The Fermiophobic Higgs Group

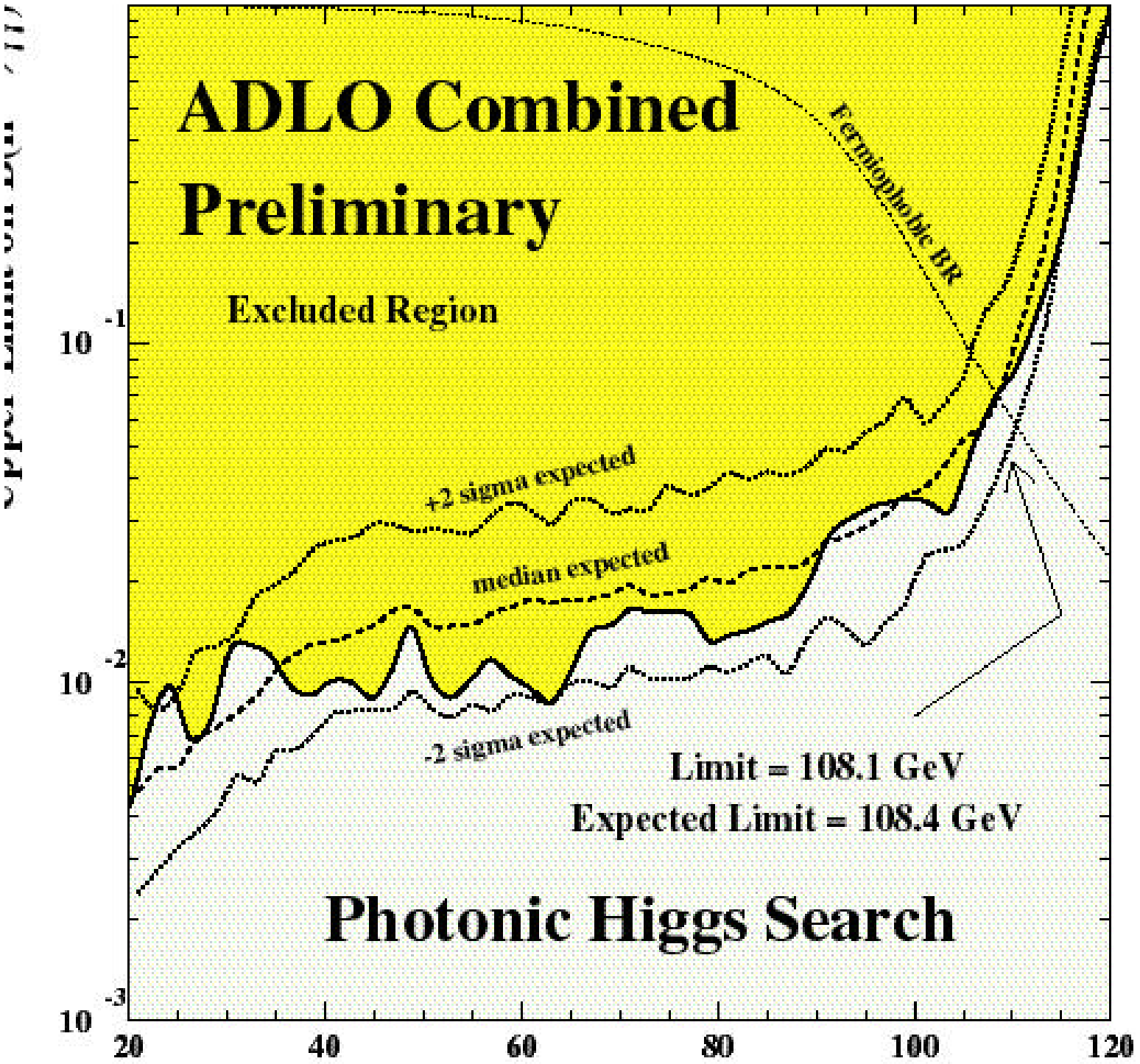
Outline:

- Review the individual photonic analyses
  - summary of candidates, individual limits
  - features of the 4 analyses
- ADLO Combination with full Y2K data
- The WW channel
  - the L3 analysis
  - combination with ADLO photonic
- Issues for further development

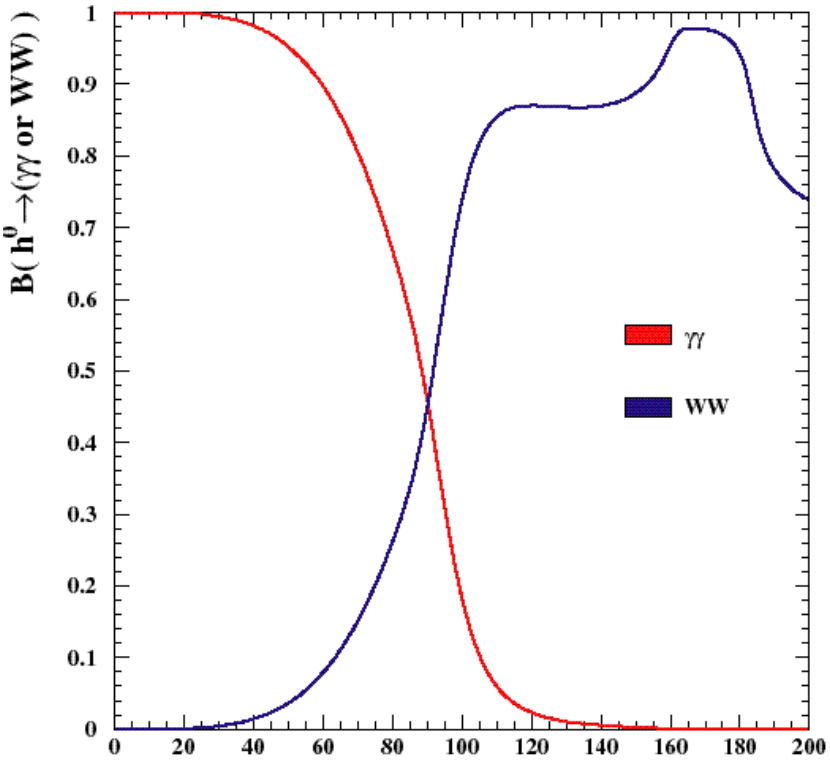
LEP-Wide Combination - Photonic

- Photonic channel only, fermiophobic limits are:
  - A: 104.5 GeV (105.1 expected)
  - D: 99.1 GeV (99.6 expected)
  - L: 104.5 GeV (105.4 expected)
  - O: 105.1 GeV (106.4 expected)
  - combined: 109.3 GeV, (107.4 expected)
- For Y2K, candidates and expected backgrounds:
  - A: 4 5.1
  - D: 15 14.9
  - L: 37 51.3
  - O: 19 24.2
- Features of the analyses:
  - A: "global analysis" … no Z decay channels
    - E from 192 GeV
  - D: only qq and neutrino channels
    - E from 189, now Y2K updated
  - L: qq, neutrino, and separate lepton channels (Y2K)
    - E from 189
    - electron channel not mass binned
  - O: qq, neutrino, and aggregate lepton channel
    - all Ecm from 88-209

ADLO Photonic-only



The WW Channel



- At this point, current limit is at BR(H→γγ)=7%, so much to be gained from adding WW
- Inclusion of WW also leads to more robust model checking

- L3 has developed WW analysis, presented 010227
  - general excess seen, so limit remains at 104.8
  - but still increases expected limit to 108.4 GeV

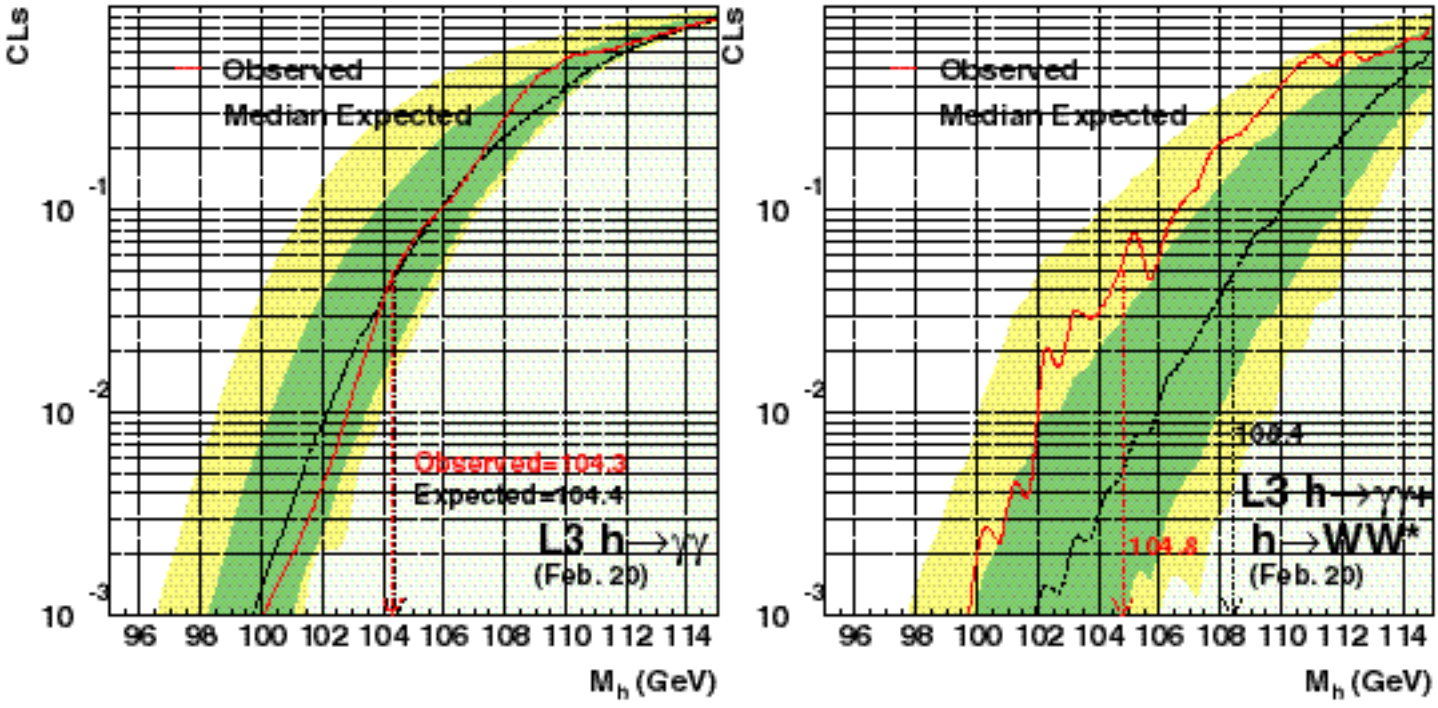
Fermiophobic Higgs boson

$h \to \gamma\gamma$

qq		νν		e^+e^-		$\mu^+\mu^-$		ττ	
data	exp	data	exp	data	exp	data	exp	data	exp
56	65.8	4	5.9	2	4.2	2	3.5	2	2.8

