Search for Chargino and Neutralino in the Golden Mode at CDF

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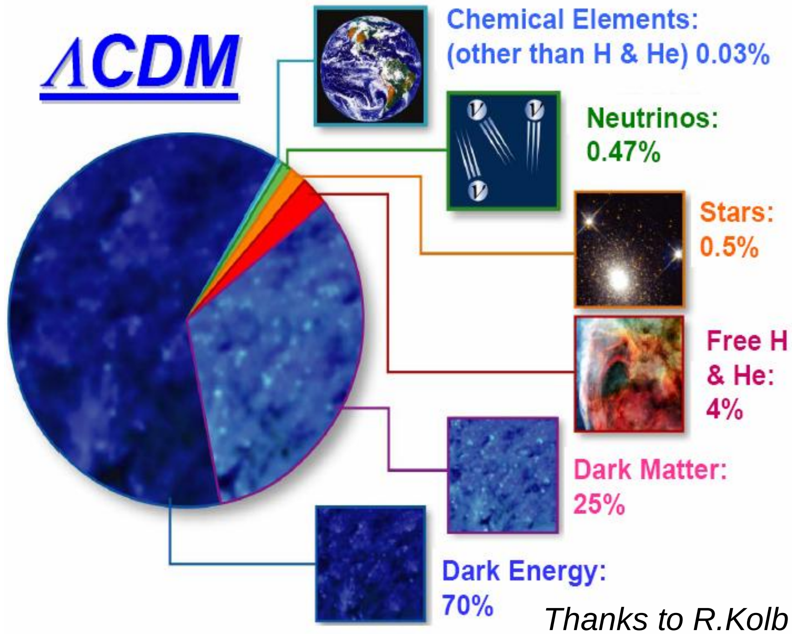
Outline

- Open questions in the Standard Model
  Supersymmetry, a possible answer
- CDF at Tevatron
  Overview of the Silicon detector
- "Trilepton" Analysis
  Prospectives for discovering SUSY

Open questions in the SM

The Standard Model is theoretically incomplete



Thanks to R.Kolb

- Hierarchy problem
- Unification
- Dark Matter

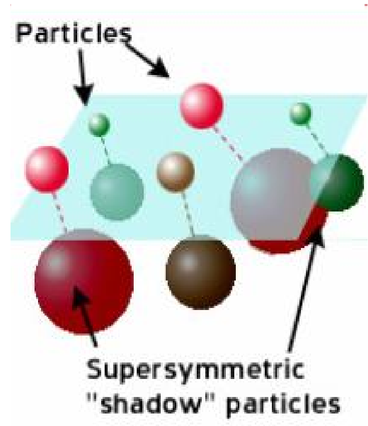
    weakly interacting particle

    mass ~ 0.1-1 TeV

Need a theory for Physics BSM!

Supersymmetry

Symmetries work well in Physics!



- New spin based symmetry

  SM fermion (boson) ⇔ boson (fermion)

- Minimal SuperSymmetric SM (MSSM)

  mirror spectrum of particles

  enlarged Higgs sector (two doublets with 5 physical states)

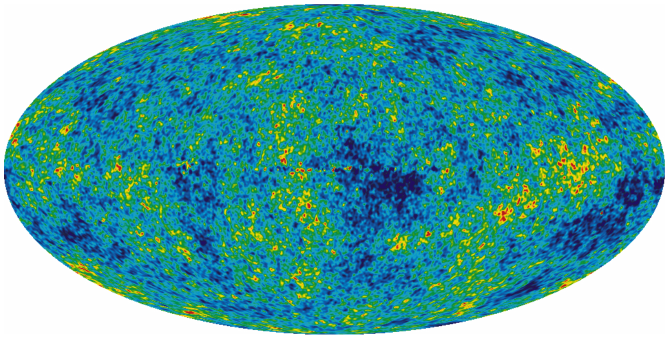
$[u, d, c, s, t, b]_{L,R}$	$[e, \mu, \tau]$	$[\nu_{e,\mu,\tau}]$	Spin $\frac{1}{2}$
$[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}]_{L,R}$	$[\tilde{e}, \tilde{\mu}, \tilde{\tau}]$	$[\tilde{\nu}_{e,\mu,\tau}]$	Spin 0
g	$W^{\pm}, H^{\pm}$	$\gamma, Z, H_1^0 H_2^0$	Spin1/Spin 0
$\tilde{g}$	$\tilde{\chi}_{1,2}^{\pm}$	$\tilde{\chi}_{1,2,3,4}^{0}$	Spin $\frac{1}{2}$

SUSY can answer the questions

SUSY can provide an excellent candidate for Dark Matter

$R = (-1)^{2j+3B+L}$

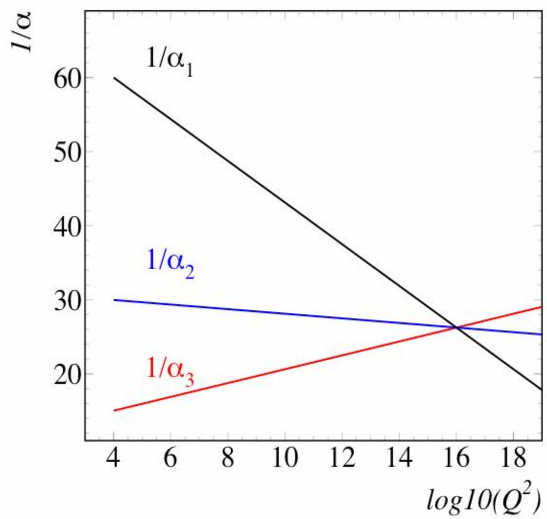
- LSP is stable if R-parity is conserved
- LSP is typically lightest neutralino
- Current mass limit > 43 GeV
- Abundance of neutralino matches Dark Matter density in the Universe



Thanks to L.Page

Moriond 2006

SUSY solves the hierarchy problem and provides gauge unification



We haven't observed superparticles yet ⇒ Supersymmetry must be a broken symmetry

Symmetry breaking

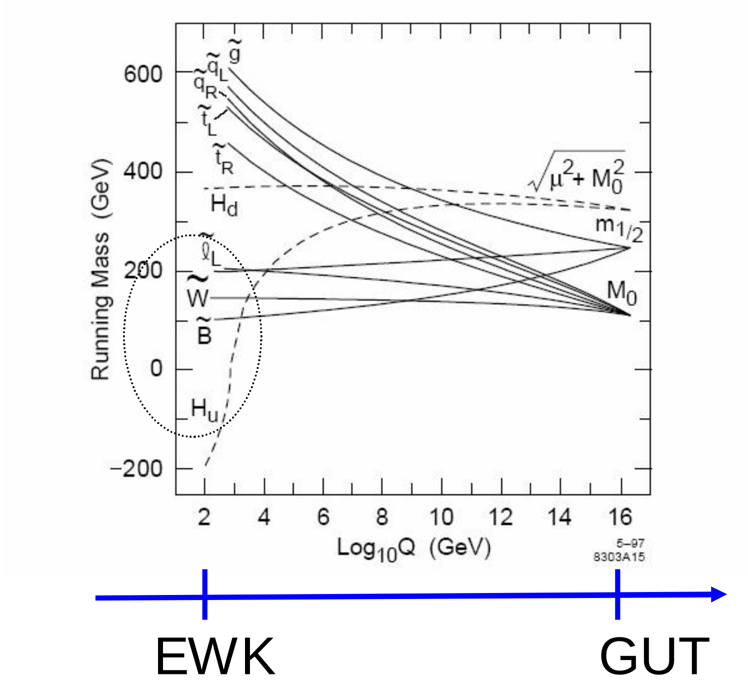
- MSSM, $L_{susy} \rightarrow L_{susy} + L_{soft}$
- more than 100 free parameters
- no knowledge of how and where the breaking occurs
- choose a model !

mSUGRA

- New superfields in “hidden” sector
- Interact gravitationally with MSSM
- Soft SUSY breaking

5 parameters at GUT scale

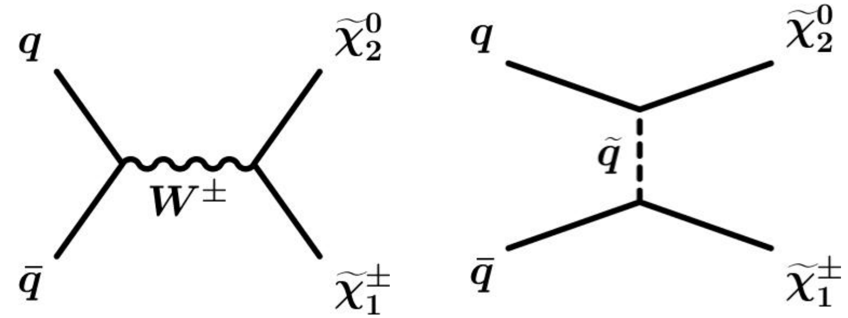
1. Unified gaugino mass $m_{1/2}$
2. Unified scalar mass m_0
3. Ratio of H_1, H_2 vevs $\tan\beta$
4. Trilinear coupling A_0
5. Higgs mass term $\mathrm{sgn}(\mu)$

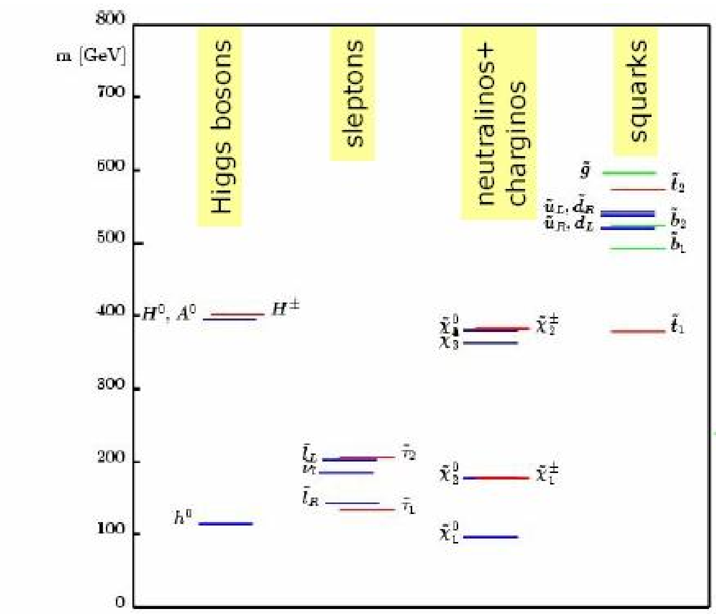


Phenomenology at TeV

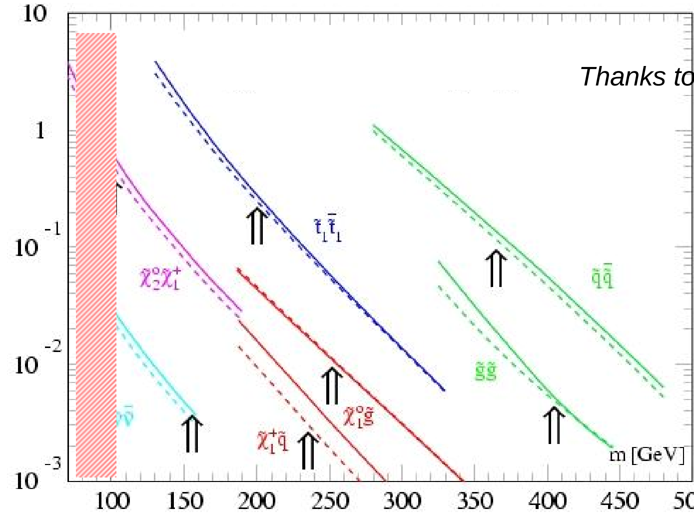
Charginos and Neutralinos expected to be light !

• Pair production at collider





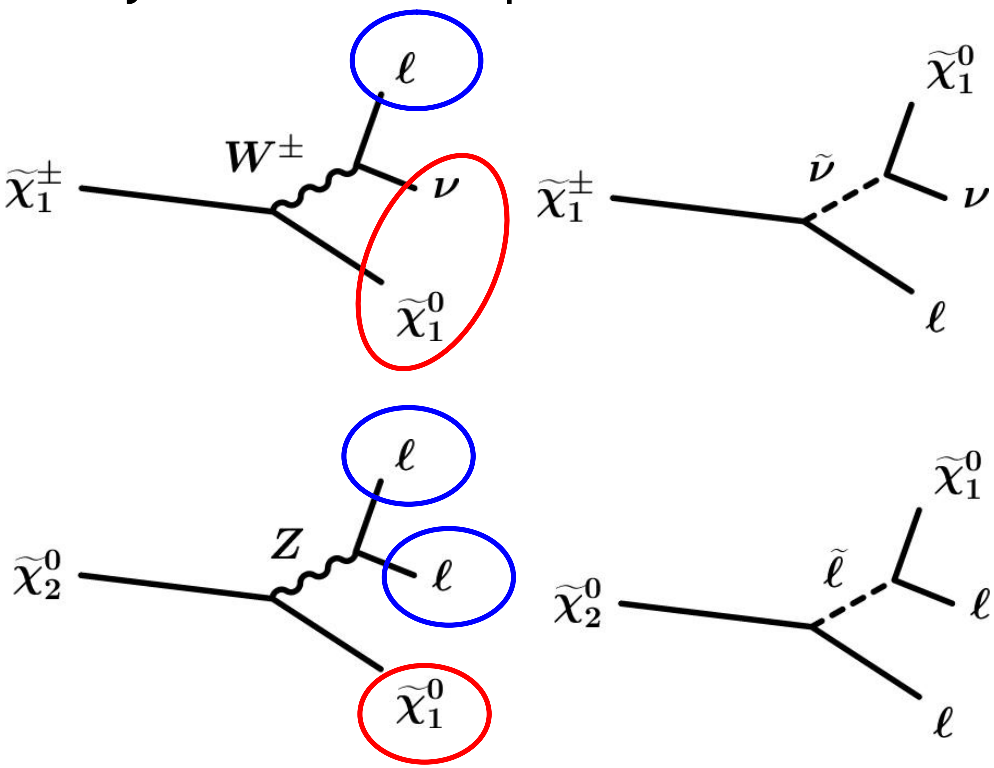
LEP II chargino mass > 103.5 GeV



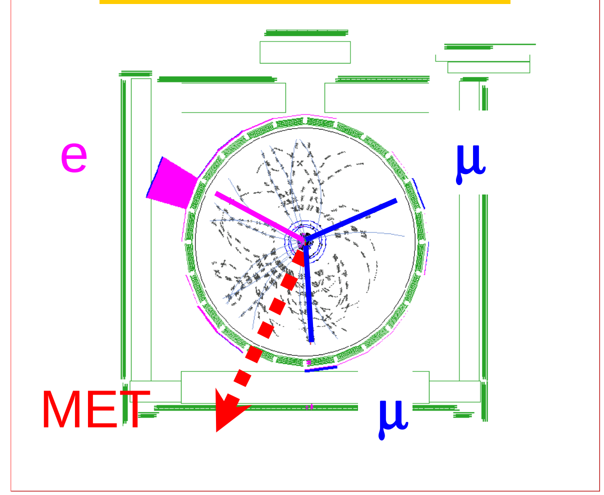
If $1fb^{-1}$ collected, 500 SUSY events !!

