$ZZ\rightarrow 4l$ measurement with the first ATLAS data

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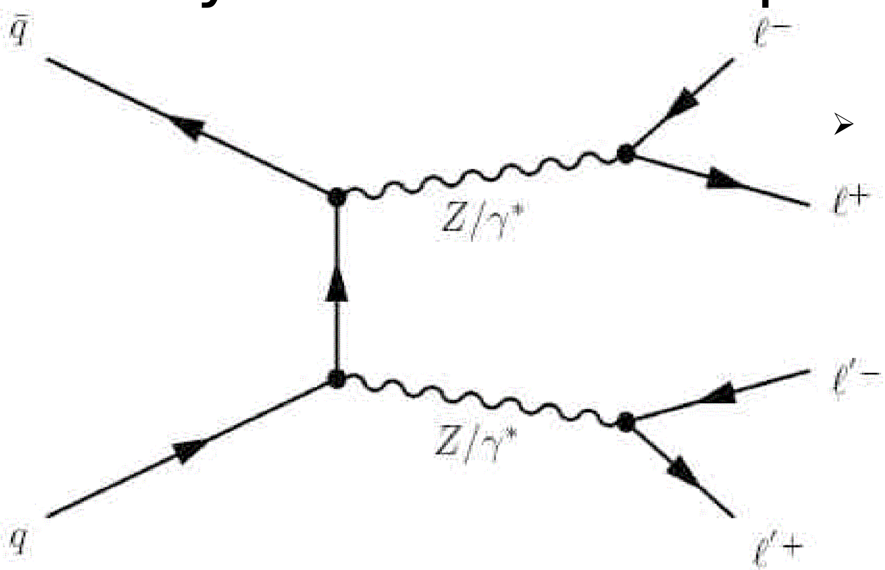
Overview

- Work done for the Computing System Commissioning (CSC) note ***"Diboson physics studies with the ATLAS detector",*** using CSC simulated data.
- Analysis:
  - Muon & electron selection
  - Lepton pairing and cuts on pairs
  - Results
- Triple Gauge Coupling (TGC) limits
- Conclusions

Motivation

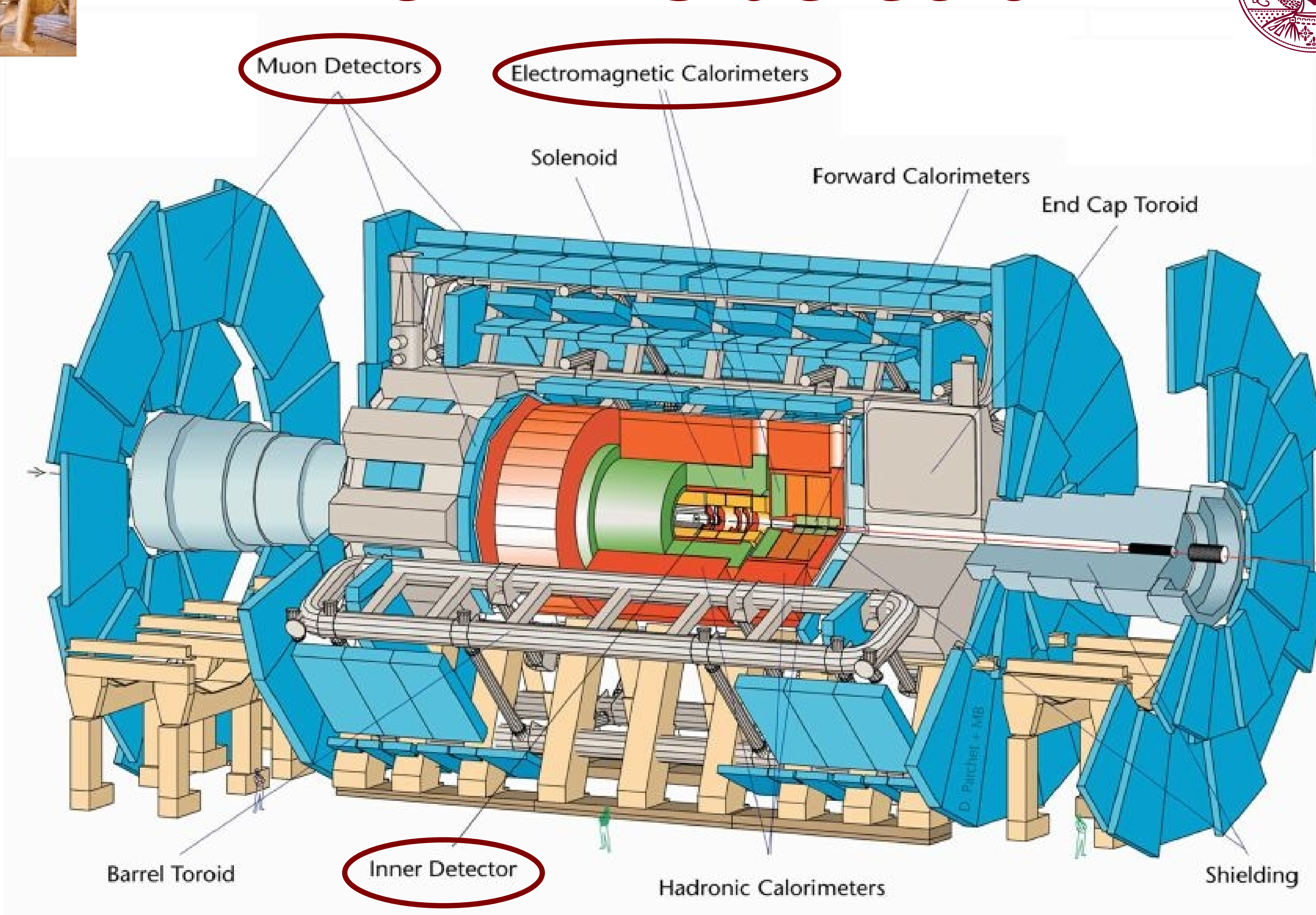
- SM cross section not measured yet
- Irreducible background to H→4l
- Develop tools for detector calibration using Z→2l
- Beyond the SM: Triple Gauge Couplings (TGCs)



- 3 event topologies: 4μ, 4e, 2μ2e
- Backgrounds: Zbb(bar), tt(bar)
- MC samples used:

Channel	Generator	Events	Filter eff.	x-sec	K factor
ZZ->4l	Pythia	43000	0.219	159fb	1.35
Zbb(bar)	Acer/Pythia	313689	0.009	52pb	1.42
tt(bar)	MC@NLO/Jimmy	152701	0.007	833pb	-

The ATLAS detector



Preselection cuts

Muons

- Combined Track (both in Inner Detector and Muon Spectrometer) OR Standalone Track (only in MS – no ID for $|\eta|>2.5$)
- chisq/DOF < 15 on match
- chisq/DOF < 15 on fit
- Pt > 6 GeV/c, $|\eta|<2.7$

