CDF Searches for New Physics

energetic leptons, jets, missing energy. . .

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Energetic Lepton Pairs

Energetic leptons have been the key to most of the more recent particle discoveries: τ, b, W, Z and t.

Heavy things tend to have energetic daughters which provide a useful signature. Leptons, especially when isolated. are particularly distinctive.

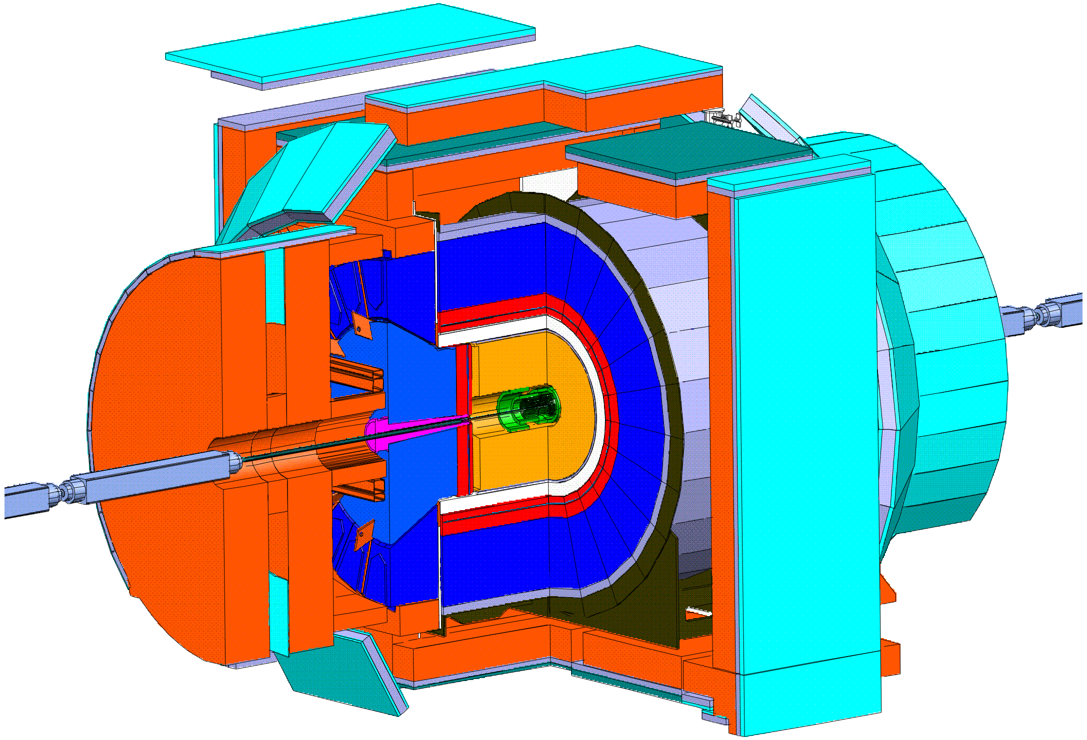
$\longrightarrow$ keep looking at data sets with energetic leptons.

$\star$ at the same time, scrutinize and pin down Standard Model (SM) processes and measure known particle properties.

a good starting point: *di-lepton pairs*, e^+e^- and $\mu^+\mu^-$.

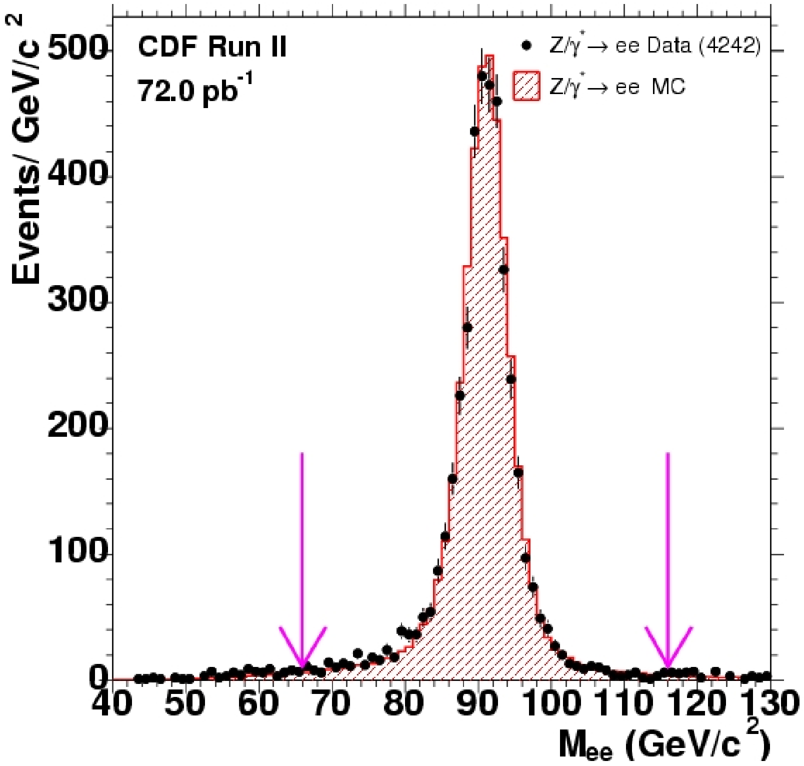
Quick CDF Overview

- upgrades to lepton coverage
- upgrade to calorimeter coverage
- new and better tracking



luminosity available for these analyses:

up to $\sim 200\text{pb}^{-1}$ which is $\sim 2\times$ Run I



The signal for $Z \to \ell^+\ell^-$ is well established.

Can we find anything interesting for $M_{\ell^+\ell^-} \gg M_Z$?

This takes the guise of a Z' search, recently extended to Randall-Sundrum–type models of extra dimensions, etc.

Of course we are not wedded to these models or any other.

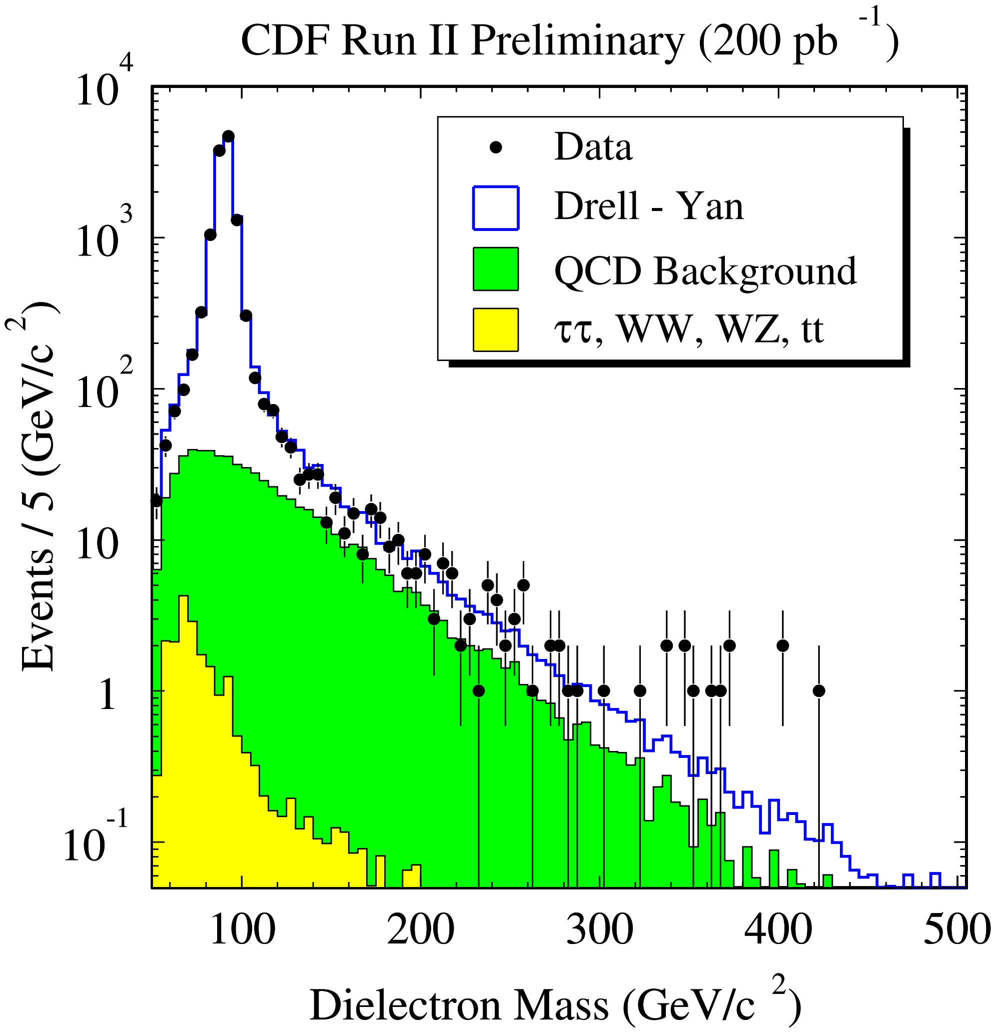
Select events with two energetic leptons (same flavor, opposite sign).