$h \to WW$

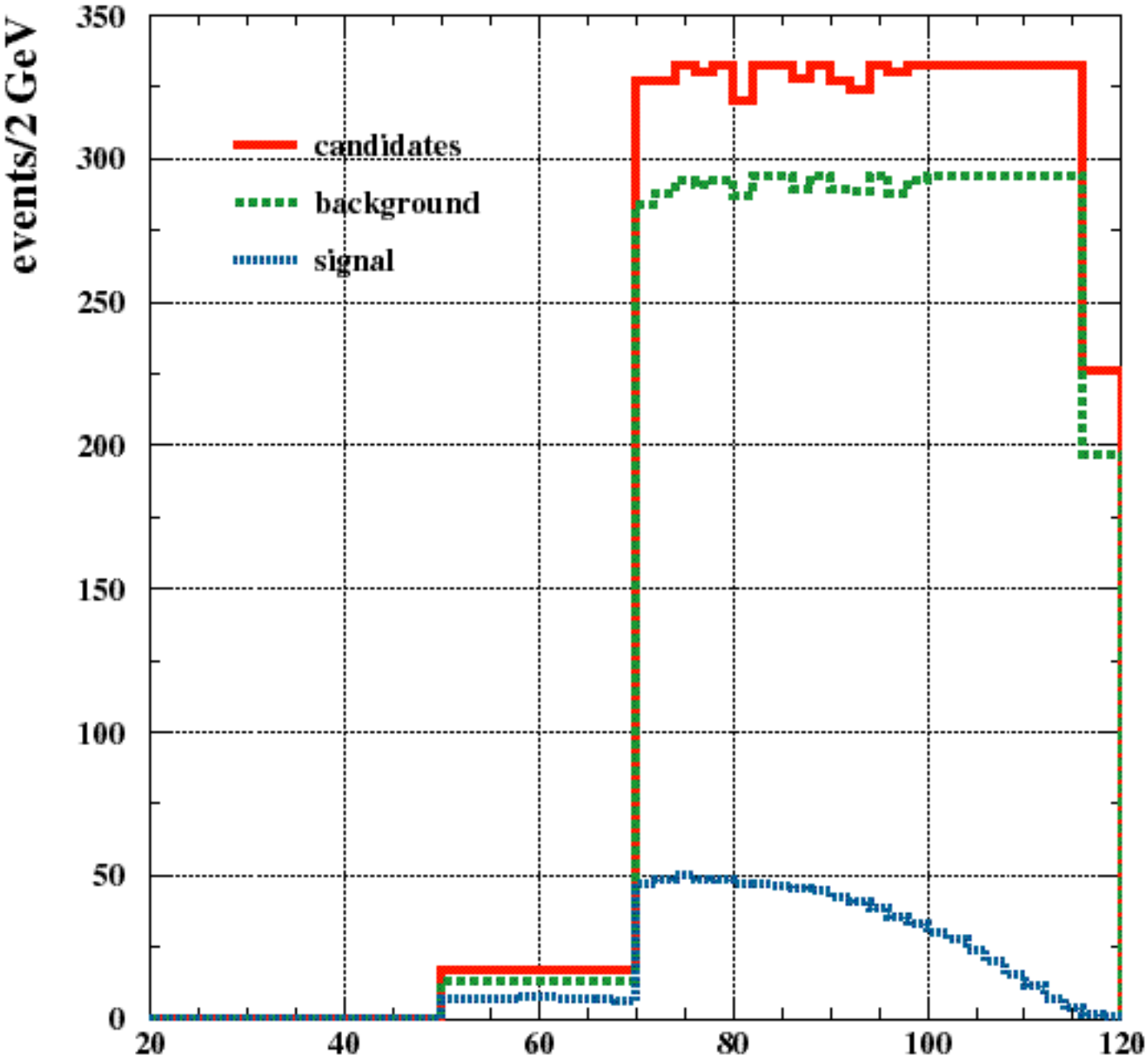
	qqqq		qql	
Z ->	data	exp	data	exp
qq	81	70.9	43	36.5
νν	10	5.4	10	5.7



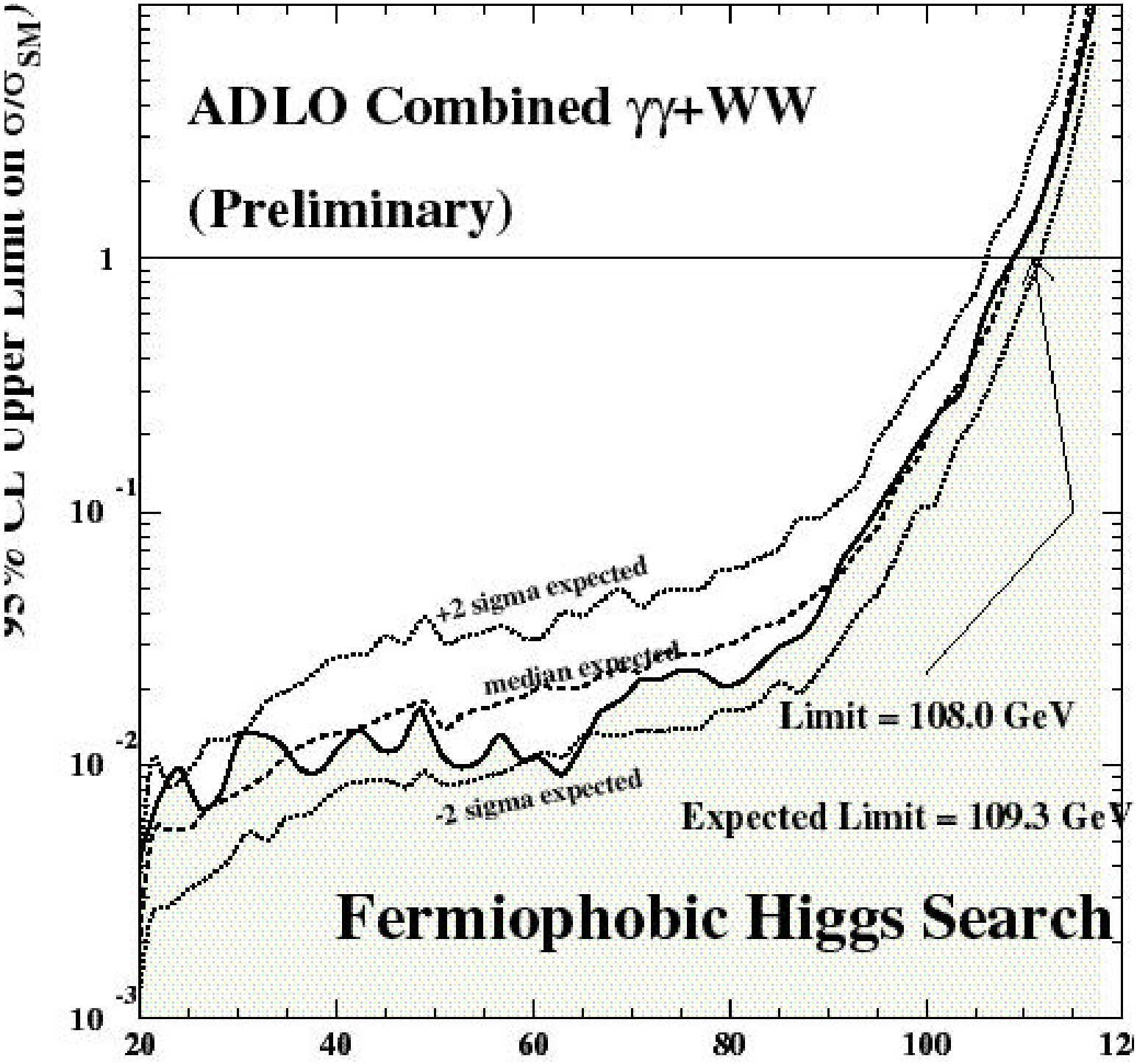
No evidence for fermiophobic Higgs

$M_h > 104.8$ GeV (at 95% C.L.)

The L3 Components



ADLO Photonic + WW



Open Questions, MJO Desires

- All the other experiments have either:
  - looked at WW in the past (D,O did not feel enough to be gained in quick early studies)
  - A is about to set a student on it!
  - O will try to find someone to finish the work
- I do not feel the WW combination is all the way there:
  - Princeton is working on its own LEP combination for verfication of my results
- We have not had time to think about the best ways to present the photonic, WW, and combined data
  - I'd like to get away from model dependence as much as possible
  - Remember: turning off the fermion couplings in HDECAY/HZHA is just a benchmark
  - We should show cross section upper limits
- I'd like to see the standard inputs in a format where mass plots can be generated
  - used to be the case …
  - helps me check for problems
  - nice summary of what the searches yield

Fermiophobic ALEPH analysis

- **Look for the process $e^+e^- \longrightarrow Z^{(*)} H$ with**
  $H \rightarrow \gamma\gamma$ and $Z \rightarrow \nu\nu/ee/\mu\mu/\tau\tau/qq$
- **Topologies characterised by the charged track multiplicity (0/2/3-4/>5)**
- **Main selections:**

  -Photon quality and isolation

  -Photon energy and transverse momentum

  -Specific cuts on the Z characteristics

  $$m^{\gamma\gamma}_{recoil} \approx m_Z$$

- **Typical efficiencies:**

nch	H ν ν	H l l	H τ τ	H q q
0	47.0 %	0.3 %	0.	0.
2	0.	36.7 %	22.4 %	0.
3-4	0.	2.0 %	14.9 %	0.
> 4	0.	0.	5.2 %	37.3 %

- **Analysis extended down to:**

  -1 GeV by using the direct measurement of the Z invisible width by single photon counting.

Analysis overview

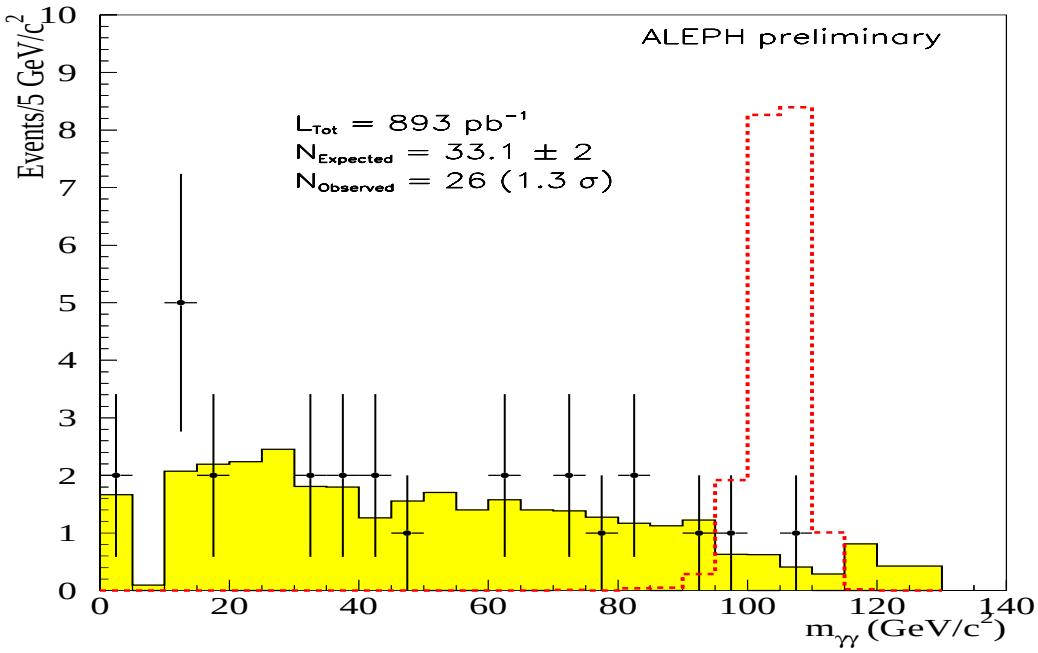
- Data:
  - All data since 1991 : L = 893 pb^{-1}
  - All Z decay channels
- Limit extraction:
  - No background subtraction
  - 5% relative systematic uncertainty including model dependency:

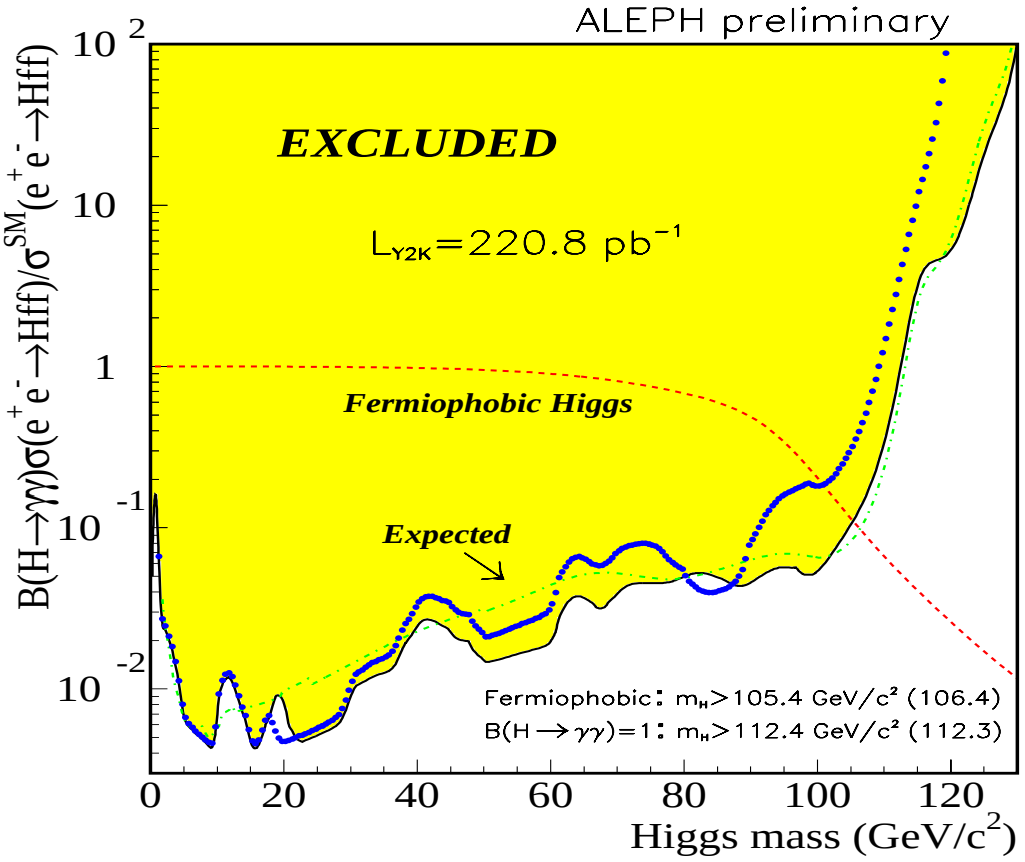
    Results are valid if :
    - Anomalous coupling parameters

      $|f_i/\Lambda^2| < 100\ TeV^{-2}$
    - Higgs decay width

      $\Gamma < 3$ GeV
  - 95% CL limit obtained with CLFFT
- Work still in progress:
  - Background subtraction
  - Cuts optimisation at the highest LEP energies

ALEPH preliminary limit





Fermiophobic Higgs at DELPHI

DELPHI has analysed $H^0 Z^0$ production
$H^0 \to \gamma\gamma$ and ($Z^0 \to q\bar{q}$ or $Z^0 \to \nu\bar{\nu}$)
in the data collected from 1997 to 2000
(1997 not included in combination)

this search is motivated by two models:
– 2HDM (type I), fermiophobic limit [1]
– anomalous Higgs couplings [2]

in addition to $H^0 Z^0$ we have $H^0\gamma^0$ and $H^0 A^0$

in addition to $H^0 \to \gamma\gamma$ (or $H^0 \to WW^*$)
we have $H^0 \to b\bar{b}$ or $H^0 \to AA$

same final states for $H^0 Z^0$ and $H^0\gamma^*$ or $H^0 A^0$
$+ \gamma\gamma\gamma\gamma$, $\gamma\gamma\gamma$, $b\bar{b}\gamma$, $b\bar{b}\gamma\gamma$, $q\bar{q}\gamma\gamma\gamma\gamma$

[1] A. Barroso et al., Phys. Rev. **D60** (1999) 35005
L. Brücher and R. Santos, Eur. Phys. J. **C12** (2000) 87

[2] K.Hagiwara et al., Phys. Lett. **B318** (1993) 155
K.Hagiwara et al., Phys. Rev. **D48** (1993) 2182

analysis of $q\bar{q}\gamma\gamma$

– the signal is produced with Pythia,
(cross-section given by [1])
– the main background ($Z + N\gamma$) with Pythia
(will be KK2f)

isolated photons are identified by
constructing double cone:
– inside $5°$, particles are clustered
– outside $15°$, energy is vetoed

background from double radiative returns
is rejected by:
– photon isolation cut
($\alpha_i > 15°$ – from definition)
– photon polar angle cut
($|\theta_i| > 42°$ – in barrel calorimeter)
– photon energy cut
($E_1 + E_2 < 0.85 E_{rr}$ or $E_1 - E_2 < 0.85 E_{rr}$)

the mass resolution (will be) improved by
a fit imposing total energy and momentum
conservation (and the recoiling system to be a Z^0).

analysis of $\nu\bar{\nu}\gamma\gamma$

– the signal is produced with Pythia,
(cross-section given by [1])
– the main background ($Z + N\gamma$) with KoralZ

isolated photons are identified by
a reconstruction cone:
– with half opening angle of $10°$, containing $E > 5$ GeV.
– transverse momentum with respect to nearest reconstructed photon(in the same hemisphere) > 5 GeV.

background:

- from double radiative returns is irreductible.
- $\gamma\gamma(\gamma)$ QED is rejected by:

– photon energy cut ($E_1 + E_2 < 0.65\sqrt{s}$)
– acoplanarity cut ($\text{Acoplanarity}_{\gamma\gamma} > 10°$)
– Recoil mass cut ($M_{\gamma\gamma}^{recoil} > 20$ GeV/c^2)

the mass resolution will be improved by
a fit forcing the recoiling system to be a Z^0.

limit derivation and presentation

– the limits are combined for each production mode using the MFLR method[3]:
energy dependence of the cross-section is fundamental
– in the 2HDM-I, HZ has the SM cross-section and a constant factor of $BR(M_H)\sin^2\delta$
– in the anomalous higgs couplings the total model cross-section must be used. There are contributions from $HZ\gamma$ vertex on production.

– the most model independent limit is:

$$\frac{\sigma(ZH)\times BR(H\to\gamma\gamma)}{\sigma^{ZH}_{SM}} \text{ .vs. } M_H$$

– the same for other decay channels
(changes in BRs and cross-sections are related !)

– for 2HDM-I, the BR is calculated according to [1]. Approaches the "standard" as $\sin^2\delta \to 1$ and $m_{H^+} \to \infty$ and $m_A \to \infty$

[3] A.L. Read, "Modified Frequentist Analysis of Search Results (The CLs Method)" in "Workshop on Confidence Limits", ed. F. James, L. Lyons and Y.Perrin, CERN Report 2000-005 (2000) p.81

Final Results – there should be a hierarchy

1. excluded cross-sections $XY \to \gamma\gamma f\bar{f}$:
limit on $\sigma(XY) \times BR_X \times BR_Y$ .vs. M_X, M_Y,
per fermion and per energy (same for $H \to WW$)
– model independent (HZ, $H\gamma^*$, HA)

2. excluded cross-section for HZ (SM like):
limit on $\frac{\sigma(ZH)\times BR(H)}{\sigma^{ZH}_{SM}}$ .vs. M_H,
per Higgs decay channel
– valid for most fermiophobic models

3. excluded mass for "fermiophobic higgs":
is just a number assuming fixed σ and BR
– a clear indication of the analysis strenght

work for the future :

– redo analysis with final data processing and new background simulations

– add $HZ \to \gamma\gamma ll$

– finalise analysis of $H \to WW^*$
(very preliminary discriminant analysis)

– finalise 2HDM-I and Anomalous Couplings

Photonic Higgs Search in L3

Data samples

$$\sqrt{s} = 189 - 209\ \text{GeV}$$

$$L \approx 640\ \text{pb}^{-1}$$

Search Channels

$$h^0 Z^0 \rightarrow \gamma\gamma q\bar{q}$$
$$\rightarrow \gamma\gamma \upsilon\bar{\upsilon}$$
$$\rightarrow \gamma\gamma \ell^+\ell^-, \ell = e, \mu, \tau$$

Main background

- ISR photons

Analysis

- $N_\gamma \geq 2$ in $45^0 < \theta < 135^0$, or $25^0 < \theta < 35^0$, or $145^0 < \theta < 155^0$; $E_{\gamma_{1,2}} > 0.1\, E_{beam}$
  - **Hadronic channel**
    - high multiplicity events, large visible energy
    - isolation criteria for the photons
      - $E_\gamma^{20^0} \leq 3.5\ GeV,\ \angle(\gamma,\gamma) \geq 50^0, \angle(\gamma, jet) \geq 25^0$
    - $|M_{recoil} - M_Z| \leq 15\ GeV$
  - **Missing energy channel**

    photon acoplanarity $\geq 3^0$, $p_{t_{\gamma\gamma}} > 1\ GeV$

    $\theta_{miss} > 15^0$ from beam pipe

    $|M_{recoil} - M_Z| \leq 15\ GeV$
  - **Lepton channel**

    2 identified e^-, μ, or at least one identified τ

    $3\ GeV < E_{lepton} < 0.85\, E_{beam}$

    $|M_{recoil} - M_Z| \leq 15\ GeV$

Results

- Upper limit on $BR(h \to \gamma\gamma)$
  - A. Favara and M. Pieri, hep-ex/970616
  - $$1 - C.L. = \frac{\int_{s}^{\infty} L(s,b)ds}{\int_{0}^{\infty} L(s,b)ds}, \quad s = f(m_h, BR(h \to \gamma\gamma))$$
  - assume σ_h^{SM}
- Lower bound on the fermiophobic Higgs mass
  - $BR(h \to \gamma\gamma)$ calculated with HDECAY
    (set to zero all fermionic couplings)

OPAL Fermiophobic Higgs Search

Mark Oreglia
University of Chicago
2 April, 2001

- data analyzed for reprocessed Y2K data
  - 211 pb^{-1}
- not so much “fermiophobic” as “photonic”
- same analysis as used for 189, 196 GeV
  - for $M_{\gamma\gamma} > 40$ GeV:
    - qq channel: 7 cand., 6.5 expected
    - ll channel: 5 cand., 6.4 expected
    - nunu channel: 1 cand., 3.9 expected
- only 2 event have mass > 90 GeV:
  - 104.4 GeV in neutrino channel
  - 100.5 GeV in leptonic channel
- current OPAL fermiophobic limit:
  - 105.5 GeV observed
  - 106.4 GeV expectd

The OPAL Photonic Analysis

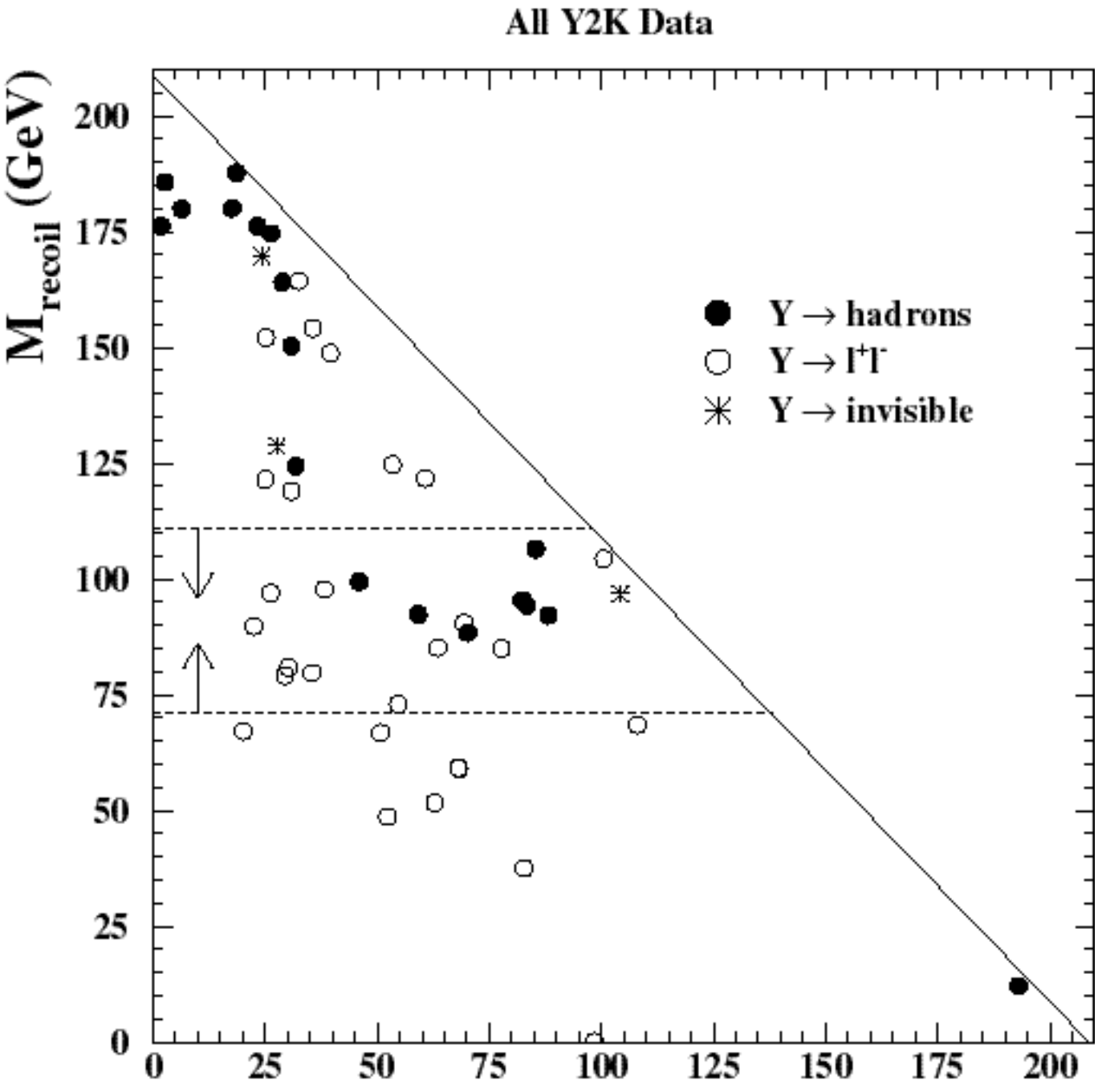
- Preselection cuts on visible E, momentum
- Photons recoil off a Z (within 20 GeV)
- All Z decay channels use same diphoton criteria:
  - $|\cos\theta| < 0.875$, $E > 5{,}10\%\ E_{beam}$
  - conversion finder -- add in converted photons (12%)

