Searches for New Particles

HEP2003 Europhysics Conference
in Aachen, Germany
17 – 23 July 2003

Arnulf Quadt
Bonn University

This Talk ...

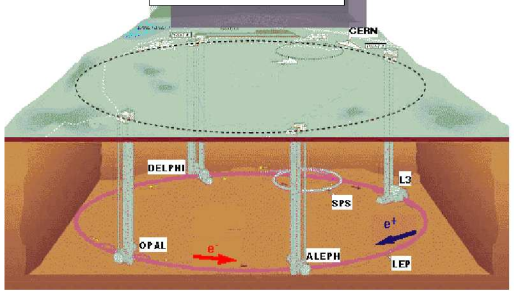
- Concentrates on results from recent data and expected sensitivities ...
  - Direct searches for particles in/beyond the SM
  - Many having gone from `preliminary' to `published'
  - Indirect constraints on physics beyond the SM
    - See Pippa Wells' talk for precision measurements in SM

- Will NOT devote (much) time to future prospects, since covered in other talks
  - LHC : S.Arcelli, E.Ros, M.Sanders
  - LHC – LC working group : G.Weiglein
  - LC studies : S.Hesselbach

- Impossible (of course) to cover everything
  - 183 relevant abstracts submitted to EPS03 alone!
  - ⇒ Selected topics and recent results

Collider Experiments Dominant

LEP



- e^+e^- collider
- $\sqrt{s}$ = 91-209 GeV
- $\int\mathcal{L} \sim$ 900 pb^{-1}/expt
- ALEPH, DELPHI, L3, OPAL

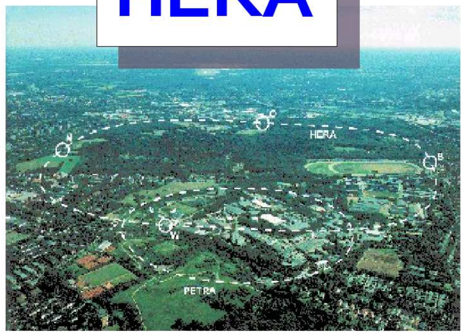
- last data in 2000
- analyses converging

Tevatron

- $p\bar{p}$ collider
- $\sqrt{s}$ = 1.8-2 TeV
- $\int\mathcal{L} \sim$ 170-200 pb^{-1}/expt
- CDF, DØ

- 2009:
  $\int\mathcal{L} \sim$ 4.4-8.6 fb^{-1}/expt

HERA



- $e^{\mp}p$ collider
- $\sqrt{s}$ = 300-320 GeV
- $\int\mathcal{L} \sim$ 130 pb^{-1}/expt
- H1, ZEUS

- last data in 2000
- 2006:
  $\int\mathcal{L} \sim$ 1 fb^{-1}/expt

... and the LHC is coming ...

Outline

Standard Model healthier than ever ... BUT ...

- **Structure, generations, ...**
  - excited fermions
  - leptoquarks
  - anomalous single top, rare decays
- **Scales, hierarchy**
  - large extra space dimensions
  - Super-Symmetry (RP-Violation)
- **Higgs bosons**
  - in Standard Model
  - in MSSM / 2HDM
  - exotic Higgs, FCNC $b \rightarrow sl^+l^-$
  - little Higgs

Excited Fermions ($f^* \rightarrow fV$, $q^* \rightarrow qg$)

➔ E.Sánchez

SM observation:
- 3 distinct fermion generations
- hierarchy of their masses
- similarity in electric charge and weak properties

⇒ could be compositeness / substructure ("preons")

⇒ consequence: excited states with $m(f^*) \geq 100$ GeV

Phenomenology (Hagiwara et al.):

f, f', (f_s) relative coupling strength to $SU(2)_L$, $U(1)_Y$,(and $SU(3)_C$)

Λ compositeness mass scale

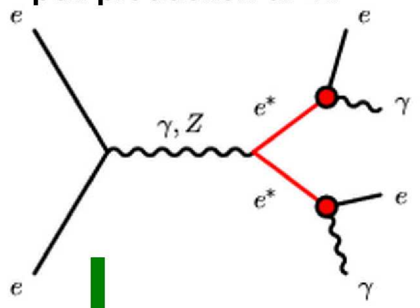
Xsec depends on m_{f^*} and f/Λ

... many f* searches ...

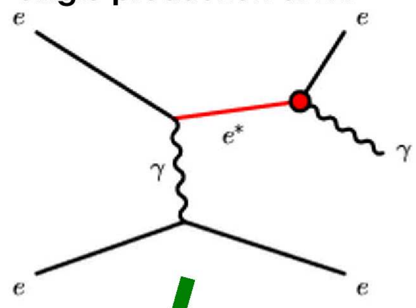
l^*, ν^*	W, Z, γ	HERA, LEP
q^*	W, Z, γ , g	HERA, LEP, TEVATRON

1st Example ($e^* \rightarrow eV$, $\nu^* \rightarrow \nu V$)

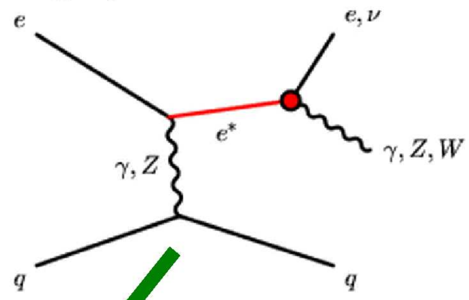
pair production at LEP



single production at LEP



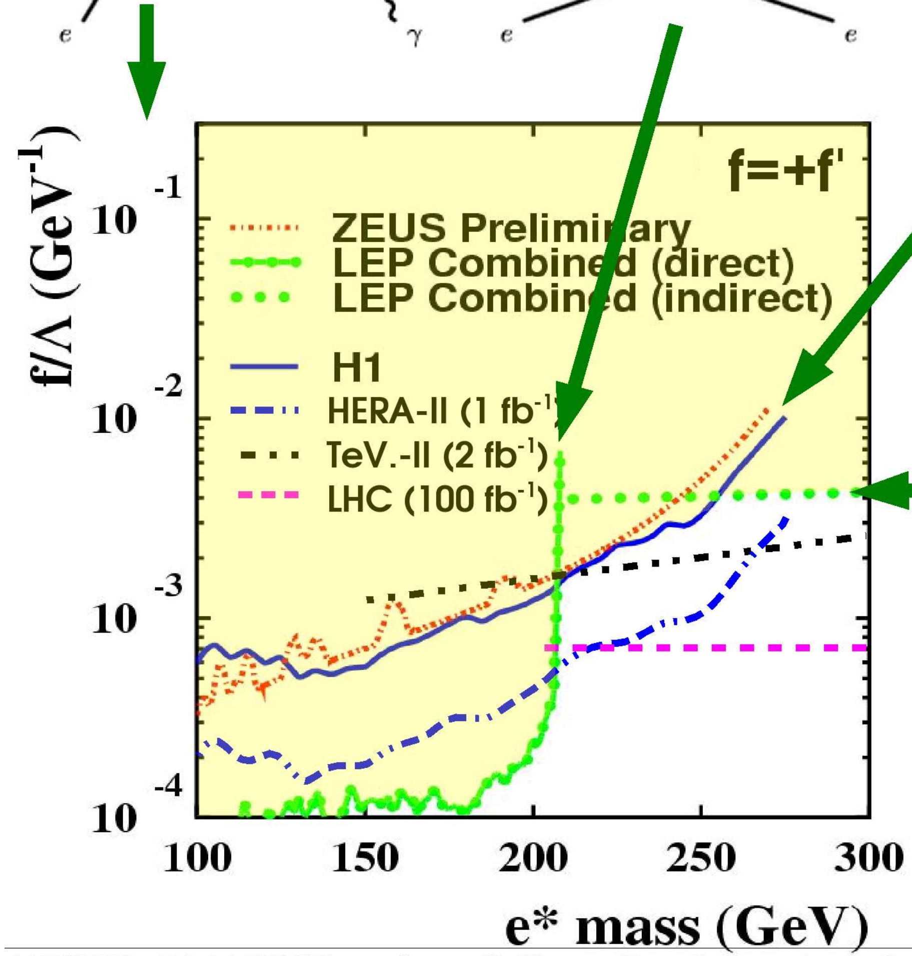
single production at HERA



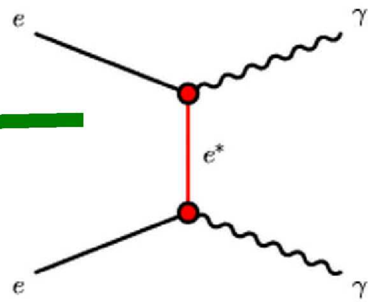
CDF-II also e* search in contact term production

(U.Baur, M.Spira, P.M.Zerwas)

$M_{e^*} > 785$ GeV



indirect constraints from LEP



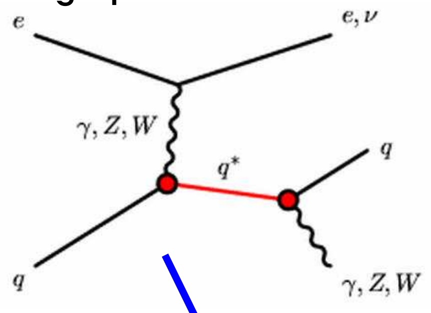
... similarly for μ* and τ*...

... similarly for ν* searches ...

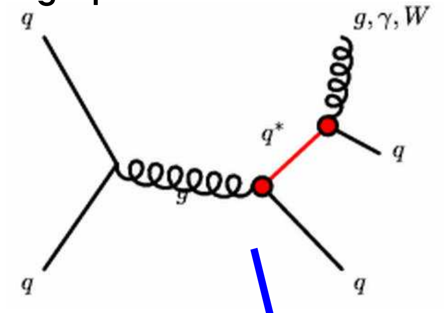
... e^-p at HERA ...

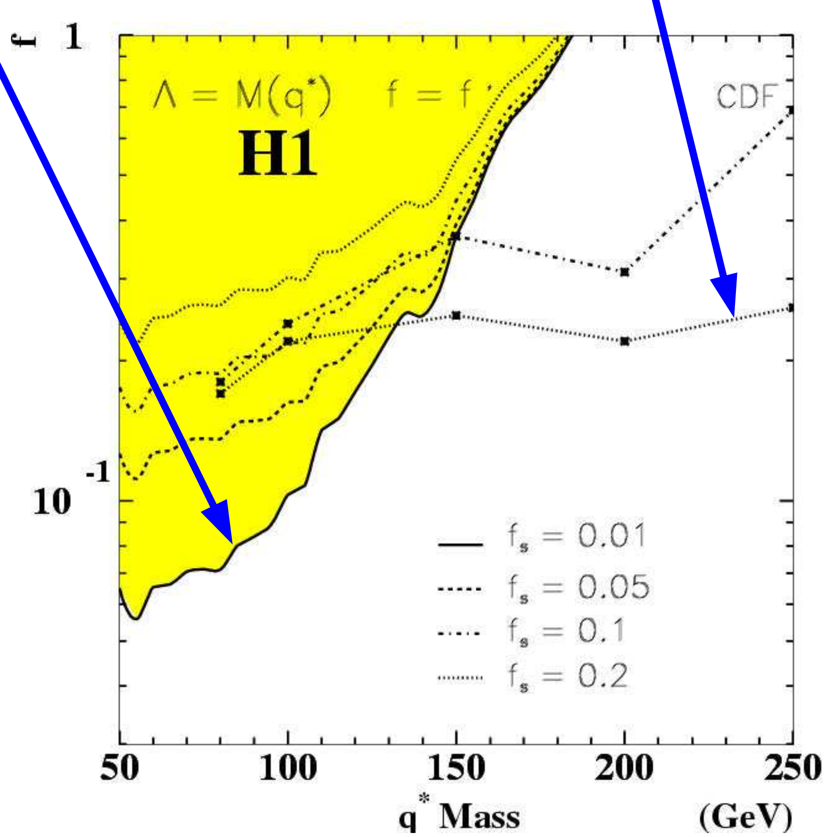
2^{nd} Example ($q^* \rightarrow qV$, $q^* \rightarrow qg$)

single production at HERA



single production at TEVATRON





from di-jet mass spectrum for $f=f'=f_s=1$ and $\Lambda=M_{q^*}$:

$M_{q^*} >$ 760 GeV (CDF,II)
775 GeV (DØ,I)
940 GeV 2 fb^{-1}

... quark substructure regime of hadron colliders ...

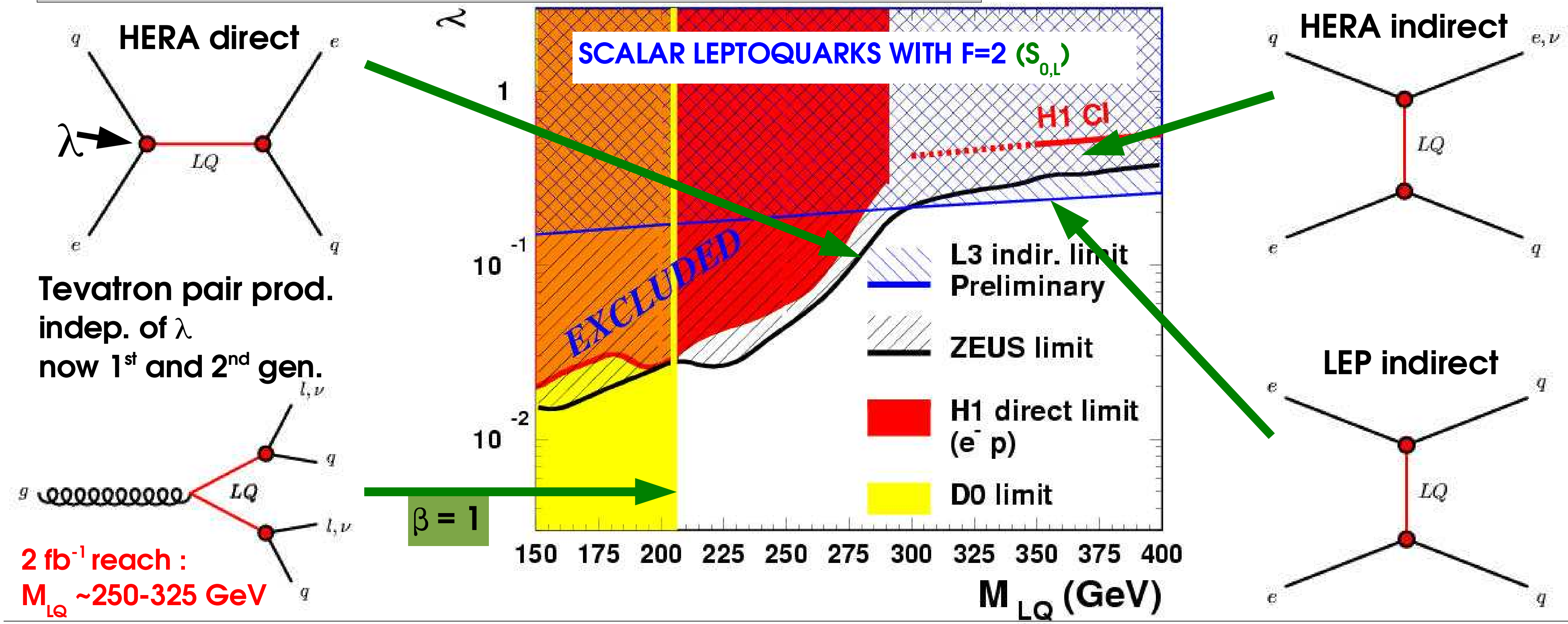
3rd Example: Leptoquarks

➔ A.Zarnecki

Motivation: Observed symmetry between lepton and quark sector
Solution: Leptoquarks (LQ), proposed by several theories
coloured spin 0,1 bosons with baryon and lepton number

Buchmüller, Rückl, Wyler (BRW) classification popular:
1.) conserve SM gauge symmetry
2.) LQ only couple to quarks, leptons and SM gauge bosons
3.) LQ only have flavour-diagonal couplings

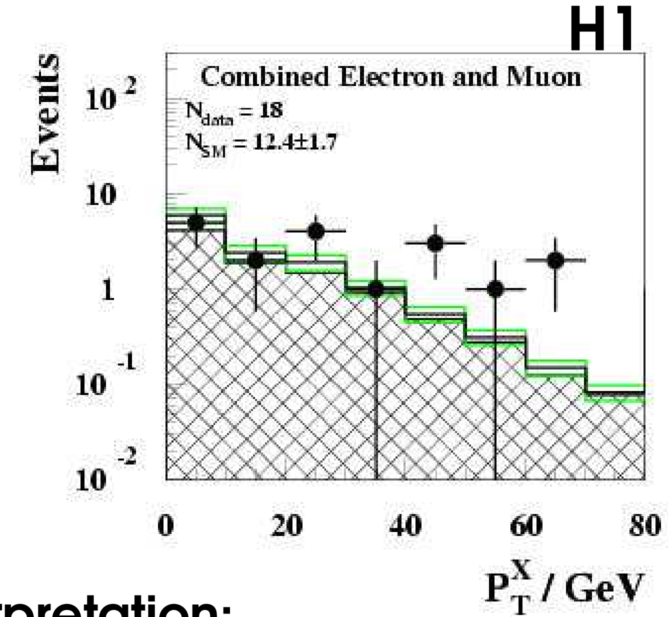
Spin	*charge Q*	*fermion Nr. F*	β_e
Scalar Vector	± 1/3, 2/3, 4/3, 5/3	0,2	0, ½, 1

