Search for the Higgs Beyond the Standard Model

John Conway
University of California, Davis

Aspen 2007

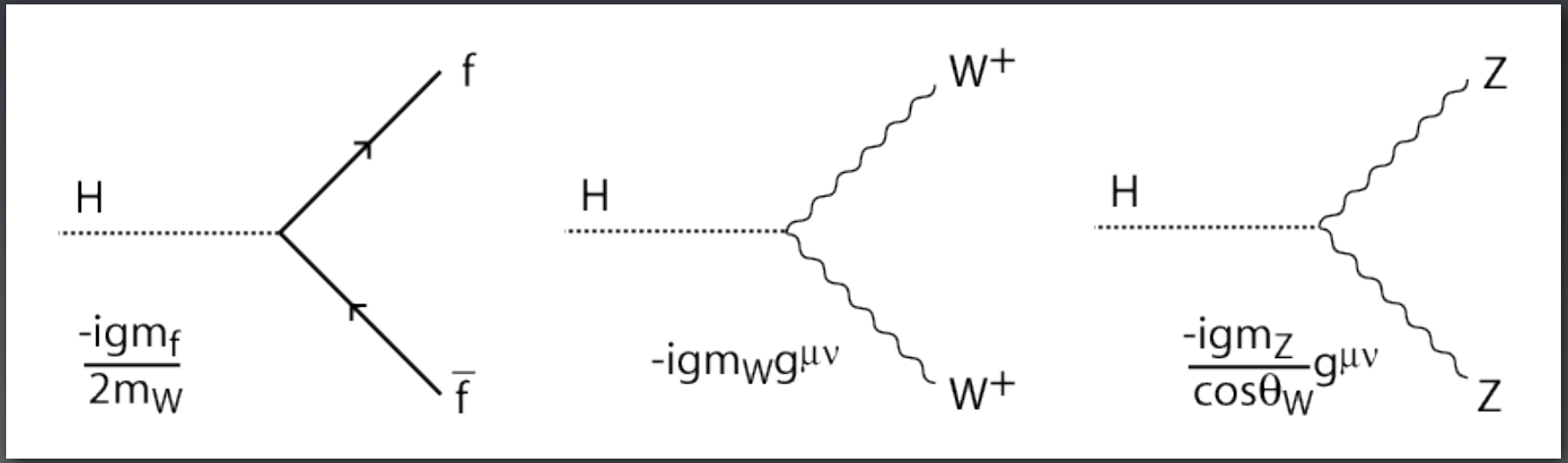
Why a BSM Higgs?

- SM requires exquisite fine-tuning
- Even MSSM has "little hierarchy" problem...
- Variants of SUSY offer some hope
- Space of possible experimental scenarios is enormous!

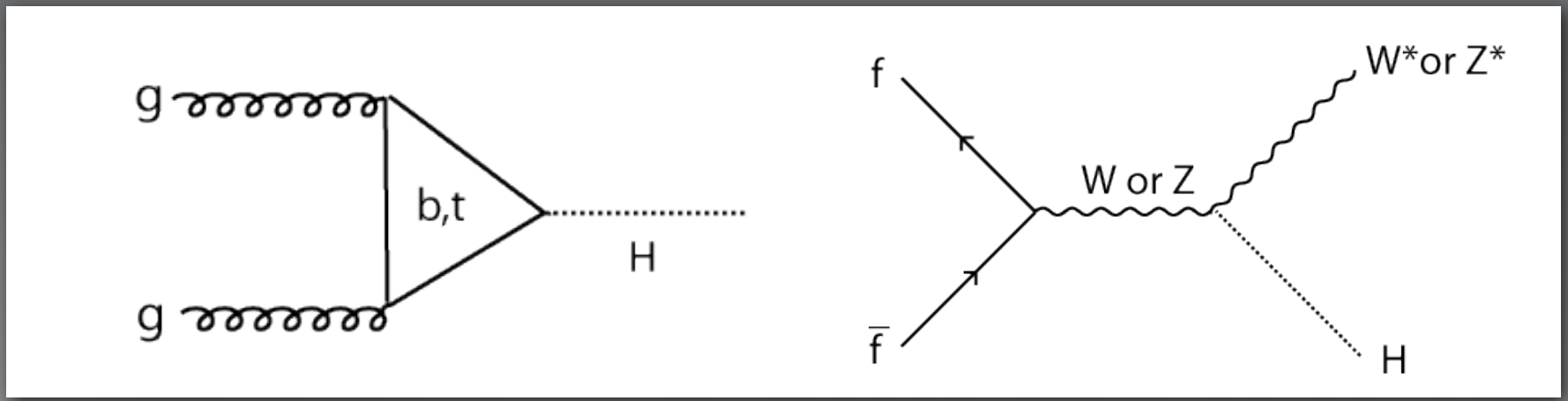
- Focus here on what is being done and what will soon be done

1. Is it a SM-like Higgs?

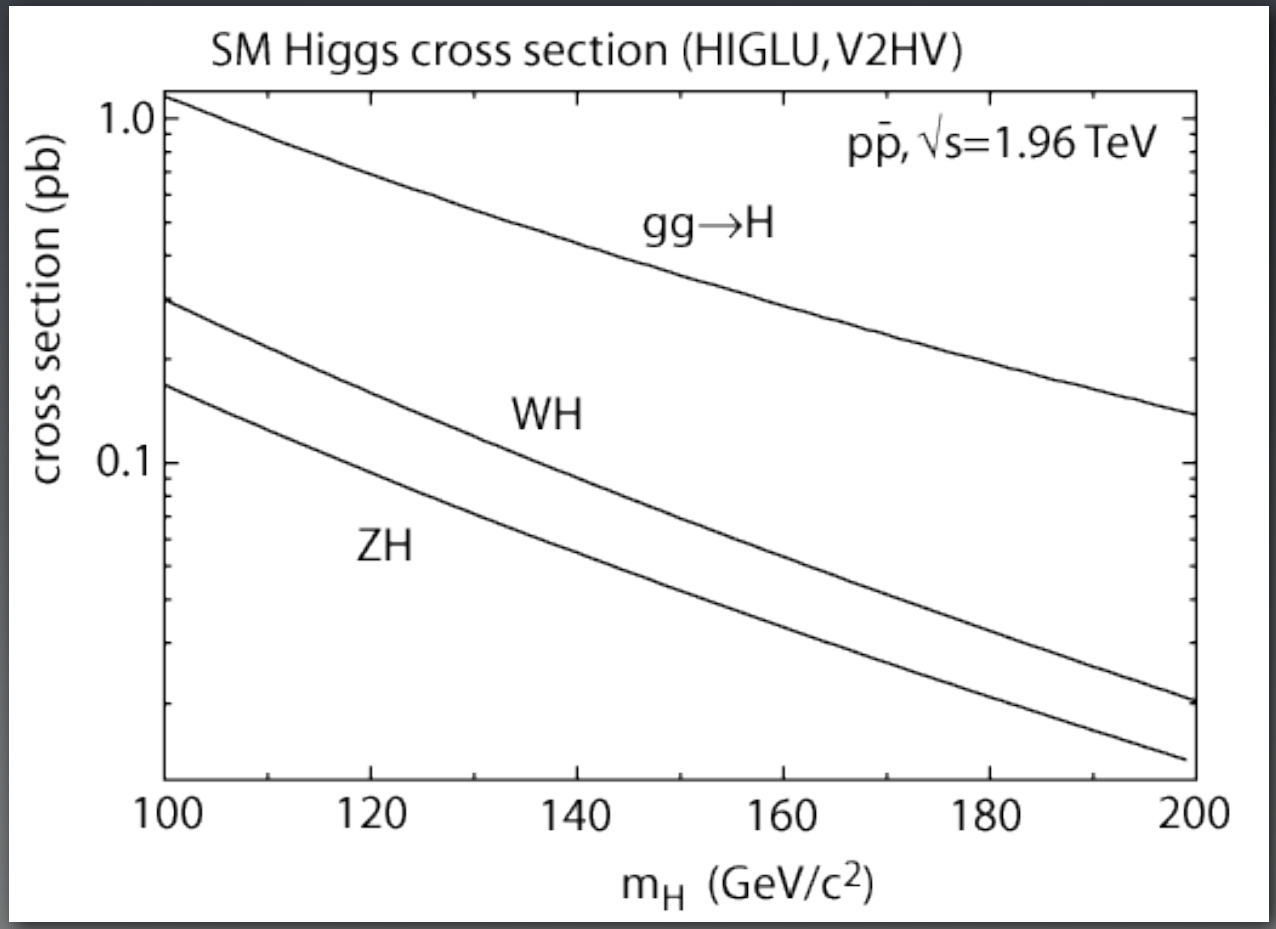
Standard Model: one complex scalar weak isodoublet



H scalar couples to fermion pairs, WW, ZZ



Tevatron gets the first shot!



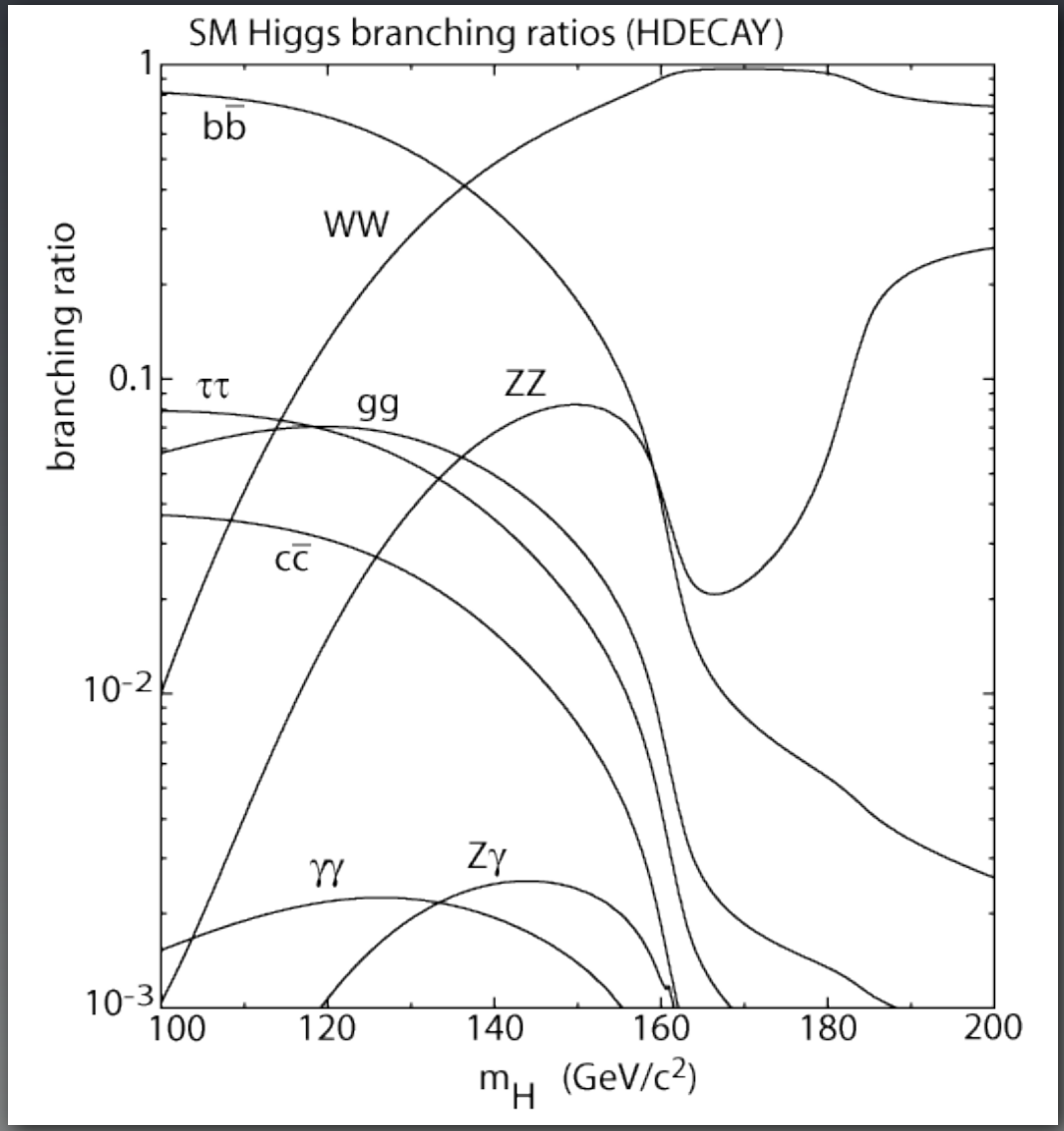
⇒ gg mode impossible; must rely on VH modes

Low mass Higgs:

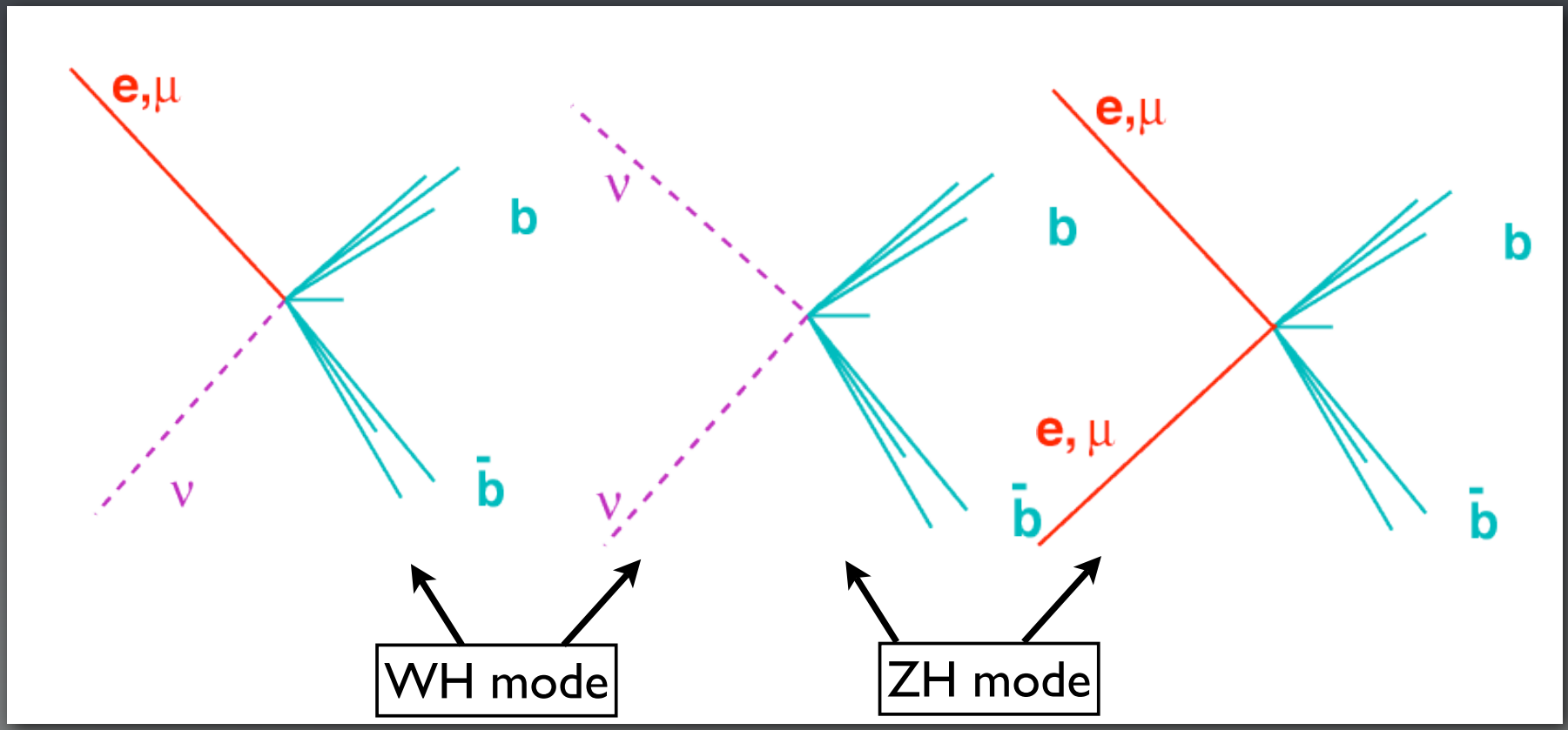
bb 70-90%
ττ 6-8%
γγ 0.2%

High mass Higgs:

WW 90-98%
ZZ 2-10%

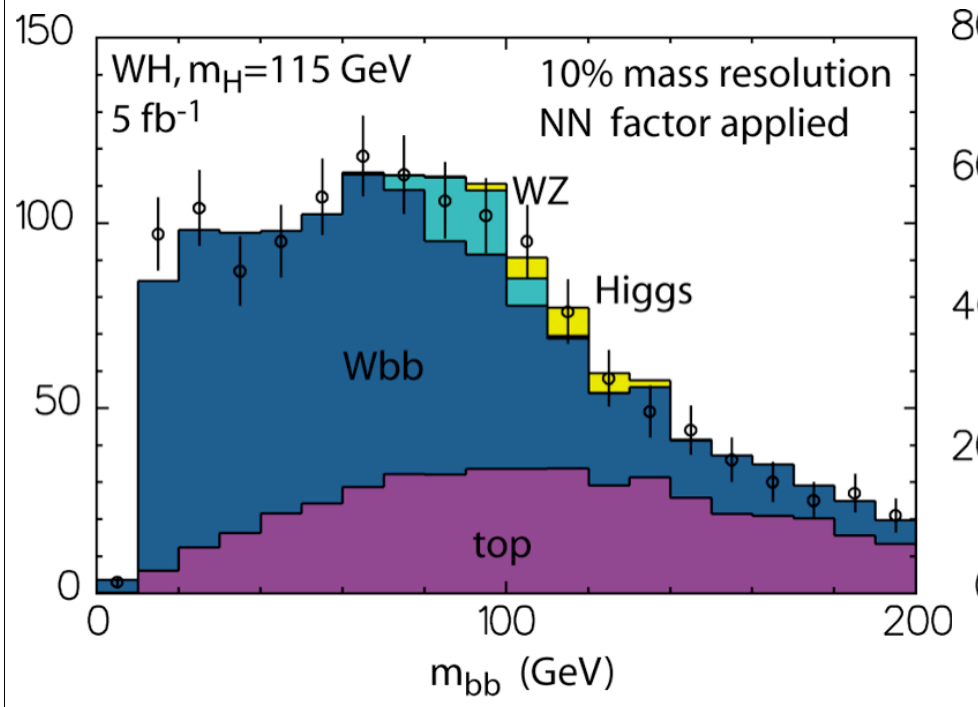


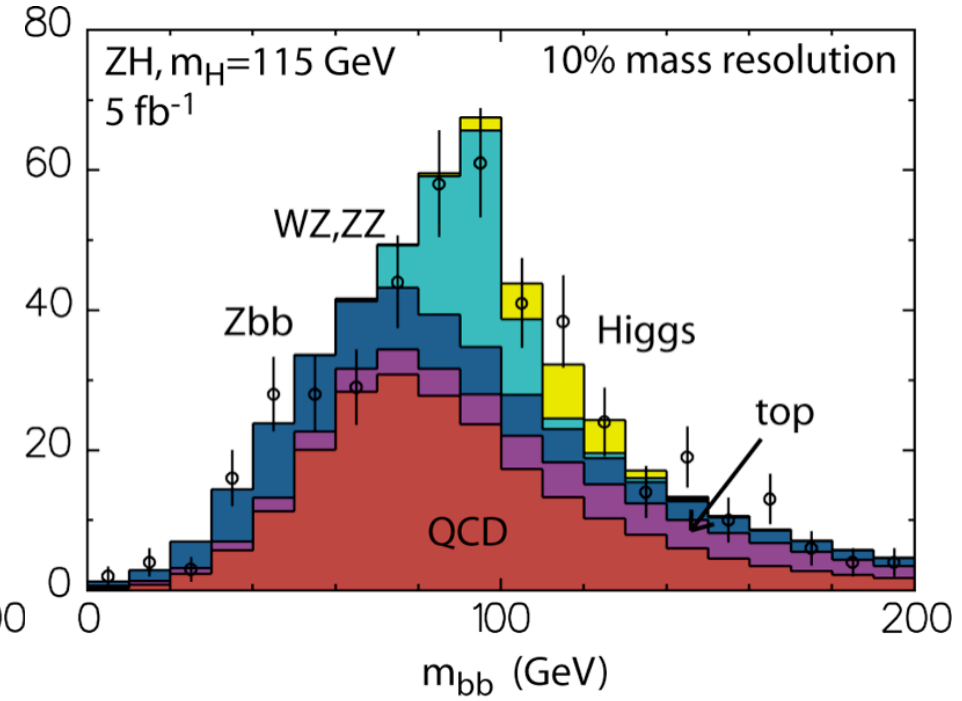
Final states for VH production:



These are the only sensitive modes at the Tevatron!

