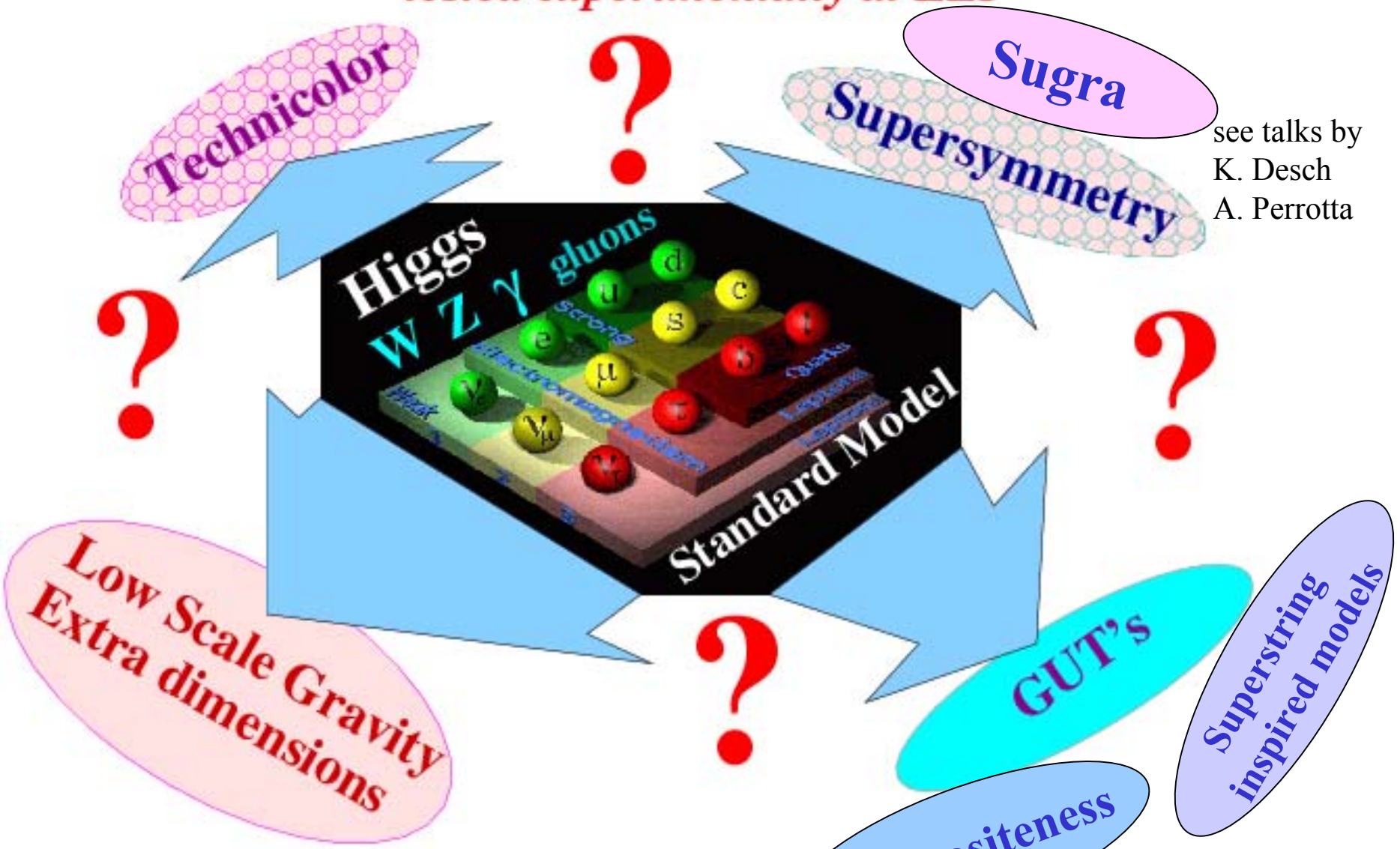
# Searches for new phenomena
## beyond supersymmetry at LEP

## *some popular directions beyond the Standard Model which have been tested experimentally at LEP*




see talks by
K. Desch
A. Perrotta

# New phenomena searched for at LEP (and other colliders)

*( a non-exaustive list with an arbitrary classification)*

**New bosons** → **Gravitons (extra-dimensions)**
**Leptoquarks (GUT)**
Technipions (Technicolor)
Extra gauge bosons: Z ‘ (E6)

**New fermions** → new leptons and quarks:
heavy charged leptons (BSM)
heavy neutrinos (BSM)
excited leptons (compositeness)

**New interactions** → Contact interactions (compositeness)
Lepton flavour violation (GUT)
Single top production (FCNC)
**Non commutative QED (string th.)**

# Search for new physics: experimental approches

## Two main approaches

**Direct Searches** → look for specific rare topologies (small expected SM background) where a specific signal could manifest itself

Direct Searches are model dependent

- high signal efficiency, because the search is optimised for the specific signal characte
- while looking for a specific signal, one might be missing something else