Phenomenology at TeV (cont'd)

Decay chain into SM particles & LSP



Golden Mode

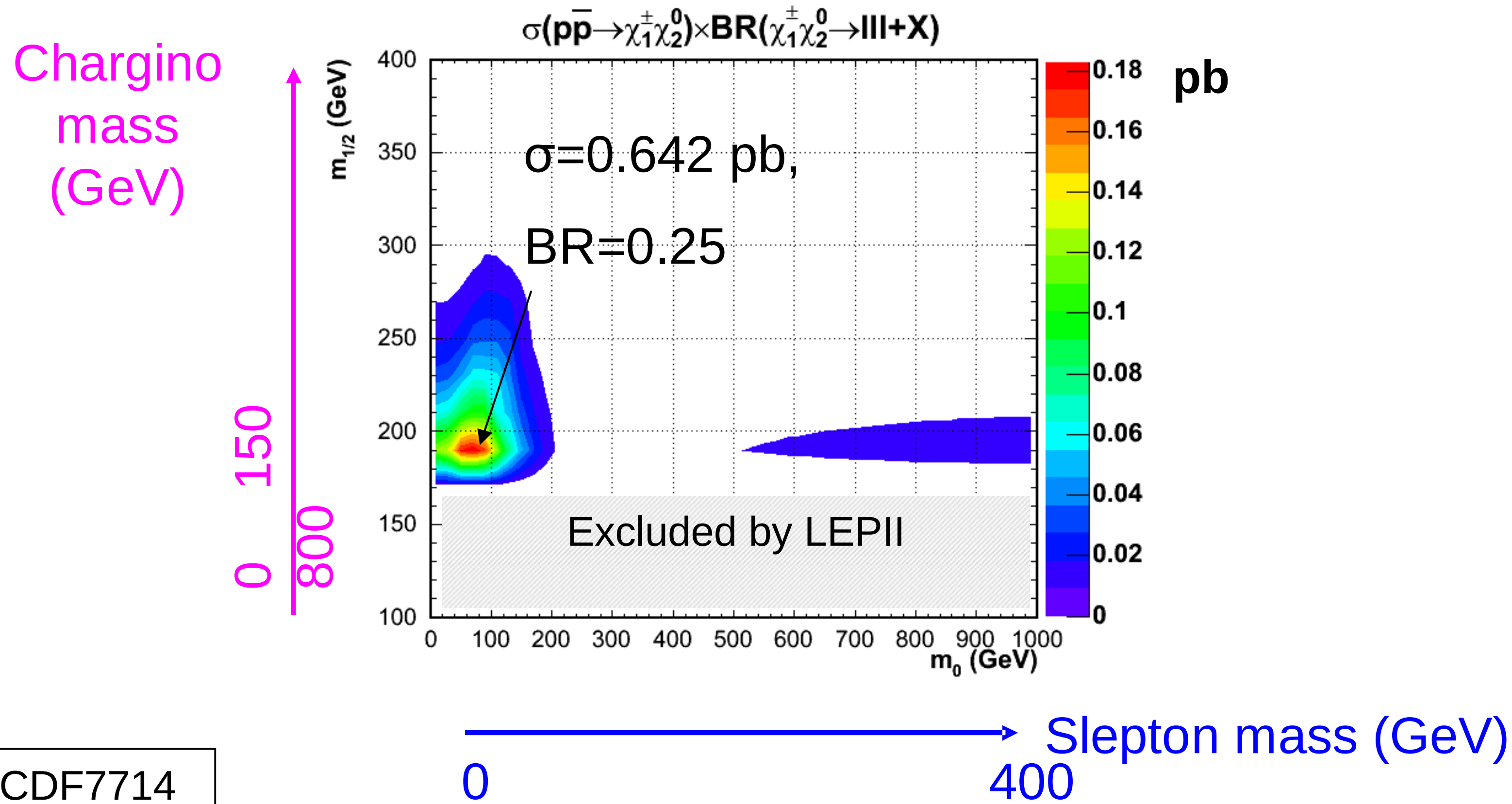


Striking signature at Hadron Colliders
THREE LEPTONS AND MISSING TRANSVERSE ENERGY

Sensitivity

Best sensitivity for low $m_{1/2}$ and low m_0

- Chargino mass ~ slepton mass with high BR into sleptons



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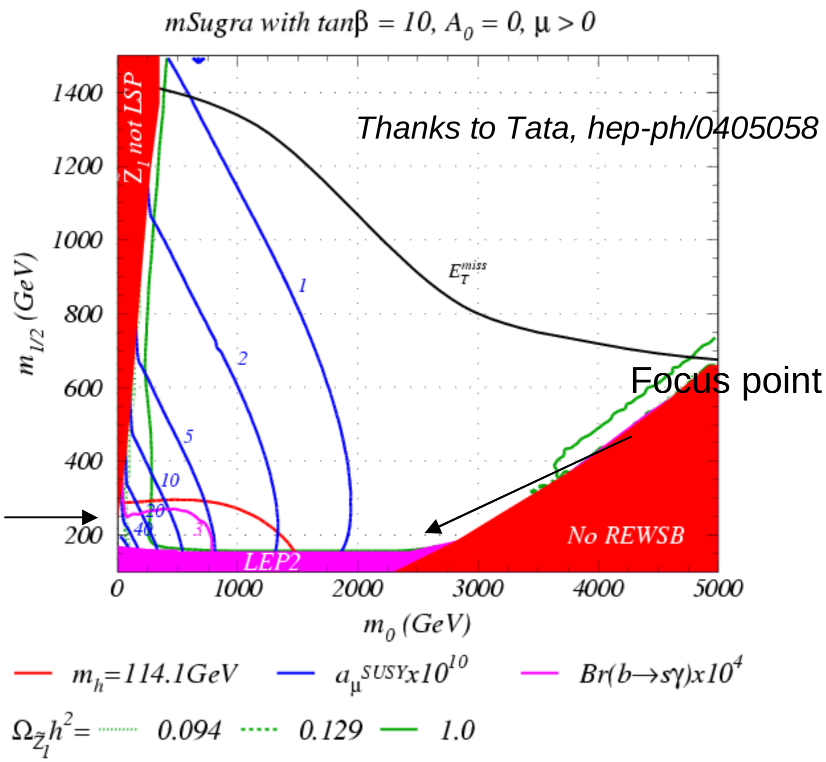
Indication from SM ?

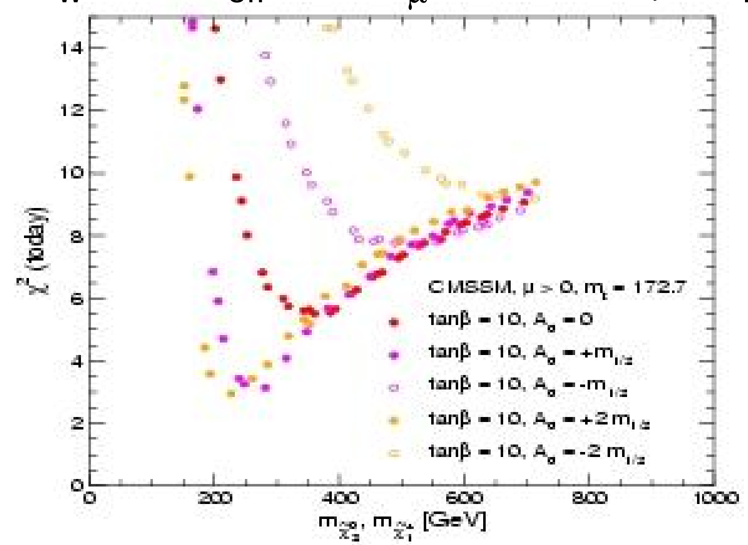
Best sensitivity in the region preferred by SM measurements and astrophysics results

- Other less constrained models already proposed (NUHM,…)

Bulk



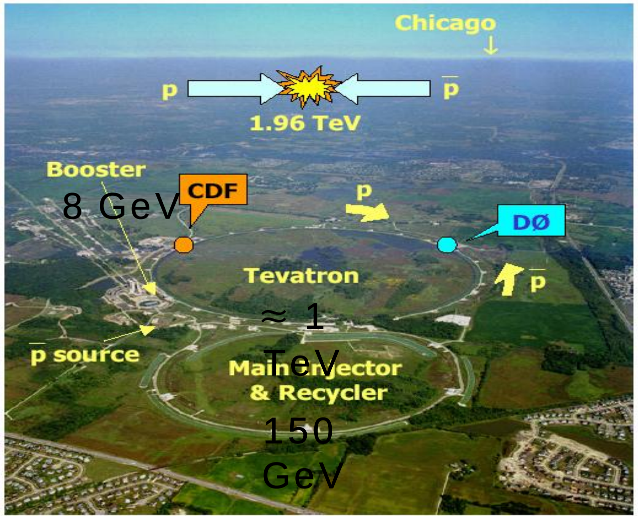
M_W, $\sin^2\theta_{eff}$, $(g-2)_\mu$, BR($b\to s\gamma$), m_h

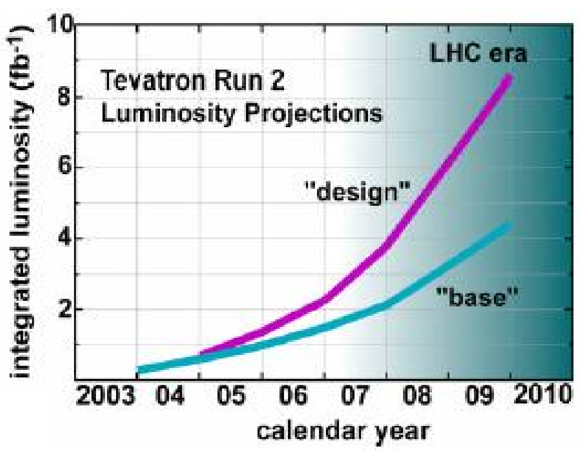


Thanks to S.Heinemeyer et al.

Hep-ph/0602220

The Tevatron collider





The Energy Frontier

- Proton-antiproton collider
- Δt = 396 ns
- Center of mass energy $\sqrt{s}$ = 1.96 TeV
- Latest record luminosity on Jan 6th

$1.7 \cdot 10^{32}\ cm^{-2}s^{-1}$ (x 10 Run I)

⇒ Demands capability to handle multiple interactions (2/3 per event)

Delivered more than 1 fb^{-1} (x 10 Run I)

Expected 4-8 fb^{-1} by 2009

⇒ Demands radiation hardness

The CDF detector @ Tevatron

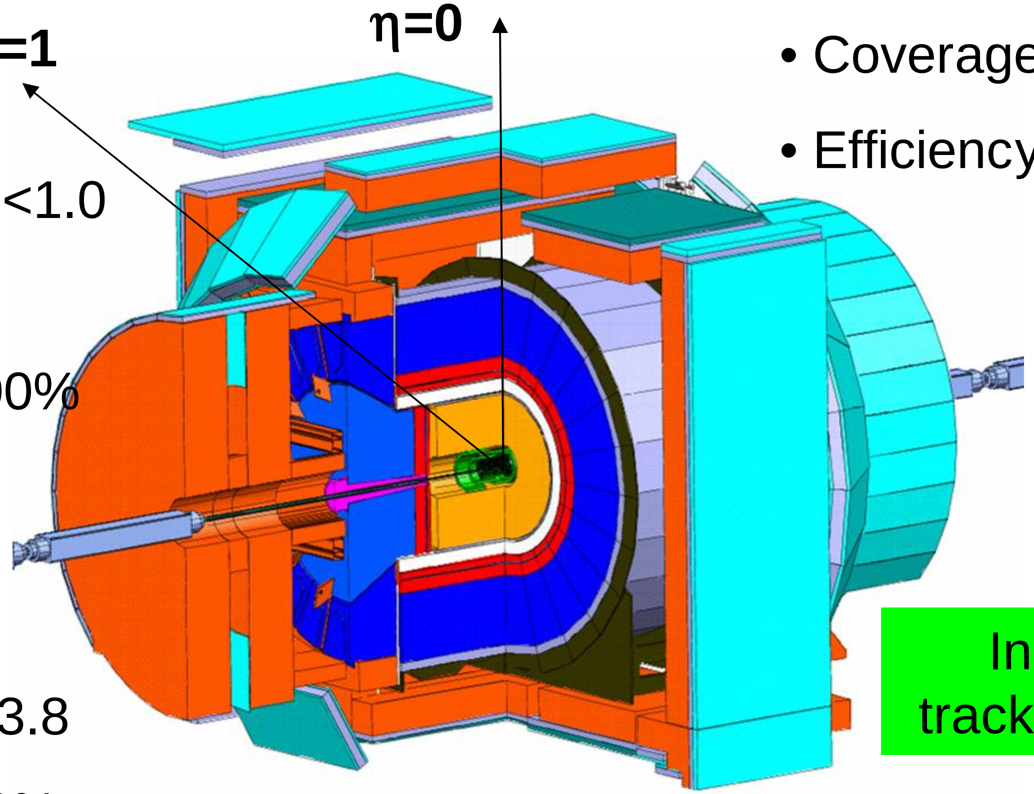
B field: 1.4 T

Muon system

- Basic coverage |η|<1.0
- Extends to |η|<1.5
- ID efficiency 80-100%

η=1

η=0



Drift chamber

- Coverage |η|< 1.0
- Efficiency 90 %

Em Calorimeter

- Coverage to |η| < 3.8
- ID efficiency 80-90%

Had Calorimeter

Inner tracker (Si)

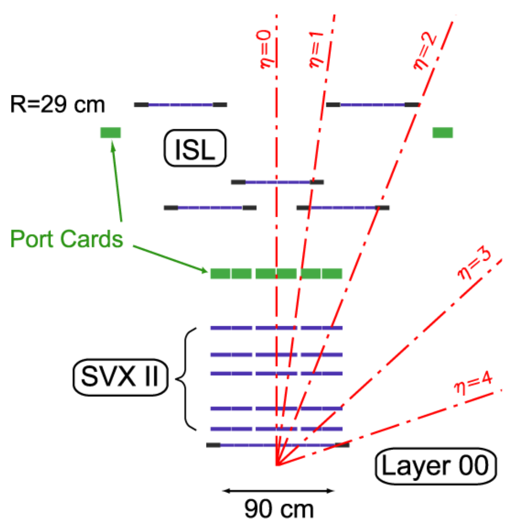
- Coverage |η|< 2.0
- Efficiency ~ 90%

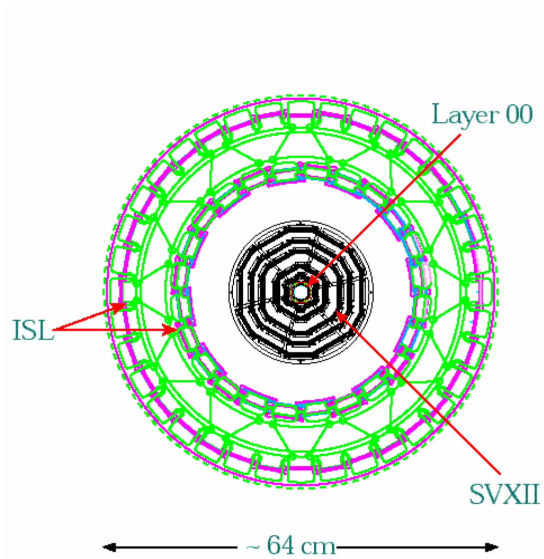
Overview of the Silicon Detector

Optimal spatial coverage and redundancy

- 6 m^2 of single/double sided microstrip silicon
  - Largest (operating) silicon detector in the world!
- Coverage up to $|z| = 0.43$ m

