Searching for CHAMPs at CDF

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for the CDF Collaboration

What are CHAMPs?

CHAMPs are CHArged Massive Particles, stable enough to traverse the detector.

Standard Model extensions predict new massive particles

➔Most searches assume particles decay promptly

➔Long-lived particles would evade these searches

- Charged: CHAMPs (this talk)
- Neutral Massive Particles (NUMPs?) (next talk: decaying to photons)

➢ Particles can be long-lived if they have:

- weak coupling constants
- limited phase space
- a conserved quantity
- "hidden valley" (potential barrier)

Examples of CHAMPs

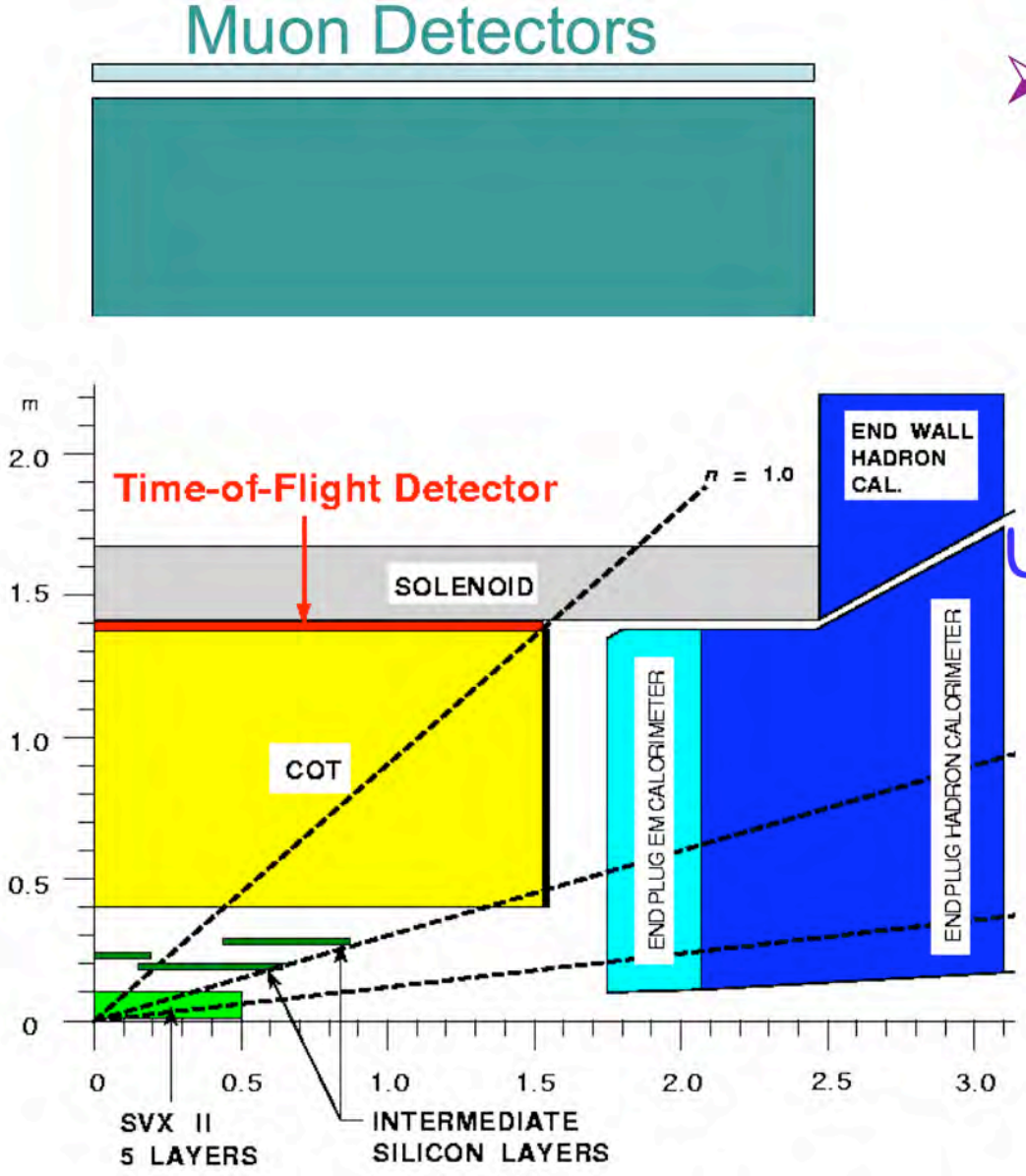
- **Supersymmetry:**
  - stable stop squark (We use this as our reference model)
    - R. Barbieri, L.J. Hall and Y. Nomura PRD **63**, 105007 (2001)
  - NLSP stau in gauge-mediated SUSY breaking
    - J.L. Feng, T. Moroi, Phys.Rev. D58 (1998) 035001
  - Light strange-beauty squarks
    - K. Cheung and W-S. Hou, Phys.Rev. D70 (2004) 035009
  - ➔ Light strange-beauty squarks
    - Matthew Strassler, HEP-ph/0607160
- **Universal Extra Dimensions (UXDs)**
  - Kaluza-Klein modes of SM particles
    - T. Appelquist, H-C. Cheng, B.A. Dobrescu, PRD 64 (2001) 035002
- **Long-lived 4th generation quarks**
  - P.H. Frampton, P.Q. Hung, M. Sher, Phys. Rep. 330 (2000) 263-348.

CHAMP Signatures

Champs give a unique signature in the detector

- CHAMPs have a lot of momentum (they are heavy)
- CHAMPs are slow (they are heavy)
  - ➔Large *dE/dx*
  - ➔Long time-of-flight
- CHAMPs are hard to stop (they are heavy)
  - ➔Lose energy mostly through ionization
  - ➔Very penetrating
- Look for "slow muons"
  - ➔Look for high transverse momentum (p_T) tracks in the muon dataset that are slow (long time-of flight)

Look for "Slow Muons"



- Look at events that trigger the muon detectors:
  - ➔ Penetrate through the calorimeter to the muon chambers
  - ➔ Matching good high-p_T track

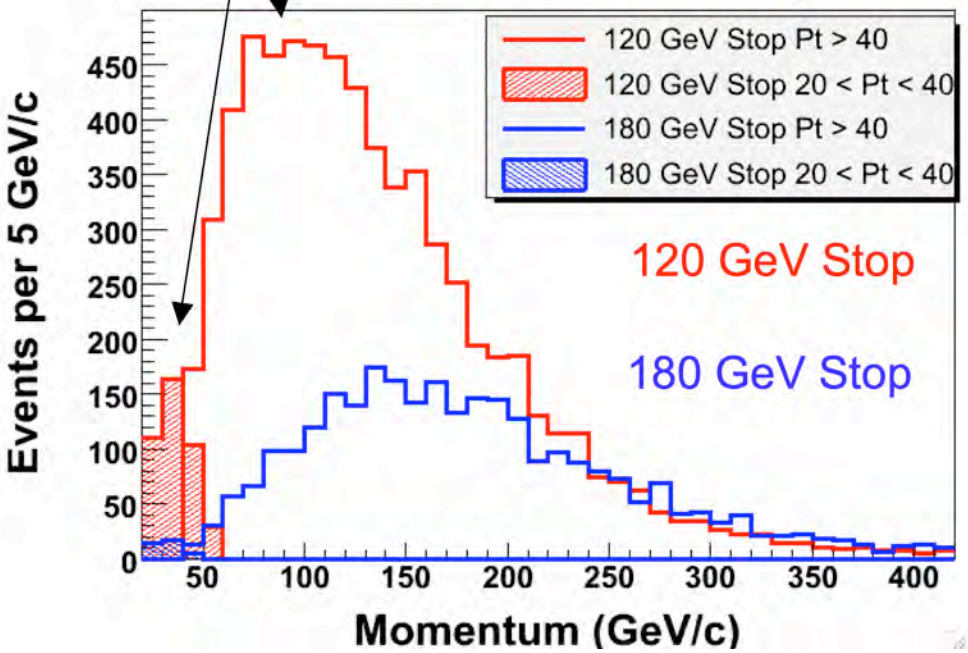
Use Time-of Flight detector to measure β

