Higgs Boson Beyond the SM
(Alternate EW Breaking Scenarios)

Nonstandard Higgs Decays

HCP 08

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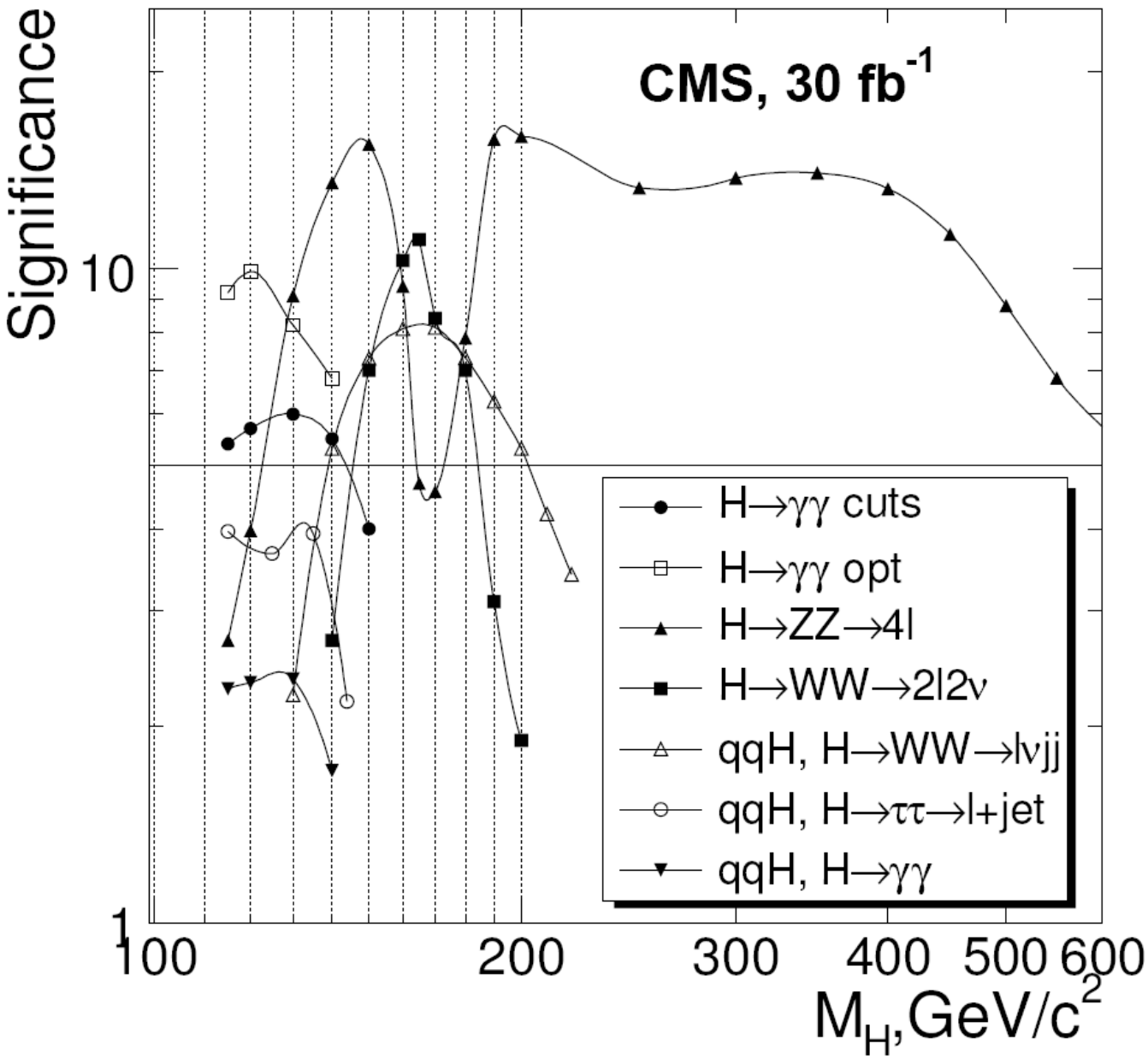
See review article w/ R. Dermisek,
J. Gunion, and N. Weiner for references
arXiv:0801.4554

Motivation

- Higgs boson is last undiscovered particle of Standard Model (SM)
- Crucial discriminant of mechanism of EWSB and expected to be related to new physics
- LEP2 SM Higgs limit says it is heavier than 114.4 GeV