**Indirect Searches** → measure precisely the SM observables; look for (small) deviations from SM expectations

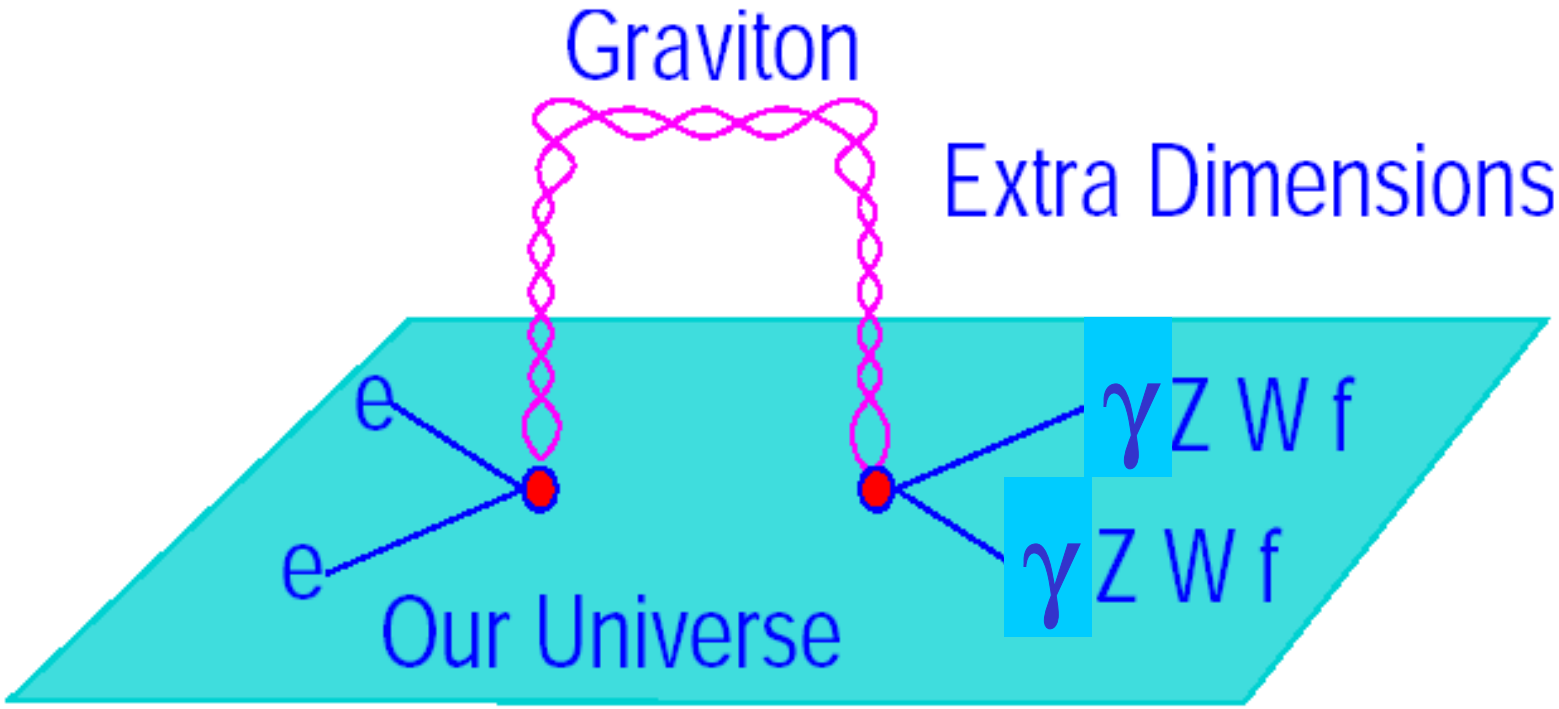
Indirect Searches are model independent

- (can be) sensitive to any kind of new physics, even the unpredicted
- if a deviation observed, difficult to disentangle which new physics process is inducing it... dedicated searches are then needed

**The two approaches are complementary**
in covering the maximum number of new physics possibilities (predicted or unpredicted)

# Search for Low-scale Gravity

## Looking into the Extra-Dimensions...



# Low-scale gravity

**Problem**: Why is $M_{Pl}$ , the mass scale at which gravity unifies w/ other forces much bigger than $M_{EW}$ , the EW unification mass scale or WHY IS GRAVITY SO MUCH WEAKER than the other forces?

**Possible solution**: Gravity propagates in extra dimensions

the actual gravity unification scale $M_D$ can be of the order of $M_{EW}$ ,

the effective 4-dim gravity constant $G_N^{-1} = M_{Pl}^2 = M_D^{n+2} R^n$

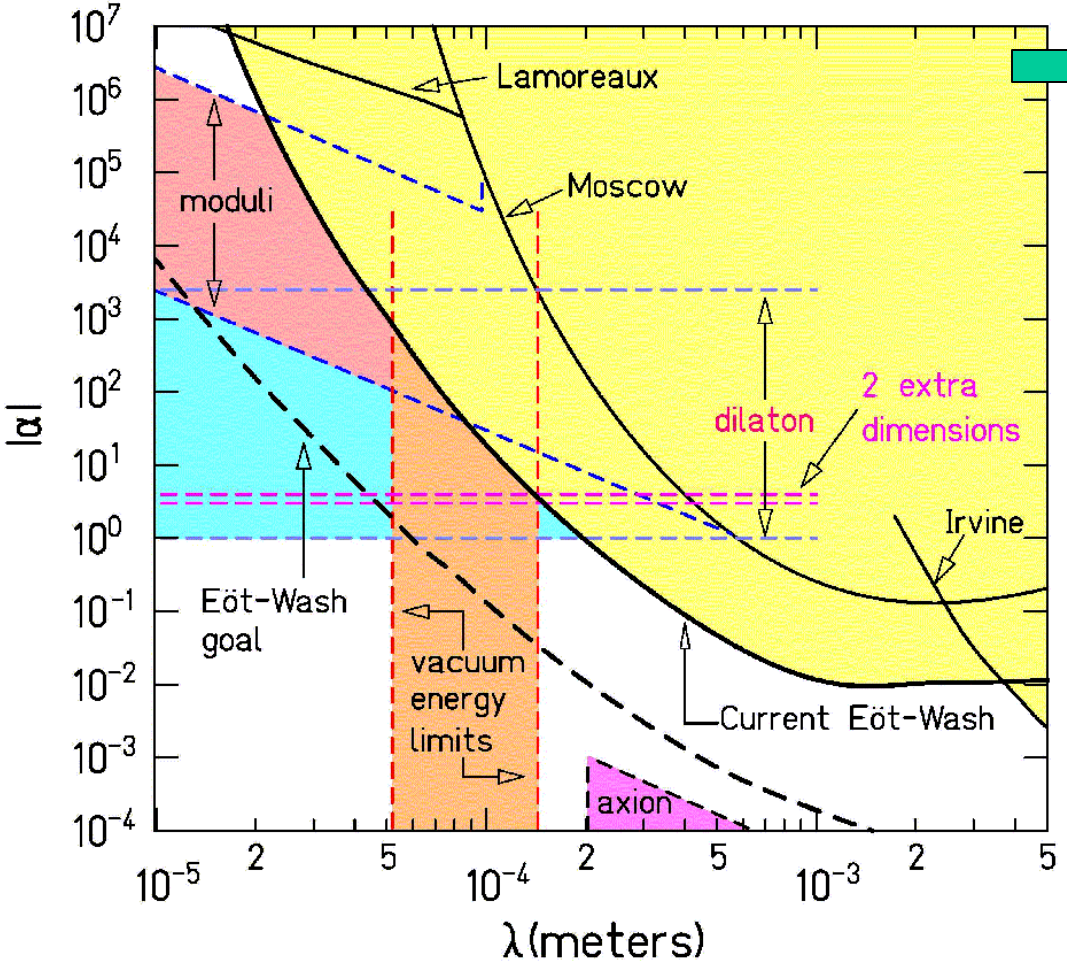
In 4+n dimensions $G'_N = 1 / M_S^2$ → $M_S \sim 1$ TeV → low-scale gravity

$M_D$ : fundamental ( 4+n dim) unification mass,

$M_S$ : mass scale, $M_S \sim M_D$

R : compactification radius

# Gravity: what is known from non-collider experiments




Experimental limits on Newton's law

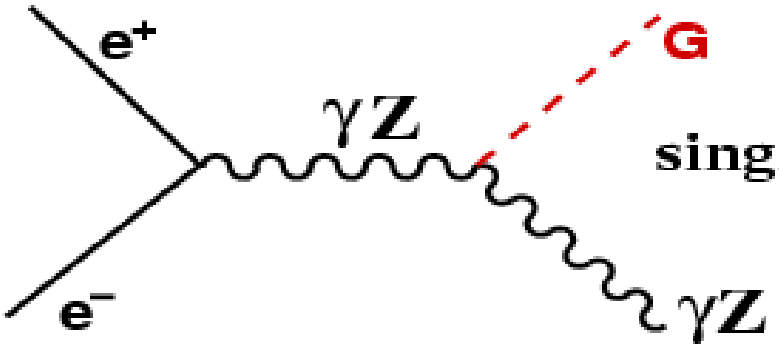
extra-dimensions must be compactified at distances in the submillimiter scale

