H -> mu mu

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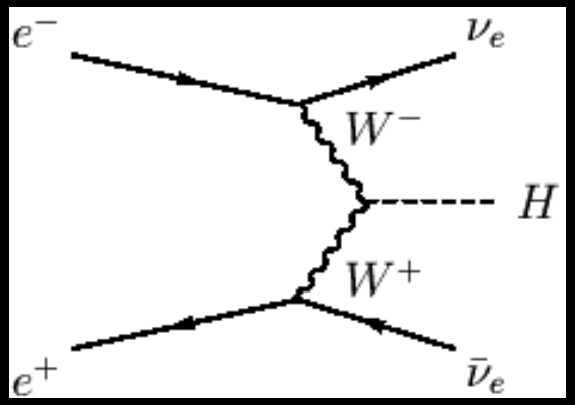
Motivation

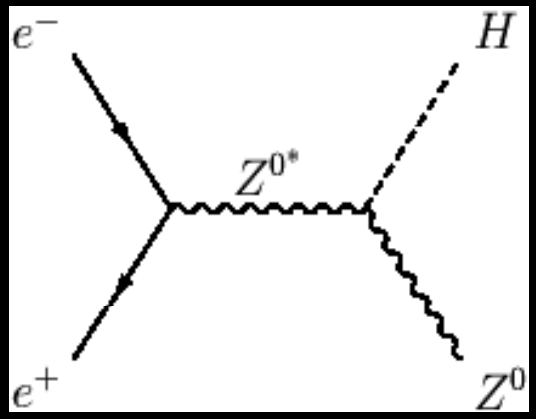
- Clean sample for benchmarking
  - Fully reconstructed event w/ recoil
  - Or empty detector w/ two muons
- Ideal channel for testing the Yukawa coupling to the second generation

Tracking algorithms, Muon ID, Tracking hardware can be benchmarked

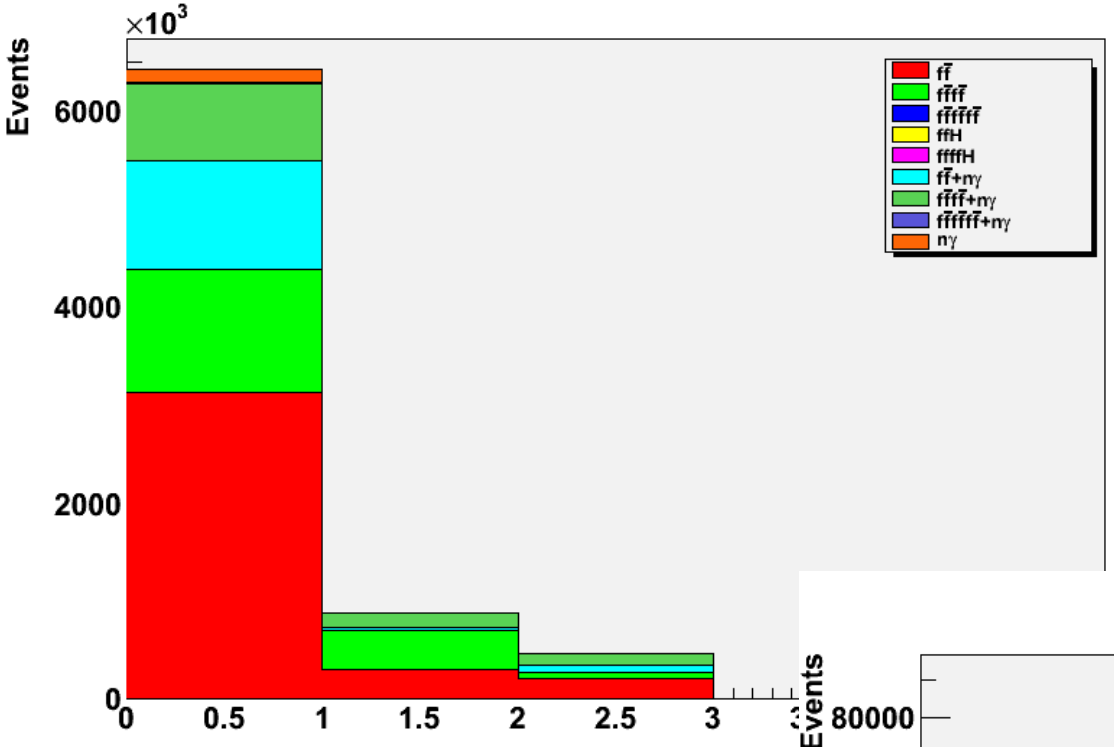
Samples

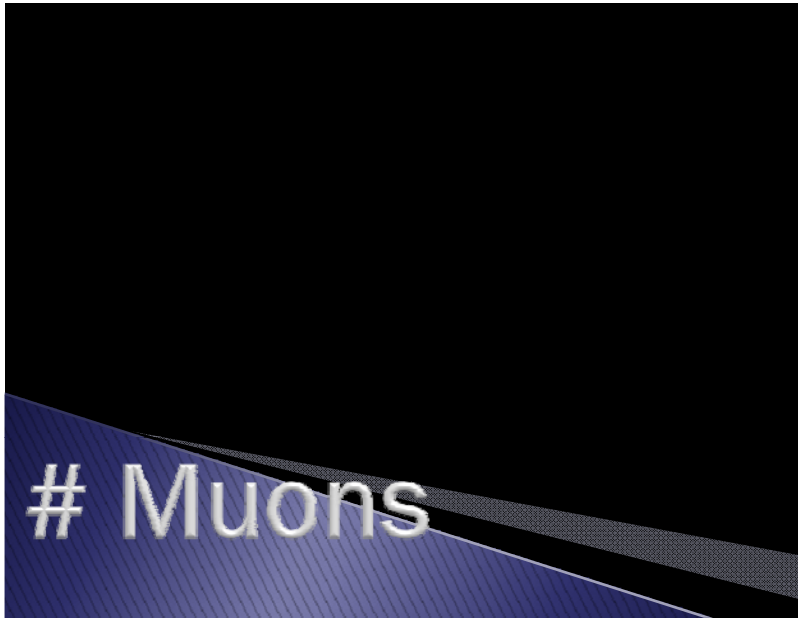
- Signal
  - Inclusive H -> mu mu
  - Recoil + WBF channel

