ZZ Observation at the Tevatron

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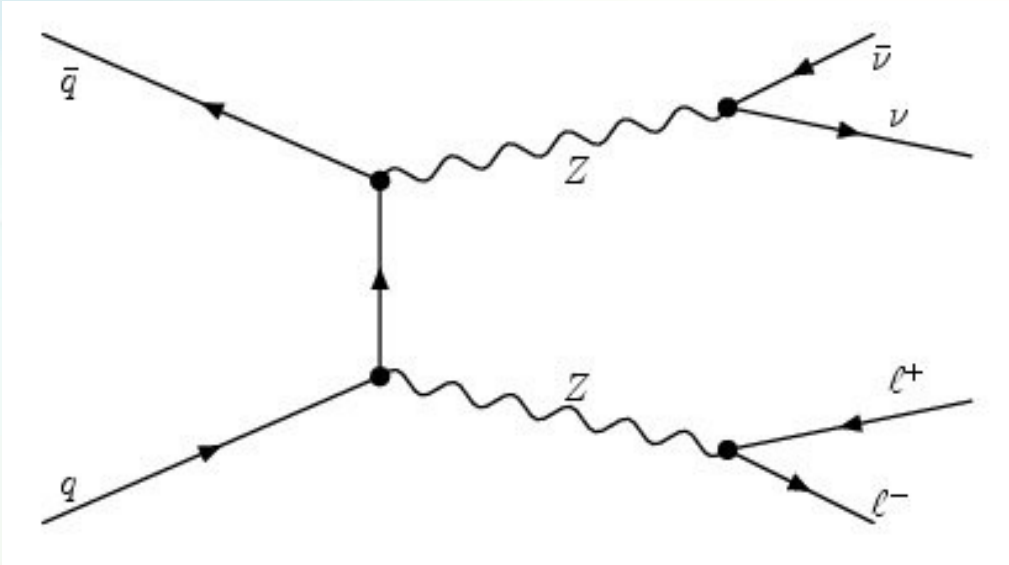
March 10, 2009

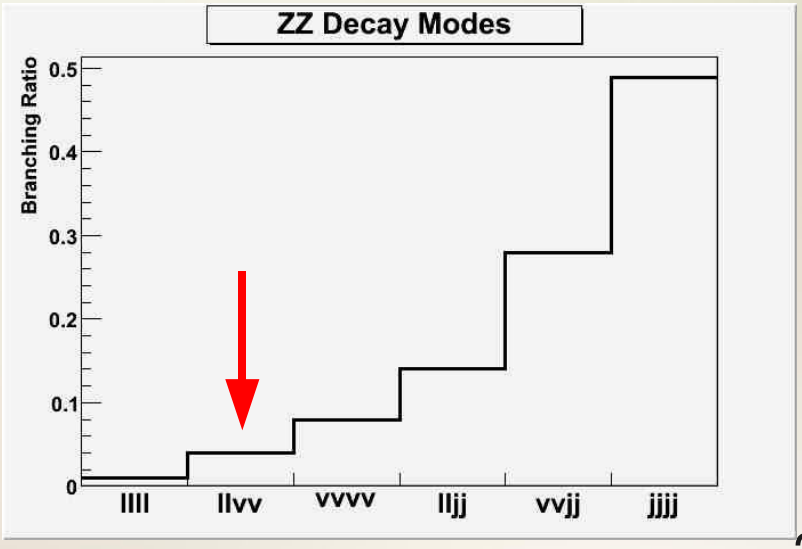
Motivation

Aside from production with a Higgs (Englert, Brout) Boson, the ZZ di-boson process has the lowest cross section and **was** the last remaining unobserved di-boson process at the Tevatron.



Use the fully leptonic mode ZZ→llvv (where l = electrons and muons):

- Small branching fractions w.r.t jet modes
- Larger branching fractions than the ZZ→llll
- Manageable Backgrounds
- Requires a large amount of data



