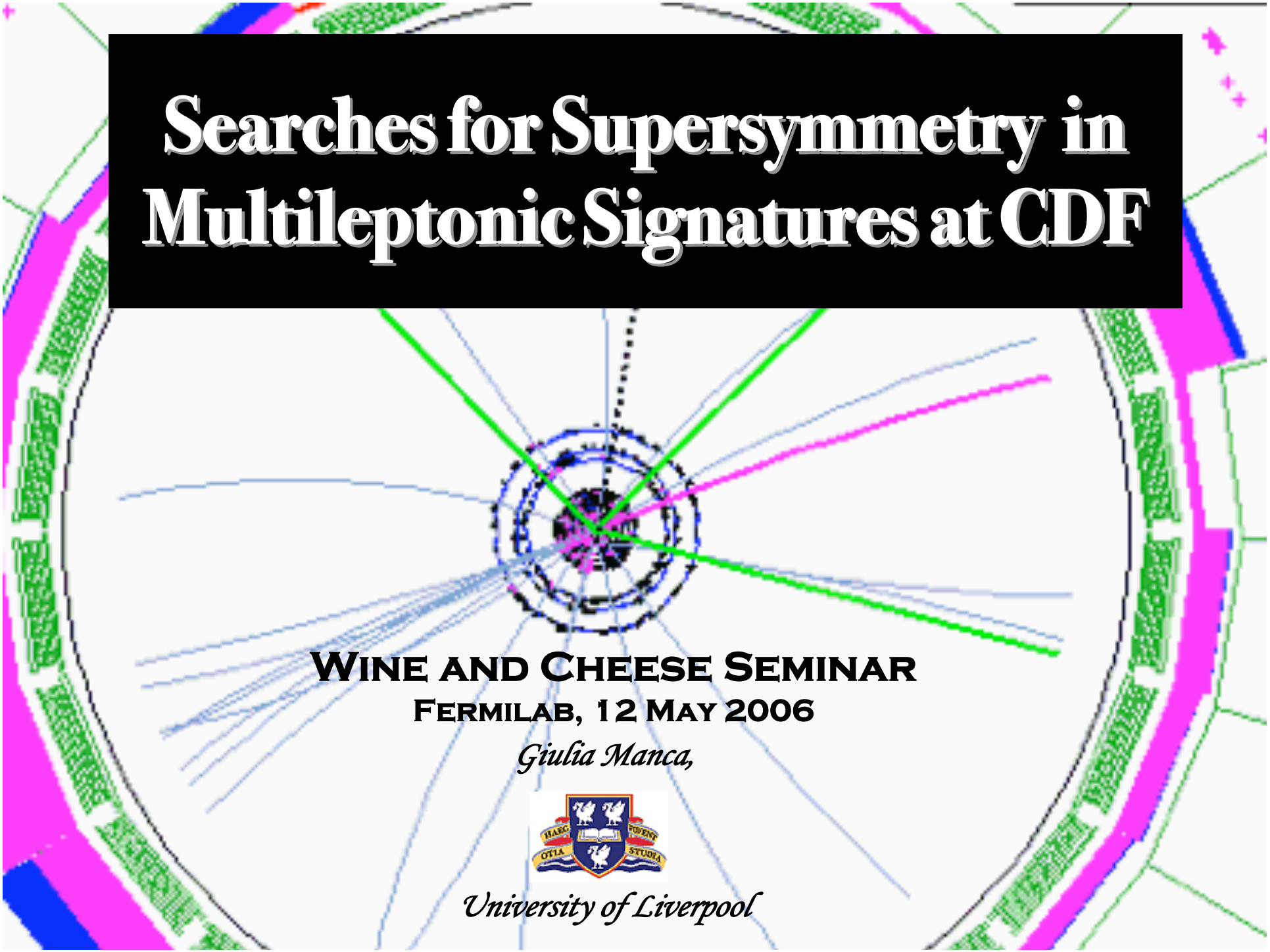
Searches for Supersymmetry in Multileptonic Signatures at CDF



Wine and Cheese Seminar

Fermilab, 12 May 2006

Giulia Manca,

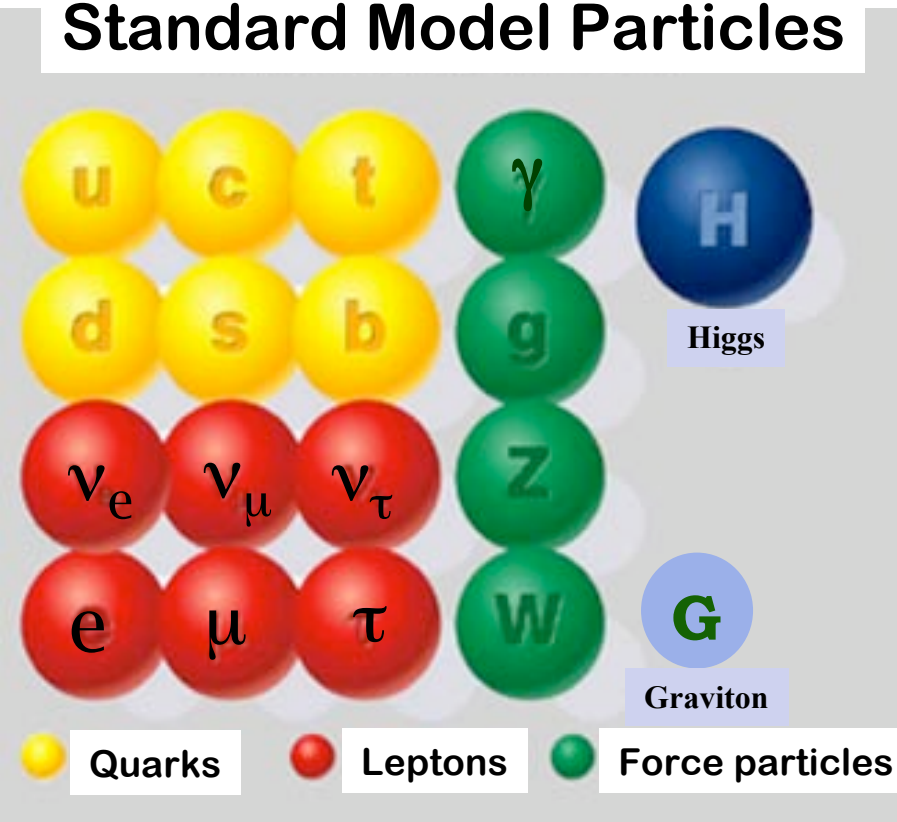
University of Liverpool

Outline

- Supersymmetry
- Searching for SUSY at CDF
- Chargino and Neutralino
  - Di/Trileptons
  - Adding more leptons…
- Conclusions
- Outlook

Supersymmetry: what ?

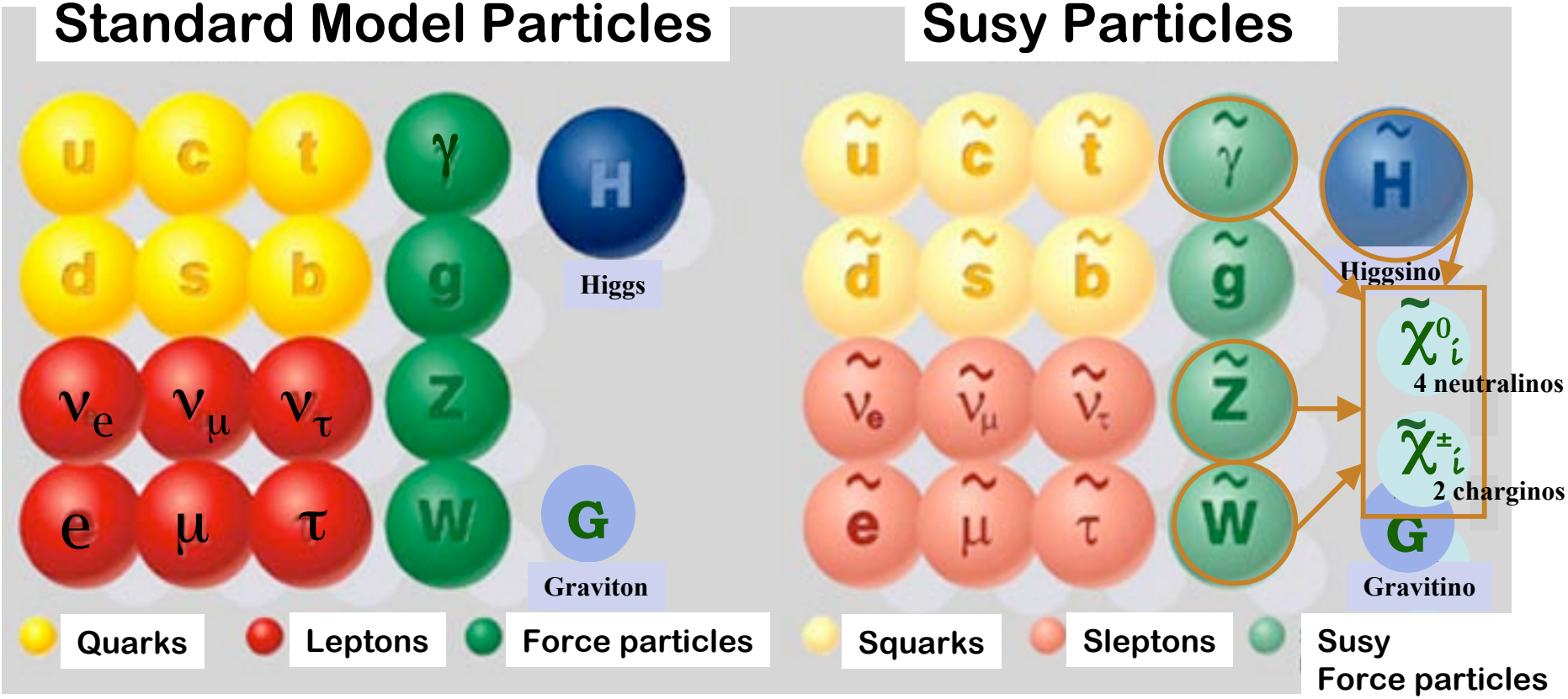
Extends the Standard Model (SM) by predicting a ***new symmetry:***
spin-1/2 matter particles (fermions) <=> spin-1 force carriers (bosons)



Supersymmetry: what ?

broken

Extends the Standard Model (SM) by predicting a ***new symmetry:***
spin-1/2 matter particles (fermions) <=> spin-1 force carriers (bosons)



New Quantum Number R-Parity $\Rightarrow R_p = (-1)^{B+L+2s}$ $\begin{cases} +1 \text{ (SM particles)} \\ -1 \text{ (Susy particles)} \end{cases}$

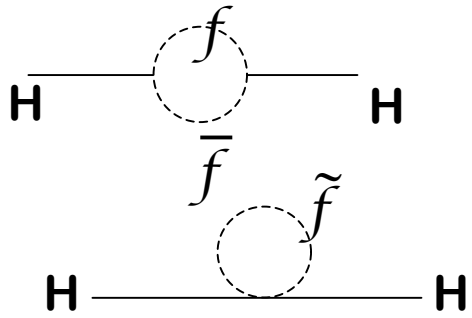
If R_p conserved Lightest SParticle (LSP) stable!

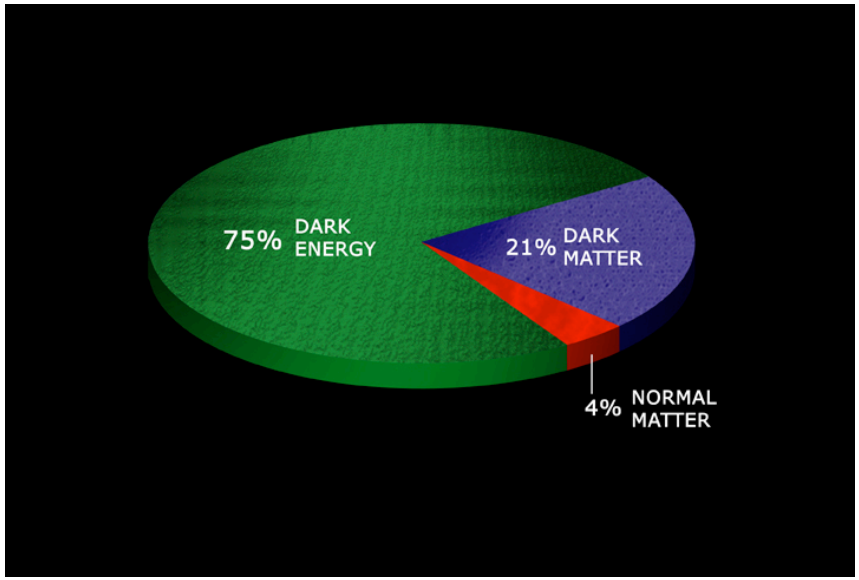
Supersymmetry: why ?

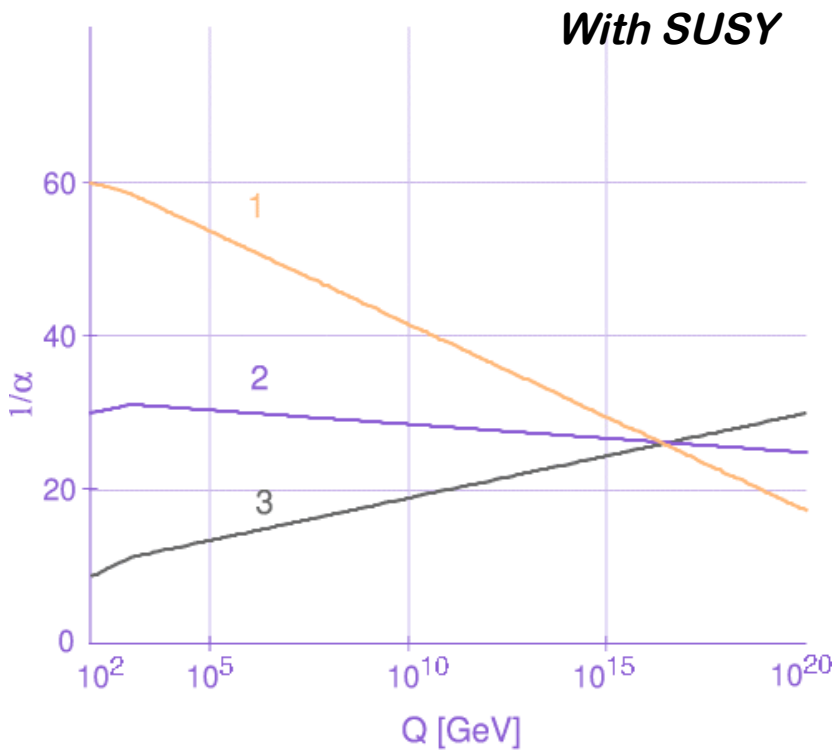
SUSY

Limitations of Standard Model

- ✓ Stabilisation of Higgs mass at EW scale
- ✓ Couplings don't unify at one scale
- ✓ Dark Matter ->LSP
- Dark Energy
- Neutrino masses
- ✓ Gravity

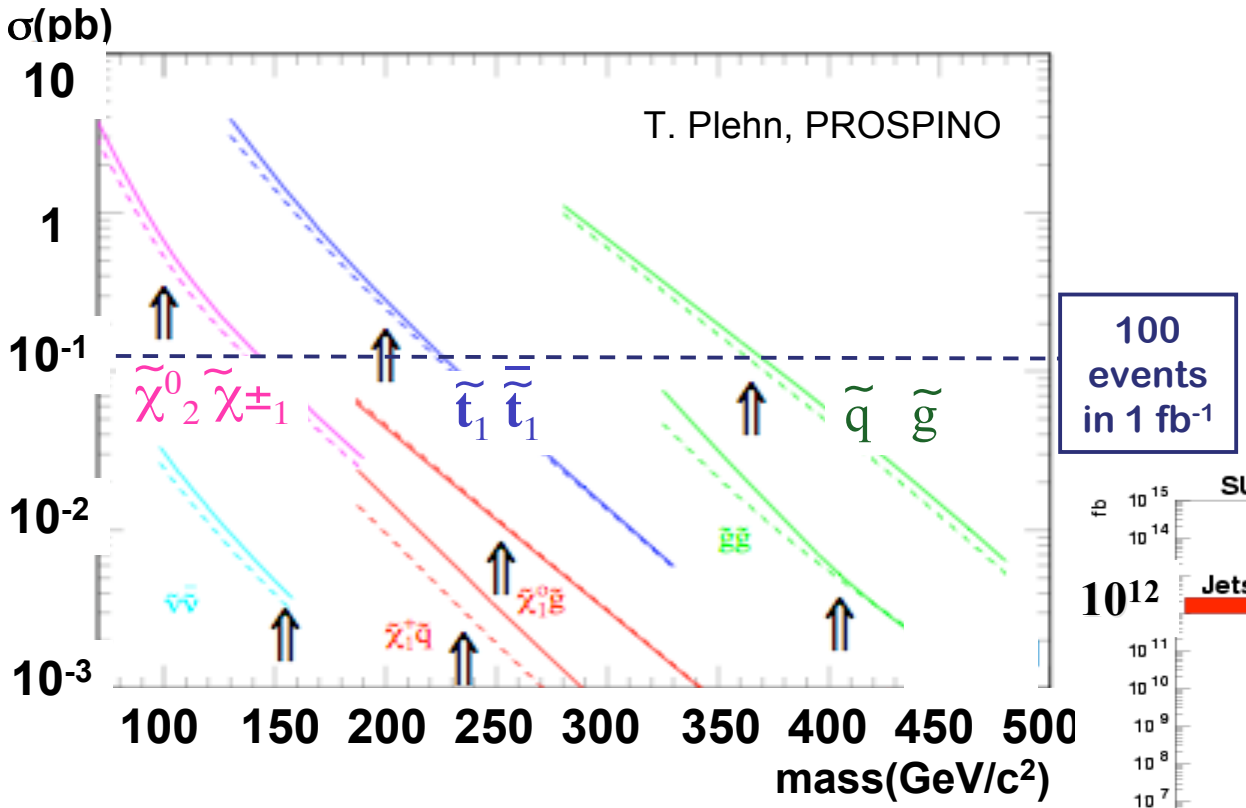




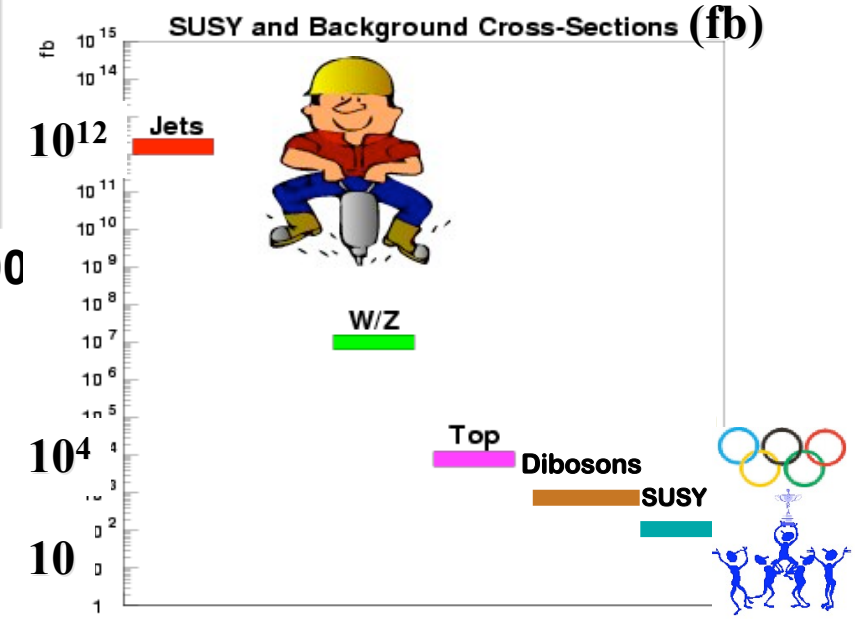


Supersymmetry: The Challenge

➡ VERY SMALL cross sections !!



100 events in 1 fb^{-1}



Compared to:
7.5x10^6 Zs, 7,000 t-antitop
and 5,000 WZ

Supersymmetry: how?

Wide range of signatures: look for SuSy specific signatures or excess in SM ones; examples:

R_p :

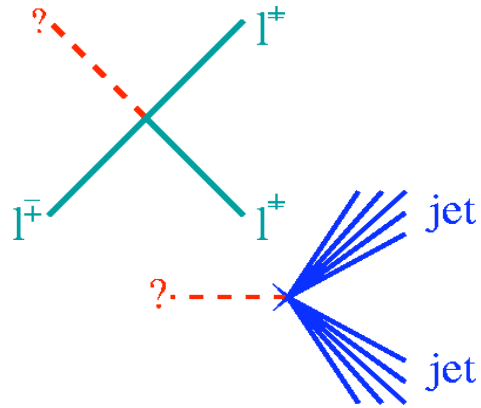
LSP ➡ Large Missing Energy $\not{E}_T$

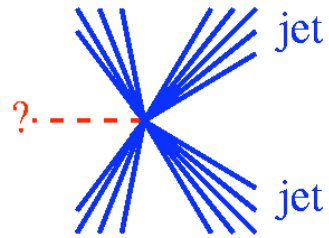
AND:

$\chi^0\ \chi^\pm$ ➡ Isolated leptons

$\tilde{q}\ \tilde{g}$ ➡ Multijets

...and many more!