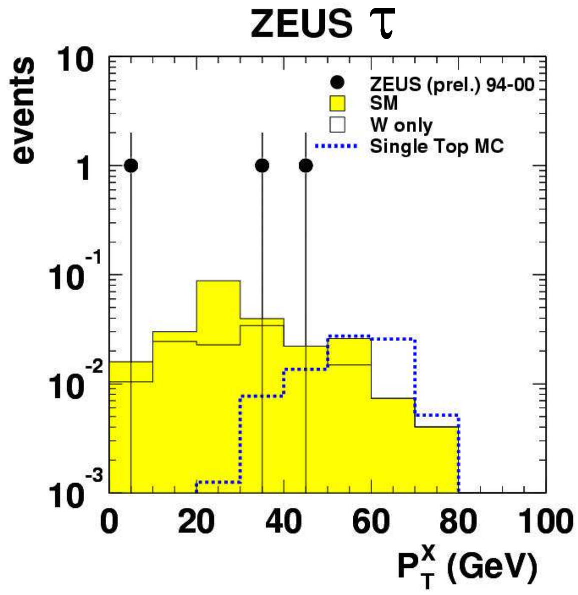


High p_T-Leptons at HERA

➔ J.Ferrando

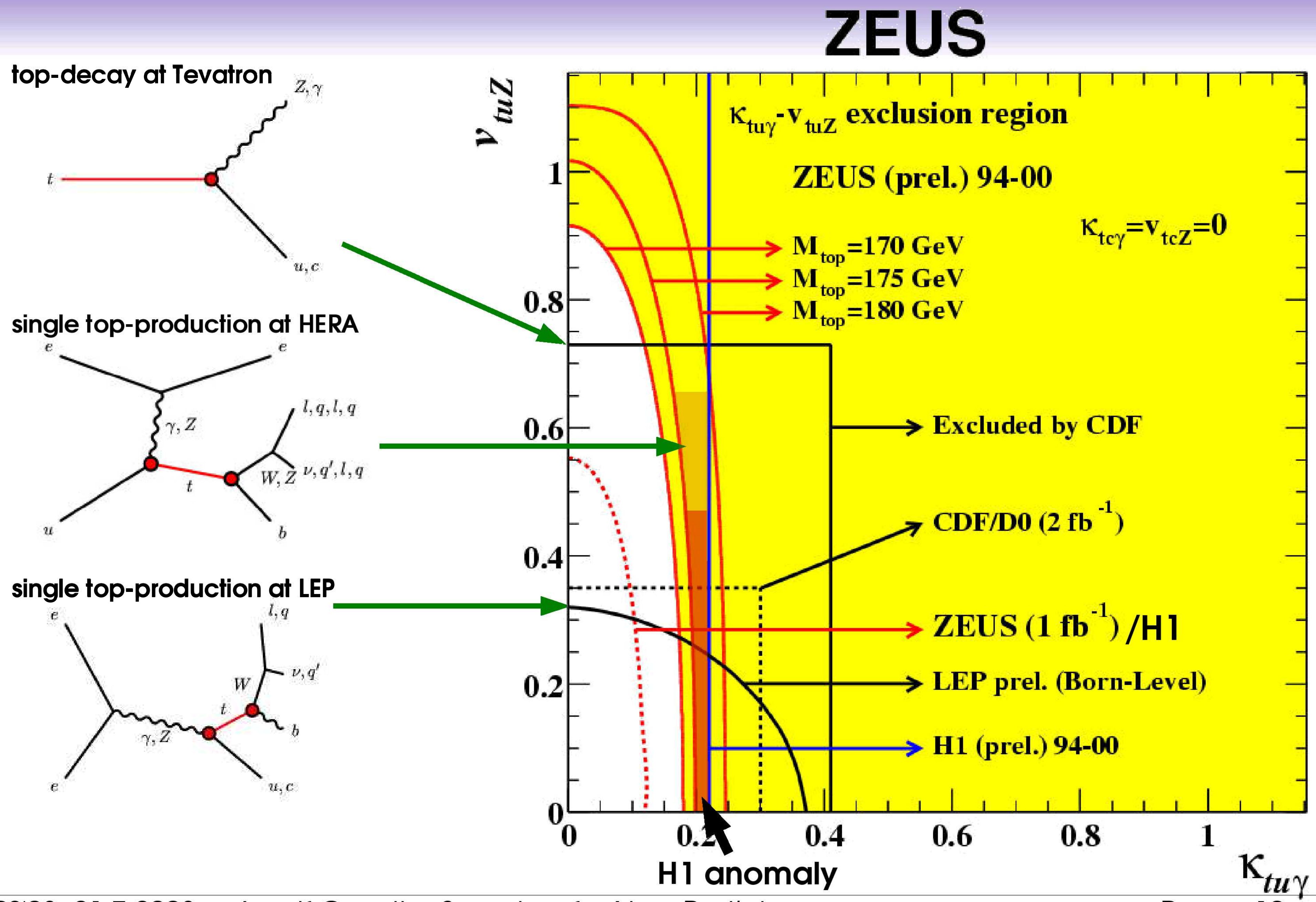
H1 (118.3 pb^{-1})	Positron obs/exp	Muon obs/exp	combined
$P_T^X > 25$ GeV	4 / 1.49 ± 0.28	6 / 1.44 ± 0.26	10 / 2.93 ± 0.49
$P_T^X > 40$ GeV	3 / 0.54 ± 0.11	3 / 0.55 ± 0.12	6 / 1.08 ± 0.22
ZEUS (130.1 pb^{-1})			Tau obs/exp
$P_T^X > 25$ GeV	2 / 2.90 ± 0.59	5 / 2.75 ± 0.21	2 / 0.12 ± 0.02
$P_T^X > 40$ GeV	0 / 0.94 ± 0.11	0 / 0.95 ± 0.14	1 / 0.06 ± 0.01





- **Interpretation:**
  FCNC single top production, at LEP (~10^{-9} fb), HERA in SM small
- anomalous contribution in SUSY, exotic quarks, multi-Higgs doublets, ...
- topology at HERA: high p_T positron / muon + large missing E_T

Anomalous Single-Top Production



Search for Extra Space Dimensions

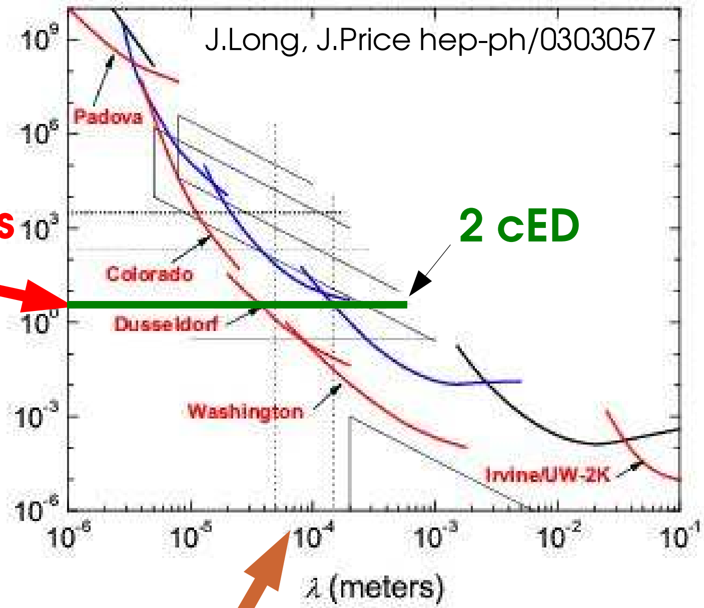
→ M.Sanders, F.del Águila, I.Antoniadis, S.Mele

$$V = -\int d\vec{r}_1 \int d\vec{r}_2 \underbrace{\frac{G\,\rho_1(\vec{r}_1)\,\rho_2(\vec{r}_2)}{r_{12}}}_{Newton} \underbrace{\left[1+\alpha \exp^{-r_{12}/\lambda}\right]}_{Yukawa\ modification}$$

Task: solve hierarchy problem,
i.e. why is $M_{pl}/m_{EW} \sim 10^{17}$ GeV soooo large ?

A proposed solution:

- gravity and gauge interactions unify at weak scale M_S
- observed weakness of gravity at distances ≥1mm due to n ≥ 2 (6 in string theories) new spatial dimensions
- gravitons move freely in all dimensions
- SM fields localized to 4-dim. space-time
- curled-up/compactified dimensions of radius R ⇒ Kaluza-Klein towers of periodic energy/mass levels



closed universe

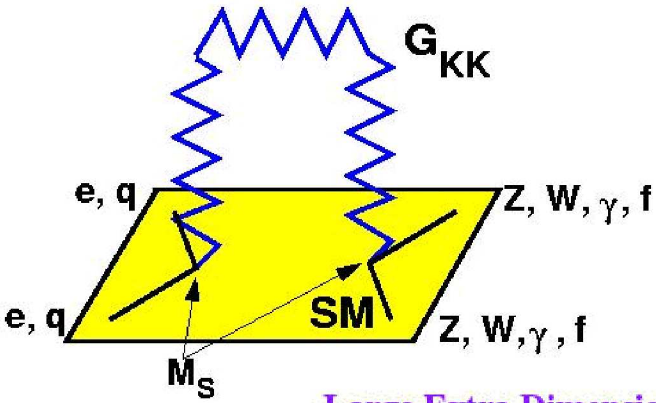
$r \ll R$ gravit. potential from gauss law in (n+4) dim.
$r \gg R$ $V \sim 1/r$

n=1	R ~ 10^{13} cm	excluded
n=2	R ~ 100 μm – 1mm	???
n=3	R ~ 3 nm	

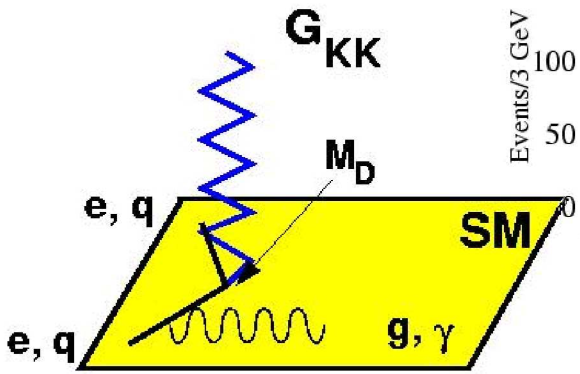
N.Arkani-Hamed, S.Dimopoulos, G.Dvali (ADD)

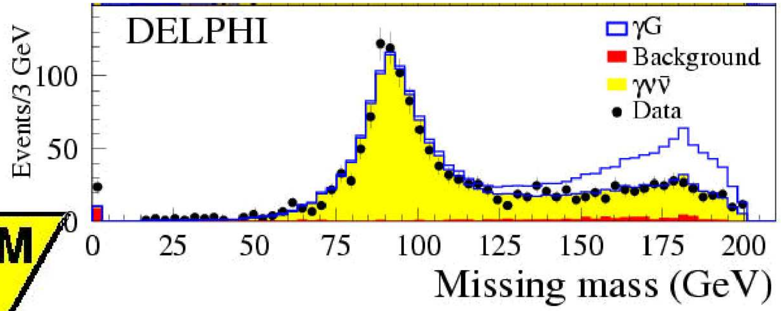
Search for Extra Space Dimensions

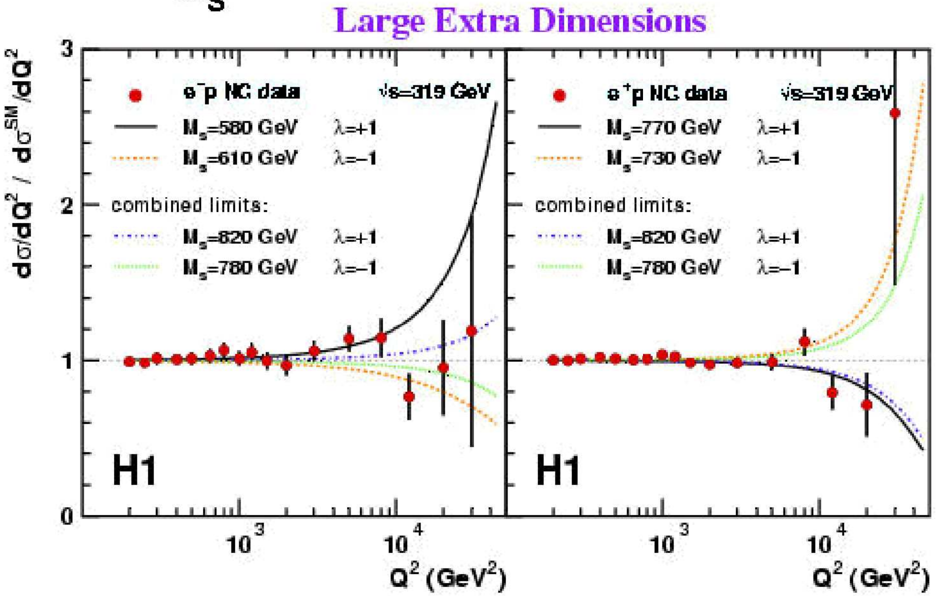
Indirect effects (virtual graviton)

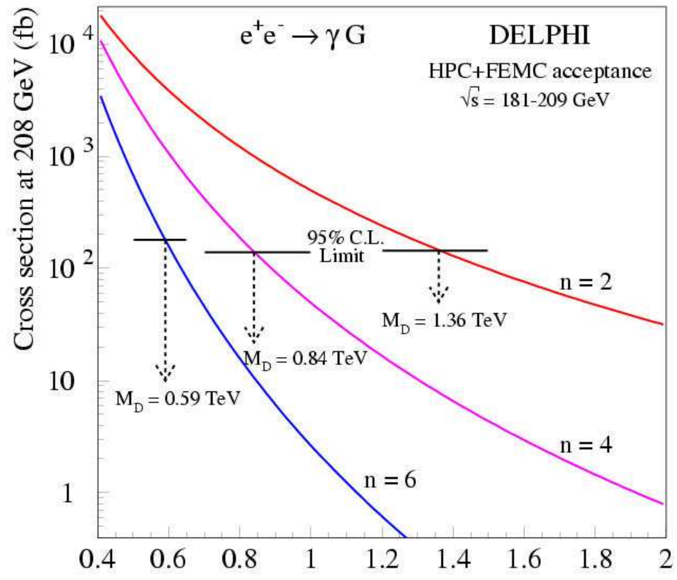


Direct effects (missing energy, mono-jets)









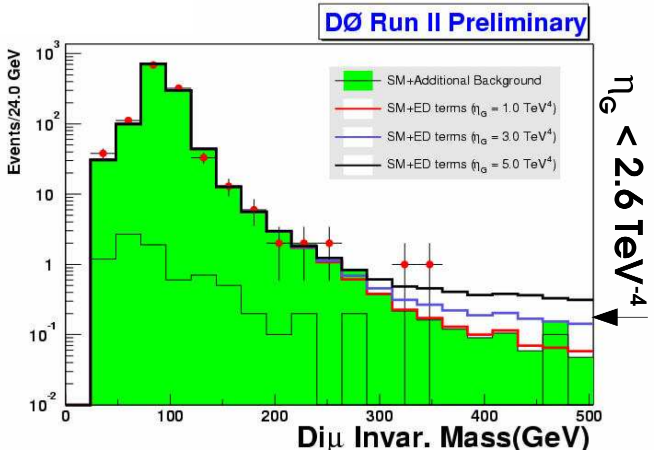
typical limits: **LEP / HERA : M_S > 0.7 - 1.2 TeV**
Tevatron-I,II: M_s > 0.8 – 1.3 TeV

DELPHI: $M_D^{(n=2)}$ > 1.36 TeV

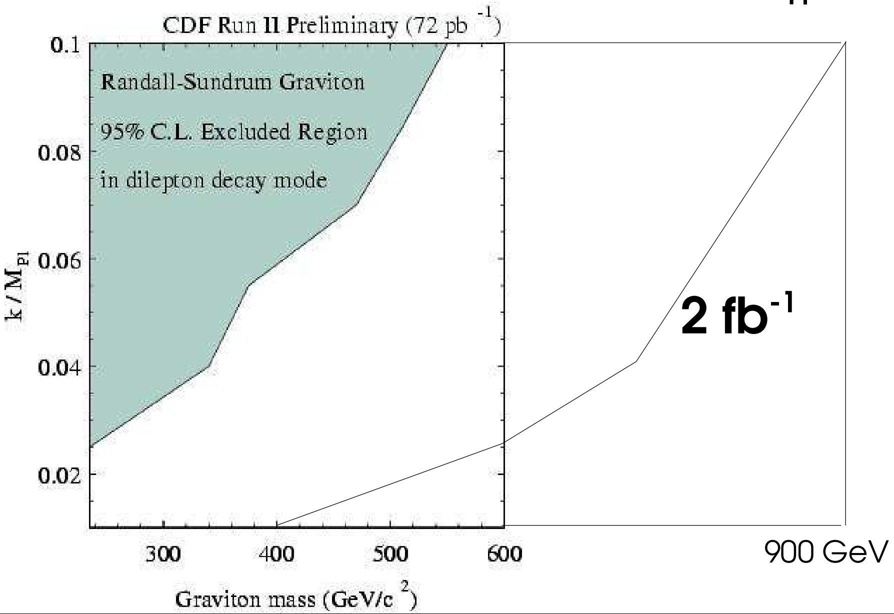
R < 0.26 mm

Search for Extra Space Dimensions

- **Di-muon channel**



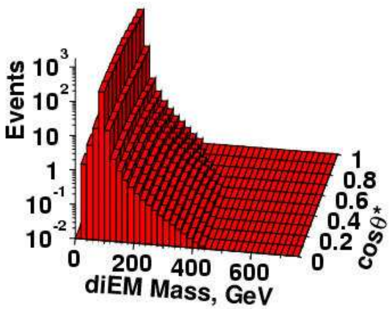
- **In Randall-Sundrum model only one compact ED**
- **Warps space-time by $e^{-2kr_c\pi}$ ⇒ coupling k/M_{Pl}**



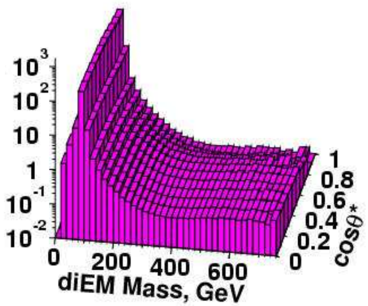
- **Di-electron/photon channel**

actually use mass vs cos θ*

SM Prediction **DØ Run-II preliminary**



ED Signal



CDF-I (110 pb^{-1})	di-EM (e, γ)	M_S > 0.85 – 0.94 TeV
CDF-I (87 pb^{-1})	Mono-Jet/ γ +MET	M_S > 1.0 (0.6-0.7) TeV for n=2 (n=6)
CDF-II (75 pb^{-1})	di-e, μ, γ ,Jet	k/M_{Pl} limits in RS
DØ-I (127 pb^{-1})	di-EM (e, γ)	M_S > 1.2 TeV
DØ-I (78.8 pb^{-1})	Mono-Jet +MET	M_D > 1.0 (0.65) TeV for n=2 (n=6)
DØ-II (120 pb^{-1})	di-EM (e, γ)	M_S > 1.28 TeV
DØ-II (30 pb^{-1})	di-μ	M_S > 0.79 TeV

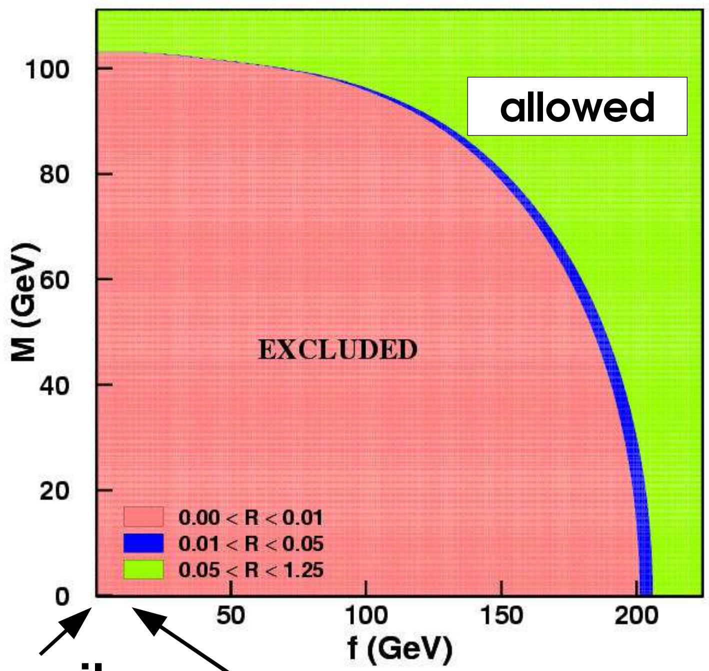
... interpretation in several different models ...

