Multi-leptons in SUSY searches

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"Workshop on multi-lepton final states in search of new Physics at the LHC"

Lisbon, March 25th 2010

Outline

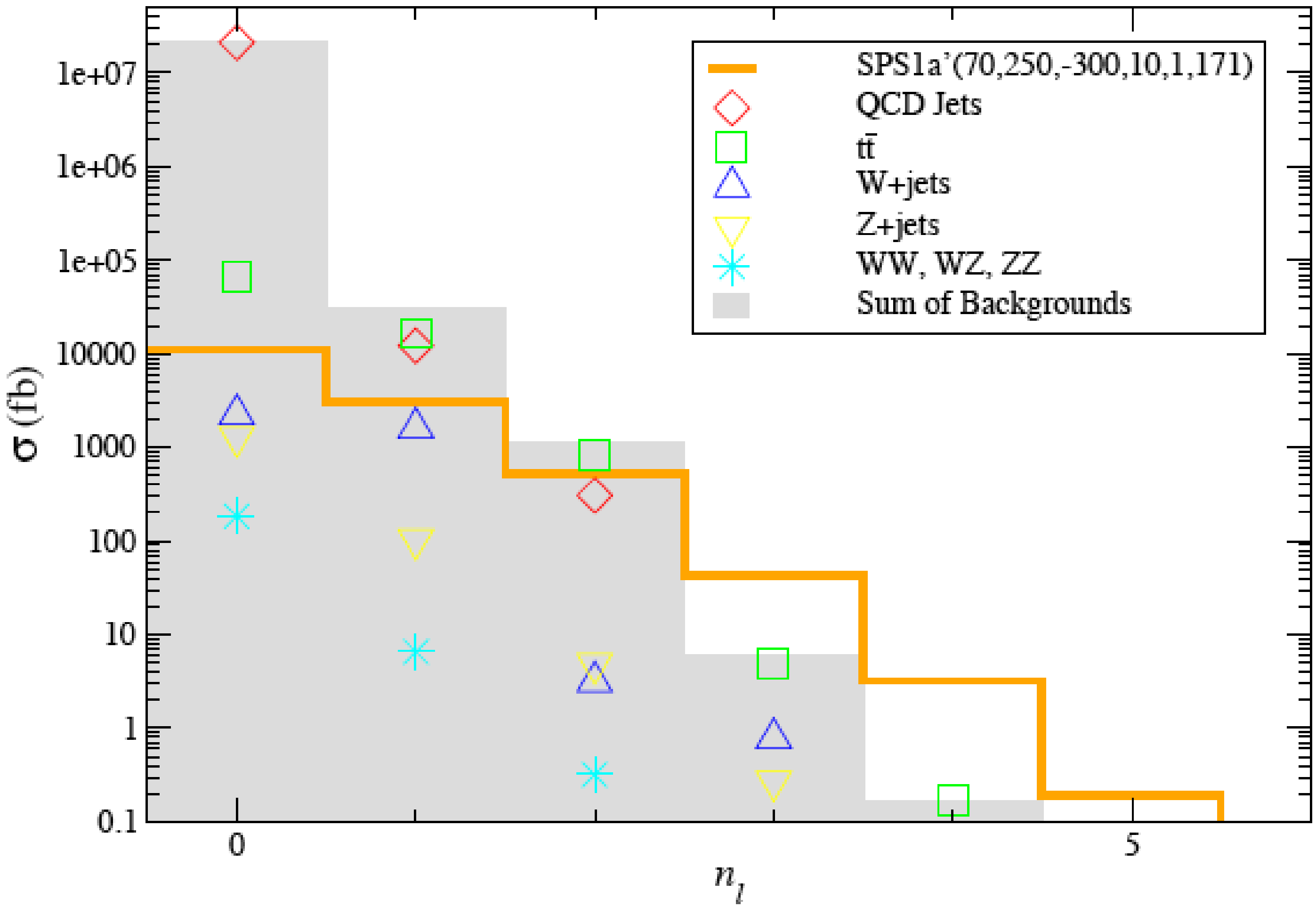
- The case for multi-leptons in SUSY searches
- A template multi-lepton analysis
  - CDF search for anomalous multi-lepton production
- Challenges for multi-lepton searches
  - Data driven estimates of backgrounds
  - Discrimination of new physics models
- Conclusions

The case for multi-leptons in SUSY searches

“Early SUSY discovery at LHC without missing ET : the role of multi-leptons”

H. Baer et all, Phys.Rev.D77:055017,2008

Isolated lepton multiplicity in events with ≥4 jets



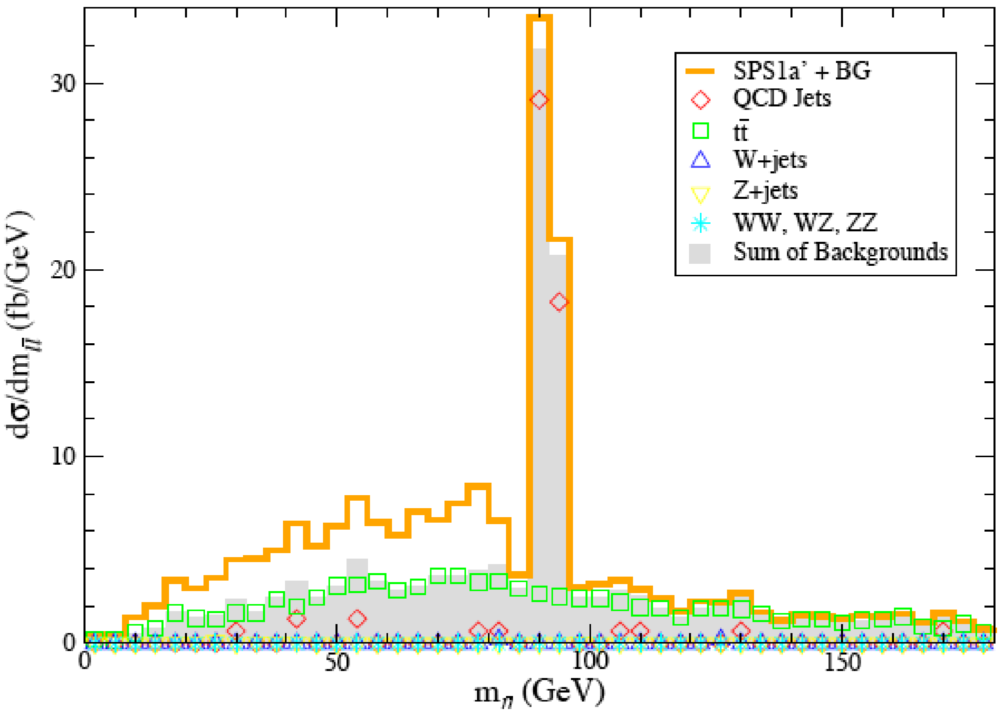
For n leptons ≥ 3 , signal is well above background

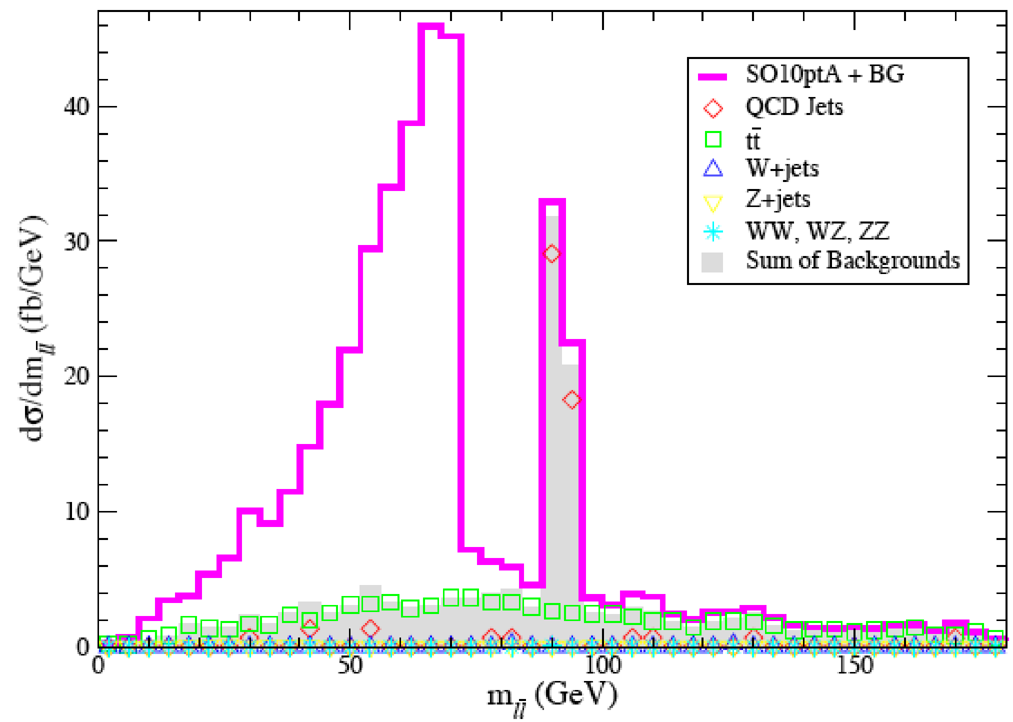
Fake leptons from jets are not simulated

The case for multi-leptons in SUSY searches

Even requiring only 2 leptons with OSSF there can be an evidence

H. Baer et all, Phys.Rev.D77:055017,2008





Characteristic invariant mass edge stands out against background

Given large enough event samples, some SUSY masses can be measured

CDF search for anomalous production of multi-lepton events

Phys.Rev.Lett.98:131804,2007

- **Search in 3 or ≥4 lepton (e, μ) data samples**

sqrt(s)=1.96 TeV
L=346 pb^{-1}

- **Dominant backgrounds**
  - Drell-Yan + additional leptons from
    - Photon conversions
    - Misidentified jets
  - Diboson (WZ,ZZ) production

- **No missing E_T or Jet cuts were applied → sensitive to multiple models**

- **Event selection**
  - All lepton tracks consistent with interaction point
  - Lepton isolation $E_T^{Iso}/E_T^{lepton} < 0.1$
  - Separation between leptons : $\Delta R \geq 0.4$
  - Rejection of OSSF lepton pairs with
    - Invariant mass between 76-106 GeV/c^2
    - Invariant mass bellow 15 GeV/c^2
    - $160^o < \Delta\phi < 200^o$
  - Invariant mass of two highest ET leptons > 20 GeV/c^2
    - To remove photon conversion and heavy flavour backgrounds

