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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, $□_W$)

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 $\begin{cases} A_{LR} = 0.23098\ (26) \\ A_{FB}^{b} = 0.23217\ (31) \end{cases}$

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(χ^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

$\rightarrow$ - (5 - 10) MeV

$m_Z, m_t, \Delta\alpha_5, \alpha_S, m_H \Rightarrow O_{Z\text{-Pole}} + m_W + x_W^{\ell\ell} + \ldots$

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 $m_t, \Delta\alpha_5, \alpha_S, m_H$
- Fit $m_t, \Delta\alpha_5$ + all/some of $\{13\ O_{Z\text{-Pole}}, m_W, x_W^{\ell\ell}\}$
- 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($\square^2$) = **0.010**

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

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

18.3/12

CL($\square^2$) = **0.11**

P($\geq$ 1 2.8□, N = 12) = **0.09**

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

17.7/10

CL($\square^2$) = **0.060**

P($\geq$ 1 3.2□, N = 10) = **0.013**

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

7.1/9

CL($\square^2$) = **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(χ^2)

New m_W in (green)

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

+ $x_W^{\nu N}$ CL(χ^2) = 0.0019 (0.0046)

Highest precision:

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

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

Non m_H-sensitive: $\Gamma_{\square}$, R_b, A_b, R_c, A_c CL(χ^2) = 0.68

m_H-sensitive observables: m_H predictions

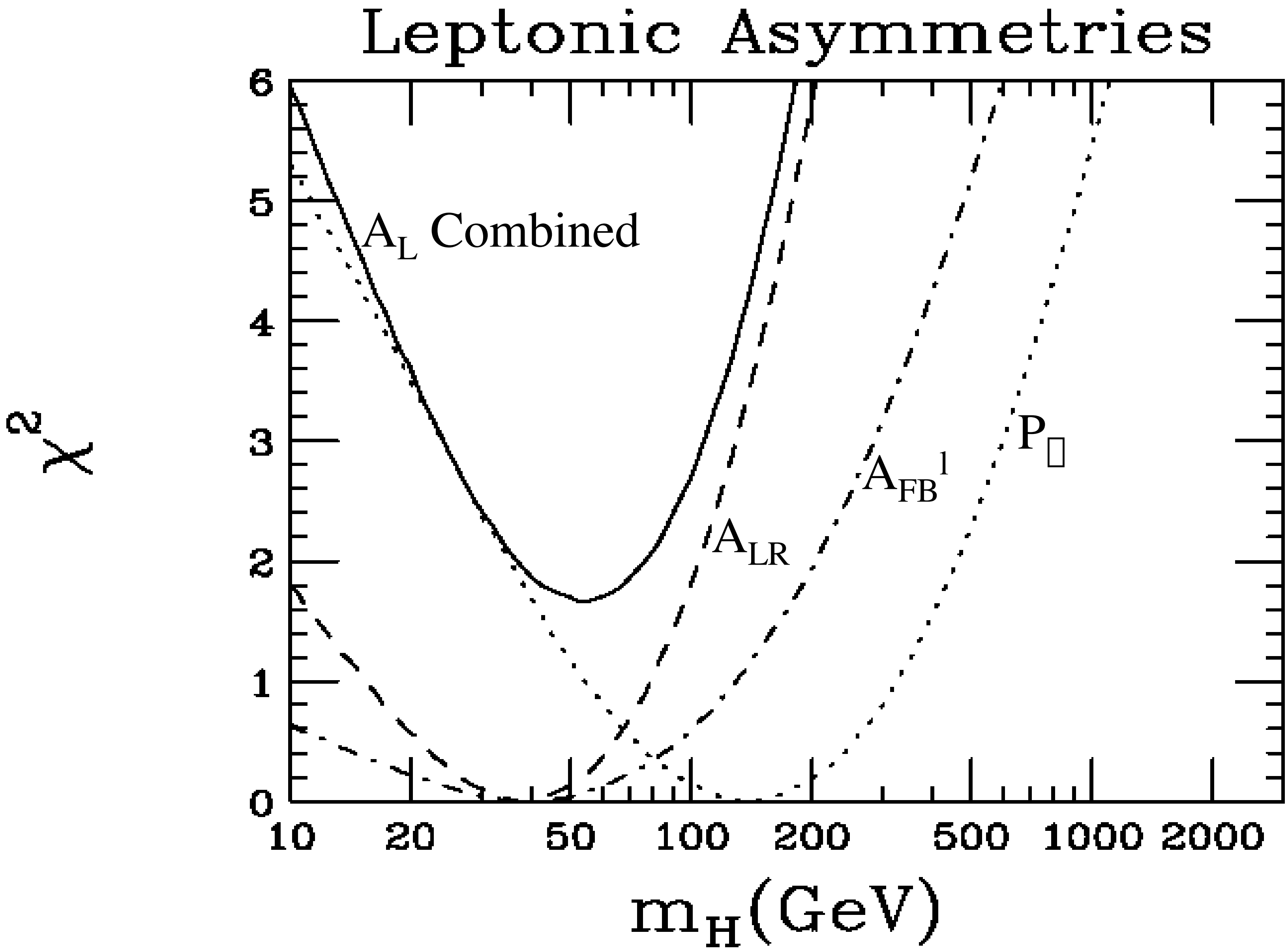
New m_W in (green)

