M. Chanowitz, LBNL
DESY-Zeuthen
2/28/03

The Direct Limit on the Higgs Mass & the SM Fit

MC PRL 87:231802, 2001
PRD 66:073002, 2002

Updated:

1) LEPEWWG/2002-02 12/02
2) 2-loop m_W Freitas, Heinemeyer, Weiglein 12/02
3) New m_W Aleph Today!

New at this meeting:

m_W = 80.426 (34)

Previously: 80.449 (34)

From 79 MeV shift in Aleph measurement,
due to systematic effect.

Improves betting odds on SM fit relative to Summer 02:
improves global fit & raises m_H prediction.

This talk: initially prepared results (based on Summer 02)
+ revised results (with new m_W)

LEP direct limit

(New m_W results in green (…)’s)

$m_H > 114$ GeV (95%) N.B., $CL(m < 114) << 5\%$

imposes important constraint on interpretation of EW data.

To test SM, consider

Fit: $CL(\chi^2) = 0.01$ (0.02) (No APV, Γ_W)

AND

$m_H > 114$: $CL(m) = 0.3$ (0.35) { CL from SM fit that $m_H > 114$

Useful to consider **TOTAL CL**:

$$CL_T = CL(\chi^2) \,|\,|\, CL(m) = 0.003 \quad (0.0066)$$

Poor CL(χ^2) due to two 3σ anomalies:

1) $x_W^{\nu N}$

2) $x[A_L] = 0.23113\ (21)$ — A_{LR}, A_{FB}^l, $A(P_\tau)$; $\chi^2 = 1.7/2$

$x[A_H] = 0.23217\ (29)$ — A_{FB}^b, A_{FB}^c, Q_{FB}; $\chi^2 = 0.05/2$

dominated by
- $A_{LR} = 0.23098\ (26)$
- $A_{FB}^b = 0.23217\ (31)$

Generic Explanations:

New physics -- **certainly possible**

Statistical fluctuation -- **fairly valued**

Underestimated systematic uncertainty

Focus on sys. uncertainty **not** because it is more likely **but** to see if it can rescue the SM.

m_H direct lower limit is central to the analysis.

Systematics

$x_W^{\nu N}$

$x[A_H]$

} Significant experimental & QCD issues

A_{FB}^b, A_{FB}^c, Q_{FB} have
important **shared** systematics (theory & exp't)

$x[A_L]$

} **3 independent** expt'l techniques
Theoretically clean

⇒ underestimated sys. uncertainty unlikely for $x[A_L]$,
more conceivable for $x_W^{\nu N}$ & $x[A_H]$,
and $x_W^{\nu N}$, A_{FB}^b contribute largest pulls, causing poor $CL(\chi^2)$.

Q: Could underestimated sys. uncertainty in $x_W^{\nu N}$, $x[A_H]$ improve SM fit?

SM Fits

SM EWRC from ZFITTER 6.30 + 2-loop m_W FHW

→ - (5 - 10) MeV

m_Z, m_t, $\Delta\alpha_5$, α_S, m_H ⇒ $O_{Z\text{-Pole}} + m_W + x_W^{\square\square} + \ldots$

Good agreement with EWWG.

$\Delta\alpha_5$ from BP (BES) -- EWWG default

Stronger constraints from "theory driven." cf MC PRL87:231802, 2001

χ^2 and "Bayesian" likelihood fits

- Vary m_t, $\Delta\alpha_5$, α_S, m_H
- Fit m_t, $\Delta\alpha_5$ + all/some of {13 $O_{Z\text{-Pole}}$, m_W, $x_W^{\square\square}$ }
- Correlations alla EWWG

(constrain $\alpha_S = 0.118(3)$ if Γ_Z, R_l, or σ_H not in fit)

Global Fits (Summer 02 m_W)

A) **All**

27.7/13

CL(χ^2) = **0.010**

P($\geq$ 1 3σ & $\geq$ 1 2.6σ, N = 13) = **0.005**

B) **- $x_W^{\nu N}$**

18.3/12

CL(χ^2) = **0.11**

P($\geq$ 1 2.8σ, N = 12) = **0.09**

C) **- $x[A_H]$**

17.7/10

CL(χ^2) = **0.060**

P($\geq$ 1 3.2σ, N = 10) = **0.013**

D) **$-x_W^{\nu N}$ - $x[A_H]$**

7.1/9

CL(χ^2) = **0.63**

Global CL's correctly reflect probability for outlyers relative to sample size.
The statistical ensemble is multiple replays of the 90's @ LEP, SLC, TeVatron.

Likelihoods for statistical fluctuation are fairly valued.

m_W: Shapes SM Global Fit

'98	80.410 (90)
'02	80.449 (34)

Heavy, precise m_W contributes to marginalization of SM fit:

*Favors $x[A_L]/A_{LR}$, forces $x[A_H]/A_{FB}^b$ to large pull.

*IF m_W were ~ 2σ lighter or ~ 3 times less precise

- $CL(\chi^2)$ increases by ~ 2 (fit B: 0.1 --> 0.2)
- no preference for $x[A_L]$ over $x[A_H]$

$m_W = 80.449$ → $x_W^l = \begin{cases} 0.23081 & \text{ZFITTER} \\ 0.23071 & \text{2-loop} \end{cases}$

80.426 → 0.23095

$x[A_{LR}] = 0.23098$

$x[A_{FB}^b] = 0.23217$

m_H-sensitive observables: CL(□^{2})

New m_W in (green)

Non-asymmetry:	m_W, □$_{□}$, R_l	
x[A_L]:	A_{LR}, $A_{FB}{}^{l}$, A[$P_{□}$]	CL(□^{2}) = 0.035 (0.067)
x[A_H]:	$A_{FB}{}^{b}$, $A_{FB}{}^{c}$, Q_{FB}	

+ $x_W{}^{□N}$ CL(□^{2}) = 0.0019 (0.0046)

Highest precision:

