Non-Standard Higgs Decays

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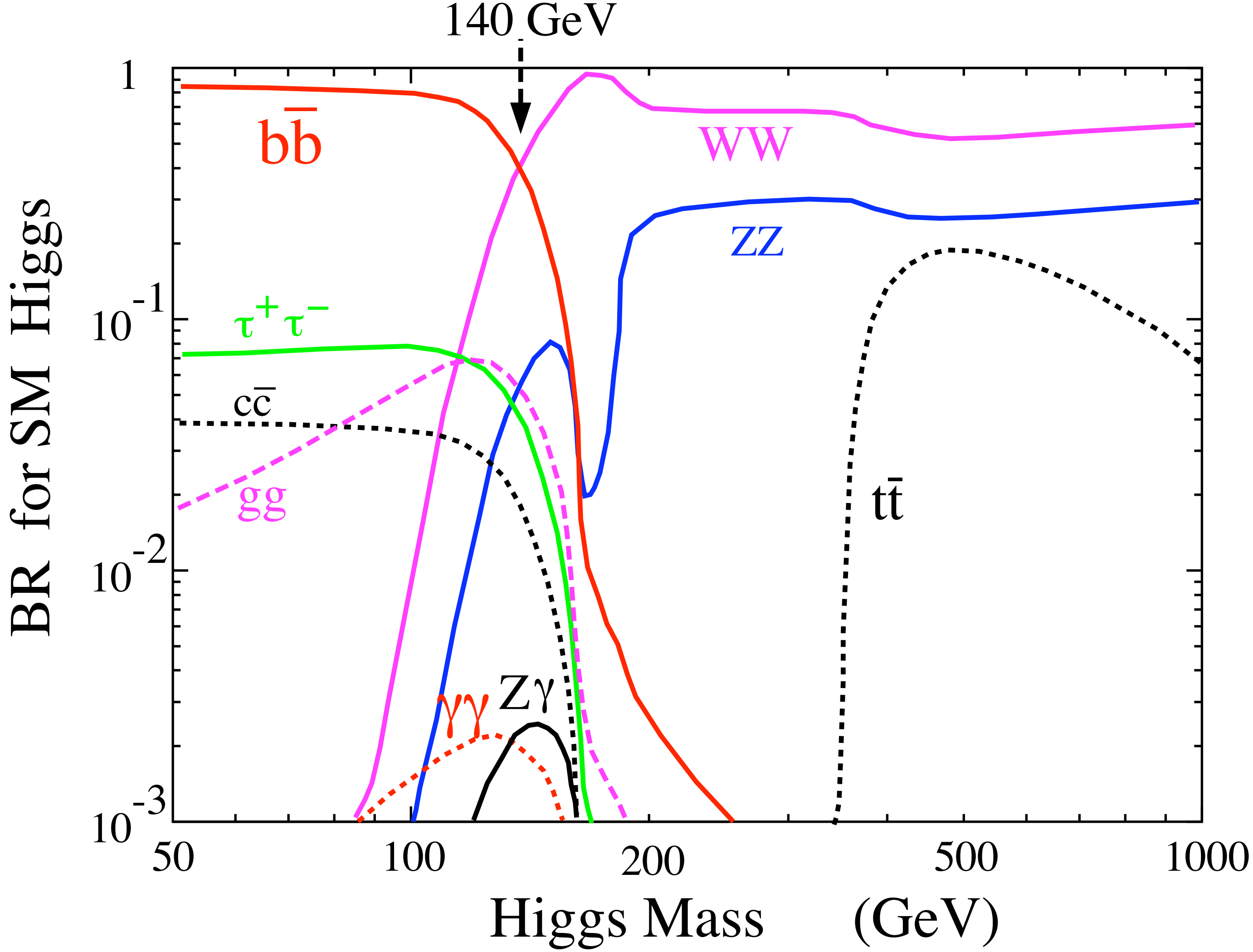
in collaboration with M McEvoy, K Rehermann, and M Schwartz

