

# Electroweak and Beyond the Standard Model Working Group - Experimental Summary

Alex Tapper & Beate Heinemann



# Introduction

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30 talks + joint sessions!

Conveners:

10 hours of talks + joint sessions!

C.-P. Yuan, B. Heinemann, A. Tapper

10 theory talks C.-P. summary

Split into six sessions:

20 experimental talks

- Electroweak precision
- Top Production
- Higgs
- Supersymmetry
- Leptoquarks, LFV, etc.
- Flavour physics

Collider breakdown:

LEP 1

Tevatron 7

HERA 8

B-factory 1

LHC 3

Joint sessions with SF

Disclaimer:

Talk follows this structure

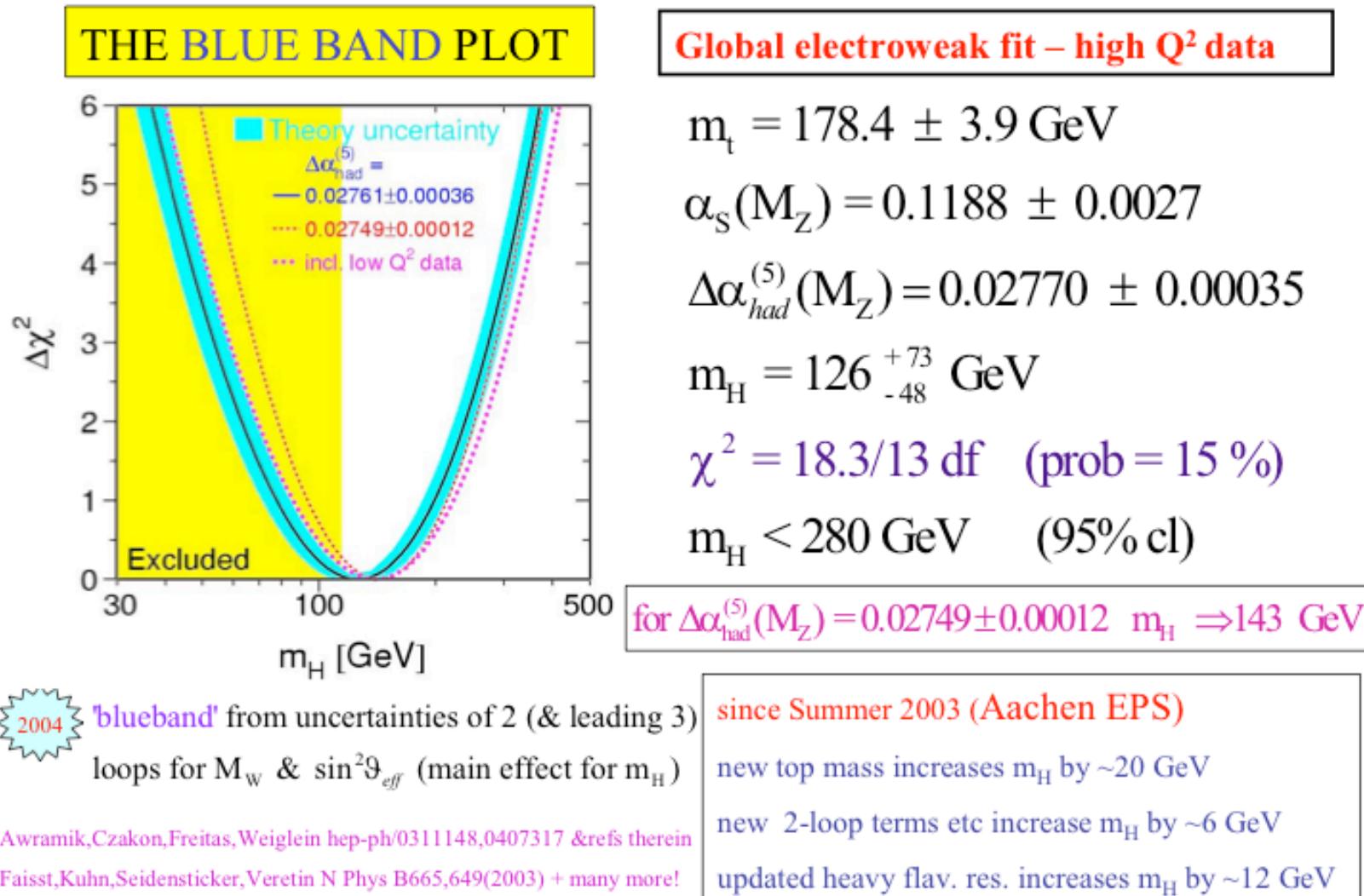
Only a small personal selection of many results. Apologies for omissions, biases and mistakes!

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# Electroweak precision

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# Fits to electroweak precision data

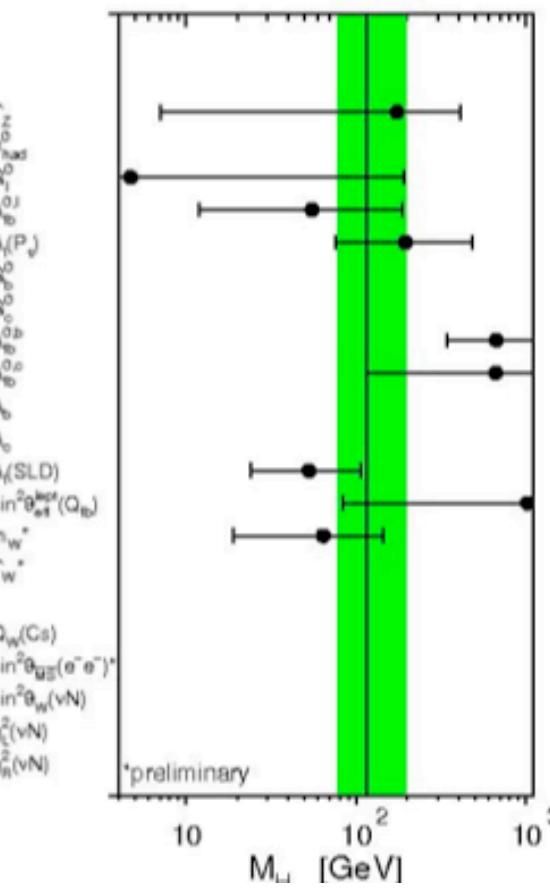


# Fits to precision electroweak data

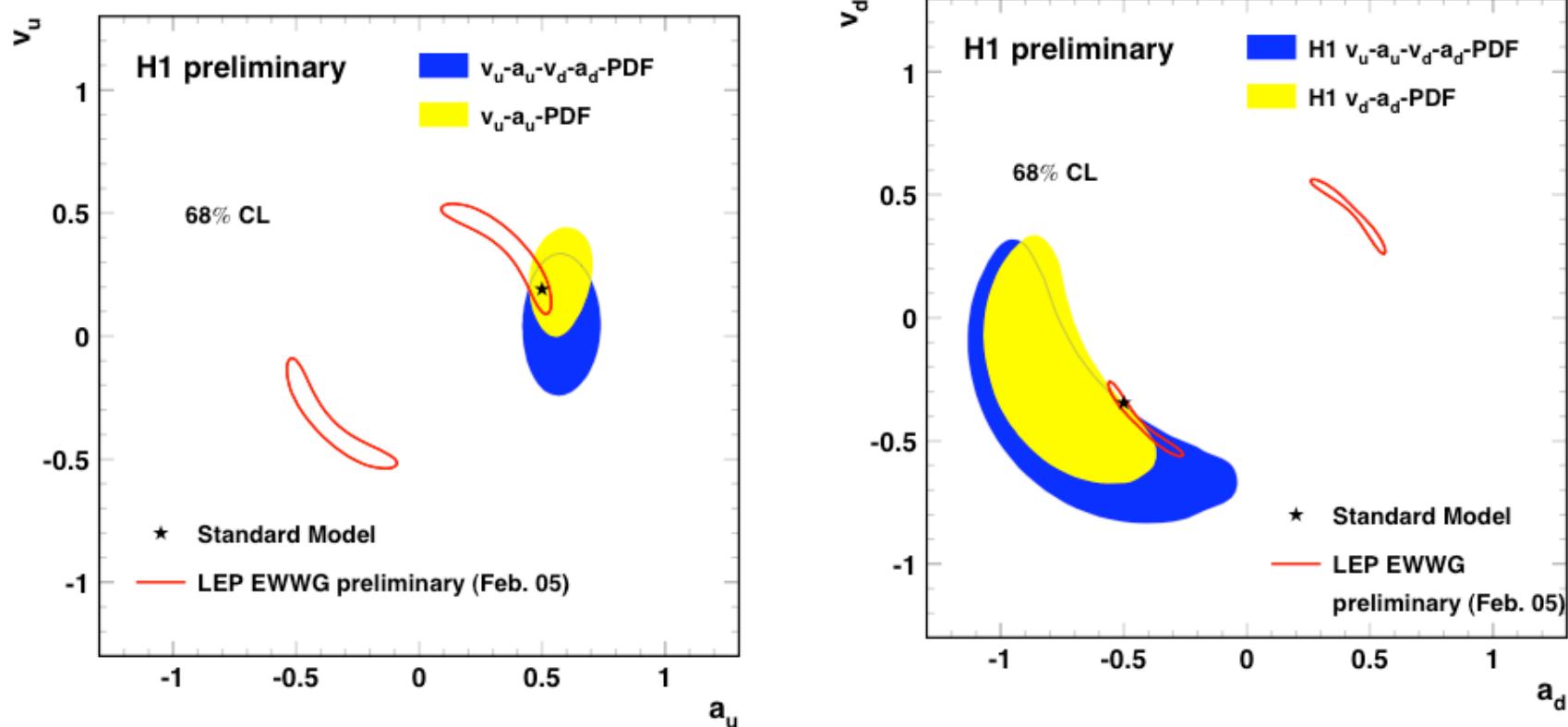
**pulls**



Higgs mass from individual measurements



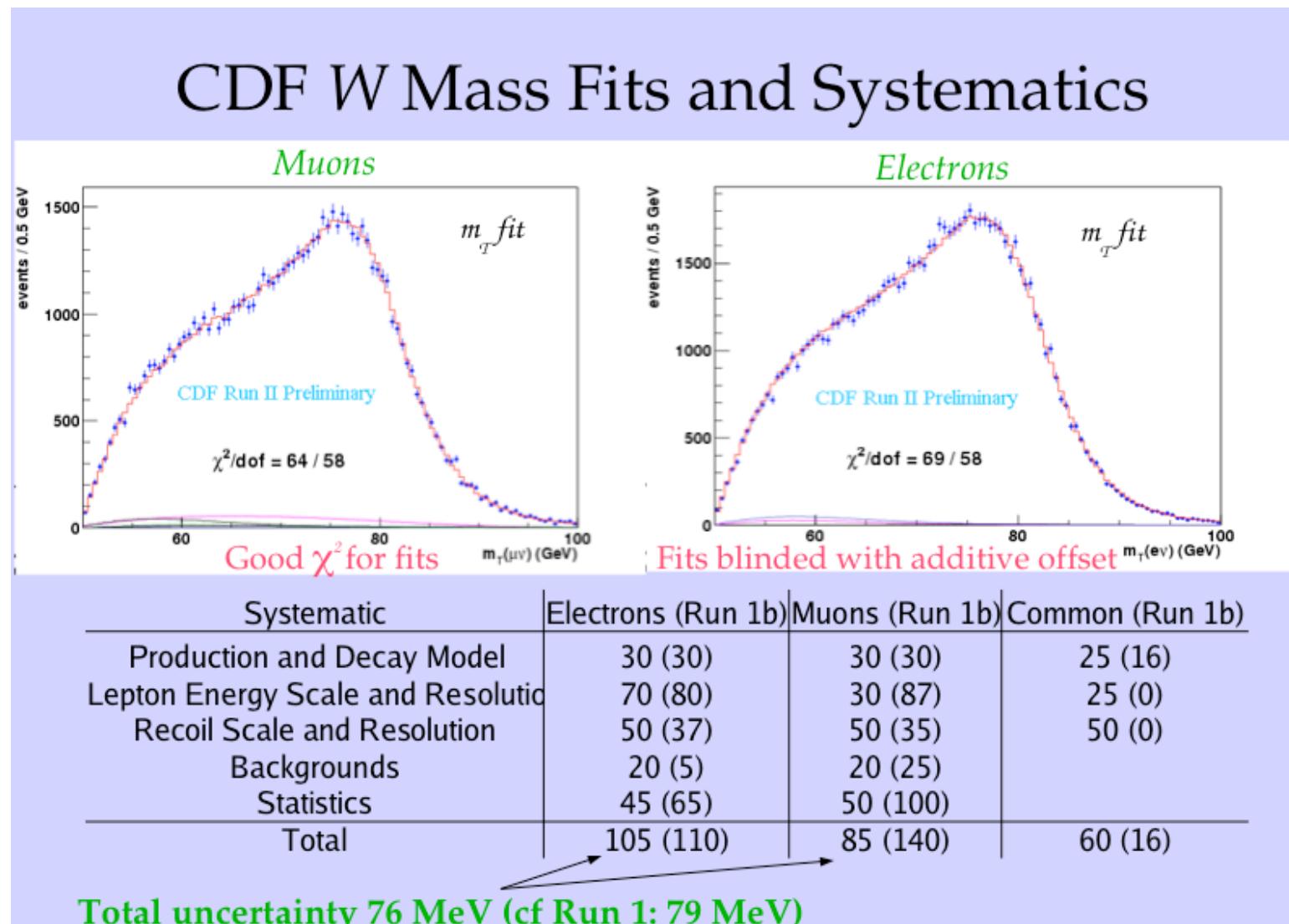
## Determination of electroweak parameters at HERA with the H1 experiment



