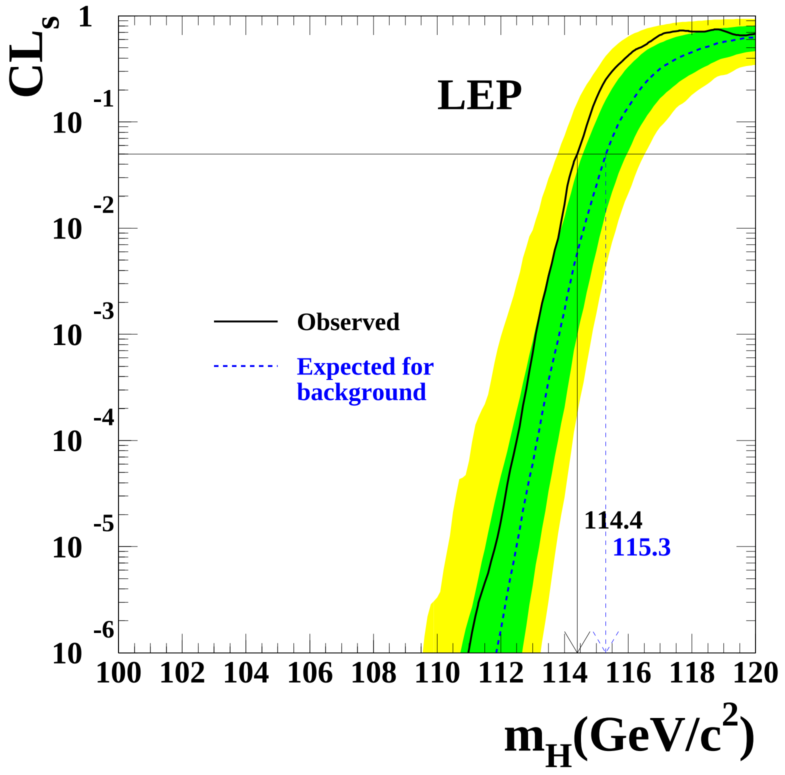
Higgs Searches – Status and Prospects

1. *Results from LEP*
2. *Results from the Tevatron*
3. *Quick Look at LHC, etc.*
4. *Concluding Remarks*

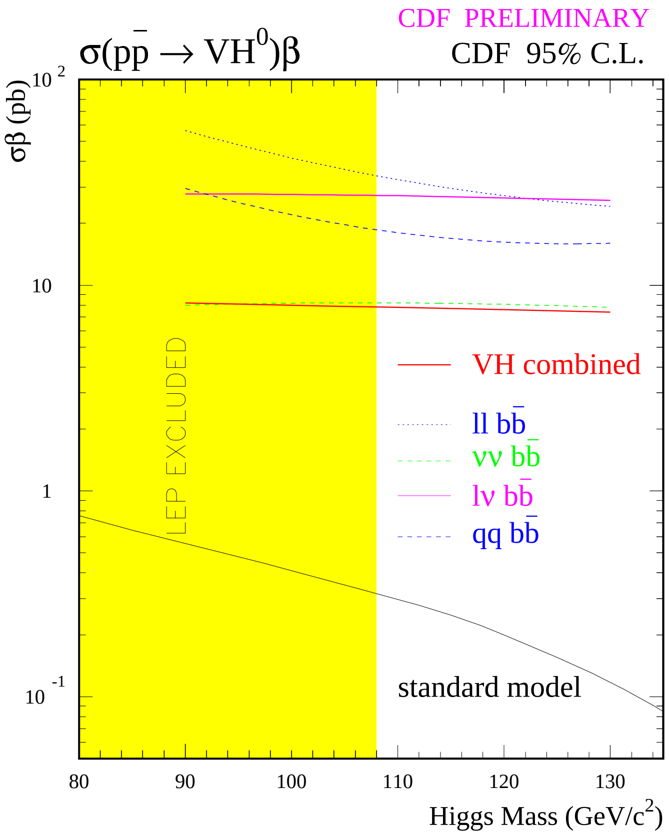
Michael Schmitt
Northwestern University

April Meeting of the American Physical Society (Denver)



Basic SM Higgs, $m_h > 114$ GeV

no more discussion of 'hints'



No real sensitivity in Run I –

how does Run II look?

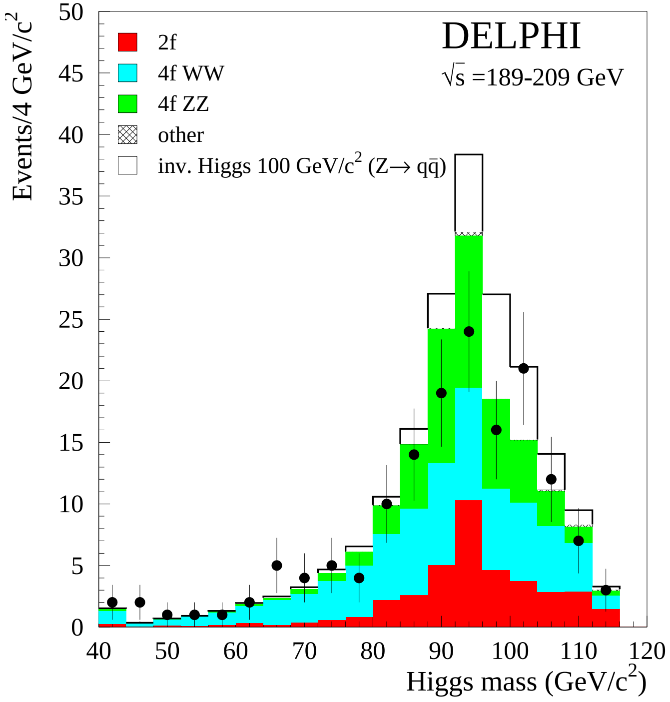
The baton has passed from LEP to the TEVATRON, and at the same time, LHC studies are improving. . .

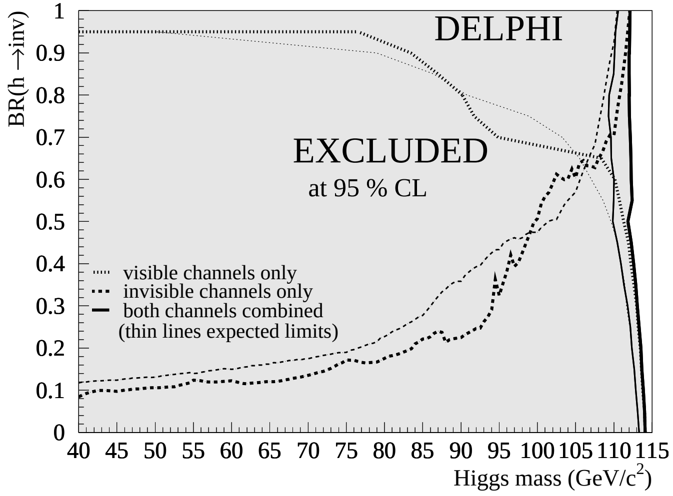
LEP Searches

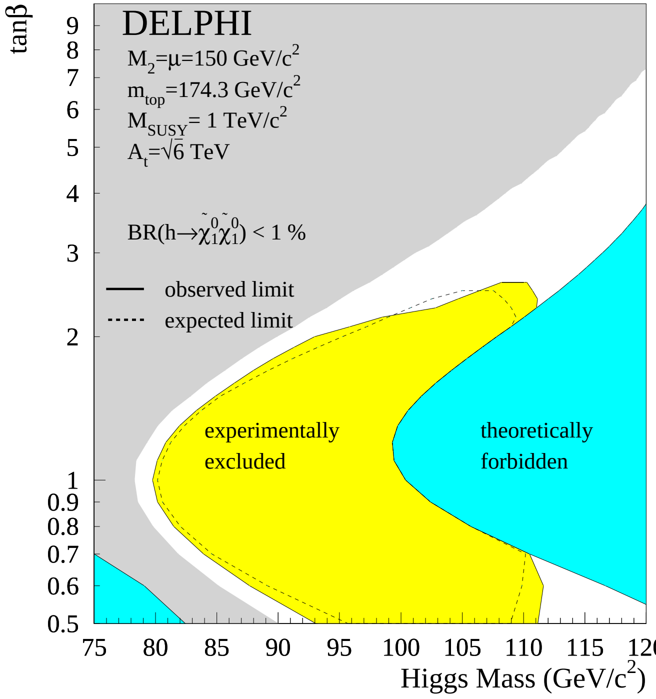
Searches for Invisible Higgs

$h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$ can dominate for some choices of MSSM parameters.

DELPHI analysis relates to $e^+e^- \rightarrow Z\,h$ with $Z \rightarrow \nu\bar{\nu}$.







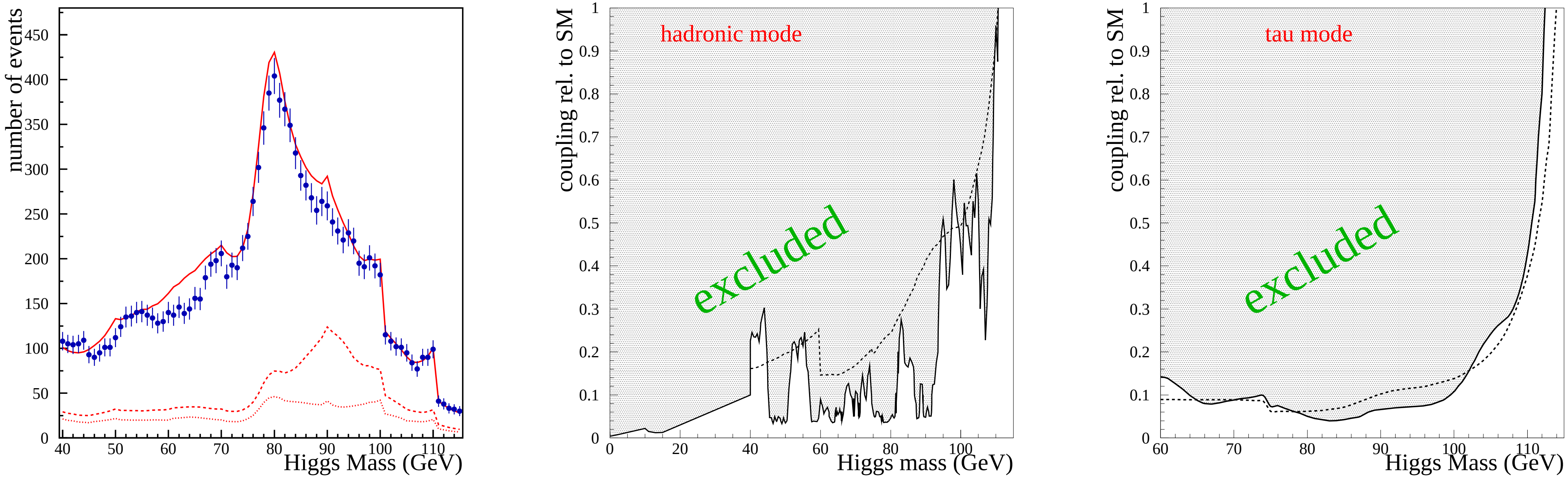
The DELPHI limit is nearly as stringent as SM Higgs!

