Searches for New Phenomena at OPAL at $\sqrt{s} = 189$ GeV

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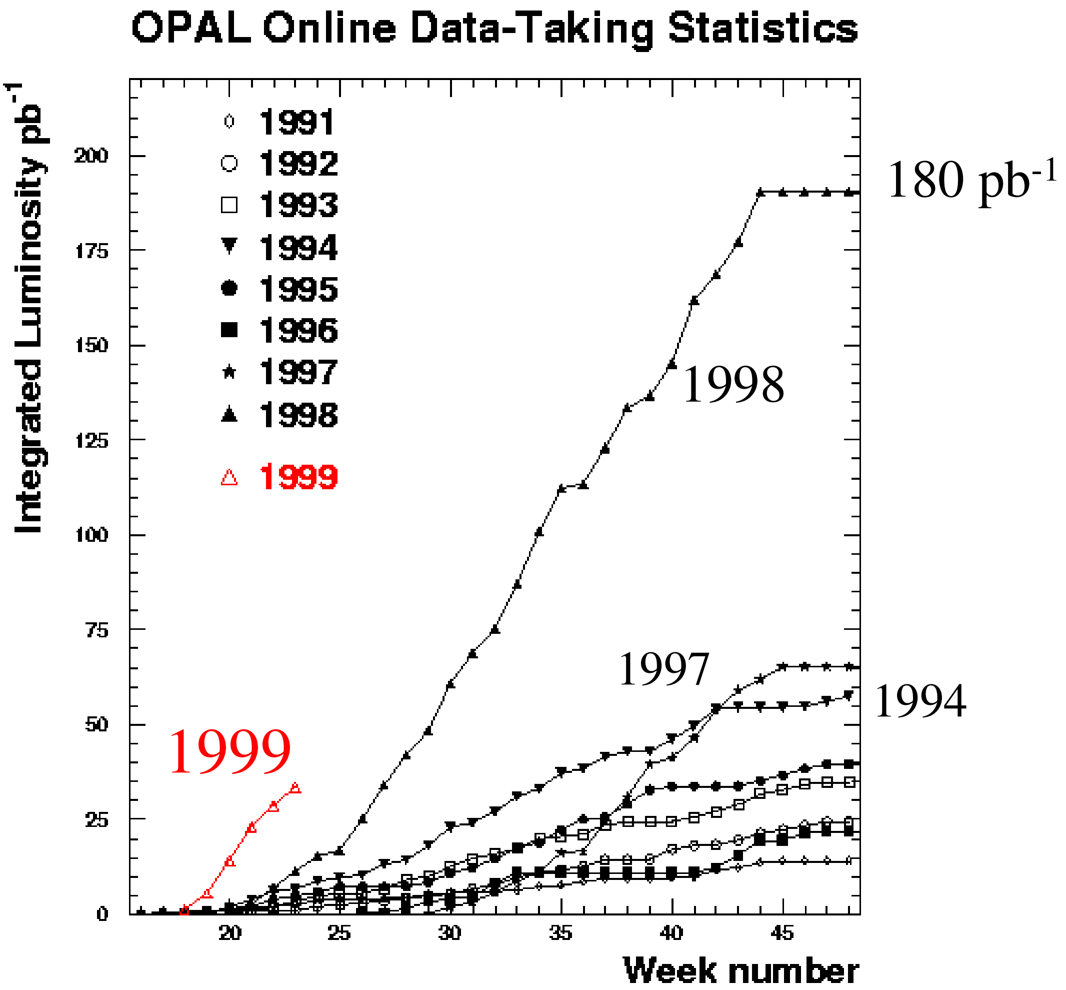
for the

OPAL Collaboration

- LEP2 Performance
- Higgs Searches in the Standard Model and the MSSM
- SUSY Searches
  - Chargino and Neutralino
  - Stop and Sbottom
- Extra Dimensions for Gravity

LEP2 Performance



Running Period	$\sqrt{s}$ (GeV)	$\int L dt$ per exp't
1989-1995	$\sim m_Z$	~160
1995+1997	130,136	~ 12
1996	161,172	~ 20
1997	183	~ 60
1998	189	~180
1999	192,196,(200)	~150?
2000	~200	~200?

LEP2 Performance

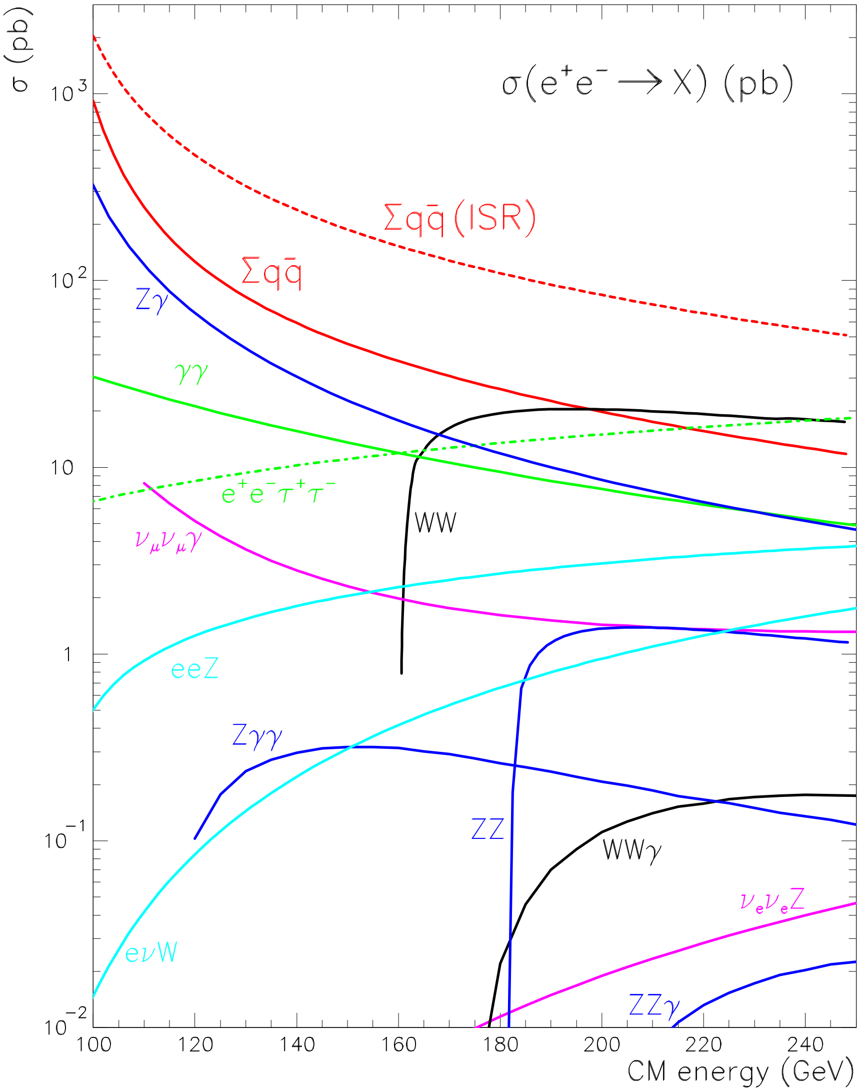
This Year:

- 3150 MV of RF
- 72 Superconducting Cavities
- Upgraded cryo plant -- cryo no longer a limitation
- Single beam accelerated to 100 GeV/beam
- Routine running at 98 GeV/beam
- 192, 196 GeV preliminary results available at EPS99 (Tampere), and Lepton-Photon 99 (Stanford)

Next Year:

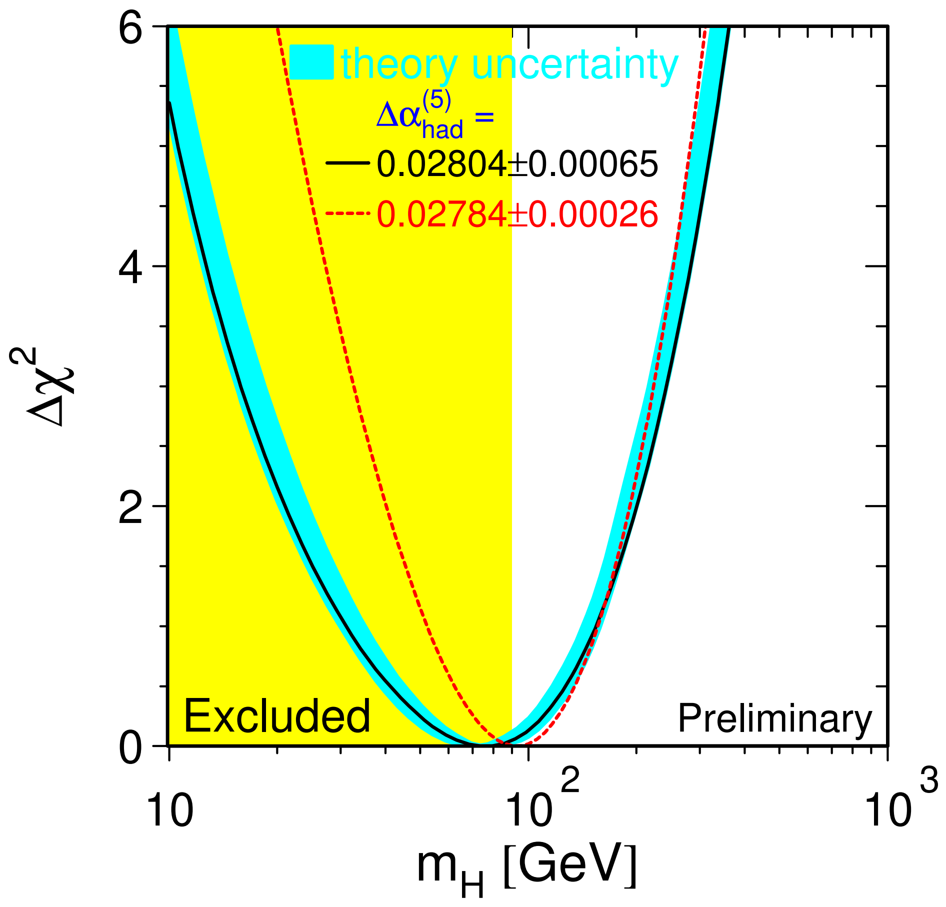
- No more RF, but thinking about how to extend the reach
- Increased bending -- dipole coils near quads (offset quads=dipoles? unlikely)
- More stable; less LHC civil engineering

Standard Model Processes in e^+e^- Collisions at High Energy



- Four-Fermion Backgrounds, W^+W^- and especially Z^0Z^0 are important to Higgs/SUSY searches. $\sigma \sim 20$ pb (W^+W^-), 1 pb (Z^0Z^0)
- Two-photon processes have *large* cross-sections -- more important for SUSY searches with small Δm (to be explained later)

Estimation of the SM Higgs Mass from Electroweak Measurements



- Logarithmic sensitivity to $\sin^2\theta_W$

  Current central value:

$$\boxed{m_H = 76^{+79}_{-43}\ \text{GeV}}$$

- 95% CL Upper limit

$$m_H < 230\ \text{GeV}$$

Some *a priori* Limits

- m_H < ~1 TeV: strongly-interacting, non-perturbative Higgs sector
- m_H < 550 GeV, Custodial Symmetry and the Triviality Bound

  Chivukula, Simmons, *Phys. Lett*. **B388**, 788 (1996)

- m_H > ~120 GeV in the SM, assuming there is *no new physics up to the Planck scale*

  -- Vacuum stability argument

  Casas, Espinosa, Quirós, *Phys. Lett*. **B342**, 171 (1995)

- m_h < ~140 MeV for the lightest CP-even Higgs in the MSSM.

  Casas, Espinosa, Quirós, *Nucl. Phys*. **B436**, 3 (1995)

- Is this more evidence for supersymmetry? We'll believe it when we see it!

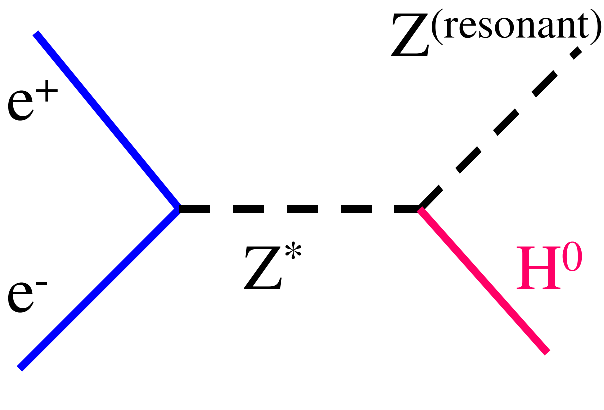
  Meanwhile, ….

  Let's go Searching!

Standard Model Higgs Production

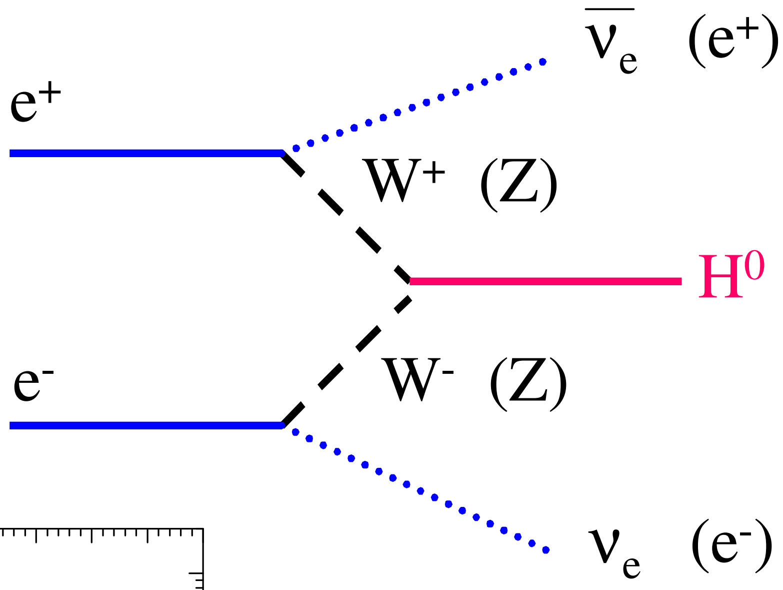
"Higgs-Strahlung"
(BJ process)

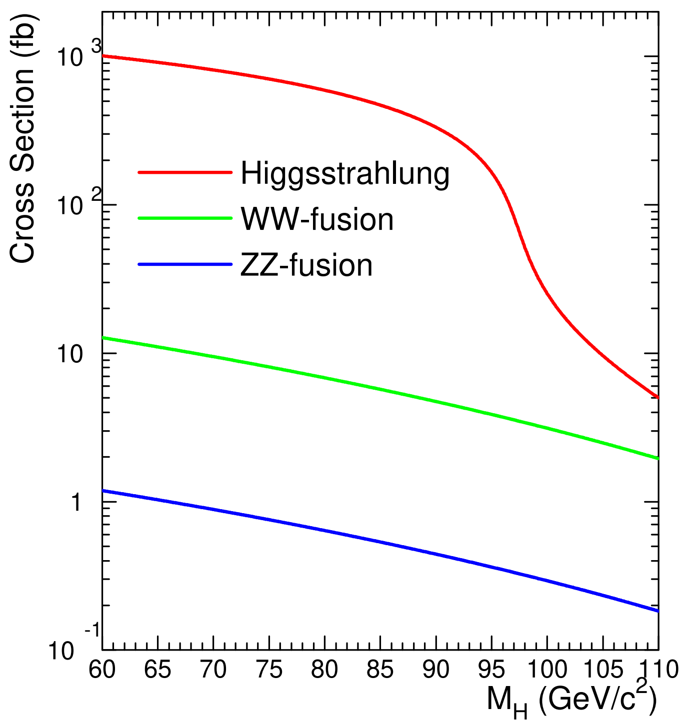
Has a kinematic cutoff at $\sqrt{s} - m_Z$



"Fusion"

"No" kinematic cutoff, but low cross-section

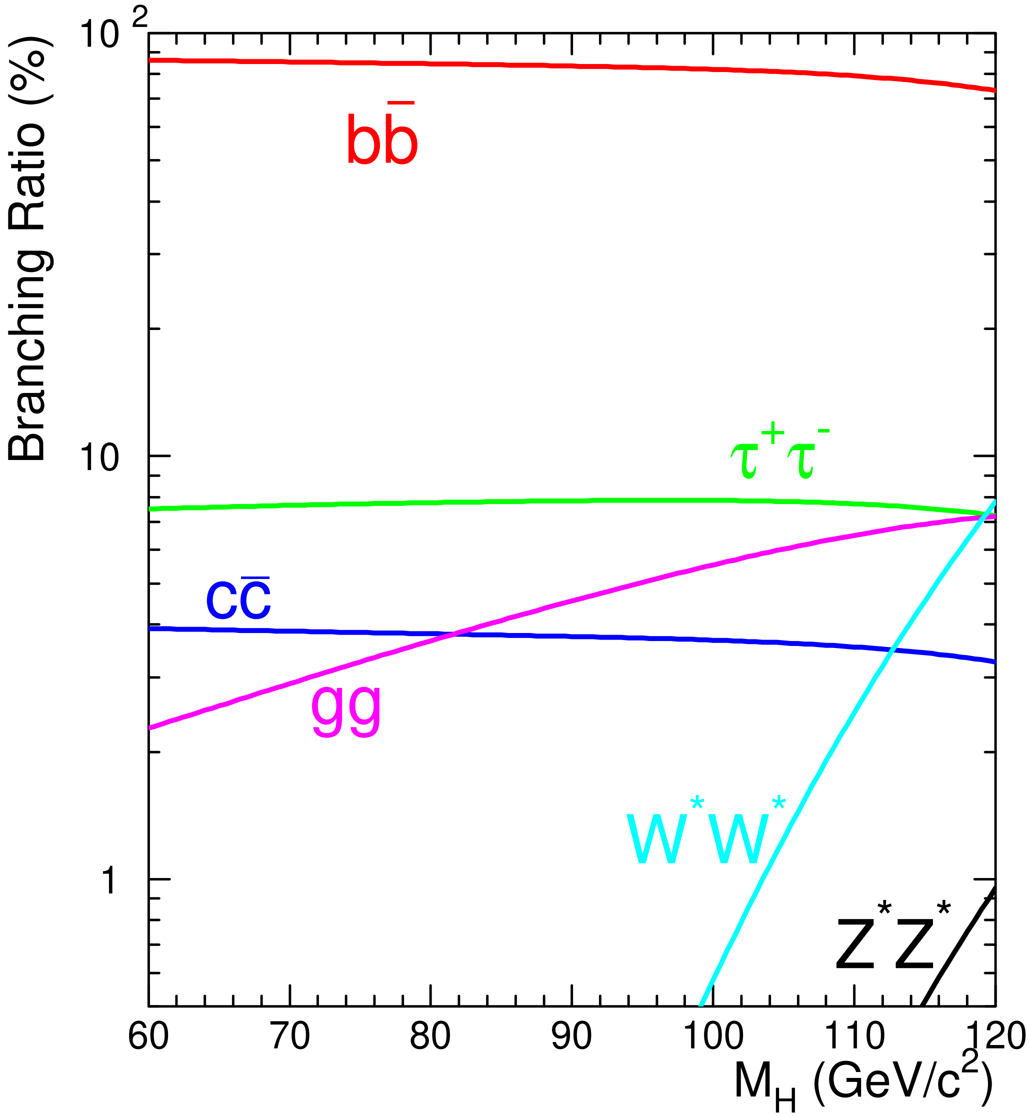




At $\sqrt{s} = 189$ GeV for a 95 GeV Higgs, σ=170 fb.

