Sensitivity of ZZ→llνν to Anomalous Couplings

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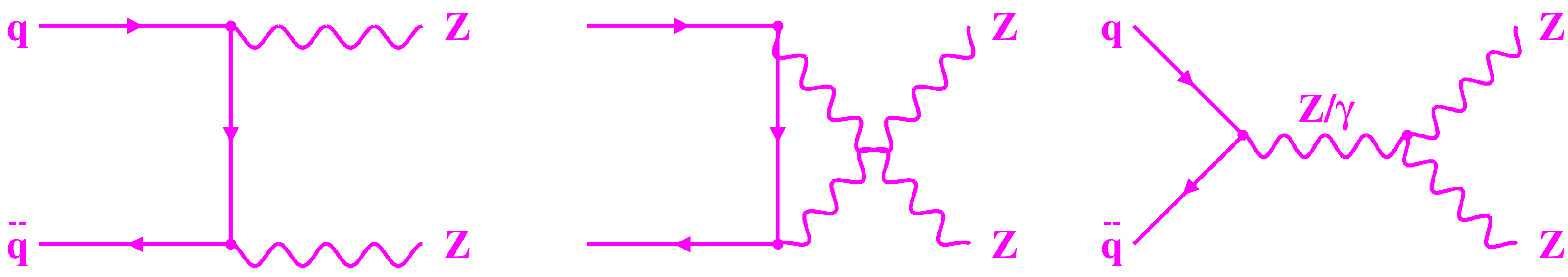
- Neutral Triple Gauge Couplings
- Fit Procedure
- Results
- Outlook

Neutral Triple Gauge Couplings



SM ZZ production diagrams　　　　Forbidden in SM

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

$$f_4^Z,\ f_5^Z,\ f_4^\gamma,\ f_5^\gamma$$

- All = 0 in SM

Anomalous Couplings

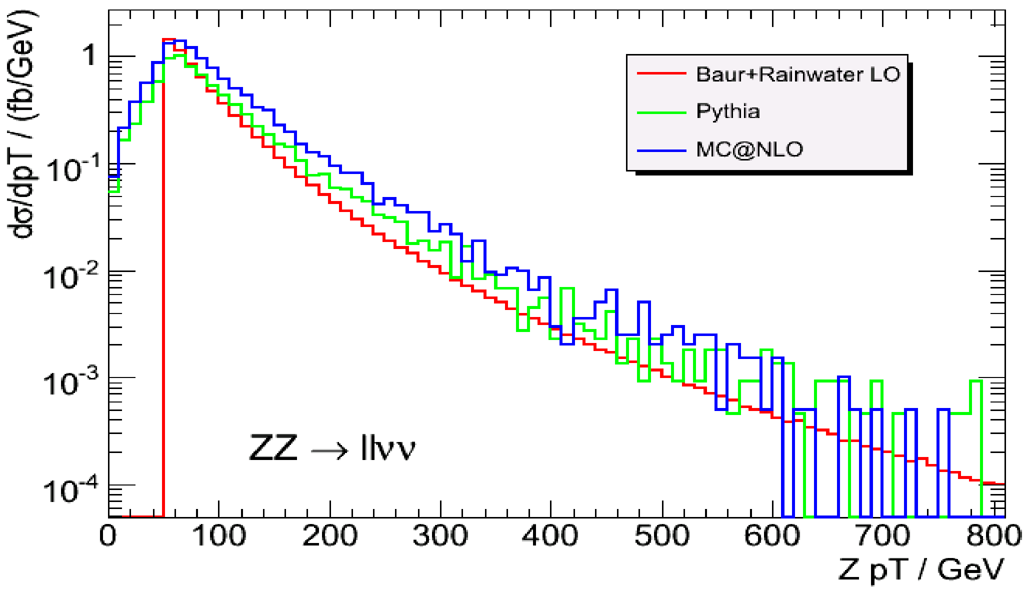
- f_4 violate CP; helicity amplitudes do not interfere with SM; cross-sections depend on f_4^2 and sign cannot be determined
- f_5 violate P; contribute to SM at one-loop level: $O(10^{-4})$
- Couplings increase with energy. Usual to introduce a form factor to avoid violation of unitarity:

$$f_i(s') = f_{0i} / (1 + s'/\Lambda^2)^n$$

- Studies below use n=3, Λ = 2 TeV
- Also assume couplings are real and only one non-zero: use f_4^Z as example, expect results for others to be similar