ZZ->llvv: Preselection

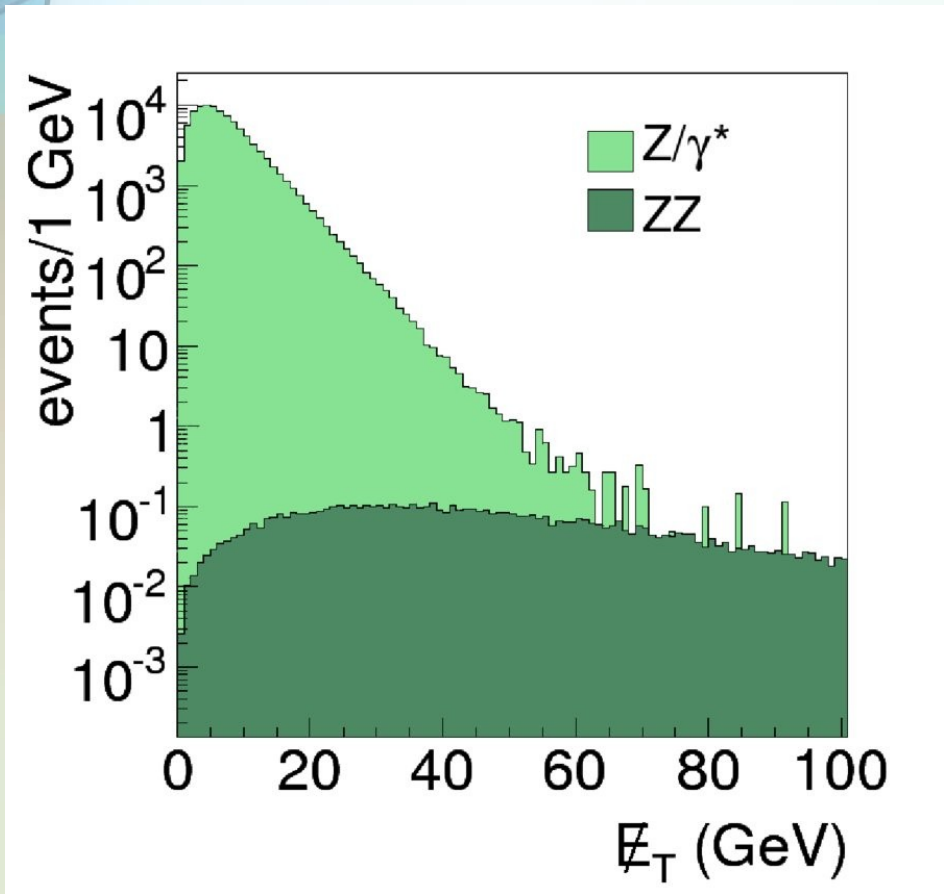
2.7fb^{-1} : OR of single electron / muon triggers
Normalize to the Z peak in Data

- 2 Leptons w/ p_T > 15 GeV
- Tight Isolation and Shape requirements
- Electrons within the central (|η| < 1.1) or forward (1.5 < |η| < 2.5) calorimeter regions
- Muons with at least one 1 hit in the Silicon Microstrop Tracker (SMT)

Reject events with additional low p_T or poorly reconstructed electrons, muon, taus, and isolated tracks

Require # of jets <= 2 w/ p_T > 15 GeV

Di-lepton Invariant Mass 70 < M_{ll} < 110 GeV



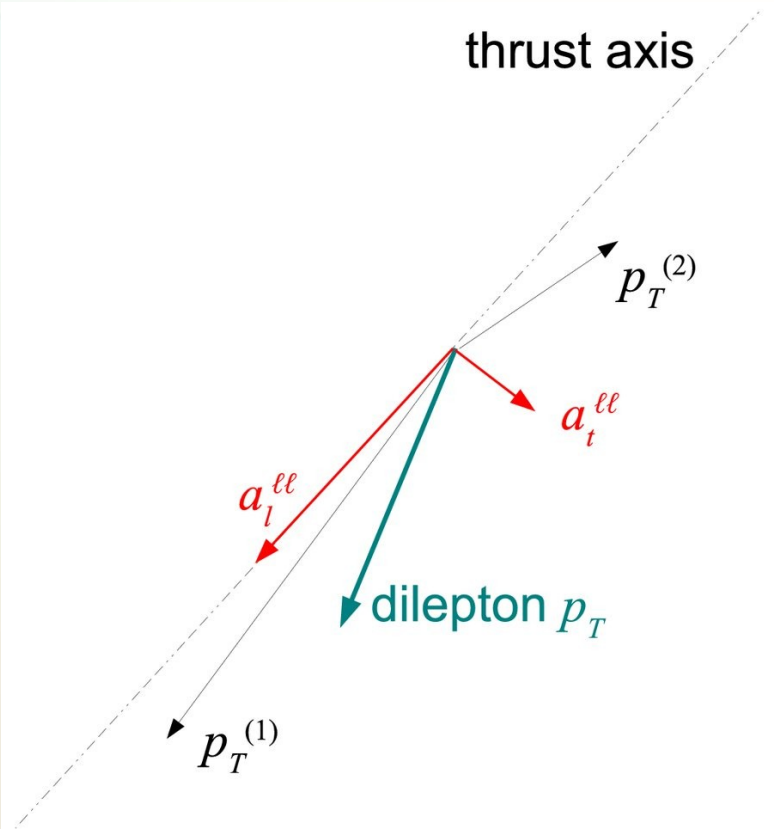
Although the MET mis-measurement tails are small, the signal is still overwhelmed due to the main Z/γ* substantial cross section.

Building a Better MET Indicator

Rather than make an unbiased or accurate estimate of the MET, build a variable which is a measure of the minimum feasible MET robust against reconstruction mistakes.