Flavor-Independent Higgs Searches

A Higgs with $m_h < 140$ GeV decays mainly to $b\bar{b}$ at tree-level.
However, radiative corrections can change this dramatically.

$\longrightarrow$ perform a flavor-independent search: abandon b-tagging and rely on kinematics.

example: ALEPH $\quad \ell^+\ell^- q\bar{q} + \tau^+\tau^- q\bar{q} +$ 4-jet channels



lower limit on m_h is 110 – 112 GeV $\quad$ (A similar result also published by OPAL.)

Searches for Bosophilic Higgses

example: L3

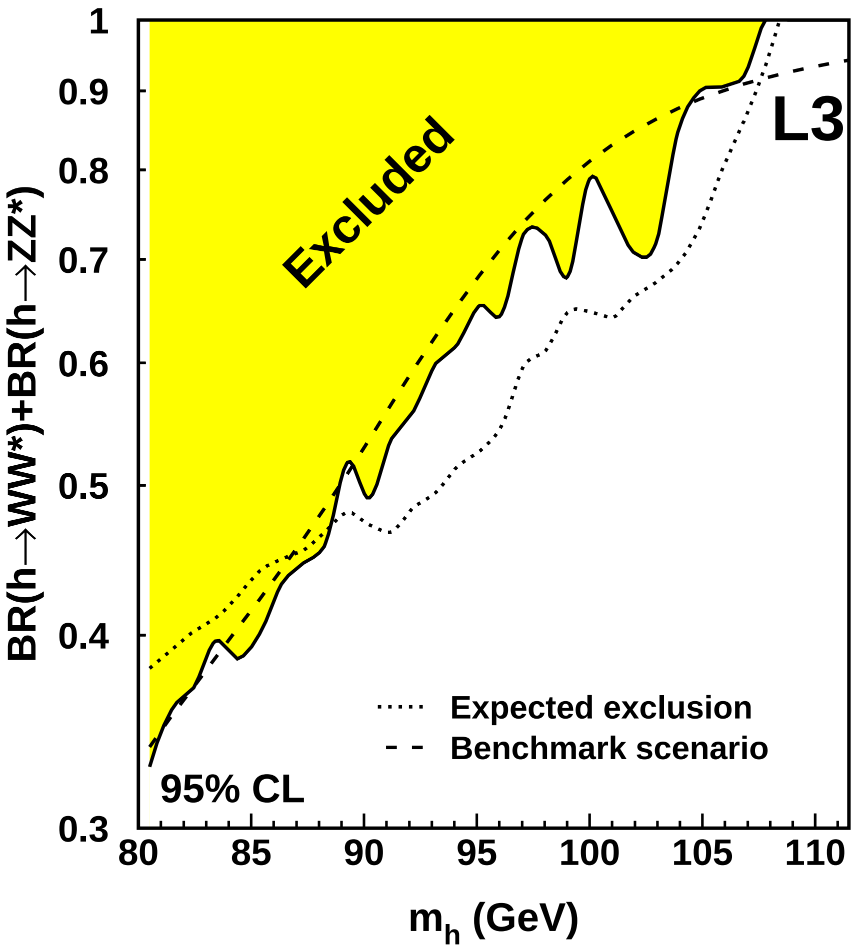
Consider Higgs which decay primarily to boson pairs $h \to VV$.

benchmark scenario: assume $\sigma_{\rm SM}$, 'turn off' all decays to fermions

$h \to \gamma\gamma$ dominates for m_h <40 GeV.

combine many channels depending on decays of Z and of V's.

$$m_h > 108 \text{ GeV}$$
for Br($h \to WW + ZZ$) =1.



Experimental Implications of Radiative Corrections

OPAL analysis of 'Higgsstrahlung,' 'Associated Production,' and 'Yukawa Production'
→ CP-conserving scenarios already well known:

$$m_h, m_A > 84 \text{ GeV and } \tan\beta \sim \mathcal{O}(2) \text{ is excluded}$$

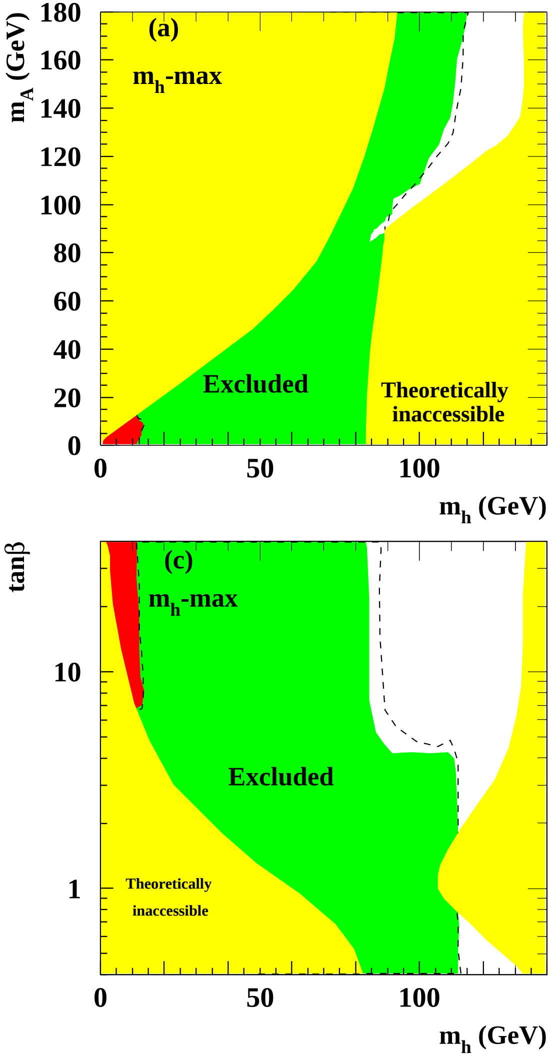
But there are some interesting special cases:

- "large μ" – $Br(b\bar{b})$ suppressed due to large negative corrections from SUSY loops flavor-independent searches are important here.
- "gluophobic" – stops and tops cancel in $g-g-h$ loops (a big problem for LHC).
- "small α_{eff}" – small $Br(b\bar{b})$, $Br(\tau^+\tau^-)$ due to additional mixing in Higgs sector

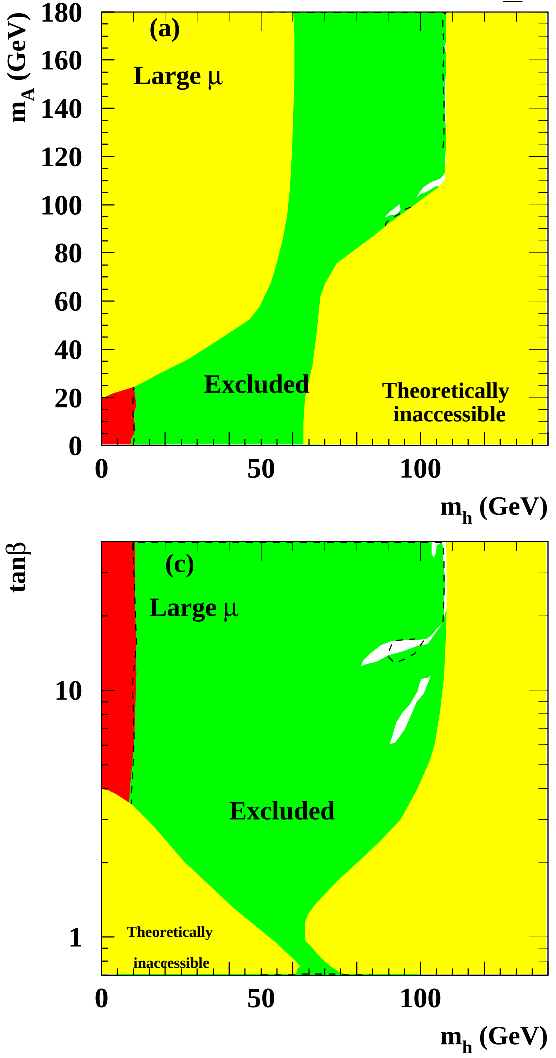
CP-violating scenario:

CP violation for MSSM higgses induced through radiative corrections (esp. $\tilde{t}_i$)

