Latest results from L3

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on behalf of the L3 Collaboration

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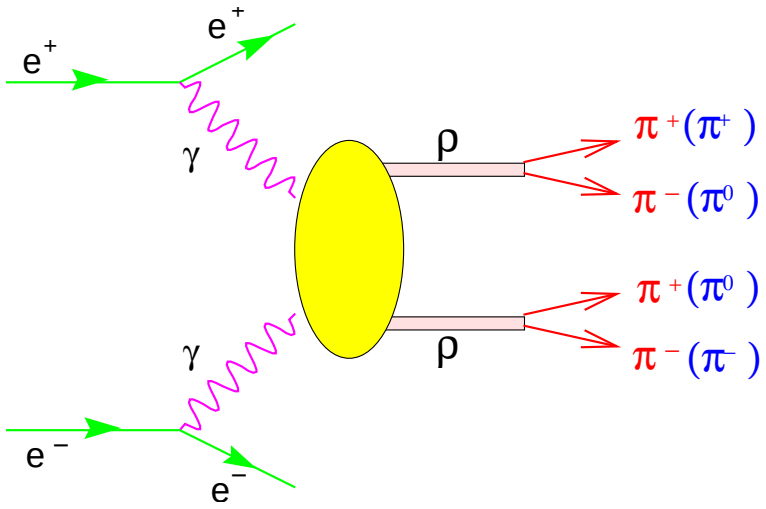
LEP-Jamboree - CERN, Switzerland

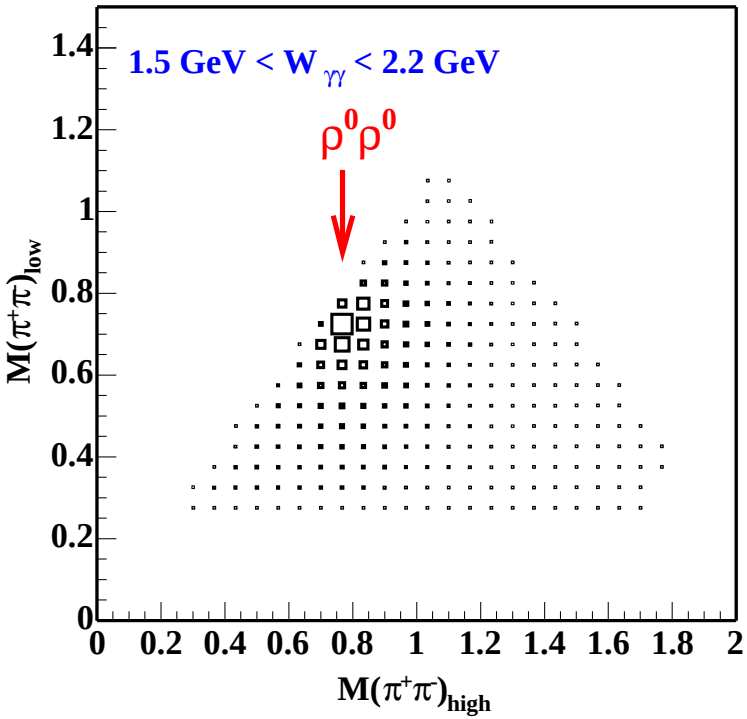
Discussed topics

Two-photon physics
QCD physics
Electroweak physics
Searches

For a complete review: `http://cern.ch/l3/conferences/Aachen2003/`

Two photon physics: $\rho\rho$ production at $Q^2 \sim 0$ GeV^2





- $\sqrt{s} = 161 - 209$ GeV
- $\pi^+\pi^-\pi^+\pi^-$ $\sim$ 73 K events
- $\pi^+\pi^0\pi^-\pi^0$ $\sim$ 7 K events

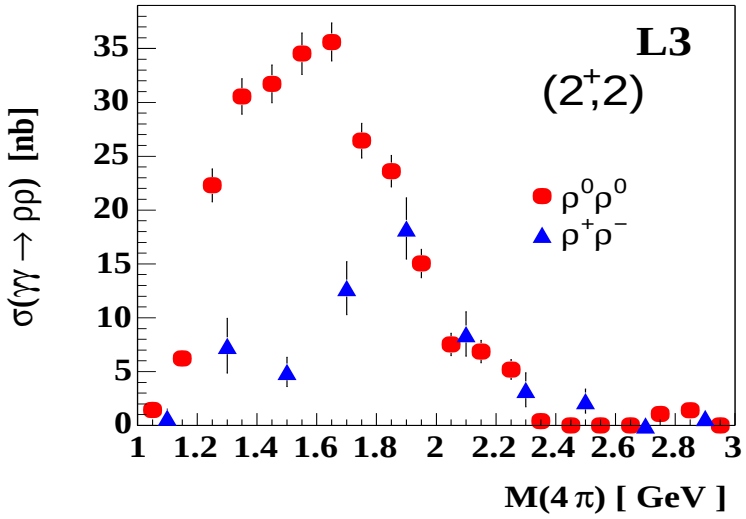
Partial wave analysis:

$\rho\rho$ state is modeled from spin-parity states:

$(J^p, J_z) = (0^+, 0); (2^+, 2); (0^-, 0); (2^+, 0); (2^-, 0(1, 2))$

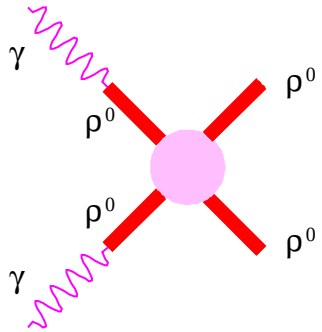
$+ 4\pi$ isotropic background [M. Althoff et al., Z. Phys. C16 (1982) 13]

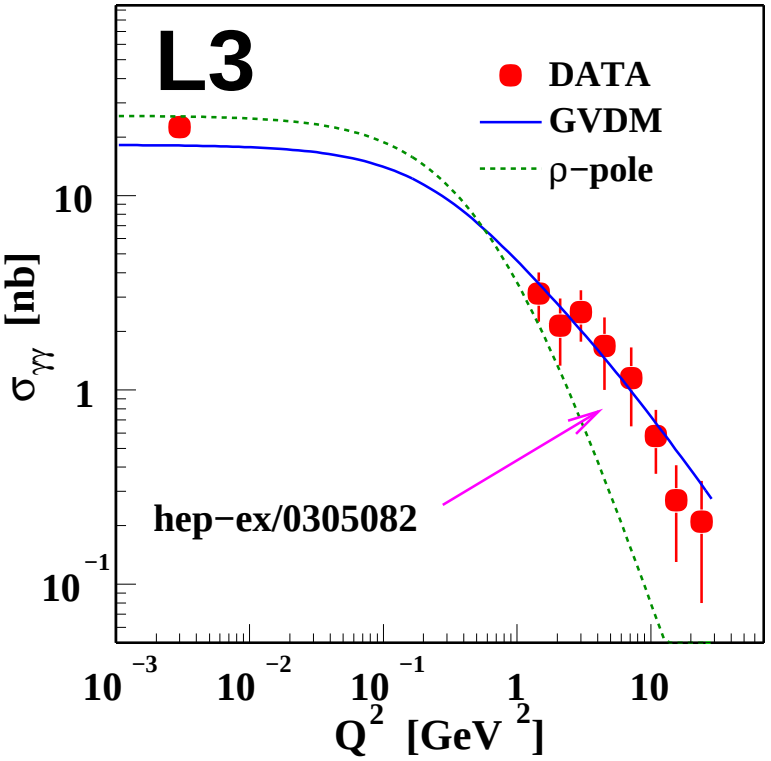
Two-photon physics: $\rho\rho$ production at $Q^2 \sim 0$ GeV^2



- $(2^+, 2)$ state is dominant
- $(0^-, 0)$, $(2^+, 0)$ and $(2^-, 0)$ states are negligible

VMD
or
resonances?

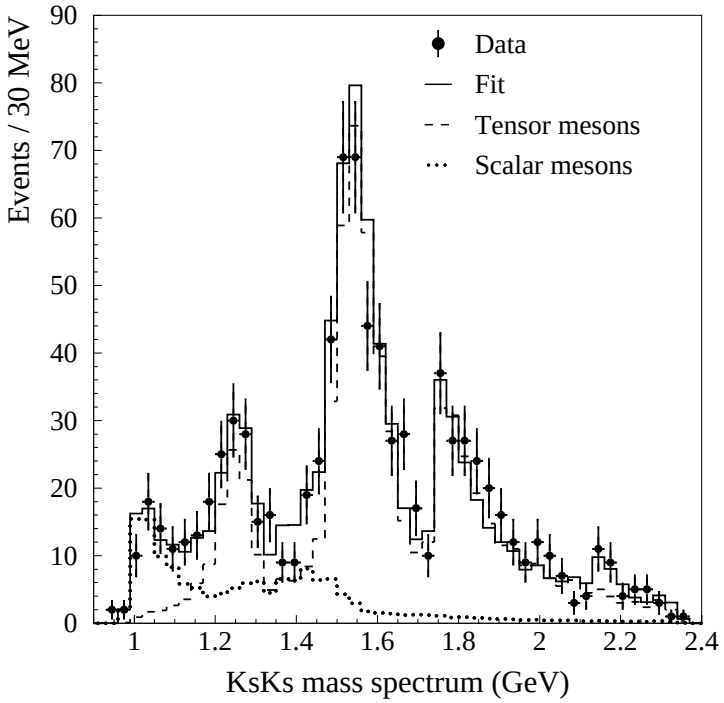




- GVDM form-factor model in agreement with data
- Ratio $\rho^+\rho^-/\rho^0\rho^0$ incompatible with I=0 or I=1

Two-photon physics: Partial wave analysis of $K^0_S K^0_S$

New analysis performed at $91 \leq \sqrt{s} \leq 209$ GeV
Only allowed states (ident. bosons): $J^{PC} = (2n)^{++},\ n = 0, 1, 2$
Two tensor SU(3) nonets hypothesis agrees well with data



First nonet (ground state)

	$a_2(1320)$	$f_2(1270)$	$f_2'(1525)$
M (MeV)	1304±10	1277±6	1523±5
Γ (MeV)	120±15	195±15	104±10
$\Gamma_{\gamma\gamma}$ (keV)	0.91*	2.55±0.15	0.13±0.03
Mix (deg)		−1±3	

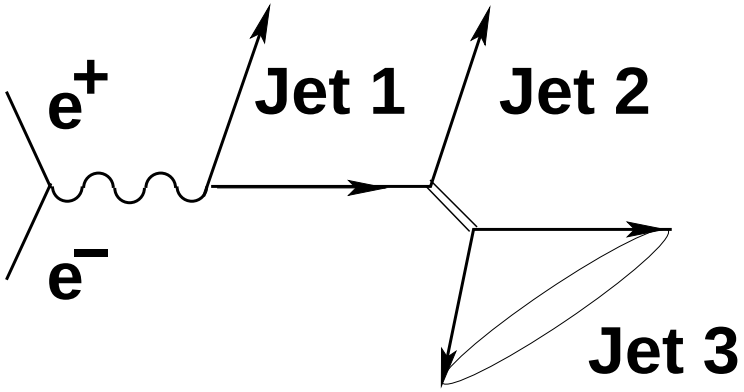
Second nonet (1^{st} rad. excit.)

