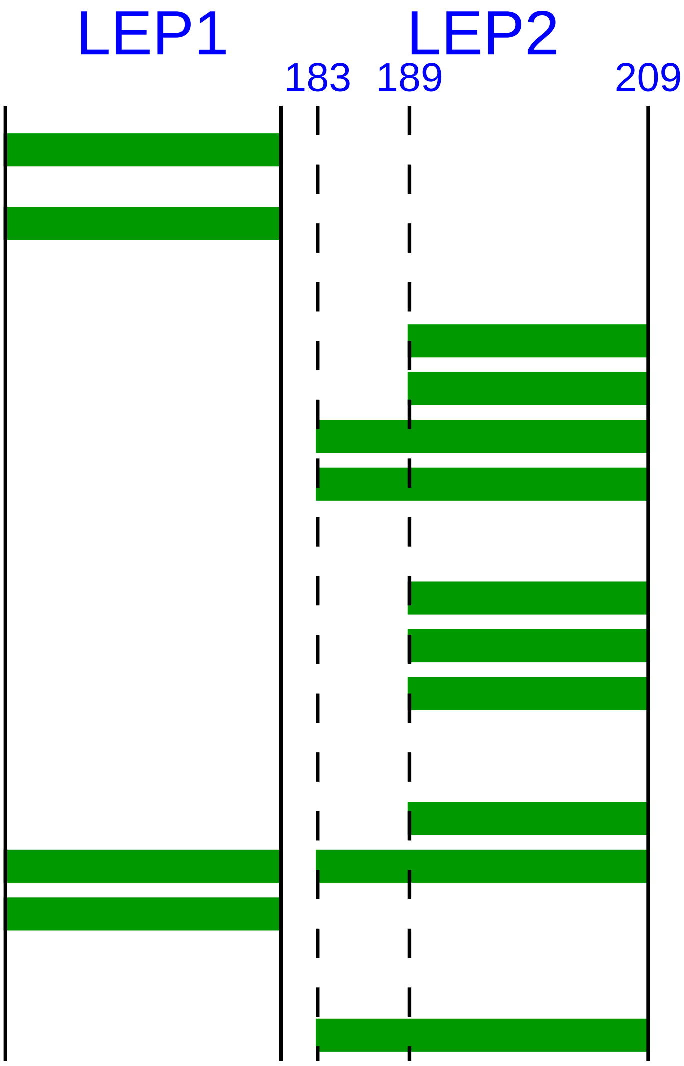
New Results from OPAL

Kirsten Sachs

LEP Physics Jamboree
28 February 2002



particle multiplicities

particle correlations

2photon
- hadronic cross-section
- di-jet production
- structure functions
- Photon production

searches
- single lepto-quark
- single top-quark
- lepton flavour violation

Higgs
- doubly charged
- decay mode independent
- Yukawa production

W mass
- $WW \rightarrow l\nu\, l\nu$

all results with the final data set

Multiplicity of unbiased gluon jets

CERN-EP-2001-076

unbiased: multiplicity in hemisphere

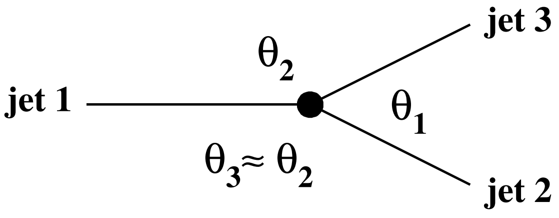
theory: $N_{\mathrm{q\bar{q}}}$ from $\mathrm{q\bar{q}}$-events; N_{gg} from gg-events

exp: $\frac{1}{2} N_{\mathrm{gg}} = N_{\mathrm{q\bar{q}g}} - N_{\mathrm{q\bar{q}}}(L, k_\perp)$; $L \sim s$; $k_\perp \sim p_\perp$

$$N_{\mathrm{q\bar{q}}}(L, k_\perp) = N_{\mathrm{q\bar{q}}}(L') + (L - L') \frac{\mathrm{d}N_{\mathrm{q\bar{q}}}(L')}{\mathrm{d}L'} \; ; \; L' = k_\perp + c_{\mathrm{q}}$$

with $N_{\mathrm{q\bar{q}}}(\sqrt{s})$ $(\mathrm{e^+e^- \to q\bar{q}})$; $\sqrt{s} = 10 - 200$ GeV

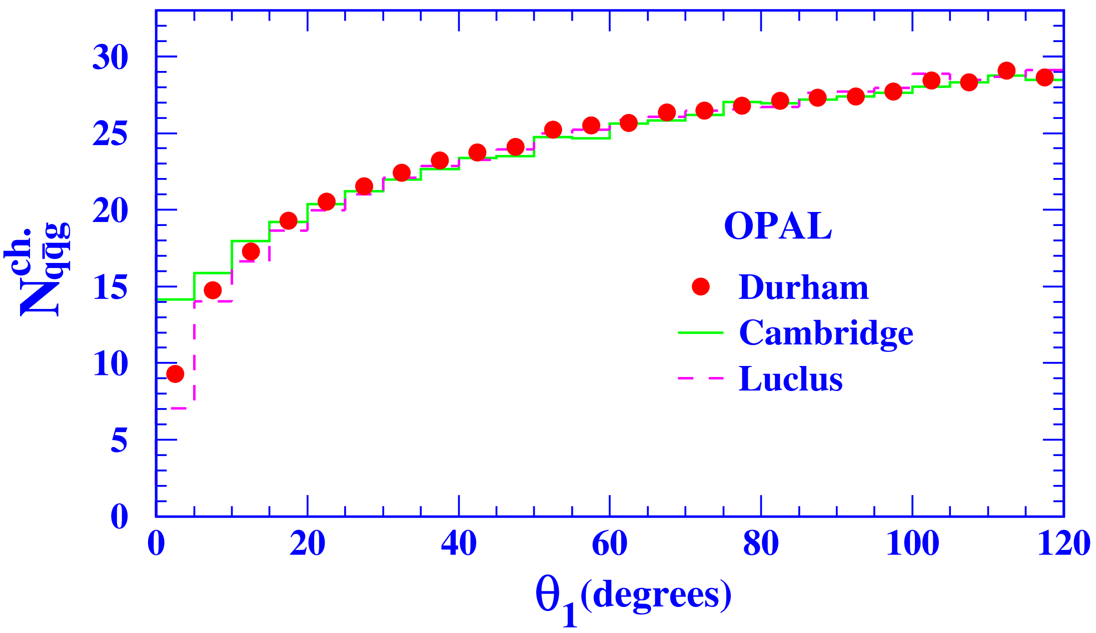
$N_{\mathrm{q\bar{q}g}}$: force events $\to$ 3 jets by adjusting $y_{\mathrm{cut}} (\sim k_\perp)$



uds (massless calculation)

Y-events

$35° < \theta_1 < 120°$

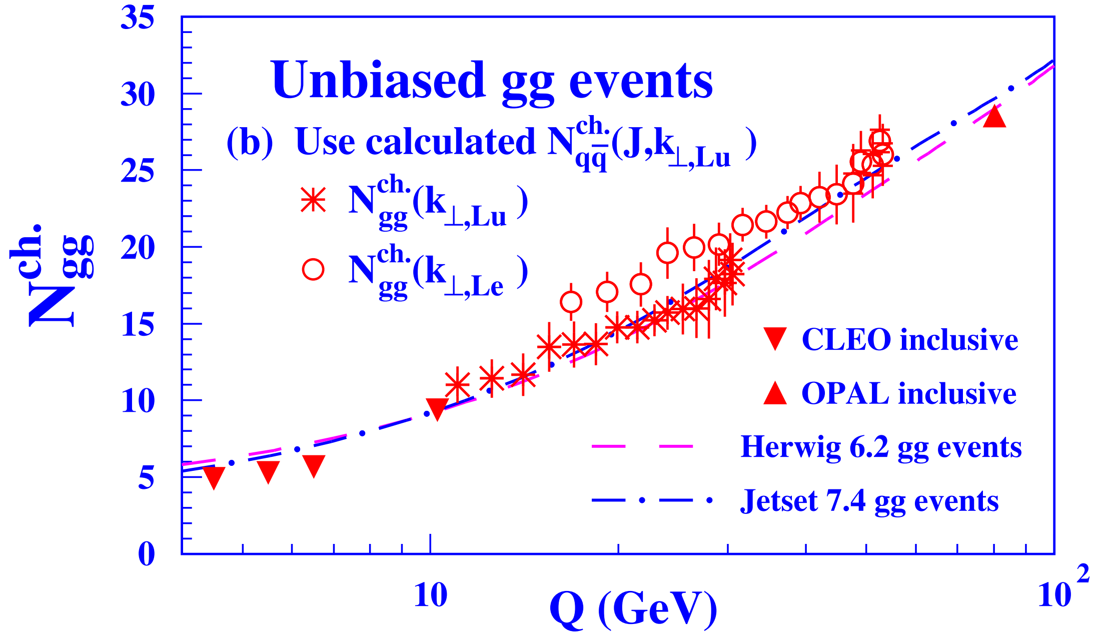


Multiplicity of unbiased gluon jets

$N_{\mathrm{q\bar{q}}}(L, k_\perp)$ with 2 schemes:

Lund: $L = \ln(s/\Lambda^2)$ $\quad p_\perp = \sqrt{\frac{s_{\mathrm{qg}}\, s_{\mathrm{\bar{q}g}}}{s}}$

Leningrad: $L = \ln(s_{\mathrm{q\bar{q}}}/\Lambda^2)$ $\quad p_\perp = \sqrt{\frac{s_{\mathrm{qg}}\, s_{\mathrm{\bar{q}g}}}{s_{\mathrm{q\bar{q}}}}}$



