OPAL Status and Results

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- 1999 Run

  1999-2000 Shutdown

- Physics Results

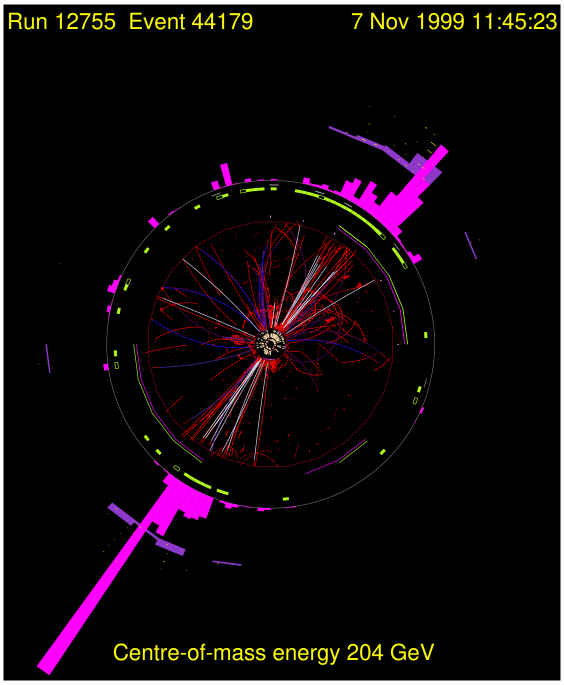
  LEP1 and LEP2 189 GeV

  PRELIMINARY $\sqrt{s} > 190$ GeV

  – Standard Model processes

  – Searches for new particles

- 2000 Beam Request

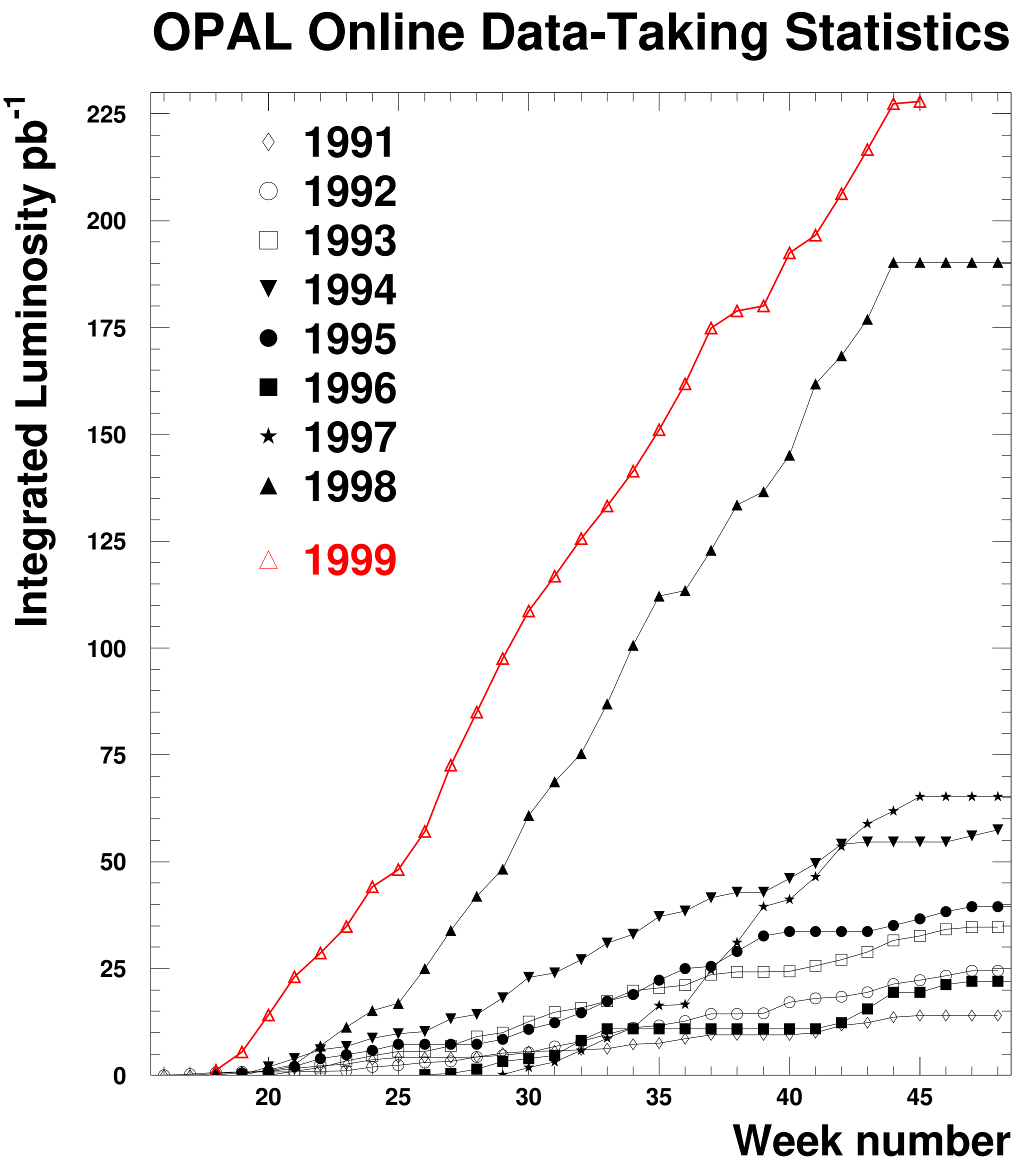


OPAL Data-taking in 1999

- No major problems since September LEPC

  Minor problems, often resulting from elderly electronics

- Lose constant time at run start to ramp chambers $\longrightarrow$ short runs less efficient



OPAL Data-taking in 1999

$\sqrt{s}$ (GeV)	$\int \mathcal{L}\mathrm{d}t$ (pb^{-1}) recorded	delivered	efficiency (%)
Z	3.98	4.51	88.2
192	29.6	32.6	90.9
196	77.8	84.4	92.2
200	78.5	86.0	91.3
202	38.0	42.0	90.5
> 190	224.0	245.0	91.4

- Thank you to LEP for a very good year

1999-2000 Shutdown

- Y2K tests of online system this week
- Open detector for repairs to poletip hadron calorimeter asap

  Close detector by (or soon after) Christmas

b Semileptonic Branching Fractions

- New measurements using full LEP1 data samples of $Z \rightarrow b\bar{b}$ events:
- $\mathrm{BR}(b \rightarrow \ell X)$ =

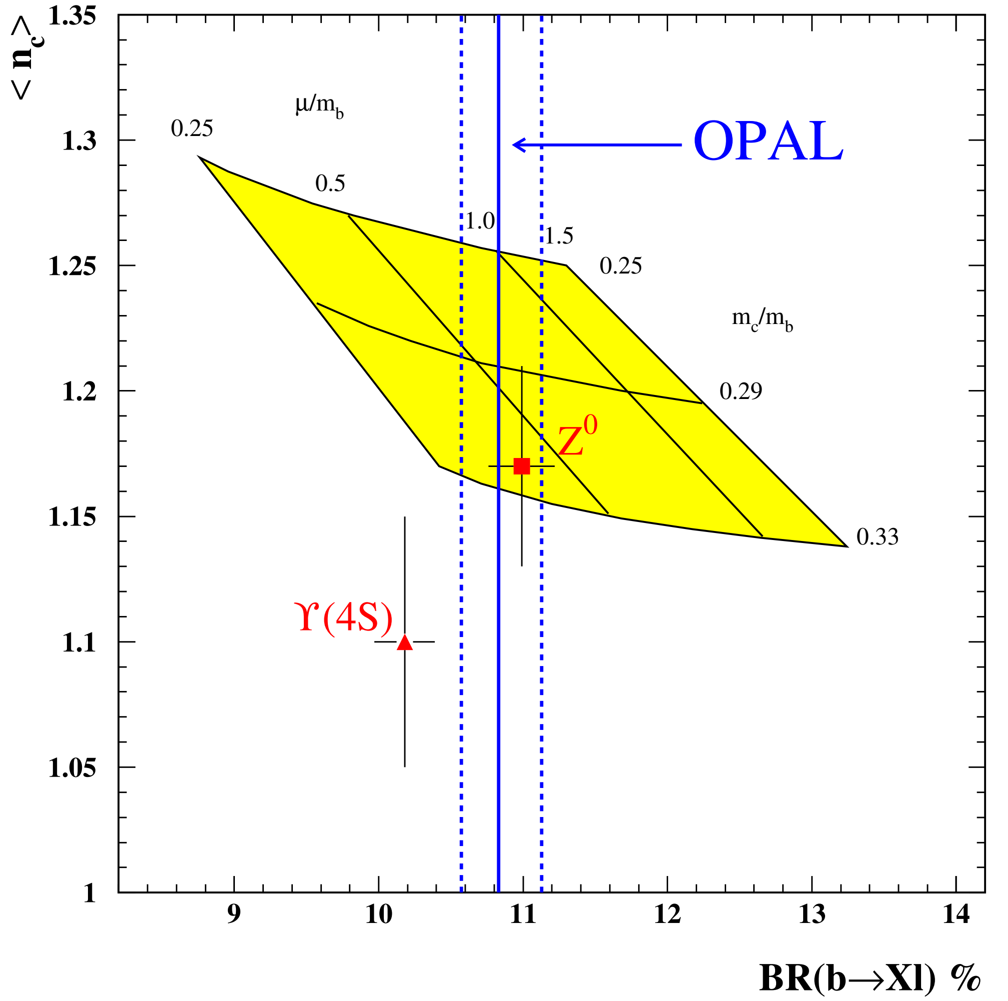
$$(10.83 \pm 0.10\,(stat.) \pm 0.20\,(syst.)\,^{+0.20}_{-0.13}\,(model))\%$$

most precise to date at Z

- $\mathrm{BR}(b \rightarrow c \rightarrow \ell X)$ =

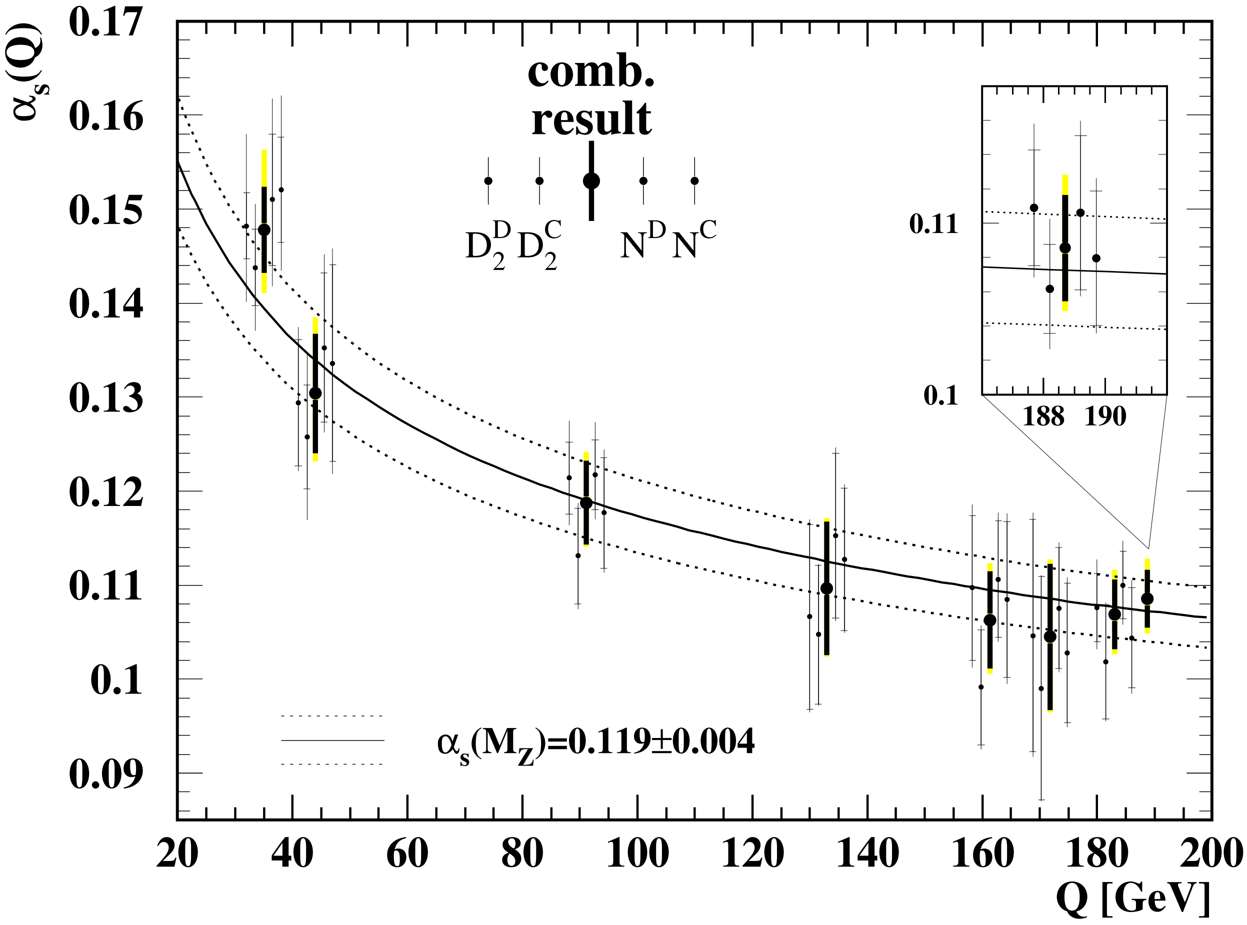
$$(8.40 \pm 0.16\,(stat.) \pm 0.21\,(syst.)\,^{+0.33}_{-0.29}\,(model))\%$$

more precise than current (published) world average



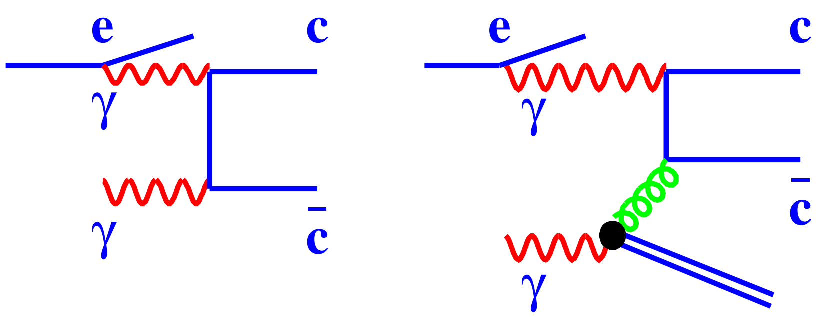
Measurement of α_s

- Consistent analysis of JADE (35, 44 GeV) and OPAL (Z, 130–189 GeV) data
- Study jet-multiplicity related observables using different jet finders
- Measure α_s using $\mathcal{O}(\alpha_s^2)$+ NLLA fits to differential 2-jet fractions and mean jet multiplicities

