Sensitivity of ZZ->llnunu to Anomalous Couplings

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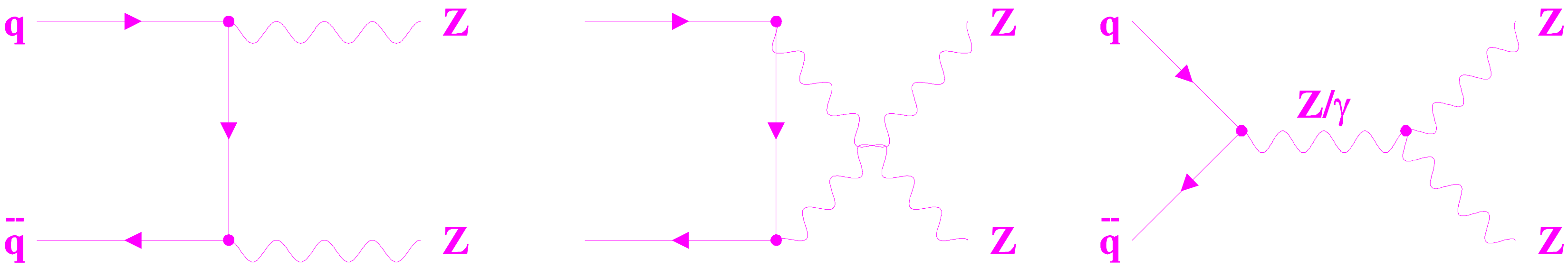
Introduction

- Advantage of ZZ->llnunu c.f. ZZ->llll
  - Larger branching ratio: 6 times as many events before cuts
- Disadvantage
  - Very large backgrounds from Z+jets and ttbar
- Investigate sensitivity of limits on anomalous couplings to background level and systematic error on background
- This is very preliminary 'work in progress'

Anomalous Couplings



Forbidden in SM

- ZZZ and ZZg vertices forbidden in SM
- Production of on-shell ZZ probes ZZZ and ZZg anomalous couplings:

f4Z, f5Z, f4g f5g

- All = 0 in SM

Anomalous Couplings

- f4 violate CP; helicity amplitudes do not interfere with SM; cross-sections depend on f4**2 and sign cannot be determined
- f5 violate P; do interfere with SM
- Couplings depend on energy. Usual to introduce a form factor to avoid violation of unitarity:

  f(s') = f0 / (1 + s'/Lambda**2)**n
- Studies below use n=3, Lambda = 2 TeV
- Also assume couplings are real and only one non-zero

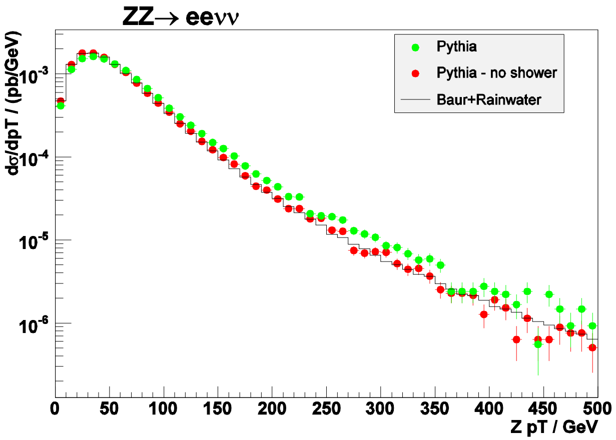
AC Monte Carlo

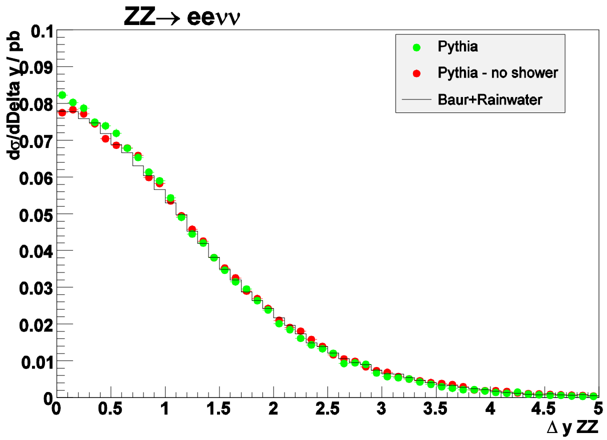
- Study AC using LO Monte Carlo of Baur and Rainwater
- First compare SM predictions for ZZ->eenunu cross-section with Pythia:

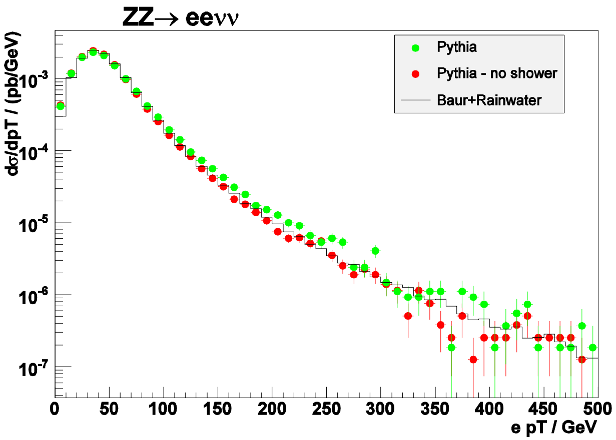
CTEQ4L pdfs; 76 < mZ < 106 GeV

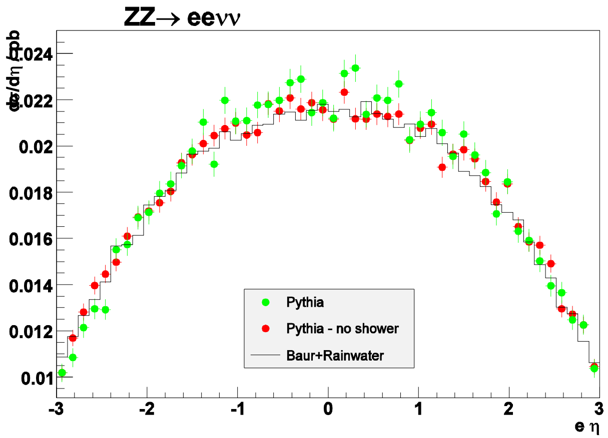
	BR	Pythia (no showers)	Pythia
No cuts	125.5 fb	126.3 fb	126.3 fb
pT(e)> 15 GeV |eta(e)| < 2.5 pTmis > 50 GeV	35.1 fb	34.5 fb	39.5 fb

Comparison with Pythia







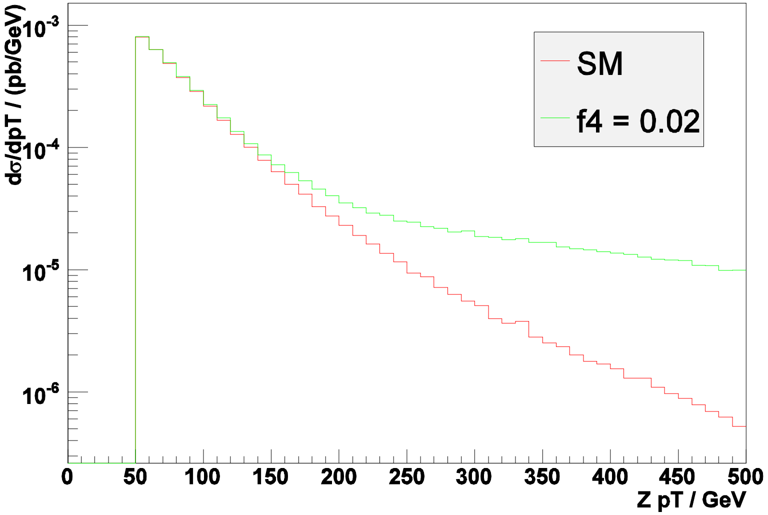


PDF dependence

- Comparisons with Pythia used out-of-date CTEQ4L because BR program used pdflib
- Have now modified it to use LHAPDF
- Following results use CTEQ6LL

pdf set	ZZ->eenunu with cuts
CTEQ4L	36.85 fb
CTEQ6LL	36.51 fb
MRST2001LO	36.90 fb

Signature of Anomalous Couplings



e.g above for ZZ->eenunu

with pT(e) > 15 GeV,

|eta(e)| < 2.5

- Anomalous couplings produce increase in ZZ invariant mass, Z pT and lepton pT distributions
- For ZZ->llnunu can use high pT(Z) cross-section to obtain limit, or fit Z pT distribution

Limits from Cross-section Measurement

- First consider measurement of ZZ->llnunu cross-section for pT(Z) > pTmin
- N.B. this is LO: pT(ll) = pTmiss
- Take pT(e) > 15 GeV, |eta(e)| < 2.5, pTmin = 50 GeV
- SM: 72.7 fb -> 727 signal events for 10 fb-1
- Calculate cross-section, hence expected events as function of f4Z
- E.g. f4Z = 0.01: 76.2 fb -> 762 signal events