	$a_2(1700)$	$f_2(1560)$	$f_2'(1750)$
M (MeV)	1730*	1570*	1755±10
Γ (MeV)	340*	160*	67±12
$\Gamma_{\gamma\gamma}$ (keV)	0.18*	0.5±0.1	0.11±0.04
Mix (deg)		-110^{+5}_{-10}	

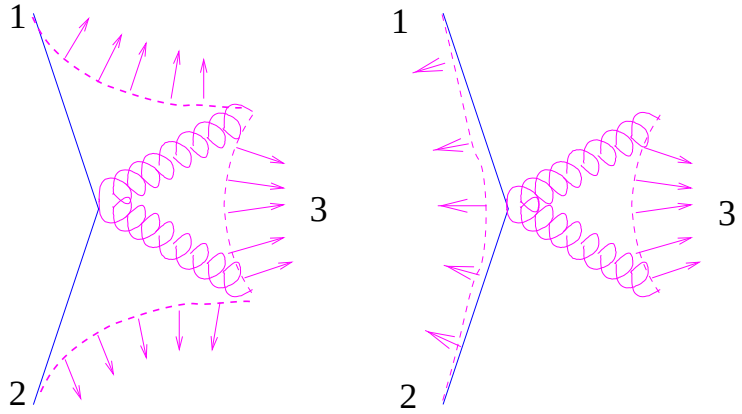
* fixed from external data

QCD: Colour Singlet and Colour Reconnection

Colour singlet exchange



Colour Reconnection during fragmentation



Select Z-peak 3-jet events gluon-tagged (anti b-tag) and study particle flow

An asymmetry variable is used as a rapidity gap discriminant:

$$A_{12}^{X} = \frac{-X_{12} + X_{23} + X_{31}}{X_{12} + X_{23} + X_{31}},$$ X_{12} is:

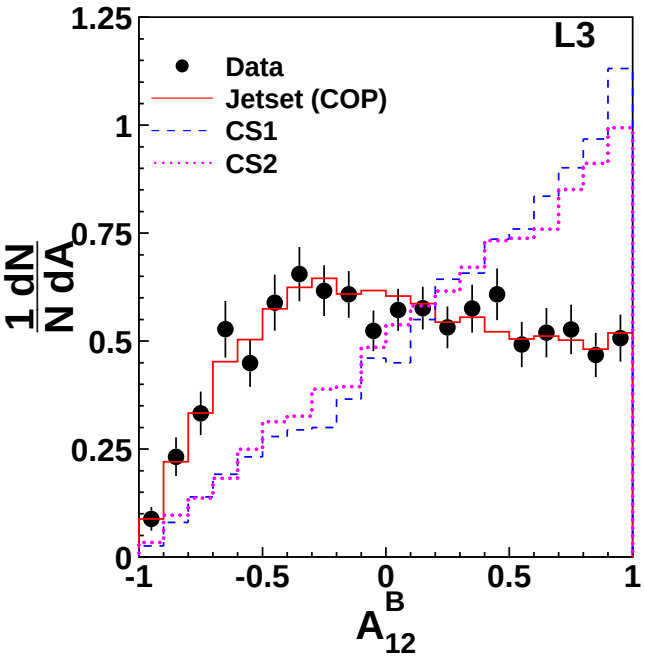
B_{12}: angle between particles and the bisector between jet 1 and 2

OR

S_{12}: maximum separation angle between particles in gap

QCD: Colour Singlet and Colour Reconnection

Colour singlet tests

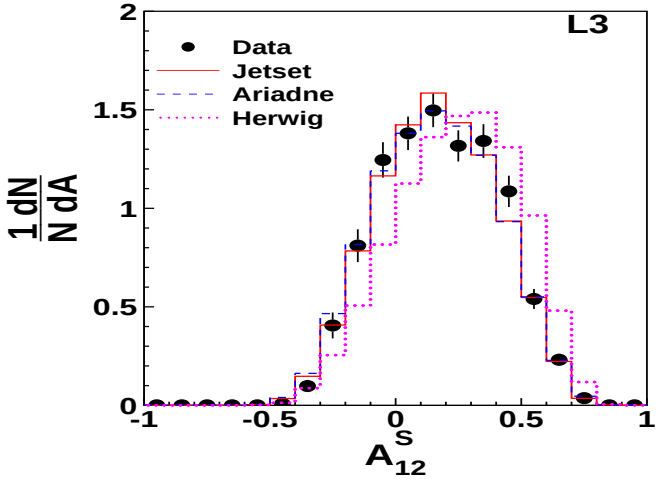


95% CL limit on CS contribution

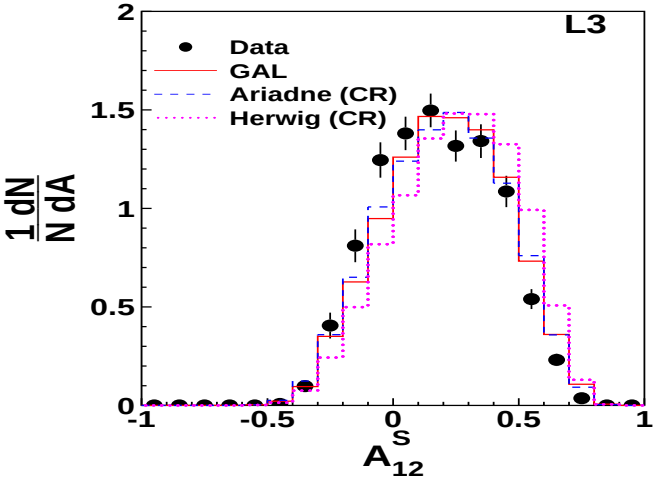
(using A_{12}^S and A_{qg}^S)

$P_{CS} < 9.0$ %

Colour Reconnection tests



W/o CR



With CR

95% CL limit on CR R-parameter

[J. Rathsman, Phys. Lett. B452 (1999) 364]

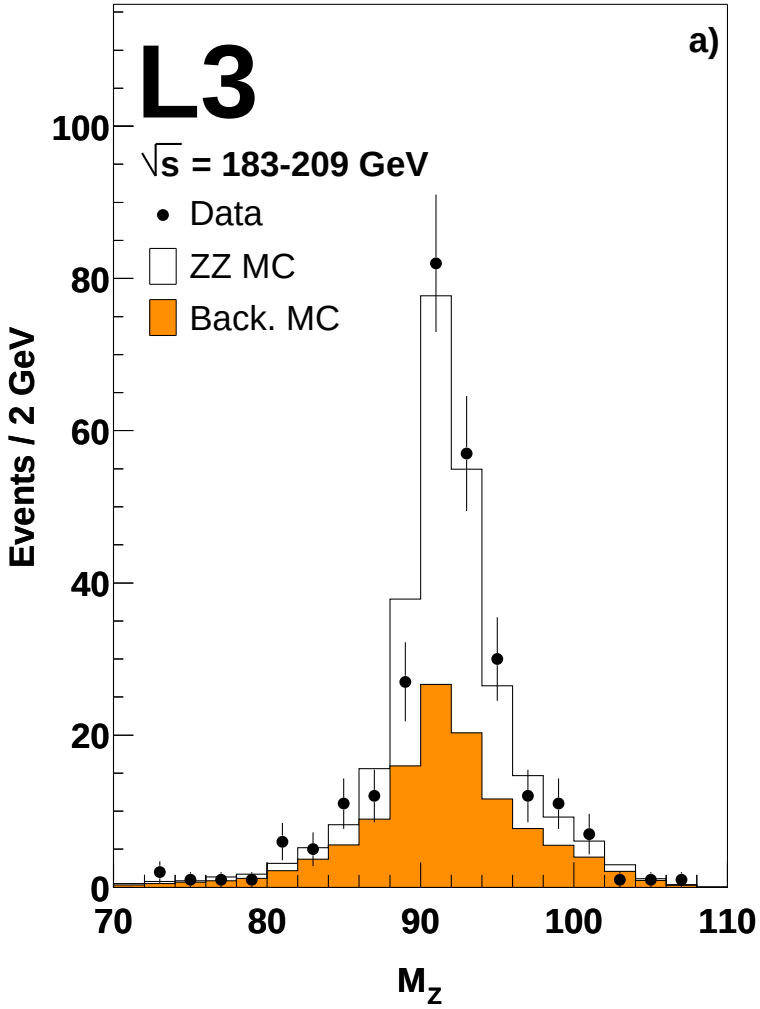
$\mathrm{R} < 2.5\%$ (negligible effect on M_{W})

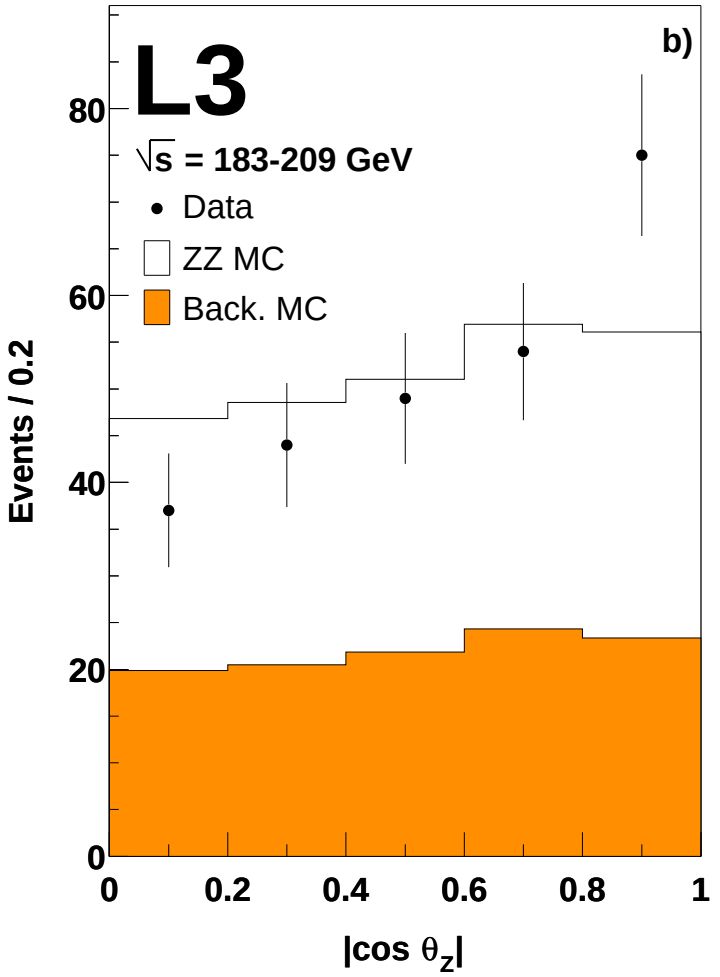
QCD: Archiving data - the L3-way

From a QCD summary paper in preparation

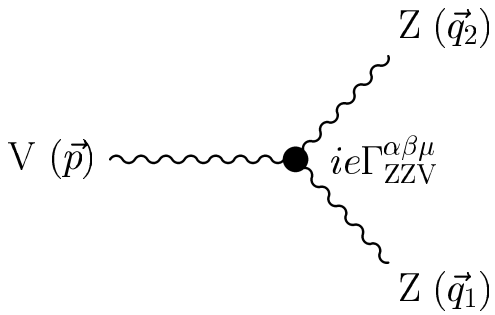
B_{T}	$\frac{1}{\sigma} \cdot \frac{\mathrm{d}\sigma}{\mathrm{d}B_{\mathrm{T}}}$		
	at $\sqrt{s} = 130.1$ GeV	at $\sqrt{s} = 136.1$ GeV	at $\sqrt{s} = 161.3$ GeV
0.000–0.020	0.082 ± 0.086 ± 0.037	0.103 ± 0.077 ± 0.090	0.117 ± 0.090 ± 0.069
0.020–0.040	4.010 ± 0.684 ± 0.468	5.454 ± 0.965 ± 0.863	9.224 ± 1.407 ± 0.577
0.040–0.060	11.651 ± 1.173 ± 0.360	11.111 ± 1.340 ± 0.898	9.486 ± 1.353 ± 0.934
0.060–0.080	8.865 ± 0.932 ± 0.289	8.945 ± 1.077 ± 0.286	8.450 ± 1.071 ± 0.344
0.080–0.100	7.778 ± 0.884 ± 0.880	7.419 ± 1.042 ± 0.468	5.530 ± 0.841 ± 0.214
0.100–0.120	4.239 ± 0.638 ± 0.388	3.464 ± 0.669 ± 0.235	4.231 ± 0.740 ± 0.197
0.120–0.140	3.780 ± 0.591 ± 0.246	3.259 ± 0.652 ± 0.210	3.080 ± 0.613 ± 0.490
0.140–0.160	2.509 ± 0.455 ± 0.091	2.237 ± 0.531 ± 0.106	3.025 ± 0.597 ± 0.137
0.160–0.180	2.031 ± 0.404 ± 0.147	1.568 ± 0.421 ± 0.101	1.894 ± 0.473 ± 0.248
0.180–0.200	1.820 ± 0.375 ± 0.127	1.865 ± 0.447 ± 0.280	1.293 ± 0.396 ± 0.173
0.200–0.220	0.897 ± 0.241 ± 0.053	1.516 ± 0.411 ± 0.237	1.069 ± 0.375 ± 0.143
0.220–0.240	0.790 ± 0.208 ± 0.099	1.074 ± 0.317 ± 0.141	1.338 ± 0.379 ± 0.228
0.240–0.260	0.363 ± 0.146 ± 0.097	0.661 ± 0.239 ± 0.066	0.408 ± 0.218 ± 0.164
0.260–0.280	0.629 ± 0.186 ± 0.166	0.548 ± 0.205 ± 0.080	0.067 ± 0.128 ± 0.019
0.280–0.300	0.227 ± 0.113 ± 0.030	0.198 ± 0.115 ± 0.041	0.710 ± 0.238 ± 0.224
0.300–0.320	0.052 ± 0.053 ± 0.020	0.252 ± 0.137 ± 0.083	0.000 ± 0.000 ± 0.000
0.320–0.340	0.086 ± 0.061 ± 0.020	0.217 ± 0.108 ± 0.138	0.078 ± 0.127 ± 0.016
0.340–0.360	0.092 ± 0.065 ± 0.045	0.108 ± 0.077 ± 0.020	0.000 ± 0.000 ± 0.000
First Moment	0.0976 ±0.0023± 0.0008	0.0999 ±0.0029± 0.0012	0.0923 ±0.0032± 0.0018
Second Moment	0.0131 ±0.0006± 0.0002	0.0141 ±0.0008± 0.0004	0.0121 ±0.0008± 0.0004

Electroweak: $e^+e^- \rightarrow ZZ$





Electroweak: ZZ final state and anomalous couplings



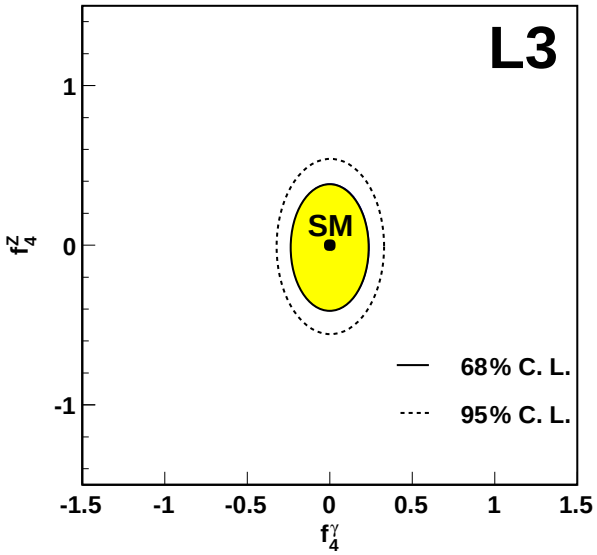
parametrised via $f_4^{\mathrm{Z},\gamma}$ (CP viol.) and $f_5^{\mathrm{Z},\gamma}$ (CP cons.)