Electrons

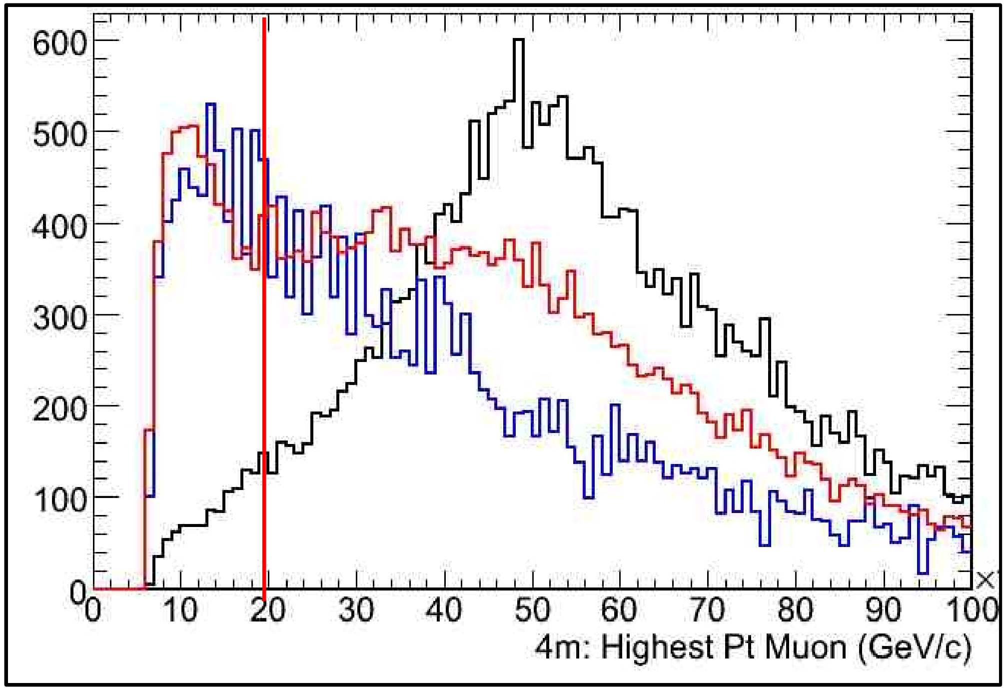
- Reconstructed as an electron or both as an electron and a soft electron, by the respective algorithms
- $0.5 < E/P < 3.0$
- Pt > 6 GeV/c, $|\eta|<2.5$