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)

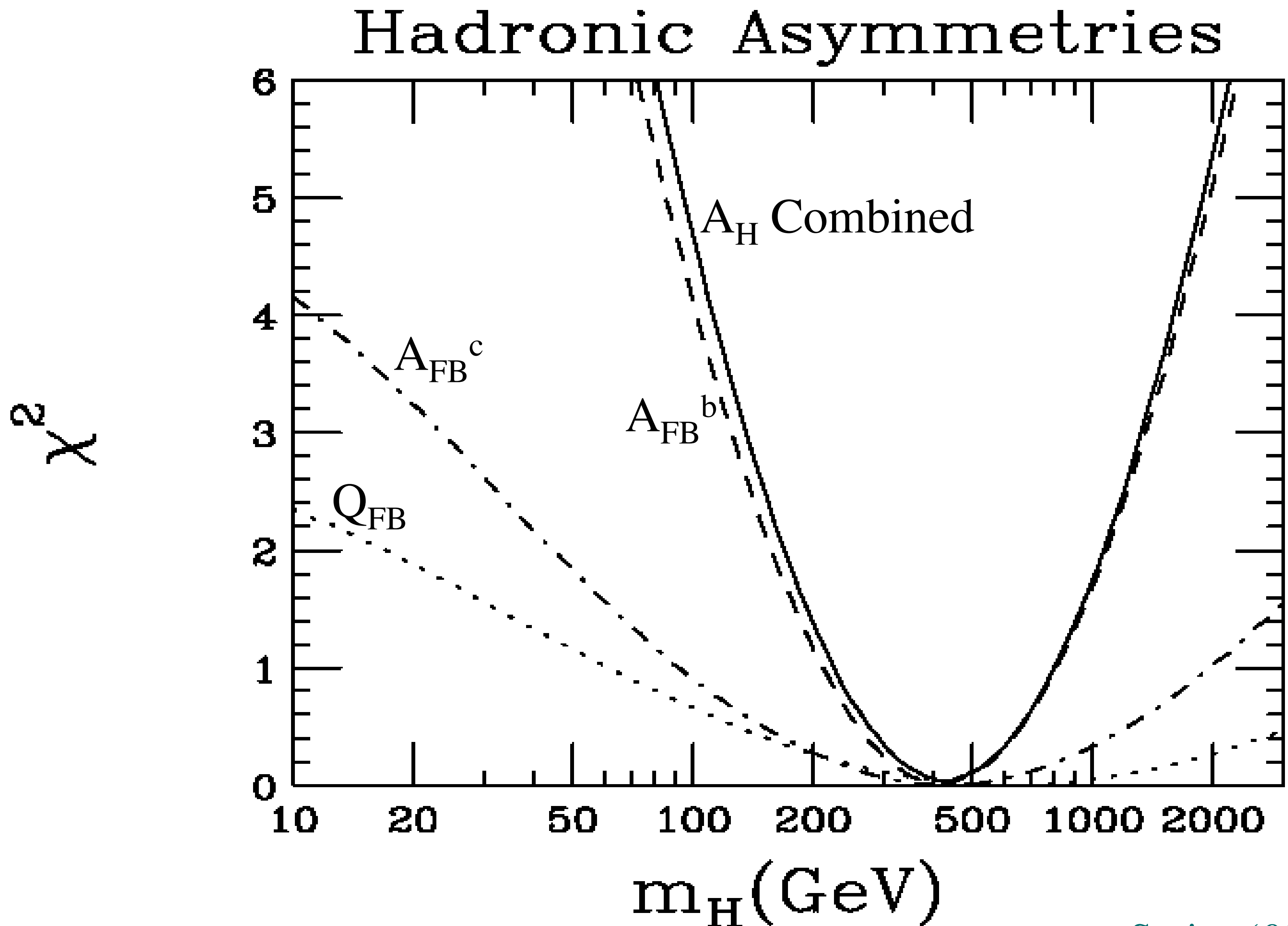
Aggregates	m_H	95%	$CL(m_H > 114)$
$x[A_L]$	55	< 143	0.10
$x[A_H]$	410	140 < m < 1200	0.97
m_W, Γ_Z, R_l	14 (17)	< 61	0.016 (0.057)

