Feasibility study for the selection of $ZZ \rightarrow \tau\tau\mu\mu$ events

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Introduction

- Aims:
  - look into selecting a sample of $ZZ \rightarrow \tau\tau\mu\mu$ events,
  - use to increase ZZ event statistics → better probe anomalous NTGC's?
- No standard production $ZZ \rightarrow \tau\tau\mu\mu$ sample exists
  - use 10000 event privately generated sample (MC@NLO + 12.0.6.5 job transforms).

Samples Used

Run	Channel	No.Events	Release	Generator	Generator Cuts
Private Sample	**$ZZ \to \mu\mu\tau\tau$**	10000	12.0.6.5	MC@NLO	-
R5146	**$Z \to \tau\tau$**	80900	11.0.4.2	PYTHIA	$m_{\tau\tau}$>60GeV, 2 leptons with p_T>5GeV and $\|\eta\|$<2.8
R5151	**$Z \to \mu\mu$**	2600	11.0.4.2	MC@NLO	$m_{\mu\mu}$>60GeV, 1 lepton with p_T>5GeV and $\|\eta\|$<2.8
R5152	**$Z \to ee$**	69550	11.0.4.2	MC@NLO	m_{ee}>60GeV, 1 lepton with p_T>10GeV and $\|\eta\|$<2.7
R5185	**$Z \to ee$**	58700	11.0.4.2	PYTHIA	Z p_T>100GeV, 2 leptons with p_T>10GeV and $\|\eta\|$<2.7
R5186	**$Z \to \mu\mu$**	95500	11.0.4.2	PYTHIA	Z p_T>100GeV, 2 leptons with p_T>5GeV and $\|\eta\|$<2.8
R5200	**t t-bar**	10000	11.0.4.2	MC@NLO	No all hadronic events
R5924	**$WW \to l\nu l\nu$**	10950	11.0.4.2	MC@NLO	-
R5931	**$ZZ \to llll$**	9000	11.0.4.2	MC@NLO	-
R5981	**$ZZ \to ll\nu\nu$**	10000	11.0.4.2	PYTHIA	2 leptons with p_T>4.5GeV and $\|\eta\|$<2.7

'True' Efficiencies

What is the best we could do if all particles were correctly reconstructed?

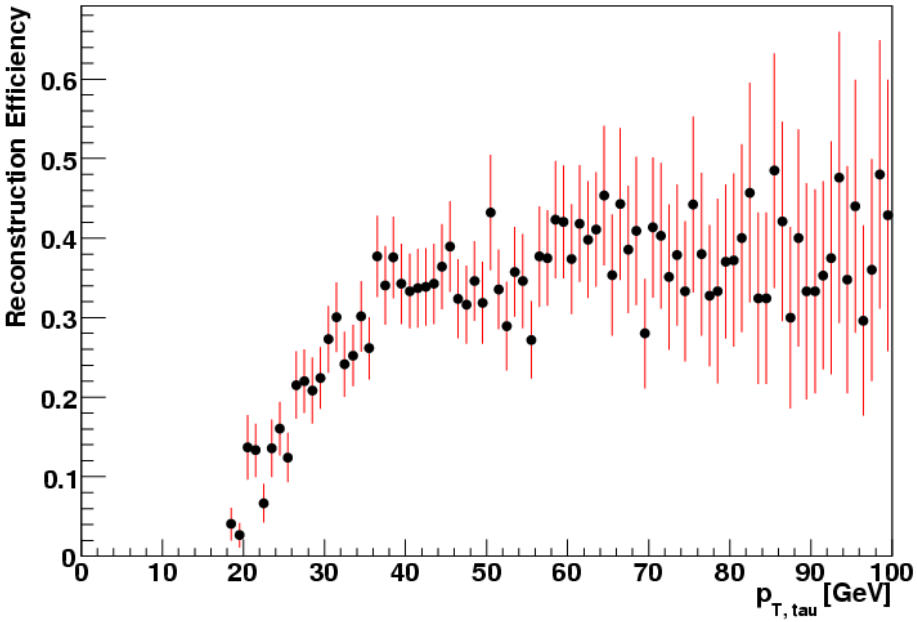
Answer this by examining what fraction of the lepton pairs produced directly by Z boson decays are within $|\eta|<2.5$ in truth:

The two τ leptons are both within $|\eta|<2.5$ in truth in 67% of reconstructed signal events.

