Search for the Higgs Beyond the Standard Model

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Aspen 2007

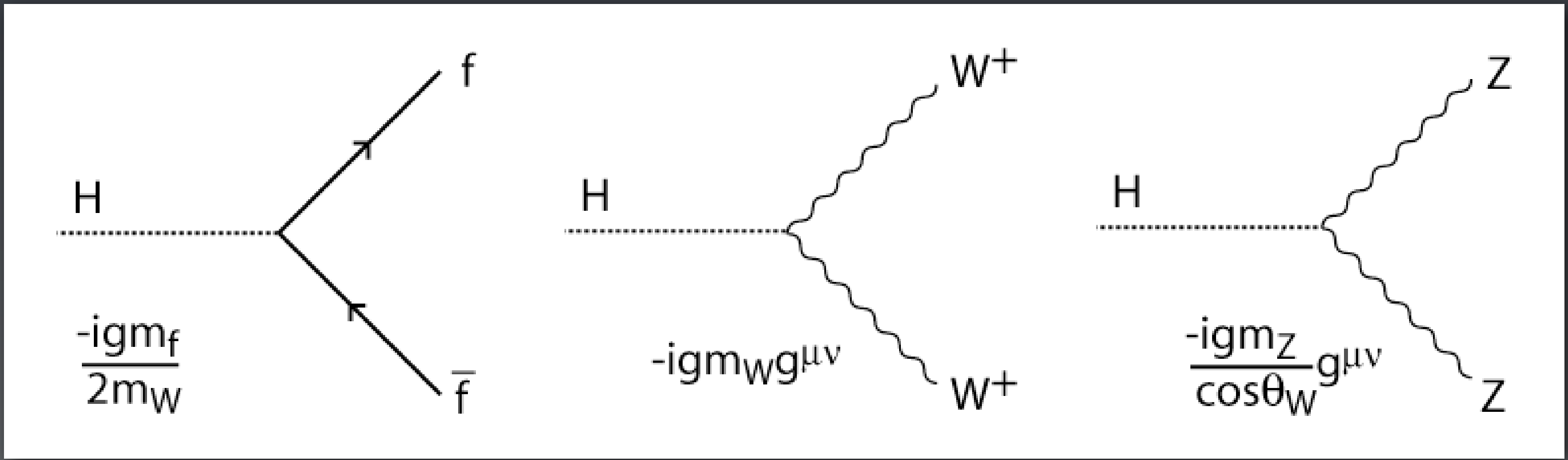
Why a BSM Higgs?

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

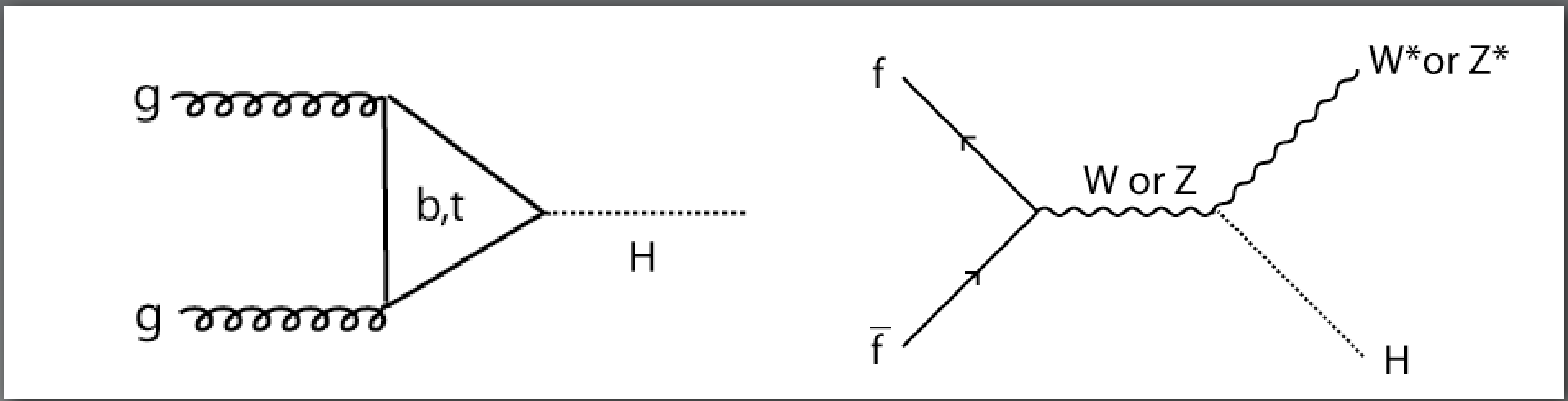
- Focus here on what is being done and what will soon be done

1. Is it a SM-like Higgs?

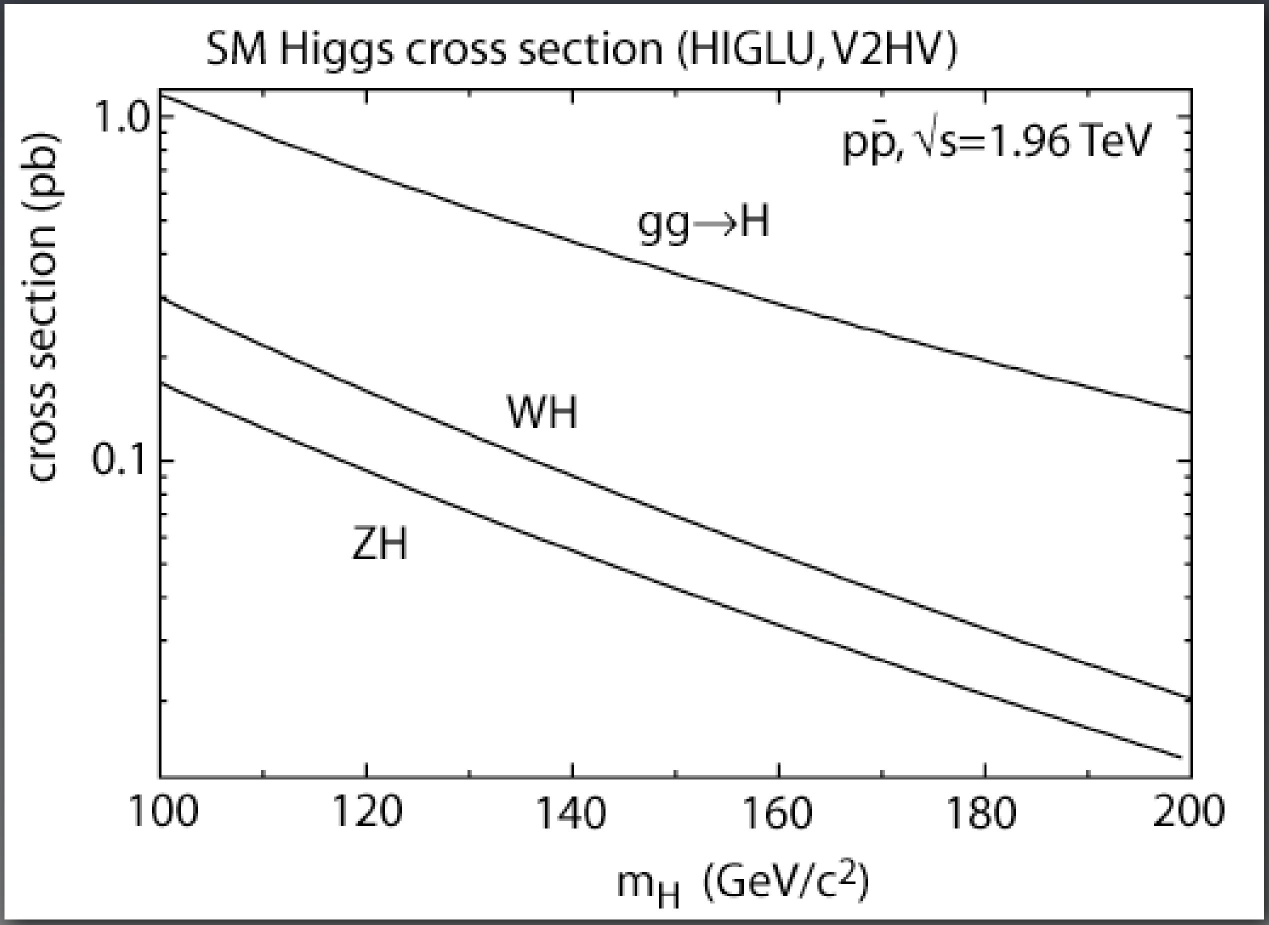
Standard Model: one complex scalar weak isodoublet



H scalar couples to fermion pairs, WW, ZZ



Tevatron gets the first shot!



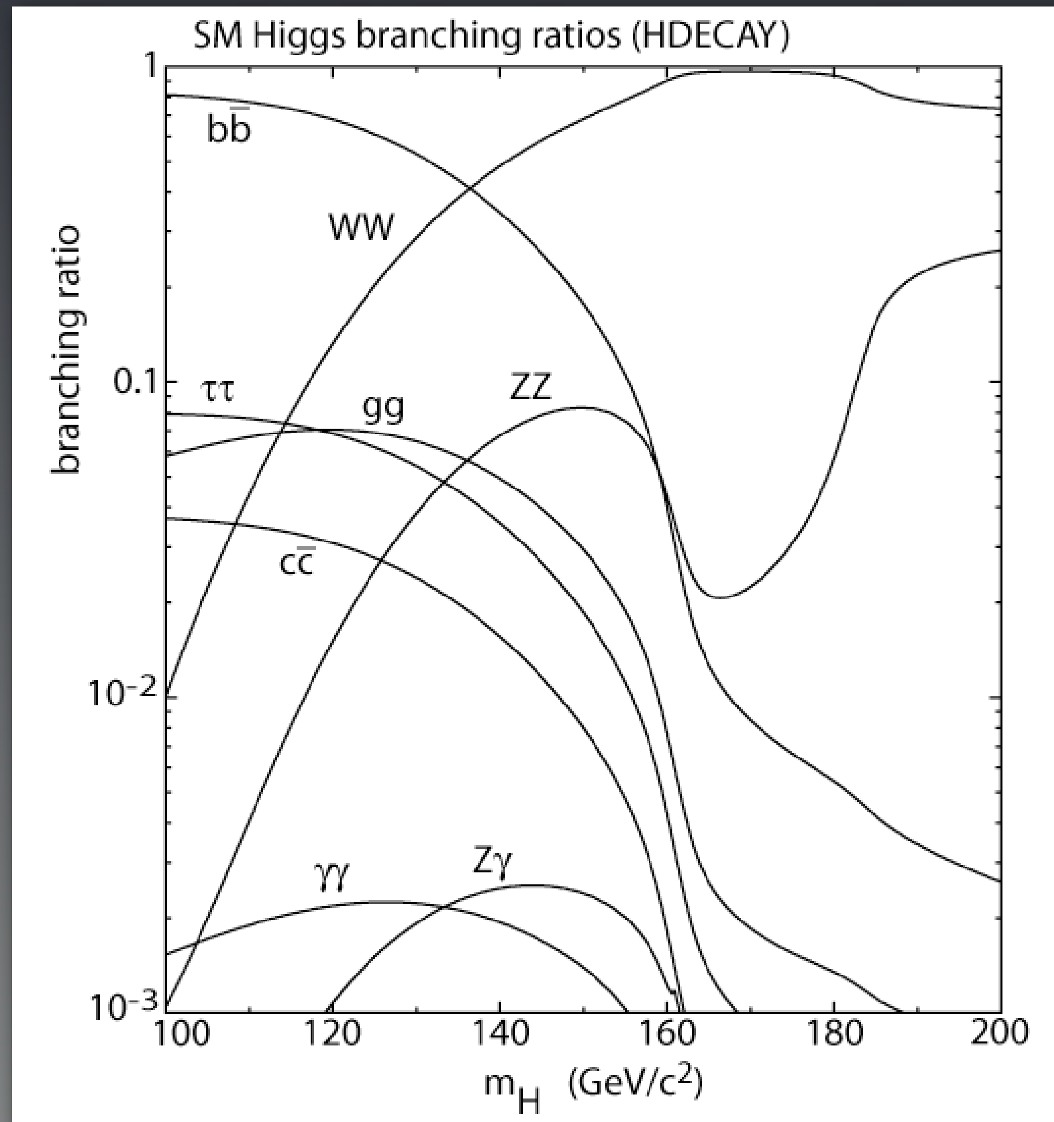
⇒ gg mode impossible; must rely on VH modes

Low mass Higgs:

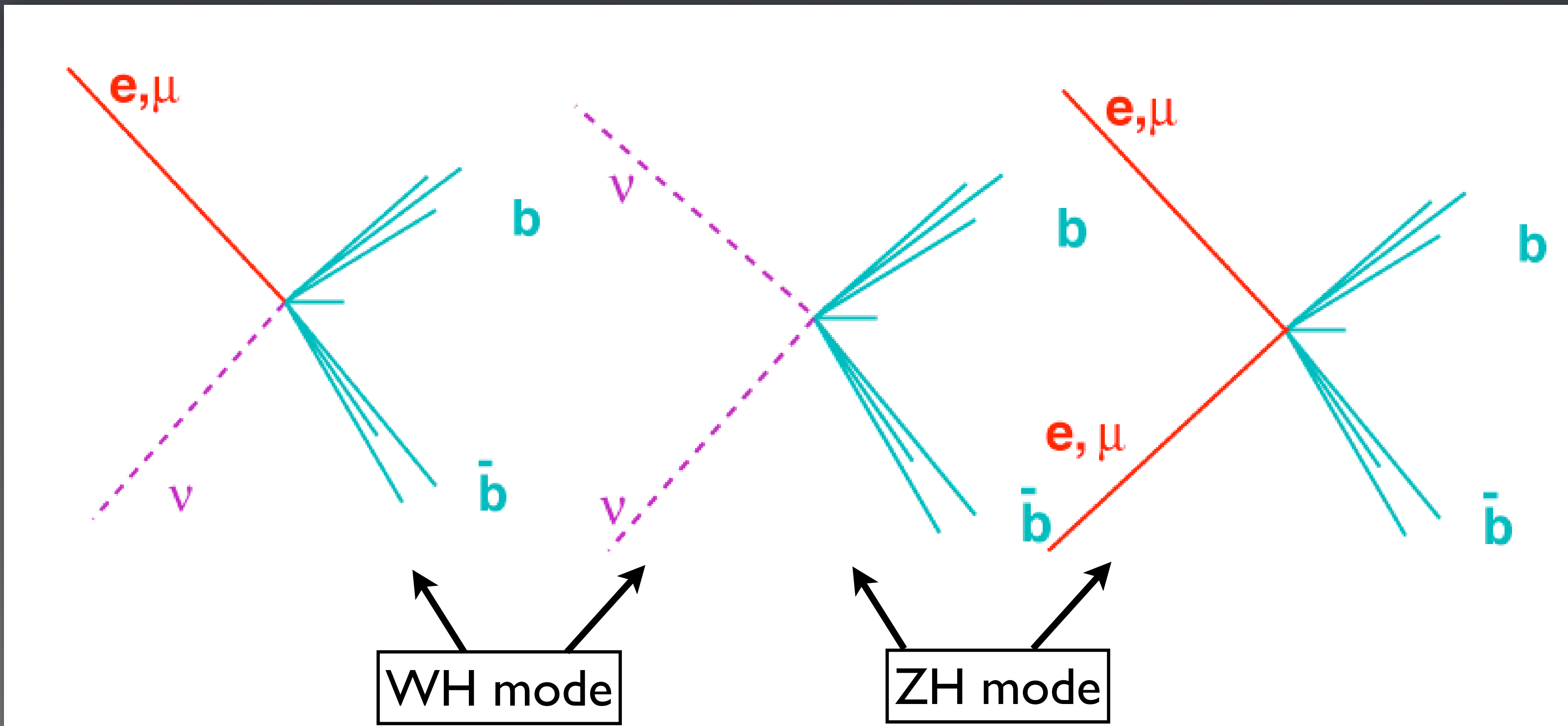
bb	70-90%
ττ	6-8%
γγ	0.2%

High mass Higgs:

WW	90-98%
ZZ	2-10%

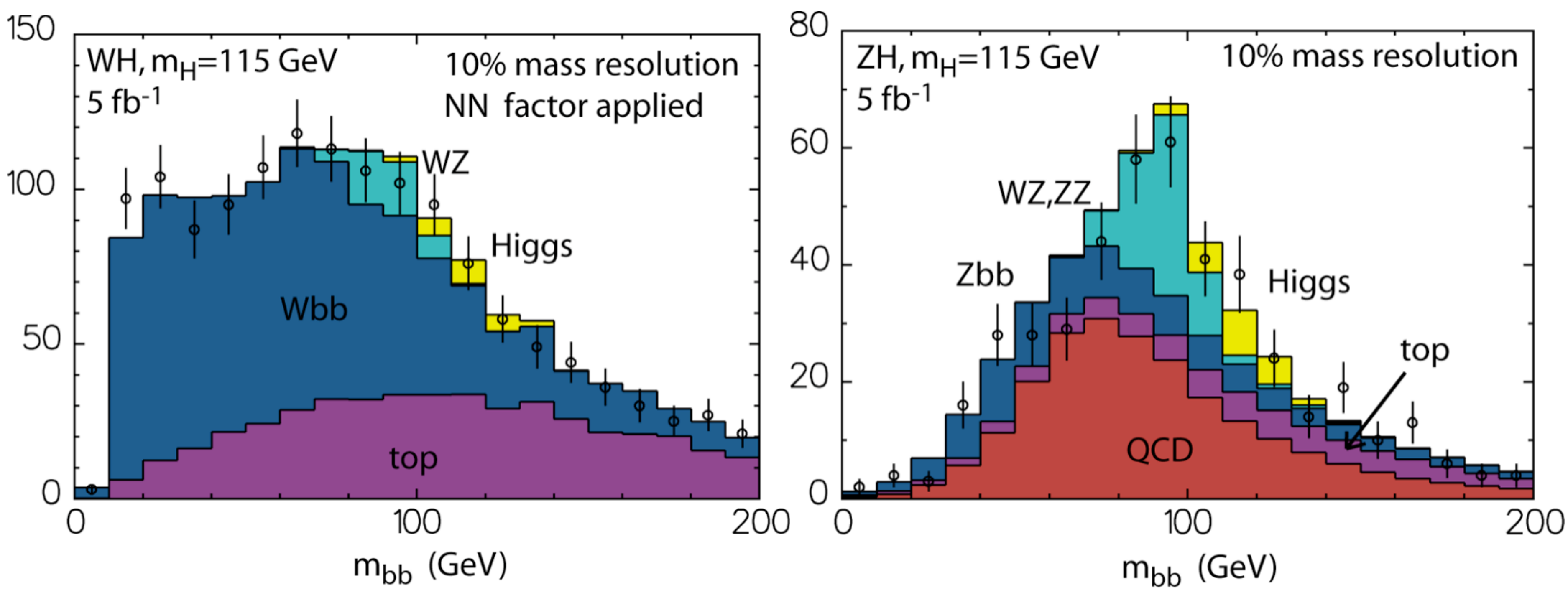


Final states for VH production:



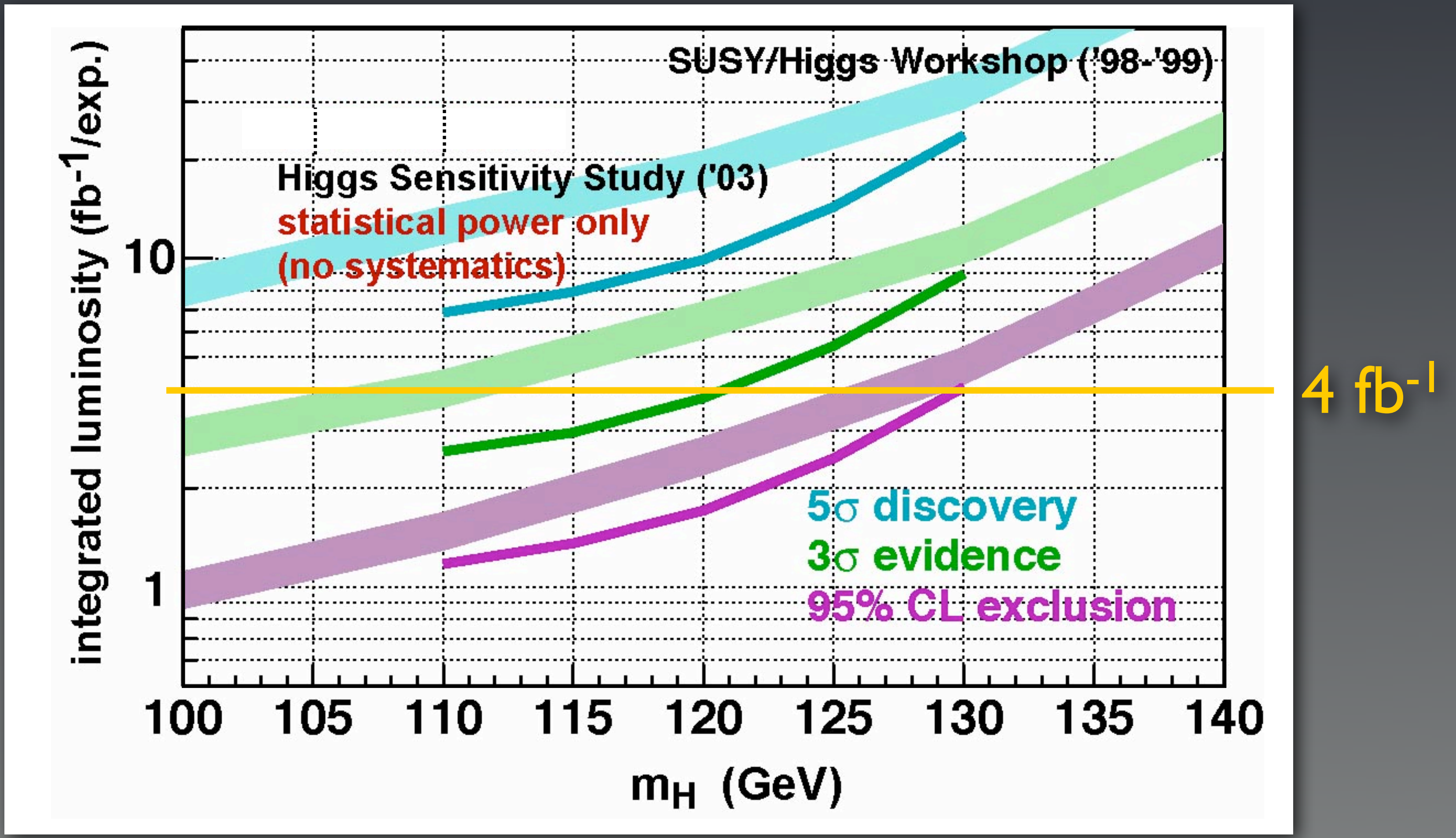
These are the only sensitive modes at the Tevatron!

Tevatron SM Higgs is extremely difficult, experimentally:

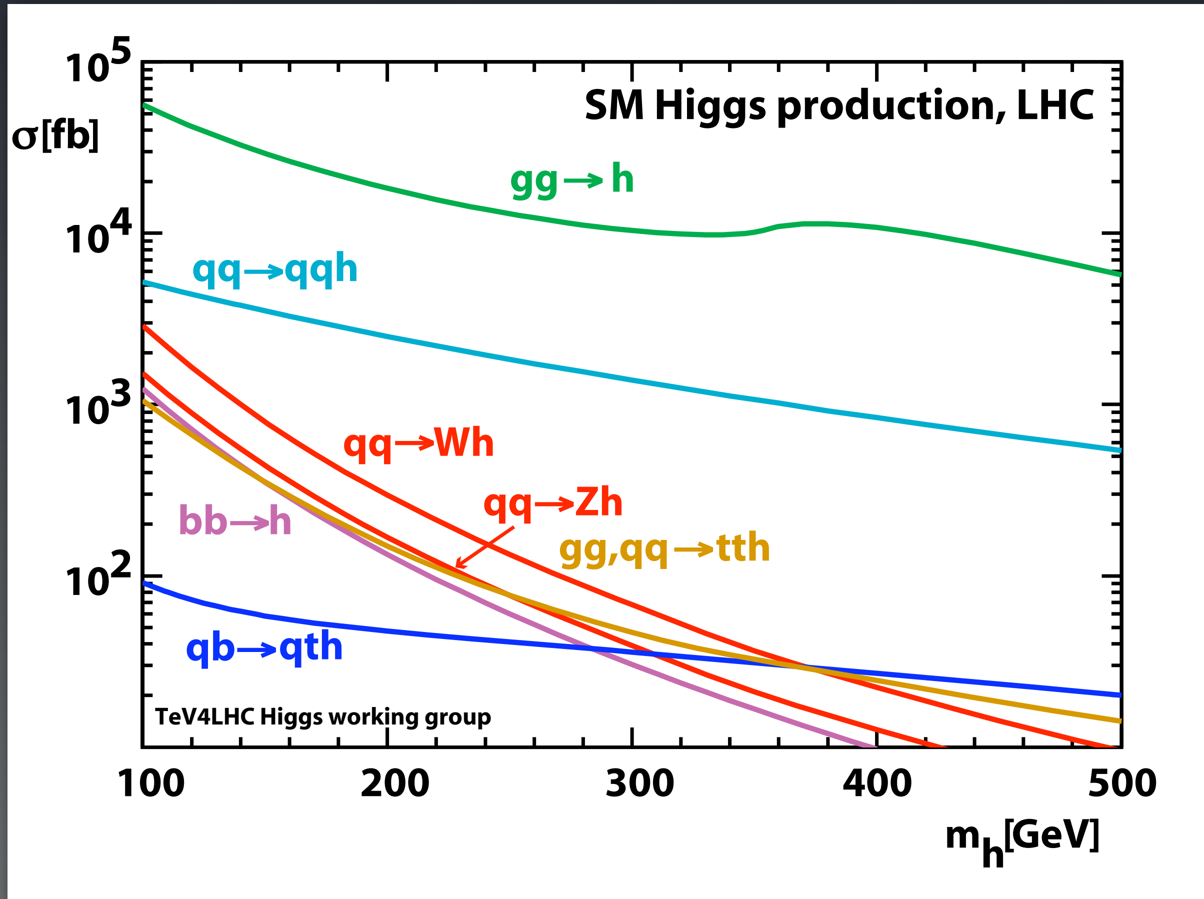


Need great b tagging and bb mass resolution, and exquisite control of background shapes

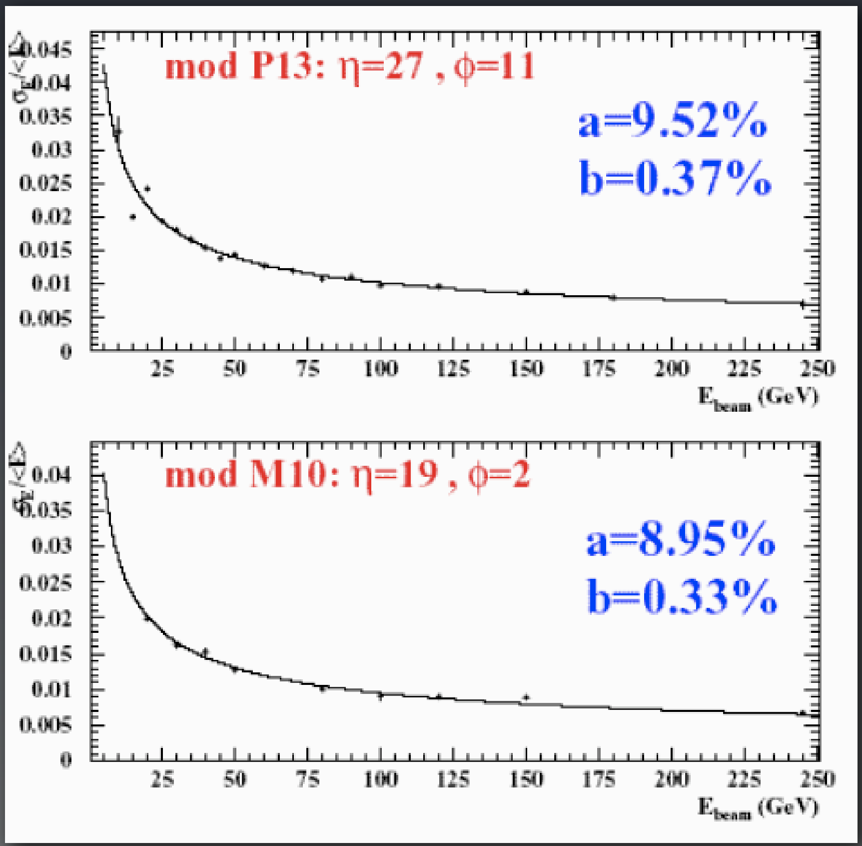
SUSY/Higgs Workshop ('00), Higgs Sensitivity Study ('03)