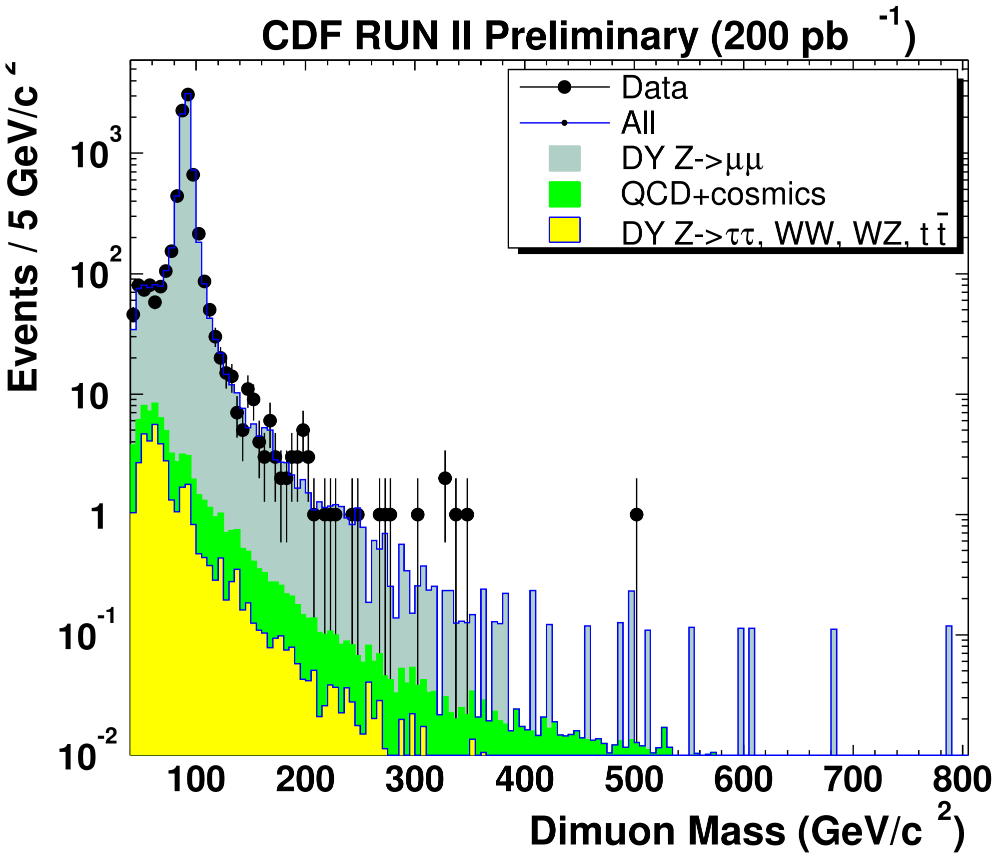
Require the leptons to be 'isolated' – away from any jet activity.
(We are not interested in leptons coming from b decays & such.)

Plot the invariant mass distribution and compare to SM expectations.

- dominated by genuine high-mass dileptons from DY.
- 'fake' leptons in multi-jet events not important at high masses
- pesky cosmic rays in muon channel

electron channel *muon channel*

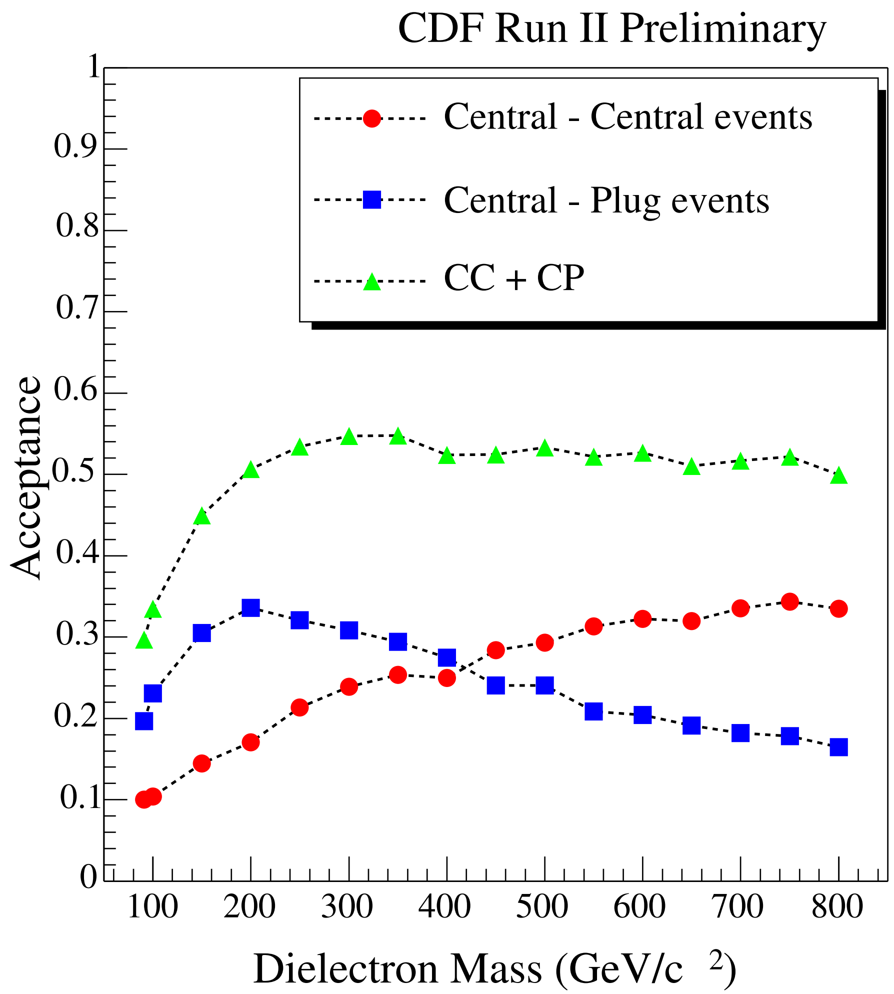




What can the CDF detector bring to bear?

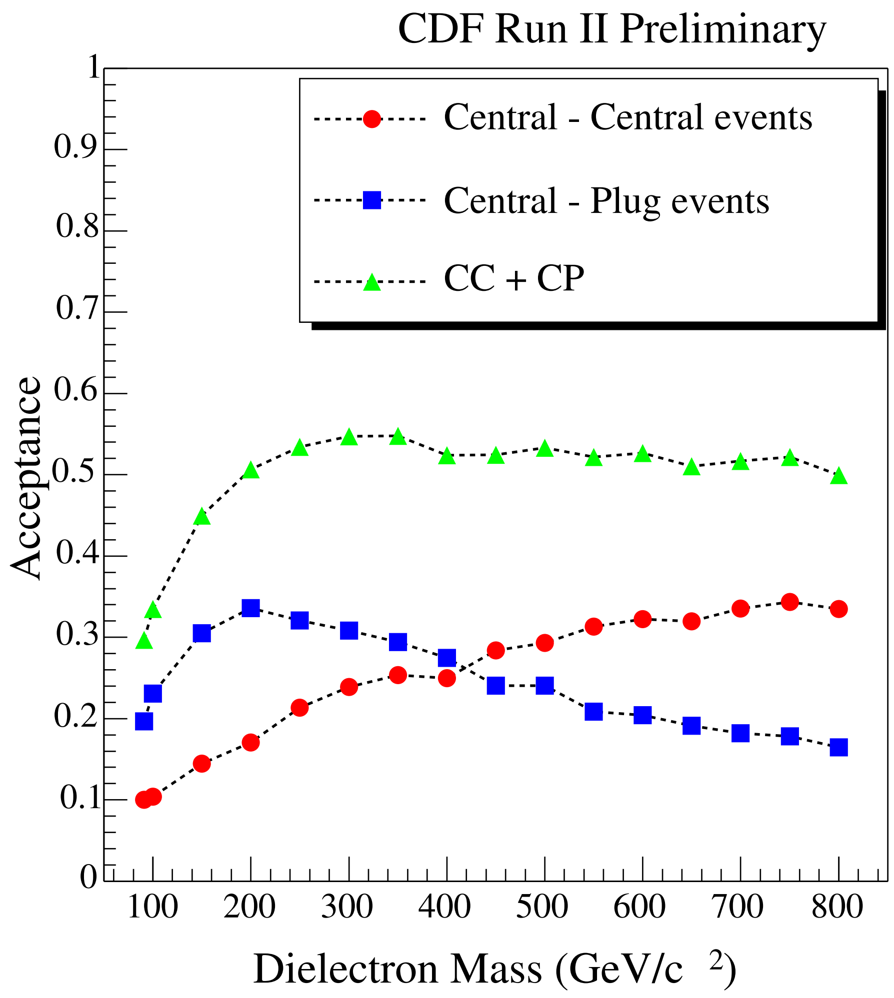
Electron coverage extends to $|\eta| \sim 2.4$ (was ~ 1)

- forward "plug" region is new
  - triggering (not easy) is a success
  - tracking comes solely from Si!
- resolution fairly good
- segmentation OK
  (central e's "clean" w.r.t QCD, plug e's a little "dirty" but OK for this)
- acceptance quite good
- reconstruction consists of matching an EM shower to a track $\epsilon \sim 1$
- identification demands a good shower-track match, and a shower shape consistent with an electron $\epsilon \sim 0.85$



Muon coverage extends to $|\eta| \sim 1$ (was ~ 0.7)

- central muon 'extension' working well
- central tracker (D.C.) covers this range well
- resolution good enough
- muon reconstruction consists of finding 'stubs' in the muon chambers and matching them to tracks in the COT $\epsilon \sim 98\%$
- identification applies quality cuts to the match, and checks for small energy deposition in the calorimetry $\epsilon \sim 90\%$



All searches are a question of backgrounds – what is left after you have applied all your cuts?

For the high-mass di-lepton searches, just three important sources of background:

1. Drell-Yan $p\bar{p} \to \ell^+\ell^-$ – which is irreducible, easily calculable, and poses no special simulation challenges. Known to $\sim$ 10%
2. "fake" leptons, including those which arise from secondary processes such as $b \to c\ell\nu$, photon coversions, $K^+ \to \mu^+\nu$. These cannot be predicted and must be estimated from control samples. Known to $\sim$ 30–50%
3. cosmic rays are not quite negligible in the muon channel, and are surprisingly difficult to assess. Known to $\sim$ 30–50%

Other sources of leptons, such as W+jets, di-bosons and top,
do not contribute in the high mass region.

So we need to estimate how many events we will select, for a given window $M_{\ell^+\ell^-} > M^{(\min)}_{\ell^+\ell^-}$, in the absense of new physics.

$M^{(\min)}_{\ell^+\ell^-}$	electrons		muons	
	expected	observed	expected	observed
150	n/a	n/a	55	58
200	70	71	21	18
250	27	30	9.5	9
300	11	14	5.2	6
350	4.6	8	3.2	1
400	2.0	2	2.3	1
450	0.9	0	1.8	1
500	n/a	n/a	1.2	1

The uncertainty on the total background estimate for, *e.g.*, $M_{\ell^+\ell^-} > 300$ GeV, is about 40% in the electron channel, and 25% in the muon channel.

No *obvious* evidence for physics BSM.

What does this mean? It means there is no new source of high-mass di-lepton pairs, with the same flavor.