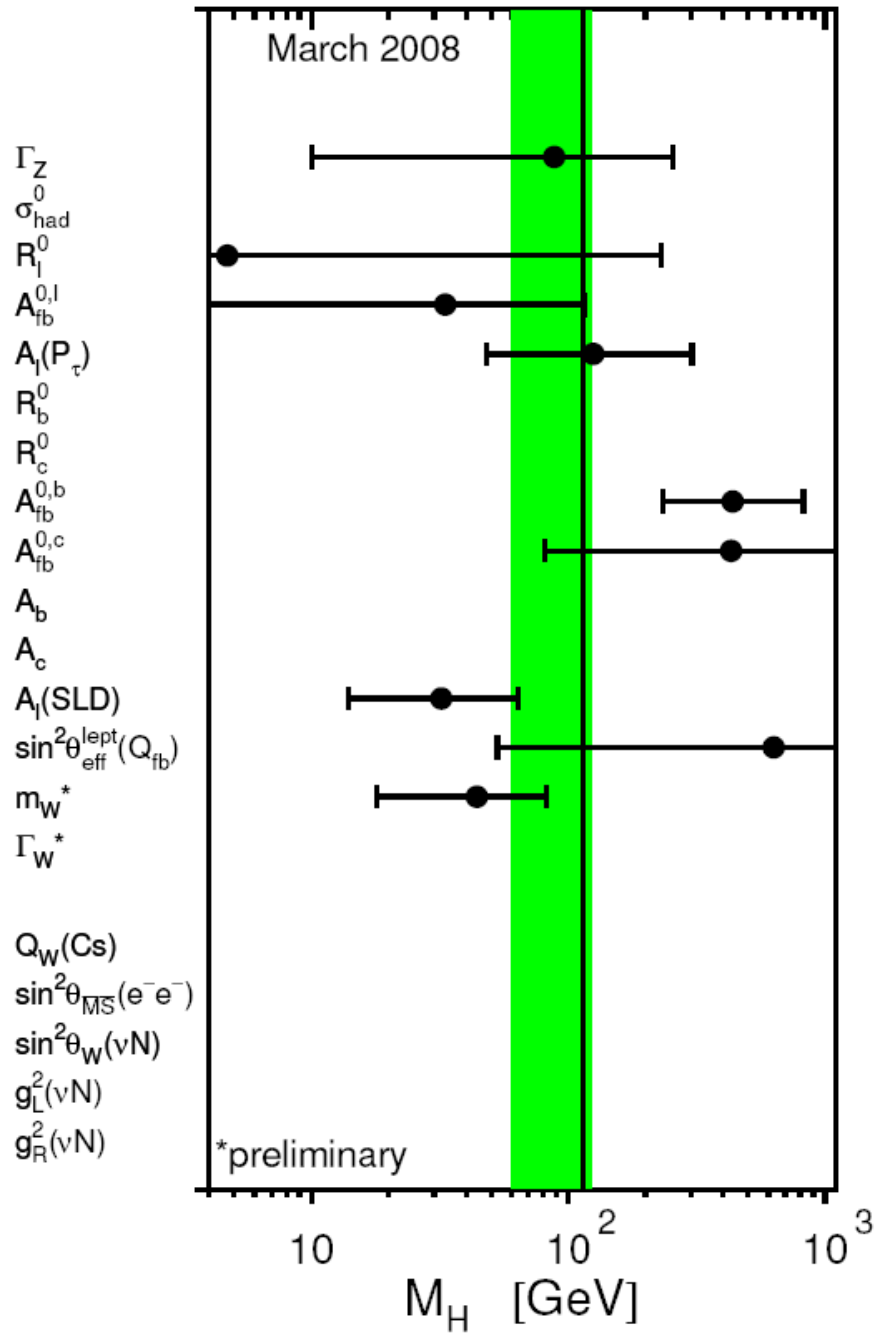
LHC is prepared for SM Higgs



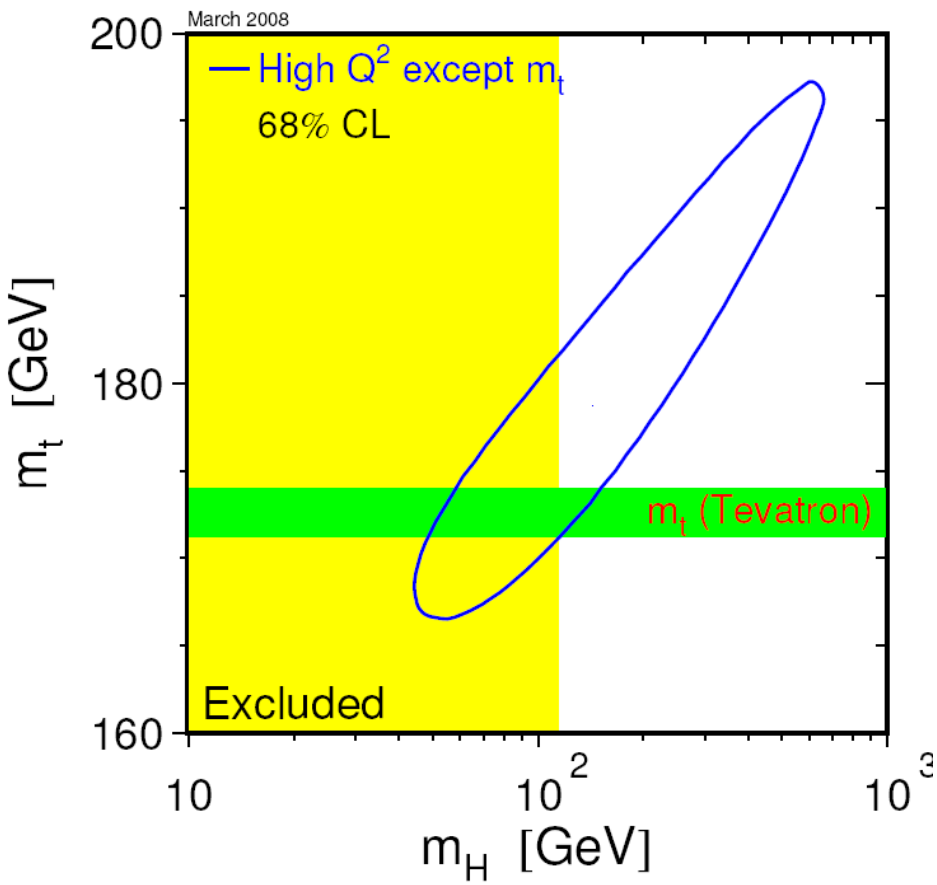
However, Higgses with nonstandard decays are a potential loophole in LHC's Higgs reach