Leningrad too high

Eden & Gustafson:

$$\frac{\mathrm{d}N_{gg}(L')}{\mathrm{d}L} = \frac{C_{\mathrm{A}}}{C_{\mathrm{F}}}\left(1 - \frac{\alpha_0 c_\tau}{L}\right)\frac{\mathrm{d}N_{\mathrm{q\bar{q}}}(L)}{\mathrm{d}L}$$

use this to determine

$$\frac{C_{\mathrm{A}}}{C_{\mathrm{F}}} = 2.232 \pm 0.008 \pm 0.108 \pm 0.082$$

Genuine Correlations

Phys.Lett. B523 (2001) 35

particle correlations in hadronic events

factorial cumulants K_n for n-particle correl.

without random and $n-1$ part $\rightarrow$ genuine

1dim: rapidity y and 3dim: $y \otimes \Phi \otimes \ln p_T$

all-charge / like-sign

increase number of cells M:

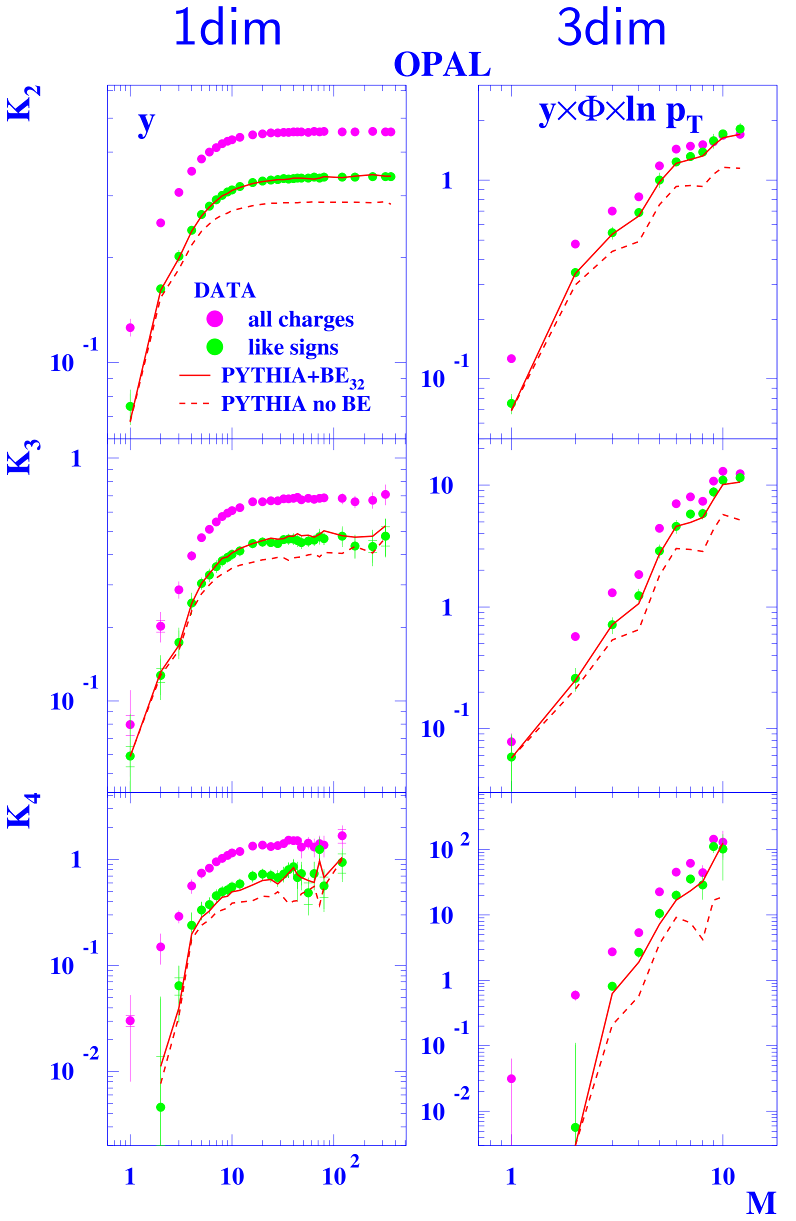
1dim: $K_n \rightarrow$ saturate

3dim: like-sign $\rightarrow$ all-charge

more particles $\rightarrow$ large correlations

good description
by PHYTHIA with BEC

study BEC models use for W-mass



Genuine Correlations

Ochs-Wosiek relation:

hierarchy for

$K_2 \leftrightarrow K_3$ and $K_2 \leftrightarrow K_4$

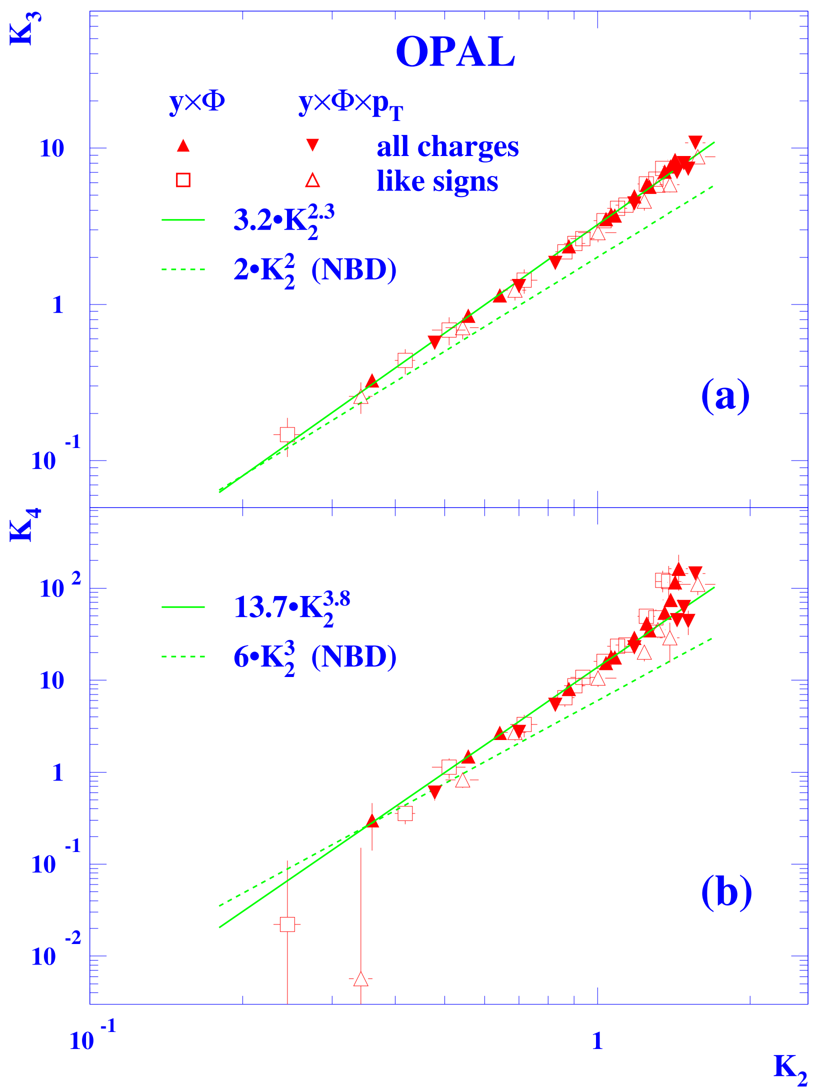
$\Rightarrow$ same mechanism ?

for $K_2 \rightarrow K_3 \rightarrow K_4$

same relation for all-charge and like-sign

$K_n = (n-1)!\,K_2^{n-1}$ (NBD)

$K_n = a_n \cdot K_2^{r_n}$ fit $\rightarrow$ determine a_n, r_n



Correlations between Antiprotons

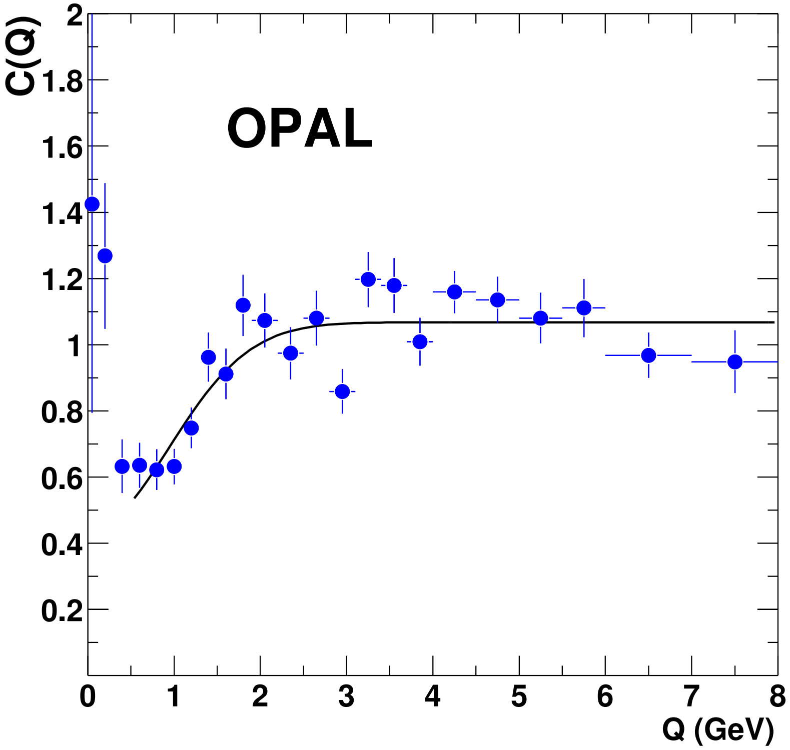
PR to come soon

Antiprotons instead of Protons
because of background

two-particle correlation function: $C(Q)$
based on phase-space density
with $Q^2 = M^2 - 4m^2$
masses: m: proton; M: $\bar{p}\bar{p}$-system