- decompose di-lepton p_T in 2 components with respect to thrust axis:
  - a_L: sensitive to p_T mis-measurement
  - a_T: sensitive to recoil activity mis-measurement
- Balance a_L and a_T individually against
  1. Calorimeter recoil activity (MET and Jets)
  2. p_T of recoiling tracks
  3. Lepton transverse momentum uncertainty
- Build a variable which gives more weight to a_T

  $\not{E}_T' = \mathrm{sqrt}(a_L^2 + (1.5\, a_T)^2)$



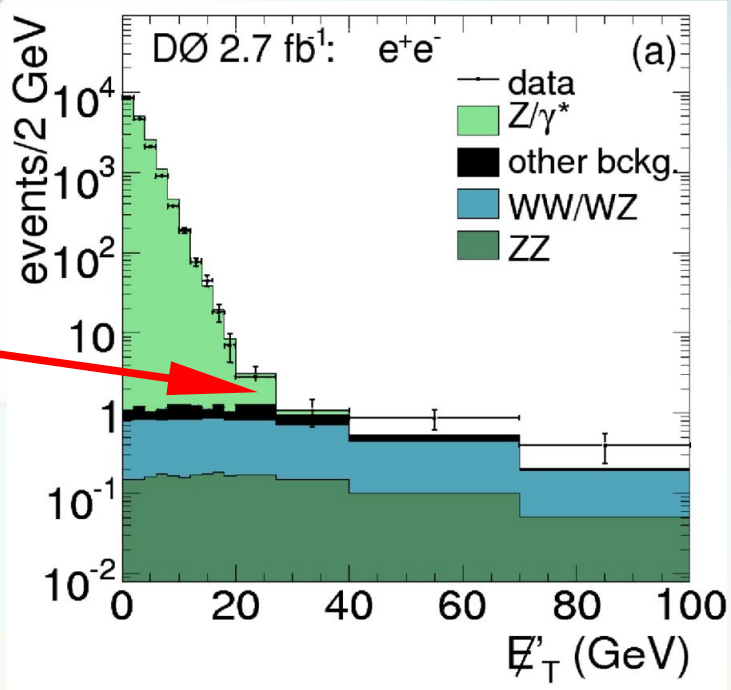
Result:

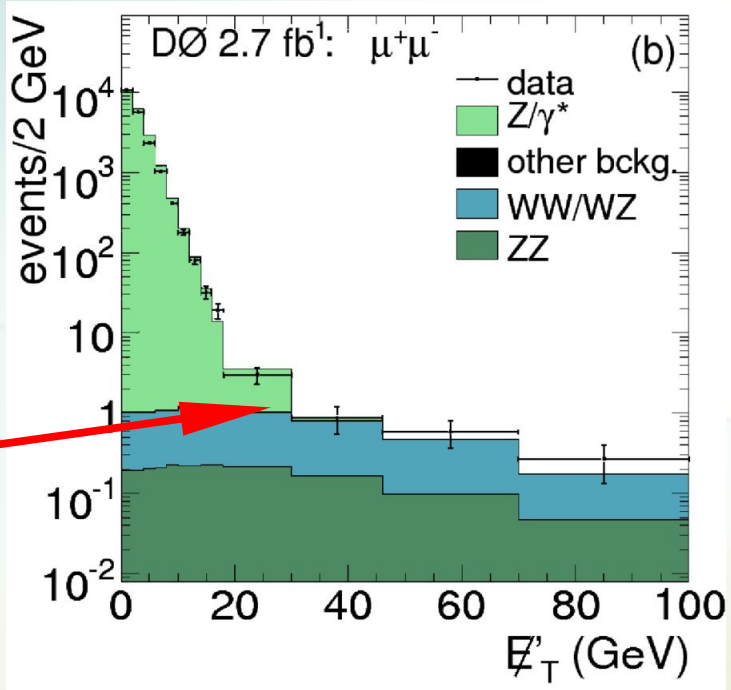
- by construction all uncertainties and mis-reconstruction can ONLY reduce the value of $\not{E}_T'$

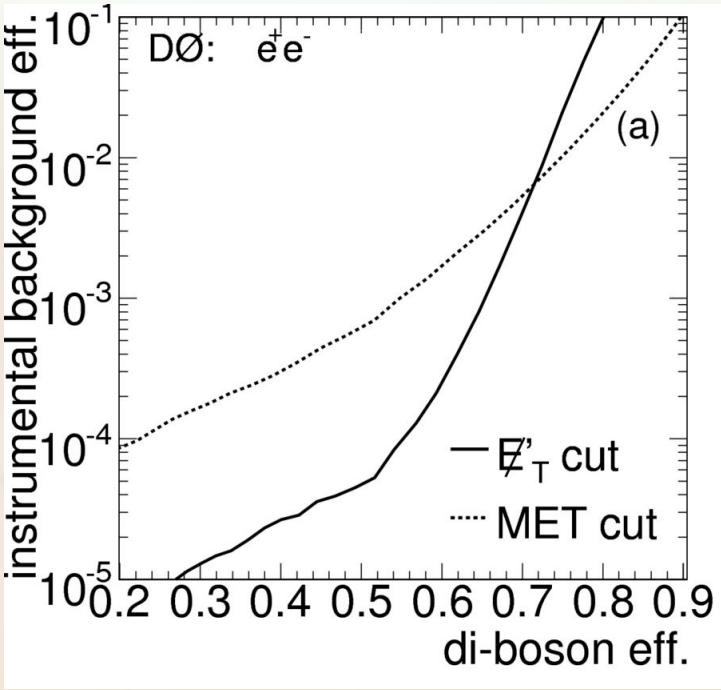
Signal Extraction

Z/γ* constrained to the region < ~40 GeV.