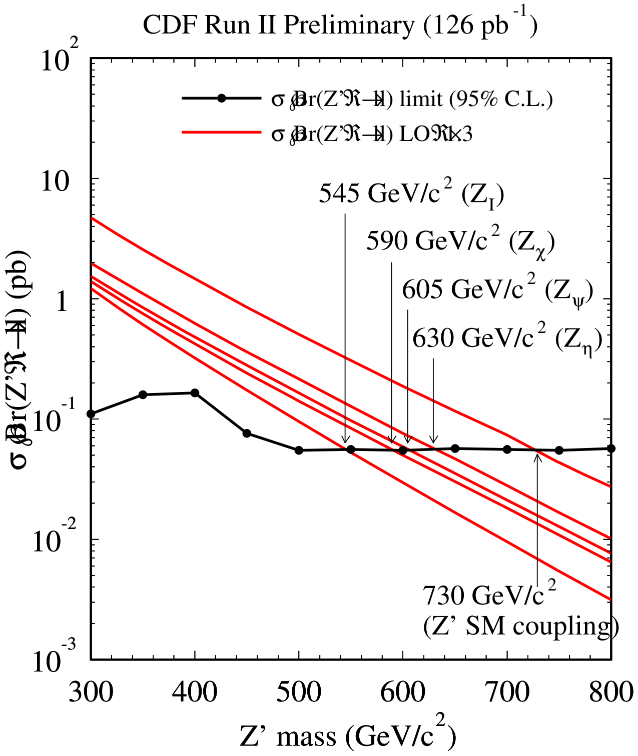
(We have not yet examined $e^{\pm}\mu^{\mp}$ events in this context.
However, we do have results for $H^{++} \to \ell^{+}\ell'^{+}$.)

We can make direct tests of specific models to constrain them or rule them out. CDF have investigated a number of models which would lead to a signal in these channels.

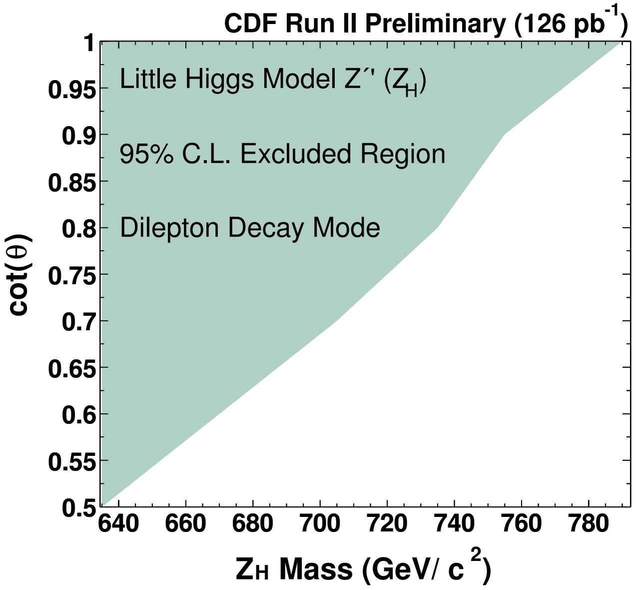
- so-called 'sequential' Z'
- theoretically-motivated Z' models (Z'_{ψ}, Z'_{χ}, Z'_{η}, Z'_{I})
- Z_H from a little Higgs model
- technicolor particles ρ_T and ω_T
- Randall-Sundrum gravitons
- large extra dimension theories
- R-parity violating sneutrinos

example limits & exclusions

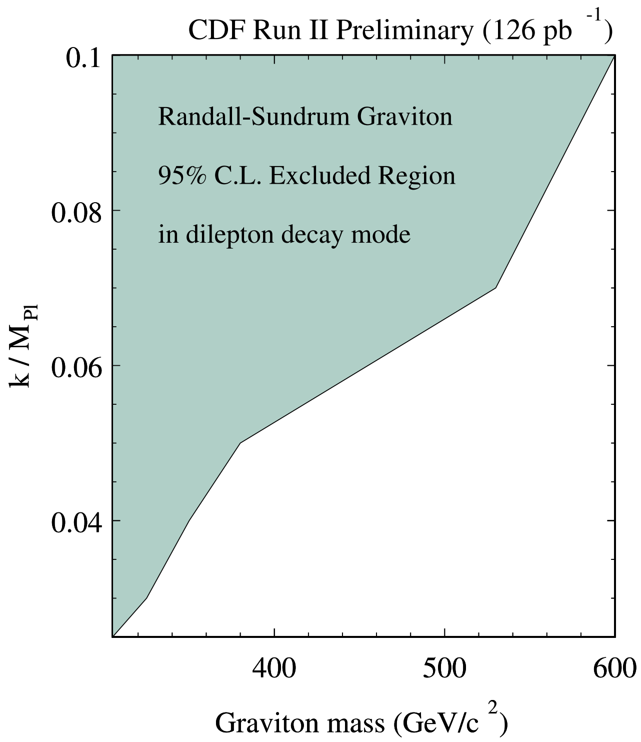
regular Z''s



little Higgs Z_H



RS gravitons

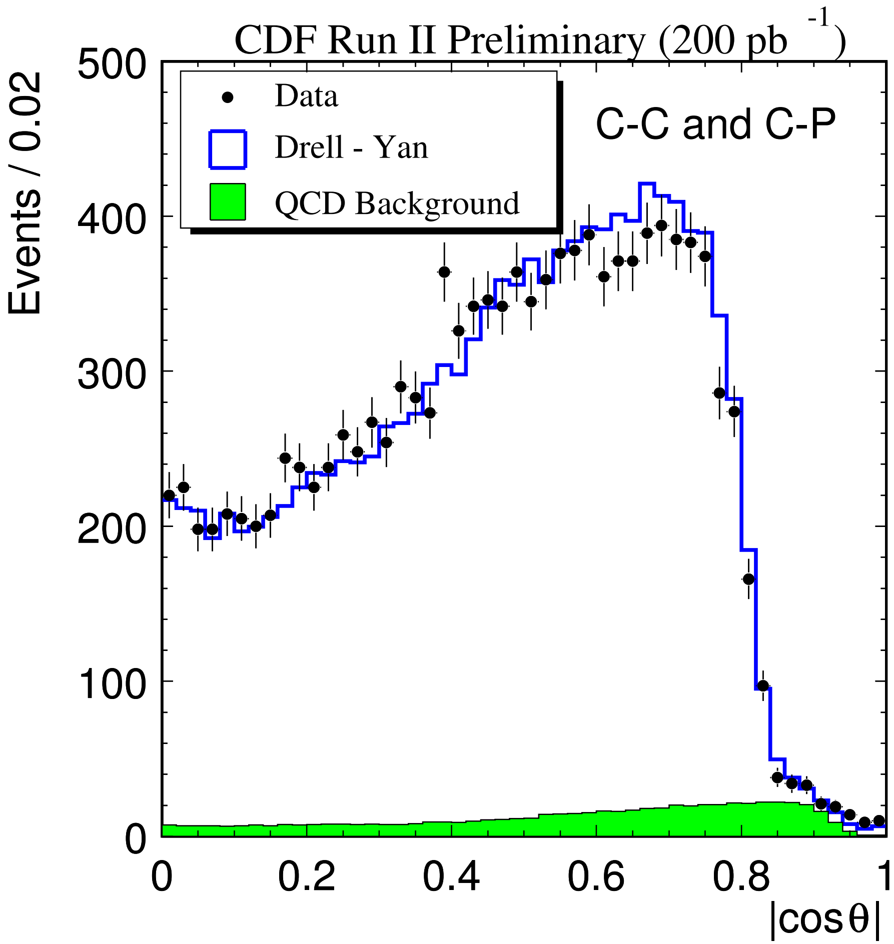


Note: The Z' signals tend to be quite narrow, while the graviton signals are broad. In this sense they cover more possibilities than one might realize.

This is not the end of the story!

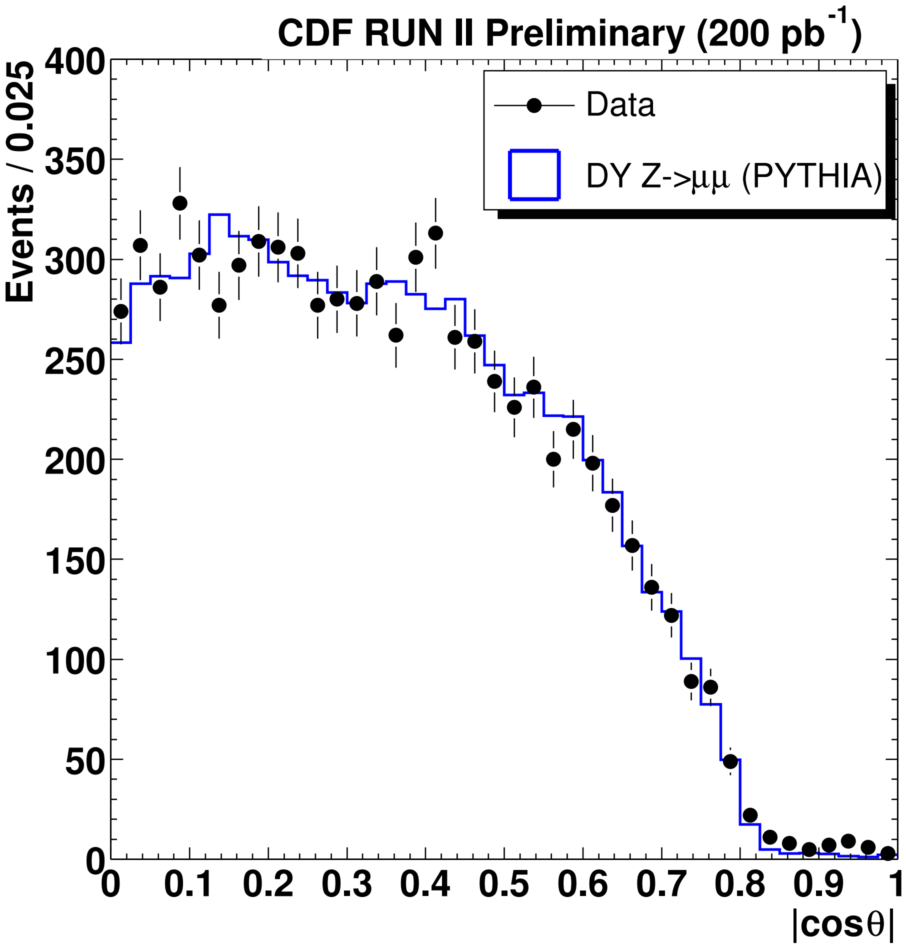
Maybe one needs to look at some shapes or other distributions.

Example: the decay angle in the di-lepton c.m. frame.