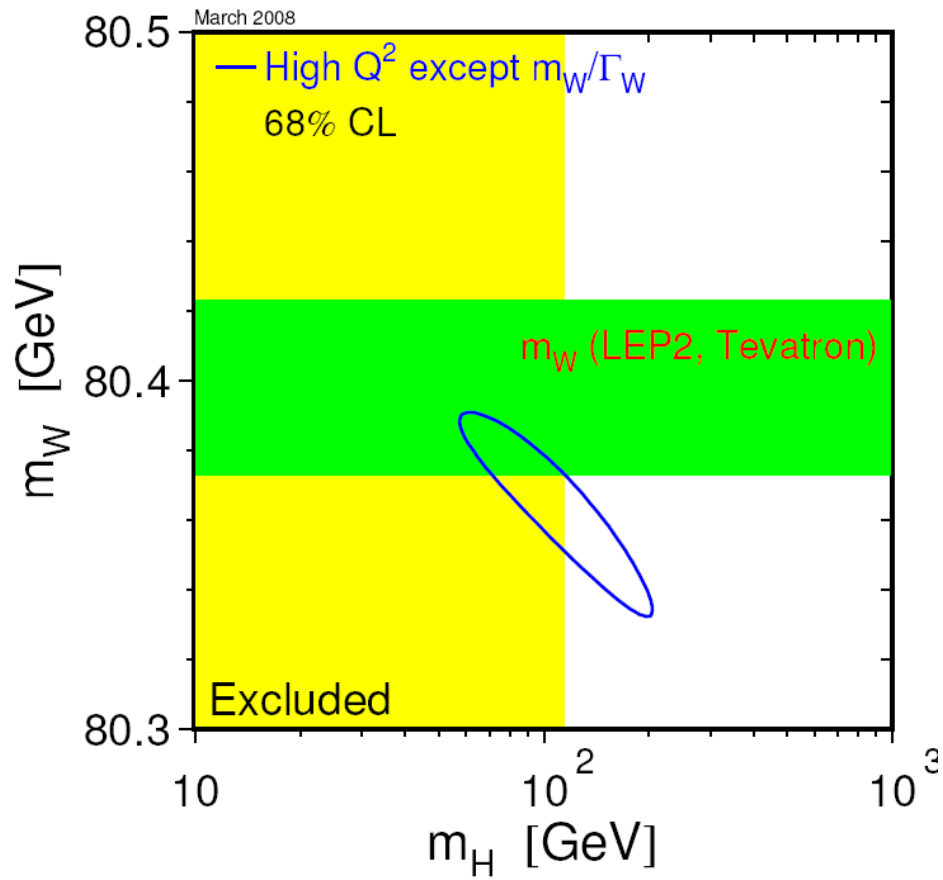
Expt'l: Electroweak Precision

Historically, a systematic preference for light Higgs masses



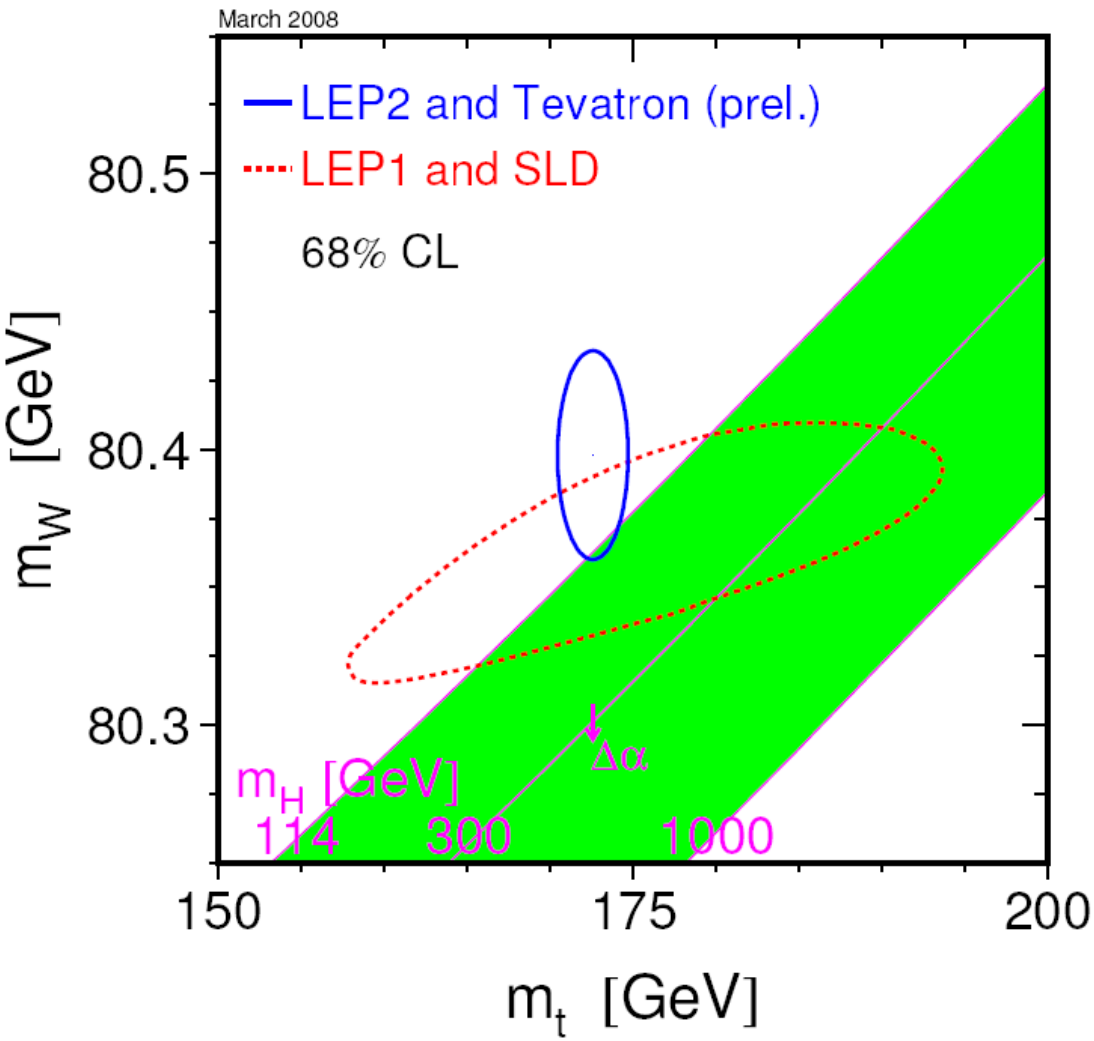
Recent Tevatron Measurements





Continues the trend...

