Searches for New Physics at the Tevatron

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for the CDF and D0 collaborations

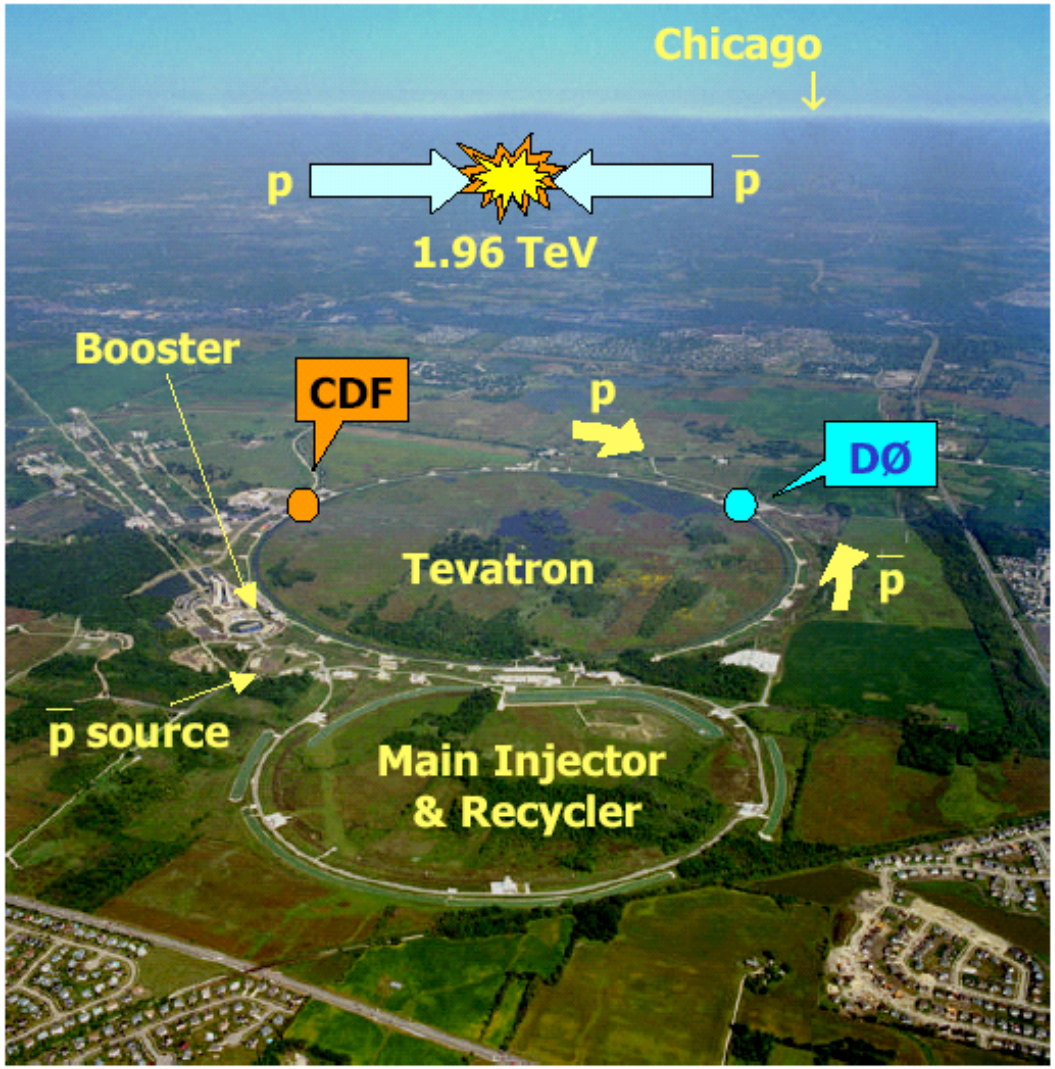
Dark Matter Symposium

May 10, 2007

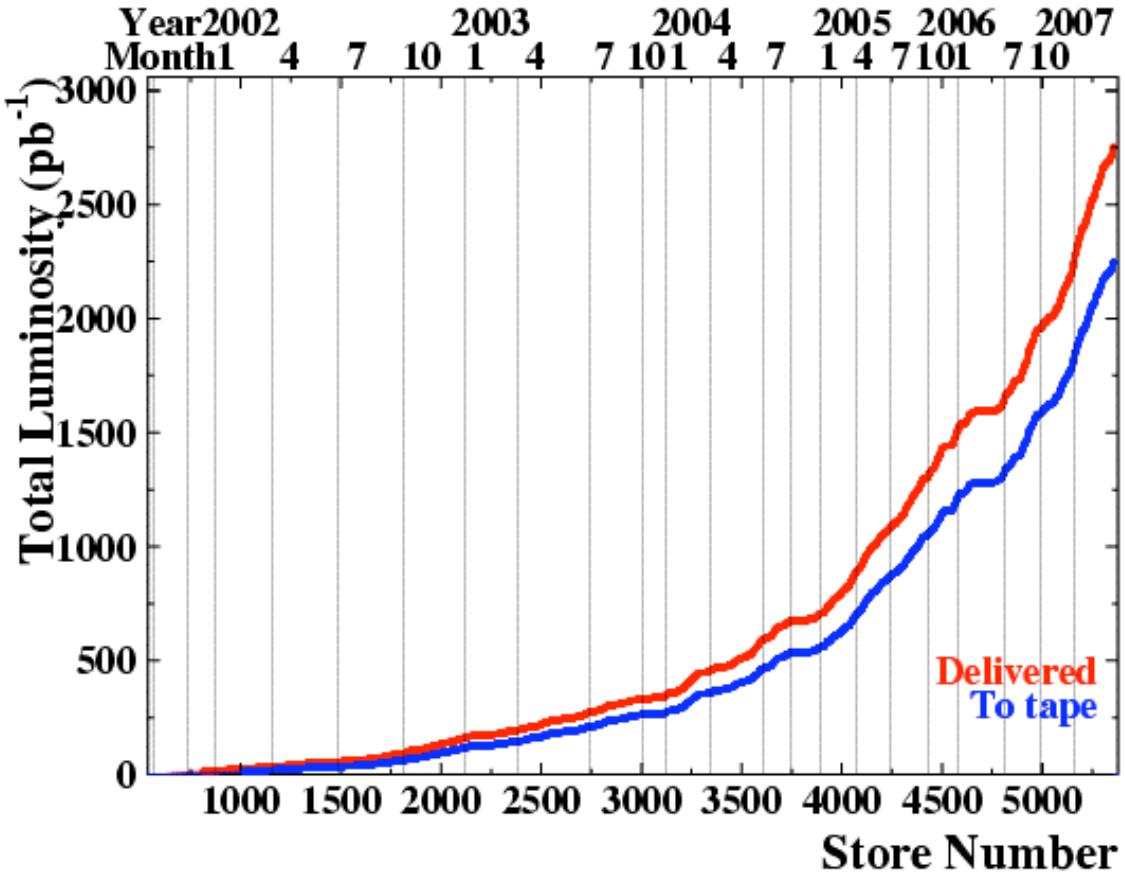
Hints of Dark Matter at the Tevatron

- Many models which could explain Dark Matter (DM) predict signatures accessible at Tevatron
- Supersymmetry (SUSY) provides a good DM candidate
  - Lightest neutralino – neutral, colorless, does not decay
    - Tevatron searches for evidence of supersymmetric particles which decay to the lightest neutralino
    - Variety of signatures, models, direct and indirect searches
- Universal Extra Dimensions (UED)
  - Lightest Kaluza-Klein particle is a DM candidate
  - Similar signatures as covered by SUSY searches

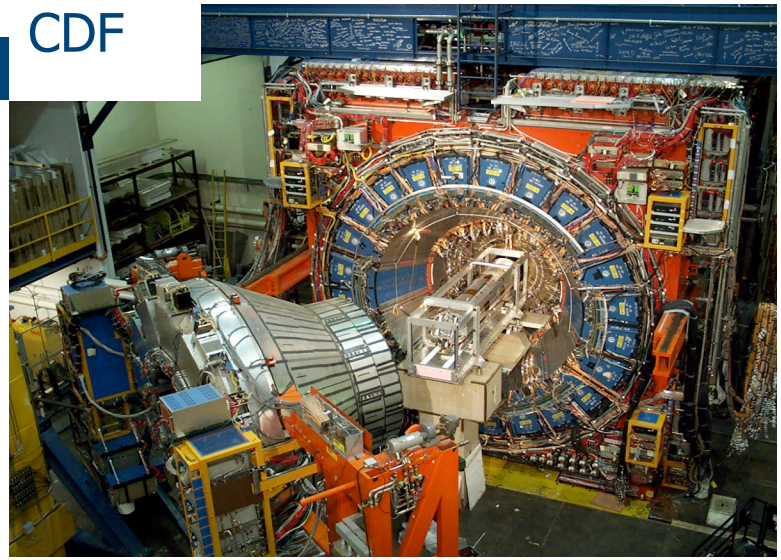
The Tevatron



Tevatron Run 2



CDF



DØ

~2.2 fb^{-1} recorded

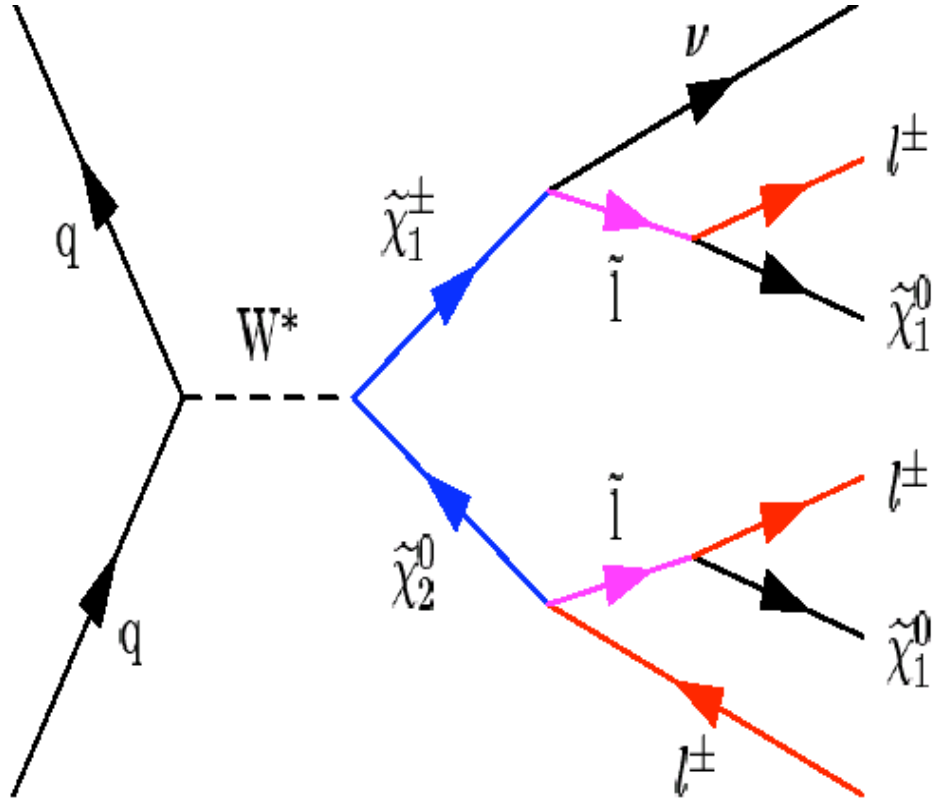
4-8 fb^{-1} by 2009

SUSY Searches at the Tevatron

- CDF and D0 have extensive programs to search for Supersymmetry
  - "standard" MSSM-inspired (or mSUGRA) signatures
    - Trileptons for chargino-neutralino
    - Jets + Missing ET for squark/gluino
    - Jets (flavor-tagged) + Missing ET for stop/sbottom
    - Multi-b or taus for SUSY higgs
  - GMSB, AMSB models
    - Long-lived particles
      - Decaying to photons
      - Charged, don't decay in detector (CHAMPS)
      - Stopped gluinos
  - Indirect searches – $B_s \rightarrow \mu\mu$

Search for Chargino-Neutralino Production

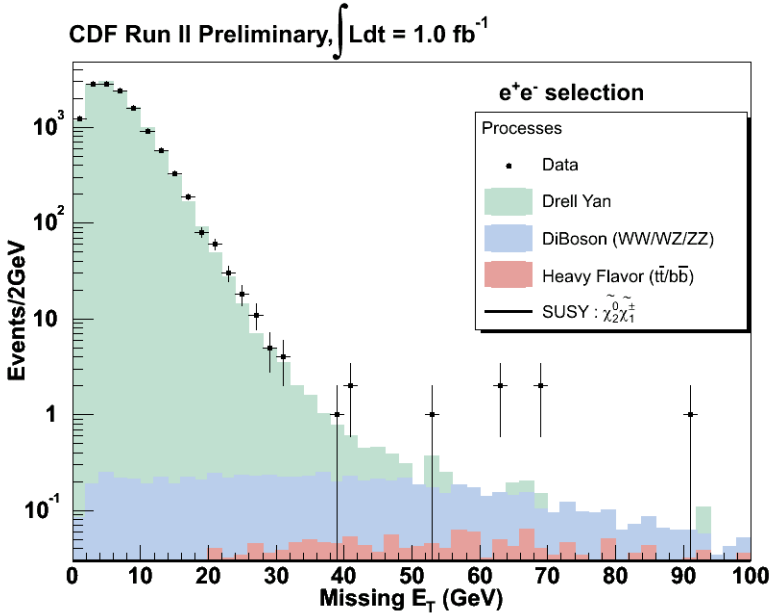
- Trileptons from chargino-neutralino: flagship analysis for discovery of SUSY at the Tevatron