Both muons are within $|\eta|<2.5$ in truth in 66% of reconstructed signal events.

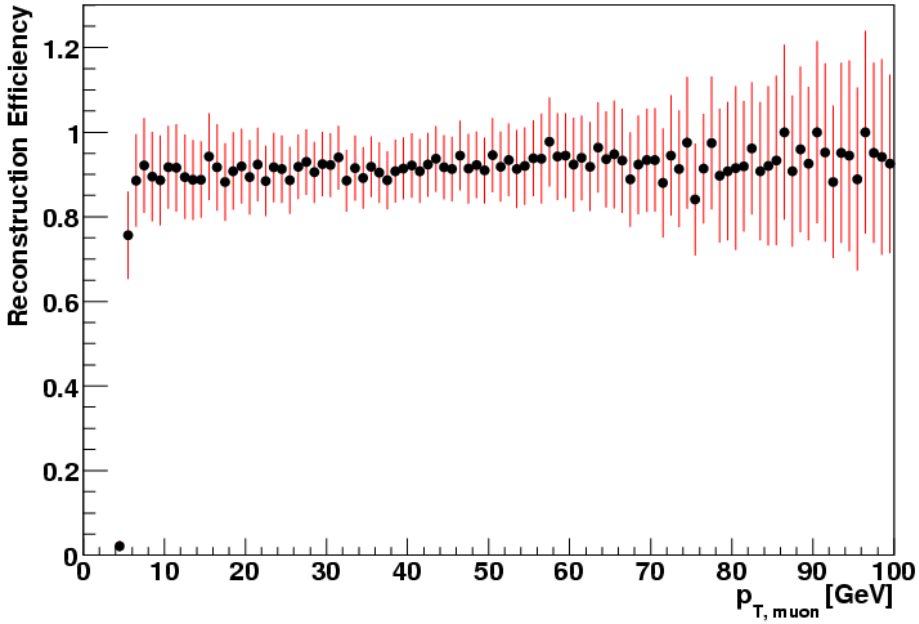
49% of reconstructed signal events have two muons and two τ leptons within $|\eta|<2.5$ in truth.

