$H \to \tau^+\tau^-$ study in the ILC

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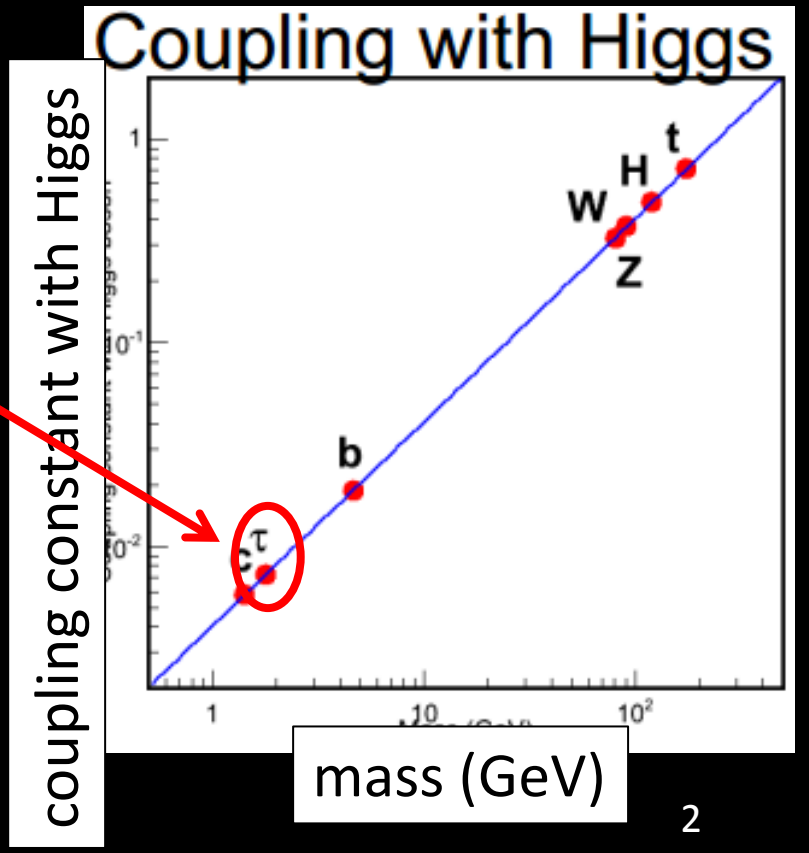
Introduction

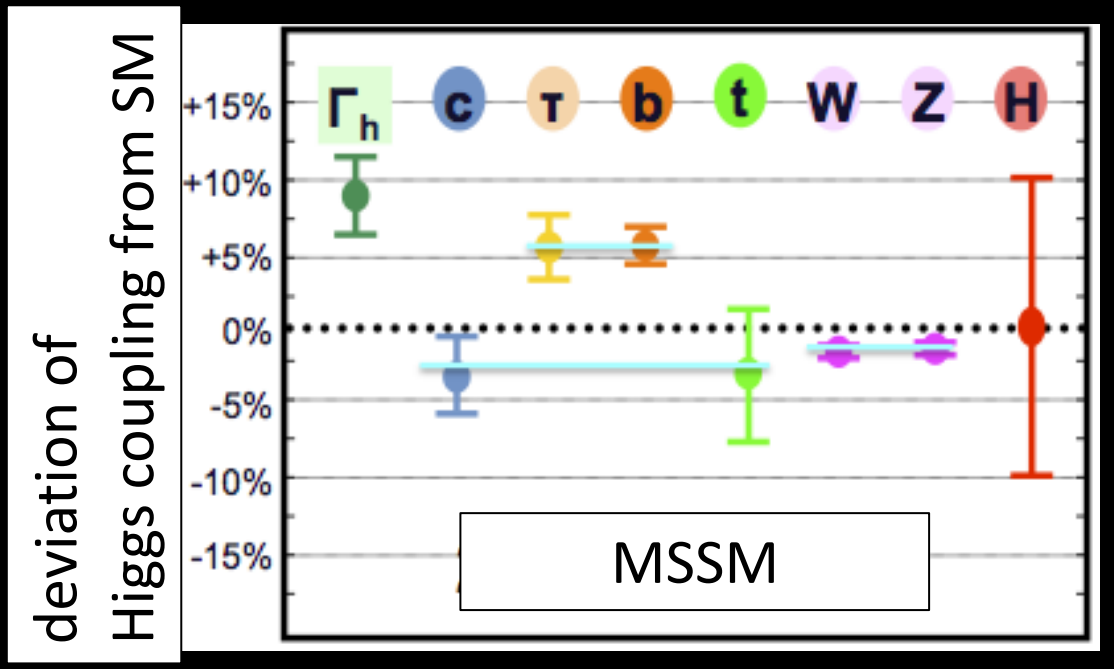
- Higgs-like particle was found at the LHC!
- Investigation of the detail of that particle is important, especially the verification of mass generation mechanism.

Full simulation of $H \to \tau^+\tau^-$ mode has not been done.



Motivation for precision measurement

Any deviation in Higgs coupling and mass relation is an indication of new physics.



The small theoretical uncertainty in τ mass makes the $H \to \tau^+\tau^-$ branching ratio an ideal probe for new physics.

Target of this study

- Estimation of precision of branching ratio of $H \rightarrow \tau^{+}\tau^{-}$ mode
- Previous study with fast simulation

  --> 4.6 - 7.1 % (M_H = 120 GeV, RDR)
- In this study, we evaluate the precision **with full detector simulation** for the first time at E_{CM} = 250 GeV.

Analysis condition

- Higgs properties
  - M_H = 120 GeV
  - Br($H \to \tau^+\tau^-$) = 8.7 %
- Machine parameters
  - E_{CM} = 250 GeV
  - Integrated luminosity L = 250 fb^{-1},
  - Polarization $P(e^+, e^-) = (+0.3, -0.8)$
- Simulation conditions
  - Full simulation with ILD model
  - Using LOI samples for now (to be updated with DBD simulation tools in the future)

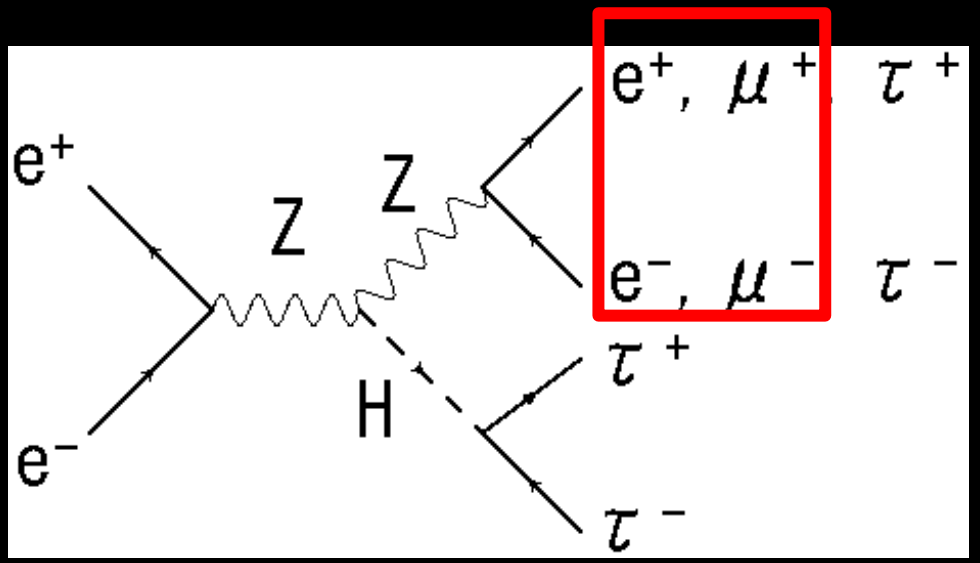
Signal

$e^+e^- \rightarrow ZH$

$\tau^+\tau^-$

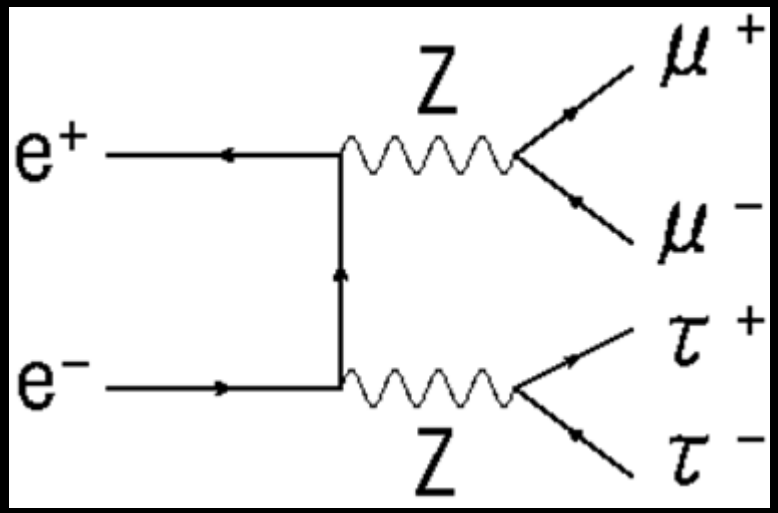
- $\nu\bar{\nu}$ (~20 %)
- $q\bar{q}$ (~70 %)
- l^+l^- (~10 %)

First step

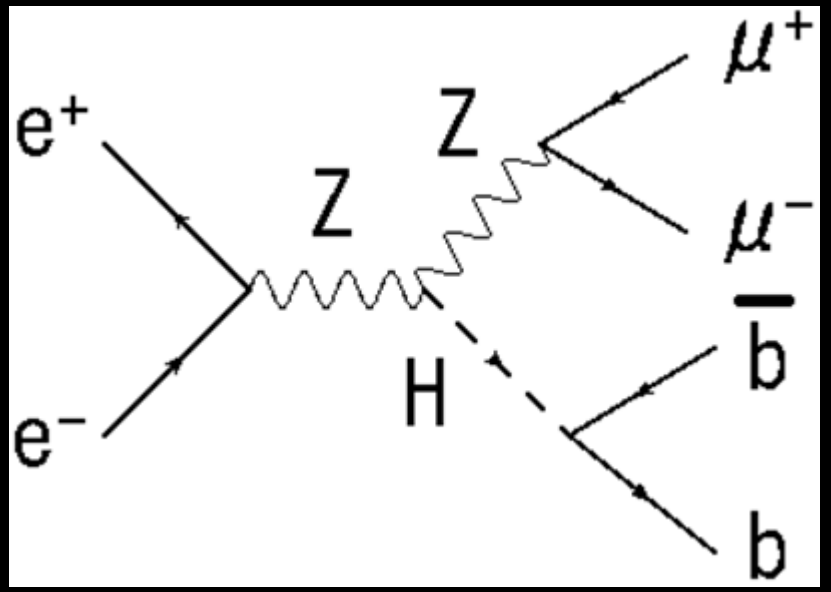


Main background

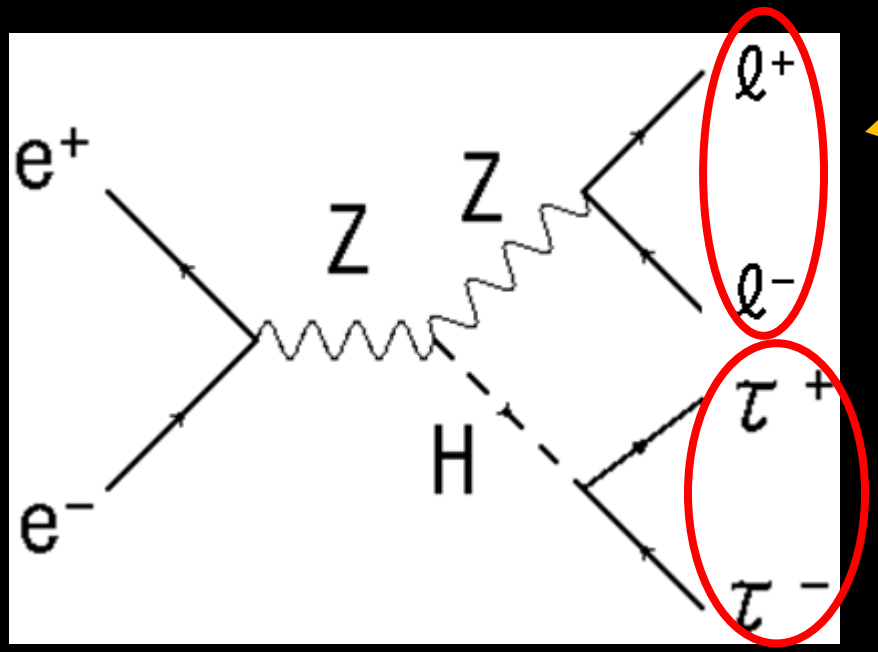
4 leptons background
$eeee, ee\mu\mu, ee\tau\tau,$
$\mu\mu\mu\mu, \mu\mu\tau\tau, \tau\tau\tau\tau$



ZH with other Higgs decays



Event reconstruction



1: Z reconstruction

- lepton ID

identify e/μ by using $\frac{E_{\mathrm{ECAL}}}{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}}$ and $\frac{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}}{P_{\mathrm{track}}}$

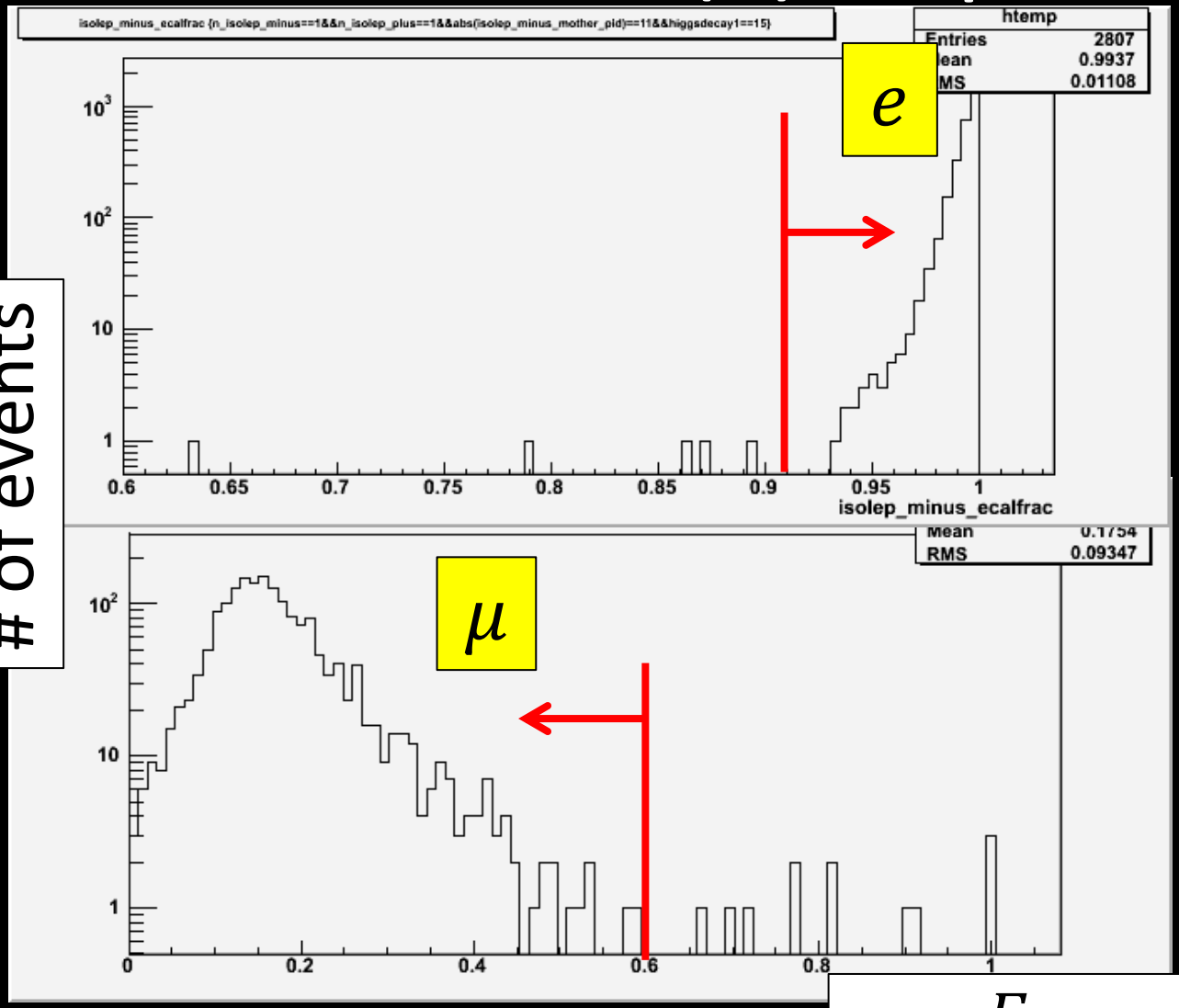
- τ rejection

do not use tracks displaced from IP

2: τ reconstruction

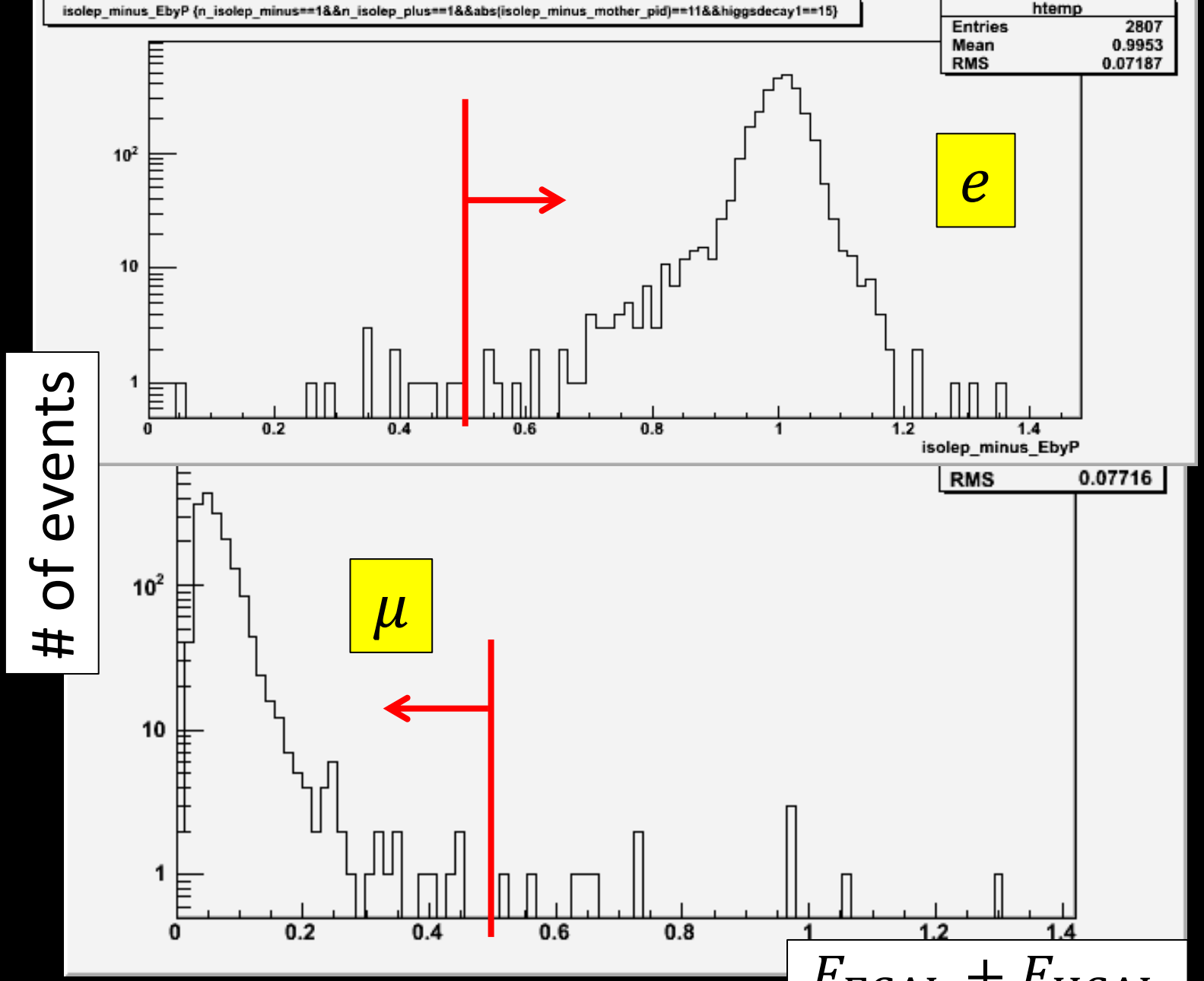
clustering based on τ mass

Z reconstruction (1): Lepton ID

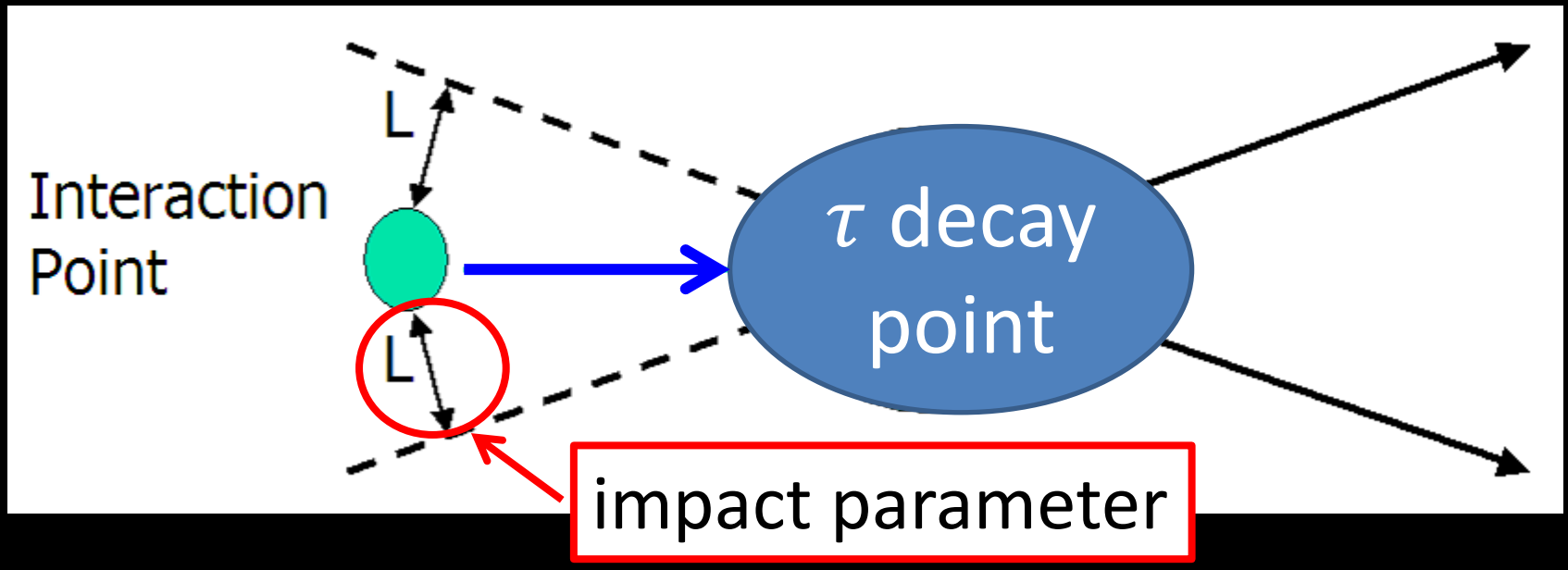


# of events

$$\frac{E_{\mathrm{ECAL}}}{E_{\mathrm{ECAL}} + E_{\mathrm{HCAL}}}$$


isolep_minus_EbyP {n_isolep_minus==1&&n_isolep_plus==1&&abs(isolep_minus_mother_pid)==11&&higgsdecay1==15}
htemp
Entries 2807
Mean 0.9953
RMS 0.07187
e
isolep_minus_EbyP
RMS 0.07716
μ
# of events
$\frac{E_{\mathrm{ECAL}} + E_{\mathrm{HCAL}}}{P_{\mathrm{track}}}$