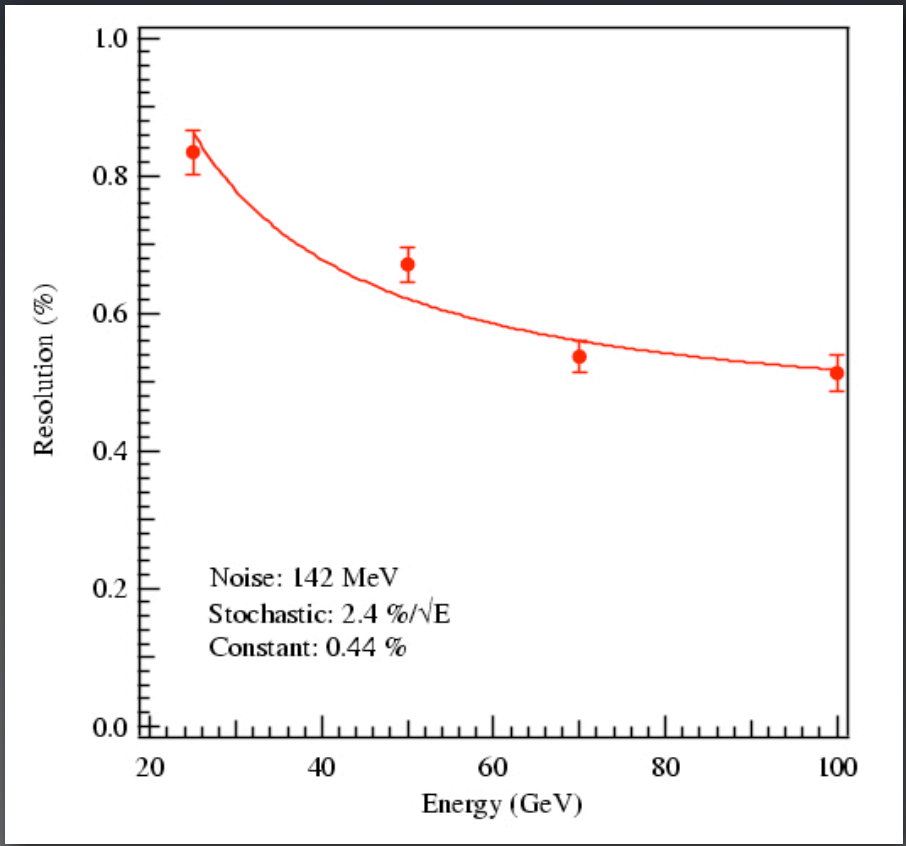


Still represents our best hope in ~1-2 years



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

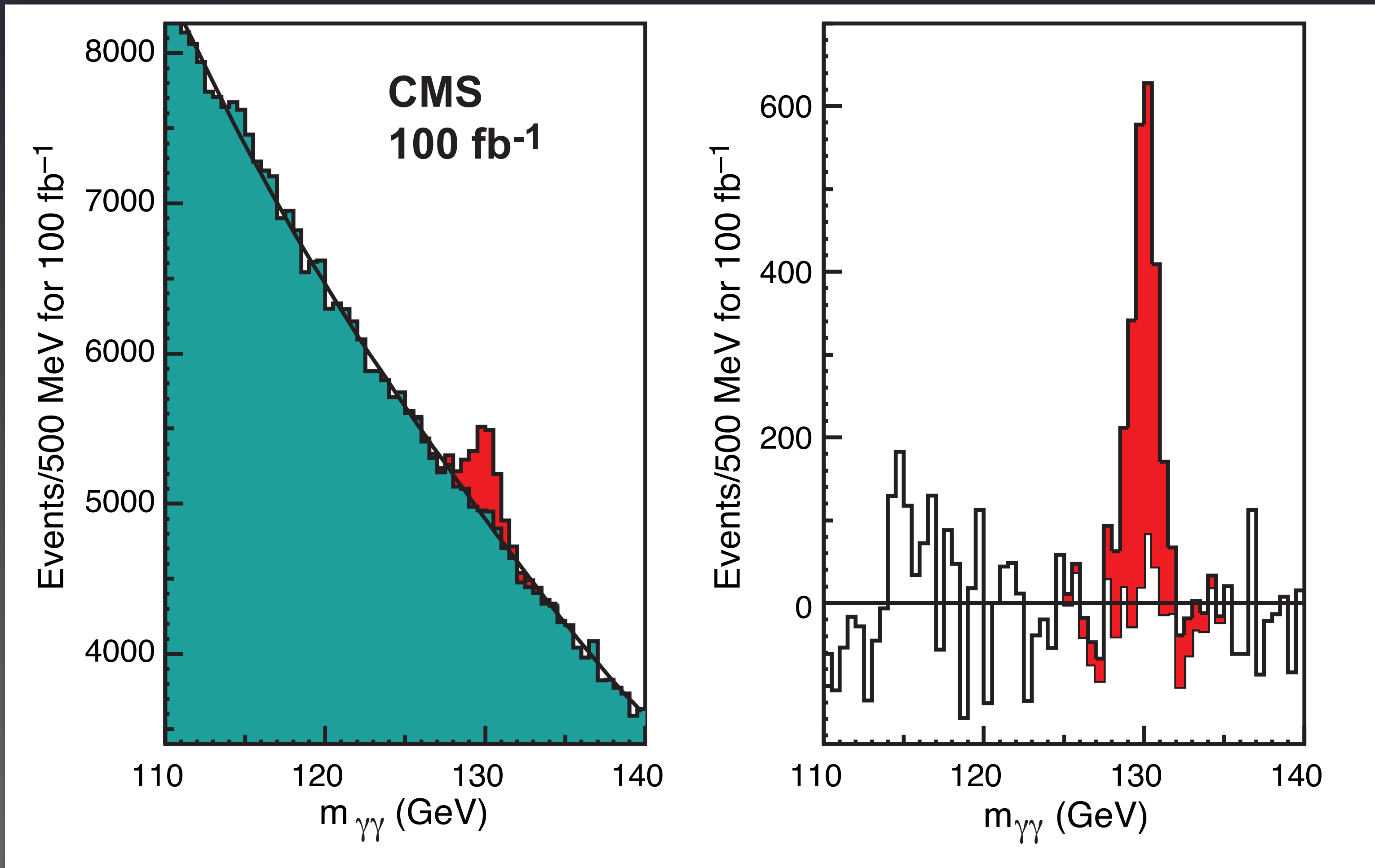




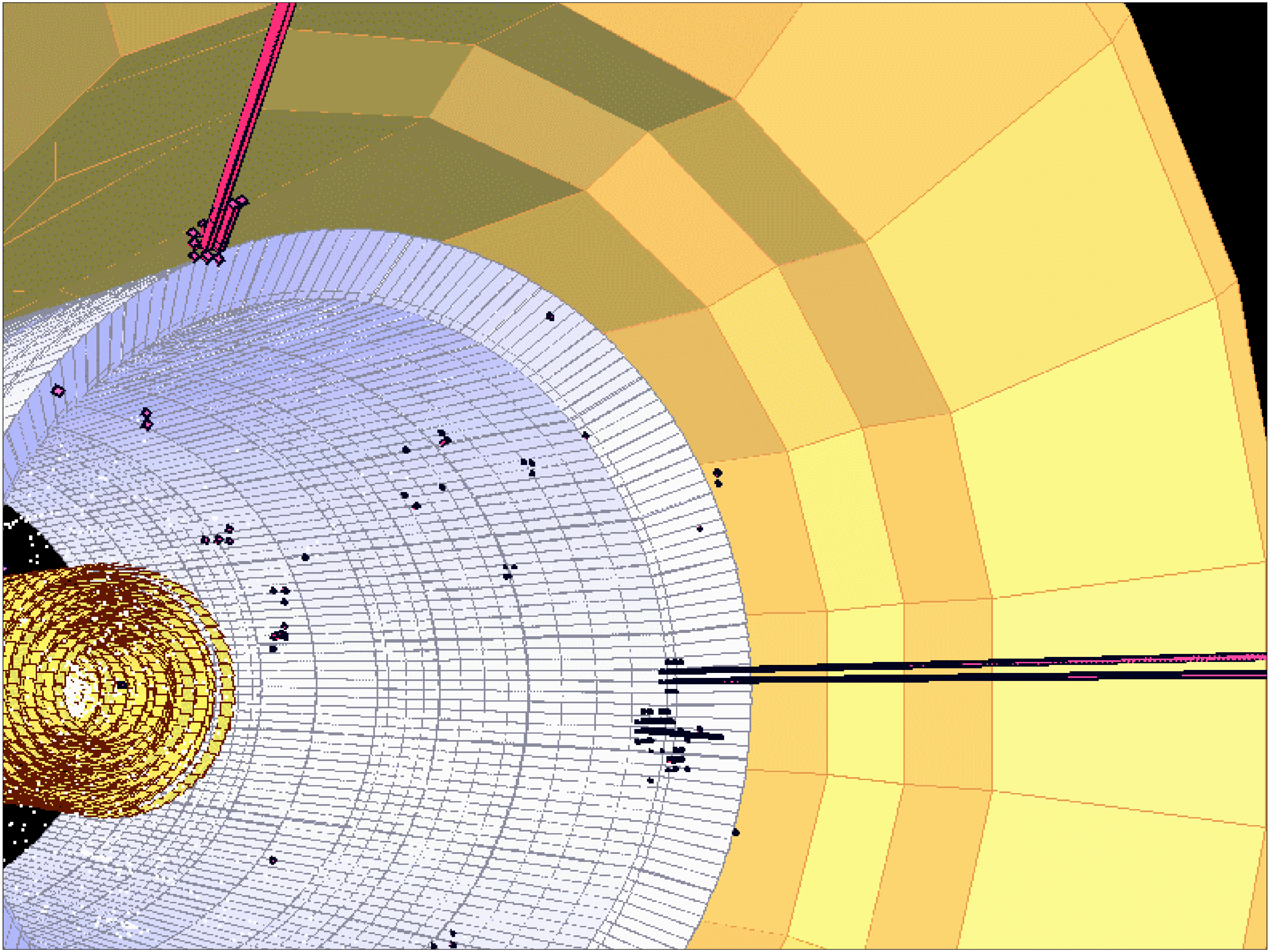
ATLAS: liquid Ar

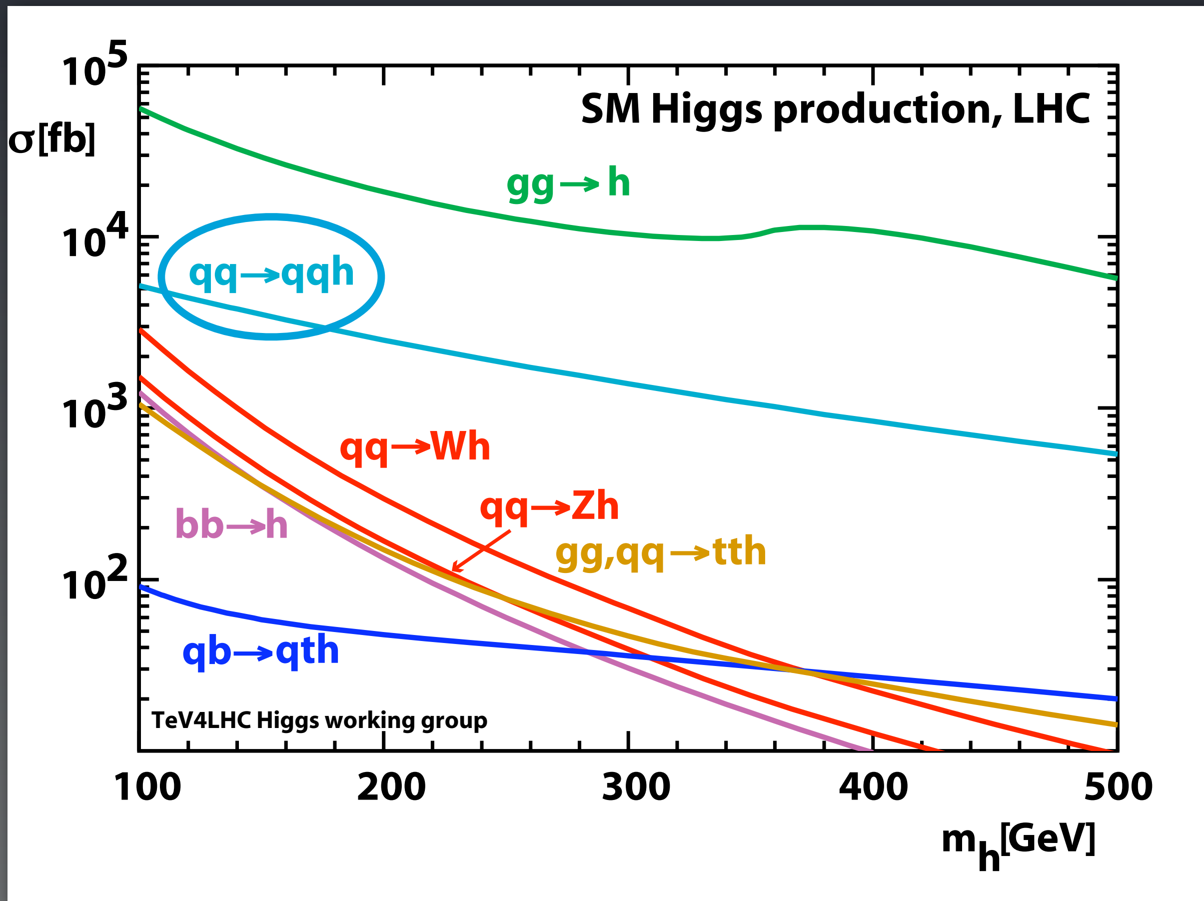
CMS: $PbWO_4$ crystals

→ both experiments will have ~0.5% resolution



- $H \rightarrow \gamma\gamma$ signal on falling background
- get 5σ with less than 10 fb^{-1}

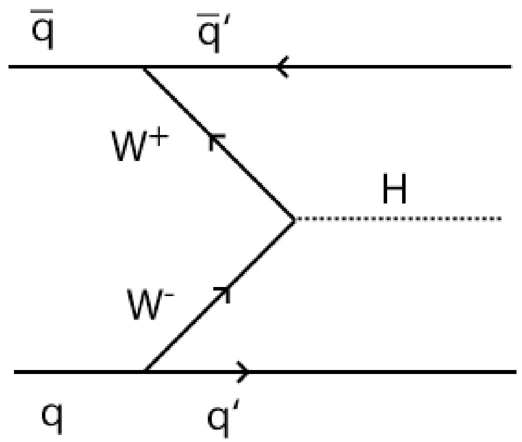


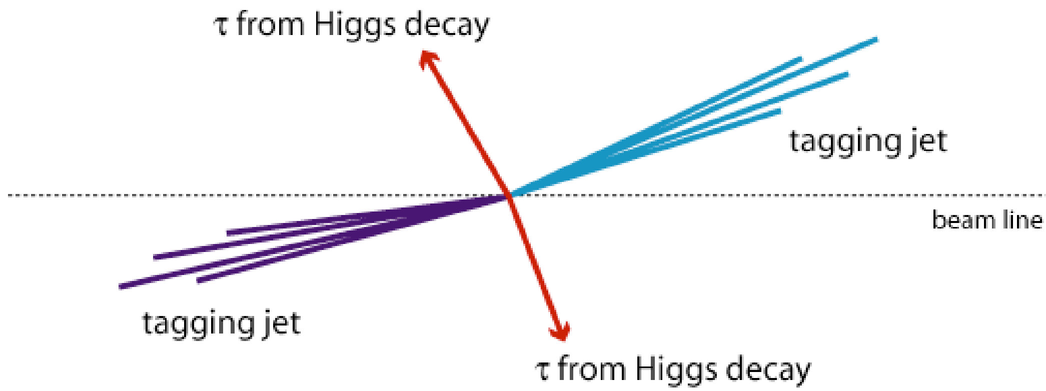


Second largest production mode at LHC:

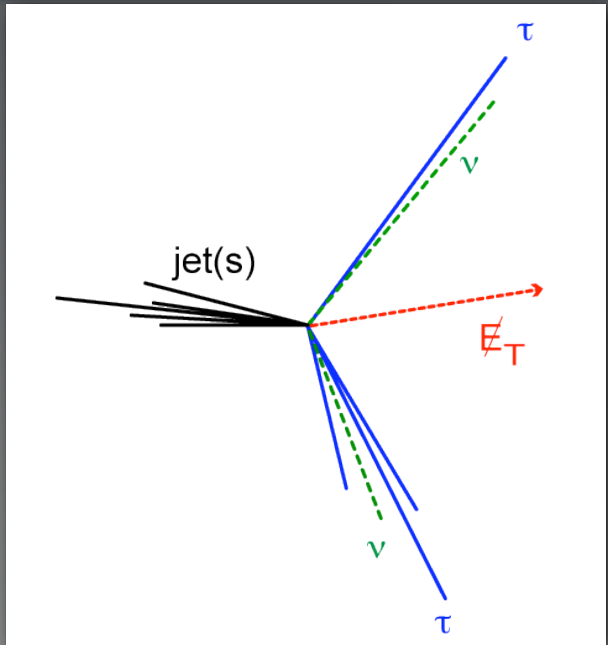
Vector Boson Fusion (VBF)

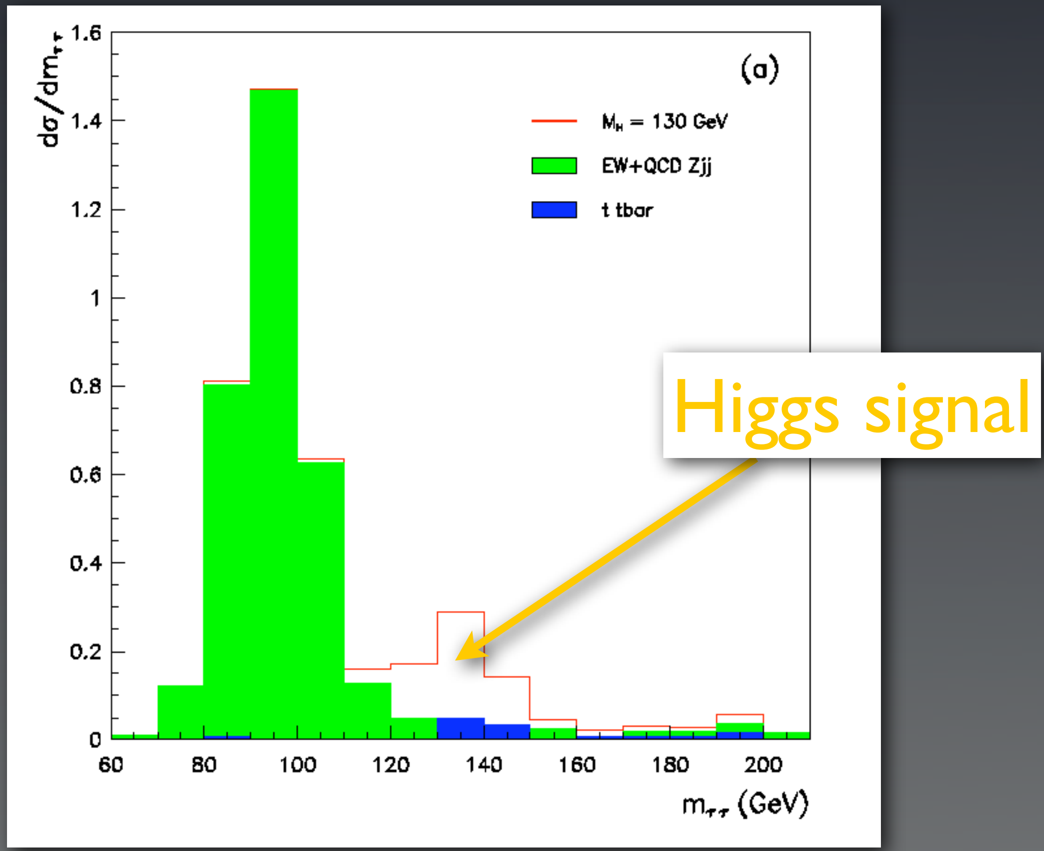
Use forward "tagging jets" to help trigger





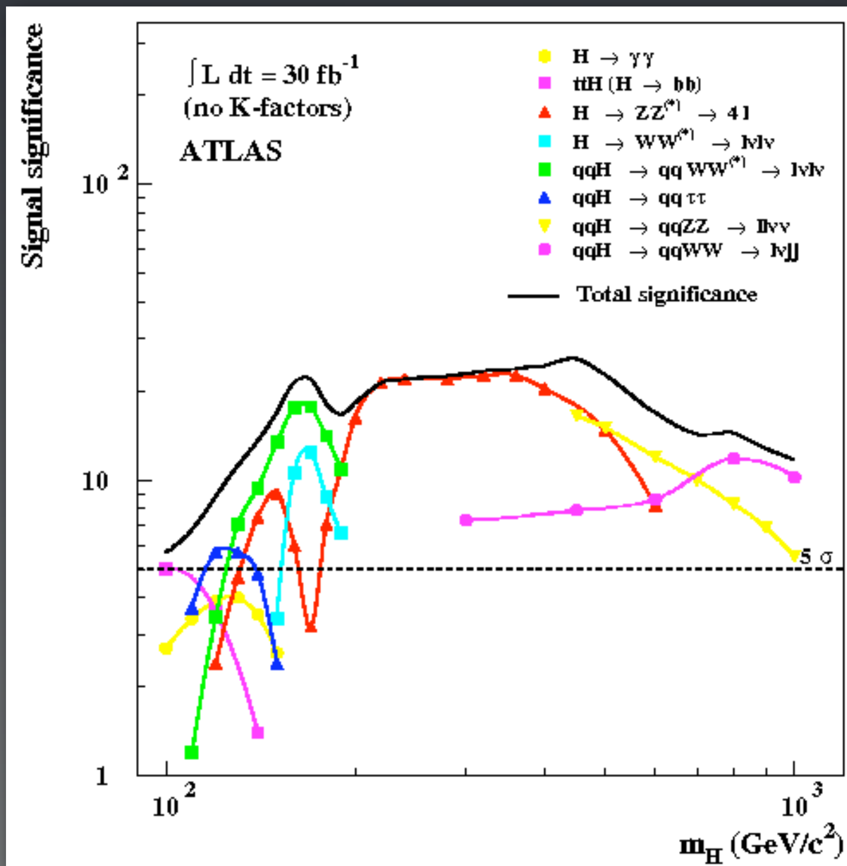
- most sensitive final state: tau pairs
- large background from $Z \rightarrow \tau\tau$
- can reconstruct tau pair mass

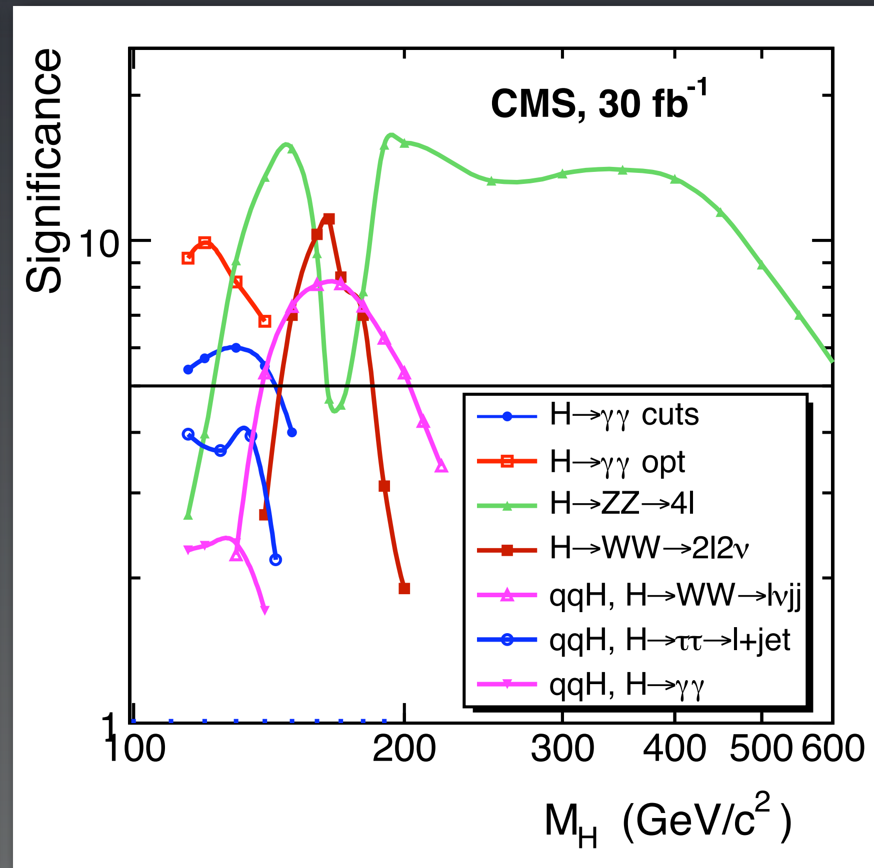




- ability to discriminate Higgs from Z depends on excellent missing p_T resolution