Reconstruction Efficiencies



Hadronically decaying
τ leptons in central η range

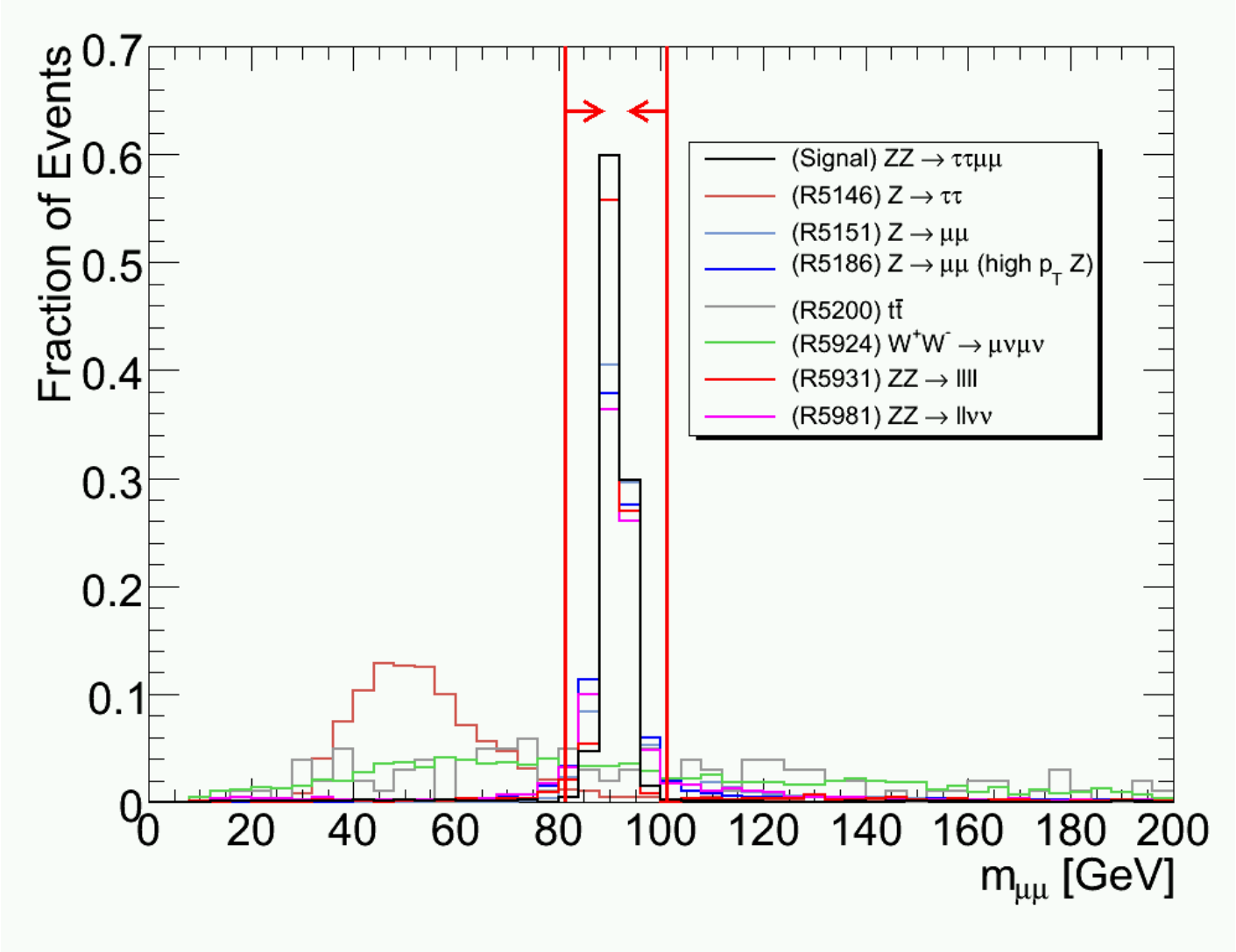
Muons in central η range



$Z \rightarrow \mu\mu$ Candidate Selection

- Selection:
  - at least two μ to be reconstructed in the event with $|\eta|<2.5$ and $p_T > 5$ GeV.
  - best $\mu\mu$ combination must have oppositely charged muons and minimum $|m_Z - m_{\mu\mu}|$.
  - best combination must satisfy $|m_Z - m_{\mu\mu}| < 10$ GeV.

$|m_Z - m_{\mu\mu}| < 10$ GeV



$Z \rightarrow \mu\mu$ Candidate Selection Results

Channel	Events In	Two good muons	Found $\mu^+\mu^-$ pair	$\lvert m_Z - m_{\mu\mu} \rvert < 10$ GeV
$ZZ \rightarrow \mu\mu\tau\tau$	330.0	181.2	175.6	169.0
$ZZ \rightarrow llll$	668.0	321.0	311.3	276.1
$ZZ \rightarrow ll\nu\nu$	2647.3	923.7	923.7	728.3
t t-bar	4623900.0	73584.9	69811.3	10062.9
$Z \rightarrow \tau\tau$	754004.0	35913.3	35661.8	1169.5
$Z \rightarrow \mu\mu$ ($Z\ p_T > 100$ GeV)	213398.0	114321.0	114288.0	96035.9
$Z \rightarrow \mu\mu$	16617400.0	8001690.0	7999520.0	6827360.0
$Z \rightarrow ee$ ($Z\ p_T > 100$ GeV)	210003.0	0.0	0.0	0.0
$Z \rightarrow ee$	16057900.0	0.0	0.0	0.0
$WW \rightarrow l\nu l\nu$	13000.1	6020.4	6020.4	849.3