A_{LR}, $A_{FB}{}^{b}$, m_W CL(□^{2}) = 0.0027 (0.006)

→ **Problems of global fit are concentrated in m_H-sensitive sector.**

Non m_H-sensitive: □$_{□}$, R_b, A_b, R_c, A_c CL(□^{2}) = 0.68

m_H-sensitive observables: m_H predictions

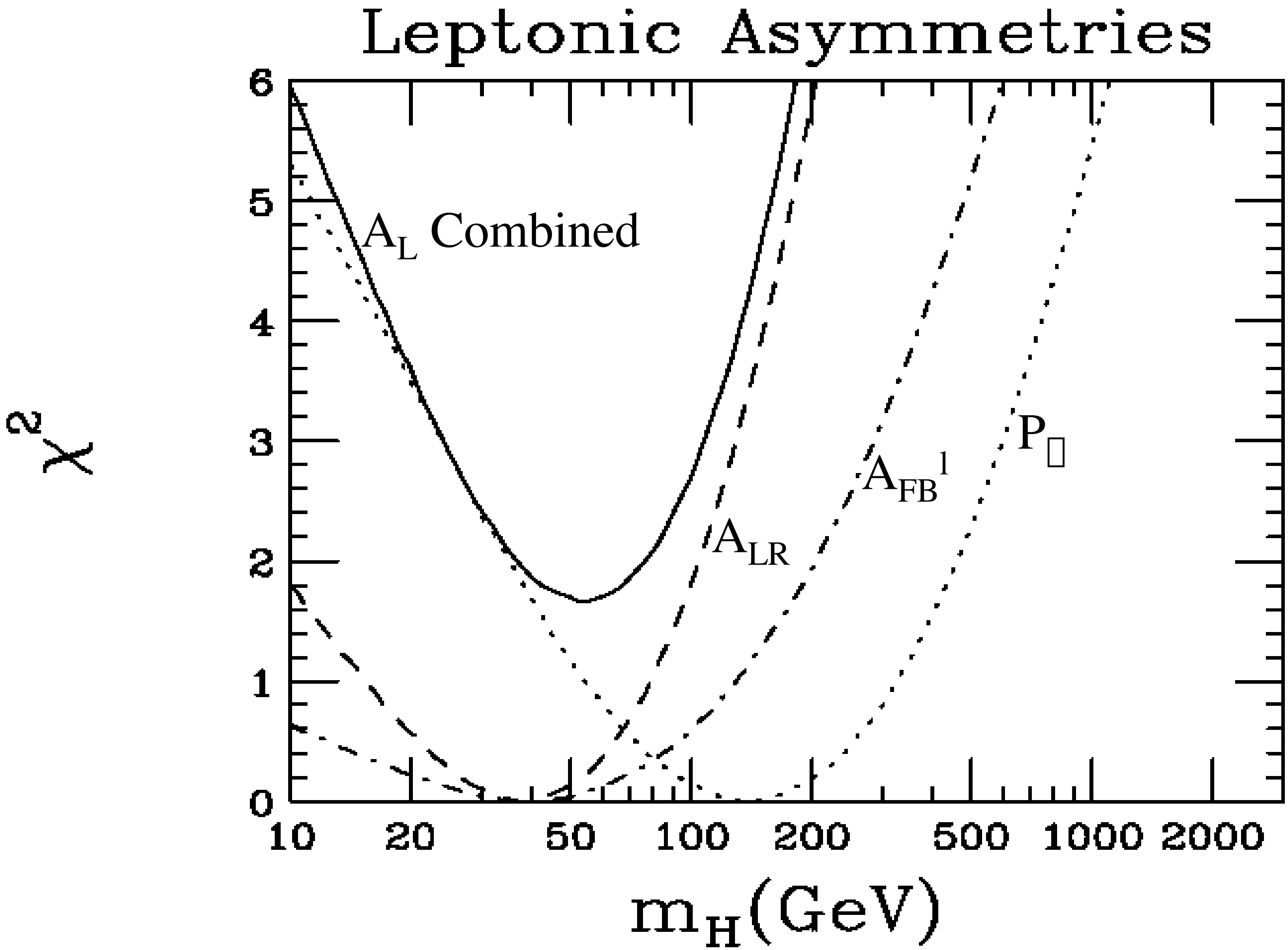
New m_W in (green)