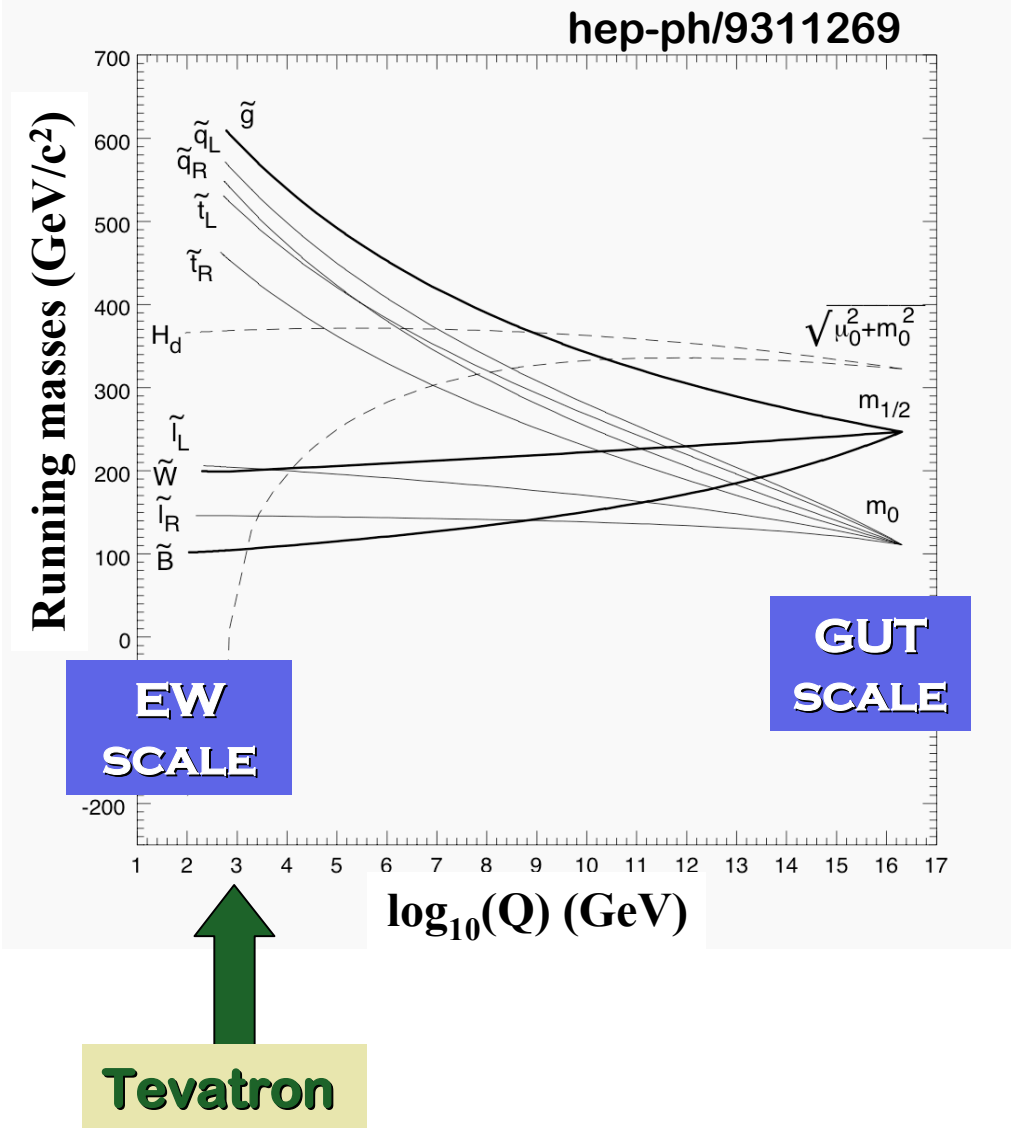


mSugra: a working model

- SUSY broken through gravity
- Five parameters:
  - m_0:common scalar mass at GUT scale
  - $m_{1/2}$:common gaugino mass at GUT scale

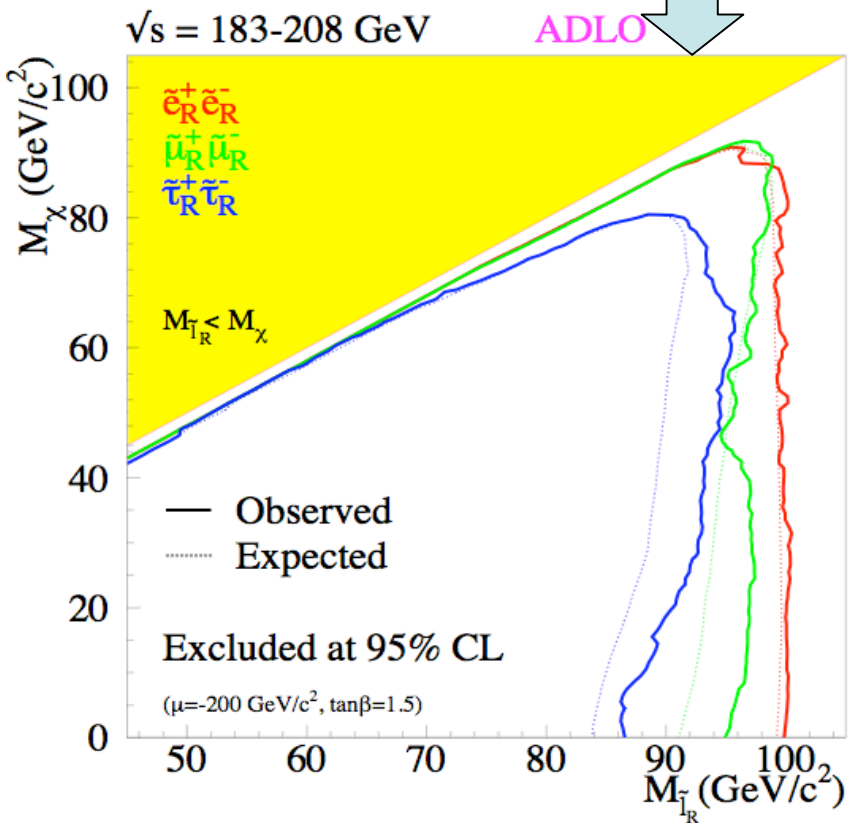
    (i.e. $M_1(GUT)=M_2(GUT)=M_3(GUT)= M_{1/2}$)
  - A_0: common trilinear scalar interaction at the GUT scale (Higgs-sfermion$_R$-sfermion$_L$)
  - $\tan\beta$: ratio of Higgs vacuum expectation values
  - Sign(μ), the higgsino mass parameter

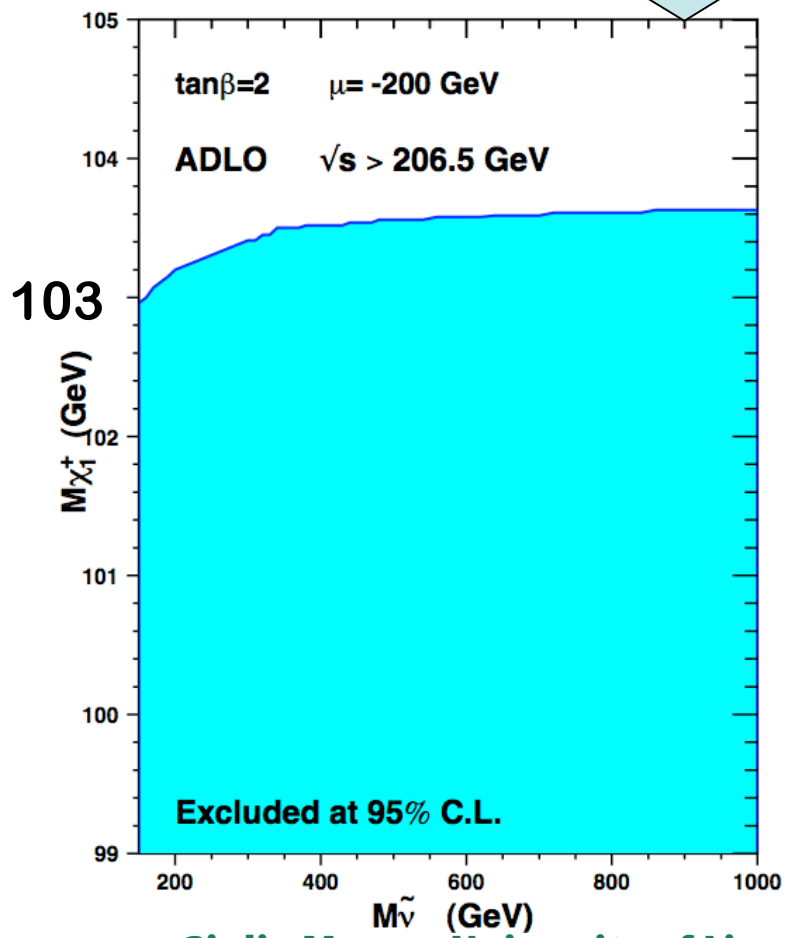
    (μ^2 determined by EWSB)
- Lightest supersymmetric particle(LSP) is the χ^0_1, stable



mSugra Existing Limits : LEP

- LSP > $M_Z/2$
- Chargino > 103 GeV/c^2 (heavy sneutrinos);
- Sleptons > 90-100 GeV/c^2 for $M(\chi_0^1)<M(\ell_R)$;





Searching for Chargino and Neutralino at

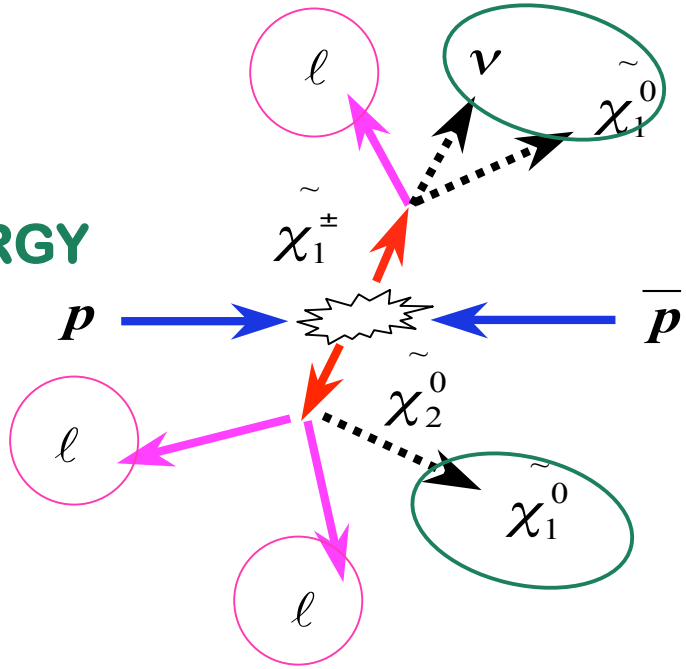
CDF II

The signature

Chargino-Neutralino production :
Striking signature

THREE ISOLATED LEPTONS

If R_p conserved,
LARGE MISSING TRANSVERSE ENERGY
from the stable LSP+ν



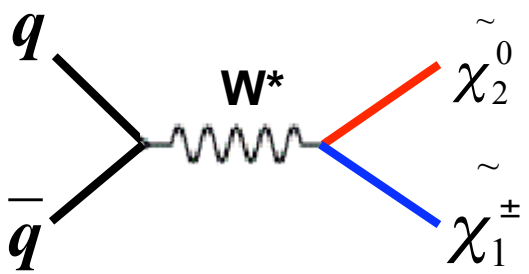
- Low background
- Easy to trigger

LITTLE MODEL DEPENDENCE

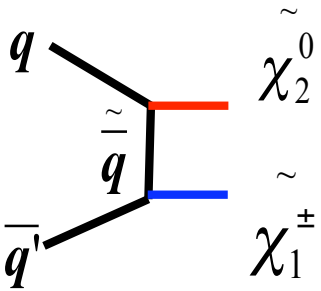
GOLDEN SIGNAL AT THE TEVATRON !!

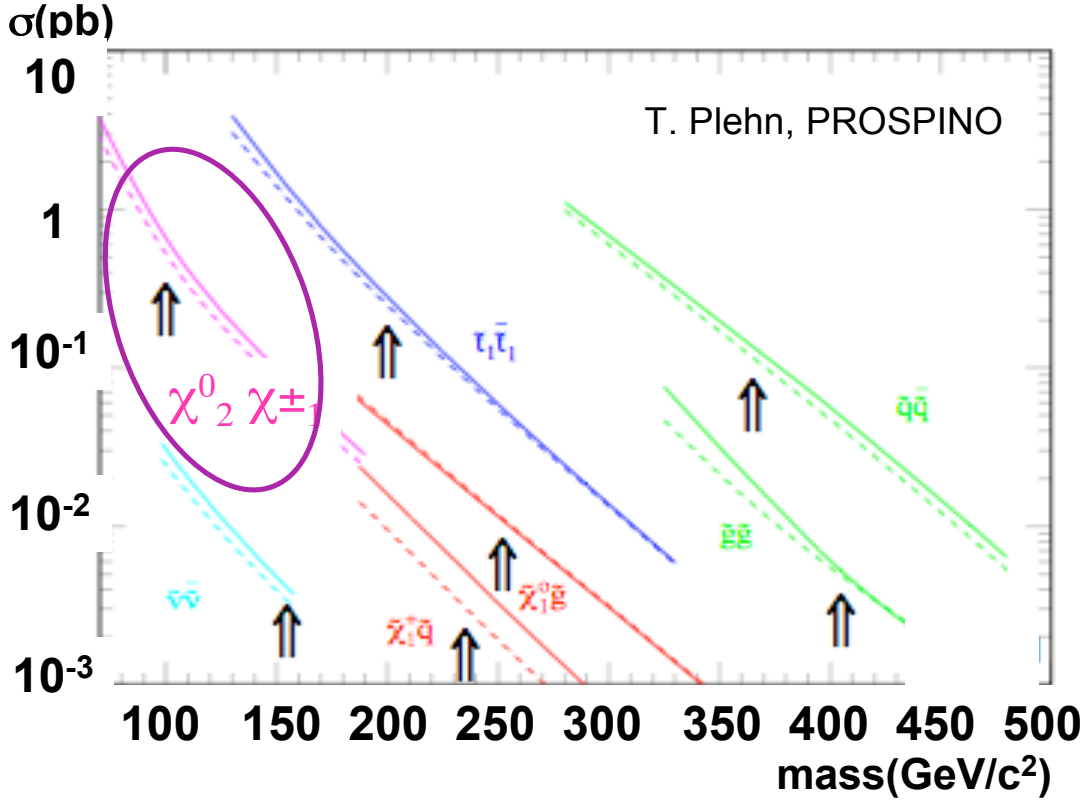
Chargino-Neutralino production...

- Low cross section (weakly produced)