Create same flavor, opposite charge pairs with lepton $\Delta R>0.2$

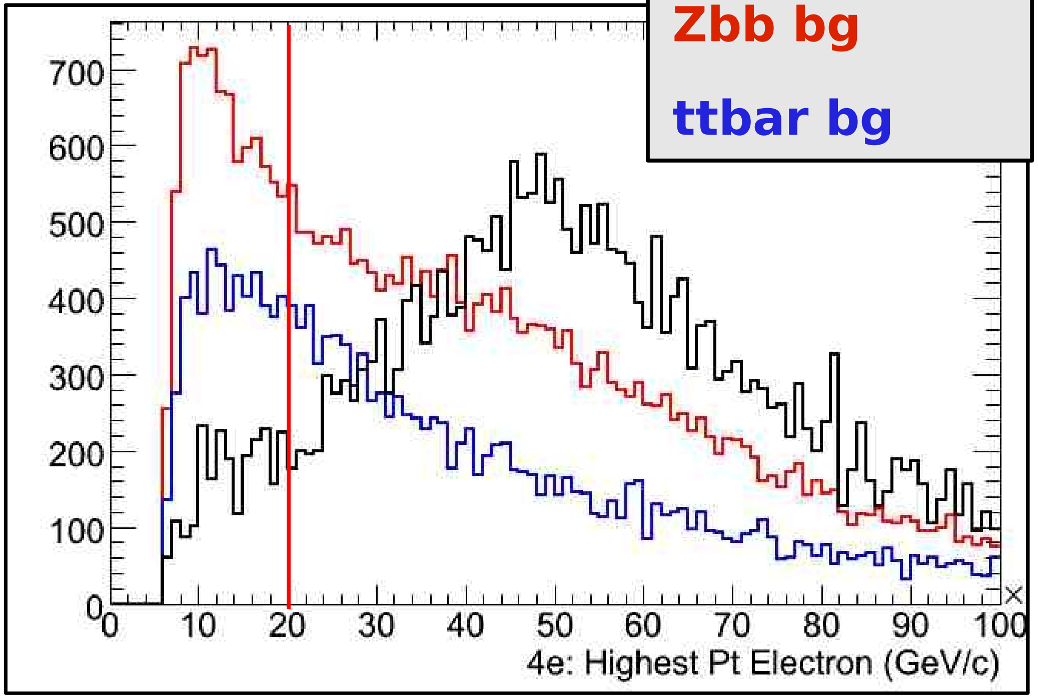
After preselection: Pt

At least one lepton in each pair with Pt > 20 GeV/c

4μ



4e



ZZ→4l signal

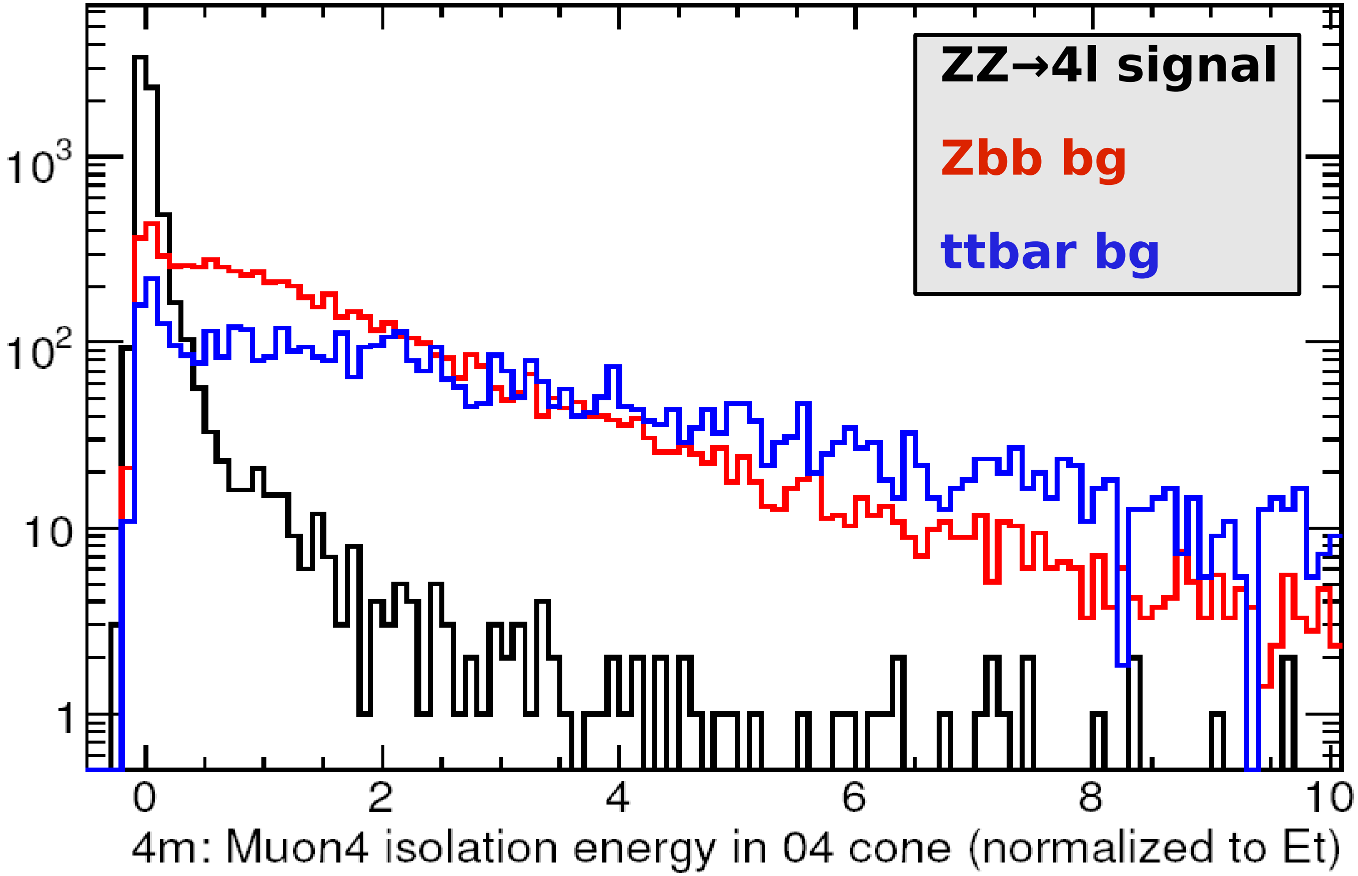
Zbb bg

ttbar bg

After preselection: Isolation

Electron: Cuts on the shower shape in the electromagnetic calorimeter

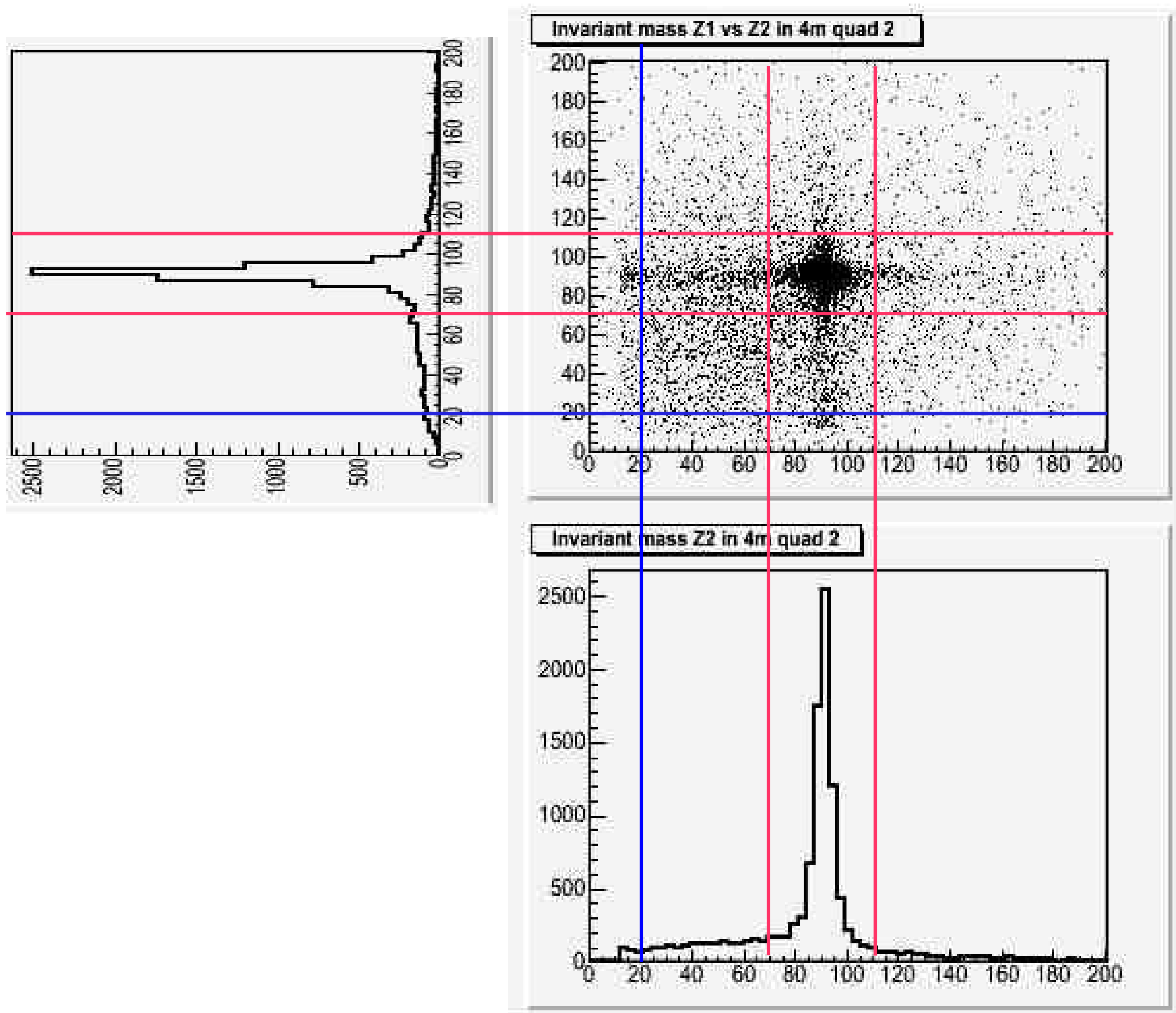
Muon: Isolation Ratio < 0.2 (energy in a cone of $\Delta R=\sqrt{\Delta\varphi^2+\Delta\eta^2}=0.4$ around the muon, divided by Et)