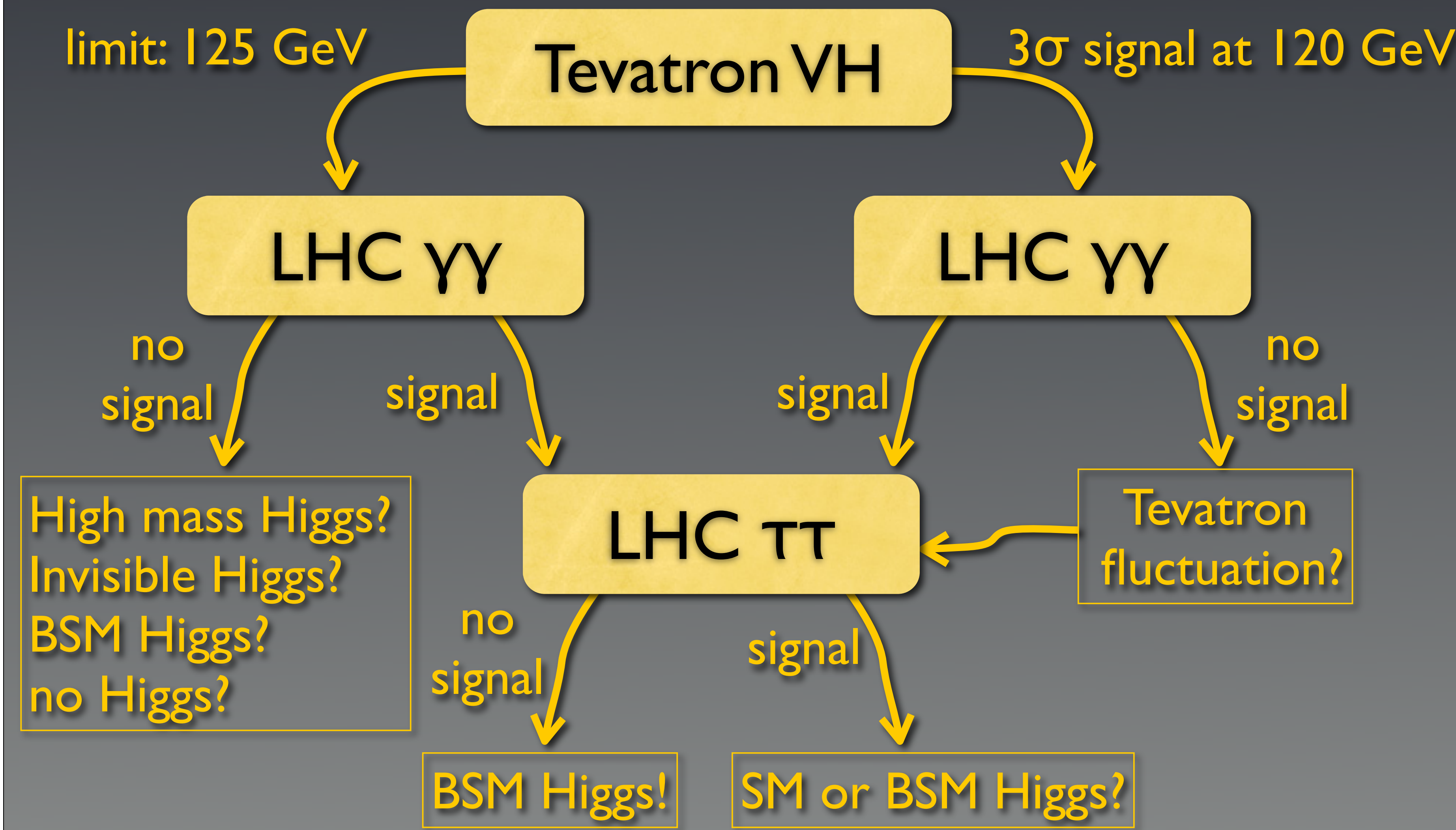
LHC SM Higgs Sensitivity



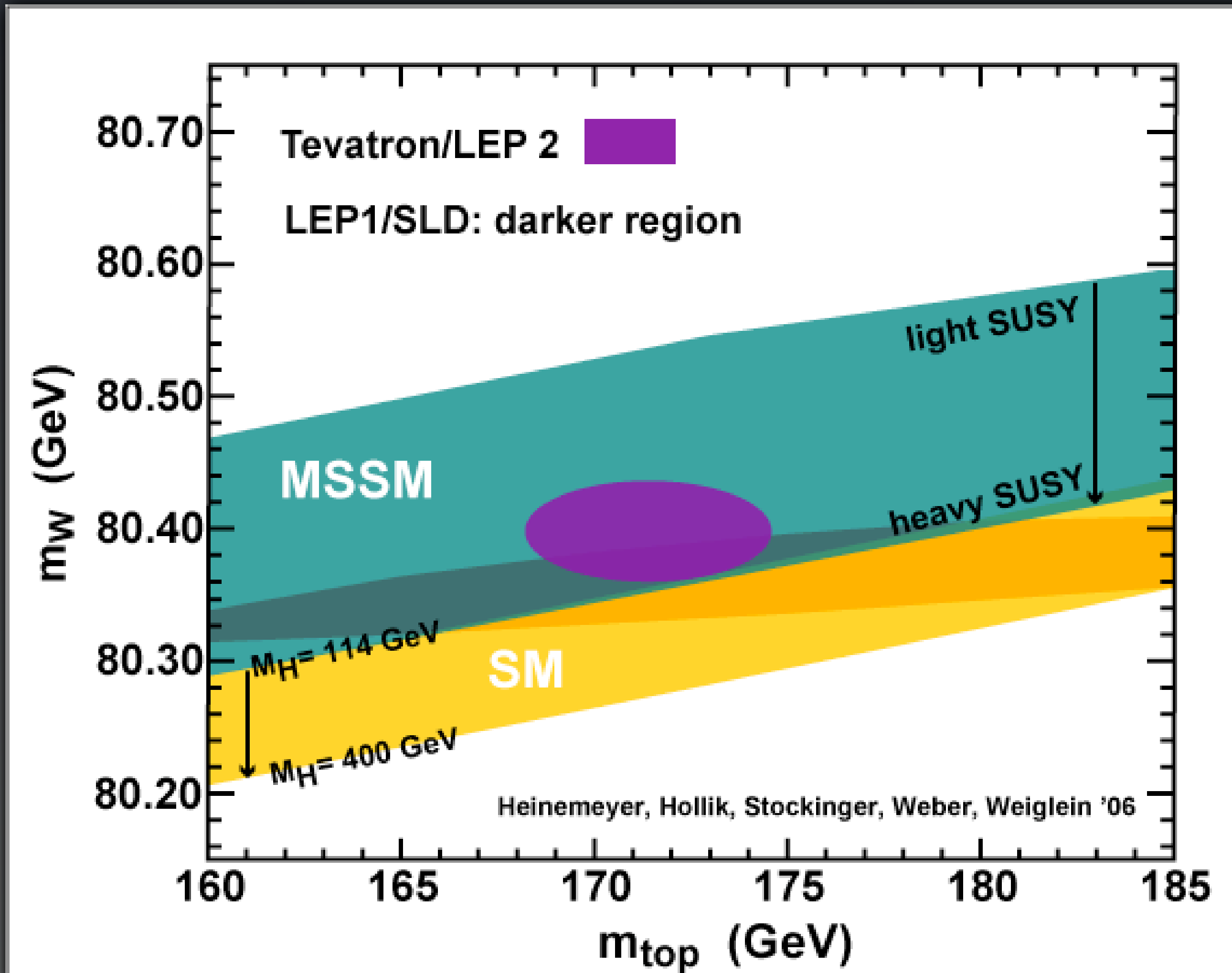


- $\gamma\gamma$ mode wins at low mass: need < 10 fb^{-1}
- VBF $\tau\tau$ mode not far behind

The situation two years from now?



- 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

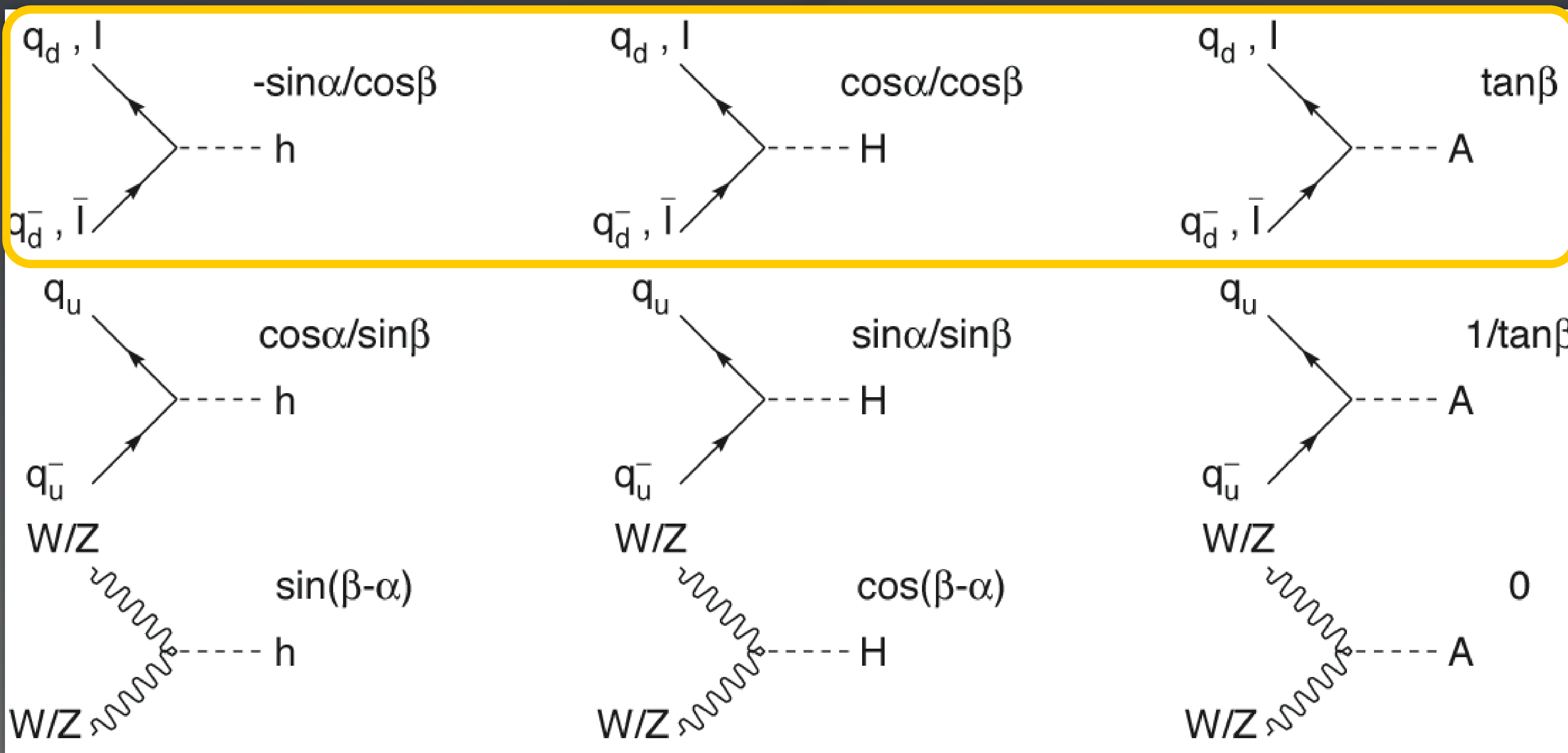


- new top, W masses from Tevatron push SM Higgs mass lower...favors MSSM

2. Is it the MSSM Higgs?

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

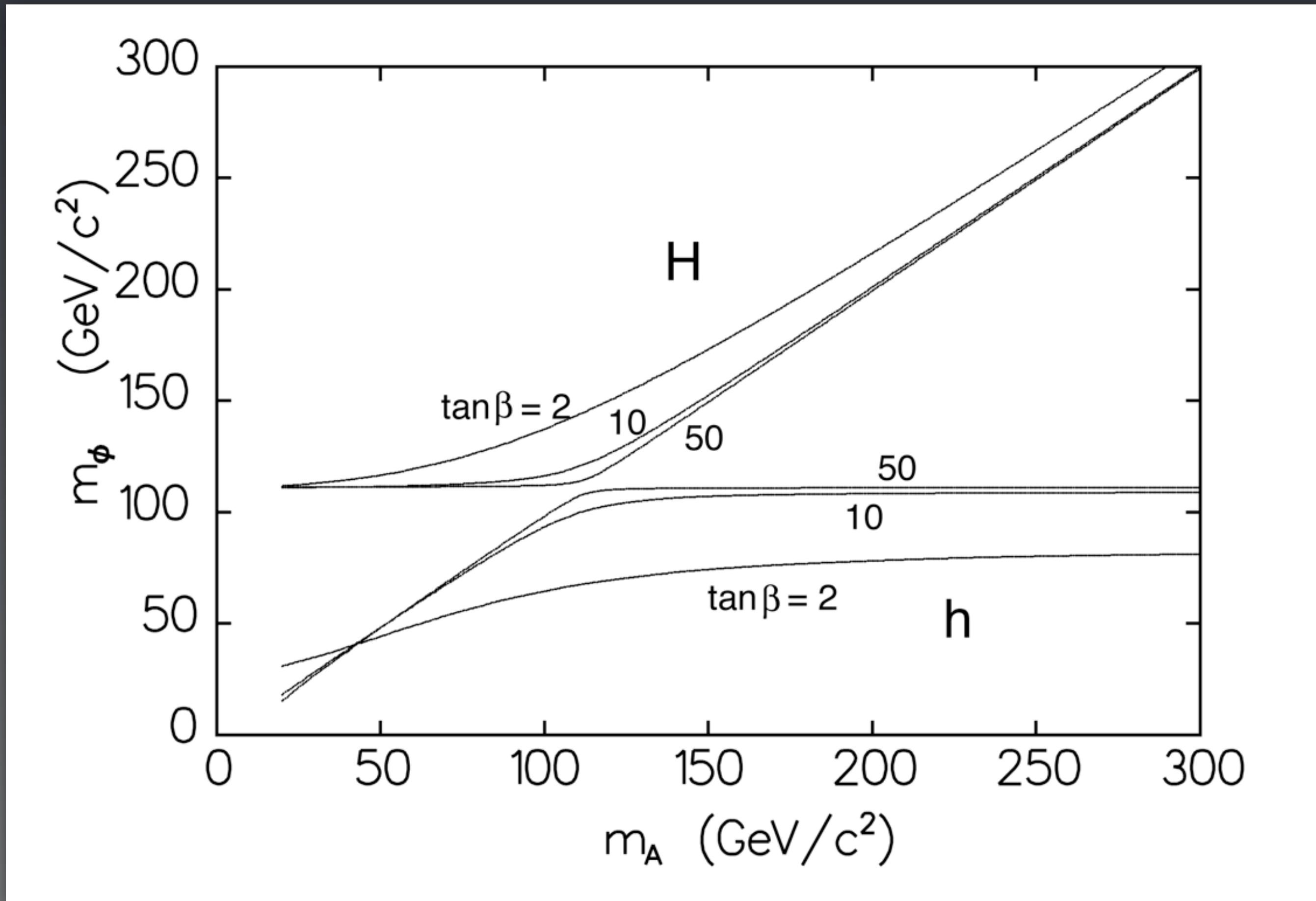
m_A, $\tan\beta = v_2/v_1$ govern masses



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

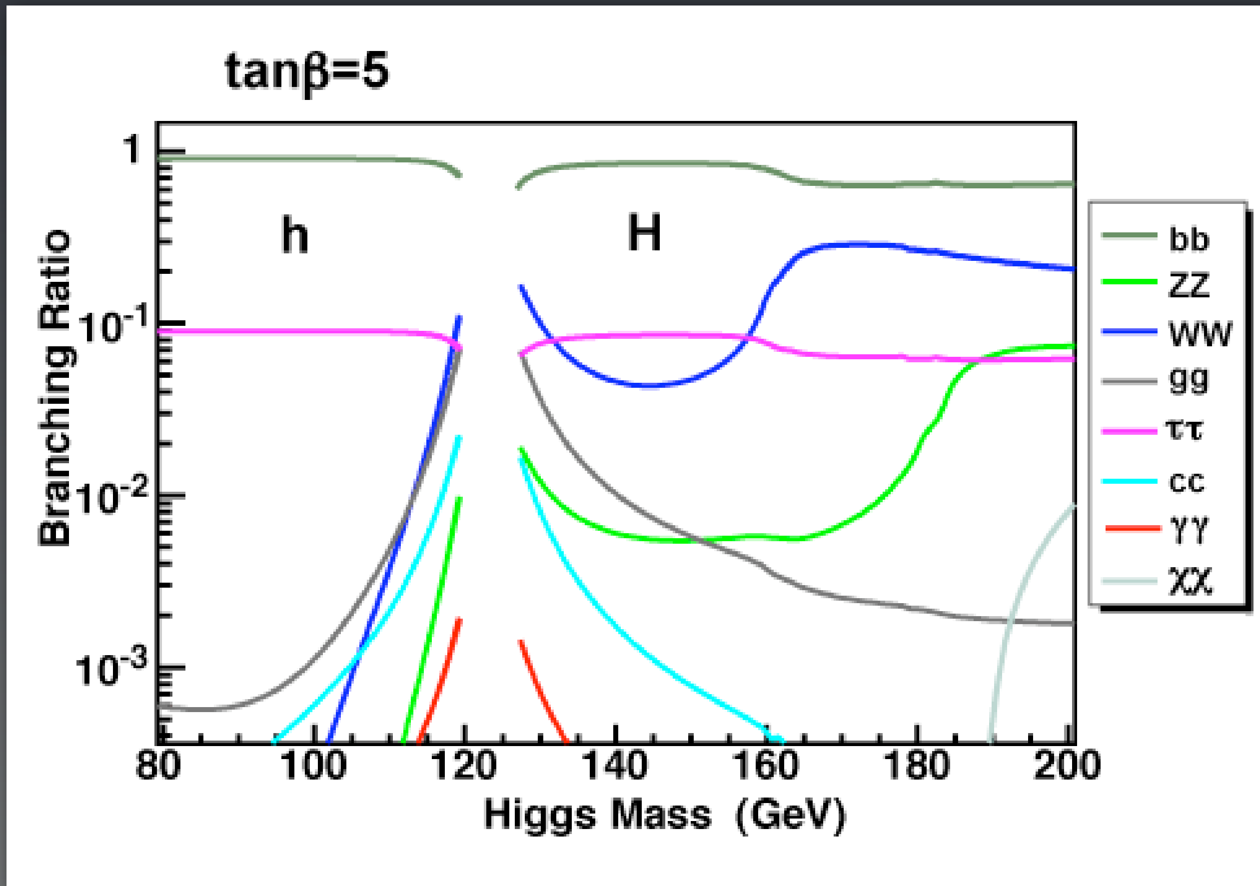
light h can be very SM-like!