Combined Plot

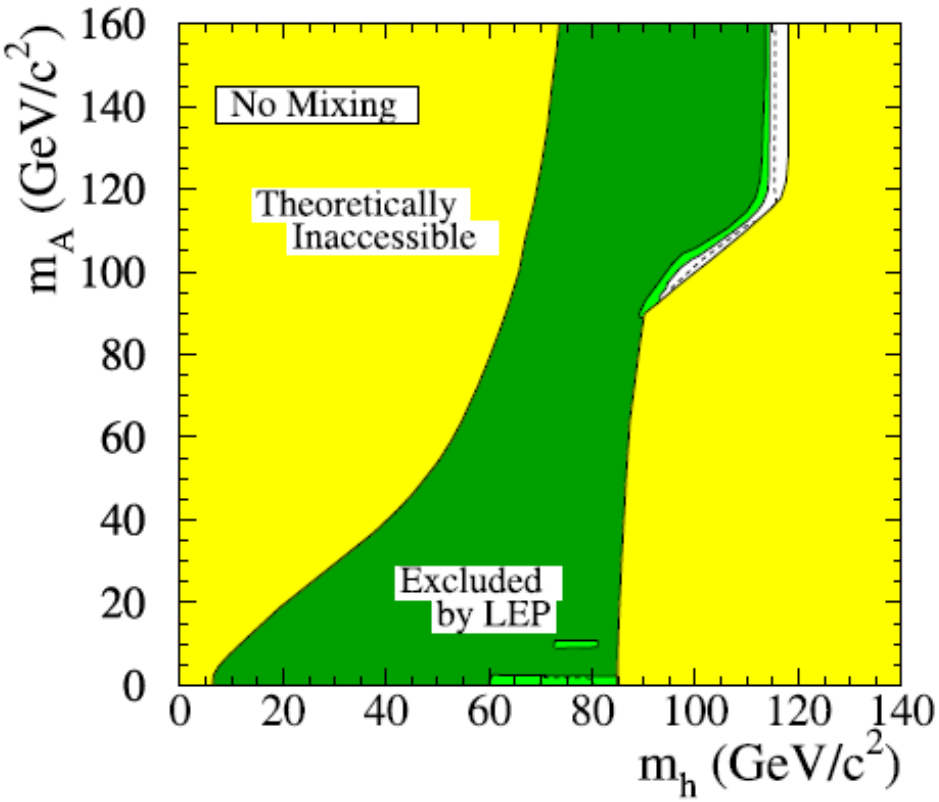


SM Higgs limits from indirect search (EWPOs) and direct search are slightly at odds

Theoretical Issues

- In many BTSM theories, e.g. MSSM, Higgs mass typically below Z mass; LEP2 Higgs limit leads to fine-tuning at O(1%)
- This “little hierarchy” problem exponentially sensitive to the Higgs mass limit

LEP limits on supersymmetric Higgs



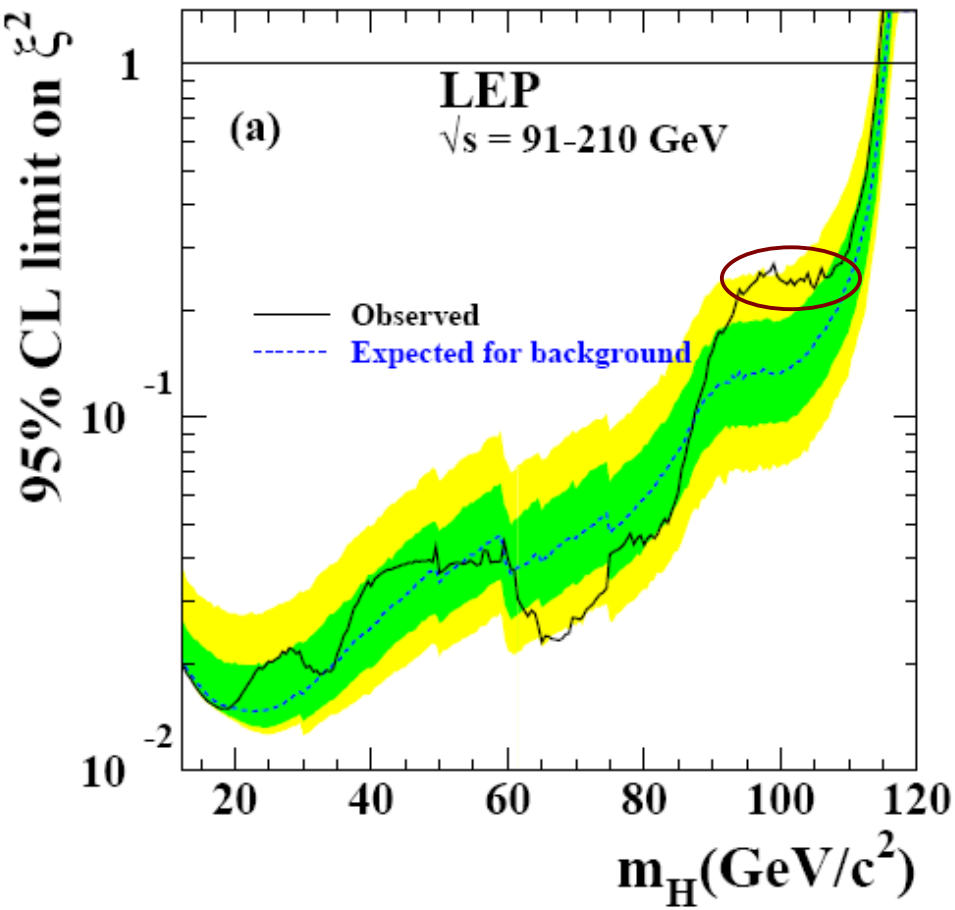
Higgs Susceptible to New Decays

- SM Higgs has a small decay width
- At 100 GeV, $\Gamma/m \sim 10^{-5}$
- If there are new states lighter than Higgs, decays into these can dominate over standard decays; weakens SM search limit
- If these states are unstable, limits on Higgs can be weaker than 114.4 GeV

