Results From the OPAL Collaboration

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- The 1997 LEP Running
- Standard Model $f\bar{f}$
- W^+W^- Physics
- Triple Gauge Coupling
- QCD
- Searches for New Particles...photons, Higgs, SUSY, excited fermions
- CP Violation (but don't cancel BaBar yet!)

The 1997 Run

- OPAL logged a total of 65 pb^{-1}

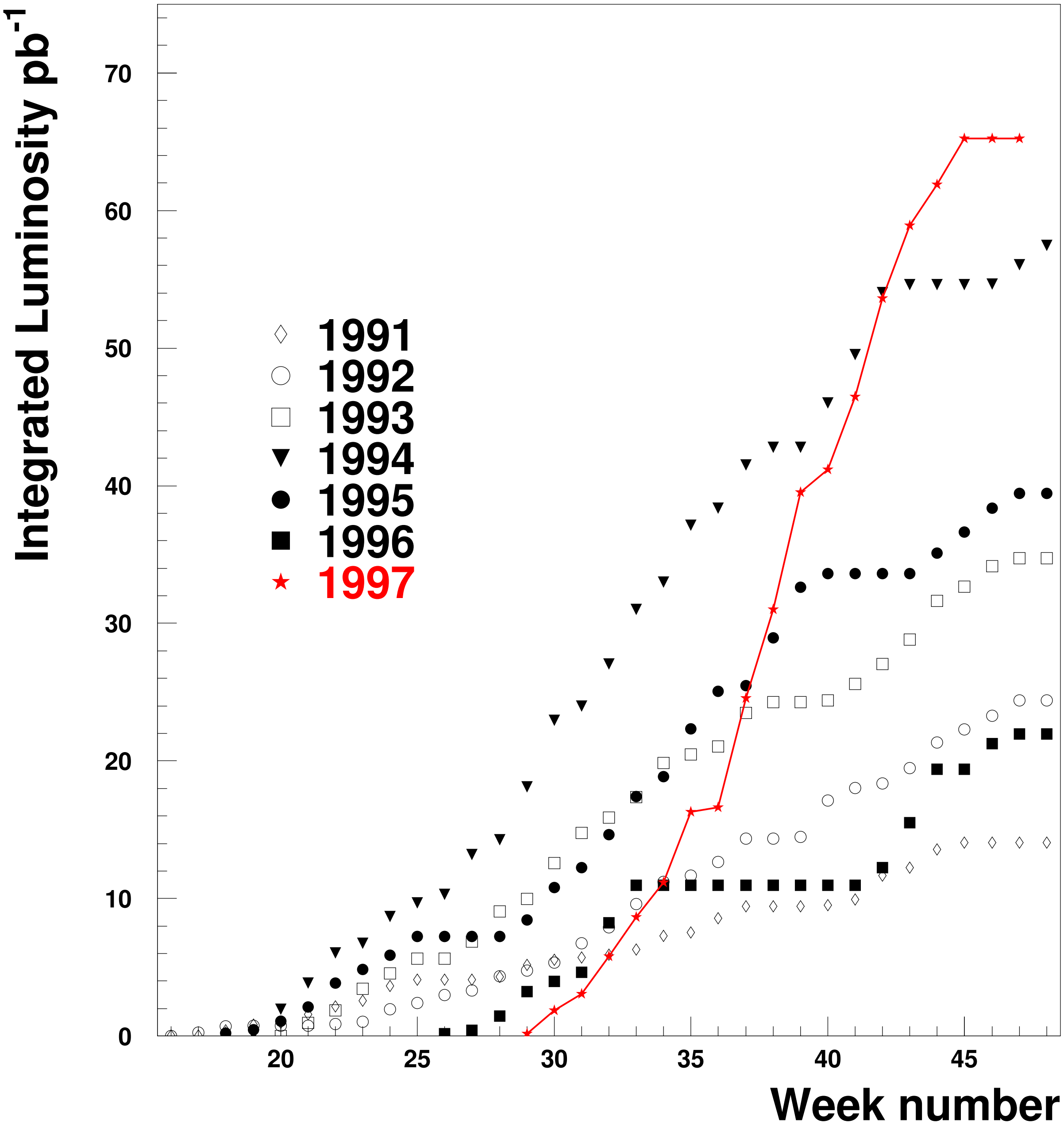
  57 pb^{-1}@ 182.6 GeV

  6 pb^{-1}@ 130, 135 GeV

  2 pb^{-1}@ 91 GeV

- ... with 91% efficiency
- LEP achieved excellent rates,
- ... but problems with vacuum

OPAL Online Data-Taking Statistics



LEP-2

The stages of LEP-2 follow the schedule of RF cavity installation.

- For 1998 cryogenics capacity below expectation $\Rightarrow$ 189 GeV.
- For 1999 get LHC cryo plant and 16 extra RF cavities $\Rightarrow$ 200 GeV !

Stage	$\sqrt{s}$ (GeV)	Year	Int. Lumi (pb^{-1})
LEP 1	91	89-95	173
LEP 1.5	130-140	1995	5
LEP 2	161	1996	10
	172	1996	10
	183	1997	$\sim$60
	189	1998	100?
	200	1999	100?
	200	2000	100???

RF Cavities:

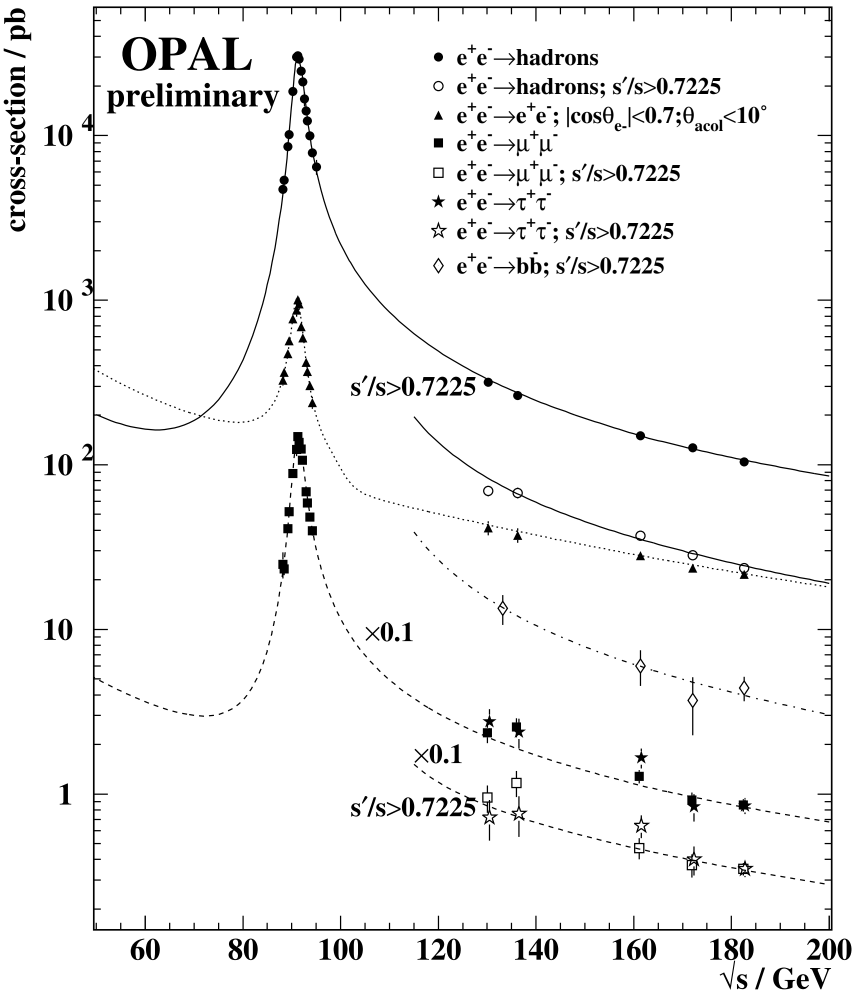
Type	Length (m)	MV/m	Voltage (MV)
Cu	2.130	1.174	2.50
Nb-sheet	1.702	5.00	8.51
Nb-film	1.702	6.00	10.24

Standard Model $f\bar{f}$ Production

- s' obtained from kinematic fit
- define non-radiative as s'/s > 0.7225 (not 0.8 anymore)
- R $= \sigma(q\bar{q}X)$ / $\sigma_{\mu\mu}^{Born}$, both inclusive of WW and ZZ production, and corrected to Born level
- $R^{inclusive}(183 \text{ GeV}) = 14.25 \pm 0.19 \pm 0.28$ 14.51
- $R^{Born}(183 \text{ GeV}) = 6.8 \pm 0.2 \pm 0.2$ 7.0
- Of special interest:
  $R_b(183) = 0.186 \pm 0.025 \pm 0.014$ 0.163

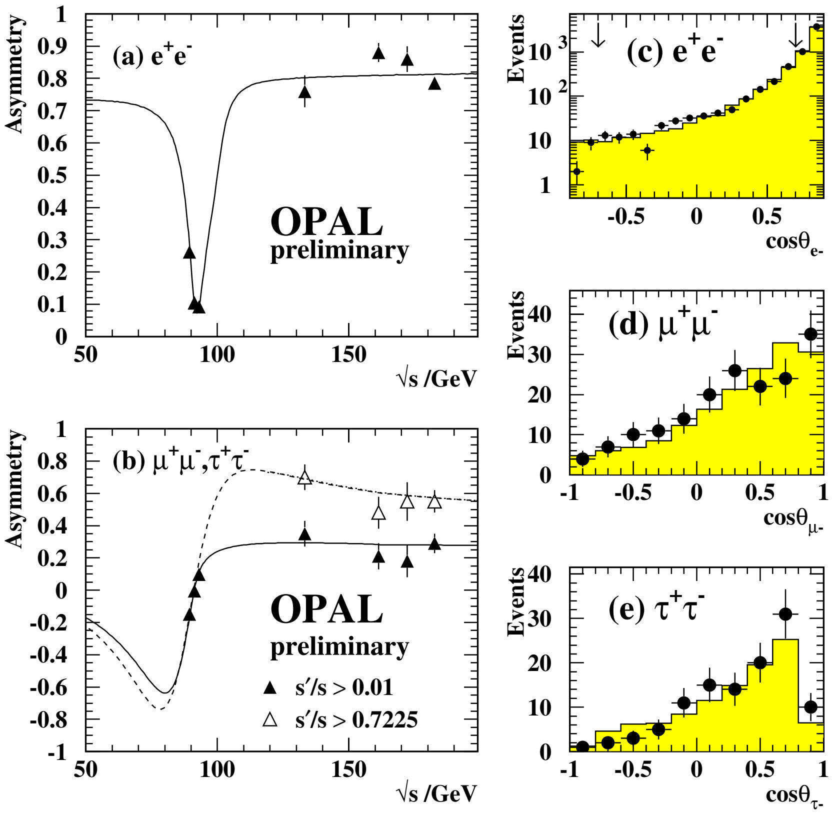
Standard Model Tests: $e^+e^- \to f\bar{f}$

- Measure total and non-radiative cross sections ($s'/s > 0.7225$)



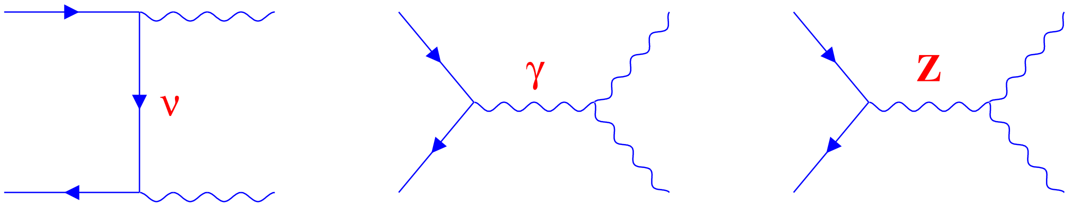
Forward-backward Asymmetries

- Exellent SM agreement (ZFITTER, ALIBABA)
- $\alpha_{em}^{-1}(182.6GeV) = 127.3^{+6.1}_{-5.0}$ (SM: 127.9 ± 0.1)



W^+W^- Production

The reaction is dominated by 3 diagrams:



