Minireview on other signatures of new physics at LEP and HERA

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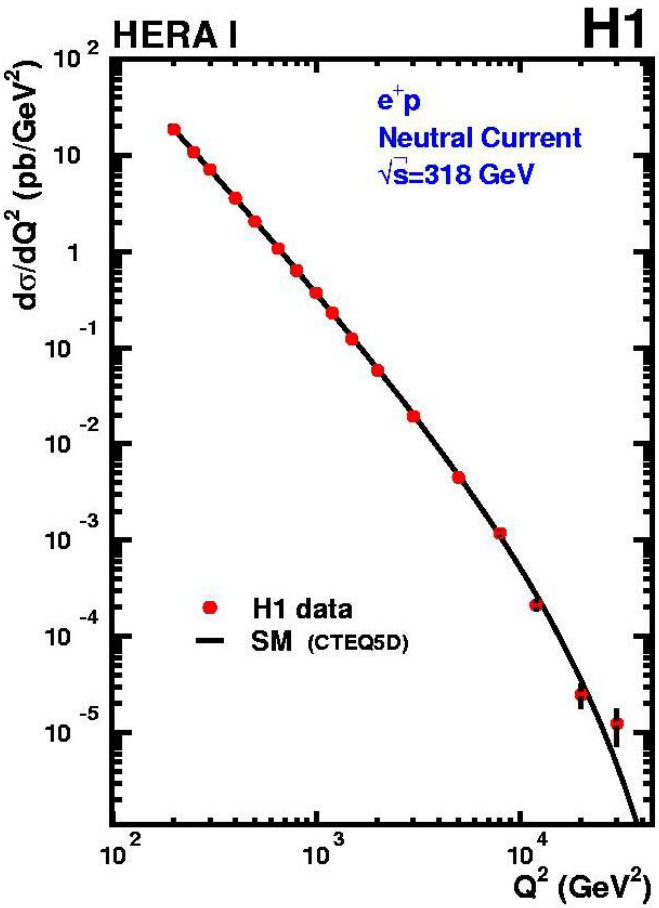
covering abstracts from
ALEPH (312, 388), L3 (443, 462), OPAL(312, 379, 889, H^{++}), H1(979), ZEUS (905)
and the LEP2 electroweak working group combination
with special thanks to
John Holt and Kirsten Sachs

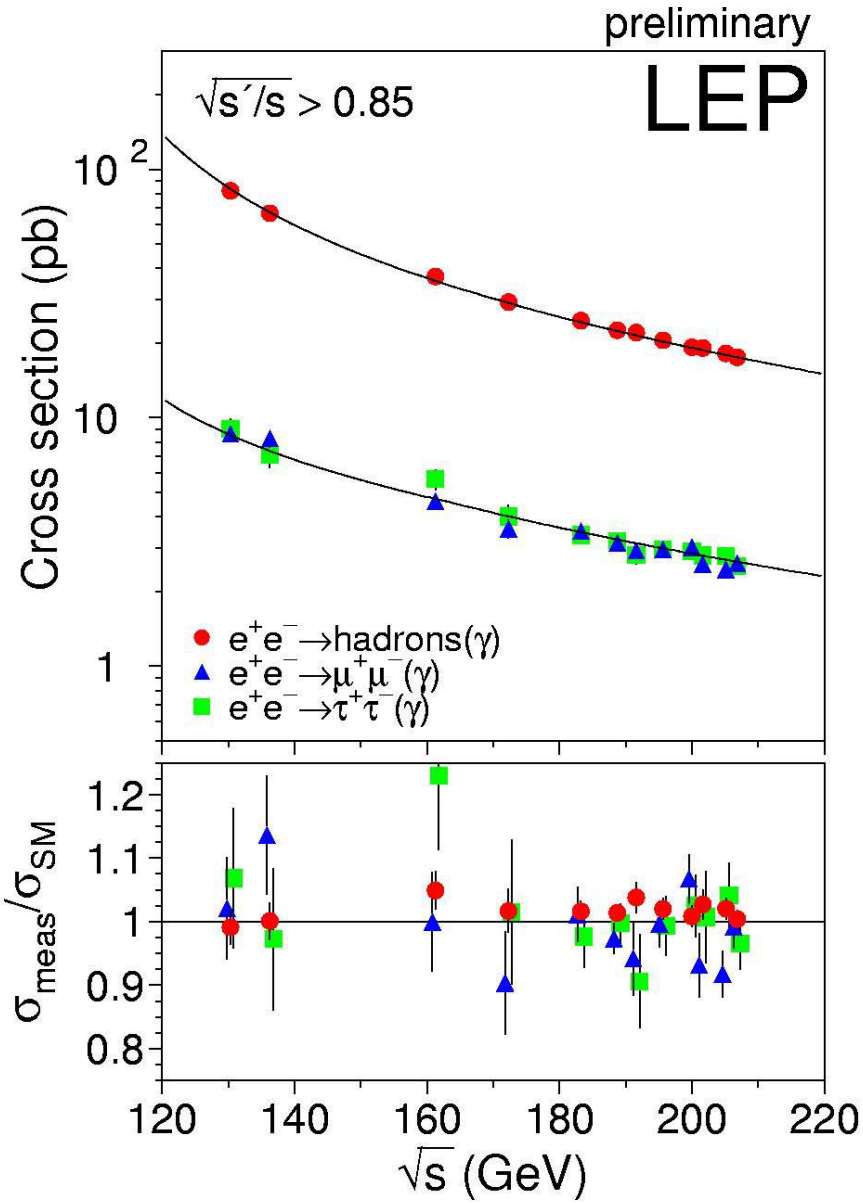
Outline

- Covered in other talks
  - Leptoquarks (B.Straub)
  - Large Extra Dimensions (G.Bernardi)
  - Excited Leptons (M.Antonelli, L.Bellagamba)
- Covered HERE:
  - Extra Z´ Bosons (LEP)
  - Non-commutative QED (OPAL)
  - Contact Interactions
    - $e^+e^- \rightarrow \gamma\,\gamma$ (LEP)
    - $e\,q \rightarrow e\,q$ (HERA)
    - $e^+e^- \rightarrow f\,f$ (LEP)
  - Doubly Charged H^{++} (OPAL)
  - Technicolor (OPAL)