Precision will improve with HERA II high luminosity data

Precision in vector couplings will also improve with long. polarised data

# W mass at the Tevatron



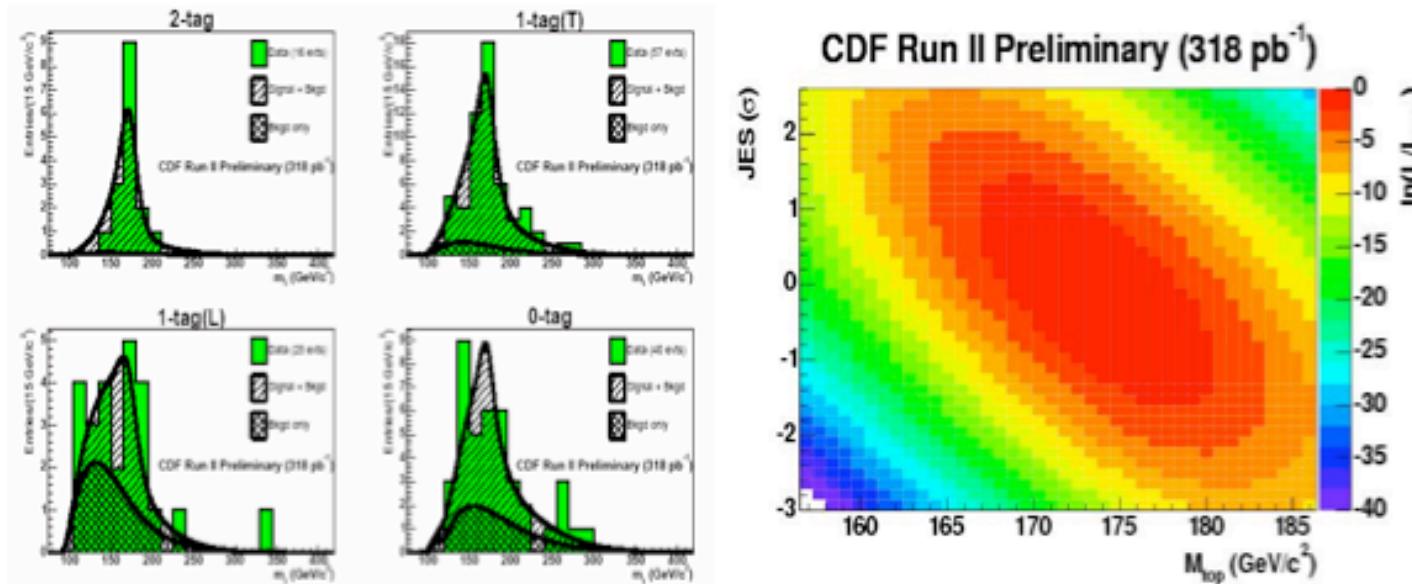
# Top mass at the Tevatron

- Use  $318 \text{ pb}^{-1}$  of data
- 2-D fit: best single top mass measurement in the world:

$$M_{top} = 173.5^{+2.7}_{-2.6} (\text{stat.}) \pm 2.5 (\text{JES}) \pm 1.7 (\text{syst.}) \text{ GeV / } c^2$$

- Cross-check using traditional 1-D fit:

$$M_{top} = 173.2^{+2.9}_{-2.8} (\text{stat.}) \pm 3.1 (\text{JES}) \pm 1.5 (\text{syst.}) \text{ GeV / } c^2$$



# Electroweak precision measurements at the LHC

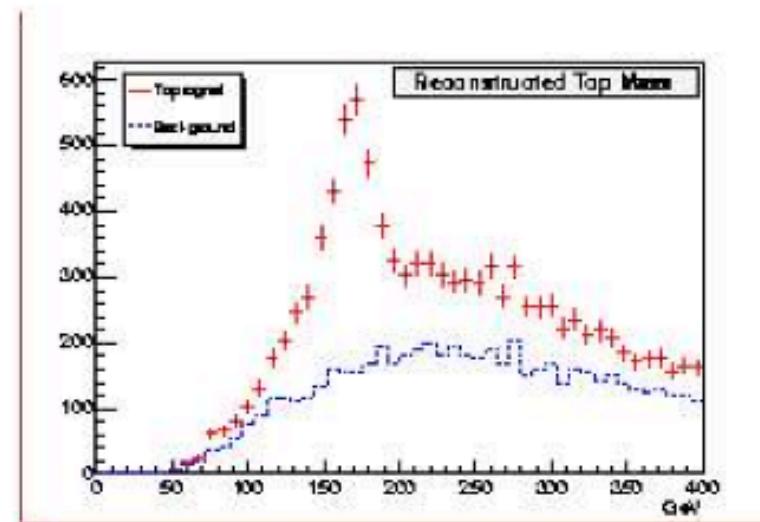
## Electroweak Precision: Status

- W/Z production at LHC will be considered as luminosity monitor.
- Current parton cross-sections are known to 5 - 10%.
- Need to know to a level of 2%  $\Rightarrow$  requires calculations to 1st order in  $\alpha_{EW}$  and to 2nd order in  $\alpha_s$  atleast.

exp. error	$\delta \sin^2 \theta_{eff} (\times 10^5)$	$\delta M_W$ [MeV]	$\delta m_t$ [GeV]	$\delta M_H$ [MeV]
today	17	34	5.1	-
LHC	14-20	15	1-2	200

ILC will do better, of course.

**150 pb<sup>-1</sup>  $\rightarrow$  a few months running**



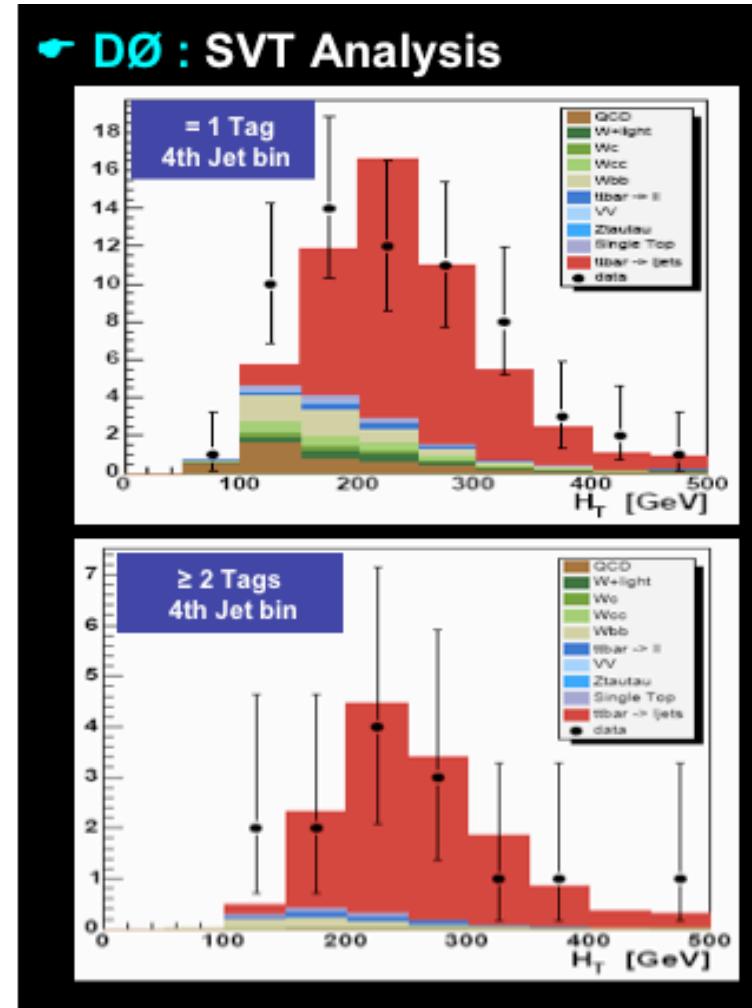
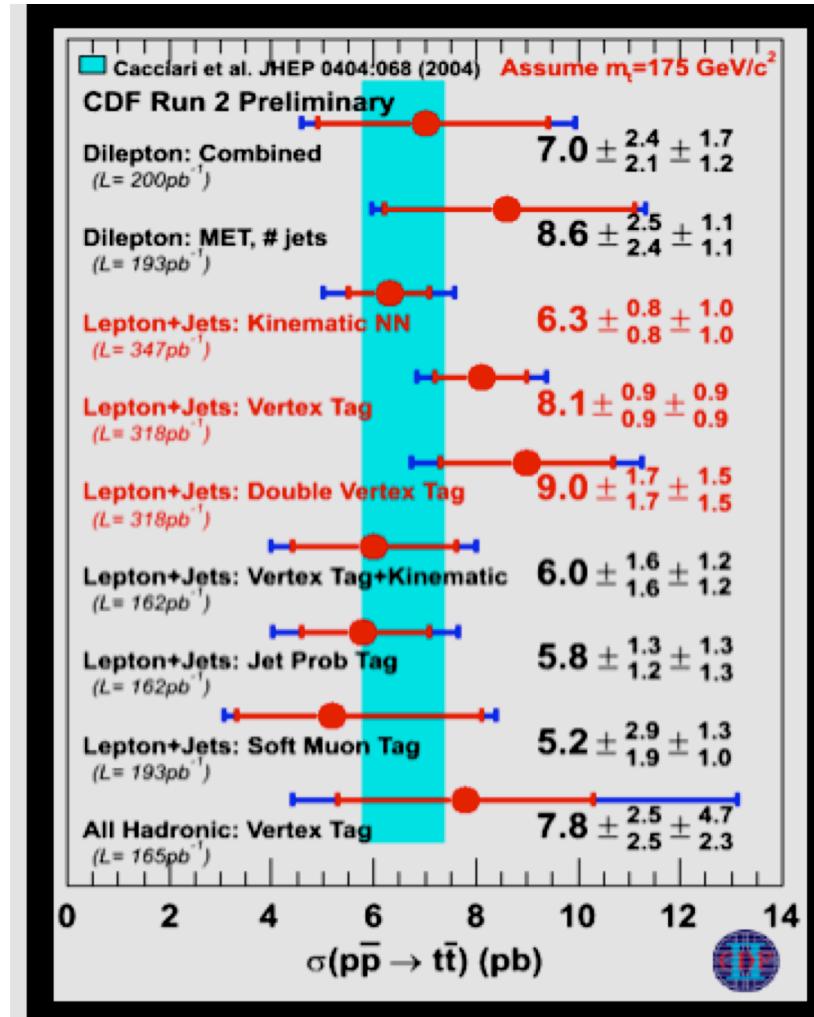
- Measure of  $\sigma(t\bar{t})$  to  $\sim 20\%$  accuracy.
- With b-tagging expect error  $\sim 10\%$

