Search for Long-Lived Particles Decaying to the Z^0 Boson

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Direct Searches For New Physics

Motivation

- What I want:
  - Same as what everyone wants
  - To find what physics lies beyond the Standard Model
- Alright, but how?
- Many possible theoretical and experimental signatures to choose from
  - Theoretical:
    - Higgs
    - SUSY
    - Extra dimensions
    - …
  - Experimental:
    - photons
    - leptons
    - neutrinos ($\not\!\!E_T$)
    - quarks (jets)
    - gauge bosons: Z^0 and $W^{\pm}$

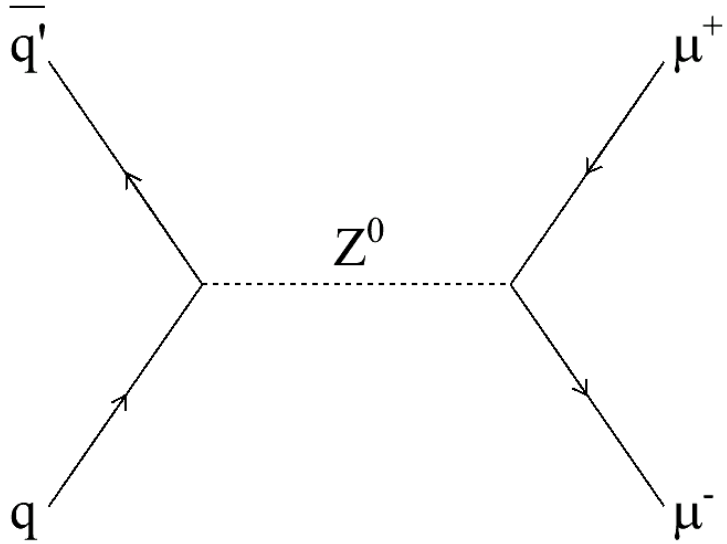
What We Do

- Our approach is to look at the gauge bosons for evidence of new physics
- We focus on new physics that couples to the Z^0
- $X \rightarrow Z^0$
  - Theoretically motivated
    - Might expect to see new physics to couple to heavy particles more strongly than the light ones
  - Experimentally clean
    - Two leptons that reconstruct to the Z^0 mass has little background
    - The dominant background is from Standard Model Z^0's

Standard Model Z^0

- To be sensitive to $X \rightarrow Z^0$, must distinguish the Z^0 from new physics with the Standard Model Z^0

- What do Standard Model Z^0 events look like?
  - Z^0 has low p_T
  - Events have little other activity in them (no jets, no $\not{E}_T$)
  - Z^0 has short lifetime



New Physics Couplings to Z^0

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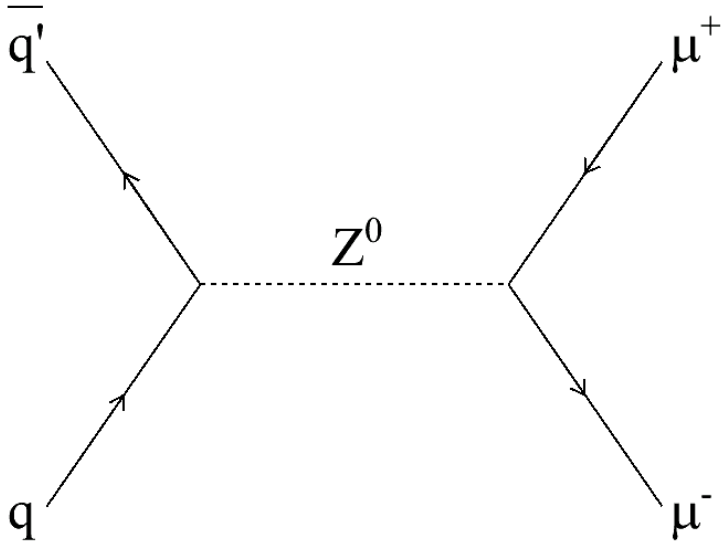
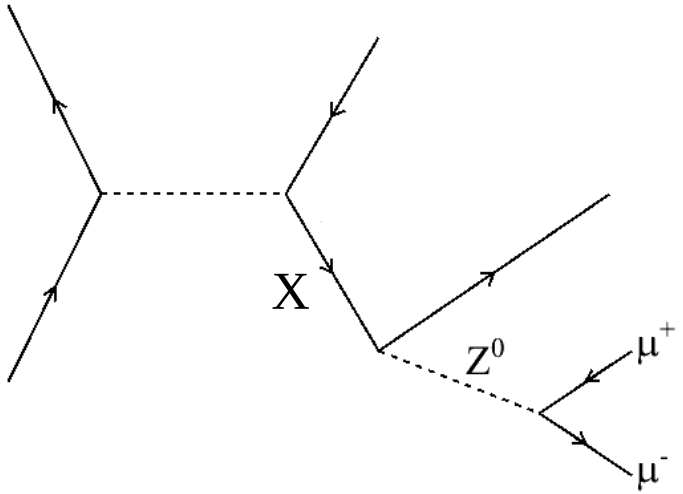
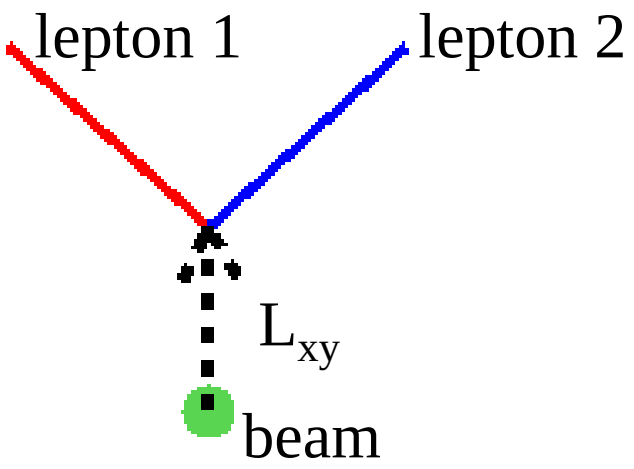