High precision hit resolution (down to 10 μm)

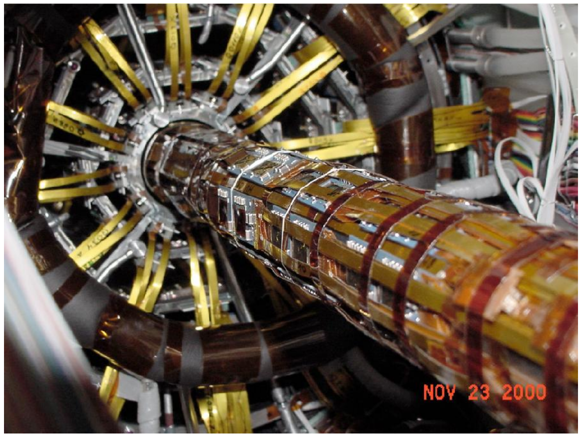




ISL
- 20.0 < r < 28.0 cm
- 2 layers (rφ-rz)
- Forward tracking

SVXII (SVX)
- 2.44 < r < 10.6 cm
- 5 layers (rφ-rz)
- 3D micro-vertexing
- L2 trigger (B-physics)

L00 Detector



Challenging technology ("LHC like") to withstand high luminosity

- rad-hard bulk & guard-ring structure
- high V_{dep} (>130V), high V_{bkg} (>1000V)

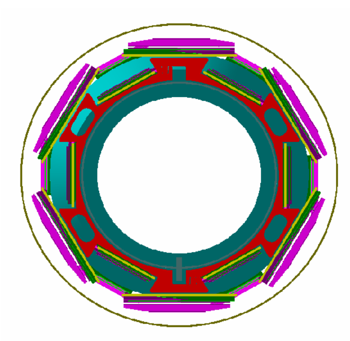
.. and to provide hit resolution in high track multiplicity environment

- 25(50) μm (readout) pitch sensors

Technology used in future upgrades

Challenging design

- two SS layers on the beam pipe
- active cooling
- electronics at large z (up to 40cm apart)



Radiation damage

Lattice damage is displacement of silicon atoms or impurities and generates “deep” energy states

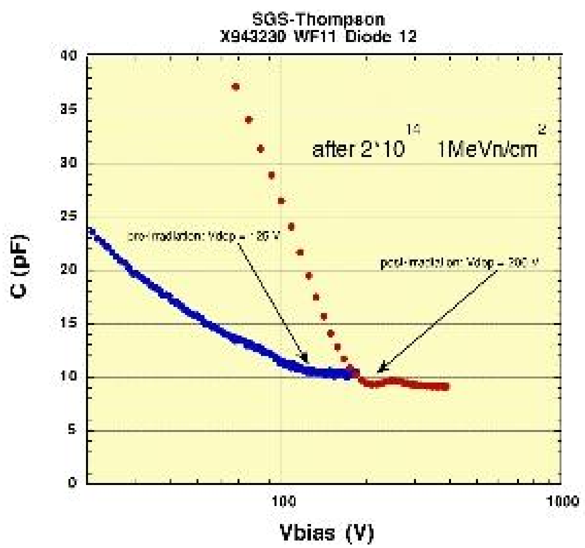
- Increases leakage current ⇒ shot noise
- Bulk type “inversion” ⇒ change depletion voltage

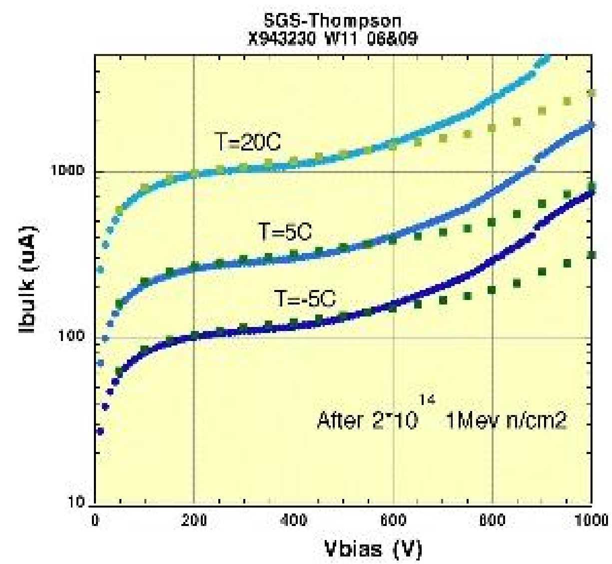
Surface damage is generation of e^+e^- in the silicon dioxide

- Reduces interstrip isolation ⇒ charge sharing reduces resolution

Expected life time ~ 8 fb^{-1}

A.Canepa, CDF5301

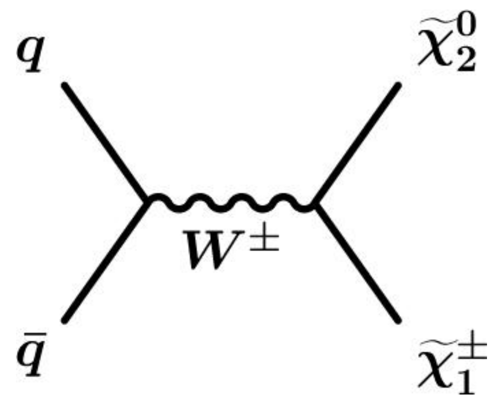




The SEARCH

New physics appears as

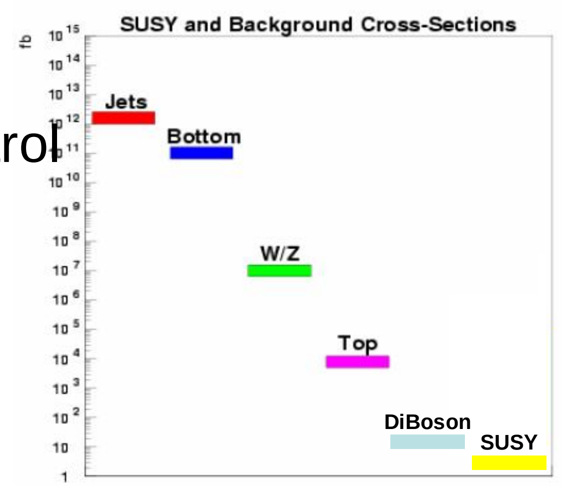
- Deviations from SM predictions
- New particles production



- Expect very small signal from New Physics

  ⇒ design efficient selection criteria for detecting NP and suppress SM

  ⇒ understand the detector resolution (“control regions”)

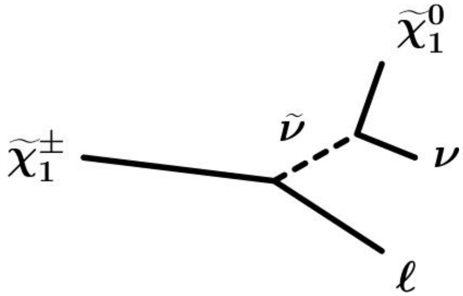


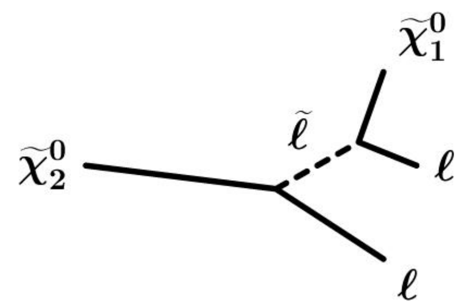
- Investigate the “signal region” ONLY when confident in background estimate

Analysis strategy

CDF achieves higher acceptance by combining several analyses

MODE	TRIGGER PATH
μμ + e/μ	High p_T Single Muon
μe + e/μ	High p_T Single Muon
ee + e/μ	High p_T Single Electron
μμ + e/μ	Low p_T Dilepton
ee + track	Low p_T Dilepton
Like Sign e/μ	High p_T Single Lepton





• the analyses based on first and second lepton generations are sensitive to low tanβ scenarios

• the analysis accepting an isolated track is sensitive to high tanβ scenarios

Standard Model background

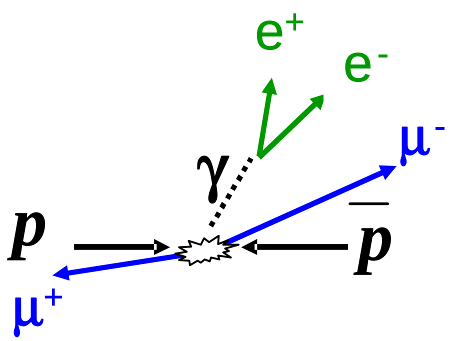
Drell Yan

& misidentified hadron (“fake” lepton)

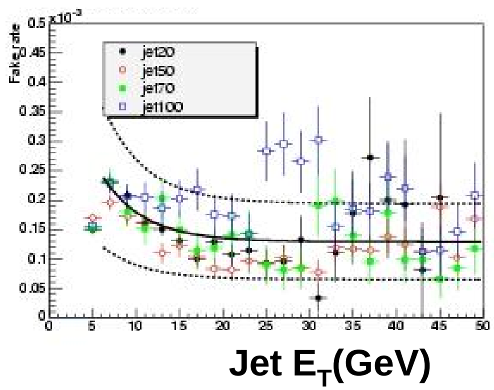
& electron from γ conversions

& misidentified track (“fake” track)

- high p_T isolated leptons
- MET due to detector resolution
- Low jet activity



Fake rate for electrons

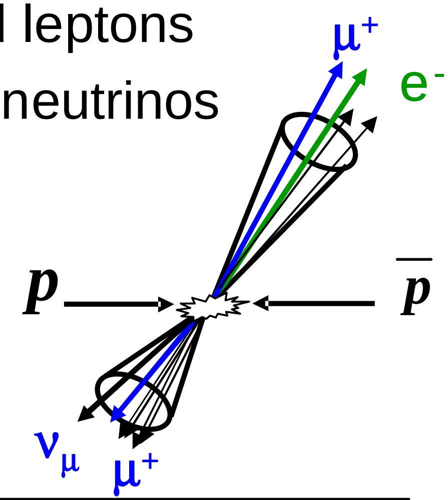


Diboson (WZ, ZZ, Wγ)

- High p_T isolated leptons
- MET due to neutrinos
- Low jet activity

QCD

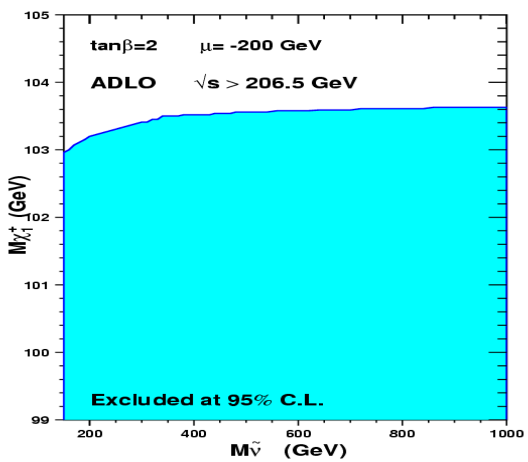
- Low p_T leptons
- Non isolated leptons
- MET due to neutrinos

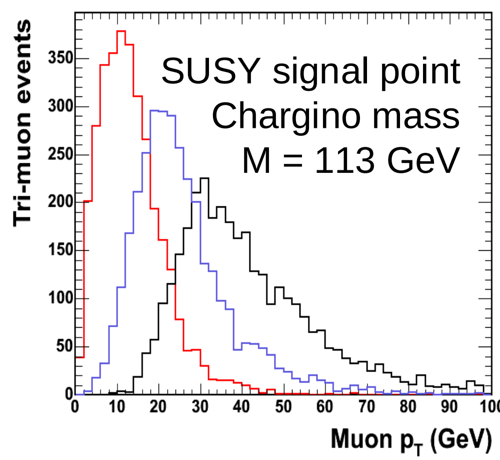


The μμ + eμ analysis

We search for SUSY in events with two muons and one additional lepton (e/μ)

- Leading muon p_T proportional to $\Delta m \equiv m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^{0})$
- LEPII limits on mass $m(\tilde{\chi}_1^{\pm}) > 103.5\text{GeV}; \quad m(\tilde{\chi}_1^{0}) > 43\text{GeV}$
- Muon p_T thresholds 20,4,4 GeV (electron E_T > 5 GeV)
- Dataset collected via the single muon trigger path (p_T > 18 GeV)





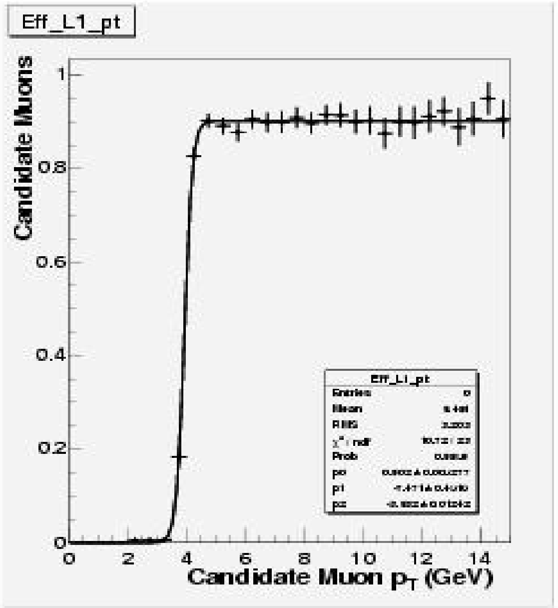
Muon trigger

Muon identified as a “good quality” track associated to segments in the muon chambers

- CDF can trigger up to $|\eta| = 1.0$ and down to muon $p_T = 1.5$ GeV
- CDF has a 3 level trigger system
- Muon trigger is based on matching the extrapolation of a track in the Central Open Tracker to hits in the muon chamber

