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Search for Extra Dimensions at LEP

- Introduction
- Combined Boson Cross Sections
- Fermion and boson pairs
- "Real Gravitons"
- Conclusions

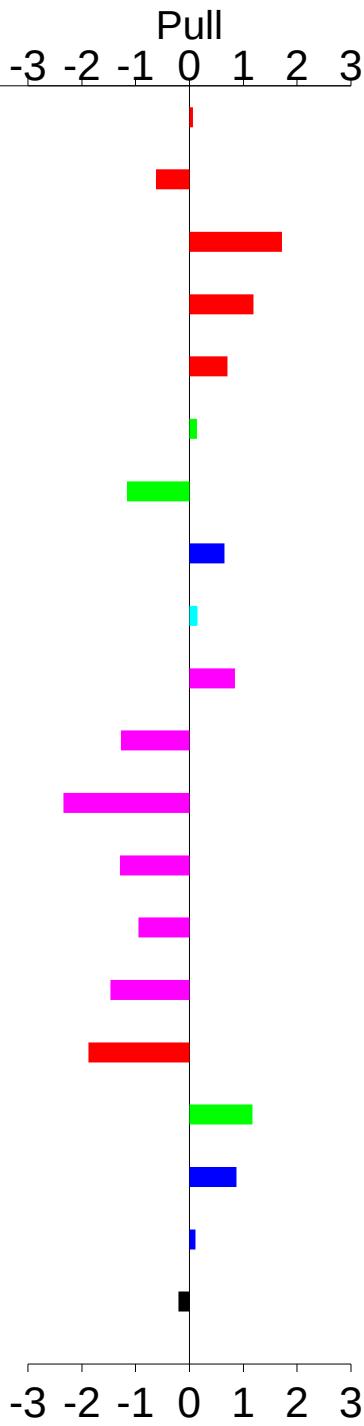
TriLEP, XII Convegno sulla Fisica al LEP
Trieste, Italy, $26^{th} - 28^{th}$ April 2000

Introduction

The Standard Model is healthier than ever:

Moriond 2000

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.07
Γ_Z [GeV]	2.4944 ± 0.0024	-.62
σ^0_{hadr} [nb]	41.544 ± 0.037	1.72
R_e	20.768 ± 0.024	1.19
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.70
A_e	0.1483 ± 0.0051	.13
A_τ	0.1425 ± 0.0044	-1.16
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.65
m_W [GeV]	80.401 ± 0.048	.15
R_b	0.21642 ± 0.00073	.85
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0988 ± 0.0020	-2.34
$A^{0,c}_{fb}$	0.0692 ± 0.0037	-1.29
A_b	0.911 ± 0.025	-.95
A_c	0.630 ± 0.026	-1.47
$\sin^2\theta^{lept}_{eff}$	0.23096 ± 0.00026	-1.87
$\sin^2\theta_W$	0.2255 ± 0.0021	1.17
m_W [GeV]	80.448 ± 0.062	.88
m_t [GeV]	174.3 ± 5.1	.11
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.20

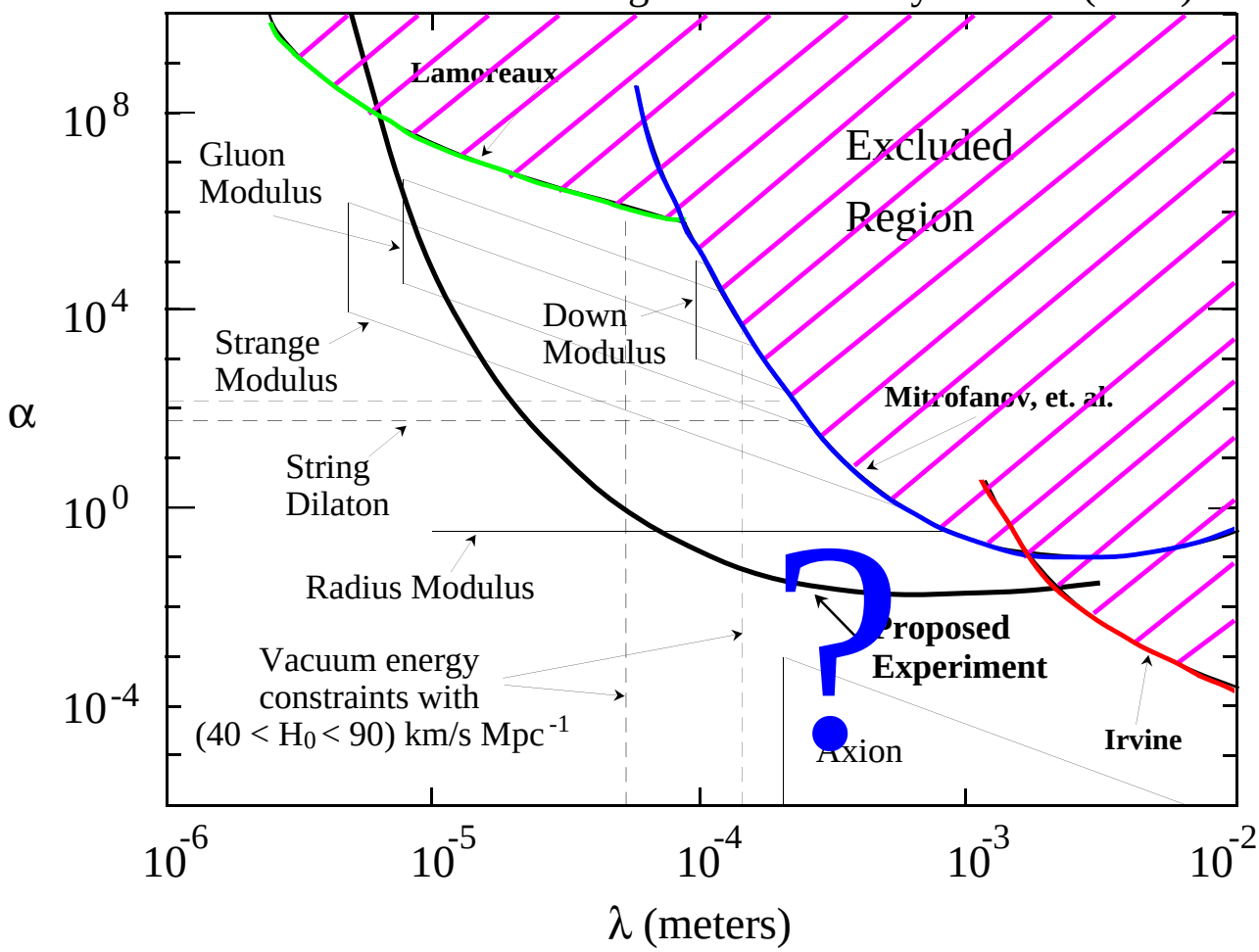


And it is tested at its characteristic distance

$1/m_{ew}$ (Easy we've built LEP such that $\sqrt{s} \simeq m_{ew}$)

Gravity is far from being tested at $1/M_{Pl} = 10^{-35}$ cm:

J.C. Long et. al. Nucl. Phys. B 539 (1999) 23



$$V(r) = -\int dr_1 \int dr_2 G_N \frac{\rho_1(r_1)\rho_2(r_2)}{r_{12}}\left(1 + \alpha e^{\frac{-r_{12}}{\lambda}}\right)$$

Introduction

Three facts:

- $\mathbf{M_{Pl}} \sim \mathbf{10^{19}}$ GeV $\gg \mathbf{m_{ew}} \sim \mathbf{10^{2}}$ GeV
- Standard Model tested at $\mathbf{1/m_{ew}}$
- Gravity far from being tested at $\mathbf{1/M_{Pl}}$

Arkani-Hamed et al. Phys. Lett. B 544 (1998) 263

(and $\mathcal{O}(\mathbf{200})$ more papers in 1 year)

- **The scale of Gravity, $\mathbf{M_S}$, is of order $\mathbf{m_{ew}}$**
- **There are n extra dimensions of size R such that with the Gauss' theorem:**

$$\mathbf{M_{Pl}^2 \sim R^n M_S^{n+2}}$$

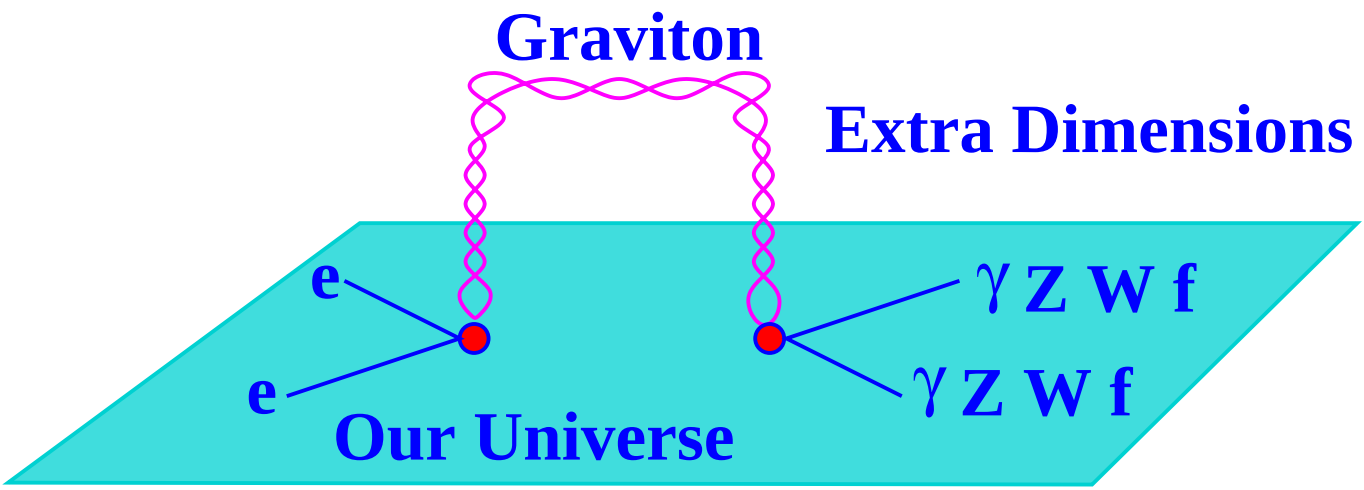
$\mathbf{M_S} \sim \mathbf{1}$ TeV $\mathbf{n = 1}$ $\mathbf{R \sim}$ **Solar System**
...unrealistic

$\mathbf{M_S} \sim \mathbf{1}$ TeV $\mathbf{n = 2}$ $\mathbf{R \sim 1mm}$
...why not?

Low Scale Gravity

Virtual Graviton Exchange

Spin 2 gravitons propagate in these extra dimensions interacting with Standard Model particles in our four ones



$$\frac{d\sigma}{d\Omega}(s,t) = \frac{d\sigma^{SM}}{d\Omega}(s,t) +$$

$$+\frac{\lambda}{M_S{}^4}\alpha_{\text{Interf.}}(s,t) + \frac{\lambda^2}{M_S{}^8}\beta_{\text{Low Scale Gravity}}(s,t)$$

λ depends on the (unknown) full theory, use ± 1 for different signs in interference

Virtual Graviton Exchange

Two approaches to investigate extra dimension effects via virtual graviton exchange.

1. **Study the combined LEP ZZ and WW cross sections and the QED limits as a function of λ/M_S^4.**

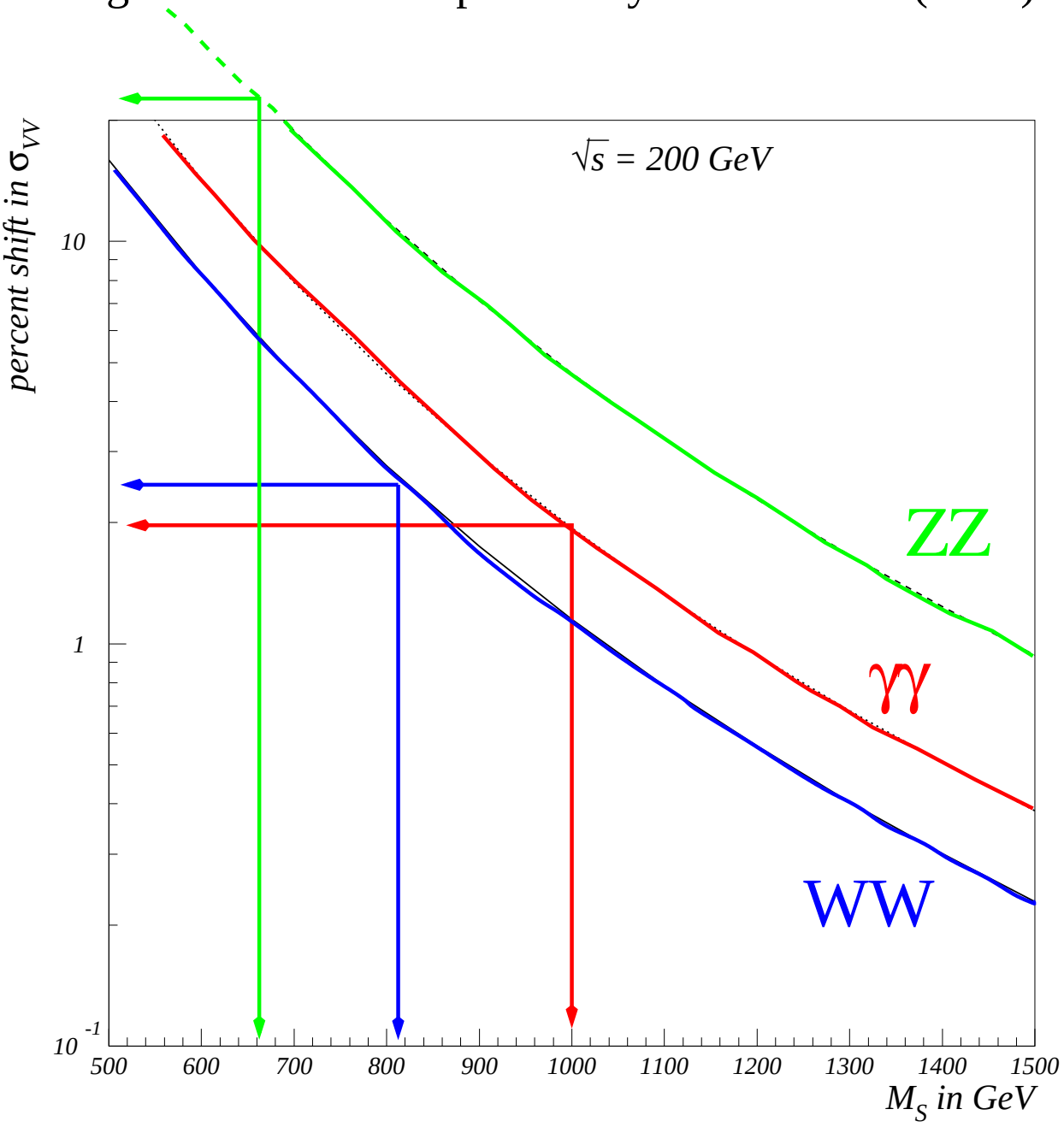
   S. Mele & E. Sanchez, hep-ph/9909294 (PRD accepted)