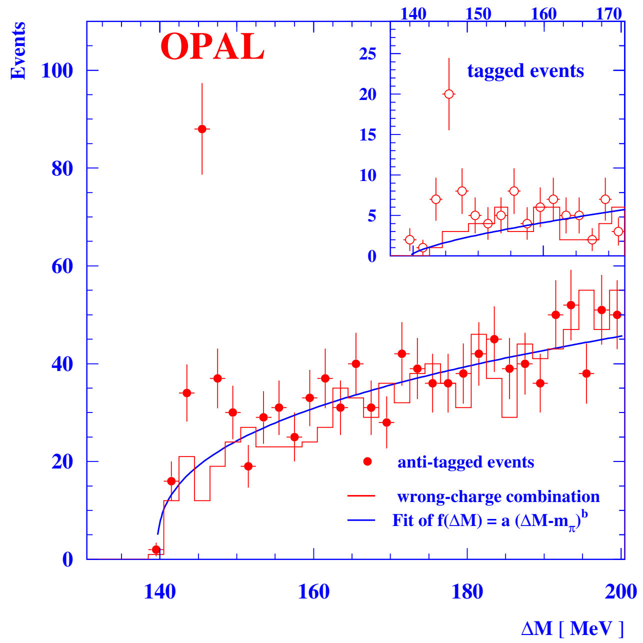


$$\alpha_s(M_{Z^0}) = 0.1199^{+0.0038}_{-0.0025}$$

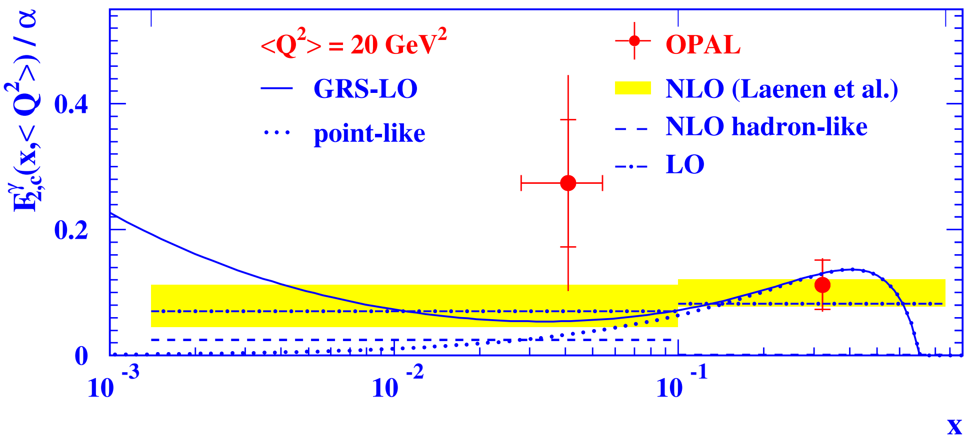
$\gamma\gamma \rightarrow \mathrm{D}^*$



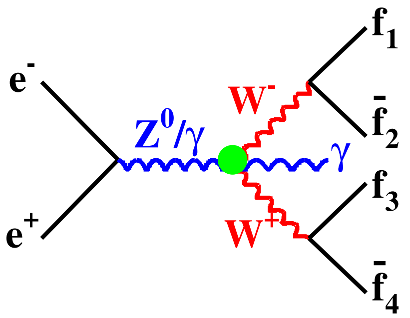
- Measure $\mathrm{D}^{*\pm}$ production in anti-tagged and single-tagged two-photon events in 183 GeV and 189 GeV data

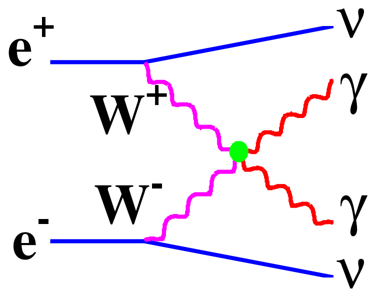


- First measurement of charm structure function of the photon

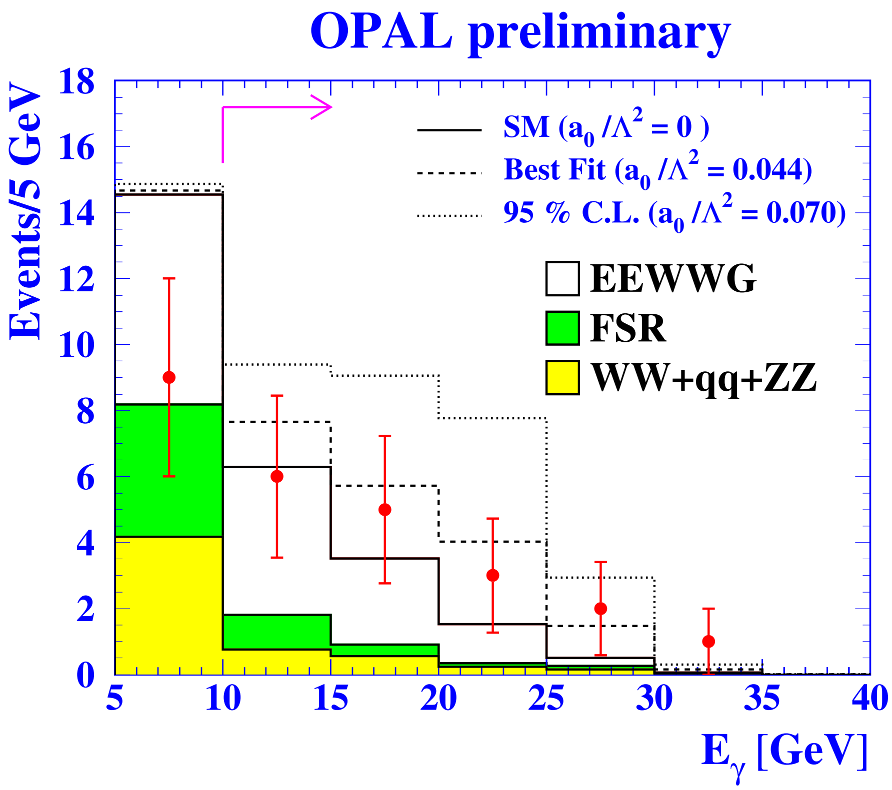


Anomalous Quartic Gauge Couplings





- Select 17 $W^+W^-\gamma$ events with $E_\gamma >$10 GeV from 189 GeV data



- Combined limits from $W^+W^-\gamma$ and $\gamma\gamma\nu\nu$

$$\begin{aligned}
-0.065\ \mathrm{GeV}^{-2} < \quad & a_0/\Lambda^2 \quad < 0.065\ \mathrm{GeV}^{-2}, \\
-0.13\ \mathrm{GeV}^{-2} < \quad & a_c/\Lambda^2 \quad < 0.17\ \mathrm{GeV}^{-2}, \\
-0.61\ \mathrm{GeV}^{-2} < \quad & a_n/\Lambda^2 \quad < 0.57\ \mathrm{GeV}^{-2},
\end{aligned}$$