**High energy Colliders LEP, HERA, Tevatron, LHC, ... can test new gravity effects at submillimiter scales**

$$R = (M_{Pl}/M_D)^{2/n} M_D^{-1}$$

# Low-scale gravity: direct search

**Direct search for graviton production**




single photon (Z) + missing energy

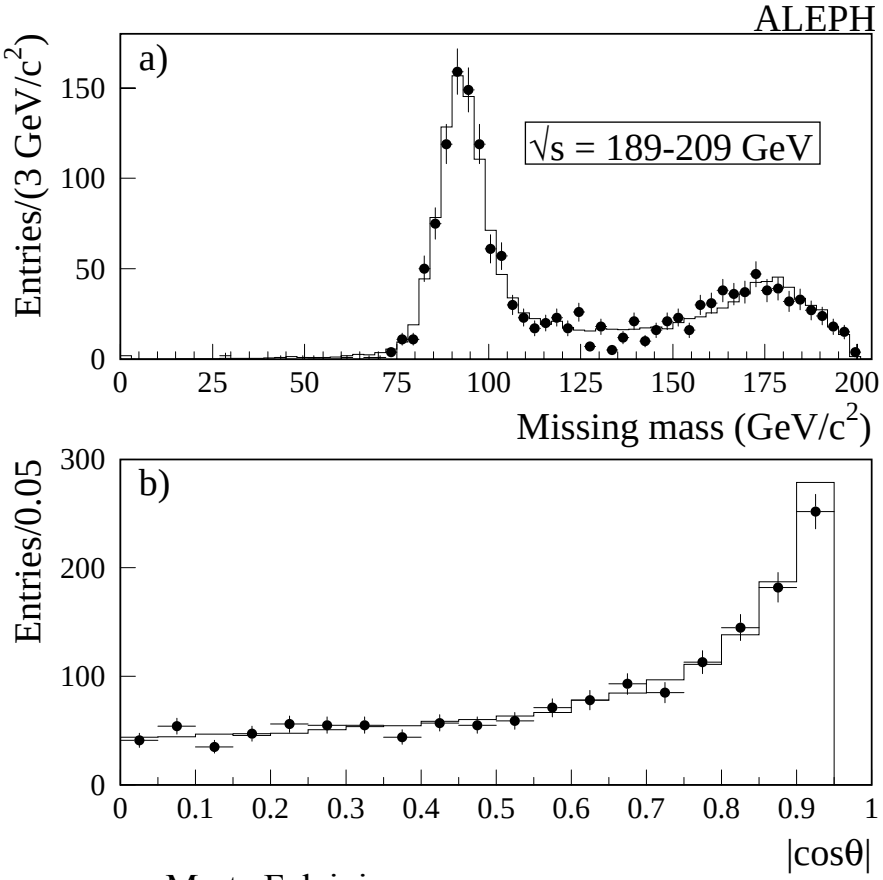
**Photon angular and energy distributions**

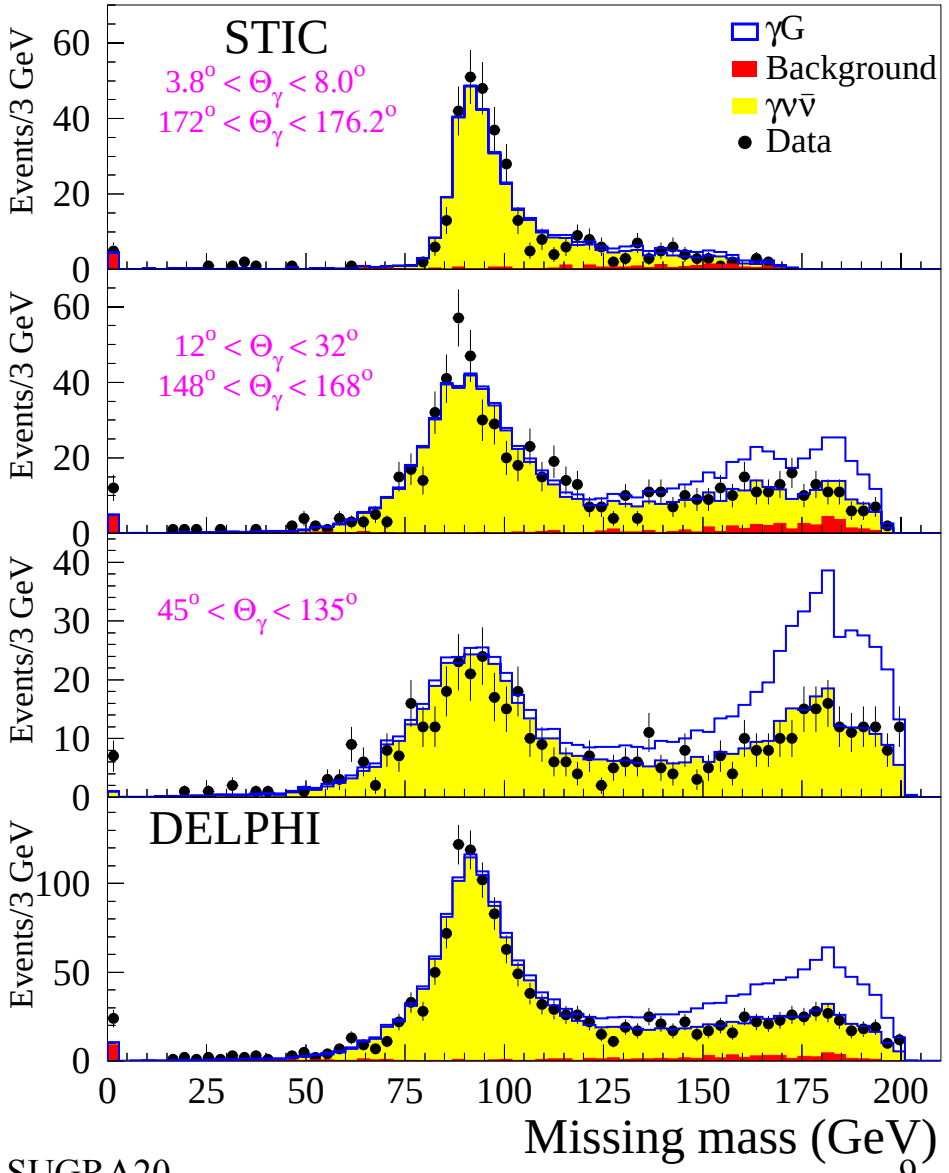
$$\frac{d^2\sigma}{d\cos\theta\, dx_\gamma} \propto \frac{1}{S}\left[\frac{\sqrt{S}}{M_D}\right]^{n+2} f(x_\gamma, \cos\theta)$$