(Event numbers normalised to 10 fb^{-1})

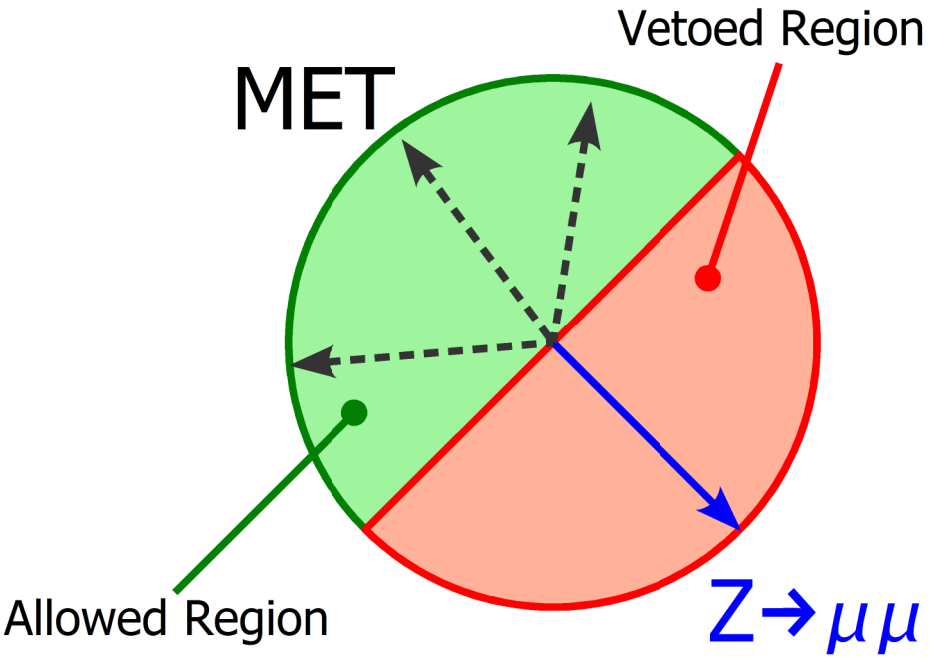
$Z \rightarrow \tau\tau$ Candidate Selection

- Consider 6 possible final states of $\tau\tau$ decay:
  - $\tau\tau \rightarrow$ Hadrons + missing E_T
  - $\tau\tau \rightarrow$ Hadrons + μ + missing E_T
  - $\tau\tau \rightarrow \mu\mu$ + missing E_T
  - $\tau\tau \rightarrow$ Hadrons + e + missing E_T
  - $\tau\tau \rightarrow$ ee + missing E_T
  - $\tau\tau \rightarrow e\mu$ + missing E_T
- Selection is similar in each case.