Quick Summary

- Nonstandard Higgs is suggested by many uncorrelated hints from experiment and theory
- Consistent scenario
  - PEWOs: Mass is lighter than 114 GeV; SM couplings normal, production unchanged
  - Cascade decays: facilitated by new light unstable particles
  - Little Hierarchy: relieved by avoiding direct search
- Pheno implications too important to ignore

Implications



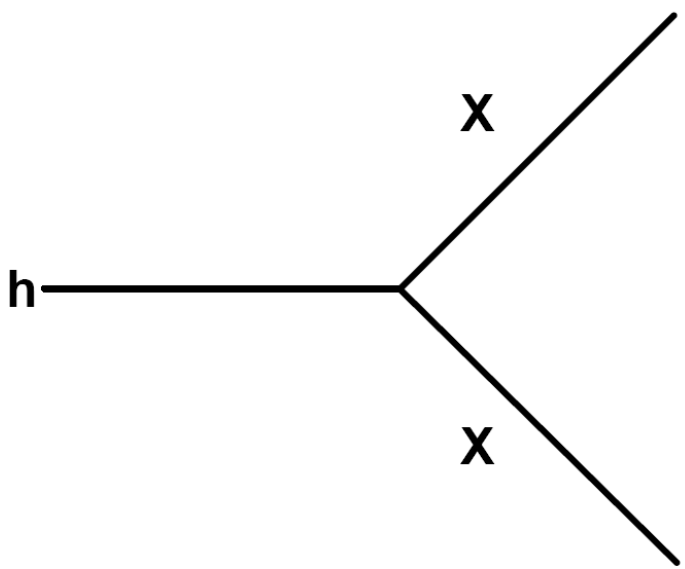
Note: Largest excess at 98 GeV is consistent w/ ξ^2 = .1

- Reduced SM branching ratio means standard searches will need more luminosity
- Typically need at least 20 times the luminosity ~ O(100 fb^{-1}); requiring SLHC?

Some Simple Examples

One New Particle

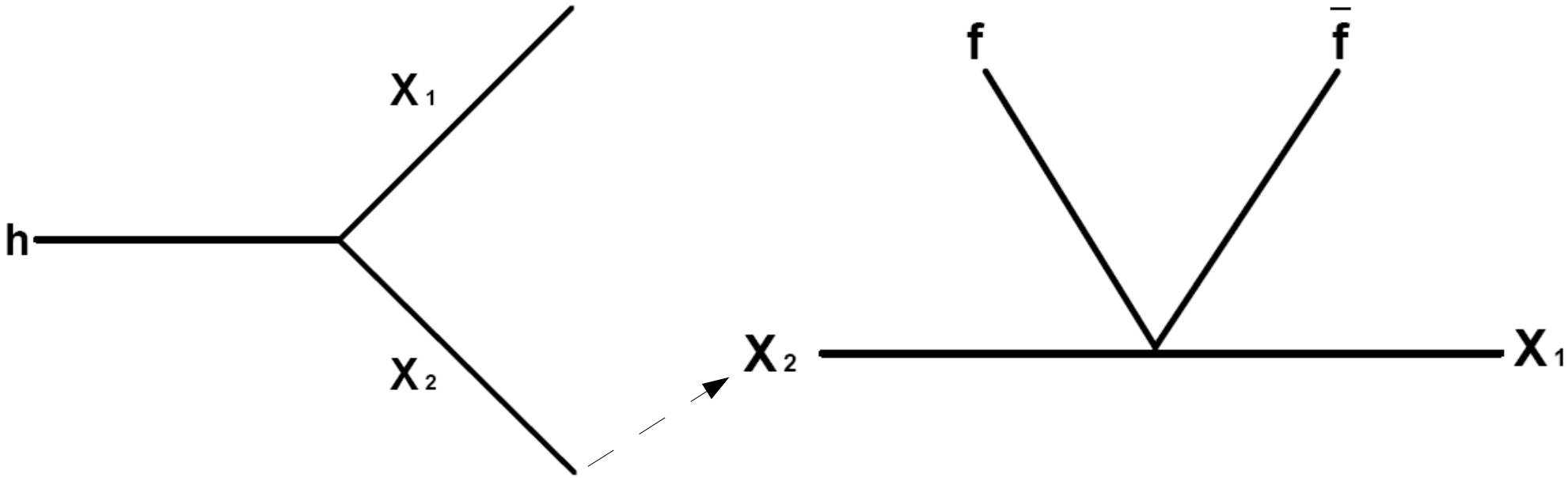
$h \to 2X \to SM$



- X = Scalar ~ Mh limit
  - Higgs-like: $X \to bb, \tau\tau$ — 110, 86 — Gunion et.al. Dermisek et.al. SC et.al. Strassler et.al.
  - Fermiophobic: $X \to gg, \gamma\gamma$ — 90-100 — Dobrescu et.al. SC et.al.
- X = Fermion — 80's — Carpenter et.al. Kaplan et.al.
  - RPV: $X \to 3q$

Two New Particles

SC, Weiner
Kribs et.al.
Graesser
De Gouvea



- X_1 is stable
- X_2 decays into X_1, giving topologies w/ both visible and missing energy $h \rightarrow X_1 X_2 \rightarrow f\,f + \text{MET}$
- Given BRs, limits roughly 100 GeV

Nonstandard Higgs Decay Cascades

- Higgs production unchanged
- Decay cascades into many SM particles (3 or more), topologies generic enough to appear in many different searches
- Objects typically softer
- Decays of light states potentially highly displaced
- Limits from LEP2 and Tevatron generically weaker, ~ 100 GeV