Expect ~30 events in 1998 data at OPAL

Standard Model Higgs Decays



For a 95 GeV Higgs,

$$\mathrm{Br}(H^0 \rightarrow b\bar{b}) \cong 84\%$$

$$\mathrm{Br}(H^0 \rightarrow \tau^+\tau^-) \cong 8\%$$

$$\mathrm{Br}(H^0 \rightarrow g\bar{g}) \cong 5\%$$

$$\mathrm{Br}(H^0 \rightarrow c\bar{c}) \cong 3\%$$

B-tagging is critical for all searches!

B-Tagging for Higgs Searches at OPAL

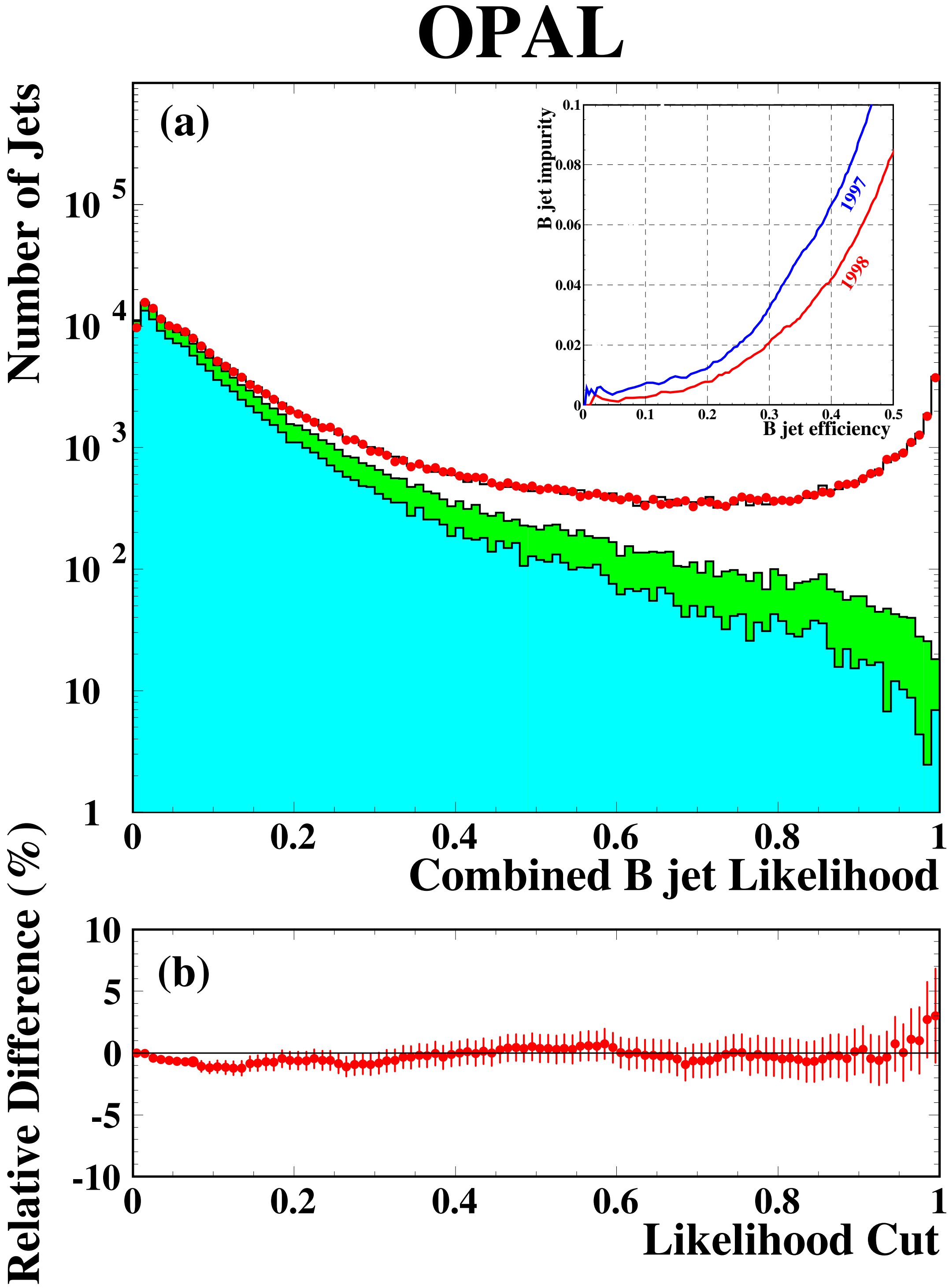
- B-tagging done for each jet in the event
  - Displaced Vertices
  - High (p,p_t) leptons
  - Kinematic Variables in a Jet
- B-tag variables combined with a Likelihood

- *Improved Vertex Finding*
  - Neural Net to order tracks as primary-like or secondary-like
  - Tear-Down, then Build-Up to get a pure vertex
  - Vertex likelihood based on L/σ_L
  - Impact parameter likelihood $\mathcal{L}_{IP}$
  - "Reduced" $\mathcal{L}_{VTX}$, $\mathcal{L}_{IP}$ omitting most significant track -- less sensitivity to mismeasured tracks
  - Variables combined in a Neural Net

- Jet kinematic variables also improved

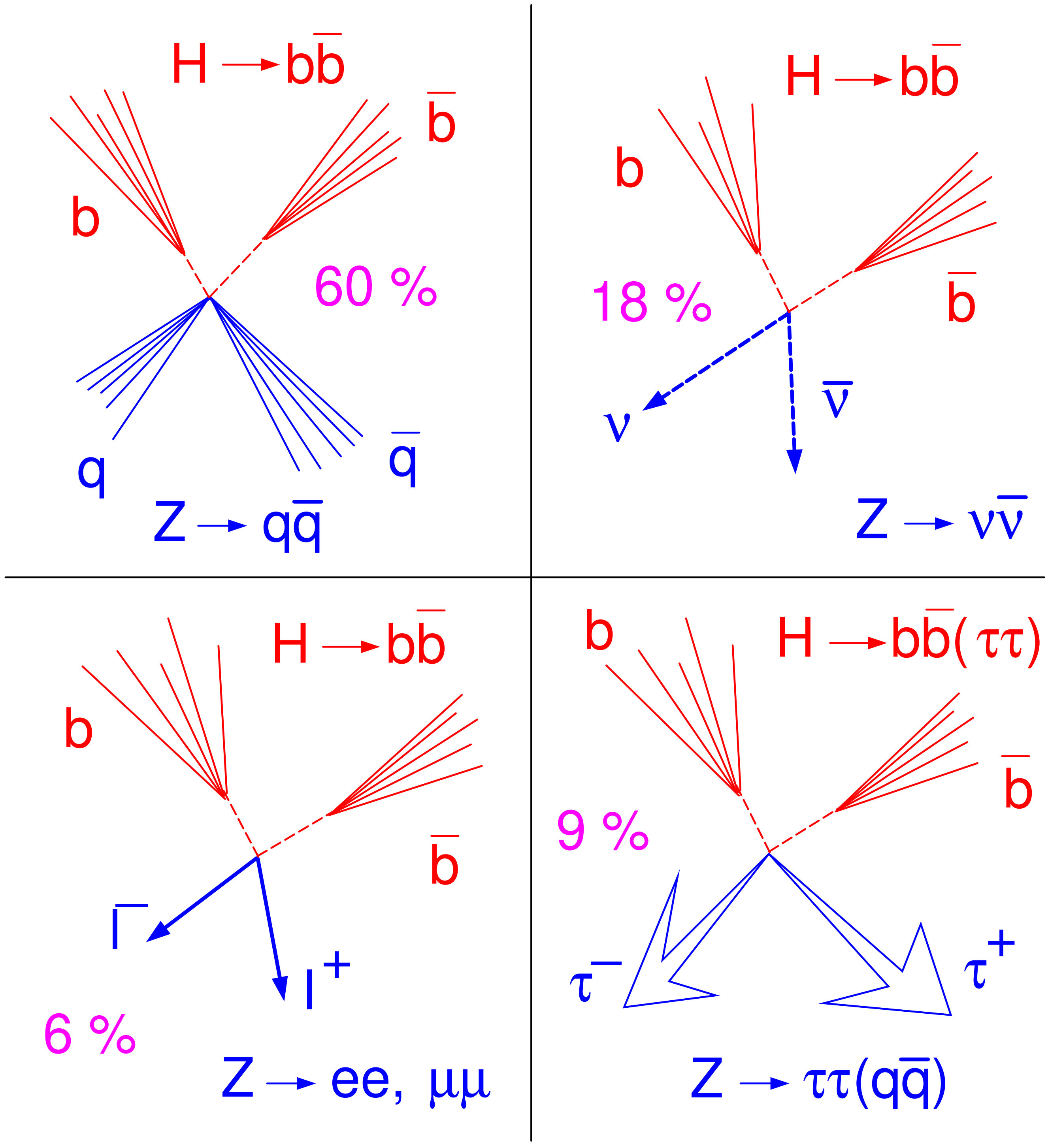
B-tag Performance

- Evaluated using the Z^0 calibration data for the same year (1998). Split between the beginning of the run and the end.
- B hadron momentum spectrum similar in Z^0 decay as in H^0 decay if m_H~91 GeV.



Standard Model Search Channels

Each Higgs search channel is named after the Z^0 decay mode.



The Four-Jet Channel

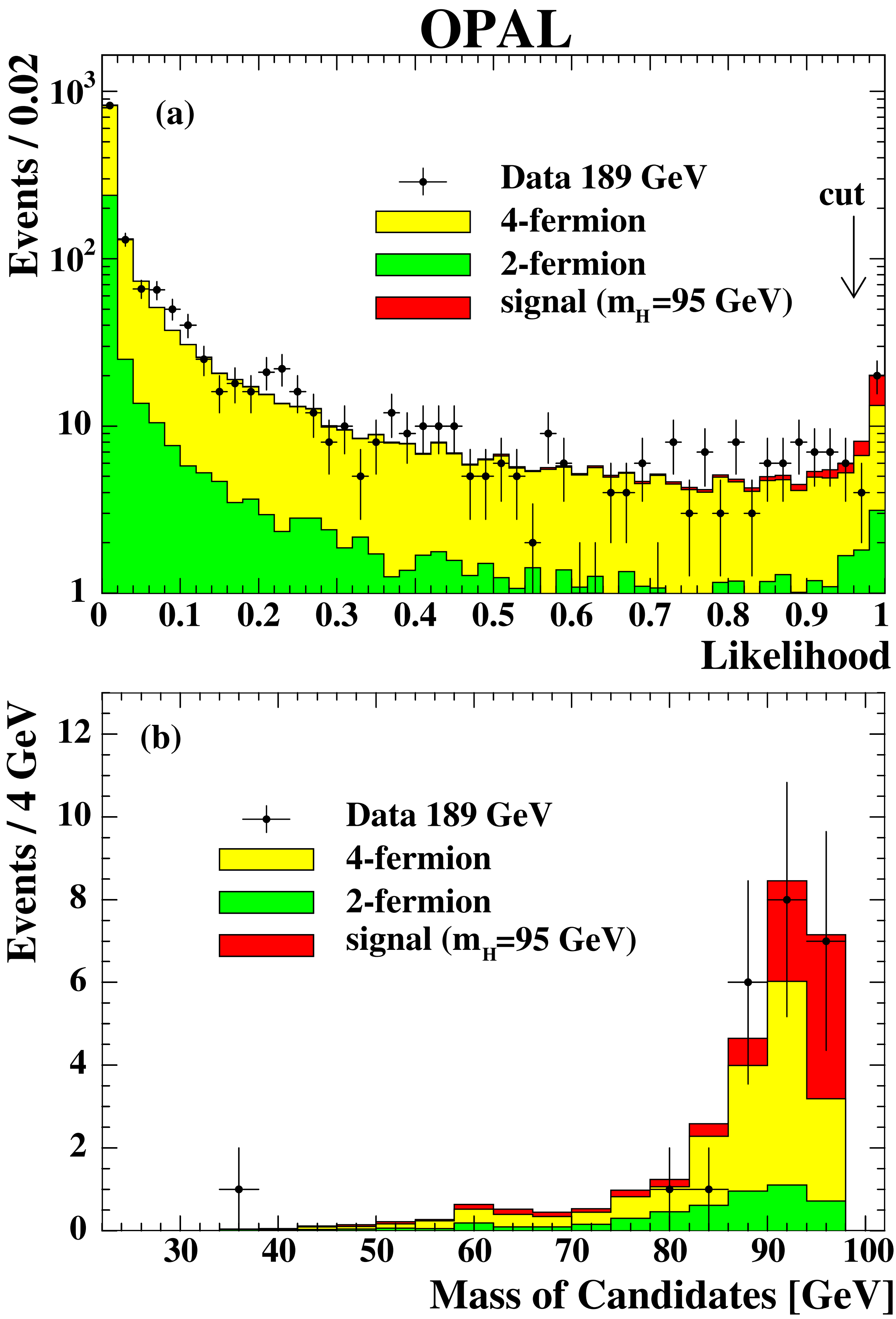
- *New particle-jet association*
  Durham seed-jets, then reassociate all tracks and clusters based on E0

- *New association of jets to* H^0 *and* Z^0
  - Uses P_{5C} and B-tag information
    $$(H^0 \to b\bar{b}, \quad Z^0 \to q\bar{q})$$
  - Likelihoods for
    - Correct
    - Swapped -- Z^0Z^0 bkg. here!
    - Others
  - For m_H=95 GeV, $P_{correct}$=71% (was 36% just with P_{5C})

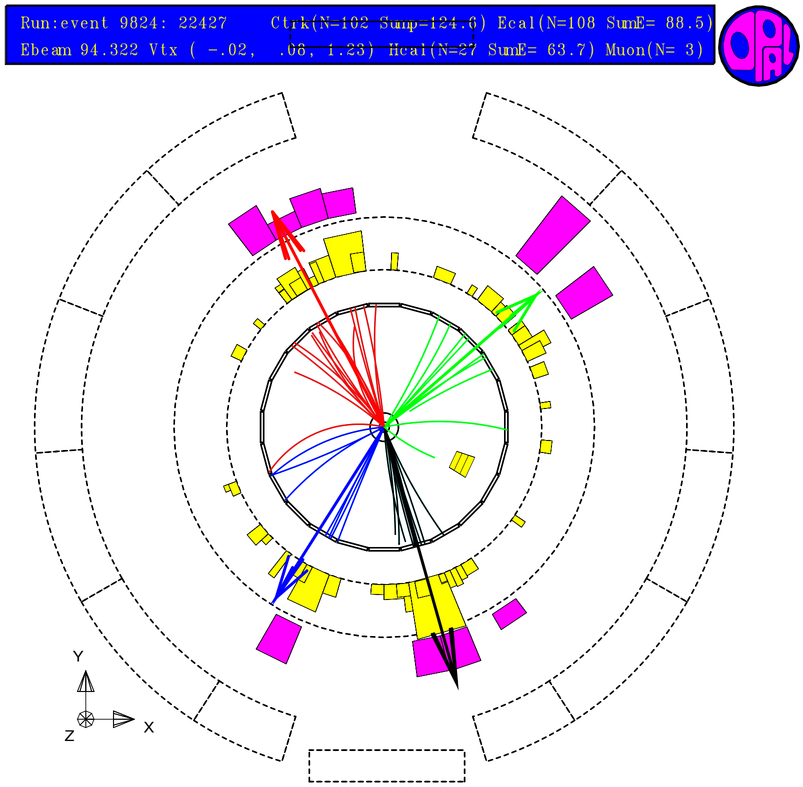
- Likelihood formed for B-tag, kinematic variables and cut on

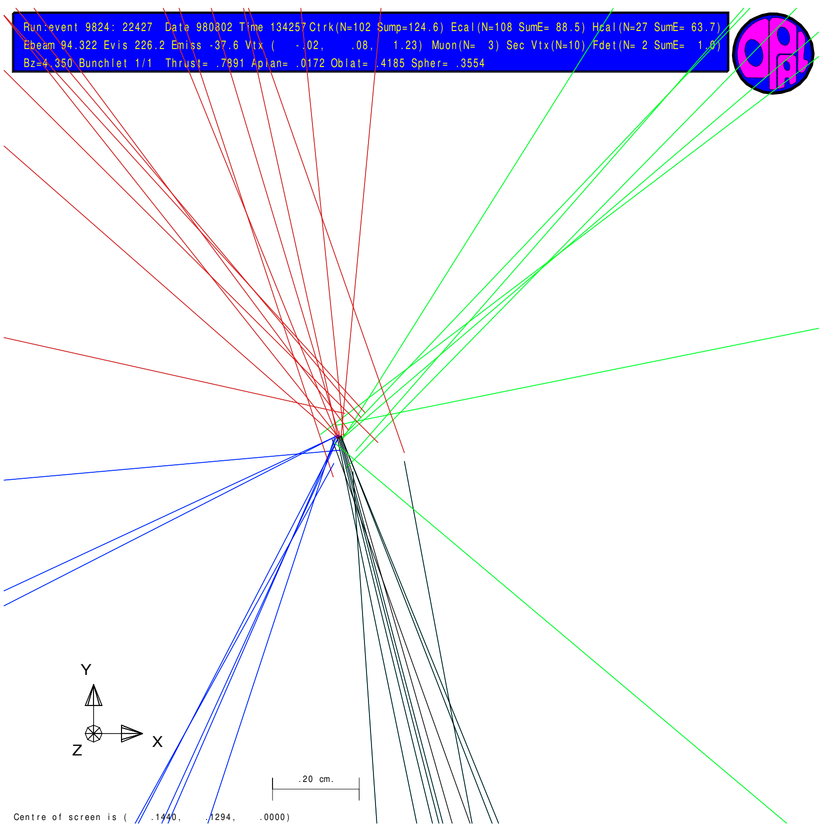
$\varepsilon = 47 \pm 2\%$ (for m_H=95 GeV)
SM backgrounds 19.9 ± 3.0
Candidates: 24