Anomalous Coupling MC

- Use leading order MC of Baur + Rainwater
  Phys. Rev. D62 113011 (2000)
- pp→ZZ→ffff No parton shower, underlying event, detector simulation
- CTEQ6L PDFs



SM prediction

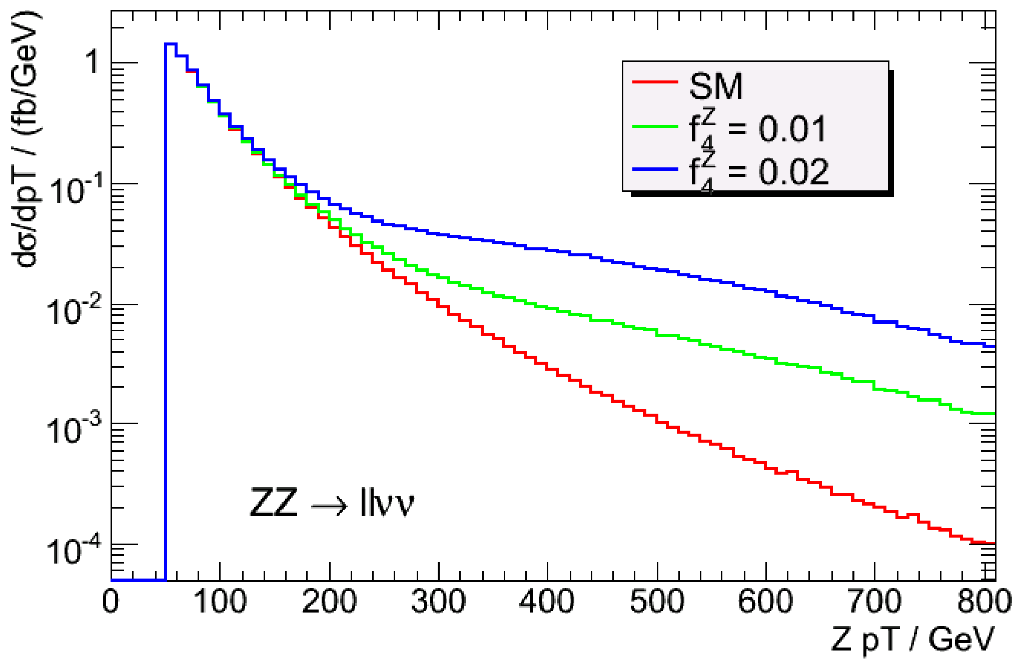
l = e, μ

$p_T(l) > 20$ GeV

$|\eta(l)| < 2.5$

$p_T(\nu\nu) > 50$ GeV

Signature of Anomalous Couplings



$p_T(l) > 20$ GeV
$|\eta(l)| < 2.5$
$p_T(\nu\nu) > 50$ GeV

- Anomalous couplings increase cross-section at high p_T
- Fit p_T distribution to obtain limits on NTGC

Fits to p_T Distribution

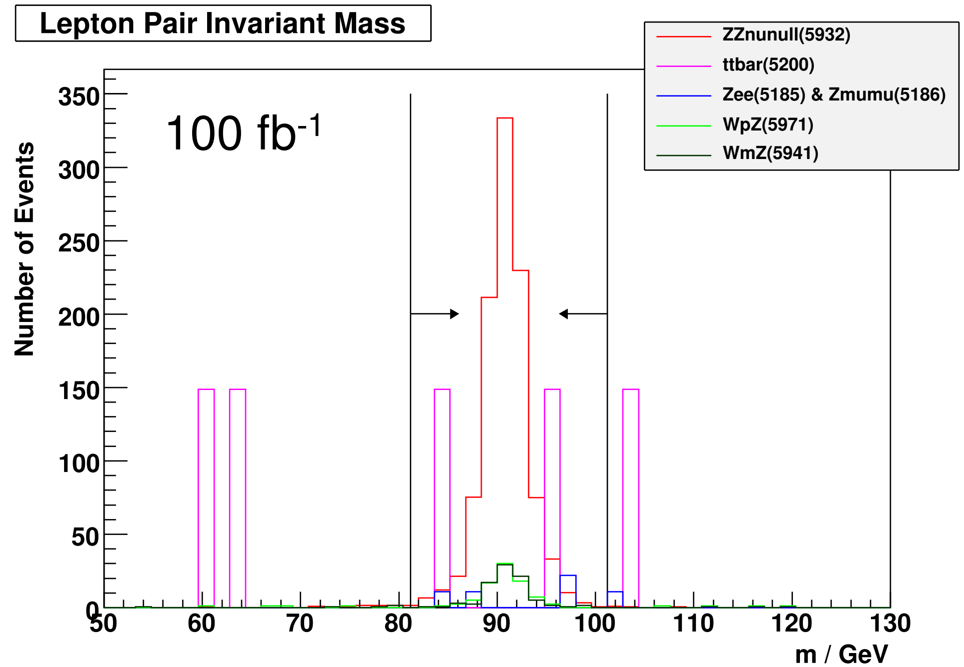
- Aim: estimate limits on anomalous couplings likely to be obtained from early ATLAS data from fit to Z(→ll) p_T distribution in ZZ→llνν channel:
  - Generate `fake data' samples
  - Binned max L fit to sum of signal + background
  - Determine mean 95% C.L.
- Use results from full MC (CSC samples) for event selection efficiency and background to obtain realistic limits
- Also assess effect of varying background and systematic errors

