New Results from OPAL

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LEP Physics Jamboree

- Final results
- Improved analyses
- Complete calibration
- Using full data set
- New analyses

OPAL submitted 65 papers to ICHEP

New results from OPAL

Searches

- SM Higgs [final]
- Fermiophobic Higgs $\longrightarrow \gamma\gamma$ [final]
- CP odd Higgs [final]
- Flavour independent Higgs search
- CP violating Higgs
- $H^{\pm}$
- $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, large Δm, small Δm
- $\tilde{t}$, $\tilde{b}$ [final]
- GMSB SUSY
- RPV $\tilde{\mathrm{f}}$
- $\ell^{*\pm}$ [final]
- Leptoquark pair production
- Long lived, heavy stable particles
- H^{++} single production

5×10^{6} Z

- $A_{\mathrm{FB}}^{\mathrm{b}}$ jet, vertex, $K^{\pm}$ charge [final]
- Inclusive b fragmentation [final]

QCD

- α_s LEP2
- x_p LEP2 [final]
- n_{ch} LEP2
- $\gamma\gamma \longrightarrow \mathrm{p\bar{p}}$ LEP2 [final]

LEP2 EW

- NC 4f [final]
- TGC $WW\gamma$, WWZ
- QGC NC, CC
- Colour reconnection study
- $\mathrm{e^+e^-} \longrightarrow \gamma\gamma(\gamma)$ [final]
- NCQED

$A_{\mathrm{FB}}(\mathrm{b})$ at Z

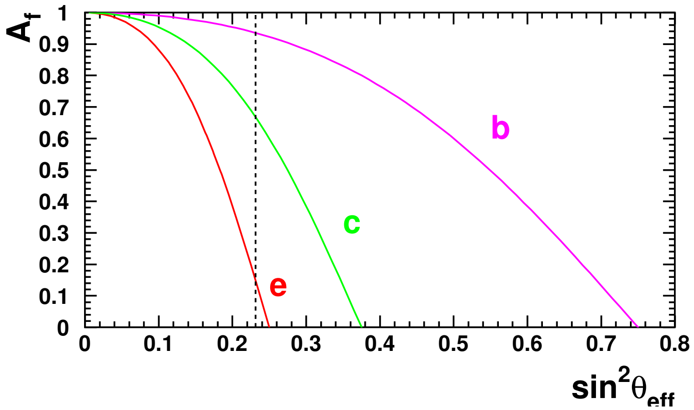
$$\frac{d\sigma}{d\cos\theta} \propto (1+\cos^2\theta) + \frac{8}{3}A_{\mathrm{FB}}\cos\theta$$

Pole asymmetry $A^{0,\mathrm{b}}_{\mathrm{FB}} = \frac{3}{4}\mathcal{A}_{\mathrm{e}}\mathcal{A}_{\mathrm{b}}$

$$\mathcal{A}_{\mathrm{f}} = \frac{2(g_{V\mathrm{f}}/g_{A\mathrm{f}})}{1+(g_{V\mathrm{f}}/g_{A\mathrm{f}})^2}$$

$$g_{V\mathrm{f}}/g_{A\mathrm{f}} = 1 - 4|Q|\sin^2\theta_{\mathrm{eff}}$$

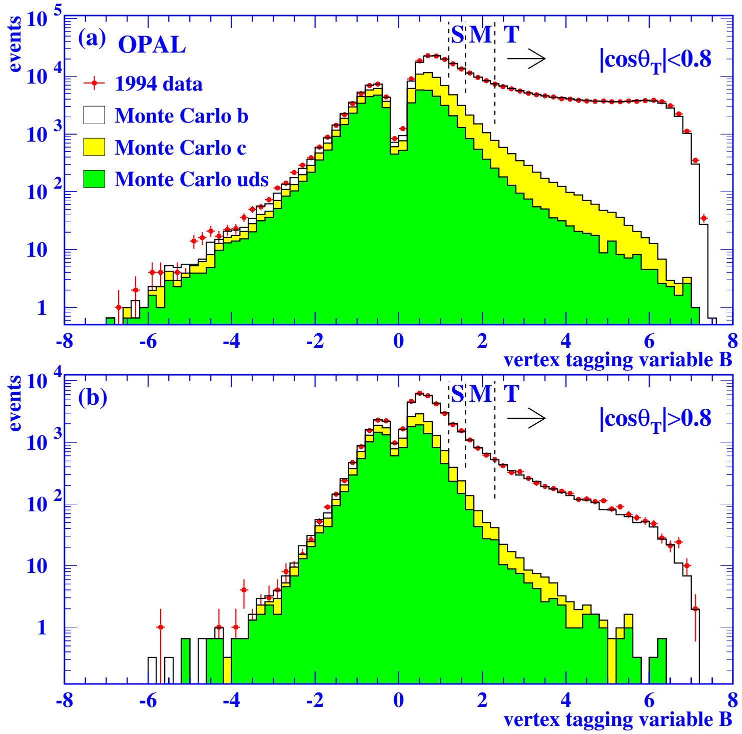
$\mathcal{A}_{\mathrm{b}} \approx 0.94$: insensitive to $\sin^2\theta_{\mathrm{eff}}$.
$A^{0,b}_{\mathrm{FB}} \Rightarrow \mathcal{A}_{\mathrm{e}}$
$\longrightarrow$ precise determination of $\sin^2\theta^{\mathrm{e}}_{\mathrm{eff}}$.



New OPAL measurement

Using jet, vertex and $K^{\pm}$ charge

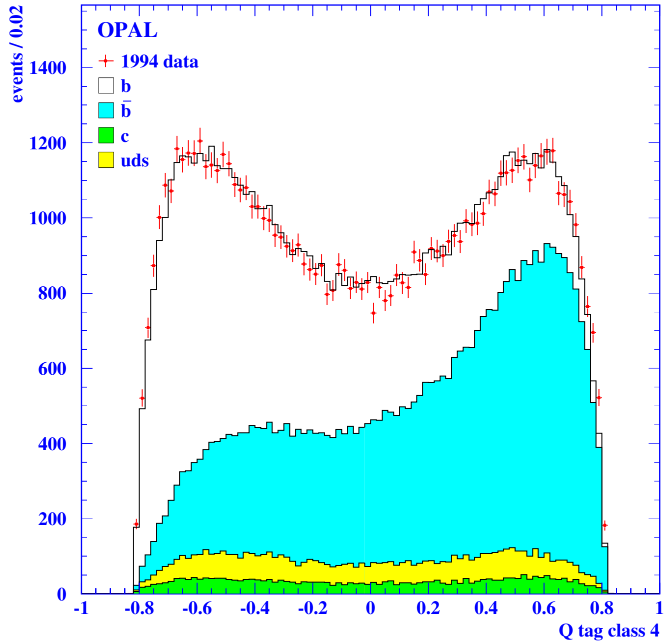
- Improved b-tag: vertex, leptons
- Extended $\cos\theta$ range
- Adding 0.5M Z from 1996-2000

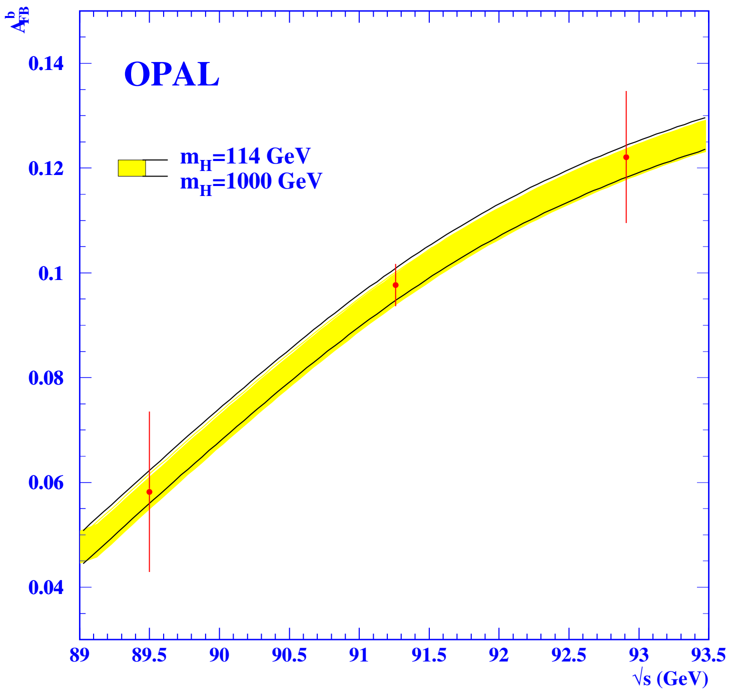


$A_{\mathrm{FB}}(\mathrm{b})$ at Z

Combination of 4 charge tags

using jet, vertex, $\mathrm{K}^{\pm}$





Sophisticated fitting procedure

$$\begin{aligned} A_{\mathrm{FB}}^{\mathrm{b}} &= 0.0582 \pm 0.0153 \pm 0.0012 \quad \mathrm{pk}-2 \\ A_{\mathrm{FB}}^{\mathrm{b}} &= 0.0977 \pm 0.0036 \pm 0.0018 \quad \mathrm{pk} \\ A_{\mathrm{FB}}^{\mathrm{b}} &= 0.1221 \pm 0.0123 \pm 0.0025 \quad \mathrm{pk}+2 \end{aligned}$$

New OPAL result

$$A_{\mathrm{FB}}^{0,\mathrm{b}} = 0.1002 \pm 0.0034 \pm 0.0018$$

$$\sin^2\theta_{\mathrm{eff}}^{\mathrm{e}} = 0.23205 \pm 0.00068$$

Previous OPAL result

$$A_{\mathrm{FB}}^{0,\mathrm{b}} = 0.1007 \pm 0.0055 \pm 0.0040$$

Final $A_{\mathrm{FB}}^{\mathrm{b}}$ using leptons will follow soon.

