Hadron Collider Physics
- Experimental Overview – Part III -

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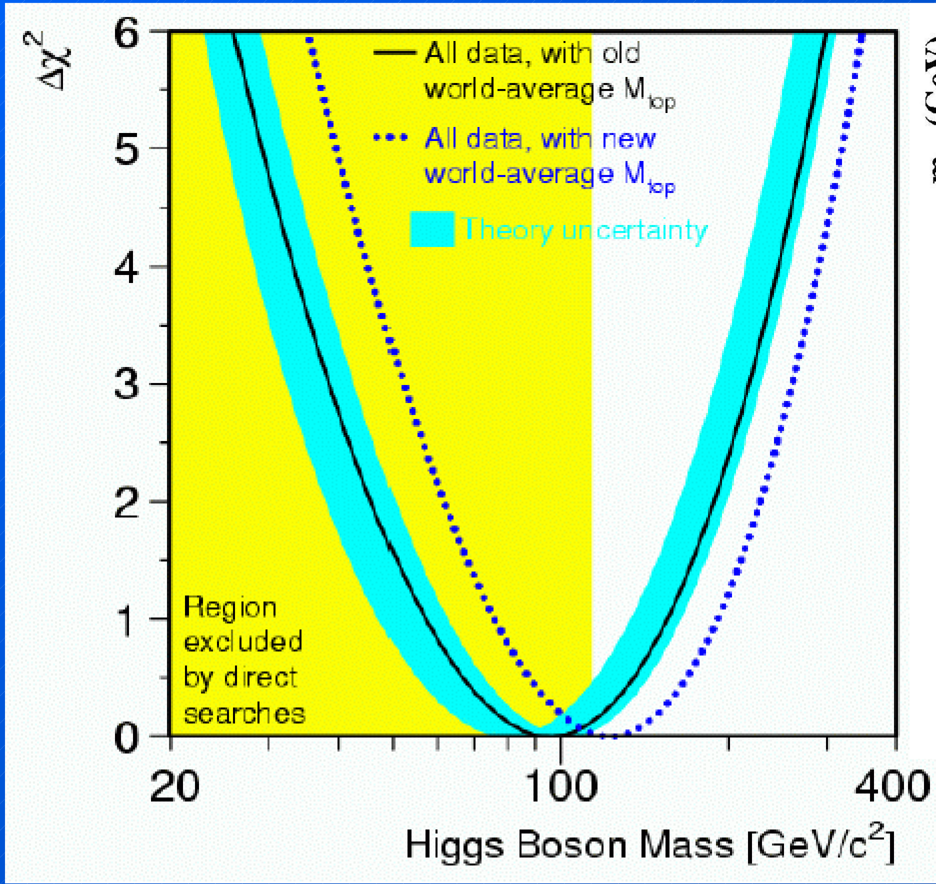
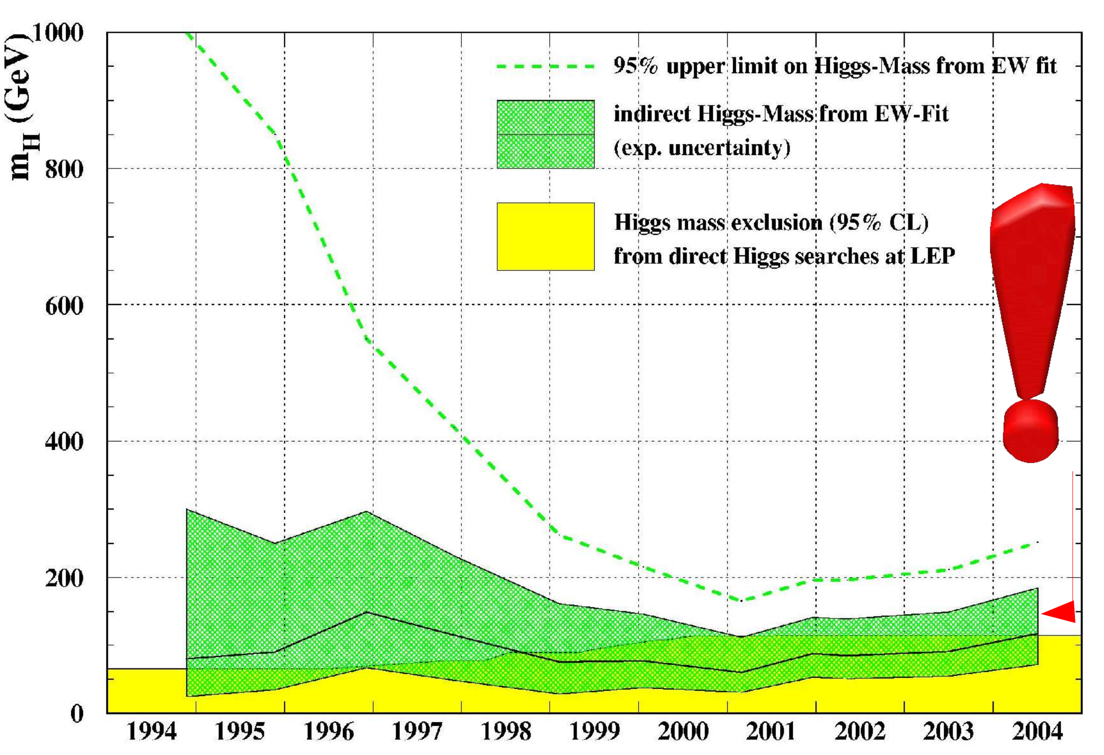
Part III

- Search for the Higgs
- Search for New Phenomena

Higgs Searches

Search for the Standard Model Higgs Boson





- Last missing particle in SM (EW symmetry breaking – mass)
- Light SM Higgs preferred
- Key to understand beyond-SM-physics (in MSSM m_H < 135 GeV)
- Search strategy a function of production and decay channel ...
- b-tagging a crucial tool

The final word from LEP:

- mass limits:

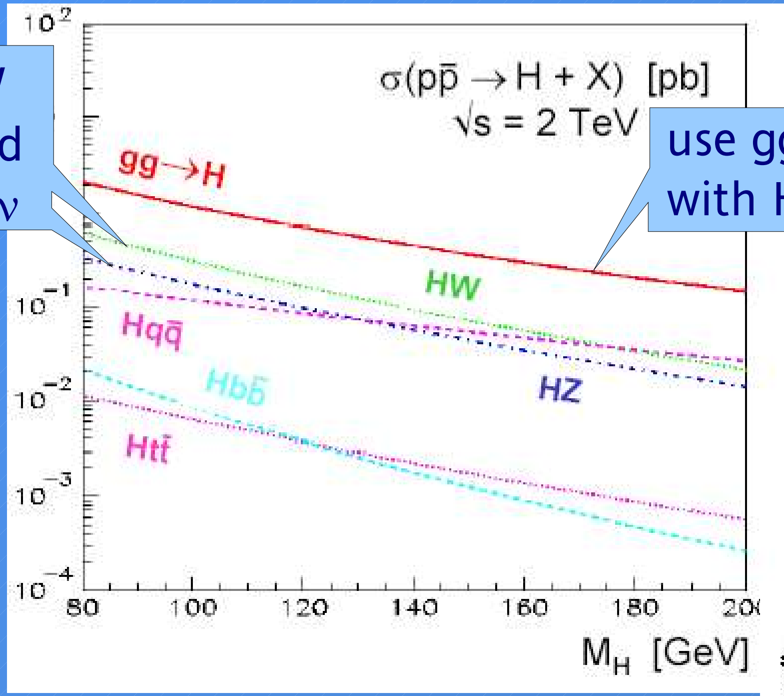
obs. m_h > 114.4 GeV

exp. m_h > 115.3 GeV

Search for the Standard Model Higgs Boson

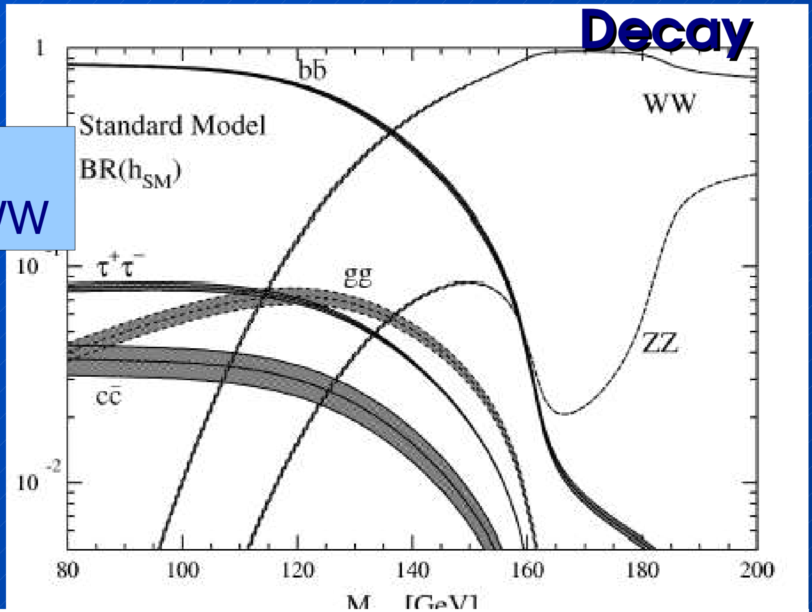
Production

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



use gg → H with H → WW

Decay

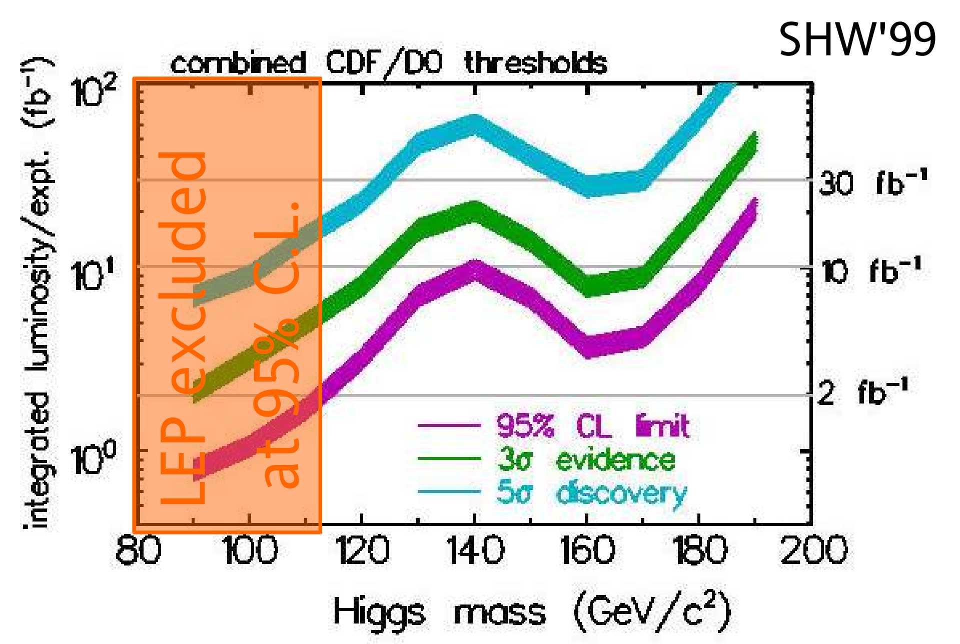


$H \rightarrow b\bar{b}$

$H \rightarrow WW^{(*)}$

Dominant decay modes

SHW'99

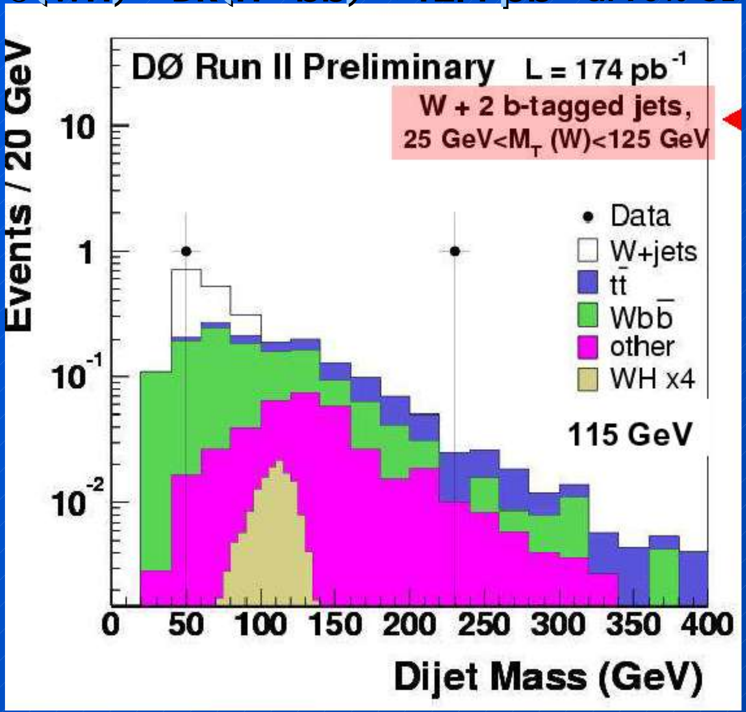


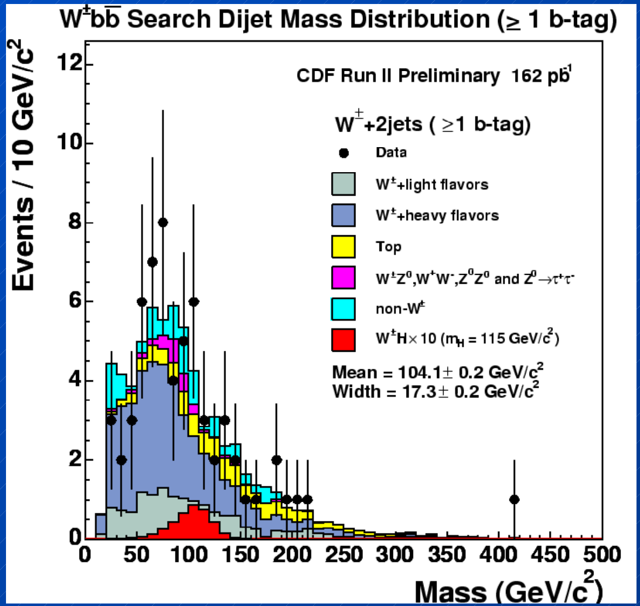
SM Higgs Search: WH → $l\nu bb$ (M_h < 140 GeV)

DØ uses sample of $W(e\nu)$+2b tagged jets
⇒ require exactly 2 jets to suppress top background
2.5 events expected and 2 events observed

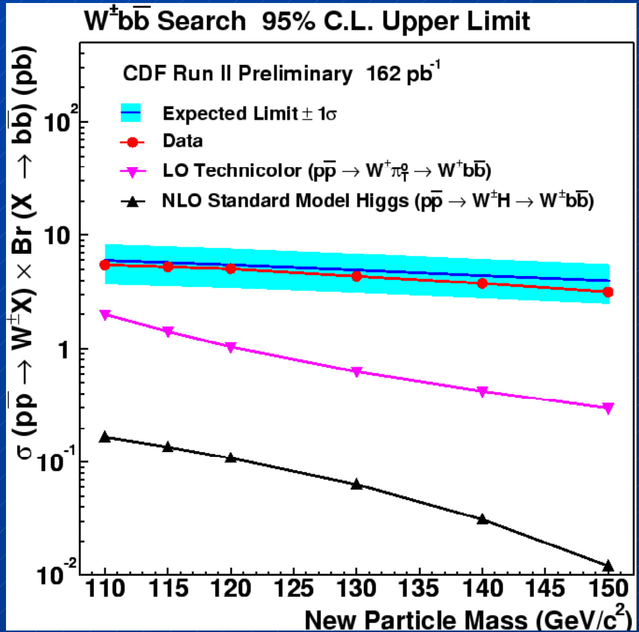
CDF uses e & μ channels
⇒ require at least 1 jet
to be b-tagged

for m_h = 115 GeV:
$\sigma(WH)$ * BR(H→bb) < 12.4 pb^{-1} at 95% CL

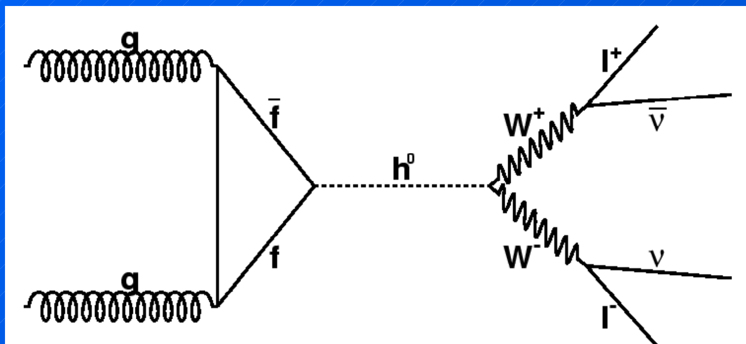


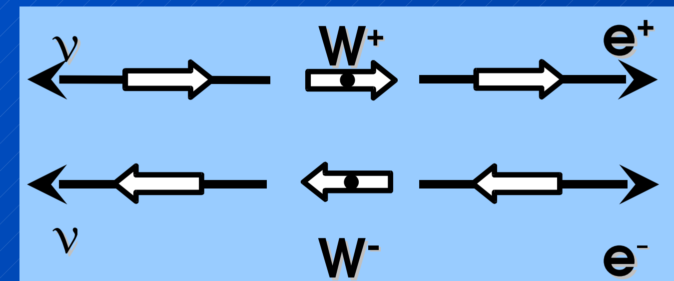


future improvements:
- extended b-tagging acceptance, efficiency
- additional kinematic variables
- better m_{bb} resolution
- add $\nu\nu bb$ channel



SM Higgs Search: H → WW → llν (M_h > 140 GeV)

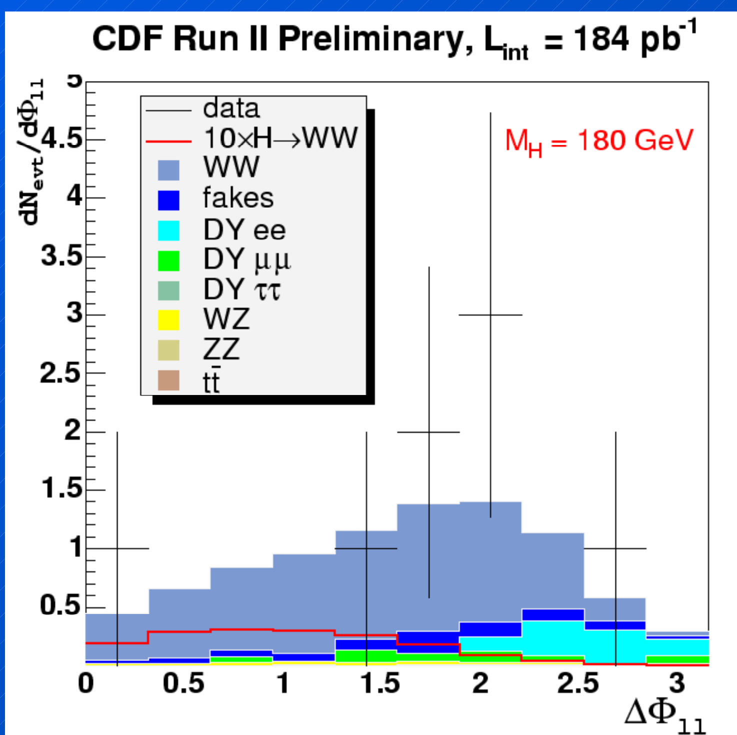


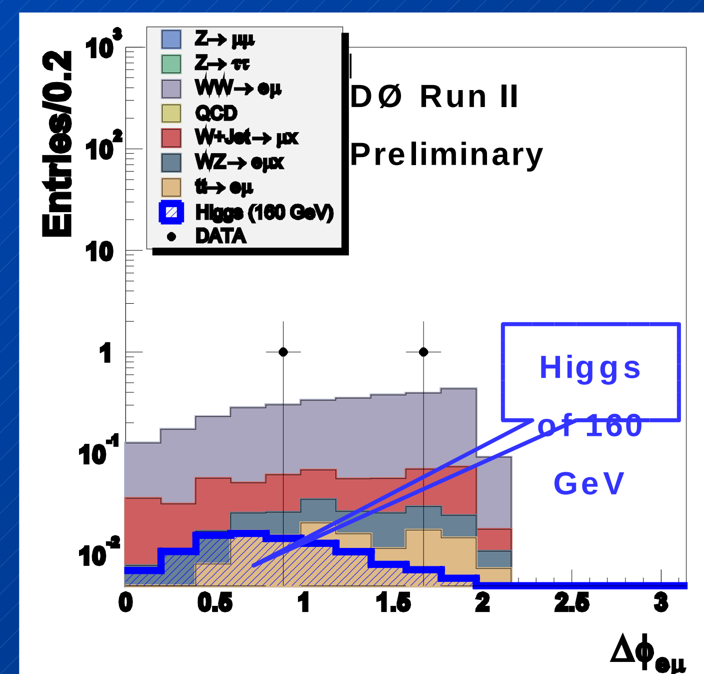


search strategy:

→ 2 high p_T leptons + missing E_T

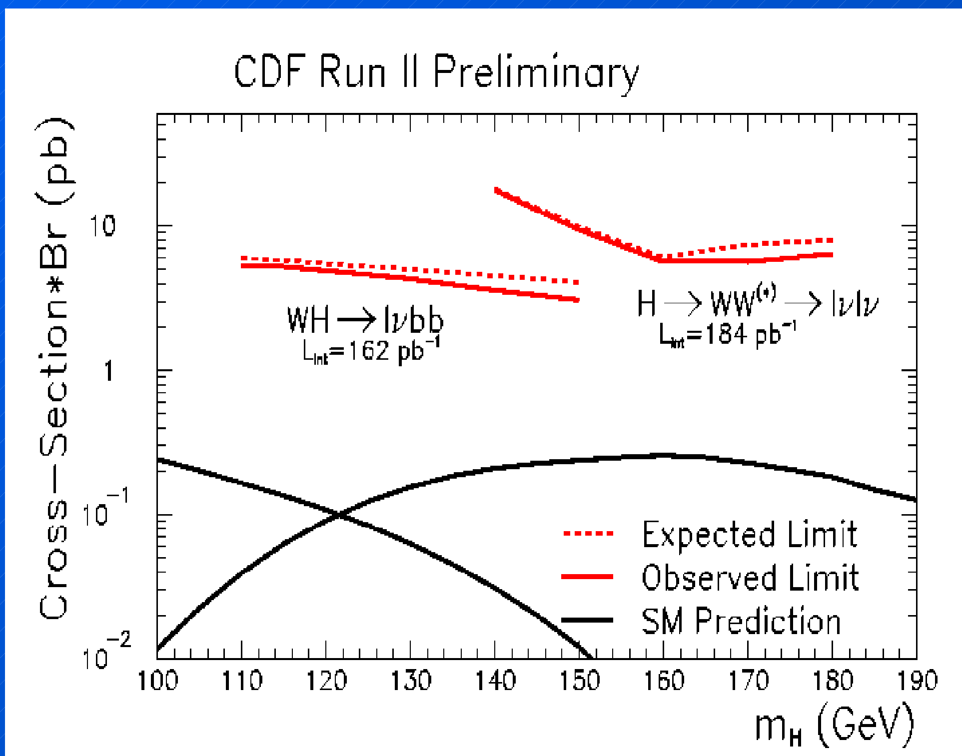
→ WW comes from spin 0 Higgs: charged leptons prefer to point in the same direction





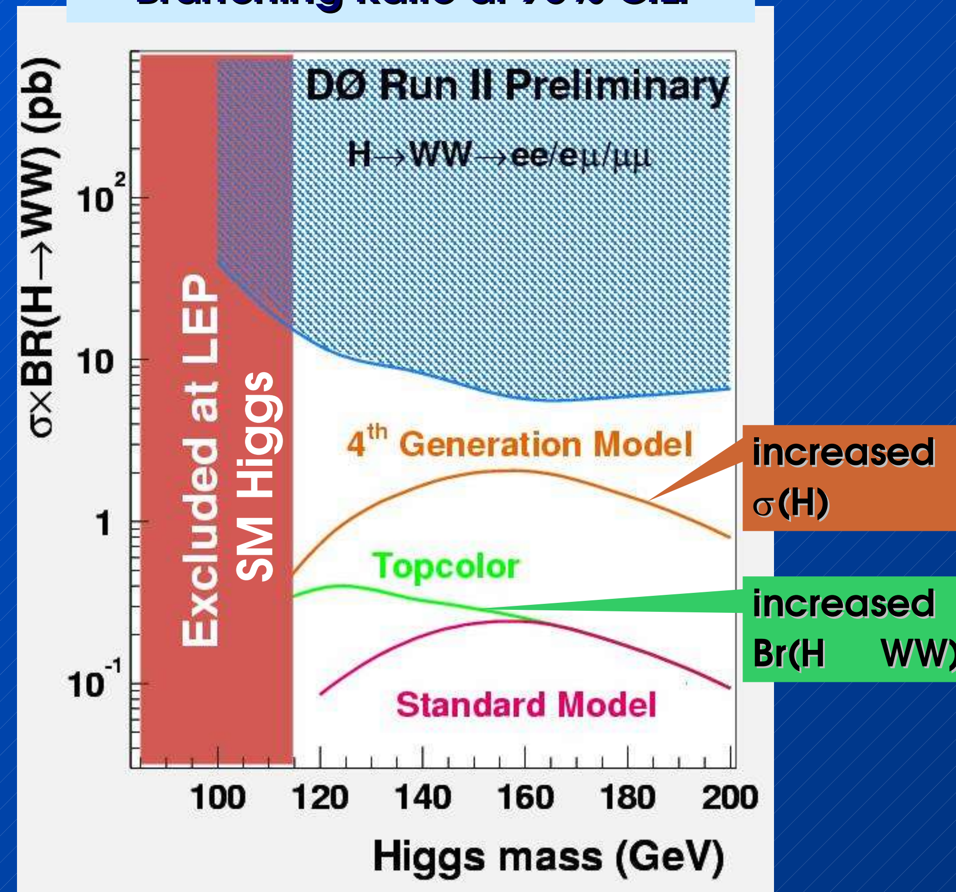
Current Limits on SM Higgs Search

both CDF and DØ set 95% CL
limits on SM Higgs production



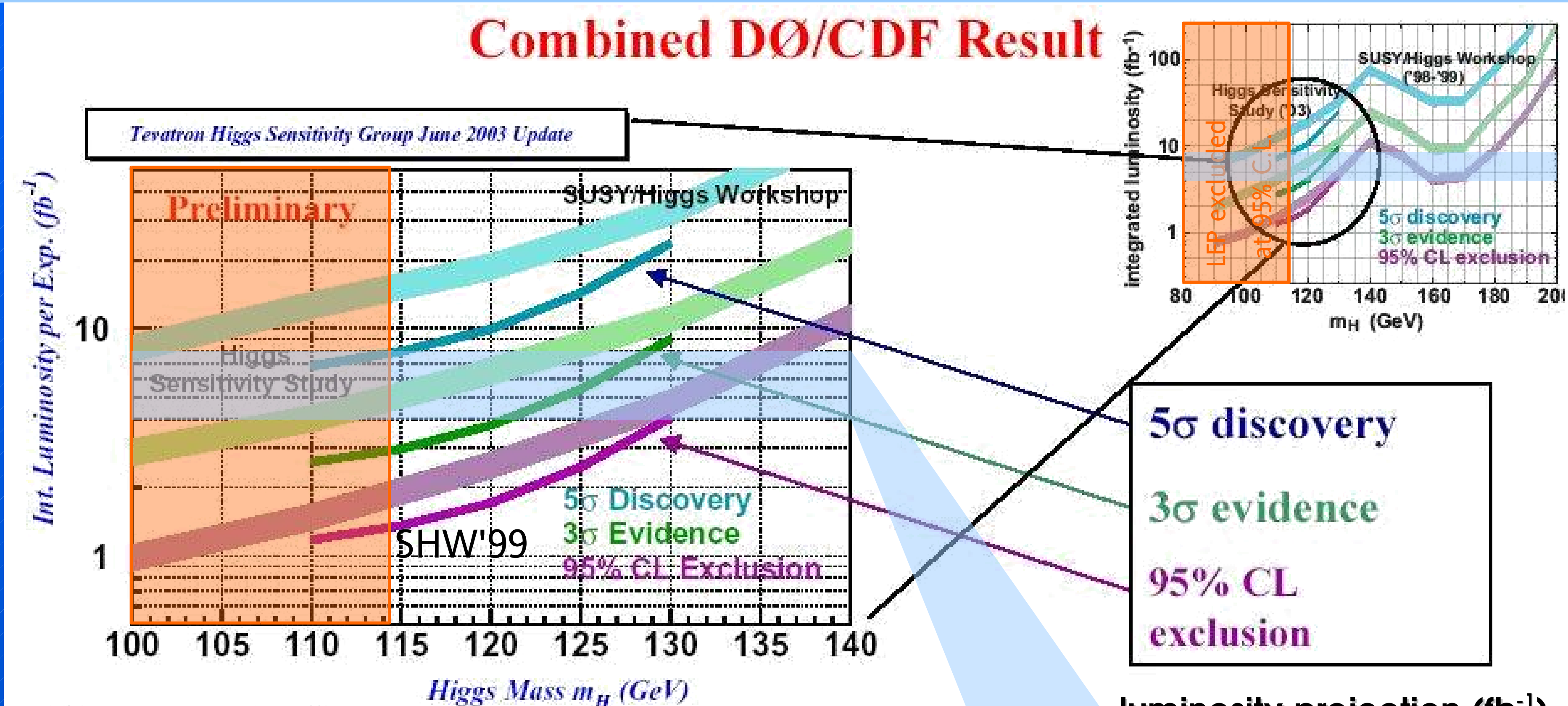
... limits already
exceeding Run I results ...

Excluded cross section times
Branching Ratio at 95% C.L.



DØ light (115 GeV) Higgs search limit
σ(WH) * BR(H → bb) < 12.4 pb-1 at 95% CL

Tevatron SM Higgs Hunting Outlook



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

- combined ll, νν, lν channels
- no systematics included yet
- no H WW* channel; impacts m_H > 125 GeV
- assumes upgraded detector
- reaching interesting sensitivity with 2 fb^{-1}

Tevatron SM Higgs Sensitivity Study 2003

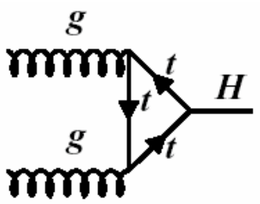
Process	SHW 1999	Xsec '03	Ratio	Analysis '03	Ratio	comment
HZ (115 GeV)	3.15	3.82	1.22	2.86	0.91	
HW (115 GeV)	2.39	2.78	1.16	2.08	0.87	
Zbb	4.34	1.73	0.4	1.99	0.46	from CDF data
Wbb	9.45	3.59	0.38	4.34	0.46	from CDF data
ZZ	1.82	2.36	1.3	2.93	1.61	PYTHIA 6.125 + K=1.34
WZ	1.45	1.79	1.45	1.84	1.27	PYTHIA 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}

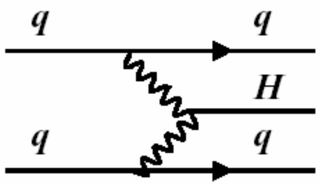
- assumes mostly running with Run-IIB silicon tracker
- assumes Jet-Mass resolution of 10%, SHW 1999 CAL reso. assumption met in Run-IIA
- improvement mainly from sophisticated analysis techniques
- ~50% less luminosity needed compared to 1999 with updated Xsec
- ~28% less luminosity needed with realistic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

SM Higgs Production at the LHC

gluon-gluon fusion dominates at small masses

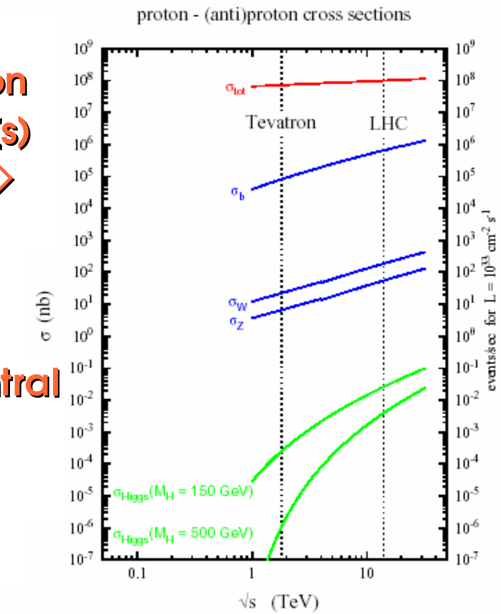


vector-boson fusion dominates at higher masses +2 outgoing quarks

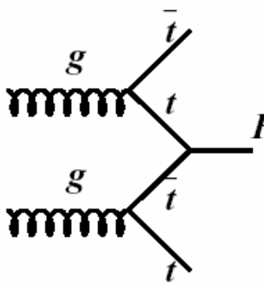


higgs prod. cross ection rises stronger with sqrt(s) than for background ⇨

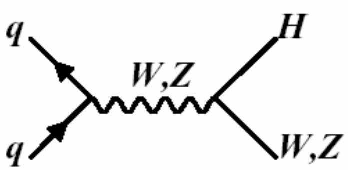
... but also stronger forward boost, TEVATRON is more central

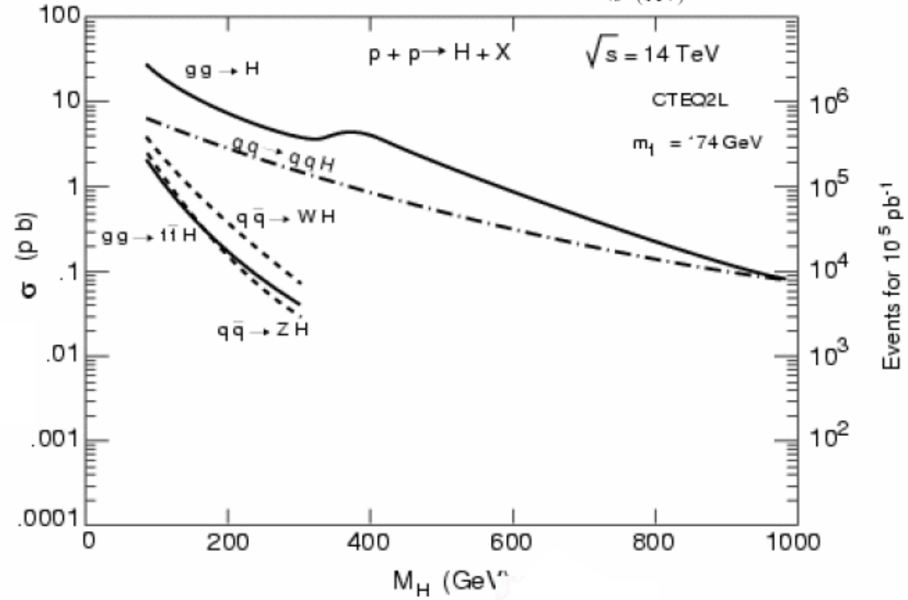


associated $t\bar{t}H$ prod. (~50-times smaller than gg)

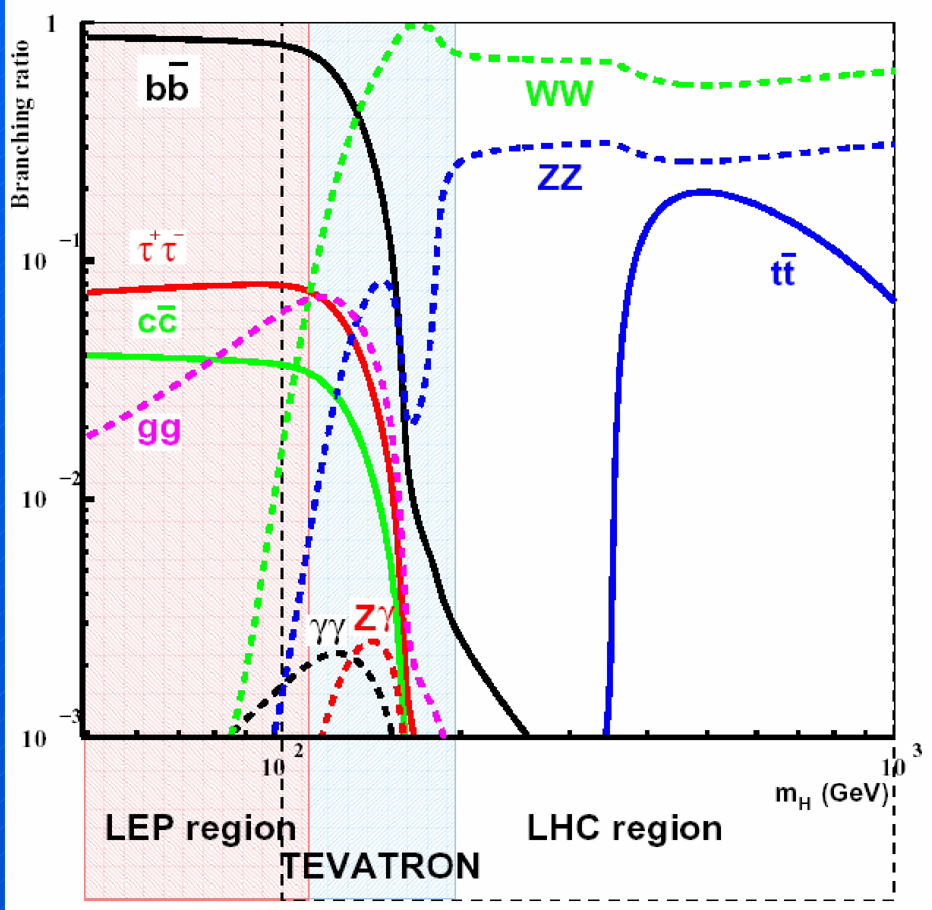


associated WH, ZH prod. (~50-times smaller than VB fusion)





Higgs Decays at LHC



$m_H < 2\,m_Z$:

$H \to \gamma\gamma$

$t\bar{t}H \to l\nu bb + X$

$H \to ZZ^* \to 4l$

$H \to WW^* \to l\nu l\nu$

$WH \to WWW^* \to l\nu l\nu l\nu, l^\pm l^\pm \nu\nu jj$

$m_H > 2\,m_Z$:

main channel is $H \to ZZ \to 4l$

`gold plated'

$H \to ZZ \to ll\nu\nu$

$H \to ZZ \to lljj$

$H \to WW \to l\nu jj$

detector performance and calibration crucial

b-tag, l/γ, particle ID, E-resolution

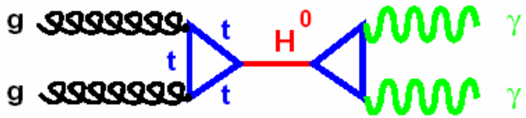
E_T^{mis} resolution, forward jet tagging ...

fully hadronic decays dominate, BUT cannot be separated from dominant background ...

$\sigma(H \to bb) \sim 20$ pb, $\sigma(bb) \sim 500$ μb

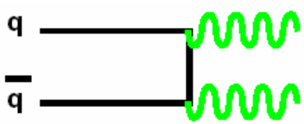
H → γγ ($m_h \leq 150$ GeV)

signal:



$\sigma \cdot \mathrm{BR} \approx 50$ fb (BR $\approx 10^{-3}$)

background:

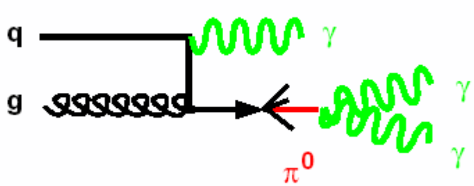


$\frac{\sigma(\gamma\gamma)}{\sigma(H\to\gamma\gamma)} \approx 60$ @$m_h = 120$ GeV

$\sigma_{\gamma\gamma} \approx 2$ pb/GeV und

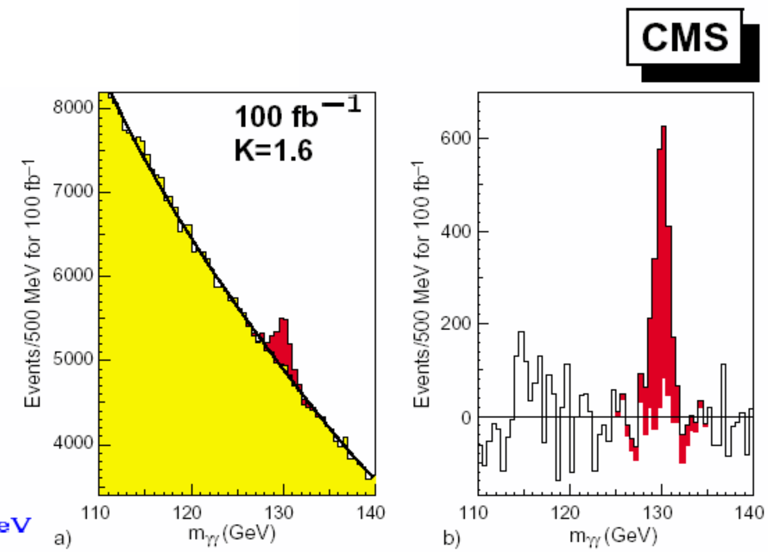
$\Gamma_H \approx$ MeV

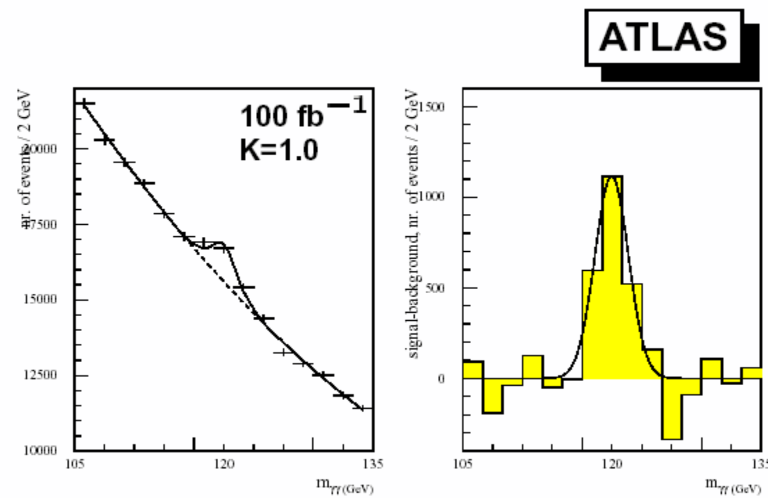
$\Rightarrow$ $\sigma(m_h)/m_h \approx 1\%$



$\Rightarrow$ $\frac{\sigma(\gamma\text{jet},\text{jet}-\text{jet})}{\sigma(H\to\gamma\gamma)} \approx 10^{6-8}$