Common Selection Scheme

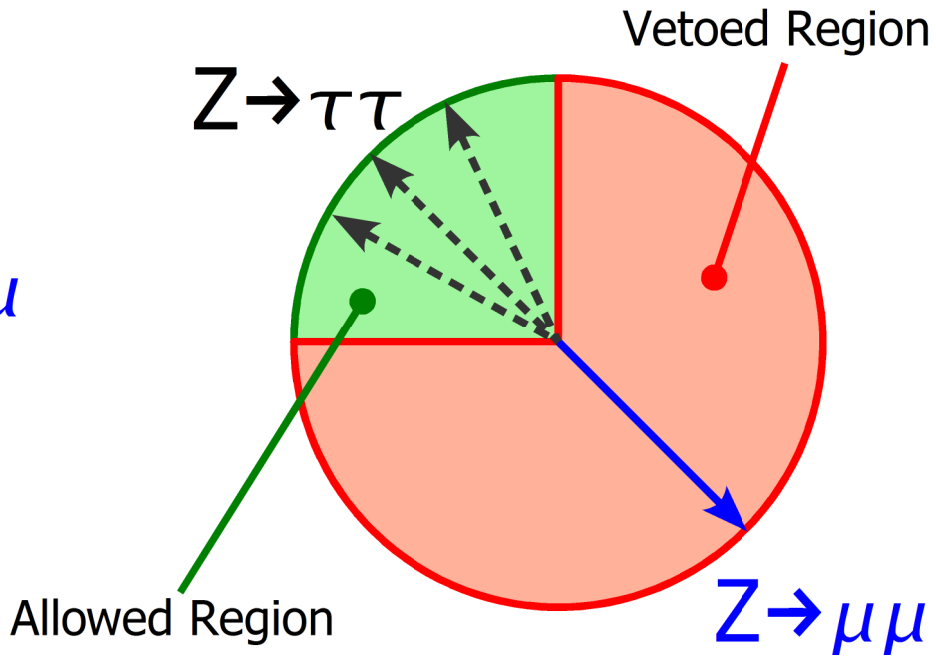
- Find at least two oppositely charged, good quality τ lepton decay candidates (e, μ, τ-jet) within $|\eta|<2.5$.
- Select the best pairing by minimising $|p_T(Z)-p_T(\tau\tau)|$. ($p_T(Z)$ refers to the transverse momentum of the first muon pair and $p_T(\tau\tau)$ refers to the combined transverse momentum of the τ lepton decay candidates and any missing energy contributions.)
- Cut on maximum value of the invariant mass of the two τ lepton decay candidates.
- Angular cuts $|\phi(\text{MET})-\phi(Z)|>(\pi/2)$ and $|\phi(Z)-\phi(\tau\tau)|>0.75\pi$ (see next slide).
- Missing energy cuts (if necessary).

Angular Cuts



$|\phi(\text{MET})-\phi(Z)|>(\pi/2)$

$|\phi(Z)-\phi(\tau\tau)|>0.75\pi$



Selection Specifics (I)

- Selection: Z → $\tau\tau$ → Hadrons + missing E_T
  - at least two τ-jets (p_T > 15 GeV, τ_{NN}>0.03*)
  - best τ-jet pair must have oppositely charged τ-jets and minimise $|p_T(Z)-p_T(\tau\tau)^{**}|$.
  - $|\phi(Z)-\phi(\tau\tau)^{**}| > 0.75\pi$ (see next slide).
- Selection: Z → $\tau\tau$ → Hadrons + μ + missing E_T
  - at least one τ-jet (τ_{NN}>0.03, p_T>15 GeV) and one (maximum two) additional μ (p_T>15 GeV)
  - best $\mu\tau$-jet combination must have oppositely charged components and minimise $|p_T(Z)-p_T(\tau\tau)|$.
  - invariant mass, $m_{\mu\tau\text{-jet}}$<80 GeV.
  - Angular cuts

* τ_{NN}= TauNeuralNetwork parameter. ** does not include MET contribution in this case

Selection Specifics (II)

- Selection: $Z \rightarrow \tau\tau \rightarrow \mu\mu$ + missing E_T
  - two (maximum three) additional μ (p_T>8 GeV).
  - best $\mu\mu$ combination must have oppositely charged muons and minimise $|p_T(Z)-p_T(\tau\tau)|$.
  - invariant mass, $m_{\tau\tau\rightarrow\mu\mu}$<50 GeV.
  - Angular cuts
- Selection: $Z \rightarrow \tau\tau \rightarrow$ Hadrons + e + missing E_T
  - at least one τ-jet (τ_{NN}>0.03, p_T>15 GeV) and one (maximum two) additional electron (eγ candidate, p_T>10 GeV).
  - best eτ-jet combination must have oppositely charged components and minimise $|p_T(Z)-p_T(\tau\tau)|$.
  - invariant mass, $m_{e\tau\text{-jet}}$<50 GeV.
  - Angular Cuts
  - MET/$p_T(Z)$<1.0

Selection Specifics (III)