Inclusive b fragmentation function

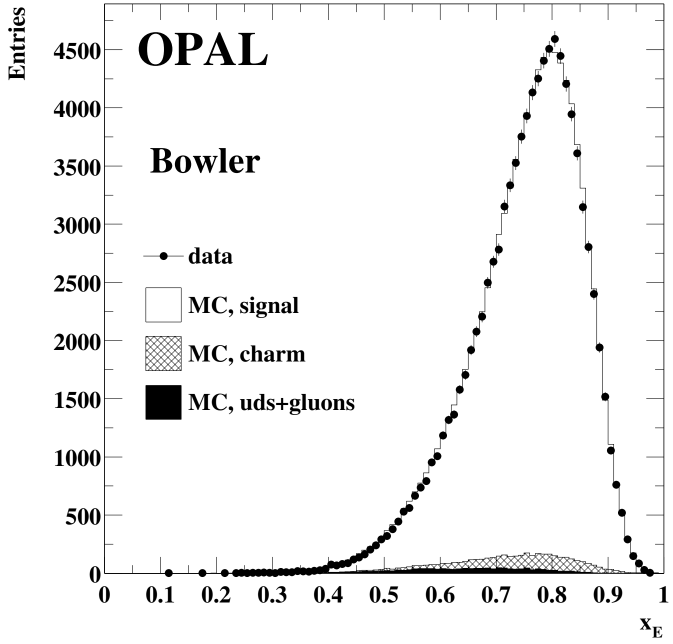
Models of fragmentation function

Comparison of observed x_E with MC

Jetset string fragmentation +

f(Bowler, Lund-symmetric, Kartvelishvili et al., Peterson et al, Collins-Spiller)

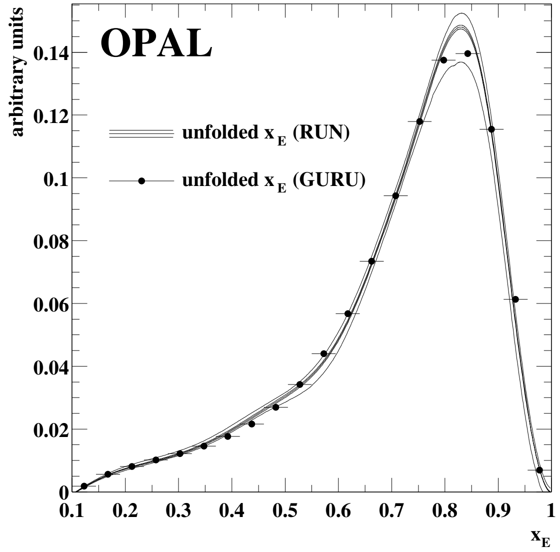
Herwig cluster model



$$x_E = E(\text{B-hadron})/E_{\mathbf{beam}}$$

Model independent x_E distribution

Unfolded x_E distribution



$$< x_E >$$

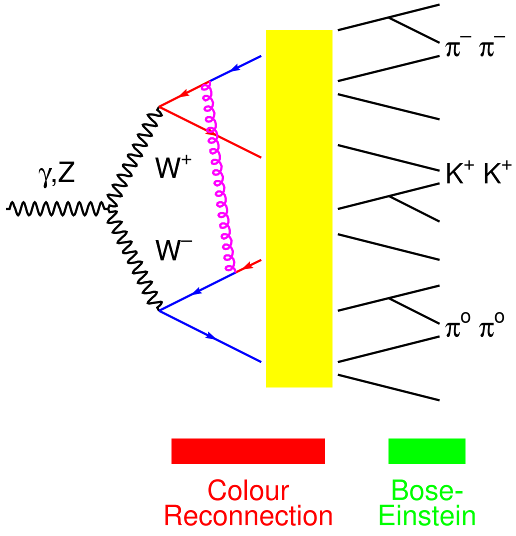
OPAL	$\mathbf{0.7193 \pm 0.0016^{+0.0036}_{-0.0031}}$
ALEPH*	$\mathbf{0.716 \pm 0.006 \pm 0.006}$
SLD**	$\mathbf{0.709 \pm 0.003 \pm 0.003 \pm 0.013}$

* Exclusive semi-leptonic

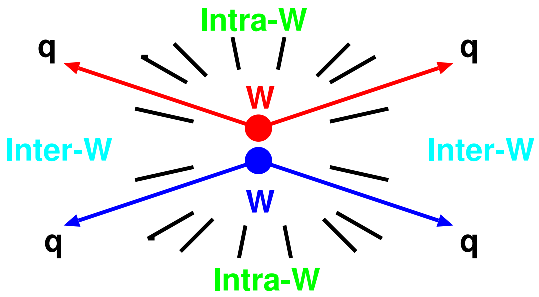
** Based on Peterson et al. fragmentation func.

Colour reconnection study in $W^+W^- \to q\bar{q}q\bar{q}$

- Possible final state interference ?

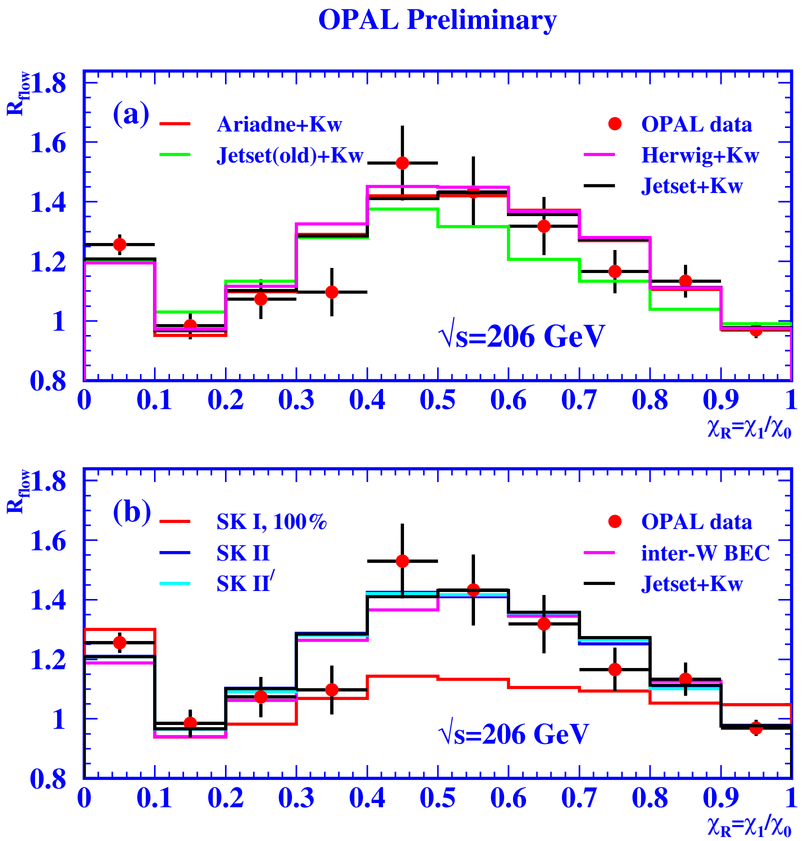


- Impact to the m_W measurement
- No definite theoretical prediction
- Test models with data



Particle flow Intra/Inter ratio

(189-209 GeV data)



Test of colour reconnection models.

e.g. in SK-I model, 38% c.r. preferred.

WWγ, WWZ TGC

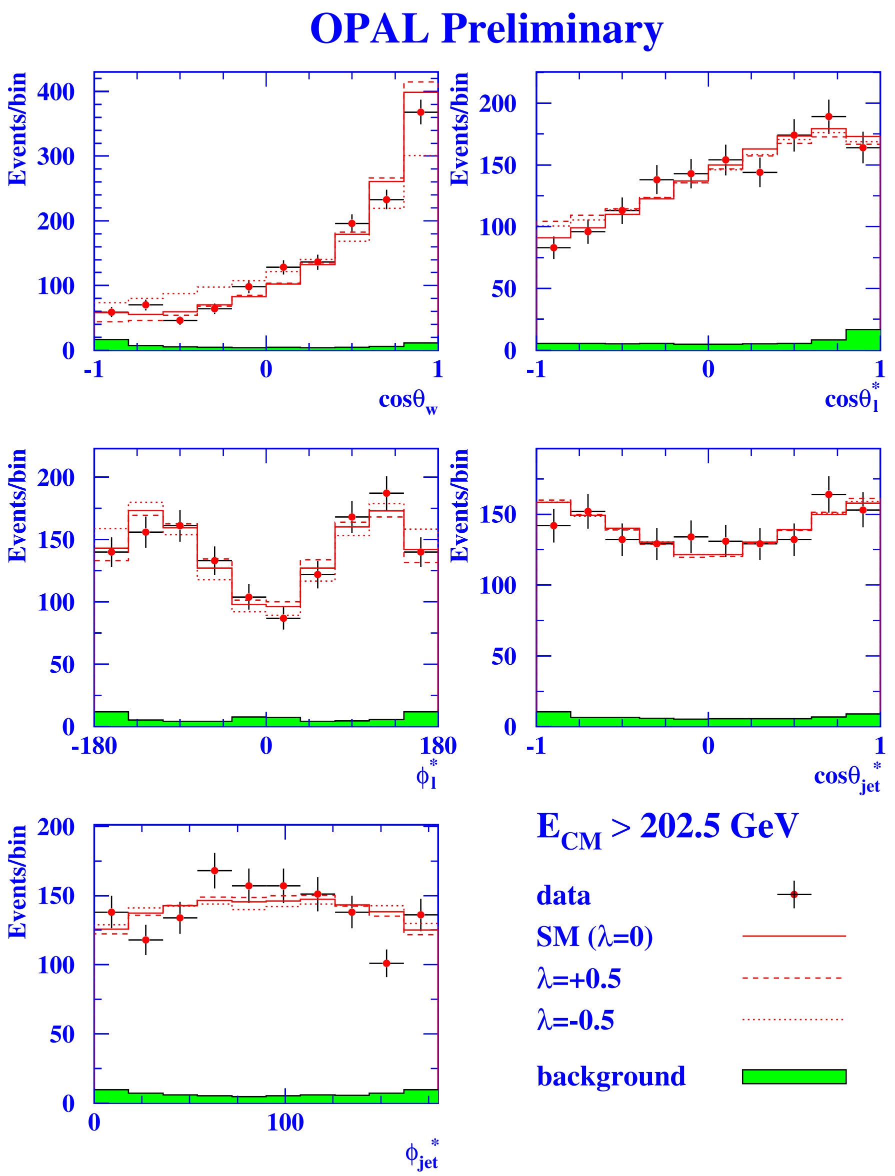
$e^+e^- \rightarrow WW$

- Update using data at 183-209 GeV
- Using new $\sim$ full $\mathcal{O}(\alpha)$ calculation
  KandY MC