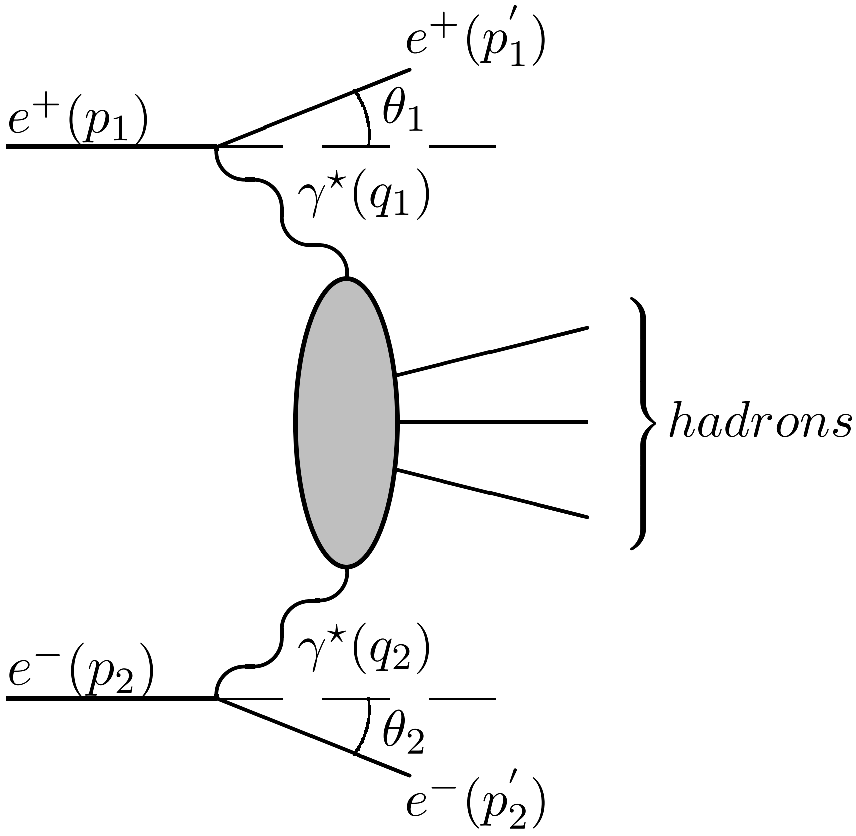
normalised by Monte Carlo (Jetset)
cross-checked with data mixed events

Fermi-Dirac correlation leads to depletion
$C(Q) = \mathcal{N}[1 - \lambda \exp(-R^2 Q^2)]$
for spin $\frac{1}{2}$: $\lambda = 0.5$



$C(Q)$ rises at very small Q:
possibly $\bar{p}\bar{p}$ final state interaction

2Photon Physics – Kinematics



$\boldsymbol{W}$: inv. mass of had. system

$$Q_{\rm i}^2 = -q_i^2 = -(p_{\rm i} - p_{\rm i}')^2$$

large $Q^2 \longrightarrow$ electron in detector (tagged)

$\longrightarrow$ determine Q^2 from electron angle

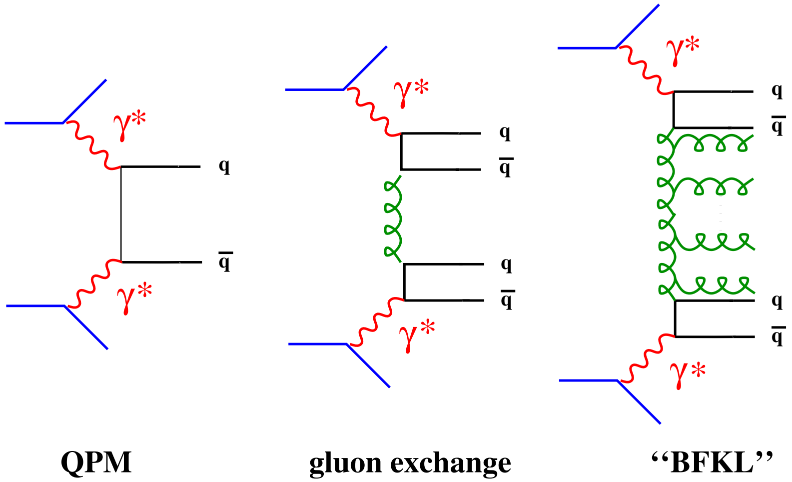
$\gamma\gamma$: untagged; $\gamma^*\gamma$: single tagged; $\gamma^*\gamma^*$ double tagged

Bjorken scale variables for deep inelastic scattering:

$$x = Q^2/2(p{\cdot}q) \quad ; \quad y = (p{\cdot}q)/(p{\cdot}k)$$

Hadronic Cross-Section in $\gamma^*\gamma^*$ Scattering

CERN-EP-2001-064



$\overline{Y} = \ln\left(W^2/\sqrt{Q_1^2 Q_2^2}\right)$

$\sim$ 'length of the gluon ladder'

PHOJET: dual parton model

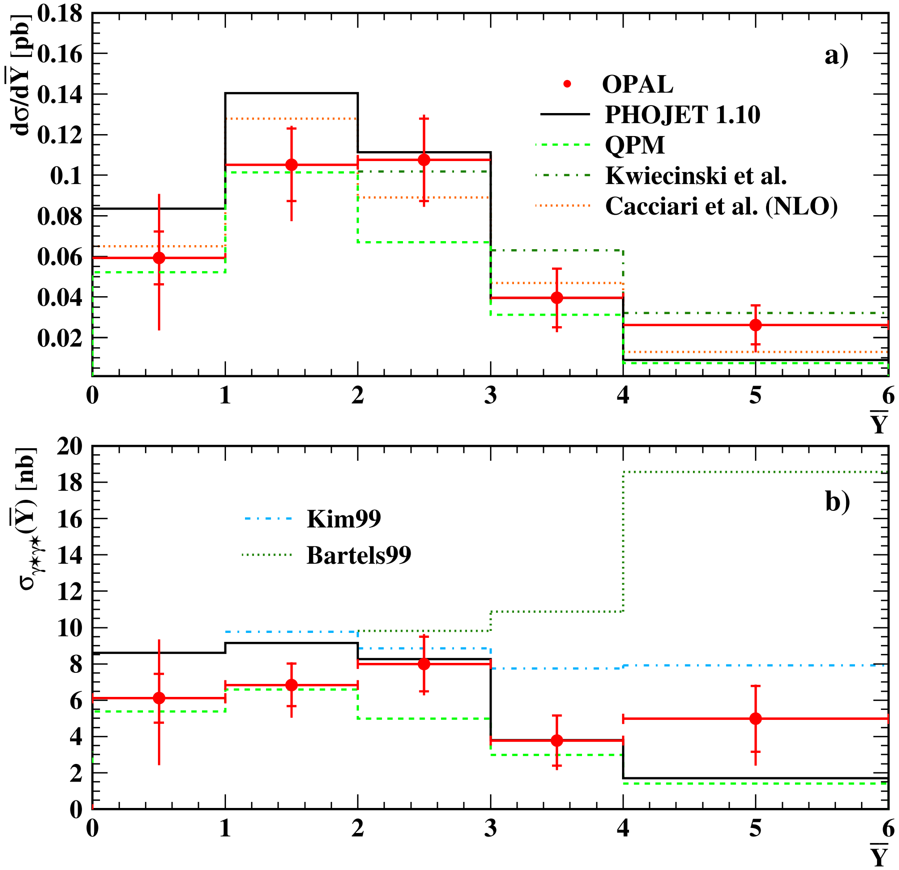
Quark Parton Model

NLO (massless quarks)

BFKL model: LO (Bartels)

NLO (Kim) HO (Kwiecinski)

$Q_1^2 \sim Q_2^2$; $\langle Q^2 \rangle = 17.9$ GeV^2



BFKL effects expected at large $\overline{Y}$

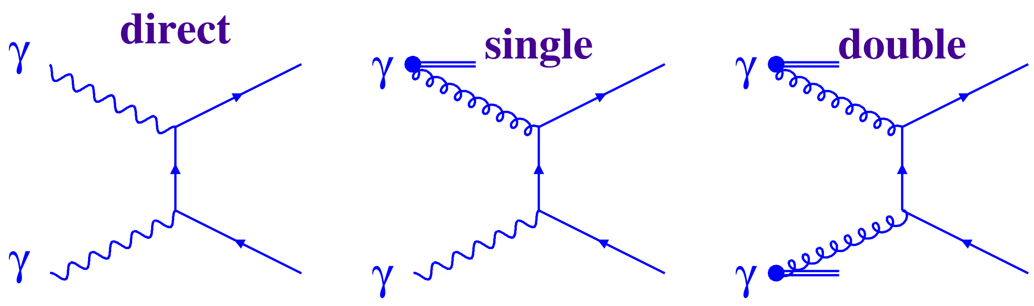
Di-Jet Production in $\gamma\gamma$ Scattering