**directly sensitive to the gravity scale**

# Low-scale gravity: direct searches

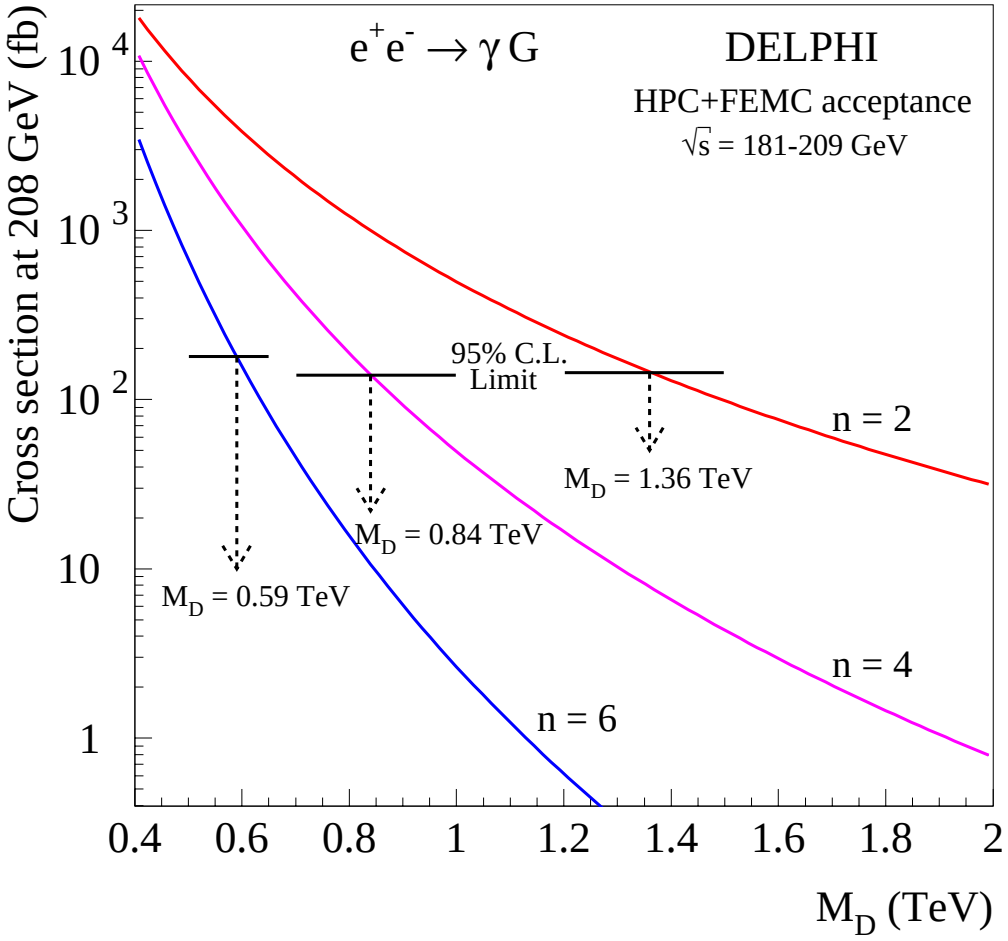
## Events with single photon+missing energy



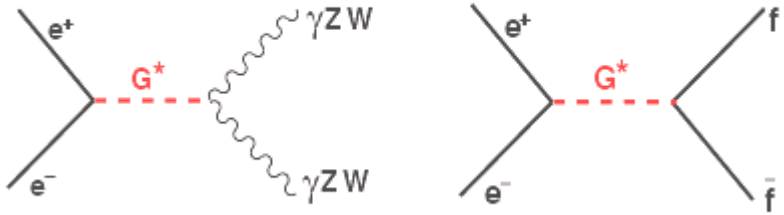
# Low scale gravity: direct search results

| n | $M_D >$ (GeV) | R < |
|---|---|---|
| 2 | 1.36 | 0.26 mm |
| 3 | 1.05 | 3.3 nm |
| 4 | 0.84 | 13 pm |
| 5 | 0.69 | 0.48 pm |
| 6 | 0.59 | 54 fm |



# Low-scale gravity: indirect searches

Virtual Graviton exchange




effect of the interaction of **gravitons G** with SM particle on the **angular distribution** of the particles in the final state

$$\frac{d\sigma}{d\cos\theta} = \underbrace{A(\cos\theta)}_{\text{SM term}} + B(\cos\theta)\left[\frac{\lambda}{M_s^4}\right] + C(\cos\theta)\left[\frac{\lambda}{M_s^4}\right]^2$$

