

# L3 Physics Results

Arno Straessner  
CERN

on behalf of the L3 Collaboration

- Searches For New Particles
- Z-Peak Data Analyses
- Two Photon Physics
- W and Z Bosons
- Data Archiving

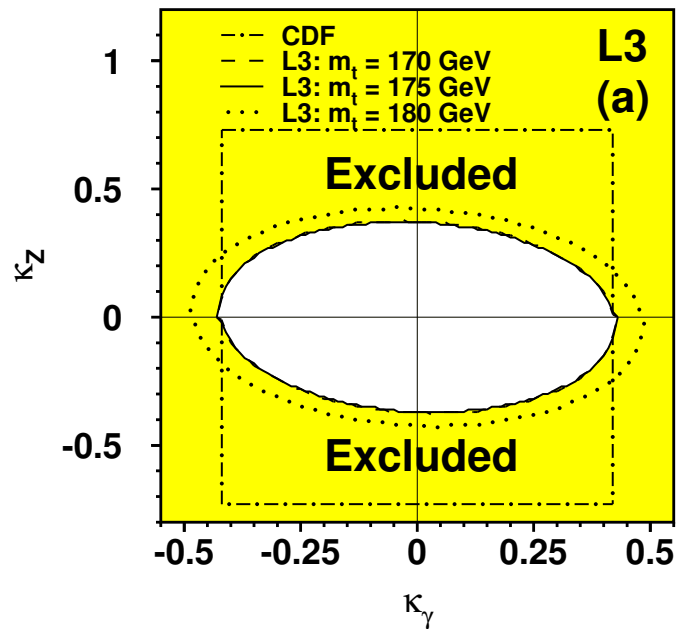
LEP Jamboree

March 6, 2003

# Searches For New Particles

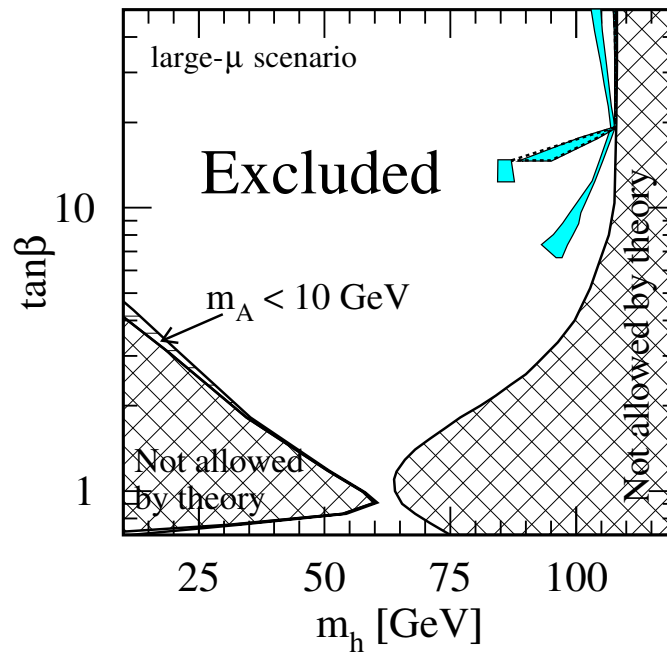
(all limits at 95% CL)

## • Single Top Production



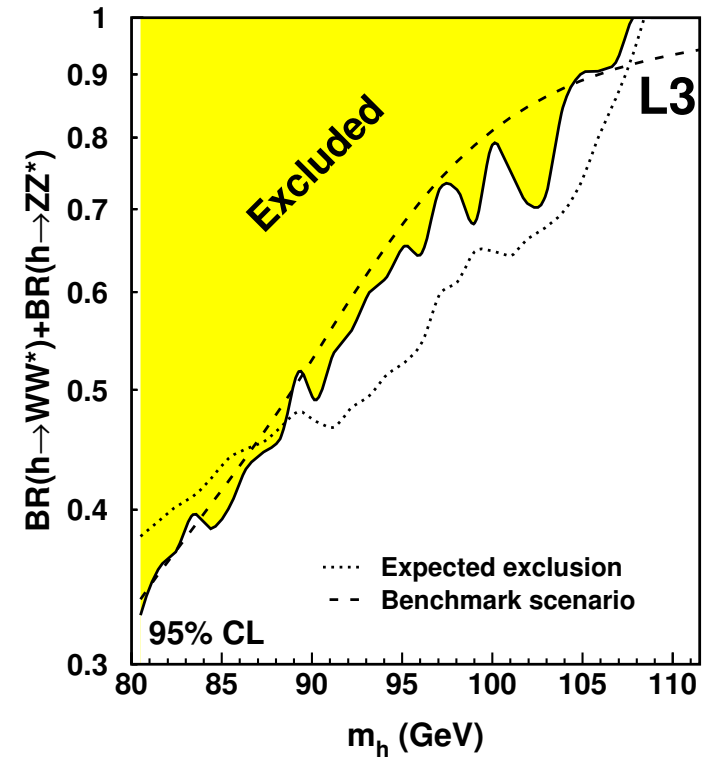
PLB 549 (2002) 290

## • MSSM Higgs Bosons



PLB 545 (2002) 30

## • $h \rightarrow WW^*/ZZ^*$

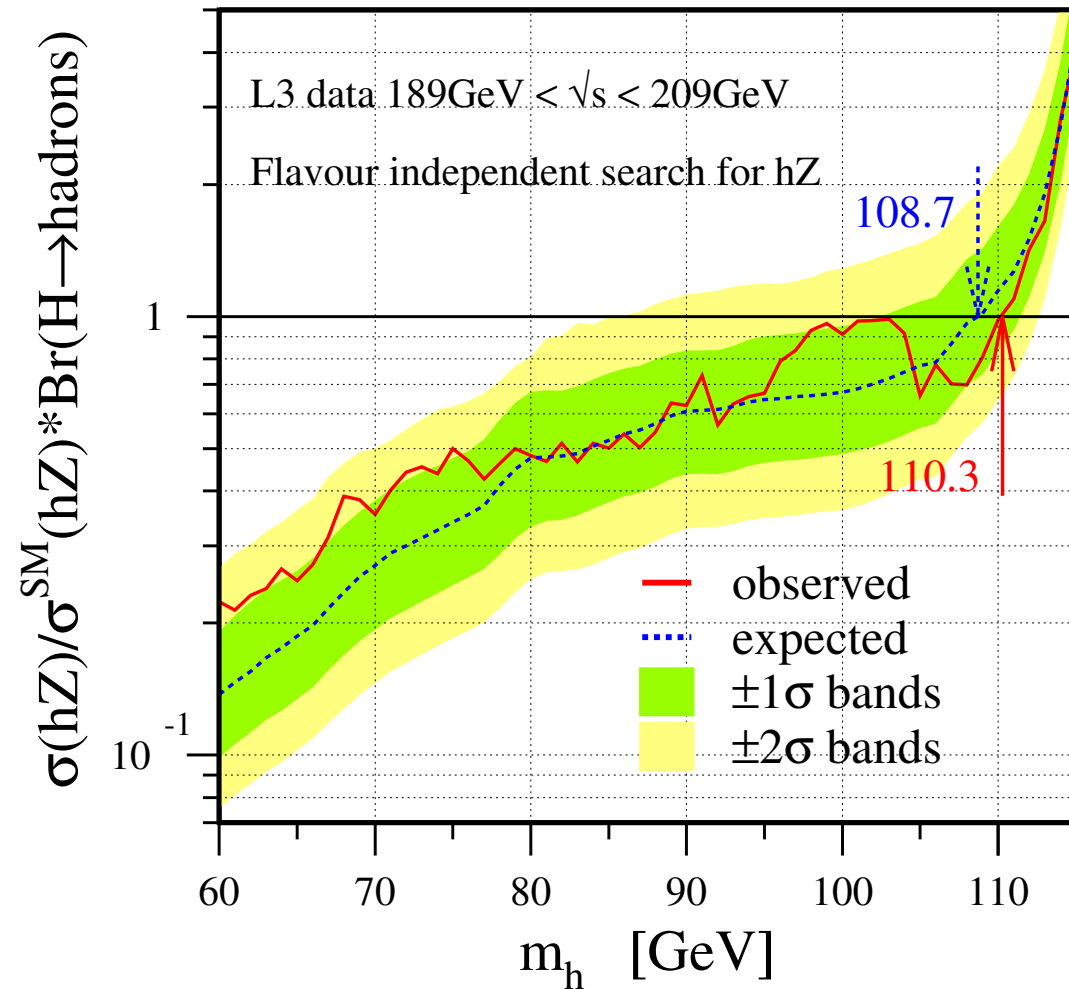
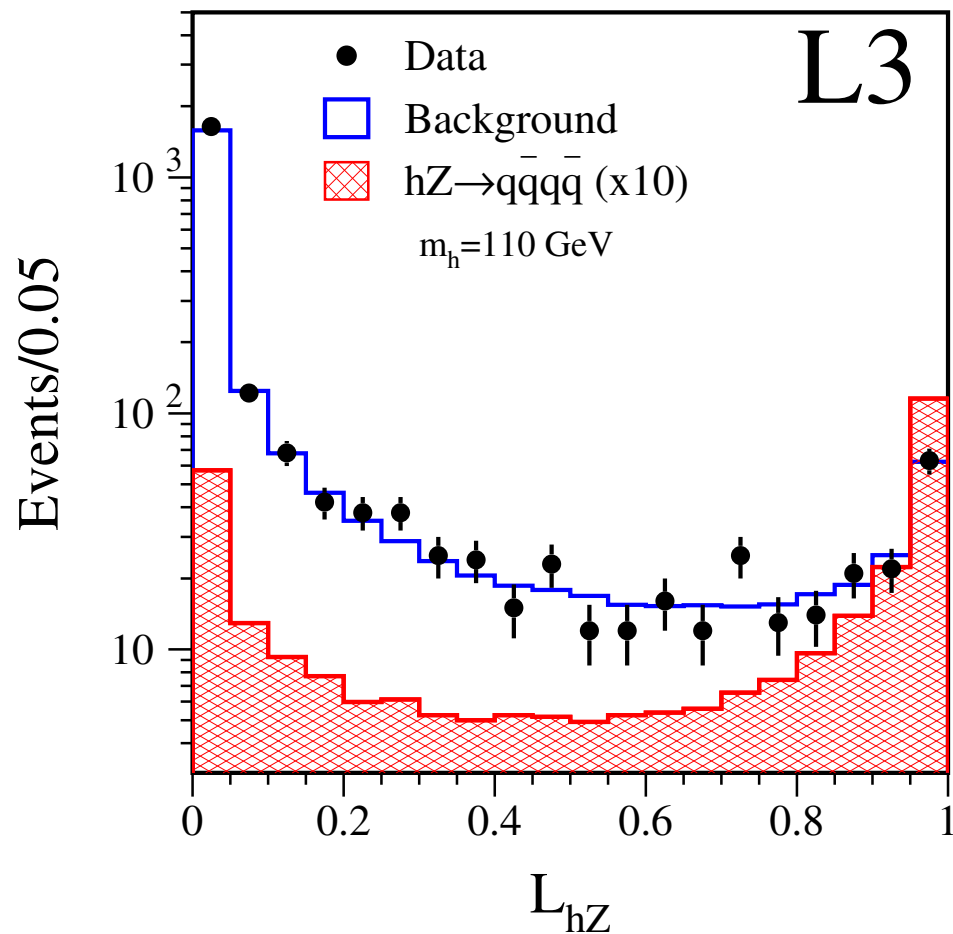


CERN-EP/2002-080

# Flavour Independent Higgs Search

- Search for hadronic decays of the Higgs boson without assuming dominating  $b\bar{b}$  decay → no b-tag applied
- Production cross section  $\sigma_{hZ} = \xi^2 \sigma_{HZ}^{SM}$

- No excess in data observed
- Derive exclusion limits:

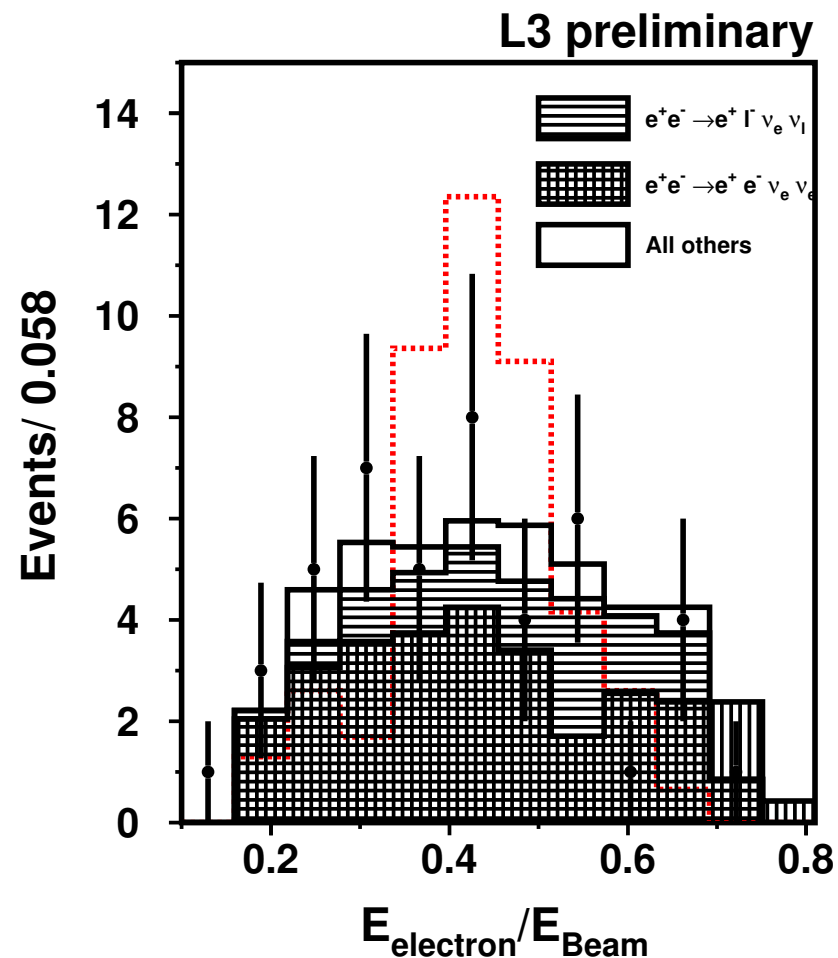


- for  $\sigma_{hZ} = \sigma_{HZ}^{SM} \rightarrow m_h > 110.3$  GeV

# Search for Scalar Electrons

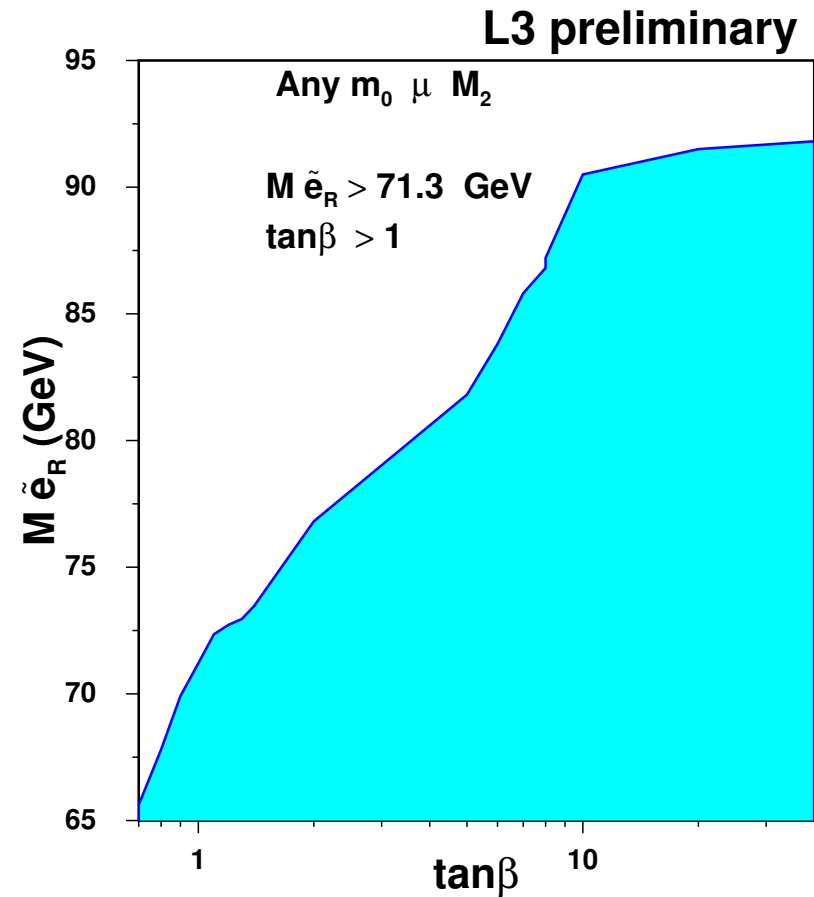
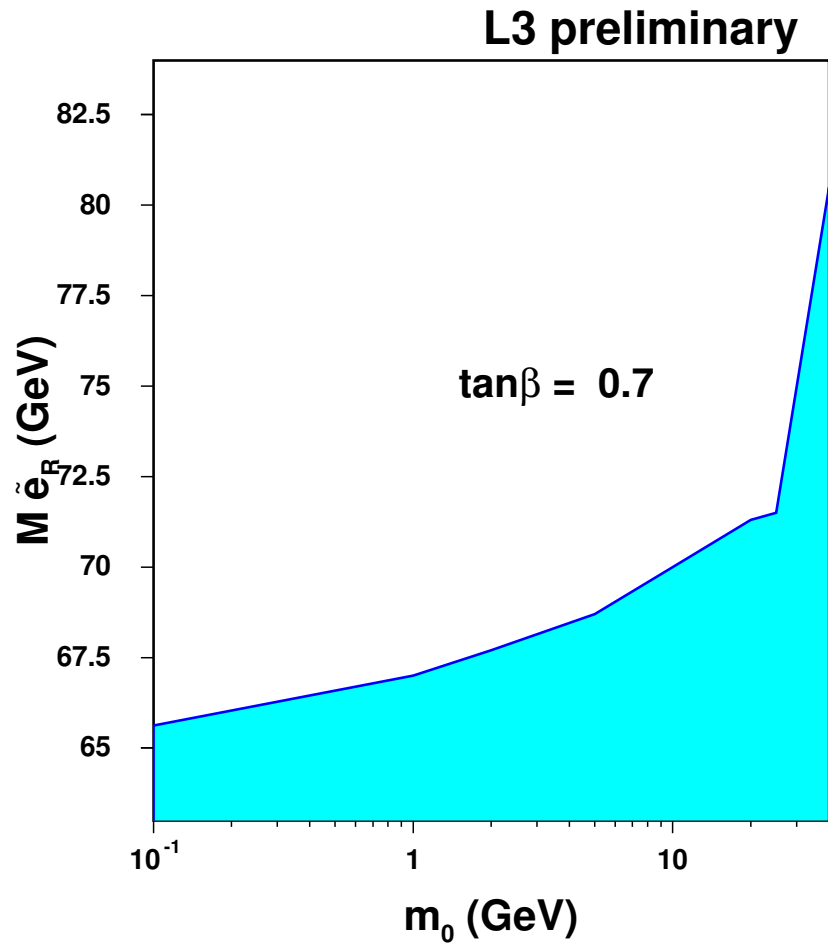
- $\tilde{e}_R$  degenerate with  $\tilde{\chi}_1^0$
- Difficult point in parameter space
- Look for  $e^+e^- \rightarrow \tilde{e}_L\tilde{e}_R$
- Decay  $\tilde{e}_R \rightarrow \tilde{\chi}_1^0 e$  invisible  $\rightarrow$  low  $E_e$
- Tag events with  $\tilde{e}_L \rightarrow \tilde{\chi}_1^0 e$
- Detector signal: single electron
- Main backgrounds:  $e\nu W, ee\nu\nu$

- Data at  $\sqrt{s} > 192$  GeV



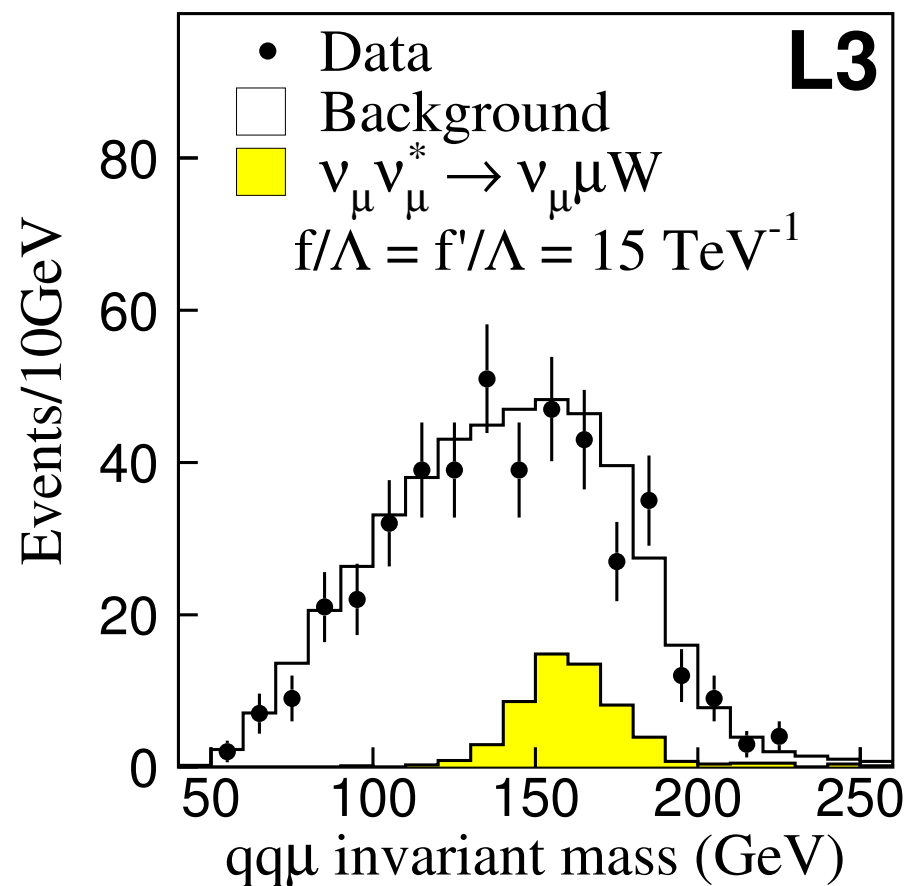
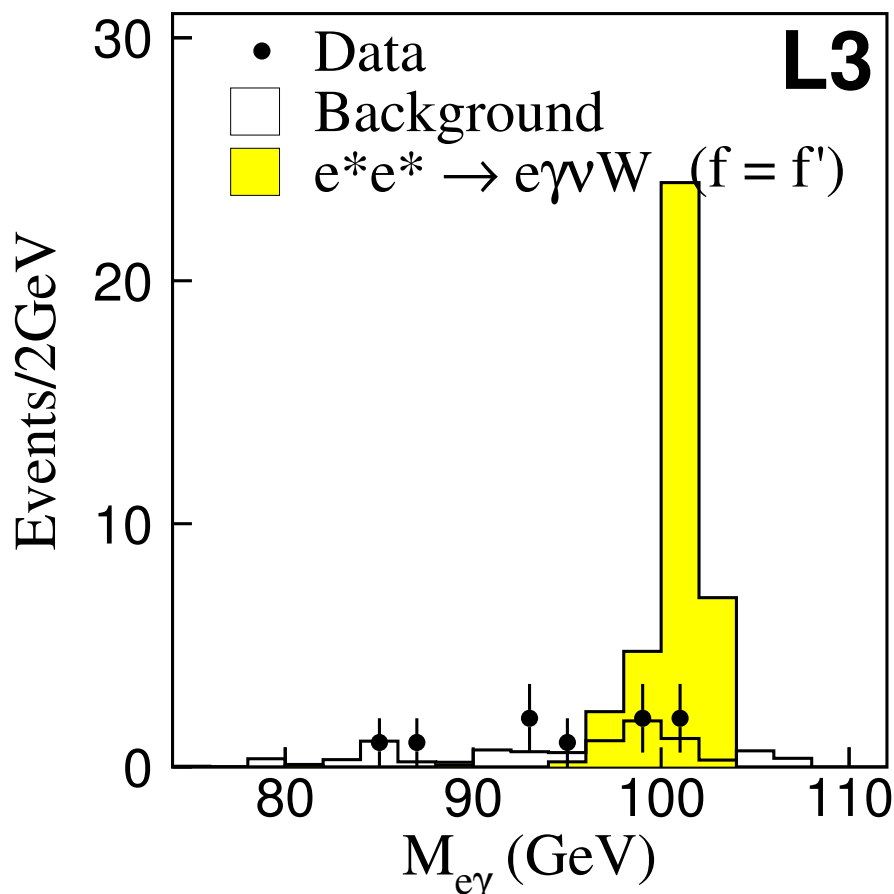
# Absolute Limits on Scalar Electron Mass

- From degenerate  $\tilde{e}_R$  searches and scalar electron results:



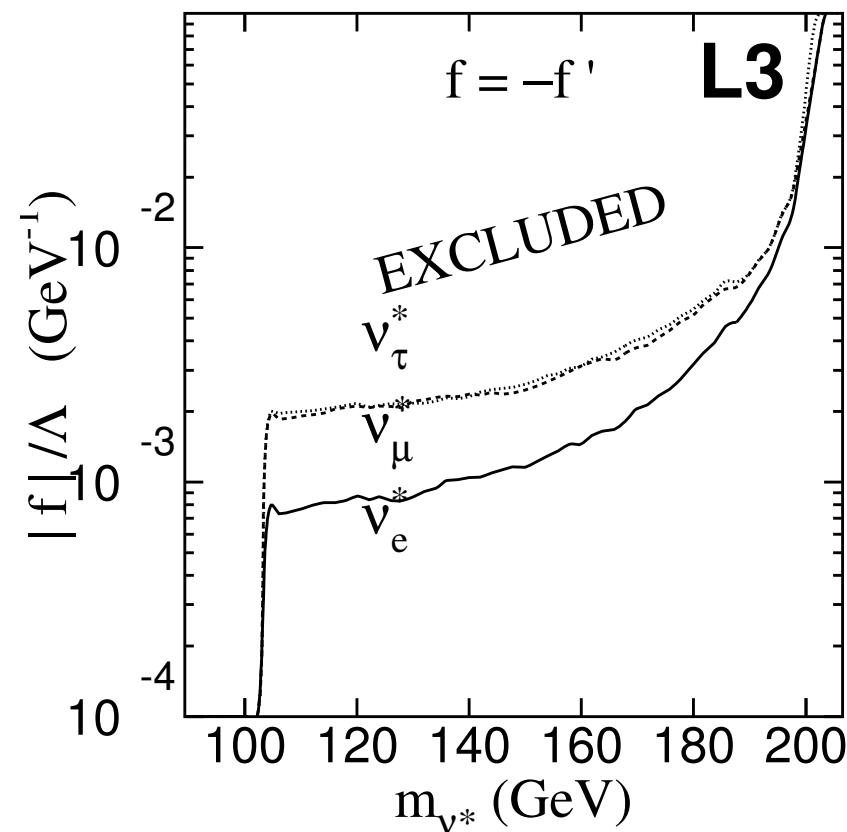
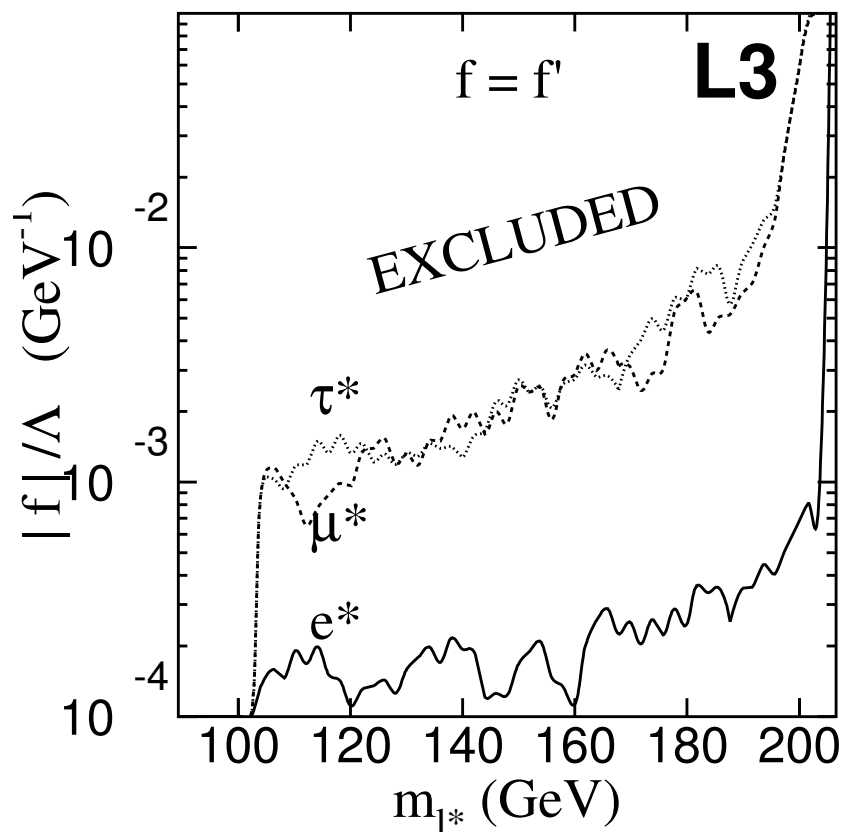
- $M_{\tilde{e}_R} > 71.3$  GeV for  $\tan\beta > 1$  (95% CL)