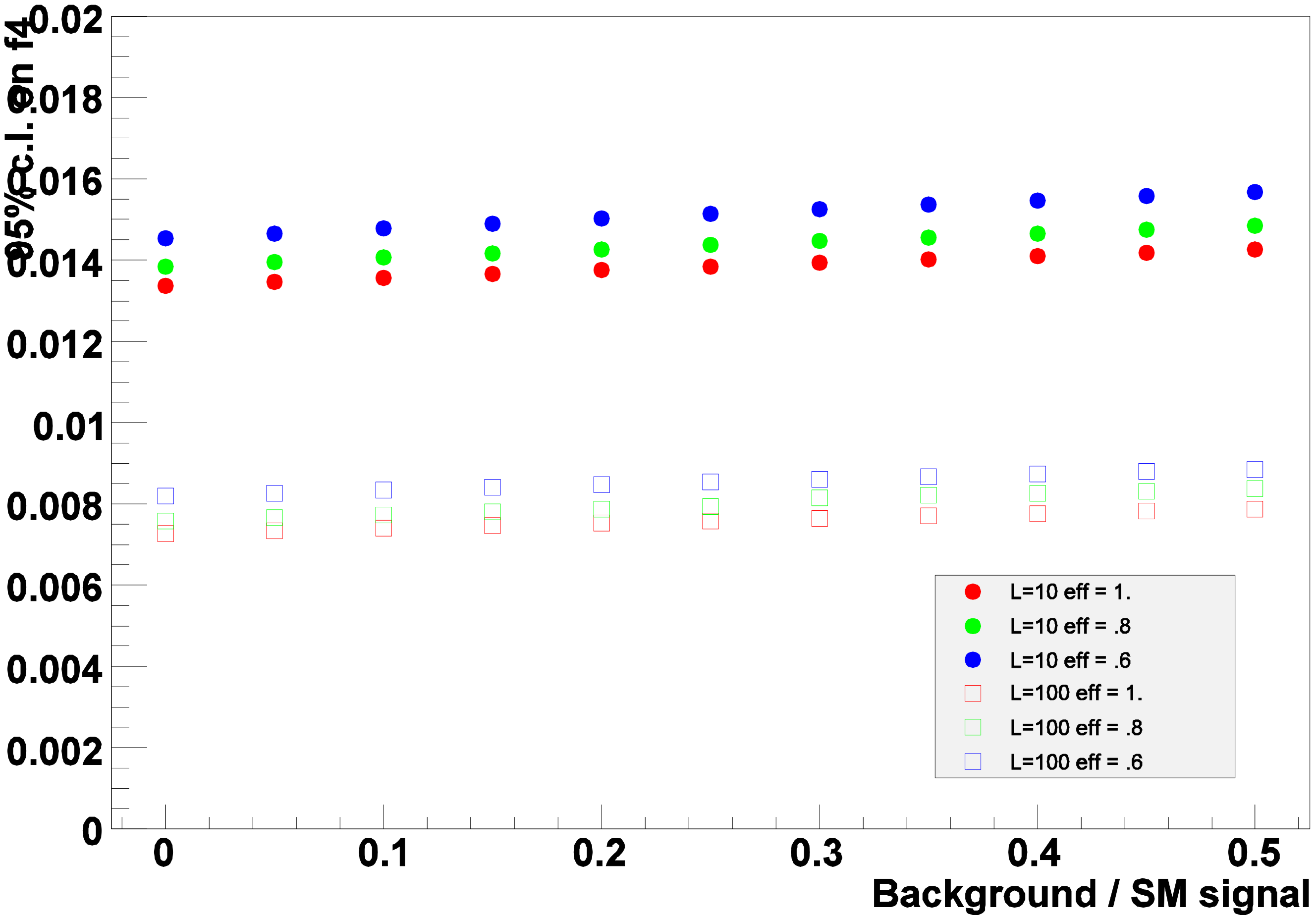
Limits from Cross-section Measurement

- Use chi-squared comparison between expected and ‘observed’ (=SM) numbers of events to determine 95% c.l. on coupling

(assume only one coupling non-zero)

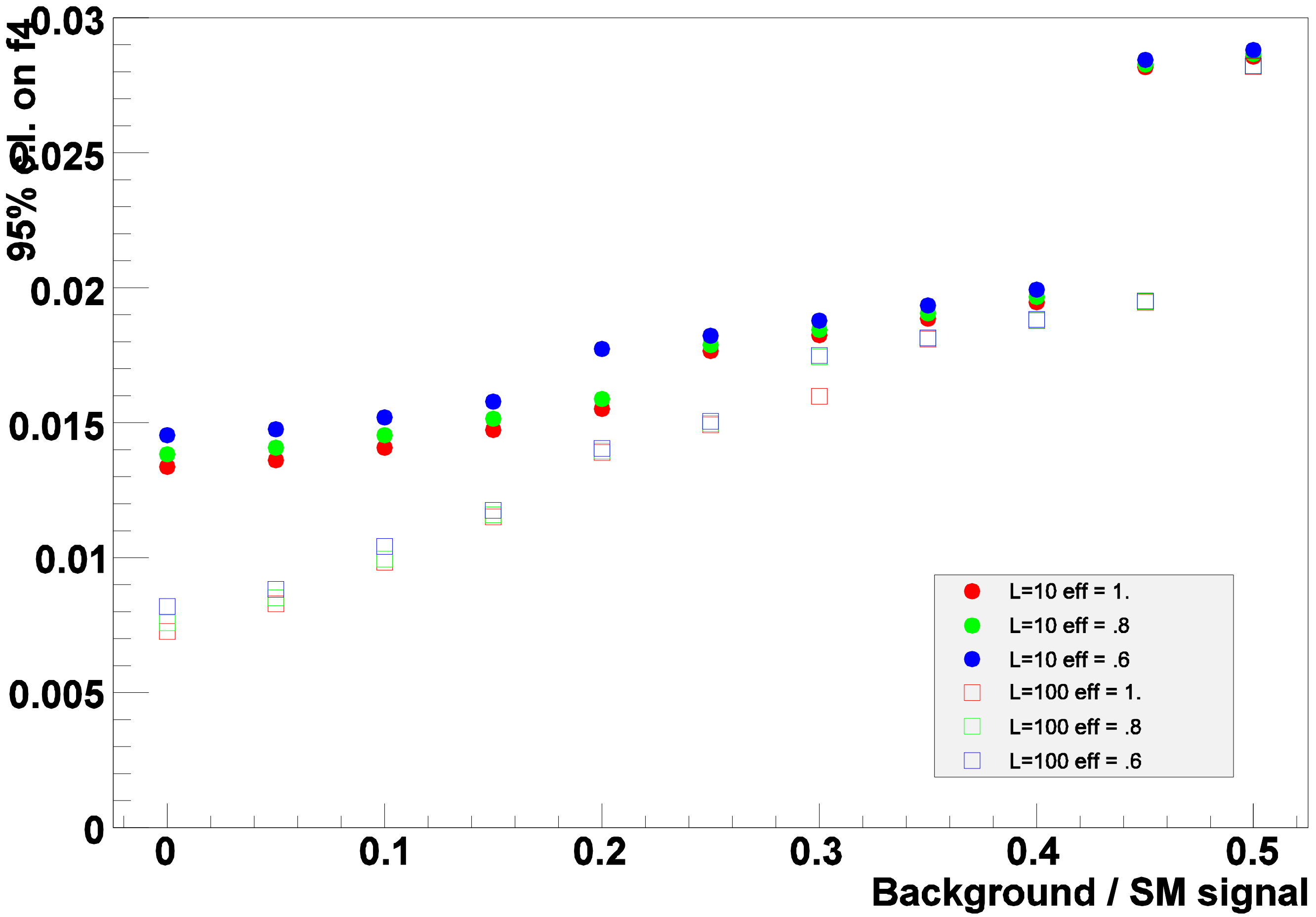
- Calculate limit as function of ratio of background to SM signal
- First assume statistical errors only, then consider effect of a systematic error on the background