2l invariant mass

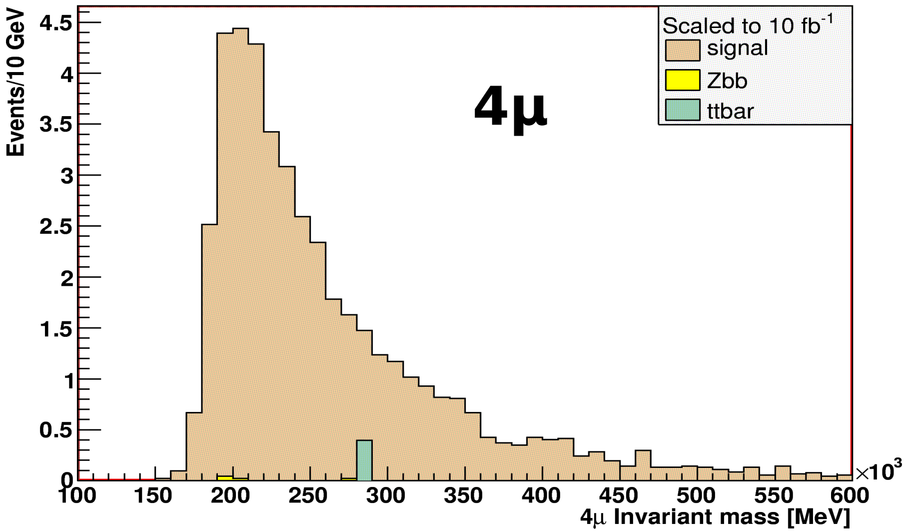
ZZ: m of both lepton pairs between 70 and 110 GeV/c

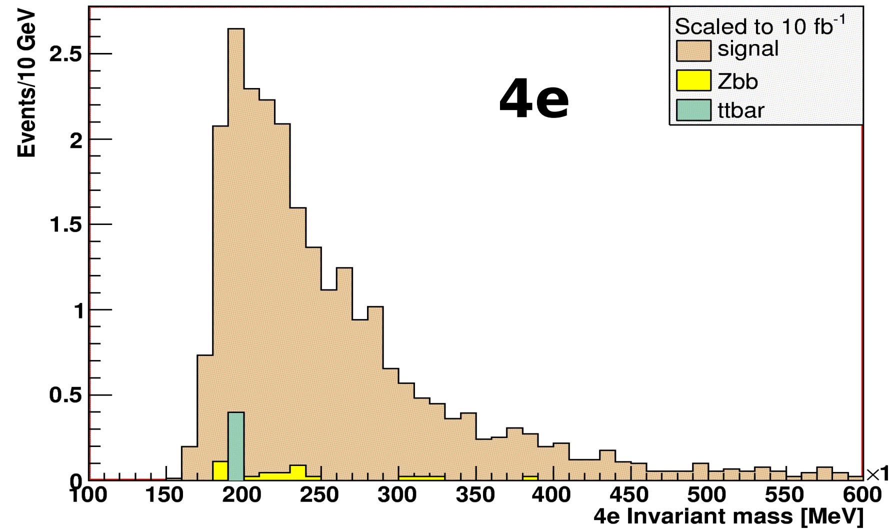
ZZ*: m(pair1) between 70 and 110 GeV/c, m(pair2) > 20 GeV/c