- U(1) and SU(2) coupling strength  $f/\Lambda$  and  $f'/\Lambda \rightarrow$  affect production and decay
- Possible decays: radiative  $\ell^* \rightarrow \ell\gamma$ ,  $\nu^* \rightarrow \nu\gamma$ 
  - CC  $\ell^* \rightarrow \nu W$ ,  $\nu^* \rightarrow \ell W$
  - NC  $\ell^* \rightarrow \ell Z$ ,  $\nu^* \rightarrow \nu Z$
- Search for all combination of decays in single and pair production



# Excited Leptons

- All data analysed → no signal found → limits on masses and couplings



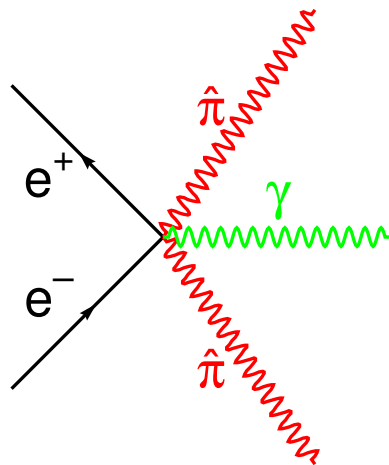
- 95% CL mass limits (in GeV):

	$m^{f=f'}$	$m^{\text{any } f, f'}$		$m^{f=-f'}$	$m^{\text{any } f, f'}$
$e^*$	102.8	96.5	$\nu_e^*$	102.6	101.5
$\mu^*$	102.8	96.6	$\nu_\mu^*$	102.6	101.4
$\tau^*$	102.8	95.6	$\nu_\tau^*$	102.6	91.3

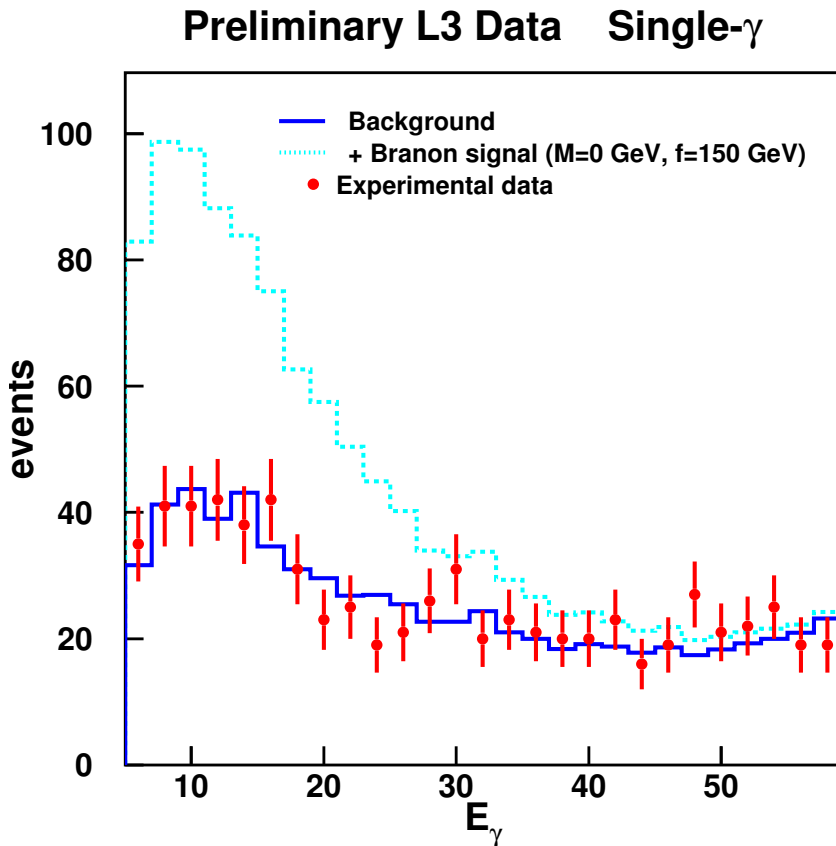
# Search For Exotic Particles: Branons

---

- Extra spatial dimensions  $\rightarrow$  graviton
  - ▷ extensively studied at LEP (from  $e^+e^- \rightarrow \gamma\gamma$ :  $M_s > 0.8 - 1.0$  TeV)
- But also branons  $\hat{\pi} \rightarrow$  brane fluctuations
- Gravitation scale  $M_F$  and brane tension scale  $f$
- Signs of extra dimensions  $\rightarrow$  gravitons for  $f \gg M_F$  and branons for  $f \ll M_F$
- Effective theory with couplings to SM particles (hep-hp/0212269)
  - $\rightarrow$  single photon production  $e^+e^- \rightarrow \hat{\pi}\hat{\pi}\gamma$



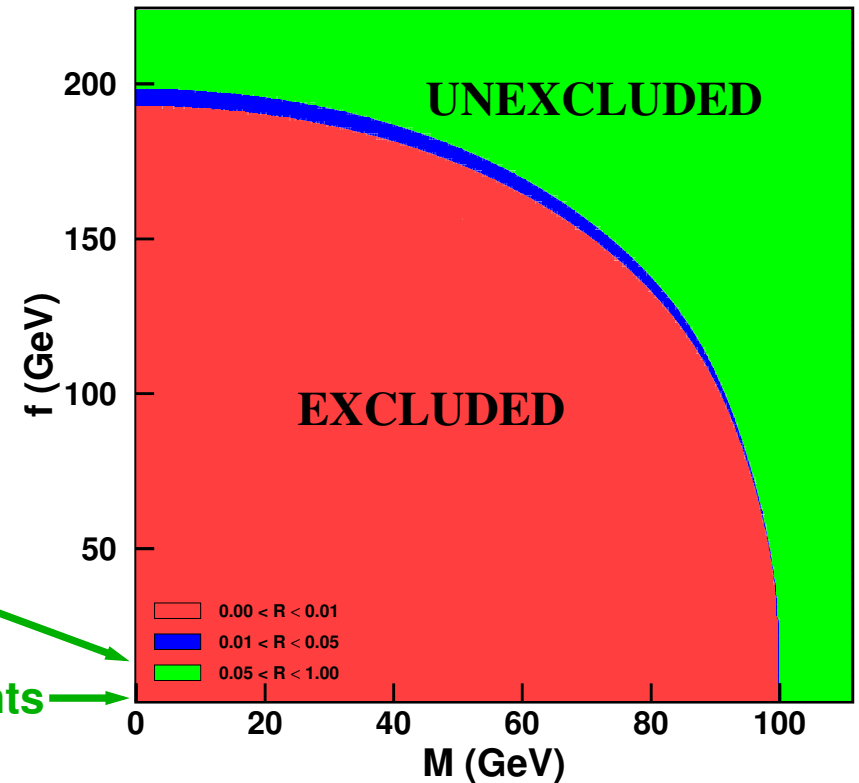
- Fit single- $\gamma$  double-differential cross section:



Supernova 1987A

Gravity Experiments

**Limits on Brane Tension**



L3 preliminary

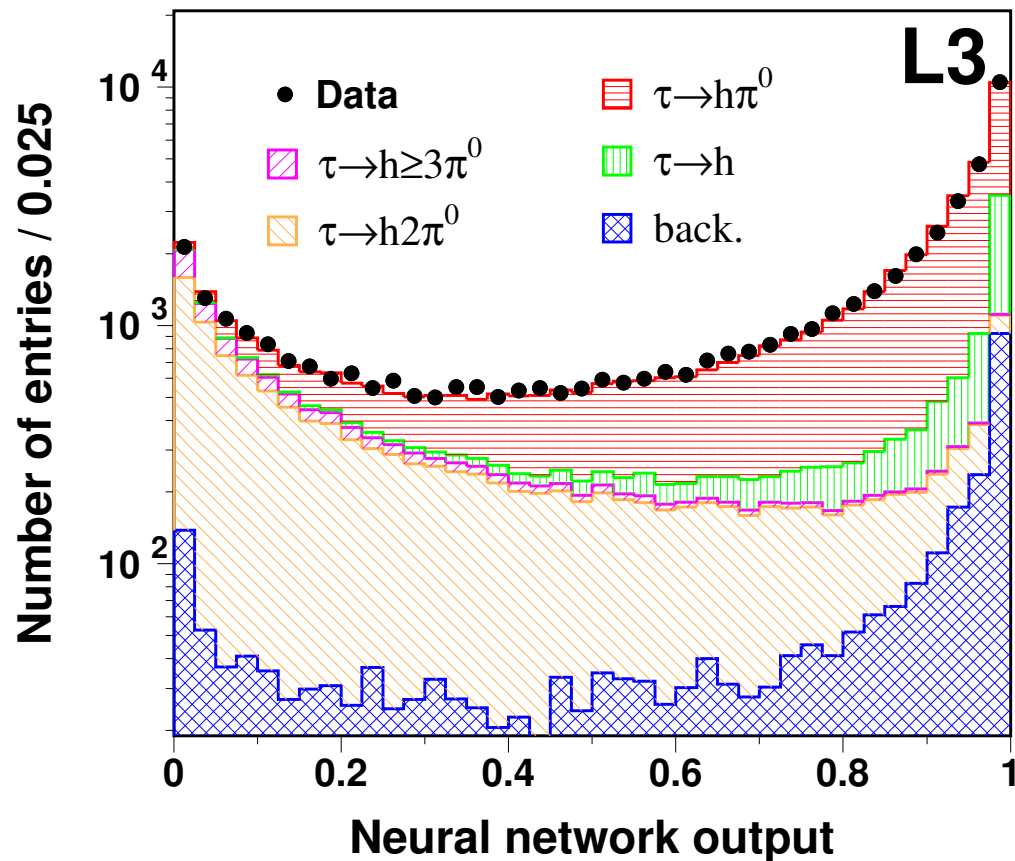
- Less stringent limits from single-Z production

# Z-Peak Data Analyses

# Tau Hadronic Branching Fractions

- $\tau$  decays into 1 or 3 charged hadrons and  $n\pi^0$

- NN separation for each decay channel

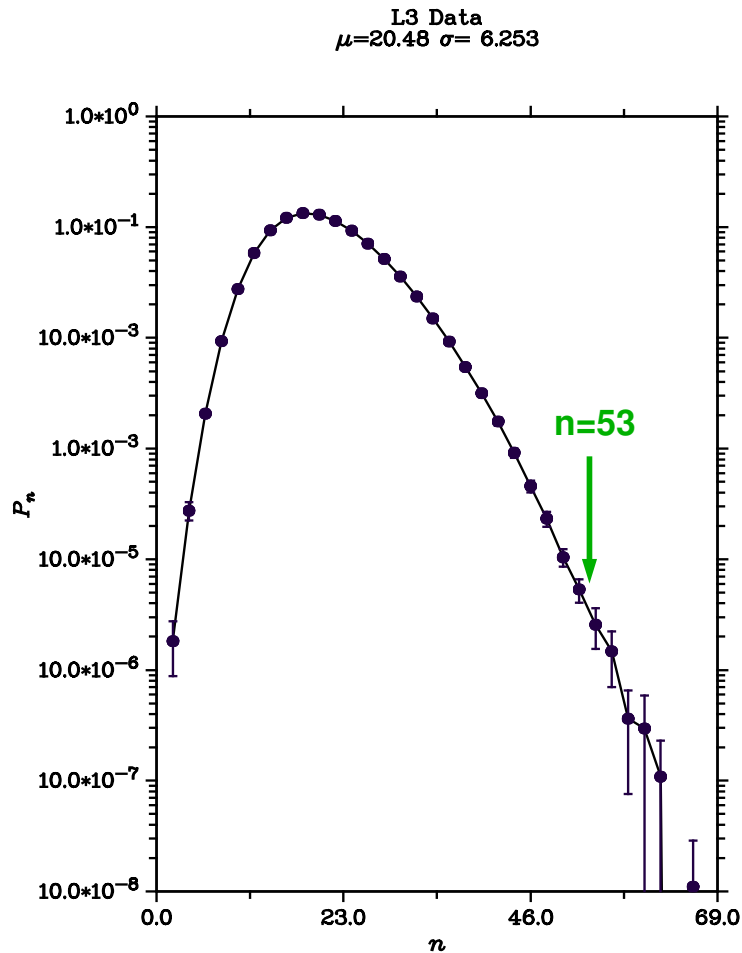


- From simultaneous fit:

$\tau$ decay channel	BR [%]
$\nu_\tau h$	$12.08 \pm 0.12 \pm 0.09$
$\nu_\tau h \pi^0$	$25.87 \pm 0.16 \pm 0.10$
$\nu_\tau h 2\pi^0$	$9.07 \pm 0.15 \pm 0.17$
$\nu_\tau h \geq 3\pi^0$	$1.33 \pm 0.11 \pm 0.10$
$\nu_\tau 3h$	$9.13 \pm 0.11 \pm 0.12$
$\nu_\tau 3h \pi^0$	$4.80 \pm 0.12 \pm 0.07$
$\nu_\tau 3h \geq 2\pi^0$	$0.71 \pm 0.08 \pm 0.04$

- Largely improves and extends our previous measurement from 1994

# Moments of Particle Multiplicity Distribution

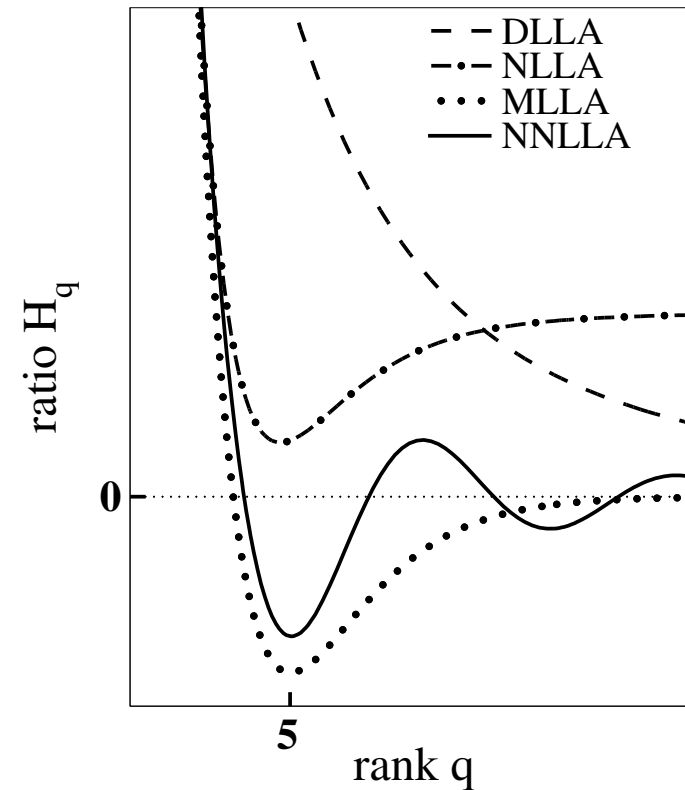


- Multiplicity distribution  $P(n)$  analysed in terms of factorial moments and cumulants

$$F_q = \frac{\sum_{n=0}^{\infty} n(n-1)\dots(n-q+1)P(n)}{\left(\sum_{n=1}^{\infty} nP(n)\right)^q}$$

$$K_q = F_q - \sum_{m=1}^{q-1} \frac{(q-1)!}{m!(q-m-1)!} K_{q-m} F_m$$

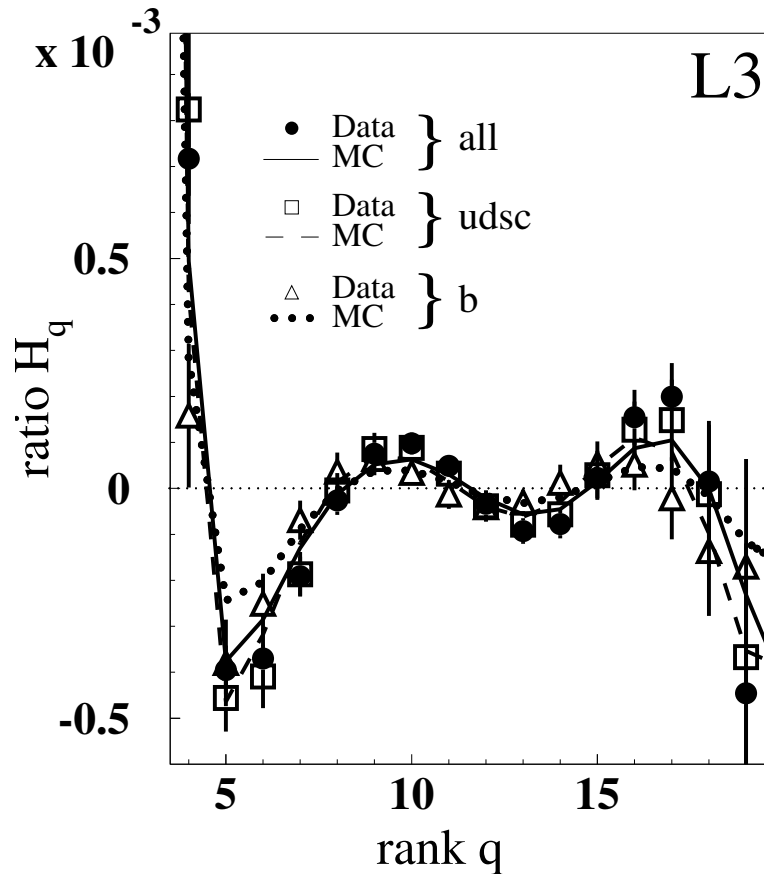
- $F_q \rightarrow$  correlation between  $q$  or less particles
- $K_q \rightarrow$  genuine  $q$ -particle correlations
- Both increase with  $q$   
 $\rightarrow$  take ratio  $H_q = K_q/F_q$



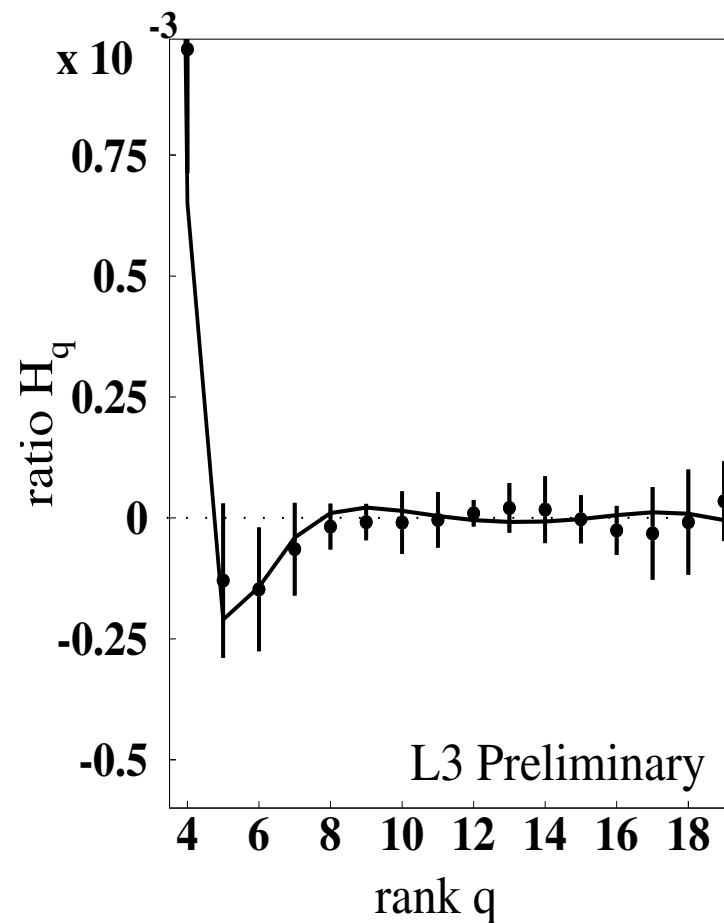
- pQCD predicts oscillations of  $H_q$

- But: oscillations may be a consequence of truncation!

● truncation at  $n=53$

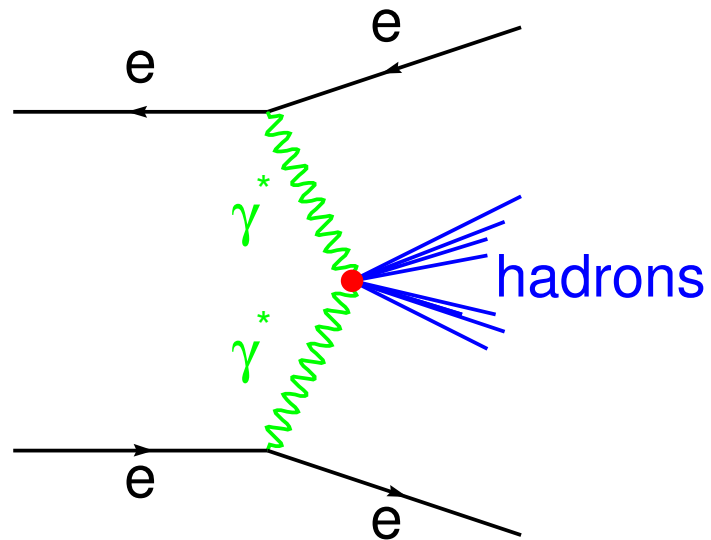


● no truncation



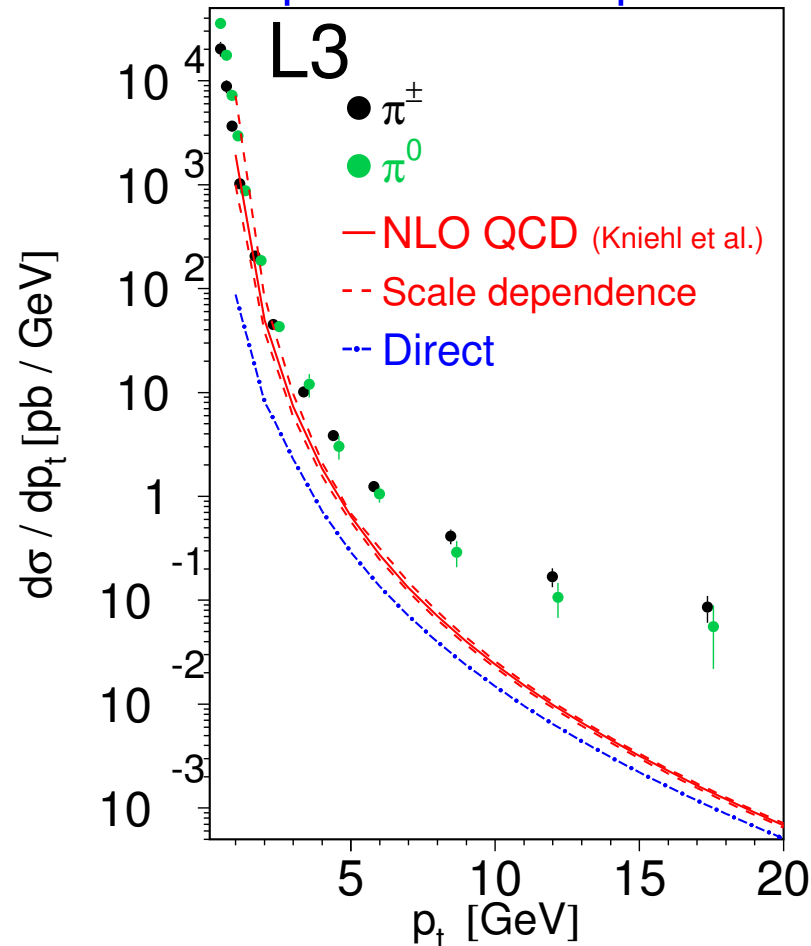
- Effect reproducible with analytical negative binomial distribution
- First minimum at  $q = 5 \rightarrow$  incompatible with DLLA and NLLA
- Data can not distinguish between MLLA (non-oscillating) and NNLLA (oscillating)

# Two-Photon Physics



# Hadron Production in Two-Photon Collisions

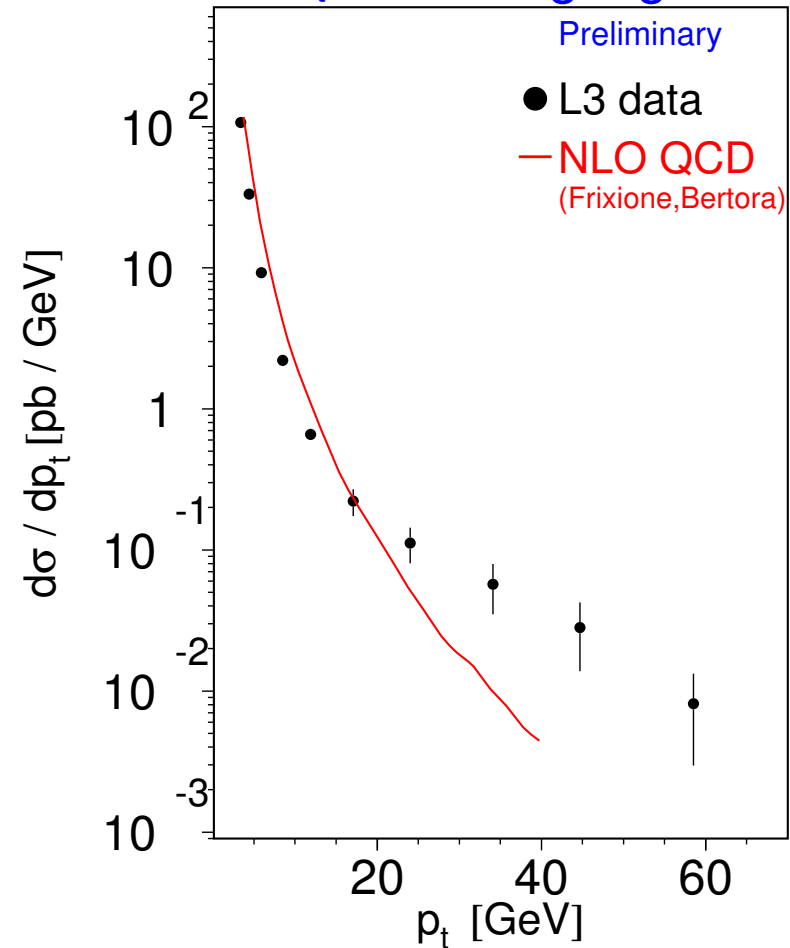
- Hadrons with high  $p_t$  are produced by direct  $\gamma^*\gamma^* \rightarrow q\bar{q}$  or QCD processes
- Inclusive production of pions:



PLB 554 (2003) 105

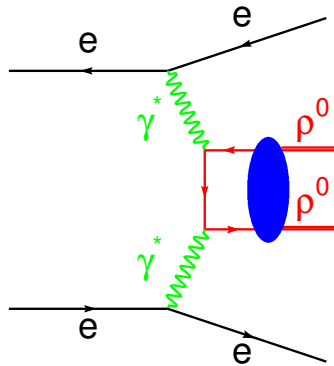
PLB 524 (2002) 44

- Compare also jet production
- Jets with  $k_t$  clustering algorithm

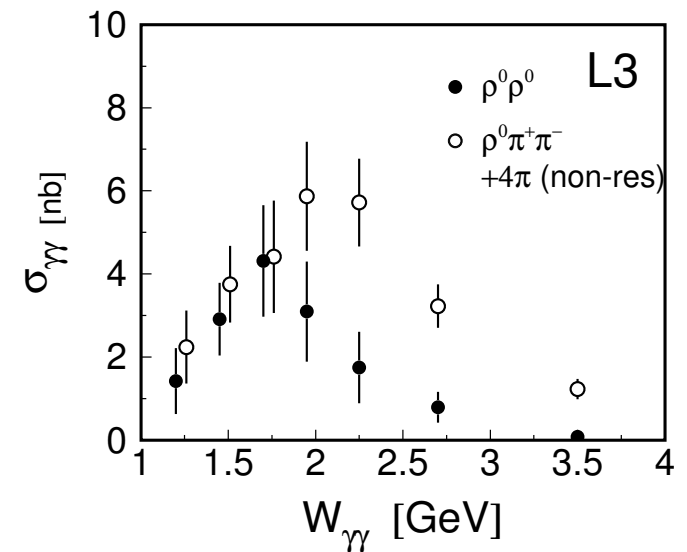
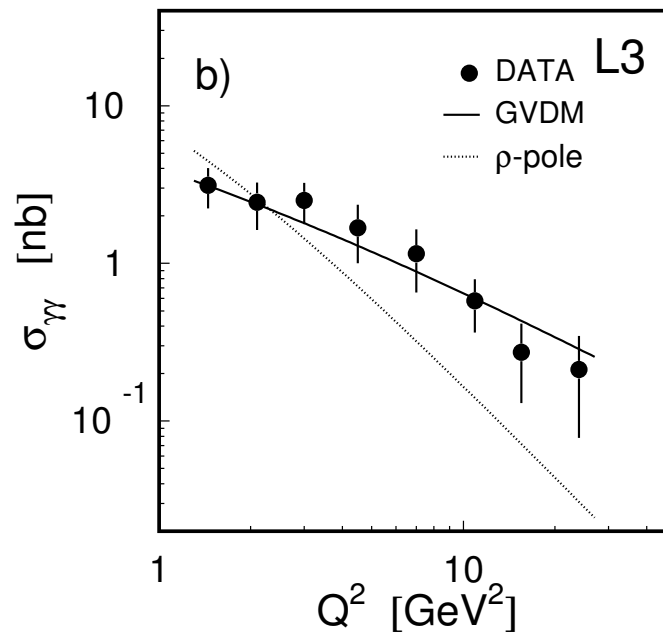
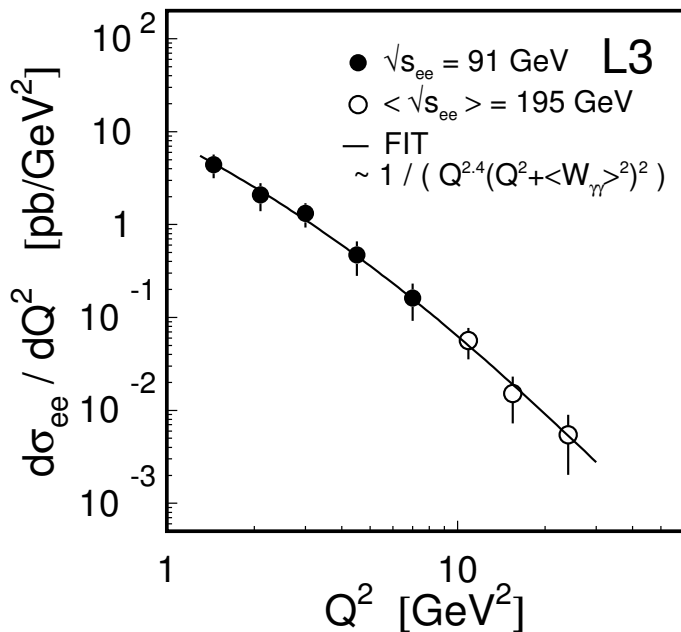


- Similar disagreement at high  $p_t$
- Not to forget the  $5\sigma$  excess in  $e^+e^- \rightarrow e^+e^-b\bar{b}X \dots$

# Exclusive $\rho^0\rho^0$ Production in Two-Photon Collisions

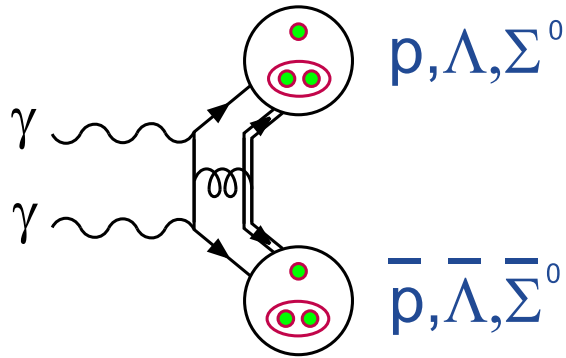


●  $\gamma^*\gamma^* \rightarrow \rho^0\rho^0$  cross section at high  $Q^2 > 1.2 \text{ GeV}^2$

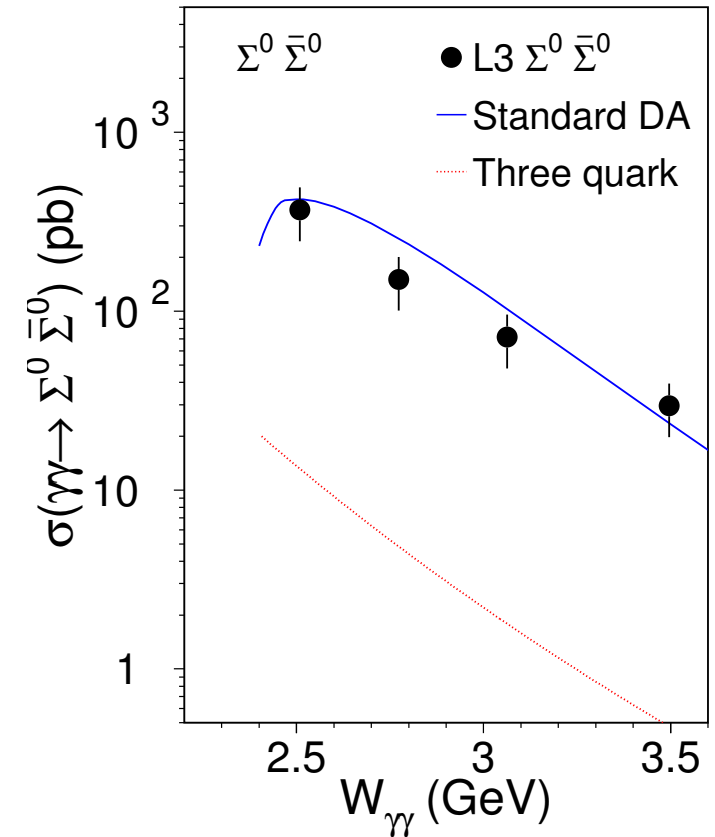
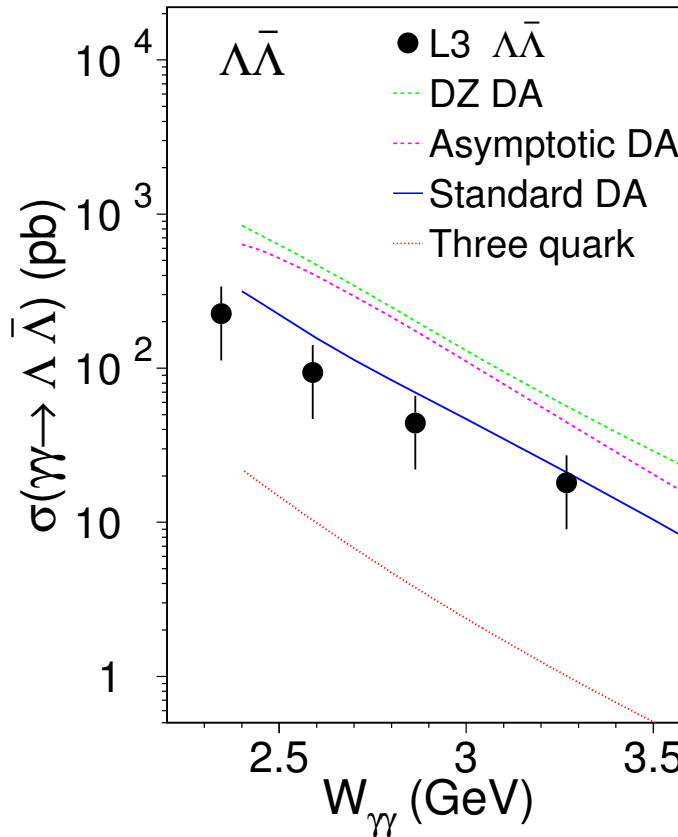
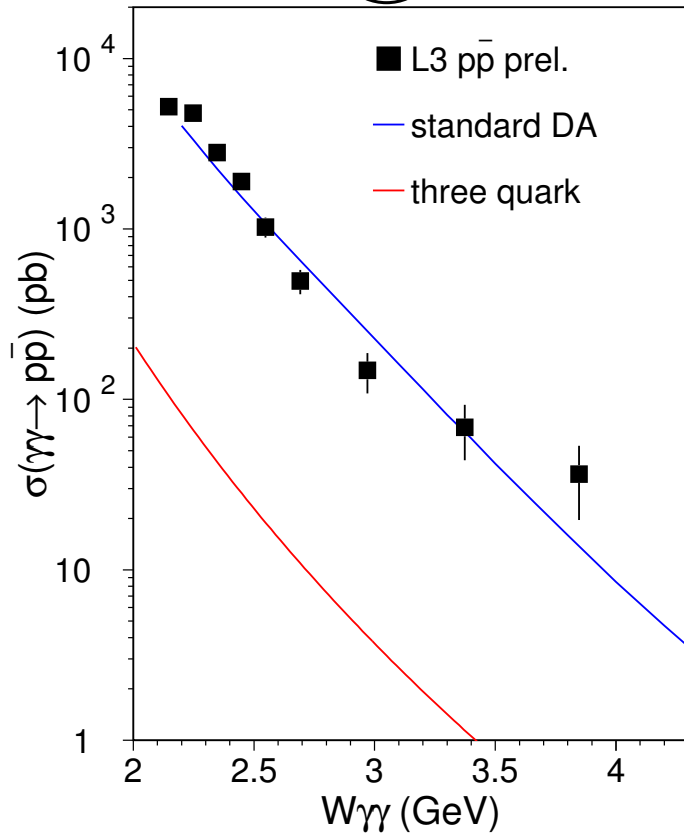


- $Q^2$  dependence of the fit to  $d\sigma_{ee}/dQ^2$  is taken from QCD calculations (Diehl et al.)
- $\sigma_{\gamma\gamma}$  well described by generalised VDM (GVDM)
- $\rho^0\rho^0$  threshold behaviour as in measurements at  $Q^2 \approx 0$

# Baryon Production in Two-Photon Collisions

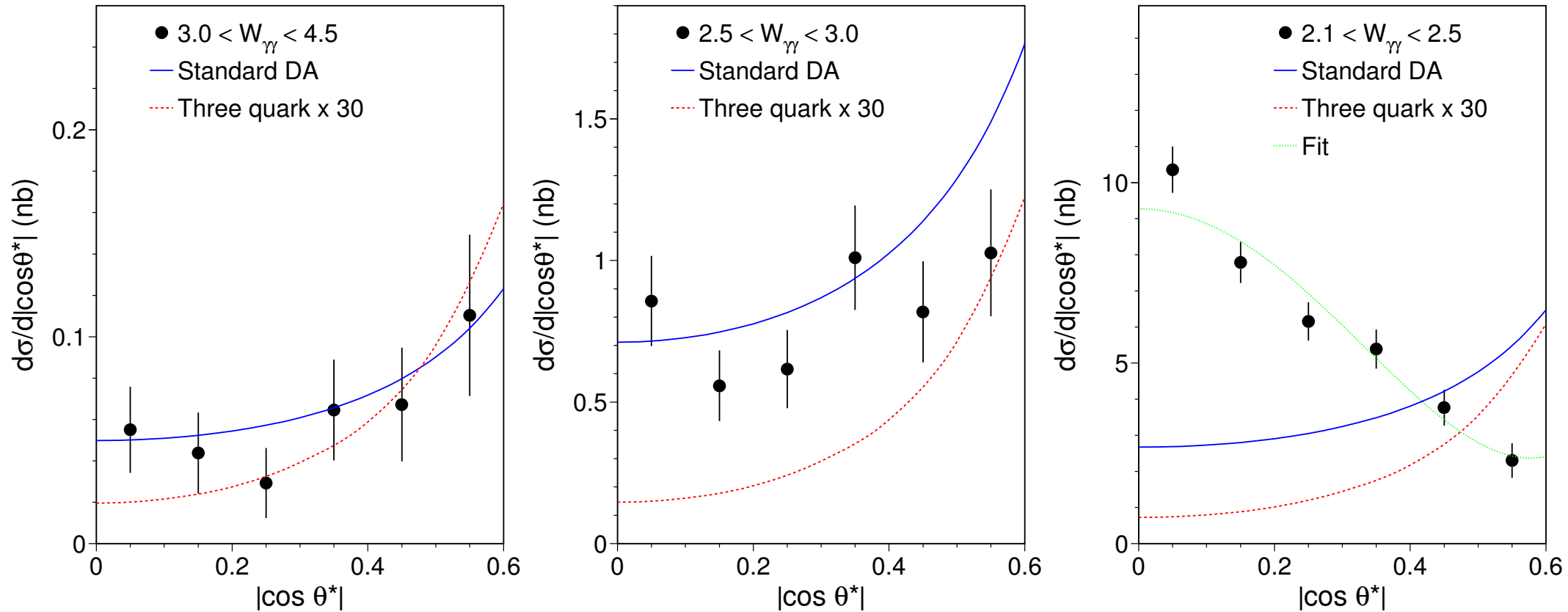


- Describe quark content of baryons with three-quark or di-quark model
- Good agreement for standard di-quark distribution amplitude (DA) for  $W_{\gamma\gamma} > 2.5$  GeV