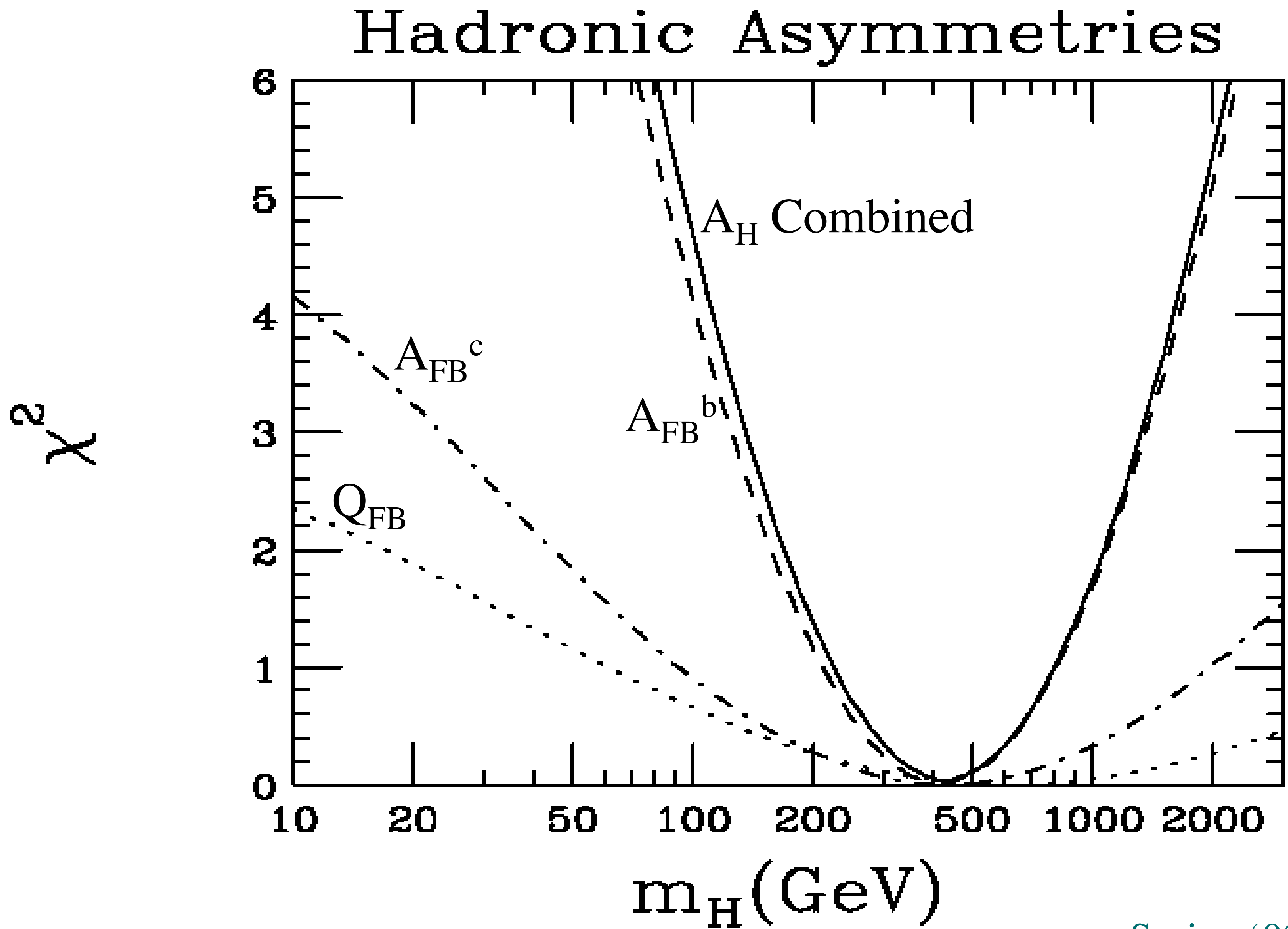
Highest Precision	m_H	95%	$CL(m_H > 114)$
A_{LR}	39	< 122	0.062
A_{FB}^{b}	410	130 < m < 1200	0.97
m_W	19 (35)	< 111	0.047 (0.12)

Aggregates	m_H	95%	$CL(m_H > 114)$
$x[A_L]$	55	< 143	0.10
$x[A_H]$	410	140 < m < 1200	0.97
m_W, Γ_Z, R_l	14 (17)	< 61	0.016 (0.057)

