Search for Charged Massive Long-Lived Particles

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for DØ collaboration

Outline

- Introduction
- Three search channels
  - pair production using ToF (Run IIa) PRL 102, 161802 (2009)
  - pair production using ToF and dE/dx (Run IIb)
  - single production using ToF and dE/dx (Run IIb)
- Combination
- Summary & outlook

Charged Massive Long-lived Particles (CMLLP)

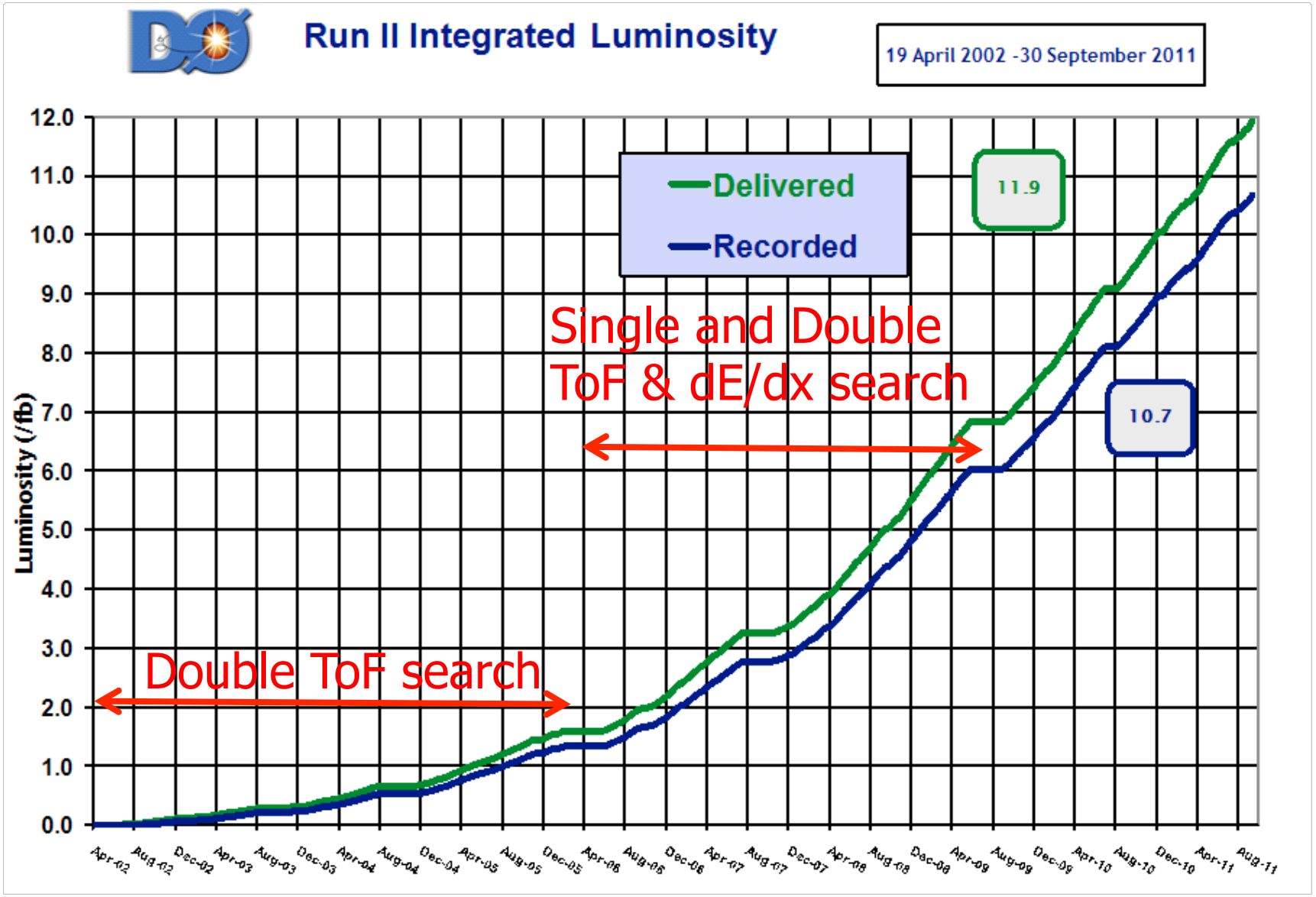
- Long-lived: $c\tau \geq$ O(meter)
- Weakly interacting
  - stau
  - wino
  - higgsino