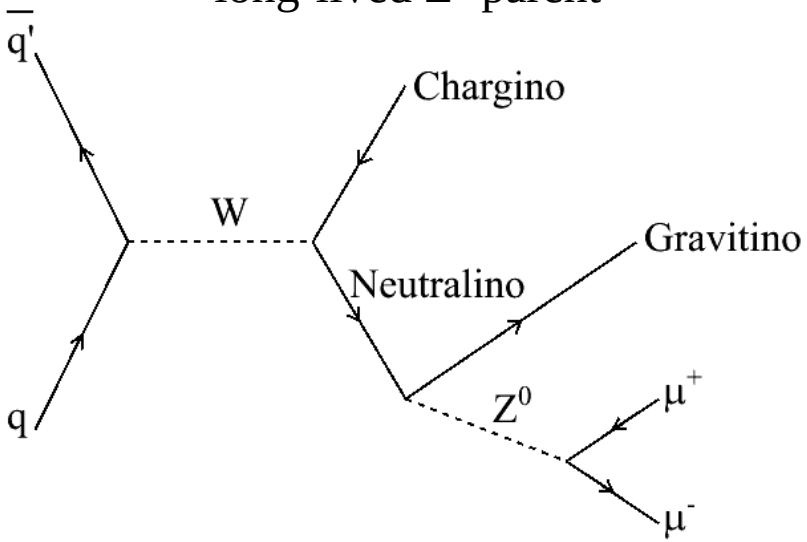
- What would Z^0 new physics events look like?
  - Z^0 has *high* p_T
  - Events *a lot* of other activity (*many* jets, *large* $\not\!\!E_T$)
  - Z^0 parents (might) have *long* lifetime

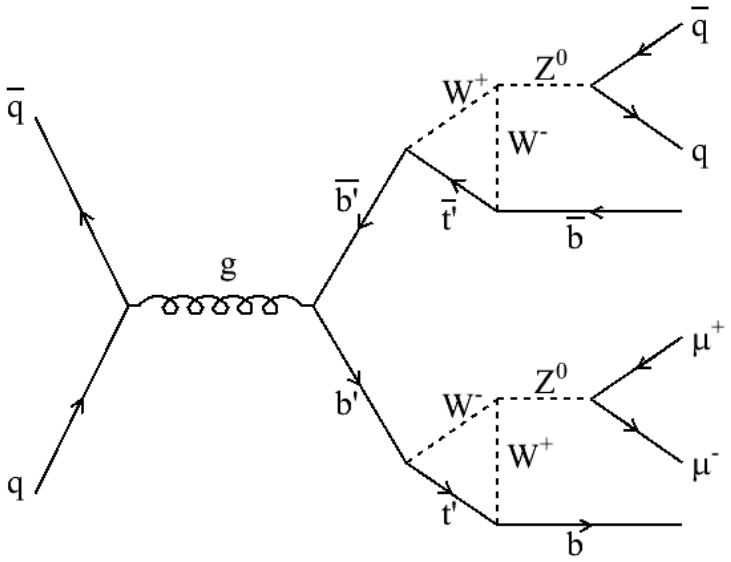


Long-Lived Particle Decaying to Z^0

- Experimentally clean
  - Vertex dileptons from Z^0's
  - Negligible background from actual displaced vertices
  - Dominant background is from tracking mistakes
- Theoretically motivated
  - Existing (and perhaps many non-existing) models predict a long-lived Z^0 parent

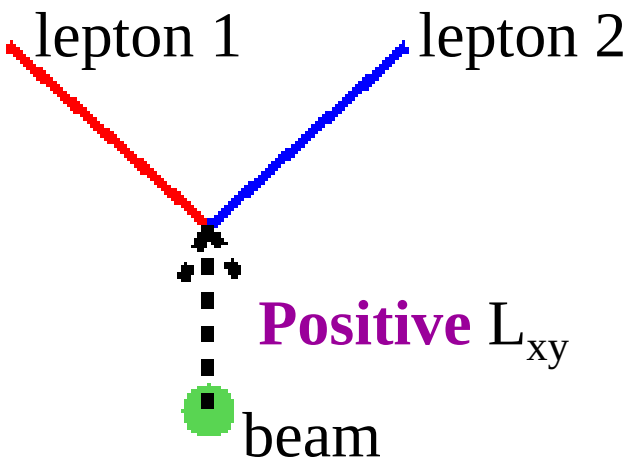






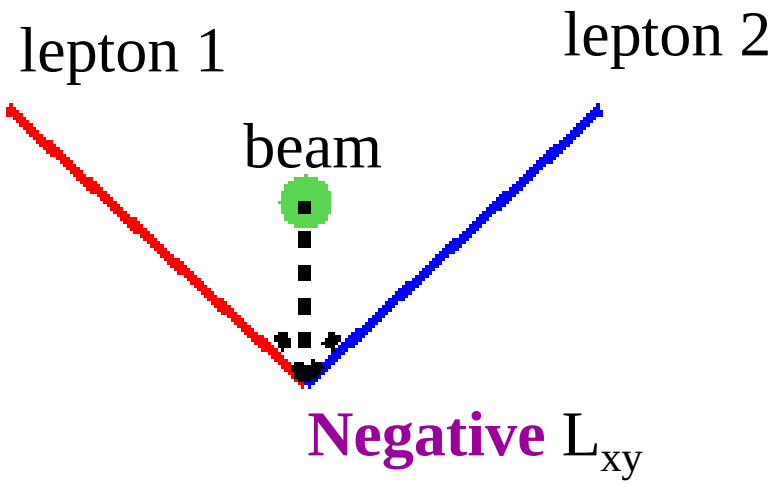
Let's Do It!

- Convention:
  L_{xy} = distance in transverse plane from beam to dilepton intersection
- Use transverse quantities because they are easier to measure



- L_{xy} sign definition
- Motivation:
  - Tracking mistakes are symmetric in L_{xy}
  - Signal has predominantly positive L_{xy}

- Search for excess above background at positive L_{xy}
- Negative L_{xy} gives a cross-check of the background
- Use $Z^0 \rightarrow \mu\mu$ channel
- Plan to use $Z^0 \rightarrow$ ee channel next

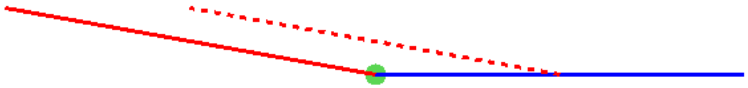


Selection Criteria

- Selection Motivation:
  - Clean sample of Z^0's
  - Well-measured tracks
  - High efficiency for signal
  - Look for large L_{xy}
- Calibrated cuts and L_{xy} calculation with $J/\psi \rightarrow \mu\mu$'s
  - Displaced vertices from B meson decay
- Two important cuts:
  - $\Delta\phi$ cut
  - Z^0 boson p_T cut