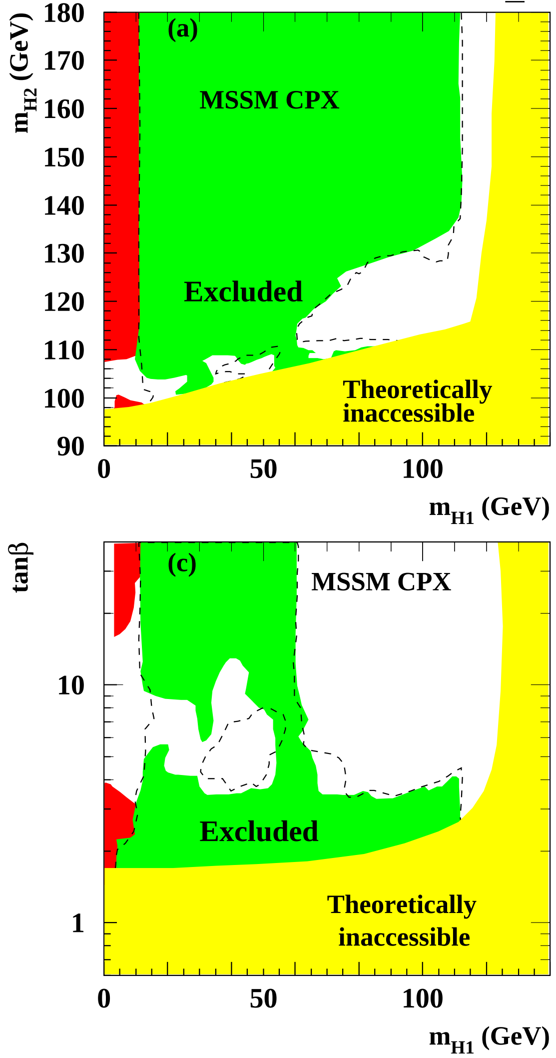
- mixing effects in Higgs sector are large when $\text{Im}(\mu A_t)$ is large and/or m_S is small.
- dramatically different phenomenology when $\arg(A_t) \sim 90°$



maximum m_h scenario



large μ scenario

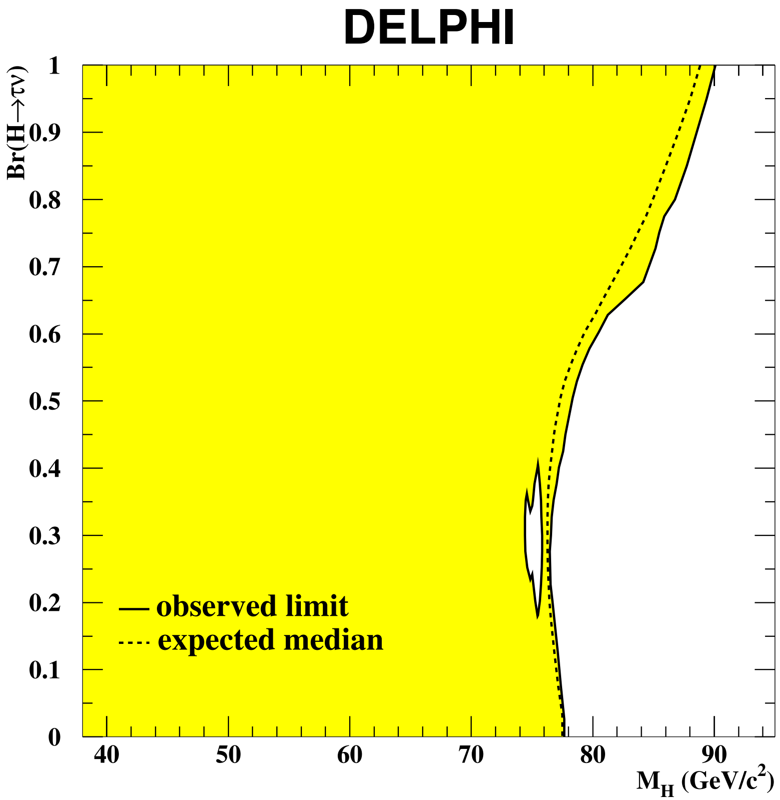


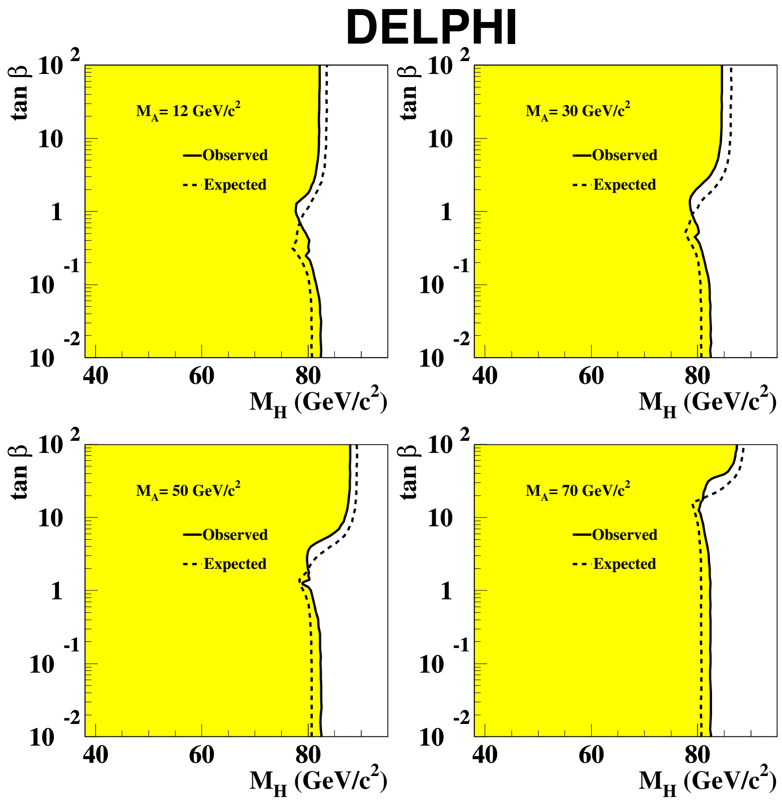
a tough CPV case

Charged Higgs Searches

general 2HDM treatment – consider $\tau\nu\tau\nu$, $cscs$, $\tau\nu cs$, W^*AW^*A and $W^*A\tau\nu$ searches very similar to $e^+e^- \to W^+W^-$ – sophisticated likelihoods used

- absolute lower limit $M_{H^\pm} > 74.4$ GeV at 95% CL
- exclusion 75–80 GeV for wide range of model parameters





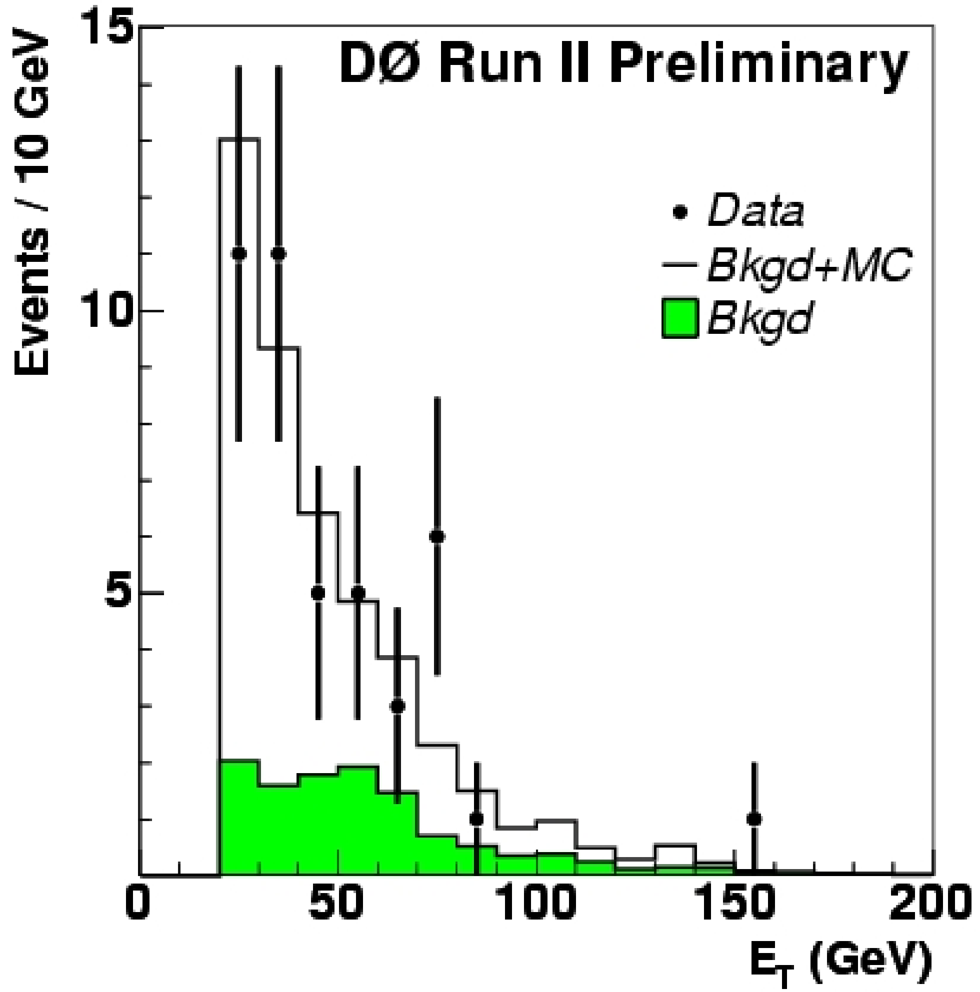
Tevatron Searches

Understanding Backgrounds

DØ: ratio of inclusive cross sections $\frac{\sigma(Z+b)}{\sigma(Z+j)}$

- select $Z \rightarrow \ell^+\ell^-$ $(\ell = e, \mu)$
- demand a tagable jet ($\sim 3/4$)
  $E_T > 20$ GeV, $|\eta| < 2.5$
- apply b-tag (scndry vtx tag)
  $\epsilon \sim 33\%$
  mistag $\sim 0.25\%$
- 27 e^+e^- + 15 $\mu^+\mu^-$ ($\sim 15\%$ bg)
- the measurement is ($\mathcal{L} \sim 190$pb^{-1})

