L3 Results up to 202 GeV

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On behalf of the L3 Collaboration

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1999 Data Sample

DAQ efficiency: 91.5%

Luminosity on tape:

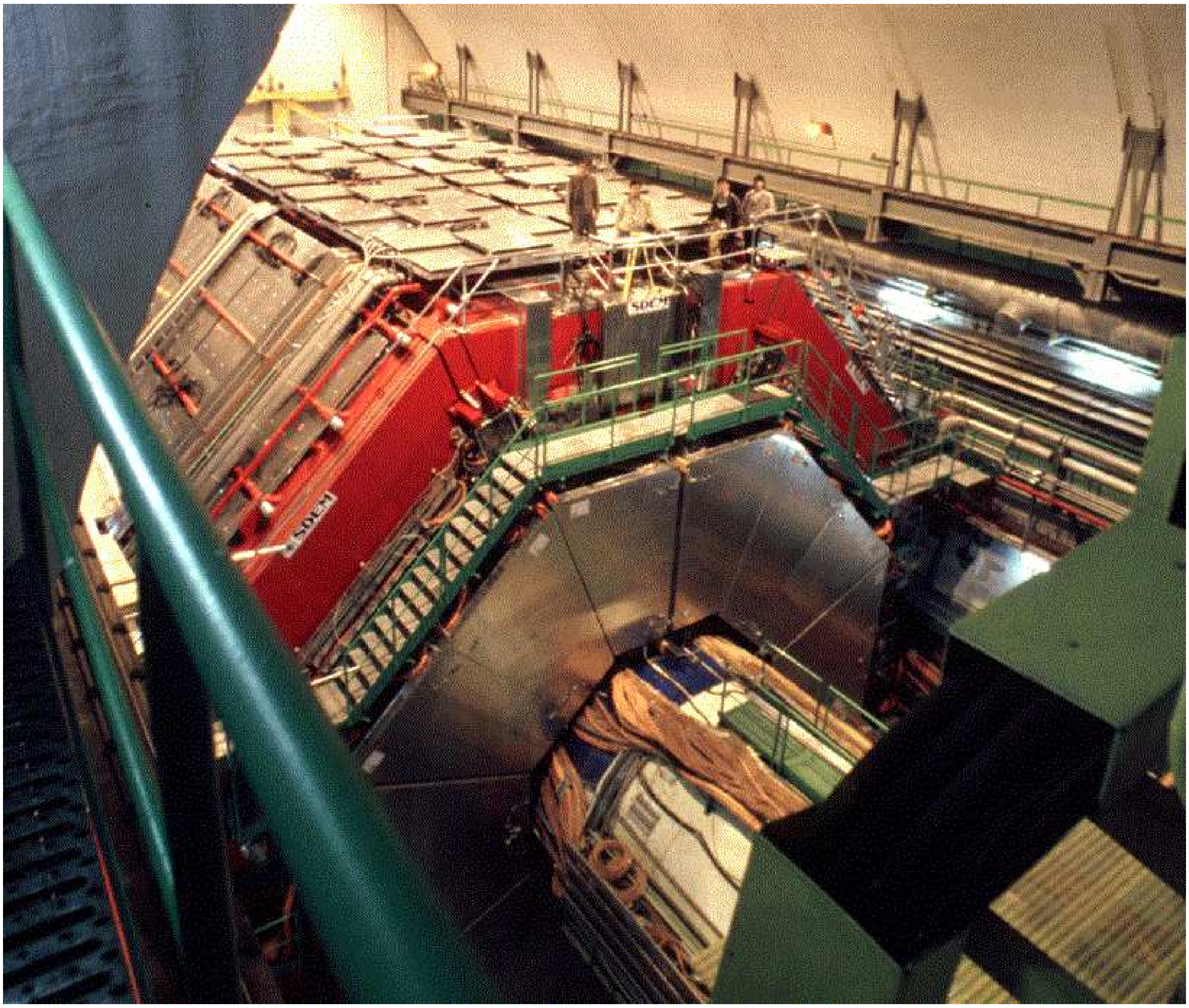
$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]
Z peak	4.0
191.6	29.7
195.5	83.7
199.5	82.8
201.7	37.0
Total	237.2

LEP200 reached and exceeded

$\mathcal{L} = 475\text{pb}^{-1}$ above W-pair threshold in total

Results are preliminary!
Limits are 95% CL

Cosmic Muon Physics

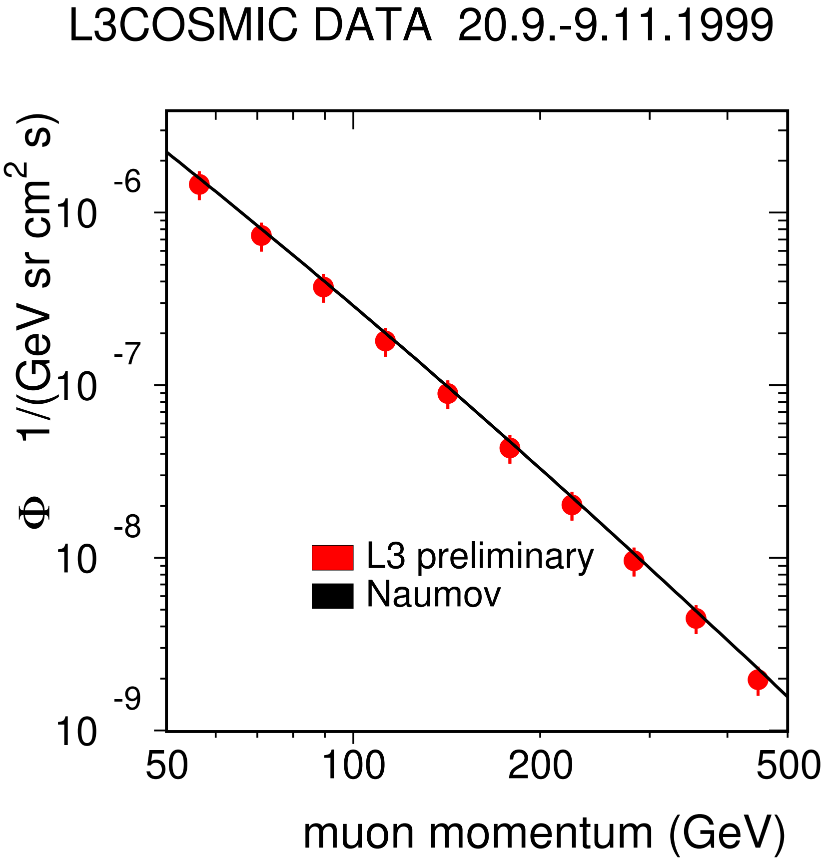


200 m^2 of scintillator tiles

- Independent muon chamber TDCs and DAQ

1999 data taking:

- 450 Hz trigger rate
- $5 \cdot 10^9$ triggers collected
- 5 Terabytes of data



Fraction of data

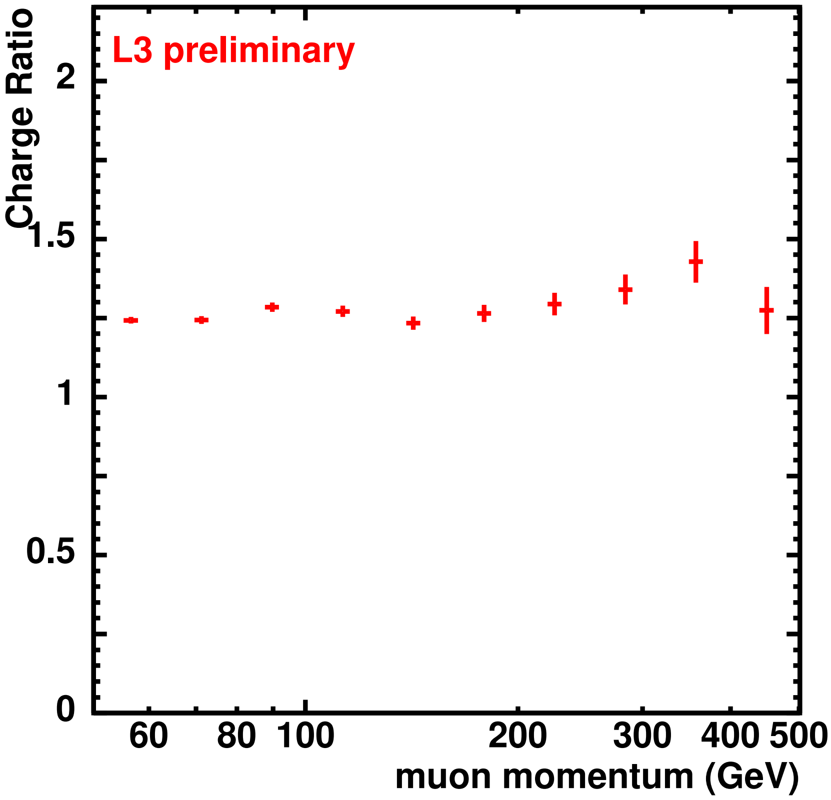
Muon flux Φ:

Zenith angle $< 10°$

Corrected for:

Efficiency

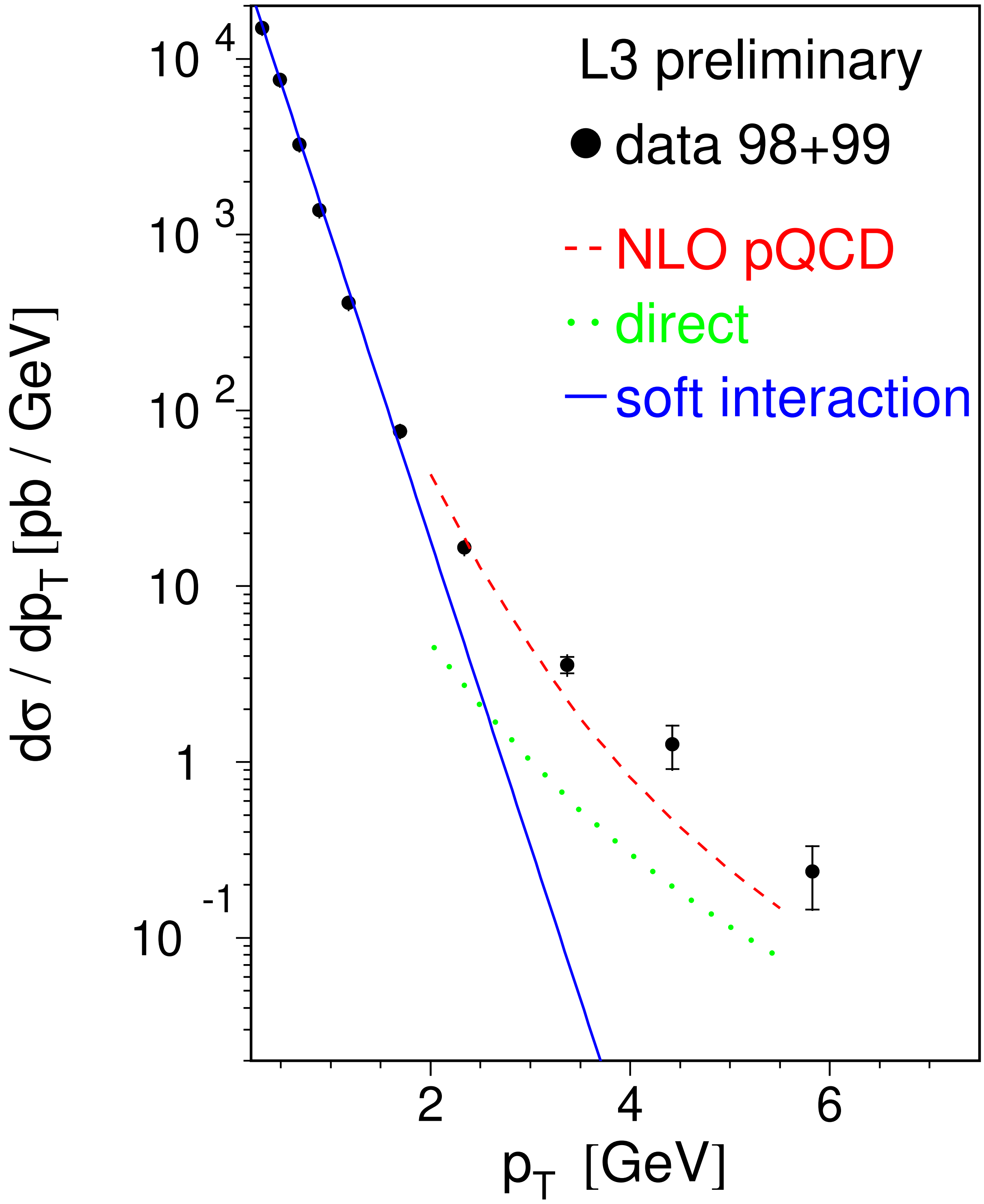
Energy loss



Charge ratio:

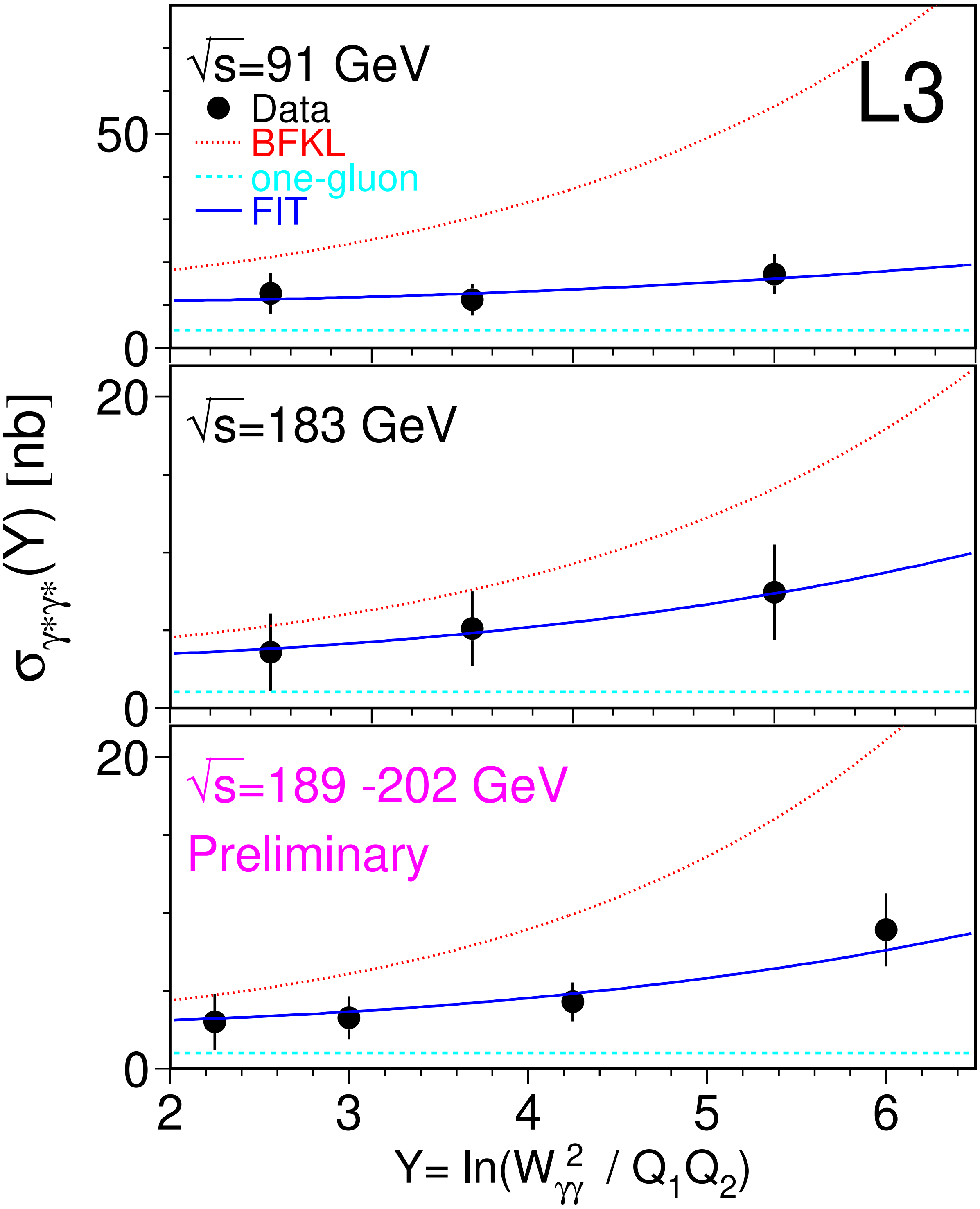
$N(\mu^+)/N(\mu^-)$

Untagged π^0 production: $e^+e^- \longrightarrow e^+e^-\pi^0 X$

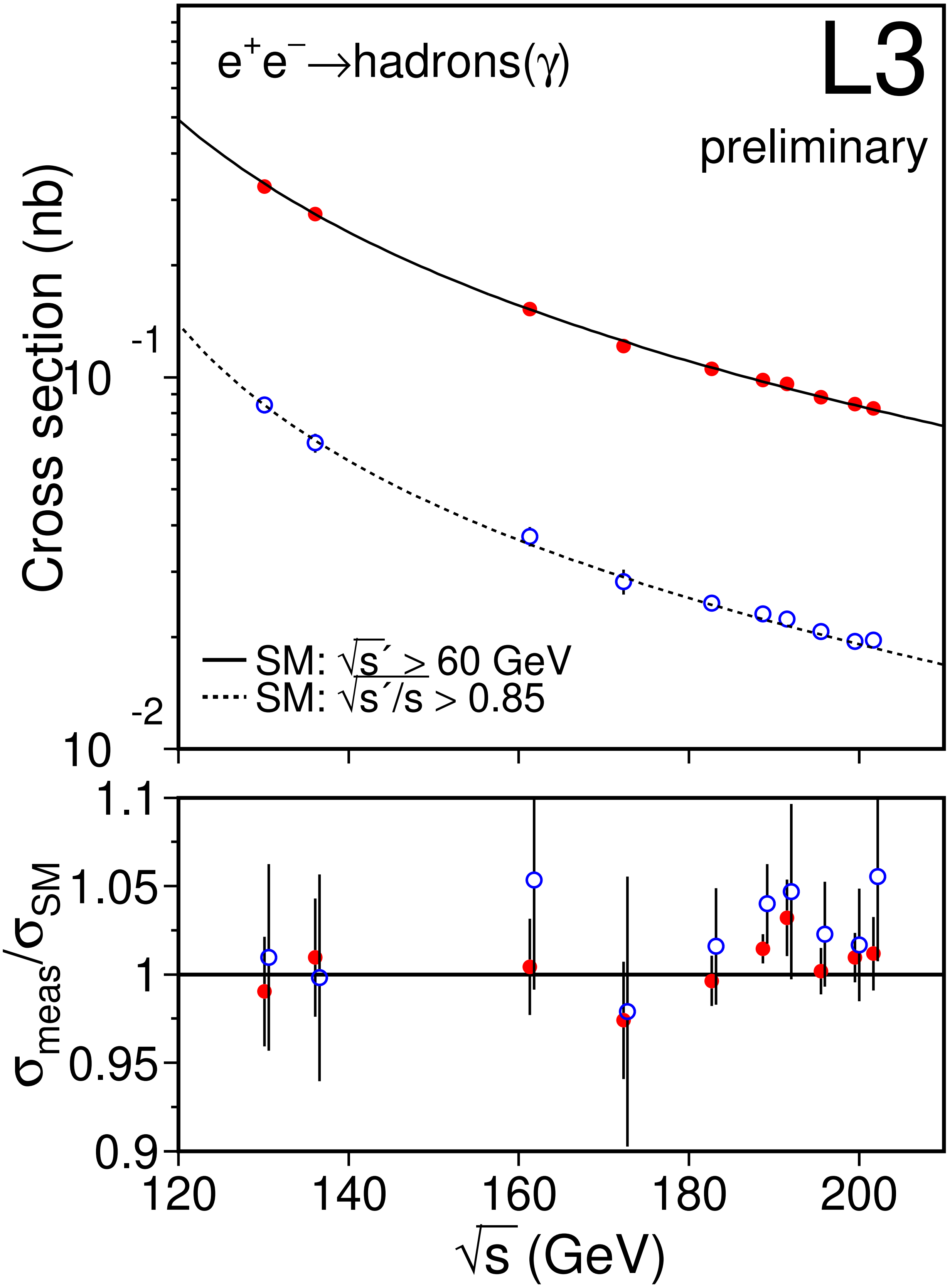


Comparison with NLO QCD calculations

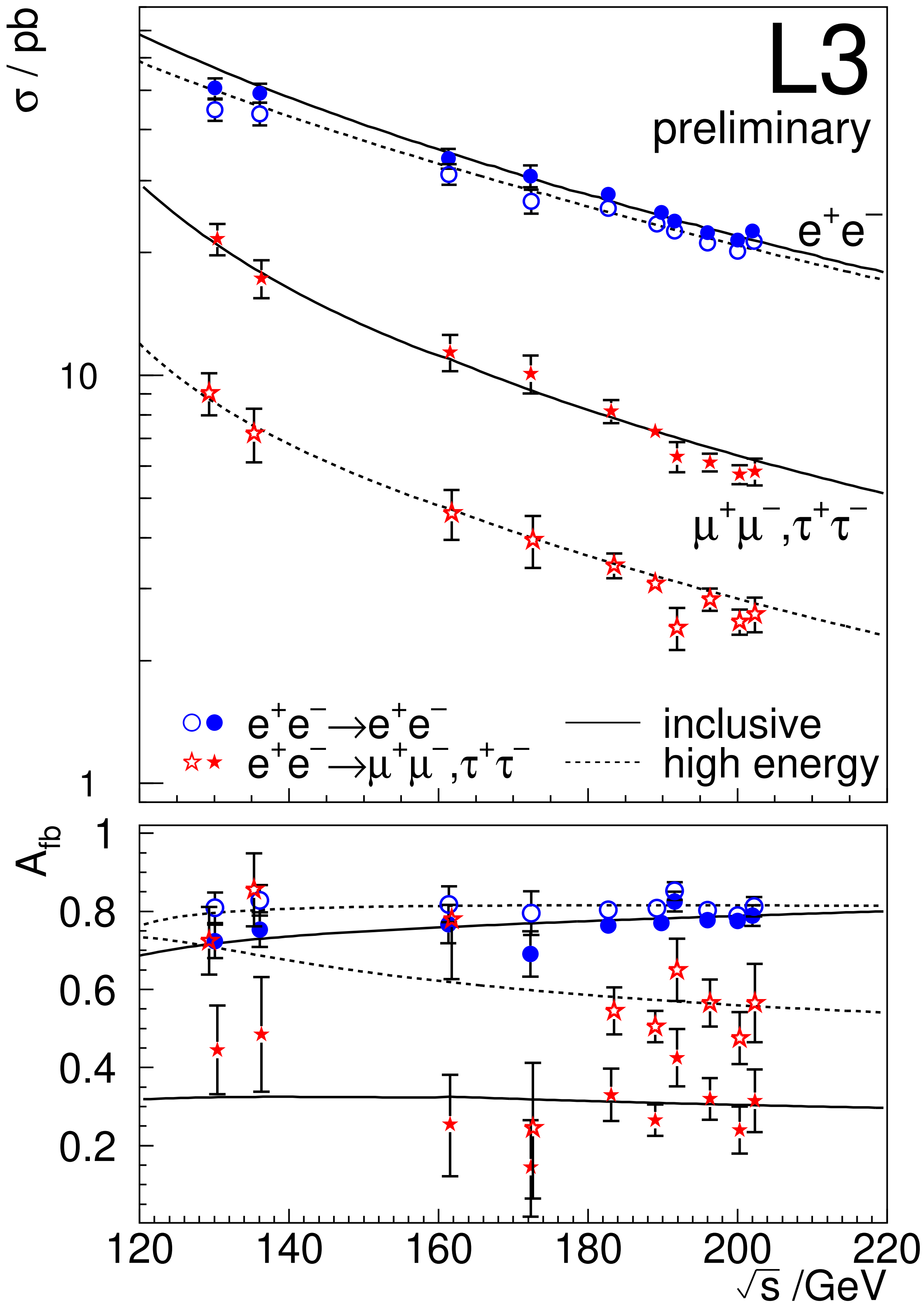
Double tagged events QPM subtracted



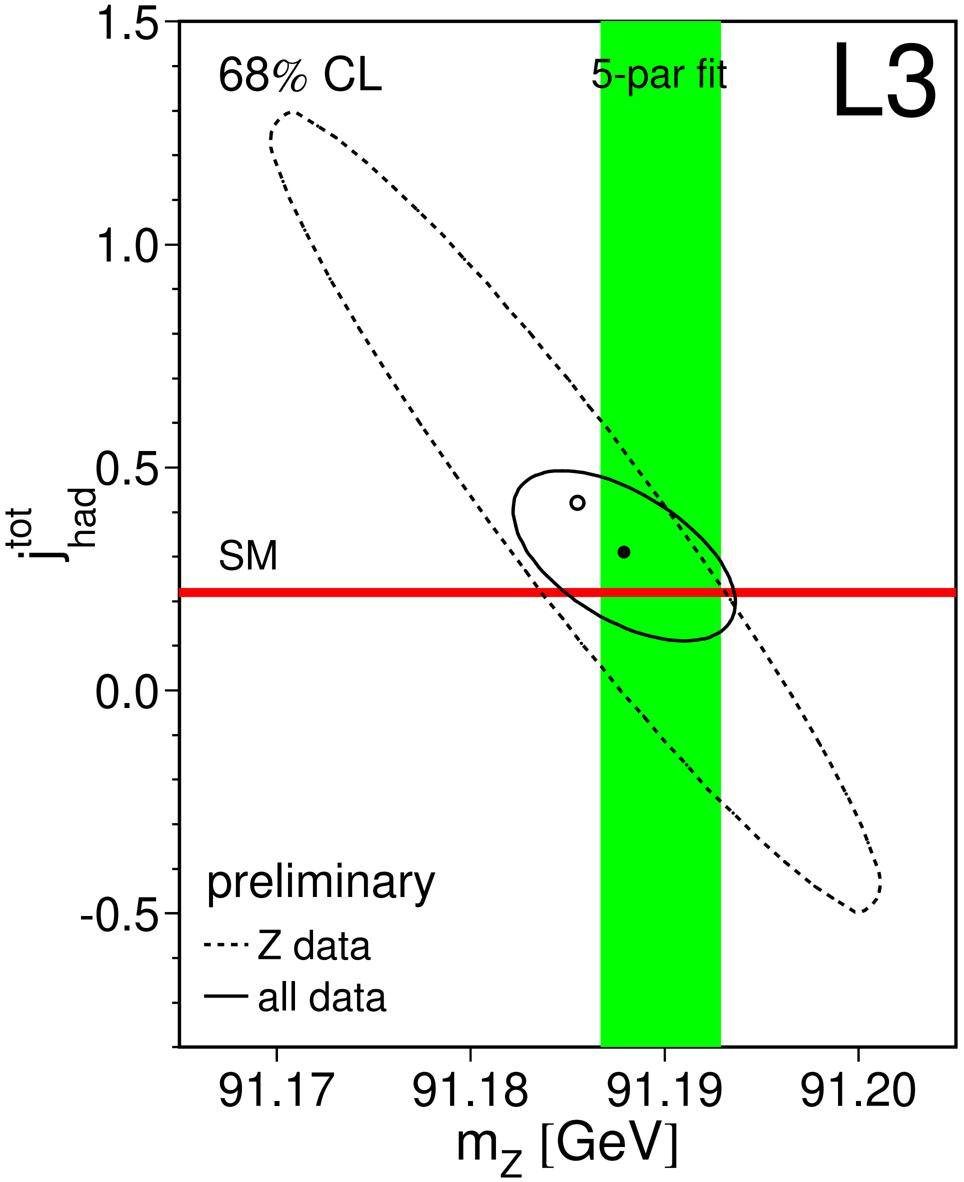
1-gluon exchange $< \sigma_{\gamma^*\gamma^*} <$ LO BFKL



$e^+e^- \to hadrons(\gamma)$
L3
preliminary
Cross section (nb)
10^{-1}
10^{-2}
SM: $\sqrt{s'} > 60$ GeV
SM: $\sqrt{s'/s} > 0.85$
$\sigma_{meas}/\sigma_{SM}$
1.1
1.05
1
0.95
0.9
120
140
160
180
200
$\sqrt{s}$ (GeV)

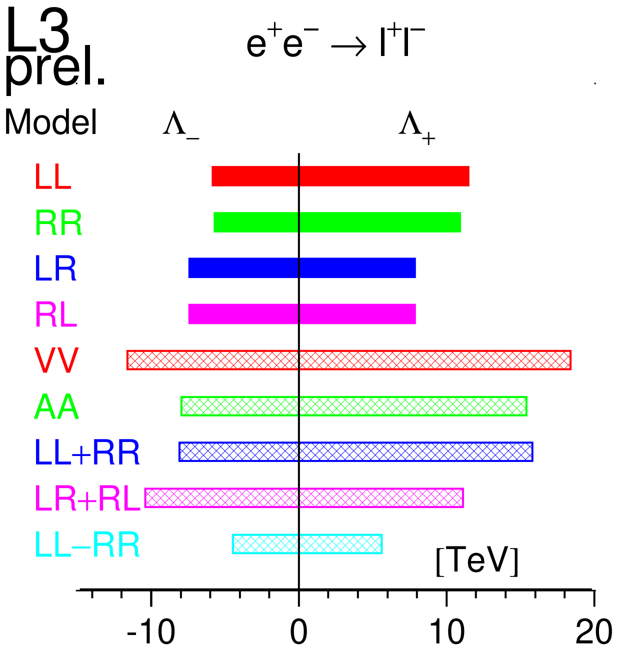

σ / pb
L3
preliminary
e^+e^-
$\mu^+\mu^-,\tau^+\tau^-$
10
1
$e^+e^- \to e^+e^-$
$e^+e^- \to \mu^+\mu^-,\tau^+\tau^-$
inclusive
high energy
A_{fb}
1
0.8
0.6
0.4
0.2
120
140
160
180
200
220
$\sqrt{s}$ /GeV

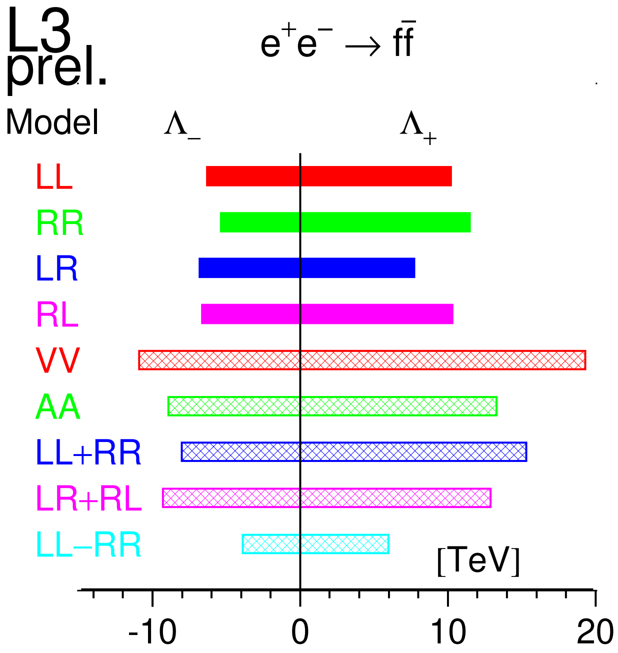
Model-independent Z-mass measurement



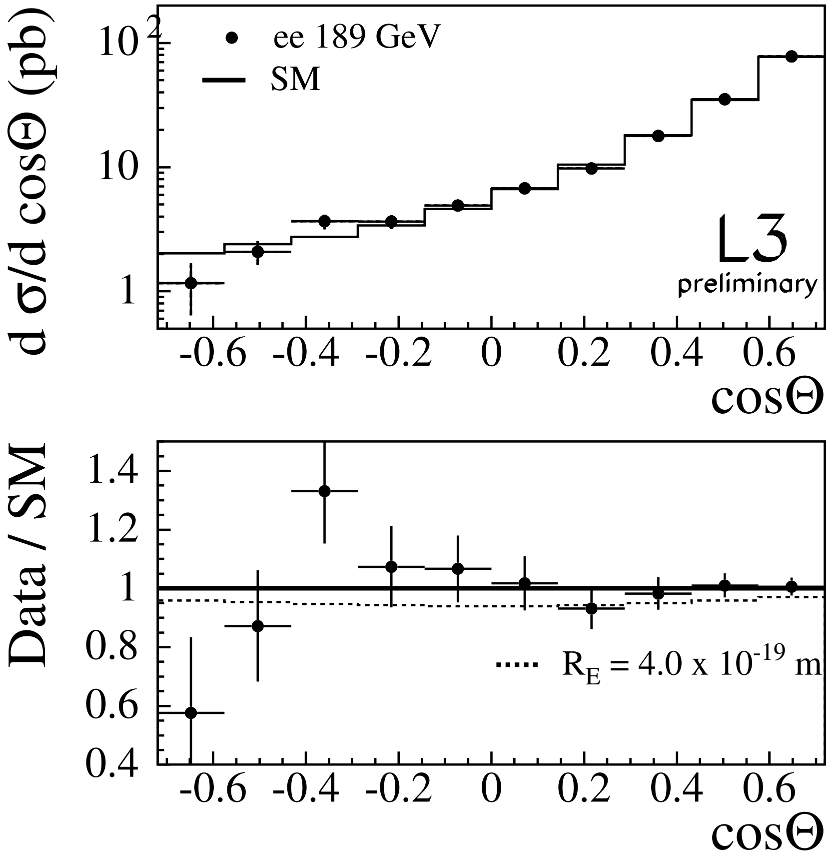
Data	j_{had}^{tot}	M_Z [MeV]
Z pole	0.44 ± 0.59	91185.2 ± 10.3
$\sqrt{s} \rightarrow 202$ GeV	0.30 ± 0.13	91187.9 ± 3.8
Standard Analysis	0.22 fixed	91189.5 ± 3.1

Contact interactions (data up to 202 GeV):





Limits on fermion size (form factor ansatz):



Data up to 189 GeV:

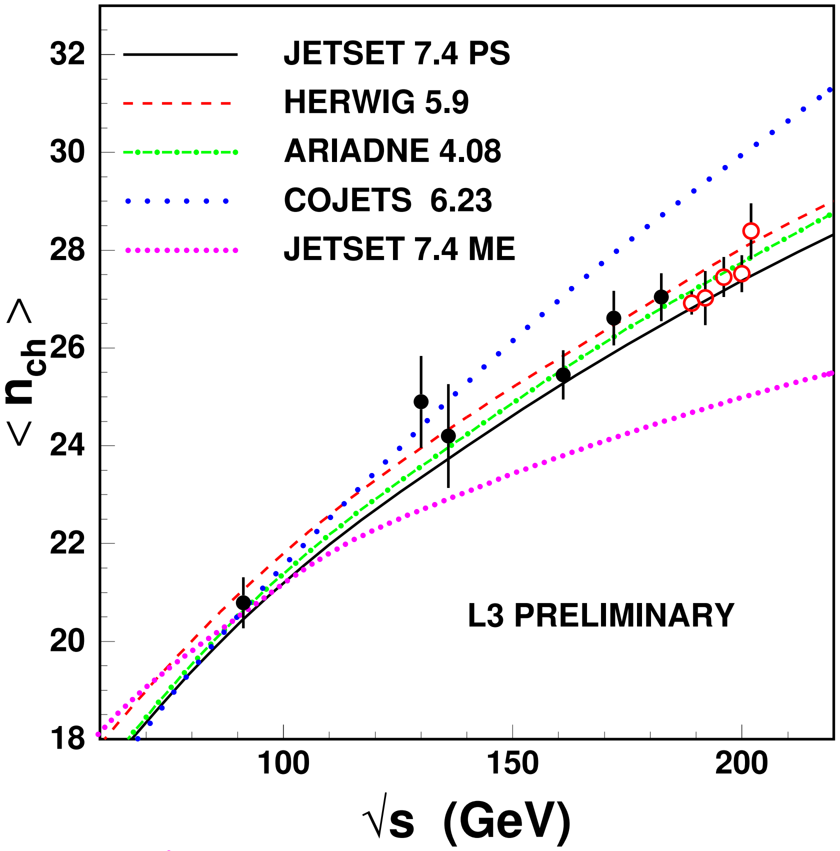
Leptons:

$R < 2.2 \cdot 10^{-19}$ m

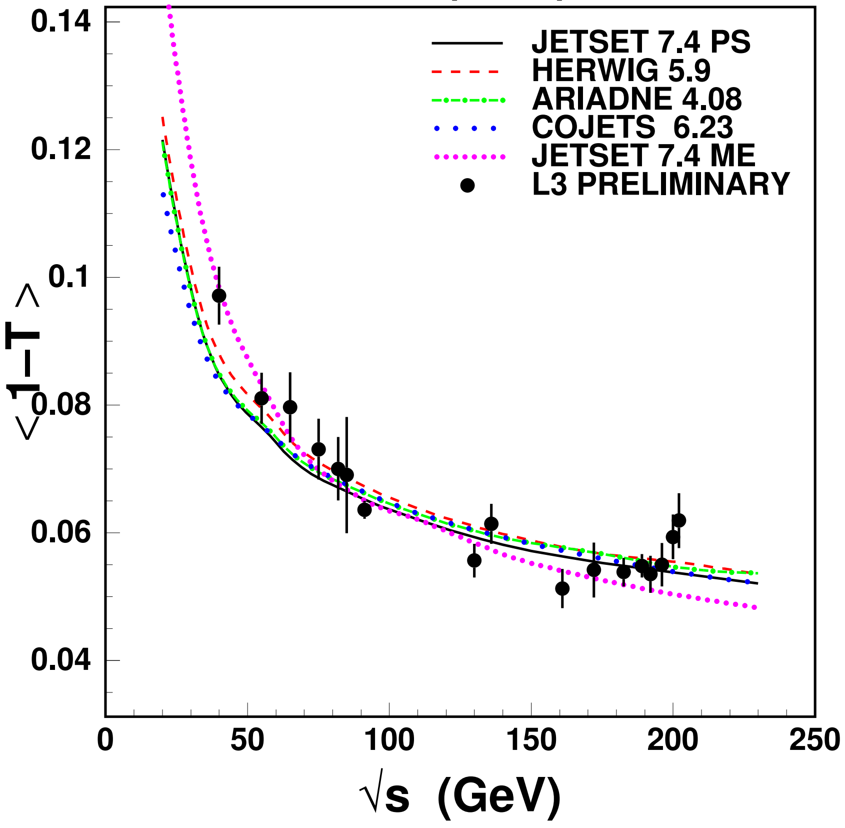
Quarks:

$R < 3.0 \cdot 10^{-19}$ m

QCD - Multiplicity and Thrust



Evolution of
charged particle
multiplicity n_{ch}

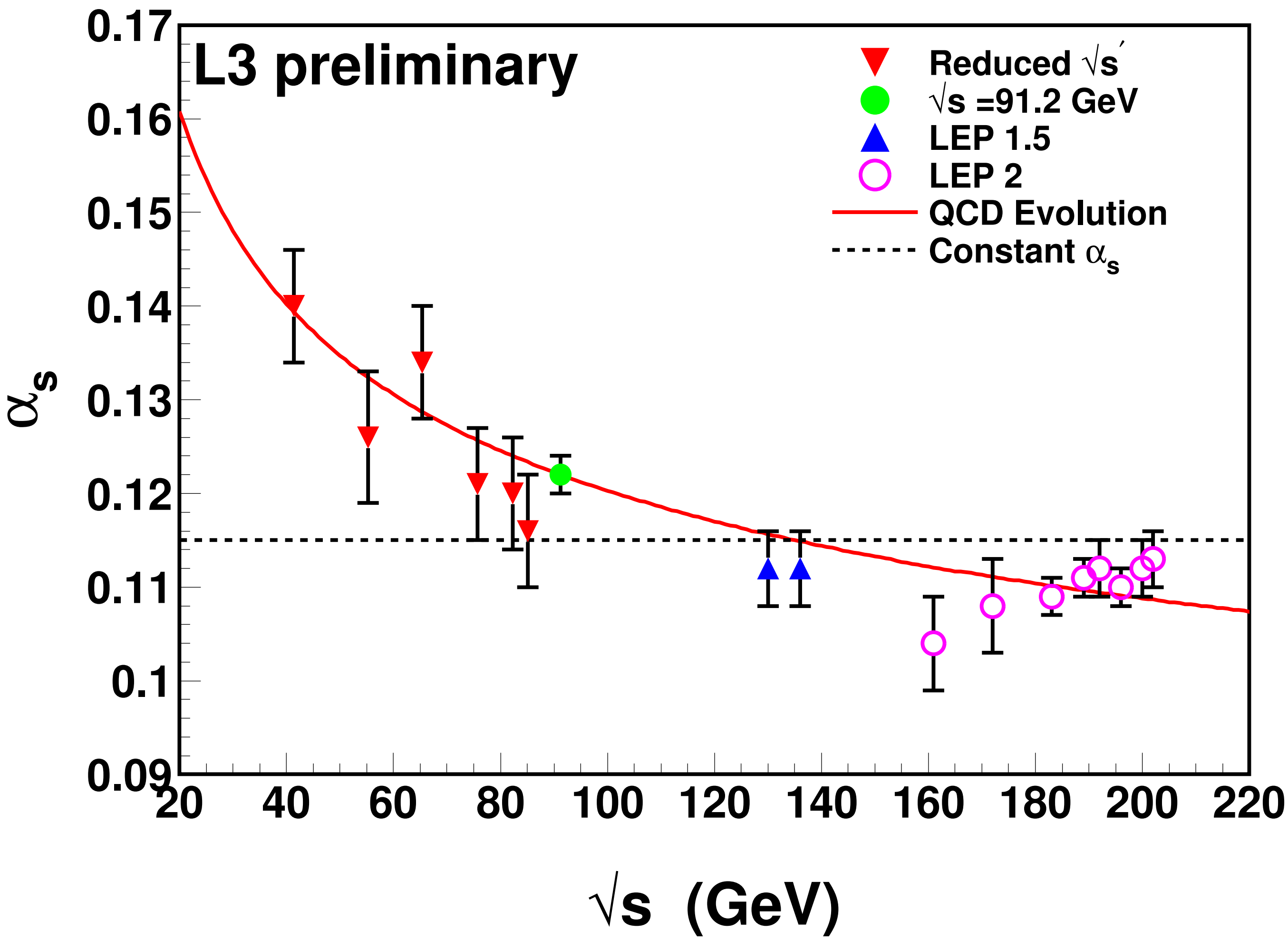


Evolution of
thrust (1–T)

QCD - α_S

	$\sqrt{s}$ [GeV]	α_S
Results:	192	0.1121 ± 0.0032
	196	0.1102 ± 0.0022
	200	0.1119 ± 0.0025
	202	0.1125 ± 0.0031

Correlated theory error: ± 0.0056 (not shown in plot)

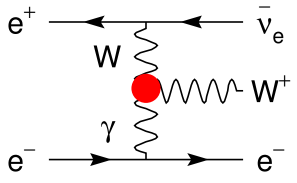


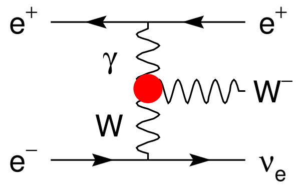
$$\alpha_S(M_Z) = 0.1220 \pm 0.0011 \pm 0.0061$$

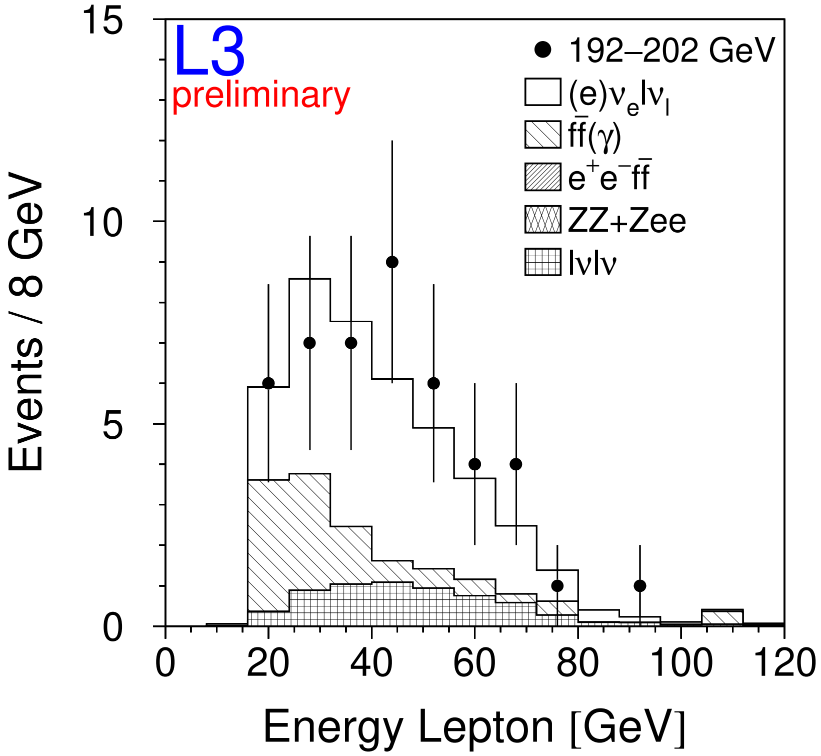
Number of active flavours:

$$6.1 \pm 1.3 \pm 2.2$$

Single W Boson Production



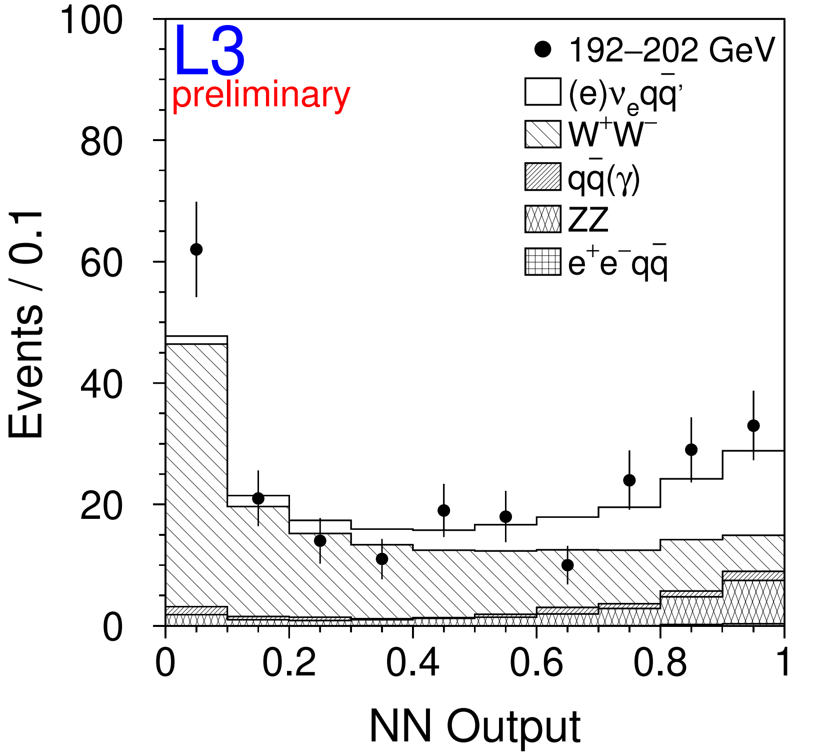




$e^+e^- \rightarrow We\nu$

Leptonic W decay:

$W \rightarrow$	$e\nu$	$\mu\nu$	$\tau\nu$
Data:	31	9	6
MC:	21.7	13.3	7.0



Hadronic W decay:

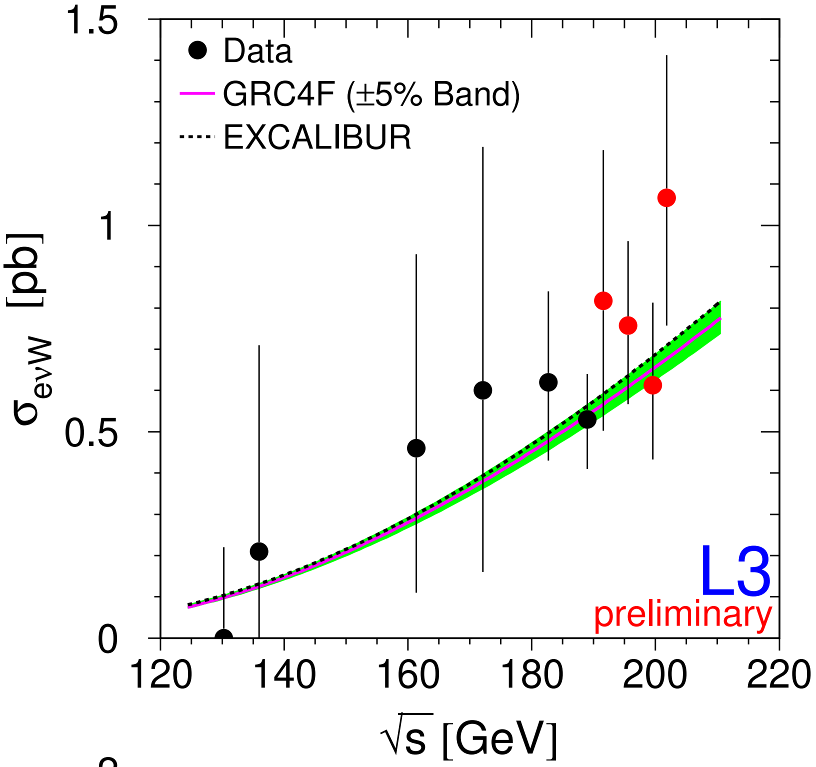
$W \rightarrow q\bar{q}'$

NN-Output > 0.6:

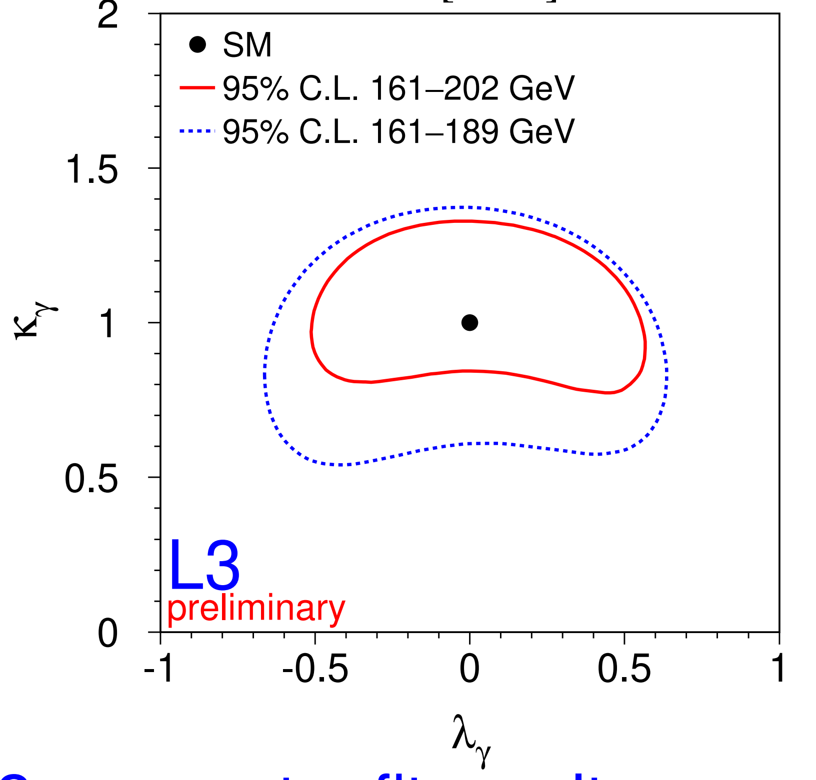
Data: 96

MC: 90.5

Single W Boson Production



Cross section:
130 GeV - 202 GeV



Electromagnetic gauge couplings κ_γ and λ_γ

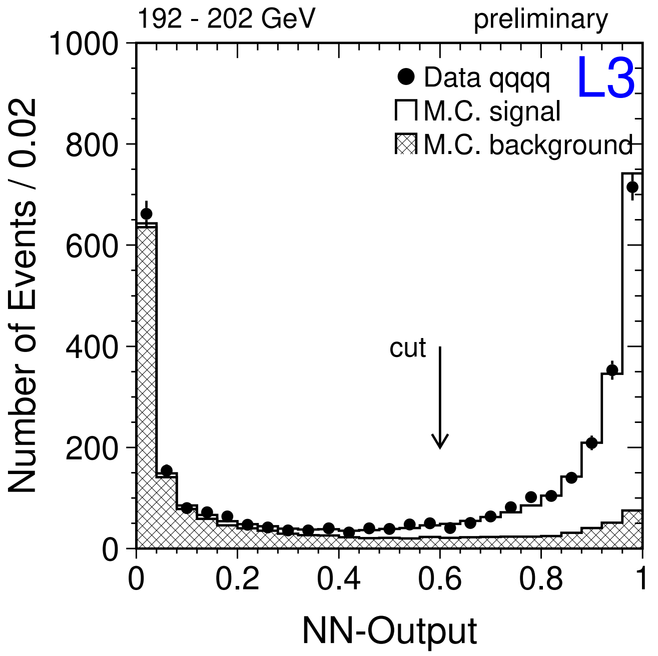
2-parameter fit result:

$\kappa_\gamma = +1.10 \pm 0.10 \pm 0.08$ (SM: 1)

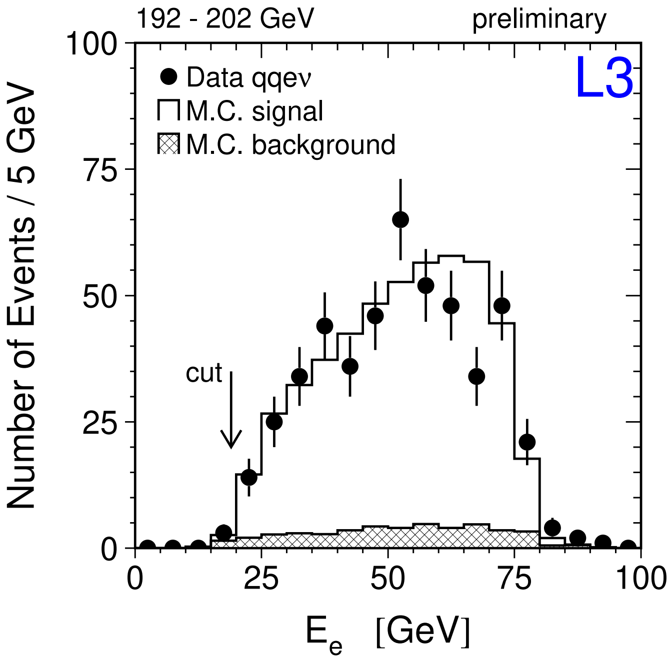
$\lambda_\gamma = -0.10^{+0.41}_{-0.22} \pm 0.11$ (SM: 0)

WW Production

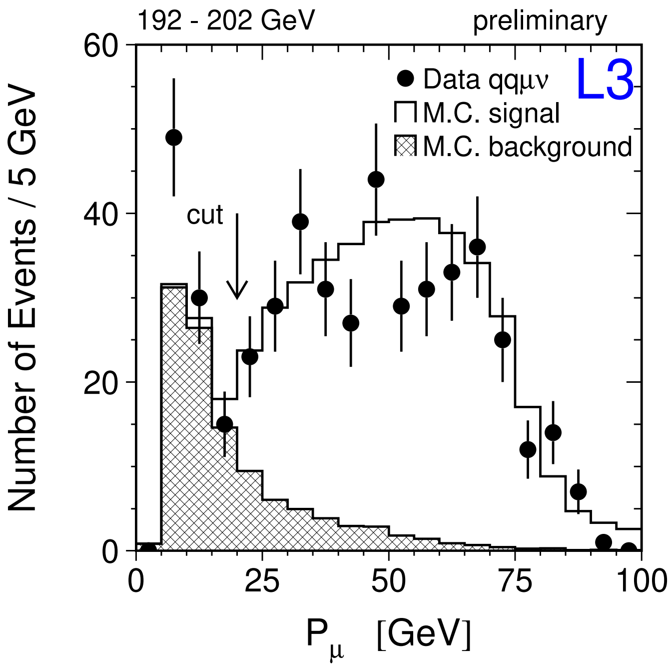
1861 $q\bar{q}q\bar{q}$ events



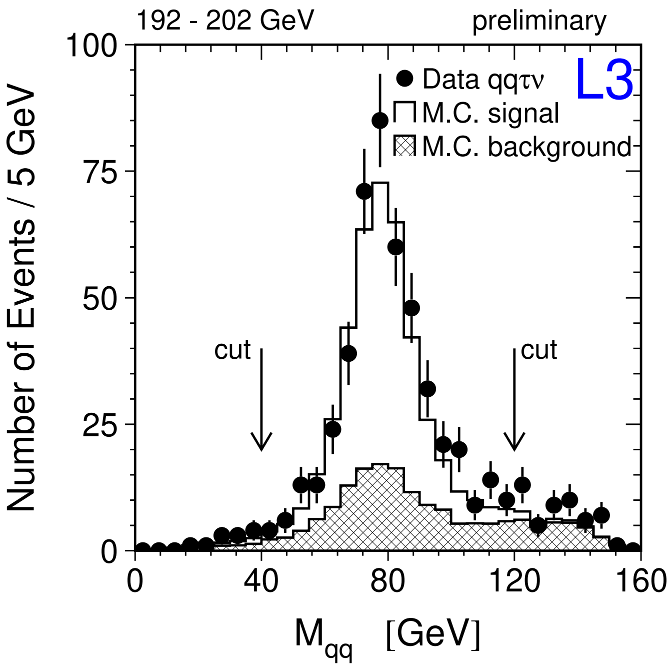
485 $q\bar{q}e\nu$ events



431 $q\bar{q}\mu\nu$ events

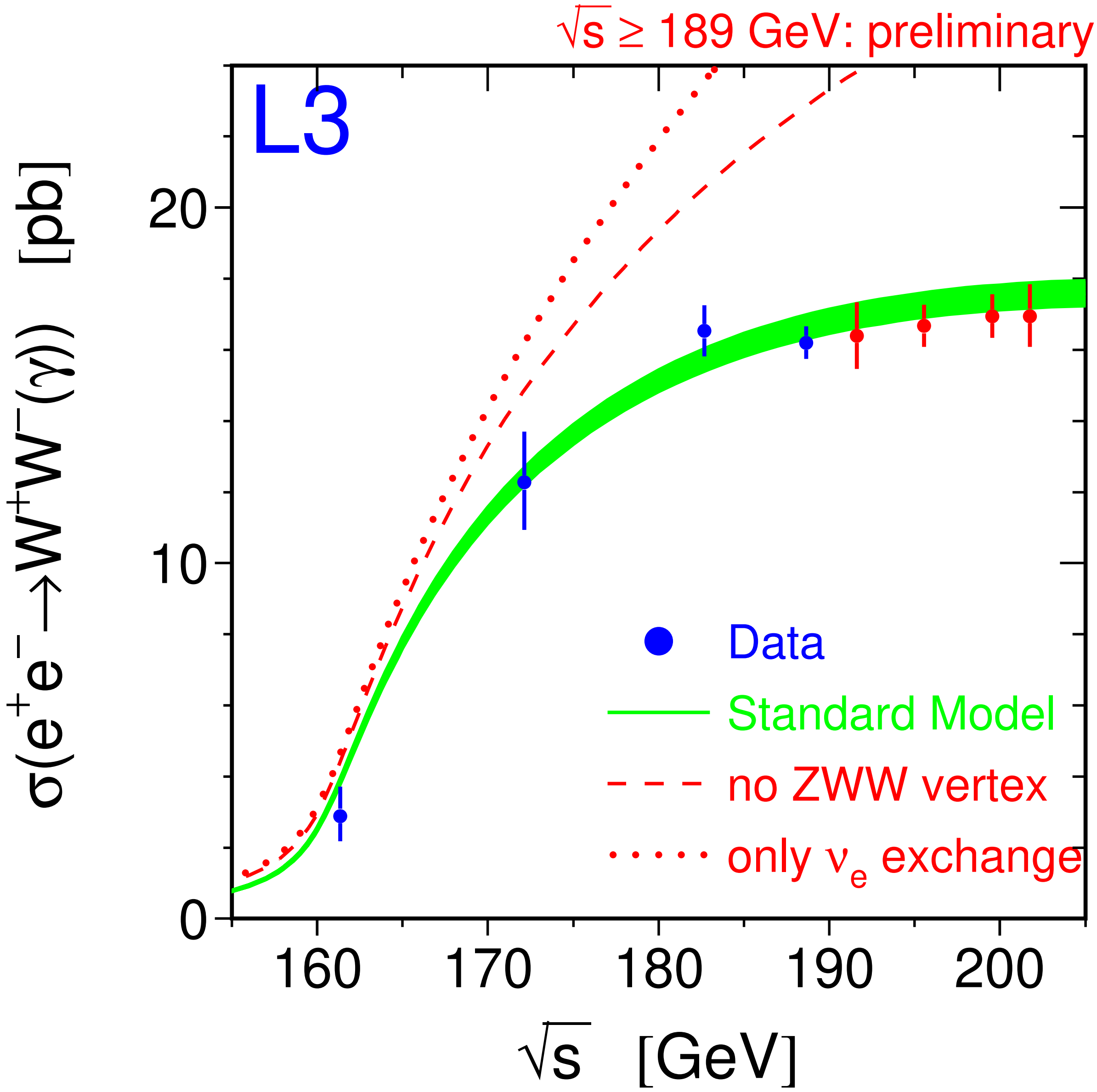


469 $q\bar{q}\tau\nu$ events



283 $\ell\nu\ell\nu$ events

3529 W-pairs in 1999

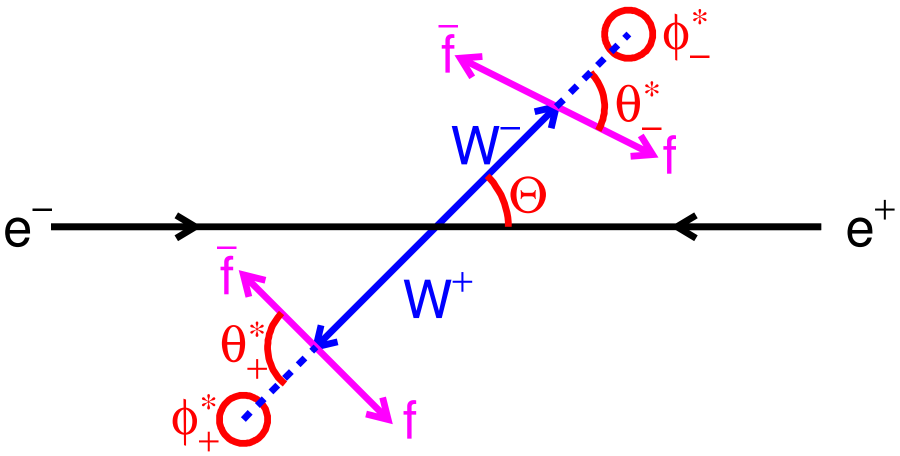


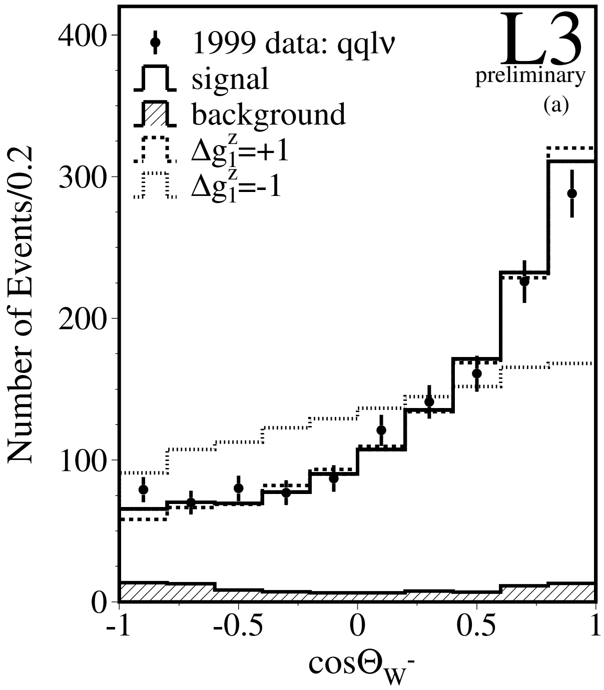
W Decay	Branching Fraction [%]	SM [%]
$e\nu$	$10.22 \pm 0.33 \pm 0.14$	10.83
$\mu\nu$	$9.87 \pm 0.35 \pm 0.15$	10.83
$\tau\nu$	$11.64 \pm 0.47 \pm 0.21$	10.83
$q\bar{q}'$	$68.27 \pm 0.49 \pm 0.33$	67.51

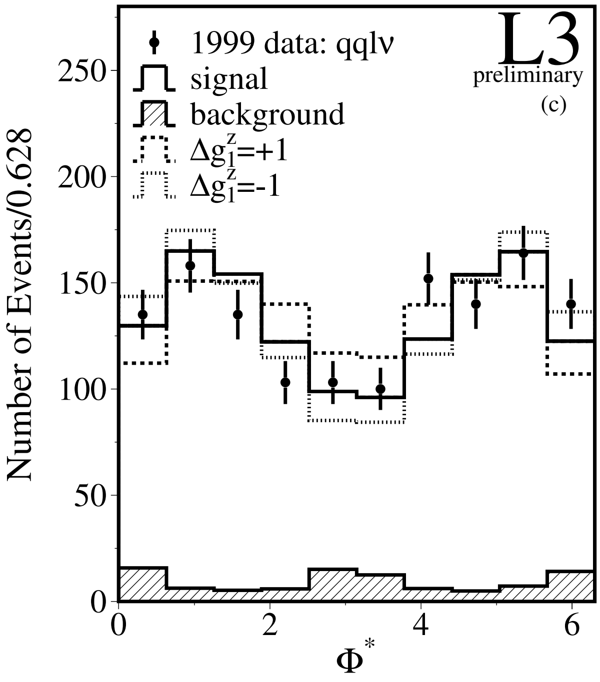
$$|V_{cs}| = 1.021 \pm 0.023 \pm 0.015$$

W Gauge Couplings

$e^+e^- \rightarrow W^+W^- \rightarrow f\bar{f}\,f\bar{f}$







1-parameter fit results (189 - 202 GeV):

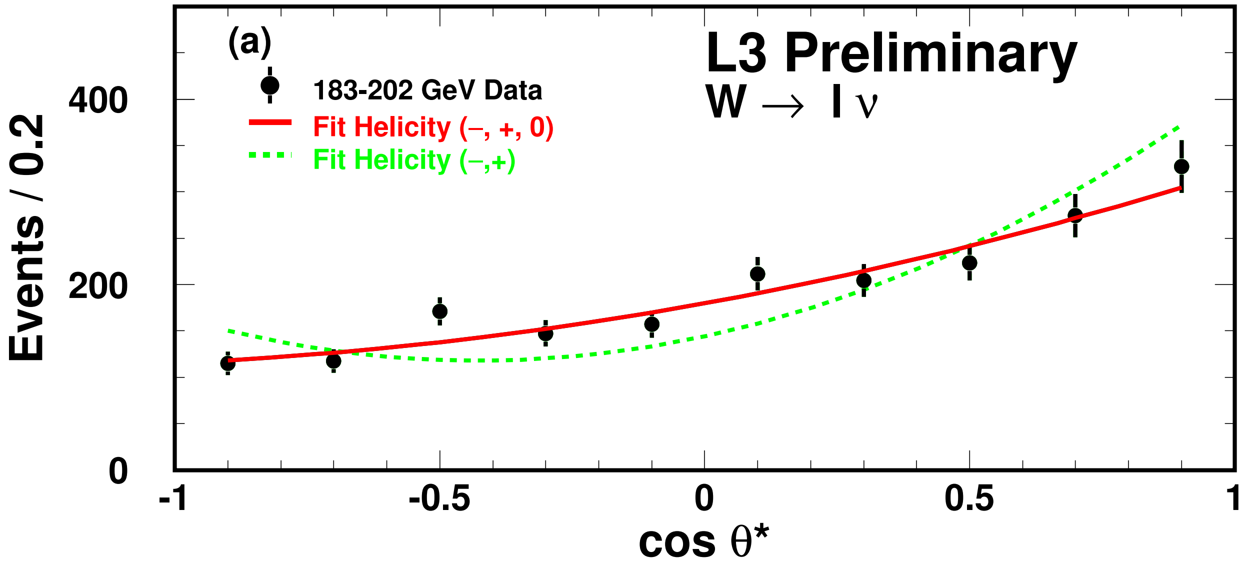
$$g_1^Z = +0.93 \pm 0.04 \pm 0.04 \qquad \text{(SM: 1)}$$