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# Top Production

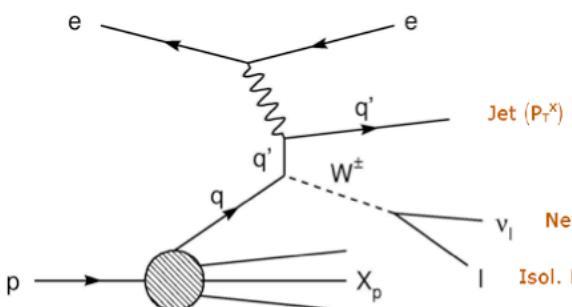
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# Top production at the Tevatron

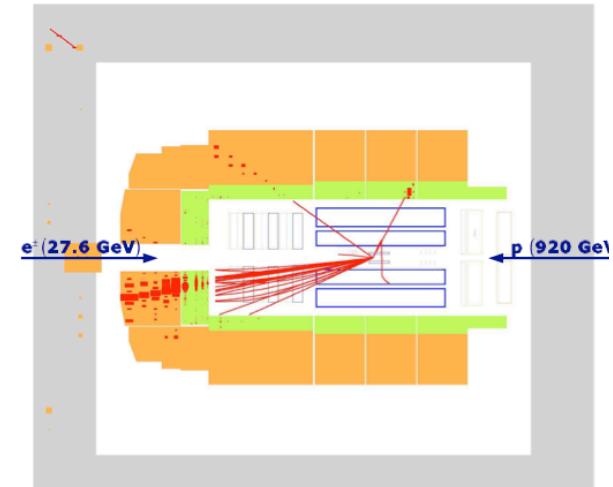
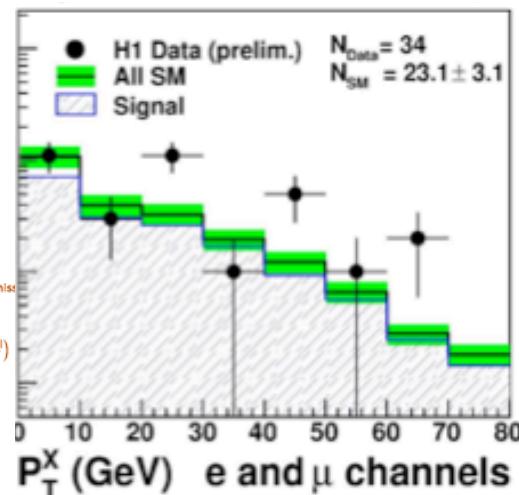


# Isolated lepton search and single top at H1

SM Signal: Production of real W Bosons



- Cross-Section  $\sigma(ep \rightarrow eWX) \approx 1\text{ pb}$  (at NLO)
- Branching Fraction  $W \rightarrow l\nu \approx 10\%$  each for  $e, \mu, \tau$

 $e^\pm p$  data (1994-2005)  $192 \text{ pb}^{-1}$ 

	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau <sup>①</sup> obs./exp. (W)
All $p_T^X$	$25/18.3 \pm 2.5$ (70%)	$9/4.8 \pm 0.8$ (85%)	$5/5.8 \pm 1.4$ (15%)
$p_T^X > 25 \text{ GeV}$	$11/3.0 \pm 0.6$ (81%)	$6/3.0 \pm 0.6$ (86%)	$0/0.5 \pm 0.1$ (49%)

①  $e^\pm p$  (1996-2000)  $108 \text{ pb}^{-1}$

# Single W boson production at ZEUS

$e^\pm p$ data (1994-2005) $192 \text{ pb}^{-1}$			
	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau <sup>®</sup> obs./exp. (W)
All $P_T^X$	$25/18.3 \pm 2.5$ (70%)	$9/4.8 \pm 0.8$ (85%)	$5/5.8 \pm 1.4$ (15%)
$P_T^X > 25 \text{ GeV}$	$11/3.0 \pm 0.6$ (81%)	$6/3.0 \pm 0.6$ (86%)	$0/0.5 \pm 0.1$ (49%)

<sup>®</sup>  $e^\pm p$  (1996-2000)  $108 \text{ pb}^{-1}$

$e^\pm p$ data (1994-2000) $130 \text{ pb}^{-1}$			
	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau obs./exp. (W)
All $P_T^X$	$24/20.6 {}^{+1.7}_{-4.6}$ (17%) <sup>®</sup>	$12/11.9 {}^{+0.6}_{-0.7}$ (16%) <sup>®</sup>	$3/0.40 \pm 0.12$ (43%)
$P_T^X > 25 \text{ GeV}$	$2/2.90 \pm 0.6$ (45%)	$5/2.75 \pm 0.21$ (50%)	$2/0.20 \pm 0.05$ (49%)

<sup>®</sup> Preselection

EPVEC LO MC predicts  $3.2 \pm 0.1 {}^{+1.1}_{-1.0}$  W events  
 (with efficiency of 39%); other SM processes  
 give  $3.2 \pm 0.6 {}^{+1.7}_{-1.6}$  events (mostly NC)



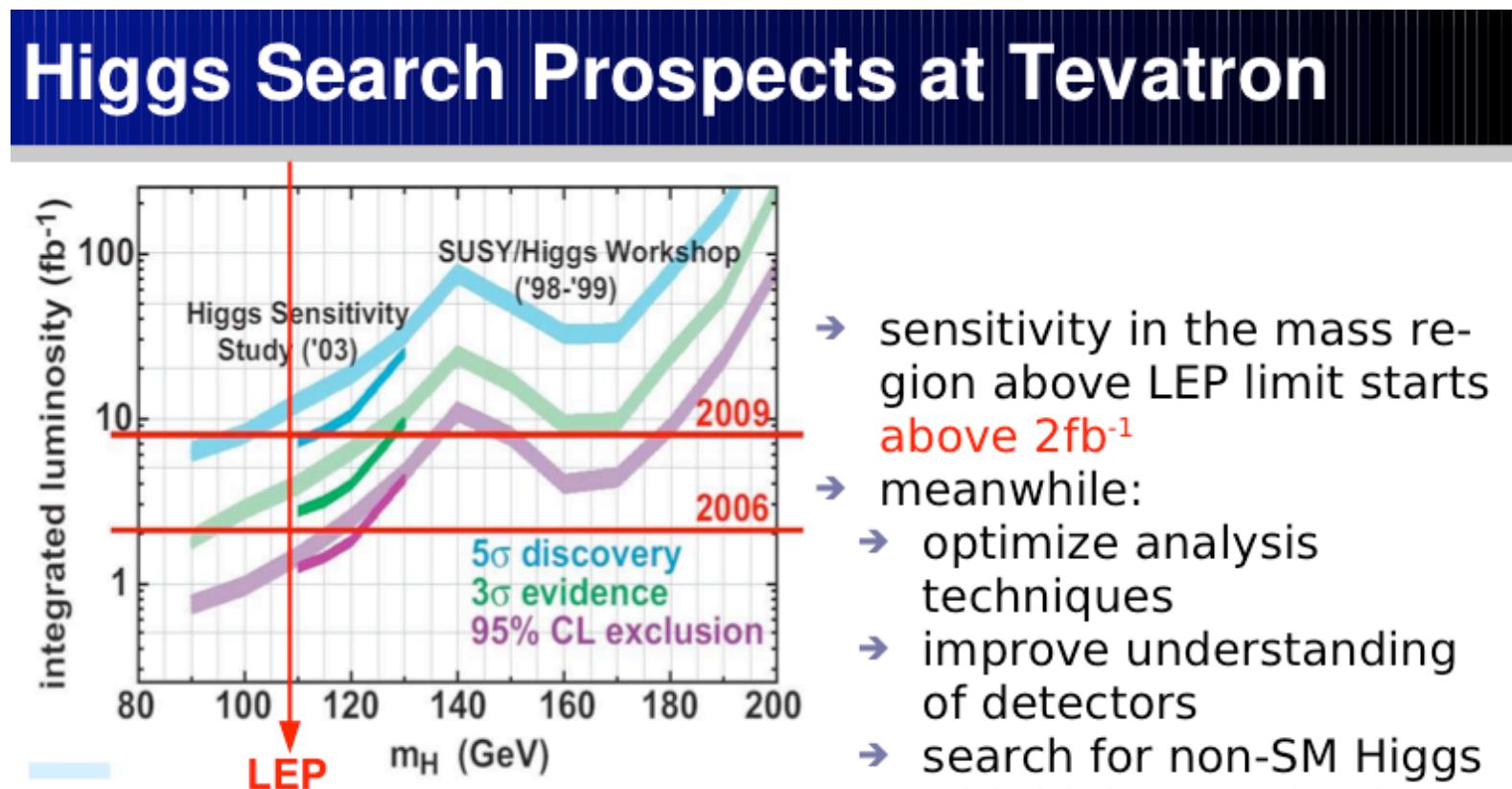
95% CL limit is  $\sigma < 2.8 \text{ pb}$

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# Higgs

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# Higgs searches at the Tevatron



- sensitivity in the mass region above LEP limit starts **above 2fb<sup>-1</sup>**
- meanwhile:
  - optimize analysis techniques
  - improve understanding of detectors
  - search for non-SM Higgs with higher production cross-section
- Integrated luminosity required per experiment, to either exclude a SM Higgs at 95% C.L. or discover it the 3 $\sigma$  or 5 $\sigma$  level (no systematics).

# Higgs searches at the Tevatron

## Search for MSSM Higgs: hbb (DØ)

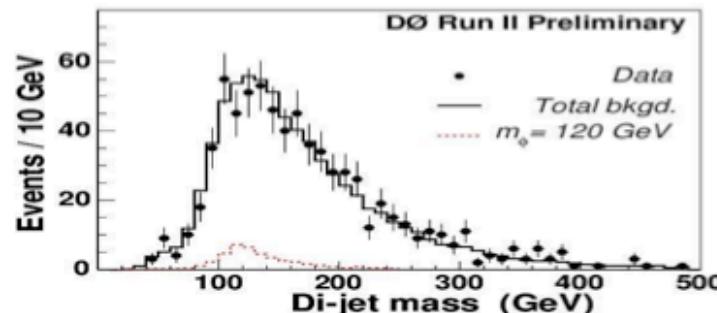
**Two Higgs Doublets  $\mathcal{H}_1, \mathcal{H}_2$  and 5 physical states**

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) (mixing angle of $h, H$ )
	$\alpha$	Higgs mass parameter
	$\mu$	common trilinear
	$A_0$	Higgs-sfermion coupling

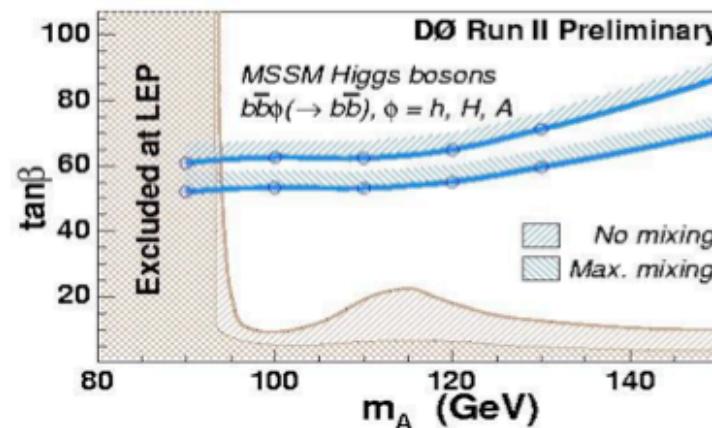
tree level:  
rad.corrected:

$m_h < m_Z < m_H$   
 $m_h < 130 \text{ GeV}$   $Br(\phi \rightarrow b\bar{b}) \sim 90\%$

- search for neutral Higgs in a Two-Higgs-doublet MSSM SUSY model
- do not distinguish between  $h, H$  and  $A$
- DØ analysis based on  $260\text{pb}^{-1}$