PLB 536 (2002) 24

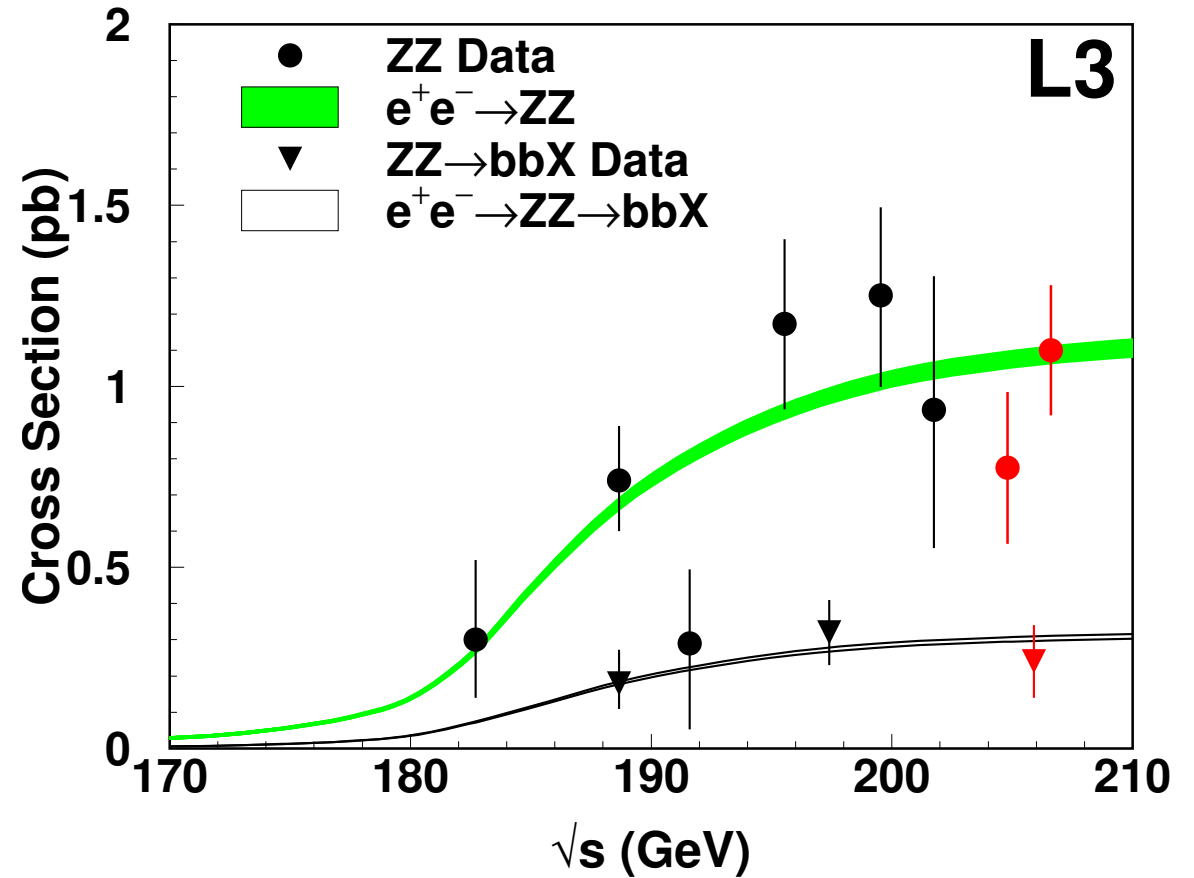
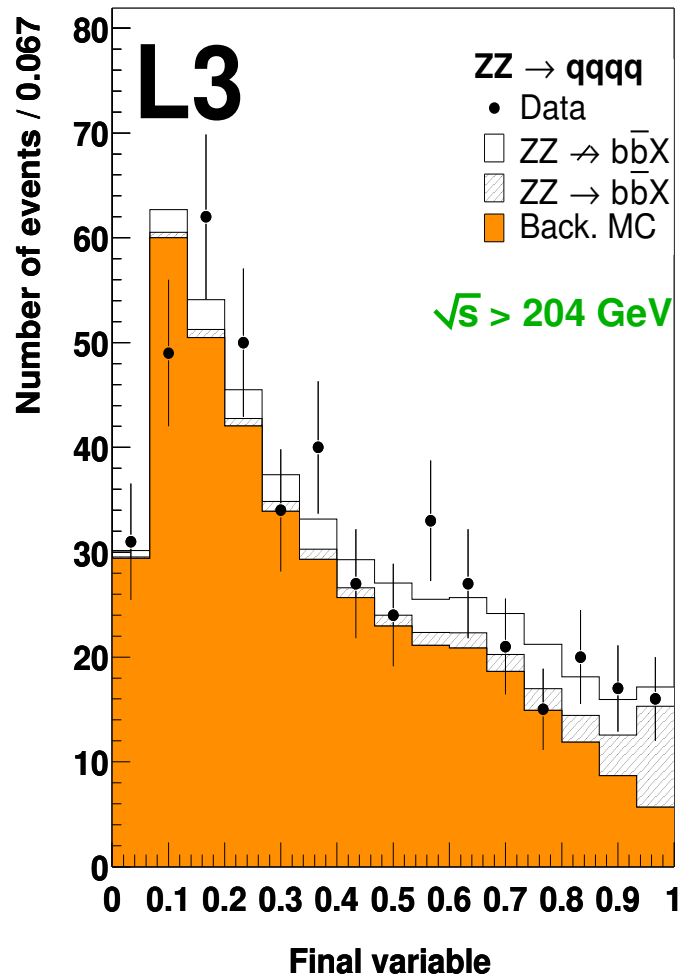
# Differential Distributions for $p\bar{p}$ Production



- Di-quark model describes high and medium  $W_{\gamma\gamma}$  region
- Different production mechanism for  $W_{\gamma\gamma} < 2.5$  GeV
- Fit to data with spherical harmonics  $Y_0^0, Y_0^2, Y_1^2, Y_2^2$
- Main contributions from:  $Y_0^2$  (92%) and  $Y_0^0$  (8%)

# W and Z Bosons

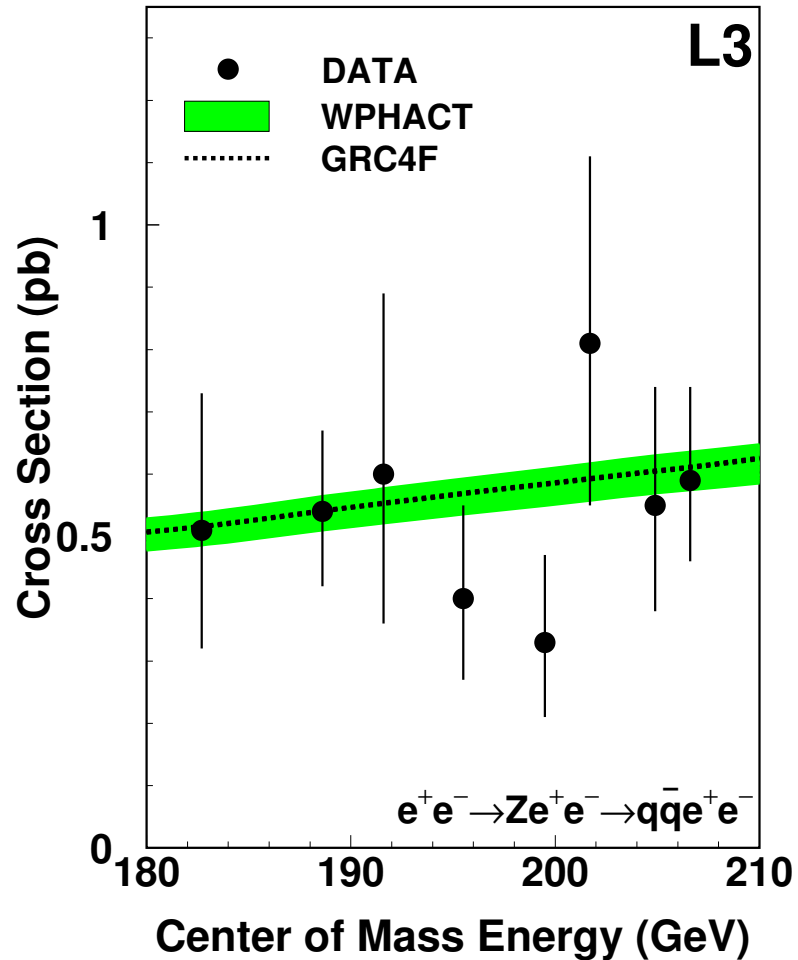
- Analysis of last data set finalised



- Ratio to SM expectation:  $R = 0.93 \pm 0.08 \pm 0.06$

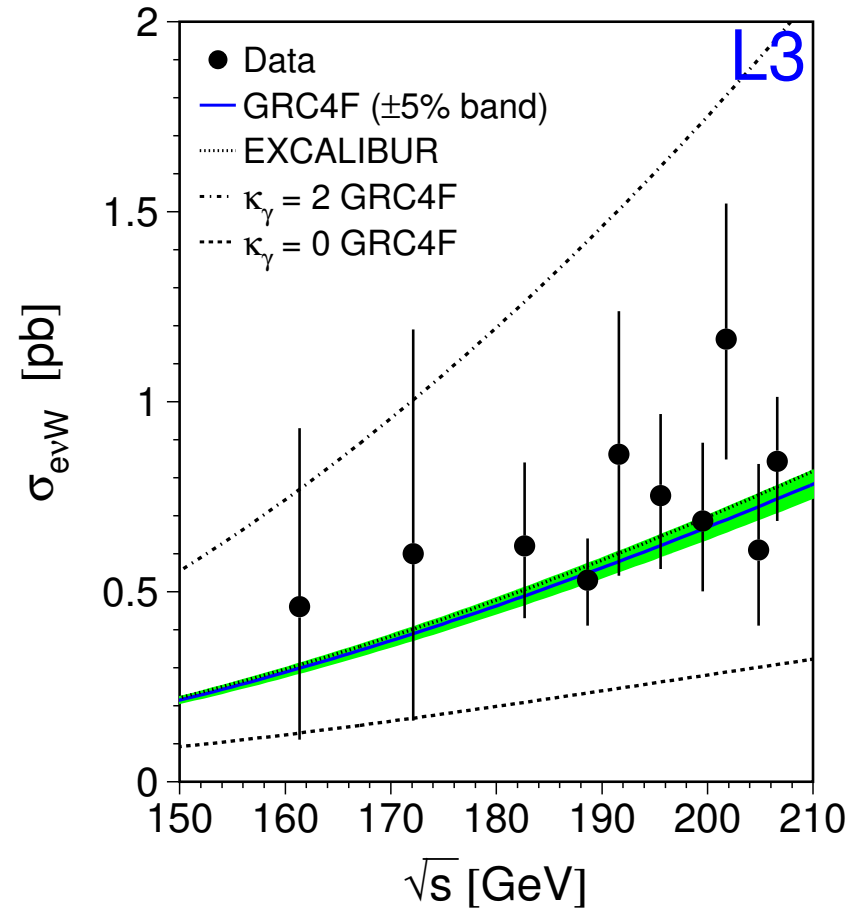
- Theory uncertainty is 2%

## • Zee Cross Section



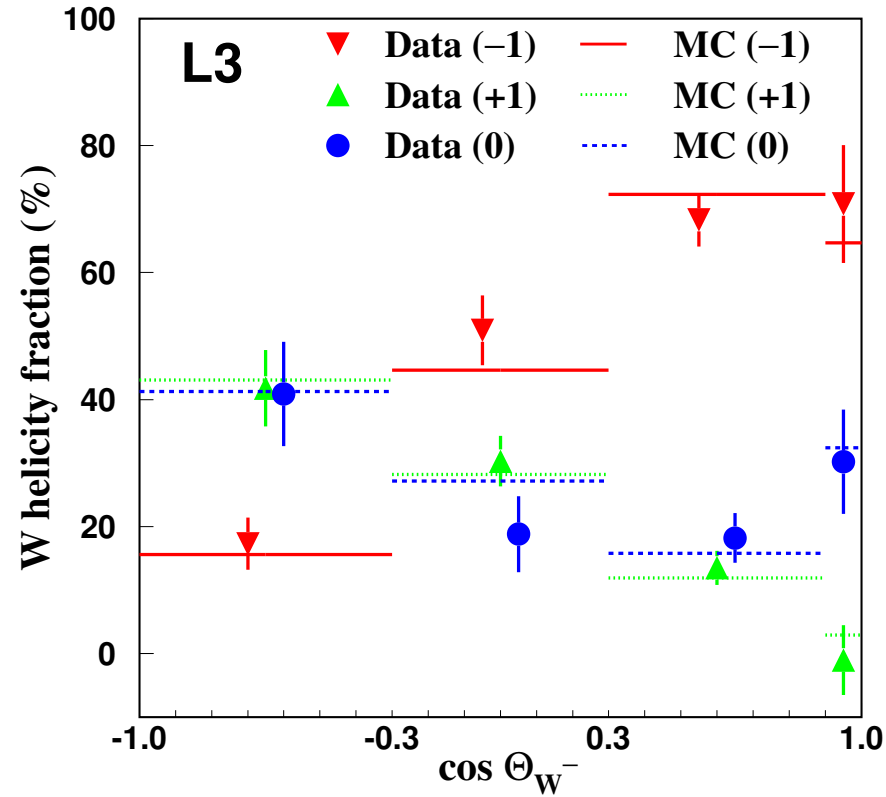
CERN-EP/2002-103

## • Single W Production and $WW\gamma$ Gauge Couplings



PLB 547 (2002) 151

● Measurement of W Polarisation



- Fraction of longitudinally polarised W bosons:  
 $0.218 \pm 0.027 \pm 0.016$  (SM 0.241)