Z reconstruction (2) : τ rejection

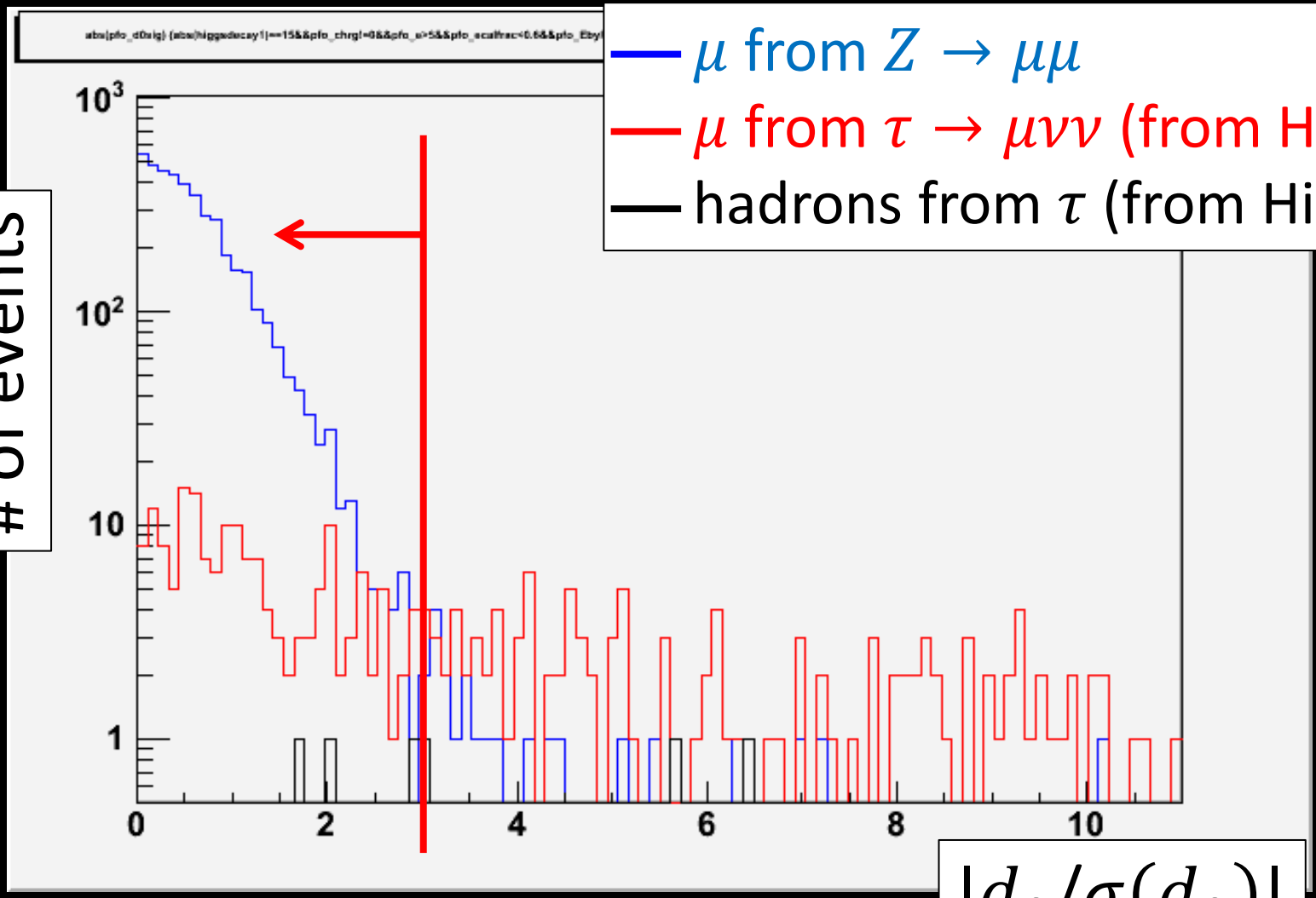


use impact parameter for τ rejection

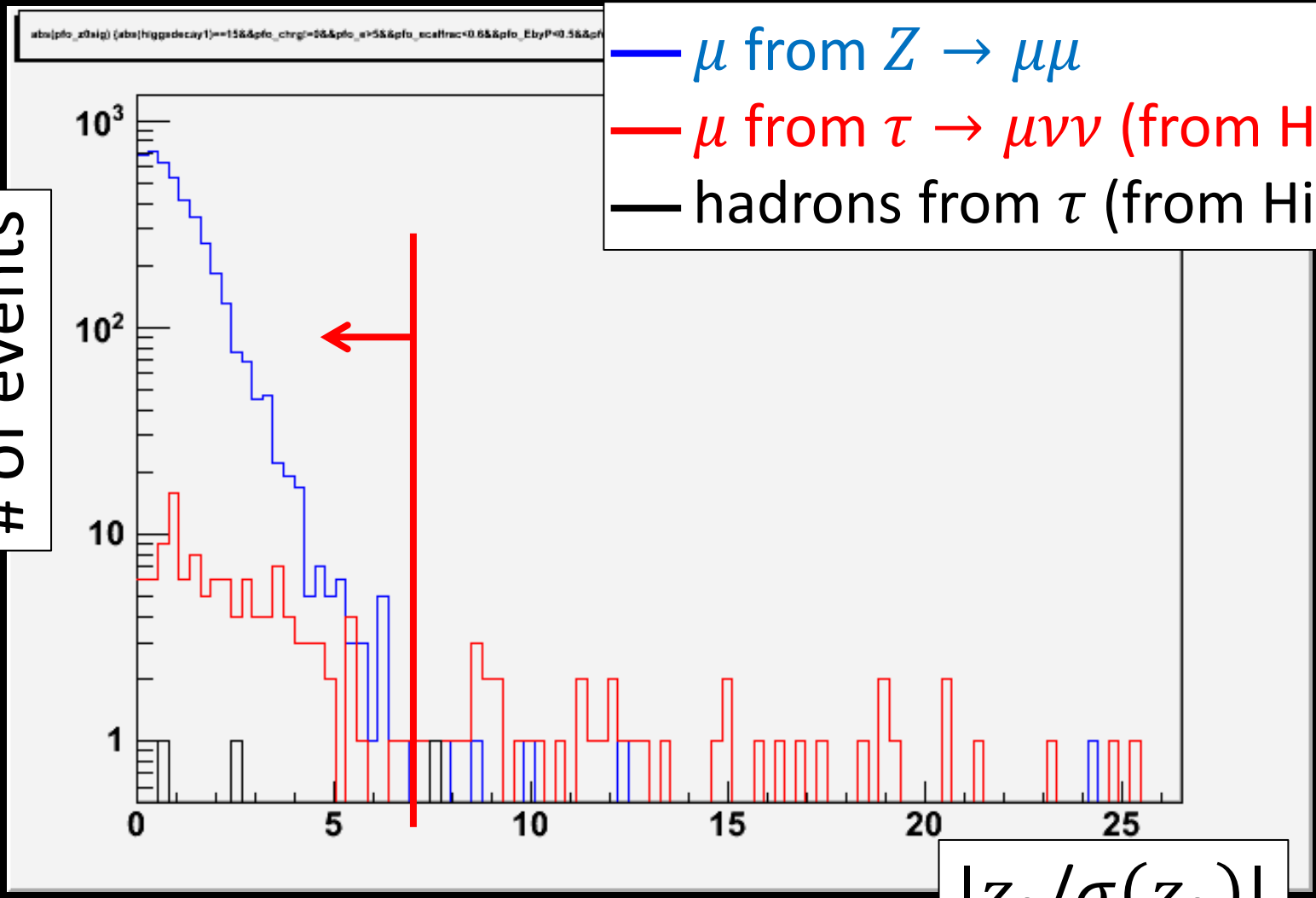
d_0: perpendicular to beam axis (x-y plane)

z_0: along to beam axis

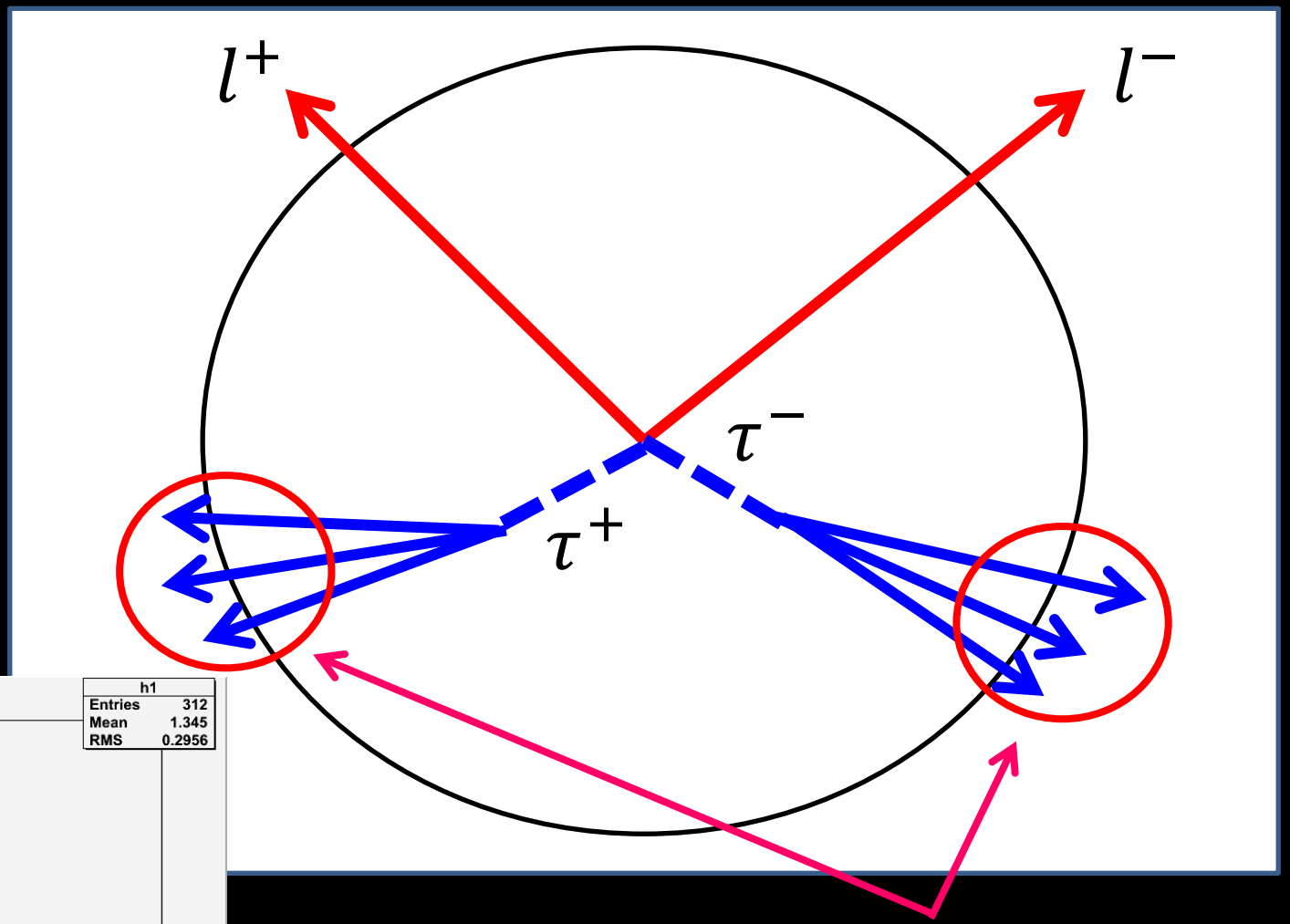
τ rejection ($Z \to \mu^+\mu^-$)

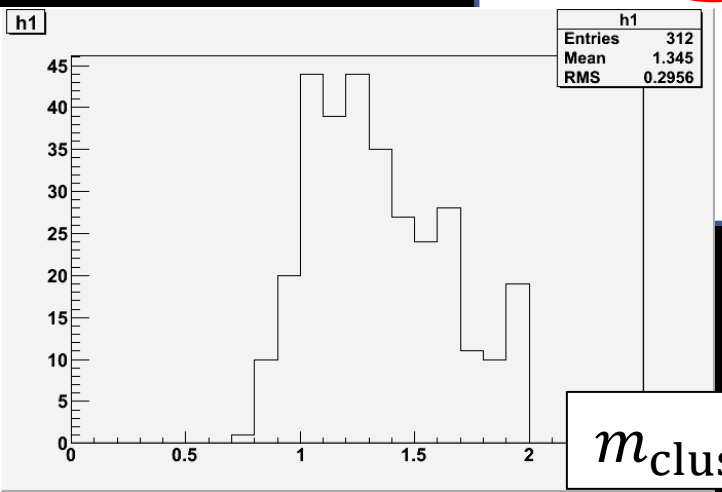


τ rejection ($Z \to \mu^+\mu^-$)



τ reconstruction





m_{cluster}

$m_{\mathrm{cluster}} < 2$ GeV

Event selection ($Z \to e^+e^-$)

Cut 0 (pre-selection):
require e^+e^- candidate,
of τ^- candidate == 1,
of τ^+ candidate == 1,

select e and τ

Cut 1: # of tracks <= 8

Cut 2: $110 < E_{\mathrm{vis}} < 240$

Cut 3: $|\cos\theta_{\mathrm{missmom}}| < 0.98$

Cut 4: $70 < M_Z < 110$

Z mass cut

Cut 5: $90 < E_Z < 120$

Cut 6: $\cos\theta_{e^-} < 0.92, \cos\theta_{e^+} > -0.92$

Cut 7: $20 < E_{e^-} < 90, 20 < E_{e^+} < 90$

Cut 8: $\cos\theta_{e^+e^-} < -0.2$

Cut 9: $\cos\theta_{\tau^+\tau^-} < -0.4$

Cut 10: $\cos\theta_{\tau^-} < 0.92, \cos\theta_{\tau^+} > -0.92$

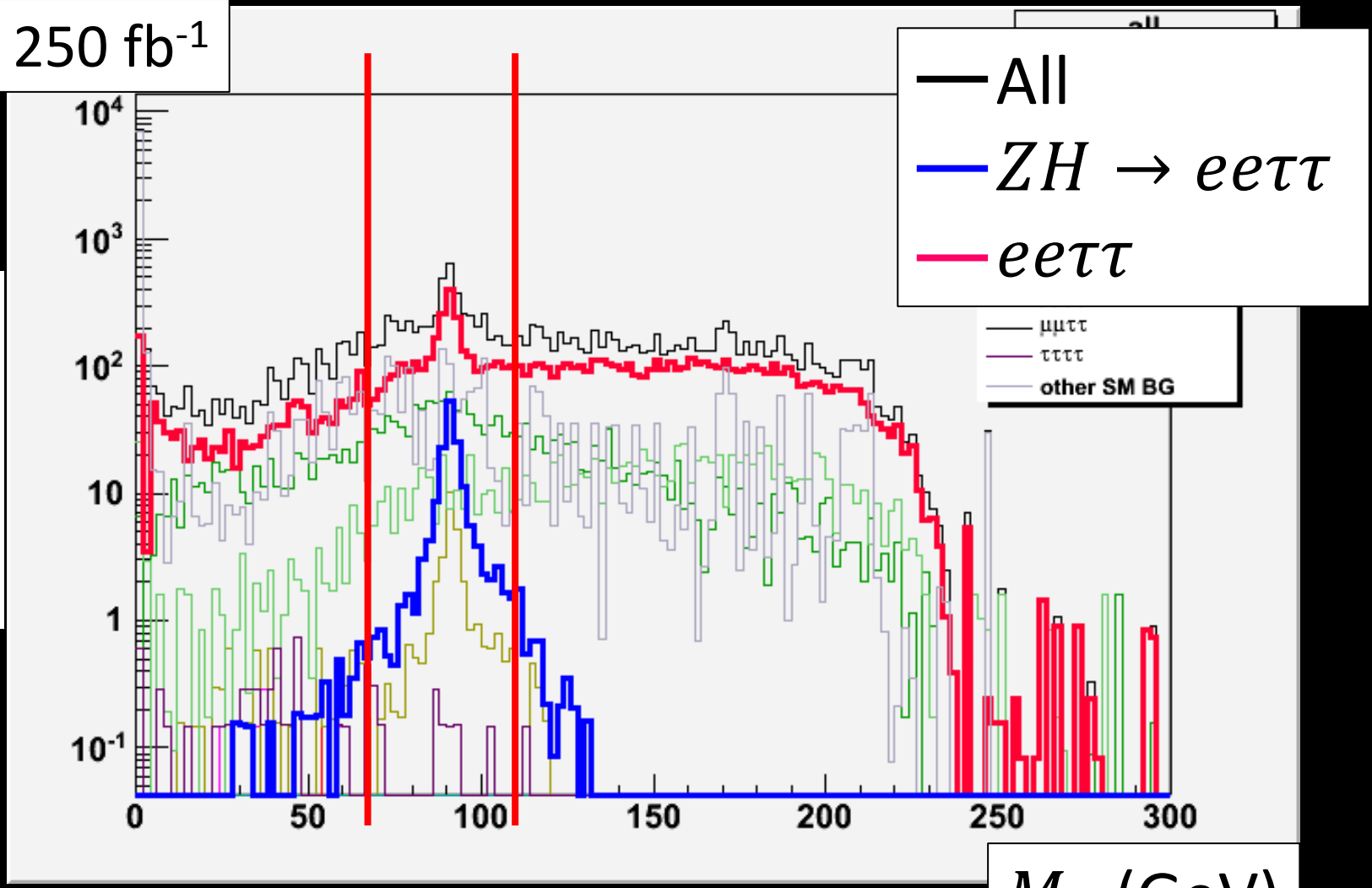
suppress
t-channel diagram

Cut 11: $116 < M_{\mathrm{recoil}} < 134$

suppress
irreducible bkg
$(ee\tau\tau)$

Event selection ($Z \rightarrow e^+e^-$)

$L = 250$ fb^{-1}



Event selection ($Z \rightarrow e^+e^-$)