- selection:
  - trigger on 3-jet events
  - off-line cut on leading jet  $E_T$  (optimized wrt  $m_H$  hypothesis)
  - $\geq 3$  b-tagged jets
- main background:
  - QCD heavy flavor ( $bbjj, ccjj, cccc, bbcc, bbbb$ )
  - QCD fakes ( $jjjj$ )
  - Other ( $Z \rightarrow bb, \rightarrow cc; tt$ )
- no excess observed



# Higgs searches at the Tevatron

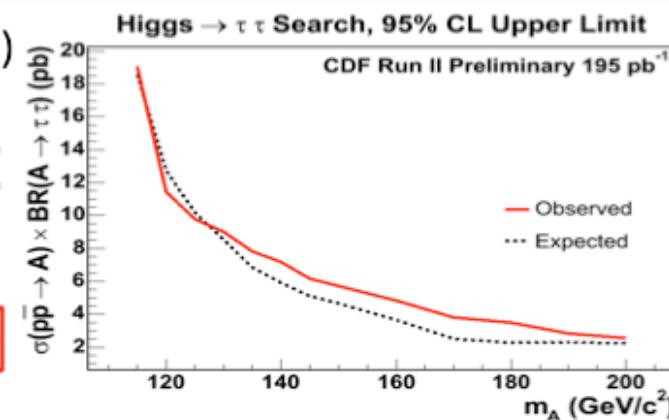
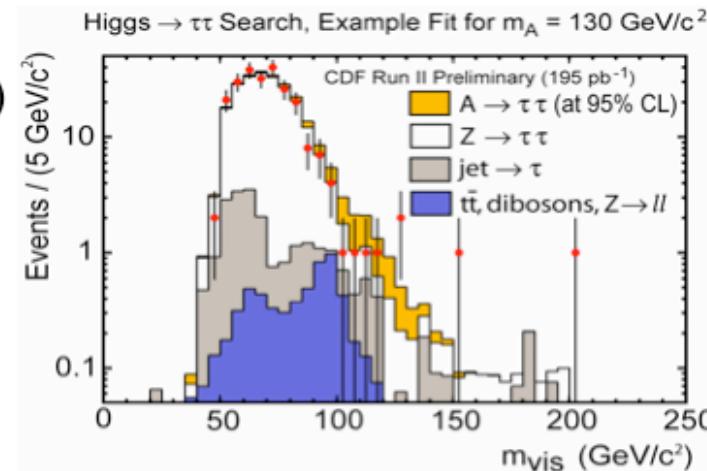
## Search for MSSM Higgs: $h \rightarrow \tau\tau$ (CDF)

- require two  $\tau$ 's:  
 $\tau \rightarrow v + \text{hadrons}$ ,  $\tau \rightarrow v\nu e/\mu$
- $\tau$  triggers (lepton + isolated track)
- Background:
  - multi-jet events
  - $W \rightarrow l\nu$
  - $Z \rightarrow ll$
- remove light quark bkgnd:  
 $H_T = |\mathbf{p}_T(\tau_1)| + |\mathbf{p}_T(\tau_2)| + ME_T > 50 \text{ GeV}$
- limit extracted from binned likelihood fit on mass-like discriminating variable  $m_{vis}(l, \tau, ME_T)$

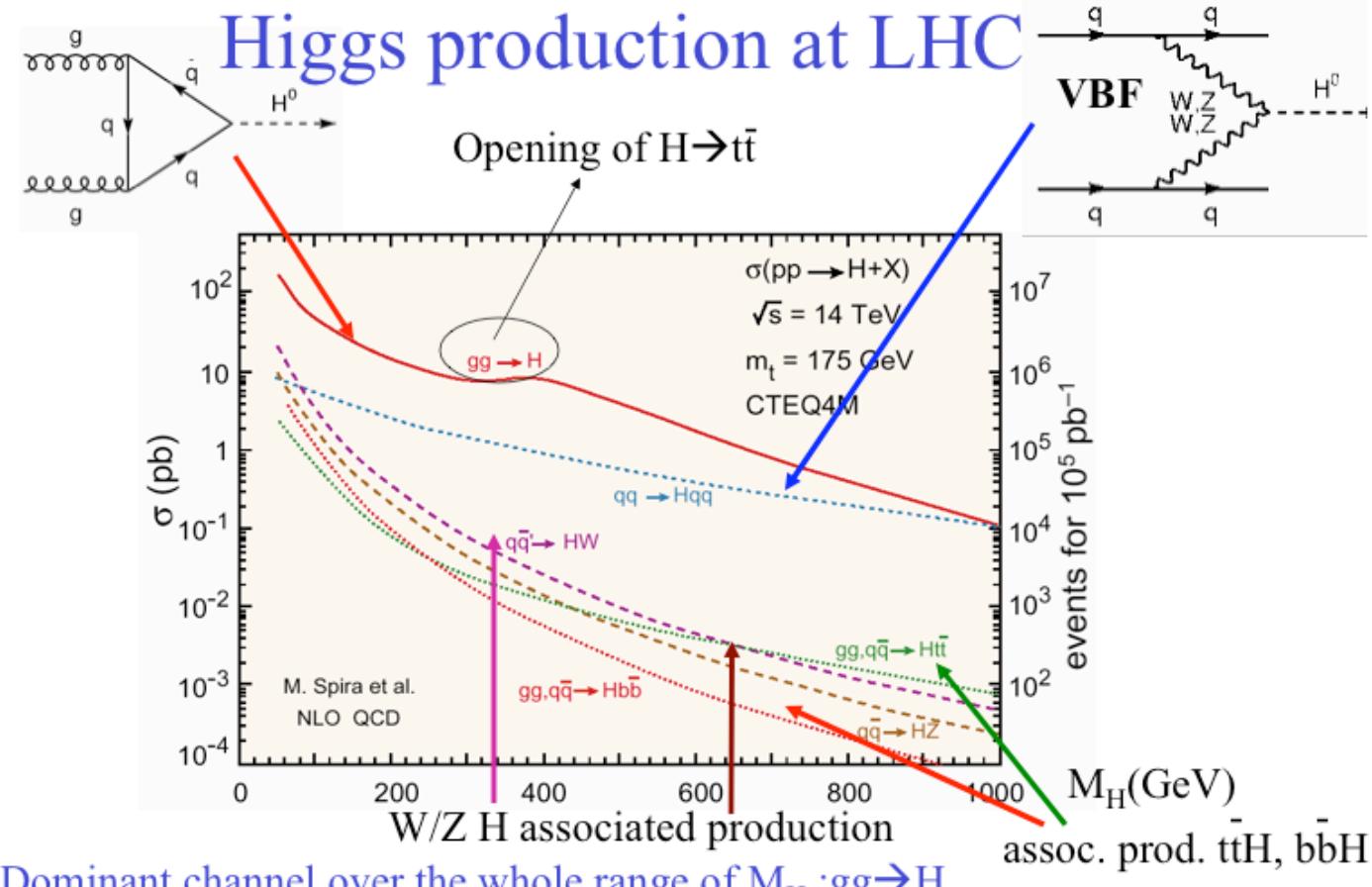
MSSM Higgs  $\rightarrow \tau\tau$  Search, final events

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

CDF Run II Preliminary



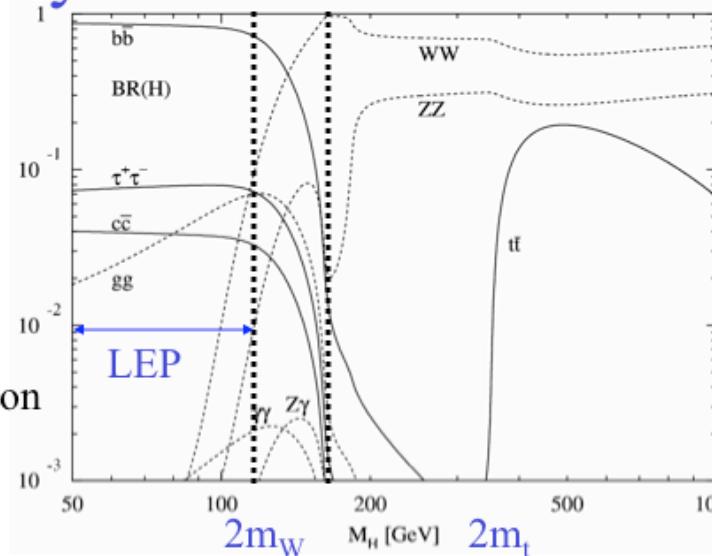
# Higgs searches at the LHC



# Higgs searches at the LHC

## Higgs decay at LHC

- $M_H < 140 \text{ GeV}$ :  
dominant decay mode  $b\bar{b}$  and  $\tau^+\tau^-$   
overwhelmed by  $b\bar{c}(\bar{c})$  (inclusive)  
 $\sigma(gg \rightarrow H \rightarrow b\bar{b}) \sim 20 \text{ pb}; \sigma(b\bar{b}) \sim 500 \mu\text{b}$   
Accessible channels :  
 $t\bar{t}H(H \rightarrow b\bar{b})$ , VBF ( $H \rightarrow \tau^+\tau^-$ )  
rare decay mode  $H \rightarrow \gamma\gamma$   
cleaner signature, inclusive production



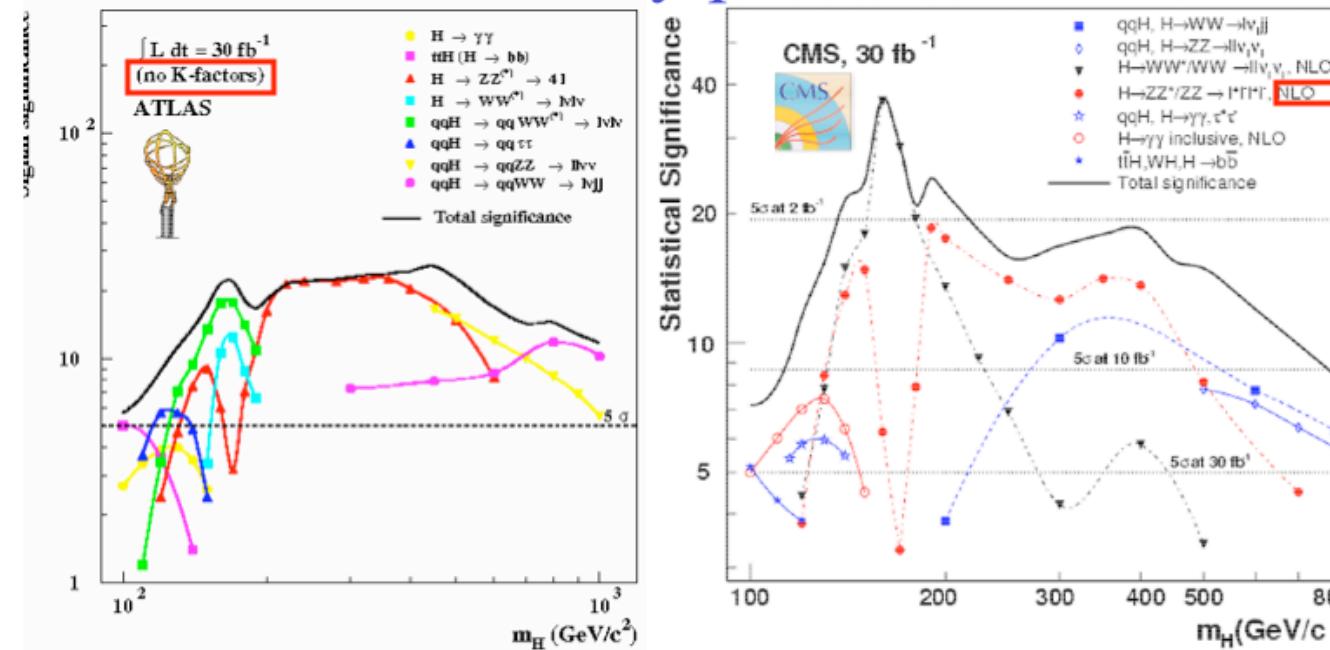
- $140 < M_H < 180 \text{ GeV}$   
WW\* and ZZ\* channels have significant BR  
 $H \rightarrow ZZ^* \rightarrow 4l$  good mass reconstruction possible, but low stat.  
 $H \rightarrow WW^* \rightarrow l l l l$  either inclusive or VBF production (better S/B)