- First DIRECT limits

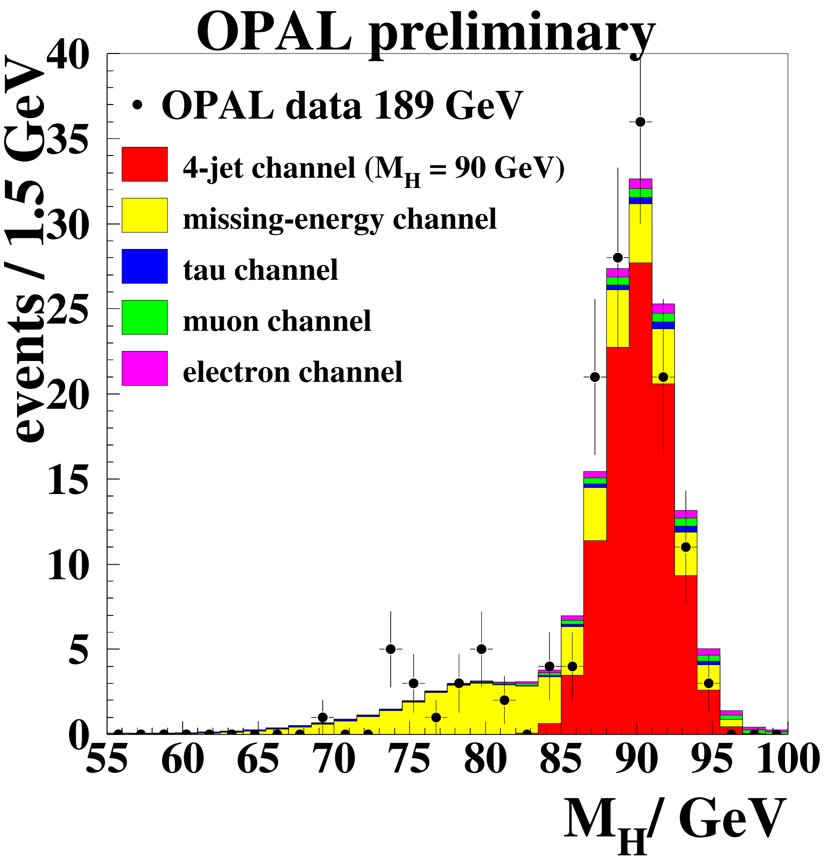
Flavour-independent Higgs Search

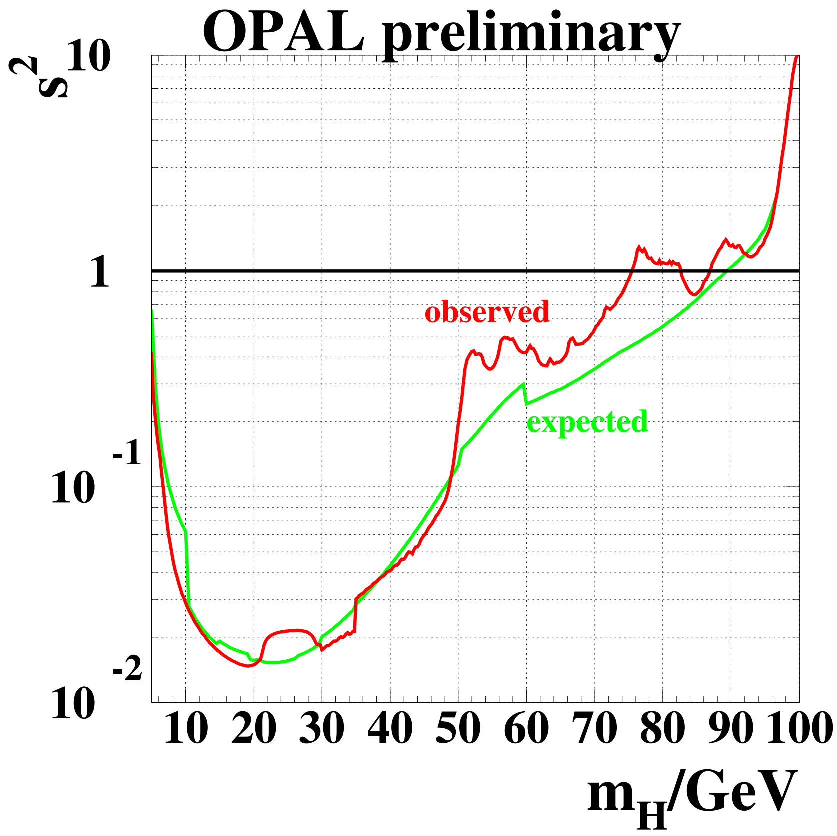
Flavour-independent search for

$e^+e^- \to h^0Z^0$

with

$h^0 \to$ hadrons

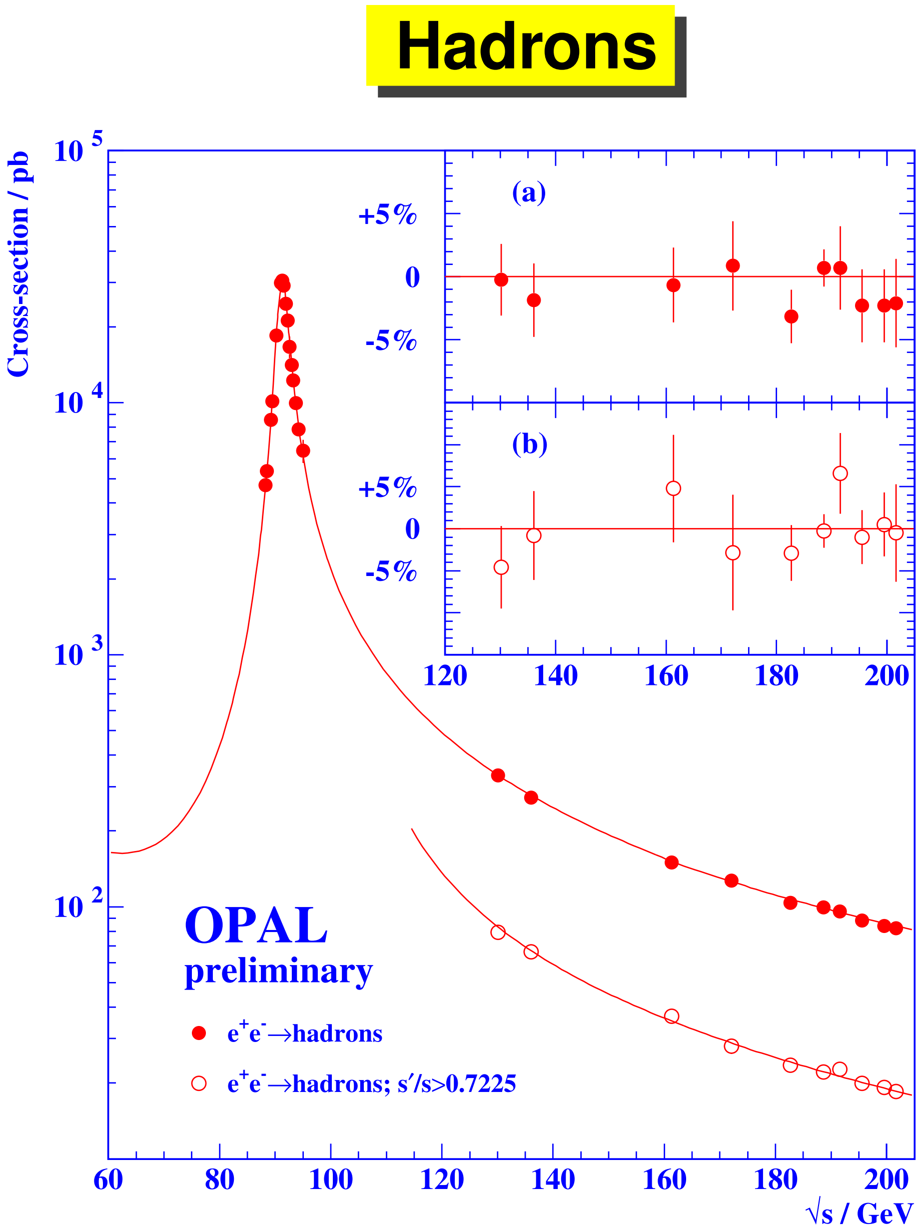


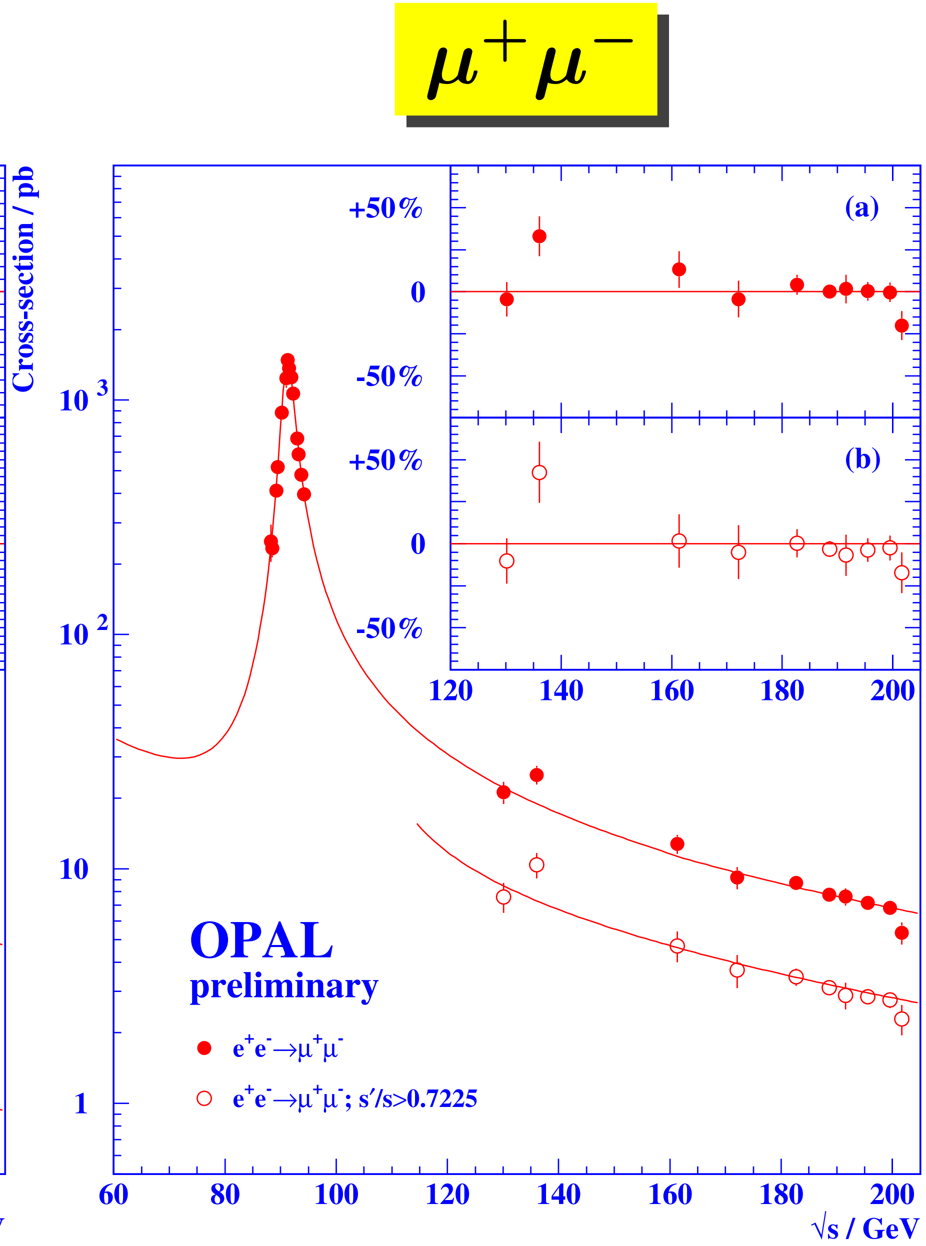


Model independent 95% c.l. limits on cross-section

$\sigma_{hZ} = s^2 \sigma^{SM}_{HZ}$

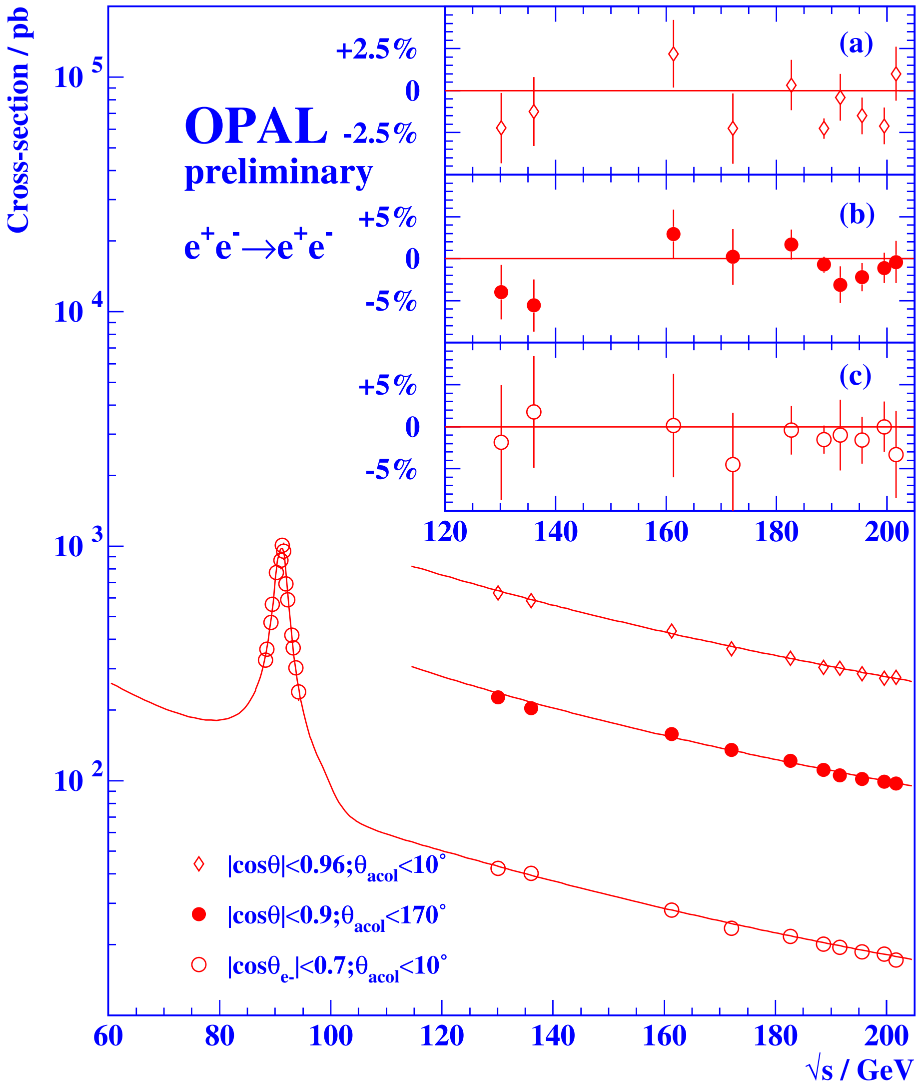
Can interpret as limits on $\sin^2(\beta-\alpha)$ in Type II 2HDM


Hadrons
Cross-section / pb
10 5
10 4
10 3
10 2
60
80
100
120
140
160
180
200
√s / GeV
OPAL
preliminary
e+e-→hadrons
e+e-→hadrons; s′/s>0.7225
(a)
(b)
+5%
0
-5%

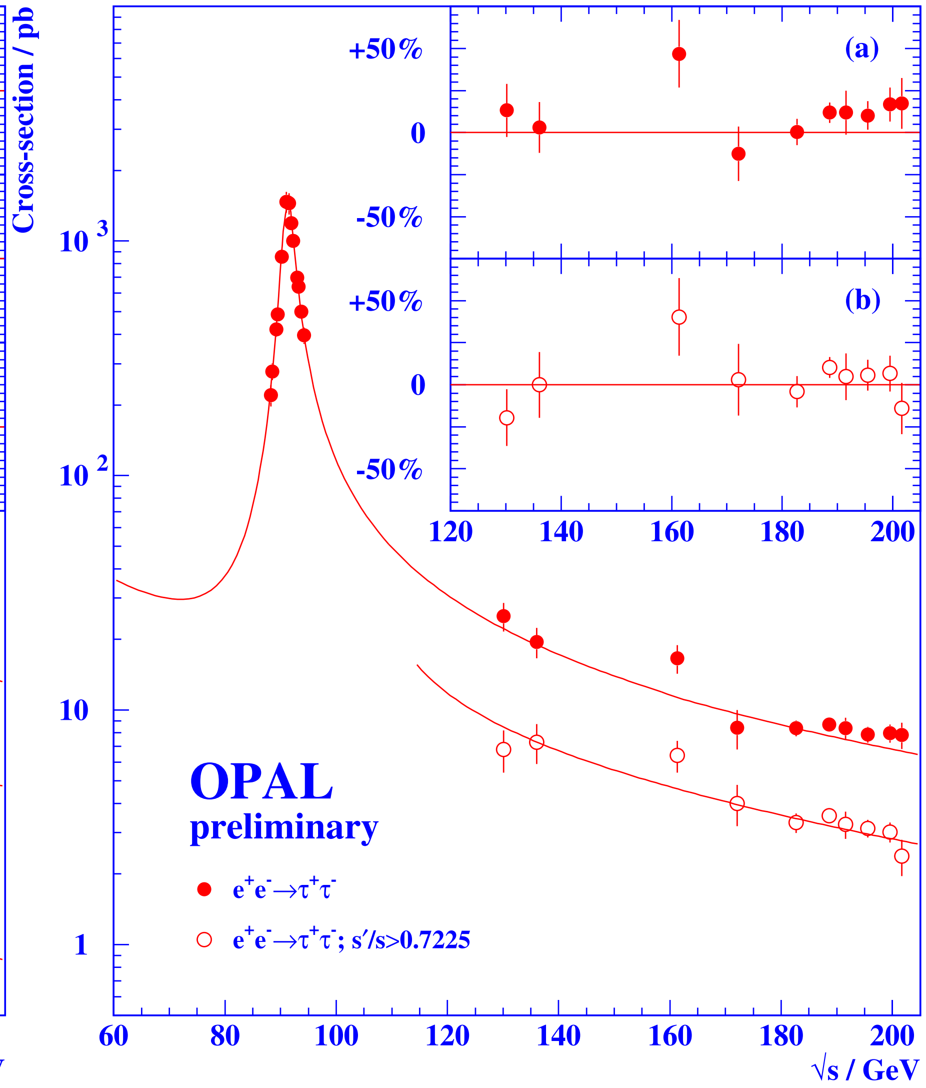

μ+μ−
Cross-section / pb
10 3
10 2
10
1
60
80
100
120
140
160
180
200
√s / GeV
OPAL
preliminary
e+e-→μ+μ-
e+e-→μ+μ-; s′/s>0.7225
(a)
(b)
+50%
0
-50%

C.P. Ward

e^+e^-

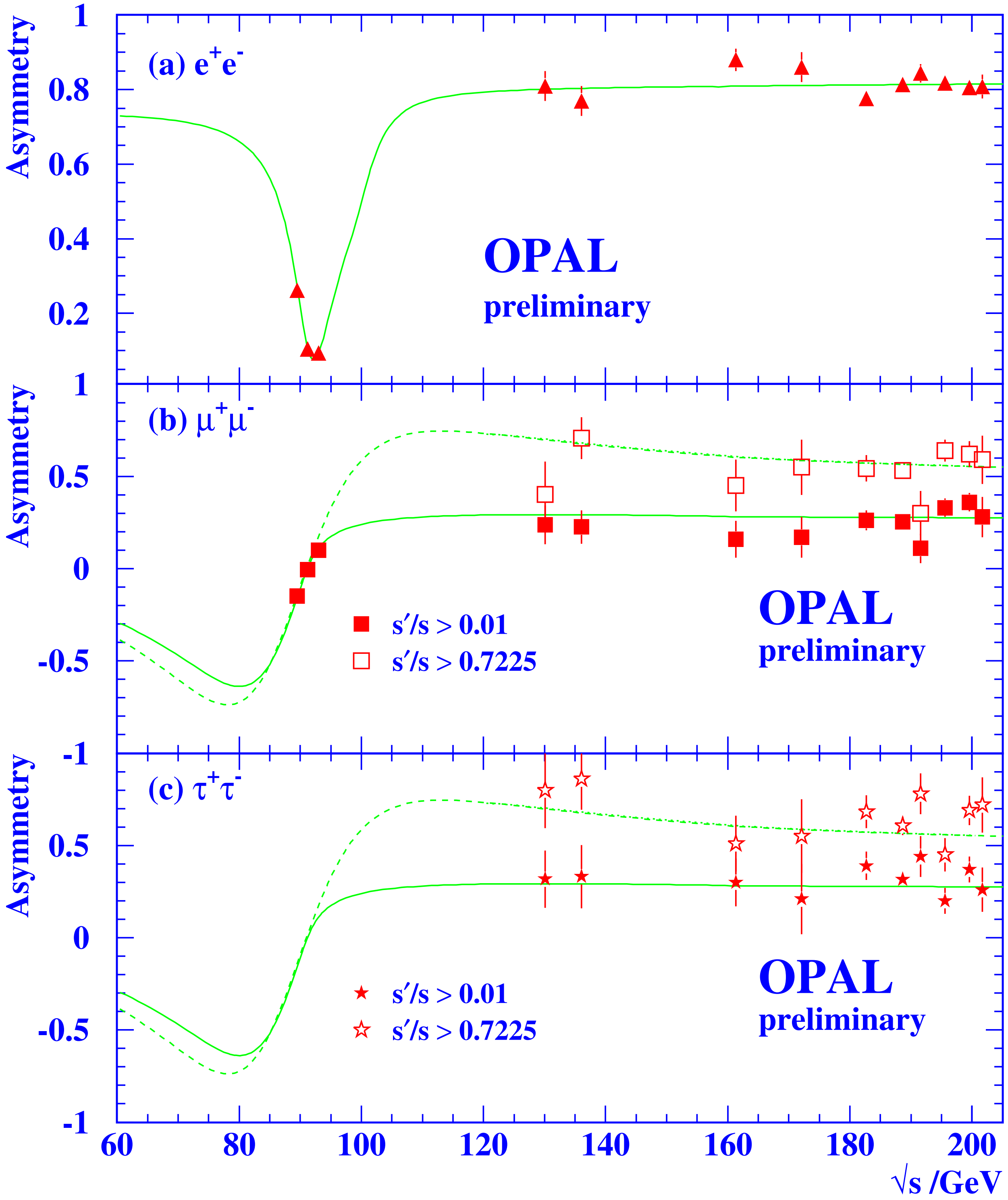


$\tau^+\tau^-$



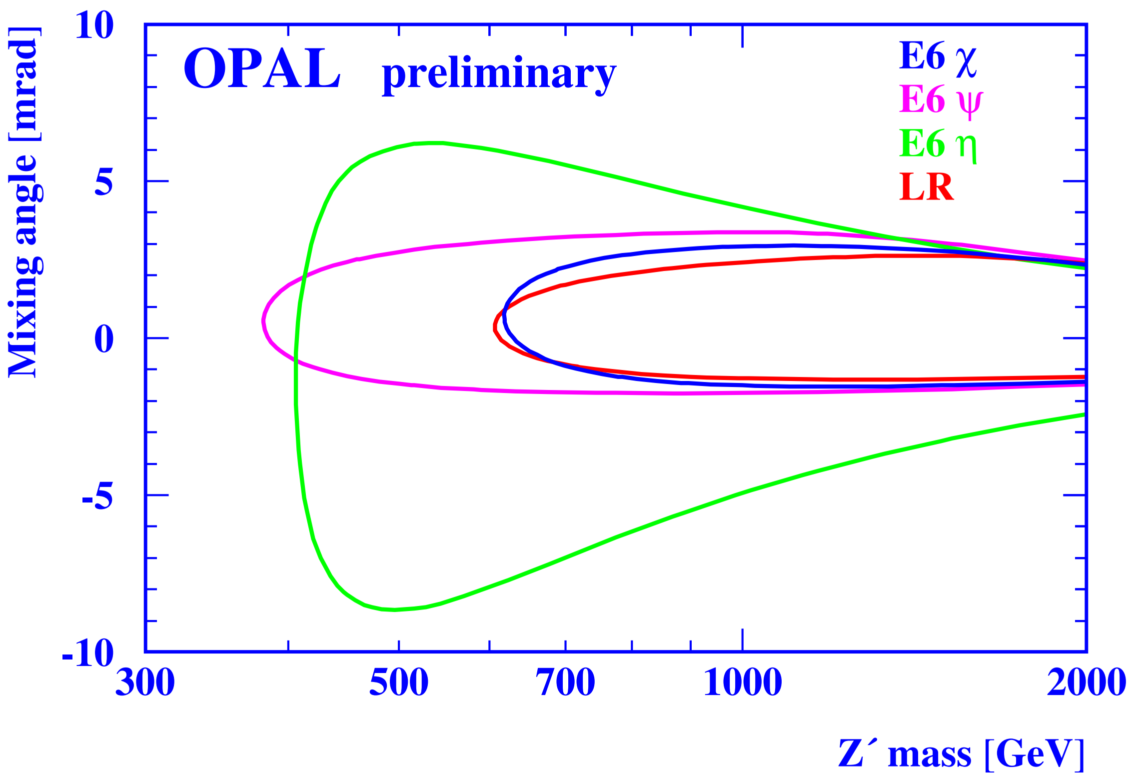
OPAL presentation to LEPC 9 November 1999