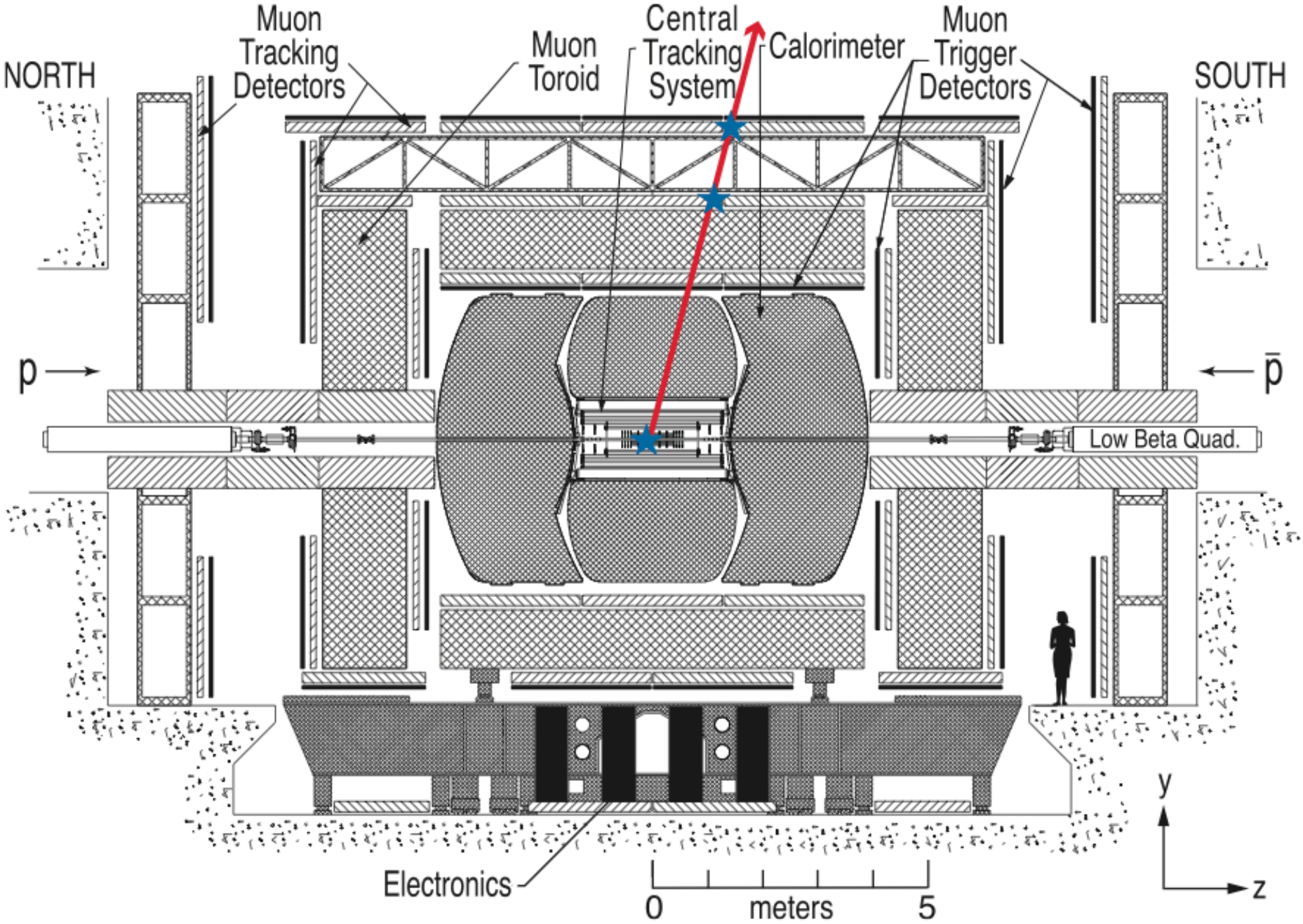
  } Propagate through detector as a slow heavily ionizing "muon"

- Color-charged
  - stop

Need to take into account detector-specific (re-)hadronization effects *(model dependent – different systematics for different detectors and analysis methods)*

DØ Luminosity



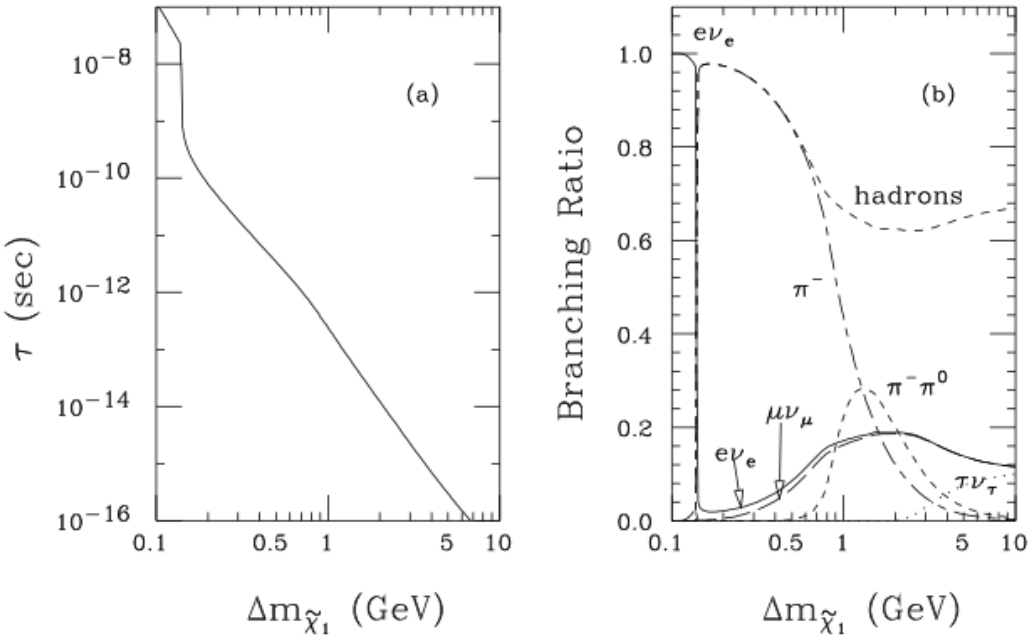

NORTH
Muon
Tracking
Detectors
Muon
Toroid
Central
Tracking
System
Calorimeter
Muon
Trigger
Detectors
SOUTH
p
p̄
Low Beta Quad.
Electronics
0
meters
5
y
z

Stop propagation

- ~60% of stops hadronize into charged particles
- Tracker is quite light, very small λ
  - keep their charge
- Then traverse calorimeter (>10 λ)
  - Need to remain charged to register in inner muon system
- Then pass through iron yoke
  - Need to remain charged to register in the outer muon system
- Stop and anti-stop behave differently
  - Stop forms baryons (charge 0, +1, +2, with model-dependent probabilities), take probability 1/3 each
  - Anti-stops form mesons, take 50% probability to be charged
  - If pair-produced, with these assumptions, to be charged in all three locations
    - Both: 4% (36% if no charge flipping)
    - At least one: 38% (84% if no charge flipping)