Genuine MET backgrounds are relatively unchanged.







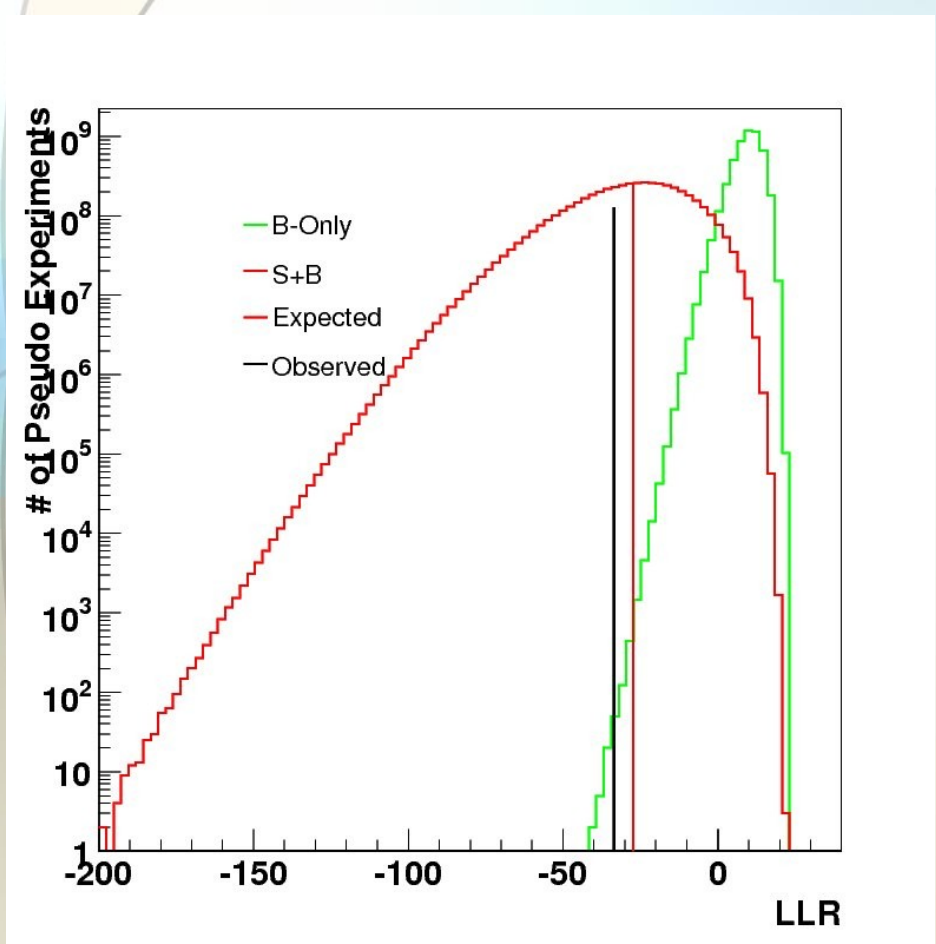
Yields after the $\not\!\!E'_T$ cut:

Sample	diem	dimu
Z->ll	0.5 ± 0.2	0.1 ± 0.1
ZZ->llνν	4.03	3.39
Tot Bckg	15.6 ± 0.4	10.9 ± 0.3
Bkgd + Signal	19.6 ± 0.4	14.3 ± 0.3
Data	28	15

Use a likelihood method to classify the remaining irreducible backgrounds.

ZZ → (llνν, llll) Combined Result

An orthogonal search has been performed at D0 in the ZZ to four charged leptons channel in which three candidate events have been found.



The combined significance is determined by calculating the probability that the background fluctuate up to our observed values from 3×10^9 pseudo-experiments.

First observation at a hadron collider:

ZZ → llνν:	2.0σ exp	2.6σ obs
ZZ → llll:	4.2σ exp	5.0σ obs
Combined:	4.8σ exp	5.7σ obs

$$\sigma(ZZ) = 1.60 \pm 0.63\ (\text{stat.})^{+0.16}_{-0.17}\ (\text{syst.})\ \text{pb}$$