pTmiss > 50 GeV; statistical errors only
Little dependence on background fraction



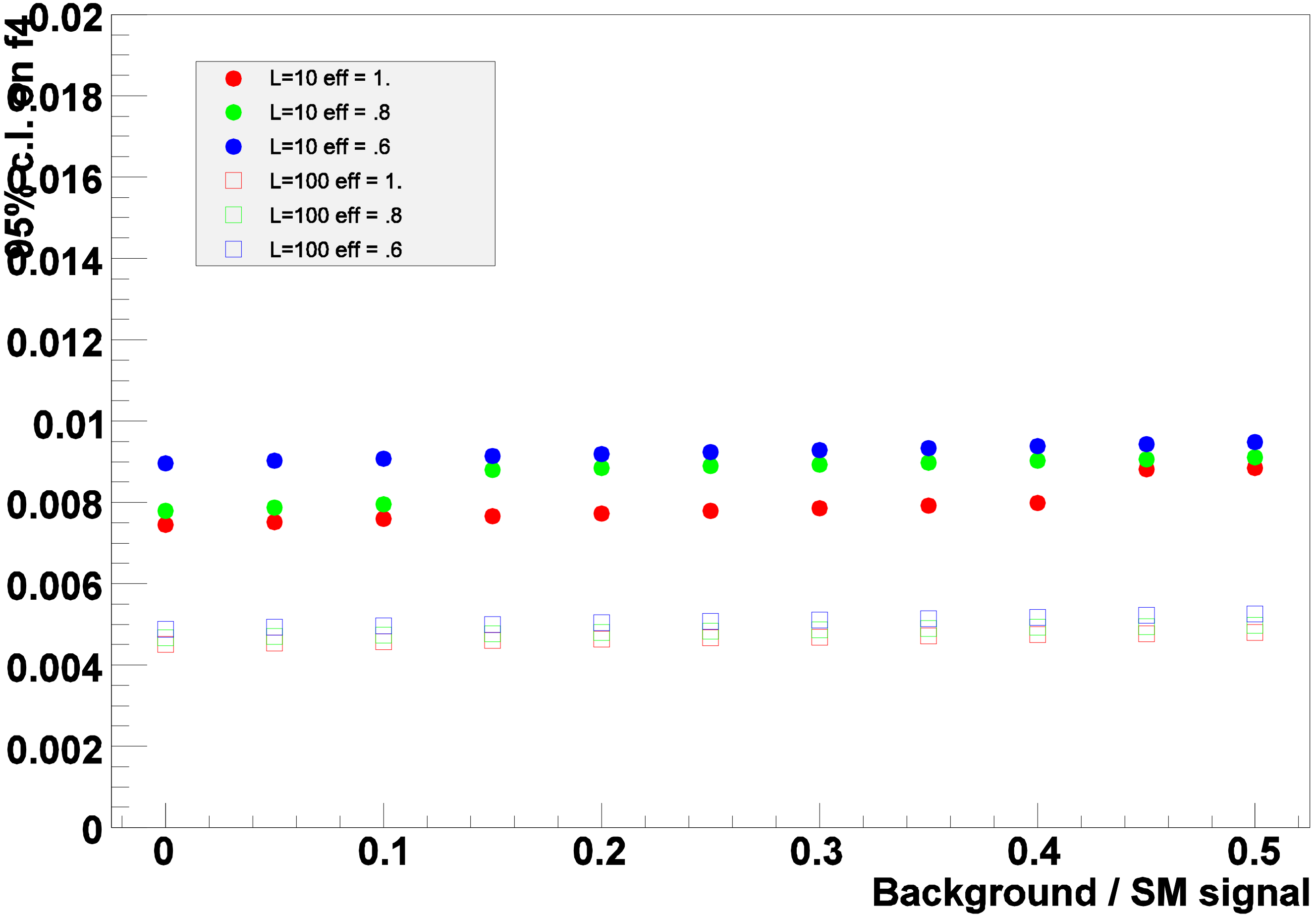
pTmiss > 50 GeV; 20% systematic error on background