- Selection: $Z \rightarrow \tau\tau \rightarrow ee$ + missing E_T
  - two (maximum three) additional e ($e\gamma$ candidate, p_T>10 GeV).
  - best ee combination must have oppositely charged electrons and minimise $|p_T(Z)-p_T(\tau\tau)|$.
  - invariant mass, m_{ee}<70 GeV.
  - Angular cuts
  - $MET/p_T(Z)<1.0$ and $|p_T(Z)-p_T(ee+MET)|/p_T(Z)<0.1$
- Selection: $Z \rightarrow \tau\tau \rightarrow e\mu$ + missing E_T
  - one (maximum two) additional μ (p_T>15 GeV) and one (maximum two) additional e ($e\gamma$ candidate, p_T>15 GeV).
  - best $e\mu$ combination must have oppositely charged components and minimising $|p_T(Z)-p_T(\tau\tau)|$.
  - invariant mass, $m_{e\mu}$<50 GeV.
  - Angular cuts
  - MET>10 GeV, $MET/p_T(Z)>0.3$ and $MET/p_T(Z)<1.0$

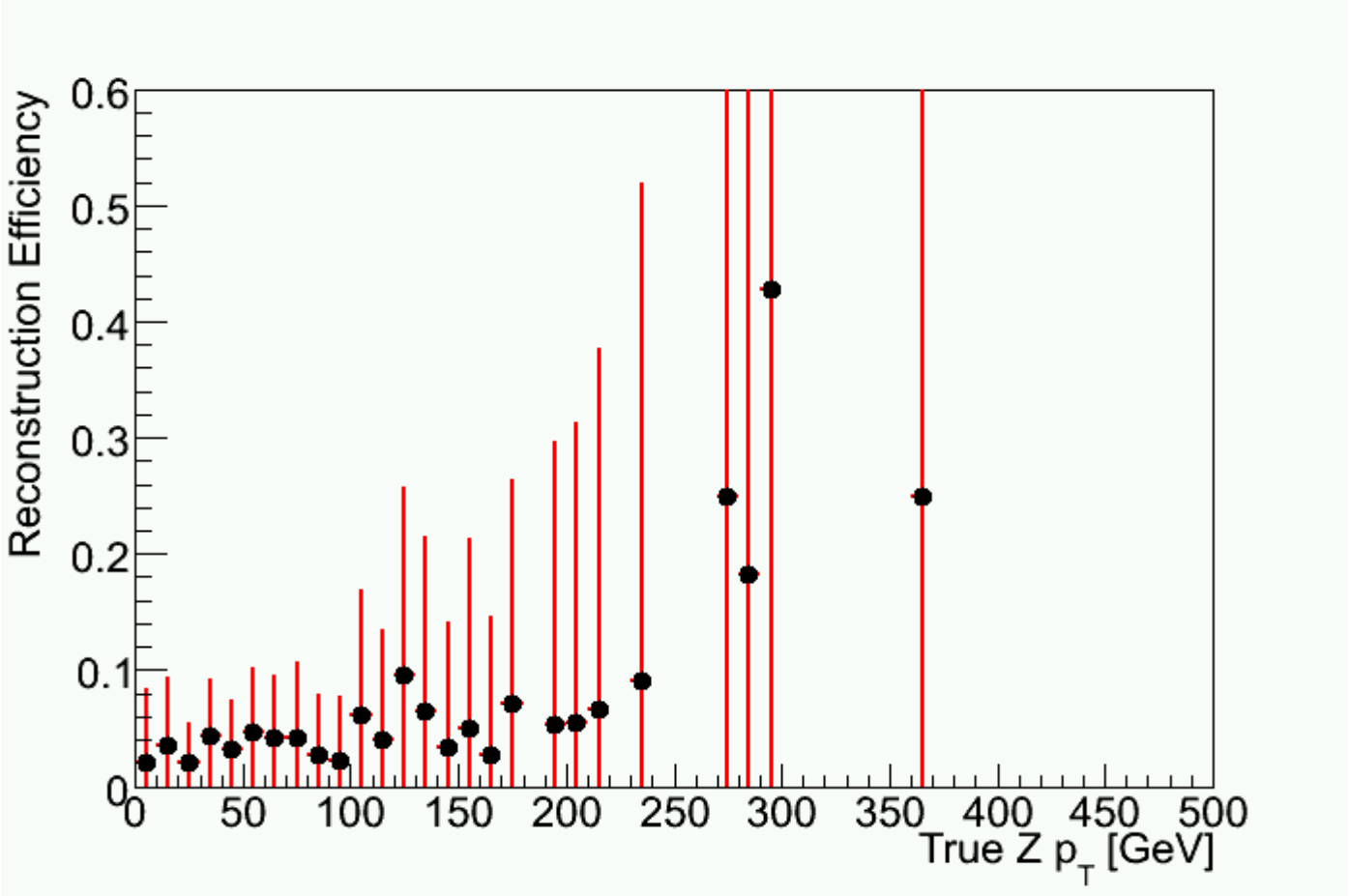
Overall ZZ→ττμμ Selection

Z → μμ + Z → ττ → ...	Signal	Background
hν**h**ν	0.9	0.0
hνμνν	1.6	0.2
μννμνν	0.9	0.0
hν**e**νν	3.2	280.4
eνν**e**νν	0.7	11.5
μνν**e**νν	2.6	0.2
Total	9.9	292.3

(Event numbers normalised to 10 fb^{-1})

- Background in channels with final state elections is much higher than in other channels. (NB These numbers are based on a handful of remaining events.)
- Excluding high background final states Monte Carlo predicts 6.0 events out of a possible 162 in truth would be selected (9.9 including high background final states) for 10fb^{-1} of ATLAS data.

Selection Efficiency vs Z p_T



- Overall signal efficiency is 3.7% (6.1% including high background channels).
