A Search For Charged Massive Long-lived Particles Using DØ Detector

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July 28th, 2009

Motivation

- ***Long-lived particle either:***

a) conserved quantum number

b) decays are suppressed by kinematics or weak couplings, lifetime > 100ns.

- ***Explore two SUSY models with charged long-lived particles:***

1. GMSB (gauge-mediated supersymmetry breaking) Model

NLSP (next lightest supersymmetry particle): lightest scalar tau lepton (stau)

heavy SUSY particles decay to stau before decaying to gravitino (LSP)

- Coupling to the gravitino leads to long lifetime of NLSP

Use "Model Line D" from the Snowmass 2001 eConf C010630, 346(2001)

2. AMSB (anormaly-mediated supersysmmetry breaking) Model

If the mass difference between the lightest chargino and lightest neutralino is small enough (<150 MeV), phase space suppression results long-lived higgsino-like chargino and gaugino-like chargino

Model parameters are described in Eur. Phys. J.C. **11**, 1(1999)

LEP II limits:

stau: 97.5 GeV chargino: 102.5 GeV

Detector Signature

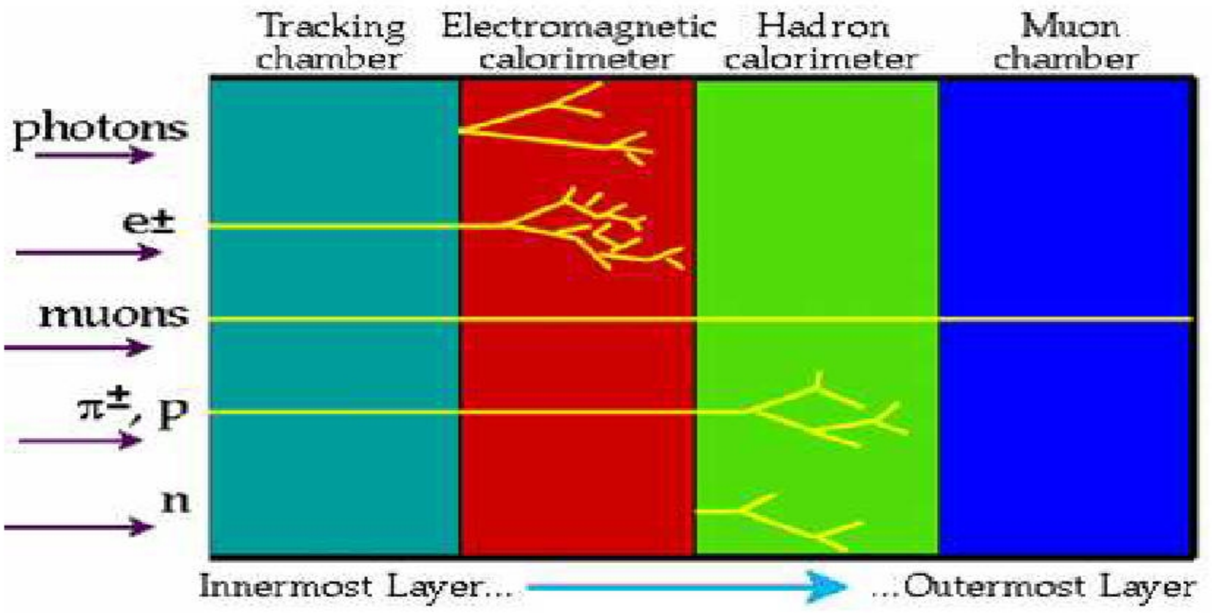
Unique signature in the collider detectors:

Charged: leaves track in the detector

Massive: moves slowly (small β)
has long time-of-flight
deposits more energy (dE/dx)