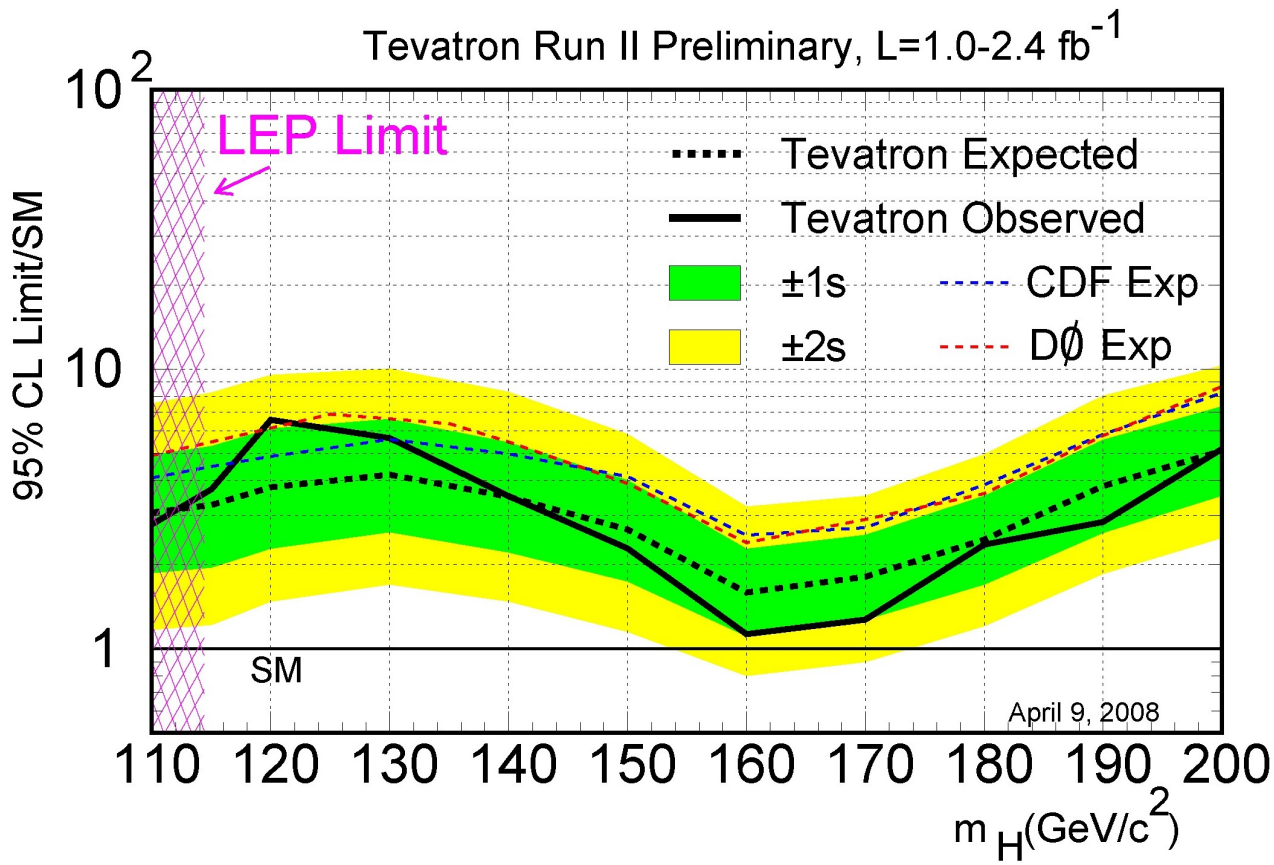
Collider Analyses
to pursue in the next few years