Usual parameters: κ_γ, g_1^Z, λ

Study also g_5^Z (C and P violating)

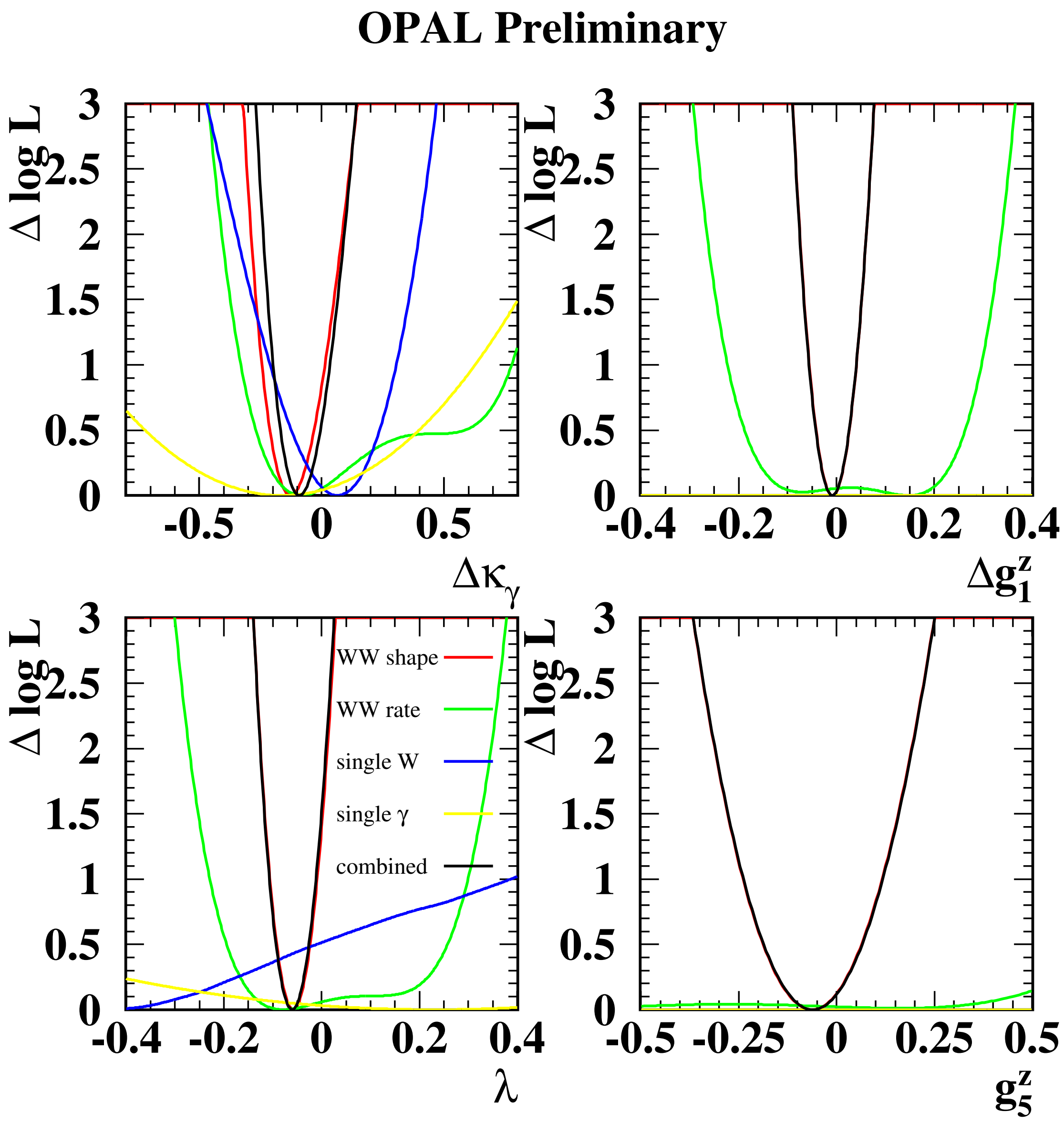
- WW production rate
- Production and decay angles $\rightarrow$
  - Study all decay modes :
    qqqq, qq$\ell\nu$, $\ell\nu\ell\nu$
  - Fit using optimal observable



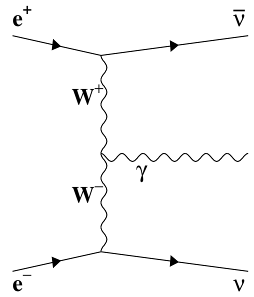
WW$\rightarrow$qq$\ell\nu$

WWγ, WWZ TGC

OPAL combined results



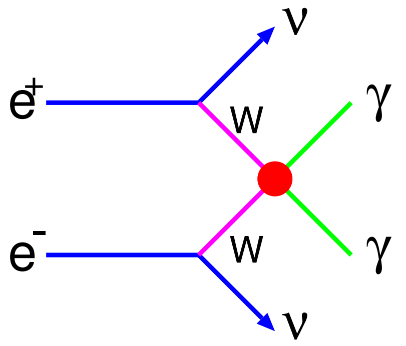
Using results from WW, Weν and new result from $\nu\nu\gamma$



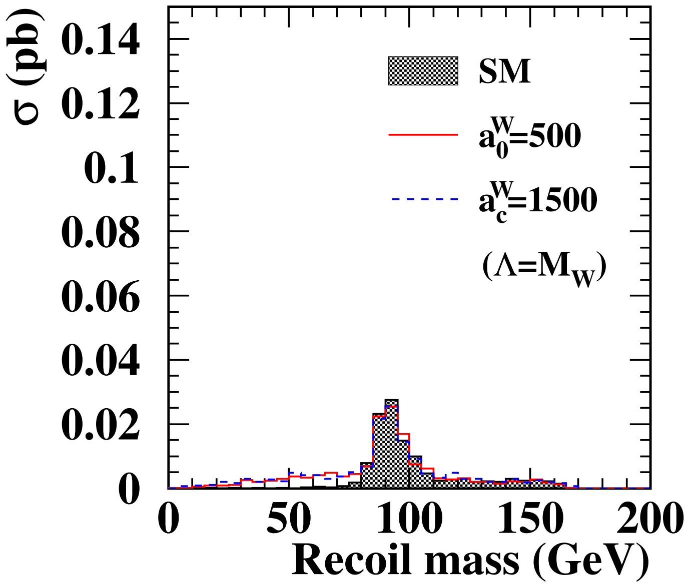
			SM
κ_γ	$=$	$+0.91^{+0.09}_{-0.08}$	1
g_1^Z	$=$	$+0.991^{+0.034}_{-0.034}$	1
λ	$=$	$-0.060^{+0.034}_{-0.033}$	0
g_5^Z	$=$	$-0.06^{+0.13}_{-0.13}$	0

$WW\gamma\gamma$, $ZZ\gamma\gamma$ Quartic Gauge Couplings

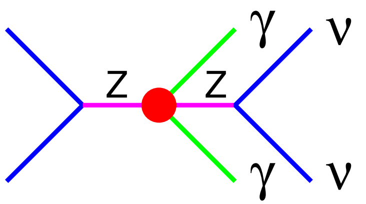
Study $e^+e^- \rightarrow \gamma\gamma\nu\bar{\nu}$ at 189-209 GeV