Stable: has a long lifetime, doesn't decay in the detector

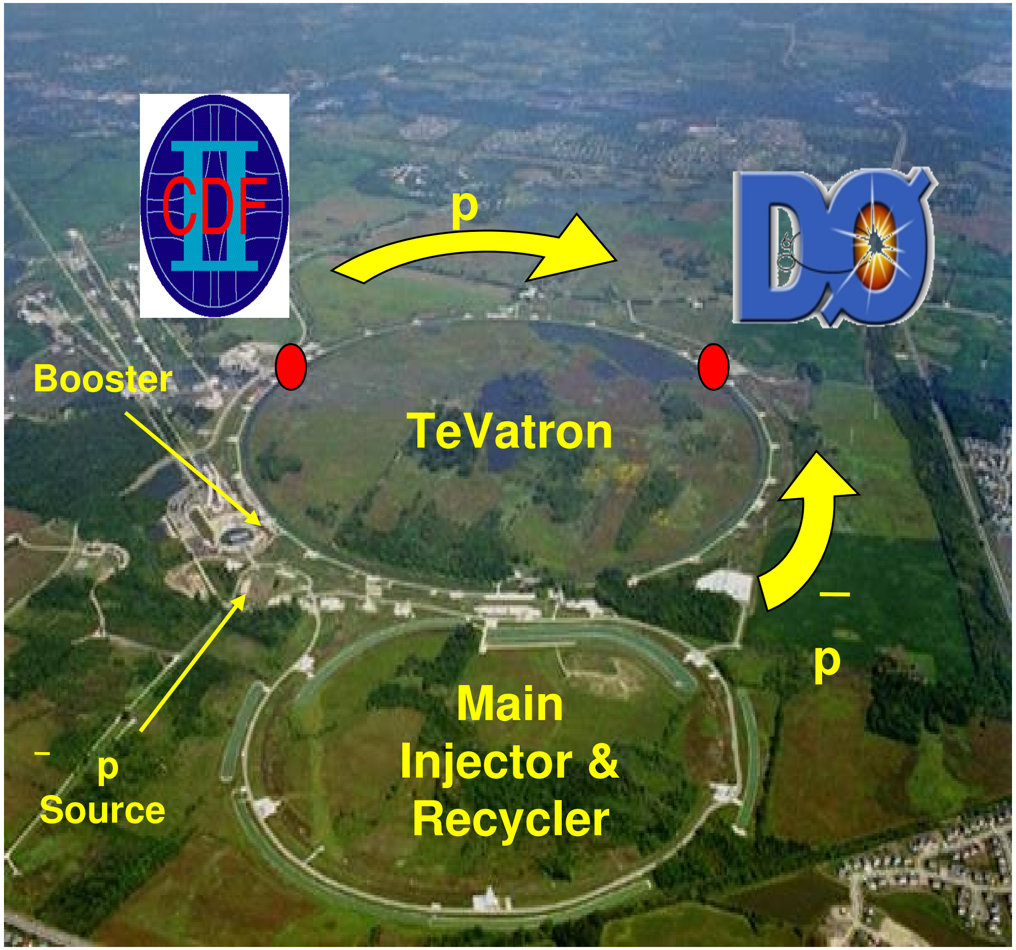
Looks like a massive slow moving muon

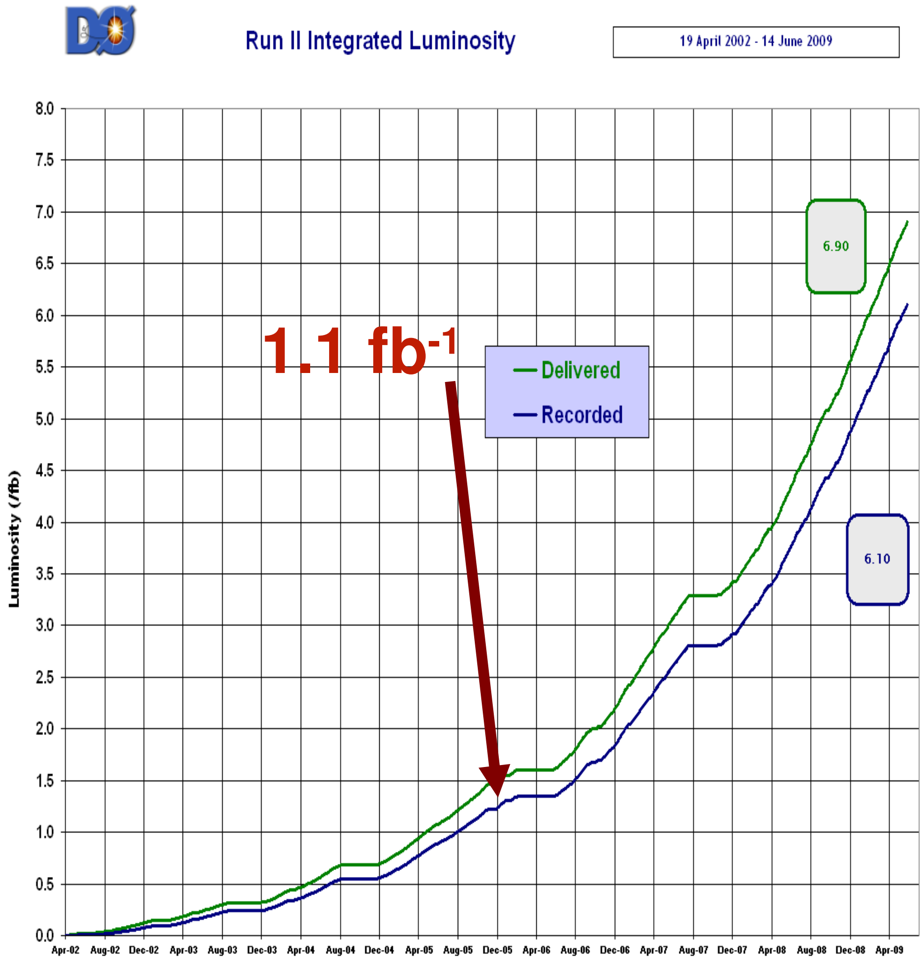


Glance at Fermilab

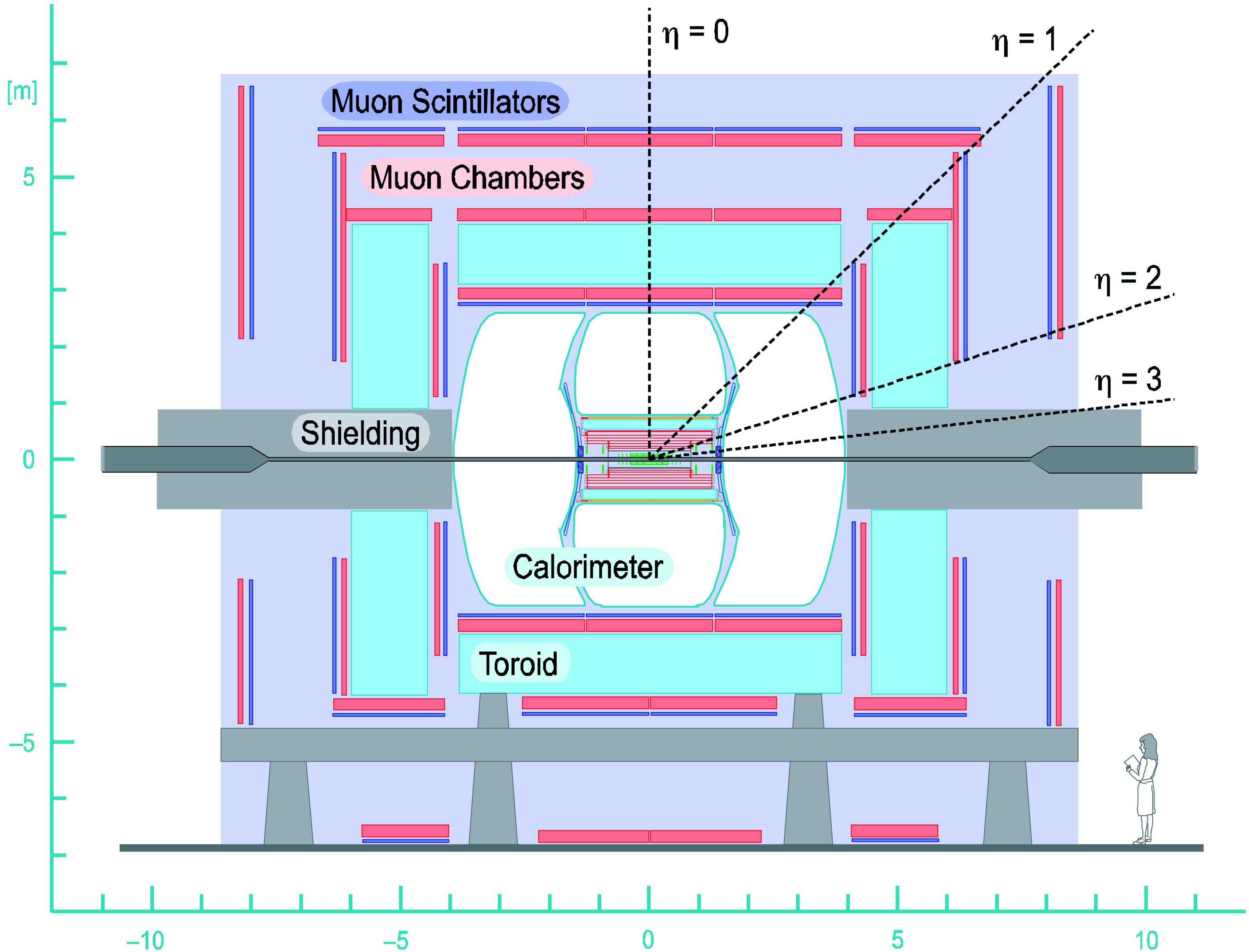
1993-96 Run I: 100 pb^{-1}, 1.8 TeV

2001-? Run II: E_{cm} = 1.96 TeV





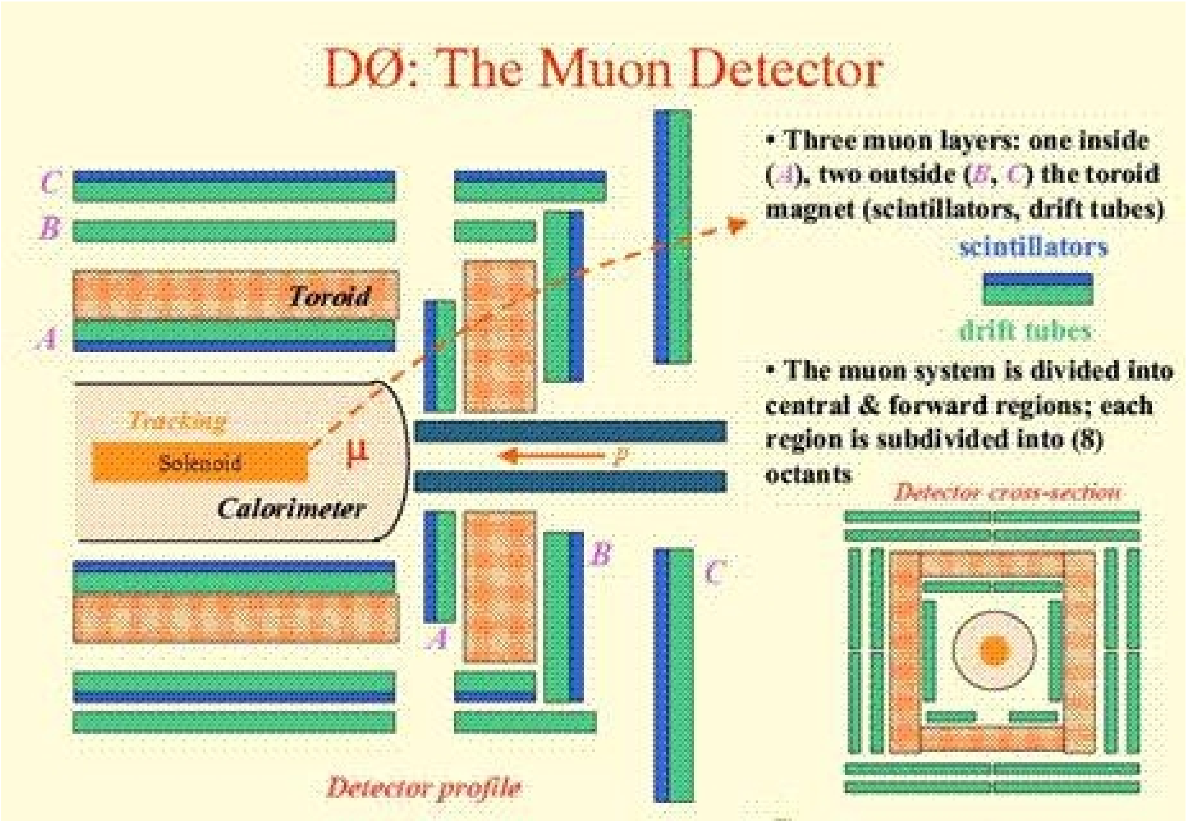
DØ Detector



[m]
5
0
–5
–10
–5
0
5
10
η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid

The Muon System

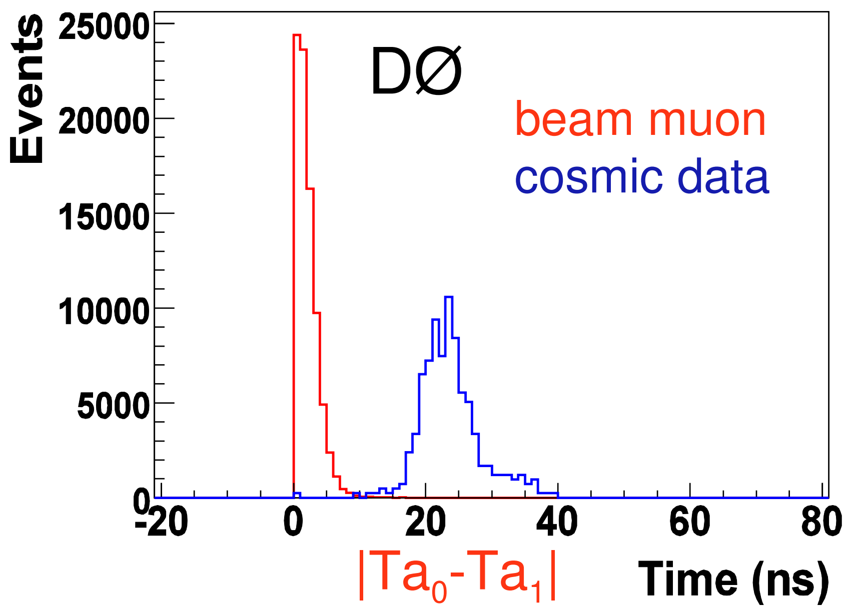
- The outmost tracking system provides time-of-flight (TOF) information and particle trajectory
- Three layers (A/B/C) form a cubic geometry
- A 1.8 T toroid magnet between A and B layer

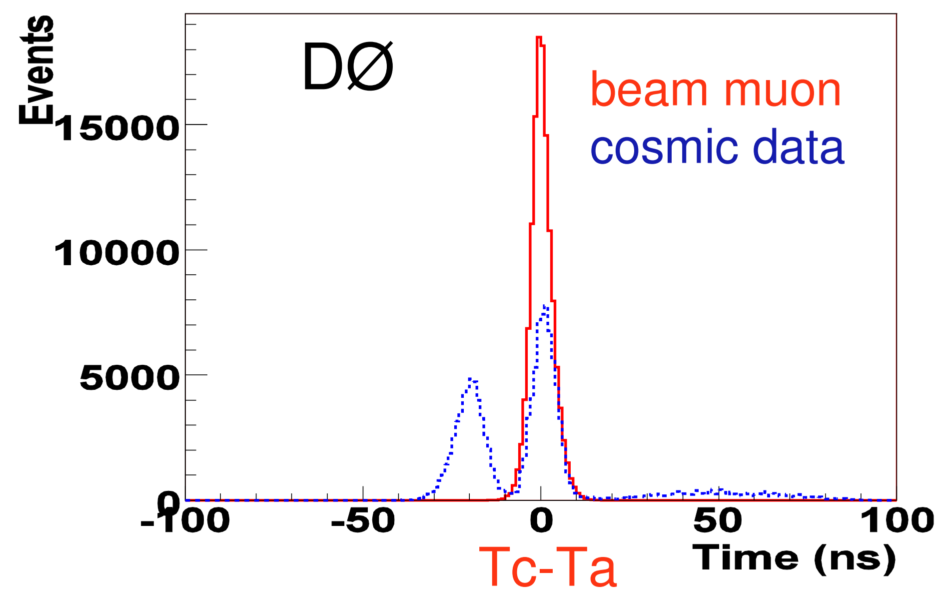


- Measures p_T
- Light speed particles arrive at zero ns
- CMSPs arrive out-of-time
- Timing resolutions : 2—4 ns in different counters