Interference term SM * *Low Scale Gravity*

*Low Scale Gravity term*

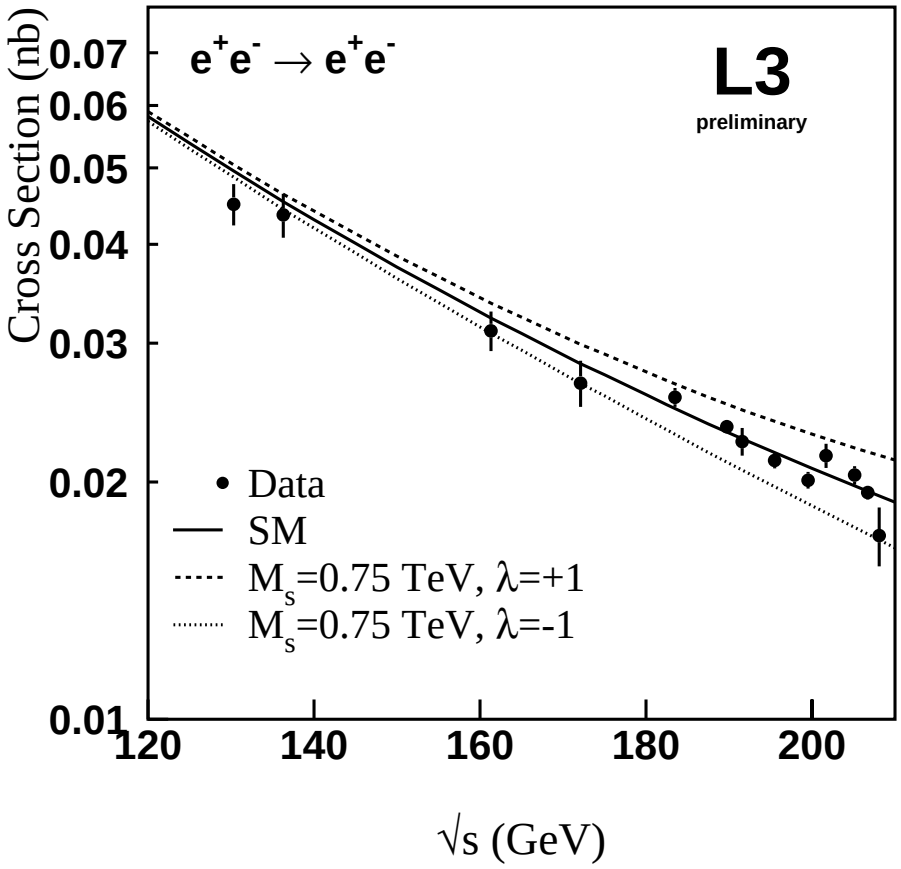
**deviation from the SM**

$\lambda$ = +/- 1 -> positive/negative interference with the SM

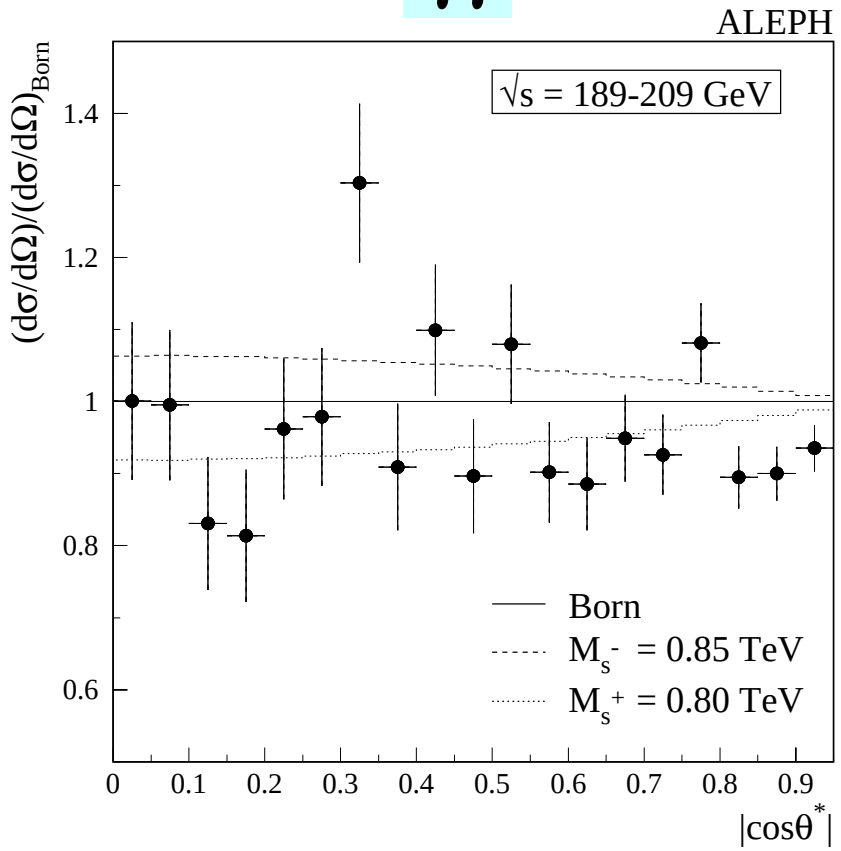
# Low-scale gravity: indirect searches

## Most sensitive channels

e+e-




γγ



# Low-scale gravity: indirect searches

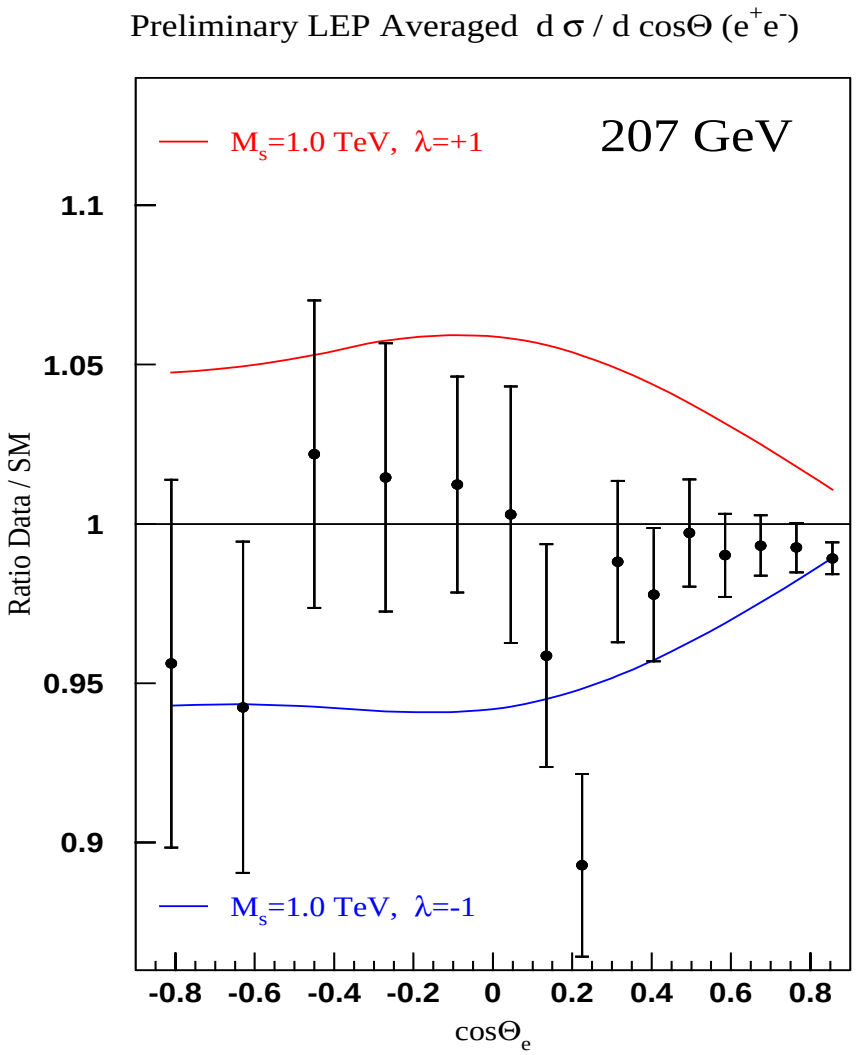
| Lower limits on $M_s$ (TeV) | | |
|---|---|---|
| final state<br>Exp.t | $e^+e^-$<br>$\lambda = 1 / -1$ | $\gamma\gamma$<br>$\lambda = 1 / -1$ |
| ALEPH | 0.81 / 1.04 | 0.80 / 0.85 |
| DELPHI | - | 0.77 / 0.70 |
| L3 | 1.04 / 1.05 | 0.84 / 0.99 |
| OPAL | 1.00 / 1.15 | 0.81 / 0.96 |

**Combined LEP limits**

**(using $e^+e^-$ final state results):**

**$M_S > 1.20 / 1.09$ TeV**

**$\lambda = 1 / -1$**

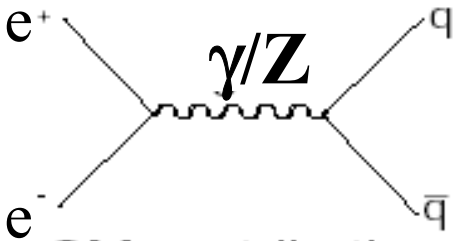


# Leptoquarks

| LQ searches @ LEP: | LQ mass reach |
|---|---|
| Direct search for LQ pair production | $\sqrt{s}/2$ |
| single LQ production | $\sqrt{s}$ |
| Indirect search for virtual effects on $q\bar{q}$ prod. | beyond $\sqrt{s}$ |