- $M_H > 180 \text{ GeV}$   
 $H \rightarrow ZZ \rightarrow 4l$  gold-plated channel « easy »

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# Higgs searches at the LHC

## Discovery potential



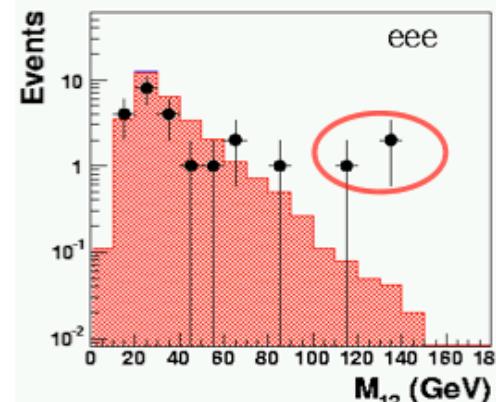
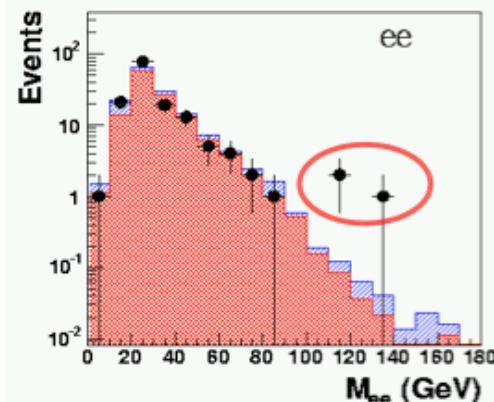
Almost all allowed mass range explored in 1<sup>st</sup> year ( $10 \text{ fb}^{-1}$ ) for ATLAS-CMS  
**With  $30 \text{ fb}^{-1}$ , more than  $7\sigma$  for the whole range** (provided systematics on the background are under control)

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# Multi leptons and Higgs at H1

## HERA II Preliminary

1996-2004  $e^\pm p$   $L=163\text{pb}^{-1}$  (ICHEP 04)



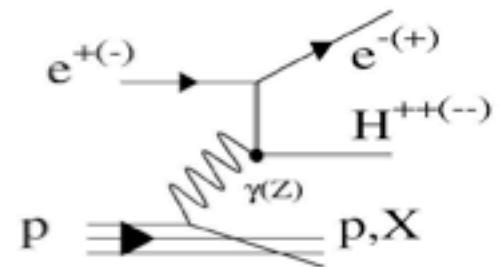
(HERA I+II)	data( $L=163\text{pb}^{-1}$ )	SM	Pair Production (Grape)
ee	147	$149.8 \pm 24.8$	125.5
eee	24	$30.4 \pm 3.9$	30.4

⇒ good agreement with SM

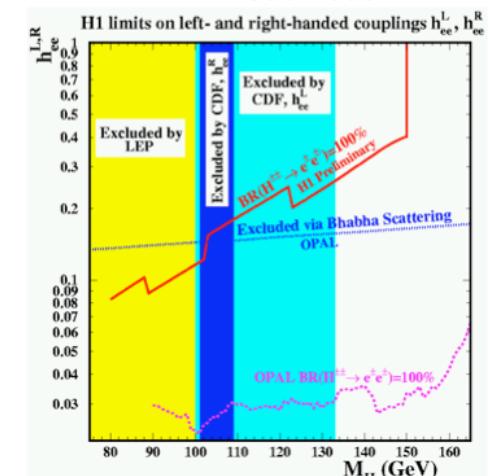
$M_{12} > 100 \text{ GeV}$

(HERA I+II)	data( $L=163\text{pb}^{-1}$ )	SM	Pair Production (Grape)
ee $M_{12} > 100 \text{ GeV}$	3	$0.44 \pm 0.01$	0.32
eee $M_{12} > 100 \text{ GeV}$	3	$0.31 \pm 0.08$	0.31

⇒ excess at high invariant mass



HERA I 1996-2000



excess of high mass multi-electrons cannot be explained by doubly charged Higgs hypothesis

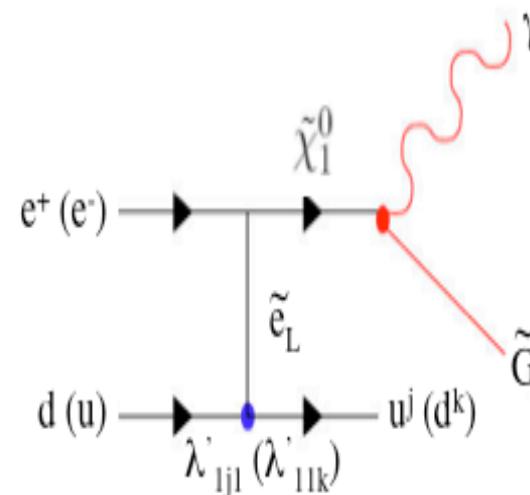
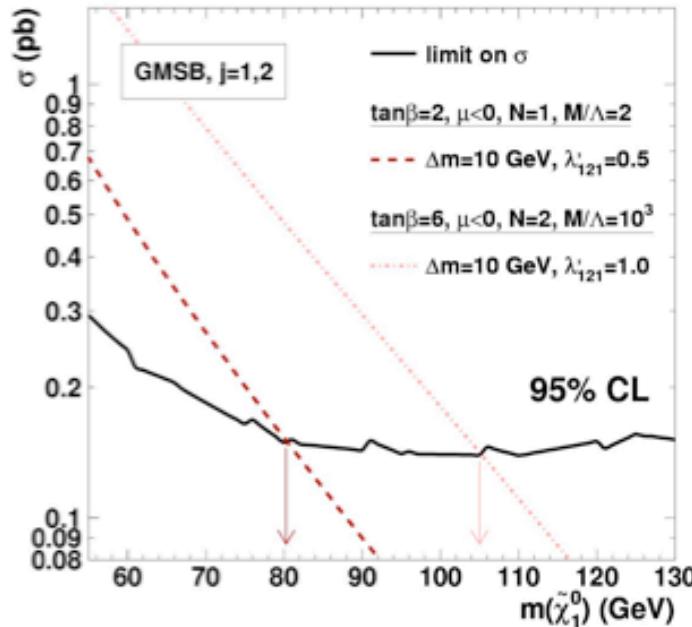
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# Supersymmetry

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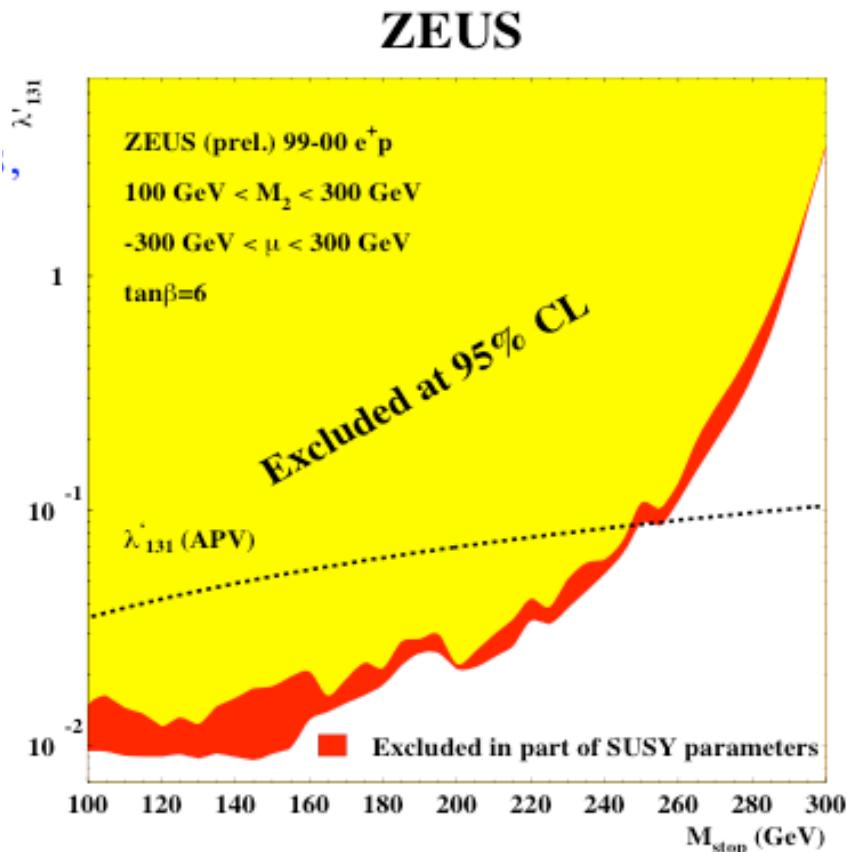
# SUSY searches at H1

## Gravitino Cross Section Limits H1 $e^+p$

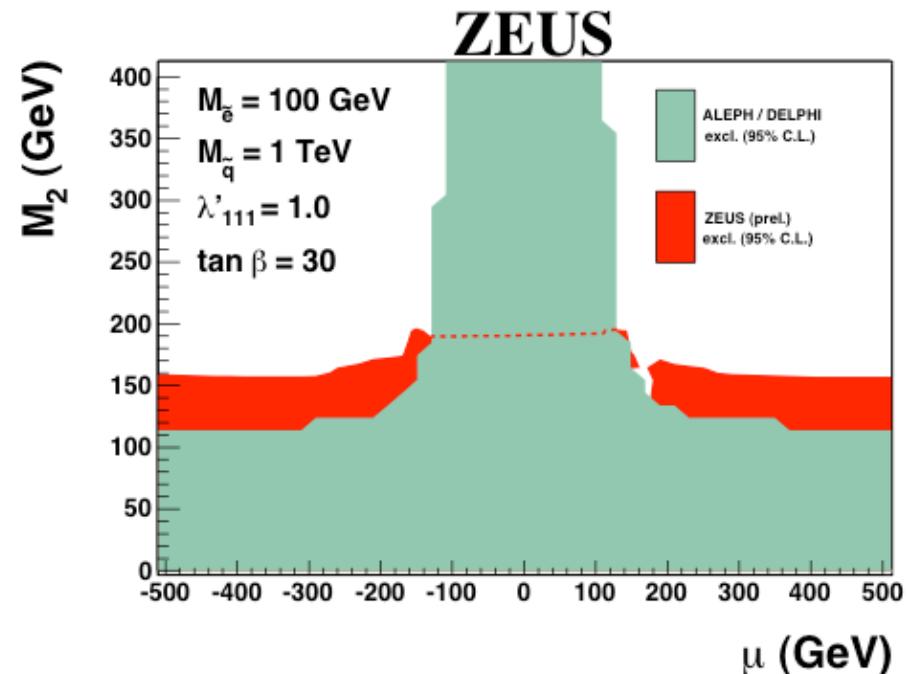


- No significant deviation from SM : derive limits on GMSB model at 95% CL
- Limits less stringent at low neutralino masses due to lower detection efficiency
- For comparison, GMSB cross sections for different couplings  $\lambda'_{121}$  and  $\lambda'_{112}$  with fixed values of  $\tan\beta$ ,  $N$  and  $\mu$

# SUSY searches at ZEUS



Search for bosonic stop decay in  
NC and CC like channels in RPV  
MSSM



Search for gaugino production in  
RPV MSSM

# SUSY searches at the Tevatron

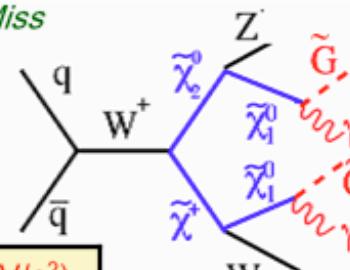


## Chargino-Neutralino in $\gamma\gamma + E_T^{Miss}$



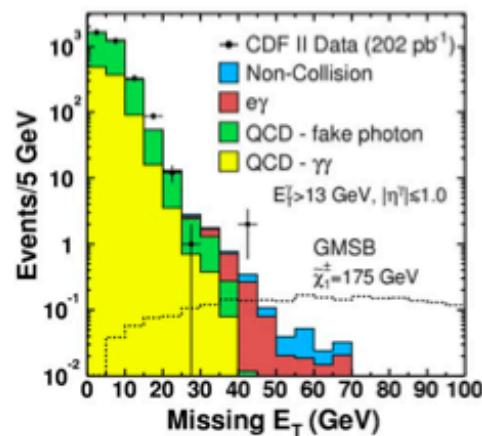
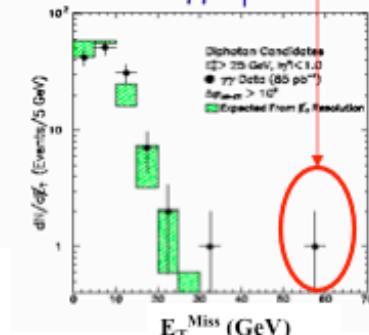
In GMSB: 2 photons+ $E_T^{Miss}$