Final results

1D limits and 2D contours

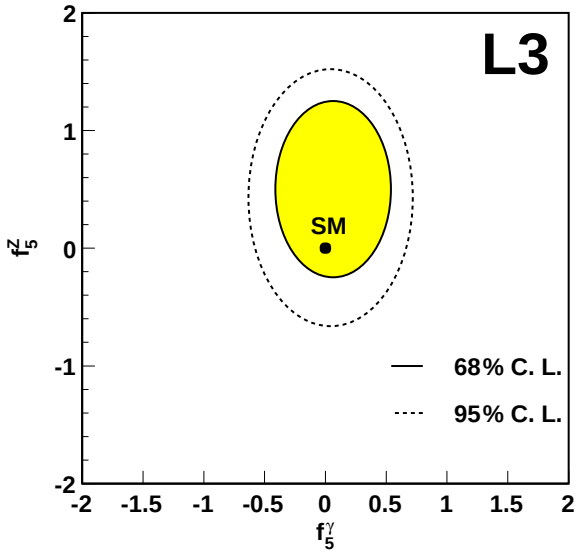
$-0.48 < f_4^{\mathrm{Z}} < 0.46$

$-0.28 < f_4^{\gamma} < 0.28$



$-0.36 < f_5^{\mathrm{Z}} < 1.03$

$-0.40 < f_5^{\gamma} < 0.47$

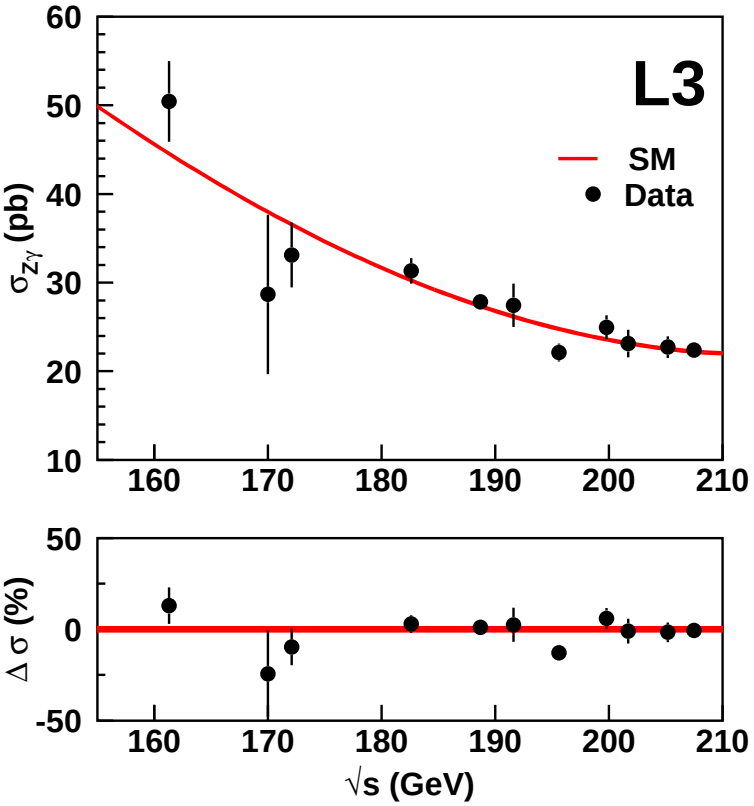


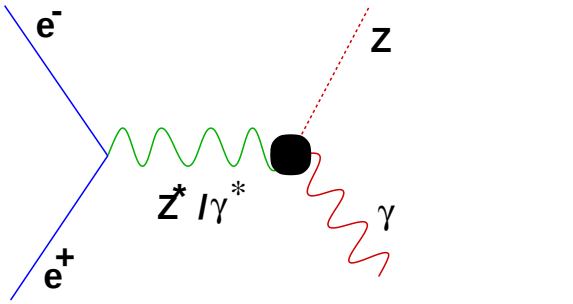
Electroweak: Zγ final state and anomalous couplings

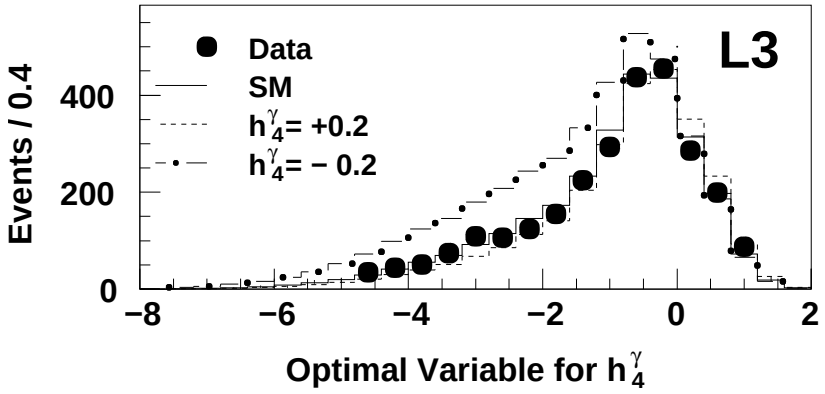
Analysed channels:

$e^+e^- \to Z\gamma \to q\bar{q}\gamma$

$e^+e^- \to Z\gamma \to \nu\bar{\nu}\gamma$







95% CL limits - CP viol.

$-0.15 < h_1^Z < 0.14 \qquad -0.06 < h_1^\gamma < 0.06$

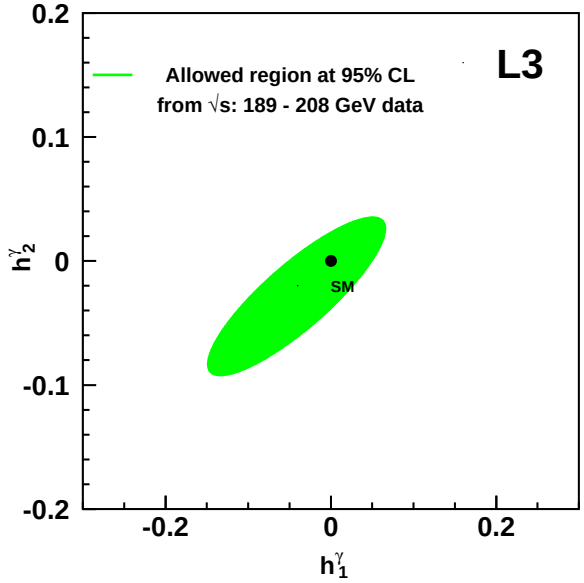
$-0.09 < h_2^Z < 0.08 \qquad -0.05 < h_2^\gamma < 0.02$

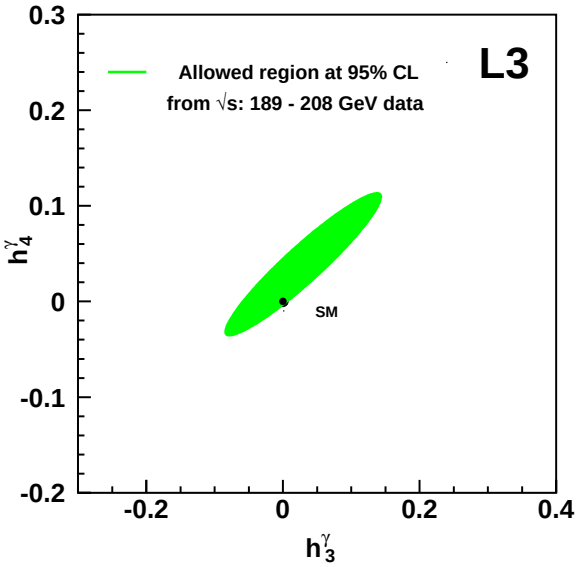
95% CL limits - CP cons.

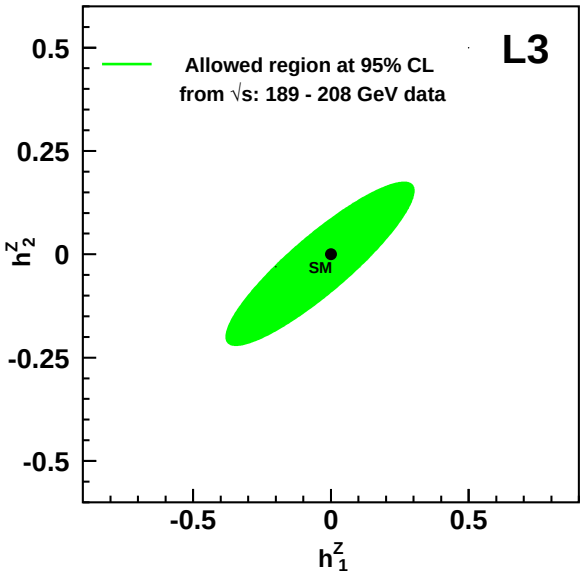
$-0.22 < h_3^Z < 0.11 \qquad -0.06 < h_3^\gamma < 0.00$

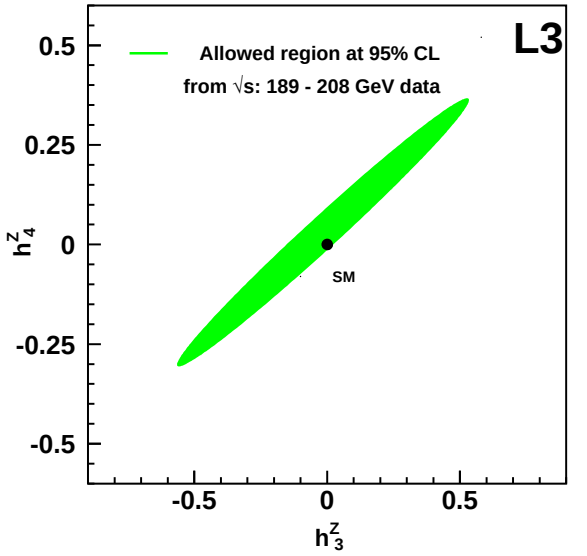
$-0.07 < h_4^Z < 0.15 \qquad 0.00 < h_4^\gamma < 0.04$

Electroweak: $Z\gamma$ final state and anomalous couplings





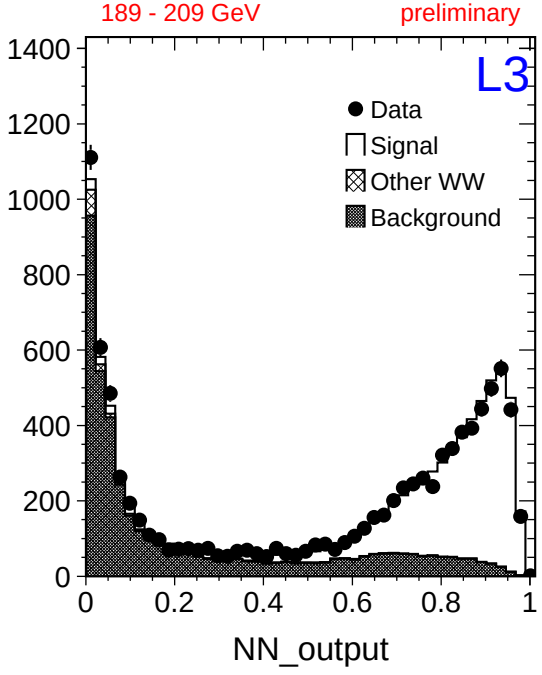




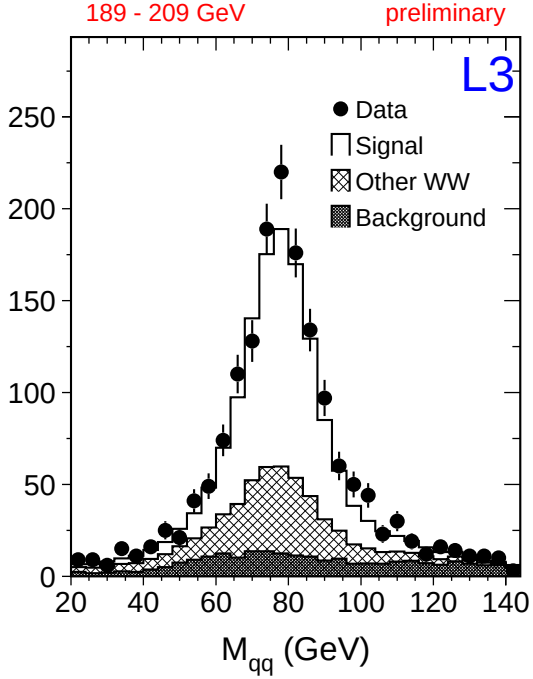
Electroweak: W pair-production

- Updated analyses of all data collected at $189 \leq \sqrt{s} \leq 209$ GeV
- Improved selections, detector calibrations, kinematic fit procedures and efficiency determination based on $\mathcal{O}(\alpha)$ MonteCarlo
- Improvements propagated to other analyses (charged Higgs search, flavour independent Higgs search, ...)