m_W, Γ_Z, R_l → Non-asymmetry observables

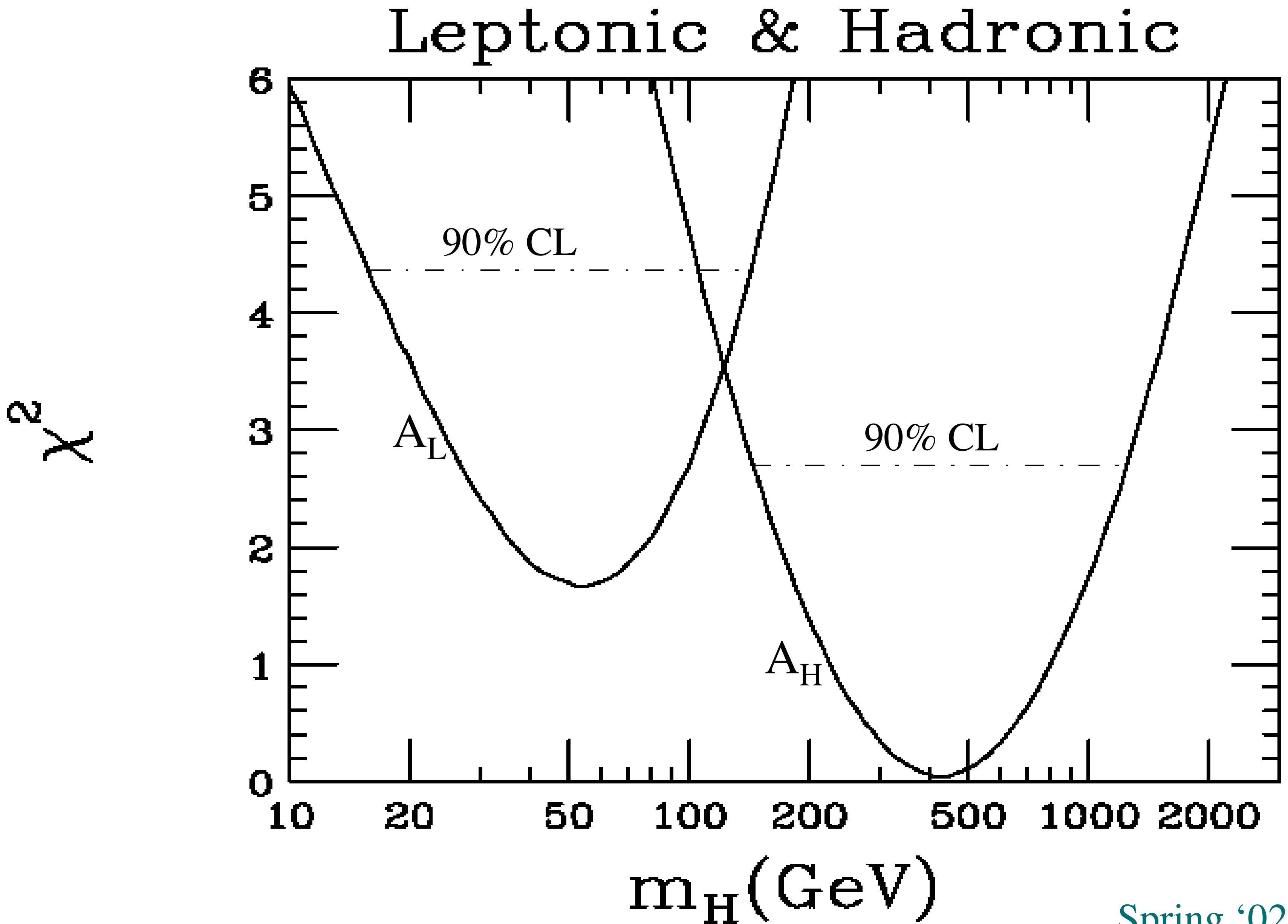
⇒ Support for m_H >114 only from $x[A_H]$ (+ $x_W^{\nu N}$)



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)