Long-lived charginos

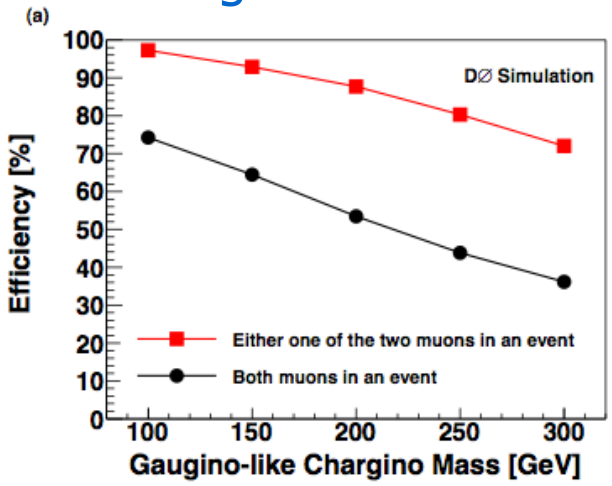
- If lightest gaugino is almost pure wino or higgsino
- Fairly common in string-theory inspired anomaly-mediated SUSY breaking models
  - Leads to mass degeneracy of lightest charged and neutral gauginos

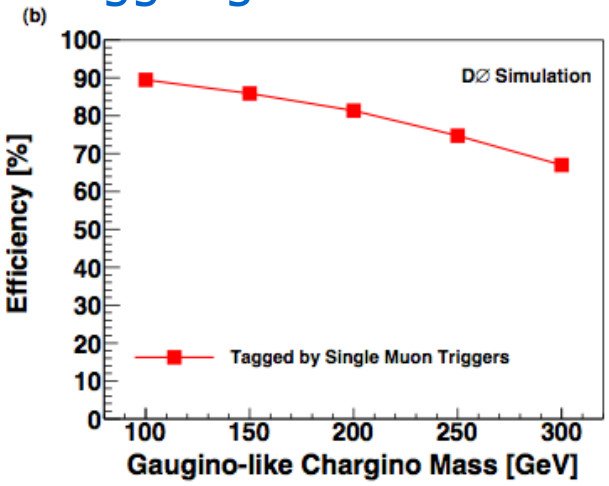


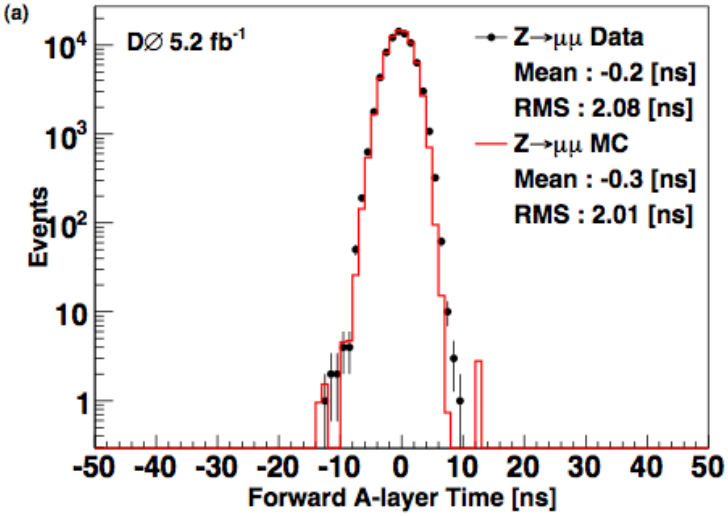
$\Delta m_{\tilde{\chi}_1}$(MeV)	125	130	135	138	140	142.5	150
$c\tau$(cm)	1155	918.4	754.1	671.5	317.2	23.97	10.89

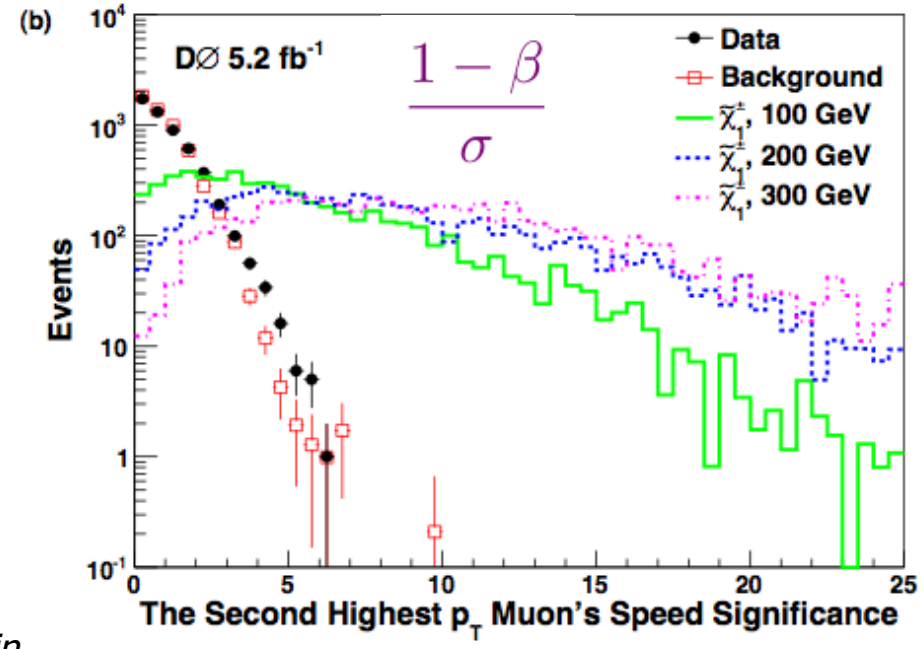
ToF in Muon System

- Muon system used for triggering and offline ToF measurement
- Readout time gate is wider than the trigger gate