Trigger of interest requires muon

$p_T > 6$ GeV at L1



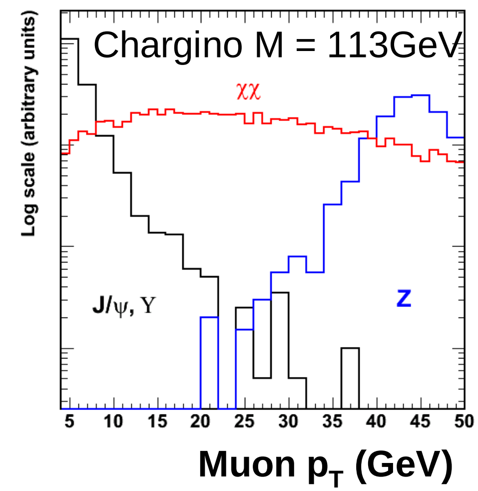
A.Canepa, CDF7196

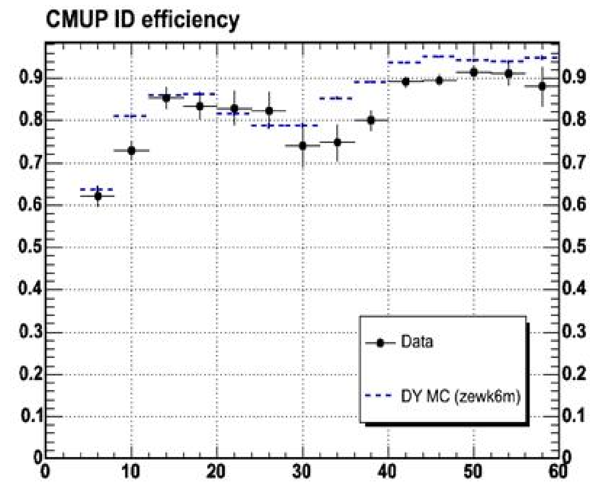
Muon identification

If chargino mass ~ 100 GeV, leptons are expected to be soft [5;20] GeV

We measure the identification probability

- Opposite sign muons with $\Delta\varphi$ > 150 deg are selected as muon candidates
- If one muon satisfies the ID criteria, the partner muon is the "probe leg"
- The probe leg is required to satisfy the ID criteria
- The background is estimated from same sign contribution (mainly decay in flight)





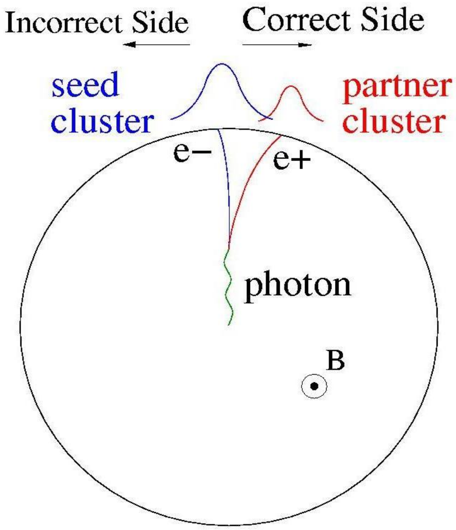
A.Canepa, CDF7197

Photon conversions

Electrons originating from photons converting in the detector are one of the major background

We measure the probability of identifying electrons from photon converting into e^+e^-

- The conversion candidates and the background candidates are selected based on calorimeter information (*)
- The removal algorithm is applied



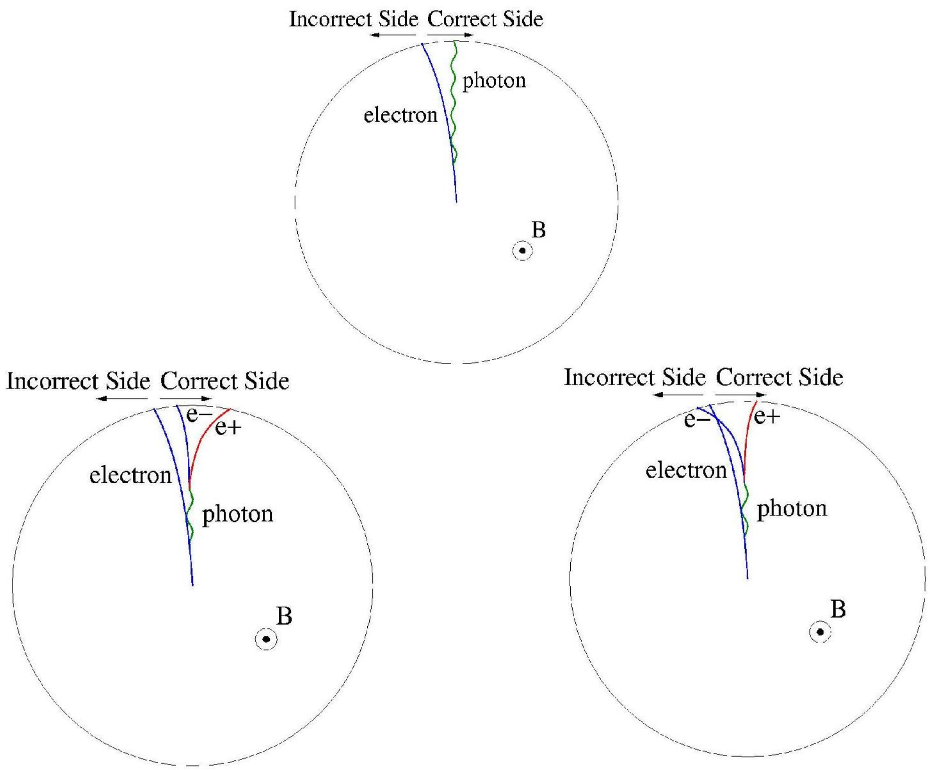
(*)

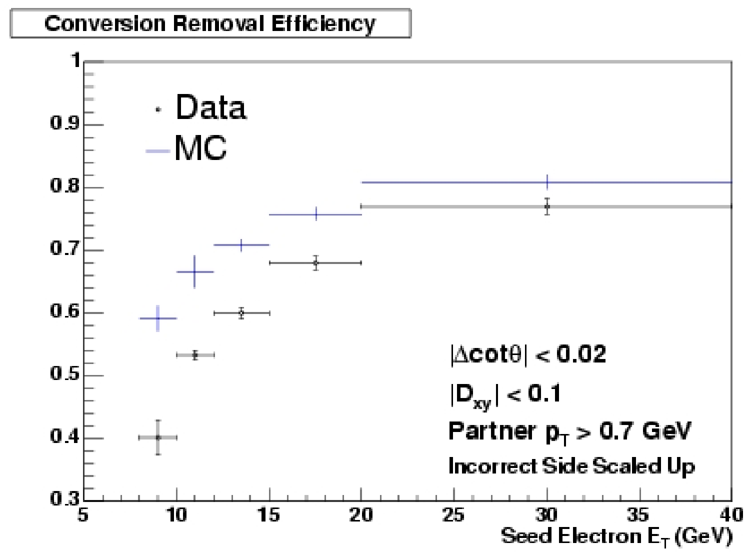
Conversion candidate: "seed" electron with partner cluster on the "correct" side

Background candidate: "seed" electron with partner cluster on the "incorrect" side

Photon conversions (cont'd)

- The background from min bias, UE and QCD is subtracted by subtracting the contribution from the "incorrect" side
- The contamination from Bremsstrahlung and "trident" events is taken into account



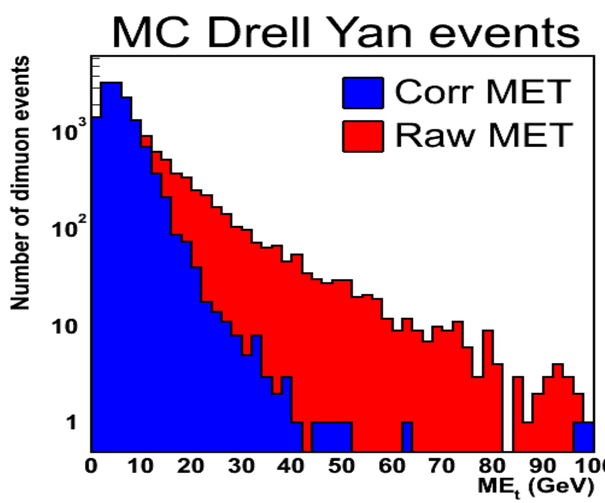


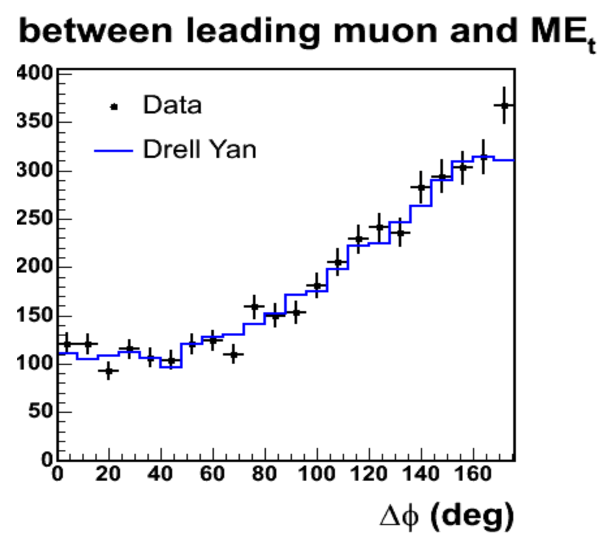
A.Canepa, CDF8073

Missing Transverse Energy

Key quantity for R-parity conserved searches

- Real MET is produced by neutral particles escaping the detector as neutrinos or neutralinos
- Calorimeter based MET must be corrected for primary vertex, additional interactions, jets (calorimeter resolution) and muons (tracking resolution)

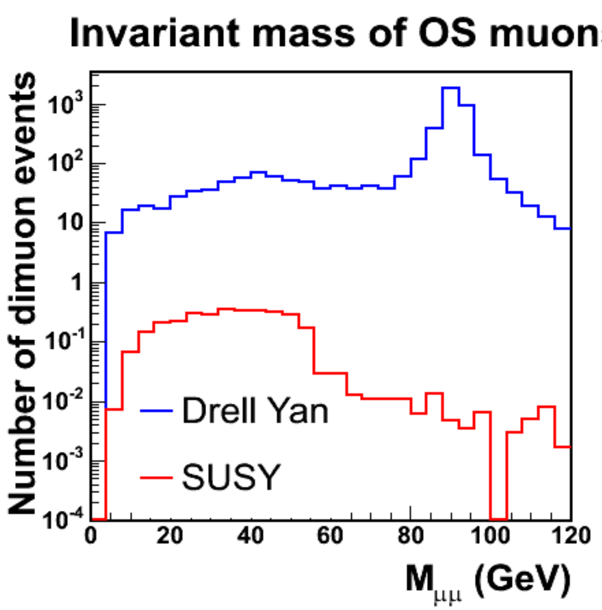


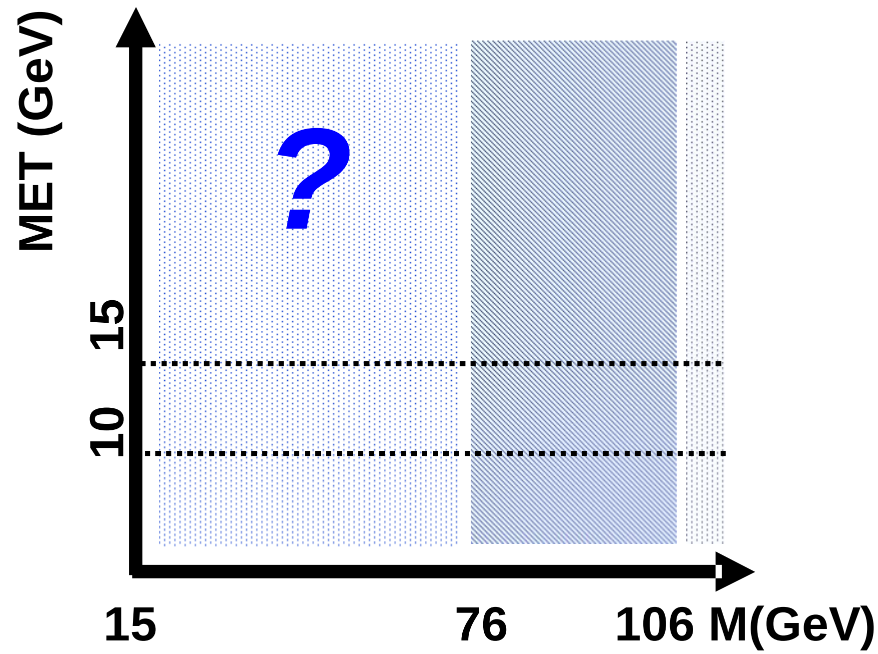


Learning from the data

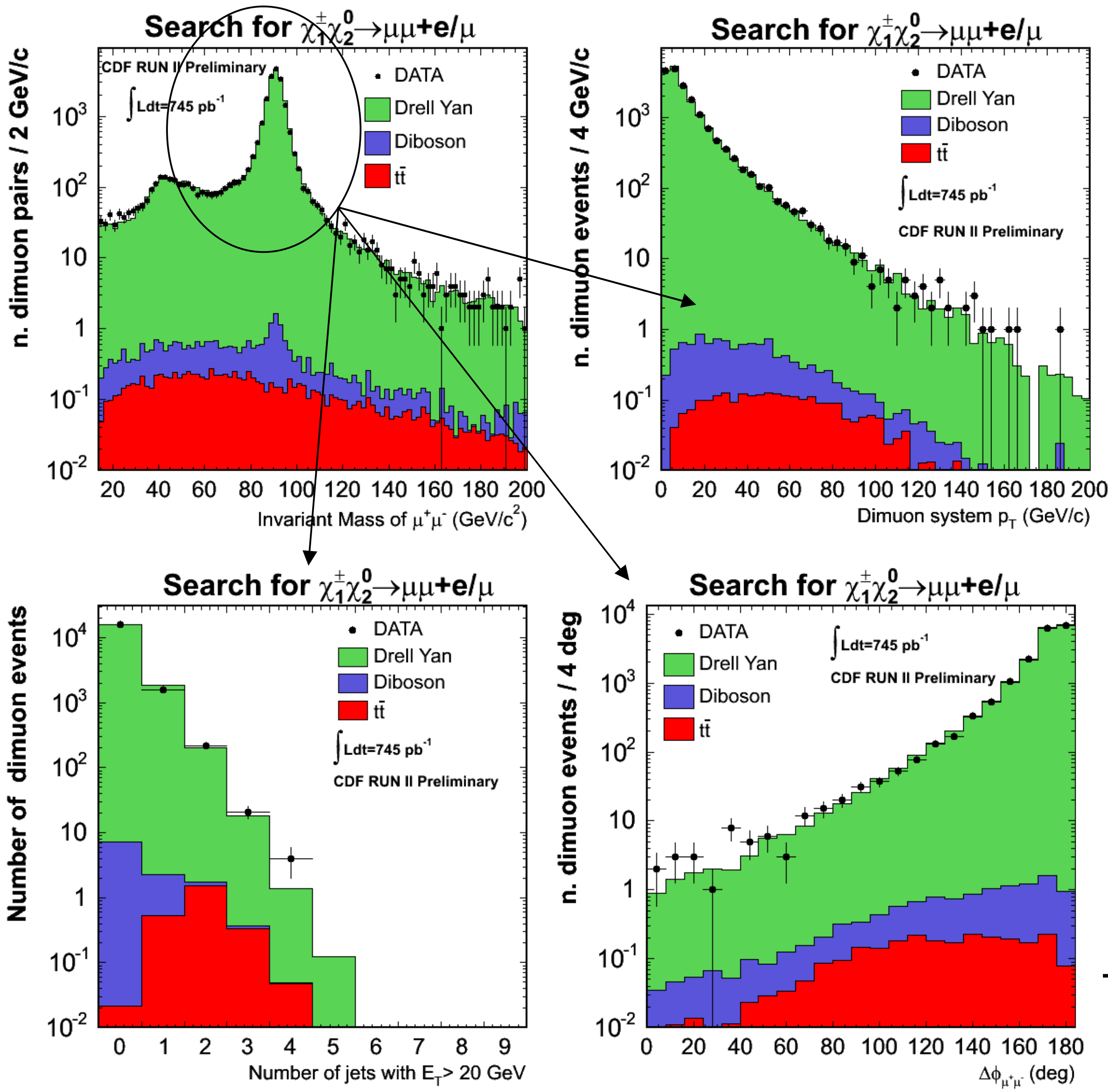
The control regions are defined according to the event selection