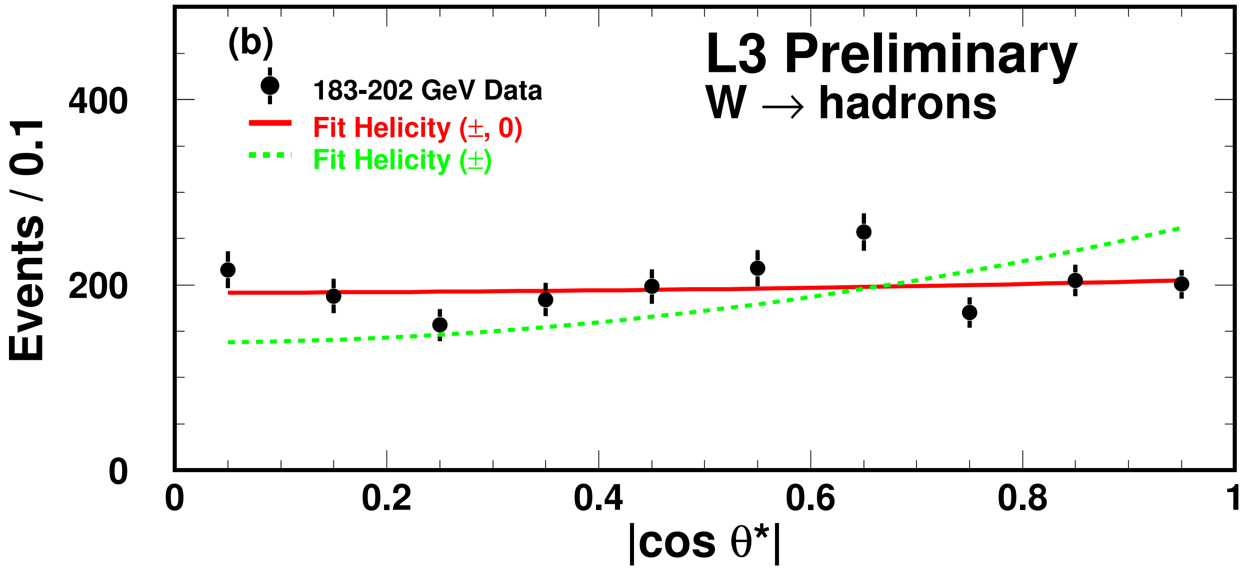
$$\kappa_\gamma = +0.80 \pm 0.08 \pm 0.14 \qquad \text{(SM: 1)}$$

$$\lambda_\gamma = -0.08 \pm 0.04 \pm 0.06 \qquad \text{(SM: 0)}$$

Longitudinal and transverse polarisation

Distribution of polar W decay angle
in W rest system, θ^*

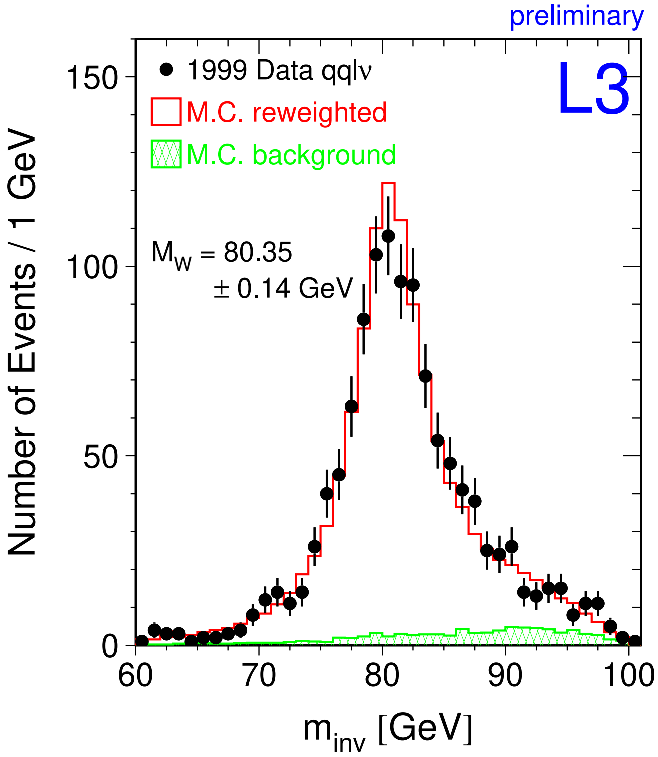


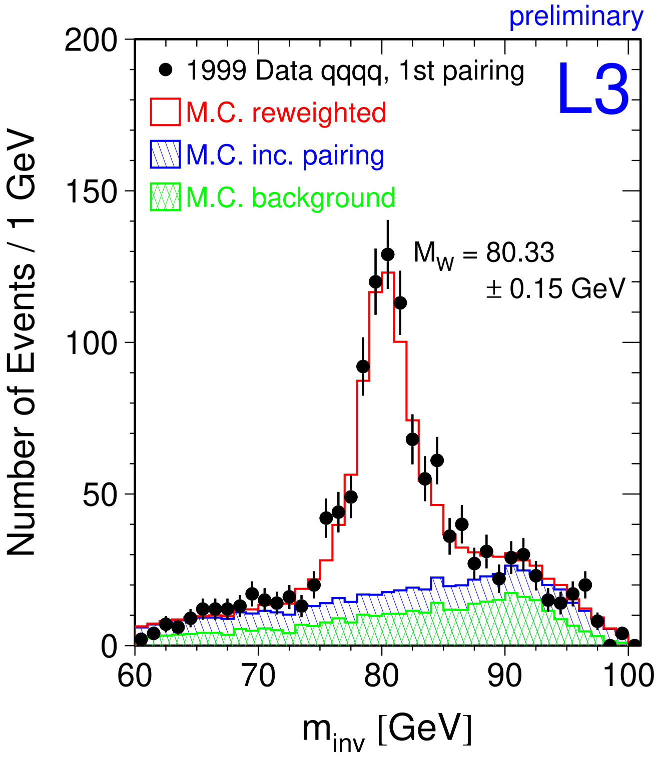


Fraction of longitudinal W bosons:

$25.9 \pm 3.5 \pm 3.0\%$ (SM: 24.8%)

WW $\rightarrow q\bar{q}\ell\nu$ WW $\rightarrow q\bar{q}q\bar{q}$





172 GeV – 202 GeV data:

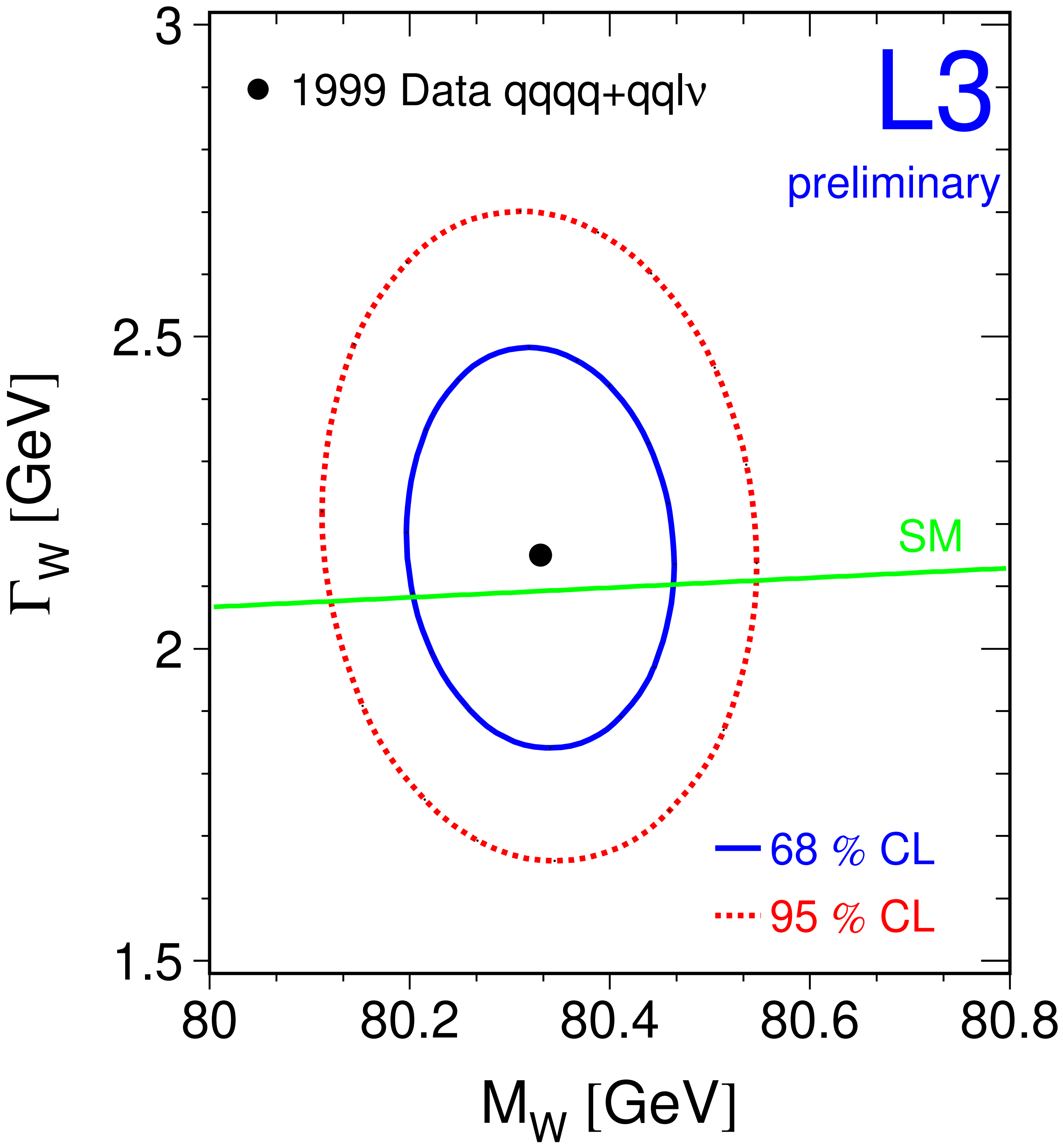
$q\bar{q}q\bar{q}$	$80.49 \pm 0.08 \pm 0.11$ GeV
$q\bar{q}\ell\nu$	$80.28 \pm 0.09 \pm 0.05$ GeV

Bias in $M_W(q\bar{q}q\bar{q})$ due to FSI (CR+BE)?

Mass difference $0.23 \pm 0.12 \pm 0.07$ GeV

calculated without FSI systematics

All combined $80.368 \pm 0.058 \pm 0.064$ GeV

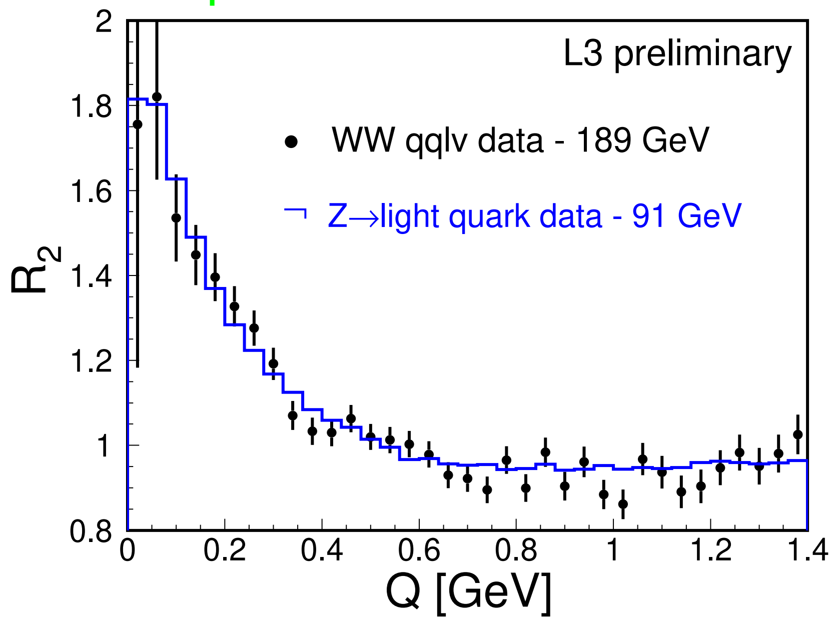


172 GeV – 202 GeV data:

$$\Gamma_W = 2.19 \pm 0.14 \pm 0.16 \text{ GeV}$$

Identical pions close in phase space:

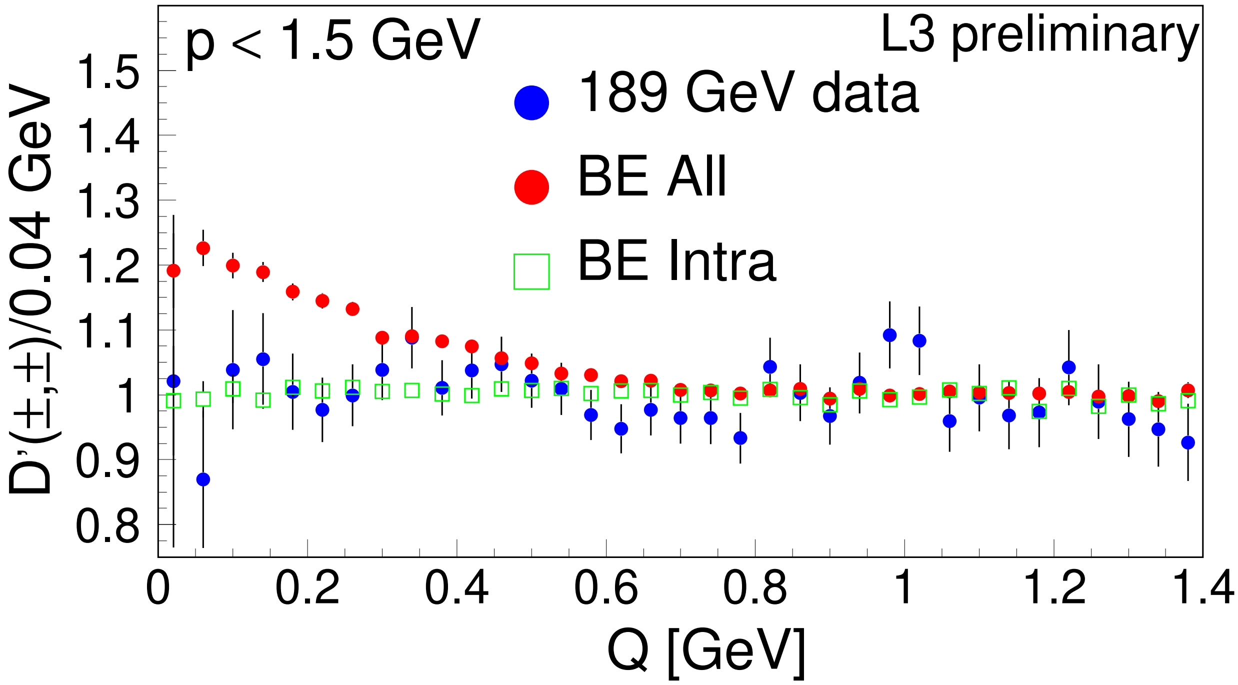
Q^2 = squared 4-momentum difference



BEC: $W^{\pm} \simeq Z$ decays ($Z \not\to b\bar{b}$)

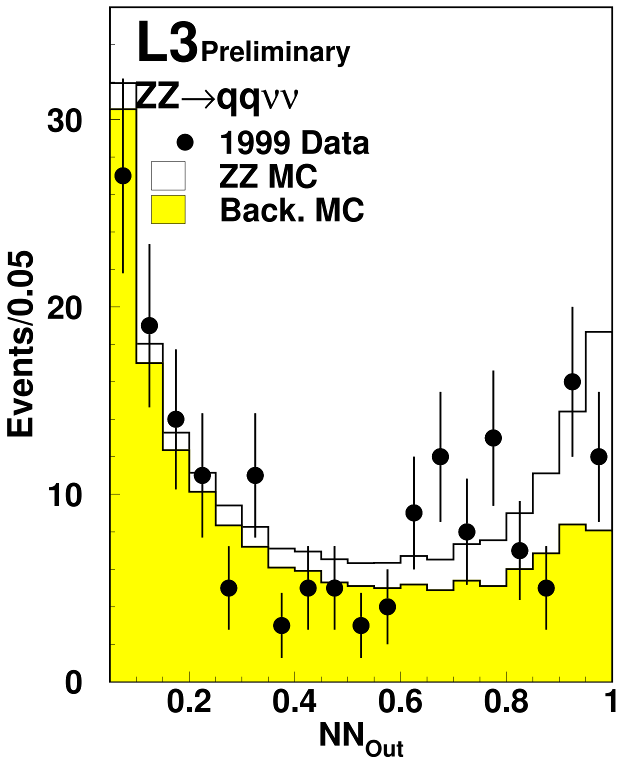
Cross talk in $W^+W^- \to q\bar{q}q\bar{q}$?

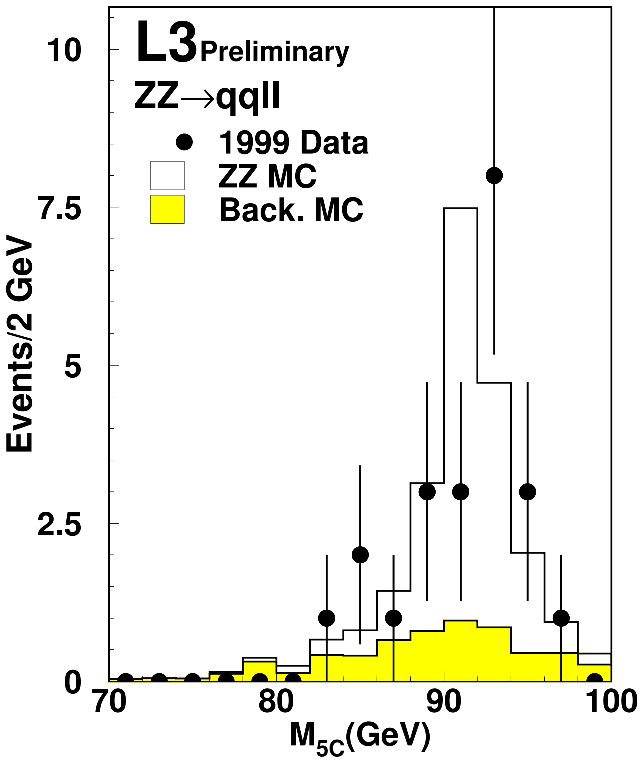
Divide out intra-W BEC

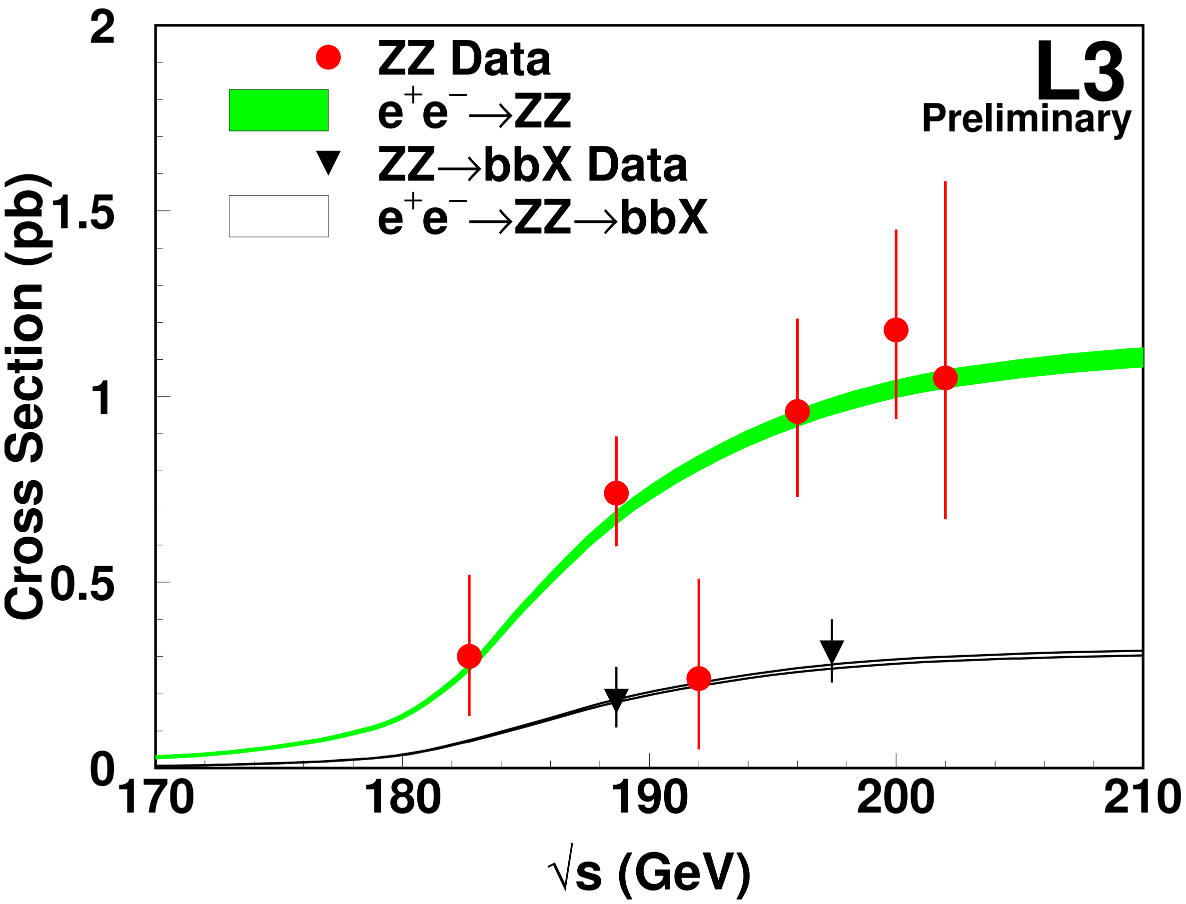


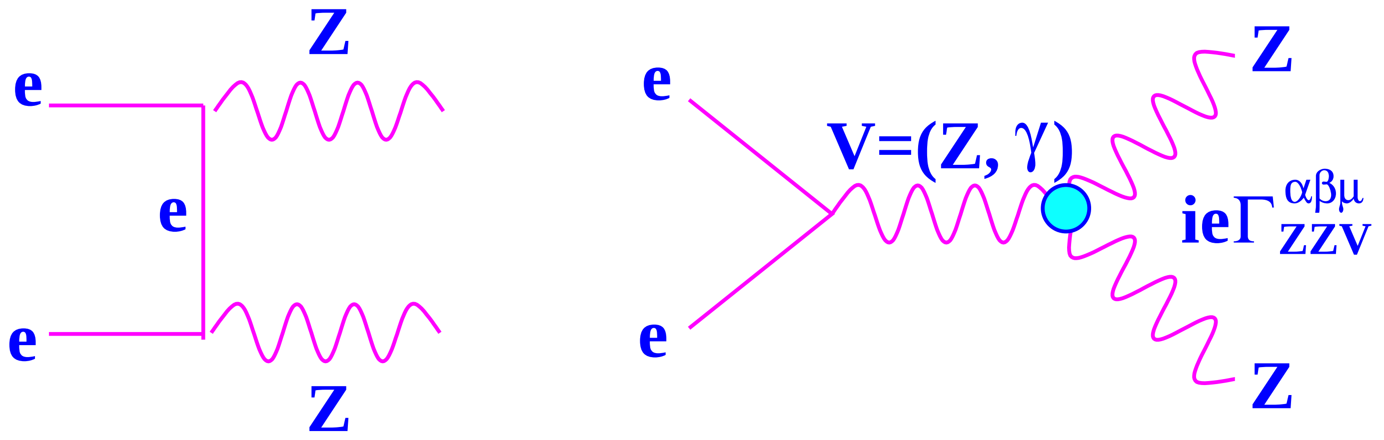
No indication for BEC between hadrons from different Ws

ZZ Production









Anomalous ZZZ and ZZγ gauge couplings:

$$\Gamma_{ZZV}^{\alpha\beta\mu} = i\frac{s - M_V^2}{M_Z^2} \times$$

$$\left[f_4^V (Q^\alpha g^{\mu\beta} + Q^\beta g^{\mu\alpha}) + f_5^V \epsilon^{\mu\alpha\beta\rho}(p_1 - p_2)_\rho \right]$$

$V = \gamma, Z$

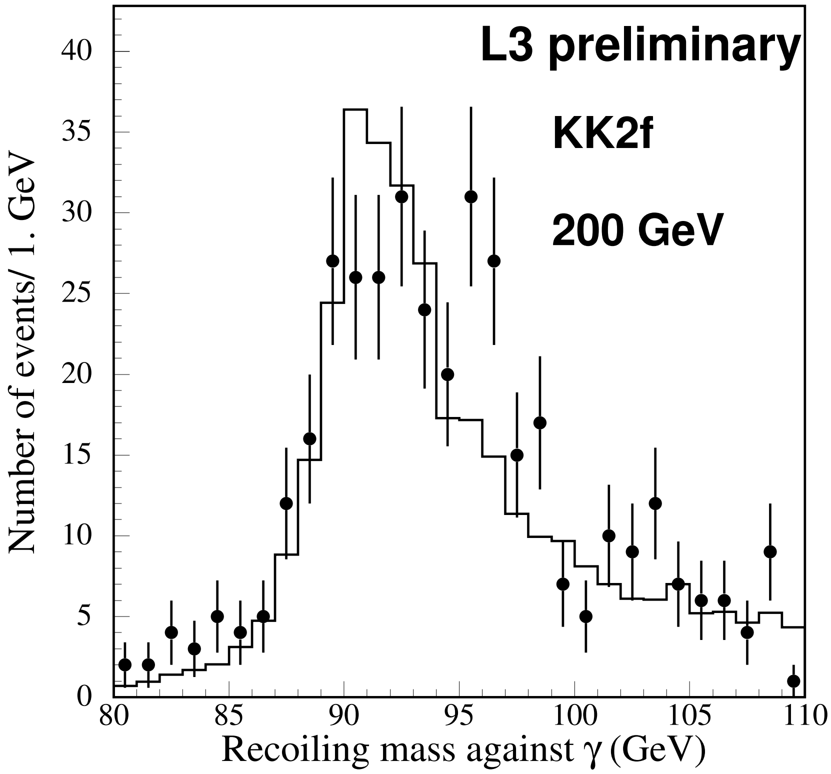
f_4^V	CP-violating	SM: 0
f_5^V	CP-conserving	SM: 0