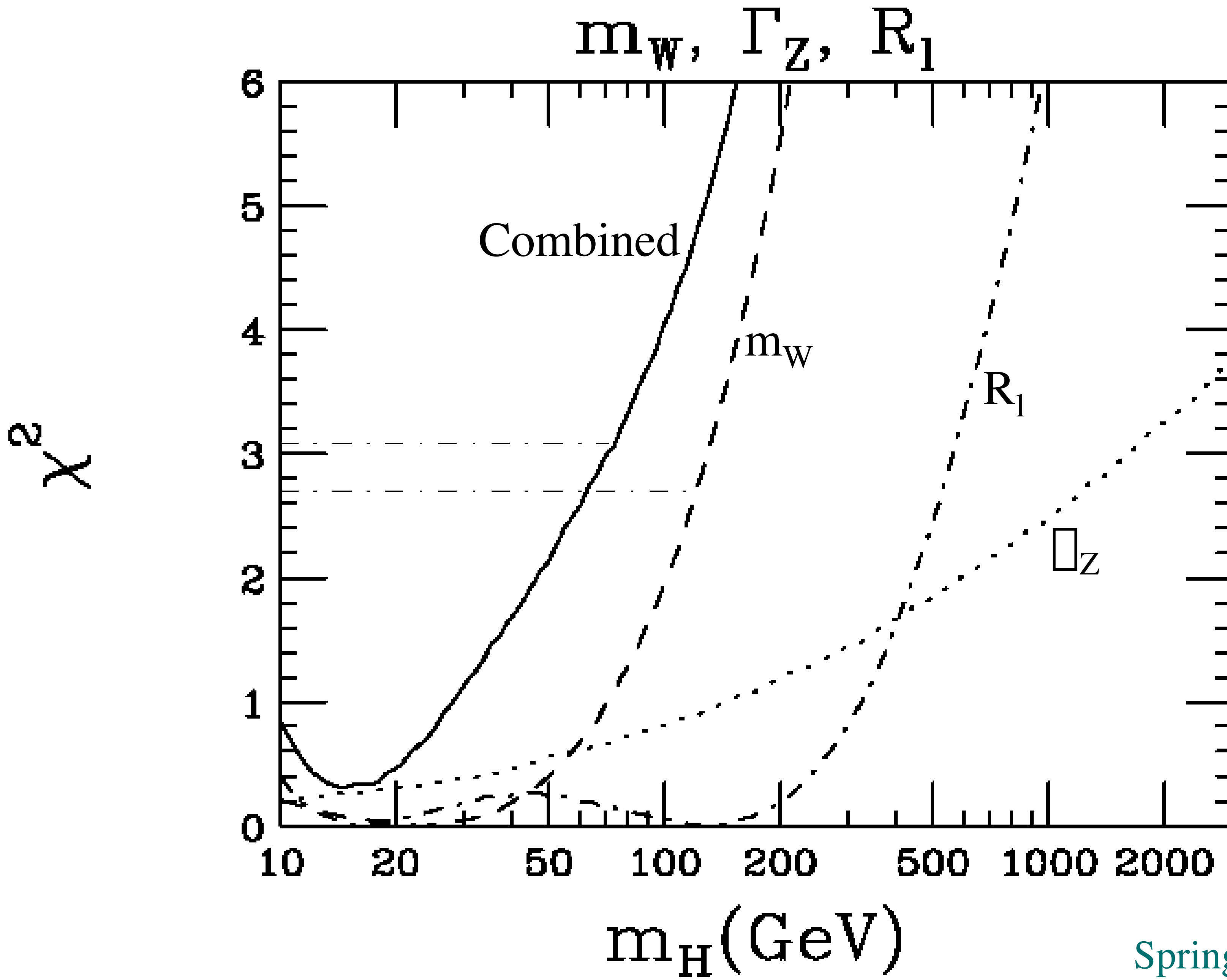

Hadronic Asymmetries
6
5
4
3
2
1
0
10
20
50
100
200
500
1000
2000
χ^2
m_H(GeV)
A_H Combined
$A_{FB}{}^c$
$A_{FB}{}^b$
Q_{FB}

Spring '02



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

Spring ‘02



m_W, Γ_Z, R_l
χ^2
Combined
m_W
R_l
Γ_Z
6
5
4
3
2
1
0
10
20
50
100
200
500
1000
2000
m_H(GeV)

Spring ‘02

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

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: $CL_T = CL(\square) \times CL(m_H > 114)$