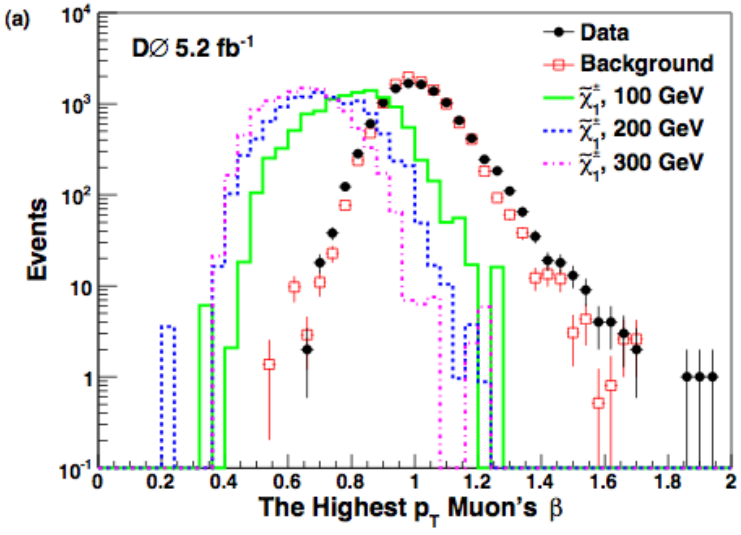


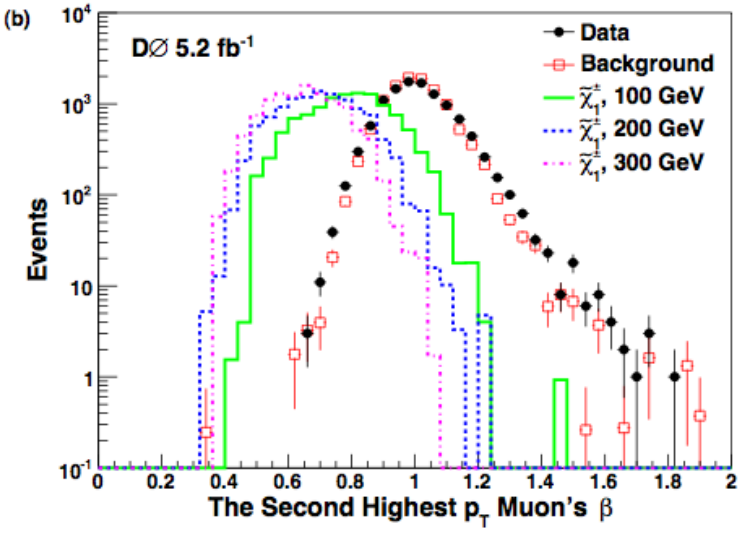


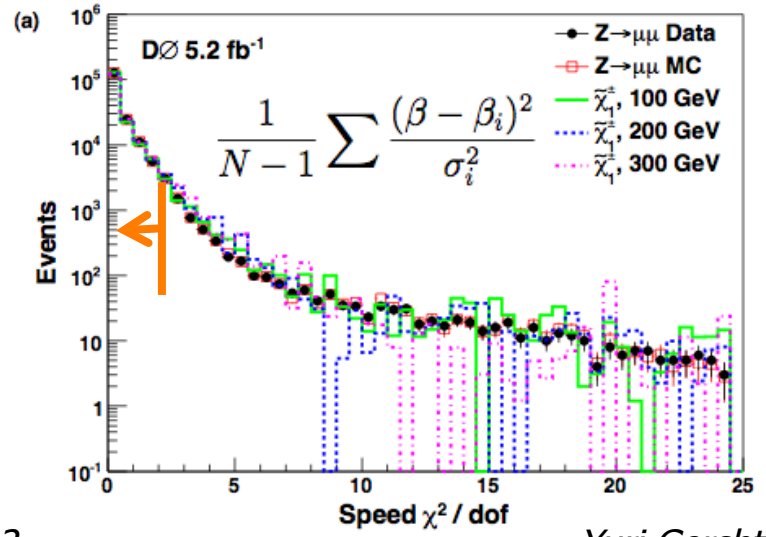


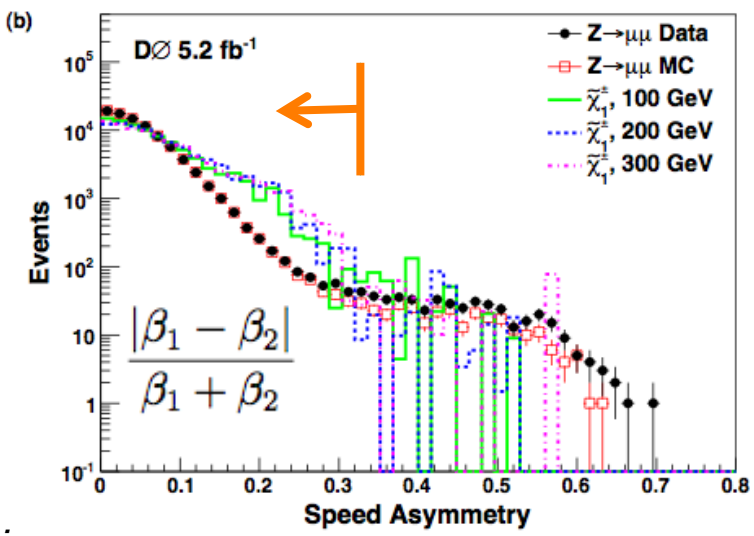
ToF in Muon System

- If two candidates are present, require small asymmetry to ensure good measurement, for single candidate – cut on speed χ^2