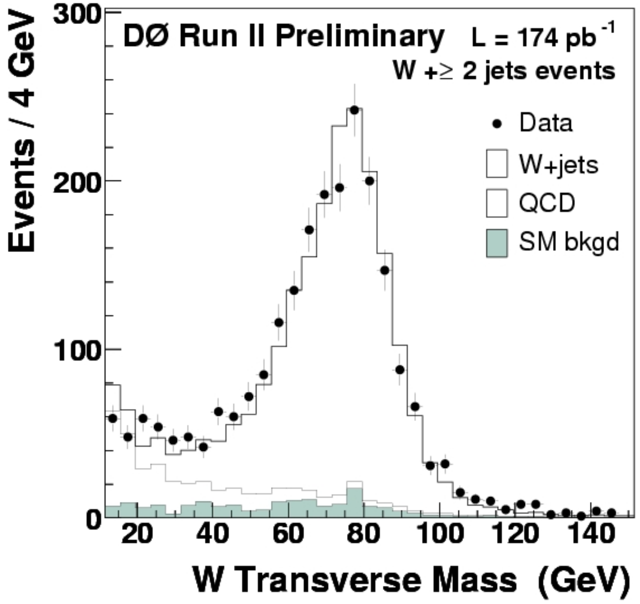
$$\frac{\sigma(Z+b)}{\sigma(Z+j)} = 0.024 \pm 0.007$$

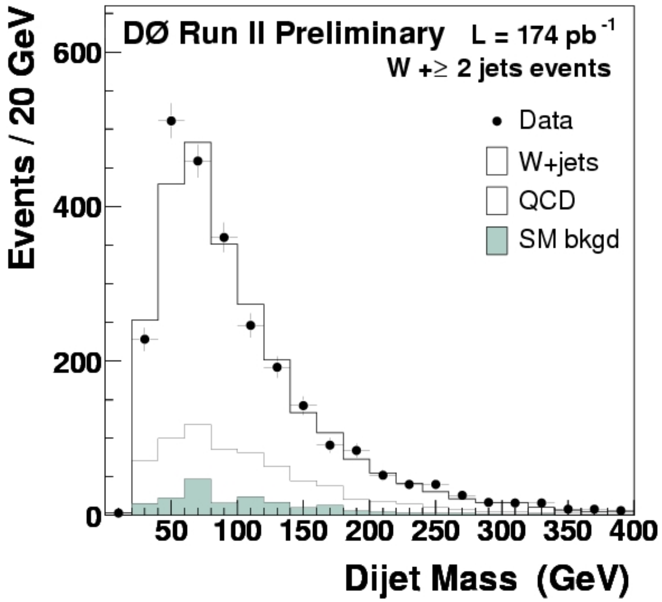


Main Channel Wh

DØ: similar approach to Wh, $h \to b\bar{b}$

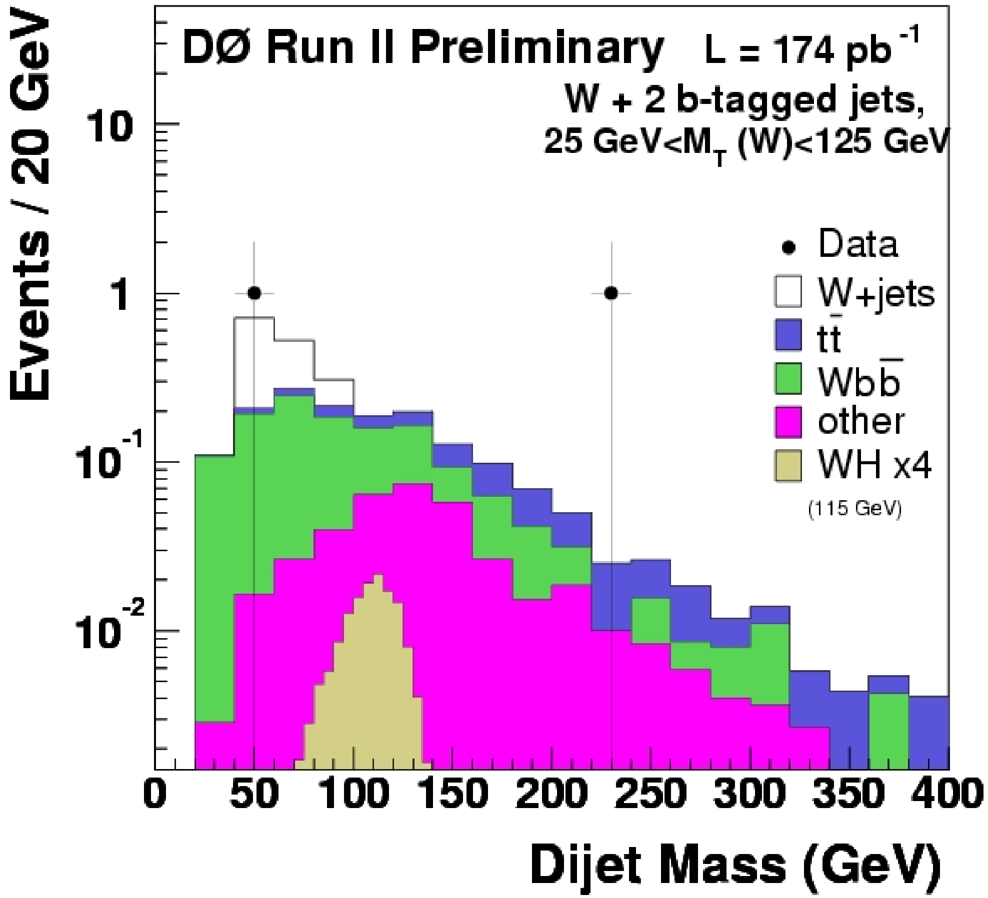
- select $W \to e\nu$, and ask for ≥ 2 jets
- good kinematic description from `ALPGEN+PYTHIA`
- require **2** b-tagged jets, for purity
- observe 8, expect 8.3 ± 2.2 events
- impose m_T cut
  observe 5, expect 6.9 ± 1.8 events
- for $\mathcal{L} = 174\text{pb}^{-1}$,
  $\sigma(Wb\bar{b}) < 20.3$ pb (95% CL)





continue cutting harder...

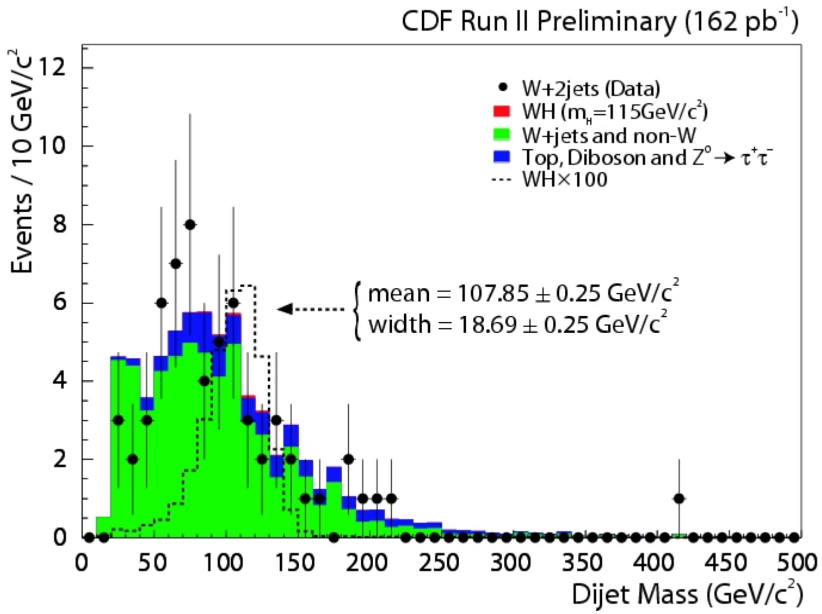
- veto 3rd jet
- demand triple-tag for two b-jets
  observe 2, expect 0.9 ± 0.4 events
  (prob(B) = 0.04, prob(S+B) = 0.23)
  must be $Wb\bar{b}$ or top
- set window for $m_h = 115$ GeV
  $\sigma(Wh) < 12.4$ pb (95% CL)

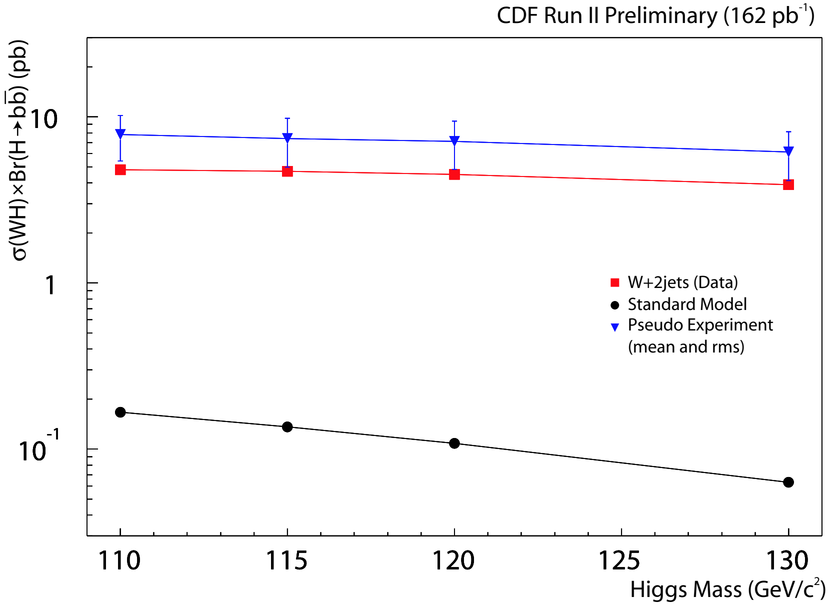


The CDF analysis:

- central electrons and muons
- $\mathcal{L} = 162 \text{ pb}^{-1}$
- require exactly 2 jets
- require ≥ 1 b-tags
- kinematic cuts optimized
- observe 62, expect 60 ± 4 events
- use binned likelihood to obtain limits

- The limit is $\sigma < 4.5$ pb at 95% CL.
- Still a factor 45 above SM.
- Backgrounds much higher than predicted by earlier studies.