Event rates and distributions (183 - 202 GeV):

1-parameter limits:

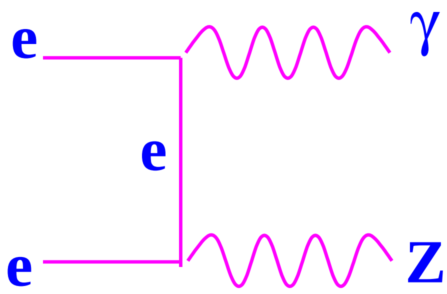
$-0.5 < f_4^\gamma < 0.5$ $\quad$ $-0.9 < f_4^Z < 0.9$

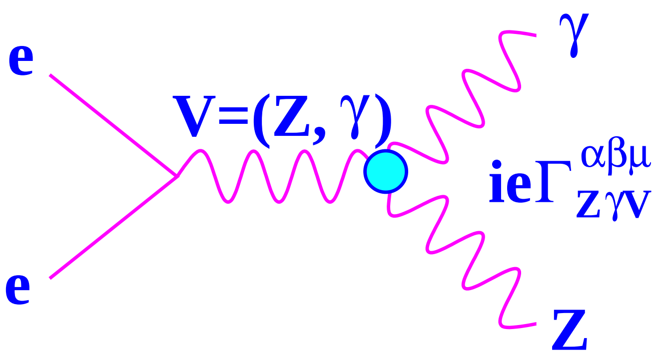
$-1.2 < f_5^\gamma < 1.3$ $\quad$ $-1.9 < f_5^Z < 2.4$



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

Photon recoil mass





Anomalous $Z\gamma Z$ and $Z\gamma\gamma$ gauge couplings:

$$\Gamma^{\alpha\beta\mu}_{Z\gamma V}(p_Z, p_\gamma, p_V) = i\frac{s - M_V^2}{M_Z^2}\sum_{i=1}^{4} h_i^V K_i(p_Z, p_\gamma, p_V)$$

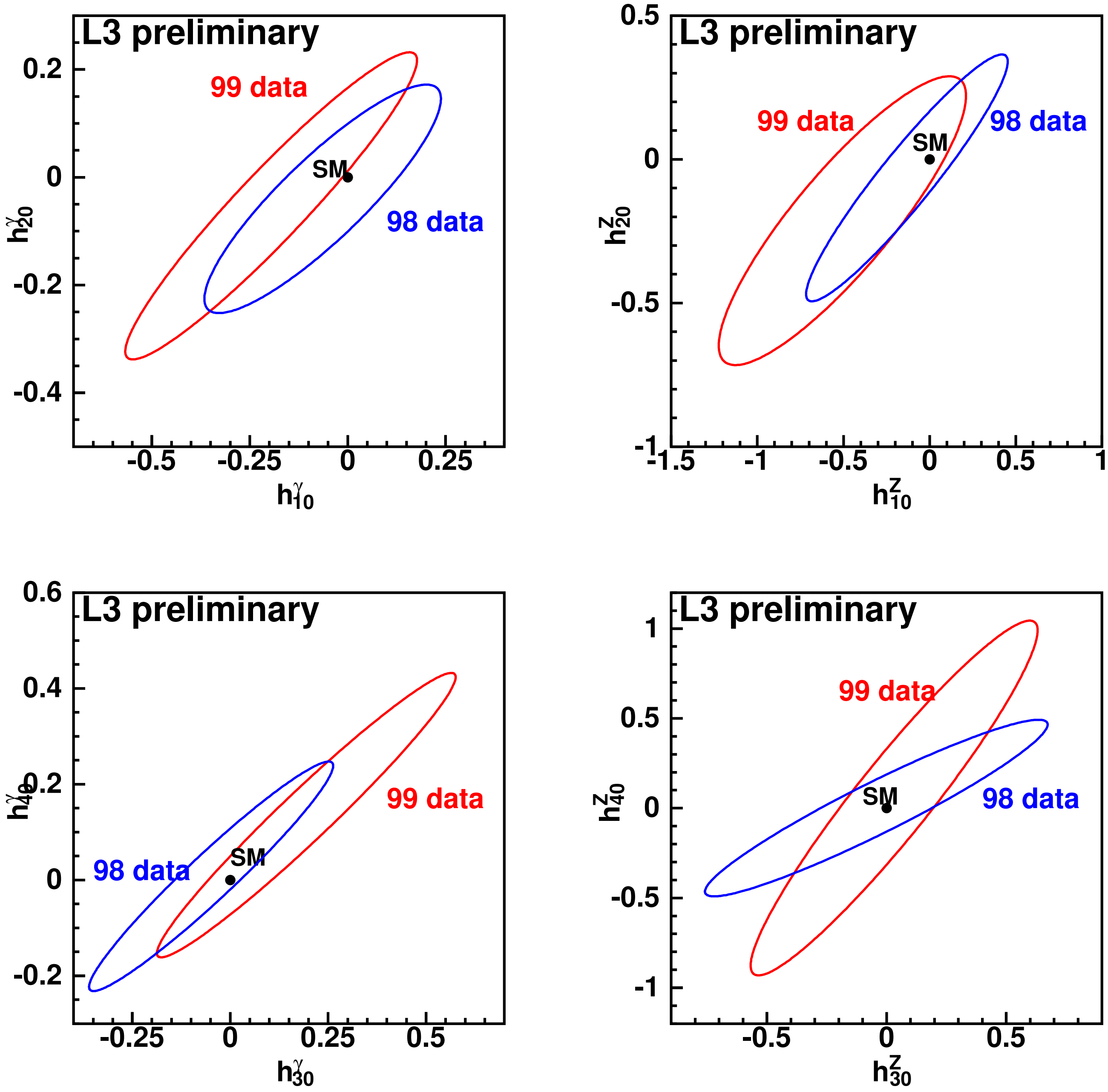
K_i real functions $\qquad V = \gamma, Z$

$h^V_{1,2}$ CP-violating SM: 0

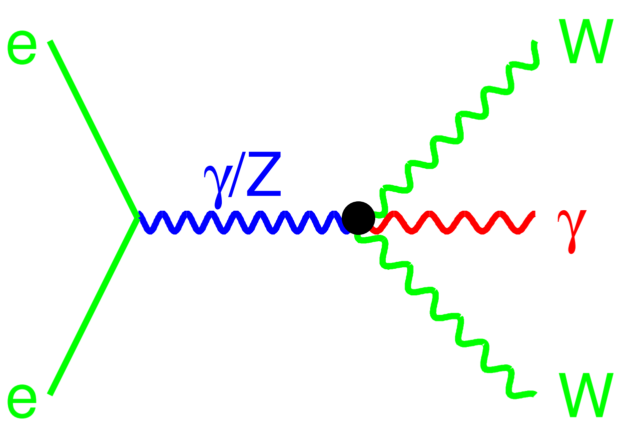
$h^V_{3,4}$ CP-conserving SM: 0

Optimal-observables analysis (183 - 202 GeV):

2-parameter contours (same CP behaviour) at 95% CL



Quartic Gauge Couplings

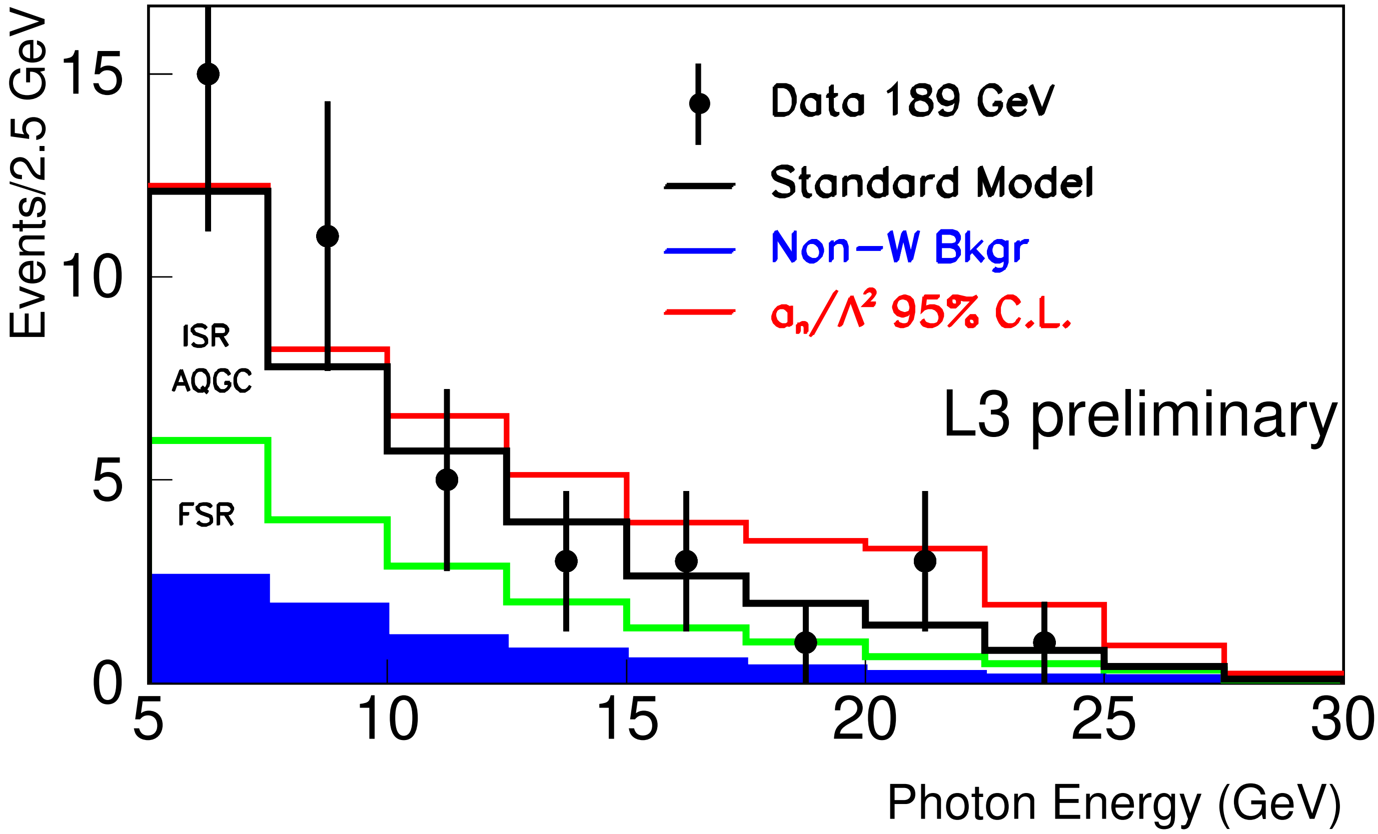


$e^+e^- \rightarrow W^+W^-\gamma$

Anomalous couplings:

a_0, a_c CP-conserving

a_n CP-violating



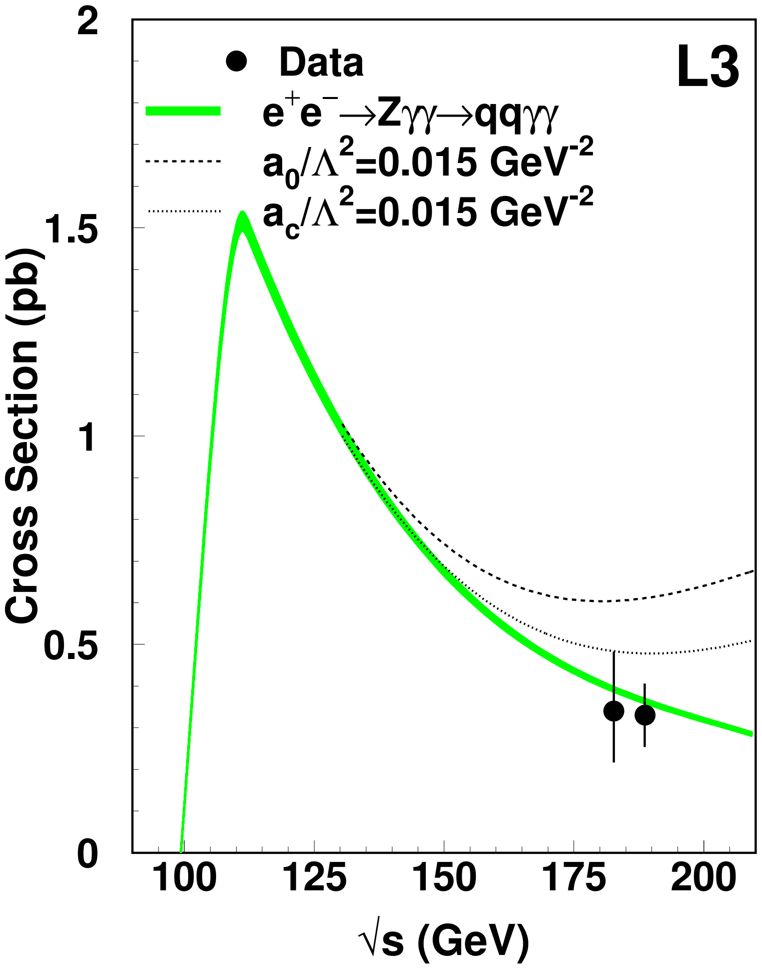
1-parameter limits [$1/\mathrm{GeV}^2$]:

$-0.390 < a_n/\Lambda^2 < 0.378$

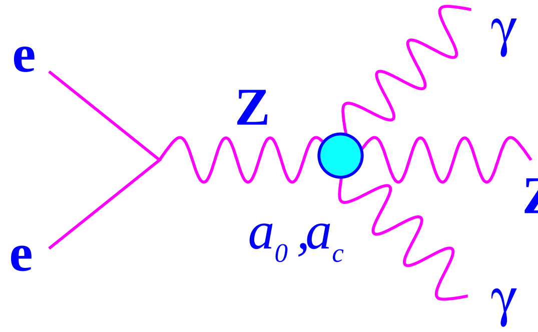
$-0.042 < a_0/\Lambda^2 < 0.045$

$-0.072 < a_c/\Lambda^2 < 0.148$

Anomalous Quartic Gauge Couplings



$e^+e^- \rightarrow Z\gamma\gamma$

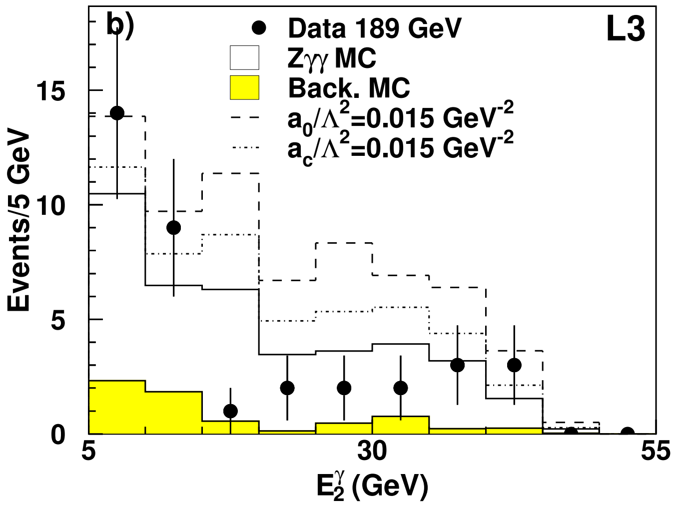


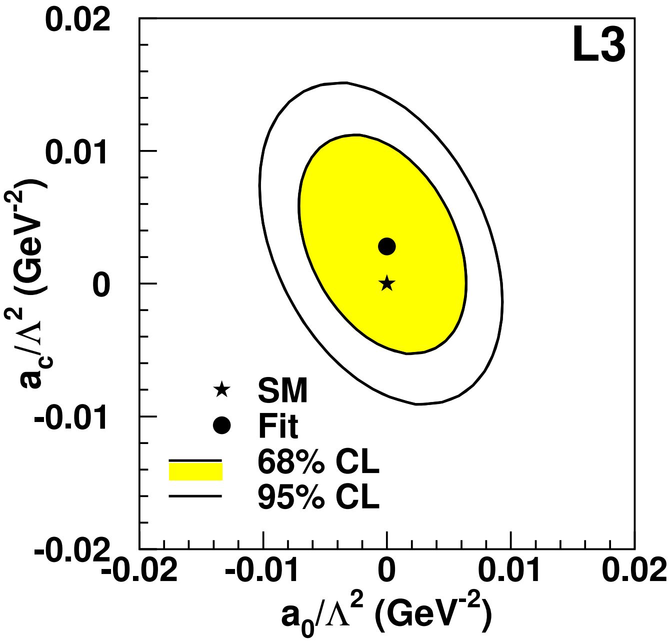
Limits $[1/\mathrm{GeV}^2]$:

$-0.009 < a_0/\Lambda^2 < 0.008$

$-0.007 < a_c/\Lambda^2 < 0.013$

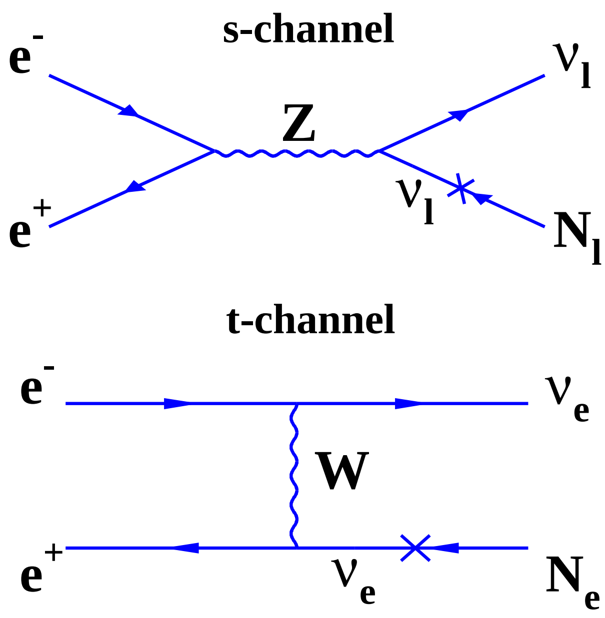
Energy spectrum of 2nd photon in $Z\gamma\gamma$ events

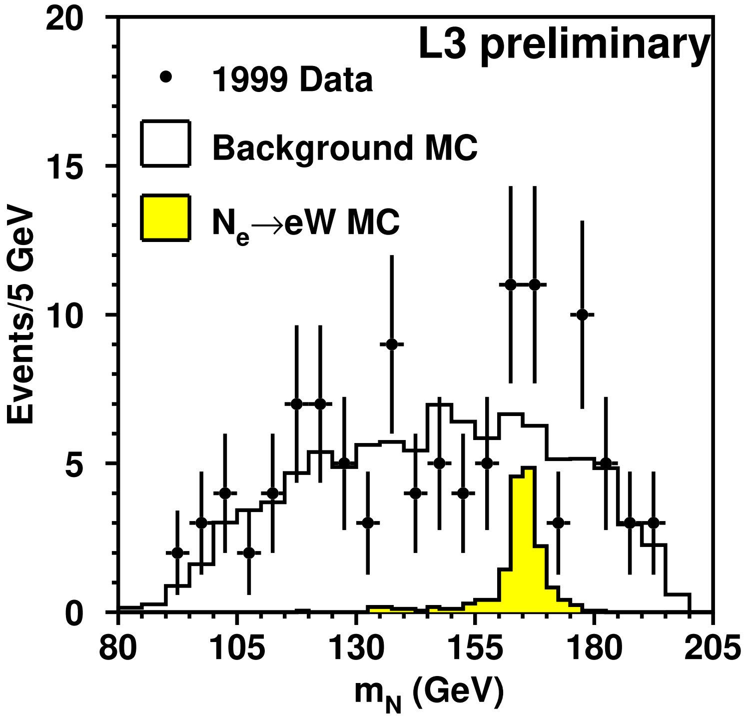




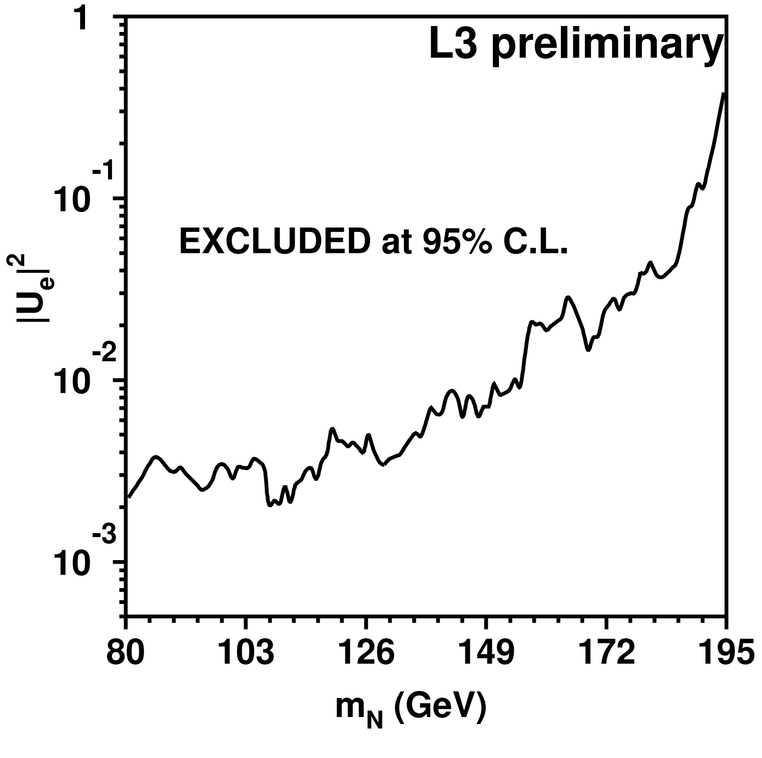
Single production: $e^+e^- \to \nu_e N_e$

Through mixing with isodoublet neutrino





$N_e \to eW \to eq\bar{q}'$ invariant mass



Limit on:

Mixing Amplitude

$|U_e|^2$

Mass limits [GeV]:

close to the kinematic limit

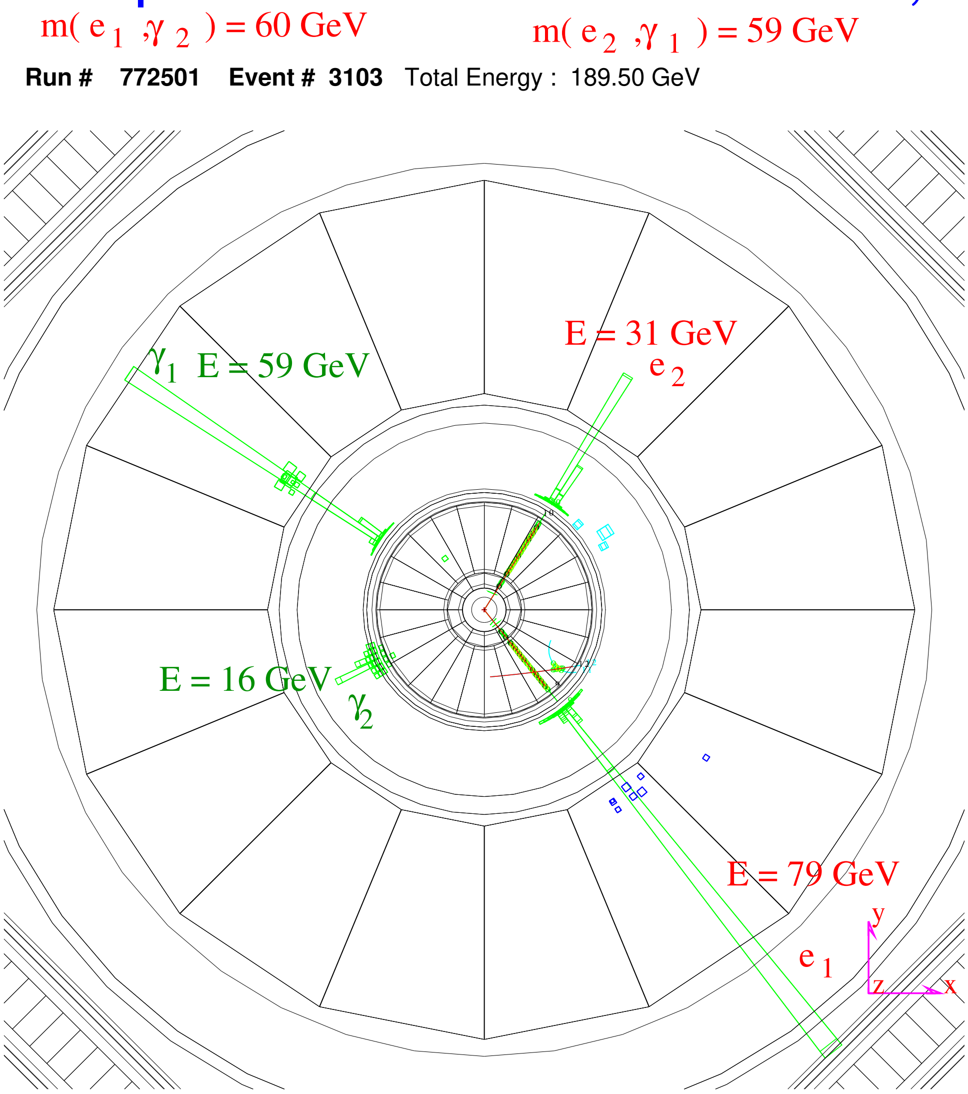
Neutral: $e^+e^- \to L^0\bar{L}^0$

Decay	Model	Dirac	Majorana
$L^0 \to eW$	Sequential	97.1	85.7
	Vector	99.5	—
	Mirror	96.9	85.7
$L^0 \to \mu W$	Sequential	97.0	88.0
	Vector	99.4	—
	Mirror	96.7	88.0
$L^0 \to \tau W$	Sequential	89.0	79.6
	Vector	96.0	—
	Mirror	89.0	79.6

Charged: $e^+e^- \to L^+L^-$

Decay	Model	Limit
$L^\pm \to \nu W$	Sequential	98.8
	Vector	99.1
	Mirror	98.7

Pair production: $e^+e^- \to \ell^*\ell^*,\ \nu^*\nu^*$



Transverse Imbalance :	.0166	Longitudinal Imbalance :	-.0202
Thrust : .7979	Major : .2969	Minor : .2251	
Event DAQ Time :	990820 54953		

Candidate for:
$e^*e^* \to e\gamma e\gamma$
(0.8 expected from SM background)

Coupling-independent mass limits [GeV]:

$\ell =$	e	μ	τ
$\ell^* \to \ell\gamma,\ \nu W,\ \ell Z$	95.6	95.6	95.5
$\nu_\ell^* \to \nu\gamma,\ \ell W,\ \nu Z$	99.2	99.2	93.1

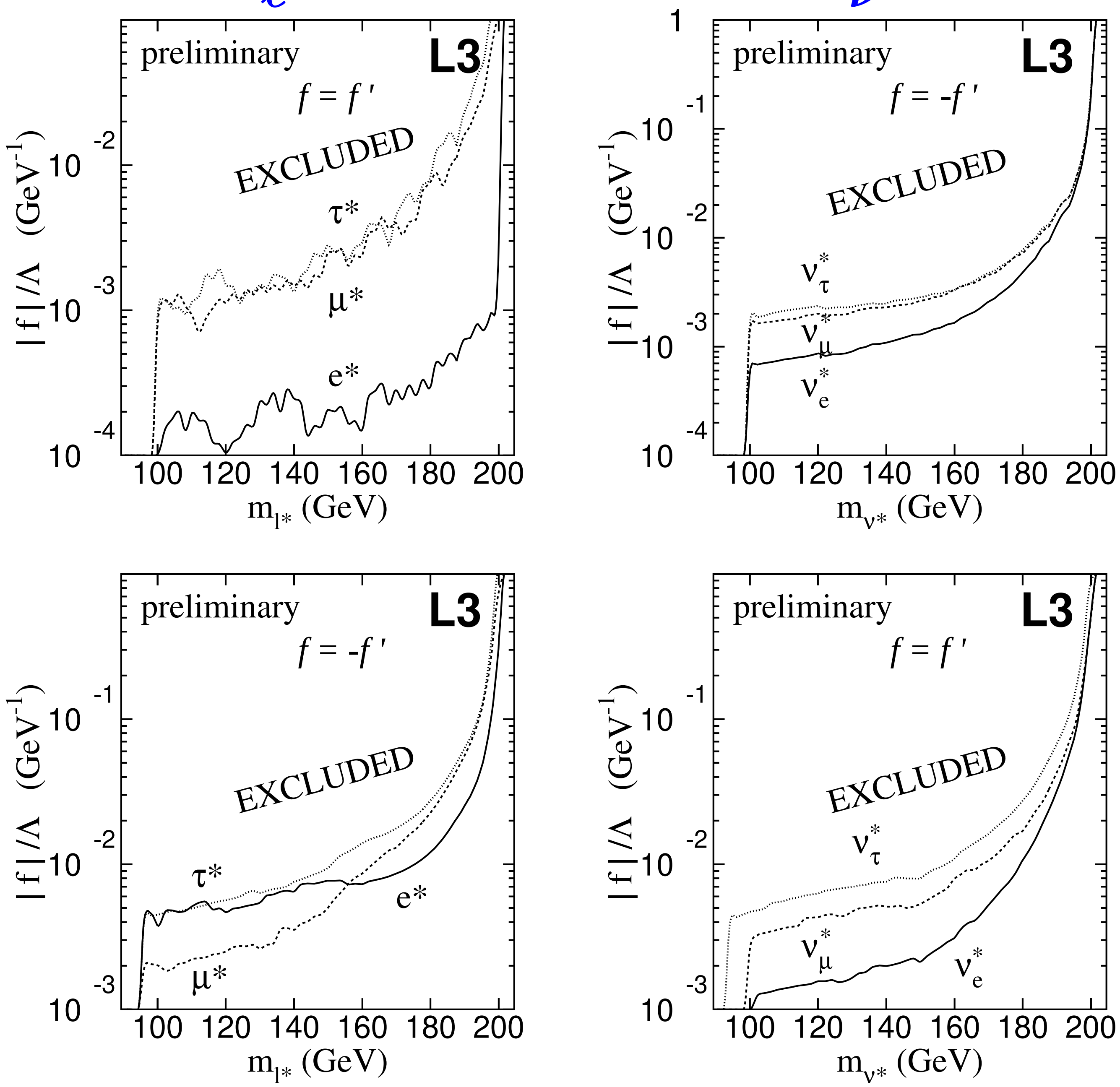
Single production: $e^+e^- \to \ell\ell^*,\ \nu\nu^*$

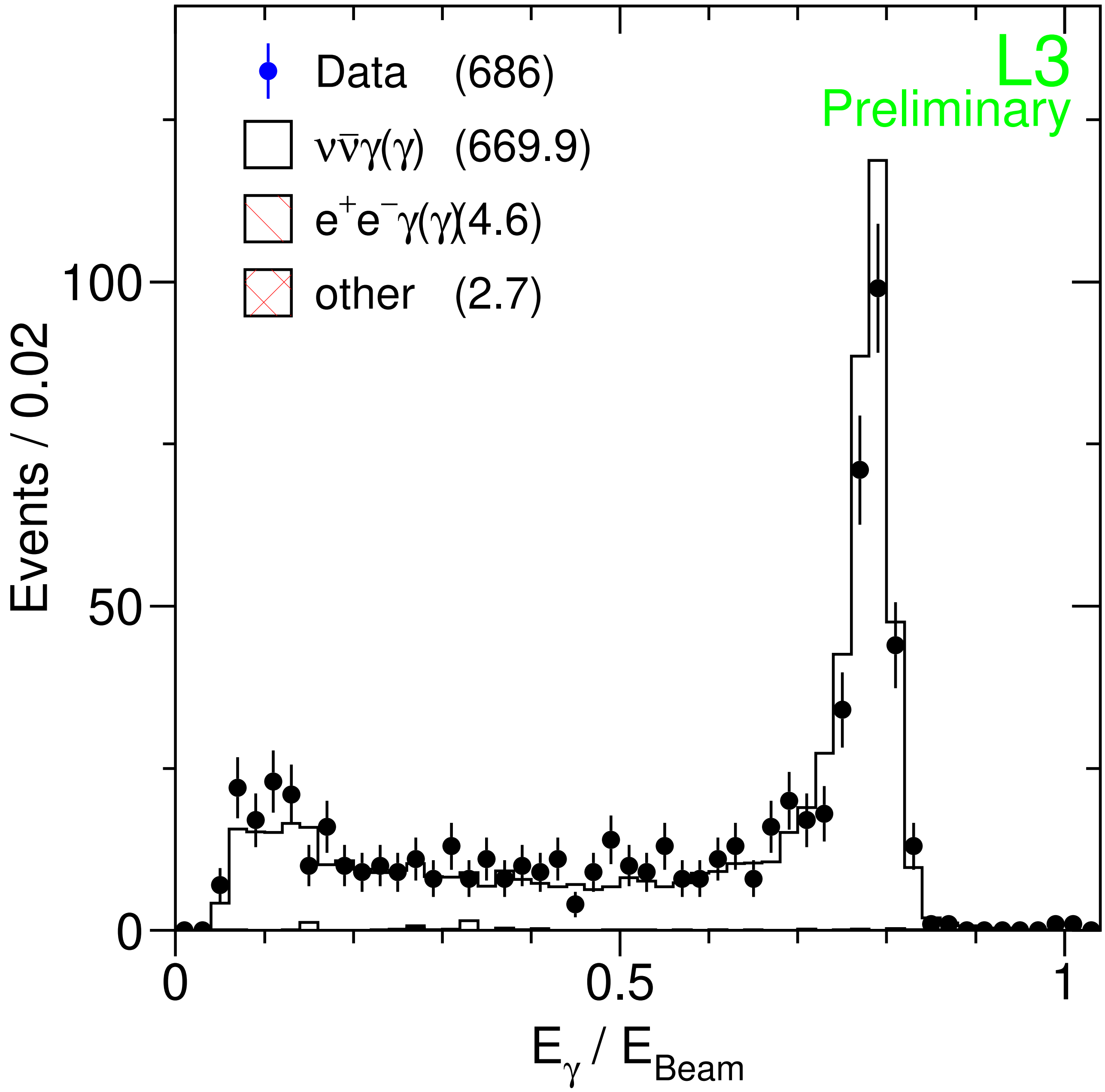
Two couplings f, f' for production and decay

Λ compositeness scale

Limits on $|f|/\Lambda$ for $f = f'$ and $f = -f'$

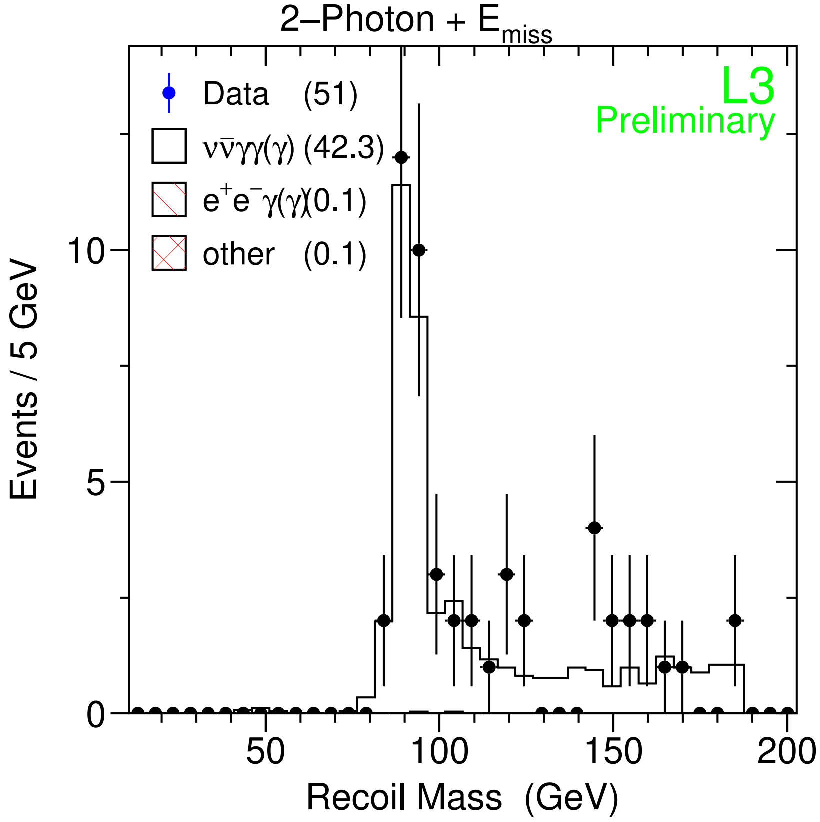
ℓ^* ν^*



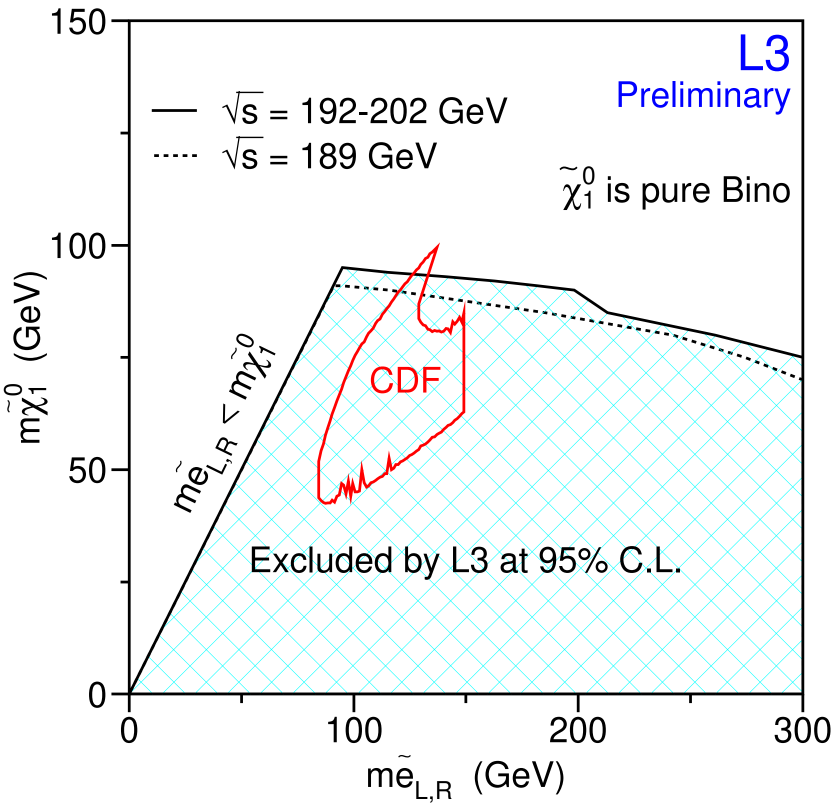


SM: $e^+e^- \rightarrow \nu\bar{\nu}\gamma$

Rate as expected from Standard Model MC



SM:
$e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$



CDF ee$\gamma\gamma$ event
Gravitino LSP
interpretation:
almost ruled out

SUSY Searches

Constrained MSSM:

R-parity conservation: pair production of S-particles

Lightest S-particle (LSP): $\tilde{\chi}^0_1$, stable, invisible

Sleptons: $e^+e^- \rightarrow \tilde{\ell}\tilde{\ell} \rightarrow \ell\ell\tilde{\chi}^0_1\tilde{\chi}^0_1$ 2 leptons, $\not{E}$

Squarks: $e^+e^- \rightarrow \tilde{q}\tilde{q} \rightarrow qq\tilde{\chi}^0_1\tilde{\chi}^0_1$ 2 jets, $\not{E}$

Charginos: $e^+e^- \rightarrow \tilde{\chi}^+_1\tilde{\chi}^-_1 \rightarrow W^*W^*\tilde{\chi}^0_1\tilde{\chi}^0_1$

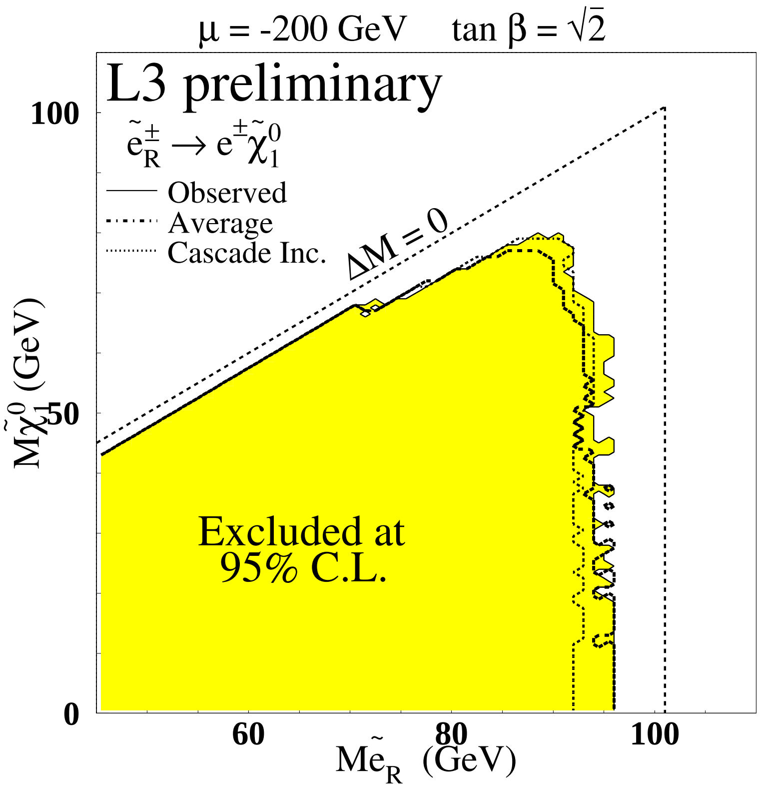
$\not{E}$ and: 4 jets, or 2 jets and 1 lepton, or 2 leptons

$\Delta M = (M_{\text{Sparticle}} - M_{\text{LSP}})$ dependent analyses

	Low ΔM		Medium ΔM		High ΔM		.OR.	
N	data	exp	data	exp	data	exp	data	exp
$\tilde{e}$	47	40.4	10	12.9	24	24.5	76	68.9
$\tilde{\mu}$	72	66.4	20	16.7	48	40.1	123	110
$\tilde{\tau}$	191	205	72	62.5	41	33.7	226	229
$\tilde{t}$	14	18.5	0	2.6	19	17.3	33	38.3
$\tilde{b}$	12	19.6	1	1.7	0	1.9	13	20.3
$\tilde{\chi}^\pm_1$	74	77.8	17	18.6	91	92.6	171	177
$\tilde{\chi}^0_2$	42	52.1	7	12.5	4	5.0	52	68.2

No signal seen

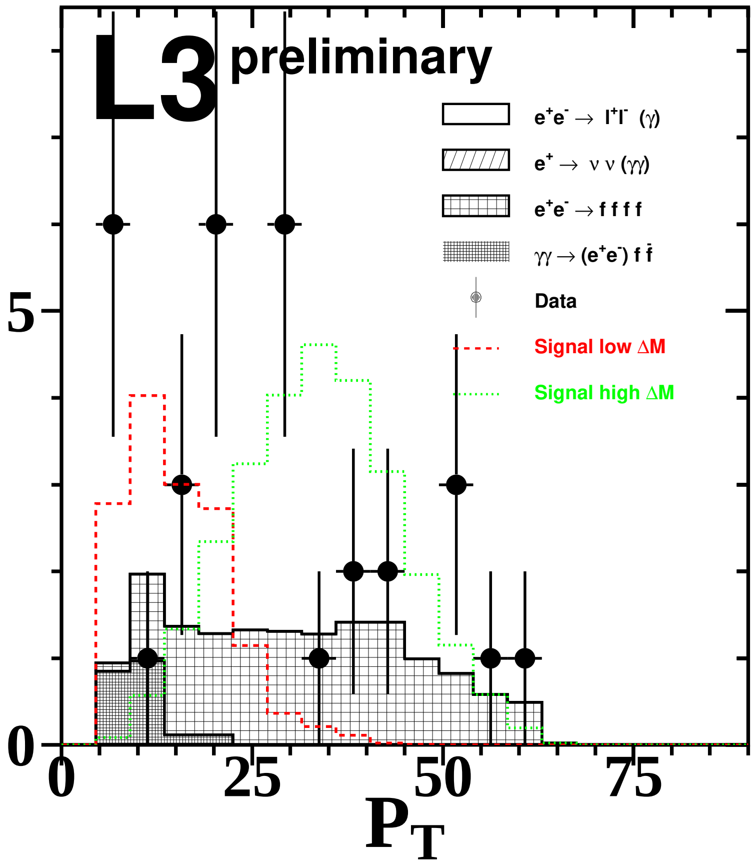
SUSY Searches - $\tilde{e}$



s-channel:
$e^+e^- \longrightarrow \tilde{e}_R^+\tilde{e}_R^-$

$\tilde{e}^\pm \longrightarrow e^\pm\tilde{\chi}_1^0$

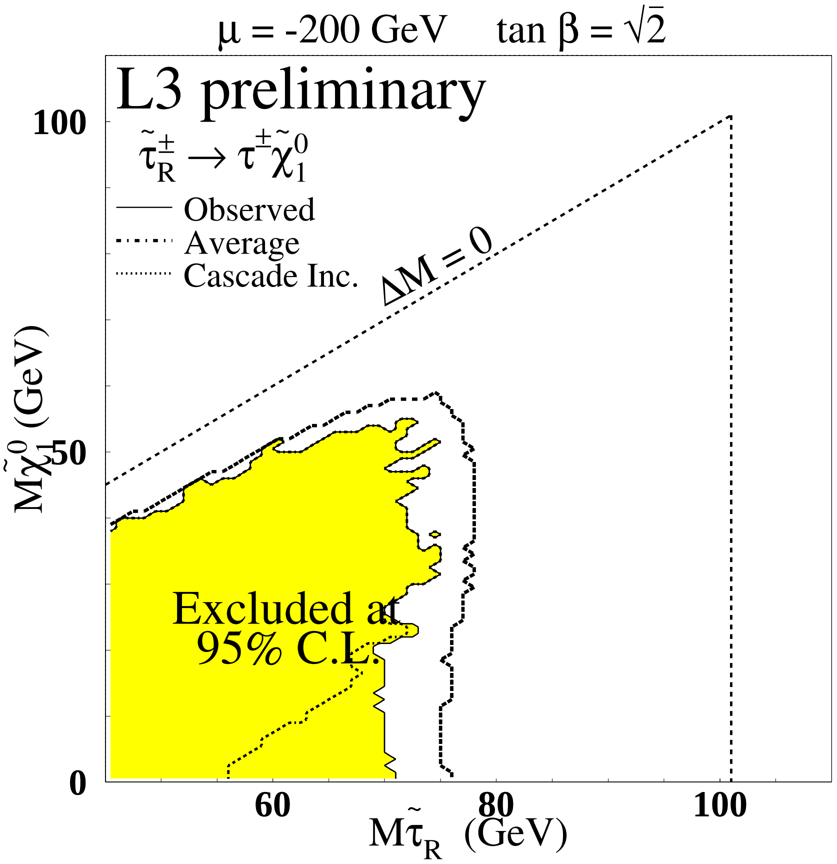
Two electrons



t-channel:
$e^+e^- \longrightarrow \tilde{e}_L\tilde{e}_R$
$\longrightarrow e_{hard}e_{soft}\tilde{\chi}_1^0\tilde{\chi}_1^0$