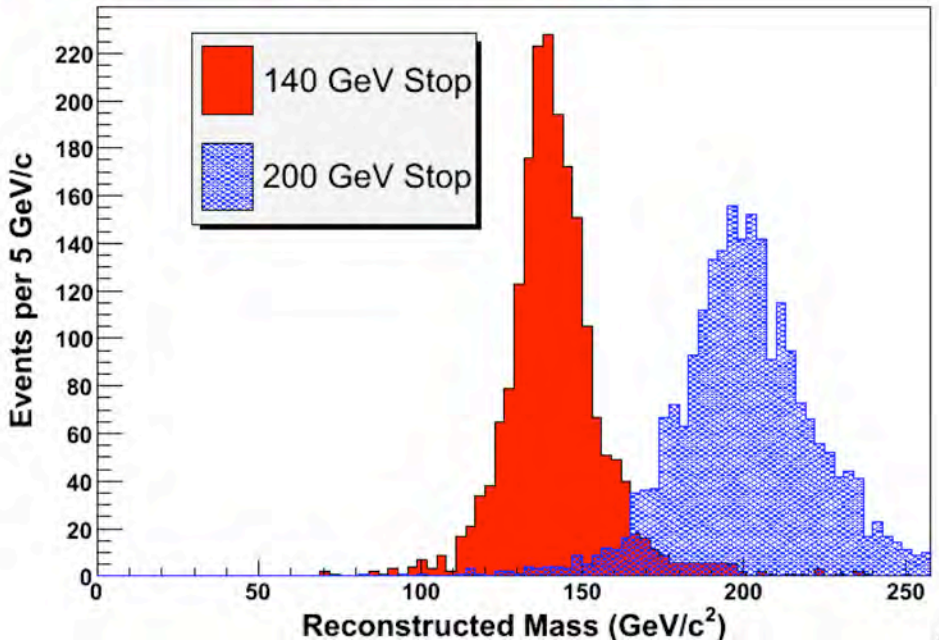
To calculate β, need:

- candidate TOF arrival time
- independent interaction t_0
- path length

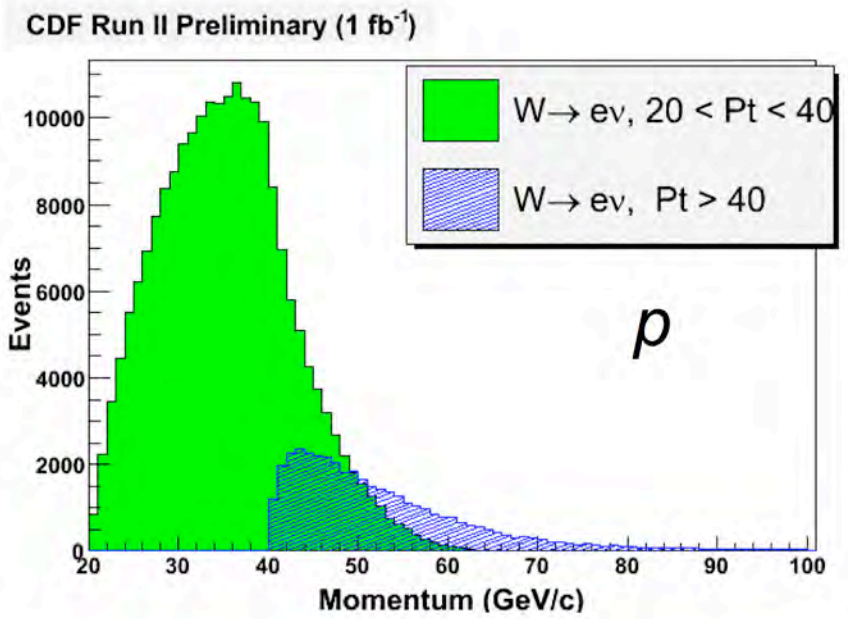
Analysis Strategy

- Use track momentum and velocity measurements to calculate mass
  - correlated for signal, uncorrelated for background
- Signal events will have large momentum
  - ➔signal region p_T > 40 GeV/c
  - ➔control region 20 GeV/c < p_T < 40 GeV/c
    - use control region to predict background shape