LEP e^+e^- and HERA ep cross-sections

- Standard Model tests at highest energies

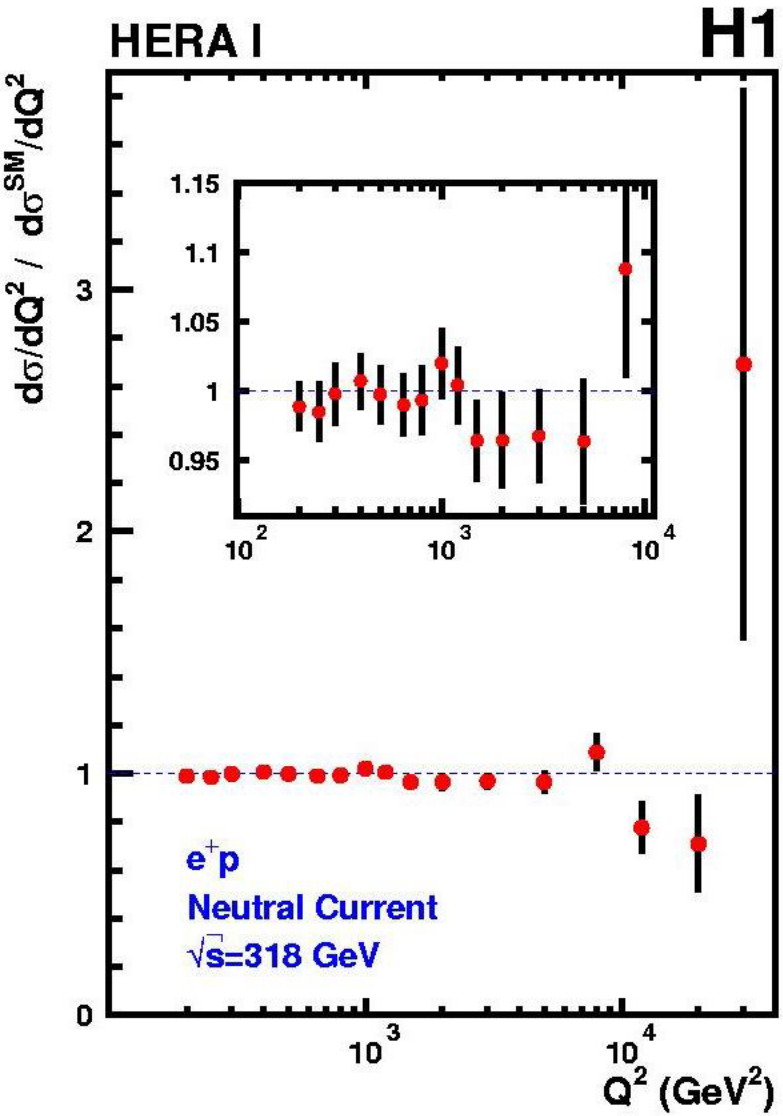




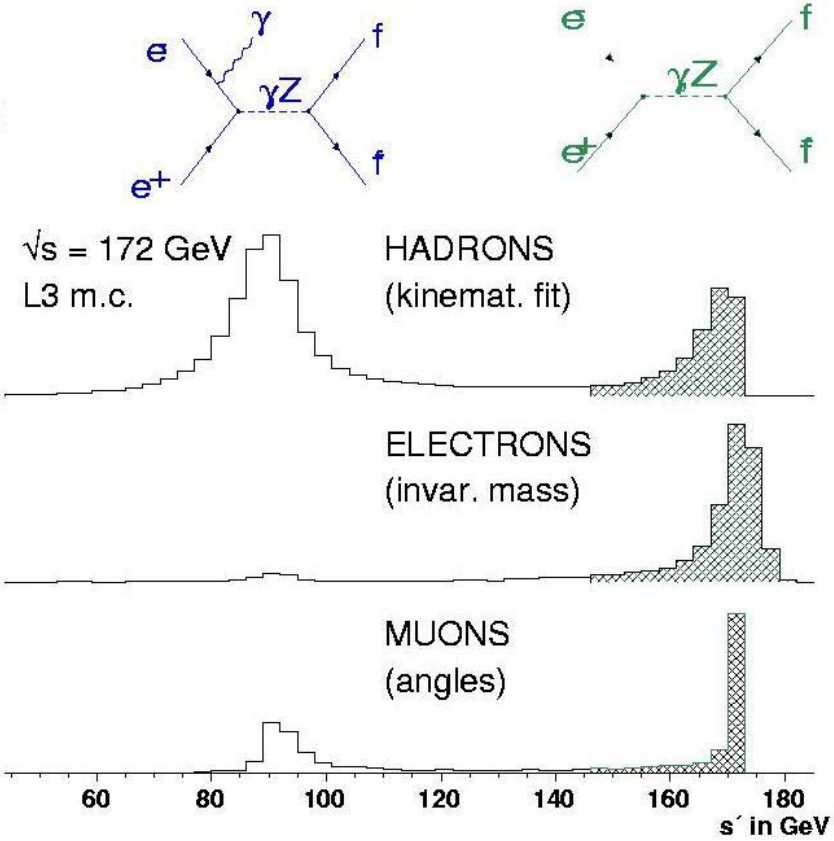
- Achieved precision per point:

Experimental Systematics

- **HERA: *inclusive measurement* of $d\sigma/dQ^2$:**
  - Resolution effects on steeply falling $\sigma(Q^2)$:
    $Q^2 = 4E_e E_e' \cos^2(\theta_e/2)$
    - Energy scale systematics:
      $\Delta E_e'/E_e' = (0.7\text{-}3)\%$
    - Scattering angle systematics:
      $\Delta\theta_e = (1\text{-}3)$ mrad
    - Luminosity
      $\Delta\mathcal{L}/\mathcal{L} = 1.5\%$

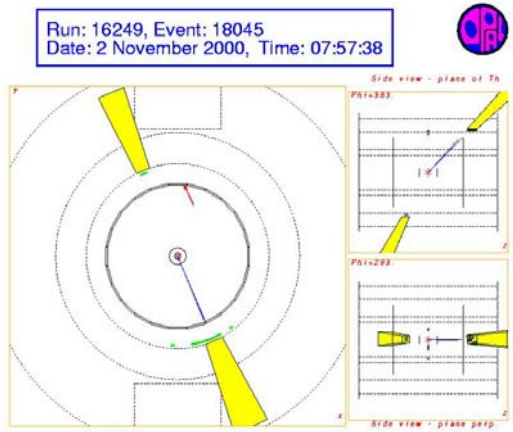


Experimental Systematics (2)



LEP2:

- $e^+e^- \rightarrow ff$: (new w.r.t. LEP1)
  - Rad. Corrections: (~.5% each)
    - Low-mass pair radiation
    - $\sqrt{s'}$definition (ISR ⊗ FSR)
    - → hep-ph / 0007180
  - $\sqrt{s'}$ reconstruction (~1%)
  - Backgrounds (esp. qq, ττ):
    - WW (and ZZ)
    - 2-photon ($\gamma\gamma \rightarrow X$) physics