2. **Investigate experimental distributions for all final states**

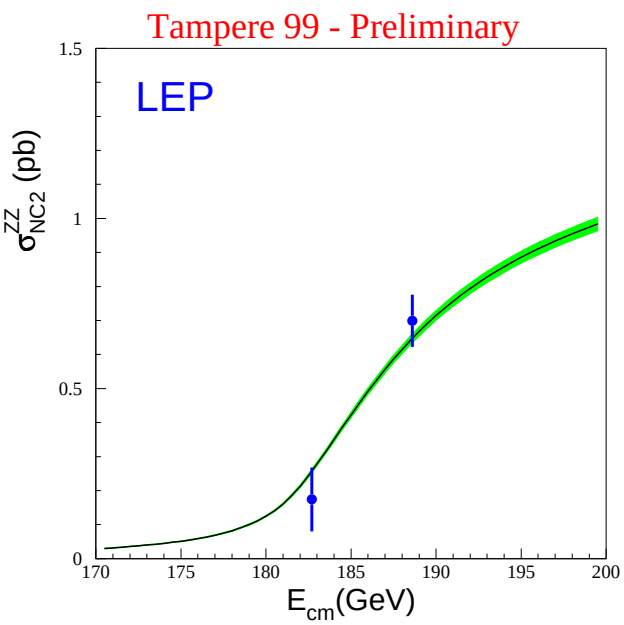
   Aleph, Delphi, L3, Opal collab., publications and submissions to EPS99 or Moriond2000

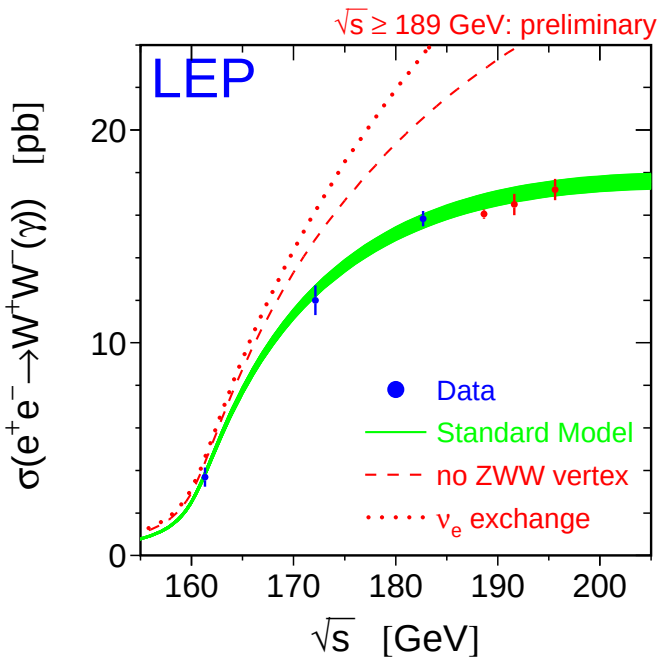
Combined Cross Sections

K.Agashe & N.G.Deshpande Phys. Lett. B 465 (1999) 60

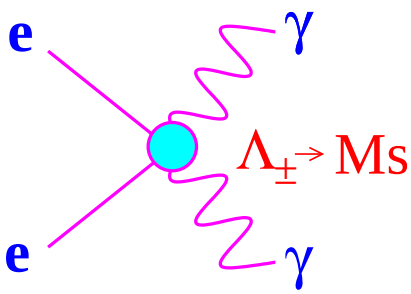


Combined Cross Sections



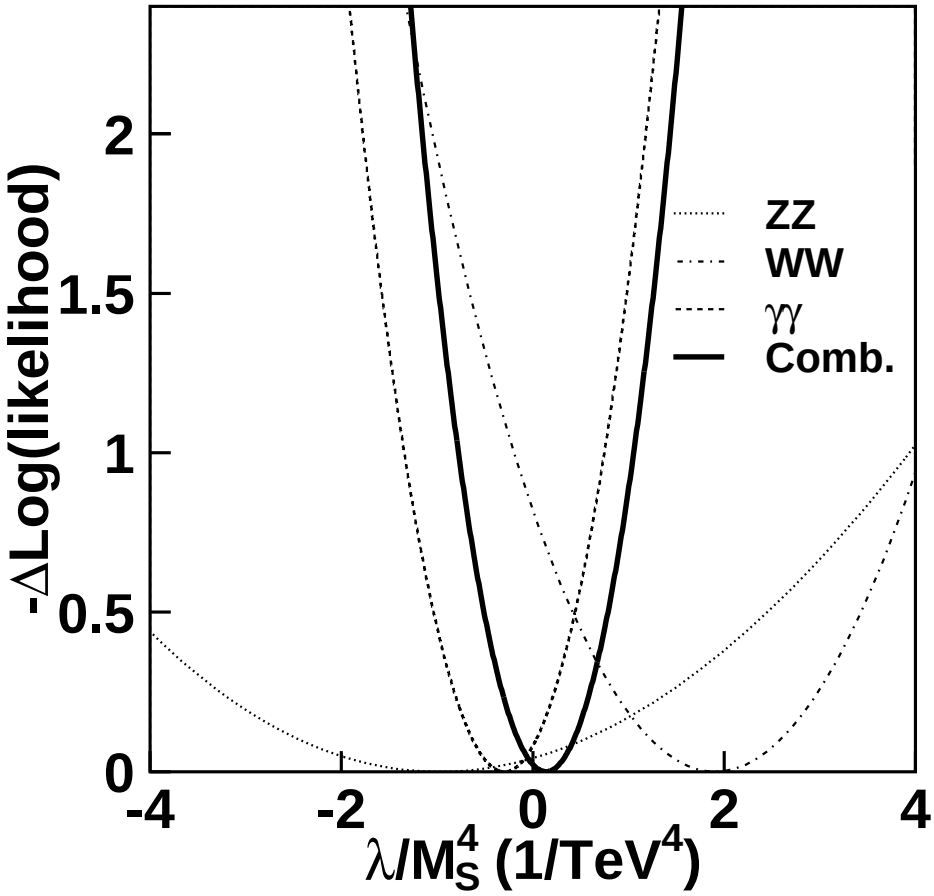


Compare measured cross sections with SM + LSG one as a function of λ/M_S^4.