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

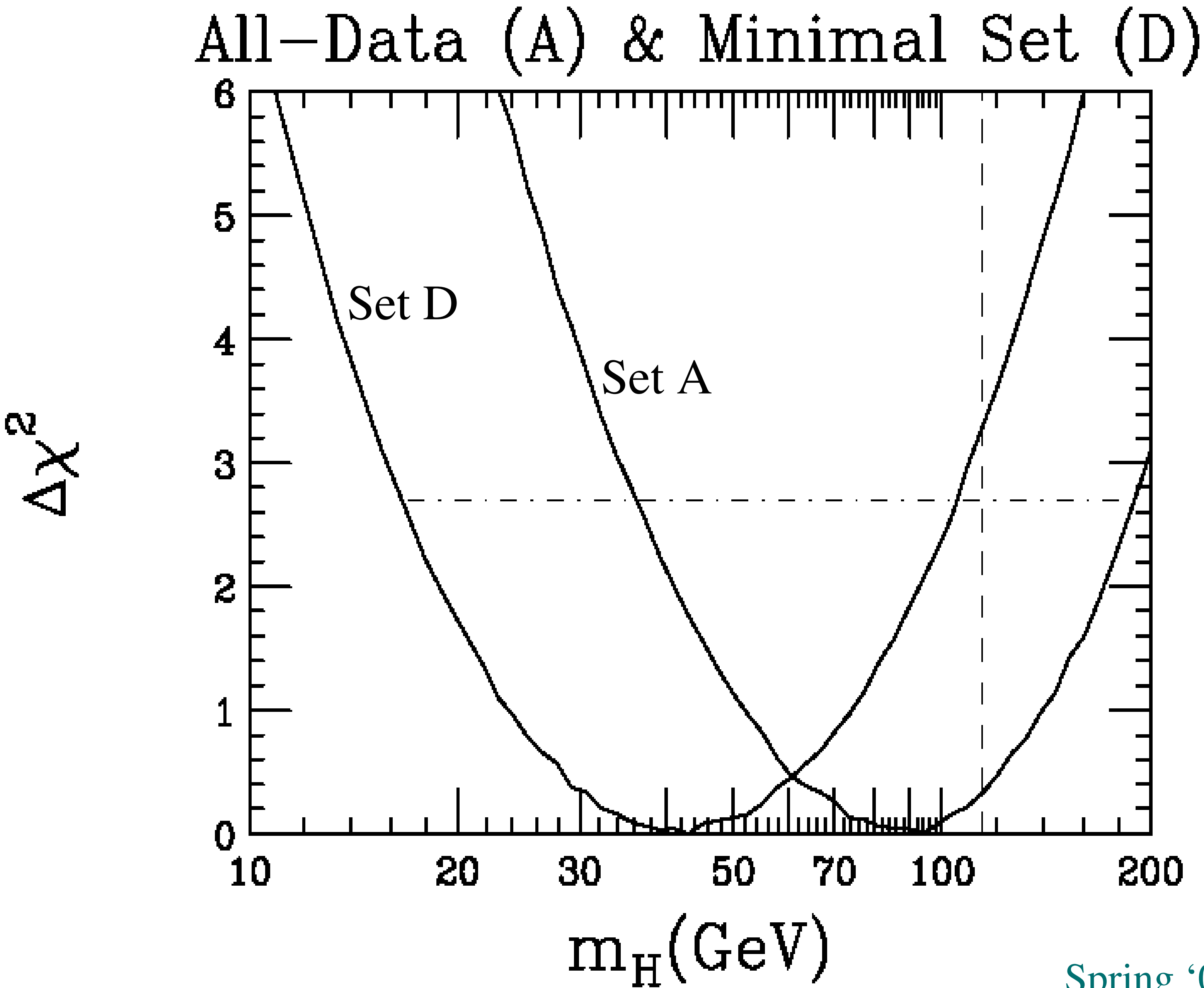
6.3/9

$m_H = 45$

$CL_T =$ **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
$\Delta\chi^2$
m_H(GeV)

Spring '02

“Bayesian” Likelihood

Summer 02

Instead of □□^{2}, get CL(m_H >114) from likelihood.

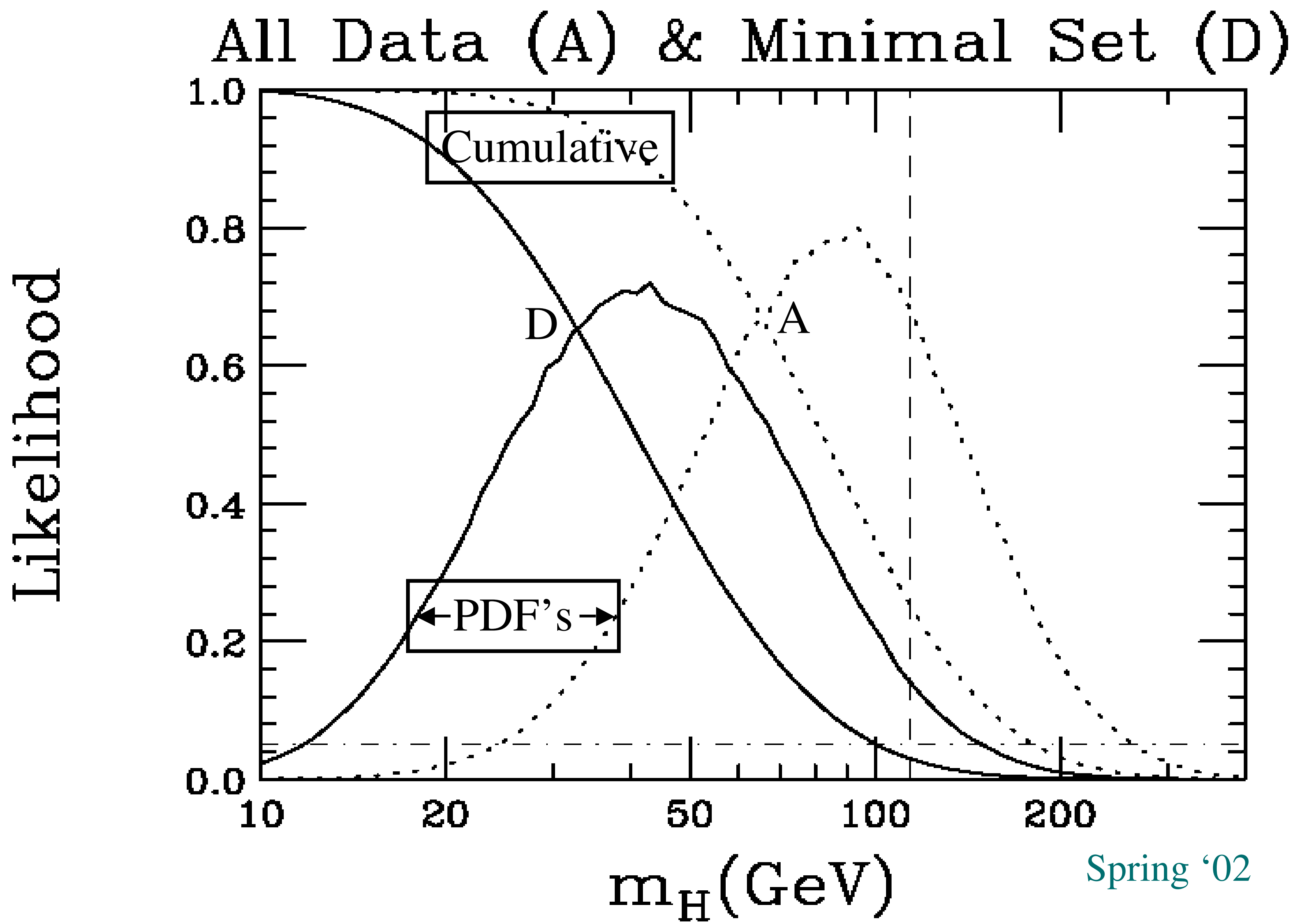
“Bayesian:”