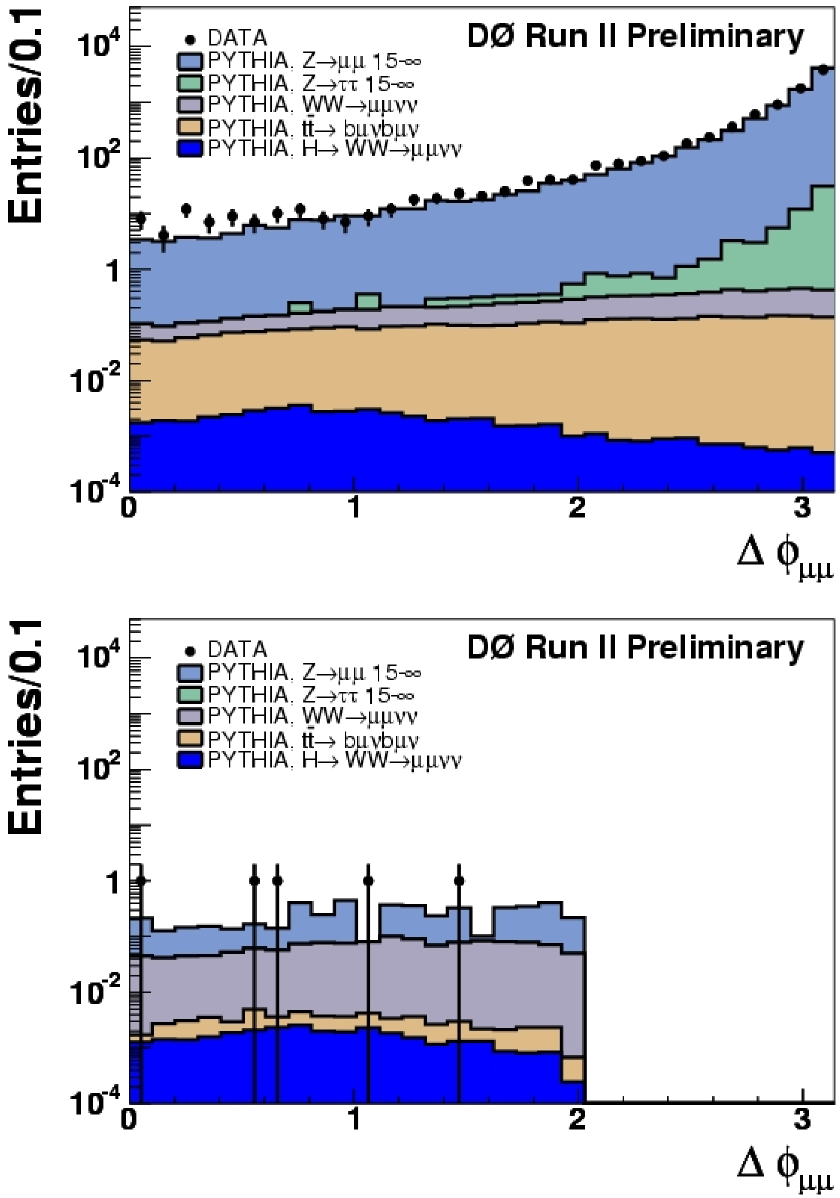




Higher Masses $h \to WW^*$

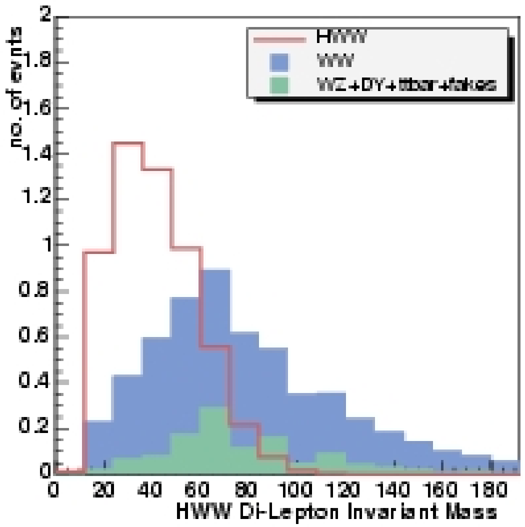
DØ is a pioneer:

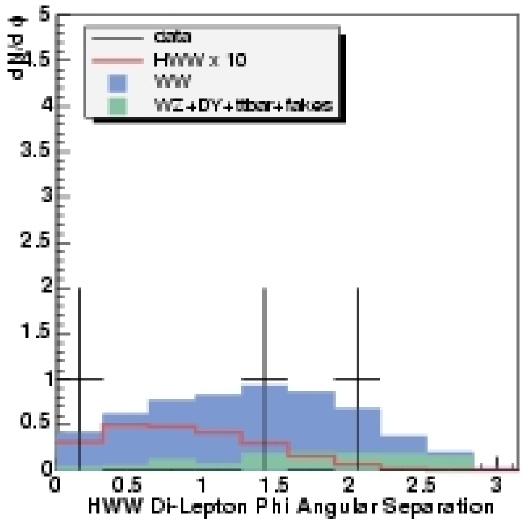
- want to find 2 W bosons
- find 2 isolated, high-p_T leptons, and demand $\not{E}_T > 20$ GeV
- apply signal-specific kinematic cuts and jet veto
- major component is continuum WW
- handful of events:
  observe 9, expect 11.1 ± 0.8 events
- upper limit is
  $\sigma < 5.7$ pb for $m_h = 160$ GeV
  $(\mathcal{L} \approx 170\text{pb}^{-1})$

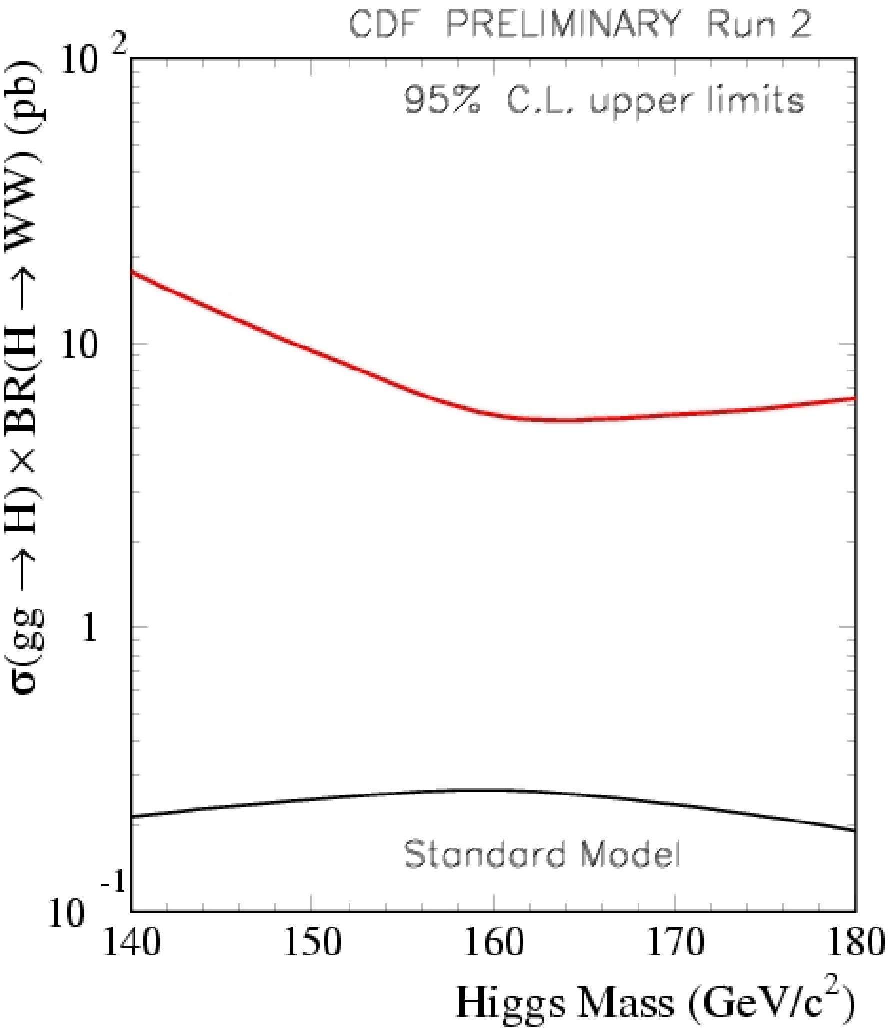


CDF: interesting differences wrt DØ

- allow no jets
- require small $M_{\ell\ell} < m_h/2$
- for $m_h = 160$ GeV,
  observe 3, expect 5.8 ± 0.6 events
- apply a binned likelihood method on $\Delta\phi_{\ell\ell}$
- for $m_h = 160$ GeV,
  $\sigma < 5.6$ pb at 95% CL