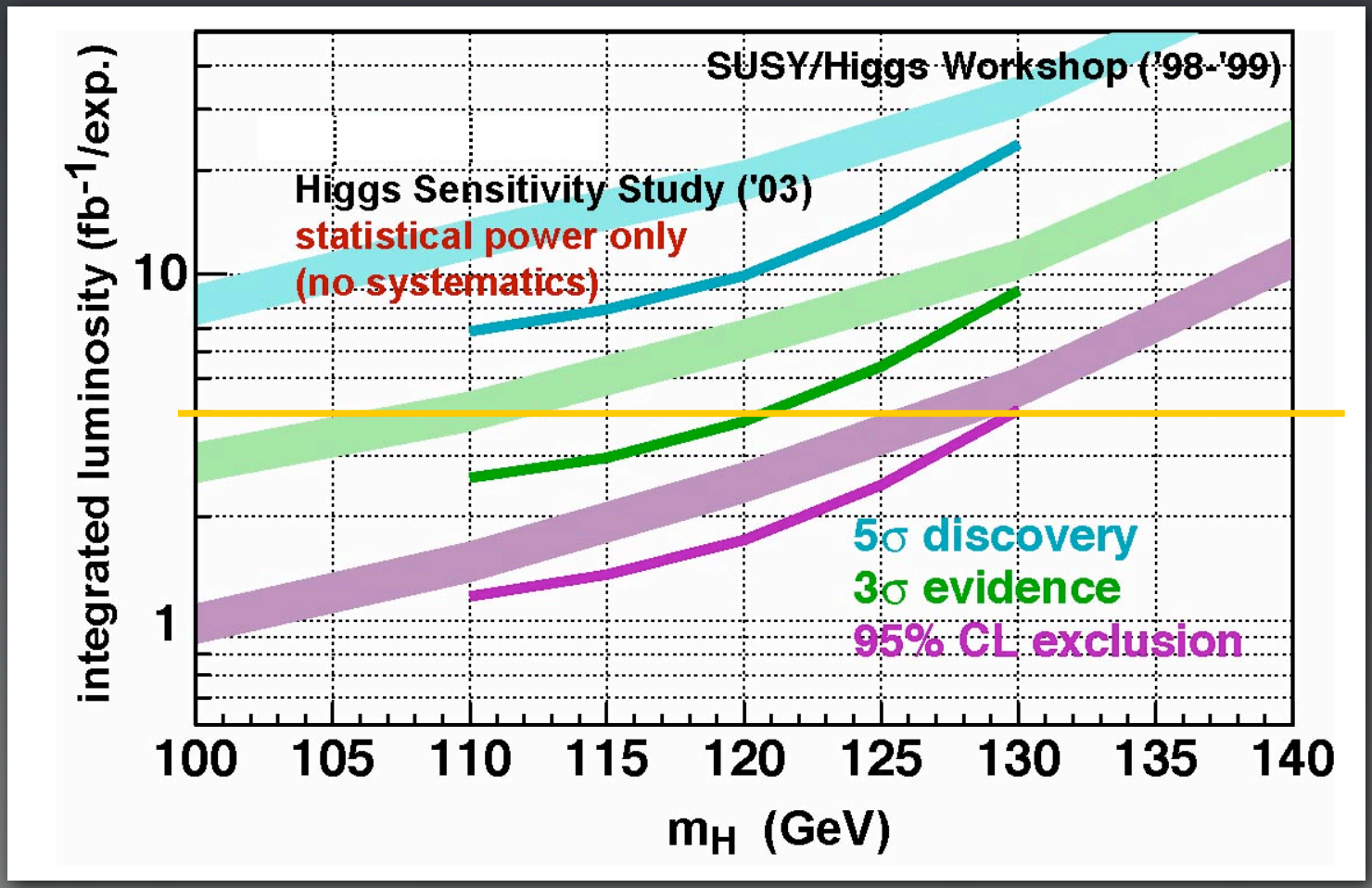
Tevatron SM Higgs is extremely difficult, experimentally:



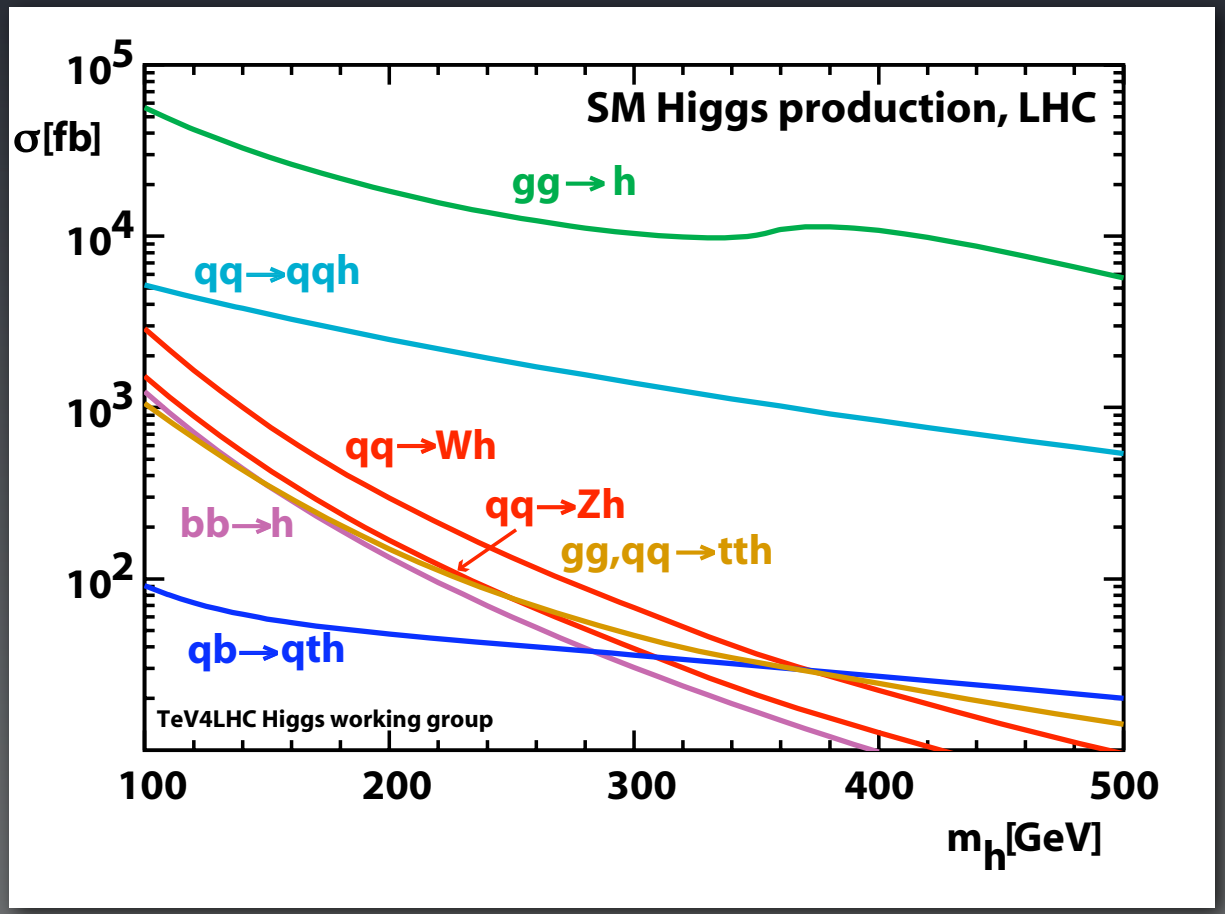


Need great b tagging and bb mass resolution, and exquisite control of background shapes

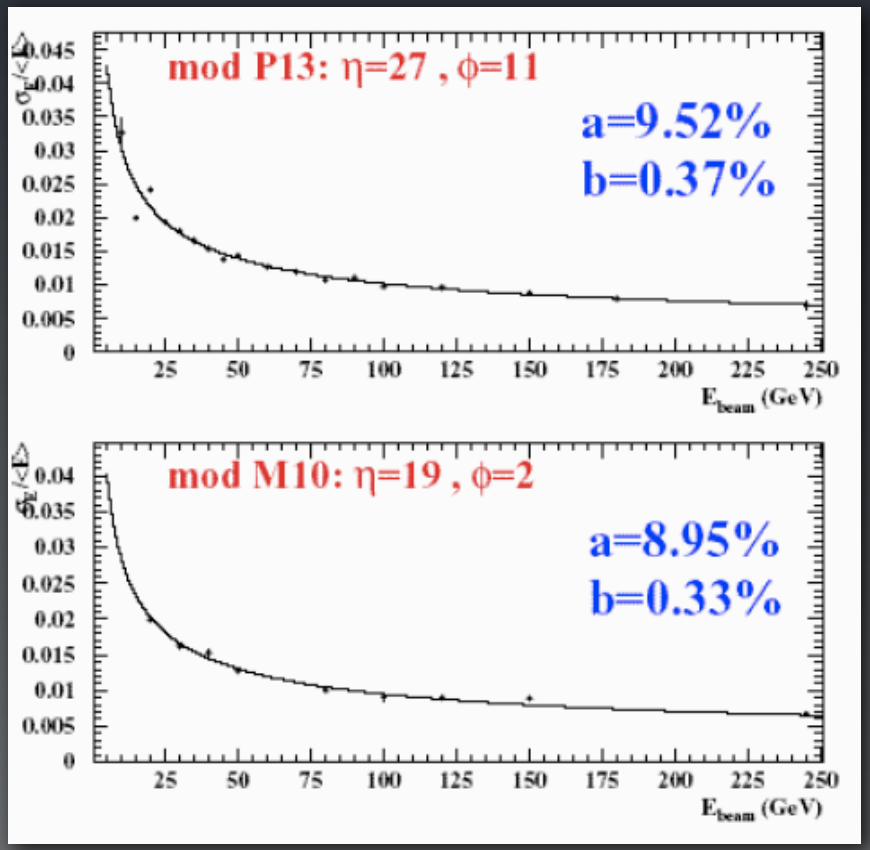
SUSY/Higgs Workshop ('00), Higgs Sensitivity Study ('03)

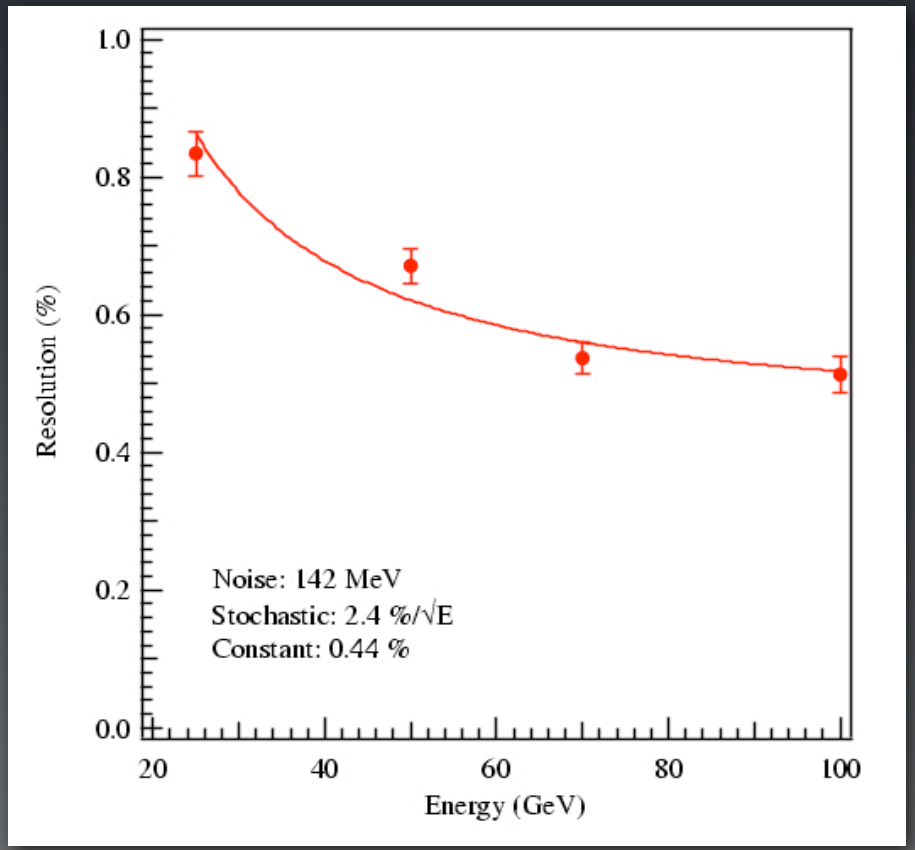


Still represents our best hope in ~1-2 years



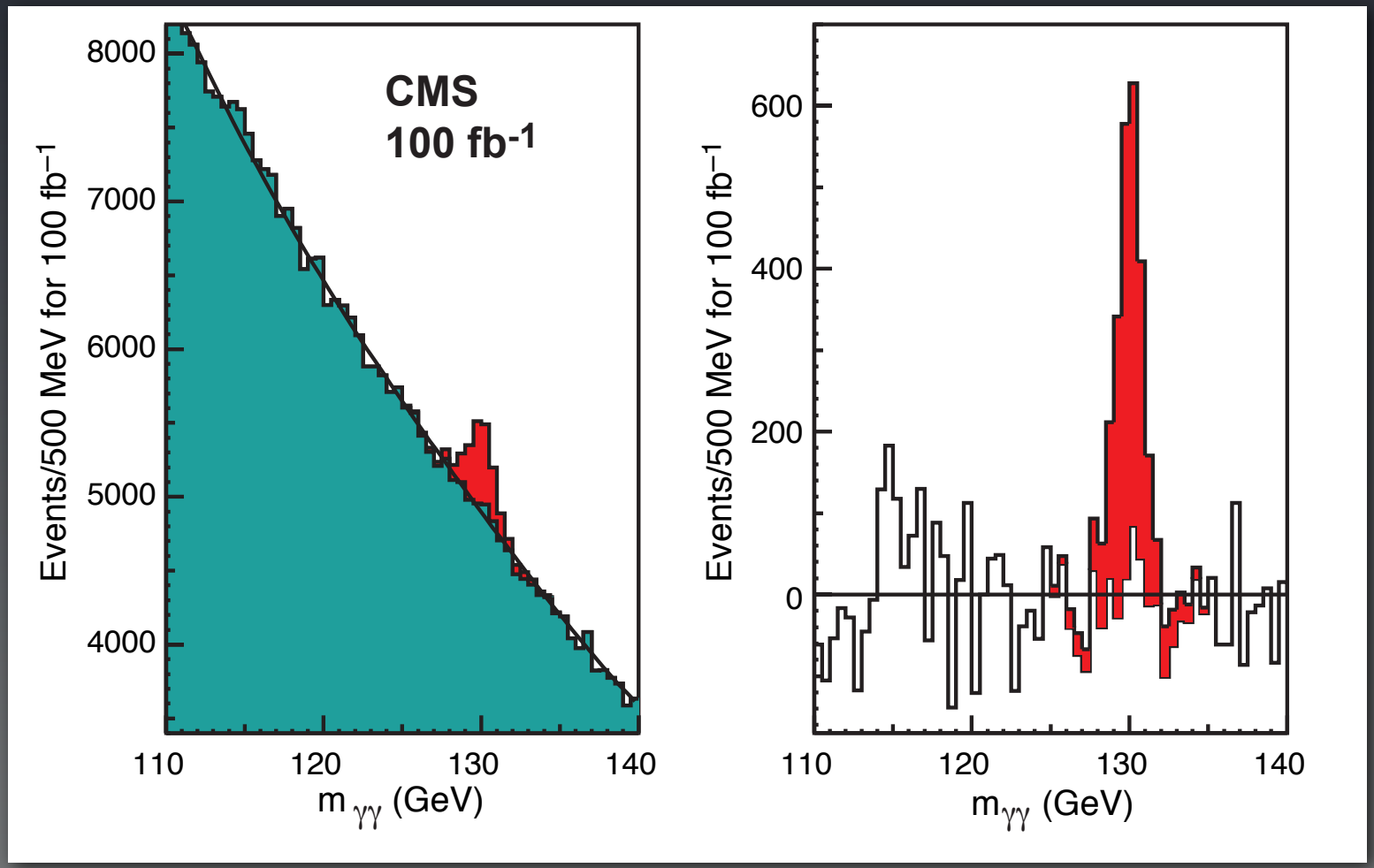
- gluon fusion dominates at LHC
- at 10^{33} luminosity, ~4000 H/day (120 GeV)
- can consider using γγ final state