OPAL-PN491

distinguish direct / resolved process

x_γ: momentum fraction in hard scattering

$x_\gamma > 0.75$: direct , $x_\gamma < 0.75$: resolved

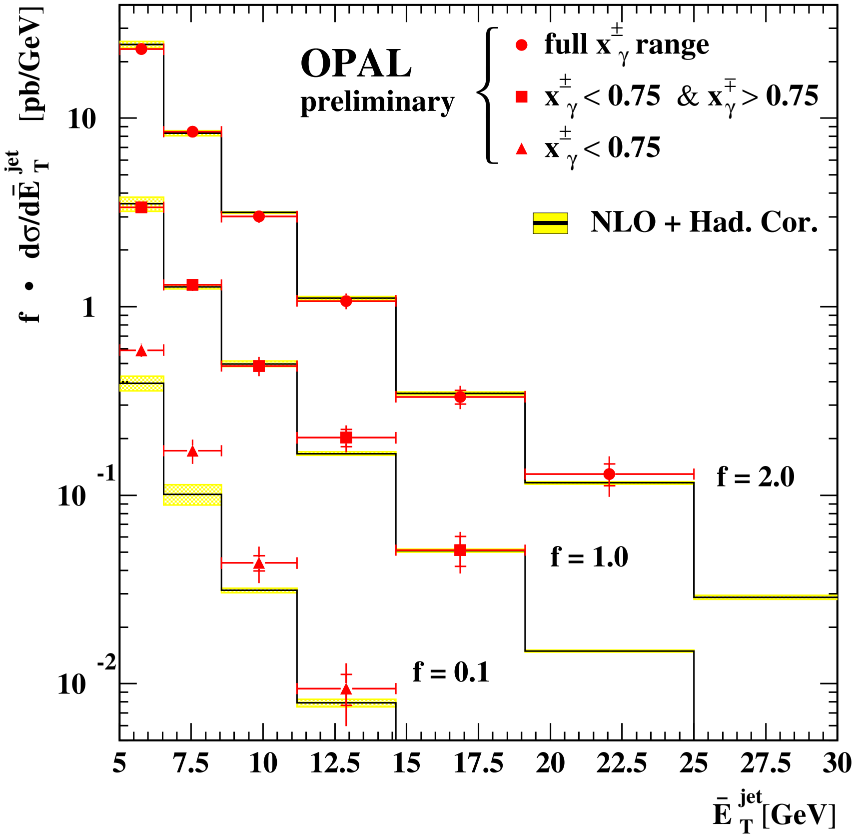


- full x_γ range
- $x_\gamma^\pm < 0.75$ & $x_\gamma^\mp > 0.75$ mainly single resolved
- $x_\gamma^\pm < 0.75$ mainly double resolved

NLO QCD: no underlying event

resolved process → underlying event

corrected transverse jet energy



new NLO calculation: Klasen etal.

EPJ direct C1 (1998) 1. and priv.comm.

Di-Jet Production in $\gamma\gamma$ Scattering

PYTHIA: incl. underlying event via multiple parton interaction (MIA)

MIA on/off $\rightarrow$ underlying event

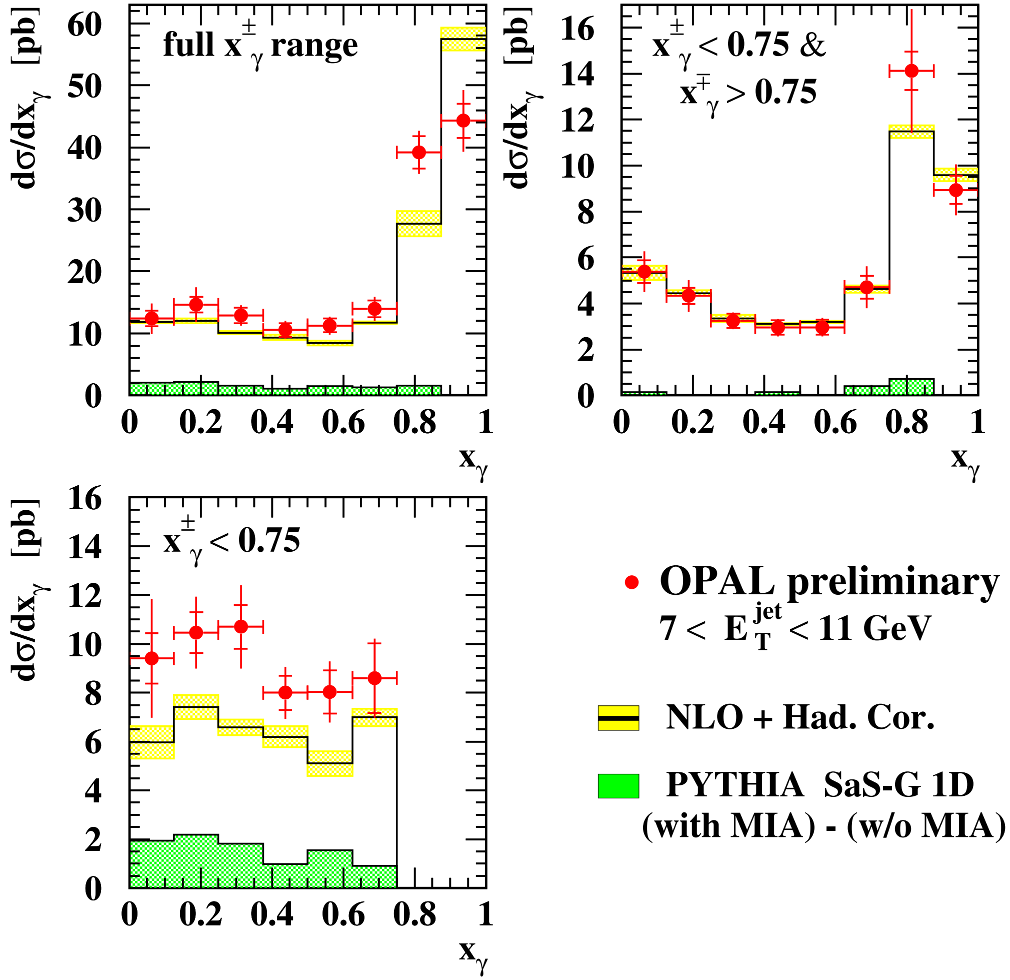
MIA small for direct and single resolved process

strong effect from MIA for double resolved events

single resolved enhanced:

MIA suppressed and

data are well described by NLO



Hadronic Photon Structure Function F_2^γ

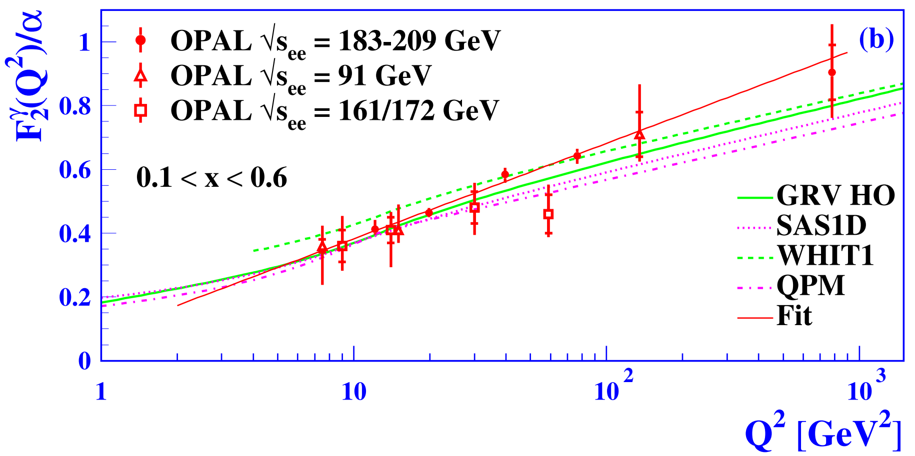
CERN-EP-2002-014

EPA: $$\frac{d^2\sigma_{e\gamma\to eX}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[(1+(a-y)^2)F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

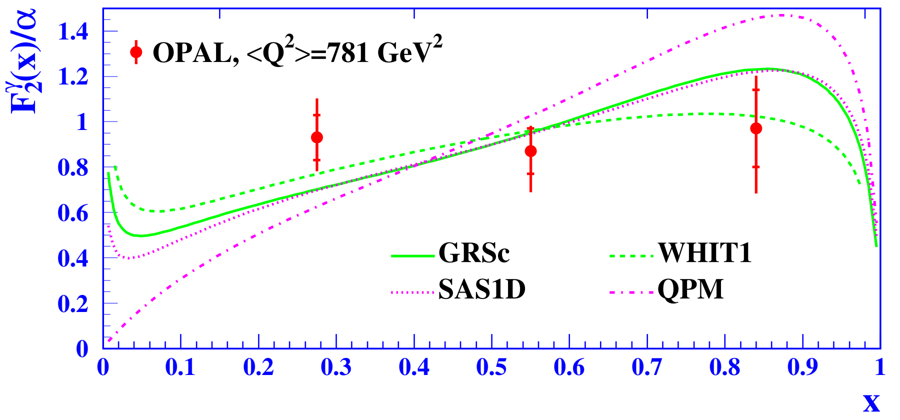
measure cross-section for $\gamma^*/\gamma \to$ unfolding $\to$ extract F_2^γ

unfolding: need good Monte Carlo description (low x – 'underlying event')