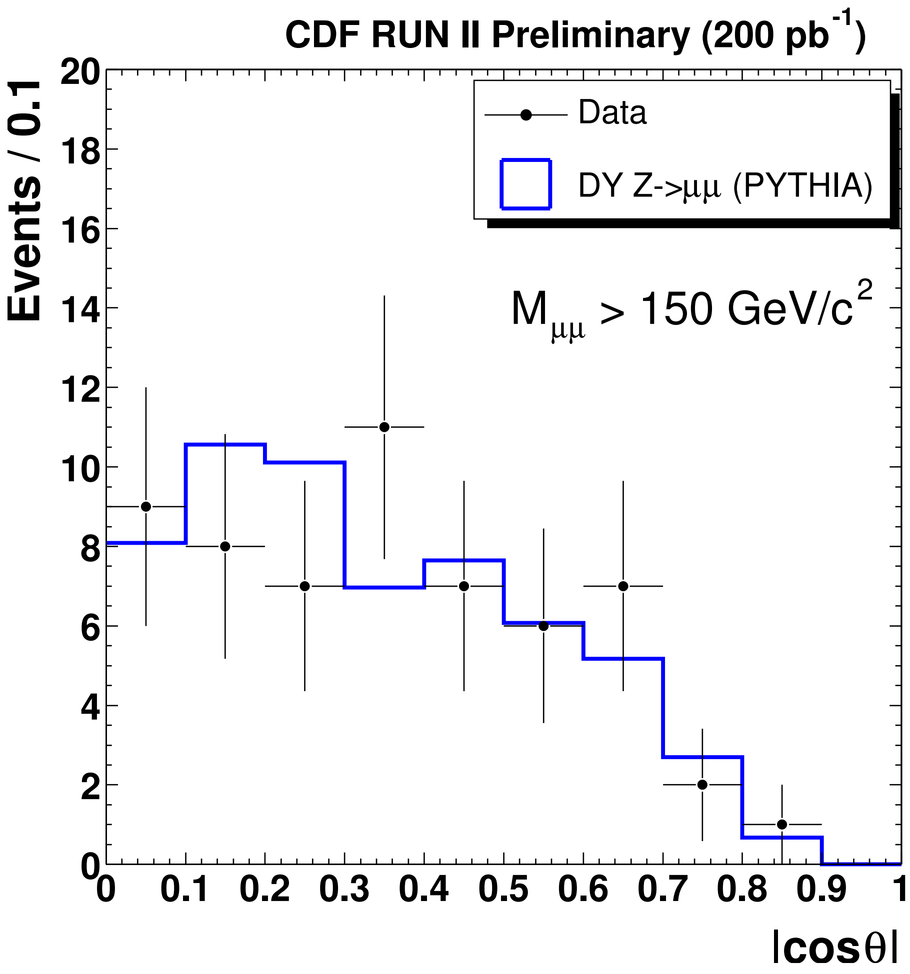


muon channel

all masses



high masses



The next step in looking for new physics, (or at least a point in which our current understanding, equiv. modeling, breaks down) is to begin carving up these inclusive data sets $p\bar{p} \rightarrow \ell^+\ell^- X$

that is, test when
$$\begin{aligned} X &= \text{one or more jets, or} \\ &= \text{large } \not{E}_T\text{, or} \\ &= \text{other leptons or isolated tracks, or} \\ &= \text{photon(s),} \\ &= \text{etc.} \end{aligned}$$

This work has begun in certain contexts...

Also, we can look at "anti-DY" samples, which have either same-sign or different-flavor lepton pairs.

Expand a little upon the possibility $\ell\ell +$ track:

We are interested in leptons coming from decays of $\tilde{\chi}_1^{\pm}$'s and $\tilde{\chi}_2^0$'s (which might themselves come from the decays of $\tilde{q}$'s)

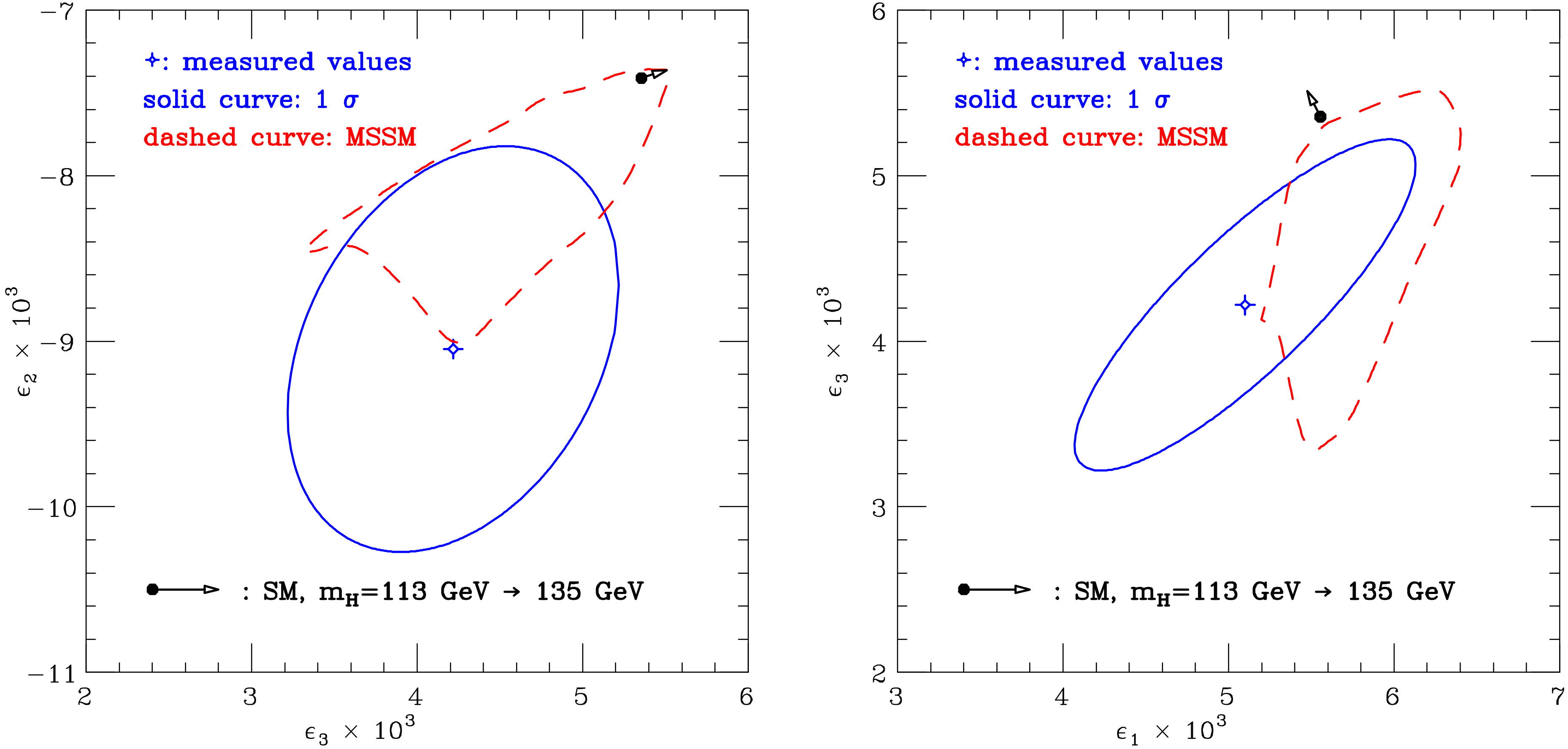
For $\tilde{\chi}_1^{\pm}$ not already excluded by LEP searches, the e's and μ's would be fairly energetic (τ's are another discussion...).

It turns out that a search for $\ell^+\ell^- +$ isolated tracks performs well with present luminosities, and better than the traditional 'tri-lepton' searches.

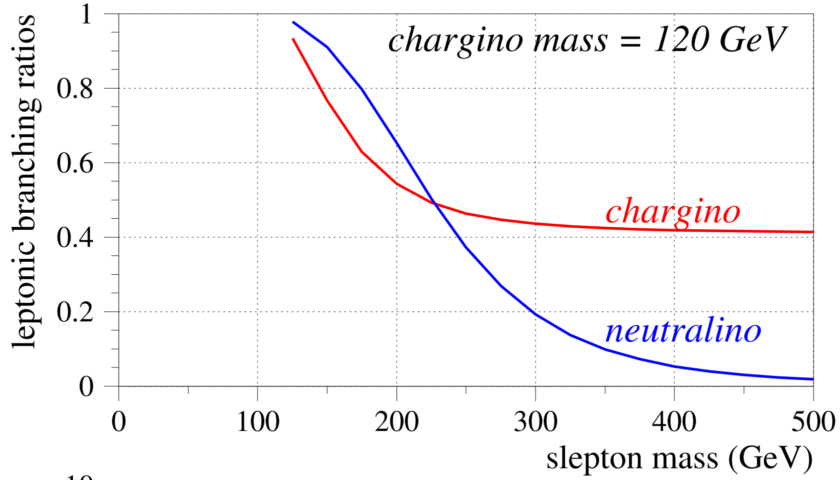
This is important becuase there are reasons to believe that $\tilde{\chi}_1^{\pm}$'s are not too much heavier than the present lower bound, and they should have enhanced branching fractions to leptons:

- this fits Altarelli's ϵ parameters better than the SM
- this is preferred by models of electroweak baryogenesis and $(g-2)_\mu$

Altarelli and others have argued that light charginos and sleptons are favored by precision electroweak measurements. `hep-ph/0106029`



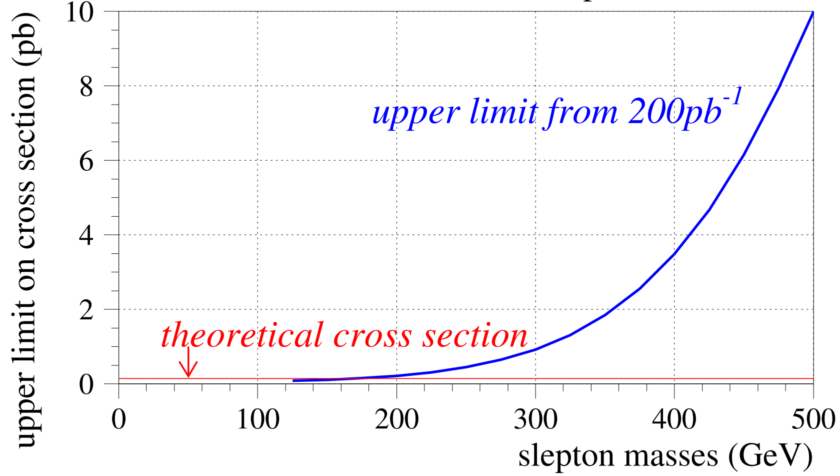
We checked the leptonic branching ratios for $\tilde{\chi}^{\pm}$ and $\tilde{\chi}_2^0$ as a function of the masses of the sleptons.