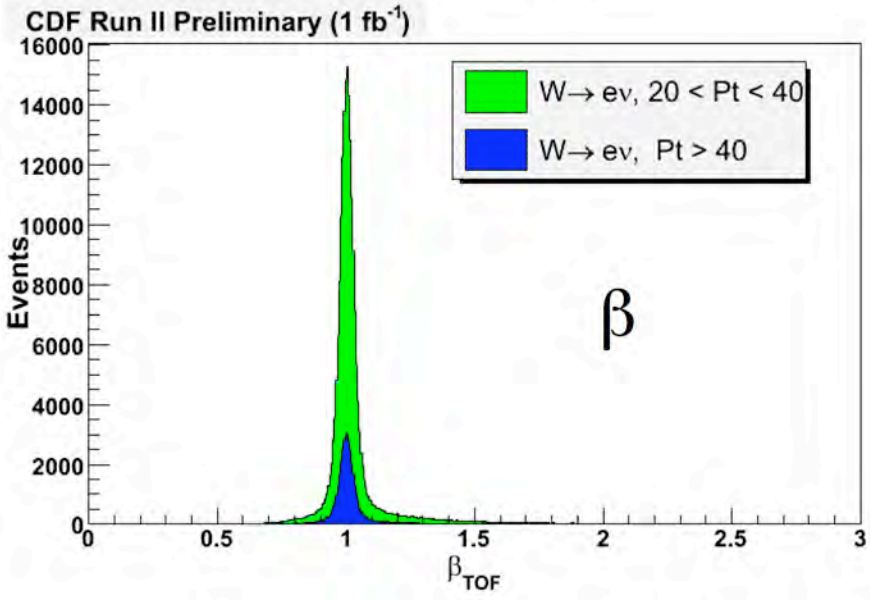


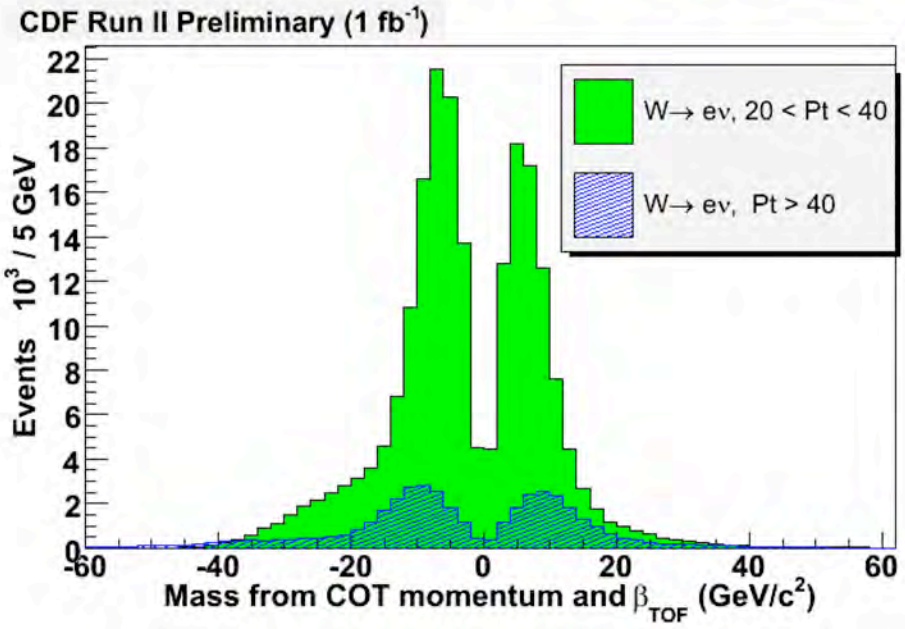
Use p and β to find Mass



$$m = p\sqrt{\frac{1}{\beta^2} - 1}$$

- $\beta > 1$ unphysical
  - ➔ assign negative mass to "tachyons"
- Control region and signal region have different momenta, so mass distributions different





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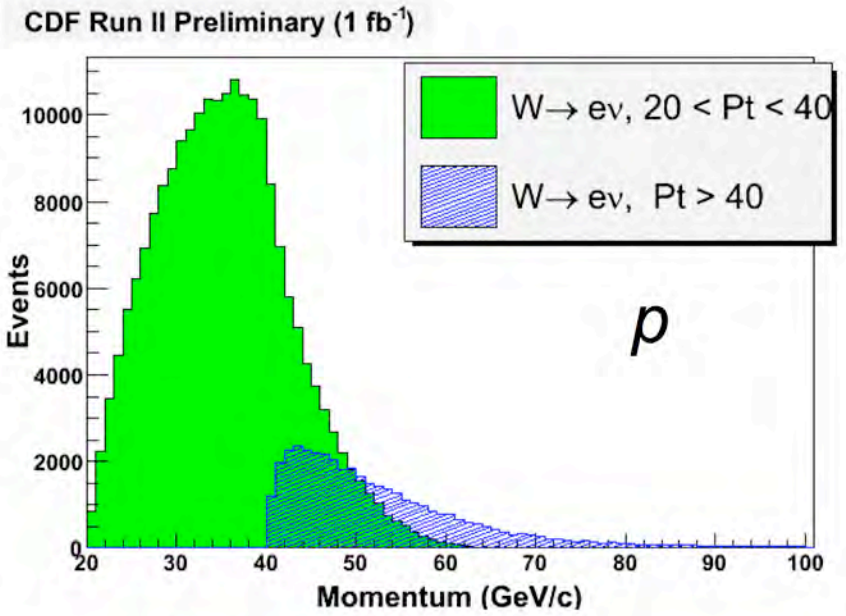

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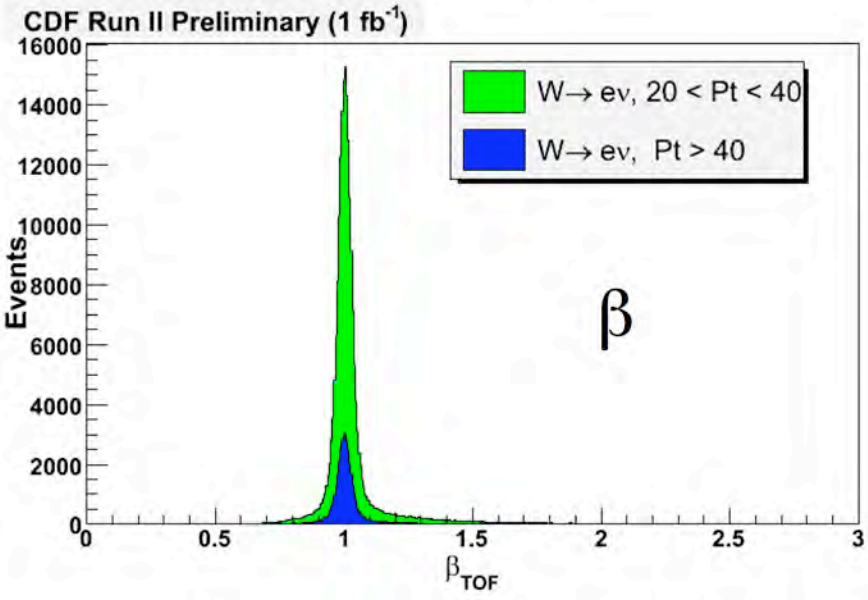
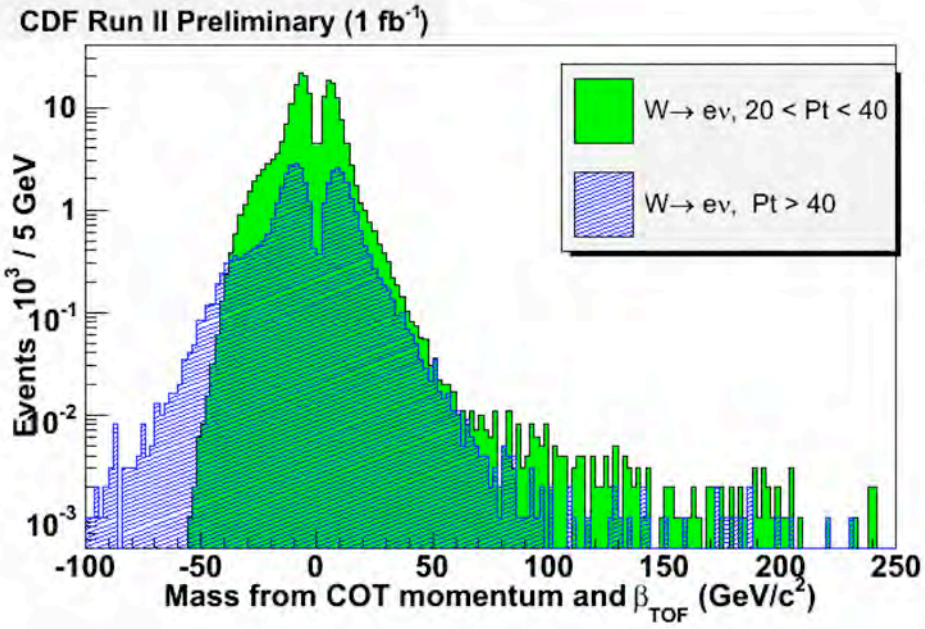
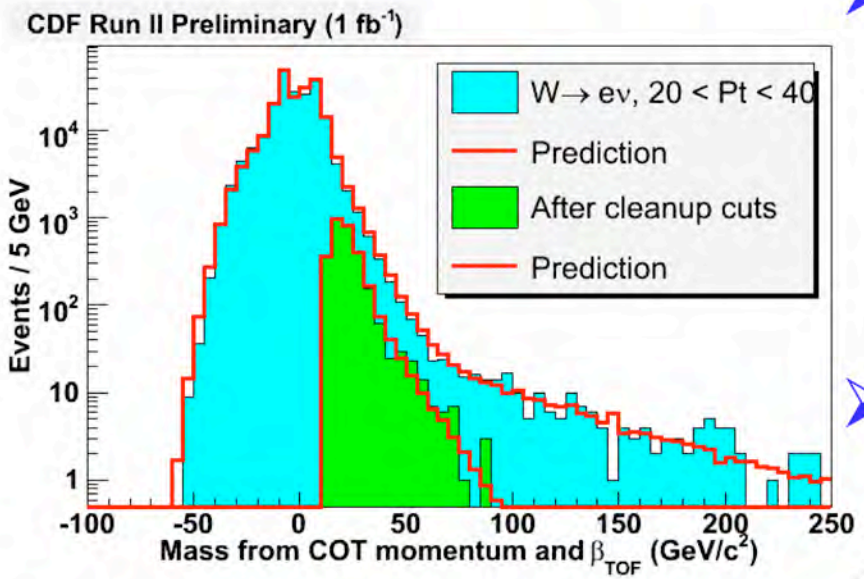