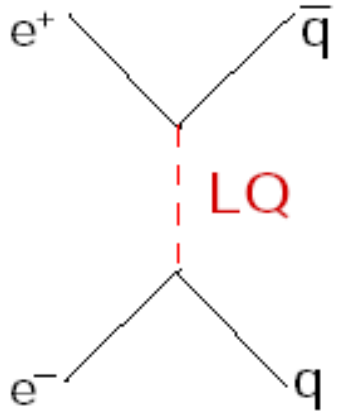
## Indirect search

$e^+ e^- \rightarrow q\,\bar{q}$



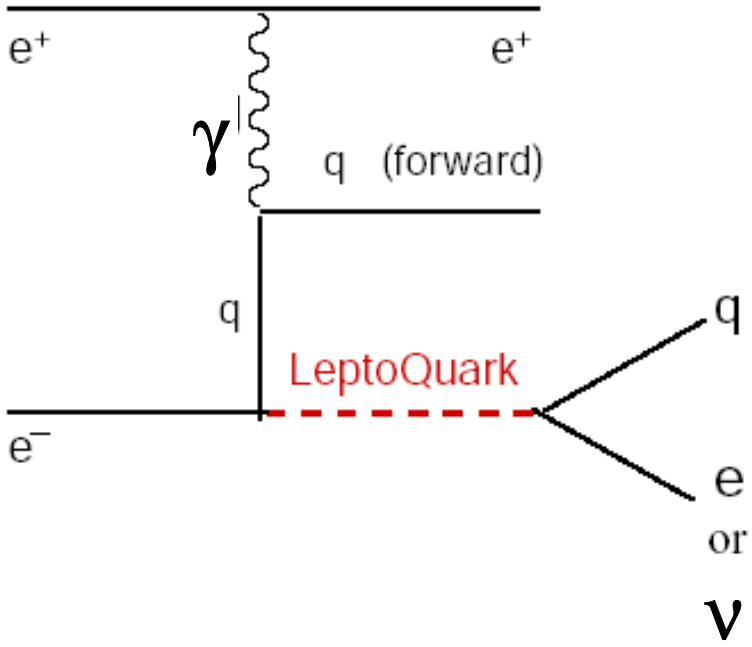

SM contribution

⊕




LQ contribution

## Direct search for single LQ production




**Signature**

in the direction transverse to the beam

jet balanced by

an isolated electron

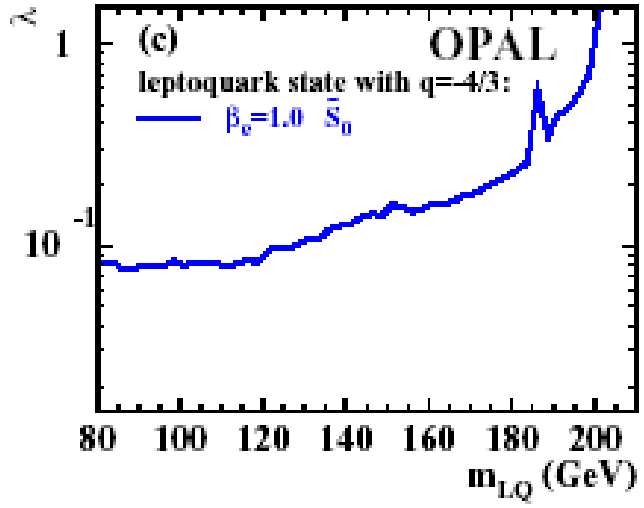
or

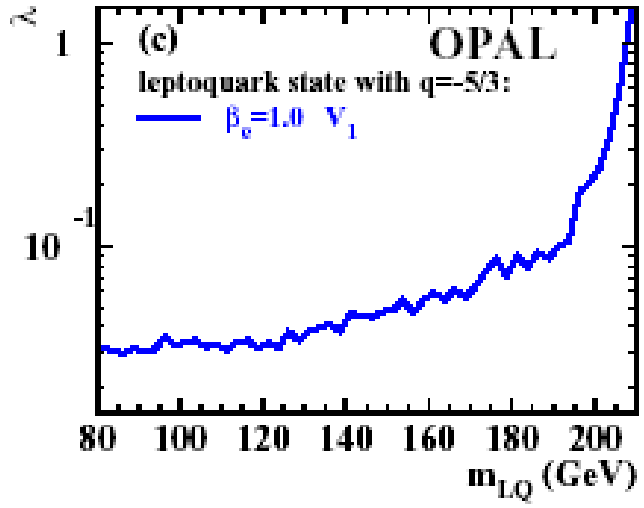
missing energy

# Leptoqurk results

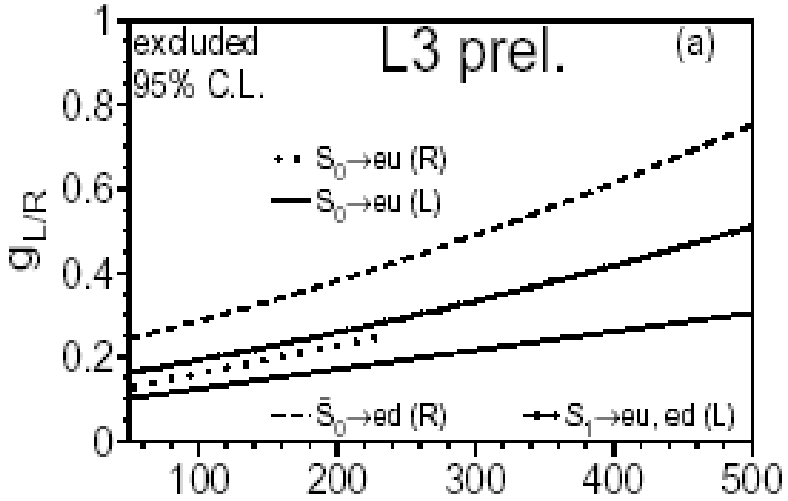
## Limits expressed in terms of coupling vs LQ mass

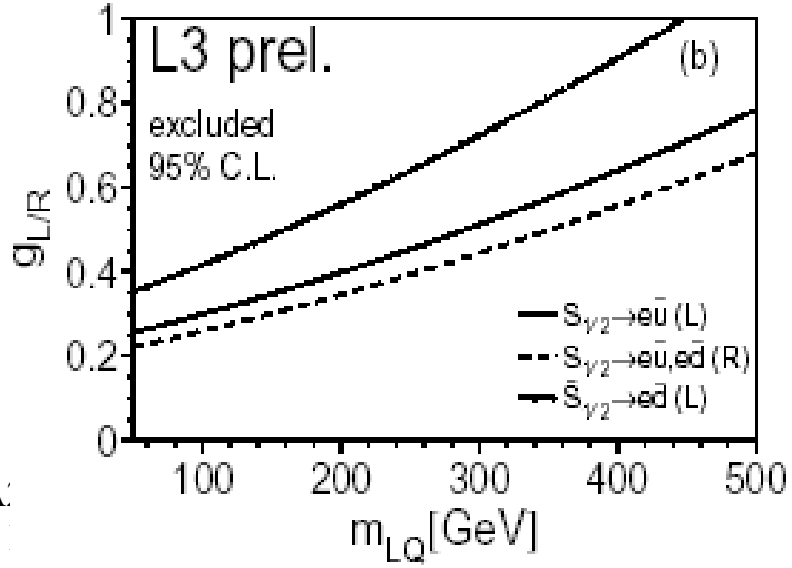
### Direct search for single LQ production




