LEP2 Standard Model

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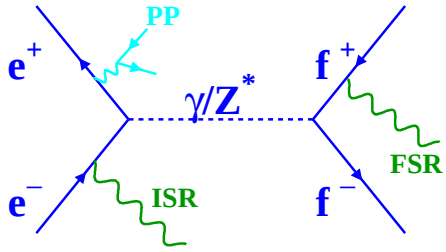
- Fermion-Pairs
  - what do we measure / data set
  - s' distribution
  - angular distribution
  - total cross-section / asymmetry
  - beyond the Standard Model
  - S-matrix
- Photon-Pairs
  - what do we measure
  - total cross-section
  - angular distribution
  - beyond the Standard Model

Status: summer 2002

Fermion Pairs

measured: (at least) 2 high energy leptons / jets within some angular range

theory:



incl. higher orders, radiative corrections, ...

minimize corrections: calculate cross-sections in phase-space close to experimental cuts

$\Longrightarrow$ ZFITTER

what is 'close to experimental cuts?'

$\rightarrow$ different flags are used

e.g. $\sqrt{s'}$ = mass of propagator / mass of $f\bar{f}$-pair

problem with ISR $\otimes$ FSR interference: on / off

$\sqrt{s}$[GeV]	year	$\mathcal{L}$[pb^{-1}]	
130	1995/97	5	
136	1995/97	6	
161	1996	10	LEP 1.5
172	1996	10	
183	1997	55	WW threshold
189	1998	185	
192	1999	29	LEP 2
197	1999	76	
200	1999	78	
202	1999	37	
202.5 - 205.5	2000	80	
205.5 - 209	2000	140	ZH threshold ?

s' distribution

sensitivity for new physics mainly at high energy (high s')

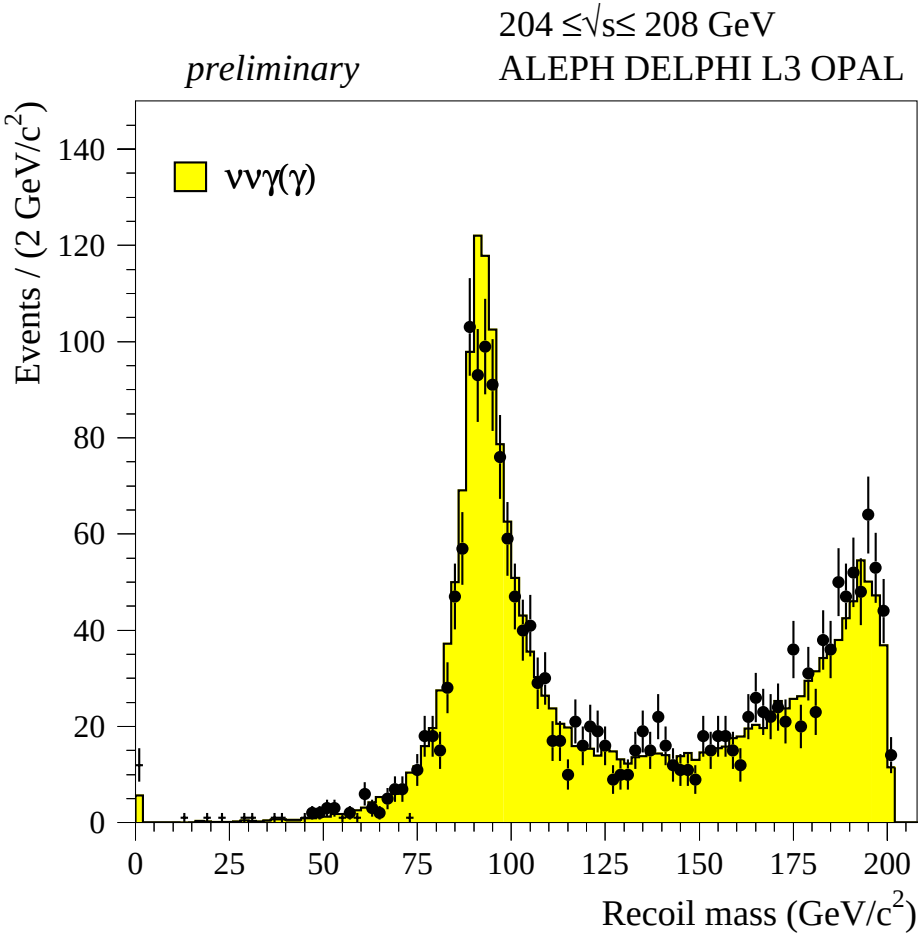
determine s' from
1. observed fermion angles
2. observed photons

for $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$
$\sqrt{s'}$ is the recoil-mass

Monte Carlo: KK2f / nunugpv
precision $\sim$ 1% (search region)

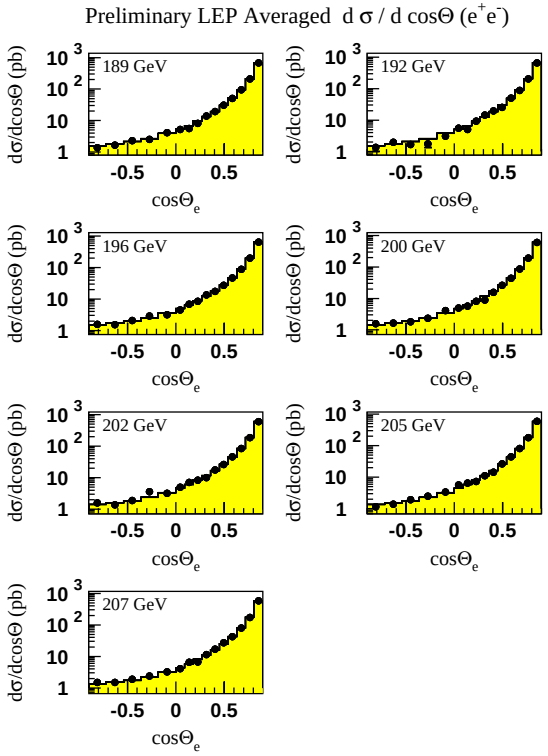
large mis-reconstruction rate
$\nu \longleftrightarrow$ LSP($\tilde{\chi}$, $\tilde{G}$) , ...
channel is used for direct searches