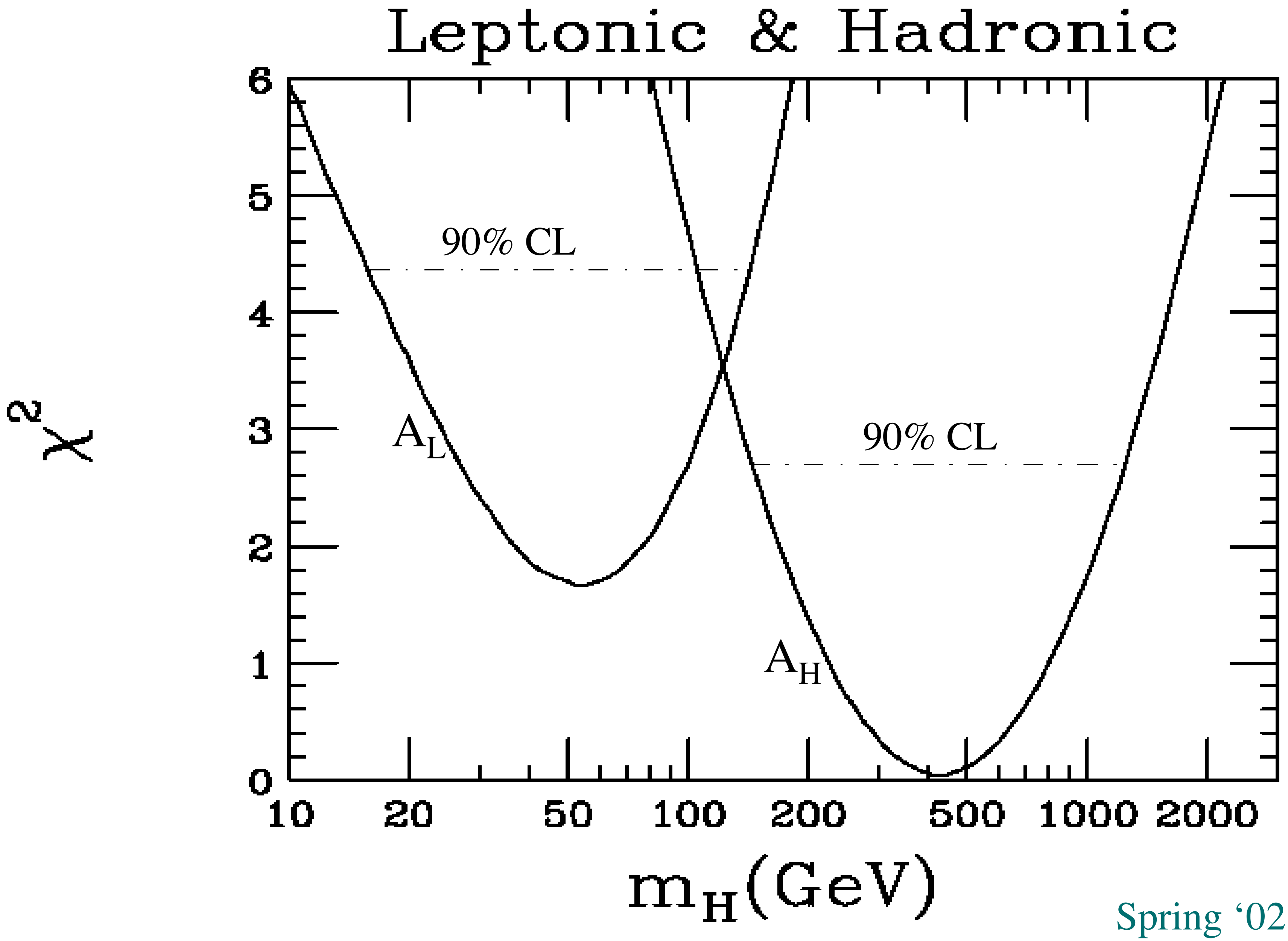
→ Non-asymmetry observables

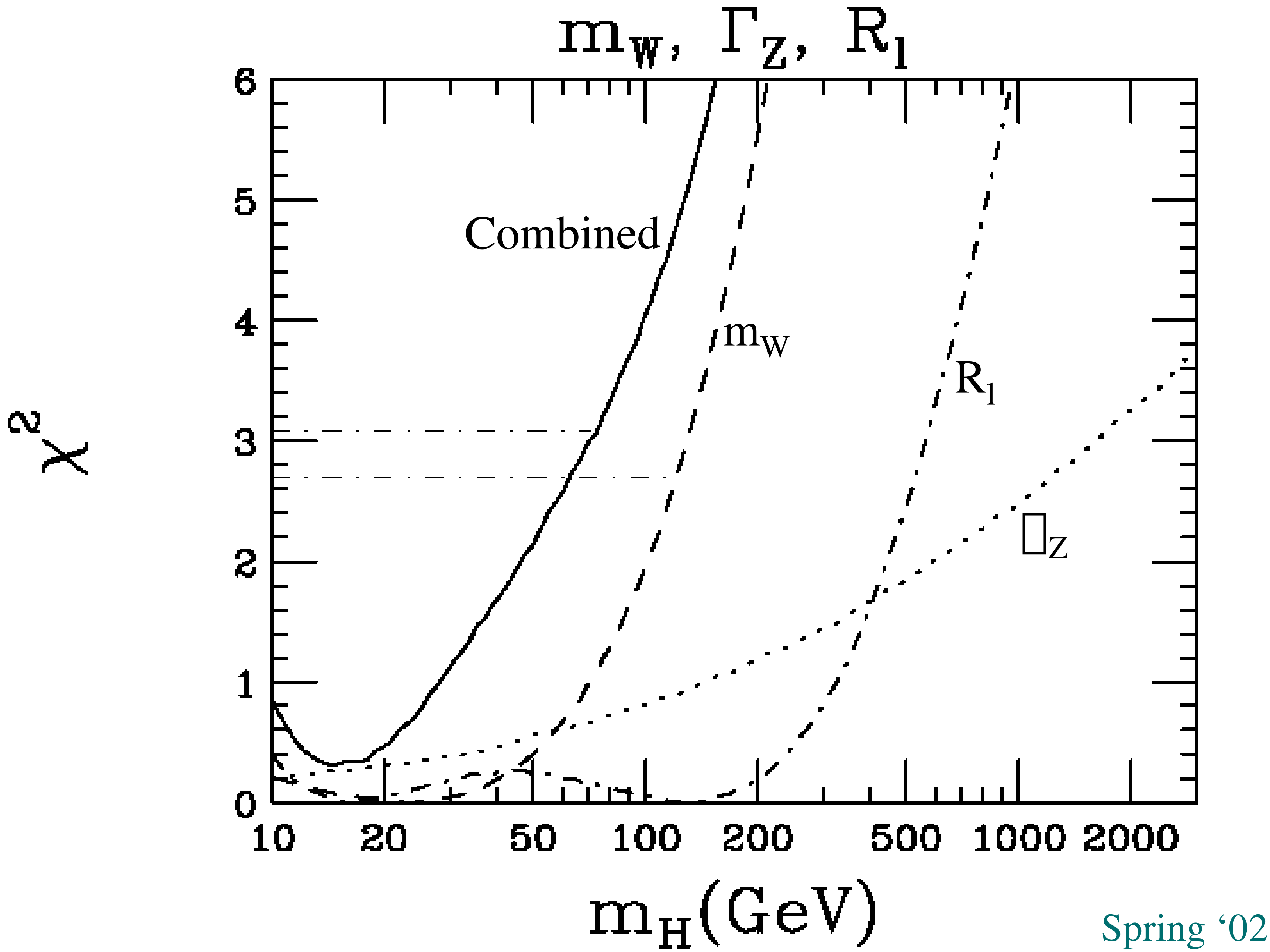
⇒ Support for m_H >114 only from $x[A_H]$ (+ $x_W^{\nu N}$)


Leptonic Asymmetries
χ^2
A_L Combined
A_{LR}
A_{FB}^{l}
P
0
1
2
3
4
5
6
10
20
50
100
200
500
1000
2000
m_H(GeV)


Hadronic Asymmetries
6
5
4
3
2
1
0
10
20
50
100
200
500
1000
2000
χ^2
m_H(GeV)
A_H Combined
A_{FB}^c
A_{FB}^b
Q_{FB}

Spring '02


Leptonic & Hadronic
6
5
4
3
2
1
0
10
20
50
100
200
500
1000
2000
χ^2
m_H(GeV)
90% CL
90% CL
A_L
A_H
Spring '02


mW, ΓZ, Rl
Combined
mW
Rl
Z
χ2
6
5
4
3
2
1
0
10
20
50
100
200
500
1000
2000
mH(GeV)
Spring '02

Global Fits: $CL_T = CL(\chi^2) \otimes CL(m_H > 114)$

Summer 02 m_W

A) **All**

27.7/13

$m_H = 90$

$CL_T =$ **0.010 ⊗ 0.30** = 0.0030

B) **$- x_W^{\nu N}$**

18.3/12

$m_H = 81$

$CL_T =$ **0.107 ⊗ 0.247** = 0.026

C) **$- x[A_H]$**

17.7/10

$m_H = 45$

$CL_T =$ **0.060 ⊗** 0.048 = 0.0029

D) **$-x_W^{\nu N} - x[A_H]$**

7.1/9

$m_H = 43$

$CL_T =$ **0.63 ⊗** 0.035 = 0.022

CL_T ~ invariant under removal of $x[A_H]$.