Combine the LEP form factor limits
Convert them into Ms ones

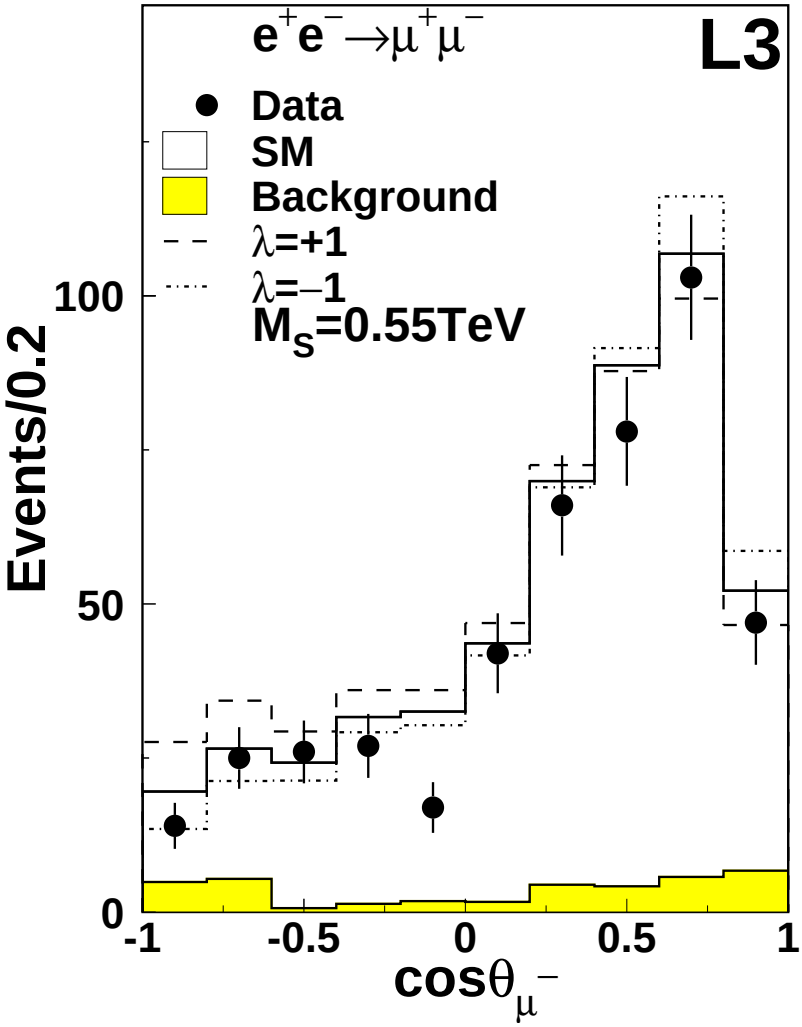
Combined Cross Sections



Process (95% CL)	$\lambda = -1$ M_S (TeV)	$\lambda = +1$ M_S (TeV)
$e^+e^- \to \gamma\gamma$	0.88	0.94
$e^+e^- \to W^+W^-$	0.85	0.68
$e^+e^- \to ZZ$	0.62	0.63
Combined	0.96	0.93

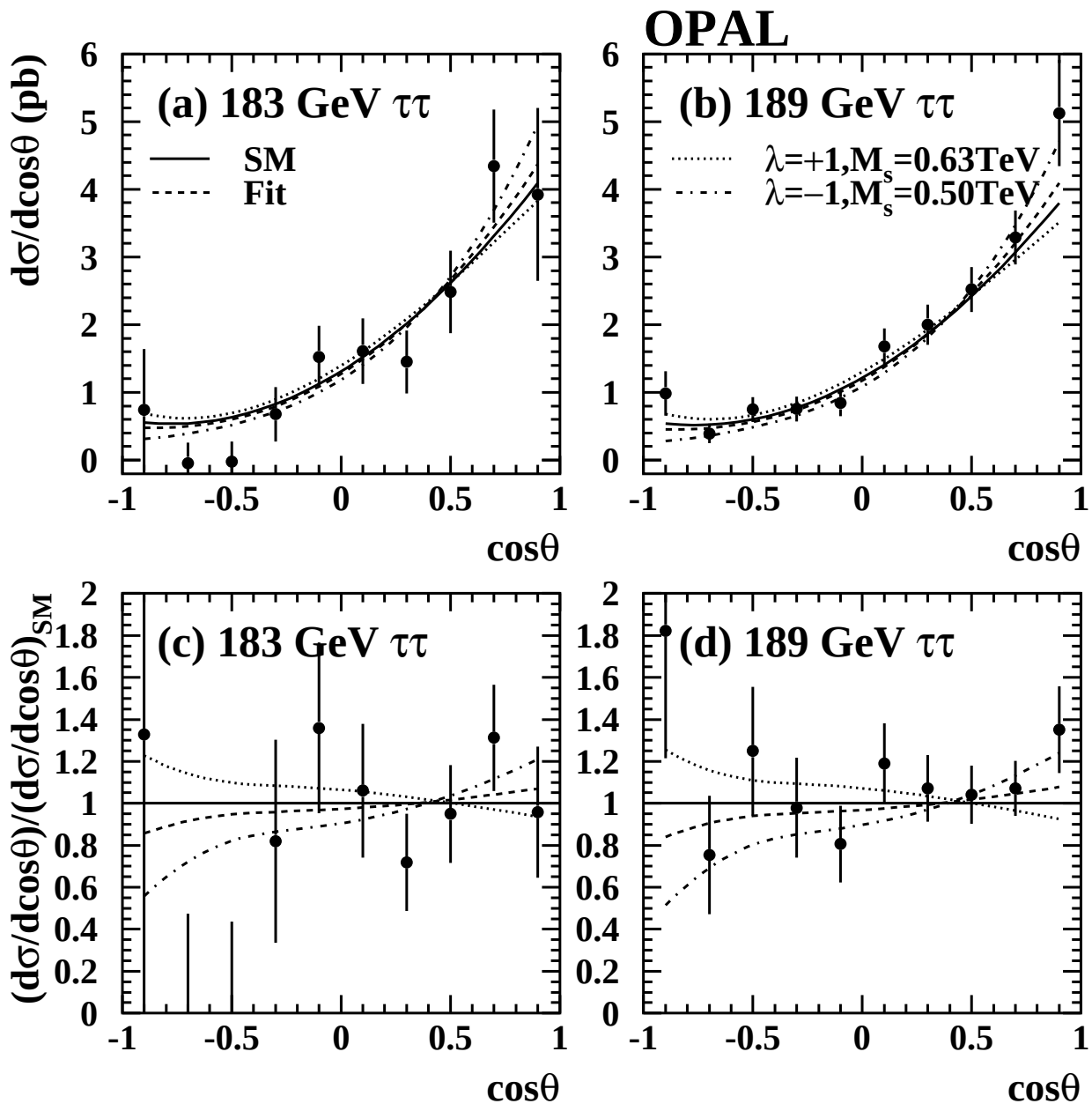
The Theory Uncertainty on $\sigma(WW)$ is the limiting factor.