- Hadronic Z decay channel:
  - $P_t[\text{jet-}\gamma] > 5$ GeV for both photons
  - cut if both $E\gamma$ correspond to ISR

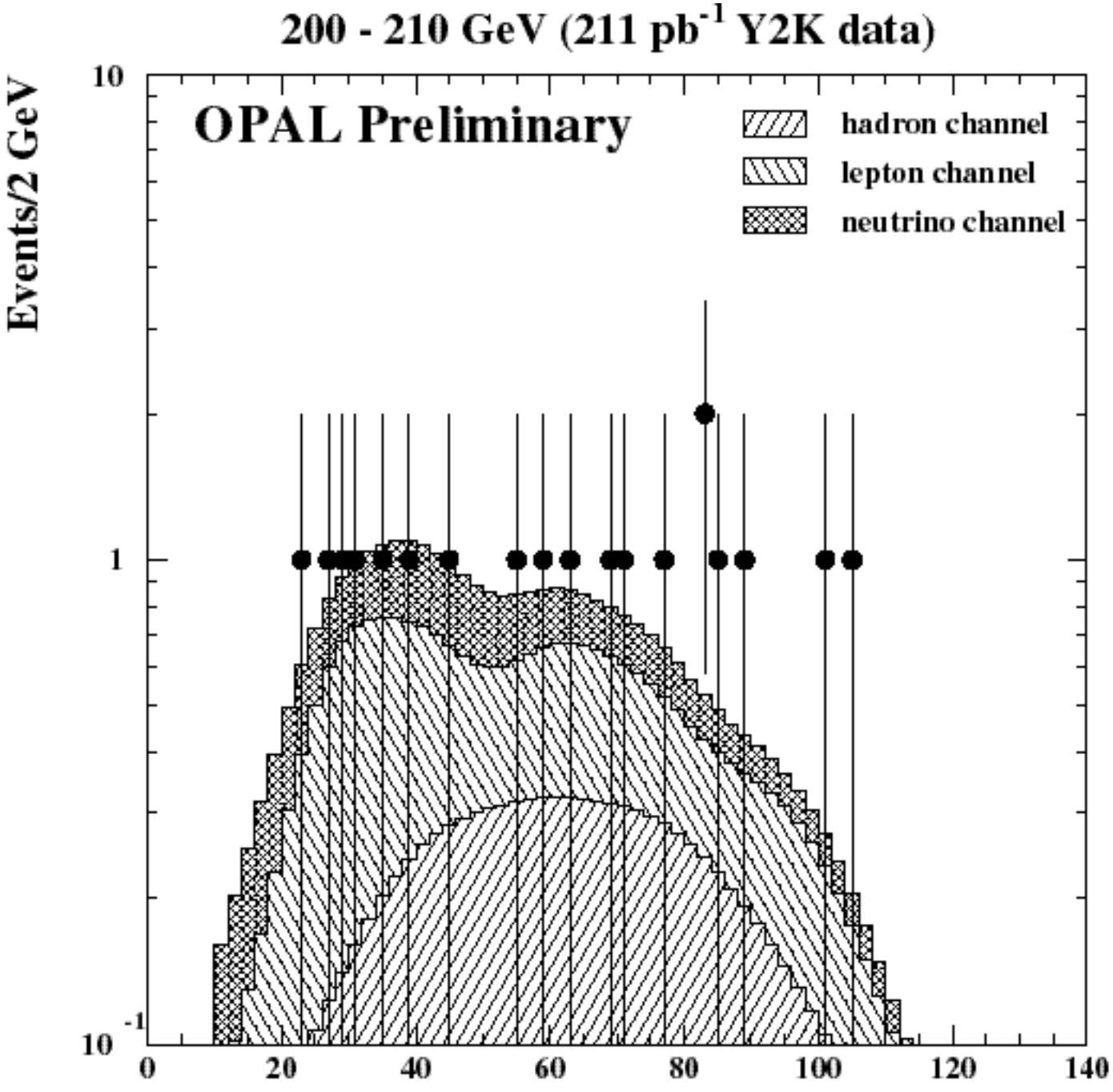
- Leptonic Z decay channel:
  - cut on multiplicities, clusters, tracks
  - allow 1-track events if stiff and not a conversion

- Neutrino Z decay channel:
  - no more than 3 tracks, 4 EM clusters
  - beam gas veto (forward E)
  - acoplanarity of the photons
  - less than 3 GeV *unassociated* calorimeter energy

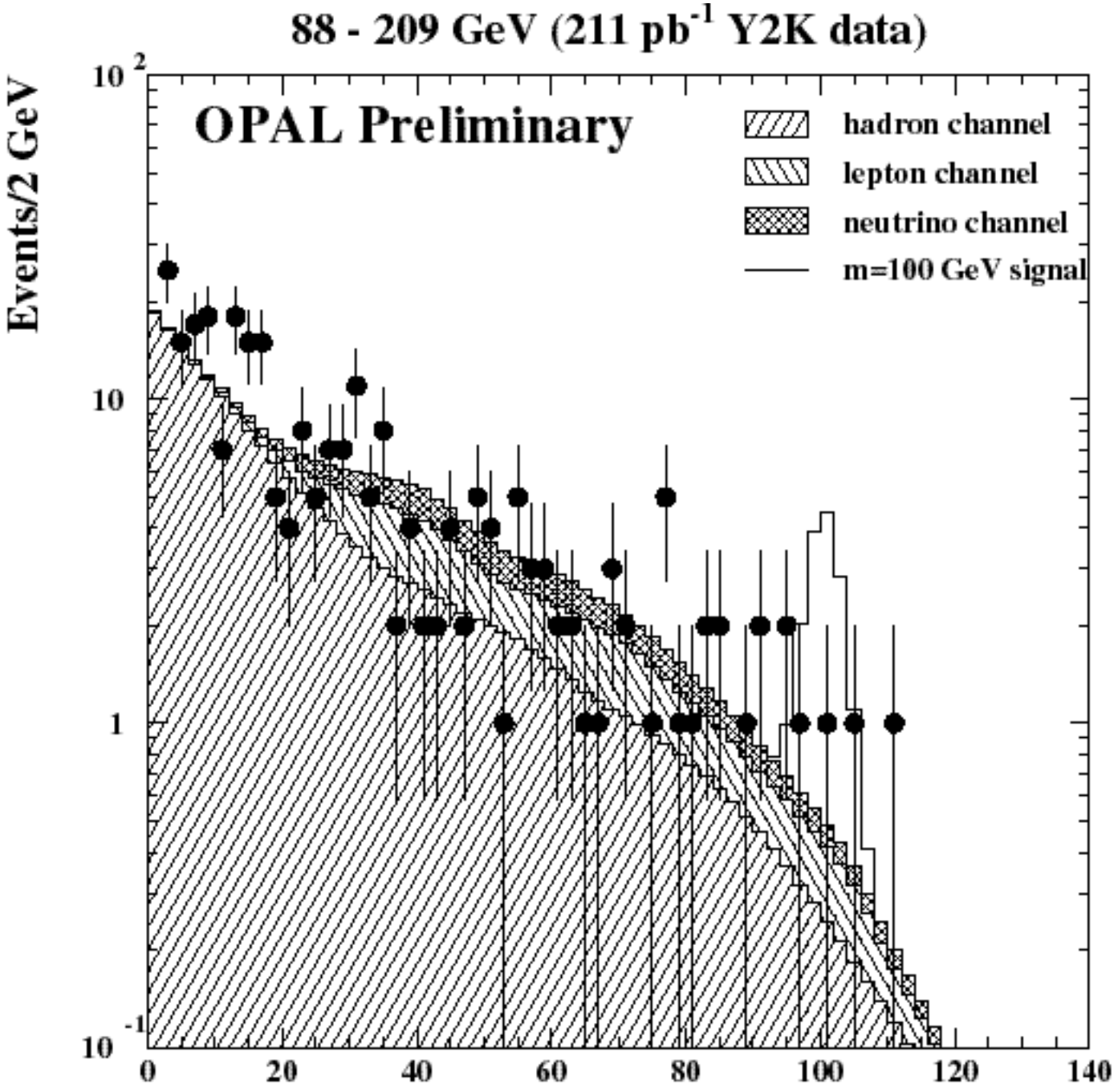
The ”Loose-Cut” Mass Distribution



The Final Diphoton Mass Distribution

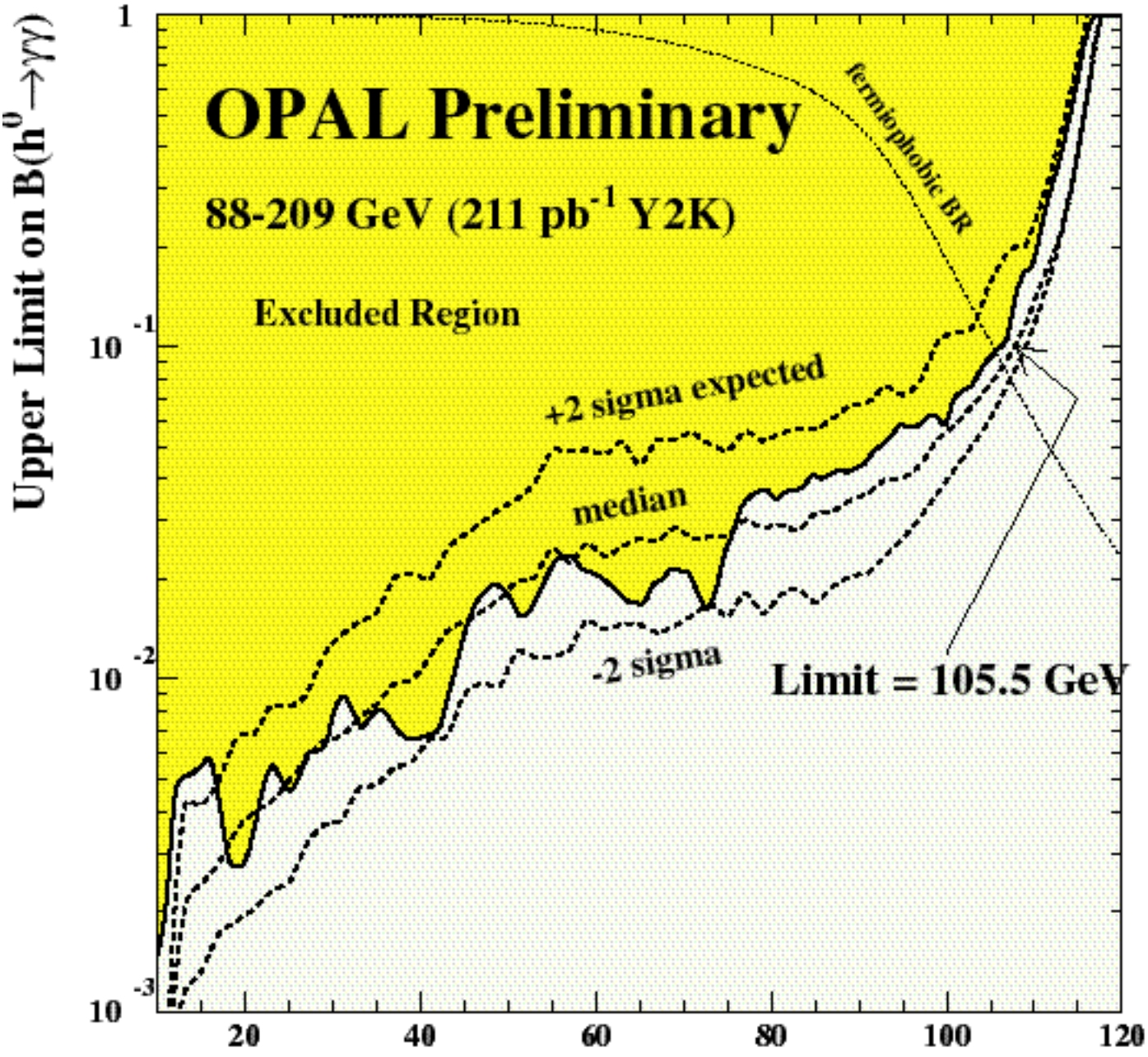


…And for all the data since 1990:



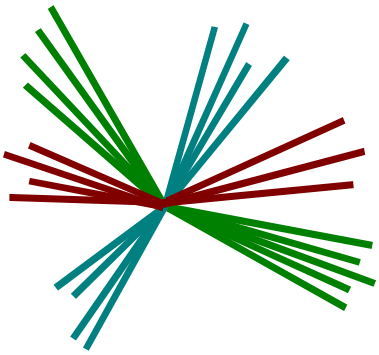
The 95% CL Fermiophobic Limit

- Using Tom Junk's statistics package "ecl"
- 1 GeV mass bins
- HDECAY used for fermiophobic BR (about 0.8 GeV lower limit than HZHA3)

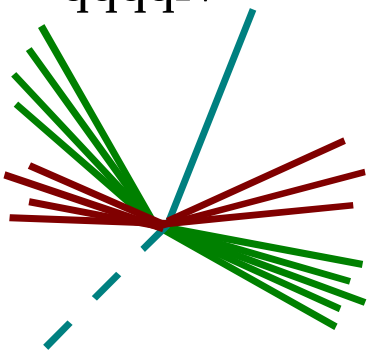


Decay Signatures

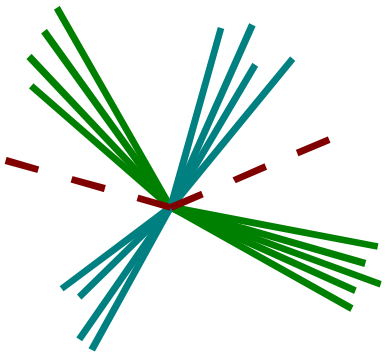
qqqqqq



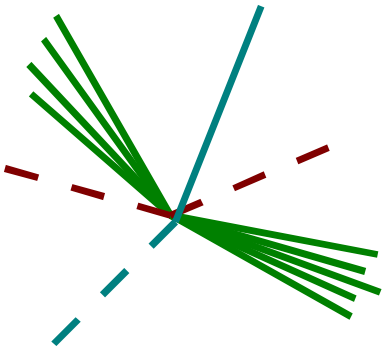
qqqqlν



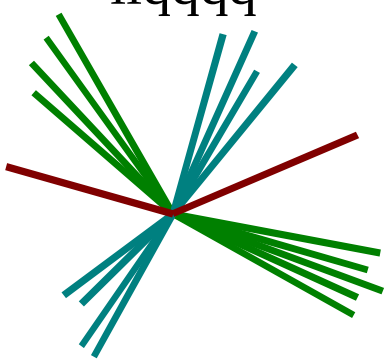
ννqqqq



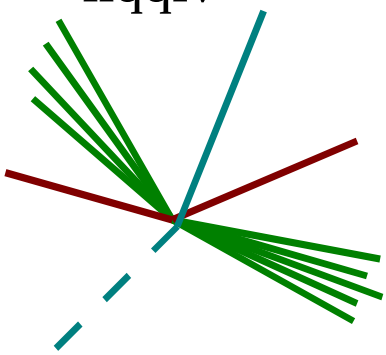
ννqqlν



llqqqq

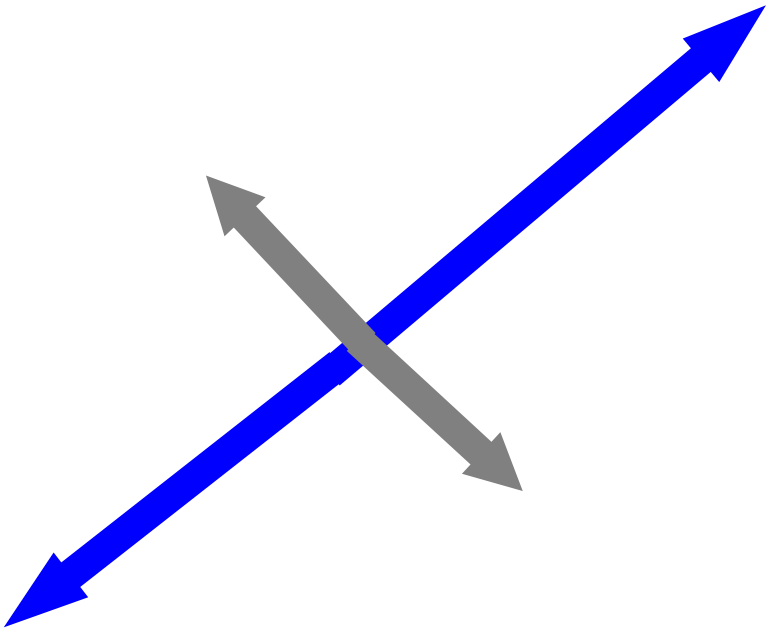


llqqlν



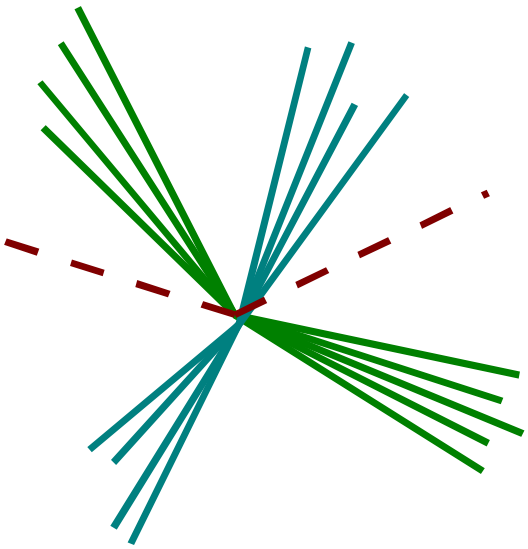
$$f_Z \bar{f}_Z f_{W1} f'_{W1} f_{W2} f'_{W2}$$

Decay details



- More favorable for Higgs to decay to one on−shell and one very off−shell W (~30GeV) rather than two off−shell W's
- Two high−energy fermions and two low energy fermions from the Higgs decay