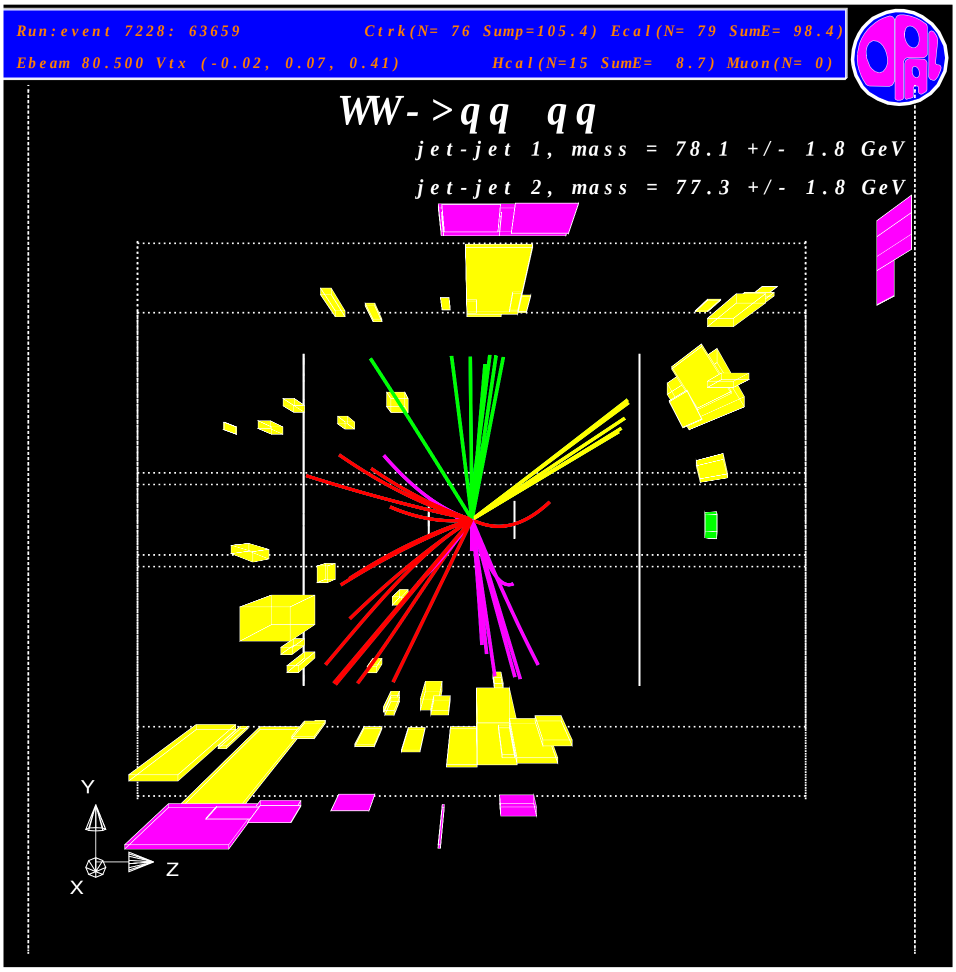
$e^+e^- \to W^+W^- \to$ 4-fermions used for:

- M_W (threshhold cross section or direct mass reconstruction)
- Triple Gauge Coupling (eventually)

We identify the following final states:

- $qqqq$ 4-jet final state about 46% of the time
- $qql\nu$ 2-jets + lepton + E_{miss} about 44%
- $l\nu l\nu$ 2-leptons + E_{miss} about 11%

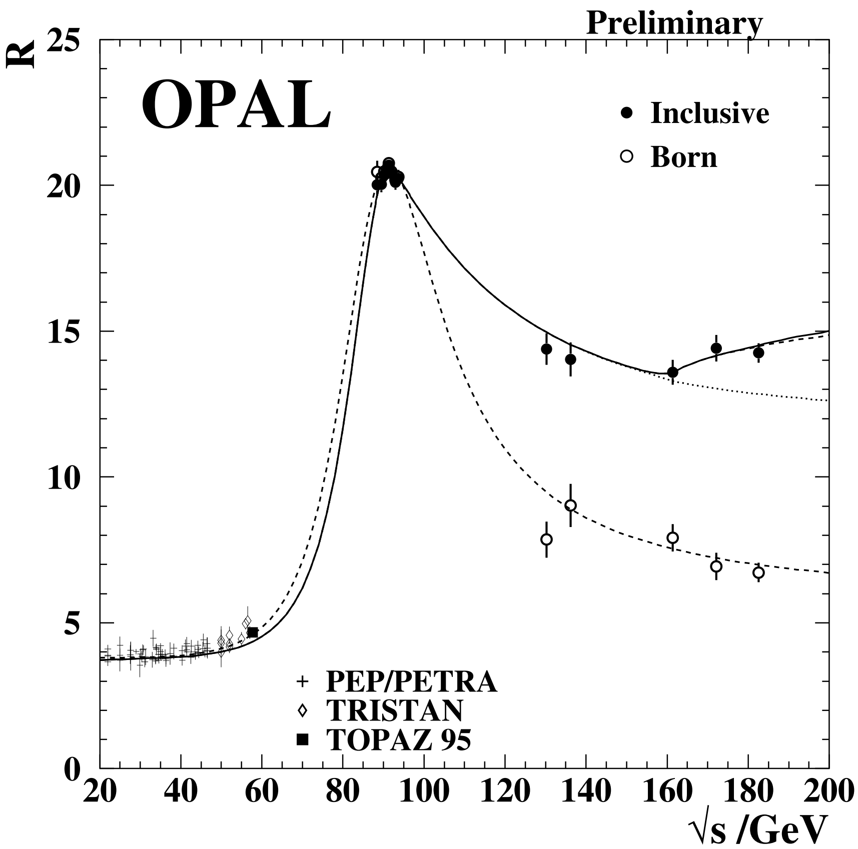
$W^+W^- \to q\bar{q}q\bar{q}$ Event Selection



hadronic jets, high multiplicity, large visible energy

- 4-jet like: $y_{34} > 0.01$, no hard ISR γ
- Kinematic fit with $E, \vec{p}$ conservation, $M_{W_1} = M_{W_2}$
  very loose cuts on $P_{\rm fit}(\chi^2)$, $M_{\rm fit}$

Some Evidence of $W^{\pm}$ Production

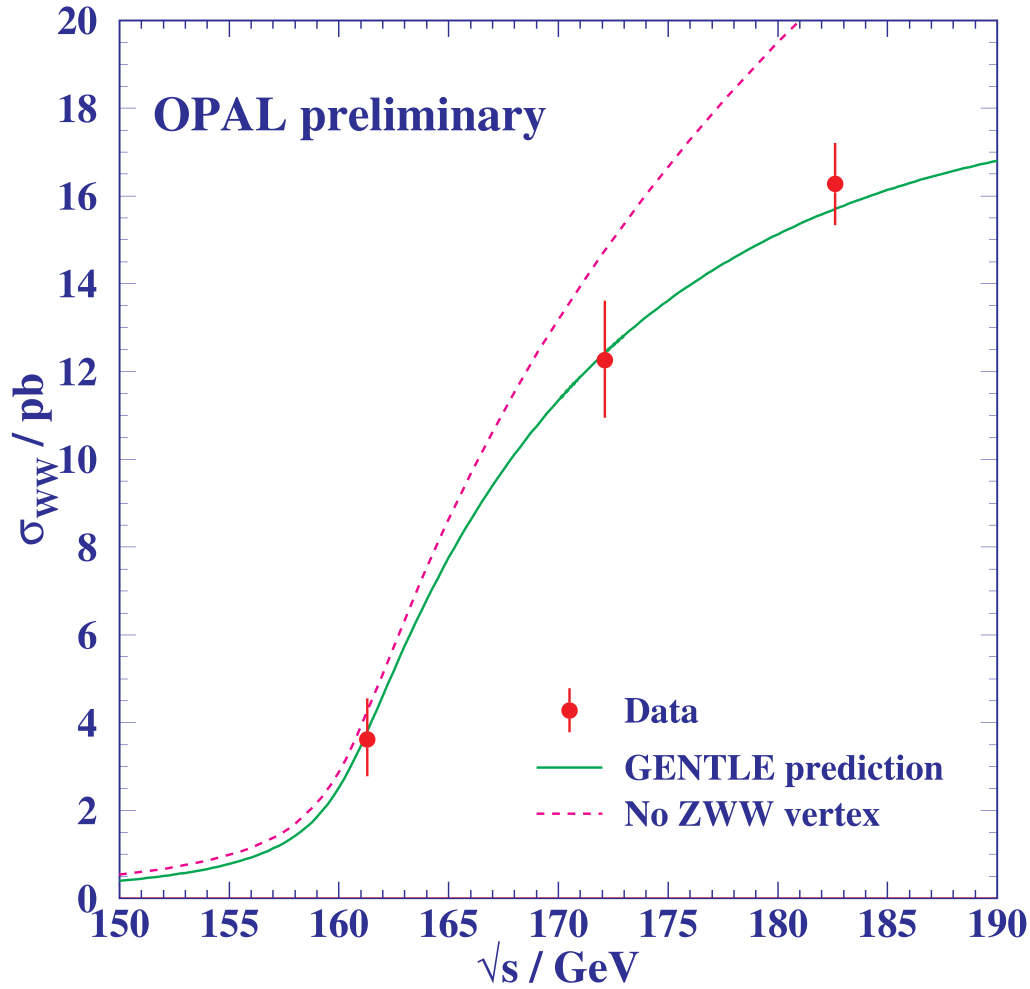


$\mathbf{W^+W^-}$ Production

- $\sigma_{WW} \;=\; 16.3 \pm 0.65 \pm 0.68\ pb^{-1}$ @ 183 GeV

Decay mode:	$\ell^+\nu_\ell\ell^-\bar{\nu}_\ell$	$q\bar{q}\ell^+\nu_\ell$	$q\bar{q}q\bar{q}$
Efficience:	77%	83%	80%
Purity:	94%	93%	80%

	N_{signal}	N_{bkg}	$N_{expected}$	N_{obs}
All ch:	639±20	94±22	733±30	754



Standard Model WW Summary

$W^{\pm}$branching ratios for $\sqrt{s}$= 161, 172, 183 GeV:

$$\begin{aligned}
\mathrm{Br}(\mathrm{W} \to \mathrm{e}\overline{\nu}_{\mathrm{e}}) &= 0.117 \pm 0.009 \pm 0.005, \\
\mathrm{Br}(\mathrm{W} \to \mu\overline{\nu}_{\mu}) &= 0.102 \pm 0.008 \pm 0.004, \\
\mathrm{Br}(\mathrm{W} \to \tau\overline{\nu}_{\tau}) &= 0.111 \pm 0.011 \pm 0.007,
\end{aligned}$$

Assuming lepton universality, we obtain:

$$\begin{aligned}
\mathrm{Br}(\mathrm{W} \to \ell^{+}\nu_{\ell}) &= 0.110 \pm 0.004 \pm 0.004. \\
\mathrm{Br}(SM) &= 0.108
\end{aligned}$$

Use for indirect determination of the hadronic BR:

$$\begin{aligned}
\mathrm{Br}(\mathrm{W} \to \mathrm{q}\bar{\mathrm{q}}) &= 0.671 \pm 0.013 \pm 0.012, \\
\mathrm{Br}(SM) &= 0.675.
\end{aligned}$$

We use this result to determine also the CKM matrix element $|\mathrm{V_{cs}}|$. Using the experimental knowledge of the sum,
$|\mathrm{V_{ud}}|^2 + |\mathrm{V_{us}}|^2 + |\mathrm{V_{ub}}|^2 + |\mathrm{V_{cd}}|^2 + |\mathrm{V_{cb}}|^2 = 1.05 \pm 0.01$,
:

$$|\mathrm{V_{cs}}| = 0.95 \pm 0.06 \pm 0.05.$$

This result is consistent in value with and has an uncertainty which is significantly lower than other determinations of $|\mathrm{V_{cs}}|$ which do not invoke unitarity.

What A Good Measurement of M_W Tells You

Within the Standard Model, M_W is sensitive to both m_{top} and M_H.

