Salvatore Mele

INFN/Napoli CERN/EP

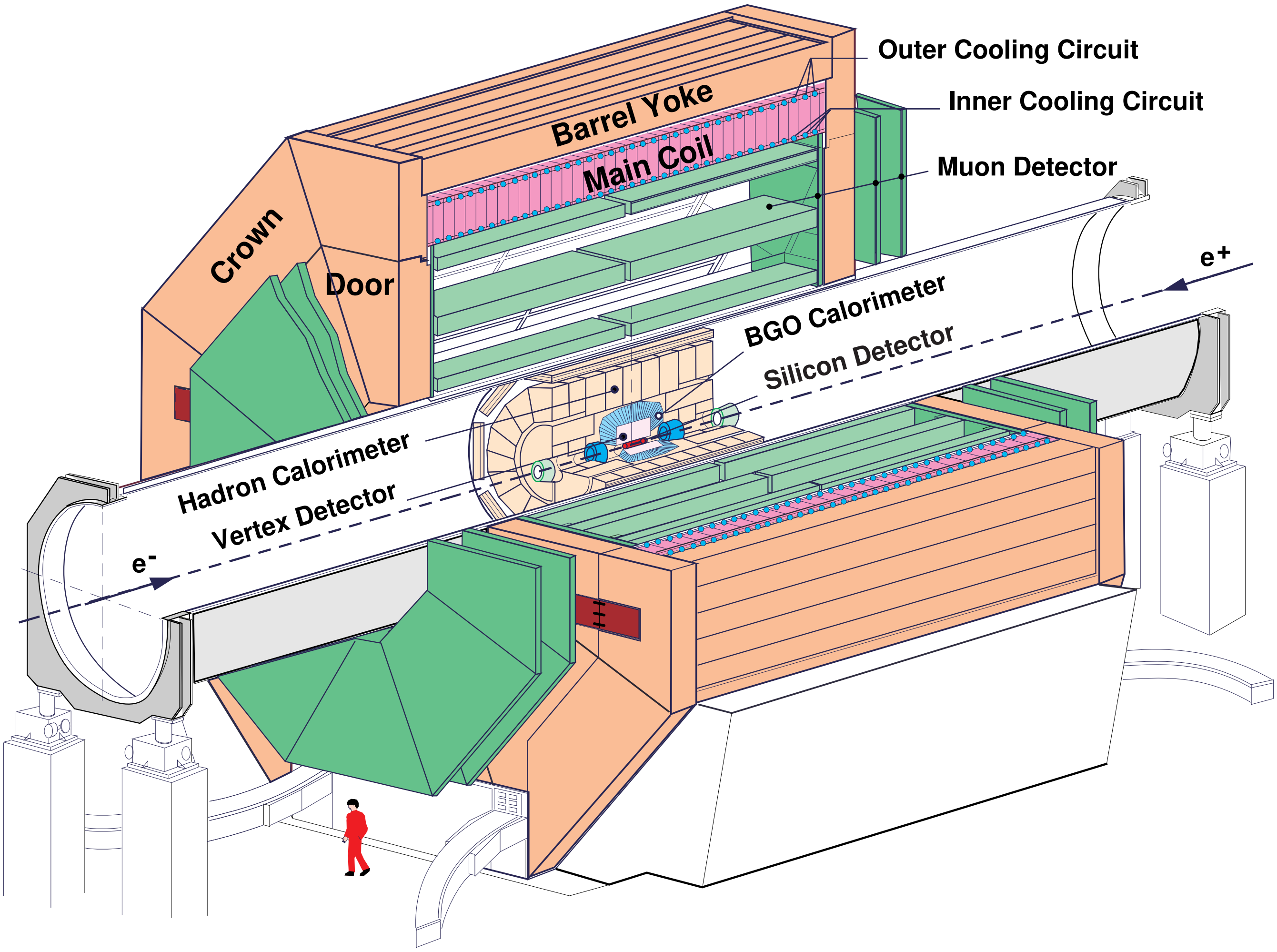
Recent Results from the L3 Experiment

http://l3www.cern.ch/analysis/latestresults.html

- The Data
- Two Fermions
- Two W
- Two (or more) Photons
- One Photon and One Z
- Two Z
- Just one W
- . . . in the Extra Dimensions

QFTHEP'99
XIV International Workshop on
High Energy Physics and Quantum Field Theory
Moscow, Russia, 27^{th} May – 2^{nd} June 1999

The Data



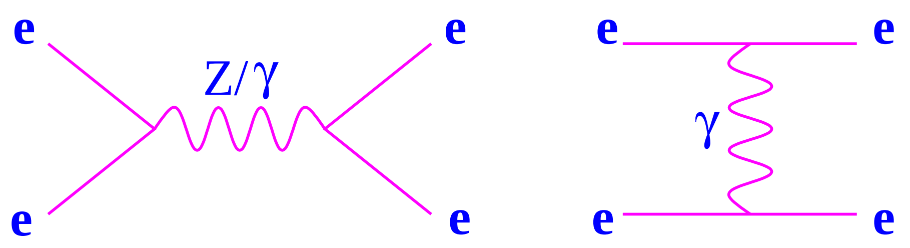
High resolution for Photon, Electron, Muons.
Hermeticity for jet reconstruction.

Focus on LEP 2 data, above the Z pole.

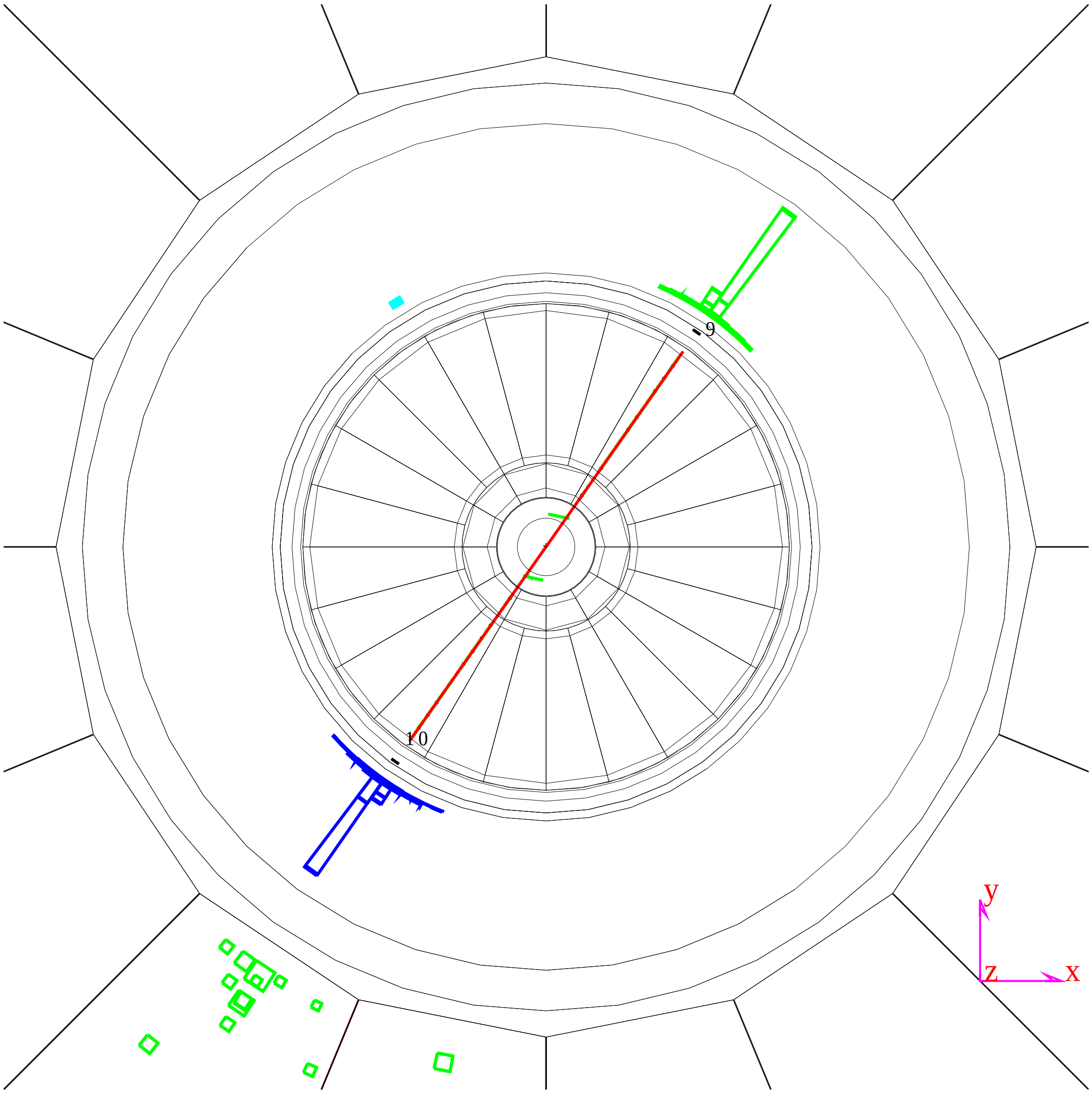
Year	$\sqrt{s}$ (GeV)	$\int \mathcal{L}dt$ (pb^{-1})	
1995	130–140	5+5	The Warm-Up Run
1996	161–172	10+10	W Pairs, W Mass
1997	183	55	Z Pairs
1998	189	175	High statistic measurements

Two Fermions

Bhabha Scattering



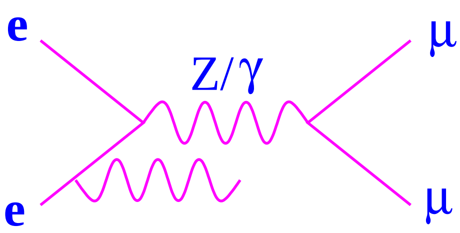
Run # **671103** **Event #** **1467** Total Energy : 183.00 GeV



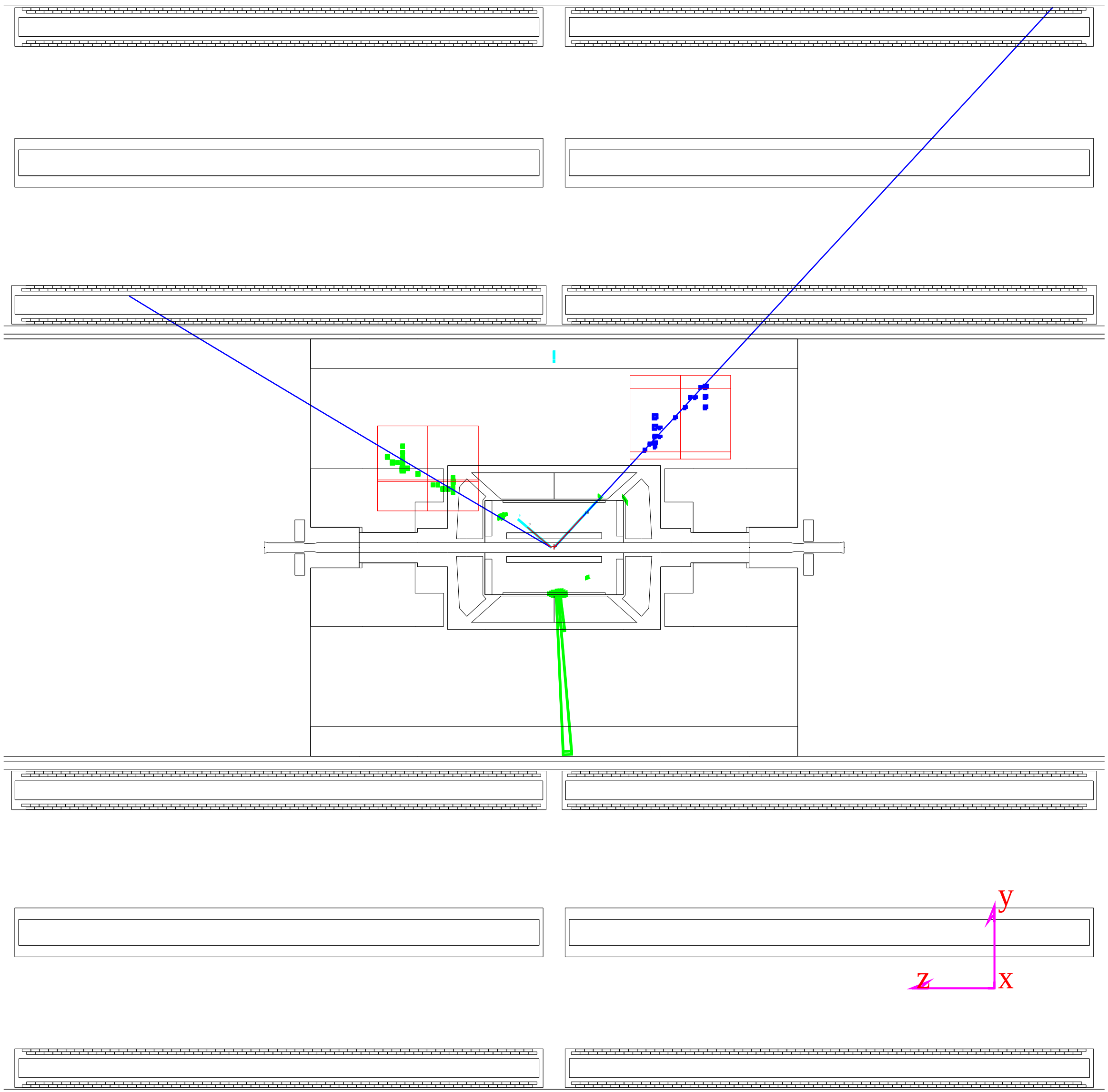
Transverse Imbalance :	.0019	**Longitudinal Imbalance :**	-.0039

Thrust :	1.0000	**Major :**	.0040	**Minor :**	.0000
Event DAQ Time :	*970801 174808*				

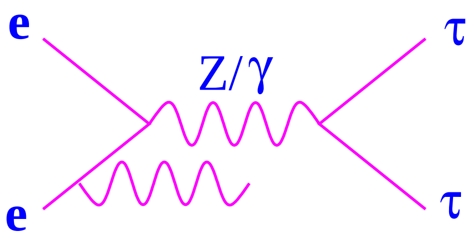
Radiative Muon Pair Production



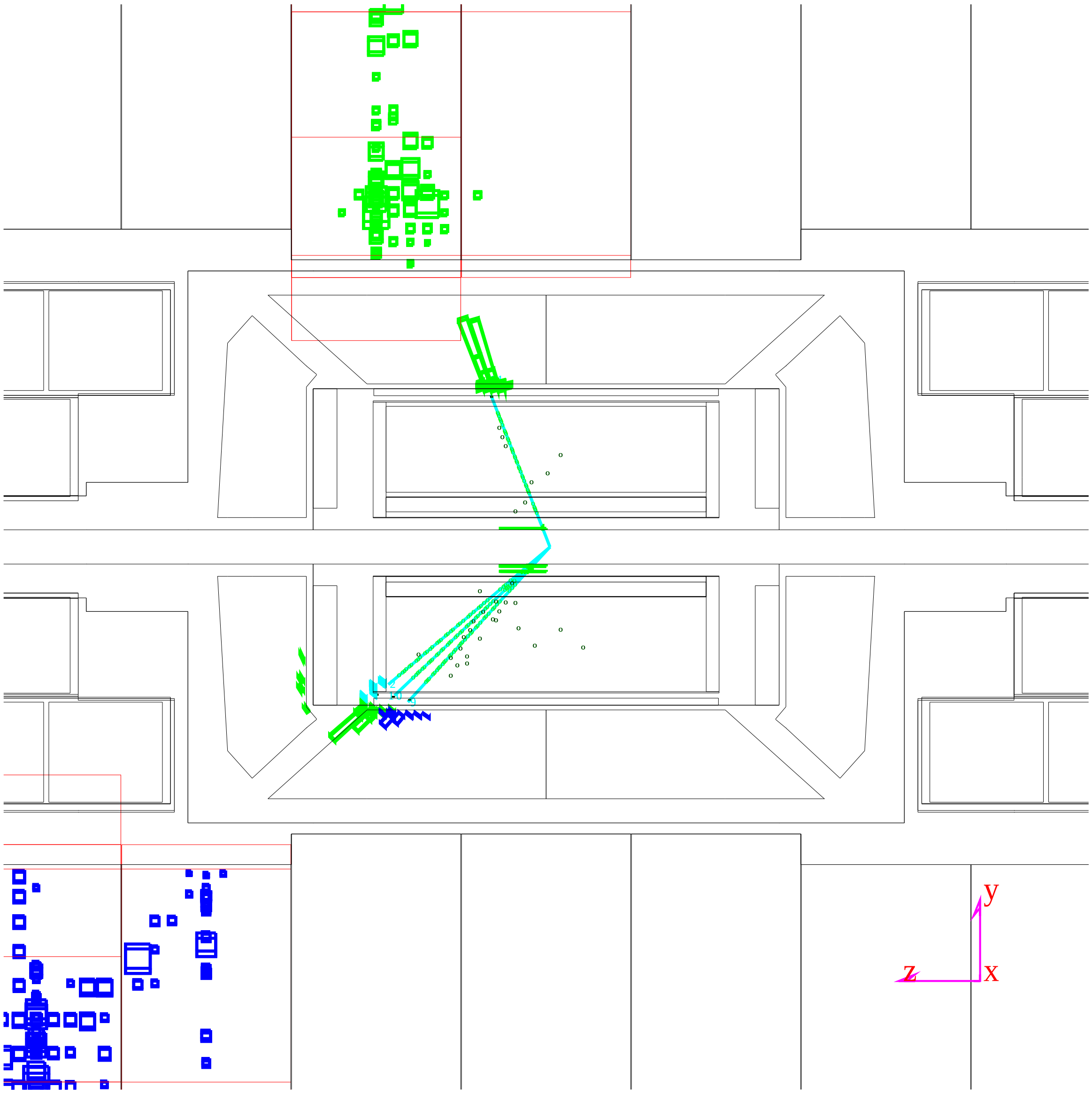
Run # 717206 Event # 4453 Total Energy : 160.00 GeV



Transverse Imbalance :	.0930	**Longitudinal Imbalance :**	-.0629
Thrust : .7837	**Major :** .4771	**Minor :** .0054	
Event DAQ Time :	*980819 181918*		



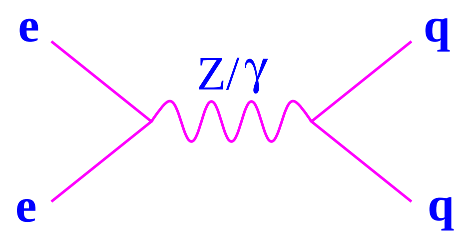
Run # **671516** **Event #** **1670** Total Energy : 75.38 GeV



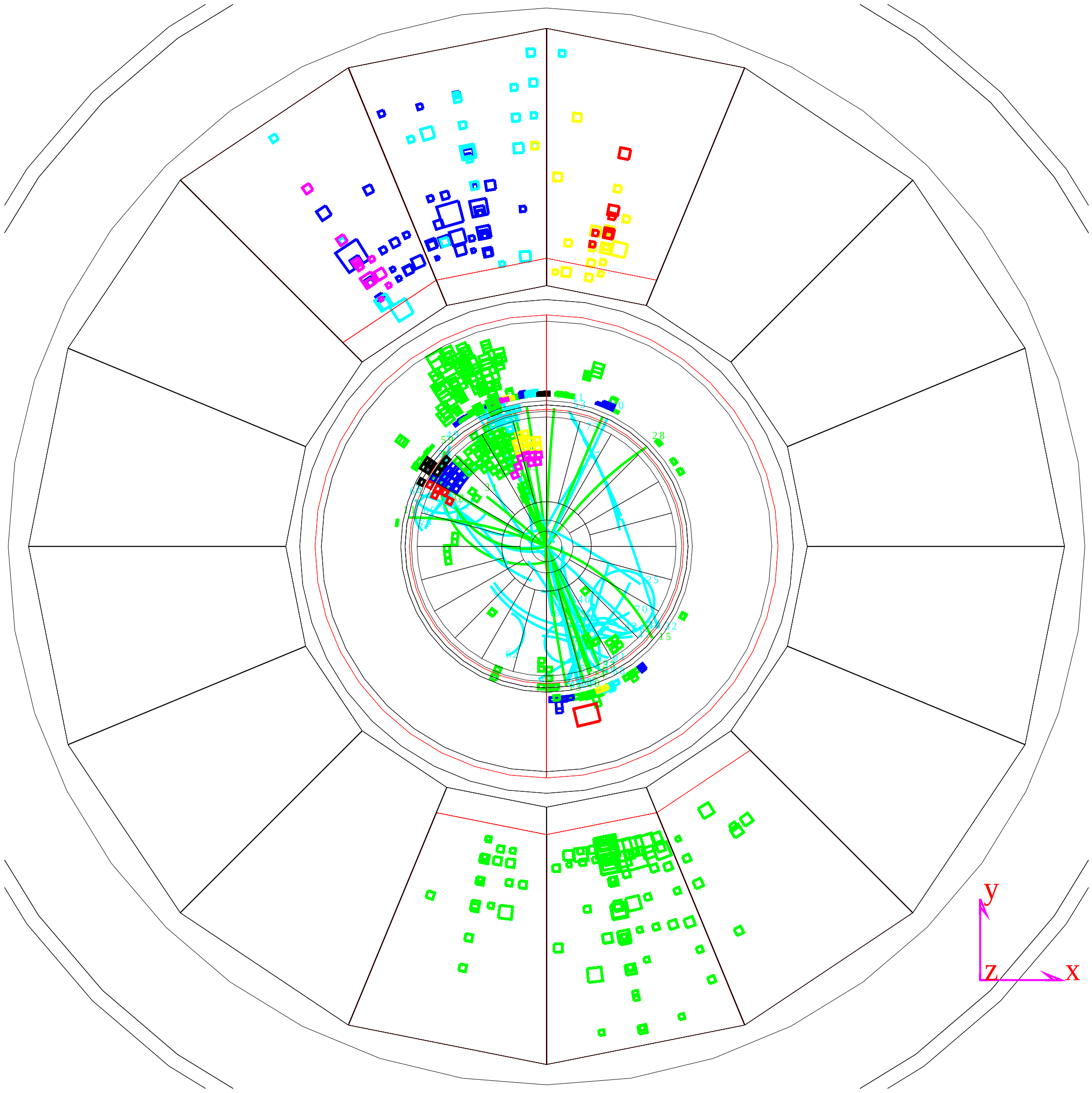
Transverse Imbalance :	.0184	**Longitudinal Imbalance :**	.5483