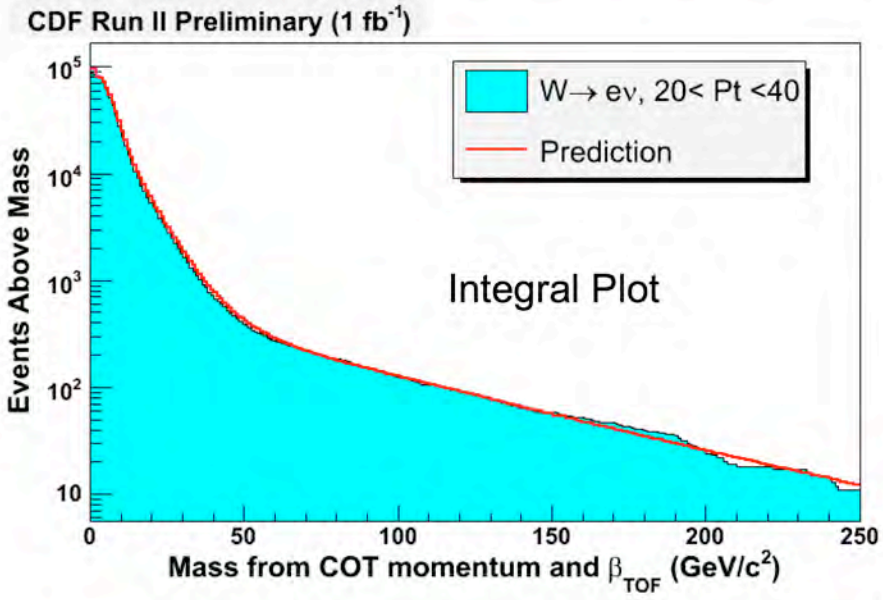
Background & Cleanup

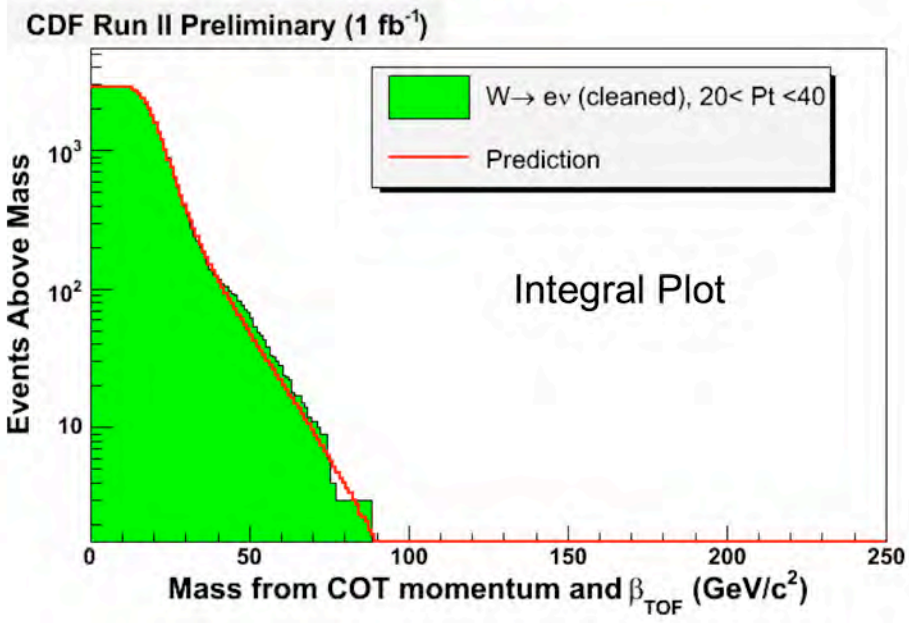
- Cosmic rays
  - ➔ Time of cosmic ray tracks uncorrelated with interaction time, could appear to be CHAMPs
    - Remove by looking for backward-going track opposite candidate
- Instrumental effects:
  1. Mismeasured event t_0
     - require TOF and tracking t_0 to agree (0.5 ns)
  2. Incorrect TOF for CHAMP candidate
     - require good tracking χ^2 when using TOF β
  3. Require $\beta < 0.9$ (i.e. "slow")
     - signal is slow; background is fast

Want to Predict Background Mass Shape



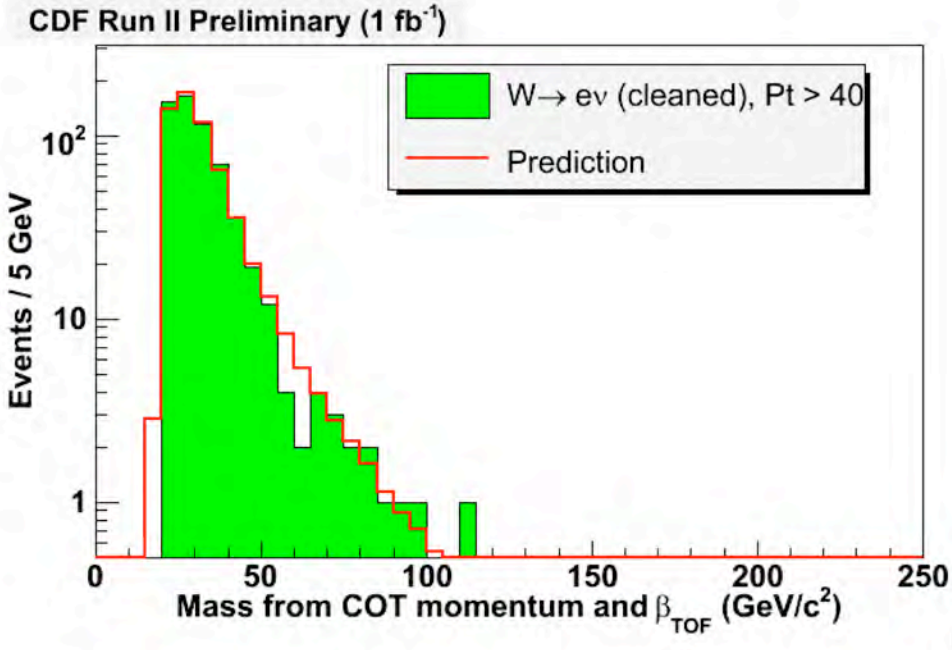
- Assume p and β are independent
  - Calculate mass bin-by-bin from p and β histograms
  - weight by bin contents
  - gives mass shape prediction
- Works!
  - p and β are largely independent in the control sample