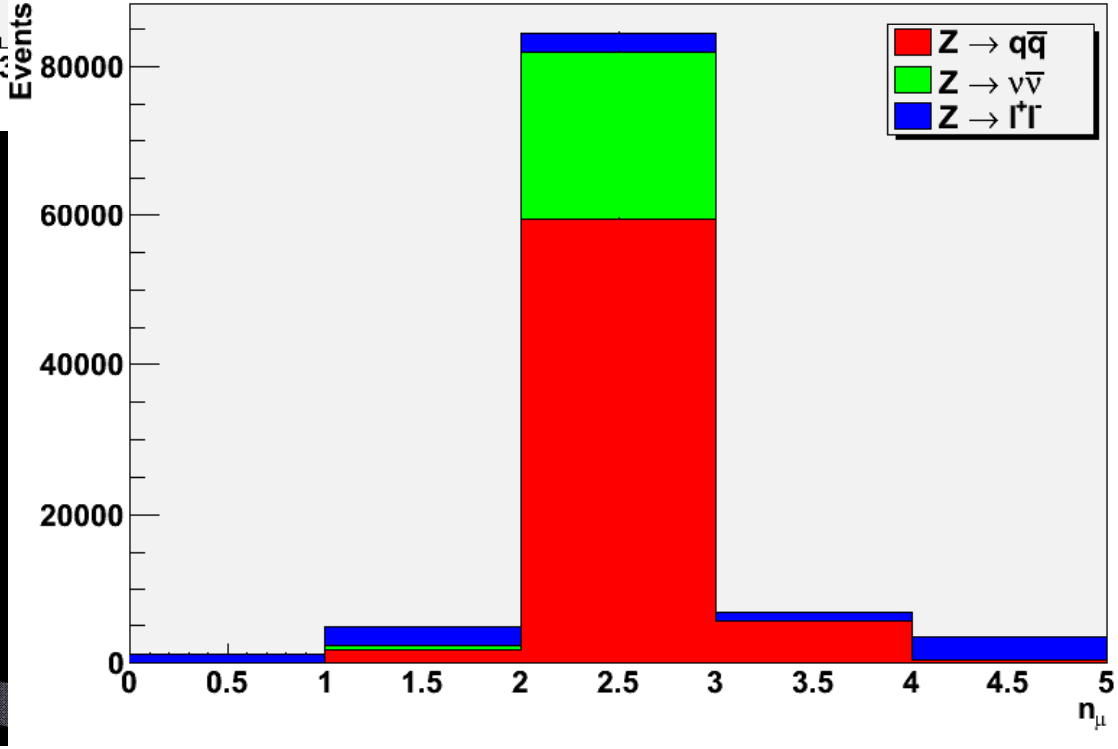


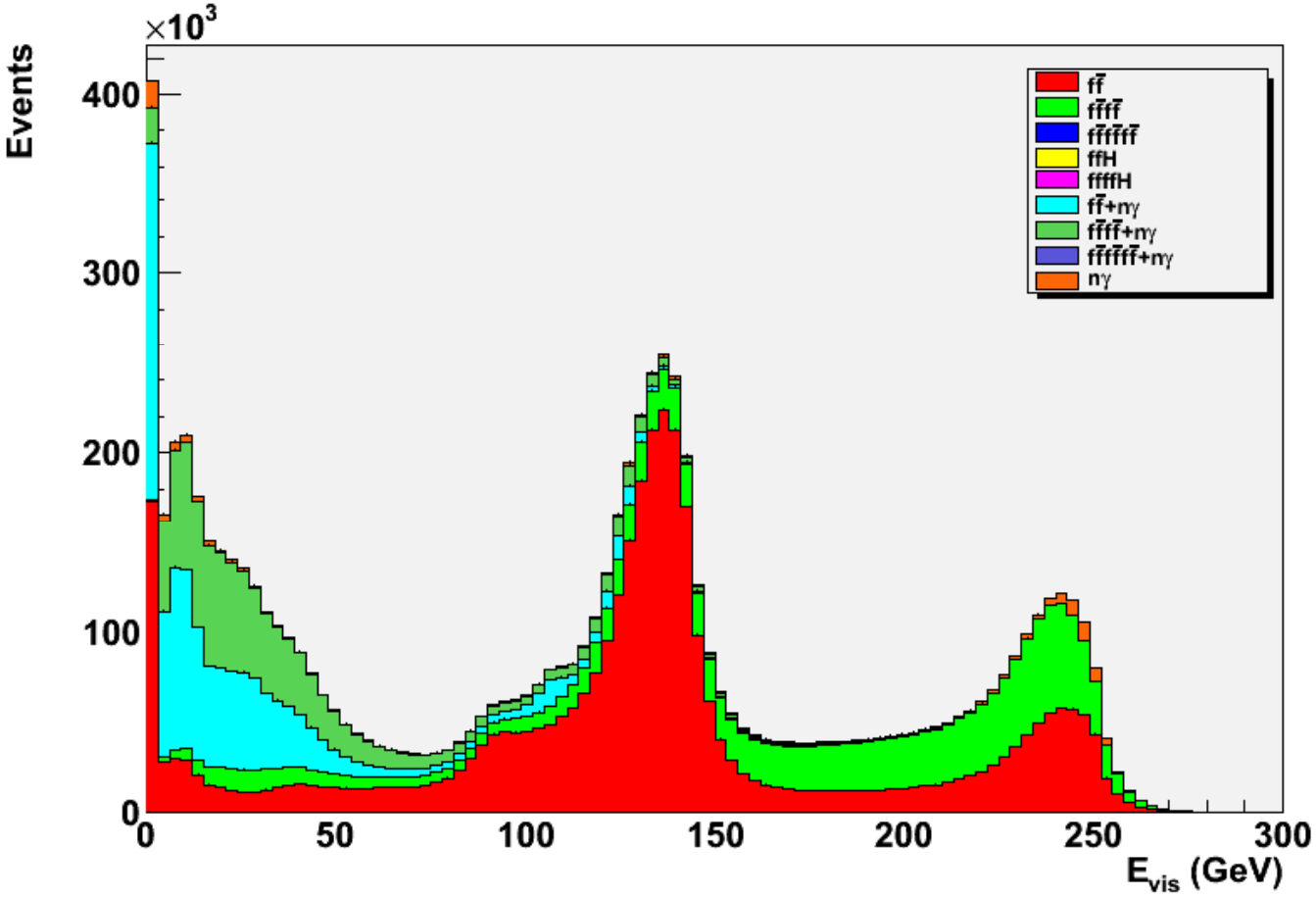


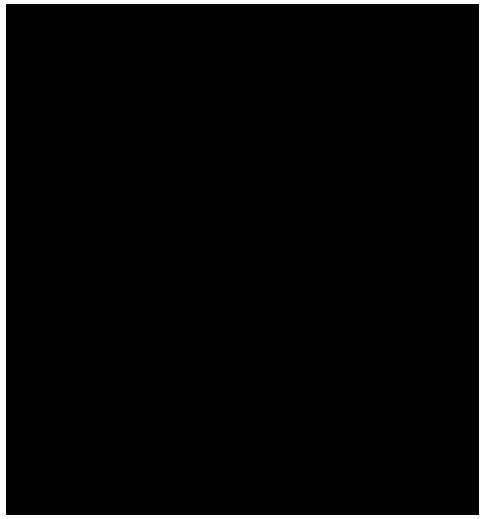
- Background
  - 2, 4, 6 fermion channels (+ n photons)
  - (after requiring two identified muons)