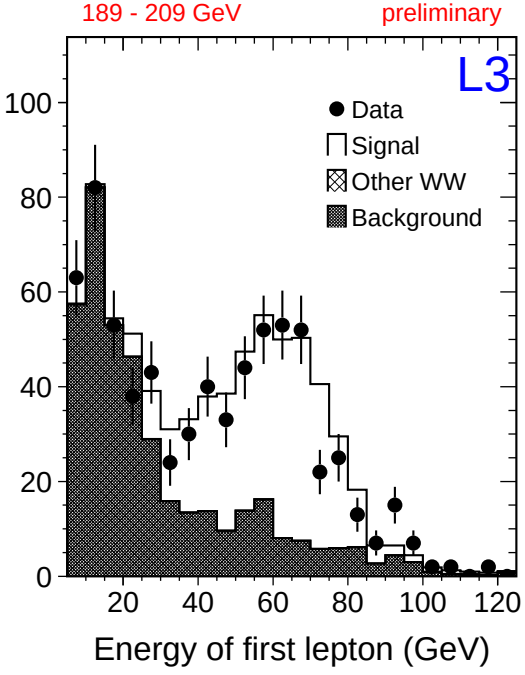
qqqq selection



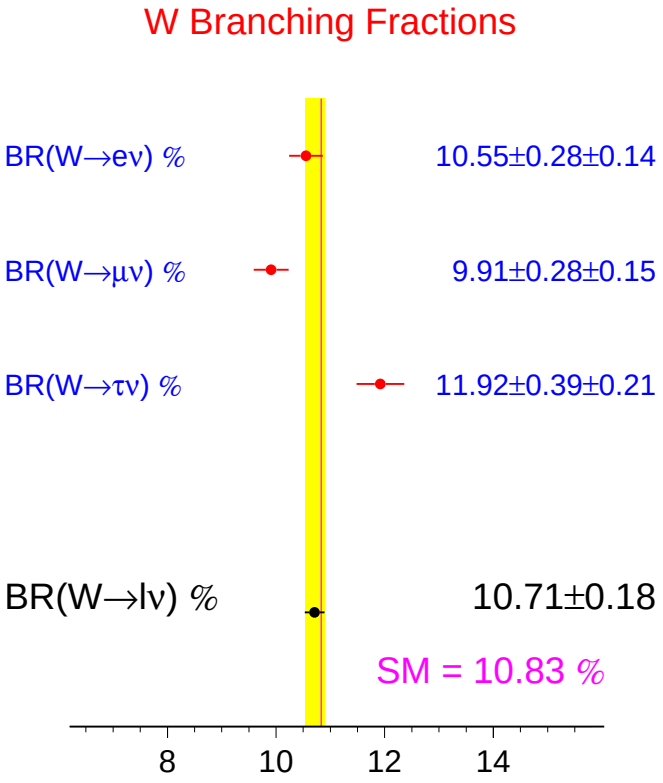
$\mathrm{qq}\tau\nu$ selection

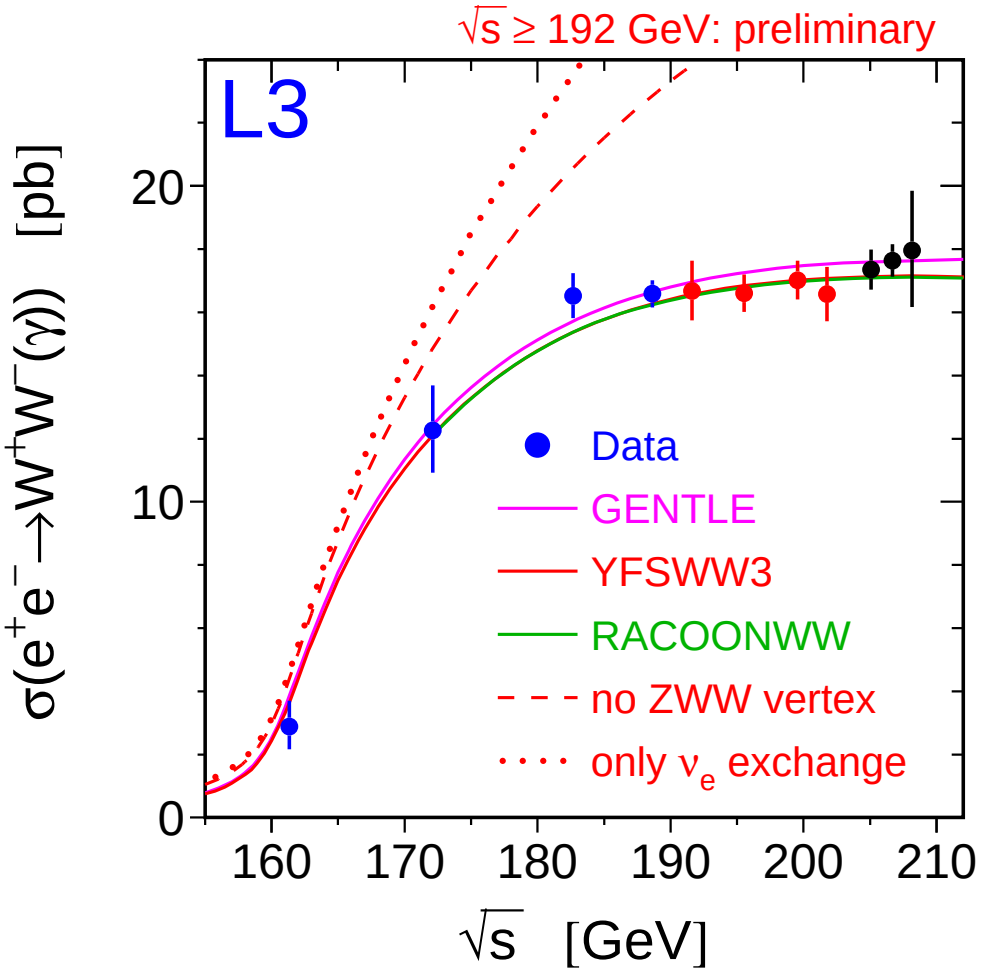


$\ell\nu\ell\nu$ selection



Electroweak: W pair-production





1-parameter fits

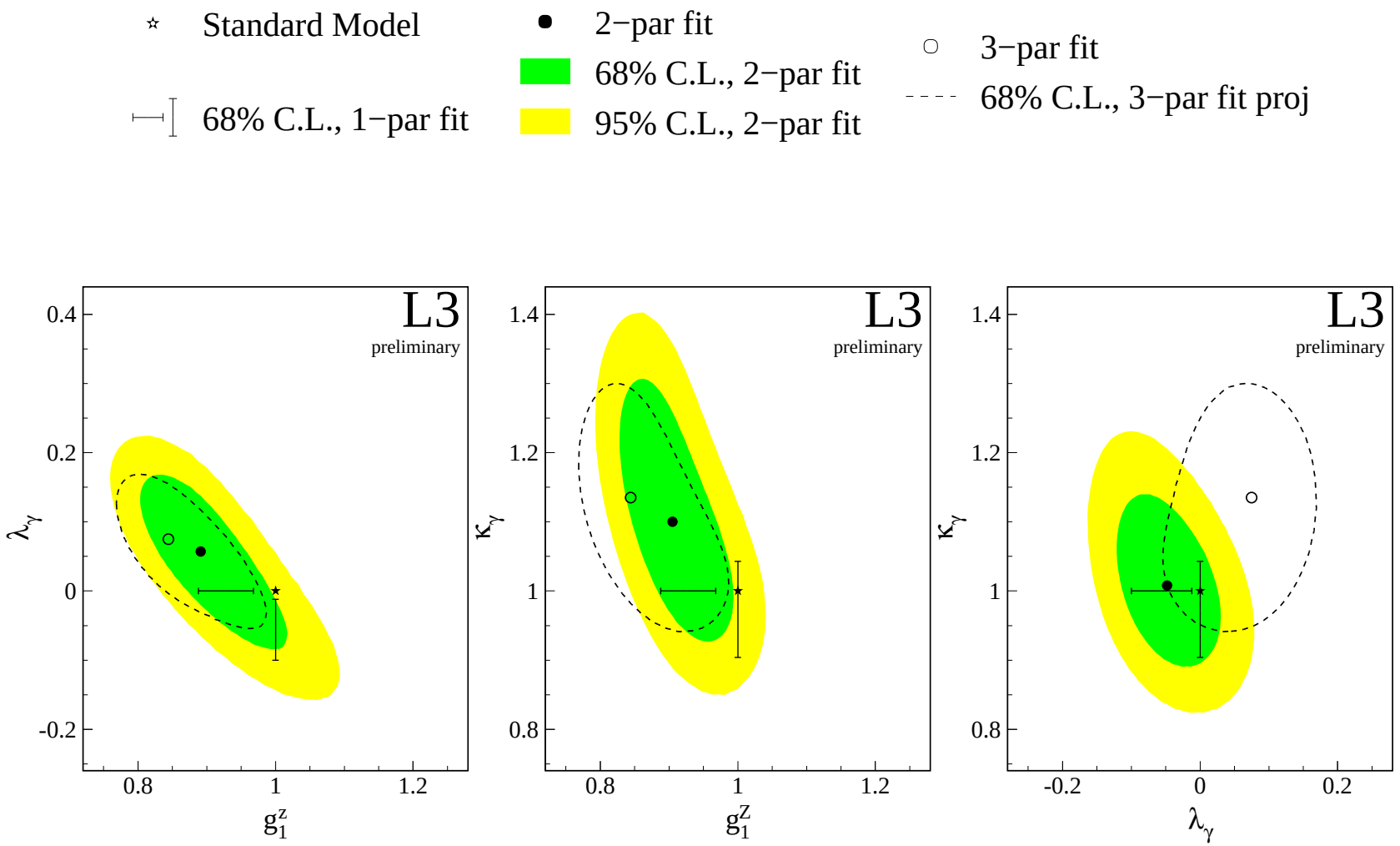
assuming:
$k_\mathrm{Z} = g_1^\mathrm{Z} - \tan^2\theta_\mathrm{W}(\kappa_\gamma - 1)$ and
$\lambda_\gamma = \lambda_\mathrm{Z}$

without any constraint:

	(SM)		(SM)
$g_1^\mathrm{Z} =$	$0.927^{+0.035}_{-0.034} \pm 0.021$ (1)	$g_5^\mathrm{Z} =$	$0.00\ ^{+0.15}_{-0.15} \pm 0.06$ (0)
$k_\gamma =$	$0.972^{+0.066}_{-0.063} \pm 0.024$ (1)	$k_\mathrm{Z} =$	$0.871^{+0.061}_{-0.057} \pm 0.035$ (1)
$\lambda_\gamma =$	$-0.057^{+0.039}_{-0.036} \pm 0.022$ (0)	$\lambda_\mathrm{Z} =$	$-0.100^{+0.071}_{-0.062} \pm 0.036$ (0)