Without $x[A_H]$, SM fit is inconsistent with search limit.

Global Fits: $CL_T = CL(\square)$ | | $CL(m_H > 114)$

New m_W

A) **All**

25.7/13

$m_H = 89$

$CL_T =$ **0.019** | | **0.35** = 0.0066

B) **- $x_W^{\square N}$**

16.5/12

$m_H = 89$

$CL_T =$ **0.17** | | **0.29** = 0.049

C) **- $x[A_H]$**

16.7/10

$m_H = 45$

$CL_T =$ **0.081** | | 0.068 = 0.0055

D) **-$x_W^{\square N}$ - $x[A_H]$**

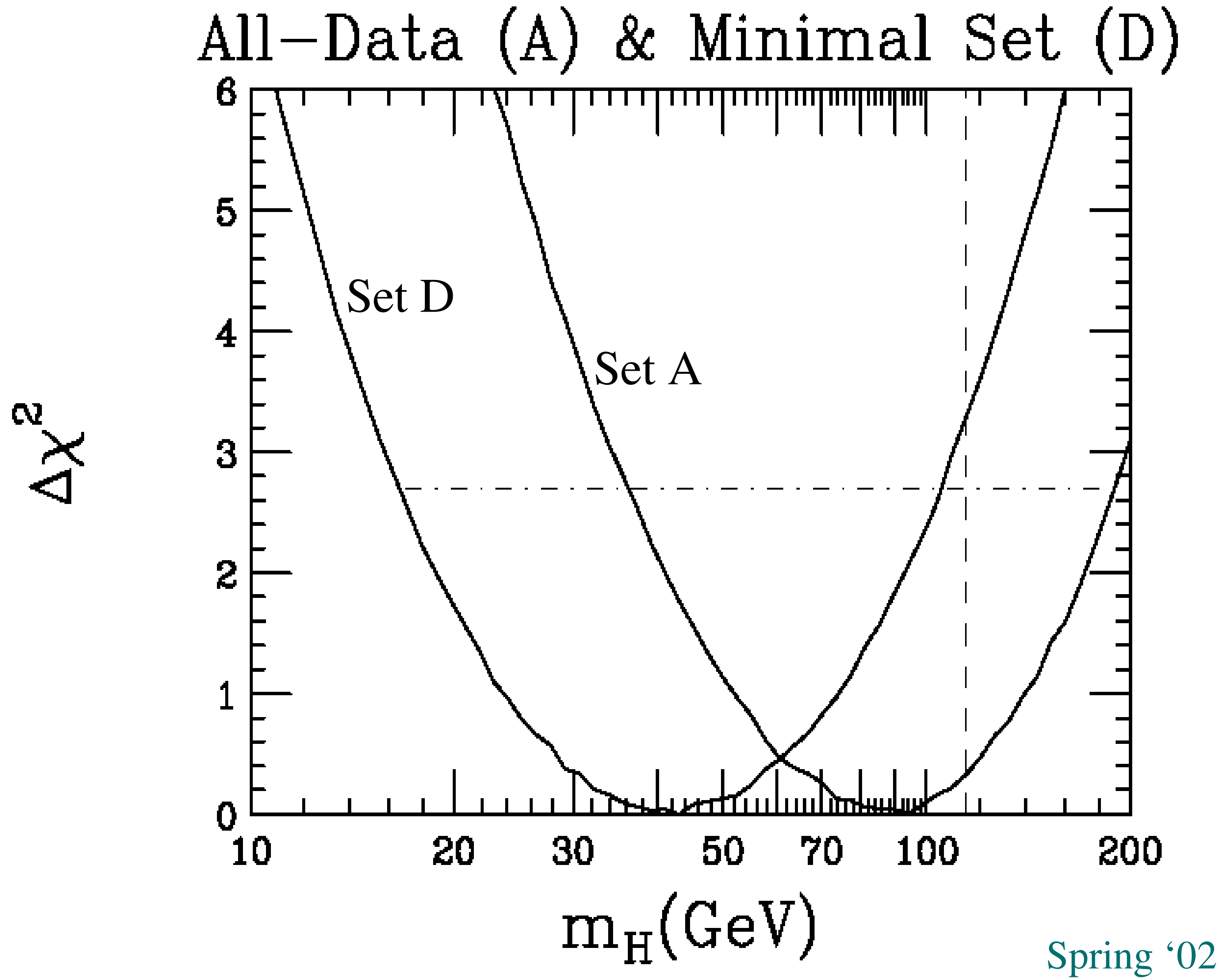
6.3/9

$m_H = 45$

$CL_T =$ **0.71** | | 0.049 = 0.035

CL_T ~ invariant under removal of $x[A_H]$.

Without $x[A_H]$, SM fit is inconsistent with search limit.


All–Data (A) & Minimal Set (D)
Set D
Set A
6
5
4
3
2
1
0
10
20
30
50
70
100
200
Δχ²
m_H(GeV)
Spring '02

“Bayesian” Likelihood

Summer 02

Instead of $\Delta\chi^2$, get $CL(m_H > 114)$ from likelihood.