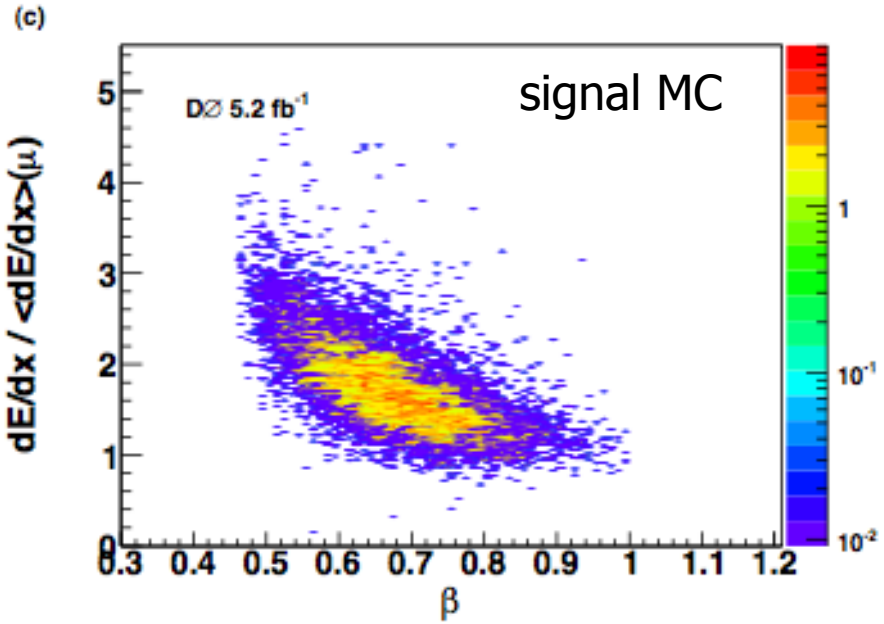


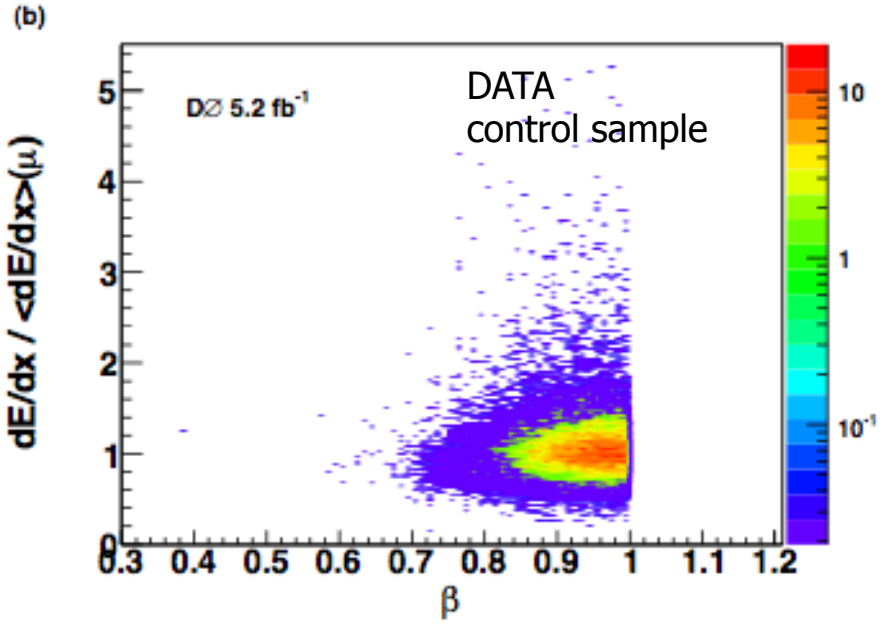




dE/dx in silicon tracker

- Exclude 20% of the highest amplitude hits to reduce Landau tails
- Measured dE/dx decreases with radiation damage – adjust MC and data for all time epochs to achieve most probable dE/dx = 1

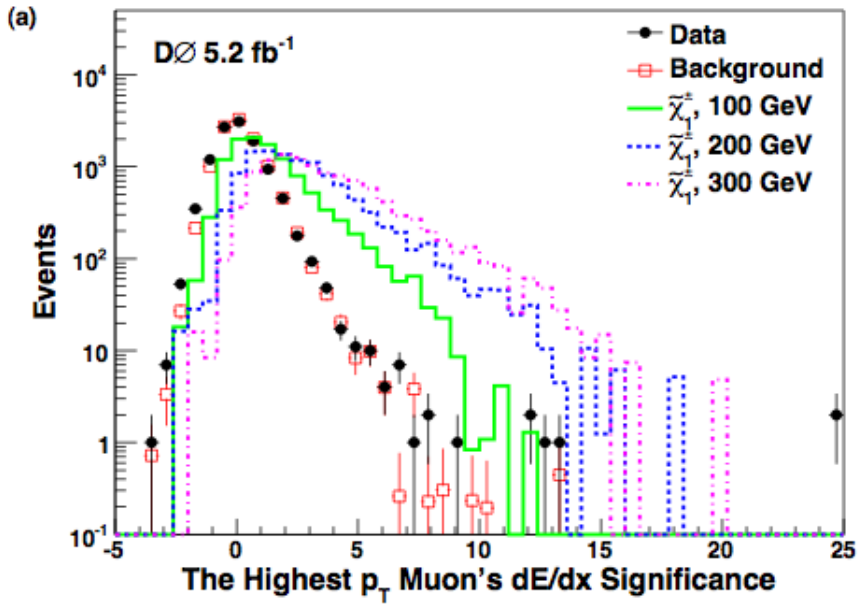


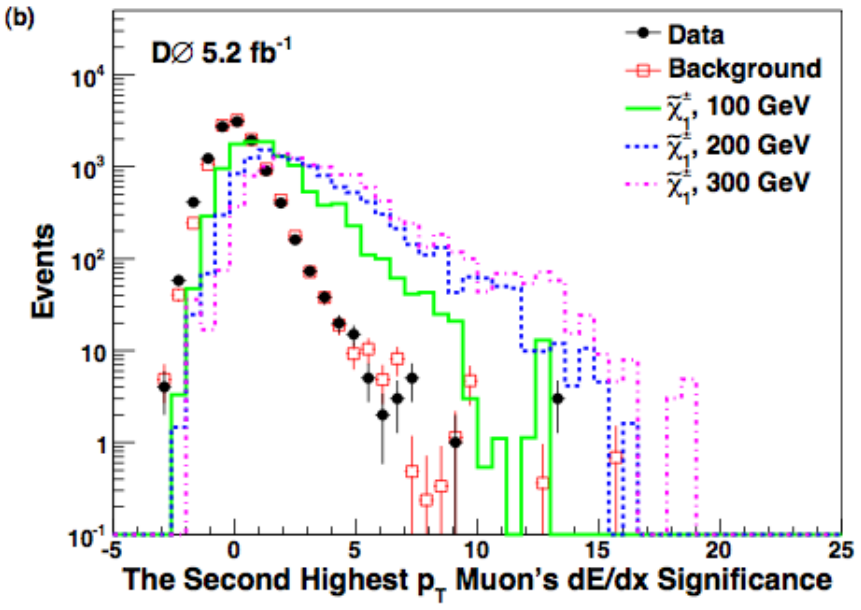


dE/dx in silicon tracker

- Exclude 20% of the highest amplitude hits to reduce Landau tails
- Measured dE/dx decreases with radiation damage – adjust MC and data for all time epochs to achieve most probable dE/dx = 1
- Model dE/dx measurement accuracy based on number of hits – introduce dE/dx significance