Strong dependence on background: limits independent of luminosity for high background



pTmiss > 150 GeV; statistical errors only

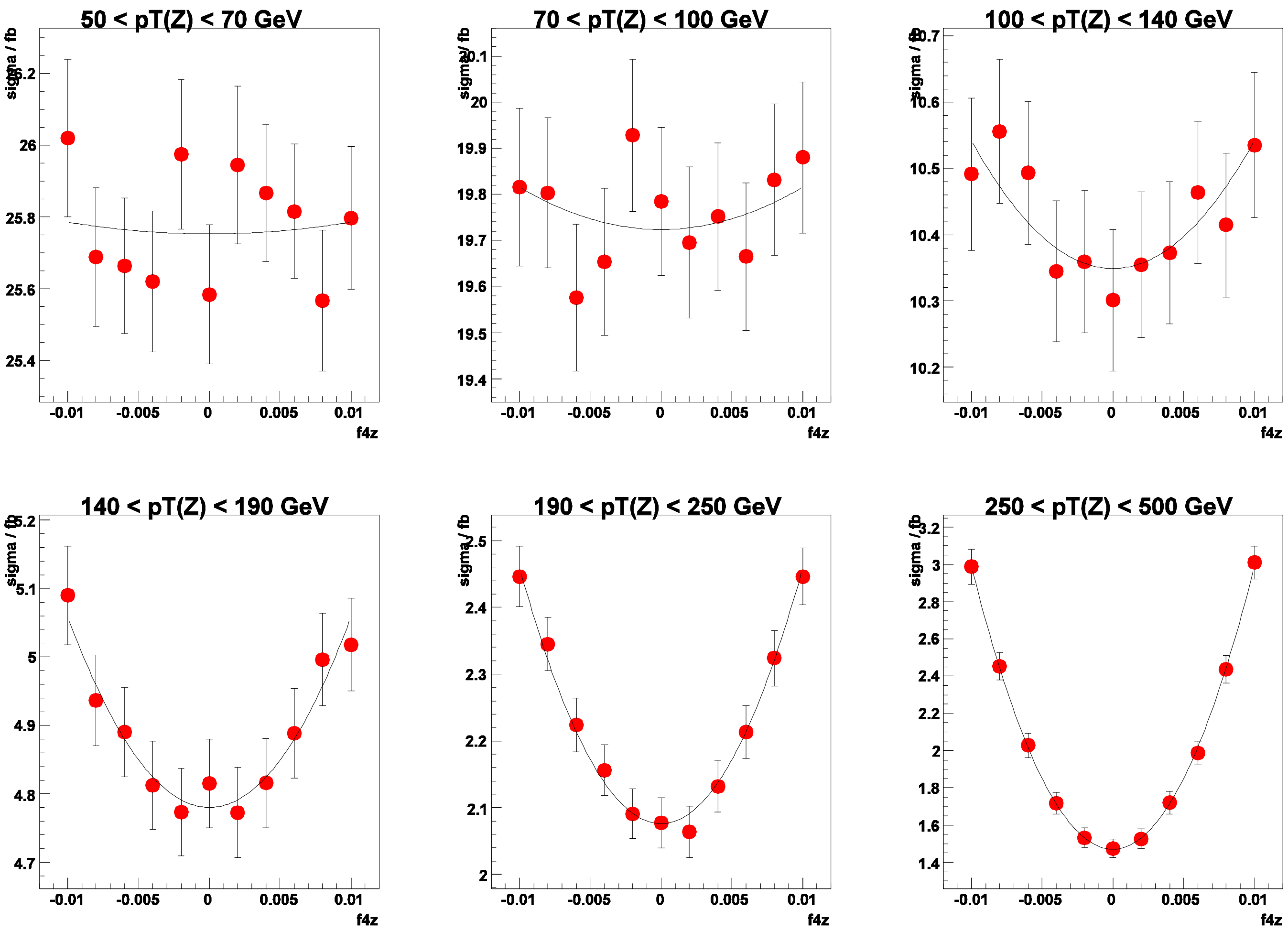
Limits much better than using pTmiss > 50 GeV