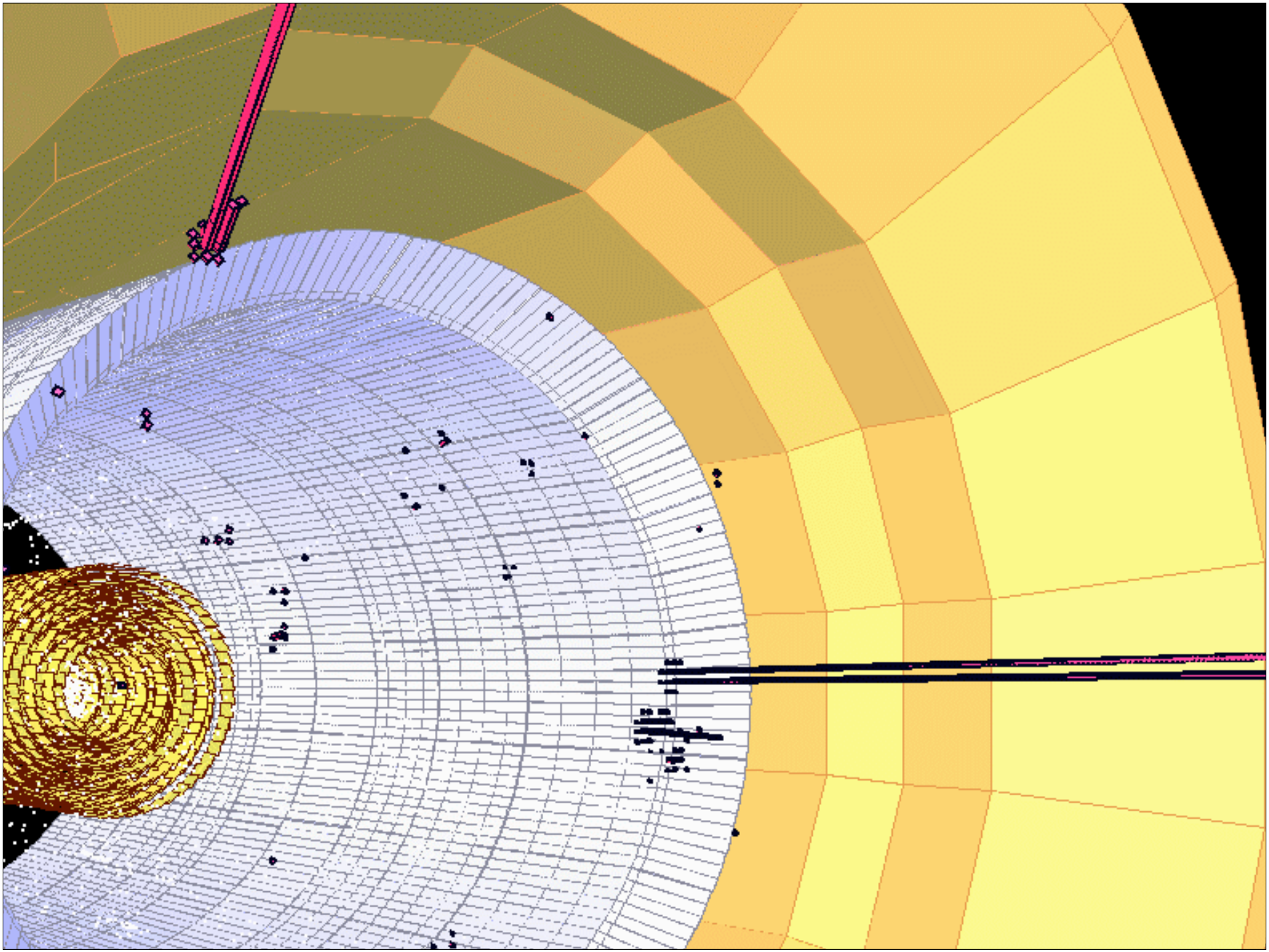


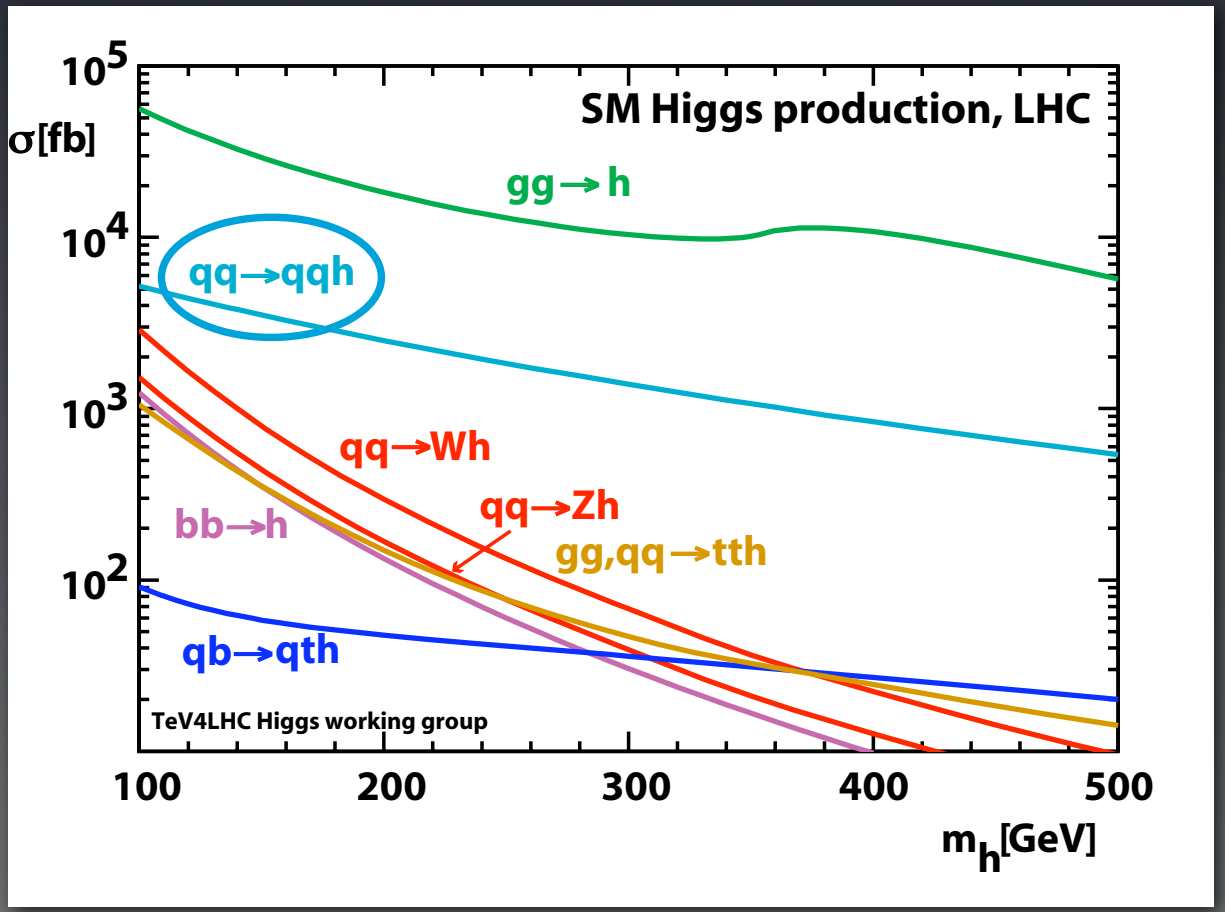
ATLAS: liquid Ar CMS: $PbWO_4$ crystals

→ both experiments will have ~0.5% resolution



- H→γγ signal on falling background
- get 5σ with less than 10 fb^{-1}

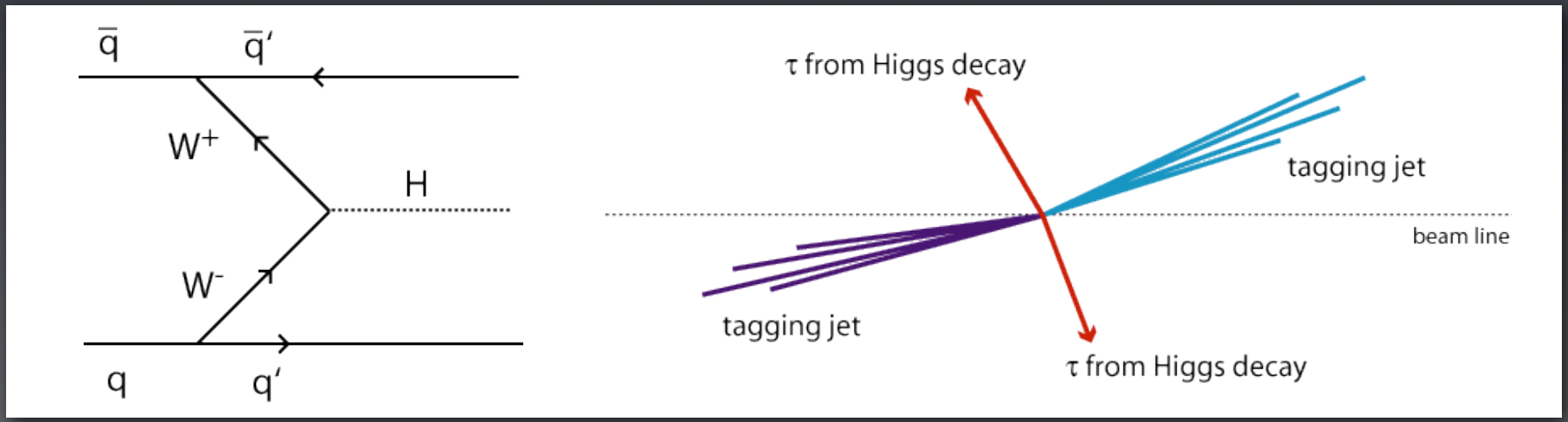




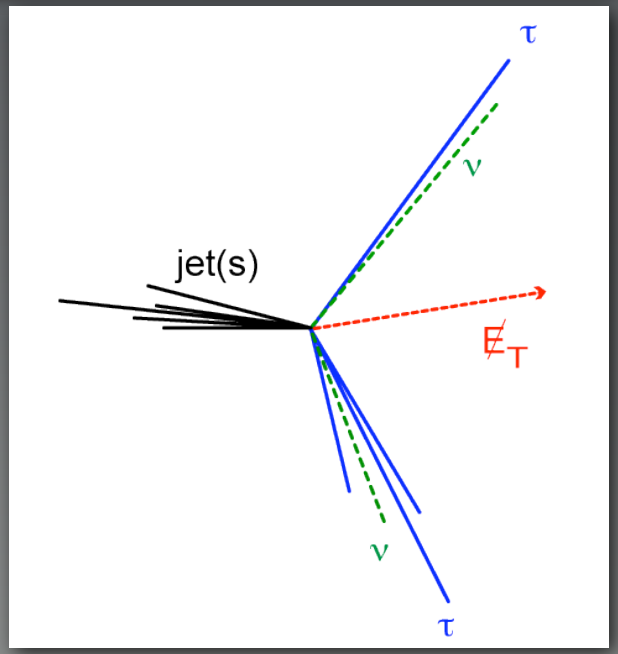
Second largest production mode at LHC:

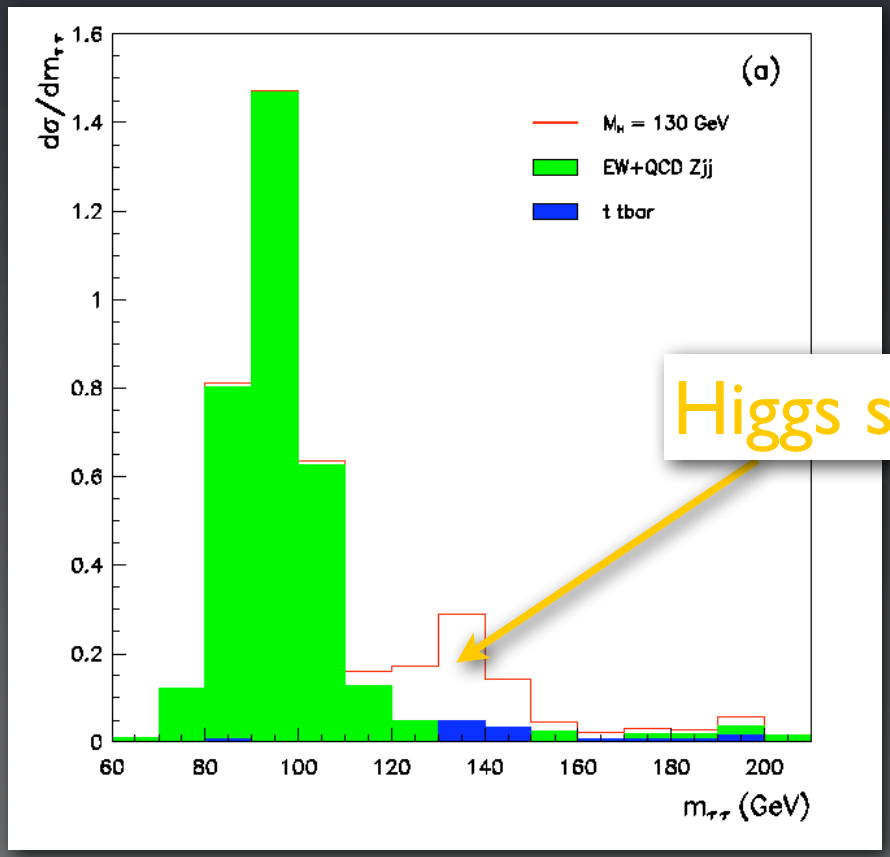
Vector Boson Fusion (VBF)

Use forward "tagging jets" to help trigger



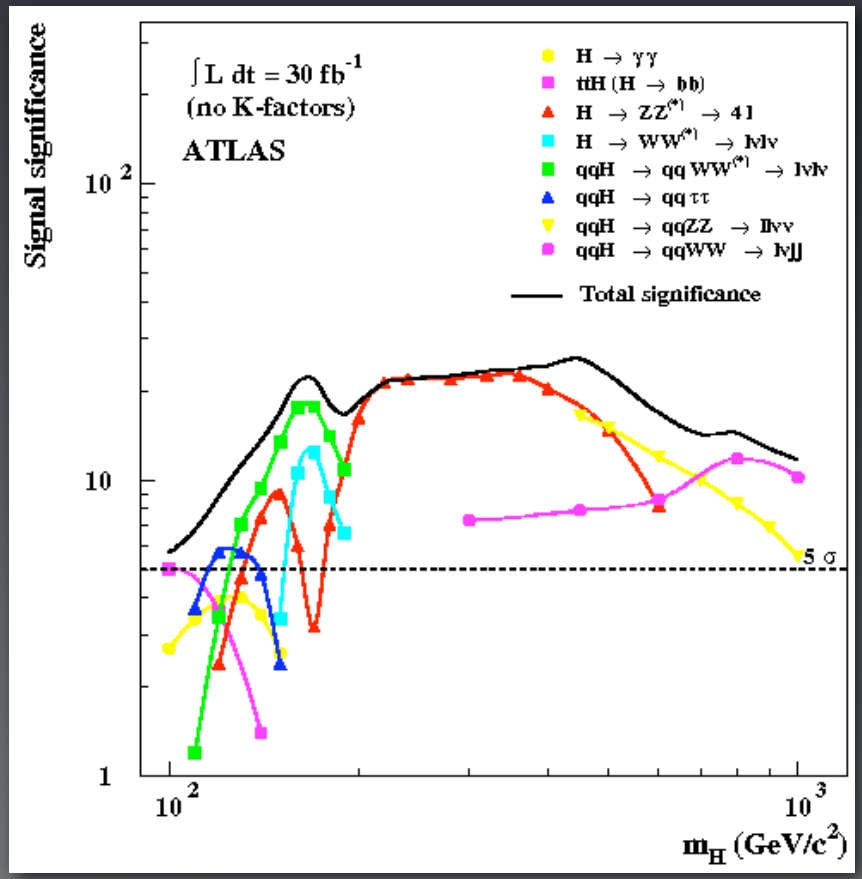
- most sensitive final state: tau pairs
- large background from $Z \rightarrow \tau\tau$
- can reconstruct tau pair mass

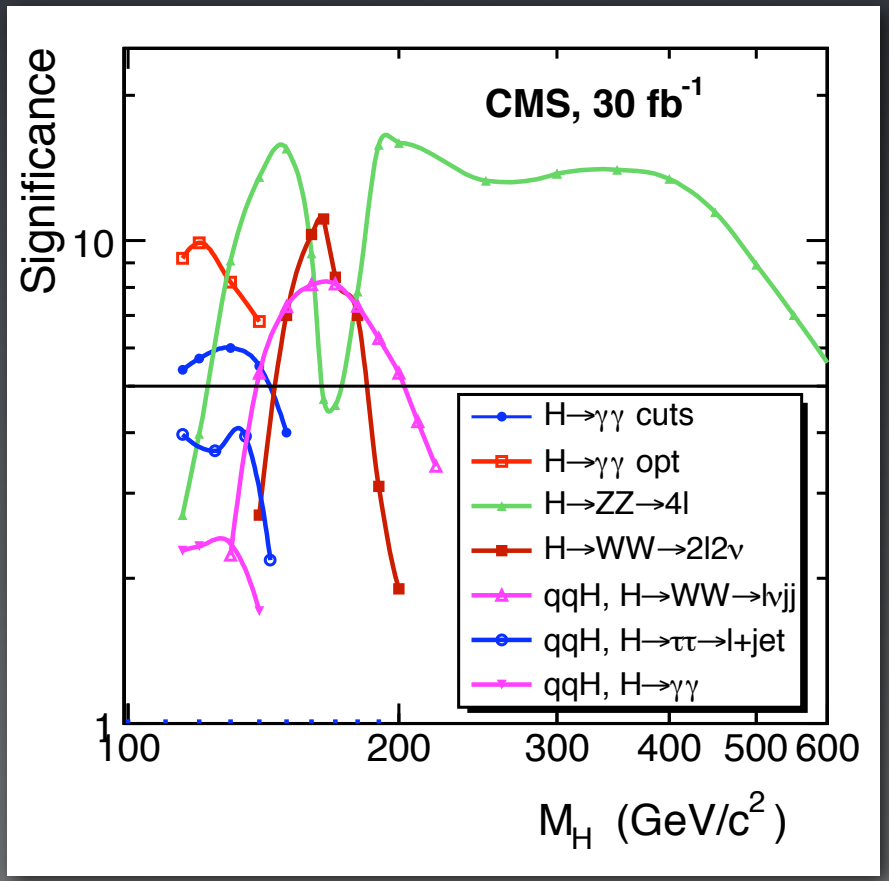




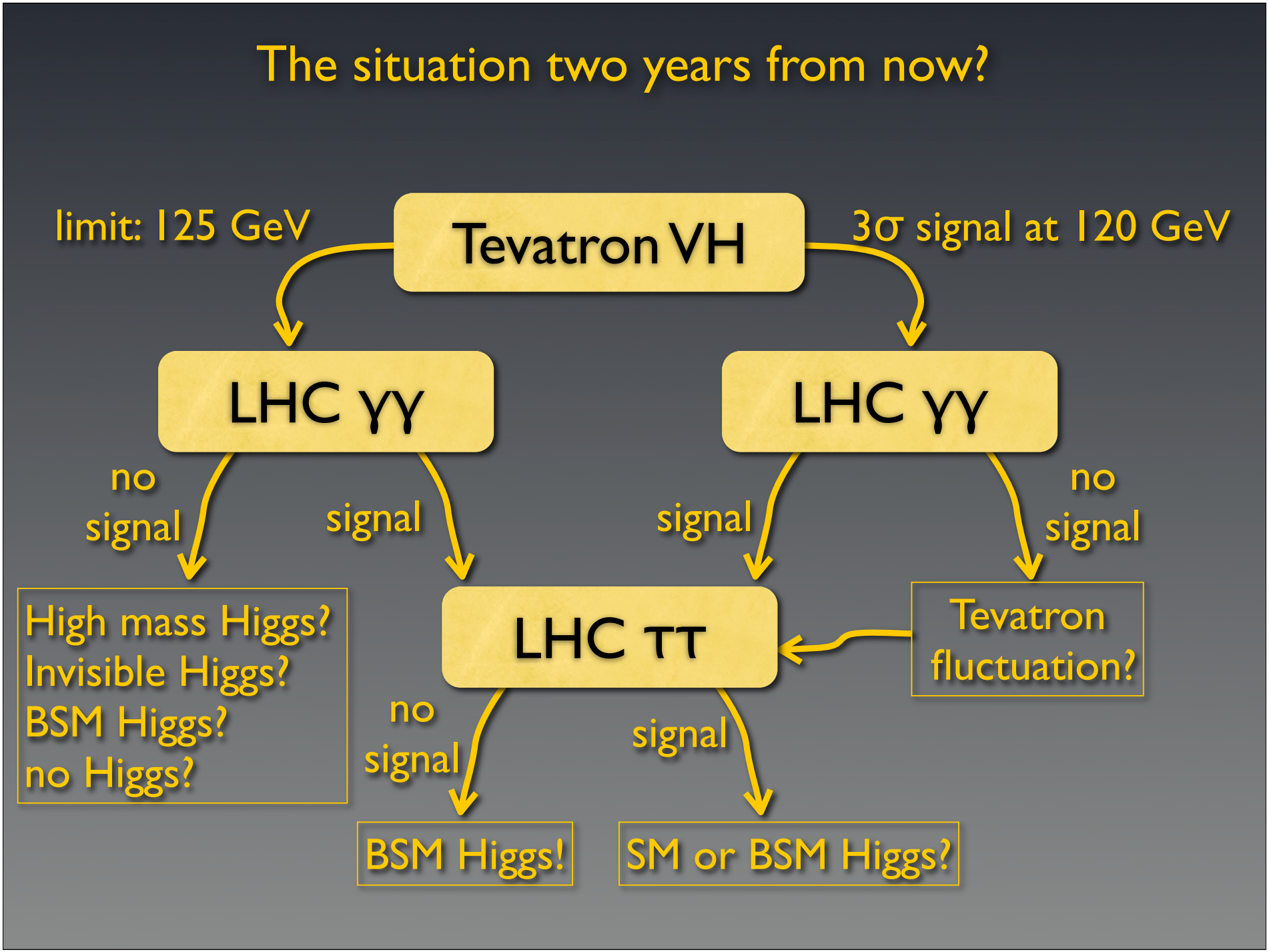
- ability to discriminate Higgs from Z depends on excellent missing p_T resolution

