolli
Tufts University

Introduction

Exciting time now at the TeVatron !

frenzy activity in physics analysis

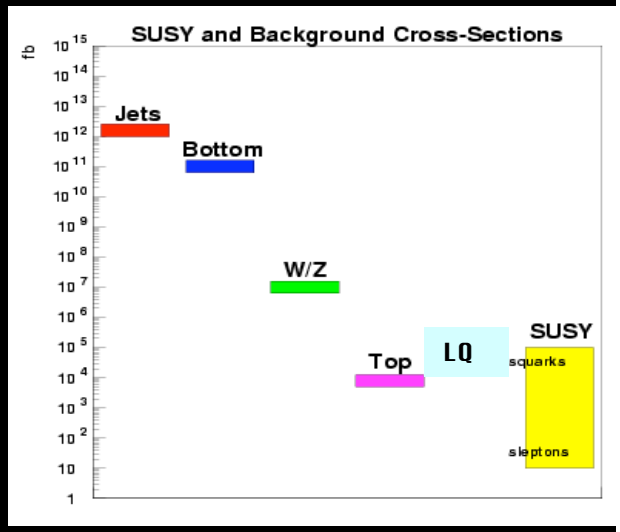
Tests of the SM
works remarkably well
Search for new physics
hints here and there...

Cross sections for various physics processes vary over many orders of magnitude:
processes of interest are often buried under heavy background
need good rejection factors, selection and analysis strategies

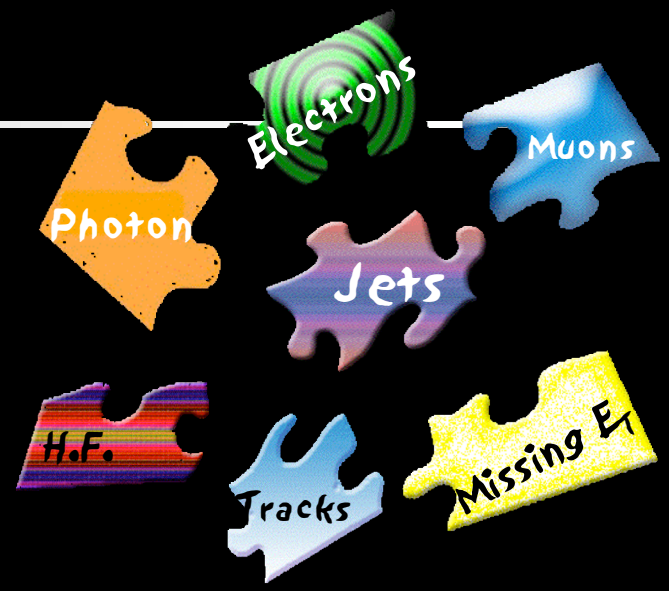
Optimize event selections for SM physics and new physics as in both cases the composition of the samples are important

Common datasets

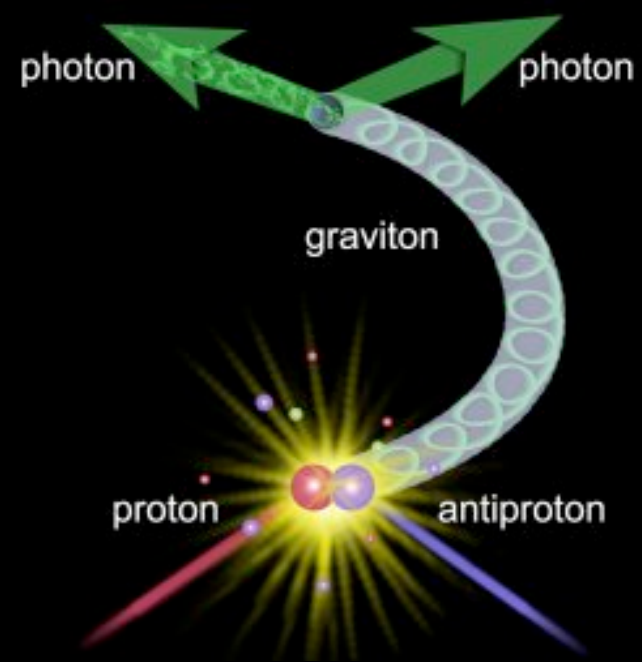
Common identification/reconstruction cuts



Outline of the talk



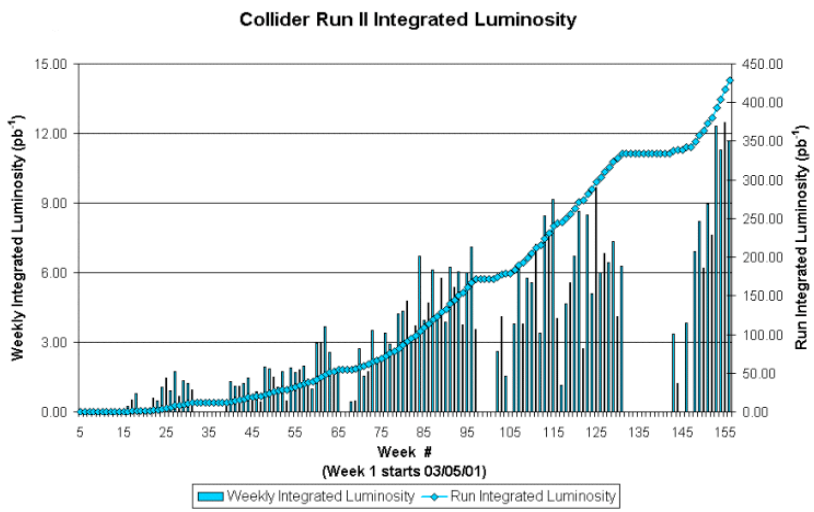
- **TeVatron Performance and CDF detector**
- **Searches and Limits**
  - **Leptons and tracks based searches**
    - dilepton searches
      - opposite sign leptons
      - same sign
    - CHAMPS
    - Magnetic Monopoles
  - **… + Missing Energy and Photons**
    - Multibosons
    - SM Higgs in WW
    - excited electrons
    - GMSB SUSY
  - **… + Jets and heavy flavors**
    - Leptoquarks
    - SM Higgs
    - SUSY (MSSM, RPV)
  - Indirect Limits from B_s

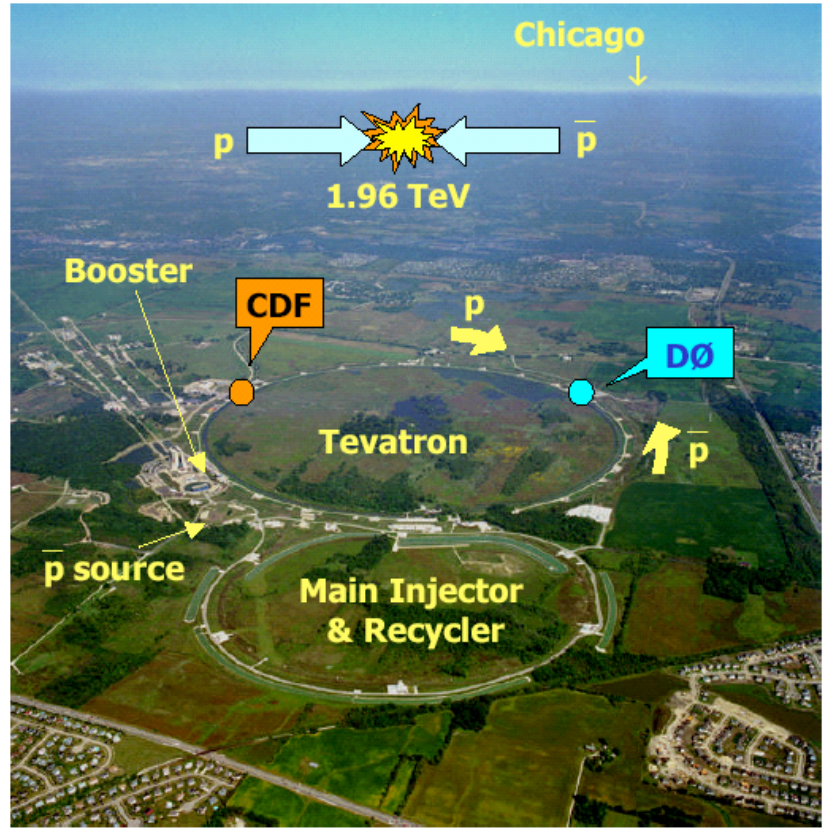


Tevatron performances

Tevatron successes in early 2004:

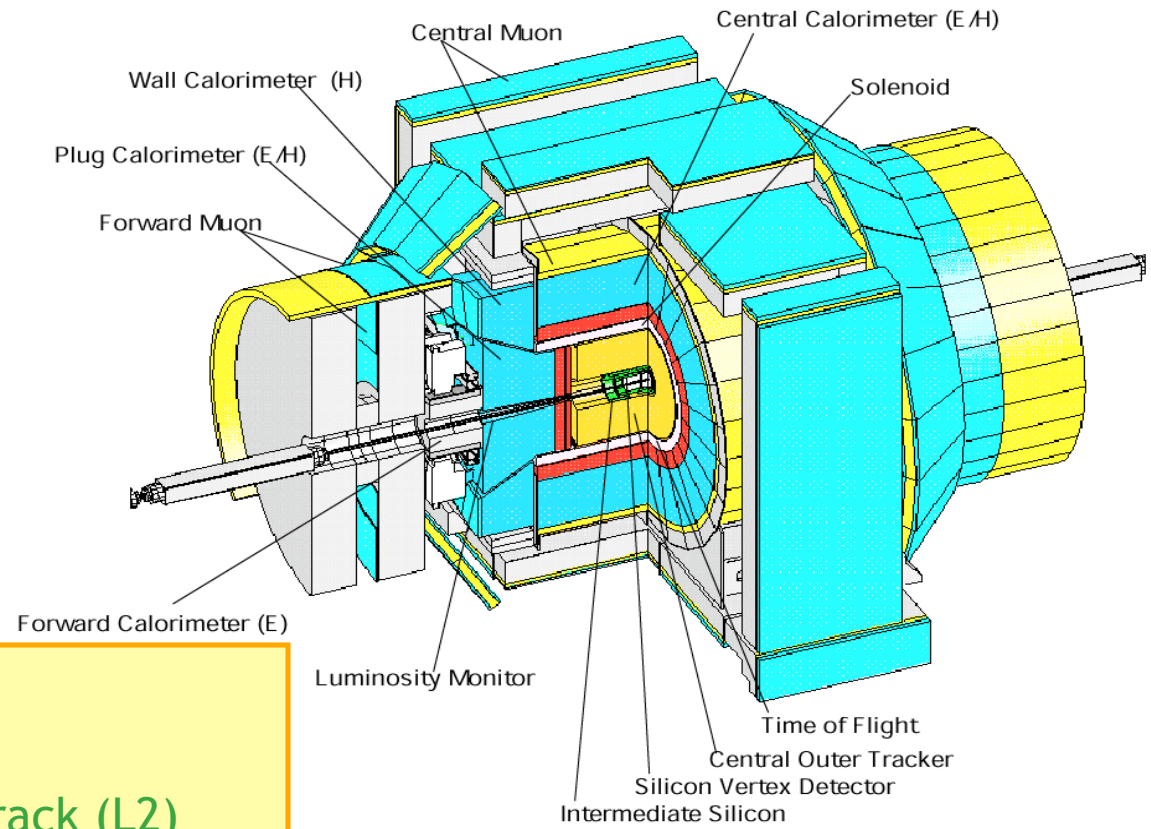
- ~430 pb^{-1} delivered
- ~350pb^{-1} on tape.
- Analyses presented here are using from 38 pb^{-1} to 240 pb^{-1} of data
- Error on luminosity is ±6%
  - 1.6% due to CLC systematic error on CLC rate
  - 4.0% due to CLC acceptance sys
  - 3.8% due to limited by knowledge of pp inelastic cross section.





CDF Run II Detector

From Run I:
- Solenoid
- Central muon system
- Central calorimeter



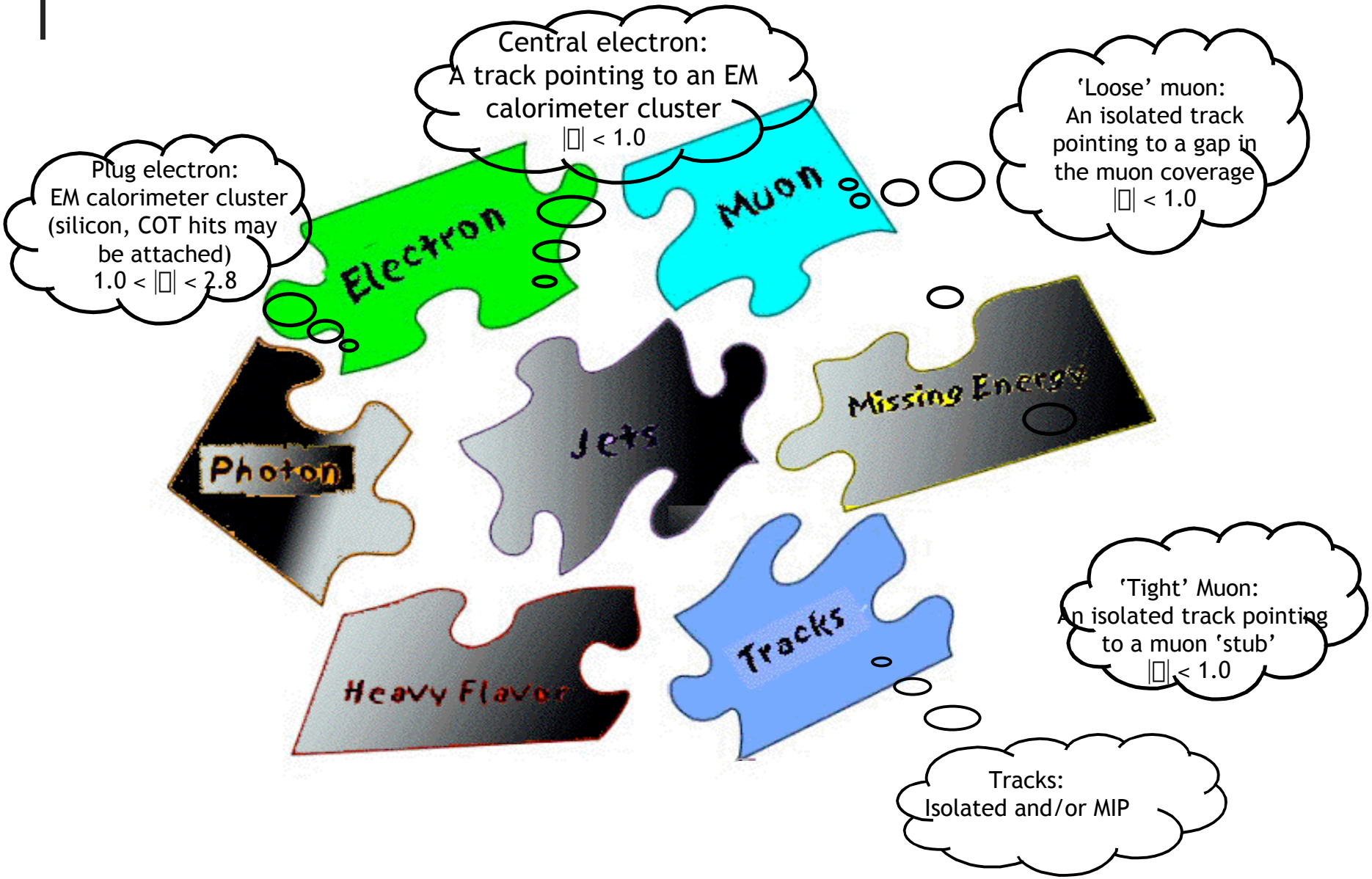
New For Run II:

- Front-end DAQ
- Trigger
  Track (L1) and Displaced Track (L2)

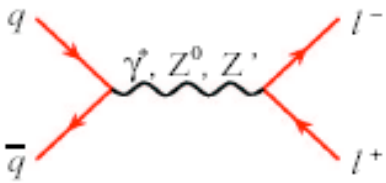
- Silicon Tracker (8 Layers) ($|\eta| < 2.0$)
- Central Outer Tracker ($|\eta| < 1.0$)