Lepton-pair Asymmetries



Constraints on Z'

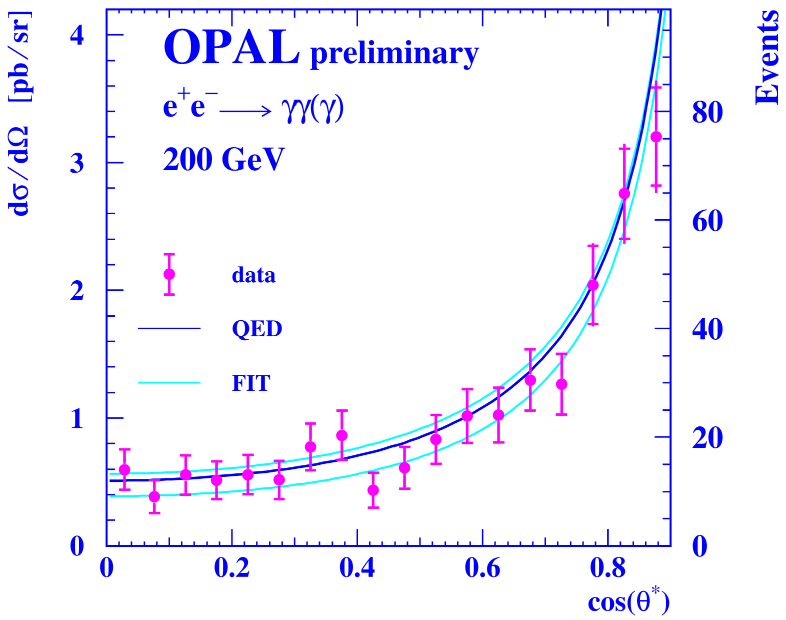
- Use LEP1 and LEP2 cross-sections and asymmetries
- 95% c.l. exclusion limits:

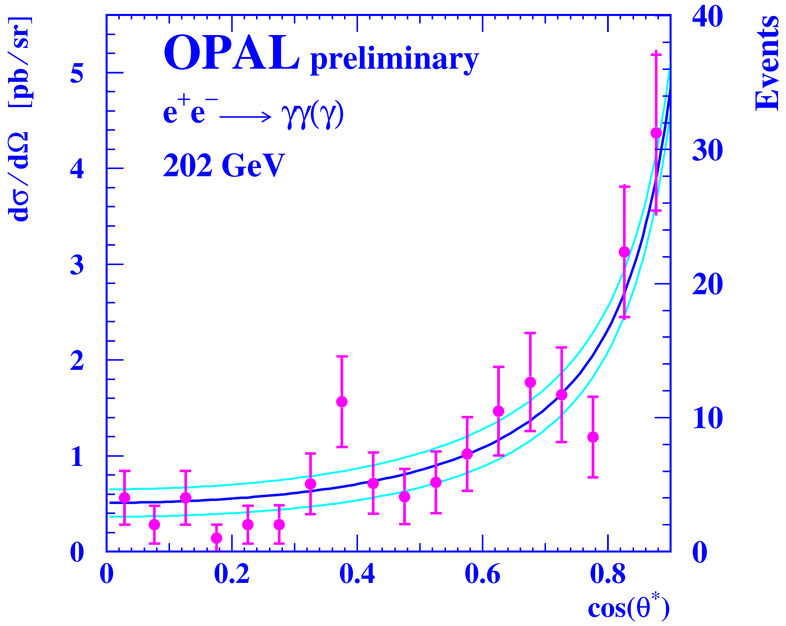


Model:	χ	ψ	η	LR
$M_{Z'}^{\rm low}$ [GeV]	676	424	438	684
$\theta_{\rm M}^{\rm up}$ [mrad]	2.48	2.84	4.92	2.21
$\theta_{\rm M}^{\rm low}$ [mrad]	–1.15	–1.28	–7.23	–0.97

- Mass limits increased by 15–60% by including 1999 data

$e^+e^- \rightarrow \gamma\gamma(\gamma)$





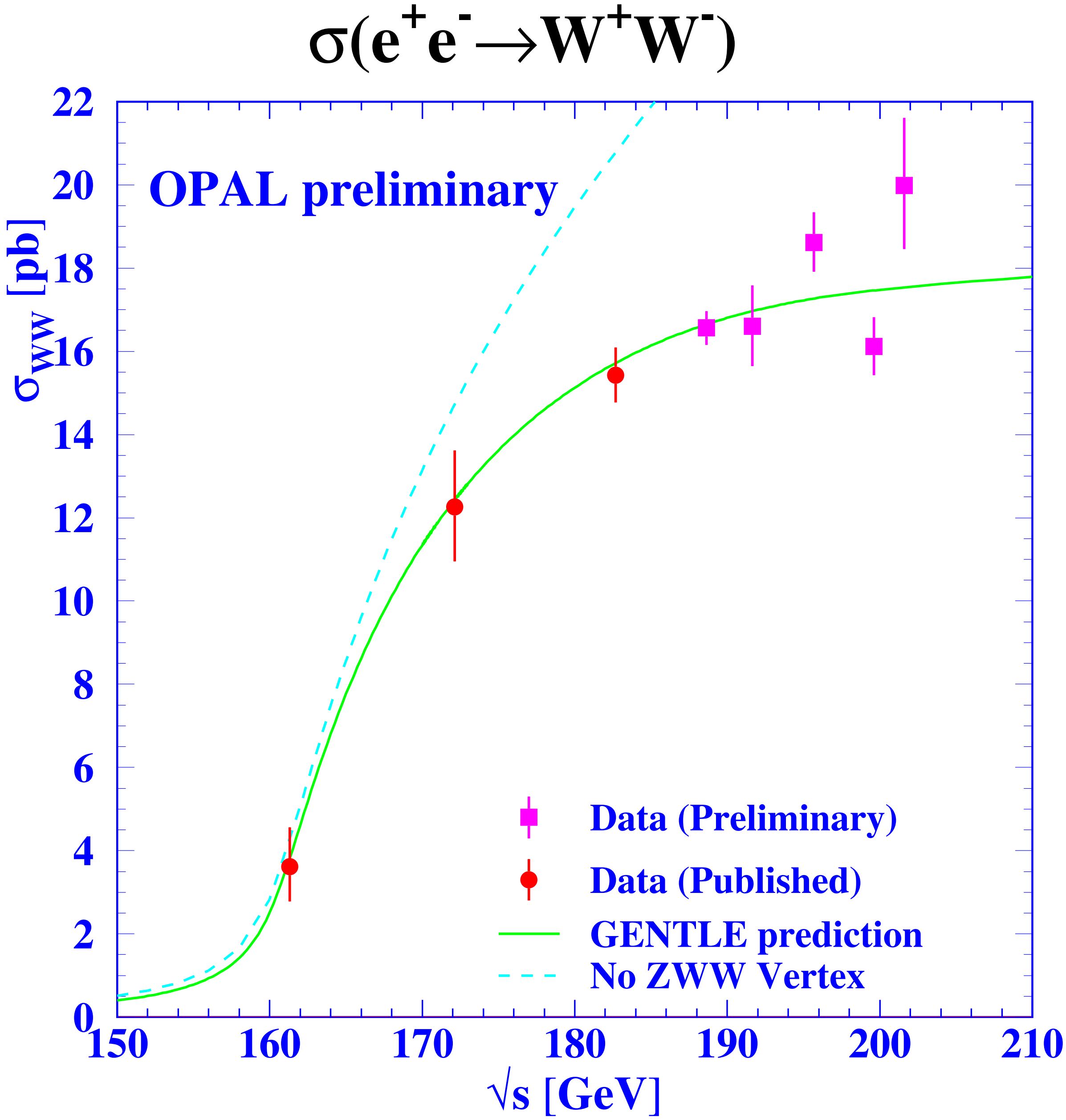
Limits on cut-off parameters at 95% cl:

$$\Lambda_+ > 295\ \mathrm{GeV} \qquad \Lambda_- > 293\ \mathrm{GeV}$$

Energy scales for graviton exchange:

$$G_+ > 641\ \mathrm{GeV} \qquad G_- > 629\ \mathrm{GeV}$$

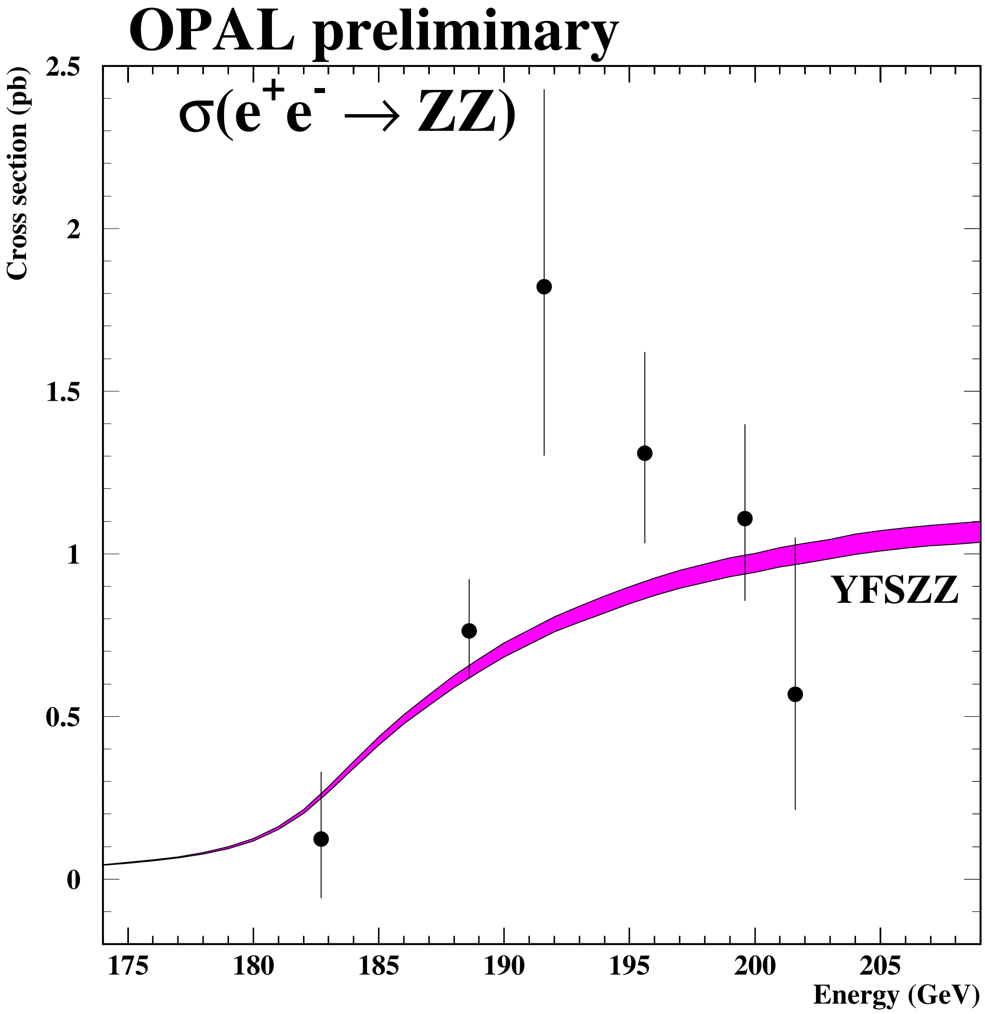
WW Cross-section



Observed events for $\sqrt{s} > 190$ GeV:

final state	observed	expected
$\ell\nu\ell\nu$	327	291
$q\bar{q}\ell\nu$	1226	1269
$q\bar{q}q\bar{q}$	1515	1492

ZZ Cross-section

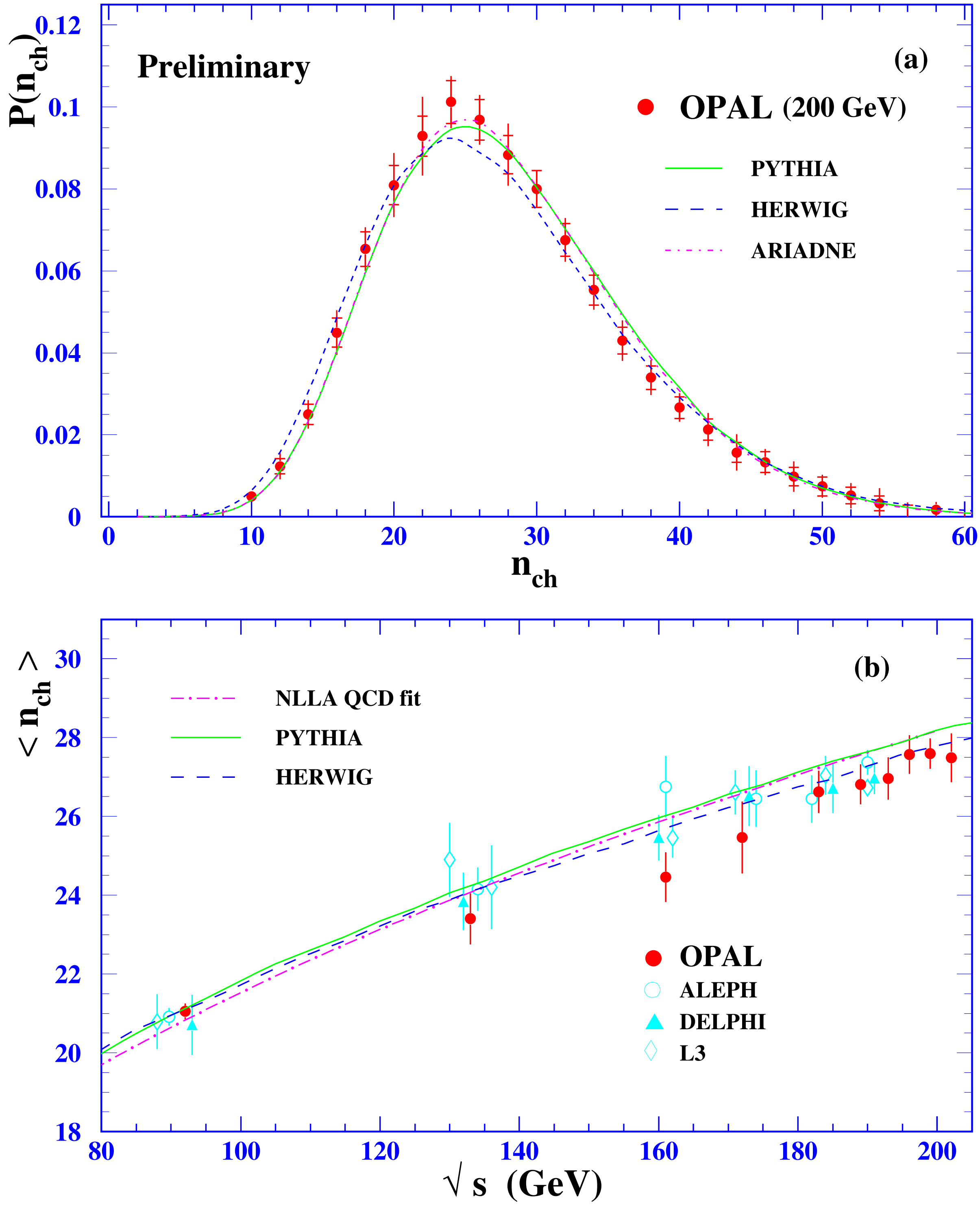


Observed events for $\sqrt{s} > 190$ GeV:

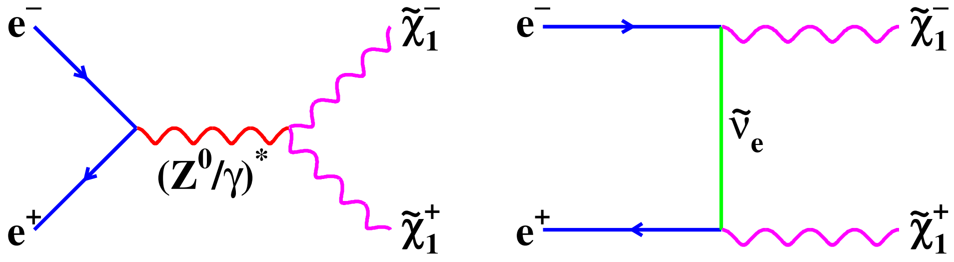
final state	observed	expected
$\ell^+\ell^-\ell^+\ell^-$	1	1.6
$q\overline{q}\ell^+\ell^-$	25	15.7
$q\overline{q}\nu\overline{\nu}$	23	23.4
$q\overline{q}q\overline{q}$	92	81
total	141	122

Charged Particle Multiplicity Distribution

- QCD studies use non-radiative events with $\sqrt{s} - \sqrt{s'} < 10$ GeV, reject W-pairs



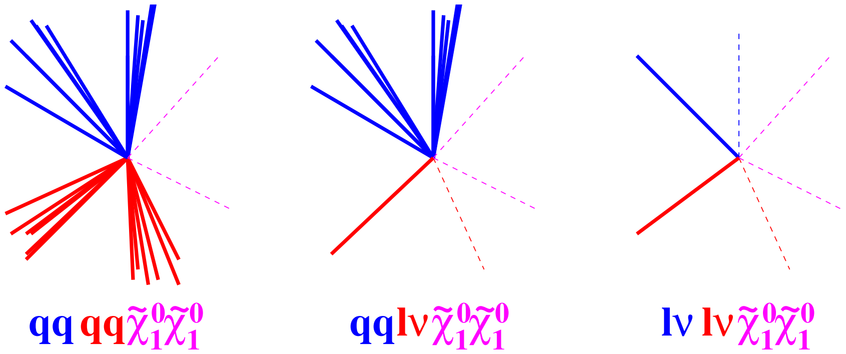
Charginos



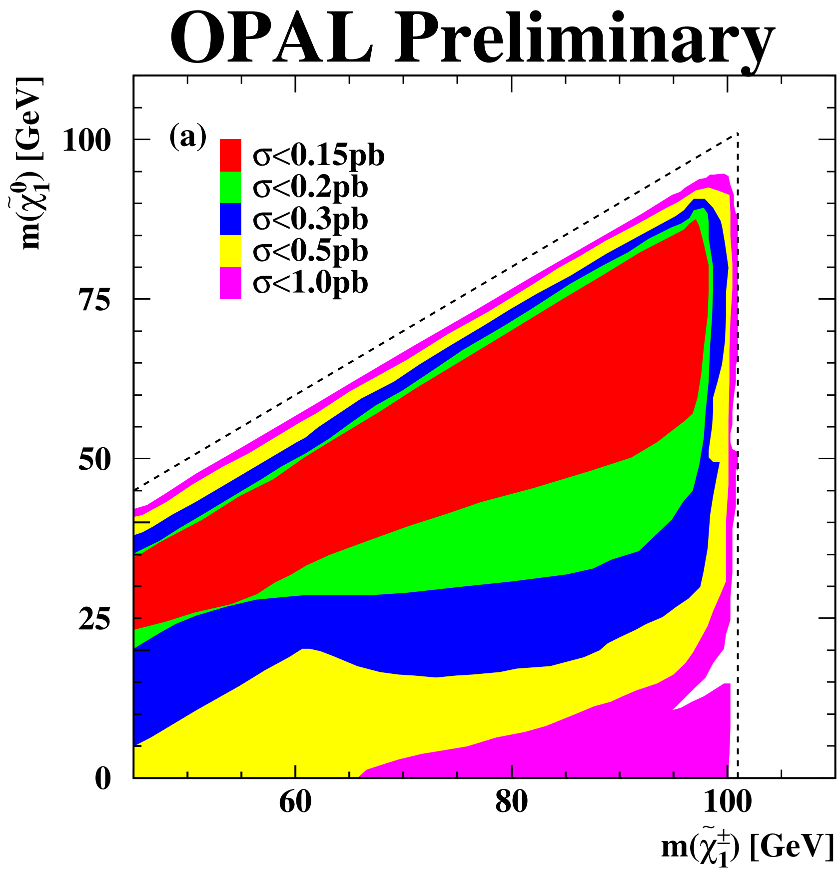
- Chargino decay via W (in a large fraction of MSSM space)

  $\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow (W^+\tilde{\chi}_1^0)(W^-\tilde{\chi}_1^0)$

- Signature : W^+W^- plus missing energy



- Data consistent with SM expectation



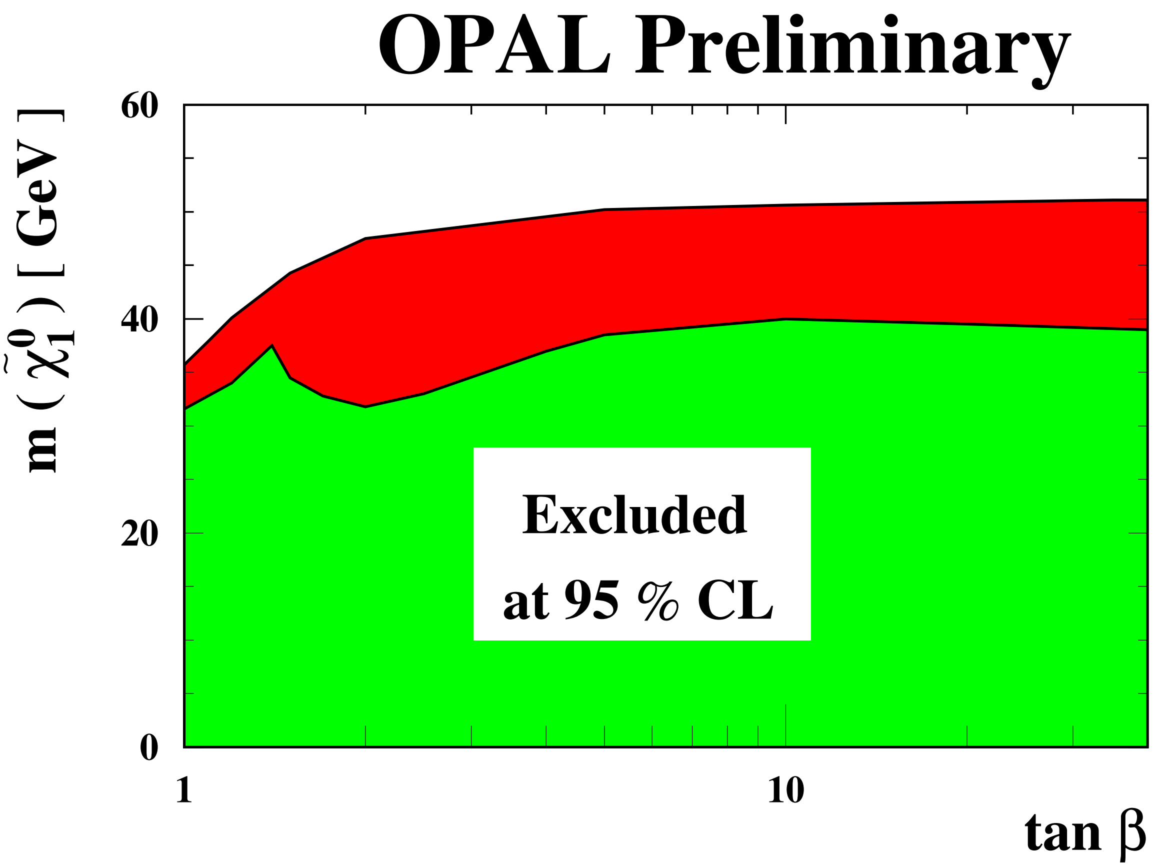
$\tilde{\chi}^+, \tilde{\chi}^0$ Mass Limits

	$\tan\beta = 1.5$	$\tan\beta = 35$
$\Delta M_+ \geq 5$ GeV	$m_{\tilde{\chi}_1^+} > 98.5$ GeV	$m_{\tilde{\chi}_1^+} > 98.5$ GeV
$\Delta M_+ \geq 10$ GeV	$m_{\tilde{\chi}_1^+} > 100.0$ GeV	$m_{\tilde{\chi}_1^+} > 100.1$ GeV
No ΔM_0 restriction	$m_{\tilde{\chi}_1^0} > 44.3$ GeV	$m_{\tilde{\chi}_1^0} > 51.1$ GeV
$\Delta M_0 \geq 10$ GeV	$m_{\tilde{\chi}_2^0} > 75.4$ GeV $m_{\tilde{\chi}_3^0} > 110.9$ GeV	$m_{\tilde{\chi}_2^0} > 100.1$ GeV $m_{\tilde{\chi}_3^0} > 129.4$ GeV

95% c.l. CMSSM $m_0 \geq 500$ GeV

- Absolute lower limits (CMSSM):

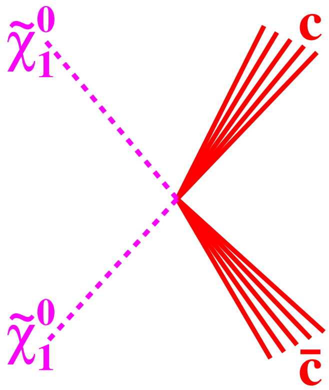
$m_{\tilde{\chi}_1^0} > 35.7$ GeV ($m_0 \geq 500$ GeV)



Squarks

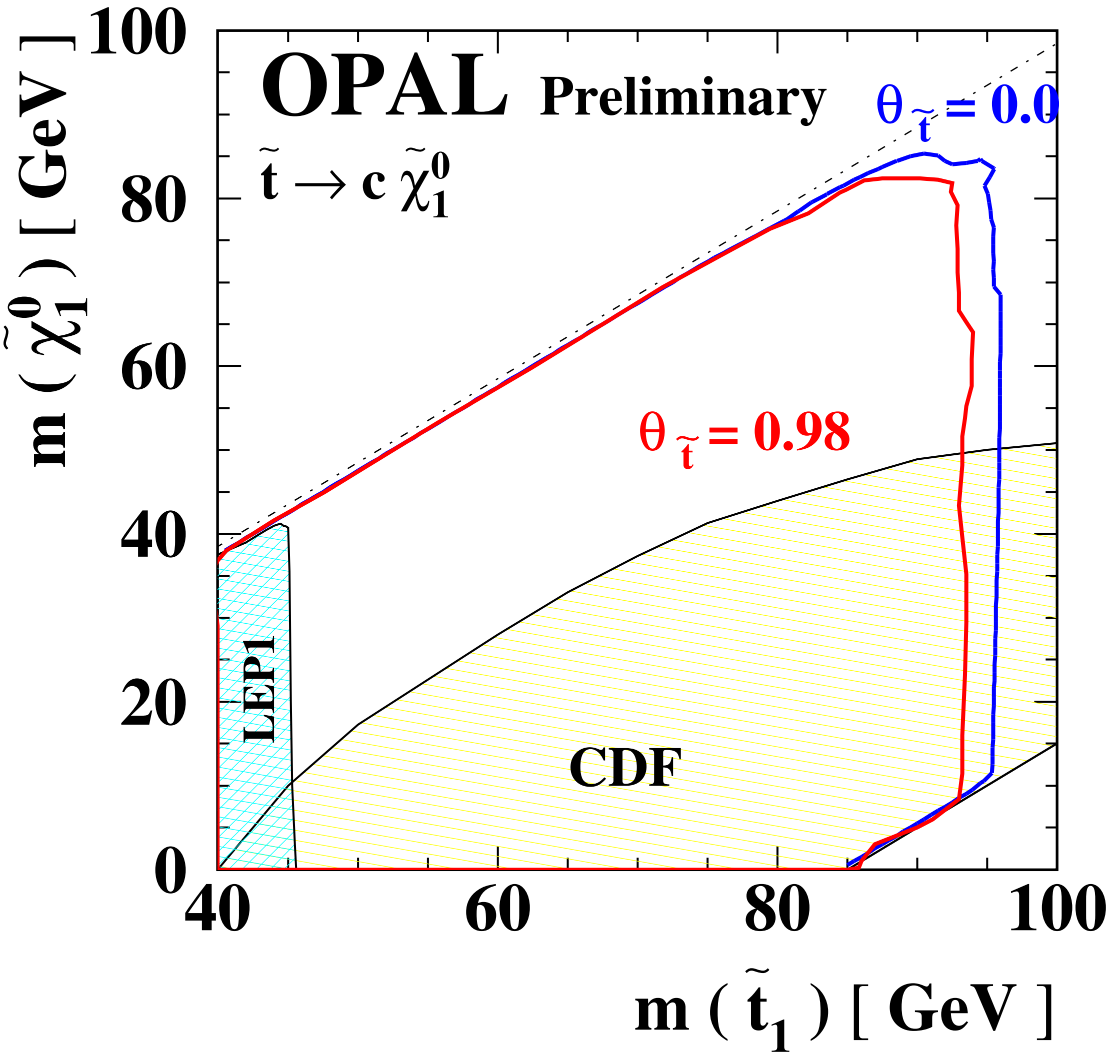
Search for

$e^+e^- \rightarrow \tilde{t}_1 \bar{\tilde{t}}_1$, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$, $\bar{\tilde{t}}_1 \rightarrow \bar{c}\tilde{\chi}_1^0$



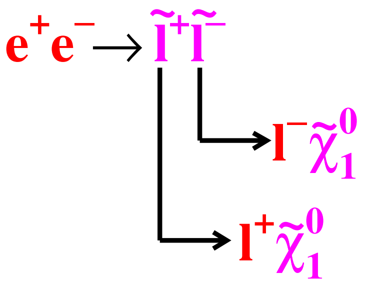
- **Acoplanar Jets**
- **Missing E_T**

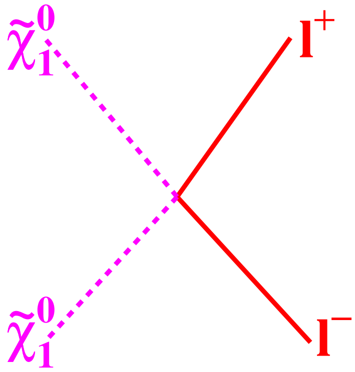
Efficiency	N_{DATA}	N_{SM}
50–60%	4	8.6 ± 1.9



Also Searched for: $\tilde{t}_1 \rightarrow b\ell^+\tilde{\nu}$, $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$