Tevatron

&

LHC

Tevatron Standard Searches

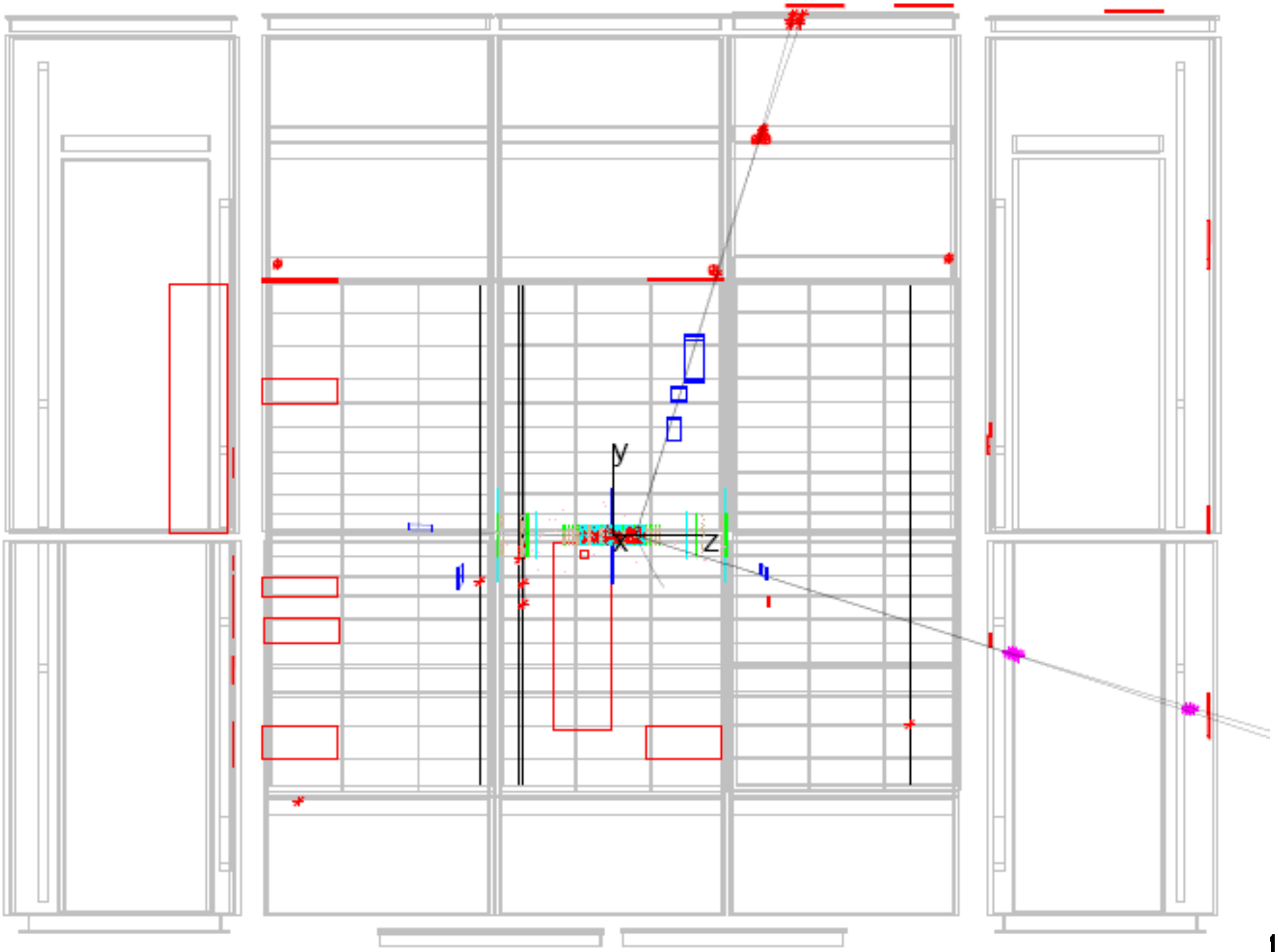


- Extend exclusion of SM Higgs
- Push little hierarchy problem and fine-tuning priors

Tevatron Nonstandard Searches

- Some clean topologies can be searched for
- HyperCP suggests a new scalar X of mass 214.3 MeV which decays to muons
- DØ is currently searching for associated $h \rightarrow 2X \rightarrow 4\mu$ signal

E.g. Signal Event by DØ



DØ Study Under Way

- Efficiency to reconstruct 4 muons is good
- Background small
- Sensitive to X masses where muon decays dominate (<450 MeV)
- Need good ideas to look for larger X masses; e.g. $h \rightarrow 4\tau$

Tevatron Message

- Statistics suggest searches best suited are optimized for specific signals
  - Standard Model searches: Improve upon LEP limit at high and/or low masses?
  - Nonstandard searches: HyperCP motivated... any other possibilities?

LHC Early Searches

- Continue to search for SM Higgs
- Some SM channels have efficiency for nonstandard decays
- However, could also appear in unexpected location

VBF h → W W*

Work in progress
w/ Gregoire

- SM search can constrain nonstandard h → dilepton + MET
- Reproducing ATLAS 2004 study, get 2% efficiency (preliminary)
- Signal ~ σ * BR * eff ~ 5 pb * .03 * .02 ~ 3 fb
- Background ~ 1.33 fb (ATLAS)
- Despite kinematic differences, original cuts do not kill nonstandard decay signal

Really Nonstandard Searches

- Sometimes displaced vertices can occur if light states are metastable
- e.g. R-parity violation $h \to \chi\chi$

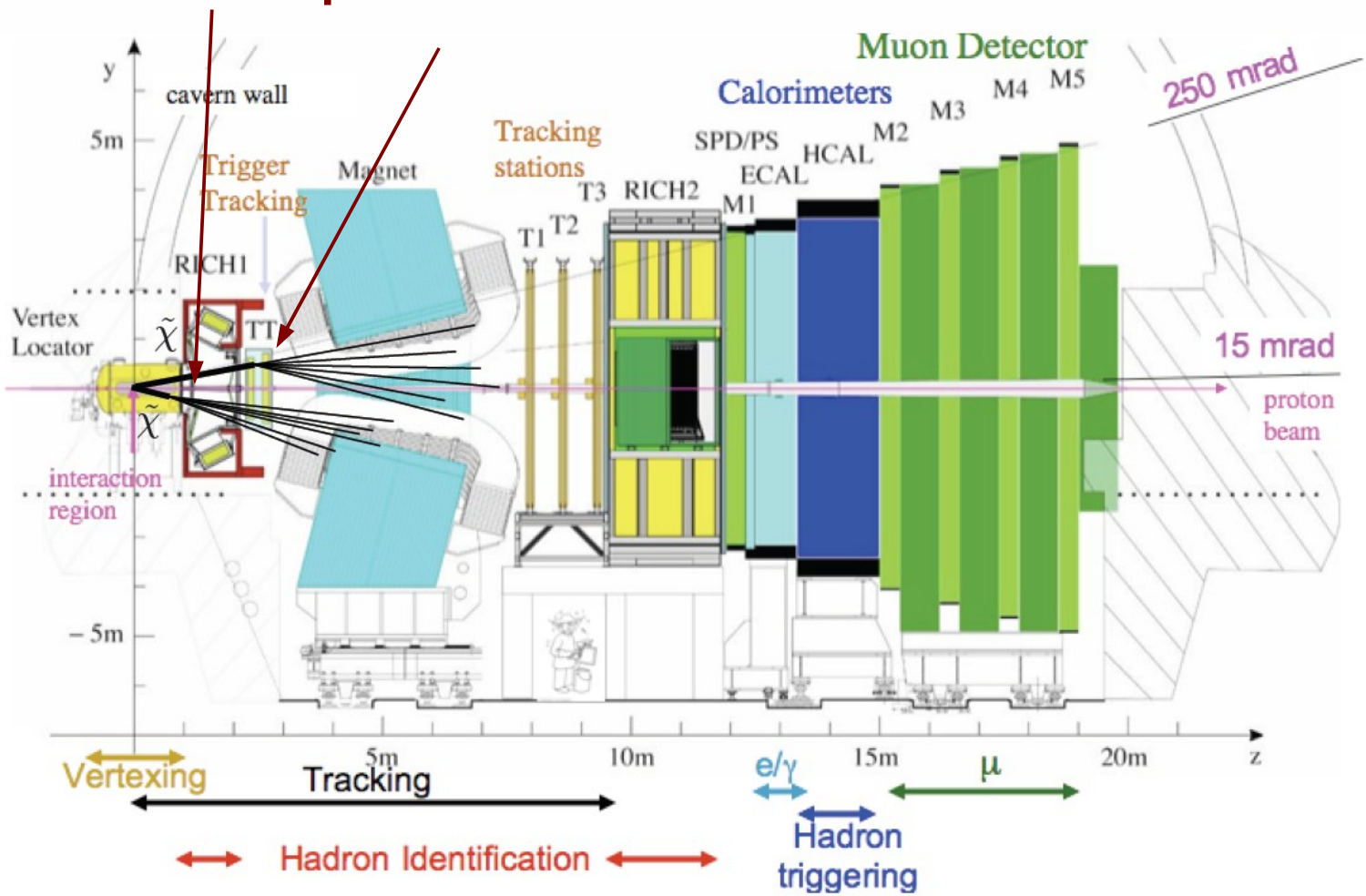
Carpenter et.al.