Standard Higgs Decays

Standard Higgs Decays

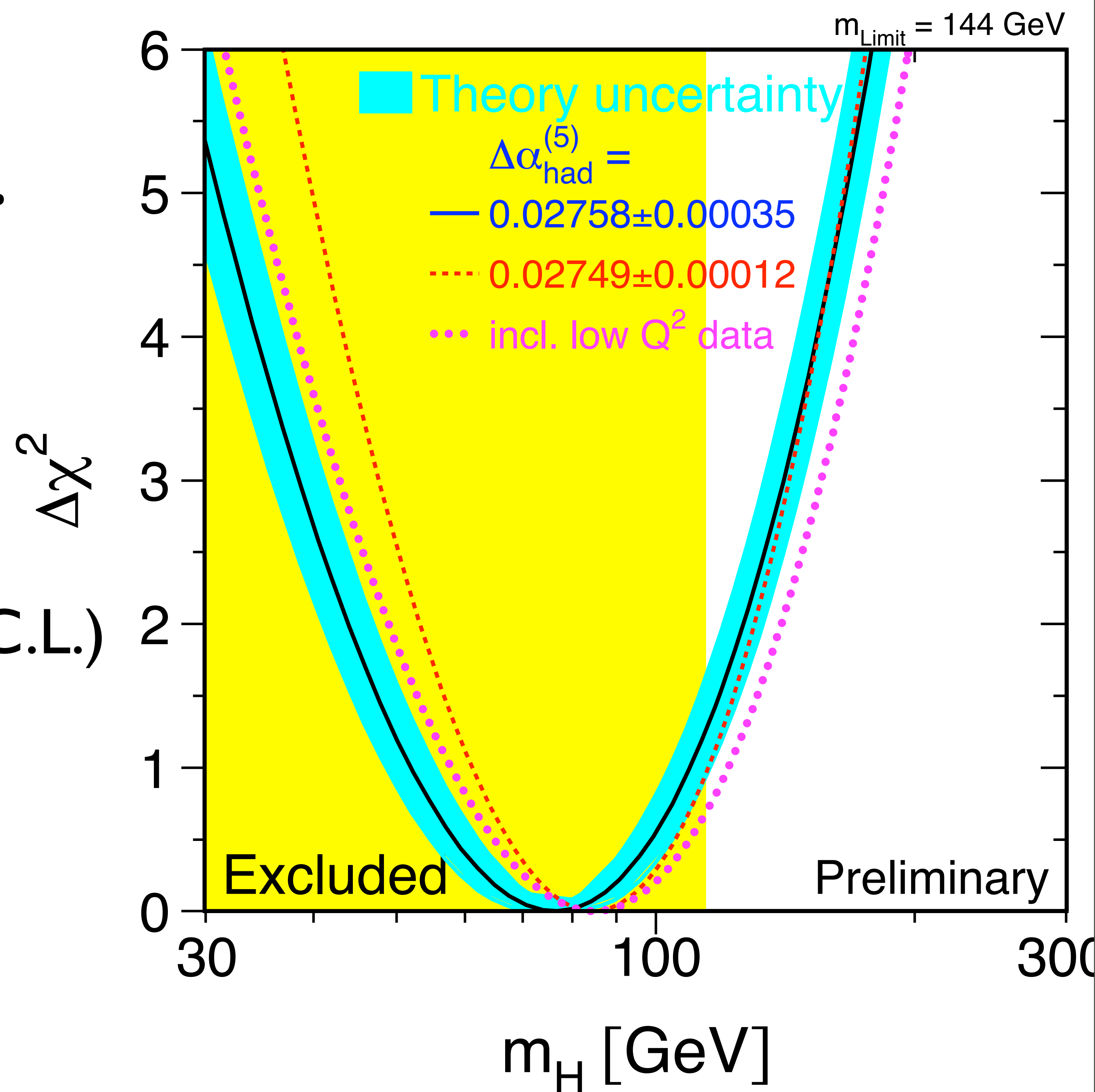


Higgs mass fit

76 $^{+33}_{-24}$ GeV

< 144 GeV (95% C.L.)