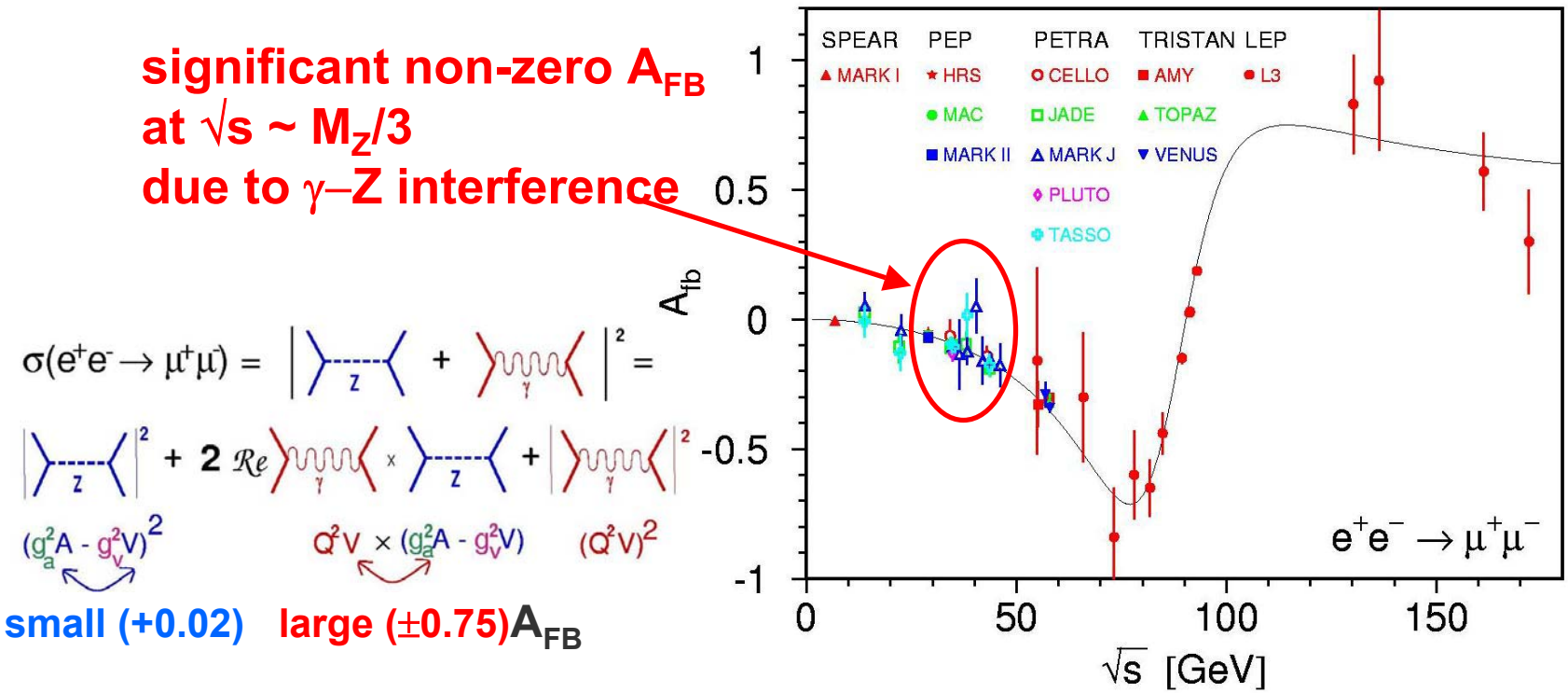


- $e^+e^- \rightarrow \gamma\gamma$
  - Conversion Prob. (~0.5%)
  - $e^+e^- \rightarrow e^+e^-$ background

Signatures of New Physics

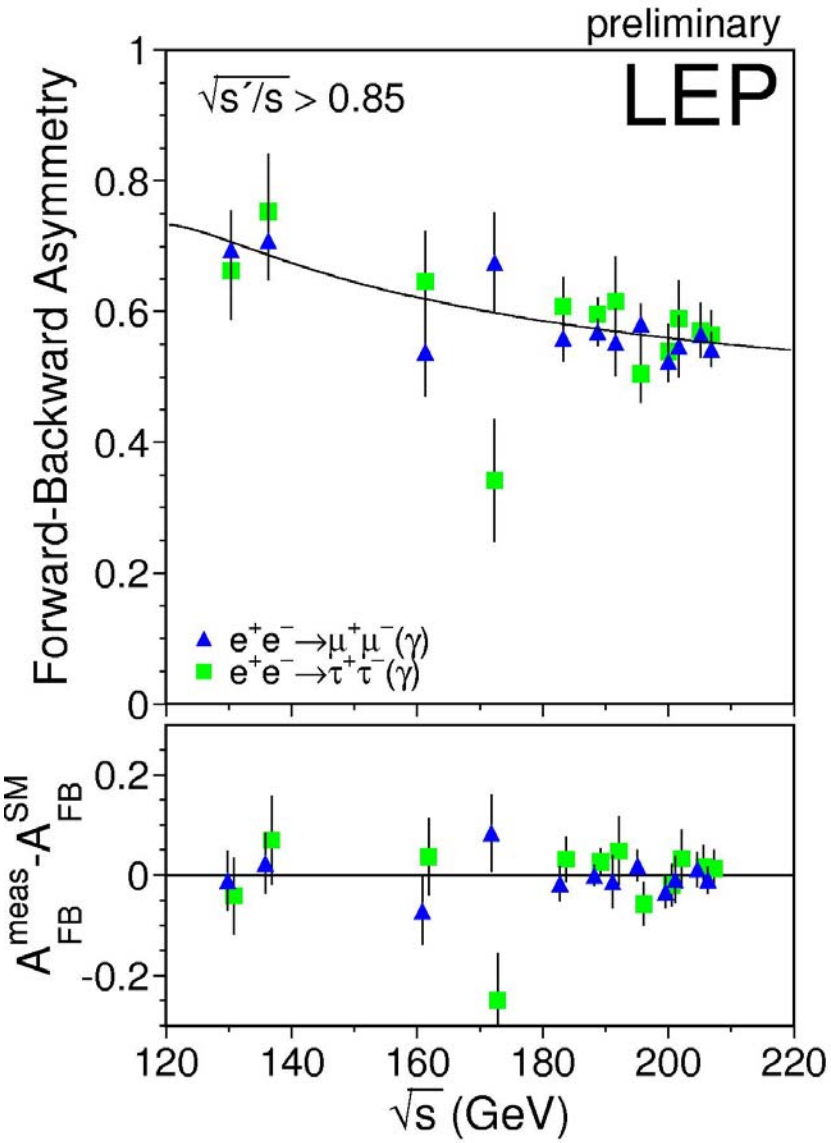
- e.g. 1981 at PETRA and PEP (2 years before UA1):

significant non-zero A_{FB}
at $\sqrt{s} \sim M_Z/3$
due to γ–Z interference

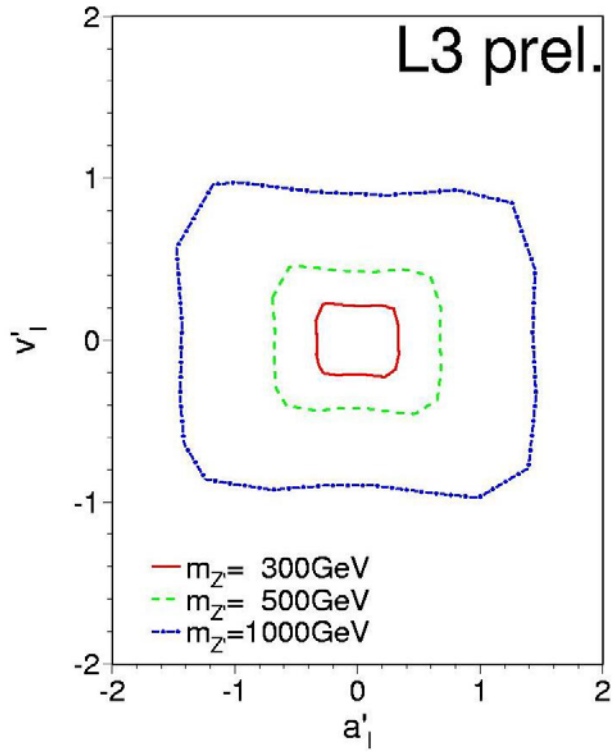


NB: **Maxima $A_{FB} = \pm 0.75$ at $s \approx (1 \pm (g_A/2)^2\alpha_Z/\alpha)\, M_Z^2$ independent of Γ_Z**
considerably lower than M_Z for large enough charge*coupling ratio:
$(g_A/2)^2\alpha_Z/\alpha = 1 / (16\sin^2\theta_w\cos^2\theta_w) = 0.35$

Limits on extra Z´ Bosons (general)