Four-Jet Channel



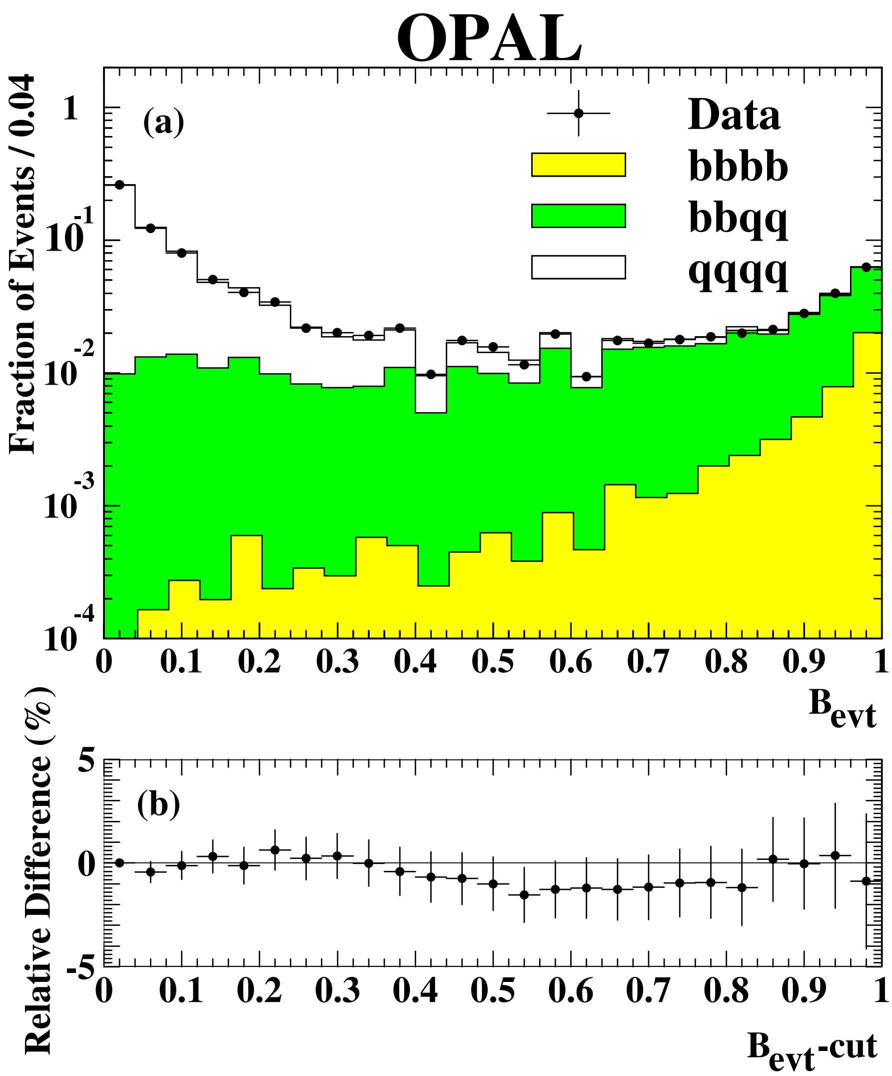
A Four-Jet Candidate





Testing the B-Tag with Overlaid Z^0 Events

- Very similar to the Z^0Z^0 background (and to the signal!)
- Tests if the B-tag is mismodeled in a dense 4-jet environment
- Use only the B-tag variables to form likelihood in data and MC for Z^0 events.
- Modeling is good to ±2%

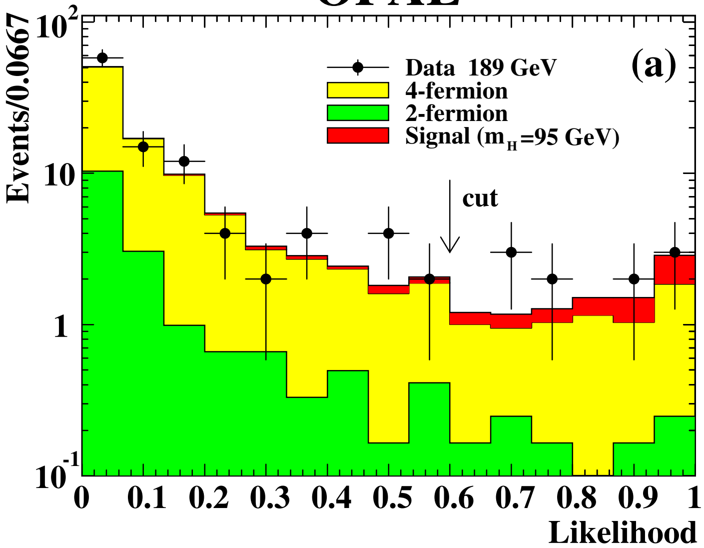


The Missing-Energy Channel

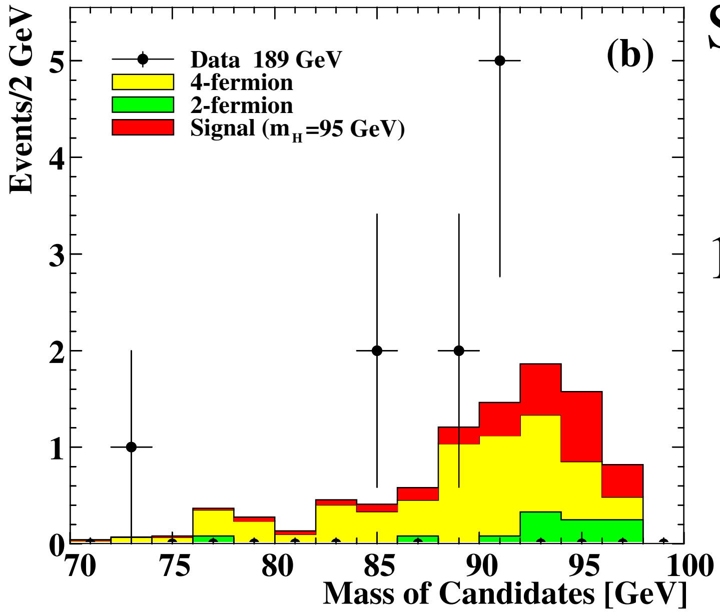
$$\boxed{H^0 \rightarrow b\bar{b}, \quad Z^0 \rightarrow \nu\bar{\nu}}$$

- B-tagging, Missing p_t, and lack of a high-energy lepton (to suppress $W^+W^- \rightarrow q\bar{q}\ell^-\bar{\nu}$ background)
  Need to take the lepton part out of the b-tag!

OPAL



For a 95 GeV Higgs,
ε = 35.4 ± 1.3%



SM bg: 6.9 ± 0.8 Events

10 Candidates

Tau and Lepton Channels

Tau Channel: really two channels

$$H^0 \rightarrow \tau^+\tau^-, \quad Z^0 \rightarrow q\bar{q}$$
$$H^0 \rightarrow b\bar{b}, \quad Z^0 \rightarrow \tau^+\tau^-$$

Both use likelihoods based on tau ID.
Only one requires B-tagging. Different Z^0 mass constraints in each.

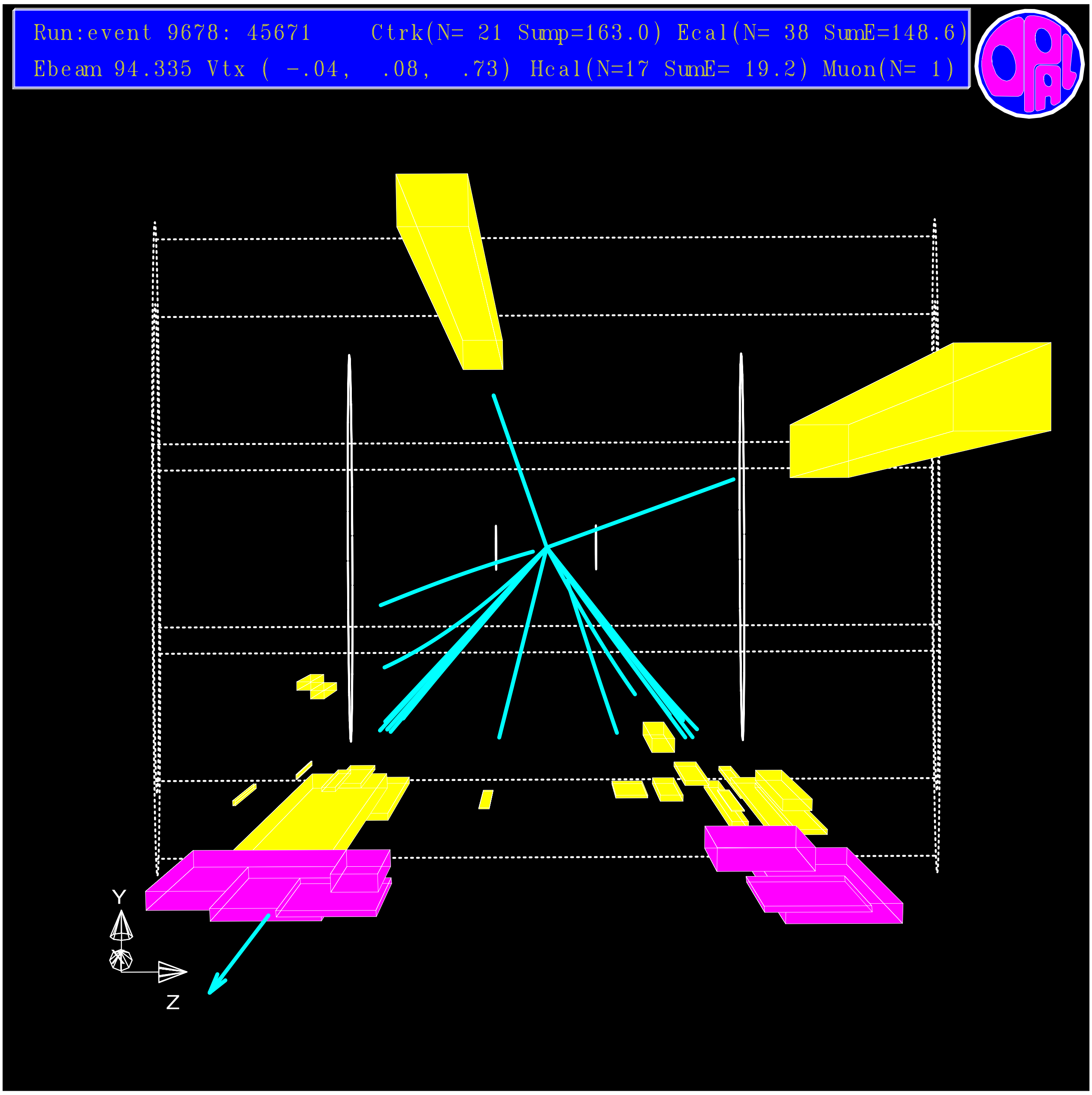
For a 95 GeV Higgs,
$\varepsilon = 34.3 \pm 2.6$ %
SM background: 4.0 ± 1.1 events
3 Candidates

Lepton Channels

$$H^0 \rightarrow b\bar{b}, \quad Z^0 \rightarrow e^+e^-, \mu^+\mu^-$$

$\varepsilon = 55.0 \pm 1.4$ % e, $\quad 64.9 \pm 1.3$ % μ
SM background: 2.6 ± 0.5 events e
2.1 ± 0.4 events μ
3 Candidates e, $\quad$ 1 Candidate μ

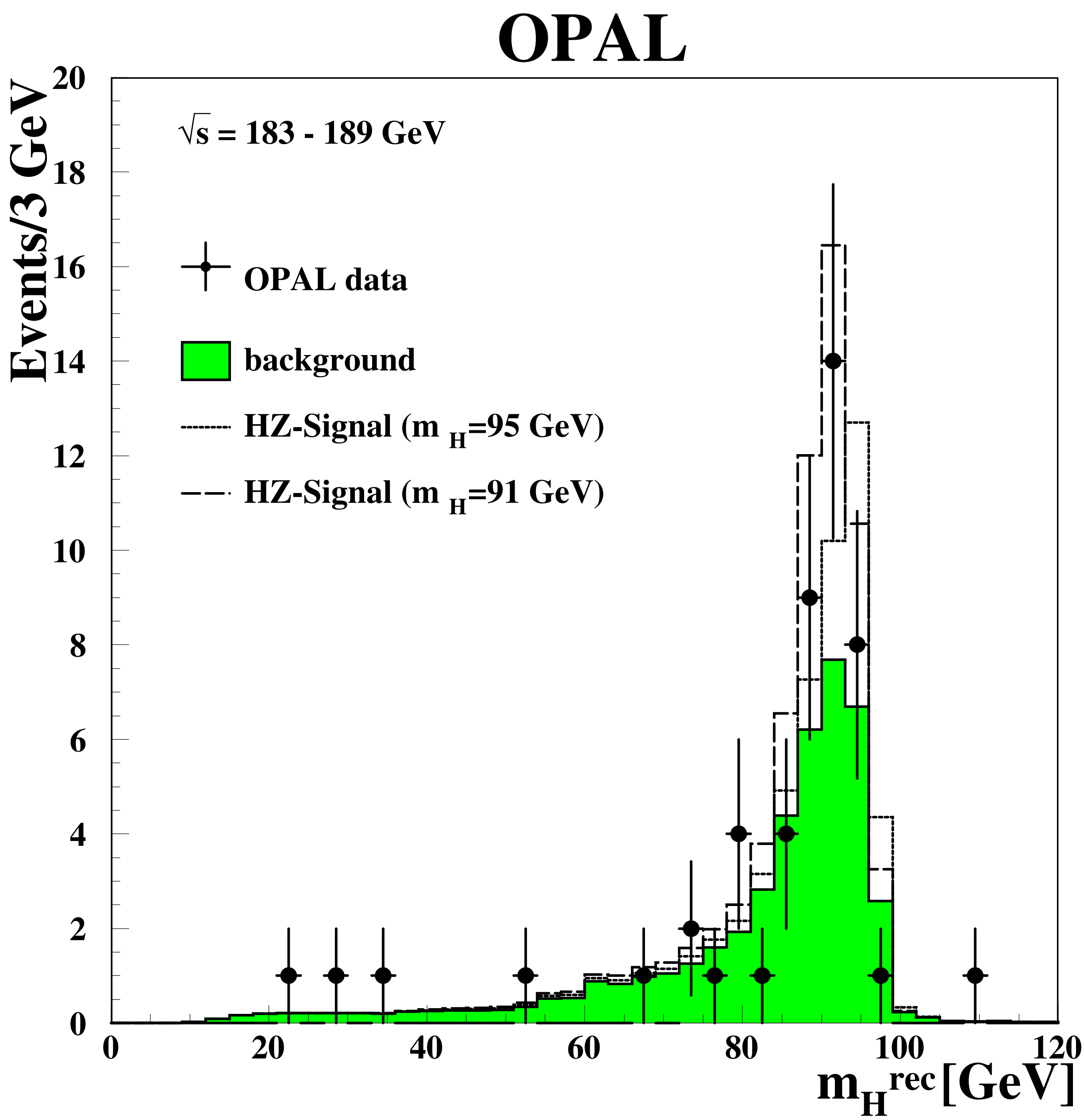
One of the $H^0Z^0 \rightarrow bbe^+e^-$ Candidates



Mass recoiling from $e^+e^- \approx m_Z$.

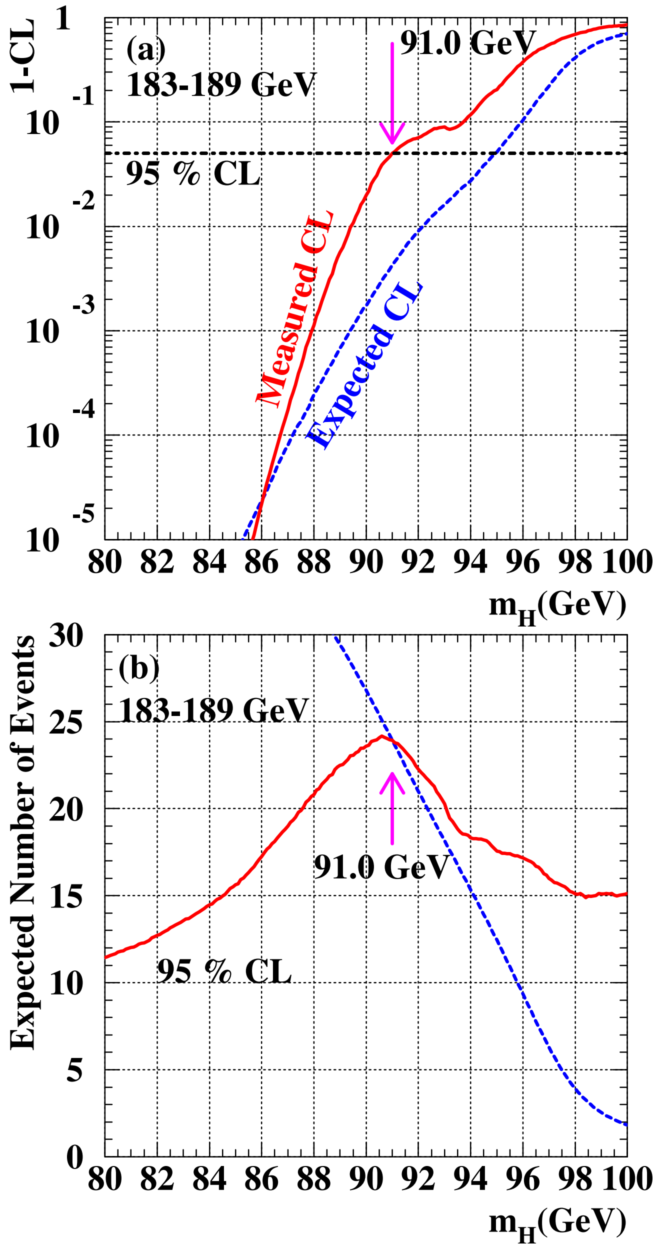
Standard Model interpretation: Z^0Z^0

Combined Candidates and Background



- All channels combined
- Signal shown form m_H=90 GeV, 95 GeV
- Kinematic limit: signal does not move in mass very much
- Observe 50 events/ SM: 44±3 (SM)
- 12.5 events signal at m_H=95 GeV, 27 events signal at m_H = 90 GeV

Standard Model Higgs Search Limits



Expected: 94.9 GeV, if there were bg only

Observed: 91.0 GeV at the 95% CL

Probability of setting a limit of 91.0 GeV or lower: ~4% (ALEPH: 90.2 GeV, ~1%)

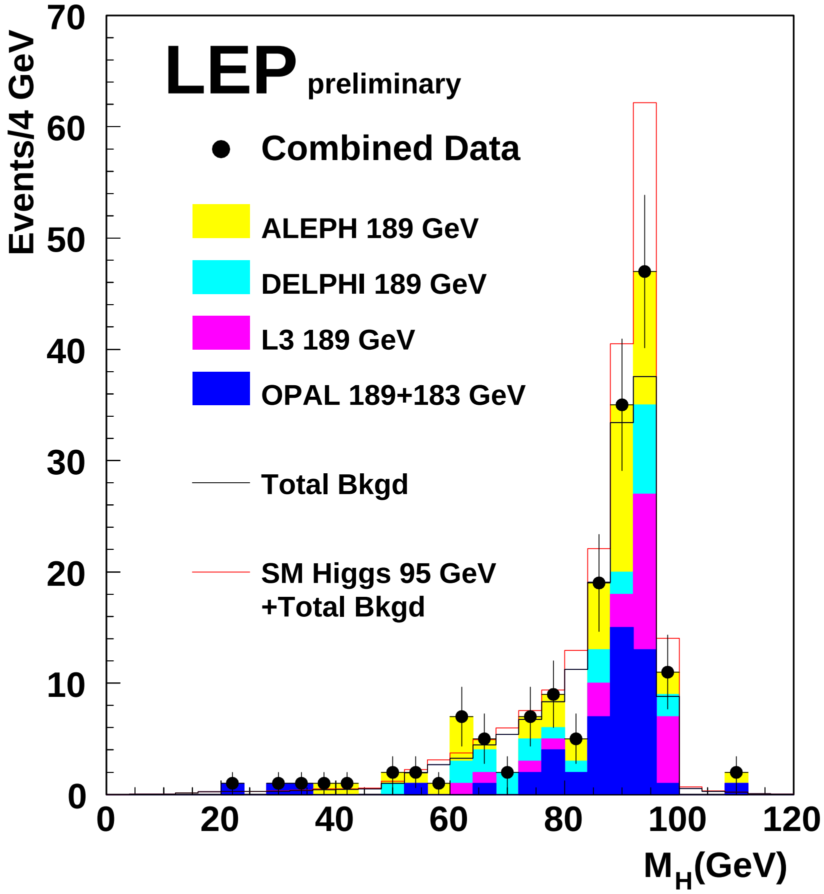
DELPHI, L3: OK.