Validation of MC background estimates : control regions

Phys.Rev.Lett.98:131804,2007

Region	Criteria Failed	Predicted Background	Observed Events
Two-Lepton Control Samples			
ee	Z veto	13948 ± 1536	14019
ee		2142 ± 230	2125
$\mu\mu$	Z veto	7474 ± 809	7499
$\mu\mu$		1264 ± 141	1339
$e\mu$		117.6 ± 12.9	112
μe		186.8 ± 22.9	203
Three-Lepton Control Samples			
$ee\ell$	Z veto	8.8 ± 1.9	12
$\mu\mu\ell$	Z veto	5.1 ± 1.2	2
$e\mu\ell$	Z veto	0.55 ± 0.04	0
$\ell\ell\ell$	Z veto	14.4 ± 2.9	14
$ee\ell$	$\Delta\phi$ only	2.1 ± 0.3	2
$\mu\mu\ell$	$\Delta\phi$ only	1.2 ± 0.2	4
$e\mu\ell$	$\Delta\phi$ only	0.35 ± 0.04	0
$\ell\ell\ell$	$\Delta\phi$ only	3.7 ± 0.3	6
Four-or-More-Lepton Control Samples			
$\ell\ell\ell\ell$	Z veto	0.15 ± 0.02	0
$\ell\ell\ell\ell$	$\Delta\phi$ only	0.006 ± 0.003	0
Three-Lepton Signal Samples			
λ_{121} scenario		3.1 ± 0.8	5
λ_{122} scenario		1.9 ± 1.0	1
Four-or-More-Lepton Signal Sample			
λ_{121}, λ_{122} scenarios		0.008 ± 0.004	0

- Inversion of selection criteria in 3 and ≥4 lepton control samples

- **Agreement between MC predictions and observations**
  - **backgrounds are validated**

1. Examine signal samples

2. Results are consistent with no signal hypothesis

3. Set exclusion limits

- ≥4 l final sample is virtually background free

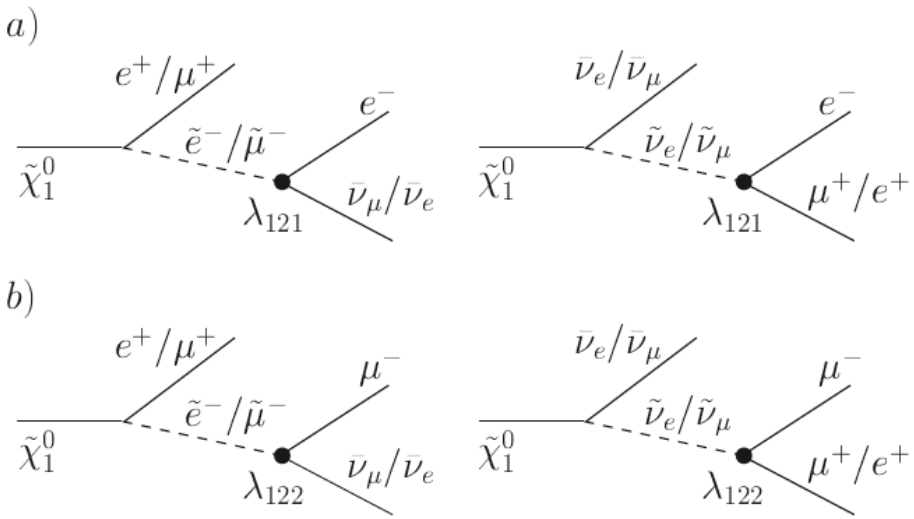
↓

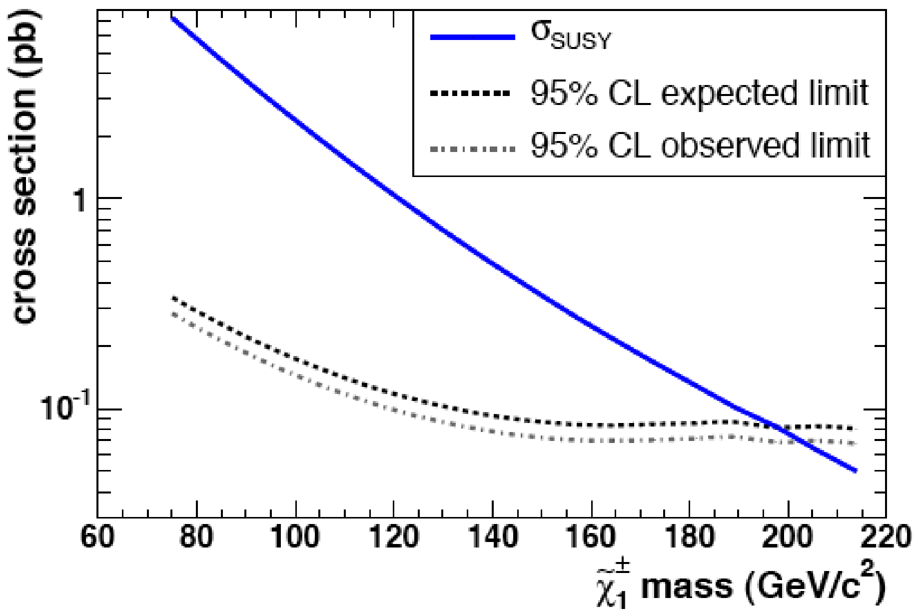
"excellent technique for detecting new physics with more Luminosity"

Limits on chargino mass

Phys.Rev.Lett.98:131804,2007

R-parity violation MSUGRA, M_0= 205 GeV/c, tan β= 5 , A_0 = 0





Systematical uncertainties on background predictions

3 leptons

Jets misidentification (13%), lepton identification (6%), luminosity (6%) , cross section (6%)
5 observed events : expected background 3.1 ± 0.7 (stat) ± 0.4 (syst)

≥4 leptons
Jets misidentified as leptons (41%), Drell-Yan+ γ MC statistics (38%)
0 observed events : expected background 0.008 ± 0.003 (stat) ± 0.003 (syst)

Challenges for multi-lepton searches

• Search for new physics in multi-leptons in a model independent way

1. Focus on topological inclusive signatures

• Multi-leptons signatures are rare searches
→ Must quantify the sum of small backgrounds
→ Deal with tails of lepton distributions

2. Use data-driven methods to estimate the background
Multiple approaches, as many cross checks as possible

• Discoveries imply a 5 sigma significance
3. Systematic uncertainties can limit the sensitivity

• Many models lead to similar predictions, if evidence of new physics is found
Which SUSY? : mSUGRA , MSSM, NMSSM ?
Other physics? : Universal Extra Dimensions, Little Higgs, fourth sequential generation of quarks, type III seesaw, ...

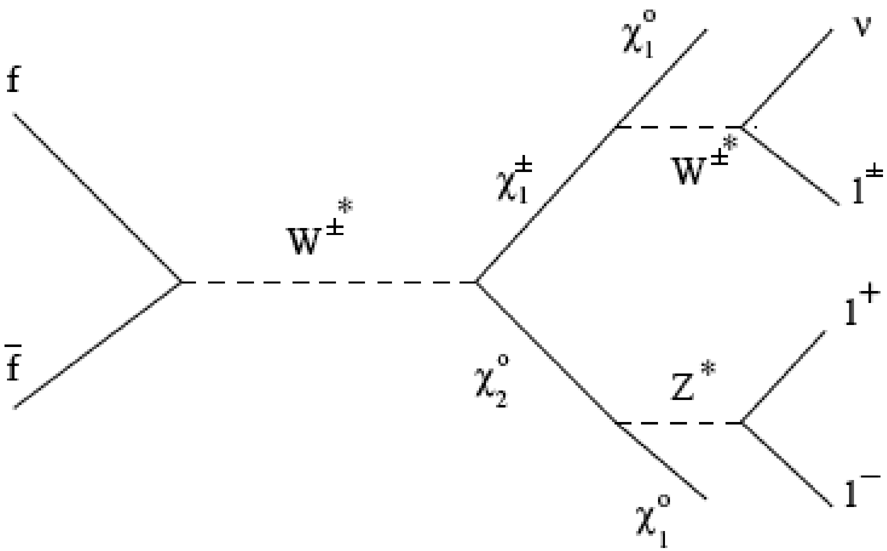
4. Strategies for the "LHC inverse problem"

Multi-lepton searches in SUSY

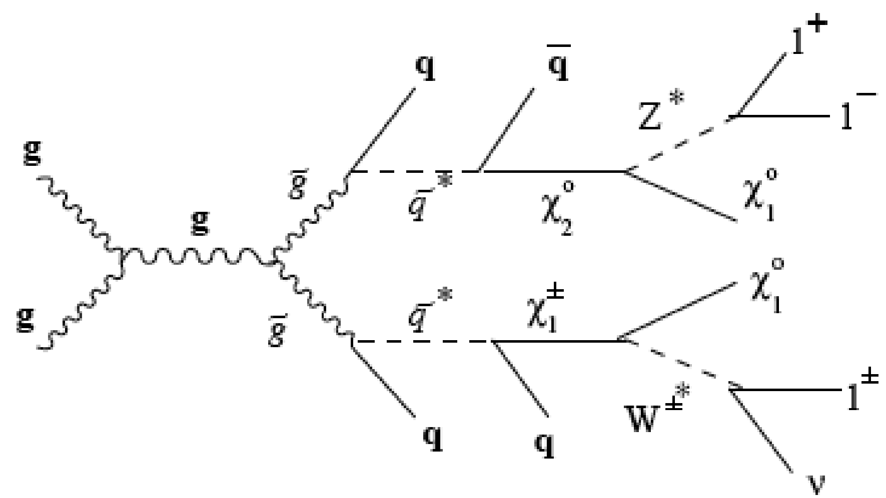
- SUSY can produce signatures with high or low p_T multi-leptons
- Even within the same model

A multi-lepton final state can be associated with multiple production mechanisms

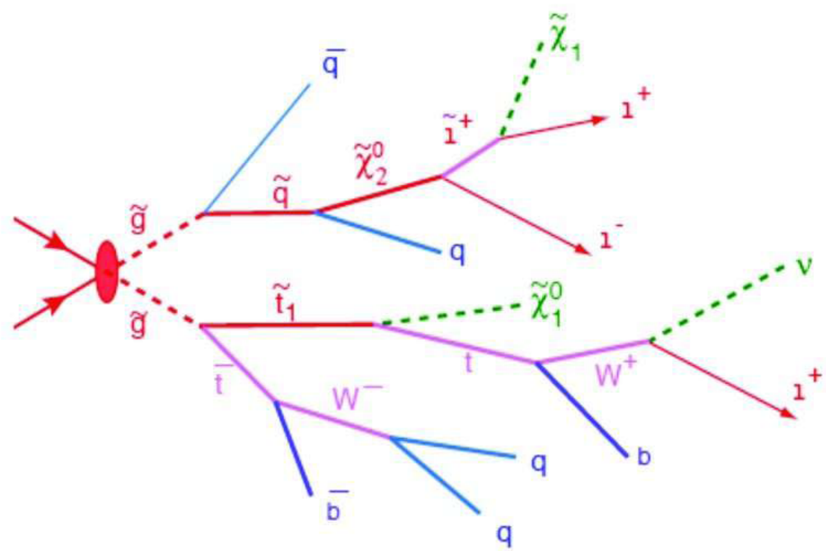
Gaugino production



Gluino production, cascade decays



Complex signature
Gluino production and decay to stop



Multi-lepton searches in Universal Extra Dimensions (UED)