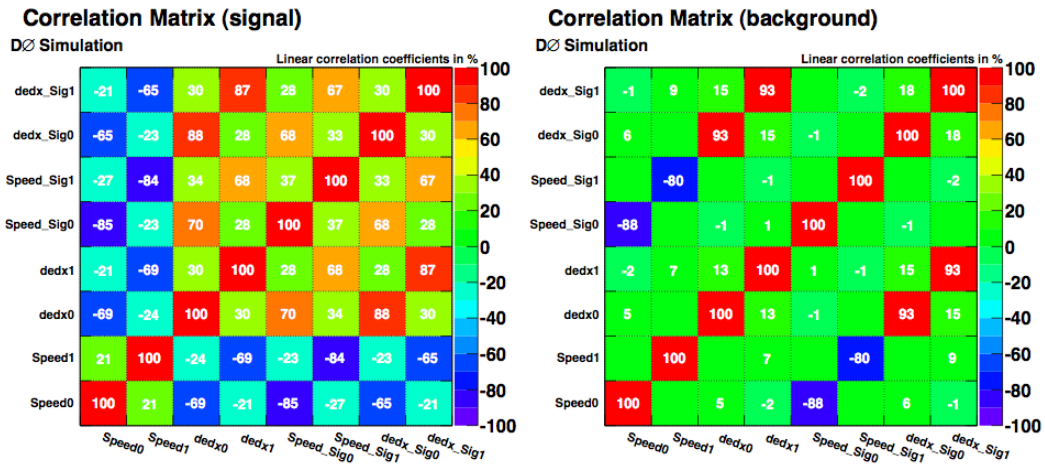
$$dE/dx \text{ significance} = \frac{dE/dx - 1}{RMS(dE/dx)_{N_c}}$$

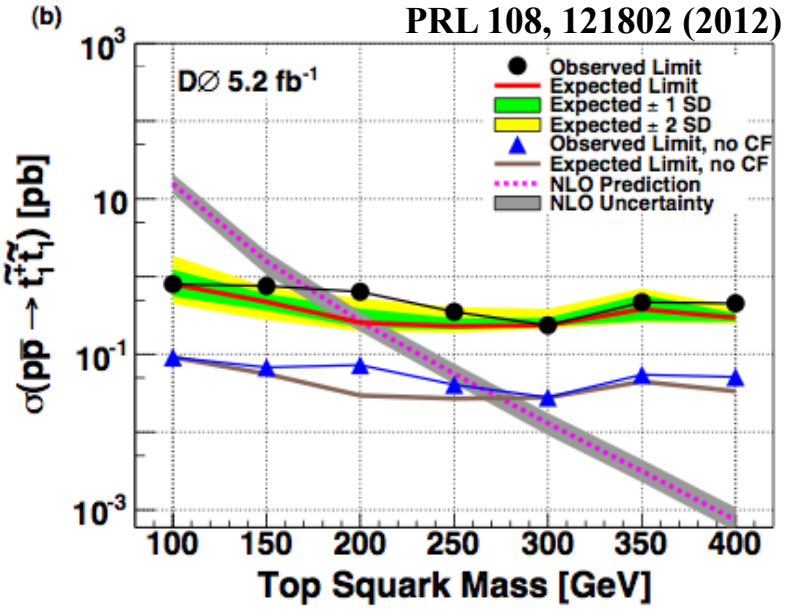


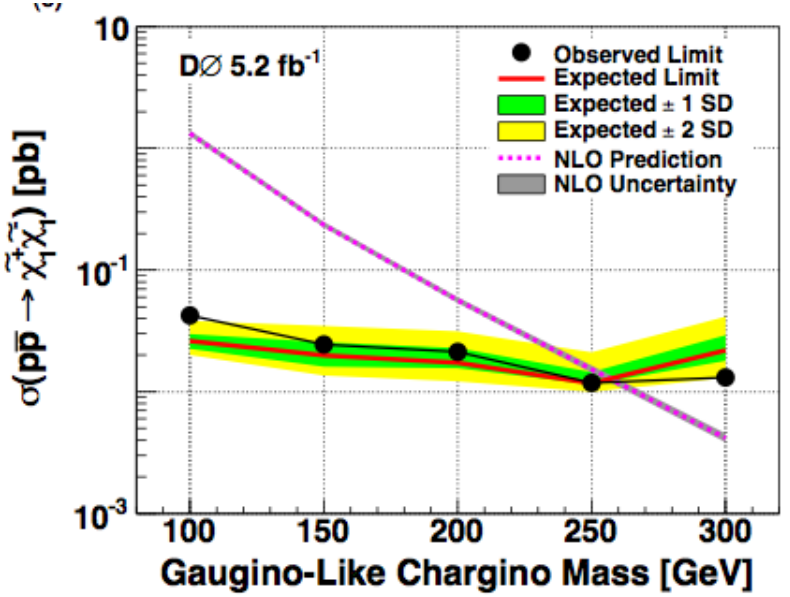


Double CMLLP Search

- Require exactly two muons
  - pT> 55, 50 GeV
  - Good quality, trigger match, cosmic veto, >= 3 silicon hits
  - β <1, β_{asym}<0.35
- Train BDT
  - β , β_{signif}, dE/dx, dE/dx_{signif}