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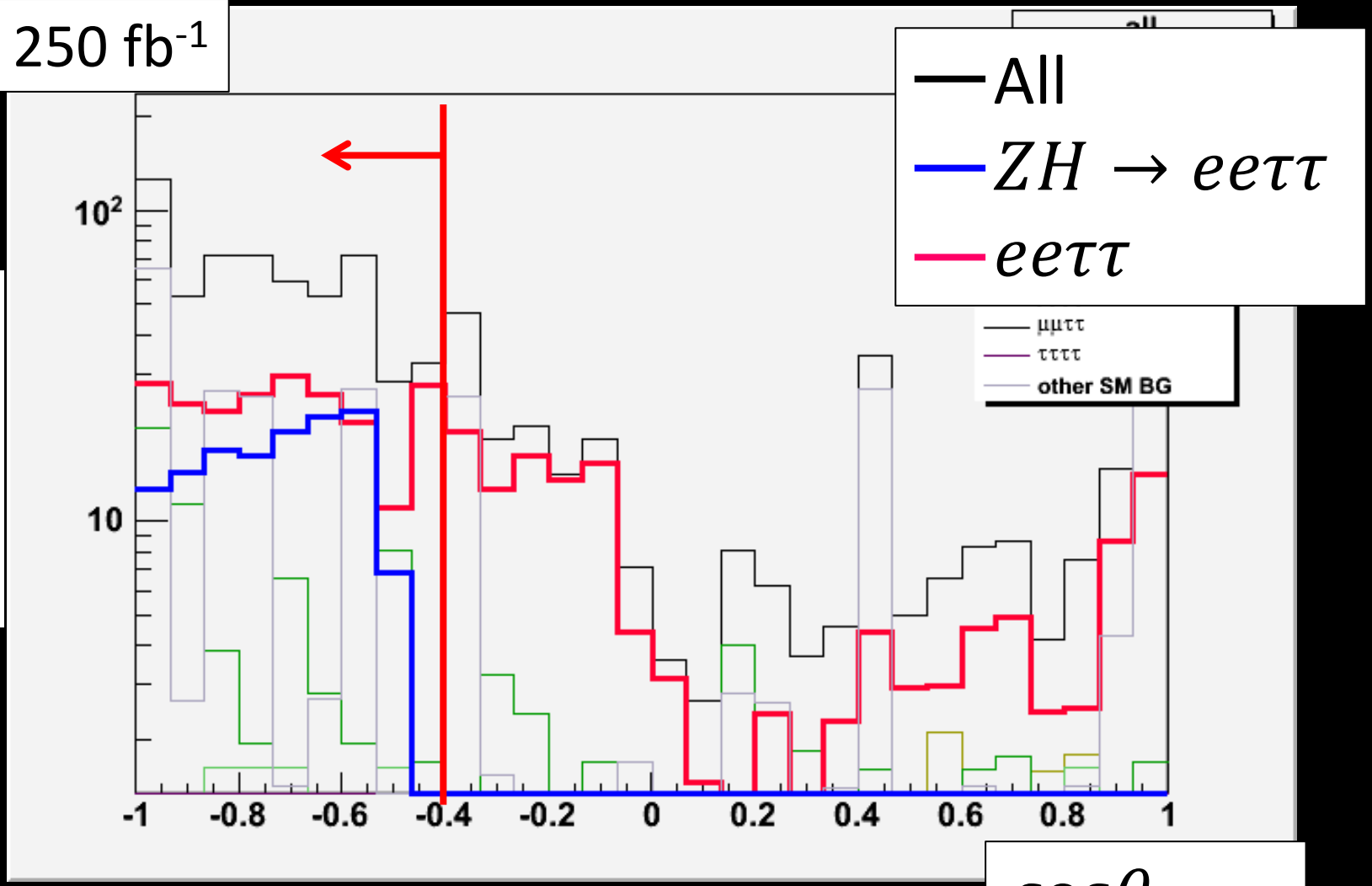
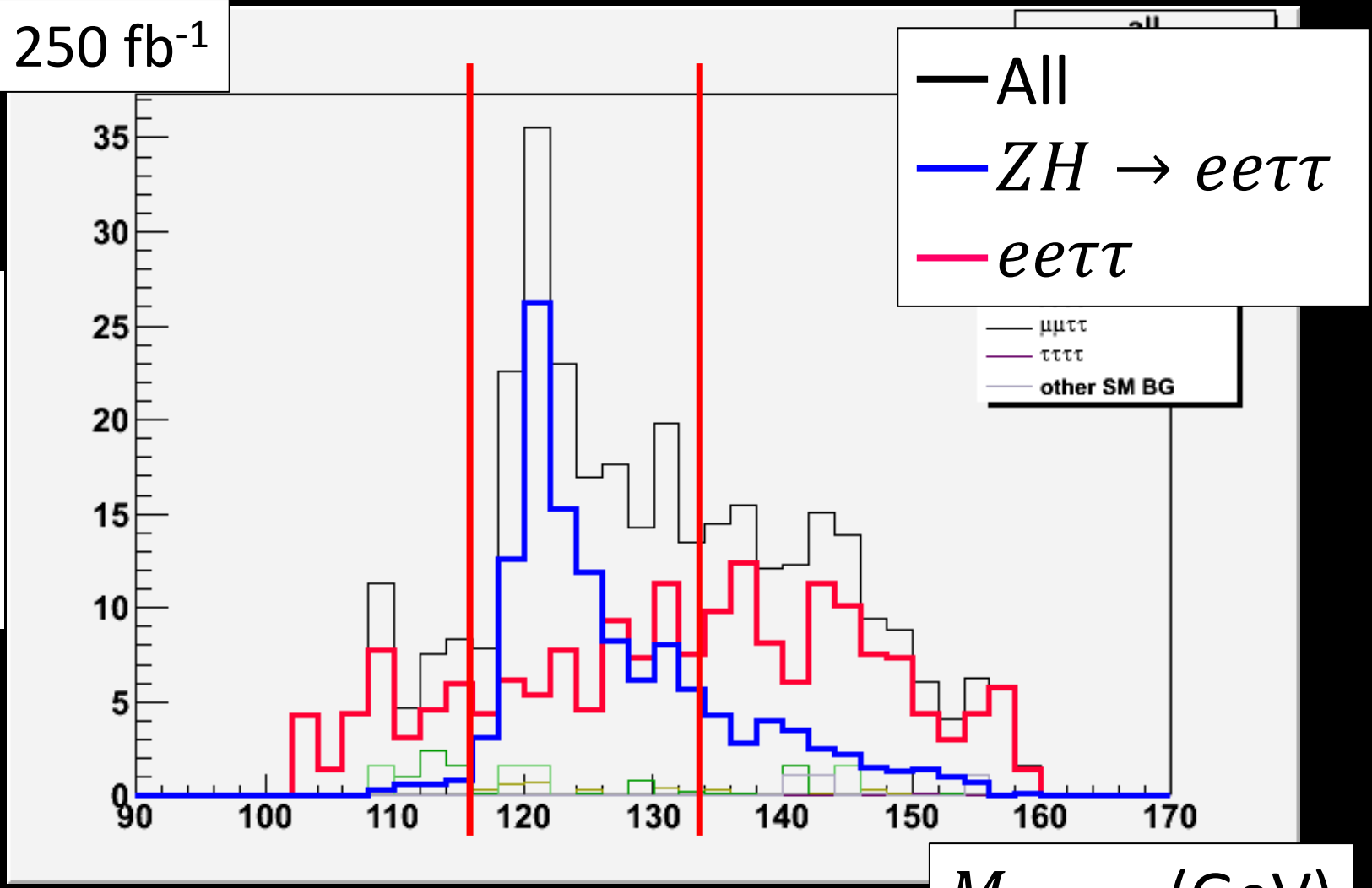


Event selection ($Z \to e^+e^-$)

$L = 250$ fb^{-1}



Event selection ($Z \to \mu^+\mu^-$)

Cut 0 (pre-selection):
require $\mu^+\mu^-$ candidate,
of τ^+ candidate == 1,
of τ^- candidate == 1

select μ and τ

Cut 1: # of tracks <= 8
Cut 2: $110 < E_{\mathrm{vis}} < 240$
Cut 3: $|\cos\theta_{\mathrm{missmom}}| < 0.98$
Cut 4: $70 < M_Z < 110$

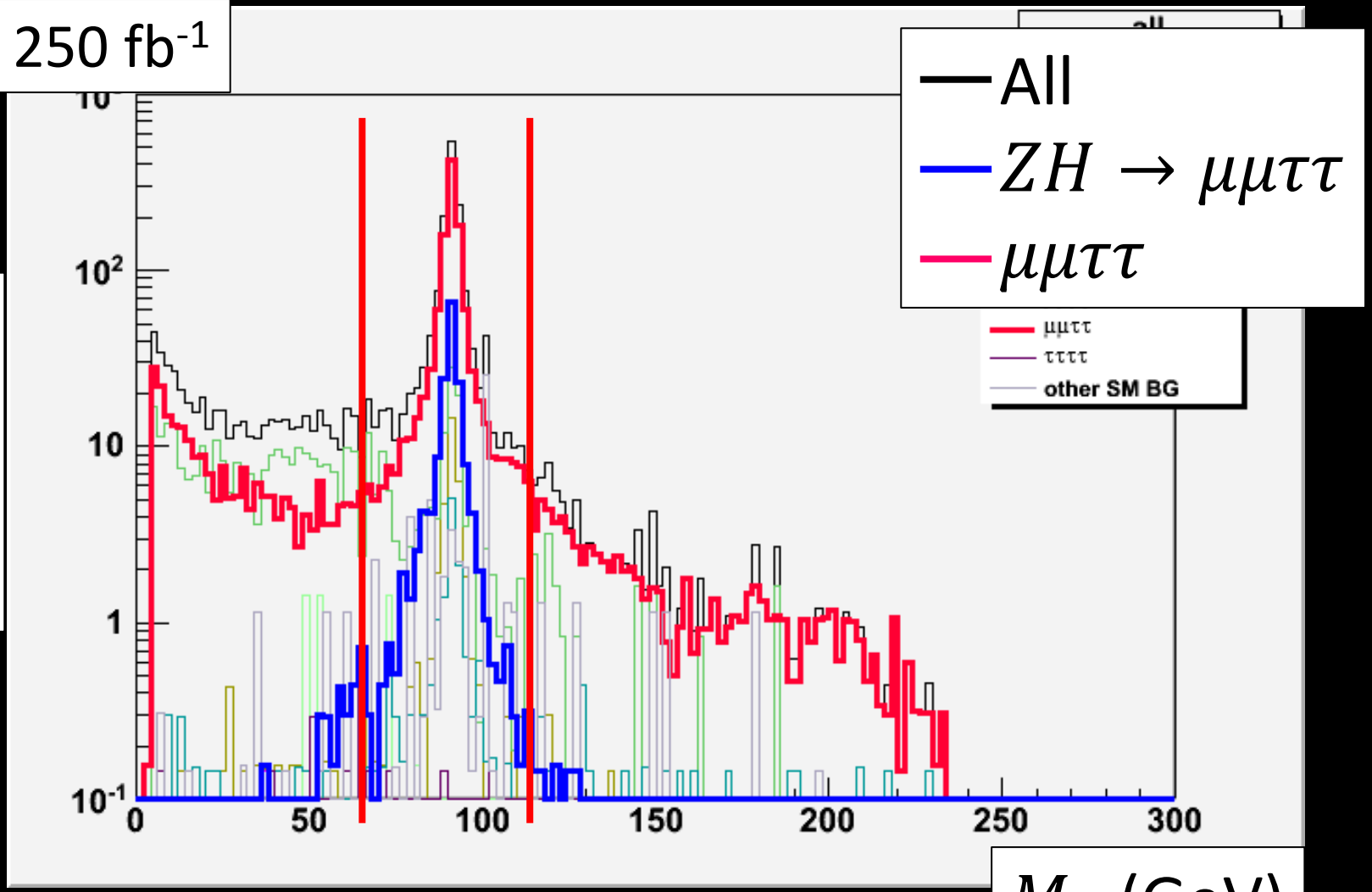
suppress no Z events

Cut 5: $90 < E_Z < 120$
Cut 6: $E_{e^+} < 90, E_{e^-} < 90$
Cut 7: $\cos\theta_{e^+e^-} < -0.2$
Cut 8: $\cos\theta_{\tau^+\tau^-} < -0.45$
Cut 9: $118 < M_{\mathrm{recoil}} < 140$

suppress irreducible bkg ($\mu\mu\tau\tau$)

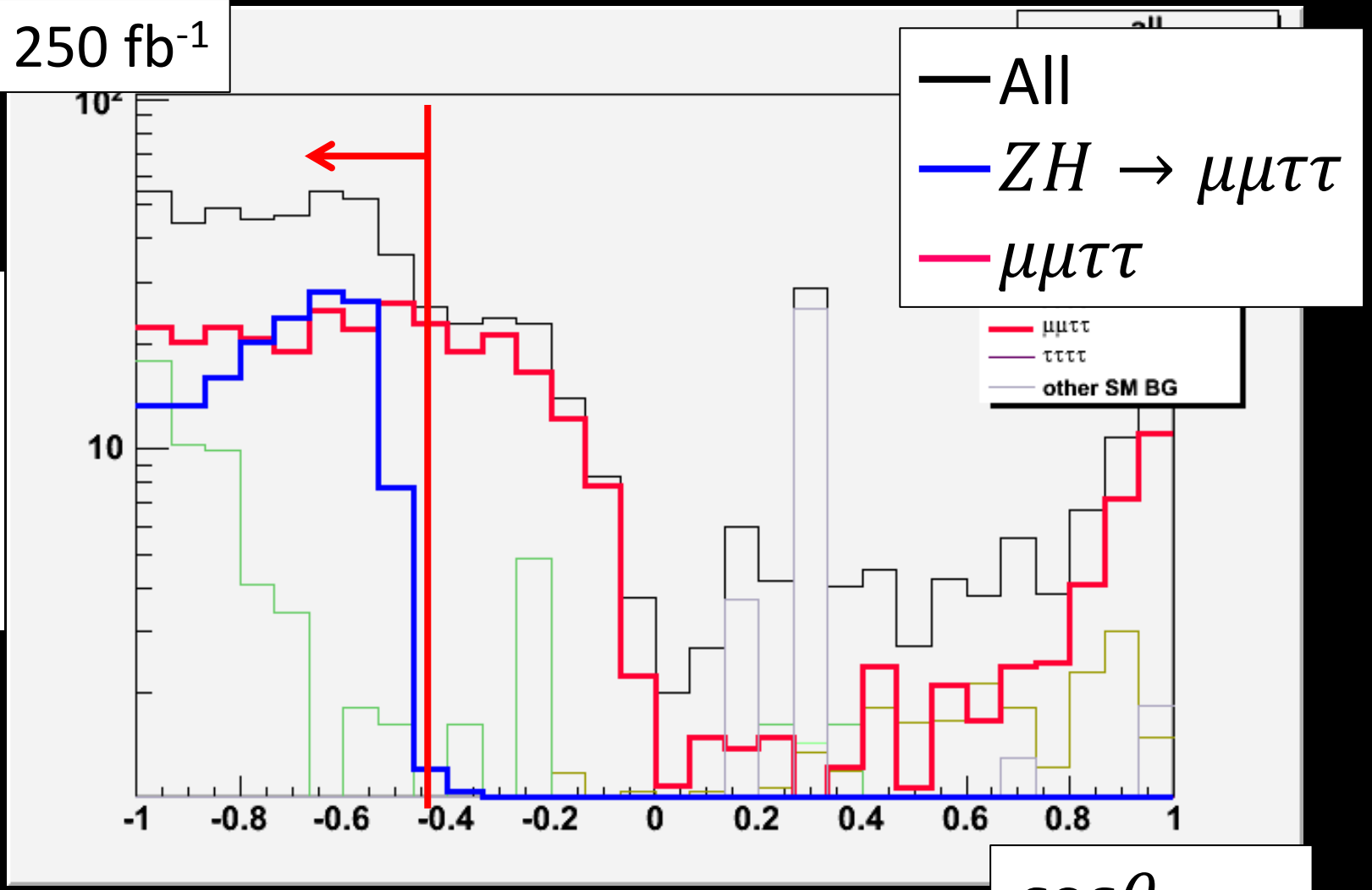
Event selection ($Z \to \mu^+\mu^-$)

$L = 250$ fb^{-1}



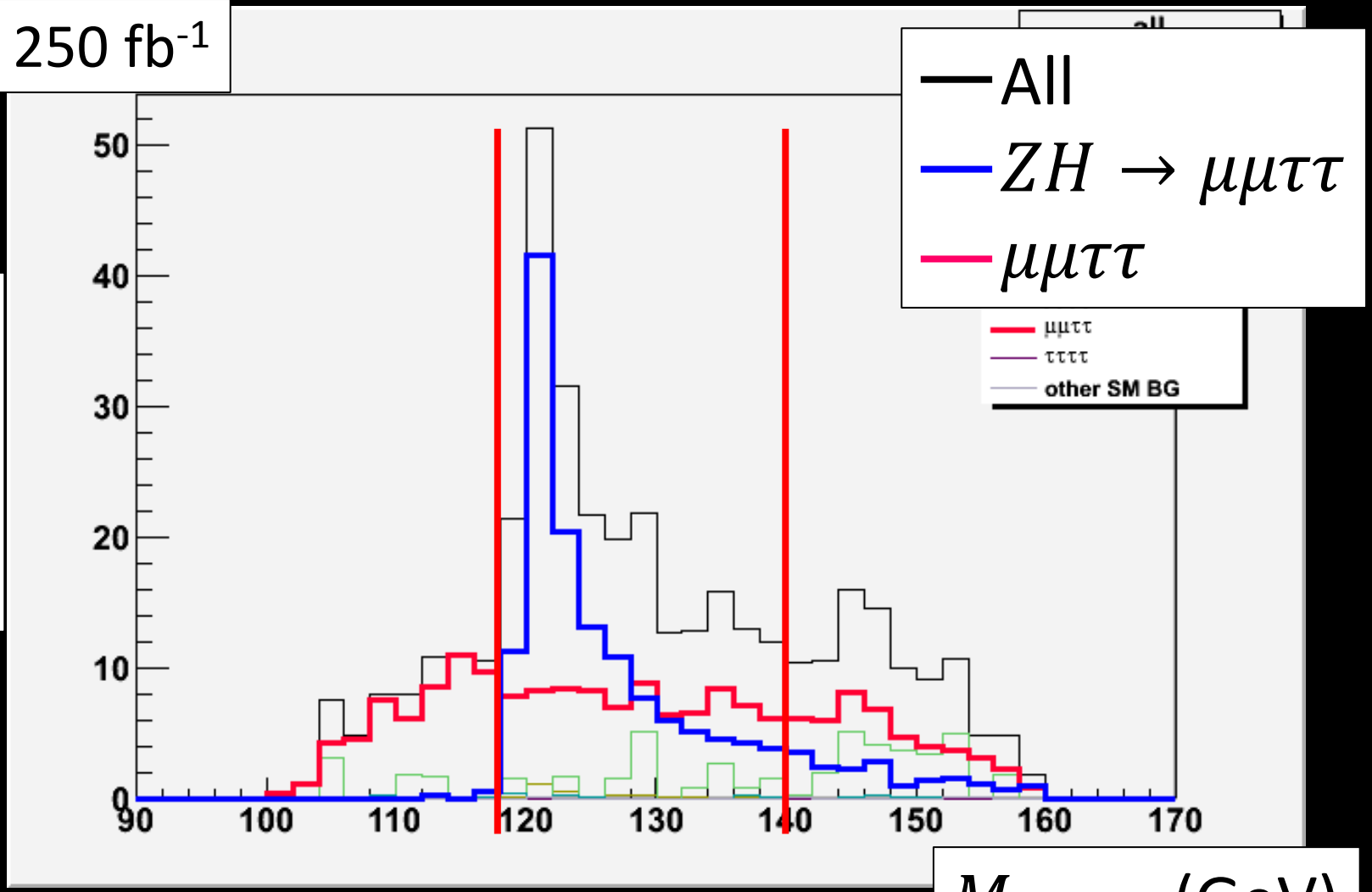
Event selection ($Z \to \mu^+\mu^-$)

$L = 250$ fb^{-1}



Event selection ($Z \to \mu^+\mu^-$)

$L = 250$ fb^{-1}



Results

	$ZH \to ee\tau\tau$	ZH no τ	$ee\tau\tau$	other 4 lep.	other SM Bkg
No cut	228.3	7320	2.382e+05	5.423e+05	1.494e+10
After cut	**97.2**	2.5	63.6	7.7	0.025

$$\text{significance}(Z \to e^+e^-) = \frac{97.2}{\sqrt{97.2 + 73.8}} = \mathbf{7.4}$$

	$ZH \to \mu\mu\tau\tau$	ZH no τ	$\mu\mu\tau\tau$	other 4 lep.	other SM Bkg
No cut	211.1	7320	3513	7.589e+05	1.494e+10
After cut	**129.5**	3.2	84.0	17.8	0.16

$$\text{significance}(Z \to \mu^+\mu^-) = \frac{129.5}{\sqrt{129.5 + 105.2}} = \mathbf{8.5}$$