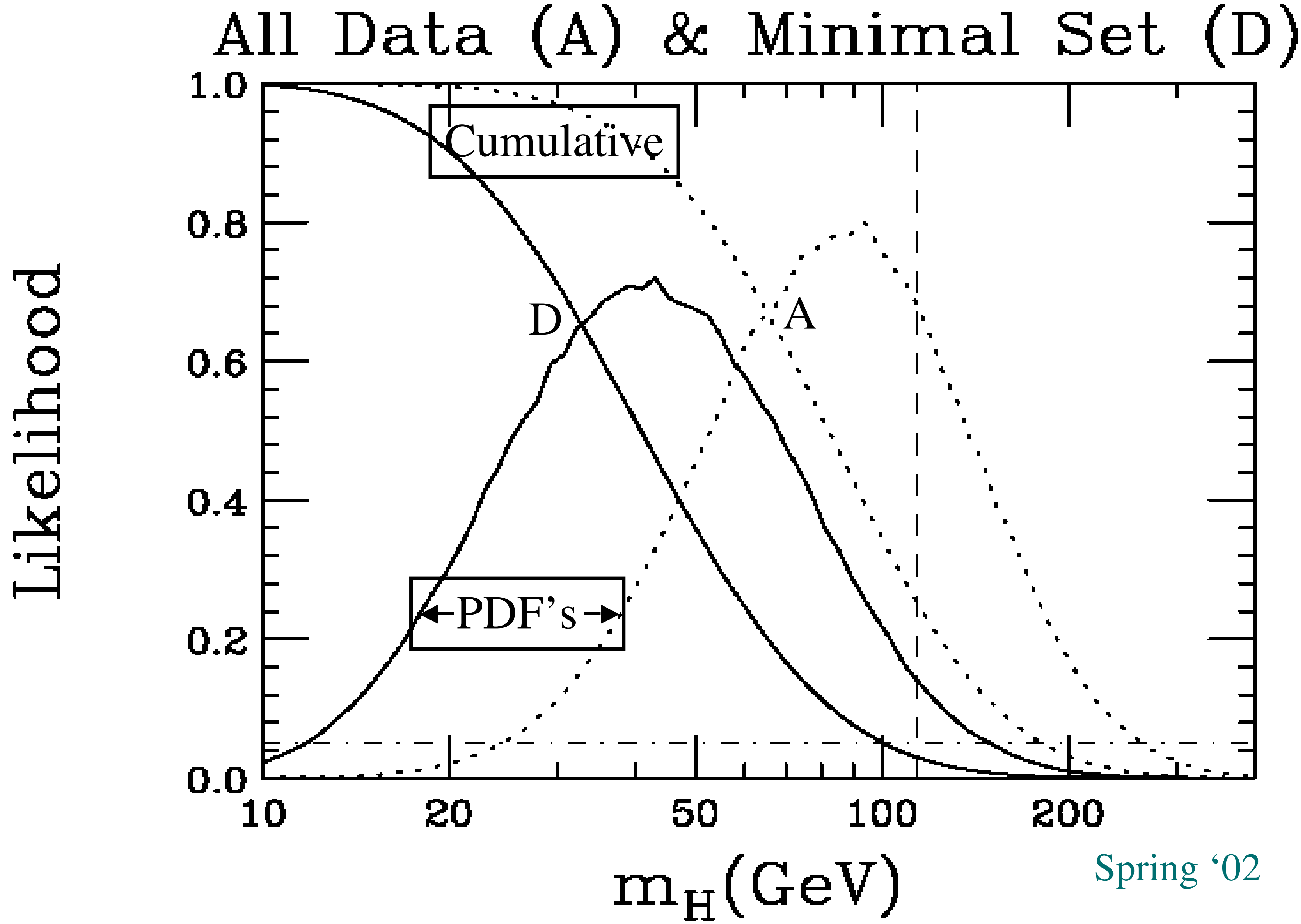
“Bayesian:”

- Probability measure $d \ln(m_H)$
- Normalize pdf to $10 < m_H < 3000$ GeV

Results agree with $\Delta\chi^2$:

E.g., ‘Fit D’ = All - $x[A_H]$ - $x_W^{\nu N}$

	PDF	**$\Delta\chi^2$**
m_H	**43**	**43**
95%	**< 102**	**< 105**
CL(m>114)	**0.032**	**0.035**