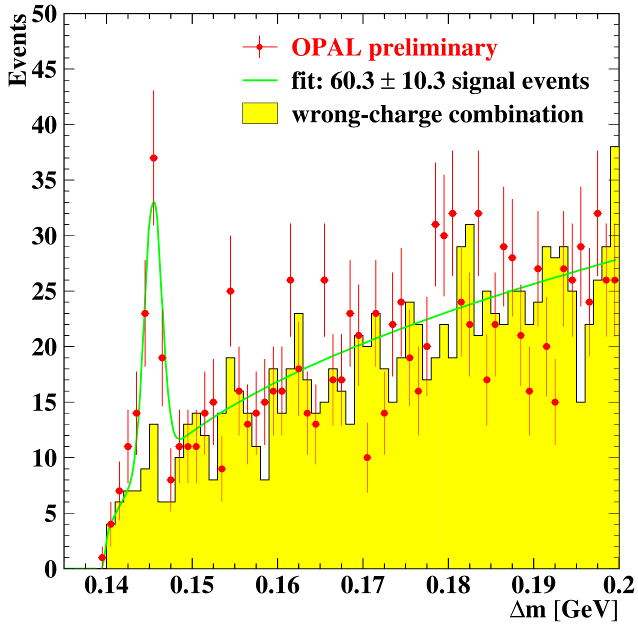
QPM: only point-like component ('direct process')



highest $\langle Q^2\rangle = 781$ GeV^2



Charm Structure Function $F_{2,c}^{\gamma}$



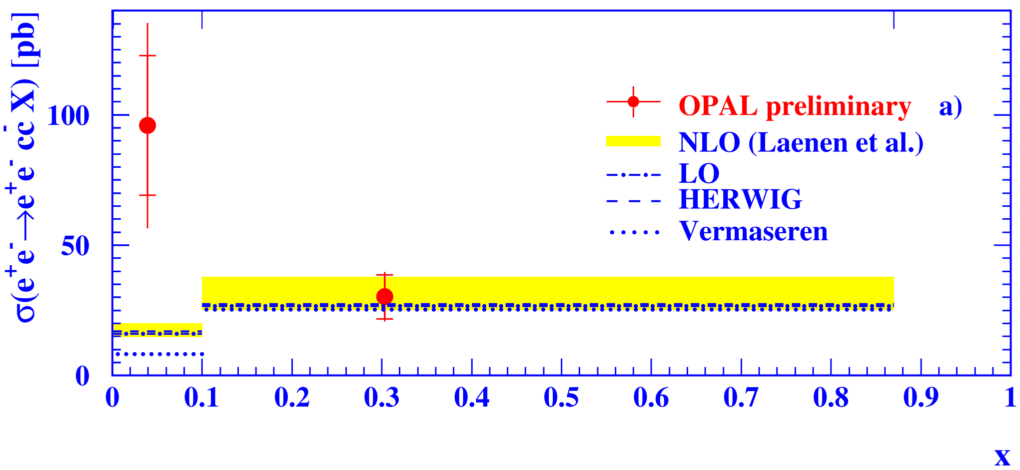
OPAL-PN490

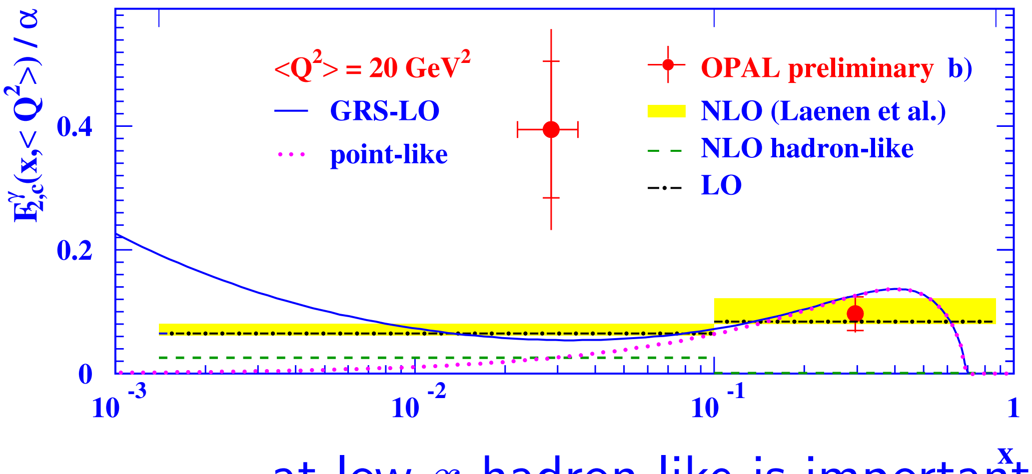
large scale (m_c)

$\gamma^*\gamma \rightarrow \mathbf{D}^* X$

exclusive reconstruction of D^* meson

mass difference $\Delta m = m_{\mathrm{D}^*} - m_{\mathrm{D}^0}$



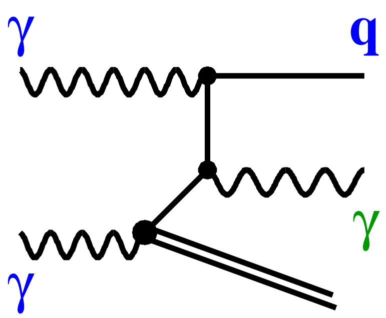


at low x hadron-like is important

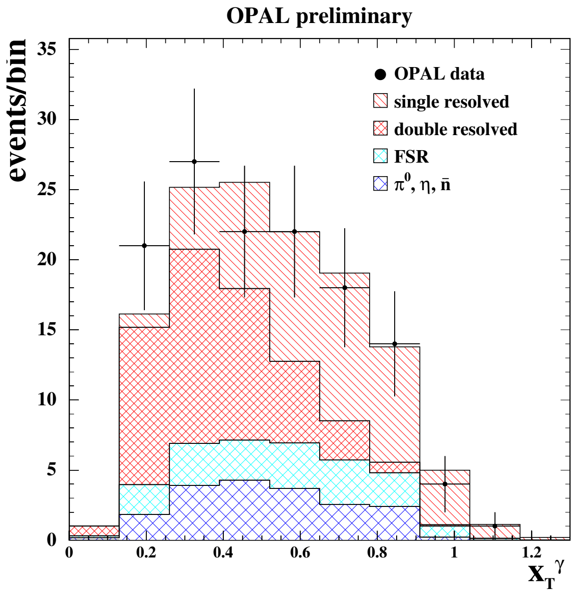
Prompt Photon production in $\gamma\gamma$ Scattering

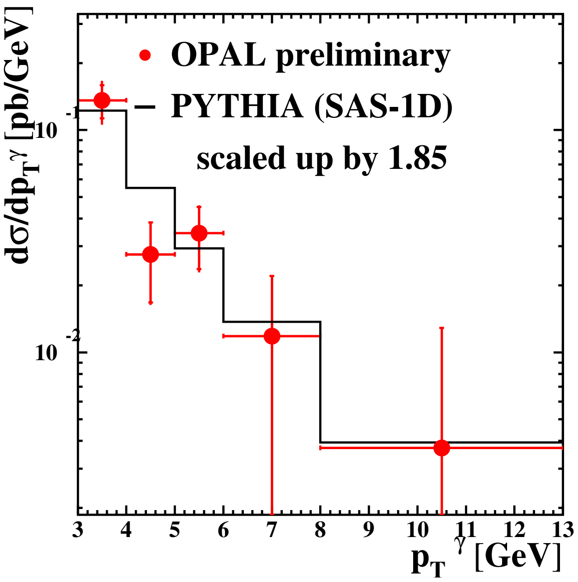
OPAL-PN492

photon production only from single/double resolved processes



different x_{T} distributions





determine from data

ratio $r =$ single/all

$r = 0.50 \pm 0.07$

PYTHIA is scaled up

shape is described well

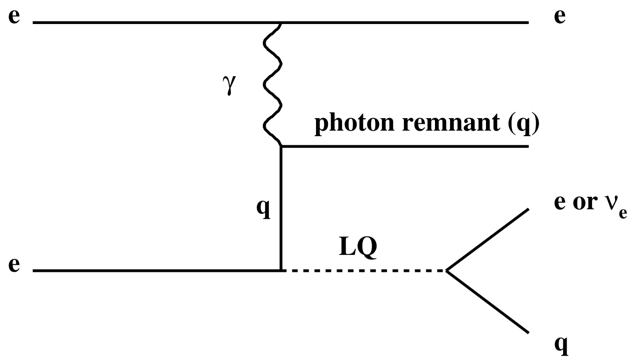
PYTHIA:

single : double $= 20 : 1$

Single Lepto-Quark Production

CERN-EP-2001-093

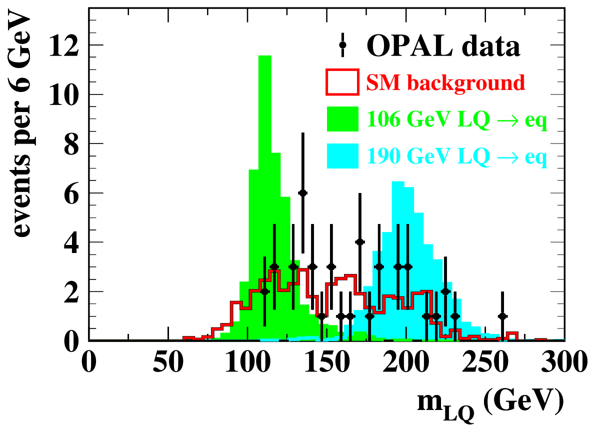
LQ at LEP: pair produced ($M_{\mathrm{LQ}} < \sqrt{s}/2$) ‘classical search’
indirect: $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}$ (t-channel) ‘deviation from SM’



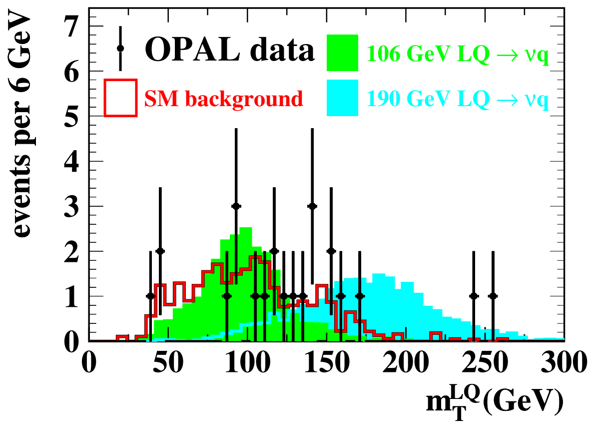
resolved $\gamma\,\mathrm{e}$ scattering

visible:
LQ decay products:
e or ν + jet

strong limits
on couplings
from HERA ⇒
topological search



$\mathrm{LQ} \to \mathrm{e\,q}$
data: 43
MC: 44.7



$\mathrm{LQ} \to \nu\,\mathrm{q}$
data: 25
MC: 26.7

Single Top Production
Phys.Lett. B521 (2001) 181

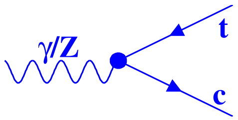
189 - 209 GeV sufficient for single top $M_{\mathrm{t}} =$ 174.3±5.1 GeV $\mathcal{L} =$ 0.6 fb

single $\mathrm{W} \to \mathrm{t\,b}$: $\mathrm{e^+e^-} \to \mathrm{e}\,\nu\,\mathrm{t\,b}$ $\sigma \sim 10^{-4}$ fb