- Dilepton control regions, high statistics
- Trilepton control regions, “signal” like regions
- Control regions with different jet multiplicity, ISR/FSR effects





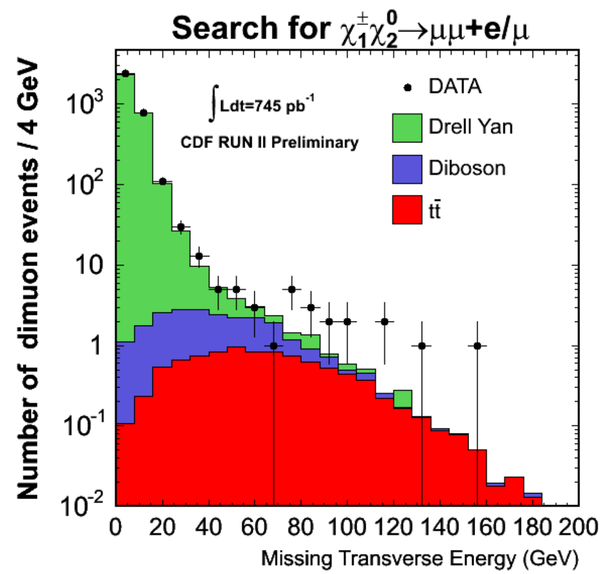
Events with two muons



Events with two muons after rejecting on-shell Zs from the dataset

SM 16231 ± 54

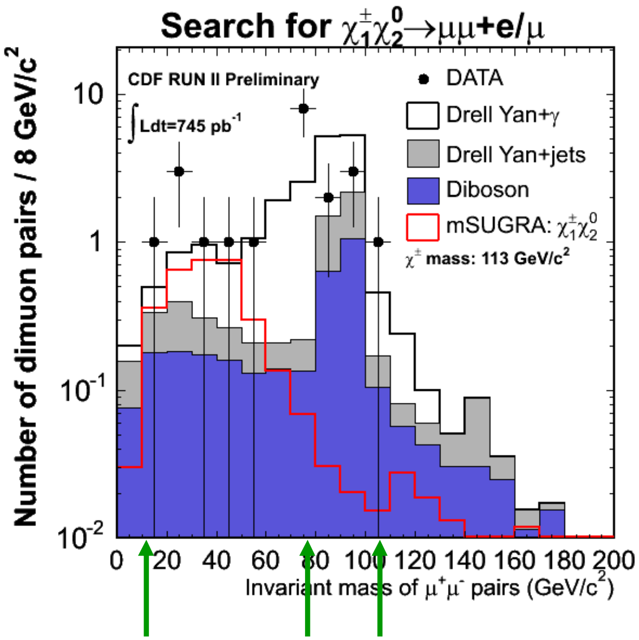
Data 15969

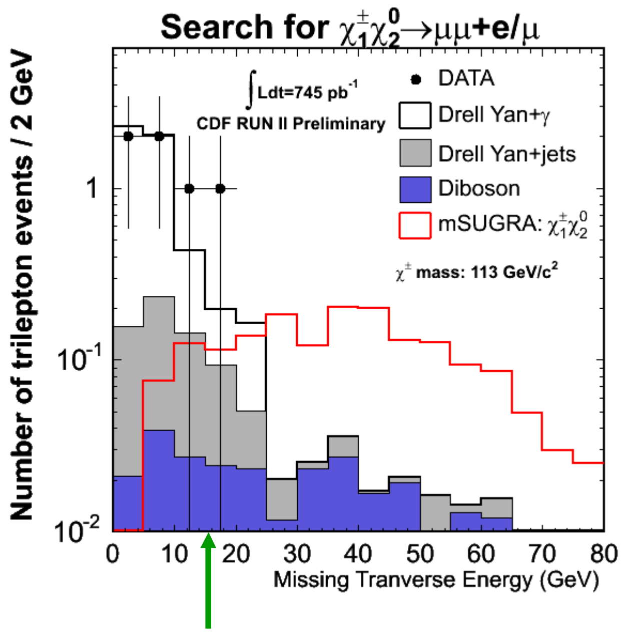


Event selection

The analysis selection criteria are applied sequentially.

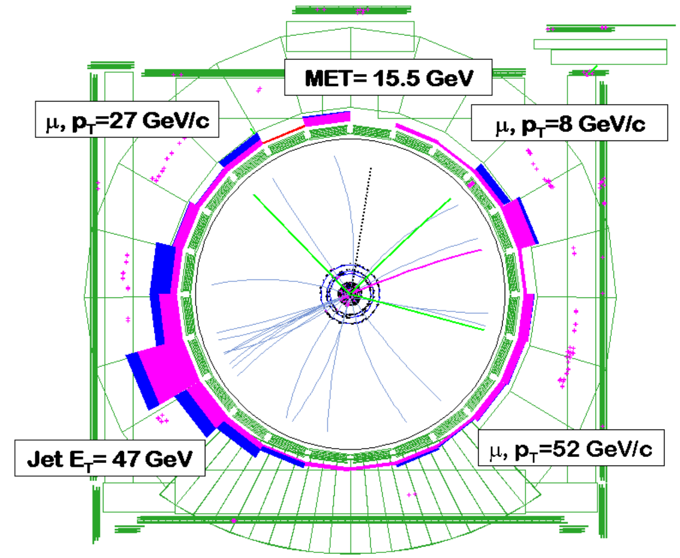
- Invariant mass of OS muons $15 < m_{\mu\mu} < 76$ or $m_{\mu\mu} > 106$ GeV
- Number of jet <2 if jet $E_T > 20$ GeV
- Missing transverse energy MET > 15 GeV





Results

PROCESS	$\mu\mu + \mu/e$
t-tbar	0.014±0.06
Diboson	0.20±0.02
DY+"fake"	0.20±0.10
DY+γ	0.22±0.11
Total SM Backg.	0.64±0.11±0.14
SUSY Signal	1.6±0.1±0.2
DATA	1



Sensitivity $S/\sqrt{B} = 2$

- Expect small signal from SUSY ⇒ Poisson statistics
- Predictions are dominated by systematic uncertainties on the SUSY signal (Lepton identification 3%, luminosity 6%)

The μe + μ/e analysis

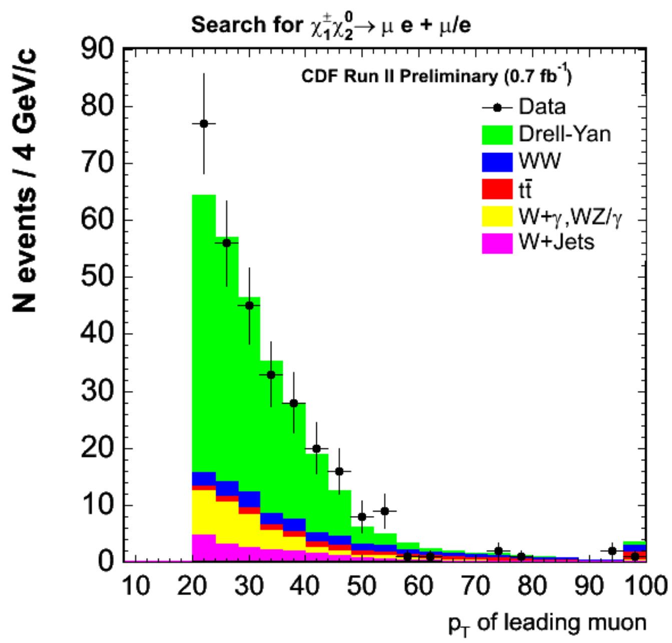
• Same selection criteria as μμ analysis but no mass requirement

⇒ Drell Yan production is reduced and diboson contribution becomes significant

• Good acceptance thanks to forward electron

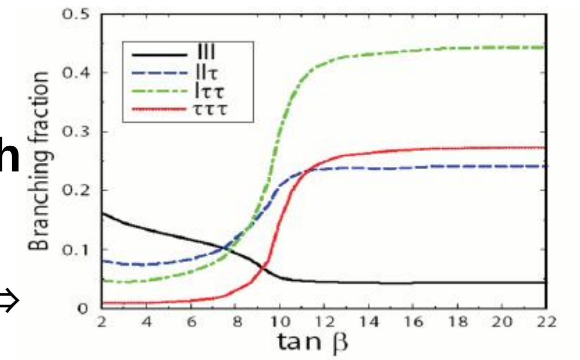
  • Dilepton selection: Tot. SM 110 ± 13; Data 118

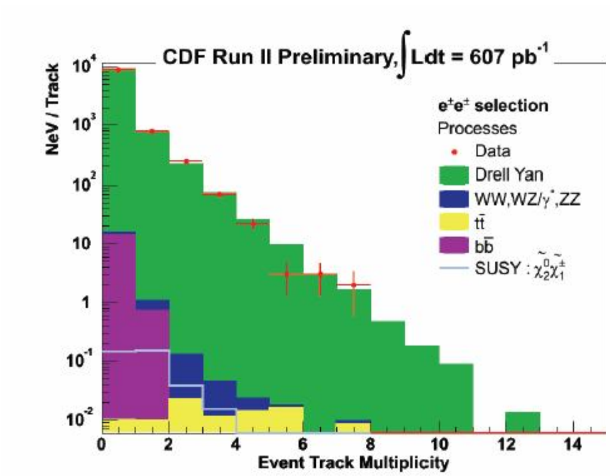
PROCESS	μe+μ/e
Diboson	0.44±0.05
DY+"fake"	0.17±0.08
DY+γ	0.14±0.08
Total SM Backg.	0.78±0.10±0.15
SUSY Signal	1.0±0.08±0.12
Observed DATA	0



The ee + track analysis

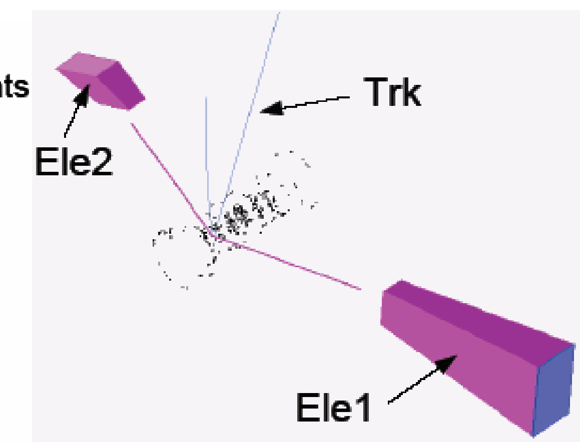
- The third object is an isolated track
  - The analysis is sensitive to prong τ decay
  - **Analysis yields up to 100% in acceptance with respect** to the ee + lepton
- Leptons originating from **τ decay are soft** $\Rightarrow$ electron thresholds $E_T > 15,5$ and $p_T > 4$ GeV





CDF Run II Preliminary, ∫Ldt = 607 pb^{-1}
Expected Signal,Background and Observed events

Sample	Expected events
Drell Yan	0.16 ± 0.12
WW+ZZ	0.17 ± 0.04
WZ/γ*	0.047 ± 0.009
tt	0.11 ± 0.07
Total Bkgd	0.49 ± 0.14
SUSY	1.21 ± 0.09
Observed	1

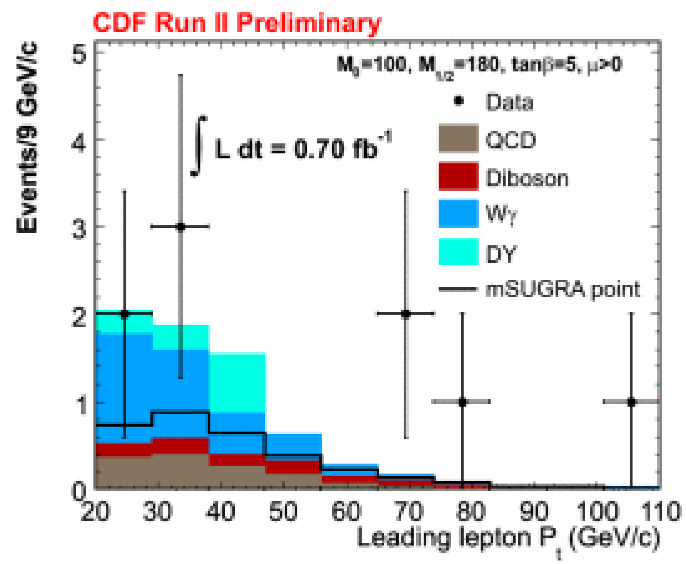


$M_0=60$ $M_{1/2}=190$ $\tan(\beta)=3$ $A_0=0$ $\mu>0$

Like Sign analysis

- The analysis is sensitive
  - chargino & neutralino production
  - gluino pair production
- The most challenging background originates from DY/W + γ
- Large MET is required: MET > 15 GeV

Mode	Obs	Predicted	$\chi\chi$ signal
ee	4	2.6 ± 0.4	0.64
eμ	5	3.5 ± 0.6	1.64
μμ	0	0.7 ± 0.1	0.91
Total	9	6.8 ± 1.0	3.19



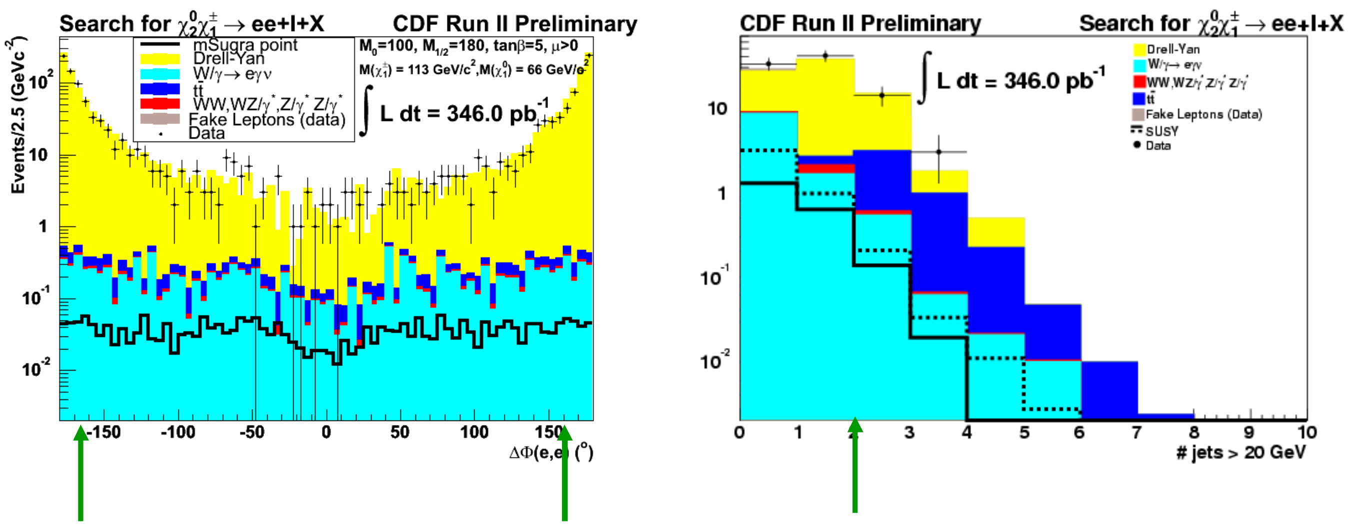
- Interesting events at high p_T
- Consistent with background prediction.