Results based on full WW and single-W [PLB547 (2002) 151] *statistics*

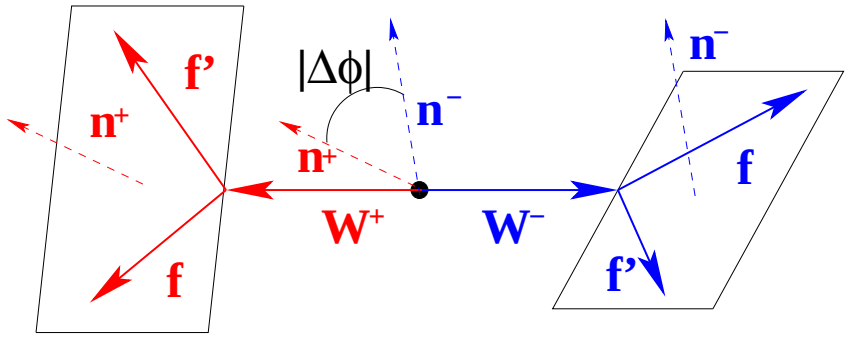
Electroweak: W pair-production and gauge couplings



Electroweak: W properties

Recently published: W polarisation studies
[Phys. Lett. B557 (2003) 147]

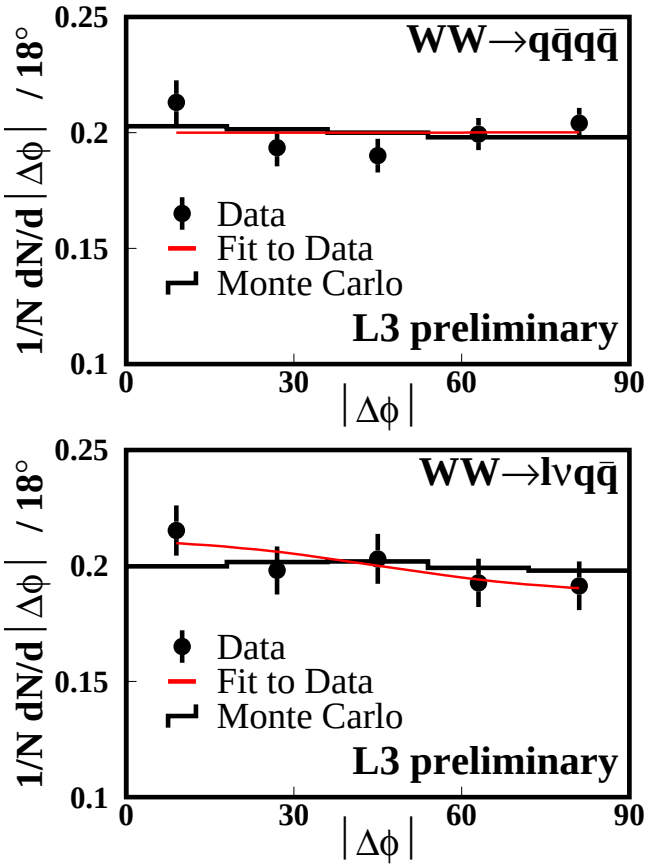
Decay planes correlations:



Data are fitted according to:

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}|\Delta\Phi|} = 1 + D\cos(2|\Delta\Phi|)$$

[M.J.Duncan, G.L.Kane, W.W.Repko,
Nucl. Phys. B272 (1986) 517]



$D(\text{L3 data}) = 0.017 \pm 0.019 \pm 0.011$
$D(\text{SM}) = 0.010 \pm 0.002$

Electroweak: Photons and missing energy

$$e^+e^- \longrightarrow \nu\bar{\nu}\gamma, \nu\bar{\nu}\gamma\gamma$$

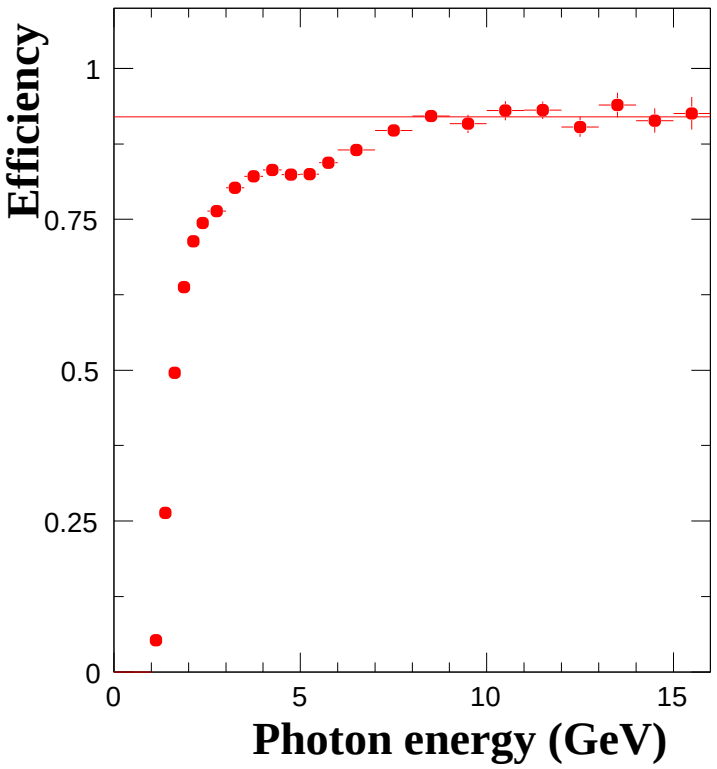
New analysis based on full statistics:

- improved detector response modeling
- cosmic ray background rejection
- trigger efficiency
- latest generation Monte Carlo:
  - *NUNUGPV* [G.Montagna et al., Nucl. Phys. B541 (1999) 31]
  - *KKMC* [S.Jadach, B.F.L.Ward, Z.Was, Comp. Phys. Comm. 130 (2000) 260]
- Unique low p_T selection $(0.016E_{beam} < p_T < 0.04E_{beam})$ for improved sensitivity to New Physics

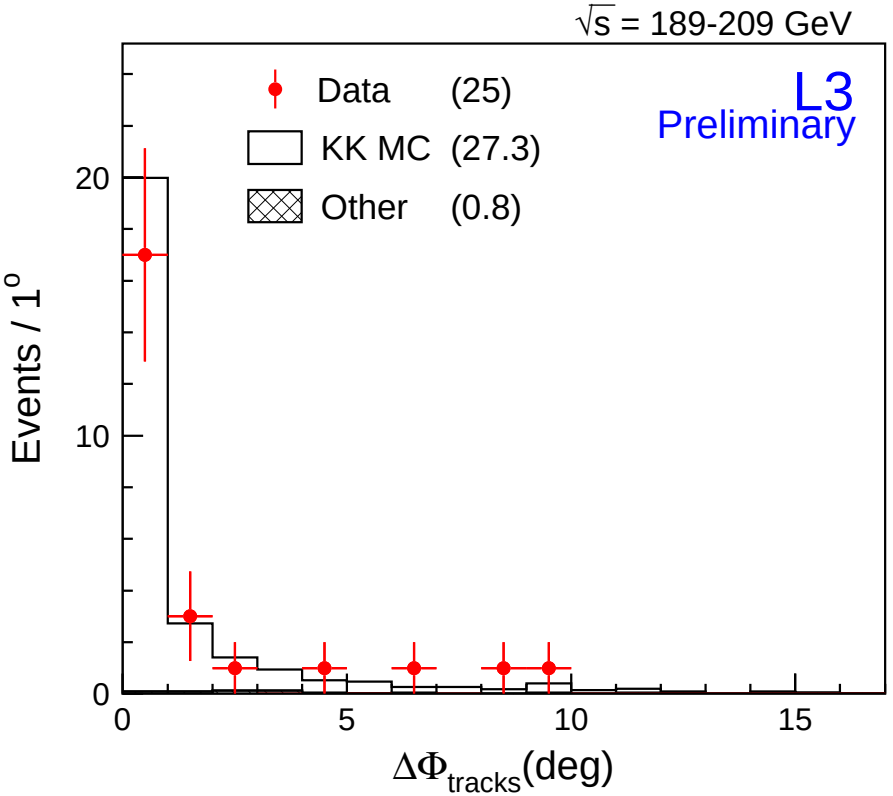
Electroweak: Photons and missing energy

Trigger efficiency barrel

dedicated sub-triggers and Bhabha's



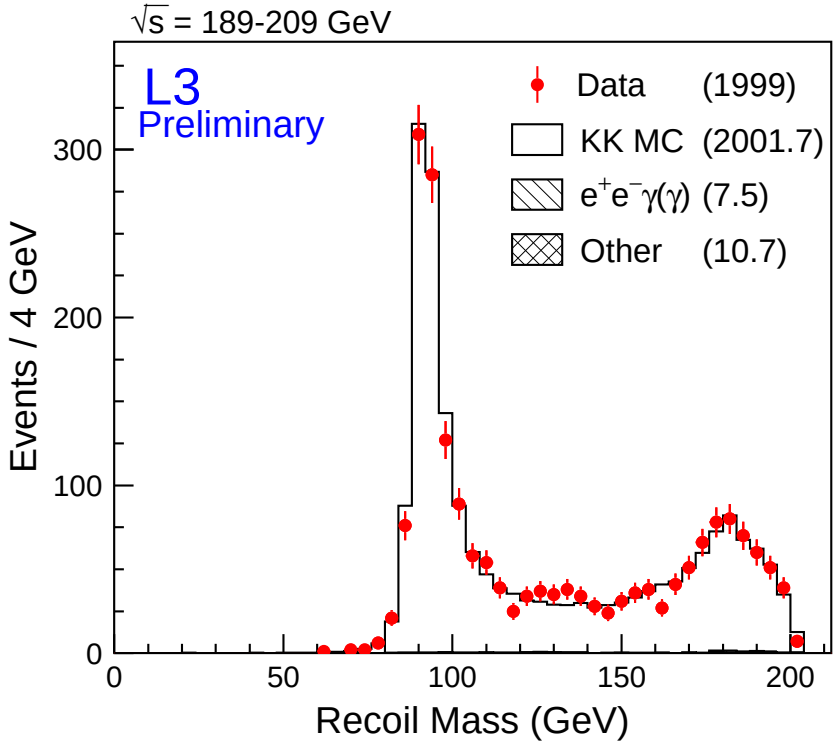
Tagged γ conversions are included in the sample