Summary

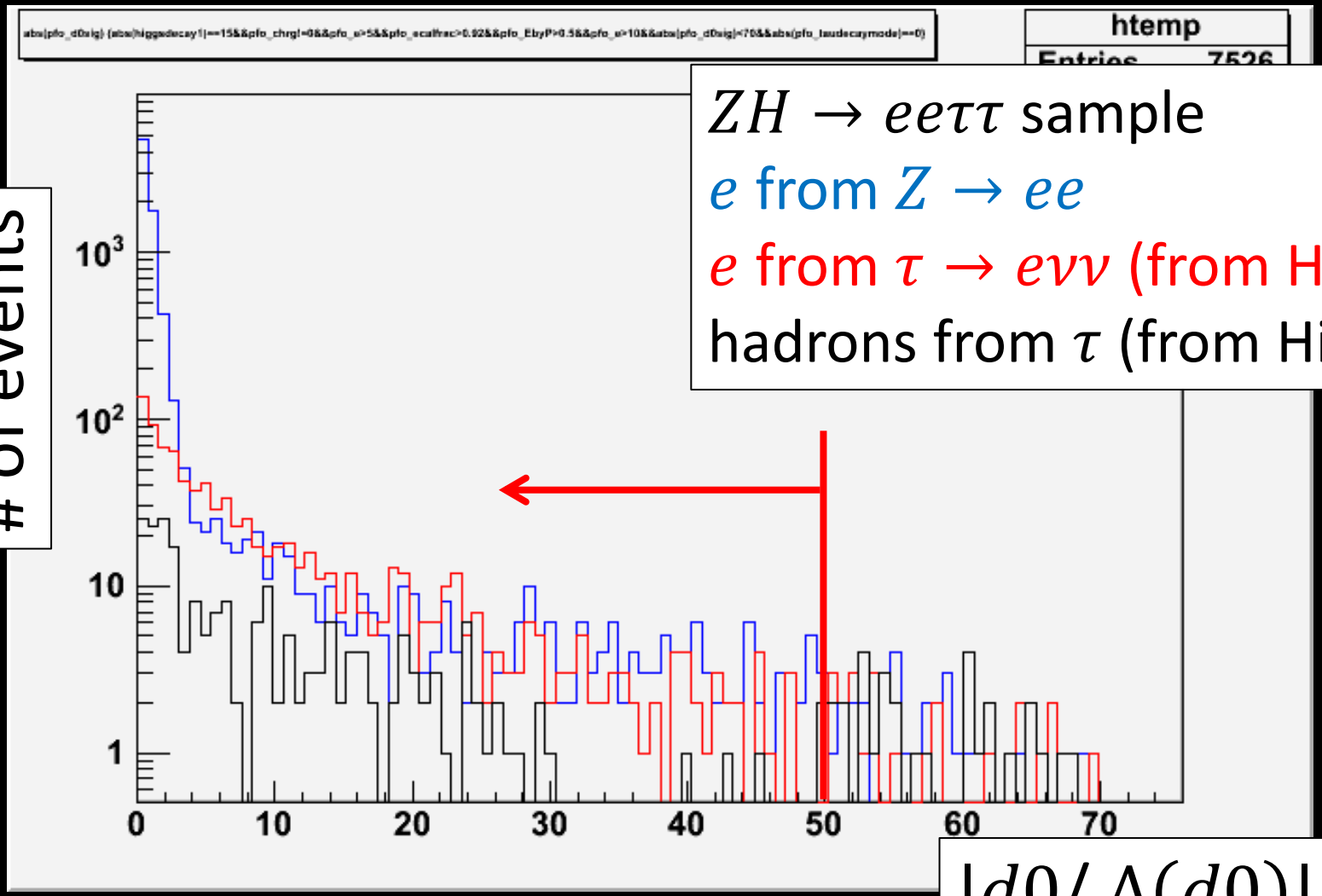
- We evaluated the precision of the branching ratio of $H \to \tau^+\tau^-$ with full detector (ILD) simulation at E_{CM} = 250 GeV.
  - $ZH \to e^+e^-\tau^+\tau^-$: estimated yield = 97.2, significance = 7.4
  - $ZH \to \mu^+\mu^-\tau^+\tau^-$: estimated yield = 129.5, significance = 8.5
- Combined significance = 11.3
  <---> $\Delta(\sigma \cdot \mathrm{Br}) / (\sigma \cdot \mathrm{Br})$ = 9 % ($Z \to l^+l^-$)
- Next step: Analysis of $Z \to q\bar{q}$

Backup slides

Lepton ID

- eID: $\frac{E_{\mathrm{ECAL}}}{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}} > 0.92, \frac{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}}{P_{\mathrm{track}}} > 0.5$
- μID: $\frac{E_{\mathrm{ECAL}}}{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}} < 0.6, \frac{E_{\mathrm{ECAL}}+E_{\mathrm{HCAL}}}{P_{\mathrm{track}}} < 0.5$

l/τ separation ($Z \rightarrow e^+e^-$)



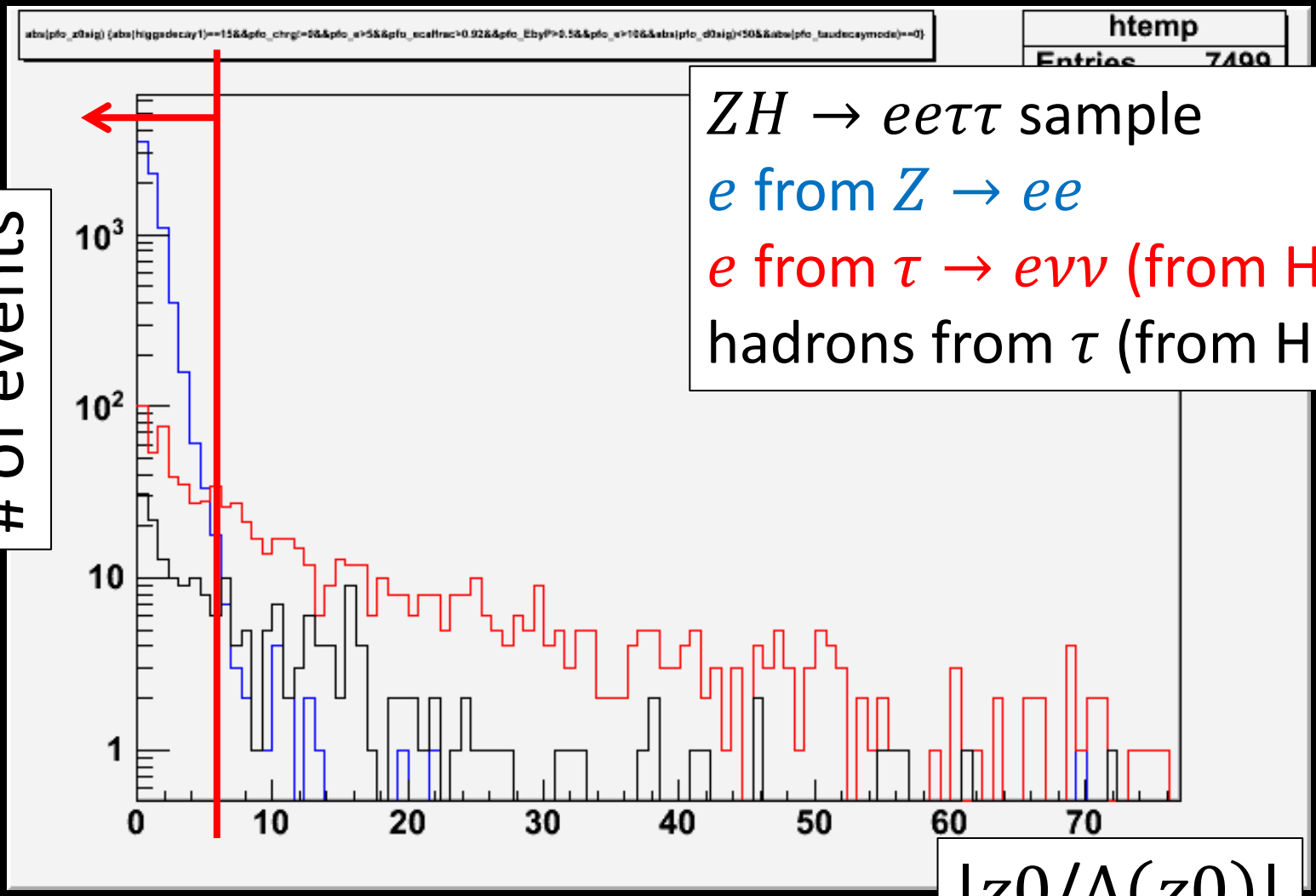
$ZH \rightarrow ee\tau\tau$ sample

e from $Z \rightarrow ee$

e from $\tau \rightarrow e\nu\nu$ (from Higgs)

hadrons from τ (from Higgs)

l/τ separation ($Z \to e^+e^-$)



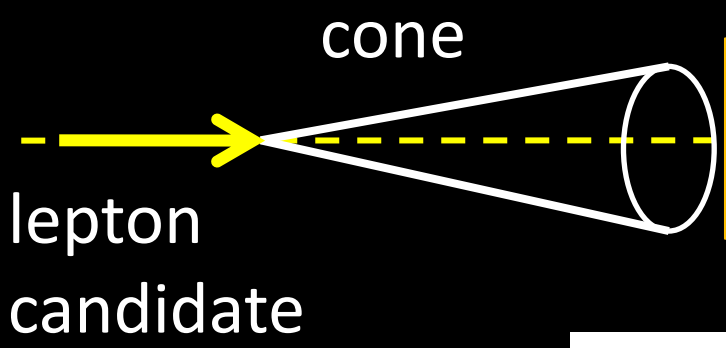
$ZH \to ee\tau\tau$ sample

e from $Z \to ee$

e from $\tau \to e\nu\nu$ (from Higgs)

hadrons from τ (from Higgs)

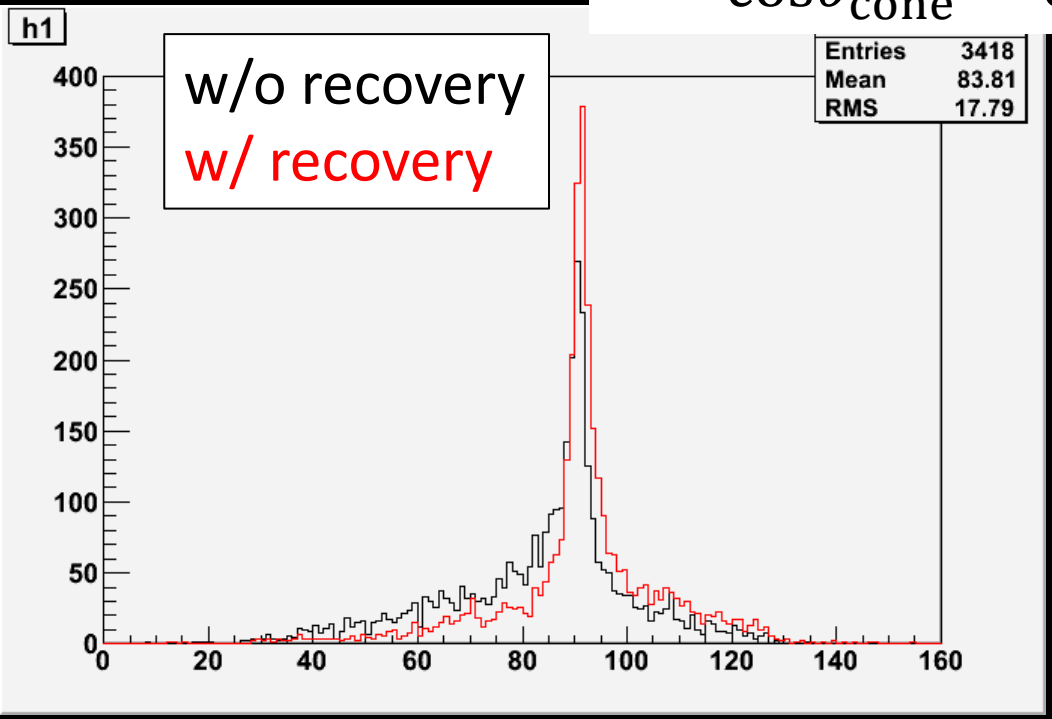
FSR / Brems recovery



Neutral particles in the cone are combined with the lepton candidate.

Z mass plot of $ZH \rightarrow ee\tau\tau$

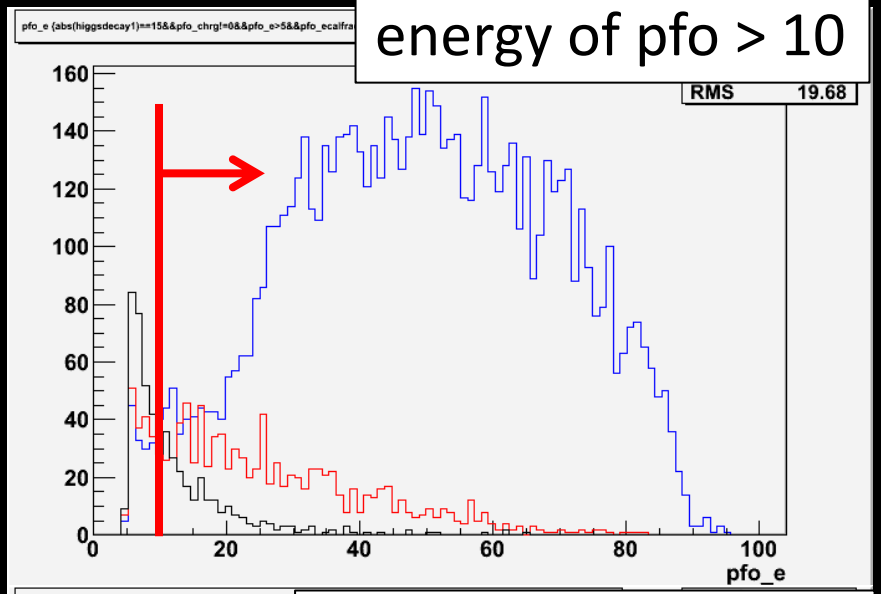
$\cos\theta_{\text{cone}} = 0.999$



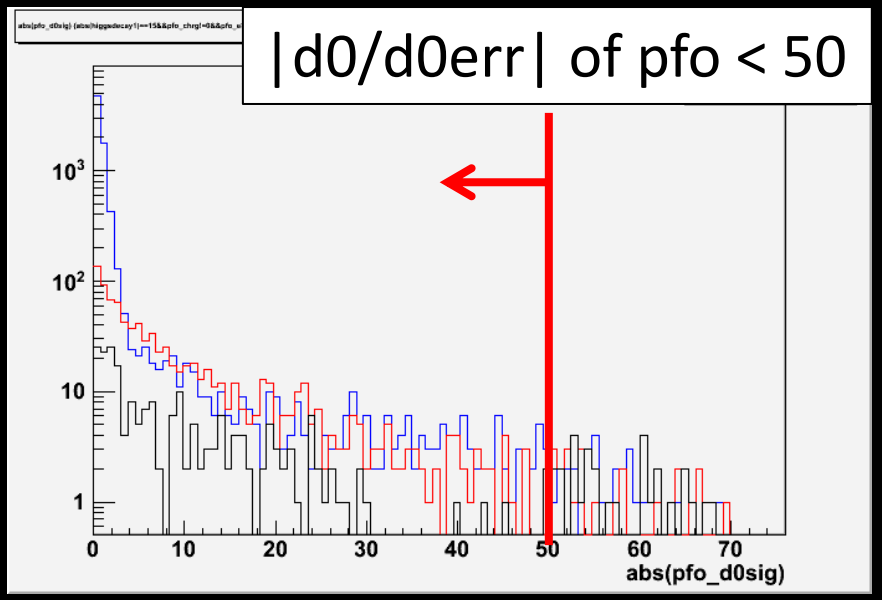
In case of more than 2 lepton tracks, the pair most consistent with Z mass is chosen.

Primary track selection ($Z \rightarrow e^+e^-$)

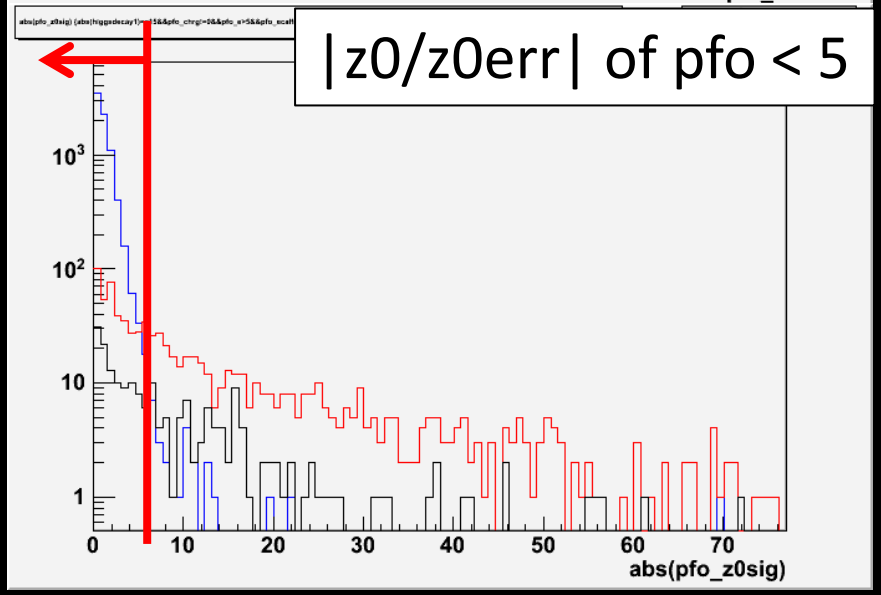
energy of pfo > 10



|d0/d0err| of pfo < 50



|z0/z0err| of pfo < 5



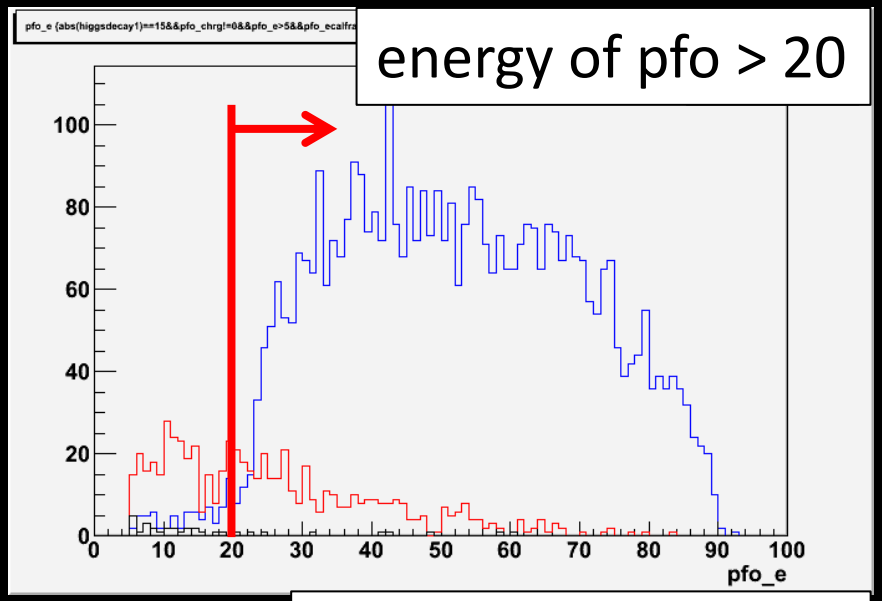
$ZH \rightarrow ee\tau\tau$ sample

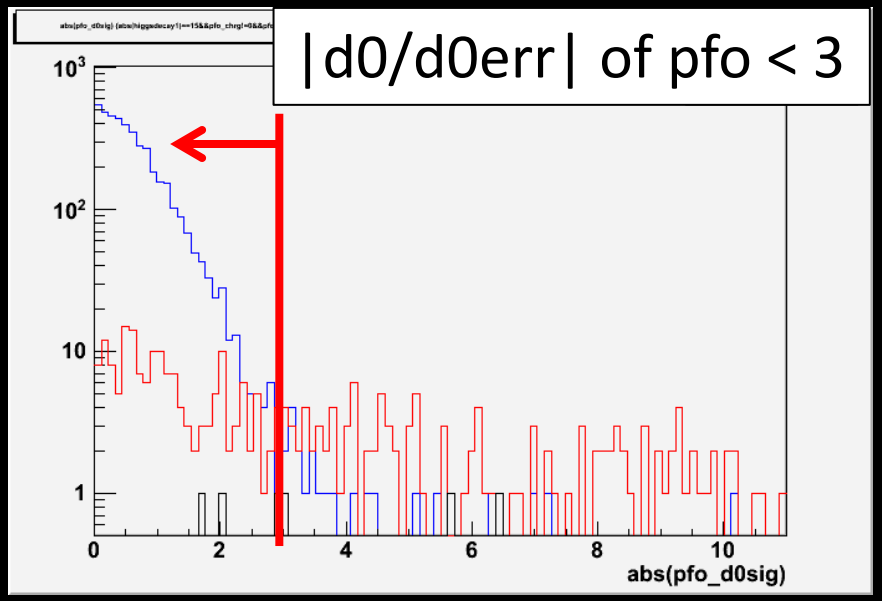
e from $Z \rightarrow ee$

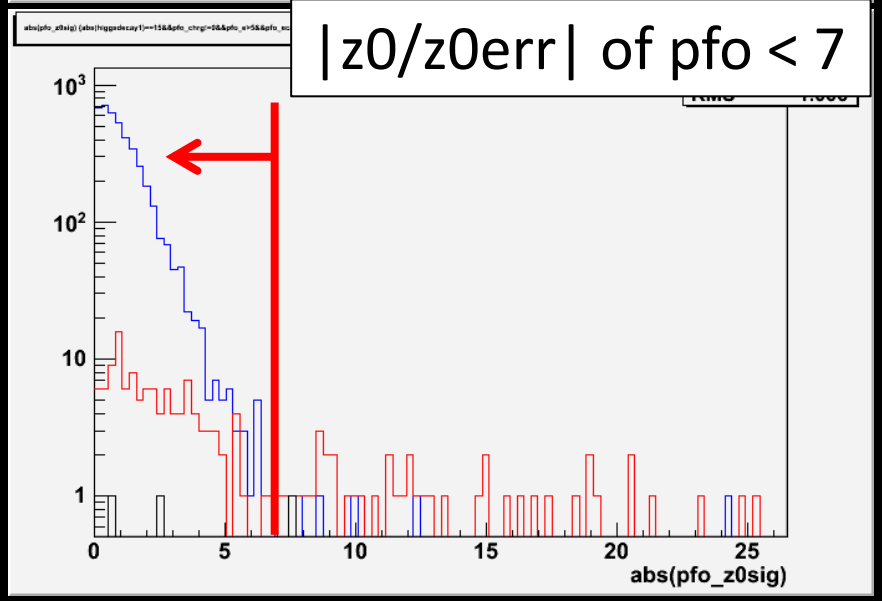
e from $\tau \rightarrow e\nu\nu$ (from Higgs)

hadrons from τ (from Higgs)