Thrust :	.8525	**Major :**	.5112	**Minor :**	.0023
Event DAQ Time :	*970803 201101*				

Quark Pair Production



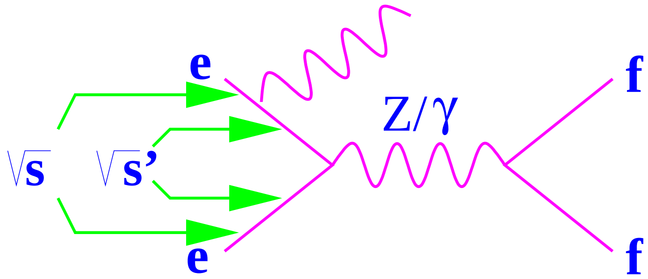
Run # 700701 Event # 2359 Total Energy : 211.50 GeV

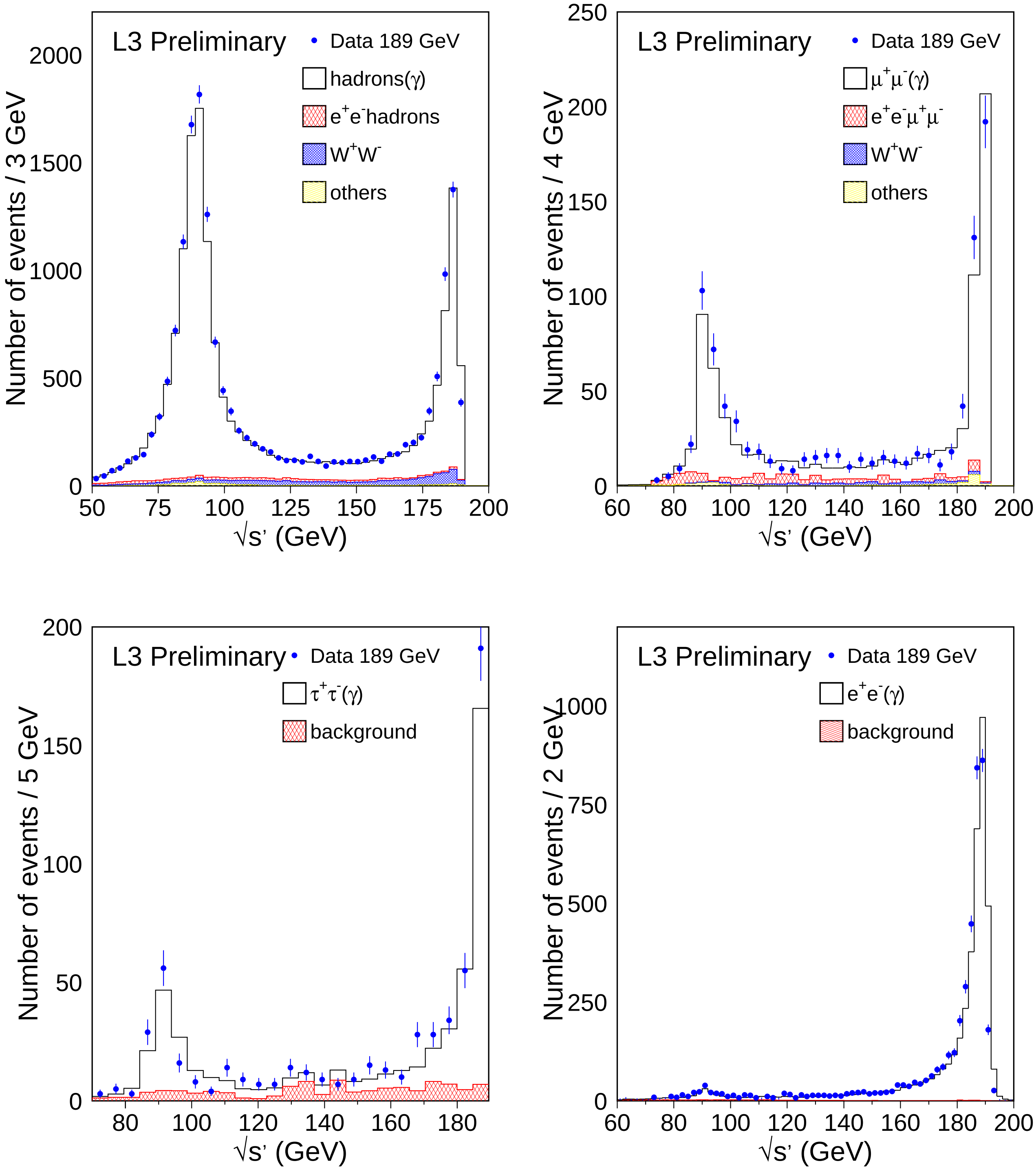


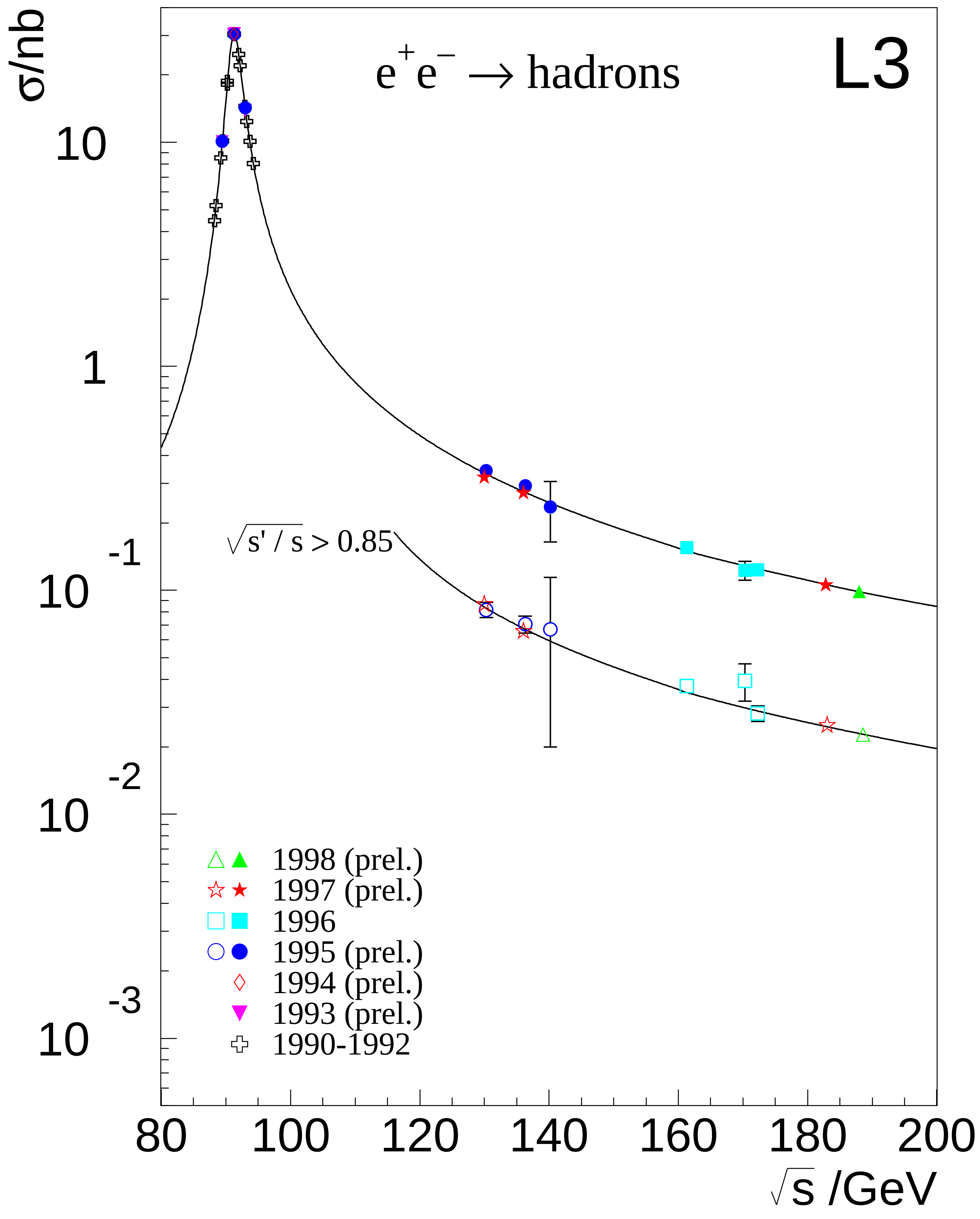
Transverse Imbalance :	.0390	**Longitudinal Imbalance :**	-.0773

Thrust :	.9121	**Major :**	.2250	**Minor :**	.0630
Event DAQ Time :	*980627 204617*				

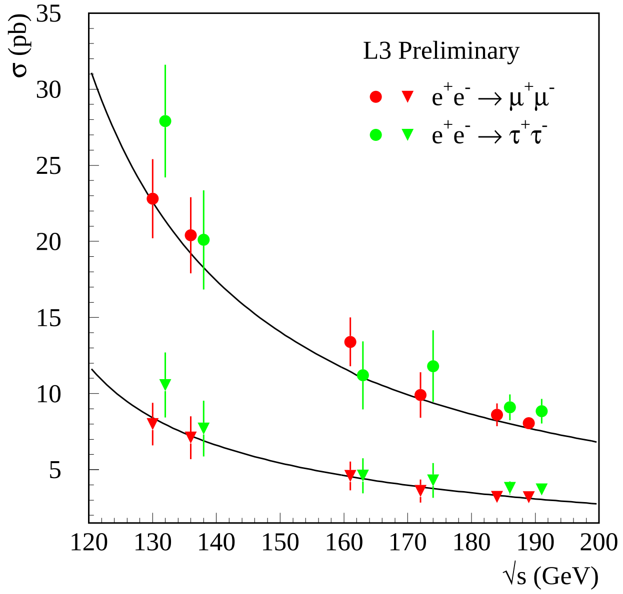
Effective Centre–of–Mass Energy

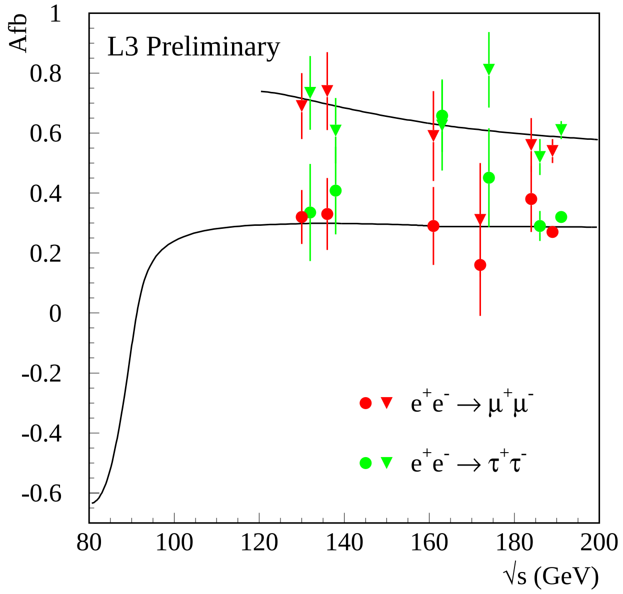


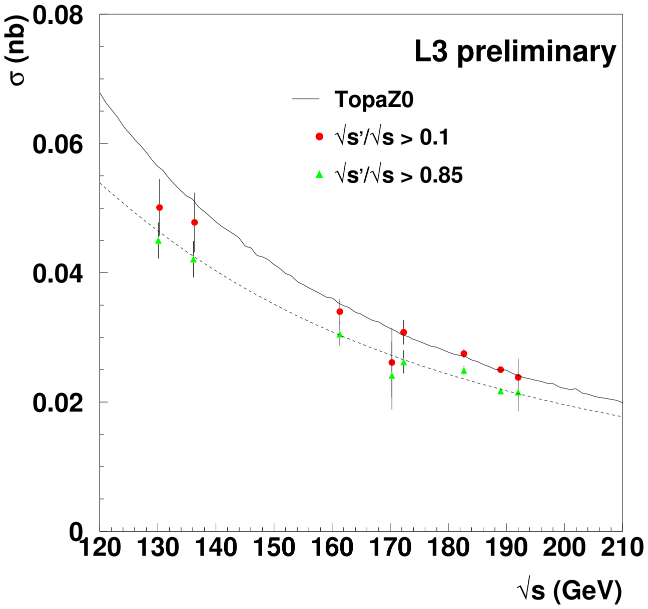


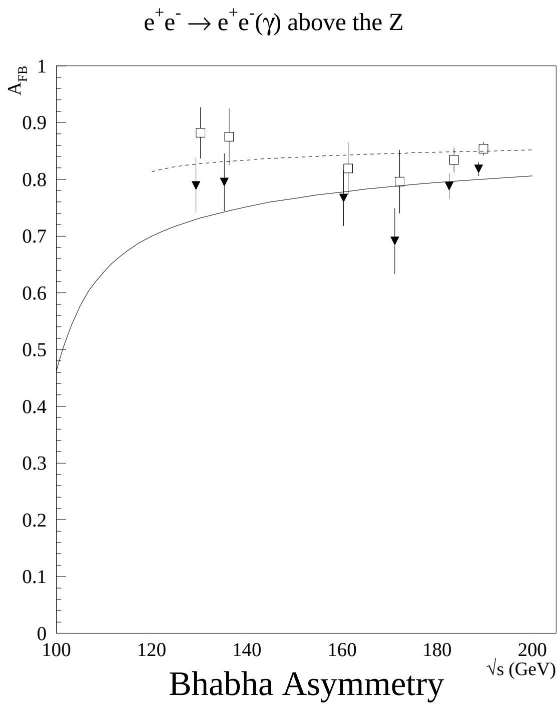


σ/nb
10
1
10^{-1}
10^{-2}
10^{-3}
$e^+e^- \to$ hadrons
L3
$\sqrt{s'/s} > 0.85$
1998 (prel.)
1997 (prel.)
1996
1995 (prel.)
1994 (prel.)
1993 (prel.)
1990-1992
80
100
120
140
160
180
200
$\sqrt{s}$ /GeV









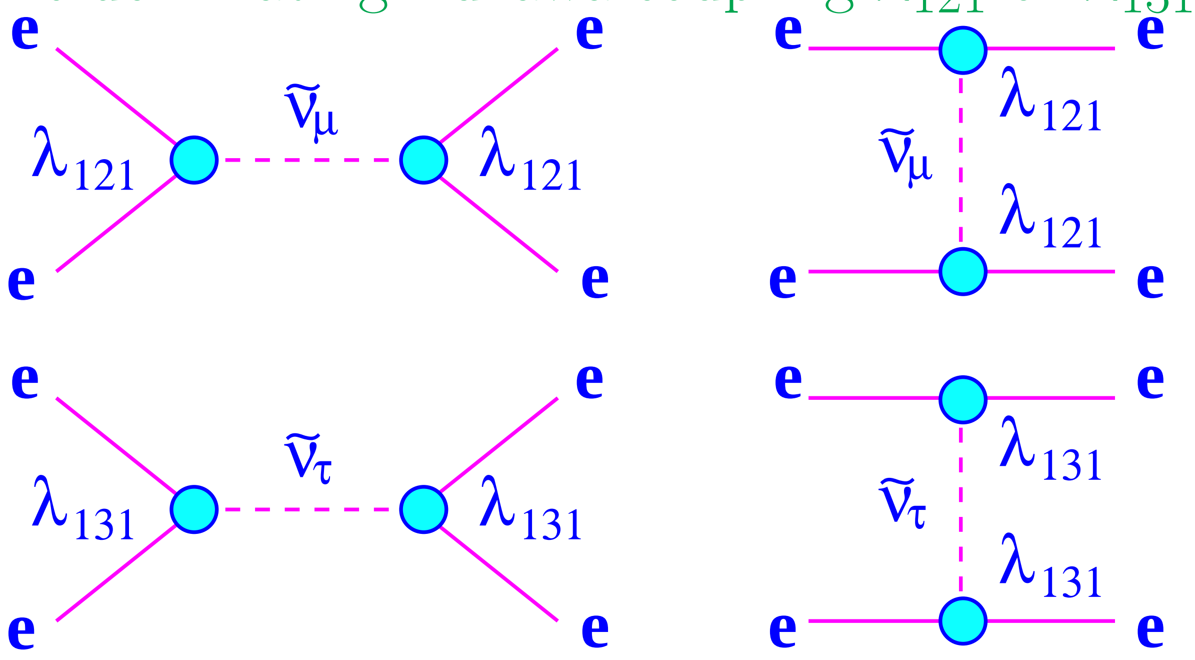
Bhabha Asymmetry

R–Parity Violating Sneutrino

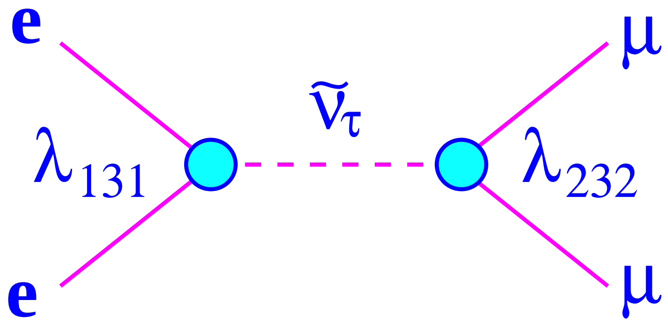
Two interesting experimental manifestation of the most general R–Parity violating superpotential:

$$W_{\not{R}} = \lambda_{ijk} L_L^i L_L^j \overline{E_R^k}$$

One dominating Yukawa coupling λ_{121} or λ_{131}:

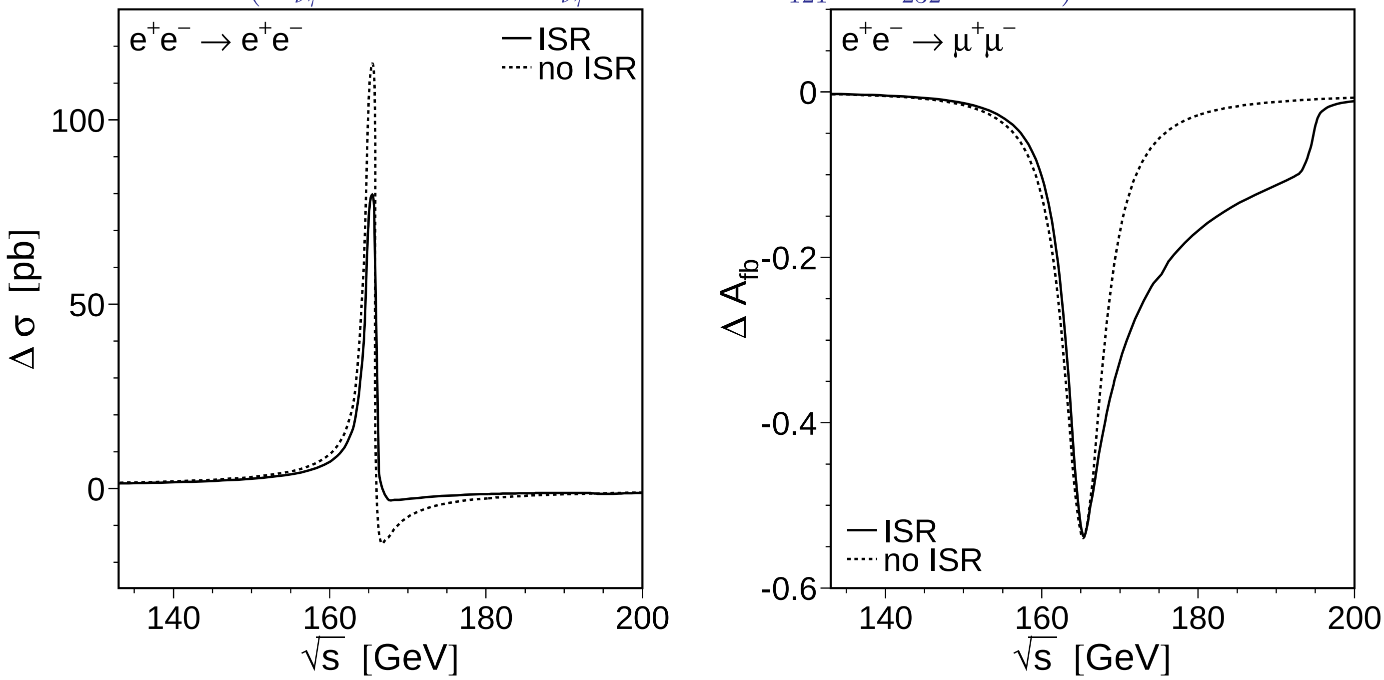


Two dominating Yukawa coupling λ_{121} or λ_{232}:

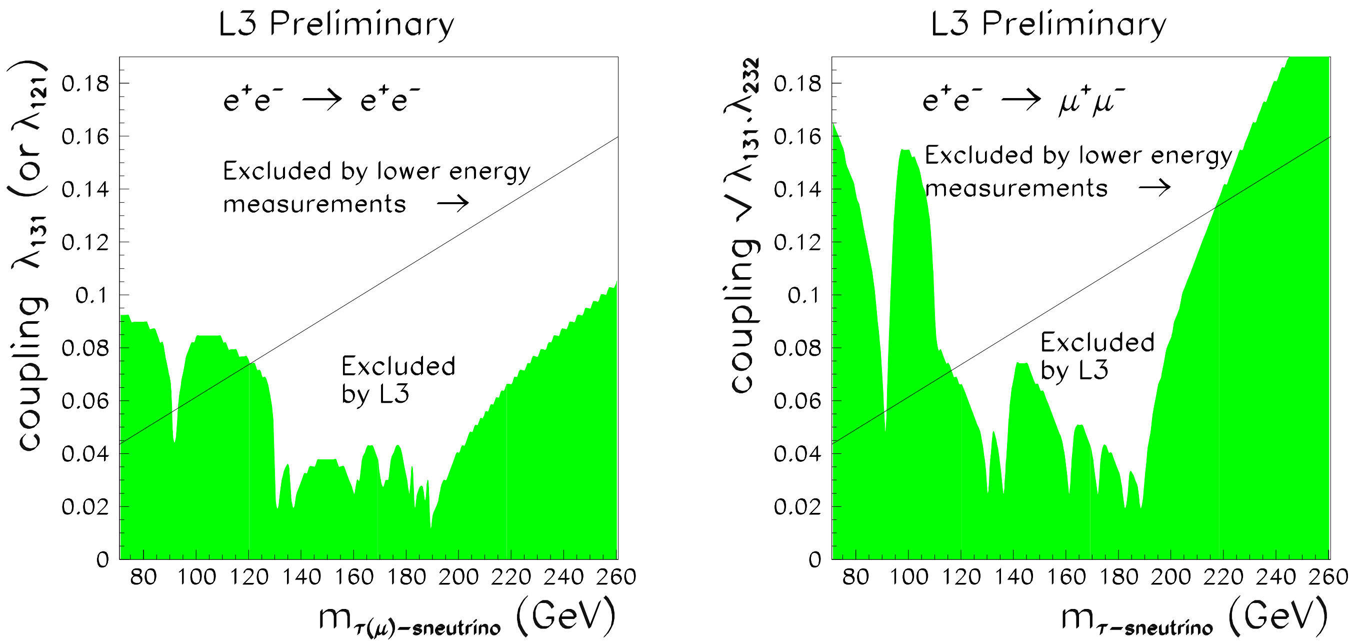


Resonant modifications to cross sections and asymmetries

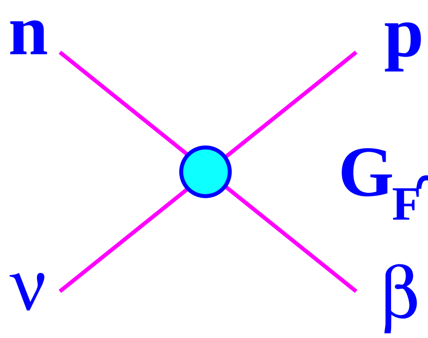
$(m_{\tilde{\nu}_\tau} = 163\ \text{GeV}\ \ \Gamma_{\tilde{\nu}_\tau} = 1\ \text{GeV}\ \ \lambda_{121} = \lambda_{232} = 0.08)$



Improvement of lower energy limits from $\Gamma(\tau \to e\nu\bar{\nu})/\Gamma(\mu \to e\nu\bar{\nu})$

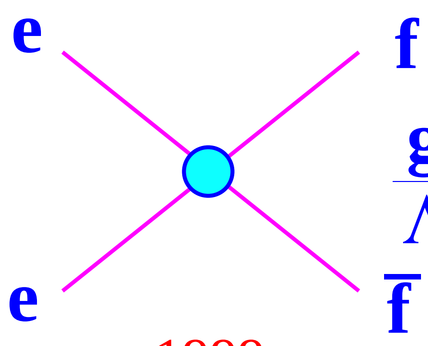


General formalism to describe New Physics from an higher scale.



$G_F \sim \frac{g^2}{M_W^2}$

1932
Fermi - beta decay
Waiting for W SPPS/LEP



$\frac{g^2}{\Lambda^2}$

1999
Fermion pair production
Waiting for ?? at LHC/FMC

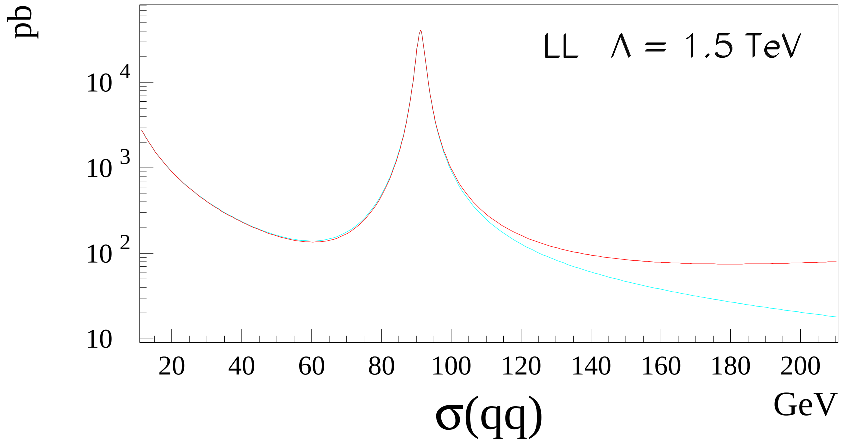
$$\mathcal{L} = \frac{1}{1+\delta_{\mathrm{ef}}} \sum_{i,j=L,R} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\overline{\mathrm{e_i}}\gamma^\mu \mathrm{e_i})(\overline{\mathrm{f_j}}\gamma_\mu \mathrm{f_j})$$

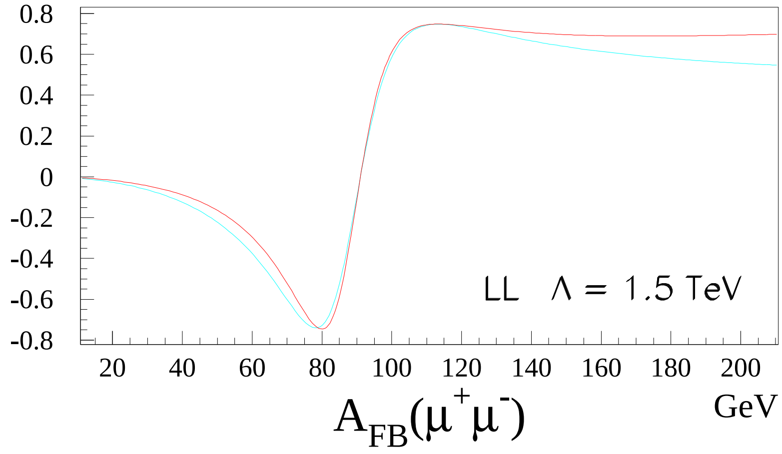
$g^2/4\pi = 1$ and η_{ij} depends on the model.

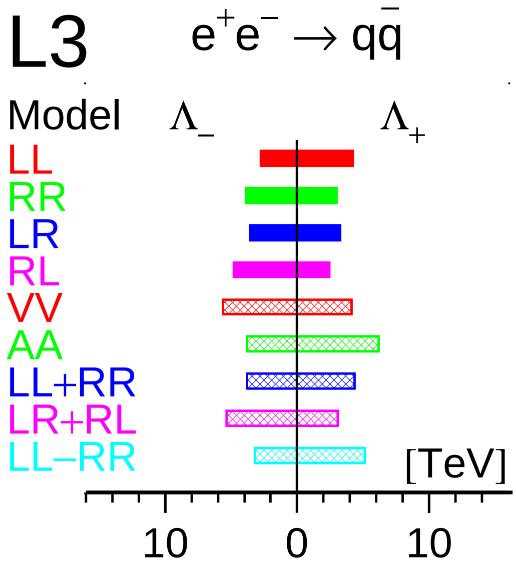
	LL	RR	LR	RL	VV	AA	LL+RR	LR+RL	LL-RR
η_{LL}	±1	0	0	0	±1	±1	±1	0	±1
η_{RR}	0	±1	0	0	±1	±1	±1	0	±1
η_{LR}	0	0	±1	0	±1	±1	0	±1	0
η_{LR}	0	0	0	±1	±1	±1	0	±1	0

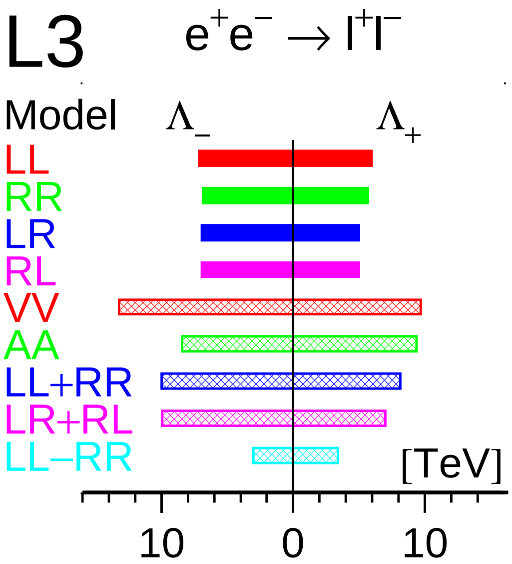
Contact Interactions

$$\frac{d\sigma}{d\Omega}(s,t) = \frac{d\sigma^{SM}}{d\Omega}(s,t) + \frac{1}{\Lambda^2}\alpha_{\text{Interference}}(s,t) + \frac{1}{\Lambda^4}\beta_{\text{New Physics}}(s,t)$$



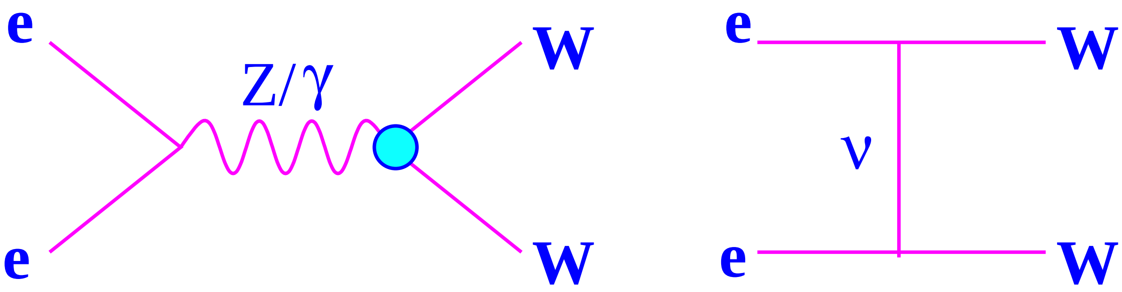






Limits at 95% Confidence Level

Two W



$$i\mathcal{L}^{WWV} =$$
$$g_{WWV}[\, g_1^V \left(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}\right) +$$
$$\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} +$$
$$\frac{\lambda_V}{m_W^2} W^\dagger_{\rho\nu} W^\mu_\nu V^{\rho\nu} +$$
$$\not{C} + \not{P} + \not{C}\not{P} + dim > 6]$$

$$V = \gamma, Z, \quad W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu, \quad V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$$

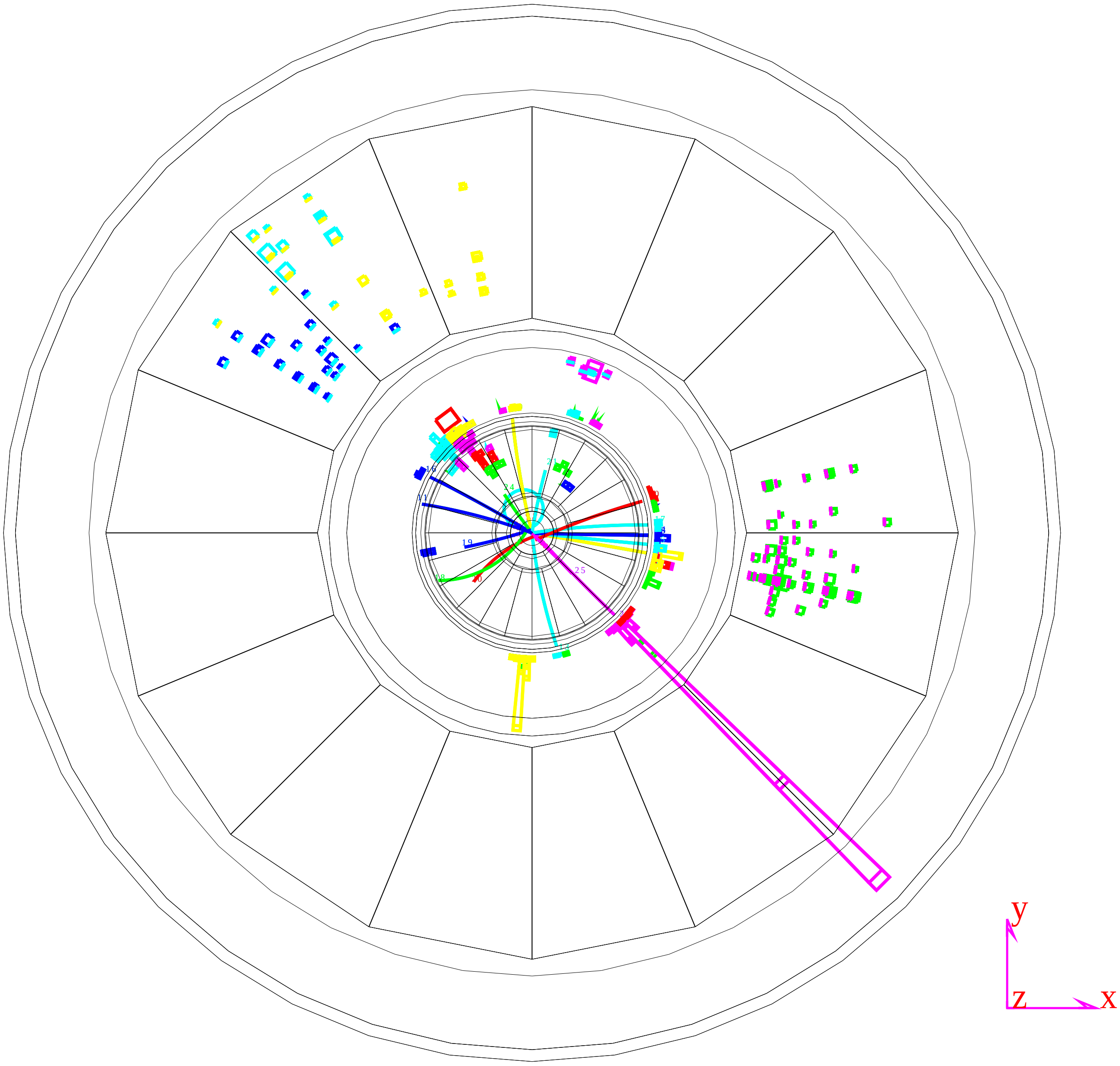
In the Standard Model:

$$g_1^Z = g_1^\gamma = \kappa_Z = \kappa_\gamma = 1; \;\; \lambda_\gamma = \lambda_Z = 0$$
$$g_{WWZ} = e\cot\theta_W; \;\; g_{WW\gamma} = e$$

Assuming $\lambda_\gamma = \lambda_Z$, $\kappa_\gamma = 1 + \cot^2\theta_W(\kappa_Z - g_1^Z)$, the triple boson vertex and possible deviations are parametrized by κ_γ, g_1^Z and λ_γ.

$e^+e^- \to W^+W^- \to q\bar{q}'e\nu$

Run # 671603 Event # 3681 Total Energy : 132.88 GeV



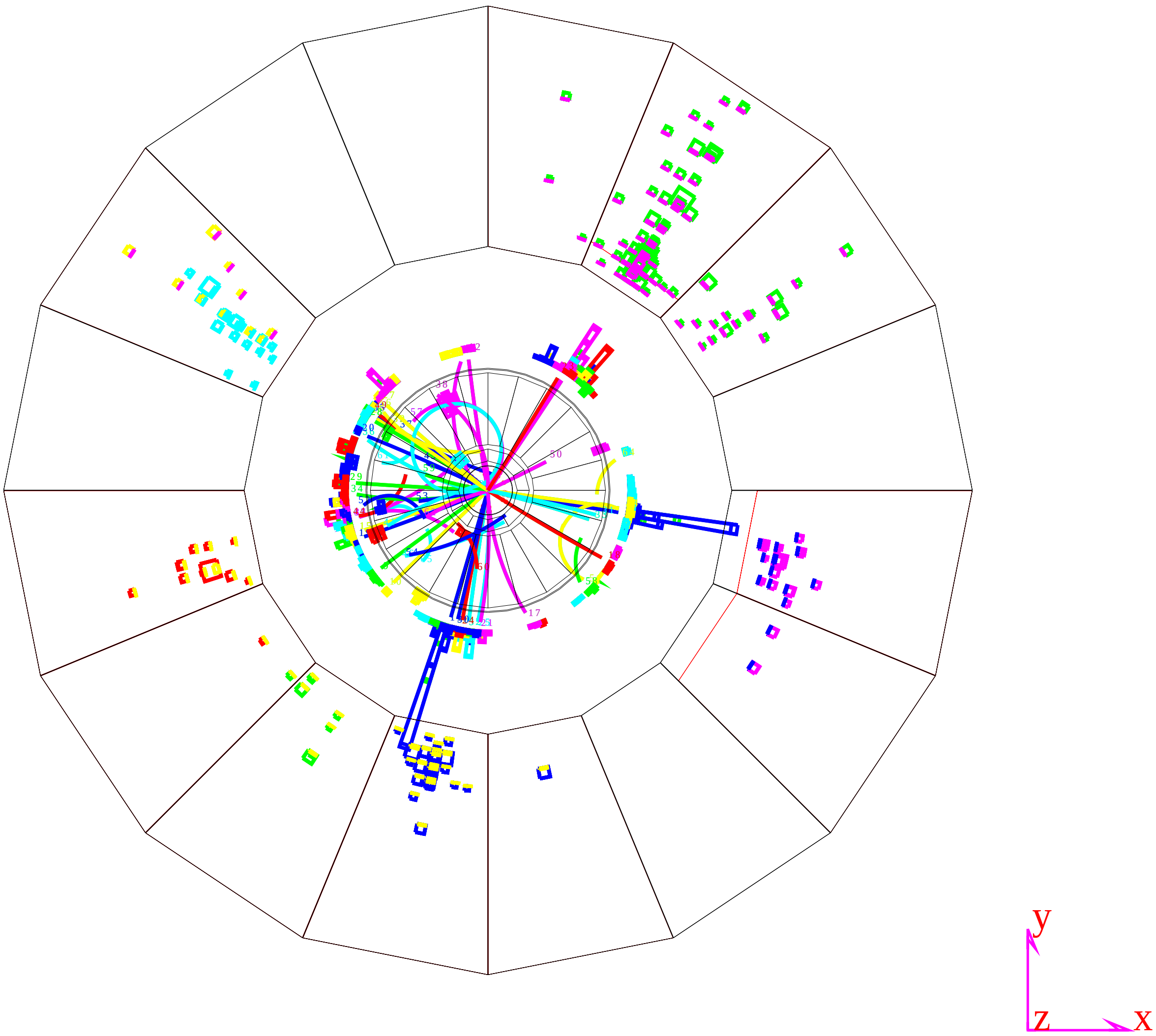
Transverse Imbalance :	.3745	**Longitudinal Imbalance :**	-.1423