Acoplanar Lepton Pairs

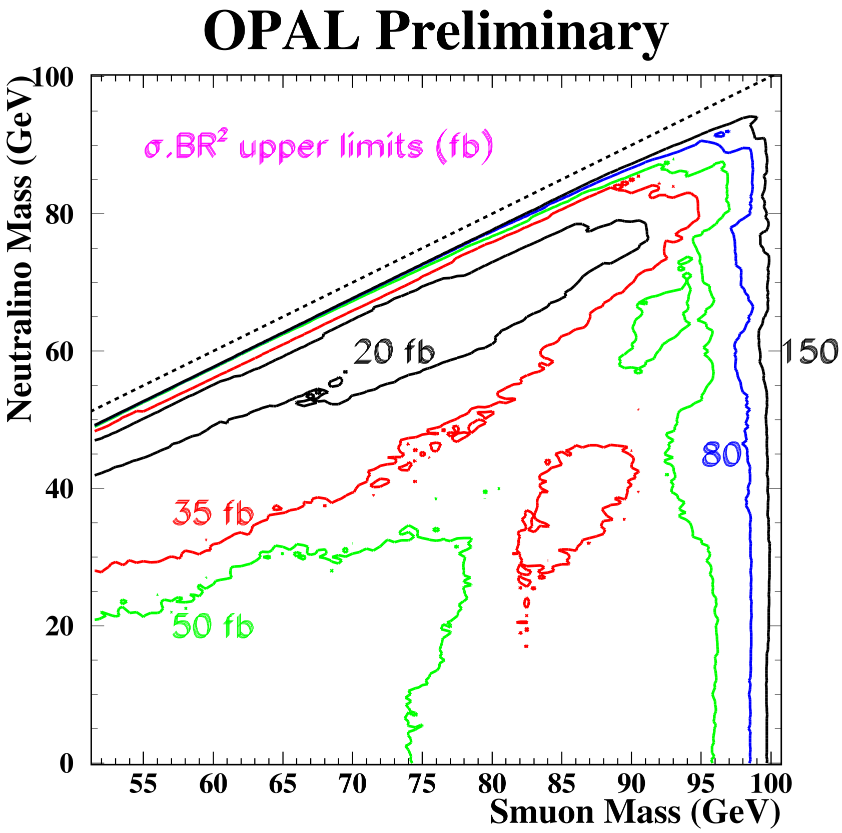




- **Acoplanar leptons**
- **Missing E_T**

Dilepton	data	SM total	Dilepton	data	SM total
ee	48	51.2±0.6	μh	39	40.5±0.5
$\mu\mu$	57	53.8±0.6	eX	30	20.5±0.7
hh	15	12.8±0.5	μX	28	18.3±0.4
$e\mu$	107	95.8±0.8	hX	9	8.2±0.3
eh	48	42.2±0.6			

95% c.l. limits on $\sigma \times BR^2$ for $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ with $\tilde{\mu} \to \mu\tilde{\chi}_1^0$



Photons + Missing Energy

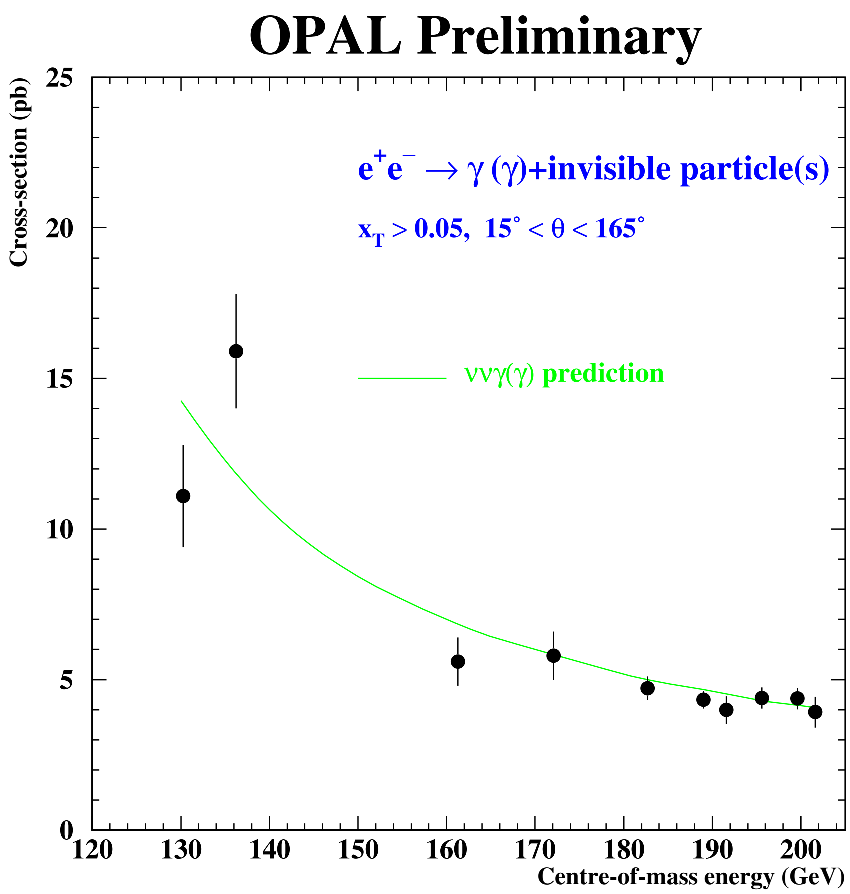
- Topology occurring in several models:

$\tilde{\chi}^0_1 \longrightarrow \tilde{G}\gamma$ in GMSB

$\tilde{\chi}^0_2 \longrightarrow \tilde{\chi}^0_1\gamma$ in MSSM

$\nu^* \longrightarrow \nu\gamma$

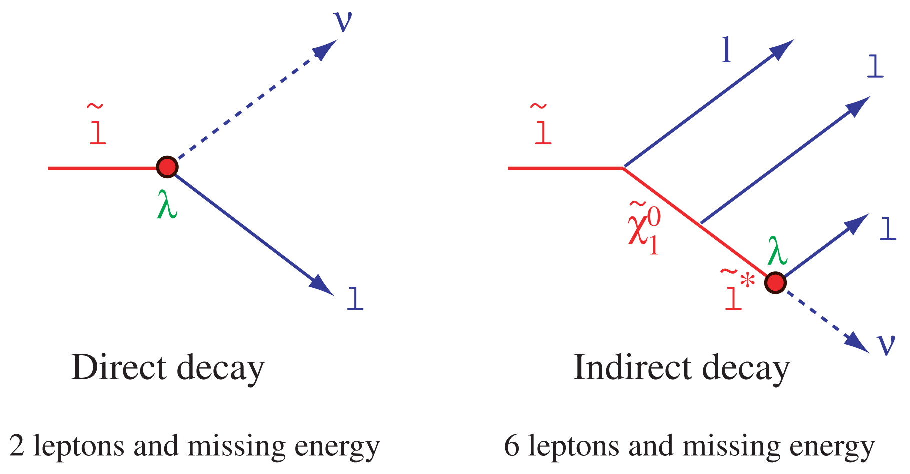
	$\sqrt{s}$ (GeV)	N_{DATA}	N_{SM}
$\gamma(\gamma) + \not{E}_T$	192–196	339	345±17
$\gamma(\gamma) + \not{E}_T$	200–202	308	300±15
$\gamma\gamma(\gamma) + \not{E}_T$	192–196	8	12.6±0.7
$\gamma\gamma(\gamma) + \not{E}_T$	200–202	19	11.1±0.6



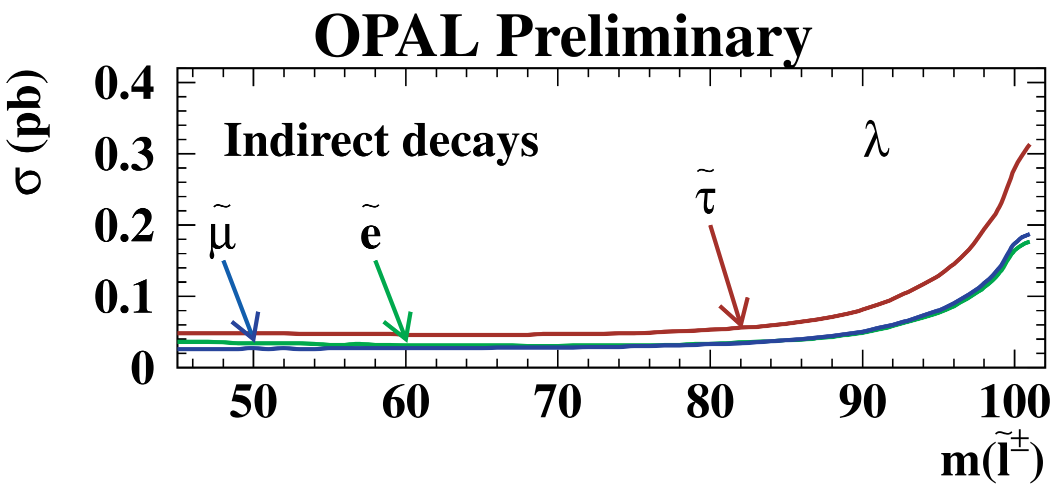
$\not{R}$-parity violating SUSY

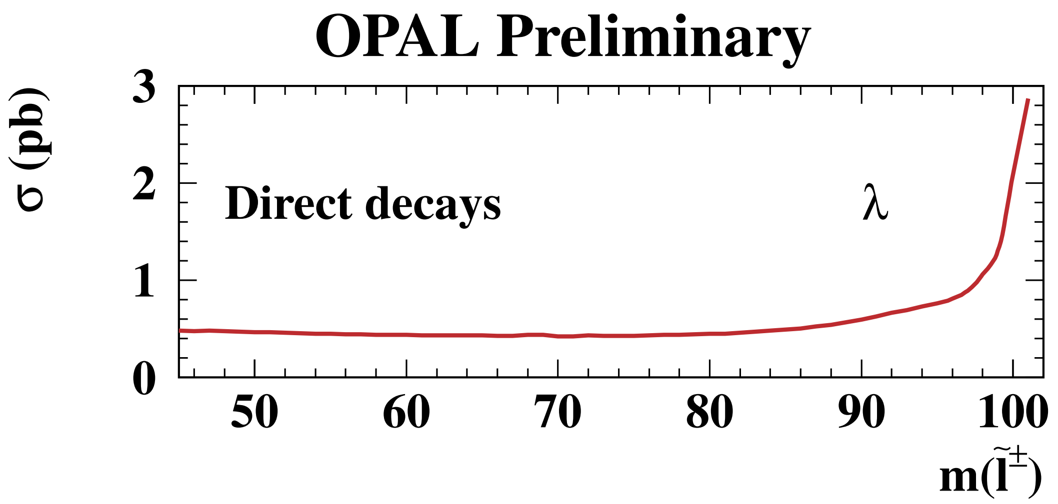
- Superpotential includes terms:

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



- Observed events consistent with expected background





GMSB SUSY: $\tilde{\ell}_R$ NLSP

$$e^+e^- \longrightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

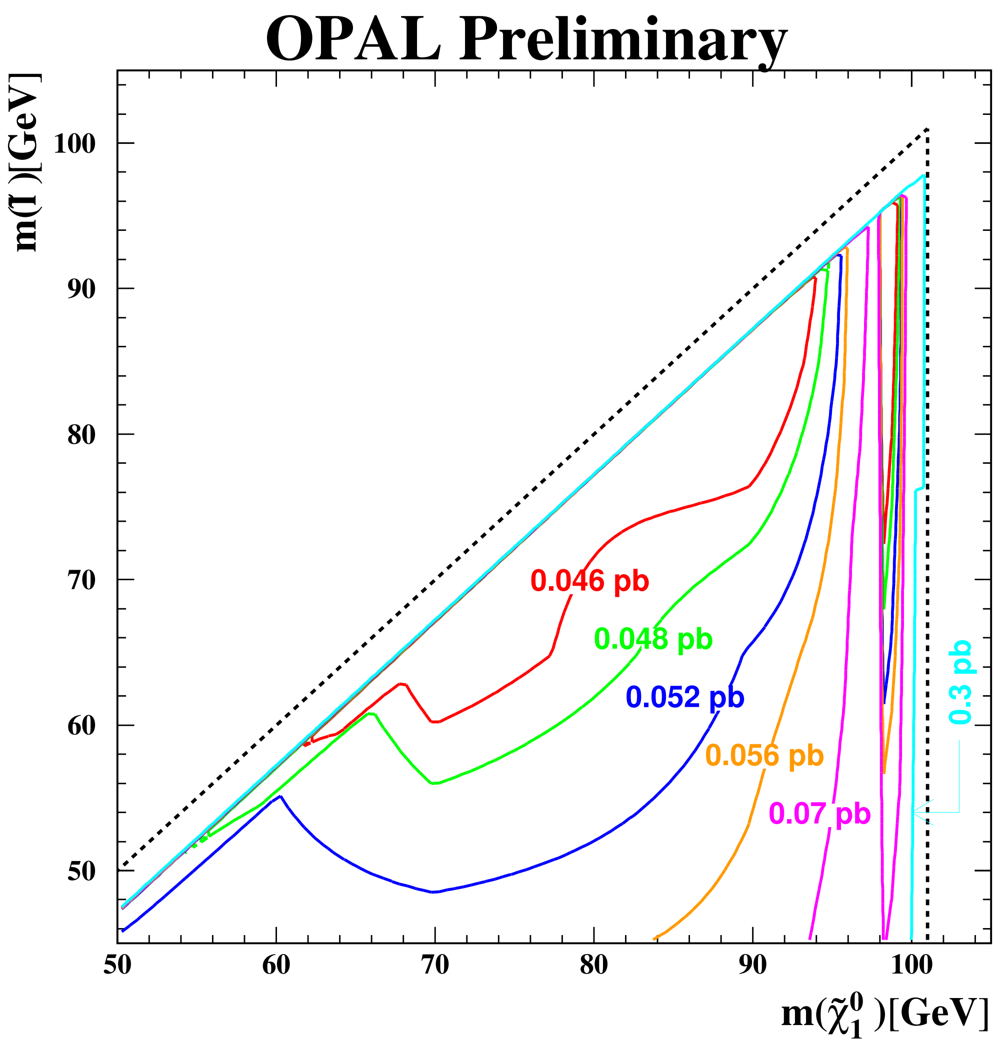
$\quad\quad\hookrightarrow (\ell)\,\tilde{\ell}$

$\quad\quad\quad\quad\hookrightarrow \ell\,\tilde{G}$

$\quad\hookrightarrow (\ell')\,\tilde{\ell}'$

$\quad\quad\quad\hookrightarrow \tilde{\ell}'\,\tilde{G}$

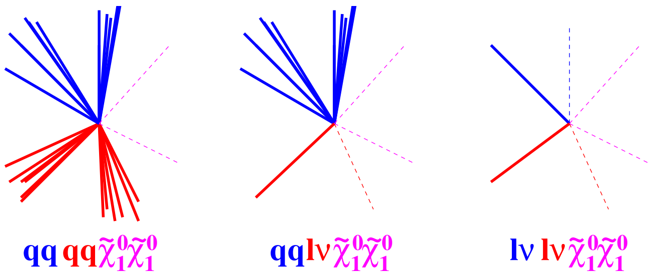
Channel	data	bkg.
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to (\ell\ell\tilde{G})(\ell'\ell'\tilde{G})$	4	1.2±0.2



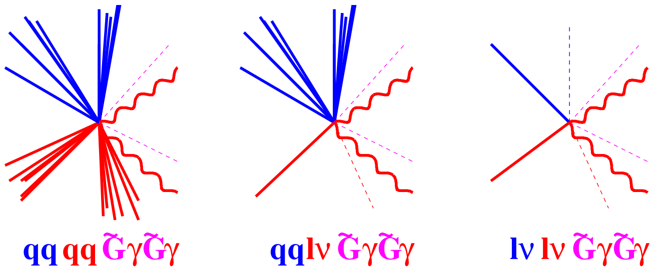
GMSB, $\tilde{\chi}_1^+\tilde{\chi}_1^-$ with $\tilde{\chi}_1^0$ NLSP: γ's + X $+ \not{E}_T$