The ee +e/μ analysis

- Same selection criteria as μμ analysis

⇒ Additional angular requirement to suppress Drell Yan production

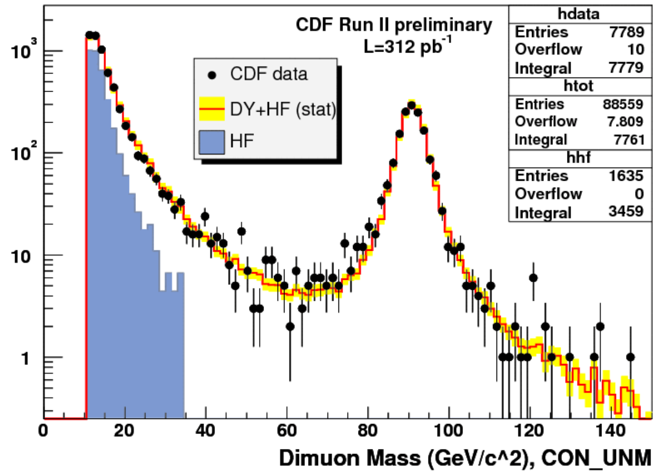
- sensitive to jet mismeasurement



Obs	Predicted	χχ signal
0	0.17 ± 0.05	0.49 ± 0.05

The $\mu\mu$ +e/μ ("low p_T" approach)

- The analysis explores a wide p_T range
  - lepton p_T thesholds is 5 GeV
- The QCD HF background becomes significant
  - data driven estimate
    - we create a HF-rich sample by requiring at least one muon with high impact parameter and we fit the HF + DY contributions to the data



Obs	Predicted	$\chi\chi$ signal
0	0.13 ± 0.03	0.17 ± 0.03

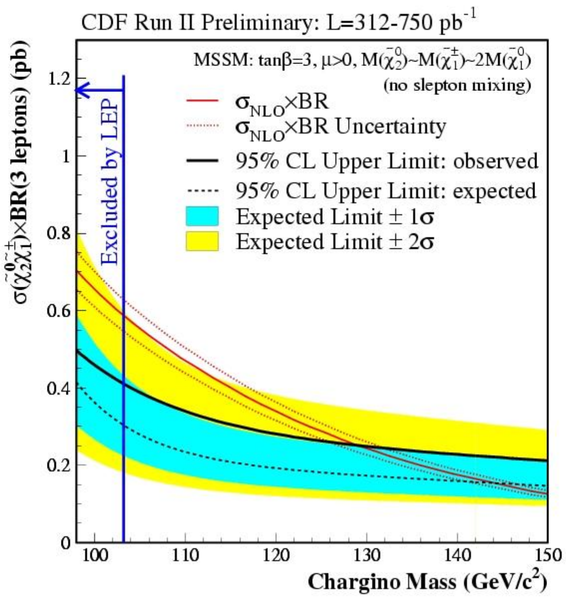
The trilepton analyses in summary

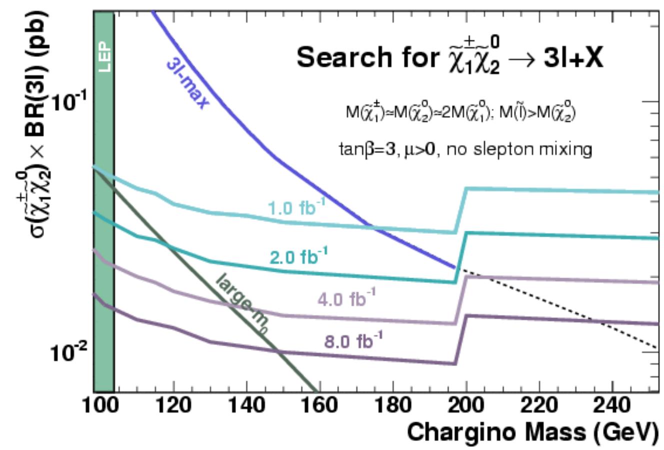
MODE	SM Backg.	SUSY	Luminosity	Data
$\mu\mu$ + e/μ	0.64±0.18	1.6	0.7 fb^{-1}	1
μe + e/μ	0.78±0.17	1.0	0.7 fb^{-1}	0
ee + e/μ	0.17 ± 0.05	0.5	0.3 fb^{-1}	0
$\mu\mu$ + e/μ	0.13 ± 0.03	0.2	0.3 fb^{-1}	0
ee + track	0.49±0.14	1.2	0.7 fb^{-1}	1
Like Sign e/μ	6.8 ± 1.0	3.2	0.7 fb^{-1}	9

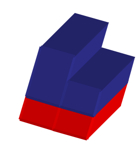
Future of trilepton @ CDF

FIRST Run II LIMIT on chargino mass at CDF

mSUGRA scenario



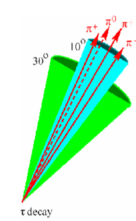




The "silver" mode ! exploring third generation

challenging search (ID ~ 50%)

high sensitivity



... at LHC ?

LHC pp collisions √s = 14 TeV

Large mass reach for DIRECT DISCOVERIES

Strongly interacting particles: LHC will see gluino squarks, H,A

Squarks/gluino cascade ⇒ Gauginos

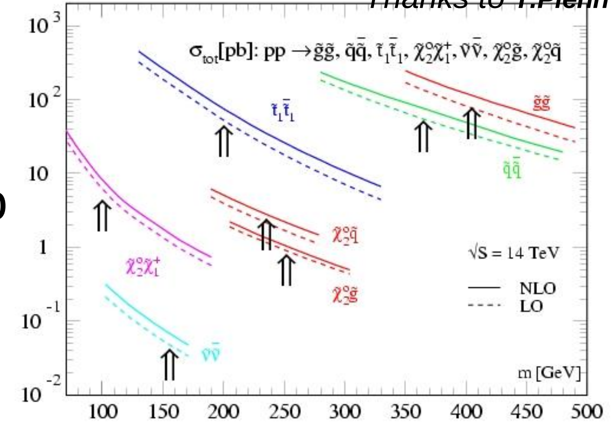
• Low S/√B

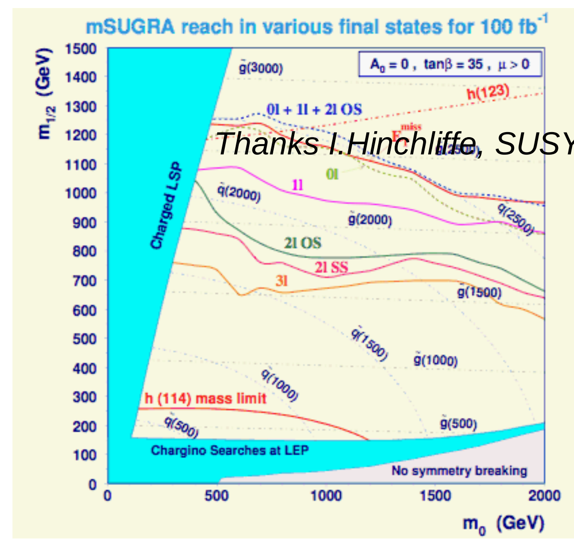
• Rare processes vetoing jets challenging when ~ 20 min bias events

If squark & gluinos too massive

The Golden Mode is the window to SUSY !!!

*Thanks to **T.Plehn***





Thanks I.Hinchliffe, SUSY05

... at ILC ?

ILC e^+e^- collisions $\sqrt{s}$ = 0.5-1 TeV

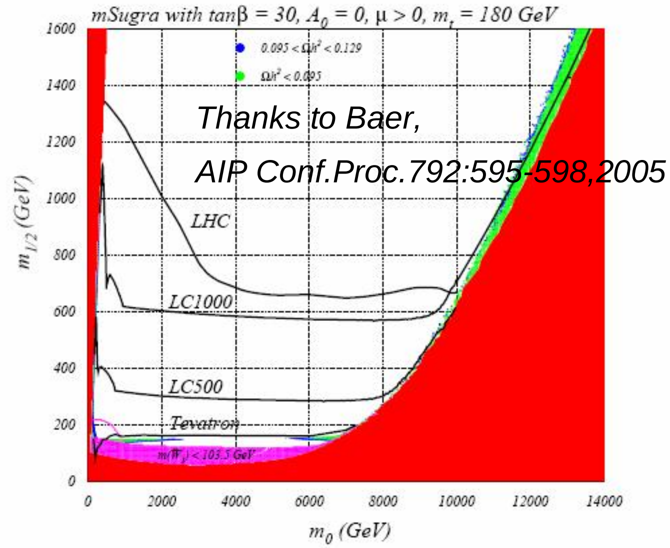
HIGH PRECISION PHYSICS

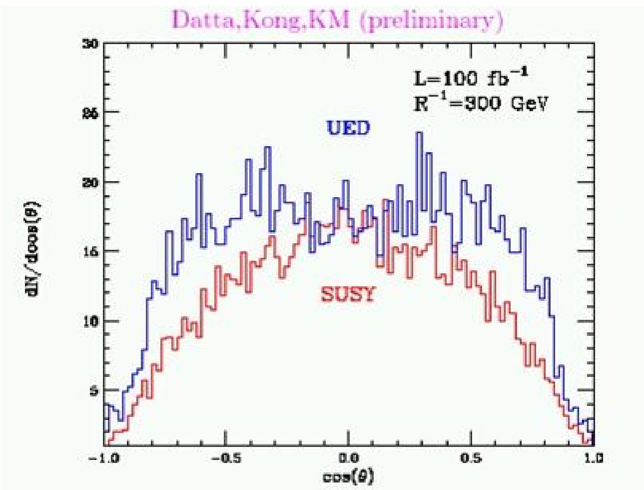
ILC optimal for weakly interacting SUSY particl

Direct pair production of charginos

- high $S/\sqrt{B}$
- well defined initial state and beam polarizatio
- clean experimental environment
- mass, spin & couplings determination

Only LHC + ILC will pin down the model for Physics BSM !!!





Summary

SUSY is a well motivated theory for physics BSM

CDF is searching for SUSY in the “Golden Mode”

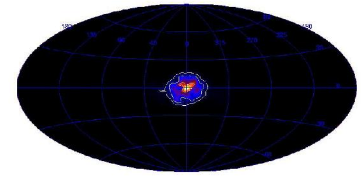
no evidence so far ….

First Trilepton result of CDF at Run II
Chargino mass m > 130 GeV

Back up slides

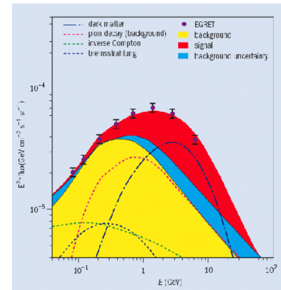
Dark Matter

• **The MeV-scale Dark Matter particle giving the 511 keV annihilation line at the galactic center**



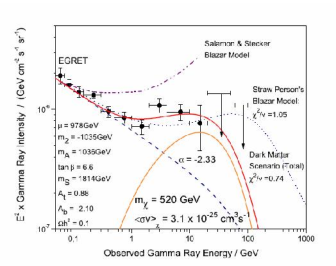
Integral

• **The 50 – 70 GeV neutralino Dark Matter particle which explains the EGRET galactic gamma ray spectrum**



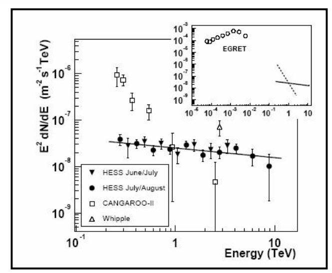
W. de Boer

• **The 500 GeV neutralino Dark Matter particle which explains the EGRET extragalactic gamma ray spectrum**



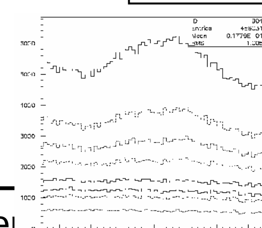
Elsässer & Mannheim

• **The 20 TeV Dark Matter particle giving the HESS signal from the galactic center**



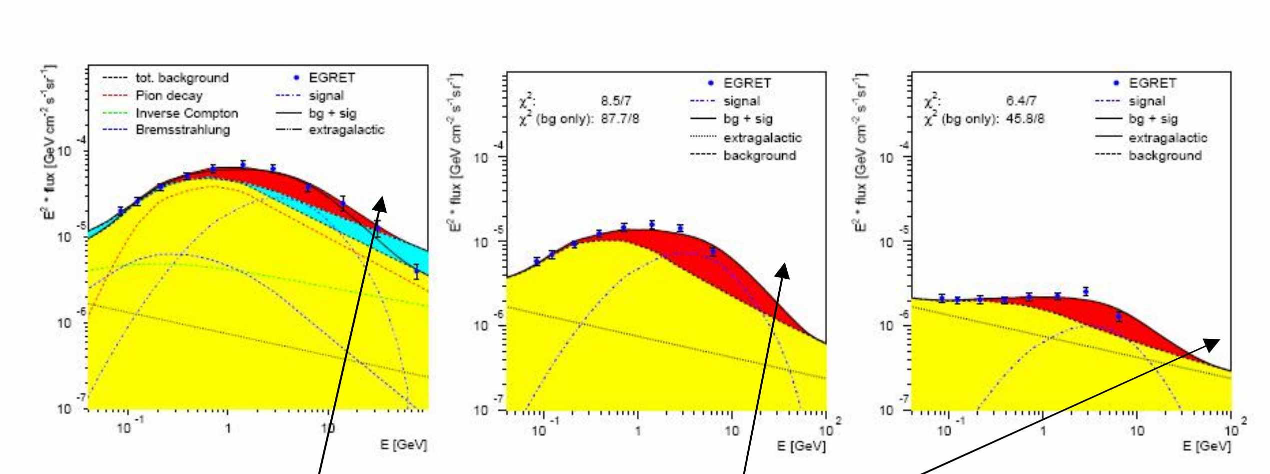
HESS

• **The few hundred GeV Dark Matter particle in Draco giving the signal in CACTUS**



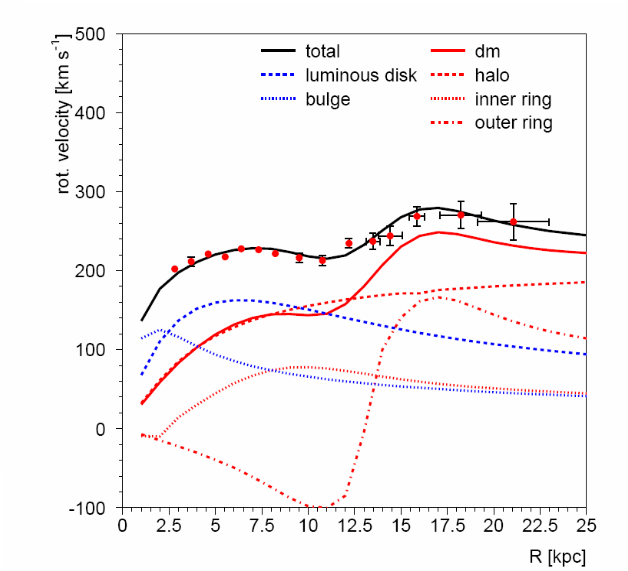
CACTUS Collab.