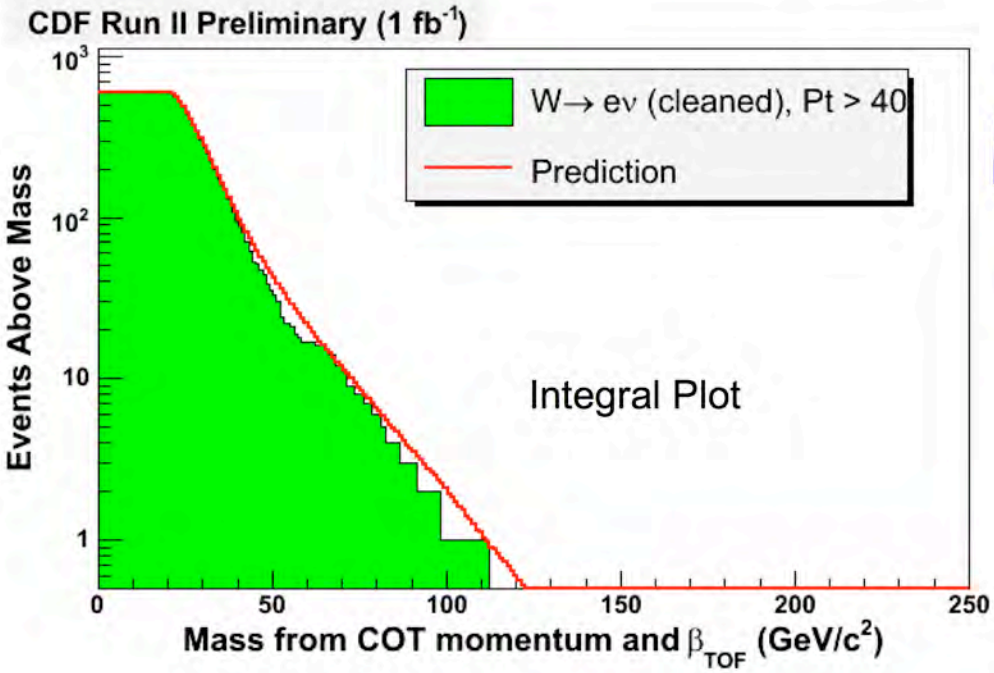




W->eν "Signal Region"

- W->eν events with electron Pt > 40 GeV
  - ➔No signal-region events above 120 GeV after cleanup cuts





Predictions generated from control-region β and signal-region p

- ➔assumes β matches in both regions

Champs Data Sample

Use Muon Datasets (1.03 fb^{-1})

➔require Central muon trigger

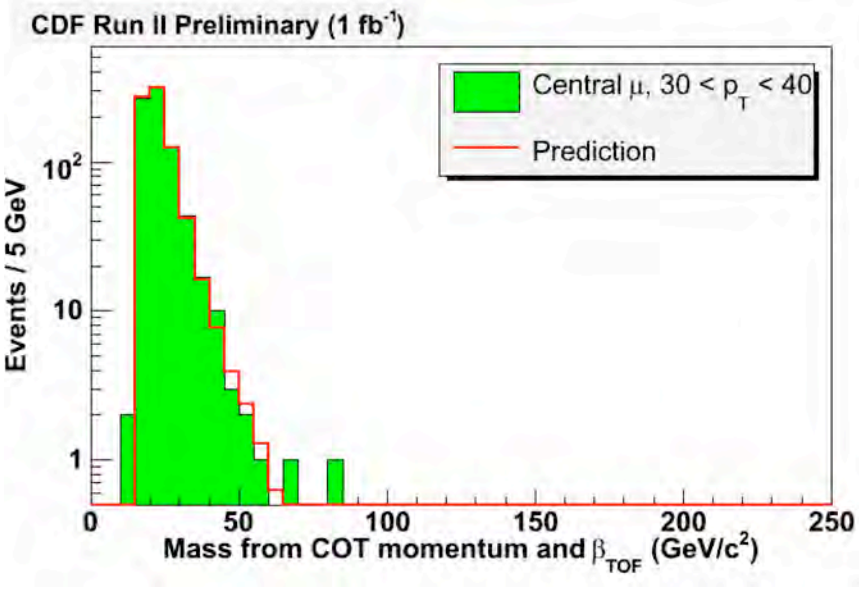
➔Many CHAMPs pair produced

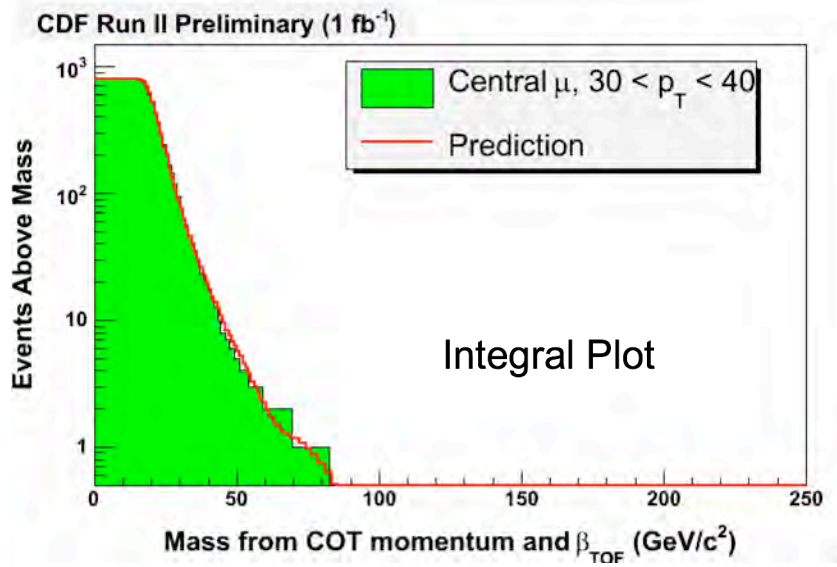
- look at 2 highest Pt good muons
- if only 1 muon, also look at highest Pt good track