The History of the SM Higgs Limit from OPAL

LEP2 Makes all the difference!

Year	$\sqrt{s}$ (GeV)	$\int L dt$ (pb^{-1})	m_H limit (95% CL) (GeV)
1989-1995	~91	~160	59.6
1996	161	~10	65.0
1996	+172	~10	69.4
1997	183	~54	88.3
1998	189	~180	91.0 (expected ~95)

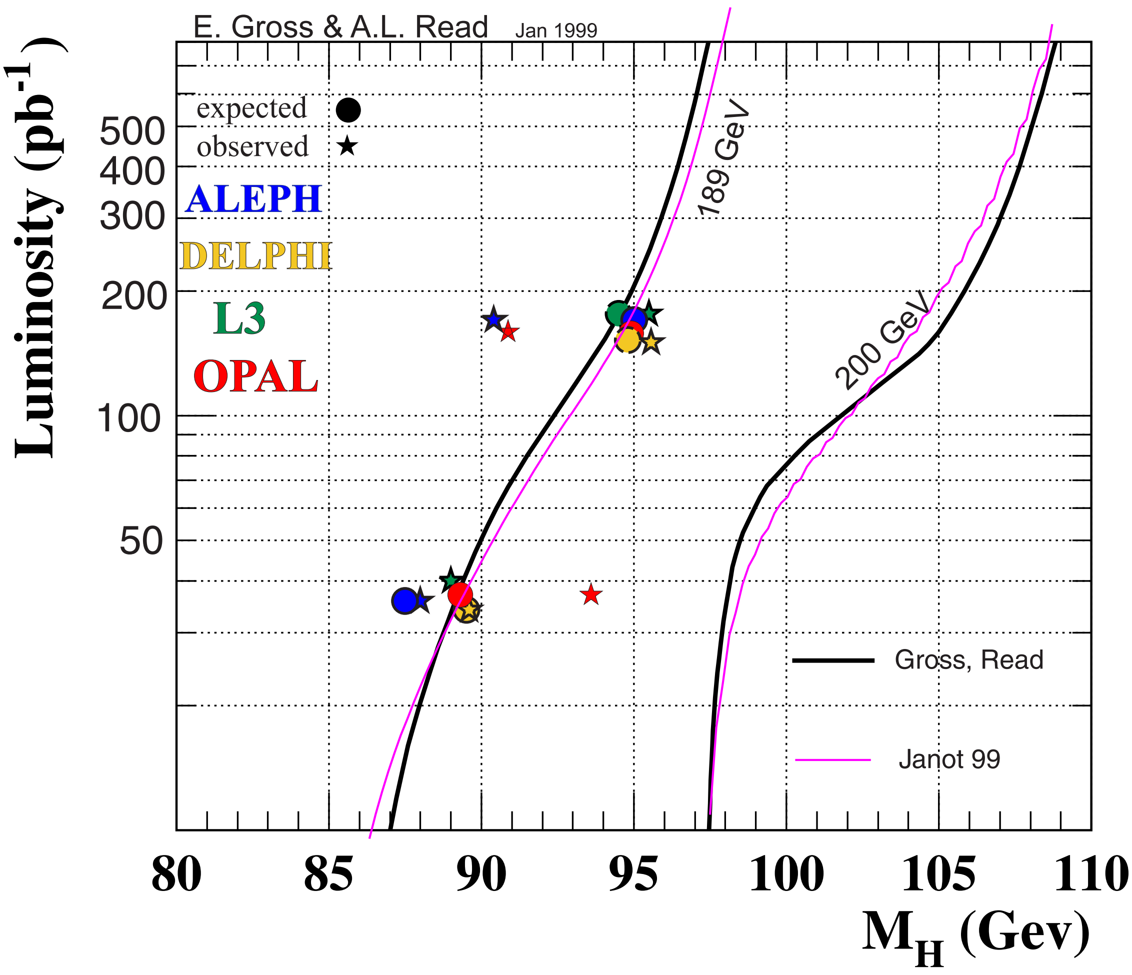
189 GeV SM Higgs Limits Around the Ring



Marta Felcini's plot from Moriond

Experiment	Expected Limit (GeV, 95%)	Observed Limit (GeV, 95%)
ALEPH	**95.7**	**90.2**
DELPHI	**94.8**	**95.2**
L3	**94.4**	**95.2**
OPAL	**94.9**	**91.0**

Prospects for the Future



CMSSM Parameters

"Standard" SUSY: SUGRA SUSY-breaking

Six Parameters to specify it:

M_2: EW scale SU(2) Gaugino mass. Assume Gaugino masses unified at GUT scale

m_0: Common sfermion mass (squark, slepton, sneutrino) at the GUT scale. Run them down to EW scale for model predictions

$\tan\beta$: Ratio of the VEV's of the two Higgs doublets

μ: Higgs mixing parameter

A_0: Common trilinear coupling (parameterizes squark mixing)

M_A: Mass of the CP-odd Higgs Boson

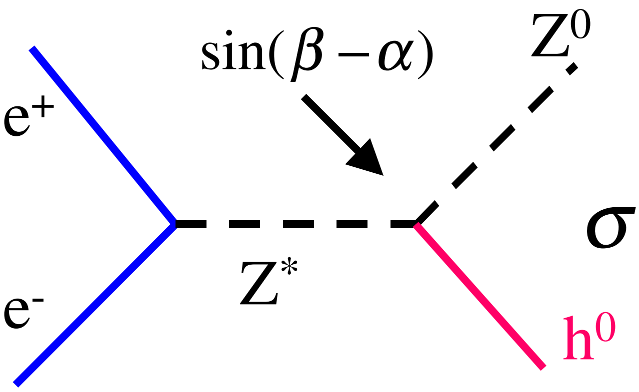
Can derive: m_h, m_H, α: mixing between h and H

The Neutral Higgses of the MSSM

Two Higgs Doublets: 5 Higgses

$\mathbf{h^0}$	light CP-even Higgs
$\mathbf{H^0}$	heavy CP-even Higgs
$\mathbf{A^0}$	CP-odd Higgs
$\mathbf{H^+, H^-}$	Charged Higgs

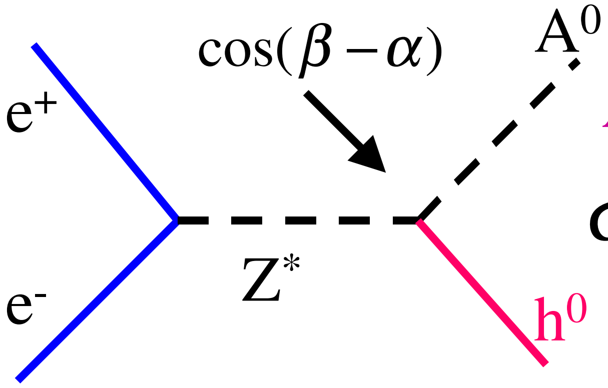
$$\boxed{m_{\mathrm{h}^0} < \sim 140\,\mathrm{GeV}}$$



Higgs-strahlung

$$\sigma_{hZ} = \sin^2(\beta-\alpha)\sigma_{hZ}^{SM}$$

And fusion processes too!



Associated Production

$$\sigma_{hA} = \cos^2(\beta-\alpha)\bar{\lambda}\sigma_{hZ}^{SM}$$

$\bar{\lambda}$: kinematic factor $(\mathrm{m_h}, \mathrm{m_A}, \sqrt{\mathrm{s}})$

Decay Modes and Detection of MSSM Higgses

Branching Fractions:

$$\left.\begin{array}{l} \mathrm{Br}(h^0 \to b\bar{b}) \\ \mathrm{Br}(h^0 \to \tau^+\tau^-) \end{array}\right\} \text{similar to SM } H^0$$

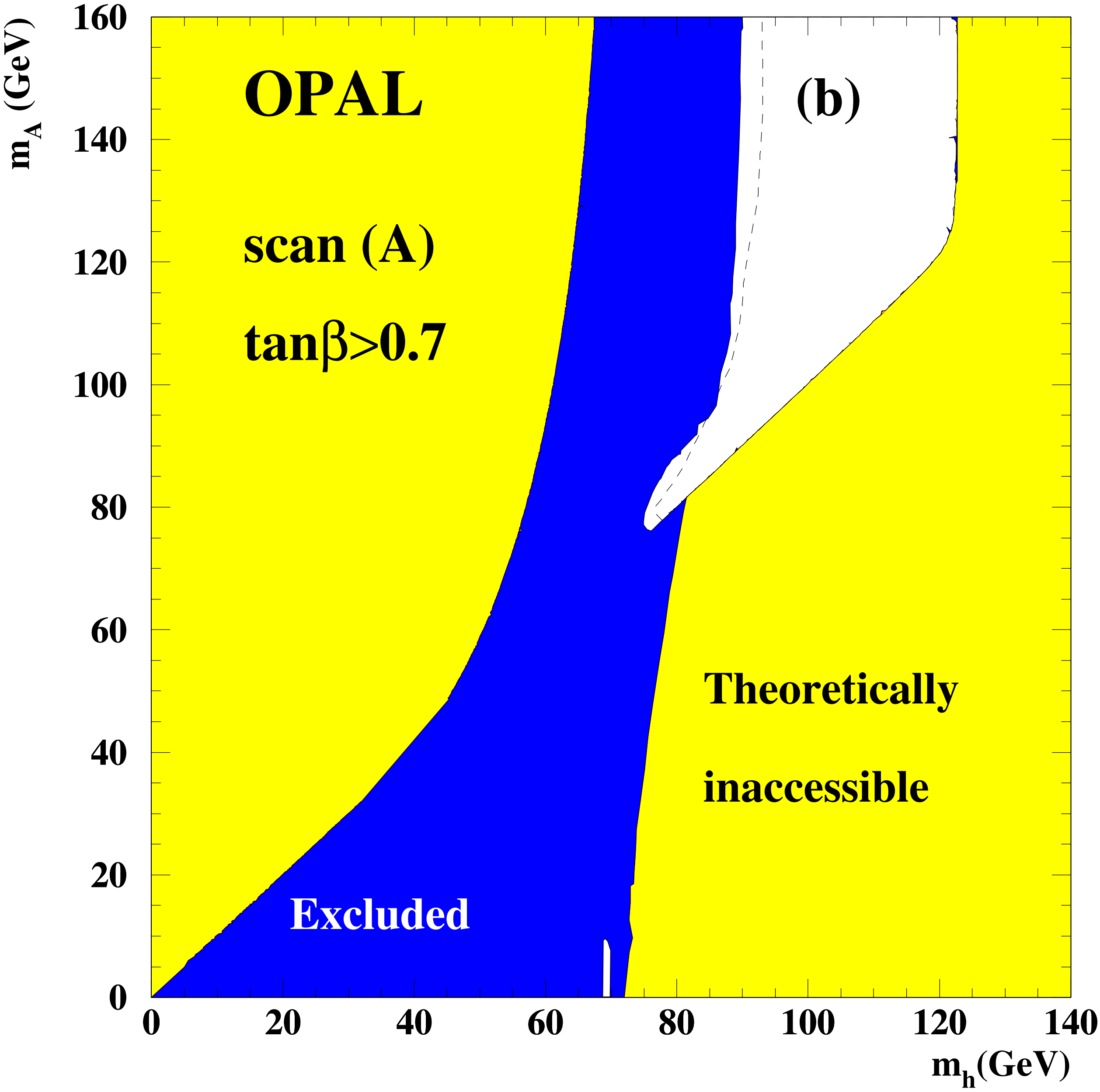
over much of parameter space, **but $h^0 \to A^0A^0$ can be dominant** when kinematically allowed.

$\mathrm{Br}(A^0 \to b\bar{b}) \sim 92\%$

$\mathrm{Br}(A^0 \to \tau^+\tau^-) \sim 8\%$

- h^0Z^0 Searches
  - Reuse SM H^0Z^0 analyses
  - Find Efficiency for processes with $h^0 \to A^0A^0$ with $A^0 \to bb$
- h^0A^0 Searches
  - No Z^0 mass constraint! Rely more on the b-tag: bbbb and $bb\tau\tau$ are main channels.
  - More ambiguities in interpretation
    Six combinations in 4-jet
    Two combinations in $bb\tau\tau$
  - Also a dedicated $A^0A^0A^0 \to 6b$ search
  - Use H^0A^0 production when allowed

OPAL MSSM Limits: m_h and m_A



Little tickmark is at tanβ ~ 0.7

Set 95% CL limits of

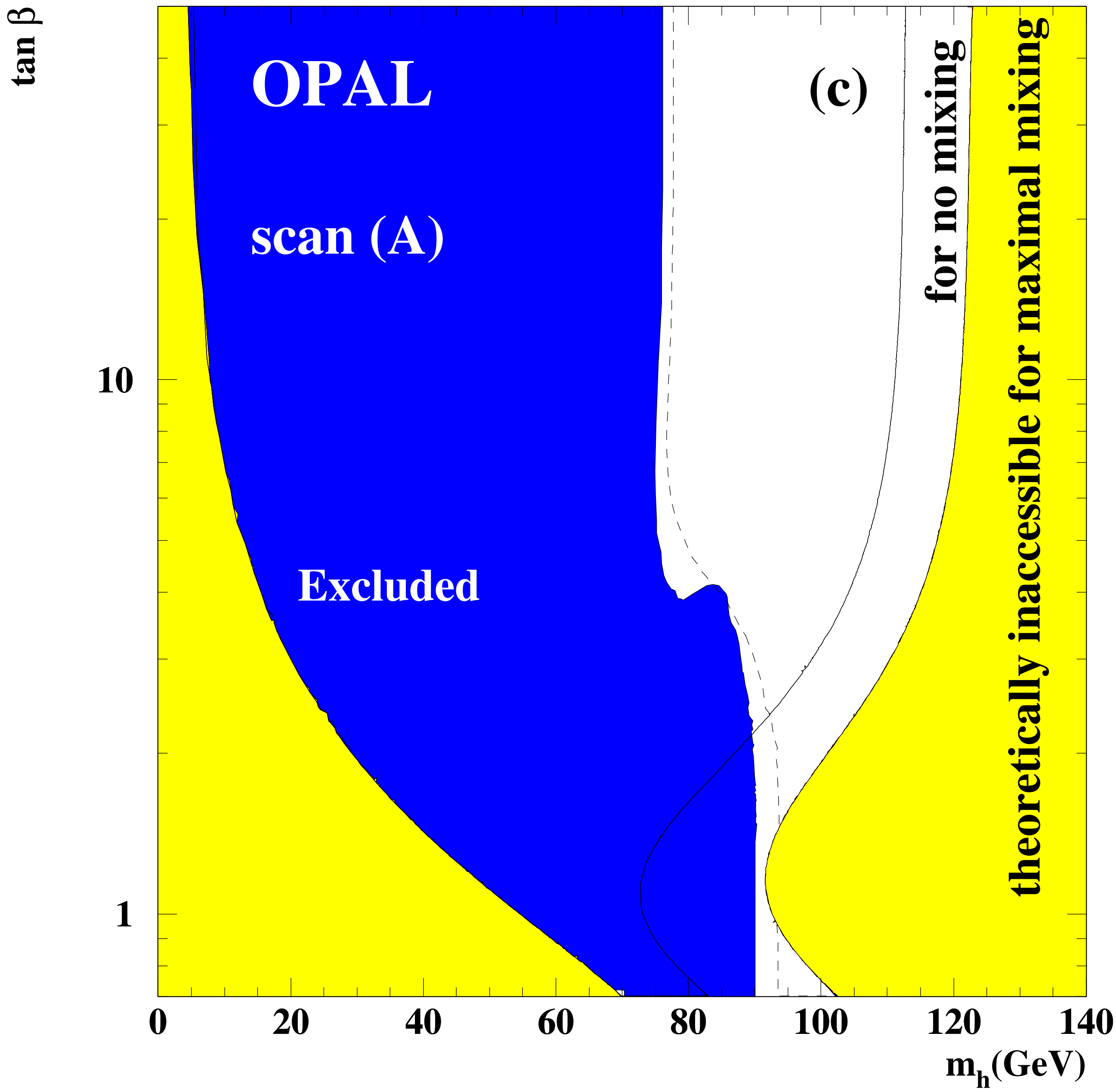
m_h > 74.8 GeV (expect 76.4)

m_A > 76.5 GeV (expect 78.2)

for 1.0 < tanβ < 50

(m_2=1.63 TeV, μ=-100 GeV, min. or max. stop mixing, m_0=1 TeV (heavy sferm.), m_{top}=175 GeV