no LEP combined cross-section



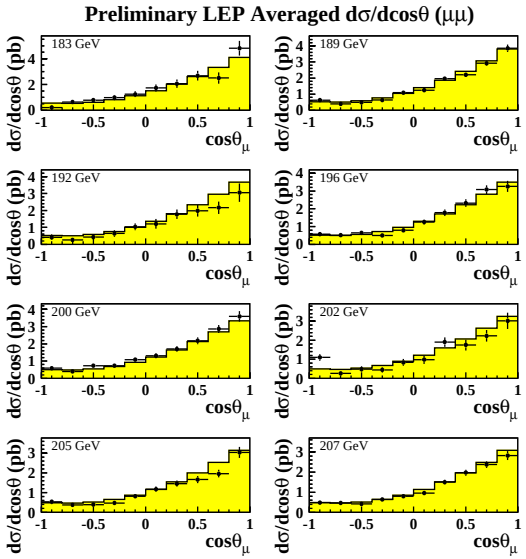
fraction $s'/s > 0.85$ qq: 22%; $\mu\mu$: 41%

Angular distribution, charged leptons

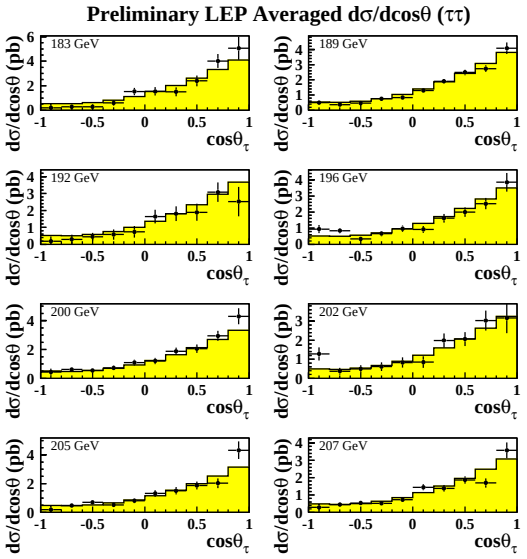


e^+e^-

LEP combined 184 – 209 GeV, high s' region
good agreement with Monte Carlo



$\mu^+\mu^-$



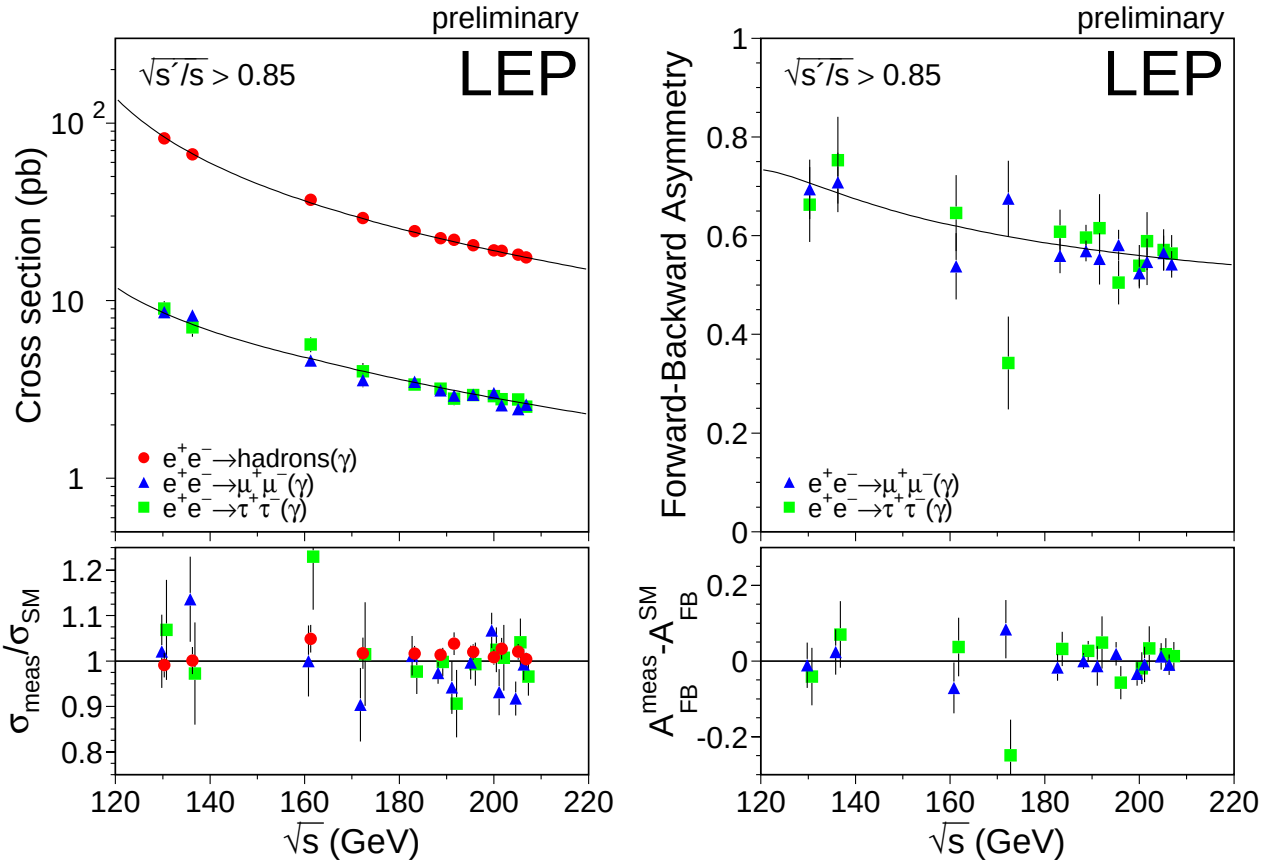
$\tau^+\tau^-$

extract total cross-section and forward-backward asymmetry
to compare to Standard Model (ZFITTER) and other models ...