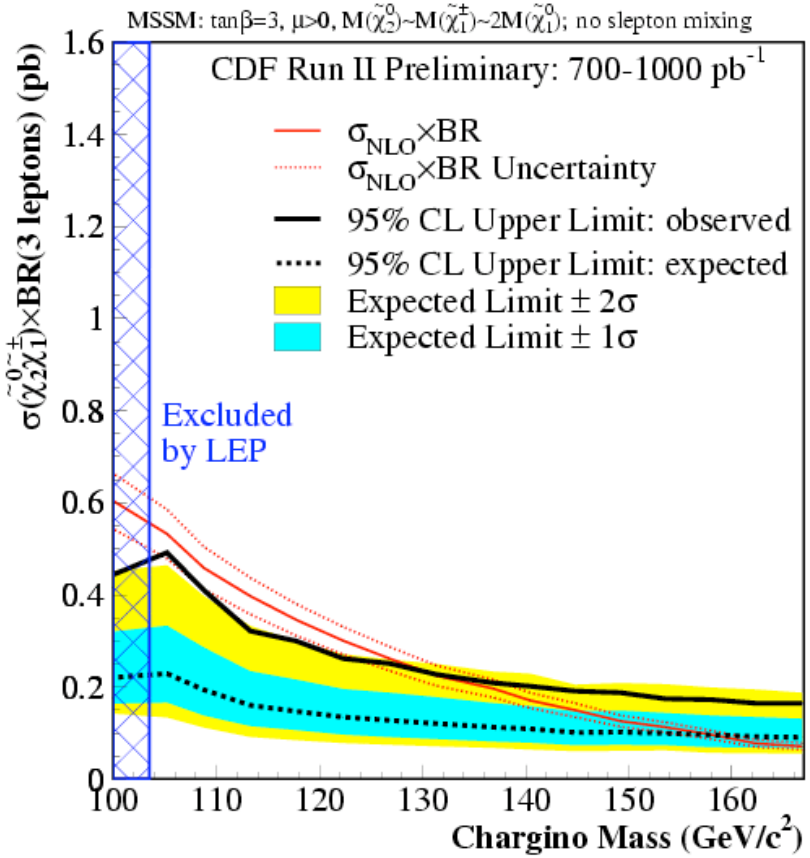
Clear signature – 3 isolated leptons, missing ET

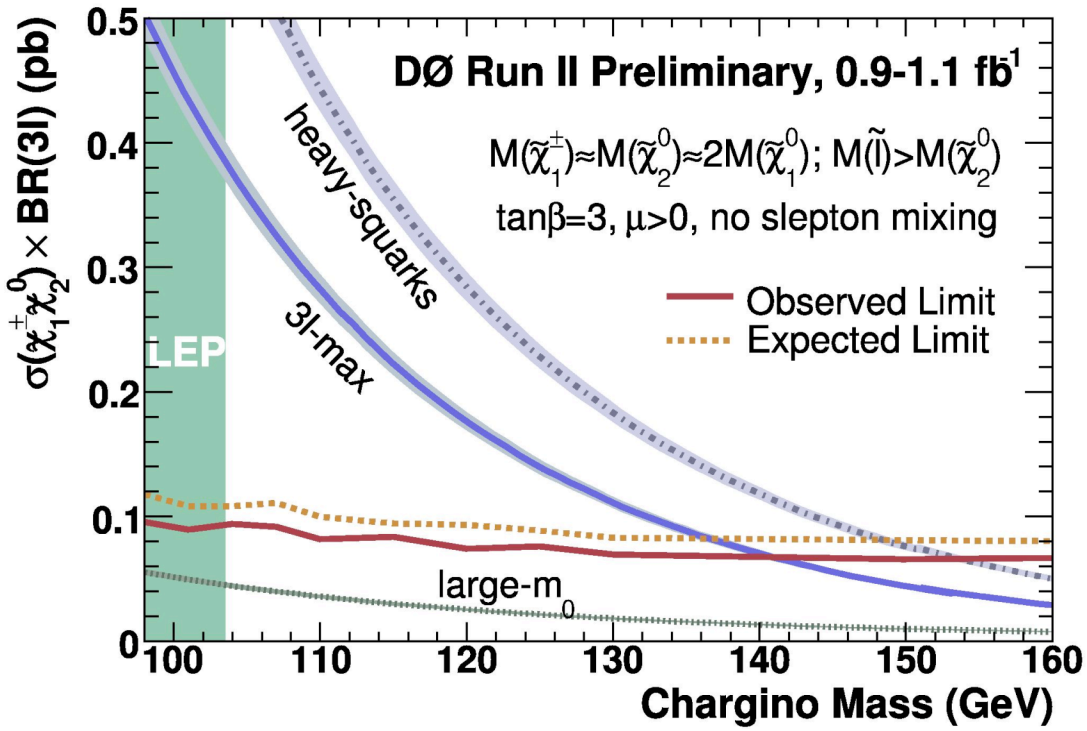
CDF and D0 Trilepton Searches

- CDF and D0 have a suite of searches for trileptons – combinations of electrons, muons, tracks (for 3rd lepton)
  - Taus are more difficult to detect, larger background from jets misidentified as taus
    - Gain acceptance by allowing track for 3rd lepton
  - Searches for more energetic leptons are simpler– fewer problematic backgrounds
  - Low energy searches needed to cover SUSY parameter space
  - Gain acceptance by searching for only two leptons – with the same sign
- Use control regions for bkg check



Constraining SUSY models

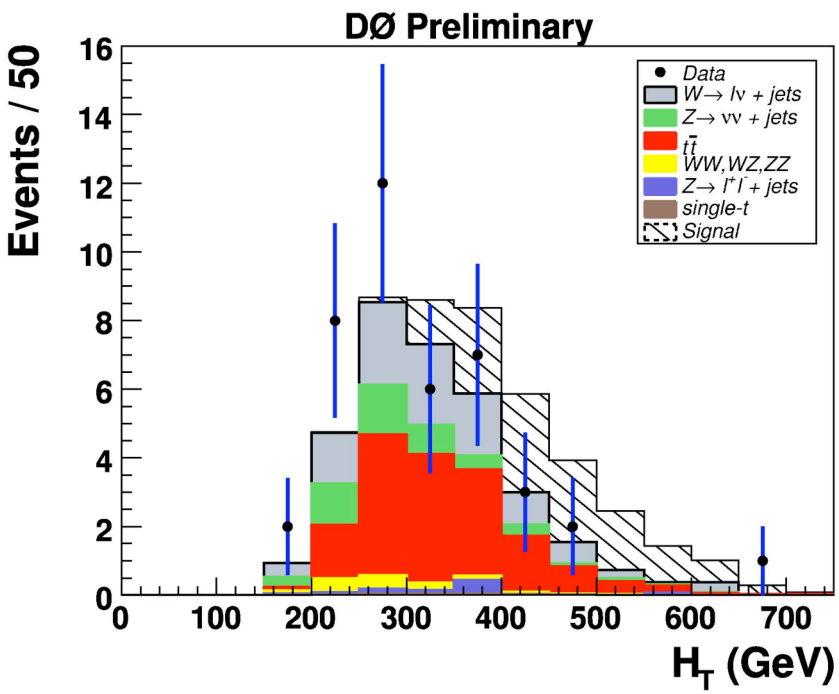


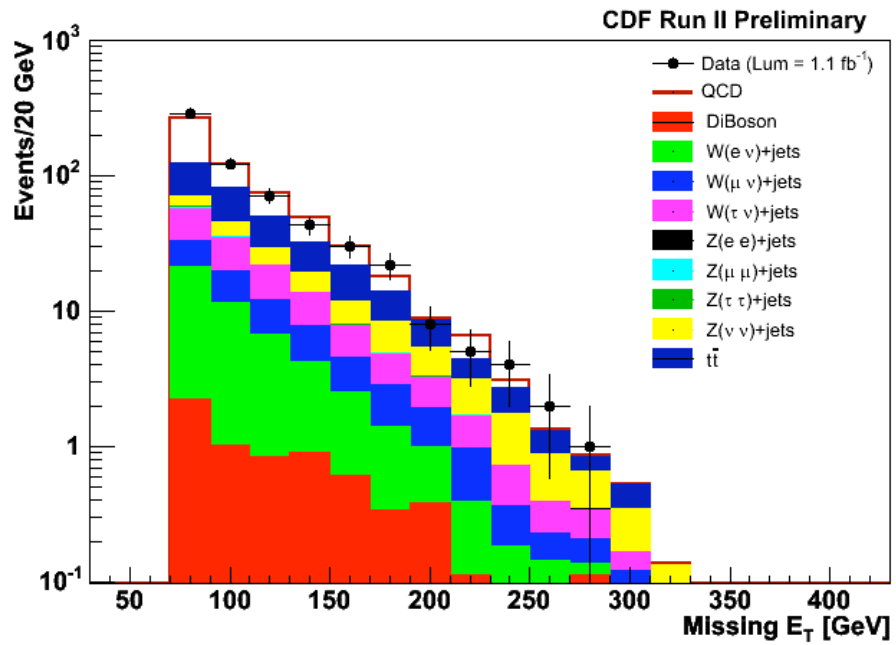


- No excess observed -- combine all trilepton channels to set a limit on the chargino mass in a specific model

Search for Squark/Gluino Production

- Generic squark/gluino production → energetic jets, large missing ET
  - One of the most powerful SUSY searches at the Tevatron
  - Also one of the most difficult – large QCD background