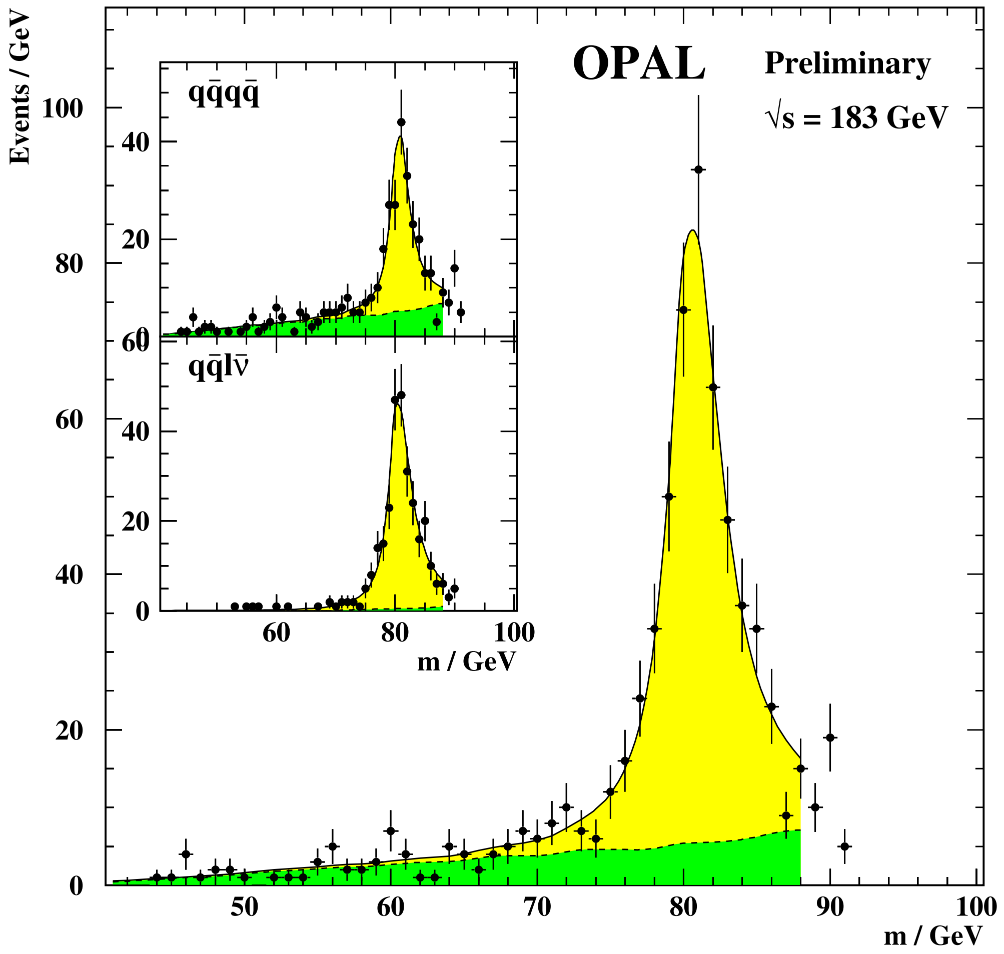
- Comparison of inferred M_W versus direct M_W = window to new physics.
- Improvement of uncertainty on direct M_W gives better inference on Higgs.

For example, with the top mass known to 5 GeV and $M_H = 100$ GeV:

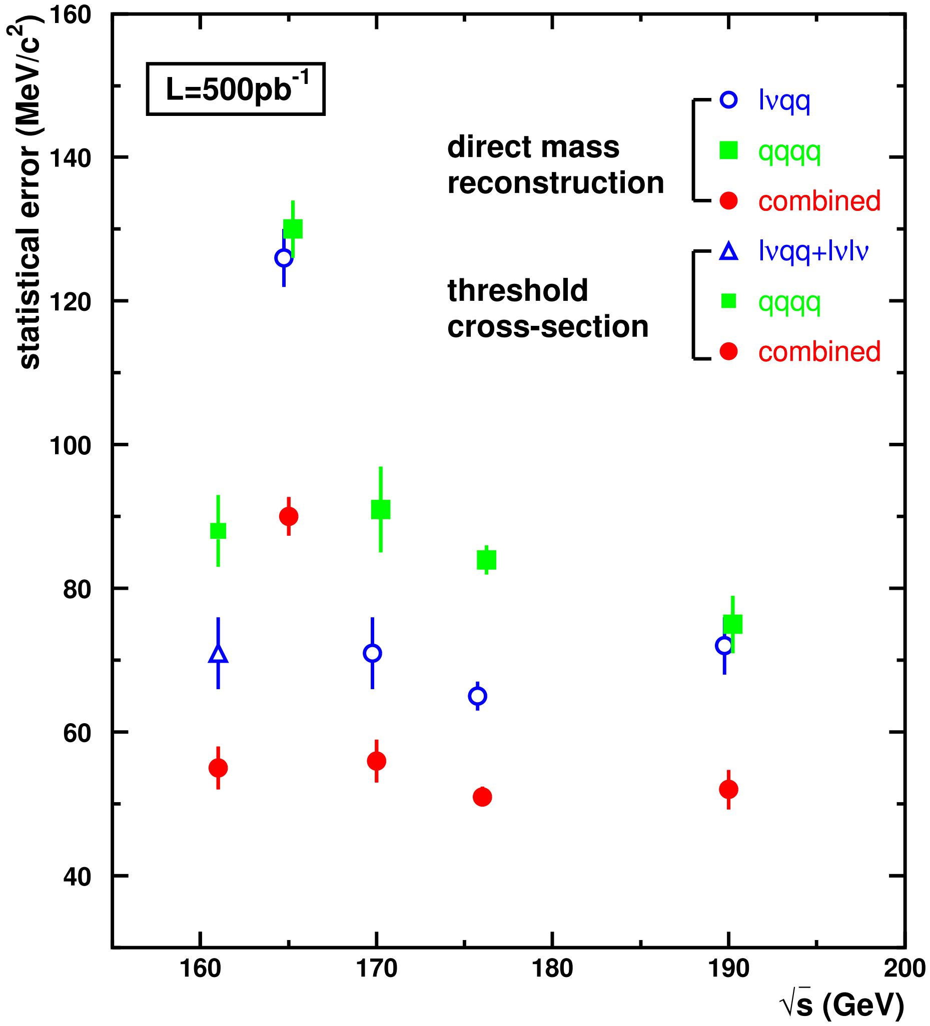
- ΔM_W=50 MeV $\Rightarrow$ ΔM_H = +140,-72 GeV
- ΔM_W=25 MeV $\Rightarrow$ ΔM_H = +86,-54 GeV

MW

- 5C fits on $q\bar{q}q\bar{q}$ and $q\bar{q}\ell^+\nu_\ell$ final states
- final values await determination of E_{beam}
- likely uncertainties: $\Delta M_{\mathrm{W}} \sim$ 140 MeV, $\Delta\Gamma_W \sim$ 350 MeV