Thrust :	.9116	**Major :**	.2435	**Minor :**	.1720

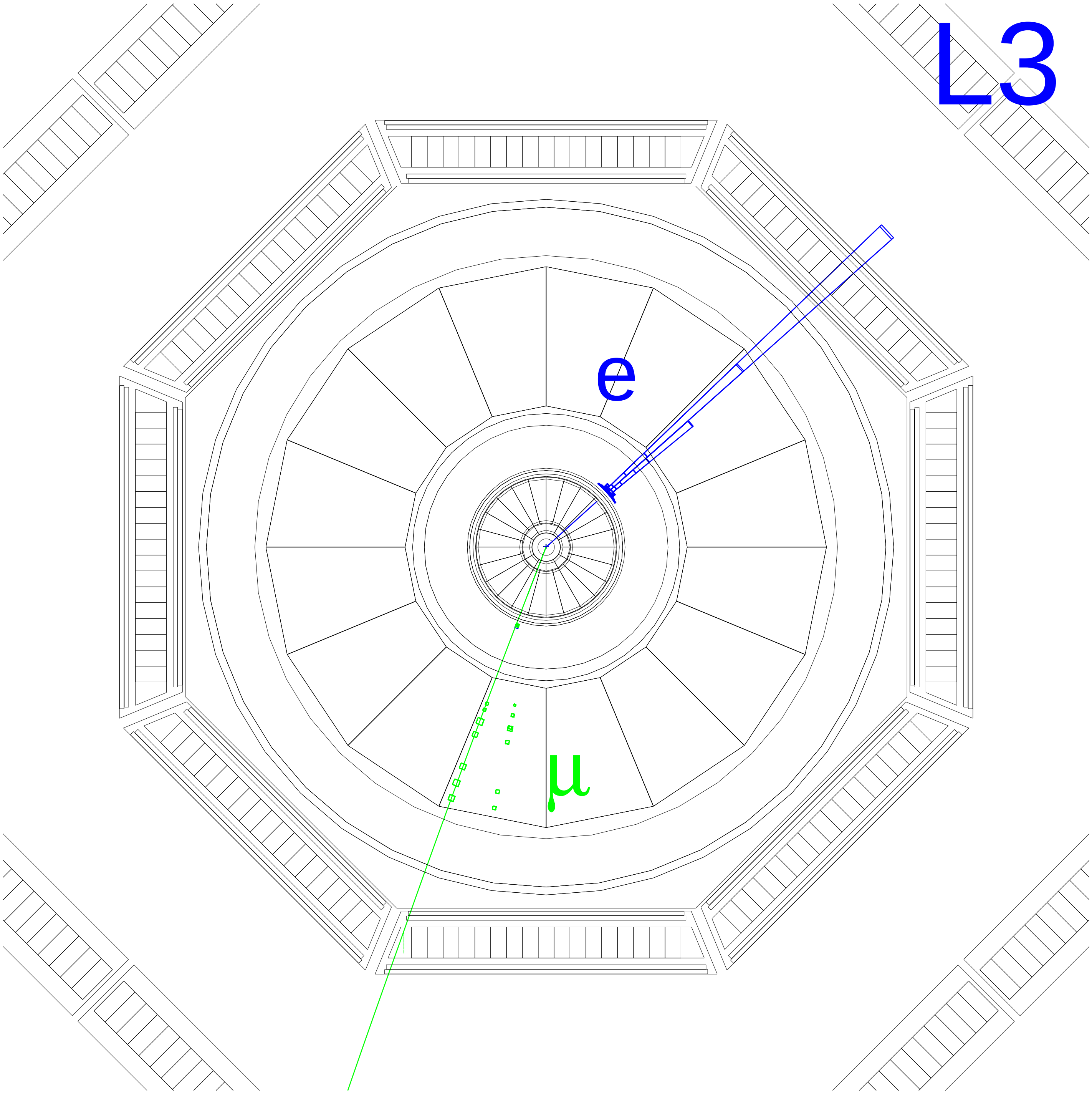
Event DAQ Time :	*970804 20633*

$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'q''\bar{q}'''$

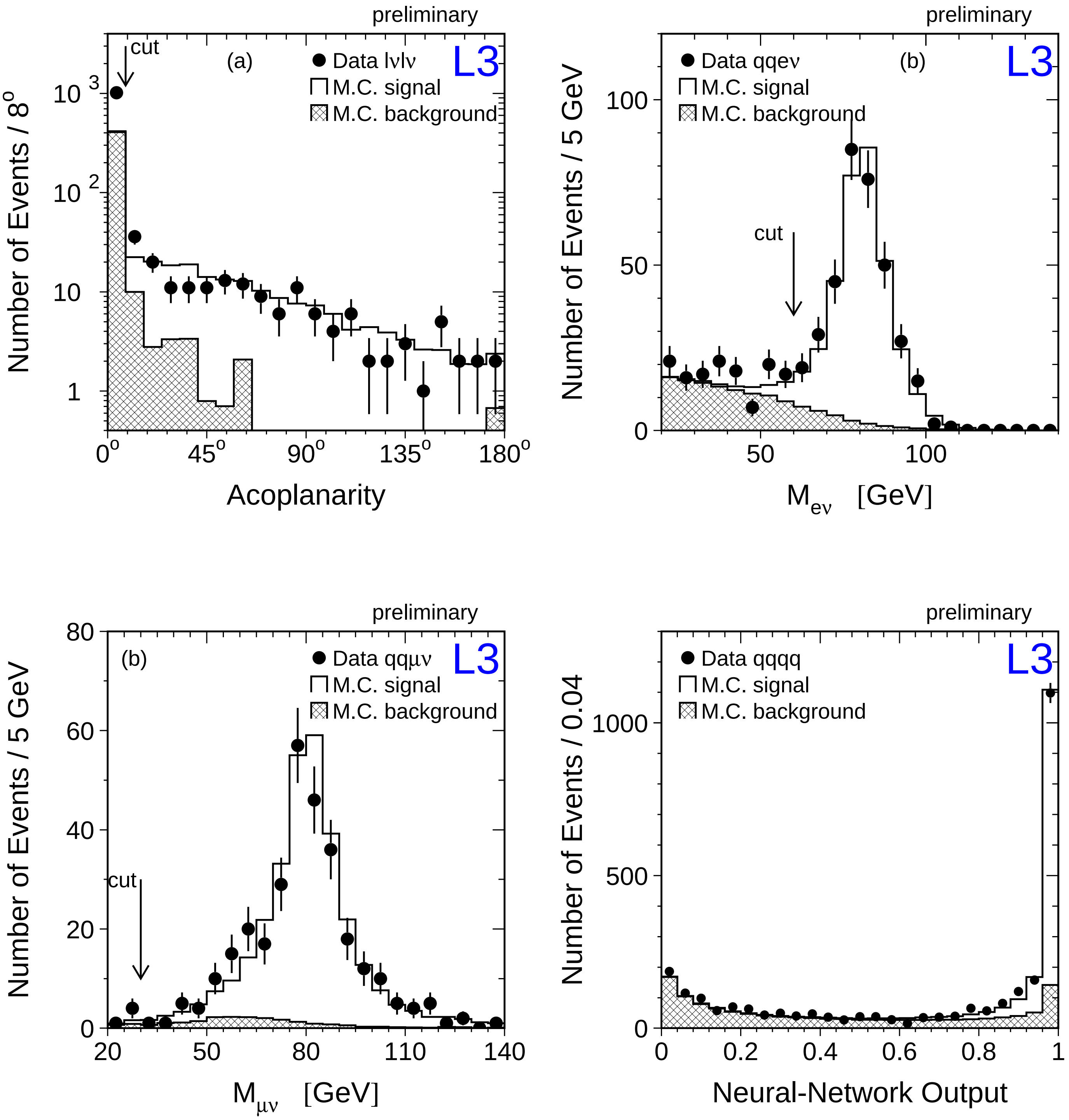
Run # 671306 Event # 1207 Total Energy : 184.13 GeV

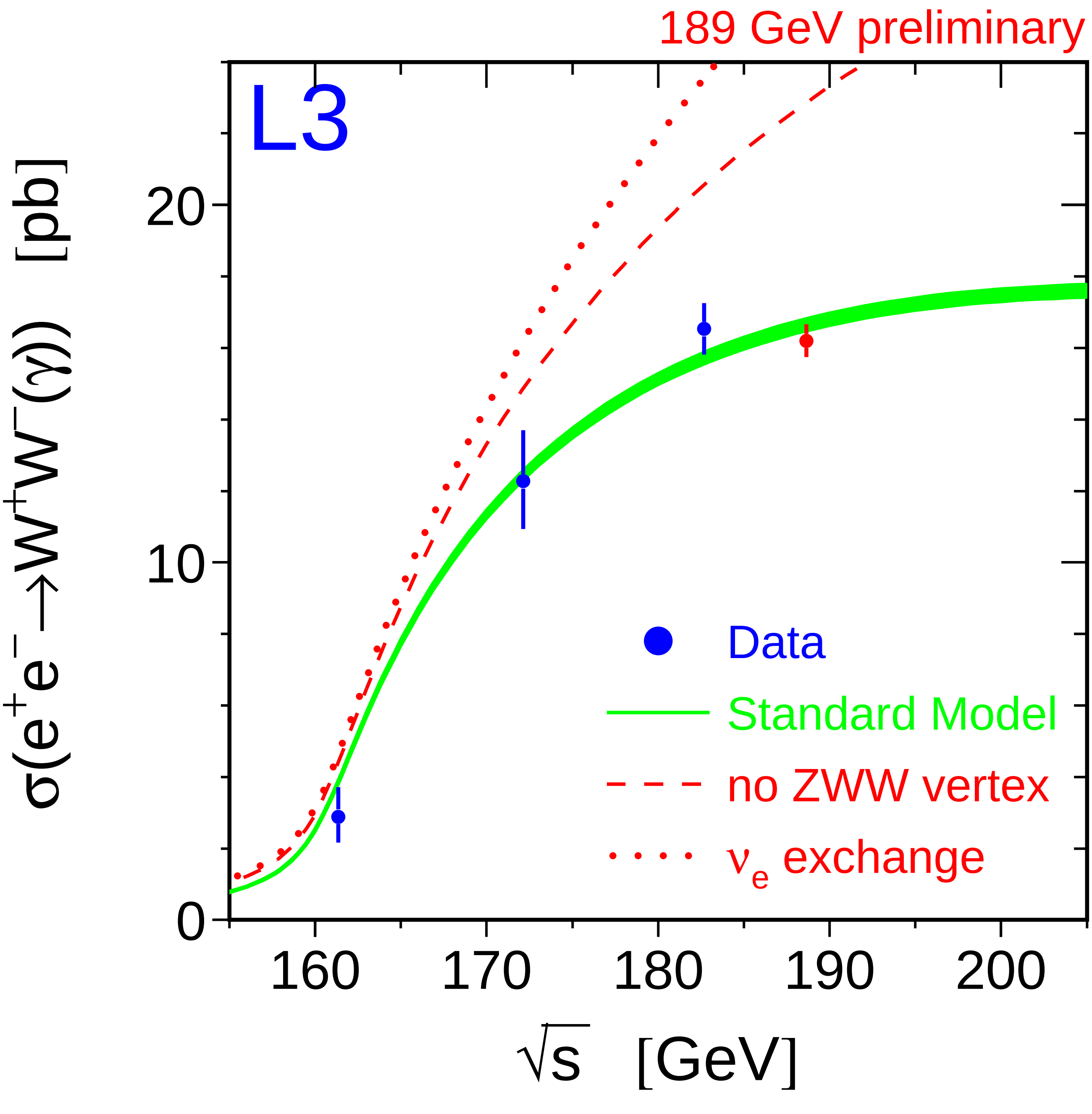


Transverse Imbalance : .0219		**Longitudinal Imbalance :** -.0724
Thrust : .7012	**Major :** .4458	**Minor :** .4600
Event DAQ Time : *970802 150113*		


L3
e
μ

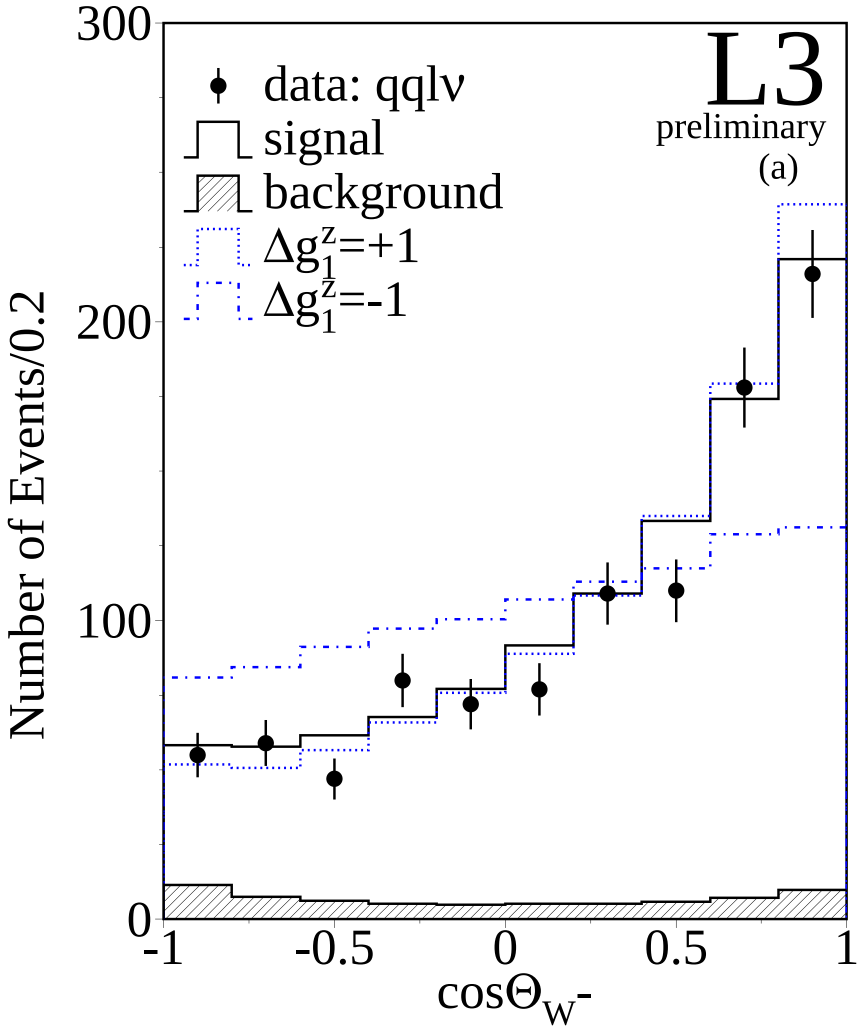
W Pair Selection





Impressive evidence of the non-Abelian structure of the Standard Model

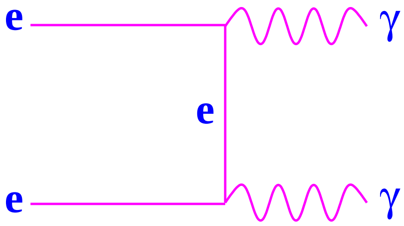
Study of total and differential cross sections and polarisation



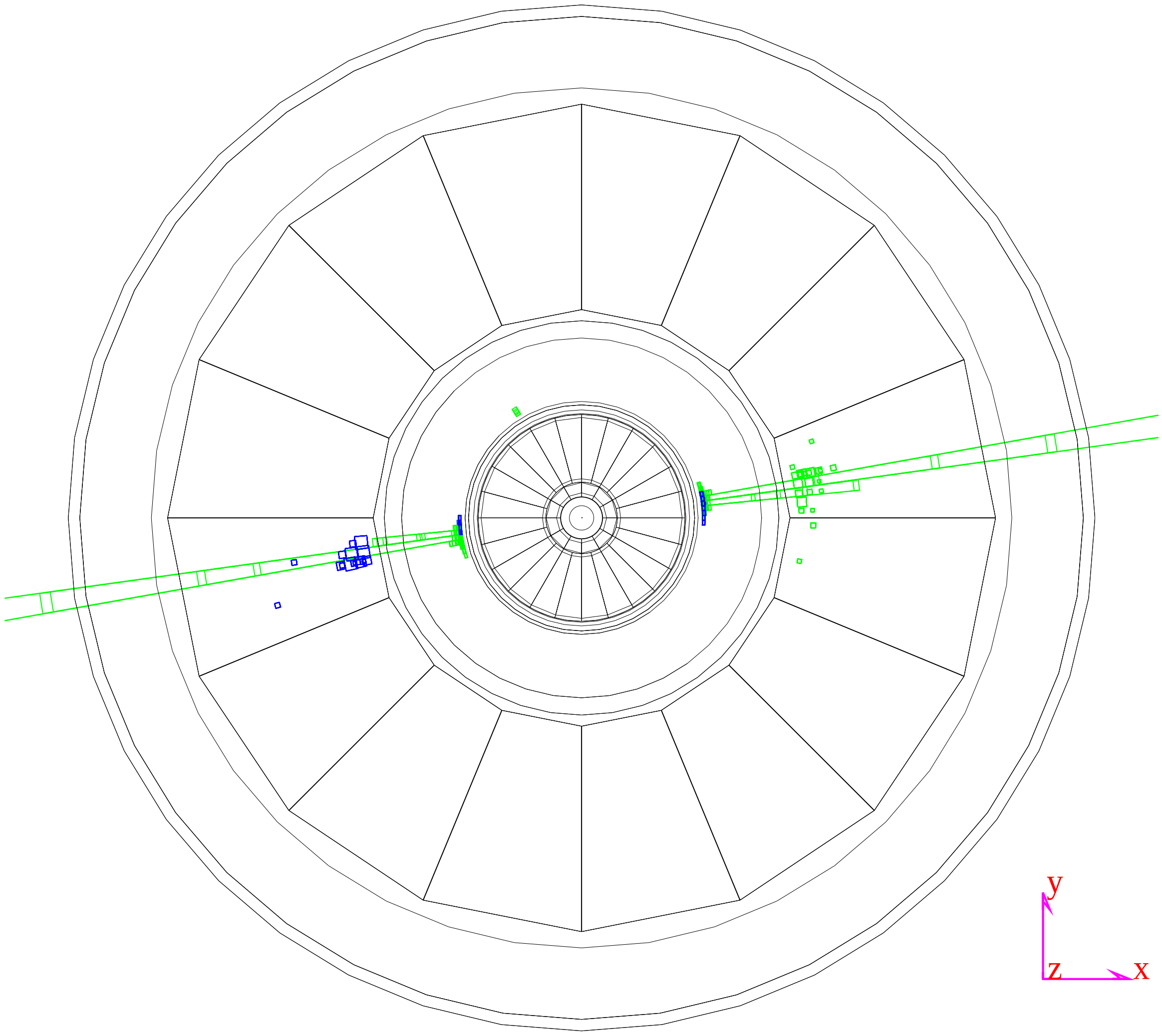
$$
\begin{aligned}
g_1^Z &= 0.88^{+0.14}_{-0.12} \pm 0.08 \text{ (68\% C.L.)}; \quad (0.62\text{–}1.22) \quad (95\% \text{ C.L.})\\
\kappa_\gamma &= 0.98^{+0.07}_{-0.07} \pm 0.03 \text{ (68\% C.L.)}; \quad (0.85\text{–}1.12) \quad (95\% \text{ C.L.})\\
\lambda_\gamma &= 0.00^{+0.07}_{-0.07} \pm 0.03 \text{ (68\% C.L.)}; \quad (\text{-}0.13\text{–}0.15) \quad (95\% \text{ C.L.})
\end{aligned}
$$

Two (or more) Photons

Two Photons



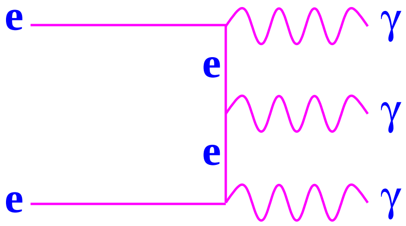
Run # **682010** **Event #** **1540** Total Energy : 187.75 GeV



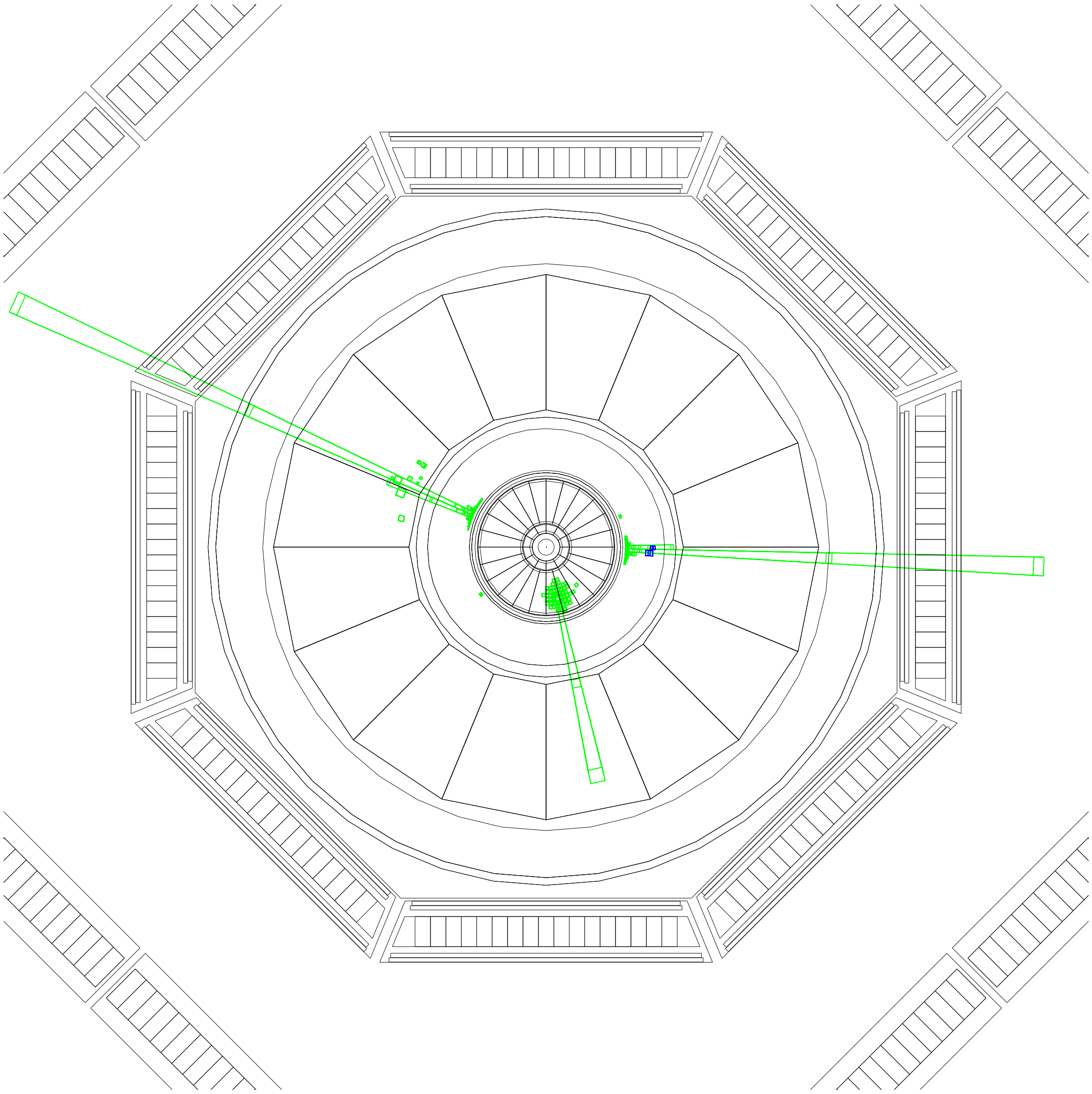
Transverse Imbalance :	.0062	**Longitudinal Imbalance :**	.0000