CDF/D0 Event selection:  
 - 2 photons  $E_T > 13/20$  GeV  
 $-E_T^{Miss} > 45/40$  GeV



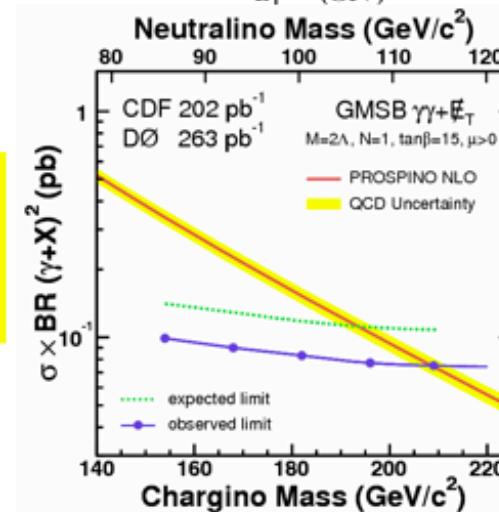
	Bkgd Exp.	Obs	Limit $m_{\tilde{\chi}_1^\pm}$ (GeV/c <sup>2</sup> )
D0	$3.7 \pm 0.6$	2	195
CDF	$0.3 \pm 0.1$	0	167

Motivated from  
 CDF-I ee $\gamma\gamma E_T^{Miss}$  event



CDF and D0  
 combined result:  
 $m(\tilde{\chi}_1^\pm) > 209$  GeV/c<sup>2</sup>

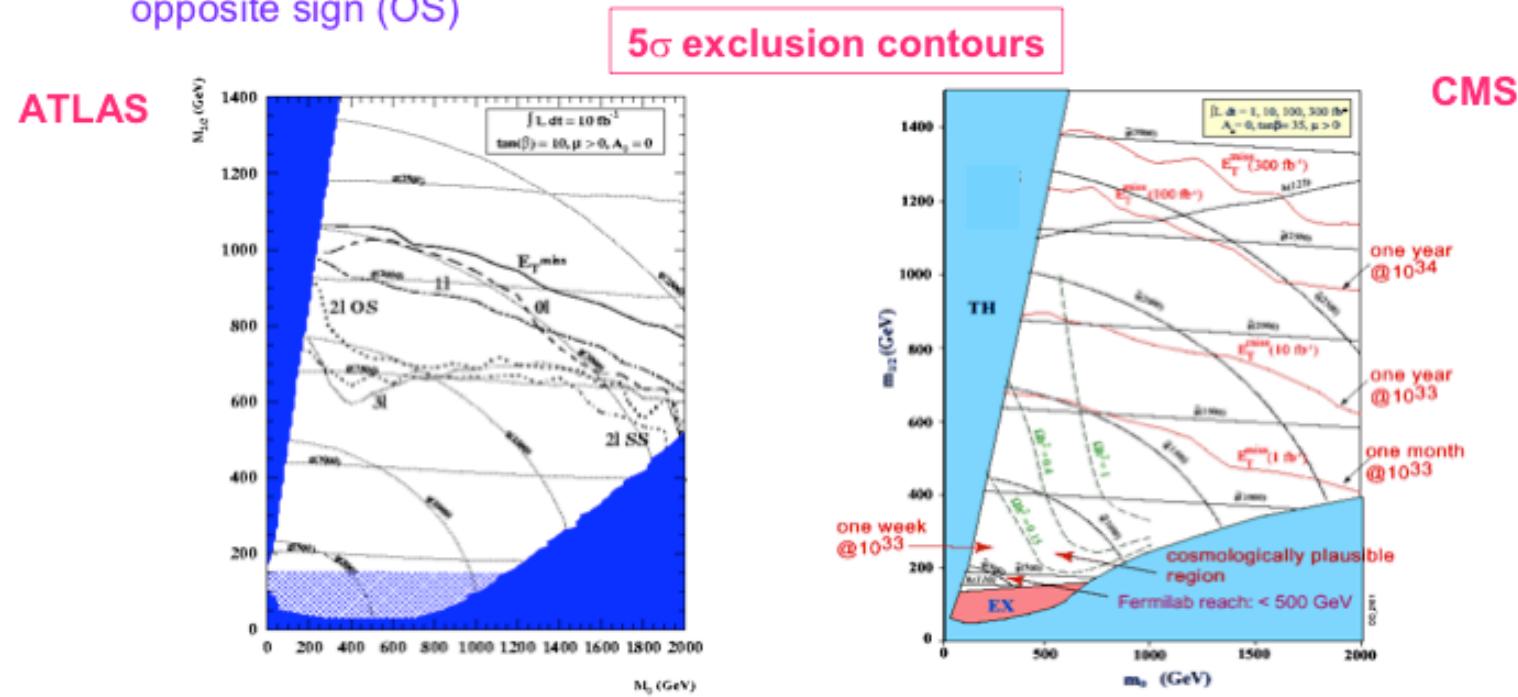
hep-ex/0504004



# SUSY searches at the LHC

## mSUGRA Reach

- mSUGRA framework: five free parameters:  $m_0$ ,  $m_{1/2}$ ,  $A_0$ ,  $\tan(\beta)$ ,  $\text{sgn}(\mu)$
- Reach sensitivity only weakly dependent on  $A_0$ ,  $\tan(\beta)$ ,  $\text{sgn}(\mu)$
- Multiple signatures on most of parameter space:  $E_T^{\text{miss}}$  (dominant signature),  $E_T^{\text{miss}}$  with lepton veto, one lepton, two leptons same sign (SS), two leptons opposite sign (OS)

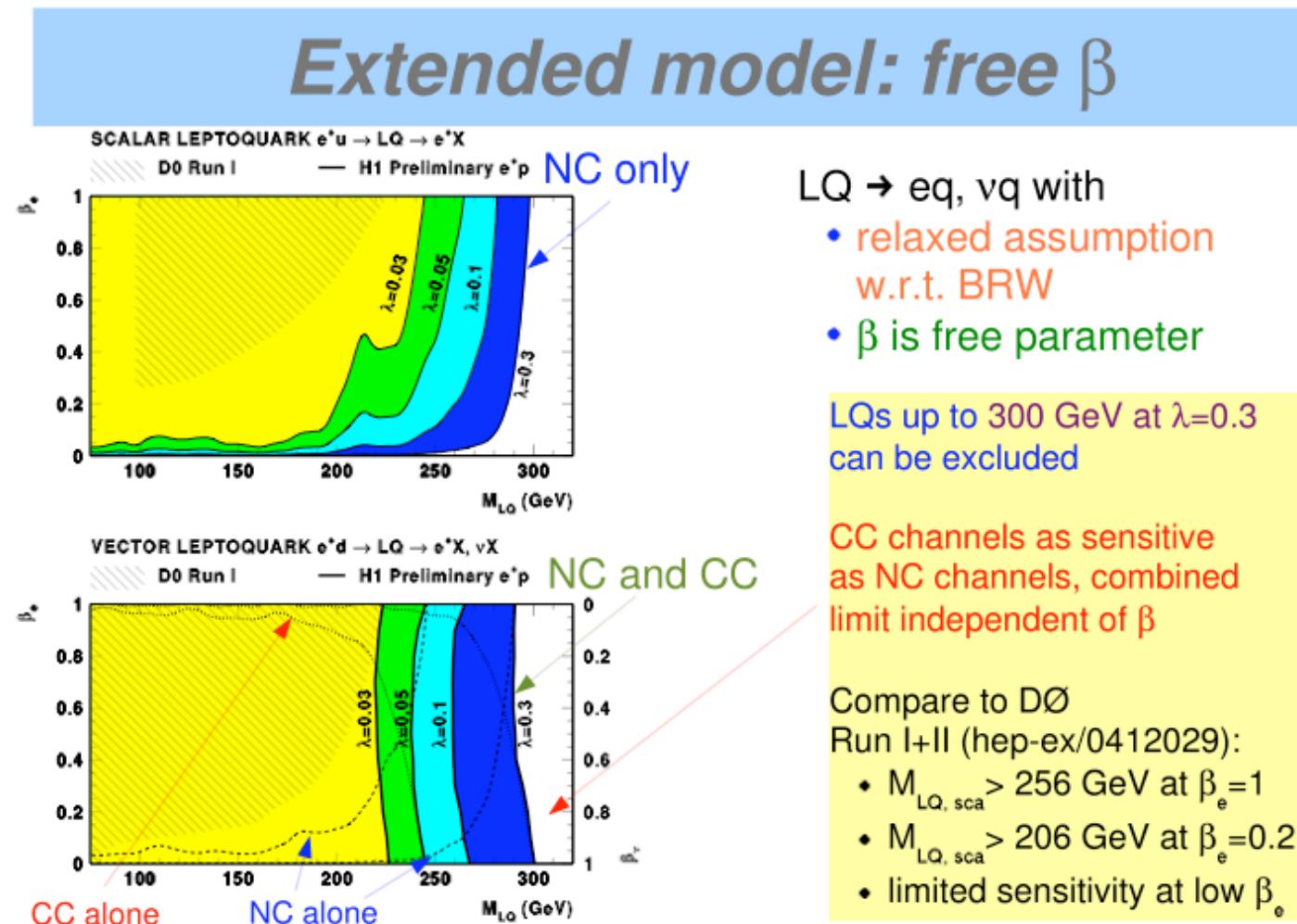


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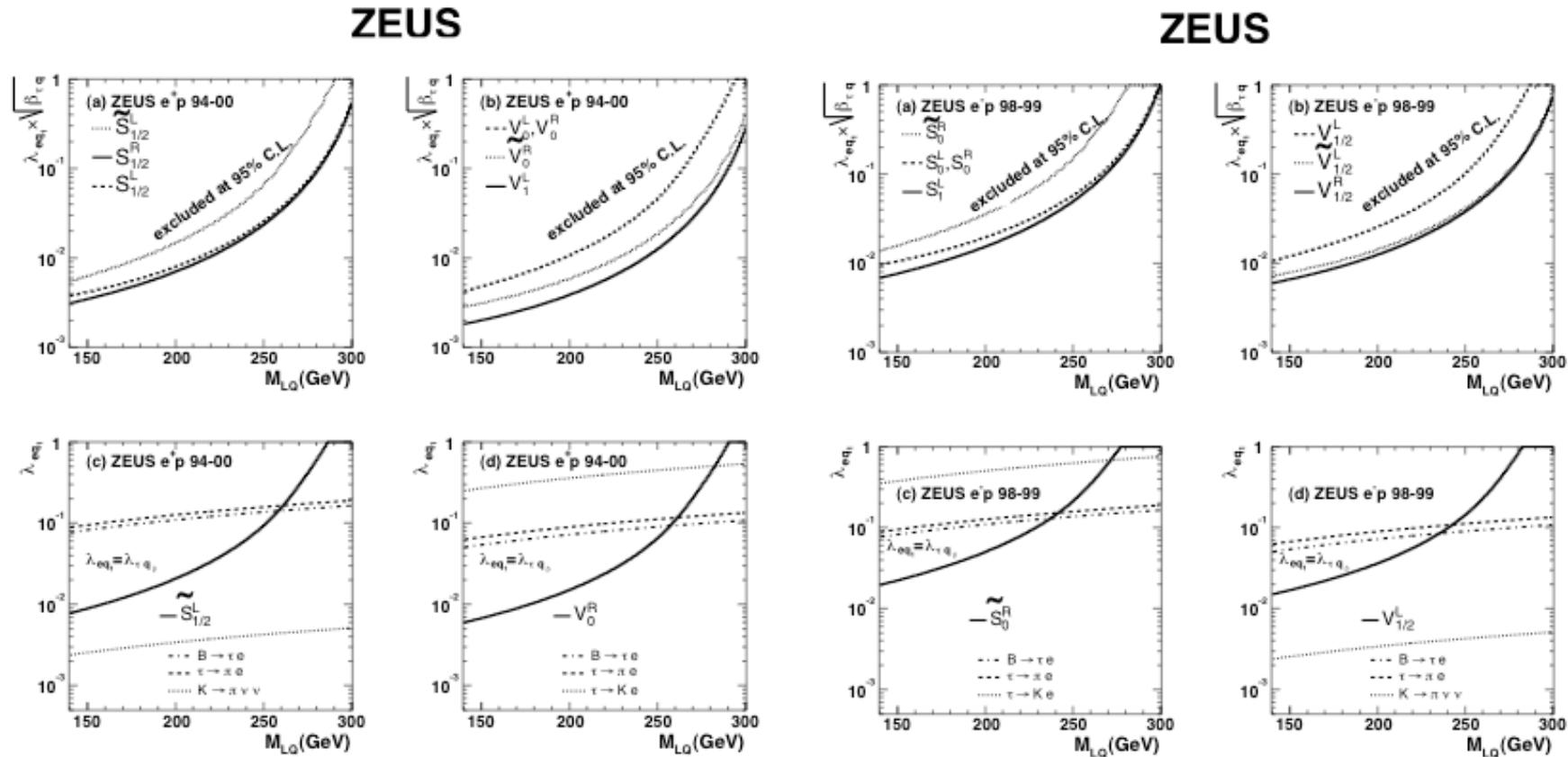
Leptoquarks, Lepton Flavour  
Violation, Extra Dimensions, New  
Gauge Bosons etc.