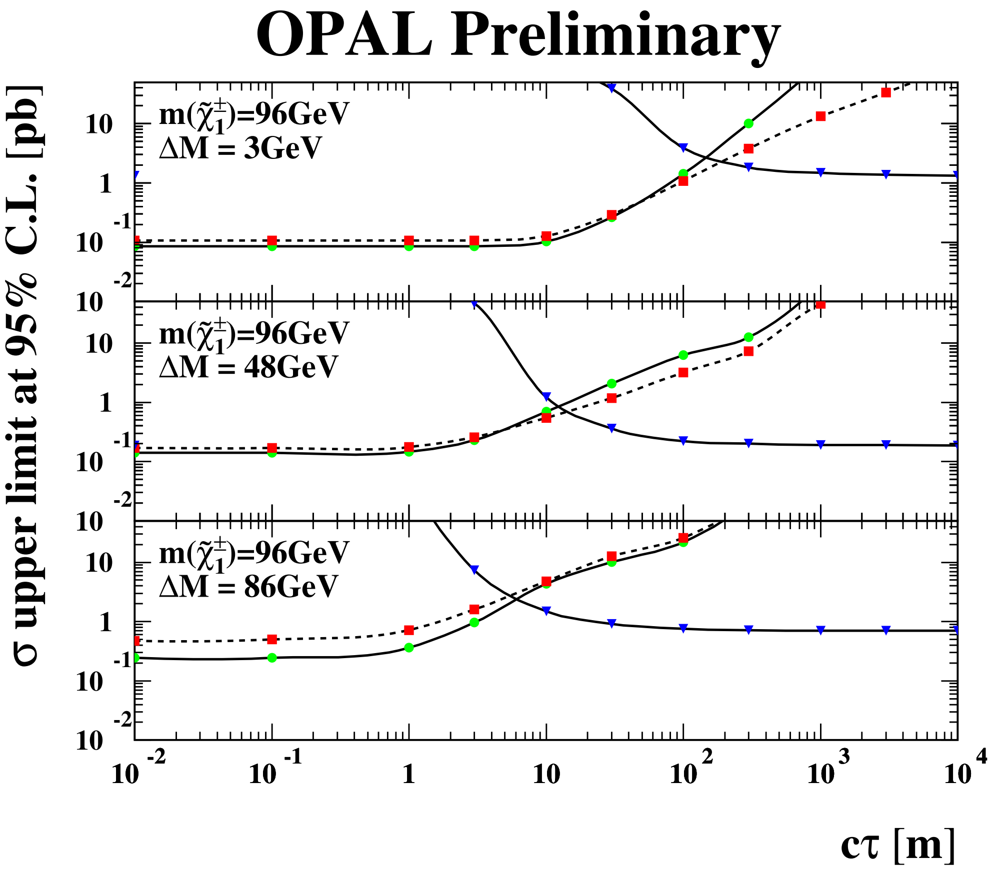
Final state topology depends on the $\tilde{\chi}_1^0$ decay length ($c\tau$)

Long τ :



Short τ :





Heavy and Excited Leptons

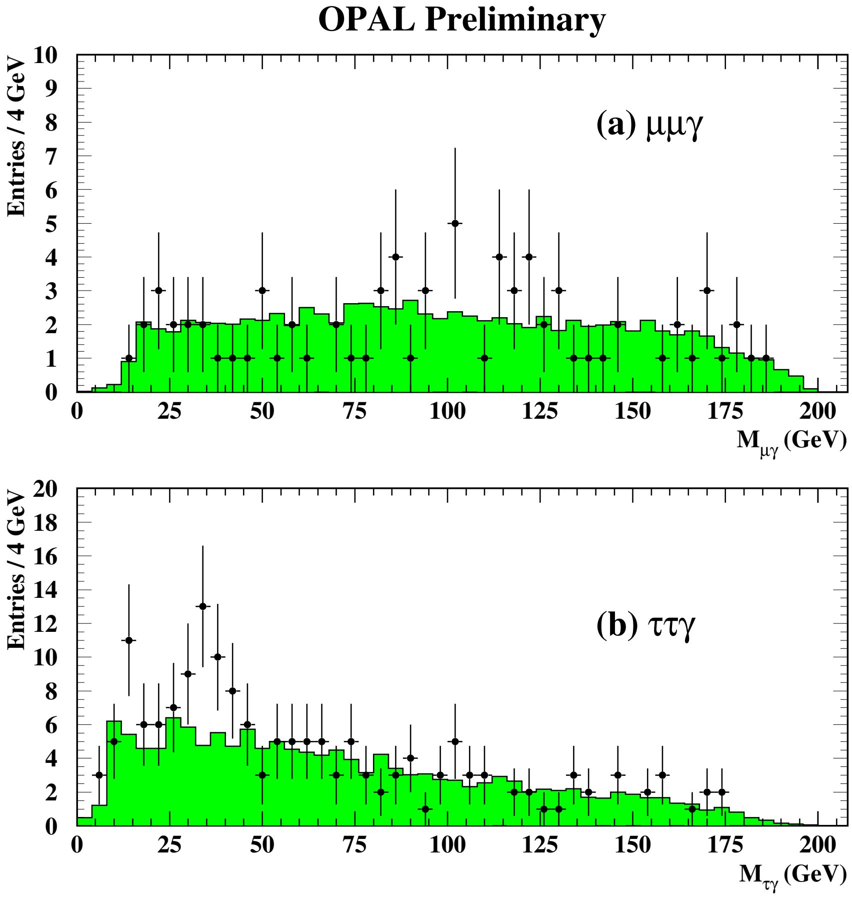
Pair production of

- Neutral heavy leptons with charged current decays
  $\mathrm{N} \to \ell \mathrm{W}$
- Excited leptons with decays via γ, W and Z $\ell^* \to \ell\gamma$, $\ell^* \to \ell \mathrm{Z}$, $\ell^* \to \nu \mathrm{W}$

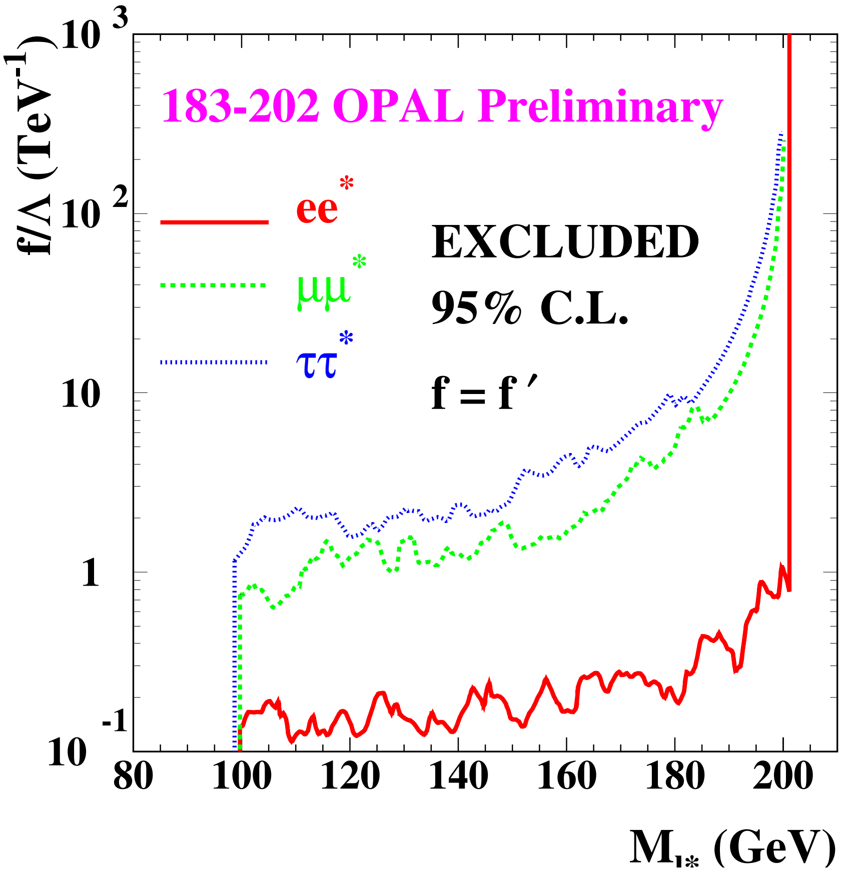
Channel	$\mathrm{N_{DATA}}$	$\mathrm{N_{SM}}$
$\mathrm{e^+e^-}$WW	4	4.9$\pm$0.5
$\mu^+\mu^-$WW	11	9.9$\pm$1.1
$\tau^+\tau^-$WW	66	54$\pm$14
$\mathrm{e^+e^-}\gamma\gamma$	7	10.4$\pm$2.6
$\mu^+\mu^-\gamma\gamma$	4	3.9$\pm$0.3
$\tau^+\tau^-\gamma\gamma$	0	3.2$\pm$0.3

Mode		Mass Limit (GeV)	
		OPAL 192–202	OPAL 183–189
$\mathrm{N} \to \mathrm{eW}$	Dirac	97.8	93.4
	Majorana	88.8	84.9
$\mathrm{N} \to \mu \mathrm{W}$	Dirac	97.1	92.9
	Majorana	87.7	83.4
$\mathrm{N} \to \tau \mathrm{W}$	Dirac	78.9	80.1
	Majorana	67.5	62.6

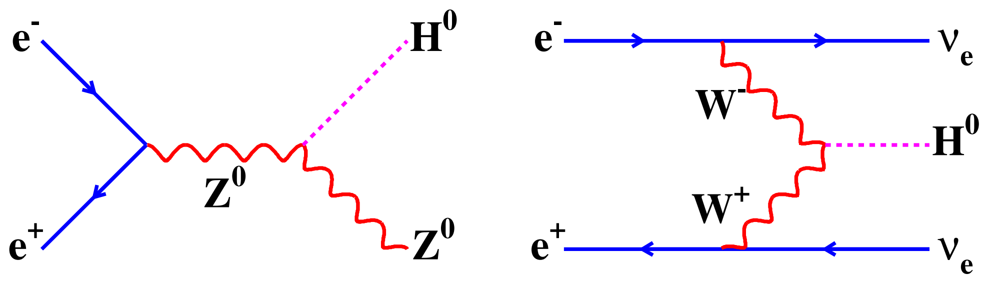
Excited Leptons



Limits on Mass and coupling / compositeness scale:

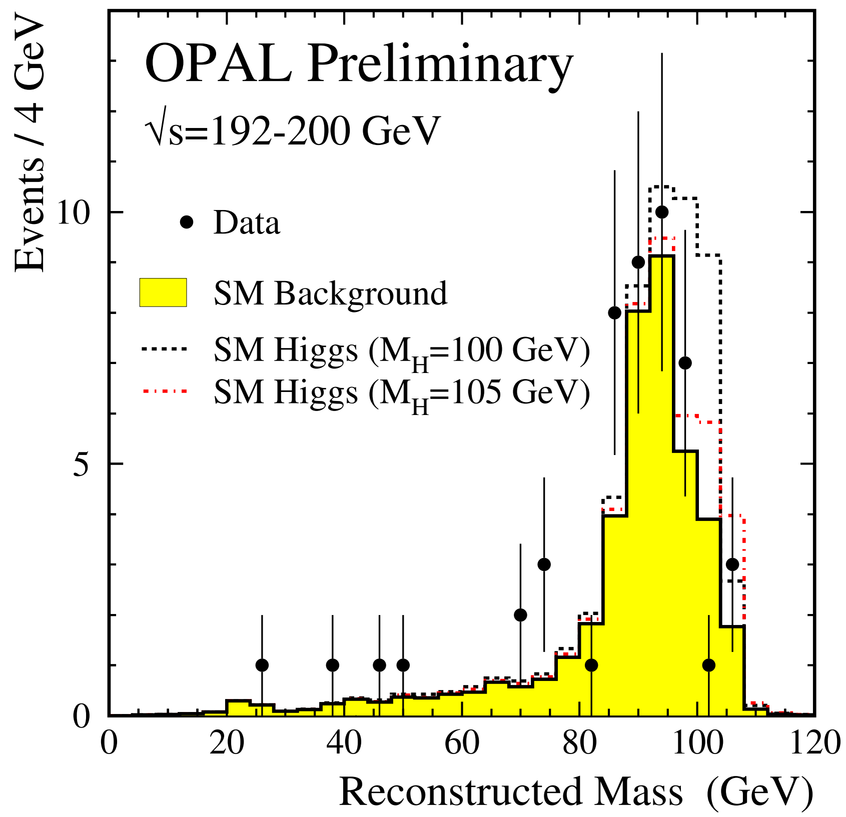


SM Higgs Search



192–200 GeV

Channel	N_{DATA}	N_{BG}
$H^0Z^0 \rightarrow b\bar{b}q\bar{q}$	29	22.1 ± 4.4
$H^0Z^0 \rightarrow b\bar{b}\nu\nu$	4	7.6 ± 1.0
$H^0Z^0 \rightarrow b\bar{b}\tau^+\tau^-$	5	5.4 ± 1.6
$H^0Z^0 \rightarrow b\bar{b}\ell^+\ell^-$	10	5.6 ± 1.4



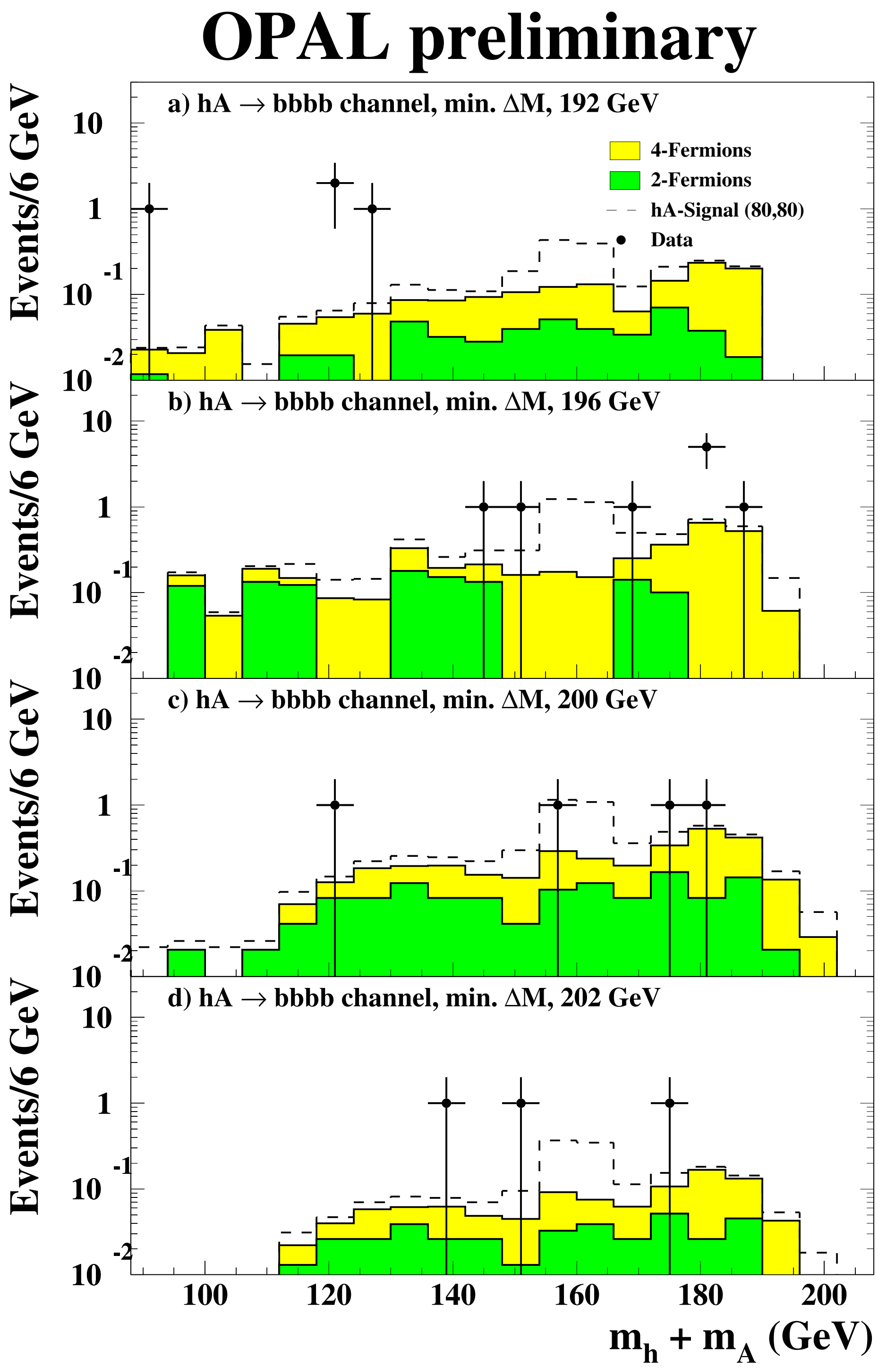
SM Higgs Search

202 GeV

Channel	N_{DATA}		N_{BG}
$H^0Z^0 \rightarrow b\bar{b}q\bar{q}$	1	82.9 GeV	3.0±0.6
$H^0Z^0 \rightarrow b\bar{b}\nu\nu$	1	106.9 GeV	1.1±0.2
$H^0Z^0 \rightarrow b\bar{b}\tau^+\tau^-$	0		0.8±0.2
$H^0Z^0 \rightarrow b\bar{b}\ell^+\ell^-$	0		0.8±0.2