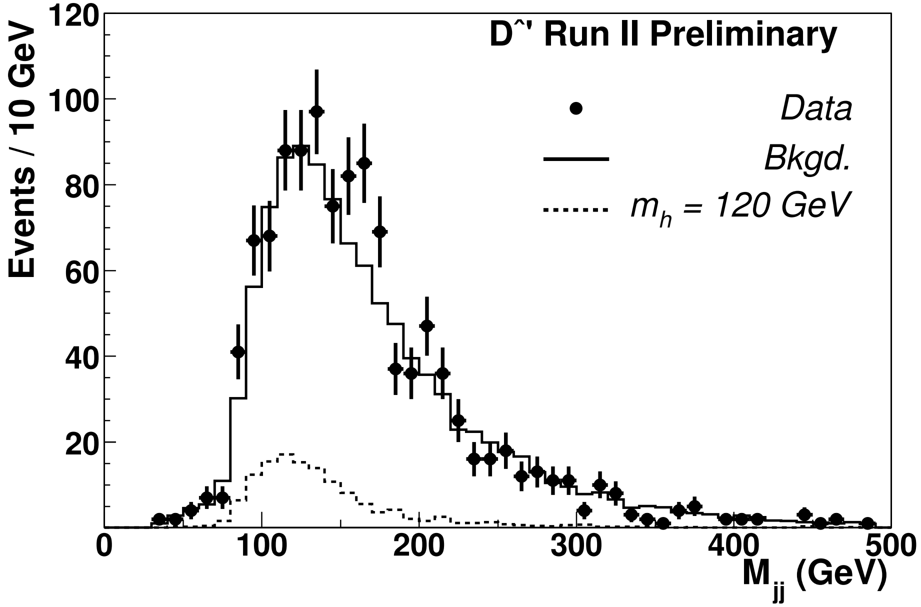


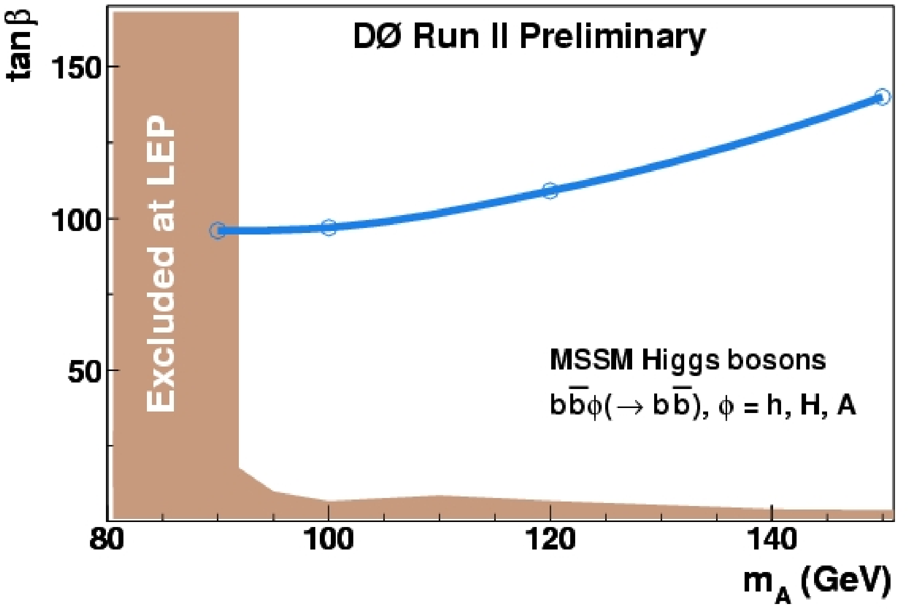


Multi-jet States

- afforded by the MSSM
- large enhancement ($\tan\beta^2$)

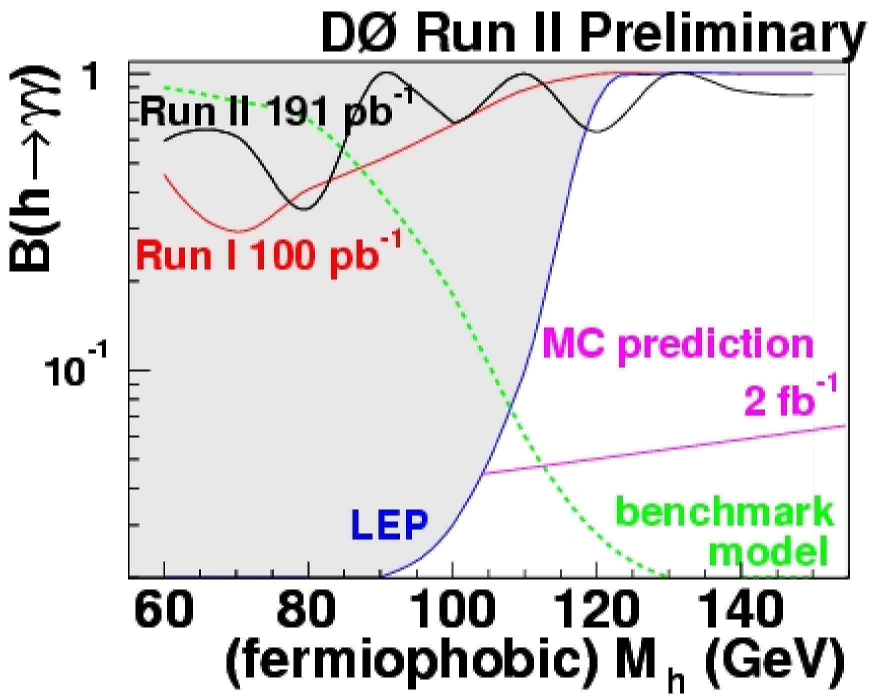
- DØ uses 130 pb^{-1} Run II data
- demand ≥ 3 jets (cuts optimized) $E_T > 15$ GeV and $|\eta| < 2.5$
- apply loose b-tag for efficiency
- compare templates to data, include contributions from A, h/H as appropriate

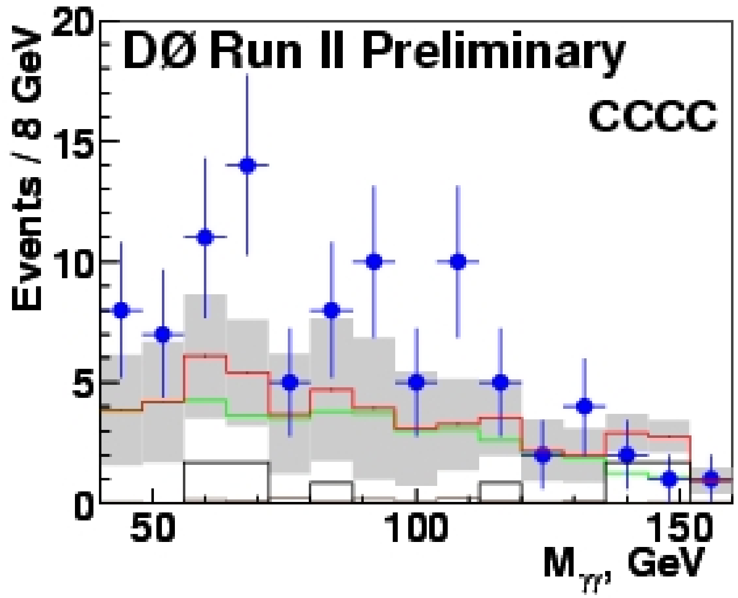


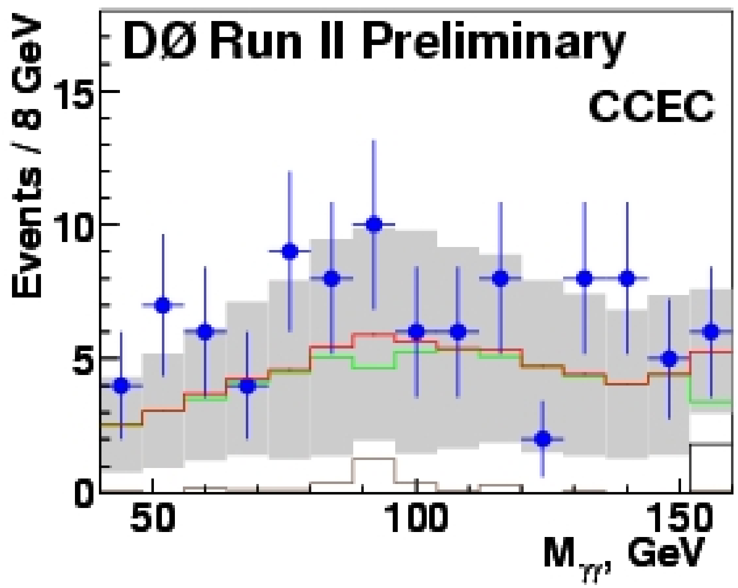


Fermiophobic Higgs → $\gamma\gamma$

- DØ uses ≈ 190 pb^{-1} of data.
- select high-E_T em clusters over a wide η range
- $p_T^{\gamma\gamma} > 35$ GeV
- count events in a mass window







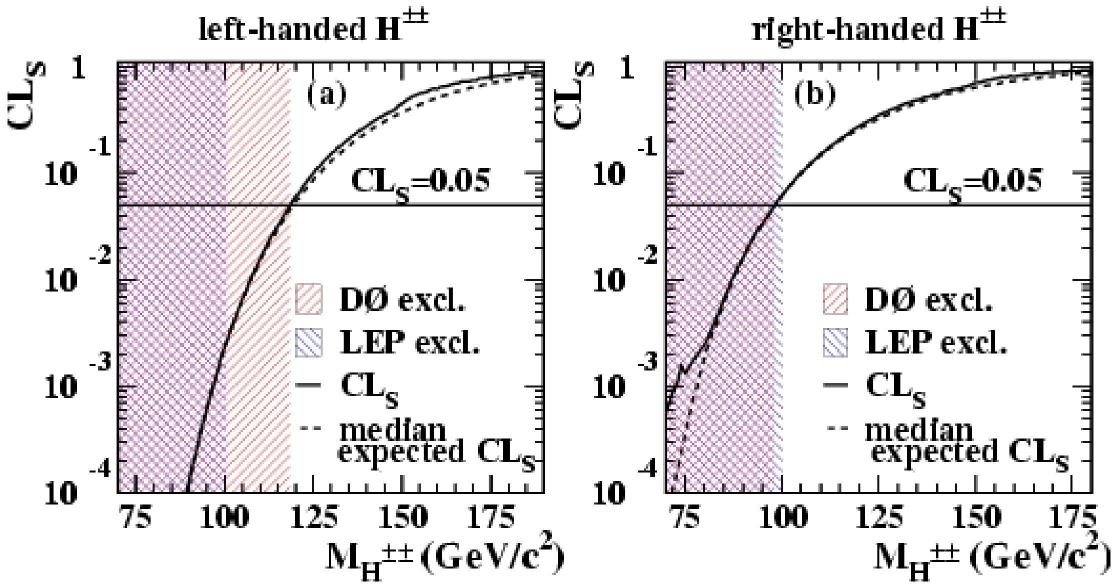
Doubly-Charged Higgs

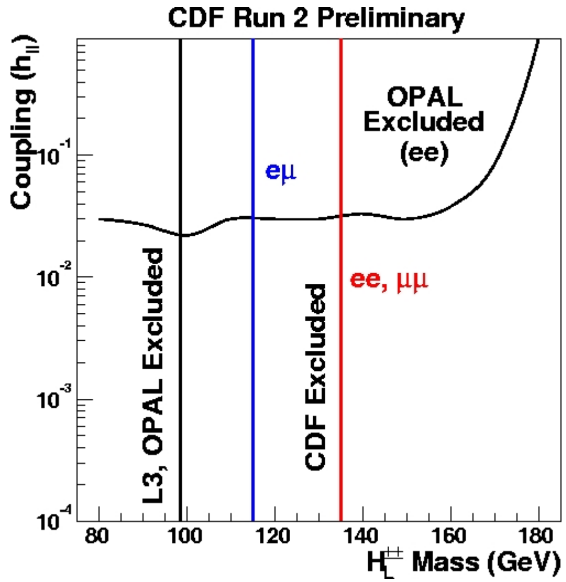
predicted in SUSY LR models focus on $H^{++} \to \ell^+ \ell'^+$

DØ	CDF
$113 pb^{-1}$ $\mu\mu$ mode only	$240 pb^{-1}$ ee, $\mu\mu$ and $e\mu$ modes

Very low backgrounds due to same-sign requirement – charge mis-ID.