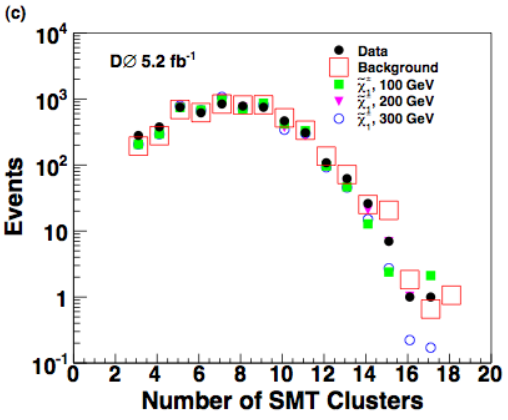


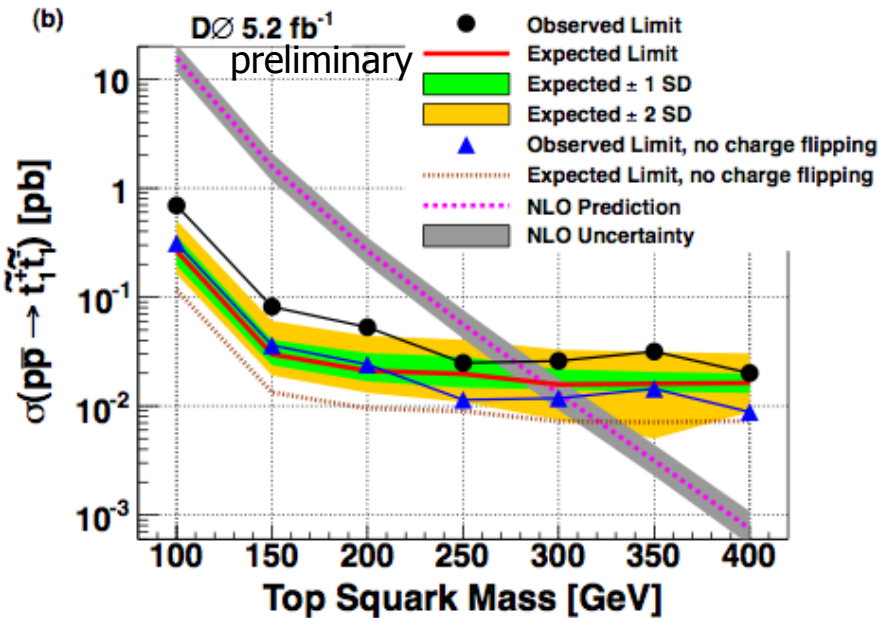


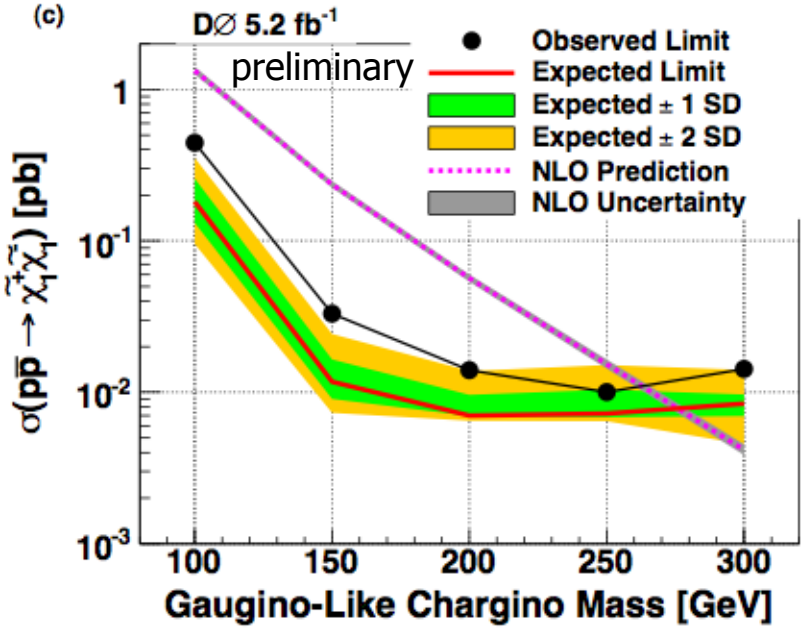


Single CMLLP Search

- Require one muon
  - pT> 60 GeV
  - isolation
  - Good quality, trigger match, cosmic veto, >= 3 silicon hits
  - β <1, χ^2/dof < 2
- Data driven background estimate using ABCD method M_T and β
  - β >1 is background dominated
  - M_T<200 GeV is background dominated (W)
- Train BDT
  - β , β_{signif}, dE/dx, dE/dx_{signif}
  - number of silicon and muon scint hits