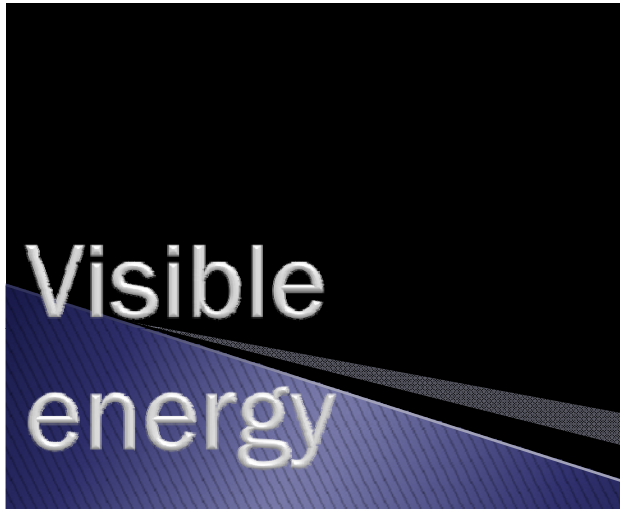

×10^3
Events
6000
4000
2000
0
0
0.5
1
1.5
2
2.5
3
ff̄
fff̄f̄
fffff̄f̄
ffH
ffffH
ff̄+nγ
fff̄f̄+nγ
fffff̄f̄+nγ
nγ

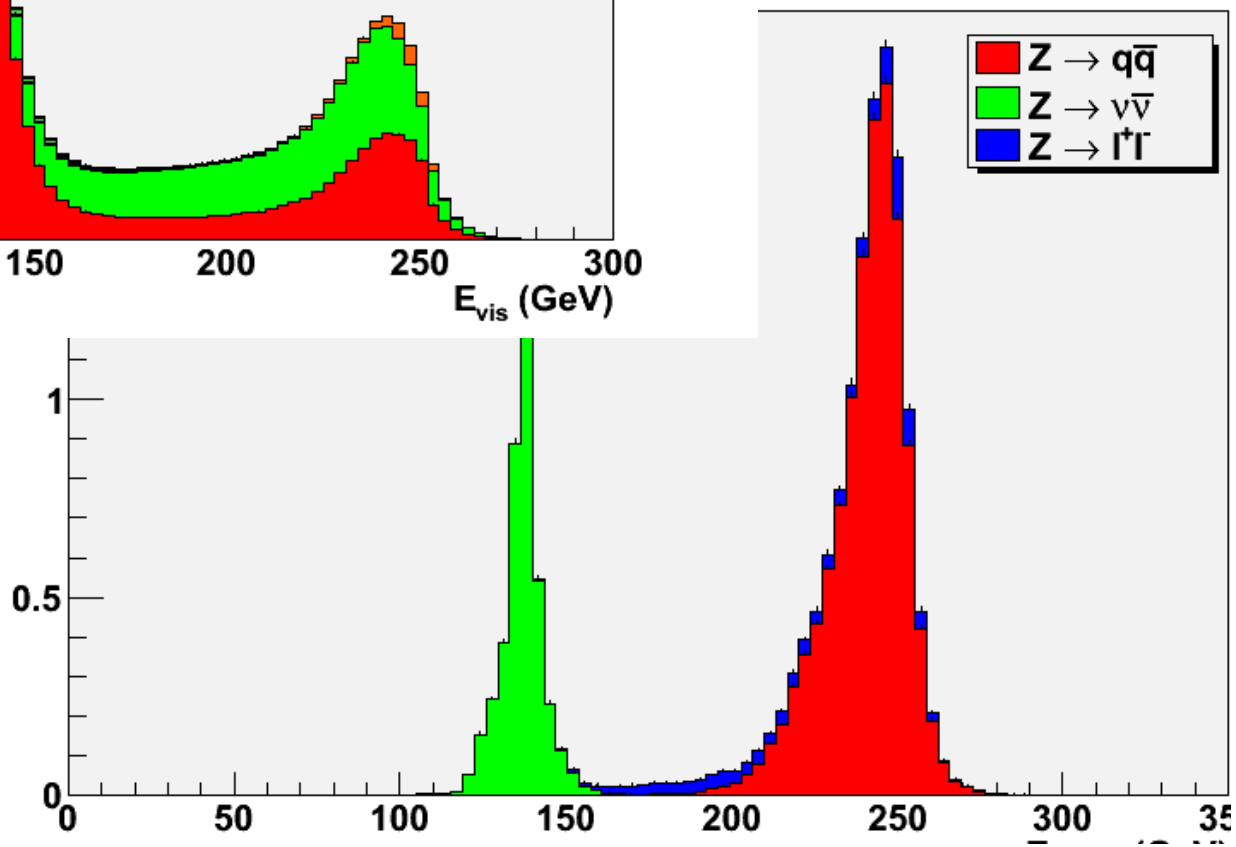

Muons


Events
80000
60000
40000
20000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
n_μ
Z → qq̄
Z → νν̄
Z → l⁺l⁻


×10³
Events
400
300
200
100
0
0
50
100
150
200
250
300
E_vis (GeV)
fermion pairs
fermion pairs + nγ
nγ