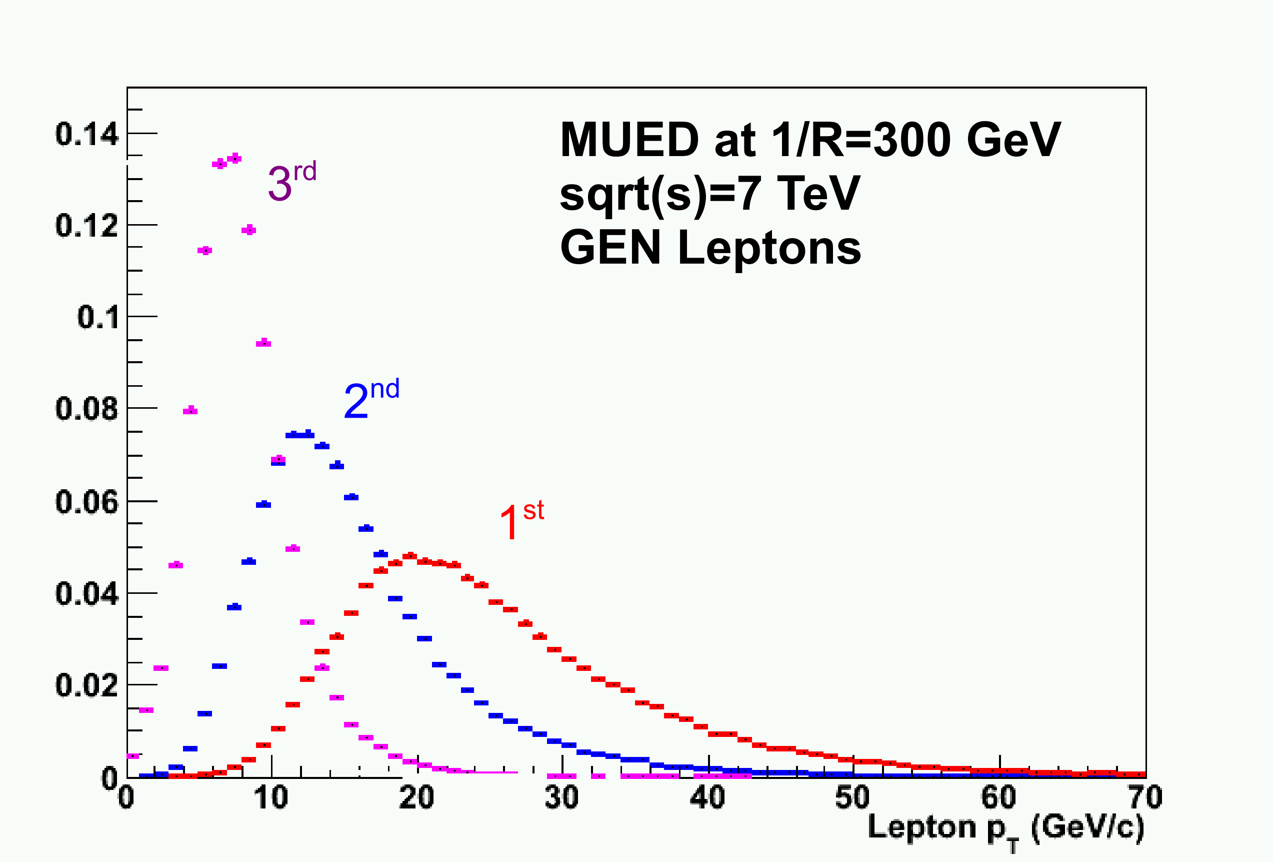
Appelquist, Cheng, Dobrescu Phys.Rev. D64 (2001) 035002

- UED produces signatures with low p_T multileptons

- All SM fields propagate along one compact flat extra ED with size ~ 1/TeV
- Model parameters : 1/R, Λ (cutoff scale) and m_{Higgs}

Golden Channel at LHC:

- Pair production of coloured KK states
- Cascade decay into 4 isolated leptons + jets + MET



Distinguishing feature of UED mass spectrum is degenerated → low p_T leptons

highest lepton with p_T < 50 GeV/c

lowest lepton with p_T ~ 5 GeV/c

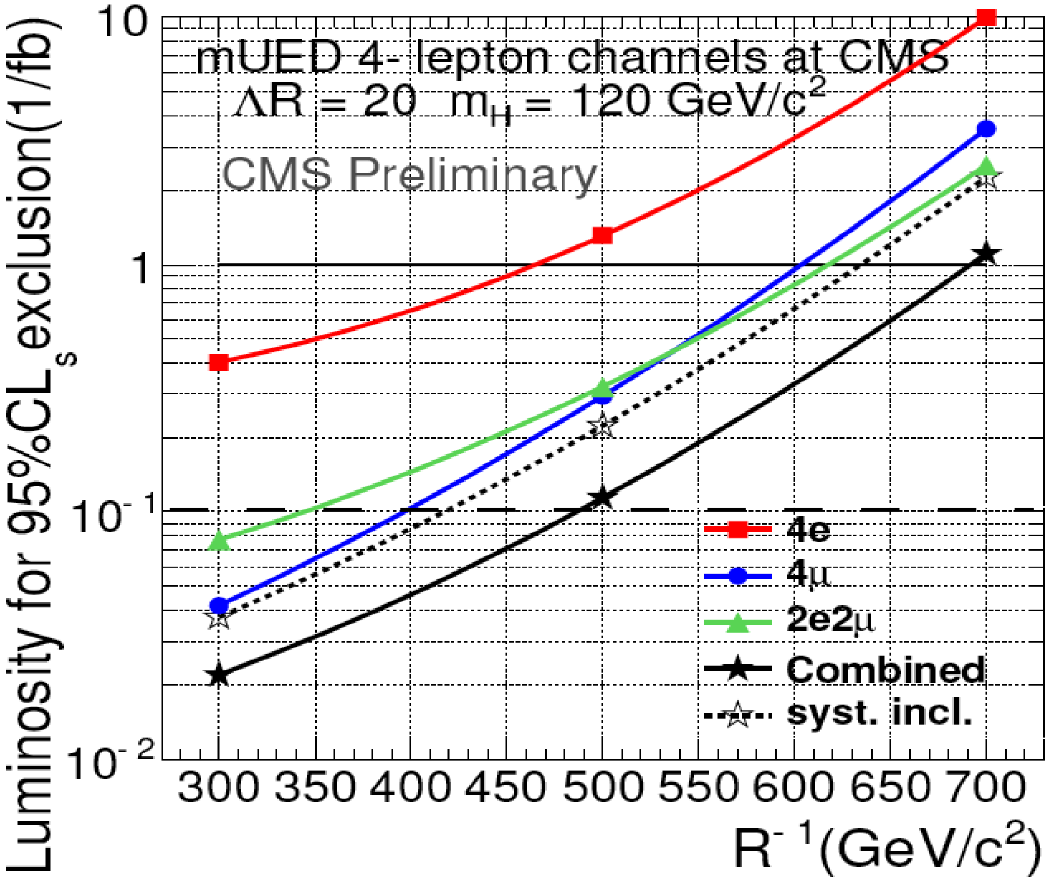
UED is a template for low p_T multilepton searches

CMS sensitivity to UED in 4 lepton final state

CMS PAS SUS-08-003

Exclusion limits

sqrt(s)=14 TeV



Can exclude at 1 fb^{-1} 1/R<640 GeV
combining all the channels

At 7 TeV might need ~ 4 times more data

Additional challenges for low p_T multi-lepton searches

- Low lepton trigger efficiency
  - Currently working on a low p_T multi-lepton trigger for CMS

- Standard reconstruction and identification lepton algorithms are tuned for higher p_T
  - Electrons are a particular challenge due to interactions with the tracker

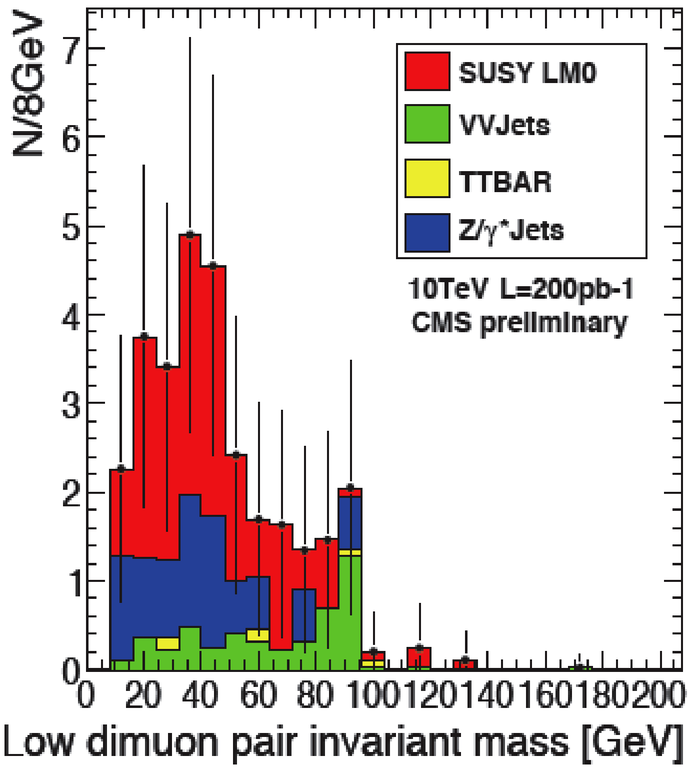
- Measurement of lepton efficiency, purity and energy resolution
  - Usual methods rely on on-shell Z boson as SM candle for higher p_T
  - Use J/Psi and Upsilon resonances or Drell-Yan production as candles?