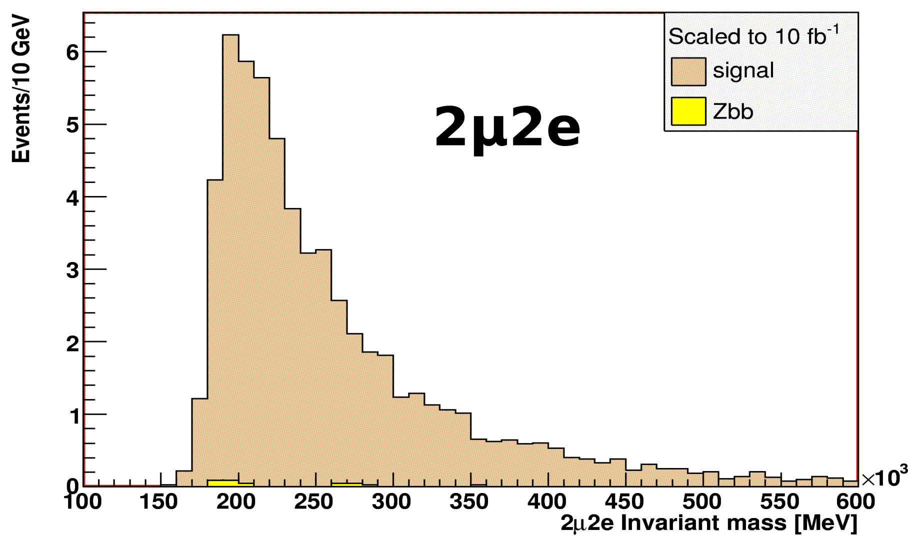


Final 4l Invariant Masses: ZZ

normalized to $10fb^{-1}$

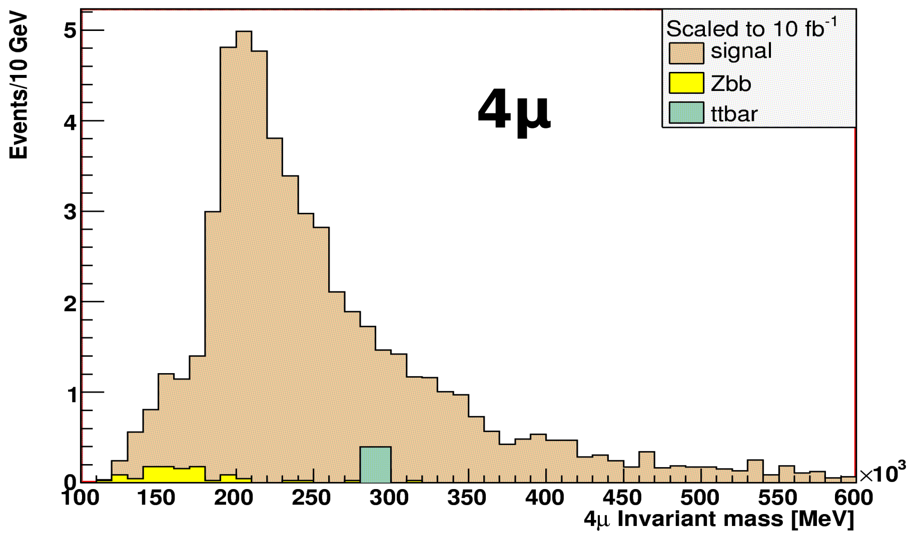


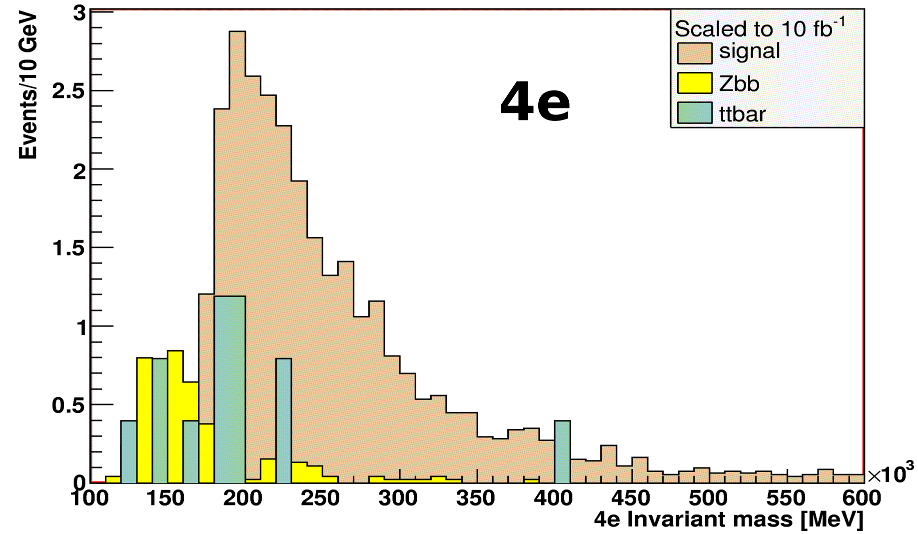


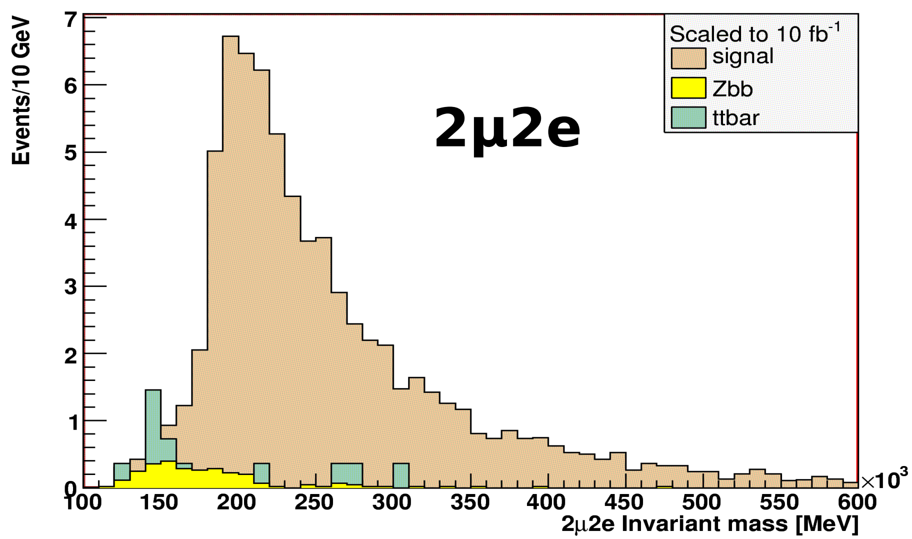


Final 4l Invariant Masses: ZZ*

normalized to $10fb^{-1}$







Efficiency summary

Signal	$ZZ \to 4\mu$ (%)		$ZZ \to 4e$ (%)		$ZZ \to 2\mu 2e$ (%)	
	ZZ^*	ZZ	ZZ^*	ZZ	ZZ^*	ZZ
Lepton Preselection	71		62		65	
Pair formation,dR	99		88		93	
Isolation, P_t^{max}	81		59		59	
Z Mass region	92	73	93	76	95	78
Total	52	41	30	24	34	28

$Zb\bar{b}$	$ZZ \to 4\mu$ (%)		$ZZ \to 4e$ (%)		$ZZ \to 2\mu 2e$ (%)	
	ZZ^*	ZZ	ZZ^*	ZZ	ZZ^*	ZZ
Lepton Preselection	6.3		11		18	
Pair formation,dR	77		59		48	
Isolation, P_t^{max}	1.3		4.3		0.7	
Z Mass region	25	2.0	26	2.2	70	8.8
Total	0.0156	0.0013	0.0692	0.0061	0.0405	0.0051

$t\bar{t}$	$ZZ \to 4\mu$ (%)		$ZZ \to 4e$ (%)		$ZZ \to 2\mu 2e$ (%)	
	ZZ^*	ZZ	ZZ^*	ZZ	ZZ^*	ZZ
Lepton Preselection	3.2		25		36	
Pair formation,dR	63		54		44	
Isolation, P_t^{max}	0.13		0.31		0.12	
Z Mass region	50	25	21	1.6	38	3.5
Total	0.0013	0.0007	0.0085	0.0007	0.0072	0.0007

Results: signal/bg

Results below are normalized to $1fb^{-1}$

	4μ events		$4e$ events		$2\mu 2e$ events		Total	
	ZZ^*	ZZ	ZZ^*	ZZ	ZZ^*	ZZ	ZZ^*	ZZ
Signal	5.72±0.06	4.52±0.05	3.17±0.04	2.59±0.04	7.56±0.07	6.18±0.06	16.5±0.10	13.3±0.09
$Zb\bar{b}$	0.11±0.01	0.009±0.003	0.48±0.02	0.042±0.007	0.28±0.02	0.035±0.006	0.87±0.03	0.086±0.010
$t\bar{t}$	0.08±0.06	0.04±0.04	0.52±0.14	0.04±0.04	0.44±0.13	0.04±0.04	1.03±0.20	0.12±0.07
Total bgr	0.19±0.06	0.049±0.040	1.00±0.14	0.082±0.040	0.72±0.13	0.075±0.040	1.90±0.20	0.20±0.07

sg/bg = 8.7 66.5

significance = 6.6 7.7

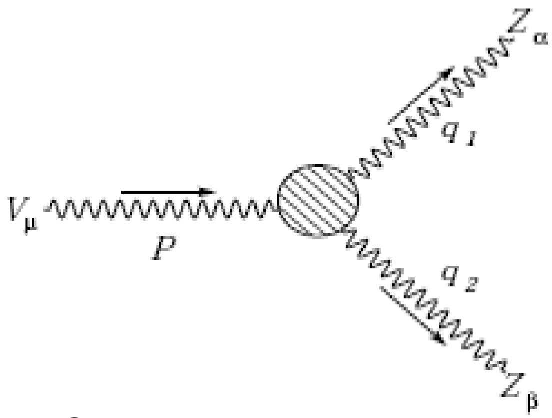
Where significance = sg/√bg, and the 95% Poisson limit for 1 and 0 events respectively is used for background