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

Results agree with □□^{2}:

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

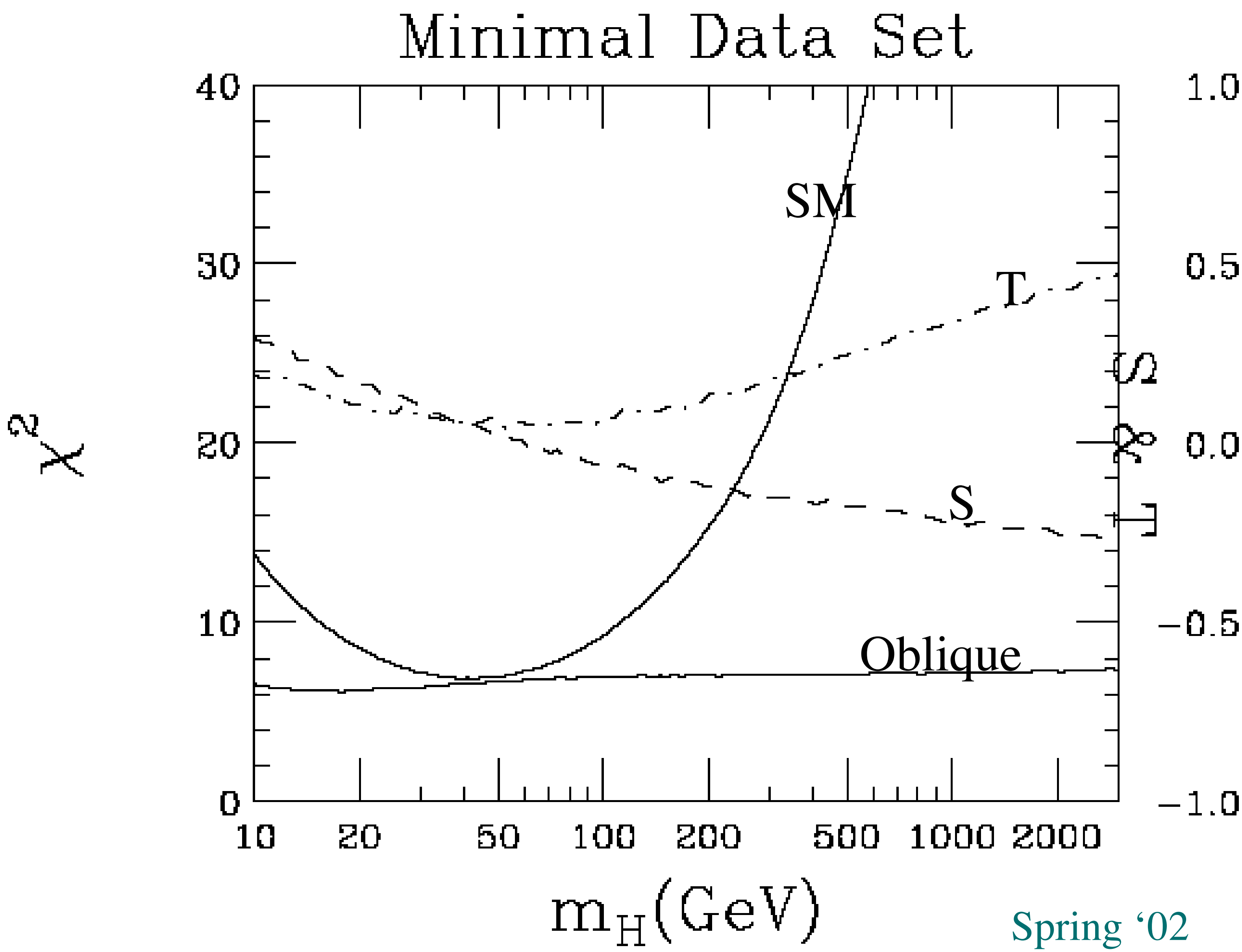
	PDF	**□□^{2}**
m_H	**43**	**43**
95%	**< 102**	**< 105**
CL(m>114)	**0.032**	**0.035**