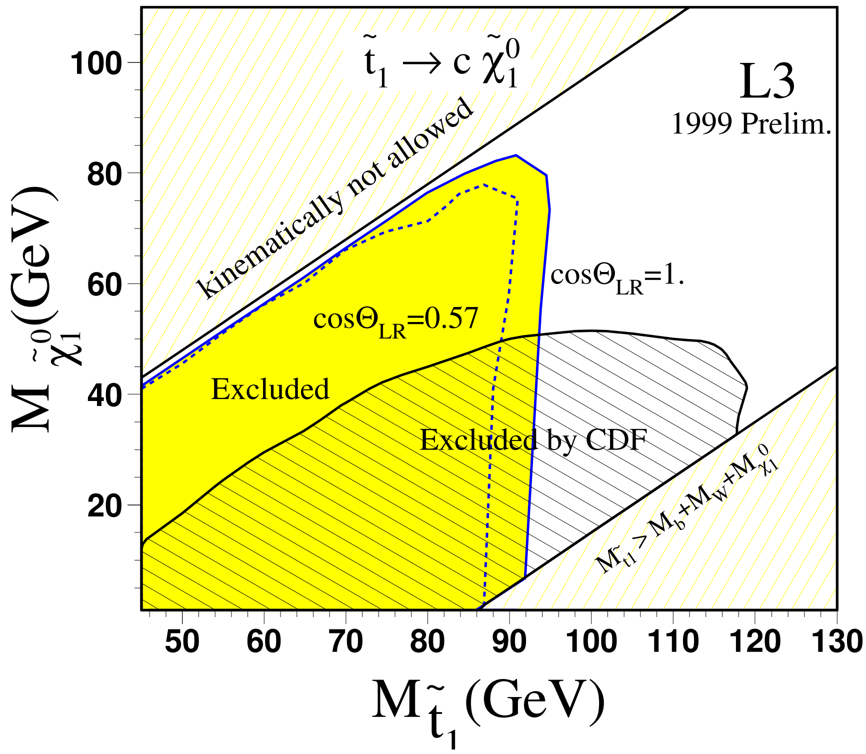
Single electron plus soft system

Data: 32
MC: 15.2



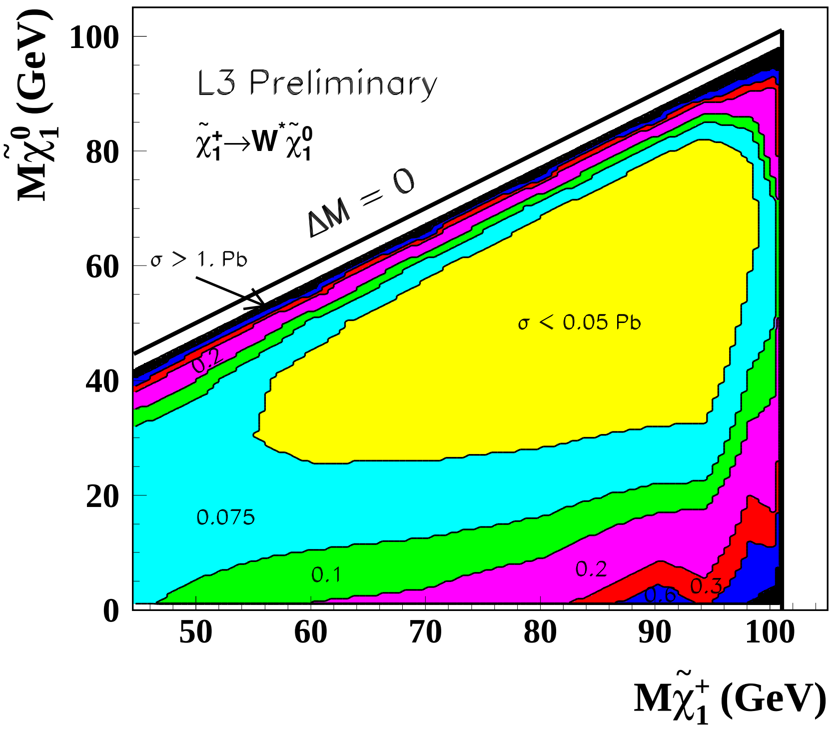
$e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^-$

$\tilde{\tau}^{\pm} \rightarrow \tau^{\pm}\tilde{\chi}^0_1$



$e^+e^- \rightarrow \tilde{t}\bar{\tilde{t}}$

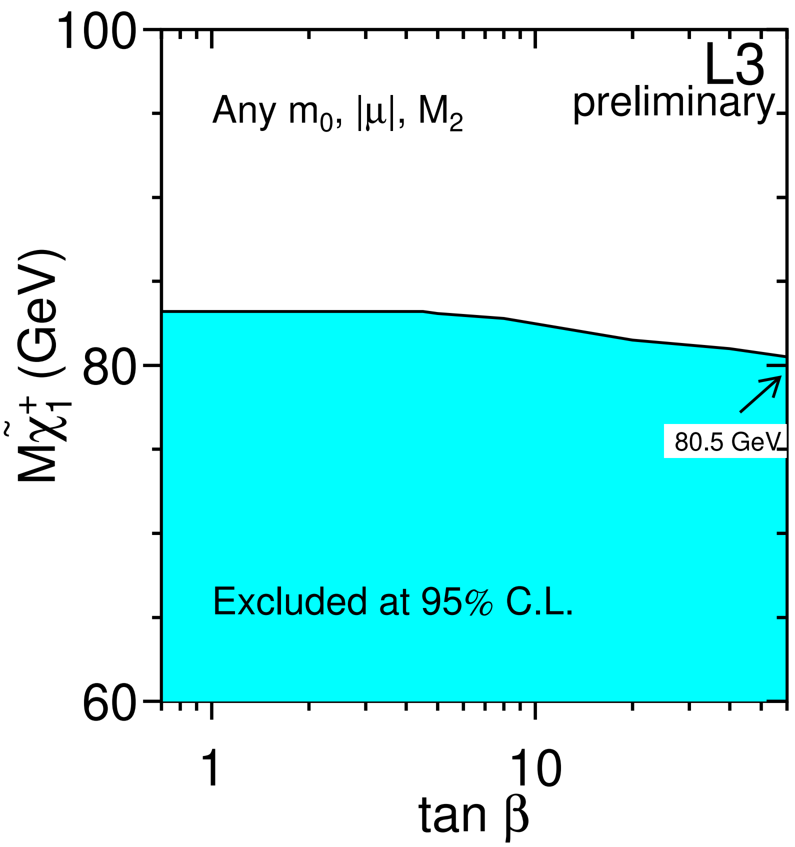
$\tilde{t} \rightarrow c\tilde{\chi}^0_1$



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

$\tilde{\chi}_1^\pm \to W^*\tilde{\chi}_1^0$

Cross section limit



Mass exclusion
in the CMSSM:
chargino searches
slepton searches

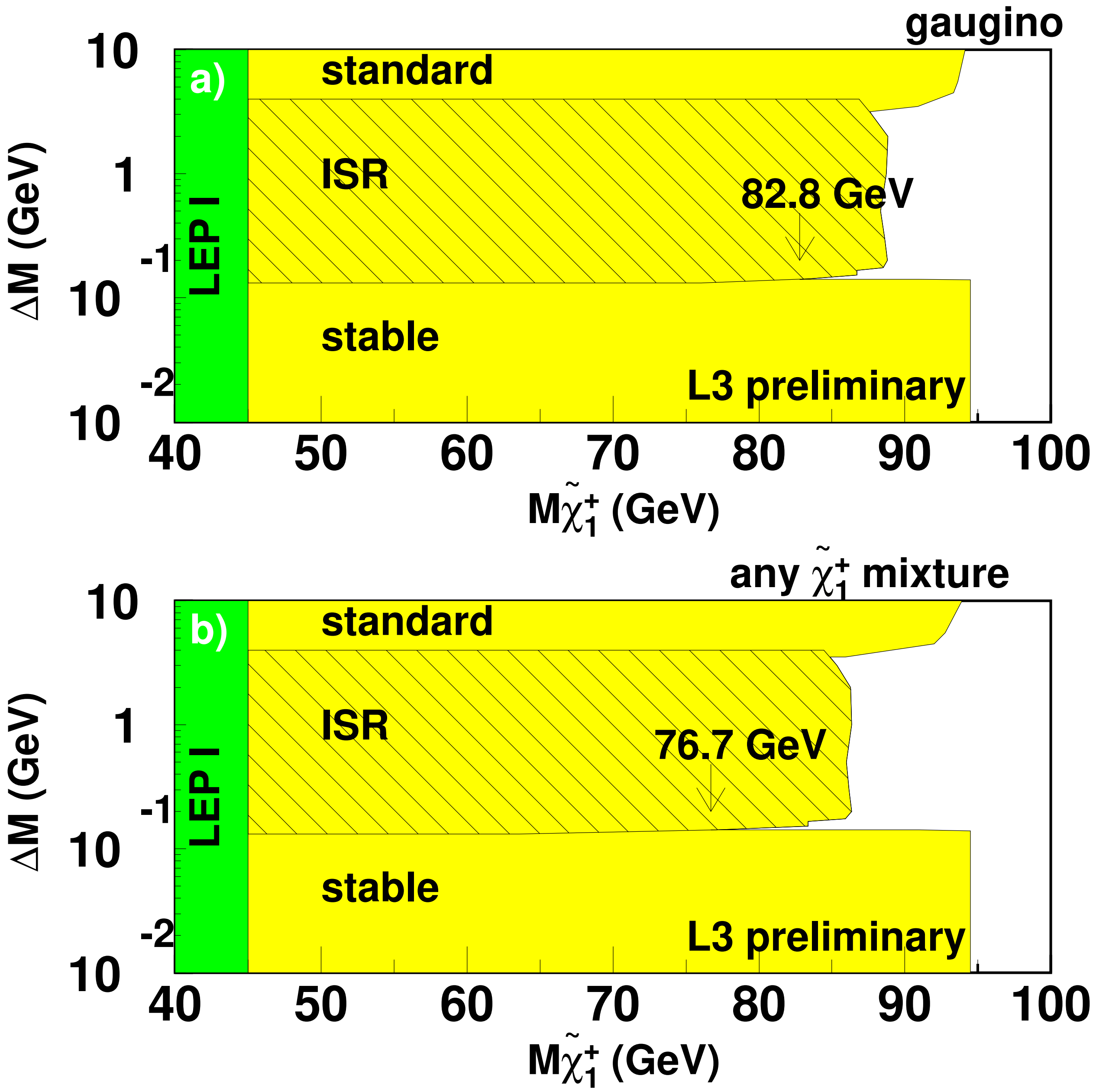
$M_{\tilde{\chi}_1^\pm} > 80.5$ GeV

For very low $\Delta M = M_{\tilde{\chi}_1^{\pm}} - M_{\tilde{\chi}_1^0}$:

Tagging by ISR:

$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma X$

Hard γ plus low-energy system X

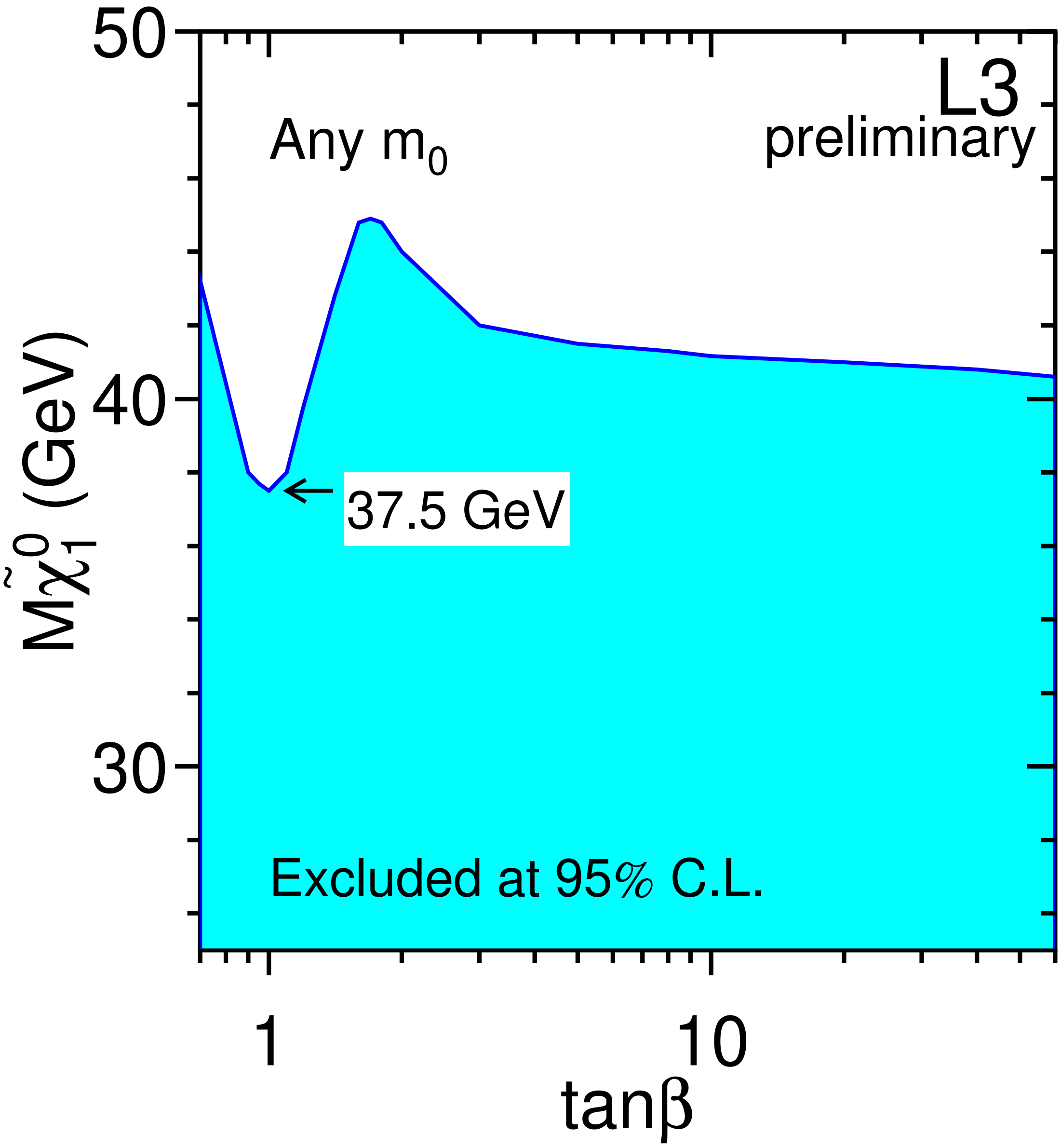


Mass exclusion in the CMSSM, based on:

neutralino search results

chargino search results

slepton search results



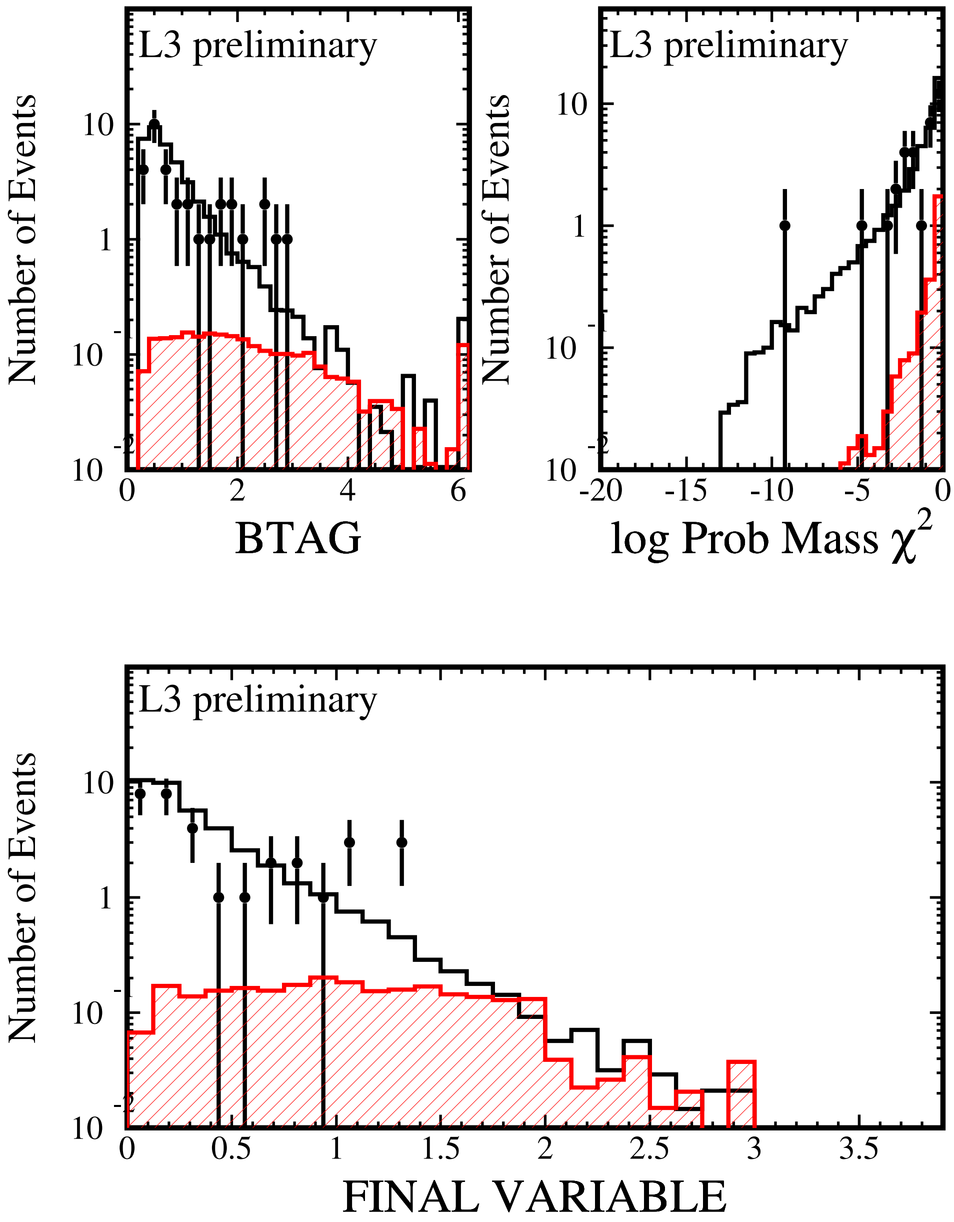
$M_{\tilde{\chi}_1^0} > 37.5$ GeV

$e^+e^- \rightarrow Z^* \rightarrow ZH \rightarrow f\bar{f}b\bar{b},\ f\bar{f}\tau^+\tau^-$

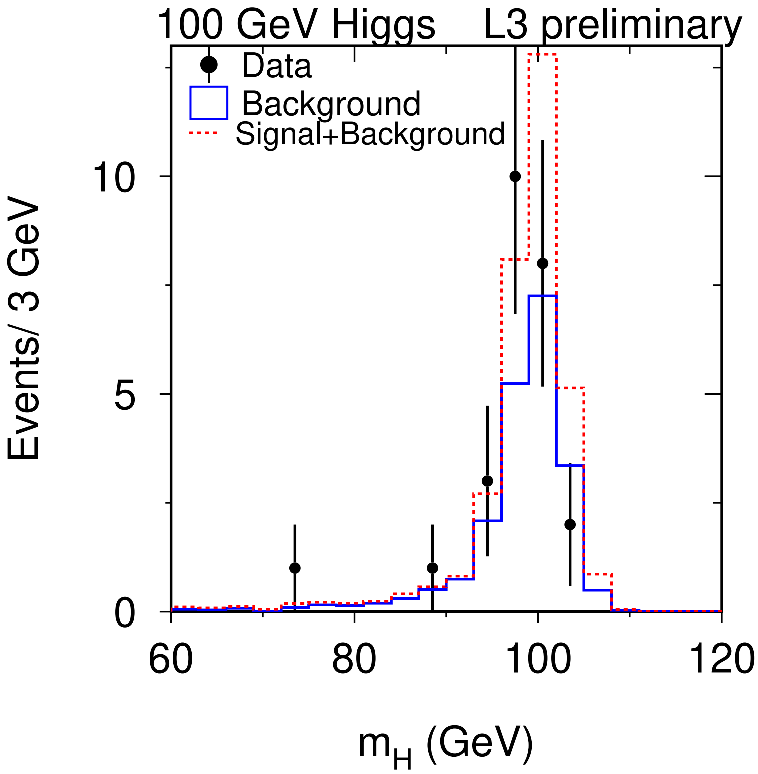
Discriminant variable combining:

B-tag, neural network
Higgs mass hypothesis

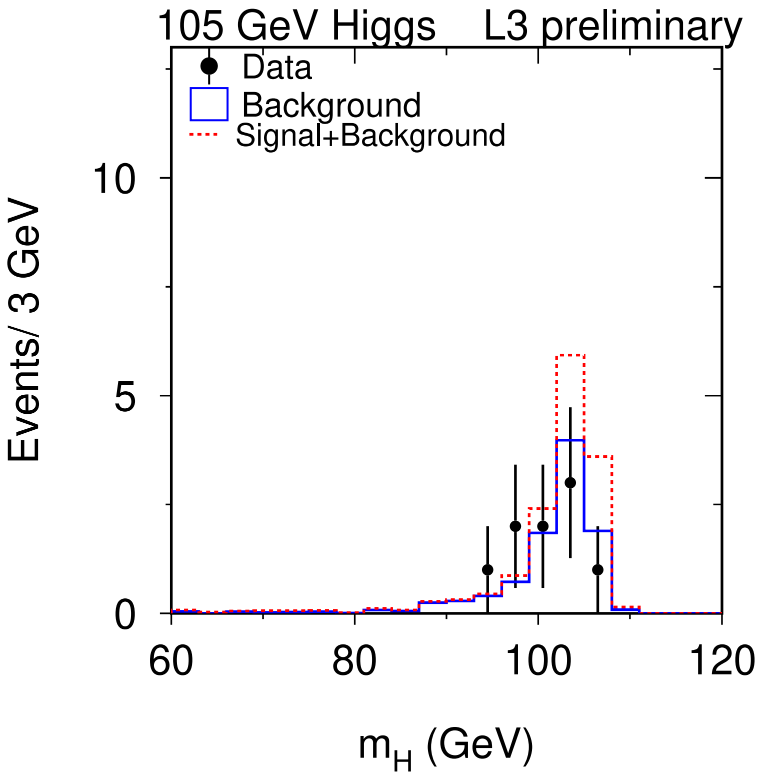
105GeV Higgs at 200 GeV optimized



Most significant candidates:

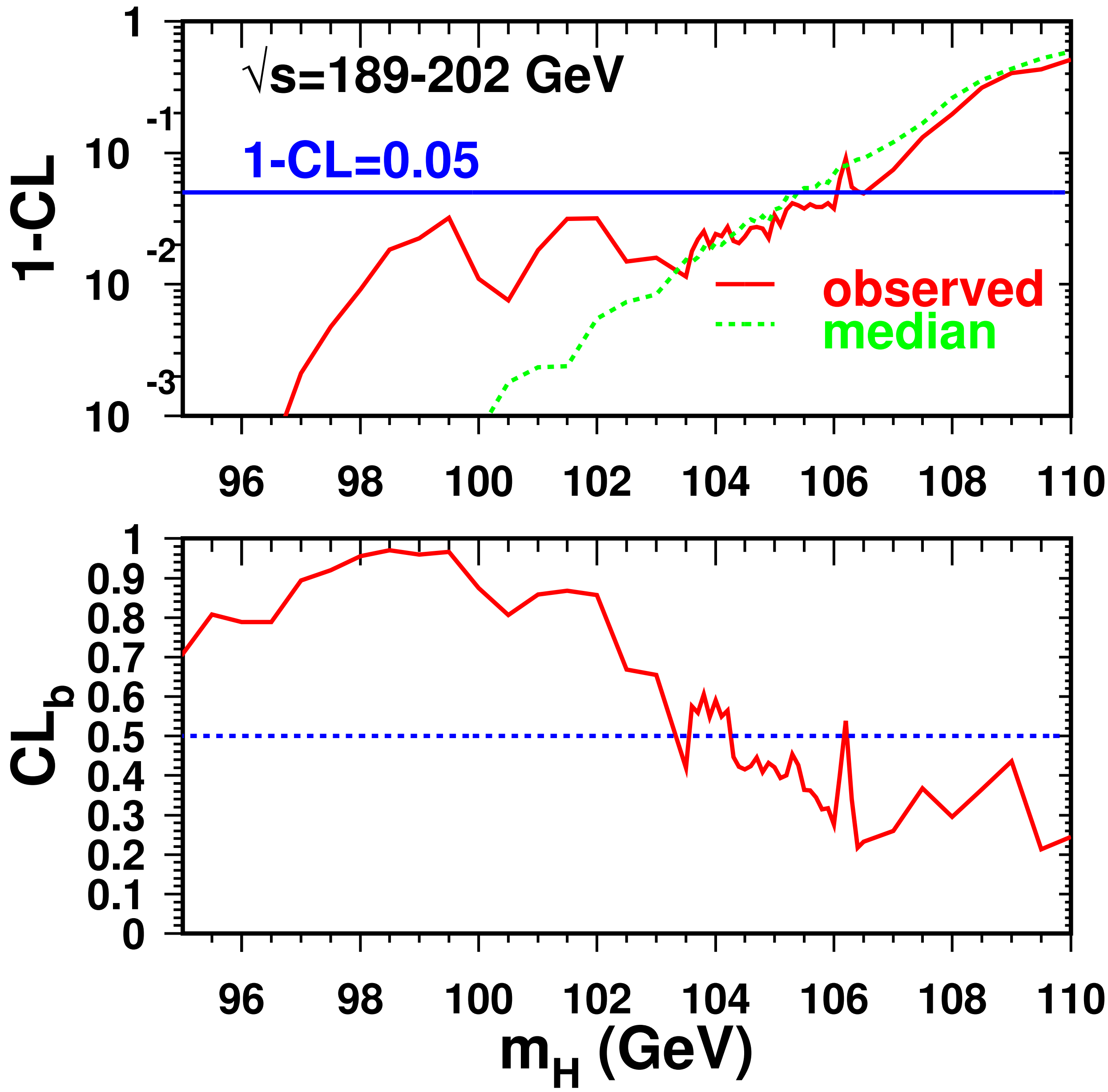


Observed	25
SM background	21.1
Higgs signal	12.1



Observed	9
SM background	9.9
Higgs signal	4.8

L3 preliminary



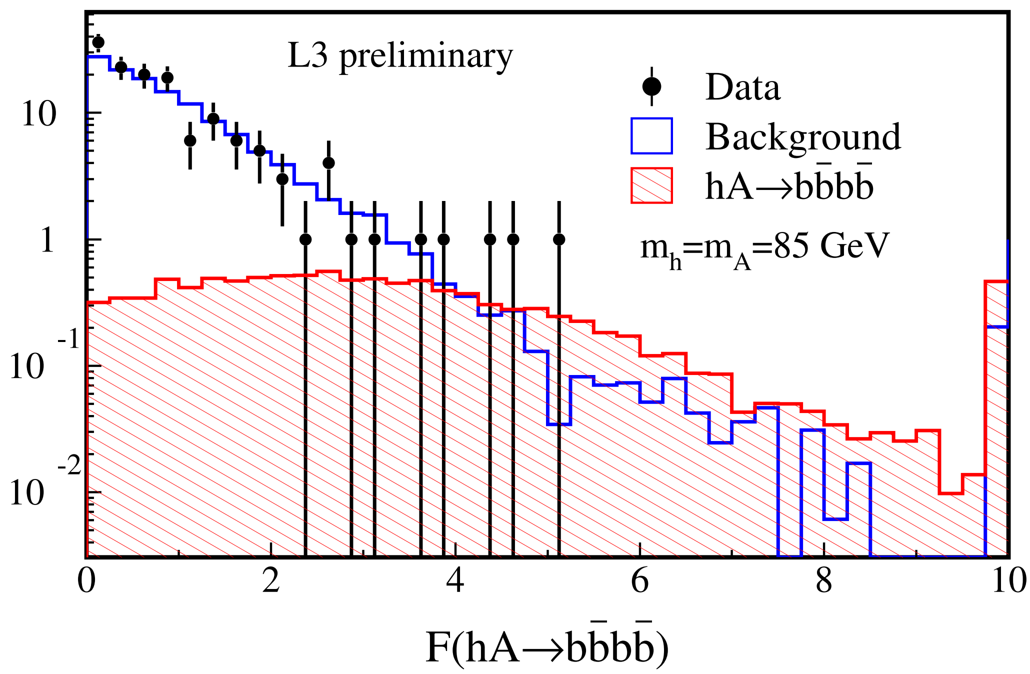
$M_{\mathrm{H}} > 106.0$ GeV

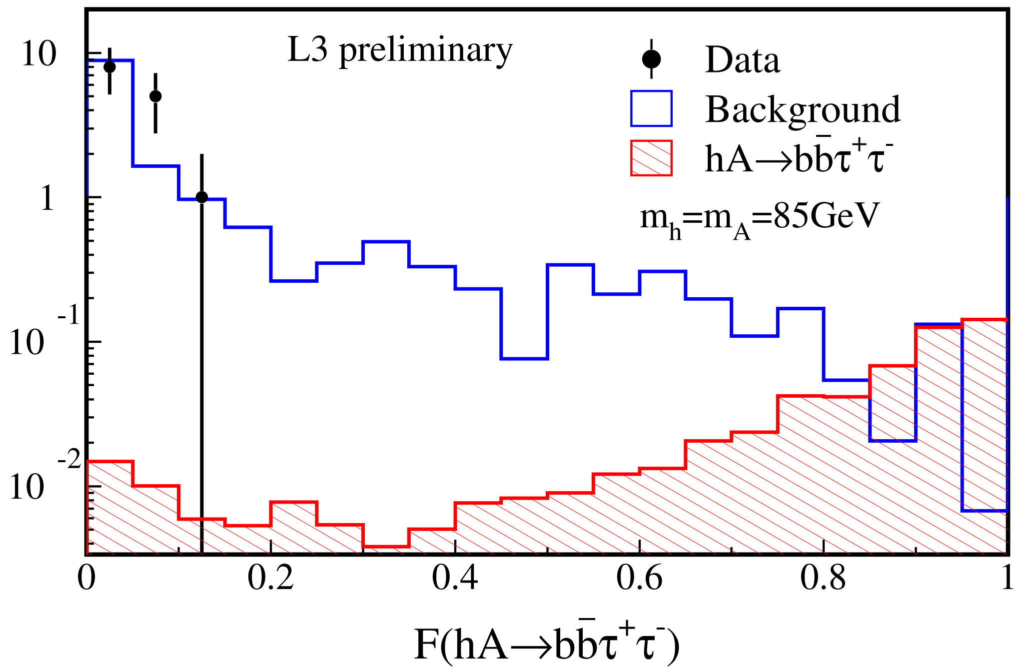
(Expected limit: 105.3 GeV)

Production: $e^+e^- \rightarrow hZ,\ hA$

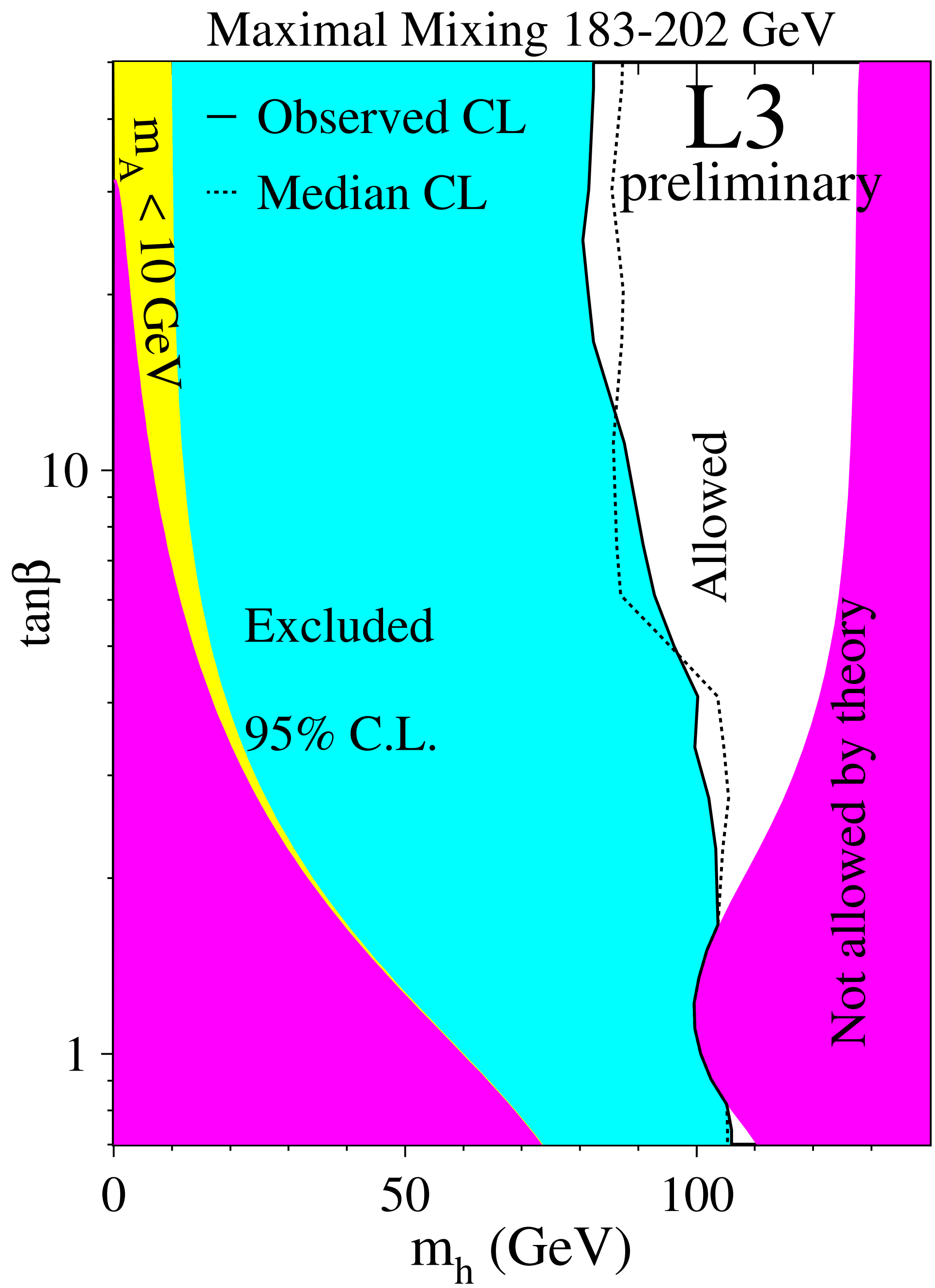
Decay: $h, A \rightarrow b\bar{b}$ (dominant), $\tau^+\tau^-$

192GeV - 202GeV





MSSM Neutral Higgs Bosons



$M_h > 80.5$ GeV (85.5 GeV expected)

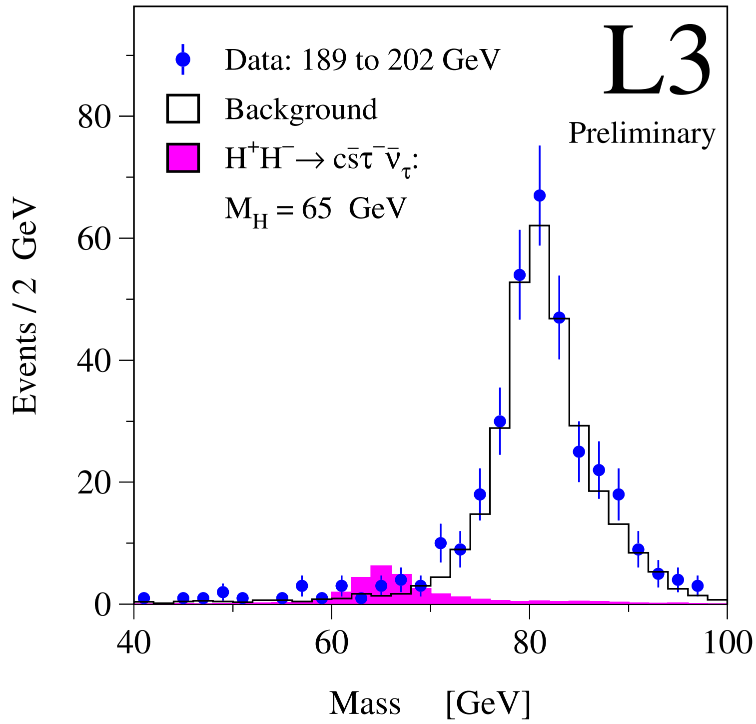
$M_A > 81.0$ GeV (86.0 GeV expected)

$0.8 < \tan\beta < 1.6$ excluded

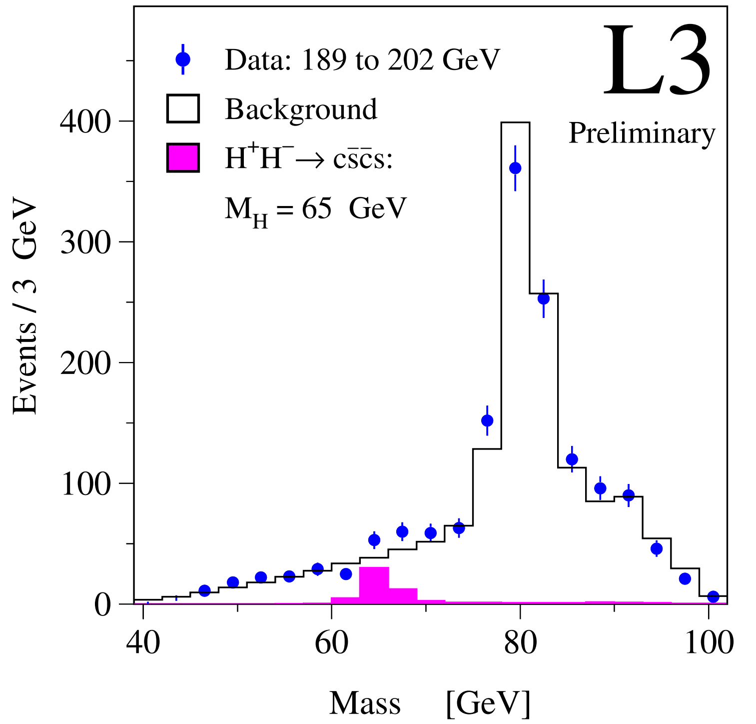
Charged Higgs Boson

Production: $e^+e^- \to H^+H^-$

Decay: $H^\pm \to cs,\ \tau\nu$



$H^+H^- \to cs\tau\nu$

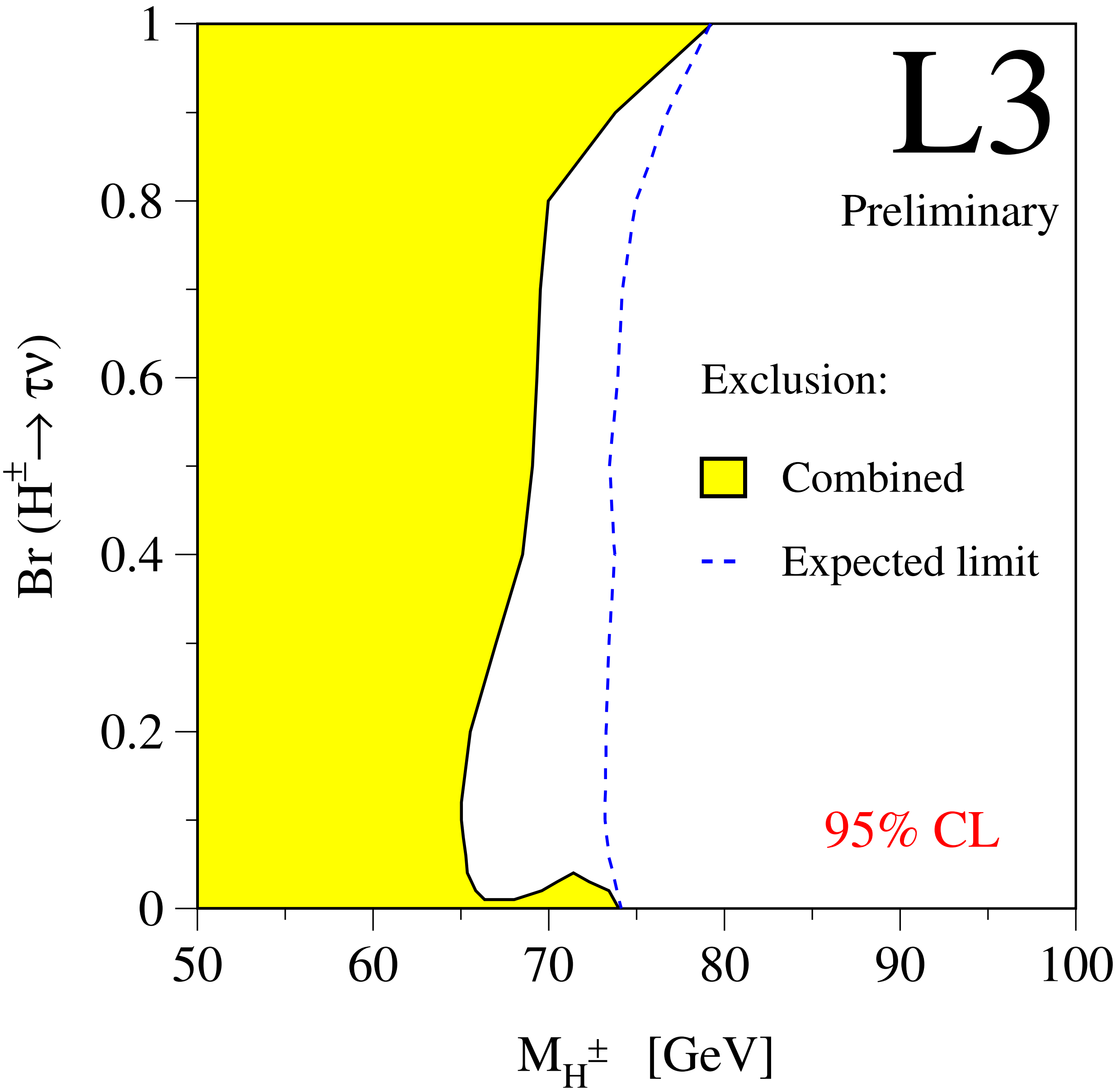


$H^+H^- \to cscs$

also $\tau\nu\tau\nu$ mode

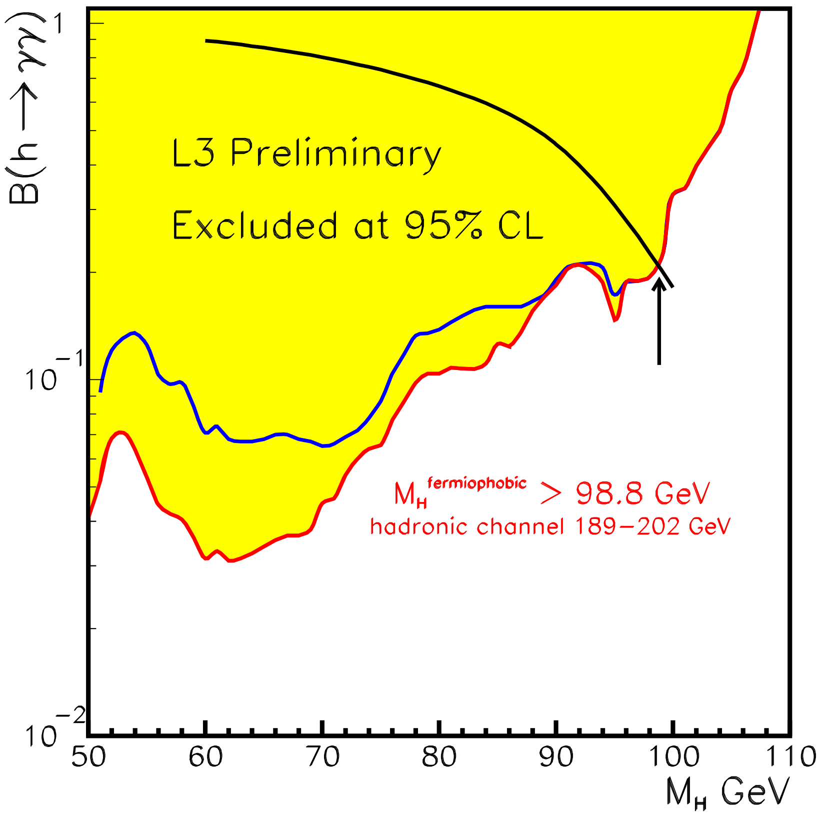
Mass exclusion:

Depending on branching fraction $H^{\pm} \rightarrow \tau\nu$



$M_{H^{\pm}} > 65.0$ GeV

(Expected limit: 73.2 GeV)



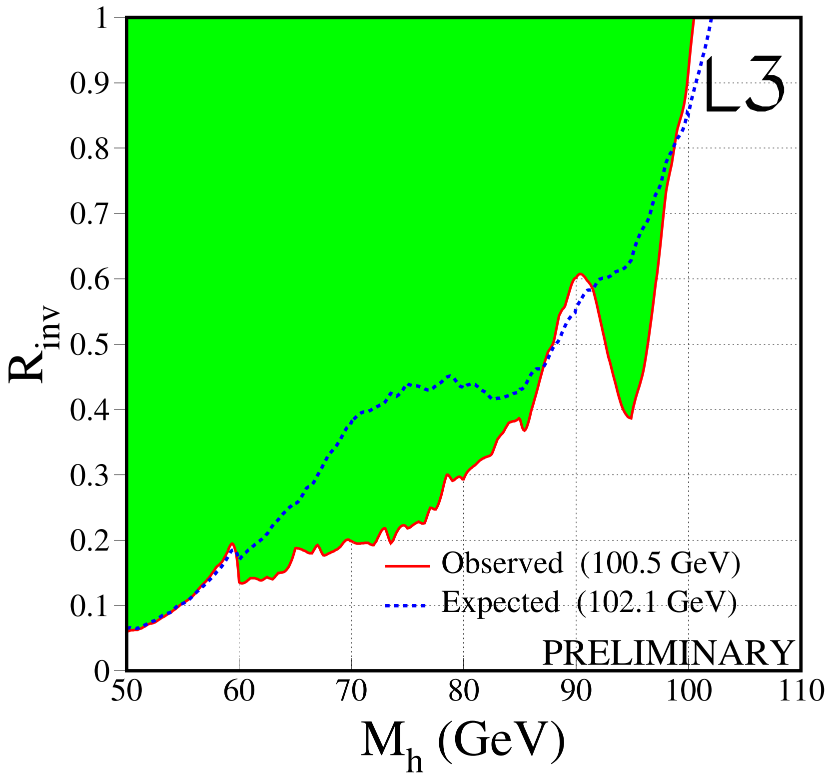
$e^+e^- \to Zh$

$Z \to q\bar{q}$

Fermiophobic Higgs

$h \to \gamma\gamma$

$M_h > 98.8$ GeV



$e^+e^- \to Zh$

$Z \to q\bar{q},\ \ell^+\ell^-$

Invisible Higgs

e.g.: $h \to \tilde{\chi}_1^0\tilde{\chi}_1^0$

$M_h > 100.5$ GeV for $R_{inv} = 1$

Successful running for L3 in 1999!

Thanks to the accelerator divisions for the excellent energy and luminosity performance in 1999!

L3 is looking forward to high energy and luminosity this year. Any fall-back energy should be as high as possible, compatible with efficient operation.

As every year, we need 2.5pb^{-1} at the Z at the beginning of the run for TEC calibration!