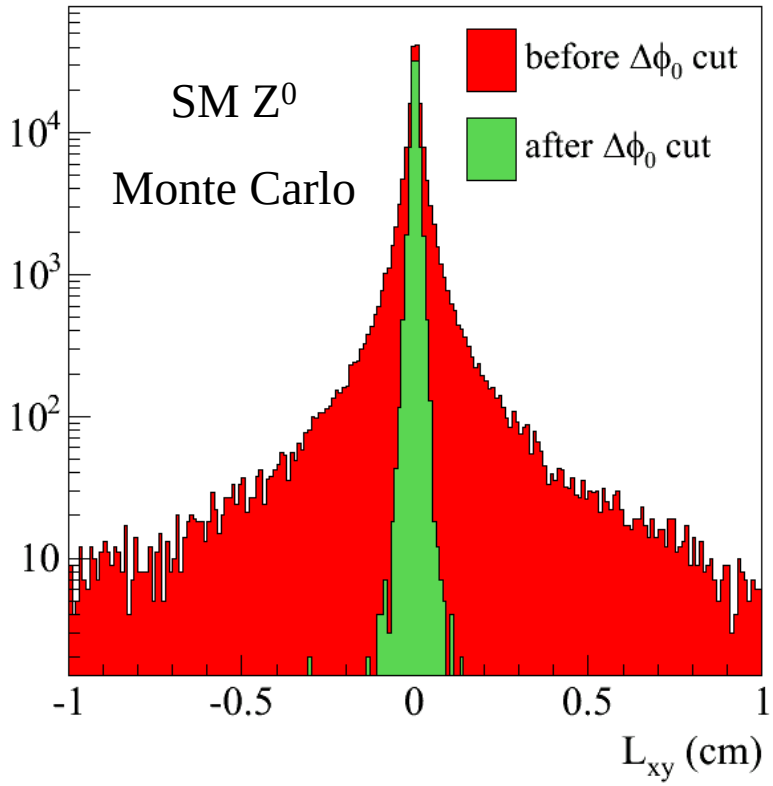
Two well-identified high p_T muons
Within Z^0 mass peak: $81 < M_{\mu\mu} < 101$ GeV
Tracking quality cuts to reduce mistakes
Cosmic Rejection Cuts
$L_{xy} > 0.1$ cm
Z^0 boson $p_T > 30$ GeV
$L_{xy} > 0.03$ cm

$\Delta\phi$ cut



- Due to the back-to-back nature of Z^0 events, even small mistakes in tracking can lead to large mistakes in L_{xy}
- Cut at:

  $\Delta\phi < 175$ deg
  - Rejects 99% of large L_{xy} tracking mistake background above 0.1 cm
  - 50 % efficient on Standard Model Z^0's
  - 90 % efficient on signal sample



Z^0 Boson p_T Cut

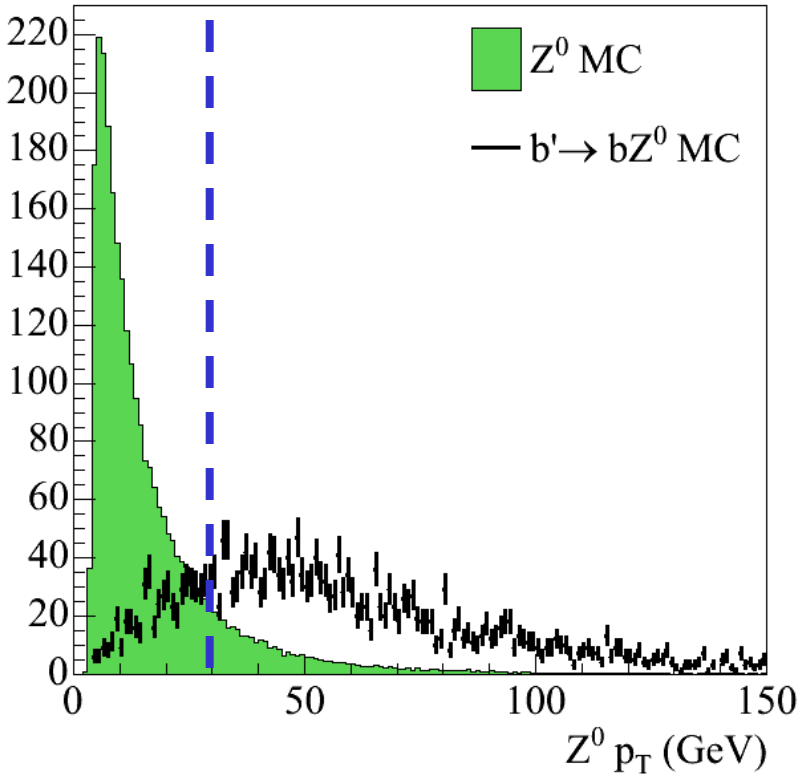
- Can use the Z^0 transverse momentum to reject Standard Model background
- Increases sensitivity to smaller lifetimes

- Cut at:

  Z^0 p_T > 30 GeV

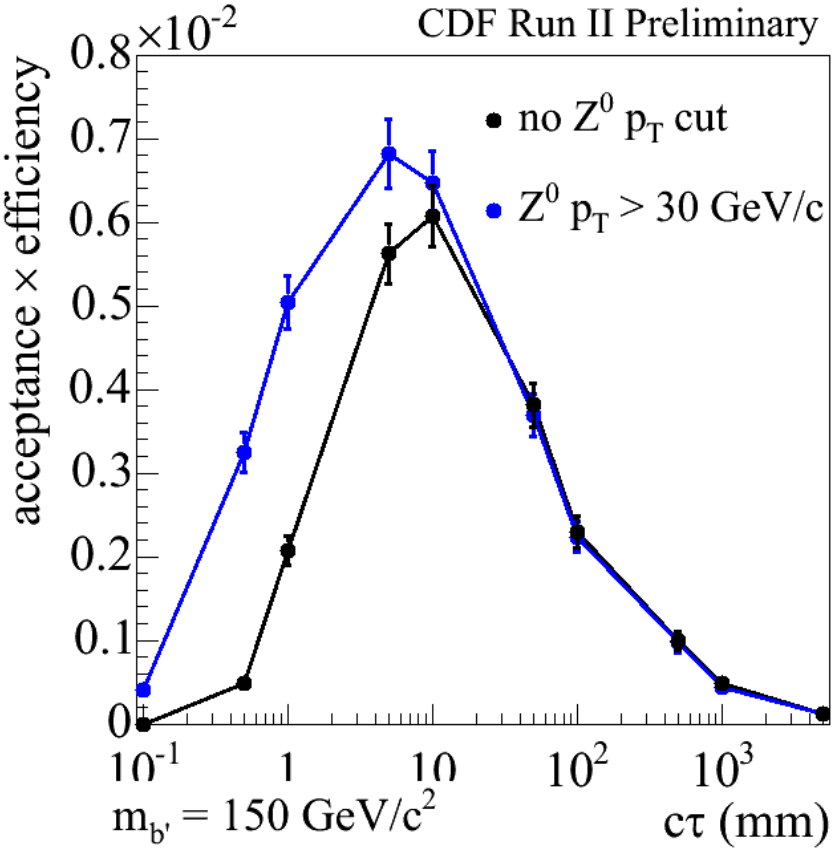
  L_{xy} > 0.03 cm

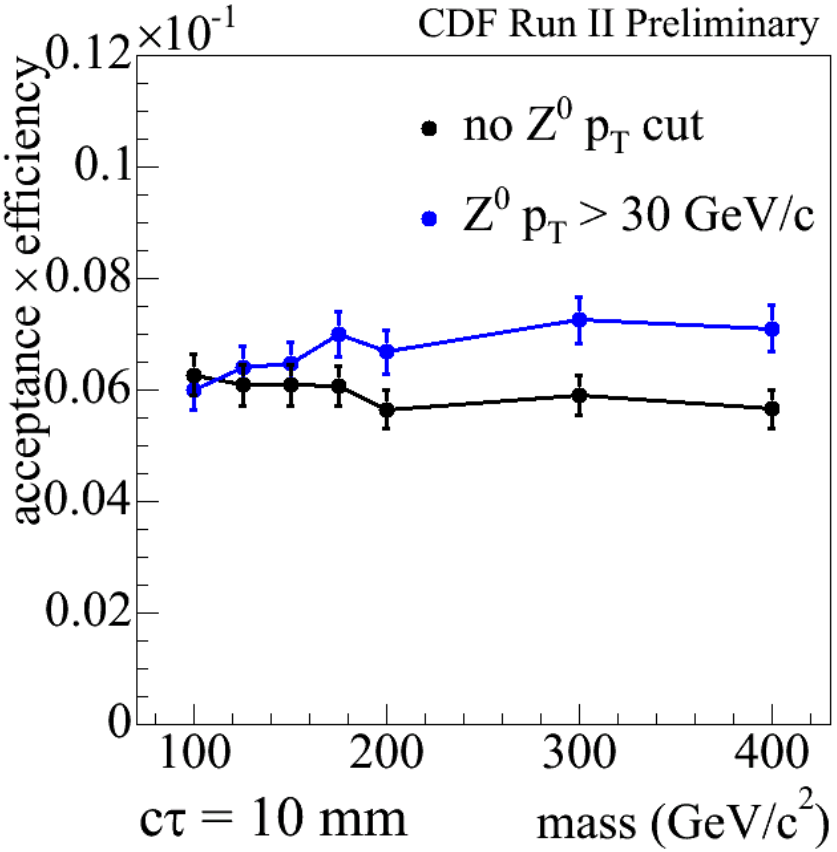
- Do not optimize heavily to retain model independence
- Use it as optional cut
  - Look at L_{xy} distribution with and without the cut



Acceptance × Efficiency

- Have calculated acceptance × efficiency of signal
  - Used a b' model
  - Note: Assumes BR(b' → b Z^0) = 1, and includes BR(Z → $\mu\mu$)