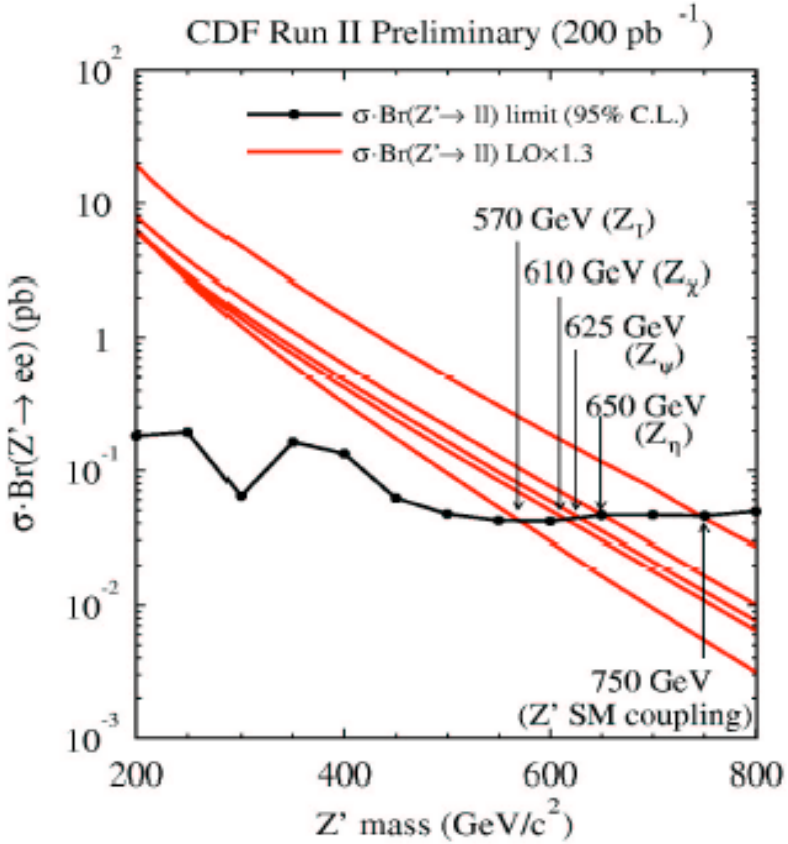
- Plug Calorimeters ($1.0 < |\eta| < 3.6$)
- Extended Muon Coverage ($|\eta| < 1.5$, gaps filled in)

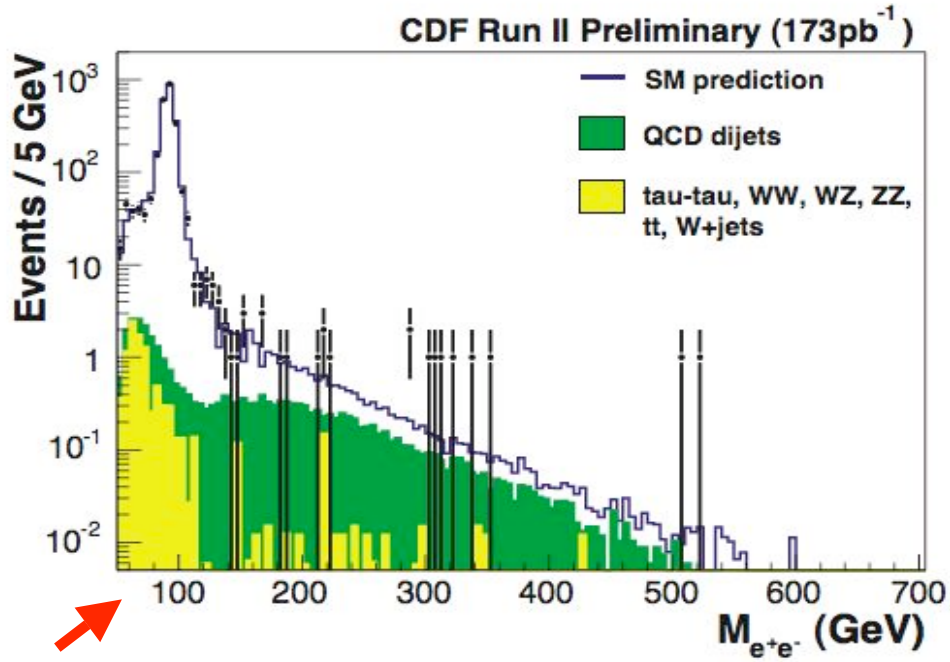
Electrons, Muons and Tracks



Searches in dileptons

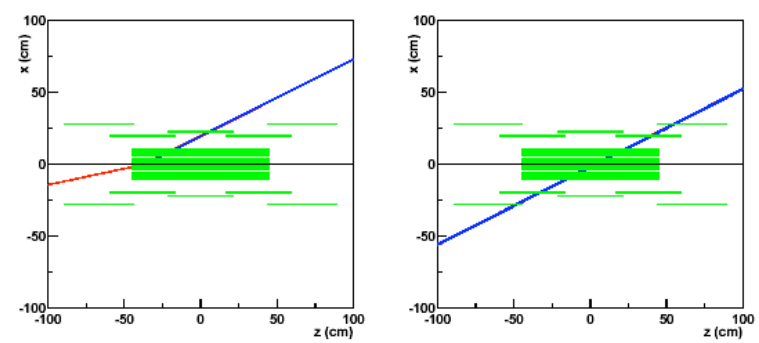






Forward electrons : $1.2 < |\eta| < 2.5$

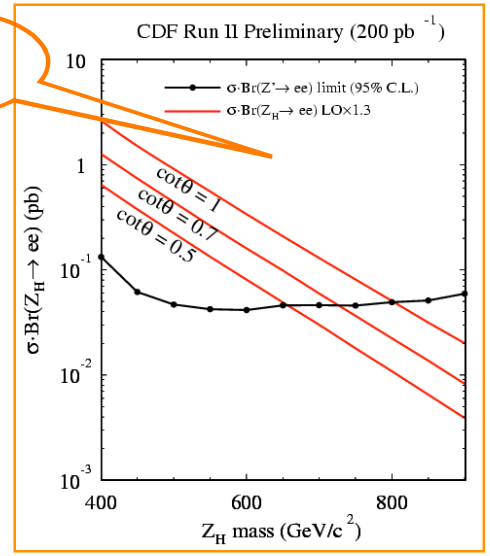
Calorimeter seeded Si tracking



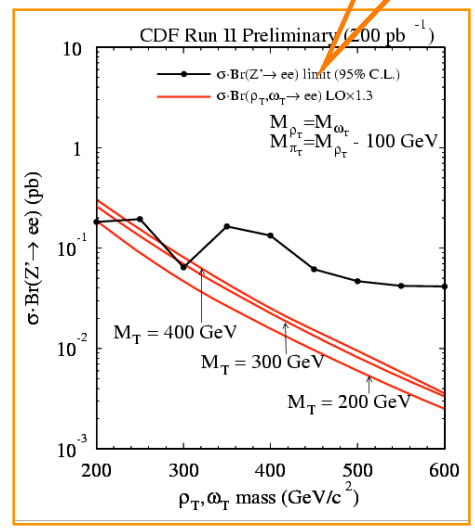
Searches in dileptons (cont'd)

Calculate the acceptances for resonant states for 3 different spin assumption (0,1,2)

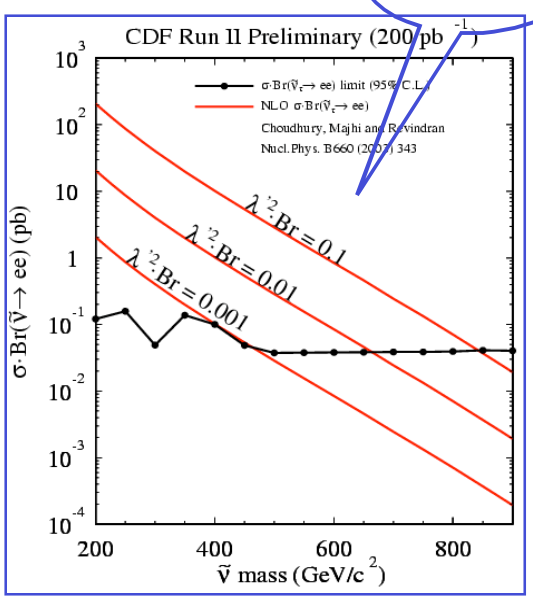
Little Higgs

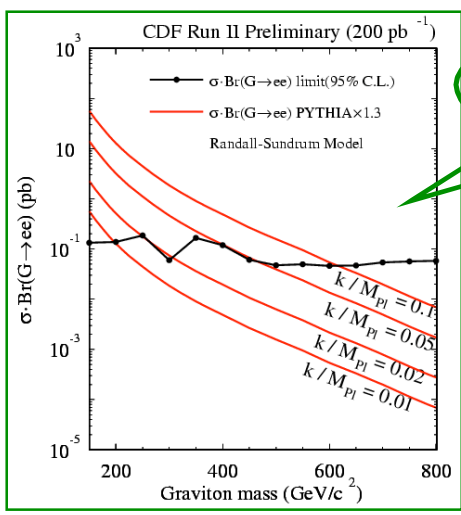


Technicolor



SUSY



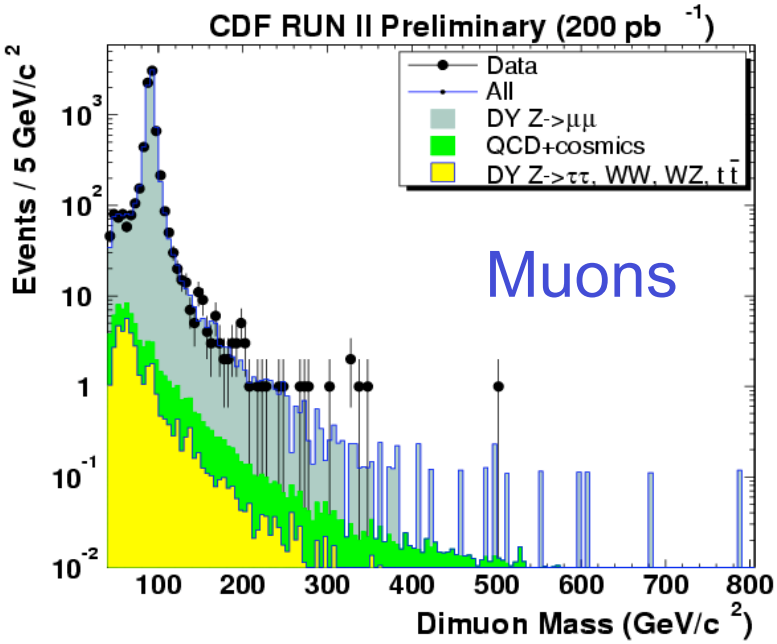


Extra-Dimensions

- Randall-Sundrum graviton model
  4-dimensional metric multiplied by *warp* factor exponentially changing with the additional dimension
  Generating a large hierarchy does not require a large r_c

The coupling of individual KK states to matter is set by the weak scale (parameters : M_G and $k/M_{P\ lanck}$)
KK states can be observed as spin 2 resonances

Searches in dileptons (cont'd)



- Z' gauge bosons: $M_{Z'} > 735 GeV/c^2$ (SM-Like)

CDF Run II Preliminary

CDF Run	Luminosity (pb^{-1})	$M_{Z',95\%C.L}$ (GeV/c^2)
IA	18.8	440
IB	88.6	575
IIA (summer '02)	16	275
IIA (winter '03)	72.0 (56.0 for CMX)	455
IIA (summer '03)	126 (110 for CMX)	585
IIA (winter '04)	200 (180 for CMX)	735

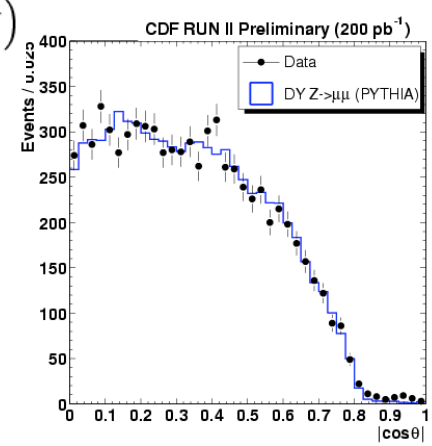
- E_6 Z' Limits:

CDF Run II Preliminary

Model	Mass Limit at 95%C.L (GeV/c^2)		
	Run I	Run II (summer '03)	Run II (winter '04)
Z'_{SM}	590	585	735
Z'_{ψ}	495	465	600
Z'_{χ}	500	455	580
Z'_{η}	520	495	635
Z'_{I}	480	425	530

- Littlest Higgs Z': $M_{Z_H} > 755 GeV/c^2$ (cosθ =0.9)

$$\cos\theta = \frac{2}{M\sqrt{M^2 + P_T^2}}\left(\ell_1^+\ell_2^- - \ell_1^-\ell_2^+\right)$$



- RS Graviton of extra dimensions: $M_G > 605 GeV/c^2$ (k/M_{Pl} =0.1)

CDF Run II Preliminary

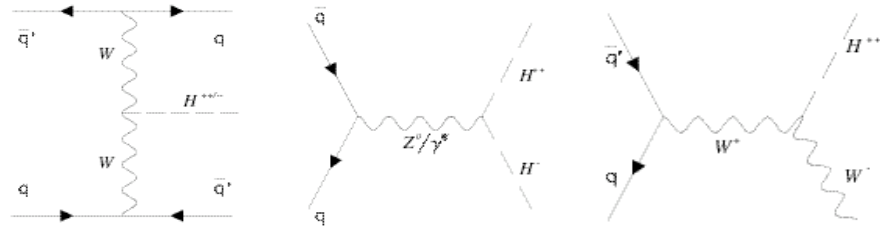
CDF Run	Luminosity (pb^{-1})	$M_{G,95\%C.L}$ (GeV/c^2) (k/Mpl = 0.1)
IA	–	–
IB	–	–
IIA (summer '02)	16	255
IIA (winter '03)	72.0 (56.0 for CMX)	370
(summer '03)	126 (110 for CMX)	475
IIA (winter '04)	200 (180 for CMX)	605

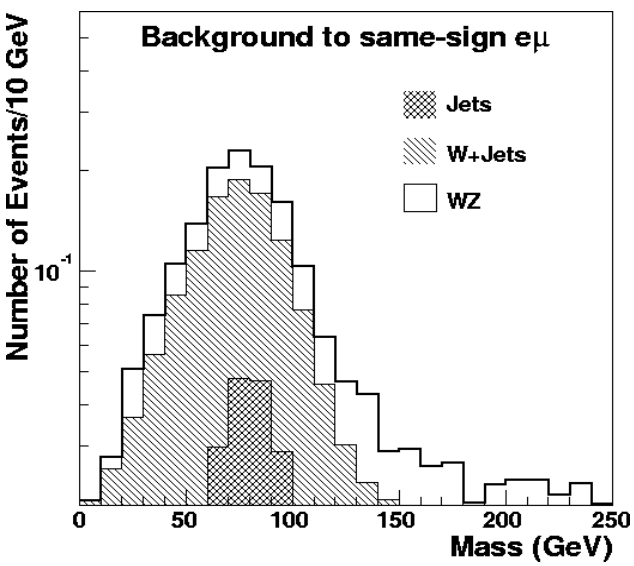
Search for doubly charged Higgs

Doubly charged Higgs are members of Higgs triplets occurring in several types of models

- extensions of the Higgs sector of the SM
- left-right symmetric models
- SUSY left-right symmetric models

At the TeVatron doubly charged Higgs can be paired-produced (Z exchange) or singly produced (WW fusion)

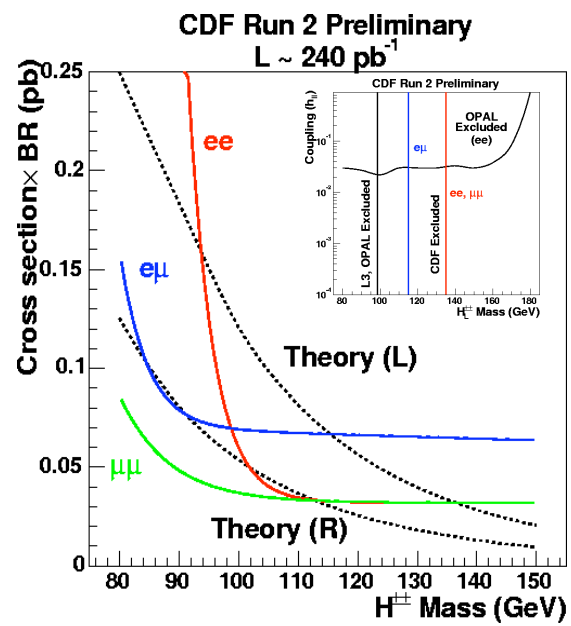




Same sign leptons signature

Very small background!