Champs Data Sample

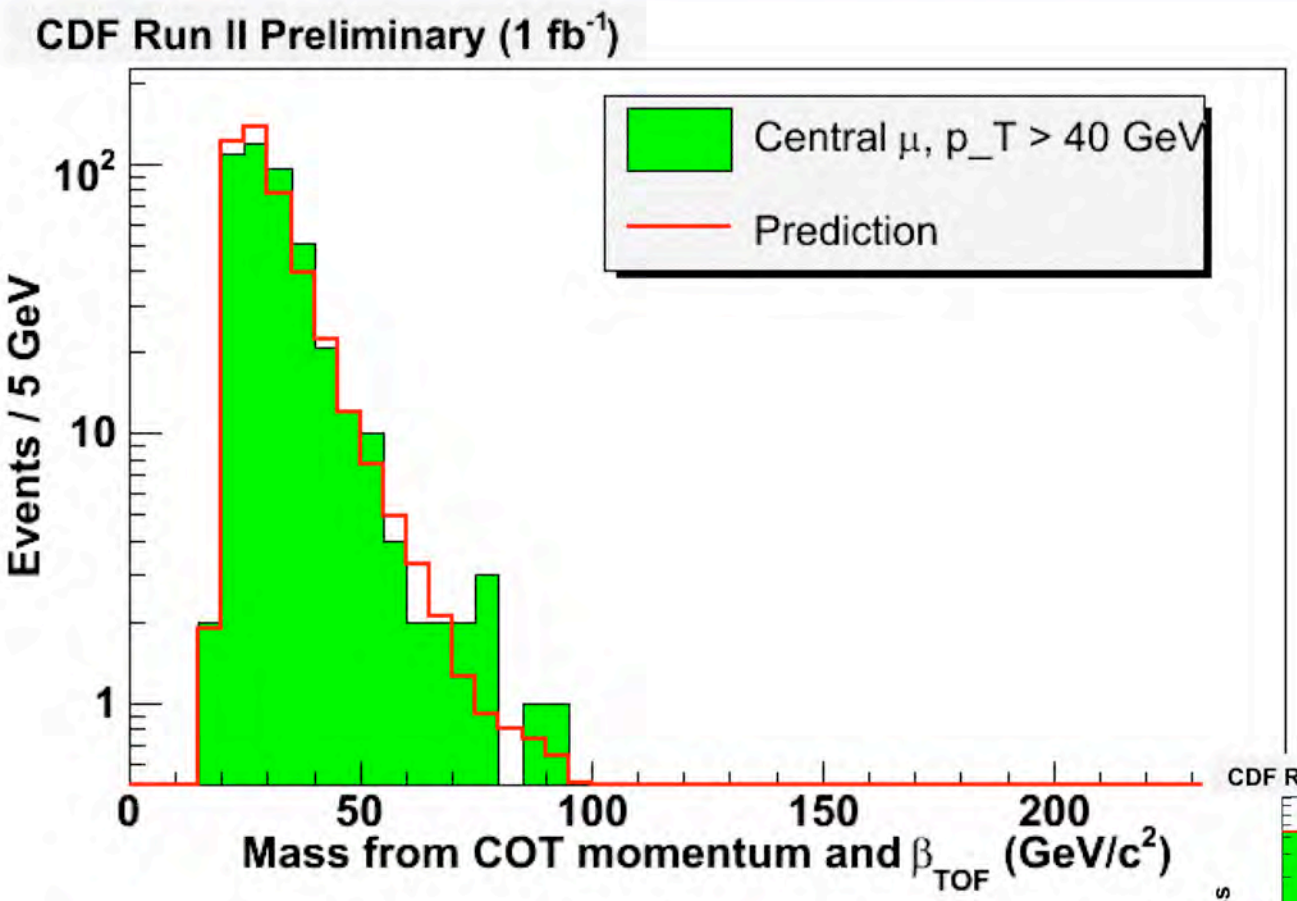
Use Muon Datasets (1.03 fb^{-1})

- ➔require Central muon trigger
- ➔Many CHAMPs pair produced
  - look at 2 highest Pt good muons
  - if only 1 muon, also look at highest Pt good track
- ➔Verify background shape prediction
  - use 20-30 GeV to predict 30-40 GeV region



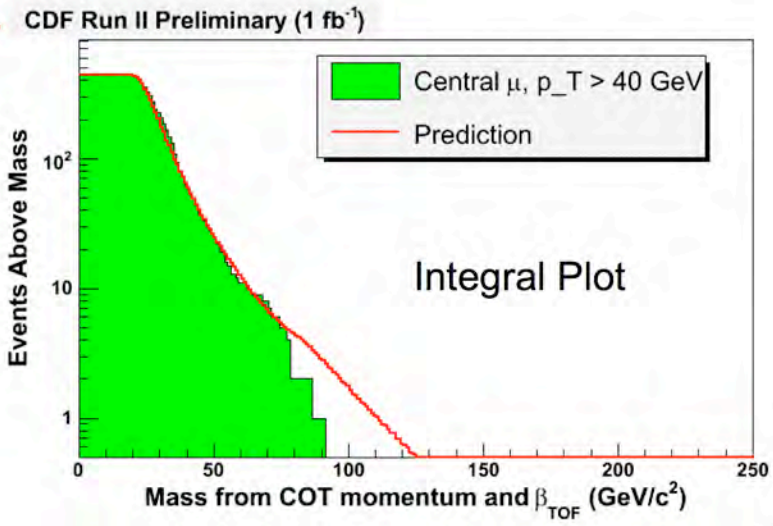


Muon CHAMP Result



Signal-region events consistent with background prediction

After cleanup, no CHAMP candidates above 100 GeV/c^2



Model-Independent Limits

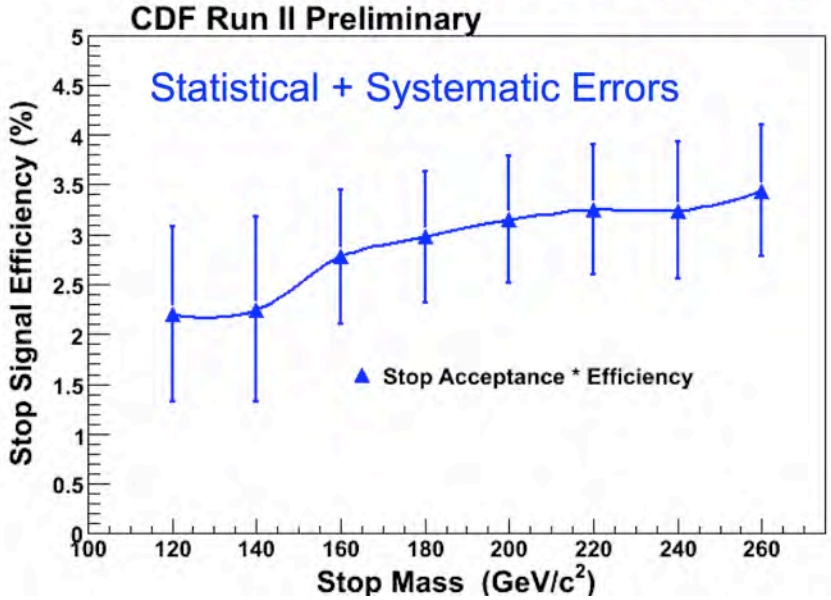
- Model-dependent factors are
  - → β and momentum distributions
  - → geometric acceptance
- For model independence, find cross section limit for *CHAMPs fiducial to Central Muon Detectors* with $0.4 < \beta < 0.9$ and $P_t > 40$ GeV
  - → strongly interacting (can hadronize neutral)
    - efficiency 4.6 ±0.5%
  - → weakly interacting
    - efficiency 20.0±0.6%
  - → No observed events above 100 GeV/c^2 in 1 fb^{-1}

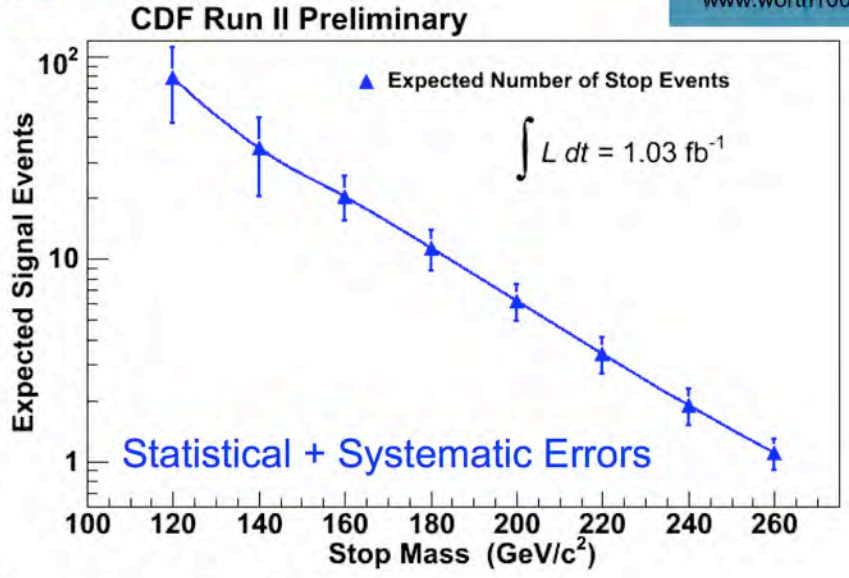
Stop Signal

Look at Stable Stop (reference model)