Event Selection

- **Select events with two good muons with standard DØ criteria**
- **Cosmic ray muons are rejected if one of the following is true:**
  - Time difference between A-layer hit of two muons, $|T_{a0}-T_{a1}| \geq 10\text{ns}$
  - C-layer time minus A-layer time for either muon, Tc-Ta < -10ns
  - Pseudo-acolinearity is $\Delta\alpha = |\Delta\varphi_{\mu\mu} + \Delta\theta_{\mu\mu} - 2\pi| < 0.05$
  - Distance-at-closest-approach (DCA) is >0.2 cm

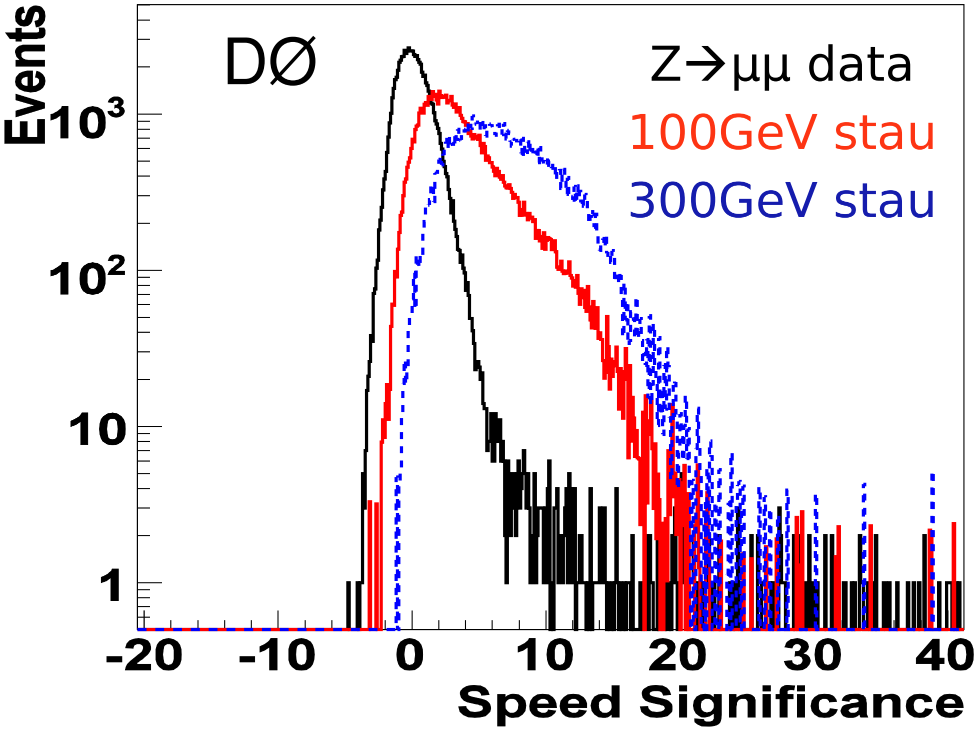




Speed and χ^2/d.o.f.

- **Calculate speed of muon at each layer**
  - v = d/t (v in units of c)
  - σ_v from timing error
- **Calculate average speed v_{avg} for each muon by taking the weighted average of individual layer speeds**

- **Speed significance of muons:** $(1-v_{avg}) / \sigma_{speed}$
  - light-speed muons will center at zero
  - CMSPs will have positive values
  - require both particles with positive speed significance