Visible
energy

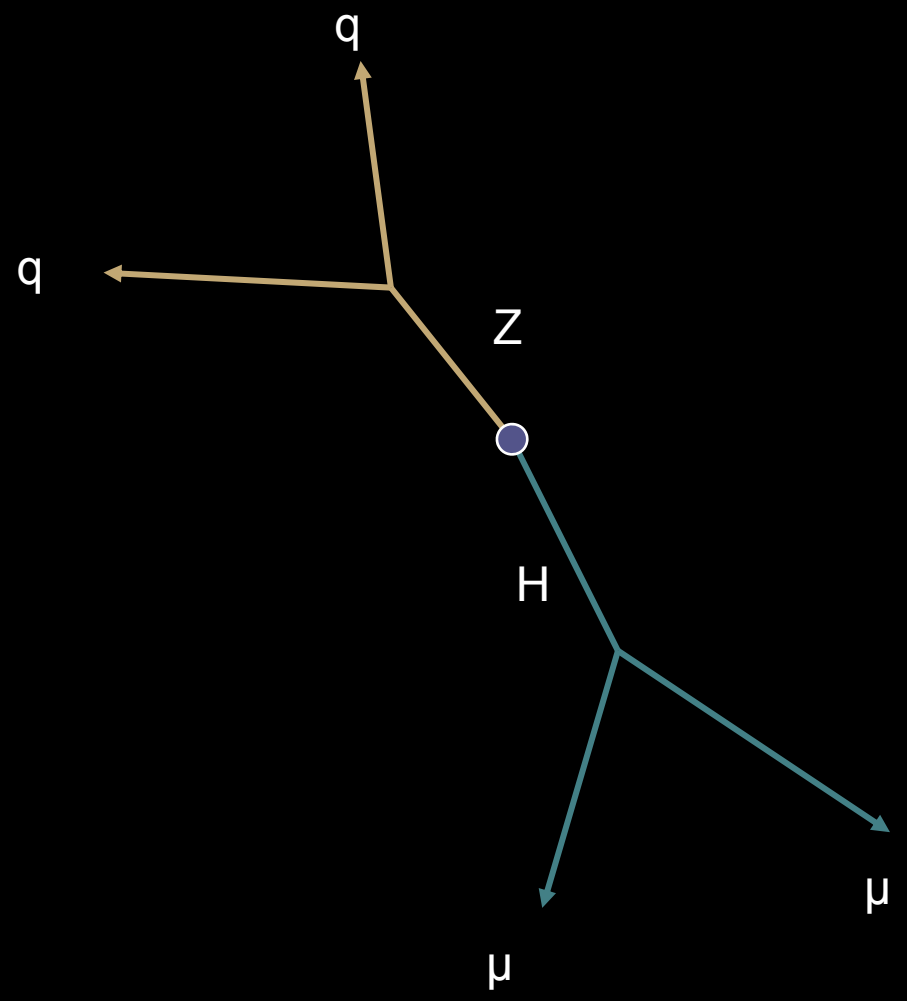

Z → qq̄
Z → νν̄
Z → l⁺l⁻
1
0.5
0
0
50
100
150
200
250
300

H -> mu mu + hadronic Z

- Prototypical recoil measurement
  - Fully reconstruct the Z, muon pair comes from the SM higgs
  - Model-independent Higgs mass measurement

EventShape

- At 250 GeV Z and H almost at rest
- Exploit acoplanarity



Backgrounds

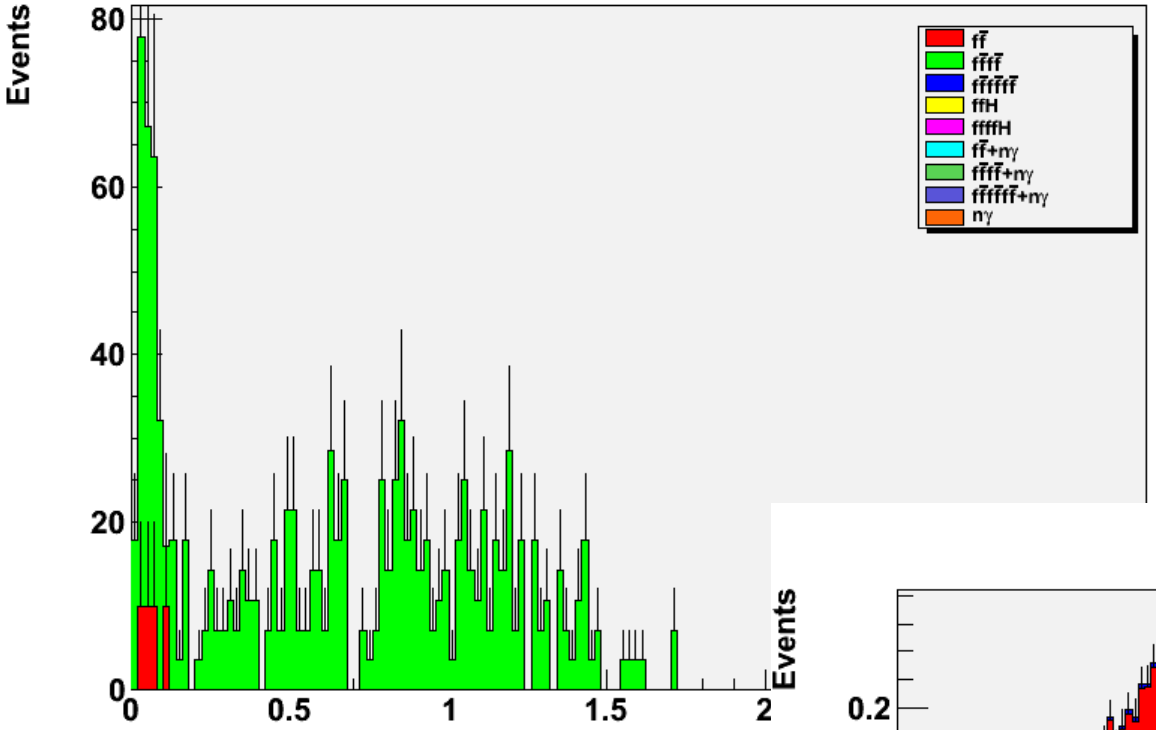
- For the hadronic channel:
  - 4f -> qqμμ is the biggest background
  - Mainly from ZZ production
  - Irreducible at some level
- Just a number game
  - ZZ vs HZ ~ 10:1
  - ZZ-> qqμμ vs HZ-> μμqq ~ 2500:1