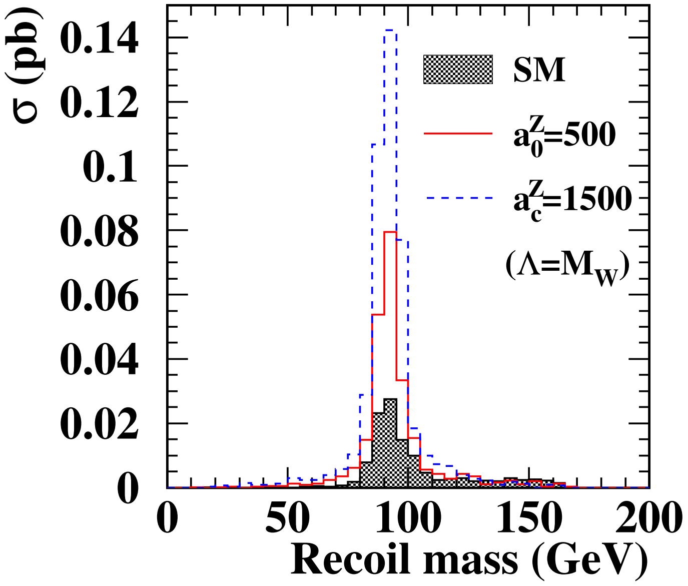
$WW\gamma\gamma$: a_0^W, a_c^W



$WW\gamma\gamma$



$ZZ\gamma\gamma$: a_0^Z, a_c^Z

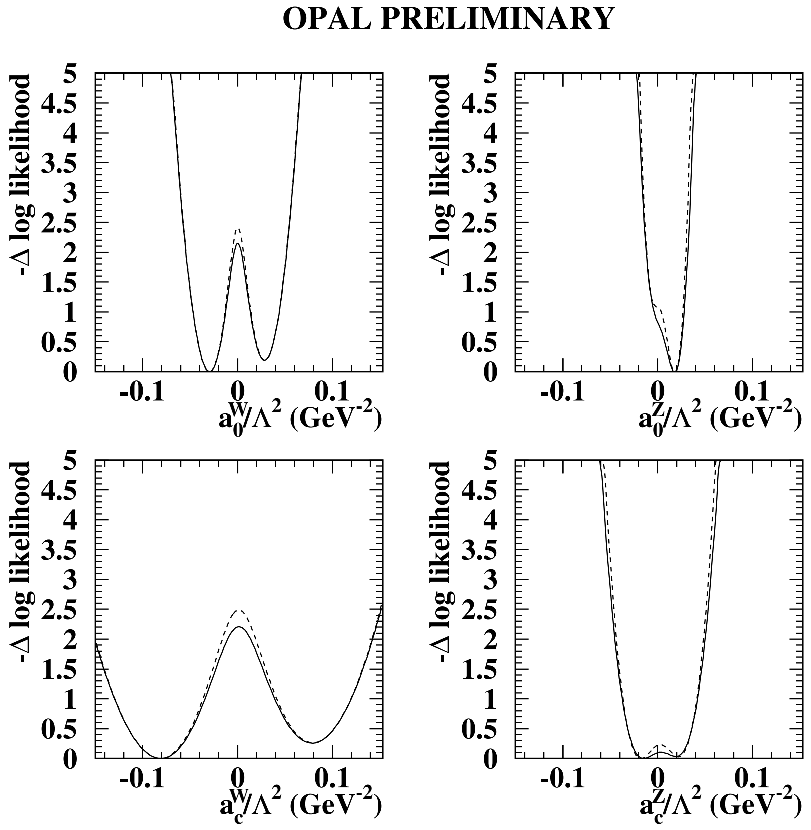


$ZZ\gamma\gamma$

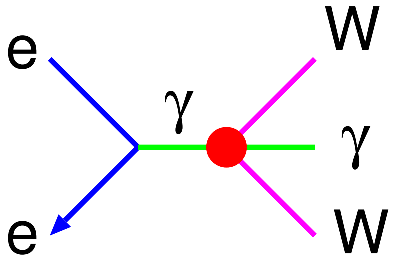
Disentangle $WW\gamma\gamma$ and $ZZ\gamma\gamma$ components using $E_{2\gamma}$ and M_{recoil}.

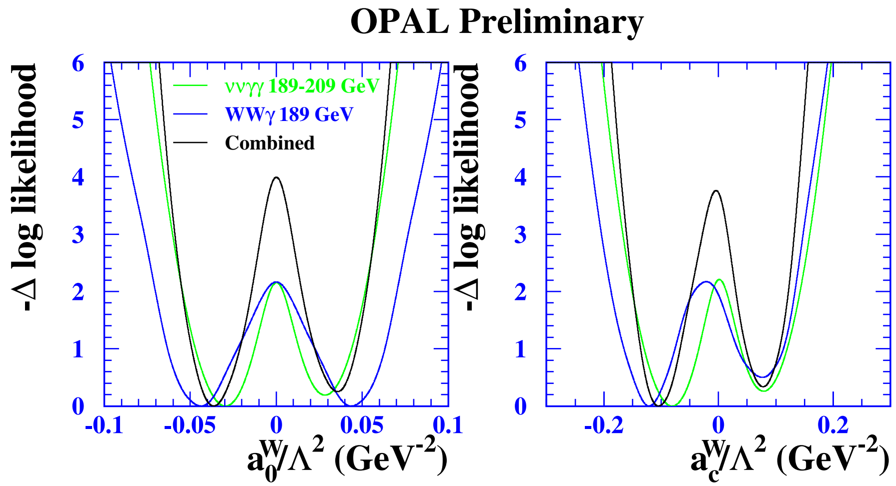
Analysis using NUNUGPV.

WW$\gamma\gamma$, ZZ$\gamma\gamma$ Quartic Gauge Couplings



Combine results of WW$\gamma\gamma$ coupling from $e^+e^- \to \mathbf{WW\gamma}$ (189 GeV)





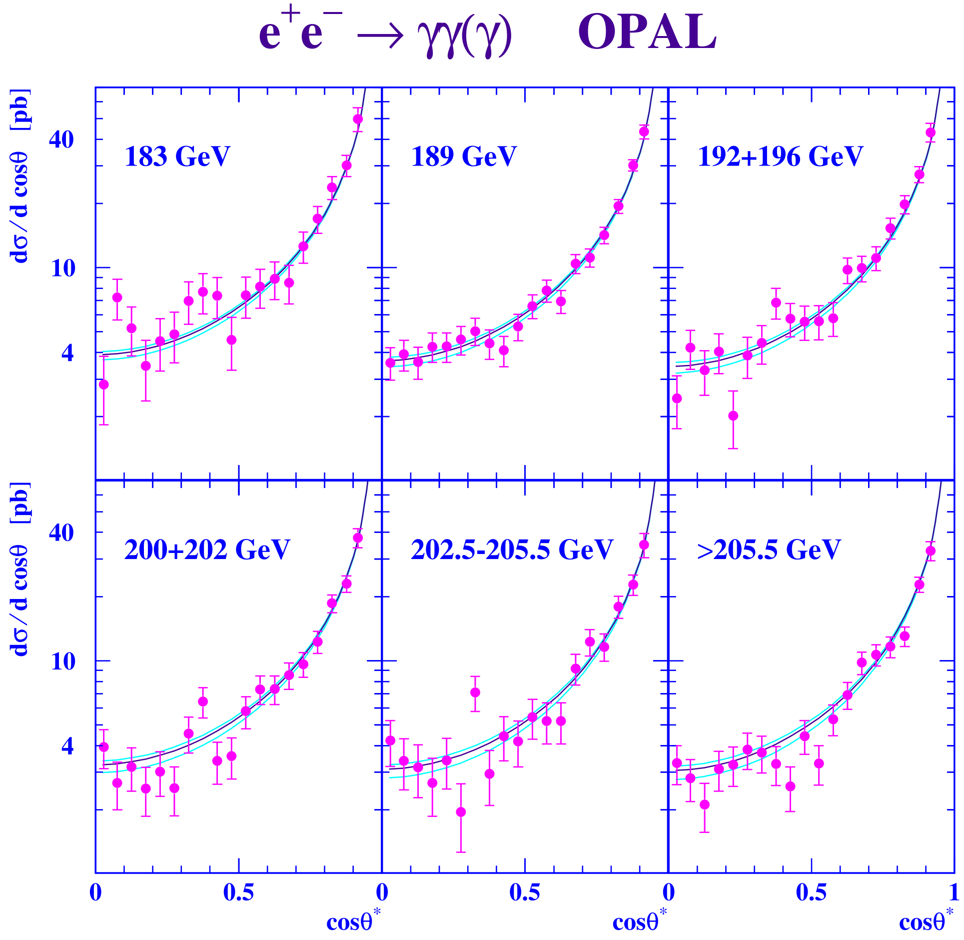
$$-0.054 < \frac{a_0^W}{\Lambda^2} < 0.052 \text{ GeV}^{-2}$$
$$-0.011 < \frac{a_c^W}{\Lambda^2} < 0.031 \text{ GeV}^{-2}$$
$$-0.15 < \frac{a_0^Z}{\Lambda^2} < 0.14 \text{ GeV}^{-2}$$
$$-0.044 < \frac{a_c^Z}{\Lambda^2} < 0.049 \text{ GeV}^{-2}$$

$\Delta \log L = 4$

$\to$ Consistent with the SM within 2.8σ

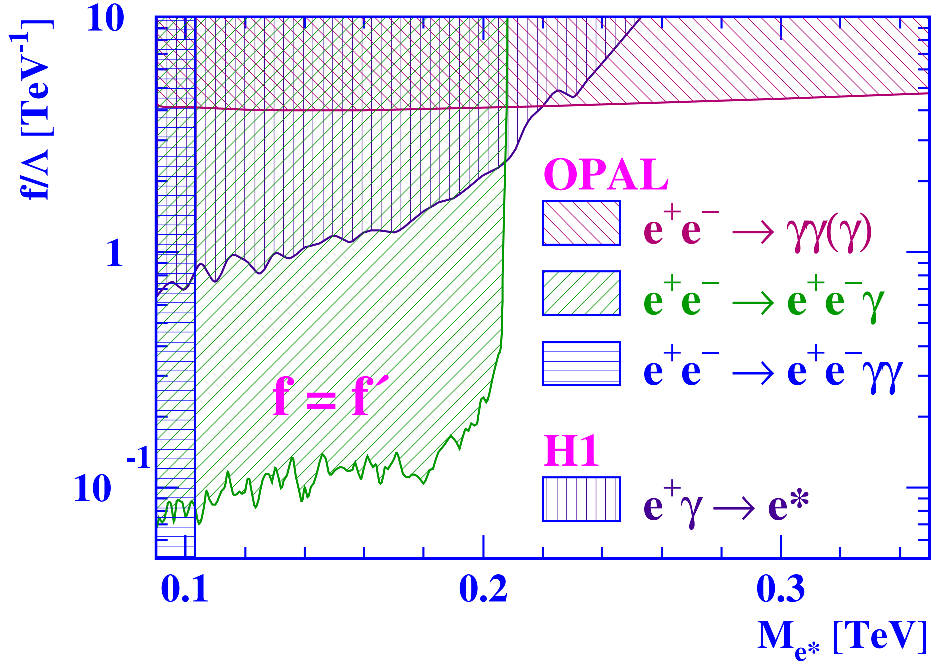
Photon pair $e^+e^- \to \gamma\gamma(\gamma)$

- Final results using data at 183-209 GeV



Constraints on new physics

cut-off parm.	$\Lambda_+ > 371$ GeV $\Lambda_- > 314$ GeV
Extra dim.	$\lambda = +1 : M_s > 805$ GeV $\lambda = -1 : M_s > 956$ GeV
e^*	$\frac{f_\gamma}{\Lambda} = \frac{1}{M_{e^*}} : M_{e^*} > 245$ GeV $\frac{f_\gamma}{\Lambda} < 4.11$ TeV^{-1}