Systematic errors

From **MC** and **data**

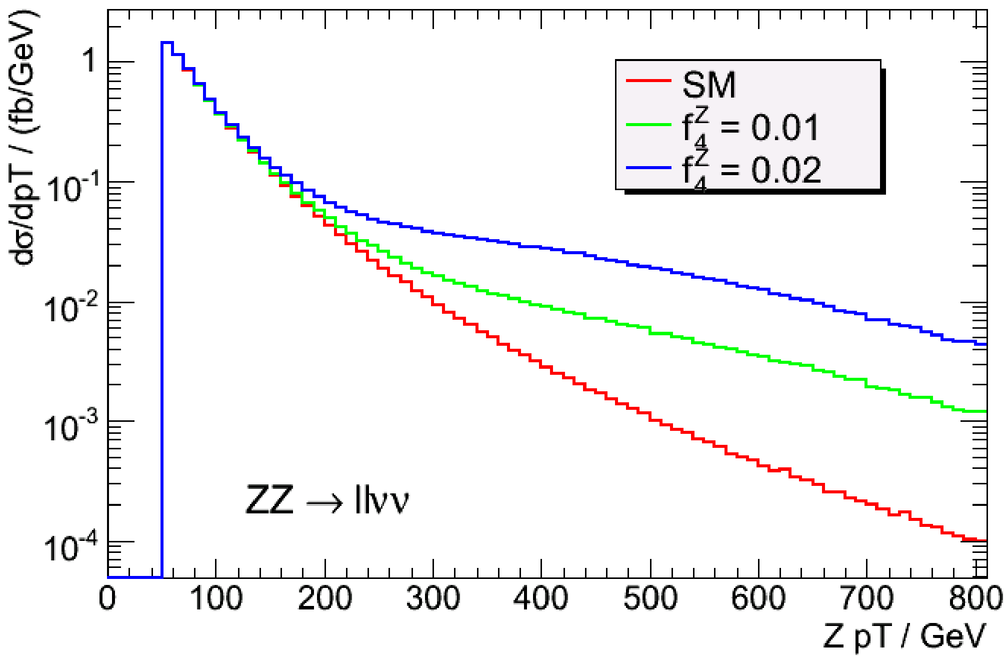
- Theoretical uncertainties: PDFs, QCD corrections (scaling uncertainty for NLO calculations): 3.4-6.2% (run MC with different structure functions/scale values)
- Luminosity: ~5% (Tevatron: 6.5% at 0.3 fb^{-1}, and got less with more accumulated luminosity)
- Trigger & Lepton identification efficiency: 2-3% (MC data with pileup and cavern backgrounds, OR real data with tag-and-probe method with $Z \rightarrow 2l$ decays)
- Jet & lepton energy scale: 2-3% (from WW & WZ Boosted Decision Trees study)
- Background estimate: ~2% (mainly from lepton identification)

TGCs: the principle



$$\Gamma^{\alpha\beta\mu}_{ZZV} = \frac{i(\hat{s} - M_V^2)}{M_Z^2}\left[f_4^V \left(P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}\right) - f_5^V \varepsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho \right]$$

$$(V = Z, \gamma)$$



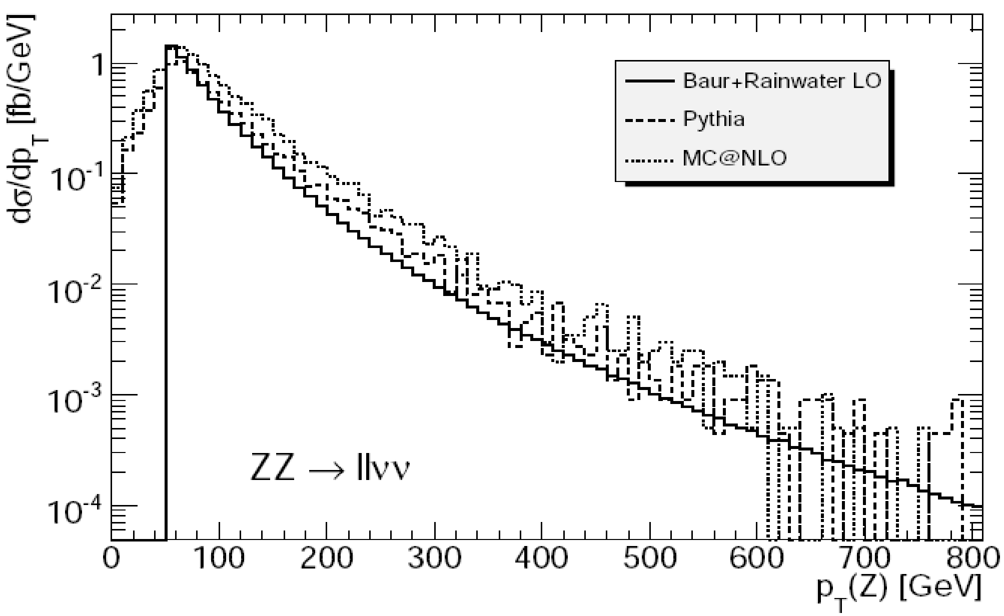
P. Ward *et al.*, University of Cambridge

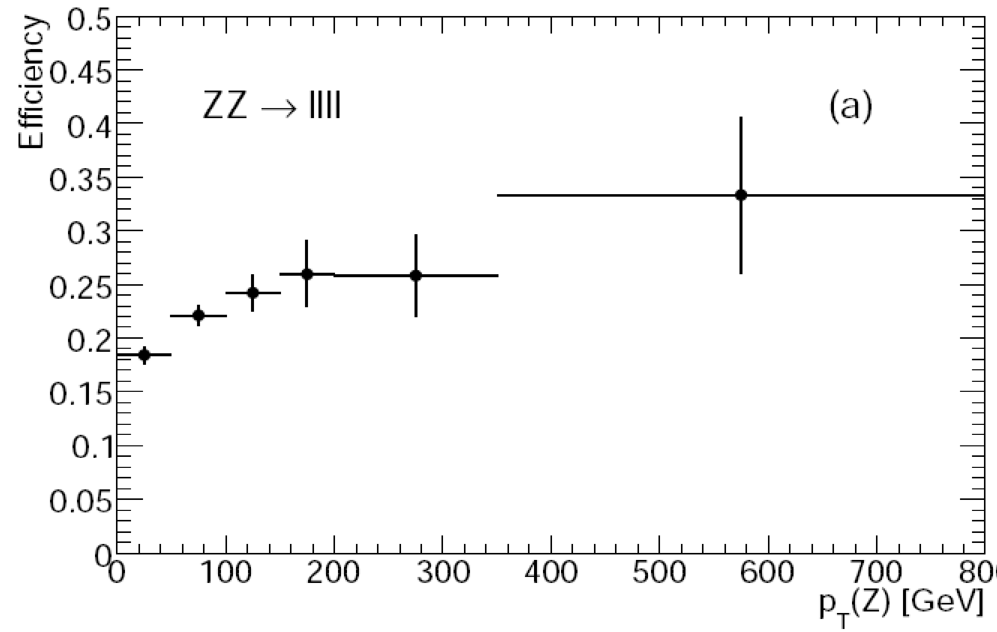
- $f_4^V = f_5^V = 0$ at tree level in the SM
- 4 parameters accessible with ZZ→4l: $f_4^Z, f_5^Z, f_4^\gamma, f_5^\gamma$
- 4 observables change with anomalous TGC: cross-section vs Pt(Z), M(ZZ), lepton angle, Z angle
- The following results are with only Pt(Z) distributions