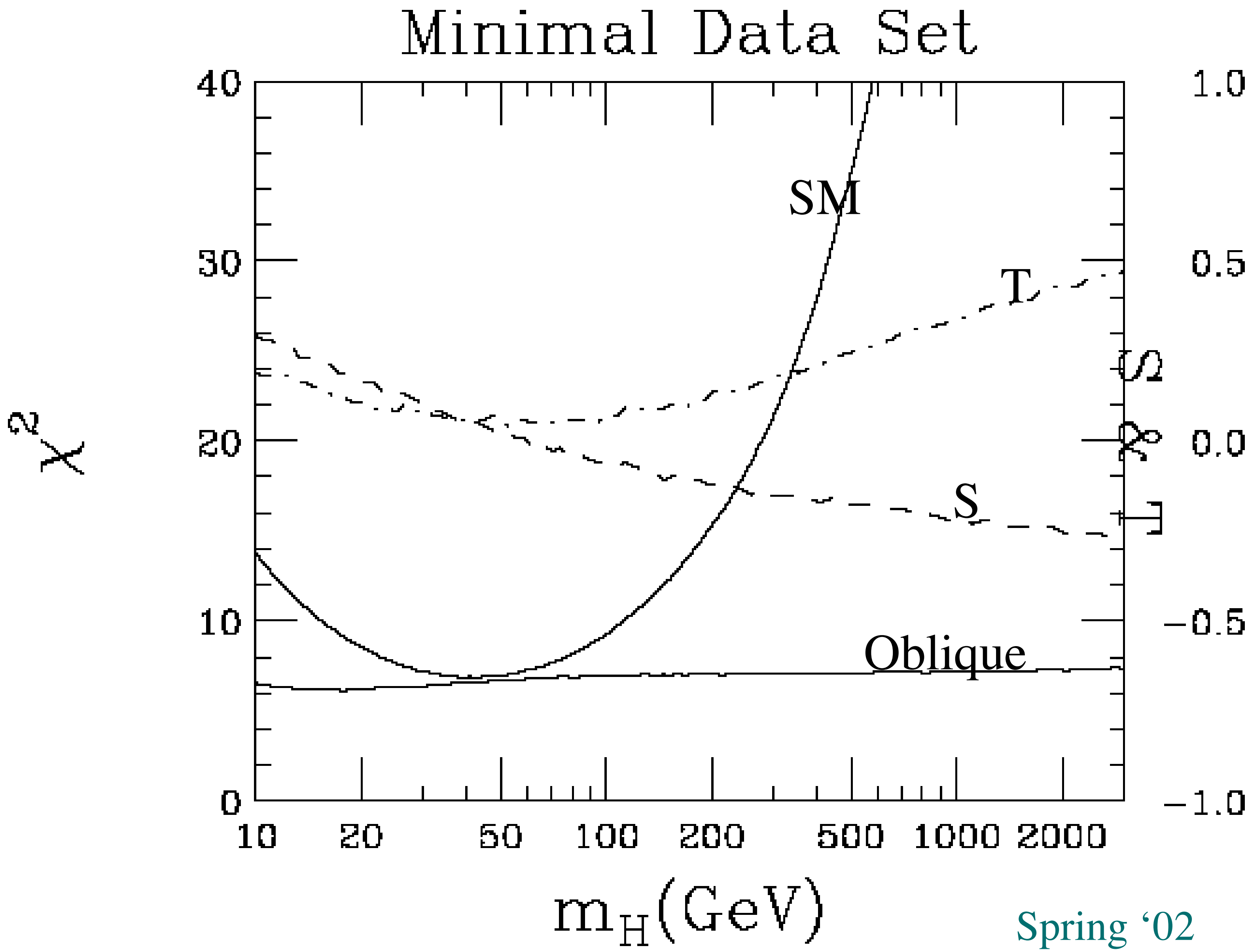


All Data (A) & Minimal Set (D)
Likelihood
1.0
0.8
0.6
0.4
0.2
0.0
10
20
50
100
200
m_H(GeV)
Cumulative
D
A
←PDF's→
Spring '02

New Physics alla oblique

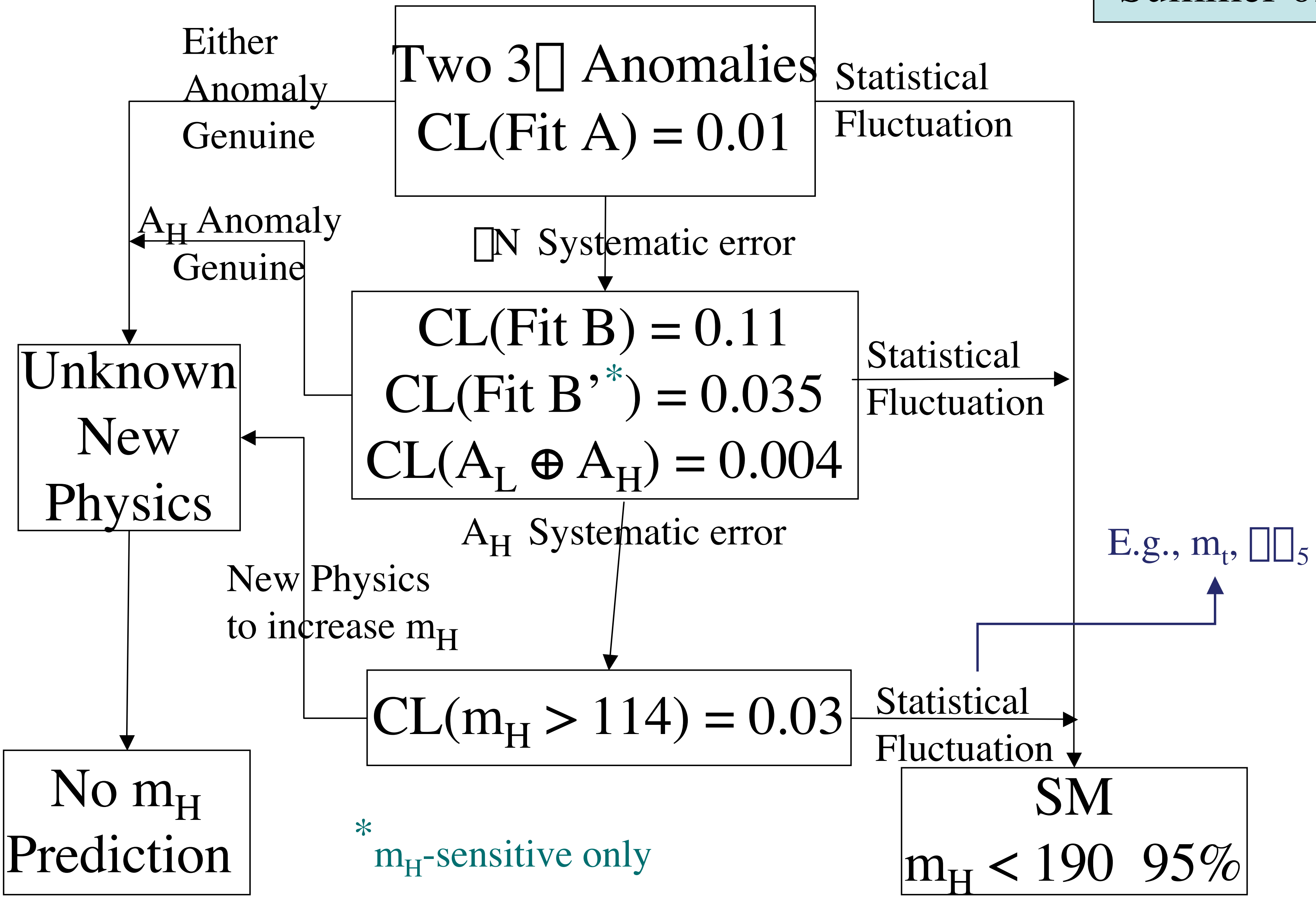
- S,T alone do not improve fits with $x[A_H]$, $x_W^{\nu N}$
- For fits with $x[A_H]$ excluded, S,T can raise m_H arbitrarily