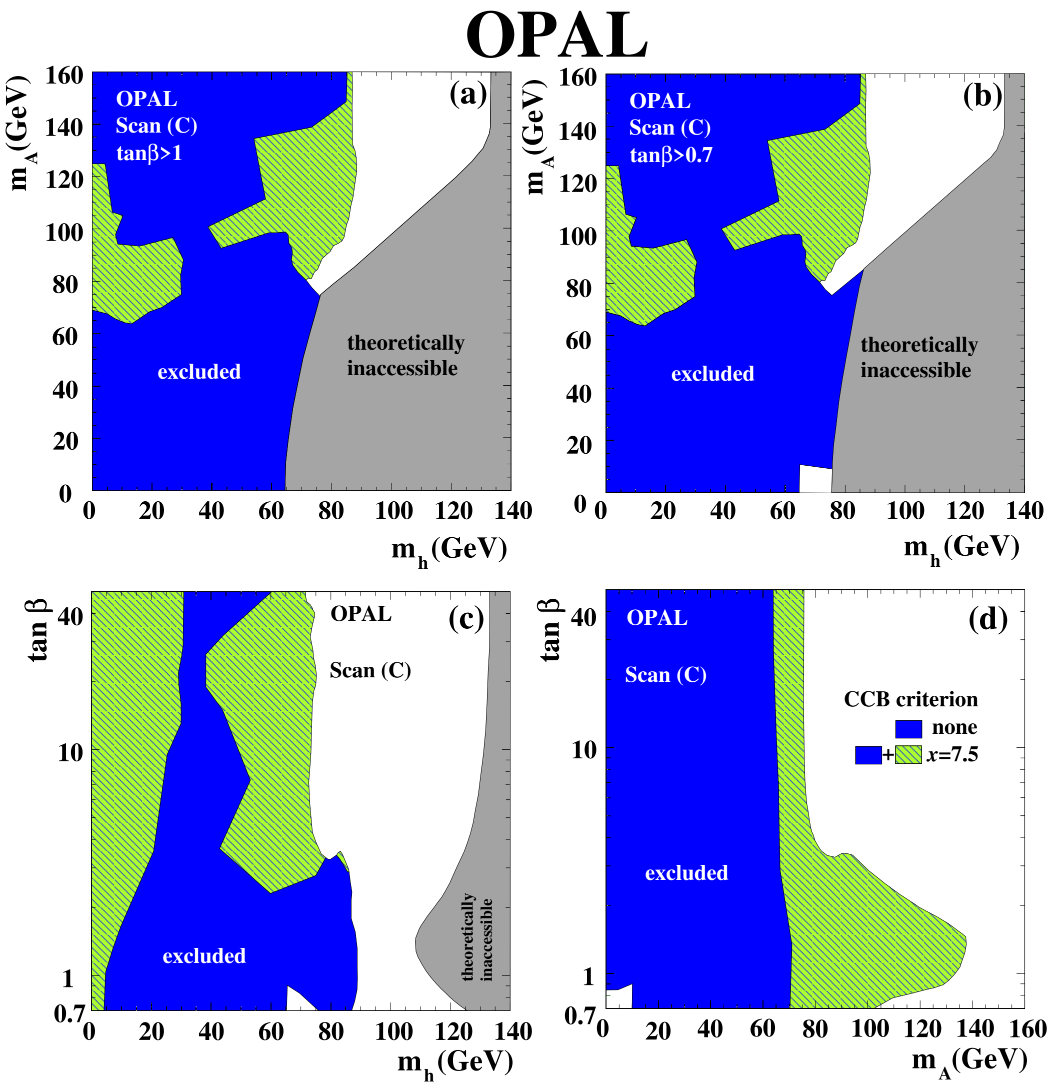
OPAL MSSM Limits: m_h and $\tan\beta$



$0.72<\tan\beta<2.19$ excluded for no stop mixing
No exclusion for maximal stop mixing

(driven by SM limit -- we expected to exclude a range). Assume: M_2=1.63 TeV, μ=-100 GeV, m_0=1 TeV, m_A<2 TeV

A General Scan of SUSY Space



-1 TeV < μ < 1 TeV $\qquad$ m_A < 2 TeV

165 GeV < m_{top} < 175 GeV

0 < m_2 < 2 TeV $\qquad$ 0 < m_0 < 1 TeV

0.7 < tanβ < 50

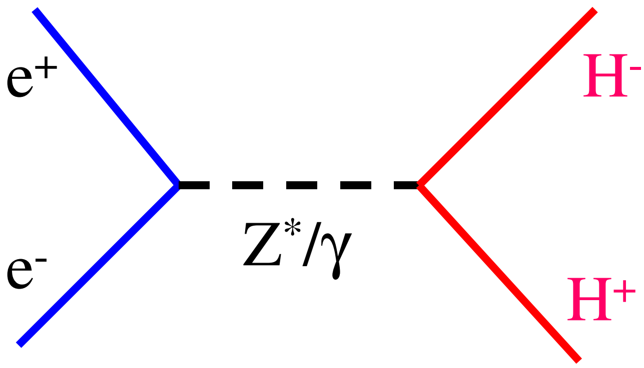
CCB criterion: excluded on CCB shown in green

$$A^2 + 3\mu^2 < 7.5\left(m^2_{\tilde{t}_L} + m^2_{\tilde{t}_R}\right)$$

Kusenko, Langacker, Segre, *Phys. Rev.* **D54**, 5824 (1996)

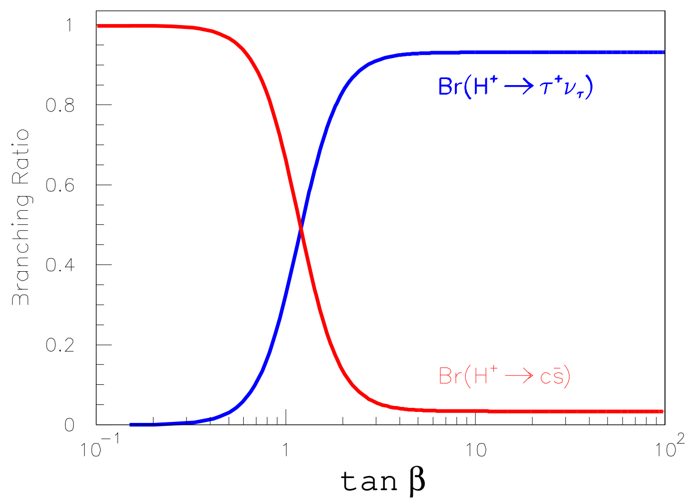
Z^0 lineshape constraint at low m_h used, and also OPAL model-independent searches at low m_h

Charged Higgs Production and Decay



- In the MSSM, $m_{H+} > m_W$ to first order
- Radiative corrections can change that
- General Two-Higgs Doublet models allow Lighter $H^{\pm}$.
- Decays:
- Three channels
  - $H^+H^- \rightarrow \tau^+\nu\tau^-\nu$
  - $H^+H^- \rightarrow cs\tau^-\nu$
  - $H^+H^- \rightarrow cscs$

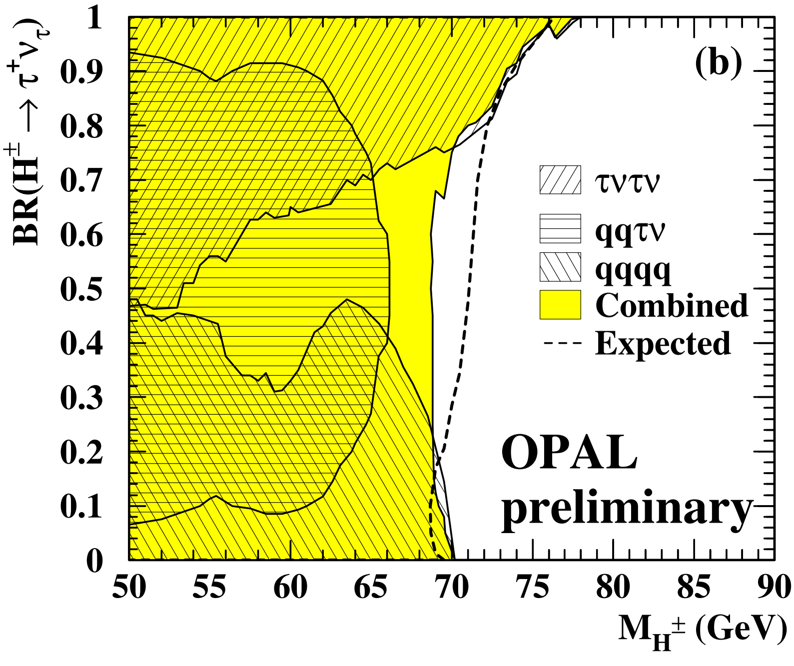
$$\boxed{\begin{array}{l} H^+ \rightarrow \tau^+\nu \\ H^+ \rightarrow c\bar{s} \end{array}}$$



Charged Higgs Limits

- Large, mostly irreducible W^+W^- bkg in the all 3 channels.

Channel	Candidates	SM Backg
Leptonic	31	26.2±0.9
Semileptonic	65	60.1±2.4
Hadronic	156	153.8±3.0



Limits on Mass of $H^\pm$ at 95% CL

BR($H^\pm \to$any): 68.7 GeV, expect 68.0 GeV

BR($H^\pm \to \tau^\pm \nu$)=1.0: 76.0

BR($H^\pm \to \tau^\pm \nu$)=0.0: 70.0

LEP-Wide Combination of Higgs Searches

Extends the sensitivity to a signal with 4 times the luminosity.

First indication of a signal on the edge of detectability may be in combination!

183 GeV searches already combined

SM Higgs Limit: 89.8 GeV
(~2 GeV gain, 4 expected. Exp't limits high)

MSSM Higgs Limits: 79.6 GeV (m_h)
80.2 GeV (m_A)
(~10 GeV gain, ~10 GeV expected)

Charged Higgs Limit: 69.0 GeV
(~10 GeV gain, ~10 GeV expected)

Currently combining 189 GeV results. Expect fast (3 weeks) combination of 1999 results. Fast decision to continue run in 2000!

The Rest of the SUSY Spectrum

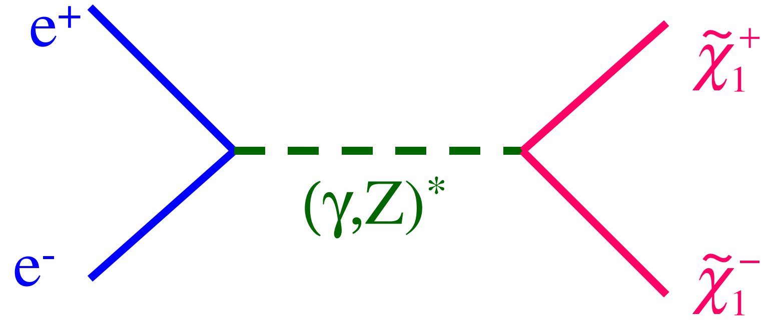
SM Particles +Higgs $R_P = 1$	SUSY Partners $R_P = -1$
γ, Z^0, H^0, h^0	★ Four Neutralinos $\tilde{\chi}^0_1$ $\tilde{\chi}^0_2$ $\tilde{\chi}^0_3$ $\tilde{\chi}^0_4$
$W^\pm$, $H^\pm$	★ Two Charginos $\chi^\pm_1$ $\chi^\pm_2$
gluon	gluino
graviton	gravitino
udscbt	★ squarks $\tilde{u}$ $\tilde{d}$ $\tilde{s}$ $\tilde{c}$ $\tilde{b}$ $\tilde{t}$
e, μ, τ	sleptons $\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$
ν_e ν_μ ν_τ	sneutrinos $\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$

★: Search presented in this talk

Chargino Search

Assume: $\tilde{\chi}_1^+$ has a short lifetime, R-parity conserving decays, $\tilde{\chi}_1^0$ is the LSP

Production: (similar to W^+W^- CC03 diagrams)



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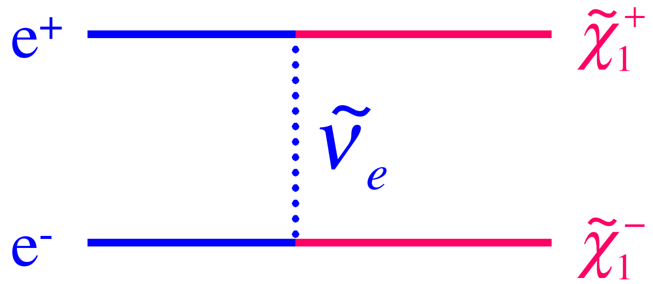


Destructive interference!

Diagram important for small m_0

Decays:

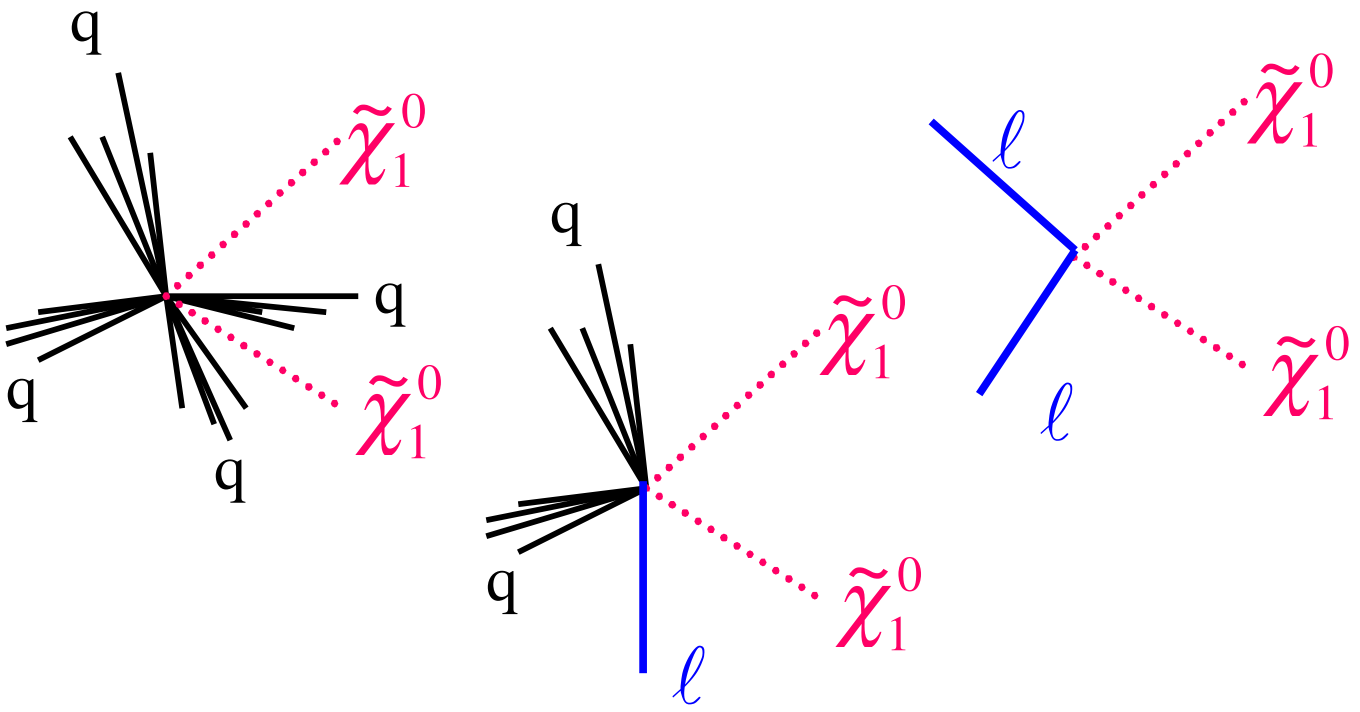
$$\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 W^+ \qquad \textit{or}$$

$$\tilde{\chi}_1^+ \to \tilde{\ell}^+ \nu_\ell, \qquad \tilde{\ell}^+ \to \tilde{\chi}_1^0 \ell^+$$

B.R.'s depend on slepton masses, m_0

Chargino Search Modes

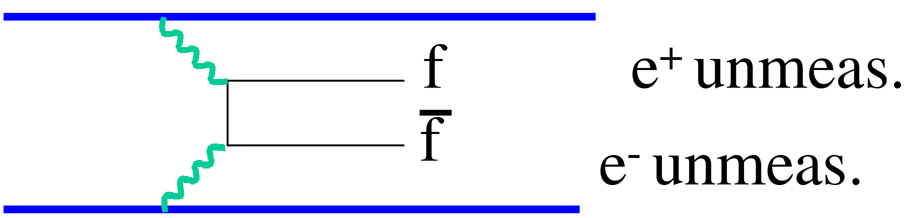
Same as W^+W^- channels, but with missing energy



Kinematics depend strongly on

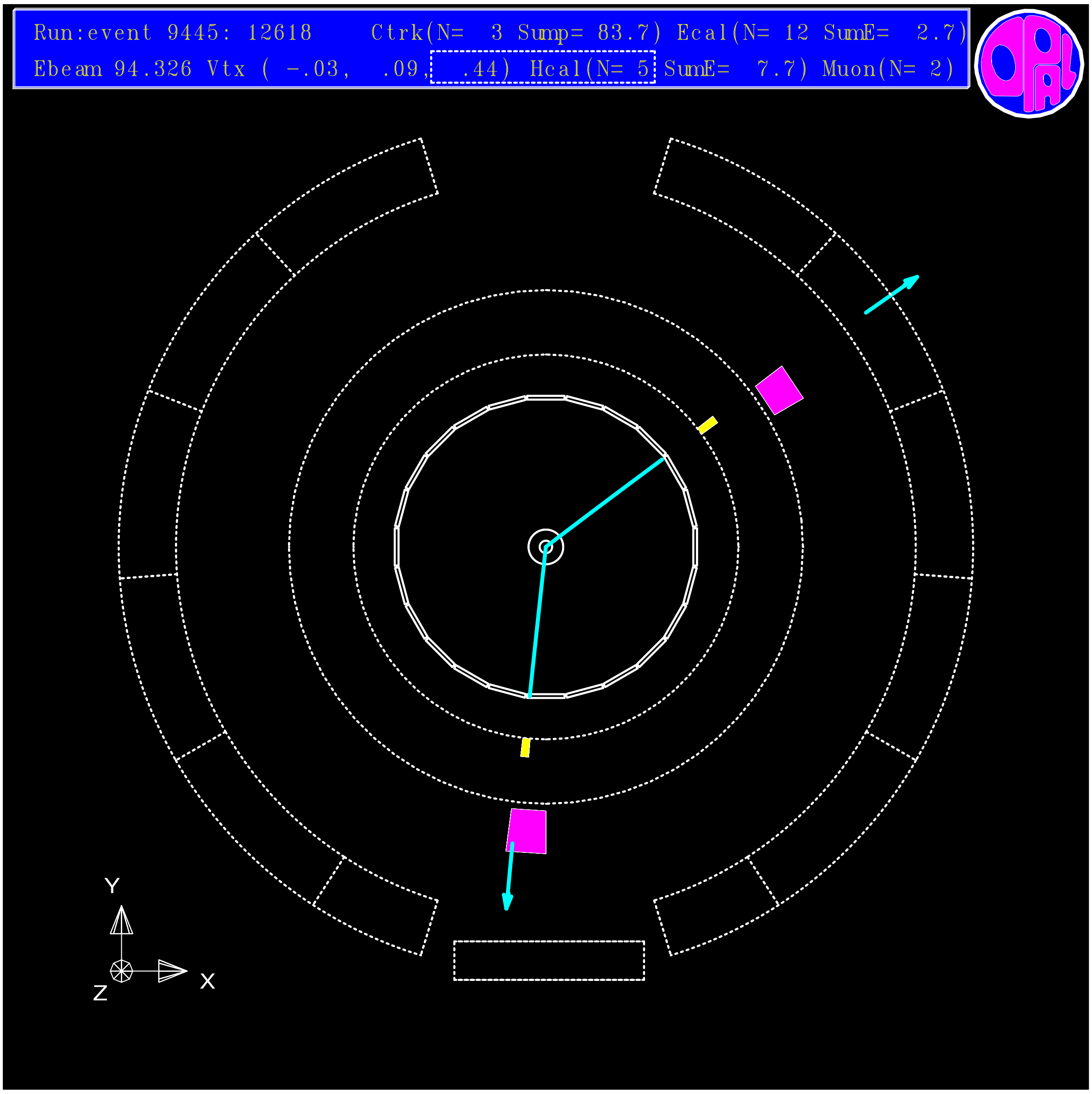
$$\Delta M = M_{\chi_1^+} - M_{\chi_1^0}$$

Low *ΔM:* Background dominated by untagged two-photon processes



High *ΔM:* Background dominated by W^+W^- production.