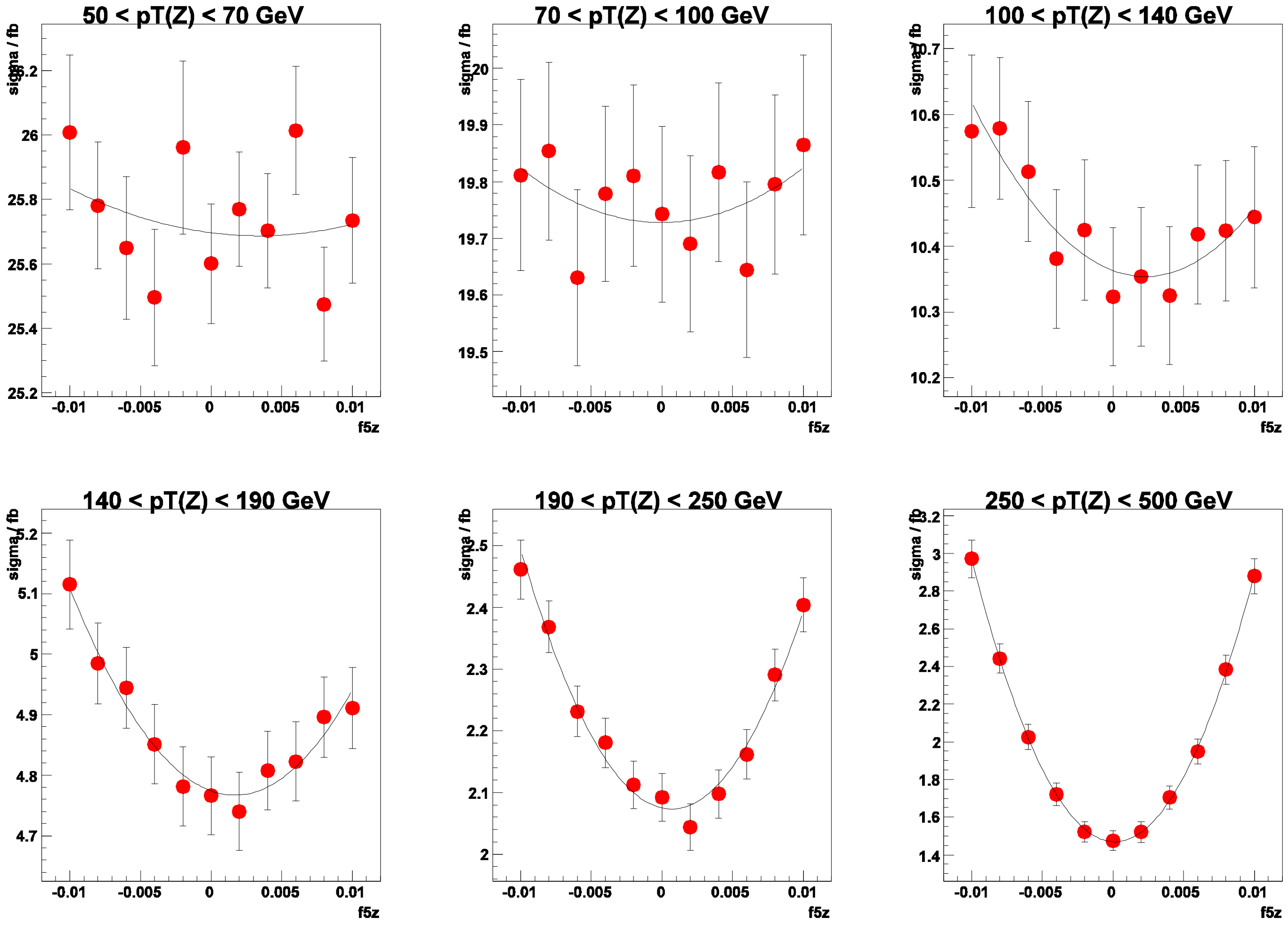
Limits from Fits to pT Distribution

- Limits from a simple cross-section measurement depend on pT cut – harder pT cut can give better limit despite much lower statistics
- Therefore better to fit pT distribution
- Results below are for ZZ->llnunu with pT(l)>20 GeV, |eta(l)| <2.5
- Use BR program to generate pT distributions for several values of couplings (only one non-zero at a time)
- In each pT bin fit cross-section to quadratic in coupling to obtain distribution at arbitrary value