Non-commutative QED in $e^+e^- \to \gamma\gamma$

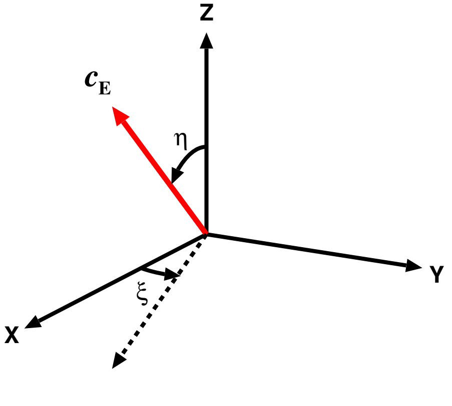
Non-commutative geometry.

$$[x_\mu, x_\nu] = i\theta_{\mu\nu} \sim 1/\Lambda^2$$

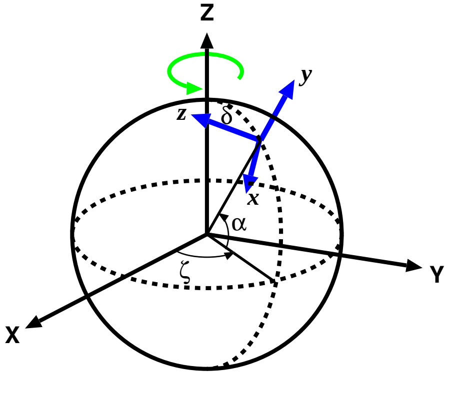
Non-commutative QED, NCQED

Study with $e^+e^- \to \gamma\gamma$

- Preferred direction: $\theta_E = \theta_{0i}$



Space



Earth

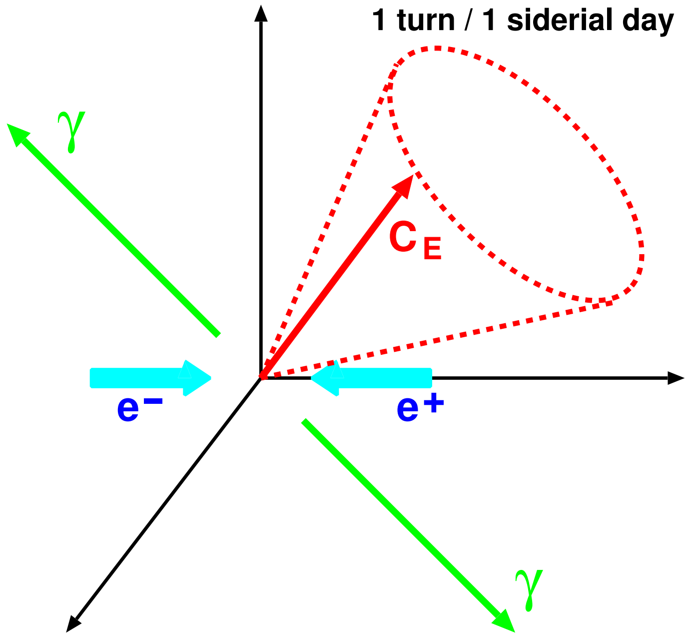
- Cross-section depends on $\theta_E \cdot p_\gamma$

$\Rightarrow$ Leads to deviations from QED.

$(|\theta_E| = 1/\Lambda^2$, η, $\xi)$ and $(\theta_\gamma$, $\phi_\gamma)$.

- Earth rotates $\to$

At OPAL, the preferred direction rotates

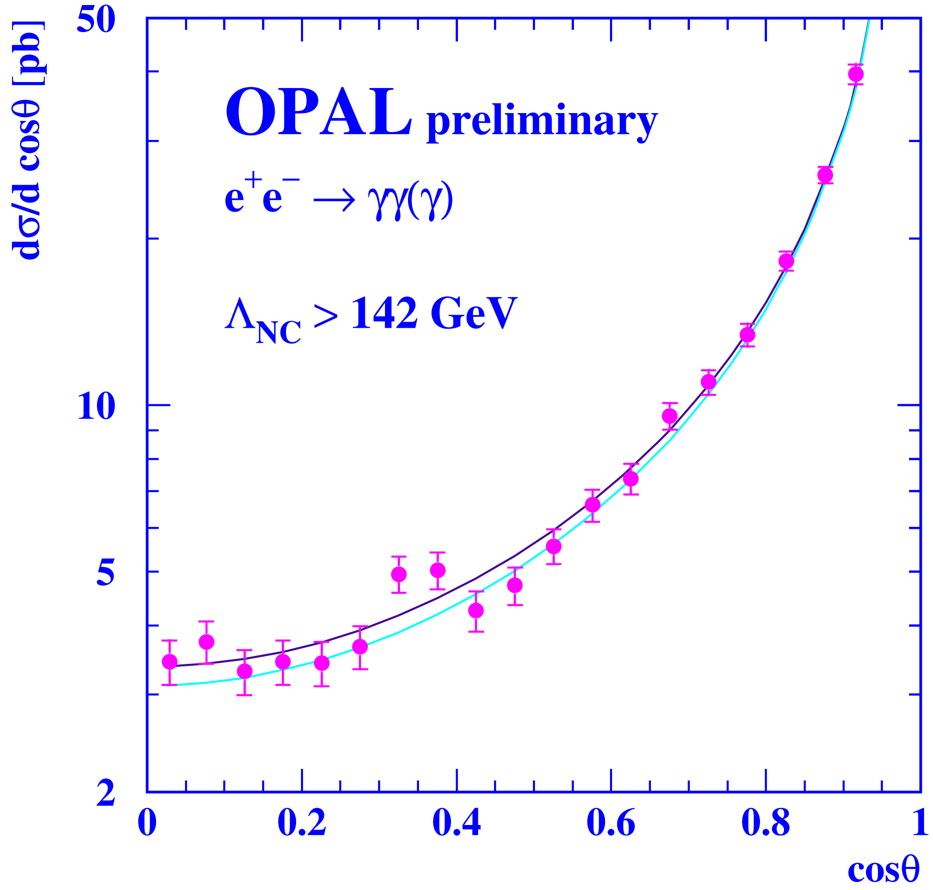


Analyse $e^+e^- \to \gamma\gamma$ events taking care of the time dependence of the c_E vector.

(OPAL PN500, J.Kamoshita hep-ph/0206223)

Non-commutative QED in $e^+e^- \to \gamma\gamma$

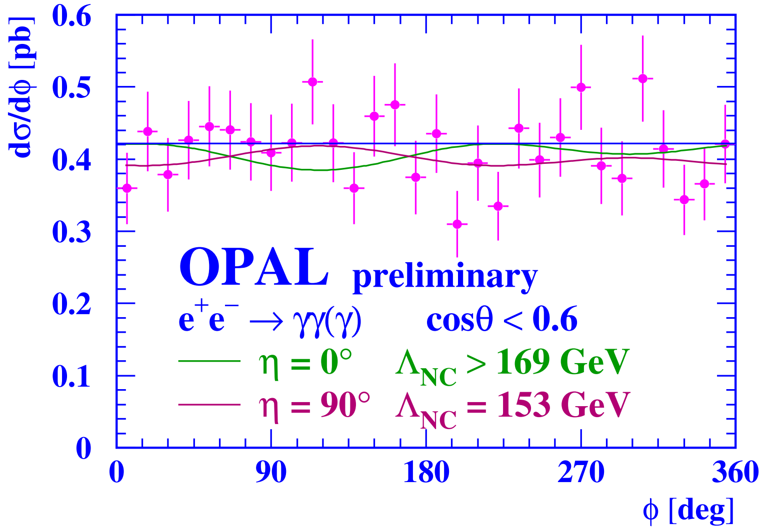
- Time averaged, ϕ integrated $\frac{d\sigma}{d\cos\theta}$



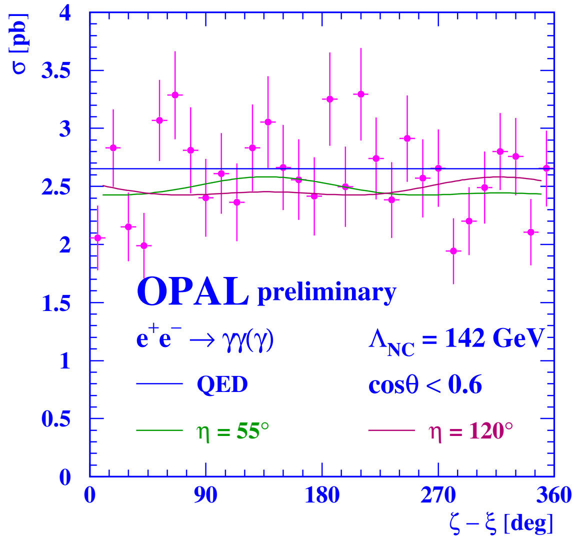
$\Lambda_{NC} > 142$ GeV at 95% CL.

(independent of other model parameters)

- Time averaged, $\cos\theta$ integrated $\frac{d\sigma}{d\phi}$



- From time dependence, ζ could be inferred.