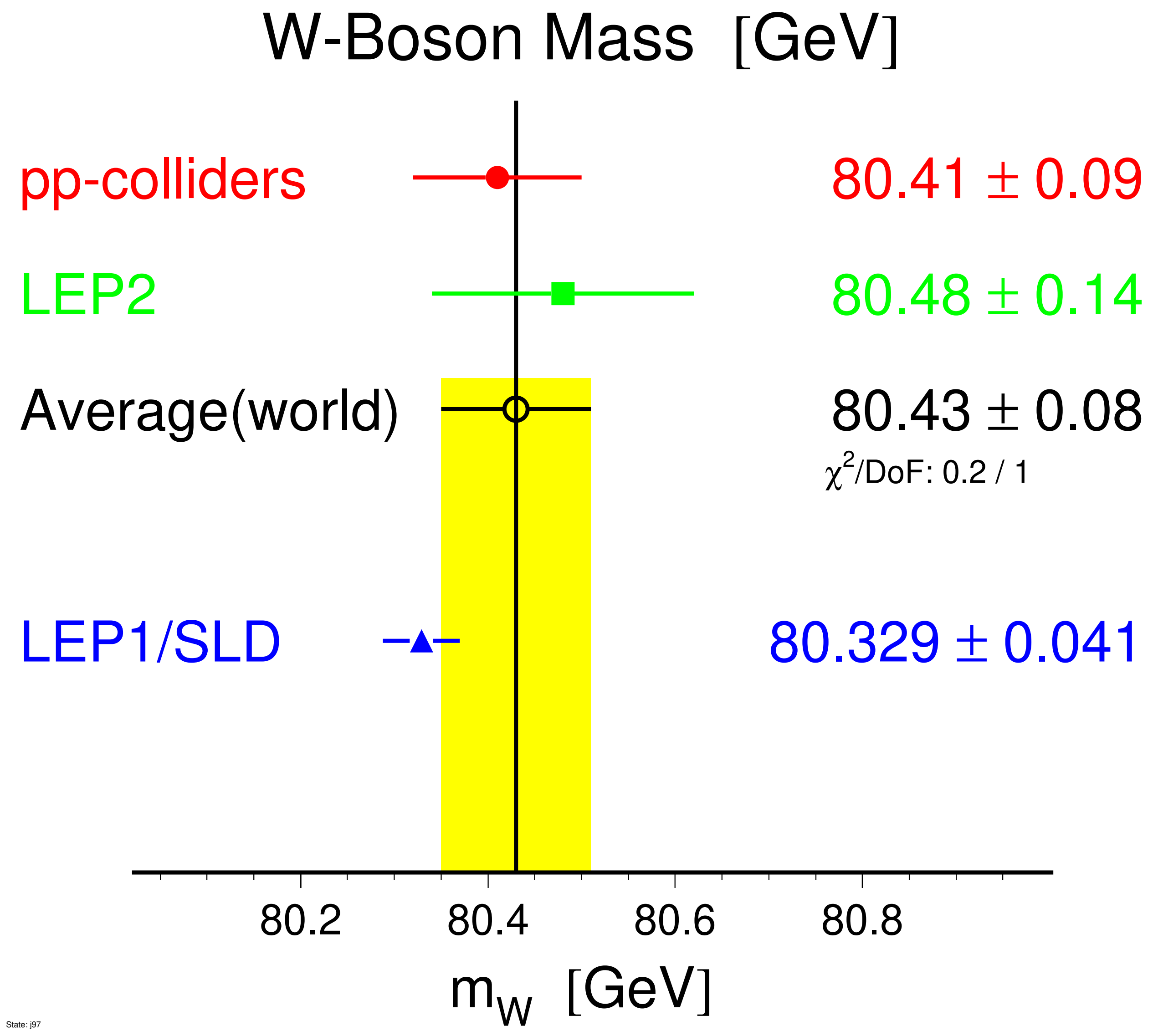


Energy Dependence of $\Delta\ M_W$

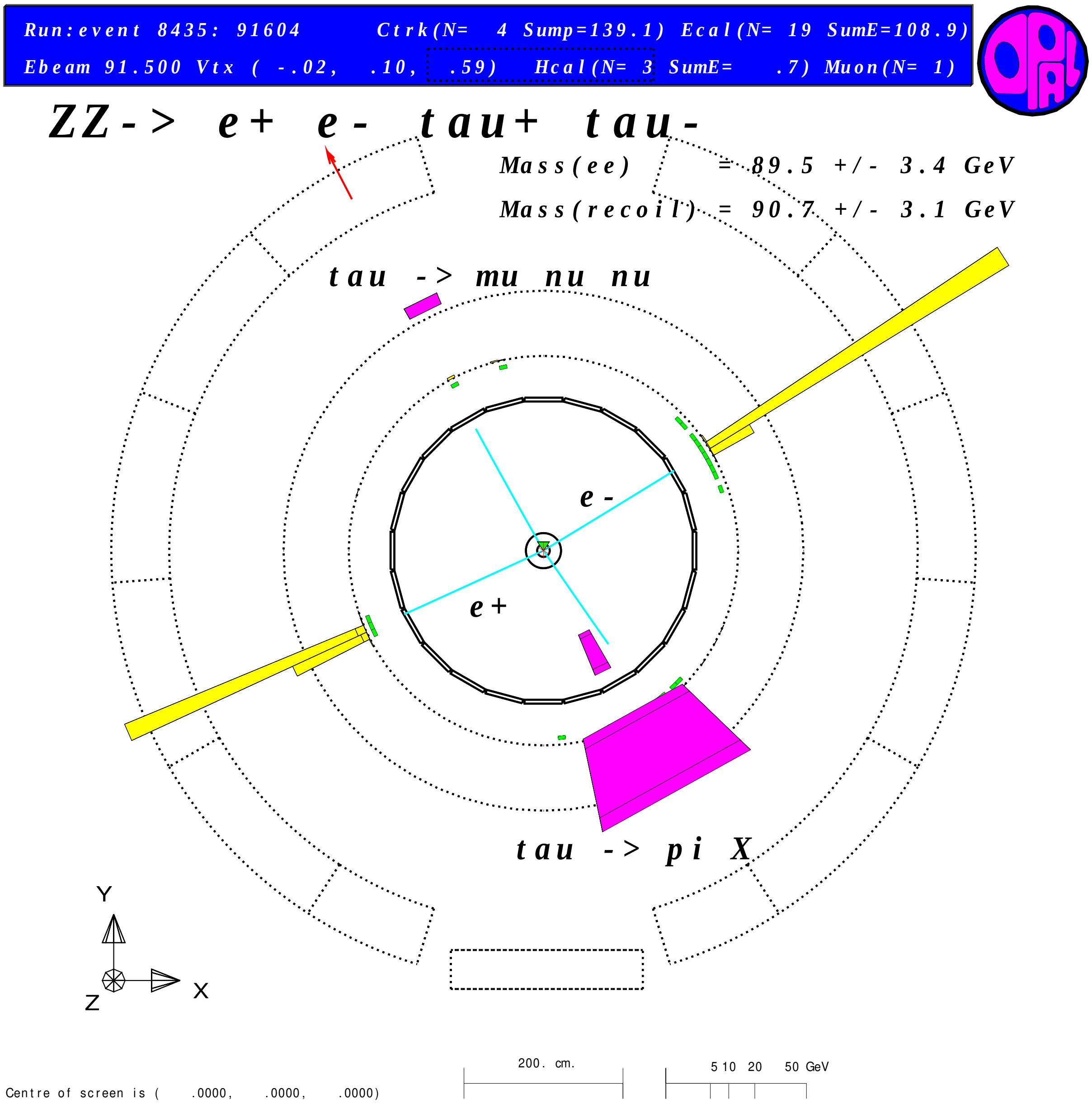


- combined LEP gets 44 MeV for $\ell\nu$qq (172) alone
- color + Bose-Einstein error limits precision for qqqq

M_W Summary – 161,172 GeV

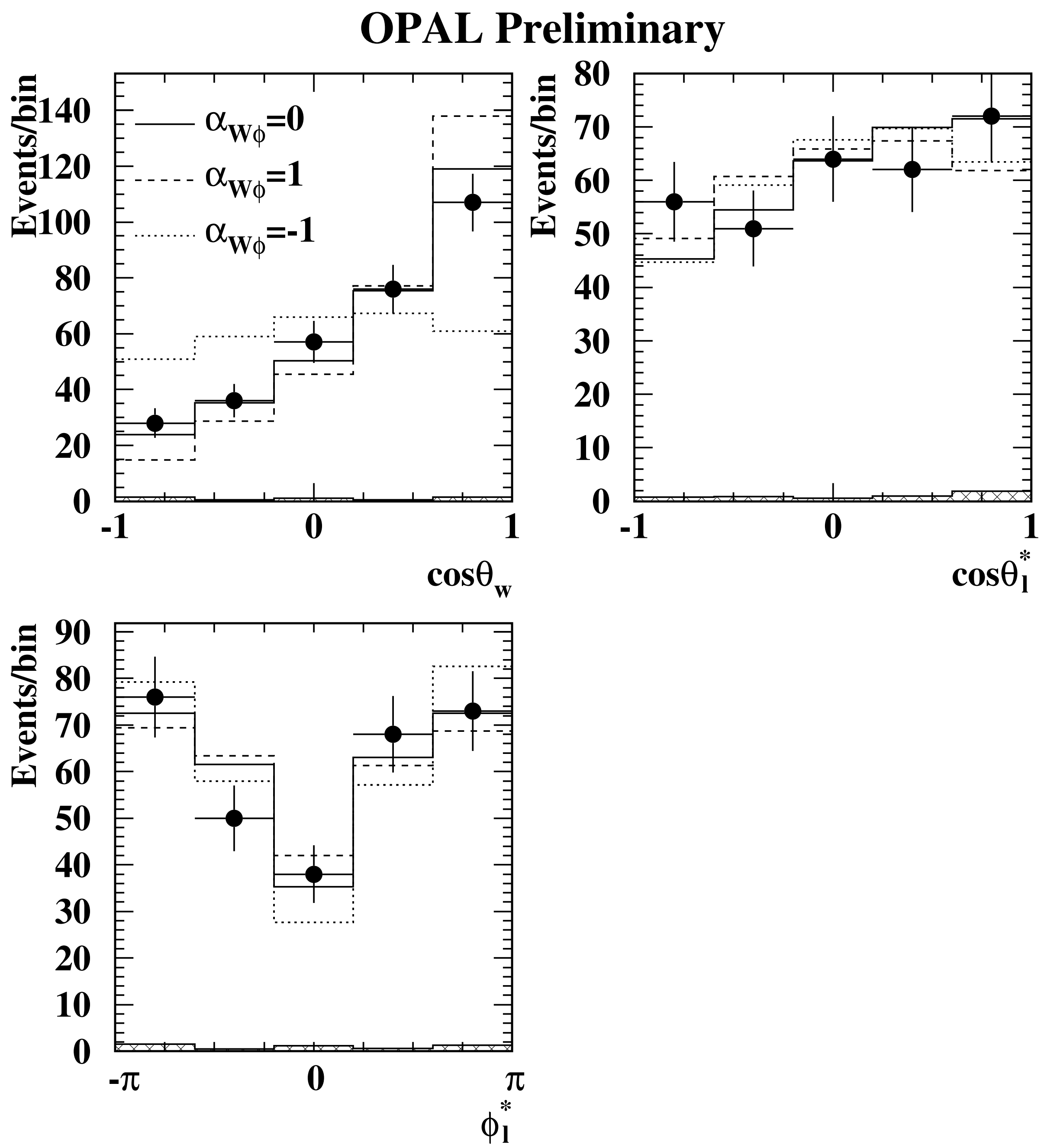


ZZ event



Run:event 8435: 91604 Ctrk(N= 4 Sump=139.1) Ecal(N= 19 SumE=108.9)
Ebeam 91.500 Vtx (-.02, .10, .59) Hcal(N= 3 SumE= .7) Muon(N= 1)
ZZ-> e+ e- tau+ tau-
Mass(ee) = 89.5 +/- 3.4 GeV
Mass(recoil) = 90.7 +/- 3.1 GeV
tau -> mu nu nu
e-
e+
tau -> pi X
Y
X
Z
Centre of screen is (.0000, .0000, .0000)
200. cm.
5 10 20 50 GeV

Triple Gauge Boson Couplings

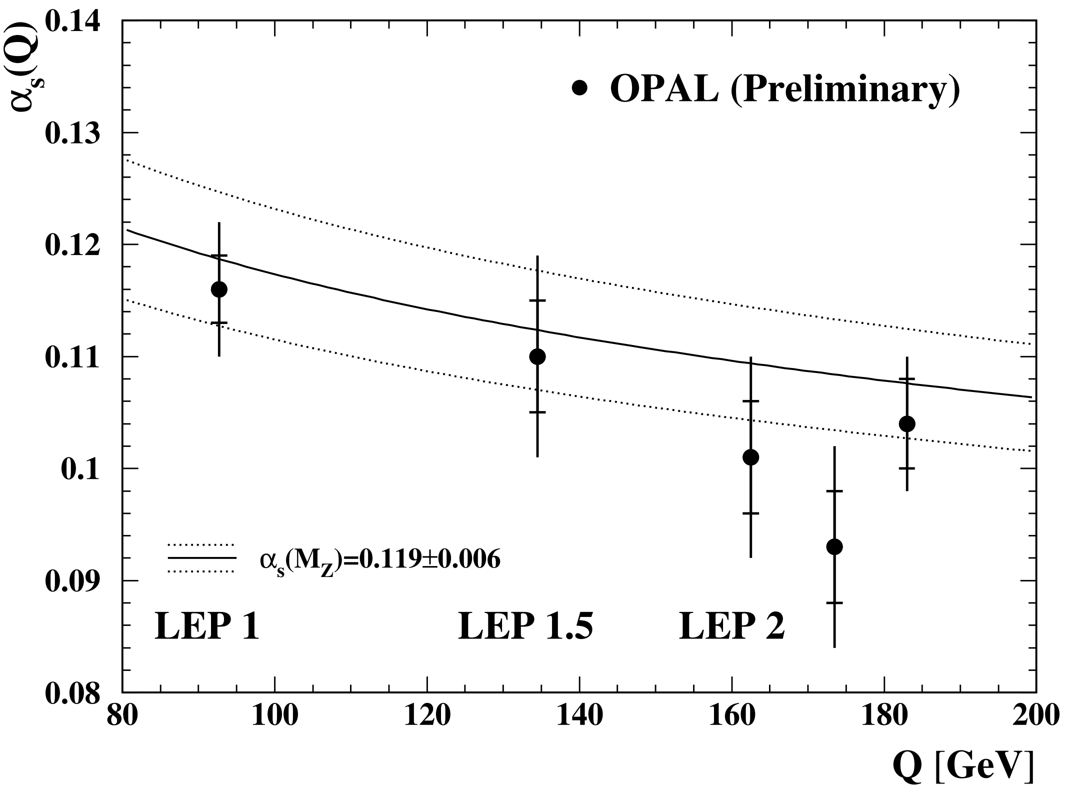


TGC Parameters

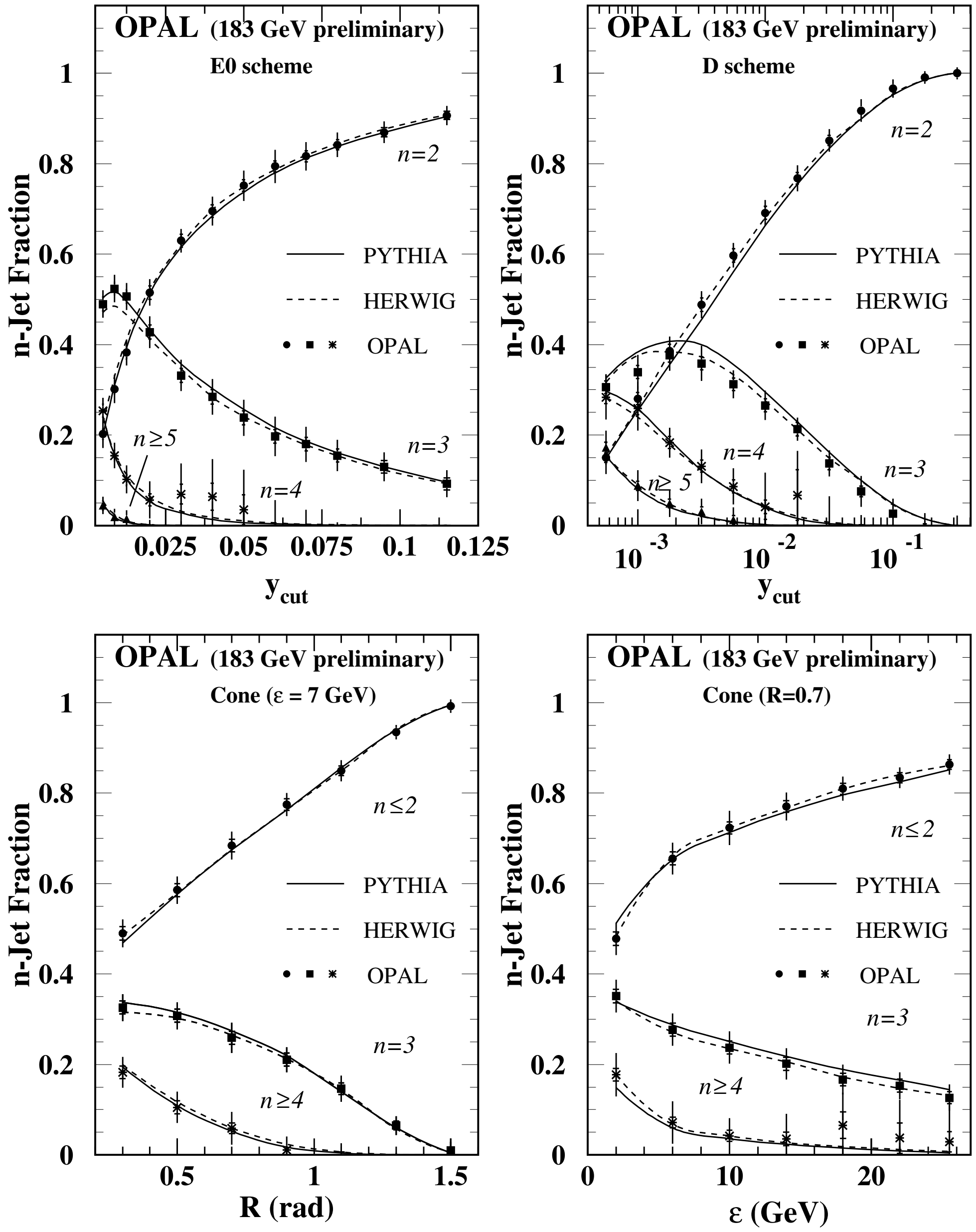
Parameter	183 GeV Measurement	Combined 172–183 GeV Measurement	Combined 172–183 GeV 95% C.L. range
$\alpha_{B\phi}(\Delta\kappa_\gamma)$	$-0.42^{+0.32}_{-0.25} \pm 0.44$	$0.03^{+0.58}_{-0.55}$	$[-1.16, \quad 1.27]$
$\alpha_{W\phi}$	$-0.06^{+0.12}_{-0.10} \pm 0.11$	-0.03 ± 0.14	$[-0.29, \quad 0.26]$
$\alpha_W(\lambda)$	$-0.14^{+0.21}_{-0.16} \pm 0.18$	$-0.06^{+0.30}_{-0.26}$	$[-0.55, \quad 0.56]$
Δg_1^z	$-0.06^{+0.22}_{-0.17} \pm 0.19$	$-0.04^{+0.24}_{-0.23}$	$[-0.47, \quad 0.44]$
$\Delta\kappa_\gamma^{(HISZ)}$	$-0.13^{+0.18}_{-0.16} \pm 0.17$	$-0.05^{+0.23}_{-0.22}$	$[-0.49, \quad 0.41]$
$\Delta\kappa$	$-0.13^{+0.17}_{-0.16} \pm 0.17$	-0.06 ± 0.22	$[-0.47, \quad 0.39]$