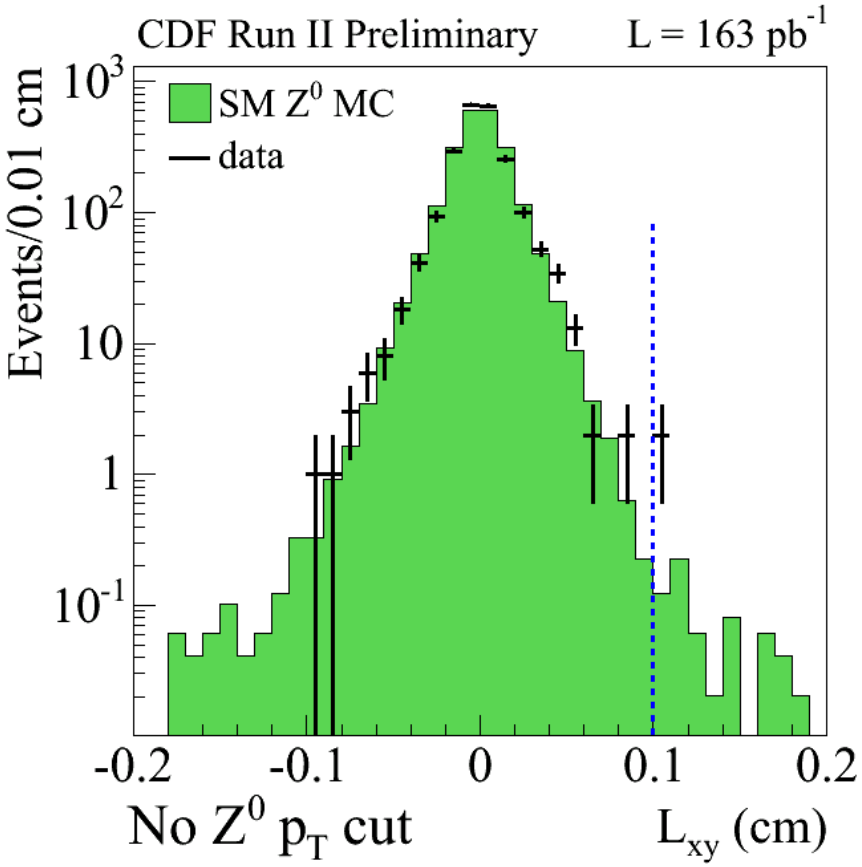


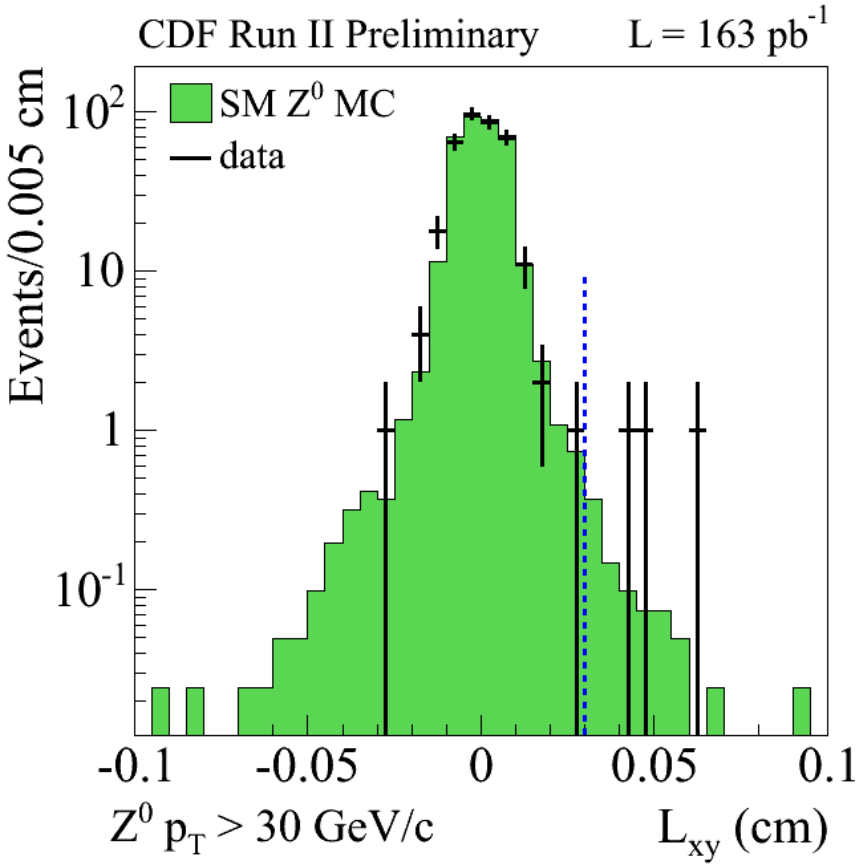
Backgrounds

- Negligible backgrounds from:
  - Cosmics
  - QCD (semileptonic B decays to muons)
- Dominant background from:
  - Tracking mistakes from Standard Model Z^0 events
  - Difficult to measure
    - Use simulated Monte Carlo
    - Can cross-check the background measurement with the data in the negative L_{xy} control region

	No Z^0 p_T cut	Z^0 p_T > 30 GeV
Background:	0.72 ± 0.27 events	1.1 ± 0.8 events

The Data





- 2 events in signal region
- Background: 0.72 ± 0.27 events
- No events is negative L_{xy} control region

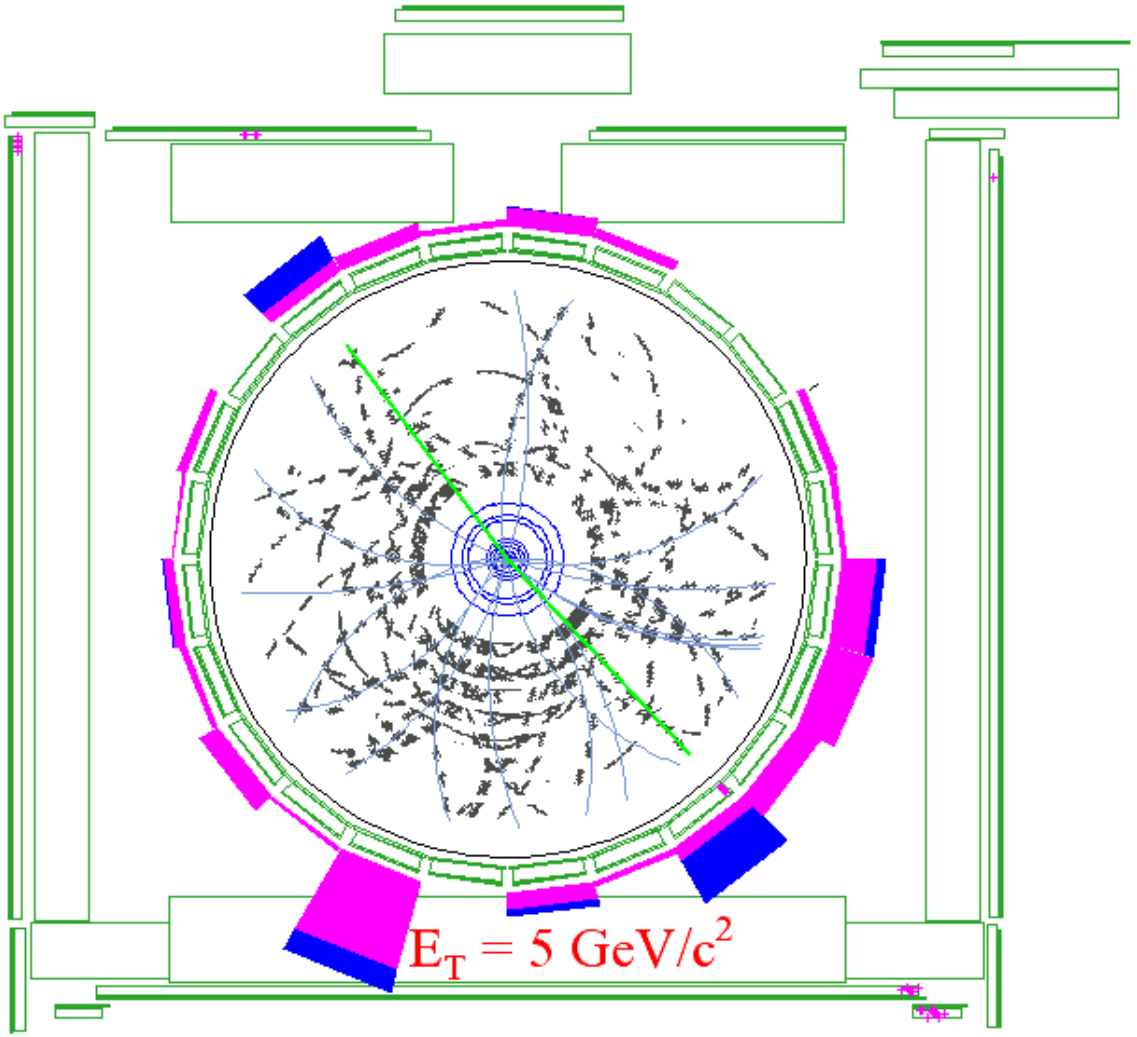
- 3 events in signal region
- Background: 1.1 ± 0.8 events
- No events is negative L_{xy} control region

Signal Events

- Have 2+3 events in signal regions
- Can look at events displays to find other information consistent with the signal or background hypothesis
- In the case of the signal:
  - Should have other activity in the event
  - Additional jets, etc.
  - In the case of the b' $\rightarrow$ b Z^0 signal:
    - b jets
    - Jets from other Z^0