Standard Model Higgs search

OPAL published, end 2000 (PL B499 (2001) 38)
SM Higgs search using 1999+2000 data

New final result

- Complete detector calibration →
- Improved analysis,
  based on MC studies,
  to gain signal sensitivity,
  in particular at high mass

CL_s sensitivity gain (%)

m_{H}(GeV)	110	115
bbqq	+32	+12
bb$\nu\bar{\nu}$	+32	+8

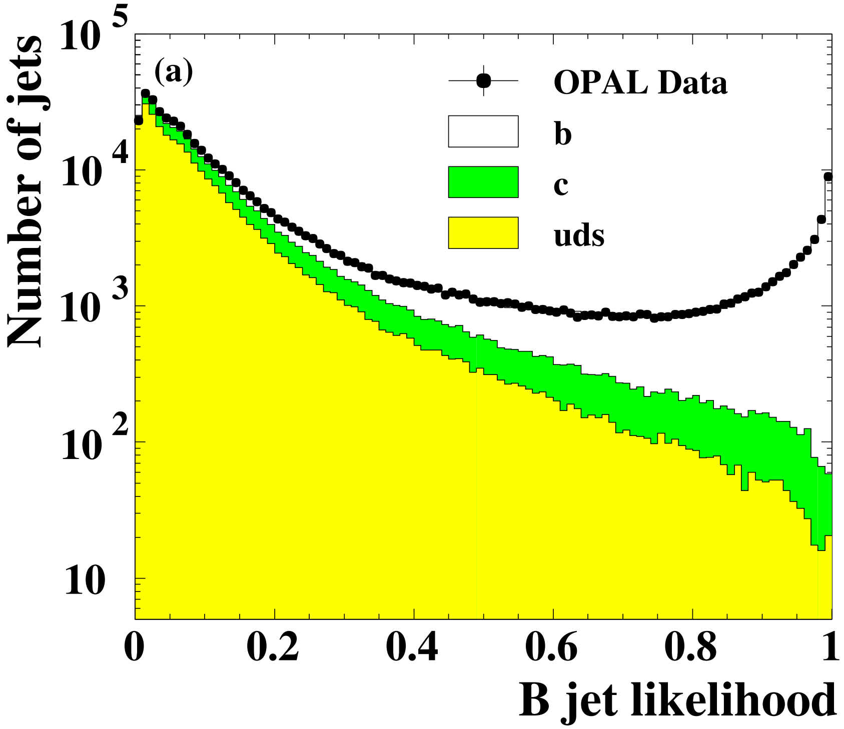
Expected m_{H} lower bound :

112.5⟶112.7 GeV

- The new analysis is applied to the data

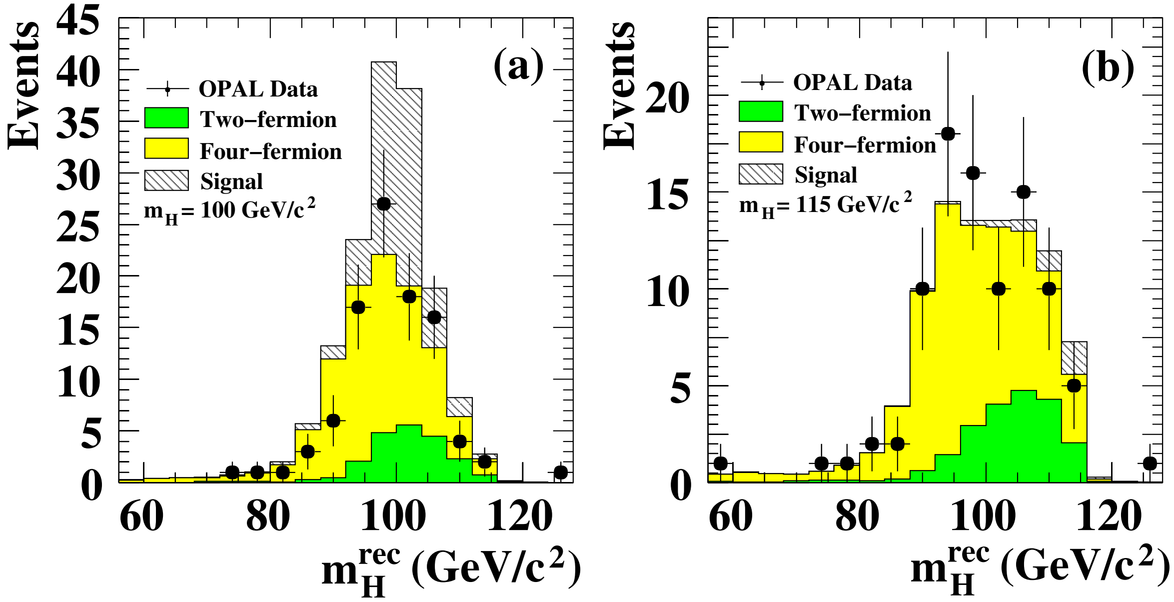
b-tag performance

Z calibration data

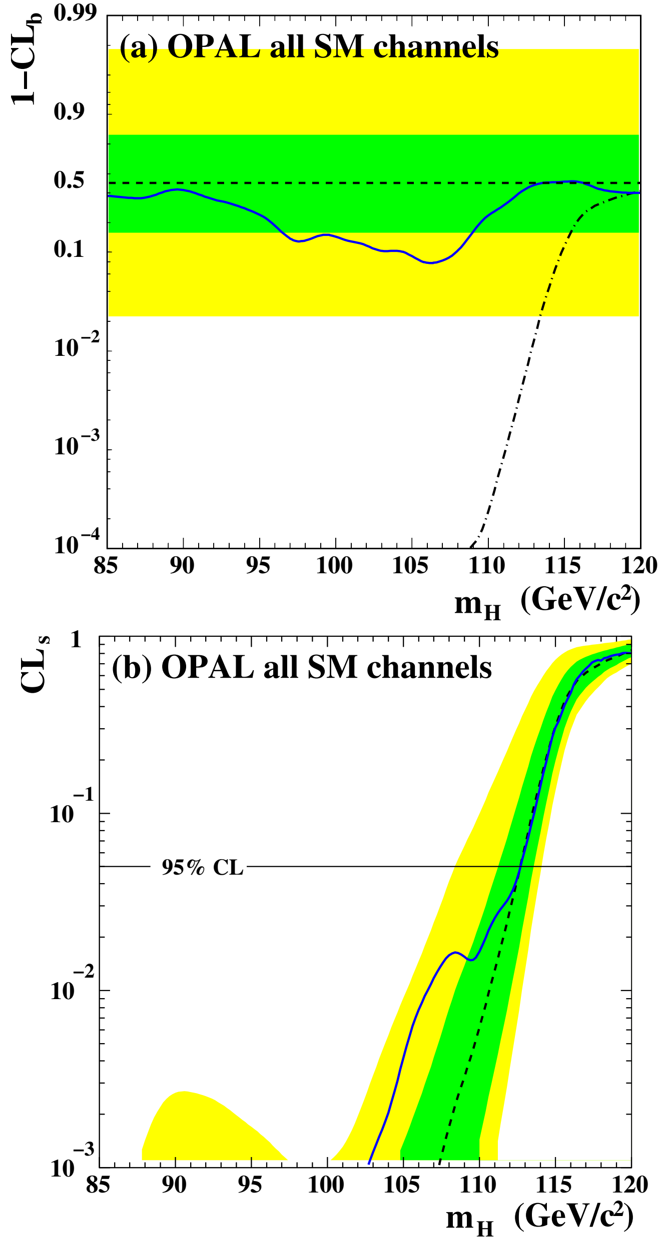


Standard Model Higgs search

Reconstructed masses



Significance



	1-CL_b min.	1-CL_b at 115 GeV	95% CL lower bound observed	expected
new	0.08 at 106 GeV	0.5	112.7	112.7

CP violation in Higgs sector in MSSM

Can arise through loop corrections. ⟵ Complex phases in the SUSY breaking terms.

Exclusion in $\tan\beta$ - m_{H_1} plane.

Compared to the CP conserving MSSM:

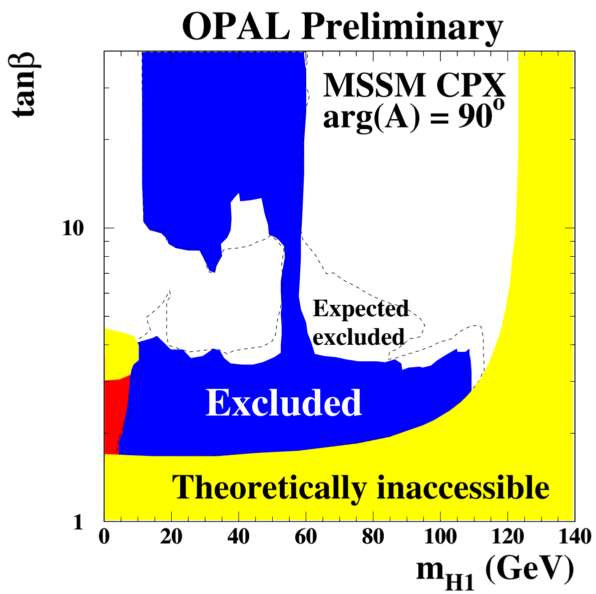
h,H (CP even), A(CP odd)
$\longrightarrow$ H_1, H_2, H_3

- Different production rates
- Different decay fractions

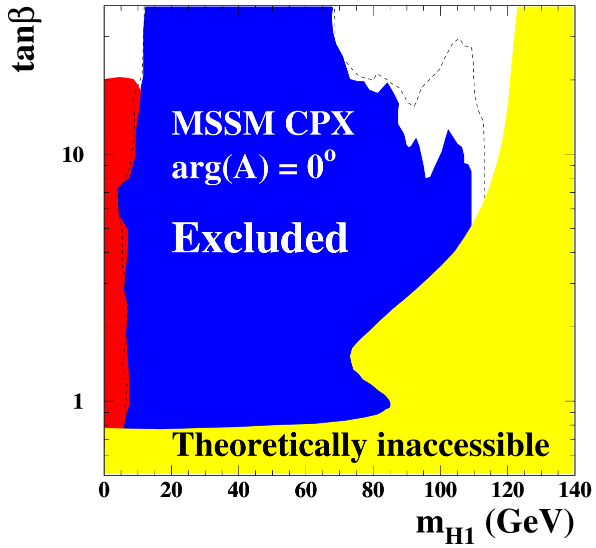
Interpretation in the context of
CP violating scenarios
of the search results at 90-209 GeV for