Thrust :	.9985	**Major :**	.0065	**Minor :**	.0036

Event DAQ Time :	*970928 53525*



Run # 671104 **Event #** 1018

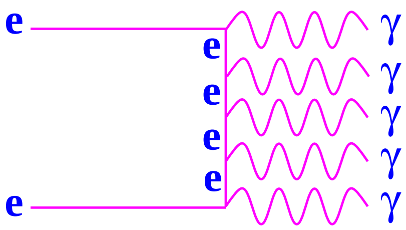


Transverse Imbalance :	.0246	**Longitudinal Imbalance :**	-.0647

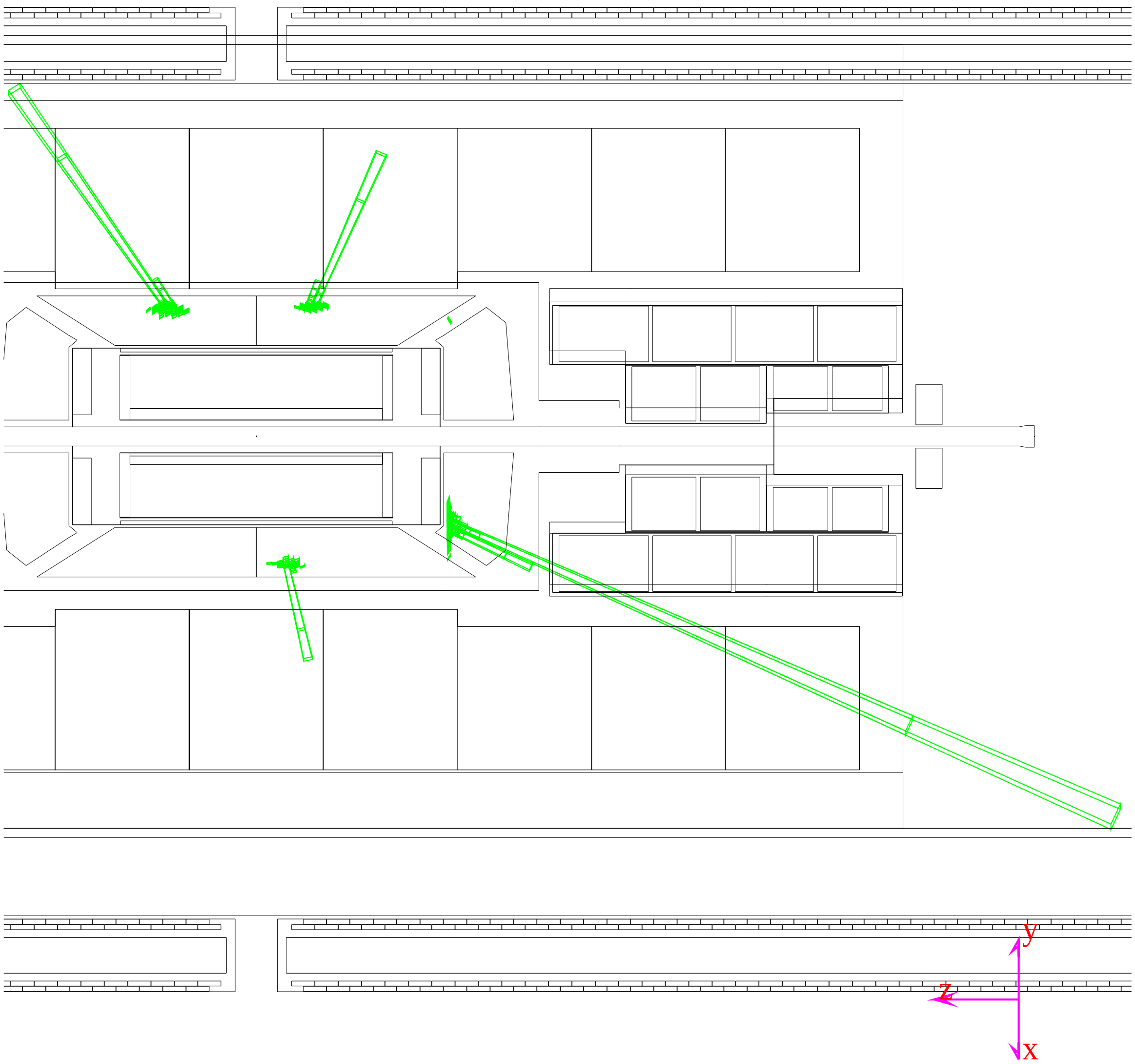
Thrust :	.6816	**Major :**	.5508	**Minor :**	.0018

Event DAQ Time :	*970801 180756*

Five Photons



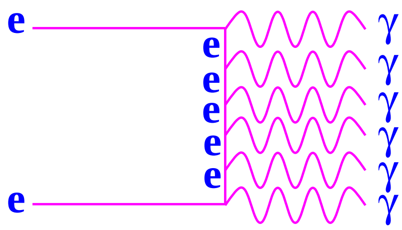
Run # **650701** **Event #** **2734** Total Energy : 90.81 GeV



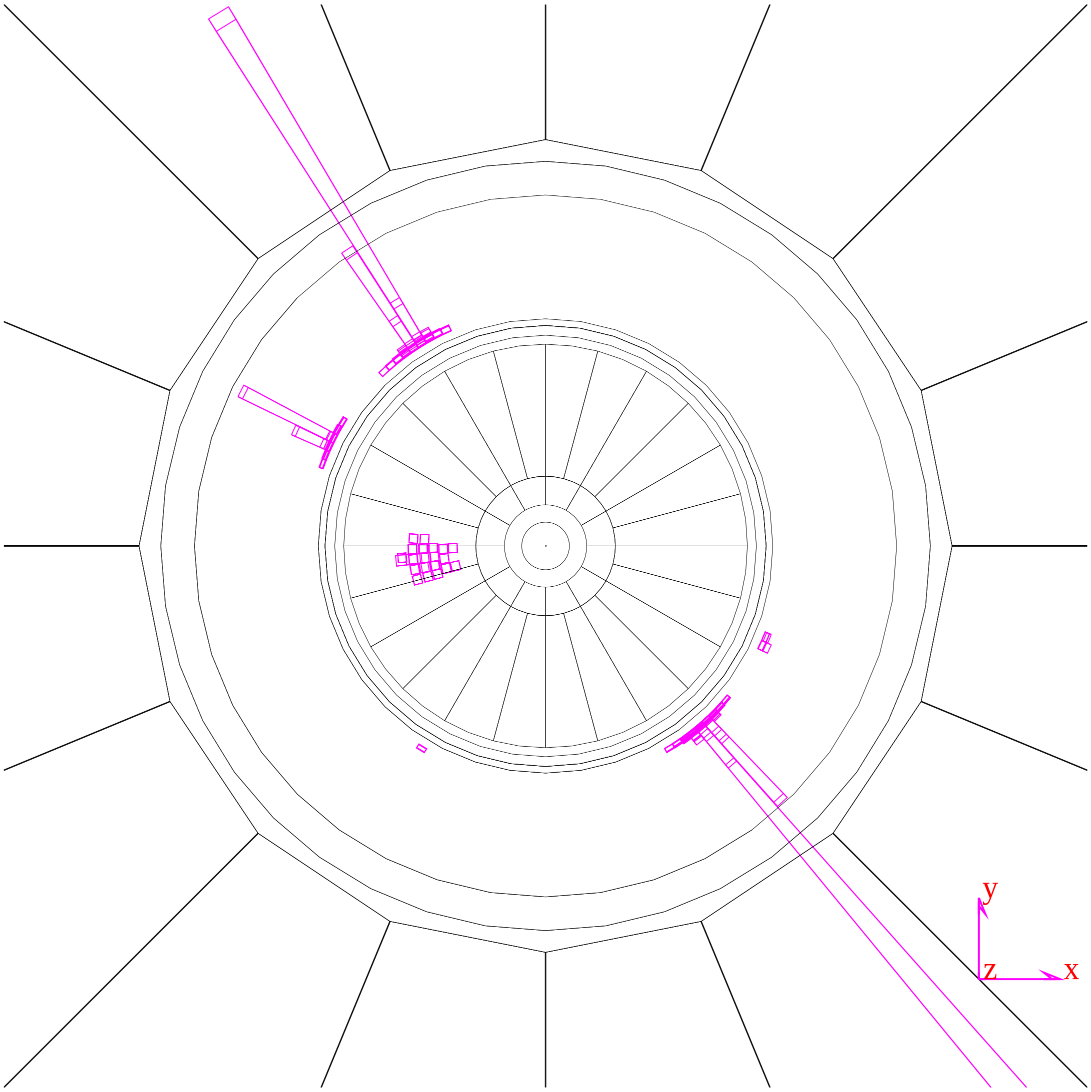
Transverse Imbalance :	.0016		**Longitudinal Imbalance :**	-.4609
Thrust : .8442		**Major :** .4065		**Minor :** .1031
Event DAQ Time :	*951104 204043*			

A fifth photon escaped down the beam pipe.

Six Photons



Run # **682013** **Event #** **916** Total Energy : 128.25 GeV

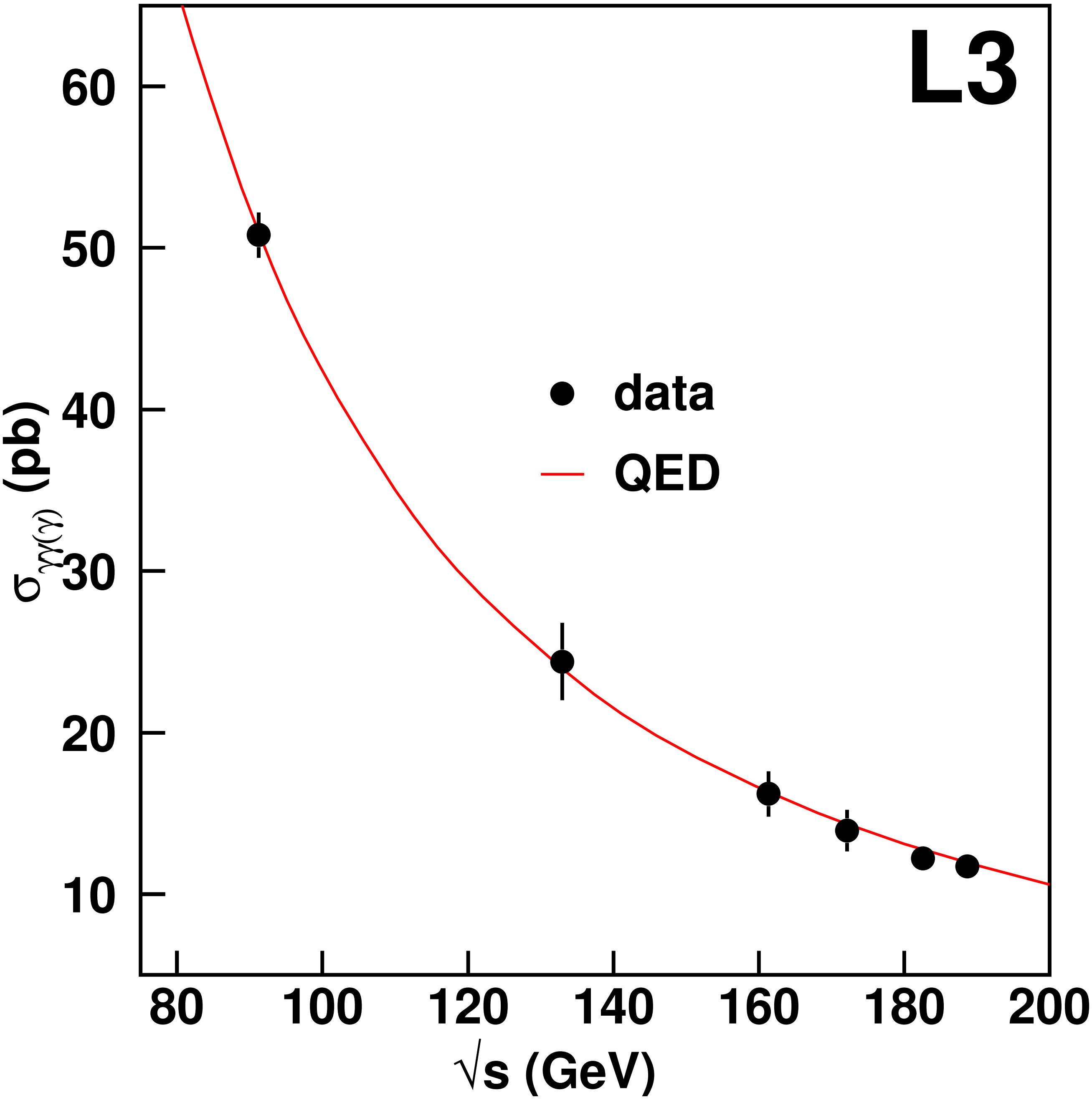


Transverse Imbalance :	.0434	**Longitudinal Imbalance :**	-.4561

Thrust :	.8101	**Major :**	.5459	**Minor :**	.0964
Event DAQ Time :	*970928 61407*				

The sixth photon escaped down the beam pipe.

Multiphoton Cross Section

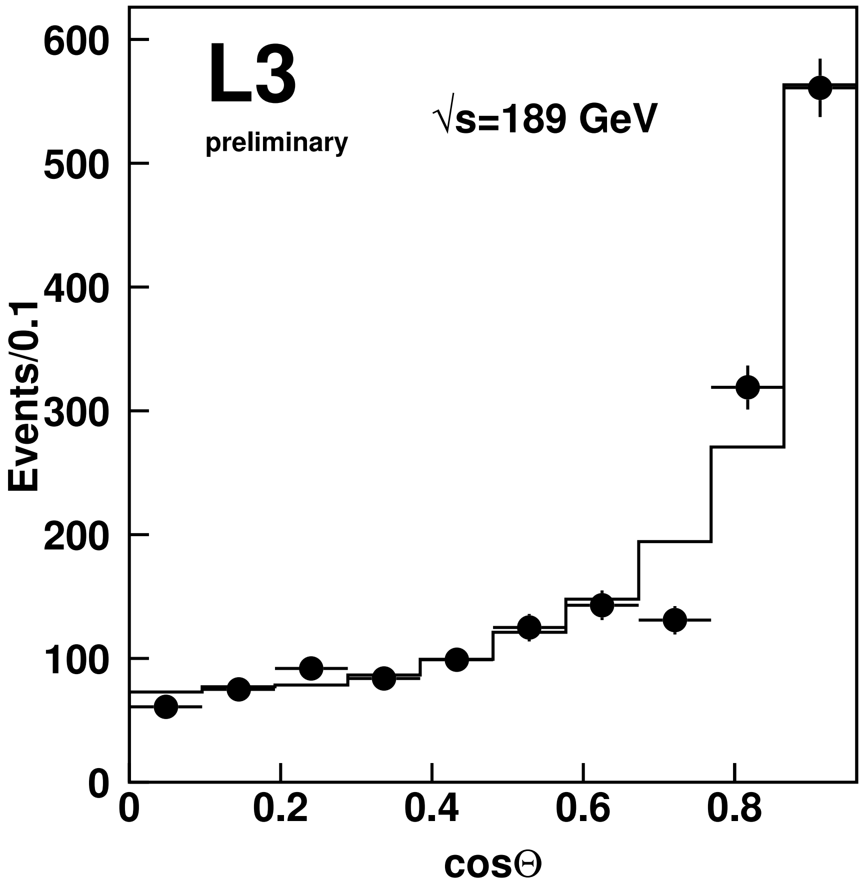


QED Deviations

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega}\left(1 + \frac{s^2}{\alpha}\frac{1}{\Lambda^4}(1-\cos^2\theta)\right)$$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega}\left(1 + \frac{s^3}{32\pi\alpha^2}\frac{1}{\Lambda'^6}\frac{1-\cos^2\theta}{1+\cos^2\theta}\right)$$

Cut-offs $\Lambda_{\pm} = \left(\frac{\alpha}{2}\right)^{\frac{1}{4}}\Lambda$



95% C.L. limits on QED deviations, excited electron mass:

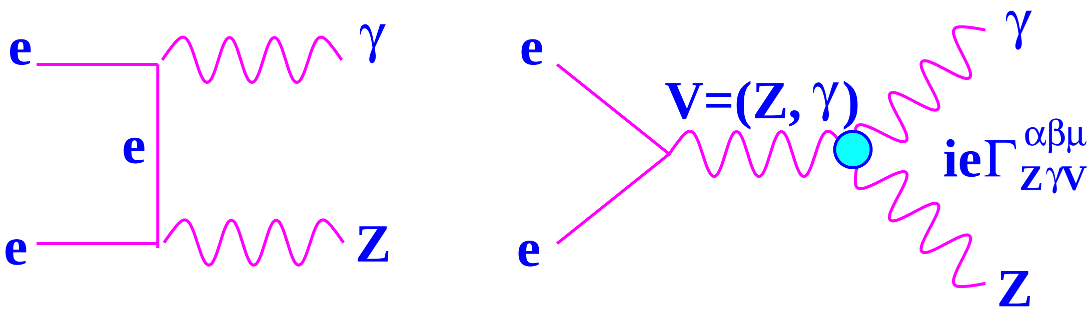
$\Lambda > 1319$ GeV $\quad \Lambda_+ > 324$ GeV

$\Lambda_- > 287$ GeV $\quad \Lambda' > 704$ GeV

$m_{e^*} > 326$ GeV (non-chiral) $\quad m_{e^*} > 254$ GeV (chiral)

One Photon and One Z

Neutral Boson Couplings



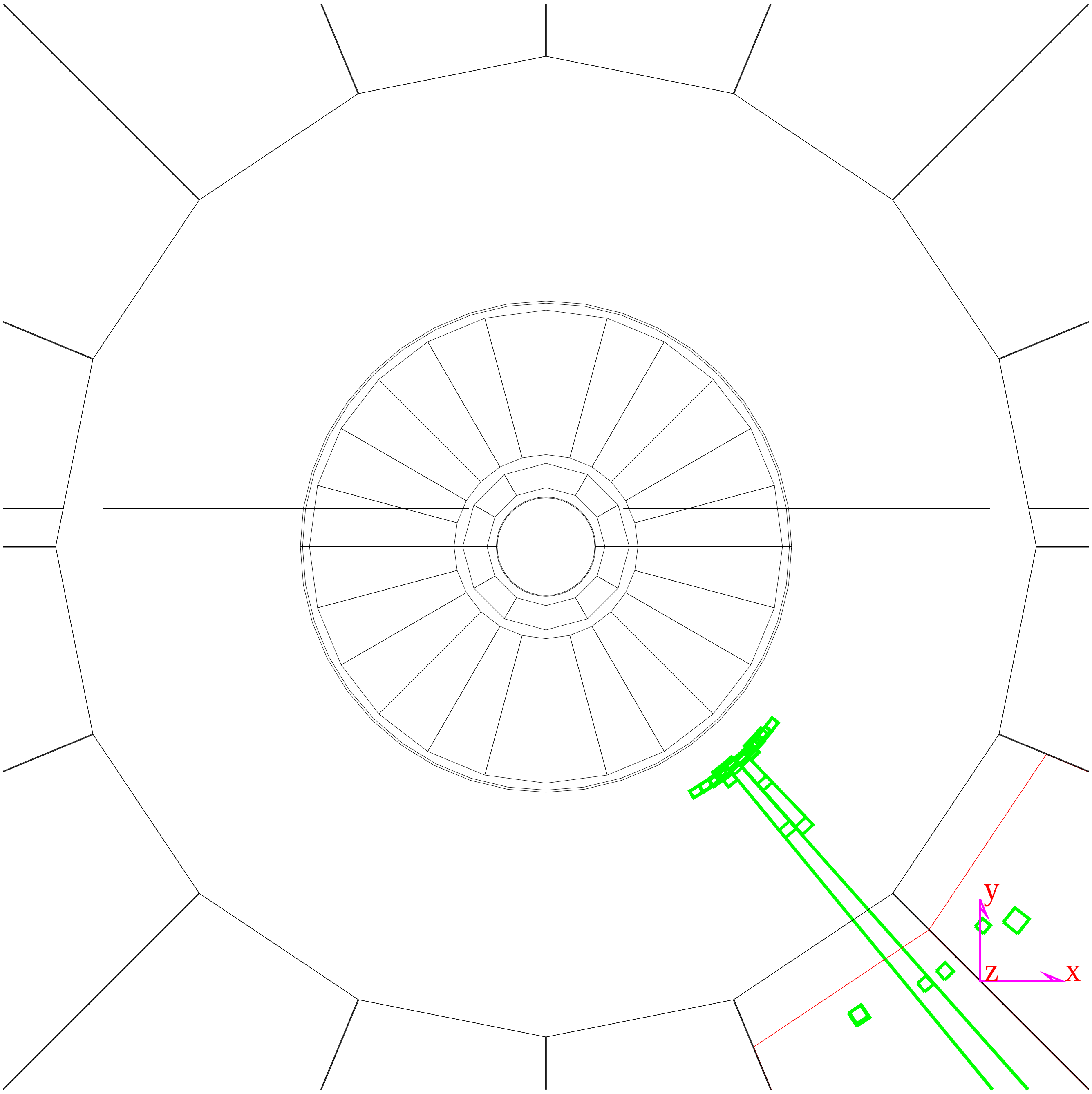
$$\Gamma^{\alpha\beta\mu}_{Z\gamma V}(q_1, q_2, P) = \frac{s - m_V^2}{m_Z^2} \times$$

$$[h_1^V(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta} + \frac{h_2^V}{m_Z^2} P^\alpha (P \cdot q_2 g^{\mu\beta} - q_2^\mu g^{\alpha\beta})$$

$$+ h_3^V \epsilon^{\mu\alpha\beta\rho} q_{2\rho} - \frac{h_4^V}{m_Z^2} P^\alpha \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma}]$$

h_1^V, h_2^V 0 in Standard Model, P-even.
h_3^V, h_4^V $\sim 10^{-4}$ in Standard Model, CP-even.