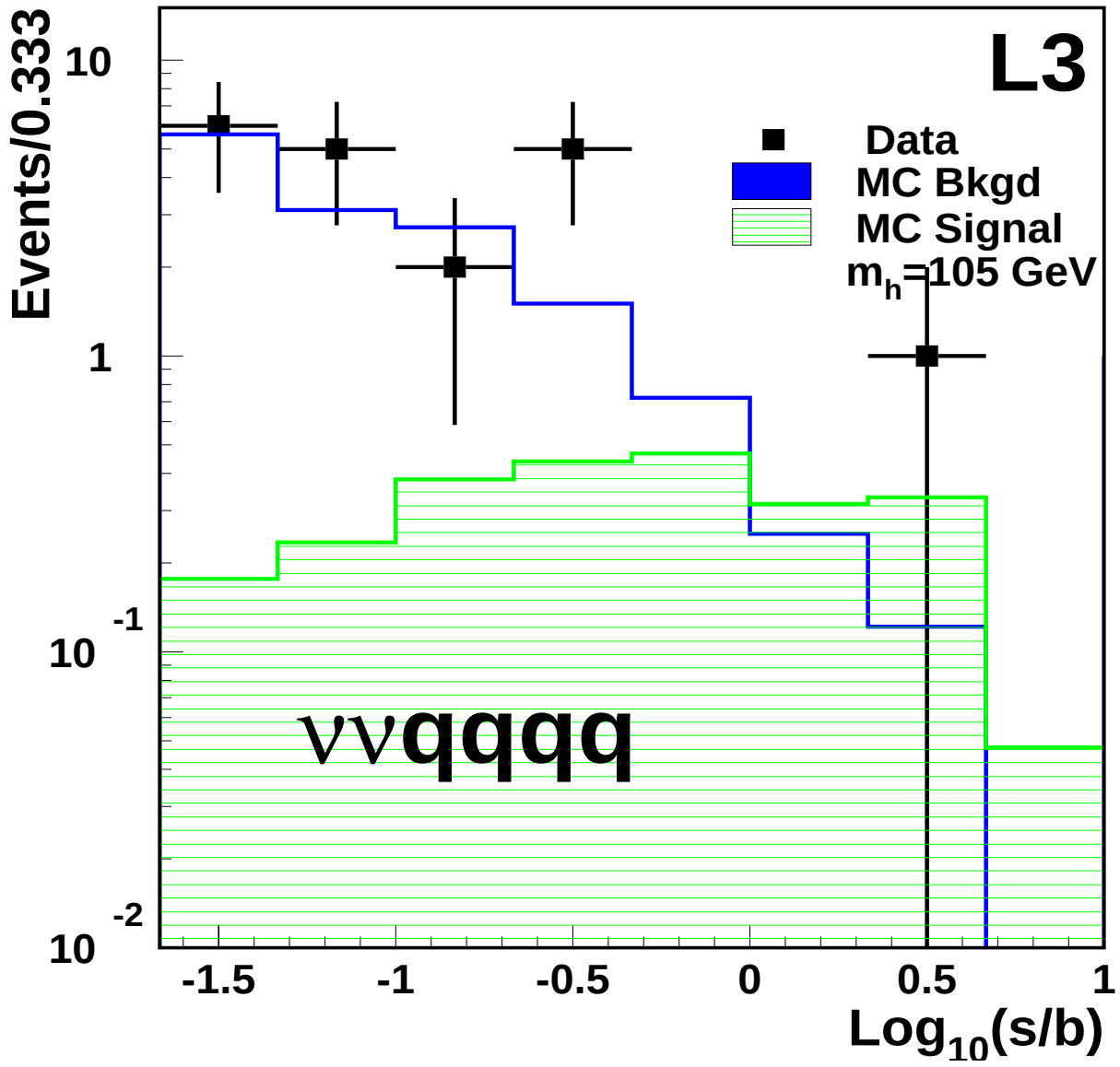
ννqqqq



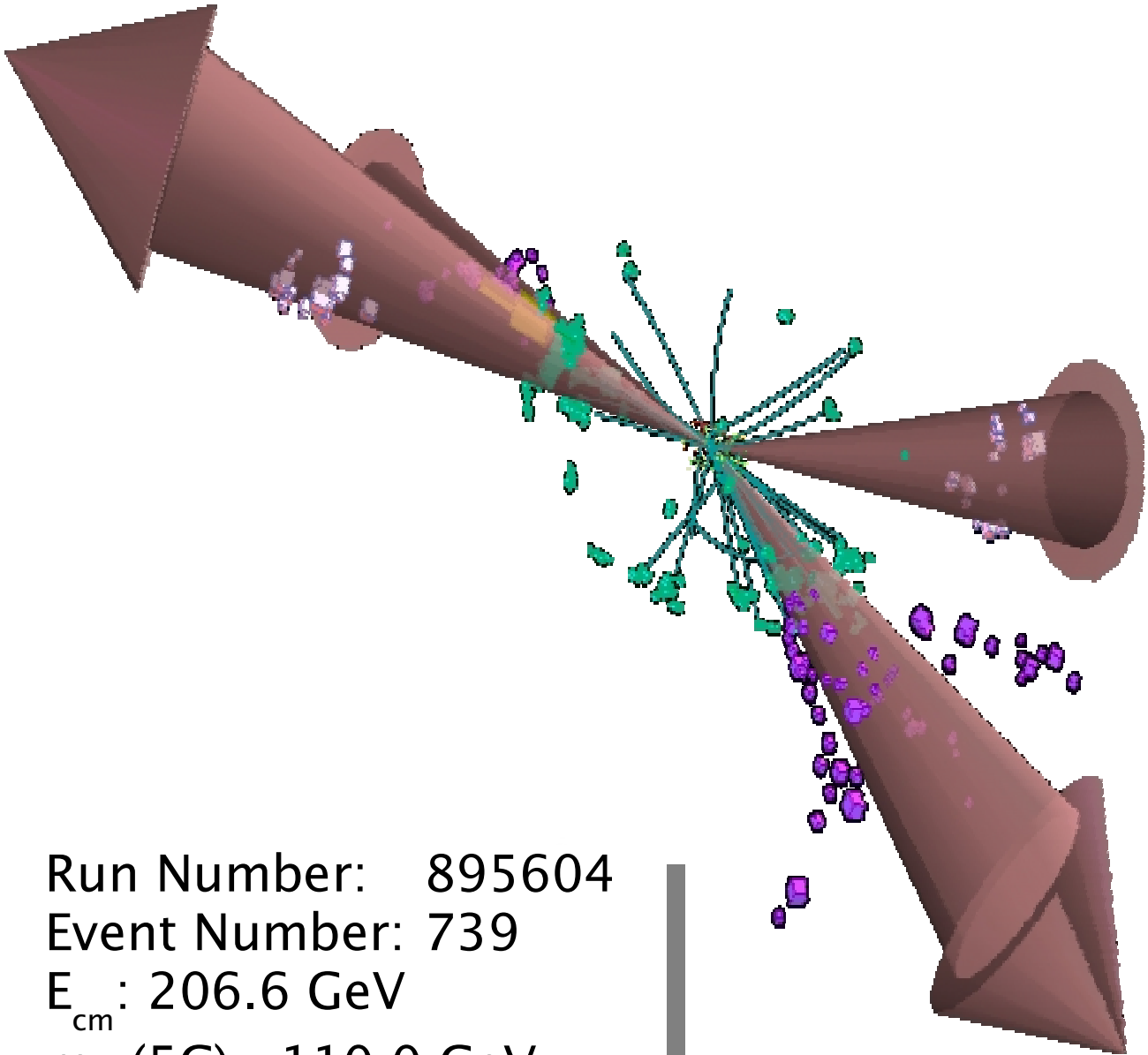
- Missing mass should be m_Z
- Major backgrounds
  - $Z/\gamma^* \rightarrow qq(gg)$
  - $WW \rightarrow qq\tau\nu$
  - $ZZ \rightarrow \nu\nu qq(gg)$

- 5C fit to four jets and recoil against the Z
- Neural network selection
  - deboosted jet system topology
  - fit masses
- Higgs mass from 5C combined with network outputs in a discriminant

ννqqqq Results

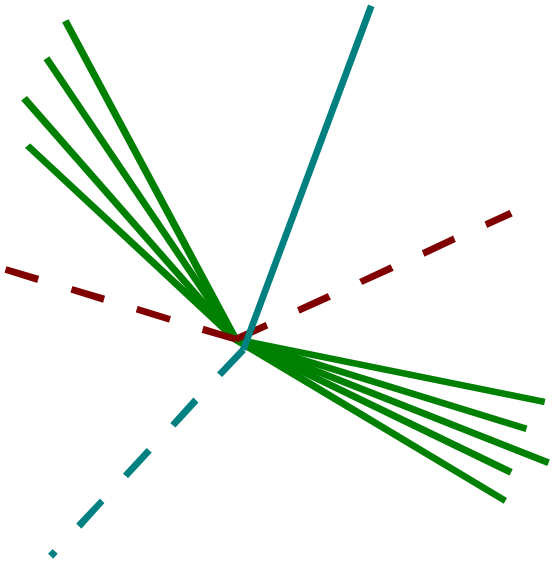


Candidate ννqqqq Event



Run Number: 895604
Event Number: 739
E_{cm}: 206.6 GeV
m_H (5C) : 110.0 GeV
$m_{missing}$: 88.1 GeV

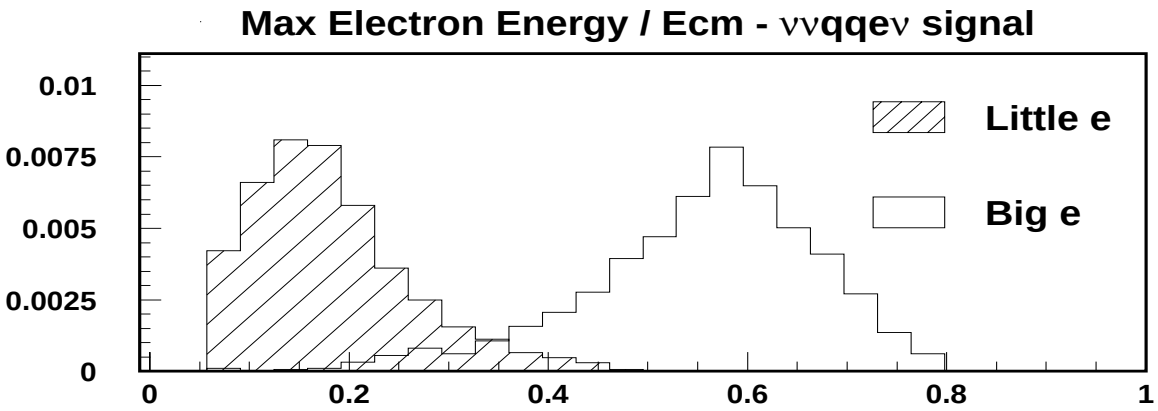
ννqqlν

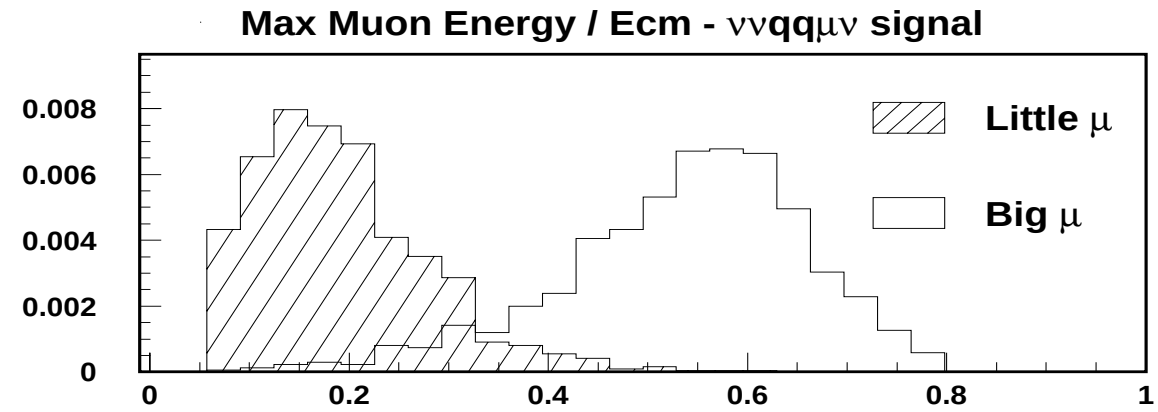


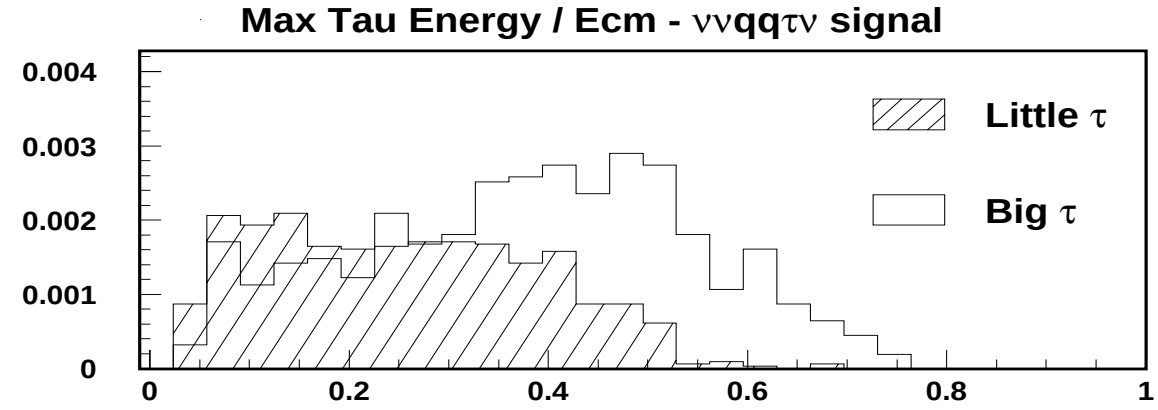
- Too many neutrinos to reconstruct m_H
- Major backgrounds
  - γγ→qqee
  - WW→qqτν
  - ZZ→qqττ

- Six subchannels
  - three leptons
  - one subchannel each for W and W*
- Six separate neural networks + one anti−qq network
- Final variable is the network output