An "Acoplanar Dilepton"

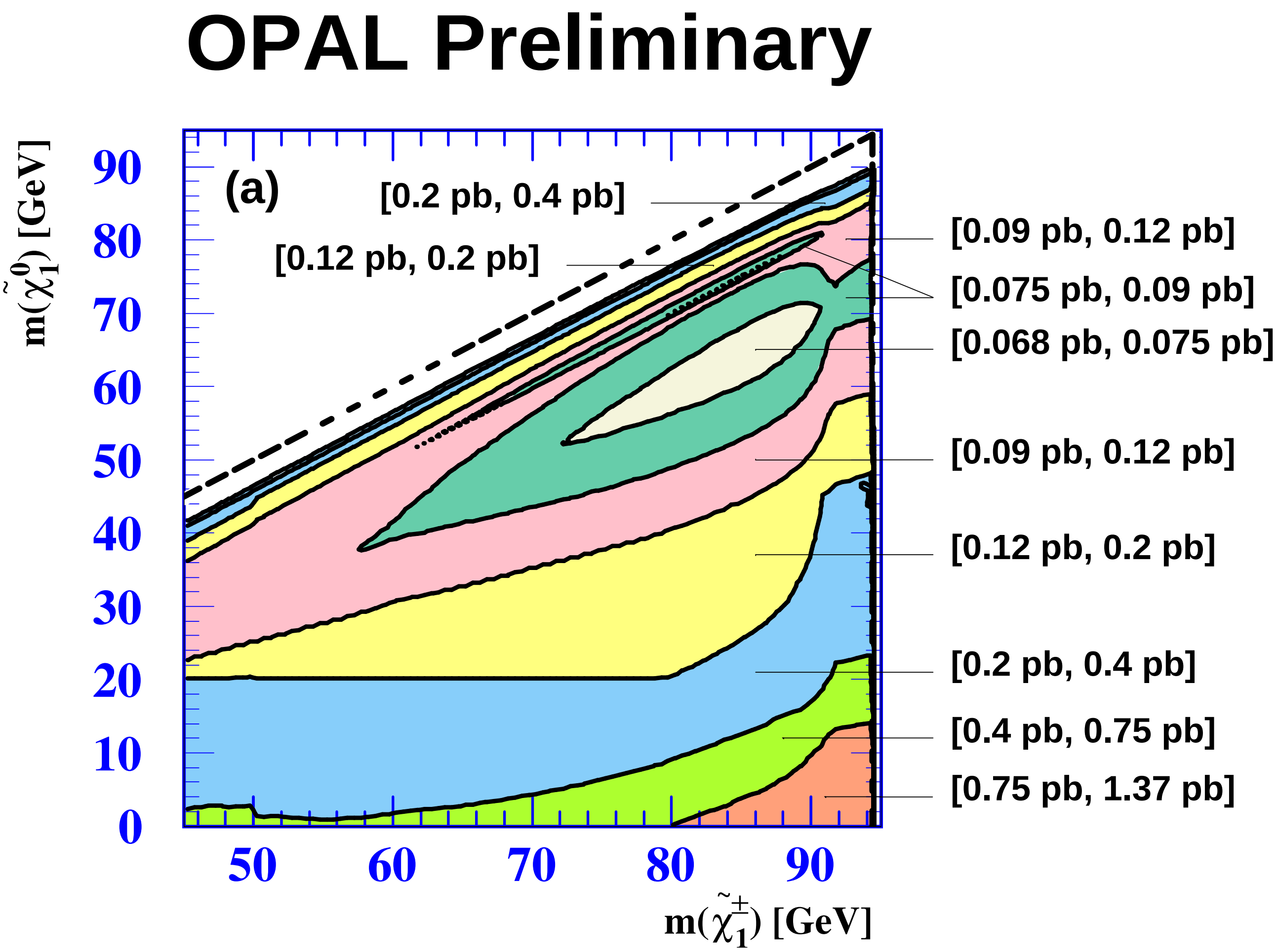


$\mu^+\mu^-$ with large missing p_t

SM interpretation:

$$W^+W^- \to \mu^+\nu_\mu\mu^-\bar{\nu}_\mu$$

OPAL Chargino Limits



Plot does not assume CMSSM

Best sensitivity away from very low, very high ΔM

In the CMSSM,

For $\Delta M>5$ GeV, $m_0>500$ GeV, $\tan\beta=1.5$,

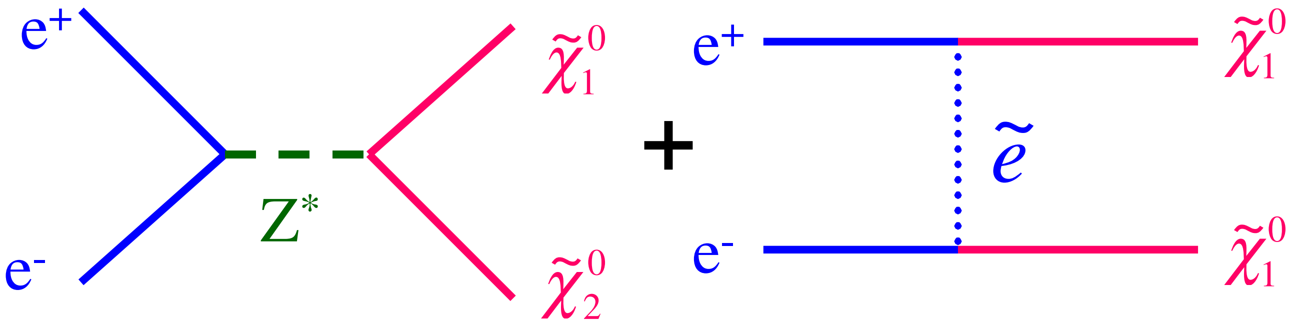
$m_{\tilde{\chi}_1^+} > 93.6$ GeV at the 95% CL

For arbitrary m_0, obtain limit of 76.9 GeV

-- destructive interference of production processes!

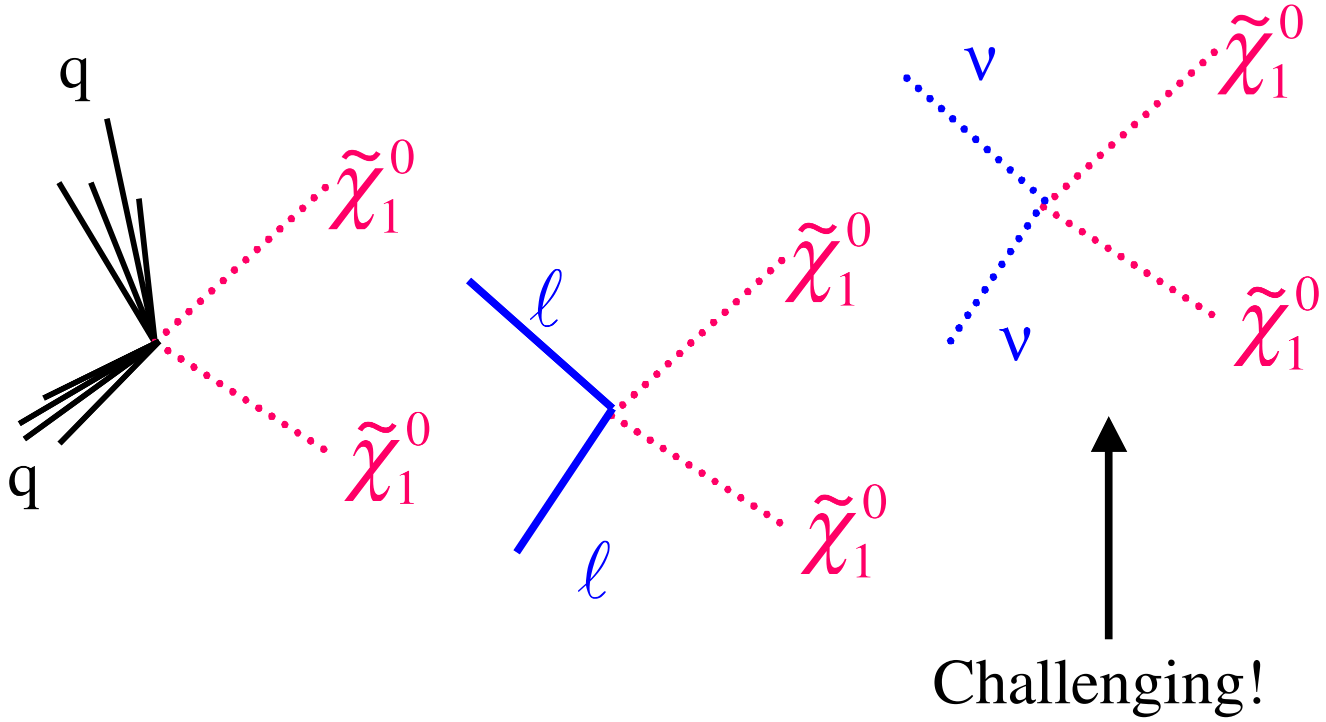
Neutralino Production and Decay

- Still assume $\tilde{\chi}_1^0$ is the LSP
- Seach for associated production of $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ in s-channel Z^0 exchange

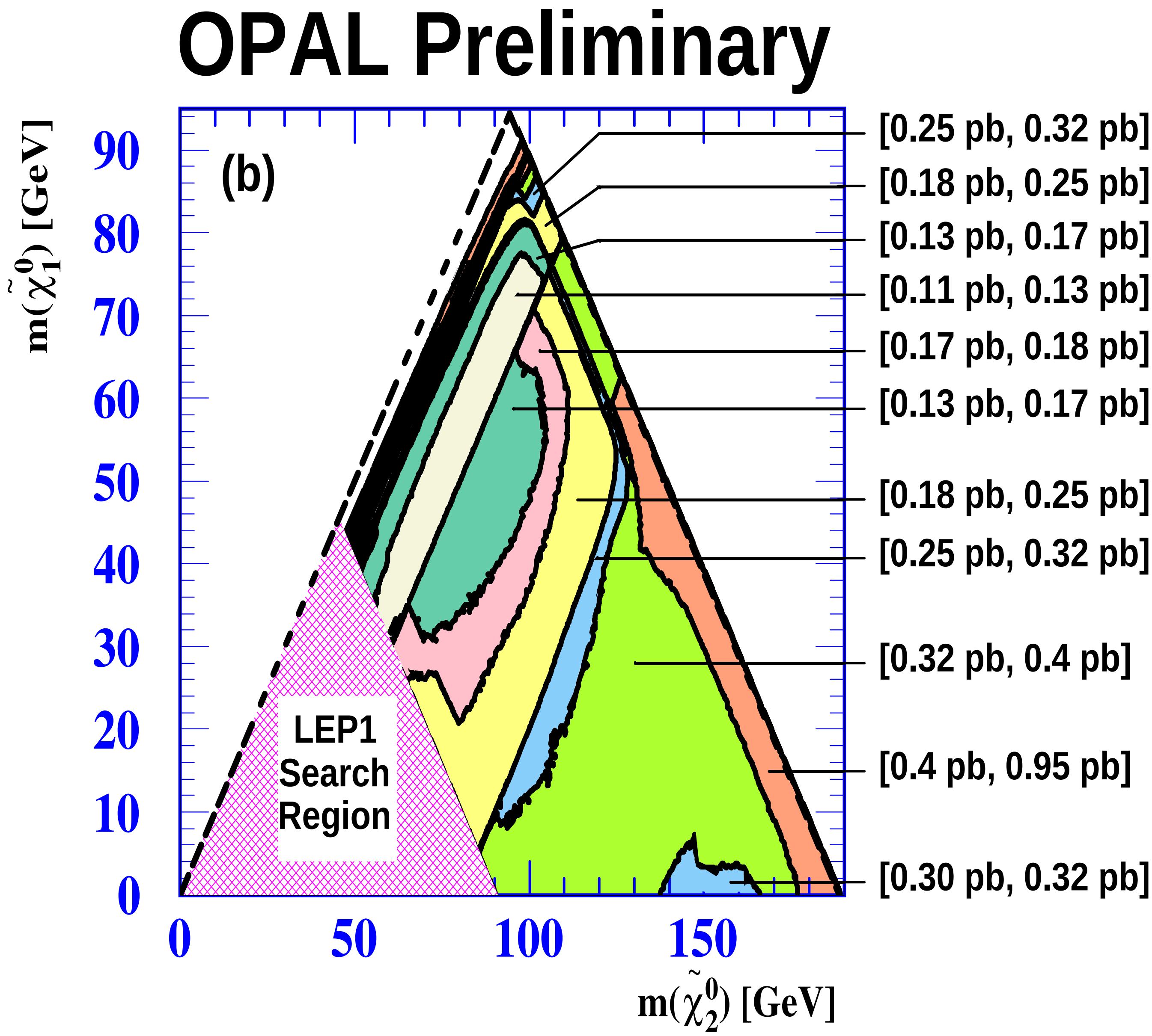


- Decays:

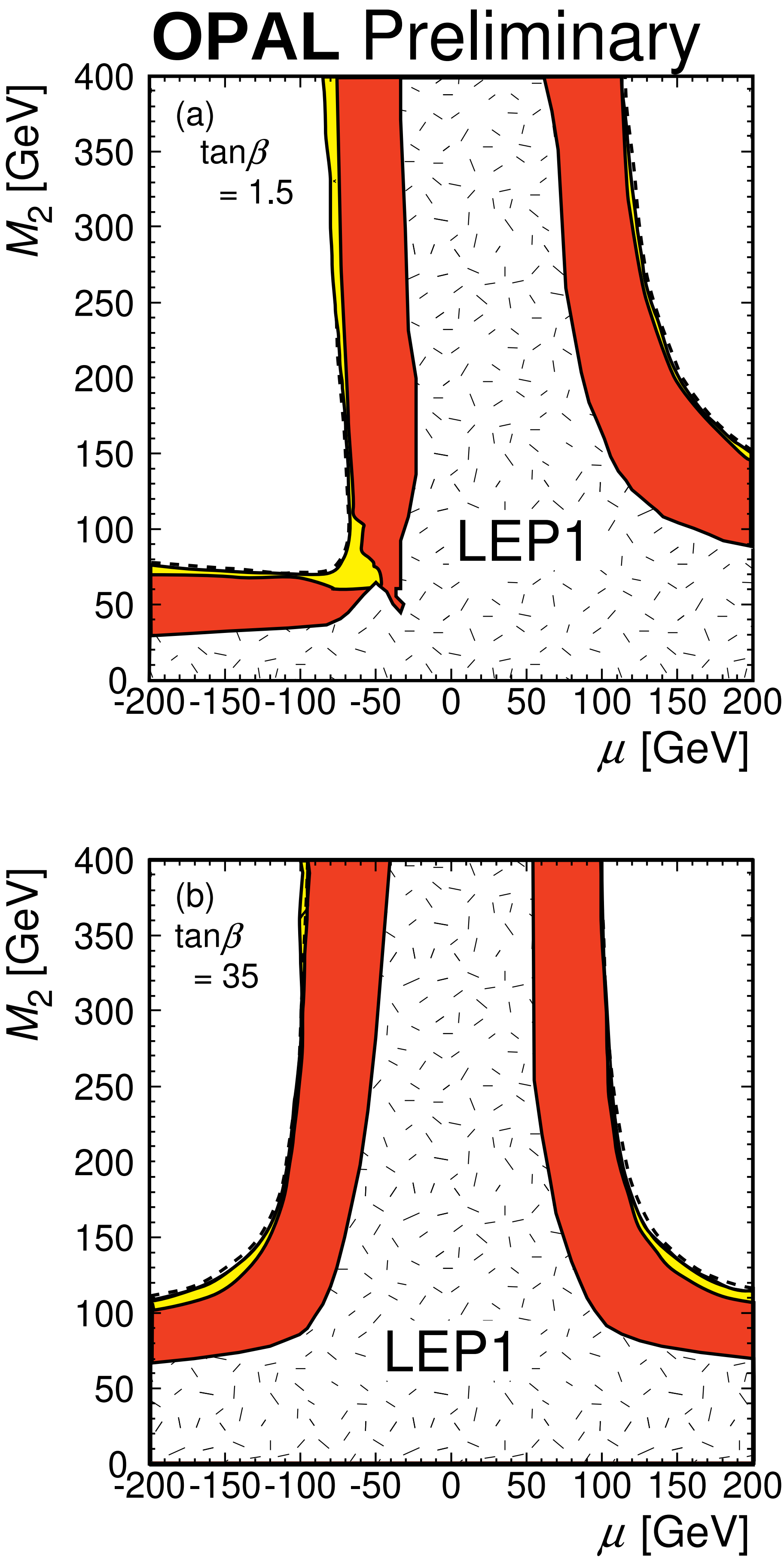
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^0$$