Event Display Example

$L_{xy} > 0.1$ cm, without the Z^0 p_T cut



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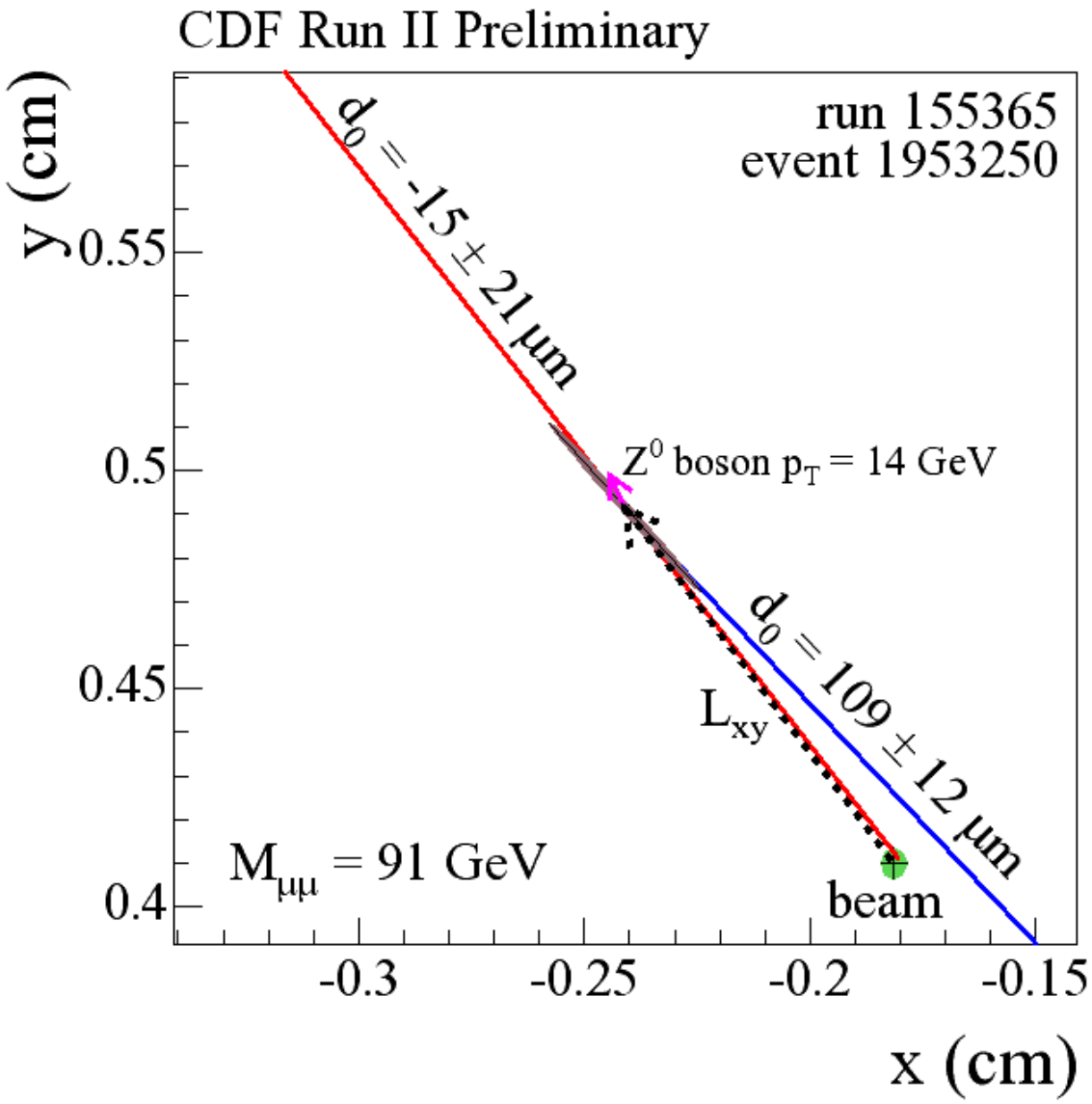
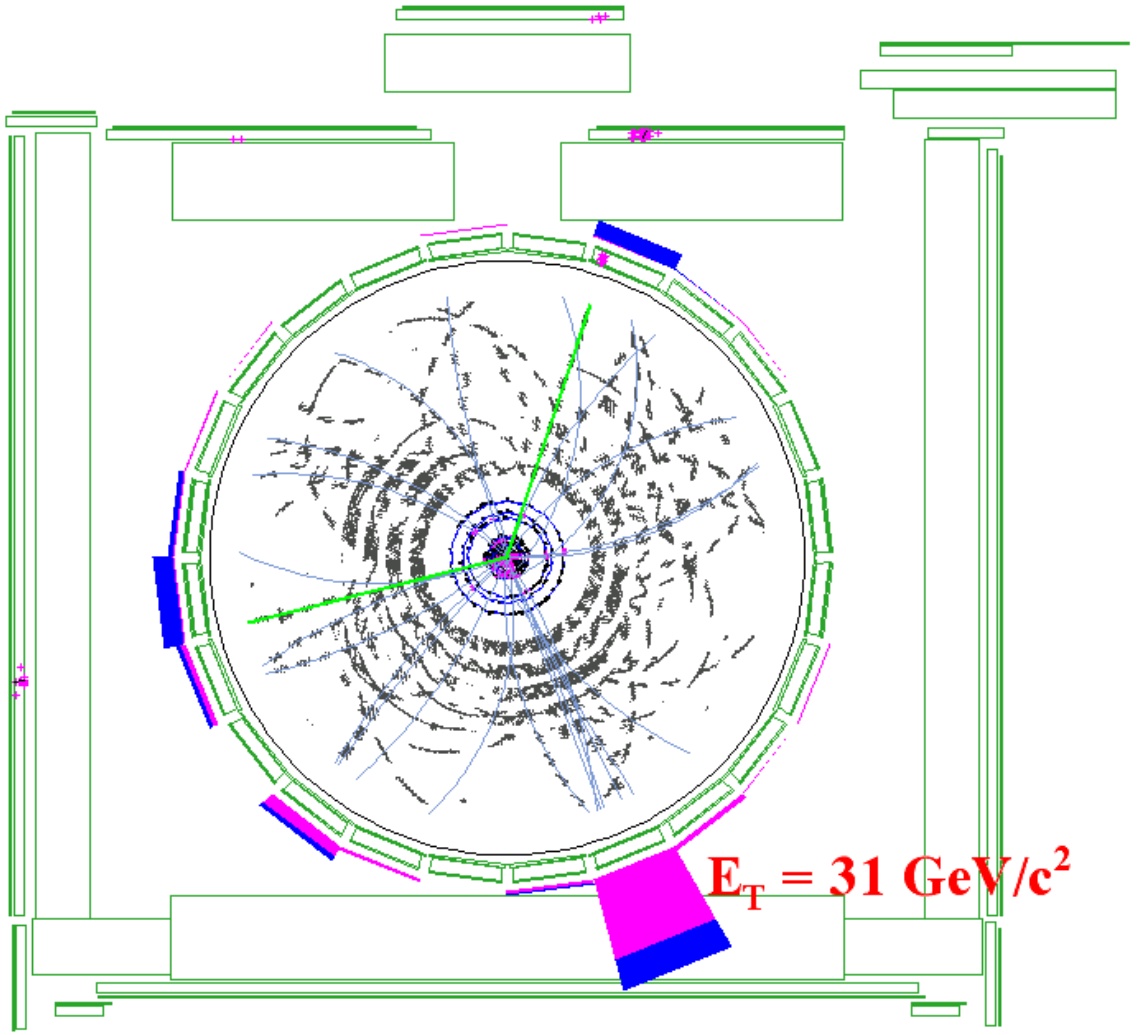