Cross-section v f4Z in pT bins



Cross-section v f5Z in pT bins



50 < pT(Z) < 70 GeV

70 < pT(Z) < 100 GeV

100 < pT(Z) < 140 GeV

140 < pT(Z) < 190 GeV

190 < pT(Z) < 250 GeV

250 < pT(Z) < 500 GeV

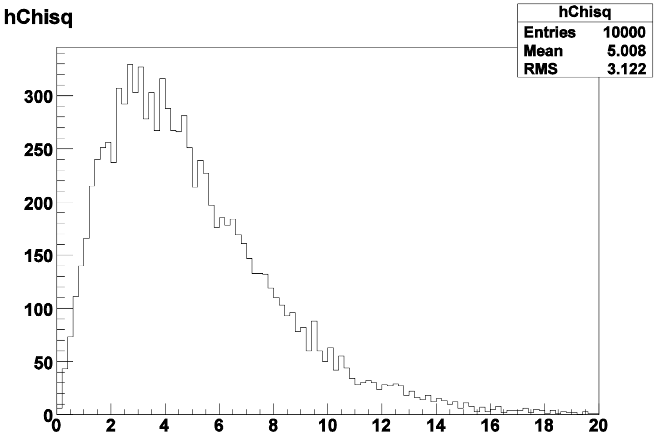
Limits from Fits to pT Distribution

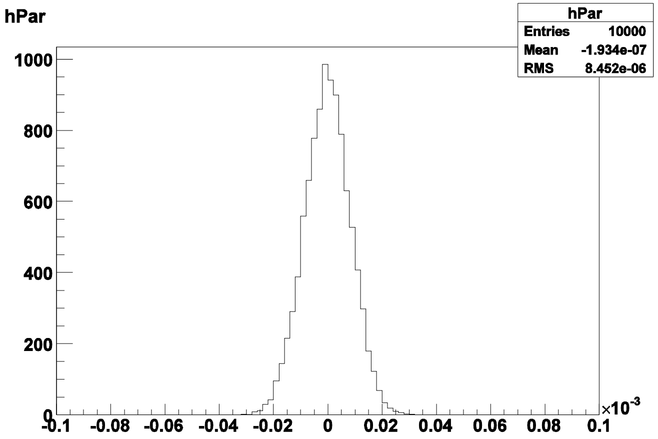
- Create ‘fake data’ sample:
  - Calculate expected SM events in each pT bin
  - Add background – constant fraction of SM
  - Apply Gaussian smearing
- Construct error matrix
  - Statistical errors plus systematic error on background assumed fully correlated
- Fit fake data sample
  - One parameter fit to f4Z**2 or f5Z
  - 95 % c.l. from X**2 – X**2min = 3.84

Limits from Fits to pT Distribution

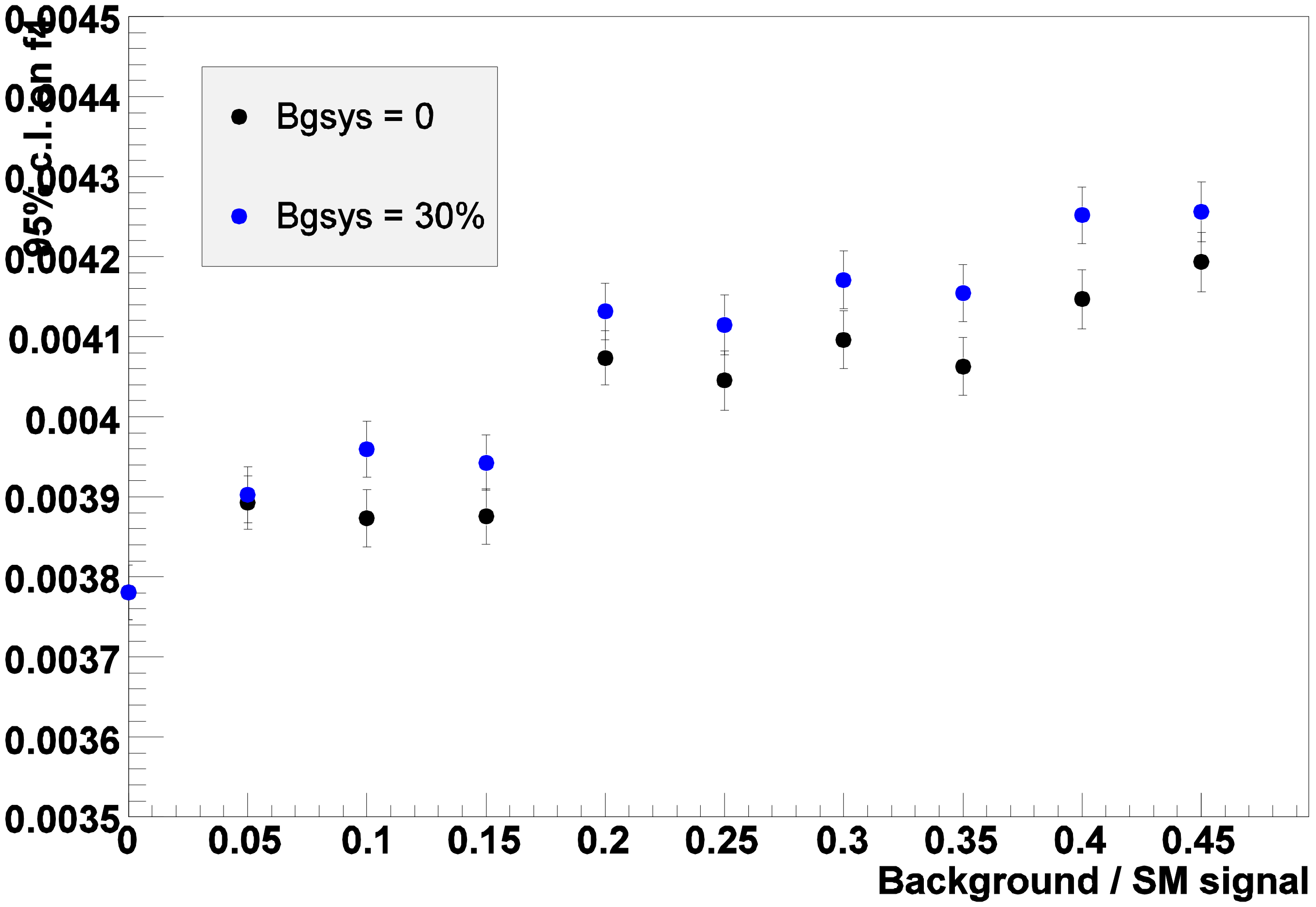
- Generate 1000 fake data samples for each value of background fraction and each value of background systematic
- Mean X**2/dof = 1
- Mean f4**2 = 0