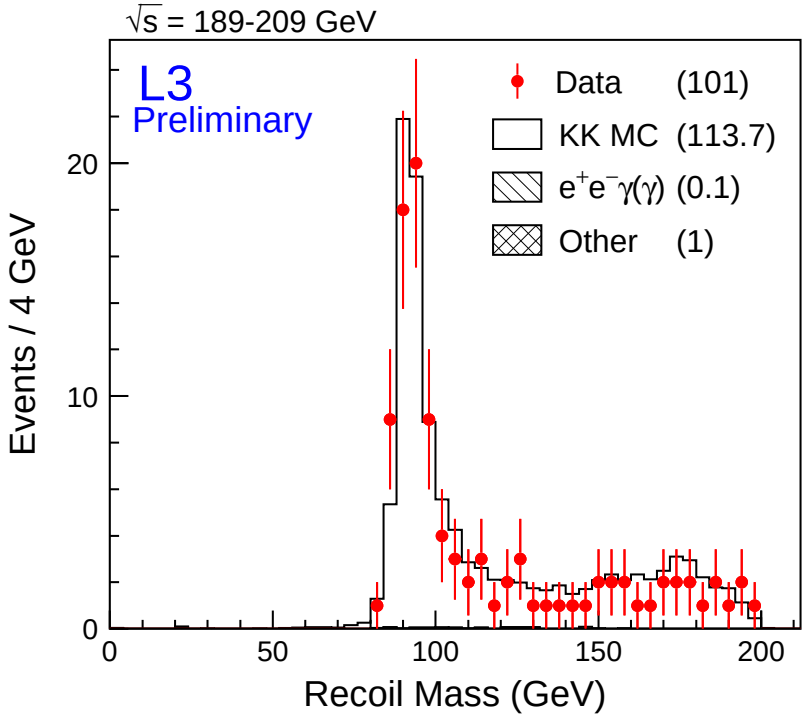
Electroweak: Photons and missing energy

$$189 \ \text{GeV} \leq \sqrt{s} \leq 209 \ \text{GeV}$$

Combined sample



Two reconstructed photons



All results archived the L3-way: publish complete tables

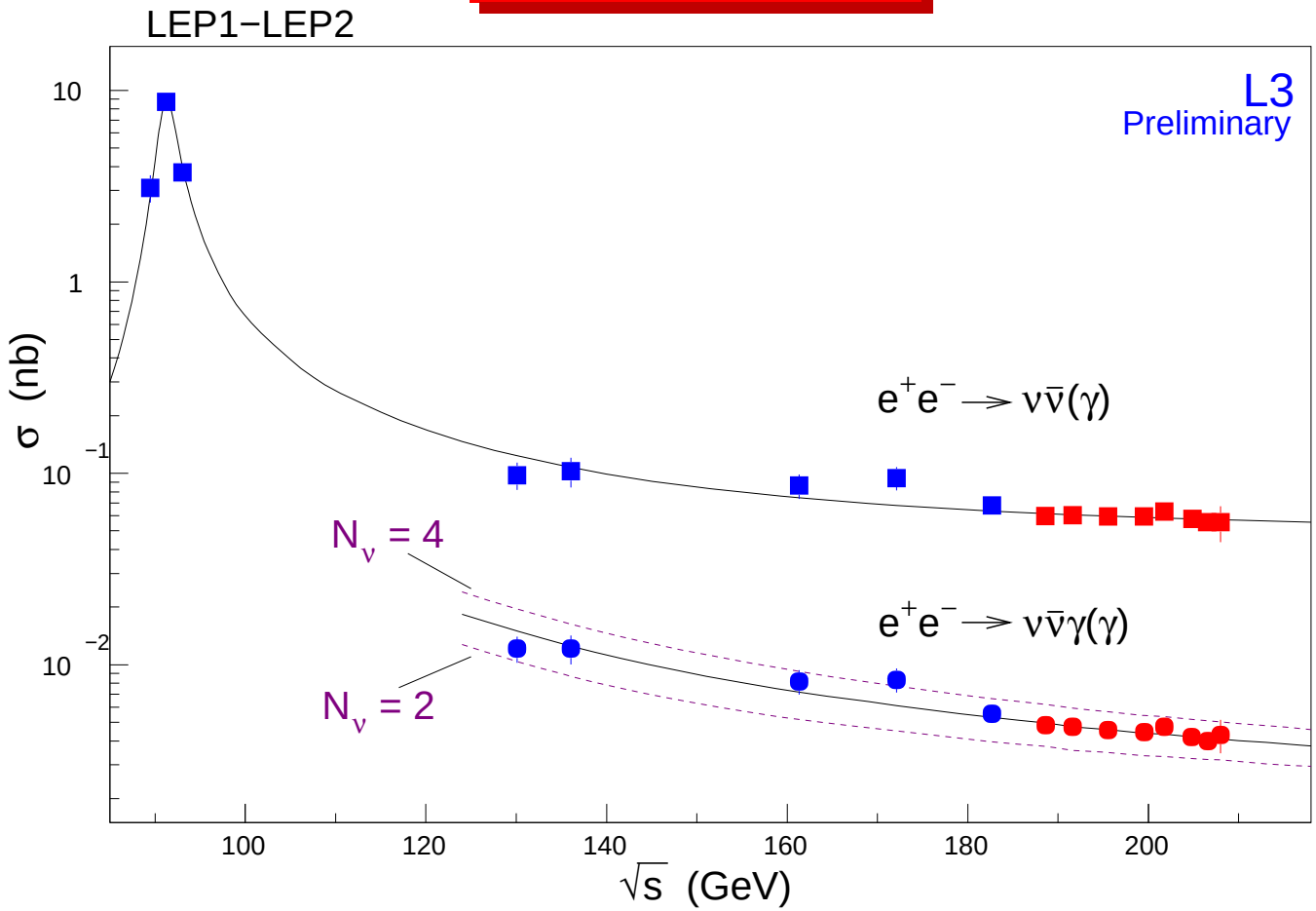
Archiving

$\cos\theta_\gamma$	Data events/Standard Model Expectation/Efficiency[%] (M_{rec} in GeV)					
	0-70	70-95	95-120	120-150	150-180	180-210
0.000–0.200	1/0.5/80	55/52.9/88	34/38.5/87	20/20.1/86	40/39.4/81	50/55.6/70
0.200–0.400	1/0.5/78	48/65.4/89	49/40.1/88	32/20.4/84	49/43.1/82	65/58.0/70
0.600–0.600	0/0.4/79	67/81.7/87	57/54.9/88	27/27.0/87	65/51.5/80	56/65.9/71
0.600–0.730	0/0.6/78	83/68.1/83	43/54.1/83	28/24.2/82	57/46.3/78	44/47.1/64
0.800–0.870	0/0.7/78	84/83.0/93	57/60.2/92	33/31.2/90	47/49.4/81	38/35.5/37
0.870–0.920	0/0.7/74	100/91.8/90	61/65.9/89	33/30.8/85	44/50.6/73	30/27.3/27
0.920–0.953	0/0.5/58	95/97.3/87	60/69.8/83	29/28.6/75	34/37.8/52	16/16.0/13
0.953–0.972	0/0.3/57	82/78.9/70	47/52.7/67	27/24.0/61	10/15.1/20	0/0./0.

All information to fit future new models to L3 precision data

Electroweak: Photons and missing energy

Cross Section

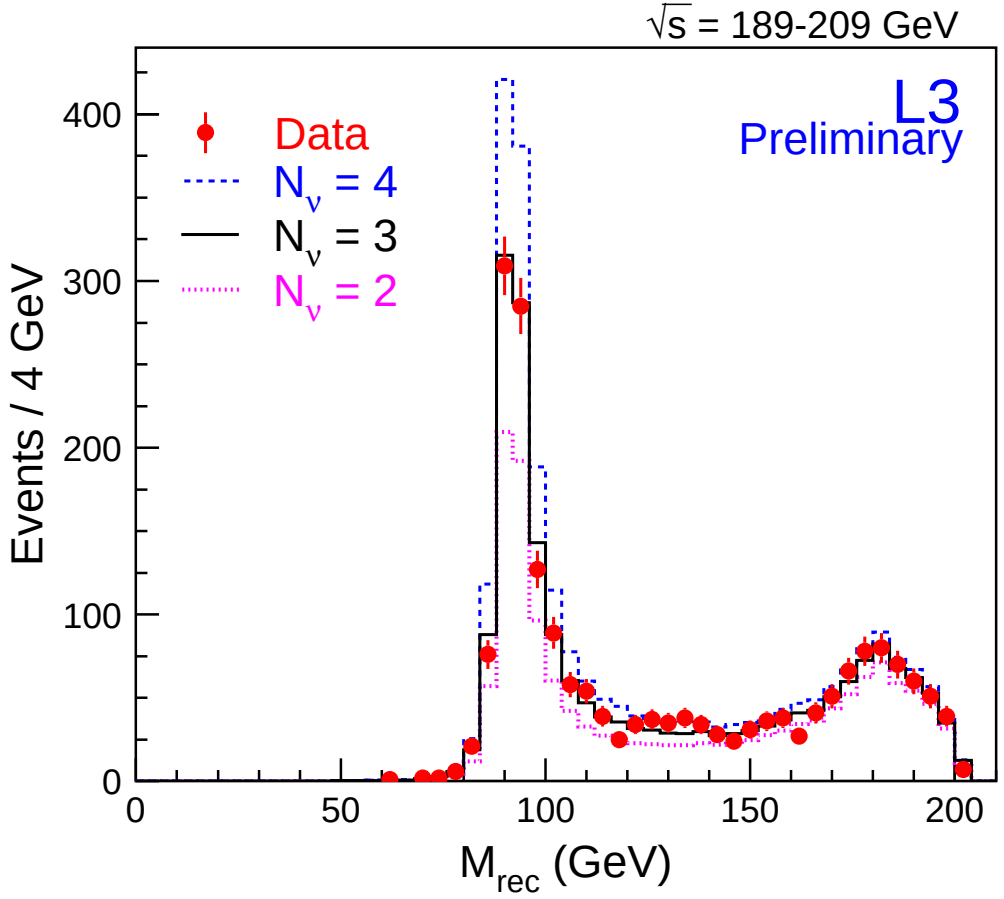


published values

Electroweak: Photons and missing energy

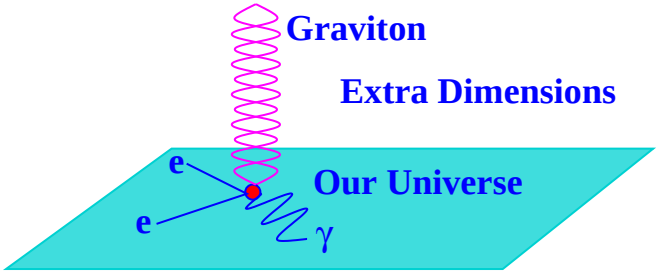
$$N_\nu = 2.95 \pm 0.08(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.02(\text{theory})$$

From a 2D fit to recoil mass and $\cos(\theta_\gamma)$



Searches: Photons and missing energy

Direct search for gravitons:

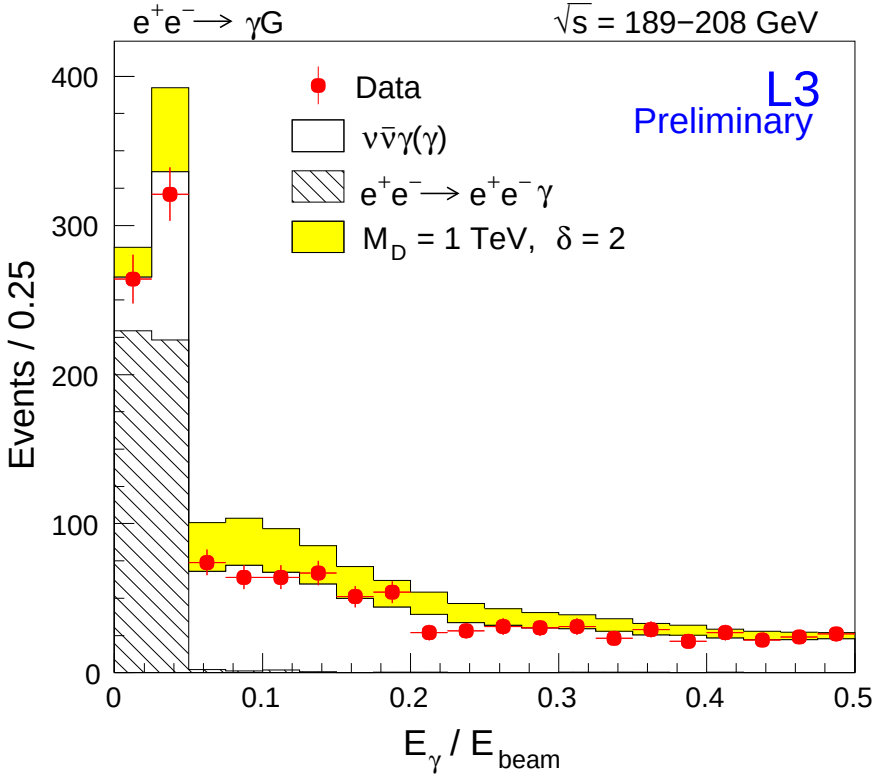


95% CL limits on scale M_D

δ	$M_D(\mathrm{TeV}) >$
2	1.50
4	0.91
6	0.65

An analogous search for super-light gravitinos gives:
$M(\tilde{G}) > 1.35 \times 10^{-5}$ eV

Low p_T selection included

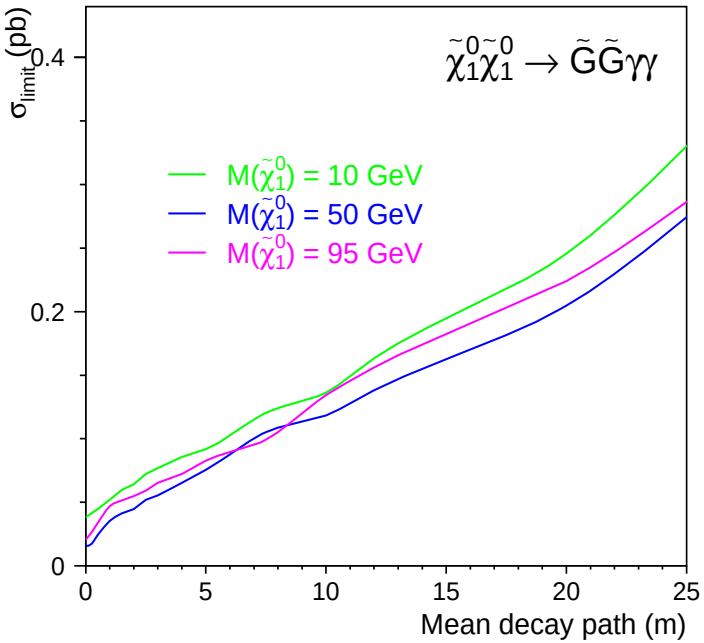


Searches: photons and missing energy

Updated analyses

Long-lived Neutralinos (GMSB)