Search for Branons and Radions

- **Branons** $\hat{\pi}$ → brane fluctuations (in ADD)
- Gravitation scale M_F and brane tension scale f
- Gravitons for $f \gg M_F$ and branons for $f \ll M_F$

$$\Rightarrow \quad e^+ e^- \to \hat{\pi}\,\hat{\pi}\,(\gamma / Z^0)$$

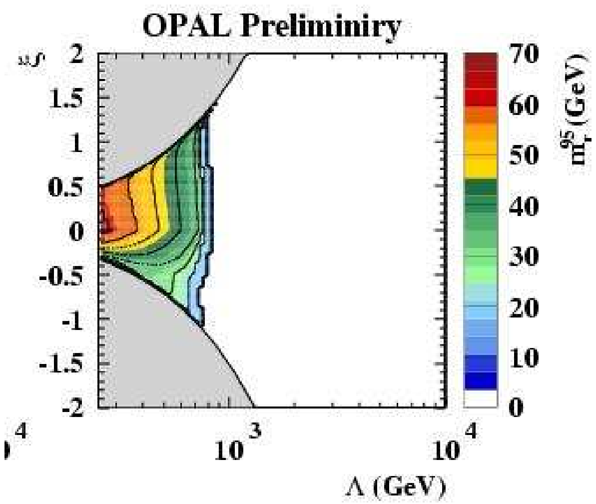
L3 Limits on the Brane Tension

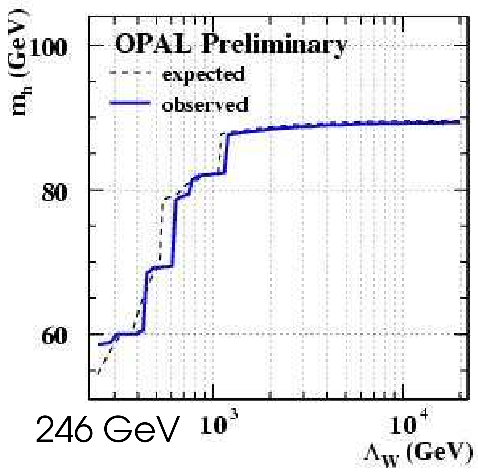


gravity exp'ts

SN1987A

- Spinless local fluctuations in RS model: **radions**
- Mixes with Higgs, couples directly to gluons
- Recycle model- and flavour-indep. Higgs search





246 GeV

Higgs limits m_h > 58 GeV

Radion mass limit depends on mixing and Λ_{EW}

➔ P.Azzurri, M.Wegner, I.Trigger, C.Rott, S.Hesselbach, T.Nunnemann, C.Schwanenberger

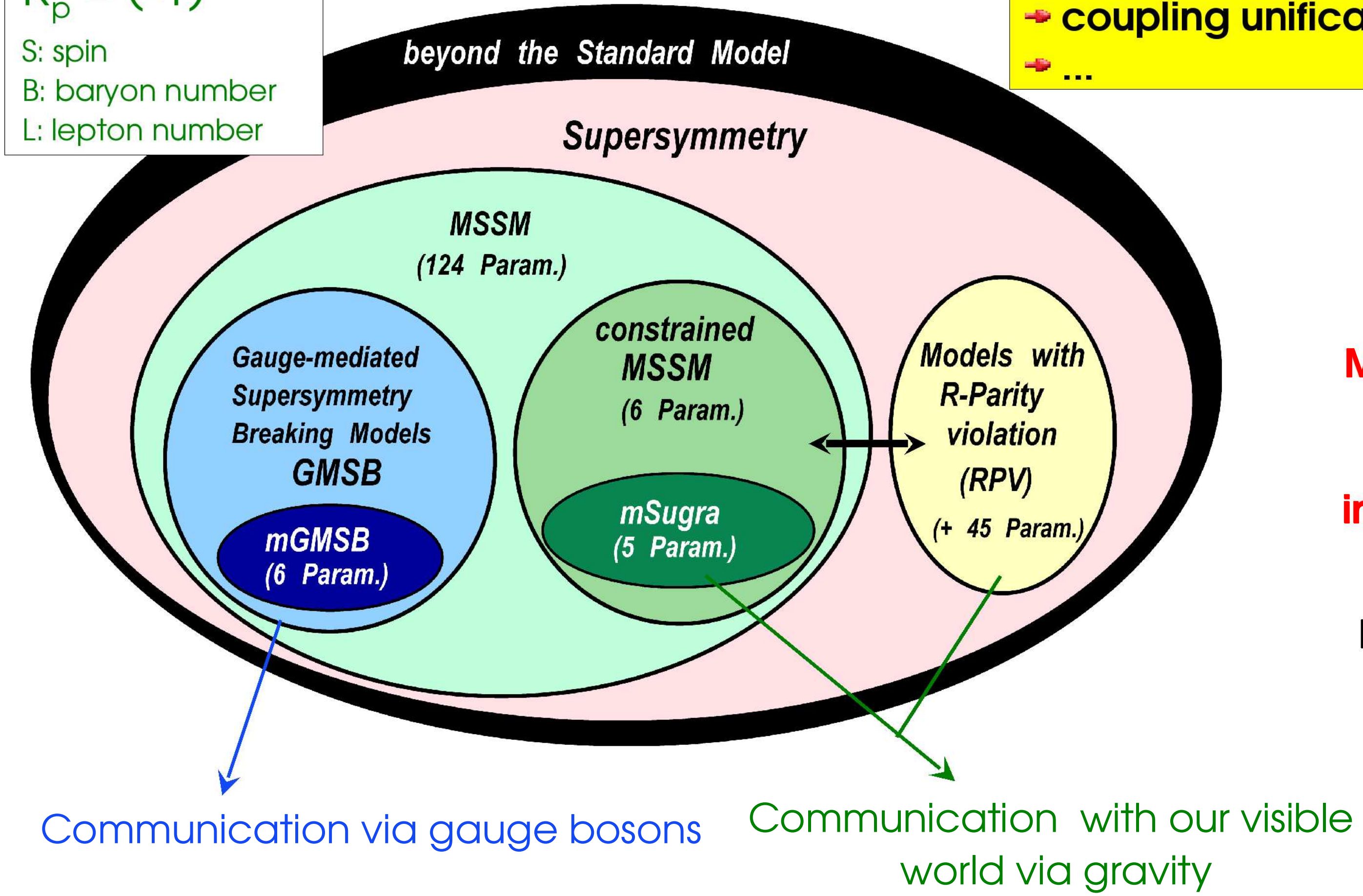
SUSY Models

- symmetry between fermions and bosons
- cancels quadratic divergences in higgs mass
- fine tuning problem
- hierarchy problem
- coupling unification
- ...

Mechanism of SUSY breaking unknown: different models

$R_p = (-1)^{2S+3B+L}$

S: spin
B: baryon number
L: lepton number

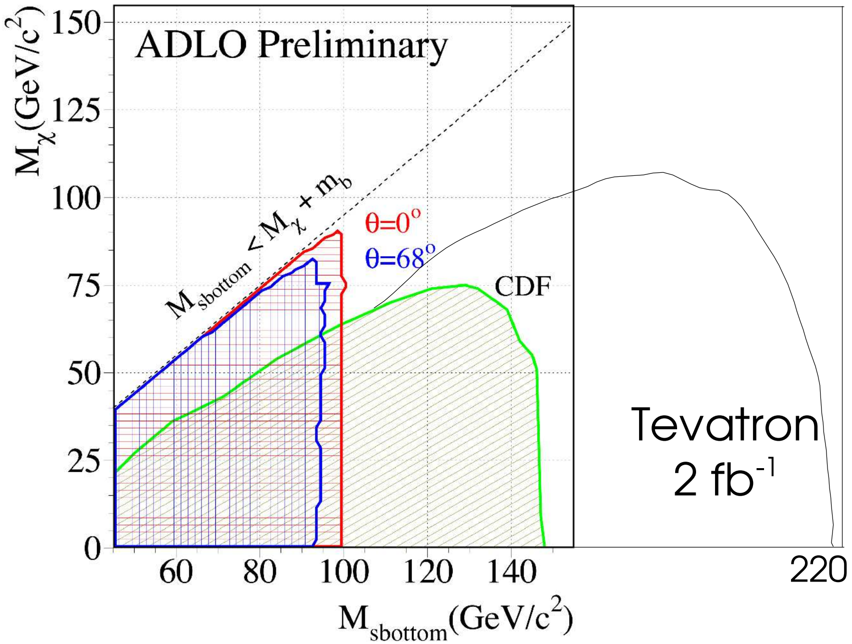


Models are used to guide the analyses and to express the results in a predictive framework

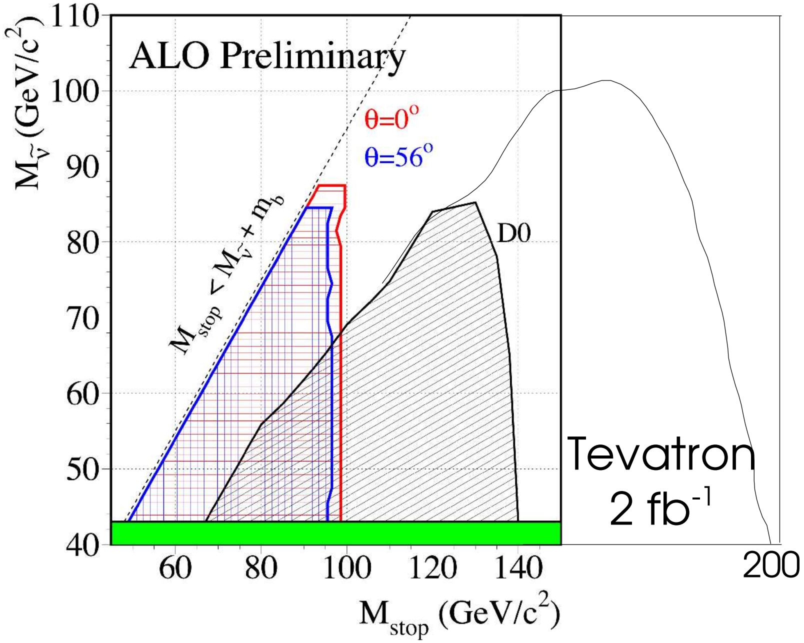
Lightest SUSY Particle, LSP:
MSSM: lightest neutralino
GMSB: lightest neutralino, charged slepton

Stop/Sbottom Searches

$e^+e^- \to \tilde{b}^+\tilde{b}^- \to b\tilde{\chi}^0_1\ b\tilde{\chi}^0_1$

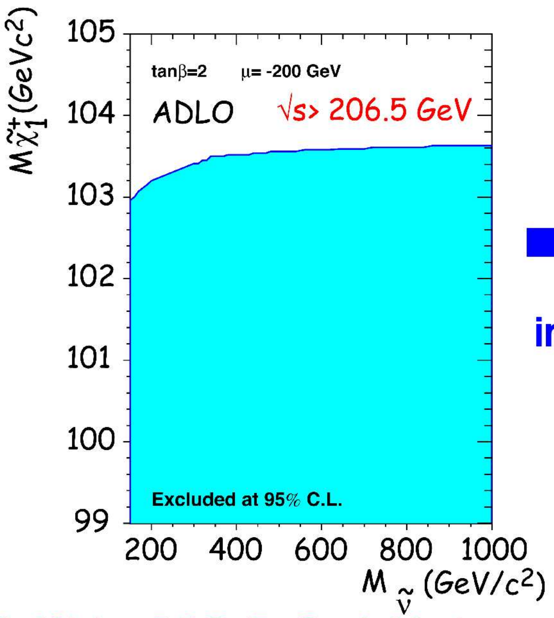


$e^+e^- \to \tilde{t}^+\tilde{t}^- \to bl^+\tilde{\nu}\ bl^-\tilde{\nu}$

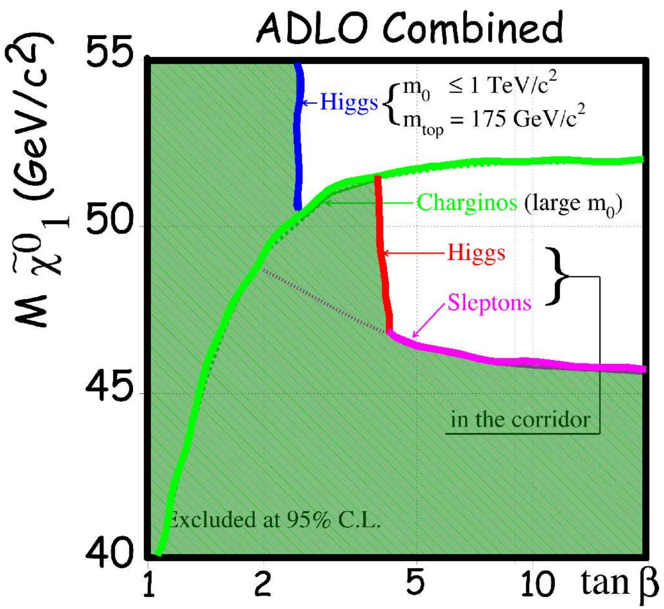


- **similarly 160 GeV stop-mass reach for** $q\bar{q} \to \tilde{t}^+\tilde{t}^- \to c\tilde{\chi}^0_1\ c\tilde{\chi}^0_1$
- **Run-II analyses ongoing ...**

Chargino and Neutralino Limits



interpret.



$M_{\tilde{\chi}_1^+} \geq 103.5$ GeV/c²

for $M_{\tilde{\nu}} > 300$ GeV/c²

Limits on the lightest SUSY particles (LSP) in the constrained MSSM.

$M_{LSP} > 46$ GeV/c²

... new Di-/Tri-lepton results from Tevatron soon ...

assumes SUSY-GUT (SU(5), SO(10)) relation : $M_1 = 5/3 \tan^2\theta_W M_2$

drop GUT relations (unification via string theory) ⇨ no collider bounds on $m_{\tilde{\chi}_1^0}$

$m_{\tilde{\chi}_1^0} > 5\ GeV/c^2$

- **if LSP is lightest neutralino**
- **responsible for observed CDM relic density**
- **respect LEP2 limits on charginos, sleptons, sneutrinos**

D.Hooper, T.Plehn (hep-ph/0212226), Bottino et al. (PRD 67,063519 (2003))

$m_{\tilde{\chi}_1^0} > 100\ MeV/c^2$

- **from SN1987A**

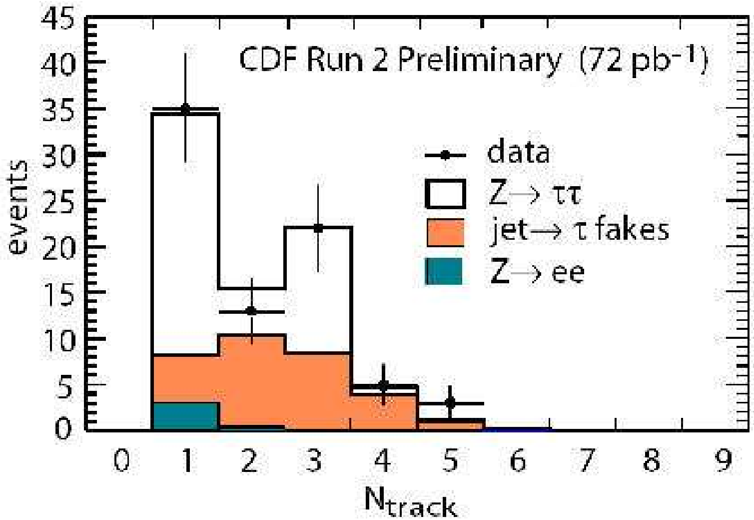
H.Dreiner et al. (hep-ph/0304289)

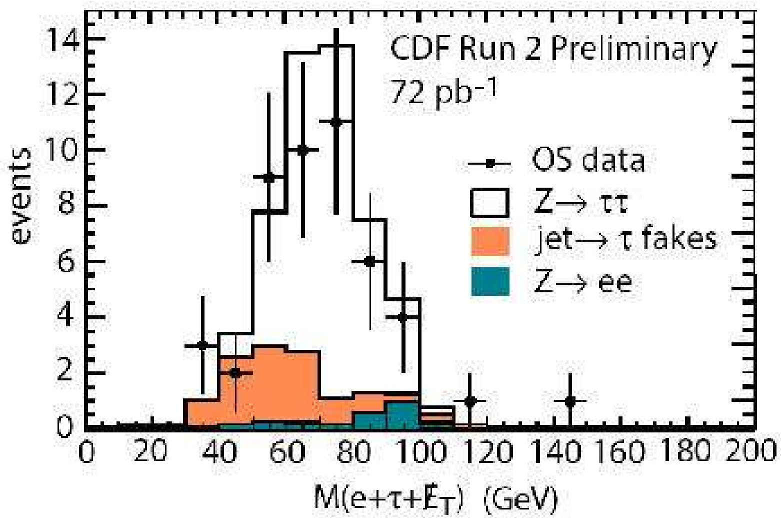
$Z \rightarrow \tau\tau$ Signal at the Tevatron

- **improved τ-finding in Run-II**
- **search for $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow$hadrons**
- **also $\tau \rightarrow \mu\nu\nu$ being analysed ...**

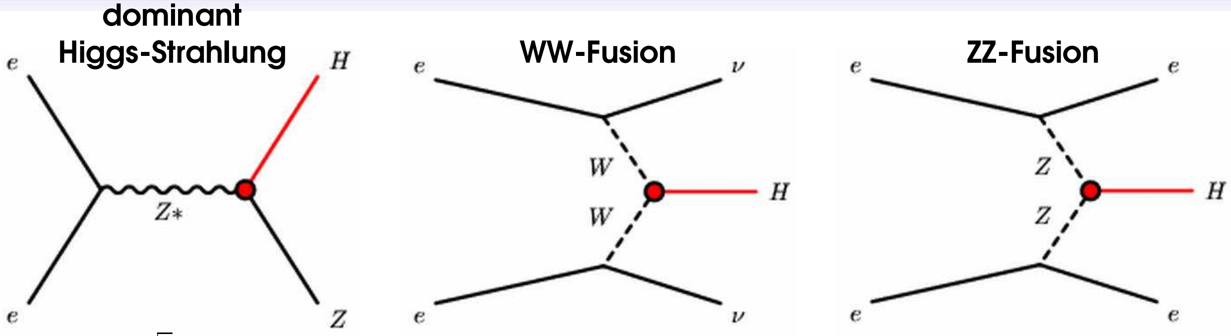
- **finding $Z \rightarrow \tau\tau$ is milestone in SUSY and Higgs searches ...**

... similar for DØ ...