Fermion-Pairs

σ (q)	σ (e) barrel	$\sigma(\mu)$	$\sigma(\tau)$	$A_{\rm fb}(\mu)$	$A_{\rm fb}(\tau)$
experimental precision					
1%	0.9%	1.6%	2.2%	0.012	0.015
theory uncertainty					
0.26%	2.0%	0.4%	0.4%	0.004	0.004

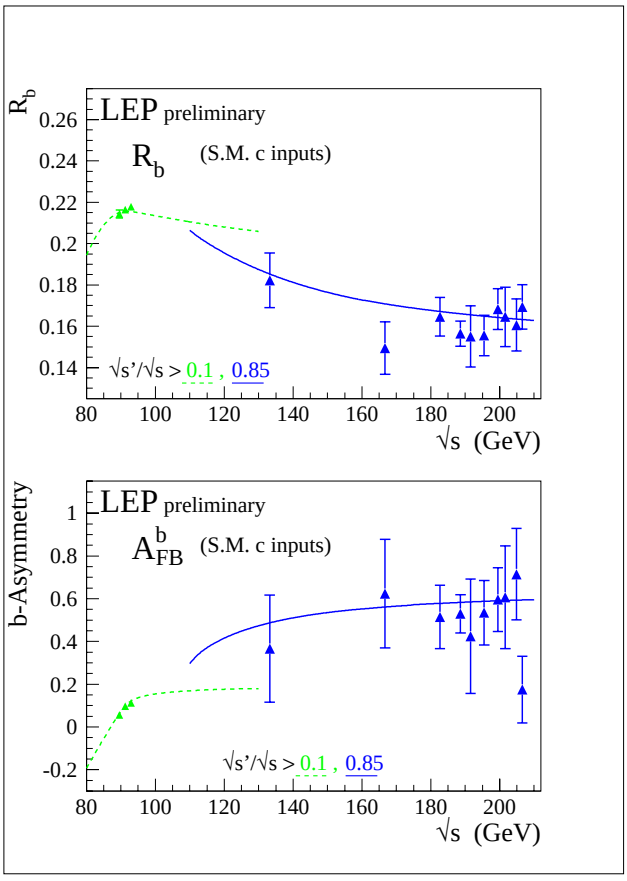
theory error:
detailed comparison ZFITTER $\leftrightarrow$ KK2f
see Yellow Report CERN 2000–09

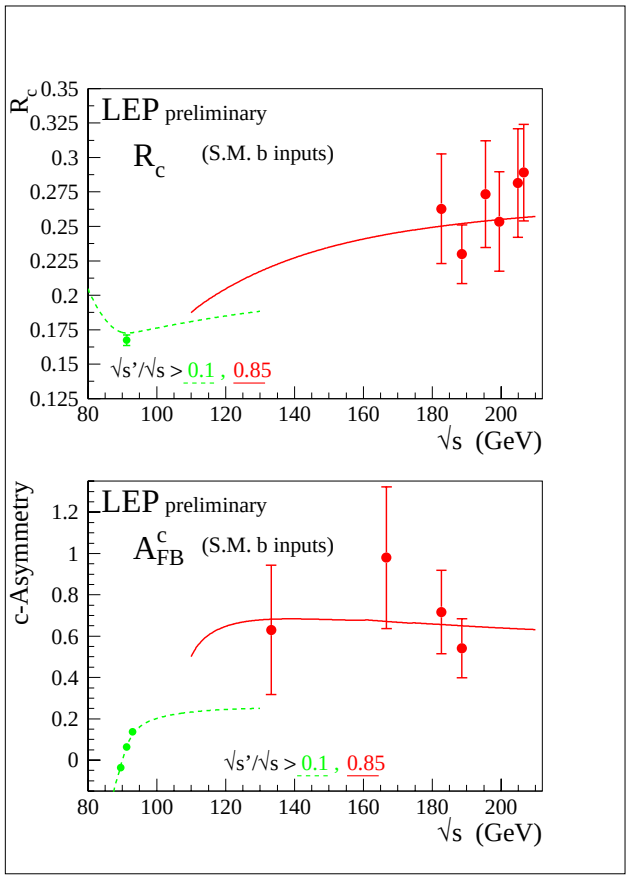


Heavy Flavours

not all experiments provide input

ECMS (GeV)	R_b ADLO	R_c ADLO	AFB_b ADLO	AFB_c ADLO
133	F F F F	- - - -	- F - F	- F - F
167	F F F F	- - - -	- F - F	- F - F
183	F P F F	F - - -	F - - F	P - - F
189	P P F F	P - - -	P P F F	P - - F
192-202	P P P -	P - - -	P P - -	- - - -
202-209	- P P -	P - - -	P P - -	- - - -





Beyond the Standard Model

new propagator:

- leptoquark: t- or u-channel, hadronic events
- Kaluza-Klein gravitons, best limits from $\mathrm{e^+e^-}$
- Z′: including mixing with Z

general ($m \gg \sqrt{s}$): contact interaction

$$\mathcal{L}_{\mathrm{eff}} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} \bar{e}_i \gamma_\mu e_i \bar{f}_j \gamma^\mu f_j$$