Primary track selection ($Z \to \mu^+\mu^-$)







$ZH \to \mu\mu\tau\tau$ sample

μ from $Z \to \mu\mu$

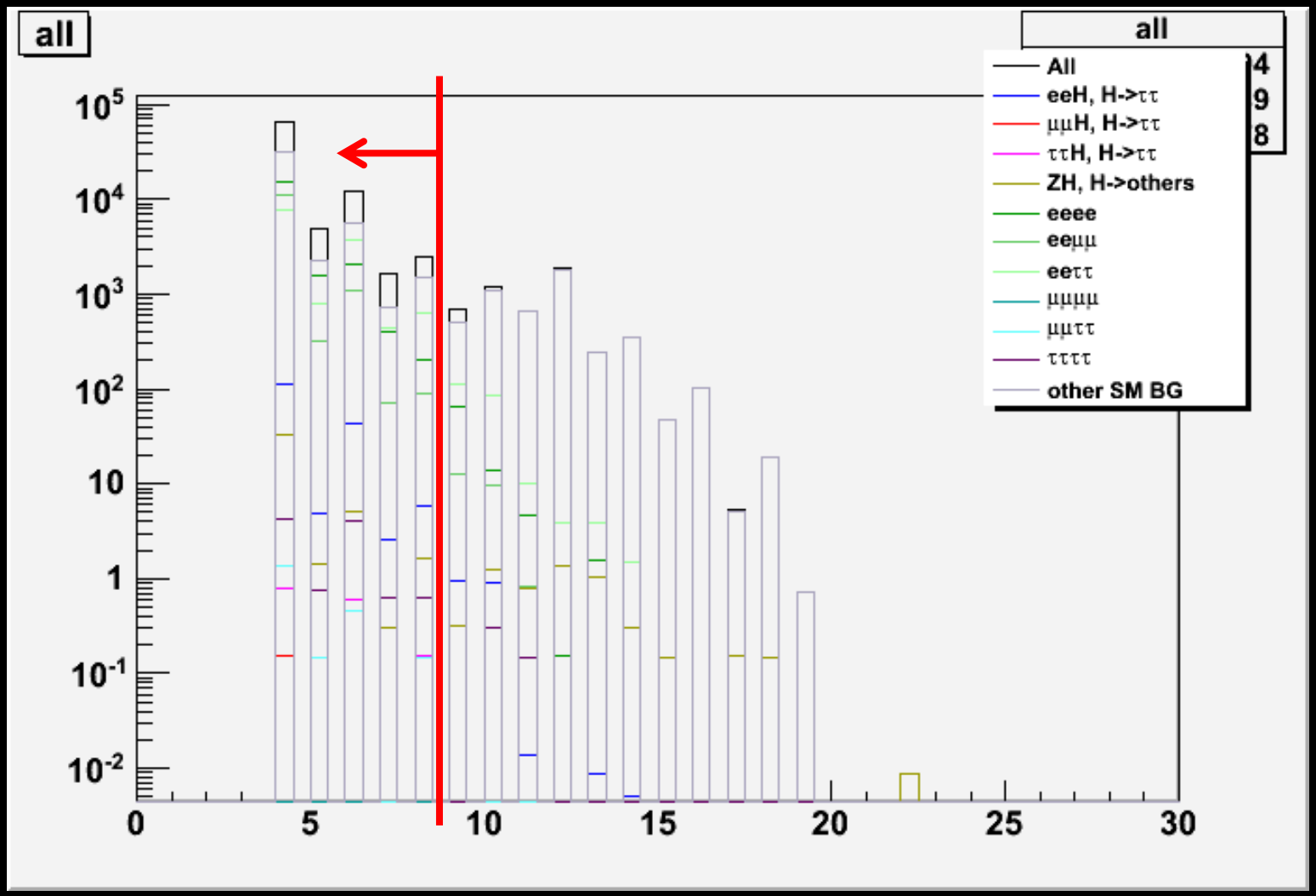
μ from $\tau \to \mu\nu\nu$ (from Higgs)

hadrons from τ (from Higgs)

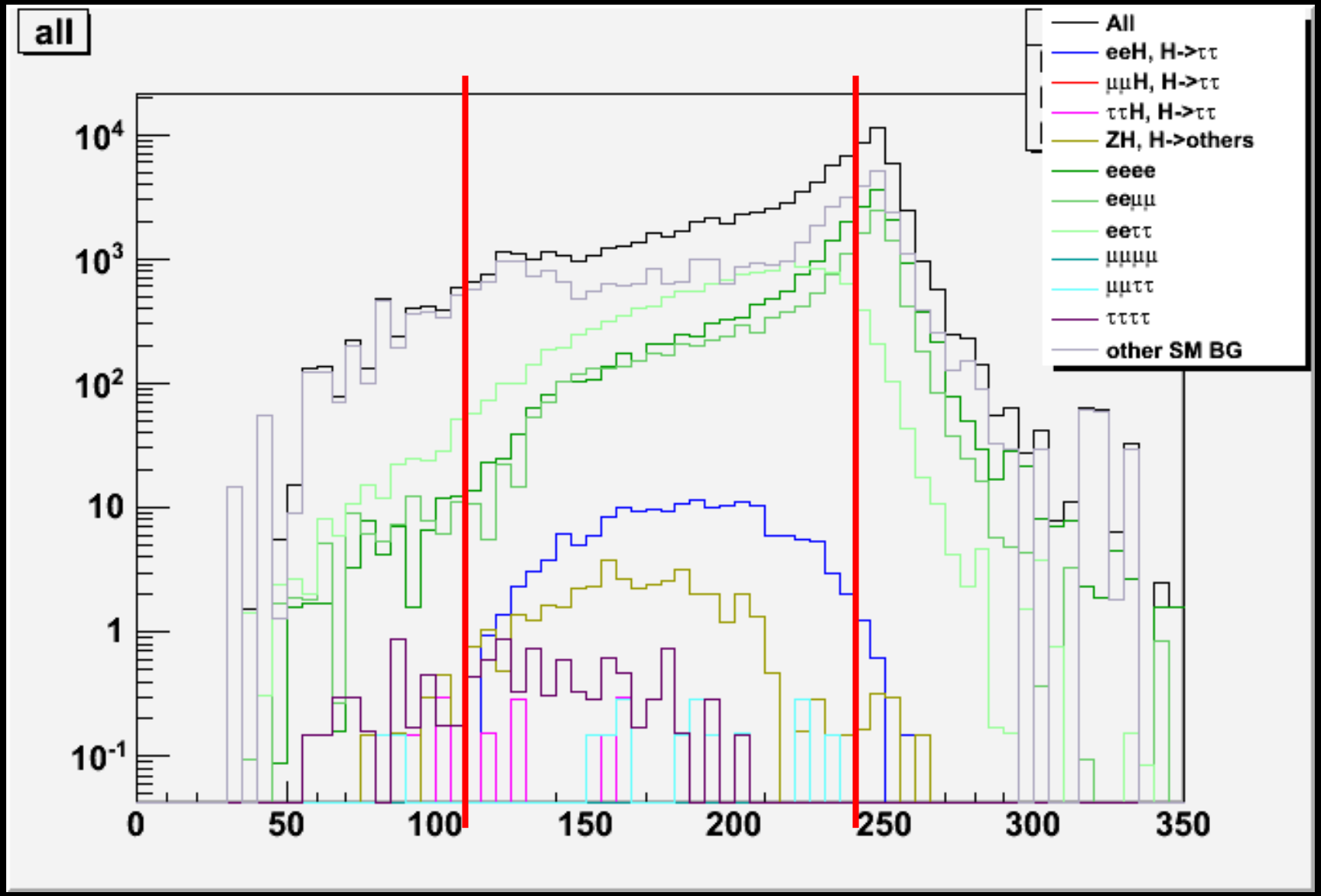
Event selection ($Z \to e^+e^-$)

Cut 0 (pre-selection):
require e^+e^- candidate,
of τ^- candidate == 1,
of τ^+ candidate == 1,
Cut 1: # of tracks <= 8
Cut 2: $110 < E_{\mathrm{vis}} < 240$
Cut 3: $|\cos\theta_{\mathrm{missmom}}| < 0.98$
Cut 4: $70 < M_Z < 110$
Cut 5: $90 < E_Z < 120$
Cut 6: $\cos\theta_{e^-} < 0.92, \cos\theta_{e^+} > -0.92$
Cut 7: $20 < E_{e^-} < 90, 20 < E_{e^+} < 90$
Cut 8: $\cos\theta_{e^+e^-} < -0.2$
Cut 9: $\cos\theta_{\tau^+\tau^-} < -0.4$
Cut 10: $\cos\theta_{\tau^-} < 0.92, \cos\theta_{\tau^+} > -0.92$
Cut 11: $116 < M_{\mathrm{recoil}} < 134$

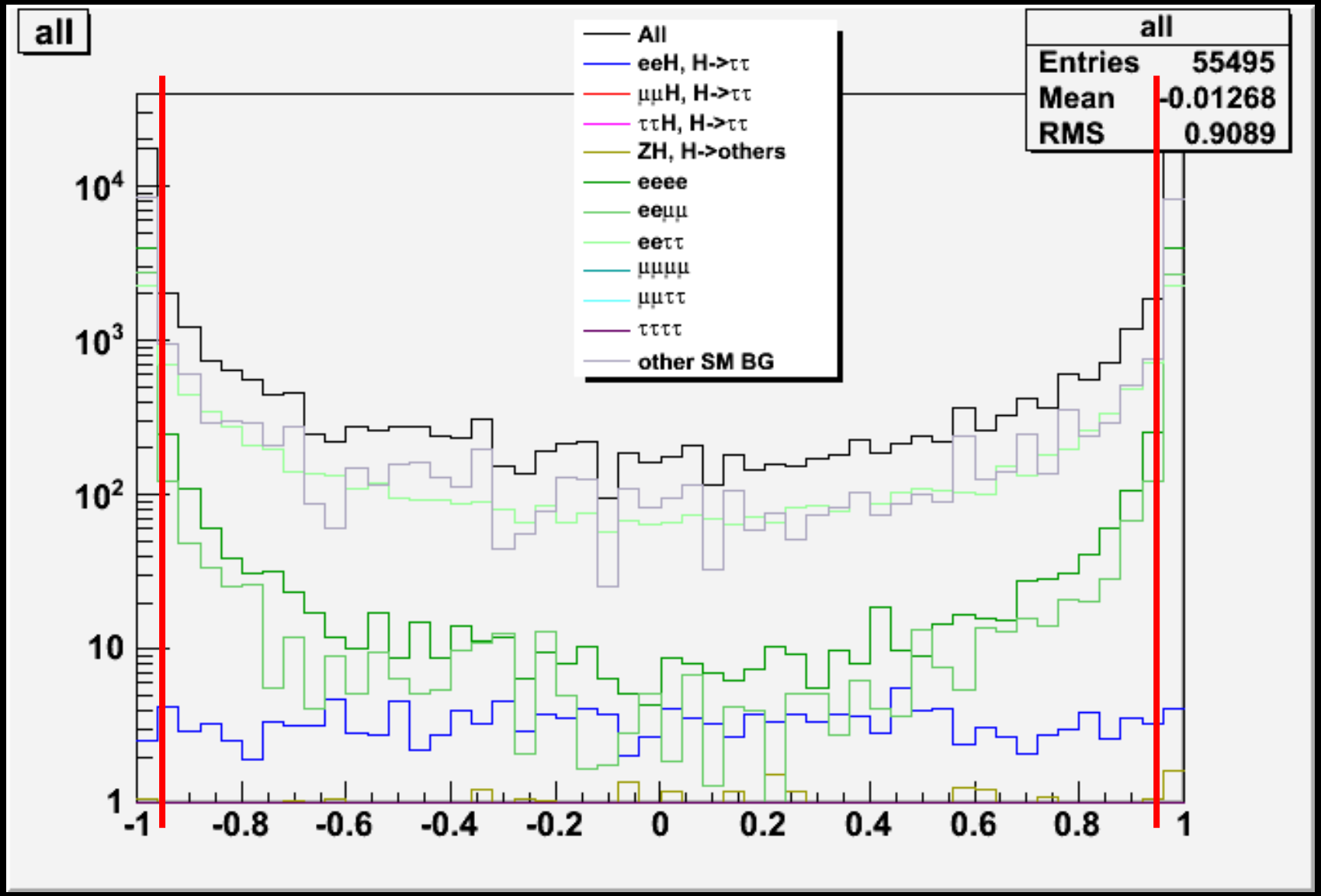
Cuts for $Z \rightarrow e^+e^-$ (after pre-selection)



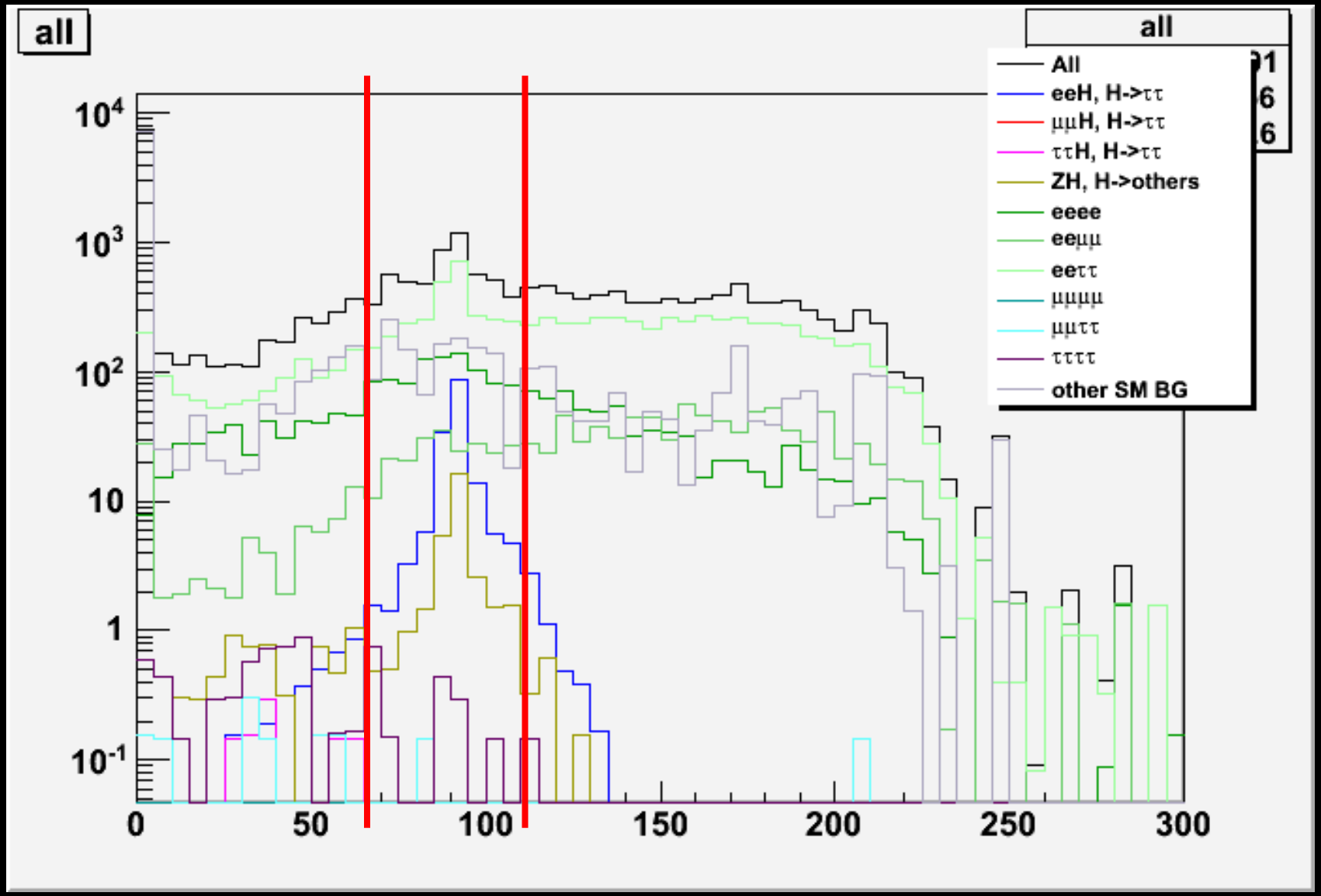
# of tracks <= 8



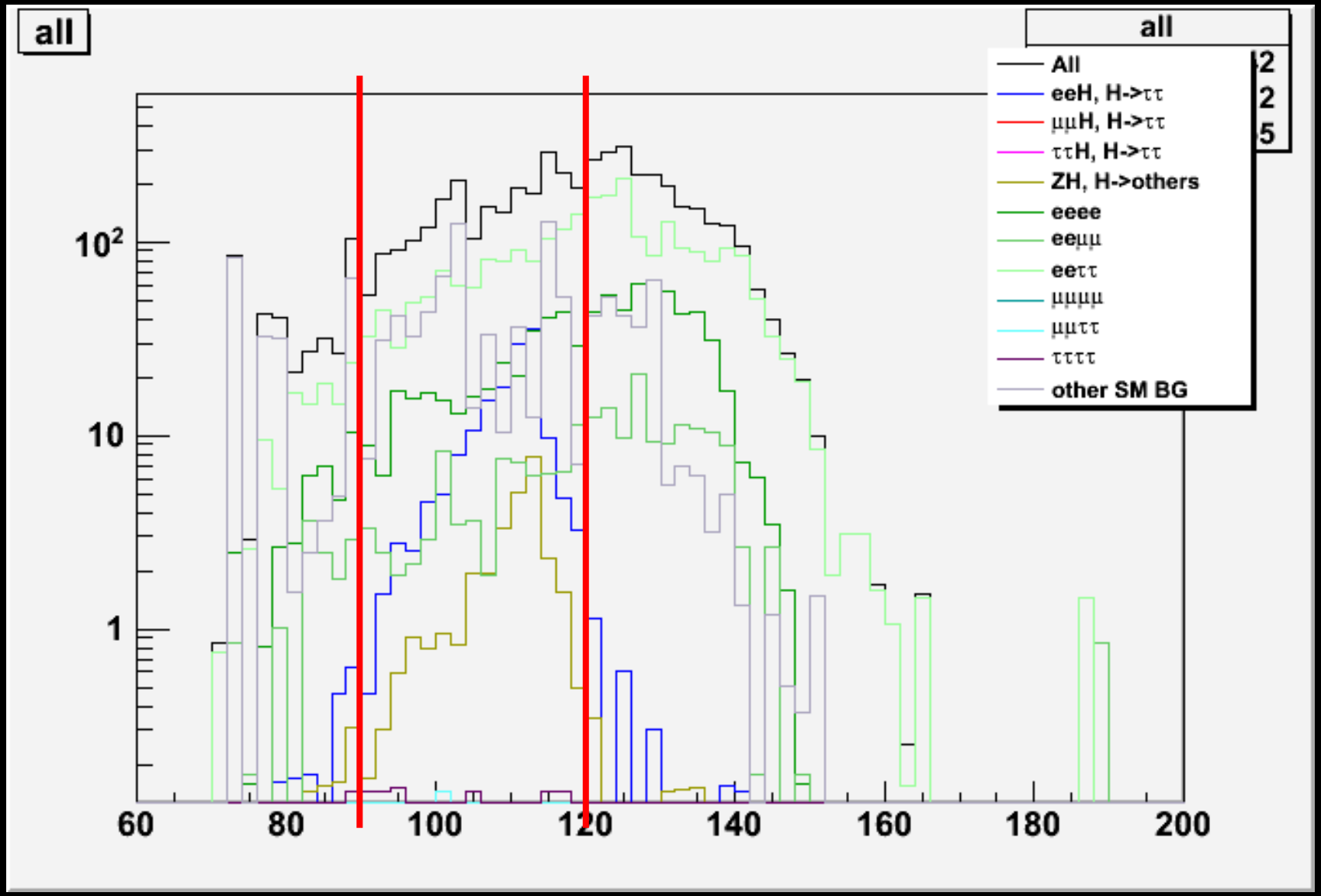
$$110 < E_{\mathrm{vis}} < 240$$



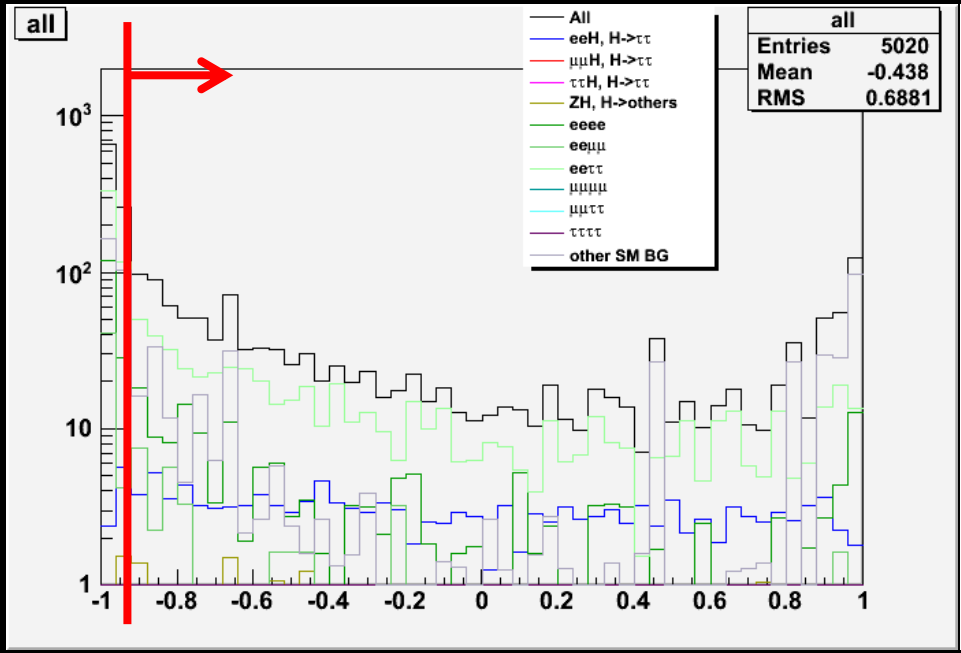
$$|\cos\theta_{\mathrm{missmom}}| < 0.98$$