Muon Pairs



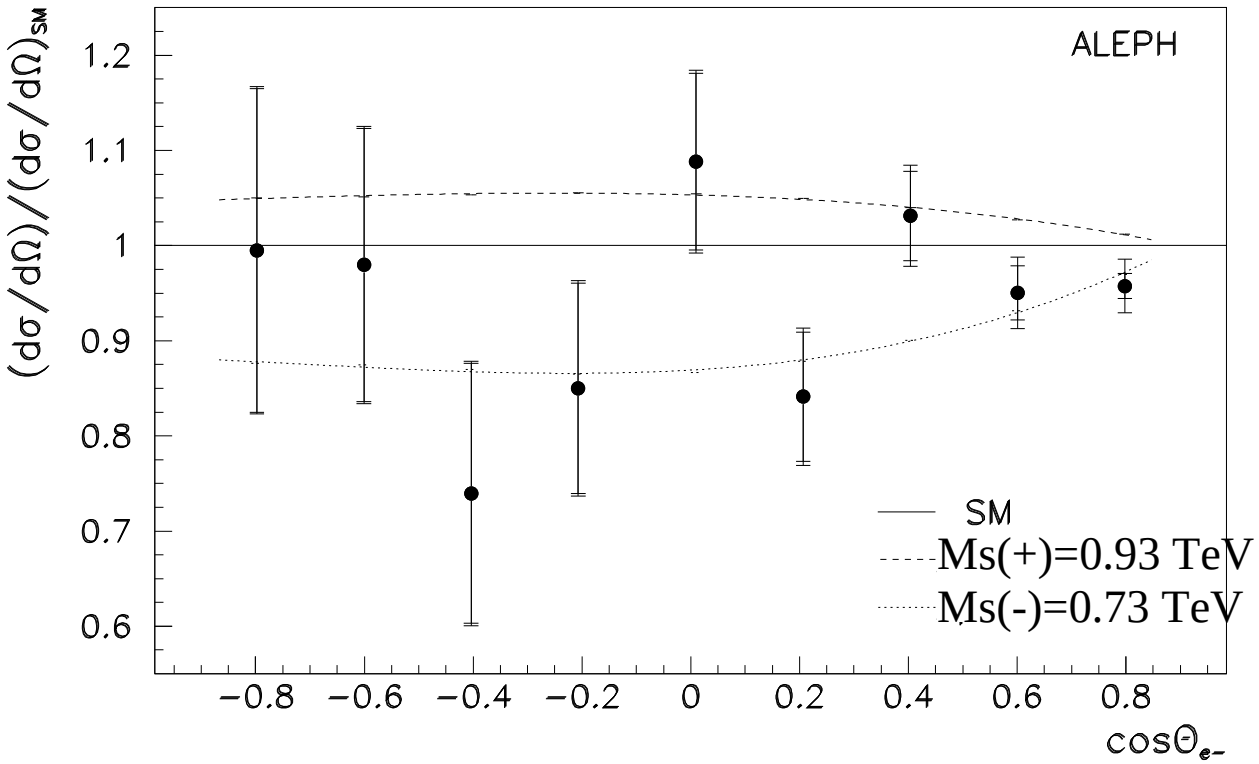
95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	189	192-202	183-189	183-189
M_S (+) (TeV)	0.61	0.72	0.69	0.60
M_S (−) (TeV)	0.56	0.59	0.56	0.63

Tau Pairs



95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	189	192-202	183-189	183-189
M_S (+) (TeV)	0.53	0.64	0.54	0.63
M_S (−) (TeV)	0.51	0.58	0.58	0.50

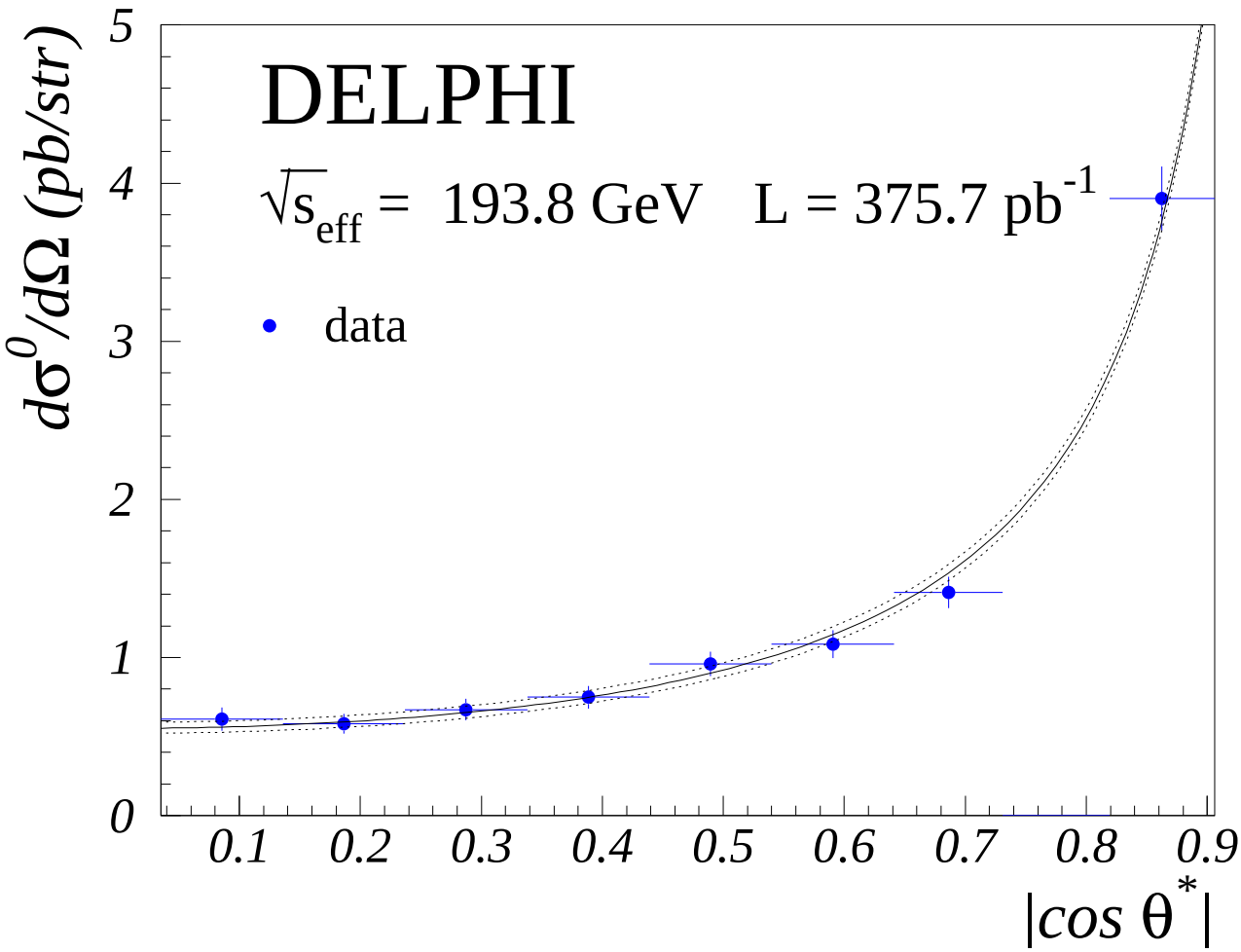
Electron Pairs



95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	189	-	130-202	-
M_S (+) (TeV)	0.92	-	0.99	-
M_S (−) (TeV)	0.71	-	0.91	-