Event Selection

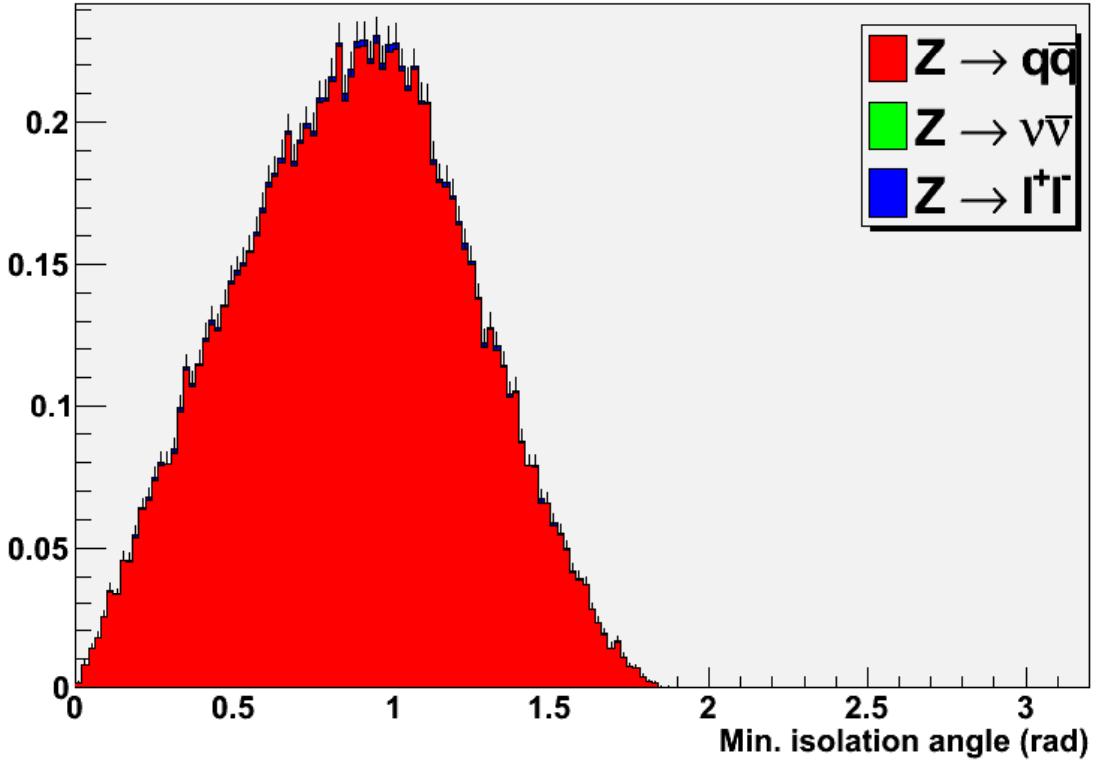
- $N_{tracks}>5$
- $E_{vis}>$ 190 GeV
- Jet Selection
  - Leading Jet $30<E_{jet1}<105$ GeV
  - Second Jet $10 <E_{jet2} < 70$ GeV
  - Jet1 $P_T<$ 90 GeV & Jet2 $P_T<$ 60 GeV
  - Y_{cut} >0.05 (forcing two jets)

Cont'd

- Dimuon Mass $100 < M_{\mu\mu} < 140$ GeV
- Angular cuts (Events are back to back)
- $\cos \theta_{\mu\mu} < -0.5$
- $\cos \theta_{BB} < -0.8$ Reconstructed Bosons tend to be really back to back
- Distance of muon to any jet (rad)
  - >0.1
- Boson Acoplanarity > 2.8 (rad)


Events
80
60
40
20
0
0
0.5
1
1.5
2
Events
$f\bar{f}$
$f\bar{f}f\bar{f}$
$f\bar{f}f\bar{f}f\bar{f}$
ffH
$ffffH$
$f\bar{f}+n\gamma$
$f\bar{f}f\bar{f}+n\gamma$
$f\bar{f}f\bar{f}f\bar{f}+n\gamma$
$n\gamma$


Muon
Isolation

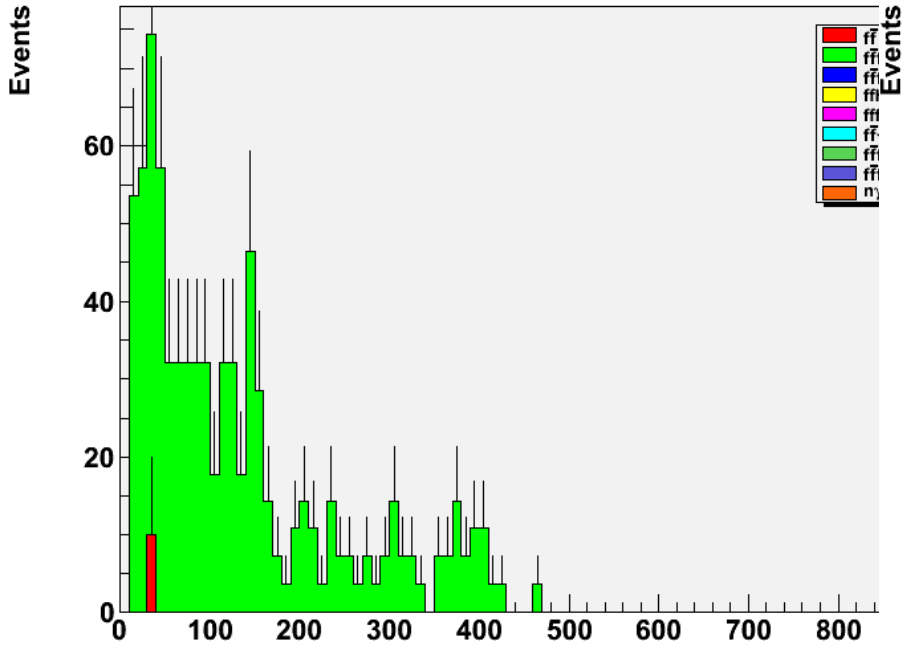

0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
Min. isolation angle (rad)
$Z \to q\bar{q}$
$Z \to \nu\bar{\nu}$
$Z \to l^+l^-$