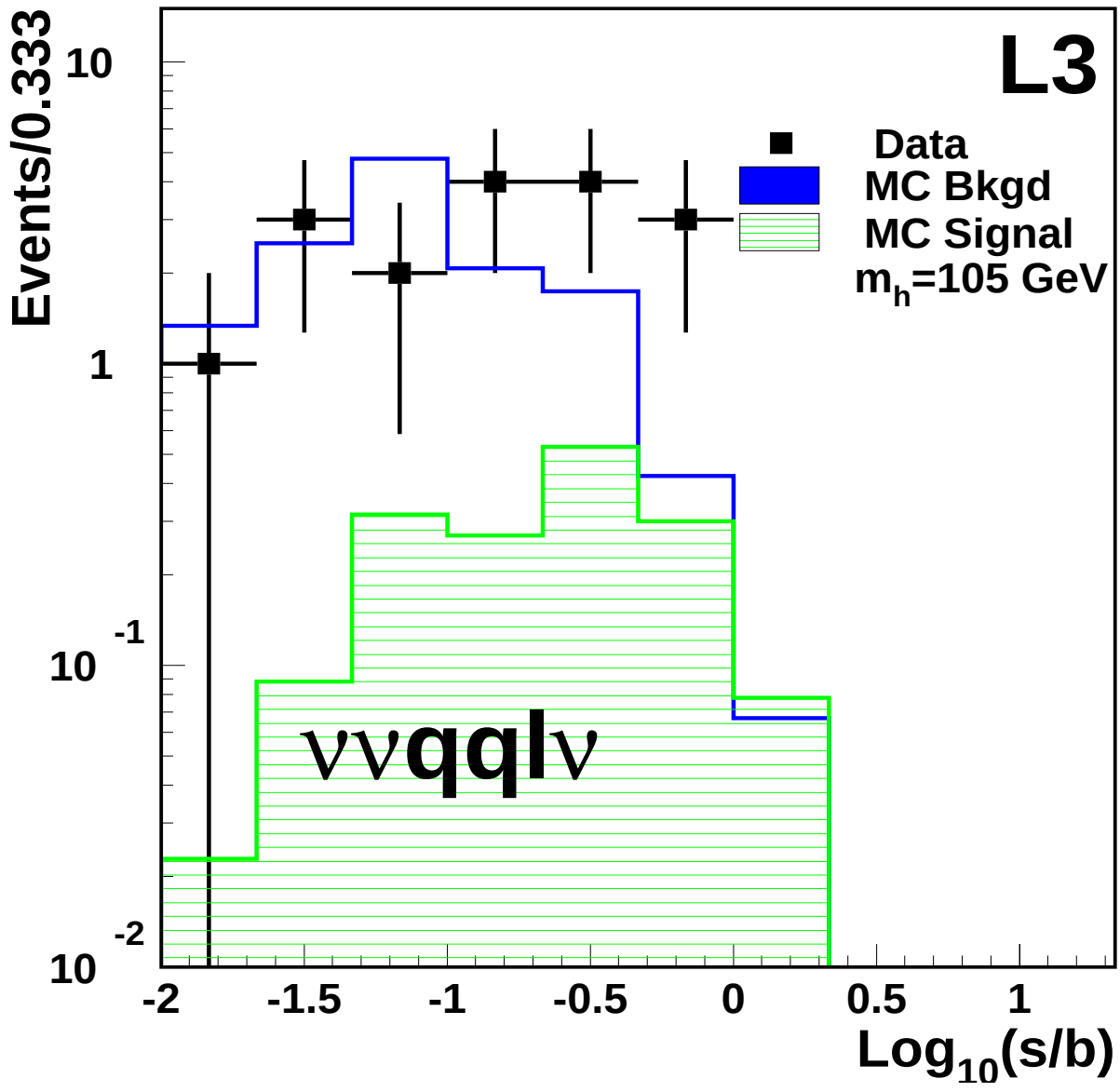
Subchannel Assignment



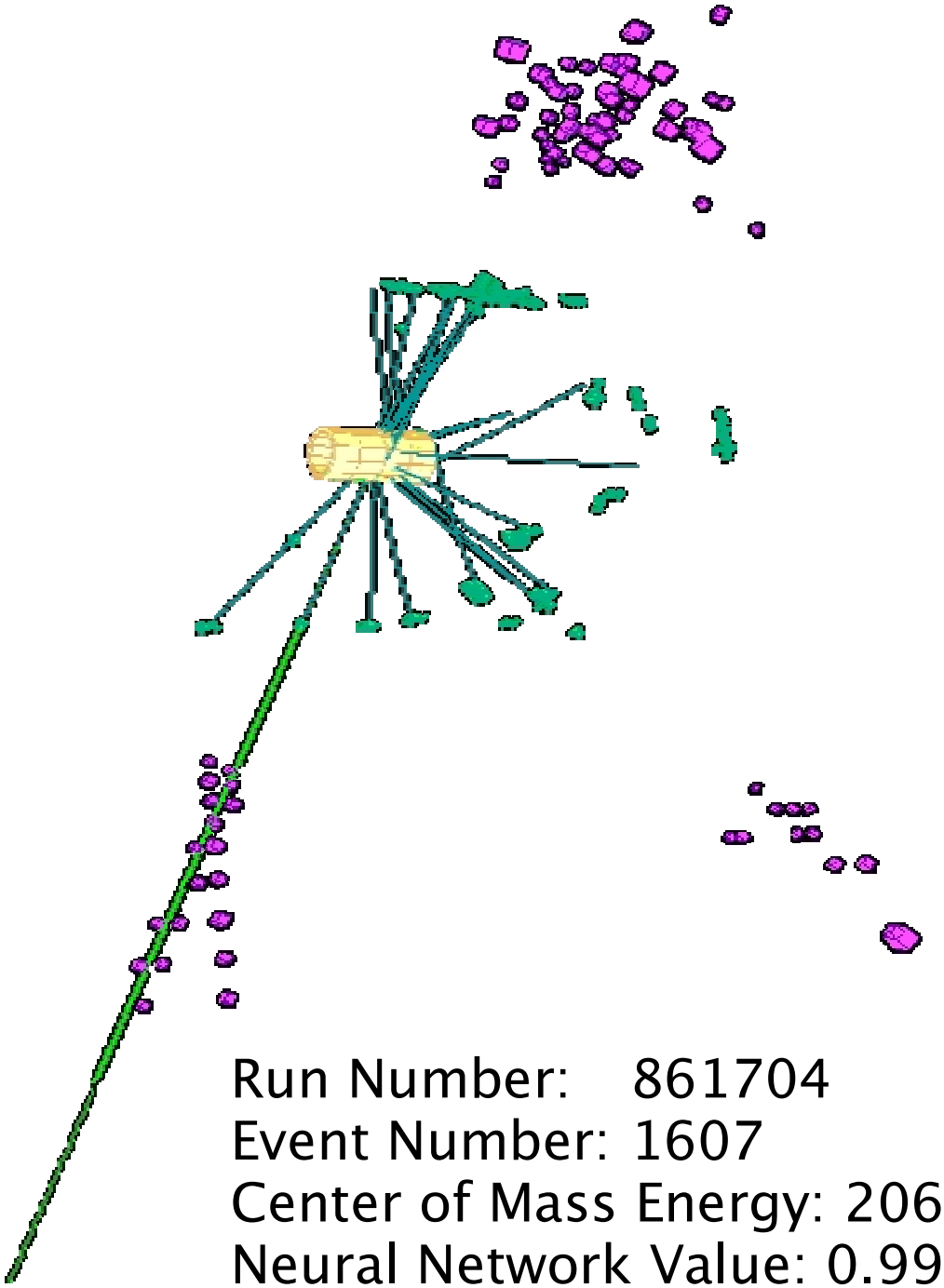




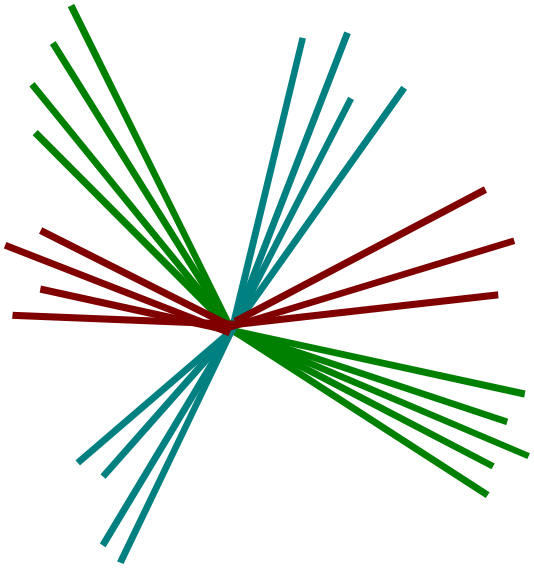
ννqqlν Results



Candidate ννqqlν Event



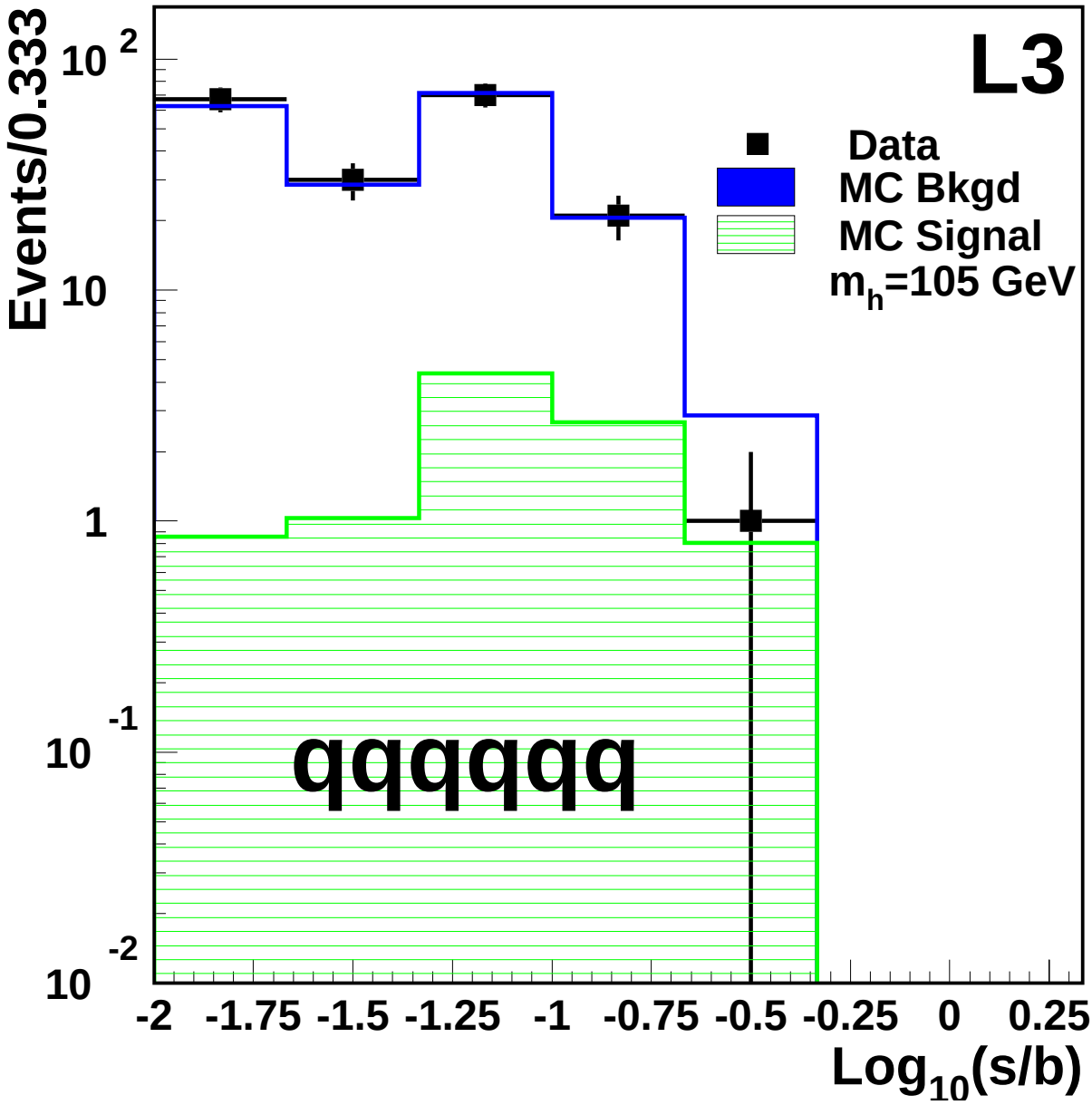
qqqqqq



- Very large multiplicity events
- Major backgrounds
  - $Z/\gamma^* \rightarrow qq(gggg)$
  - $WW \rightarrow qqqq(gg)$
  - $ZZ \rightarrow qqqq(gg)$