CERN-EP/2002-092

# Spin Density Matrix

L3 Preliminary : 189–209 GeV

- SDM element in  $\cos \theta_W$ -bin  $k$  from projection operators  $\Lambda_{\tau\tau'}^{W^-}(\theta_{f-}^*, \phi_{f-}^*)$ :

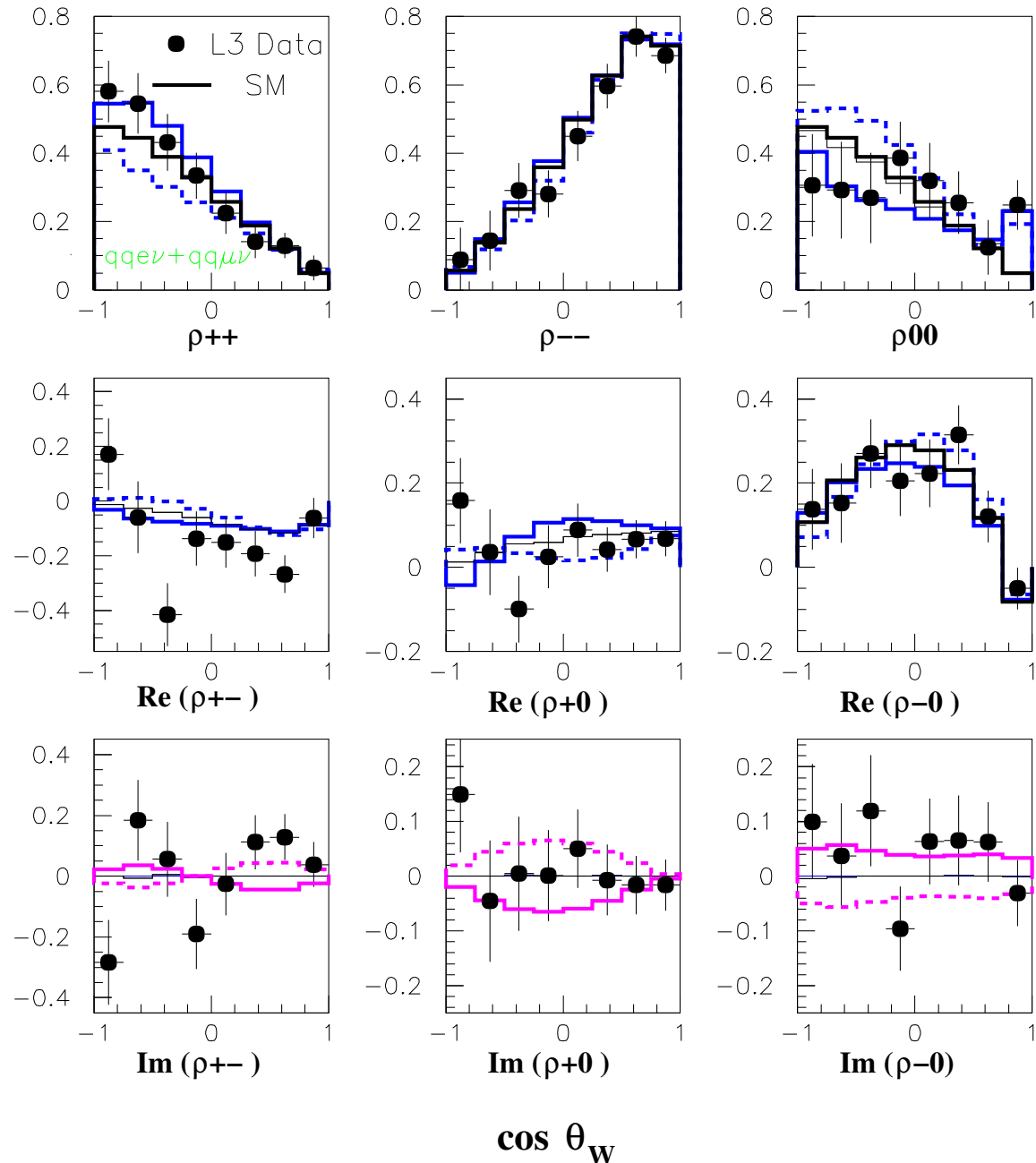
$$\rho_{\tau\tau'}^{W^-} = \frac{1}{N_k} \sum_{i=1}^{N_k} \Lambda_{\tau\tau'}^{W^-}(i)$$

- Fermion angles in  $W$  rest frame:

$$\theta_{f-}^*, \phi_{f-}^*$$

- Analysis of  $qqe\nu$  and  $qq\mu\nu$  channels with all L3 data
- Distributions corrected for efficiency and background
- Sensitive to CP violating couplings

$$\begin{aligned} - \Delta\kappa_\gamma &= +0.5 \\ \cdot\cdot \Delta\kappa_\gamma &= -0.5 \\ - \tilde{\lambda}_Z &= +0.5 \\ \cdot\cdot \tilde{\lambda}_Z &= -0.5 \end{aligned}$$



# Test of CP and CPT

L3 Preliminary : 189–209 GeV

- CP invariance:

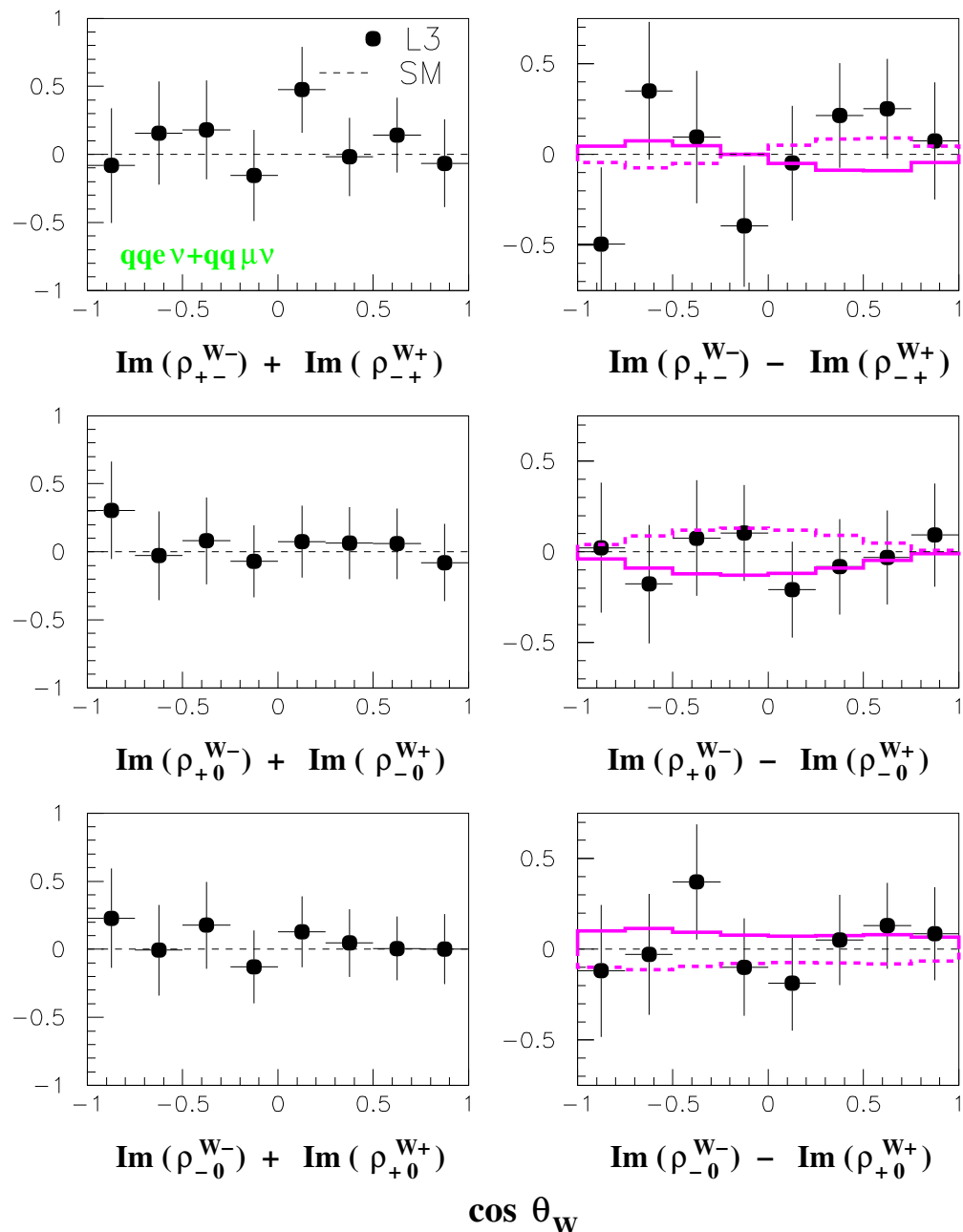
$$\text{Im}(\rho_{\tau\tau'}^{W^-}) - \text{Im}(\rho_{-\tau-\tau'}^{W^+}) = 0$$

- CPT invariance:

$$\text{Im}(\rho_{\tau\tau'}^{W^-}) + \text{Im}(\rho_{-\tau-\tau'}^{W^+}) = 0$$

- Fit of CP violating W couplings in preparation

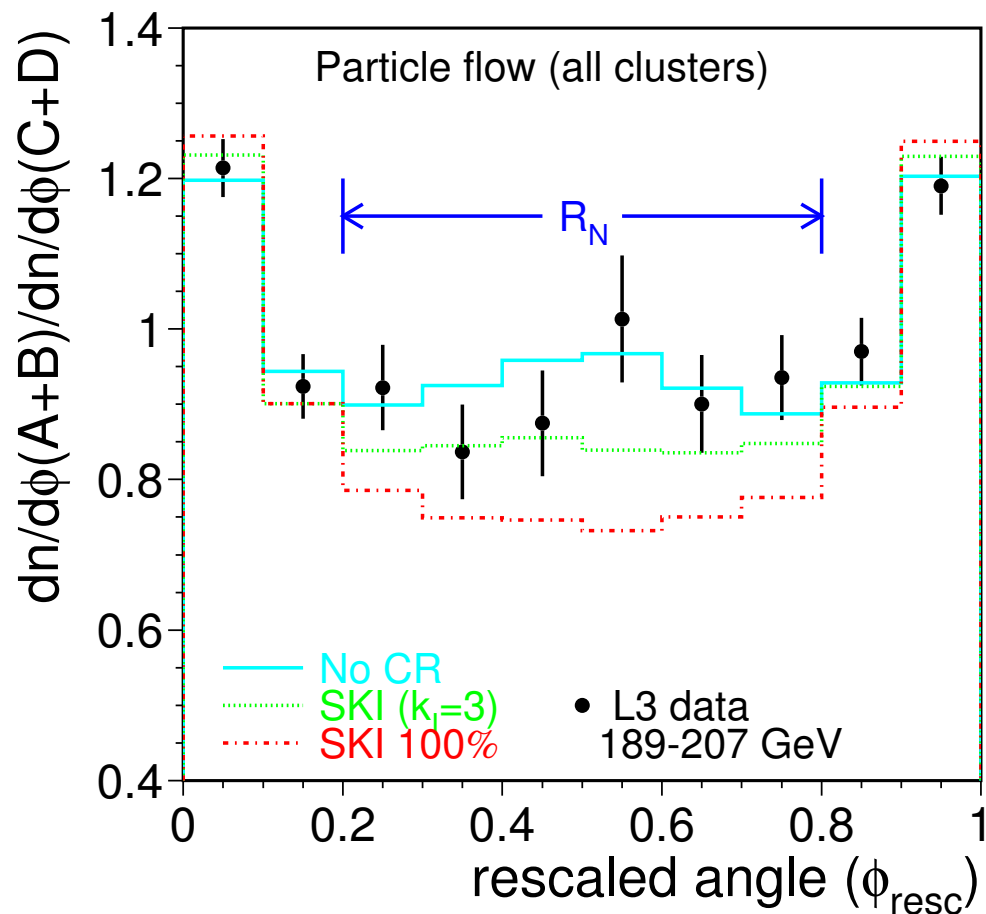
$$\begin{aligned} -\tilde{\lambda}_Z &= +0.5 \\ \tilde{\lambda}_Z &= -0.5 \end{aligned}$$