New variables

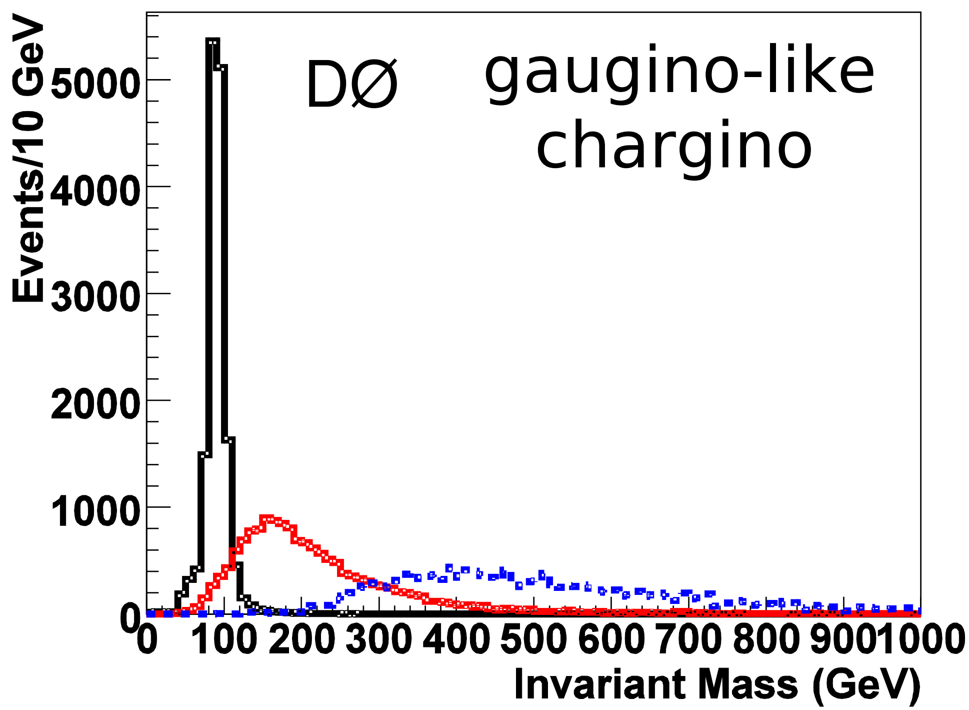
- **Three types of signals:**

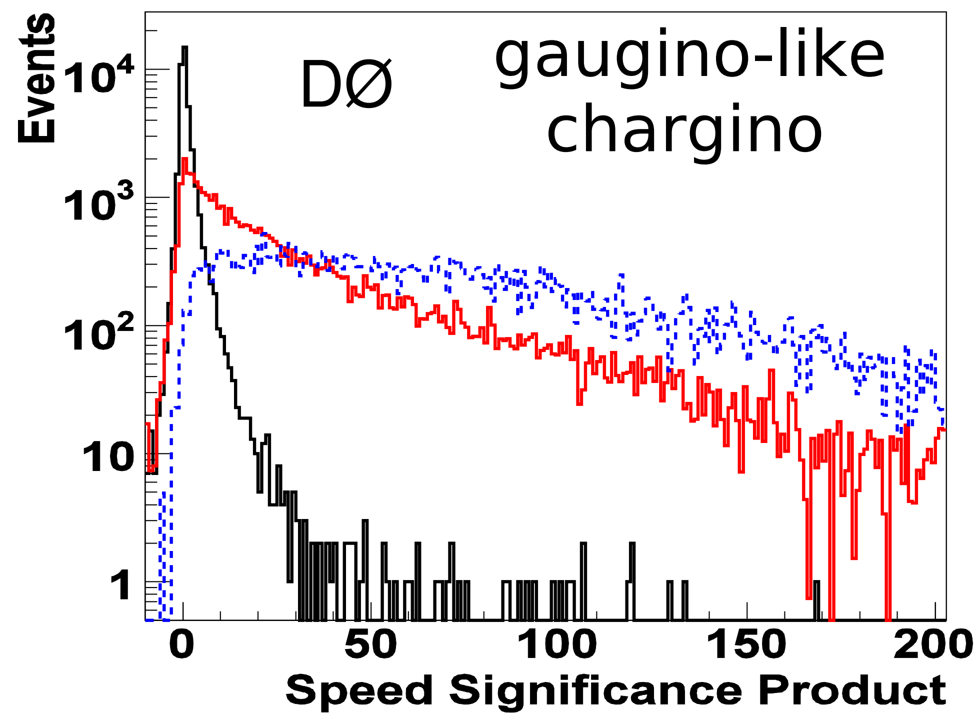
same data   same analysis code different MC signals

- **New variables needed to classify the signal and backgrounds**

Invariant mass and *speed significance product* of the muon pair

Z→uu Data   CMSP (100 GeV)   CMSP (300 GeV)





Background Estimation

- **Clean physics background**

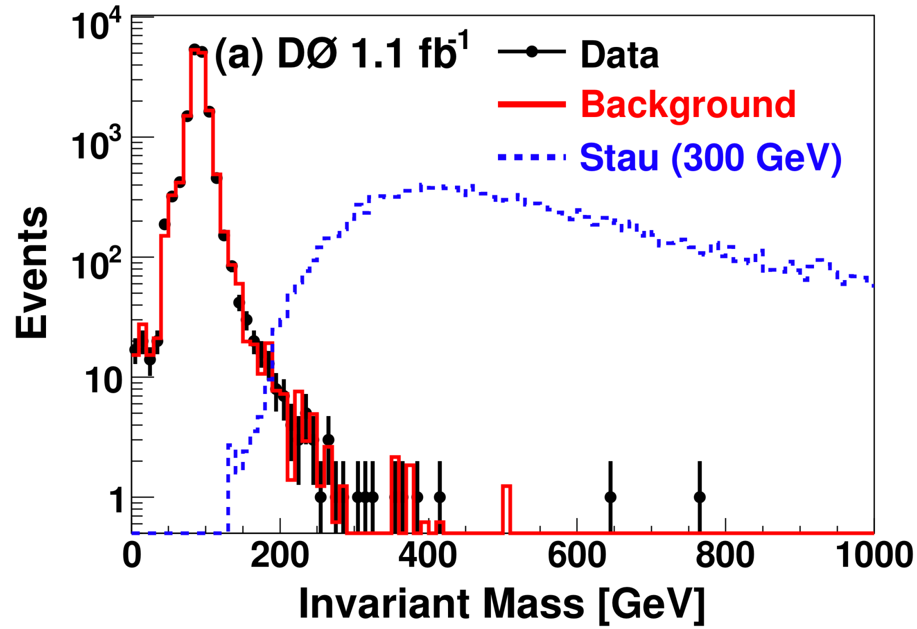
No SM physics background with high-p_T massive long-lived particles

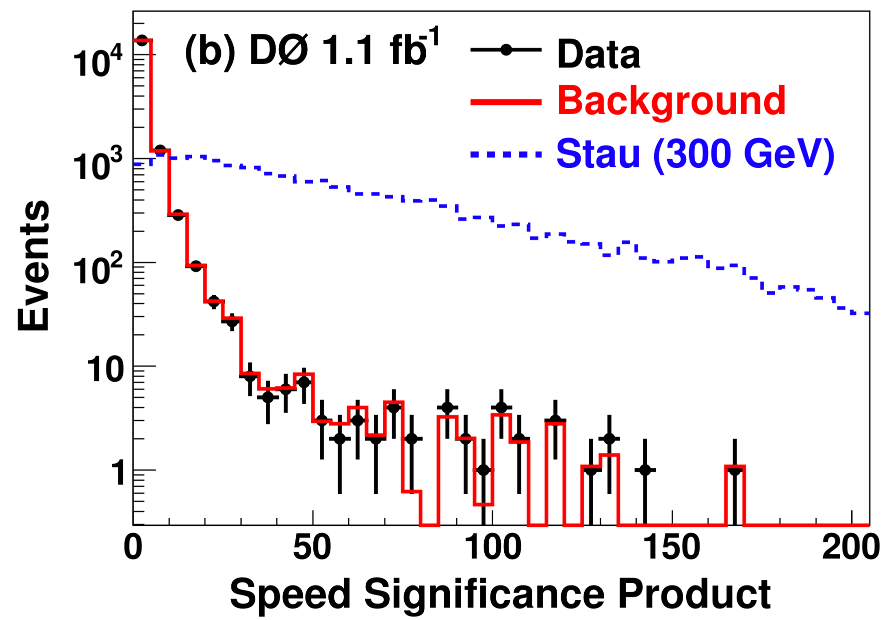
- **Concern of the limitations of the detector performance**
  - Mis-measured p_T of particles lead to large invariant mass
  - Mis-measured TOF of muons lead to small speed and positive speed significance
- **Estimation done with real data**
  - Invariant mass is simulated from the data events with two negative speed significance muons

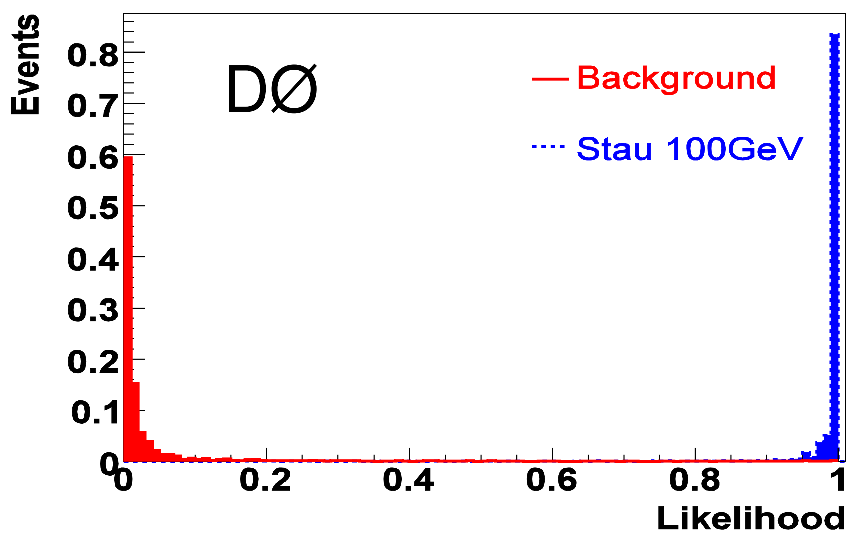
  -- No signal contamination
  - The speed significance product is simulated from the data events with the invariant mass in Z peak region