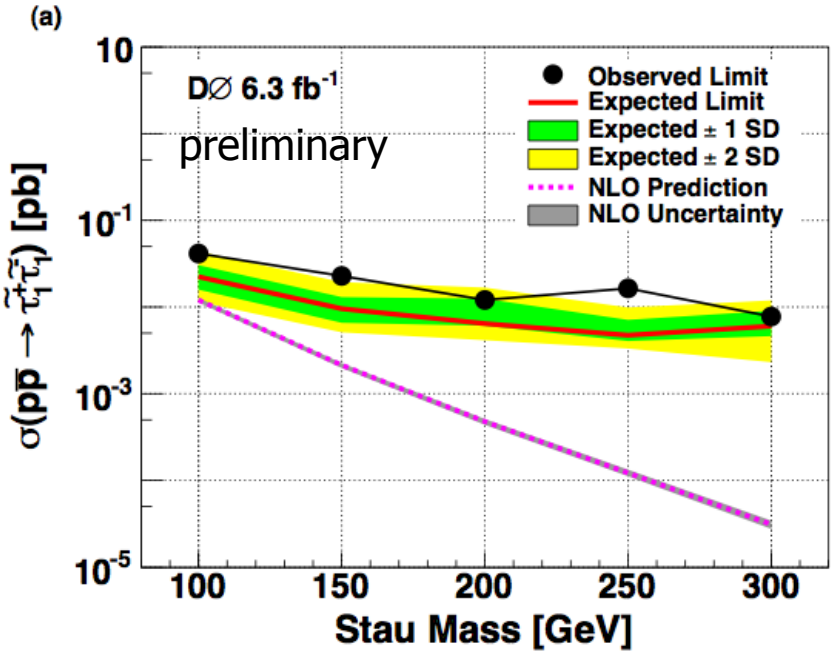


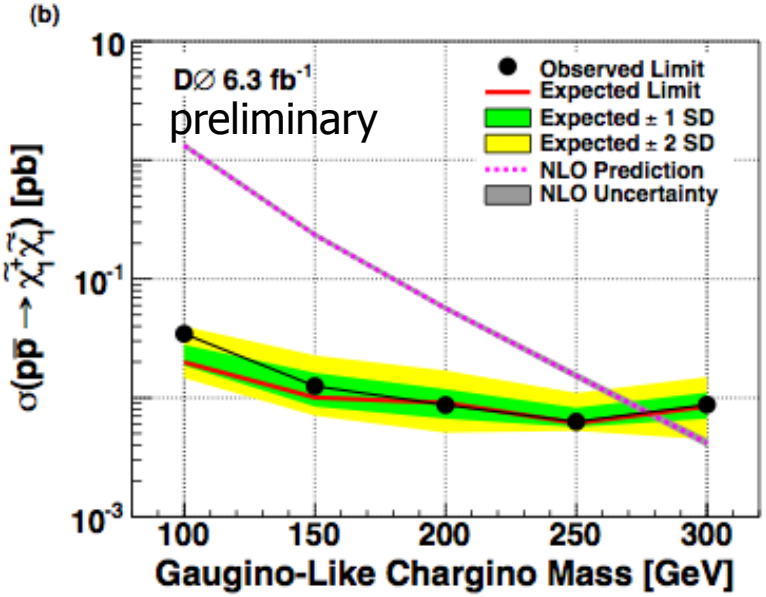


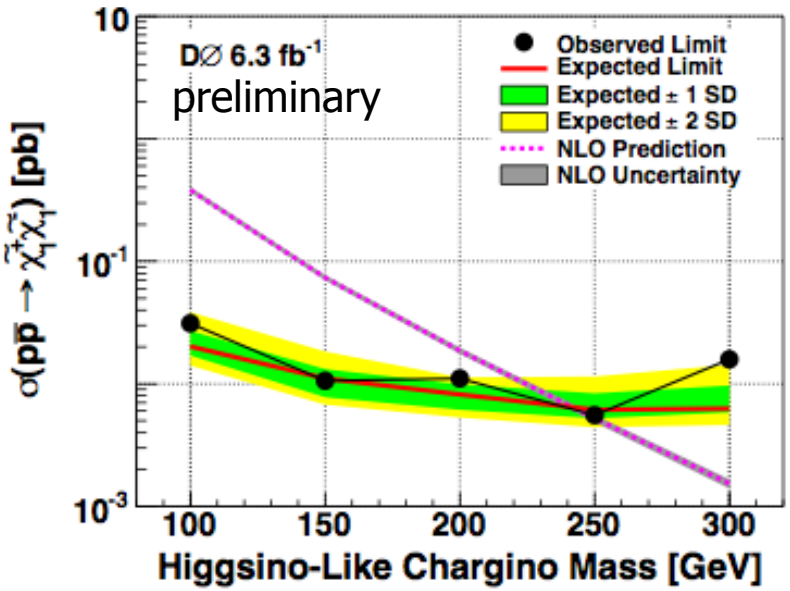


Combination

- Remove events with two CMLLP's from single analysis
- Instead of cutting on BDT, use the entire shape for likelihood analysis







Summary

- We searched for charged massive long-lived particles in DØ data using time of flight and ionization measurements
- For color-neutral particles, our result excludes long-lived charginos below 250-275 GeV depending on model
- For long-lived stop the result has somewhat different systematic error from propagation of stop hadrons in matter

backups

Selection details: single CMLLP

- Single muon trigger without L2 tight timing cut
- At least one muon in the event, only highest p_T muon is used
  - muon quality cut:
    - ✓ $|\eta_{det}|<1.6$
    - ✓ mediumnseg3 without cosmic veto
    - ✓ medium track
    - ✓ NPtight isolation
  - analysis cut:
    - ✓ |zatDCA|<40cm
    - ✓ $p_T>60$GeV
    - ✓ $\beta<1$, speed $\chi^2<2.$, where $\text{speed } \chi^2 = \frac{1}{N-1}\Sigma\frac{(\beta-\beta_i)^2}{\sigma_i^2}$
    - ✓ matching $\chi^2<100.$ between muon and central track
    - ✓ cosmic ray veto (timing cut and psuedo-acolinearity cut $\Delta\alpha = |\Delta\phi + \Delta\theta - 2\pi|$)

Selection details: double CMLLP

- Single muon trigger without L2 tight timing cut
- Exactly two muons in the event
  - muon quality cut:
    - ✓ $|\eta_{det}|<2.0$
    - ✓ mediumnseg3 without cosmic veto
    - ✓ medium track
    - ✓ NPtight isolation
  - analysis cut:
    - ✓ |zatDCA|<40cm
    - ✓ $p_T(1)>55$GeV, $p_T(2)>50$GeV
    - ✓ $\beta_{1,2}<1$, speed asymmetry $|\beta_1-\beta_2|/|\beta_1+\beta_2|<0.35$
    - ✓ matching $\chi^2<100.$ between muon and central track
    - ✓ cosmic ray veto (dca cut, timing cut and psuedo-acolinearity)