- Signal is approximately constant with Z p_T

Conclusions

- A signal efficiency of 3.7% can be achieved with low backgrounds.
- A higher signal efficiency of 6.1% can be achieved, by including other decay channel, but backgrounds may increase.
- More statistics needed, particularly at higher Z p_T values.
- Other backgrounds, such as Zbb, should be considered in any future study.
- ZZ→$\tau\tau\mu\mu$ channel would be worth returning to look at in more detail for 100fb^{-1} of ATLAS data.

Backup Slides

$Z \rightarrow \tau\tau \rightarrow$ Hadrons + missing E_T

Channel	Preselection	Good τ-jet pair	$\lvert\Phi(Z)-\Phi(\tau\tau)\rvert>0.75\pi$
ZZ→μμττ	169.0	1.3	0.9
ZZ→llll	276.1	-0.1	0.0
ZZ→llνν	728.3	0.0	0.0
t t-bar	10062.9	0.0	0.0
Z→ττ	1169.5	0.0	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	2.2	0.0
Z→μμ	6827360.0	0.0	0.0
WW→lνlν	849.3	0.0	0.0

(Event numbers normalised to 10 fb^{-1})

$Z \rightarrow \tau\tau \rightarrow$ Hadrons + μ + missing E_T

Channel	Preselection	Good μ/τ-jet pair	$m_{\mu\tau\text{-jet}}$ < 80 GeV	|Φ(Z)-Φ(MET)| >0.75Pi	|Φ(Z)-Φ(ττ)| >0.75Pi	MET cuts
ZZ→μμττ	169.0	2.9	2.8	2.5	2.1	1.6
ZZ→llll	276.1	2.4	1.4	0.8	0.7	0.2
ZZ→llνν	728.3	0.0	0.0	0.0	0.0	0.0
t t-bar	10062.9	0.0	0.0	0.0	0.0	0.0
Z→ττ	1169.5	0.0	0.0	0.0	0.0	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	2.2	0.0	0.0	0.0	0.0
Z→μμ	6827360.0	0.0	0.0	0.0	0.0	0.0
WW→lνlν	849.3	0.0	0.0	0.0	0.0	0.0

(Event numbers normalised to 10 fb^{-1})