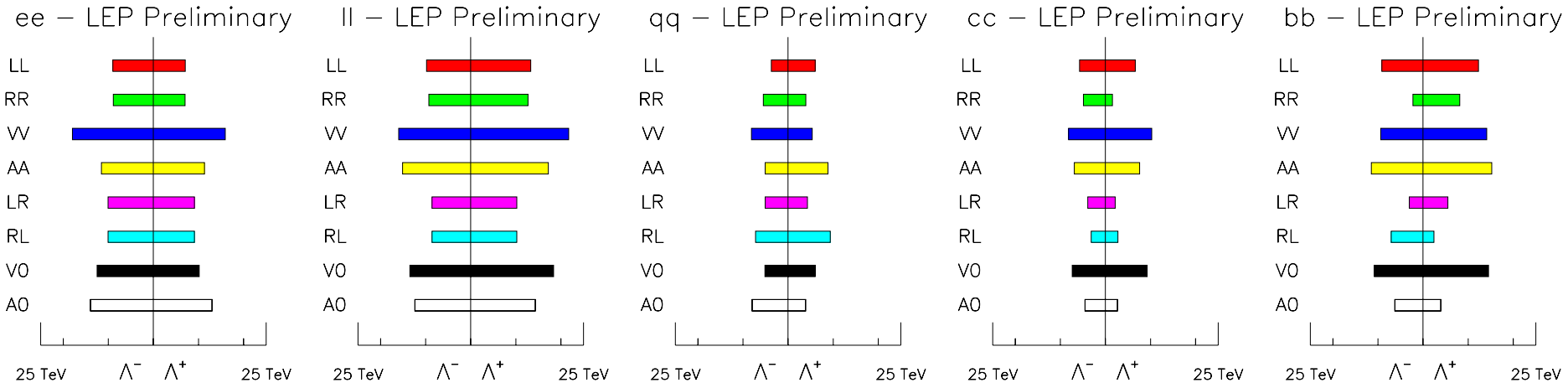
Λ scale of interaction
$g^2 = 4\pi$; $\eta = 0, \pm 1$; $\delta = 1$ for Bhabhas, 0 else

various models

Model	η_{LL}	η_{RR}	η_{LR}	η_{RL}
$\mathrm{LL}^{\pm}$	± 1	0	0	0
$\mathrm{RR}^{\pm}$	0	± 1	0	0
$\mathrm{VV}^{\pm}$	± 1	± 1	± 1	± 1
$\mathrm{AA}^{\pm}$	± 1	± 1	∓ 1	∓ 1
$\mathrm{LR}^{\pm}$	0	0	± 1	0
$\mathrm{RL}^{\pm}$	0	0	0	± 1
$\mathrm{V0}^{\pm}$	± 1	± 1	0	0
$\mathrm{A0}^{\pm}$	0	0	± 1	± 1