TGCs: the method

In collaboration with P. Ward et al., University of Cambridge

- Use *LO Baur-Rainwater (BR) MC* to generate Pt(Z) distributions for different f_i^V
- Fit cross-section to quadratic function of f_i^V in bins of Pt(Z)
- *Correct for NLO effects* with the ratio of full NLO MC to the Standard Model (f_i^V =0) BR one
- Find *efficiency* from full MC (events after all cuts/truth events)





TGCs: likelihood

Expected events = BR x-section × NLO correction × efficiency × luminosity

- Generate fake event samples based on this expectation for signal and $Zb\bar{b}$ background
- Binned Likelihood in each Pt(Z) bin:

$$L = \int_{1-3\sigma_b}^{1+3\sigma_b} \int_{1-3\sigma_s}^{1+3\sigma_s} g_s \, g_b \, \frac{(f_s \nu_s + f_b \nu_b)^n \, e^{-(f_s \nu_s + f_b \nu_b)}}{n!} \, df_s \, df_b \quad \text{with} \quad g_i = \frac{e^{(1-f_i)^2/2\sigma_i^2}}{\int_0^\infty e^{(1-f_i)^2/2\sigma_i^2}} \; (i = s, b)$$

with one free parameter ($\nu_s(f_i^V)$). In all bins

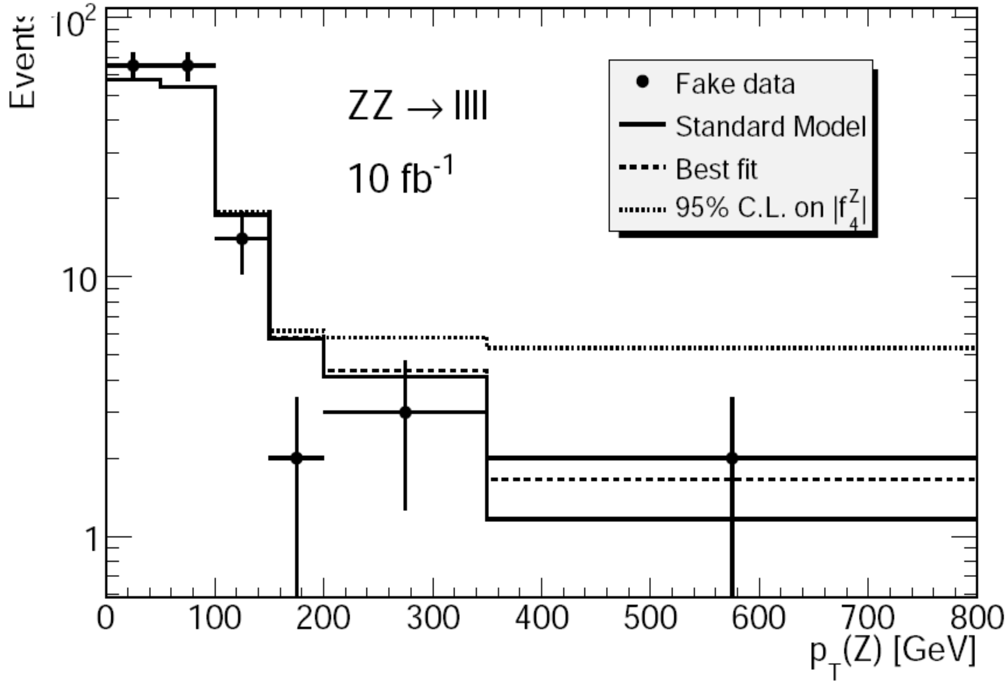
$$LL = -2 \sum_{k=\text{channels}} \sum_{i=\text{bins}} \log(L_i^k)$$

- Minimizing this, we get the most likely f_i^V value and the CLs.

TGCs: results

f_4^Z	f_5^Z	f_4^γ	f_5^γ
$ZZ \to \ell\ell\ell\ell$			
[−0.010, 0.010]	[−0.010, 0.010]	[−0.012, 0.012]	[−0.013, 0.012]
$ZZ \to \ell\ell\nu\nu$			
[−0.012, 0.012]	[−0.012, 0.012]	[−0.014, 0.014]	[−0.015, 0.014]
Combined			
[−0.009, 0.009]	[−0.009, 0.009]	[−0.010, 0.010]	[−0.011, 0.010]
LEP Limit			
[−0.30, 0.30]	[−0.34, 0.38]	[−0.17, 0.19]	[−0.32, 0.36]