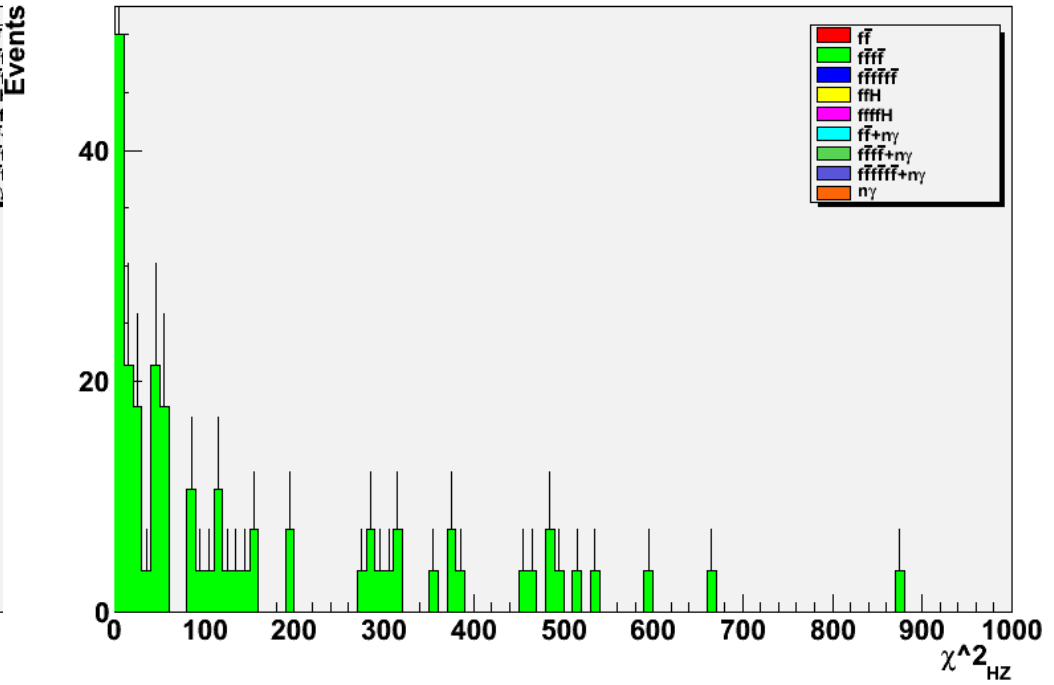
Event chisquare

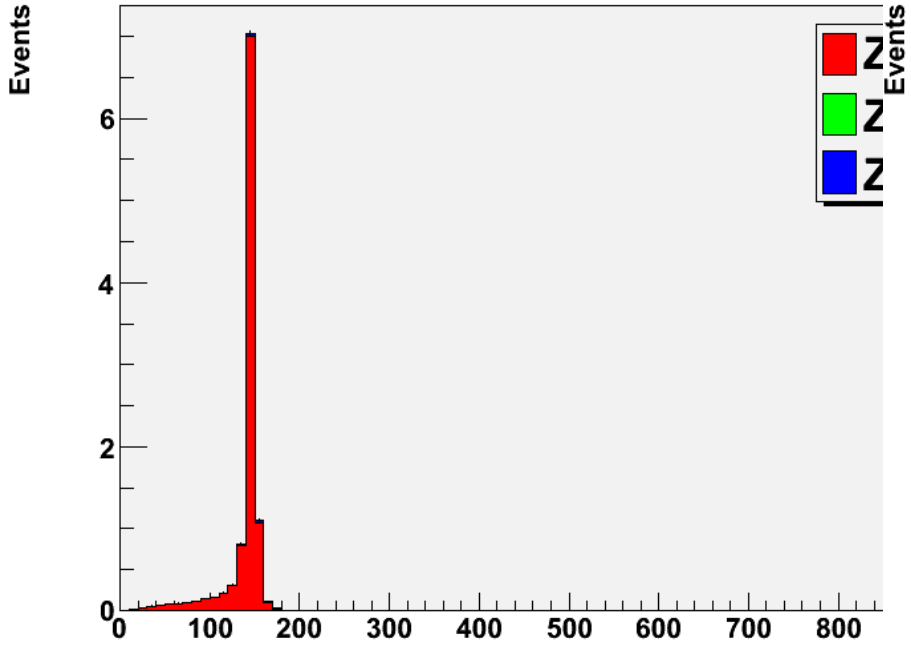
$$\chi^2_{ZZ} = \left(\frac{m_{Jet,Jet} - m_Z}{\sigma_{Jet,Jet}} \right)^2 + \left(\frac{m_{\mu\mu} - m_Z}{\sigma_{\mu\mu}} \right)^2$$

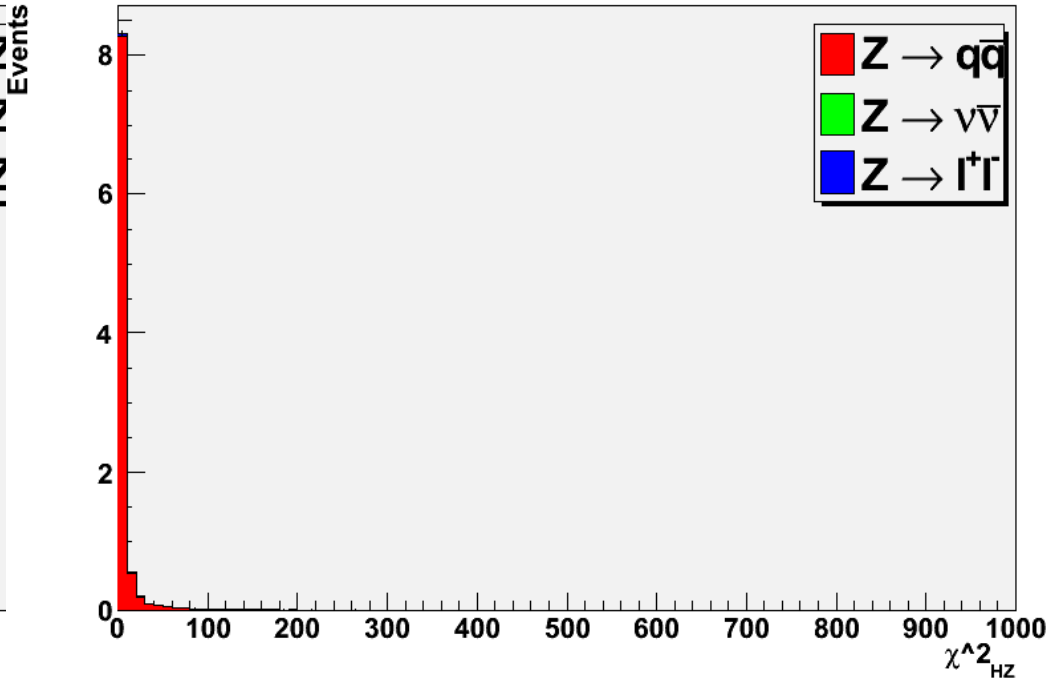
$$\chi^2_{HZ} = \left(\frac{m_{Jet,Jet} - m_Z}{\sigma_{Jet,Jet}} \right)^2 + \left(\frac{m_{\mu\mu} - m_H}{\sigma_{\mu\mu}} \right)^2$$

Testing the compatibility the event with either hypothesis !