QCD

- Good agreement with QCD predictions over wide range of variables
- Observables thrust, jet broadening, Durham 2-jet rate, and heavy jet mass fitted to obtain $\alpha_s(183\ \mathrm{GeV})$:



QCD Jet Distributions – 183 GeV



New Particle Searches

- Searches are now mostly organized by event topology:

  anomalous photon rates

  acoplanar photons, dileptons

  large missing energy

  decay into $b\bar{b}$

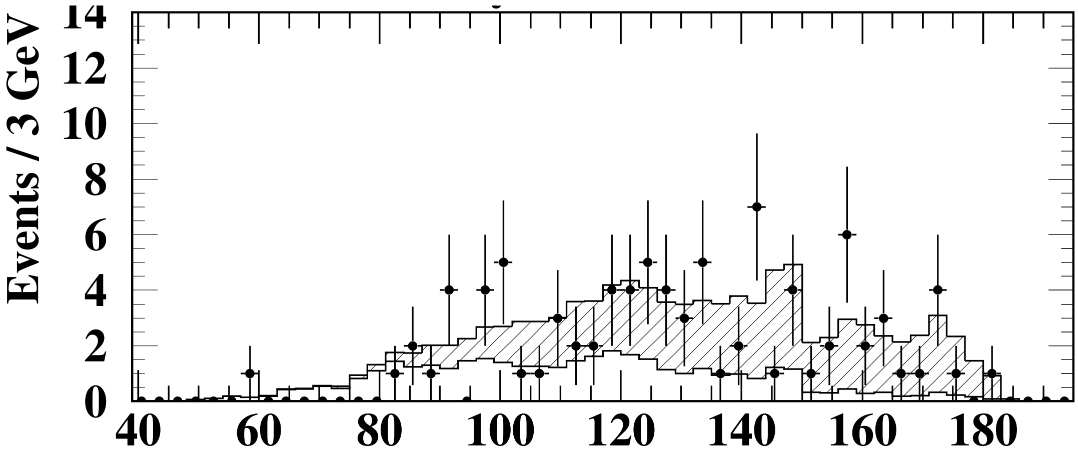
  dijet or diphoton resonances

- Ever-increasing LEP energy great for SUSY searches
- On-mass Z^0boosts Higgs cross section
- New, improved b-tagging
- New, improved photon finding, conversions

Anomalous 4-jet Production

In 1997, LEP ran for 6 pb^{-1}at 130 and 135 GeV; The anomalous dijet resonance reported by ALEPH was not confirmed.

	No mass window		$\|M - 105\ \text{GeV}\| < 2\sigma$ Without W-Pair Veto	
Data Sample	Observed	Expected	Observed	Expected
130–136 GeV	13	14.7 ± 0.6	1	1.6 ± 0.2
183 GeV	64	71.9 ± 1.0	12	10.4 ± 0.4
All $\sqrt{s}$ 133–183 GeV	89	105.5 ± 1.2	17	16.5 ± 0.5

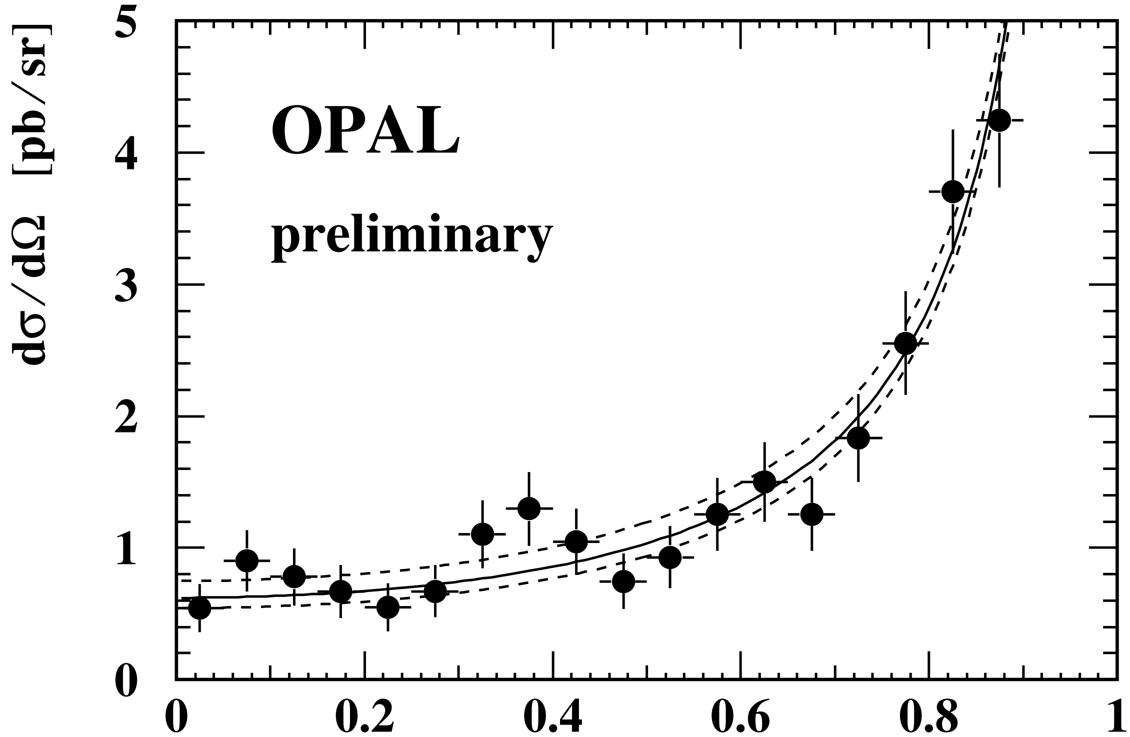


$\gamma\gamma$ Cross Section

QED process, measure cut-off parameters $\Lambda_\pm$:

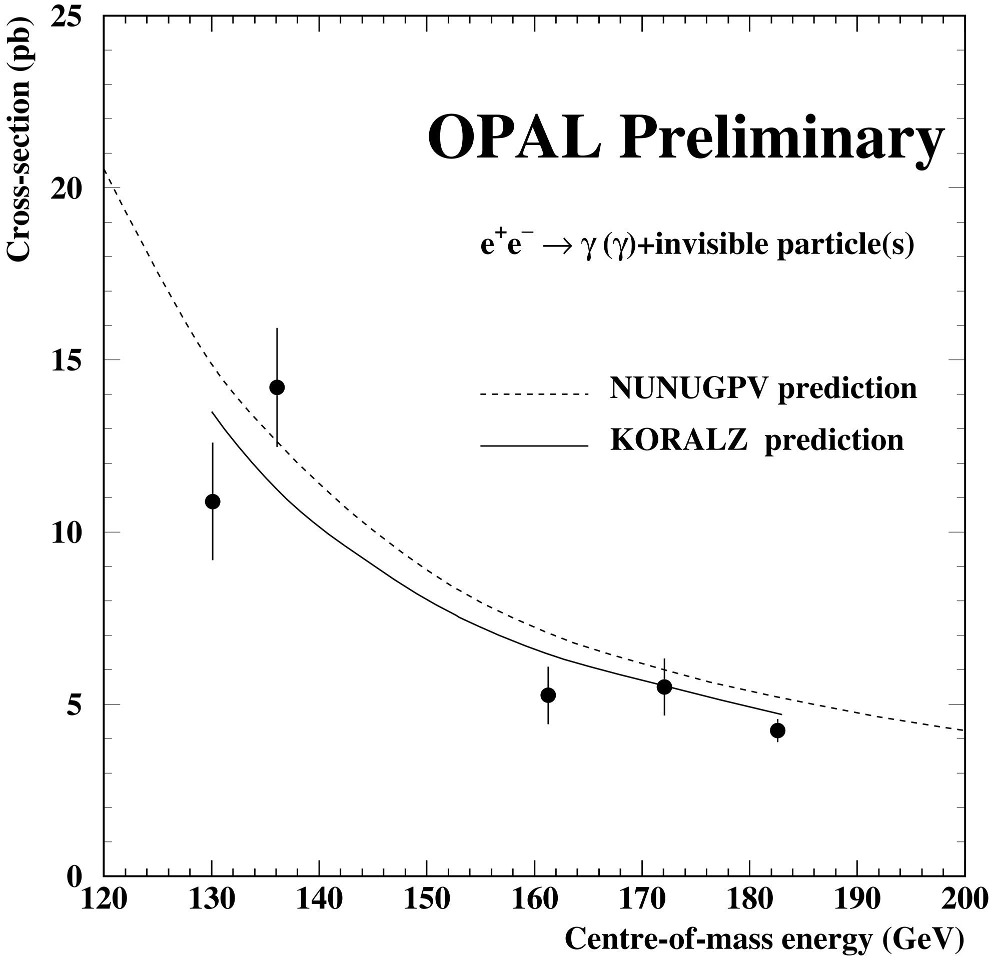
$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_\pm} = \frac{\alpha^2}{s}\;\frac{1+\cos^2\theta^*}{1-\cos^2\theta^*}\;\left[1 \pm \frac{s^2}{2\Lambda_\pm^4}\sin^2\theta^*\right]$$

$\Lambda_+ > 228$ GeV, $\Lambda_- > 258$ GeV



Single γ Final States

- Sensitive to new physics: viz., $\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 \gamma$
- Main background from $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$
- 183 Gev: 160 events observed, 177±5 expected