MSSM h, H masses

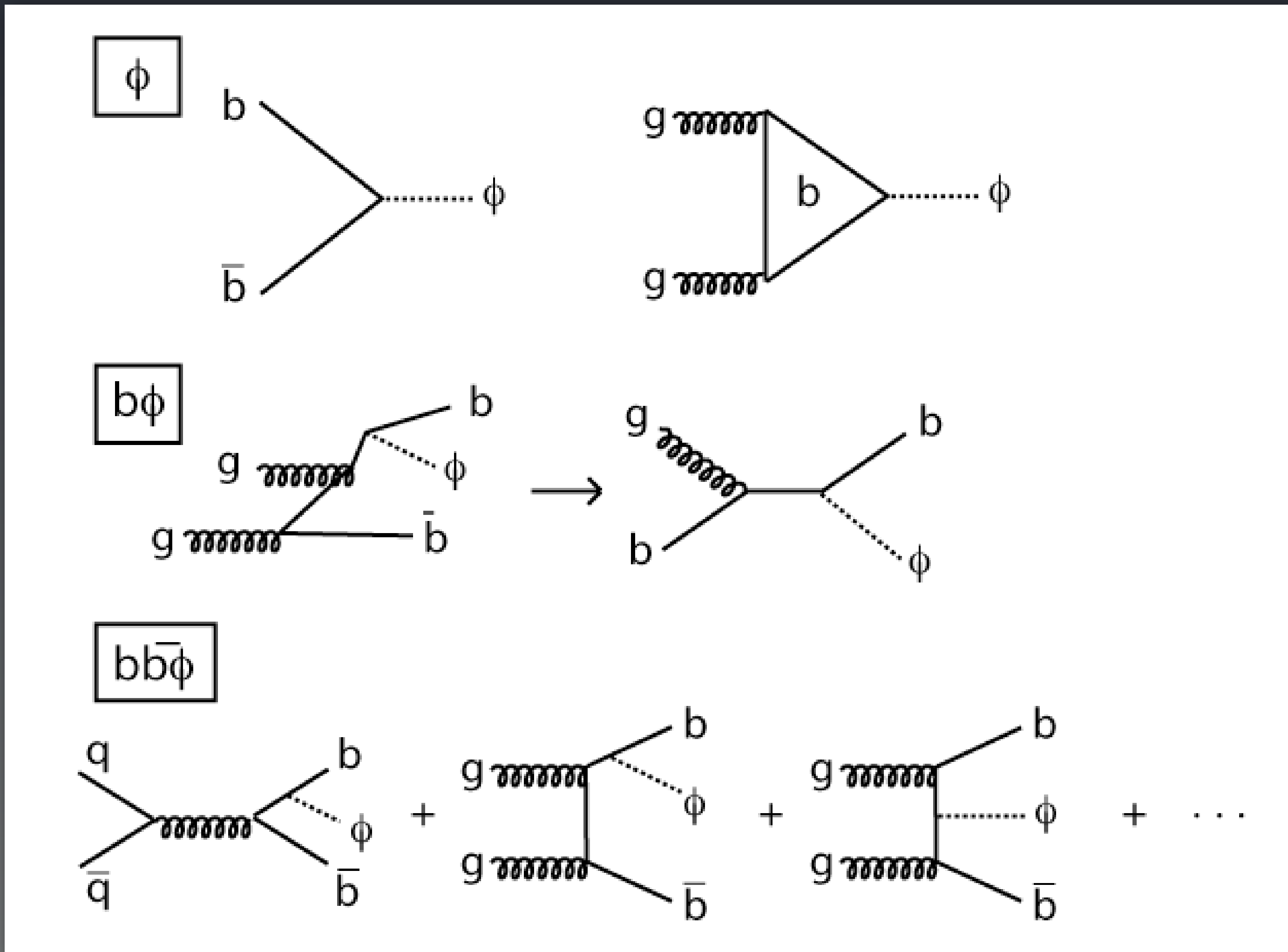


As m_A increases, it is nearly degenerate with either h (at low m_A) or H (at high m_A)

MSSM h, H branching ratios

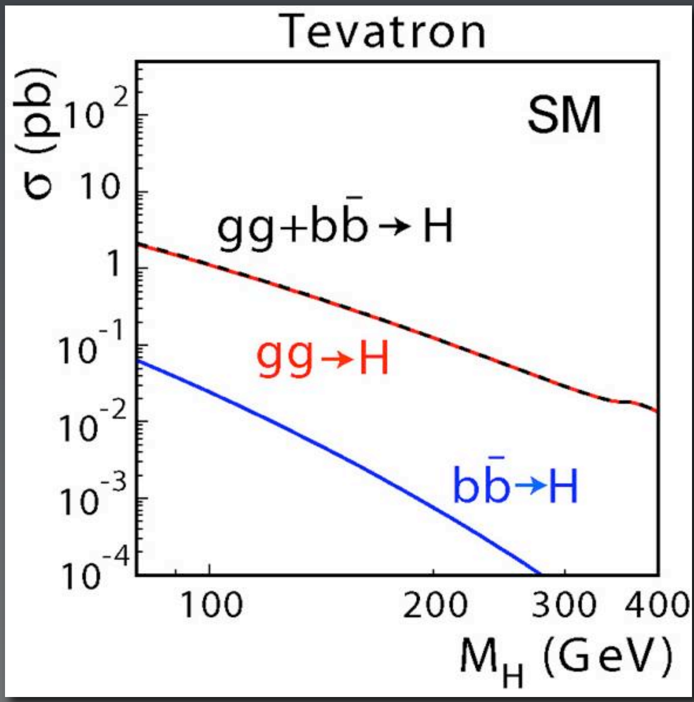


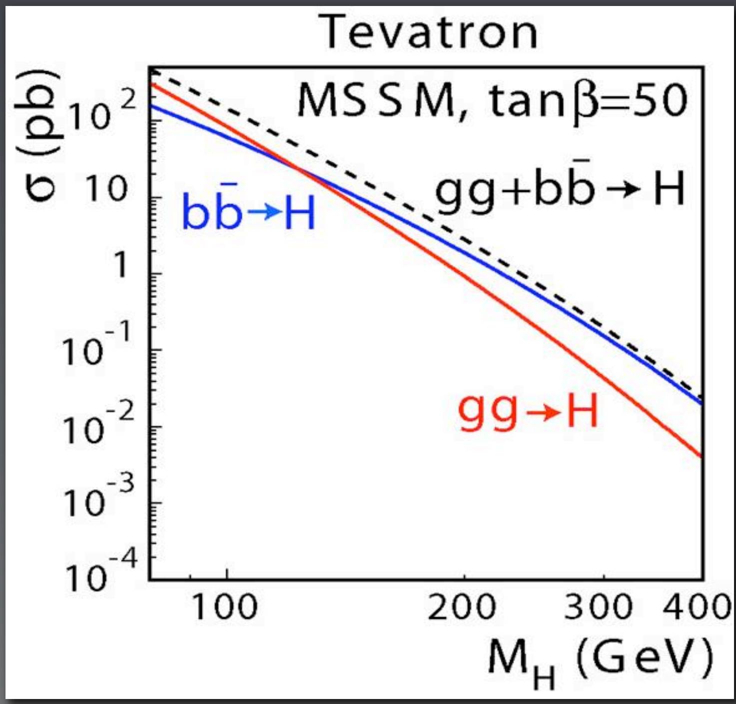
- bb and ττ BRs stable at ~90% and ~9% respectively
- γγ BR is very m_A-dependent!