Events
0
20
40
60
0
100
200
300
400
500
600
700
800


Events
0
20
40
0
100
200
300
400
500
600
700
800
900
1000
χ^2_HZ
ff̄
ffff̄
ffffff̄
ffH
ffffH
ff̄+nγ
ffff̄+nγ
ffffff̄+nγ
nγ


Events
0
2
4
6
0
100
200
300
400
500
600
700
800


Events
0
2
4
6
8
0
100
200
300
400
500
600
700
800
900
1000
χ^2_HZ
Z → qq̄
Z → νν̄
Z → l⁺l⁻

Selection Efficiencies (hadronic)

Cut	Events		Efficiency	
	Signal	Background	Signal	Background
00 two muons required	4663389.3	17.18	92.8%	96.0%
01 Charged Tracks hadronic	26665.9	12.03	65.0%	95.9%
02 Evis hadronic Cut	19567.1	11.98	64.7%	95.7%
03 Jet Selection Cut	16683.6	11.82	63.8%	94.4%
04 Muon Mass Window	1519.3	11.49	62.1%	91.8%
05 MuonMuon Angle Cut	1297.9	11.32	61.2%	90.5%
06 BosonBoson Angle Cut	1129.3	10.9	58.9%	87.2%
07 Min Isolation Angle Cut	870.7	10.84	58.5%	86.6%
08 Boson Acoplanarity Cut	792.1	10.51	56.8%	84.1%
09 ZZ qqqmm chisquare Cut	260.7	10.04	54.3%	80.4%
10 HZ qqqmm chisquare Cut	71.4	8.86	47.9%	71.0%

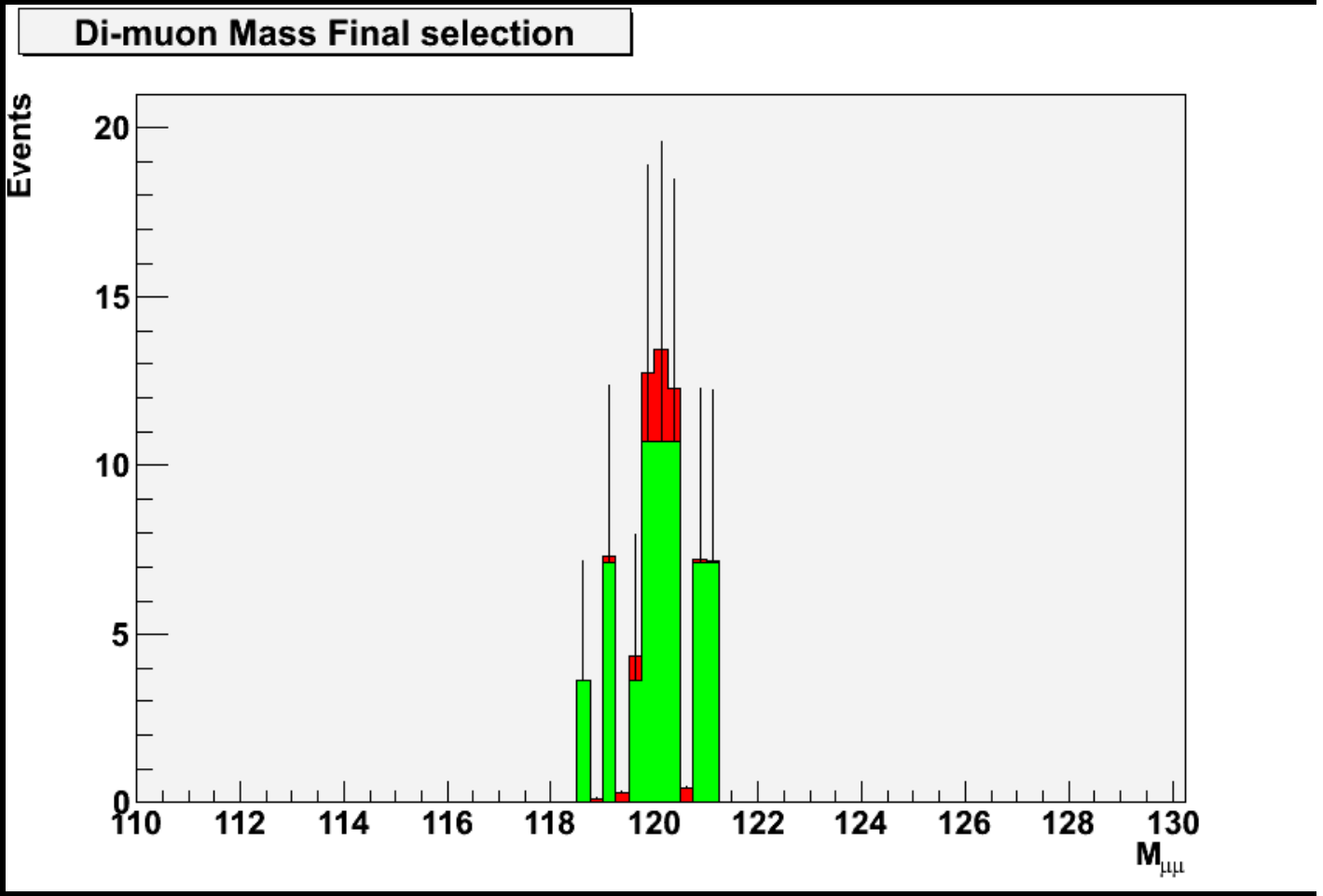
Cut	Z to qq			Z to nunu			Z to ll		
	Events	Total Efficency	channel efficiency	Events	Total Efficency	channel Efficiency	Events	Total Efficency	Channel efficiency
00 two muons required	11.9	64.3%	96.0%	4.1	22.0%	96.0%	1.2	6.6%	64.3%
01 Charged Tracks hadronic	11.9	64.2%	95.9%	0	0.0%	0.0%	0.1	0.8%	7.8%
02 Evis hadronic Cut	11.9	64.1%	95.7%	0	0.0%	0.0%	0.1	0.6%	6.1%
03 Jet Selection Cut	11.7	63.3%	94.4%	0	0.0%	0.0%	0.1	0.6%	5.6%
04 Muon Mass Window	11.4	61.5%	91.8%	0	0.0%	0.0%	0.1	0.6%	5.5%
05 MuonMuon Angle Cut	11.2	60.6%	90.5%	0	0.0%	0.0%	0.1	0.5%	5.4%
06 BosonBoson Angle Cut	10.8	58.4%	87.2%	0	0.0%	0.0%	0.1	0.5%	4.9%
07 Min Isolation Angle Cut	10.7	58.0%	86.6%	0	0.0%	0.0%	0.1	0.5%	4.9%
08 Boson Acoplanarity Cut	10.4	56.4%	84.1%	0	0.0%	0.0%	0.1	0.4%	4.1%
09 ZZ qqqmm chisquare Cut	10.0	53.9%	80.4%	0	0.0%	0.0%	0.1	0.4%	3.9%
10 HZ qqqmm chisquare Cut	8.8	47.6%	71.0%	0	0.0%	0.0%	0.1	0.3%	2.7%