- Drell-Yan+Jets background become more important
- Processes with Heavy Flavours (b,c) dominate isolated lepton spectrum at small p_T
  - Need adequate data-driven methods to estimate these backgrounds

CMS SUSY search with trimuons

CMS PAS SUS-09-003

sqrt(s)=10 TeV
L=200 pb^{-1}

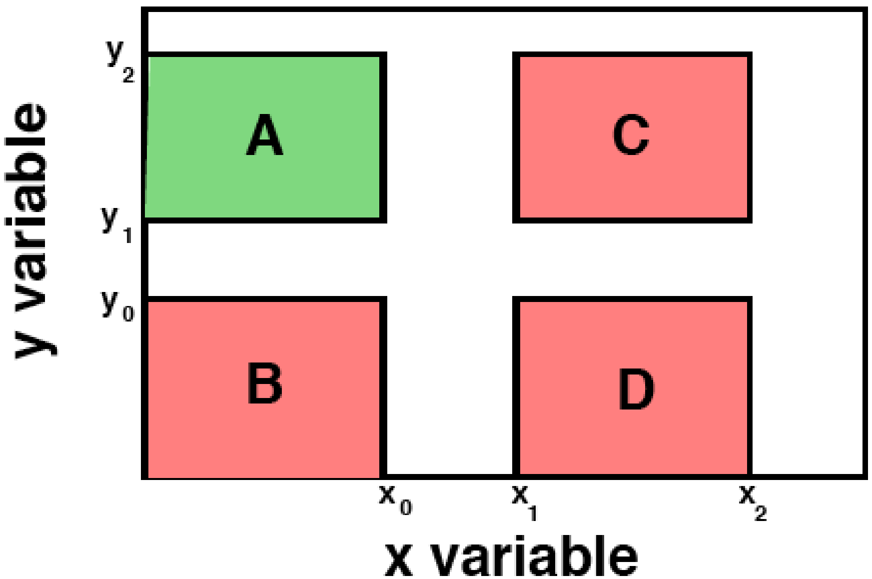


- **Search in trimuon sample**
- **Dominant backgrounds**
  - Drell-Yan + Jets
  - ZW and ZZ production (irreducible)
  - ttbar production
- **Event selection**
  - 3 prompt and clean muons
    - **Discrimination between "signal" and "background" muons**
      - **Relative isolation in tracker and calorimeter < 0.15**
      - **Significance of transverse impact parameter < 4**
  - One OS lepton pair
  - Low mass OS pair with invariant mass between **20-86 GeV/c^2**
    - Rejection of Z, heavy resonances Υ , J/Psi
- **For sqrt(s) = 7 TeV, sensitivity to SUSY is increased with missing E_T and Jet cuts**

Data driven background estimation: ABCD method

CMS PAS SUS-09-003

- Used to estimate backgrounds with non-prompt and fake muons
  Drell-Yan+Jets and ttbar



$N_X \equiv$ N background events in control region X

Region A ≡ signal region
Regions B,C,D contain background only

- Goal : estimate N_A
- If x and y variables are **uncorrelated**
  Count N_B,N_C,N_D
  and estimate N_A using

$$N_A/N_B=N_C/N_D$$

Trimuon search : Extrapolate the number of trimuons events with 2 “tight” muons and 1 “non-accepted” muon towards the signal region with 3 “tight” muons

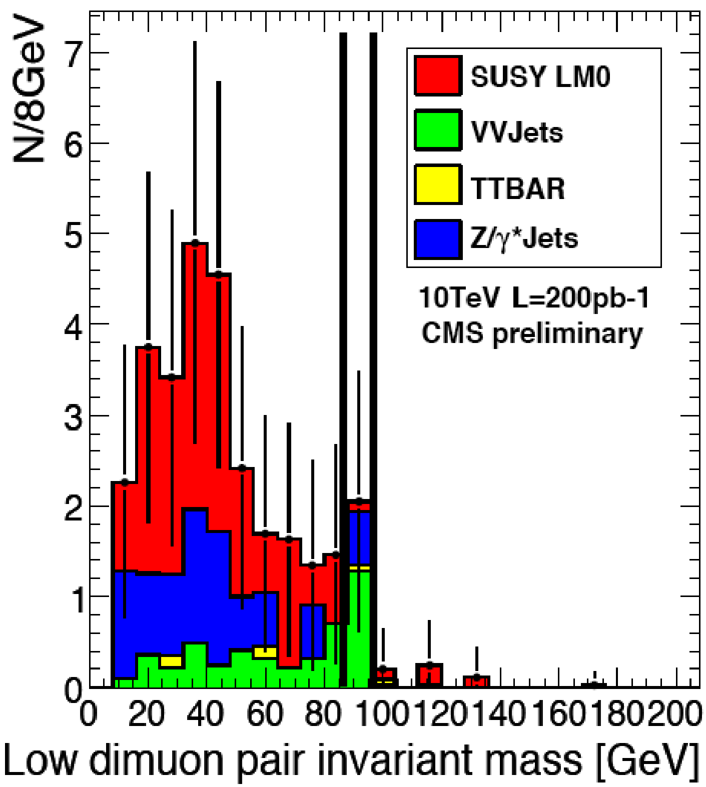
Variables: muon isolation (iso) and significance of transverse impact parameter (Sdxy)

Region A: all muons with iso < 0.15 and Sdxy < 4 (signal region)
Region B : third muon with iso < 0.15 but Sdxy > 4
Region C : third muon with iso > 0.15 but Sdxy < 4
Region D: third muon with iso > 0.15 and Sdxy > 4 (populated by fakes)

Data driven background estimation: Z candle method

CMS PAS SUS-09-003

- Used to estimate ZW and ZZ backgrounds
- Diboson have similar topology as the signal
- Observation of Z-peak in trimuon events can be used to calibrate selection efficiency
  - **Extrapolate Diboson contribution to signal region from Z region**



Signal region → $20<M_{\mu\mu}<86$ GeV/c^2

Control region → $86<M_{\mu\mu}<96$ GeV/c^2

Estimate background in signal region as

$$N_{sig}=N_{M[86,96]}.R$$

where R is a MC correction factor

R=1.72± 0.14 (stat)±0.03 (sys)

Contamination from SUSY and other backgrounds

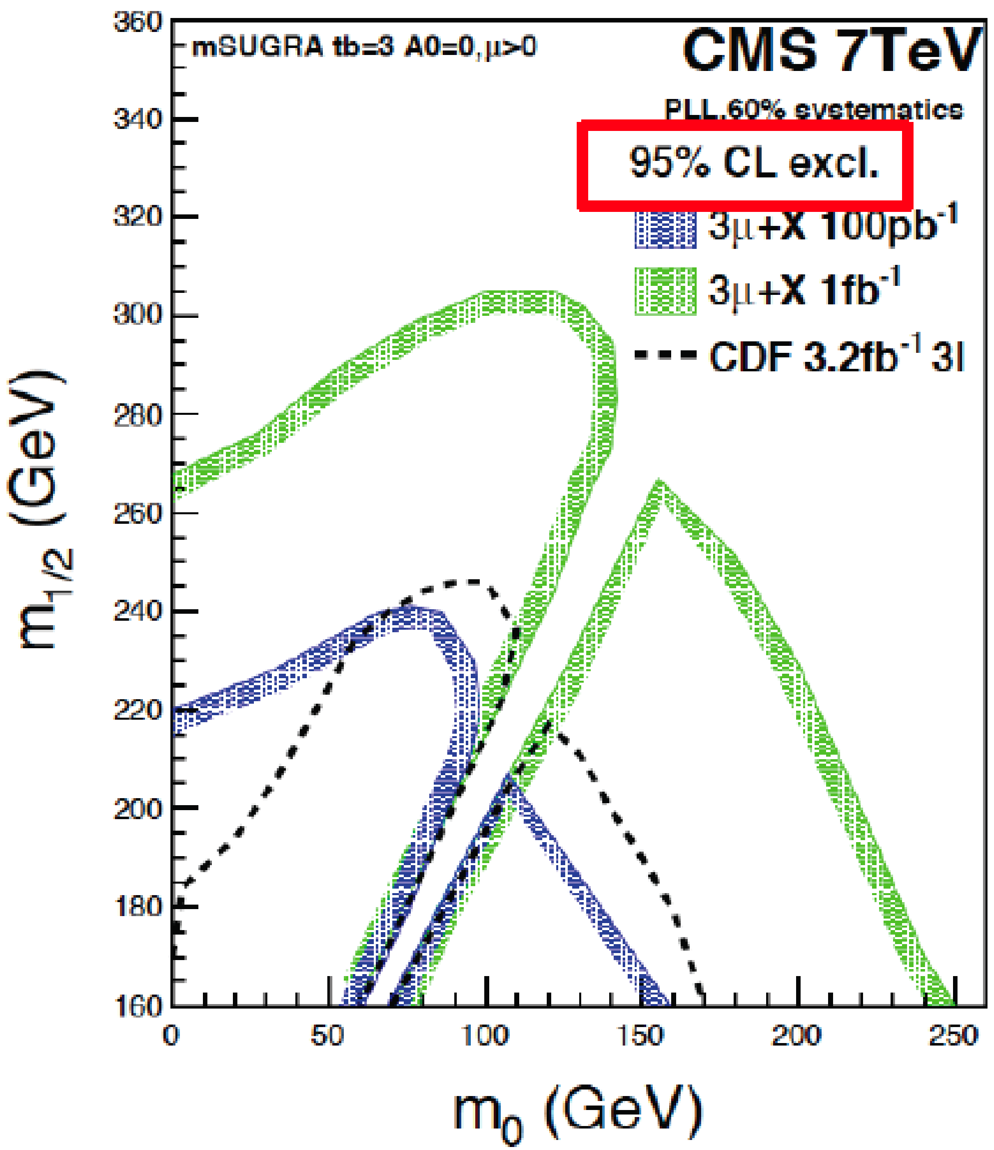
	incl. SUSY	no SUSY
NBkg Z candle	4.0 ± 2.7	3.8 ± 2.6
NBkg ABCD	6.8 ± 2.6	5.8 ± 2.4
NBkgDD total	10.8 ± 3.7	9.6 ± 3.5