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

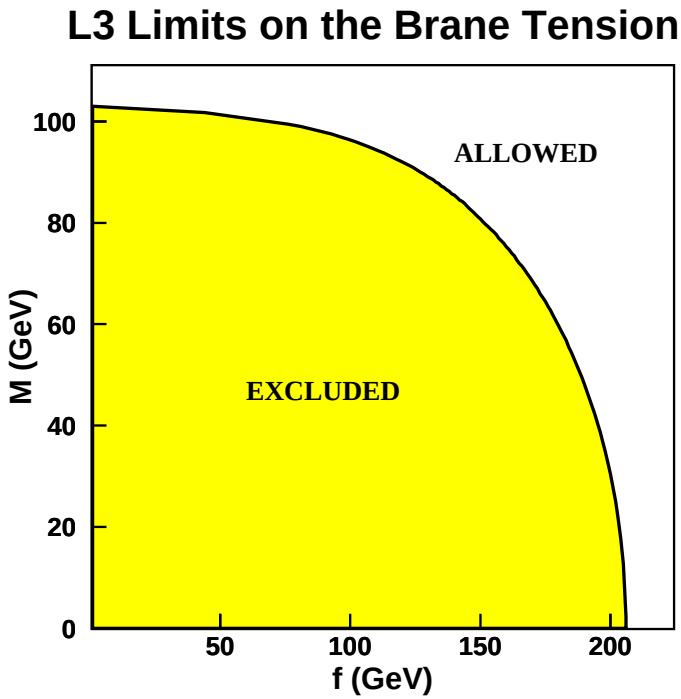


Branons

95% CL limits for:

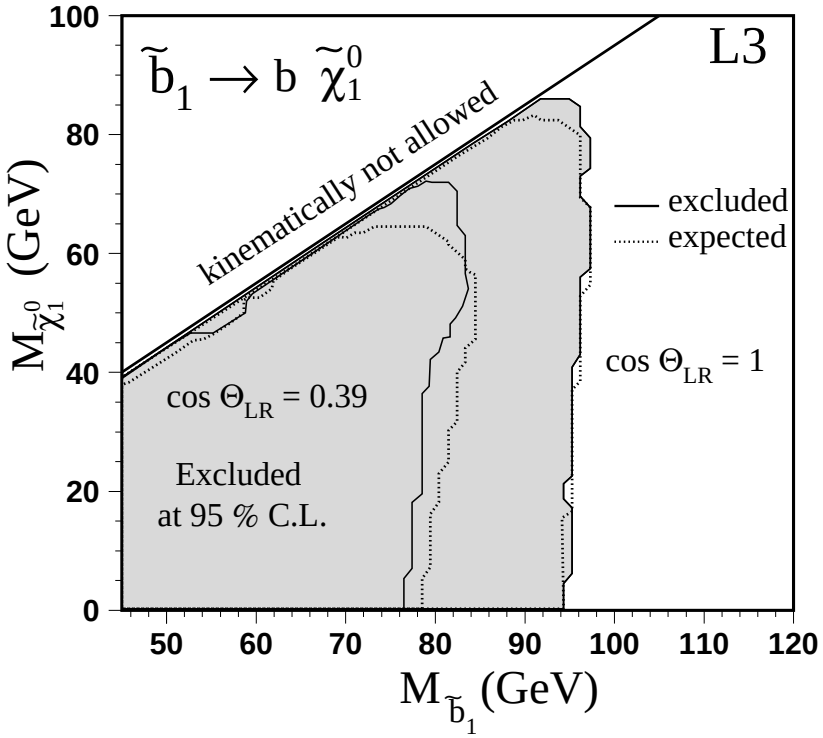
M = branon mass

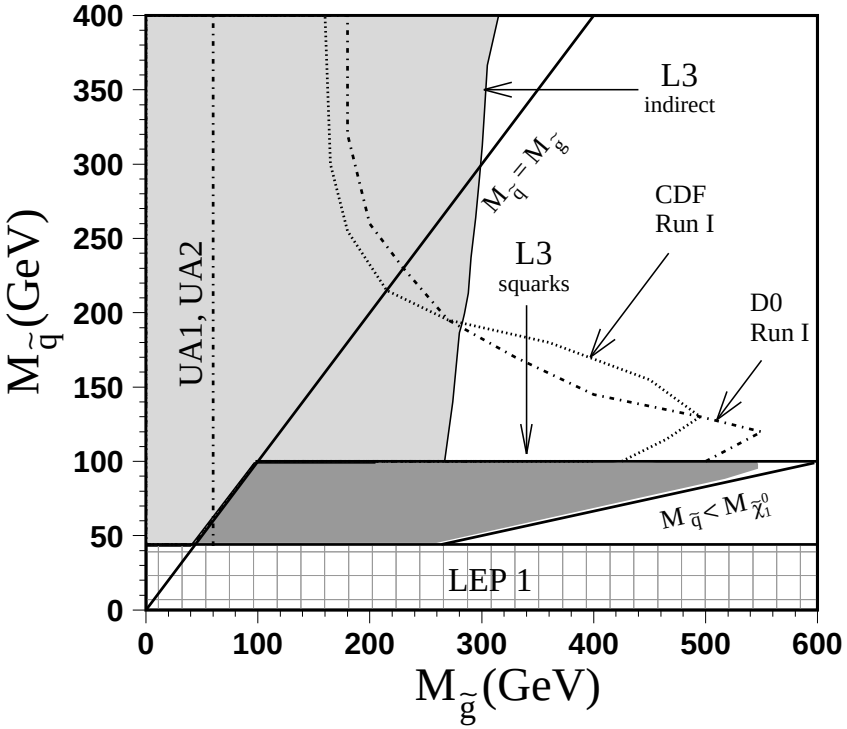
f = brane tension scale



Searches: Scalar quarks

Channels:	$e^+e^- \to \tilde{b}\bar{\tilde{b}}$,	$\tilde{b} \to \tilde{\chi}^0_1 b$	Acoplanar b-jets
	$e^+e^- \to \tilde{t}\bar{\tilde{t}}$,	$\tilde{t} \to \tilde{\chi}^0_1 c$	Acoplanar jets
	$e^+e^- \to \tilde{t}\bar{\tilde{t}}$,	$\tilde{t} \to \tilde{\nu} b \ell$	Acoplanar jets and leptons
	$e^+e^- \to \tilde{q}\bar{\tilde{q}}$,	$\tilde{q} \to \tilde{\chi}^0_1 q$	Acoplanar jets





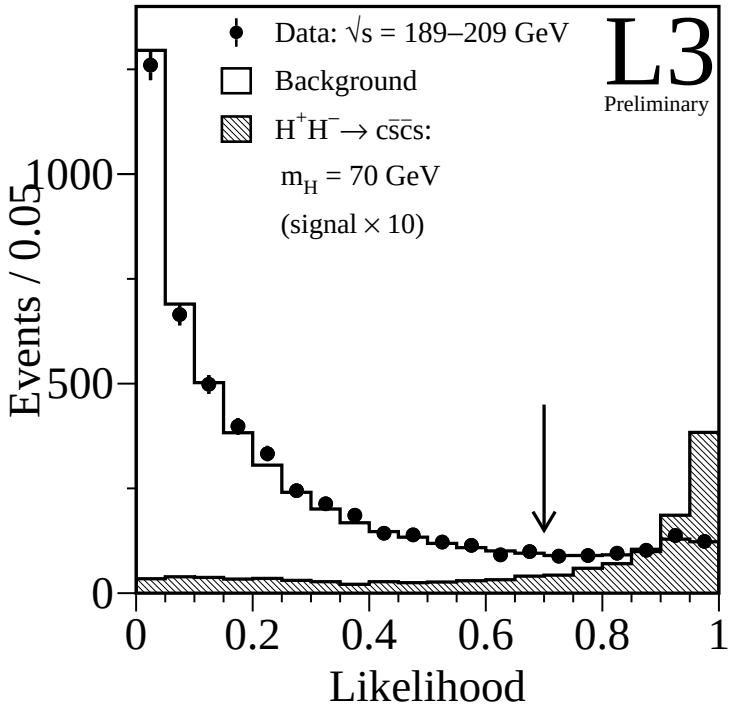
$M(\tilde{b}) > 95$ GeV (95% CL) for $\cos\theta_{LR} = 1$

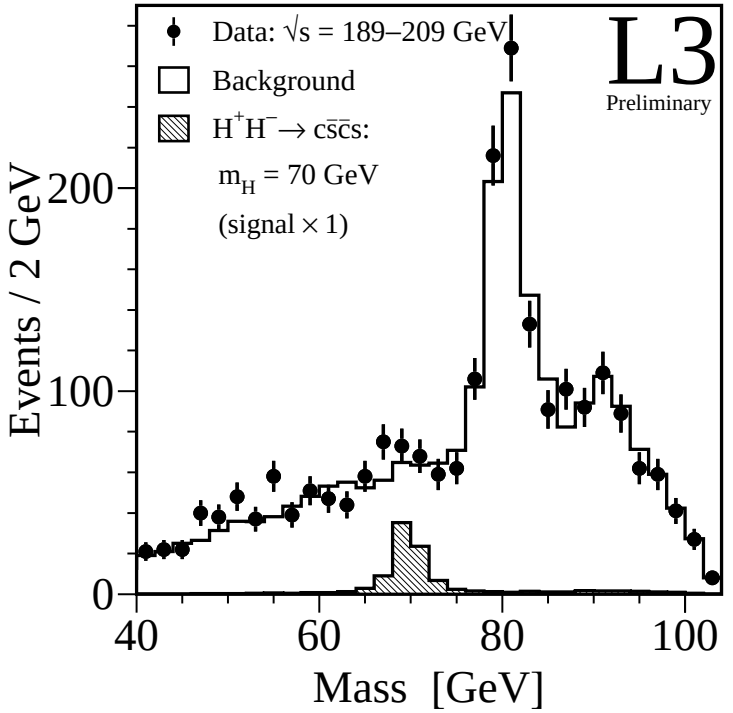
Searches: Charged Higgs

Final analysis based on WW selections

- Likelihood based:
  - $\cos\theta_{\mathrm{H}}$, mass and energy difference, θ_{min}, WW matrix element, $\cos\theta_{\mathrm{thr}}$, NNet-out
- Mass dependent analysis

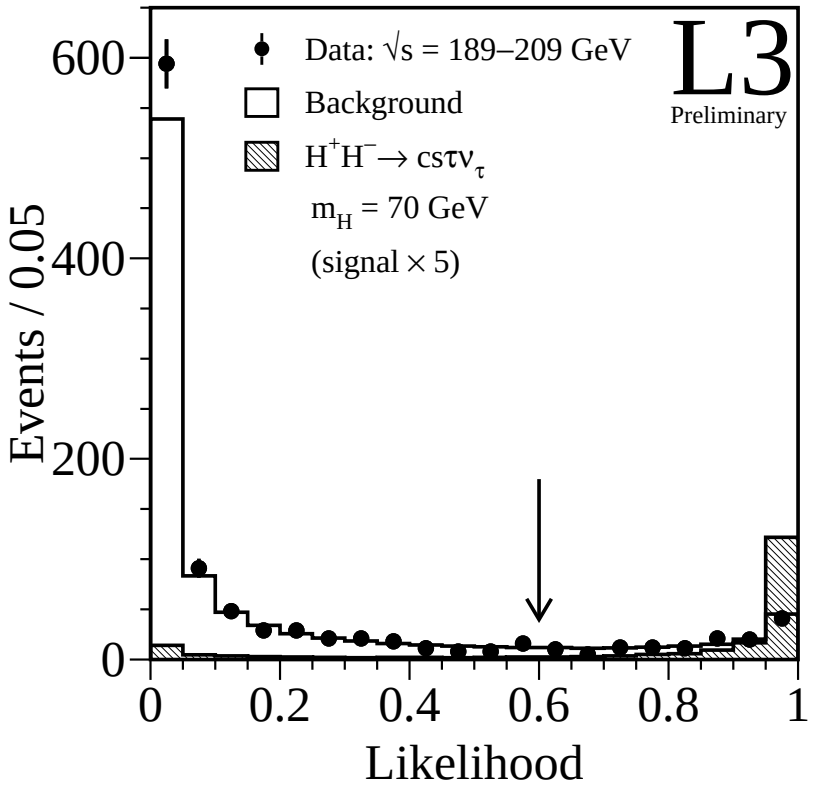
$$\mathrm{e^+e^-} \rightarrow \mathrm{H^+H^-} \rightarrow \mathrm{cscs}$$

