Searches for physics beyond the standard model in final states with long lived particles.

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For the DØ Collaboration

18th International Conference on Supersymmetry and Unification of Fundamental Interactions

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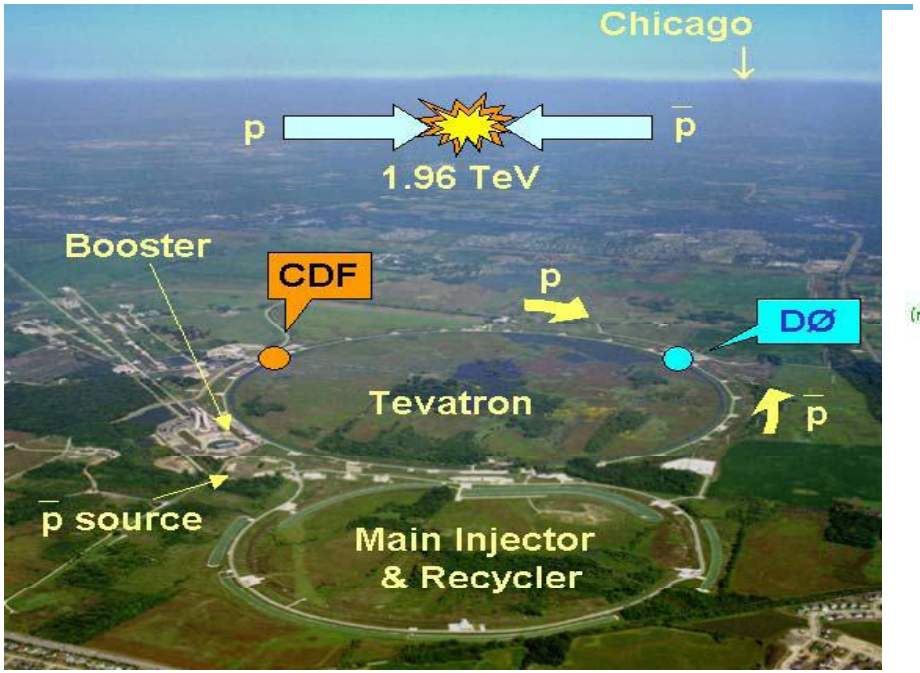
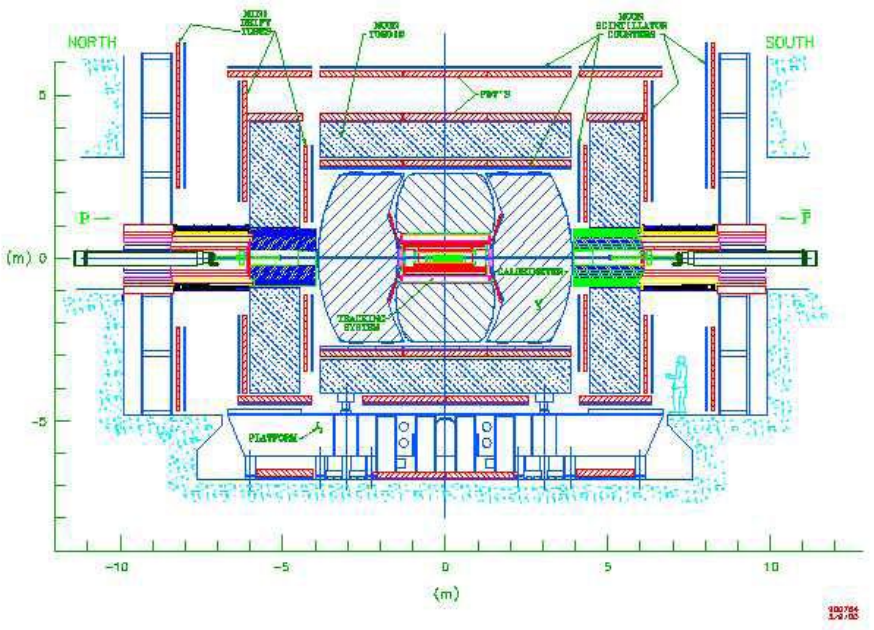
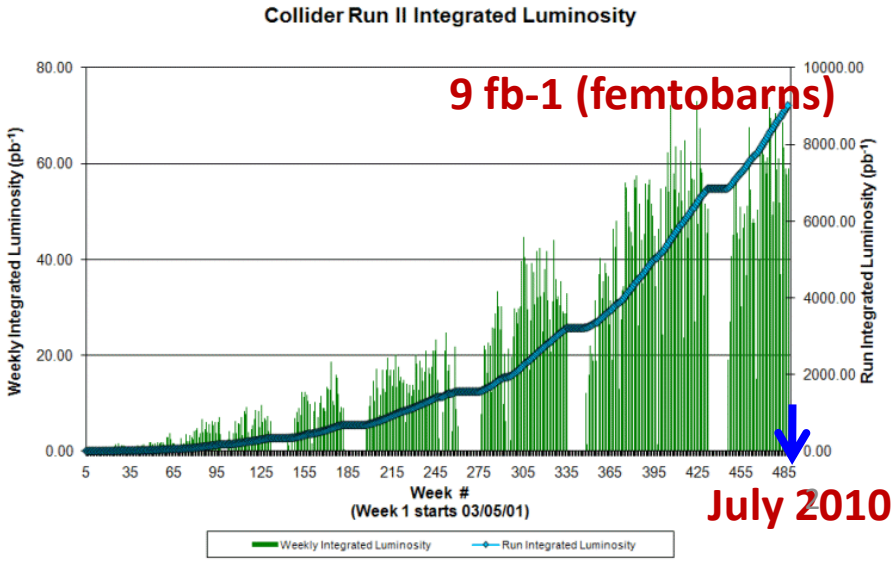
The DØ Detector





- Tevatron is performing extremely well
- Instantaneous luminosity > 3.5 X 10^{32} cm^{-2} s^{-1}
- Delivered 9 fb^{-1} integrated luminosity up to July
- DØ collected 8 fb^{-1}
- More to come