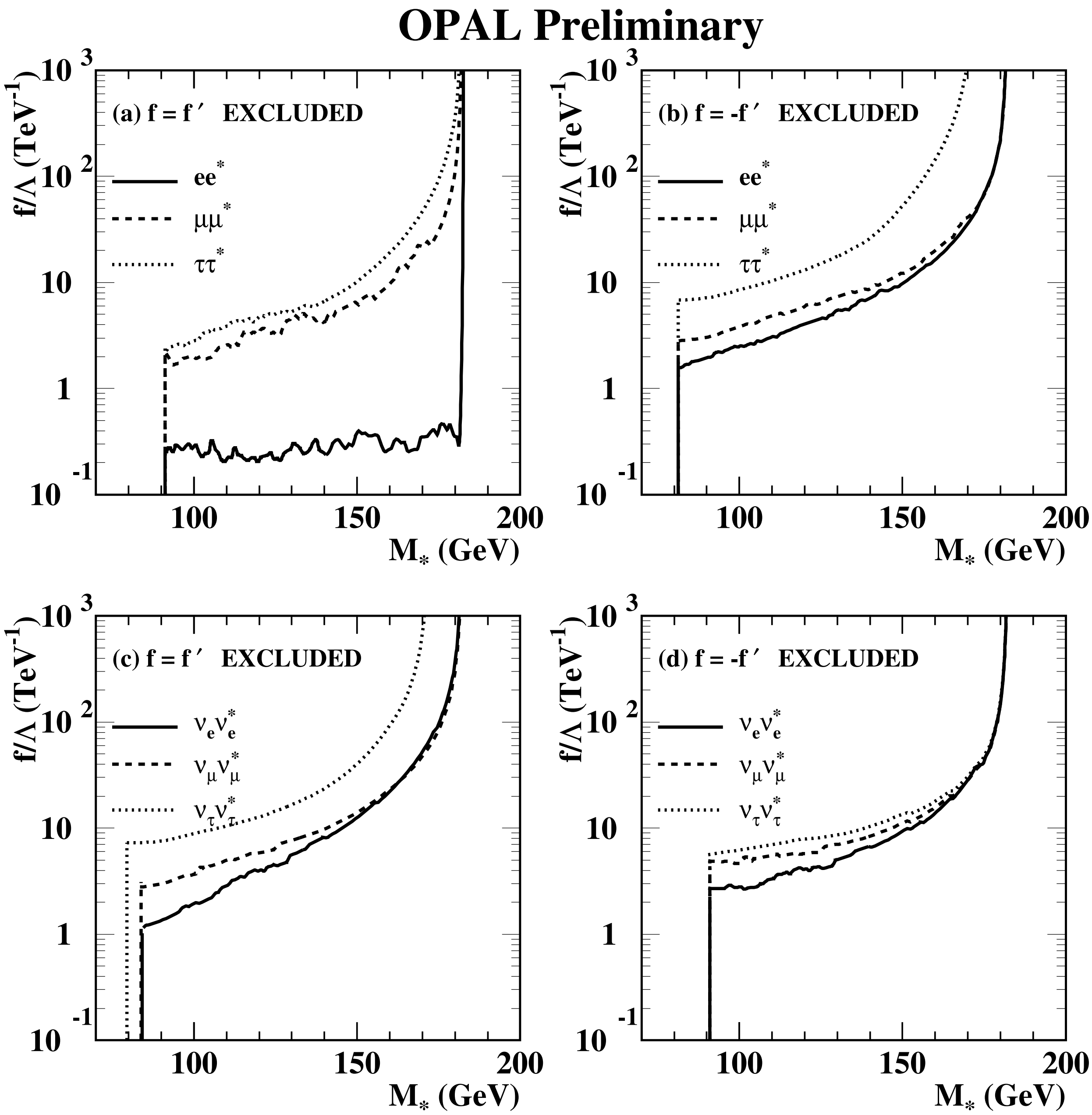
Excited Leptons

Effective Lagrangian for excited leptons:

$$\mathcal{L}_{\ell\ell^*} = \frac{1}{2\Lambda}\bar{\ell}^*\sigma^{\mu\nu}\left[gf\frac{\boldsymbol{\tau}}{2}\mathbf{W}_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu}\right]\ell_{\mathrm{L}} + \mathrm{h.~c.},$$

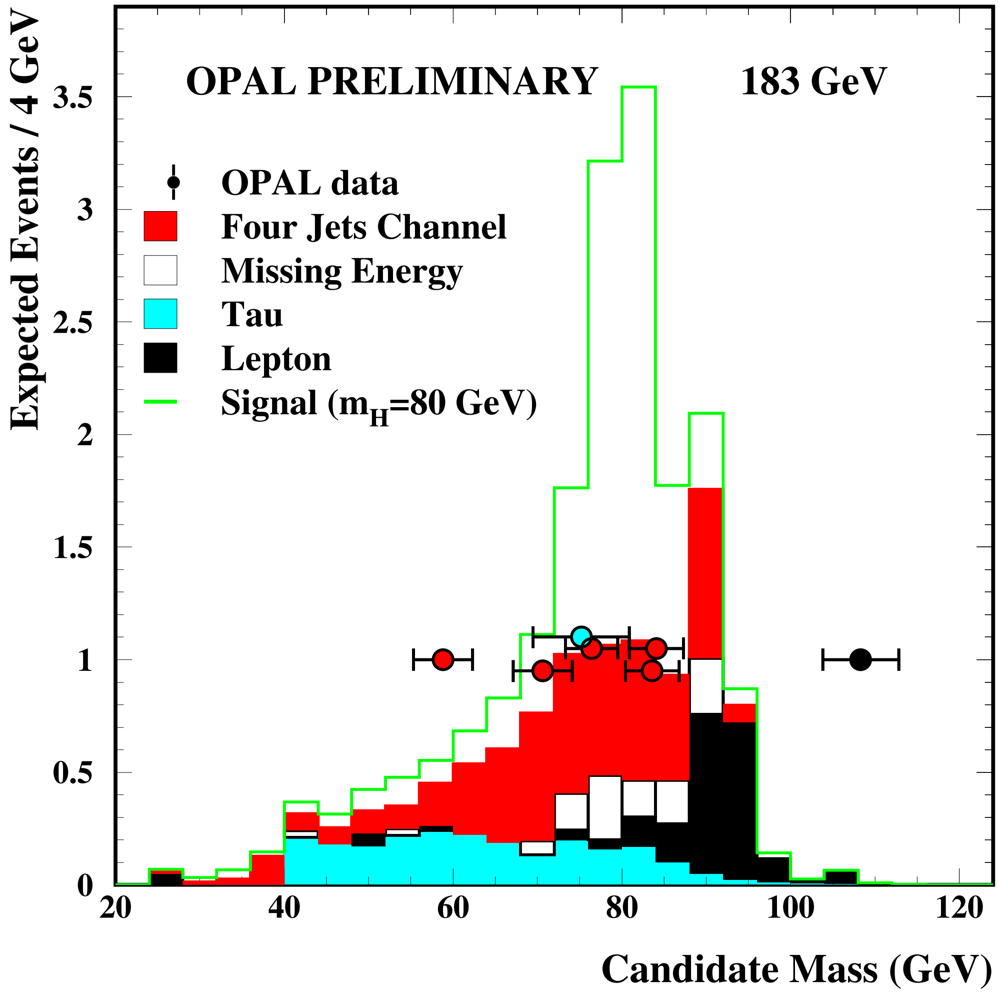
- Λ has units of energy and can be regarded as the "compositeness scale,"
- f and f' are couplings associated with the different gauge groups.
- $\ell^*\to\ell\gamma$, $W\nu$ and $\nu^*\to\nu\gamma$
- Get limits in terms of f/Λ, with $f = \pm f'$
- At 183 GeV, obtain overall lower mass limits of $\sim$ 91 GeV

183 GeV Limits for ℓ^*, ν^*



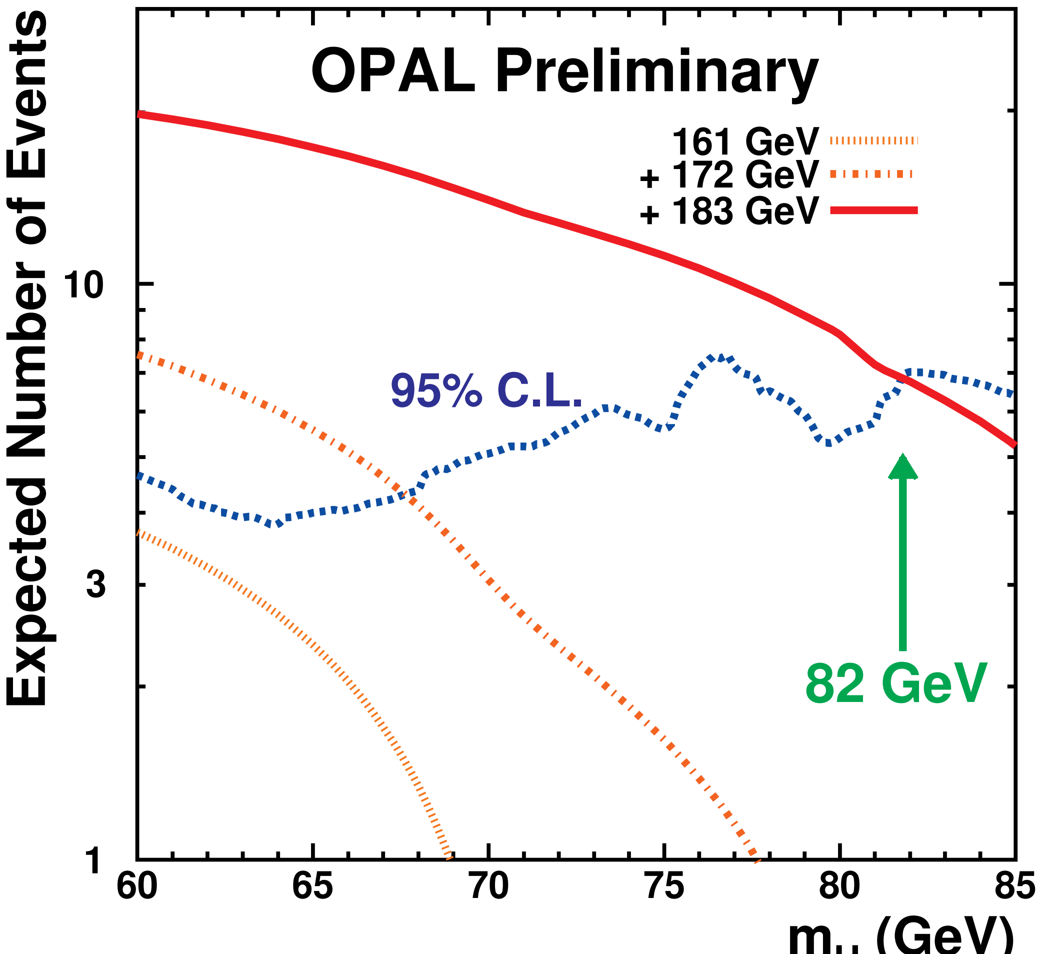
Search for the SM Higgs

- $e^+e^- \rightarrow$ ZH in $q\bar{q}+$ [$b\bar{b}$, $\tau^+\tau^-$, $e^+e^-+\mu^+\mu^-$]
- Better efficiency now with new likelihood methods in $q\bar{q}q\bar{q}$, $q\bar{q}\nu\bar{\nu}$
- For this presentation, 39 pb^{-1}analyzed
- No more background-free searching!