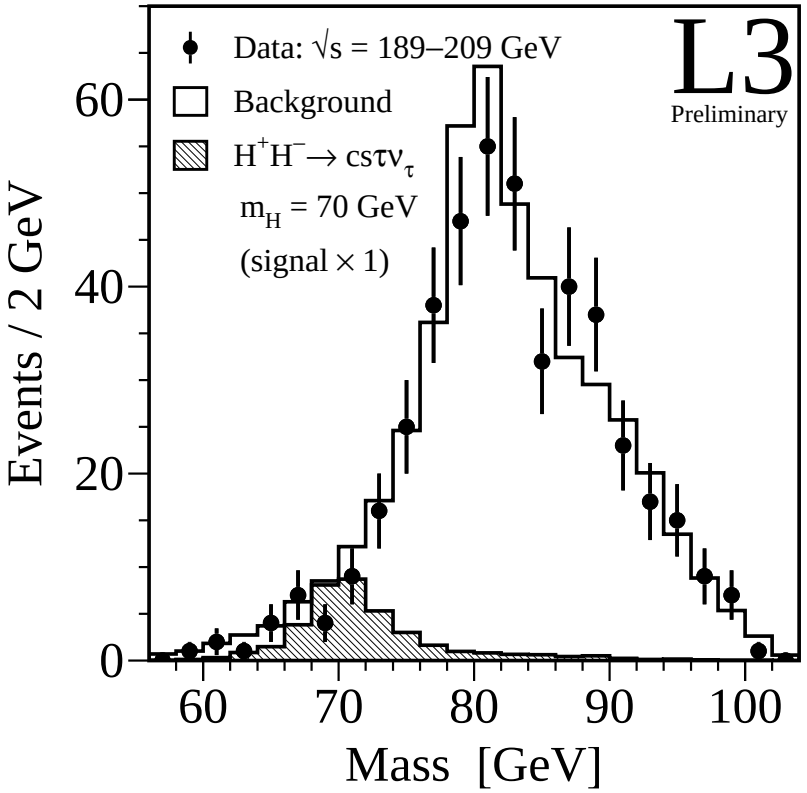




Searches: Charged Higgs

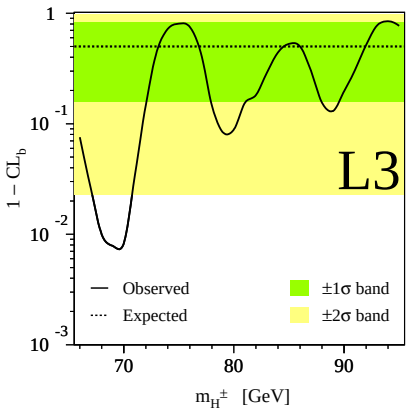
$$e^+e^- \rightarrow H^+H^- \rightarrow cs\tau\nu$$



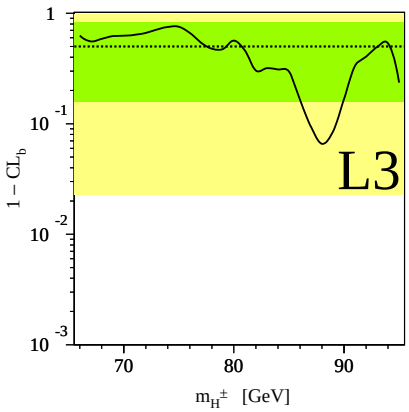


Searches: Charged Higgs - final results

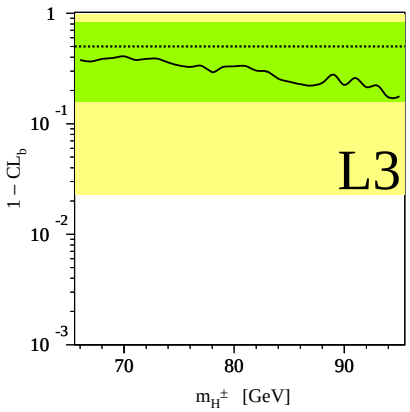
$\mathrm{Br}(\mathrm{H} \to \tau\nu) = 0.0$



$\mathrm{Br}(\mathrm{H} \to \tau\nu) = 0.5$

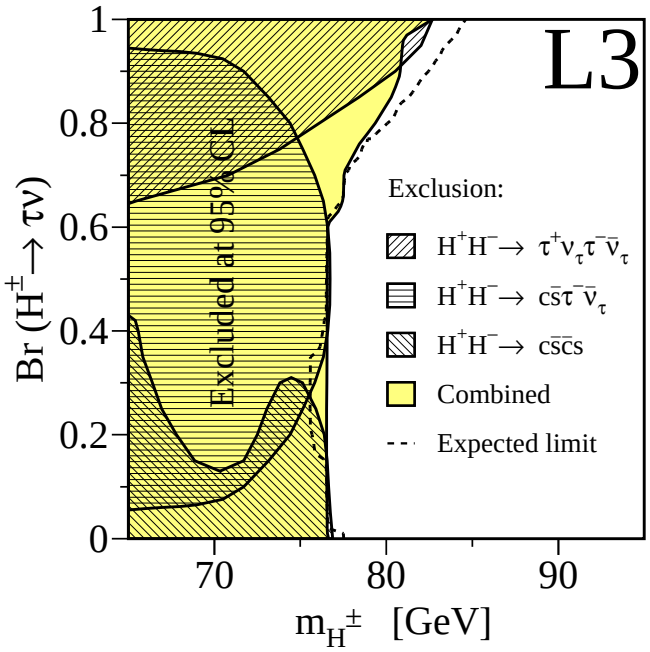


$\mathrm{Br}(\mathrm{H} \to \tau\nu) = 1.0$



Limits at 95% CL on $M_{\mathrm{H}^\pm}$

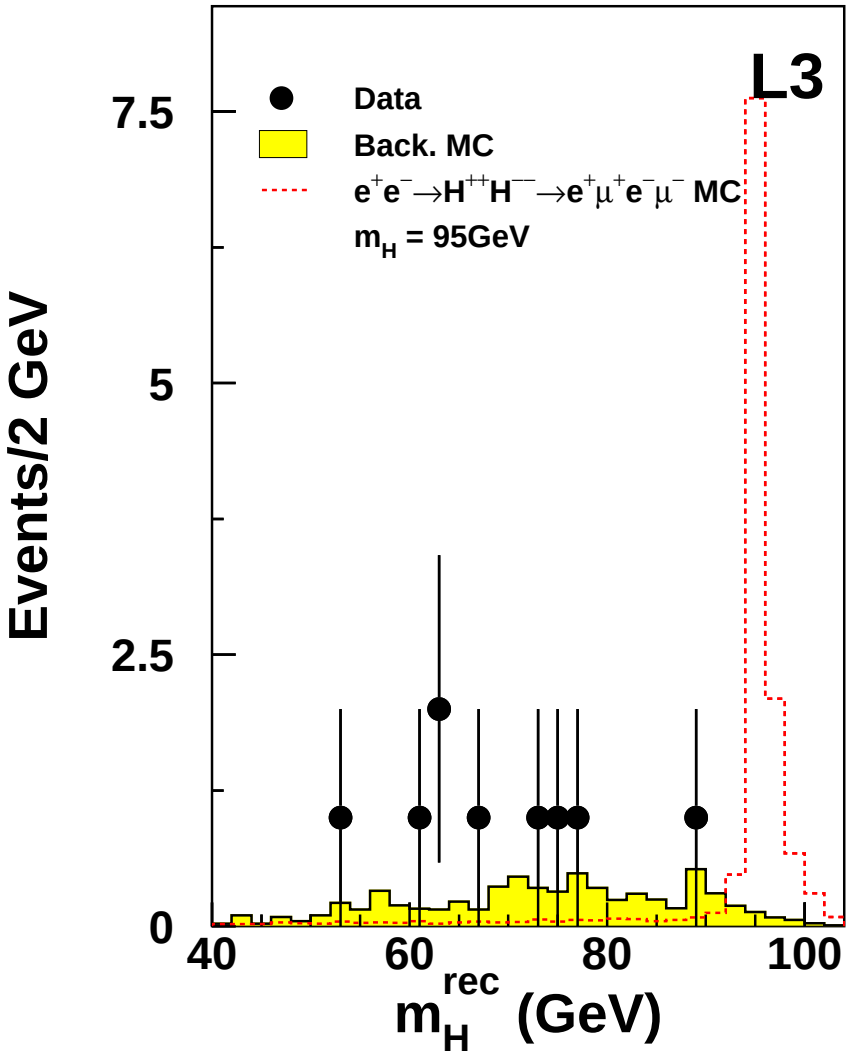
$\mathrm{Br}(\tau\nu)$	Observed	Expected
0.0	76.7 GeV	77.5 GeV
0.5	76.6 GeV	76.5 GeV
1.0	82.7 GeV	84.6 GeV
0.26	76.5 GeV	75.6 GeV



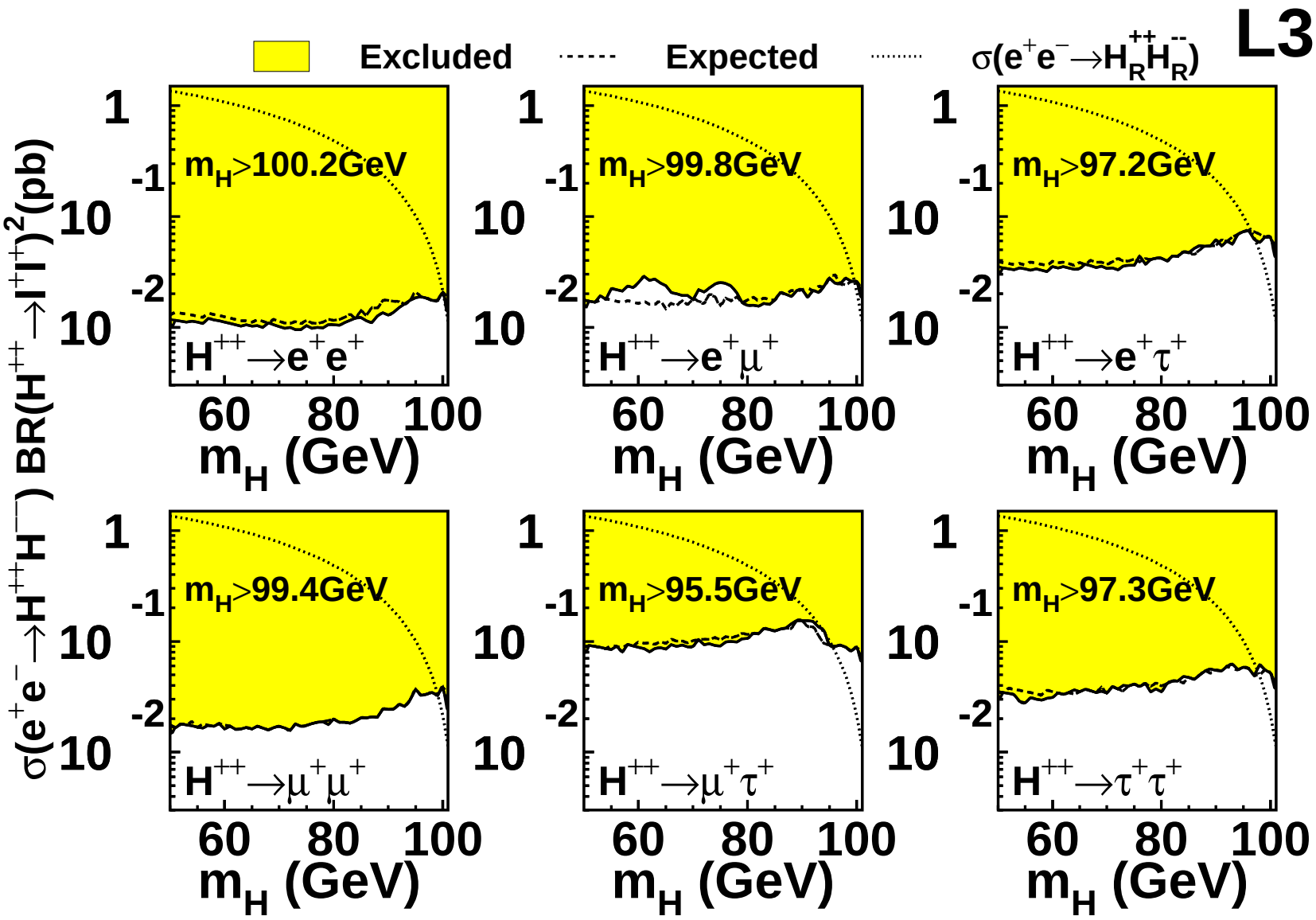
Searches: Doubly charged Higgs

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

- possible scenario in Higgs triplet models
  - Symmetric LR
    Pati, PRD10 (1974) 10
  - left-handed Higgs
    Gelmini, PLB99 (1981) 411
- couples only to charged leptons (leptonic number violation possible)
- very clean detector signature: look for four charged leptons



Searches: Doubly charged Higgs



Outlook and conclusions

- Data "archiving" by publishing detailed tables (QCD, $\gamma\gamma$, $\gamma\not{E}$, ...)

L3 in a nutshell:
$\sim$10 students $\sim$10 FTE

- 52 **abstracts submitted to EPS2003 - Aachen**
- 40 **papers published since the end of LEP**
- 8 **papers published since last LEP-Jamboree**
- 12 **drafts circulating in the collaboration**
- $\sim$30 **additional publications foreseen**

- **Key analyses will be published in the next few months**
- **We are successfully completing our physics program**