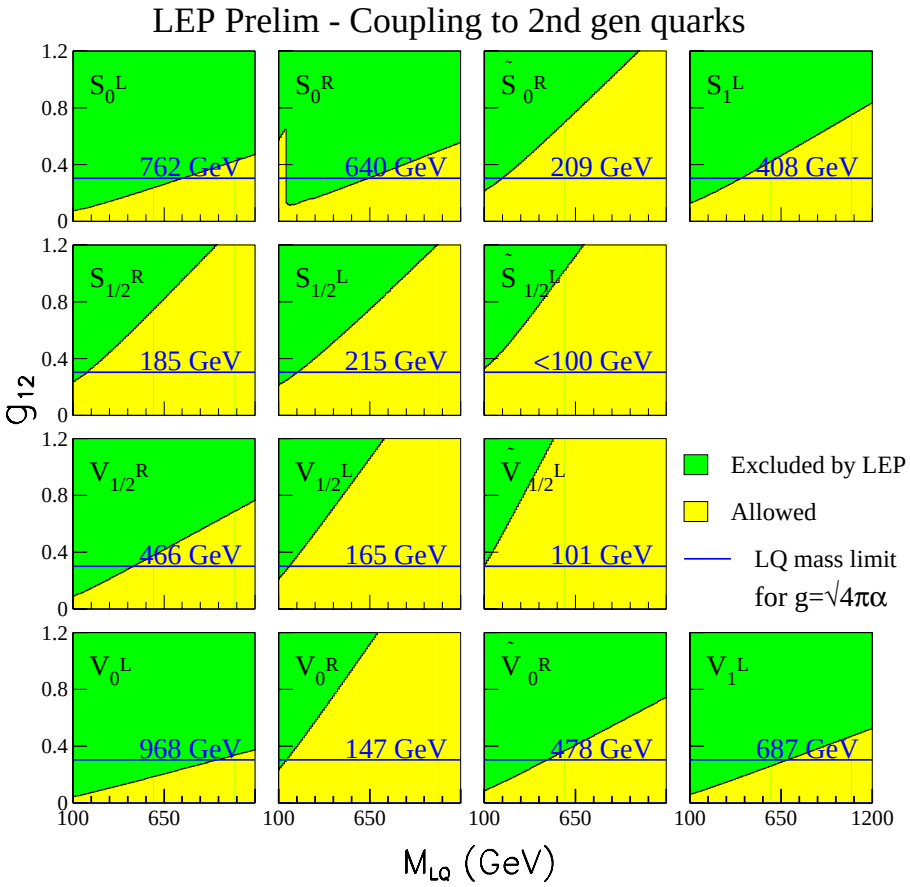
fit to cross-sections and asymmetries

Contact Interactions

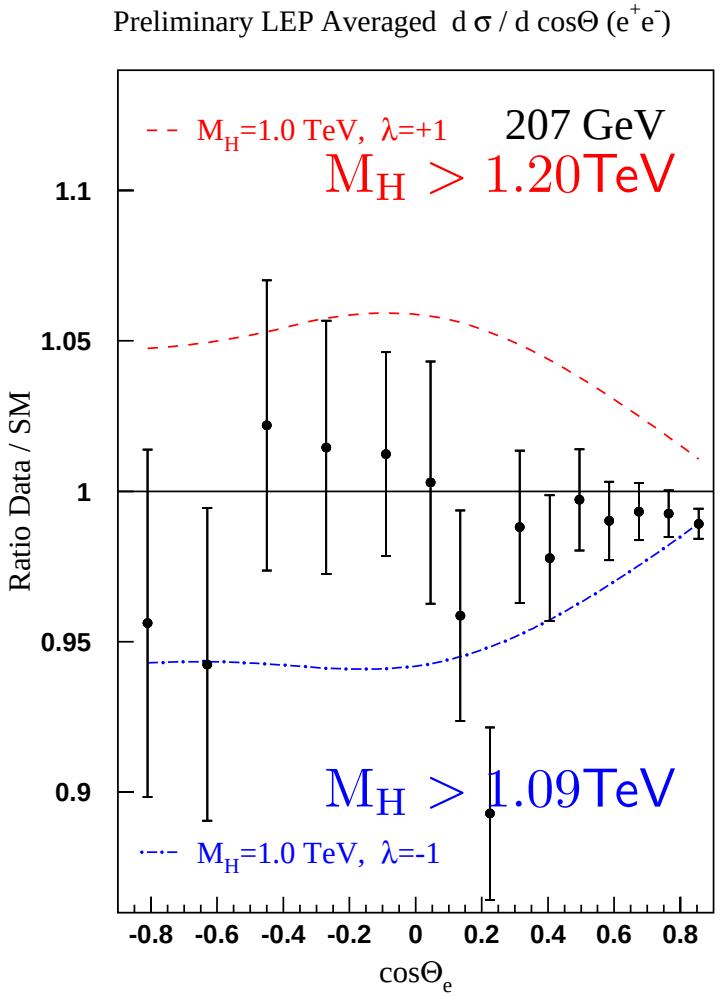


(TeV)	$e^+e^- \to e^+e^-$		$e^+e^- \to \ell^+\ell^-$		$e^+e^- \to q\bar{q}$		$e^+e^- \to c\bar{c}$		$e^+e^- \to b\bar{b}$	
Model	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
LL	9.0	7.1	9.8	13.3	3.7	6.0	5.7	6.6	9.1	12.3
RR	8.9	7.0	9.3	12.7	5.5	3.9	4.9	1.5	2.2	8.1
VV	18.0	15.9	16.0	21.7	8.1	5.3	8.2	10.3	9.4	14.1
AA	11.5	11.3	15.1	17.2	5.1	8.8	6.9	7.6	11.5	15.3
LR	10.0	9.1	8.6	10.2	5.1	4.3	3.9	2.1	3.1	5.5
RL	10.0	9.1	8.6	10.2	7.2	9.3	3.1	2.8	7.0	2.4
V0	12.5	10.2	13.5	18.4	5.1	6.0	7.4	9.2	10.8	14.5
A0	14.0	13.0	12.4	14.3	8.0	3.9	4.5	2.7	6.3	3.9

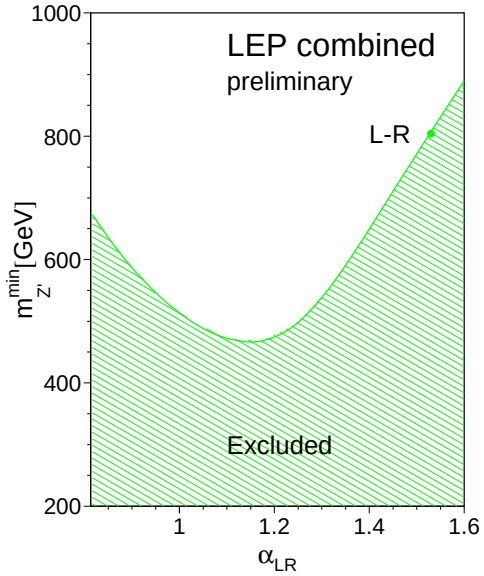
Leptoquarks

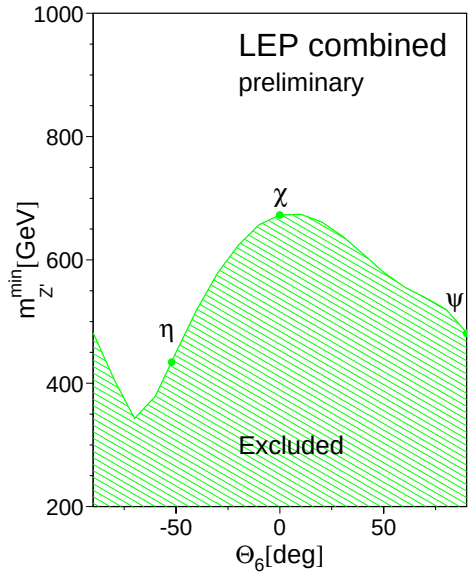


Low Scale Gravity



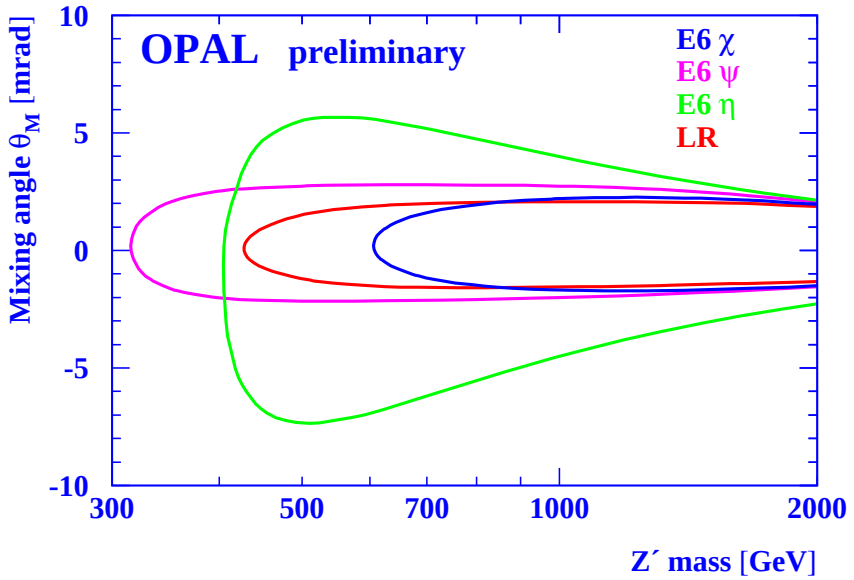
Z′





several models, mass limits from LEP2

in general mixing Z / Z′ possible
changes Z properties → use LEP1 data
no LEP1 combined cross-sections
→ no combined limits on mixing