DØ	CDF
observe 3, expect 1.5 ± 0.4	(ee) obs. 0, expect 1.6 ± 0.8 ($\mu\mu$) obs. 0, expect 1.0 ± 0.6 ($e\mu$) obs. 0, expect 0.6 ± 0.3
"first hadron result" (to be publ)	draft in circulation





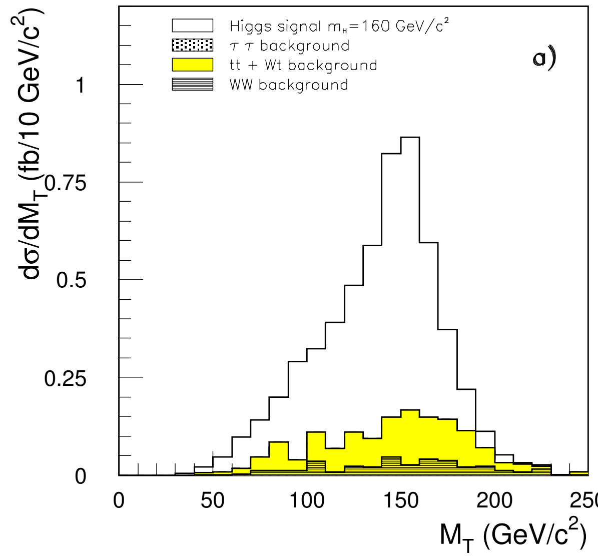
LHC & etc.

Vector Boson Fusion

New ATLAS study for SM $H \to WW^*$ and $\tau^+\tau^-$ produced via vector-boson fusion.

- VBF gives second largest cross section
- two jets in the 'forward' region in opposite hemispheres
  $\longrightarrow$ impact of pile-up carefully studied
- no central jets due to lack of color exchange between quarks
  $\longrightarrow$ careful examination of fake central jets
- basic signature is 2 forward jets and high-p_T lepton
- use $\Delta\phi_{\ell\ell}$: leptons tend to be close together
- veto b-jets

$h \to WW^* \to e\mu \not{E}_T$ very clean: S/B = 4.6 fb/1.2 fb
excellent disc'y pot'l $m_H = 160$ GeV & $\mathcal{L} = 30\text{fb}^{-1}$
can normalize $t\bar{t}$ & verify spin-0

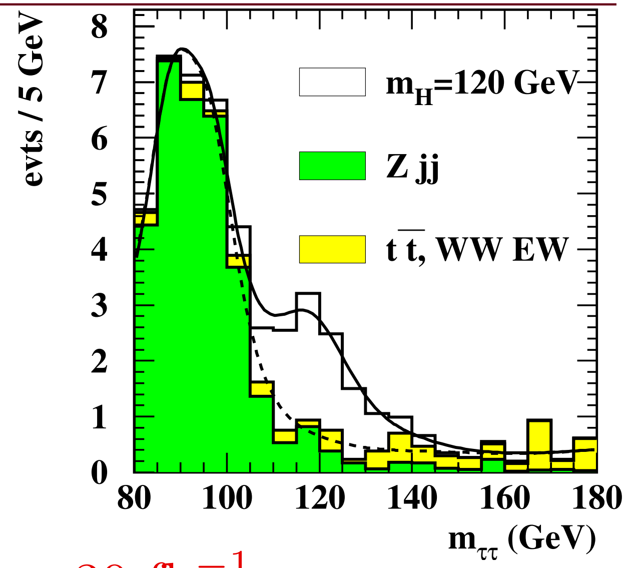


$h \to WW^* \to e$+jets more background:
more useful as cross-check

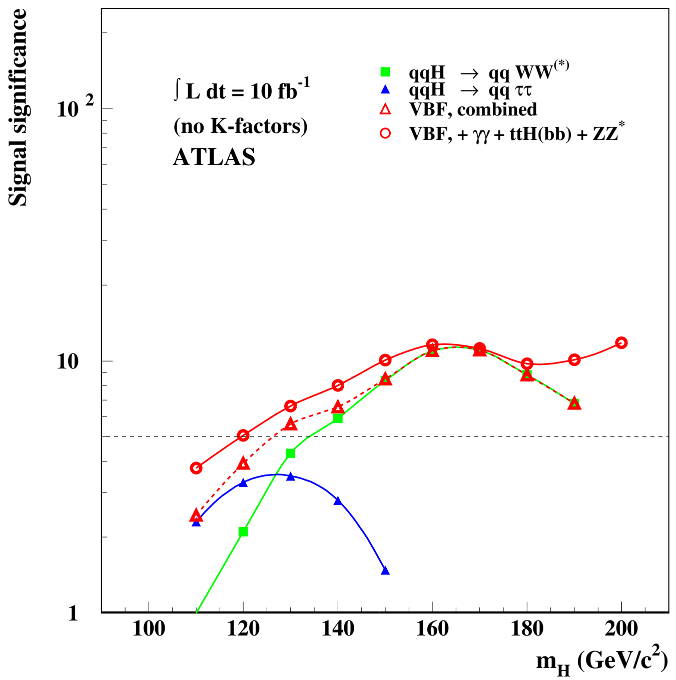
$\mathbf{h} \rightarrow \tau^+\tau^- \rightarrow e\mu \not{E}_T$ also clean
but σ(signal) very small: 0.54fb
(plot shows $\mathcal{L} = 30\text{fb}^{-1}$)

$\mathbf{h} \rightarrow \tau^+\tau^- \rightarrow \ell\ had.\ \not{E}_T$ less effective but still useful

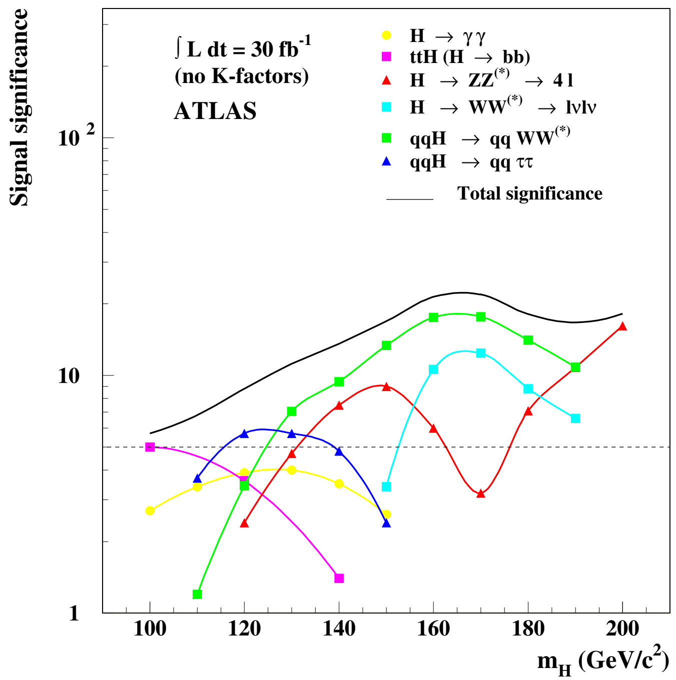
Combined: expect $\sim 5\sigma$ significance for 30fb^{-1}



10 fb^{-1}



30 fb^{-1}



Di-jet Mass Resolution

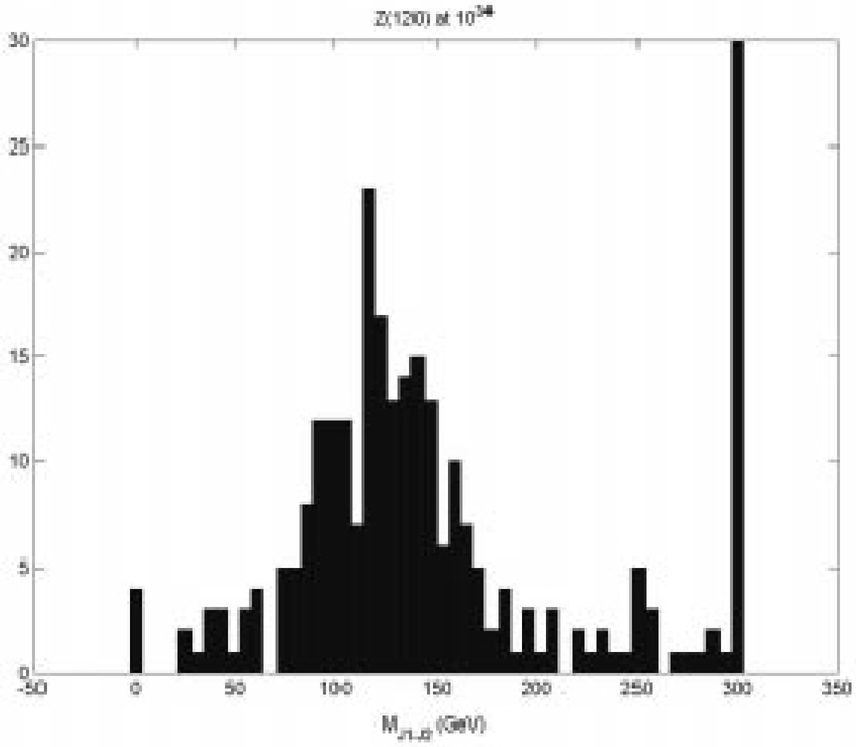
Fresh thinking (Dan Green) on the problem of di-jet mass resolution