95% CL intervals at 10 fb^{-1}

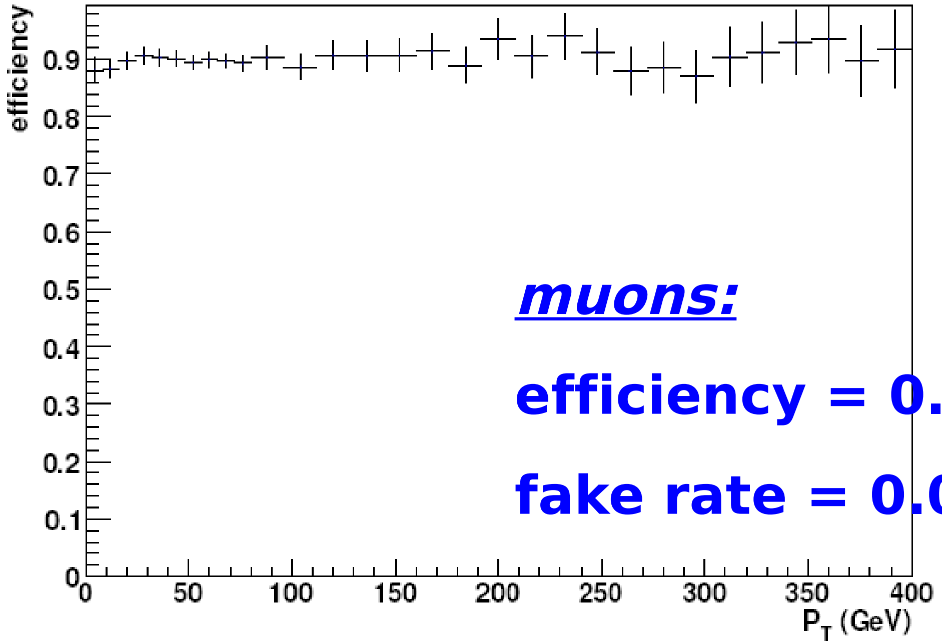


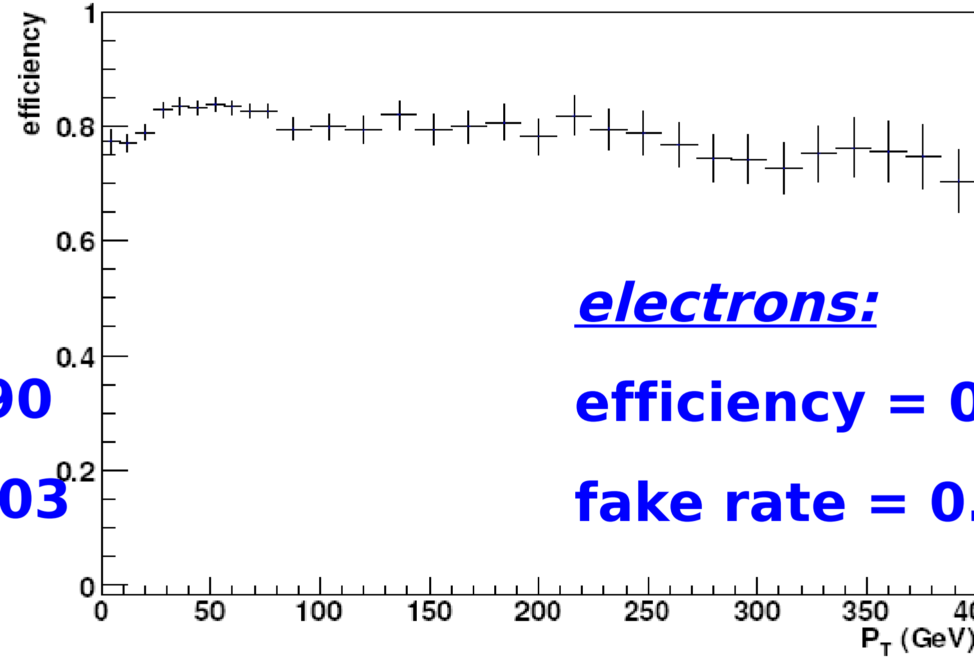
Conclusions

- Baseline $ZZ \rightarrow 4l$ analysis done
- Signal expectation at 1 fb^{-1}: *13.3 ZZ*, *16.5 ZZ** events, with at least an order of magnitude lower background
- Systematic errors need to be better understood
- TGC limit measurement is promising to improve the LEP limits with the first 10 fb^{-1} of data
- Many ideas for improvements/optimizations

Extras

Single lepton effic./fakes





muons:

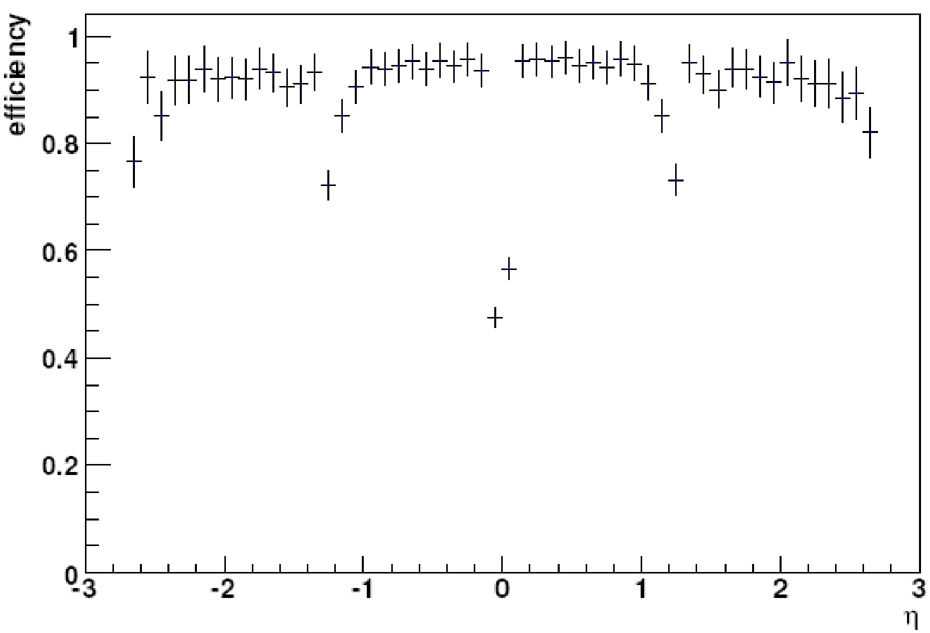
efficiency = 0.90

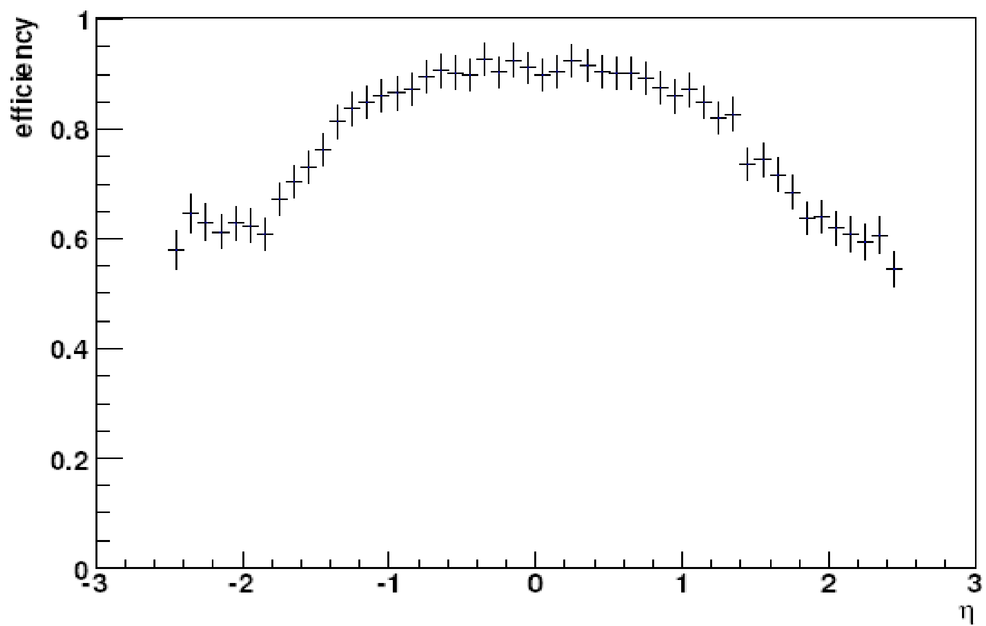
fake rate = 0.003

electrons:

efficiency = 0.76

fake rate = 0.001





Future plans

- Use also low-Pt muons (only ID track and MS hits)
- Look into more ways to reduce bg
  - Vertexing/IP for $Zb\bar{b}$
  - Et(miss) for $t\bar{t}$
- Assess & correct lepton-to-Z mis-assignment
  - preliminary study shows ~4% mis-assignment!
- Tune cuts for ZZ*→4l? (relevant for low Higgs mass)
- Refine Z mass cut for on-shell Z: constrained fit ?
- *Calculate ZZ→4l background to H→4l from data*

For TGCs:

- Use the rest of the observables to improve limit (advantage over the ZZ→llνν channel)
- Multi-dimensional fits ?