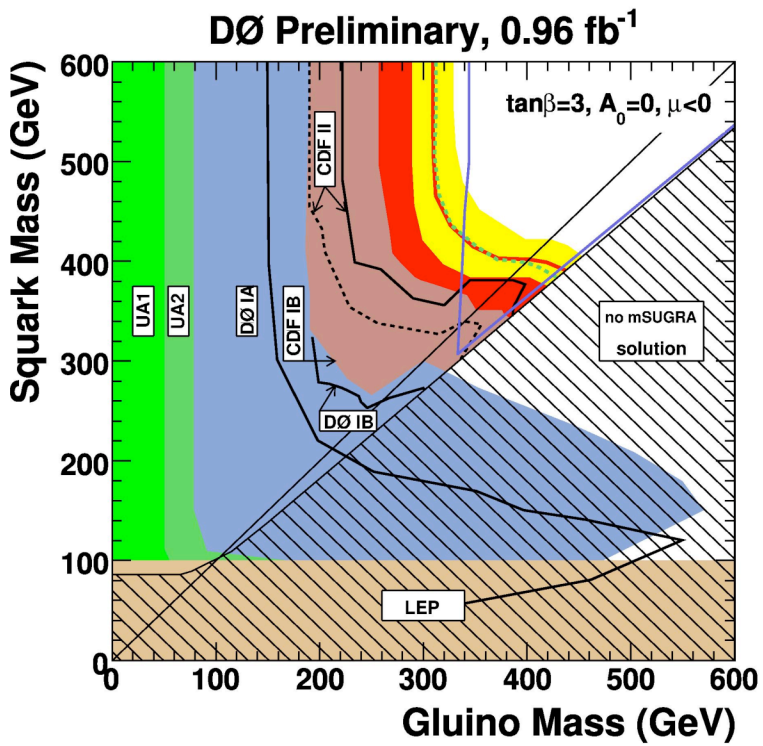


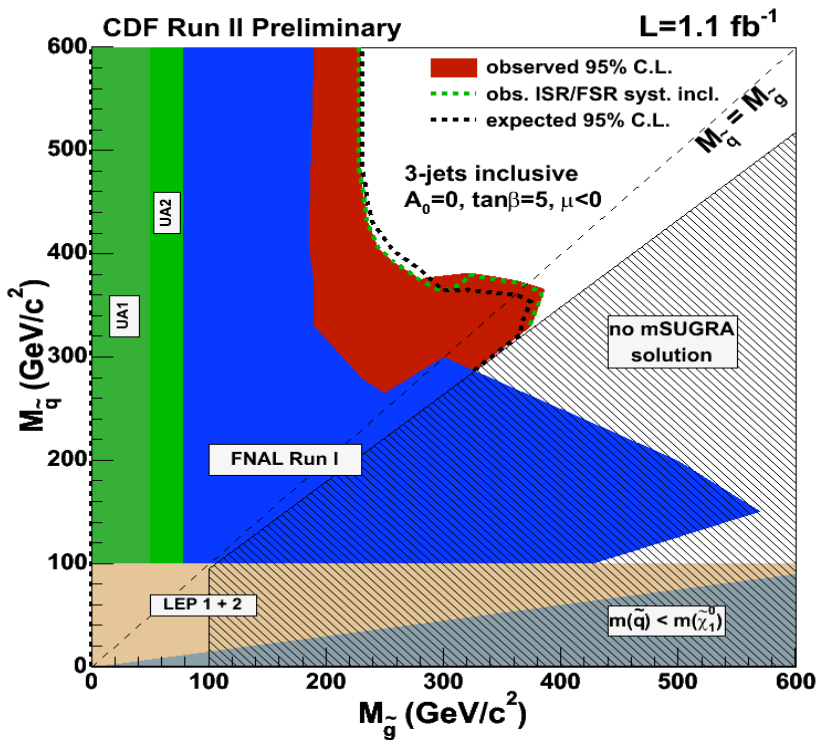


HT = scalar sum of ET of jets

Limits on Squark/Gluino Production

- No excess found -- interpret in mSUGRA





Msquark < 391 excluded

Mgluino < 309 excluded

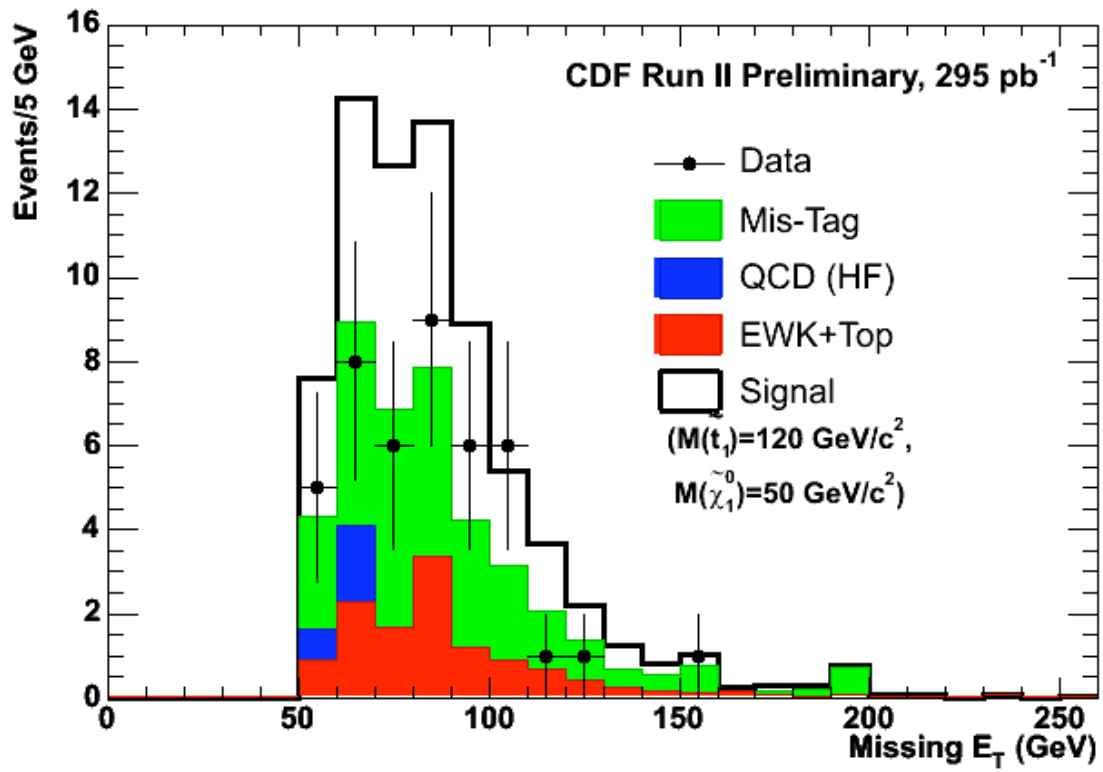
Mgluino < 380 excluded for Mg~ Mq

Mgluino < 230 excluded -- any Msquark

Searches for Stop/Sbottom

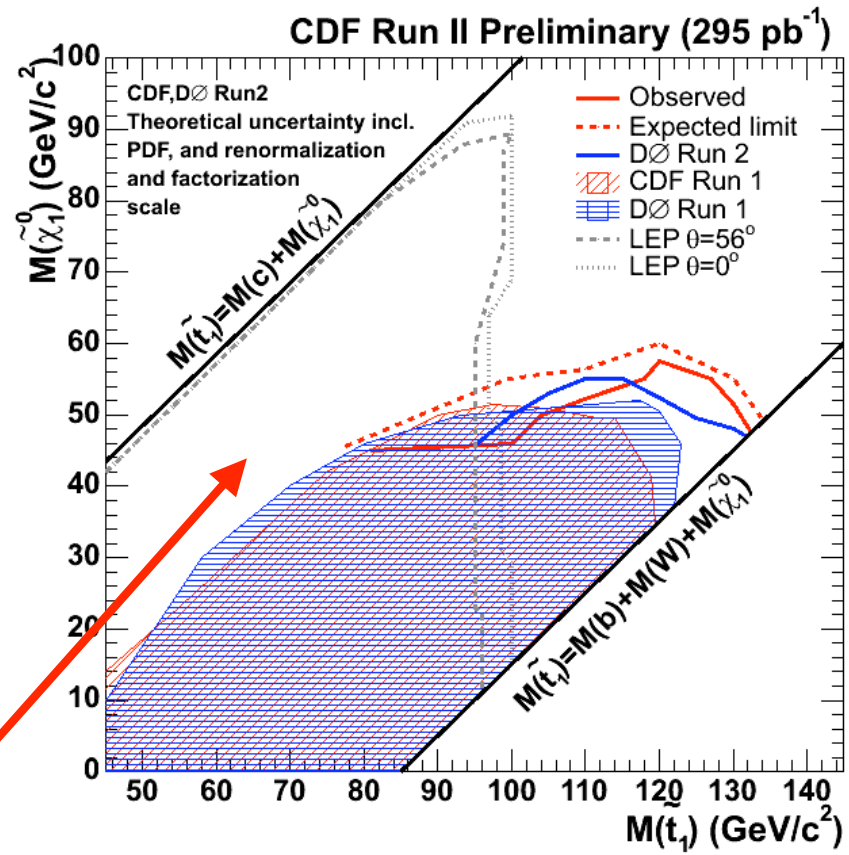
- Third generation squarks could be light!
- Devise specific searches
  - Production : stop or sbottom pairs, or through gluino decays
  - Decay:
    - $b \rightarrow b\chi^0$
    - Stop depends on mass:
      - Heavy: $t \rightarrow t\chi^0$
      - Medium: $t \rightarrow b\chi^{\pm} \rightarrow bW\chi^0$
      - Light: $t \rightarrow c\chi^0$

Search for $t \rightarrow c\,\chi^0$ -- acoplanar charm jets + Missing ET



Light Stop Search Results

- No excess found, set limits on stop production
- A light stop squark is consistent with baryogenesis (eg, Balazs, Carena, Wagner: hep-ph/0403224)
  - $m(\tilde{t})-m(\tilde{\chi}_1^0)\approx 15\text{-}30$ GeV/c^2
  - $m(\tilde{t})<165$ GeV/c^2



Can we do better?

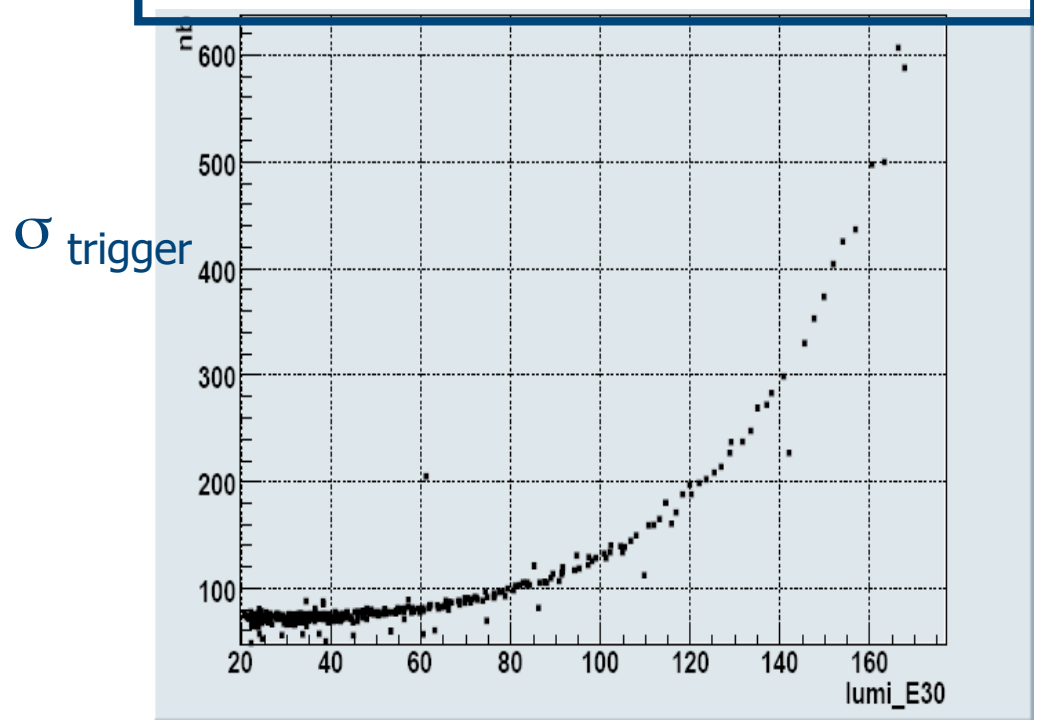
Triggering on MET (CDF-specific)

- Trigger is an online filter
  - Reduces 2.5 million collisions per second in the Tevatron to 100 collisions per second that we can keep for later analysis
  - Done in three stages of increasing precision and processing time (Level 1,2,3)
- Missing ET is difficult to trigger on
  - Rate (number of events satisfying trigger/time) depends on beam conditions, detector conditions
  - Rate grows at instantaneous luminosity increases
    - Total trigger budget needs to accommodate entire physics program
  - Balance of needs:
    - High thresholds to manage trigger rate
    - Low thresholds for analyses

Current CDF Calorimeter Trigger

- Designed many years before Run 2 began, built on Run 1 experience using then-current technology
  - Used for jets, photons, electrons, Missing ET
- Limitations:
  - Calculation of Missing ET is done at low resolution
  - Clustering into trigger jets uses simple algorithm → introduces huge rate from fake jets at high instantaneous luminosity

2-Jets + Missing Et: Higgs searches



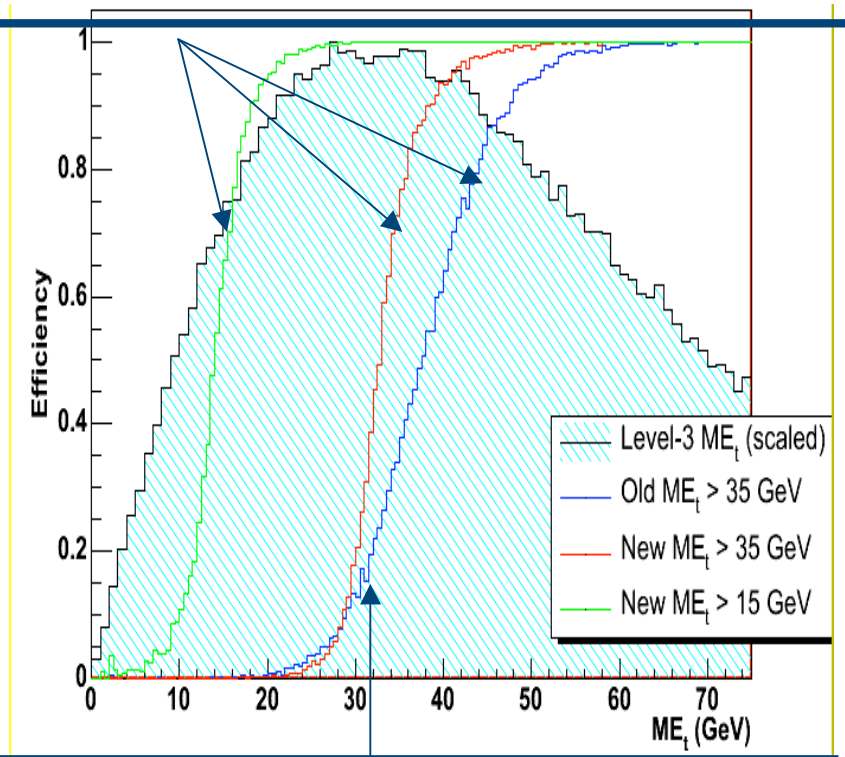
Instantaneous luminosity

Physics cross section is ~ constant with luminosity

Upgraded CDF Calorimeter Trigger

- Improvements:
  - Clustering done in software (fixed cone algorithm → jet centroid)
  - Missing ET calculated with higher resolution
- Trigger rate reduction
  - New clustering will reduce fakes
  - Better position matching – can implement geometric cuts
- Will be able to lower Missing ET cut at trigger level
  - Allow lower cuts at analysis level
- Upgraded CDF Calorimeter trigger is currently being commissioned
  - For technical details, see Gene Flanagan's talk at last week's Real Time 2007 conference!