All Data (A) & Minimal Set (D)
Cumulative
D
A
PDF's
Likelihood
1.0
0.8
0.6
0.4
0.2
0.0
10
20
50
100
200
m_H(GeV)
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 $\neq$ 0
χ^2 =	7.1/9	6.1/7
CL =	0.63	0.53
m_H =	43	All m_H allowed

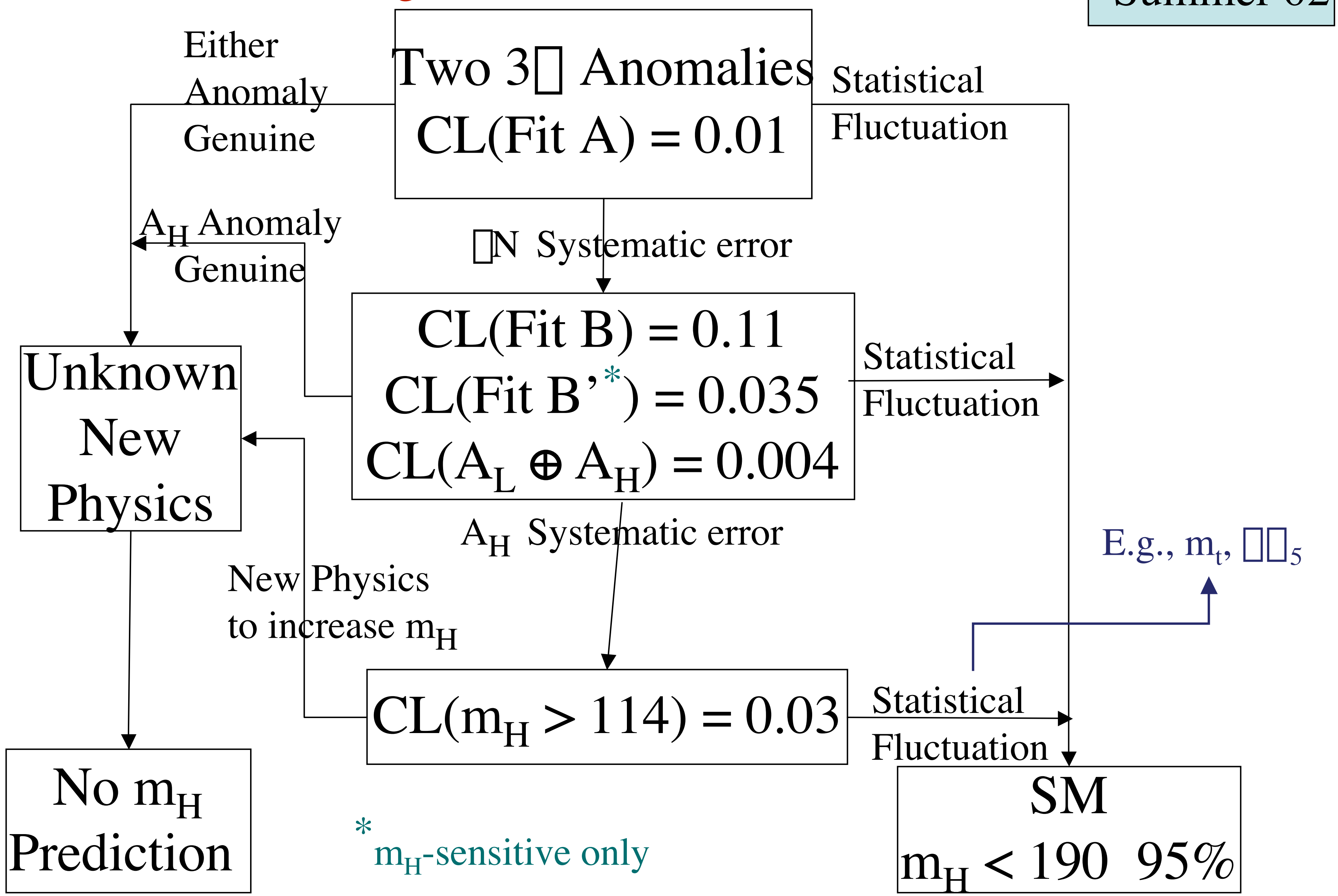


Minimal Data Set
40
30
20
10
0
1.0
0.5
0.0
−0.5
−1.0
SM
T
S
Oblique
S & T
χ2