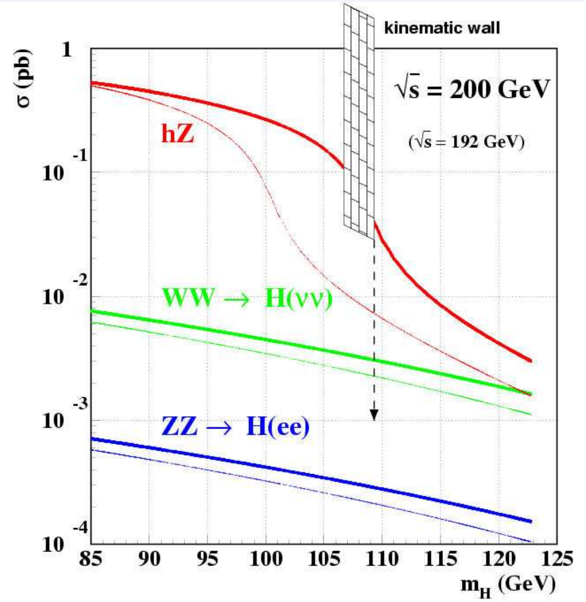




Search for SM Higgs-Boson at LEP



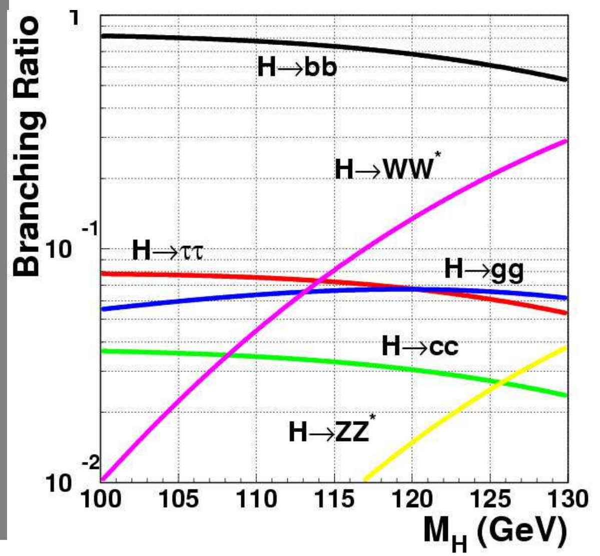
$m_H \leq \sqrt{s} - m_Z$



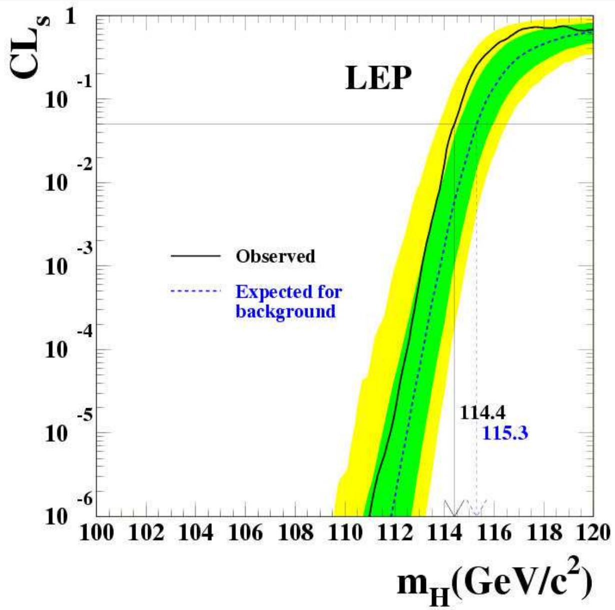
- 2461 pb^{-1} (536 pb^{-1} above 206 GeV) of LEP data
- mainly $H \to bb$, also $H \to \tau\tau$
- combined all channels, all energies, all experiments

NEW:

- full reprocessing (all)
  final detector calibrations, alignment constant,b-tagging tuning ...
- new generators (DELPHI), more MC statistics (all)
- precise LEP c.m. energy propagated (all)
- upgrades for (some) analyses
  - rejection of beam-related background (ALEPH 4-Jet)
  - revised analyses (OPAL): jet-pairing (4-Jet) and ANN (Emis)
  - backwd extension of analyses down to bb-threshold (DELPHI)
  - ...



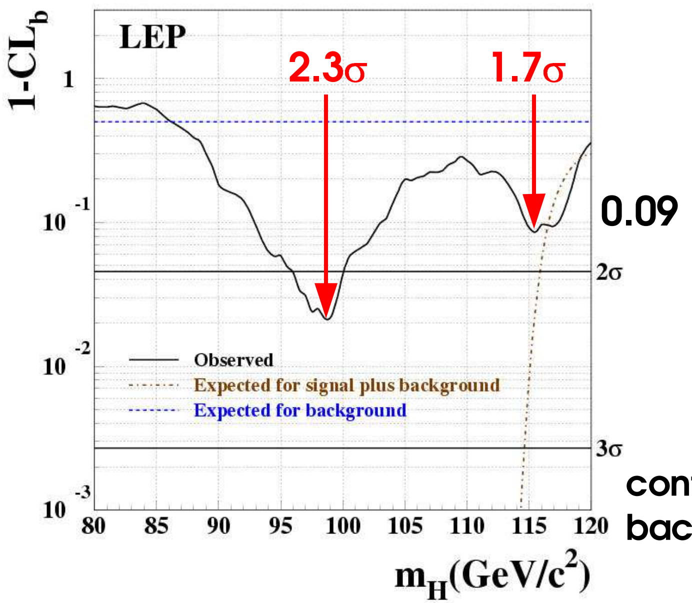
SM Higgs Searches at LEP (cont'd)



confidence level for signal+ background hypothesis

mass limits: m_h(GeV) >

experiment	expected	observed
ALEPH	113.5	111.5
DELPHI	113.3	114.2
L3	112.4	112
OPAL	112.7	112.8



confidence level for background hypothesis

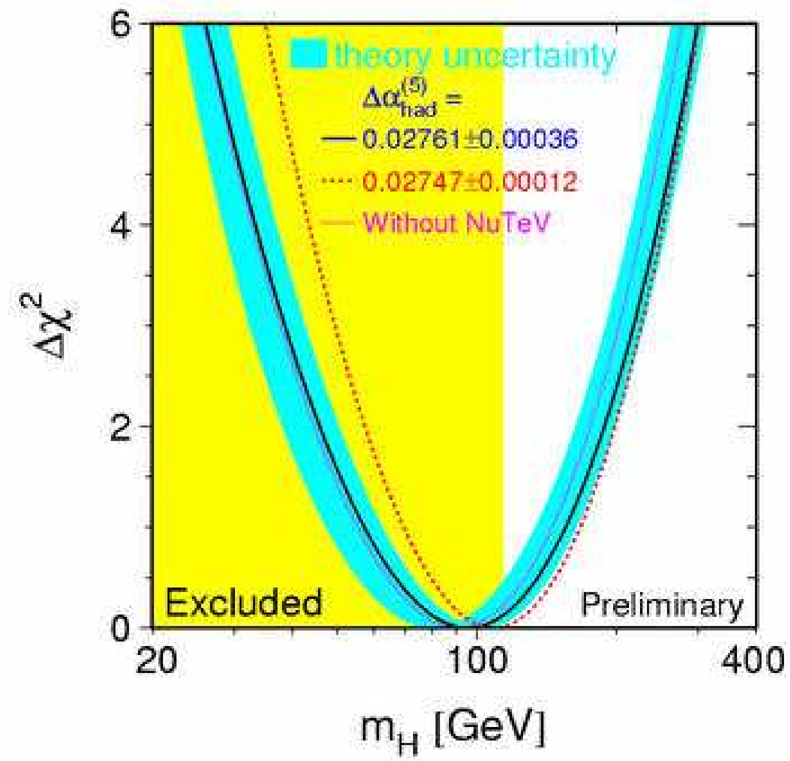
The final word from LEP:

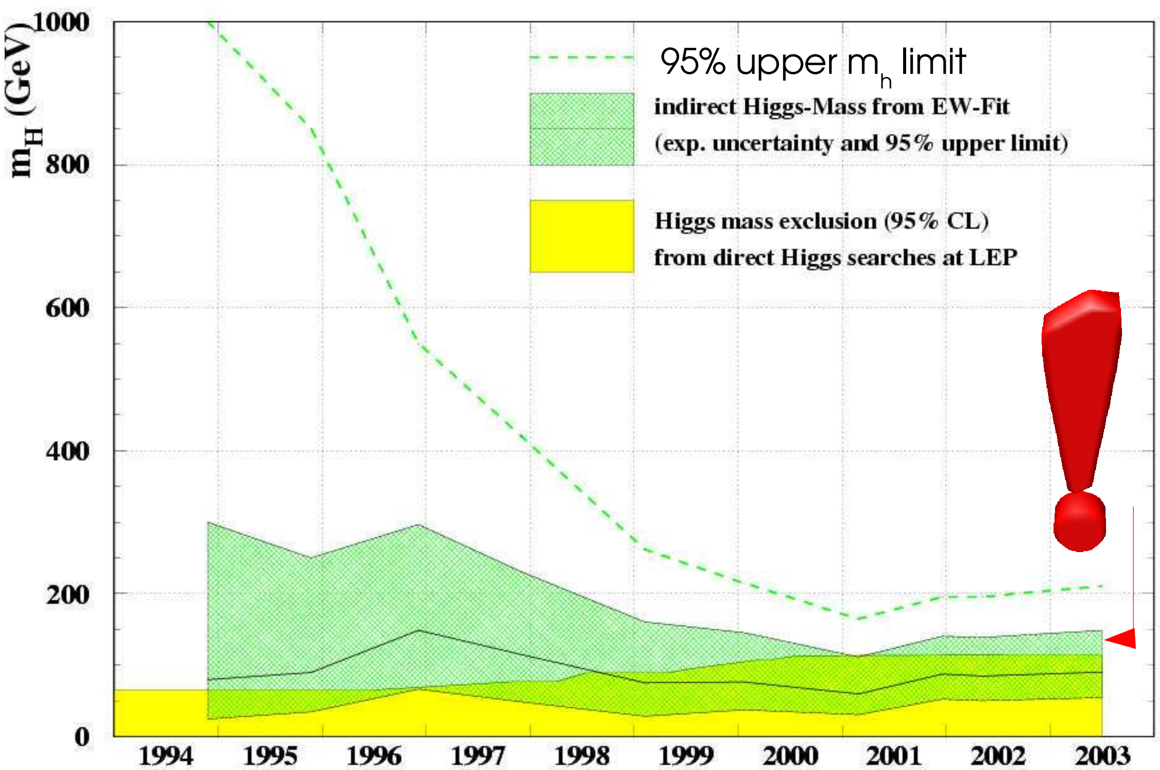
CERN-EP/2003-011
submitted to Phys.Lett.B

- mass limits:
  obs. m_h > 114.4 GeV
  exp. m_h > 115.3 GeV
- at $m_h \approx$ 115 GeV about 1.7σ excess
  ⇒ compatible with SM Higgs boson
  as well as with background-only

SM Higgs Search – Status Quo

➔ P.Wells

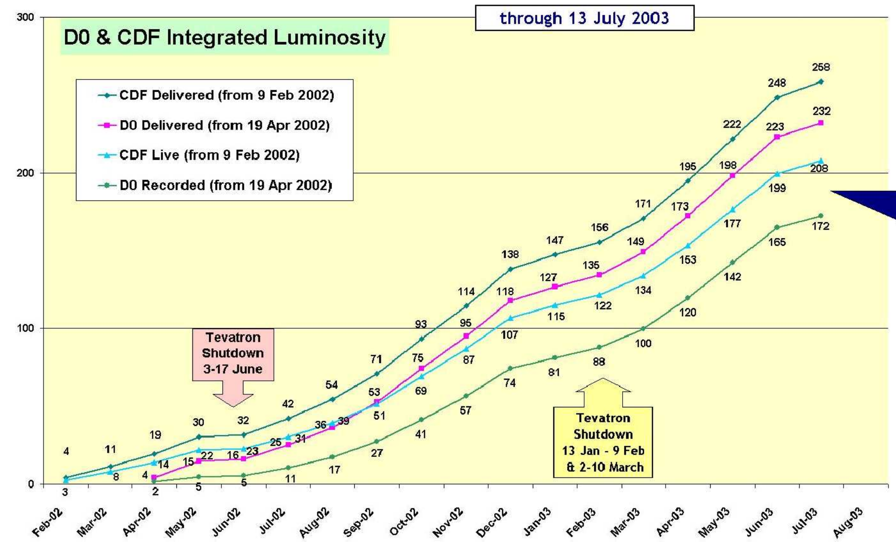




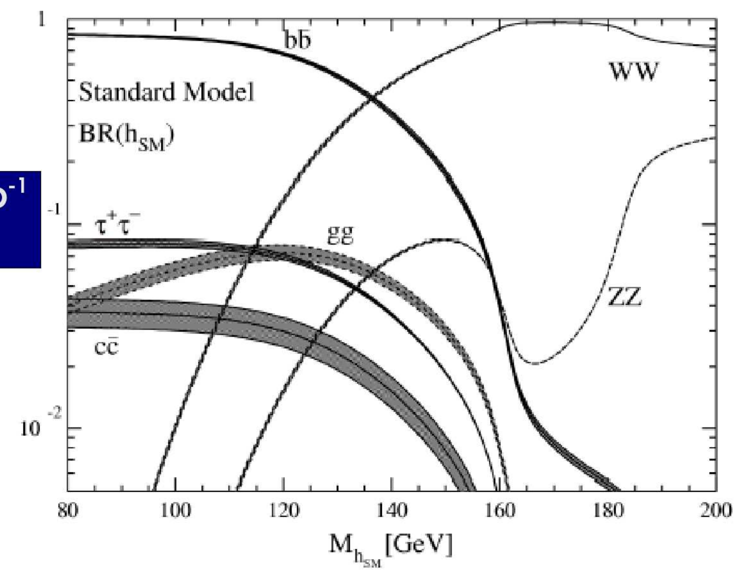
$$m_H = 91^{+58}_{-37}\ GeV$$

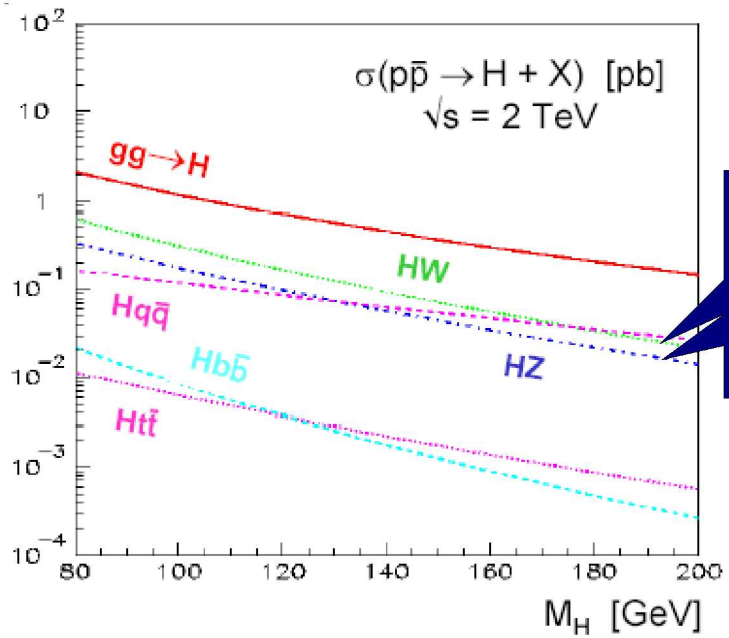
$$m_H < 219\ GeV$$ (95% CL)