Full Simulation Results

Tom Barber

Diboson Meeting 13th August 2007

11.0.4	12.0.6
ε = 3.2%	**ε = 2.6%**
S/B =2.25	**S/B =1.96**



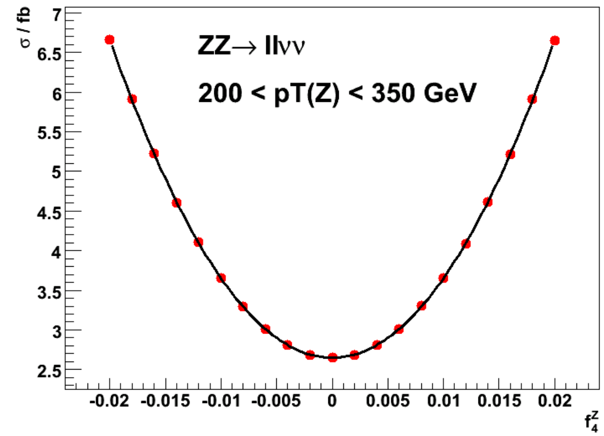
Process	$ZZ \rightarrow ll\nu\bar{\nu}$	$ZZ \rightarrow 4l$	$Z + jets$	$t\bar{t}$	WZ	Wt	WW	$Z \rightarrow \tau\tau$
$p_T^l > 20$ GeV, $\lvert\eta_l\rvert < 2.5$	13006	5430	$1.31\ 10^6$	$4.53\ 10^5$	27122	225	49110	$2.17\ 10^5$
Third lepton veto	10187	311	$1.90\ 10^5$	42887	5287	75	37556	$1.69\ 10^5$
$\lvert m_{ll} - 91.2\text{ GeV}\rvert < 10$ GeV	10016	265	$1.74\ 10^5$	11020	4530	38	8377	4014
$p_T^{\text{miss}} > 50$ GeV $\lvert p_T^{\text{miss}} - p_T^Z\rvert / p_T^Z < 0.35$ $\phi_{\text{miss}} - \phi_Z < 35°$	3795	34	378	1787	942	0	1826	0
Jet Veto ($p_t^{jet} > 30$ GeV and $\lvert\eta_{jet}\rvert < 3$)	3443	30	44	596	763	0	1668	0
$p_T(l^+l^-) > 100$ GeV	**1016**	**8**	**44**	**298**	**167**	**0**	**2**	**0**
Statistical Error:	23	1	22	211	13	0	23	0