  -- the signal contamination is negligible
  - 100k simulated background events are generated and normalized to the number of the Z/Drell-Yan events passing all the selection criteria

Likelihood Function







- Discriminant function:
  $g(x)=S(x)/(S(x)+B(x))$
  in range [0, 1]
- Optimize cut on expected limits for every mass point in three signals

Systematic Studies

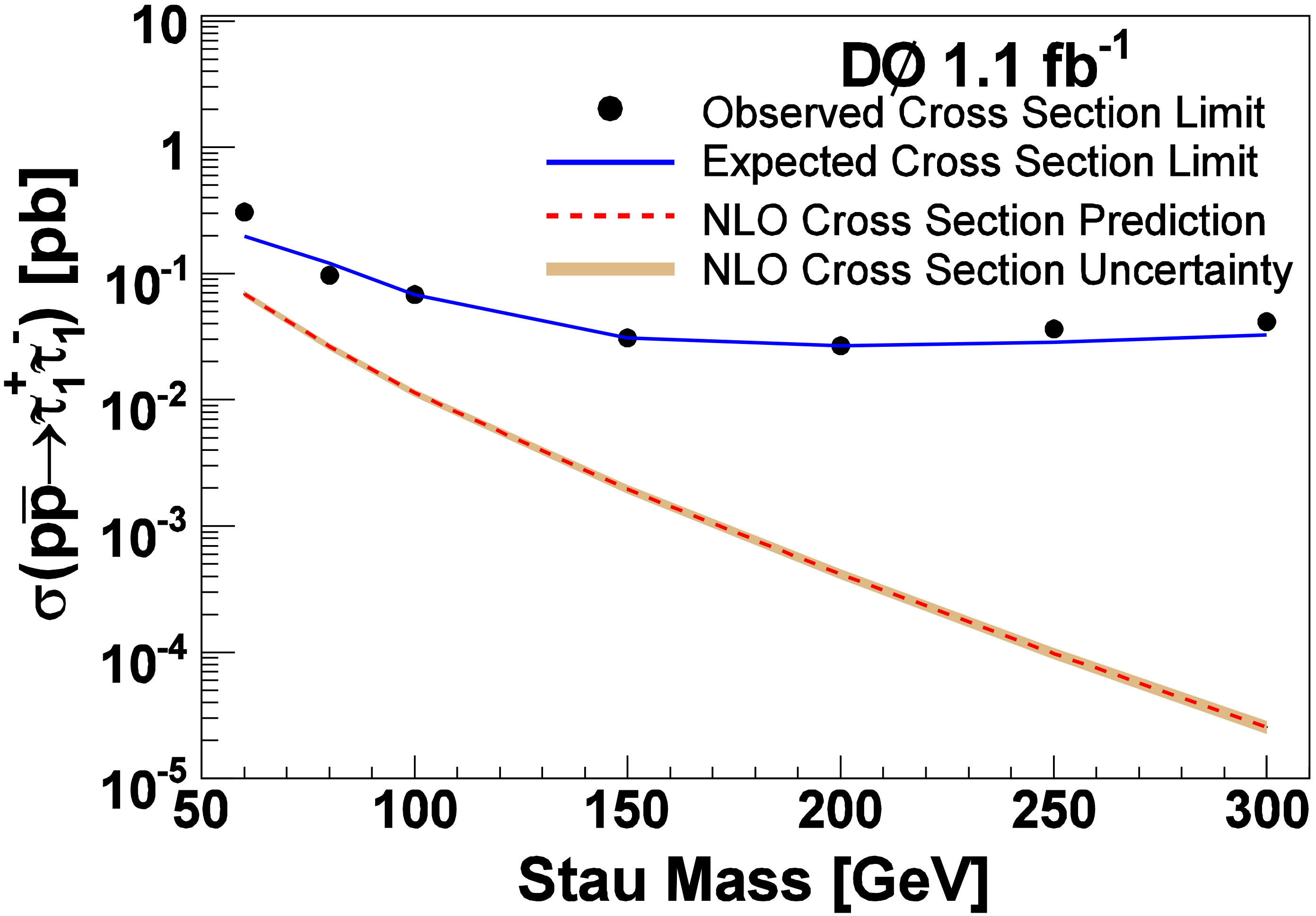
- **Background estimation:**

Vary the criteria for selecting the events to simulate the background.

- **Signal acceptance:**
  - Time-of-flight smearing
  - L1 Muon trigger gate accuracy
  - Muon ID and data/MC scale factor
  - Uncertainty in PDFs
  - Zero bias events over-lay
- **Luminosity uncertainty**
- **Predicted signal cross section:**

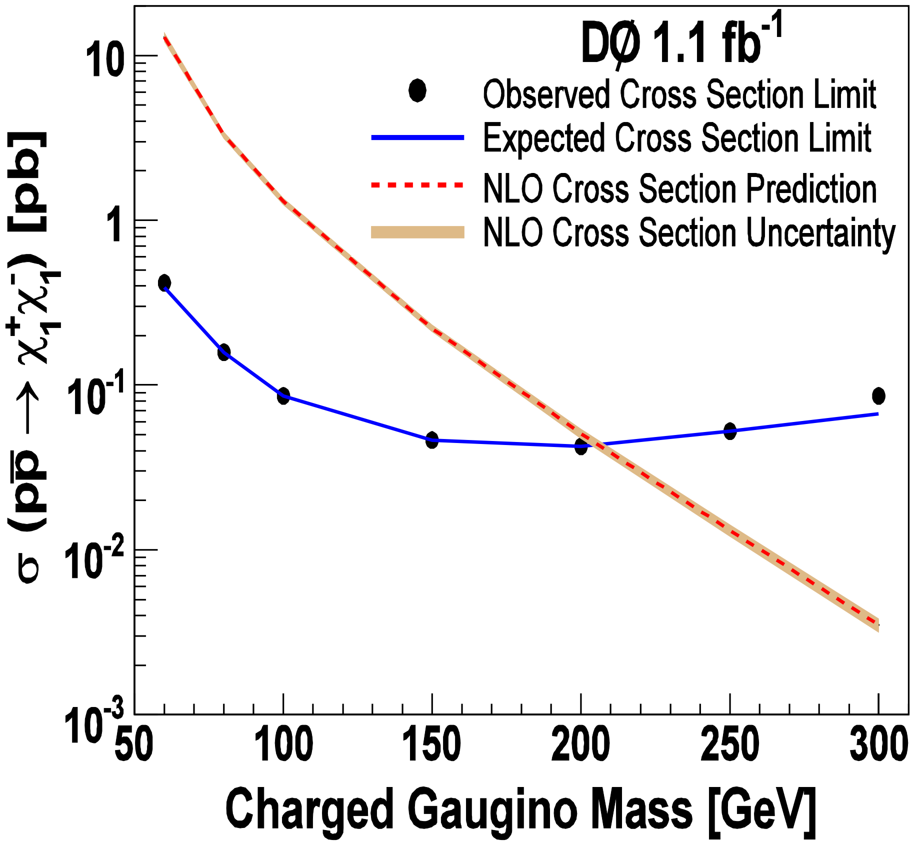
PDFs and Rescaling (very small, shown in figures)