Tevatron Luminosity and Prospects

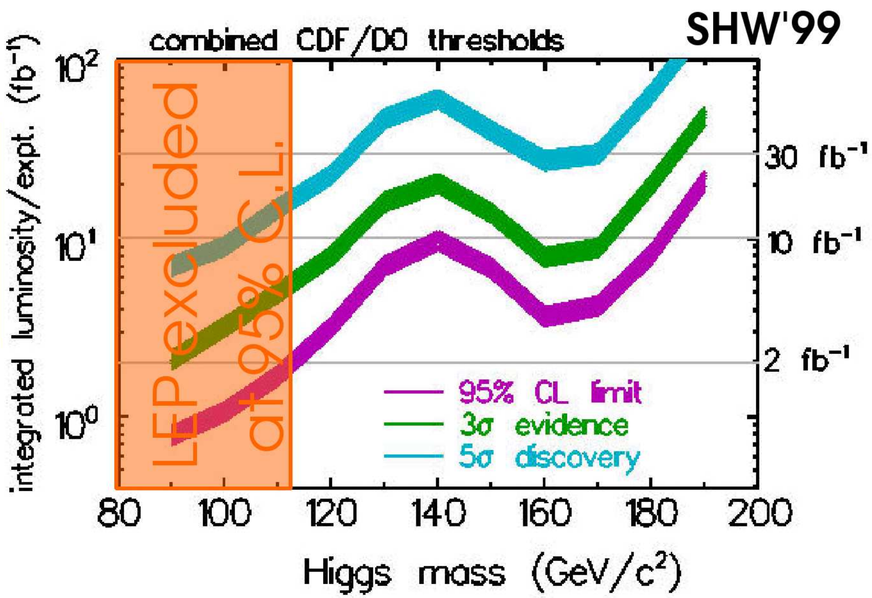


170 – 210 pb^{-1} recorded





use HZ and HW with H→ bb,WW and Z→ ll, Z→ νν, W→ lν



SM Higgs Search at the Tevatron

Improved Understanding due to Data

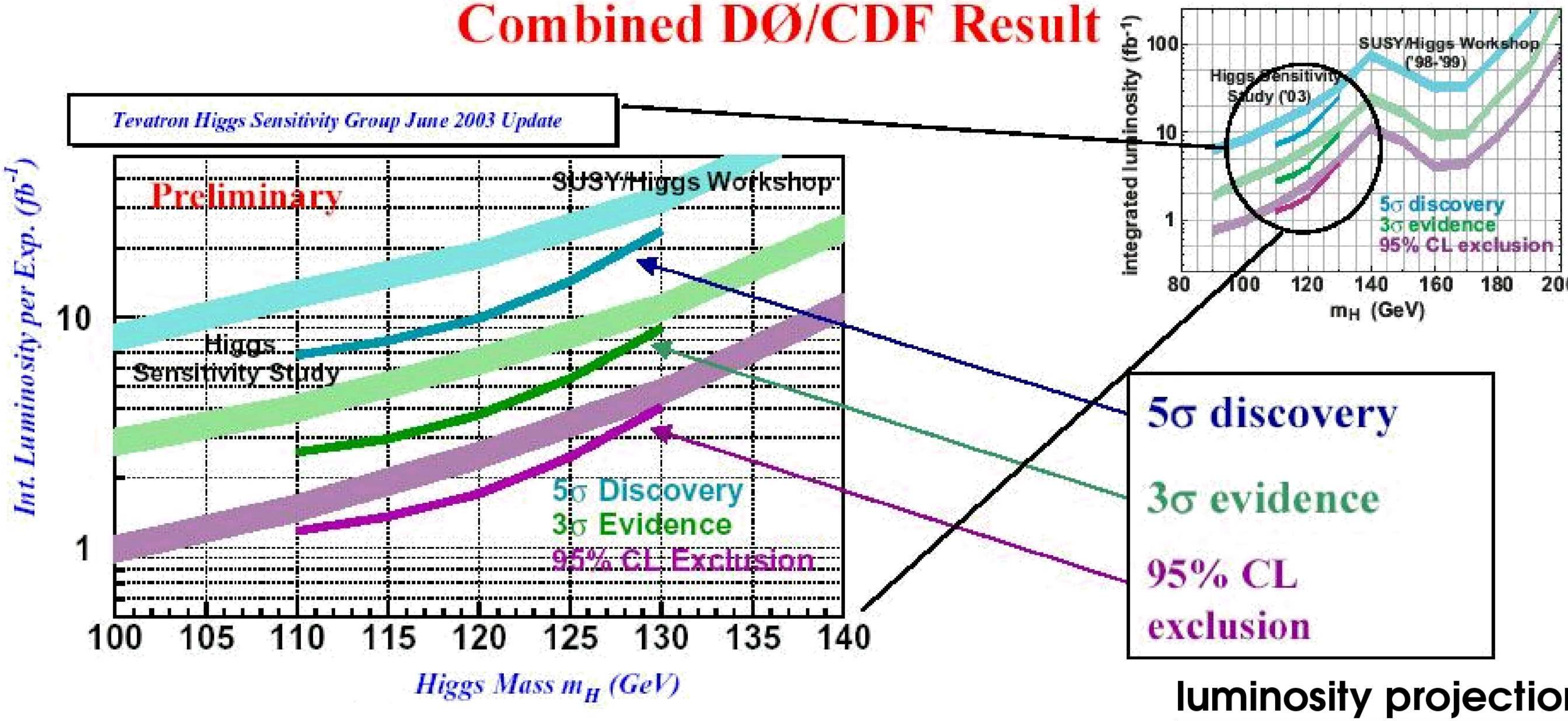
Process	*SHW 1999*	*Xsec '03*	*Ratio*	*Analysis '03*	*Ratio*	*comment*
HZ (115 GeV)	**3.15**	**3.82**	**1.22**	**2.86**	**0.91**	
HW (115 GeV)	**2.39**	**2.78**	**1.16**	**2.08**	**0.87**	
Zbb	4.34	1.73	0.4	1.99	0.46	from CDF data
Wbb	9.45	3.59	0.38	4.34	0.46	from CDF data
ZZ	1.82	2.36	1.3	2.93	1.61	PYTHIA 6.125 + K=1.34
WZ	1.45	1.79	1.45	1.84	1.27	PYTHIA 6.125 + K=1.34
tt	3	6.53	2.18	5.48	1.83	average of NLO calc.
qtb	0.31	0.8	2.62	0.68	2.22	NLO calc.
tb	4.7	0.49	0.1	0.35	0.08	NLO calc
QCD	25.06	17.3	0.69	11.16	0.45	from current study
total bgd	**50.11**	**34.59**		**28.77**		
Significance	**0.78**	**1.12**		**0.92**		

nr. events for 1 fb^{-1}

- **assumes mostly running with Run-IIB silicon tracker**
- **assumes Jet-Mass resolution of 10%,**
  SHW 1999 CAL reso. assumption met in Run-IIA
- **improvement mainly from sophisticated analysis techniques**
- **~50% less luminosity needed compared to 1999 with updated Xsec**
- **~28% less luminosity needed with realistic trigger efficiency,**
  QCD ... Bgd from data compared to SHW '99

SM Higgs Search at the Tevatron

Combined DØ/CDF Result



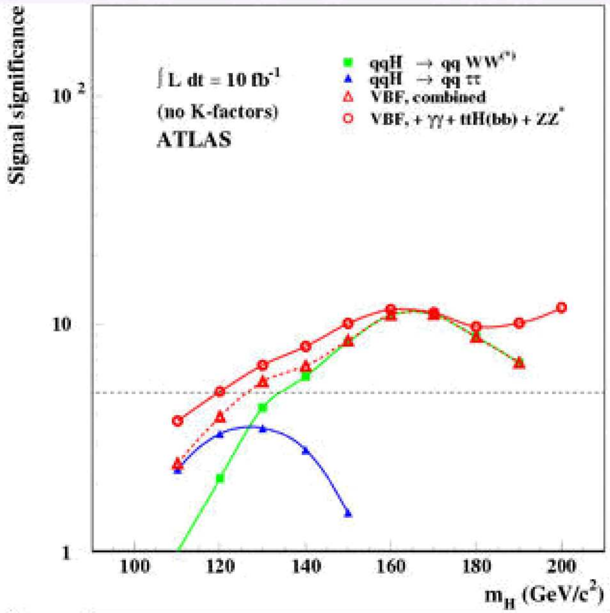
- combined ll, νν, lν channels
- no systematics included
- no h → WW channel; impacts m_H > 125 GeV

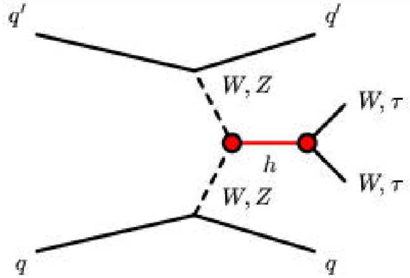
luminosity projection (fb^{-1})

year	baseline	design
2003	0.28	0.3
2004	0.59	0.68
2005	0.98	1.36
2006	1.48	2.24
2007	2.11	3.78
2008	3.25	6.15
2009	4.41	8.57

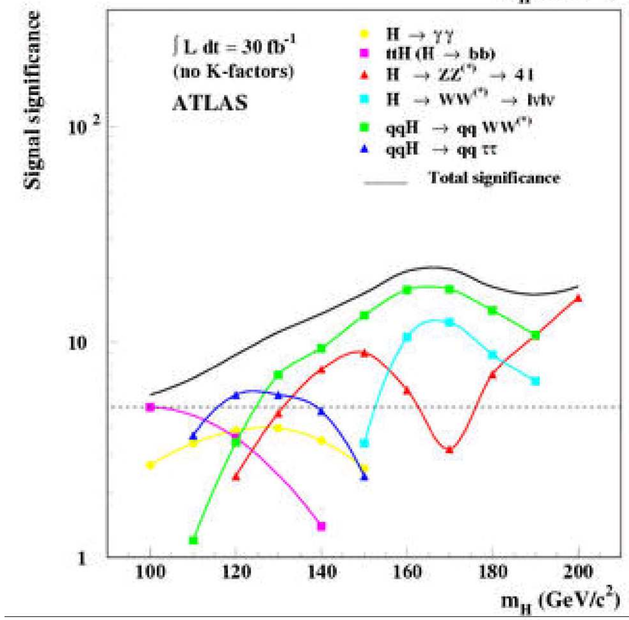
Higgs Searches at the LHC

➔ S.Arcelli





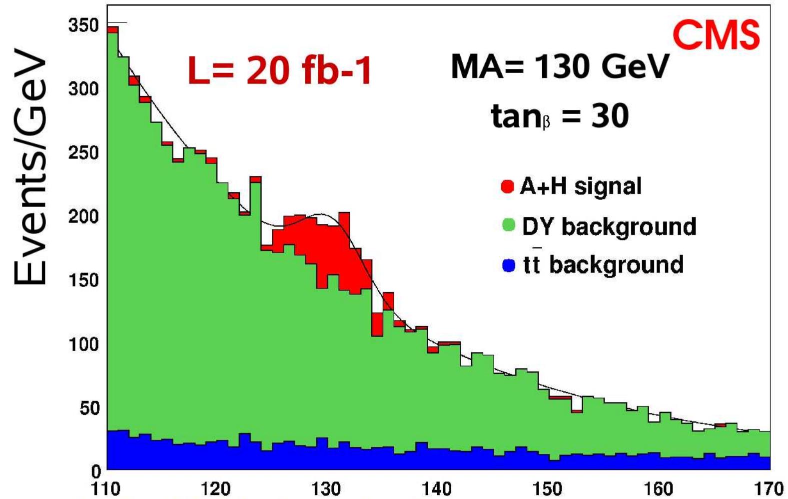
- VBF discovery potential for 10 fb^{-1} at m_H > 135 GeV
- with others m_H > 120 GeV
- coupling studies ongoing



- full mass range > 5σ with 30 fb^{-1}

<u>theory progress:</u>

NLO ttH	S.Dawson et al. '02;
(also pt and η)	W.Beenaker et al.'01
NLO gg → γγ (bgd)	Binoth et al.'00
NNLO gg → H	Harlander, Kilgore '03
	Anastasiou, Melnikov '02
	Ravindra, Smith van Neerven '03
NLO bg → Hb	Campbell et al. '02
NNLO bb → H	Harlander, Kilgore '03
WH- ZH production	Ciccolini et al. '03
...	



- ➔ br(h,A → μμ) ~3 ×10^{-4} but σ ~ $\tan^2\beta$
- ➔ expect $dM_{h,A}/M_{h,A}$~0.1% for 300 fb^{-1}
- ➔ at tan β >20 : $\Gamma_{hA} > \sigma(M_{\mu\mu})$

measure the width and constrain tanβ

2-Higgs Doublet Models

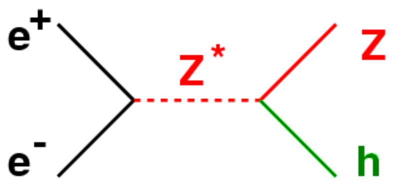
Two Higgs Doublets $\mathcal{H}_1, \mathcal{H}_2$ and 5 physical states

$$\mathcal{H}_1 = \Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}; \quad \mathcal{H}_2 = \phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}$$

2 CP-even neutral Higgses	h^0, H^0	$m_h < m_H$
1 CP-odd neutral Higgs	A^0	
2 charged Higgses	$H^\pm$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$m_h < m_Z < m_H$	
rad.corrected:	$m_h < 130$ GeV	

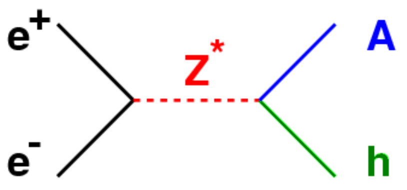
couples to	type I	type II	type III	type IV
'd-type' leptons	Φ_2	Φ_1	Φ_2	Φ_1
'u-type' quarks	Φ_2	Φ_2	Φ_2	Φ_2
'd-type' quarks	Φ_2	Φ_1	Φ_1	Φ_2

for example: MSSM



"Higgsstrahlung"

$\sigma_{hZ} = \sin^2(\beta - \alpha)\, \sigma_{HZ}^{SM}$



"Associated Production"

$\sigma_{hA} = \cos^2(\beta - \alpha) \bar{\lambda} \sigma_{\nu\bar{\nu}}^{SM}$

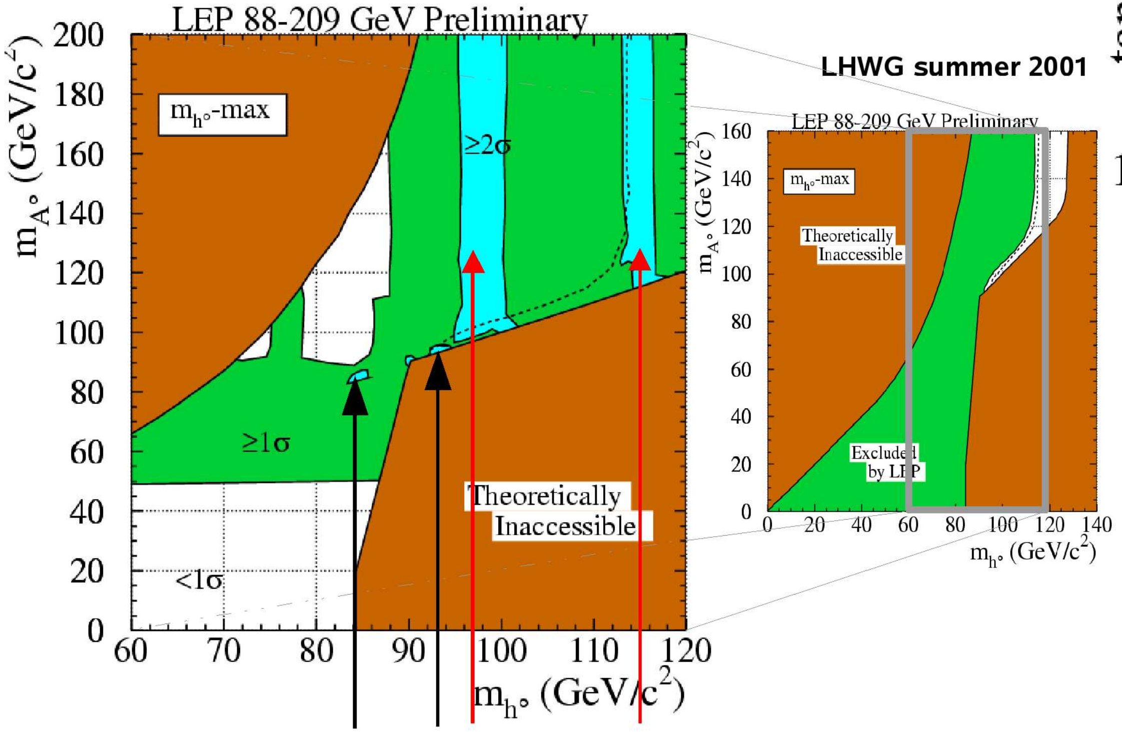
$g_{hff} \propto \cos\alpha$

$\Rightarrow$ fermiophobic for $\alpha = \pi/2$
i.e. might couple only to bosons, not to fermions