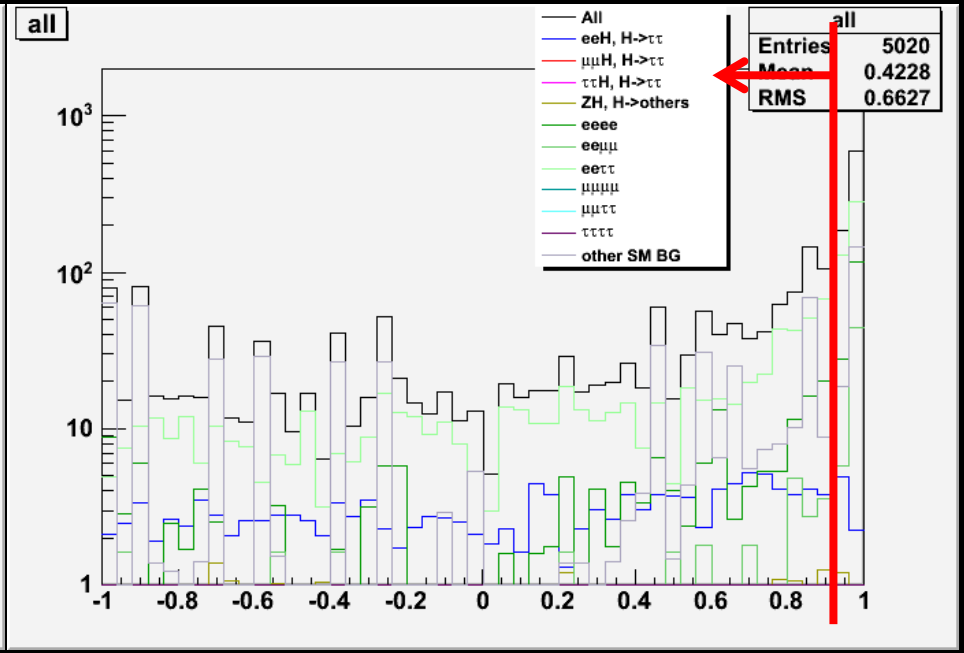

all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
10^4
10^3
10^2
10
1
10^-1
0
50
100
150
200
250
300

$$70 < M_Z < 110$$

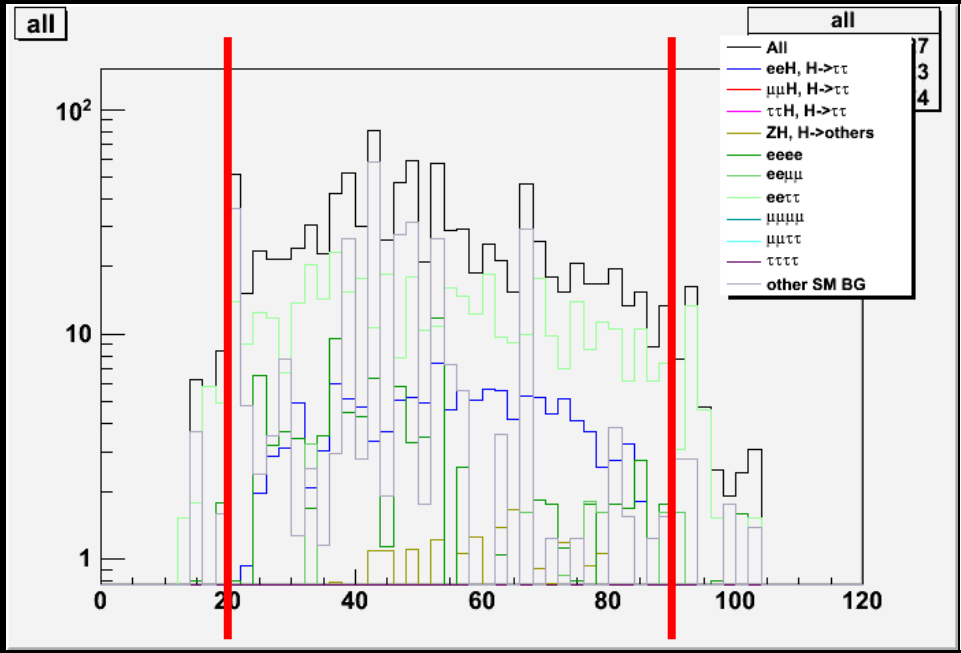

all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
2
2
5
10²
10
1
60
80
100
120
140
160
180
200

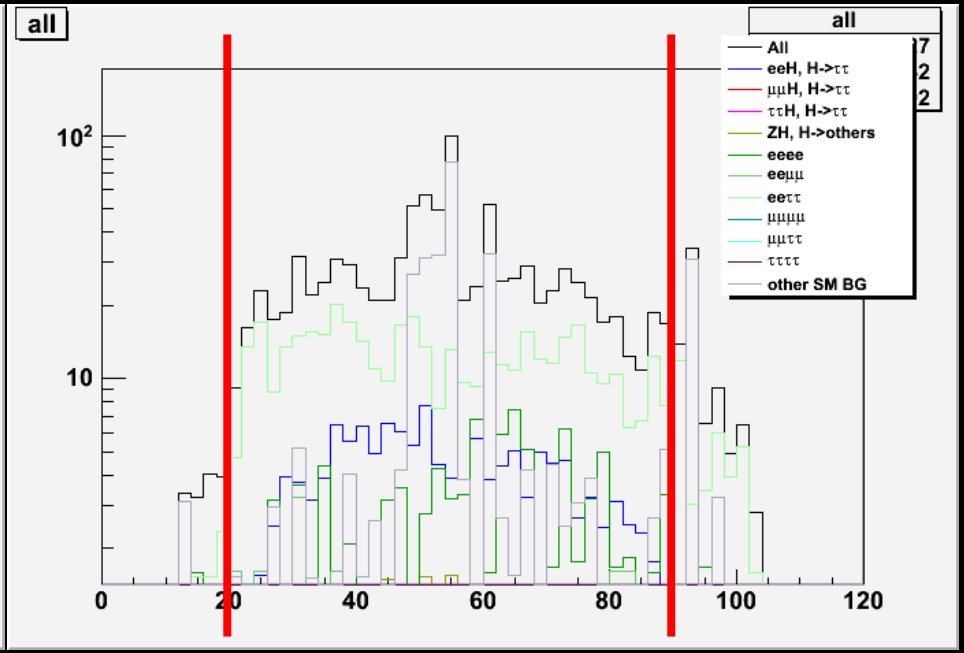
$$90 < E_Z < 120$$



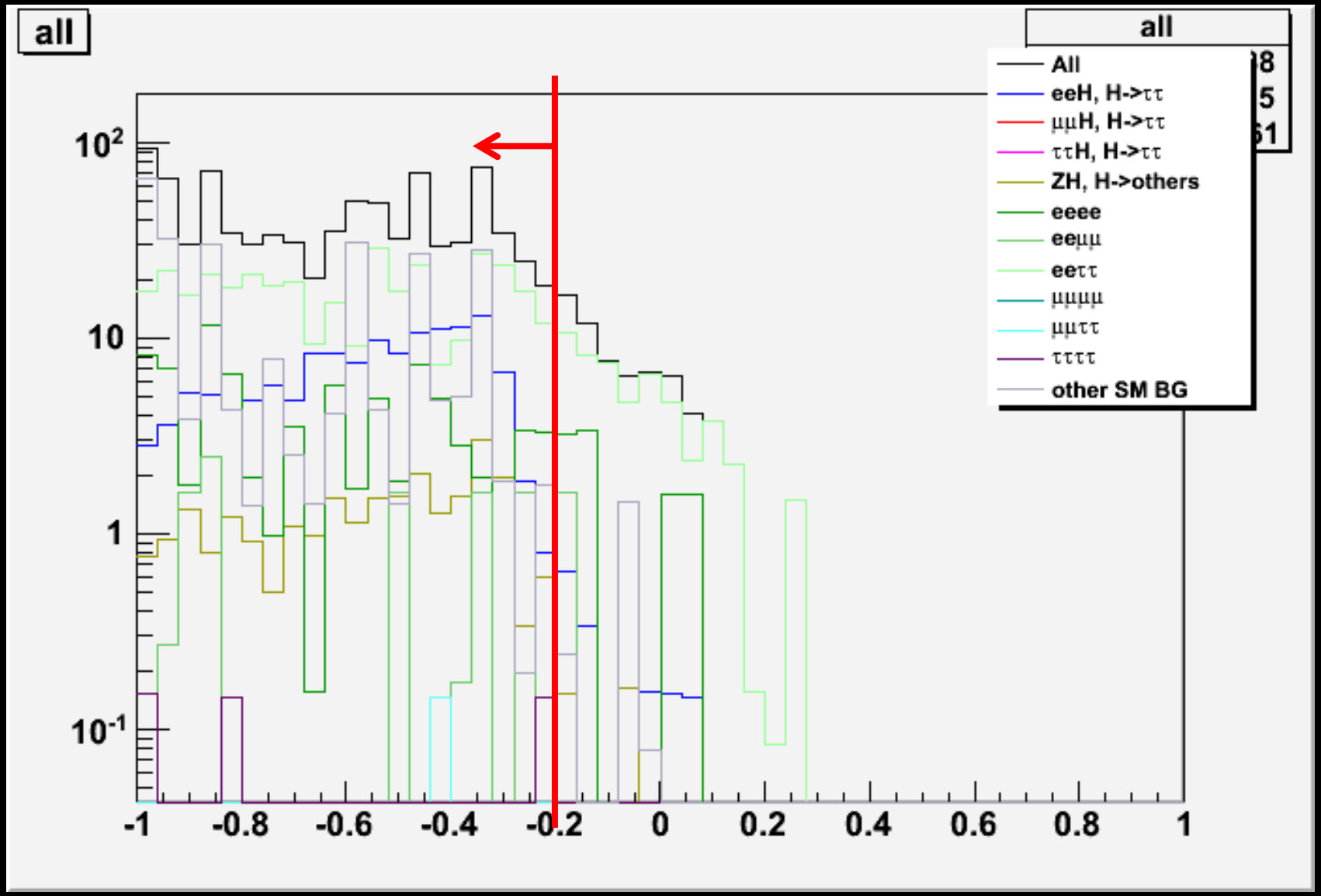


$$\cos\theta_{e^+} > -0.92, \cos\theta_{e^-} < 0.92$$

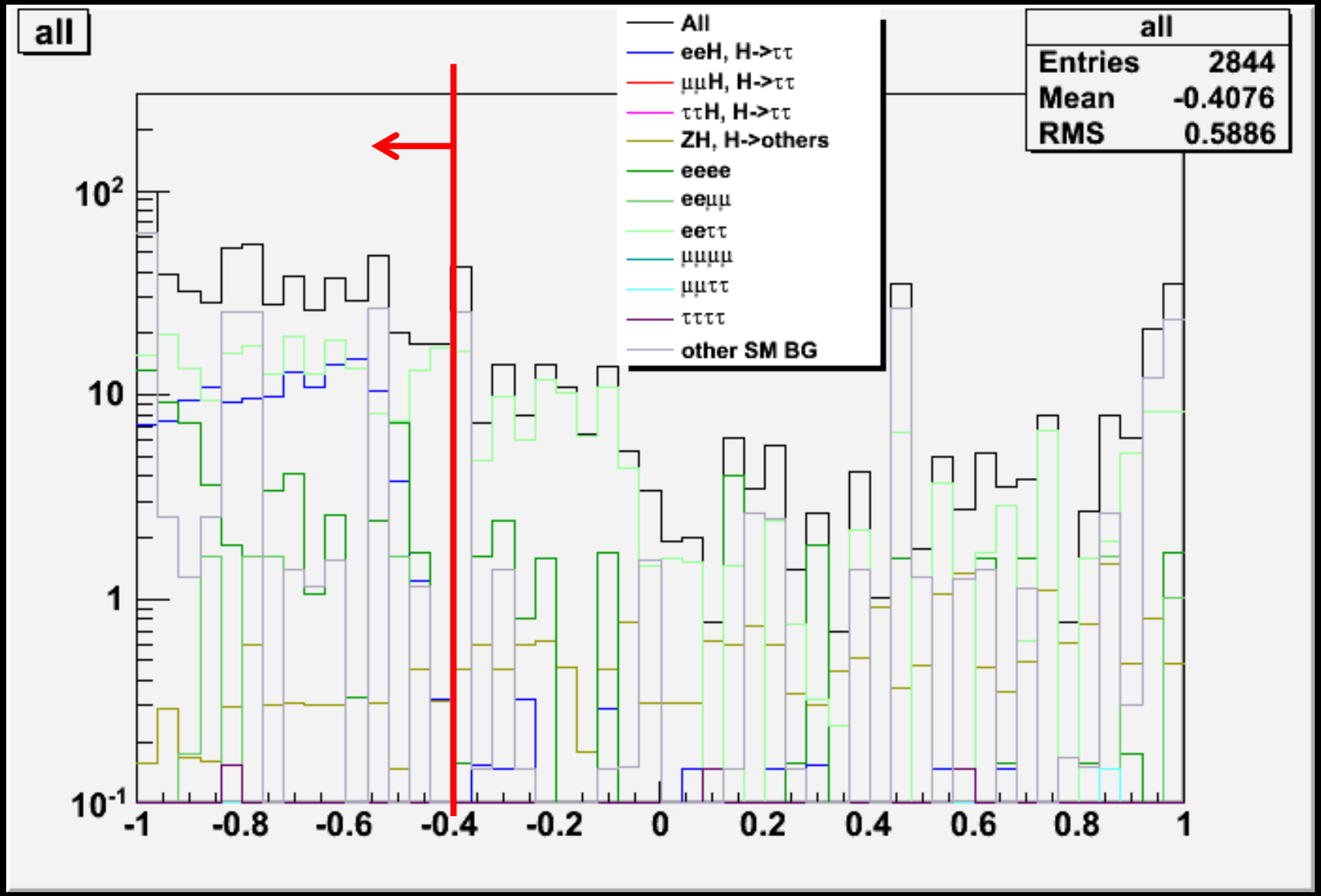




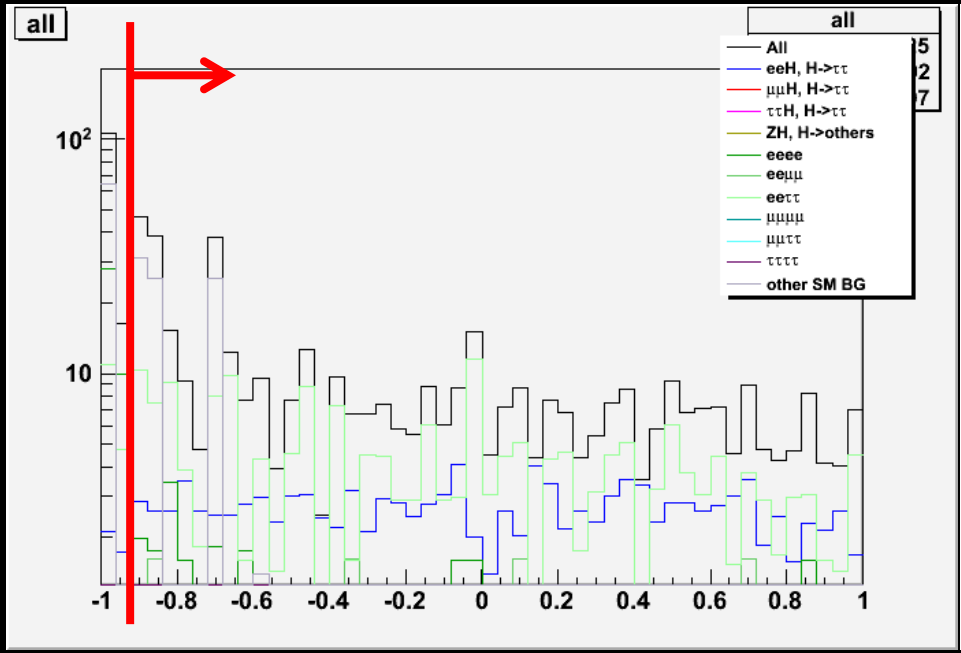
$$20 < E_{e^+} < 90, 20 < E_{e^-} < 90$$