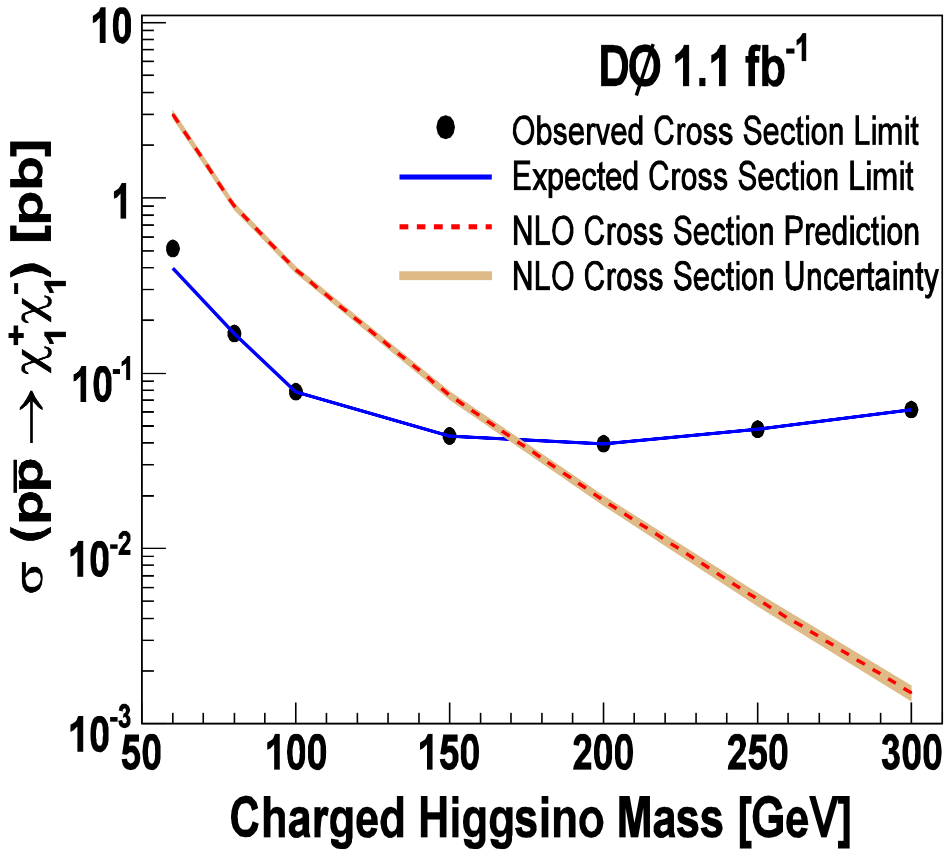
Final Results --- I



We put a 95% C.L. cross section upper limit on the production of stable staus, from 0.31 pb to 0.04 pb, for stau masses in the range 60--300 GeV.

Final Results --- II





Using the nominal values of the NLO cross section, we obtain 95% C.L. lower mass limits of 206 GeV for gaugino-like charginos, and 171 GeV for higgsino-like charginos.

Summary

- **Results with 1.1 fb $^{-1}$ data:**
  - We found no evidence of the signal
  - We set cross section limits which vary from 0.31 pb to 0.04 pb, for staus between 60 GeV and 300 GeV.
  - We exclude gaugino-like charginos with mass < 206 GeV
  - We exclude higgsino-like charginos with mass < 171 GeV
- **Paper:**
  - *PRL 102, 161802(2009)* , arXiv: *0809.4472*
  - Already used in models by theorists (J.A. Hewitt, arXiv: 0812.0980 and 0903.4409)
- **Future plan:**

Extend to larger data set (include dE/dx information)

Backup Slides

Model Parameters

Stau

Parameter	Description	Value
Λ_m	Scale of SUSY breaking	19 to 100 TeV
M_m	Messenger mass scale	$2\Lambda_m$
N_5	Number of messenger fields	3
$tan\beta$	Ratio of Higgs VEVs	15
$sgn\mu$	Sign of Higgsino mass term	+1
C_{grav}	Factor multiplying effective mass of gravitino	1

Charginos

Model	μ(GeV)	M_1(GeV)	M_2(GeV)	M_3(GeV)	$tan\beta$	Squark Mass (GeV)
gaugino-like chargino	10,000	$3M_2$	varied from 60 to 300	500	15	800
higgsino-like chargino	varied from 60 to 300	100,000	100,000	500	15	800

Analysis Details --- I

Stau

Mass (GeV)	Signal Acc. ($x10^{-3}$)	Exp. Signal Events	Predicted Background	Obs. Events
60	64 ± 1 ± 5	4.7	30.9 ± 2.2 ± 1.9	38
80	38 ± 1 ± 5	1.1	2.6 ± 0.6 ± 0.4	1
100	56 ± 1 ± 4	0.7	1.6 ± 0.5 ± 0.3	1
150	123 ± 2 ± 13	0.3	1.7 ± 0.5 ± 0.2	1
200	139 ± 2 ± 11	0.1	1.7 ± 0.5 ± 0.2	1
250	133 ± 2 ± 13	0.01	1.7 ± 0.5 ± 0.3	1
300	117 ± 2 ± 13	0.004	1.9 ± 0.5 ± 0.2	2

Analysis Details --- II

Gaugino-like Chargino

Mass (GeV)	Signal Acc. ($x10^{-3}$)	Exp. Signal Events	Predicted Background	Obs. Events
60	32 ± 1 ± 3	445	23.6 ± 1.9 ± 1.4	24
80	24 ± 1 ± 3	85	1.9 ± 0.5 ± 0.3	1
100	46 ± 1 ± 4	65	1.6 ± 0.5 ± 0.3	1
150	85 ± 1 ± 9	20	1.2 ± 0.4 ± 0.1	1
200	89 ± 1 ± 7	5	1.9 ± 0.5 ± 0.0	1
250	74 ± 1 ± 7	1	1.7 ± 0.5 ± 0.3	1
300	59 ± 1 ± 7	0.2	1.7 ± 0.5 ± 0.1	2

Analysis Details --- III

Higgsino-like Chargino

Mass (GeV)	Signal Acc. (x10^{-3})	Exp. Signal Events	Predicted Background	Obs. Events
60	29 ± 1 ± 2	94	17.9 ± 1.7 ± 1.1	21
80	24 ± 1 ± 3	23	1.6 ± 0.5 ± 0.3	1
100	49 ± 1 ± 4	20	1.6 ± 0.5 ± 0.3	1
150	89 ± 1 ± 9	7	1.4 ± 0.5 ± 0.1	1
200	96 ± 1 ± 8	2	1.9 ± 0.5 ± 0.0	1
250	81 ± 1 ± 8	0.5	1.7 ± 0.5 ± 0.3	1
300	64 ± 1 ± 7	0.1	1.7 ± 0.5 ± 0.1	1

Talk by Jo Ann Hewett, LISHEP 2009.