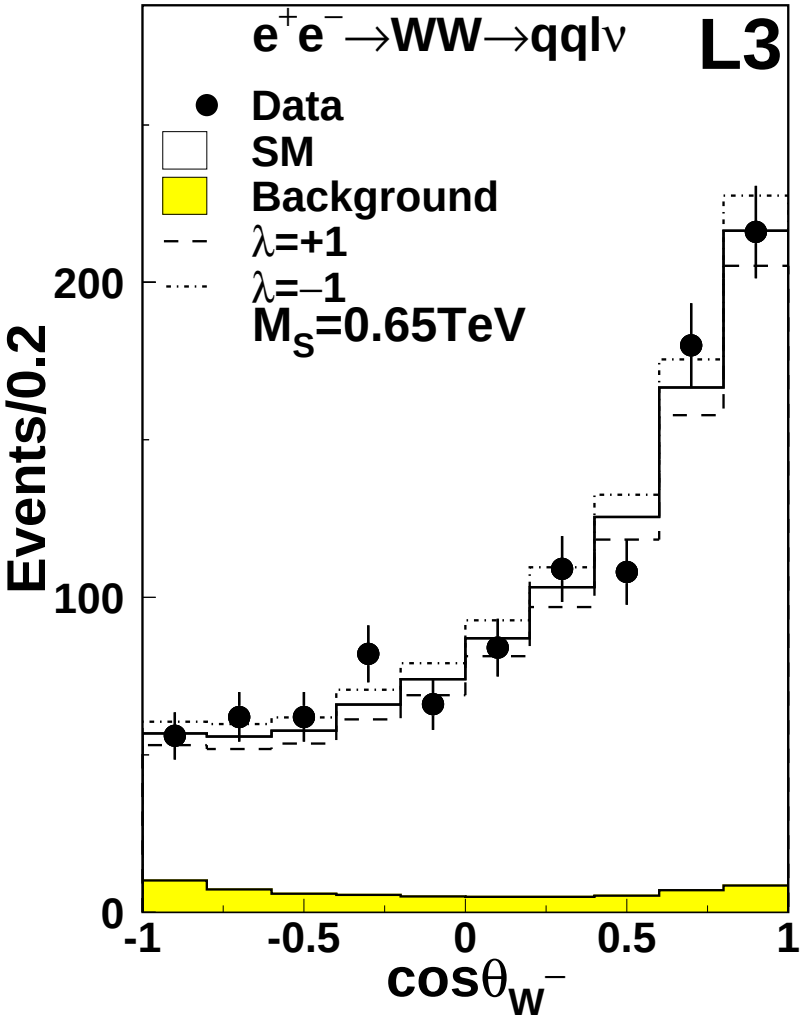
The electron channel dominates any combination.

Photon Pairs



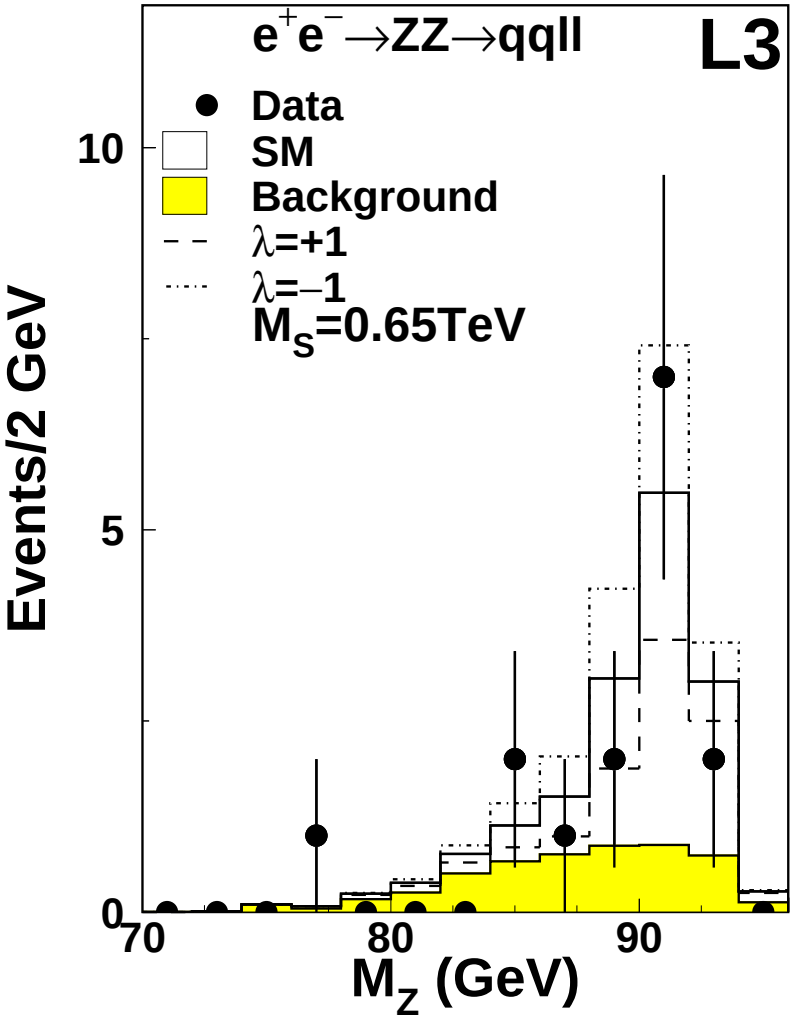
95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	189-202	91-202	130-189	183-189
M_S (+) (TeV)	0.92	0.71	0.79	0.75
M_S (−) (TeV)	0.81	0.69	0.80	0.69