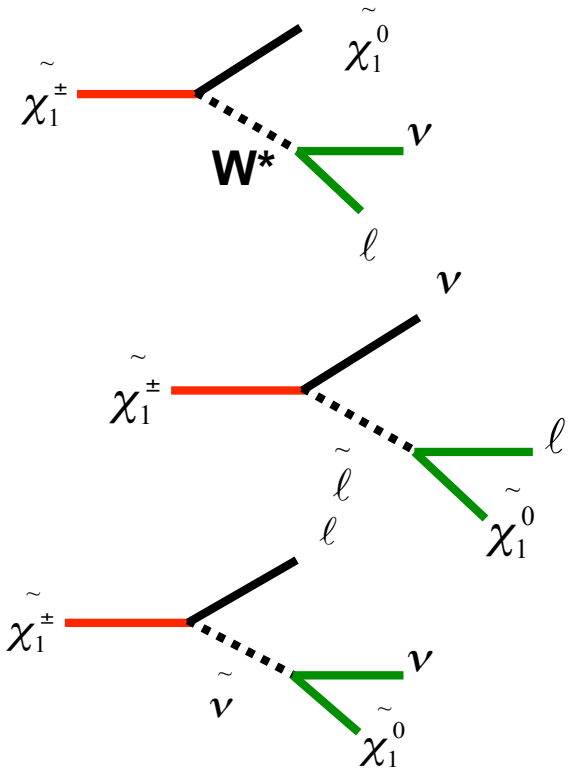
t-channel interferes destructively



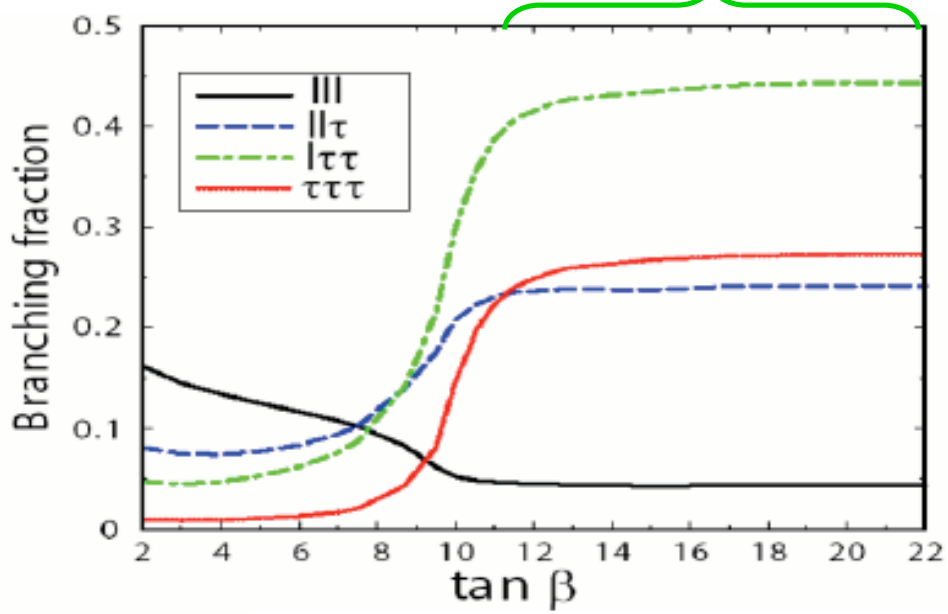


...and decay

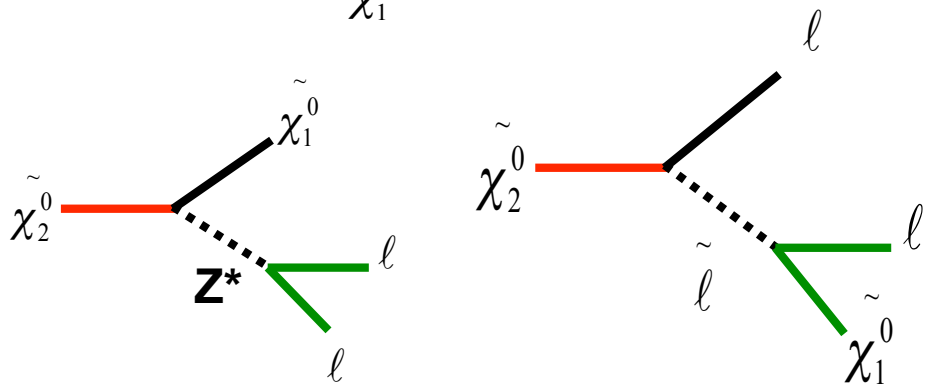
Chargino Decay

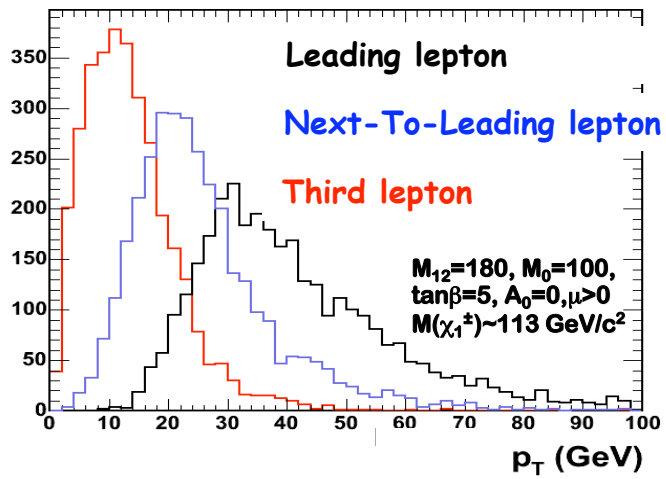


Leptons of 3rd generation are preferred

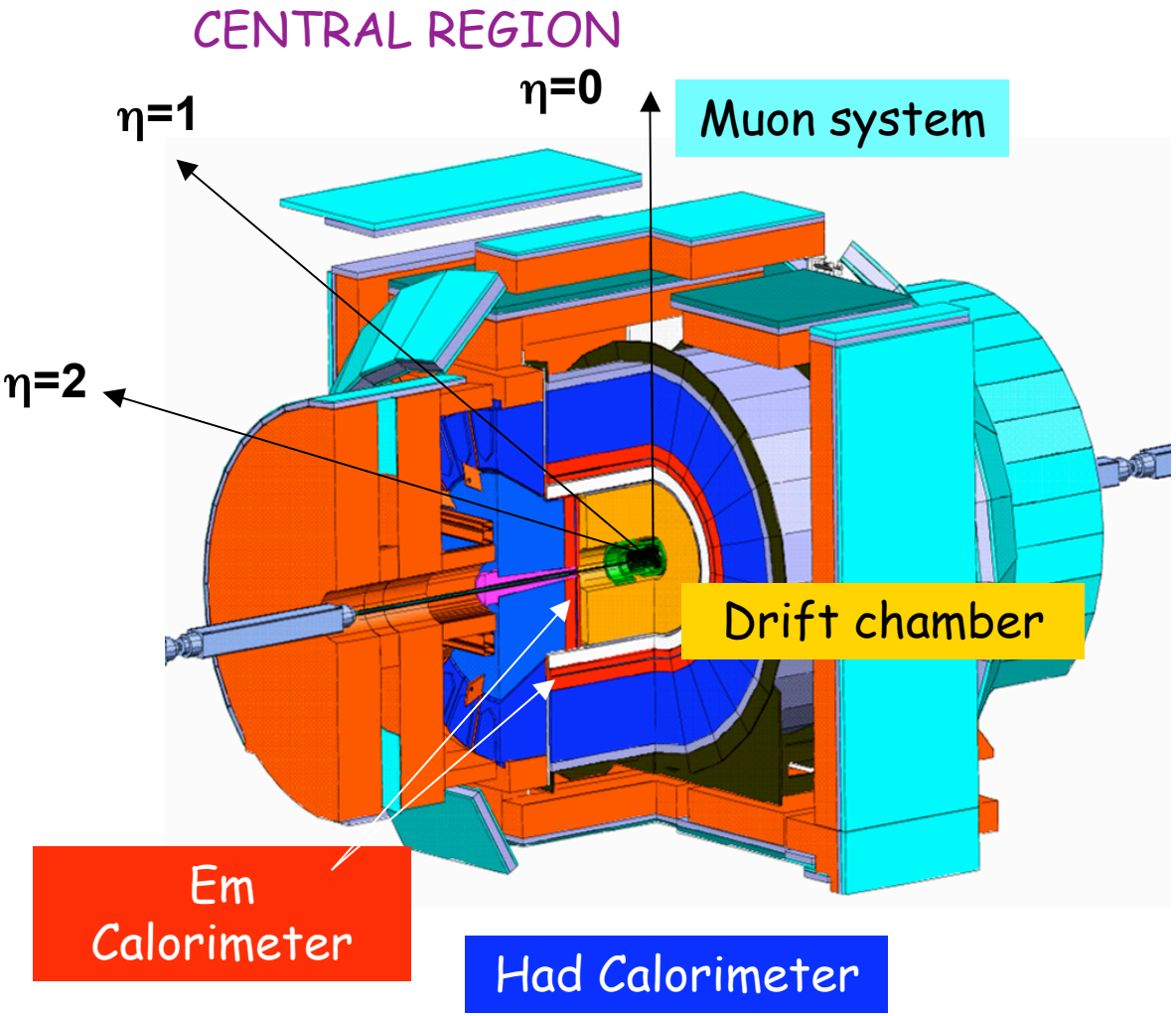


Neutralino Decay

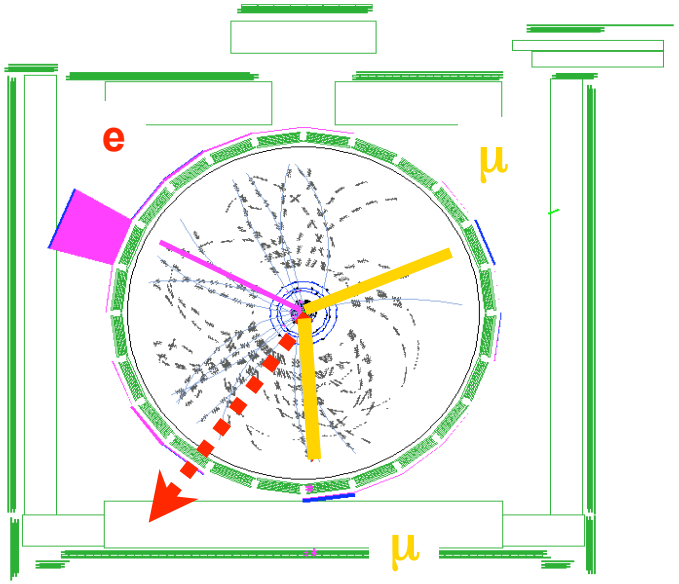




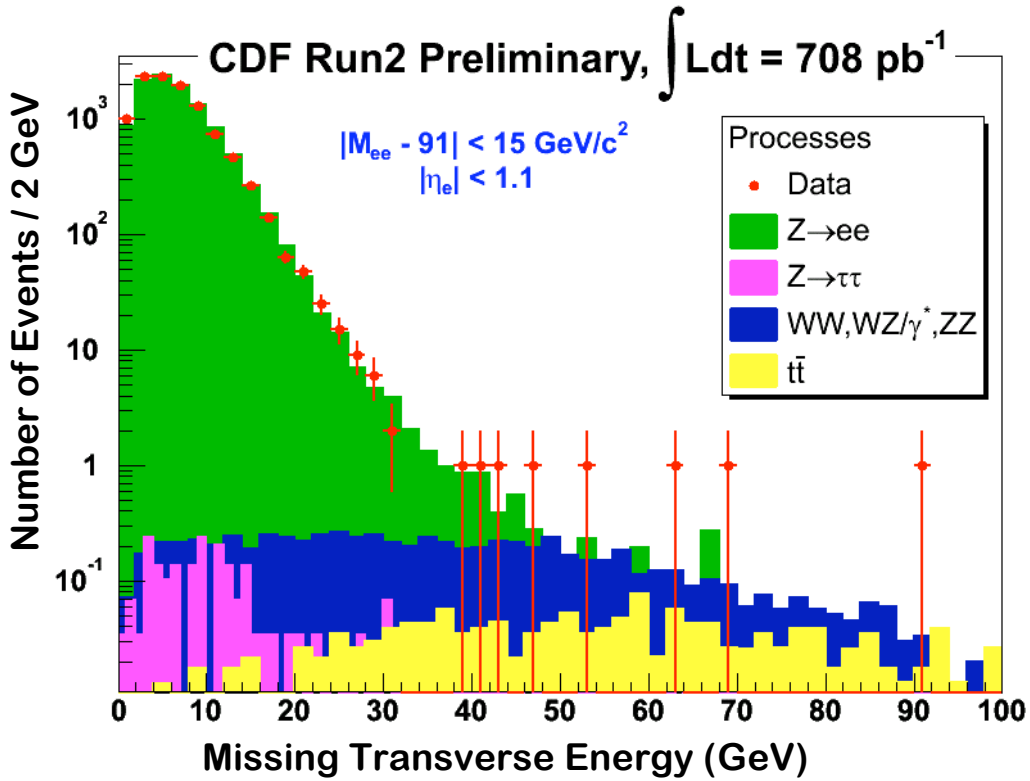
Finding SUSY at CDF



The Missing Energy (MET)



Missing Transverse Energy (MET)



Real MET

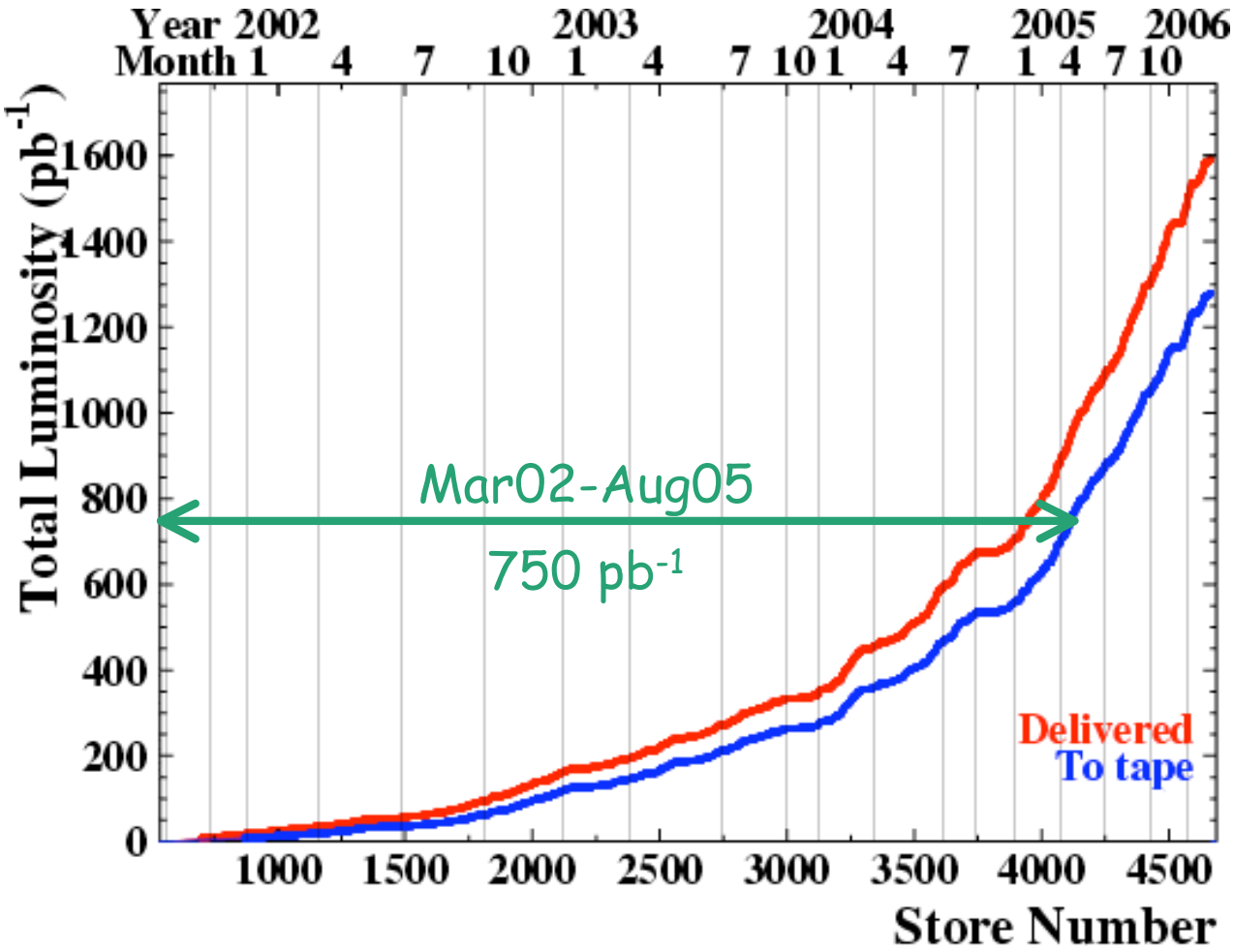
- ✓ Particles escaping detection

Fake MET

- ✓Muon p_T or jet E_T mismeasurement
- ✓Instrumental effects
- ✓Cosmic ray muons
- ✓Mismeasurement of the vertex

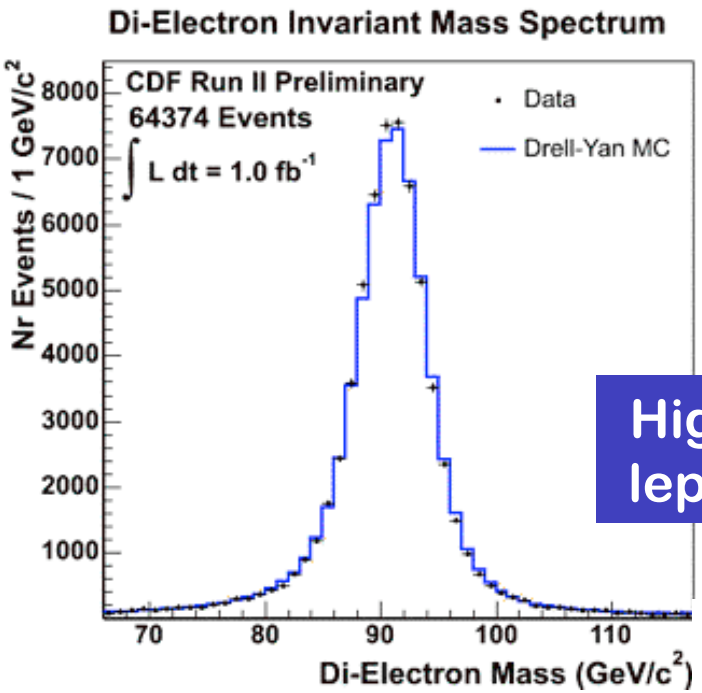
Trileptons Analyses

The Data

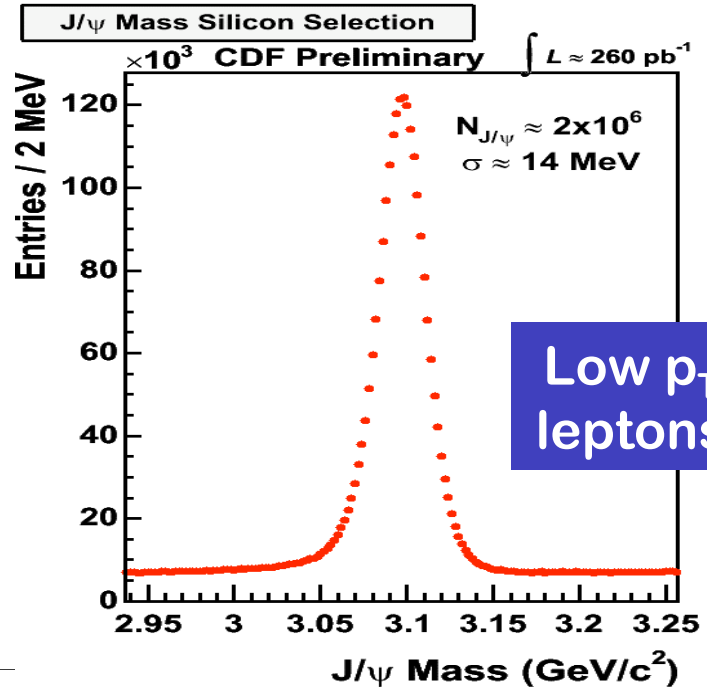


Many thanks to the accelerator division !!

Leptons to discover SUSY: The SM Calibration Samples

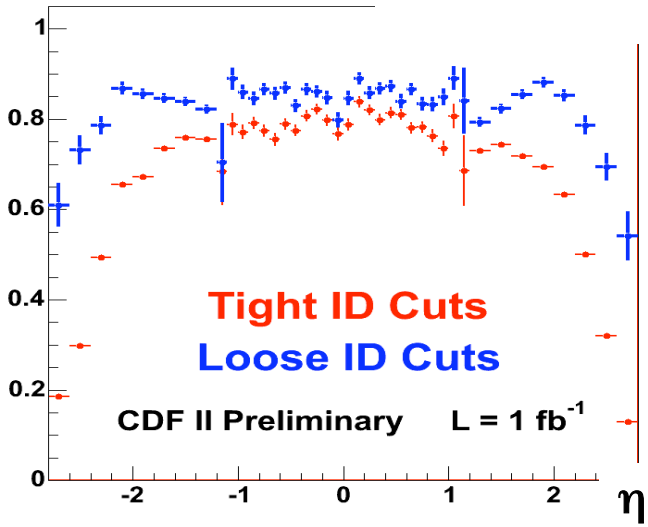


High p_T leptons

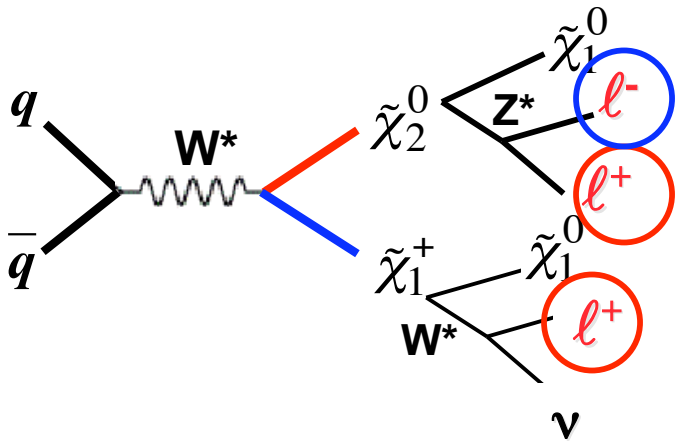


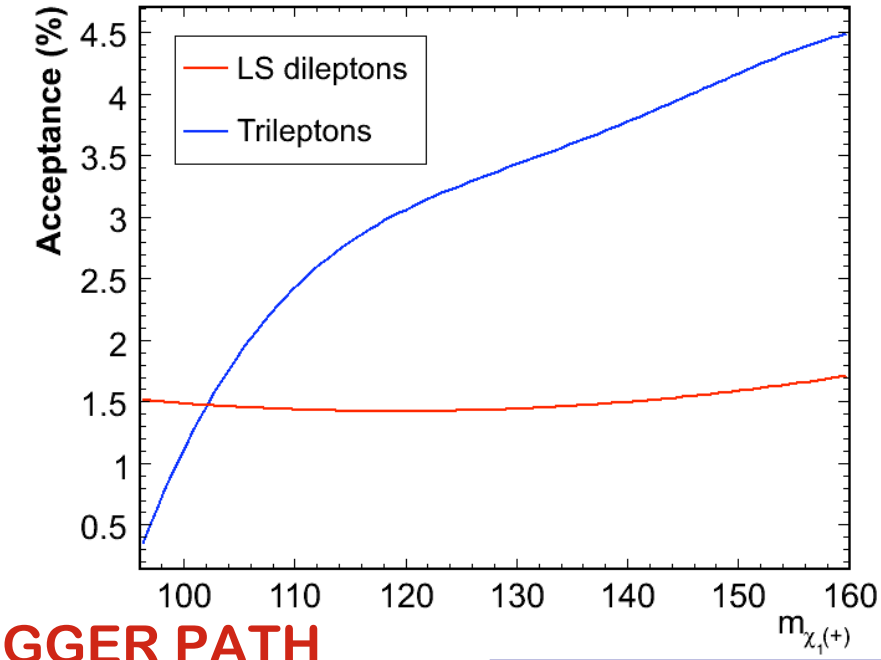
Low p_T leptons

- Lepton ID efficiencies
- Trigger efficiencies
- Calorimeter Calibration
- Lepton E and P Scale
- Luminosity



Analyses Overview





CHANNEL	LUM	TRIGGER PATH
$e^\pm e^\pm, e^\pm\mu^\pm, \mu^\pm\mu^\pm$	710	High p_T Single Lepton
$\mu\ell$ + e/μ	750	High p_T Single Lepton
ee + e/μ	350	High p_T Single Lepton
μμ + e/μ	310	Low p_T Dilepton
ee + track	610	Low p_T Dilepton

No third lepton requirement => Higher acceptance

Use e/mu only =>Very small backgrounds

Sensitive to taus as 3rd lepton => Keeps acceptance at high tanβ

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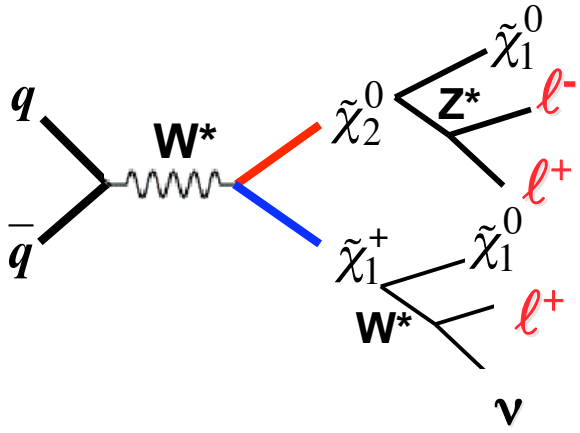
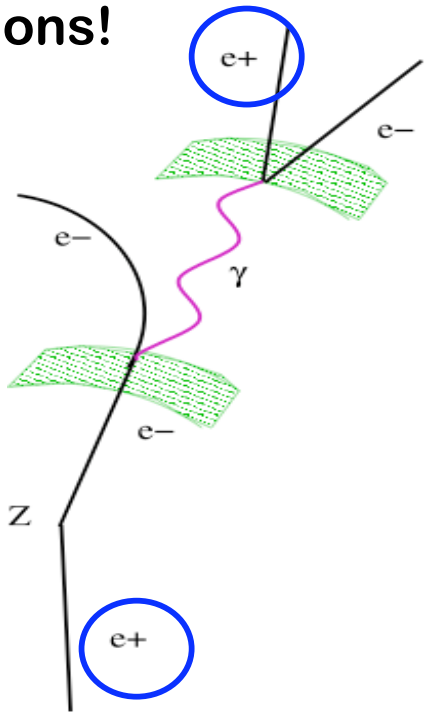
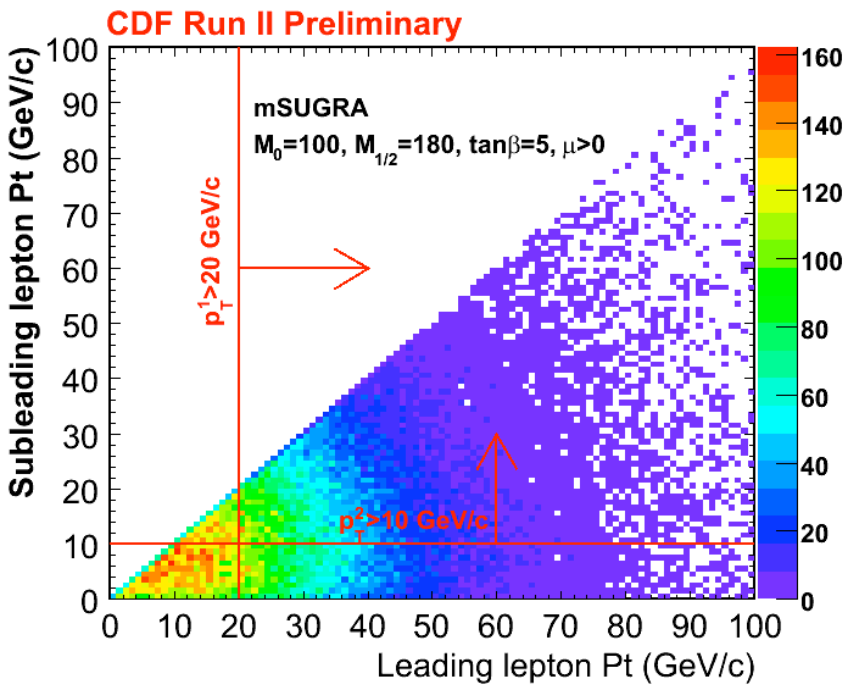
Like-Sign Dileptons

- Sensitive to both chargino-neutralino and squark-gluino production
- Ask for 2 high-pt (20,10) isolated leptons of the same charge
- Main background : conversions!