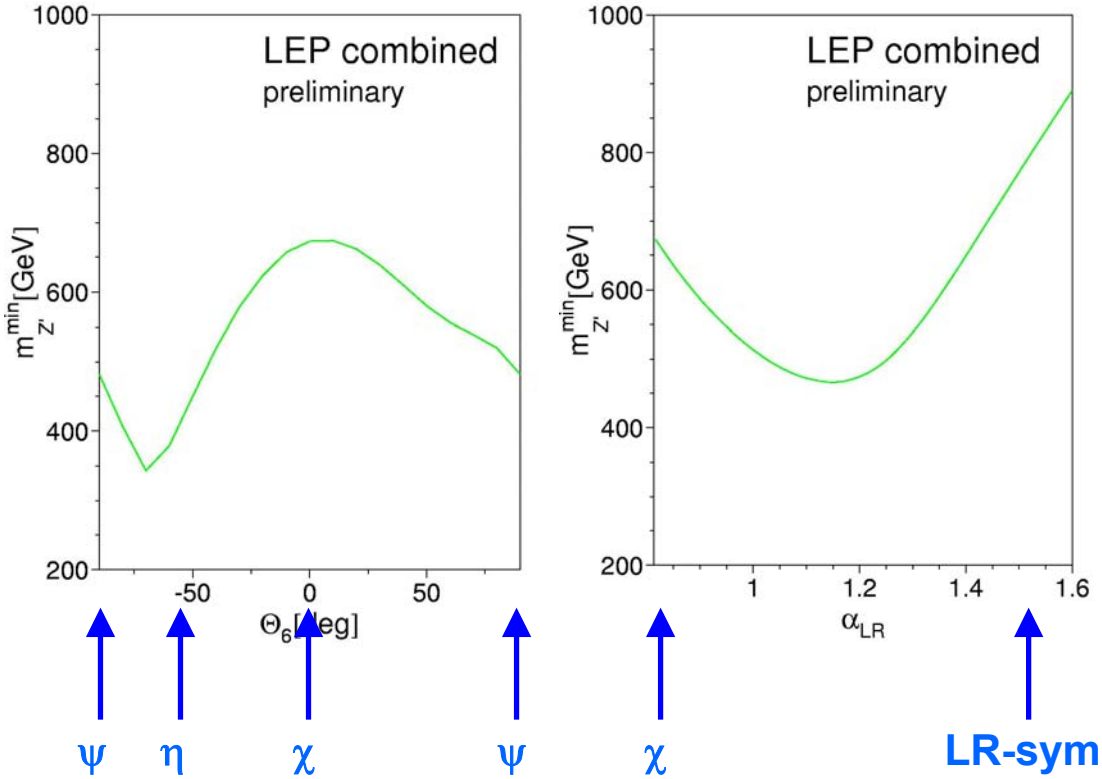
- LEP 1 lineshape :
  $\theta_M(Z'\text{-}Z) < 4\times10^{-3}$ (L3)
- →Assume No Z´-Z Mixing
  $\theta_M(Z'\text{-}Z) = 0$
- General limits:



Limits on Extra Z´ Bosons (special models)

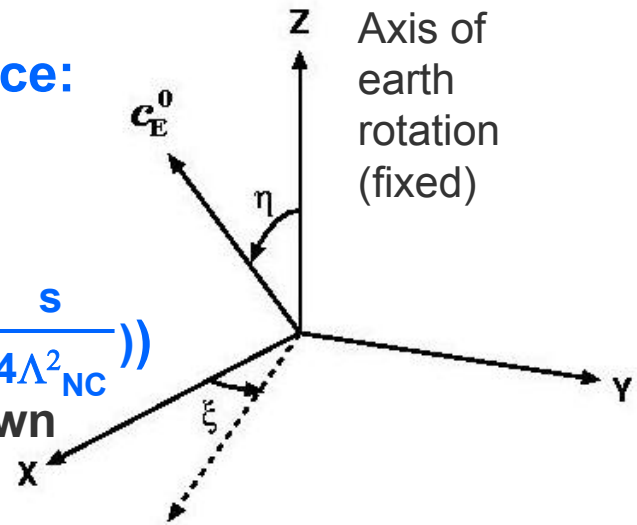
- **GUT E(6)** → SU(5) x $U(1)_\chi$ x $U(1)_\Psi$:
  linear combination $Z' = Z_\chi \cos\theta_6 + Z_\Psi \sin\theta_6$
  superstring-motivated η- model: $\sin\theta_6 = \sqrt{(5/8)}$
- **Left-Right (Symmetric) Models** $SU(2)_L x SU(2)_R x U(1)_{B-L}$
  linear combination $Z' = W^3{}_R \alpha_{LR} + B_{B-L}/(2\alpha_{LR})$
- **Sequential Standard Model** (Z´ couplings same as Z)

Limit in Model	CDF (GeV)	LEP (GeV)
χ	595	673
ψ	590	481
η	620	434
L-R sym	630	804
SSM	690	1787



`Fuzzy Space Scale´ Λ_{NC} in NCQED

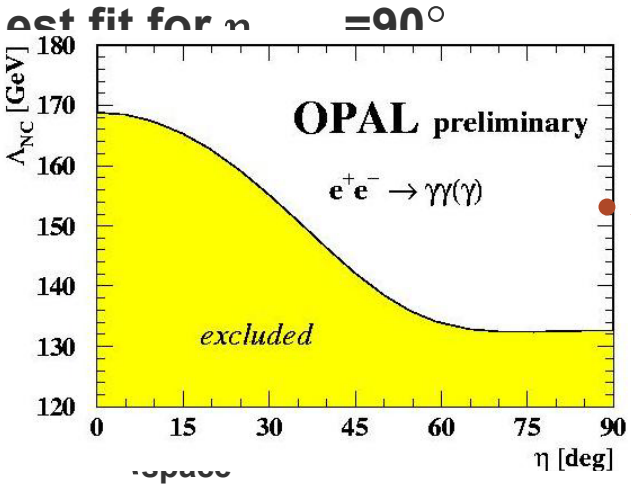
- **Non-commutative space-time geometry**
  - Regularizes divergencies in QFT: Snyder (1947)
  - Renewed Interest: Quantisation of strings with background fields
    Connes, Douglas, Schwarz JHEP02 (98) 3, Seiberg, Witten JHEP09 (99) 32
  - **Uncertainty relation**
    $[X_\mu, X_\nu] = i\theta_{\mu\nu}$ with $\theta_{\mu\nu} \propto 1/\Lambda^2_{NC}$ fundamental scale (of fuzzy coords), naturally ~ $1/M^2_{Pl}$, but possibly ~$1/TeV^2$ (large xtra dim)
  - Only NC-QED (w/o quarks) constistently formulated
- **Non Commutative QED**
  - **Selects preferred direction(s) in space:**
    Electric part: $\vec{\theta}_E = (\theta_{01}, \theta_{02}, \theta_{03}) = 1/\Lambda^2_{NC}\, \vec{c}_E^{\,0}$
  - **Modifies $e^+e^- \to \gamma\gamma$ according to**
    $d\sigma/d\Omega = d\sigma/d\Omega_{SM}(1 - \sin^2\theta \sin^2(\vec{p}_\gamma^{\,0}\vec{c}_E^{\,0} \frac{s}{4\Lambda^2_{NC}}))$
    where direction (η,ξ) is fixed, but unknown