10
20
50
100
200
500
1000
2000
mH(GeV)

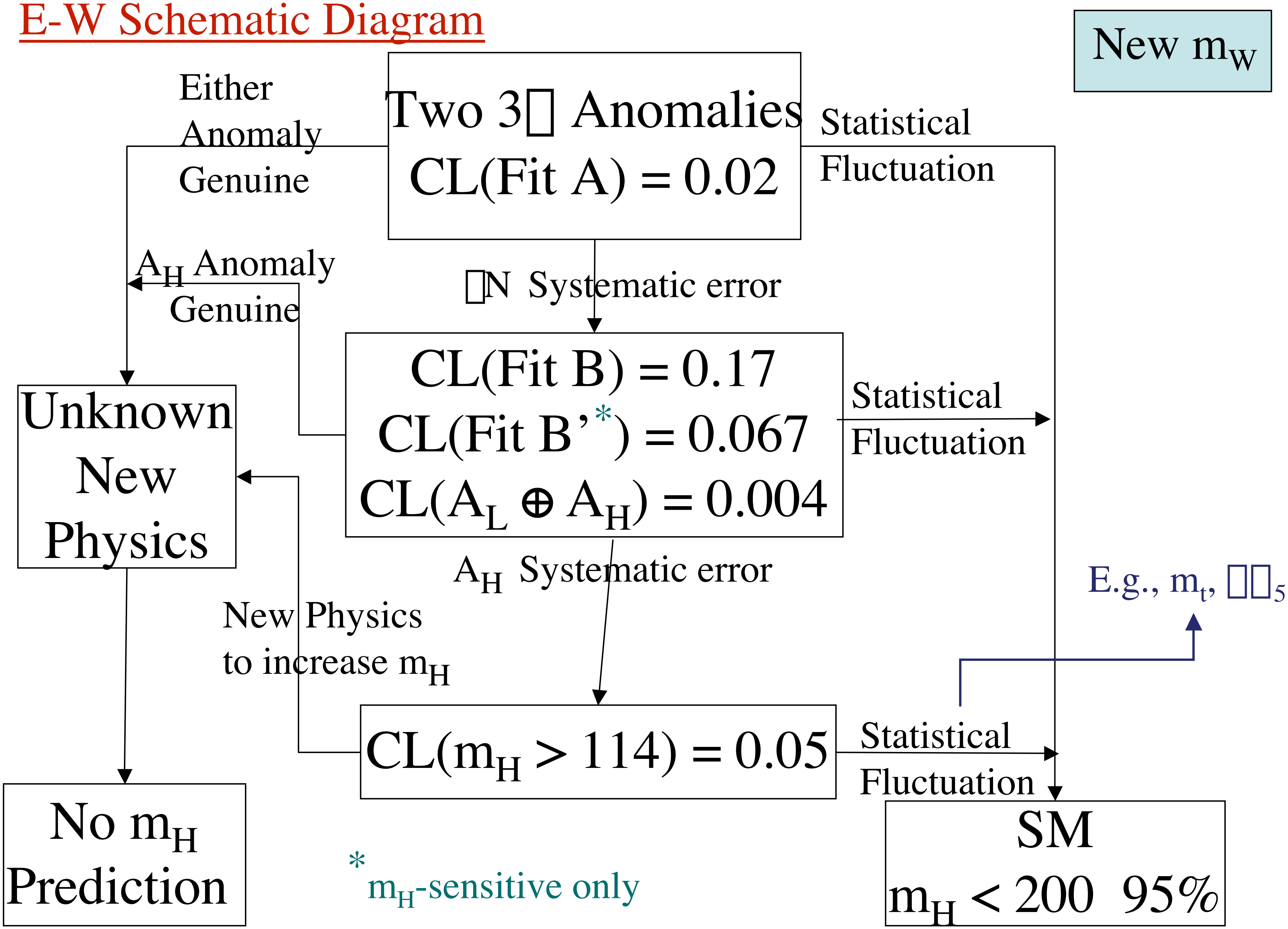
Spring '02

E-W Schematic Diagram

Summer 02



E-W Schematic Diagram



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

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

Systematic error hypothesis for both 3□ 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.