Outline

Slow moving, escapes the detector

- Long-lived Staus / Charginos

Delayed Decay

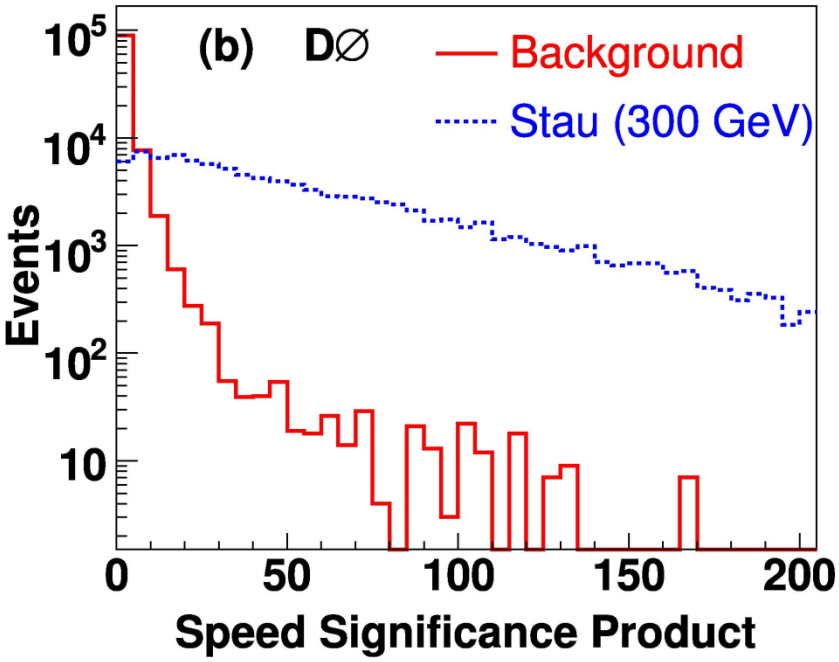
- Long Lived particles decaying to b jets
- Long Lived Neutralinos decaying to electrons/photons
- Stopped Gluinos
- Long Lived Neutralinos decaying to dimuons

Charged Massive Stable Particles

- **Stau, Charginos (Higgsino and Gaugino)**

GMSB with stau NLSP (if stau → gravitino decays suppressed)

Long-lived charginos are expected
If there is a "wino-LSP" (small $\tilde{\chi}_1^+$ - $\tilde{\chi}_1^0$ mass difference)
They would appear like slow moving muons
-> Make use of the Time of Flight information