$$\tau_\chi \simeq \frac{384\pi^2 \cos^2\theta_w}{\alpha\,|U_{21}|^2\,\lambda''^2}\frac{m_{\tilde{q}}^4}{m_\chi^5}$$

$$\sim \frac{3\mu\mathrm{m}}{c\,|U_{21}|^2}\left(\frac{10^{-2}}{\lambda''}\right)^2\left(\frac{m_{\tilde{q}}}{100\ \mathrm{GeV}}\right)^4\left(\frac{30\ \mathrm{GeV}}{m_\chi}\right)^5$$

LHCb as discovery machine

Displaced Vertices!



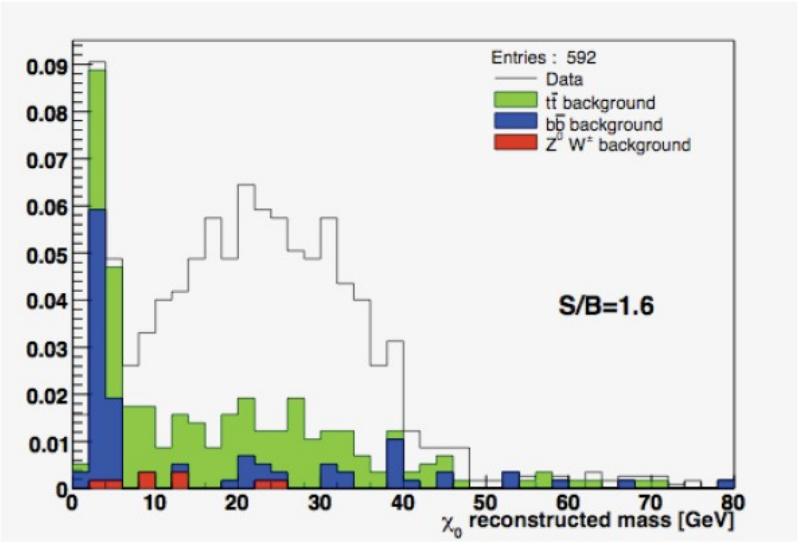
Slide from David E. Kaplan Aspen '08

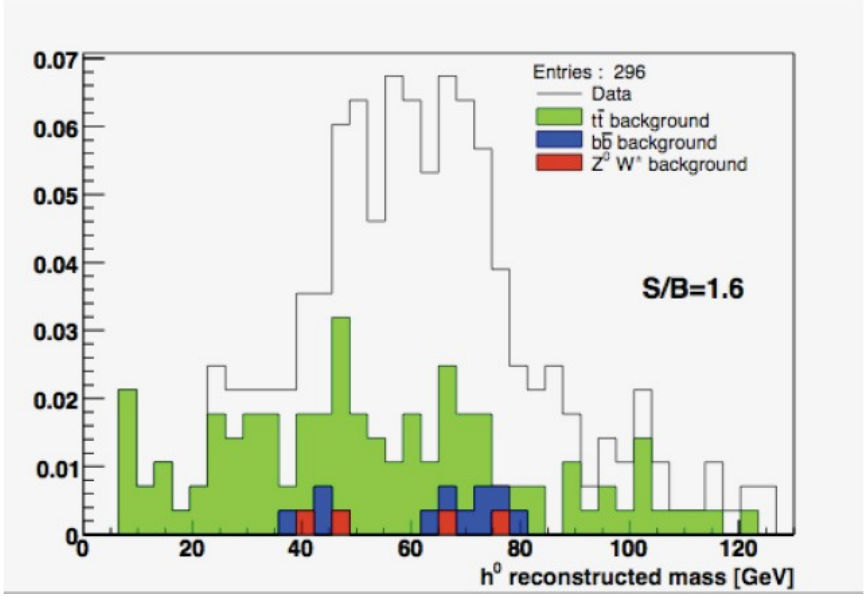
Require vertex
1) 5 tracks
2) r > 60 μm
3) 200 μm < z < 0.4 m

Can produce 1000's of double displaced events in a year

LHCb Simulation

LHCb simulated data after acceptance requirements and cuts:





Could reconstruct the Higgs and measure its mass with ~10% accuracy.

N. Gueissaz, (2007)
CERN-THESIS-2007-038

Slide from David E. Kaplan

Aspen Winter '08

LHC Message

- Signals potentially appear in unexpected places
  - In SM search: VBF $h \rightarrow W W^*$ is sensitive to $h \rightarrow$ dilepton + MET
  - LHCb: advantage for decays with highly displaced vertices
- LHC statistics allows searches to be run unoptimized to be inclusive to more signals

No Higgs after 30 fb^{-1}?

- Check standard searches for excesses
- Use available info to design searches for nonstandard Higgses
  - e.g. SUSY events can determine if Higgs decays into superpartners and its topology

Conclusion

- Higgs is crucial element of EWSB
- Nonstandard Higgs decays make standard searches ineffective
- Higgs can appear in unexpected places, so it's best to be prepared