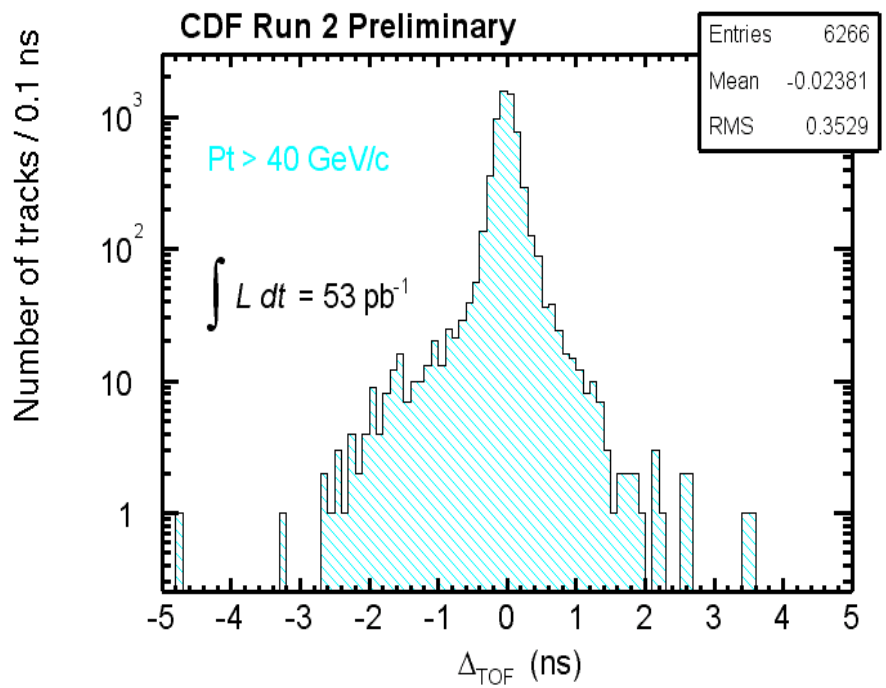
Decay Channels	# predicted Evts
ee	$1.8^{+0.8}_{-0.6}$
μμ	$0.8^{+0.6}_{-0.5}$
eμ	$0.9^{+0.4}_{-0.4}$



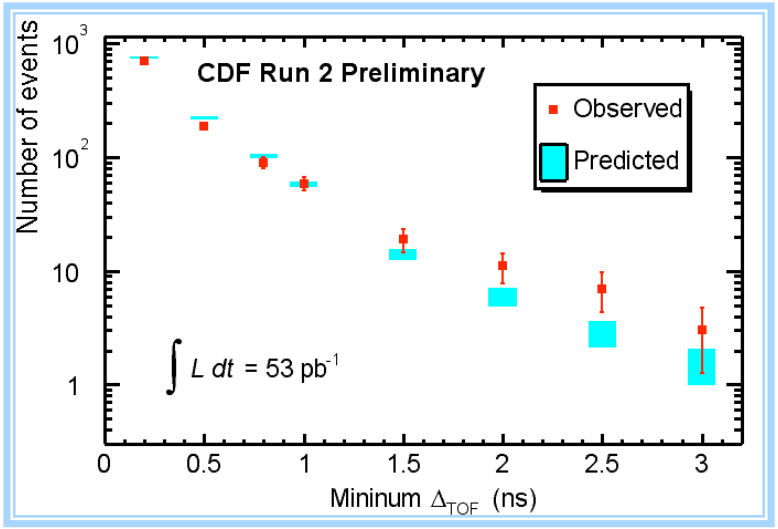
CHArged Massive ParticleS

- Long lived particles escaping the CDF detector
  - looking at high pt muon trigger
- Isolated, slow moving
  - p_t > 40 GeV/c to have full tracking efficiency
  - long time of flight through the detector

- TOF measurement
  - RunII TOF system provides sensitivity to higher □□ than dE/dx (LEP searches)
  - event t_0 from tracks with P_T > 20 GeV/c
    - tested with W electron sample
  - Looking for tracks with high $TOF_{tracks} - t_0$

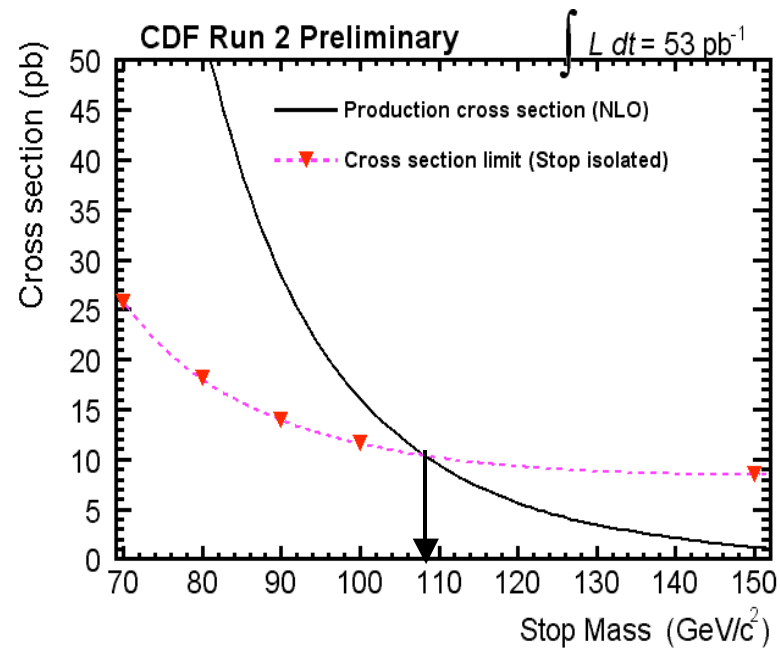


CHArged Massive ParticleS



Predicted/observed events in the signal region (statistical uncertainties only).

Interesting NLSP cases in GMSB
- stop or stau as the lightest SM partners
- stop - strongly interacting
- stau - weakly interacting



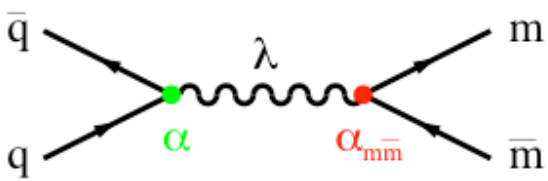
The counting experiment required □(TOF) > 2.5 ns.

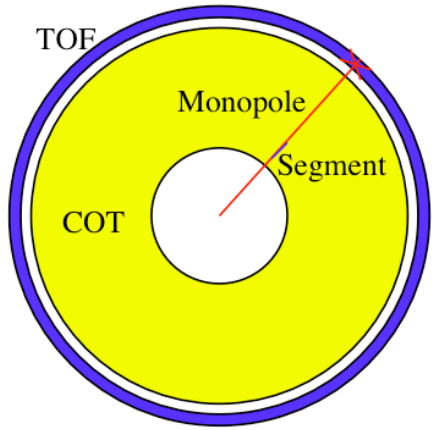
This point has a background prediction of 2.9 +/- 0.7 (stat) +/- 3.1 (sys), with 7 observed.

M(stop) > 108 GeV @ 95% CL.

Magnetic Monopoles

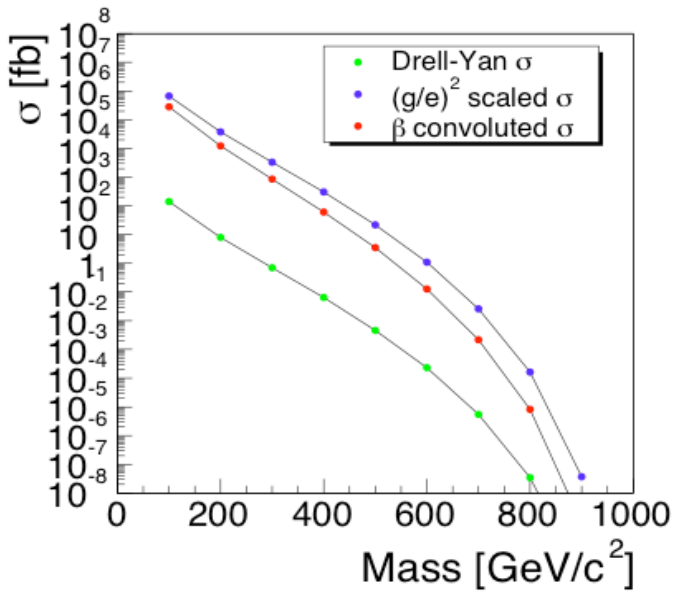
- Drell-Yan like production:





Like an electric charge in electric field

- Use replacement $e \rightarrow g\beta$.

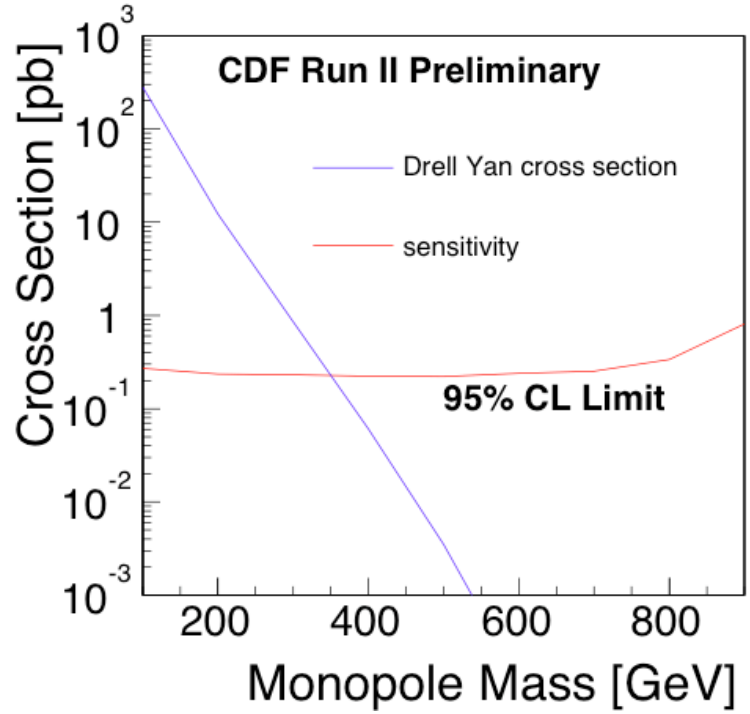


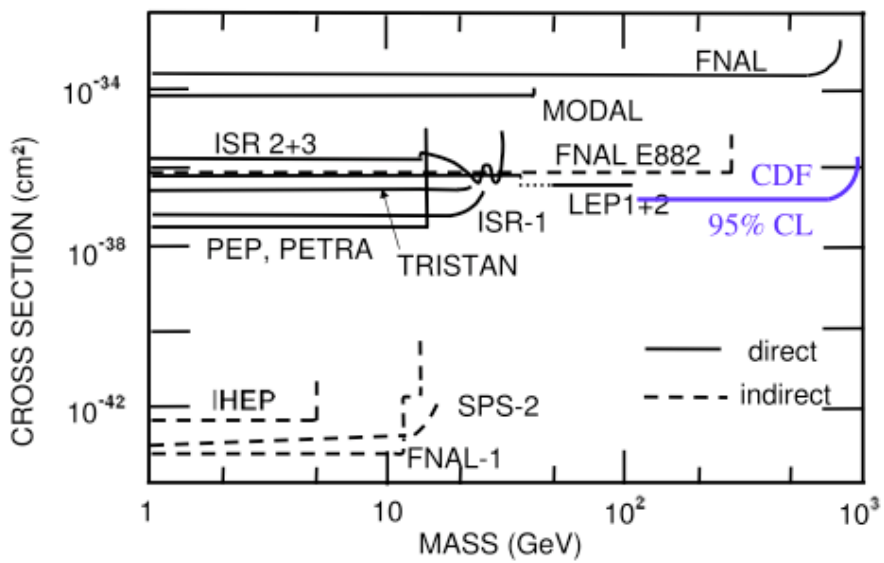
Non-pertubative coupling—$g/e \sim 68.5$—no reliable calculations from field-theory. Use as benchmark.

Magnetic Monopoles

Effect	Efficiency	Statistical Uncertainty	Systematic Uncertainty
TOF acceptance (MC)	plot: ~ 65%	plot	4%
TOF response	100%	negl.	negl.
TOF spoilers	86%	1%	5%
TOF timing (MC)	plot: ~ 100%	plot	plot
TOF digital	100%	negl.	negl.
COT width cut	100%	negl.	negl.
COT segment finding	94%	5%	3%

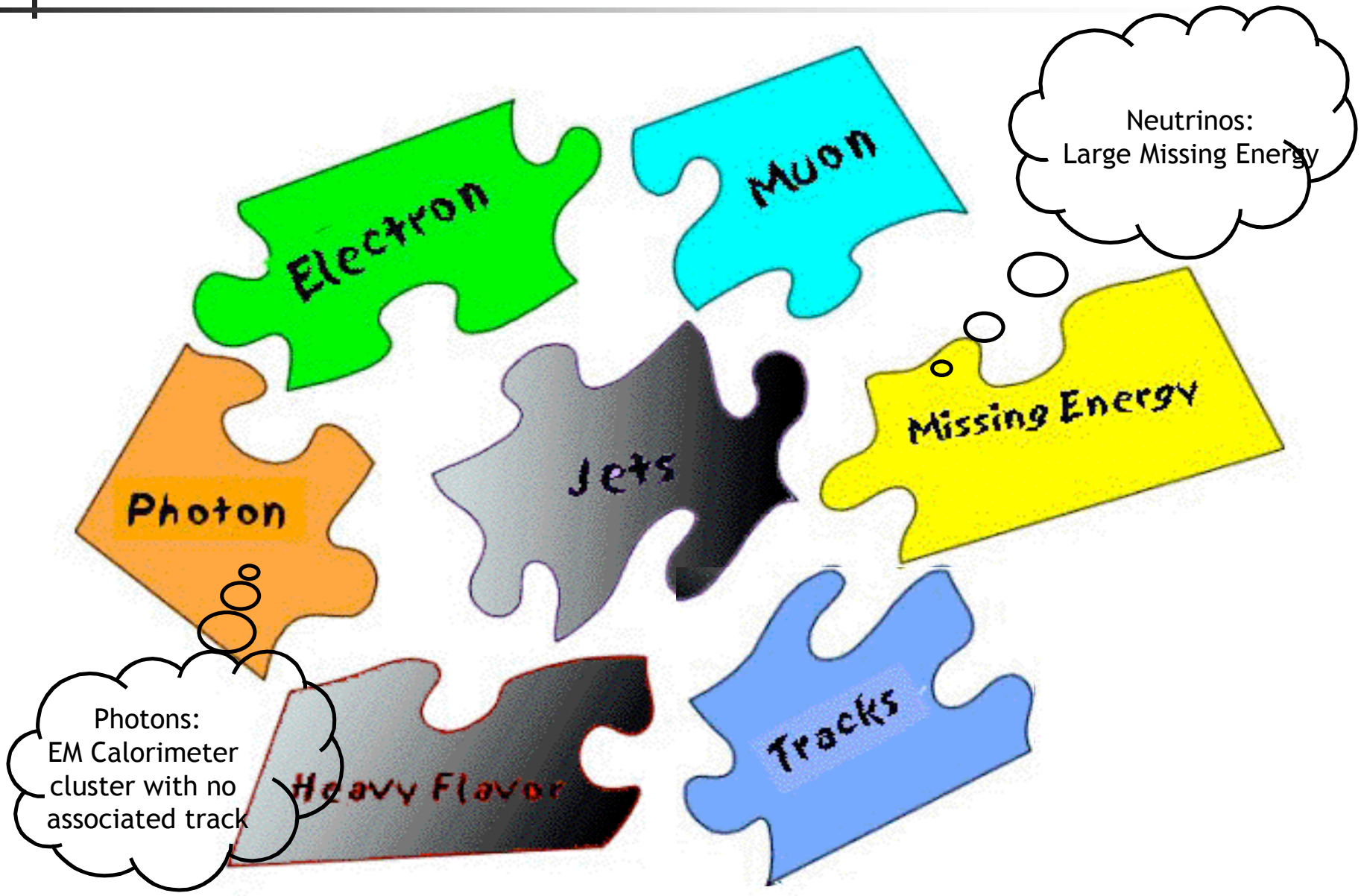
Table 1: Summary of efficiency.