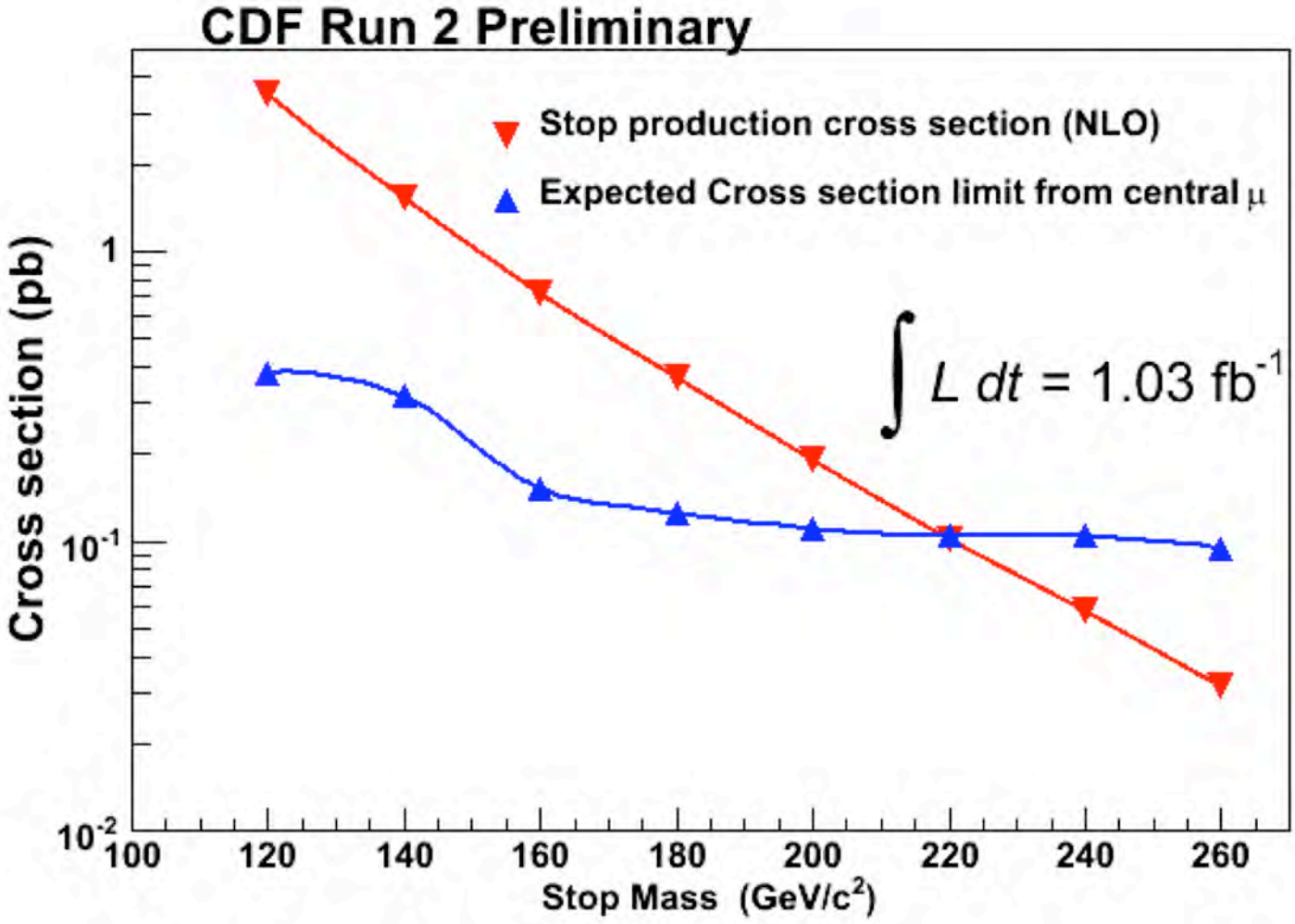
R. Barbieri, L.J. Hall and Y. Nomura PRD **63**, 105007 (2001)

- ➔Pair produced
- ➔Get kinematic and geometric acceptance
  - Pt > 40 GeV; 0.9 > β > 0.4; TOF Fiducial
- ➔Must be charged:
  - in tracking chamber for identification
  - in muon detectors for trigger





Expected Stop Limit



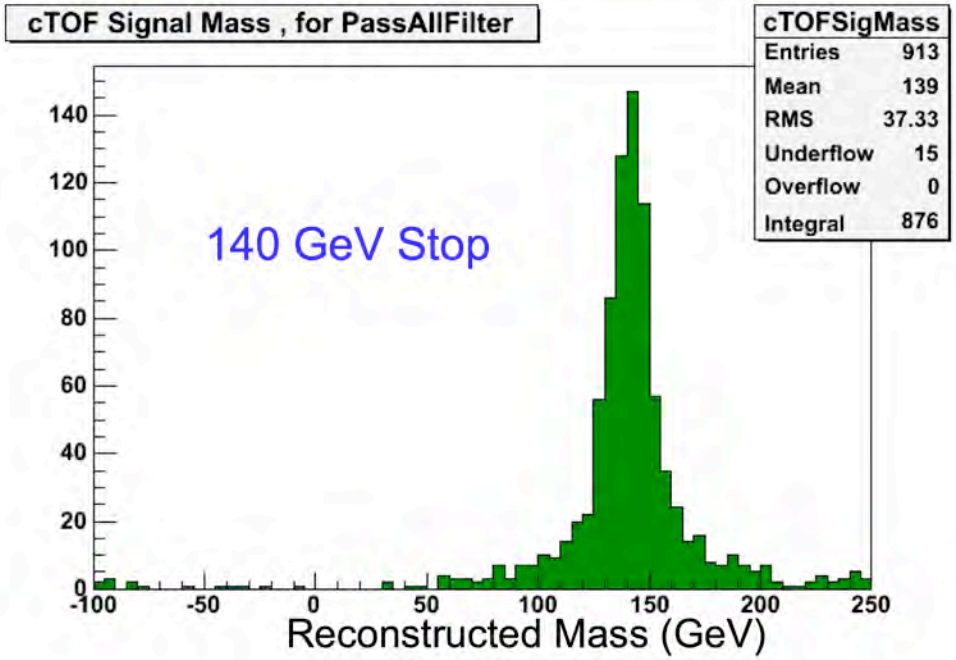
Actual limit should exclude stable stops between 120 and about 220 GeV/c^2