- study impact of multiple interactions
- optimize cone size
- correct for energy registered at 90° from the main jets
  $\longrightarrow$ distinguishes jet fragmentation from pileup
- keep only the "core" energy fragments – trim soft stuff
- use the jet mass to monitor pileup (etc.)
  ad hoc correction to be tuned with MC and data

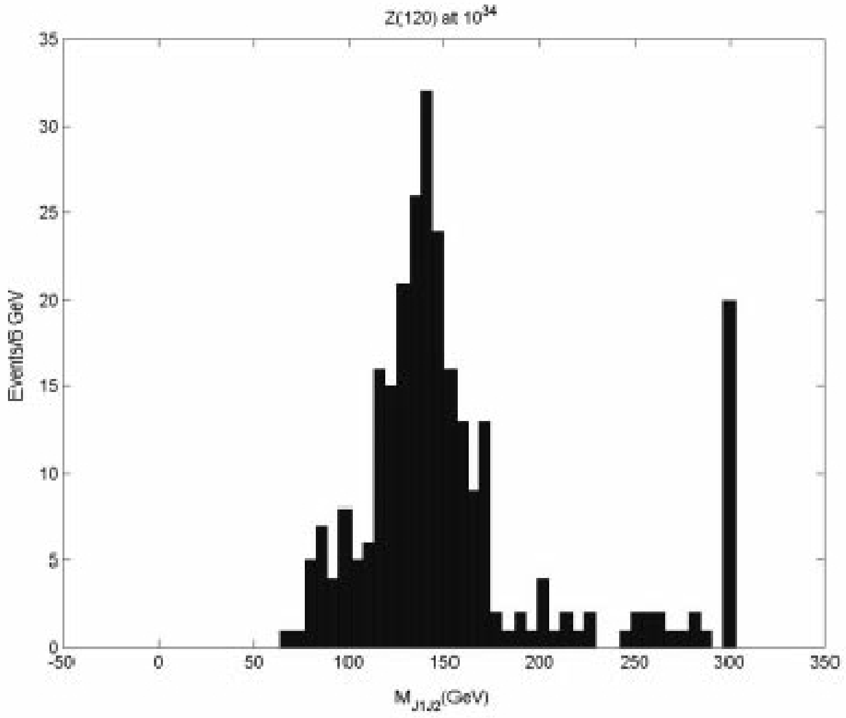
Example signal: a Z' with mass 120 GeV:

	mean (GeV)	resolution (%)
raw	124	25%
trim jet interiors	111	17%
jet mass corr.	138	13%

before



after



NMSSM Higgses at a $\gamma\gamma$ Collider

After so many tiny signals requiring so much luminosity, here is the possibility of a Higgs factory!

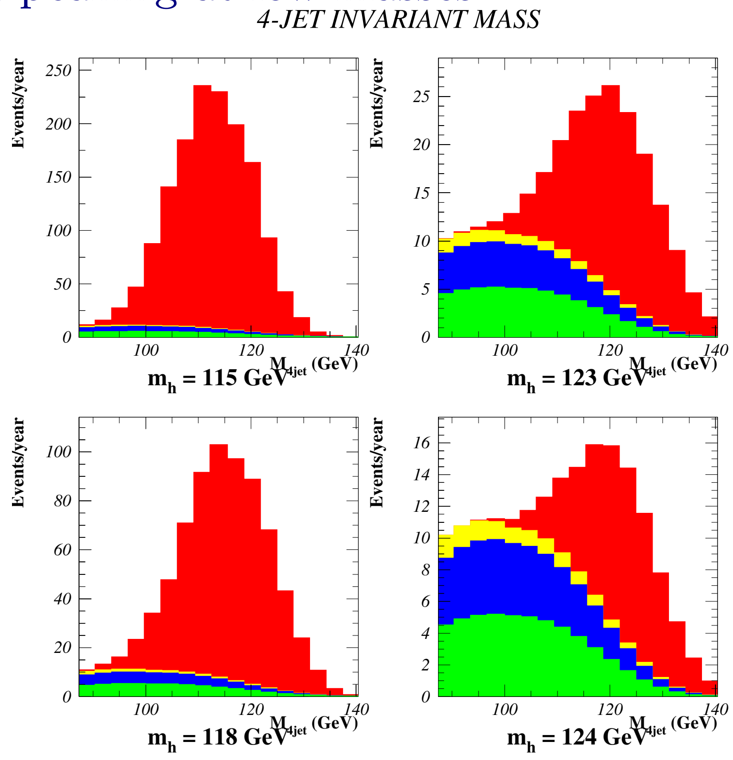
- NMSSM extends MSSM Higgs sector by one more scalar, releases mass relations.
- decays such as $h \to aa$ can dominate ($a \to b\bar{b}$)
- explore using a low-energy $\gamma\gamma$ collider – an early CLIC demonstration!
- study $b\bar{b}\,b\bar{b}$ and $b\bar{b}\tau^+\tau^-$ channels with realistic beams, fast detector simulation.
- main backgrounds are $\gamma\gamma \to 4$ fermions, peaking at low masses

with a peaked beam spectrum:

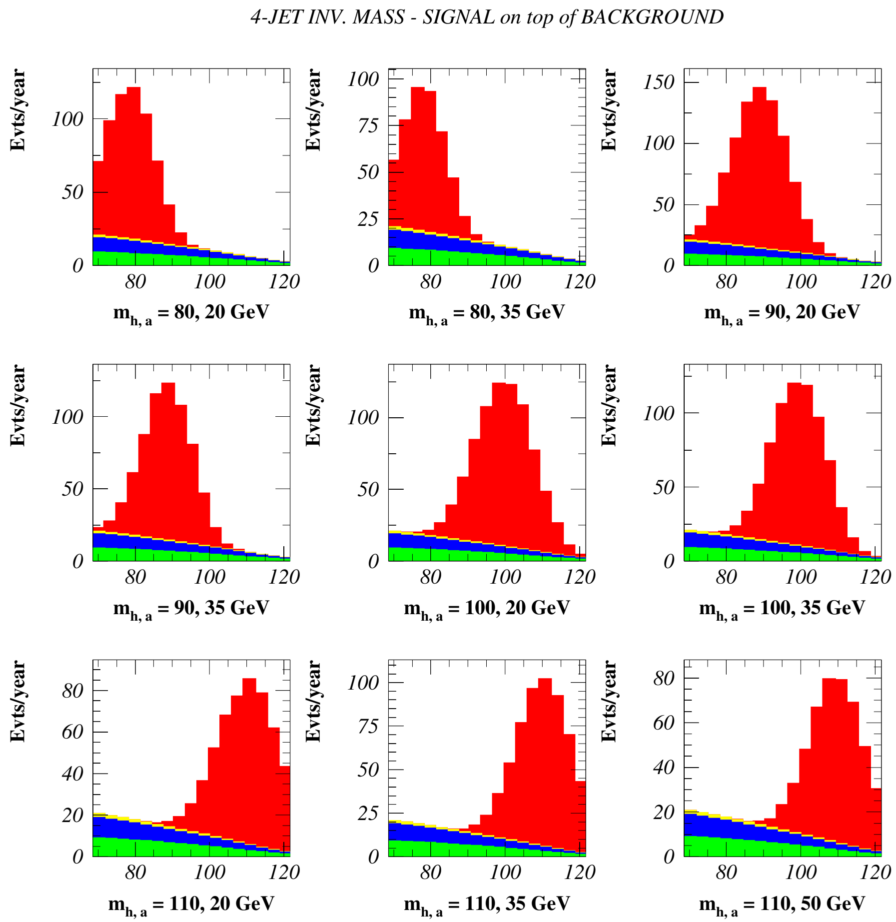
		events/year	
m_h	m_a	$b\bar{b}\,b\bar{b}$	$b\bar{b}\,\tau\tau$
115	56	1390	56
118	41	635	92
123	35	147	20
124	59	71	4.5

The yields are startling!

(Michal Szleper / NWU)

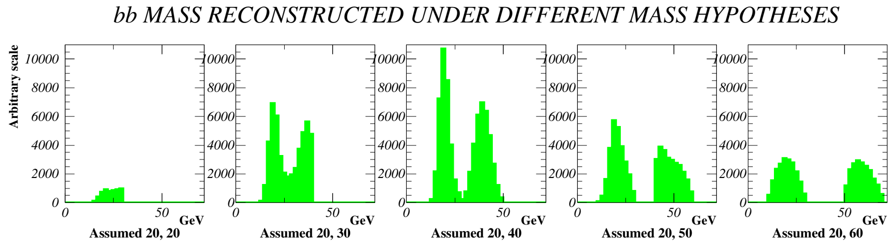


If one does not know the right Higgs mass, then run in the 'broad-band' mode which sweeps across $\sqrt{s_{\gamma\gamma}}$.



A good signal is obtained for a wide range of masses.

A clever filtering technique for $h \rightarrow a_1 a_2$ for dissimilar masses.



Concluding Remarks

the news is good...

- Higgs physics is broadening!

  $\longrightarrow$ very sophisticated and well executed LEP analyses

- Tevatron Higgs physics is taking off!

  $\longrightarrow$ far away from expected signals, but real work has begun

- The future looks wild and wonderful!

  $\longrightarrow$ best LHC channel is purely leptonic $h \to \ell\nu\ell'\nu'$!

  $\longrightarrow$ lots of imagination in long-term studies