OPAL Neutralino Limts



CMSSM Parameter Scan: m_2 and μ

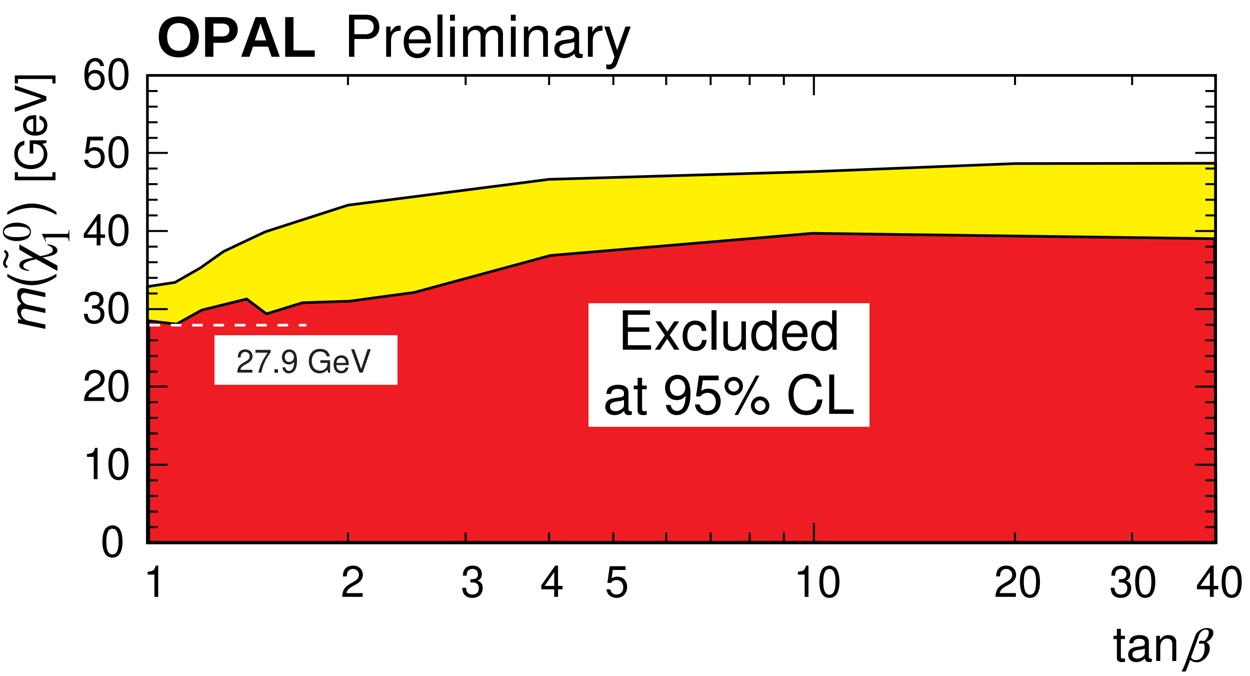


Dark: all m_0

Light: m_0>500 GeV

Dashed: Kinem. limit for prod of $\chi_1^+ \chi_1^-$

$\tilde{\chi}_1^0$ *LSP Mass Limit*



Yellow: Excluded at 95%, $m_0 > 500$ GeV

$$\boxed{m_{\chi_1^0} > 32.8\ \mathrm{GeV}}$$

Red: Excluded at 95%, all m_0

$$\boxed{m_{\chi_1^0} > 27.9\ \mathrm{GeV}}$$

Uses Chargino and Neutralino search results. Limits also valid for $\tan\beta \rightarrow 1/\tan\beta$.

Searches for Stop and Sbottom

Motivation:

- Stop can be light because of mixing of partners of Right-handed and Left-handed top quarks

$$\tilde{t}_1 = \tilde{t}_L \cos\theta_{\tilde{t}} + \tilde{t}_R \sin\theta_{\tilde{t}}$$

$$\tilde{t}_2 = -\tilde{t}_L \sin\theta_{\tilde{t}} + \tilde{t}_R \cos\theta_{\tilde{t}}$$

  mass splitting of eigenstates: stop can be lighter than the top

- Sbottom can be light for the same reason if $\tan\beta > 40$.

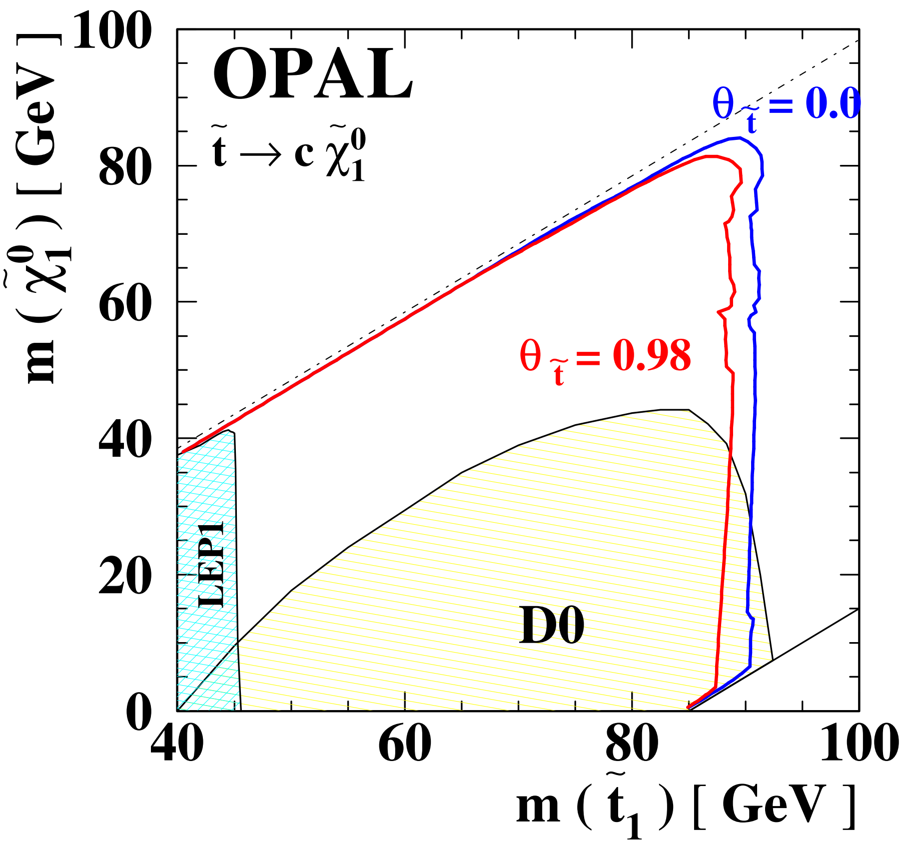
Decays: (R-parity conserving)

$$\tilde{t}_1 \to c\chi_1^0 \qquad \tilde{b}_1 \to b\tilde{\chi}_1^0$$

$$\tilde{t}_1 \to b\tilde{\nu}_\ell \ell^+$$

Signature: Two jets and missing p_T, or
Two jets and two leptons and missing p_T

Stop Limits



Lower right-hand corner:

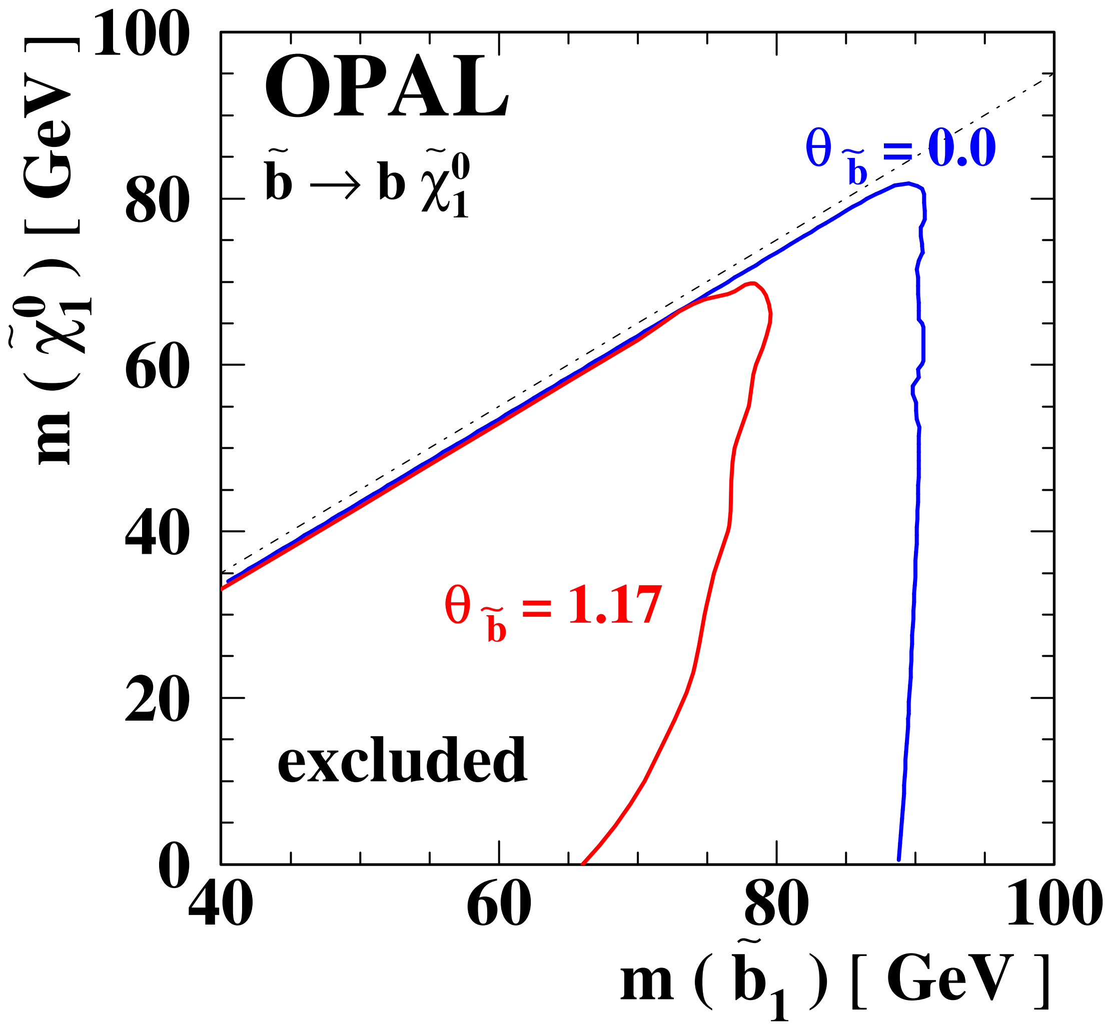
$$\tilde{t}_1 \rightarrow b\tilde{\chi}^0_1 W^+$$

Unexcluded (for now)

No mixing: $m_{\tilde{t}_1} > 90.3$ GeV at 95% CL
(ΔM > 10 GeV)
If Stop decouples from the Z^0 $m_{\tilde{t}_1} > 87.2$ GeV

(worst case)

Sbottom Limits



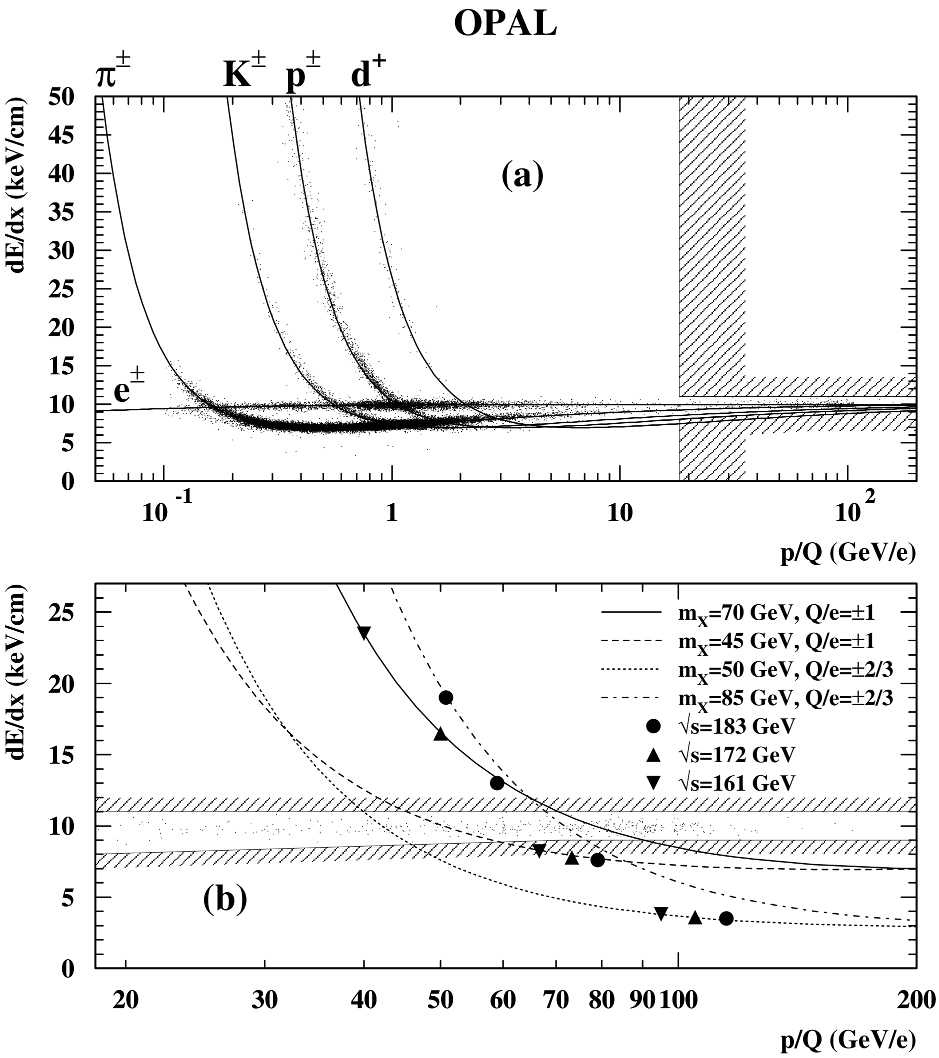
$\Delta M > 7$ GeV:

95% CL limit = 88.6 GeV, no mixing

65.8 GeV, if sbottom decouples from the Z^0

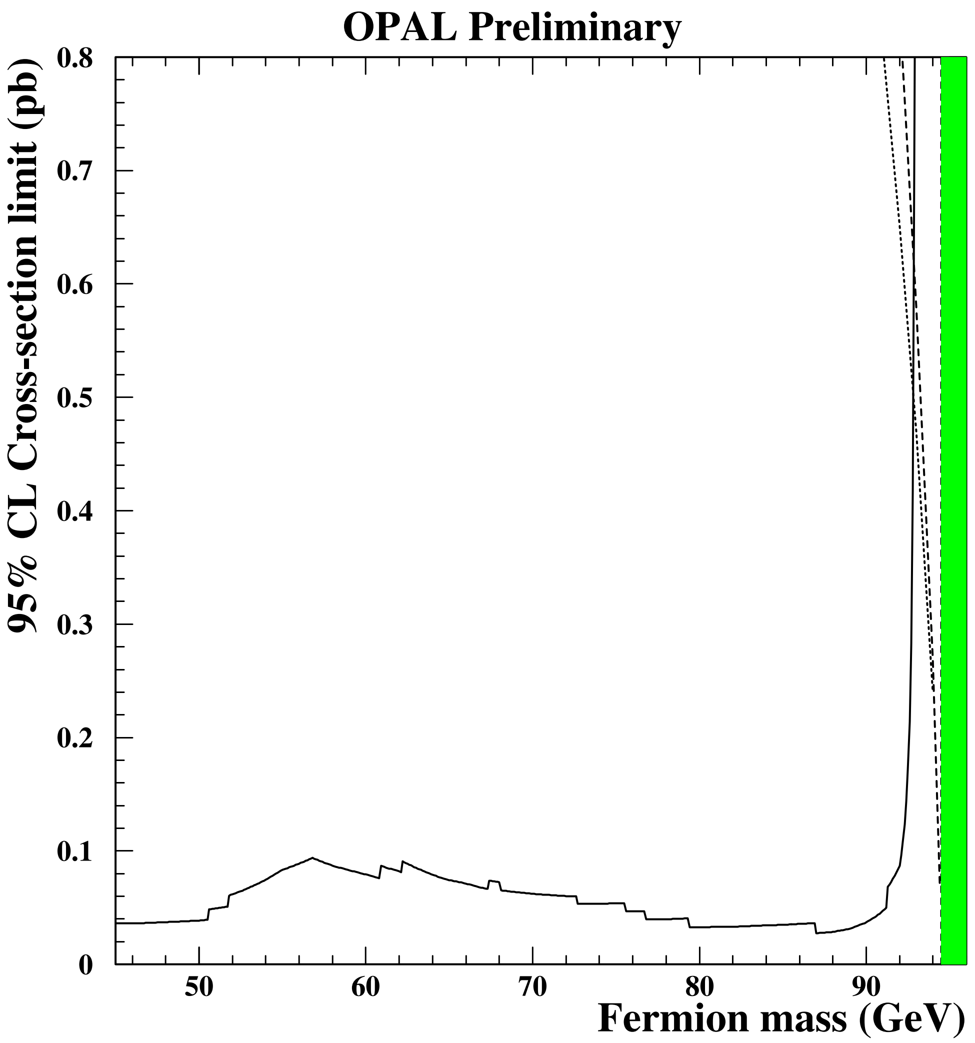
Closing a Loophole: Stable Heavy Particle Search

- Uses OPAL's 4.0 Bar tracking chamber -- excellent dE/dx measurement
  Require two tracks with anomalous dE/dx
  very low background
- Also kinematic analysis -- low momentum, balanced particles. Main background: mismeasured μ-pairs



Stable Heavy Particle Limits

Candidates: 1 in dE/dx search (0.1 SM expect)
6 in kin. search (2.4 SM expect)



Long-Lived chargino
limit (shown): 93.0 GeV (95% CL)
Slepton limit: 86.2 GeV (lower cross-sect)

Gravity Off the Wall

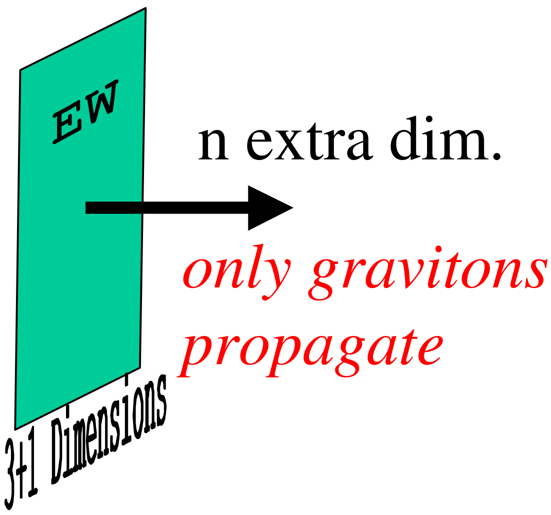
Heirarchy Problem: Why is Gravity so weak? Or, why is

$$m_{Planck} >> m_{EW}$$

Hypothesis: Maybe it's not! Maybe we just see the 3+1 dimensional projection of it. If there are n extra dimensions of radius r, then

$$m^2_{Planck} \sim r^n m^{2+n}_{eff}$$

with $m_{Eff} = m_{EW}$ to solve the heirarchy problem.



$$r \sim 10^{30/n-19} \text{ m}$$

More dimensions→ smaller dimensions.

n=1: cosmological r

n=2: r~1mm.