LHC SM Higgs Sensitivity

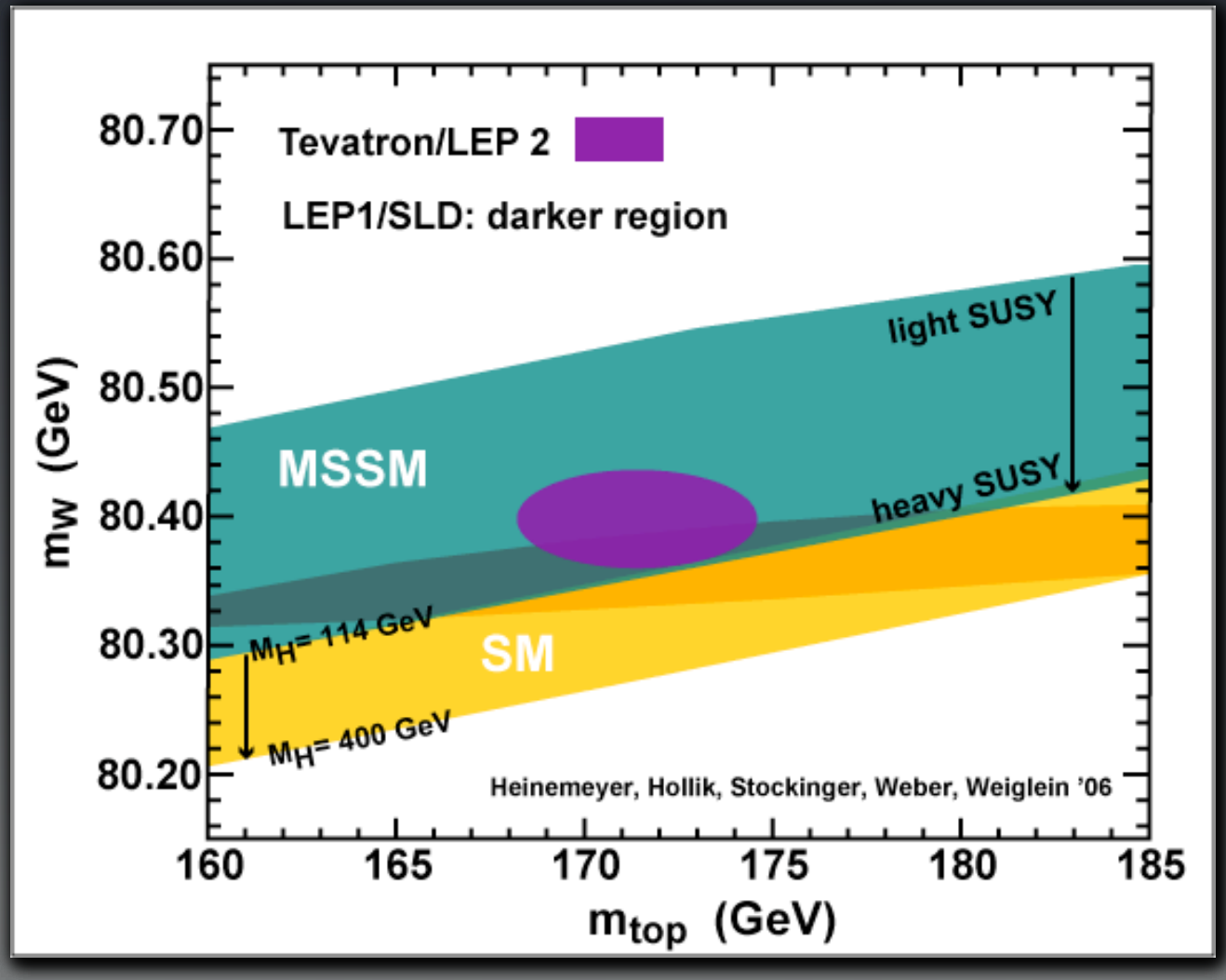




- γγ mode wins at low mass: need < 10 fb^{-1}
- VBF ττ mode not far behind


The situation two years from now?
limit: 125 GeV
Tevatron VH
3σ signal at 120 GeV
LHC γγ
LHC γγ
no signal
signal
signal
no signal
High mass Higgs?
Invisible Higgs?
BSM Higgs?
no Higgs?
LHC ττ
Tevatron fluctuation?
no signal
signal
BSM Higgs!
SM or BSM Higgs?

- The Tevatron will give us a hint
- No matter what, the first question at the LHC is whether we see a $\gamma\gamma$ signal
- Whether we see a $\gamma\gamma$ signal or not, we must then look for a ditau signal
- Whatever we find in the ditau channel, we still have years of work to determine if it's a SM Higgs or not - need to measure couplings
- LHC may not be able to answer the question!
- only ILC can measure Higgs couplings accurately enough

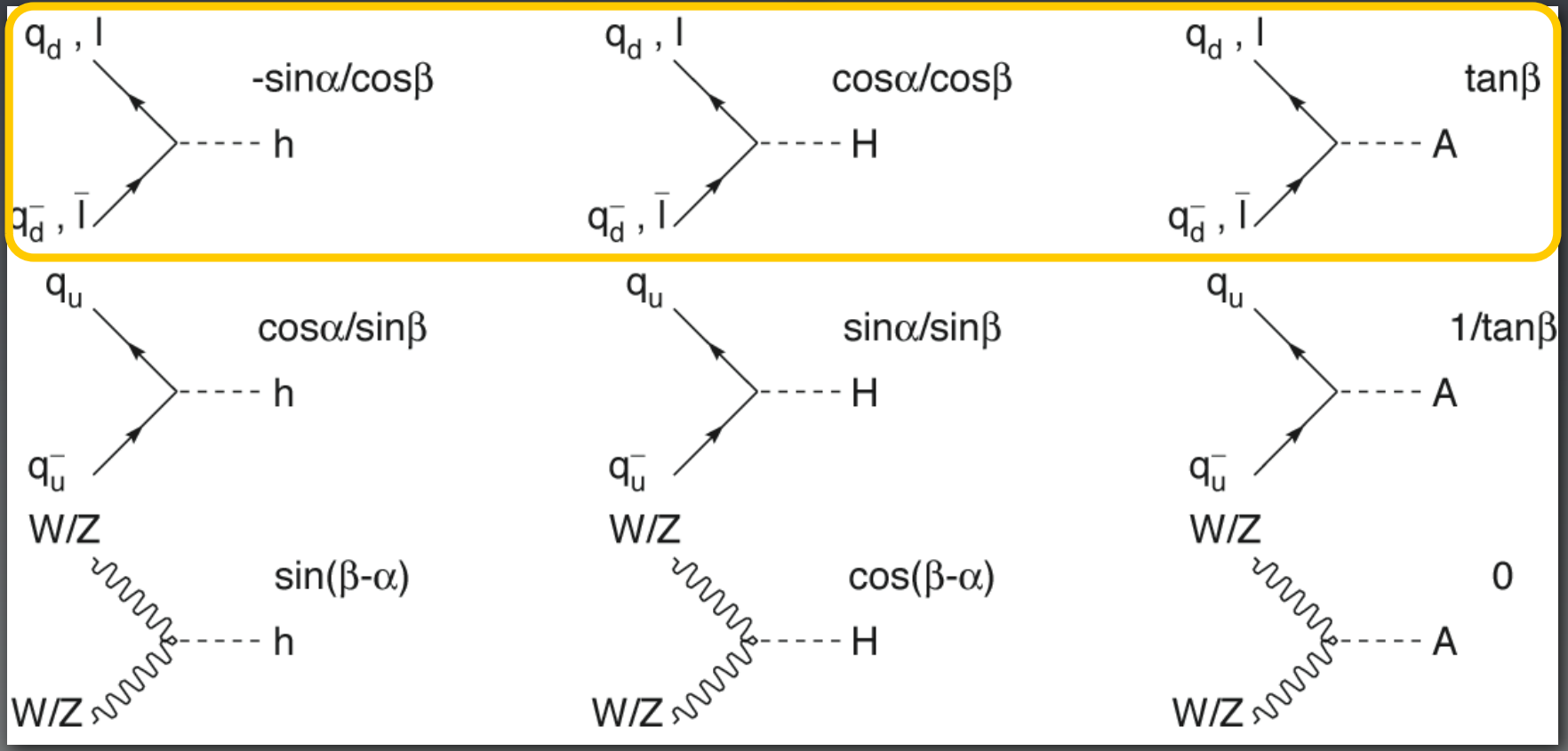


- new top, W masses from Tevatron push SM Higgs mass lower...favors MSSM

2. Is it the MSSM Higgs?

MSSM: two Higgs doublets ⇒ h, A, H, $H^{\pm}$

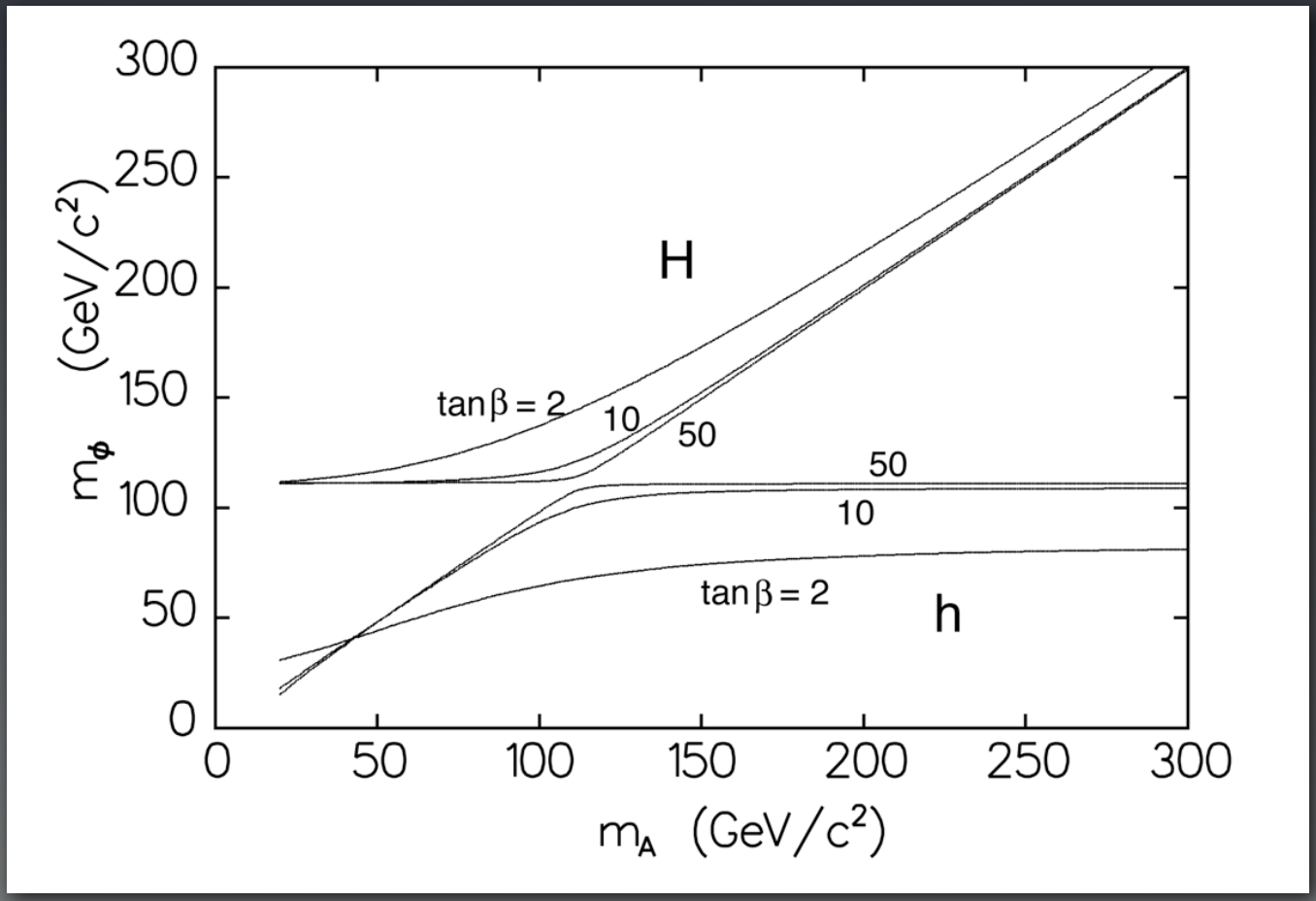
m_A, $\tan\beta = v_2/v_1$ govern masses



$\tan\beta \sim m_t/m_b$ ⇒ top row enhanced

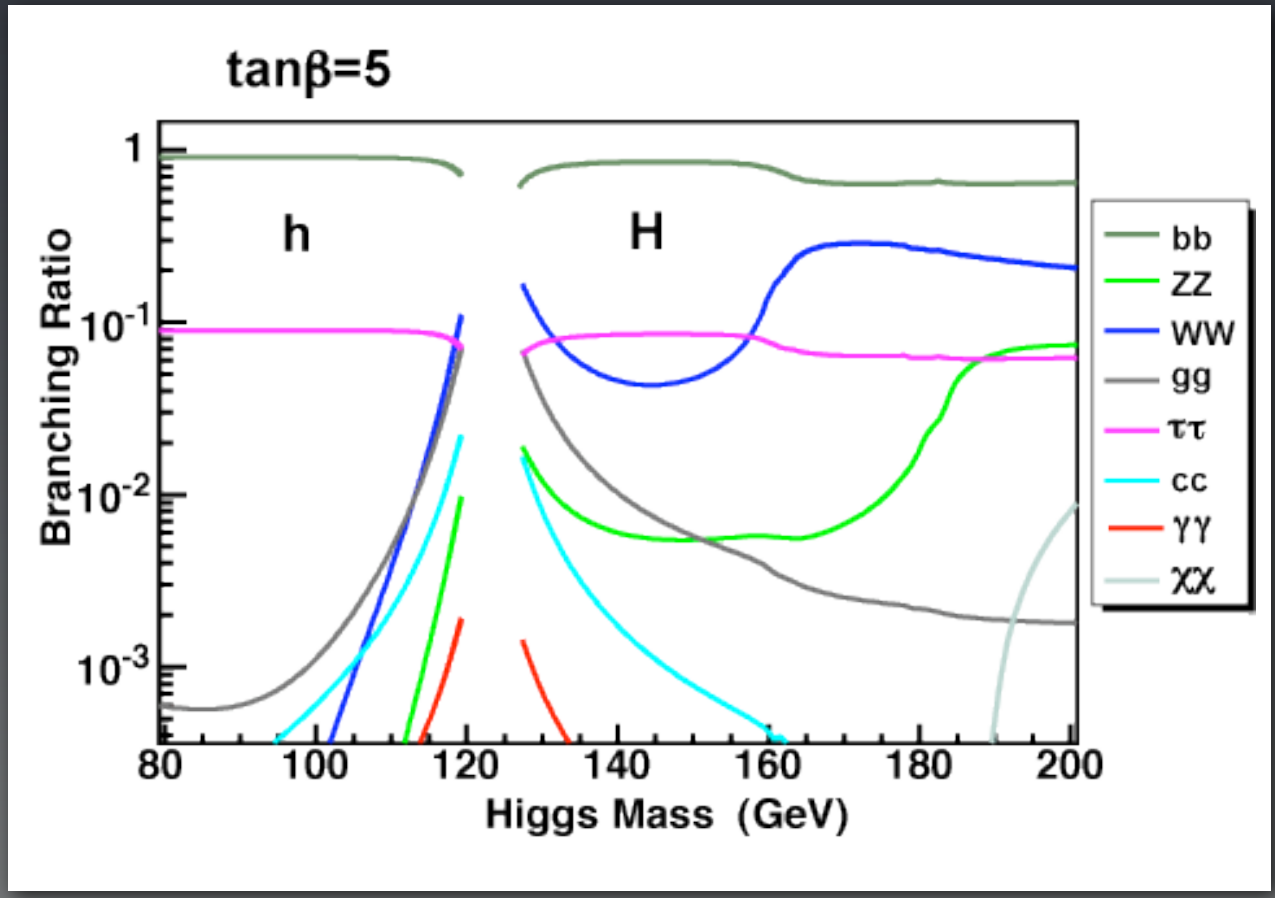
light h can be very SM-like!