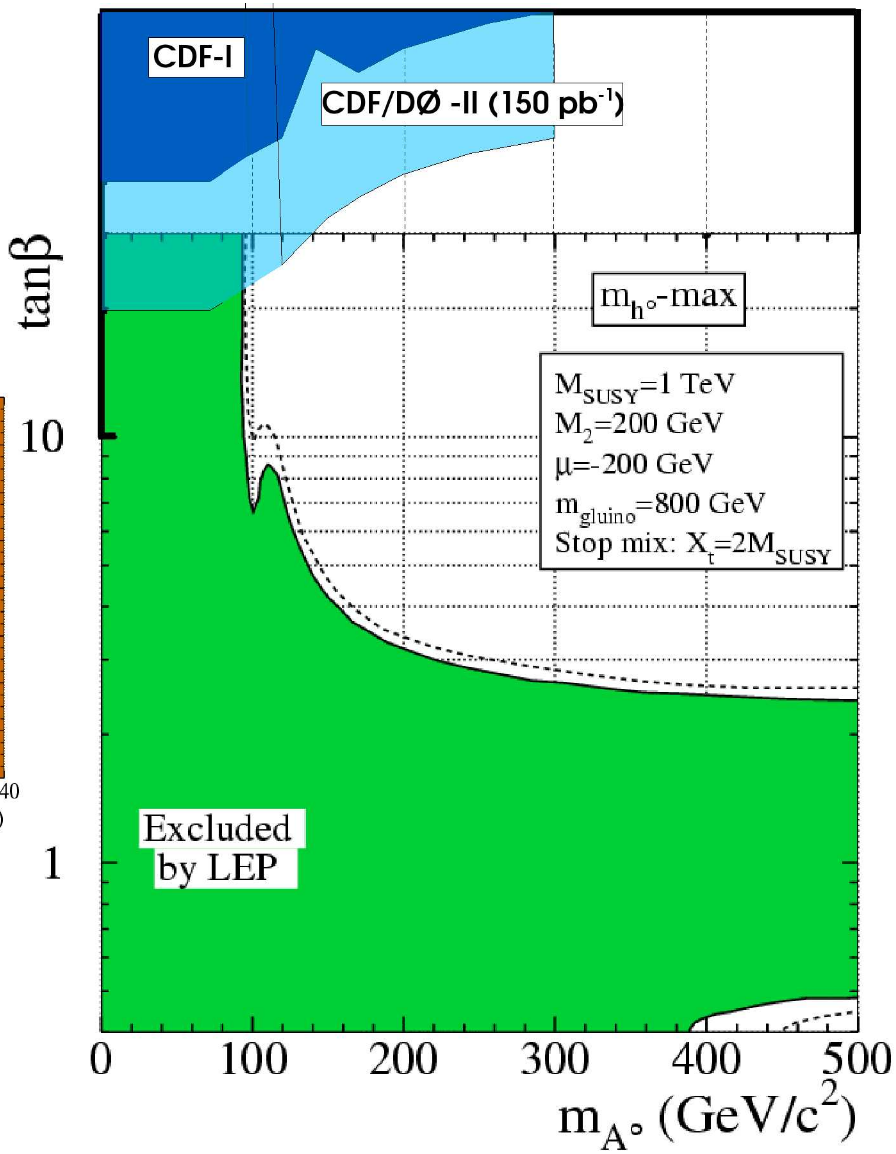
CP-Conserving MSSM Higgs Search

→ P.Bechtle

so far 3 benchmark scenarios:
- no stop mixing
- max m_h
- large μ (suppressed $h \to bb$)



from hA searches from hZ searches



mass limits: $m_A > 92$ GeV/c²

$m_h > 91$ GeV/c²

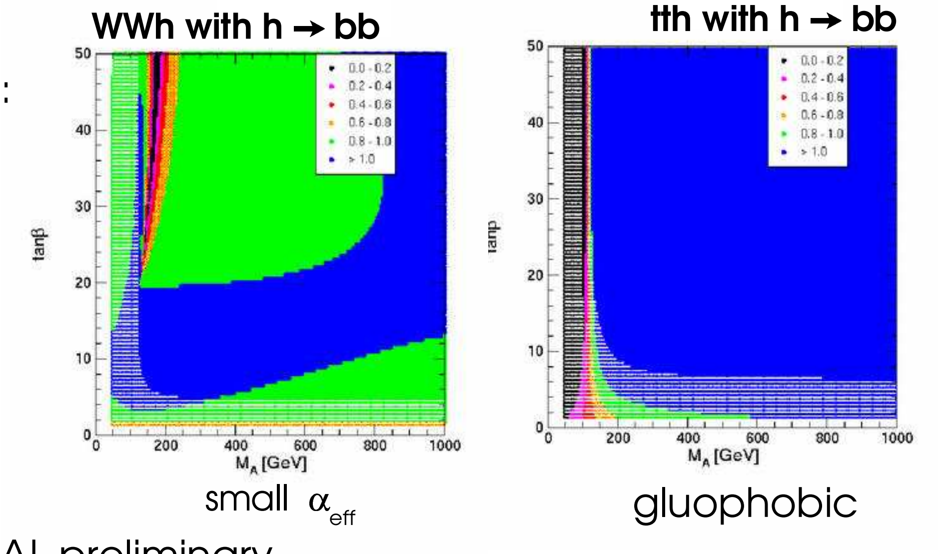
CP-Conserving MSSM Higgs Search

M.Carena et al. hep-ph/0202167

Now also LHC-inspired scans:
- **gluophobic ($gg \to h$ suppressed)**
- **small α_{eff} ($h \to bb$, $\tau\tau$ suppressed)**
- **modified M_{SUSY}, reverted μ-sign**
- **... improved calculations ...**

M.Frank et al.
A.Brignole et al.

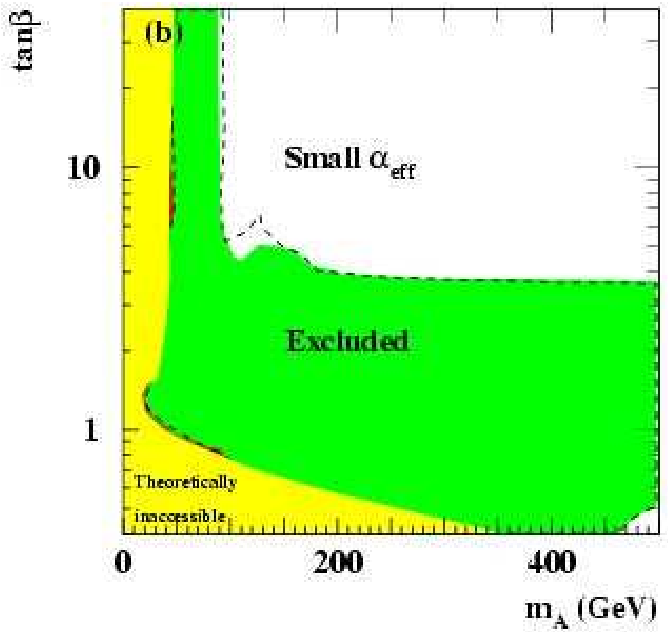
$\sigma_{MSSM} / \sigma_{SM}$:



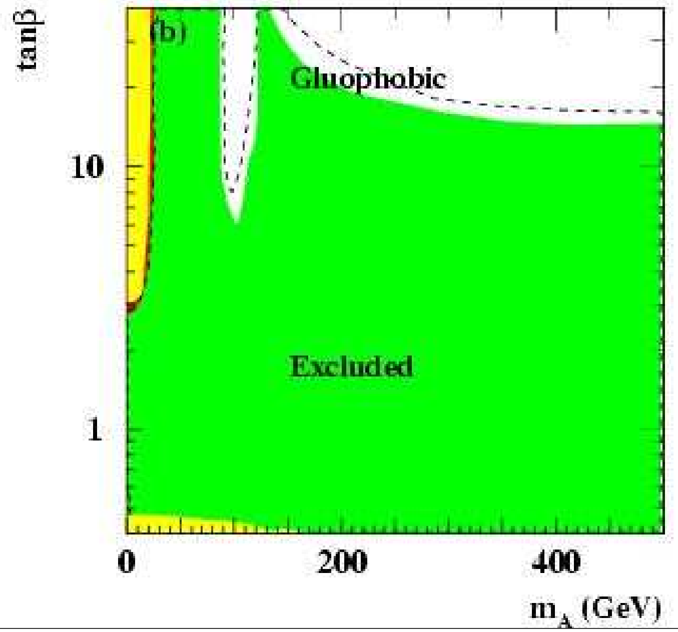
Red: **Z-width, Yukawa searches, decay indep. Higgs**

Green: **excluded**

OPAL preliminary



OPAL preliminary



h → bb suppression out of LEP reach ...

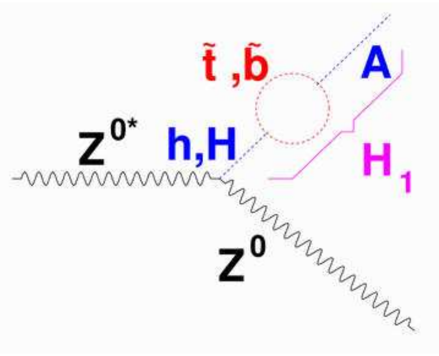
... and even more benchmark scans done ...

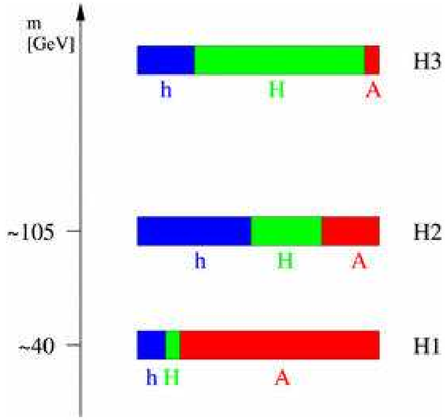
... to be combined by LHWG ...

CP-Violating MSSM Higgs Search

- Trilinear couplings A_u break SUSY and Arg $A_u \neq 0$ introduces CP violation
- CP violation in Higgs sector: (A.Pilaftsis et al.)
  $\Rightarrow$ A, h, H not eigenstates
  $\Rightarrow$ new eigenstates H_1, H_2, H_3
- Arg $A_u \neq 0$ motivated by baryogenesis
- benchmark with large μ, Arg A_u, small M_{SUSY}
- mixing and coupling suppression

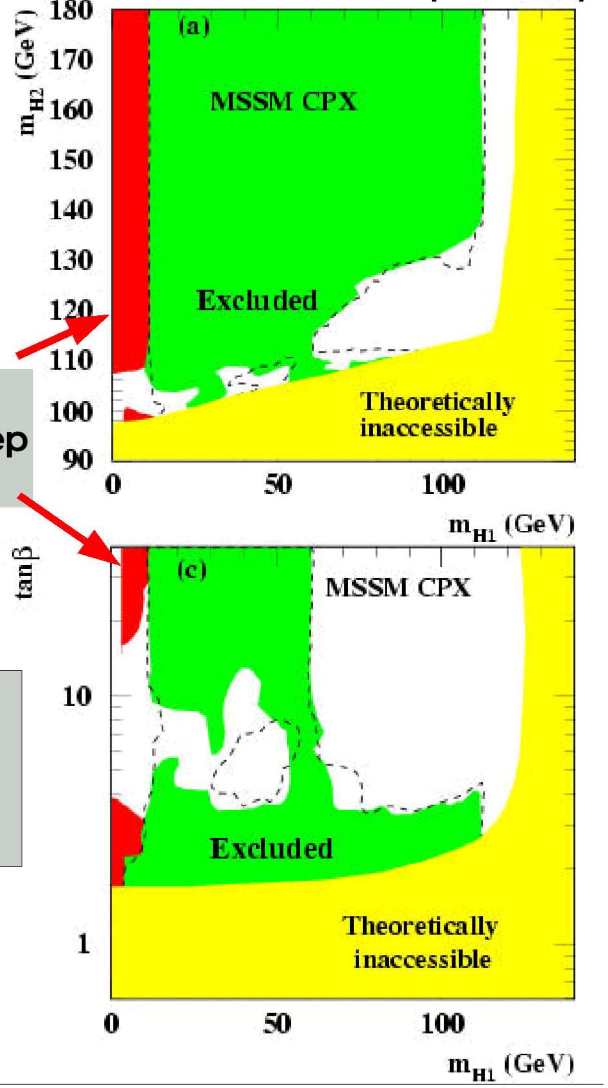
OPAL preliminary





Z^0-width or model-indep h-searches

unexcluded regions at low m_h !

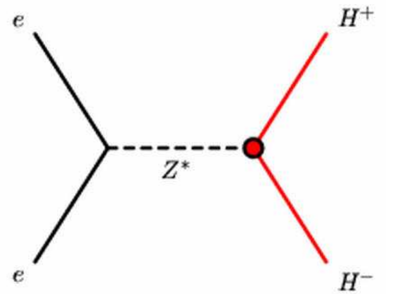


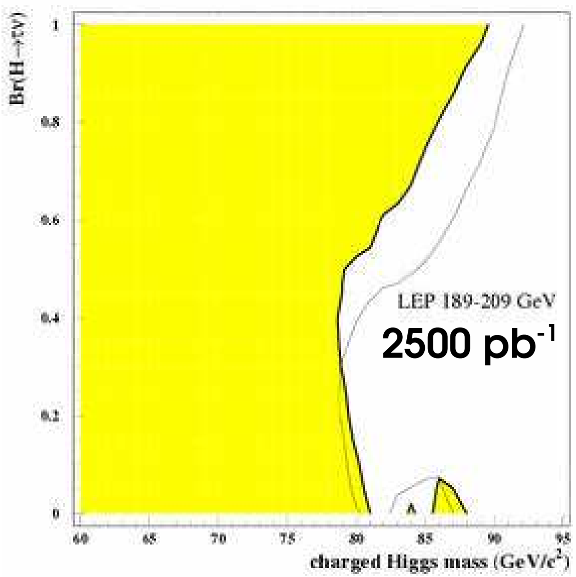
... search for H_1 and H_2 in H_iZ and H_iH_j ...

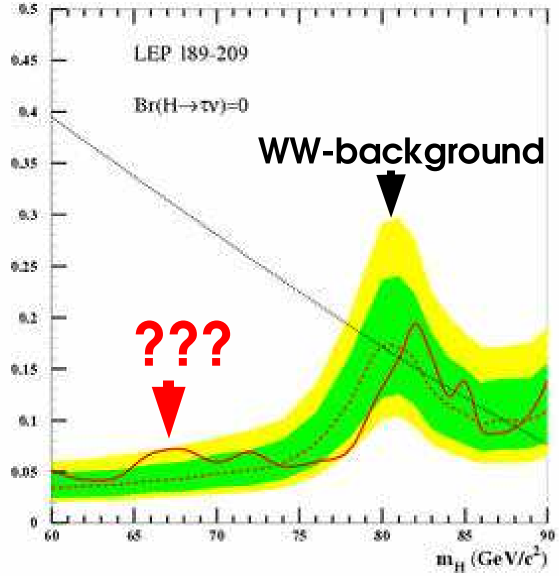
Charged Higgs Bosons $H^{\pm}$

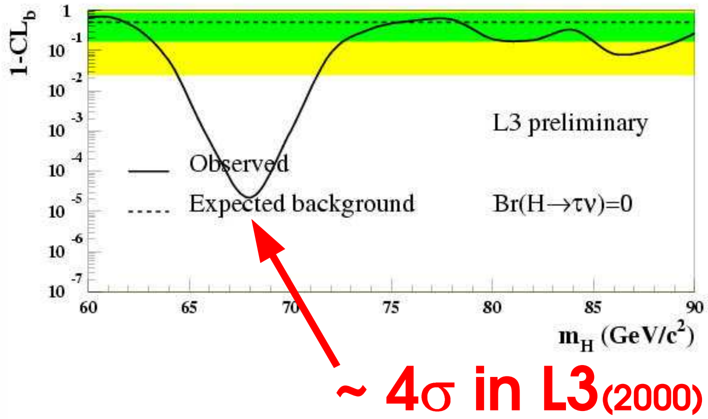
➔ J.Cuevas

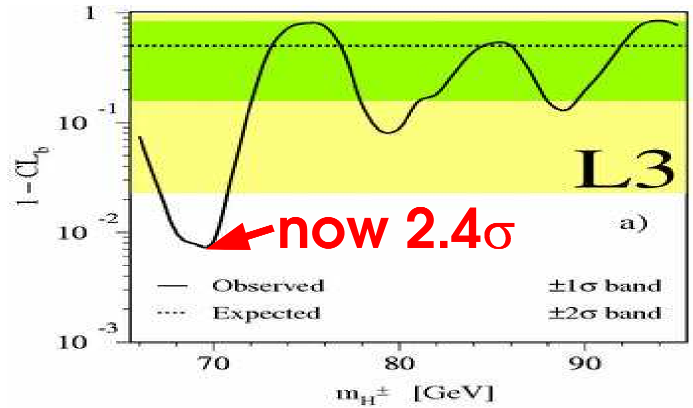
- in 2HDM type-II: down/up fermions to $\mathcal{H}_1/\mathcal{H}_2$
- at born level: $m_{H\pm} > m_{W\pm}$; with rad.corr. can have $m_{H\pm} < m_{W\pm}$
- scalar $H^{\pm}$ (signal) ↔ vector $W^{\pm}$ (Bkgd)
- assume (3 channels) $Br(H^{\pm} \rightarrow c\bar{s}) + Br(H^{\pm} \rightarrow \tau\nu) = 1$











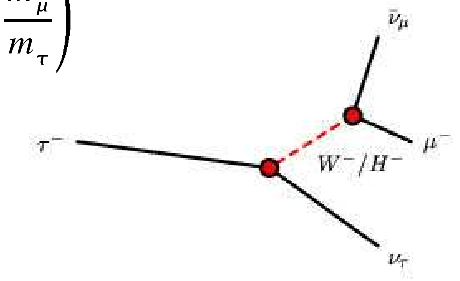
... new results (DELPHI, OPAL, L3) to be combined ...