$R_j(\text{reject.}) > 10^3$

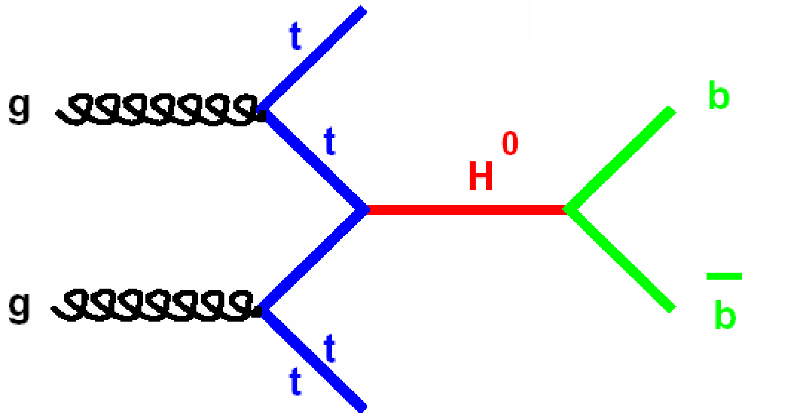




$\Rightarrow S/\sqrt{B}\,(\text{CMS}) \sim 1.1\, S/\sqrt{B}\,(\text{ATLAS})$

most demanding channel for EM-cal

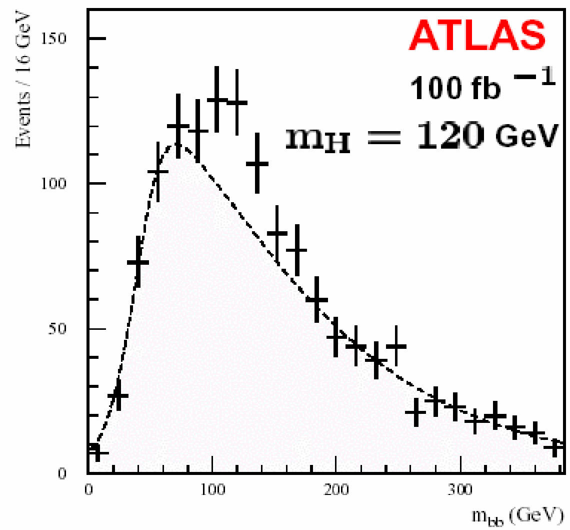
$t\bar{t}H \to t\bar{t}b\bar{b}$ ($m_h \leq 130$ GeV)

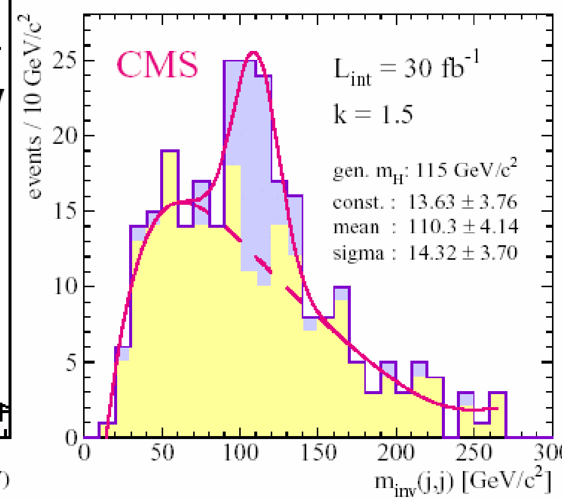


$\to \sigma \cdot \mathrm{BR} \approx$ 300 fb

complex final state

$H \to b\bar{b},\ t \to bjj,\ t \to bl\nu$





$m_H \sim 115$ GeV $10\ \mathrm{fb}^{-1}$ per experiment

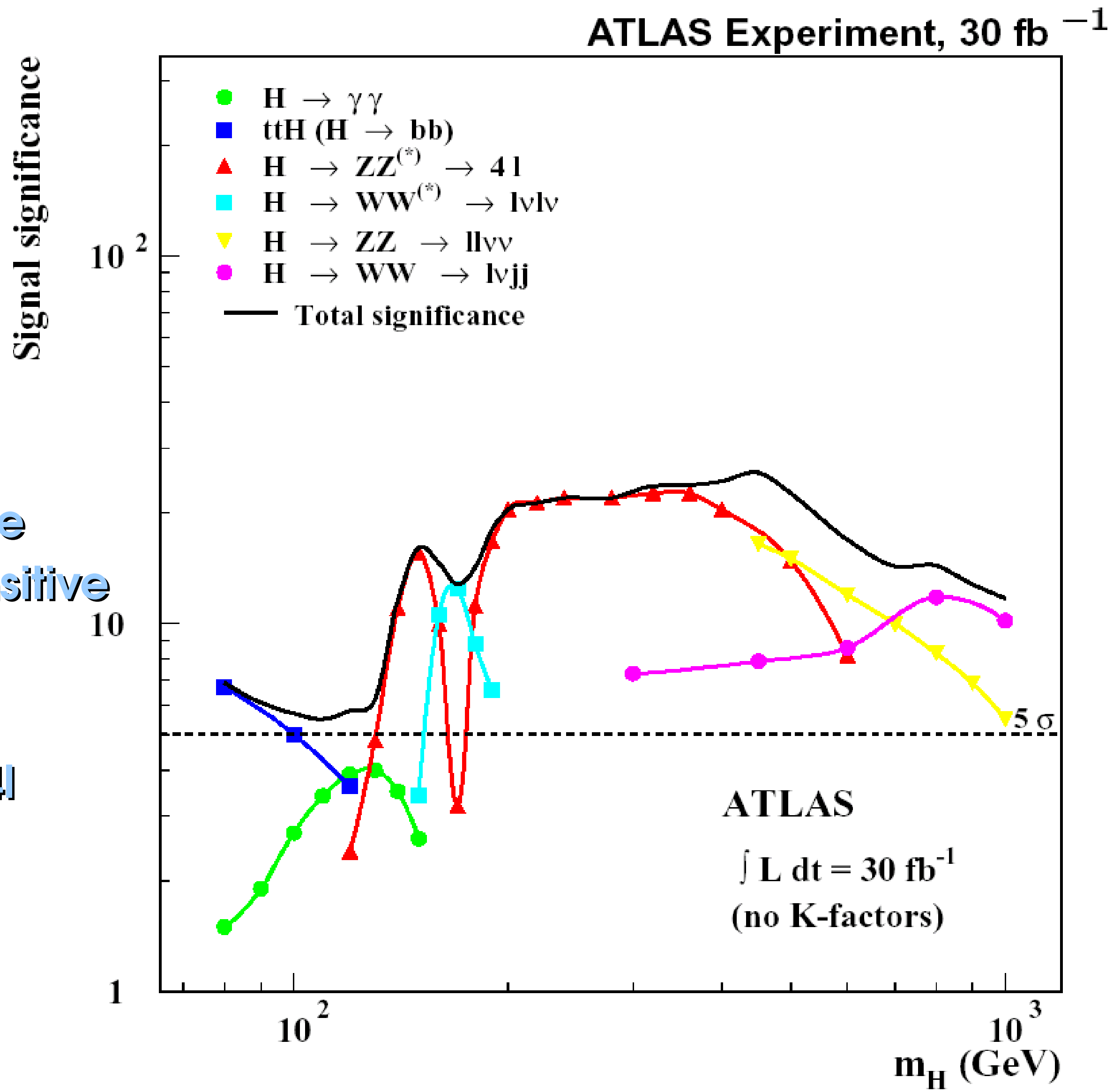
	$H \to \gamma\gamma$	$t\bar{t}H \to t\bar{t}b\bar{b}$
S	300	30
B	7800	90
S/B	0.04	0.33
$S/\sqrt{B}$	3.4	3.2

backgrounds:

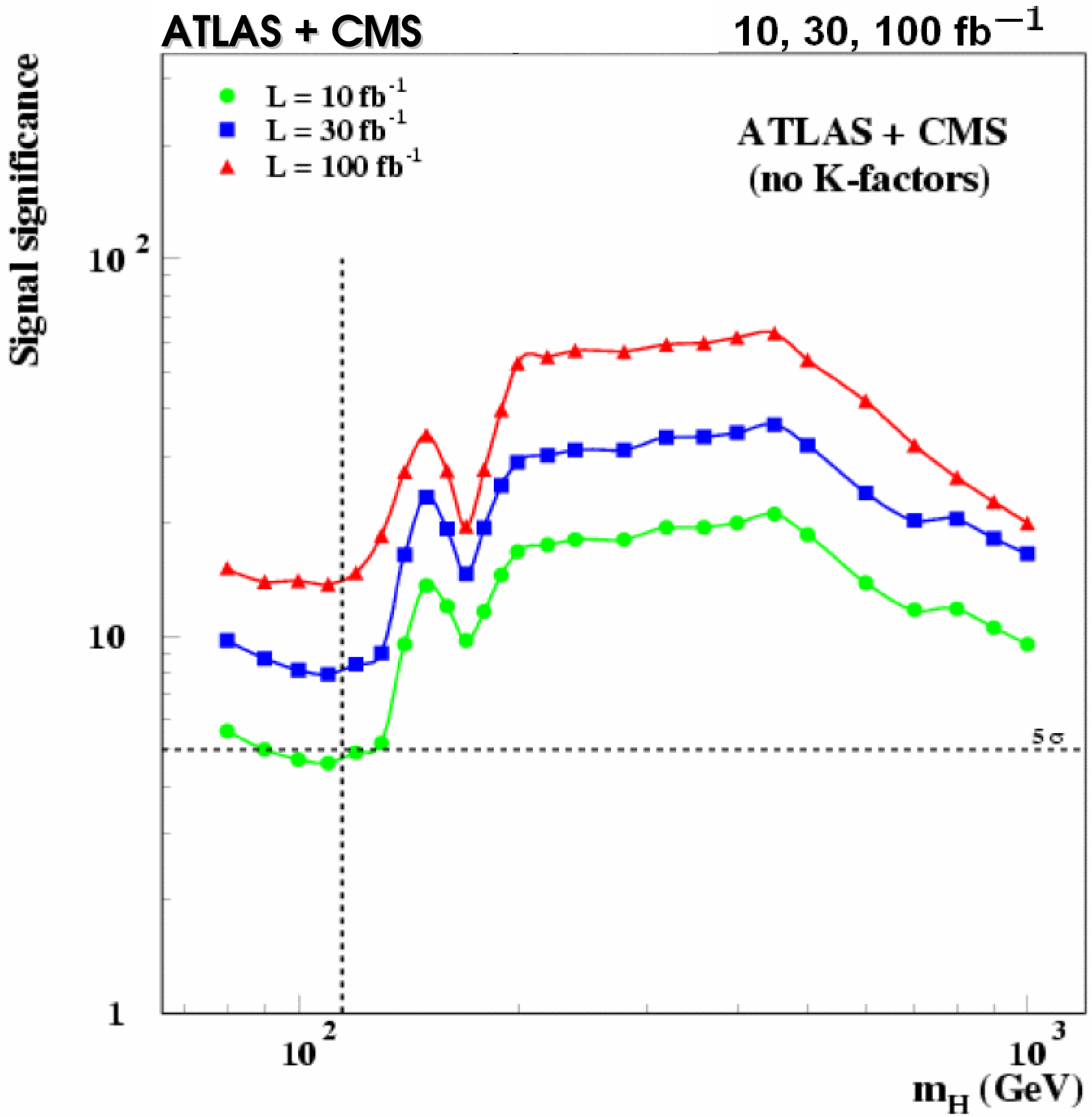
- 4b final state combinatorics
- Wjjjjjj, WWbbjj
- ttjj

LHC Discovery Potential

- significance S/B
- full GEANT detector simulation
- LO cross sections for signal and background
- good sensitivity in full mass range
- typically 2 or more channels sensitive
- $m_H > 2\,m_Z$: discovery `easy' in gold-plated channel $H \to ZZ^{(*)} \to 4l$

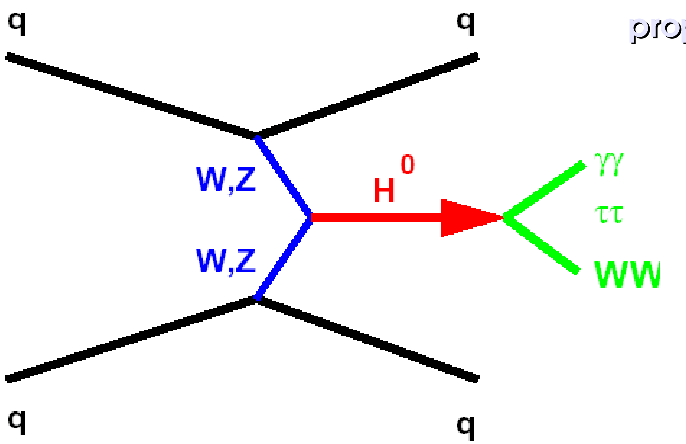


LHC Discovery Potential

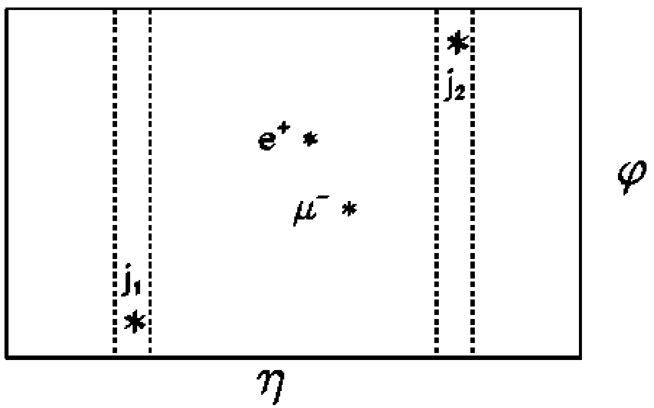


- SM Higgs can be discovered with 10 fb^{-1} at 5 significance
- discovery easier at high masses
- full mass range could be excluded with 1 month of data
- **BUT**
  ATLAS and CMS need ~10 fb-1 of good and understood data (1 year ?)

Weak-Boson Fusion



proposal: D.Zeppenfeld

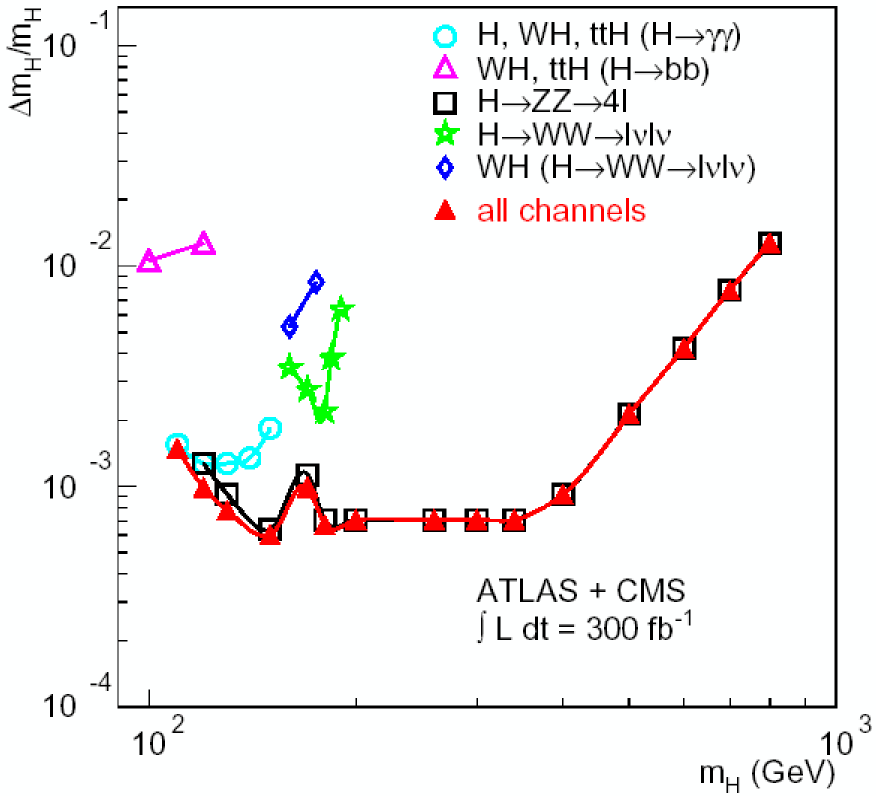


- additional discovery potential
  - @ mh=120 GeV =4pb (20% of htot)
- possible to find invisible Higgs
- important for measurement of parameters
  - Higgs coupling to bosons and fermions, total width ...

signature:

- 2 high-p_T forward jets
- low central jet activity
- isolated central leptons (depending on channel)

Higgs Mass at LHC



MSSM Higgs	$\Delta m/m(\%)$, 300 fb^{-1}
$h, A, H \to \gamma\gamma$	0.1 - 0.4
$H \to 4l$	0.1 - 0.4
$H/A \to \mu\mu$	0.1 - 1.5
$h \to b\bar{b}$	1 - 2
$H \to hh \to b\bar{b}\gamma\gamma$	1 - 2
$A \to Zh \to b\bar{b}ll$	1 - 2
$H/A \to \tau\tau$	1 - 10

dominant uncertainties:

- γ/l energy scale (0.1 % assumed)
- goal 0.02% (Z → ll)

similar studies for σ * Br rate

⇨ can differentiate SM and MSSM

Higgs Coupling at LHC

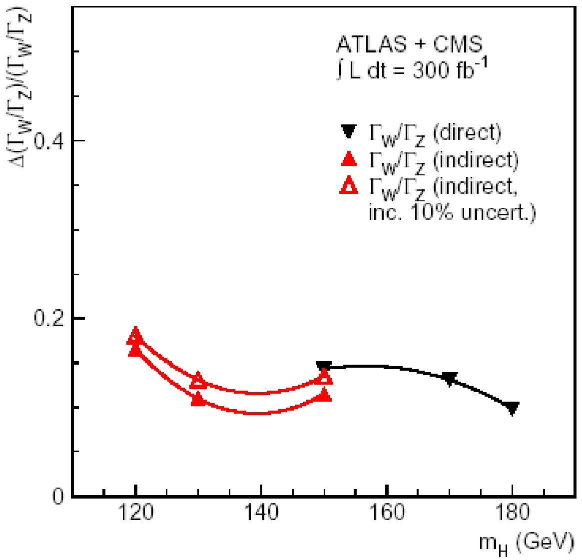
can measure ratio of Higgs couplings without any assumptions

coupling to bosons

$$\frac{\sigma\times BR(H\to WW^*)}{\sigma\times BR(H\to ZZ^*)} = \frac{\Gamma_g\Gamma_W}{\Gamma_g\Gamma_Z} = \frac{\Gamma_W}{\Gamma_Z}$$ direct

$$\frac{\sigma\times BR(H\to\gamma\gamma)}{\sigma\times BR(H\to ZZ^*)} = \frac{\Gamma_g\Gamma_\gamma}{\Gamma_g\Gamma_Z} = \frac{\Gamma_W}{\Gamma_Z}$$ indirect

using $\Gamma_W \sim \Gamma_\gamma$, 10% theoretical uncertainties



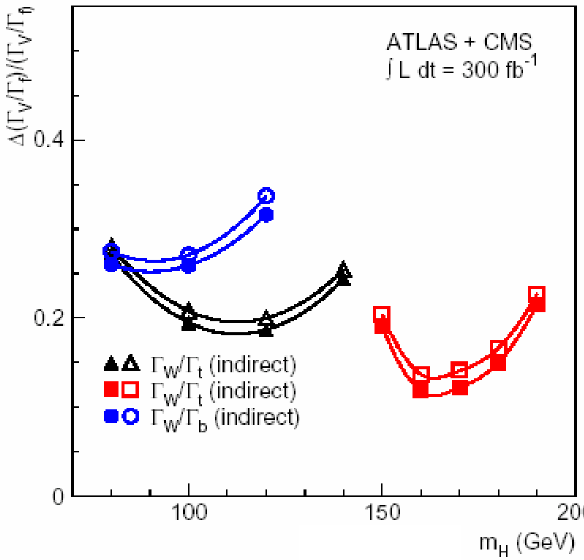
coupling to fermions

$$\frac{\sigma\times BR(qq\to qqH(H\to WW^*))}{\sigma\times BR(qq\to qqh(H\to\tau\tau))} = \frac{\Gamma_W\Gamma_W}{\Gamma_W\Gamma_\tau} = \frac{\Gamma_W}{\Gamma_\tau}$$ direct

WBF

$$\frac{\sigma\times BR(WH(H\to\gamma\gamma))}{\sigma\times BR(H\to\gamma\gamma)}\frac{\Gamma_W\Gamma_\gamma}{\Gamma_g\Gamma_\gamma} \approx \frac{\Gamma_W}{\Gamma_t} * C_{QCD}$$ indirect