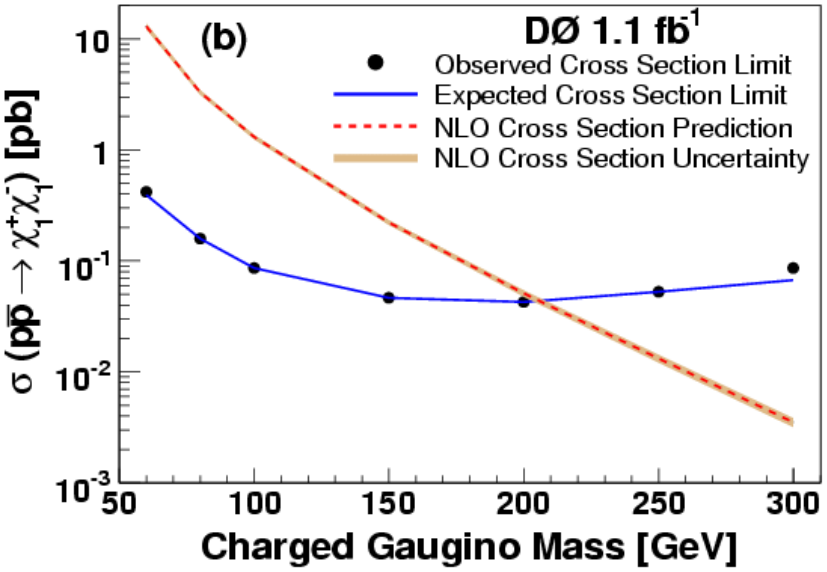


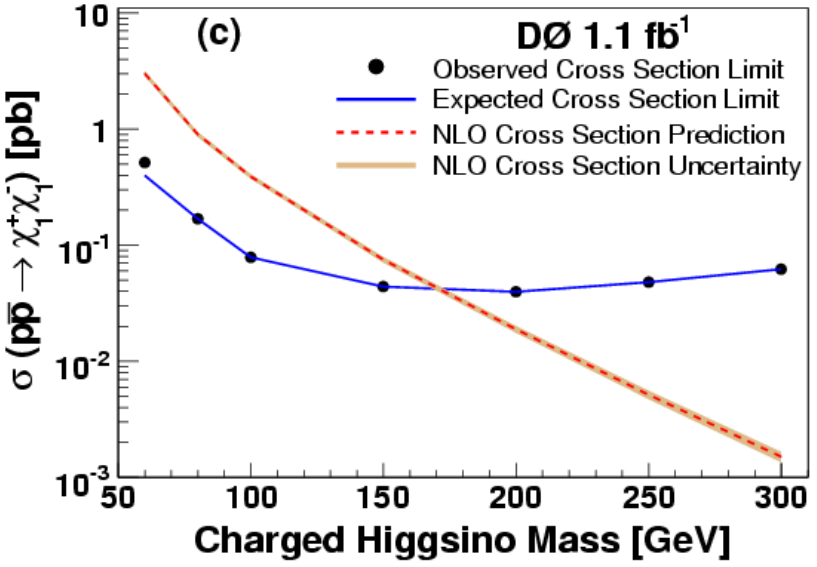
Dimuon Triggers

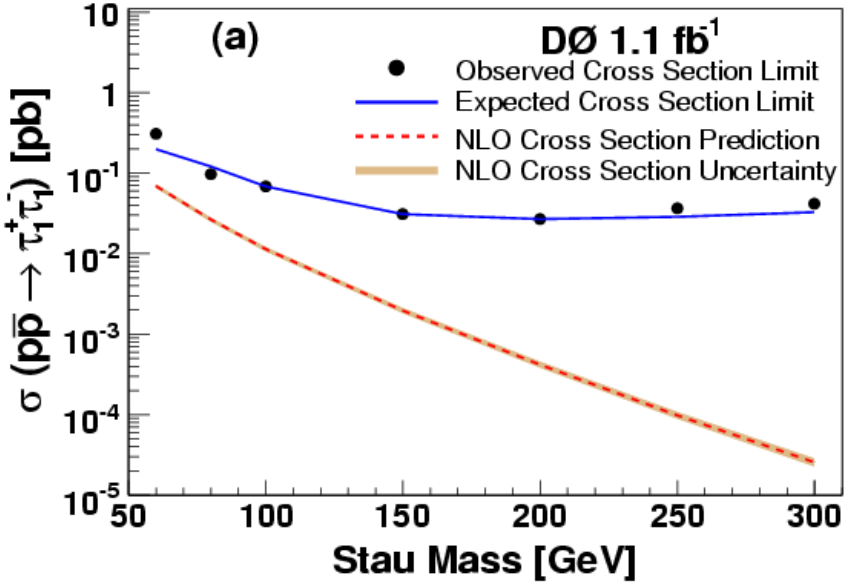
Event Signature: Two muon like objects

speed – velocity
speed significance – speed / error in speed
speed significance product – product of the significance for the two muons

Charged Massive Stable Particles







Data set – 1.1 fb-1

Cross section limit for

Stable staus – 0.31 pb to 0.04 pb in the mass range 60 to 300 GeV

Mass limit for

Chargino (gaugino type) – 206 GeV

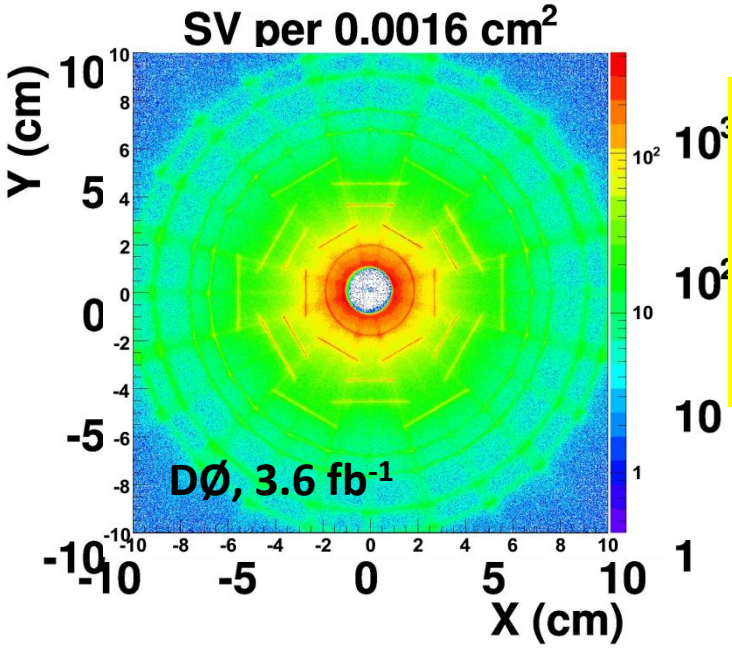
Charginoh (Higgsino type) – 171 GeV

Published - PRL 102 , 161802 (2009)

Long Lived Particles decaying to $b\bar{b}$ pairs

Proposed in Hidden Valley Models – ν meson may prefer to couple to heavy fermions (helicity suppression)

- Could be a novel way to find Higgs (SM Higgs couples to HV Higgs to give mass to ν meson

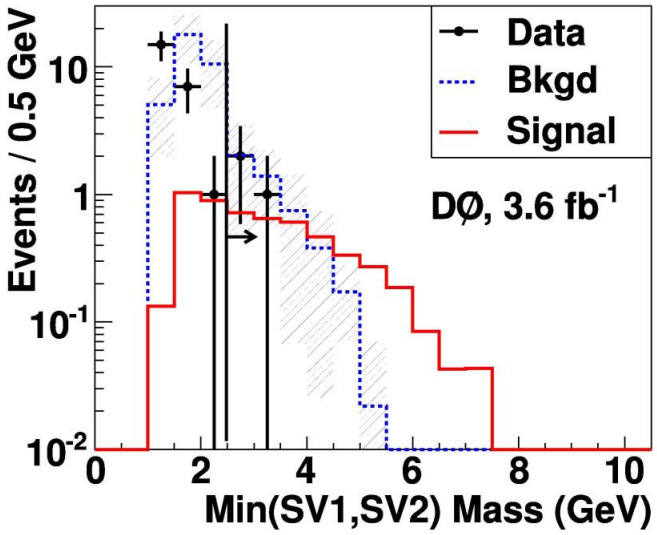


Secondary Vertex

- SV from 1.6 cm to 20 cm w.r.t. PV
- SV with ≥ 4 tracks
- SV outside busy region (SV map in Silicon tracker)

Event Selection:

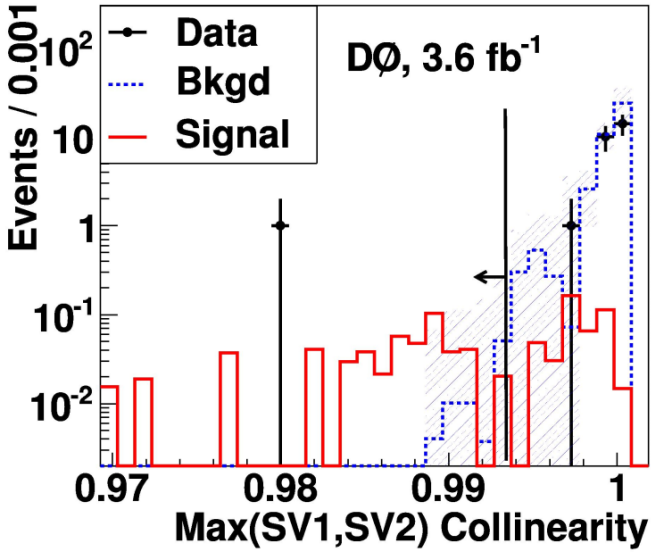
- 1 jet, p_T>10 GeV
- ≥1 jet with a muon, p_T>4 GeV
- 1 Primary Vertex (PV)
- ≥ 2 Secondary Vertex (SV)