MSSM h, H masses

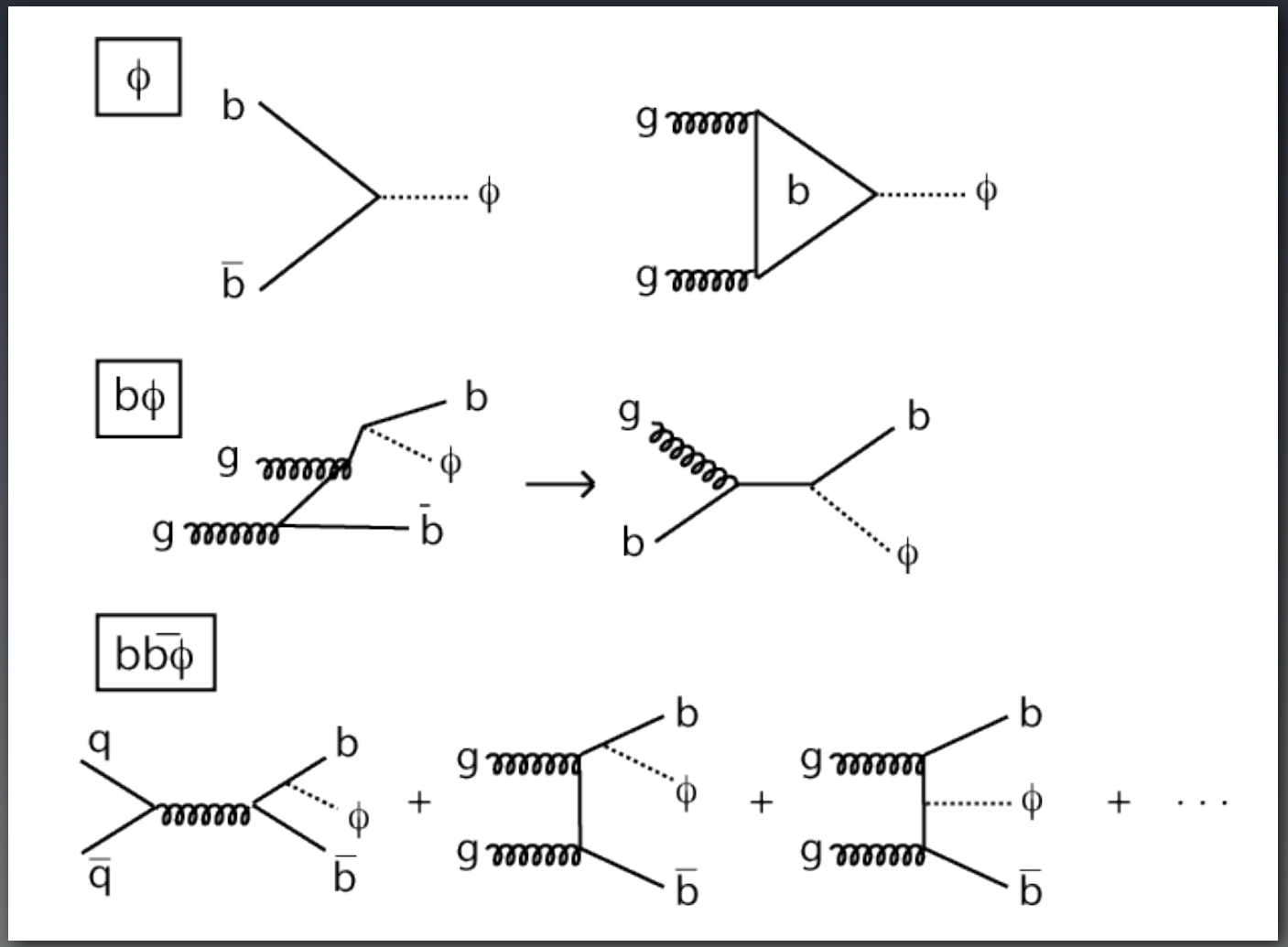


As m_A increases, it is nearly degenerate with either h (at low m_A) or H (at high m_A)

MSSM h, H branching ratios

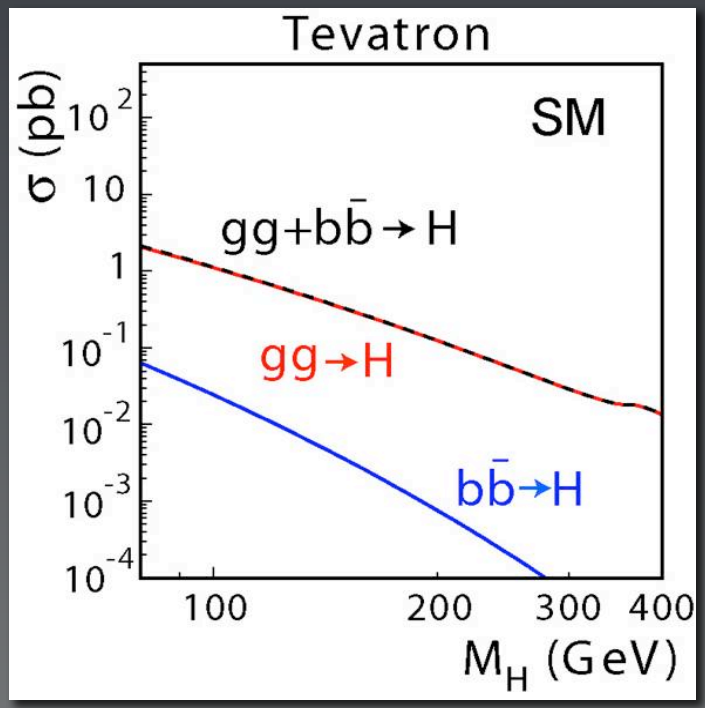


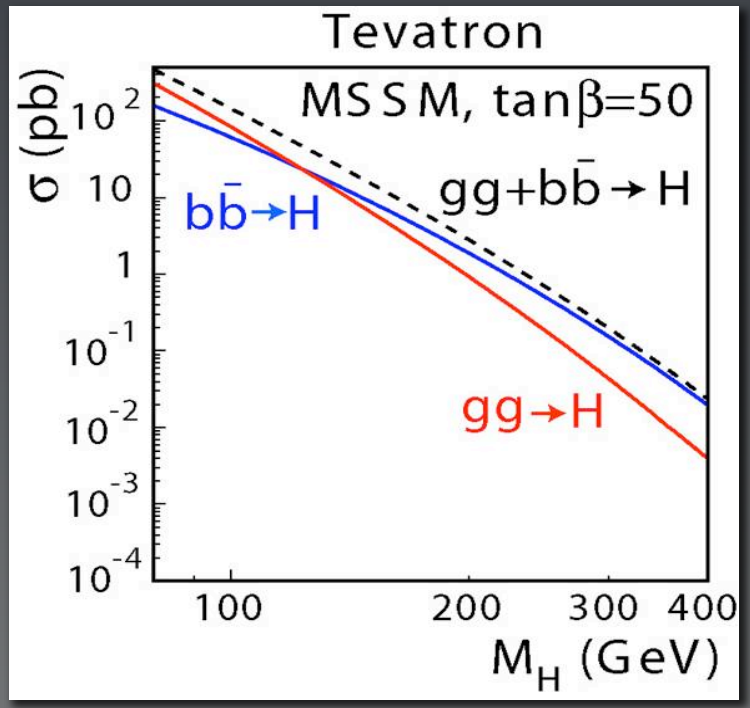
- bb and ττ BRs stable at ~90% and ~9% respectively
- γγ BR is very m_A-dependent!



- all of these are enhanced like $\tan^2\beta$
- can look for $\phi \rightarrow$ bb or $\tau\tau$
- Tevatron and LHC have sensitivity

Tevatron MSSM Higgs production





⇒ large tanβ puts Tevatron into the ~10 pb range

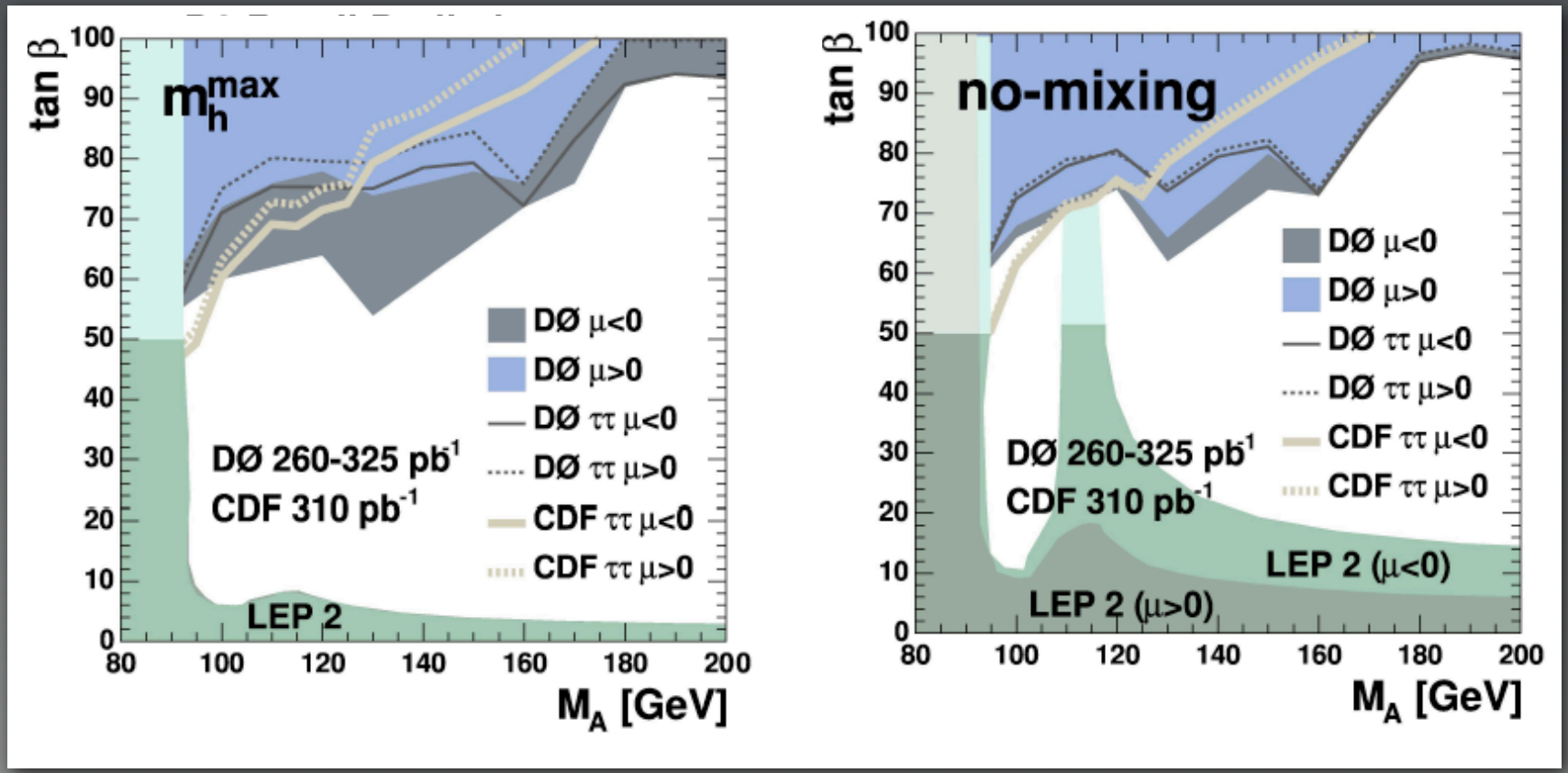
MSSM Higgs results until end 2006

LEP 2

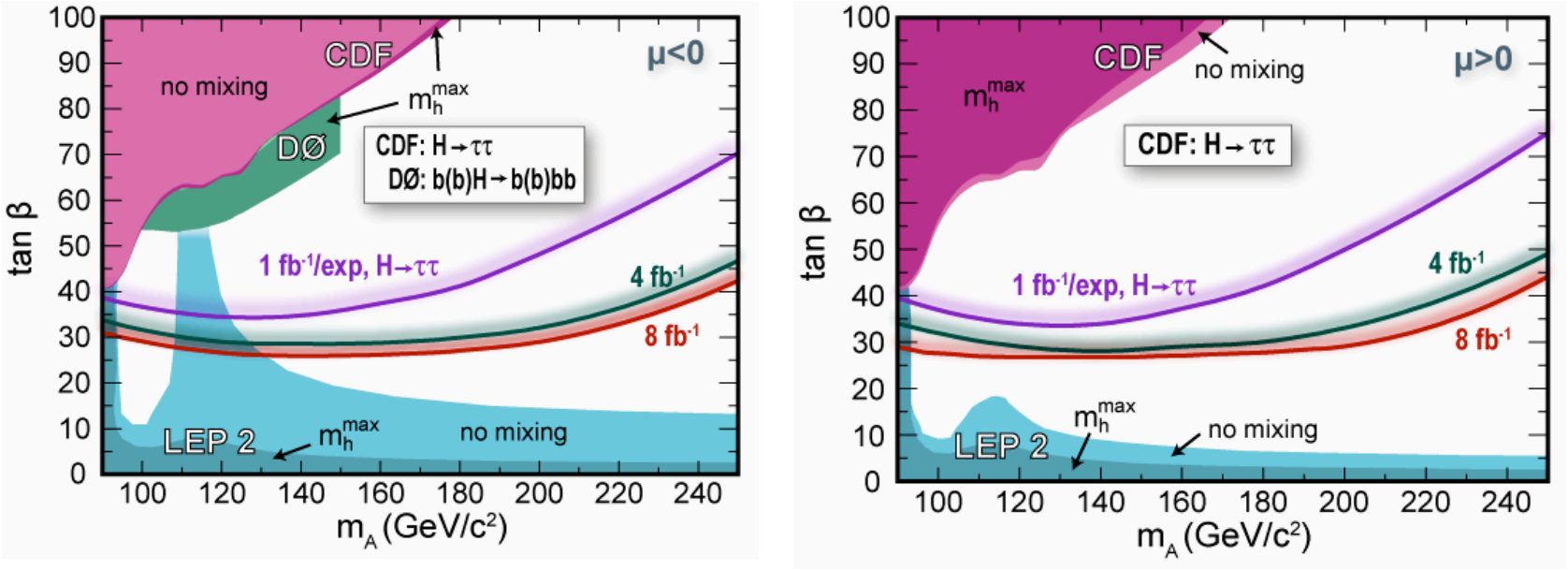
CDF $\tau\tau$ search, 310 pb^{-1}

D0 $\tau\tau$, $\tau\tau b$ search 350, 288 pb^{-1}

D0 bbb(b) search 950 pb^{-1}

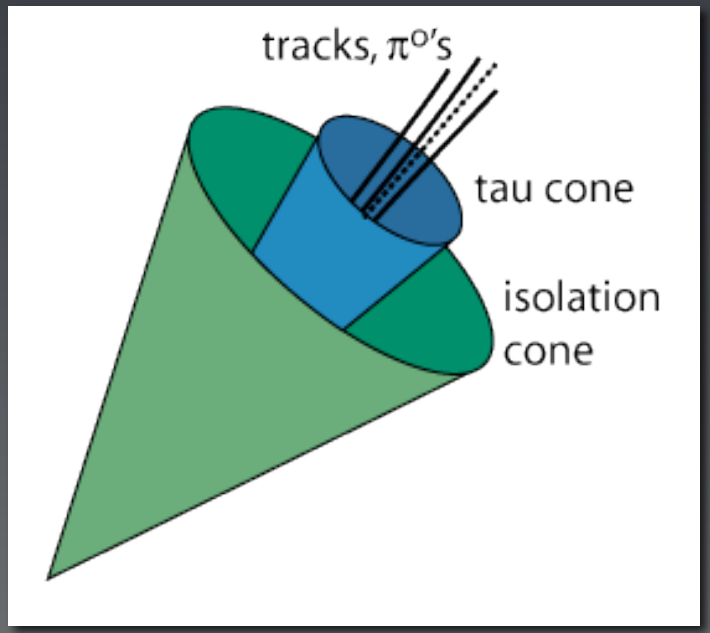


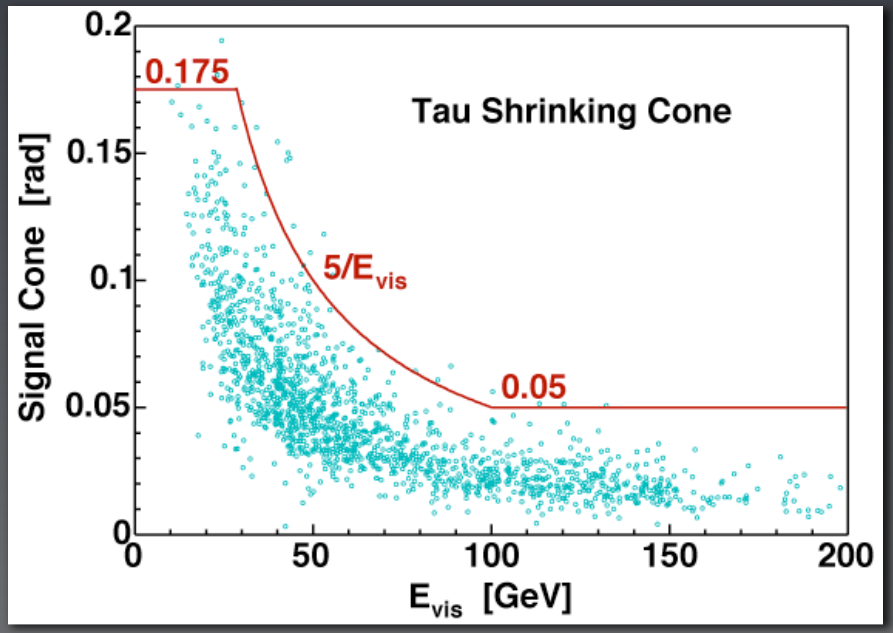
CDF observed, expected sensitivity



CDF: ττ result updated to 1 fb^{-1}

Tau Reconstruction in CDF

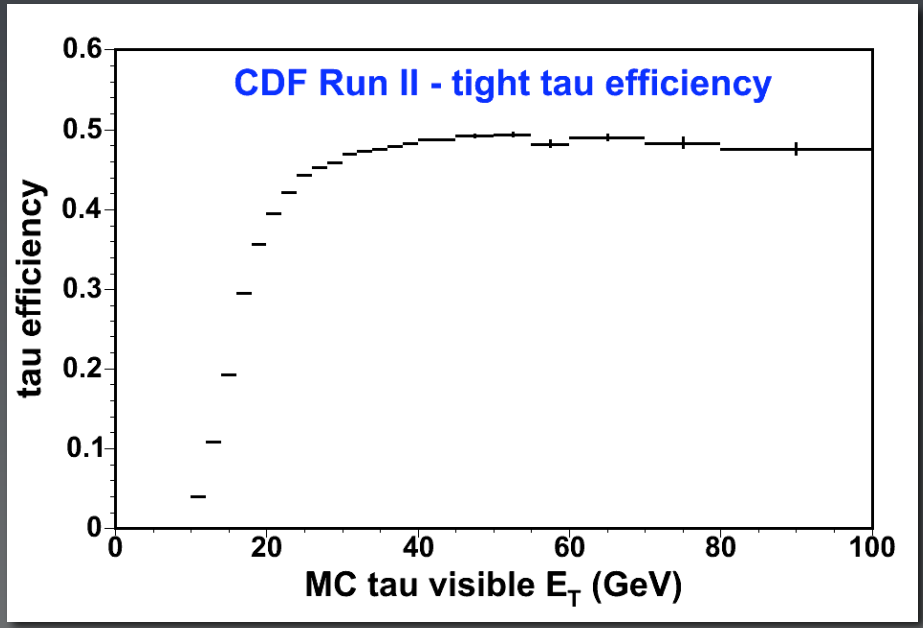


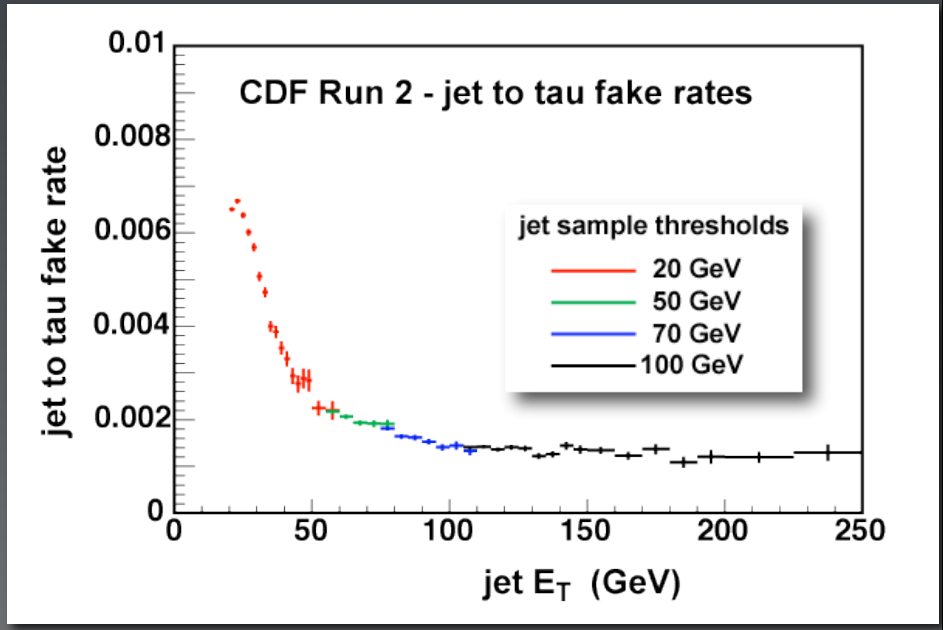


Cone-based algorithm: reconstruct hadronically decaying taus from $\pi^{\pm}$ and π^{o}