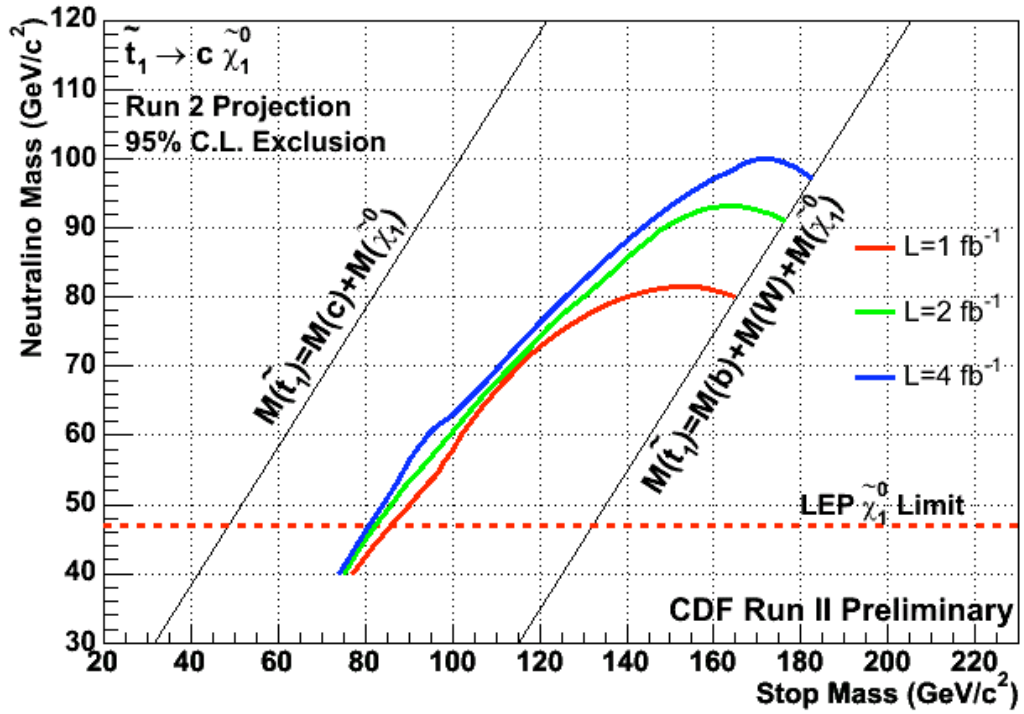
Missing ET trigger efficiency (ZH monte-carlo



Missing ET from ZH production (→ννbb)

Stop Quark: Result and Future

- Future light stop reach :
  - L=1 fb^{-1}: $m(\tilde{t})<160$ GeV/c^2
  - L=4 fb^{-1}: $m(\tilde{t})<180$ GeV/c^2
- Hope to cover more parameter space (eg, improved MET,jets trigger)

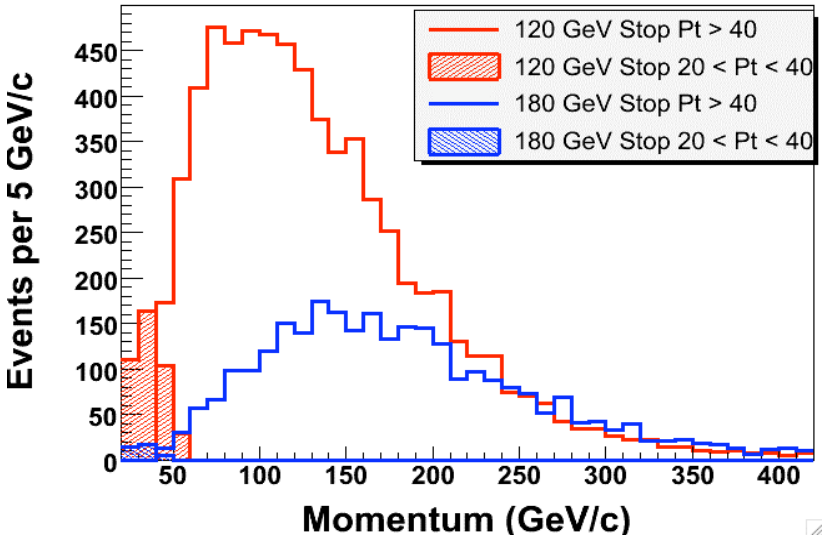


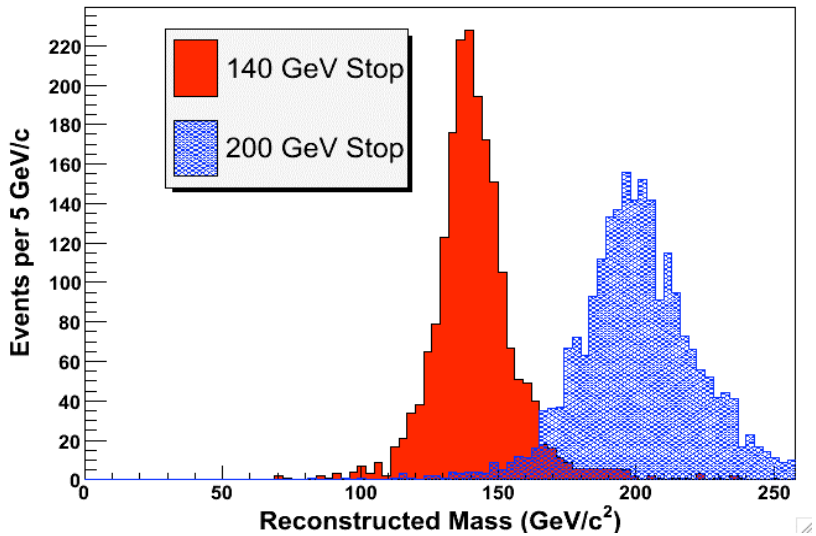
Long-lived Exotic particles

- Several models predict long-lived particles: charged or neutral, decaying inside or outside detector
  - Charged
    - looks like slow muon ← CHAMPS analysis
  - Neutral
    - decay inside detector
      - delayed photons ← CDF analysis
      - delayed jets ← D0 analysis

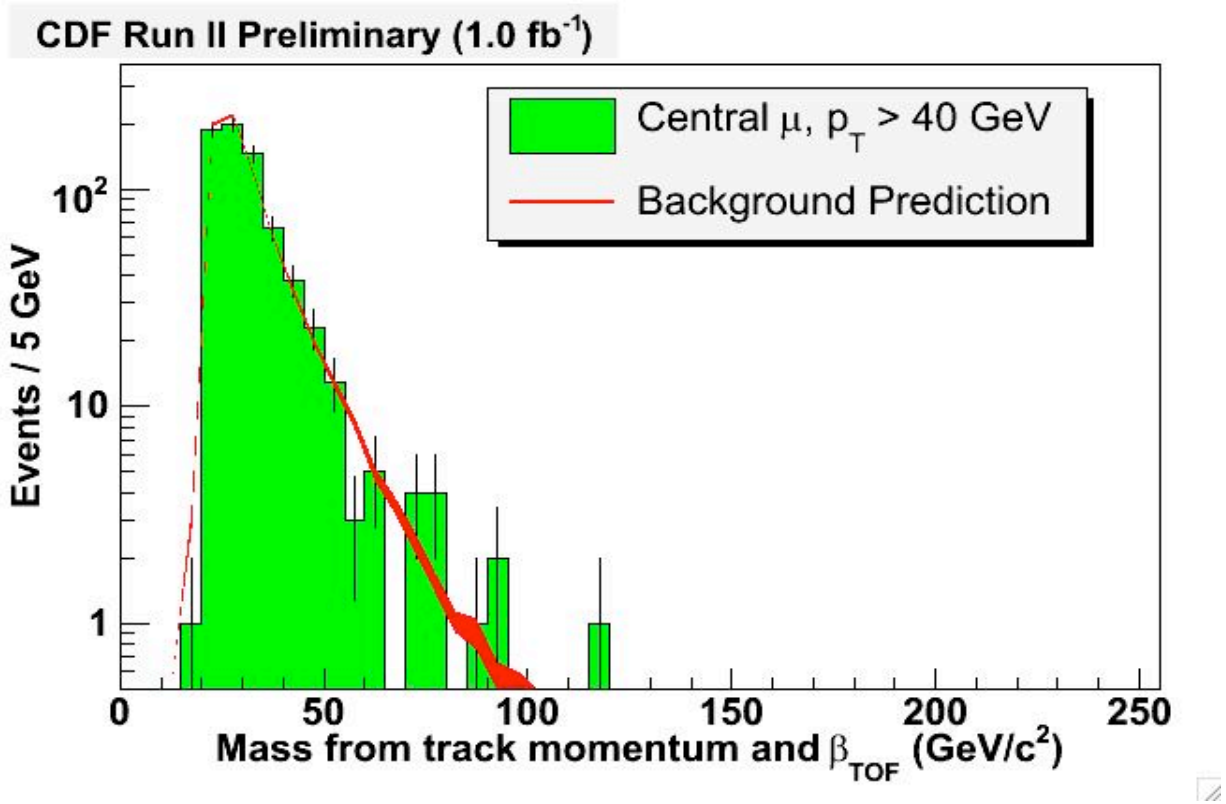
CDF Champs Search

- CHAMPS leave a unique signature
  - Look like slow, heavy muons – penetrating, long Time-of-Flight measured in detector, large ionization dE/dX
  - Large mass (from velocity and momentum measurements)
- Use control datasets to validate mass measurement





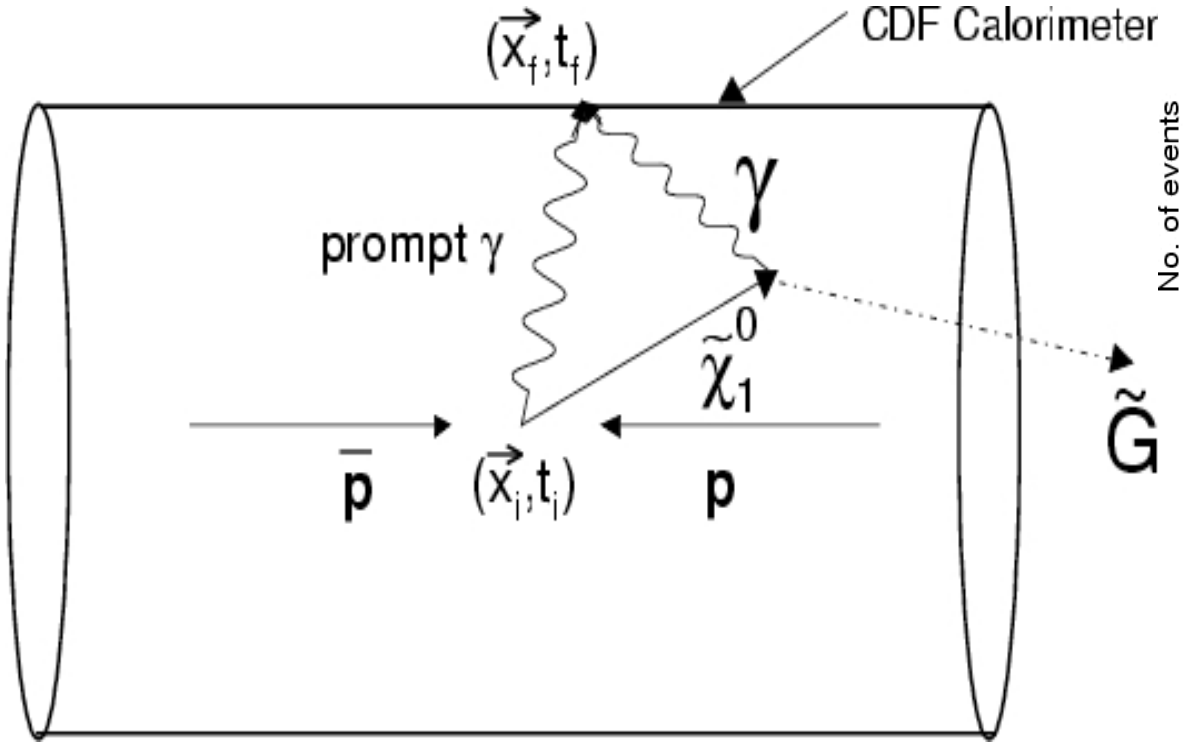
CHAMPS results

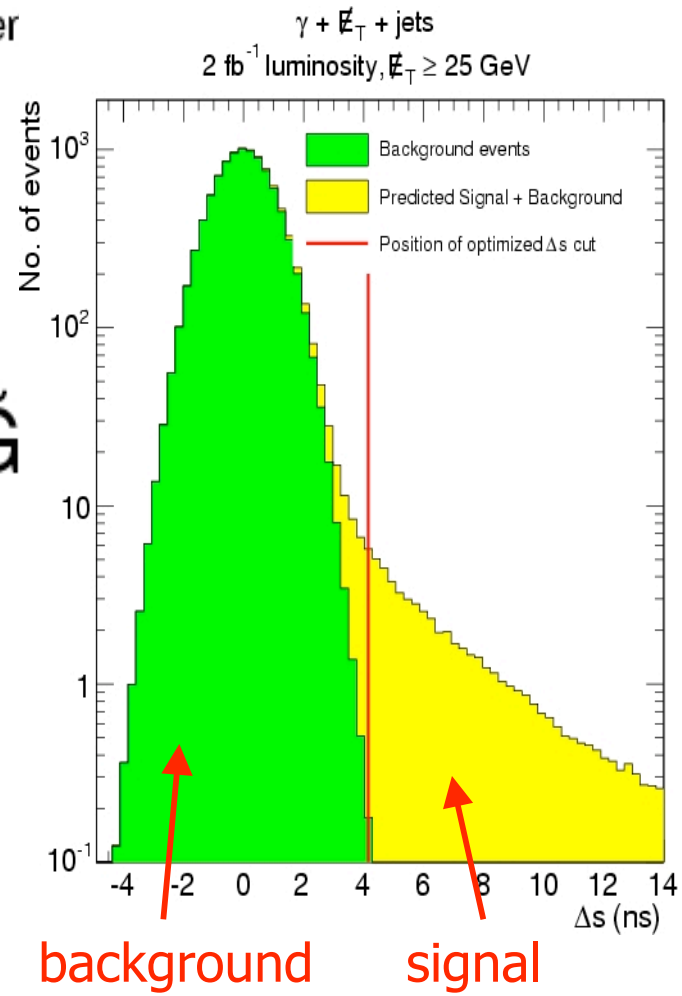


- Signal region – no candidates with M>120. consistent with expected background
- Exclude stable stop with M<250 GeV/c^2 at 95%CL