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## Search for leptoquarks and lepton flavour violation at H1



## Search for lepton flavour violation at ZEUS



Use LFV results to place limits on leptoquark masses and couplings.

Most stringent to available in some cases, particularly in the tau channel

## Non-SUSY and non-Higgs searches at the Tevatron

### Magnetic monopoles

Dirac magnetic monopoles have a large magnetic charge

Highly ionizing, produce many delta rays  
Bend in  $r$ - $z$  plane, not  $r$ - $\varphi$  plane

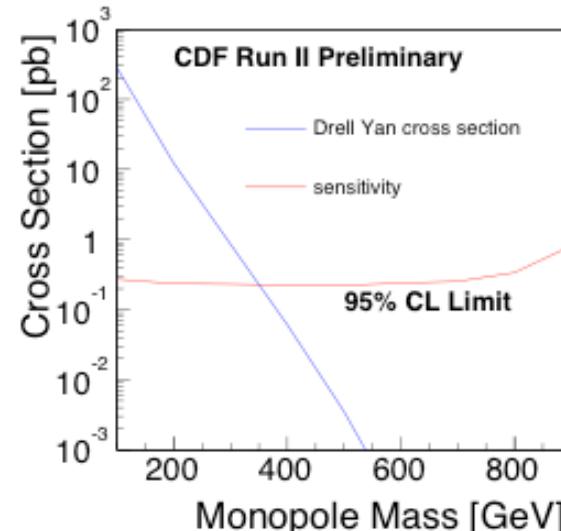
CDF took  $36\text{pb}^{-1}$  of data with a special monopole trigger

require large light pulses from time-of-flight scintillator bar  
reconstruct in central-outer-tracker with special tracking algorithm

Unusual properties of monopoles mean background is effectively zero

No events found

Mass limit of  $M > 350 \text{ GeV}$   
for Drell-Yann pair production



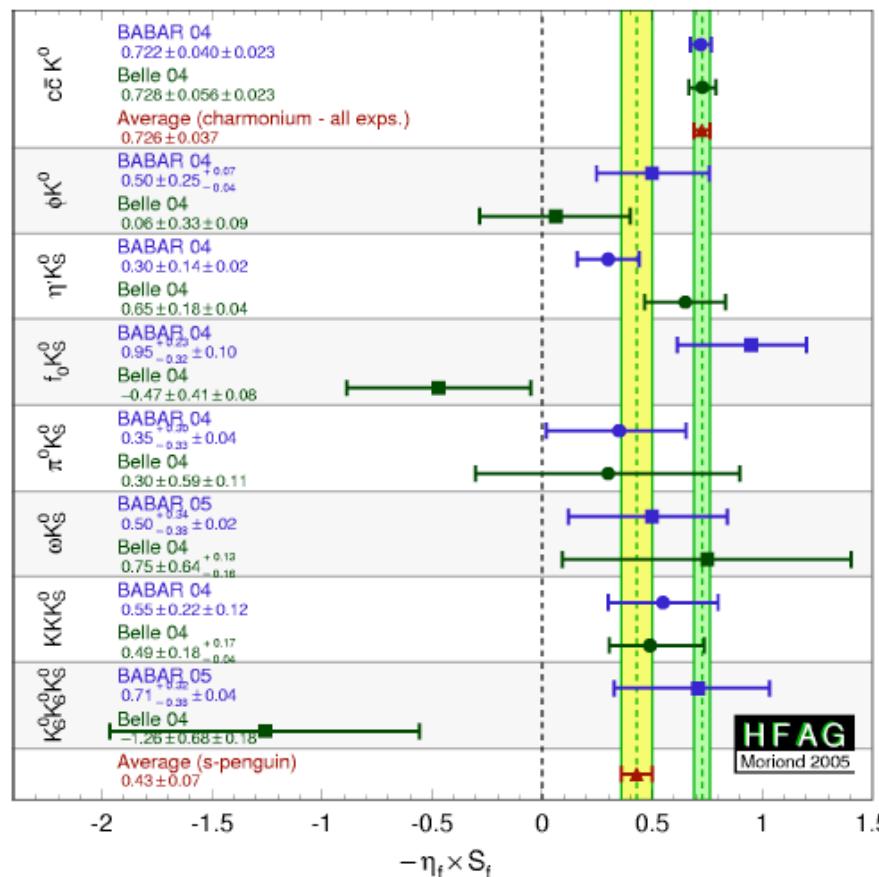
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# Flavour Physics

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## Searches for new physics in the flavour sector at B factories

### Combined “sin $2\beta$ ” Results



**BABAR+Belle:**  
 $\Delta S \sim -3.7 \sigma$

BaBar only:  
 $\Delta \sin 2\beta \approx -2.9\sigma$

Belle only:  
 $\Delta \sin 2\beta \approx -2.9\sigma$

...but comparison  
 ignores subleading  
 diagrams !

## Searches for new physics in the flavour sector at the Tevatron

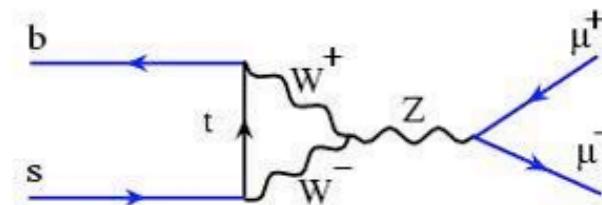
### $B_s \rightarrow \mu\mu$ : Beyond the SM

- Look at decays that are suppressed in the

Standard Model:  $B_{s(d)} \rightarrow \mu^+\mu^-$

- Flavor changing neutral currents(FCNC) to leptons
  - No tree level decay in SM
  - Loop level transitions: suppressed
  - CKM , GIM and helicity( $m/m_b$ ): suppressed
  - SM:  $BF(B_{s(d)} \rightarrow \mu^+\mu^-) = 3.5 \times 10^{-9} (1.0 \times 10^{-10})$

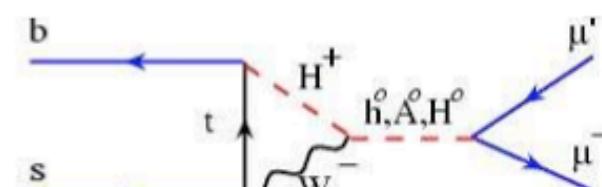
G. Buchalla, A. Buras, Nucl. Phys. B398,285



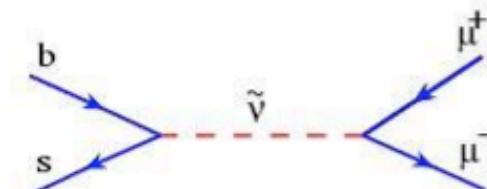
- New physics possibilities

- Loop: MSSM: mSugra, Higgs Doublet
  - 3 orders of magnitude enhancement
  - Rate  $\propto \tan^6 \theta / (M_A)^4$

Babu and Kolda, Phys. Rev. Lett. 84, 228



- Tree: R-Parity violating SUSY



One of the best indirect search channels at the Tevatron

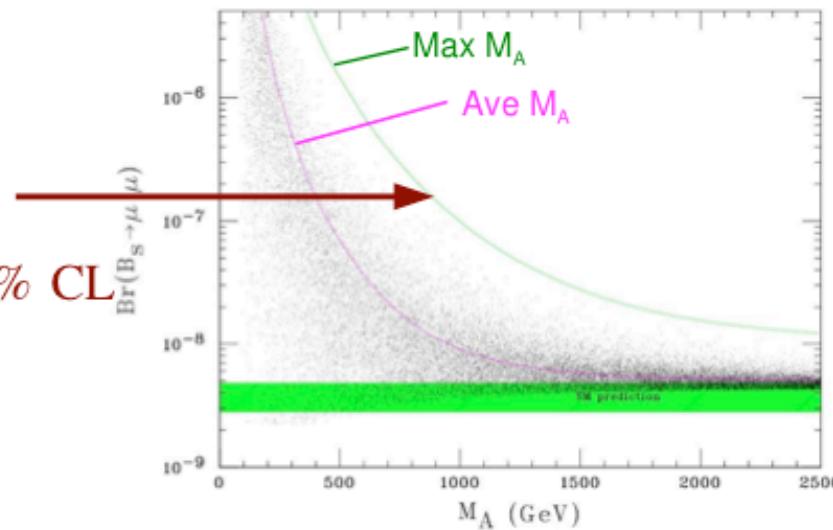
## Searches for new physics in the flavour sector at the Tevatron

 $B_s \rightarrow \mu\mu$ : MSSM

- Combined  $B_s \rightarrow \mu^+\mu^-$  result:  
Bayesian approach with a flat prior.  
Systematic errors on  $f_{B_s}$  and  
 $BF(B^+ \rightarrow J/\psi K^+)$  correlated.

$$BF(B_s \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-7} \text{ 95% CL}$$

- SM Prediction
  - SM:  $BF(B_s \rightarrow \mu^+\mu^-) = 3.5 \times 10^{-9}$
  - No sensitivity for SM rate



- No strong SUSY:MSSM limits from  $B_s \rightarrow \mu^+\mu^-$ 
  - Too many MSSM parameters
  - If  $B_{s(d)} \rightarrow \mu^+\mu^-$  observed:  $M_A < 800 \text{ GeV}$
  - $\tan\beta = 50$