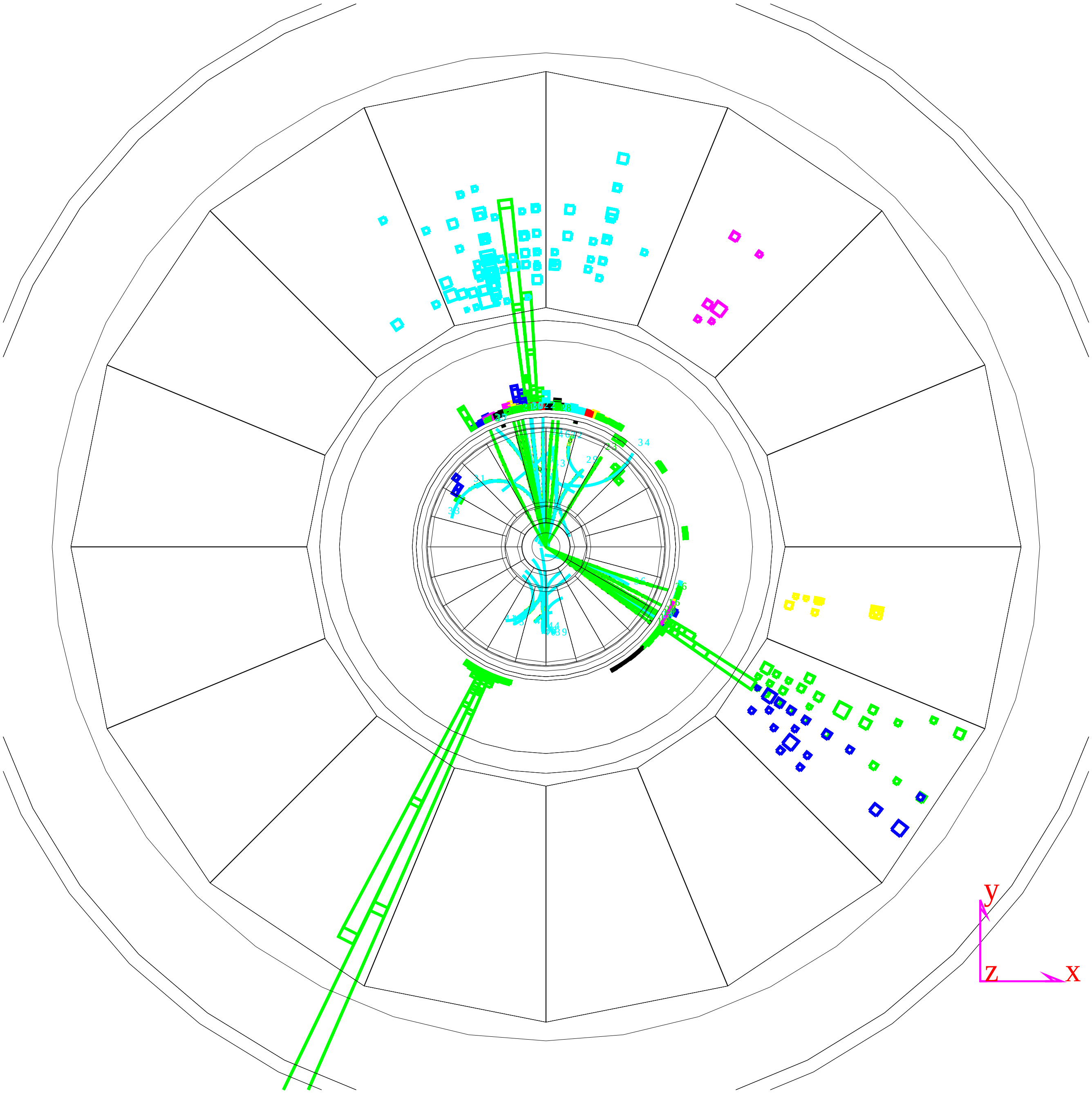
Run # 673115 Event # 224 Total Energy : 69.00 GeV



Transverse Imbalance :	.6895	**Longitudinal Imbalance :**	-.7241
Thrust : 1.0000	**Major :** .0000	**Minor :** .0000	
Event DAQ Time :	*970813 44506*		

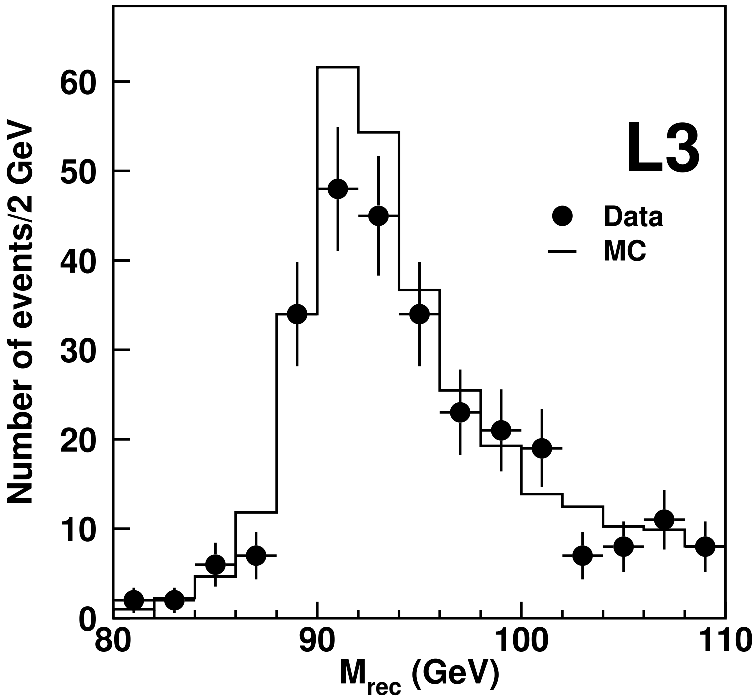
$e^+e^- \to \gamma Z \to \gamma q\bar{q}$

Run # 671302   Event # 3555   Total Energy : 183.00 GeV

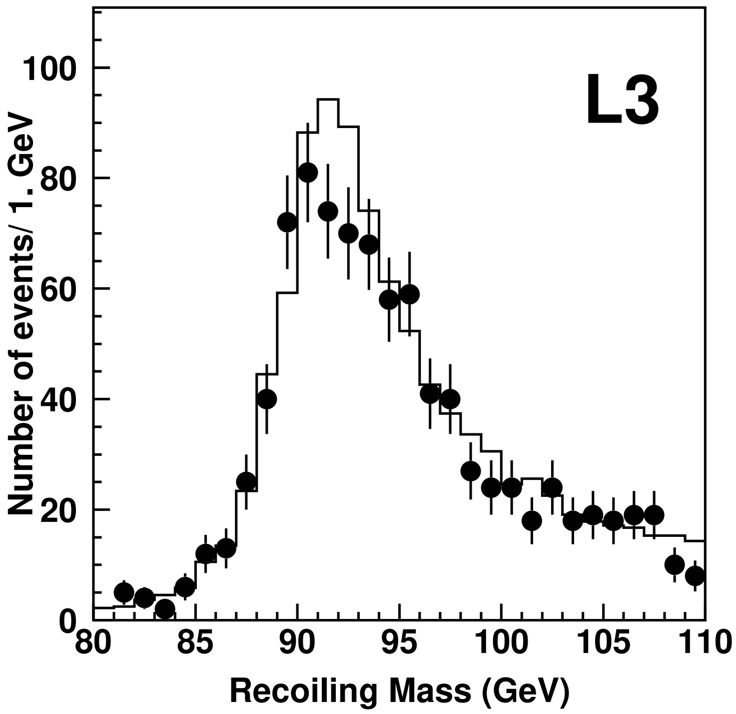


Transverse Imbalance :	.0080	**Longitudinal Imbalance :**	-.0287
Thrust : .8696	**Major :** .3386	**Minor :** .0379	
Event DAQ Time :	*970802 132946*		

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



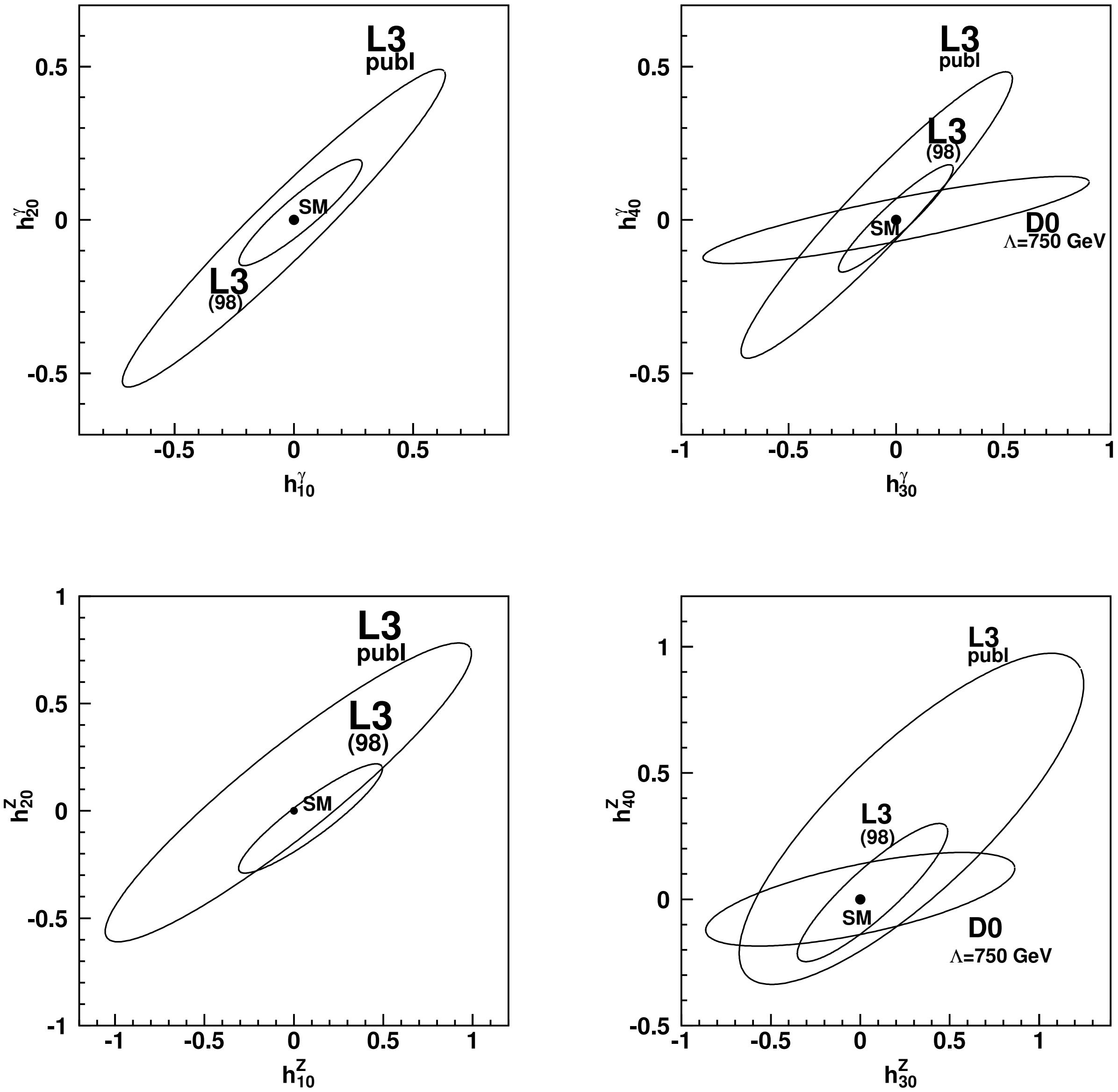
$$e^+e^- \longrightarrow \gamma Z \longrightarrow \gamma q\bar{q}$$



Limits on Anomalous Couplings

At 95% Confidence Level

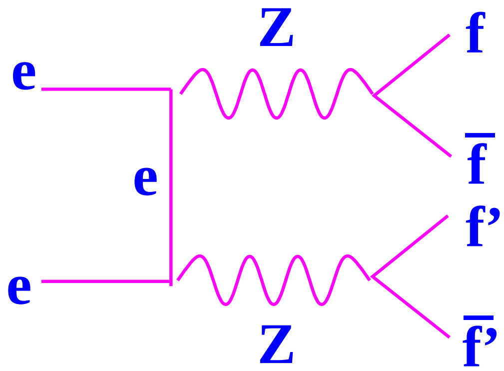
$$-0.08 < h_1^Z < 0.21 \qquad -0.09 < h_1^\gamma < 0.08$$
$$-0.12 < h_2^Z < 0.06 \qquad -0.05 < h_2^\gamma < 0.07$$
$$-0.15 < h_3^Z < 0.15 \qquad -0.09 < h_3^\gamma < 0.07$$
$$-0.09 < h_4^Z < 0.10 \qquad -0.05 < h_4^\gamma < 0.06$$



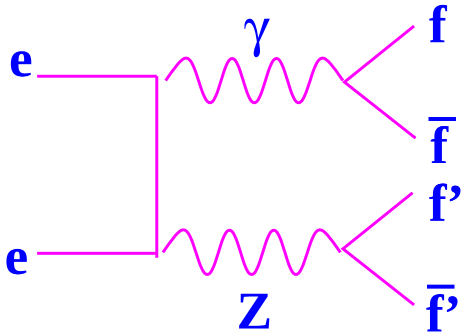
$$\lim_{s\to\infty} h_i^V = 0 \Longrightarrow h_i^V = \frac{h_{i0}^V}{(1+s/\Lambda^2)^j} \quad i = 1,3 \rightarrow j = 3; \quad i = 2,4 \rightarrow j = 4$$

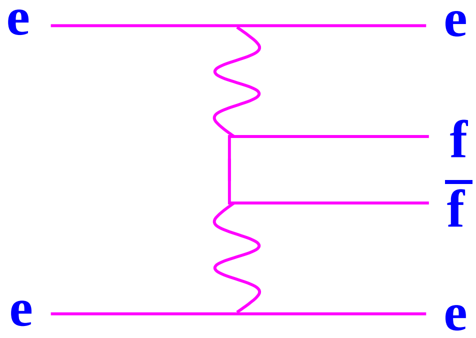
Two Z

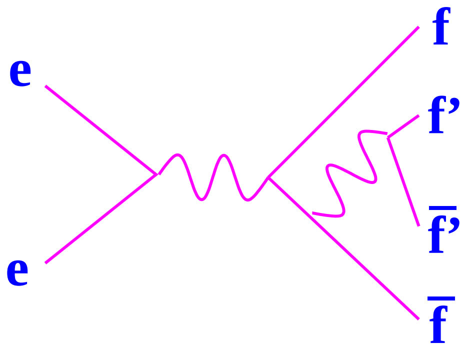
Z Pair Production

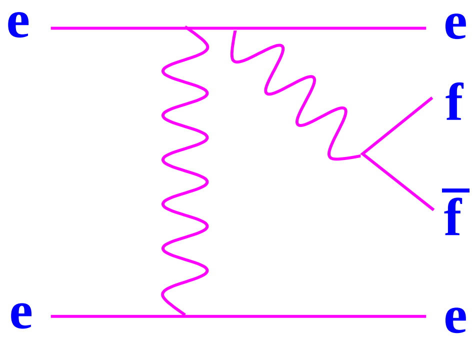


Pay attention to:

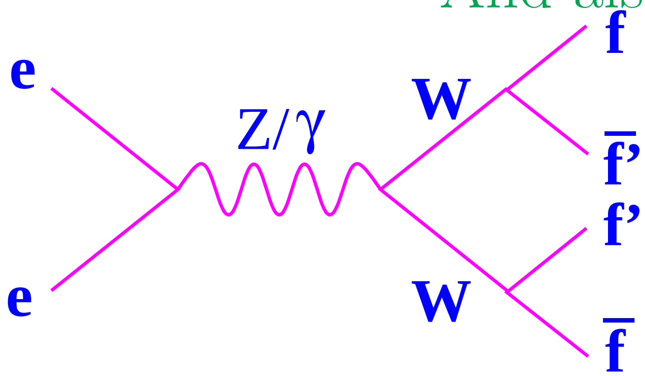


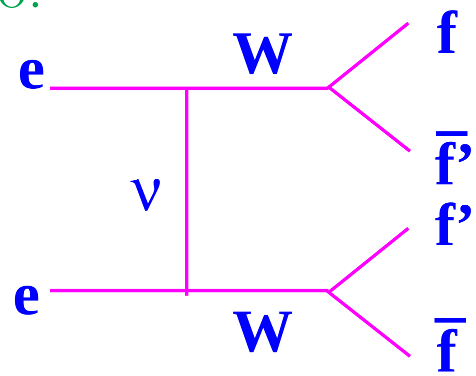




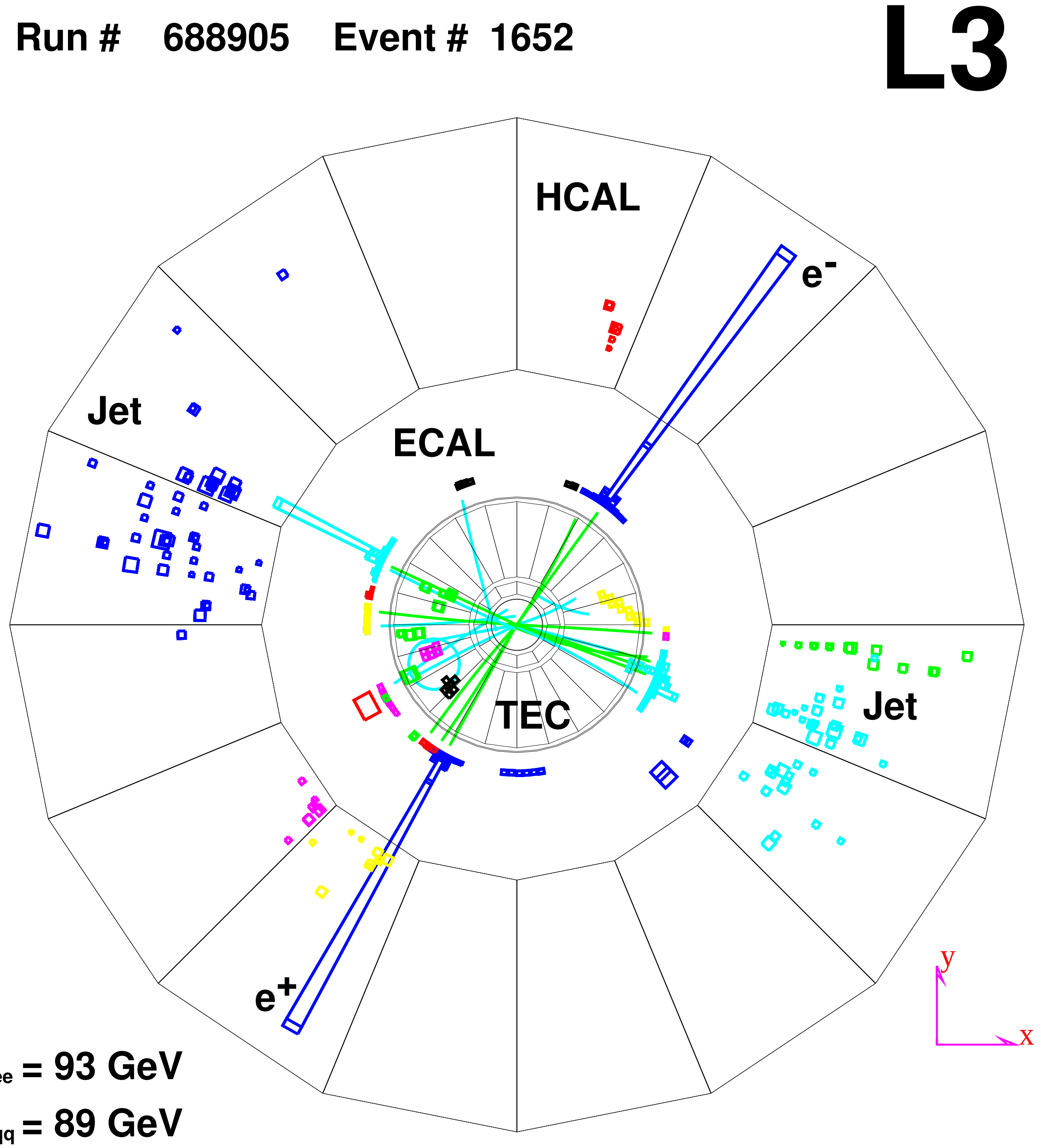


And also to:





Run # 688905 Event # 1652

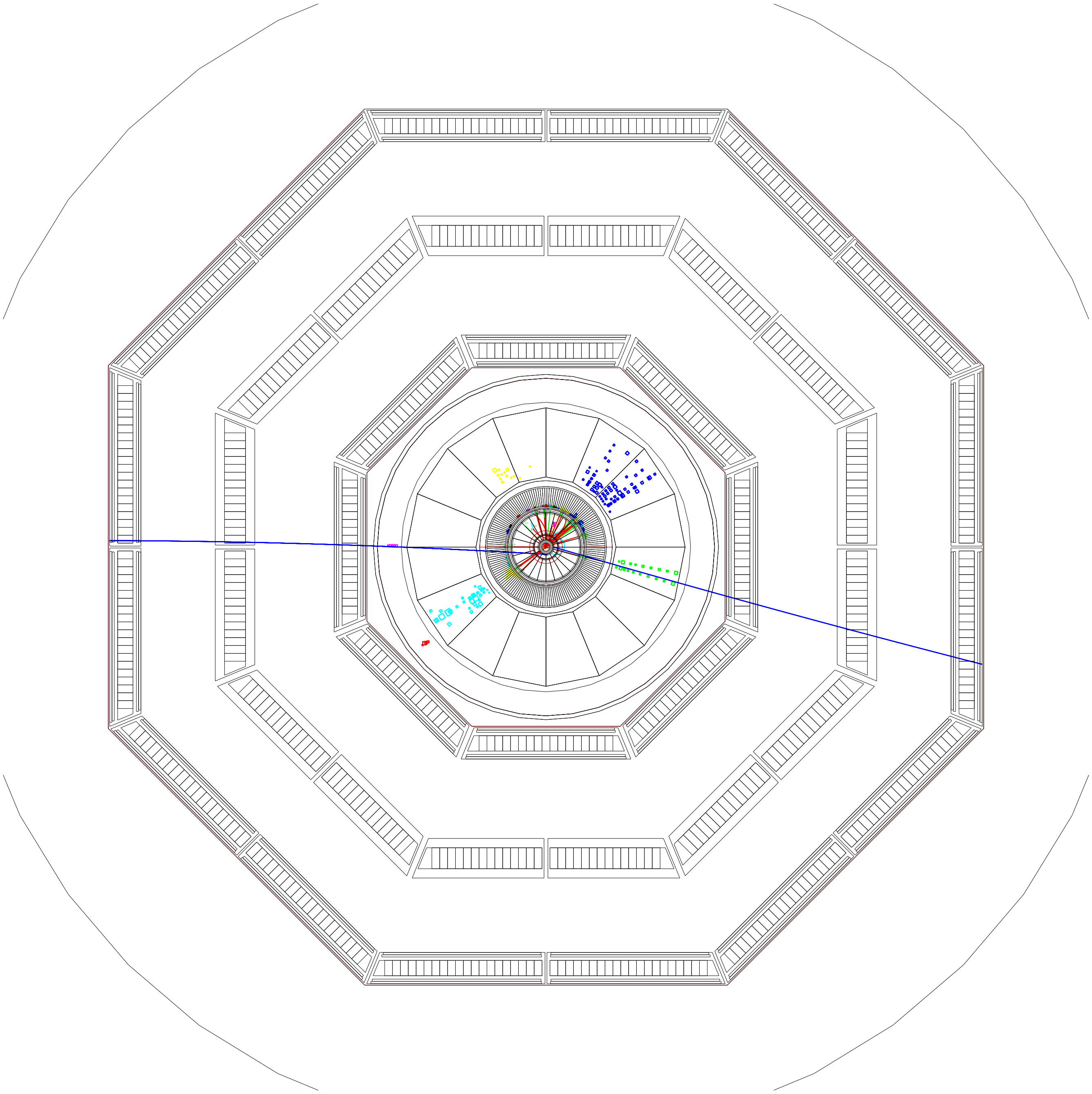


M_{ee} = 93 GeV

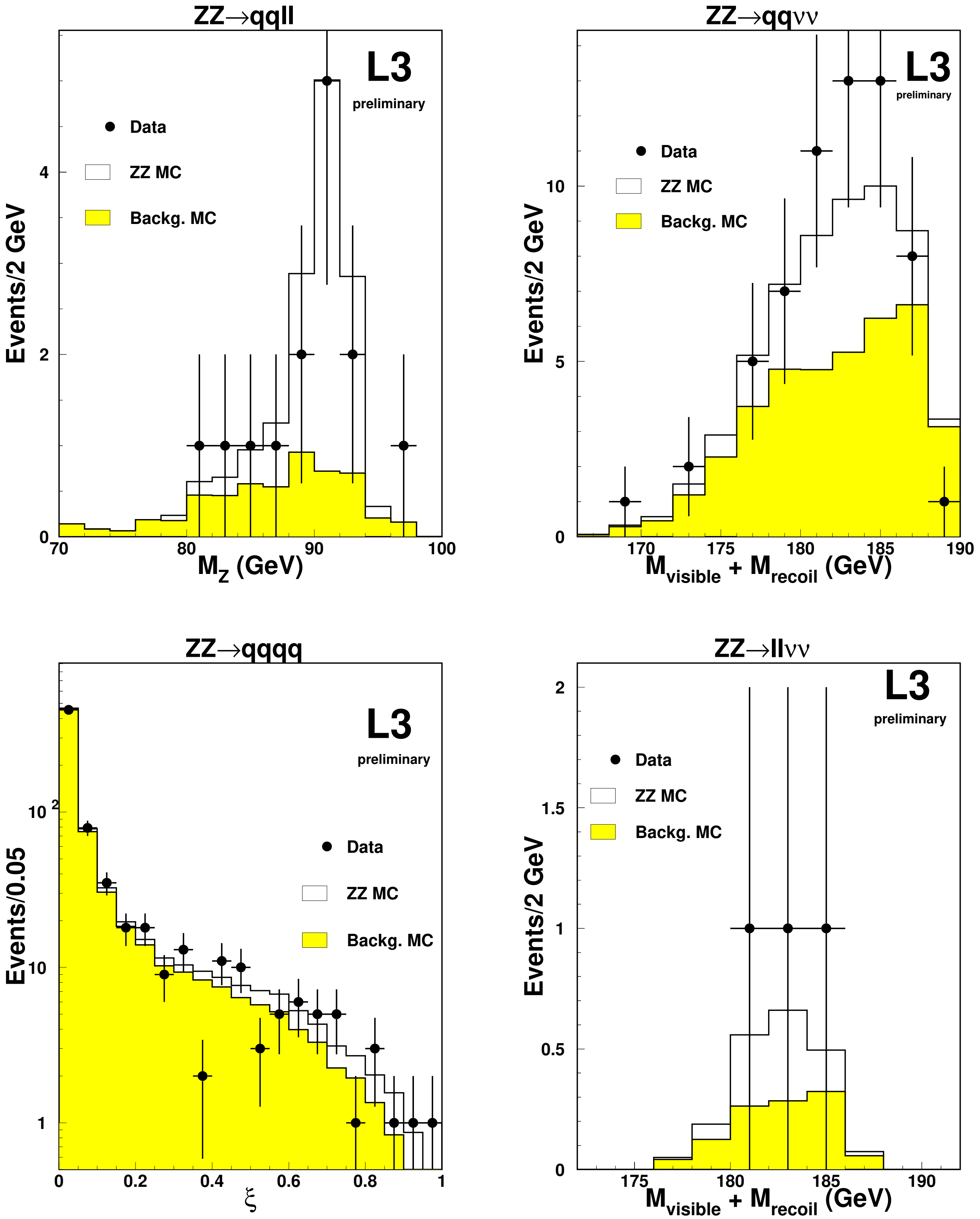
M_{qq} = 89 GeV

M_{5C} = 91 GeV

Run # **705301** **Event #** **24** Total Energy : 171.88 GeV

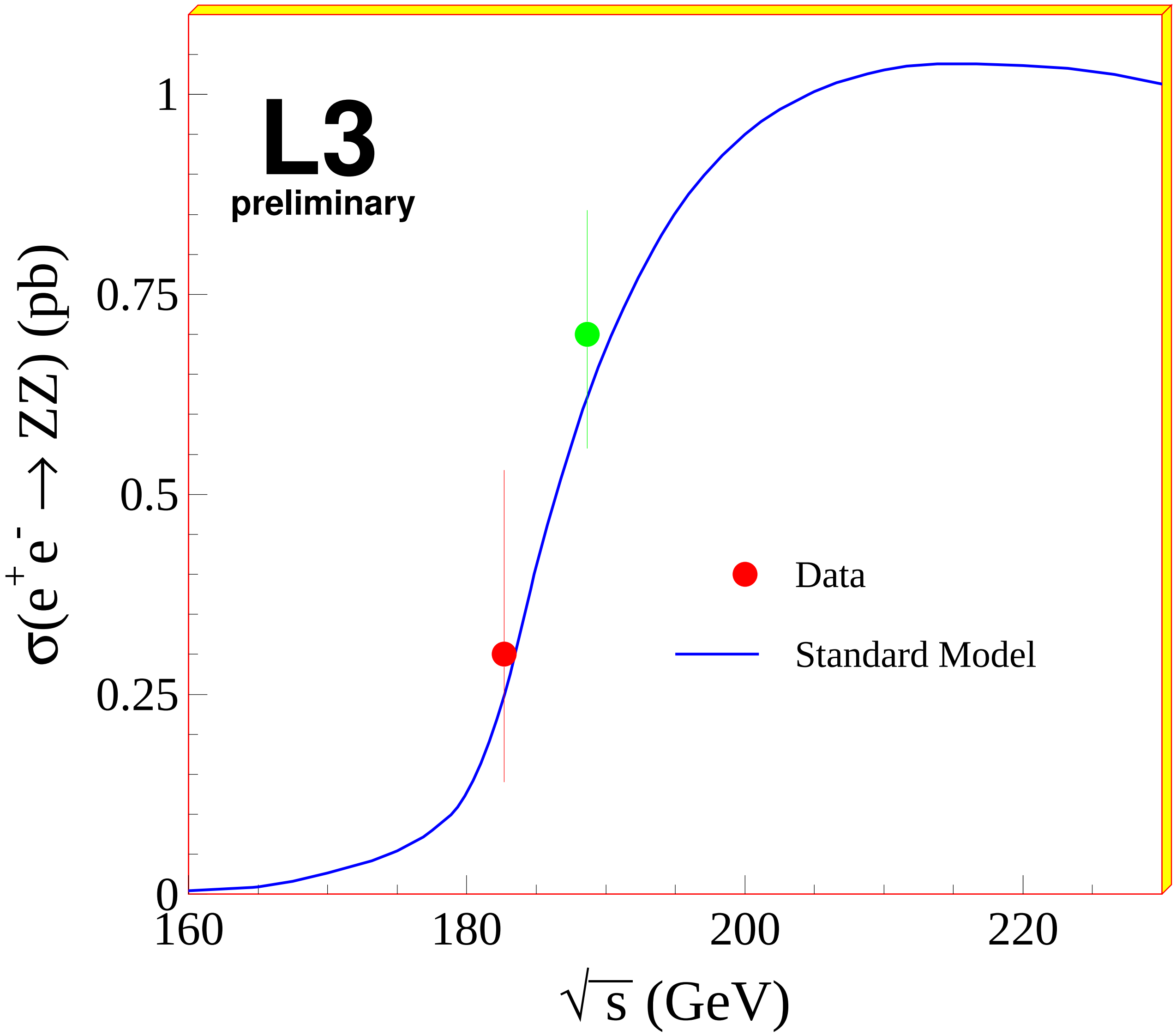


Transverse Imbalance :	.0830		**Longitudinal Imbalance :**	-.0744	
Thrust :	.8584	**Major :**	.4065	**Minor :**	.1667
Event DAQ Time :	*980713 51332*				

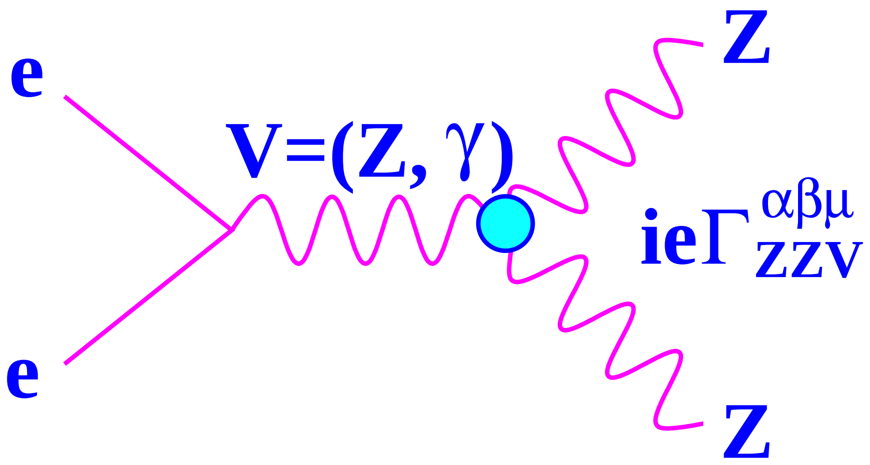


ZZ→qqll
L3
preliminary
Data
ZZ MC
Backg. MC
Events/2 GeV
M_Z (GeV)
ZZ→qqνν
L3
preliminary
Data
ZZ MC
Backg. MC
Events/2 GeV
M_visible + M_recoil (GeV)
ZZ→qqqq
L3
preliminary
Data
ZZ MC
Backg. MC
Events/0.05
ξ
ZZ→llνν
L3
preliminary
Data
ZZ MC
Backg. MC
Events/2 GeV
M_visible + M_recoil (GeV)

ZZ Cross Section



$\sqrt{s}$	Measured $\sigma(ZZ)$	SM $\sigma(ZZ)$
183 GeV	$0.30^{+0.22}_{-0.16}{}^{+0.07}_{-0.03}$pb	0.25pb
189 GeV	$0.68^{+0.15}_{-0.14}$pb	0.62pb



$$\Gamma^{\alpha\beta\mu}_{ZZV}(q_1, q_2, P) = \frac{s - m_V^2}{m_Z^2} \times$$

$$[if_4^V(P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) + if_5^V \epsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho]$$

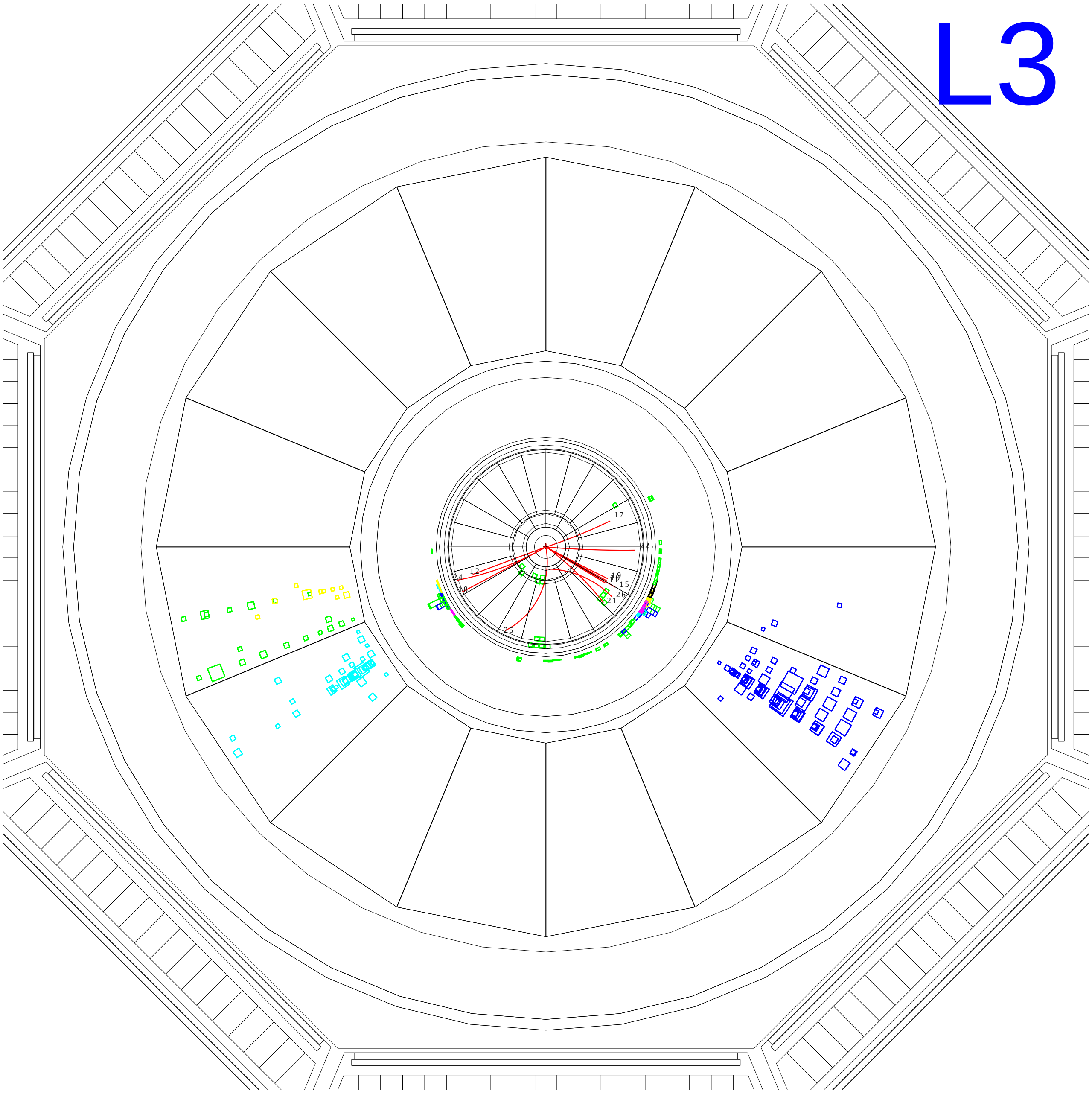
f_4^V conserves CP; f_5^V violates CP

At 95% C.L.:

$-1.7 < f_4^Z < 1.8 \quad -4.7 < f_5^Z < 4.7$

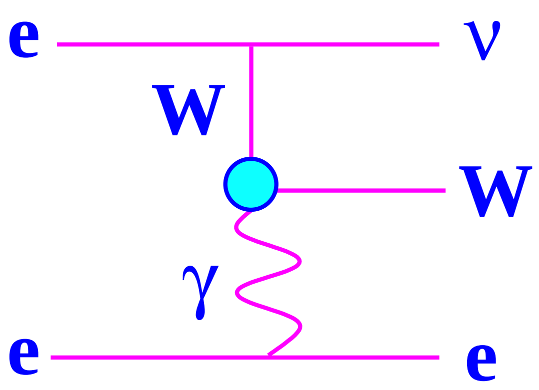
$-1.0 < f_4^\gamma < 1.1 \quad -2.8 < f_5^\gamma < 2.9$