Delayed Photon Analysis

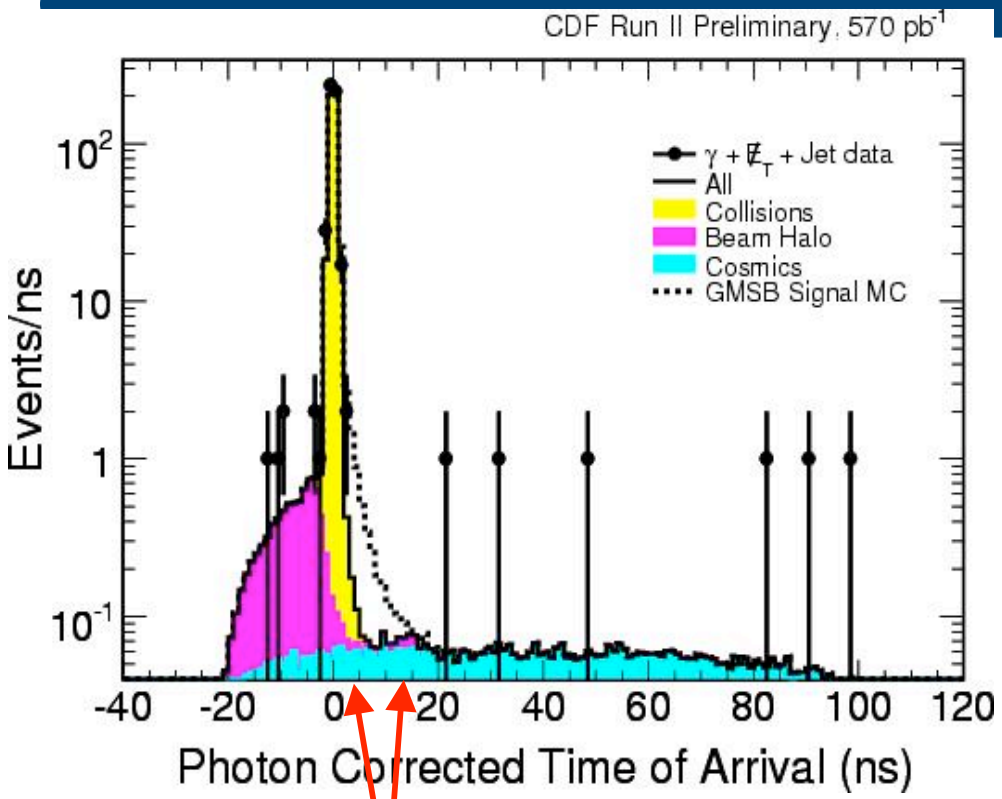
- Relies on EM calorimeter timing detector





Measure photon arrival time➔

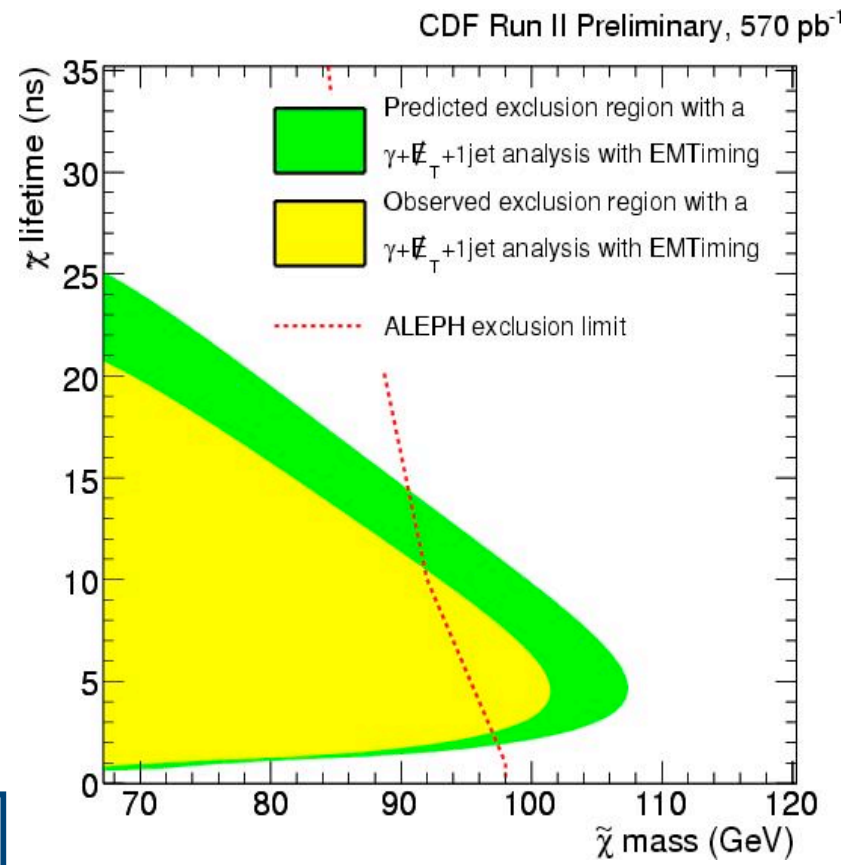
Search for Delayed Photons



signal region

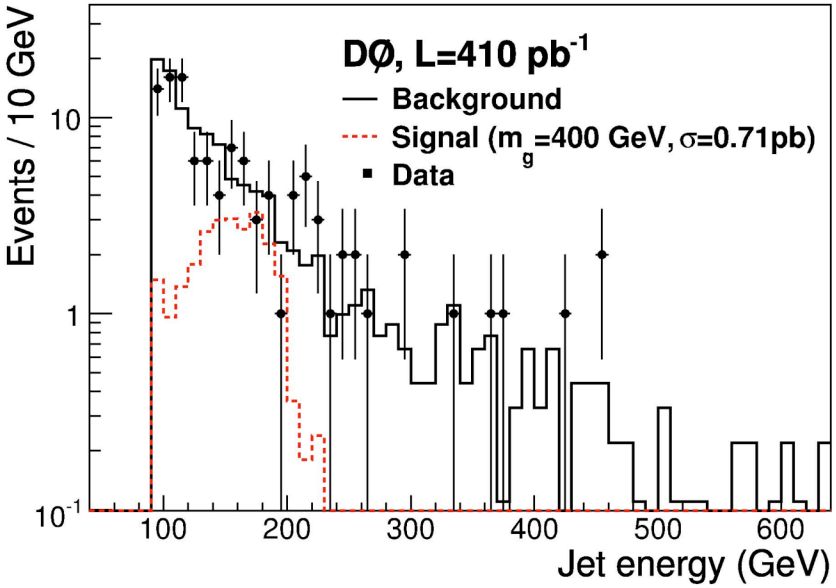
No new physics found here, so far

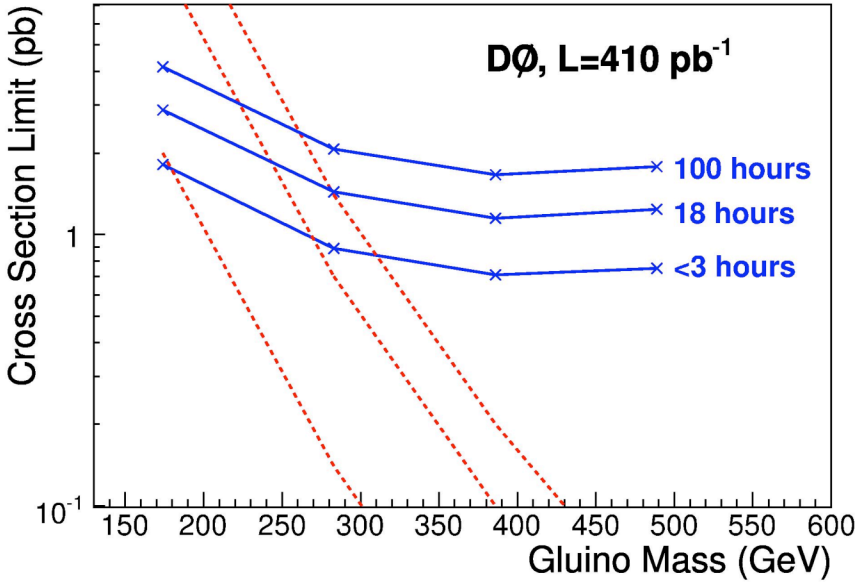
Interpret in GMSB



D0 Search for Stopped Gluinos

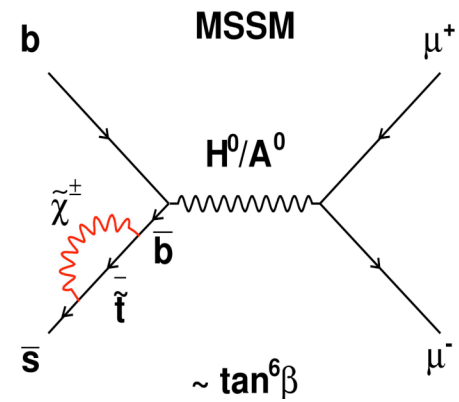
- "Split-SUSY" models (SUSY scalars heavy compared to SUSY fermions) predict long-lived gluinos
  - Stop in calorimeter, decay later (10us – 100 hours)
  - Look for events with calorimeter energy and nothing else

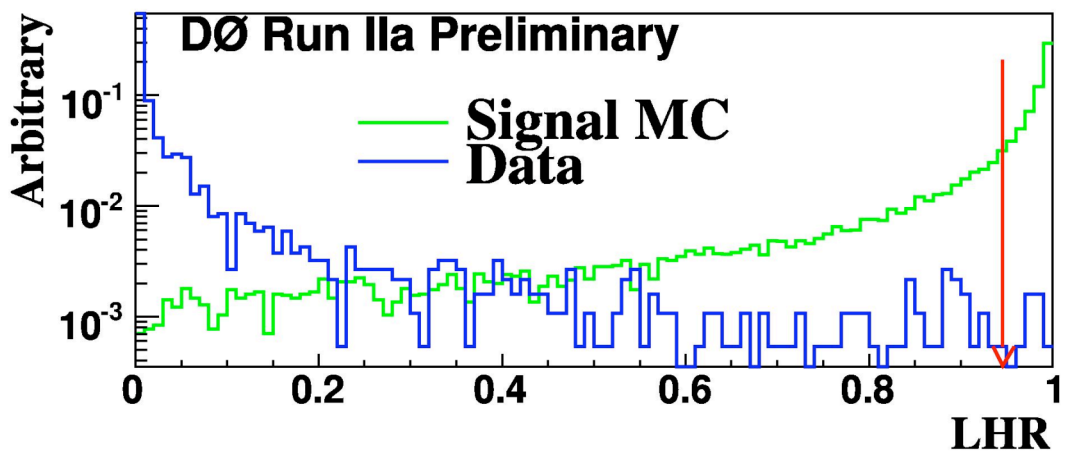


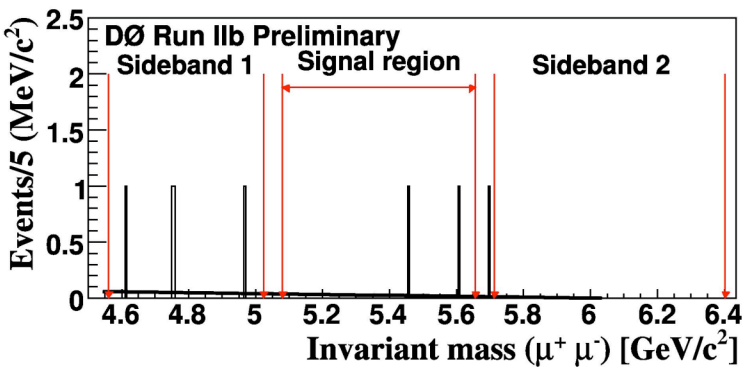


Indirect SUSY searches -- $B_s \rightarrow \mu^+\mu^-$

- Standard model predicts $B_s \rightarrow \mu^+\mu^- = (3.8 +/- 0.9)\times10^{-9}$
- SUSY rate may be enhanced ~ $\tan^6\beta$
- Separate from huge background using likelihood ratio w/event characteristics, eg:
  - decay length significance
  - B-meson isolation
  - Pointing angle
  - B and muon impact parameter
  - Vertex information