Charged Higgs Bosons $H^\pm$ (cont'd)

- In 2HDM **type-II** external constraints from (OPAL) : $m_{H^\pm} > 1.28 \tan\beta$ GeV

$$\frac{Br(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} = 0.9726 \left(1 + 4\eta \frac{m_\mu}{m_\tau}\right)$$

$$\eta = -\frac{m_\tau m_\mu}{2}\left(\frac{\tan\beta}{m_{H^\pm}}\right)^2$$

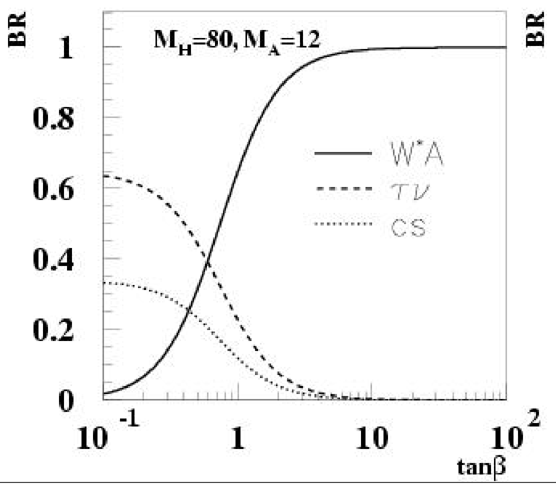


- Complements earlier study of $b \to \tau^- \bar{\nu}_\tau X$: $m_{H^\pm} > 1.89 \tan\beta$ GeV

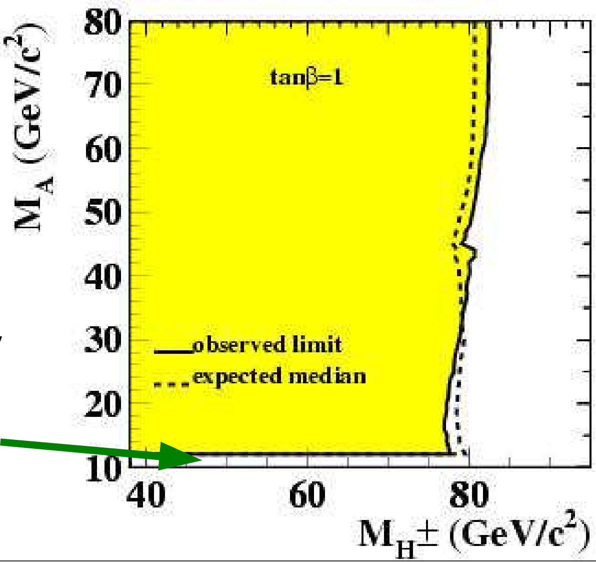
In 2HDM (type I):

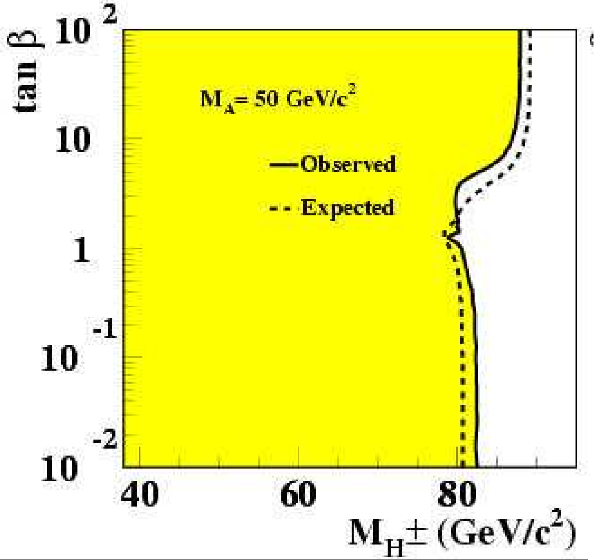
- $H^{+-} \to W^{*+-} A^0$ dominates for tan β>1 if kinem.allowed
- search in LEP2 data also for
  - $H^+H^- \to W^*A\ W^*A \to$ qqbb qqbb
  - $H^+H^- \to W^*A\ W^*A \to l\nu$bb qqbb
  - $H^+H^- \to \tau\nu\quad W^*A \to \tau\nu$ qqbb

... typical exclusion limits (DELPHI) ...



m_A below bb not covered



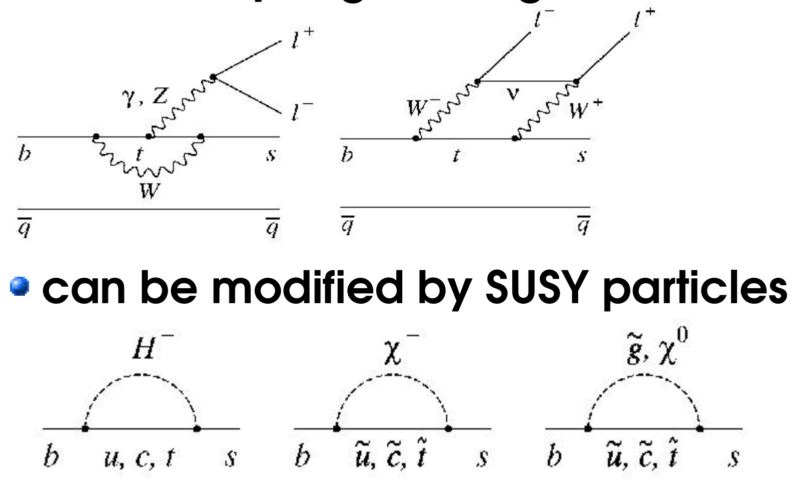


Search for $B \to K^{(*)} l^+ l^-$

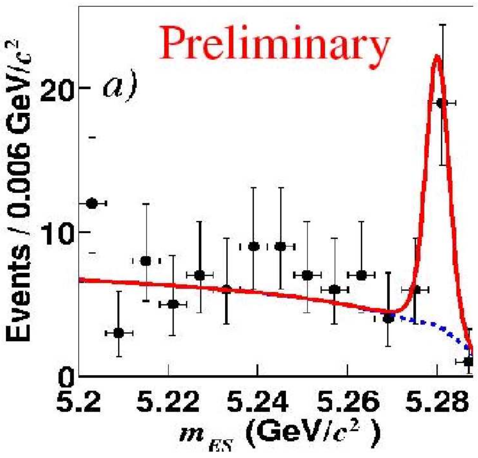
➔ M.Convery

BABAR :
(88.5 ± 0.9) 10^6 $B\bar{B}$ pairs

- **in SM via penguin diagrams**
- **can be modified by SUSY particles**



Combined $B \to K l^+ l^-$ fits

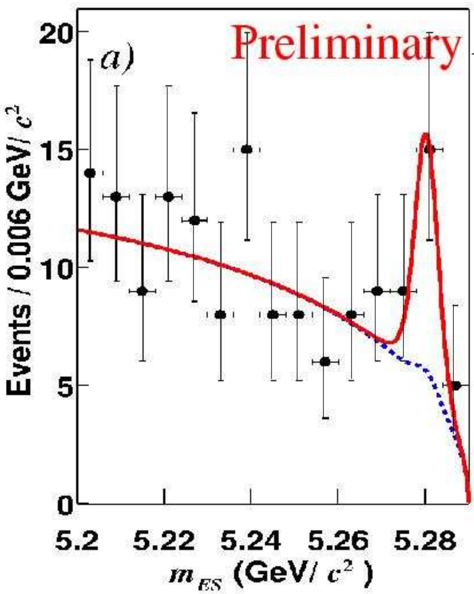


$Br(B \to K\, l^+ l^-) = (0.68^{+0.17}_{-0.15} \pm 0.04) \times 10^{-6}$

theory: 0.3 – 0.69 * 10^{-6}

➪ **7**σ

Combined $B \to K^* l^+ l^-$ fits



$Br(B \to K^*\, l^+ l^-) = (1.40^{+0.57}_{-0.49} \pm 0.21) \times 10^{-6}$

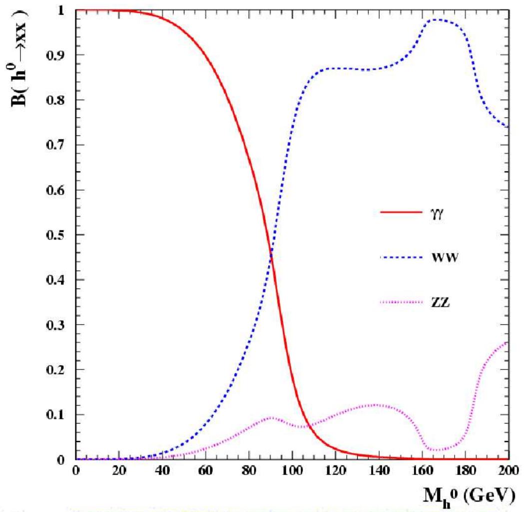
theory: 0.8 – 2.01 * 10^{-6}

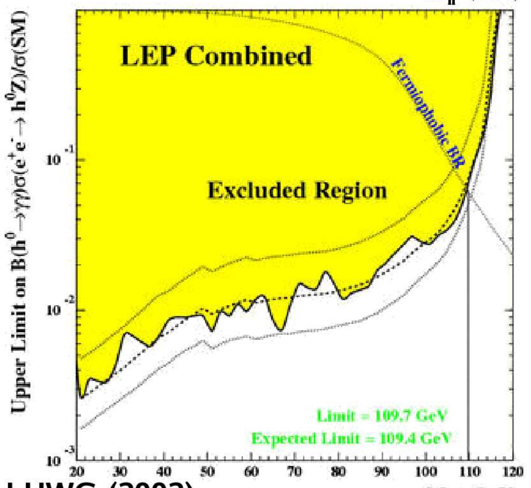
➪ **3**σ

Fermiophobic Higgs Searches

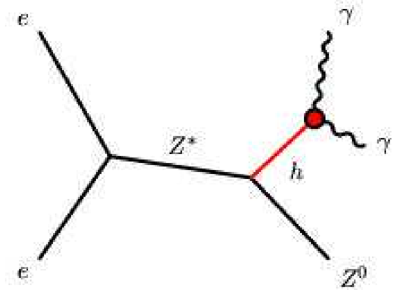
➔ D.Baden

- In 2HDM - type I Higgs coupling to fermions g_{Hff} ~ cos α can go to zero (→ ` fermiophobic Higgs')
- Increase of bosonic Higgs decays (in SM Br(H → $\gamma\gamma$) ≈ 0.1% for m_h≡90 GeV)

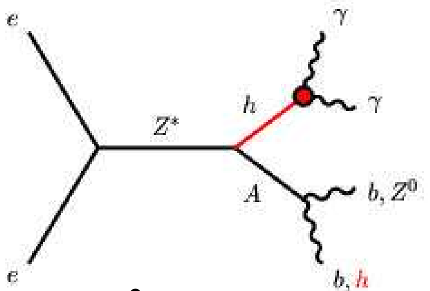




LHWG-(2002)



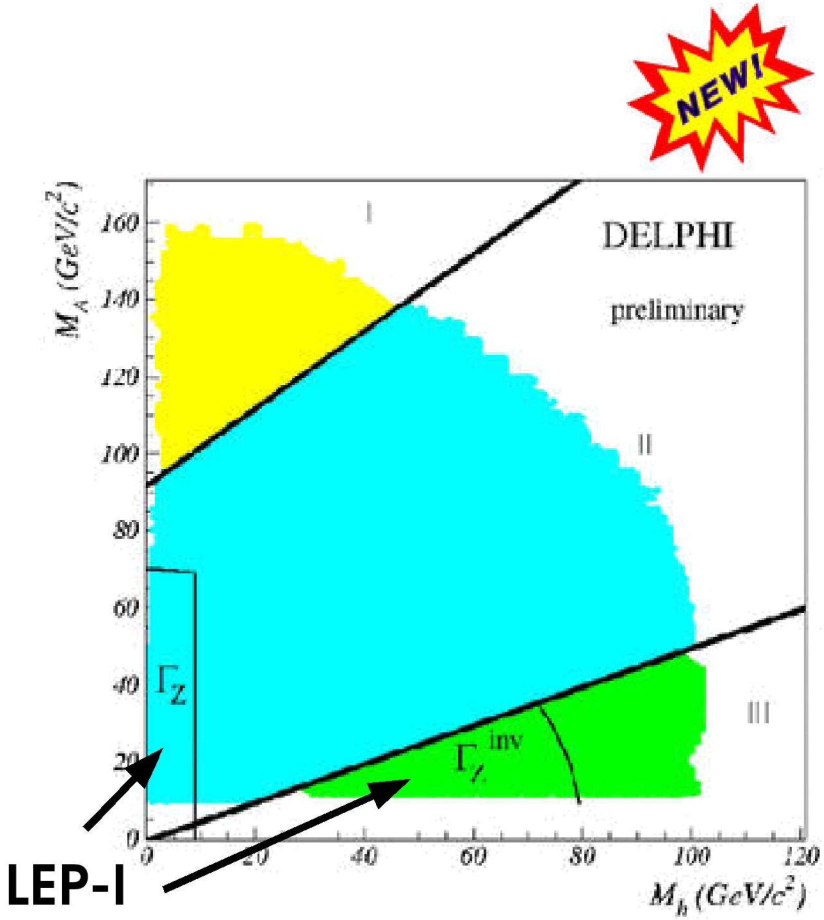
σ ~ $\sin^2(\beta-\alpha)$



σ ~ $\cos^2(\beta-\alpha)$

At SM production rate:
m_h > 109.7 GeV (obs.)
m_h > 109.4 GeV (exp.)

@Tevatron-I/II > 80 GeV



Doubly Charged Higgs Bosons $H^{\pm\pm}$

➔ J.Cuevas

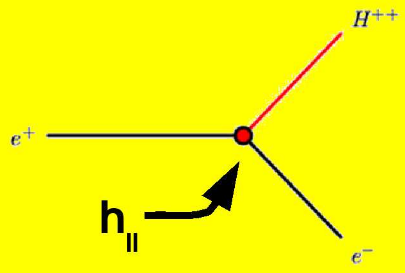
Motivation:

in LR-symmetric models → large mass for right-handed Majorana neutrino
→ small ≠0 neutrino mass via see-saw mechanism
→ right-handed weak force ?

in Higgs triplet models → generate small ≠0 neutrino mass

⇒ predict low mass doubly charged Higgs, m($H^{\pm\pm}$) ~ 100 GeV

decays: $H^{++} \to l^+ l^+$ (dominant), lepton-nr. violation
$H^{++} \to H$ + gauge boson (negligible)



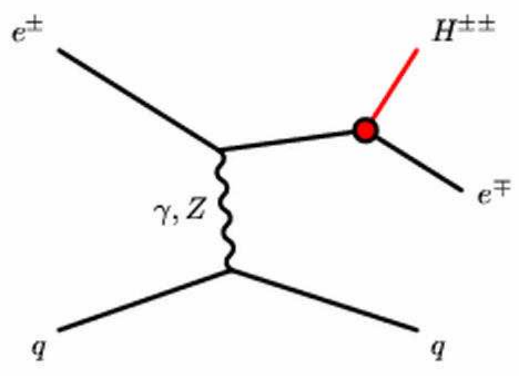
limits on Yukawa couplings from

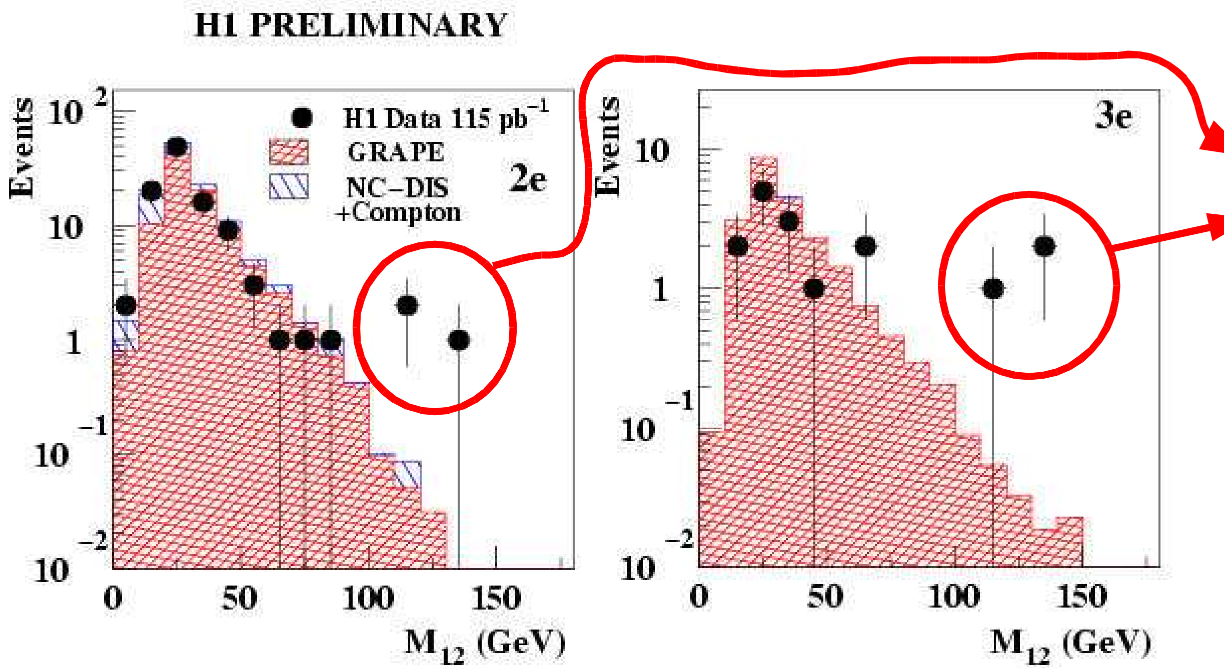
- muonium conversion ($\mu^+e^- \to \mu^-e^+$) $\sqrt{h_{ee} h_{\mu\mu}} \leq 7.6 \cdot 10^{-3}\, GeV^{-1} M_H$
- avoiding $(g-2)_\mu$ contributions $h_{\mu\mu} \leq 5.0 \cdot 10^{-3}\, GeV^{-1} M_H$

...search for same-sign multi-lepton events ...at LEP, HERA, TEVATRON ...

Single $H^{\pm\pm}$ Production at HERA

- recent excitement (2002) from high mass multi-electron events in H1



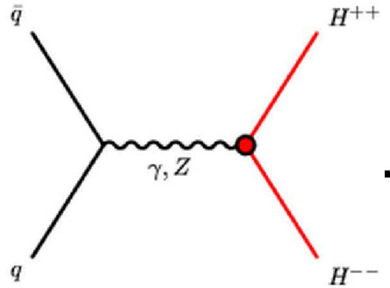


exprmt	selection	Data	SM
H1	2e M > 100	3	0.25 ± 0.05
H1	3e M > 100	3	0.23 ± 0.04
ZEUS	2e M > 100	2	0.77 ± 0.08
ZEUS	3e M > 100	0	0.34 ± 0.09

- no excess in ZEUS
- no excess in $\mu\mu$-channel
- in dedicated $H^{\pm\pm} \rightarrow ee$ search 1/0.34 events
- $\Rightarrow$ something else ... ?