### Indirect search for virtual LQ effects

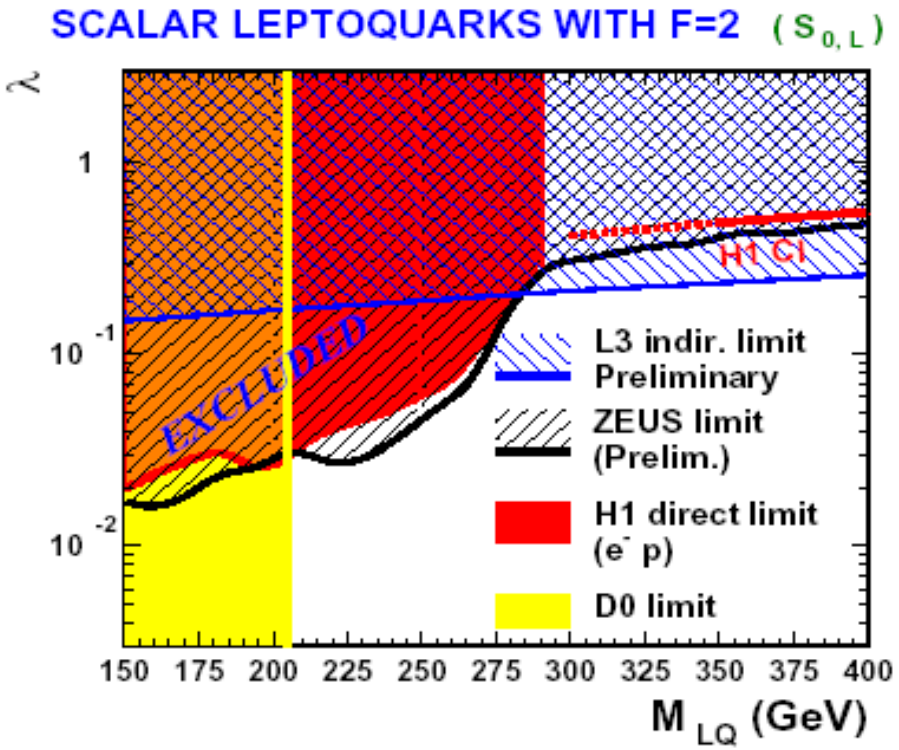


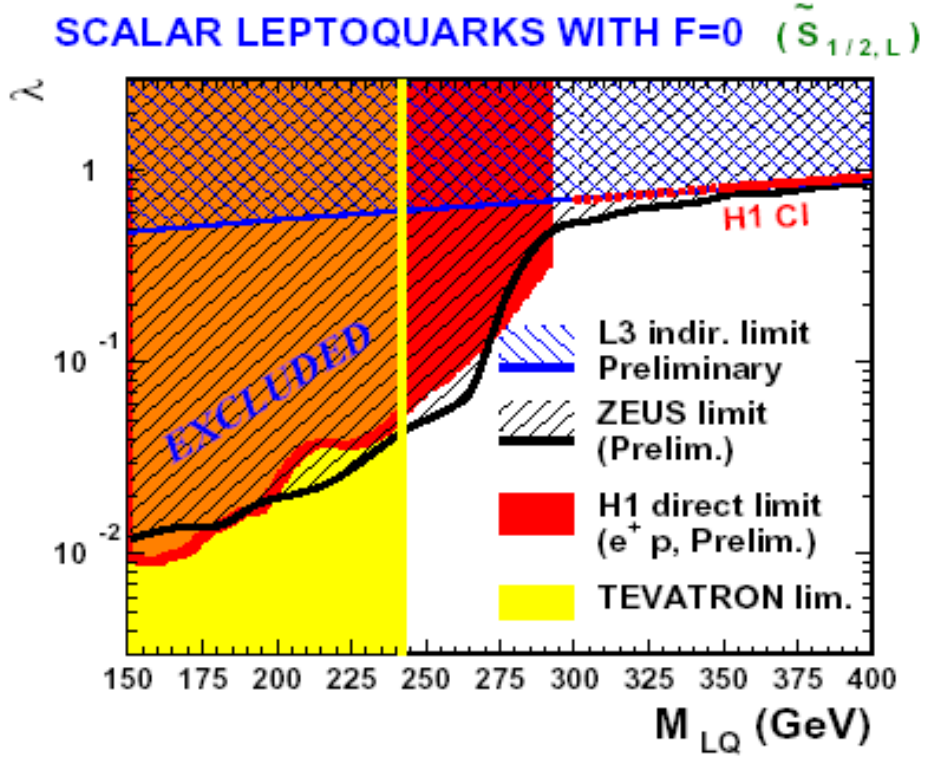




SUGRA
tern U., Boston,

# Leptoquark searches at colliders

## Leptoquarks have been searched for at LEP, HERA and Tevatron




from Straub 2003

# Non-commutative QED

**Non-commutative space-time geometry:** Regularizes divergencies in QFT: Snyder (1947)

Renewed Interest: Quantisation of strings w/ background fields

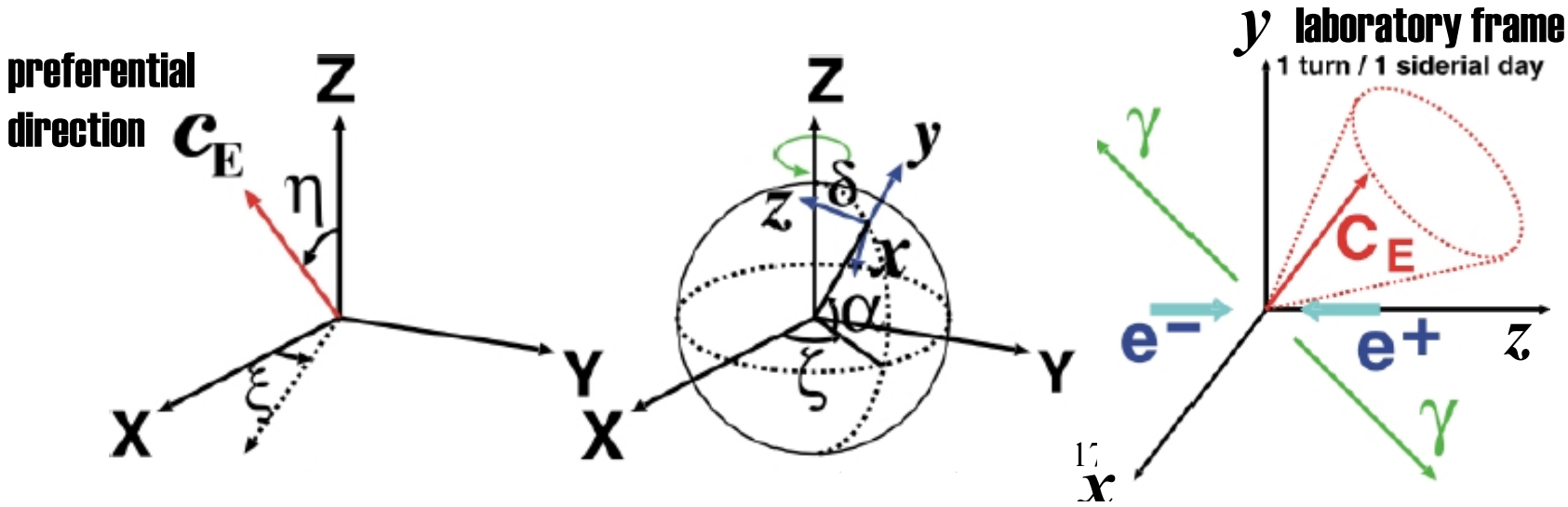
Connes, Douglas, Schwarz JHEP02 (98) 3, Seiberg, Witten JHEP09 (99) 32

Uncertainty relation $[X_\mu, X_\nu] = i\theta_{\mu\nu}$ , $\theta_{\mu\nu} \propto 1/\Lambda^2_{NC}$ $\Lambda_{NC}$ =fund.l scale~ $M_{Pl}$, or ~TeV if large ED

Only NC QED (w/o quarks) constistently formulated