This is a naive view.

Lowering the slepton masses greatly increases the leptonic BR's, as expected.

There is a huge impact (two orders of magnitude) on the net acceptance, and hence, on the upper limit on the cross section.

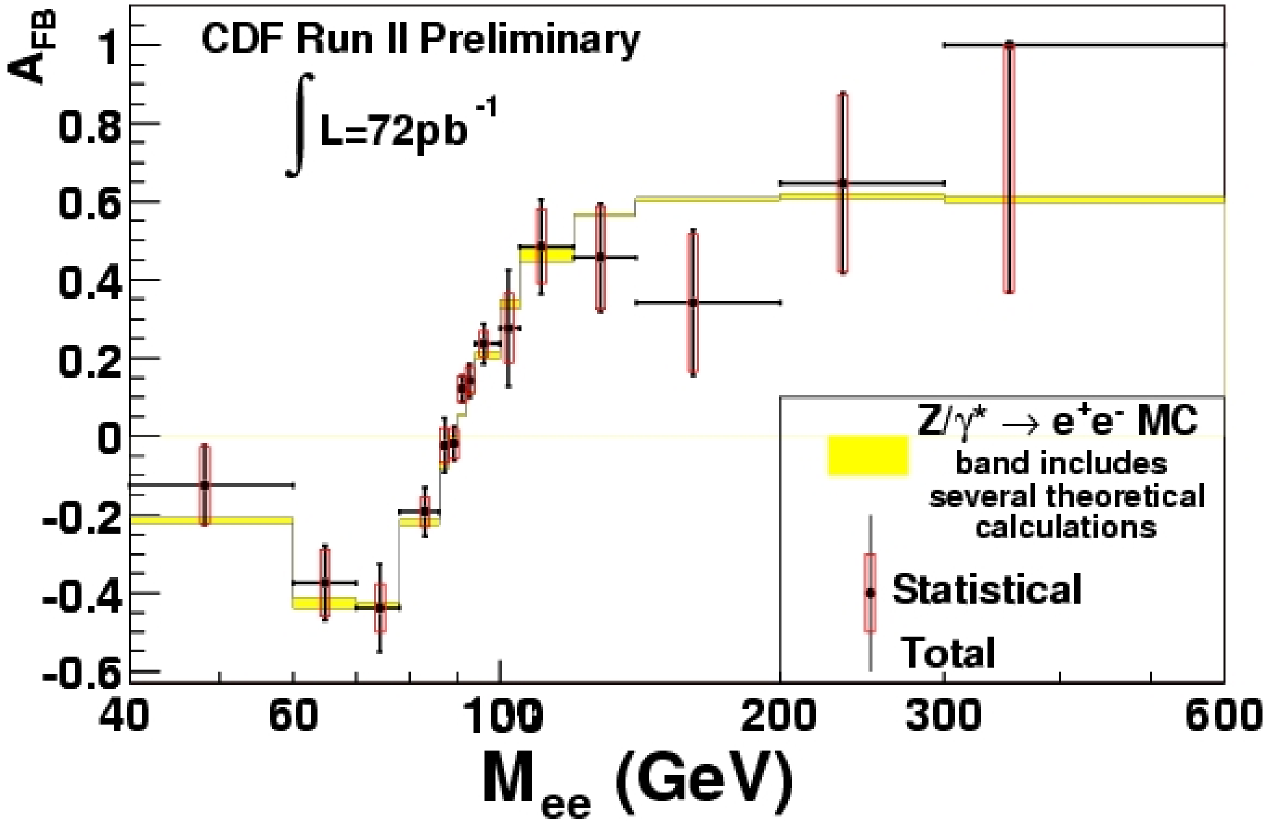


We might actually have sensitivity for $\mathcal{L} \sim 200\ \mathrm{pb}^{-1}$!

Another route one can – and should – take is to look for *indirect* effects.

The proto-typical example would be the disturbance of A_{FB} through interference effects from the tail of a high-mass Z'.

CDF has a nice measurement of A_{FB} in the electron channel.



Look for deviations for $M_{\ell^+\ell^-} > 150$ GeV.

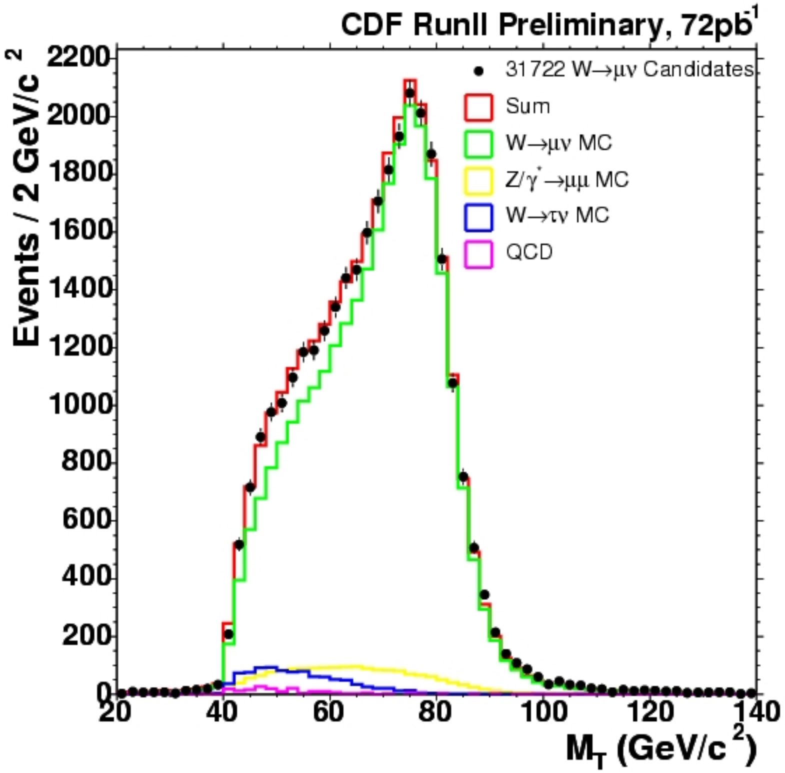
$\longleftarrow$

Along similar lines, precision measurements of electroweak processes might provide a view onto new physics BSM.

The U.Michigan & Northwestern groups collaborate in these measurements in the muon channels.

One can especially appreciate the excellent work from students Jian Kang and Alexei Varganov, among others.

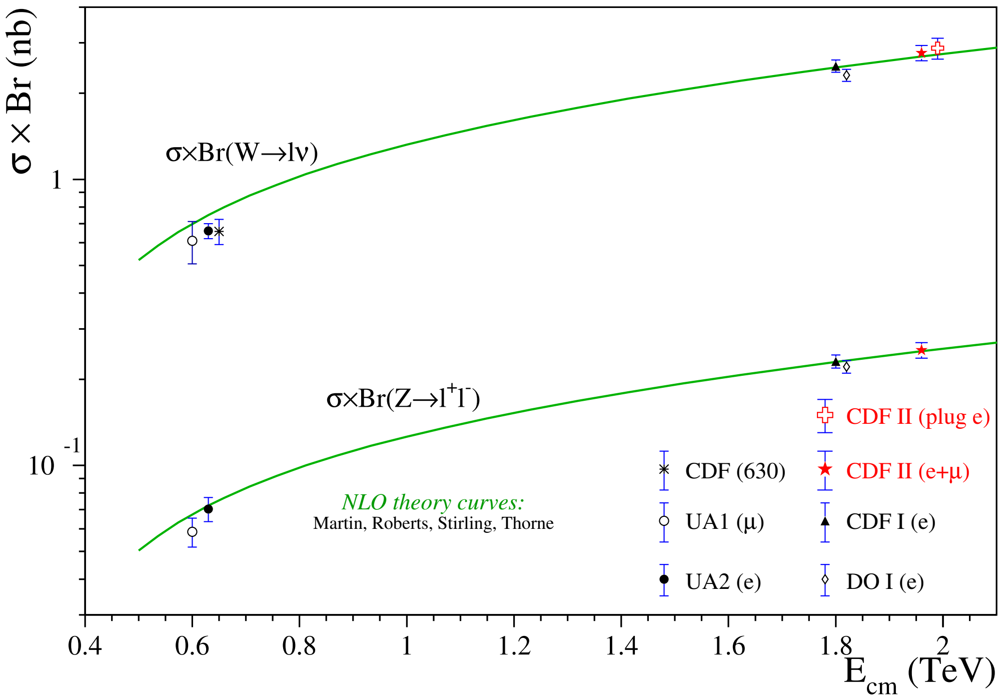
We are completing precision ($\sim 2\%$) measurements of inclusive W and Z cross sections and their ratio.