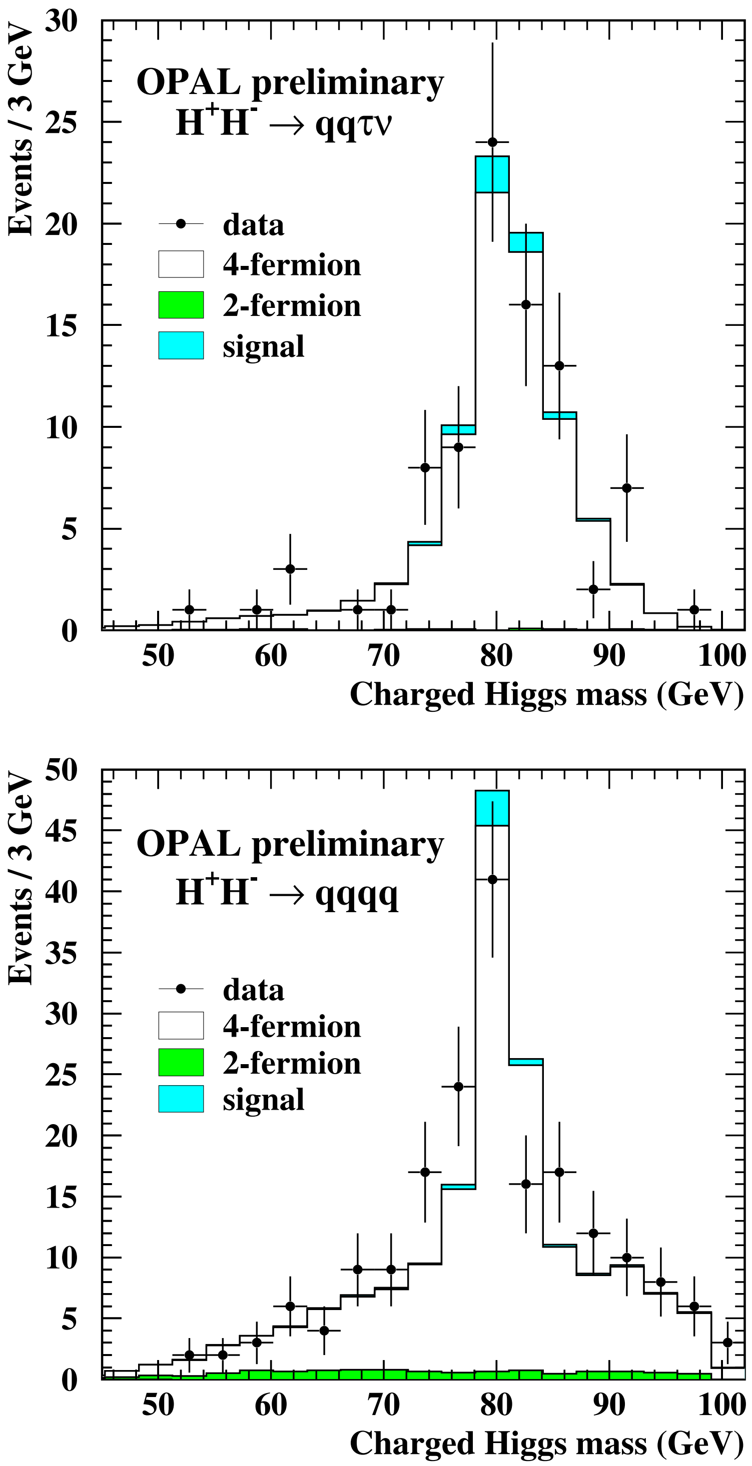
$e^+e^- \longrightarrow A^0h^0$

Channel	N_{DATA}	N_{BG}
$A^0h^0 \to b\bar{b}b\bar{b}$	18	9.3±2.3
$A^0h^0 \to \tau^+\tau^- b\bar{b}$	5	7.1±3.1



Charged Higgs Search

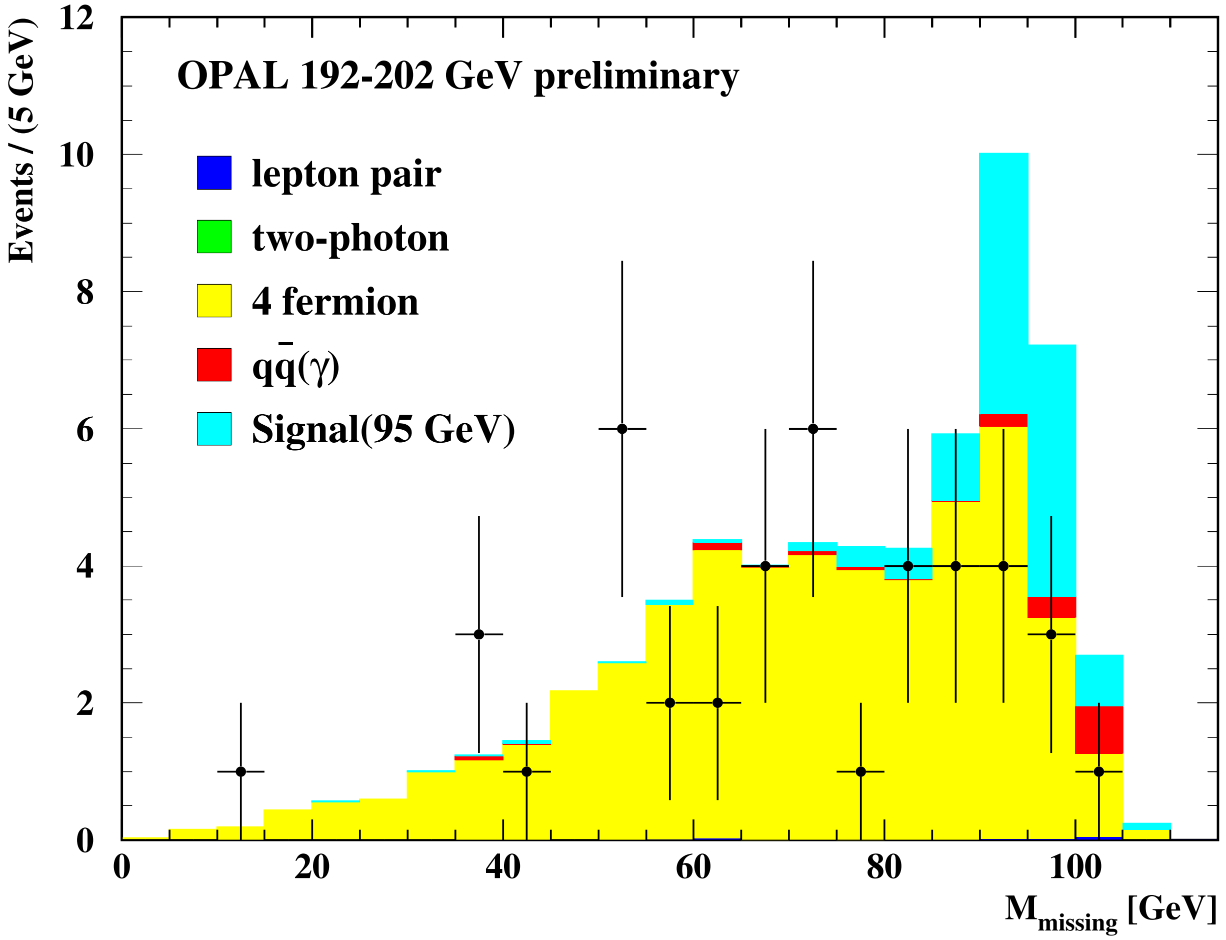
Channel	N_{DATA}	N_{BG}
$H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\overline{\nu_\tau}$	84–97	71–75$\pm$1.2
$H^+H^- \rightarrow \tau^+\nu_\tau q\overline{q}'$	87	81.5$\pm$2.8
$H^+H^- \rightarrow q\overline{q}'q\overline{q}'$	188	172.9$\pm$3.4



Invisible Higgs Search

- $e^+e^- \rightarrow h^0Z^0$, with $Z^0 \rightarrow q\bar{q}$ and $h^0 \rightarrow$ invisible

Channel	N_{DATA}	N_{BG}
$h^0 \rightarrow$ invisible	42	53 ± 5

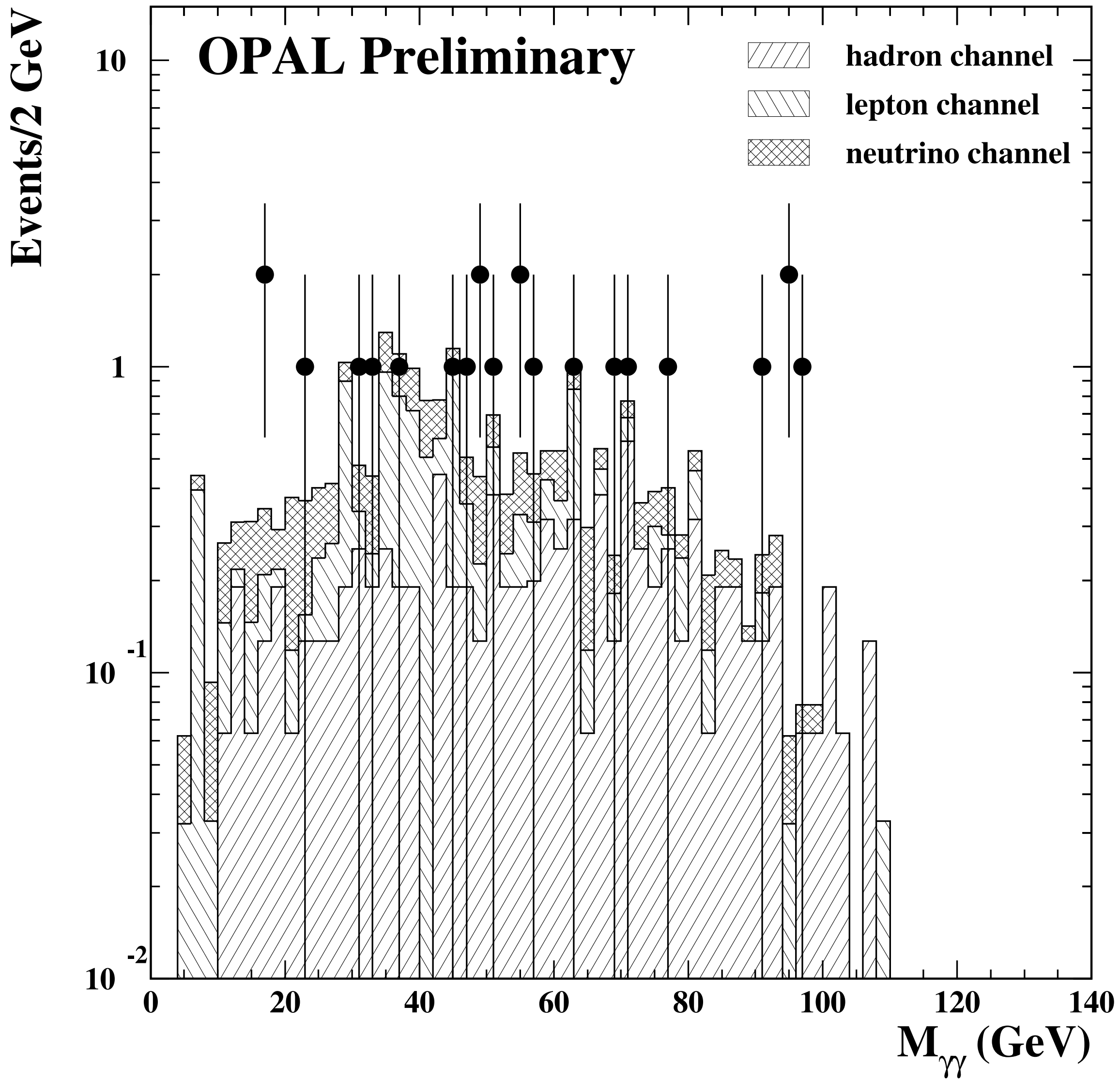


$h^0 \to \gamma\gamma$

- $h^0 \to \gamma\gamma$ can be large in e.g. bosonic models (no tree-level couplings to fermions)

Channel	N_{DATA}	N_{BG}
$h^0Z^0 \to \gamma\gamma q\bar{q}$	14	8.8±0.7
$h^0Z^0 \to \gamma\gamma\ell\ell$	5	7.5±1.4
$h^0Z^0 \to \gamma\gamma\nu\bar{\nu}$	3	6.2±0.3

192-202 GeV, up to P114



Beam Request for 2000

- Emphasis on **HIGH ENERGIES**
- $\int \mathcal{L}\mathrm{d}t$ needs:
  - Many SUSY channels: $\sim$ few pb^{-1}
  - Higgs: more $\mathcal{L}\mathrm{d}t$ needed for visible effect (SM $\sim$ 50 pb^{-1})
  - Rule of thumb: gain from 2 GeV increase in $\sqrt{s}$ as long as $\mathcal{L}\mathrm{d}t$ does not fall by factor 2
  - SM physics (M_{W}) needs $\mathcal{L}\mathrm{d}t$
- Before July LEPC
  - Run at **HIGHEST ENERGY** consistent with $\sim$ 1 pb^{-1} / day
  - 0.5 pb^{-1} at Z at start of year
- After July LEPC
  - Wait and see

Summary

- OPAL data taking in 1999 very successful
  $\int \mathcal{L}\mathrm{d}t >$ 200 pb^{-1} - more than any previous year
- Many ongoing physics analyses, both LEP1 and LEP2
- Most results from $>$ 190 GeV data in reasonable agreement with SM predictions, but...
- See small excesses (probability 0.1% – 5%) in several channels; no definite new physics signal $\longrightarrow$ need more high energy data
- We look forward to another good year
  high energy
  high $\int \mathcal{L}\mathrm{d}t$
  .....hope for some exciting new physics