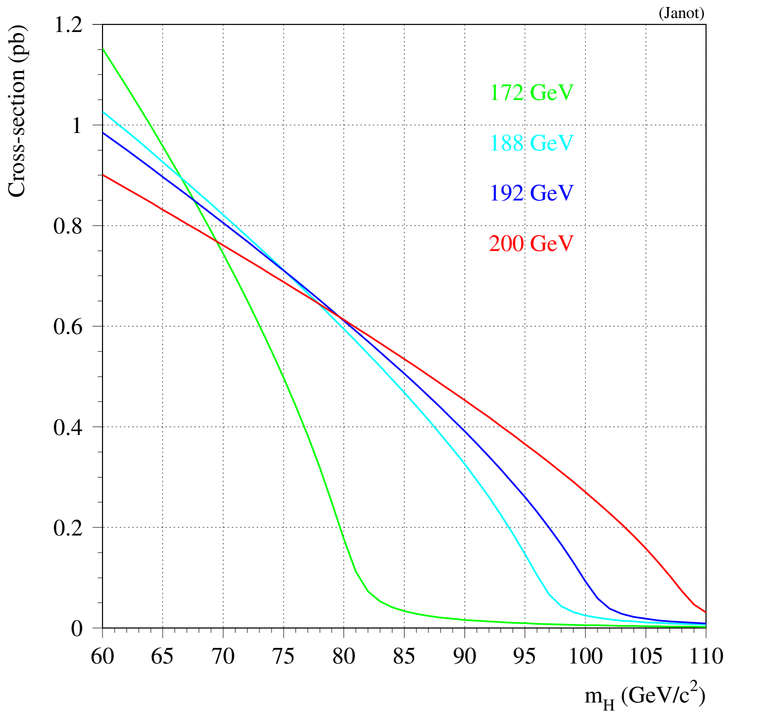


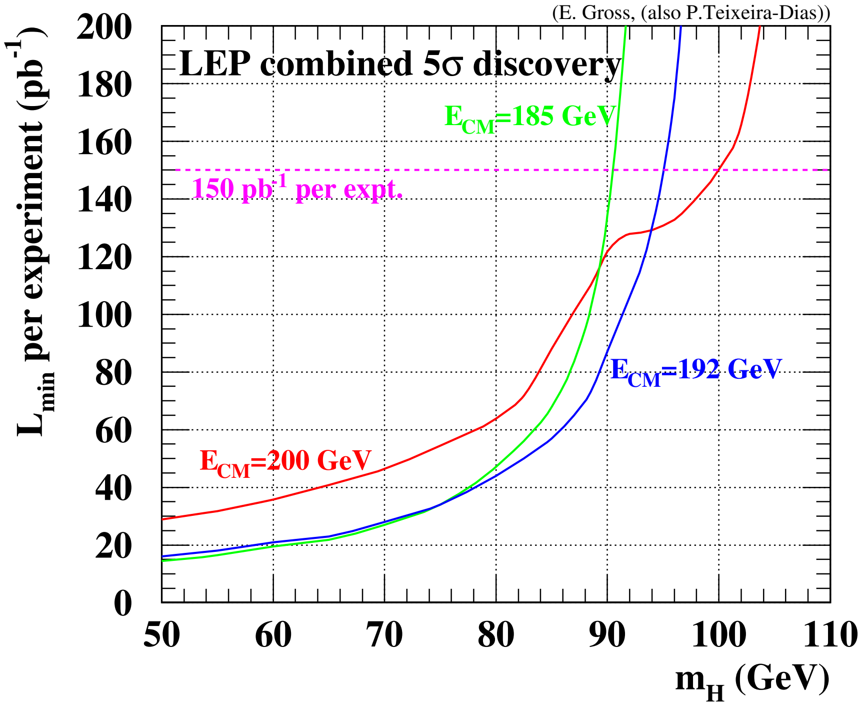
SM Higgs

- OPAL obtains lower mass limit of 82 GeV



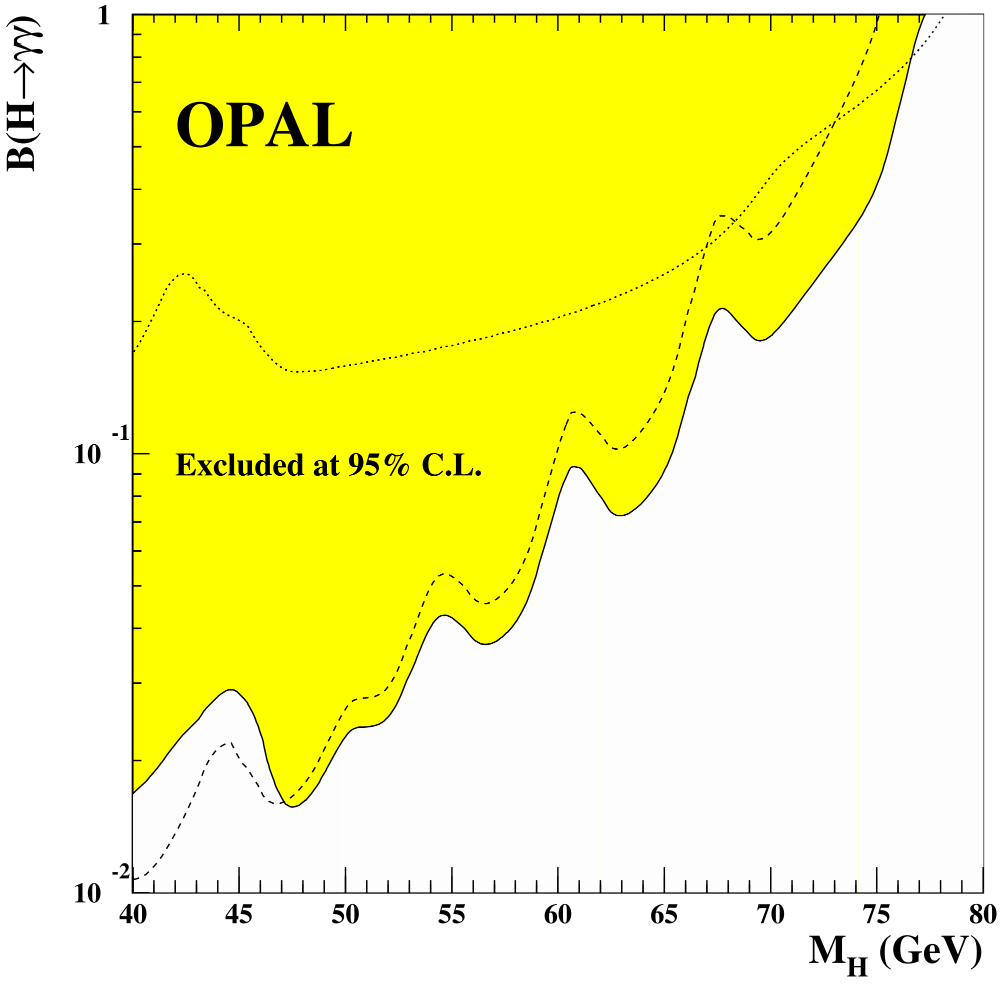
SM Higgs Discovery Potential





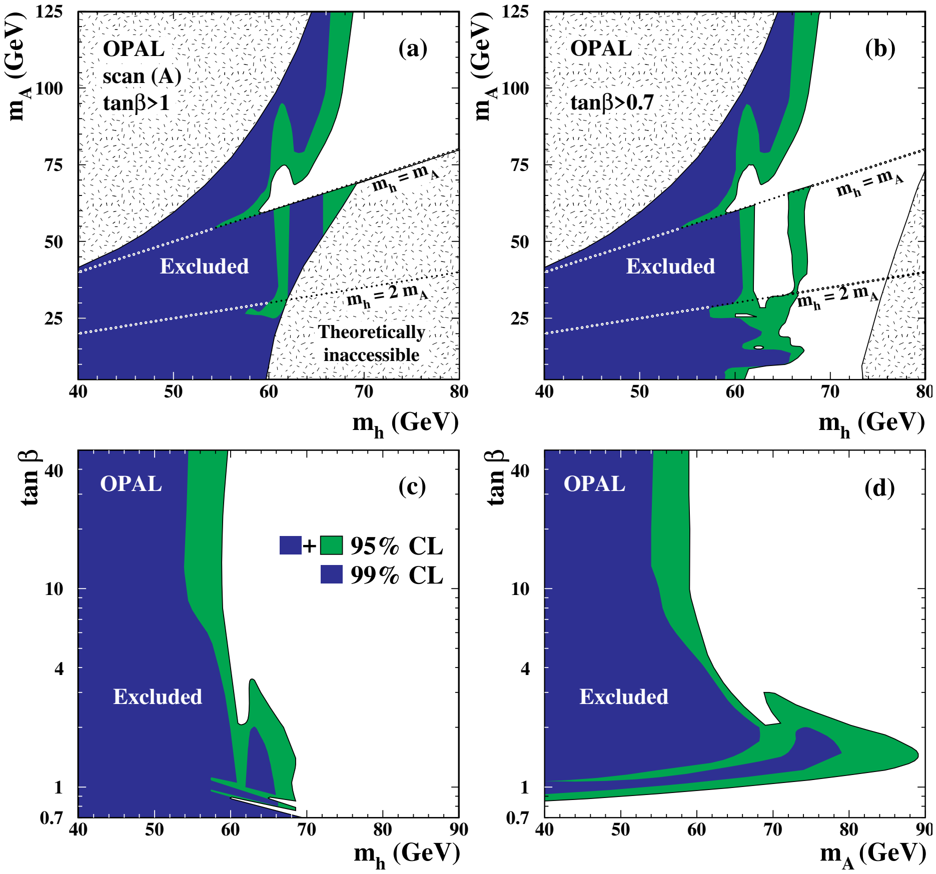
Be Afraid. Be Very Afraid.

- What if the Higgs has an aversion to fermions?
- ...Di-photon coupling dominates for low M_H
- We have published a limit of 77 GeV for $\sqrt{s}=$ 130-172 GeV; will get around 91 GeV with the 183 GeV data.



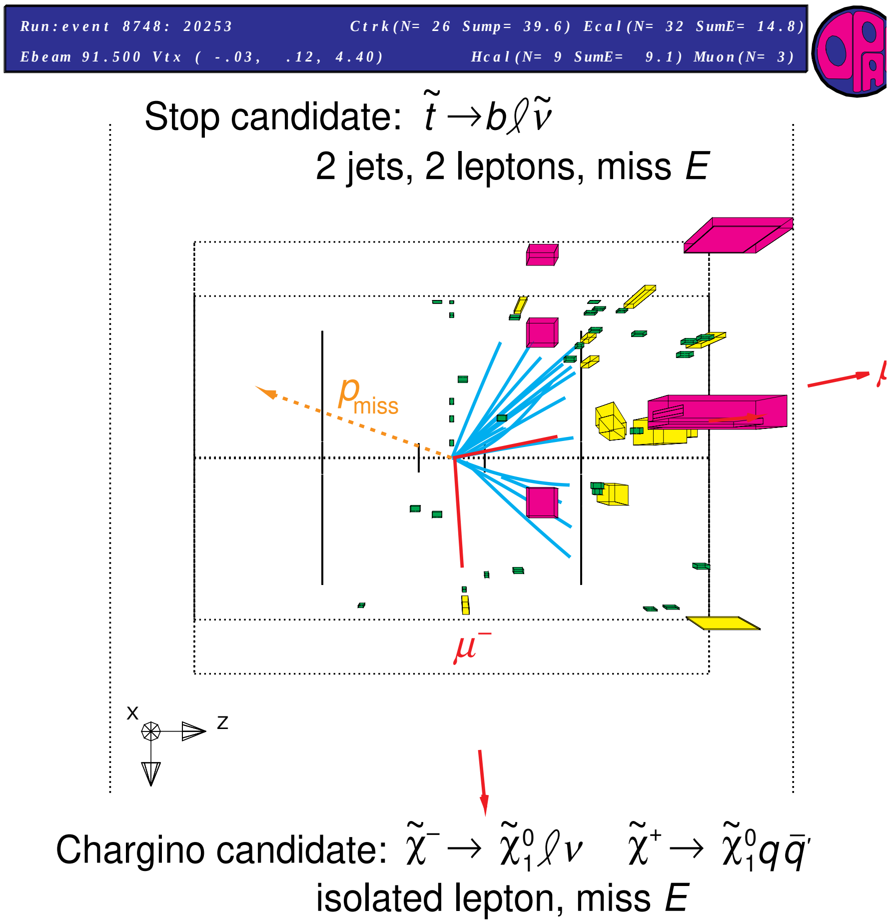
MSSM Higgs

- New search (130 – 172 GeV data) to set more general limits on m_h and m_A in the MSSM and all 2-doublet models
- higher limits, better coverage than previously
- General MSSM has > 100 parameters; 5 commonly discussed!
  these parameters are SCANNED to create limit plots:



Search for SUSY Particles

- Search for final states with missing E
- … but there will be backgrounds



SUSY Search Modes

- Charginos:

  $e^+e^- \rightarrow \tilde{\chi}^+\tilde{\chi}^-, \tilde{\chi}^+ \rightarrow W^{*+}\tilde{\chi}^0$

  get missing E and: 4 jets, or jjℓ, or 2ℓ

- neutralinos:

  $e^+e^- \rightarrow \tilde{\chi}^0_2\tilde{\chi}^0_1, \tilde{\chi}^0_2 \rightarrow Z^*\tilde{\chi}^0_1$

  get missing E and: 2 jets or 2 leptons

- sleptons:

  $e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-, \tilde{\ell} \rightarrow \ell\tilde{\chi}^0$

  get missing E and 2 leptons

- squarks:

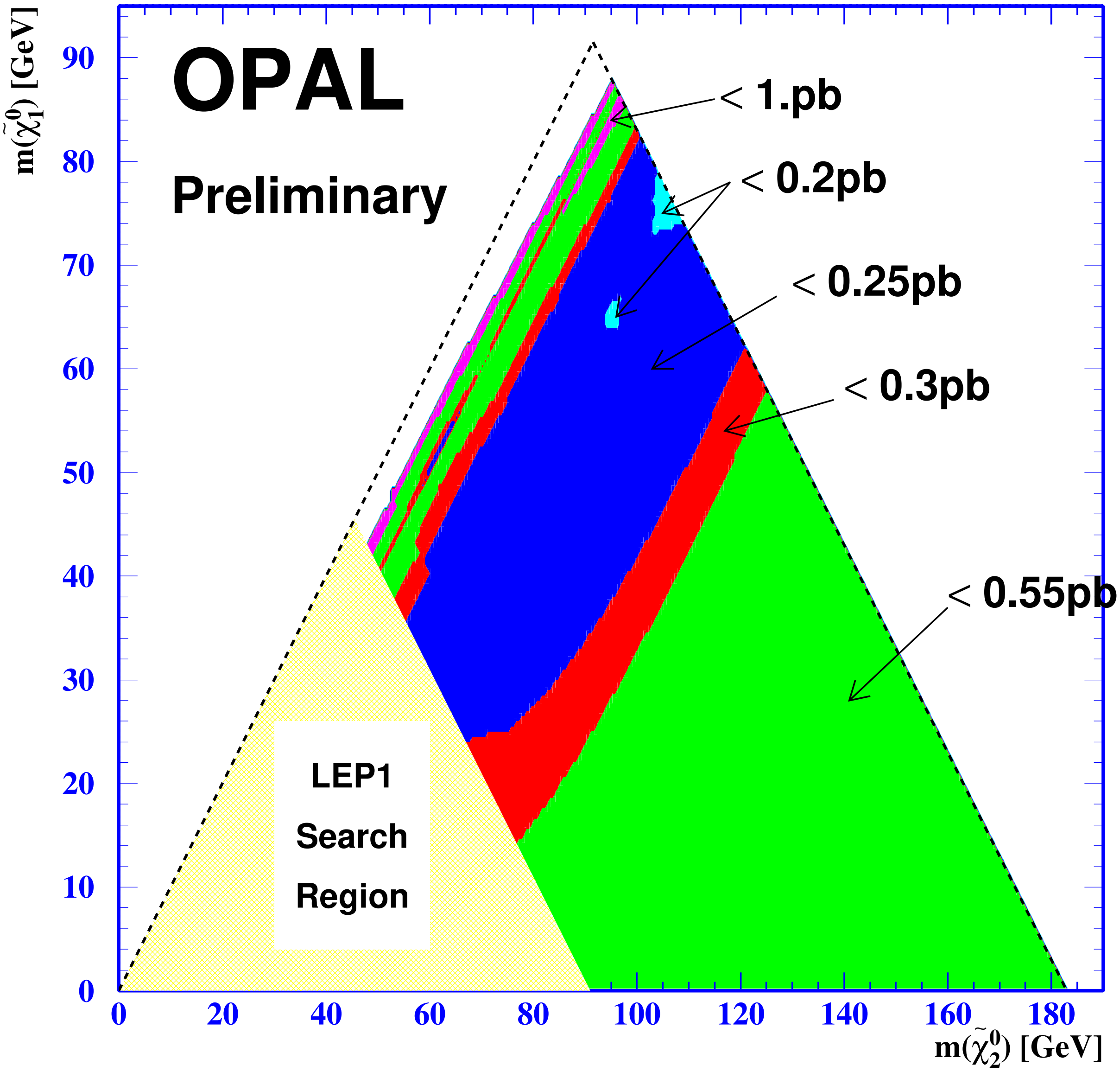
  $e^+e^- \rightarrow \tilde{t}\bar{\tilde{t}}, \tilde{t} \rightarrow c\tilde{\chi}^0$ or $b\ell\tilde{\nu}$

  $e^+e^- \rightarrow \tilde{b}\bar{\tilde{b}}, \tilde{b} \rightarrow b\tilde{\chi}^0$

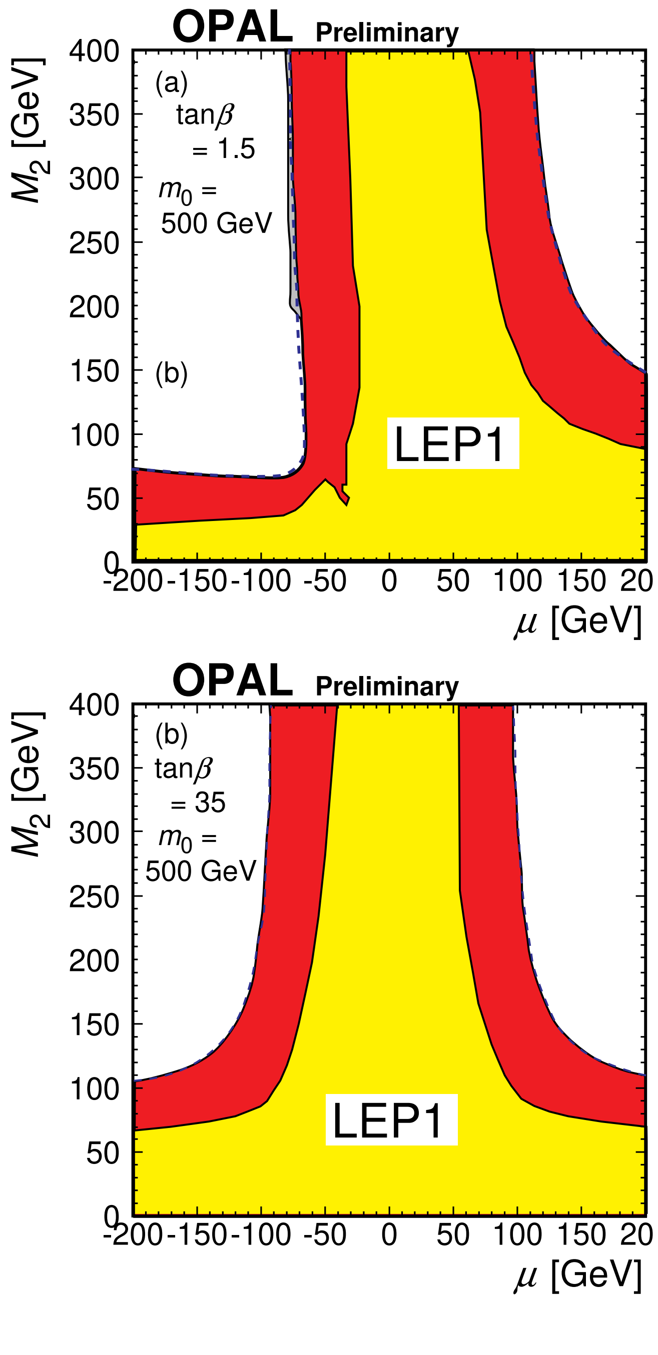
  get missing E and: 2 jets or jj$\ell\ell$

SUSY Mass Limits

- Assuming $\mathrm{BR}(\tilde{\chi}_2^0 \to Z^* \tilde{\chi}_1^0) = 100\%$:



Chargino Excluded Region



R-Parity Violating SUSY

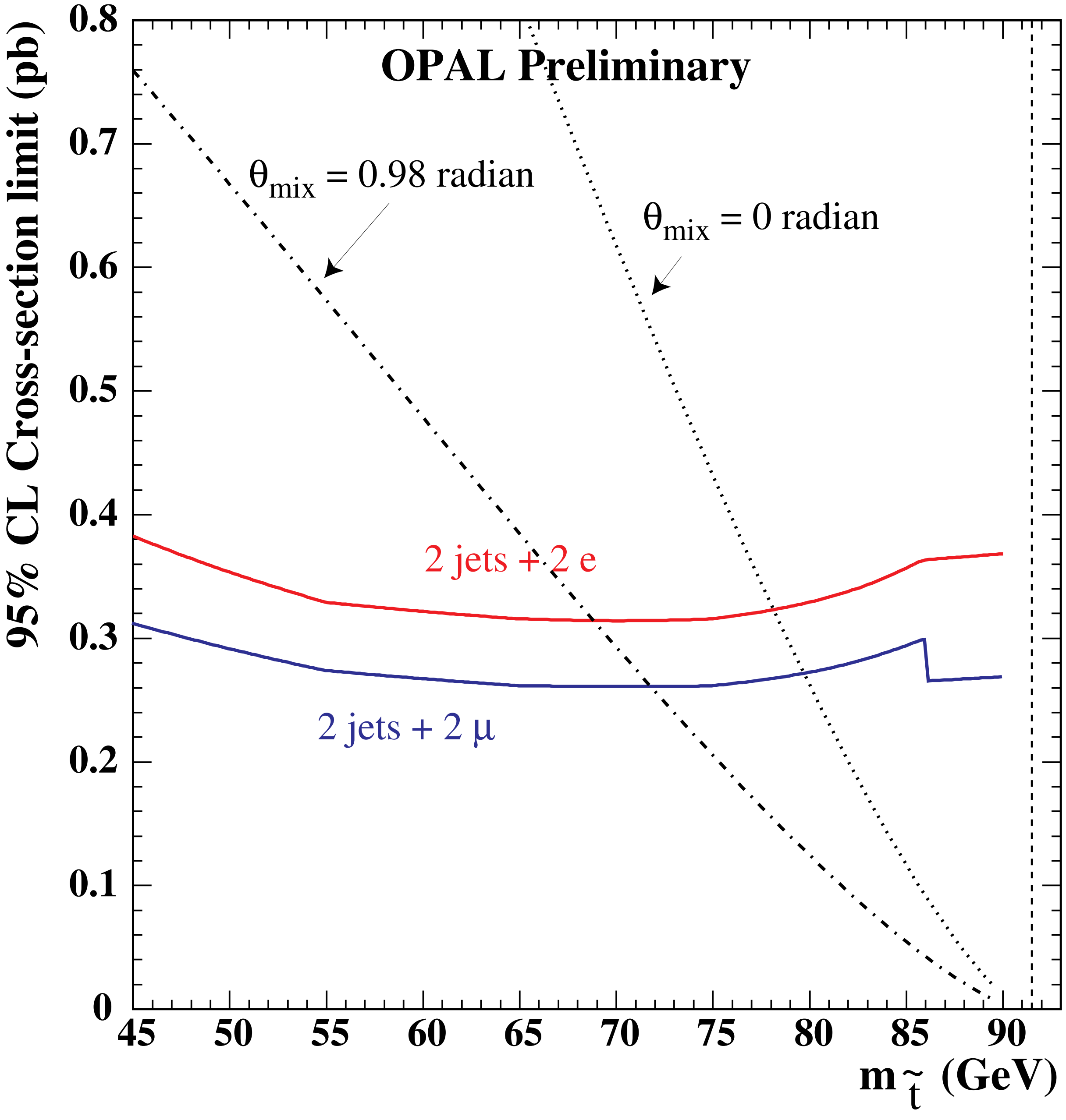
Parametrised with a gauge-invariant super-potential:

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda^{'}{}_{ijk} L_i Q_j \overline{D}_k + \lambda^{''}{}_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k,$$

- i, j, k are the generation indices of the superfields
- 9 λ couplings for the triple lepton vertices
- 27 $\lambda^{'}$ for the lepton-quark-quark vertices
- 9 $\lambda^{''}$ couplings for the triple quark vertices
- therefore a total of 45 new couplings
- 5 initial parameters completely determining all sparticle masses and couplings in the constrained MSSM framework
- search for $\tilde{\chi}^{+} \rightarrow \ell_i^{+} \ell_j^{+} \ell_k^{-}$
- If the lightest neutralino is considered to be the LSP, the lightest chargino decays to $\tilde{\chi}_1^0$ plus a virtual W*:

$$\tilde{\chi}_1^0 \rightarrow \ell_i^{-} \nu_j \ell_k^{+},$$
$$\tilde{\chi}_1^0 \rightarrow \ell_i^{+} \overline{\nu}_j \ell_k^{-},$$
$$\tilde{\chi}_1^0 \rightarrow \nu_i \ell_j^{-} \ell_k^{+}$$
$$\tilde{\chi}_1^0 \rightarrow \overline{\nu}_i \ell_j^{+} \ell_k^{-}$$

Some 183 GeV RPV Results



Finally, A New Result from LEP-1

- CP violation investigation uses 24 $B^0 \rightarrow J/\psi K_S^0$ candidates out of 4.4M Z^0decays
- reconstruct proper decay time in events with 60% purity
- Bayesian probability: $\mathrm{CL}(\sin 2\beta > 0) = 68.5\%$