W. de Boer, 2003-2005



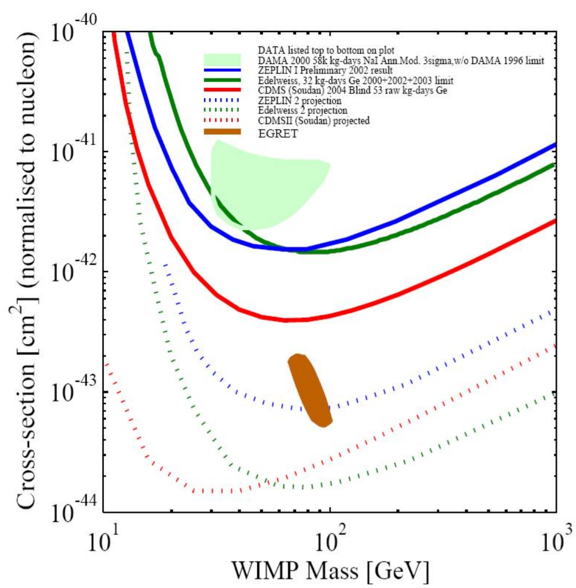
Excess of gamma-rays

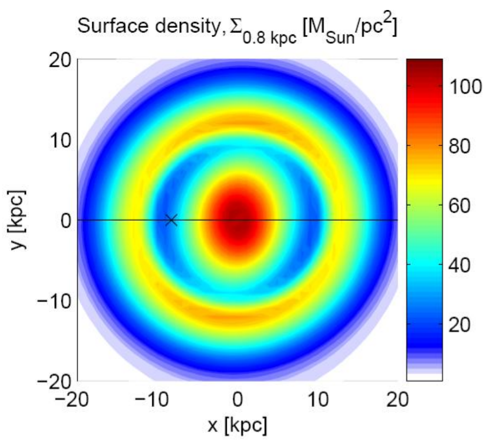
Filled by 65 GeV neutralino annihilation

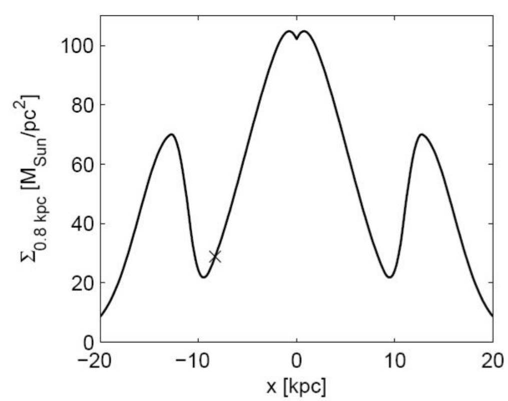


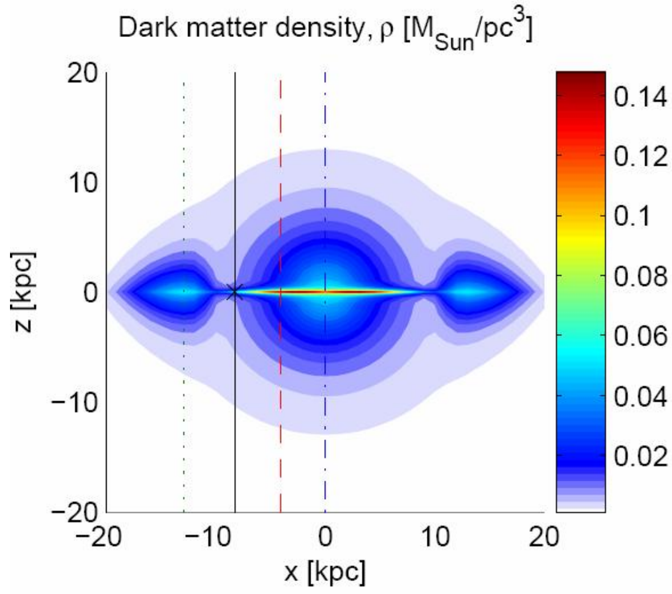
Galactic rotation curve

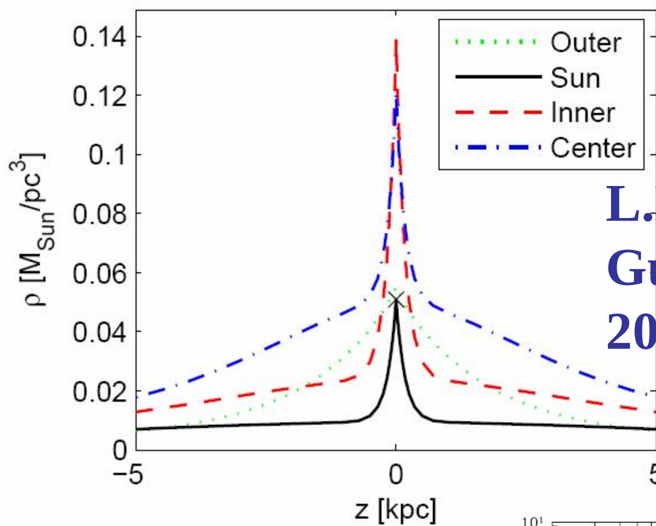
Data explained by 50-100 GeV neutralino?



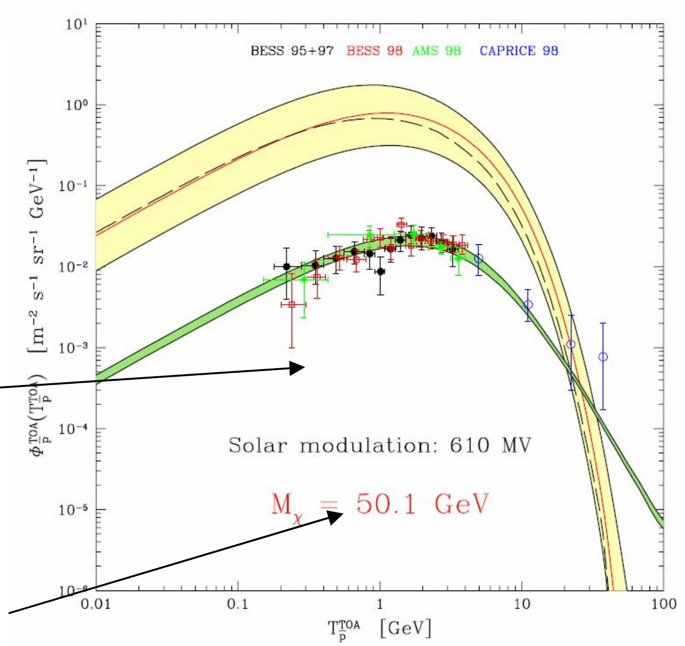








L.B., J. Edsjö, M. Gustafsson & P. Salati, 2006



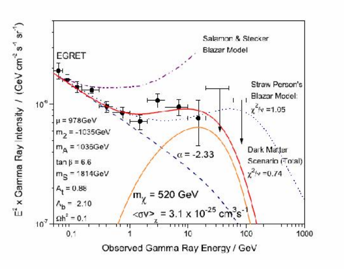
DM density concentrated to the galactic plane

Antiprotons pose a major problem for this type of model:

Expected antiproton flux from de Boer's supersymmetric models

Standard (secondary) production from cosmic rays

- **The 500 GeV neutralino Dark Matter particle which explains the EGRET extragalactic gamma ray spectrum**



Elsässer & Mannheim

EGRET points will change as GLAST resolves more AGNs

Diffuse cosmic gamma-rays

Idea (L.B., Edsjö & Ullio, 2001): Integrated gamma-signal over all large- and small-scale structure may give observable diffuse gamma-ray flux for CDM-type cuspy halos and substructure. Redshifted gamma line in favourable cases.

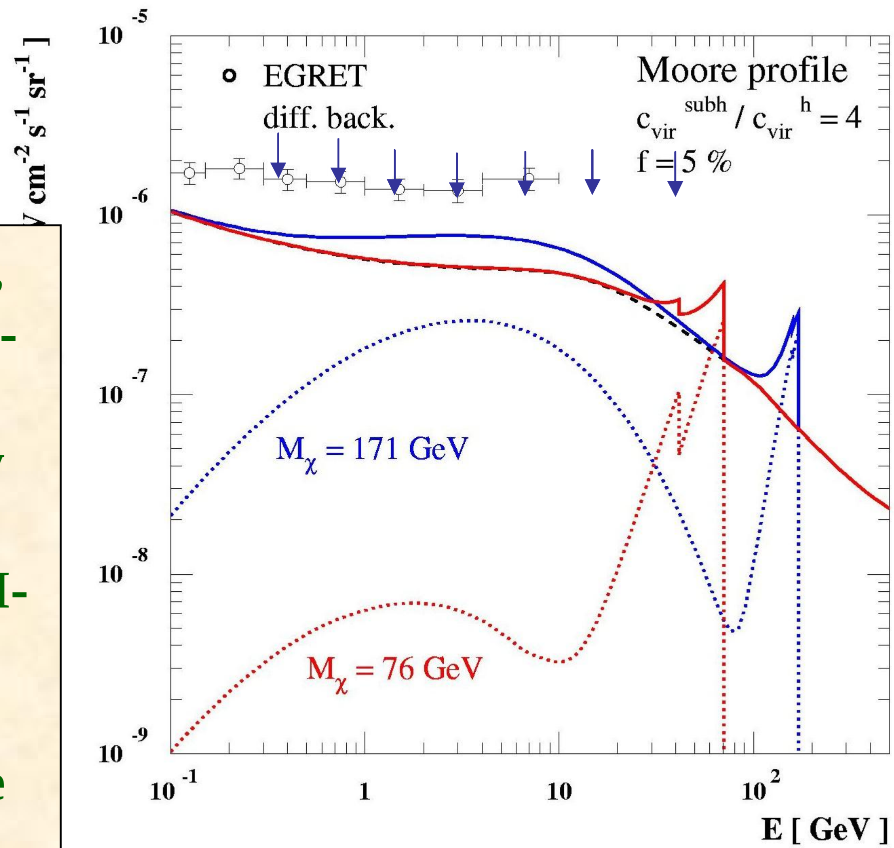
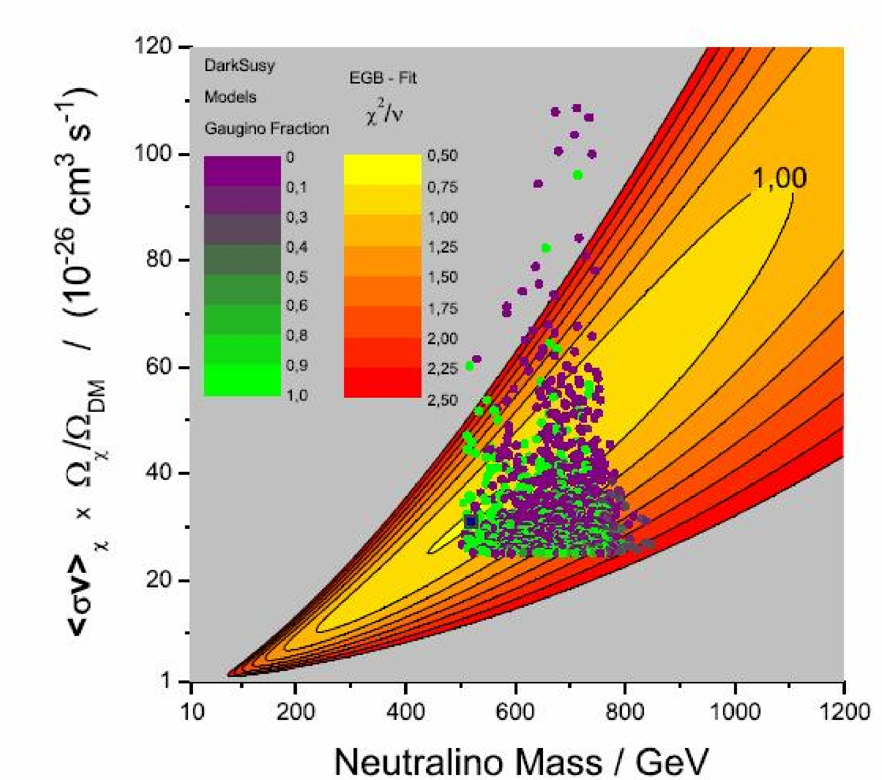
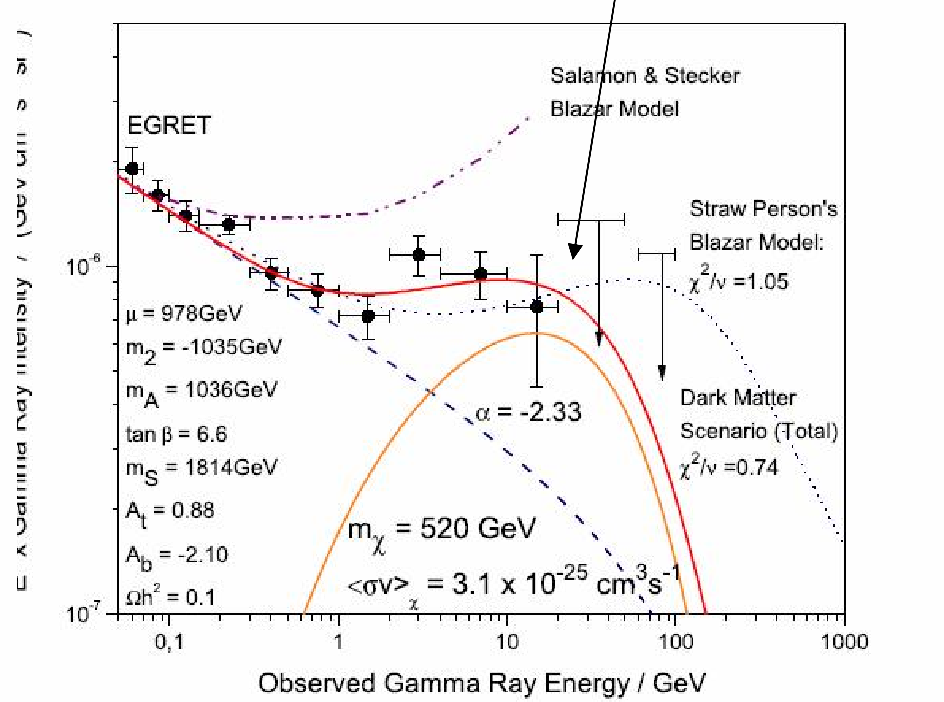


FIG. 13: Extragalactic gamma-ray flux (multiplied by E^2) for two sample thermal relic neutralinos in the MSSM (dotted curves), summed to the blazar background expected for GLAST (dashed curve). Normalizations for the signals are computed assuming halos are modelled by the Moore profile, with 5% of their mass in substructures with concentration parameters 4 times larger than c_{vir} as estimated with the Bullock et al. toy model.

Could the diffuse extragalactic gamma-ray background be generated by neutralino annihilations?