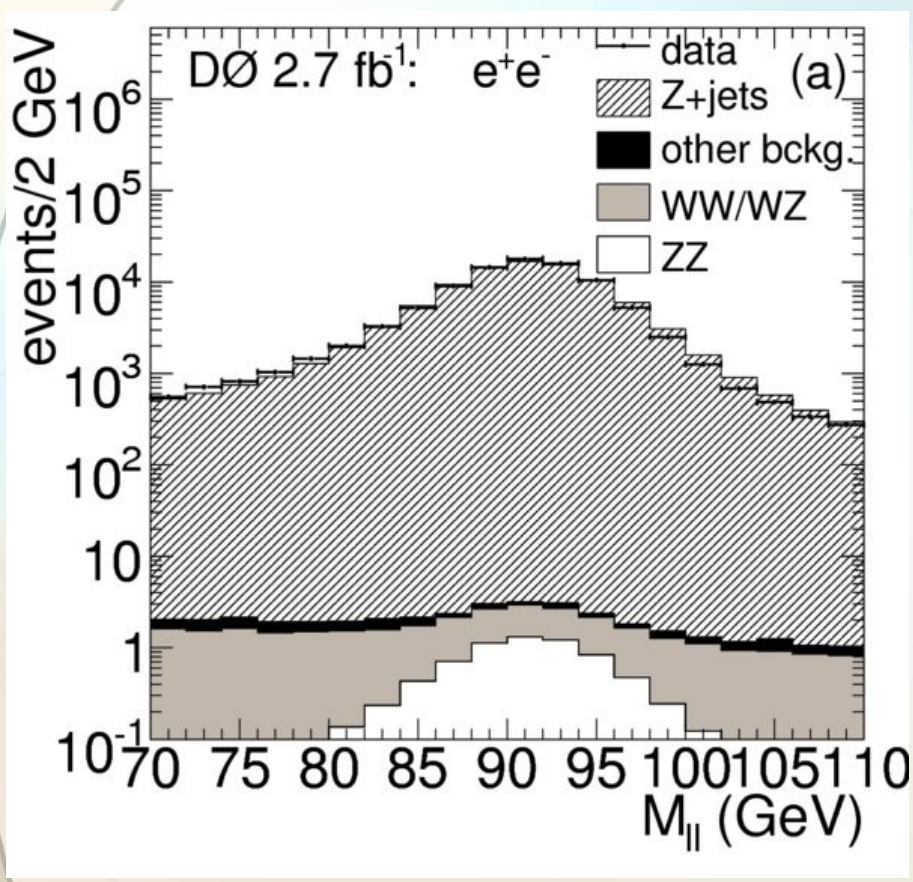
Predicted Standard Model cross section: 1.4 ± 0.1 pb

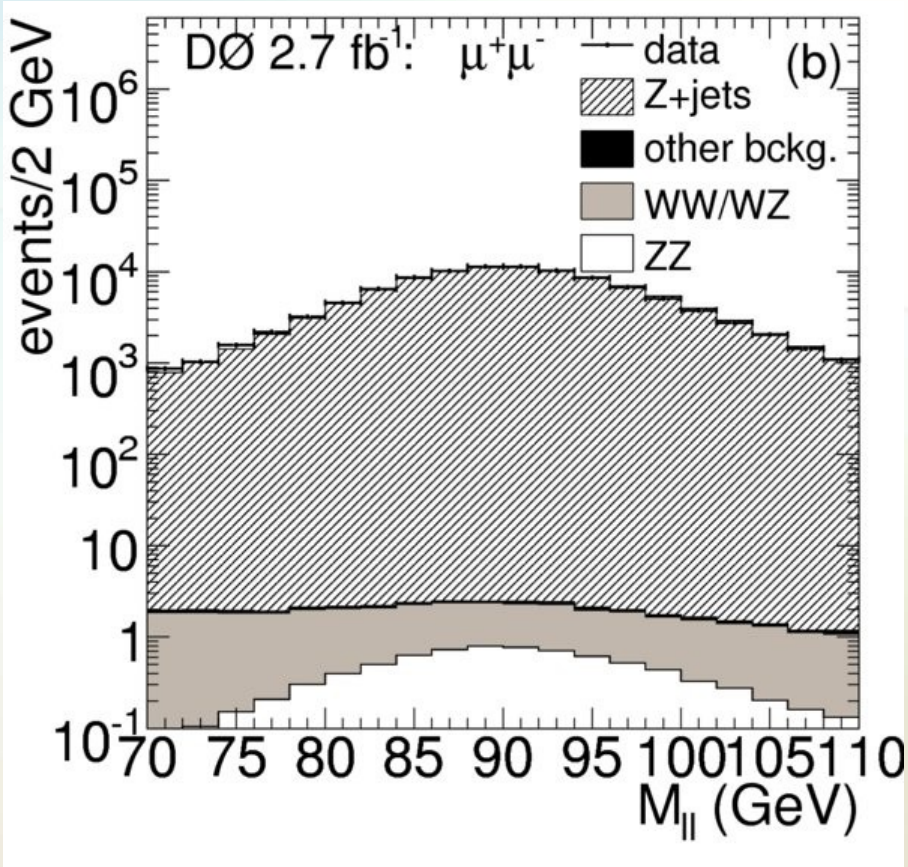
ZZ → llνν published in PRD **78**, 072002 (2008)
ZZ → llll and combination published in PRL **101**, 17183 (2008)

vertical red line: expected LLR from pseudo-experiments
vertical black line: value observed from data

Backup Slides

Dilepton Invariant Mass @ Preselection





Defining METPrime

$$\hat{a}_t = \vec{t}_\perp / |t| \qquad \hat{a}_l = \vec{t}_{||} / |t|$$

1) Project the di-lepton pT:

$$a_t^{\ell\ell} = \vec{p_T}^{\,\ell\ell} \cdot \hat{a}_t$$
$$a_l^{\ell\ell} = \vec{p_T}^{\,\ell\ell} \cdot \hat{a}_l$$