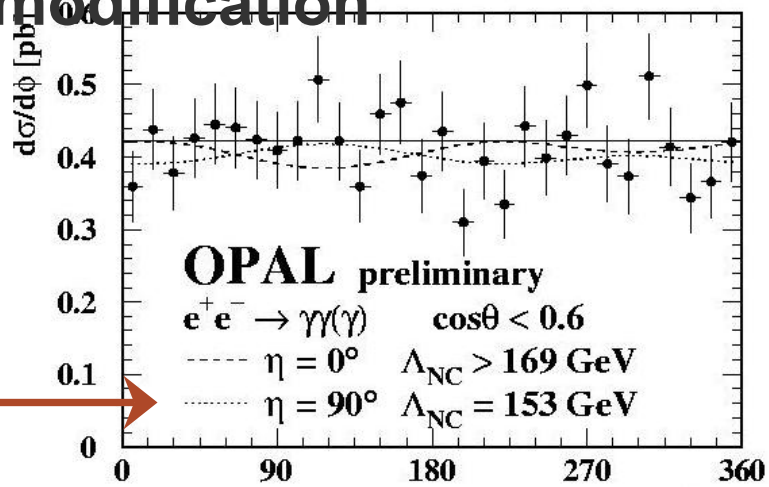


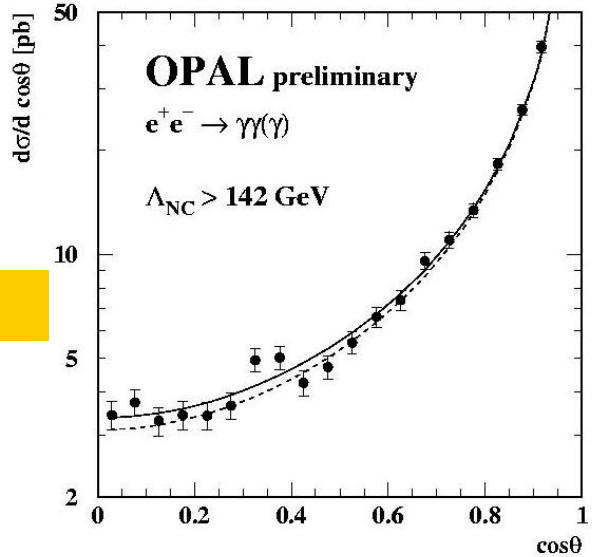
OPAL limits on Λ_{NC}

- Data: 5235 $e^+e^- \rightarrow \gamma\gamma$ events, $<\sqrt{s}>=196.6$ GeV, background < 0.3%
- Signature: Time-dependent modification

$d\sigma/d\Omega_{lab}(\eta_{lab}(t),\xi_{lab}(t))$







for $\eta_{space}=90°$

850)TeV^{-4} (2.2 s.d)

egrated $d\sigma/d\theta(\eta_{space})$:

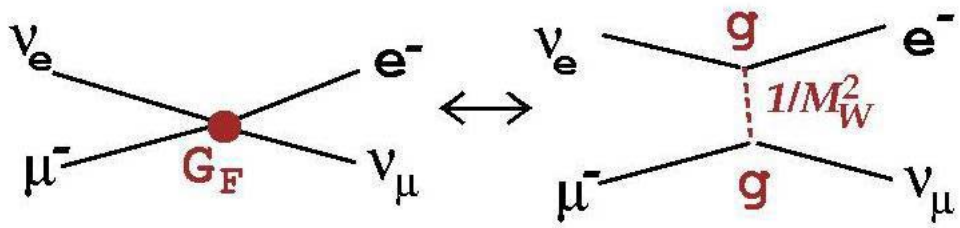
L Λ_{NC} > 142 GeV (≅1.4x10^{-18}m)

m)

s))

Contact Interactions (theory)

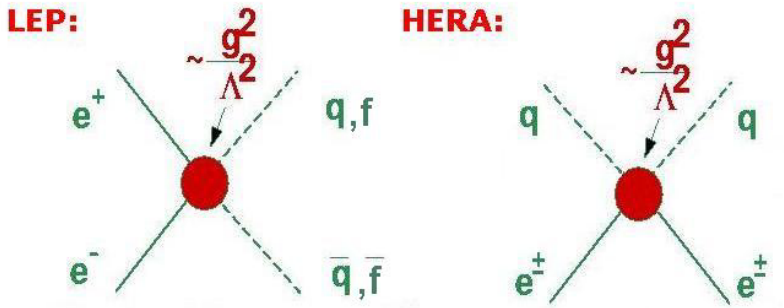
- General description of New Physics in Lagrangian
  - History:



$$\mathcal{L} \propto \frac{g^2}{M_W^2} \cdot [\bar{\nu}_L \gamma^\mu \mu_L][\bar{e}_L \gamma_\mu \nu_L]$$

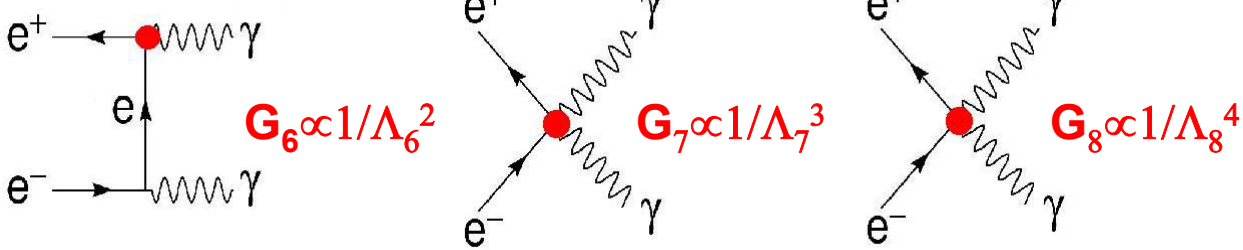
  - Fermions:

$$\mathcal{L} = \sum_{i,j=L,R} \frac{g_{new}^2}{\Lambda_{ij}^2} \eta_{ij} [\bar{e}_i \gamma^\mu e_i][\bar{f}_j \gamma_\mu f_j] \qquad \eta_{ij} = -1, 0, 1$$



  - Bosons:

O.J.P.Eboli, A.A.Natale, S.F.Novaes, PLB271 (1991) 274



Contact Interactions ($e^+e^- \to \gamma\gamma$)

LEP 2 — 2 Photon

- **Modified cross-sections:**

$$\left(\frac{d\sigma}{d\Omega}\right)_6 = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{\alpha s}{\Lambda_6^4}(1+\cos^2\theta),$$

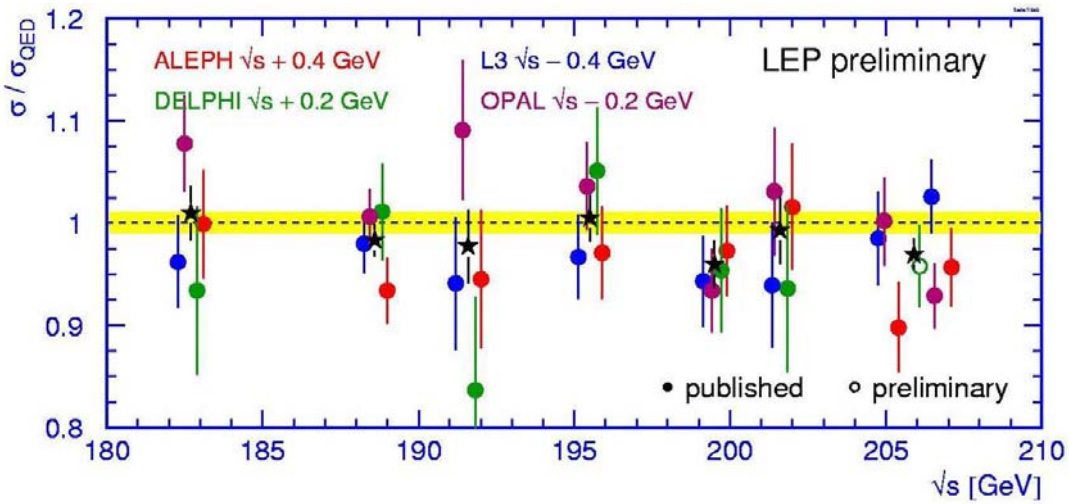
$$\left(\frac{d\sigma}{d\Omega}\right)_7 = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{s^2}{32\pi\Lambda_7^6},$$

$$\left(\frac{d\sigma}{d\Omega}\right)_8 = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{s^2 m_e^2}{64\pi\Lambda_8^8},$$