Tevatron: D0 Stable Particle (= Chargino) Search

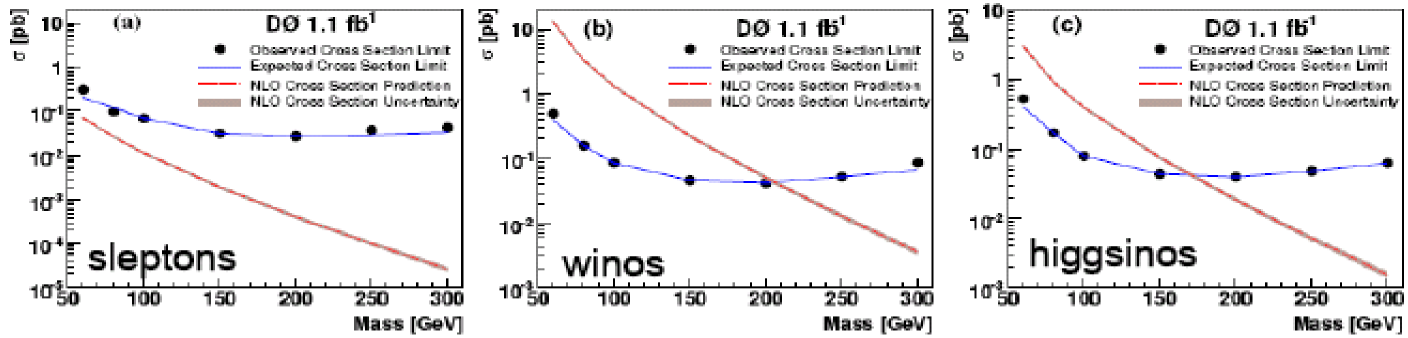


FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos, and (c) chargino mass for pair produced higgsino-like charginos.

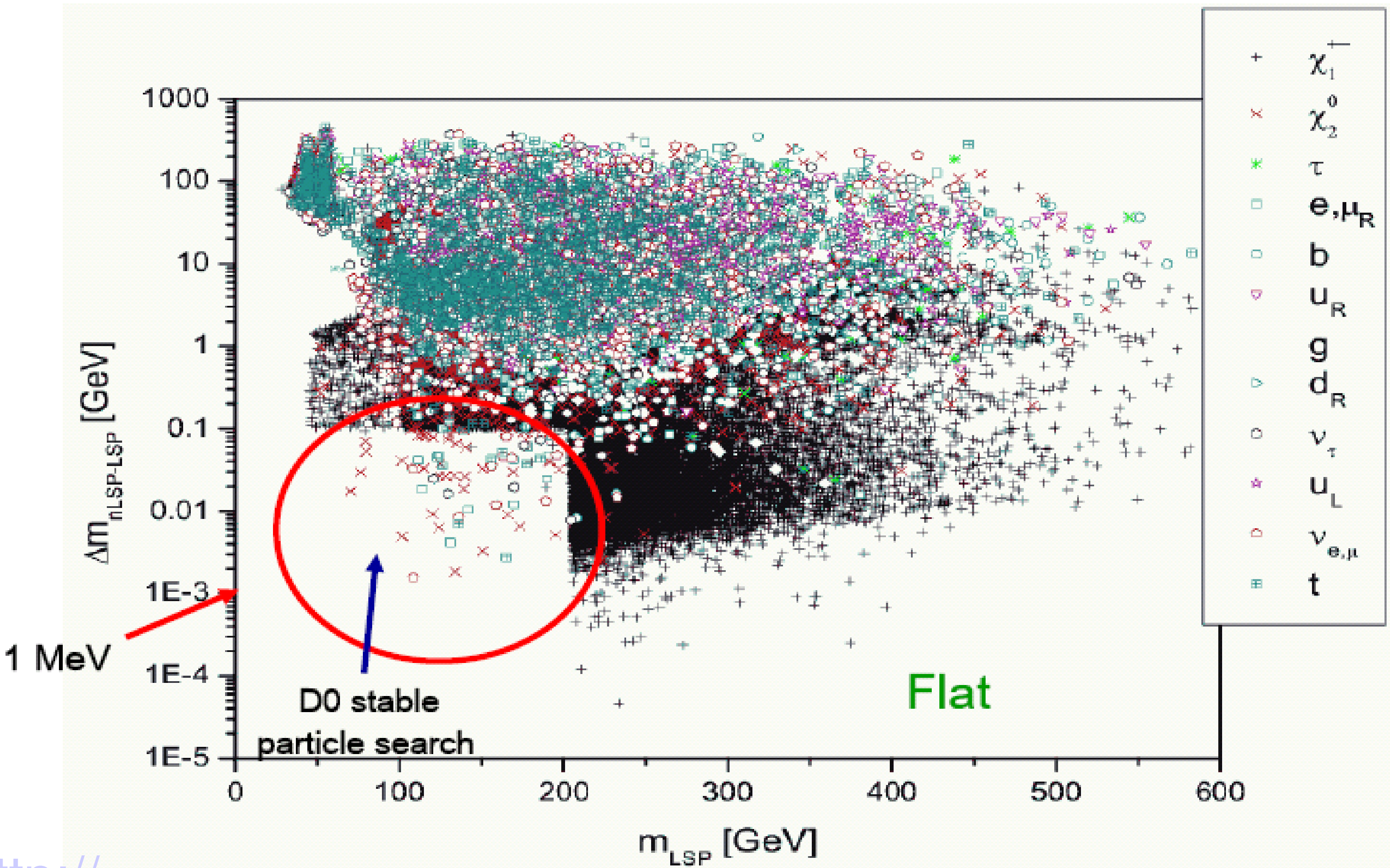
Interpolation: $M_\chi > 206\ |U_{1w}|^2 + 171\ |U_{1h}|^2$ GeV

- This is an *incredibly* powerful constraint on our model set!
- No applicable bounds on charged sleptons..the cross sections are too small.

- Cited by arXiv: 0812.0980 and 0903.4409

Tom Rizzo at the LHC2FC workshop

nLSP-LSP Mass Difference



http://indico.cern.ch/getFile.py/access?contribId=42&resId=0&materialId=slides&confId=40437

Experimental Strategy

- **Search for CMSPs by measuring TOF**

DØ Muon Trigger gates are adjusted so that light-speed muons from the collision point will arrive at the gate center of zero ns. Helps to reject cosmic rays and affect the signal acceptance

The DØ master clock is adjusted to synchronize with the accelerator clock seasonally – need corrections