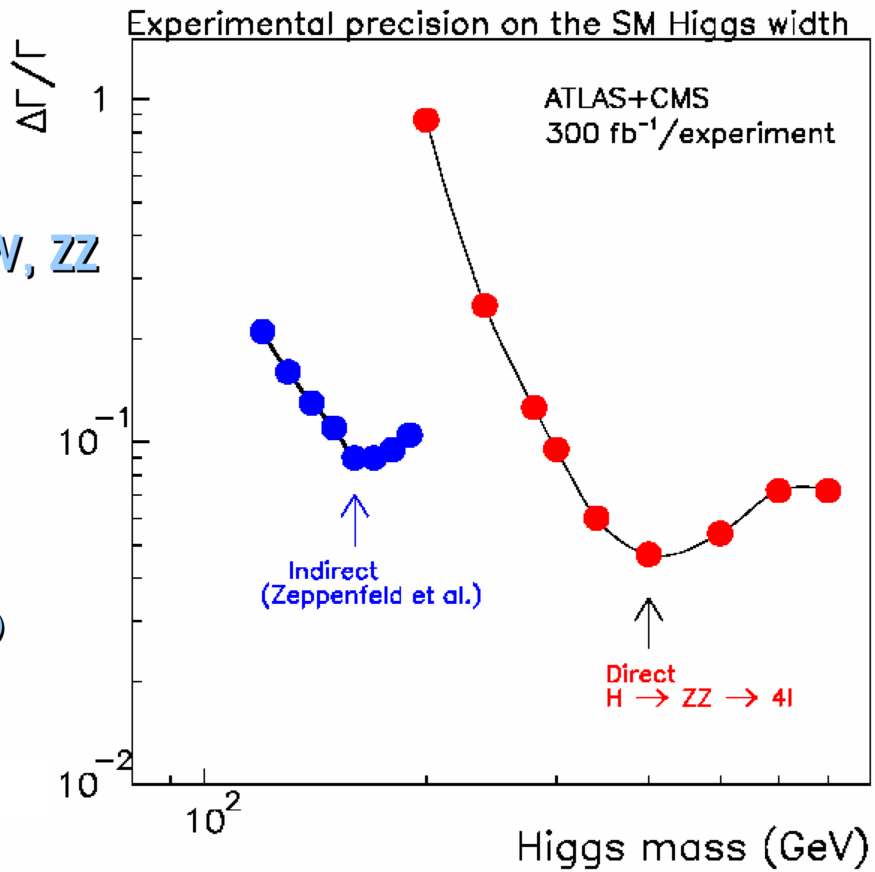
Wh and tth



Higgs Width at LHC

direct:

- for m_h>200 GeV obtaind Higgs width from mass distribution (H → ZZ → 4l)
  (in SM $\Gamma_H > \Gamma_{Detector}$)



indirect: Zeppenfeld et al.: Phys. Rev. D62 (2000), hep-ph/0002036

- at lower masses from rates of
  qq → qqH (WBF) and qq→H with H → γγ, ττ, WW, ZZ

assumptions:

- $\Gamma_Z = z\Gamma_W = z_{SM}\Gamma_W$ (WBF is mixture of ZZ→H and WW→H)
- ratio of b and τ Yukawa coupling given by masses

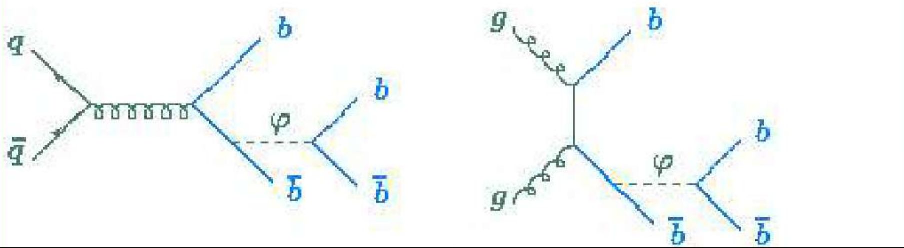
$$\frac{\Gamma_b}{\Gamma_\tau} = 3\,c_{QCD}\frac{g^2_{hbb}}{g^2_{h\tau\tau}} = 3\,c_{QCD}\frac{m_b^2(m_h)}{m_\tau^2}$$

- Higgs width dominated by decays to bb, ττ, WW, ZZ, gg, γγ

Search for MSSM Higgs at the Tevatron

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

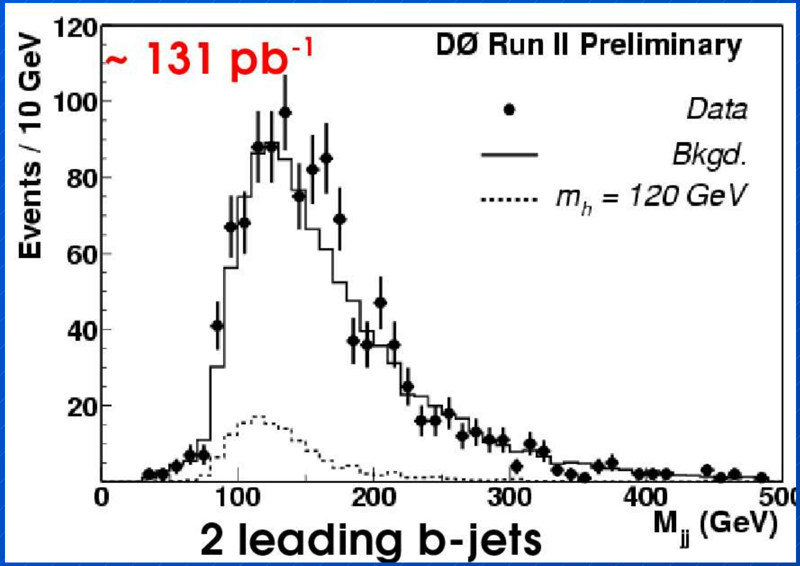
2 CP-even neutral Higgses	h^0, H^0	$m_h < m_H$
1 CP-odd neutral Higgs	A^0	
2 charged Higgses	$H^\pm$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$m_h < m_Z < m_H$	
rad.corrected:	$m_h < 130$ GeV	$Br(\phi \to b\bar{b}) \sim 90\,\%$

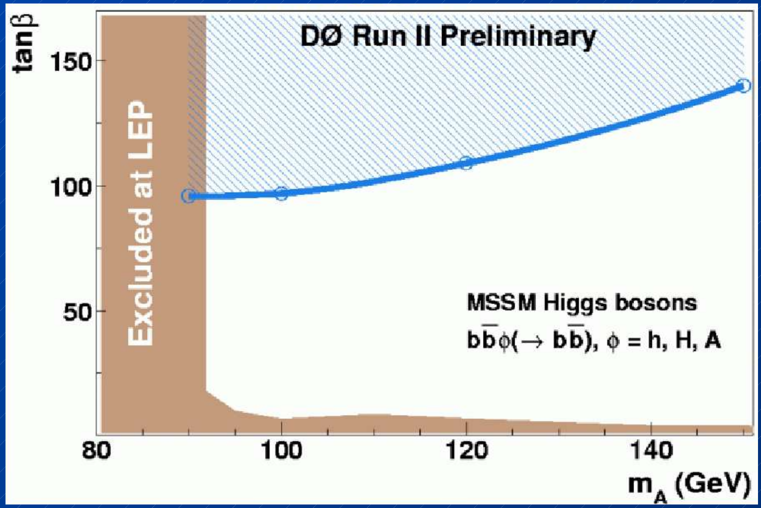


MSSM predicts larger Higgs cross setions for some values of parameter space than SM

Using NLO cross section calculations and assuming no difference between A and h/H DØ performs search for MSSM Higgs

- multi-jet high ET sample
- 3 or more jets b-tagged



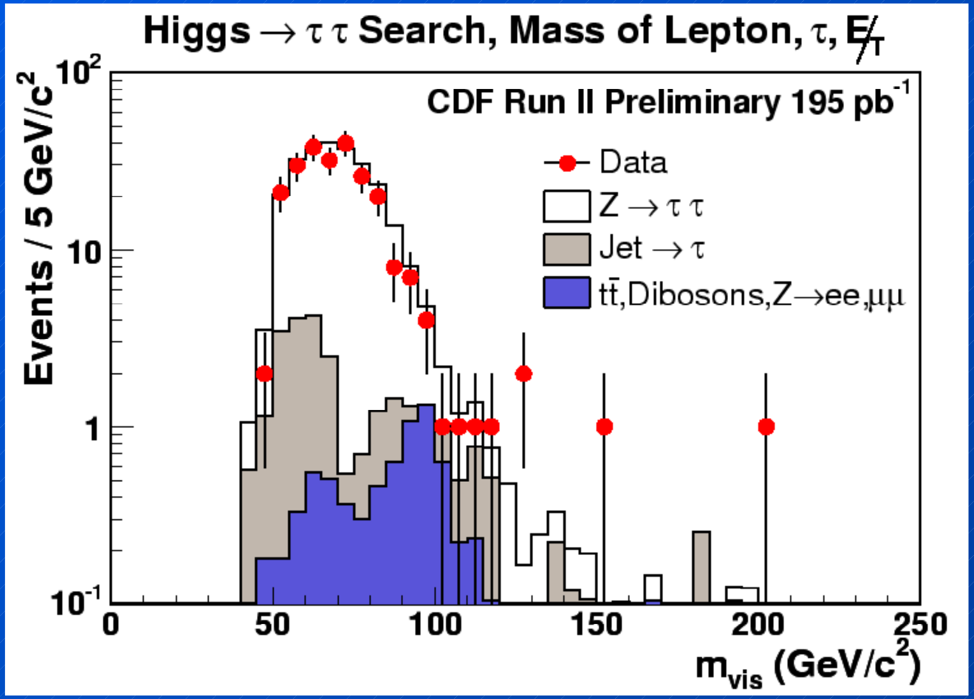


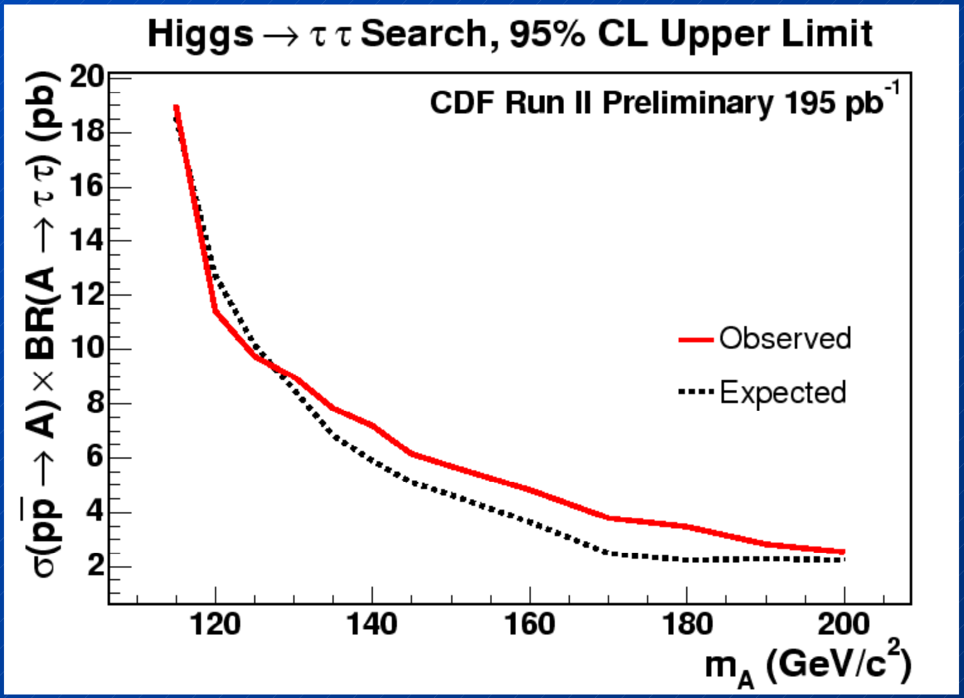
Search for MSSM Higgs at the Tevatron

CDF searches for $p\bar{p} \rightarrow h/A + X$

- with A decaying into ττ pair
- ~8% branching ratio at high tanβ
- lower backgrounds then $b\bar{b}$ pairs
- no access seen over backgrounds

	$\tau_h \tau_e$	$\tau_h \tau_\mu$	Combined
$Z \rightarrow \tau\tau$	132.3 ± 17.1	104.1 ± 13.3	236.4 ± 29.5
$Z \rightarrow ll$	1.8 ± 0.2	4.9 ± 0.4	6.7 ± 0.6
$t\bar{t}, VV$	0.7 ± 0.1	0.8 ± 0.1	1.5 ± 0.1
$jet \rightarrow \tau$	12.0 ± 3.6	7.0 ± 2.1	19.0 ± 5.7
Total predicted	146.8 ± 17.5	116.8 ± 13.5	263.6 ± 30.1
Data	133	103	236





Searches for New Phenomena

Motivation

Summer 2003

	Measurement	Fit	$\vert O^{meas}-O^{fit}\vert/\sigma^{meas}$
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02767	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960	
σ_{had}^0 [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01636	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477	
R_b	0.21638 ± 0.00066	0.21579	
R_c	0.1720 ± 0.0030	0.1723	
$A_{fb}^{0,b}$	0.0997 ± 0.0016	0.1036	
$A_{fb}^{0,c}$	0.0706 ± 0.0035	0.0740	
A_b	0.925 ± 0.020	0.935	
A_c	0.670 ± 0.026	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1477	
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.426 ± 0.034	80.385	
Γ_W [GeV]	2.139 ± 0.069	2.093	
m_t [GeV]	174.3 ± 5.1	174.3	
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229	
$Q_W(Cs)$	-72.84 ± 0.46	-72.90	

- **Structure, generations, ...**
  - excited fermions
  - leptoquarks
  - anomalous single top, rare decays
- **Scales, hierarchy**
  - large extra space dimensions
  - Super-Symmetry (RP-Violation)

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

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

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

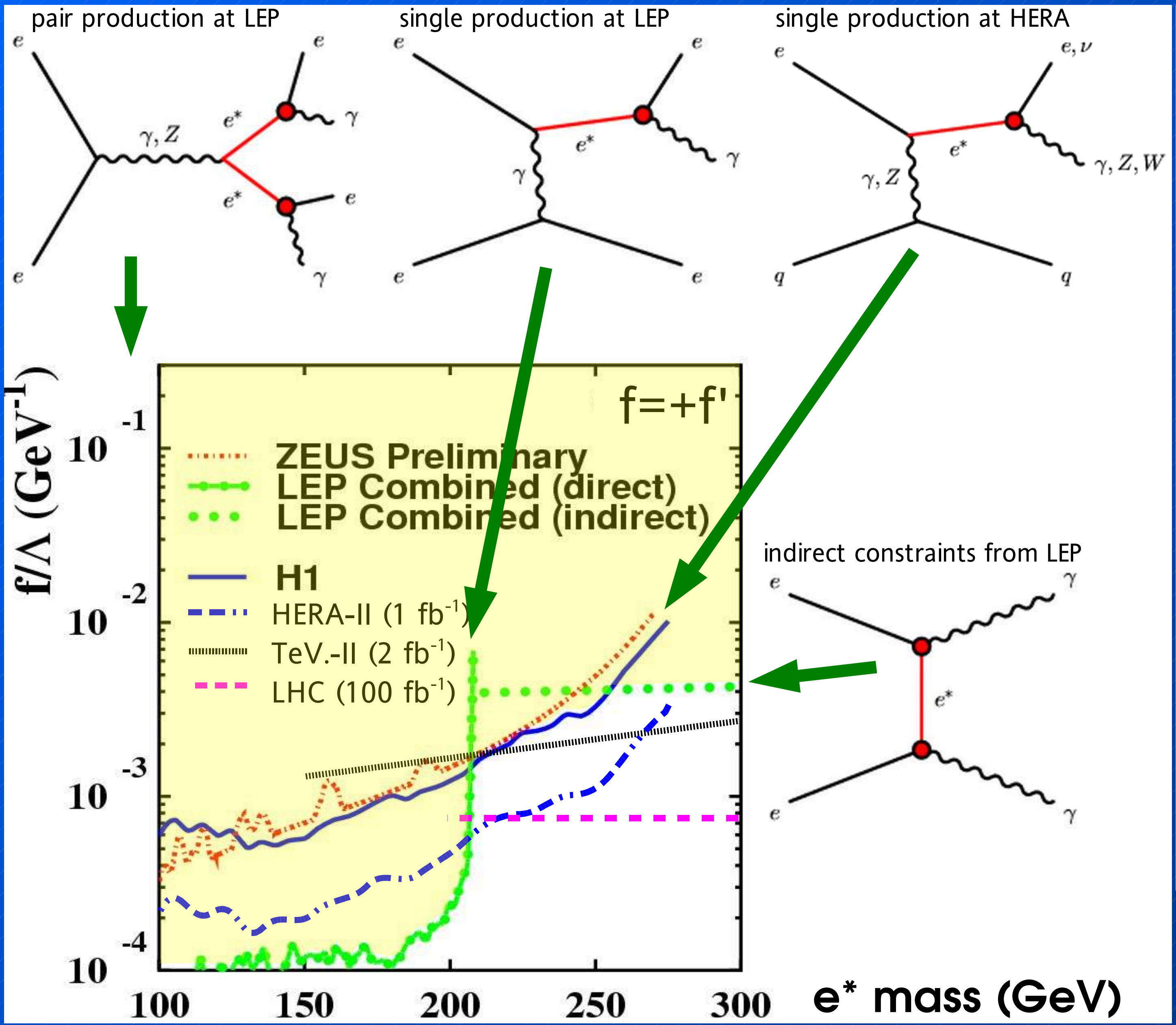
Phenomenology (Hagiwara et al.):

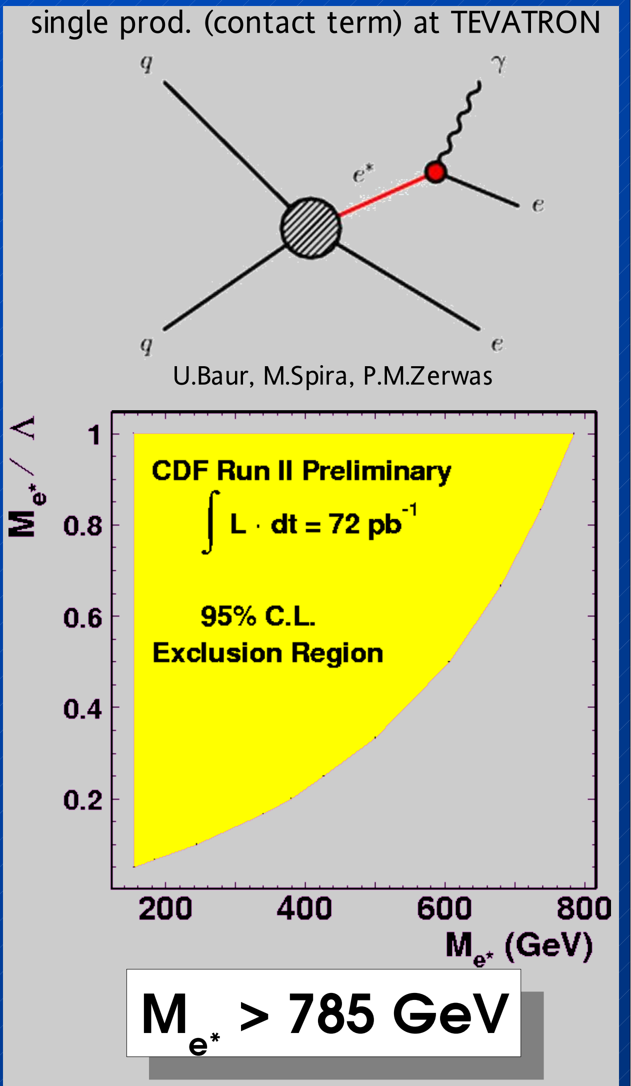
f, f', (f_s)	relative coupling strength to $SU(2)_L$, $U(1)_Y$,(and $SU(3)_C$)
	compositeness mass scale
Xsec	depends on m_{f^*} and f/

... many f* searches ...

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

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



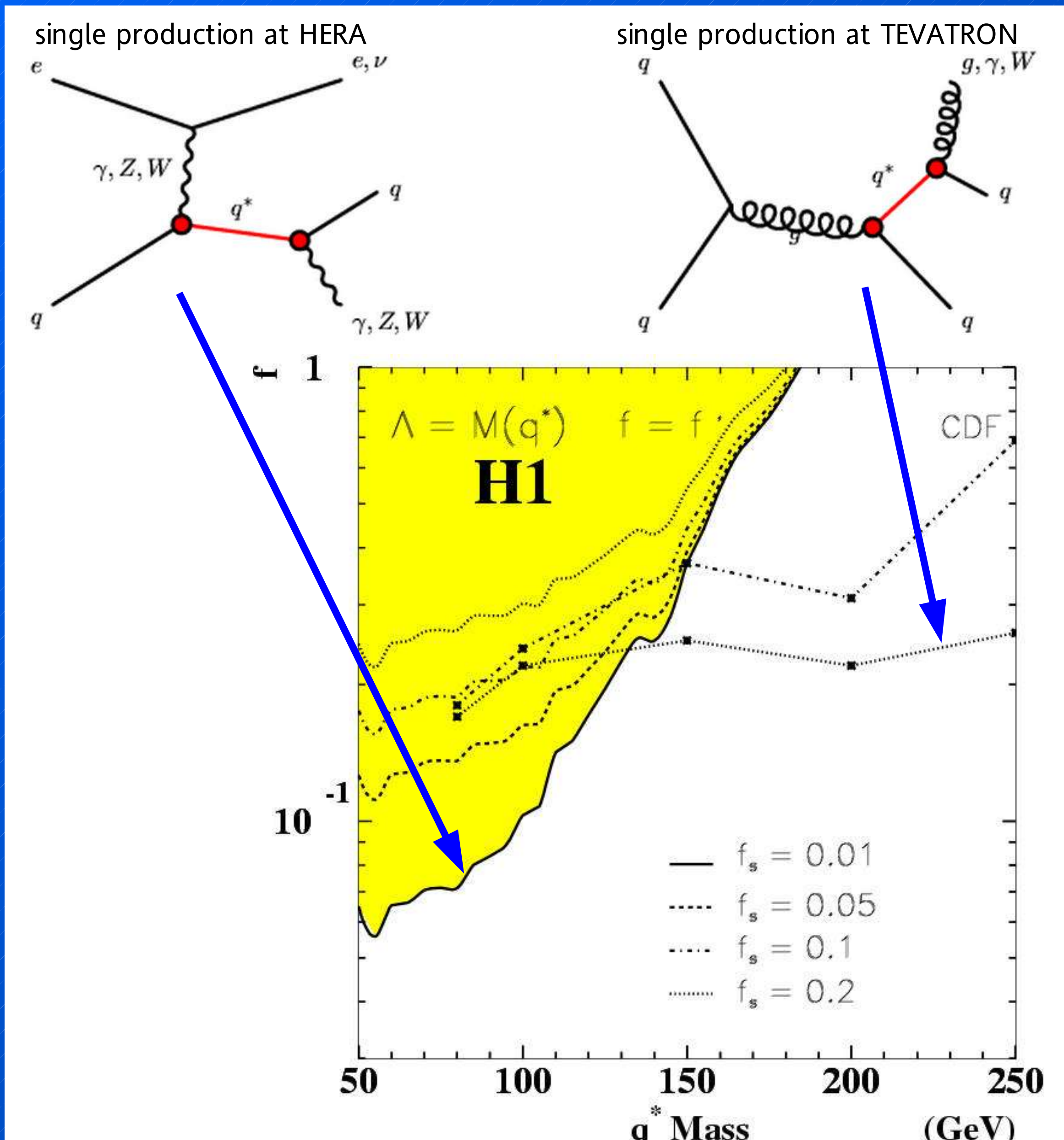


... similarly for μ^* and τ^*...