Best Limit WorldWide

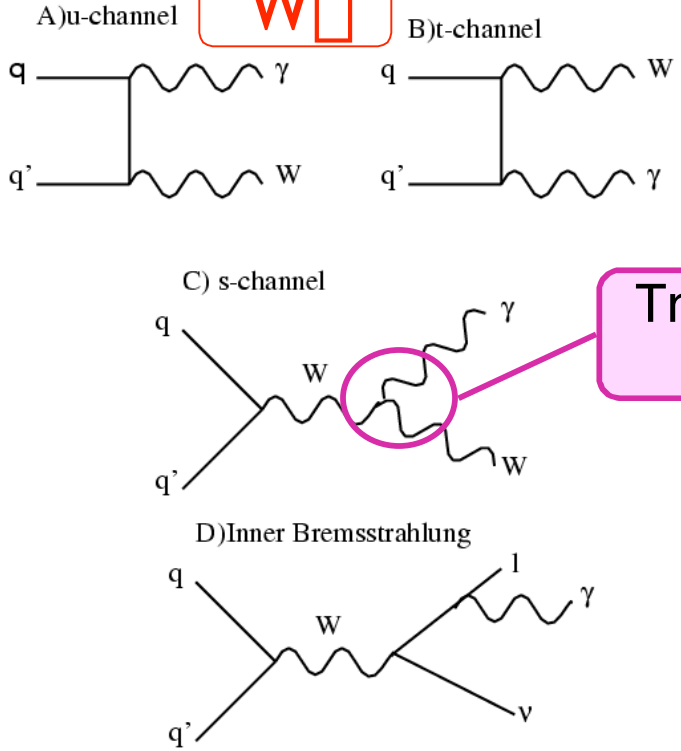
+ Photons & Neutrinos Final States



Di-boson Signals

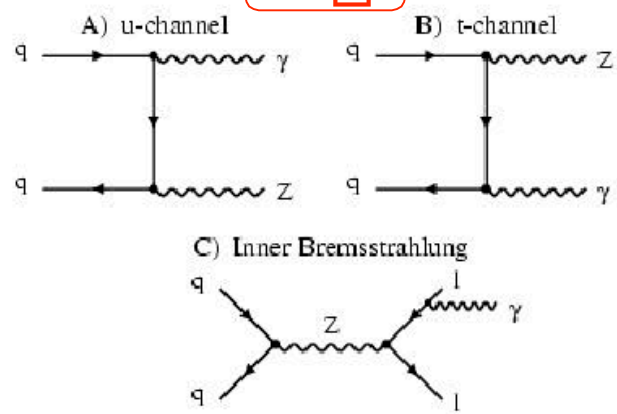
Test of gauge couplings (as predicted by the SM) and a window on new physics

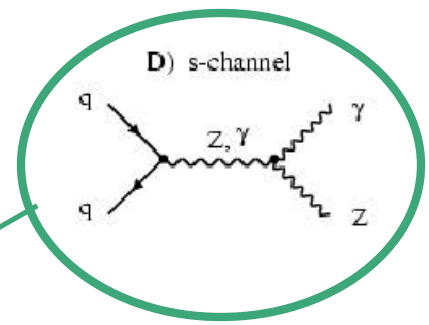
W□



Triple Boson Coupling

Z□





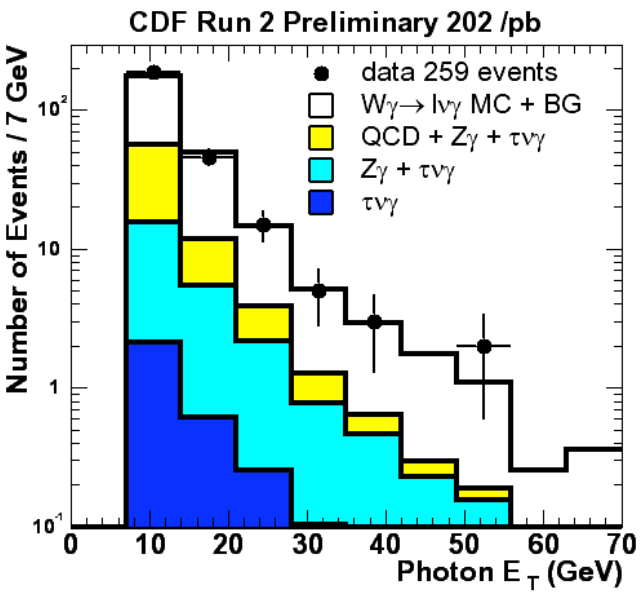
Non SM!

W□ at CDF

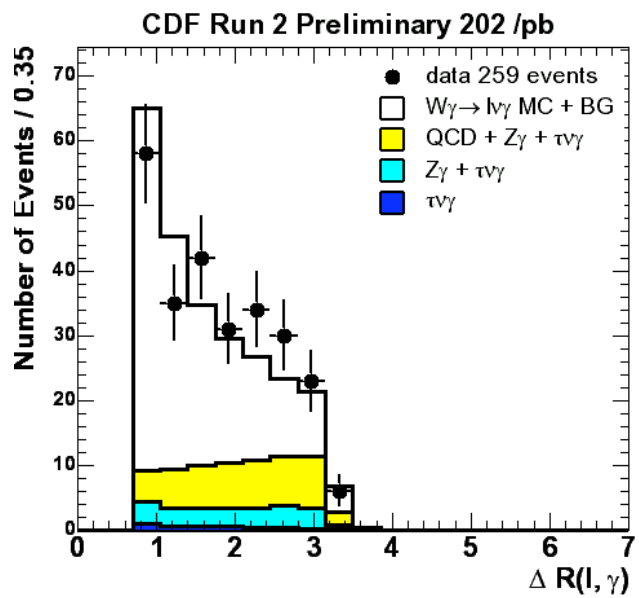
- First select W→lν events :
  - Electrons : E_T>25 GeV; missing−E_T>25 GeV
  - Muons : E_T>20 GeV; missing−E_T>20 GeV
- Then look for additional photons :
  - E_T(photon) > 7 GeV
  - $|\eta^\gamma| < 1.1$
  - $\Delta R(l,\gamma) > 0.7$

□(W□)□BR(W□ l□) = 19.7
± 1.7 (stat) ± 2.0 (sys)
± 1.1 (lumi) pb

For E_T(□) > 7 GeV and □R(l, □) > 0.7:
□(W□)□BR(W□ l□) (Theory) = 19.3 ± 1.4



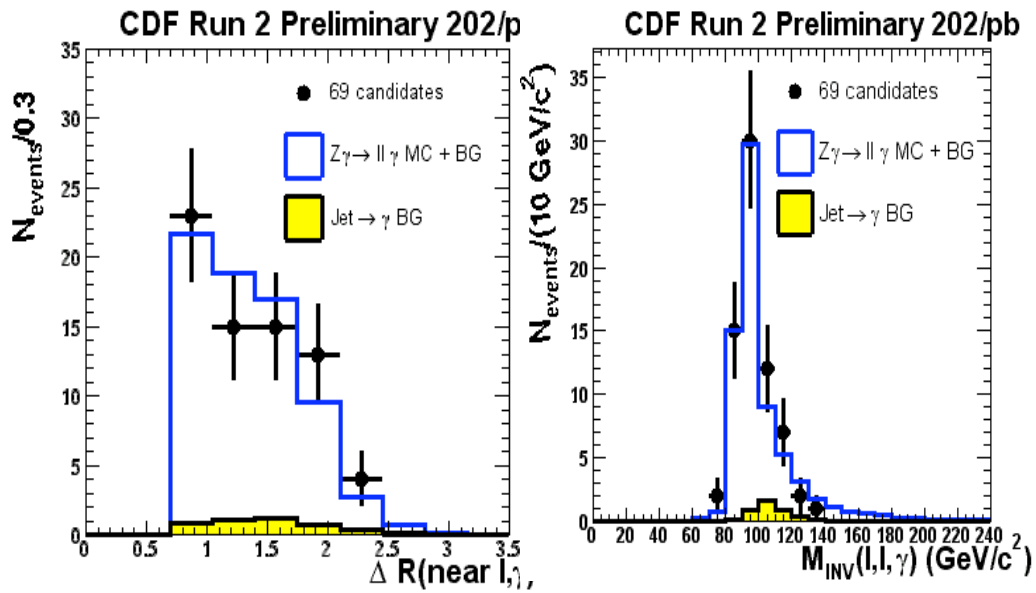
data well described over all photon E_T's and separations

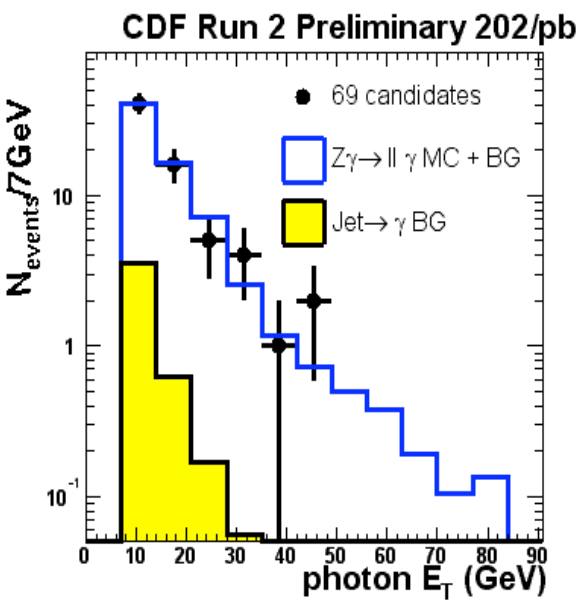


Z□ at CDF

□(Z□)□BR(Z□ ll) =5.3
± 0.6 (stat) ± 0.4 (sys)
± 0.3 (lumi) pb

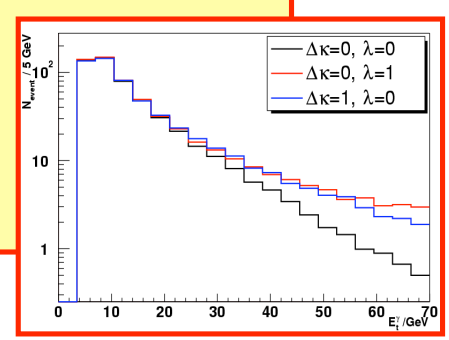
For E_T(□) > 7 GeV and □R(l, □) > 0.7:
□(Z□)□BR(Z□ ll) (Theory) = 5.4 ± 0.4





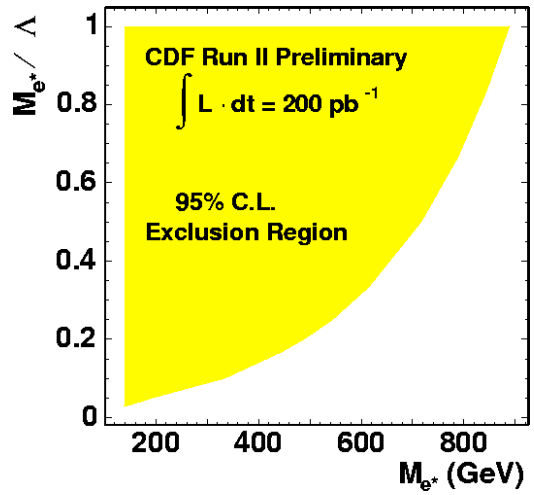
Now V+□cross-sections well established, we are:

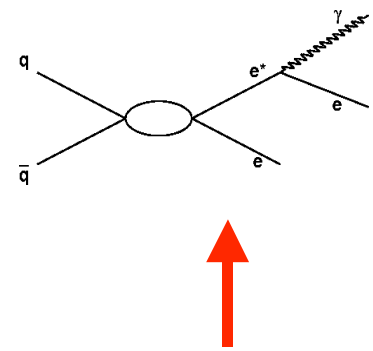
- optimizing sensitivity to anomalous coupling and new physics
- testing the Standard Model in ways unique to the TeVatron (e.g. observing RAZ in W □production)



Excited electrons at CDF

Observation of excited states of quarks and leptons might confirm the hypothesis that they are not elementary particles , but composite states



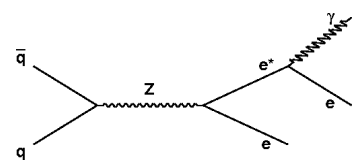


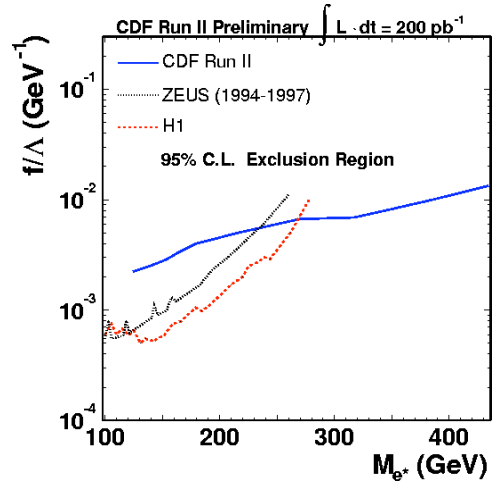
CDF searched for excited electron (e^*) using high pt electron data (L=200 pb^{-1})

At Tevatron, e^* can be produced via contact interactions or gauge mediated interactions

- Select events with eeγ in the final state
- Look for resonance in M($e\gamma$)
- SM backgrounds :

  Z γ+ DY , Z+jets, WZ, Multi-jets, $\gamma\gamma$+jets, …

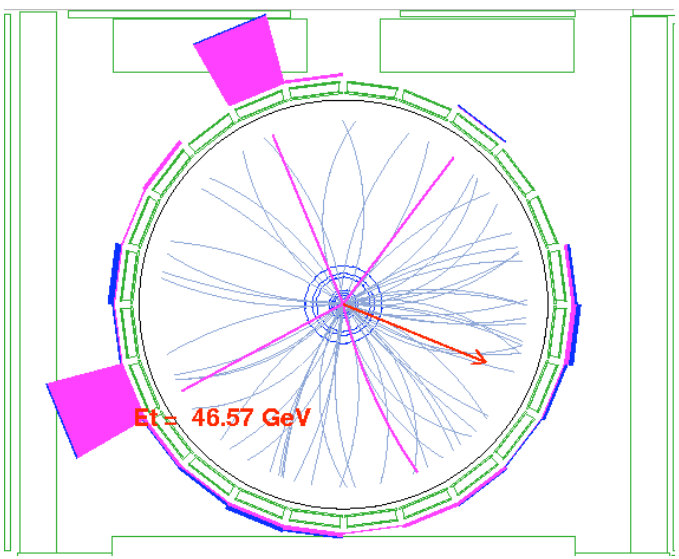


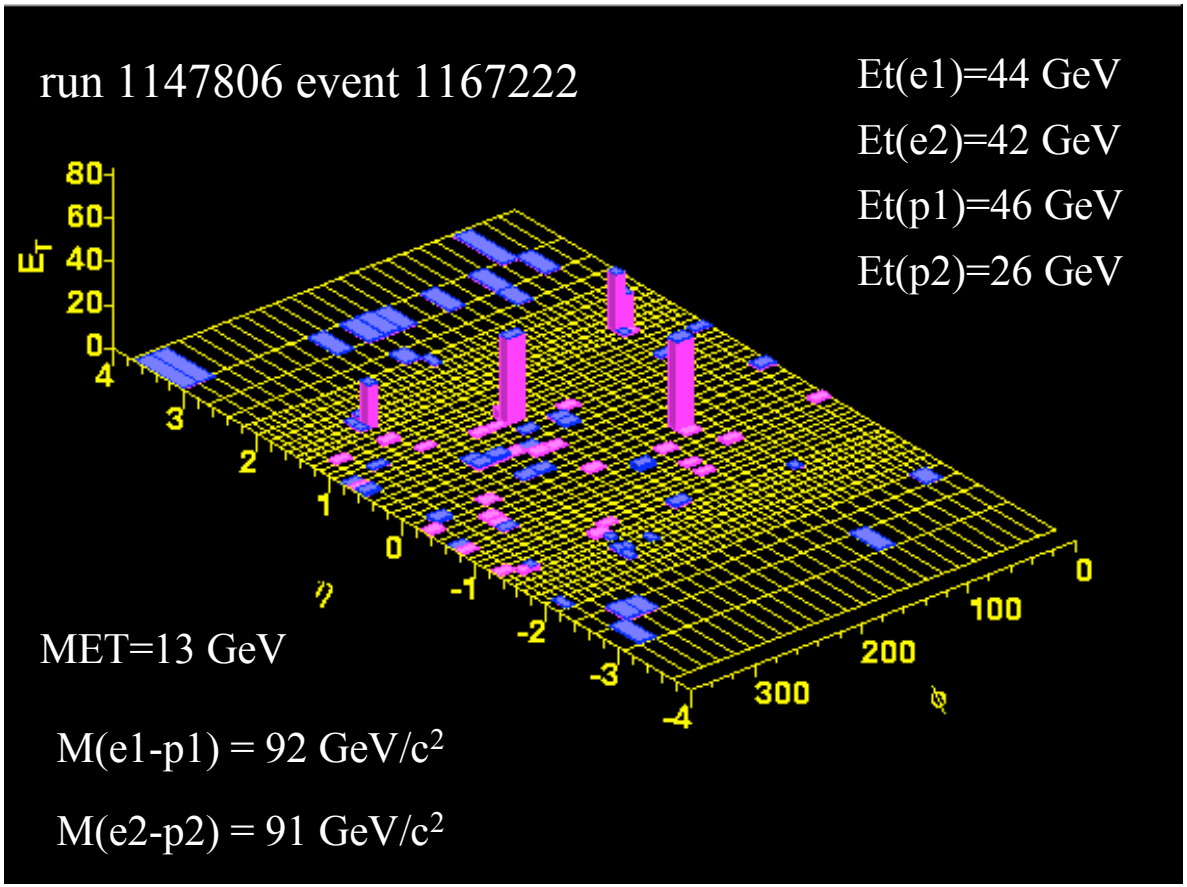


Expect 3 events, observe 3 events

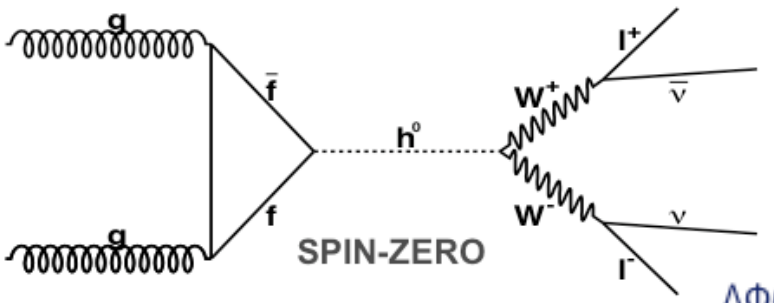
Excited electrons

- 4 EM candidates
  - Could be ZZ event!