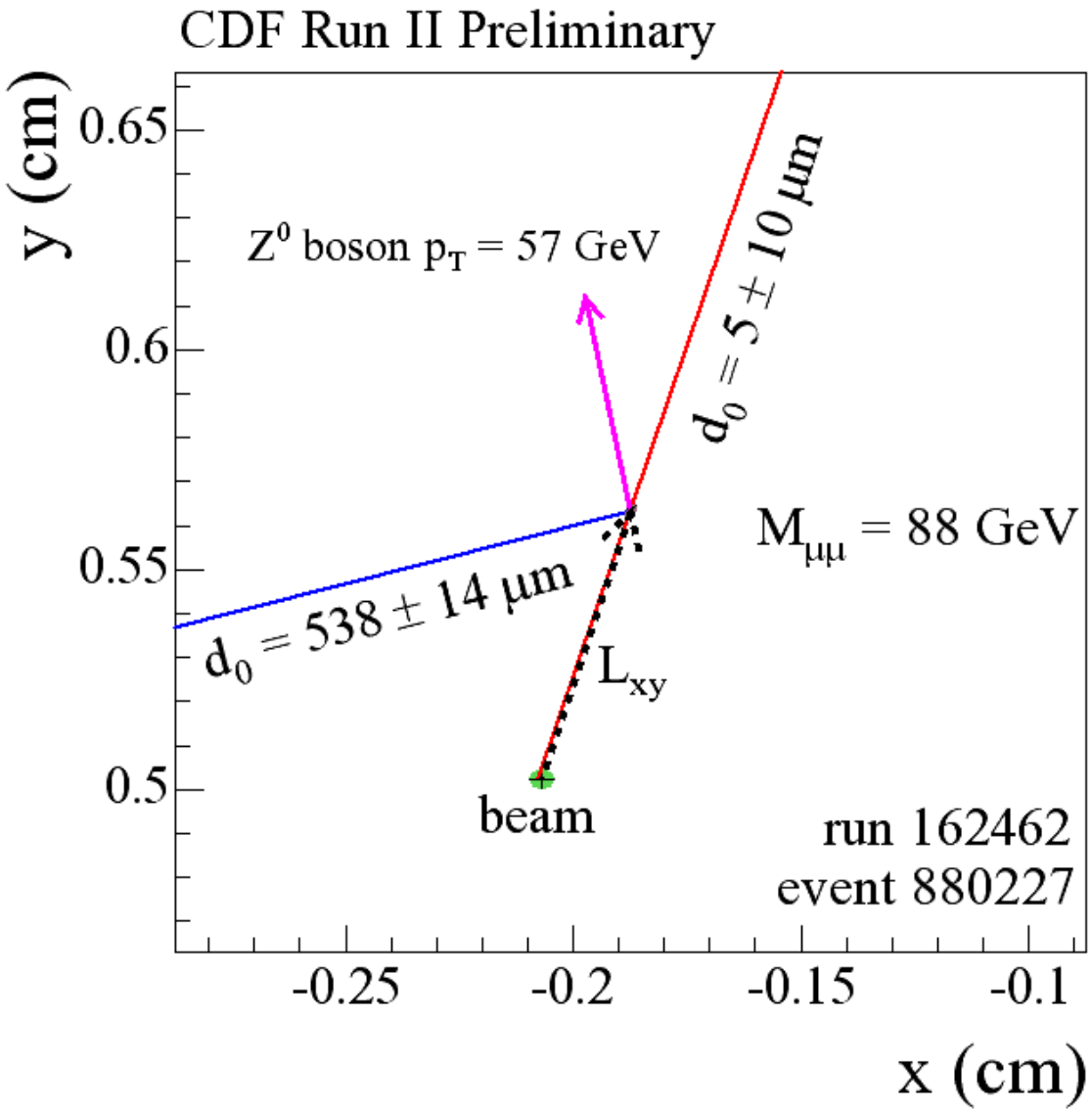
Event Display Example

L_{xy} > 0.03 cm, with the Z^0 p_T > 30 GeV cut



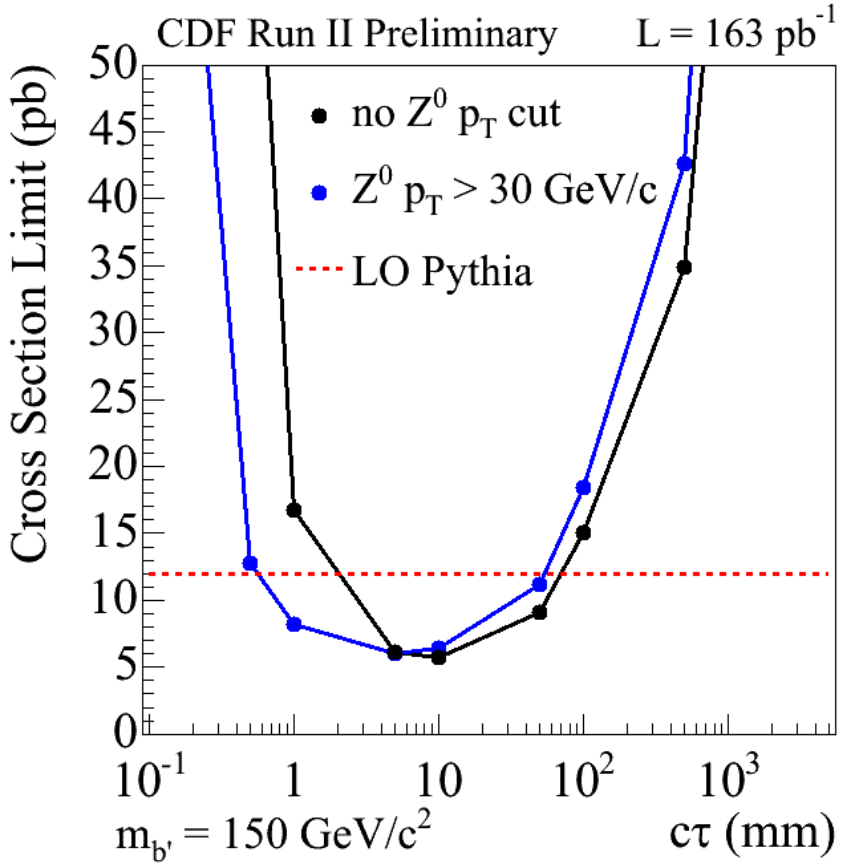
Event Display Example

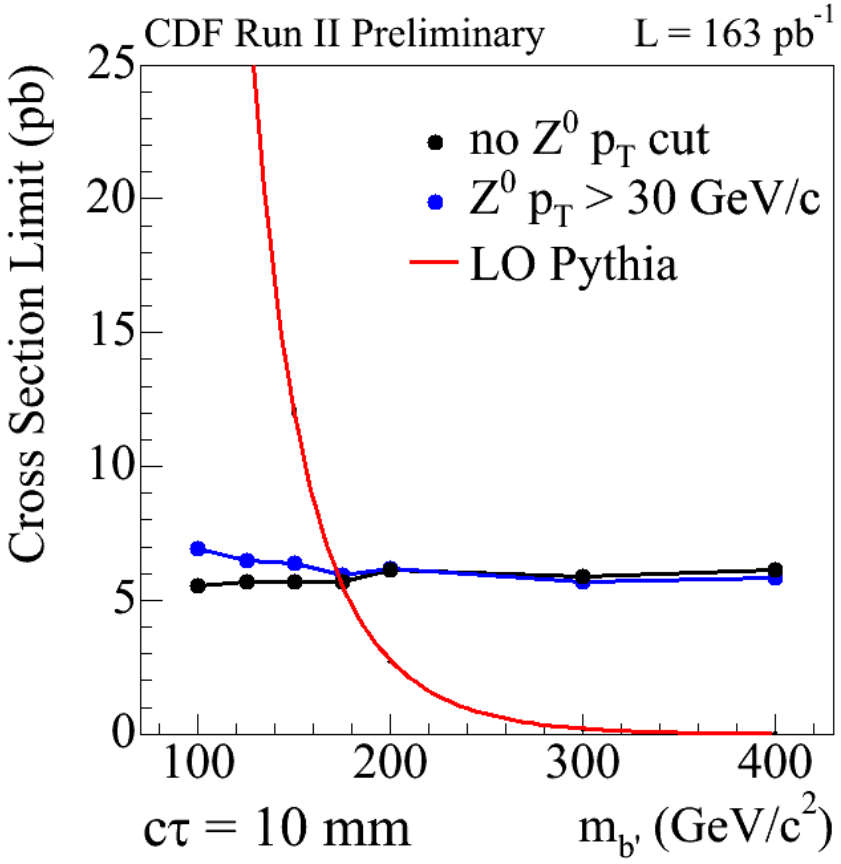
L_{xy} > 0.03 cm, with the Z^0 p_T > 30 GeV cut



Limit

- No significant excess of signal above background
- Set a 95 % confidence limit on the b' model using Pythia at LO





Limit – Lifetime vs. Mass

- At $m_{b'}$ = 150 GeV, exclude at 95 % confidence:

  $2.0 < c\tau < 70$ mm

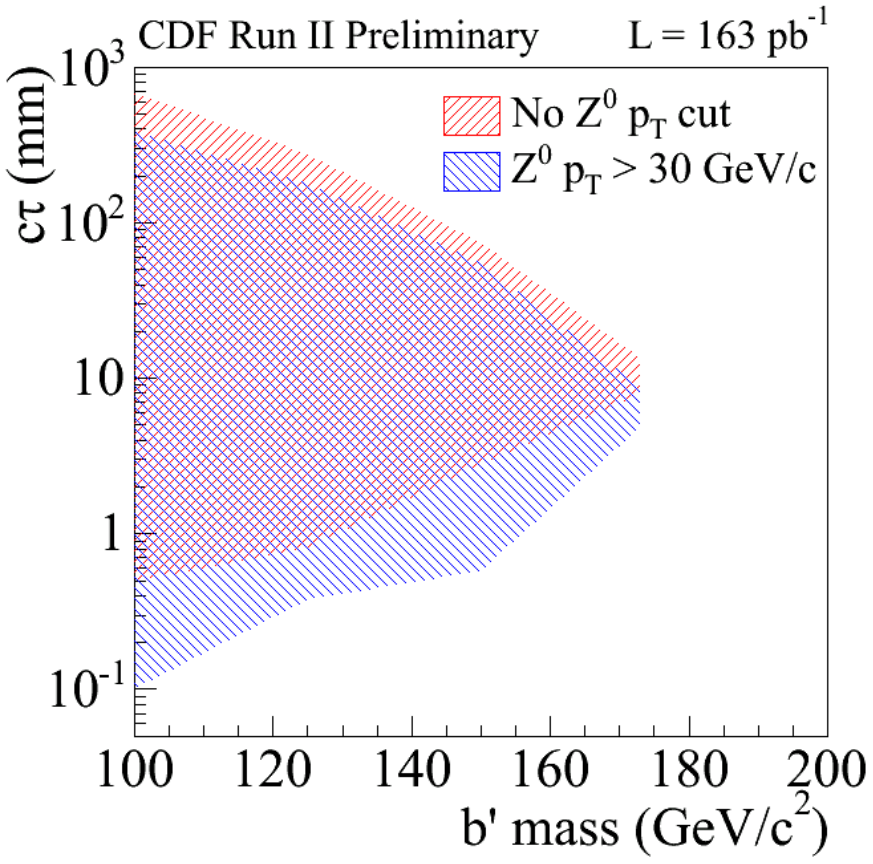
  $0.55 < c\tau < 52$ mm

- At $c\tau$ = 10 mm, exclude at 95 % confidence:

  $m_{b'} < 174$ GeV

- Model only valid if $m_{b'} < m_t$

- More generally, we exclude a region in mass and lifetime parameter space



Conclusions

- We have completed a search and set a limit on long-lived particles decaying to Z^0's at CDF in the dimuon channel
- Will now look at dielectrons
  - Will use experience gained from dimuon channel
  - Have greater acceptance for electrons
- Can do more searches using Z^0 bosons!
- And a lot more tools to use…

- What would Z^0 new physics events look like?
  - Z^0 has *high* p_T
  - Events *a lot* of other activity (*many* jets, *large* E_T)
  - Z^0 parents (might) have *long* lifetime