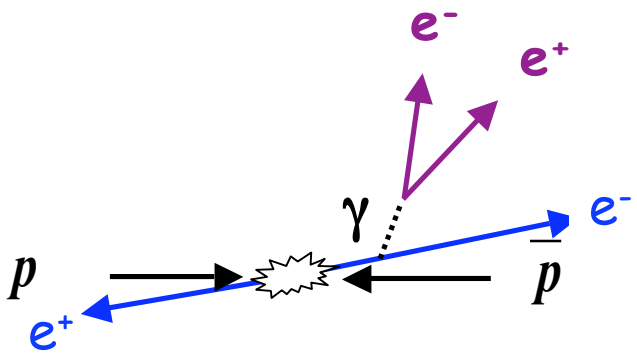




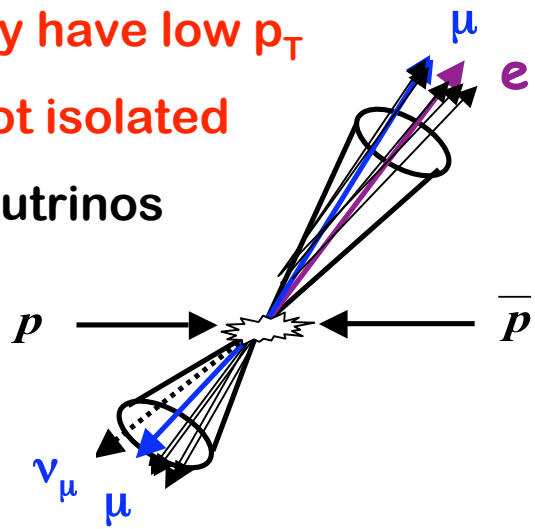


Backgrounds: how to reduce them?

- DRELL YAN PRODUCTION + additional lepton
  - Leptons have mainly high p_T
  - Small MET
  - Low jet activity



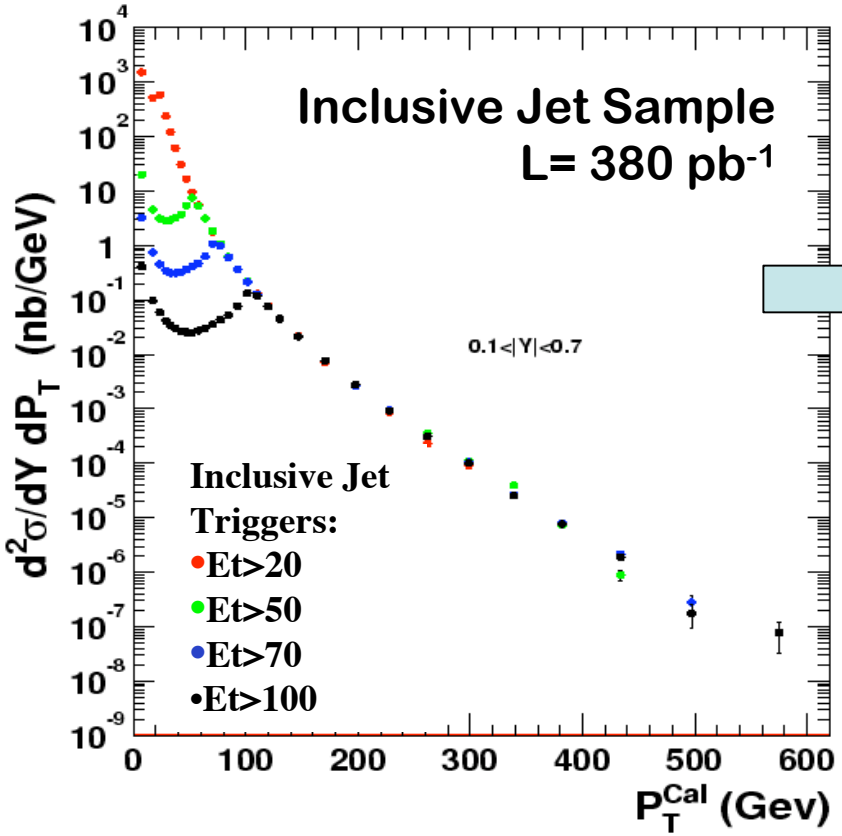
- HEAVY FLAVOUR PRODUCTION
  - Leptons mainly have low p_T
  - Leptons are not isolated
  - MET due to neutrinos

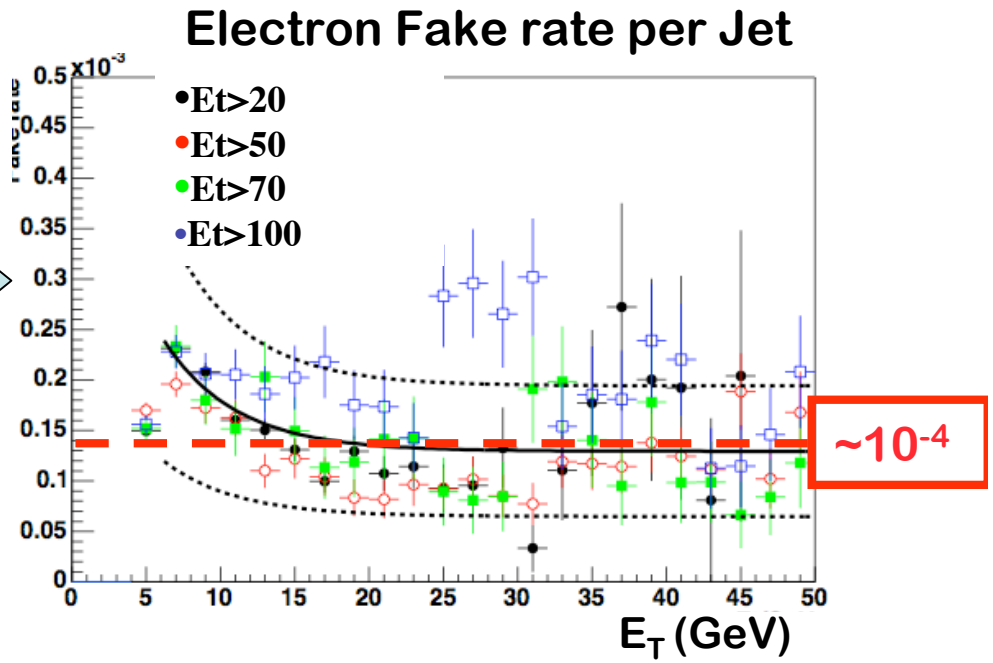


- DIBOSON (WZ,ZZ) PRODUCTION
  - Leptons have high p_T
  - Leptons are isolated and separated
  - MET due to neutrinos

irreducible background

Jets Faking Leptons





Inclusive Jet Sample with different trigger thresholds used to extract Fake rates and test Jet Energy Scale

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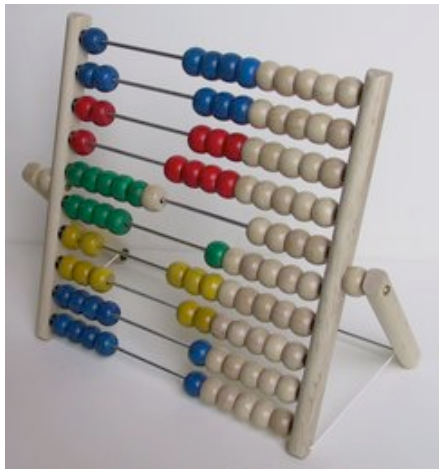
Analysis Strategy

COUNTING EXPERIMENT



- Optimise selection criteria for best signal/background value;
- Define the signal region and keep it blind
  - Test agreement observed vs. expected number of events in orthogonal regions ("control regions")
  - Look in the signal region and count number of SUSY events !!

    (Or set limit on the model)

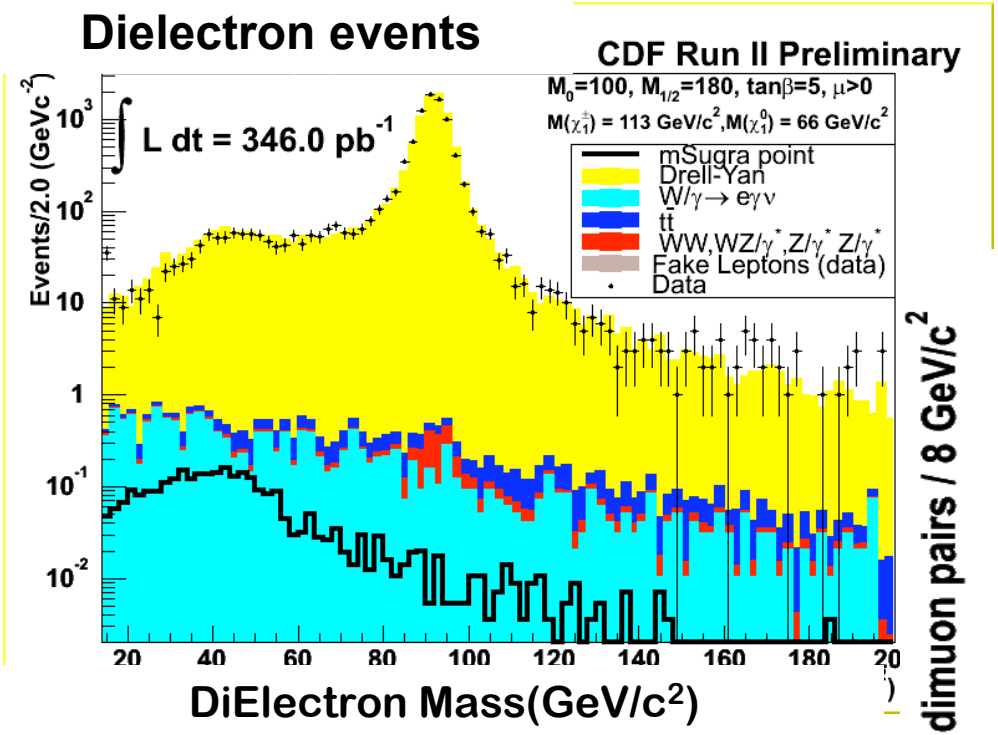
The Basic Selection

- **Two leptons** preselection
  - 1st lepton: 20(15,5), 2nd 10(8,5) GeV/c
- **Invariant Mass**
  - reject resonances
- $\Delta\Phi(\ell\ell)$
  - reject Drell-Yan
- **Low jet activity**
  - reject ttbar,W+jets,Z+jets
- **High Missing Transverse Energy**
  - further Drell-Yan rejection

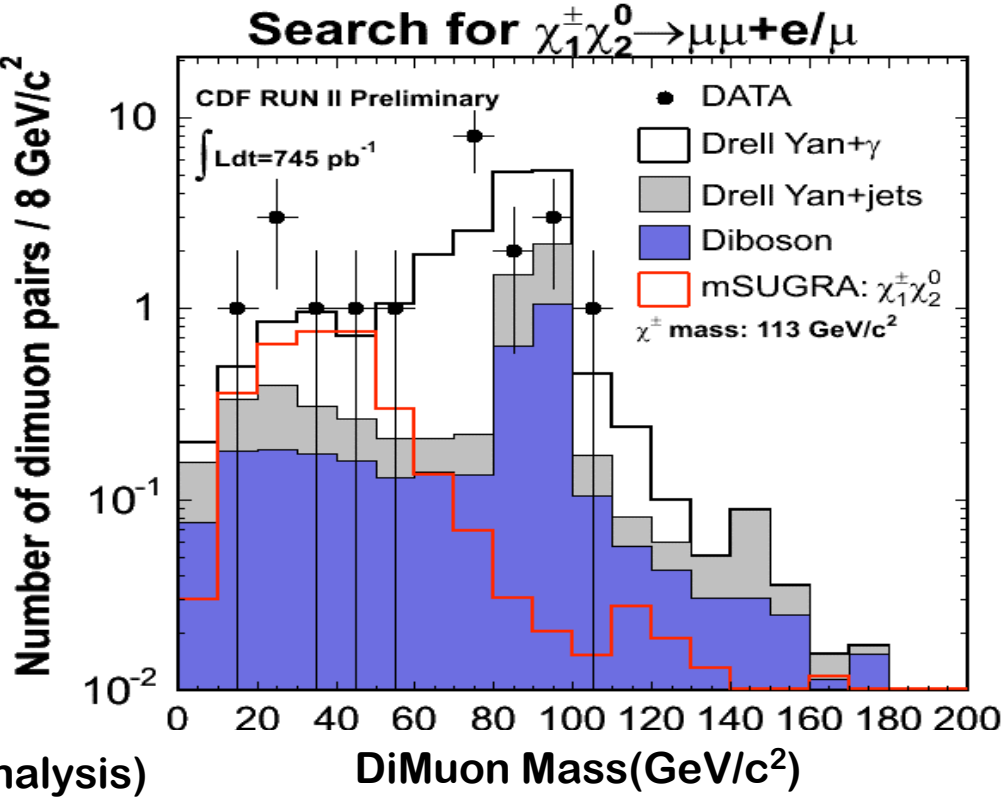
Minimal number of cuts to keep analysis simple while rejecting the most overwhelming backgrounds

Selection criteria: (I) Mass

Rejection of J/Ψ, Υ and Z



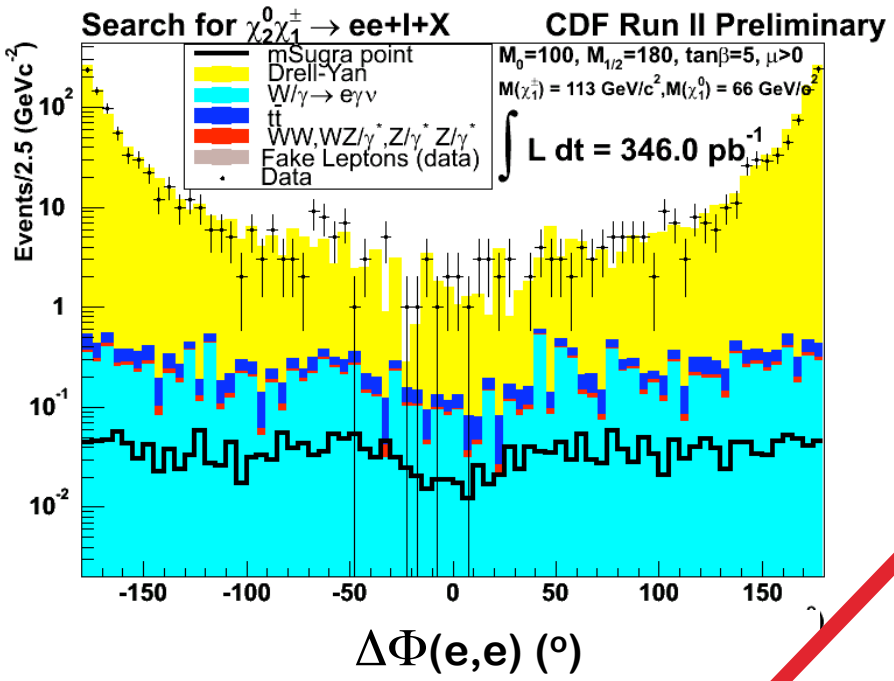
Asking for the third lepton…

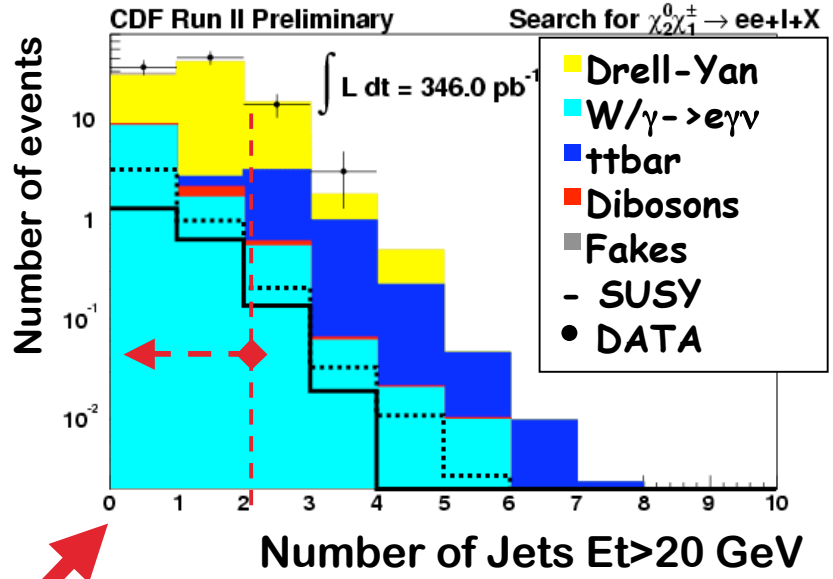


- $M_{\ell\ell}$<76 GeV & $M_{\ell\ell}$>106 GeV
- $M_{\ell\ell}$> 15 (20,25) GeV
- min $M_{\ell\ell}$< 60 GeV (dielectron+track analysis)

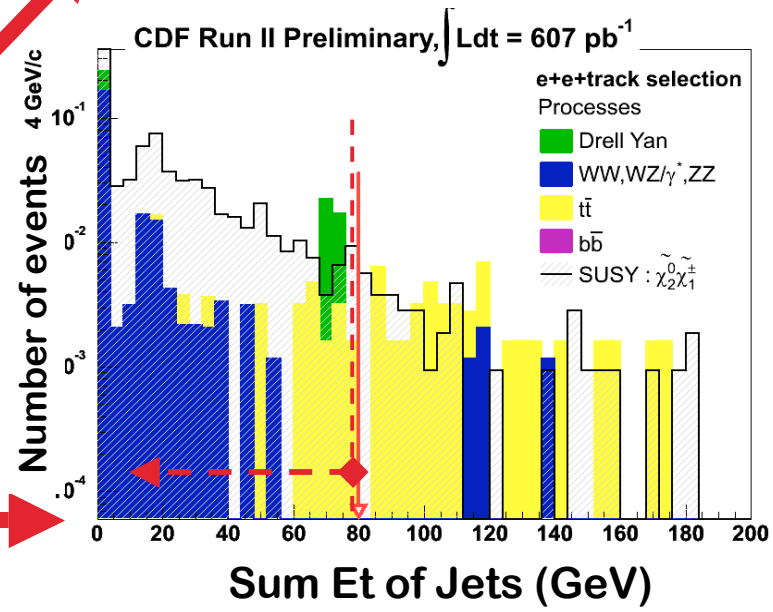
(II) $\Delta\Phi(\ell,\ell)$ and Jet Veto

Rejection of DY and high jet multiplicity processes





Analysis	Kinematic Variable	Kinematic Cut
Trilepton analyses	Jet E_T > 20 GeV	n. Jets < 2
Dielectron + track analysis	$H_T = \Sigma jetE_{Tj}$	H_T < 80 GeV