- **Observed at LEP:**

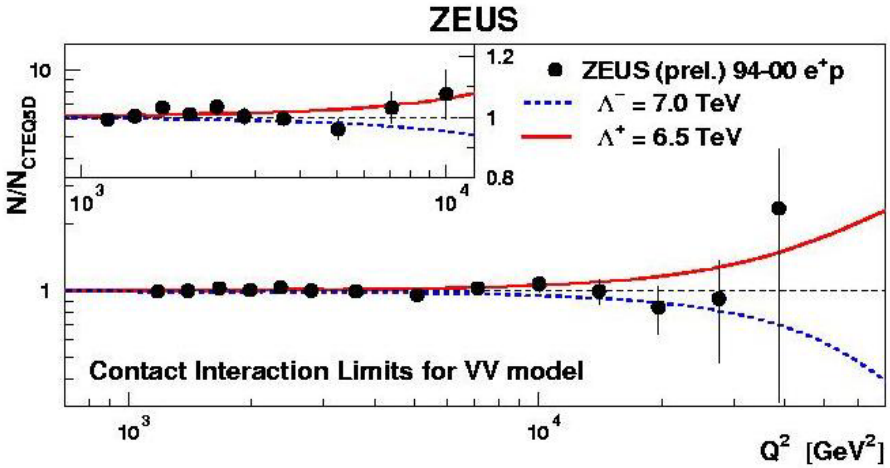
Total cross-section ratio:

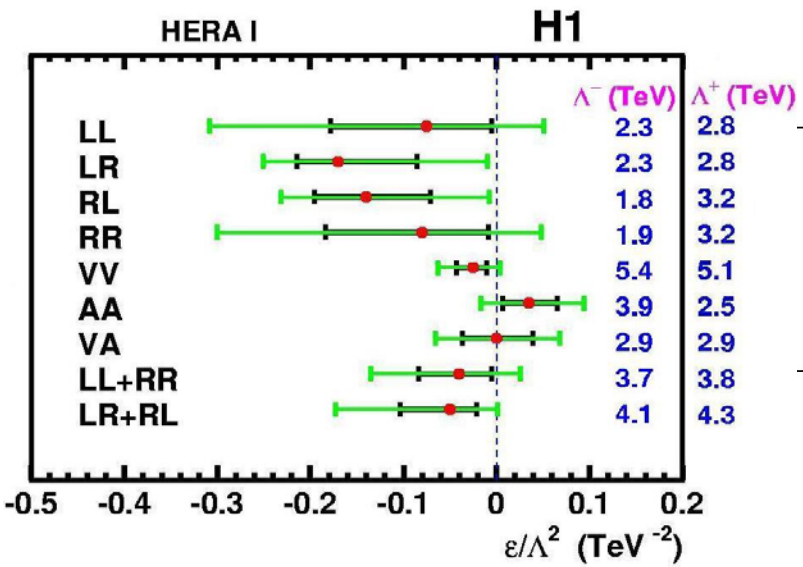
Experiment	cross-section ratio
ALEPH	0.953±0.024
DELPHI	0.974±0.032
L3	0.978±0.018
OPAL	0.999±0.016
global	0.982±0.010



- **Limits (95%CL):**
  - $\Lambda_6 > 1595$ **GeV** $\cong \Lambda_+ > 392$ **GeV a la S.Drell** ($\Lambda_+^4 = \alpha/2\ \Lambda_6^4$)
  - $\Lambda_7 > 831$ **GeV**
  - $\Lambda_8 > 23$ **GeV**

Contact Interactions (HERA: e-u, e-d)





- Fits to various combinations of η_{ij}, consistent with APV
- $g_{new} = \sqrt{4\pi} \sim 5.5 g_{weak} \sim 11e$
- Leptoquarks: $g_{new}/\Lambda = \lambda_{LQ}/M_{LQ}$

ZEUS (prel.) 1994-2000 $e^{\pm}p$	Coupling structure								95% C.L. [TeV]	
	η^{ed}_{LL}	η^{ed}_{LR}	η^{ed}_{RL}	η^{ed}_{RR}	η^{eu}_{LL}	η^{eu}_{LR}	η^{eu}_{RL}	η^{eu}_{RR}	Λ^-	Λ^+
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	7.0	6.5
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$	5.3	4.6
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	3.4	3.3
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$			4.0	2.7
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$		4.7	4.7
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$	4.3	4.2
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$		5.6	5.6
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$	4.8	4.8
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$	2.6	3.9
U1					$+\eta$	$-\eta$			4.1	3.6
U2					$+\eta$		$+\eta$		5.8	5.3
U3					$+\eta$			$+\eta$	5.8	5.2
U4						$+\eta$	$+\eta$		6.4	5.9
U5						$+\eta$		$+\eta$	6.0	5.5
U6							$+\eta$	$-\eta$	2.8	3.7

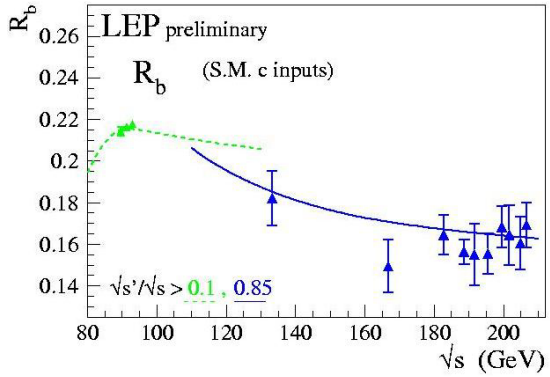
- Limits on electroweak quark radius:
  $r_q < 0.7 \times 10^{-18}$m (ZEUS), 0.8×10^{-18}m (H1), 0.6×10^{-18}m (H1, $r_q = r_e$)

Contact Interactions (LEP: e-q, e-Q, e-l)

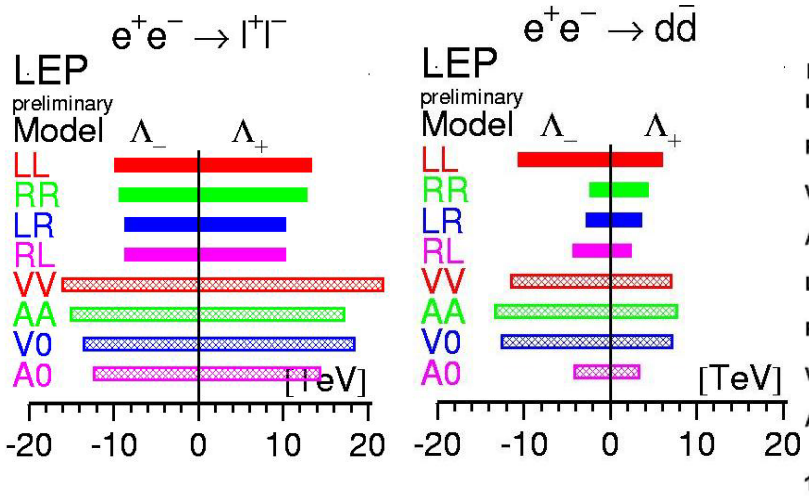
- **Models considered:**

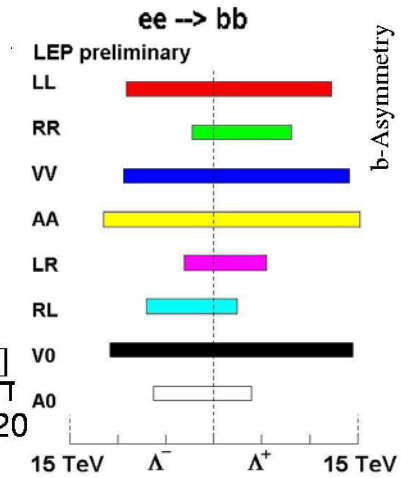
Model	LL	RR	LR	RL	VV	AA	V0	A0
η_{LL}	±1	0	0	0	±1	±1	±1	0
η_{RR}	0	±1	0	0	±1	±1	±1	0
η_{LR}	0	0	±1	0	±1	∓1	0	±1
η_{RL}	0	0	0	±1	±1	∓1	0	±1