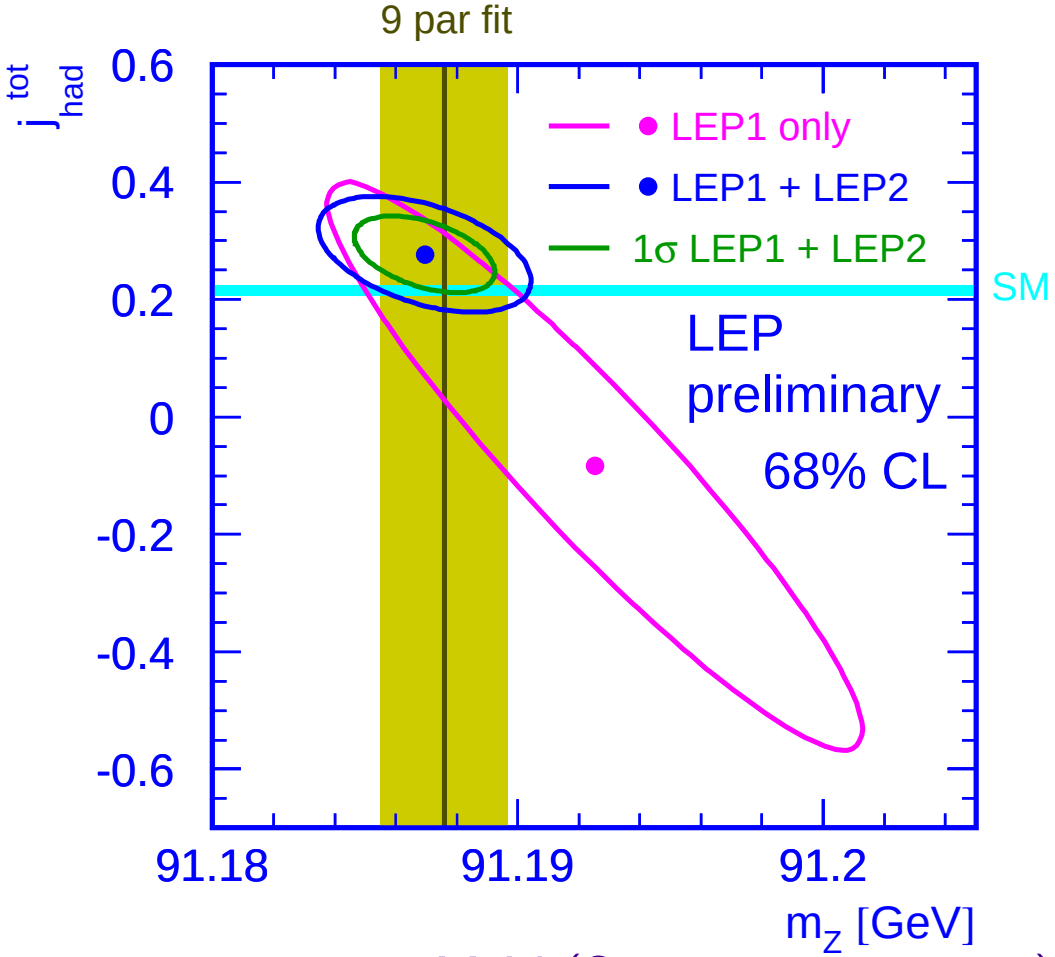


S-matrix

if Z is not the Standard Model Z what is its mass?

Lineshape fit determines M_Z, Γ_Z, σ_h^0, ...
88% of all LEP1 events: hadrons at 3 energy points
have to assume shape of resonance

add free parameter $j_{\rm had}^{\rm tot}$ (γ/Z interference)



$M_Z = 91192.5 \pm 5.9$ MeV (S-matrix, LEP1 only)
$M_Z = 91186.9 \pm 2.3$ MeV (S-matrix, LEP1 + LEP2)
$M_Z = 91187.6 \pm 2.1$ MeV (9 parameter fit)

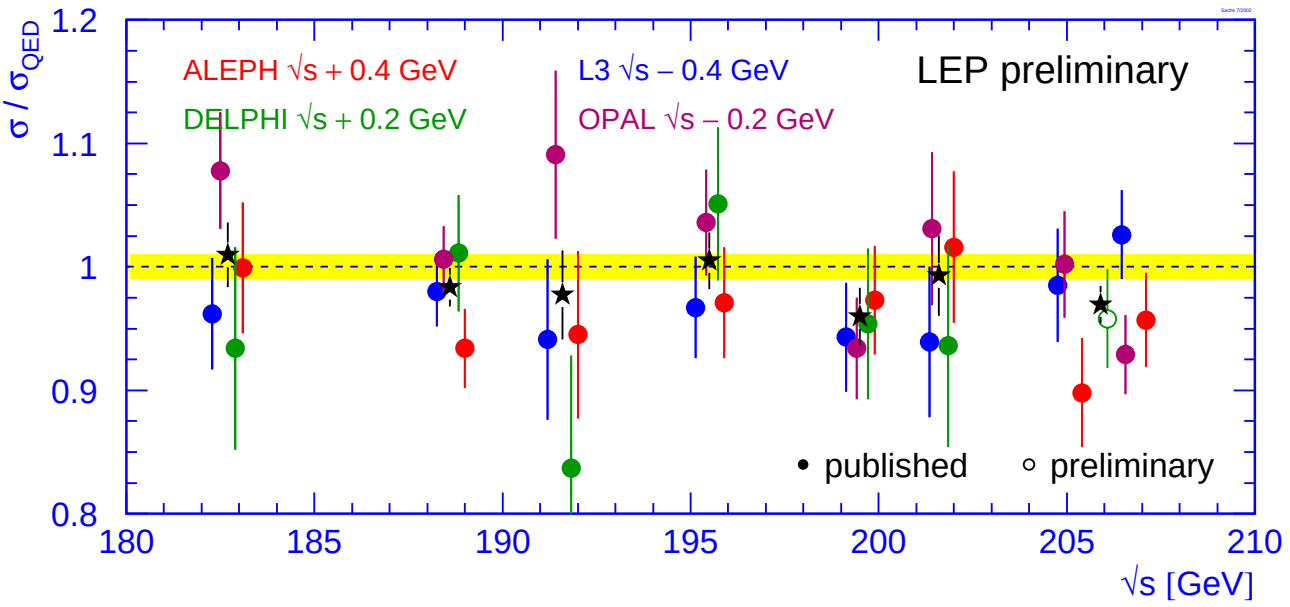
Photon-Pairs

$e^+e^- \to \gamma\gamma$, pure QED (0.2% weak contribution)
only 2 calculations available:
Born-level, 3rd order Monte Carlo $\Rightarrow$
no estimate of theory error, depends on corrections