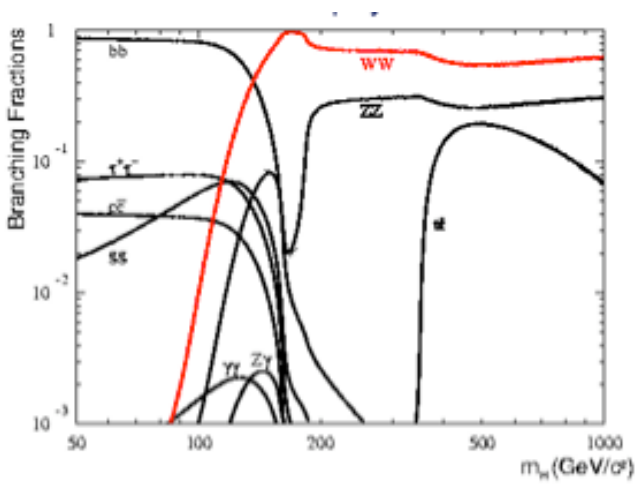


Searches for SM Higgs in WW

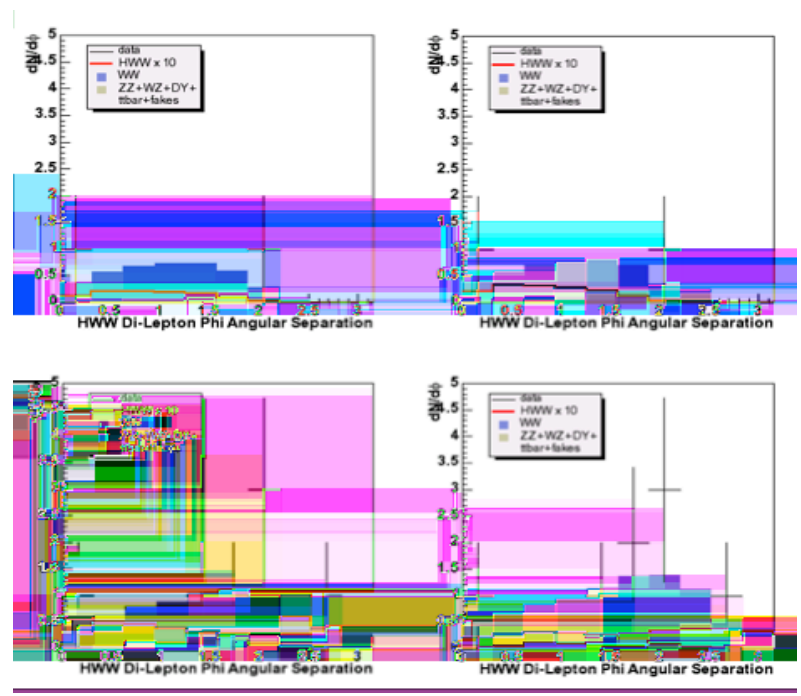


Dominant @ the TeVatron for m(H) > 135 GeV/c^2

ΔΦ(lep1,lep2) distributions of signal and backgrounds can be used to set a 95% CL limit on cross-section x branching ratio of the process

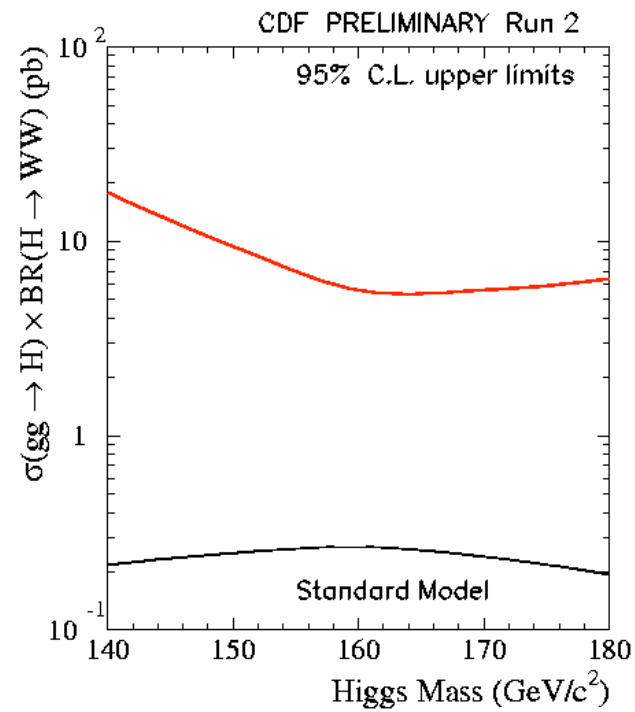


σ·BR(gg→h^0→WW*) as a function of higgs mass



Searches for SM Higgs in WW

higgs mass (GeV)	140	150	160	170	180
$\sigma(gg \rightarrow h^0)$ (pb)	0.45	0.36	0.30	0.25	0.21
BR($H \rightarrow WW^*$)	0.48	0.68	0.90	0.97	0.94
int luminosity (1/pb)	184 ± 11				
total acceptance (%)	0.124±0.012	0.228±0.023	0.402±0.040	0.476±0.048	0.449±0.045
expected signals	0.10±0.01	0.15±0.02	0.22±0.03	0.22±0.03	0.17±0.02
WW background	3.51±0.41	3.82±0.45	4.45 ± 0.52	5.38±0.63	6.49±0.76
all other background	0.68±0.16	0.90±0.24	1.34±0.35	1.91±0.47	2.40±0.55
95% CL limit max-lik (pb)	18.4	9.8	6.2	8.2	8.8
95% CL limit ΔΦ-binned	17.8	9.4	5.6	5.6	6.4



Comparison with THWG

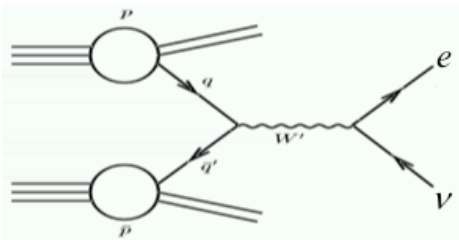
Assumed Higgs Mass (GeV)	140	160	180
Signal Accpt: Ours currently	0.104	0.224	0.172
Interpolated THWG prospect	0.442	0.276	0.176
Backgrounds: Ours currently	4.189	5.788	8.895
Interpolated THWG prospect	8.096	.8096	.6992
S/sqrt(S+B): Ours currently	.0503	.0914	.0570
Interpolated THWG prospect	0.151	0.265	0.188

@ 184/pb scale

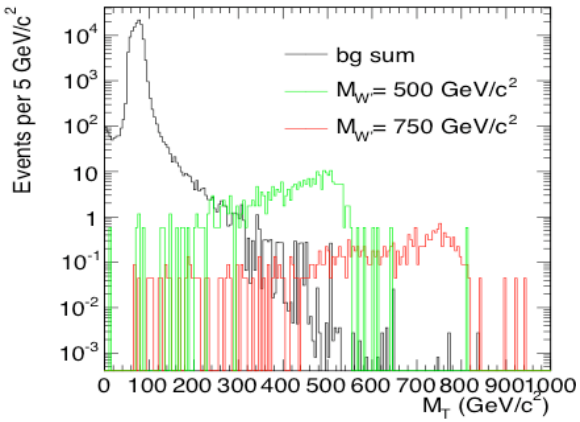
- THWG prospects are basically for fb^{-1} scale, of which excessive signal manipulation and background control are different and easier than when data is lacked

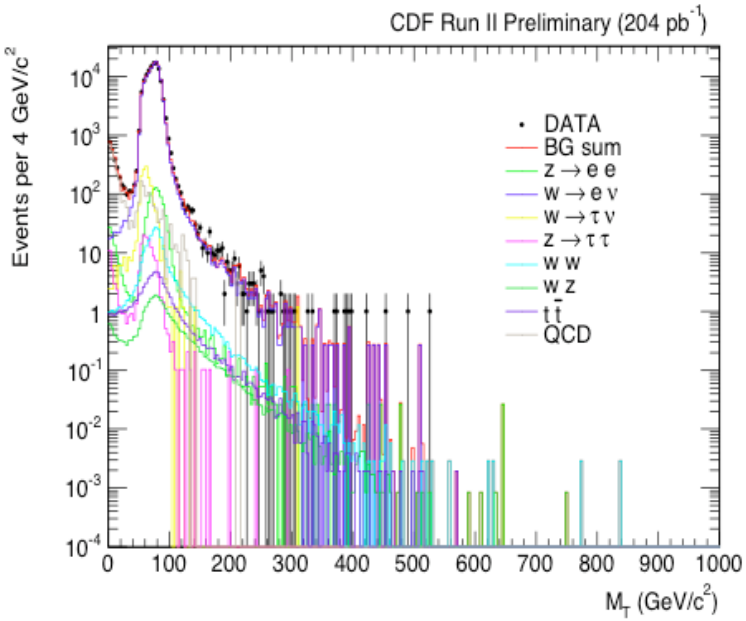
Search for W'

Look for an excess in the "electron" and "neutrino" transverse mass distribution over standard model expectation.



1. One Central electron (Et > 25 GeV)
2. MET > 25 GeV
3. Dilepton events (e e or e mu) removal
   - for removal of ttbar, DY and diboson
   - 2nd electron Et > 15 GeV in central or plug
   - muon Pt > 15 GeV
4. 2/5 < "MET / eET" < 5/2
   - to reduce QCD background





	Number of events in M_T (GeV/c^2)		
	> 200	> 250	> 300
Expected (SM)	66.1	24.8	10.0
Observed	72.0	33.0	14.0
95% CL	22.6	19.3	12.1

We excluded 23 or more signal events at 95% confidence level above M_T = 200 GeV/c^2 at 204 pb^-1 of data

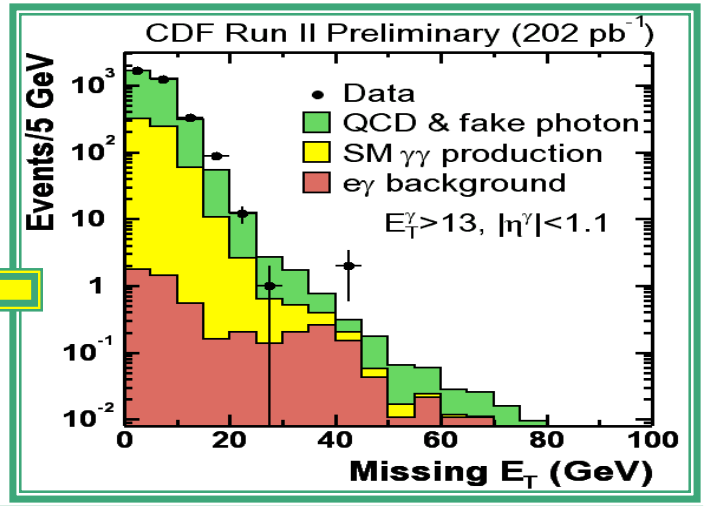
without systematic uncertainties.

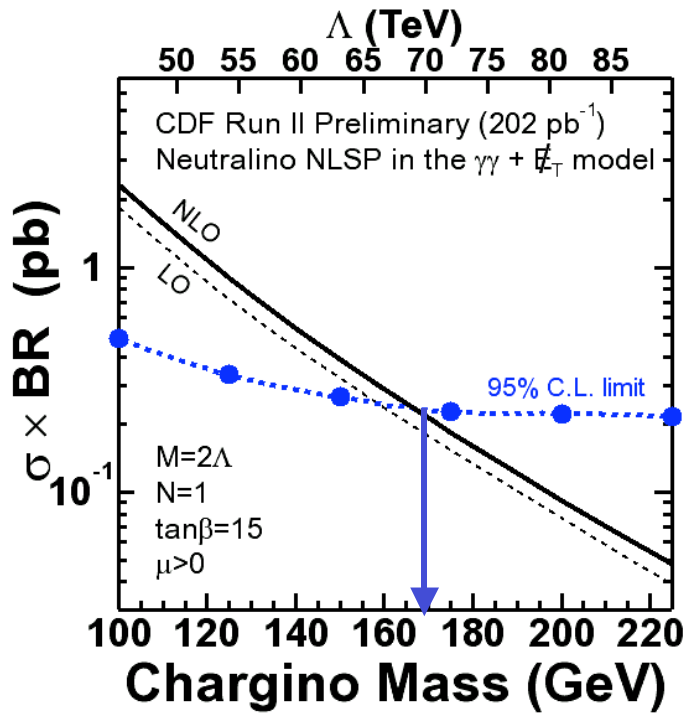
SUSY searches in diphoton + $\not{E}_T$

GMSB scenario
NLSP = $\square^0_1 \square \quad \square G$

$p\bar{p} \square (X \square) \square^0_1 \square^0_1$ → $2 \square + \not{E}_T$

Sample selection (202 pb^{-1})
- 2 central photons E_T > 13 GeV
- cosmic rays and beam halo rejection



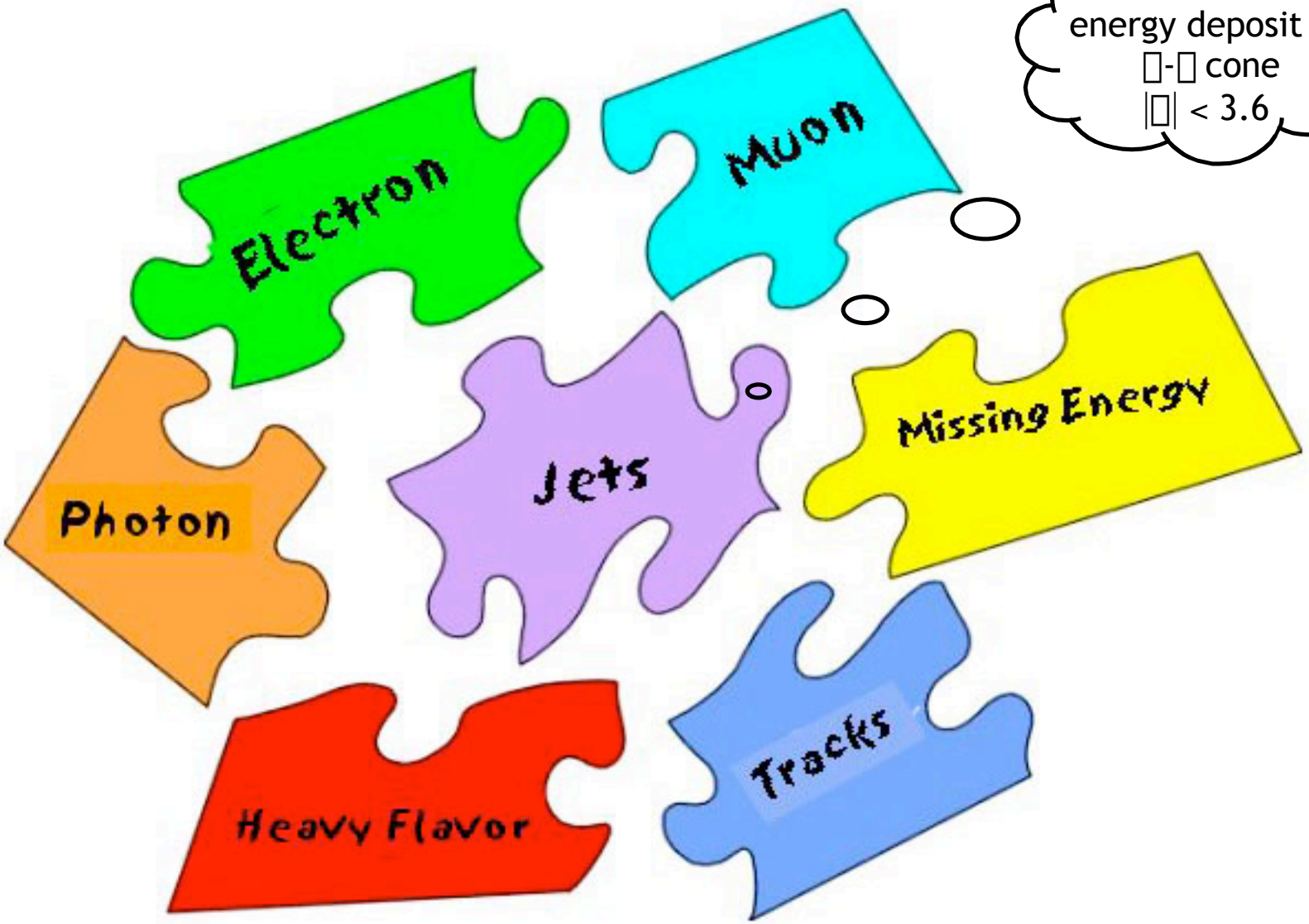


For E_T > 45 GeV
Expected Background: $0.60^{+0.50}_{-026} \pm 0.29$
Observed: 0

→ **$M(C_1)$ > 168 GeV @ 95% C.L.**

Completing the puzzle (almost..)