Conclusions

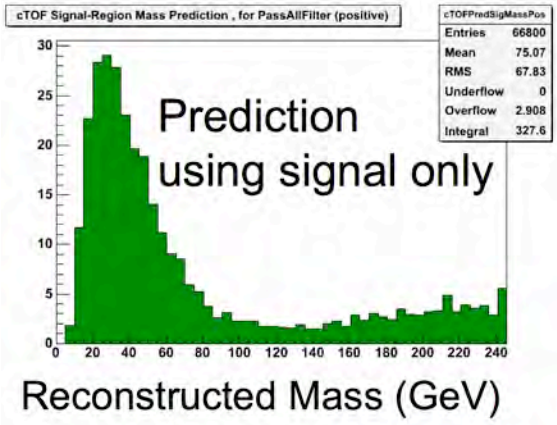
- We are searching for CHAMPs in CDF
  - ➔Low backgrounds
    - Combining Tracking and TOF information
- No signal seen in Central Muons with 1 fb^{-1}
- Expect to exclude stop masses
  - 120 to about 220 GeV/c^2 (95% C.L.)
- Much more to do:
  - ➔Additional models
    - staus, Universal extra dimensions, heavy quarks…
    - doubly charged massive particles
  - ➔more acceptance and more data are available…

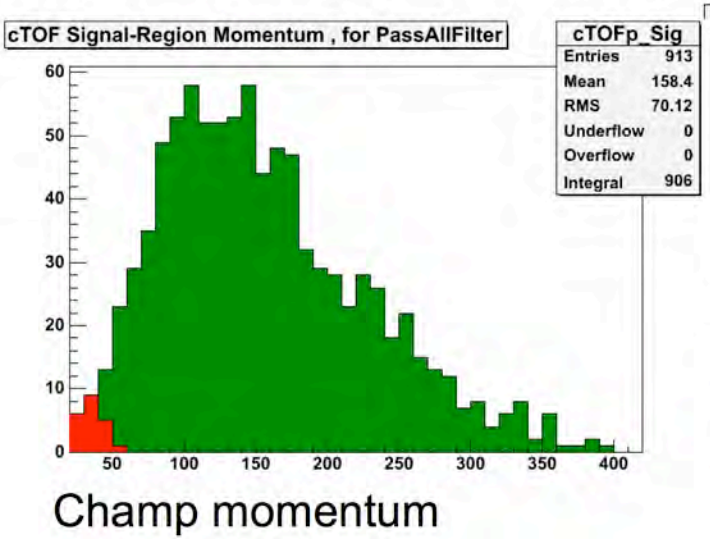
Backup

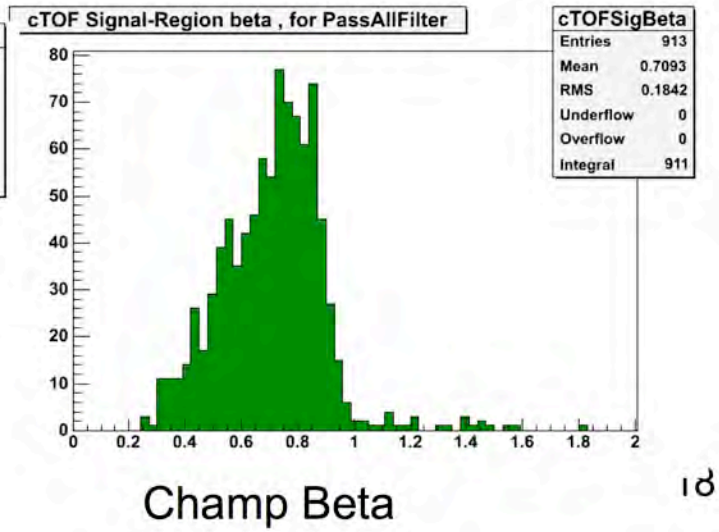
CHAMP Signal Mass



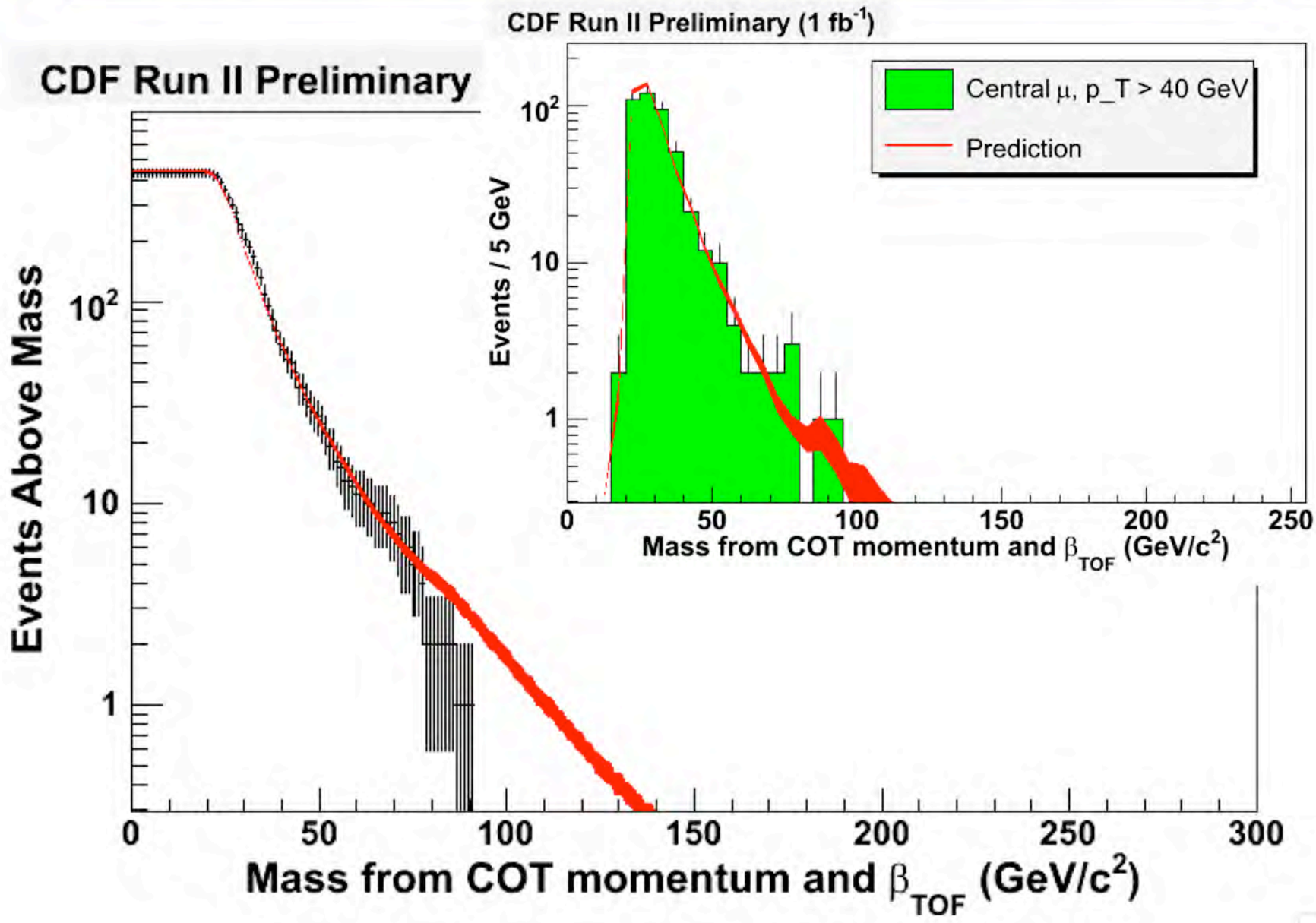
Reconstructed CHAMP signal mass has good resolution







Signal Region Uncertainties



Cleanup cuts

- Require TOF t_0 to be no more than 0.5 ns earlier than COT t_0
  - ➔66% efficient, but this will improve with next ntuple version
- Require COT χ^2 < 500 when track refit assuming β_{TOF}
  - ➔92% efficient in W->eν