... similarly for ν^* searches

... e⁻p at HERA ...

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



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

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

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

3^{rd} Example: Leptoquarks

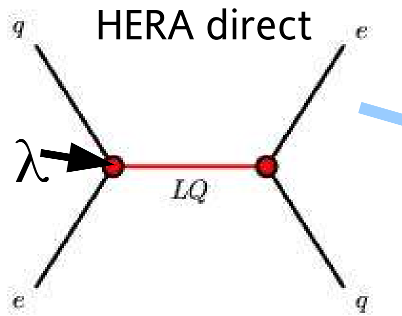
Motivation: Observed symmetry between lepton and quark sector
Solution: Leptoquarks (LQ), proposed by several theories
coloured spin 0,1 bosons with baryon and lepton number

Buchmüller, Rückl, Wyler (BRW) classification popular:

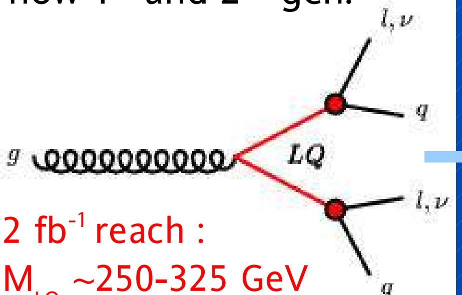
1.) conserve SM gauge symmetry
2.) LQ only couple to quarks, leptons and SM gauge bosons
3.) LQ only have flavour-diagonal couplings

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

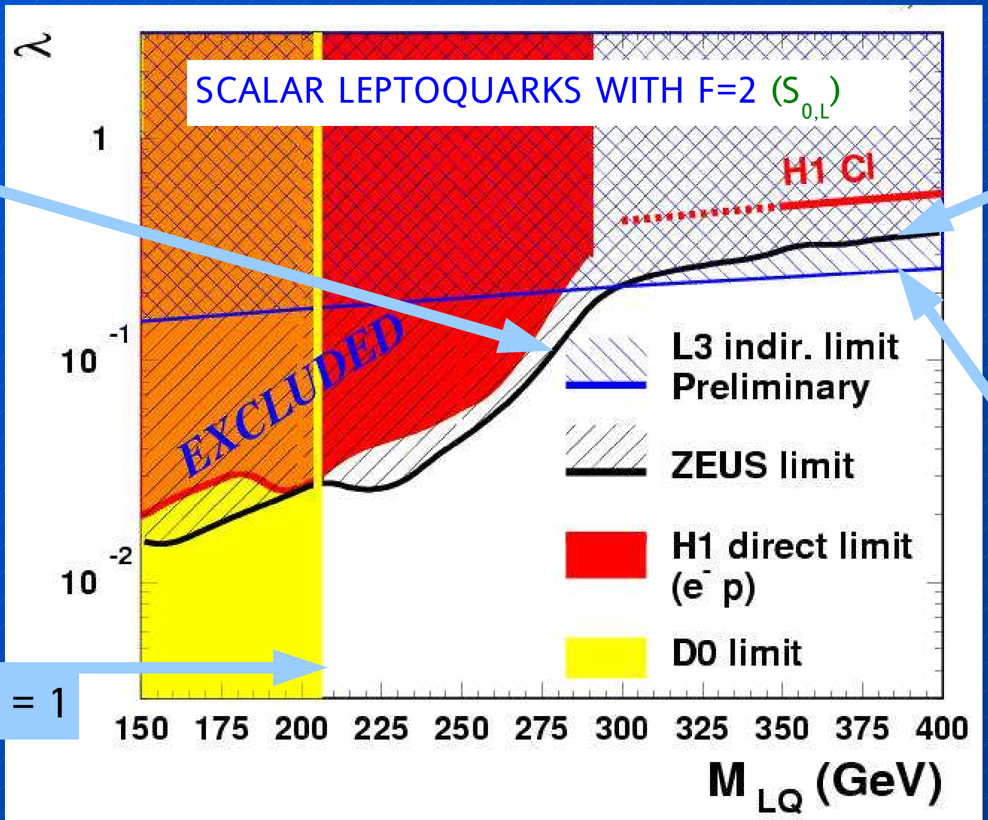
HERA direct



Tevatron pair prod.
indep. of λ
now 1^{st} and 2^{nd} gen.

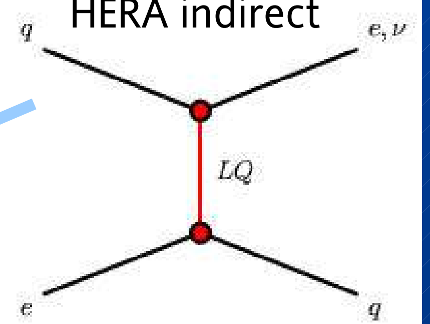


2 fb^{-1} reach :
M_{LQ} ~250-325 GeV

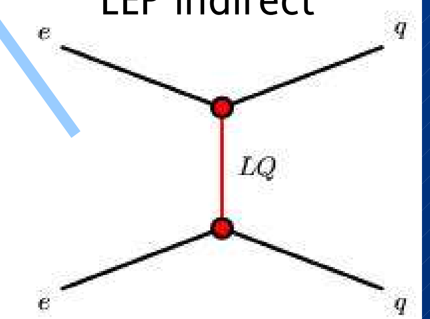


β = 1

HERA indirect

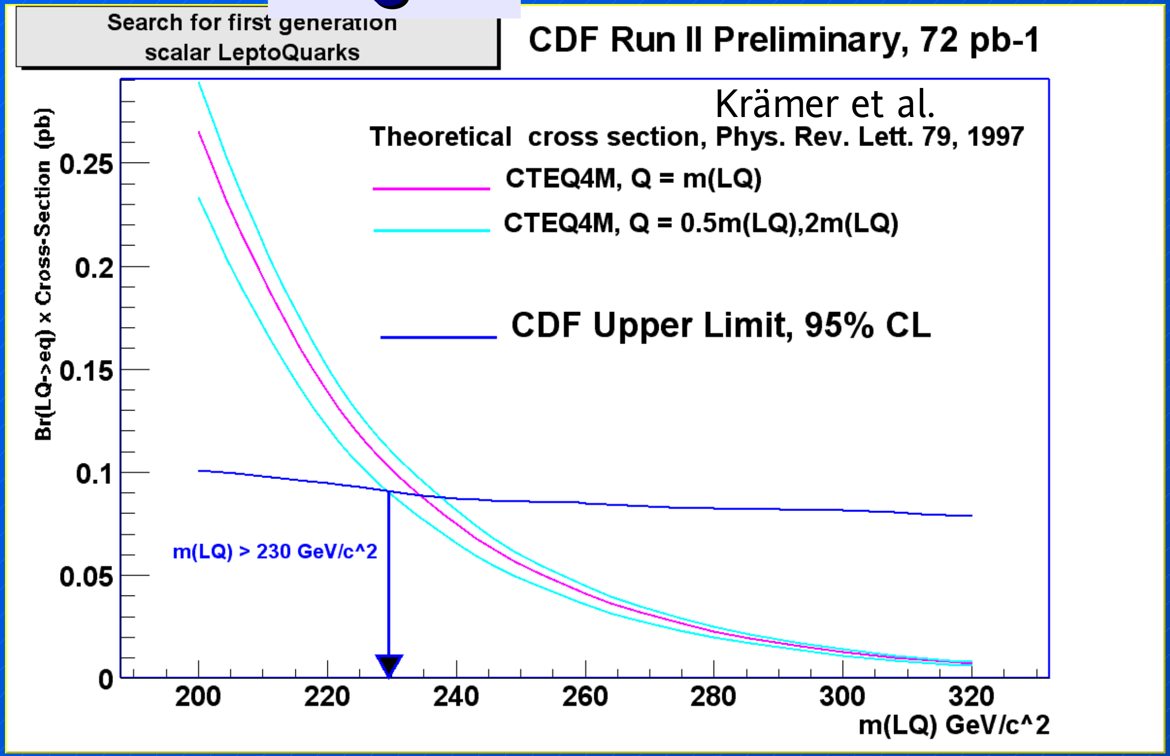


LEP indirect

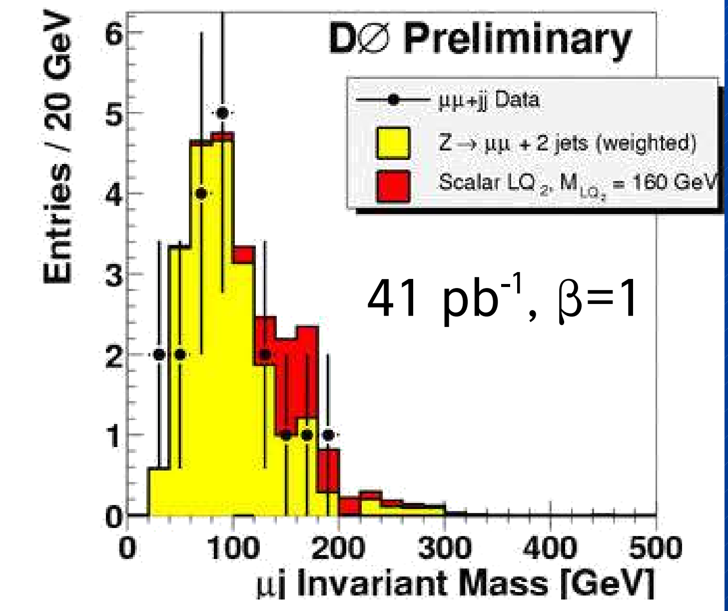


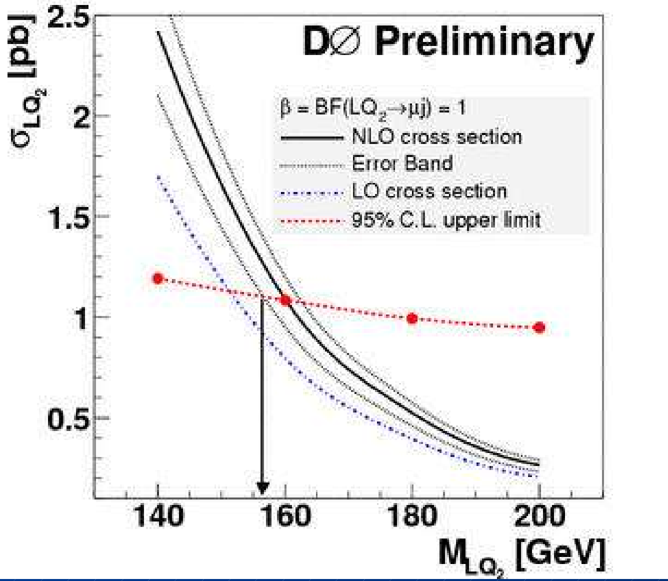
Leptoquark Searches at the Tevatron-II

1st gen.



2nd gen.





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

M_{LQ} > 107 GeV in ννqq (76 pb^{-1})

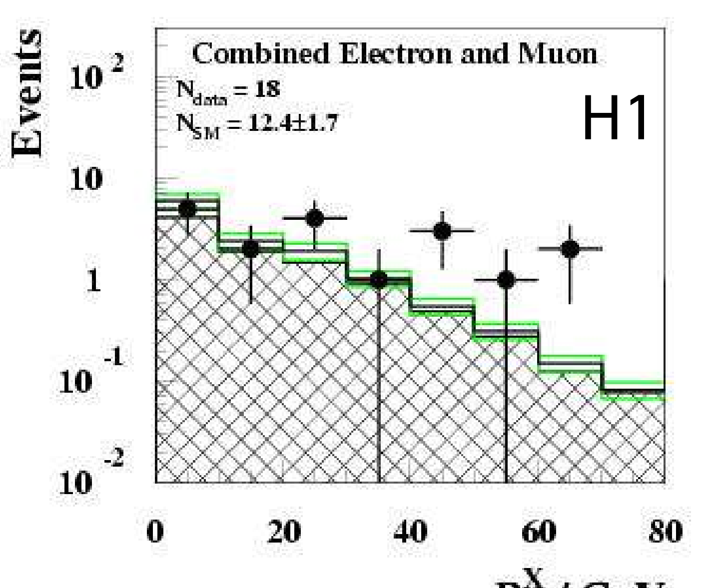
DØ-II M_{LQ} > 179 GeV in eeqq (41 pb^{-1})

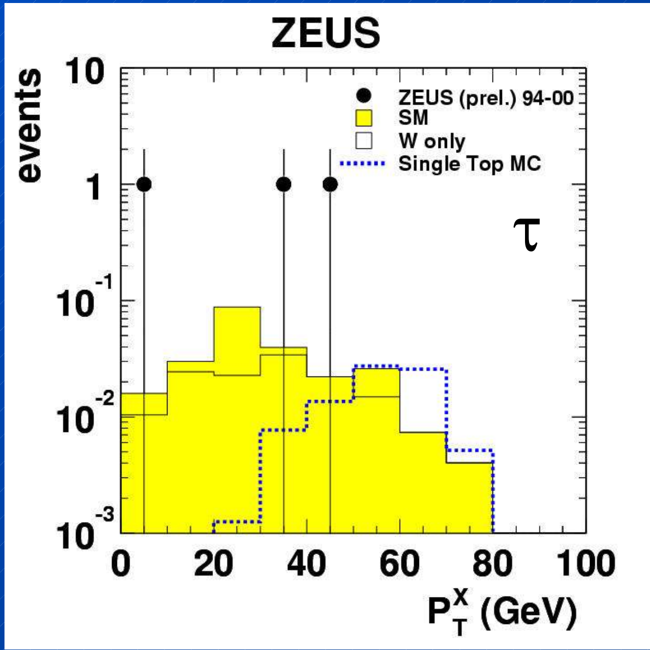
M_{LQ} > 157 GeV in μμqq (41 pb^{-1})

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

High-P_T Leptons at HERA

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



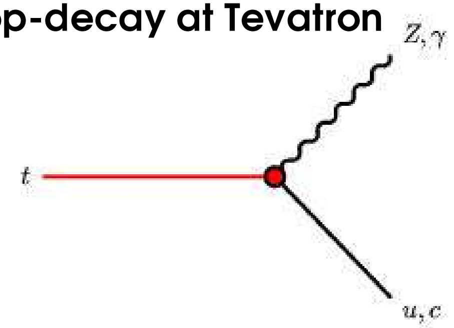


- **Interpretation:**

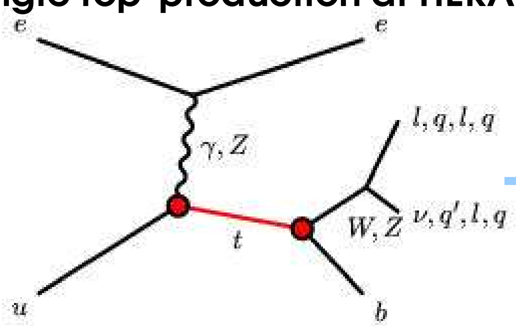
  FCNC single top production, at LEP (~10^{-9} fb), HERA in SM small
- anomalous contribution in SUSY, exotic quarks, multi-Higgs doublets, ...
- topology at HERA: high p_T positron / muon + large missing E_T

Anomalous Single-Top Production

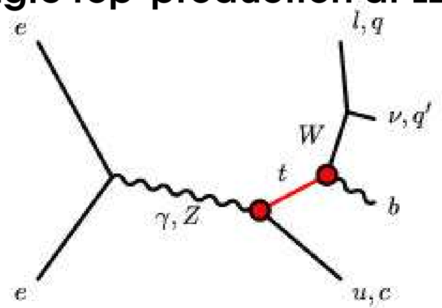
top-decay at Tevatron

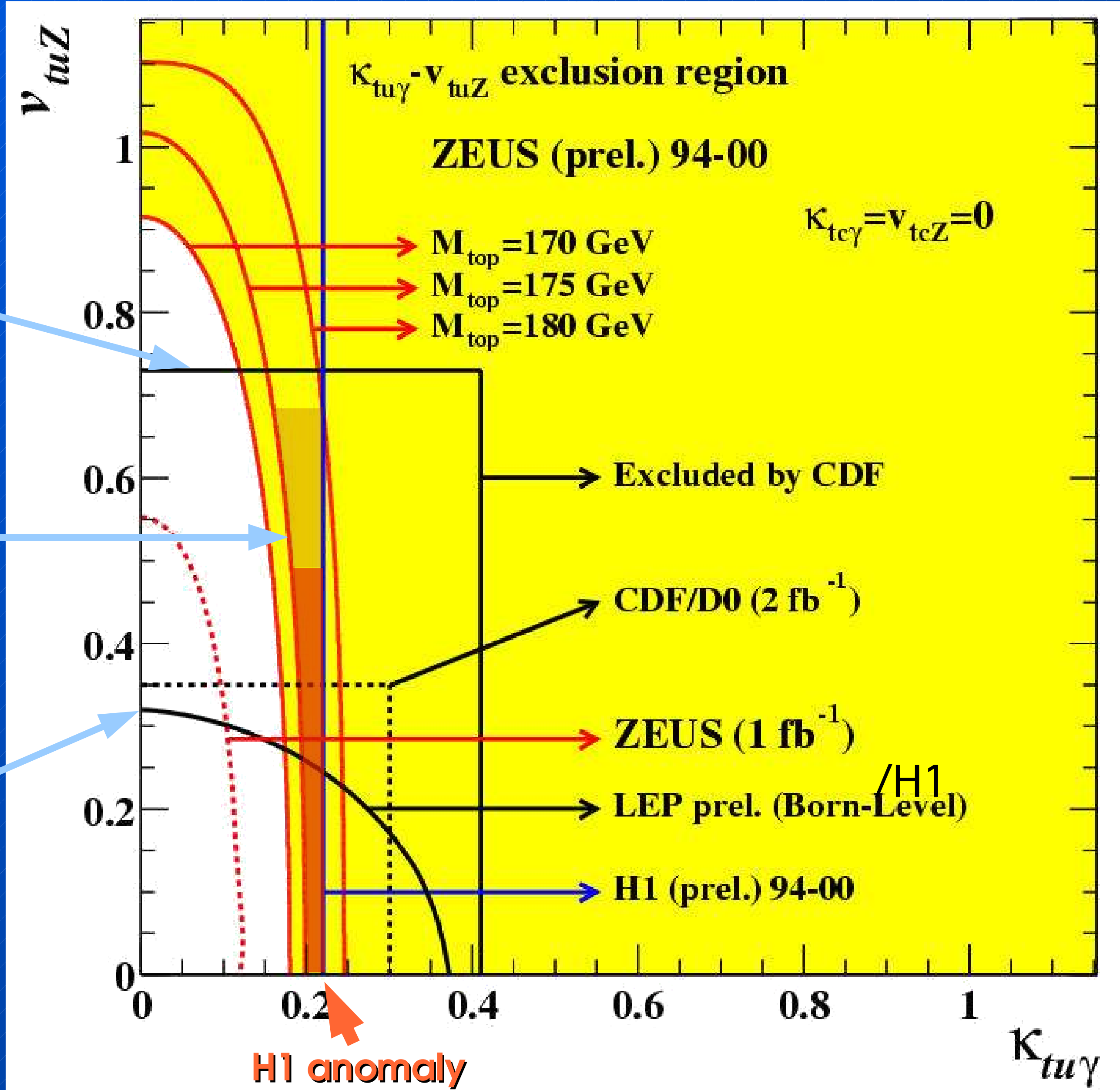


single top-production at HERA



single top-production at LEP





Search for Extra Space Dimensions

Task: solve **hierarchy problem,**

i.e. why is M_{pl}/m_{EW} ~ 10^{17} GeV soooo large ?