Events expected in 100fb-1 of data

Calculation of Signal Distribution

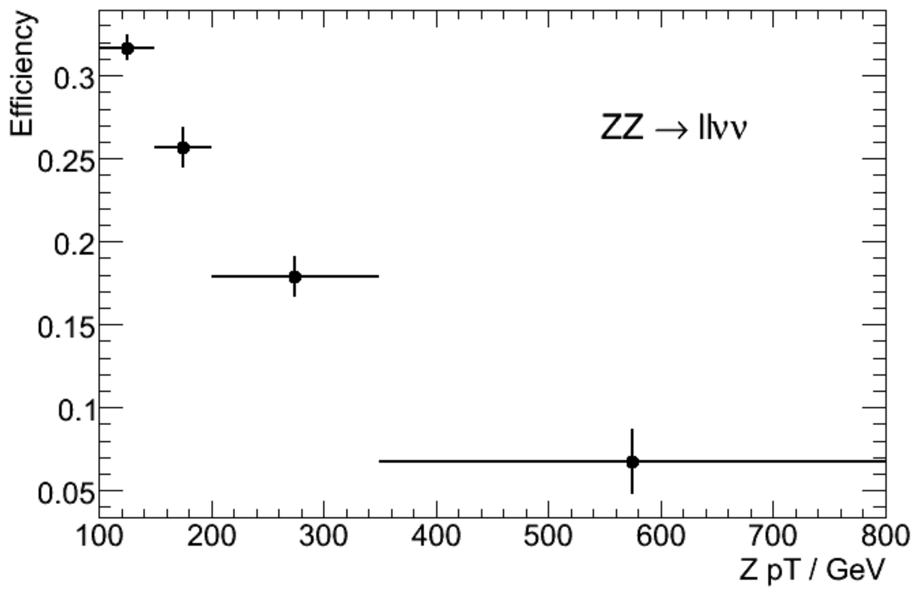
- Use BR MC to calculate LO cross-section at several values of f_4^Z

  $p_T(l) > 20$ GeV, $|\eta(l)| < 2.5$, $p_T(\nu\nu) > 50$ GeV



- Fit to quadratic in f_4^Z to obtain cross-section at arbitrary f_4^Z
- Correct for NLO effects using ratio MC@NLO / BR(SM)
- Expected number of events = cross-section x efficiency x luminosity

Signal Efficiency



Efficiency = events passing selection cuts divided by events generated with $p_T(l) > 20$ GeV, $|\eta(l)| < 2.5$, $p_T(\nu\nu) > 50$ GeV

- Efficiency from full MC using Tom's event selection
- Drops with p_T due to jet veto
- Fit results have some dependence on binning

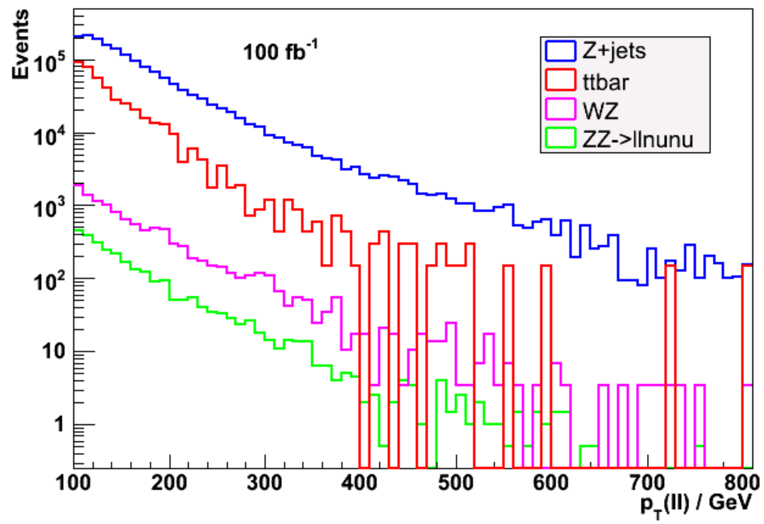
Reasonable variations change limits for 10 fb^{-1} by 10 – 15%

Background Distribution

- Too few full MC events pass cuts to determine background shape
- Before cuts, background shape fairly similar to signal for $p_T > 100$ GeV
- Assume background / SM signal flat:

  0.51 +- 0.21

  (error from MC stats)



- Background level has only small effect on limits

`Fake Data' Samples

- Construct from expected numbers of SM signal and background events
- Add Gaussian fluctuations for systematic errors:
  - Signal: 7.2% correlated (6.5% lumi, 3% lepton ID) plus MC stat error on efficiency in each bin
  - Background: 41% correlated (MC stats)
- Add Poisson fluctuation to total number of events

Fits to p_T Distribution

- One-parameter binned maximum likelihood fit to $(f_4^Z)^2$
- Likelihood for each bin is Poisson convolved with Gaussians for nuisance parameters representing systematic errors:

$$L_i = \int df_s \int df_b \, G(f_s,\sigma_s) \, G(f_b,\sigma_b) \, P(n; f_s \underbrace{\nu_s}_{\text{Depends on } f_4^Z} + f_b \nu_b)$$