Demand no activity in isolation annulus to dosctriminate against jets

CDF tau ID performance

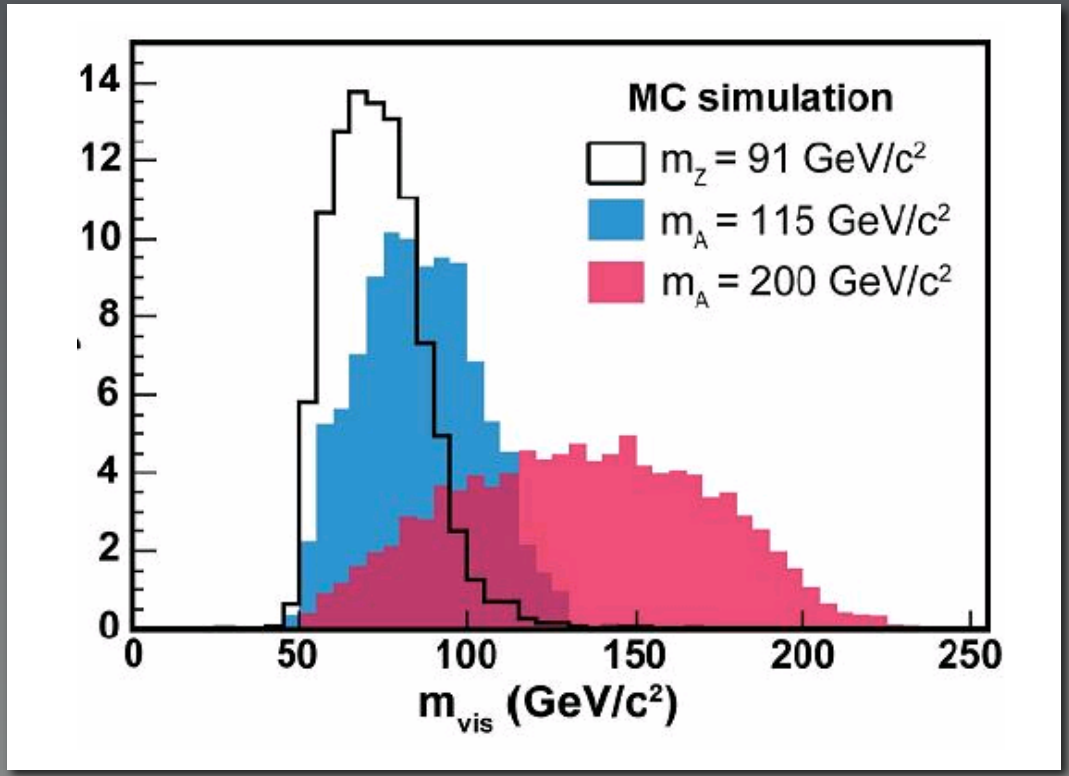




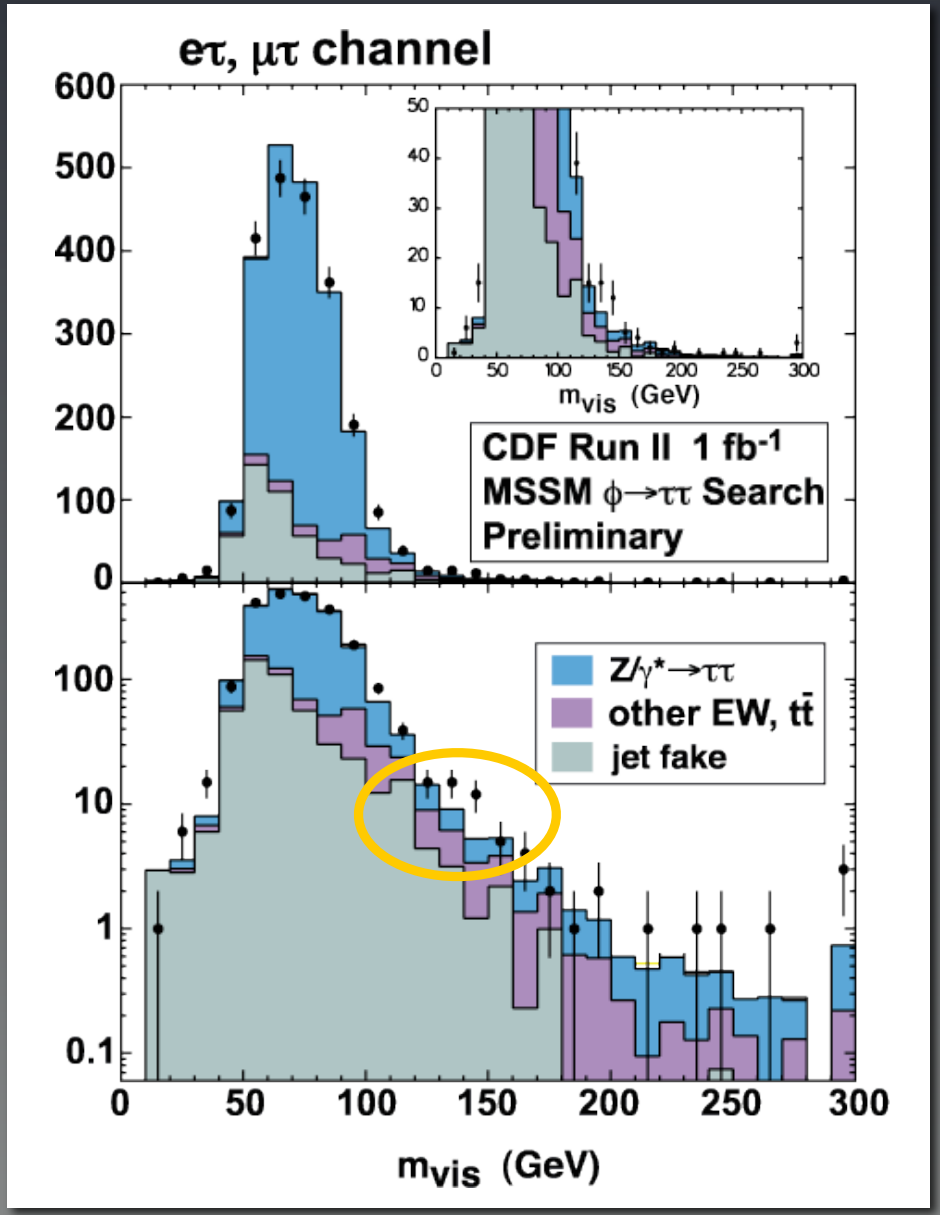
efficiency

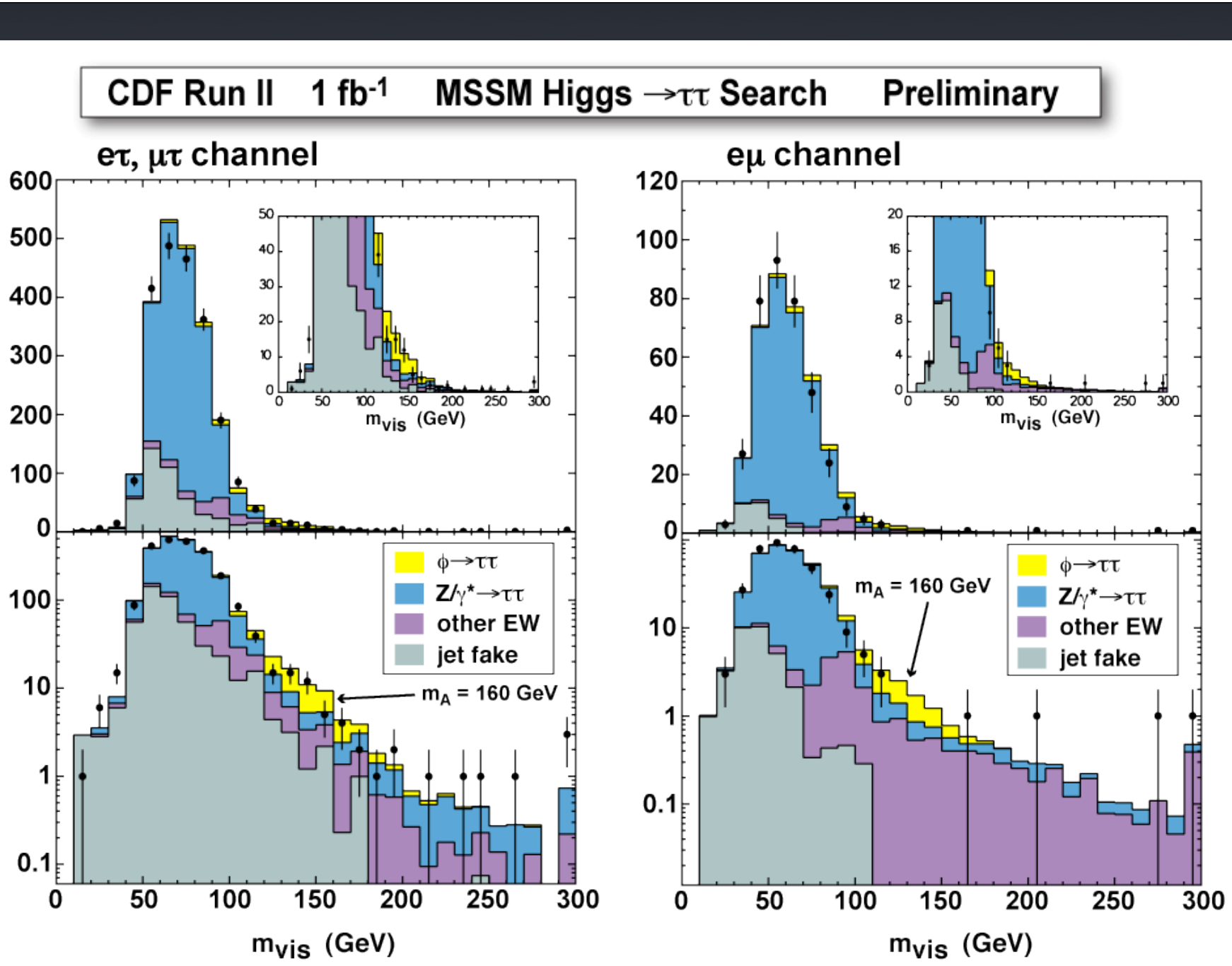
jet → tau fake rate

- select events with e+τ, μ+τ, e+μ
- low thresholds: 10/20 GeV (ℓτ), 6/8 GeV (eμ)
- to discriminate against Z background we use "visible mass" ($\ell + \tau + \not{E}_T$)

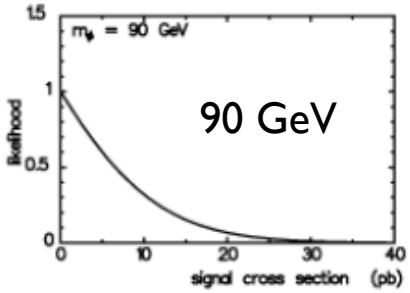


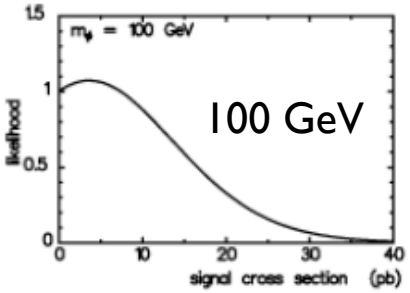
- performed analysis "blind" with respect to setting cuts, method, etc.
- opened the box in December and this is what we saw!

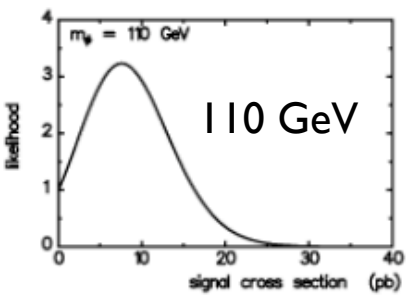


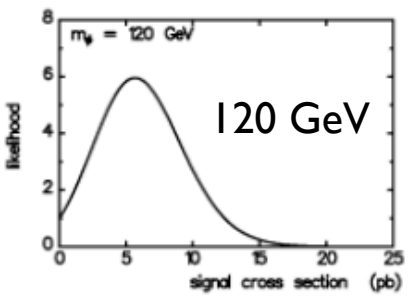

CDF Run II 1 fb-1 MSSM Higgs →ττ Search Preliminary
eτ, μτ channel
eμ channel
φ→ττ
Z/γ*→ττ
other EW
jet fake
mA = 160 GeV
mvis (GeV)

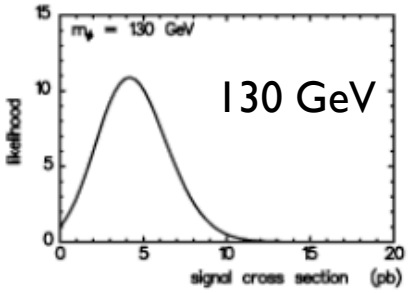
Likelihood versus Higgs cross section for different Higgs masses:

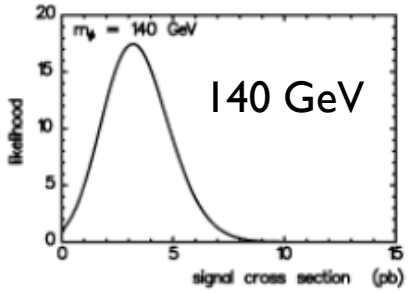


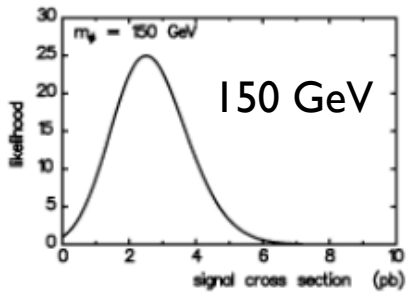


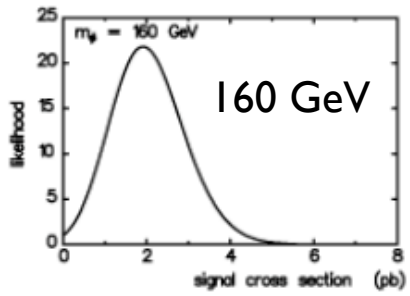


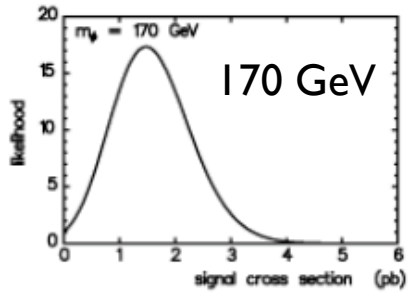


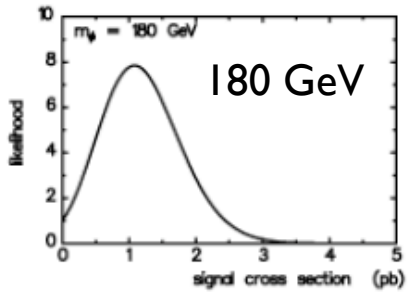


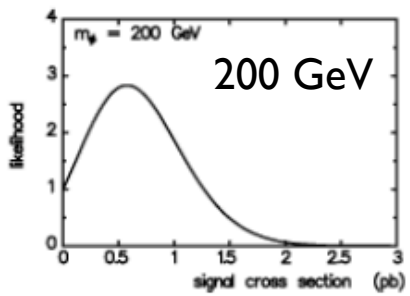


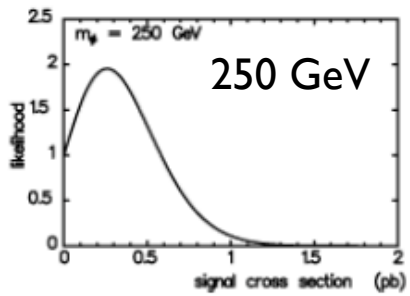




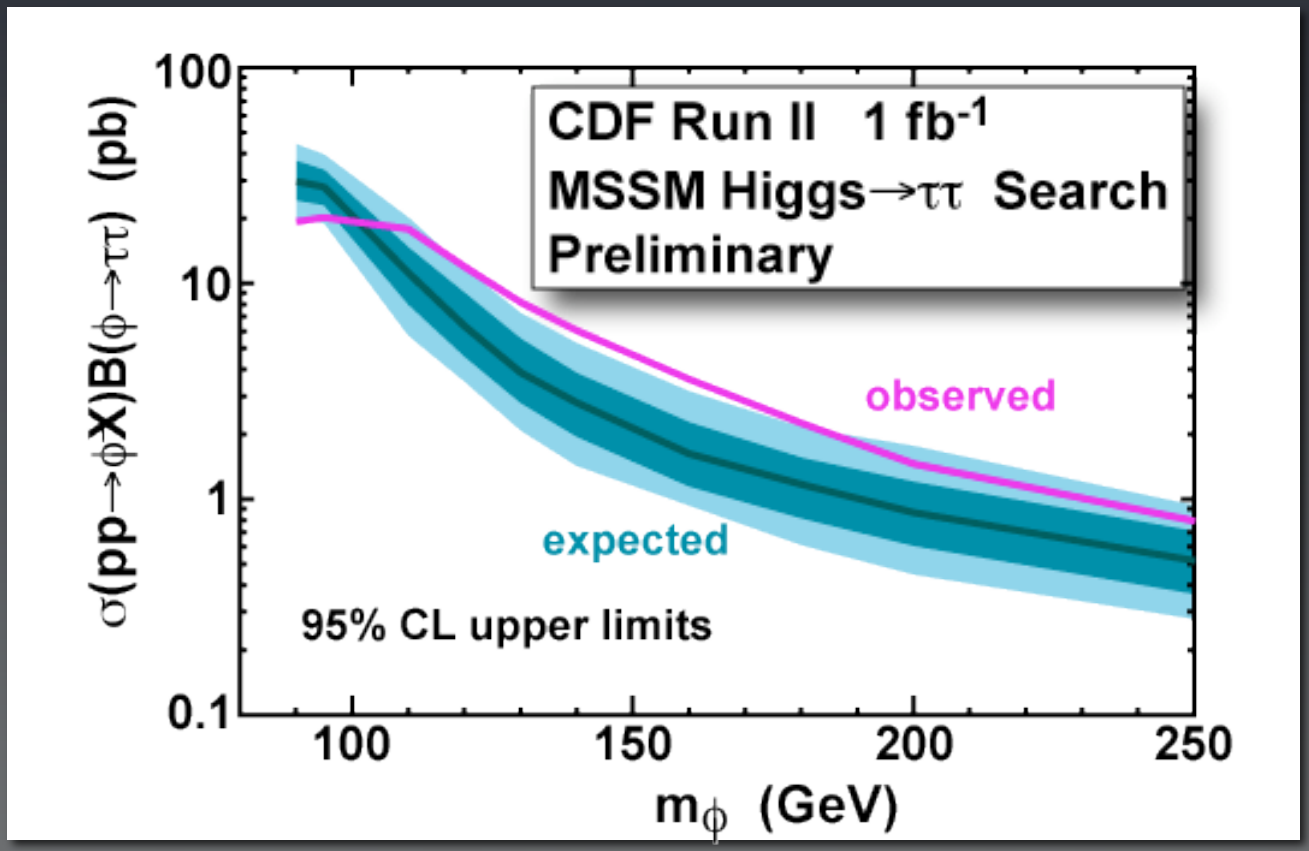




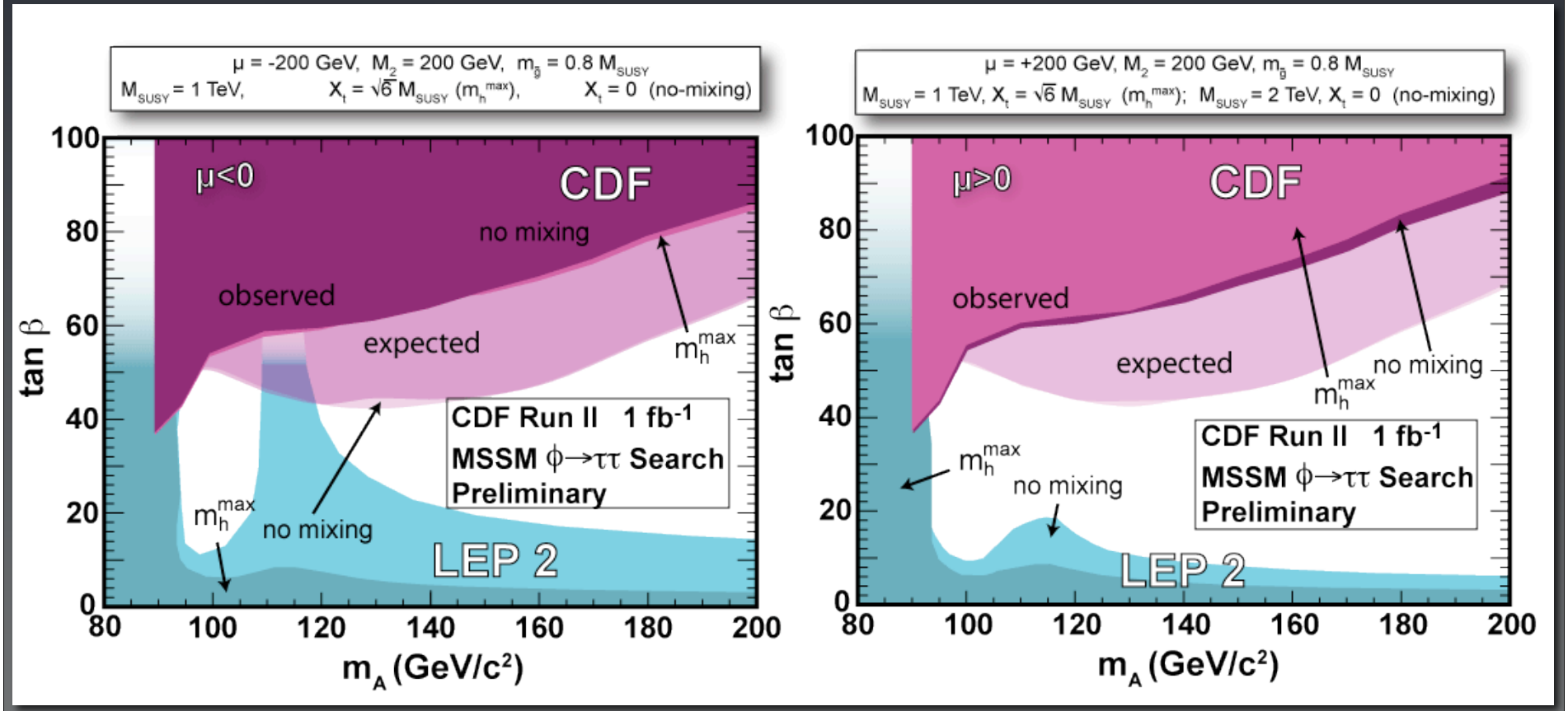




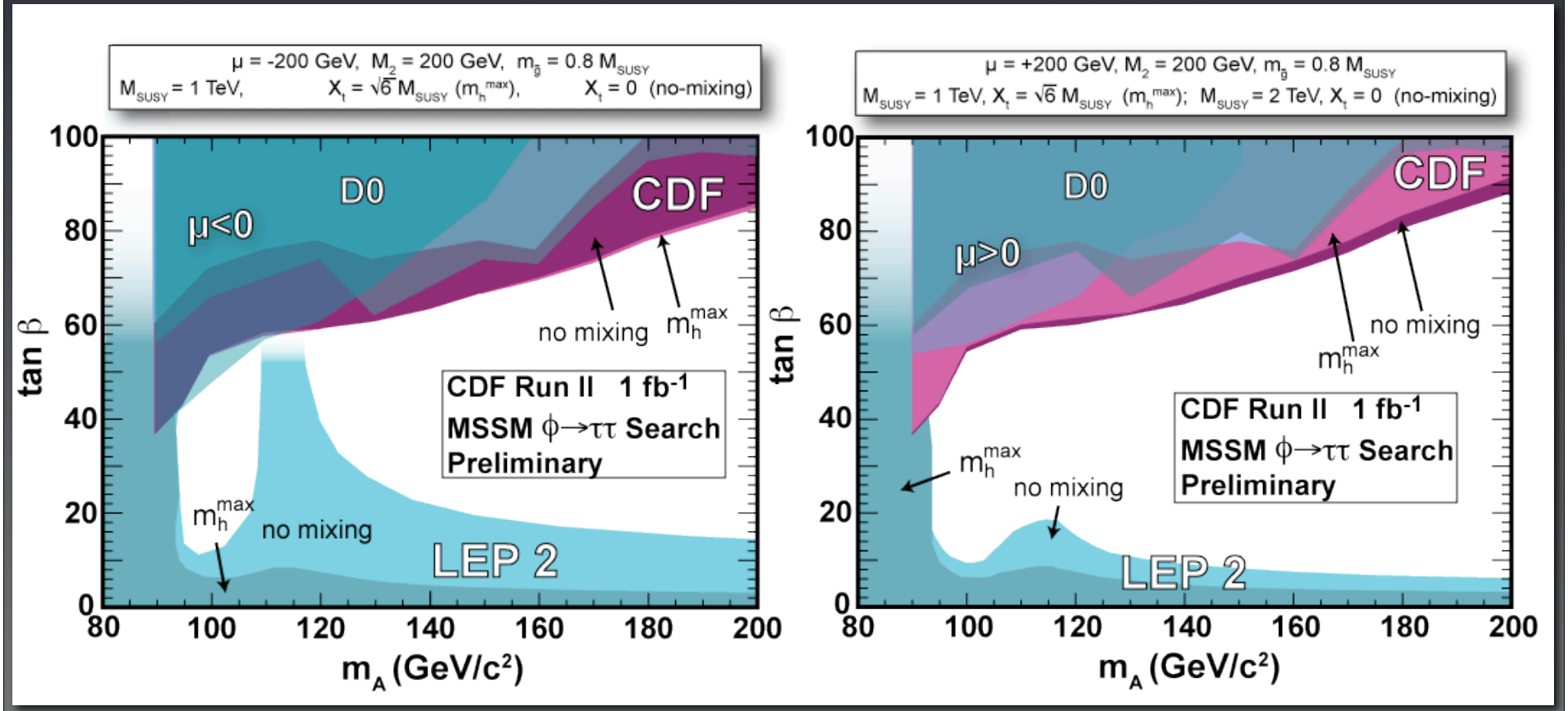
needless to say, this hurts our 95% CL limits...



- observed limits stray from expected (for no signal)
- have done many cross checks - everything looks fine!

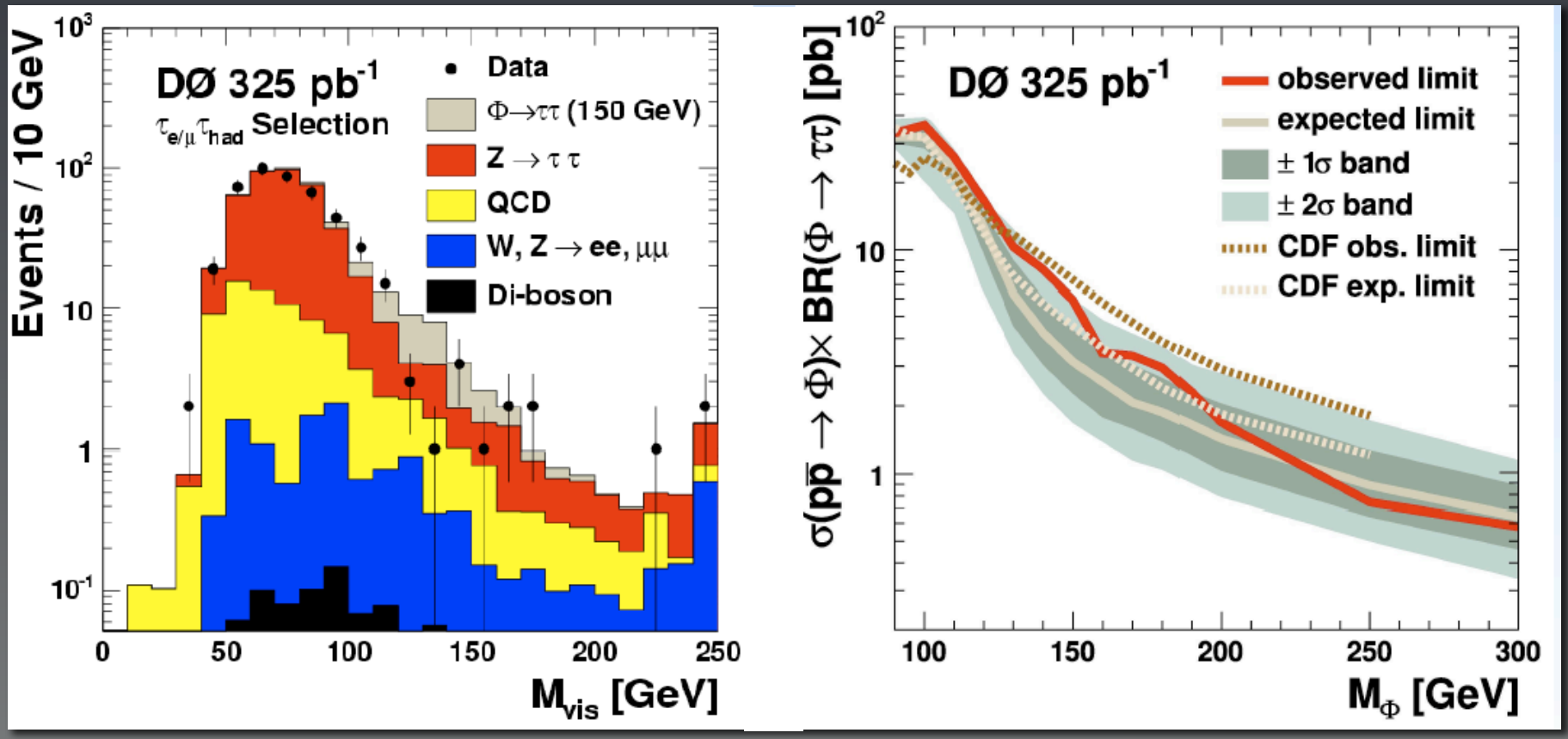


- obvious conclusion: more data!
- will have double this by summer
- working on ττb channel



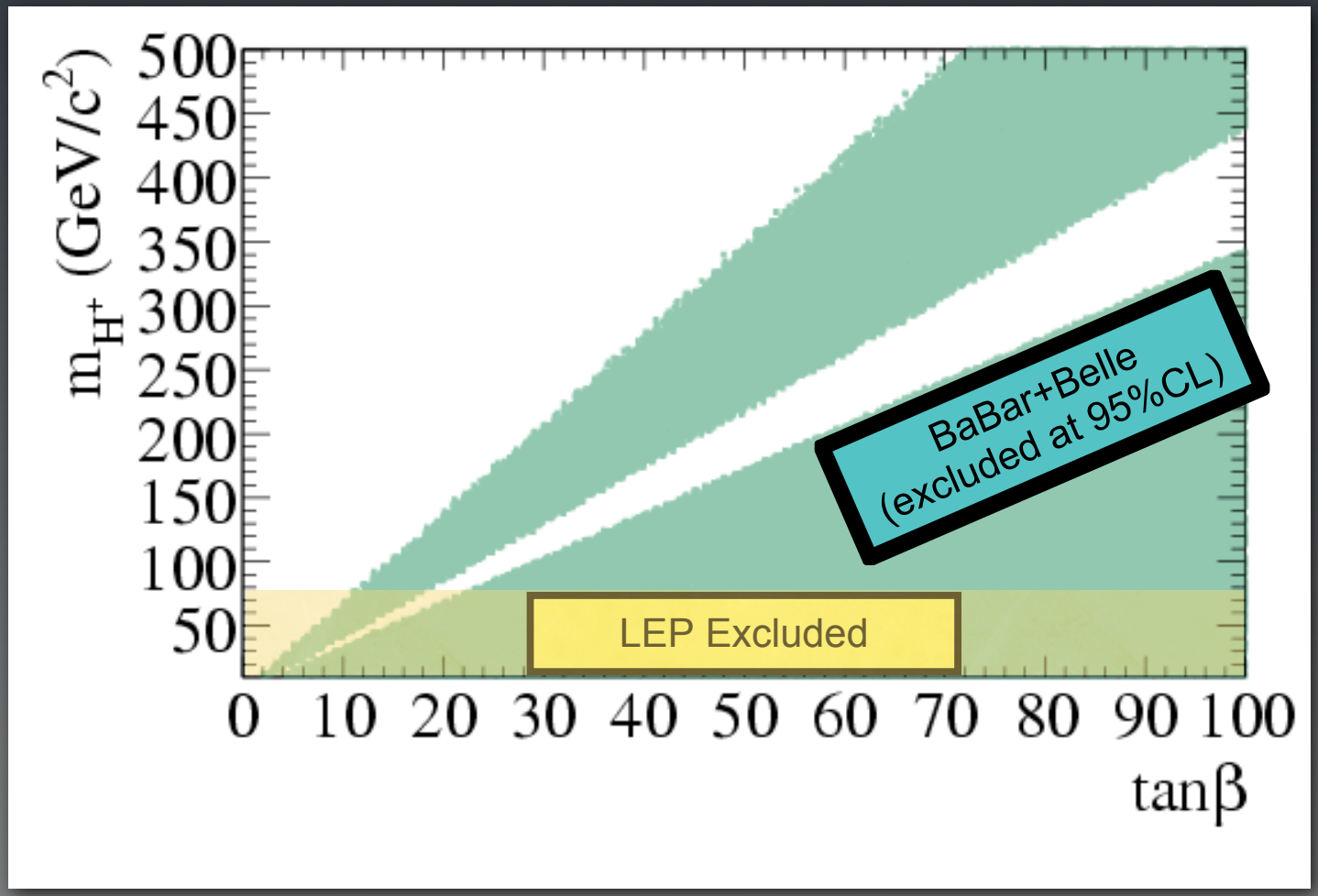
- obvious conclusion: more data!
- will have double this by summer
- working on ττb channel

D0 - 350 pb^{-1} eτ, μτ result



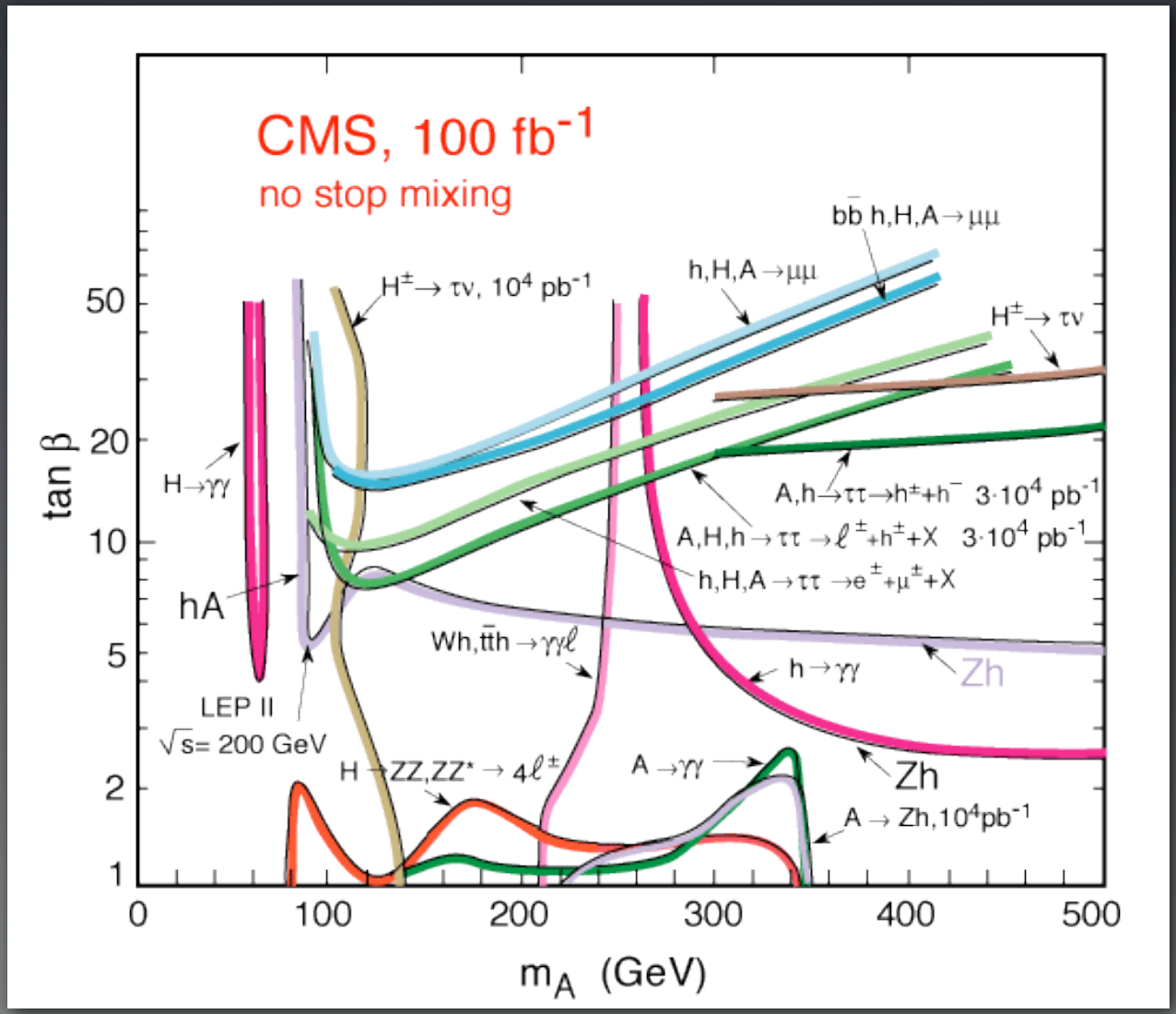
Looking forward to 1 fb^{-1} update!