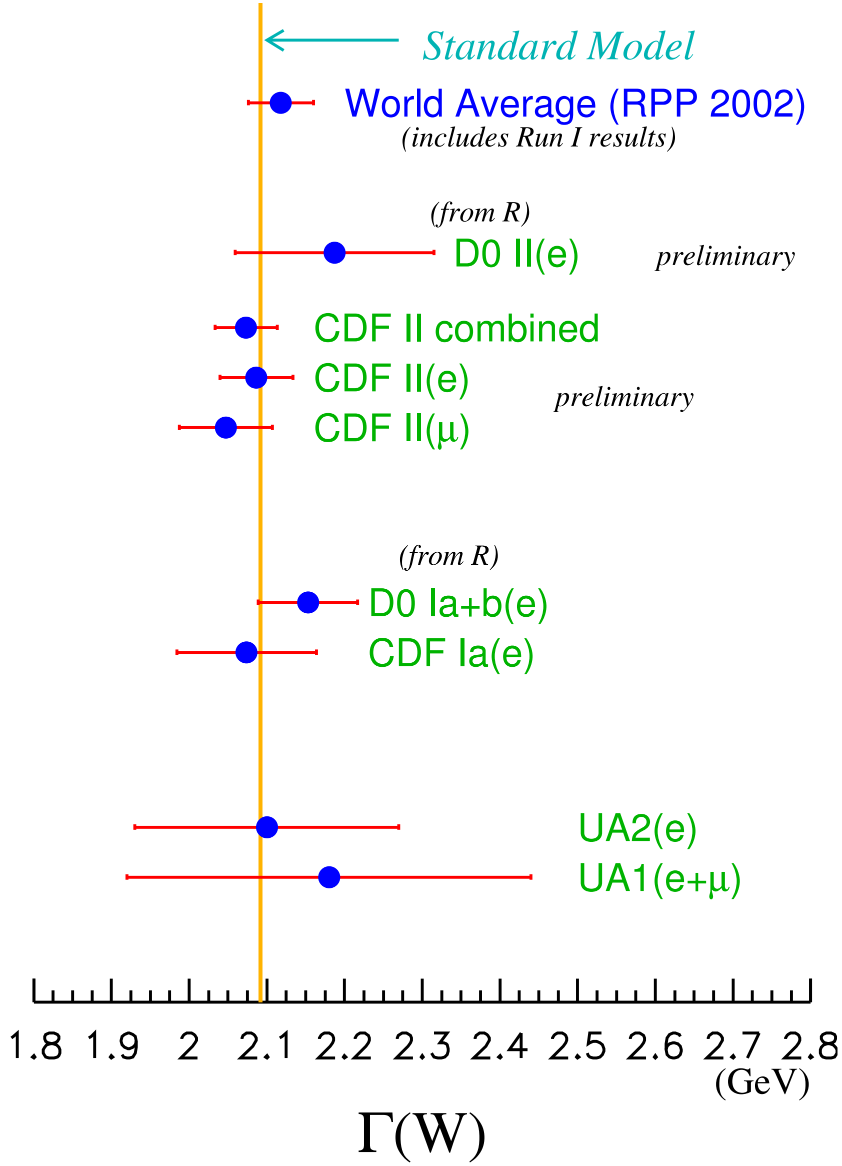


Given these and other precision measurements, one can always hope for a contradiction with the SM.

additional benefits:

1. tie down empirical SM parameters
2. constrain quantum corrections



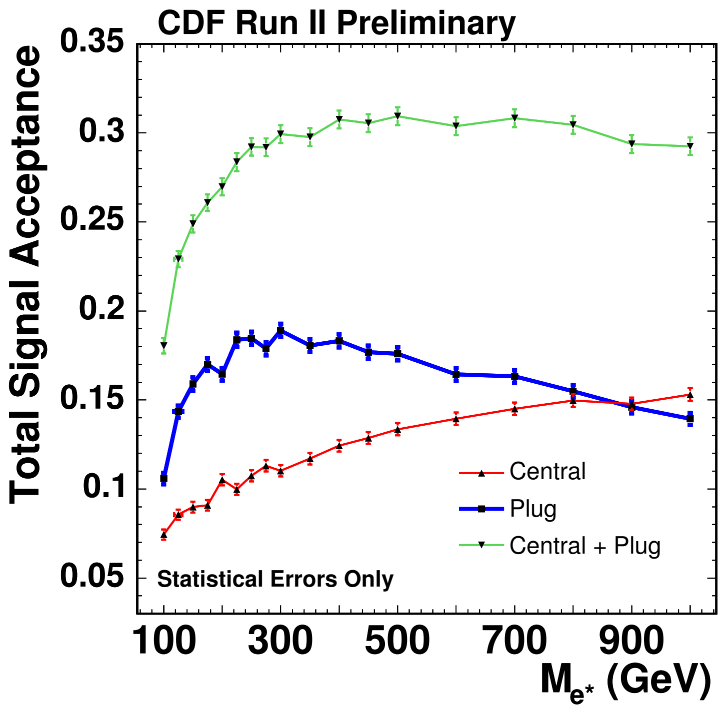


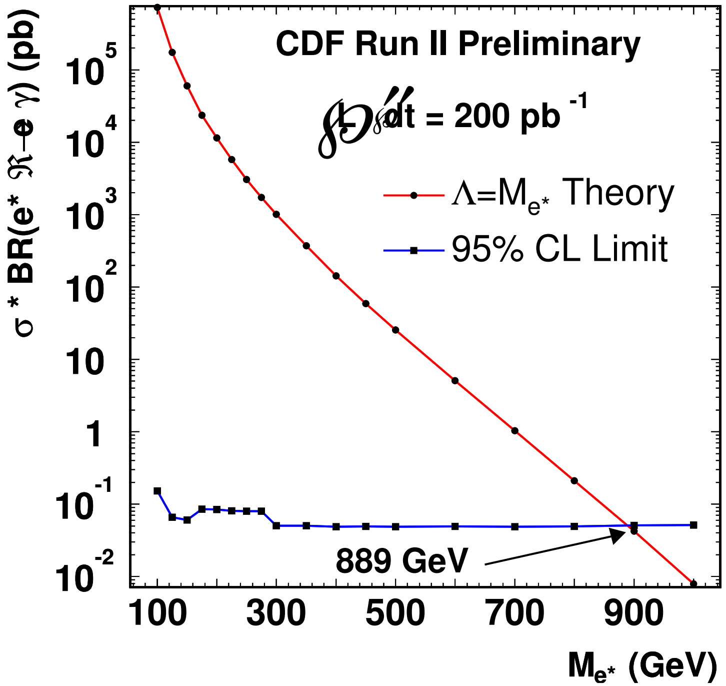
To some extent, the investigation of pieces of the inclusive final states has already begun.

For example, a simple and obvious generalization would be to consider the Drell-Yan – like production of heavier (BSM) lepton states.

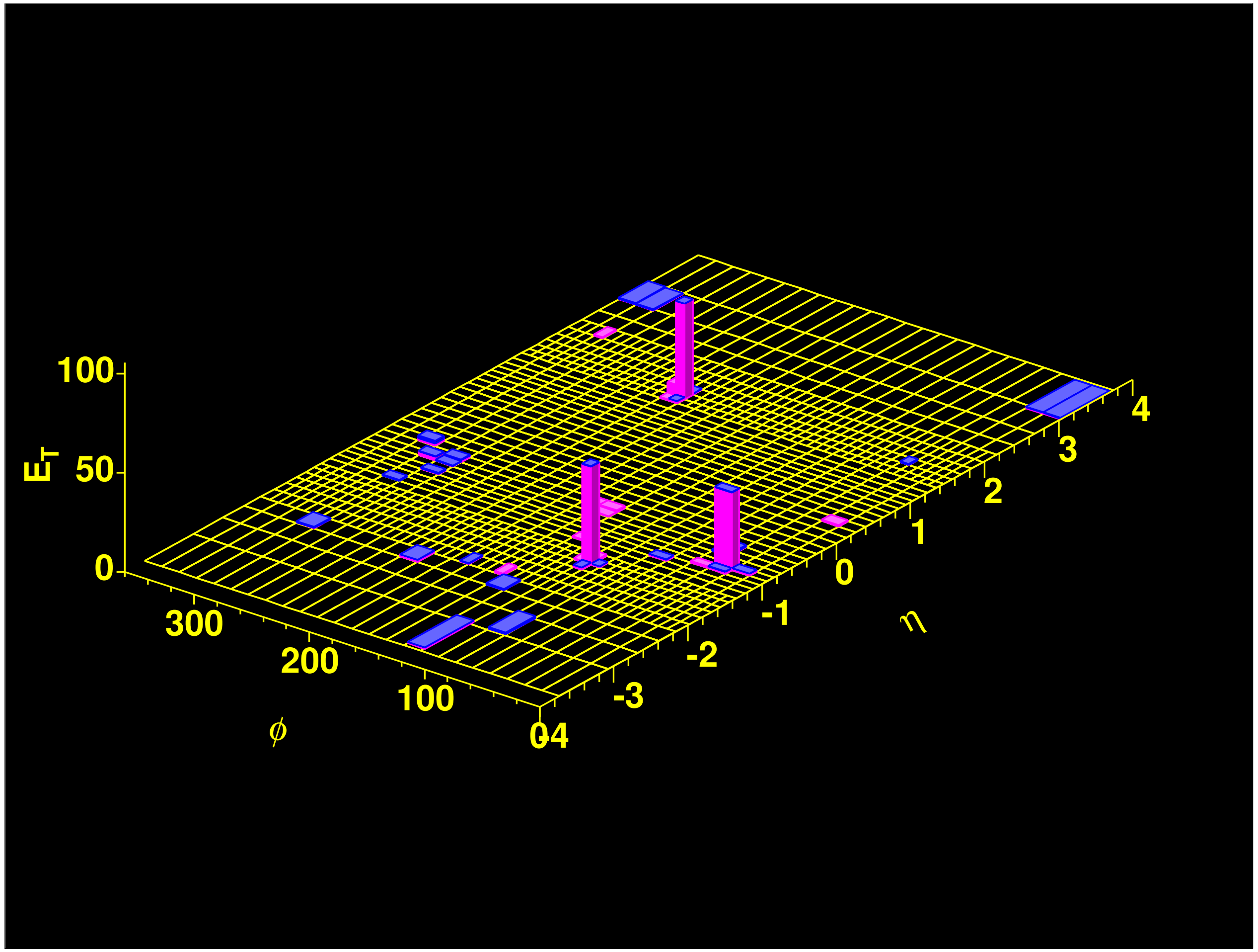
One could "add" a photon, and the search is then (more) sensitive to

- excited electrons $e^\star \to e + \gamma$
- gauge-mediated Supersymmetry $\tilde{e} \to e + \tilde{\chi}_1^0 \to e + \gamma + \tilde{G}$