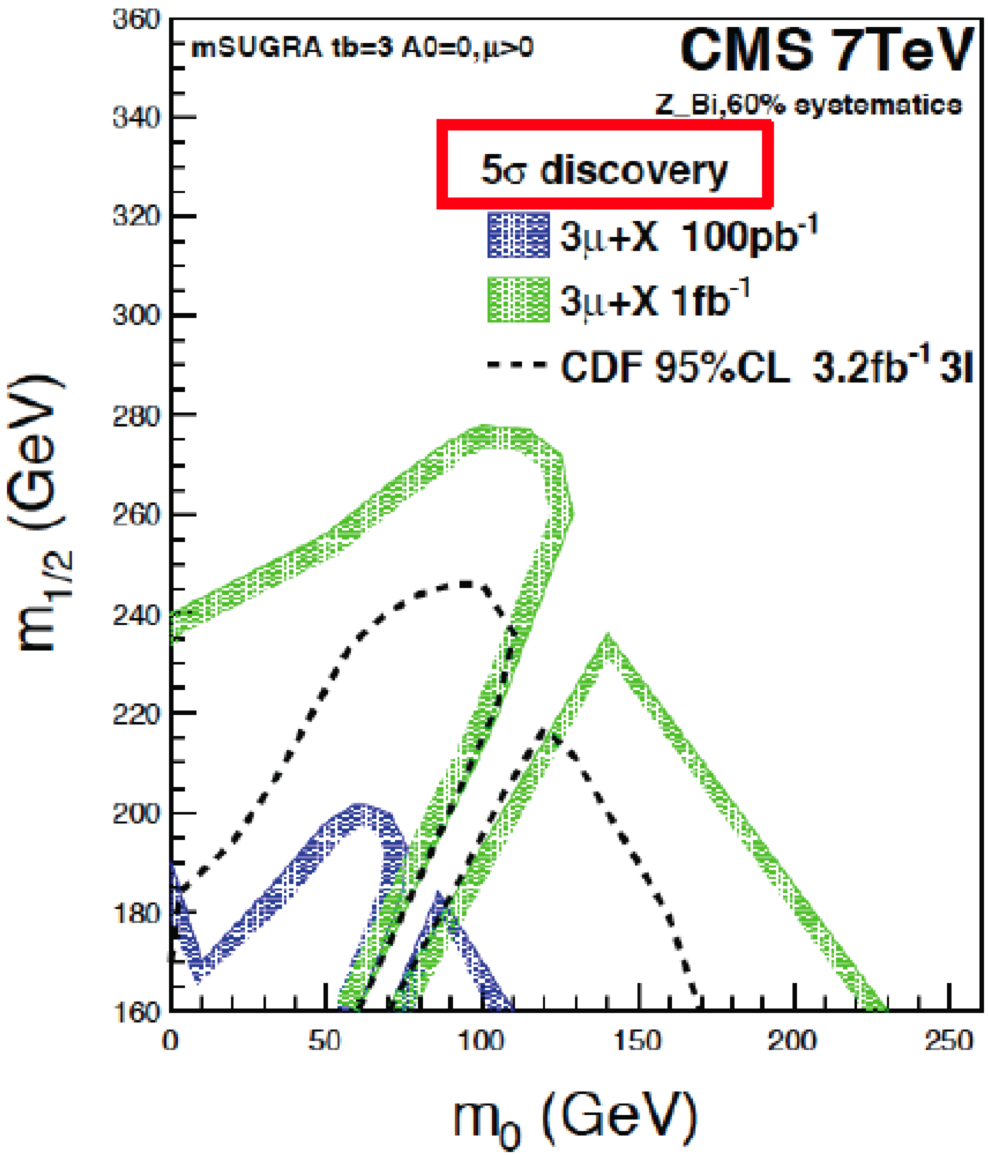
Validity of data driven estimations

	low mass OS muons M[20,86]GeV
NSignal(LM0)	15.3 ± 3.9(stat) ± 1.2(sys)
NBkgMCTruth	9.3 ± 3.0(stat) ± 0.8(sys)
NBkgDD total	10.8 ± 3.7(stat) ± 0.9(sys)

CMS sensitivity to MSUGRA in trimuon at 7 TeV

Preliminary





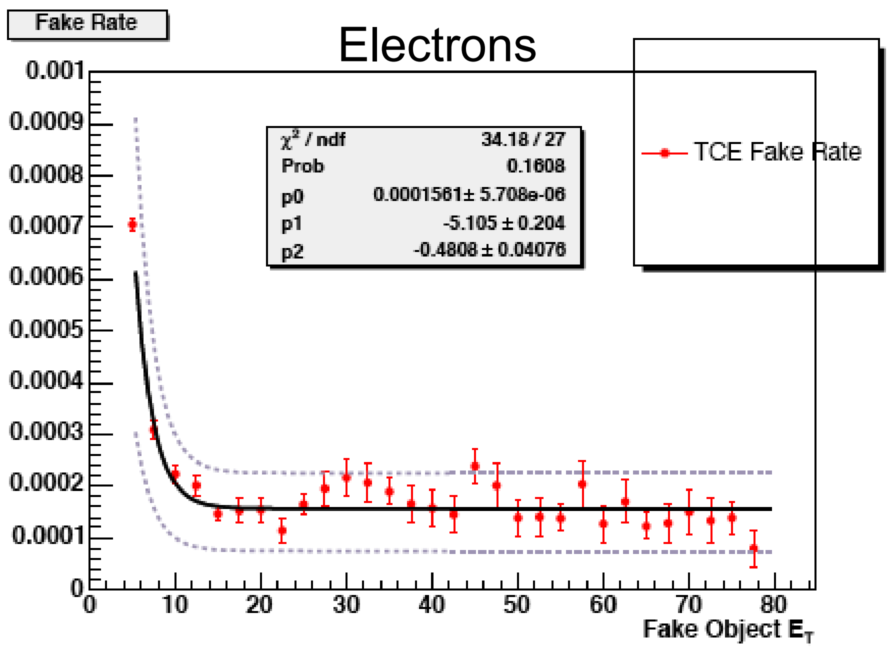
Data driven estimation of Fake leptons background

- Estimate background from fake leptons
  - For muons, pions or kaons that penetrate the calorimeters or decay in flight to muons
  - For electrons, jets (light flavours) misidentified as electrons

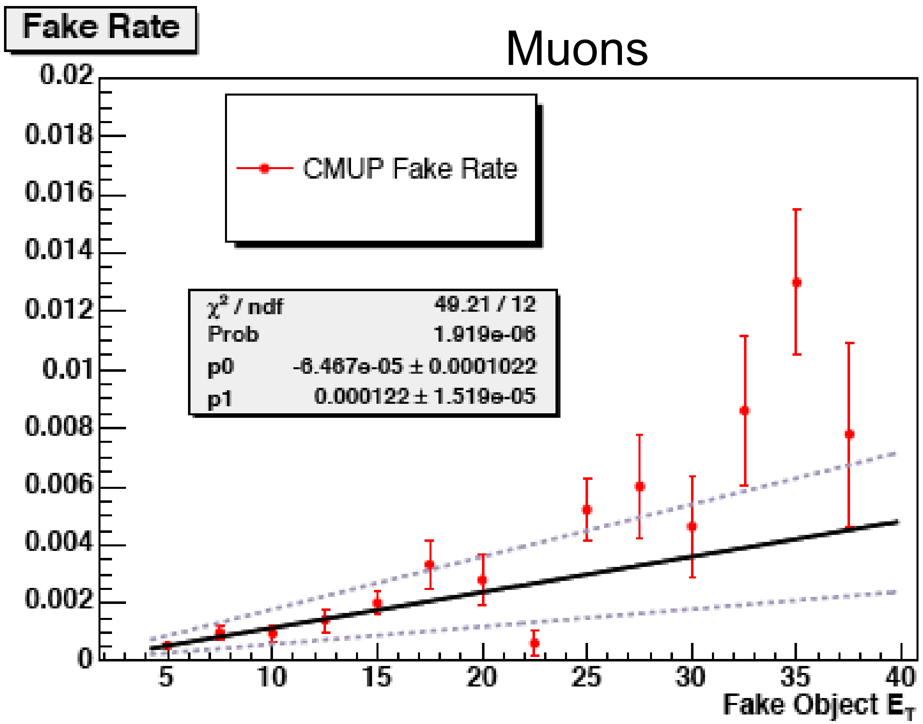
CDF search,Phys.Rev.D79:052004,2009

- **Use multi-jet datasets to measure the fake rate, i.e .the probability that object is misidentified as lepton, parametrized as function of E_T and η of the object**

Electrons



Muons



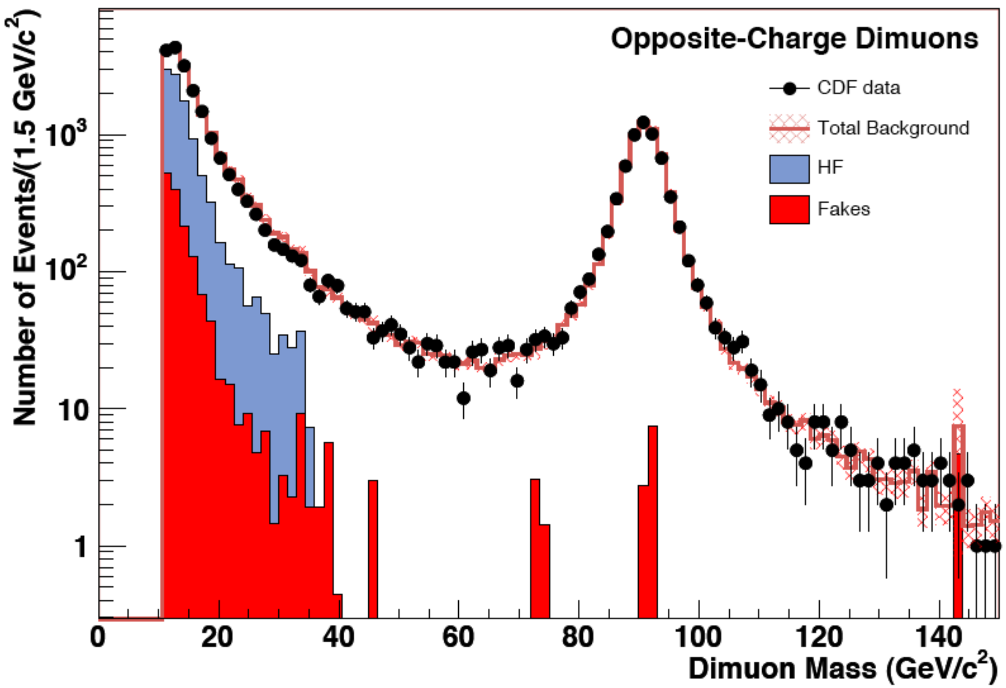
- **To estimate background from real muon pair + fake lepton**
Require two good leptons and model the third lepton by applying the fake rate to jets (or isolated tracks)