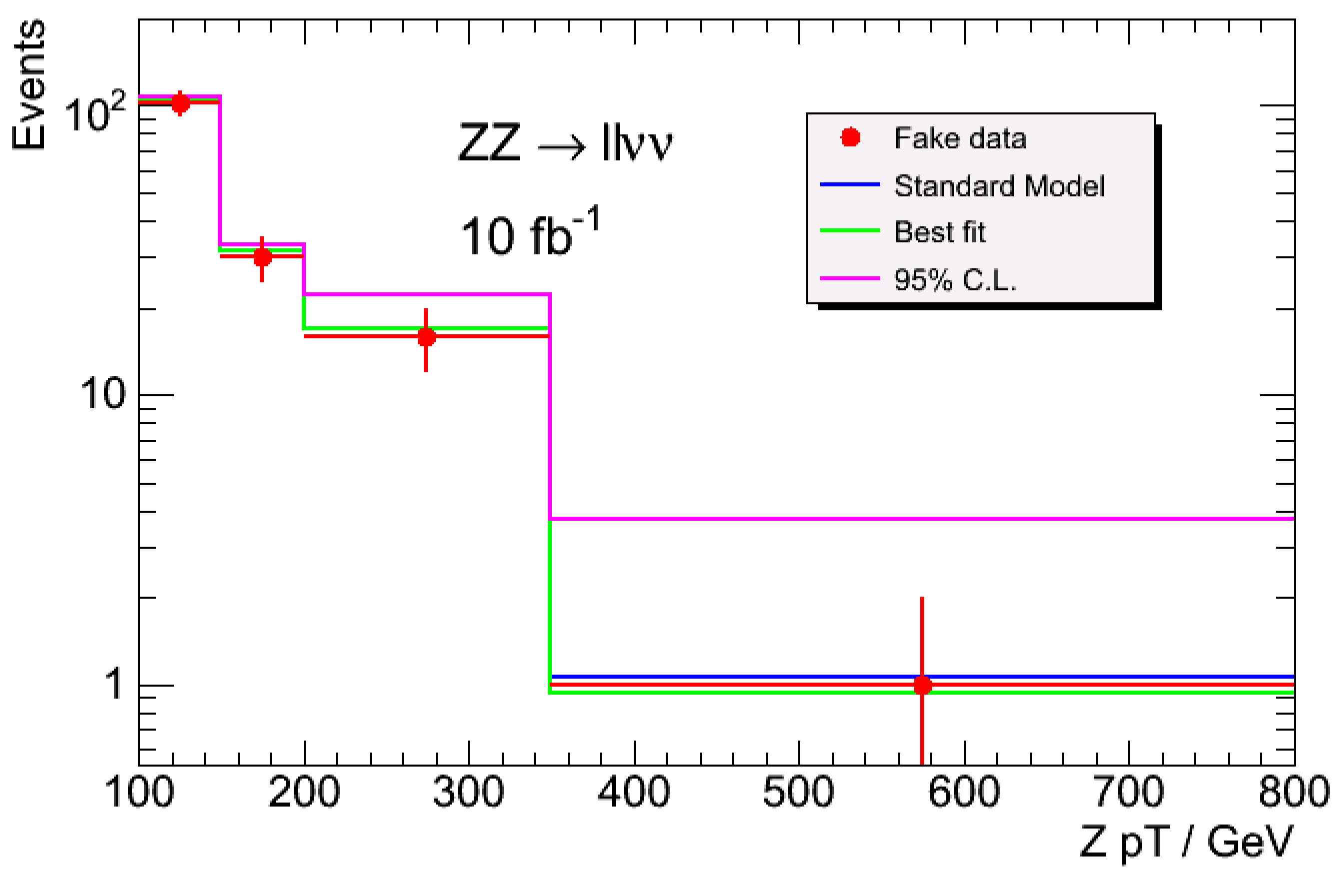
n = number of `data' events

ν_s, ν_b = expected signal, background

σ_s, σ_b = fractional systematic errors

- Minimize L = - $\ln(\Pi_i L_i)$
- 95% C.L. from $L - L_{min} = 1.92$
- Negative $(f_4^Z)^2$ allows for downward fluctuations
- Lower bound to prevent negative predictions