Does limit specific  
SUSY models

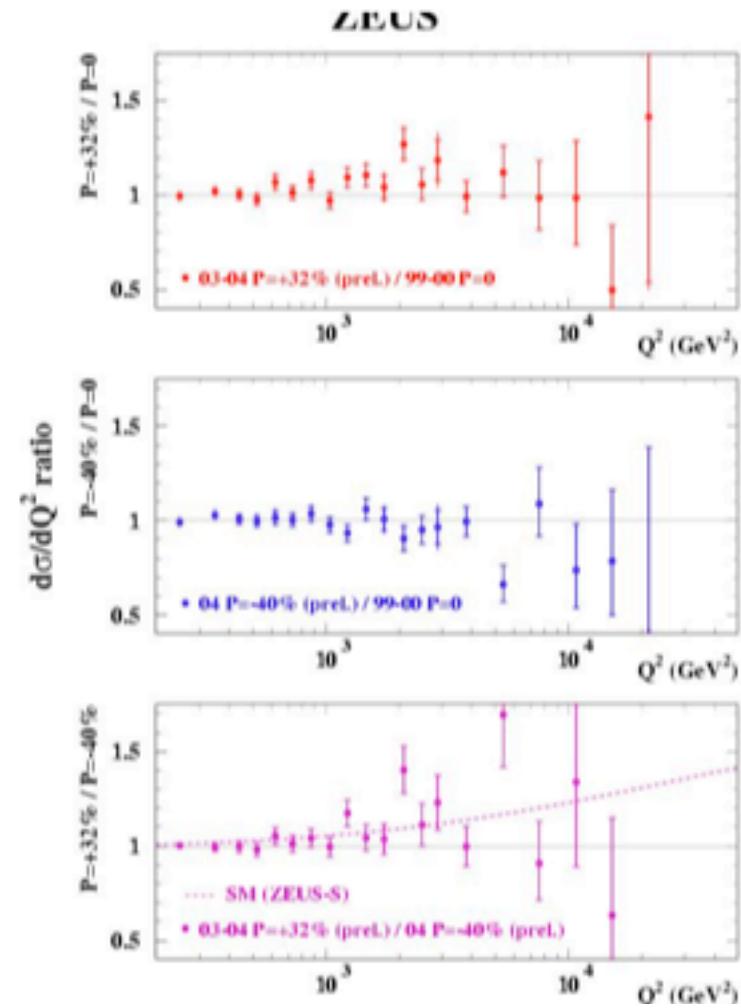
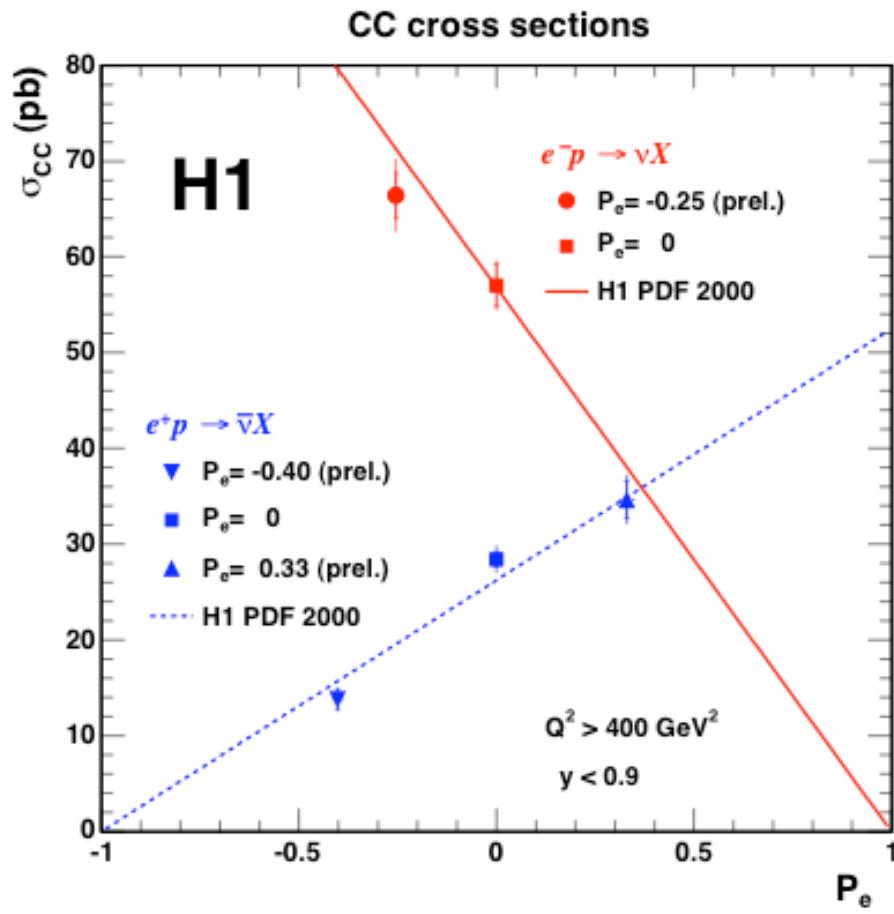


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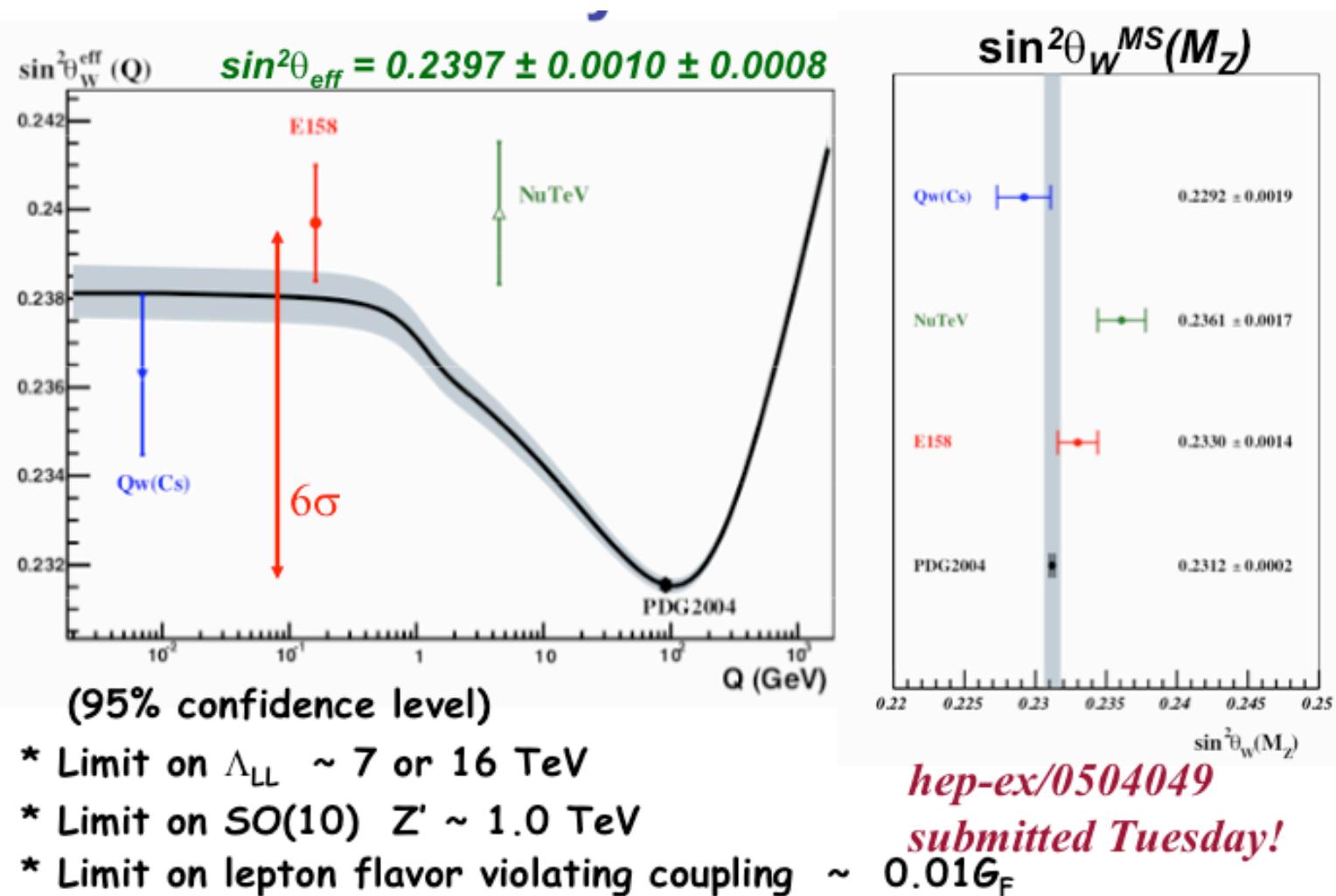
# Joint Sessions with Structure Functions Working Group

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# High $Q^2$ CC and NC DIS with polarised leptons

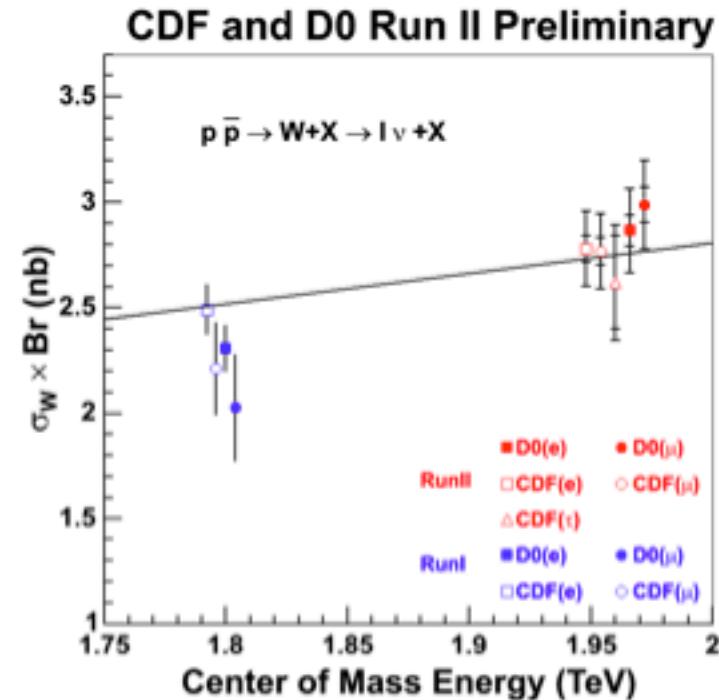
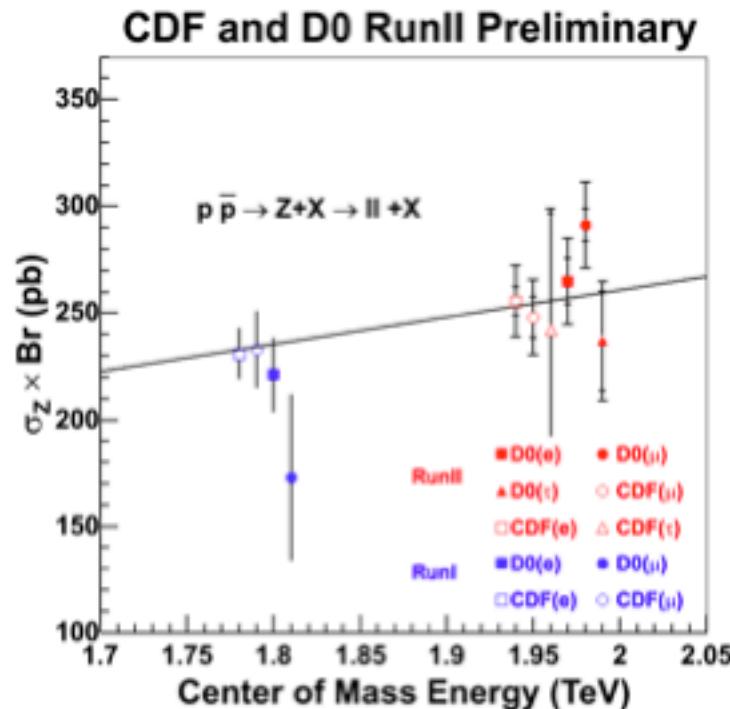


## Mixing angle from parity violating Moller scattering (SLAC E158)



# W and Z cross sections at the Tevatron

Benchmark analyses for all high pT lepton analyses



Systematics limited measurements ~2-3% level (excl luminosity)

Dominant contributions from acceptance (large contributions from PDF

# Summary and future prospects

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- Electroweak Standard Model provides an almost perfect picture of all our observations. Measurements still coming in from Tevatron, HERA and fixed target experiments.
- A few tantalising deviations from the Standard Model at B factories and H1. Watch this space for further developments.
- HERA still able to place competitive limits on many processes beyond the standard model (SUSY, LFV, Leptoquarks...)
- Tevatron should be sensitive to SM Higgs within the next year or so. Already able to place limits that restrict allowed phase space in many SUSY and other new physics scenarios.
- Vast discovery potential of the LHC to come.

Thanks to all the speakers for the fascinating talks and the organisers for a lively and stimulating workshop!

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