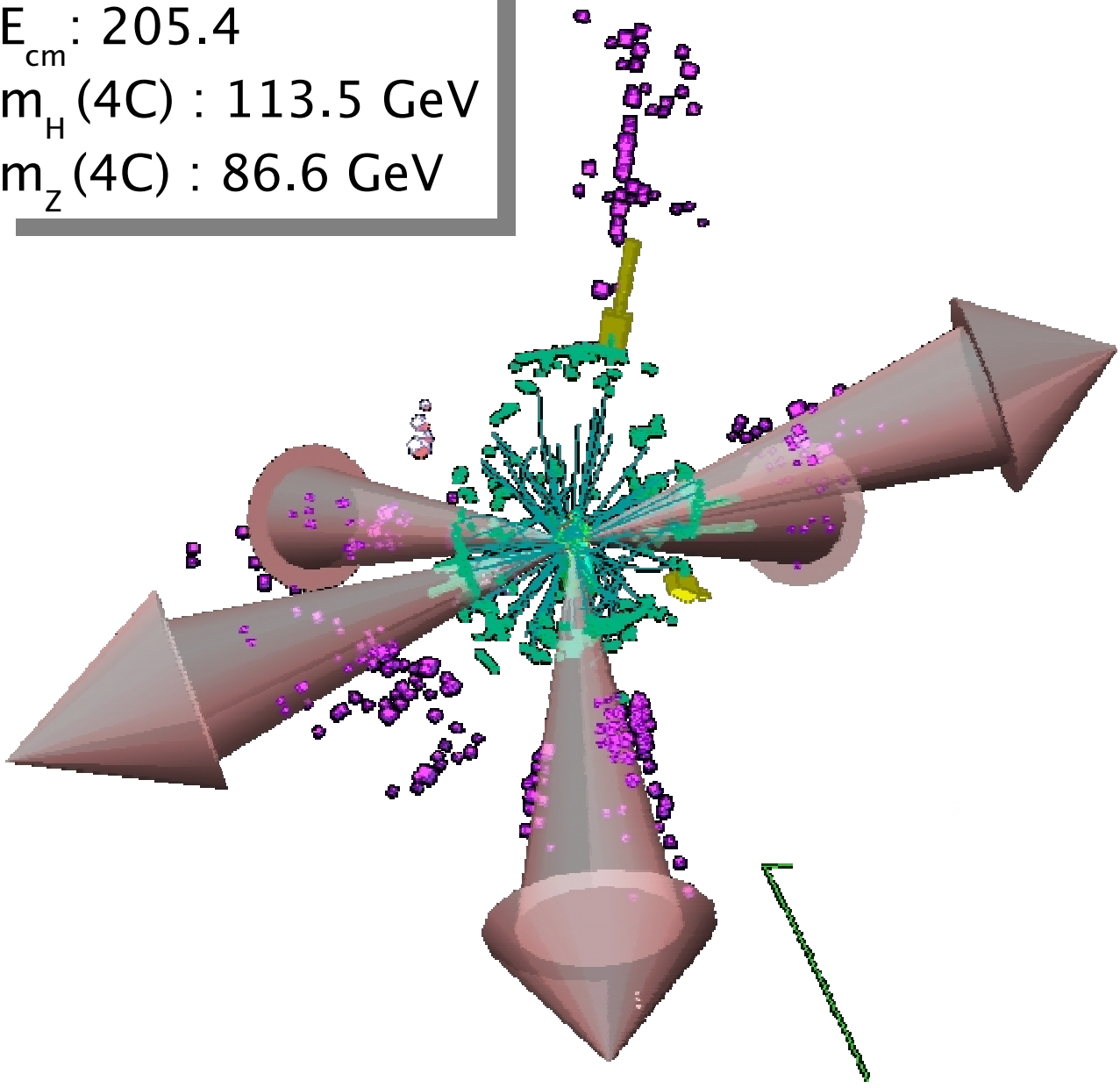
- Force to six jets with Durham
- 4C fit
- Neural network selection
  - Topological variables
  - χ^2 for WW
  - Best Z and W mass
- Discriminant combination final variable

qqqqqq Results

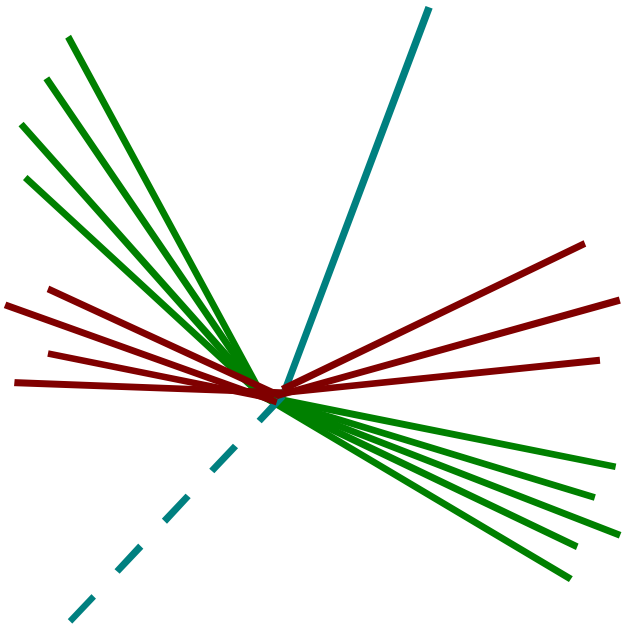


Candidate qqqqqq Event

Run: 848401
Event: 3826
E_{cm}: 205.4
m_H (4C) : 113.5 GeV
m_Z (4C) : 86.6 GeV



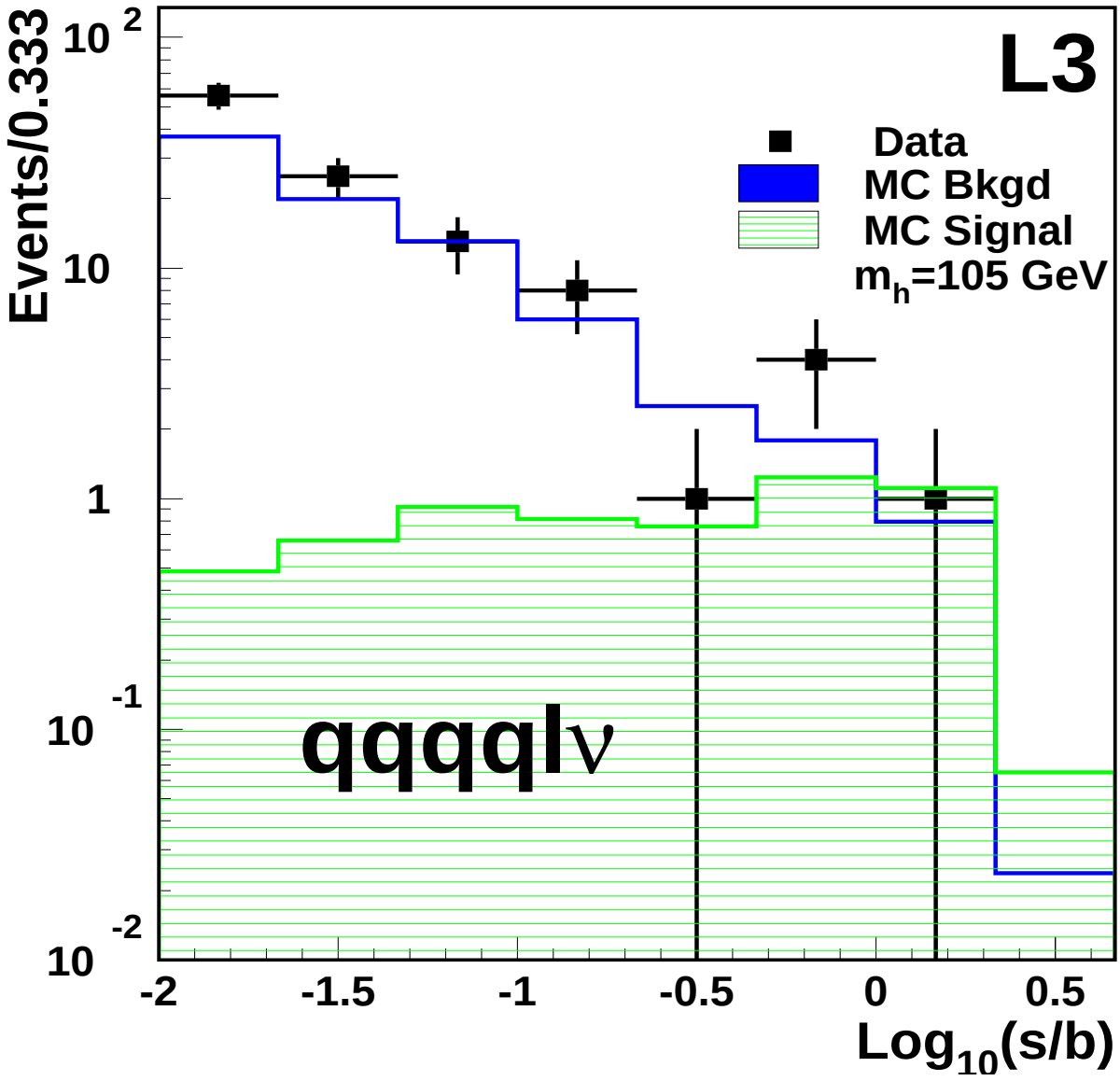
qqqqlν



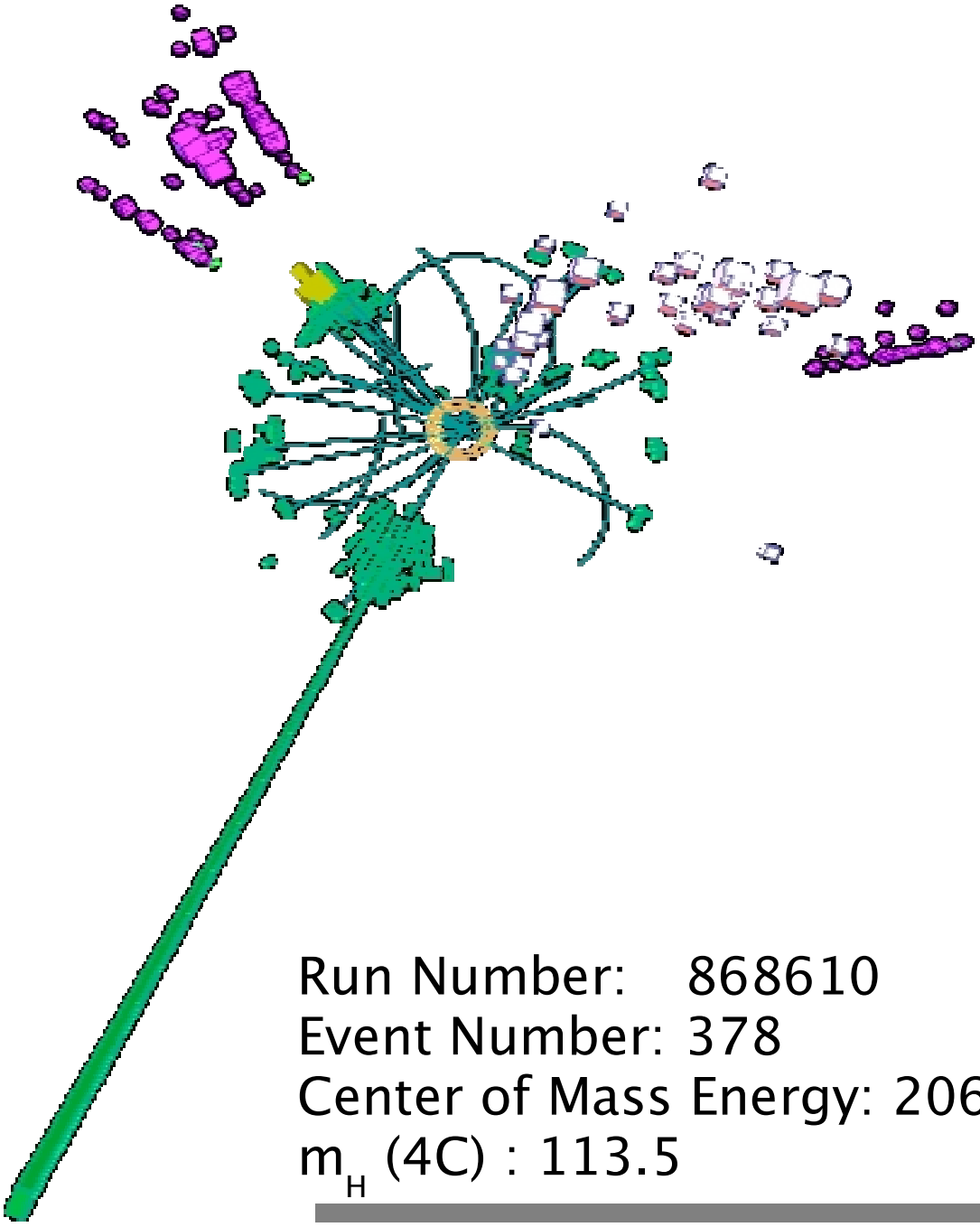
- Leptons from semileptonic decay of quarks in jets
  - Z/γ*→qq
  - WW→qqqq
  - ZZ→qqqq

- Six subchannels
- 4C fit to produce neutrino
- Six separate neural networks, one per subchannel
- Combined discriminant from networks, reconstructed m_H

qqqqlν Results



Candidate qqqqlν Event



Run Number: 868610
Event Number: 378
Center of Mass Energy: 206.8
m_H (4C) : 113.5