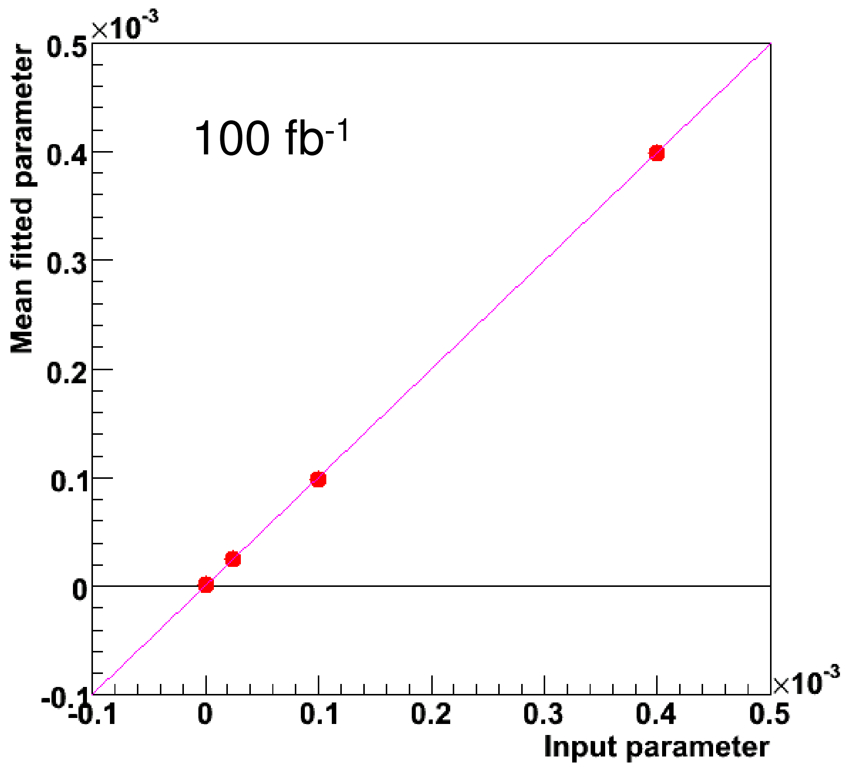
Example Fit


Events
10^2
10
1
$ZZ \to ll\nu\nu$
$10\ fb^{-1}$
Fake data
Standard Model
Best fit
95% C.L.
100
200
300
400
500
600
700
800
Z pT / GeV

Test Fit

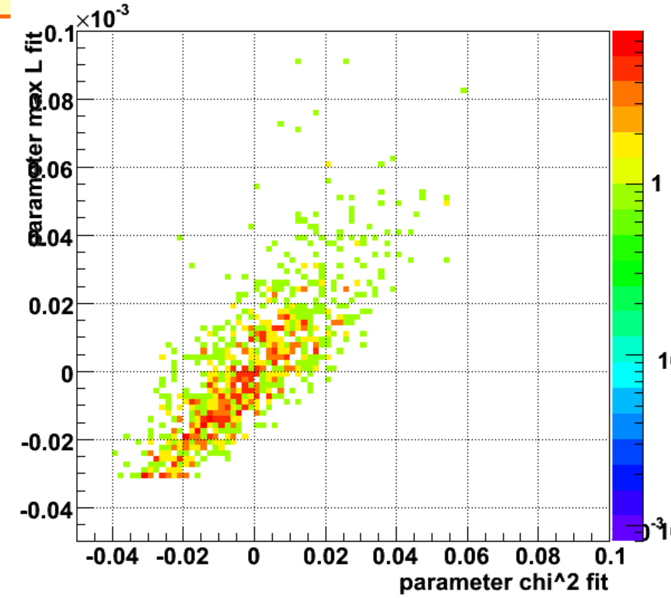
- Make `fake data' with various input values of $(f_4^Z)^2$ to test fit
- Mean fitted parameter in excellent agreement with input parameter