FCNC:

$\mathrm{e^+e^-} \to \mathrm{t\,c}$

$\mathrm{t} \to \mathrm{b\,W}$



via CKM mixing: $\sigma \sim 10^{-9}$ fb

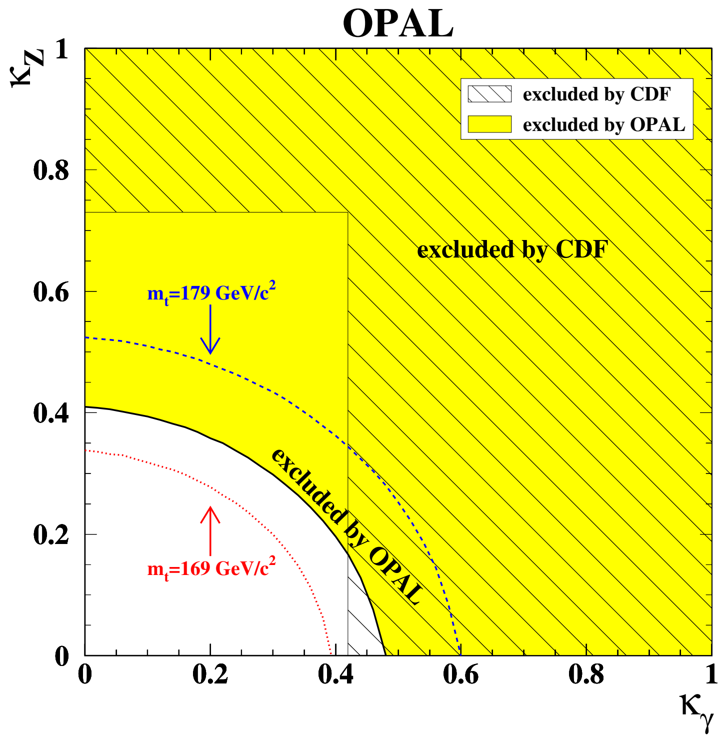
via anomalous couplings: $\sigma =$?

events: 85 selected, 84.1 expected

$\to$ limits

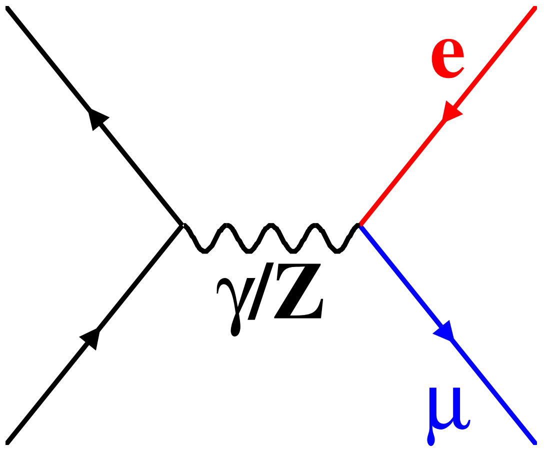
- for each $\sqrt{s}$ on $\sigma <$ 0.24 – 1 pb
- on anomalous couplings: $\kappa_\gamma - \kappa_Z$
- on $\mathrm{BR(t \to Z\,c) + BR(t \to Z\,u)}$
  $\Sigma\mathrm{BR} <$ 13.7% (m_{t} =174.3 GeV)

  CDF: $\Sigma\mathrm{BR} <$ 33%



Lepton Flavour Violation

Phys.Lett. B519 (2001) 23



LFV possible via ν oscillations or SUSY
no measurable effects at LEP2 predicted

search for events with 2 leptons, of different flavour
$\ell\ell'$ in barrel, no additional photons
no missing momentum (apart from τ decay)

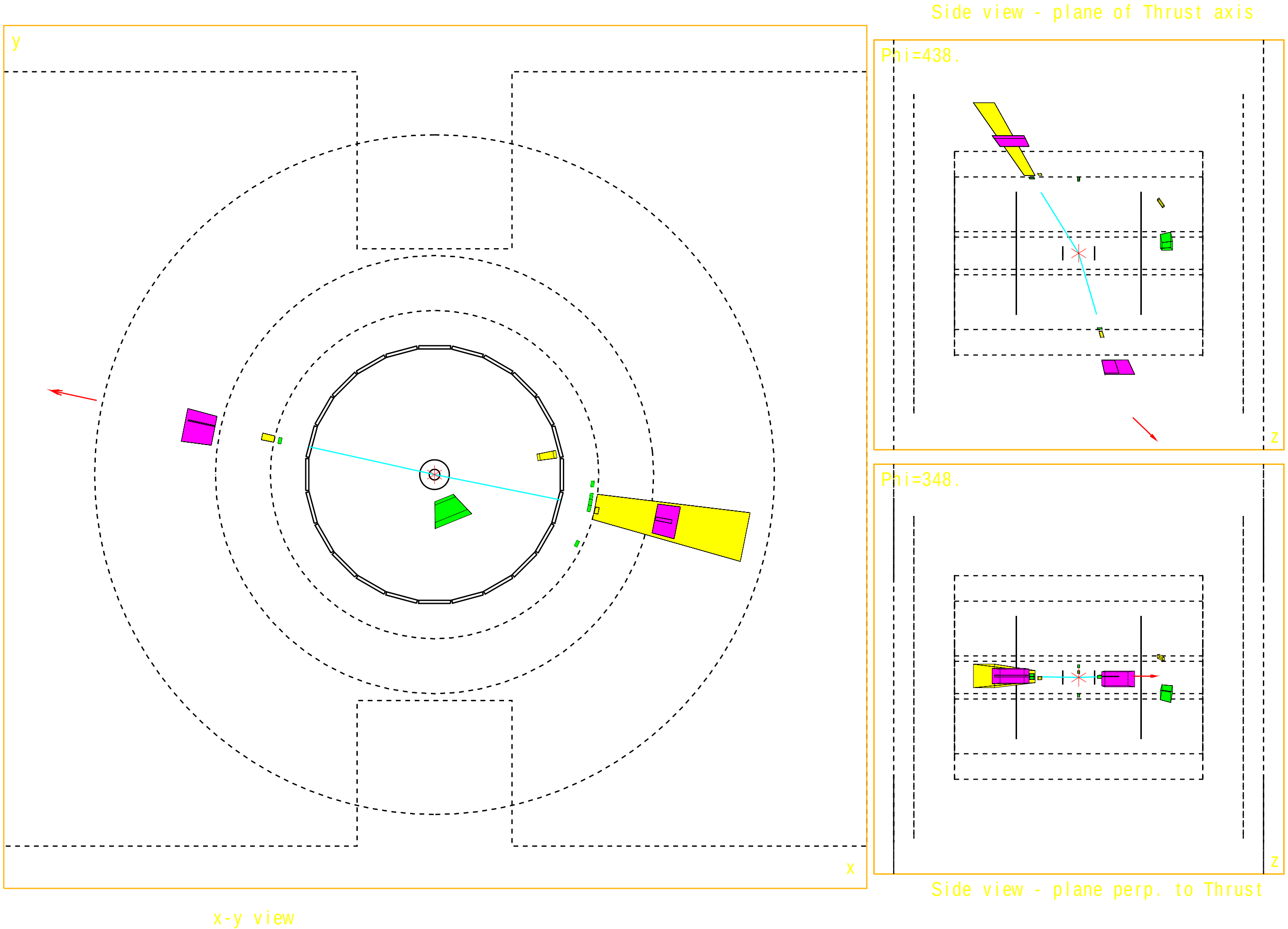
type	ϵ	Data	MC	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$	other
$e\mu$	56%	1	0.019	0	0	0.015	0.004
$e\tau$	24%	5	5.01	4.55	0.02	0.52	0.004
$\mu\tau$	22%	11	14.3	0.02	5.90	8.40	0

1-prong hadron misidentification rate: e: 3% μ: 1.6%

Lepton Flavour Violation

$\mathbf{e}\boldsymbol{\mu}$ candidate

expected BG: 0.019 events



$E_{\mathrm{vis}} = 0.93\sqrt{s}$

$E_{\mathrm{e}} = 0.90 \pm 0.02 \cdot E_{\mathrm{beam}}$; $E_{\mu} = 0.89 \pm 0.11 \cdot E_{\mathrm{beam}}$

$\alpha_{\mathrm{e}\mu} = 165°$; forward cluster: $E = 7.2 \pm 2.5$ GeV

kinematic fit for $\mathrm{e}\,\mu\,\gamma$: P $=$ 41%

Doubly charged Higgs

CERN-EP-2001-082

$e^+e^- \rightarrow H^{++}H^{--}$

$H^{++} \rightarrow \ell^+\ell^+$, $\ell = e, \mu, \tau$

assume short lifetime

large coupling ($h_{\tau\tau} > 10^{-7}$)

predicted by LR models with B/L violation

limits on couplings for:

$H^{++} \rightarrow e^+e^+$ from Bhabhas

$H^{++} \rightarrow \mu^+\mu^+$ from muonium ($\mu^+e^- \leftrightarrow \mu^-e^+$)