As expected

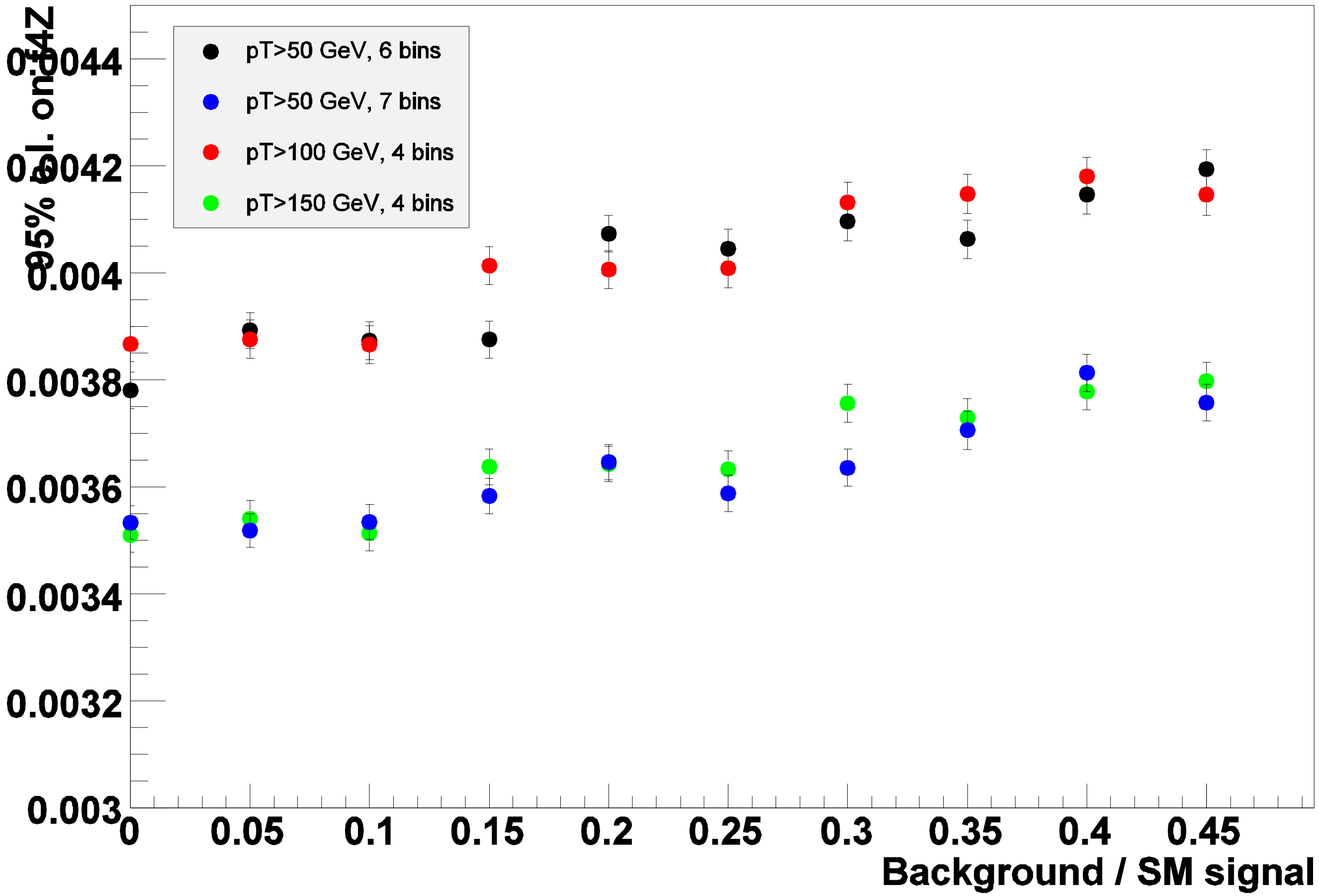




Results for 100 fb-1, eff = 1.0 from Fit in Range 50 GeV < pT < 500 GeV



Results for 100 fb-1, eff = 1.0 from Different Fit Ranges and Binning



Summary so far….

- Limits worse with more background – but not dramatically so
- Limits worse with large systematic error on background – but not dramatically so
- BUT this was assuming constant background – unrealistic
- AC have little effect at low pT, so limits not too sensitive to overall normalization of pT distribution
- Limits depend on binning of pT distribution – will need to be optimized for given integrated luminosity

Next Steps

- Investigate effect of more realistic (steeply falling) background distribution
- Investigate optimal binning
- Estimate limits for expected experimental efficiency/background
- Set up framework for 2-D couplings
- Think how we are going to predict expected pT distribution (reweighting, fast MC etc.)