Background Sample Composition

Cut	ff	ffff	ff+ng	ffff+g
two muons required	750830	98364.3	2415000	399187
Charged Tracks hadronic	1010	20642.9	5000	9
Evis hadronic Cut	660	18907.1	0	0
Jet Selection Cut	530	16153.6	0	0
Muon Mass Window	80	1439.3	0	0
MuonMuon Angle Cut	80	1217.9	0	0
BosonBoson Angle Cut	40	1089.3	0	0
Min Isolation Angle Cut	10	860.7	0	0
Boson Acoplanarity Cut	10	782.1	0	0
ZZ qqmm chisquare Cut	0	260.7	0	0
HZ qqmm chisquare Cut	0	71.4	0	0

Final mass plot

Hot off the press:
Cross section for
H-> mu mu
0.074+/-0.008 fb



H + invisible

- ‘Empty’ detector allows for precision measurement
  - No confusion for tracking, no PFA
- Signal sample is swamped by SM background

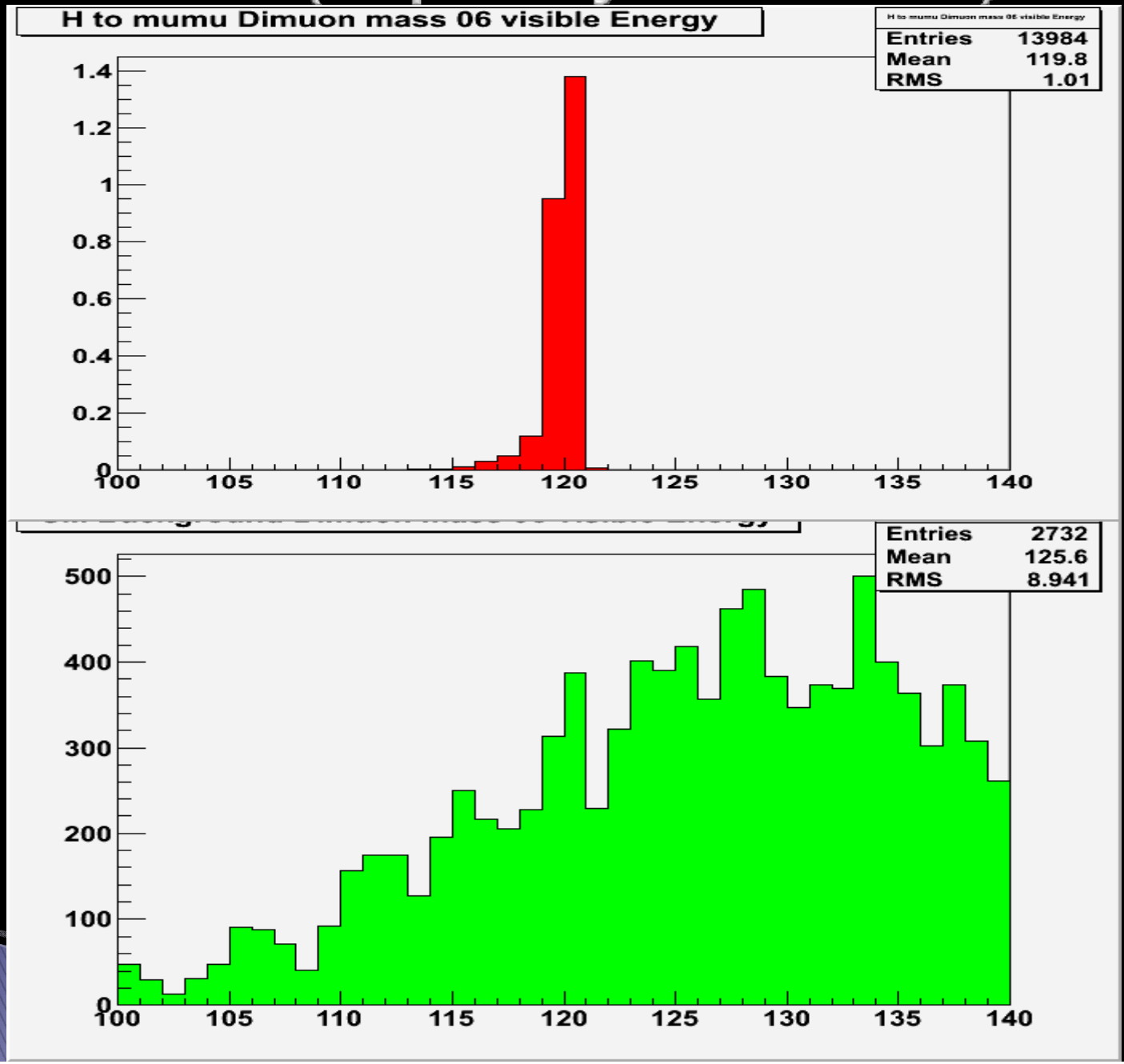
Cut and count

- 2 identified muons and no other tracks
- 130 GeV < Visible energy < 150 GeV
- 80 GeV < charged energy < 150 GeV
- Missing mass > 40 GeV
- Missing momentum < 90 GeV
- 100 GeV < mass < 130 GeV
- Cos(muon opening angle) < -0.35

Selection Efficiencies (invisible)

Cut	H to mumu		SM Background	
	Events	Efficiency	Events	Efficiency
00 two muons required	17.2	92.8%	4663389.3	2.20%
01 Charged tracks	4.06	21.9%	4376478.9	2.10%
02 visible Energy	3.42	18.5%	706483.1	0.03%
03 charged Energy	3.41	18.4%	694598.6	0.02%
04 missing mass	3.41	18.4%	165200.7	0.01%
05 missing momentum	3.41	18.4%	38384.3	0.01%
06 mass	3.31	17.9%	17595.0	0.00%
07 muon opening angle	3.30	17.8%	15687.1	0.00%

Muon Mass (hopefully not final...)



H mu mu LOI note

- In preparation
  - Hadronic channel 70 % complete
  - Invisible channel remains to be done
- First draft this week

Summary

- Higgs + hadronic Z is shaping up quite nicely
- Higgs + invisible has just started and needs work
- H -> mu mu is a great channel for detector benchmarking
  - For LOI, we limit ourselves to measuring a cross-section
- Also great channel for algorithm benchmarking
  - Mapping out the post-LOI work

What could be improved ?

- Improved Track reconstruction
  - I think we can do better than 300 MeV
  - Something for post LoI
- Bremsstrahlung recovery …
- Muon ID
  - Could use some work post LoI
- Multivariate techniques
  - We could if we had enough events to train