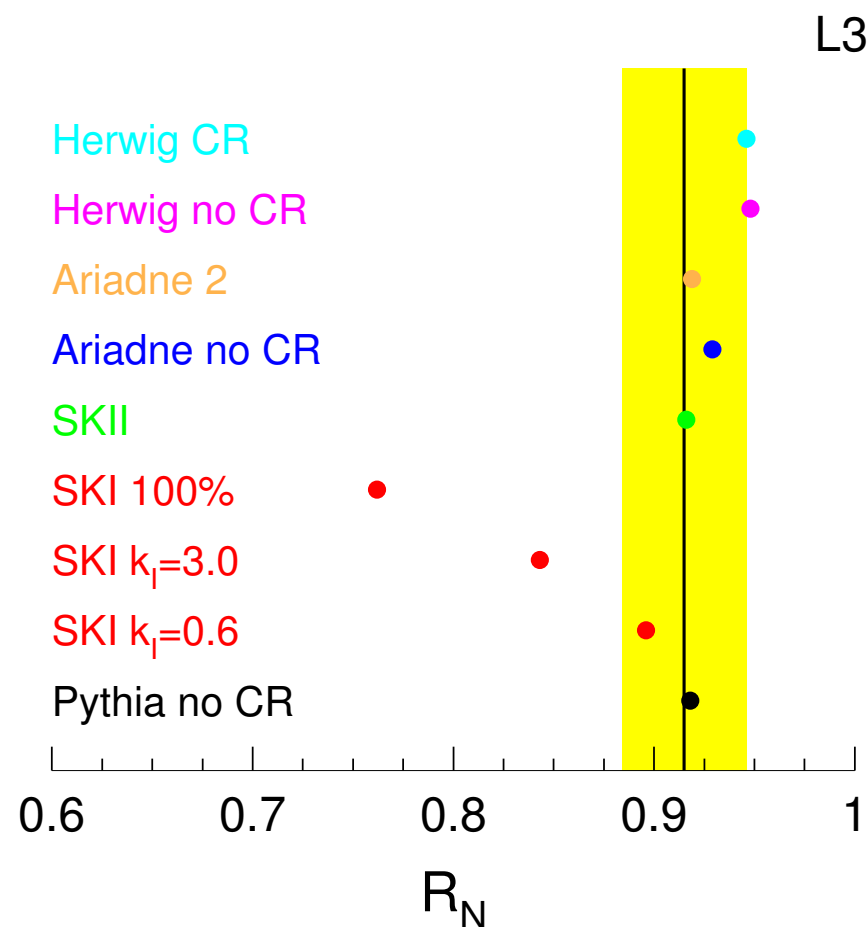
- Current status:
  - ▷ Working on systematic uncertainties
  - ▷ Mainly:  $O(\alpha)$  EW corrections
    - fragmentation
    - colour reconnection

# CR Studies - Update of Particle Flow Analysis

- Analyse particle flow  $F$  between jets in  $W^+W^- \rightarrow qqqq$  events
- Ratio of intra- $W$  regions and inter- $W$  regions  $\rightarrow$  integrate  $\rightarrow R_N$



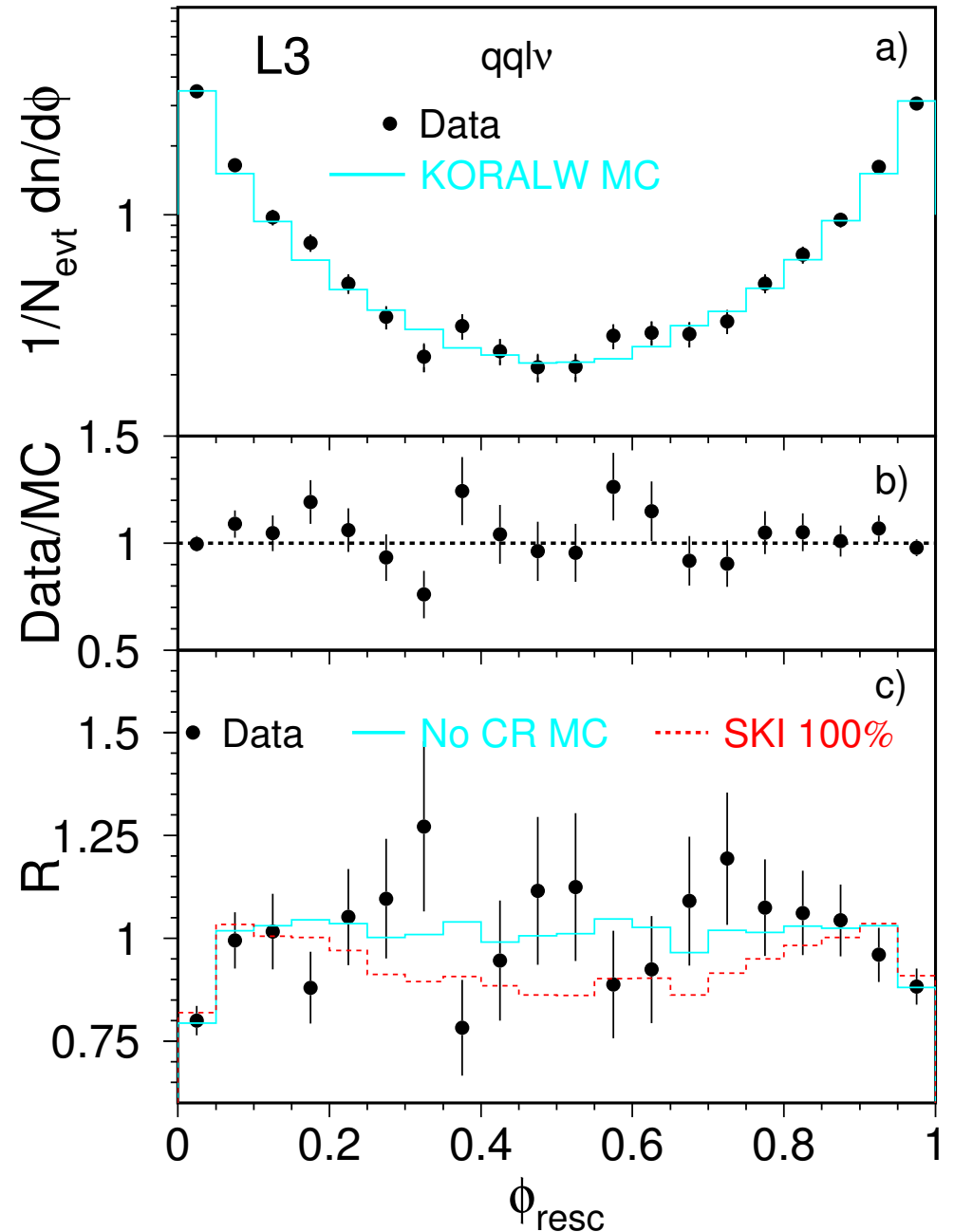
- In SK1 model:  $\chi^2$  minimum at  $k_T = 0.08$   
 $\rightarrow$  6% reconnection probability
- 68% and 95% C.L. upper limits at  $k_T = 1.1$  and  $2.1$   
 $\rightarrow$  45% and 64% reconnection prob.



# Particle Flow Analysis of $qql\nu$ Events

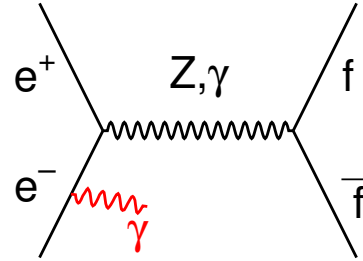
- $qql\nu$  channel: treat lepton and neutrino as particles in 4-jet reconstruction

- Ratio  $R = F(qqqq)/2F(qql\nu)$   
→ more model independent but less sensitive

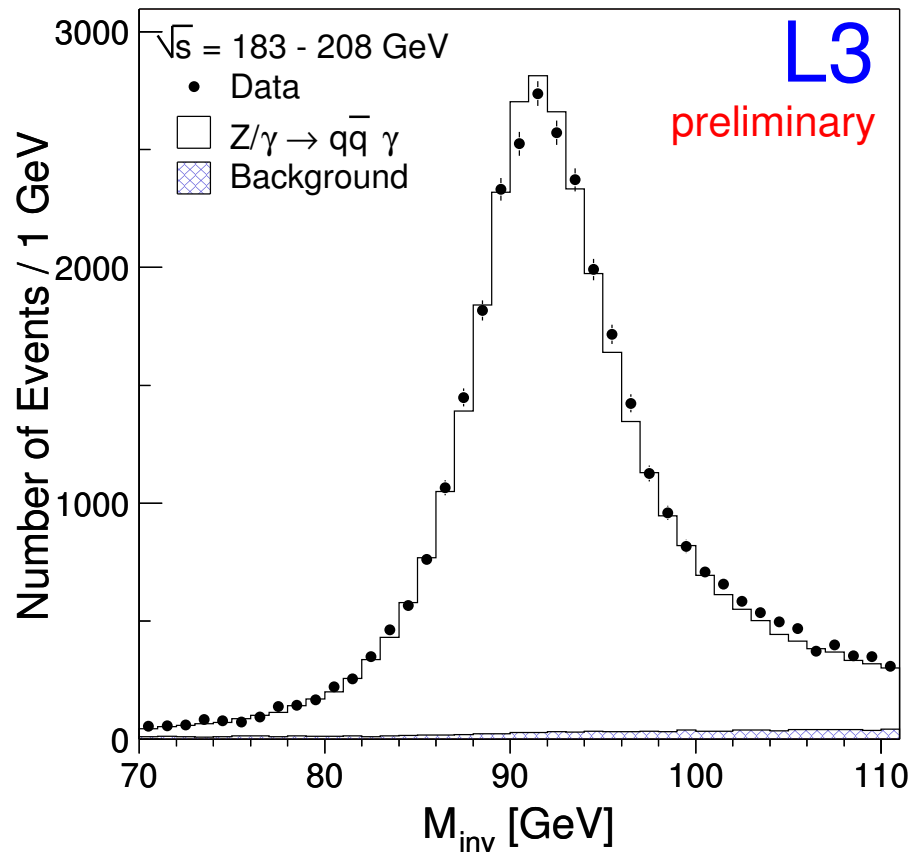


# Z Mass and Beam Energy Measurement

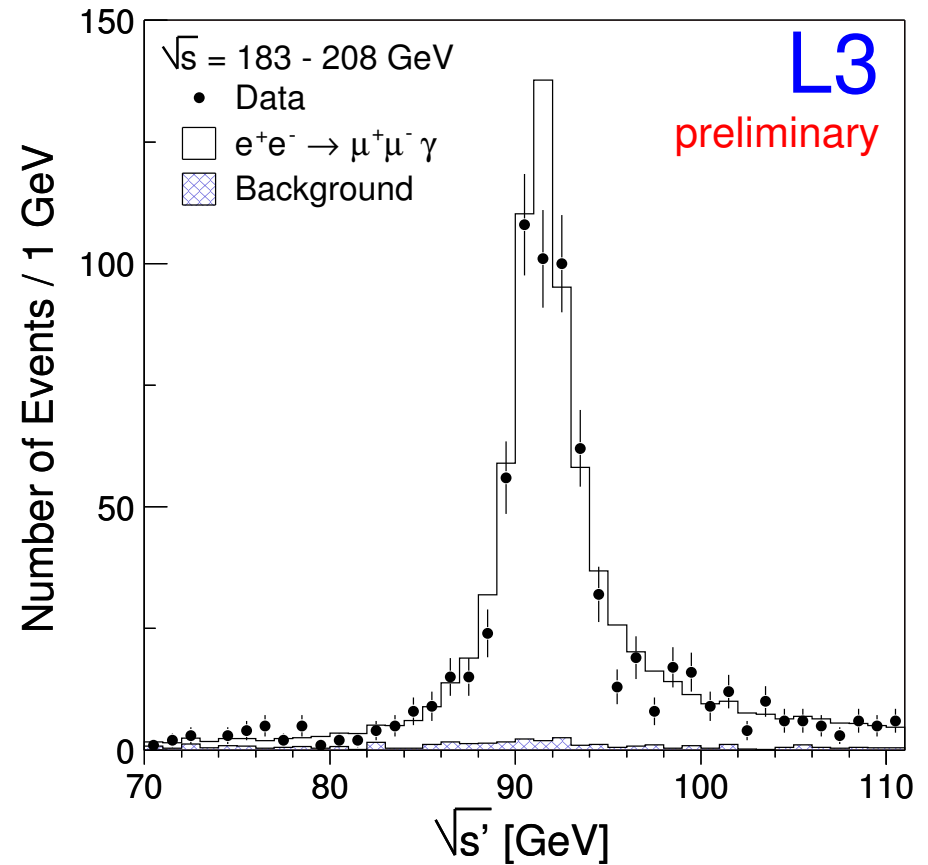
- Select radiative  $e^+e^- \rightarrow q\bar{q} + \gamma$  and  $e^+e^- \rightarrow \mu^+\mu^- + \gamma$  events



- Invariant  $q\bar{q}$  mass from kinematic fit



- $\sqrt{s'}$  from muon angles



# Z Mass and Beam Energy Measurement

---

- Main systematic uncertainties in each channel:
  - ▷ Hadronisation from comparison of Pythia, Ariadne and Herwig (36 MeV)
  - ▷ Determination of muon angles from comparison of muon chamber track and MIP signal in calorimeter (11 MeV)

- From all data at  $\sqrt{s} = 183 - 209$  GeV:

$$m_Z(\mu\mu\gamma) = 91.181 \pm 0.107 \pm 0.028 \text{ GeV}$$

$$m_Z(q\bar{q}\gamma) = 91.233 \pm 0.031 \pm 0.051 \text{ GeV}$$

- Channels combined:

$$m_Z(f\bar{f}\gamma) = 91.222 \pm 0.033 \pm 0.042 \text{ GeV}$$

- Converted into LEP beam energy:

$$\Delta E_{\text{beam}} = -E_{\text{beam}} \frac{m_Z(f\bar{f}\gamma) - m_Z}{m_Z}$$

$$\Delta E_{\text{beam}} = -0.034 \pm 0.036 \pm 0.041 \text{ GeV}$$

- No deviation from result of LEP energy working group

# Data Archiving

- Best way to archive data: publish physics results in an adequate form  
→ analysis and interpretation within future theories and models
  - ▷ Tables with efficiencies, data and Monte Carlo counts, differential cross sections, . . .
- All data and MC samples are stored in Castor
- Additional data streams in HBOOK ntuple format for searches and W physics with condensed information → Castor
- Considering translation into ROOT trees
- Reconstruction, simulation and analysis software runs on Linux/RedHat 7
- Cernlib and Castor access needed
- We need PC cluster with above specifications (“museum system”) as discussed and agreed with IT

# Conclusion

---

- Since LEP shutdown: in total 32 publications
- Currently: 12 circulating paper drafts
- Near future: another 30 topics to be published
  
- Number of PhD students:  $\approx 12$   
Number of post-docs/senior physicists: 10-15 (FTE)
  
- More analyses will be completed in 2003:
  - Fermion Pair Production
  - W Physics
  - Searches for New Particles
  - Two-Photon Physics
  - ...