Jets:
energy deposit in
ϕ-η cone
$|\eta| < 3.6$



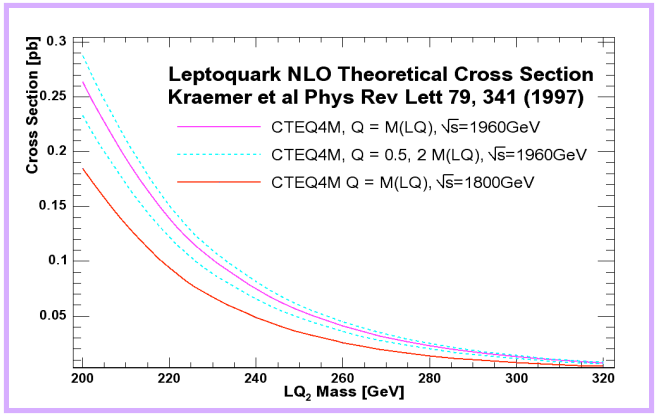
Leptoquarks

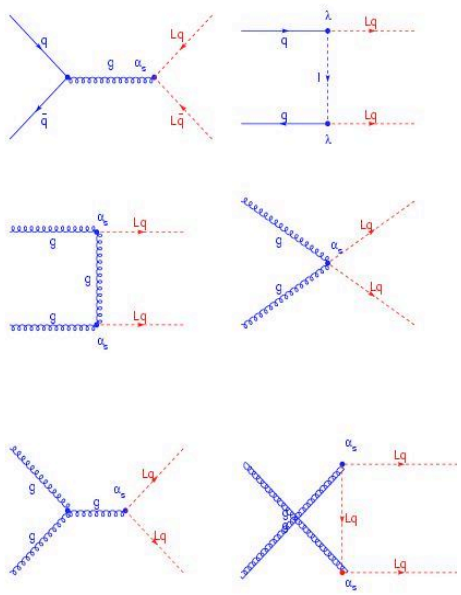
Several extension of the SM model
(GUTS, Technicolor, Compositeness, RPV-SUSY)
assume an additional symmetry
between leptons and quarks

Carry both lepton (L) and baryon (B) numbers
Couple to quark and lepton of the same generation

quarks	u	c	t
	d	s	b
leptons	ν_e	ν_μ	ν_τ
	e	μ	τ

At the TeVatron they are pair produced





Their decay is controlled by λ = BR (LQ→ lq)

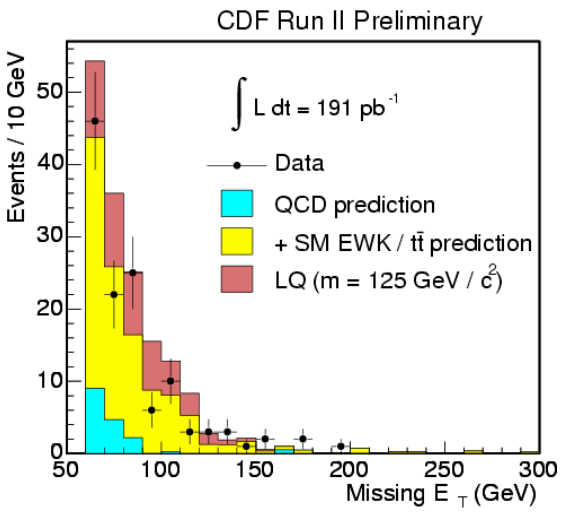
Experimental signature:
high P_T isolated lepton(s)
and/or $\not{E}_T$ + 2 jets

LQ search in □□jj

Signature: Large MET and 2 jets

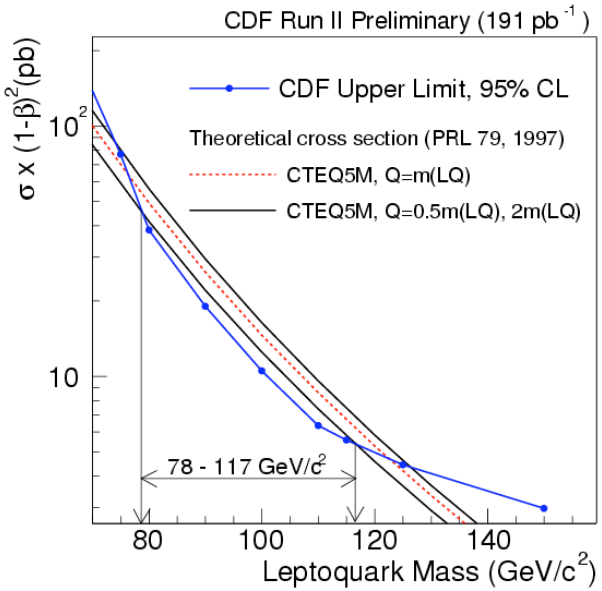
□′ =BR(LQ□ □q) = 1

Flavor independent



Sample Composition:
- W/Z + jets
- top
- QCD fakes

Expected =118±14



124 events seen after analysis cuts

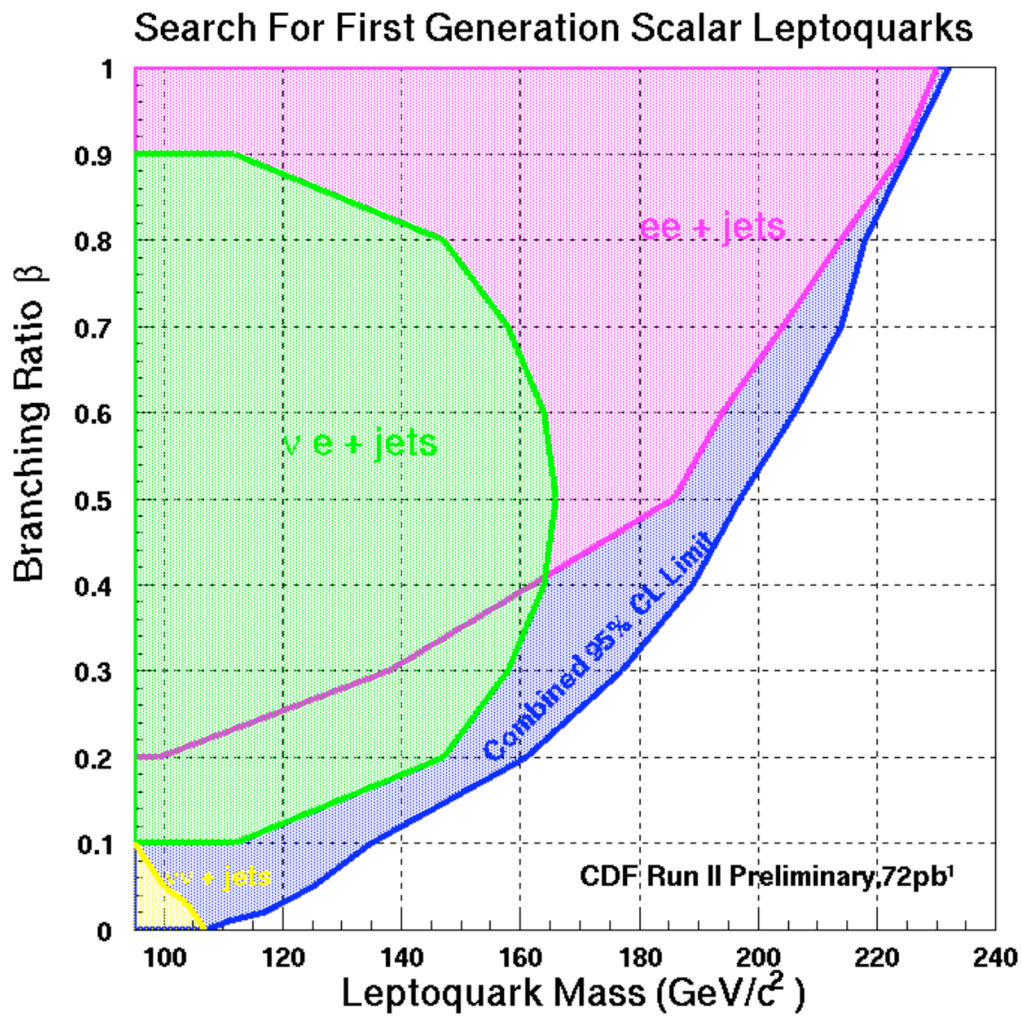
M(LQ) > 117 GeV/c² @ 95 % C.L.

1st generation LQ

$\beta' = BR(LQ \to eq) = 1$

$\beta' = BR(LQ \to eq) = 0.5$

$\beta' = BR(LQ \to \nu q) = 1$



2nd generation LQ

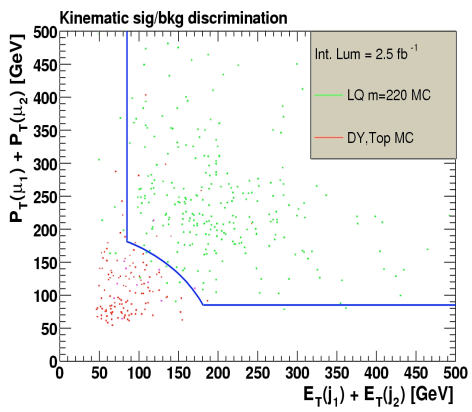
Signature: 2 muons and 2 jets

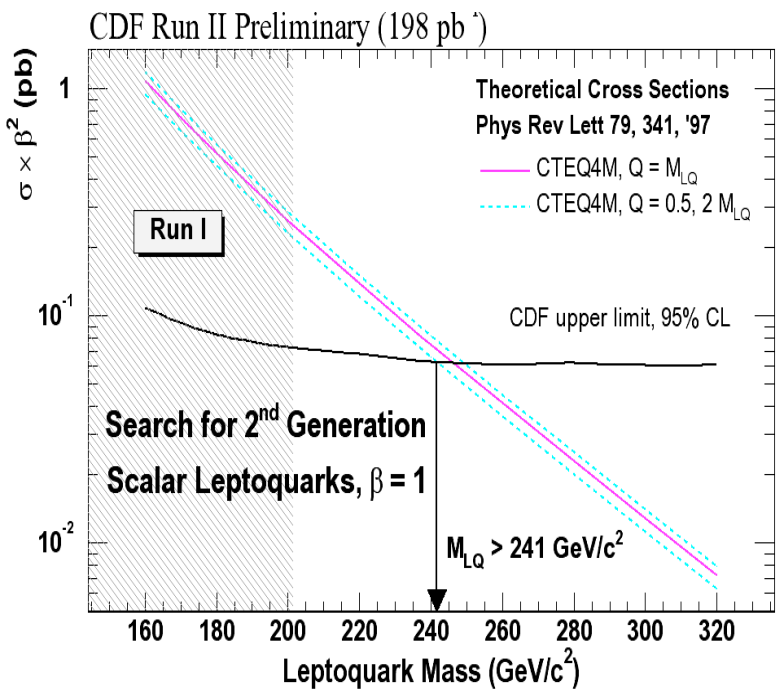
□ =BR(LQ□ □q) = 1

Tight □'s selection complemented by □ + track selection

Background:
- Z + 2 jets
- top
- QCD fakes

expected 3.15 ± 1.17





2 events seen after analysis cuts

M(LQ) > 241 GeV/c^2 @ 95% C.L.

2nd generation LQ

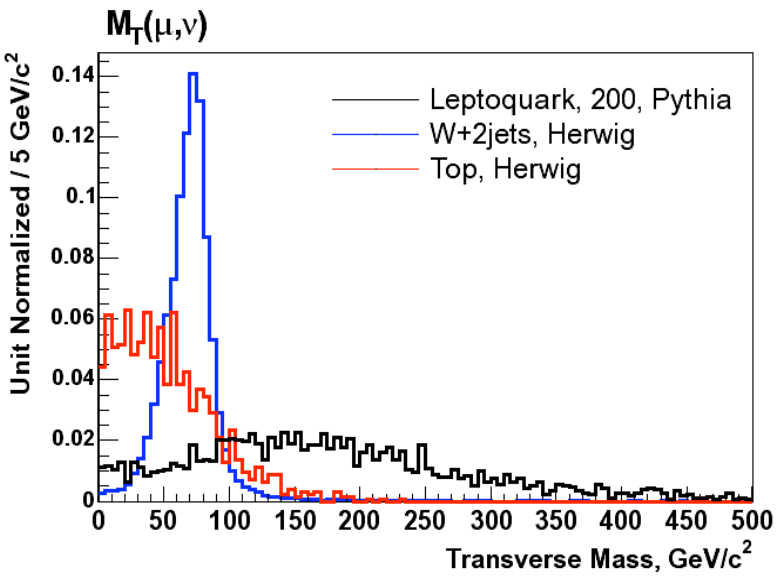
β =BR(LQμ μq) = 0.5

In Progress

Signature: 1 muon, E_T and 2 jets

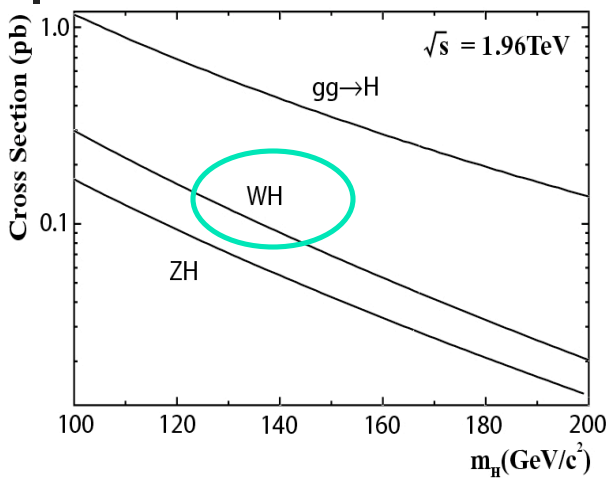
Backgrounds
- W+2jets
- Top (W-->munu)
- QCD

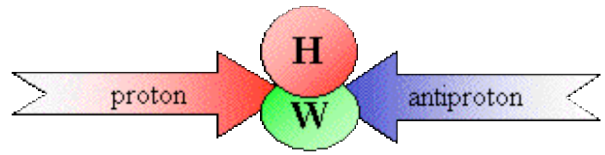
Data Selection
- ✓ Muon P_T>25, MET>60 GeV
- ✓ 2 jets, @ E_T>30GeV
- ✓ Veto aligned (Muon, MET) and (MET,jets)
- ✓ E_T(jet1)+E_T(jet2) > 80 GeV
- ✓ M_T(MET,Muon) > 110 GeV
- ✓ MET/Sqrt(SumEt) > 4.5



DØ Run I Limit	180 GeV
CDF Run I Limit	164 GeV
CDF Run II 200pb^{-1} Sensitivity	~200 GeV

S.M. Higgs Searches at CDF

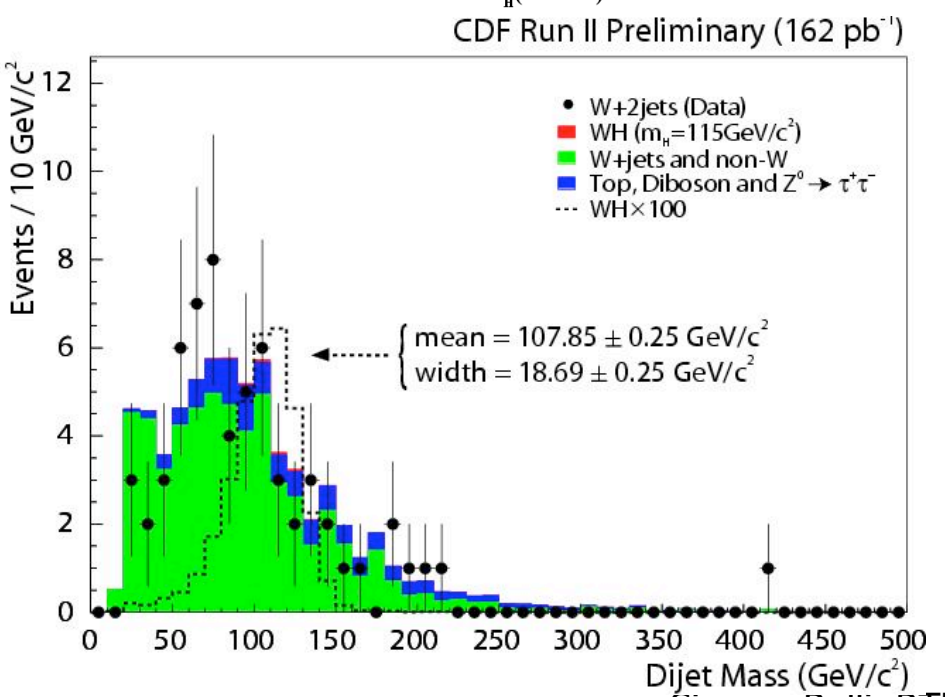




$p\bar{p} \to WH \to l\nu b\bar{b}$

Selection:

- High pt lepton data
- One high pt central *e* or μ, large MET (MET>20 GeV)
- 2 jets (at least one is tagged as b-jet)
- Veto events with >1 lepton (suppress ttbar)

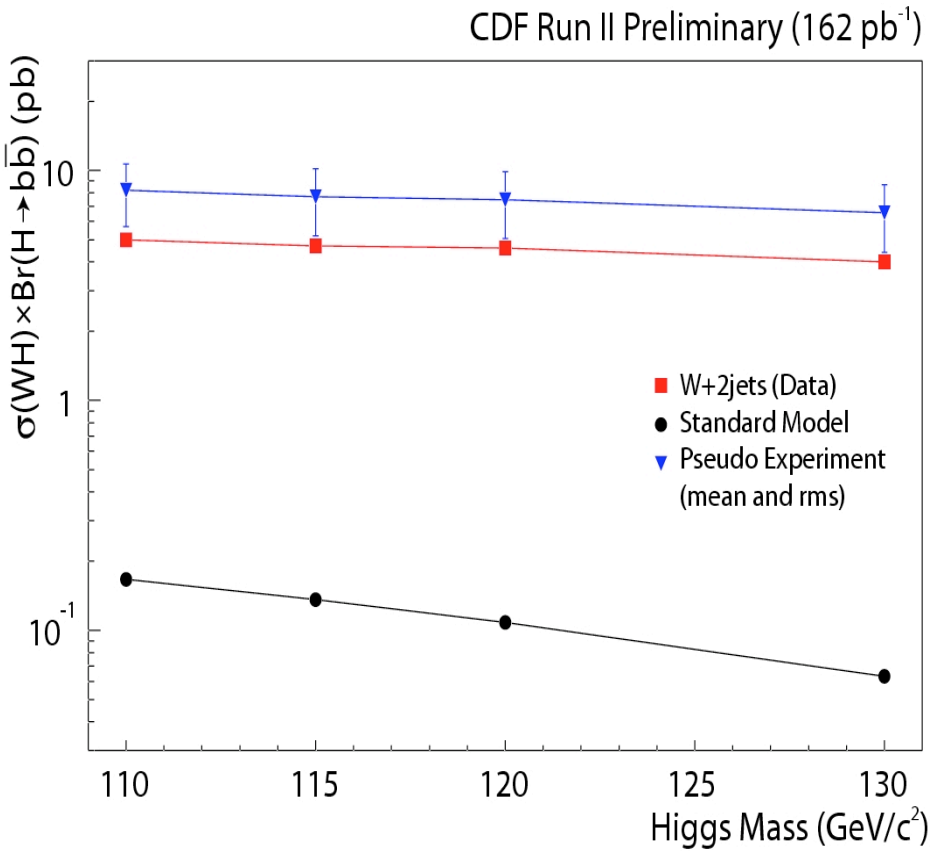


Backgrounds:

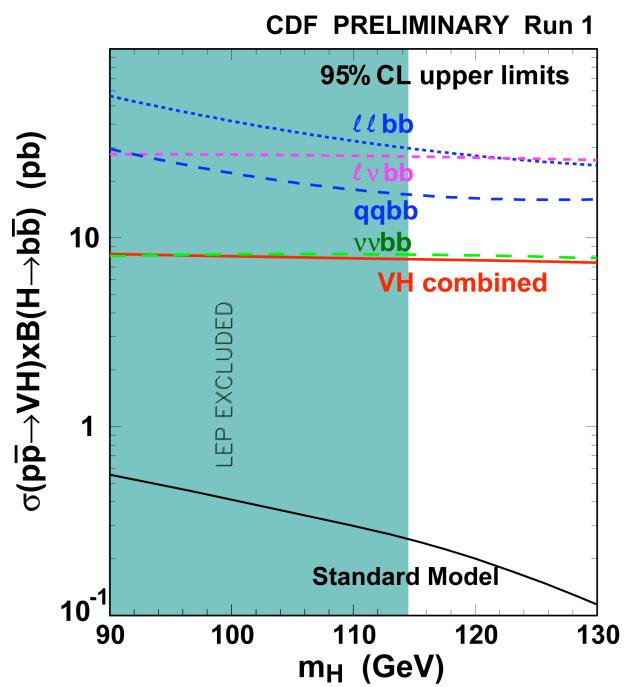
- Mistags
- Wbb, Wcc, Wc
- QCD
- tt, single t, di-boson, Z(→ tt)

S/ B = 0.054

Higgs Search (cont'd)



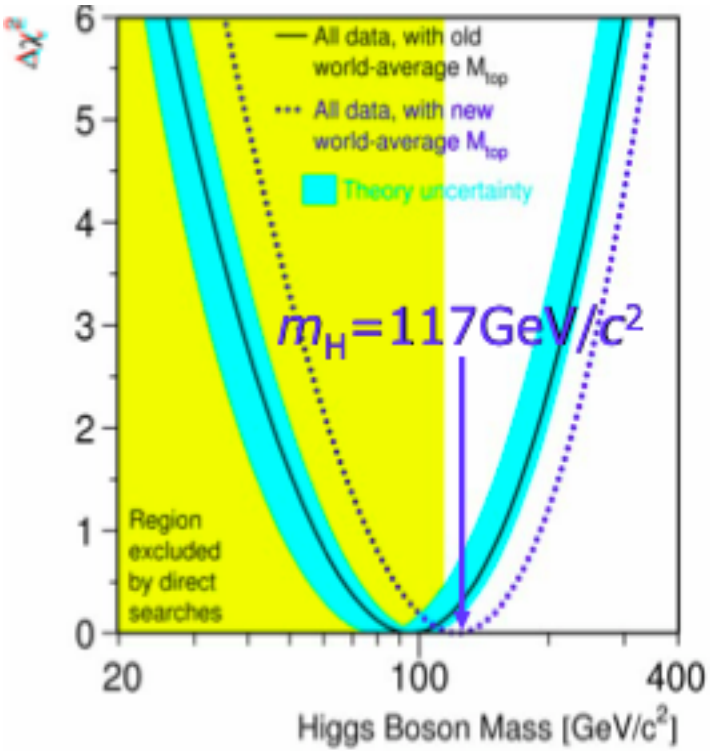
Future improvements :
Include forward electron
Improvement jet energy resolution
Improve b-tagging
Combine with other channels

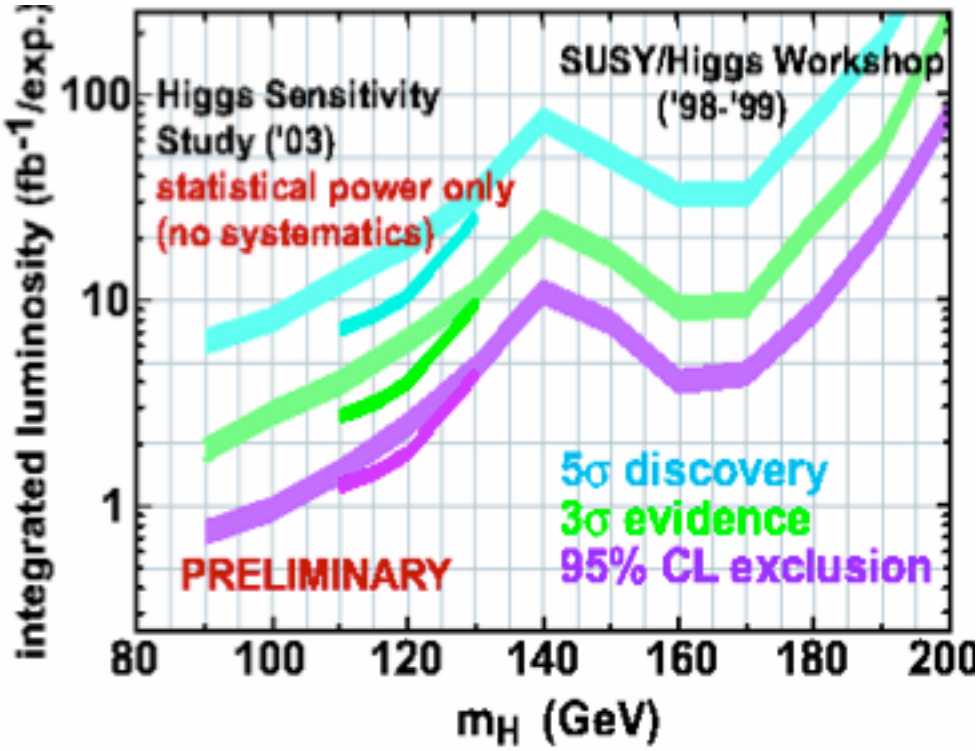


Improved limit over Run1, but sensitivity of current search is limited by statistics

Higgs Sensitivity in Run II

Still much more luminosity needed

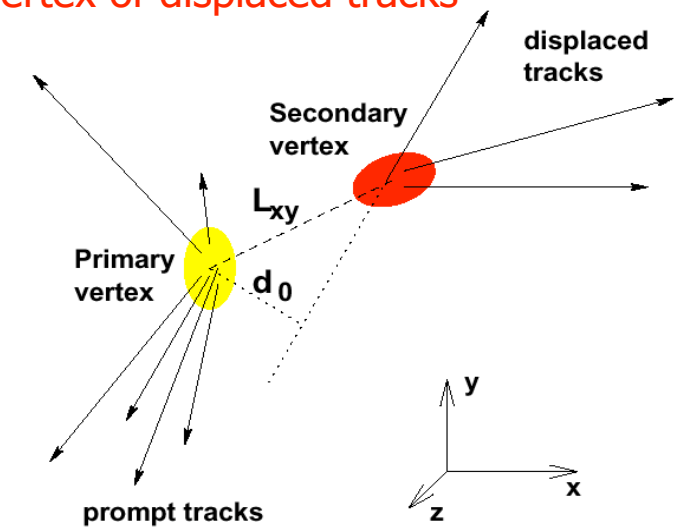




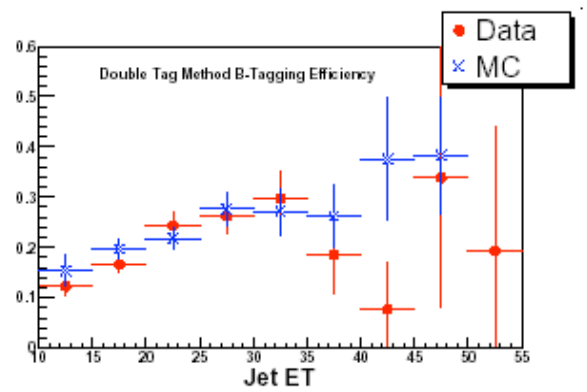
Searches for exotica in MET + HF-jet

B-hadrons are long-lived and massive

Vertex of displaced tracks



B-tagging efficiency per jet



Physics Processes

SUSY

- Sbottom $\tilde{b}_1 \to b\tilde{\chi}_1^0$
- Stop $\tilde{t}_1 \to c\tilde{\chi}_1^0$
- Gluino $\tilde{g} \to b\tilde{b}_1$

Higgs

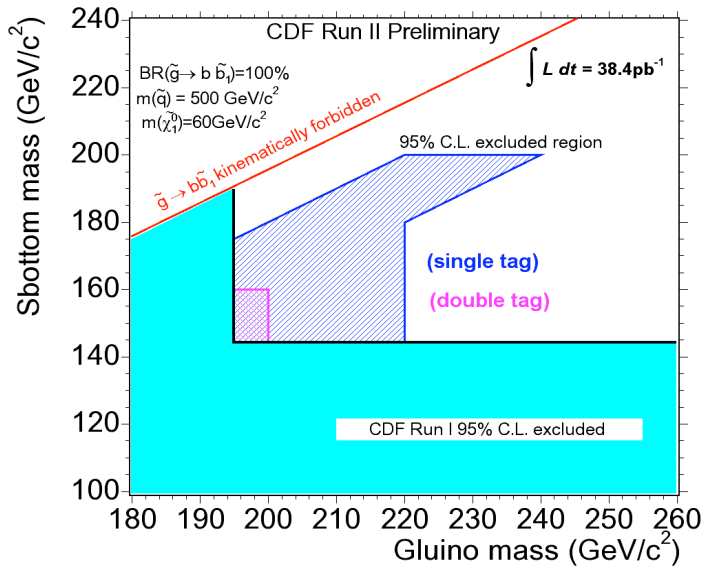
- SM Higgs $ZH \to b\bar{b}\nu\bar{\nu}$

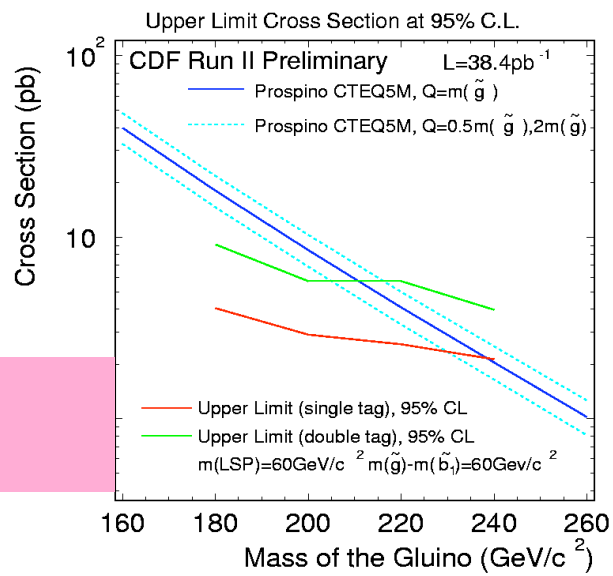
Searches for sbottom from gluino decay

- Squarks and gluinos – relatively high cross sections
  - But difficult to detect – jet-based searches
- Search for scalar Bottom quark:
  - Gluino pair production:

    g →sbottom + b

    (4 b-jets)
  - Sbottom pair production
- Use Missing Et + jets data sample
  - 1st Run 2 search to tag b-jets
- Analysis on a small sample so far
  - Update coming soon

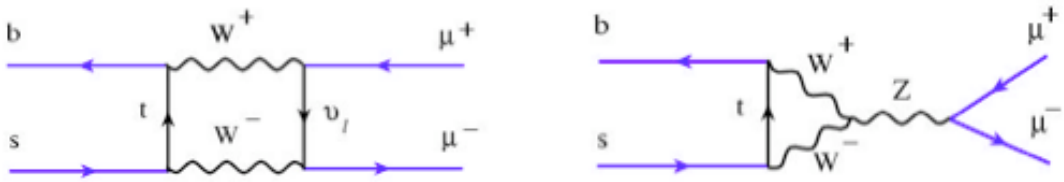




Single tag yields better limit on small data sample
Double tag dominated by small statistics

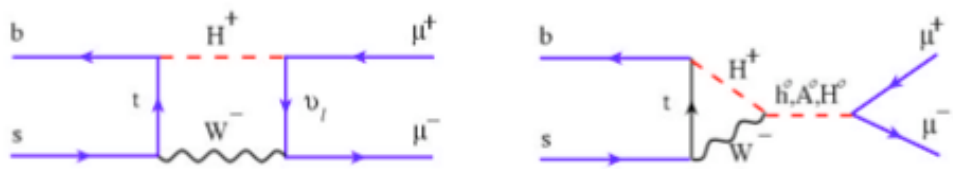
SUSY in B decays

In the Standard Model B→μμ is a FCNC decay…
only possible at the loop level



BR(B_s□ □□) ~ 3.5 □10^{-9}

Several extensions to SM allow for BR >> BR(SM)

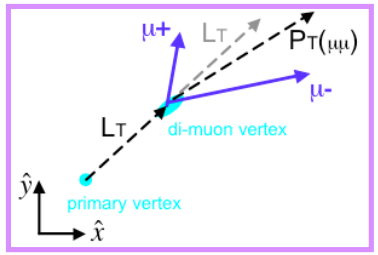


BR(B_s□ □□) enhanced by factor 10-1000 (tan□)