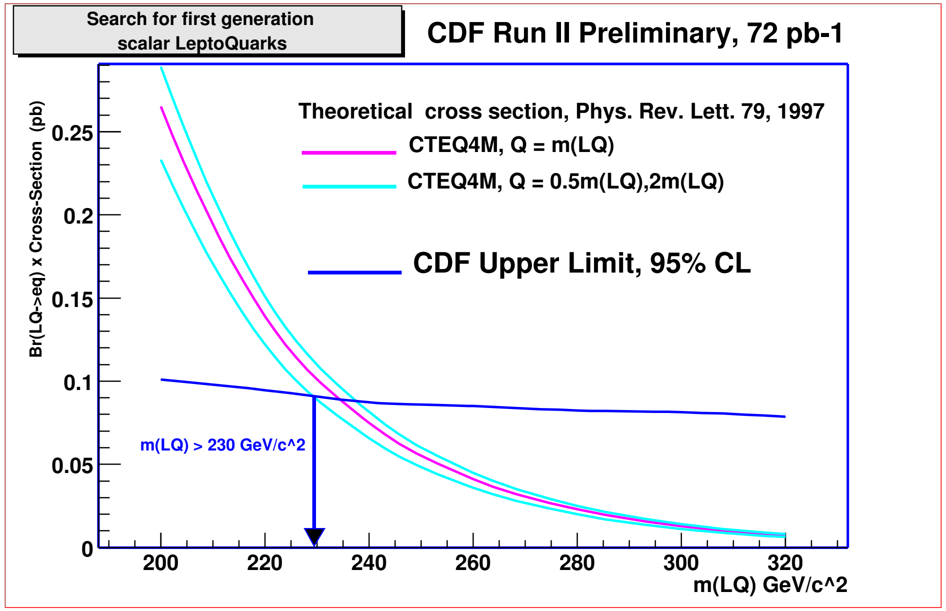


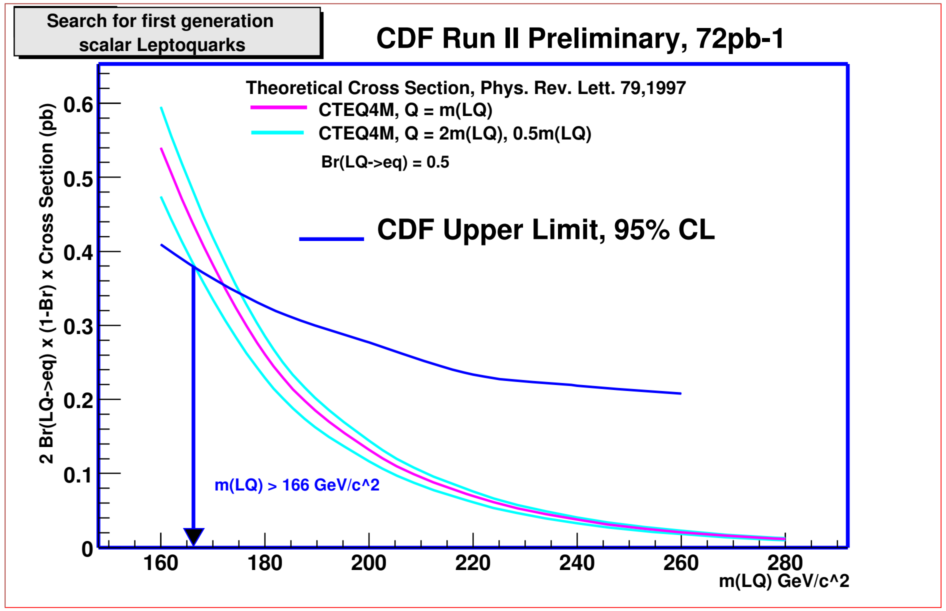


This particular search has turned up some very pretty events:



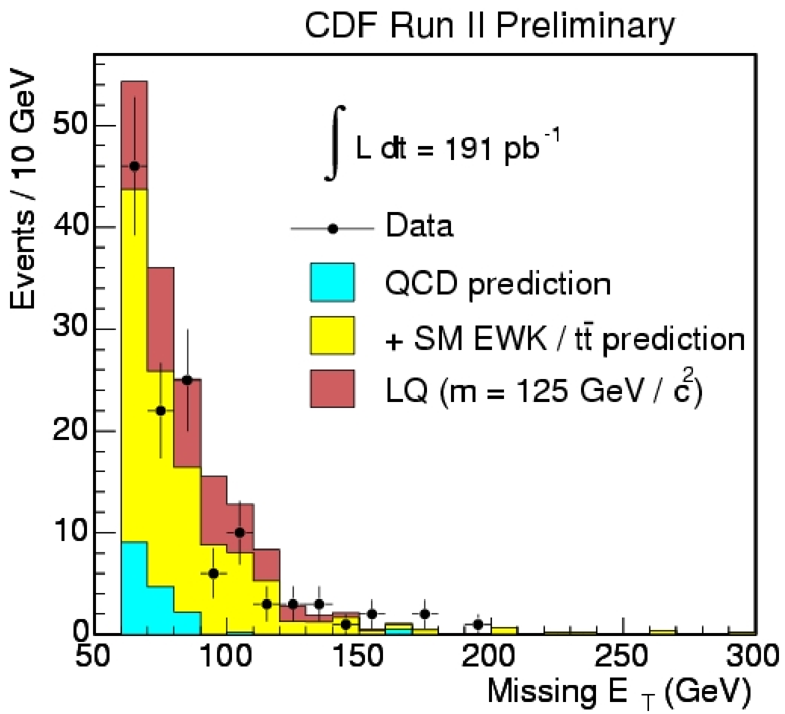
Or, looking in another ‘direction,’ ask for two high-E_T jets possibly $\not{E}_T$ and you are talking about a *lepto-quark search.*

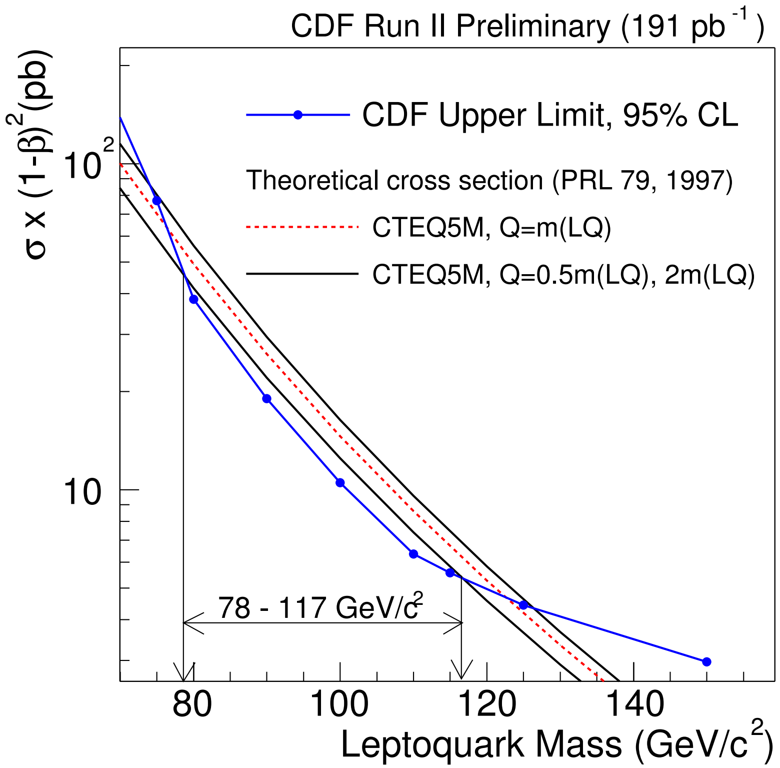




$p\bar{p} \rightarrow LQ\overline{LQ}$ and $LQ \rightarrow e + \text{Jet}$ or $\rightarrow \nu + \text{Jet}$.

We can drop the requirement of a lepton altogether,
and search for Jets and $\not{E}_T$ as evidence for the $\nu\bar{\nu}$ channel



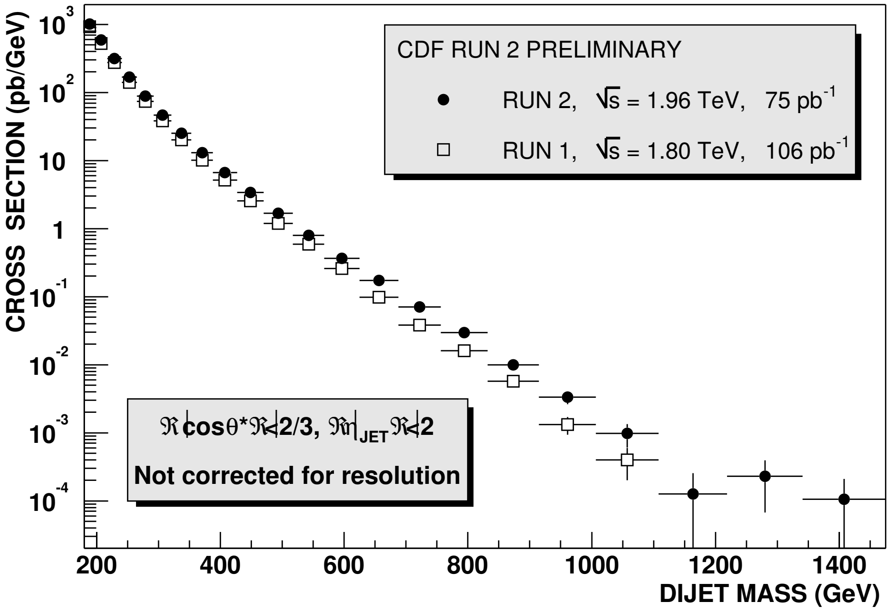


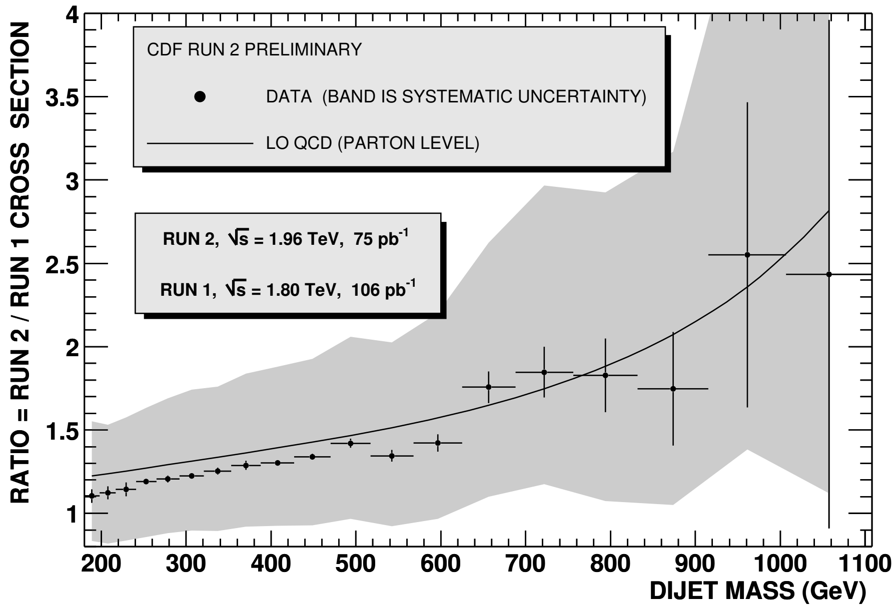
Suppose there is no new physics with significant missing energy.