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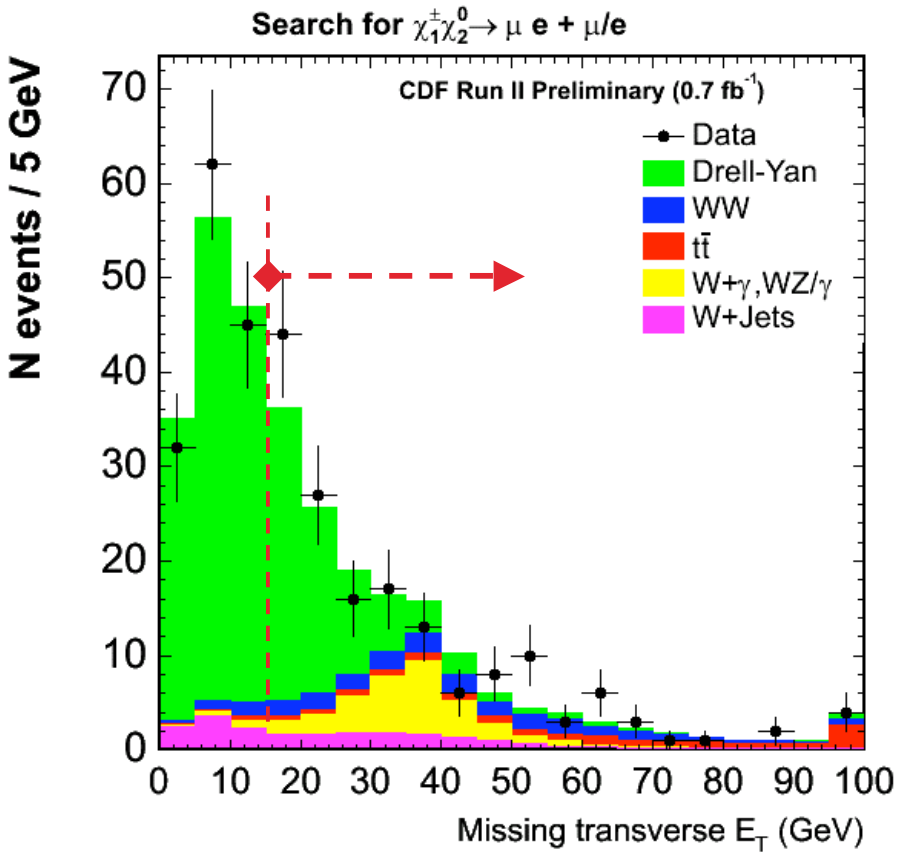
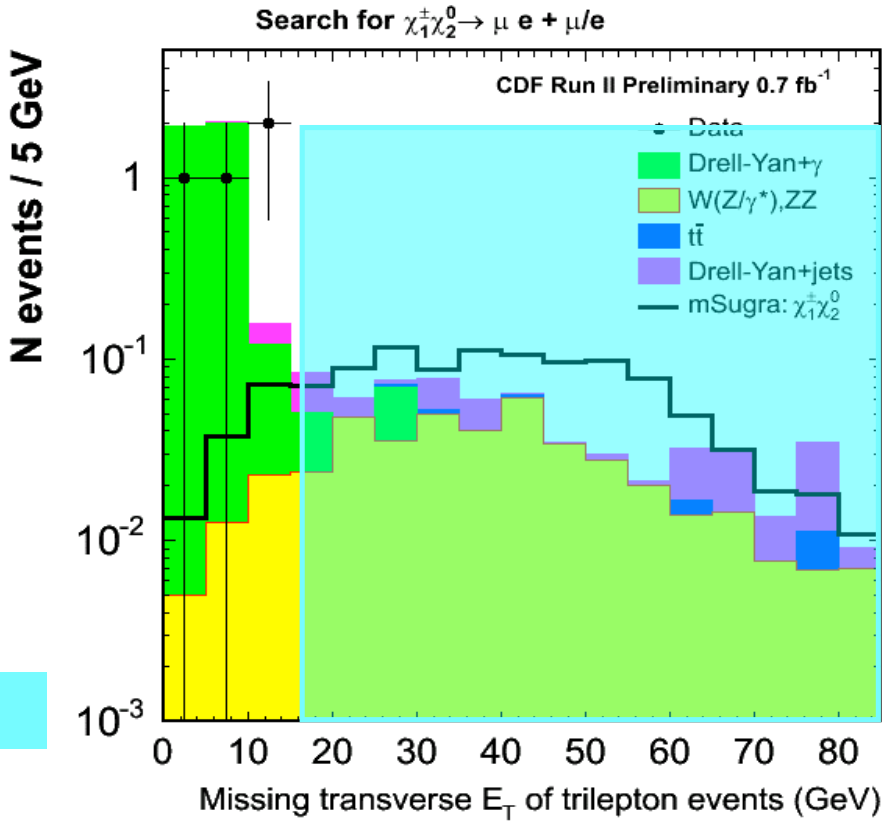
(III) MET selection

Further reducing DY by asking MET > 15 GeV





...Still BLIND !

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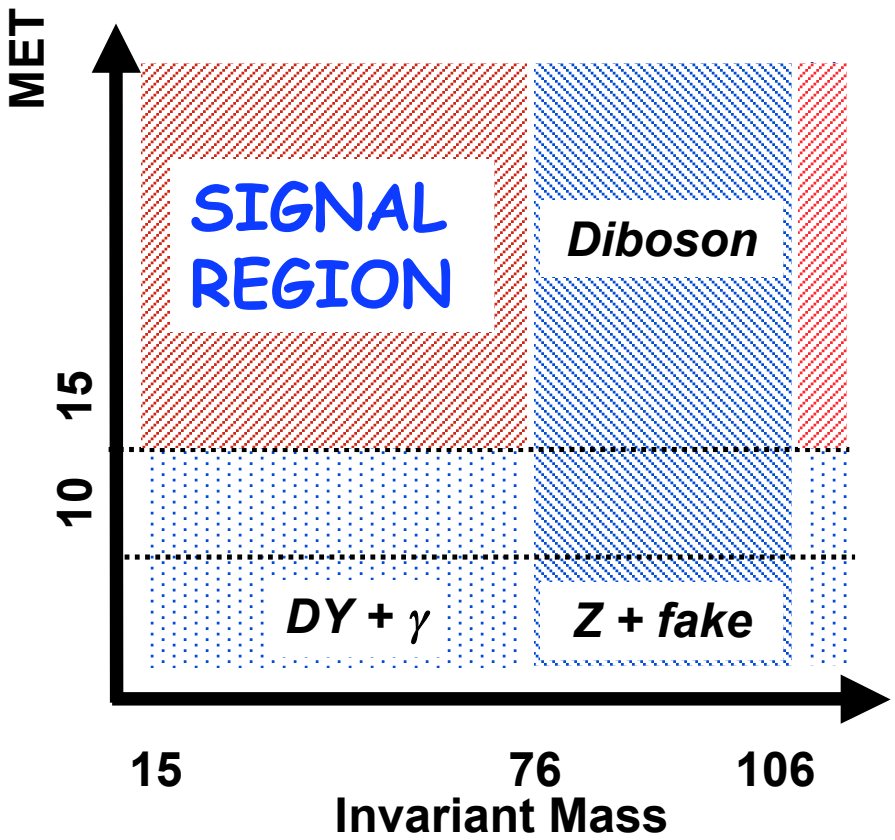
Understanding of the Data: The Control Regions

Control regions defined as a function of M($\ell\ell$) and MET:

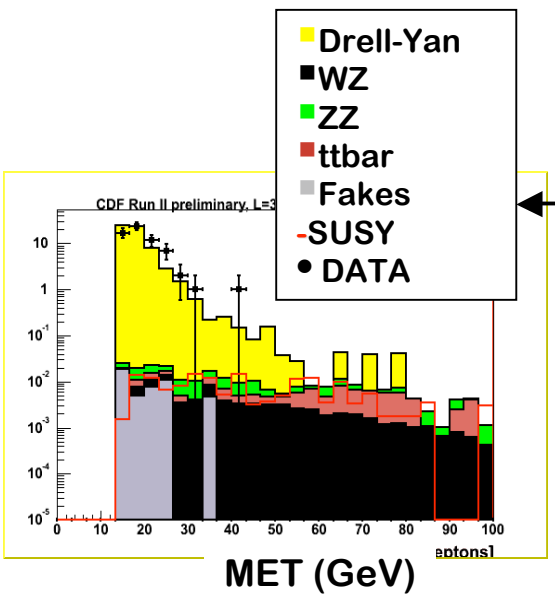


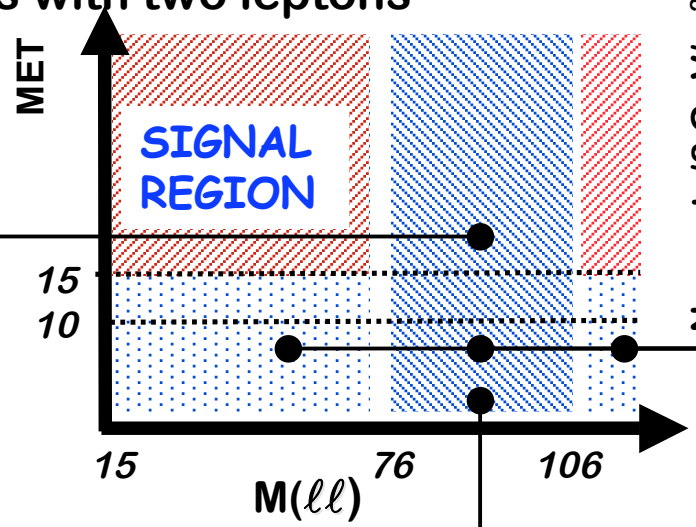
Each CONTROL REGION is investigated:

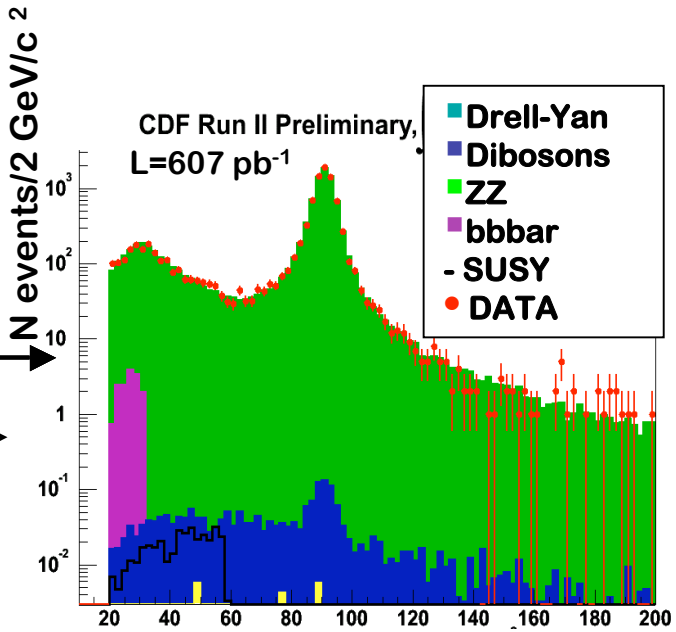
- ✓ with different jet multiplicity
  check NLO processes
- ✓ with 2 leptons requirement
  gain in statistics
- ✓ with 3 leptons requirement
  signal like topology

Control Regions for Trilepton Analyses

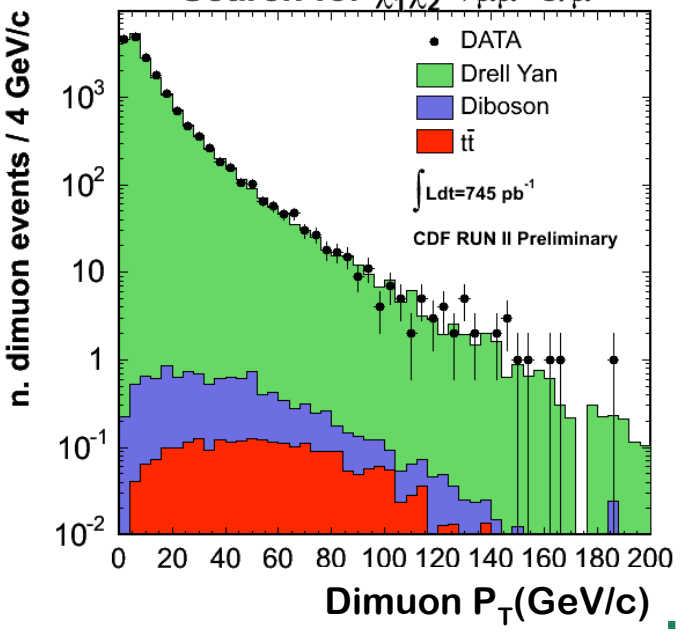
Testing Control Regions with two leptons







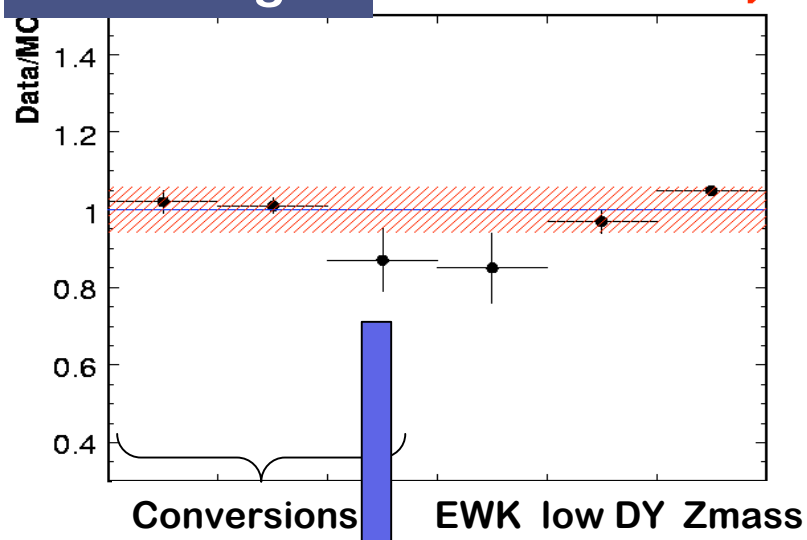
Search for $\chi_1^{\pm}\chi_2^0 \rightarrow \mu\mu + e/\mu$



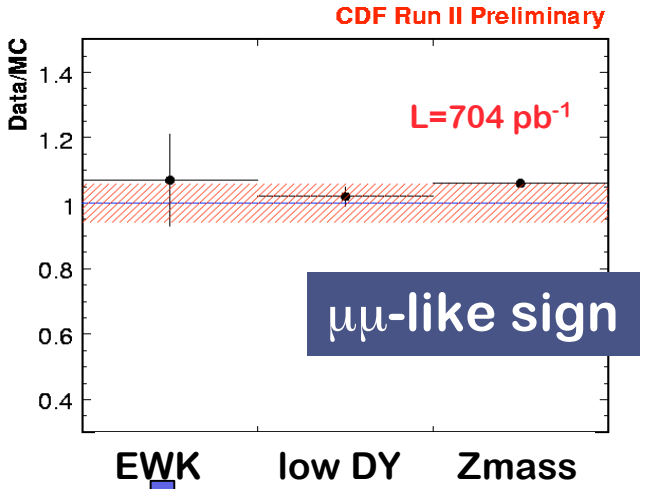
LS-dilepton analysis has additional Control Regions to test conversion removal

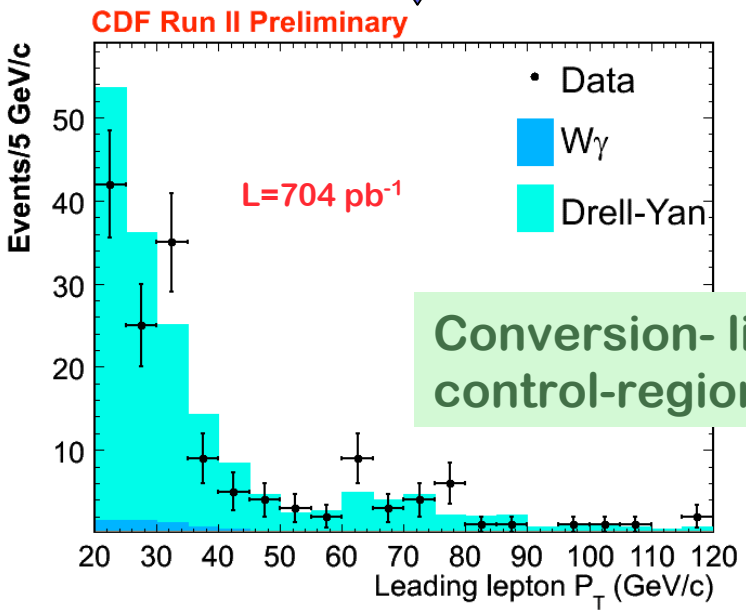
LS-Dileptons Control Regions

ee-like sign

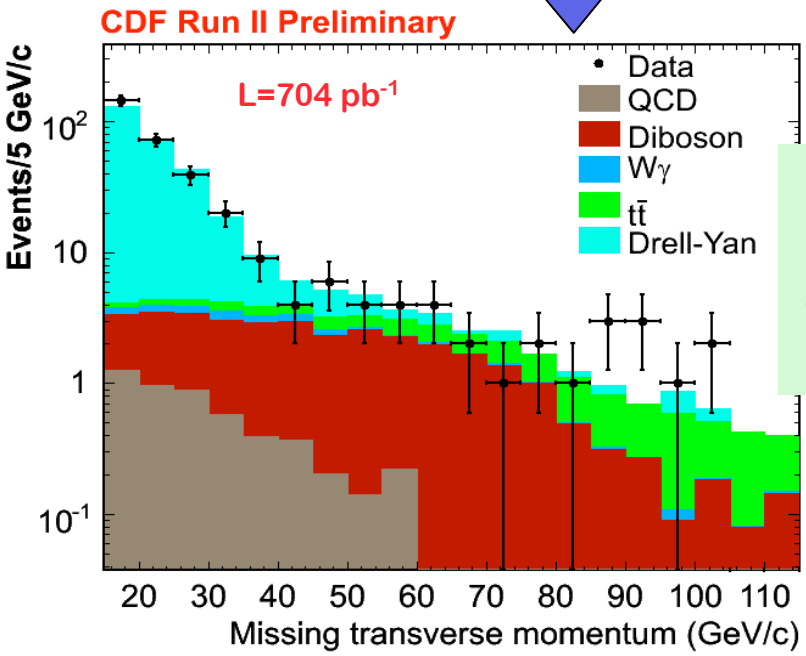


Very good agreement between SM prediction and observed data





Conversion- like control-region



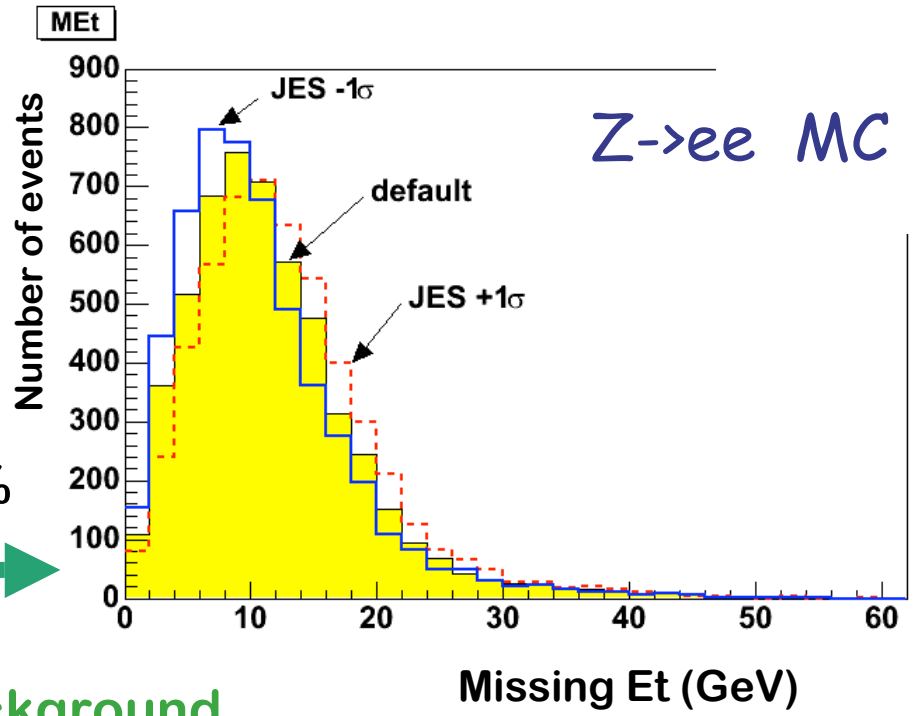
Signal-like but opposite sign

Systematic uncertainty

Major systematic uncertainties affecting the measured number of events

ee+lepton (high-pt)

- Signal
  - Lepton ID 5%
  - Muon p_T resolution 7%
- Background
  - Fake lepton estimate method 5%
  - Jet Energy Scale 22%



- Common to both signal and background
  - Luminosity 6%
  - Theoretical Cross Section 6.5-7%
  - PDFs 7%

Let’s look at the signal region !

Results !