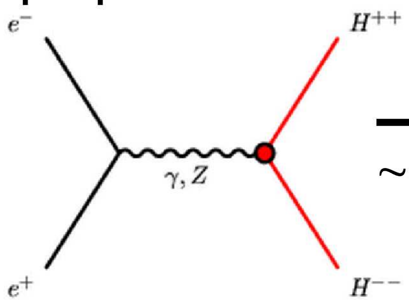
Doubly Charged Higgs Bosons $H^{\pm\pm}$

pair production at TEVATRON



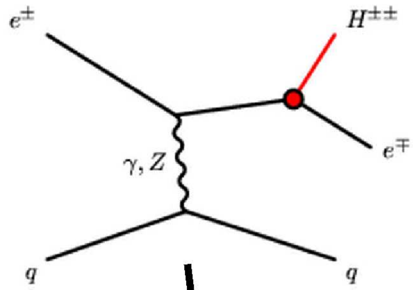
CDF-II (e,μ), DØ-II (μ)
2 fb^{-1}: > 150 – 200 GeV

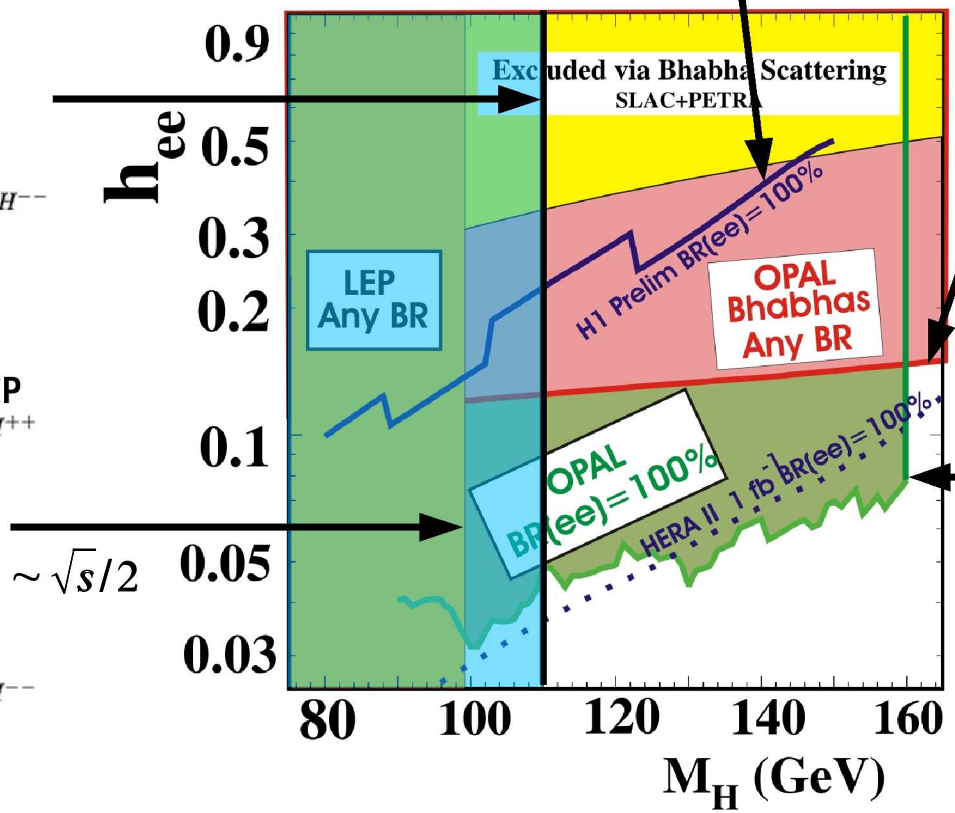
pair production at LEP



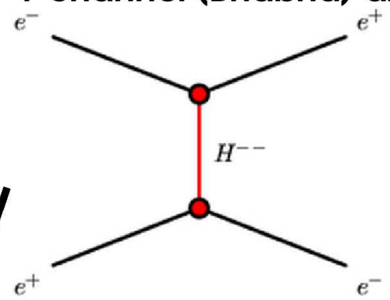
OPAL (e,μ,τ; no lifetime)
DELPHI (τ; any lifetime)
L3 (e,μ,τ; no lifetime)

single production at HERA



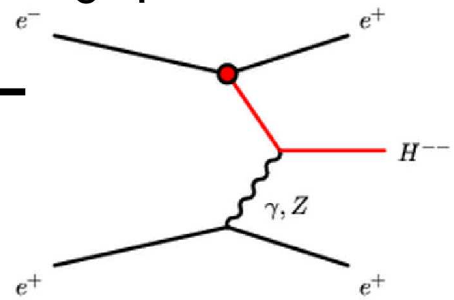


t-channel (Bhabha) at LEP



- lumi measurement ok
- would change angular distribution

single production at LEP



- very forward e might get lost

Conclusions

- Expect physics beyond the Standard Model ...
  - we are groping in the dark – where will we find it ?
- Fundamental scale / structure
  - EW $\leftrightarrow$ TeV $\leftrightarrow$ M_{pl}
- Experiments:
  - model-independent searches
  - searches within numerous models
  - rare decay measurements
  - precision EW measurements
  - a lot more sensitivity in our hand (HERA-II, Tevatron-II, LHC ...)
  - ...
- New physics at/from TeV scale
  - due to EW-symmetry breaking / Higgs sector (Tevatron, LHC, linear collider)

... next 5 to 10 years will tell ...

Acknowledgements

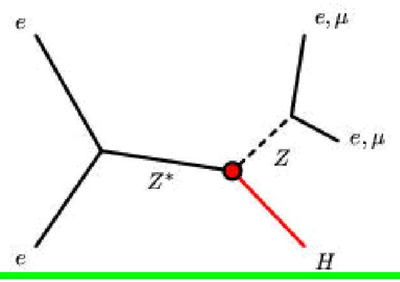
- Many contributors both directly and indirectly to this talk, including
  - New results and plots
  - New combinations
  - Suggestions about what to show
  - Suggestions about what *NOT* to show
- All mistakes and inconsistencies are mine!
- In particular, thanks to (not a complete list):

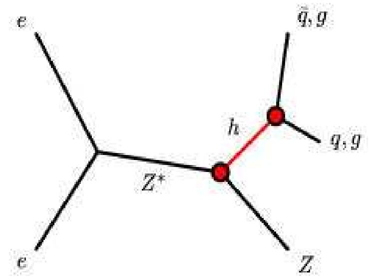
F.Bedeschi, G.Broijmanns, D.Dannheim, *Herbi Dreiner*, E.Gallo, J.Hobbs, G.Landsberg, H.Logan, C.Mariotti, S.Mele, P.Newman, T.Nunnemann, C.Rembser, A.Schöning, R.Tenchini, M.Wegner, T.Wengler, A.Zarnecki

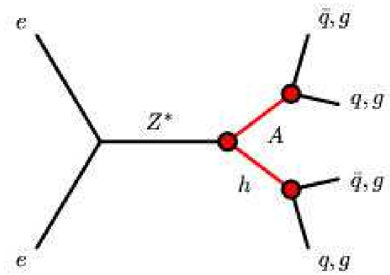
... and many more ...

Decaymode- and Flavour-Independent Higgs

➔ M.Boonekamp

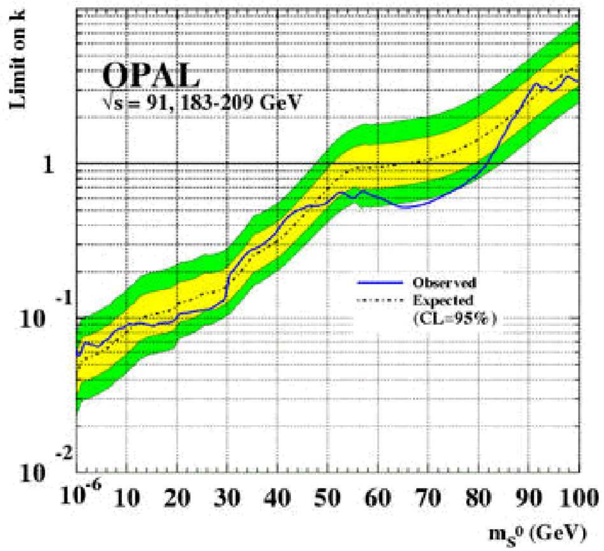


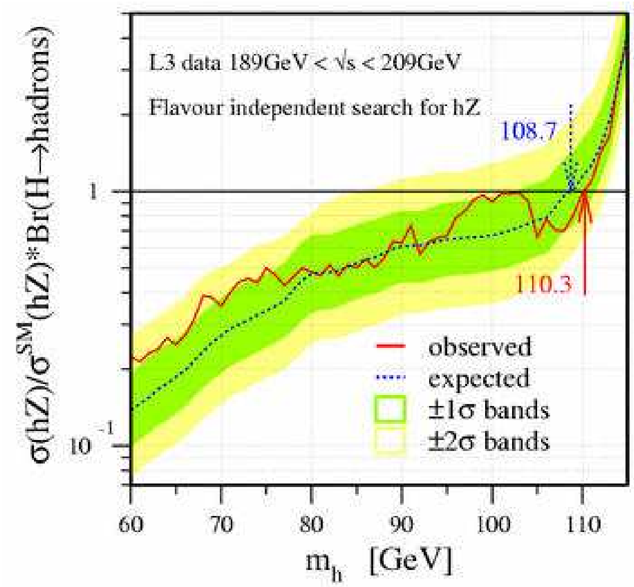


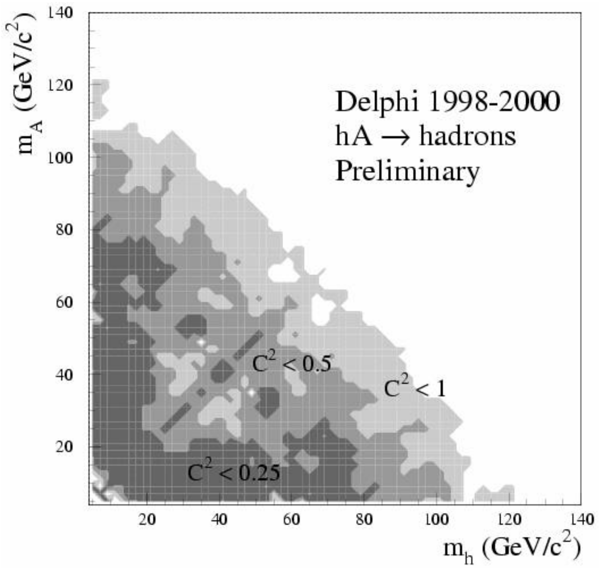


$$\sigma_{S^0Z^0} = k \cdot \sigma_{H_{SM}Z^0}$$

$c^2 = \sigma^{95} / \sigma^{SM}(hZ) * Br(h,A \rightarrow hadrons)$







cross-section exclusions:

k<0.1 @ 1 keV < m_{s^0} < 19 GeV

k<1 @ m_{s^0} < 81 GeV

absolute mass limit for SM coupling strength

... also OPAL, ALEPH ...

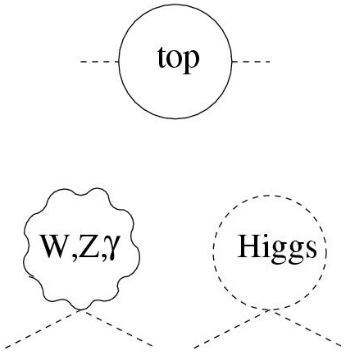
... LEP analyses being finished, to be combined ...

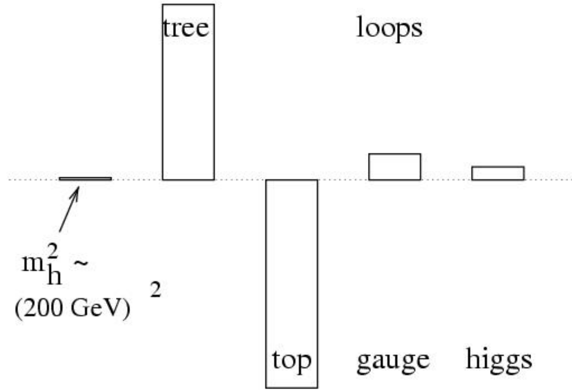
'Little' Higgs

→ H.Logan, E.Ros

- in SM quadratically divergent loops in Higgs mass rad. corrections
- fine tuning problem to 1% can be addressed by SUSY ...

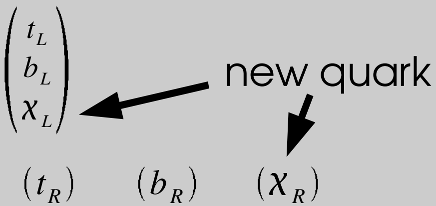
⇒ cancellation of loops one by one (top-loop dominant)





in little Higgs theory:

- Higgs is pseudo-Goldstone boson (from global symmetry breaking)
- left-handed SU(3) triplet
- three right-handed quark singlets



➔ χ_R cancels top loop divergence at one-loop

➔ gauge and Higgs loops cancelled by new bosons

➔ built-in SU(3) symmetry enforces relations between couplings

m_χ ~ 900 GeV – 2 TeV

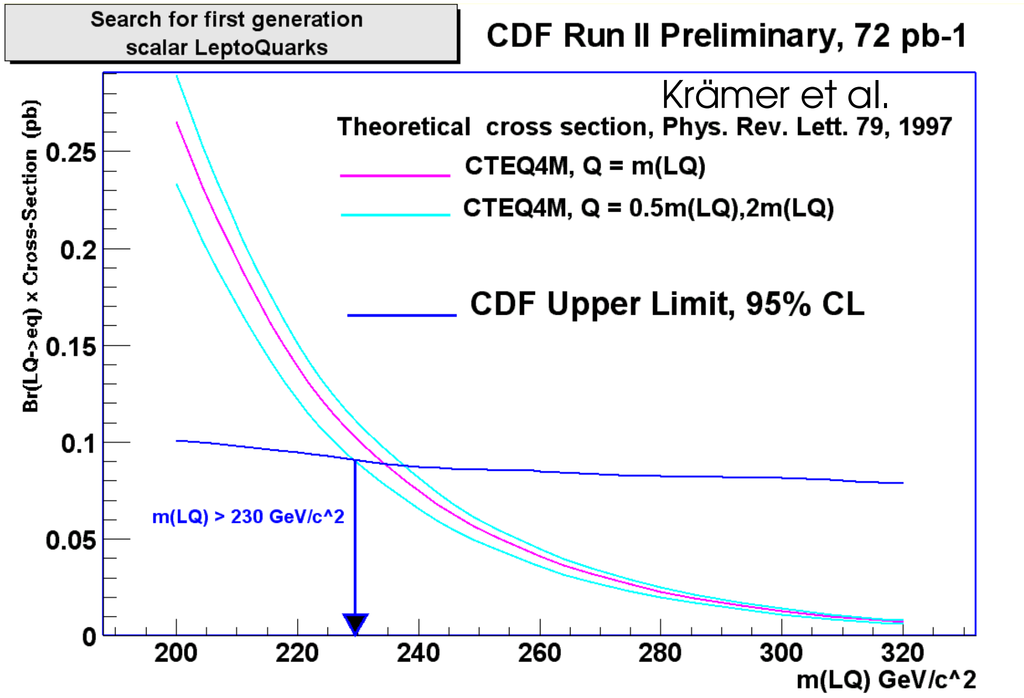
Arkani-Hamed, Cohen, Georgi

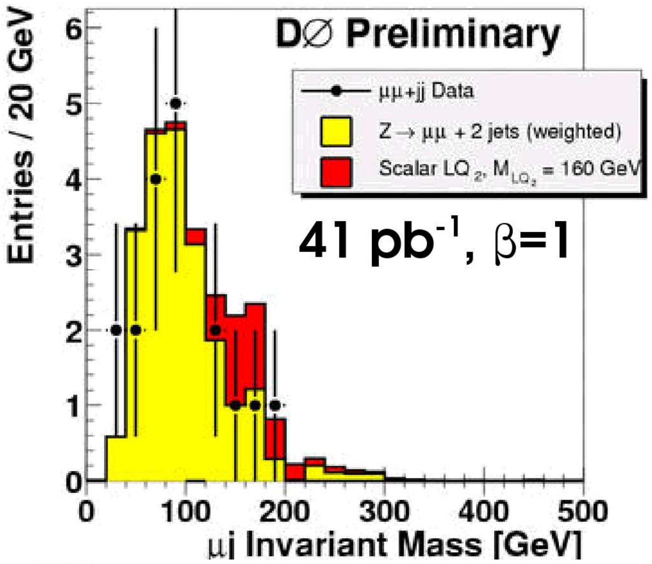
experimental search:

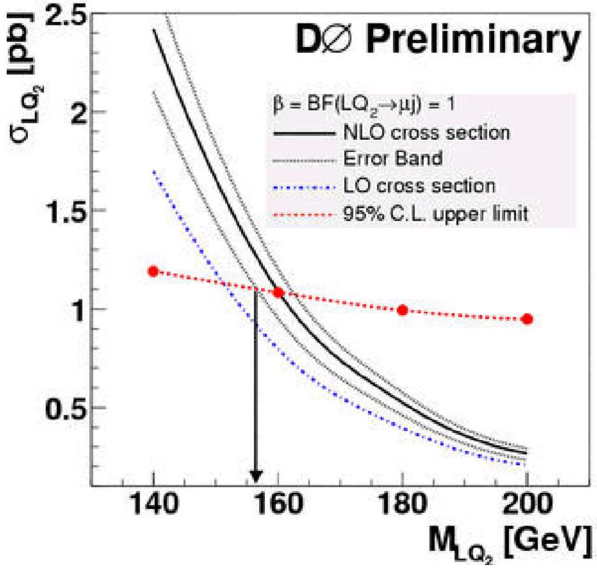
- pair-production of charge 2/3 quark
  $\chi \rightarrow$ h+t, W+b, Z+t
- single production of new gauge bosons
  quantum nrs model-dep., mix with W,Z
- new scalars, m=100 GeV – 2 TeV
  often additional higgs doublets ...

Leptoquark Searches at the Tevatron-II

1st gen. **2nd gen.**







CDF-II M_{LQ} > 230 GeV in eeqq (72 pb^{-1})

M_{LQ} > 107 GeV in $\nu\nu$qq (76 pb^{-1})

DØ-II M_{LQ} > 179 GeV in eeqq (41 pb^{-1})

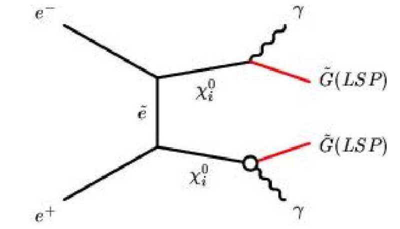
M_{LQ} > 157 GeV in $\mu\mu$qq (41 pb^{-1})

... reach up to M_{LQ} ~250-325 GeV (2 fb^{-1}) ...

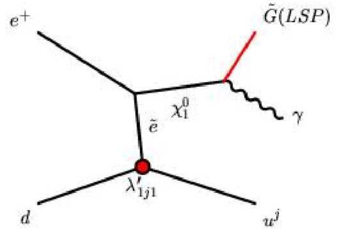
Limits on RP-Violating GMSB

➔ C.Schwanenberger

LEP: R_p conserving SUSY



HERA: R_p violating SUSY



- HERA competitive with LEP for $\lambda'_{1j1} \approx 1$
- improved sensitivity from HERA-II
- first limits on independent of λ'_{121} squark masses