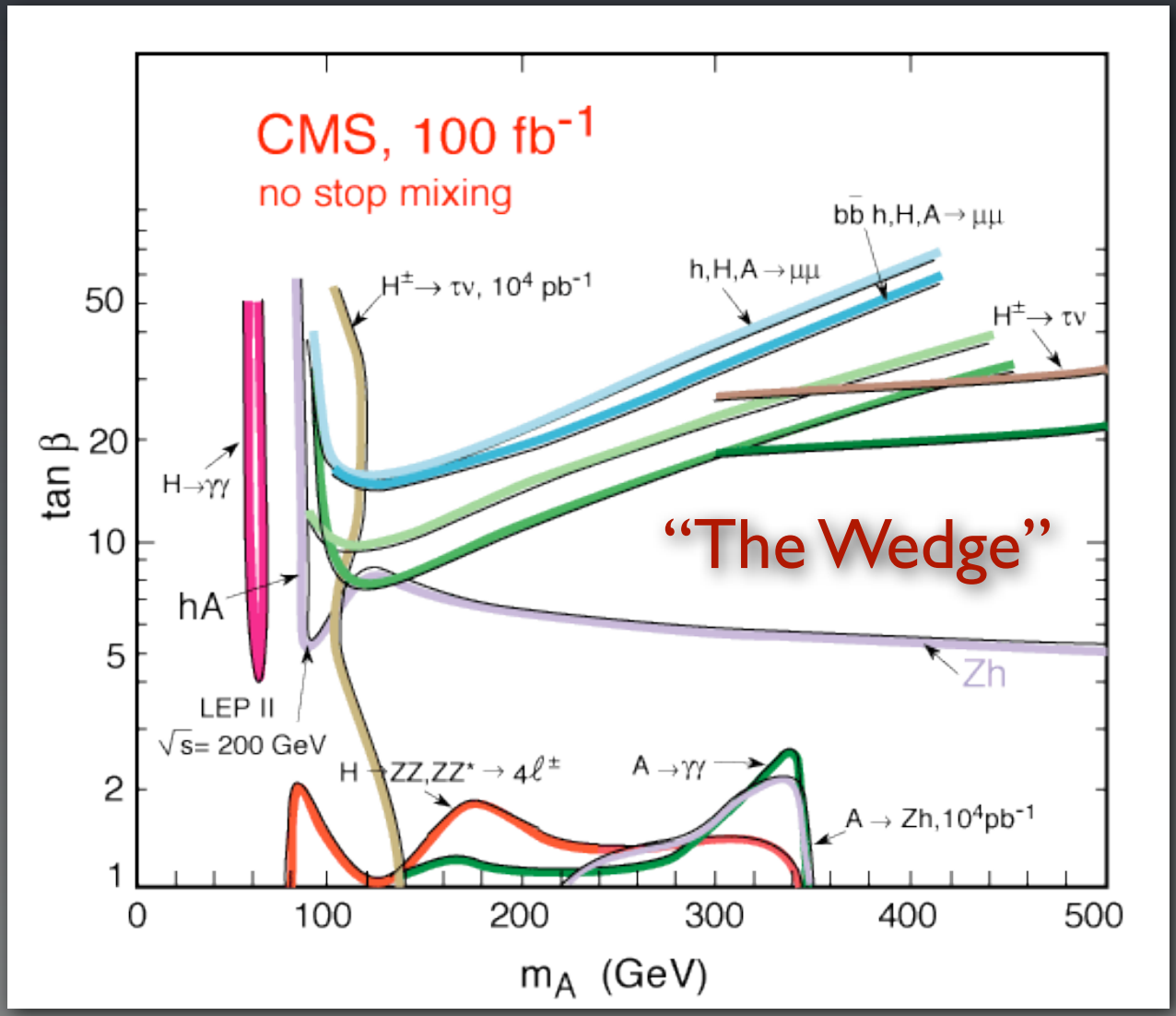
Belle and BaBar exclude charged Higgs via $B \to \tau\nu$



Paul Jackson (INFN Roma), DPF/JPS 2006

(See Marcela's talk later this week)


CMS, 100 fb-1
no stop mixing
bb̄ h,H,A→μμ
h,H,A →μμ
H±→ τν, 10⁴ pb⁻¹
H±→ τν
A,h→ττ→h±+h⁻ 3·10⁴ pb⁻¹
A,H,h→ττ→ℓ±+h±+X 3·10⁴ pb⁻¹
h,H,A→ττ→e±+μ±+X
H→γγ
hA
Wh,tt̄h→γγℓ
h→γγ
Zh
LEP II
√s= 200 GeV
H→ZZ,ZZ*→4ℓ±
A→γγ
Zh
A→Zh,10⁴pb⁻¹
tan β
m_A (GeV)
0
100
200
300
400
500
1
2
5
10
20
50

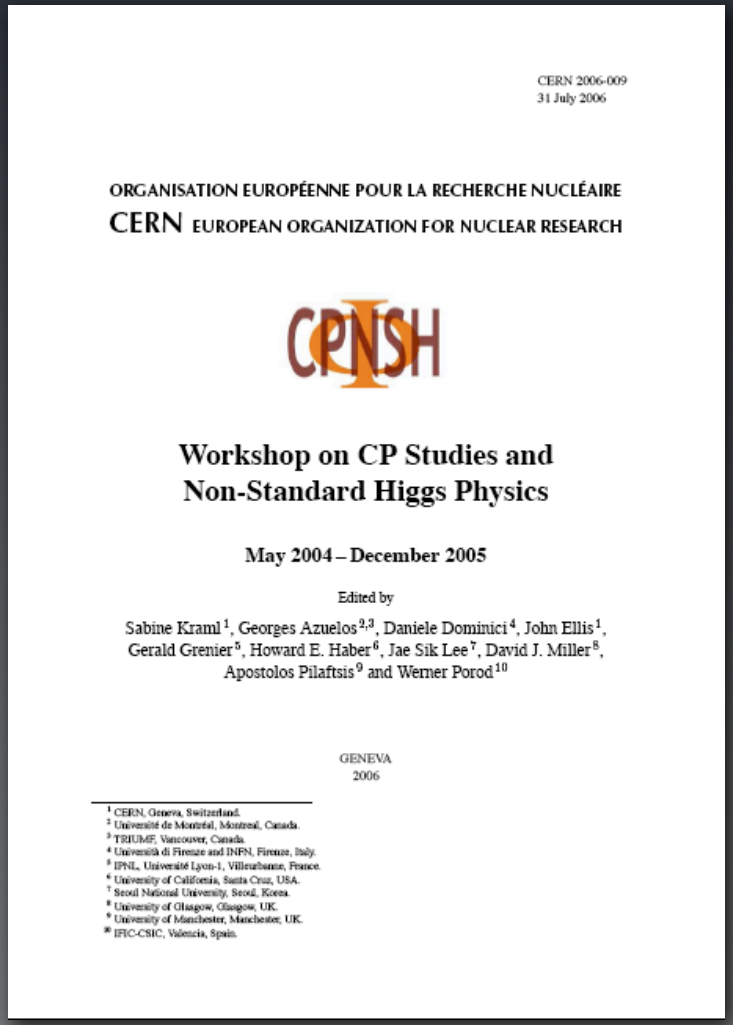

CMS, 100 fb-1
no stop mixing
bb̄ h,H,A → μμ
h,H,A → μμ
H± → τν, 10⁴ pb⁻¹
H± → τν
H → γγ
hA
"The Wedge"
Zh
LEP II
√s= 200 GeV
H → ZZ,ZZ* → 4ℓ±
A → γγ
A → Zh,10⁴pb⁻¹
tan β
50
20
10
5
2
1
0
100
200
300
400
500
mA (GeV)

3. A SUSY variant?

Not enough experimental work so far on non-SM, non-MSSM Higgs searches!

CPNSH workshop report out:

- $\not{CP}$ 2HDM
- MSSM with CP phases
- NMSSM (MSSM+singlet)
- RPV MSSM
- extra gauge groups
- Little Higgs models
- Large extra dimensions
- Warped extra dimensions
- Higgsless Models
- Strongly interacting Higgs
- Technicolor
- Higgs Triplets



CERN 2006-009
31 July 2006

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CPNSH

Workshop on CP Studies and Non-Standard Higgs Physics

May 2004 – December 2005

Edited by

Sabine Kraml [1], Georges Azuelos [2,3], Daniele Dominici [4], John Ellis [1], Gerald Grenier [5], Howard E. Haber [6], Jae Sik Lee [7], David J. Miller [8], Apostolos Pilaftsis [9] and Werner Porod [10]

GENEVA
2006

[1] CERN, Geneva, Switzerland.
[2] Université de Montréal, Montreal, Canada.
[3] TRIUMF, Vancouver, Canada.
[4] Università di Firenze and INFN, Firenze, Italy.
[5] IPNL, Université Lyon-1, Villeurbanne, France.
[6] University of California, Santa Cruz, USA.
[7] Seoul National University, Seoul, Korea.
[8] University of Glasgow, Glasgow, UK.
[9] University of Manchester, Manchester, UK.
[10] IFIC-CSIC, Valencia, Spain.

http://kraml.web.cern.ch/kraml/cpnsh/

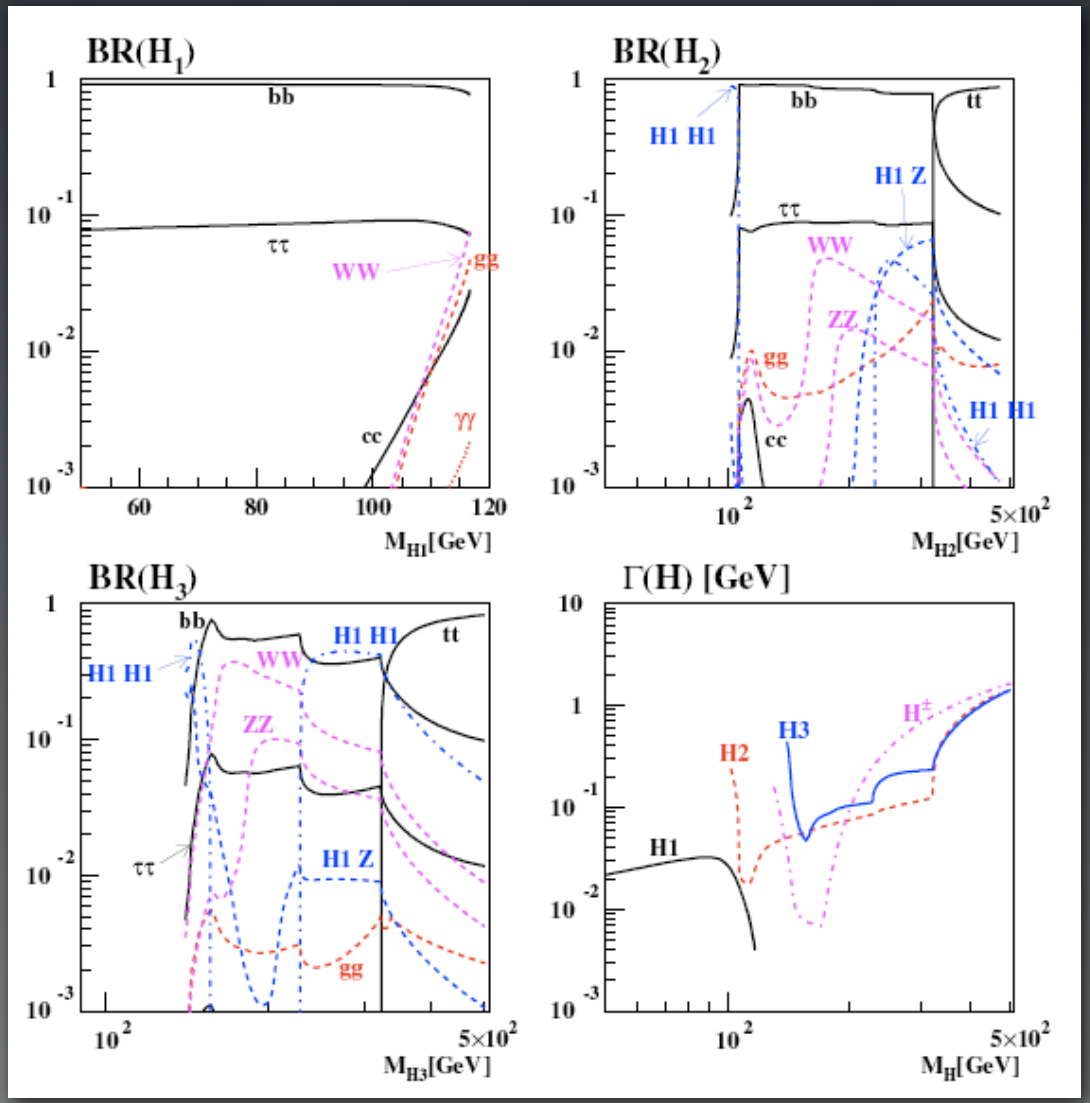
"Higgs Hunters Guide to non-standard Higgs"

One example: MSSM with CP phases

Three Higgs bosons H_1, H_2, H_3

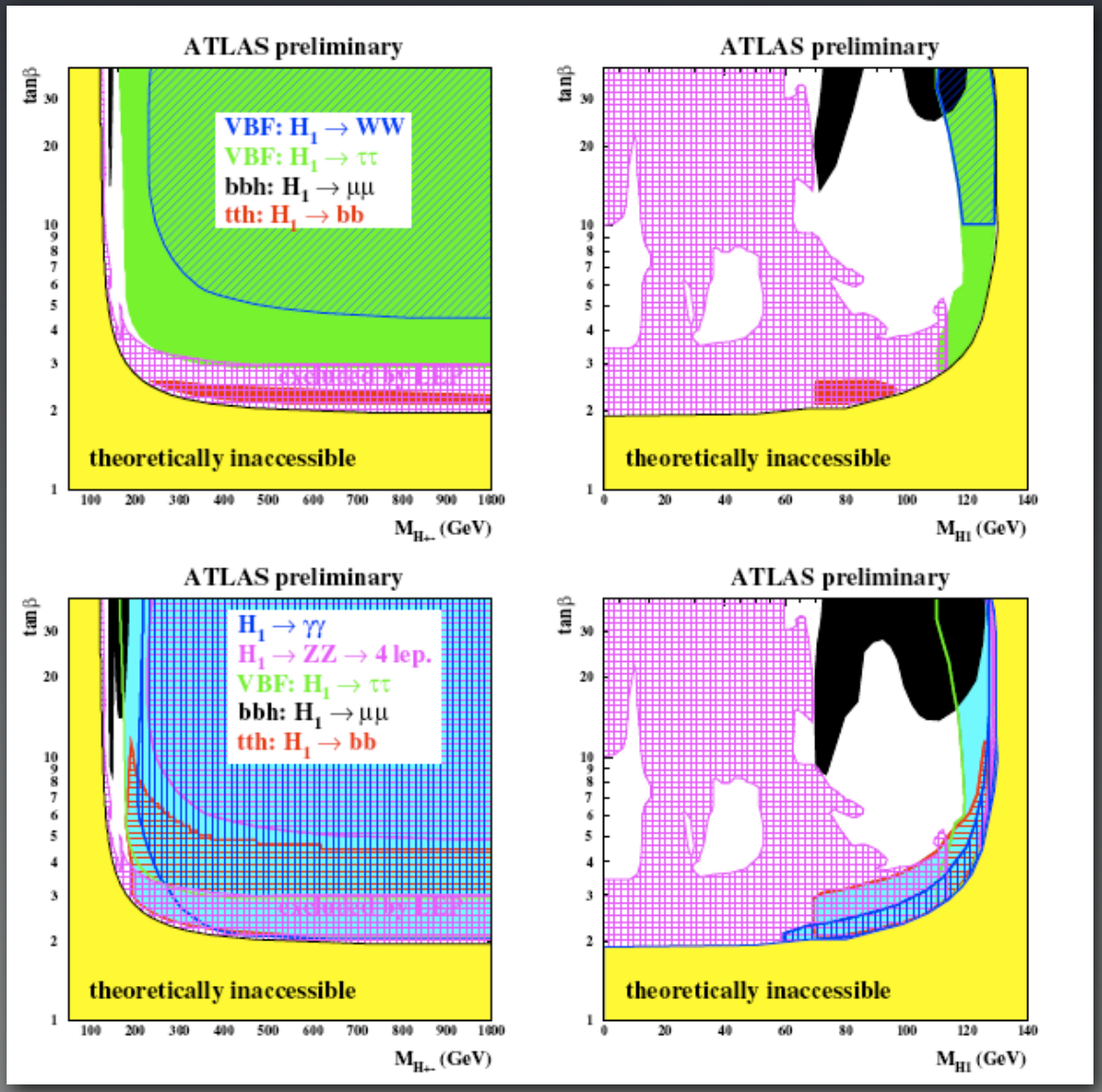
Branching ratios look somewhat familiar!

Use SM, MSSM searches to probe the model



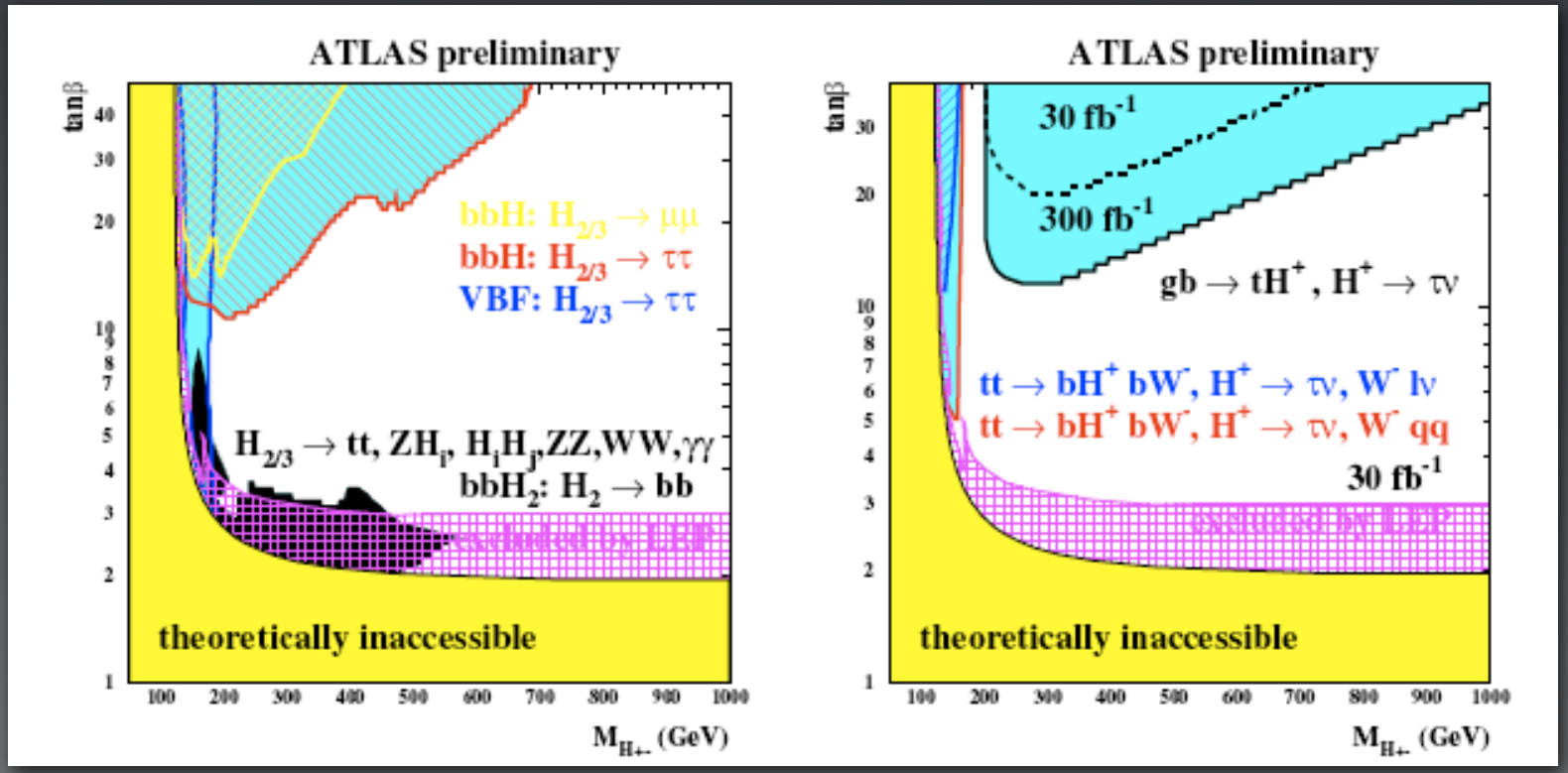
CPNSH report

ATLAS reach for $H^{\pm}$, H_1



M. Schumacher , CPNSH report

ATLAS reach for H_2, H_3



M. Schumacher , CPNSH report

more later today from Jack Gunion on NMSSM...

Summary

- A single SM Higgs scalar is disfavored
- Tevatron has a great deal yet to say
  - SM Higgs - WH and ZH production
  - SUSY Higgs - $\tau\tau$(b) and bbb(b) modes
- LHC will initially explore $\gamma\gamma$, then $\tau\tau$
- If LHC sees SM-like Higgs, the work has just begun
- If no SM-like Higgs signal seen, life gets very interesting indeed...