2) Calculate a calorimeter correction:

$$\delta a_t^{cal} = 2 \times min(\Sigma \vec{E_T}^{\,jets} \cdot \hat{a}_t, \not{E}_T \cdot \hat{a}_t, 0)$$
$$\delta a_l^{cal} = 2 \times min(\Sigma \vec{E_T}^{\,jets} \cdot \hat{a}_l, \not{E}_T \cdot \hat{a}_l, 0)$$

3) Calculate a track correction:

$$\delta a_t^{trk} = (\Sigma \vec{p_T}^{\,t\,jet}) \cdot \hat{a}_t$$
$$\delta a_l^{trk} = (\Sigma \vec{p_T}^{\,t\,jet}) \cdot \hat{a}_l$$

4) Calculate a lepton σ(pT) correction:

$$\vec{p_T}' = (1 - \sigma)\vec{p_T}, \text{ etc...}$$
$$a_t^{\ell\ell'} = \vec{p_T}^{\,\ell\ell'} \cdot \hat{a}_t'$$
$$\delta a_t^{\ell\ell} = a_t^{\ell\ell'} - a_t^{\ell\ell}$$
$$\delta a_l^{\ell\ell} = (-\sigma_1 \vec{p_T}^{\,(1)} + \sigma_2 \vec{p_T}^{\,(2)}) \cdot \hat{a}_l$$

5) Wrap it all together:

$$a_t = a_t^{\ell\ell} + \delta a_t^{cal} + k' \times \delta a_t^{trk} + k \times \delta a_t^{\ell\ell}$$
$$a_l = a_l^{\ell\ell} + \delta a_l^{cal} + k' \times \delta a_l^{trk} + k \times \delta a_l^{\ell\ell}$$

$$a_t' = max(a_t, 0) \qquad a_l' = max(a_l, 0)$$

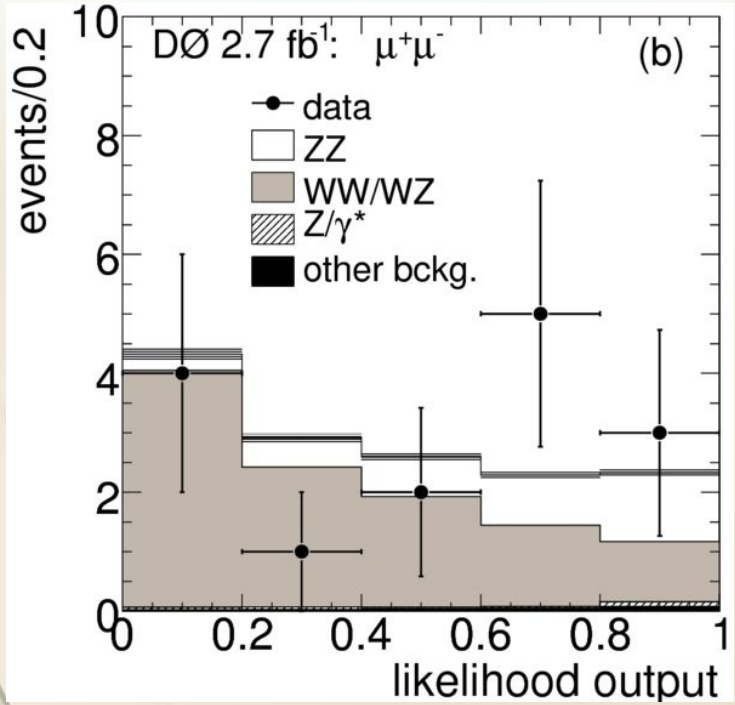
$$\not{E}_T' = \sqrt{a_l'^2 + (1.5a_t')^2}$$