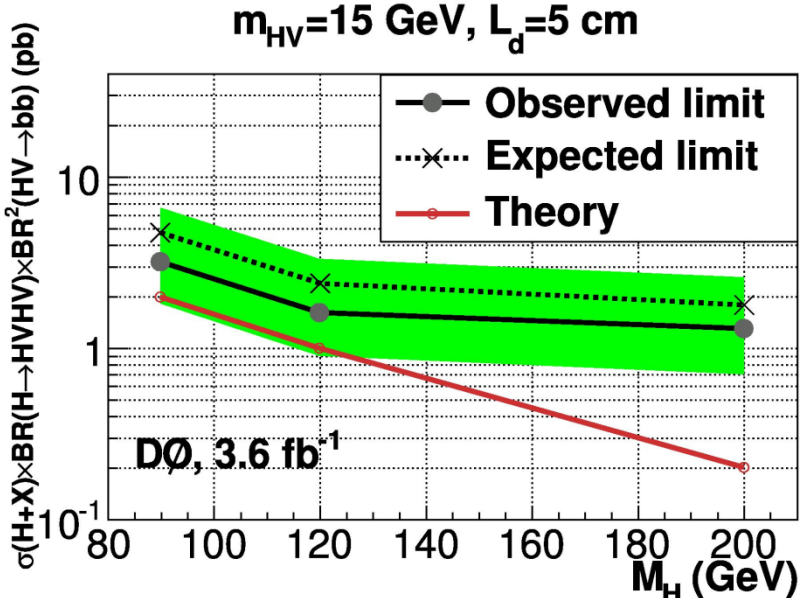
SV invariant Mass:

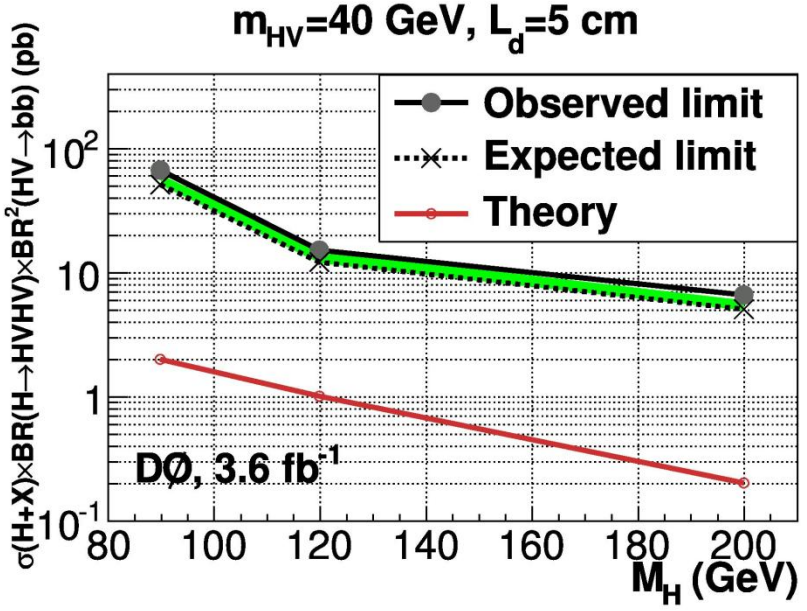
- Assume all tracks are pions
- Use their 4-momenta

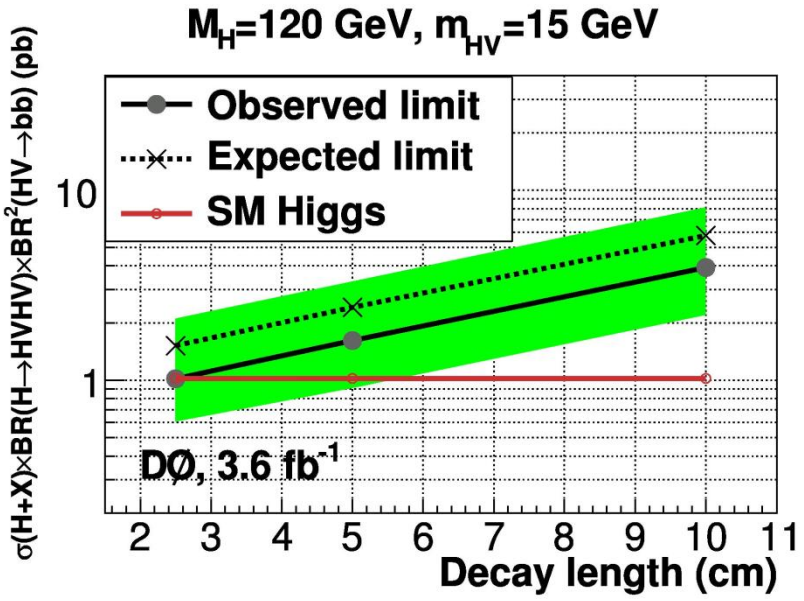
SV Collinearity:
Cosine of angle between vector sum of momenta of attached tracks and the direction of SV to PV



Long Lived Particles decaying to $b\bar{b}$ pairs







Three possible Hidden Valley (HV) scenarios coming from a Higgs decay:

- mH = 120 GeV, mHV = 15 GeV, decay length = 50 mm
- mH = 120 GeV, mHV = 40 GeV, decay length = 50 mm
- mH = 90 GeV, mHV = 15 GeV, decay length = 50 mm