Cavendish experiments?

Larger n: HEP!

Limits on Gravitational Interactions in Extra Dimensions

- Recent interest in the theory/phenomenology community

  Giudice, Rattazzi, Wells, CERN-TH/98-354
  Hewett, SLAC-PUB-8001
  Mirabelli, Perelstein, Peskin, SLAC-PUB-8002
  Rizzo, SLAC-PUB-8036

- Graviton exchange at close range modifies production of μ, τ, γ pairs in e^+e^- collisions.

- Can be tested without a new Monte Carlo -- Readily available measurements are on hand

$$\frac{d\sigma}{dz} = \underbrace{A(z)}_{\text{SM}} + \underbrace{B(z)\left[\frac{\lambda}{M_s^4}\right]}_{\text{Interference}} + \underbrace{C(z)\left[\frac{\lambda}{M_s^4}\right]^2}_{\text{New Interaction}}$$

$$z \equiv \cos\theta$$

Extra Dimension Phenomenology

(Hewett)

$$A(z) = \sum_{i,j=\gamma,Z} N_c \frac{\pi\alpha^2}{2s} \beta P_{ij} \left[A_{ij}^e A_{ij}^f (1+\beta^2 z^2) + 2\beta B_{ij}^e B_{ij}^f z A_{ij}^e C_{ij}^f (1-\beta^2) \right]$$

$$B(z) = -\sum_{i=\gamma,Z} \frac{N_c \alpha s}{4} P_i \left[2\beta^3 z^3 v_i^e v_i^f - \beta^2 (1-3z^2) a_i^e a_i^f \right]$$

$$C(z) = \frac{N_c s^3}{32\pi} \left[1 - 3\beta^3 z^2 + 4\beta^4 z^4 - (1-\beta^2)(1-2\beta^2 z^2) \right]$$

β: speed of produced particle pair
v, a: SM vector, axial couplings to γ, Z

combinations:

$$A_{ij}^f = v_i^f v_j^f + a_i^f a_j^f$$

$$B_{ij}^f = v_i^f a_j^f + a_i^f v_j^f$$

$$C_{ij}^f = v_i^f v_j^f - a_i^f a_j^f$$

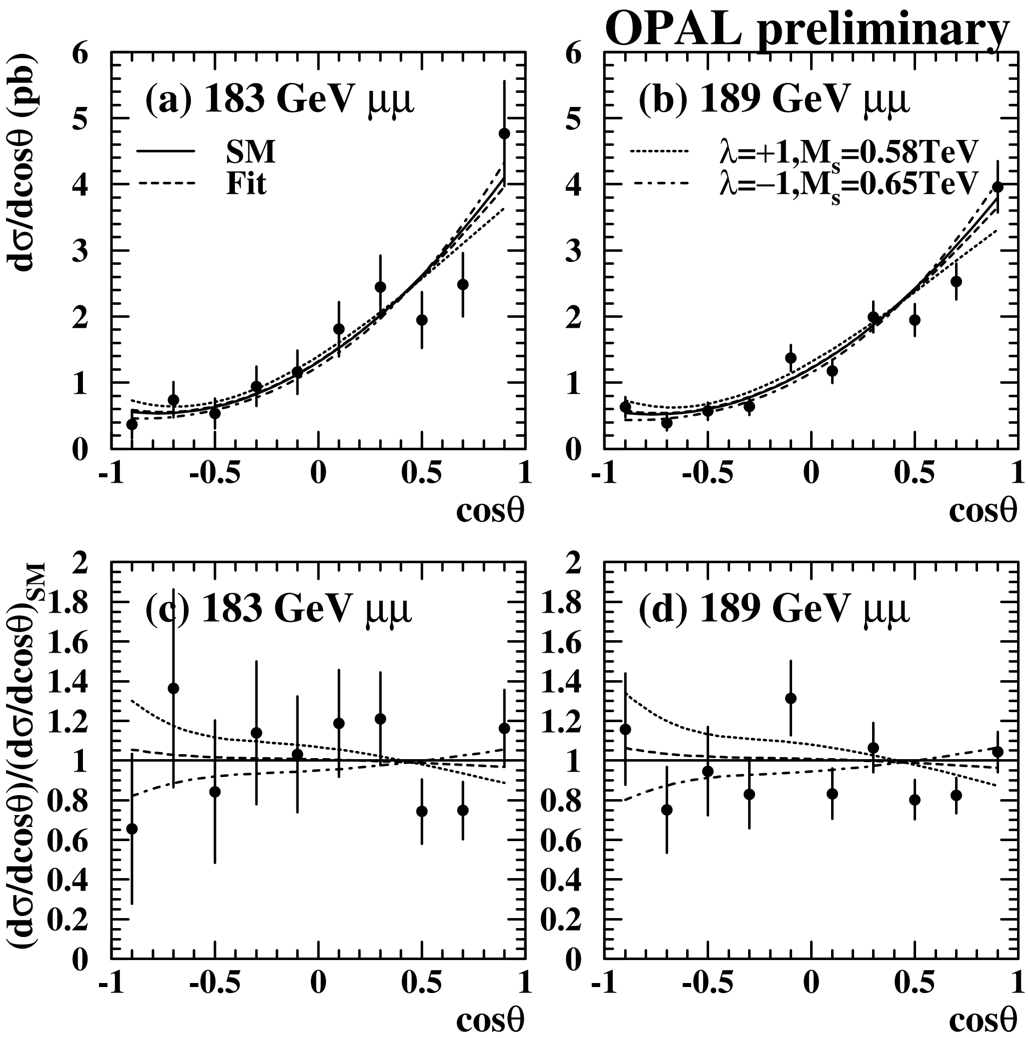
Kinematics

$$P_\gamma = P_{\gamma\gamma} = 1$$

$$P_Z = P_{\gamma Z} = P_{z\gamma} = s(s-m_Z^2)/((s-m_Z^2)^2 + m_Z^2\Gamma_Z^2)$$

$$P_{ZZ} = s^2 / \left[(s-m_Z^2)^2 + m_Z^2 \Gamma_z^2 \right]$$

Consistency of Muon Pair Angular Distributions with Extra Dimensional Gravity



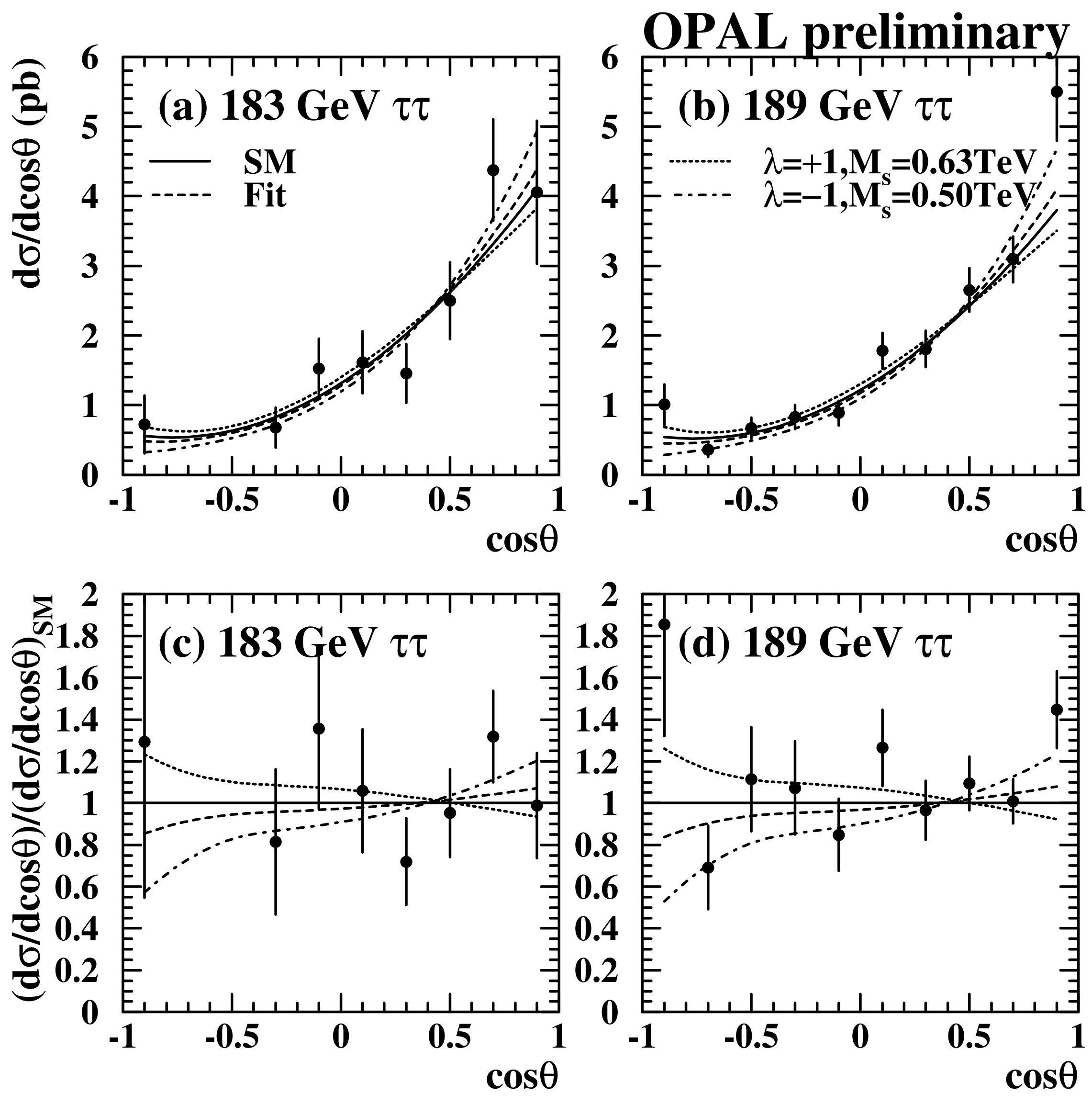
SM: solid

Best fit with new interaction: dashed

95% CL on M_s with λ=1: dotted

95% CL on M_s with λ=-1: dot-dashed

Consistency of Tau Pair Angular Distributions with Extra Dimensional Gravity



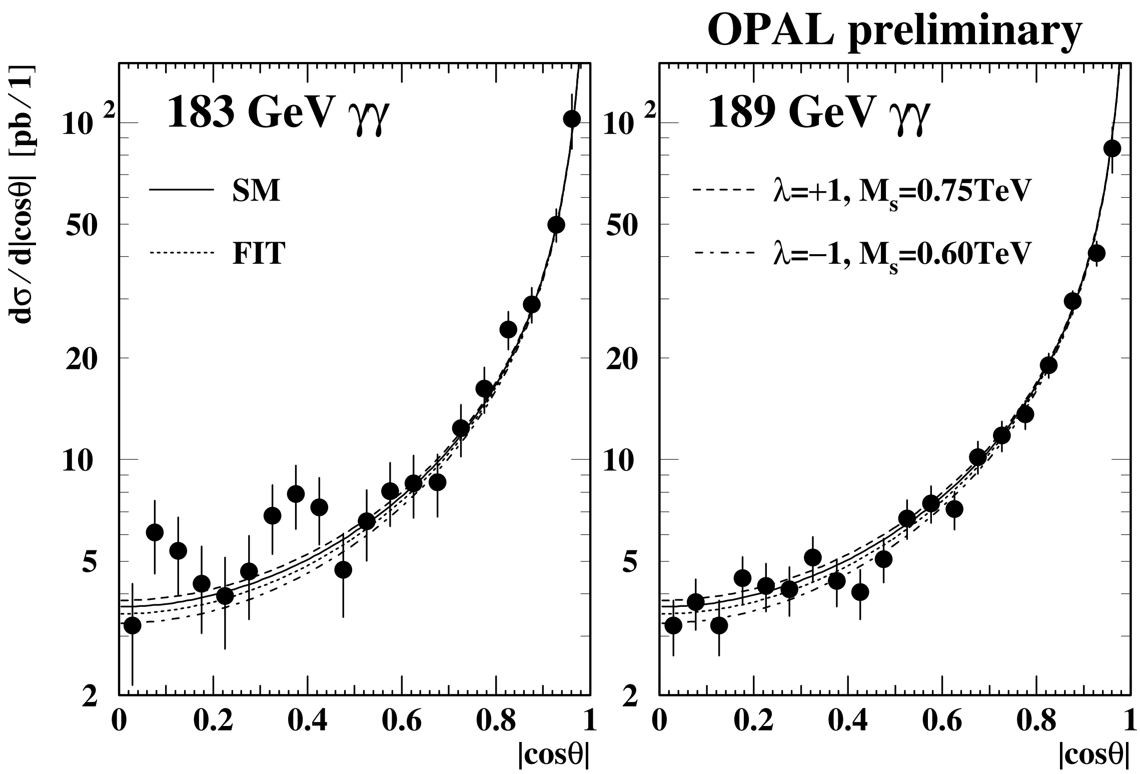
SM: solid

Best fit with new interaction: dashed

95% CL on M_s with λ=1: dotted

95% CL on M_s with λ=-1: dot-dashed

Consistency of Photon Pair Angular Distributions with Extra Dimensional Gravity



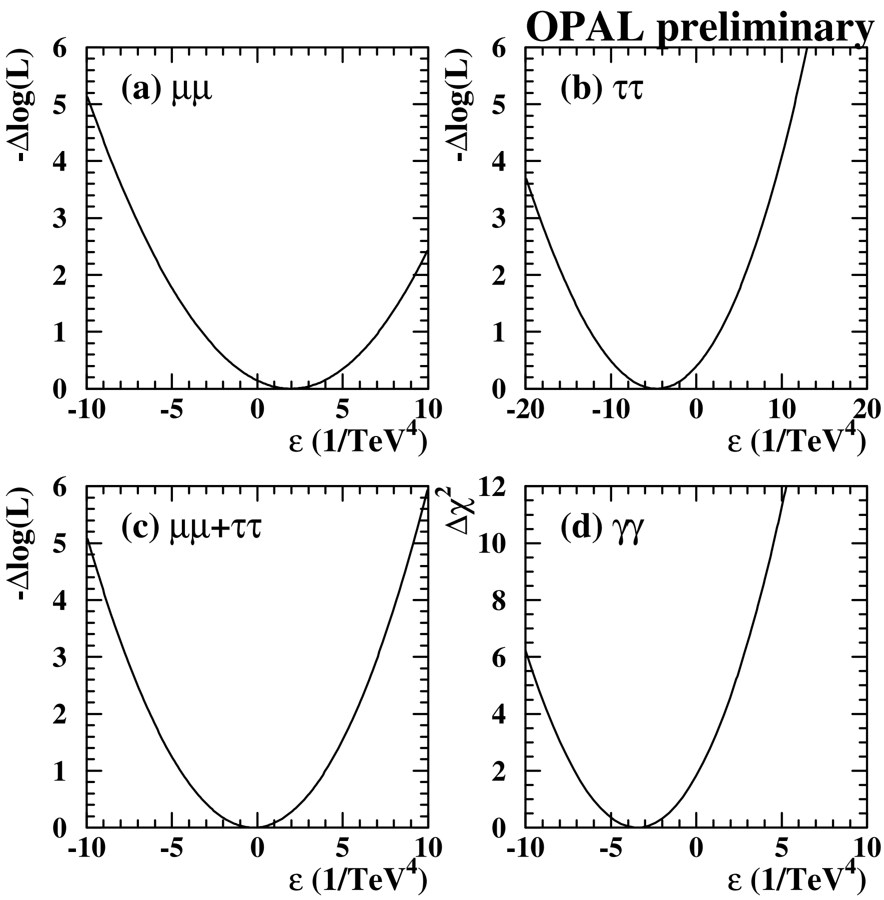
SM: solid

Best fit with new interaction: dashed

95% CL on M_s with λ=1: dotted

95% CL on M_s with λ=-1: dot-dashed

Likelihood Fit to Anomalous Angular Distributions from Extra-Dimensional Gravity



95% CL M_s limits, using 183 and 189 GeV data

(M_s limits in TeV):

	$\lambda = +1$	$\lambda = -1$
e:	0.58	0.65
μ:	0.63	0.50
τ:	0.65	0.64
γ:	0.75	0.60

Summary

Broad variety of searches for new phenomena at OPAL in the LEP2 era

- Higgs, SM and MSSM
  - SM Higgs limit: 91.0 GeV at 95% CL (expected 94.5)
  - h, A limits at 74.8, 76.5 GeV
  - Charged Higgs limit at 68.7 GeV
- SUSY: Chargino, neutralino, stop, sbottom
  - LSP neutralino limit at 27.9 GeV (SUGRA CMSSM, for all param values)
  - Stop, Sbottom limits determined by LEP energy + kinematics
- Other subjects not presented, but covered within OPAL:
  - Gauge-mediated SUSY-breaking models
  - R-parity violating SUSY
  - General two-Higgs doublet models.
  - Higgs $\rightarrow$ invisible SUSY particles
  - Single, multiple photons+missing E
- Ready to search new phenomena at LEP2

`http://www.cern.ch/Opal/PPwelcome.html`