- SM Higgs hZ (+ WW, ZZ fusion)
- MSSM hA

with enhancement of the analysis
in certain phase space



Maximal
CP violation



CP conserving

Searches in GMSB SUSY topology

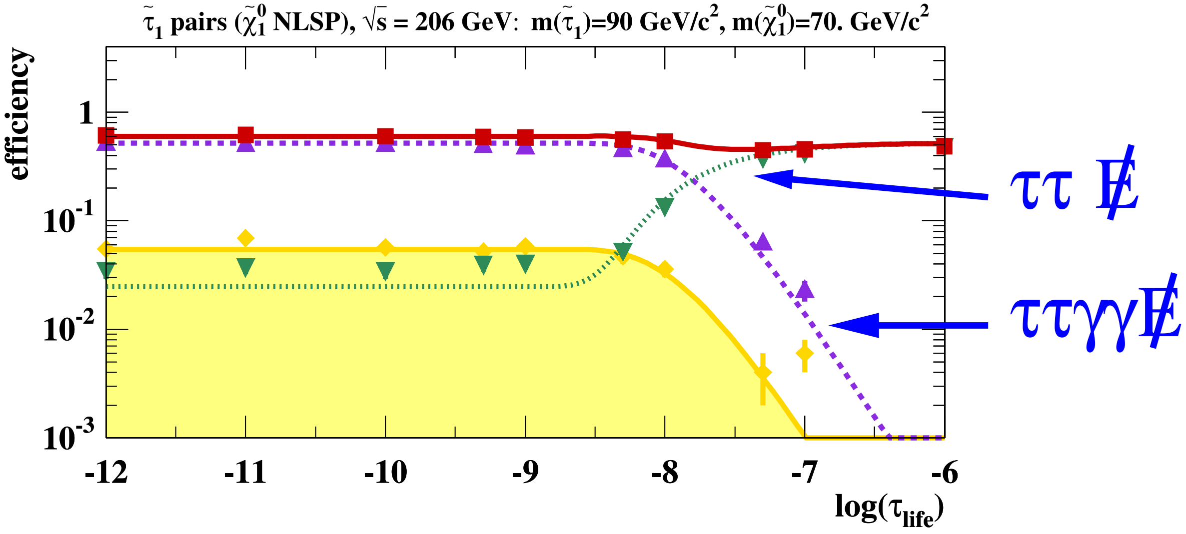
- $\tilde{G}$ is the LSP, weakly interacting, light($\ll$ GeV)
- $\tilde{\chi}_1^0$ or $\tilde{\tau}$ ($\tilde{\ell}$) is the NLSP with arbitrary lifetime ($\tilde{\chi}_1^0 \to \tilde{G}\gamma$, $\tilde{\ell} \to \tilde{G}\ell$)

$\Rightarrow$ searches for particles in scenarios with

- all NLSP types, all NLSP lifetimes
- MC for all processes, NLSP lifetime
- take efficiencies overlaps of analyses into account

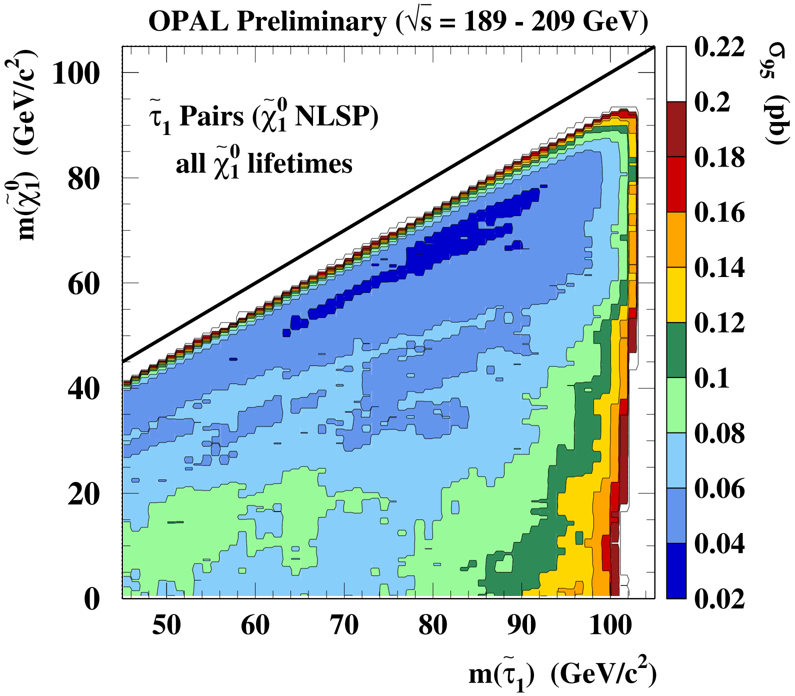
Example: $e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tilde{\chi}_1^0\,\tau^-\tilde{\chi}_1^0$

$\tilde{\chi}_1^0 \to \tilde{G}\gamma$



Cross-section limit on

$\tilde{\tau}_1^+\tilde{\tau}_1^-$ production

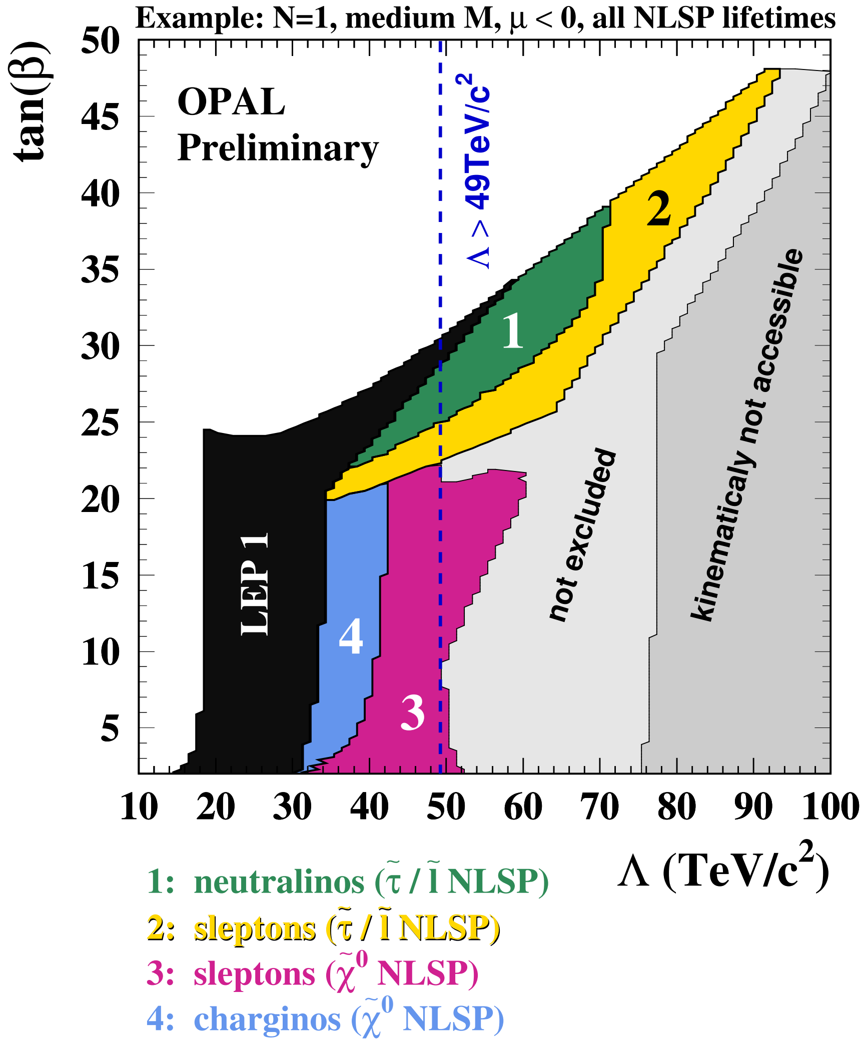


Searches in GMSB SUSY topology

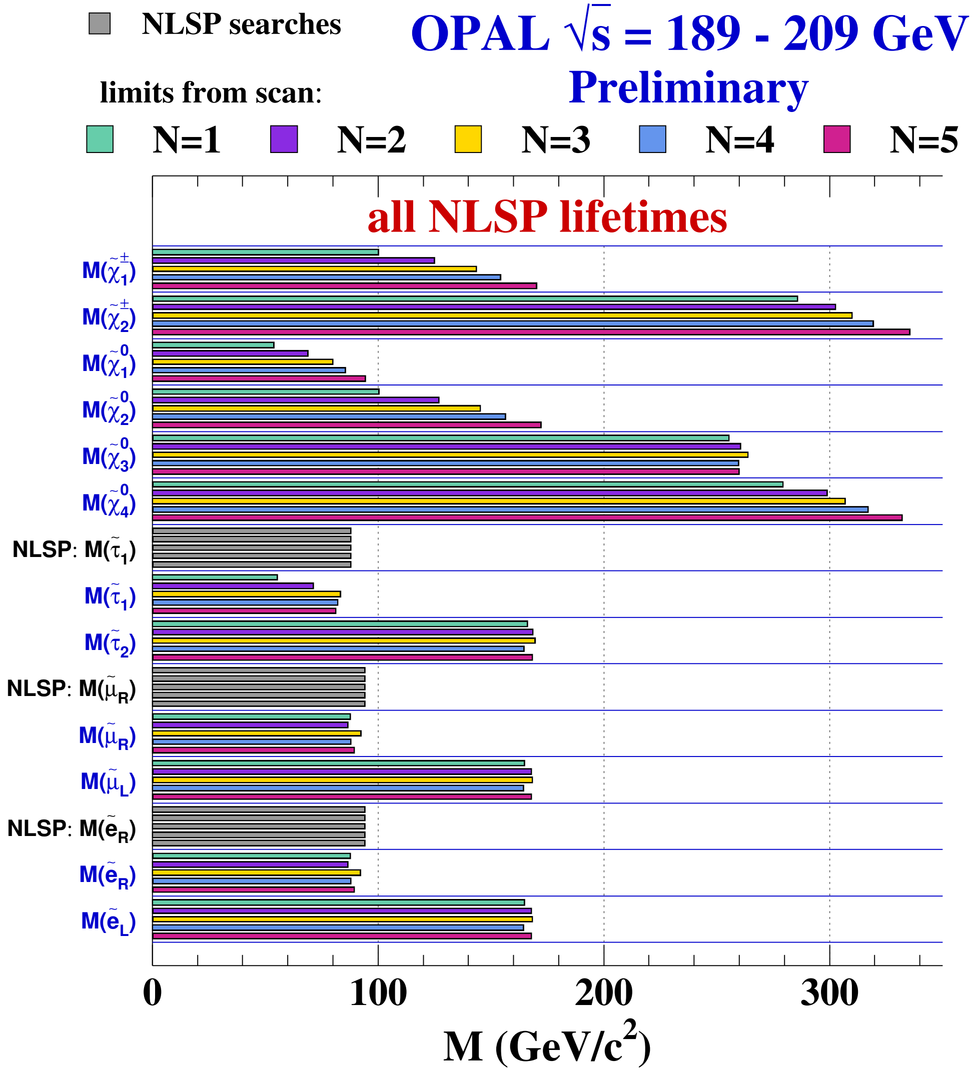
- Scan over GMSB parameter space

$\longrightarrow$limits on the SUSY particle mass scale Λ

Example for a specific parameter set:



- Limit on Λ translated into constraints on the particle masses:



Doubly charged Higgs H^{++}

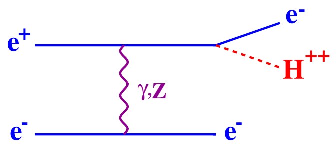
Motivated by

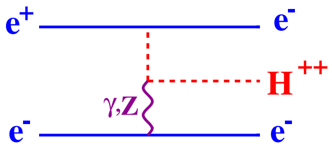
recent report by H1 of an excess of high mass (≈120 GeV) electron pair.