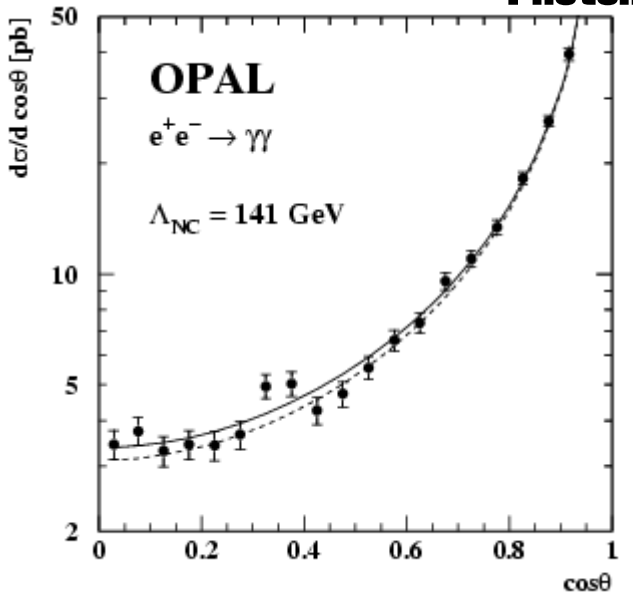
## NC QED selects preferred direction(s) in space: modifies $e^+e^- \rightarrow \gamma\gamma$

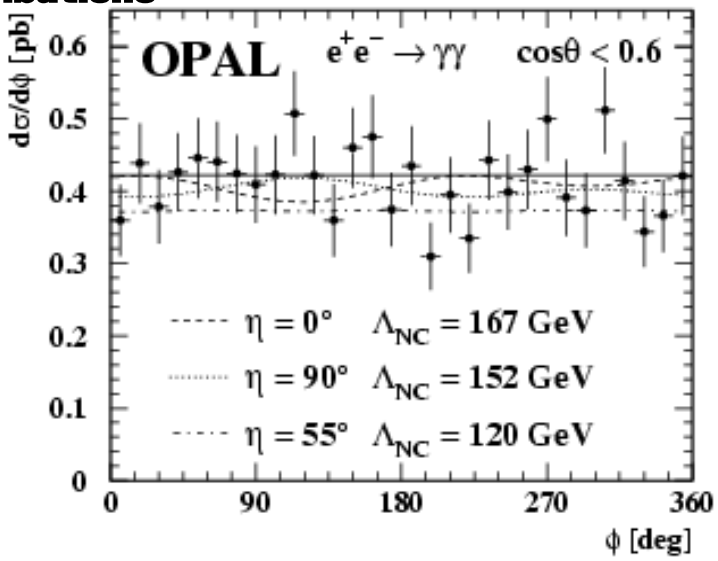
according to $d\sigma/d\Omega = d\sigma/d\Omega_{SM}[\,1 - \sin^2\theta \sin^2(\,p_\gamma{}^0 c_E{}^0 \frac{s}{4\Lambda^2_{NC}}\,)\,]$



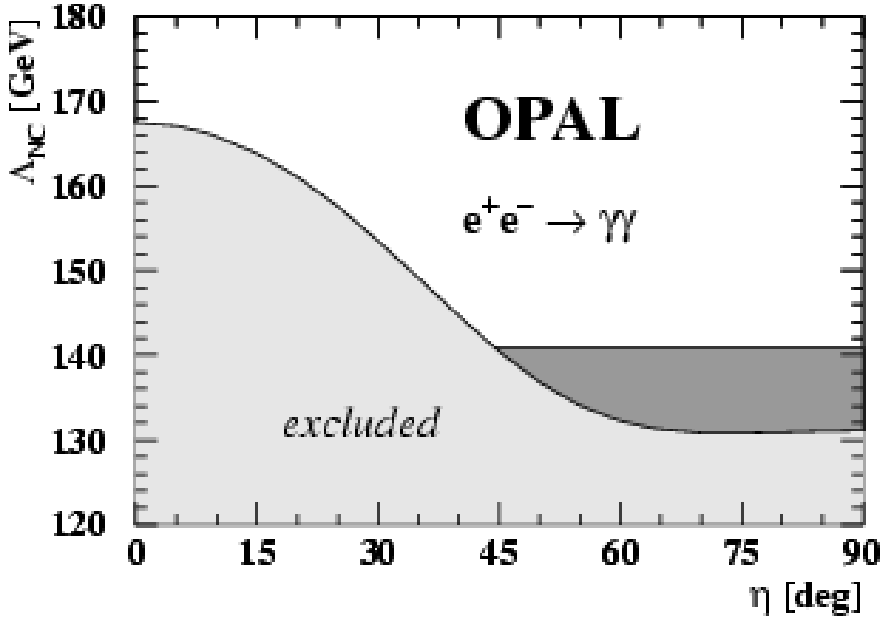
# Search for NC QED: results

## Photon angular distributions




**$\Lambda_{NC}$ = 142 GeV**
**independent of the preferred direction**



# Summary

Many Models beyond the SM have been tested at LEP
Limits on New Particle masses
and other model parameters have been set

the MOTIVATION for PHYSICS BEYOND SM is strong
New PHYSICS could be close by (or not)
only MORE DATA (Hera,Tevatron, LHC,..) WILL TELL