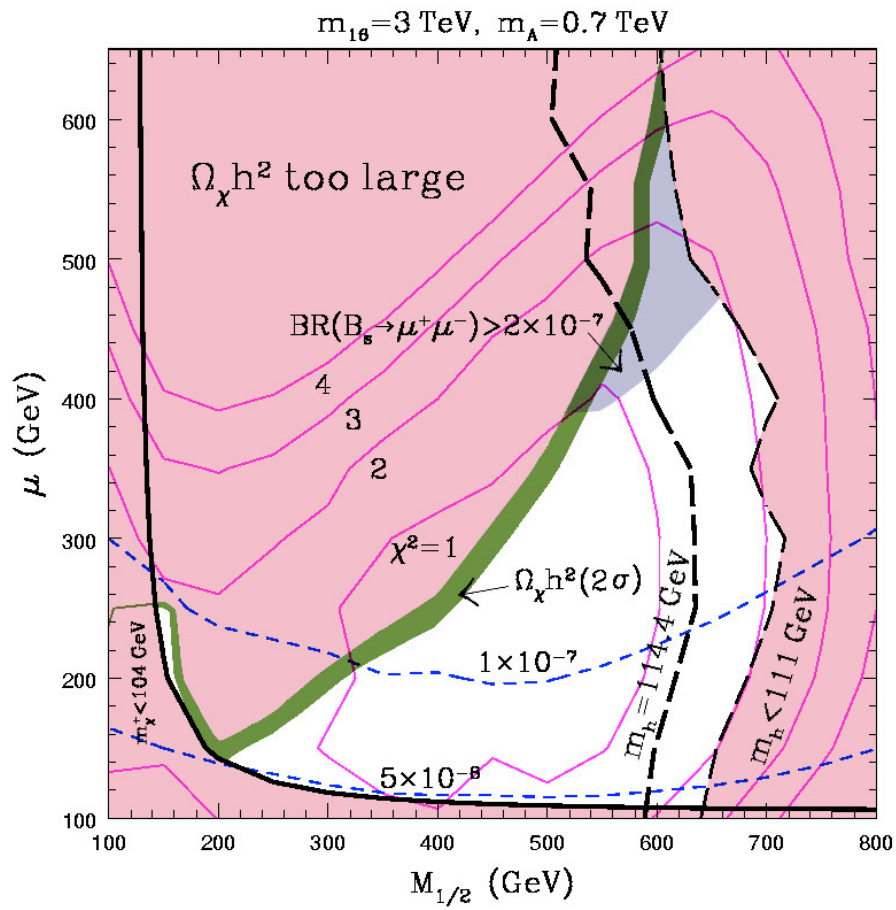






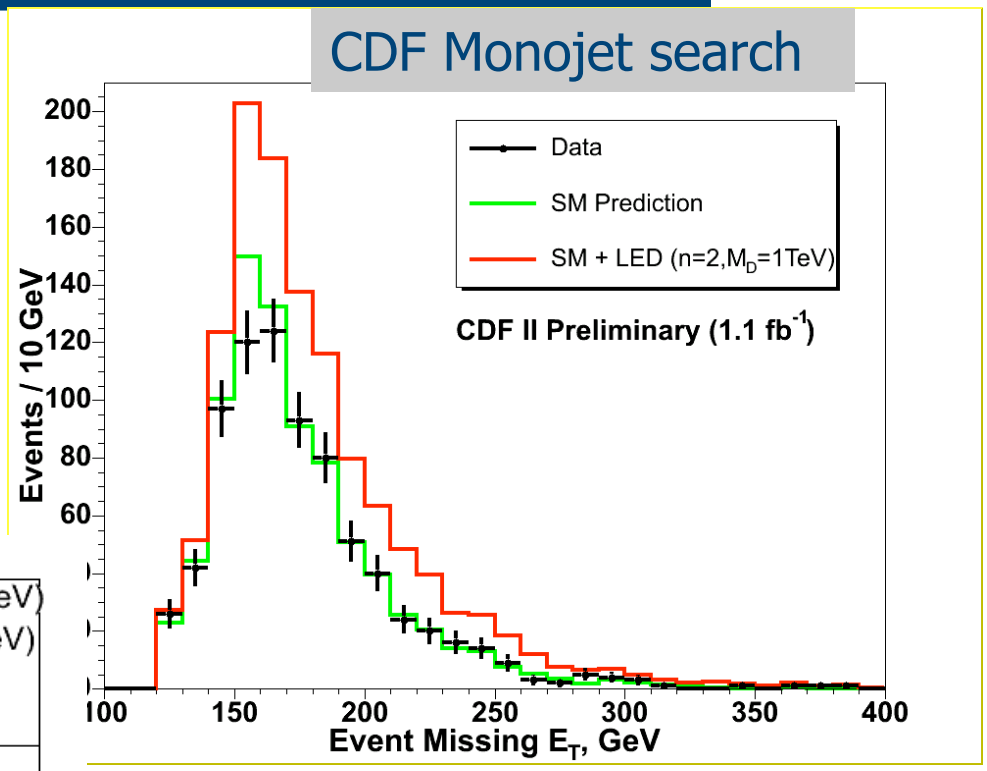
$B_s \rightarrow \mu\mu$: Result and Future

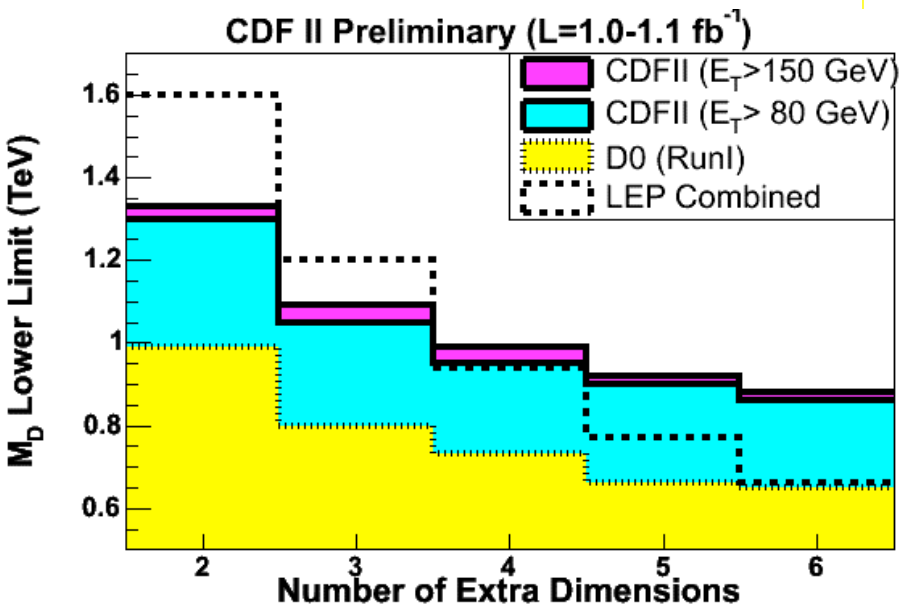
- Result – observation consistent with background expectation
- Branching Ratio Limits:
  - CDF (780 pb^{-1}):
    - $BR(B_s \rightarrow \mu\mu) < 10 \times 10^{-8}$ at 95%C.L.
  - DØ (2 fb^{-1}):
    - $BR(B_s \rightarrow \mu\mu) < 9.3 \times 10^{-8}$ at 95%C.L.
- Future: Tevatron will probe values of 2×10^{-8}



Dark Matter from Universal Extra Dimensions models

- Lightest KK particle can be DM candidate
  - Tevatron signatures
    - Similar to SUSY
    - Trileptons (Run 1)
    - Monojets

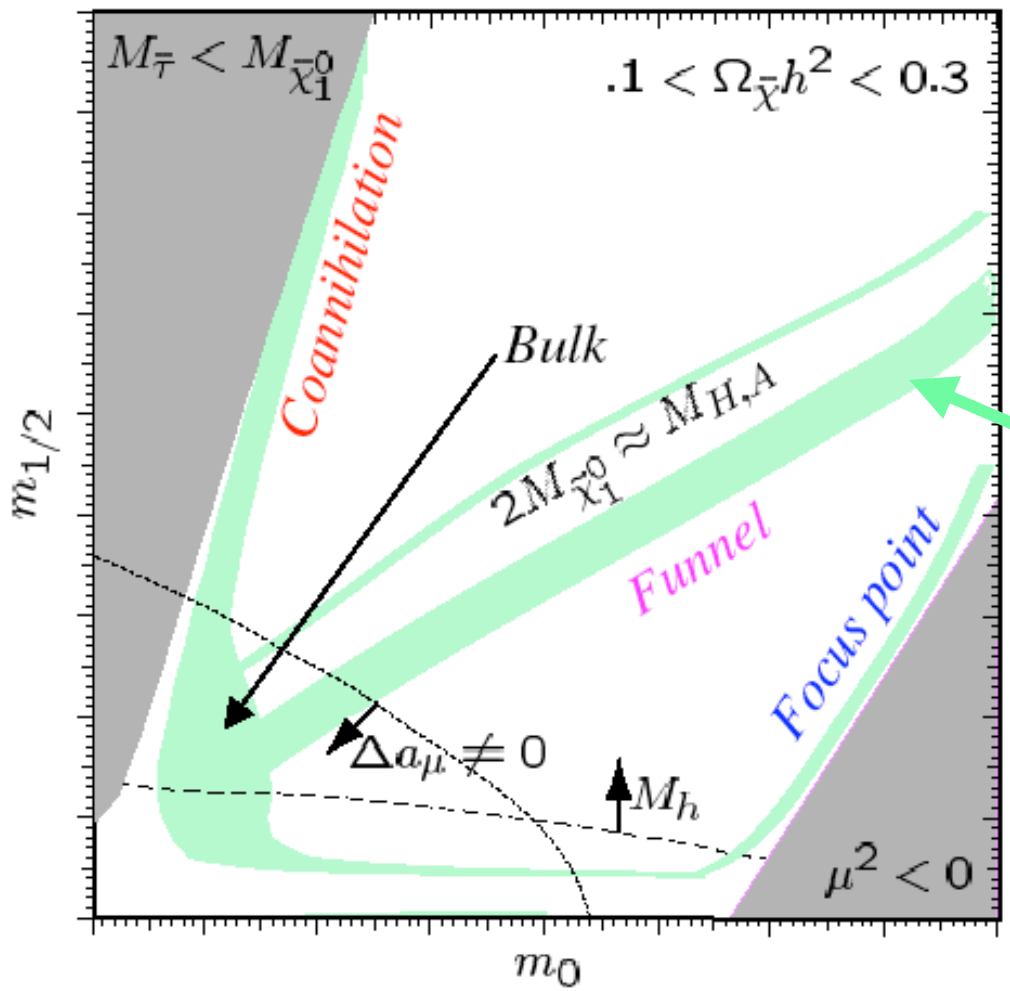




Set limits on MD vs N extra dimensions in ADD model

Other models in progress

Concluding remarks: SUSY and Cosmology Data



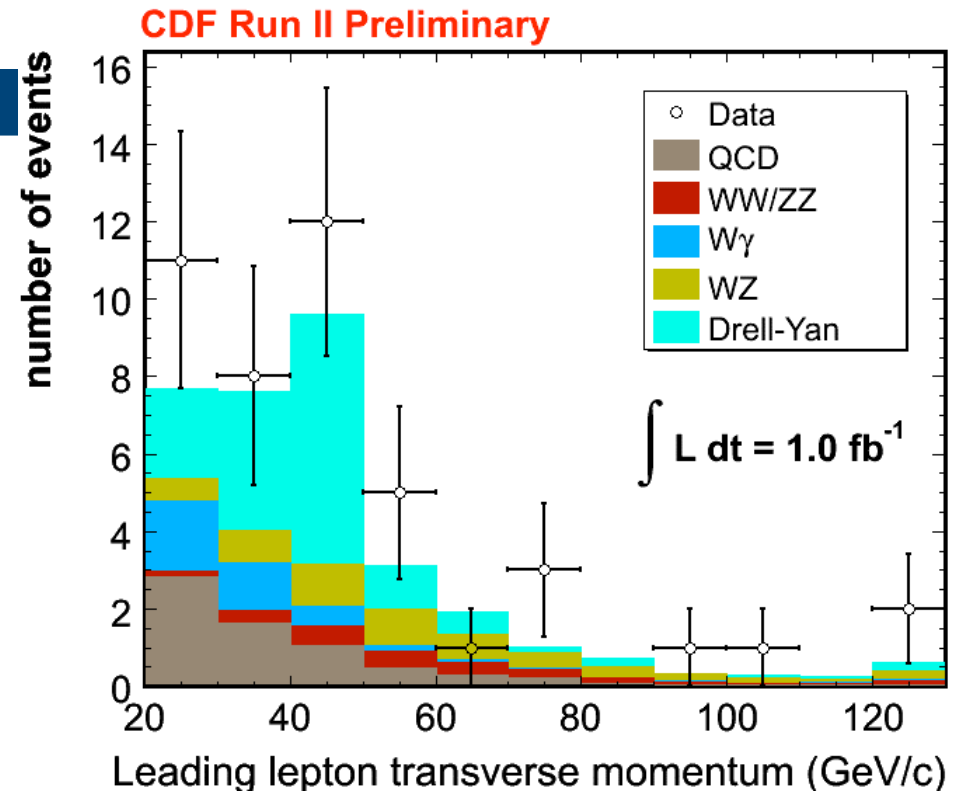
Consistent with cosmology data on dark matter