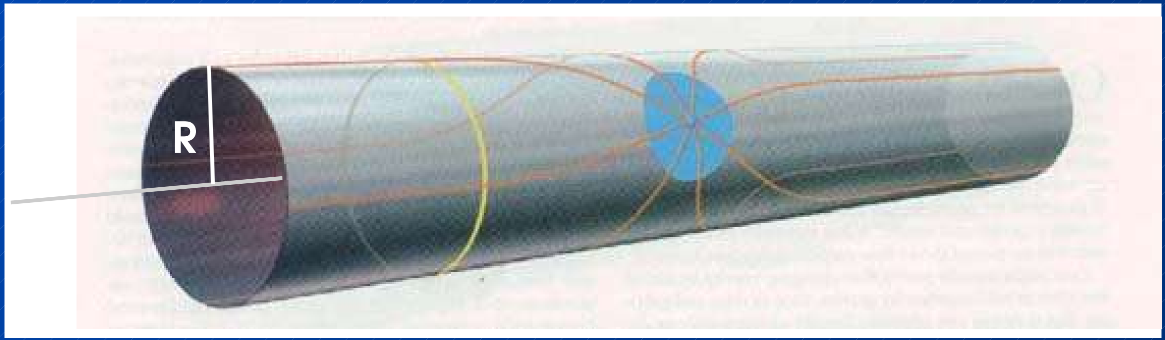
A proposed **solution**:

- 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

r R gravit. potential from Gauss law in (n+4) dim.

r R V ~ 1/r

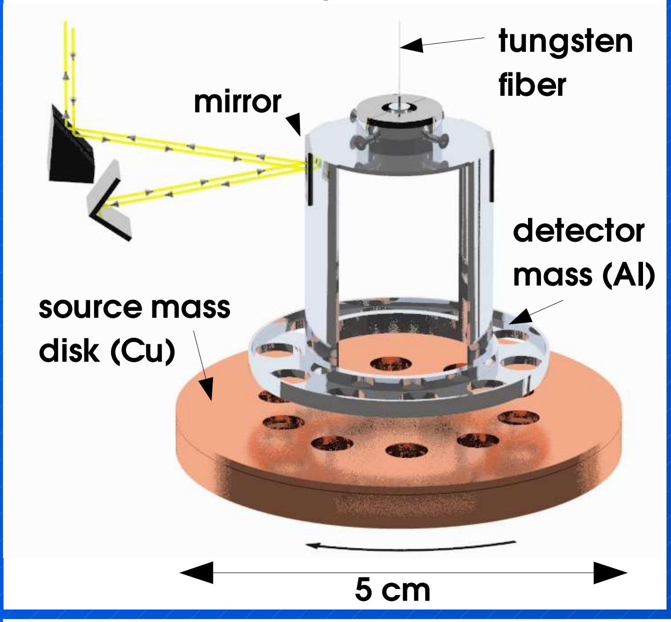
n=1	R ~ 10^{13} cm	excluded
n=2	R ~ 100 µm – 1mm	???
n=3	R ~ 3 nm	



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

Search for Extra Space Dimensions

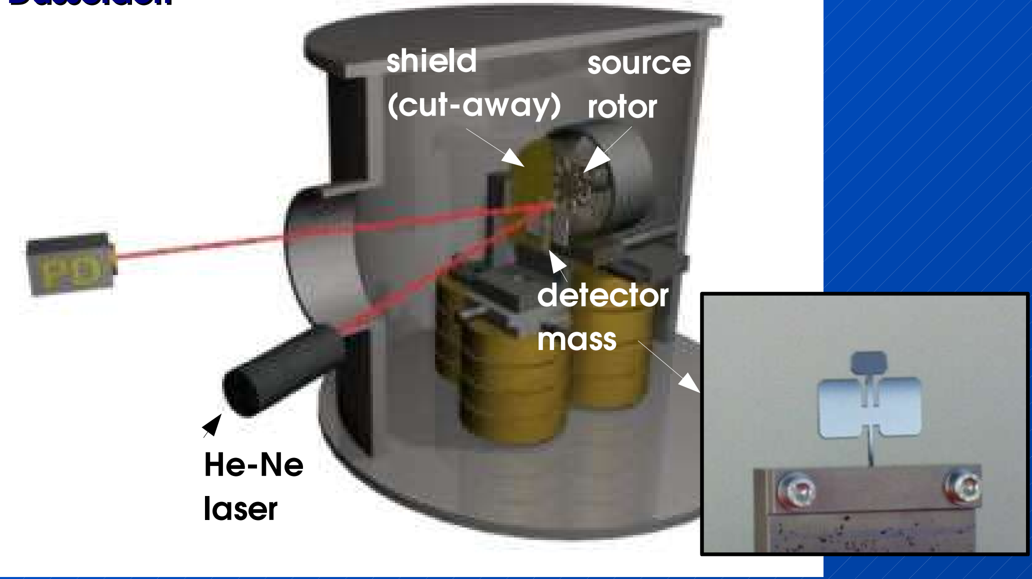
Eöt-Wash short-range torsion pendulum

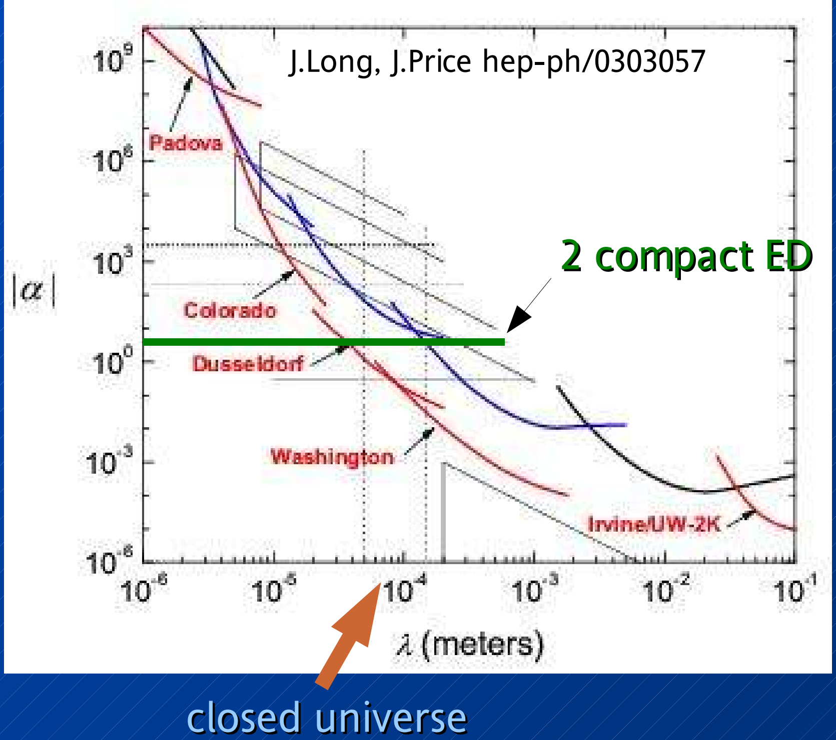


extra space dimensions modify Newtons Law:

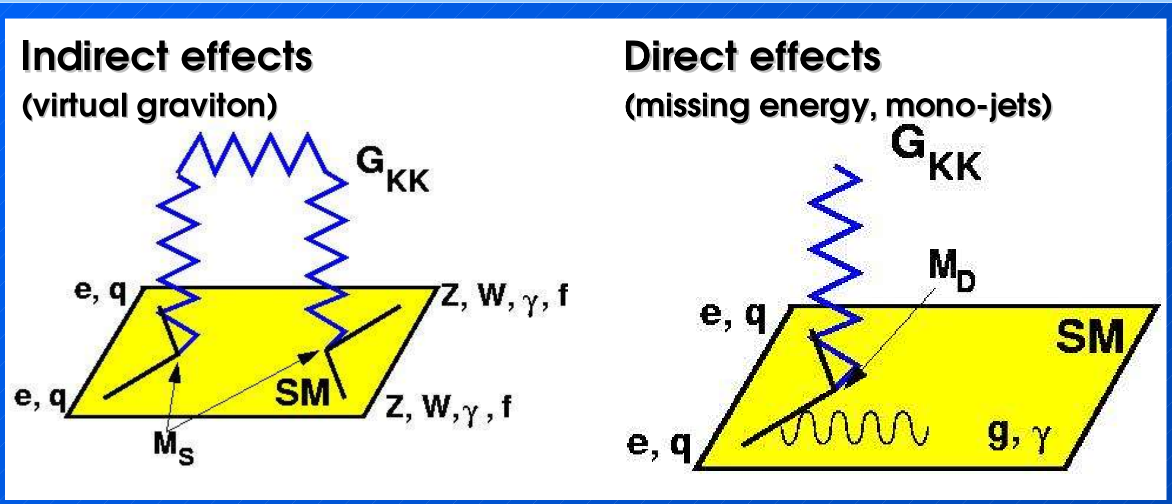
$$V = -\int d\vec{r}_1 \int d\vec{r}_2 \underbrace{\frac{G\rho_1(\vec{r}_1)\rho_2(\vec{r}_2)}{r_{12}}}_{Newton} \underbrace{\left[1+\alpha \exp^{-r_{12}/\lambda}\right]}_{Yukawa\ modification}$$

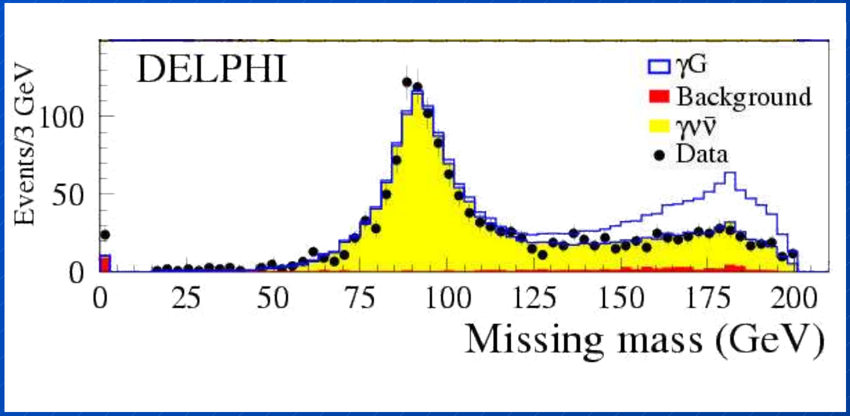
Düsseldorf

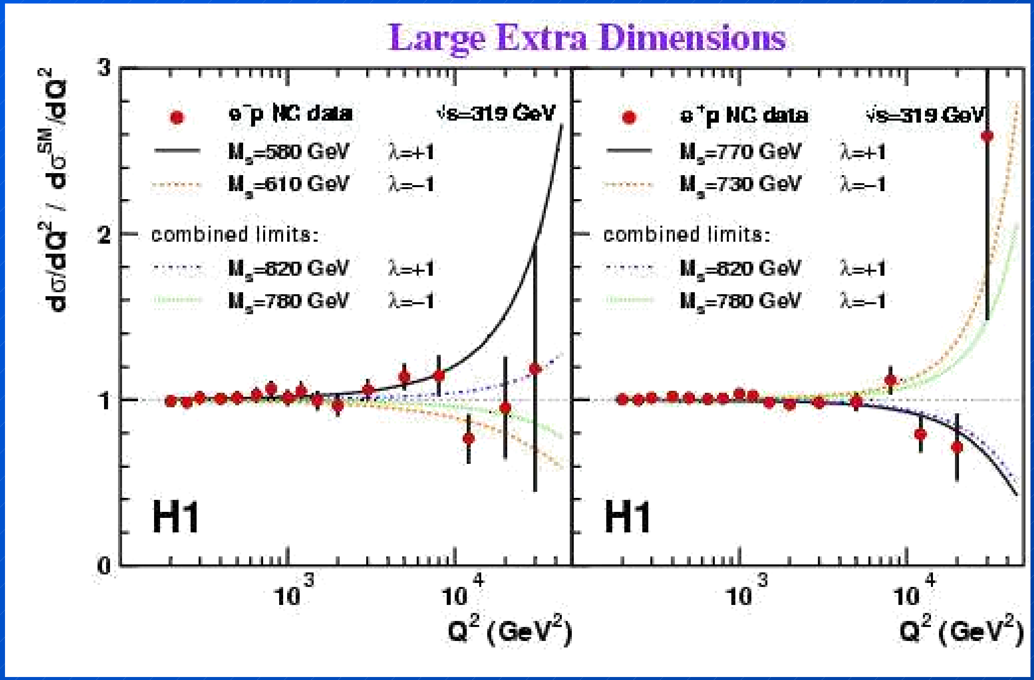


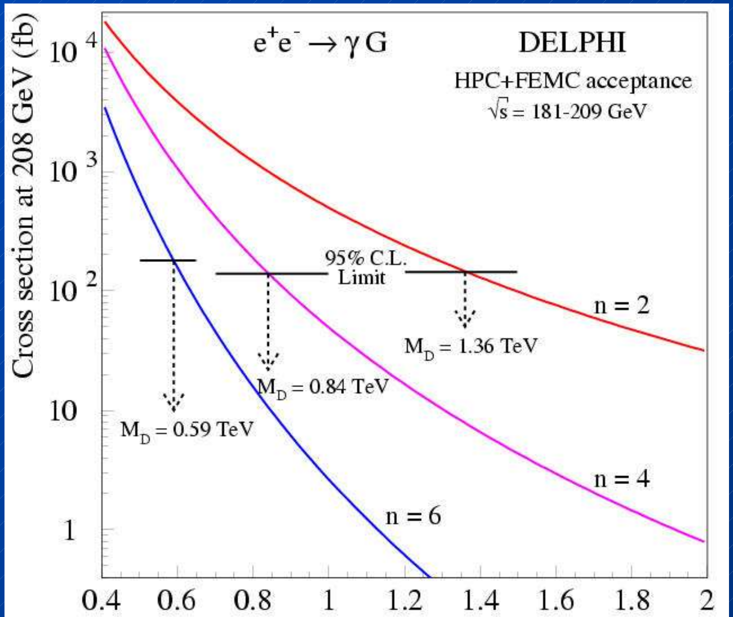


Search for Extra Space Dimensions









$M_D^{(n=2)}$ > 1.36 TeV; R < 0.26 mm

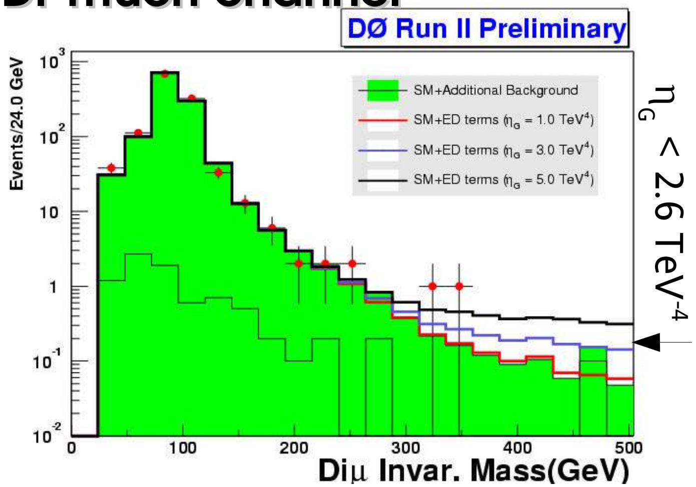
typical limits:

LEP / HERA: M_s > 0.7 - 1.2 TeV

Tevatron-I,II: M_s > 0.8 – 1.3 TeV

Search for Extra Space Dimensions

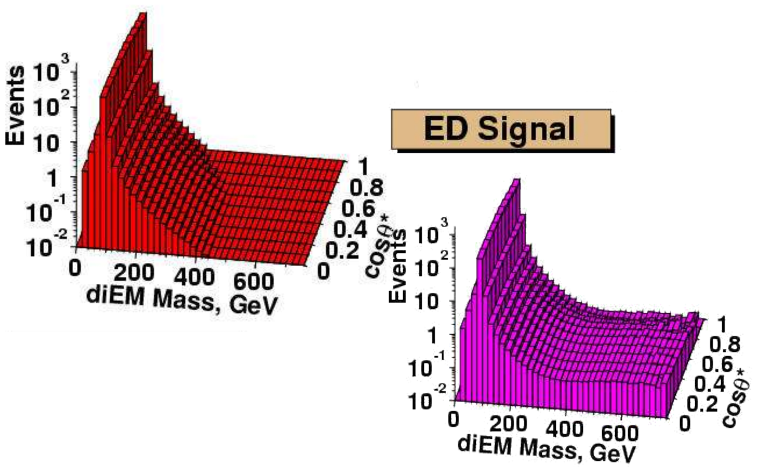
- Di-muon channel



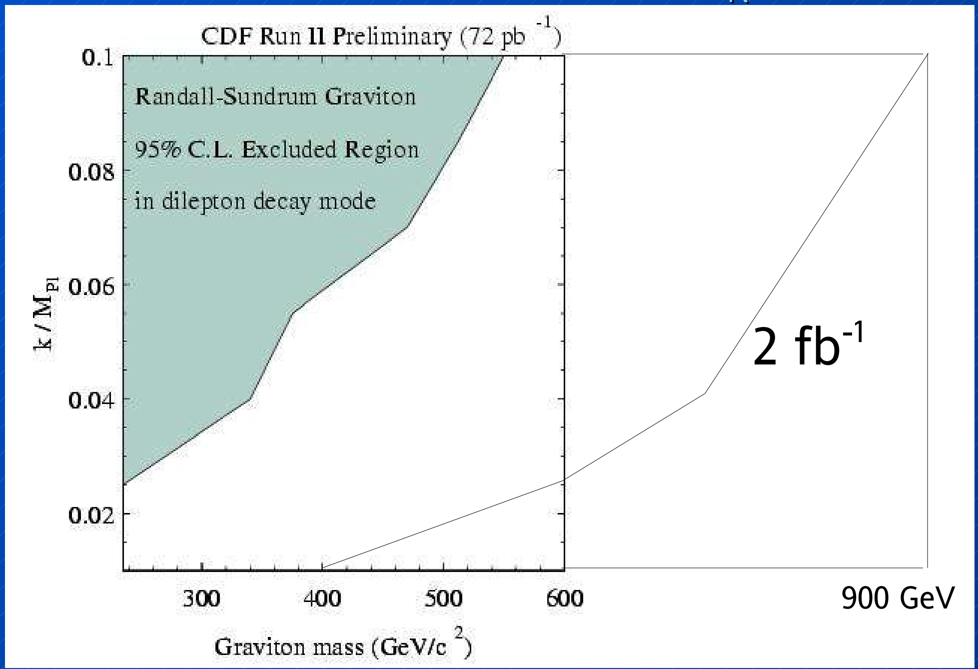
- Di-electron/photon channel

actually use mass vs cos *

SM Prediction DØ Run-II preliminary



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



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 ...

Summary - Part III

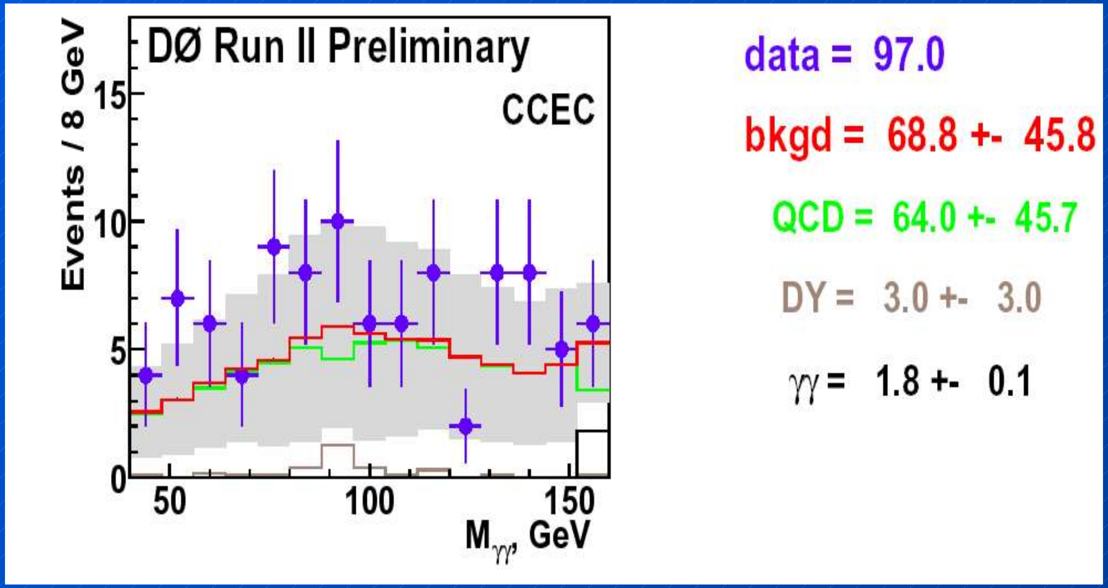
- Search for the Higgs
- Search for New Phenomena

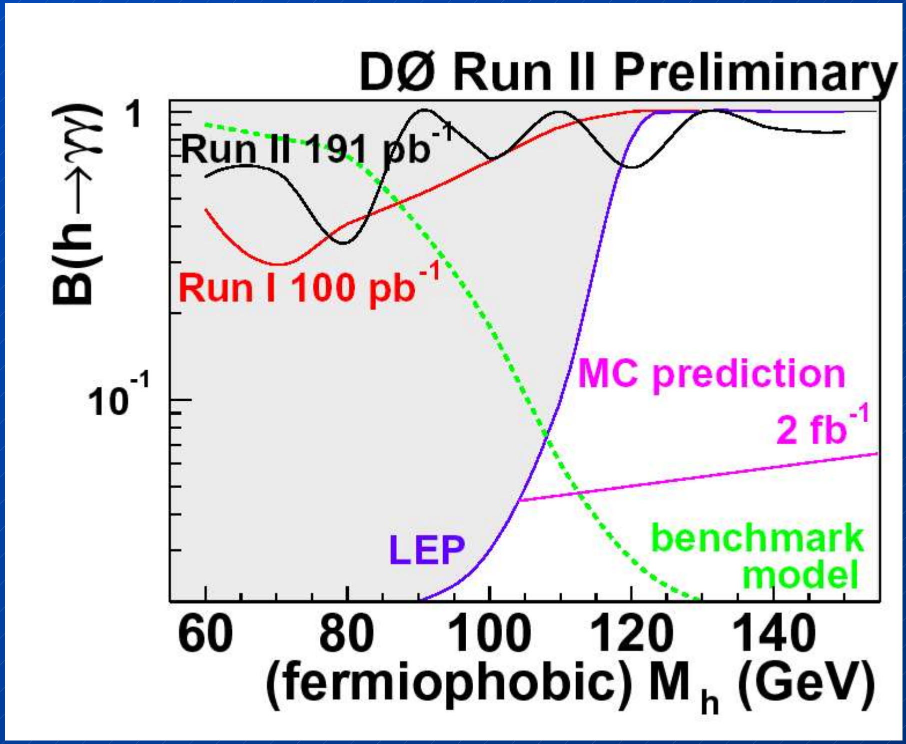
Backup Slides

Search for H → γγ

- In **2HDM - type I** Higgs coupling to fermions g_{Hff} ~ cos   can go to zero (` **fermiophobic Higgs**')
- **Topcolor Higgs**: only top has non-zero fermion coupling
- Increase of bosonic Higgs decays (in SM Br(H   gg) 0.1% for m_h=90 GeV)
- look for peaks in γγ mass spectrum for high p_T isolated γ's

...no kinematic wall at Tevatron...