Discriminating variables:
$m_{□□}$, c□, □□ (dimuon, vertex) & isolation

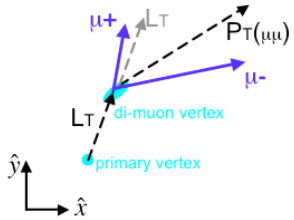
For real B_s→μ+μ− expect:

- $M_{\mu\mu} = M(B_s)$
- $\lambda = c L_T M_{\mu\mu}/P_T(\mu\mu)$ to be large
- L_T and $P_T(\mu\mu)$ to be co-linear
- few additional tracks



In general:

- $M_{\mu\mu} \neq M(B_s)$
- $\lambda = c L_T M_{\mu\mu}/P_T(\mu\mu)$ will be smaller
- L_T and $P_T(\mu\mu)$ will not be co-linear
- more additional tracks



B_s □ □□

Collect sample using Di-Muon Triggers

↓ **76k events**

Make reconstruction requirements & Constrain to a common 3D vertex

↓ **2981 events**

Apply cuts to discriminate Signal from Background

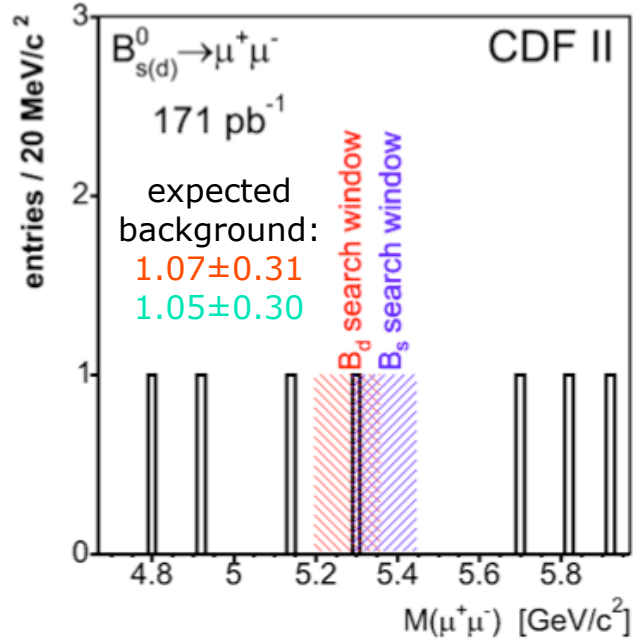
↓ **? events**

Estimate BR using:

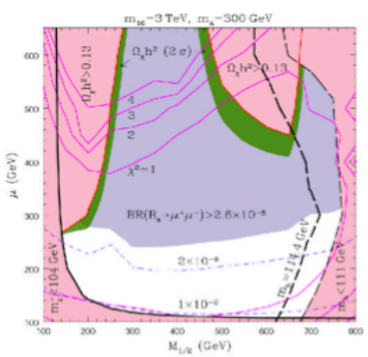
$$BR(B_s \to m^+m^-) = \frac{(N_{candidates} - N_{bg})}{a \cdot e_{total} \cdot s_{Bs} \cdot \int Ldt}$$

Strategy:

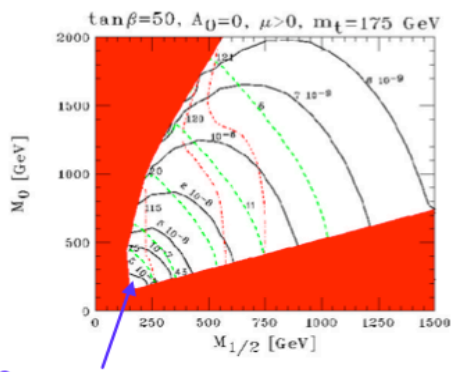
- "blind" ourselves to data in signal region
- use sideband data to understand background
- employ *a priori* optimiztn
- don't "open box" until expected sensitivity warrants (< 0.5 RunI)



This new limit...



Eliminates this entire plane
(raising MA to ~400 GeV opens it back up).



Just begins to eat into allowed parameter space in this plane.

At 90% CL:

BR($B_s \to \mu^+\mu^-$) < 5.8 x 10^{-7}

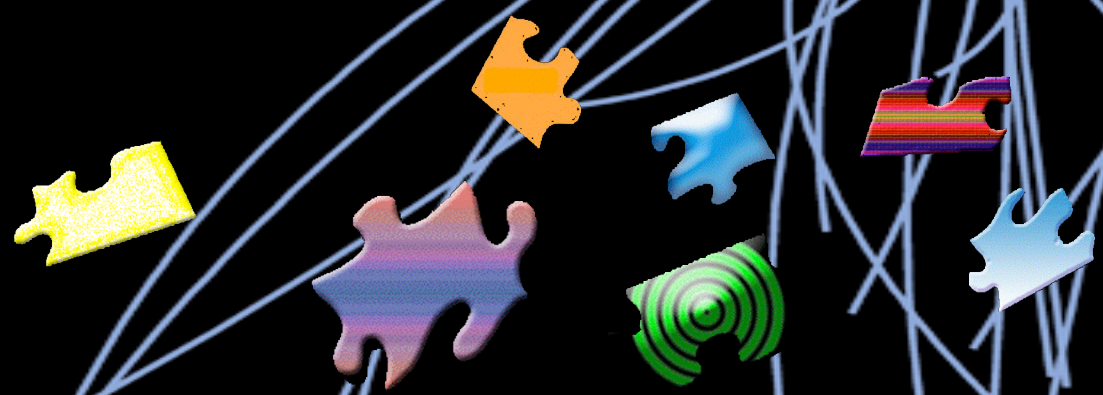
BR($B_d \to \mu^+\mu^-$) < 1.5 x 10^{-7}

Conclusions

Many exciting results are currently produced at CDF
First exotics physics papers will be submitted very soon!

A signature-based approach is complemented by Model-Based searches
same signature, different physics

The Puzzle is becoming more and more interesting!



Backup Slides

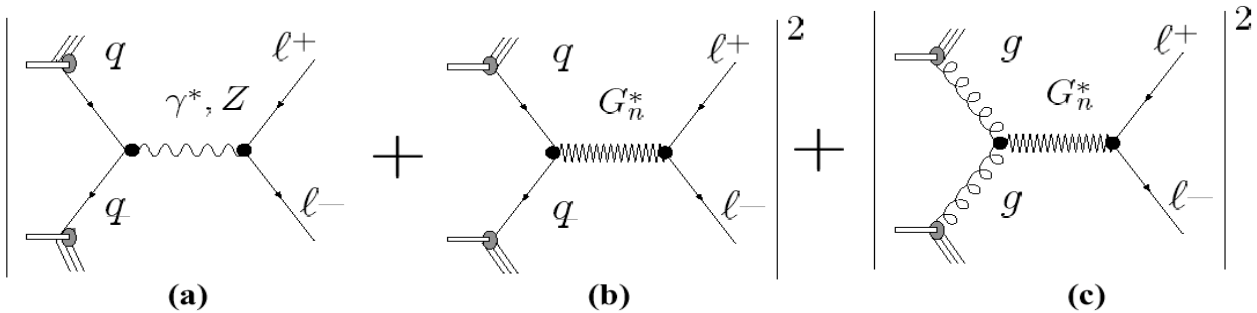
COT aging issues

What does "COT Aging" mean?

- Drift chamber aging
  - Decline in operating performance with time
  - More specifically, loss of gain under irradiation
  - Usually caused by deposits on wire surfaces
- How do we detect aging
  - Loss of gain means less charge – shorter pulse widths
  - Decrease of COT hit widths, COT/XFT efficiency
  - Small chambers directly monitor gas going to chamber
- Details:
  - http://www-cdf.fnal.gov/upgrades/cot/aging_committee.html

Large Extra Dimensions (LED)

- Weakness of gravity is explained by Extra Dimensions
  - SM is confined to 3D-world (brane)
  - Gravity propagates in ED and is as strong as other interactions but this is apparent only to (3+n)-dimensional observer
- Can detect LED via virtual graviton effects
  - Searched for anomalies in e^+e^- and $\gamma\gamma$ events



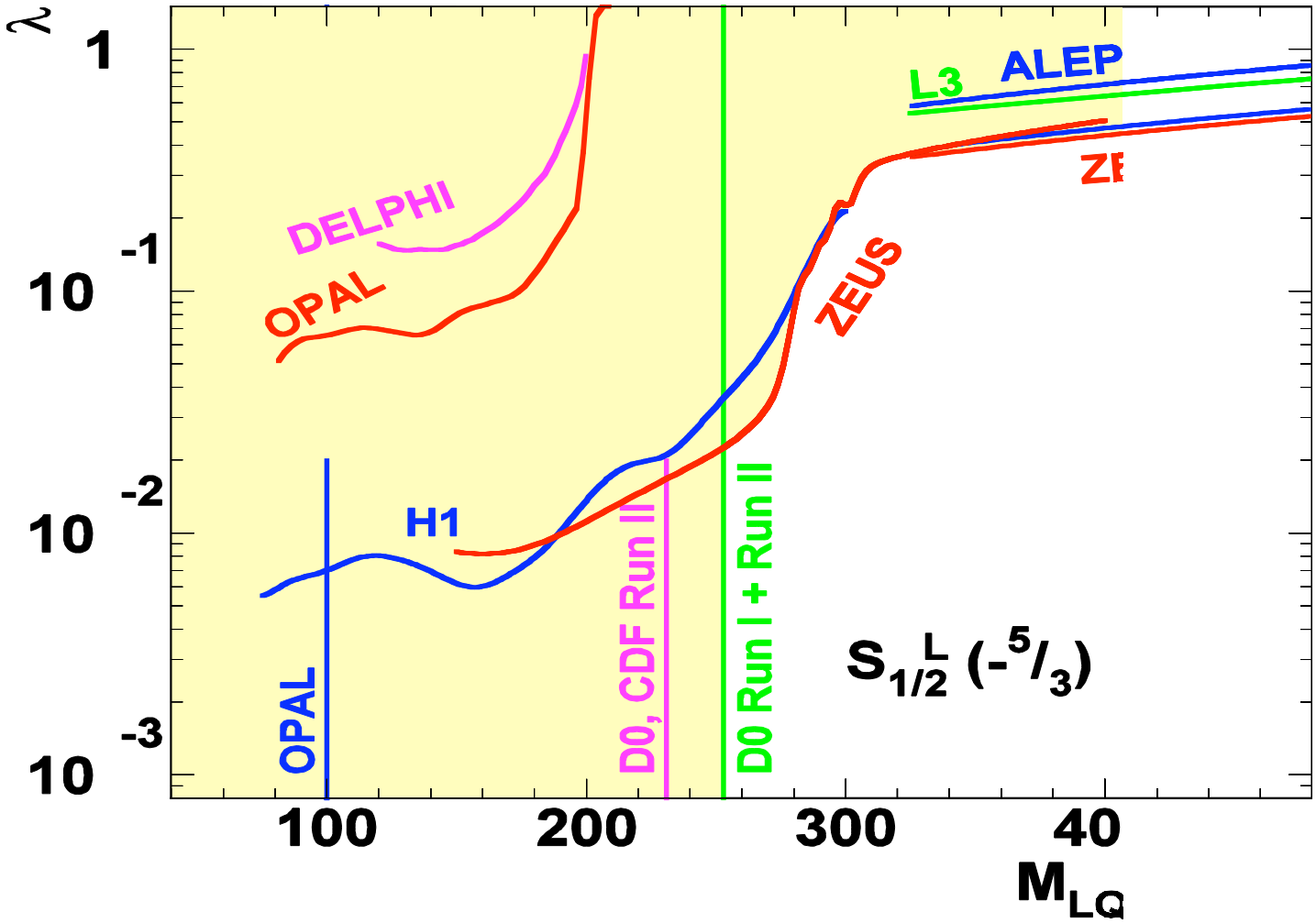
  - Also searched for monojet signatures
    - Jet recoiling against G_n

Old Higgs mass limit from M_{Top}

Old:

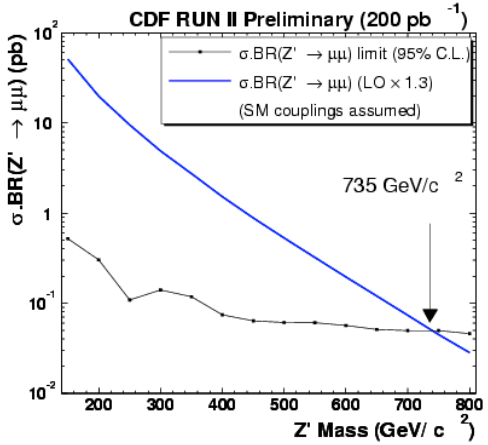
$$
\begin{aligned}
M_{top} &= 174.3 \pm 5.1 \text{ GeV} \\
\log M_H &= 1.98^{+0.21}_{-0.22} \\
M_H &= 96^{+60}_{-38} \text{ GeV} \\
\text{or} &< 219 \text{ GeV } (95\% \text{ CL})
\end{aligned}
$$

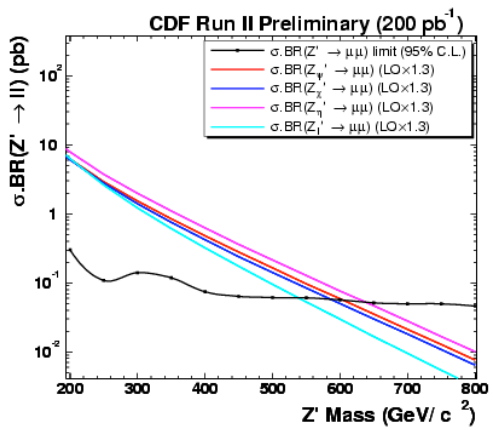
LQ limits compared to HERA



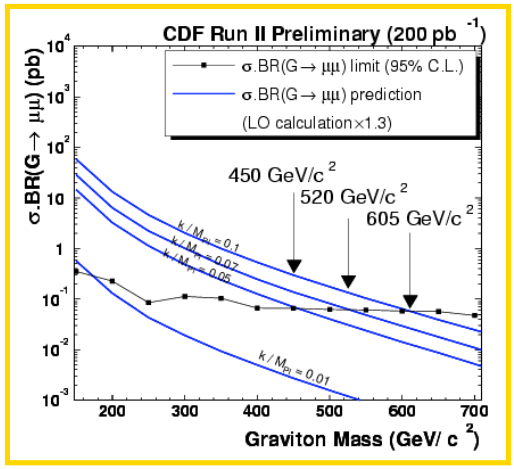
Dimuons searches at CDF

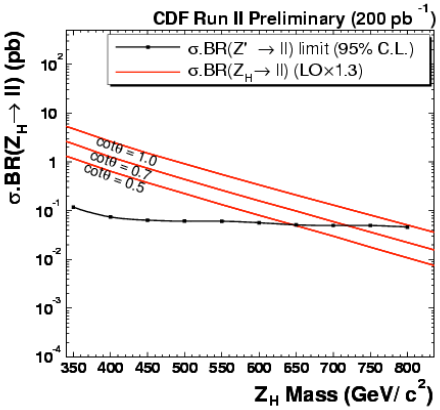
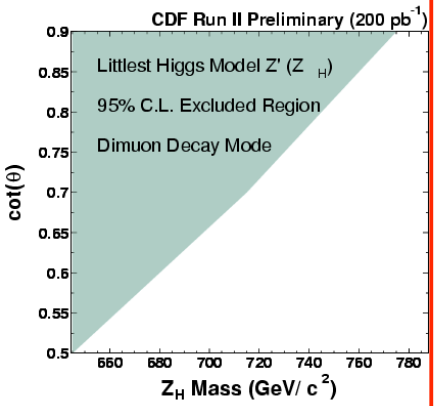
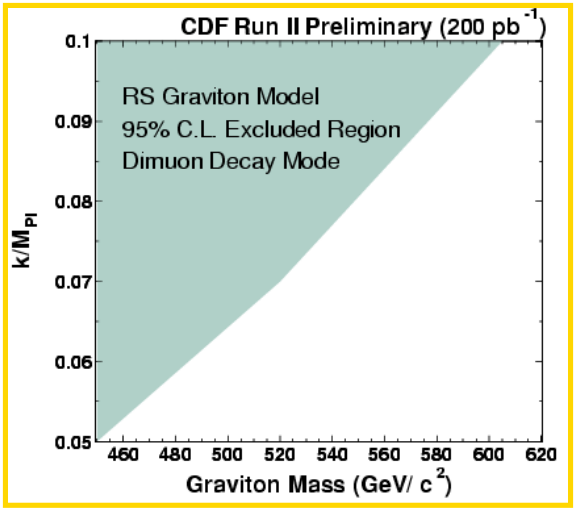
Cross section and mass limits on SM-like and E6 Z':





Cross section and mass limits on RS G:



Cross section and mass limits on Littlest Higgs Z':

We use the same cross section*BR curve as of SM-like Z' for the Littlest Higgs model limits.