No significant excess is observed

Limits are set on

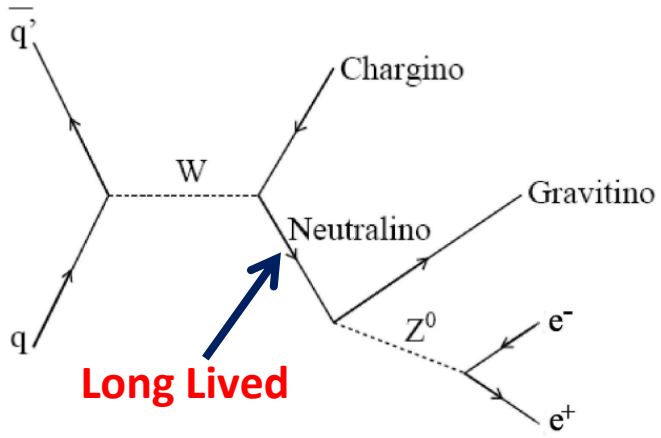
σ(H+X) x BR(H→HV HV) x BR2 (HV→bb) vs. Higgs mass and ν-hadron decay length

PRL 103, 071801 (2009)

Long Lived Particle decaying to e/γ pairs

GMSB

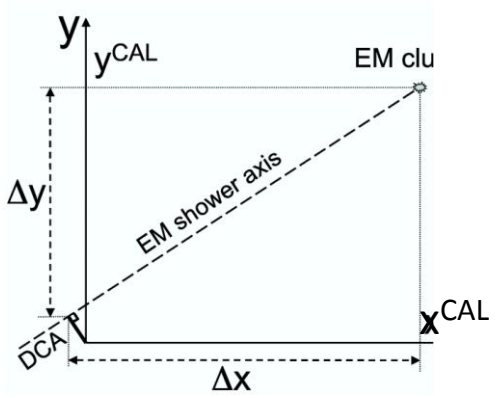
Theoretical models: GMSB, Hidden Valley, b'



b' → Z + jets, Z → ee

ν (Hidden Valley models) meson → ee

Precisely reconstruct EM shower direction



Event Selection:

Trigger: Single EM

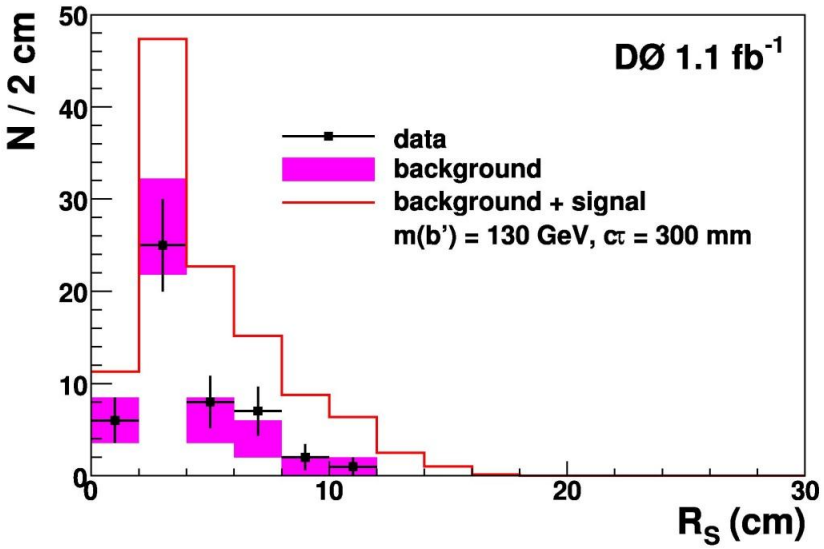
Offline Criteria:

- **2 good, isolated EM clusters (originating from the same point in space)**
- **$|\eta| < 1.1$, $p_T > 20$ GeV**
- **Primary vertex obtained from γ pointing**
- **Reconstructed primary vertex radius**

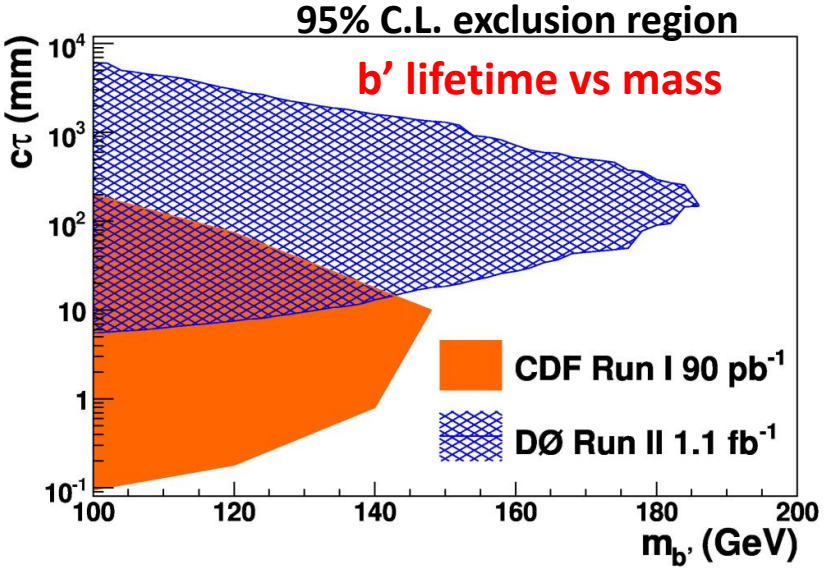
Use the shower direction to reconstruct the common vertex.
No track is required.
Analysis is valid for both electrons and photons