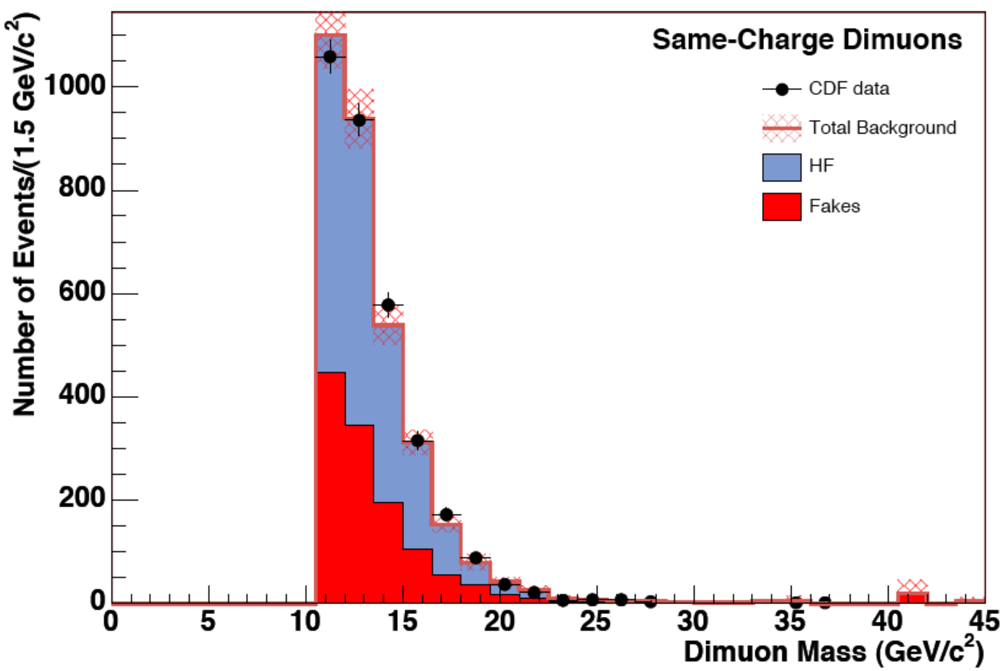
- In this search the fake leptons background is determined to be (50± 25) % in both the total inclusive dataset and the signal region

Data driven estimation of Heavy Flavour background

- **Heavy Flavours backgrounds particular relevant for low p_T leptons**
- **Construct an enriched Heavy Flavour (HFR) dataset by reversing muon impact parameter cut and requiring $M_{\mu\mu} < 35$ GeV/c^2.**
- **Fit the observed dimuon mass distribution with**
  absolute fake dimuon + absolute Drell-Yan (from MC simulation) + shape of HFR
  only free parameter is the normalization of the Heavy Flavour background

CDF search,Phys.Rev.D79:052004,2009



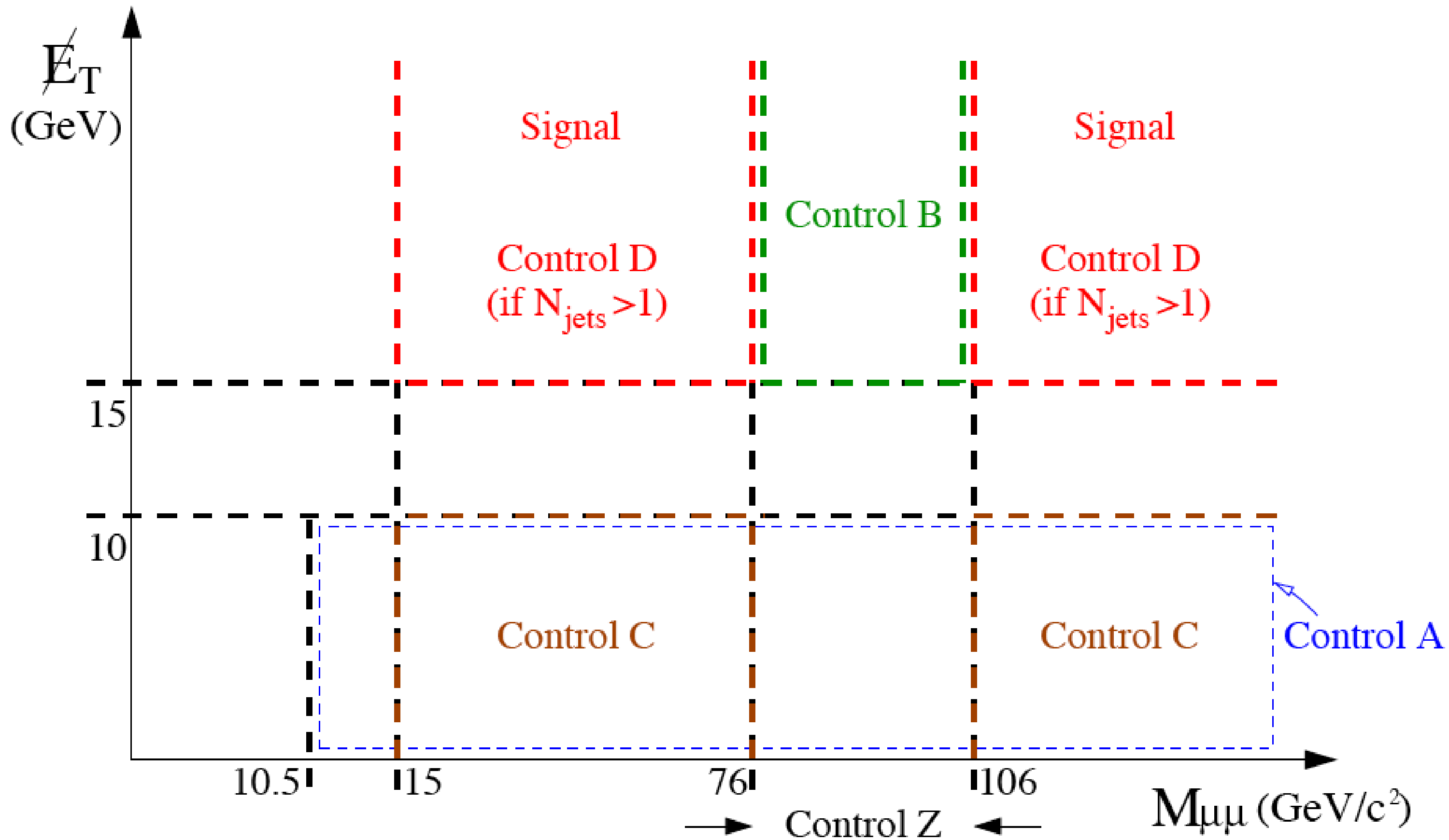


- Trilepton HF backg. is estimated by requiring that the normalized HFR sample has a third lepton
  If no statistics, extrapolate from neighbouring dimuon or trimuon control regions
- Systematic uncertainty of the method is ~ 5 %.

Background control regions

CDF search,Phys.Rev.D79:052004,2009

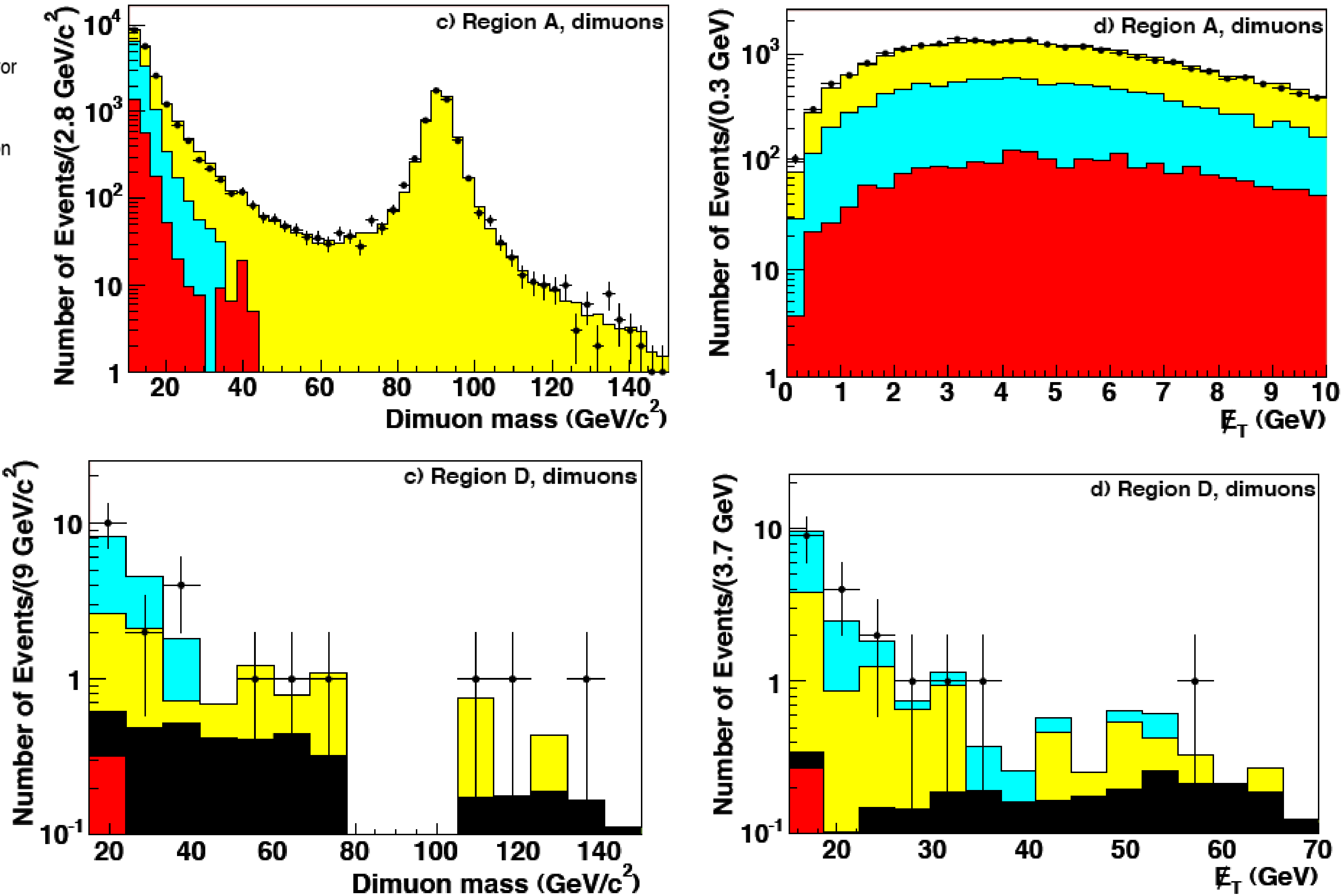
- Define control regions with dimuon mass and missing E_T observables