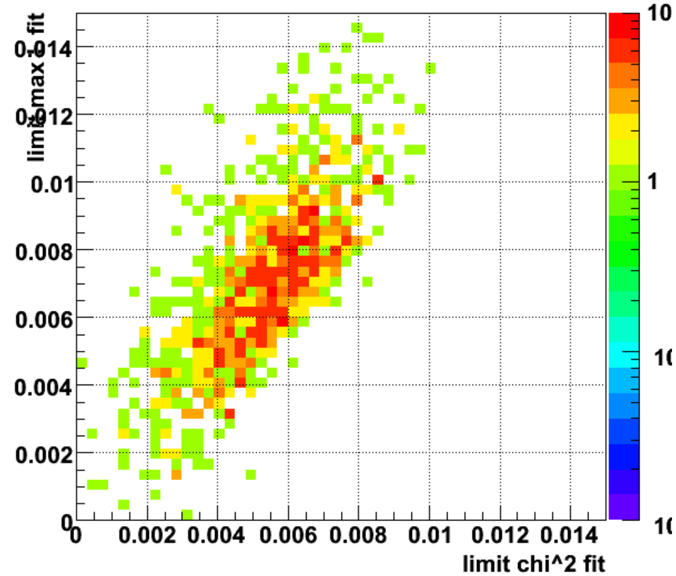
  (but distribution distorted by lower bound on parameter at low luminosities for small f_4^Z)



Test fit on 100 fb^{-1}

- Compare with X^2 fit using full correlation matrix (only suitable for high luminosity)
- Generate 1000 fake data samples for high luminosity and fit with both fits
- Good correlation between parameter values at minimum
- 95% C.L. limits tend to be higher for max likelihood fit – seems to result from treatment of systematic errors, but not understood





Results from Max L Fit

Lumi / fb^{-1}	95% C.L.
1	0.023
10	0.011
30	0.0088

- Mean 95% C.L. on $|f_4^Z|$ from 1000 fits
- Background level and systematic errors not important for early data
- No background: limits improve by 10%
- No sys errors: limits improve by 7%

With as little as 1 fb^{-1} can improve LEP limits by order of magnitude

LEP: $|f_4^Z| < 0.3$
no form factor

Fit Variations

- Assess effect of varying background level and systematics on limits for 10 fb^{-1}

Variation	95% C.L.	Change
Default	0.0110	-
Bg / SM sig. = 0.2	0.0104	5%
No background	0.0100	10%
Δsys(bg) = 20%	0.0108	2%
Δsys(bg) = 0	0.0106	4%
Stat errors only	0.0102	7%

ZZ→llll

- Work has started to include ZZ→llll channel
- Branching ratio factor of 6 lower than ννll channel
- Efficiency much higher, background lower
- First indications are that sensitivity is similar to llνν channel

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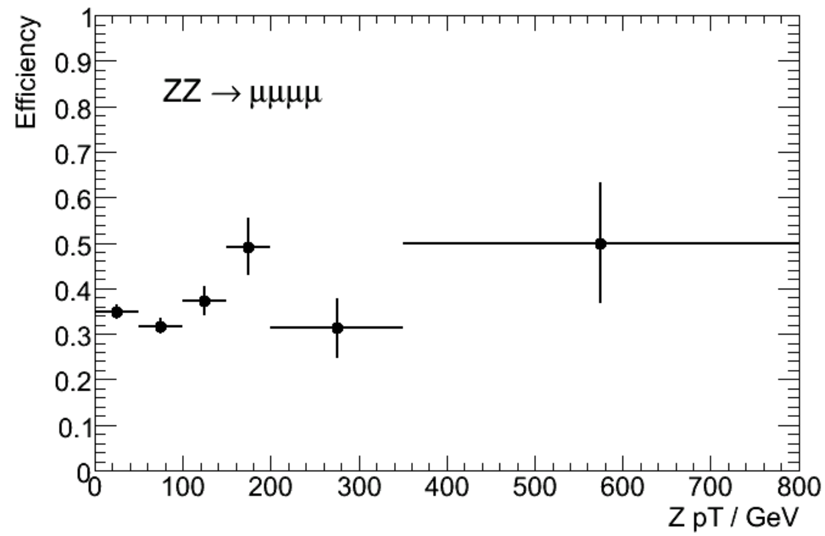

Summary and Outlook

- Expect to achieve worthwhile limits with as little as 1 fb^{-1} of data (and maybe less)
- Much still to do for a `real' analysis:
  - Understand why max L fit gives higher limits
  - Unbinned likelihood fit for lowest luminosities?
  - How to determine background distribution from data?
  - Set up framework for 2-D couplings
- Include 4-lepton channel – now in progress