W Pairs



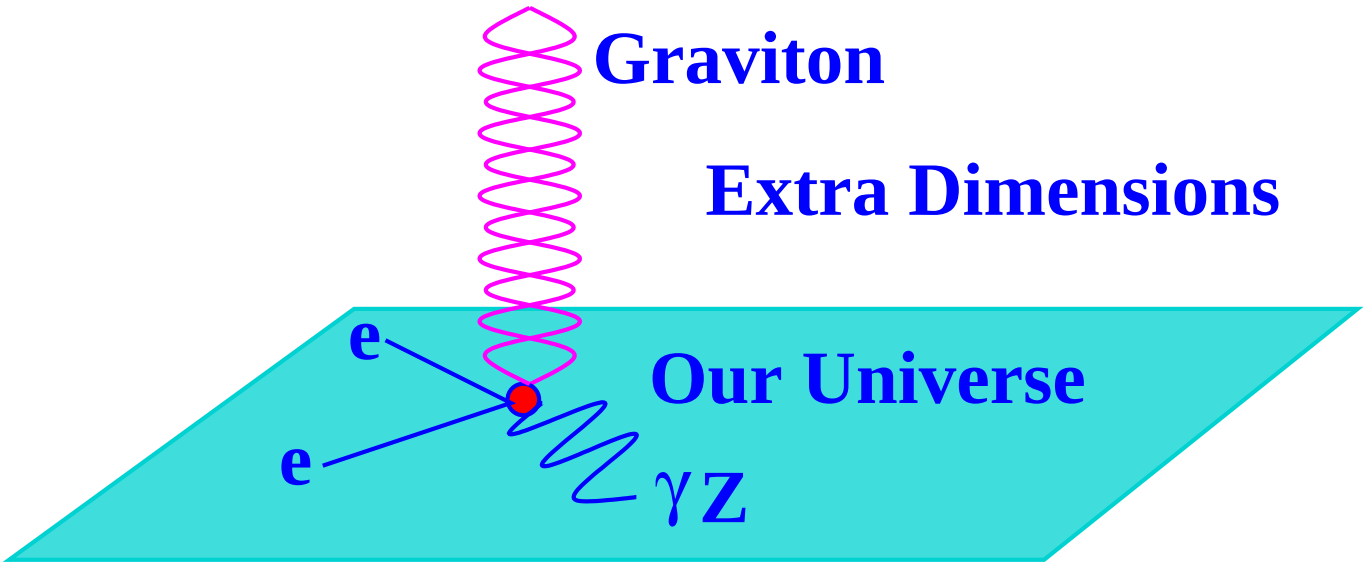
95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	-	-	183-189	-
M_S (+) (TeV)	-	-	0.79	-
M_S (−) (TeV)	-	-	0.78	-

Z Pairs



95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	-	-	183-202	-
M_S (+) (TeV)	-	-	1.1	-
M_S (−) (TeV)	-	-	1.2	-

Real Graviton Production

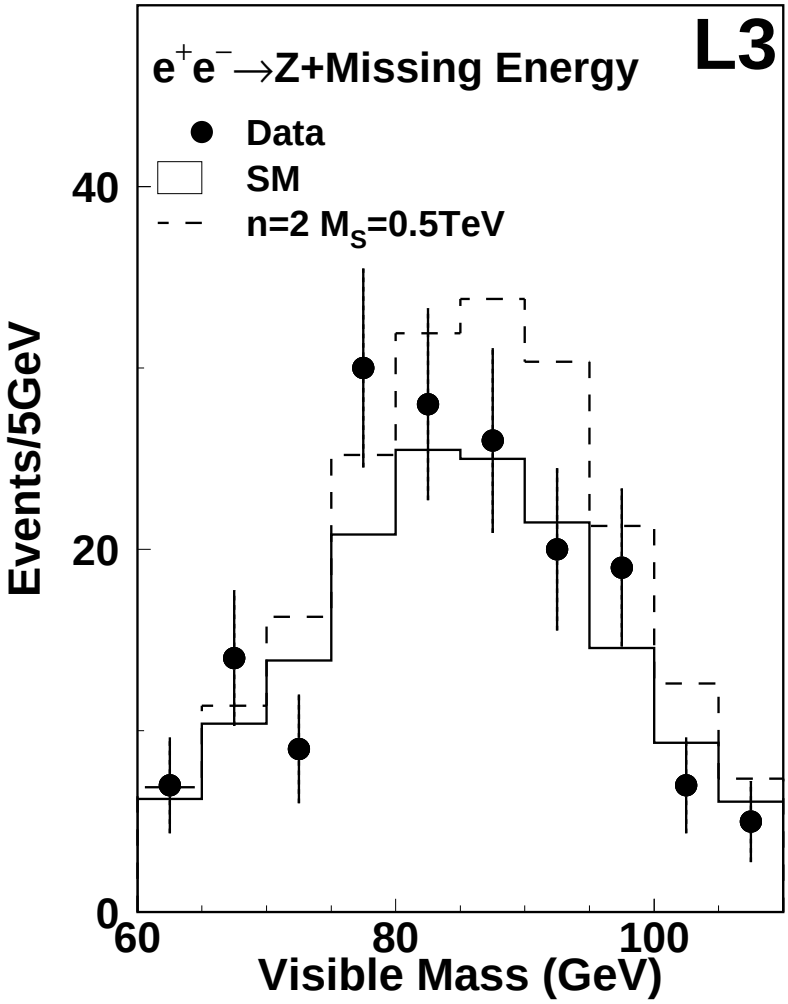


Gravitons can also be emitted in the extra dimensions leaving a photon or a Z in our universe...

Due to the continuous structure of the Kaluza-Klein modes, there is no resonance.

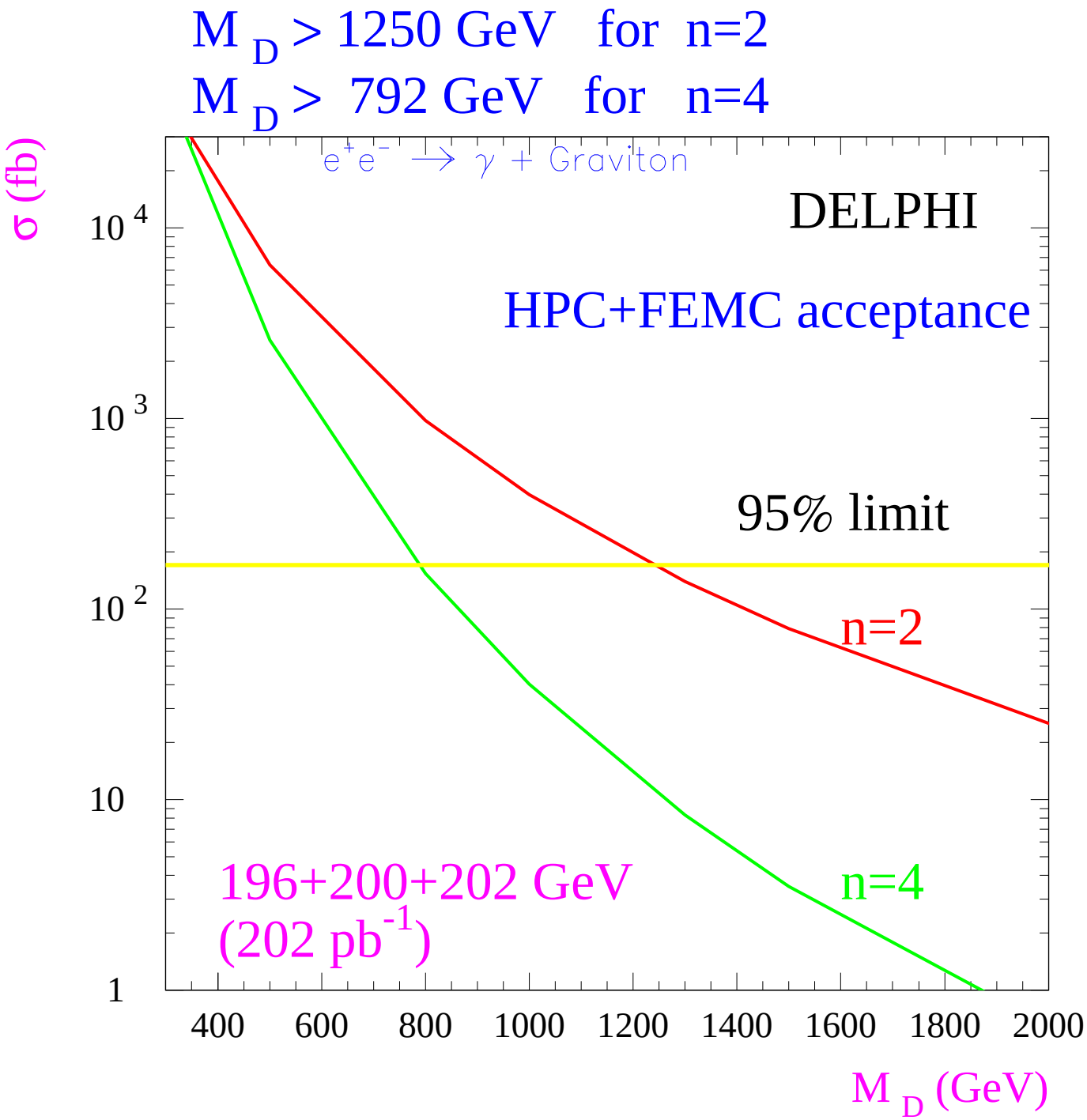
Explicit dependence on the number of extra dimensions.