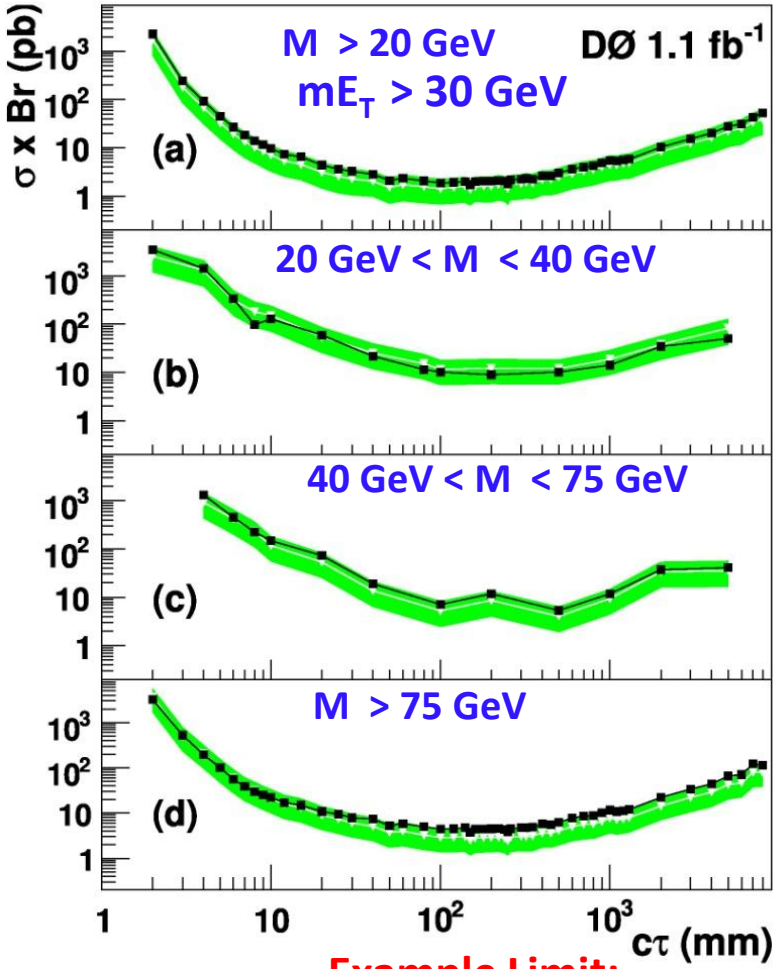
Long Lived Particle decaying to e/γ pairs

PRL 101, 111802 (2008)



Background – prompt Z decays





Example Limit:

- $c\tau = 100$ mm
- $mE_T > 30$ GeV
- $M > 20$ GeV

$\sigma \times BR < 1.9$ pb

Stopped Gluinos

In "Split SUSY" , squarks are ultra-heavy and gauginos are light
-> Long Lived gluinos.

Such gluinos form R-hadrons (carry R-parity) by combining with light quarks.
R-hadrons can be both charged and neutral.
Neutral R-hadrons can become charged through nuclear interactions.
Charged R-hadrons lose energy by ionisation and which may stop in the calorimeter.
After a while they decay into gluon + $\tilde{\chi}_1^0$ (100% branching fraction)

Gluino lifetime can be hours
This analysis – lifetime > 10 μs (decays a bunch crossing later),
lifetime < a few hours so that data gets recorded consistently

Event Signature: jets + missing ET (wide hadron shower, no muon)
Main background is cosmic muons
• At the Tevatron ~500 "stopped gluinos" expected in ~2 fb^{-1} for m(gluino) = 300 GeV

Stopped Gluinos - signature

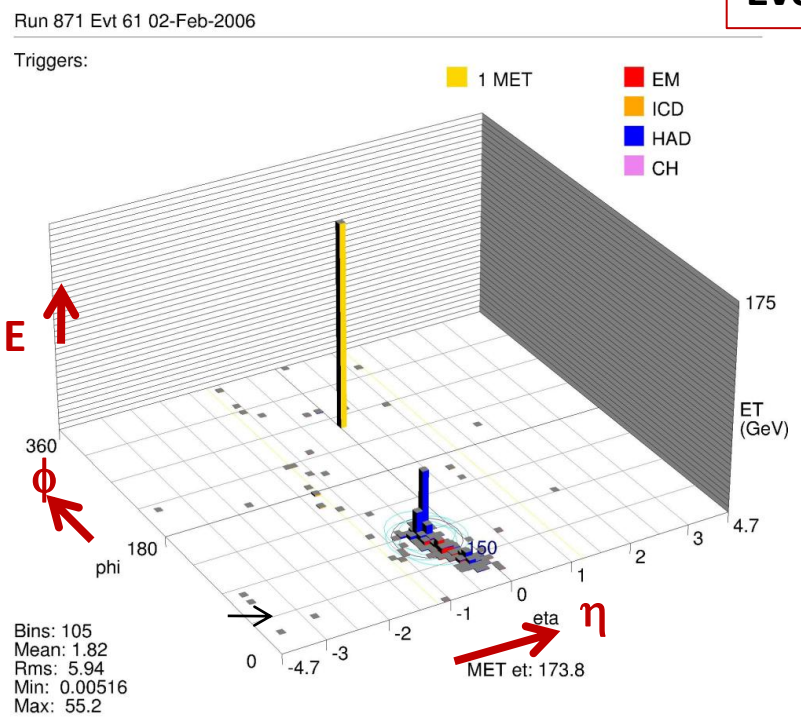
Search Strategy:

Look for a randomly oriented monojet

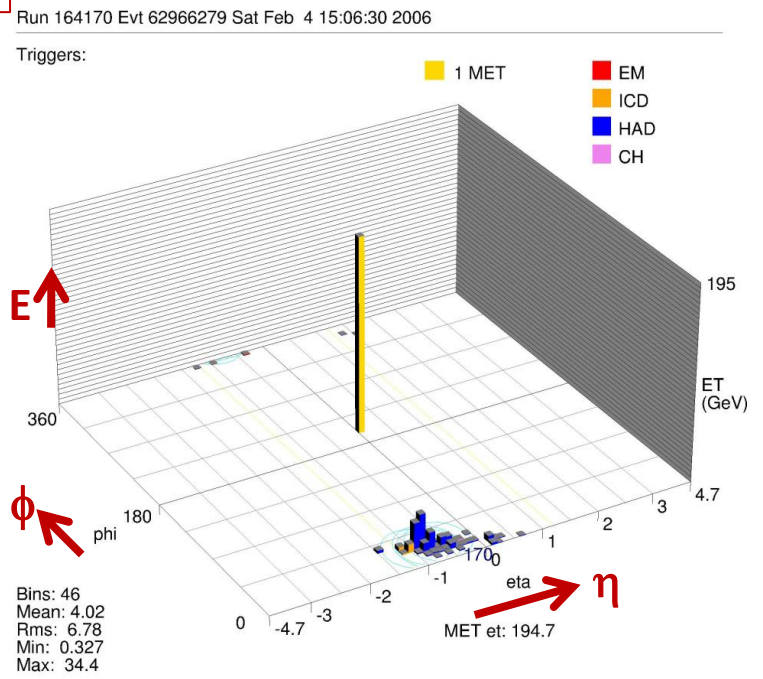
In an otherwise empty event

(diffractive-gap trigger)

Event Display



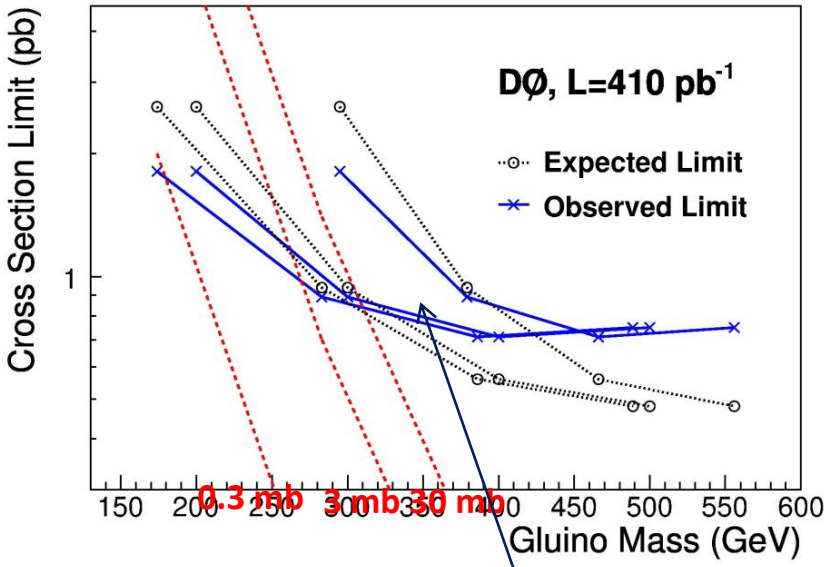
Signal Monte Carlo



Experimental Data (candidate Event)

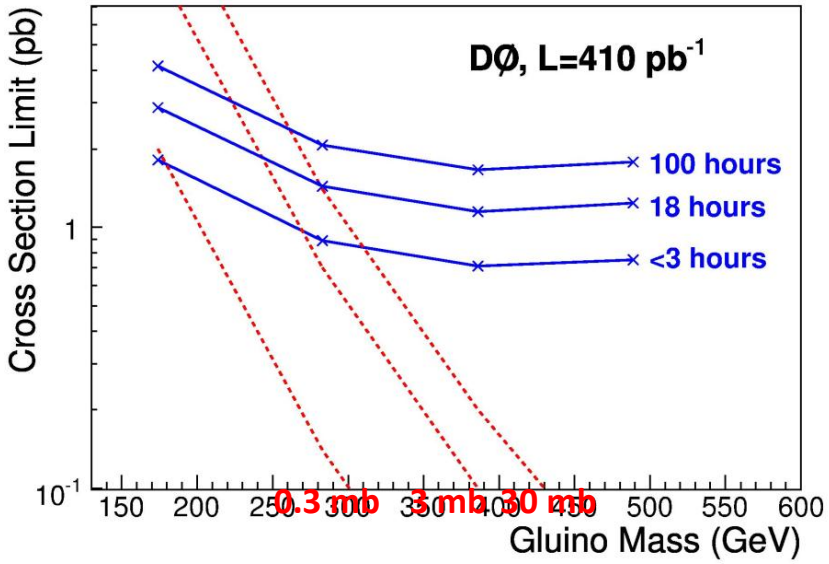
Stopped Gluinos

A large theoretical uncertainty arises from the variation in the conversion cross section of a neutral Gluino-hadron to a charged Gluino-hadron (varied from 0.3 mb to 30 mb)



$\tilde{\chi}_1^0$ **masses – 50, 90, 200 GeV**

Gluino lifetime < 3 hours



$\tilde{\chi}_1^0$ **mass – 50 GeV**

Signal degrades for very large gluino lifetimes (low trigger efficiency)

Cross section of ~ 1 pb for gluino stopping in D0 detector and Decaying to gluon and neutralino of mass 50 GeV is excluded

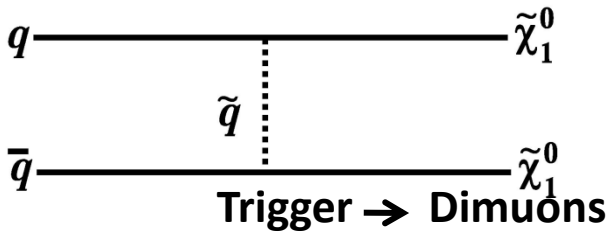
PRL 99 13801 (2007)

Long Lived Particles decaying to two muons

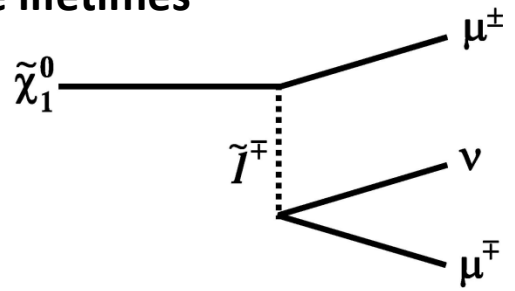
R-parity violating SUSY and Hidden Valley theories