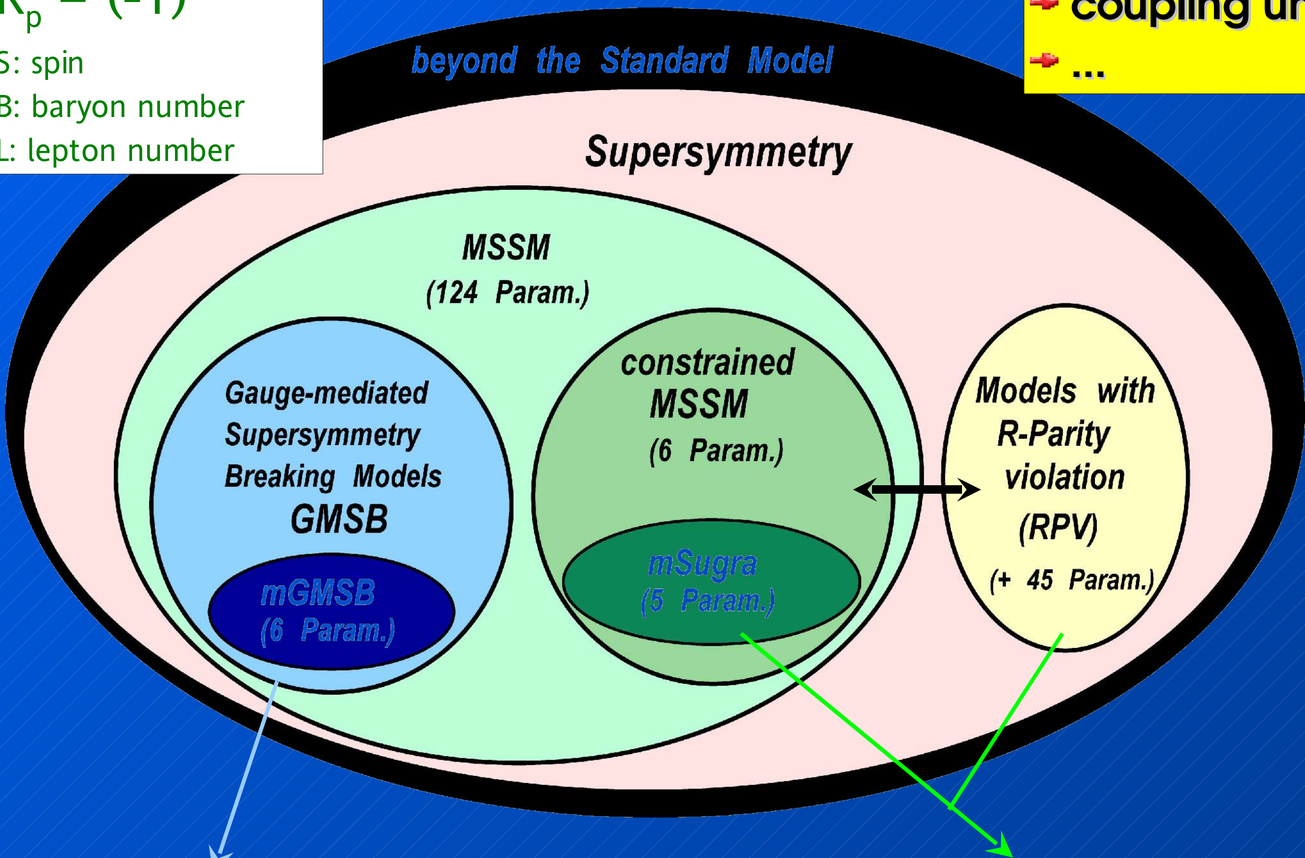
Super-Symmetry Models

Mechanism of SUSY breaking unknown: different models

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

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

S: spin
B: baryon number
L: lepton number



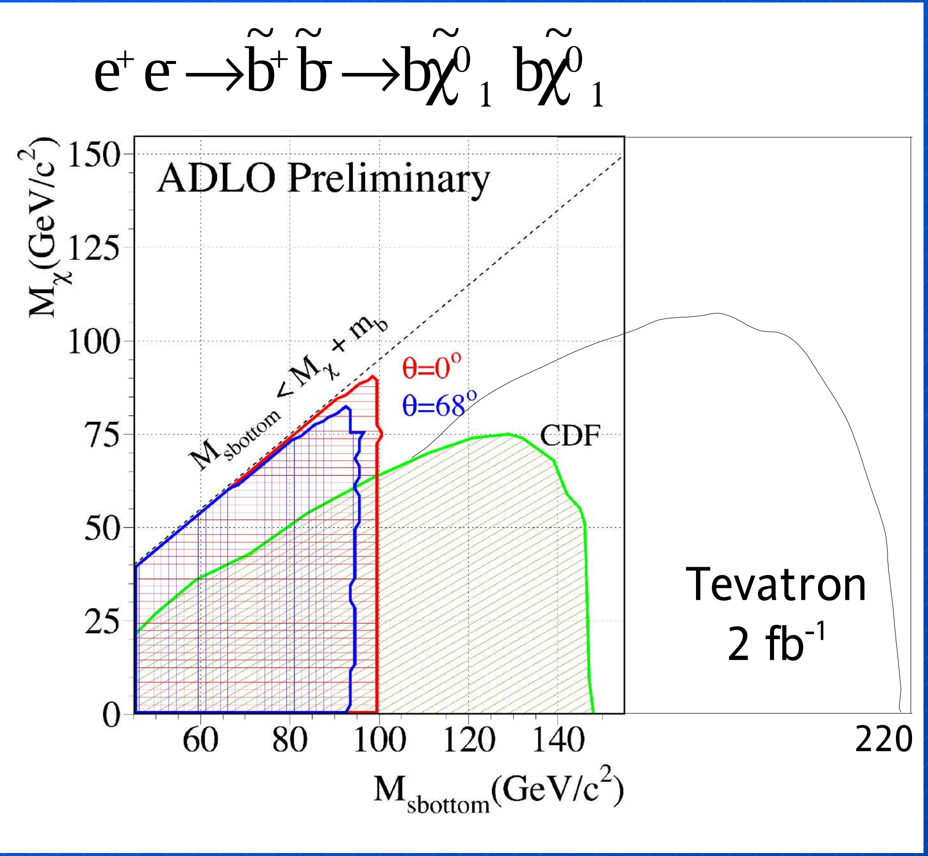
Models are used to guide the analyses and to express the results in a predictive framework

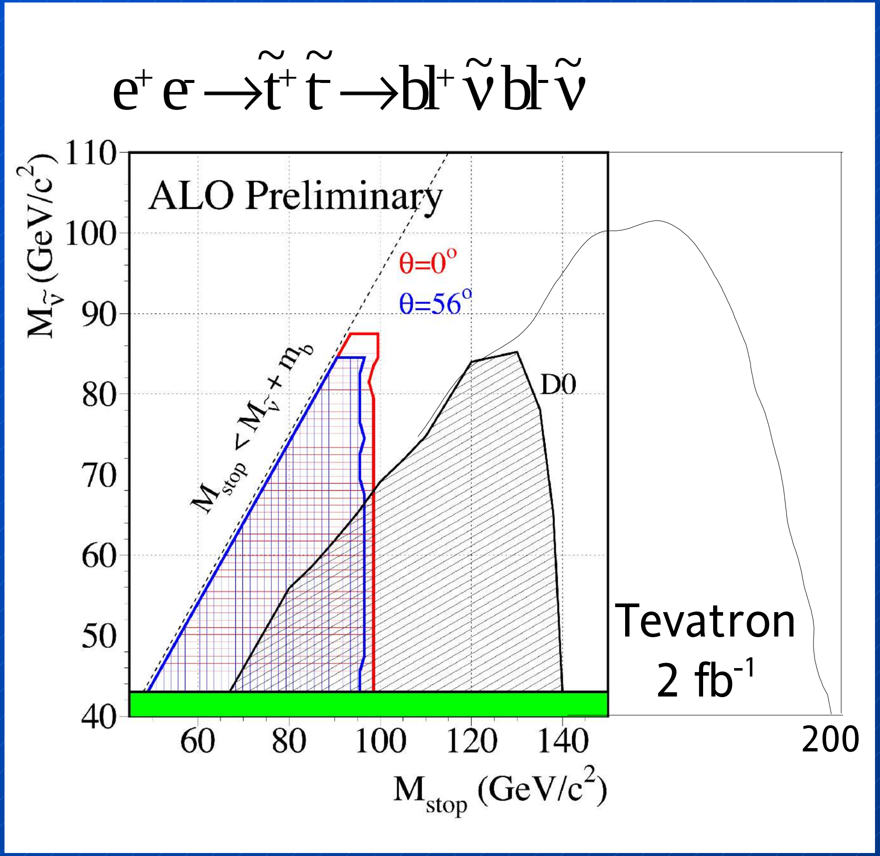
Communication via gauge bosons

Communication with our visible world via gravity

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

Stop/Sbottom Searches



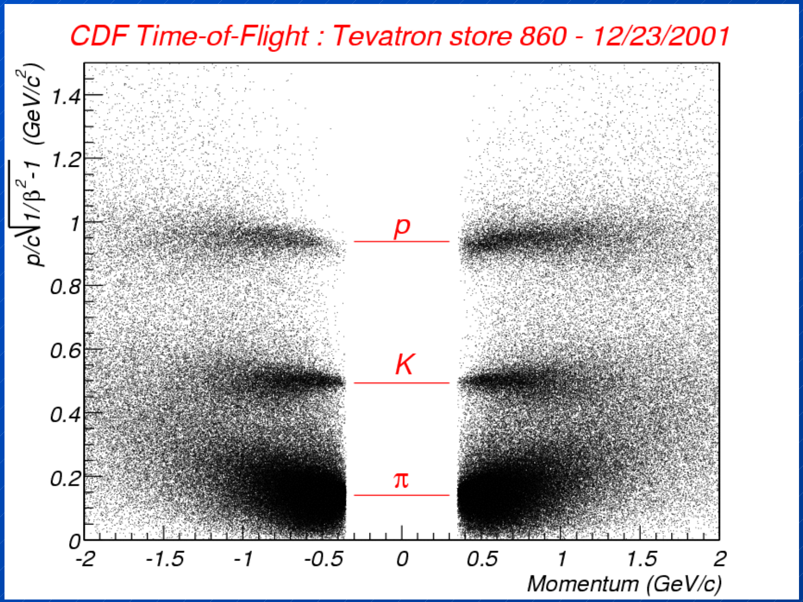


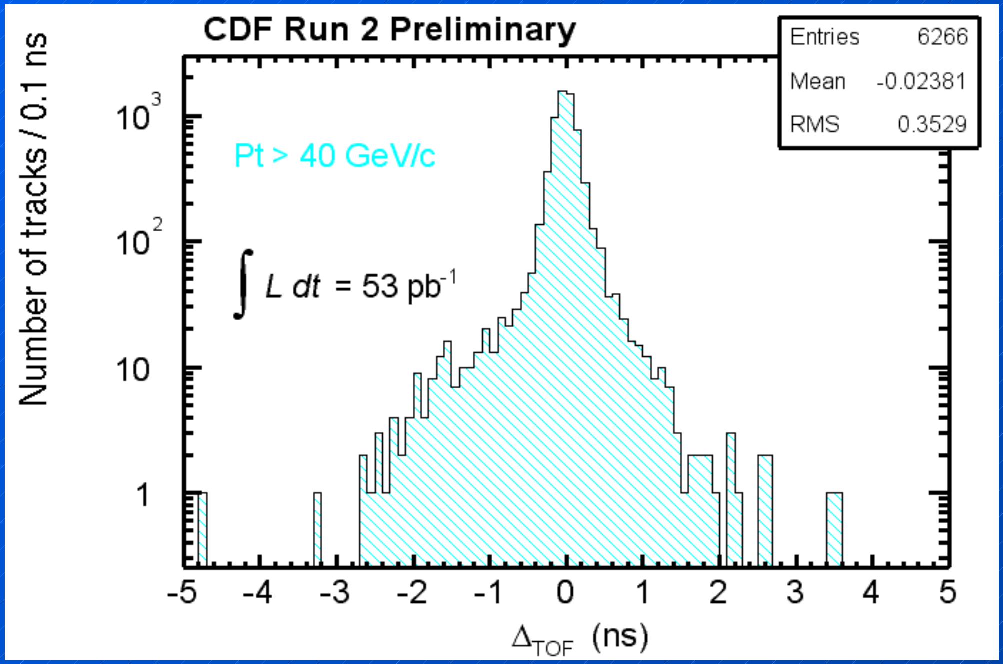
- similarly 160 GeV stop-mass reach for
- Run-II analyses ongoing ...

$$qq \rightarrow \tilde{t}^+\tilde{t}^- \rightarrow c\tilde{\chi}^0_1\ c\tilde{\chi}^0_1$$

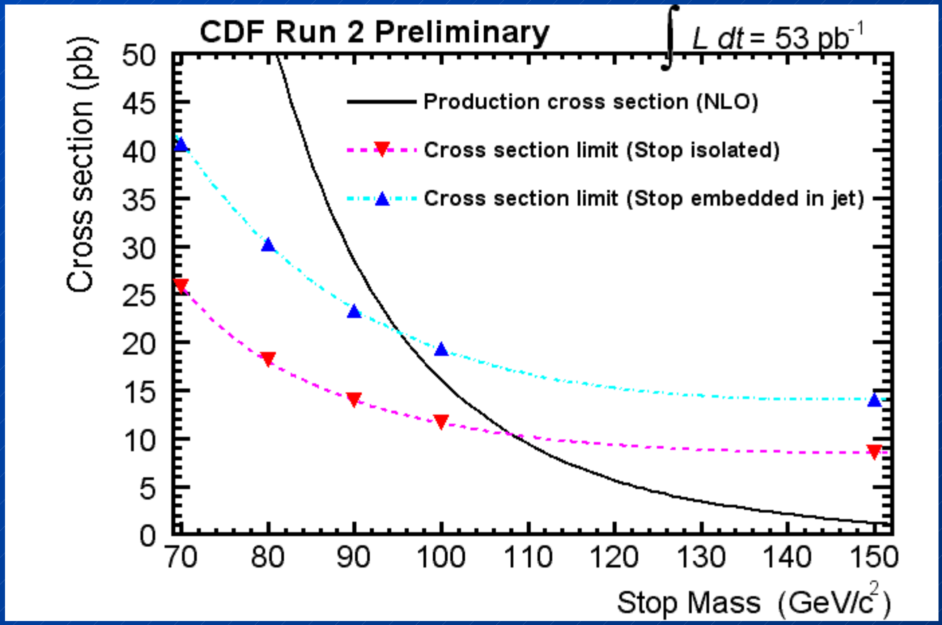
Charged Massive Particles

- General search for charged massive particles (heavy stops ?) carried out by CDF
- use time-of-flight system (TOF) to measure mass of charged particle/track

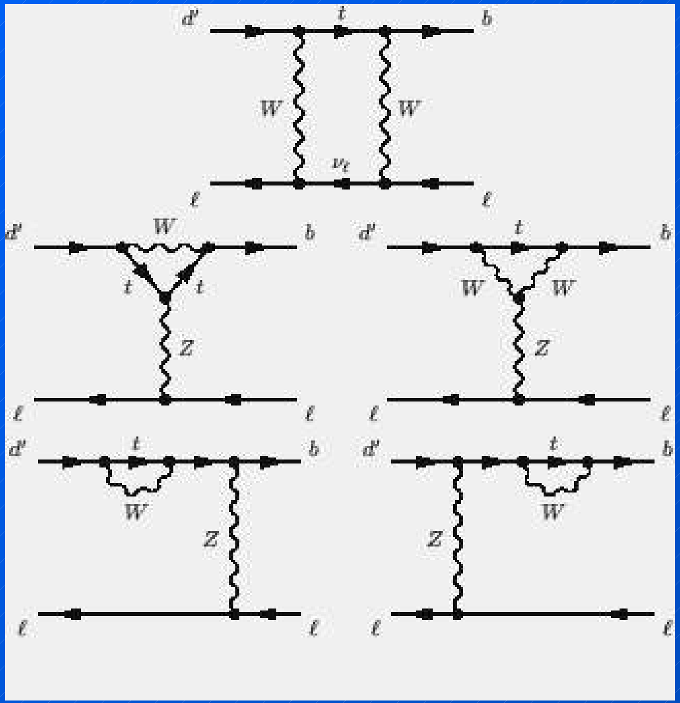




- obtain cross section limit from TOF distribution for heavy particles ⇨



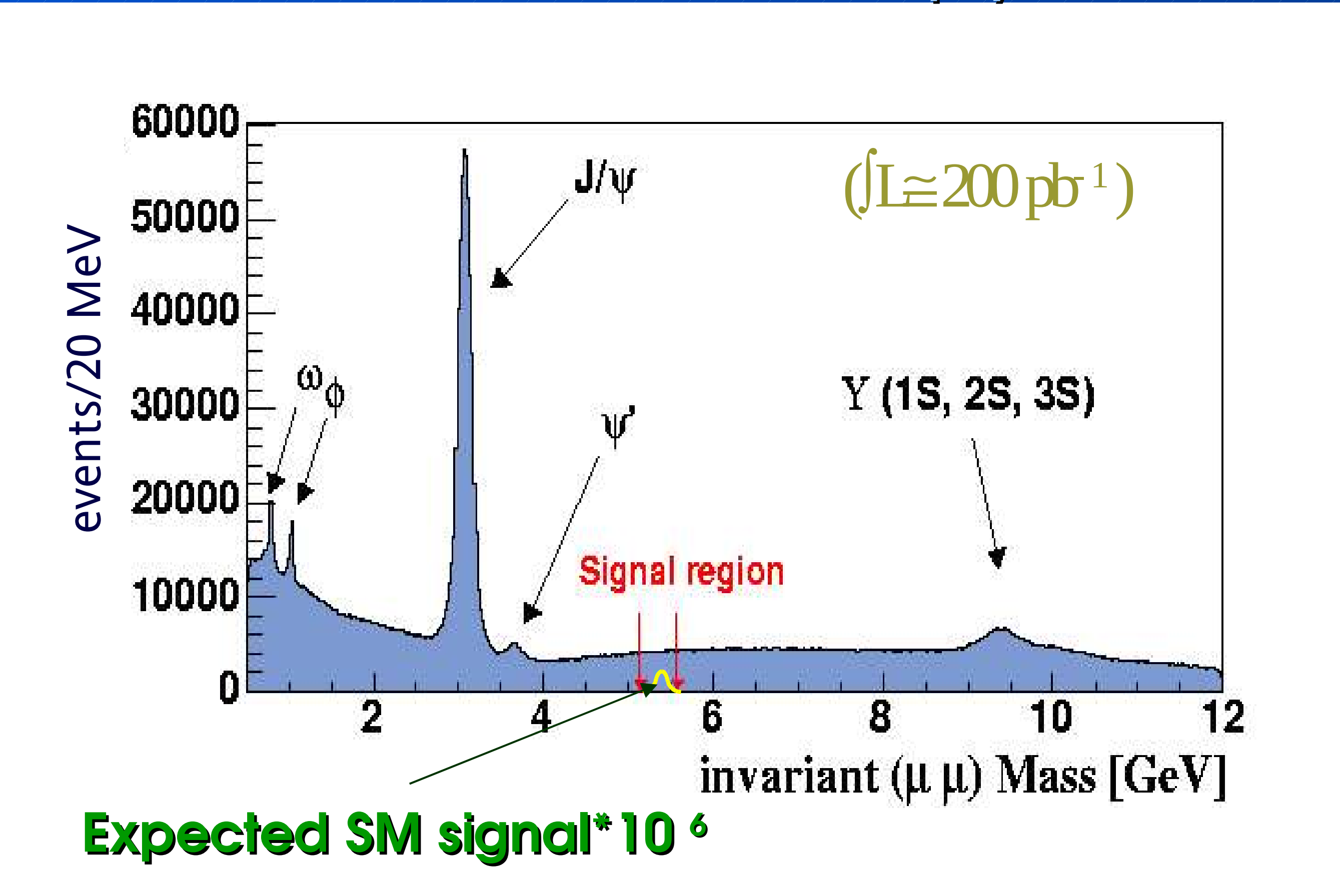
Search for $B_s \rightarrow \mu^+\mu^-$



Standard Model prediction

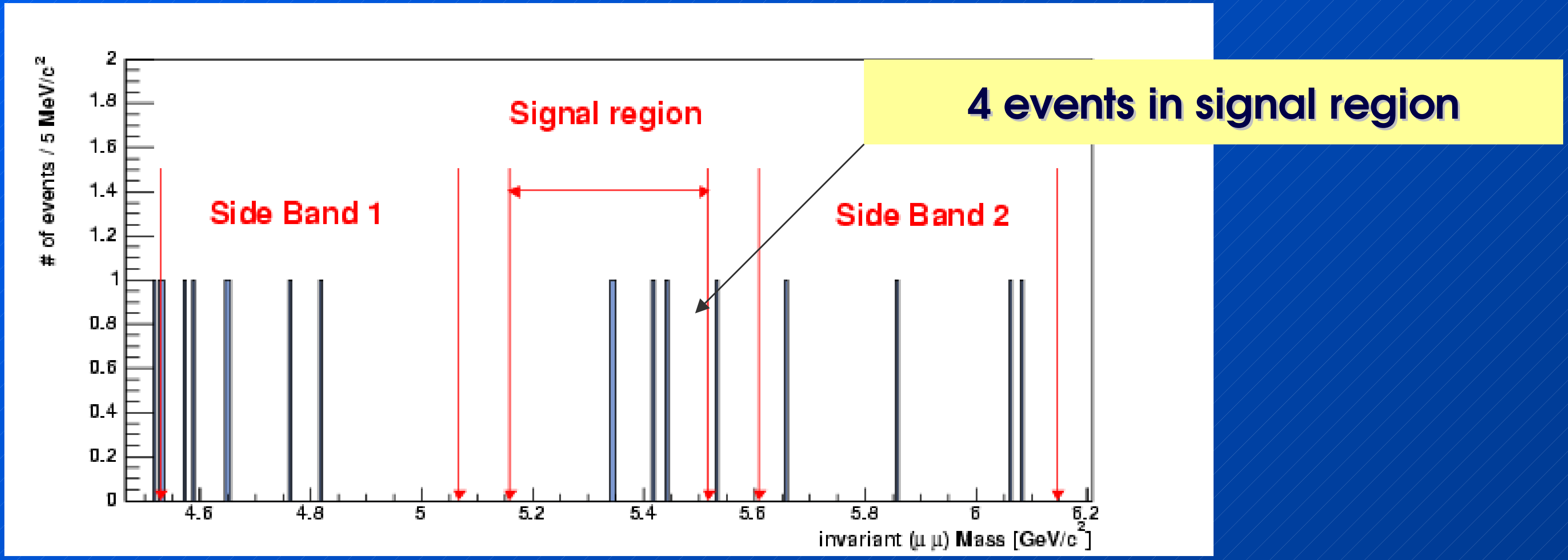
$BR(B_s \rightarrow \mu^+\mu^-) = (3.4 \pm 0.5) \cdot 10^{-9}$

... excellent place to look for SUSY and other new physics ...