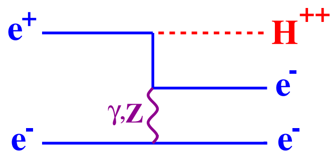
- OPAL search for H^{++} pair production

$\longrightarrow$ has set limit on $M_{H^{++}} > 98.5$ GeV

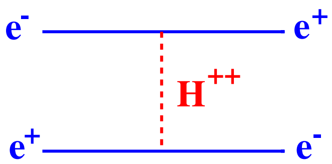
- Here we consider H^{++} single production and extend the accessible mass range







- Also consider effect to $e^+e^- \longrightarrow e^+e^-$



Direct searches

Using OPAL data 189-209 GeV, 600 pb^{-1}

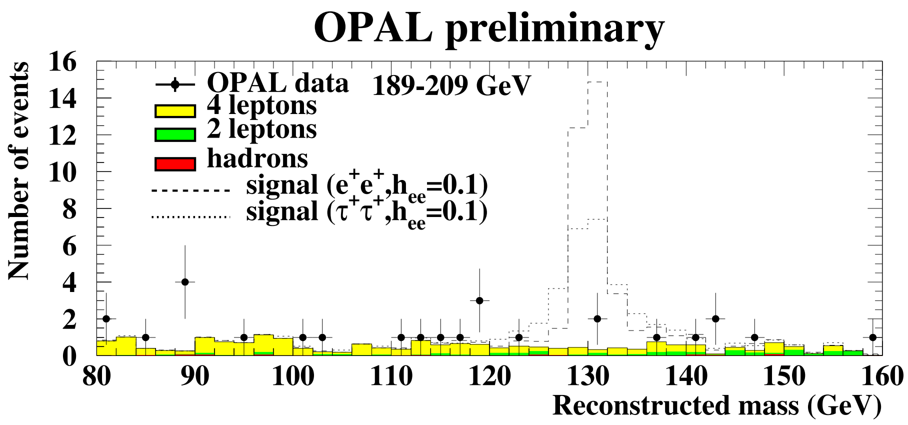
- Search for H^{++} of $M < 160$ GeV

($H^{++} \longrightarrow WW$ rate is unknown)

- Assume H^{++} decays $\ell^+\ell^+$

3 visible leptons in the final states

(lepton flavour blind analysis)



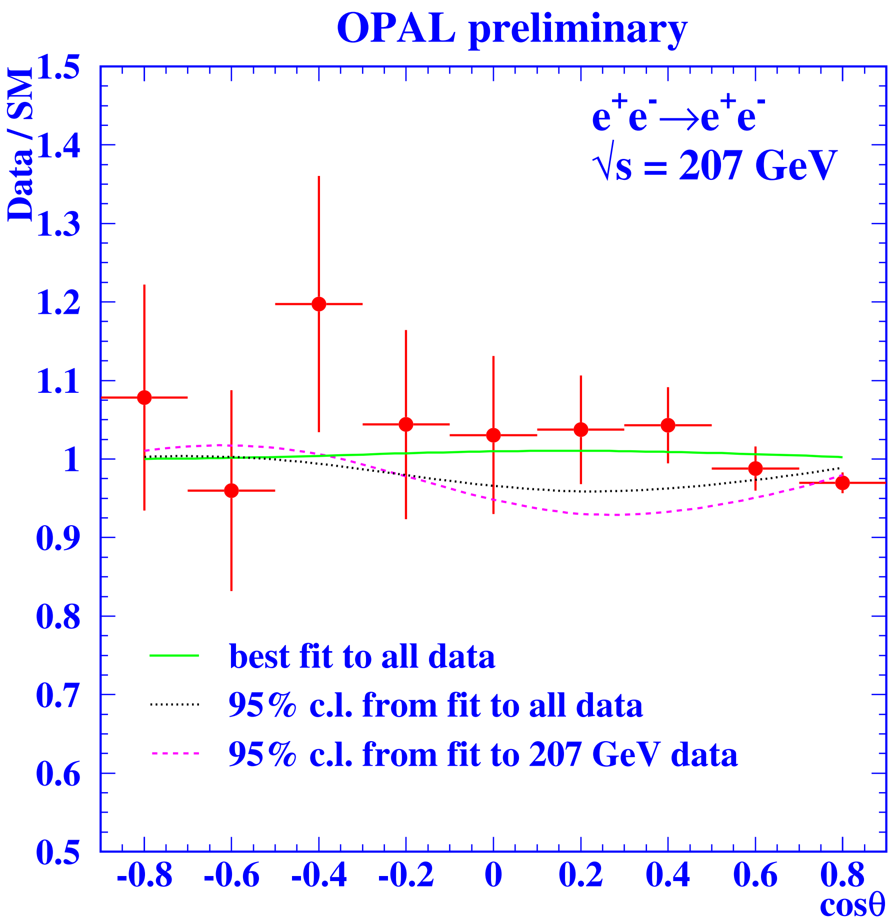
No excess observed

$\longrightarrow$ limit on h_{ee} as a func of $M_{H^{++}}$

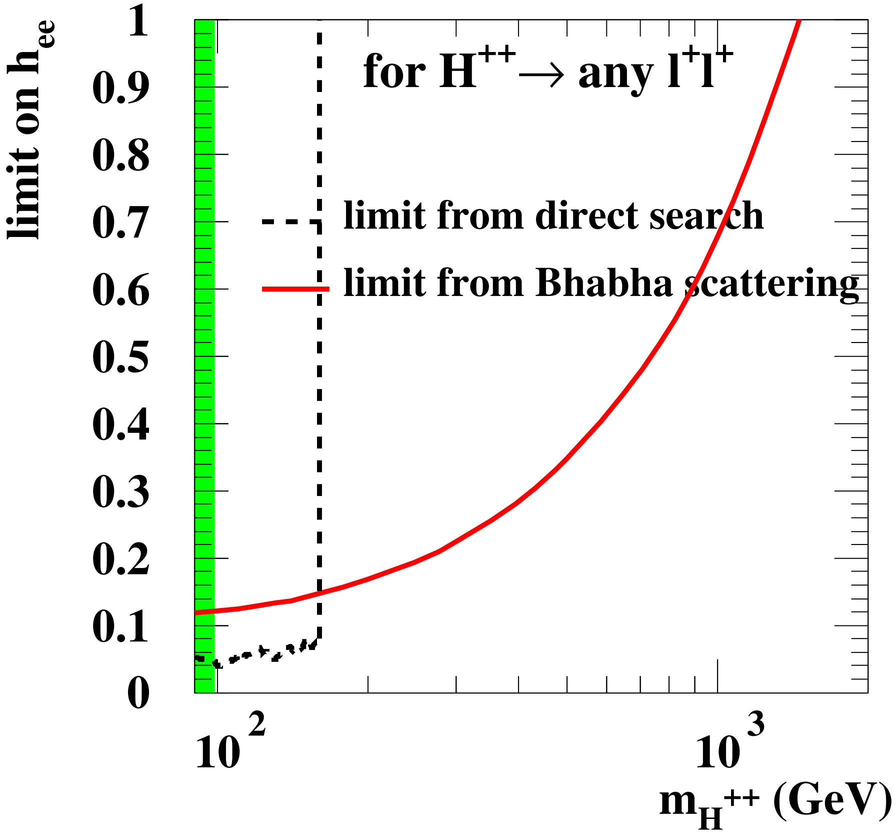
Doubly charged Higgs H^{++}

Indirect limit from $e^+e^- \to e^+e^-$

Analyse deviations from the SM
using OPAL data at 183-209 GeV



Limits in the $h_{ee} - m_{H^{++}}$ plane



Conclusion

Many new results are produced. **New analyses developed.**

More results in the pipeline. **$\approx$ 50 PhD students in OPAL**

Searches

- SM Higgs [final]
- Fermiophobic Higgs $\longrightarrow \gamma\gamma$ [final]
- CP odd Higgs [final]
- Flavour independent Higgs search
- CP violating Higgs
- $H^{\pm}$
- $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, large Δm, small Δm
- $\tilde{t}$, $\tilde{b}$ [final]
- GMSB SUSY
- RPV $\tilde{f}$
- $\ell^{*\pm}$ [final]
- Leptoquark pair production
- Long lived, heavy stable particles
- H^{++} single production

5×10^6 Z

- A_{FB}^{b} jet, vertex, $K^{\pm}$ charge [final]
- Inclusive b fragmentation [final]

QCD

- α_s LEP2
- x_p LEP2 [final]
- n_{ch} LEP2
- $\gamma\gamma \rightarrow p\bar{p}$ LEP2 [final]

LEP2 EW

- NC 4f [final]
- TGC WWγ, WWZ
- QGC NC, CC
- Colour reconnection study
- $e^+e^- \longrightarrow \gamma\gamma(\gamma)$ [final]
- NCQED