Light neutral particle lives long enough to travel at least 5 cm

RPV couplings are small → Large lifetimes

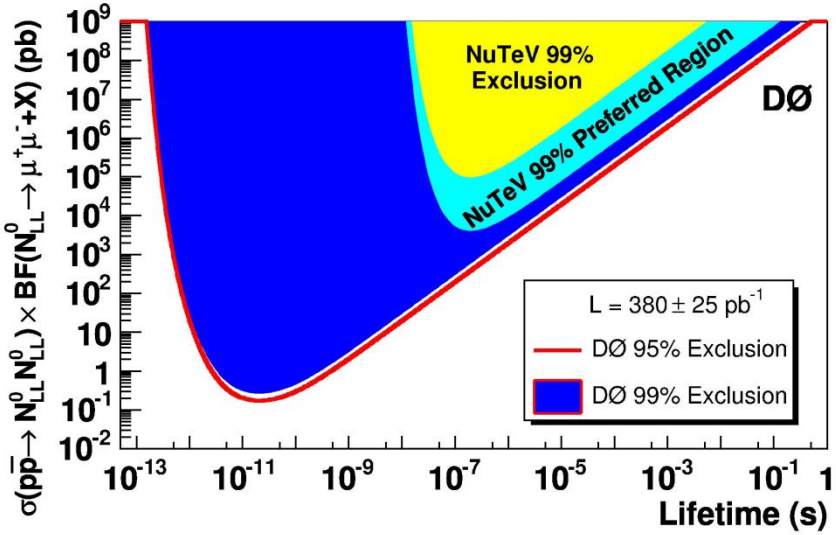


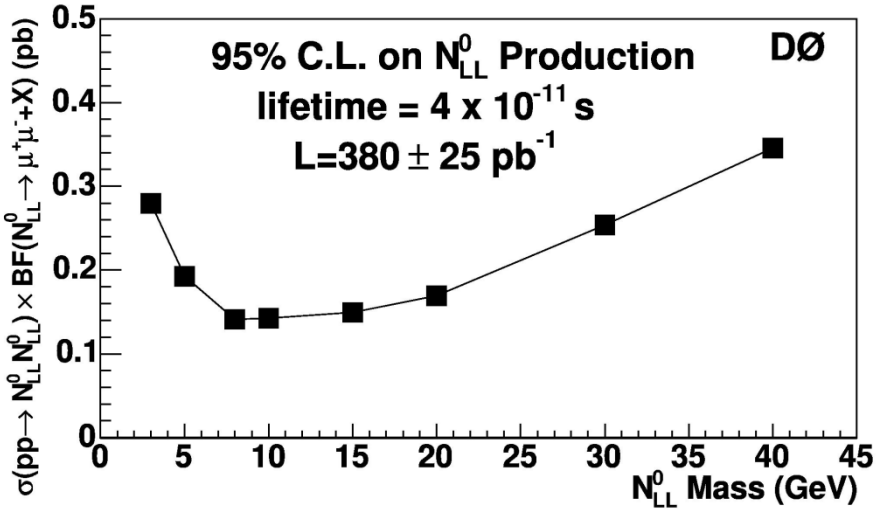
Trigger → Dimuons



Signature → Two opposite sign isolated muons forming a vertex with large DCA wrt Primary V

In the absence of excess signal like events, limits are set on mass and lifetime of the N_{LL}^0

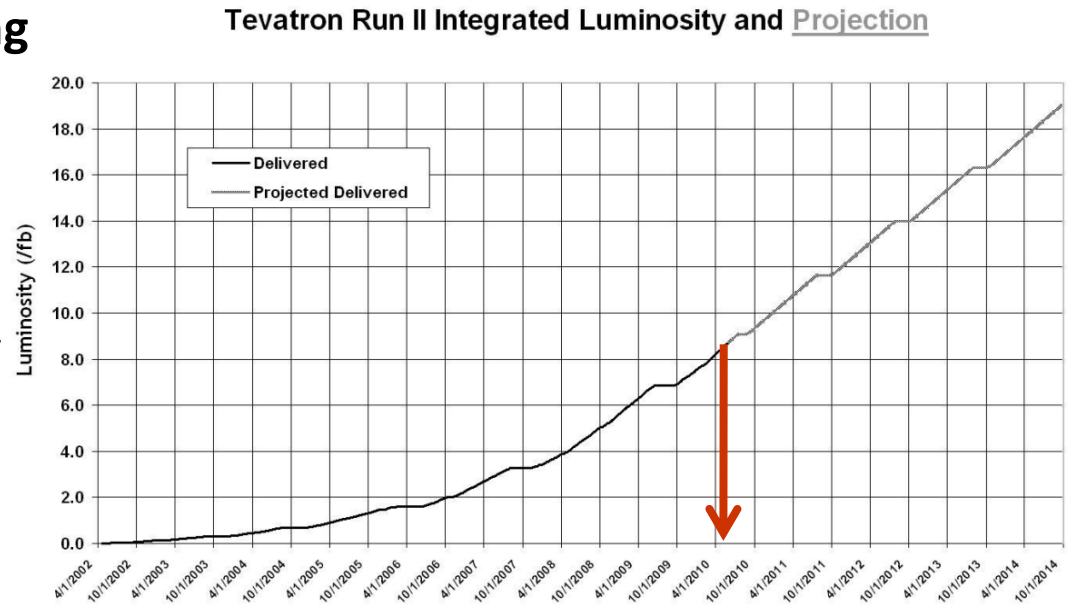




- **PRL 97, 161802 (2006)**

Future

- Tevatron Experiments are collecting ~2 fb-1 / year of pp collisions.
- By the end of 2011 run, the statistics of all measurements will be increased by a big factor.
- Analysis techniques are constantly improving.
- Another set of new and better results expected in the near future.



August 2010

DØ public results:

http://www-d0.fnal.gov/Run2Physics/WWW/results.htm