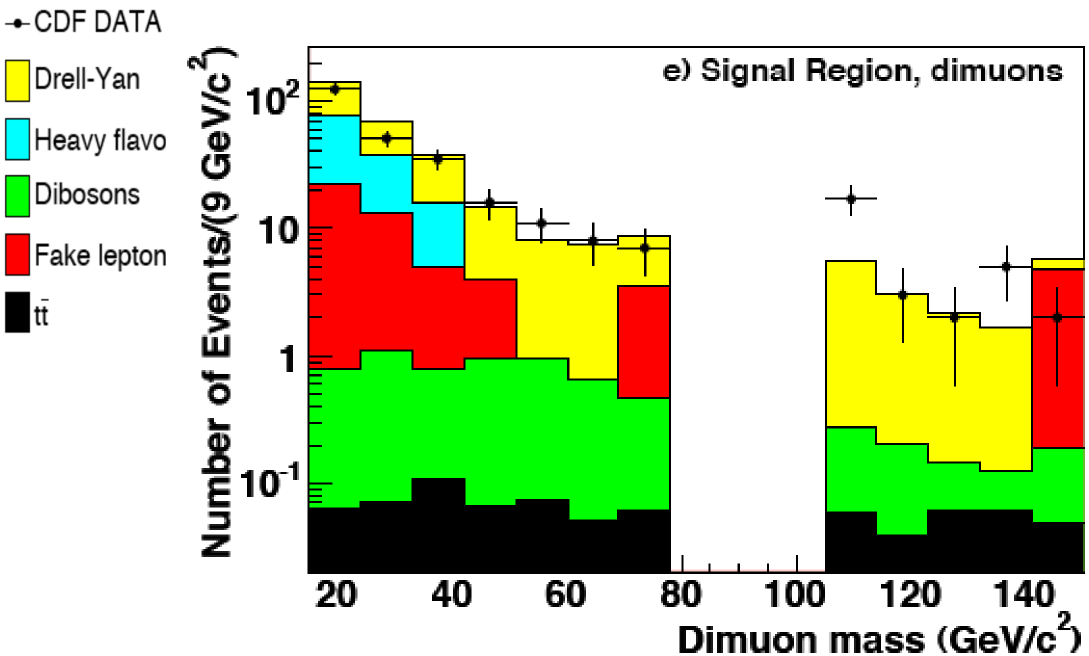
Region Z : Luminosity, trigger efficiencies and muon identification scale factors
Region A: Heavy Flavour and Fake Leptons
Region B: Background prediction in low-event yield region
Region C: High population of Heavy Flavour
Region D: sensitive to ttbar background

Background control regions

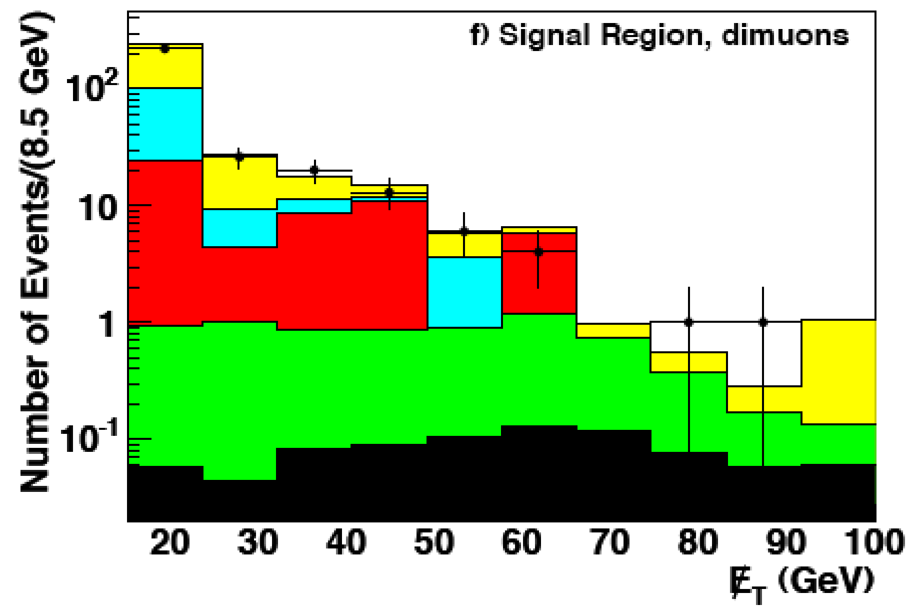
CDF search,Phys.Rev.D79:052004,2009

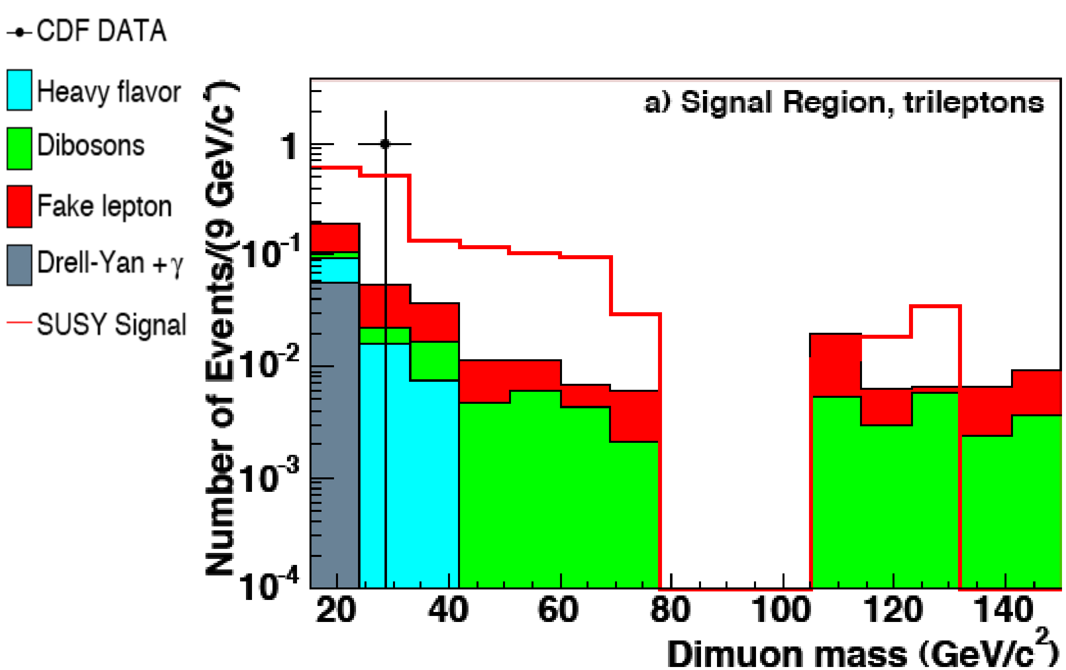


Signal multilepton+missing E_T control regions



CDF search,Phys.Rev.D79:052004,2009





- **Agreement between background predictions and observed data**

- **Critical control region**
Dimuon events with all signal-region cuts, but before the requirement of a third lepton

↓

Trilepton signal is a subset of this region

Discrimination of new physics models at LHC

Bhattacherjee,B., "Multijet Discriminators for New Physics in Leptonic Signals at the LHC"

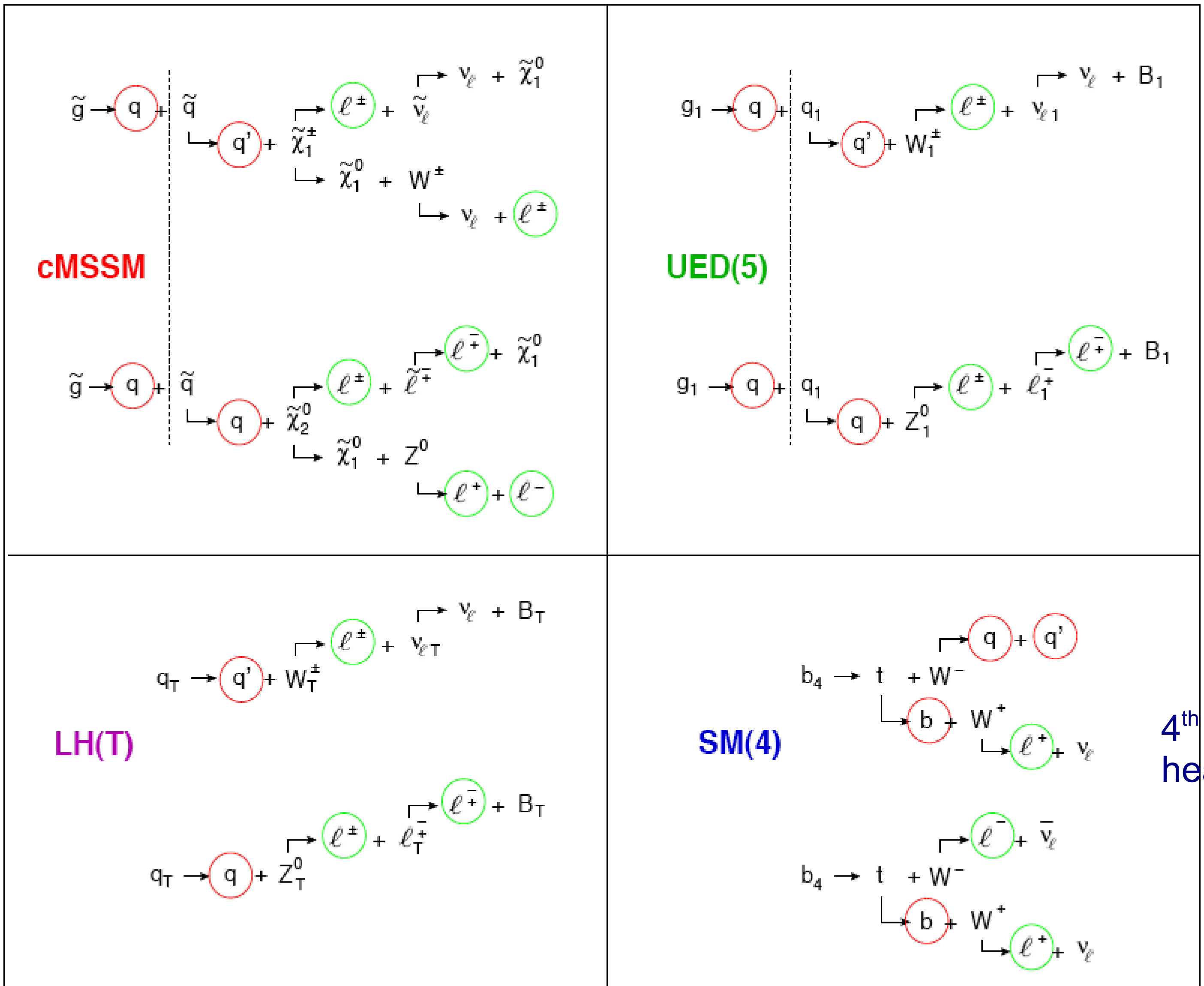
Goal: **Find simple and robust discriminators for models with ≥ 3 leptons + n Jets**

Constrained MSSM

Universal ED (4+1)

Little Higgs with T-parity conservation

4^{th} Generation with heavy b_4 quarks



Multi-jet discriminators

Bhattacherjee,B., "Multijet Discriminators for New Physics in Leptonic Signals at the LHC"