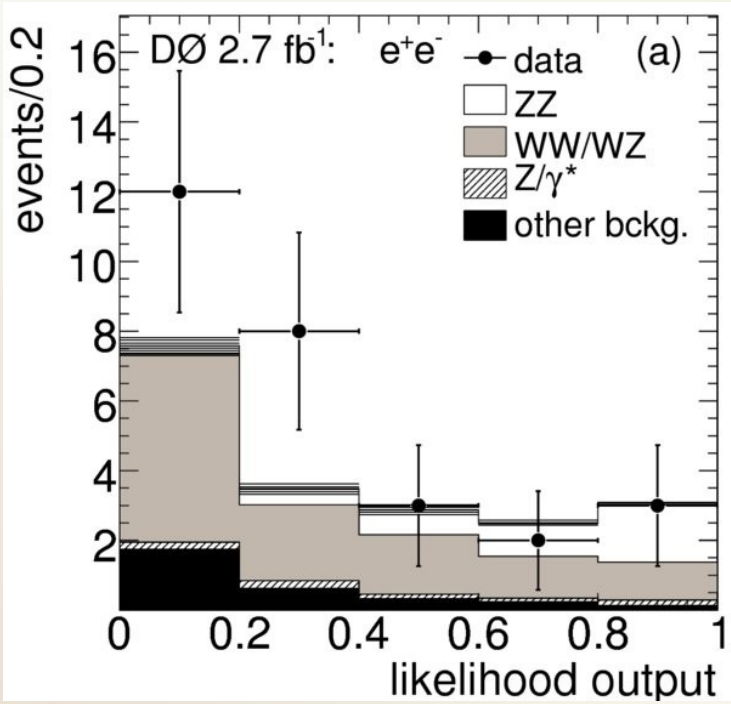
ZZ → llvv: Likelihood Distribution

The ZZ signal is extracted from the remaining backgrounds using a likelihood

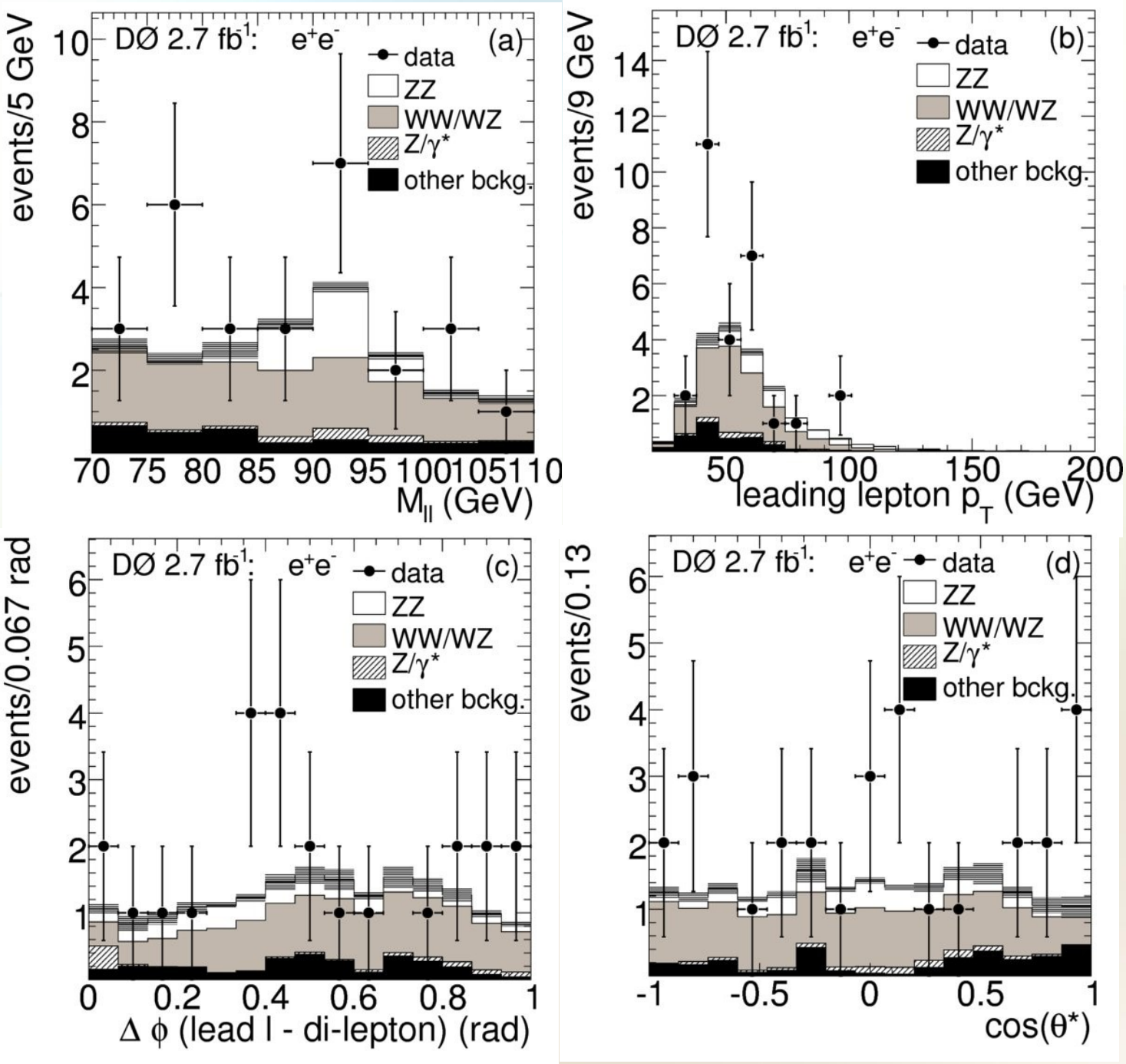
Likelihood Variables:

- Di-lepton mass (diem)
- Chi2 probability (dimu)
- Leading lepton pT
- ΔΦ(lead lep, di-lep)
- cos(θ*)