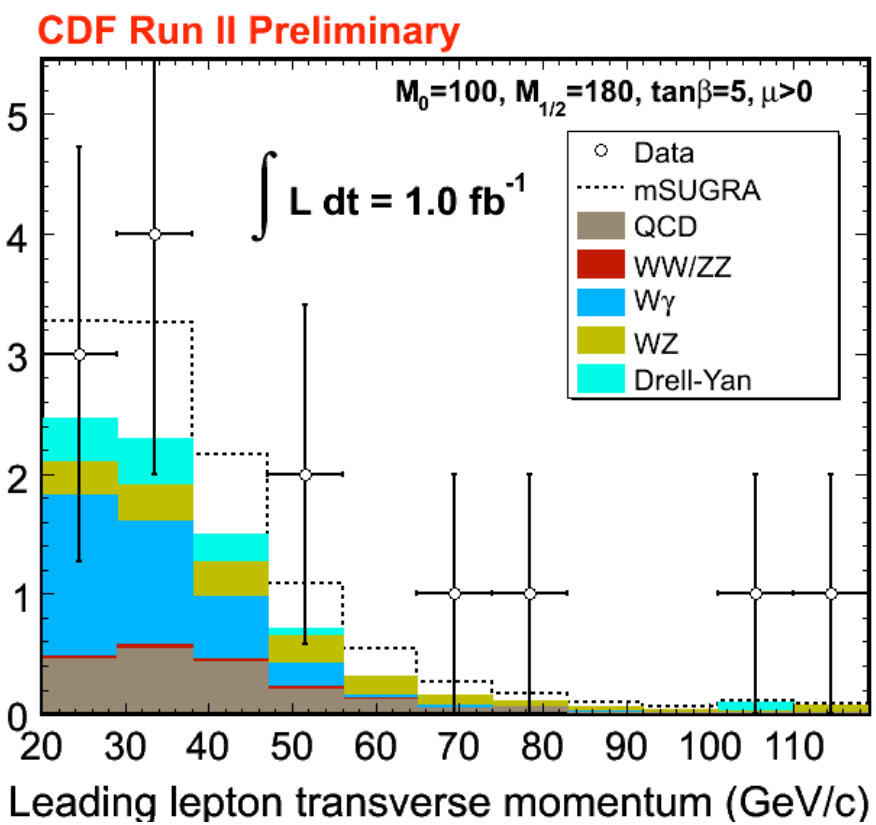
Tevatron (or LHC) can probe cosmologically interesting regions – stay tuned for more developments!

Backup slides

Like-Sign dileptons

- Signature-based search -- low Standard Model background
- Currently: chargino-neutralino production



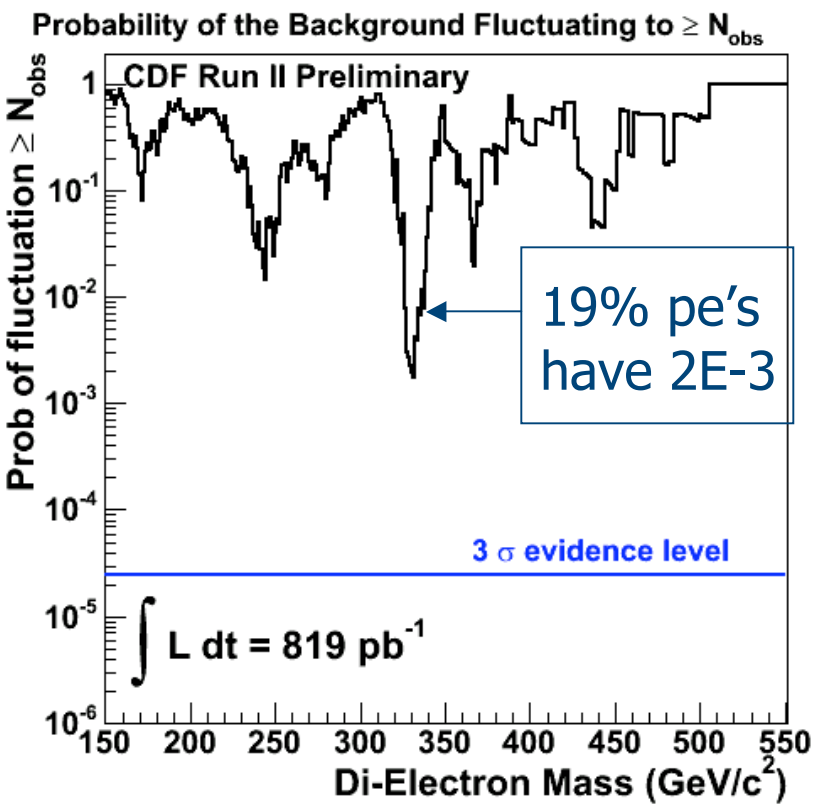


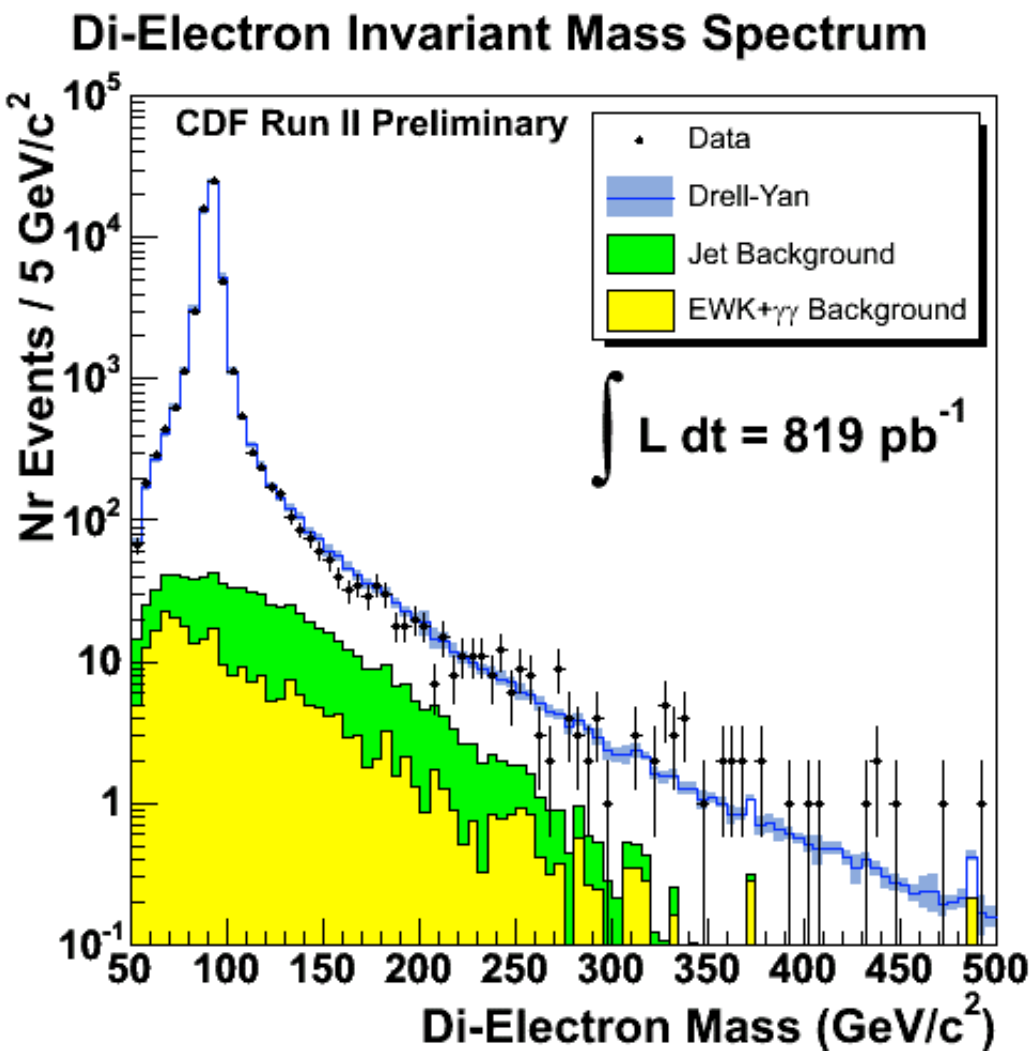
Basic selection: expect 34+/-4, see 44

Tight selection: expect 8 +/- 1, see 13

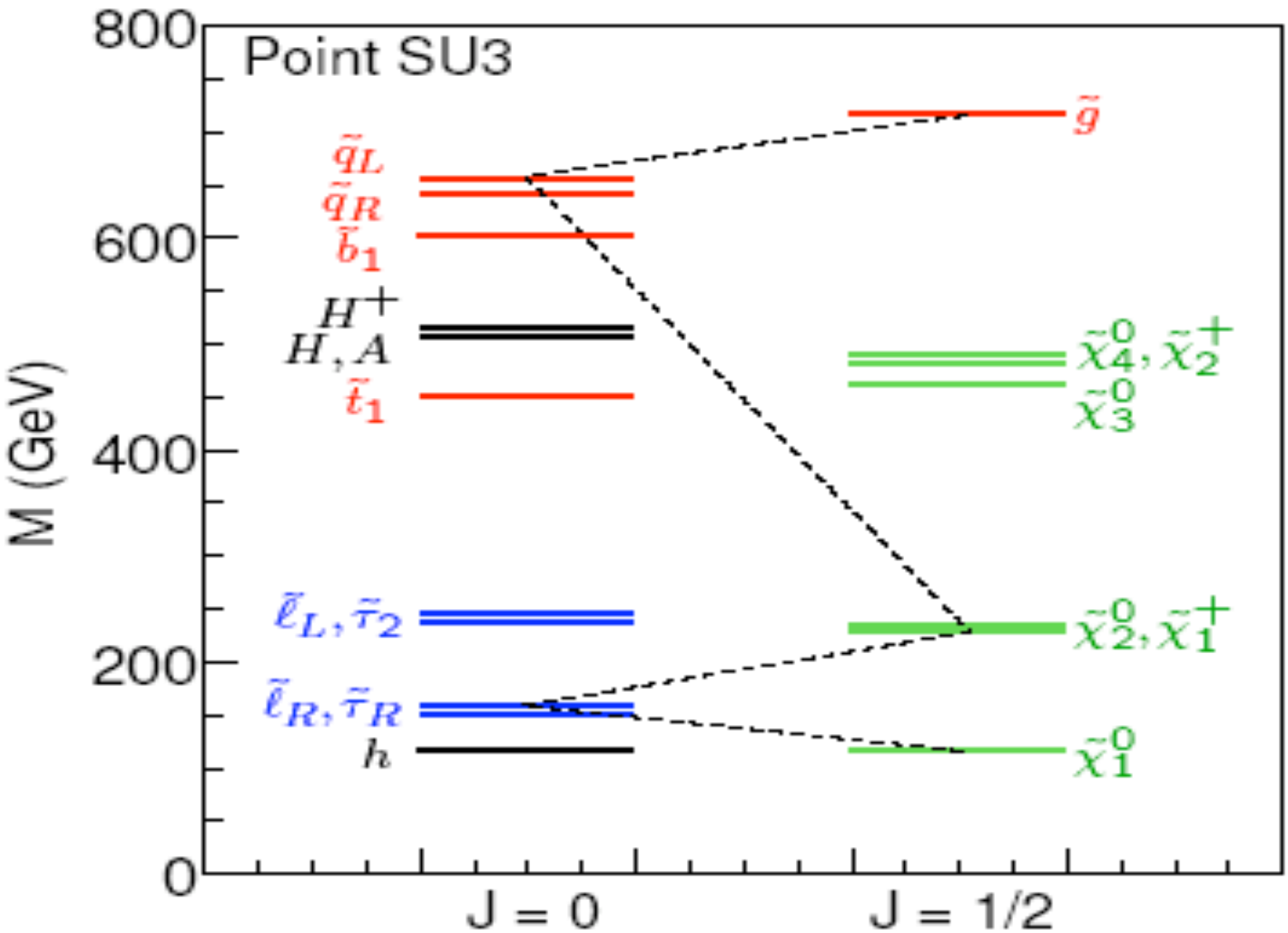
High mass dileptons

- High ET electrons, optimized to look for high-mass resonances (150-950 GeV)
- Applied to spin-1 Z' and spin-2 RS Graviton