$Z \rightarrow \tau\tau \rightarrow \mu\mu$ + missing E_T

Channel	Preselection	2nd Good μμ pair	$m_{\mu\mu}$ < 50 GeV	|Φ(Z)-Φ(MET)|>0.75Pi	|Φ(Z)-Φ(ττ)|>0.75Pi
ZZ→μμττ	169.0	1.4	1.1	1.0	0.9
ZZ→llll	276.1	57.0	0.6	0.3	0.0
ZZ→llνν	728.3	0.0	0.0	0.0	0.0
t t-bar	10062.9	0.0	0.0	0.0	0.0
Z→ττ	1169.5	0.0	0.0	0.0	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	0.0	0.0	0.0	0.0
Z→μμ	6827360.0	0.0	0.0	0.0	0.0
WW→lνlν	849.3	0.0	0.0	0.0	0.0

(Event numbers normalised to 10 fb^{-1})

$Z \rightarrow \tau\tau \rightarrow$ Hadrons + e + missing E_T

Channel	Preselection	Good e/τ-jet pair	$m_{e\tau\text{-jet}}$ < 80 GeV	|Φ(Z)-Φ(MET)| >0.5Pi	|Φ(Z)-Φ(ττ)|>0.75Pi and MET cuts
ZZ→μμττ	169.0	6.6	6.2	4.8	3.2
ZZ→llll	276.1	1.8	0.0	0.2	0.0
ZZ→llνν	728.3	0.8	0.8	0.5	0.3
t t-bar	10062.9	0.0	0.0	0.0	0.0
Z→ττ	1169.5	0.0	0.0	0.0	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	192.2	67.0	60.3	38.0
Z→μμ	6827360.0	1452.8	726.4	484.3	242.1
WW→lνlν	849.3	0.0	0.0	0.0	0.0

(Event numbers normalised to 10 fb^{-1})

$Z \rightarrow \tau\tau \rightarrow ee + \text{missing } E_T$

Channel	Preselection	Good μ/τ-jet pair	$m_{\mu\tau\text{-jet}}$ < 80 GeV	|Φ(Z)-Φ(MET)| >0.5Pi	|Φ(Z)-Φ(ττ)| >0.75Pi	MET cuts
ZZ→μμττ	169.0	8.5	6.8	5.1	4.1	0.7
ZZ→llll	276.1	97.1	3.1	1.1	0.7	0.0
ZZ→llνν	728.3	2.6	1.6	1.1	1.1	0.3
t t-bar	10062.9	0.0	0.0	0.0	0.0	0.0
Z→ττ	1169.5	9.2	9.2	9.2	9.2	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	1474.8	775.4	643.5	516.2	11.2
Z→μμ	6827360.0	1937.1	1694.9	1210.7	928.5	0.0
WW→lνlν	849.3	0.0	0.0	0.0	0.0	0.0

(Event numbers normalised to 10 fb^{-1})

$Z \rightarrow \tau\tau \rightarrow e\mu$ + missing E_T

Channel	Preselectio	Good μ/τ-jet pair	$m_{\mu\tau\text{-jet}}$ < 50 GeV	|Φ(Z)-Φ(MET)| >0.5Pi	|Φ(Z)-Φ(ττ)| >0.75Pi	MET cuts
ZZ→μμττ	169.0	7.8	4.7	3.9	3.4	2.6
ZZ→llll	276.1	2.8	0.4	0.4	0.3	0.2
ZZ→llνν	728.3	0.0	0.0	0.0	0.0	0.0
t t-bar	10062.9	0.0	0.0	0.0	0.0	0.0
Z→ττ	1169.5	0.0	0.0	0.0	0.0	0.0
Z→μμ (Z pT> 100 GeV)	96035.9	26.8	8.9	2.2	0.0	0.0
Z→μμ	6827360.0	0.0	0.0	0.0	0.0	0.0
WW→lνlν	849.3	0.0	0.0	0.0	0.0	0.0

(Event numbers normalised to 10 fb^{-1})