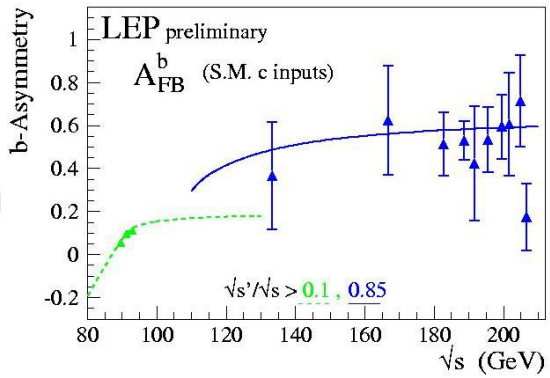
- **LEP Data used:**
  all 2f measurements, e.g.:



- **Measures *all kinds* of e-f combinations, e.g.:**



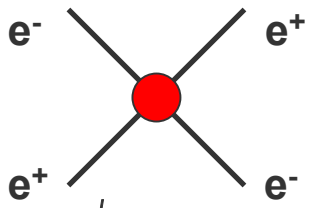




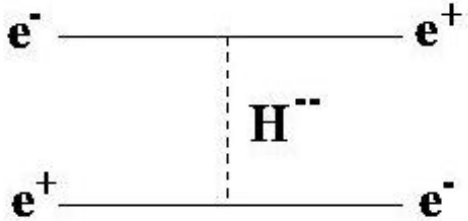
- **Limits on electroweak radii:**
  $r_f < (0.2\text{- }0.4)\times10^{-18}$m

Search for Doubly Charged Higgs (via CI)

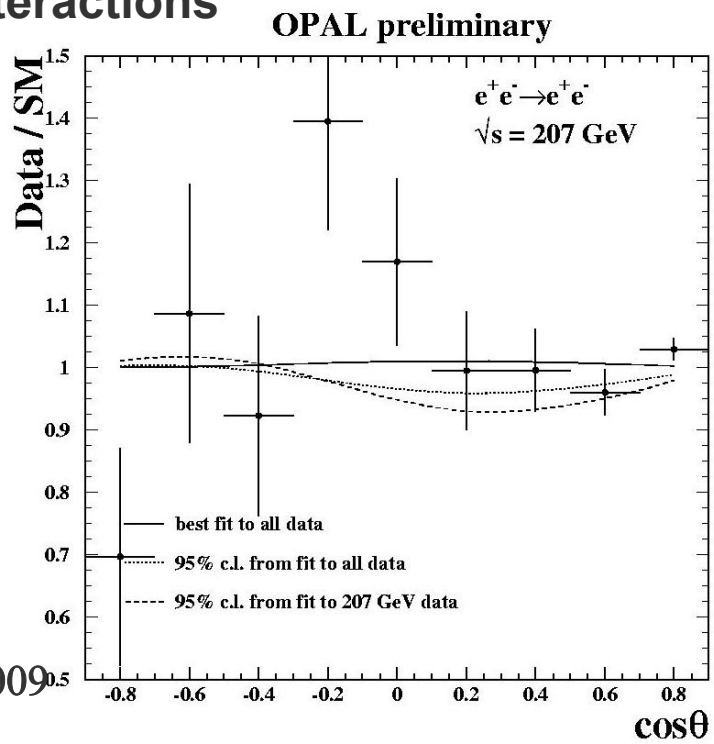
- H^{++} appear in various beyond-SM models
  - Higgs triplet, Gauged $U(1)_{B-L}$, (SUSY) L-R models
  - Decay below WW threshold to like-sign leptons, naturally flavor violating
  - Couplings model dependent, not generally $\propto$ mass
- **Indirect search in Bhabha scattering** (OPAL PN 502)
  - High mass: limits from Contact Interactions
    $g / \Lambda_{RR} = h_{ee} / M(H^{++})$



  - Mass ~ $\sqrt{s}$: explicite MC modelling modified cos θ distribution

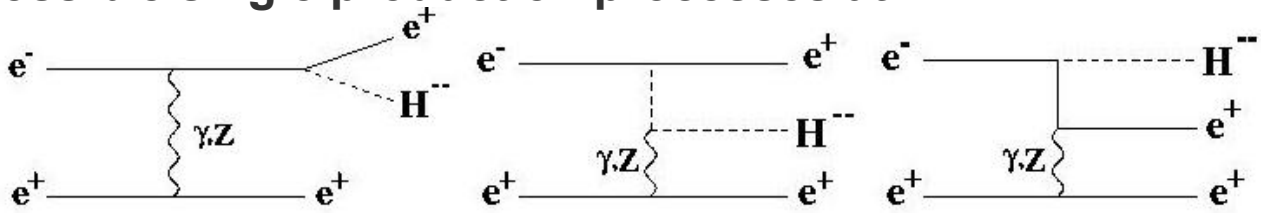


e.g. for $M(H^{++})$=130 GeV: h_{ee}=–0.004±0.009



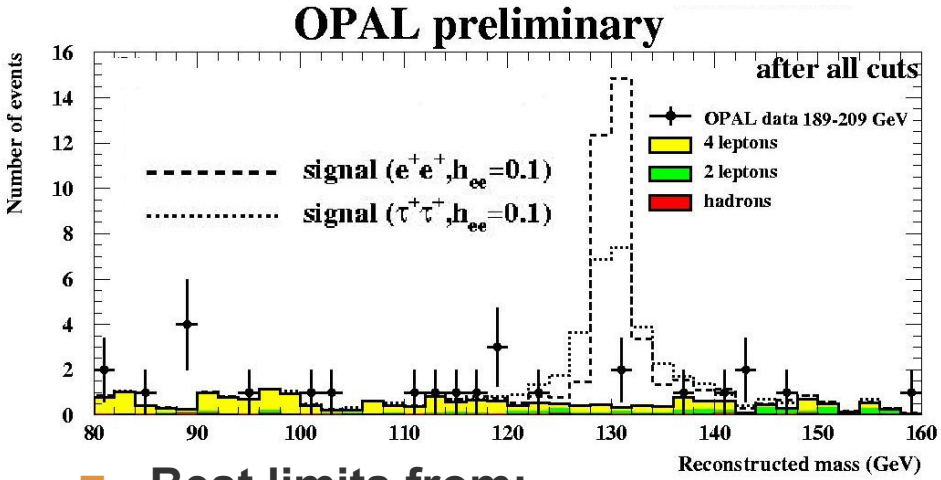
Search for Doubly Charged Higgs (direct)