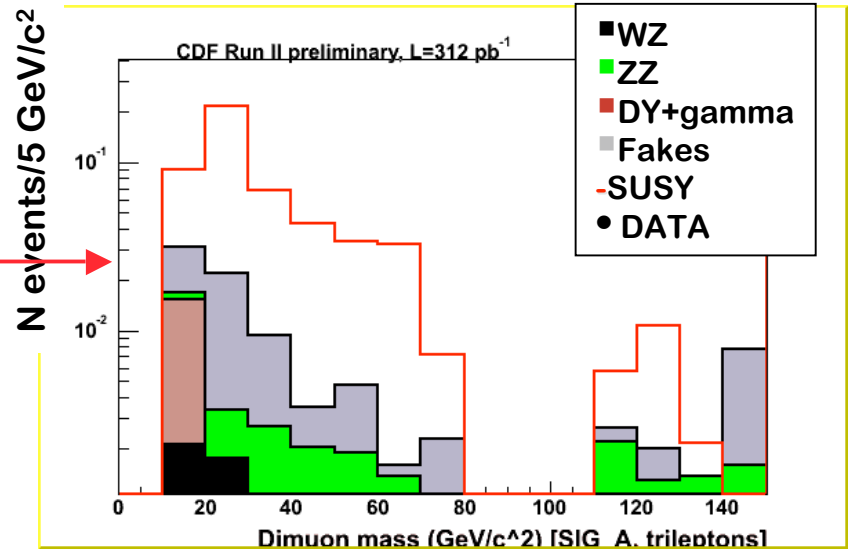
Look at the "SIGNAL" region

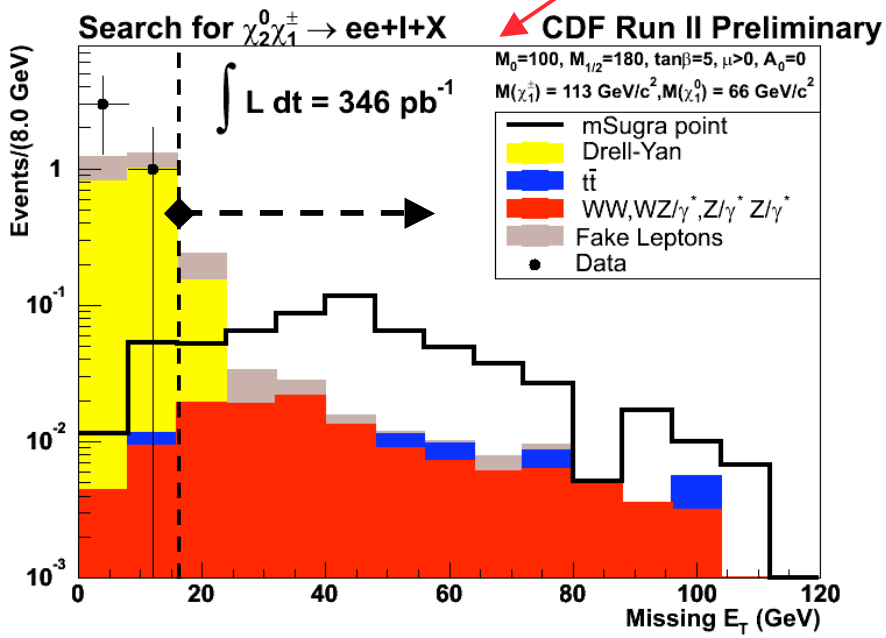
	Analysis	Luminosity (pb^{-1})	Total predicted background	Example SUSY Signal	Obs-erved data
LS dileptons	$e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}, \mu^{\pm}\mu^{\pm}$	710	6.80±1.00	3.18±0.33	?
Low-Pt trileptons	$\mu\mu$ +e/μ (low-p_T)	310	0.13±0.03	0.17±0.04	
	ee+track	610	0.48±0.07	0.90±0.09	
High-Pt trileptons	ee + e/μ	350	0.17±0.05	0.49±0.06	
	$\mu\mu$ +e/μ	750	0.64±0.18	1.61±0.22	
	μe +e/μ	750	0.78±0.15	1.01±0.07	

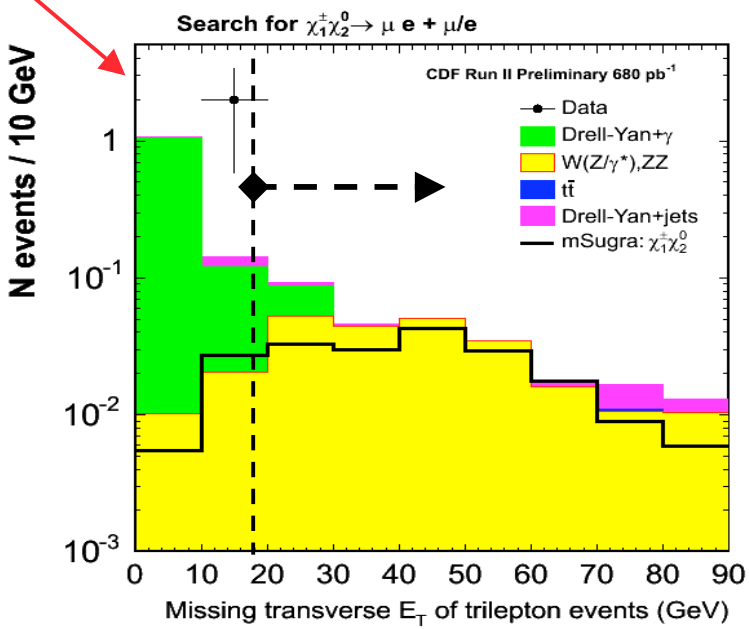
Results !

Look at the "SIGNAL" region

Analysis	Luminosity (pb^{-1})	Total predicted background	Example SUSY Signal	Observed data
$e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}, \mu^{\pm}\mu^{\pm}$	710	6.80±1.00	3.18±0.33	9
$\mu\mu$ +e/μ (low-p_T)	310	0.13±0.03	0.17±0.04	0
ee+track	610	0.48±0.07	0.90±0.09	1
ee + e/μ	350	0.17±0.05	0.49±0.06	0
$\mu\mu$ +e/μ	750	0.64±0.18	1.61±0.22	1
μe +e/μ	750	0.78±0.15	1.01±0.07	0





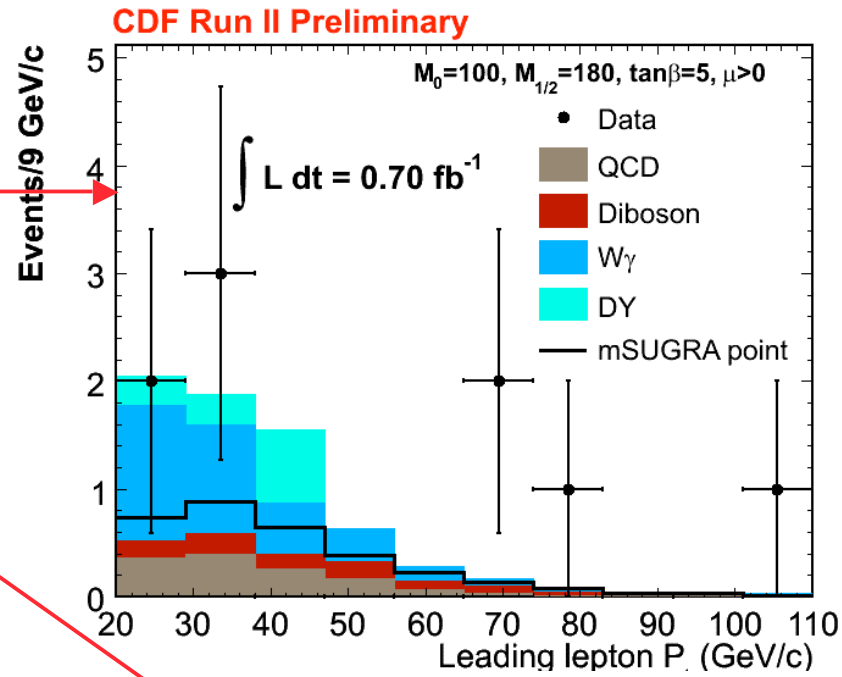


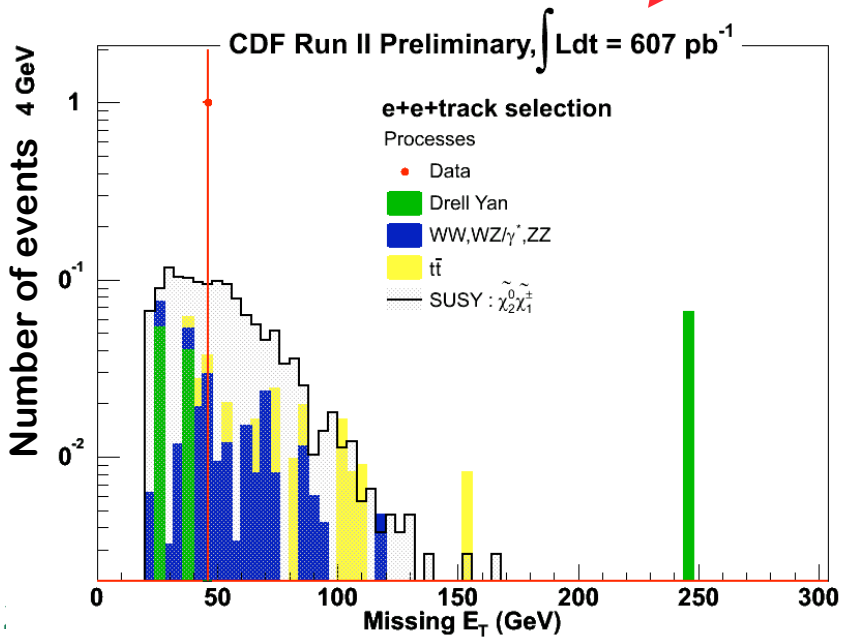
'pool

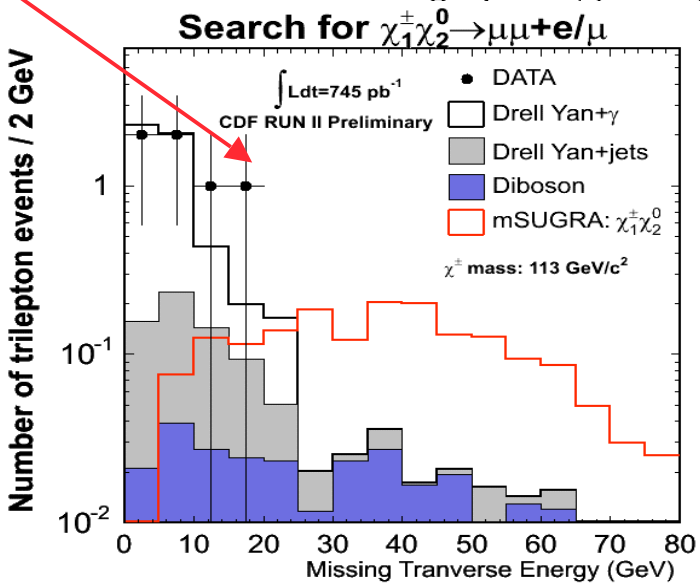
Results !

Look at the "SIGNAL" region

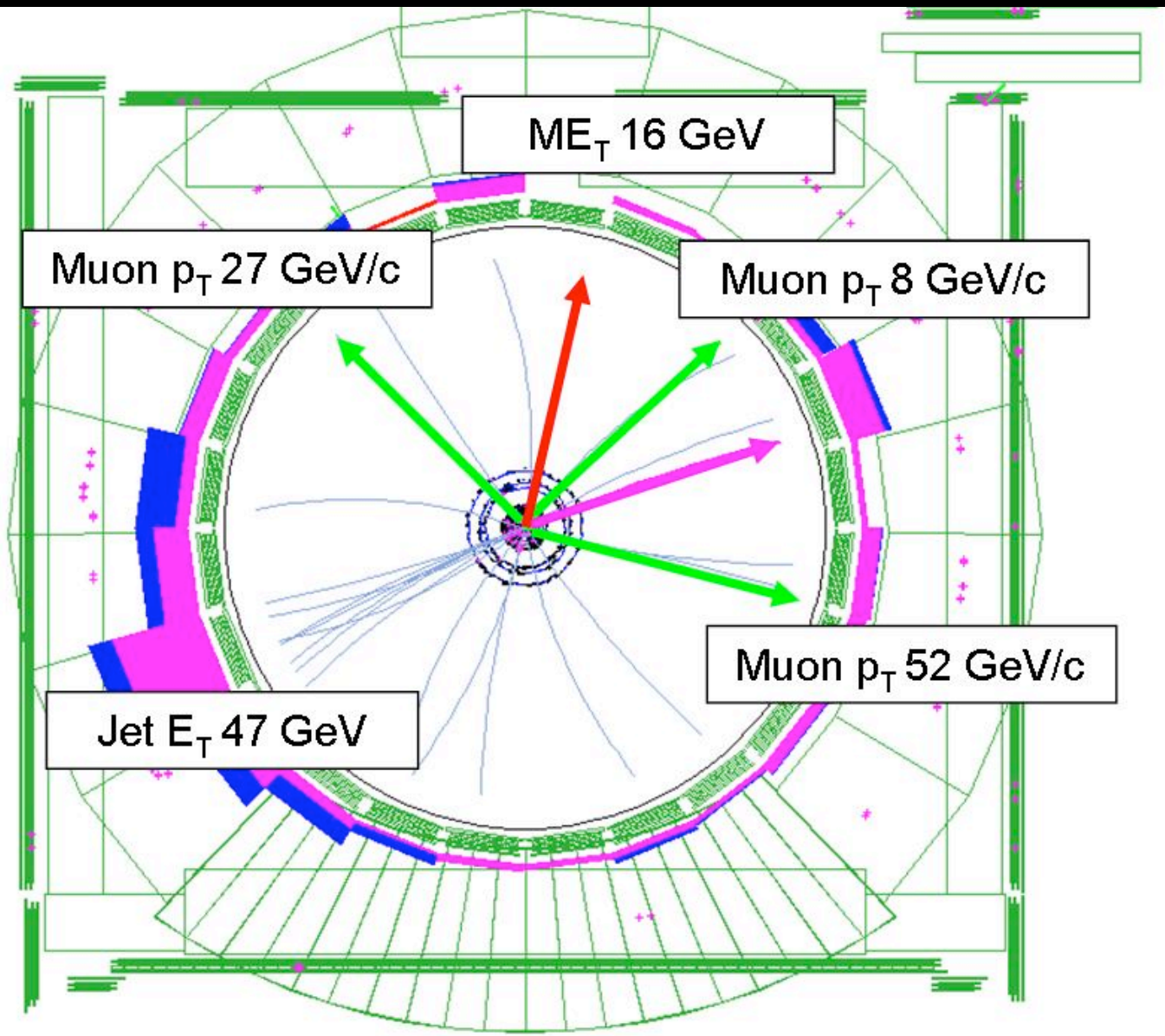
Analysis	Luminosity (pb^{-1})	Total predicted background	Example SUSY Signal	Observed data
$e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}, \mu^{\pm}\mu^{\pm}$	710	6.80±1.00	3.18±0.33	9
$\mu\mu$ +e/μ (low-p_T)	310	0.13±0.03	0.17±0.04	0
ee+track	610	0.48±0.07	0.90±0.09	1
ee + e/μ	350	0.17±0.05	0.49±0.06	0
$\mu\mu$ +e/μ	750	0.64±0.18	1.61±0.22	1
μe +e/μ	750	0.78±0.15	1.01±0.07	0





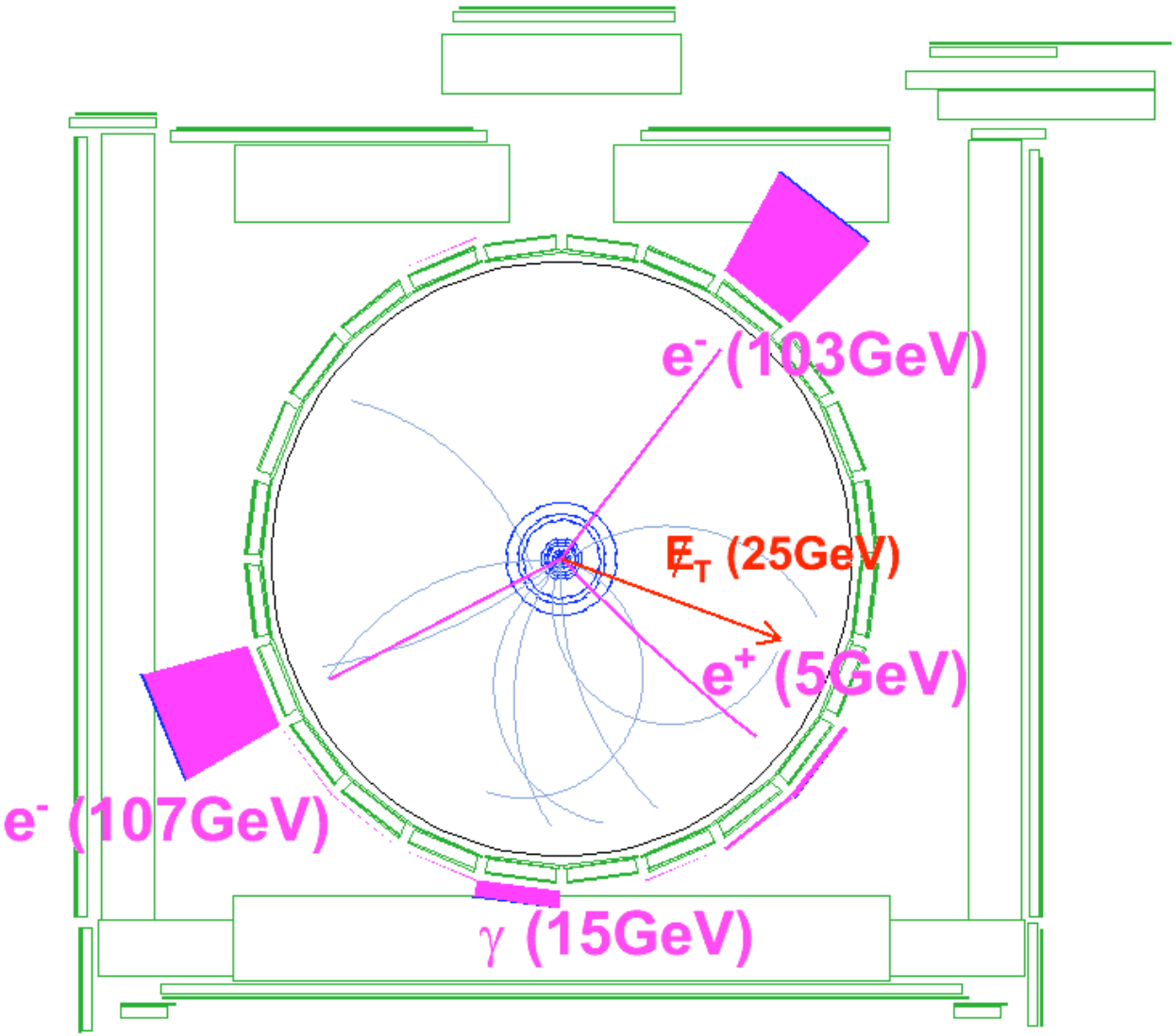


Trimuon Event



Highest lepton-pt event

In the ee like-sign analysis, we observe one interesting event



Limit

No SUSY :(

- Combined all analyses to obtain a limit on the mass of the chargino in mSugra-like scenario
  - ➡ with no slepton mixing
  - ➡ slepton masses ~ neutralino masses
- Observed limit:

  $M(\chi^{\pm}_1) \sim 127$ GeV/c^2

  σxBR ~ 0.25 pb

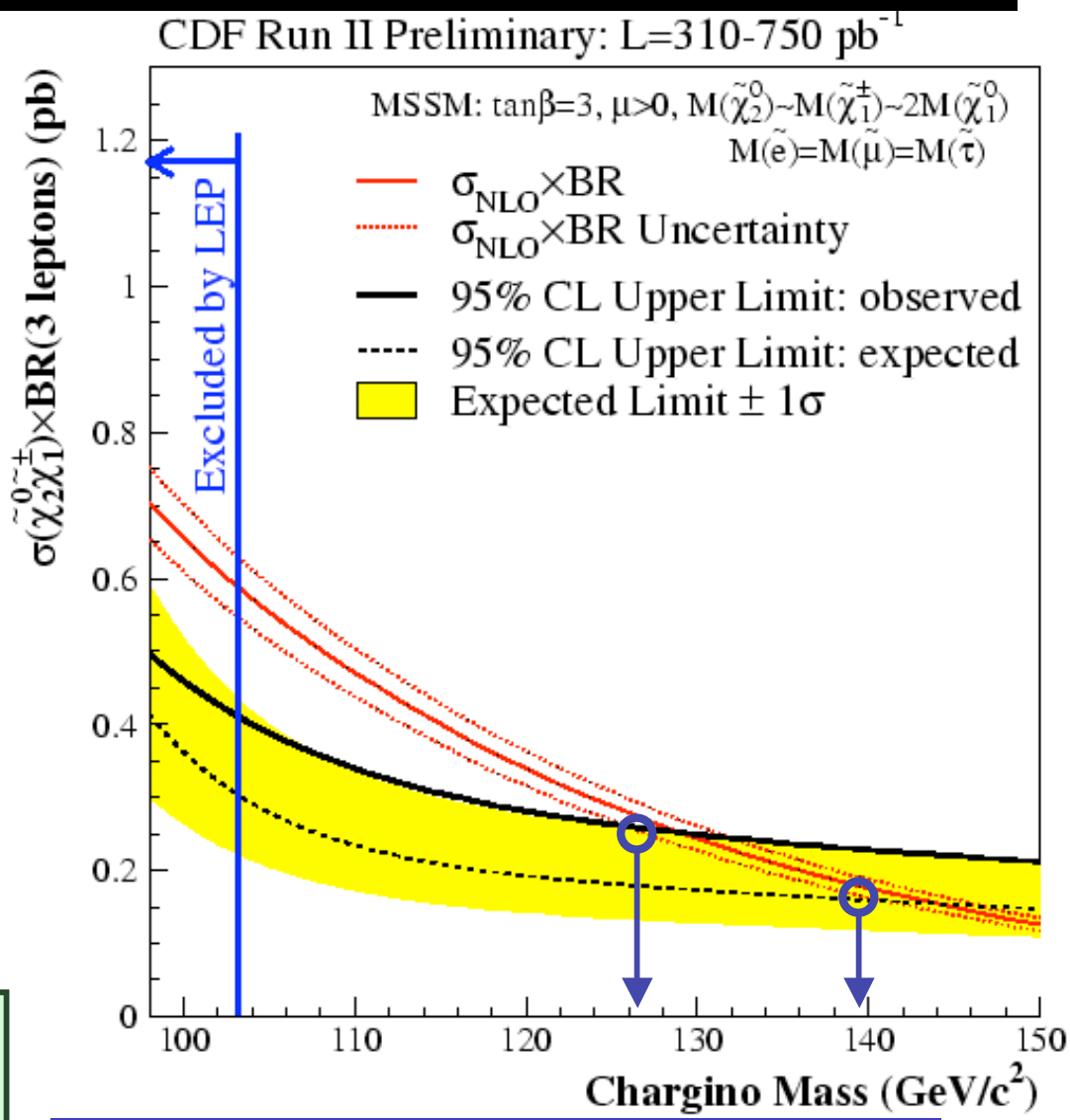
- Sensitive up to masses

  $M(\chi^{\pm}_1) \sim 140$ GeV/c^2

  σxBR ~ 0.2 pb

D0 limit in similar scenario:

$M(\chi^{\pm}_1) > 116$ GeV/c^2

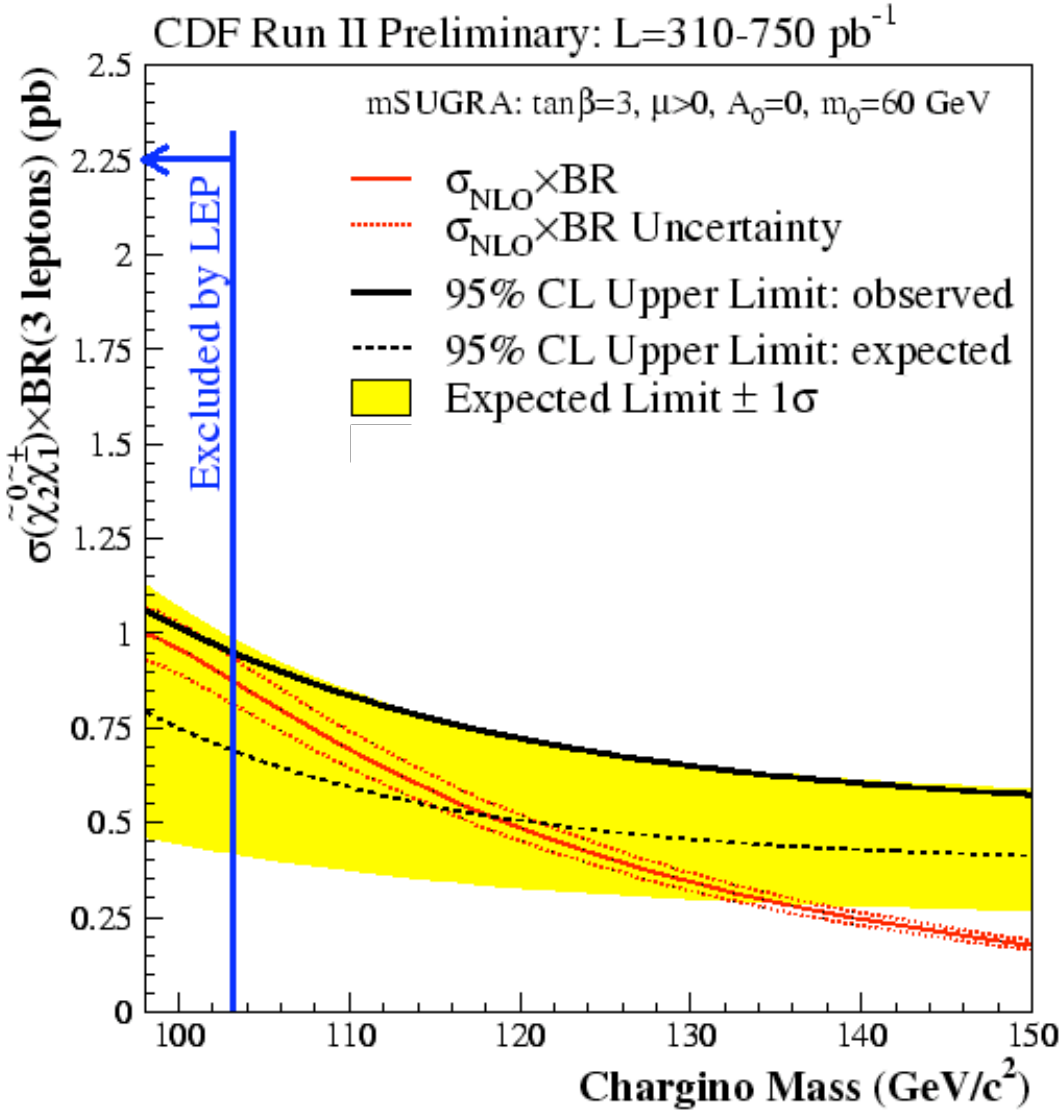


Beyond LEP and Tevatron Run I !

Looking at different models…

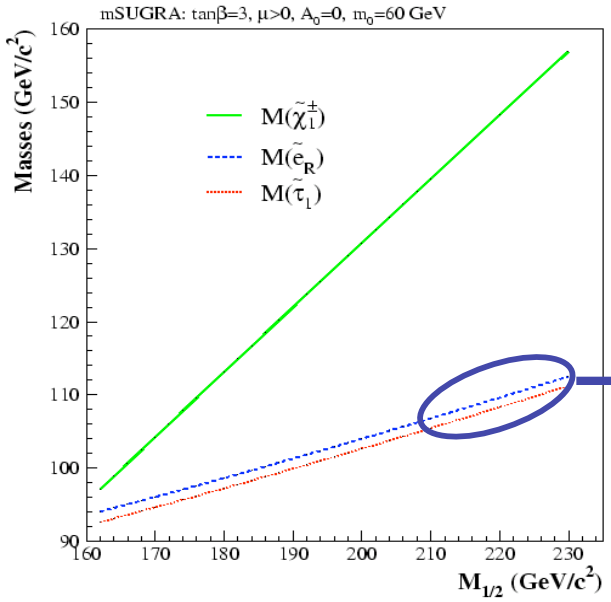
But : the limit we can set depends on the model !

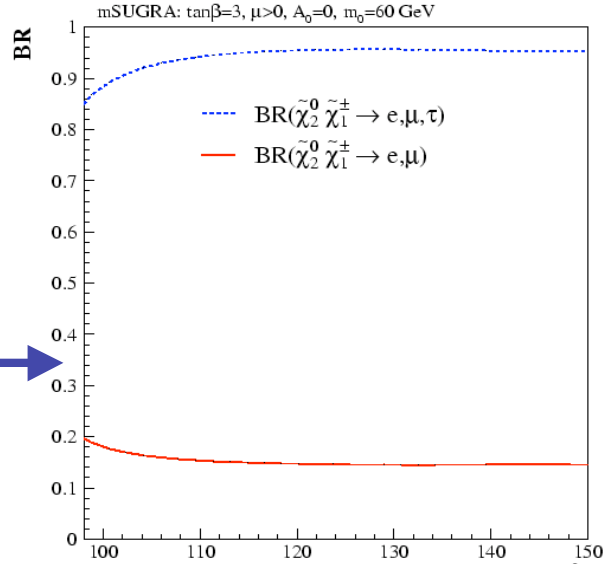
In "standard" mSugra
Sensitive to chargino masses of ~ 116 GeV/c²

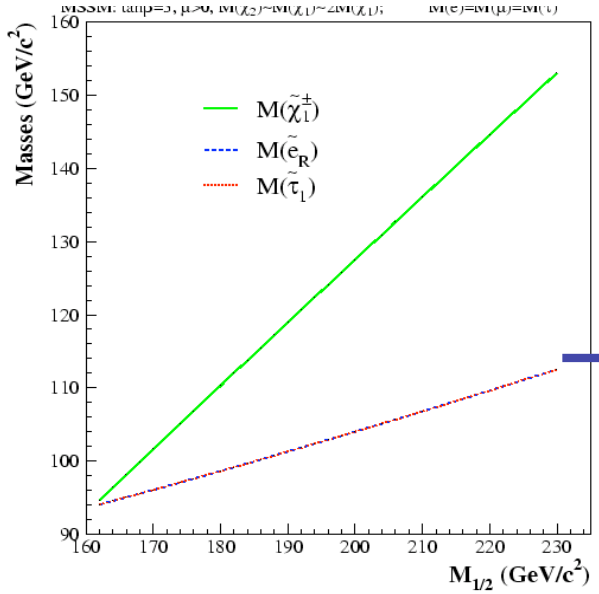


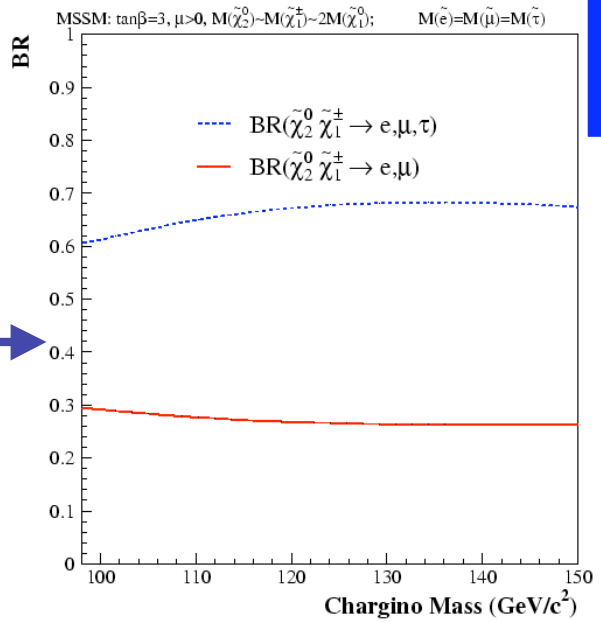
Not able to exclude this particular region of parameter space with these results …

The differences in the models









In Standard mSugra the BR into taus is enhanced

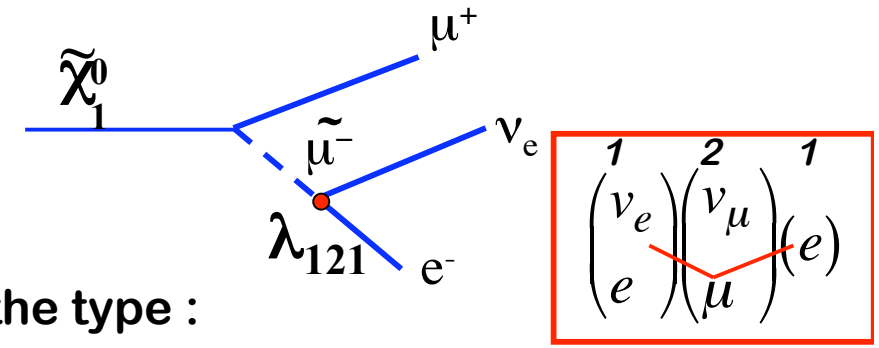
↓

smaller acceptance

From trileptons to multileptons...

R-Parity Violating SuperSymmetry

- If R-Parity violated sparticles :
  - Do not need to be pair-produced
  - Can decay into SM particles



- Extra terms in the Super-Potential of the type :

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

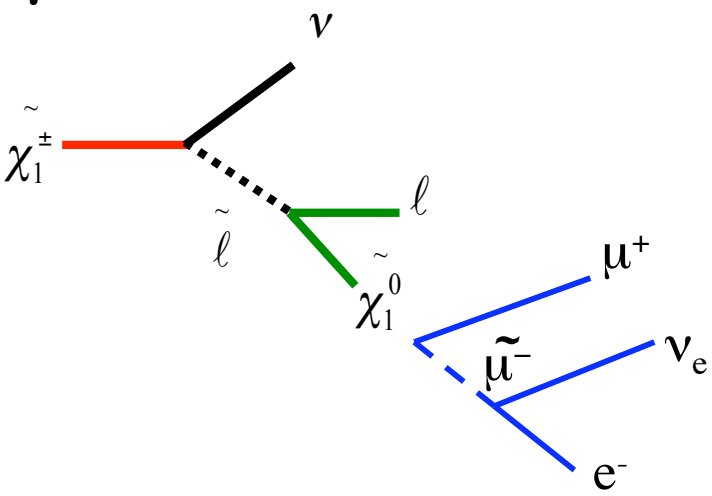
violates Lepton number conservtion

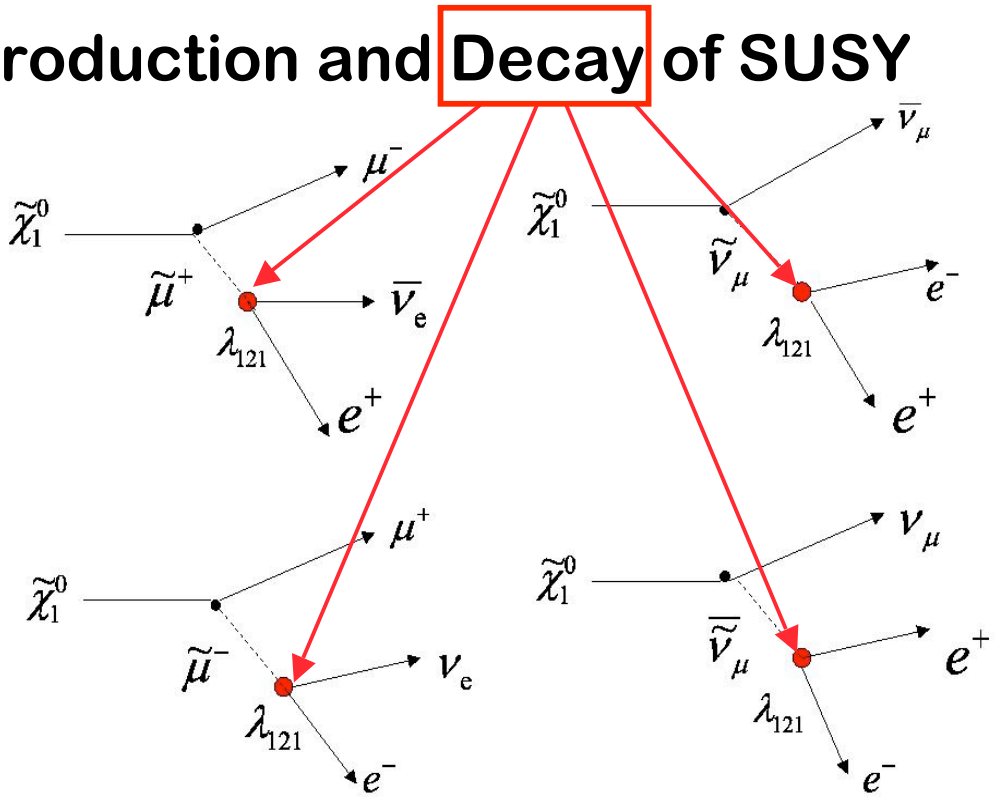
violates Baryon number conservation

- $\lambda, \lambda', \lambda''$: couplings of the RPV vertex;

R Parity Violation

- RPV can be tested in Production and Decay of SUSY particles





RPV decay of LSP(χ^0_1)

At least four leptons in final state !

- λ_{121} ->(eeee,eeeμ,eeμμ) +νν
- λ_{122} ->(μμμμ,μμμe,μμee) +νν

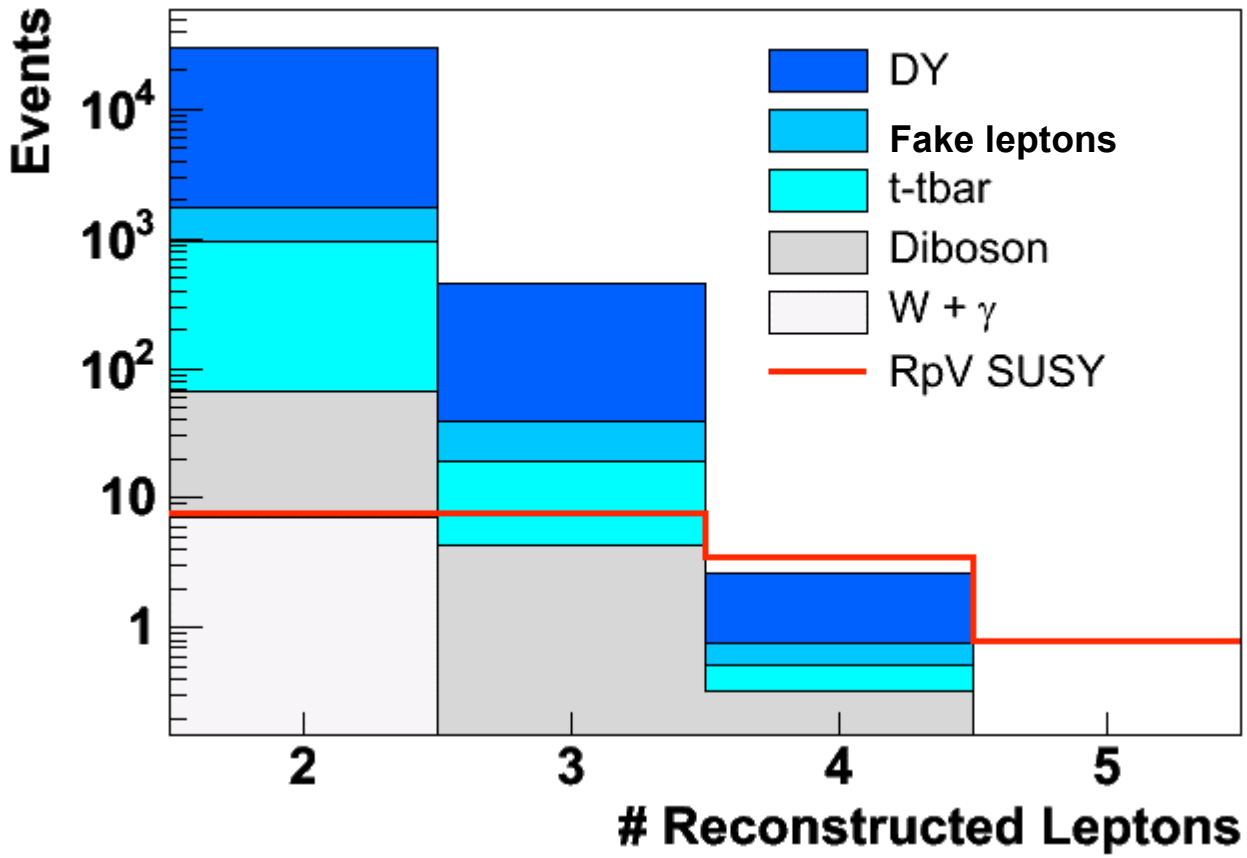
} *Only one $\lambda_{ijk} \neq 0$: at the time*

LSP assumed to decay within the detector (|d0|<0.02 cm)

Backgrounds

- Similar backgrounds to trileptons analyses
  - Challenge: conversions
- Sensitive to all new physics with >4 leptons in the final state!!