Sparticle Spectrum



SUSY Particles

Particles R=1 $\quad R = (-1)^{3B+L+2S} \quad$ **SParticles R=-1**

fermions S=1/2	e μ τ	leptons	sleptons	$\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$	bosons S=0			
	ν_e ν_μ ν_τ	neutrinos	sneutrinos	$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$				
	u c t	quarks	squarks	$\tilde{u}$ $\tilde{c}$ $\tilde{t}$				
	d s b			$\tilde{d}$ $\tilde{s}$ $\tilde{b}$				
bosons S=1	$W^\pm$ $H^\pm$	gauge particles	charginos	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$	fermions S=1/2			
	γ Z^0 h^0 H^0 A^0		neutralinos	$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$				
	g_i		gluinos	$\tilde{g}_i$				
	G		gravitino	$\tilde{G}$				

MSSM

MSSM has 124 parameters:

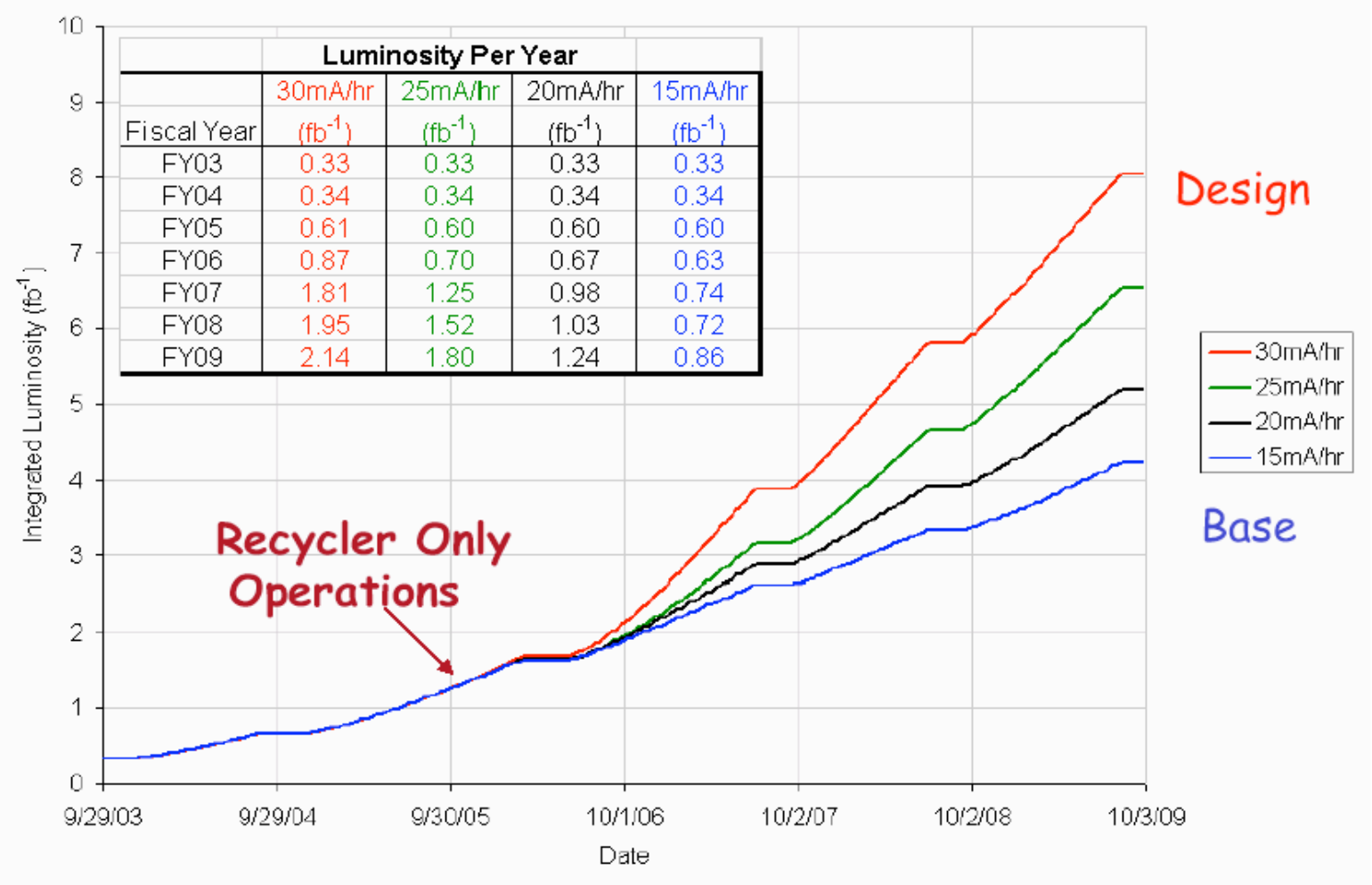
M_1, M_2, M_3, Gaugino masses, Sfermion masses

$\tan\beta$, μ, m_A Higgs(ino) mass/mixing

A_τ, A_b, A_t (+45 RPV)

- **SUSY is a broken symmetry**

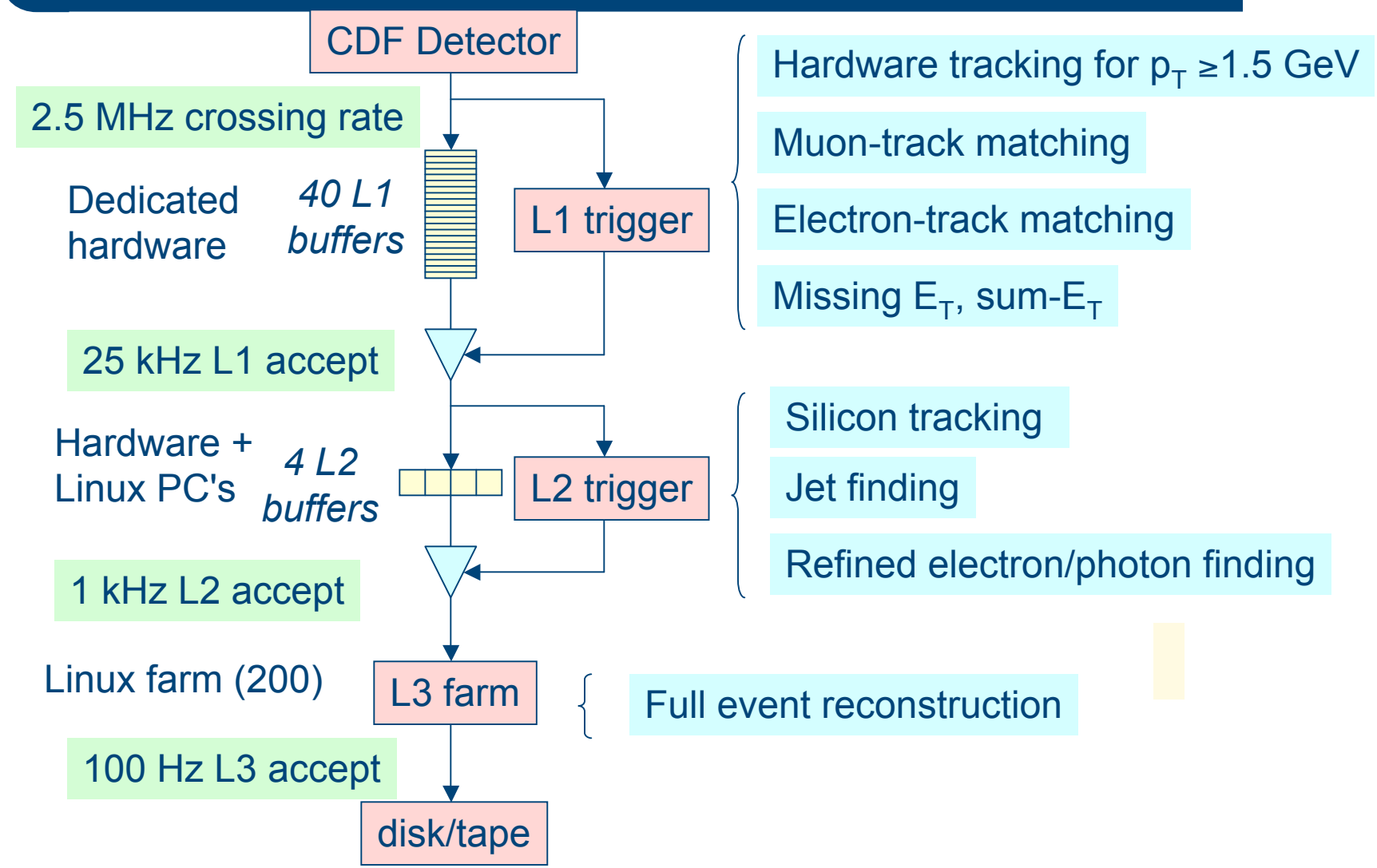
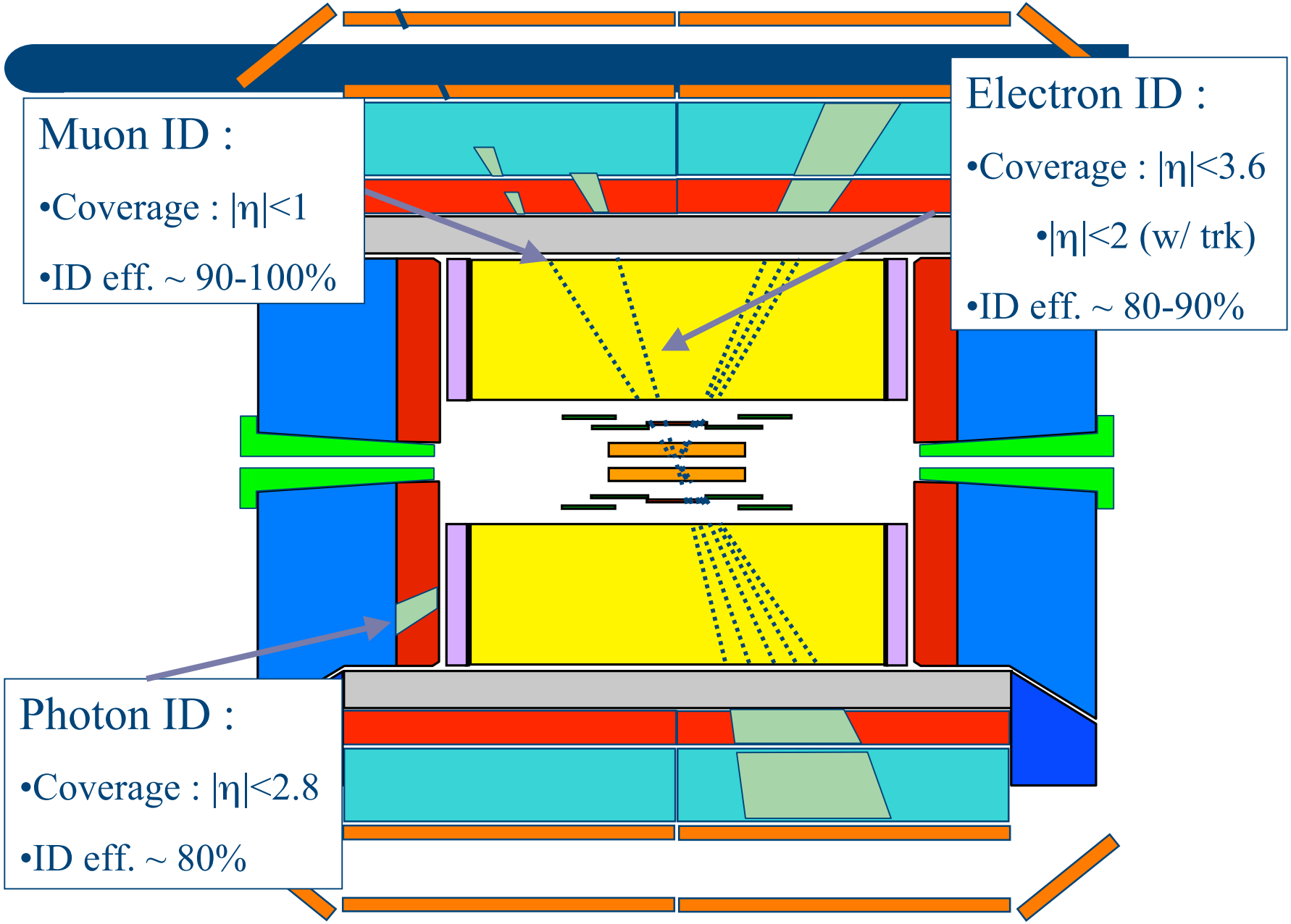
Tevatron: Future



Luminosity Per Year				
	30mA/hr	25mA/hr	20mA/hr	15mA/hr
Fiscal Year	(fb^{-1})	(fb^{-1})	(fb^{-1})	(fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

Triggering at hadron colliders

The trigger is the key at hadron colliders



Measurement of Final State Objects with the CDF Detector