Strategy: Use ratios of lepton and jet multiplicities

Variable	Definition
$N_2^{(n)}$	number of events with n hard leptons and ≤ 2 identifiable jets
$N_3^{(n)}$	number of events with n hard leptons and ≥ 3 identifiable jets
$\widetilde{N}_0^{(n)}$	number of events with n leptons and no hard jet
$\widetilde{N}_1^{(n)}$	number of events with n leptons and ≥ 1 hard jet
$\widetilde{\nu}$	number of events with ≥ 1 hard leptons and no hard jets
$\widetilde{\nu}_0$	number of events with no hard lepton and no hard jets
$\widetilde{\nu}'$	number of events with ≥ 1 hard lepton and ≥ 1 hard jet
$\widetilde{\nu}'_0$	number of events with ≥ 1 lepton and ≥ 1 hard jet

$$D_n = \frac{N_3^{(n)}}{N_2^{(n)}} \qquad \widetilde{D}_n = \frac{\widetilde{N}_1^{(n)}}{\widetilde{N}_0^{(n)}} \qquad \Delta_\ell = \frac{\widetilde{\nu}}{\widetilde{\nu}_0} \qquad \Delta'_\ell = \frac{\widetilde{\nu}'}{\widetilde{\nu}'_0}$$

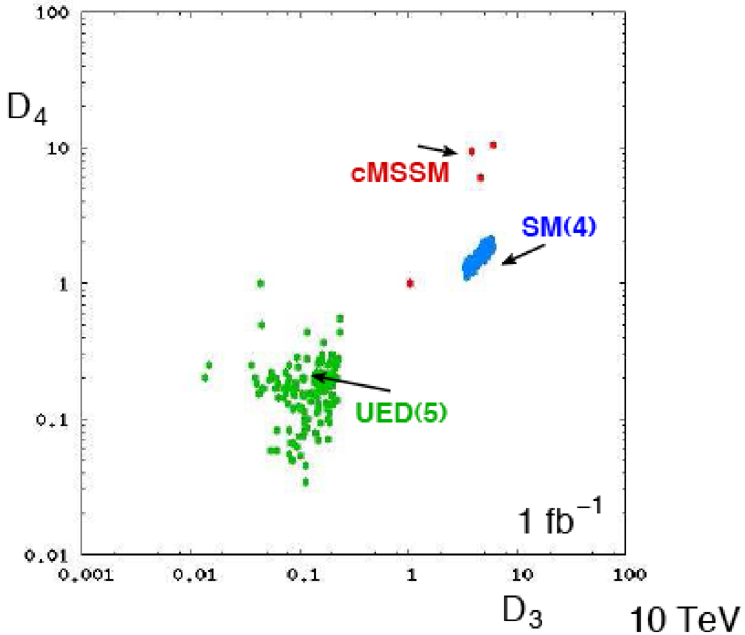
(n) leptons = 3,4

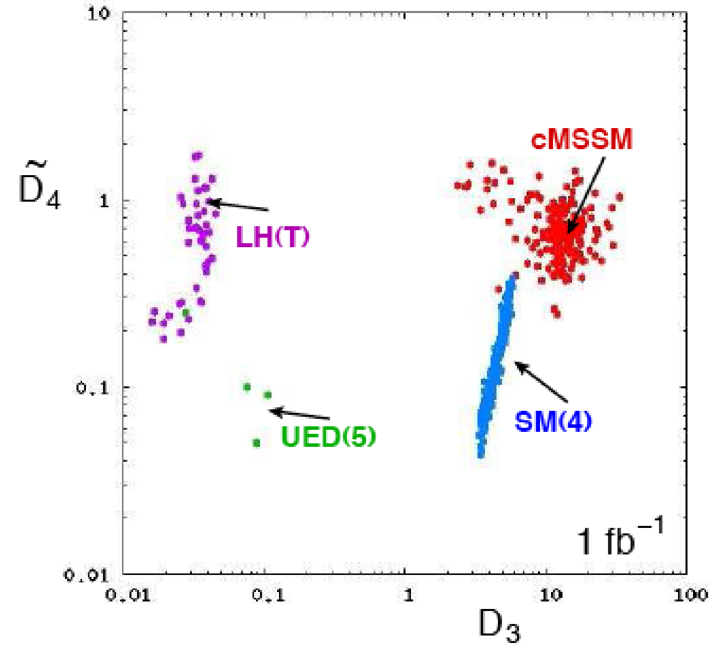
- a lepton is "hard" if $p_T \geq 50$ GeV
- a jet is "hard" if $p_T \geq 150$ GeV

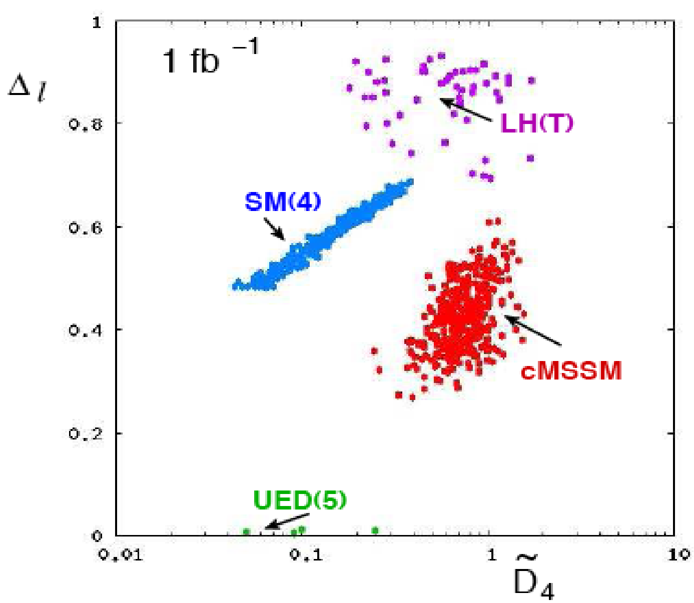
→ Choices driven by the mass degeneracy of UED(5) for the large part of parameter space

Multi-jet discriminators

- **Make correlation plots of the ratios**
- **See where the data point is w.r.t. to model prediction**







- Clear discrimination between models
- For all plots data point should map to same model
- Necessary but not sufficient condition to identify model

Even for inclusive multi-lepton analysis, experimental reliability of jet multiplicity distribution is important to identify the physics model

Multichannel approach

Dube, S., "Addressing the Multi-Channel Inverse Problem at High Energy Colliders"

Organizing principles

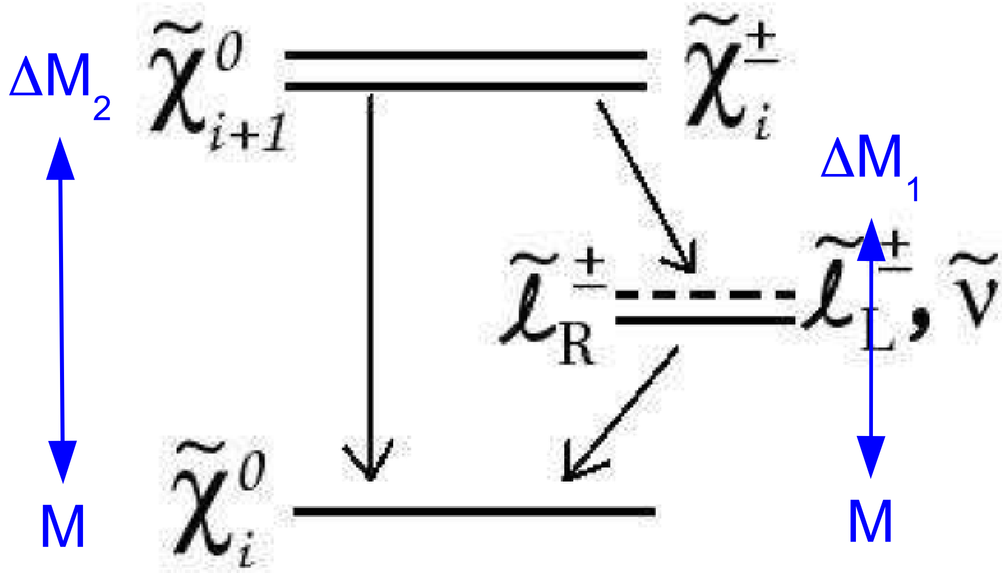
- **Report experimental sensitivity as σB**
- **Identify relevant multi-channels**

  0 τ

  1 τ $\tilde{\chi}_1^{\pm} \rightarrow \tau\nu\tilde{\chi}_1^0$

  2 τ $\tilde{\chi}_2^0 \rightarrow \tau\tau\tilde{\chi}_1^0$

  3 τ (Both)



- **Identify universal parameters**

  M (mass of lowest state)

  ΔM1 (mass difference between lowest state and intermediate state)

  ΔM2 (mass difference between lowest and highest state

Multi-channel approach

Dube, S., "Addressing the Multi-Channel Inverse Problem at High Energy Colliders"

- $\{\sigma B\}_i$: measured experimental sensitivity for channel with i taus, assuming B=1
- Parametrize $\{\sigma B\}_i$ as function of general mass parameters M , ΔM1 , ΔM2

$$\{\sigma B\}_i^{-1} = f_i(M) \times h_i(\Delta M_1, \Delta M_2)$$

$$f(M) = 1 + a_1(M) + a_2(M)^2$$

$$\begin{aligned} h(\Delta M_1, \Delta M_2) \;=\; & c_0 + c_1(\Delta M_2) + d_1(\Delta M_1) \\ & + c_2(\Delta M_2)^2 + d_2(\Delta M_1)^2 \\ & + e_2(\Delta M_1 \times \Delta M_2). \end{aligned}$$

- Coefficients are determined from experimental data and detailed simulation of experimental acceptance as function of mass parameters

$$\frac{1}{\sigma_{XM}} = \sum_{i=0}^{3} \frac{B_i}{\{\sigma B\}_i}$$

The model provides B_i and the mass spectrum

σ_{XM} is the measured multichannel cross section for the model

σ_{XM} experimental sensitivity should be compared with model total σ

Already being used in Tevatron analysis

Conclusions

- HEP experiments have been performing multi-lepton inclusive analysis
  - For LHC early running, might need to focus on SUSY searches with jet and missing E_T cuts
- Multiple data-driven methods to estimate the backgrounds have been proposed and tested
  - More ideas are welcome, especially to control backgrounds to low p_T leptons
- Theoretical and experimental systematics uncertainties can be important
  - example : Interplay between hadronization and UE models and measured isolated lepton multiplicity
- Strategies for the LHC inverse problem have been proposed : On-Shell Effective theories, multi-jet discriminators, multi-channel σ_{XM}
  - Promising results, but not extensively tested in realistic conditions