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

Tevatron MSSM Higgs production





⇒ large tanβ puts Tevatron into the ~10 pb range

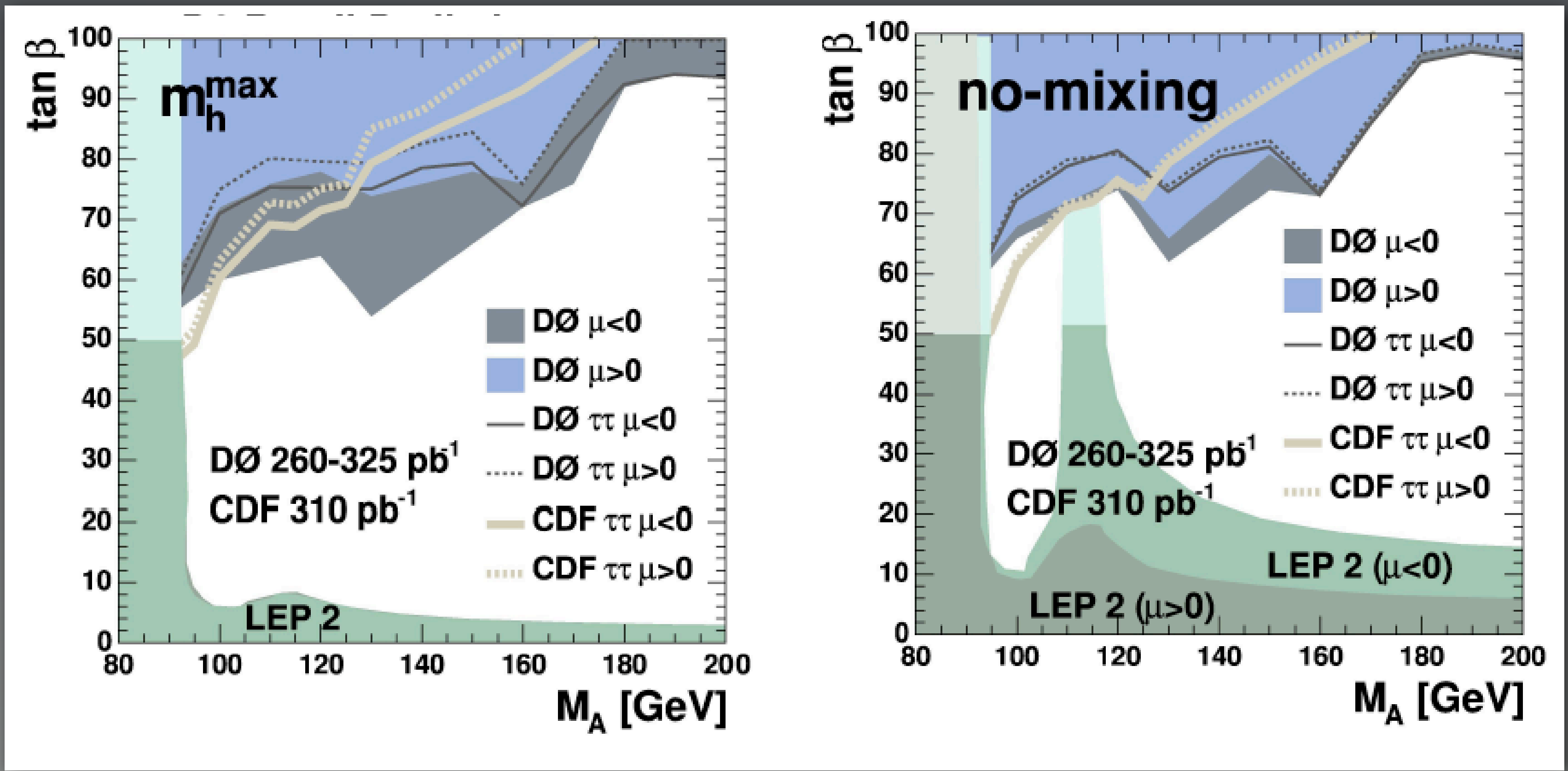
MSSM Higgs results until end 2006

LEP 2

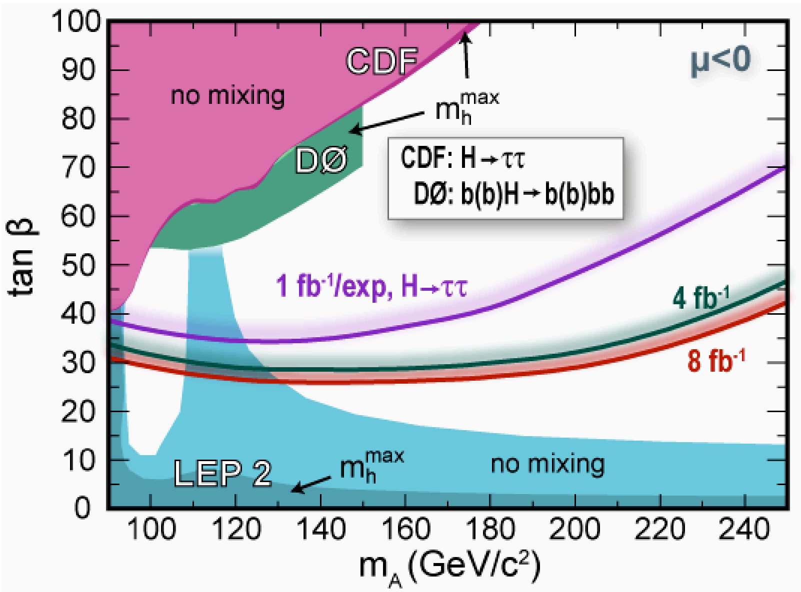
CDF ττ search, 310 pb^{-1}

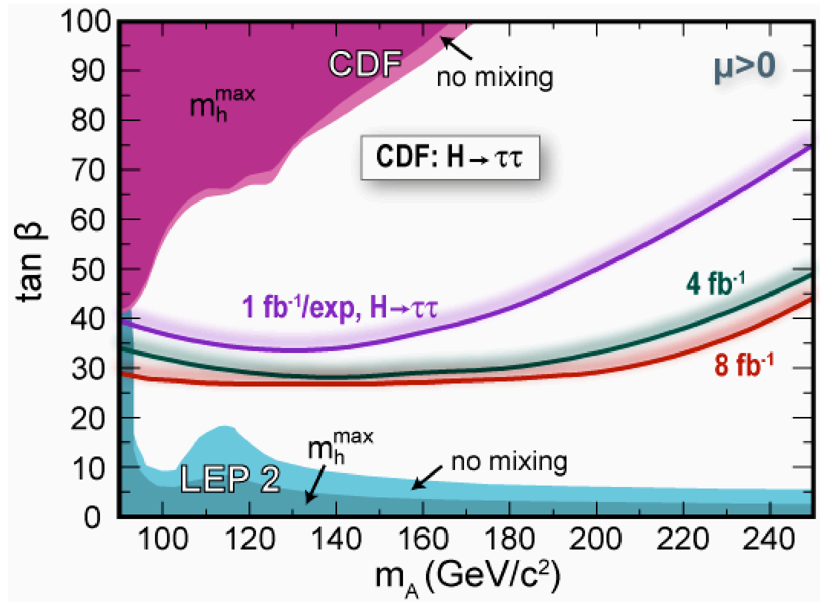
D0 ττ, ττb search 350, 288 pb^{-1}

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



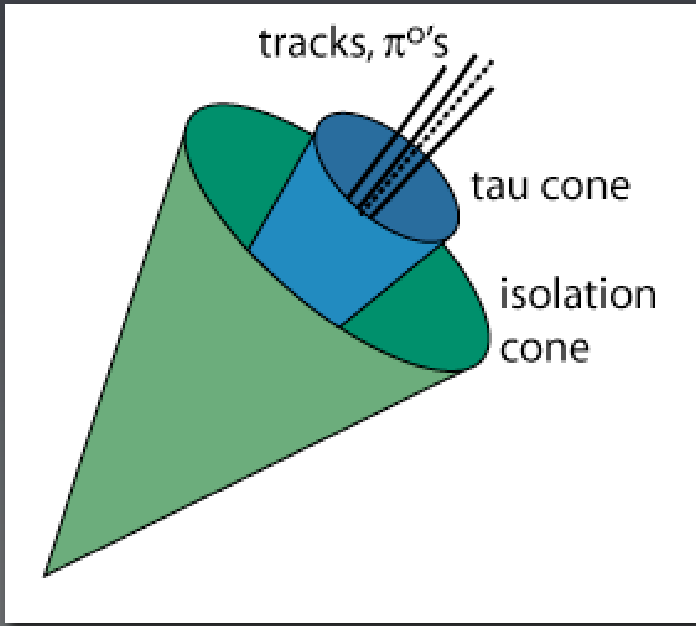
CDF observed, expected sensitivity

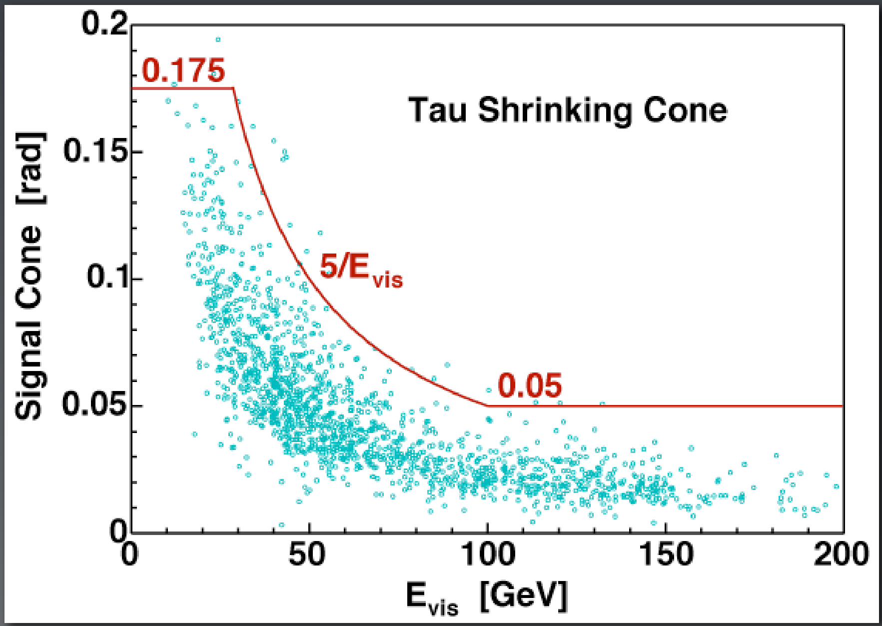




CDF: ττ result updated to 1 fb^{-1}

Tau Reconstruction in CDF

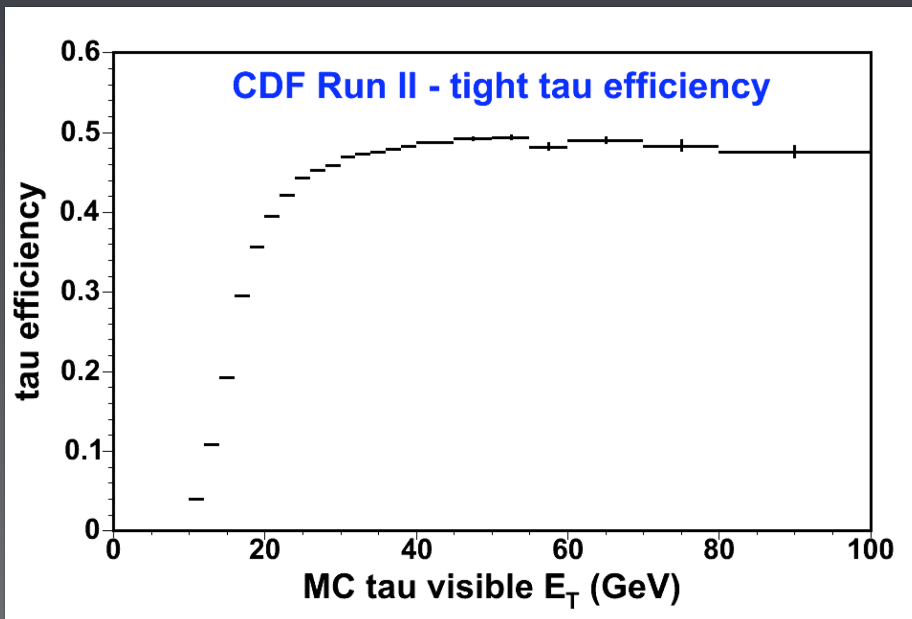




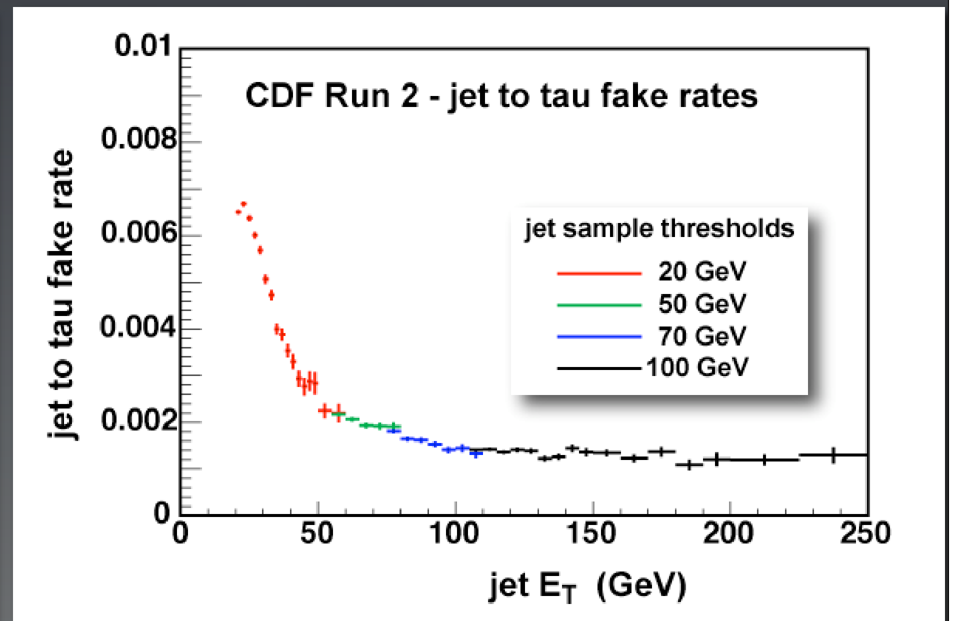
Cone-based algorithm: reconstruct hadronically decaying taus from $\pi^{\pm}$ and π^{o}

Demand no activity in isolation annulus to dosctriminate against jets

CDF tau ID performance

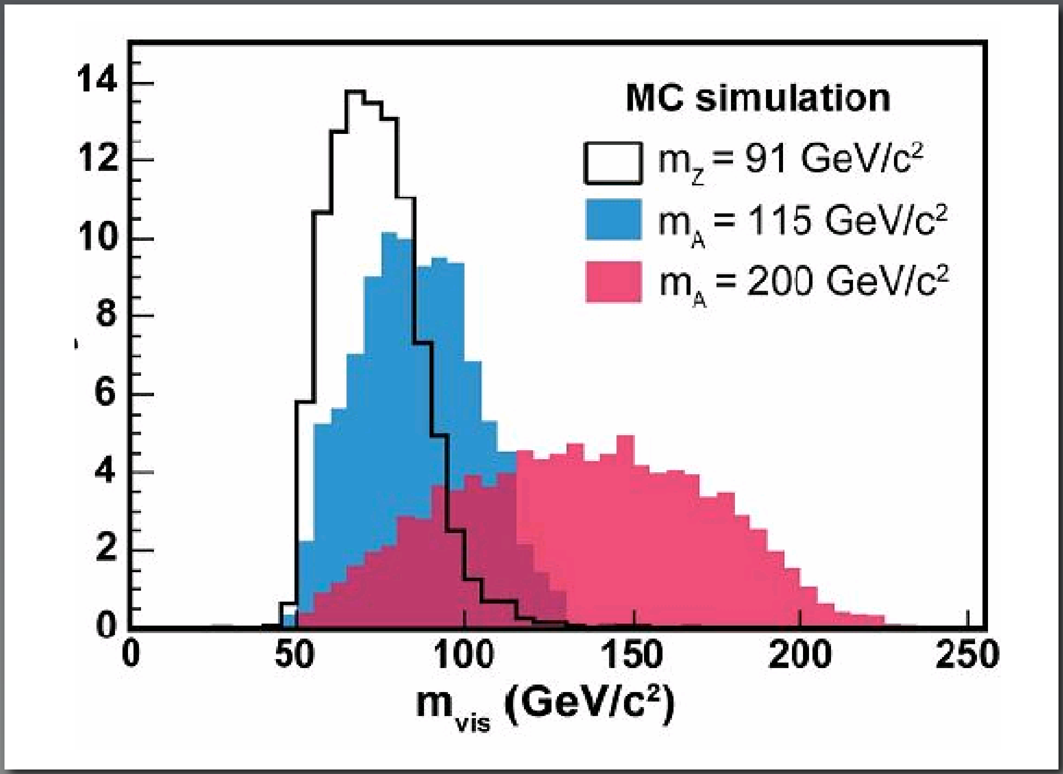


efficiency

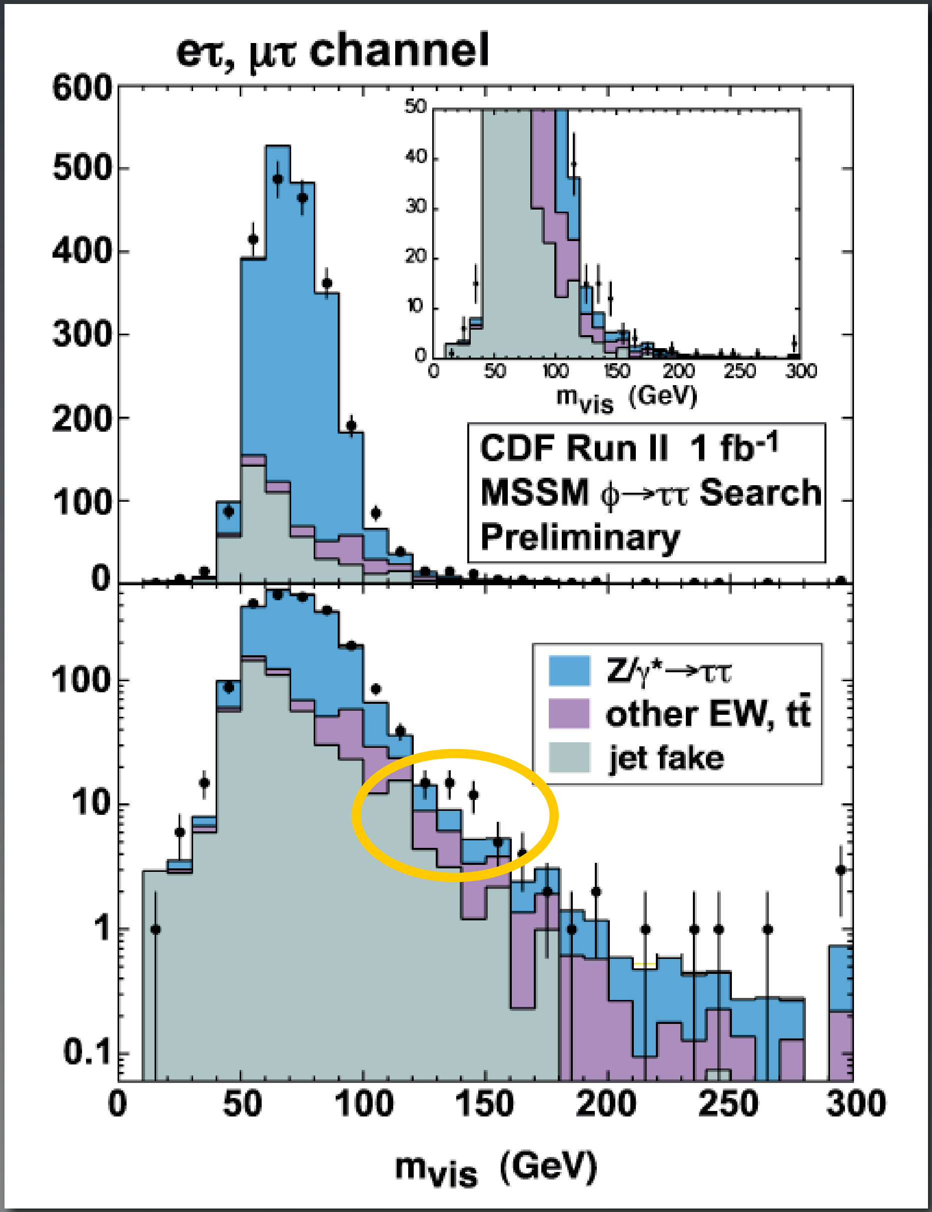


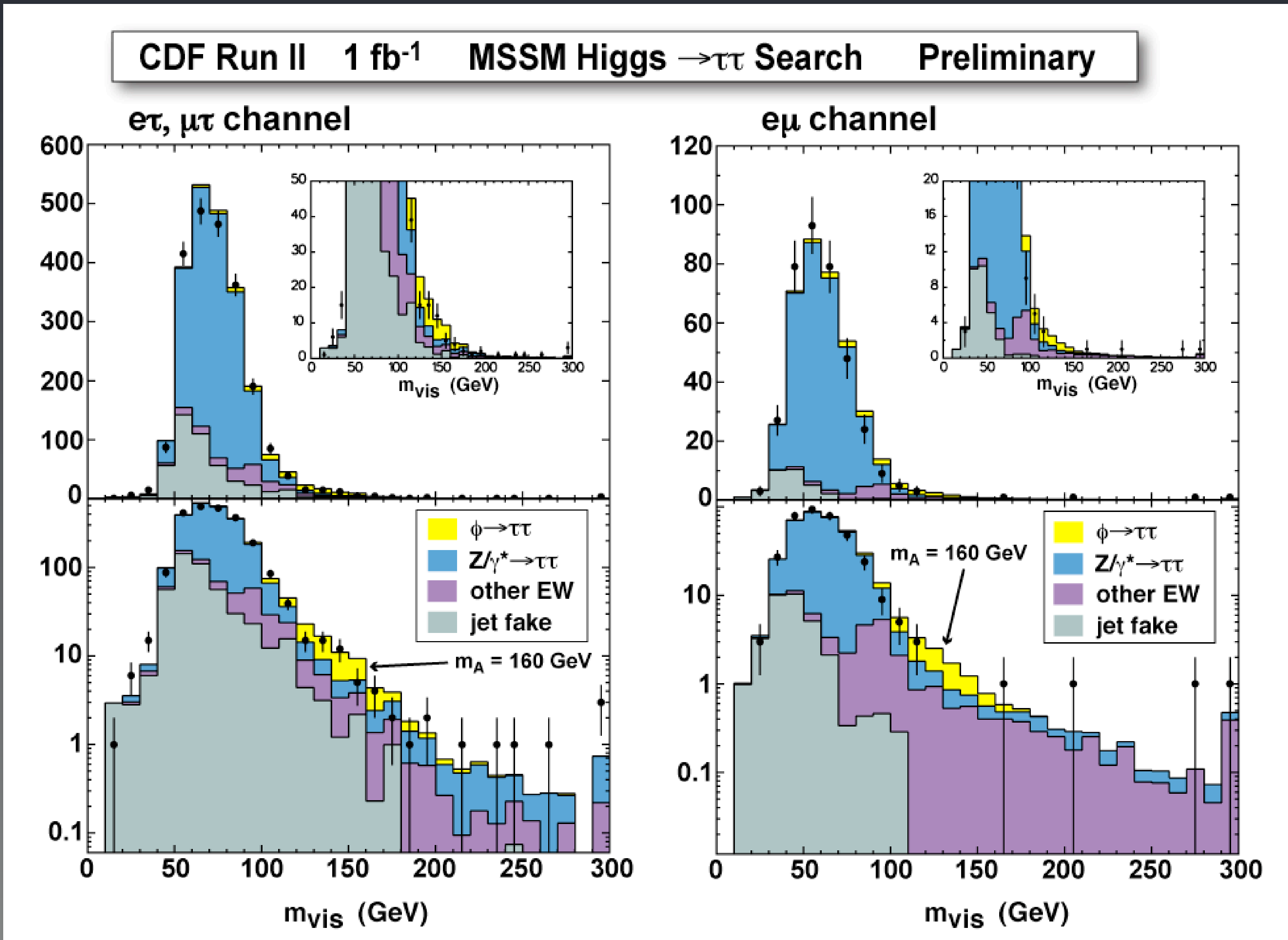
jet → tau fake rate

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



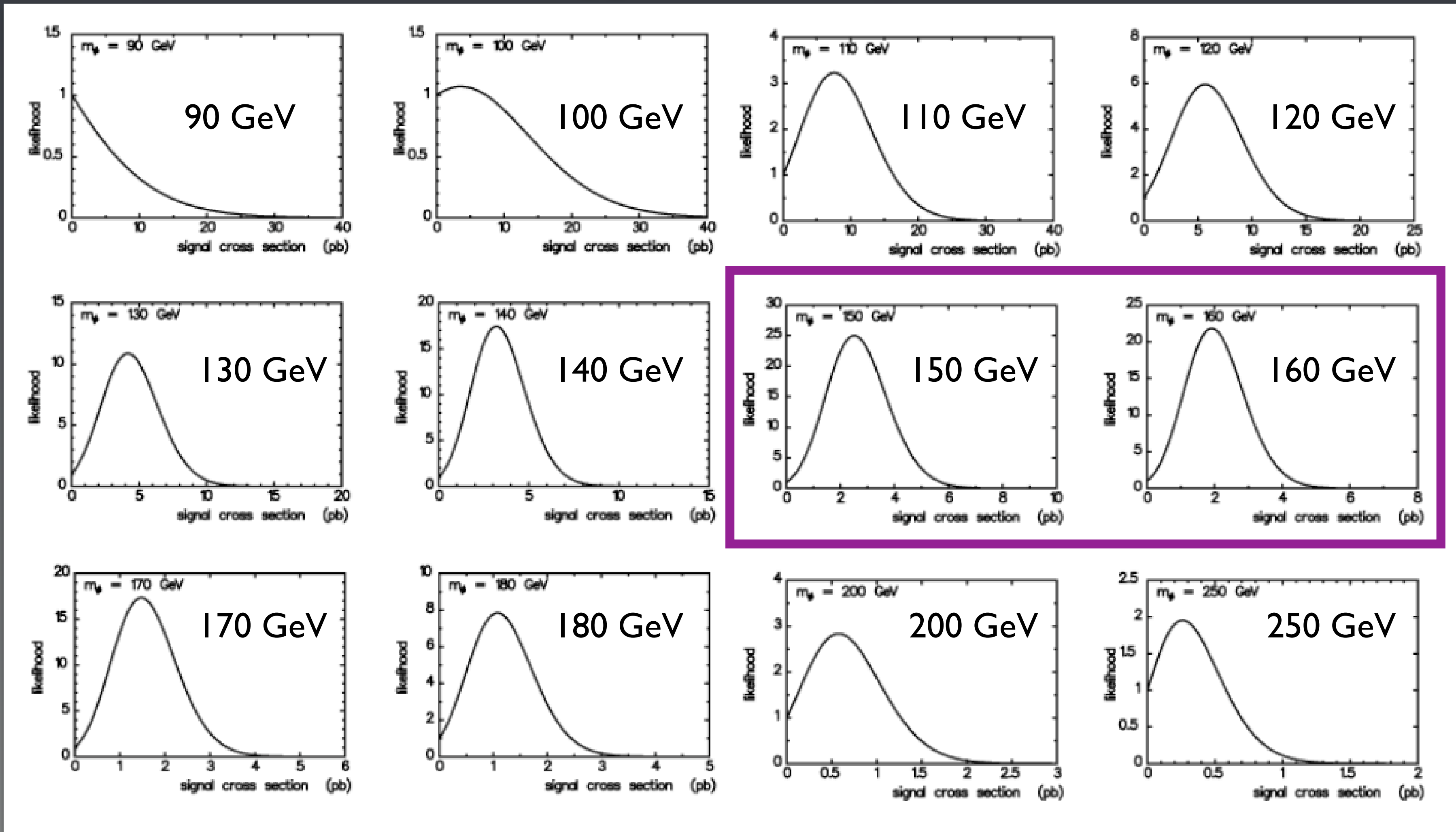
- performed analysis "blind" with respect to setting cuts, method, etc.
- opened the box in December and this is what we saw!