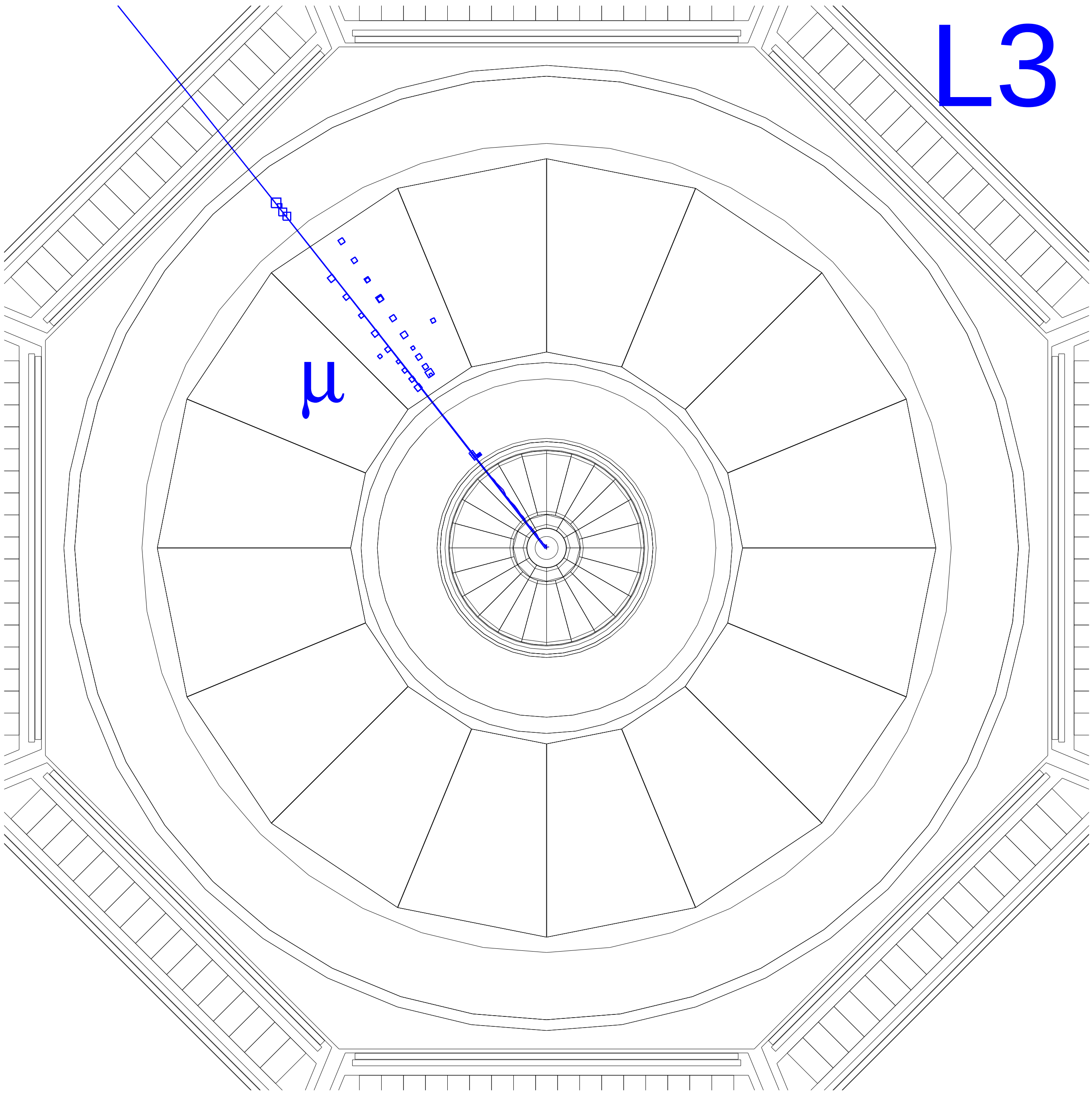
Just One W

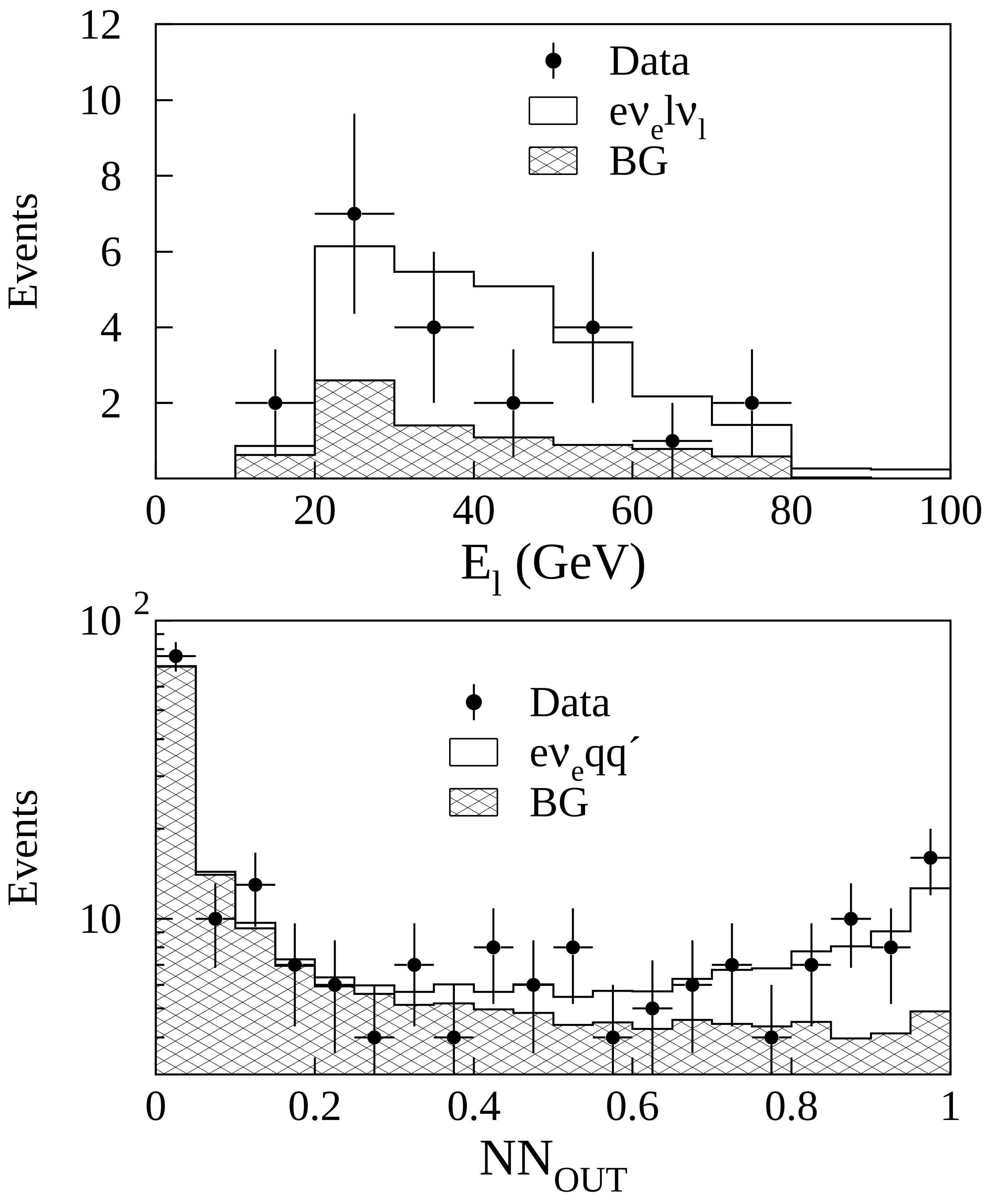


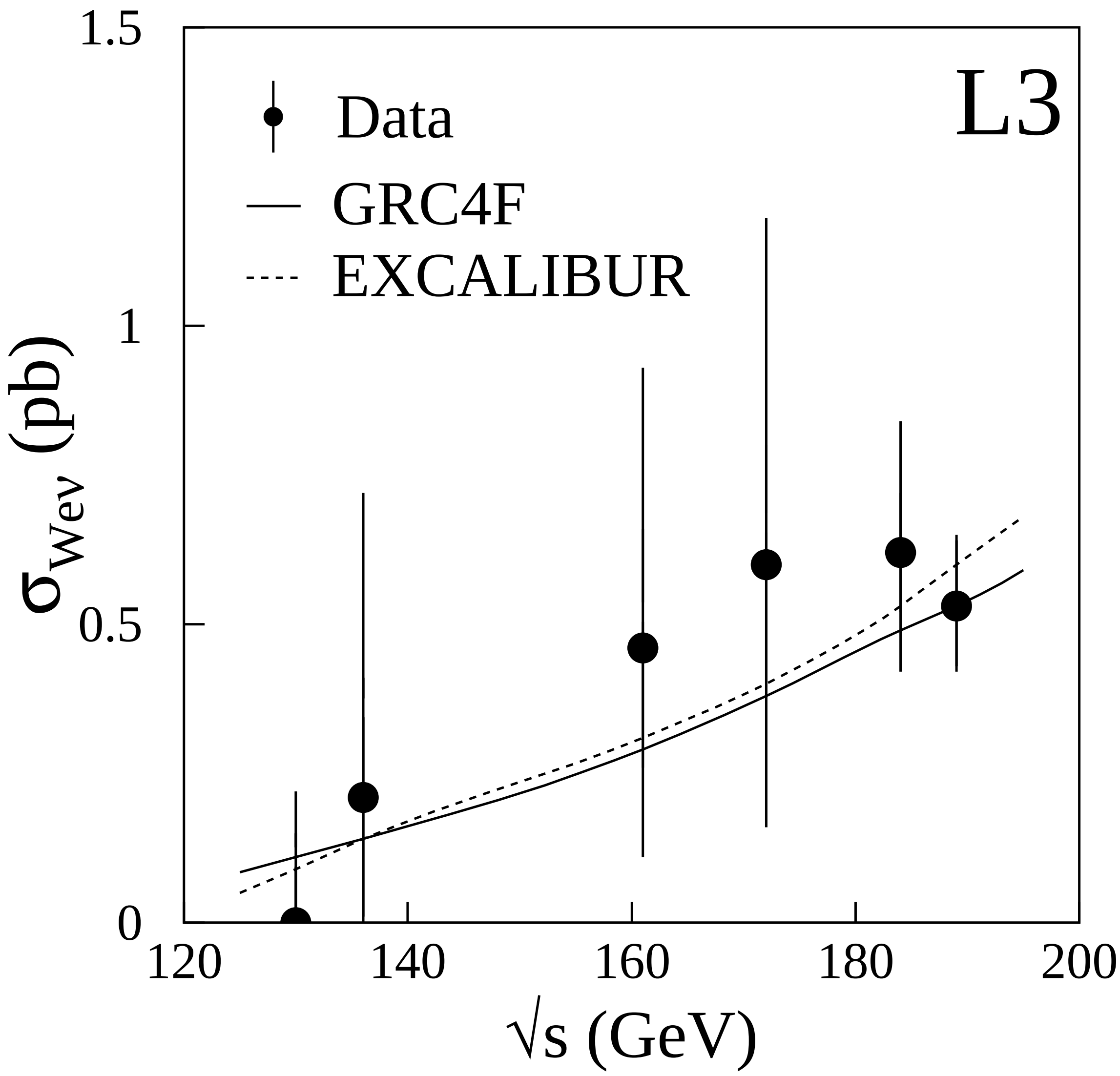
- The Higgs in $e^+e^- \rightarrow ZH \rightarrow \nu\bar{\nu}b\bar{b}$? No b-content!
- Supersymmetry? Incompatible visible mass clustering!

The Single Lepton Events






Data
$e\nu_e l\nu_l$
BG
Events
0
20
40
60
80
100
2
4
6
8
10
12
E_l (GeV)
Data
$e\nu_e qq'$
BG
Events
10^2
10
0
0.2
0.4
0.6
0.8
1
NN_{OUT}



Sensitive to WWγ couplings.

$$\kappa_\gamma = 1.07^{+0.15}_{-0.17} \text{ (68\% C.L.); } \quad (0.58\text{–}1.22) \quad \text{(95\% C.L.)}$$
$$\lambda_\gamma = 0.30^{+0.68}_{-0.19} \text{ (68\% C.L.); } \quad (\text{-}0.64\text{–}0.61) \quad \text{(95\% C.L.)}$$

...In the Extra Dimensions

An Experimentalist Understanding

Hierarchy problem:

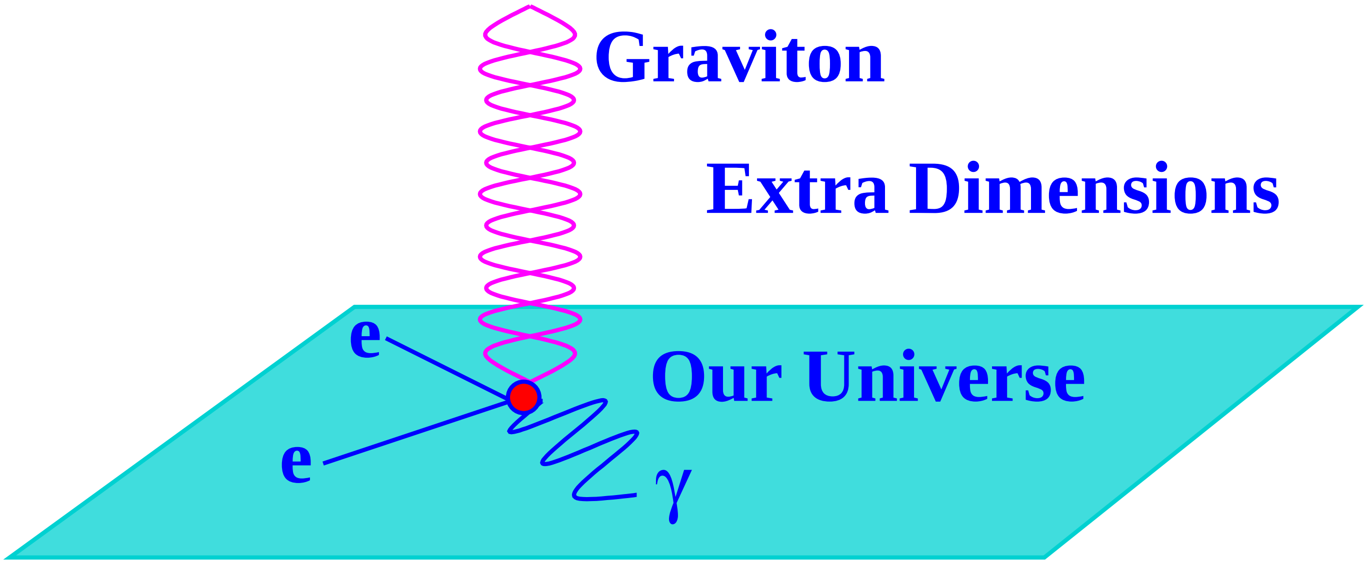
$$M_{Pl} \sim 10^{18}\ \mathrm{GeV} \gg M_{ew} \sim 10^{3}\ \mathrm{GeV}$$

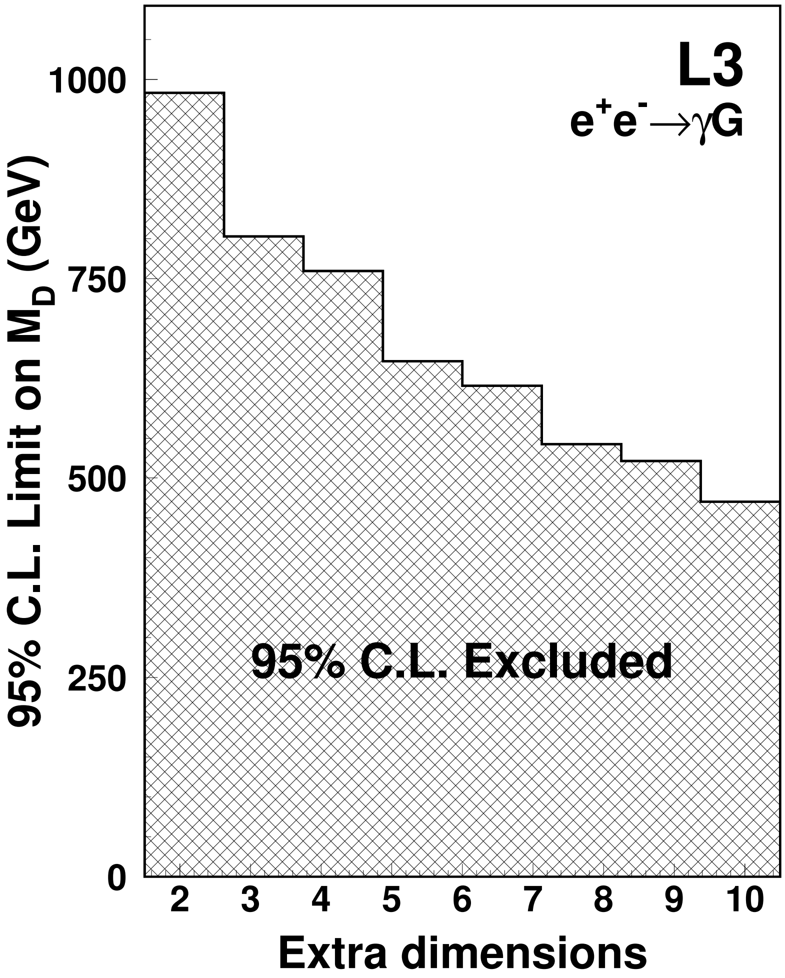
- Standard Model successfully tested at $1/M_{ew}$
- Gravity far from being tested at $1/M_{Pl}$
- Proposed solutions (Susy...) searched for and not found at $1/M_{ew}$

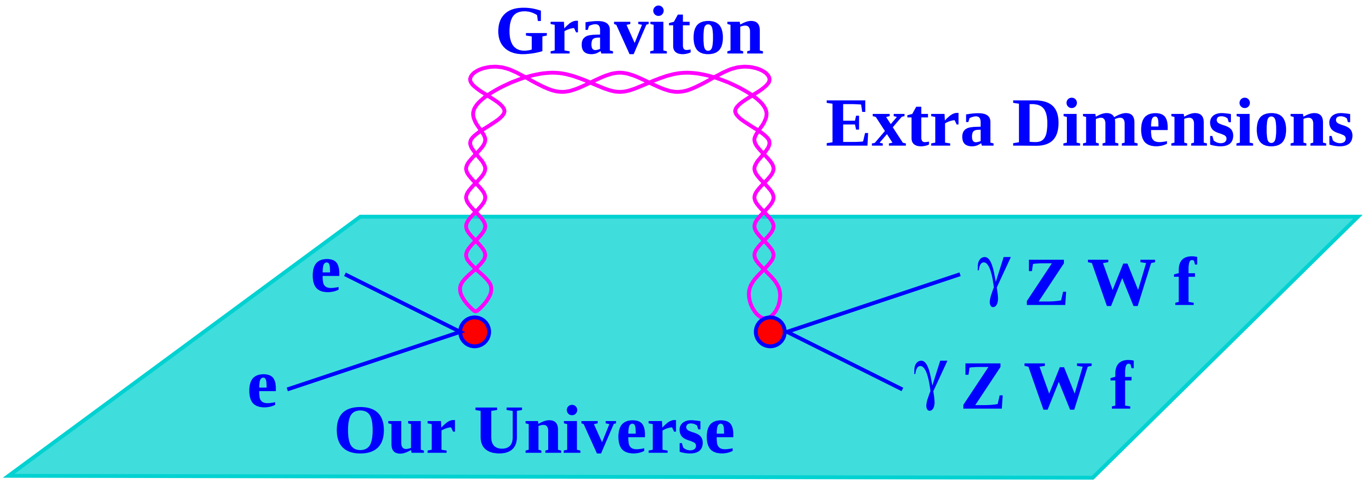
Arkani-Hamed et al. [PLB 544 (1998) 263]:

- The scale of Gravity, M_S, is of order M_{ew}
- There are n extra dimensions of size R such that
$$M_{Pl}^2 \sim R^n M_S^{n+2}$$
- As soon as $n > 2$ the experimental tests of Gravity can not exclude this
- Spin 2 gravitons propagate in these extra dimensions interacting with Standard Model particles in our four ones

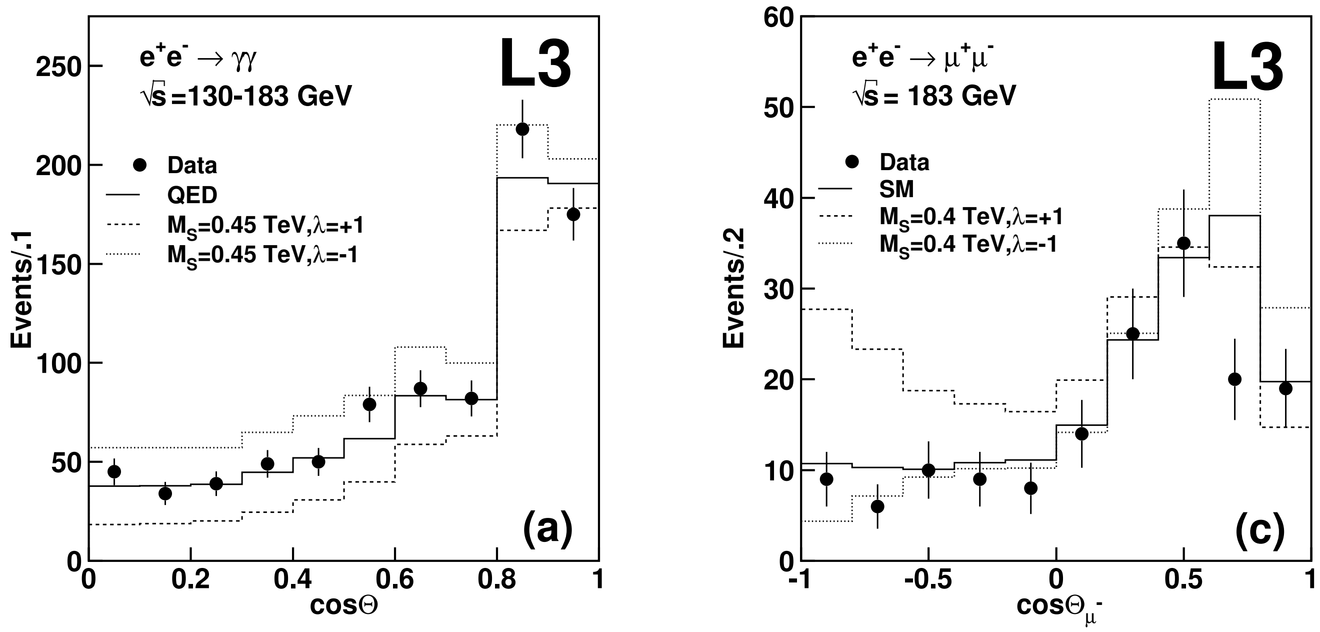
Real Graviton Production







$$\frac{d\sigma}{d\Omega}(s,t) = \frac{d\sigma^{SM}}{d\Omega}(s,t) + \frac{\lambda}{M_S^4}\alpha_{\rm Interf.}(s,t) + \frac{\lambda^2}{M_S^8}\beta_{\rm Low\,Scale\,Gravity}(s,t)$$



$$\lambda = -1 \quad M_s > 630 \text{ GeV}$$
$$\lambda = +1 \quad M_s > 770 \text{ GeV}$$

Conclusions

- The Fermions and Boson sectors of the Standard Model have been extensively studied at LEP 2
- No deviation from the expectation are observed in the statistically increasing precision of the measurements
- The amount of investigated physics topics is found in excess with respect to the expectations
- Fast reactions to new theoretical idea
- Another LEP run started, and single beams at 100 GeV were circulated !

The opening table for future talks on LEP Results:

Year	$\sqrt{s}$ (GeV)	$\int \mathcal{L}dt$ (pb^{-1})	
1995	130–140	5+5	The Warm-Up Run
1996	161–172	10+10	W Pairs, W Mass
1997	183	55	Z Pairs
1998	189	175	High statistic measurements
1999	**192-196**	**200**	**Observation of the Higgs Boson**
2000	**200**	**200**	**Discovery of Supersymmetry**