GeV ”bump”? (Moskalenko, Strong, Reimer, 2004)





Rates computed with

06

ladel

Steep (Moore) profile needed for DM substructure; some fine-tuning to get high annihilation rate

Elsässer & Mannheim, Phys. Rev. Lett. 94:171302, 2005

Energy range is optimal for GLAST!

Breaking mechanisms

Model	Name	Breaking mechanism and scale	Parameters
mSugra, cMSSM	Minimal Supergravity Constrained MSSM	Gravity (GUT)	M_0,$M_{1/2}$, A_0,tanβ, sgn(μ) or μ
GMSB	Gauge Mediated Symmetry Breaking	Gauge messengers (10 TeV)	Λ_m,M_m, tanβ, N_5, sgn(μ), C_{grav}
AMSB	Anomaly Mediated Symmetry Breaking	"conformal anomaly"	$M_{3/2}$,m0(other term),tanβ,sgn(μ),

In mSugra : 3 isolated leptons + MET

In GMSB : 2 photons + E_T

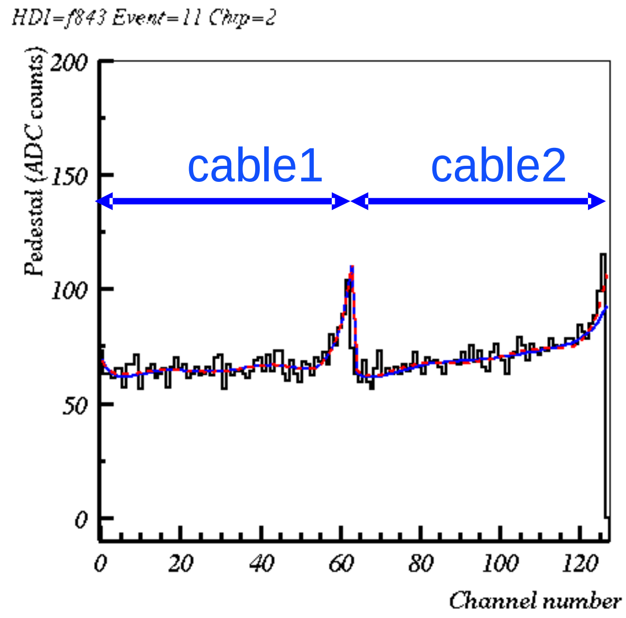
In AMSB : long-lived particles

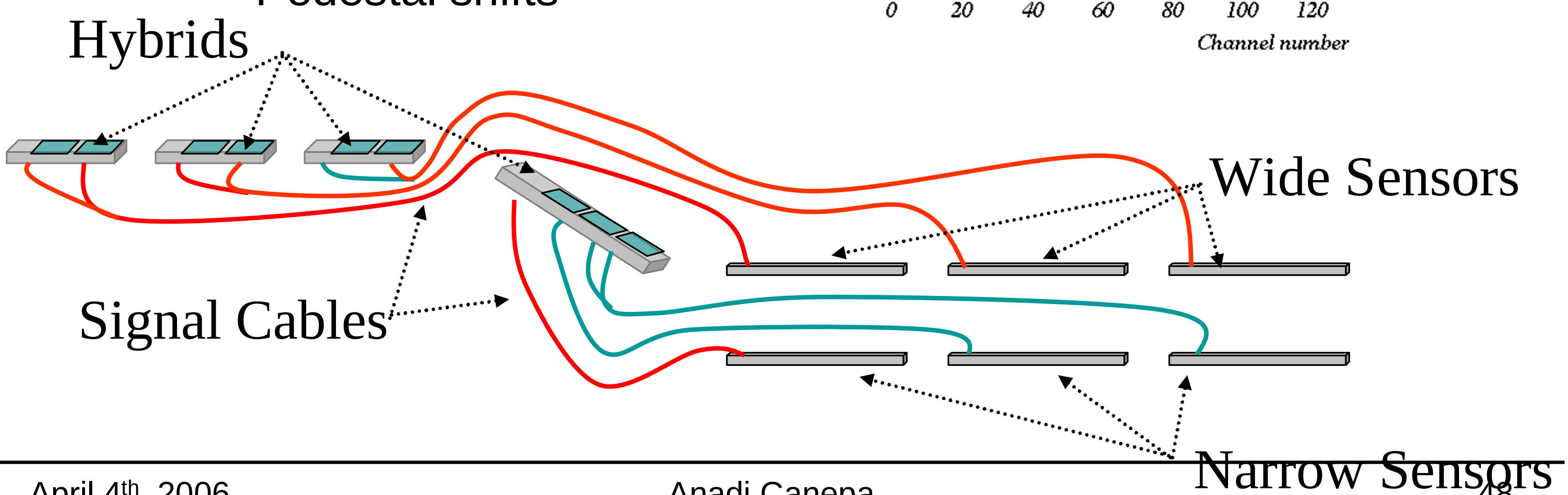
In R_p models : >3 leptons

(and many more signatures in each model depending on the parameters !)

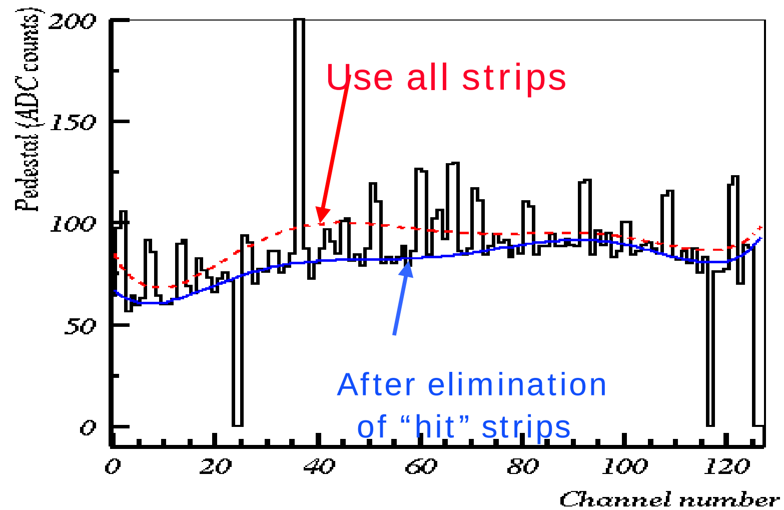
Cables in L00

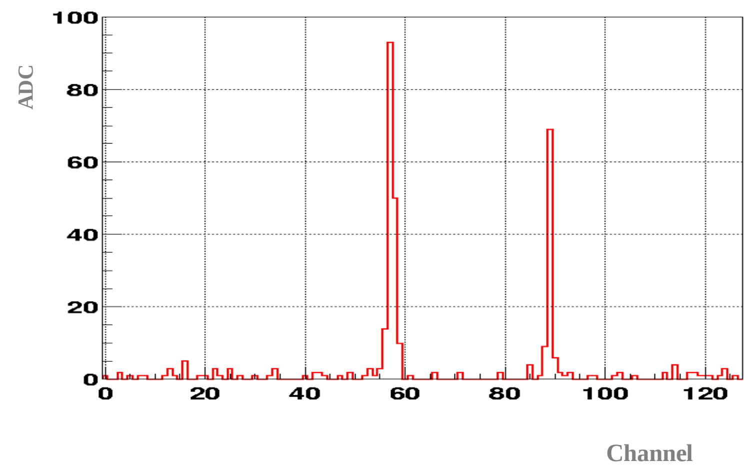
- Noise picked up by analog signal cables
  - Effects are seen at edges of cables, within one sensor
  - Both coherent and incoherent sources
    - Noise shapes
    - Pedestal shifts



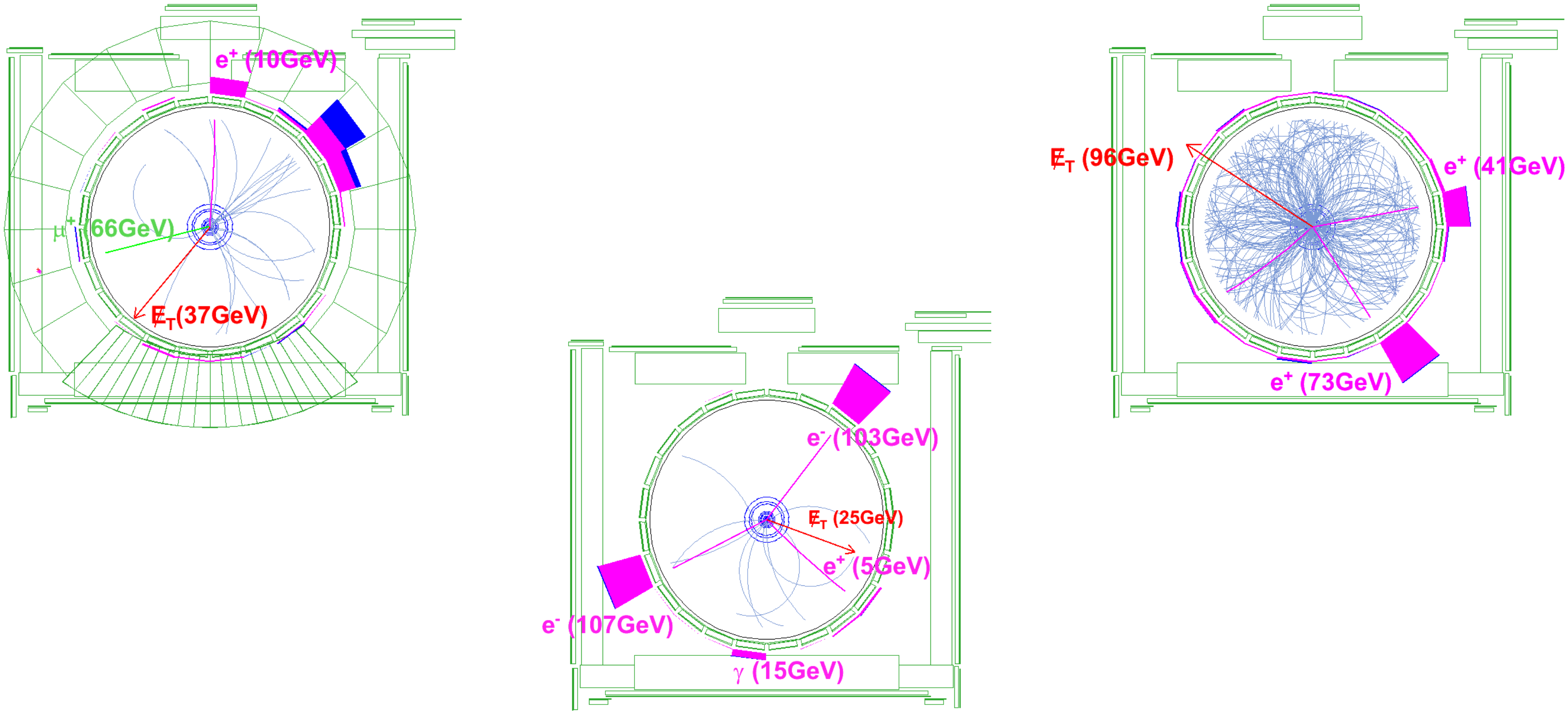


- Problem solved offline
  - Readout all strips in L00
  - Use this information to fit for an event-by-event pedestal
    - $\chi 2$ fit to Chebyshev polynomials
  - Tested by embedding MC clusters in data
    - 95% efficiency with 95% purity
    - No impact on cluster size or centroid resolution
  - Implications for CDF
    - L00 can't be in online track trigger
    - Readout time may be a bottleneck





Like Sign ana – evd of events



Systematic uncertainties

Major systematic uncertainties affecting the measured number of events

Ø Signal

§ Lepton ID 5%

§ Muon p_T resolution 7%

Ø Background

§ Fake lepton estimate method 5%

§ Jet Energy Scale 22%

Ø Common to both signal and background

§ Luminosity 6%

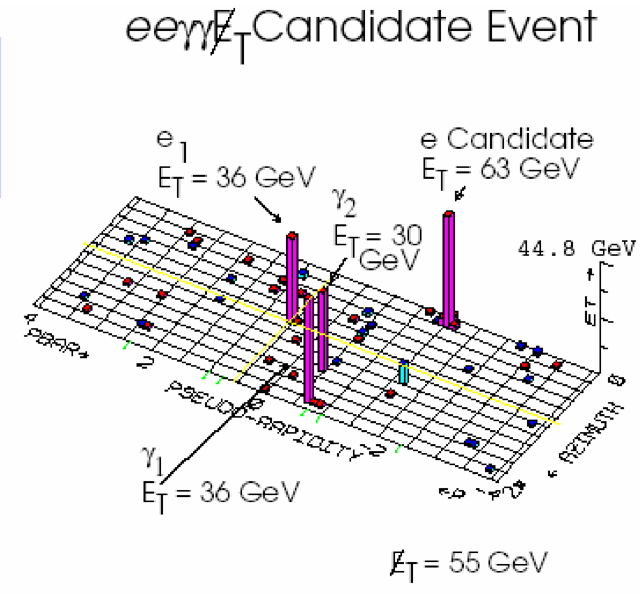
§ Theoretical Cross Section 6.5-7%

Trilepton at D0

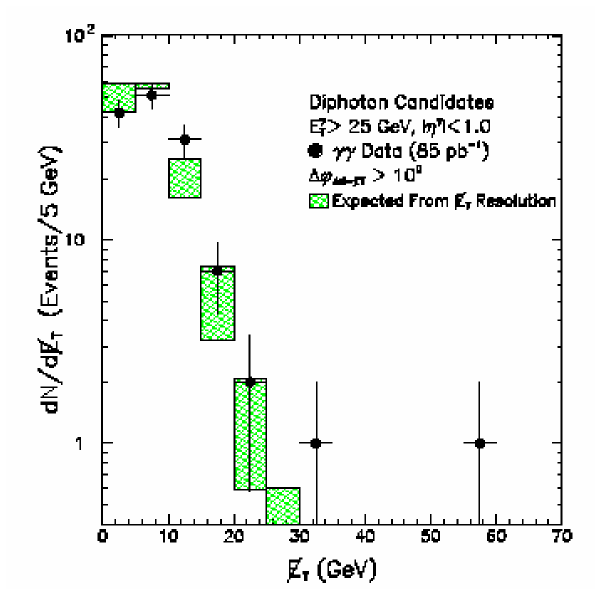
Selection	SM expected	OBSERVED
ee+t	0.21±0.12	0
eμ+t	0.31±0.13	0
μμ+t	1.75±0.57	2
$\mu^{\pm}\mu^{\pm}$	0.64±0.38	1
eτ+t	0.58±0.14	0
μτ+t	0.36±0.13	1
SUM	3.85±0.75	4

M(eτ) (GeV/c^2)

• GMSB



- Run I event:
  - 2 e, 2 γ and E_t=56 GeV
  - SM expectaction: 10^{-6} Events
- Interpretations in GMSB:
  - Selectron
  - Chargino/Neutralino
- Visible in inclusive diphoton E_t spectrum
- Searched by Tevatron Run II, LEP and HERA



AMSB

In the AMSB scenario (χ^0_1 LSP)

- $\chi^{\pm}_1$ is the NLSP (Next-to-Lightest-Supersymmetric Particle)
- lives long enough to decay outside the detector;
  - $c\tau$ and the BR depend almost entirely upon the mass difference $\chi^{\pm}_1$-χ^0_1