Single Z



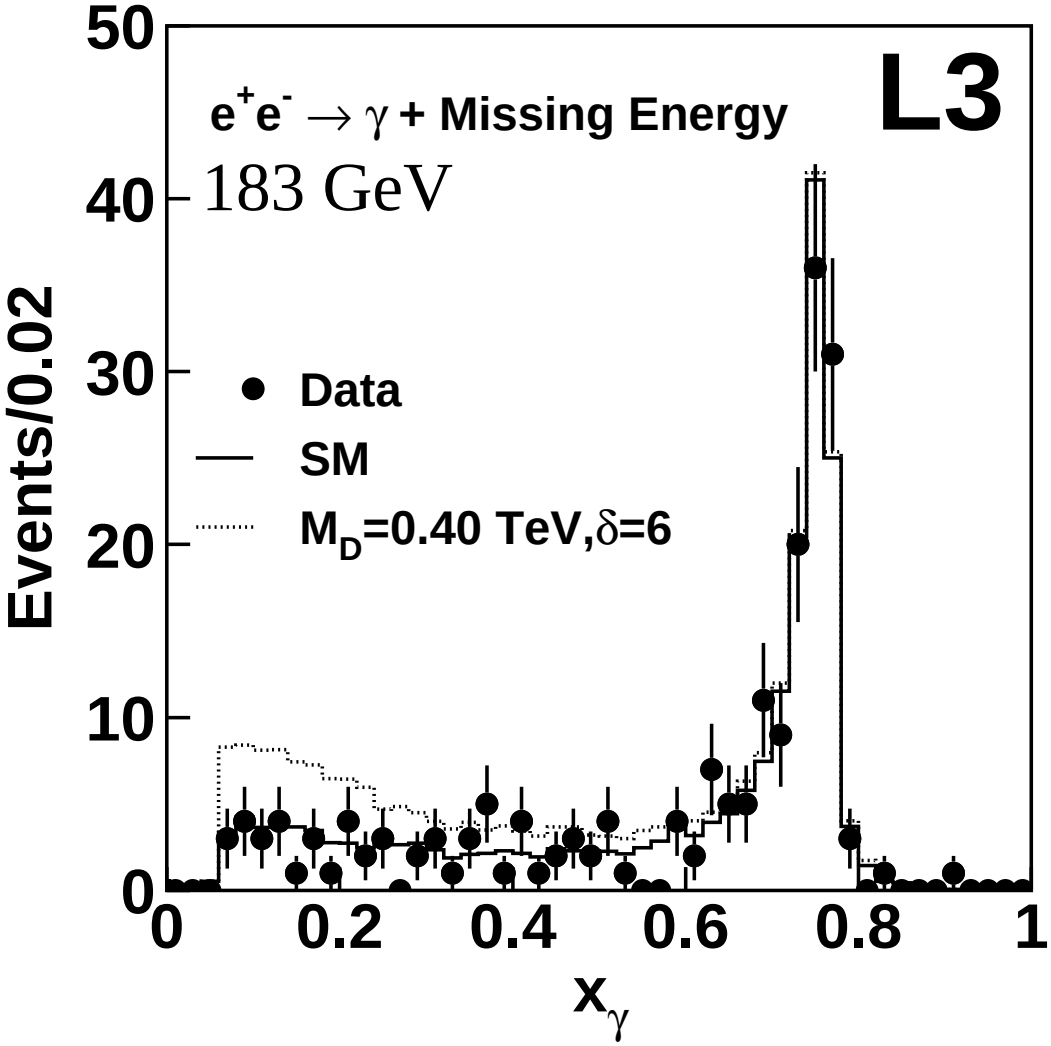
95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	-	-	189	-
M_D (n=2) (TeV)	-	-	0.6	-
M_D (n=3) (TeV)	-	-	0.4	-
M_D (n=4) (TeV)	-	-	0.3	-

Single Photon



Modification of the single photon cross section.

Single Photon



95% CL	Aleph	Delphi	L3	Opal
$\sqrt{s}$ (GeV)	189-202	196-202	189	189
M_D (n=2) (TeV)	1.1	1.2	1.1	1.1
M_D (n=3) (TeV)	0.9	-	0.9	0.9
M_D (n=4) (TeV)	0.7	0.8	0.7	0.7
M_D (n=5) (TeV)	0.6	-	0.6	0.6
M_D (n=6) (TeV)	0.5	-	0.5	0.5

Conclusions

A fast and exhaustive reaction of the LEP community to a brand new idea

No evidence for deviations from the Standard Model

Excluded size of the Extra Dimensions from LEP (meters)

REFERENCE SIZES	n	Limit
1 light Year ~ 10^{+16}		
1 AU = $1.5 \times 10^{+11}$	1	10^{+13}
Typical cell size ~ 10^{-5}	2	10^{-3}
DNA Molecule size ~ 10^{-7} Typical Molecule size ~ 10^{-8}	3	10^{-9}
Bohr Radius = 0.53×10^{-10}	4	10^{-11}
$\lambda_{COMPTON}$ of the electron = 3.8×10^{-13}	5	10^{-13}
	6	10^{-14}
Typical Nucleus Size ~ 10^{-14} Proton Size ~ 2.8×10^{-15} electron or quark size ~ 10^{-18}	7	10^{-15}