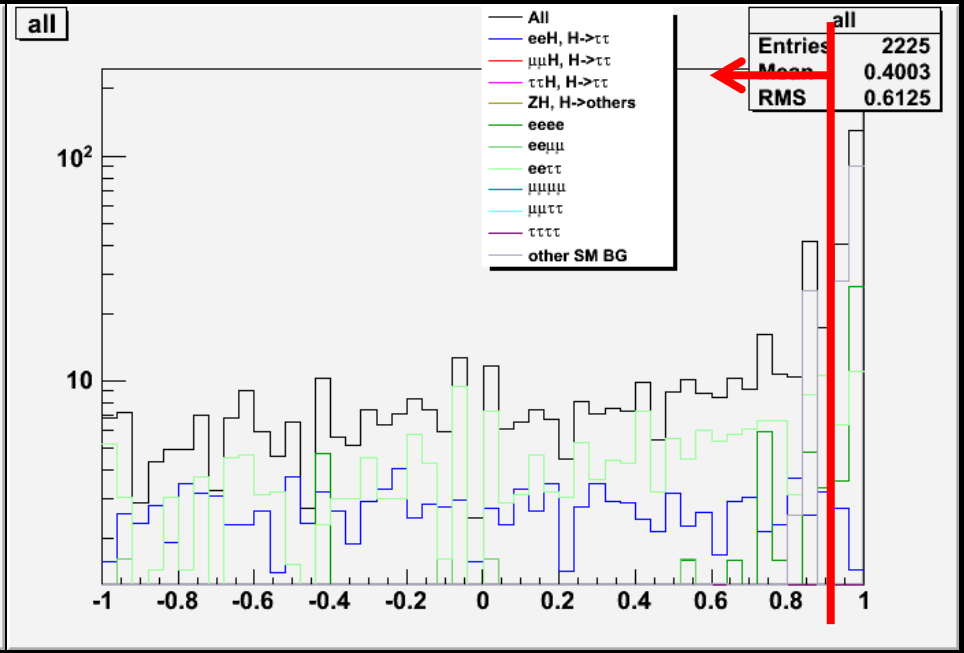


$$\cos\theta_{e^+e^-} < -0.2$$

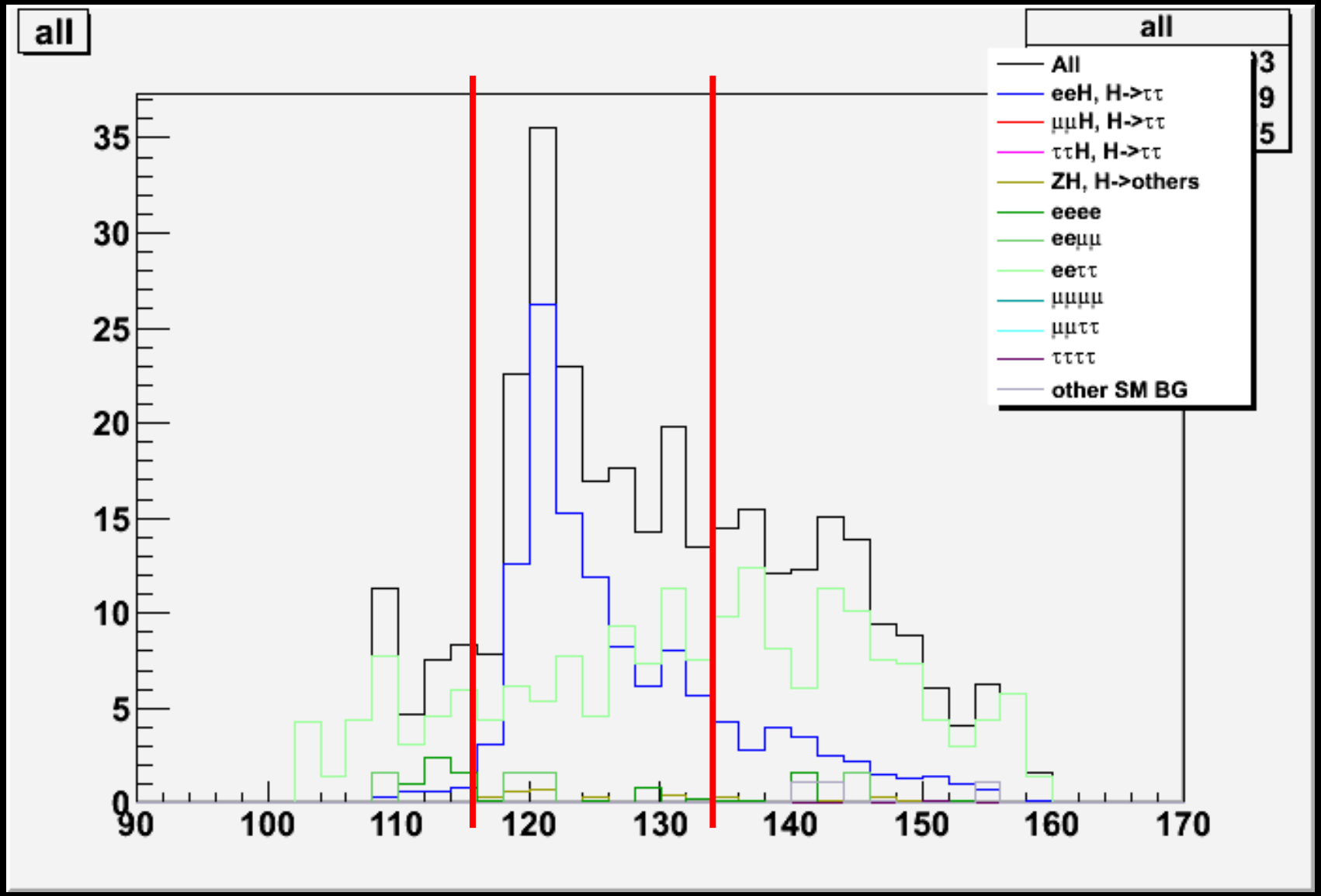


$$\cos\theta_{\tau^+\tau^-} < -0.4$$





$$\cos\theta_{\tau^+} > -0.92, \cos\theta_{\tau^-} < 0.92$$



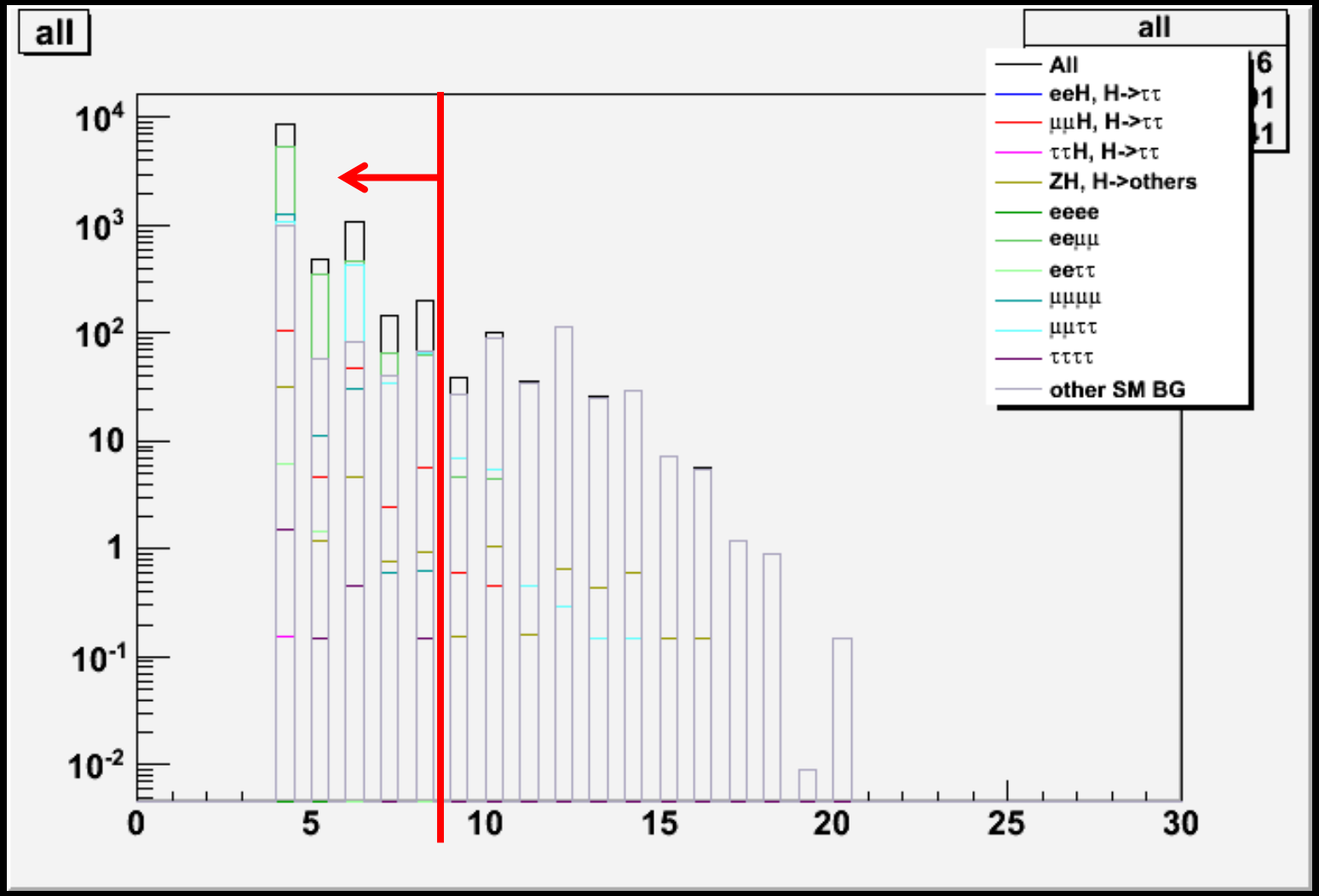
$$116 < M_{\mathrm{recoil}} < 134$$

Cuts	eeH	not $H \to \tau\tau$	$ee\tau\tau$	other 4 leptons	ee	$e\gamma$	$\gamma\gamma$	other SM Bkg	sig.
none	228.3	7320	2.382e+05	5.243e+05	4.325e+09	3.022e+09	7.532e+09	6.350e+07	0.00187
pre-sel	171.3	47.05	1.338e+04	2.091e+05	4.692e+06	1.365e+06	4.146e+06	4.702e+04	0.0534
# of tracks <= 8	169.4	41.56	1.316e+04	2.083e+05	4.560e+06	1.352e+06	4.131e+06	4.218e+04	0.0532
$110 < E_{\mathrm{vis}} < 240$	167.4	39.41	1.216e+04	1.562e+04	2.422e+06	8.830e+05	3.406e+06	2.563e+04	0.0642
$\lvert\cos\theta_{\mathrm{missmom}}\rvert < 0.98$	164.4	38.33	8987	3164	6.936e+05	4.364e+04	31.26	1.044e+04	0.189
$70 < M_Z < 110$	154.7	30.60	2653	1039	6177	2.091e+04	23.83	1130	0.863
$90 < E_Z < 120$	150.6	28.99	1085	394.5	0	1.840e+04	23.83	638.3	1.05
$\cos\theta_{e^-} < 0.92$ $\cos\theta_{e^+} > -0.92$	136.2	25.43	473.8	111.5	0	225.0	0	311.9	3.80
$20 < E_{e^-} < 90$ $20 < E_{e^+} < 90$	135.5	25.40	407.1	100.9	0	225.0	0	259.3	3.99
$\cos\theta_{e^-e^+} < -0.2$	134.0	25.05	354.7	89.55	0	225.0	0	257.5	4.07
$\cos\theta_{\tau^-\tau^+} < -0.4$	132.2	4.159	214.6	64.91	0	0	0	151.2	5.55
$\cos\theta_{\tau^-} < 0.98$ $\cos\theta_{\tau^+} > -0.98$	124.7	3.697	186.8	19.69	0	0	0	3.545	6.78
$116 < M_{\mathrm{recoil}} < 134$	97.19	2.491	63.61	7.657	0	0	0	0.025	7.43

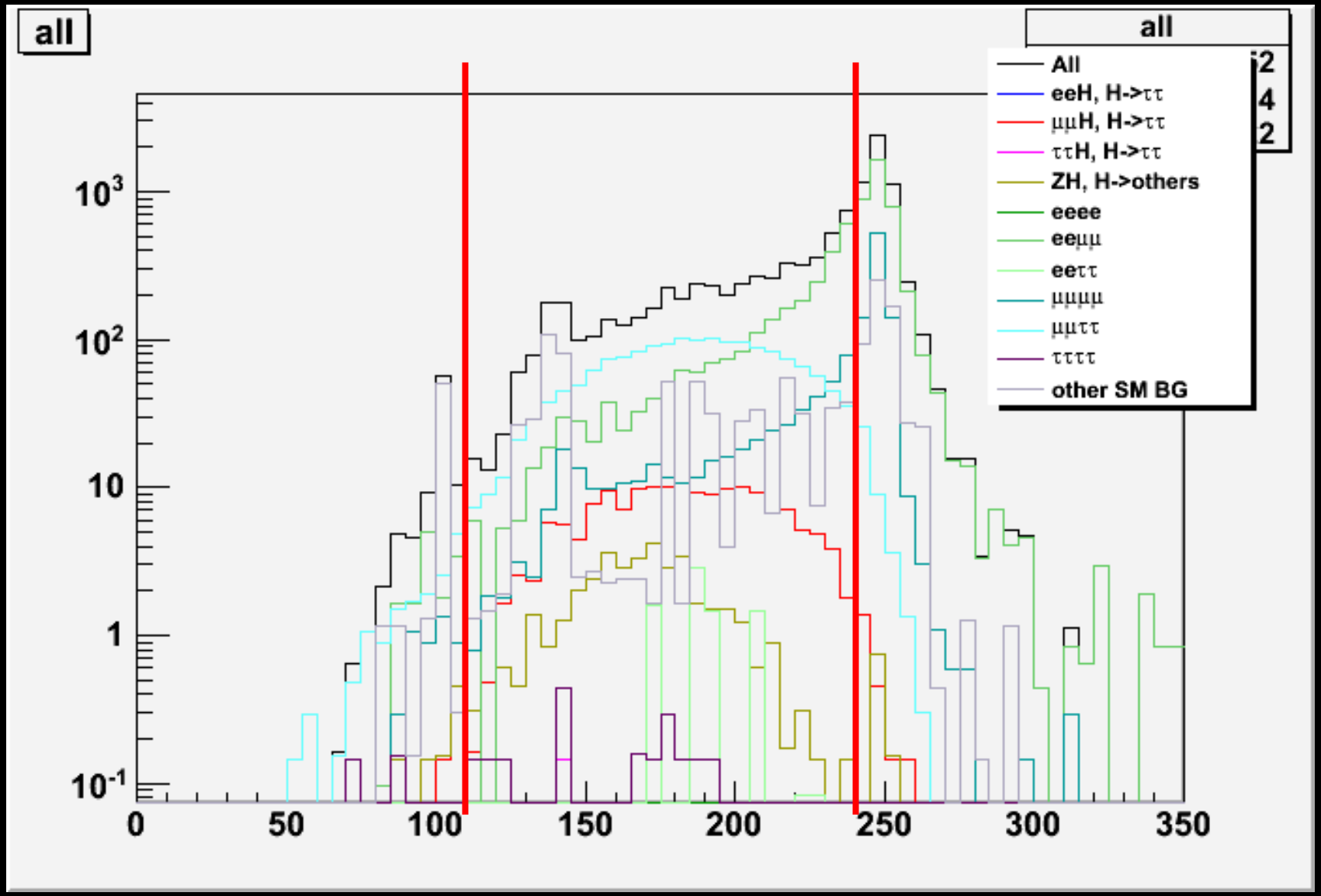
Event selection ($Z \to \mu^+\mu^-$)

Cut 0 (pre-selection):
require $\mu^+\mu^-$ candidate,
of τ^+ candidate == 1,
of τ^- candidate == 1
Cut 1: # of tracks <= 8
Cut 2: $110 < E_{\mathrm{vis}} < 240$
Cut 3: $|\cos\theta_{\mathrm{missmom}}| < 0.98$
Cut 4: $70 < M_Z < 110$
Cut 5: $90 < E_Z < 120$
Cut 6: $E_{e^+} < 90, E_{e^-} < 90$
Cut 7: $\cos\theta_{e^+e^-} < -0.2$
Cut 8: $\cos\theta_{\tau^+\tau^-} < -0.45$
Cut 9: $118 < M_{\mathrm{recoil}} < 140$

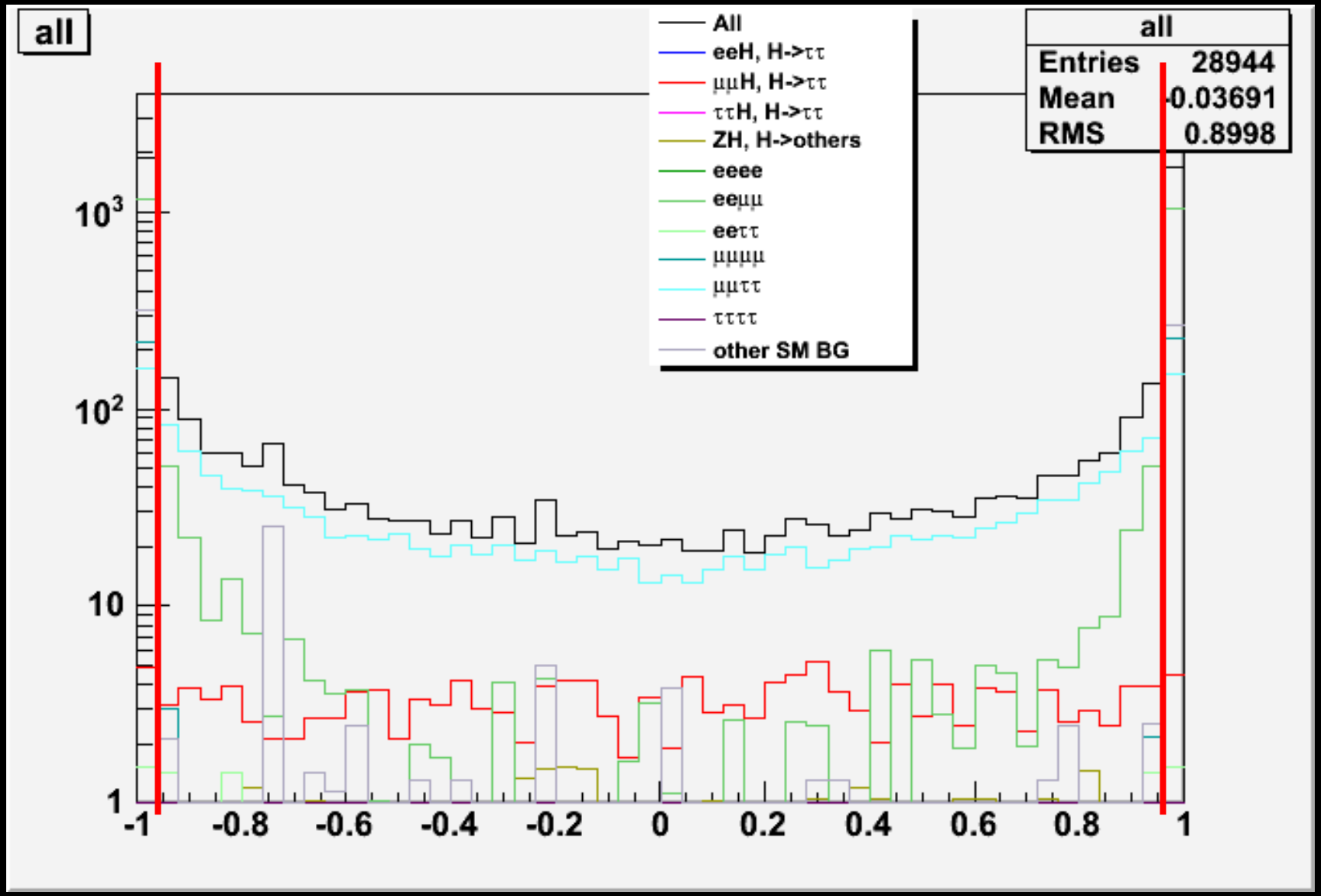
Cuts for $Z \rightarrow \mu^+\mu^-$ (after pre-selection)