What do we learn from our jet channels then?

Look at the di-jet invariant mass distribution.

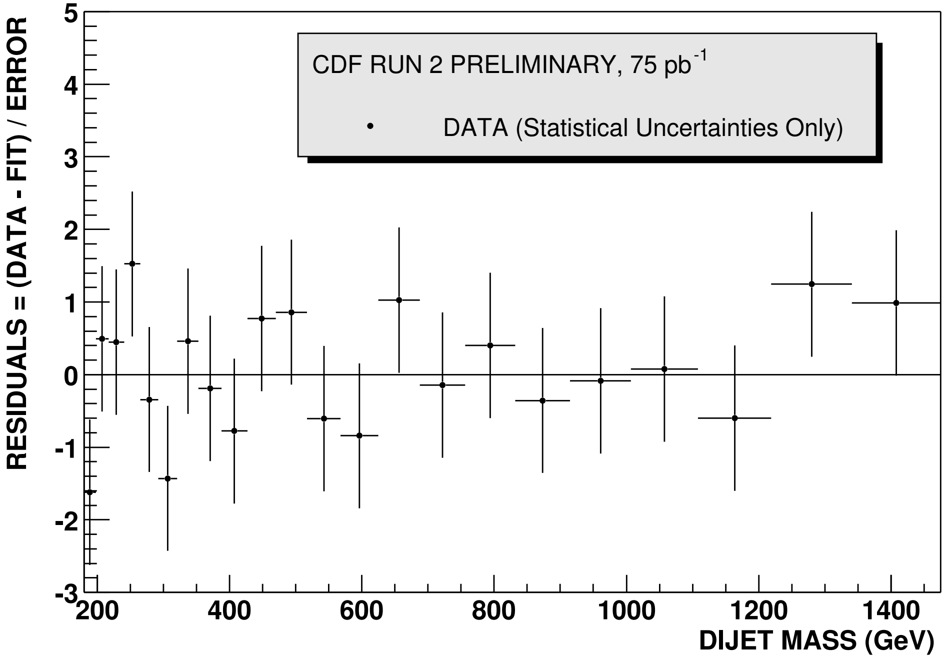
this is a comparison of Run II and Run I

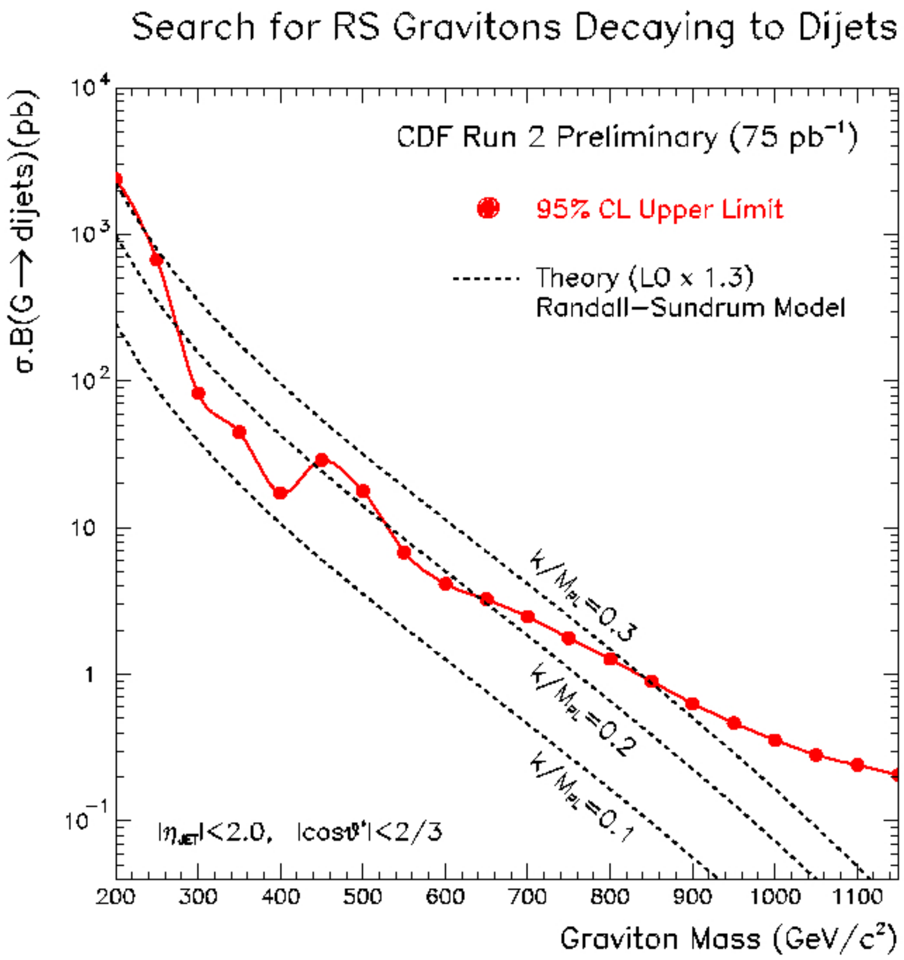




Bump Search:

Try to find a bump on top of a smooth continuum using a empirical fit.





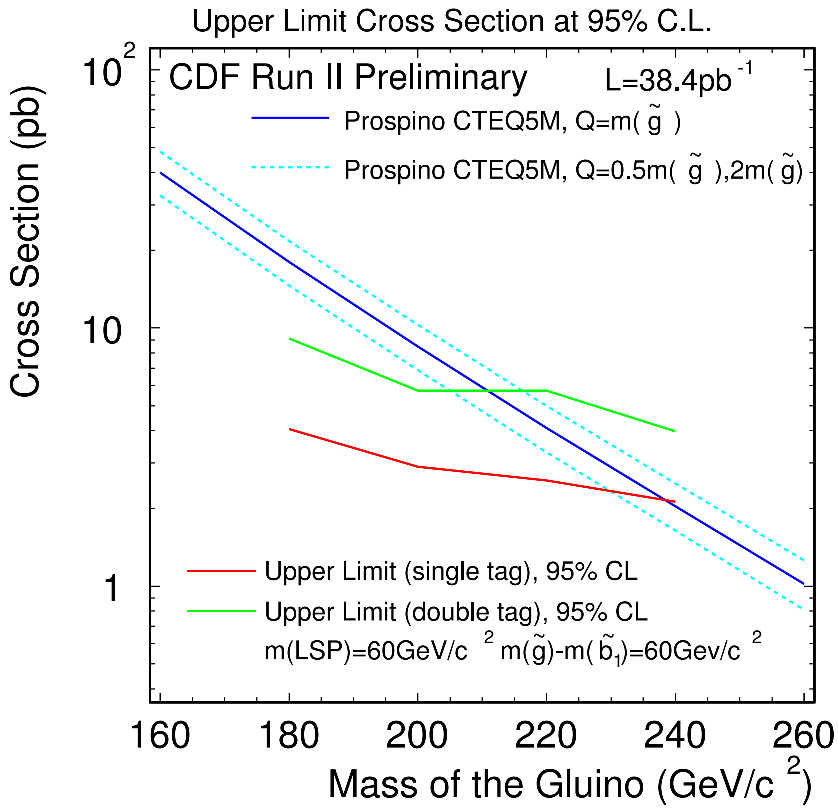
No signs of any bump!

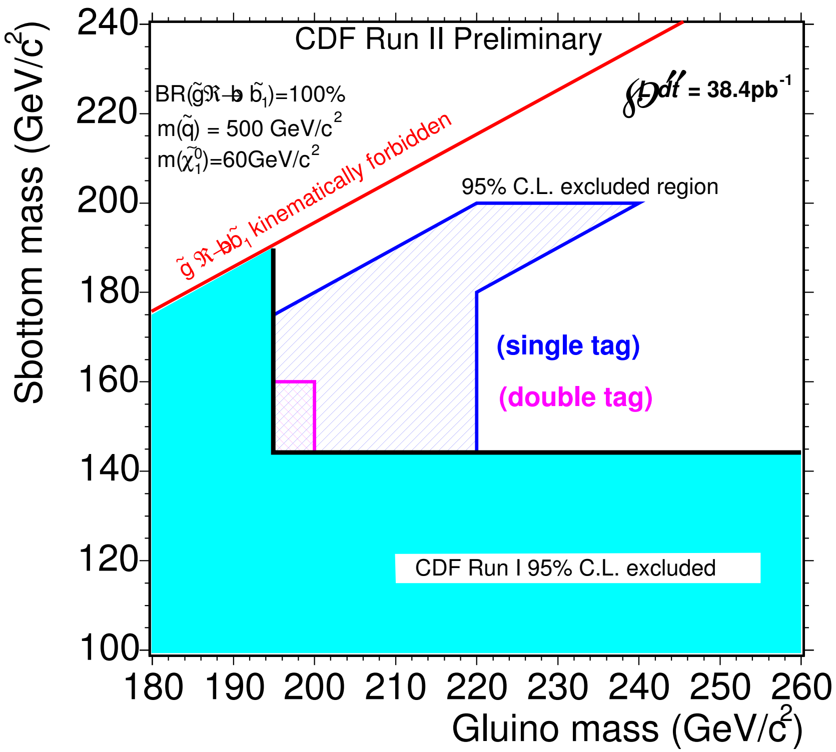
One can set limits on a host of models. . .

One can also wonder about heavy flavor jets.

One exploratory foray into this territory comes in a search for gluinos in the channel $\tilde{g} \rightarrow \tilde{b}b$ followed by $\tilde{b} \rightarrow b\tilde{\chi}_1^0$.

The events would have four b-jets and $\not{E}_T$.





Concluding Remarks

- CDF have obtained many limits and exclusions, and many more are on the way. *But this is NOT the point.*

- CDF are attacking their data set, looking in many places with different perspectives for something beyond the Standard Model.

- The two main approaches are coupled:
  1. direct searches with leptons, photons, jets and/or $\not\!\!E_T$
  2. precision measurements of SM processes

- *No one knows where New Physics will turn up...*