	SM	S,T ≠ 0
χ^2 =	7.1/9	6.1/7
CL =	0.63	0.53
m_H =	43	All m_H allowed


Minimal Data Set
40
30
20
10
0
1.0
0.5
0.0
−0.5
−1.0
10
20
50
100
200
500
1000
2000
SM
T
S
Oblique
χ^2
T & S
m_H(GeV)
Spring '02

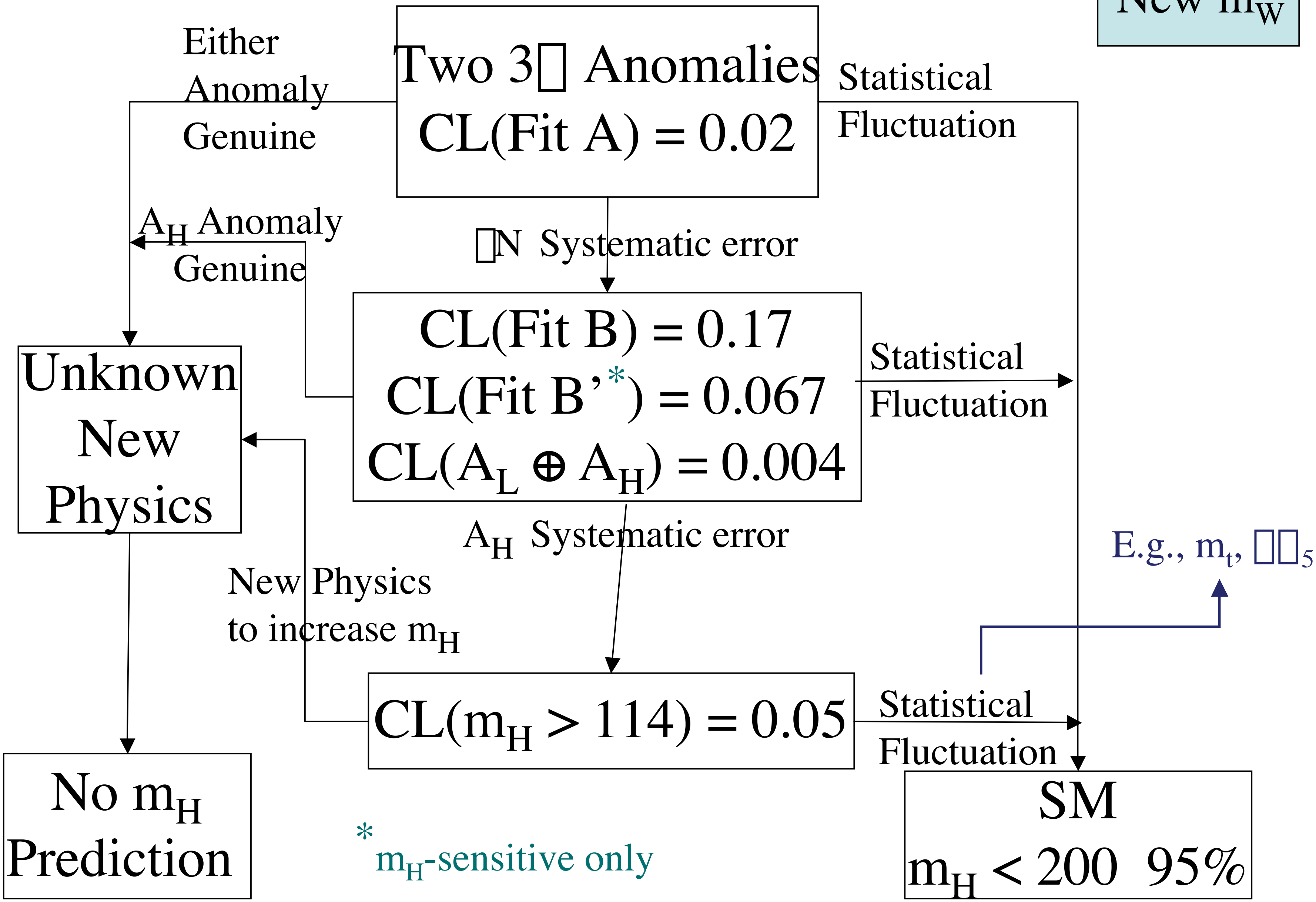
E-W Schematic Diagram

Summer 02



E-W Schematic Diagram

New m_W



With new m_W, betting odds that data reflects SM statistical fluctuation are improved, but both 3σ anomalies remain.

Still not clear if anomalies result from new physics, systematic effects, or statistical fluctuation.

Systematic error hypothesis for both 3σ anomalies now implies $m_H < 114$ GeV at 95% CL, in conflict with the direct lower limit, $m_H > 114$ GeV.

The E-W decade @LEP/SLC/FNAL has verified the SM at quantum loop level for non m_H-sensitive observables.

However, $x[A_{FB}^b]$ - $x[A_{LR}]$ discrepancy has proven to be a stubborn problem that refuses to go away.

LEP II limit on m_H makes problem even more stubborn:

- New physics is favored whether A_{FB}^b attributed to sys. error or not
  ⇒ no prediction for m_H until new physics is known.
- SM & usual m_H prediction require statistical fluctuations of both anomalous and non-anomalous measurements.

What's it all mean?

Beats me --- a great puzzle!

- The answer could begin to emerge at the TeVatron and will surely begin to emerge at LHC.
- Final clarity will probably require revisiting the Z boson with even greater precision, as for instance at Giga-Z.