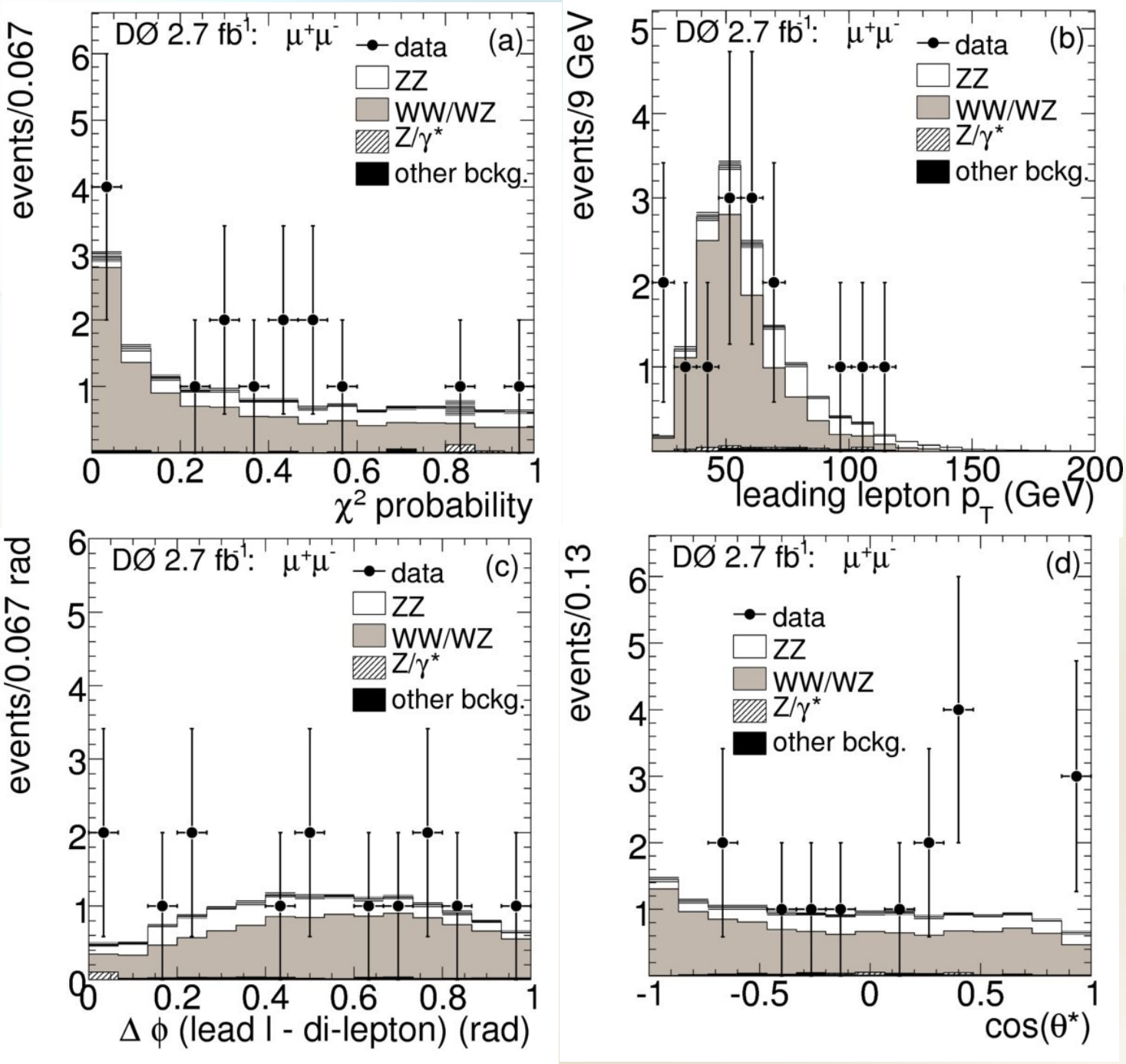




ZZ → llνν: Dielectron Likelihood Inputs



ZZ → llνν: Dimuon Likelihood Inputs



ZZ → llll: Candidate Events

Subchannel	$4e_{2C}$	$4e_{3C}$	$4e_{4C}$	4μ	$2\mu 2e_{0C}$	$2\mu 2e_{1C}$	$2\mu 2e_{2C}$
Luminosity (fb^{-1})	1.75 ± 0.11	1.75 ± 0.11	1.75 ± 0.11	1.68 ± 0.10	1.68 ± 0.10	1.68 ± 0.10	1.68 ± 0.10
Signal	0.084 ± 0.008	0.173 ± 0.015	0.140 ± 0.012	0.534 ± 0.043	$0.058^{+0.007}_{-0.006}$	0.352 ± 0.040	$0.553^{+0.045}_{-0.044}$
$Z(\gamma)$+jets	$0.030^{+0.009}_{-0.008}$	$0.018^{+0.008}_{-0.007}$	$0.002^{+0.002}_{-0.001}$	0.0003 ± 0.0001	$0.03^{+0.02}_{-0.01}$	0.05 ± 0.01	$0.008^{+0.004}_{-0.003}$
$t\bar{t}$	–	–	–	–	$0.0012^{+0.0016}_{-0.0009}$	0.005 ± 0.002	$0.0007^{+0.0009}_{-0.0005}$
Observed events	0	0	2	1	0	0	0