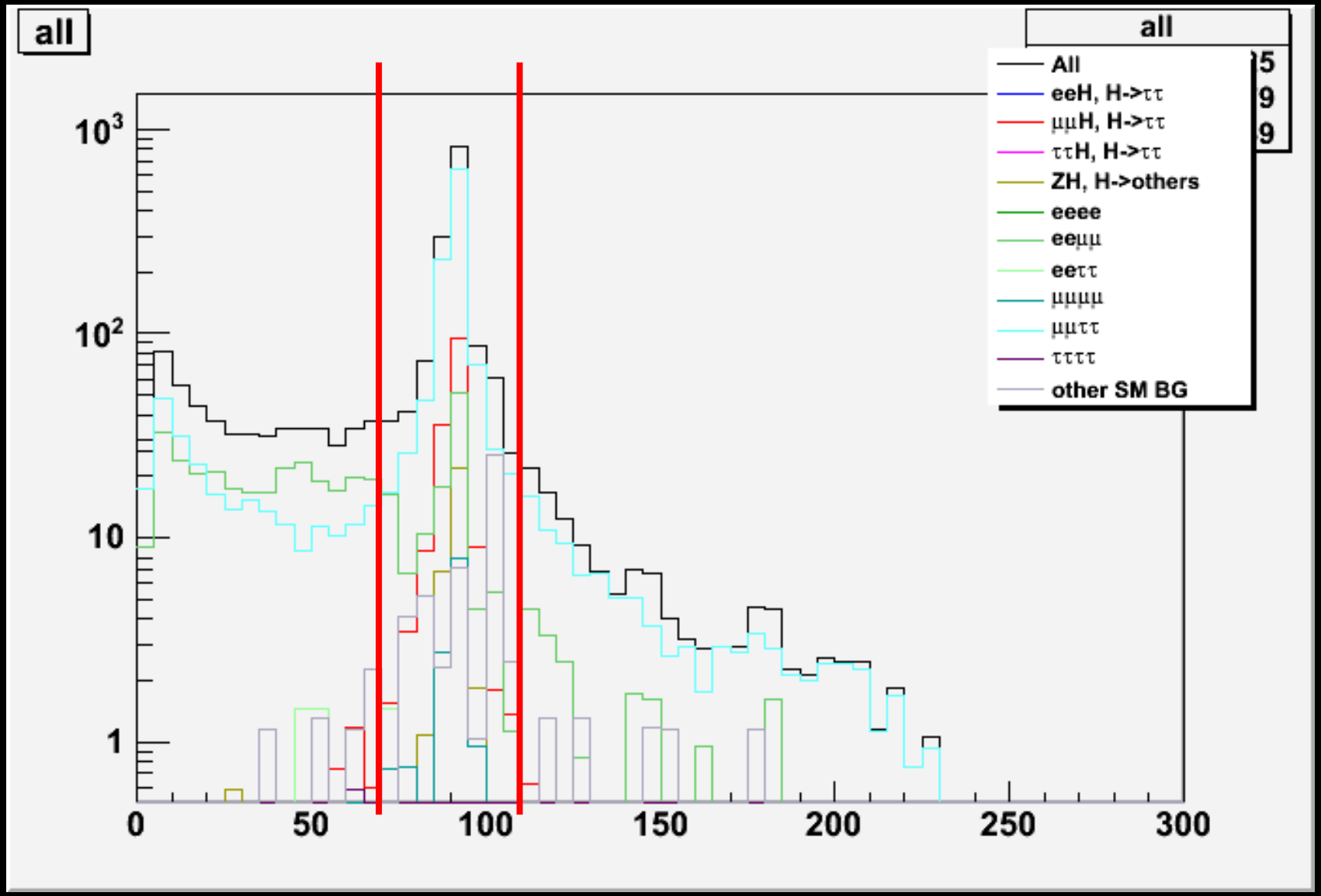
# of tracks <= 8



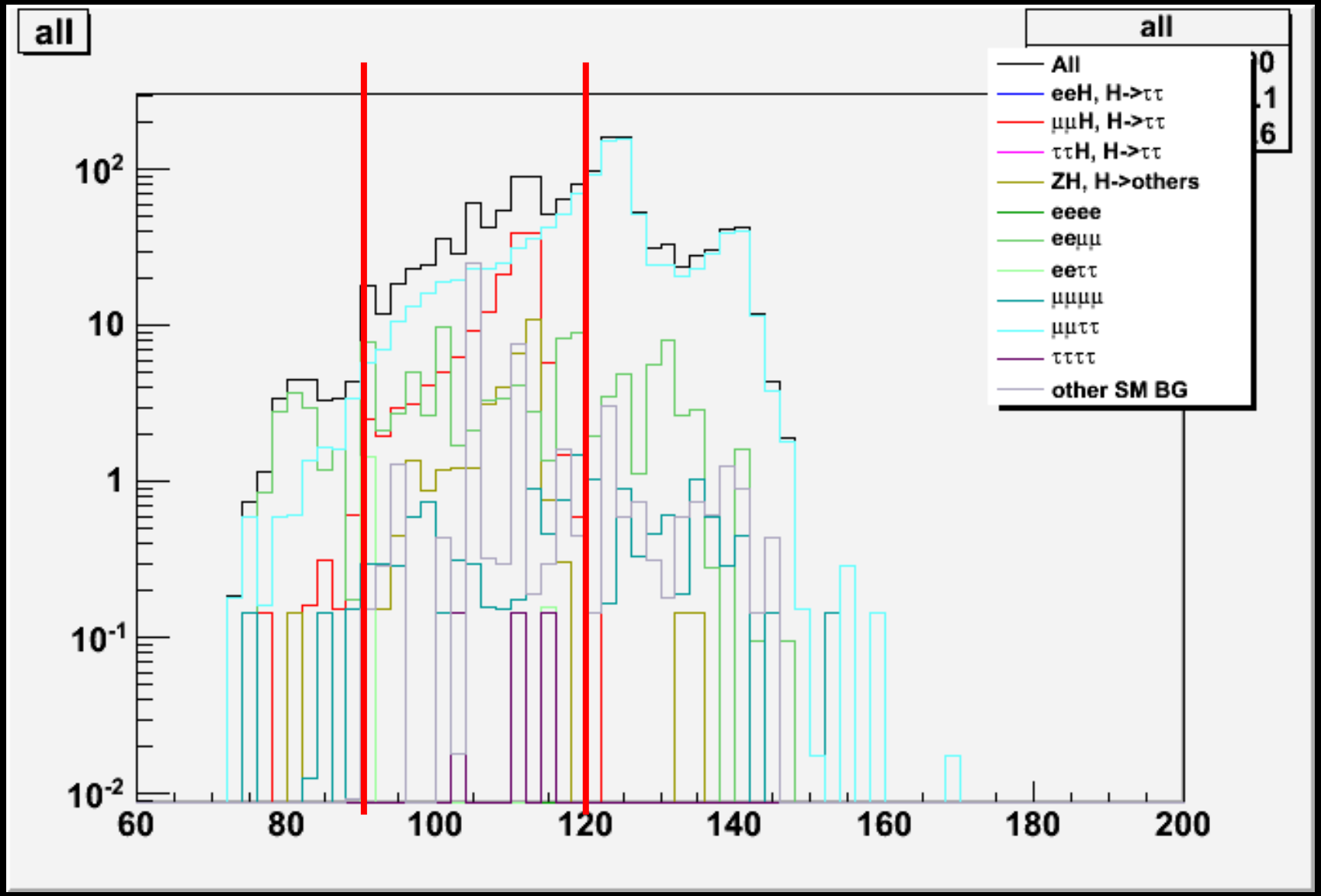
$$110 < E_{\mathrm{vis}} < 240$$



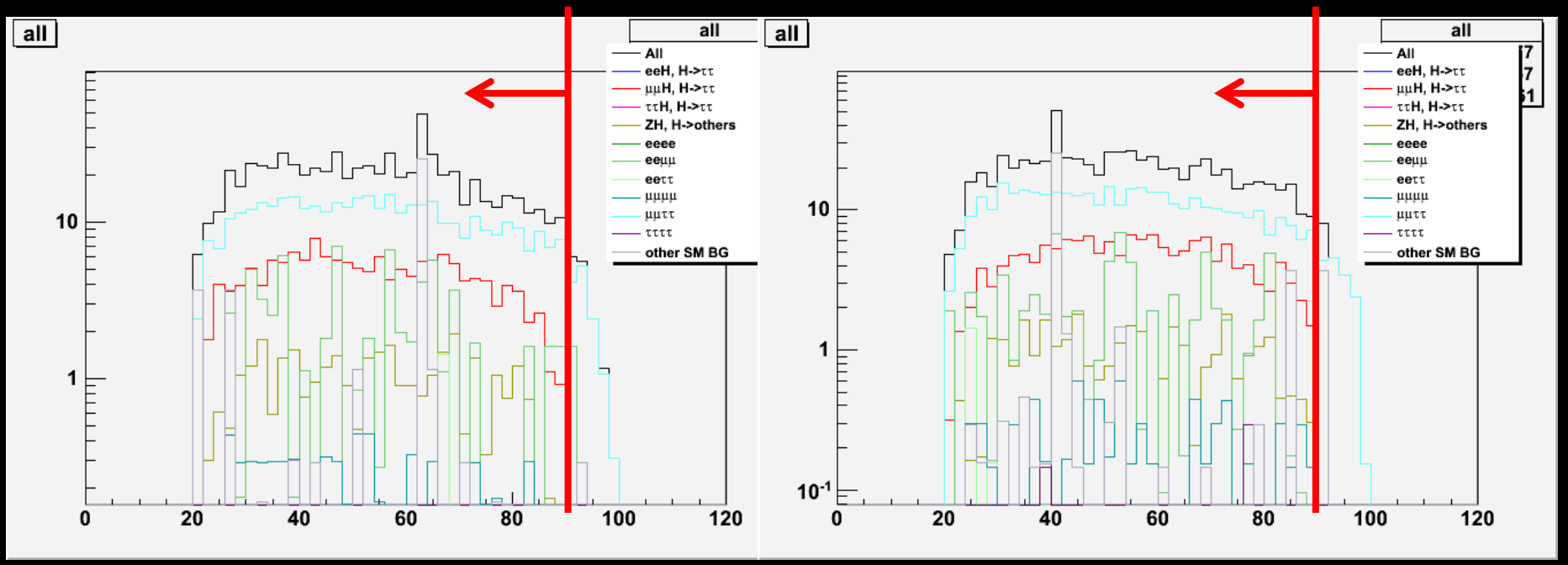
$$|\cos\theta_{\mathrm{missmom}}| < 0.98$$


all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
10³
10²
10
1
0
50
100
150
200
250
300

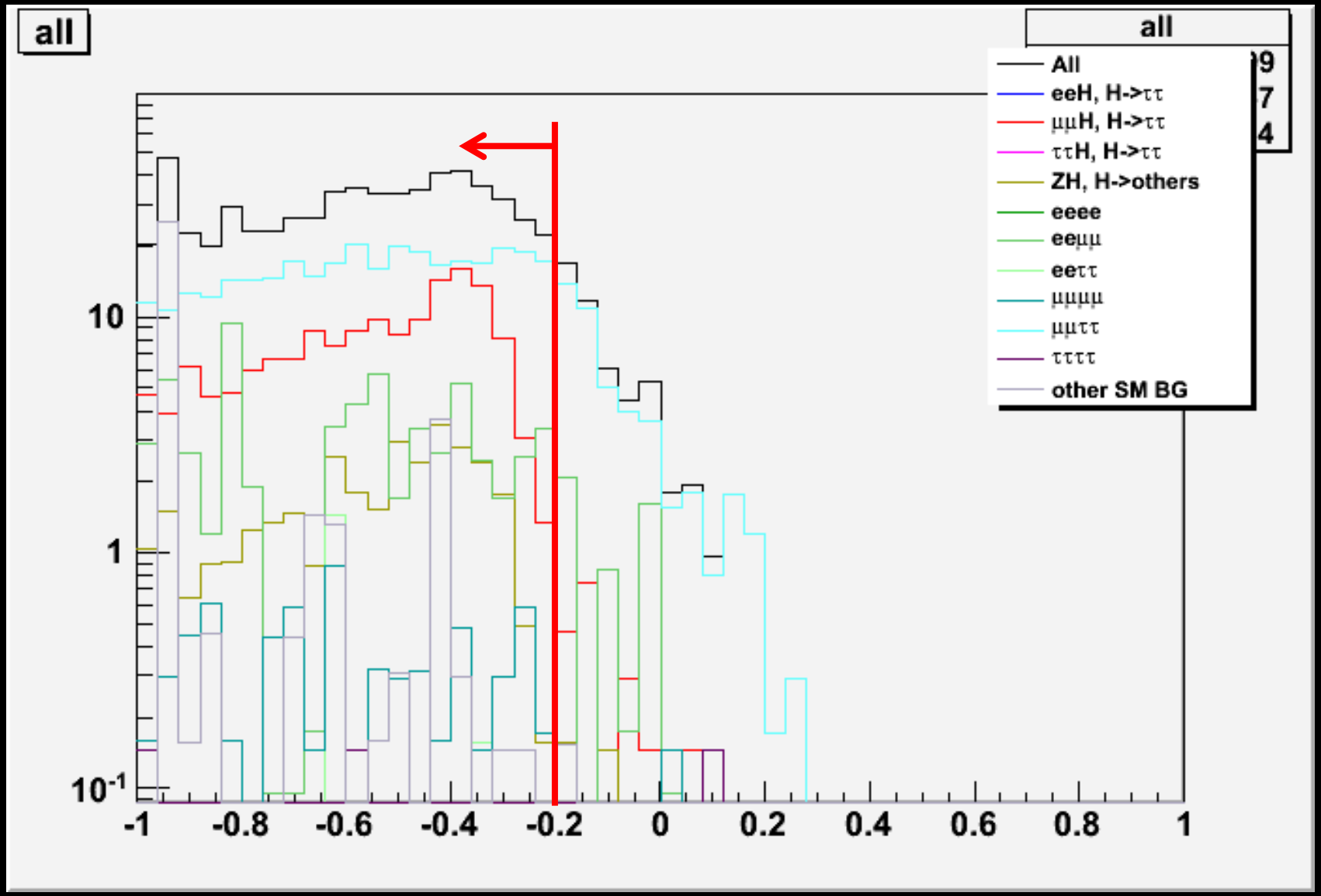
$$70 < M_Z < 110$$


all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
10^2
10
1
10^-1
10^-2
60
80
100
120
140
160
180
200

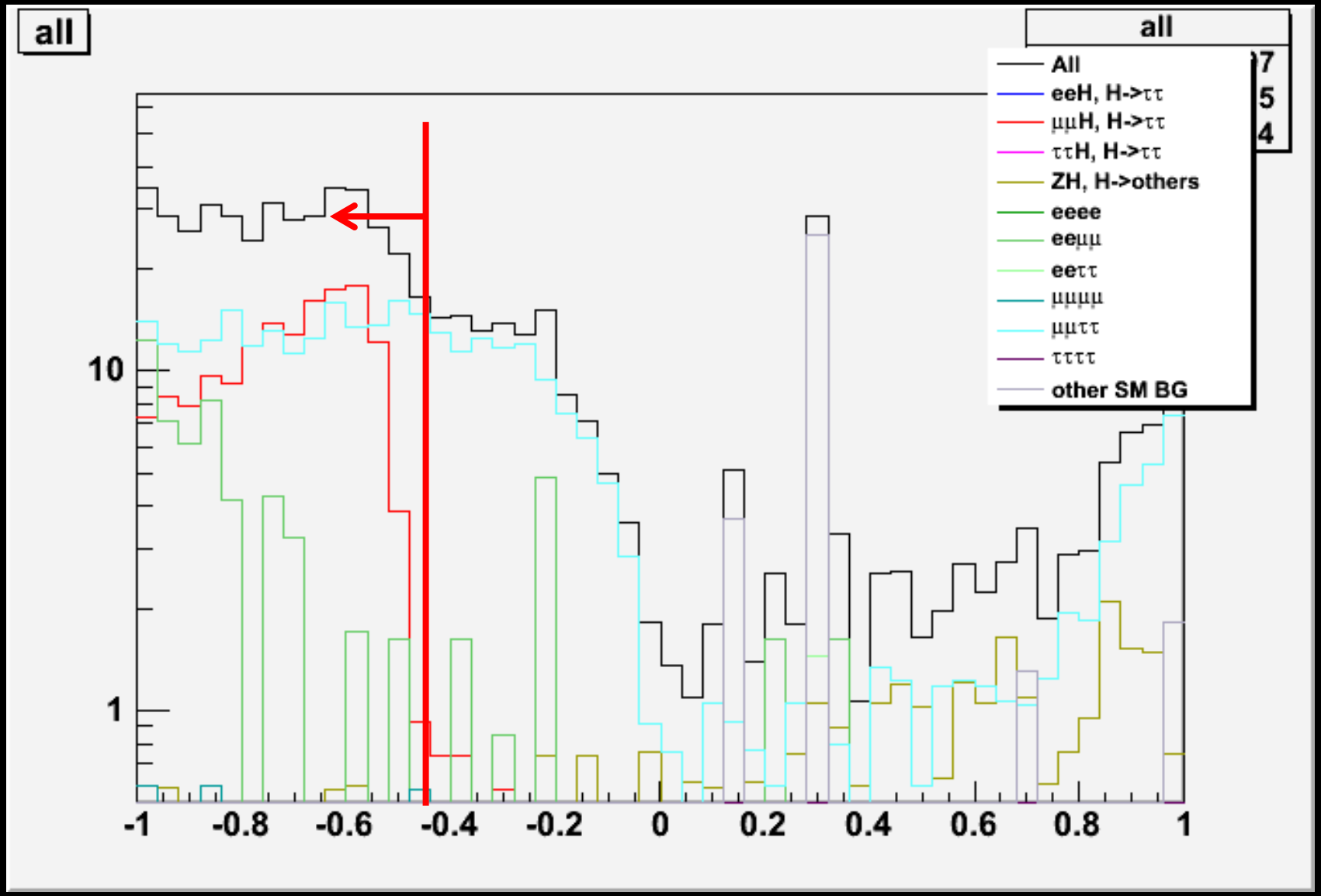
$$90 < E_Z < 120$$


all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
10
1
0
20
40
60
80
100
120
all
all
All
eeH, H->ττ
μμH, H->ττ
ττH, H->ττ
ZH, H->others
eeee
eeμμ
eeττ
μμμμ
μμττ
ττττ
other SM BG
10
1
10-1
0
20
40
60
80
100
120

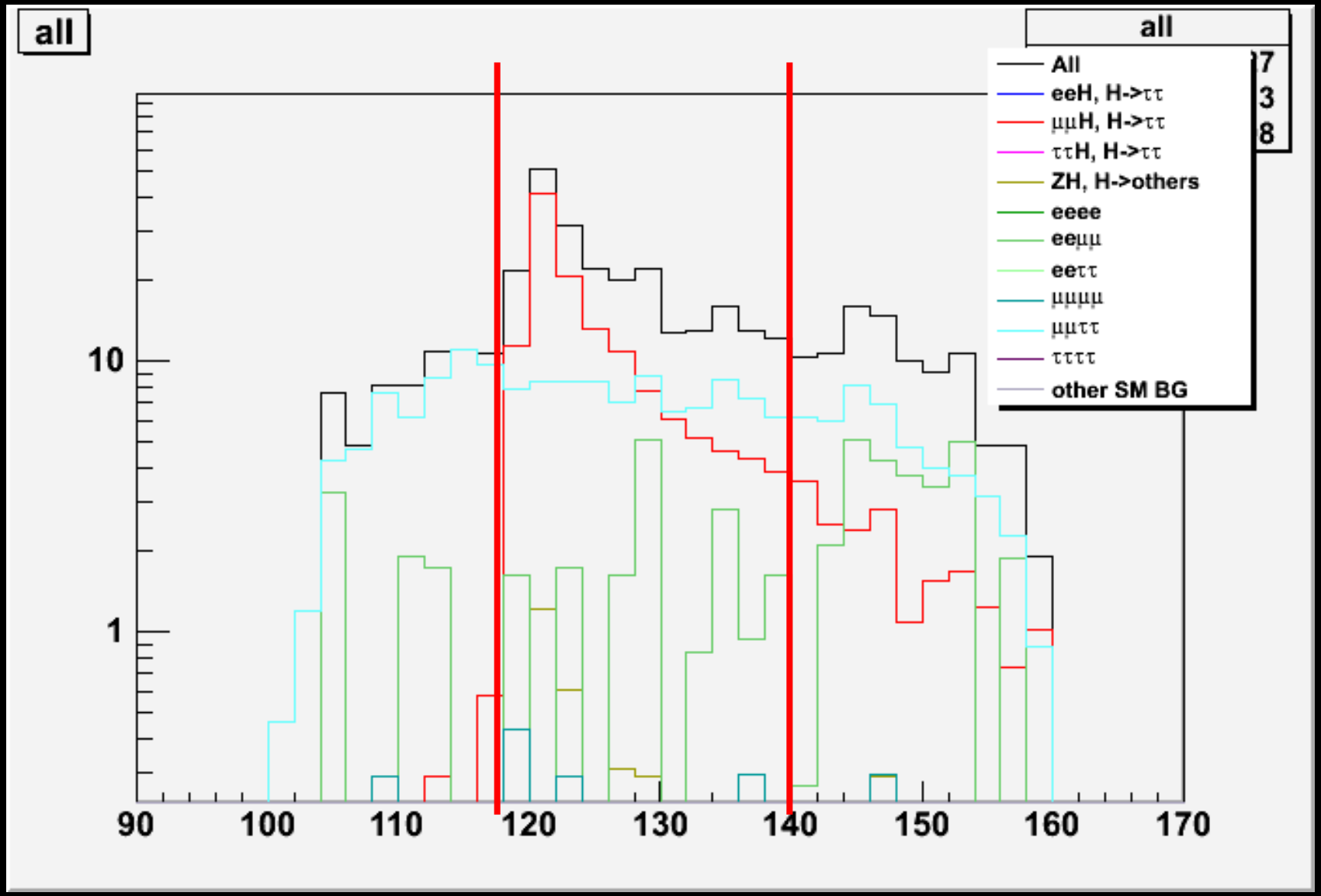
$$E_{e^+} < 90, E_{e^-} < 90$$



$$\cos\theta_{e^+e^-} < -0.2$$



$$\cos\theta_{\tau^+\tau^-} < -0.45$$



$$118 < M_{\mathrm{recoil}} < 140$$

Cuts	$\mu\mu H$	not $H \to \tau\tau$	$\mu\mu\tau\tau$	other 4 leptons	ee	$e\gamma$	$\gamma\gamma$	other SM Bkg	sig.
none	211.1	7320	3513	7.589e+05	4.325e+09	3.023e+09	7.532e+09	6.350e+07	0.00187
pre-sel	168.5	43.01	1698	7547	0	6062	71.56	1598	1.28
# of tracks <= 8	167.4	39.65	1684	7538	0	6062	71.56	1266	1.29
$110 < E_{\mathrm{vis}} < 240$	164.8	37.85	1629	2973	0	3081	33.17	638.7	1.78
$\lvert\cos\theta_{\mathrm{missmom}}\rvert < 0.98$	160.6	36.97	1423	434.1	0	0	0	61.42	3.49
$70 < M_Z < 110$	156.2	33.01	1078	129.0	0	0	0	47.94	4.11
$90 < E_Z < 120$	154.6	32.55	394.5	81.93	0	0	0	38.15	5.86
$E_{e^-} < 90$ $E_{e^+} < 90$	154.6	32.55	366.4	73.89	0	0	0	34.01	6.01
$\cos\theta_{e^+e^-} < -0.2$	152.8	32.23	321.4	68.64	0	0	0	33.85	6.19
$\cos\theta_{\tau^+\tau^-} < -0.45$	149.0	3.948	184.2	52.78	0	0	0	0.603	7.54
$118 < M_{\mathrm{recoil}} < 140$	129.5	3.185	84.02	17.76	0	0	0	0.155	8.46