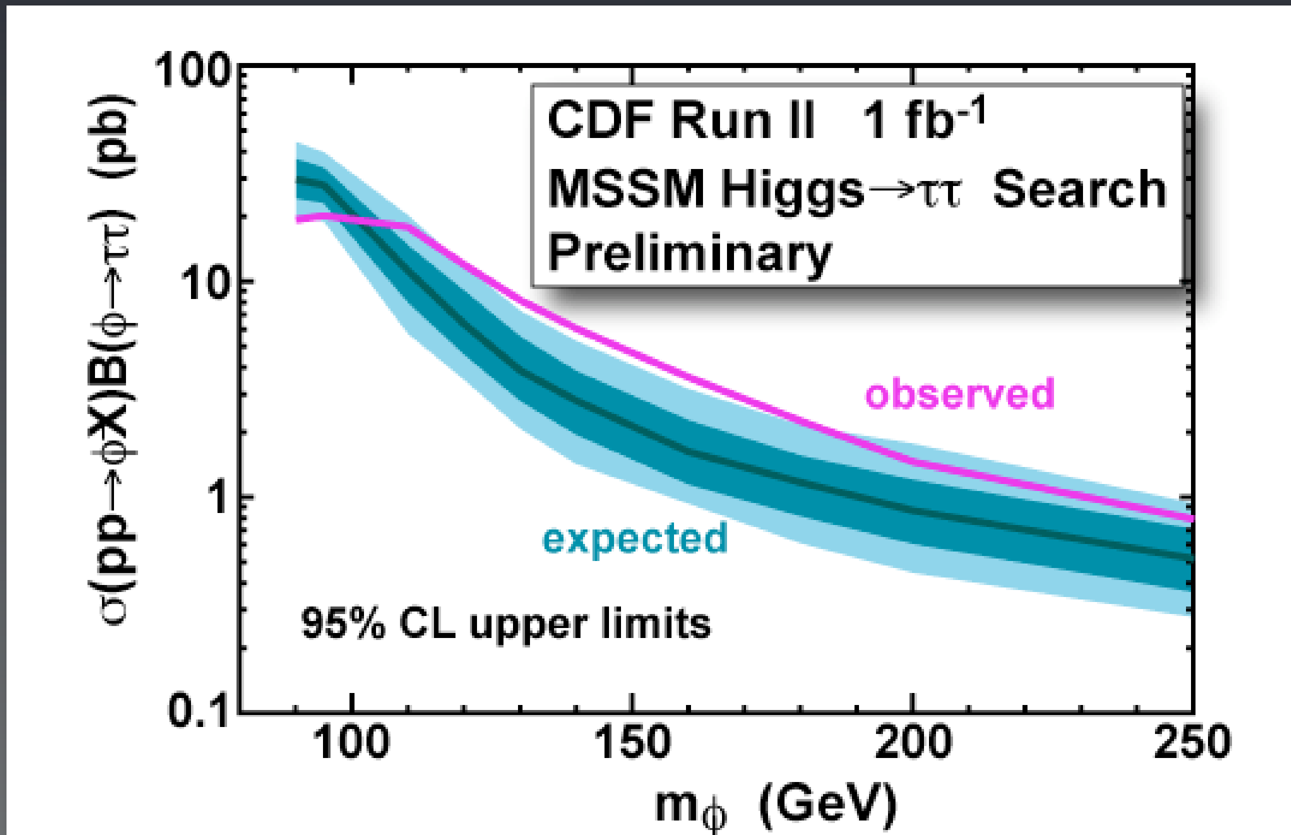


CDF Run II 1 fb-1 MSSM Higgs →ττ Search Preliminary
eτ, μτ channel
eμ channel
φ→ττ
Z/γ*→ττ
other EW
jet fake
mA = 160 GeV
mvis (GeV)

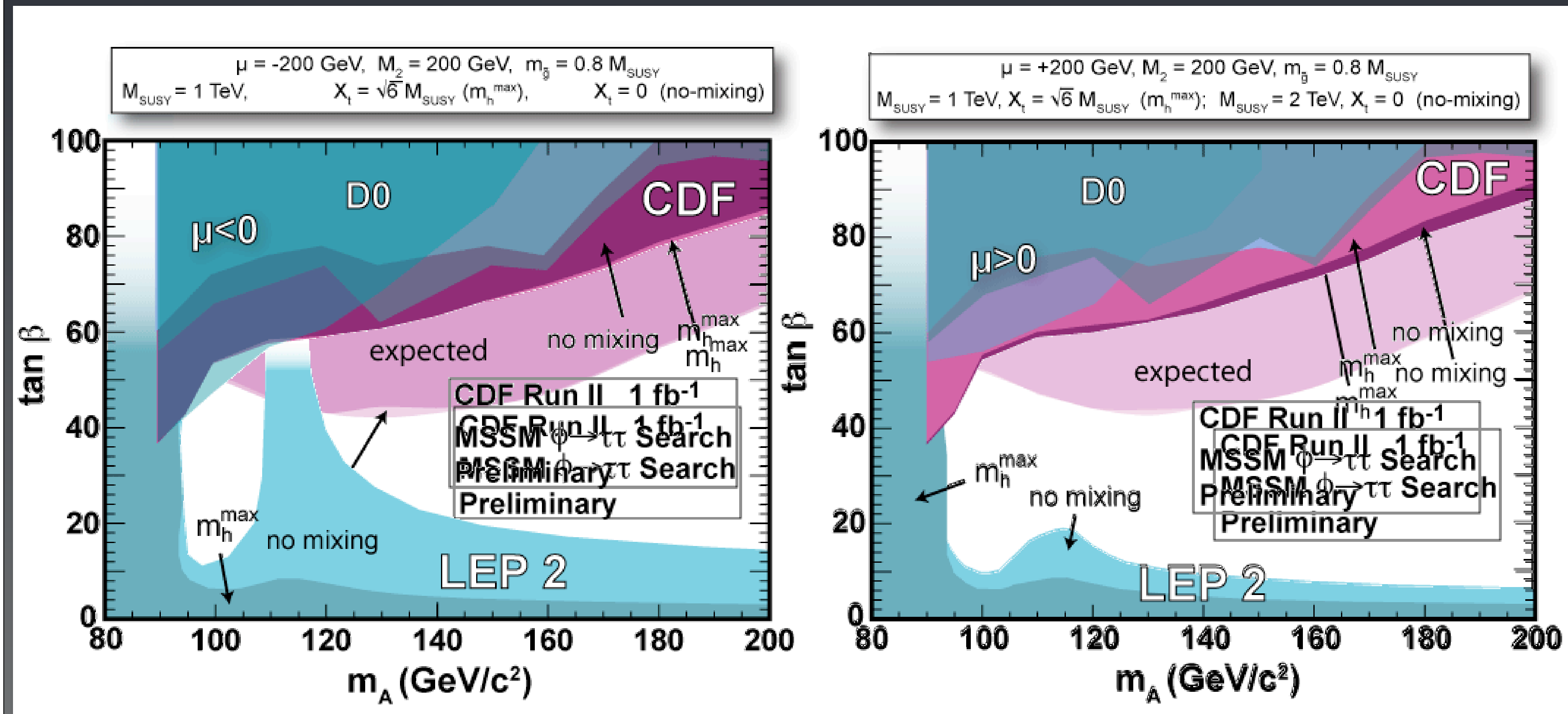
Likelihood versus Higgs cross section for different Higgs masses:



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

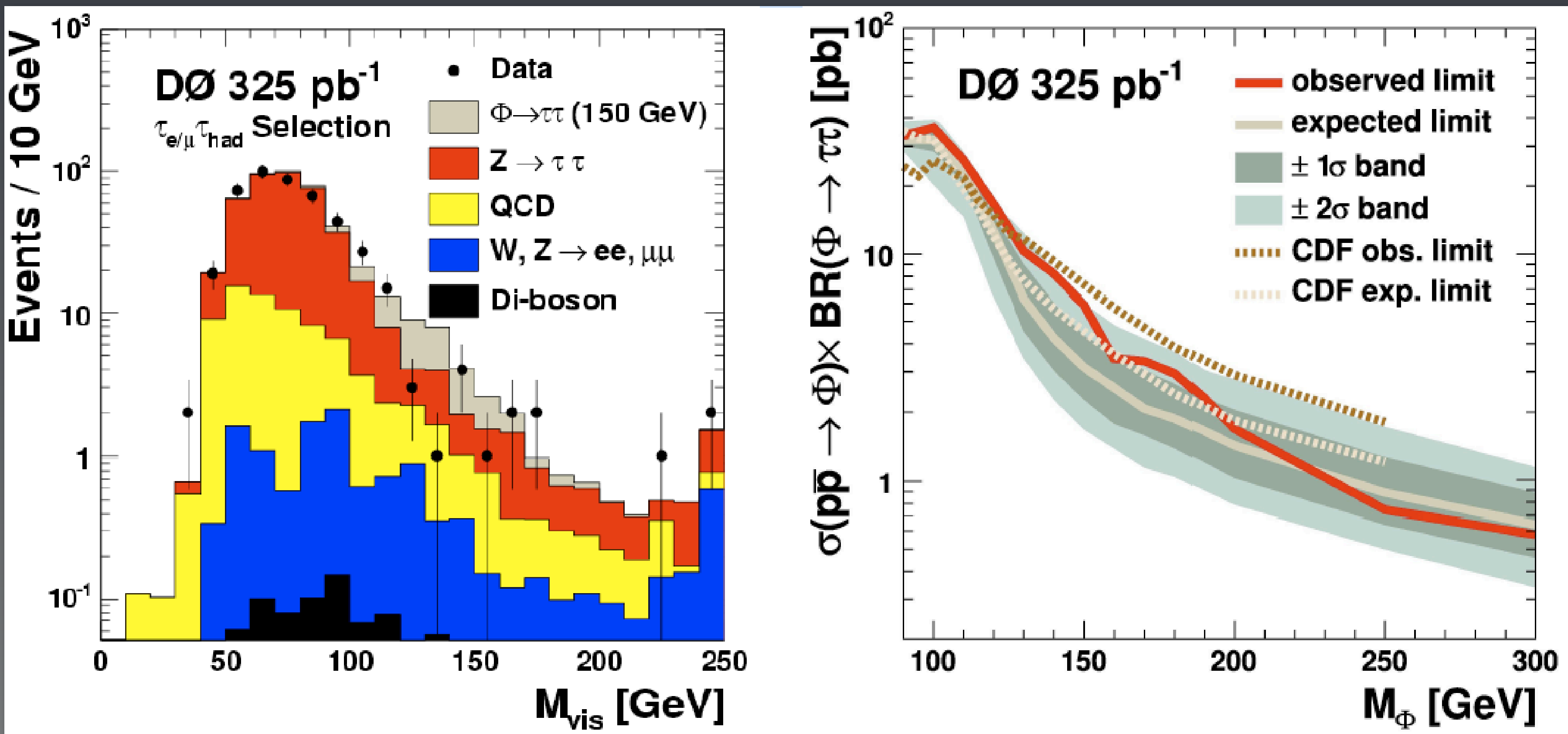


- observed limits stray from expected (for no signal)
- have done many cross checks - everything looks fine!



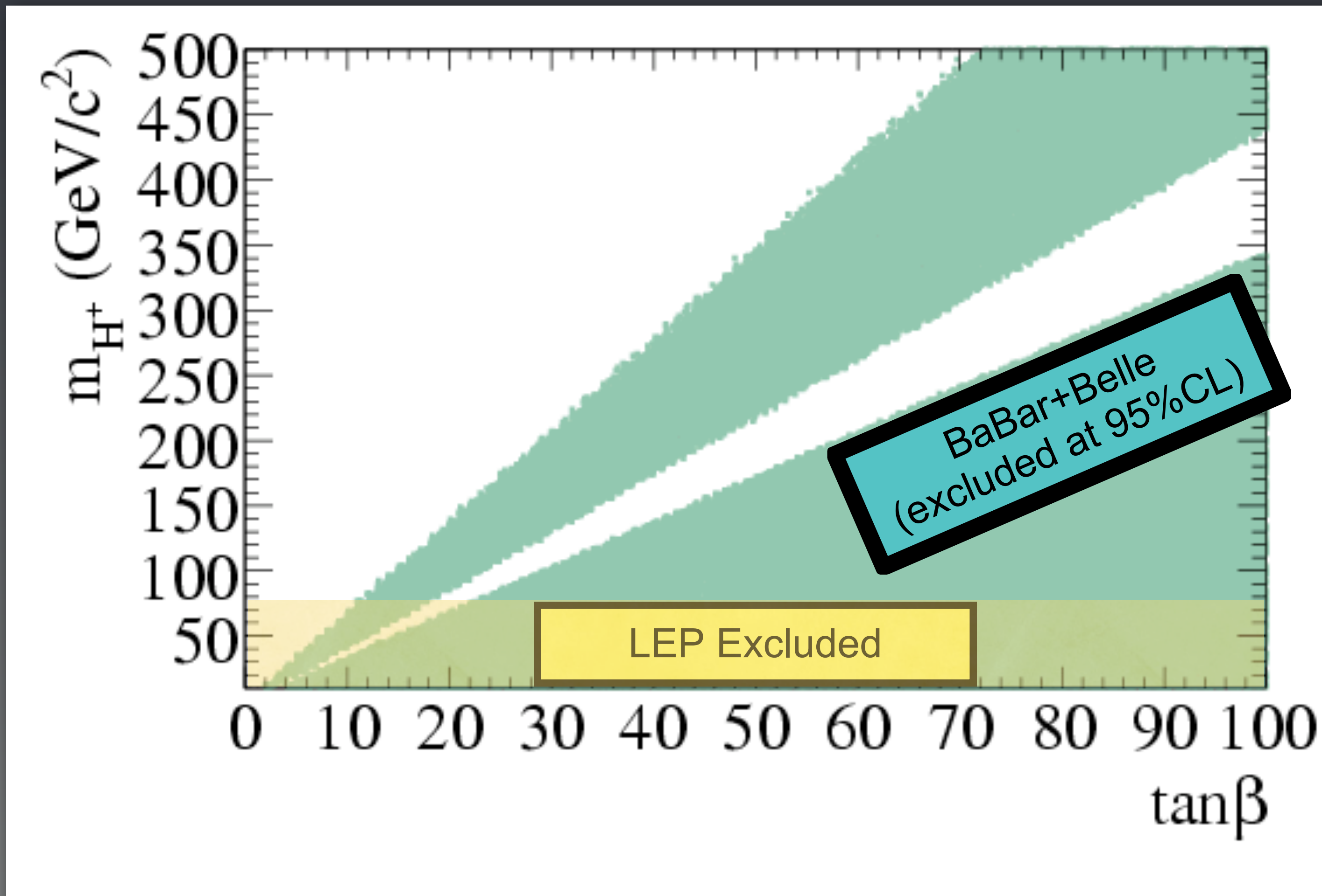
- obvious conclusion: more data!
- will have double this by summer
- working on $\tau\tau b$ channel

D0 - 350 pb^{-1} eτ, μτ result



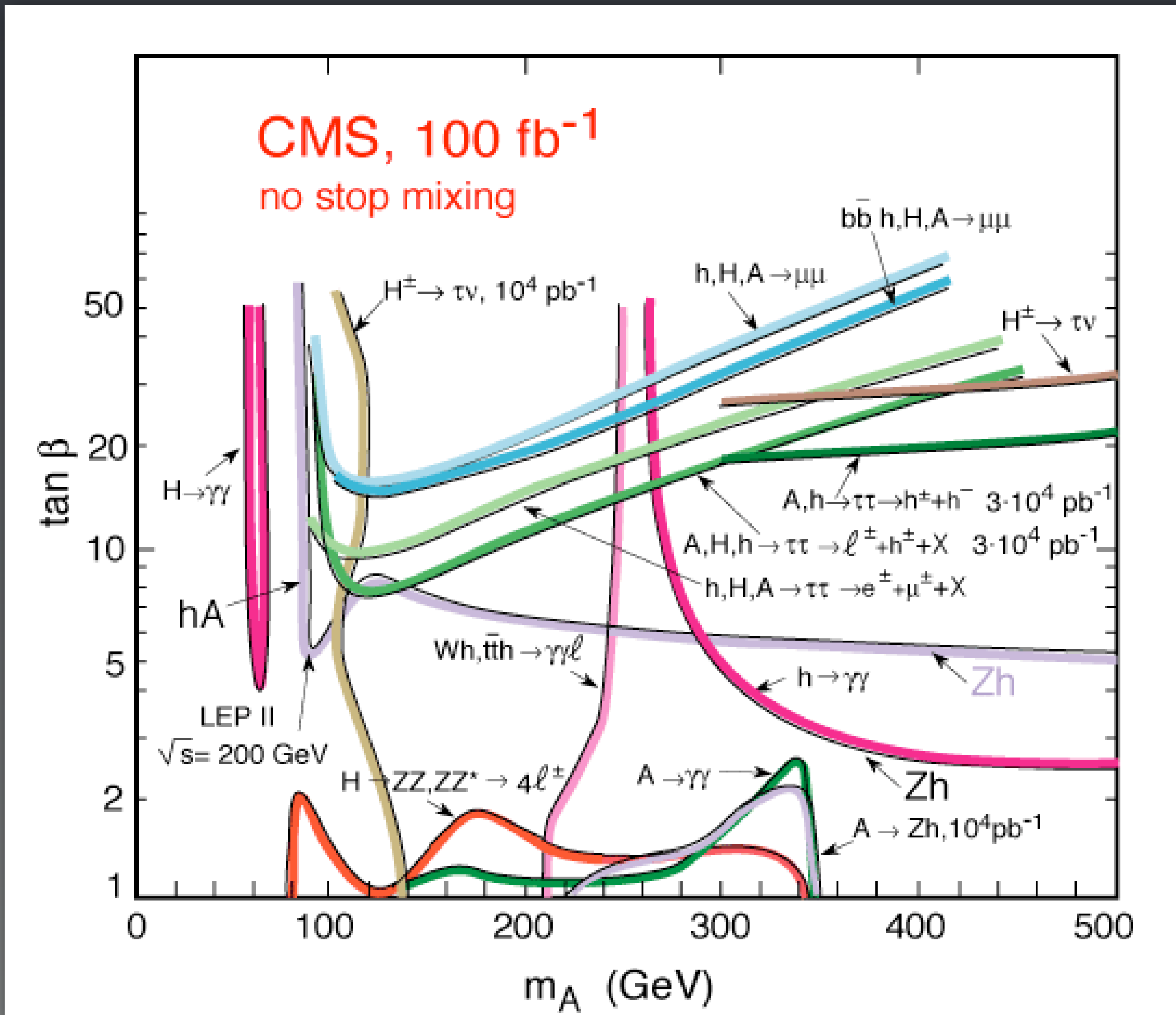
Looking forward to 1 fb^{-1} update!