	$\cos\theta$	acolinearity	rad.correction
A	< 0.95	$< 20°$	up to -5%
D	< 0.90	$< 50°$	up to 9%
L	< 0.96	$< 160°$	up to 28%
O	< 0.93	$p_l < p_1, p_2$	up to 8%

rad.corrections depend on selection and angle

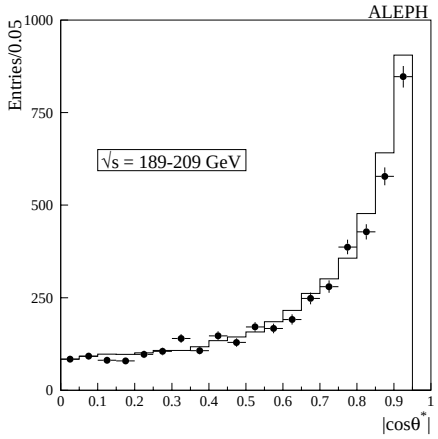
for now assume 1% theory error, fully correlated

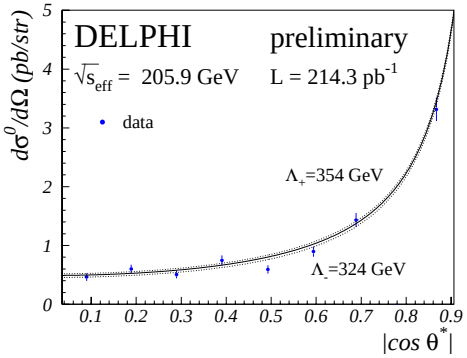


average: $\sigma_{\mathrm{LEP}}/\sigma_{\mathrm{QED}} = 0.982 \pm 0.010$

Angular Distribution

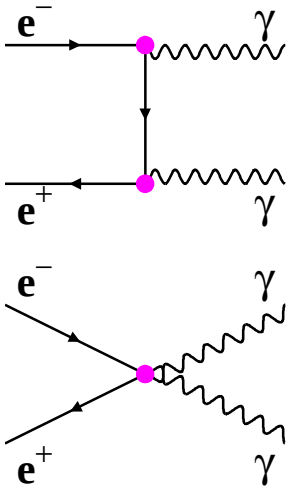
simultaneous fit to 4 experiments

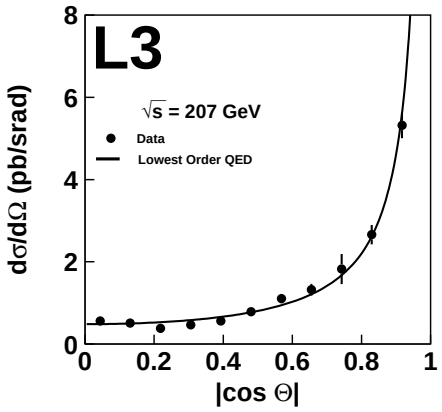


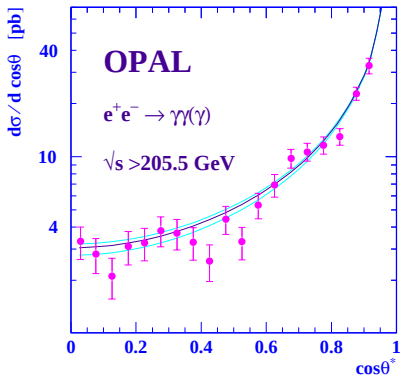


$\Lambda_+ > 392$ GeV
$\Lambda_- > 364$ GeV

$\Lambda' > 831$ GeV

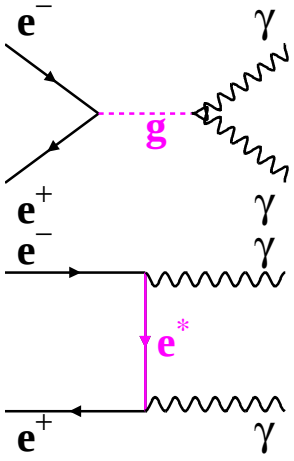






$\lambda = +1$ $M_s > 933$ GeV
$\lambda = -1$ $M_s > 1010$ GeV

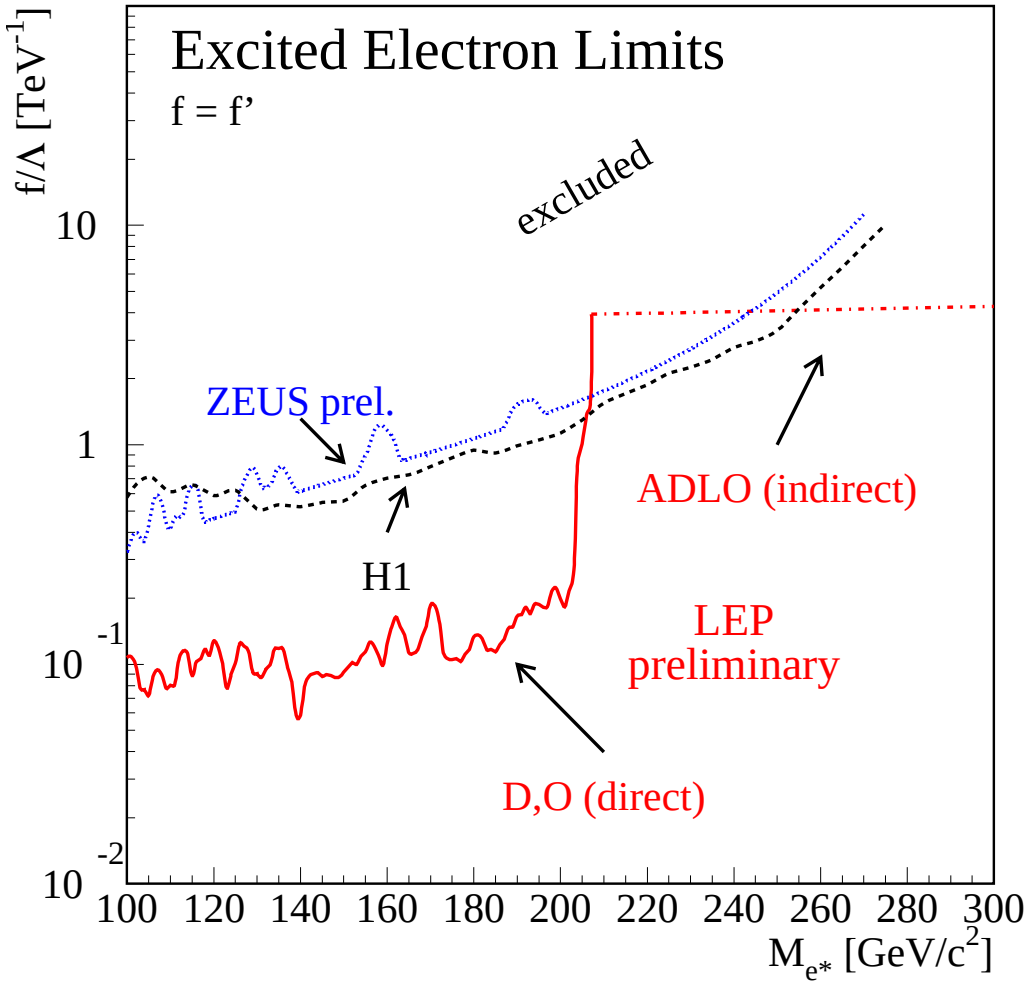
$f/\Lambda < 3.9 \mathrm{TeV}^{-1}$
$M_{e^*} = 200$ GeV



Excited Electrons

direct searches:
LEP: pair production ($e^+e^-\gamma\gamma$)
single production ($e^+e^-\gamma$)
HERA: $e\gamma$ fusion

indirect search:
LEP: e^* exchange



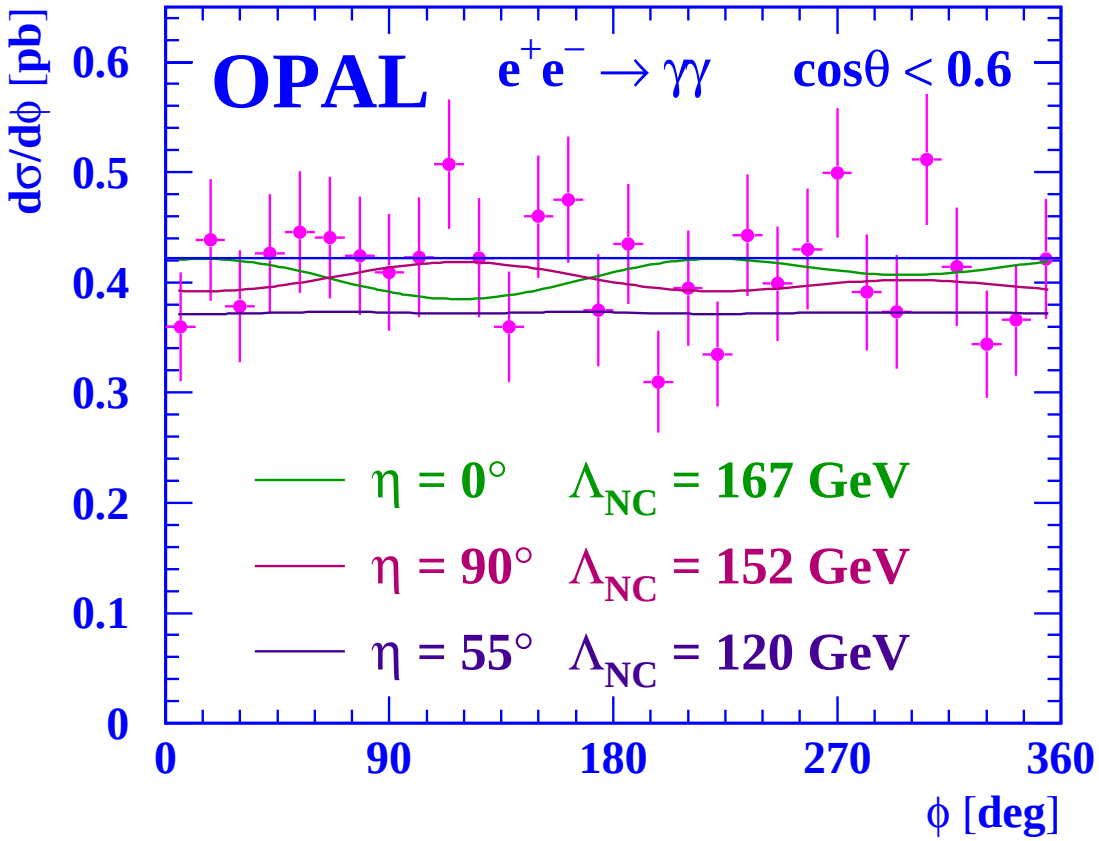
Pure (NC)QED

non commutative geometry $\rightarrow$
unique direction in space (η, ξ), scale Λ

cross-section depends on θ, ϕ and time
and orientation of the detector

limit from $\cos\theta$ distribution (for OPAL)
independent on η: $\Lambda > 141$ GeV

more information from ϕ distribution



first limits on NCQED from collider experiment

Conclusion

LEP provided data to study a variety of physics

prime example how 4 collaborations
can act as one experiment 'ADLO'

final analyses not finished yet
high precision of data forced theorists
to improve calculations to sub % level

fermion- and photon pair cross-sections
mainly for indirect searches
complement direct searches
at Tevatron and HERA

no 'discovery'
but a much better understanding of
the Standard Model