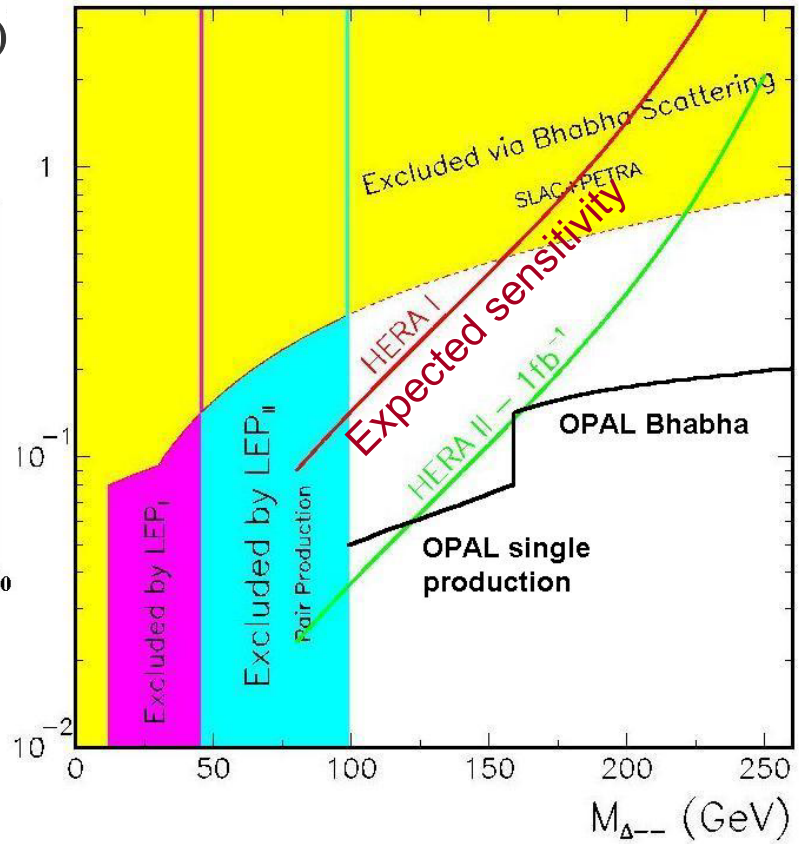
- Possible single production processes at LEP



- OPAL search for single H^{++} production
  - 3 inclusive „l“-jets w/o „l“- ID → h_{ee}
  - All decay modes (ee,eμ,eτ,μμ,μτ,ττ)
  - Main backg.: 4leptons from SM

Yves Sirois, SUSY02, Hamburg





- Best limits from:
  - below WW thresh.: Single H^{++}
  - Above WW thresh.: Bhabha

Technicolor (TC, theory)

- ***TC: Alternative mechanism of Eweak Symmetry Breaking: Breaking of global chiral symmetry of technifermions***
- **Extended Technicolor (ETC) (needed to explain $m_{fermion}$)**
  - **Broken to Color + Technicolor**
  - **N_D=9 Technifermion Doublets → „walking“ TC-coupling**
- **Technicolor Straw Man Model (TCSM, K.Lane, PRD60 (99)):**
  - **Few free parameters for low-energy „walking“ ETC**

ergy „walking“ ETC

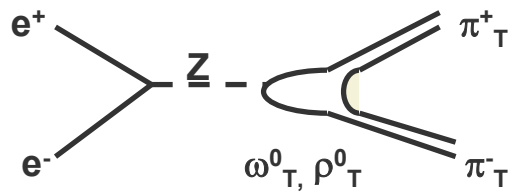
pseudoscalar Technimesons

→ $\pi^+_T \pi^-_T$ or $\gamma \pi^0_T$

π^-_T or $\gamma \pi^0_T$

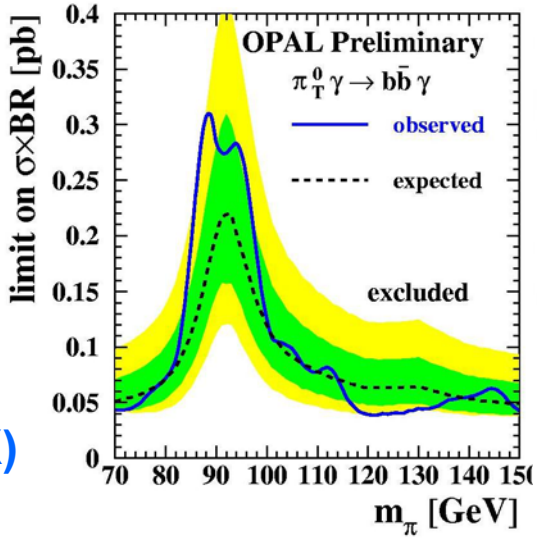
ptons ∝mass

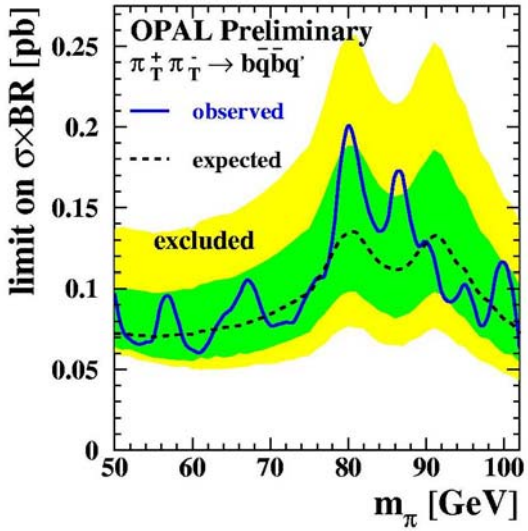
q $\bar{q}$ or

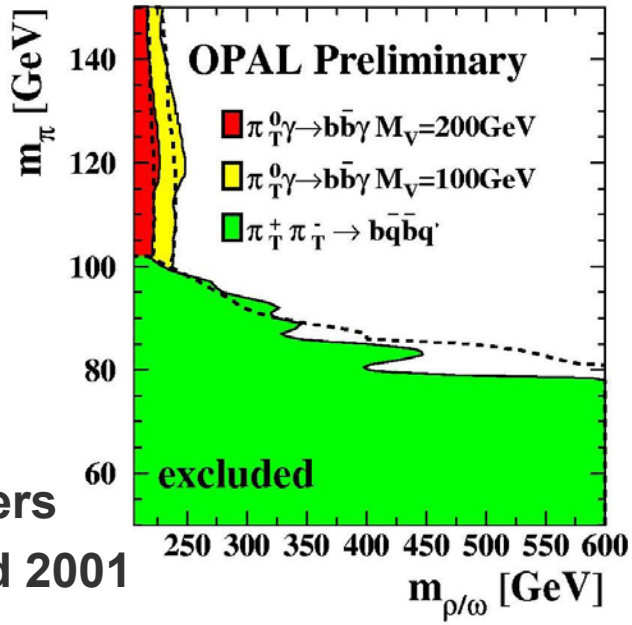


Technicolor (results)

- OPAL data $\sqrt{s}$=200-209 GeV
- Results valid for all $m(\rho^0_T, \omega^0_T) > \sqrt{s}$
  - Model independent limits: σ x BR($\pi_T \rightarrow X$)
    - Structure from WW, ZZ and γZ background
  - Interpretation within TCSM model:
    - Significant regions excluded
    - Lower limit $m(\pi_T) > 77$ GeV for $N_D = 9$
    - Lower limit $m(\pi_T) > 62$ GeV independent of TCSM parameters
    - Similar limits: DELPHI, Moriond 2001







Conclusions

- Percent Precision of SM measurements at LEP and HERA
  - Rich field for interpretations beyond the SM
  - Limits extend way beyond $\sqrt{s}$ (e.g. Z´, CI)
  - No evidence for fuzzy coords or extended objects at ~10^{-18}m
- Direct searches constrain special Beyond-SM theories
  - First constraints on M(H^{++})>100 GeV from LEP
  - Lower mass limit for Technipions
- Let`s try further at HERA and Tevatron and wait for...

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