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

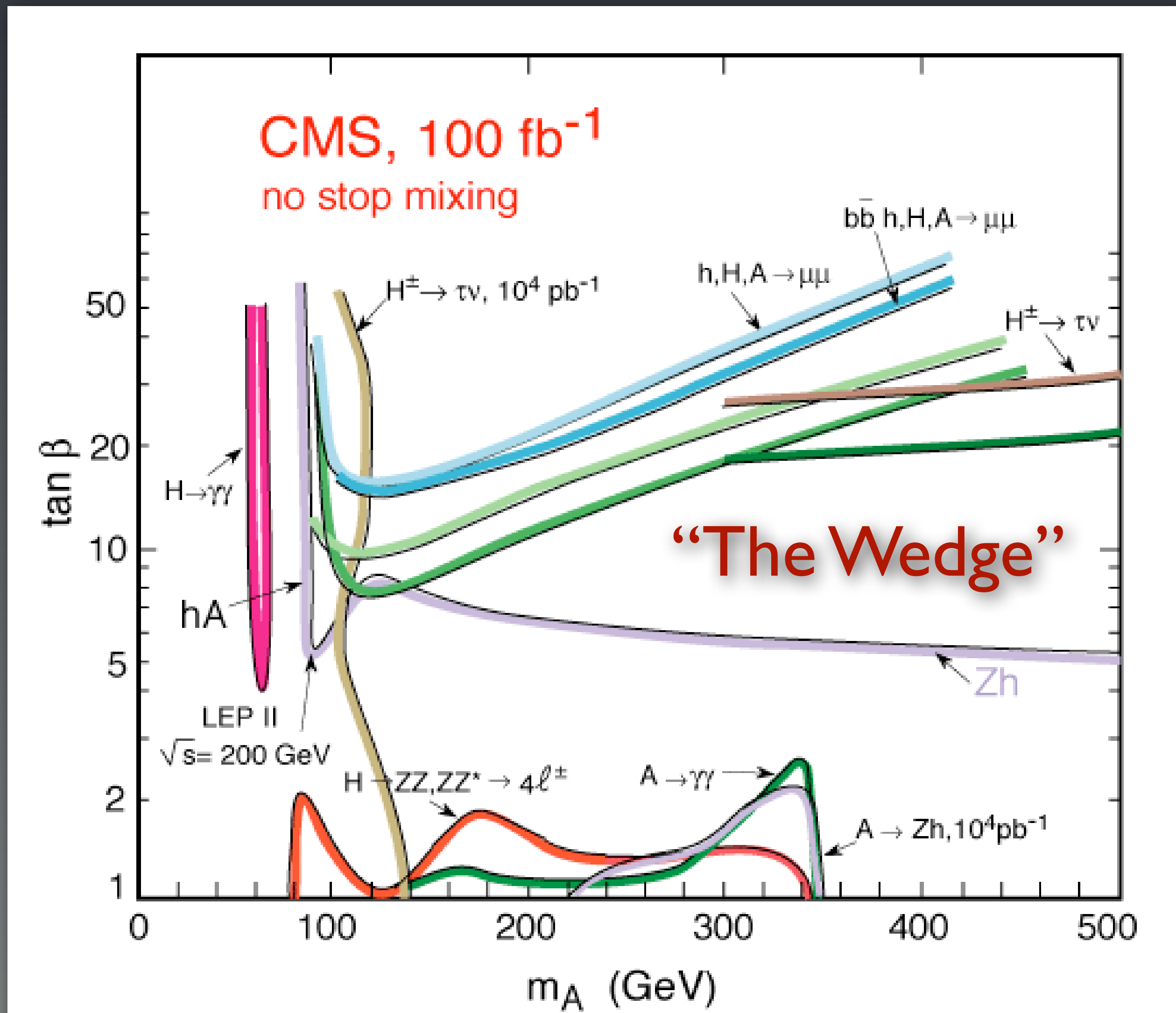


Paul Jackson (INFN Roma), DPF/JPS 2006

(See Marcela's talk later this week)



CMS, 100 fb^{-1}
no stop mixing
$b\bar{b}$ h,H,A → μμ
h,H,A → μμ
H$^{\pm}$ → τν, 10^{4} pb^{-1}
H$^{\pm}$ → τν
H → γγ
A,h → ττ → h$^{\pm}$+h^{-} 3·10^{4} pb^{-1}
A,H,h → ττ → ℓ$^{\pm}$+h$^{\pm}$+X 3·10^{4} pb^{-1}
h,H,A → ττ → e$^{\pm}$+μ$^{\pm}$+X
hA
Wh,$t\bar{t}$h → γγℓ
h → γγ
Zh
LEP II
$\sqrt{s}$= 200 GeV
H → ZZ,ZZ* → 4ℓ$^{\pm}$
A → γγ
Zh
A → Zh,10^{4}pb^{-1}
tan β
m$_{A}$ (GeV)



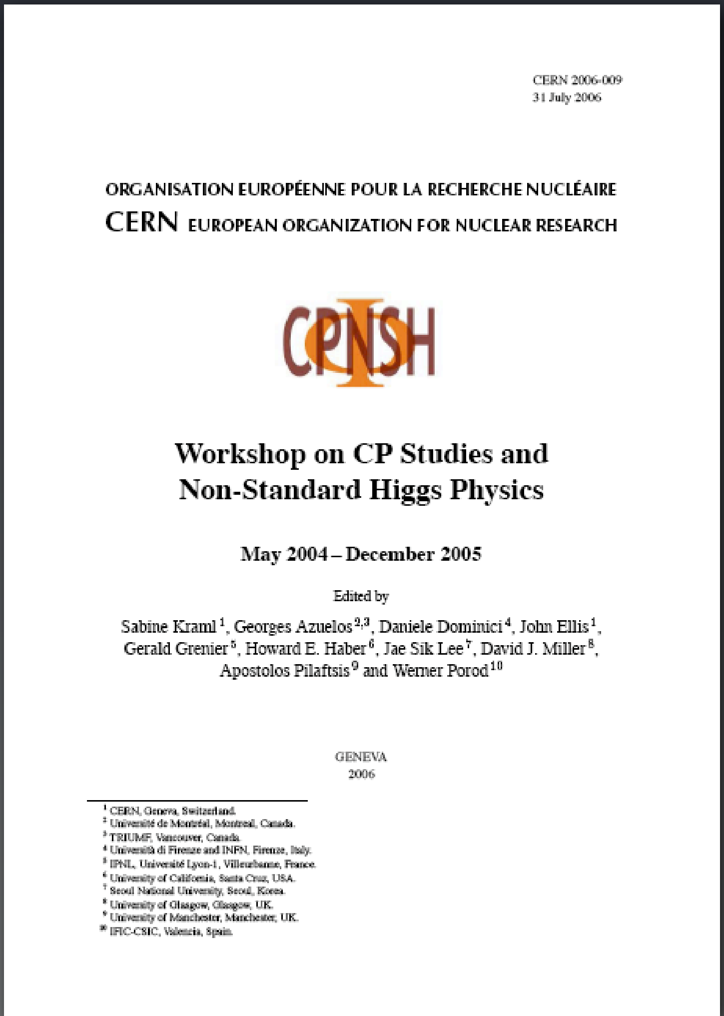
CMS, 100 fb^{-1}
no stop mixing
bb̄ h,H,A→μμ
h,H,A→μμ
H±→ τν, 10⁴ pb⁻¹
H±→ τν
H→γγ
hA
LEP II
√s= 200 GeV
"The Wedge"
Zh
H→ZZ,ZZ*→ 4ℓ±
A→γγ
A→ Zh,10⁴pb⁻¹
tan β
m_A (GeV)

3. A SUSY variant?

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

CPNSH workshop report out:

- $\not{C}\not{P}$ 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

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

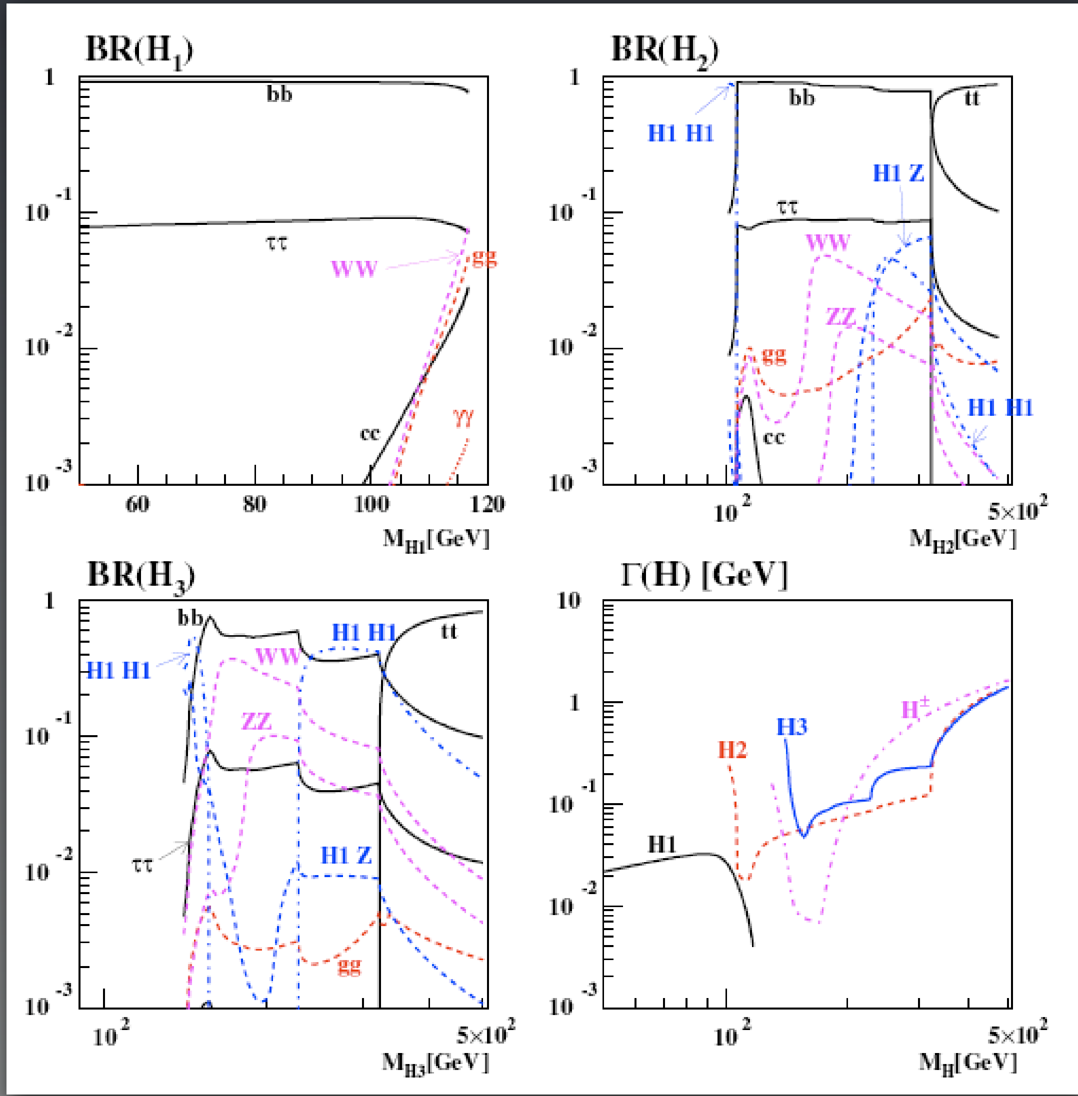
"Higgs Hunters Guide to non-standard Higgs"

One example: MSSM with CP phases

Three Higgs bosons H_1, H_2, H_3

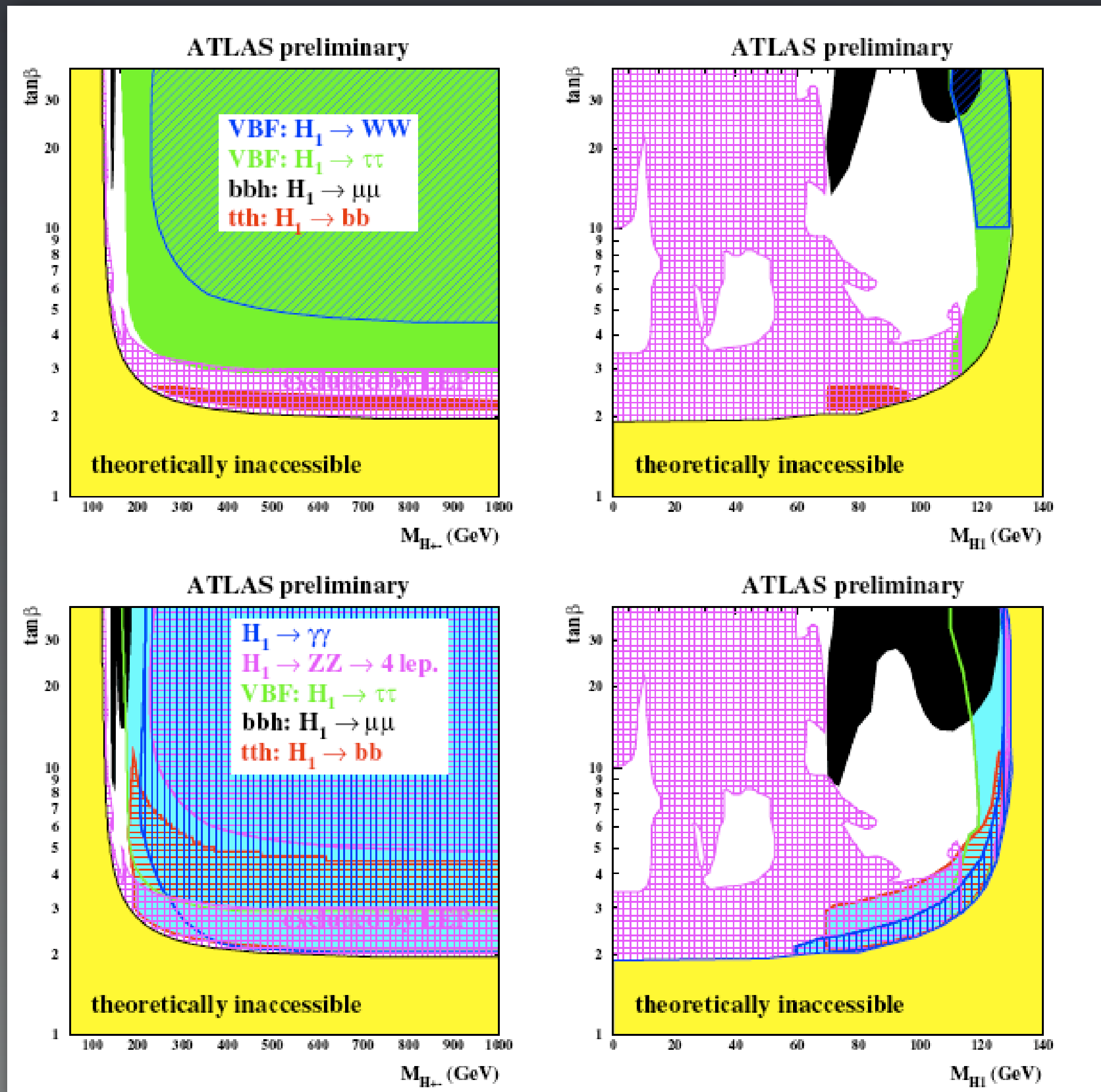
Branching ratios look somewhat familiar!

Use SM, MSSM searches to probe the model



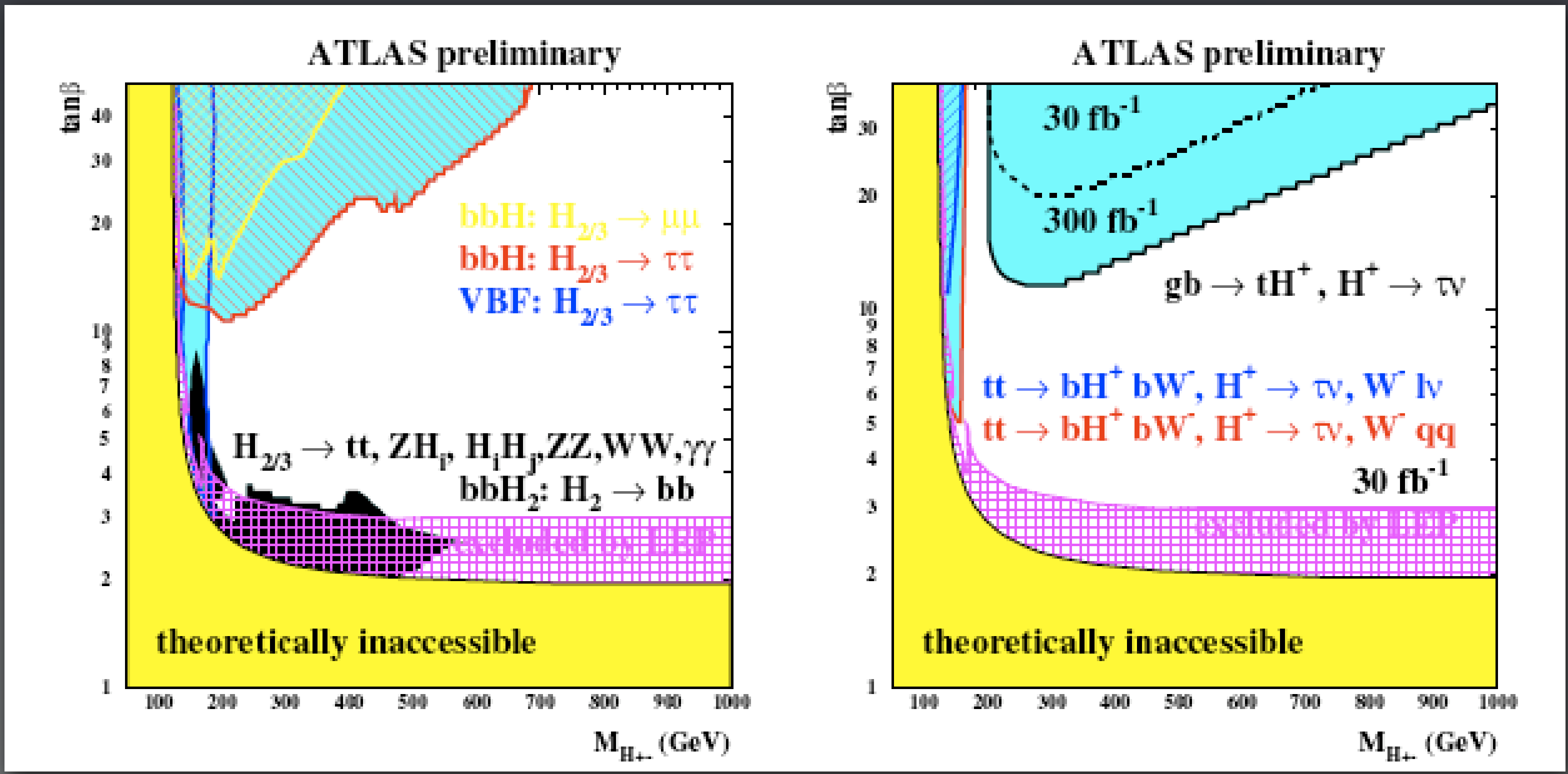
CPNSH report

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...