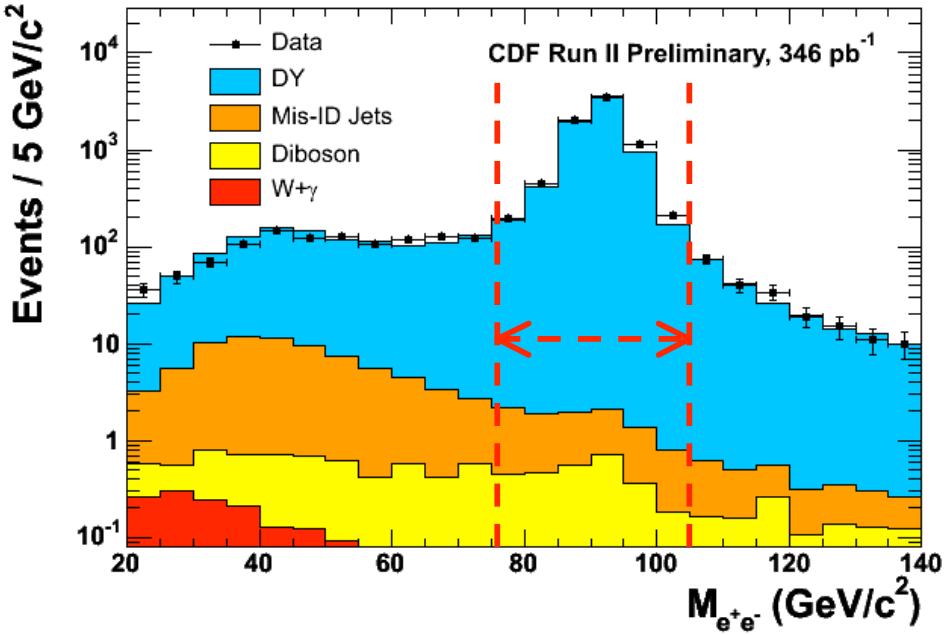
Luminosity = 346 pb^{-1}



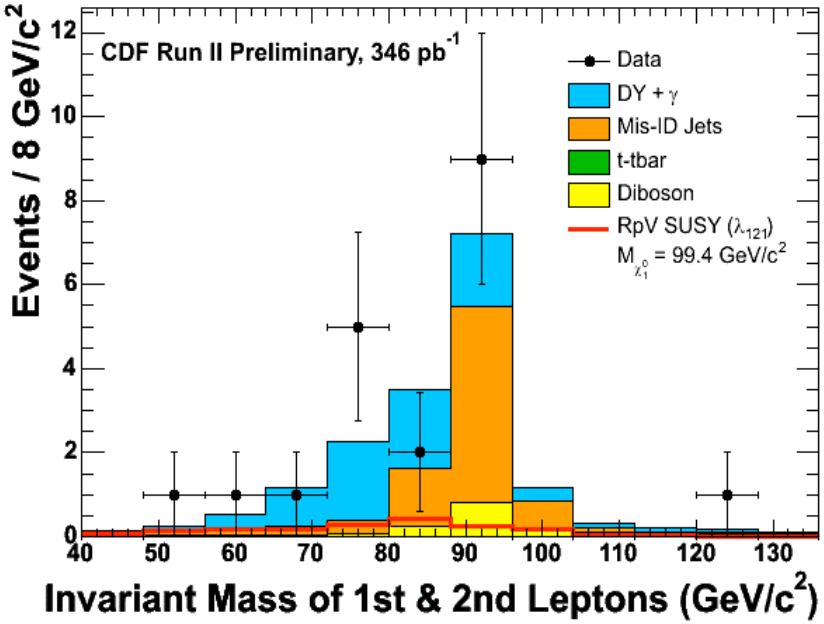
Control Regions

- Chosen changing the requirements on the lepton selection criteria, delta-phi, invariant mass

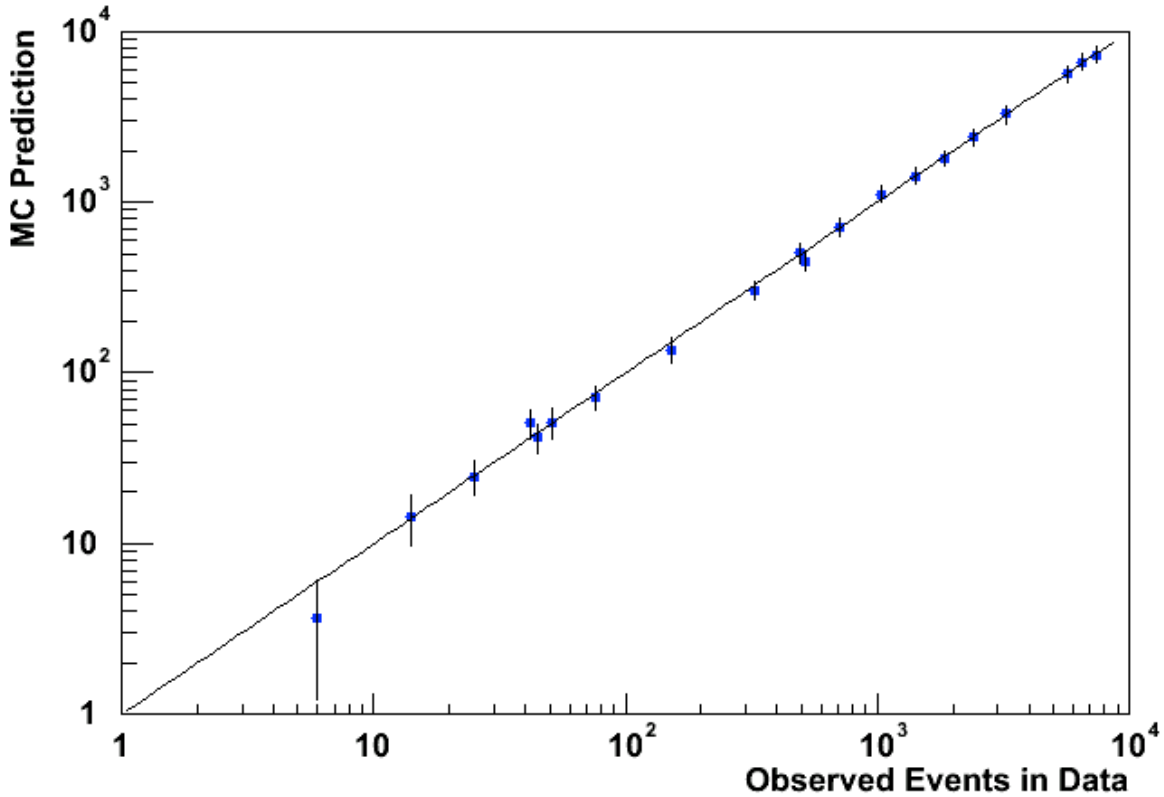
Dielectron events



Trilepton events



Control Region Overview



- 26 total control regions
  - By lepton type
  - Inside & outside Z window
  - Number of leptons
  - Fail $\Delta\phi$ cut
- Plot shows relative agreement of all control regions.
  - Error bars = $\pm 1\sigma$
  - Line = perfect agreement

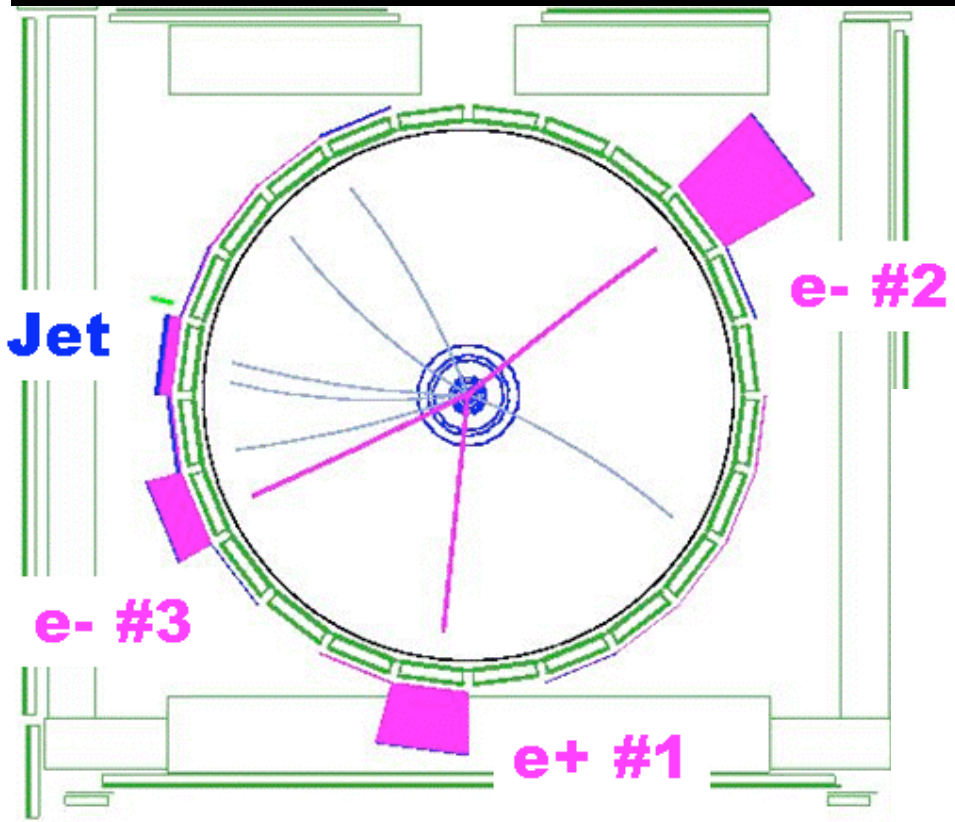
Signal Regions

Trilepton Signal Regions		
Dataset	ee(μ)+e/μ (λ_{121})	μμ(e)+e/μ (λ_{122})
$Z/\gamma^* + \gamma$	2.1 ± 0.8	1.2 ± 1.0
$W\ Z/\gamma^*$	0.2 ± 0.1	0.1 ± 0.1
Fakes	0.5 ± 0.3	0.3 ± 0.2
Total Background	2.9 ± 0.8	1.8 ± 1.0
RpV SUSY (λ_{121})	3.8 ± 0.4	-----
RpV SUSY (λ_{122})	-----	4.0 ± 0.4
Data		

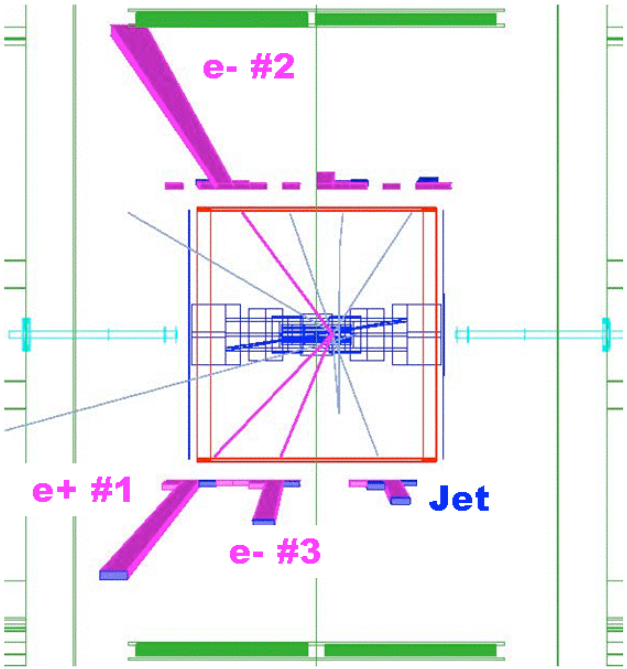
≥ 4 Signal Region	
Dataset	Signal
$Z/\gamma^* + \gamma\gamma$	0.001 ± 0.001
$Z/\gamma^* + Z/\gamma^*$	0.004 ± 0.002
Fakes	0.004 ± 0.003
Total Background	0.008 ± 0.004
RpV SUSY (λ_{121})	1.5 ± 0.2
RpV SUSY (λ_{122})	1.5 ± 0.3
Data	

Signal regions are consistent with background and no signal

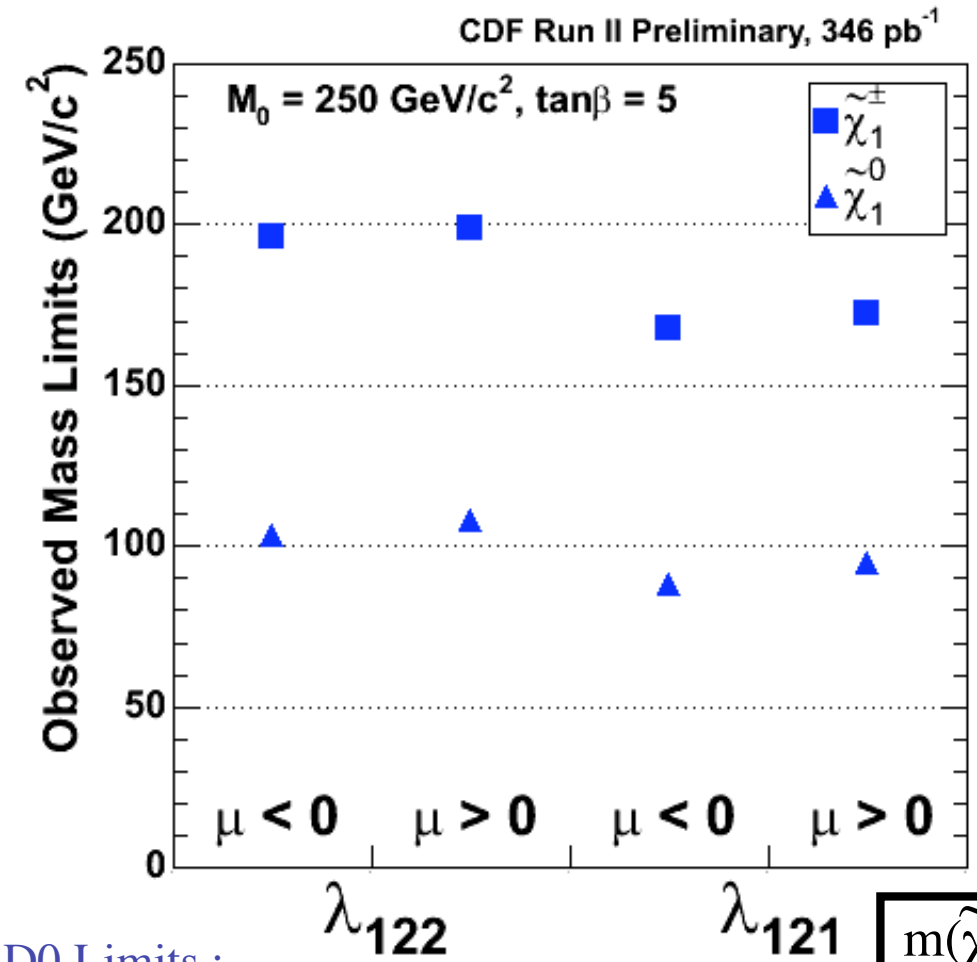
Event Display

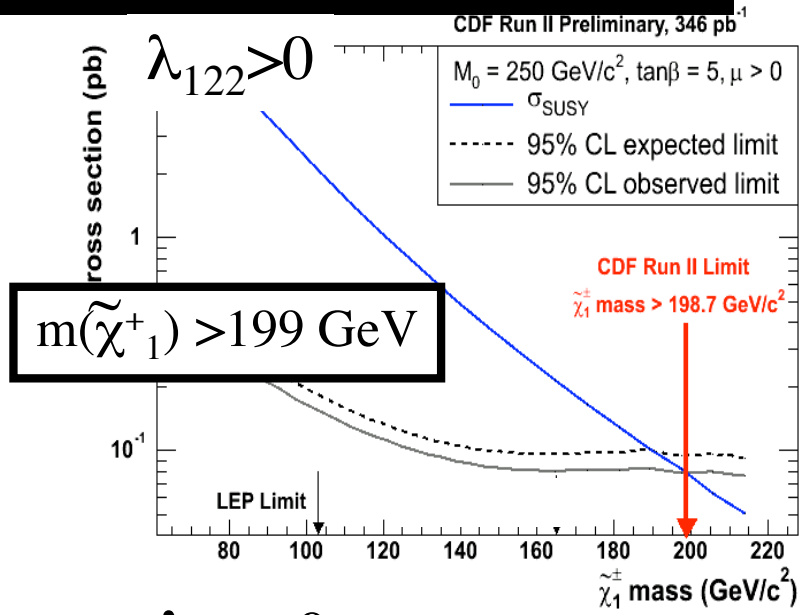


e+ #1	30 GeV
e- #2	50 GeV
e- #3	13 GeV
Jet	16 GeV

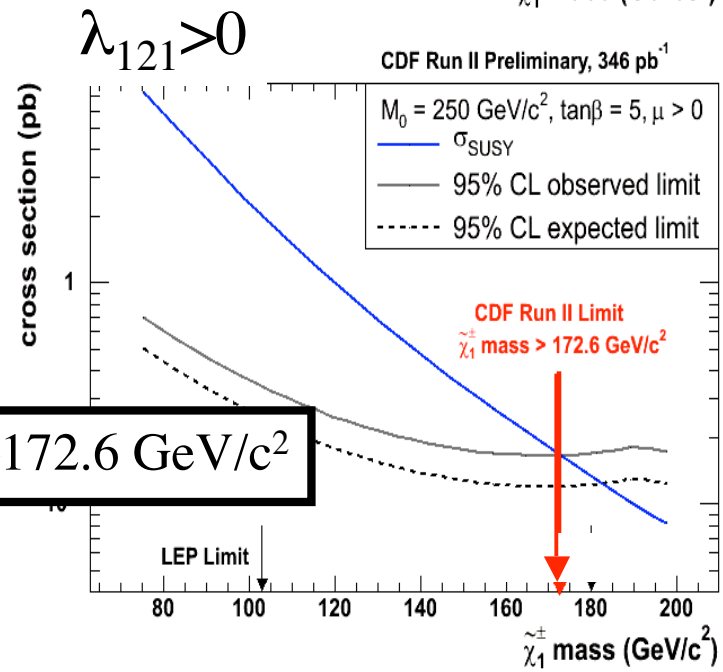


Limits !





$m(\tilde{\chi}^+_1)$ >199 GeV



$m(\tilde{\chi}^+_1)$ >172.6 GeV/c^2

D0 Limits :

λ_{122} >0 : $m(\chi^+_1)$ >229 GeV/c^2

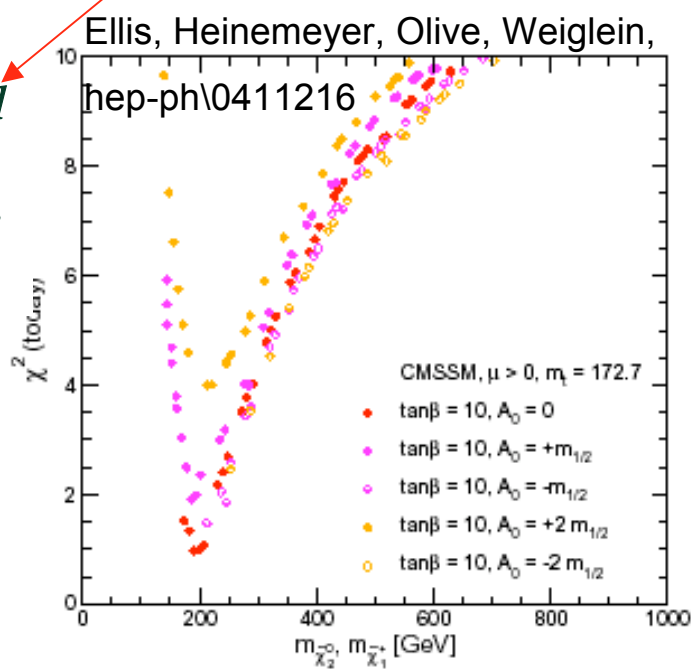
λ_{121} >0 : $m(\chi^+_1)$ >231 GeV/c^2

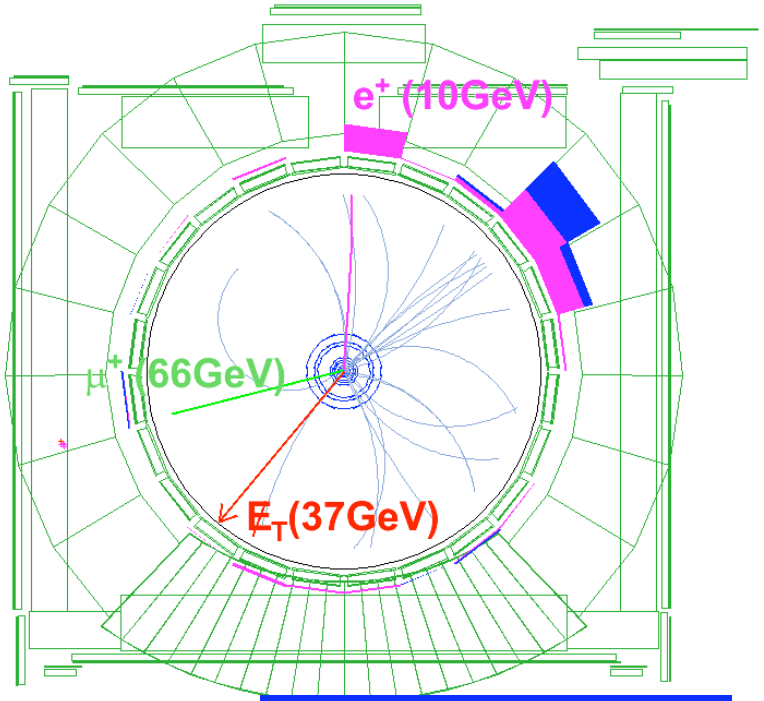
Summary and Outlook: Chargino and Neutralino in mSugra

Multileptons signatures:

- CDF analysed first bunch of data and observed no excess
- Set limit already beyond LEP results ! (although model dependent)
- 1.5 fb^{-1} of data collected and ready to be analysed
- With 4-8 fb^{-1} by the end of RunII we should be sensitive to Chargino masses up to ~250 GeV and σxBR ~ 0.05-0.01 pb !!

Favoured by EW precision data





One eμ like sign event…