Search for $B_s \rightarrow \mu^+\mu^-$

- blind analysis (240 pb^{-1}):
- efficiency of selection cuts = (38.6 ± 0.7)%
- background prediction = 3.7 ± 1.1 event



$BR(B_s \rightarrow \mu^+\mu^-) < 4.6 \cdot 10^{-7}$ (@95% CL)

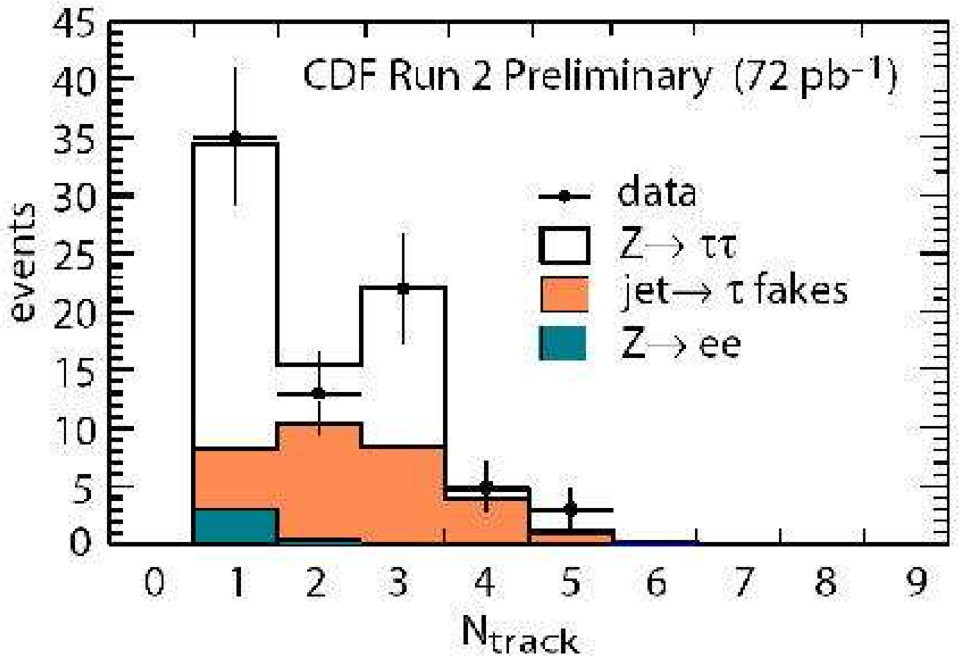
similar for CDF
new best limits, but more potential

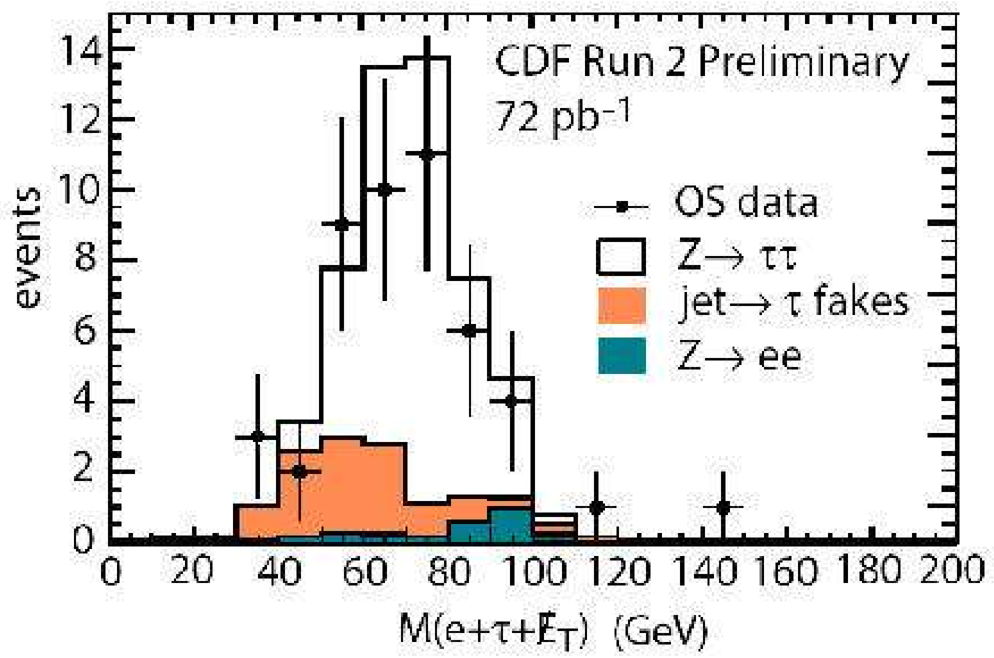
$Z \to \tau\tau$ Signal at the Tevatron

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

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

... similar for DØ ...





Doubly Charged Higgs Bosons

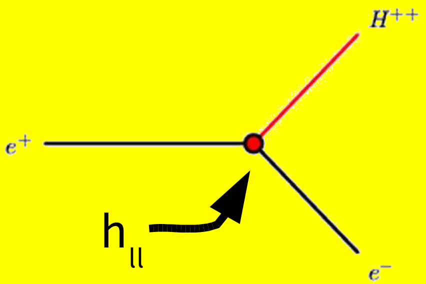
Motivation:

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, $m(H^{\pm\pm}) \sim 100$ GeV

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



limits on Yukawa couplings from

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

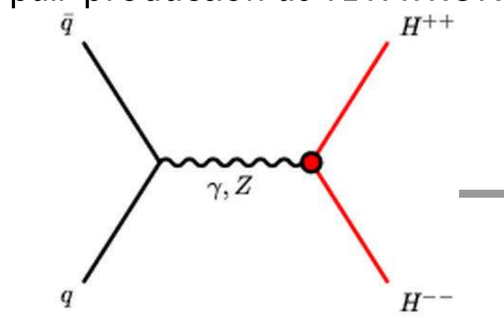
...search for same-sign multi-lepton events ...at LEP, HERA, TEVATRON ...

Doubly Charged Higgs Bosons

DØ (113 pb^{-1}) $M(H_L) > 118$ GeV (μμ)

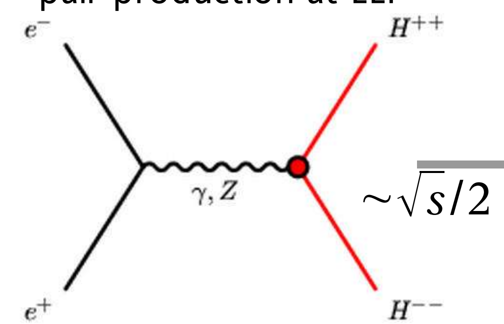
CDF (240 pb^{-1}) $M(H_L) > 136$ GeV (μμ)

pair production at TEVATRON



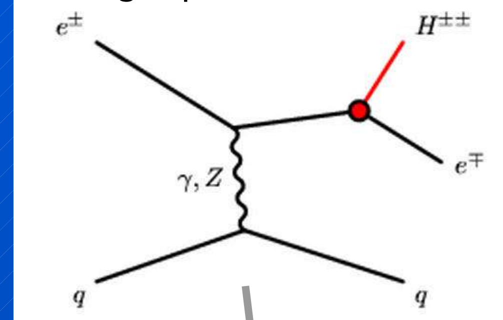
CDF-II (e,μ), DØ-II (μ)
2 fb^{-1}: > 150 – 200 GeV

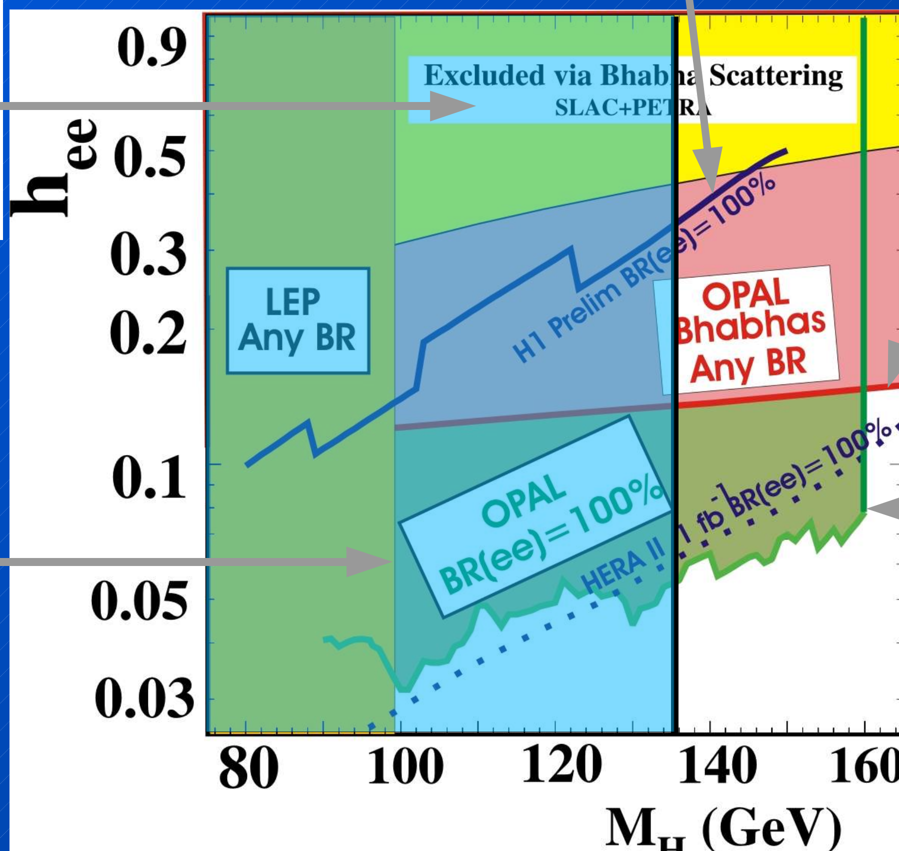
pair production at LEP



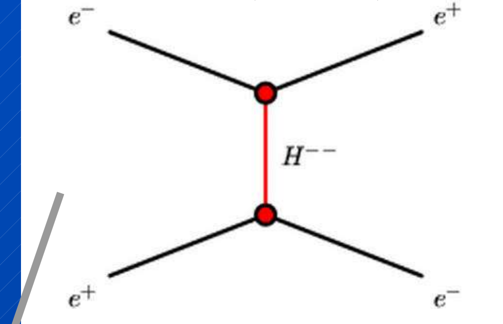
OPAL (e,μ, ; no lifetime)
DELPHI (; any lifetime)
L3 (e,μ, ; no lifetime)

single production at HERA



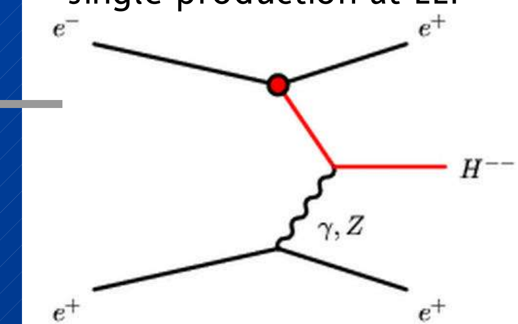


t-channel (Bhabha) at LEP



- lumi measurement ok
- would change angular distribution

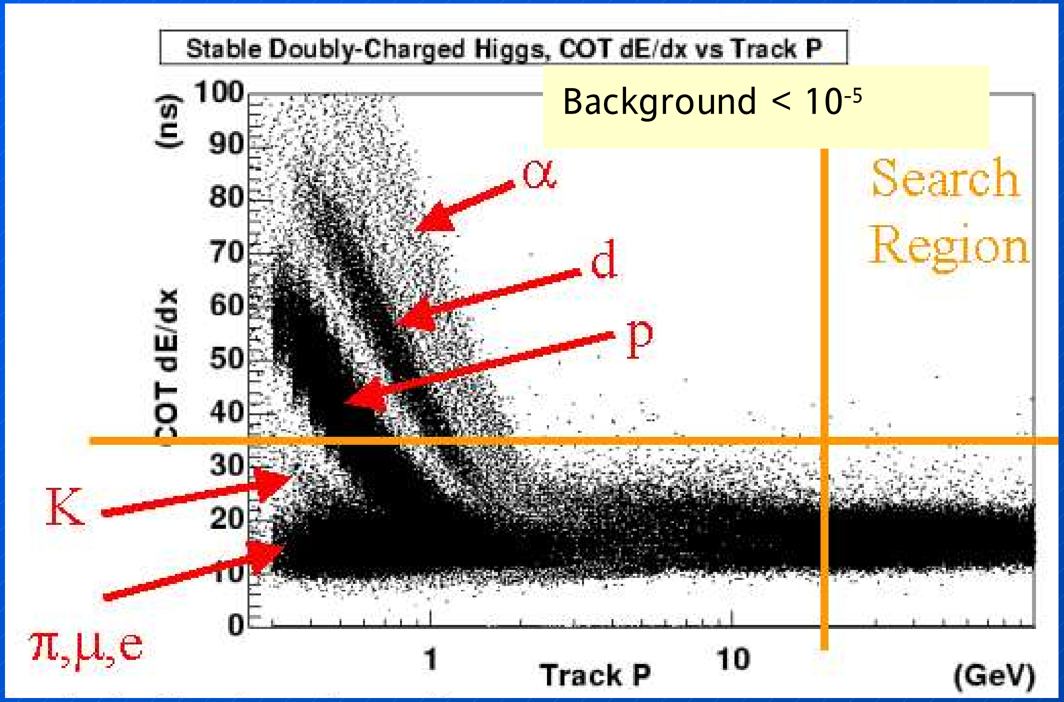
single production at LEP

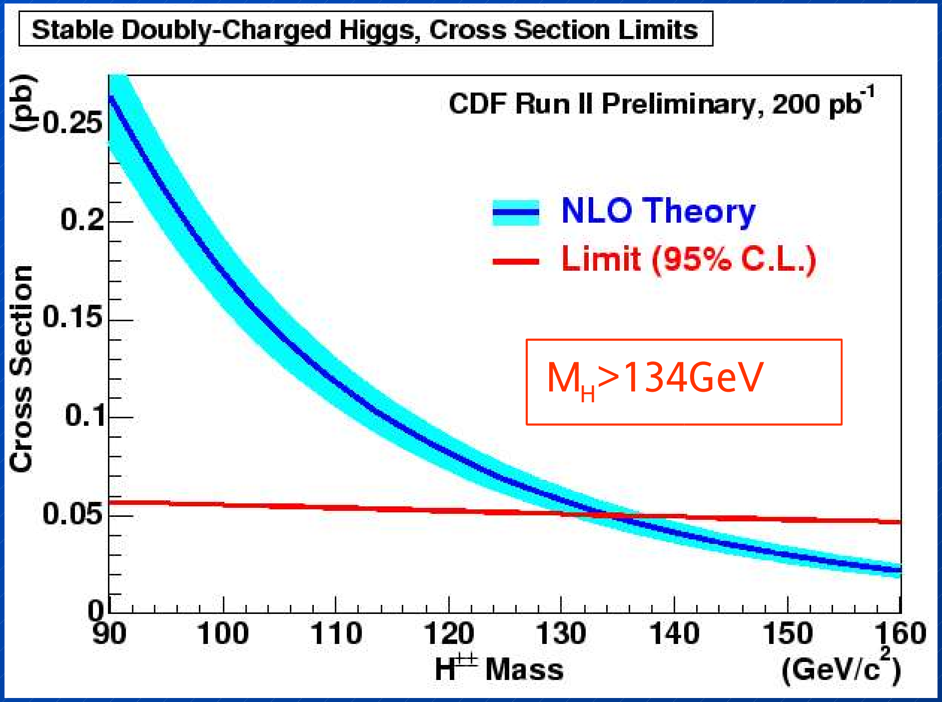


- very forward e might get lost

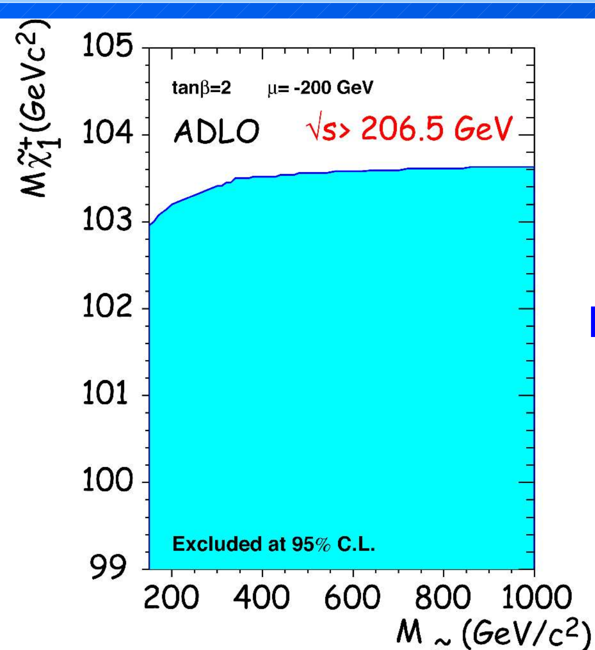
Doubly Charged Higgs Bosons

if H^{++} long lived expect two highly ionizing tracks in drift chamber ...

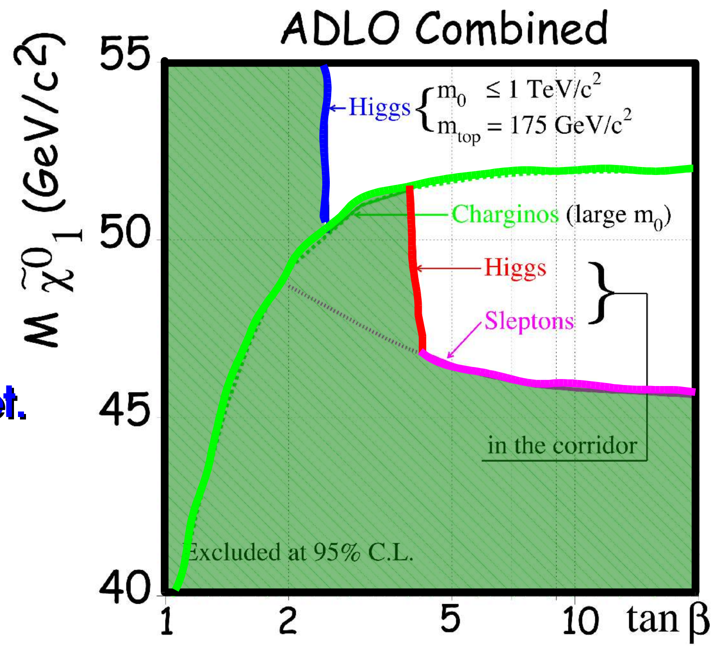




Chargino and Neutralino Limits



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 $m_{\chi_1^0}$

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

➔ 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)