$H^{++} \rightarrow e^+\mu^+$ from decays $\mu^+ \rightarrow e^+e^-e^+$

select 2 lepton pairs

data: 28 ; MC: 31.8 events

$\exists$ limits on $\sigma \times \mathrm{BR}$ for all final states

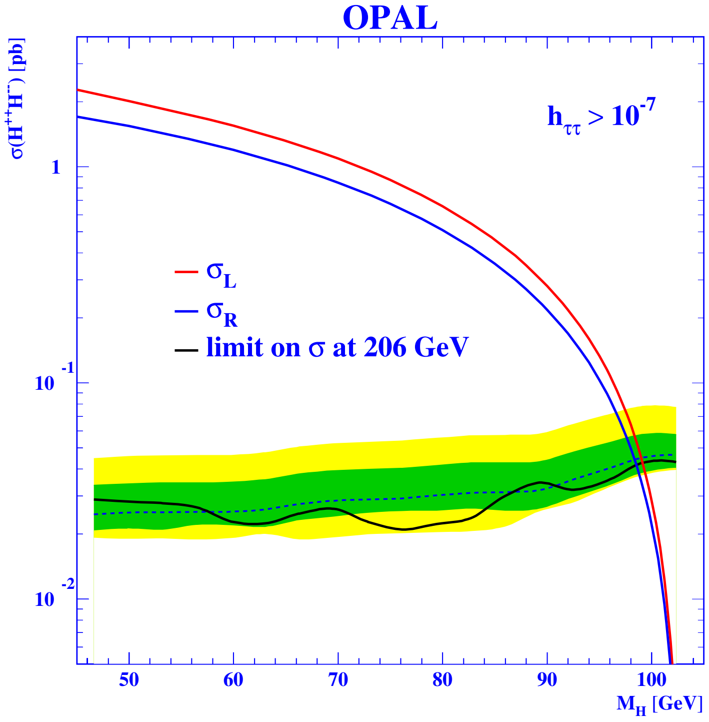
assume $\mathrm{BR}(H^{++} \rightarrow \tau^+\tau^+) = 100\%$

$\Rightarrow$ limit on $\sigma(H^{++}H^{--})$

compare with model

$\Rightarrow$ limit on mass: $H_L^{++} > 99.0$ GeV

$H_R^{++} > 98.5$ GeV



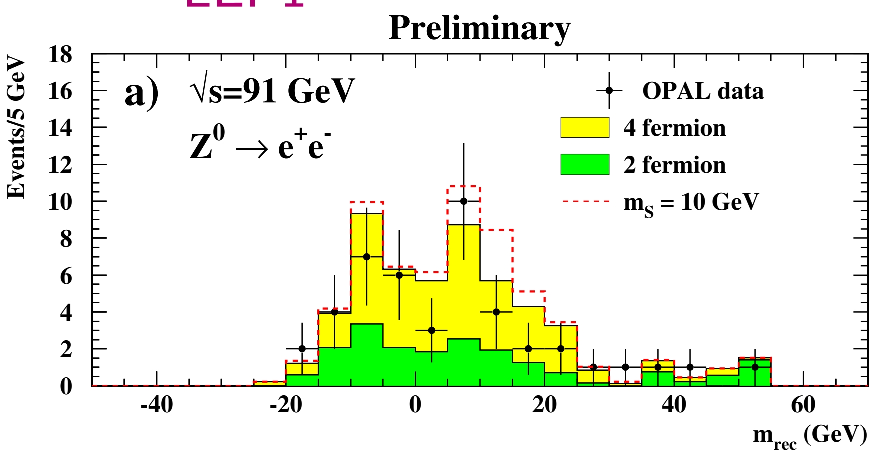
Decay mode independent Higgs ($S^0 \rightarrow X$)

$e^+e^- \rightarrow S^0\,Z$; $Z \rightarrow e^+e^-, \mu^+\mu^-$; S^0: any recoil system OPAL-PN495

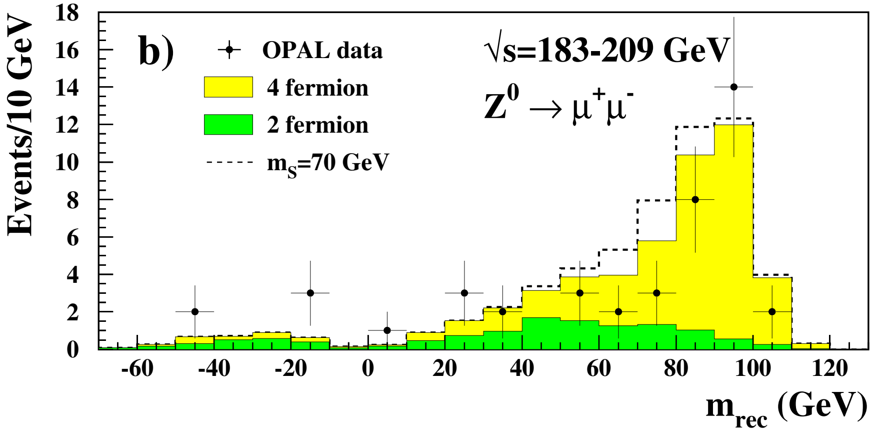
Z: identified lepton pair, mass constraint m_{S^0} = recoil mass

	LEP1		LEP2	
$Z \rightarrow$	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$
data	45	66	54	43
background	55	54	47	52

LEP1



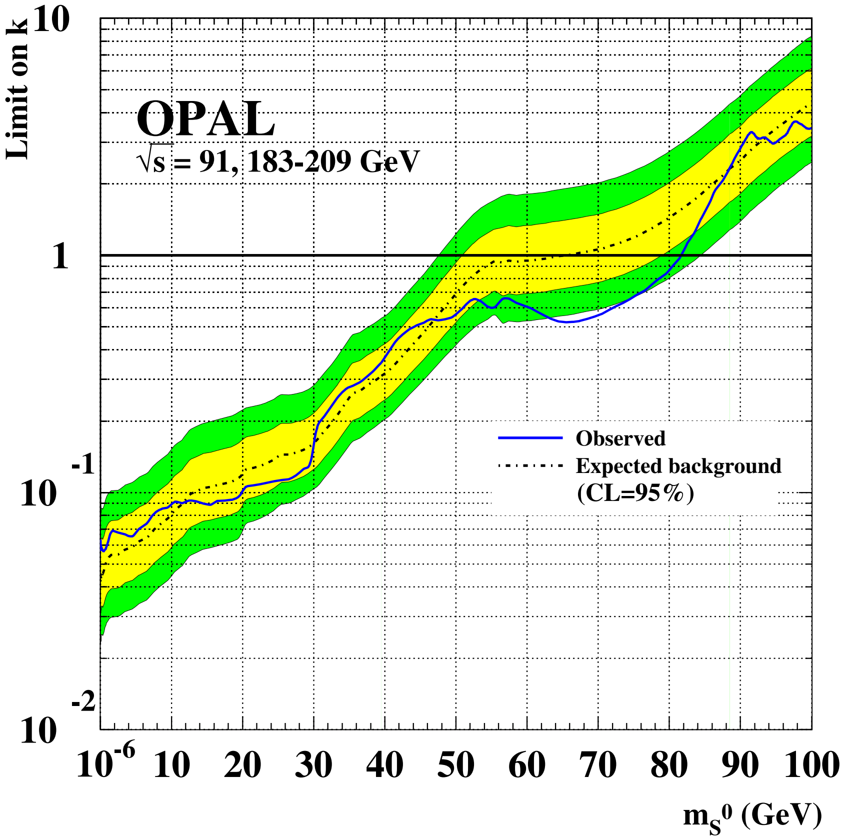
LEP2



Decay mode independent Higgs

single scalar: $\sigma_{\mathrm{S^0 Z}} = k \cdot \sigma_{\mathrm{H_{SM} Z}}$

for $k = 1$: limit on $m_{\mathrm{S^0}} > 81$ GeV



uniform Higgs:

spectrum of scalars $\mathrm{S_i}$: $m_{\mathrm{A}} < m(\mathrm{S_i}) < m_{\mathrm{B}}$

for normalised coupling: limits on mass range

limits for any coupling can be derived

stealthy Higgs: $\mathrm{H} \rightarrow$ phions (invisible)

(Binoth, van der Bij, hep-ph/9908256)

$\rightarrow \Gamma_{\mathrm{H}}$ large, depending on #modes / coupling ω

$\Longrightarrow$ limits on ω vs m_{H}

Yukawa Production of Light Higgs

CERN-EP-2001-077

2HDM type II

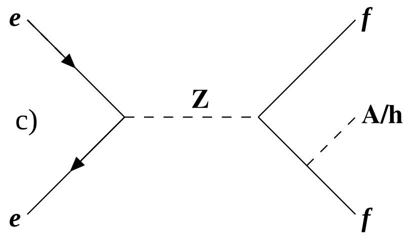
$e^+e^- \rightarrow \mathrm{h\,Z}$ can be small

$$(\sin^2(\beta-\alpha) \sim 0)$$

$e^+e^- \rightarrow \mathrm{h\,A}$ maybe forbidden

$$(m_\mathrm{h} + m_\mathrm{A} > \sqrt{s})$$

$\Rightarrow$ **Yukawa production**:

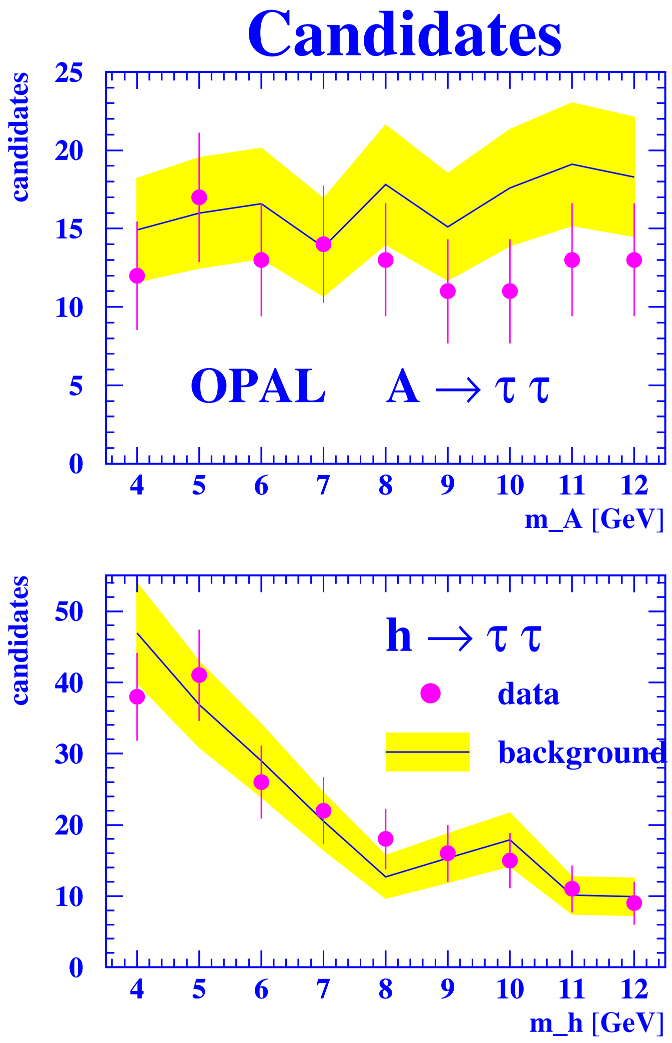


$\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$; $\mathrm{h/A} \rightarrow \tau\tau$

enhance d-coupling ξ_d

$\xi_\mathrm{d}^\mathrm{A} = \tan\beta$

$\xi_\mathrm{d}^\mathrm{h} = -\sin\alpha/\cos\beta$

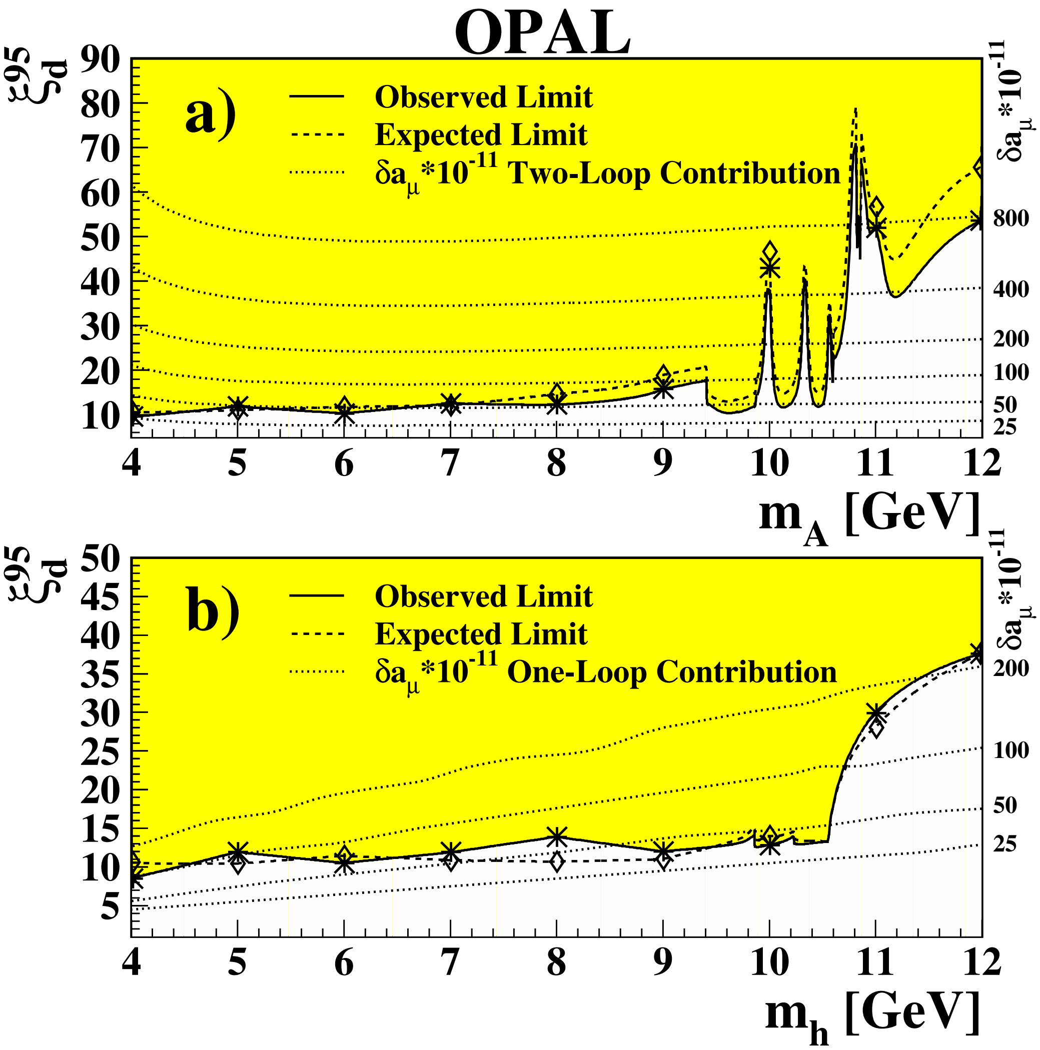


select $\mathrm{b\bar{b}}\,\tau^+\tau^-$ events @LEP1

likelihood selection optimised

for h / A separately

Yukawa Production of Light Higgs



$\mathrm{BR}(\mathrm{h/A} \to \tau\tau) \sim$ 85% for $m < 9.4$ GeV, $\xi_\mathrm{d} \approx 10$
larger masses $\Rightarrow$ mixing $\mathrm{h/A} \leftrightarrow (\mathrm{b\bar{b}})$ bound state

contributions from light Higgs to:
$a_\mu = (g-2)/2: \ a_\mathrm{exp} - a_\mathrm{theo} = (25 \pm 16) \cdot 10^{-10}$

hep-ex/0202024

one-loop < two-loop, and opposite sign;

h and A have opposite sign

W Mass from $\ell\nu\ell\nu$ Events

PR to come soon

limited by statistics

$\mathrm{BR}(\mathrm{W} \to \ell\nu) \approx 10\%$; $\tau\nu$ not used

limited mass resolution due to neutrinos

2 variables are sensitive to m_{W}:

- leptonic energy (2 end points)
- pseudo mass (1 step)

parametrisation from Monte Carlo

simultaneous fit of 3 parameters:

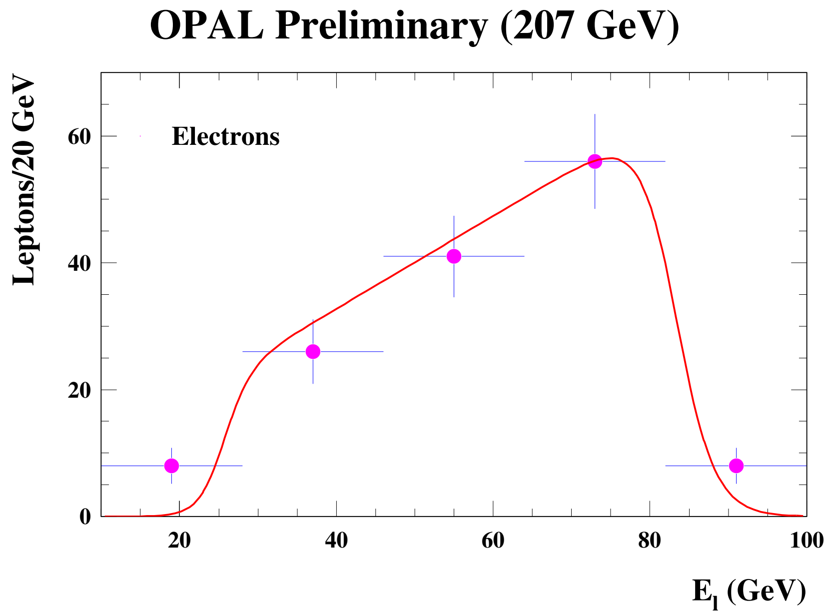
$$m_{\mathrm{W}} = \mathbf{80.43 \pm 0.41 \pm 0.14}\ \mathrm{GeV}$$

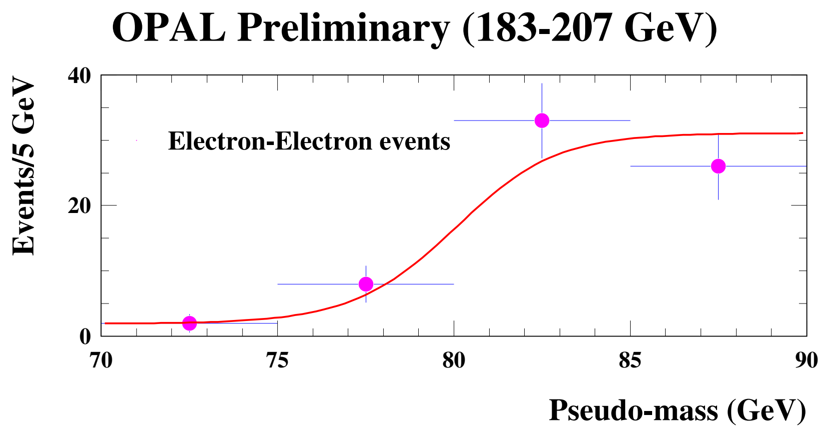
dominated by statistical error

systematic error reducible

$\Rightarrow$ alternative technique

for high luminosity machine





Conclusion

final results arrive using
the full LEP2 data set

many results
still to come

this is only the
tip of the iceberg

stay tuned