LEP II Bound:
> 114.4 GeV



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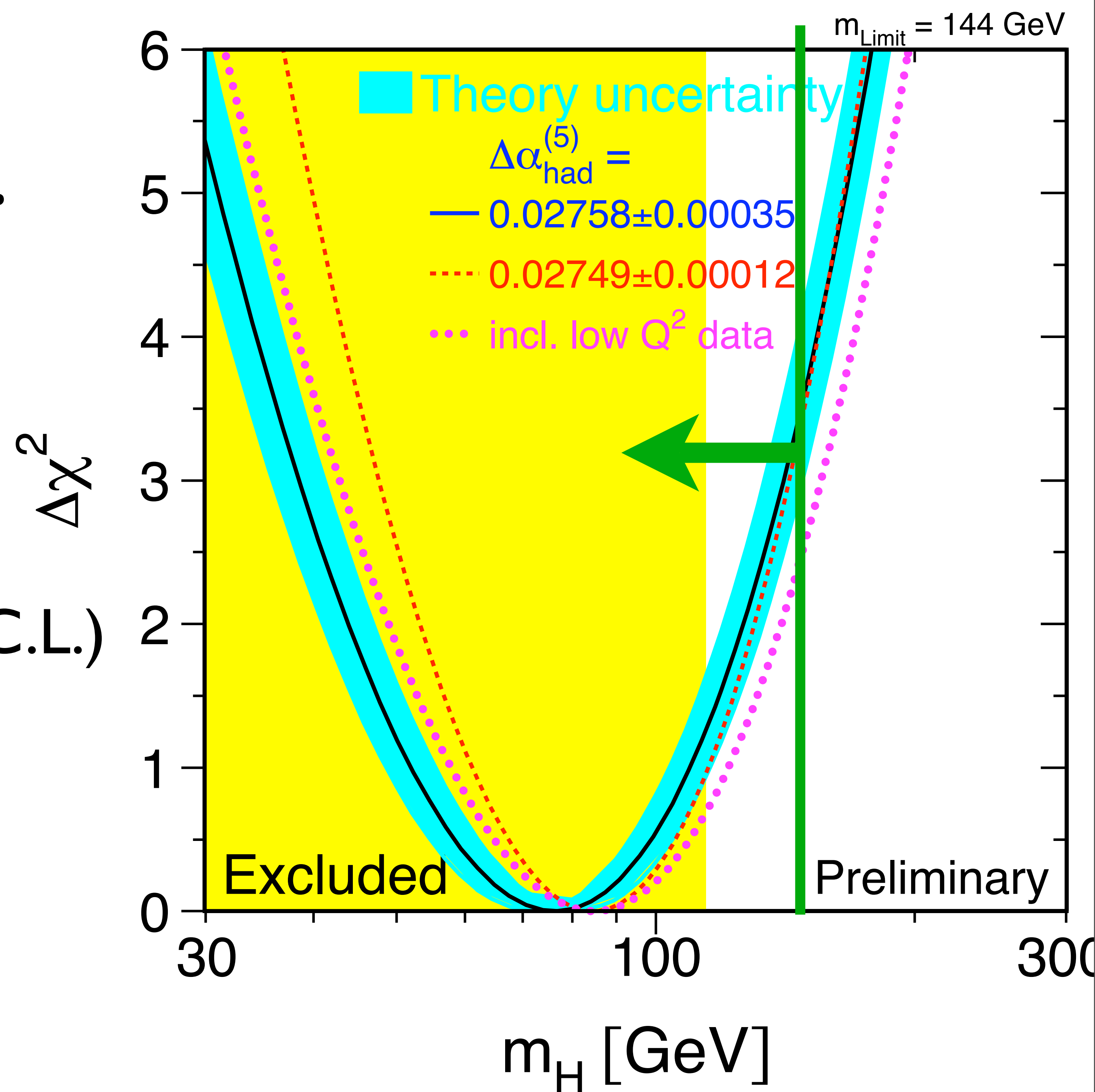
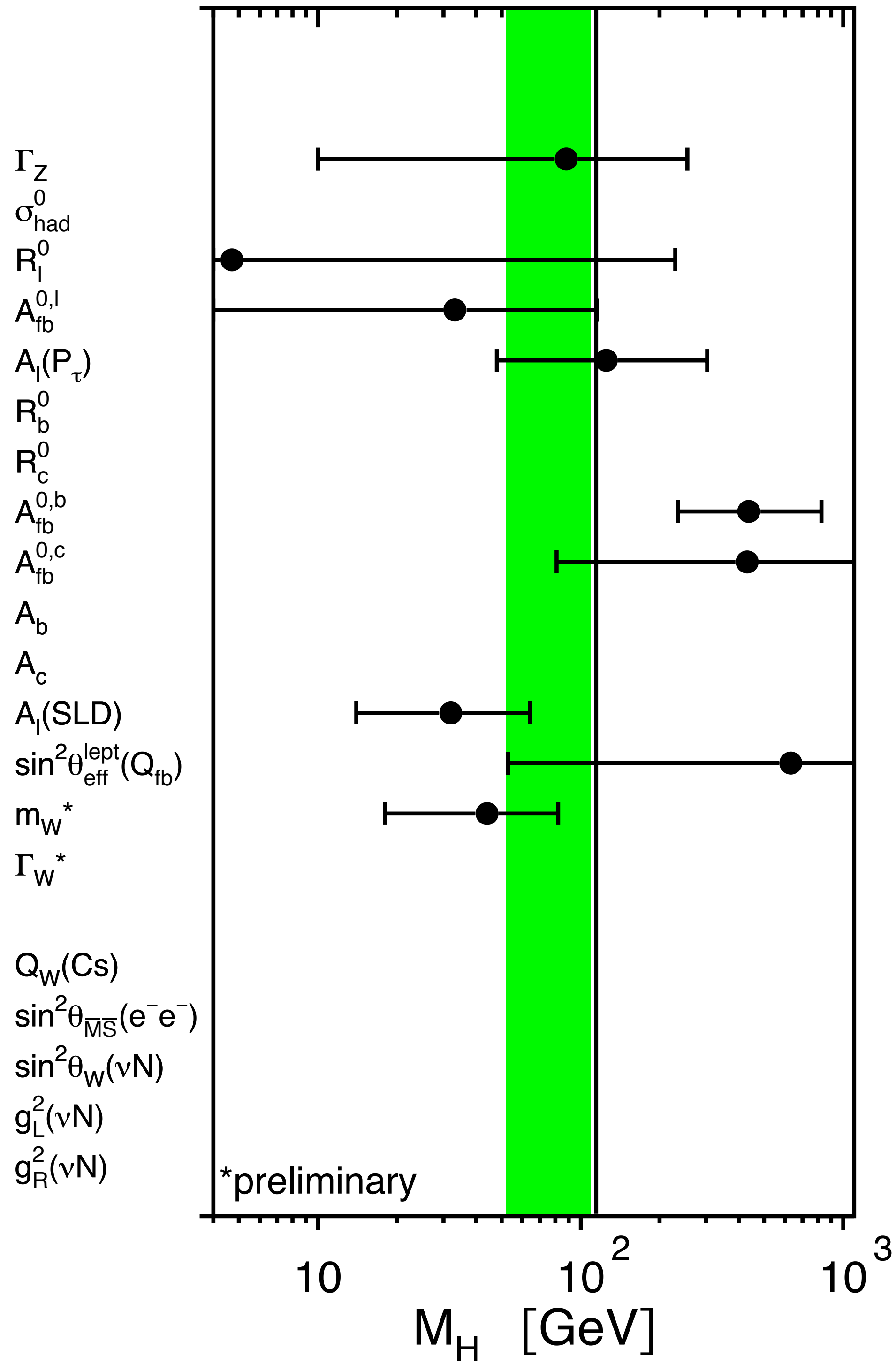


Sensitivity to m_h

Discrepancy in observables sensitive to the Higgs mass

$$\chi^2/\text{dof}=11/4$$

Gambino, '04



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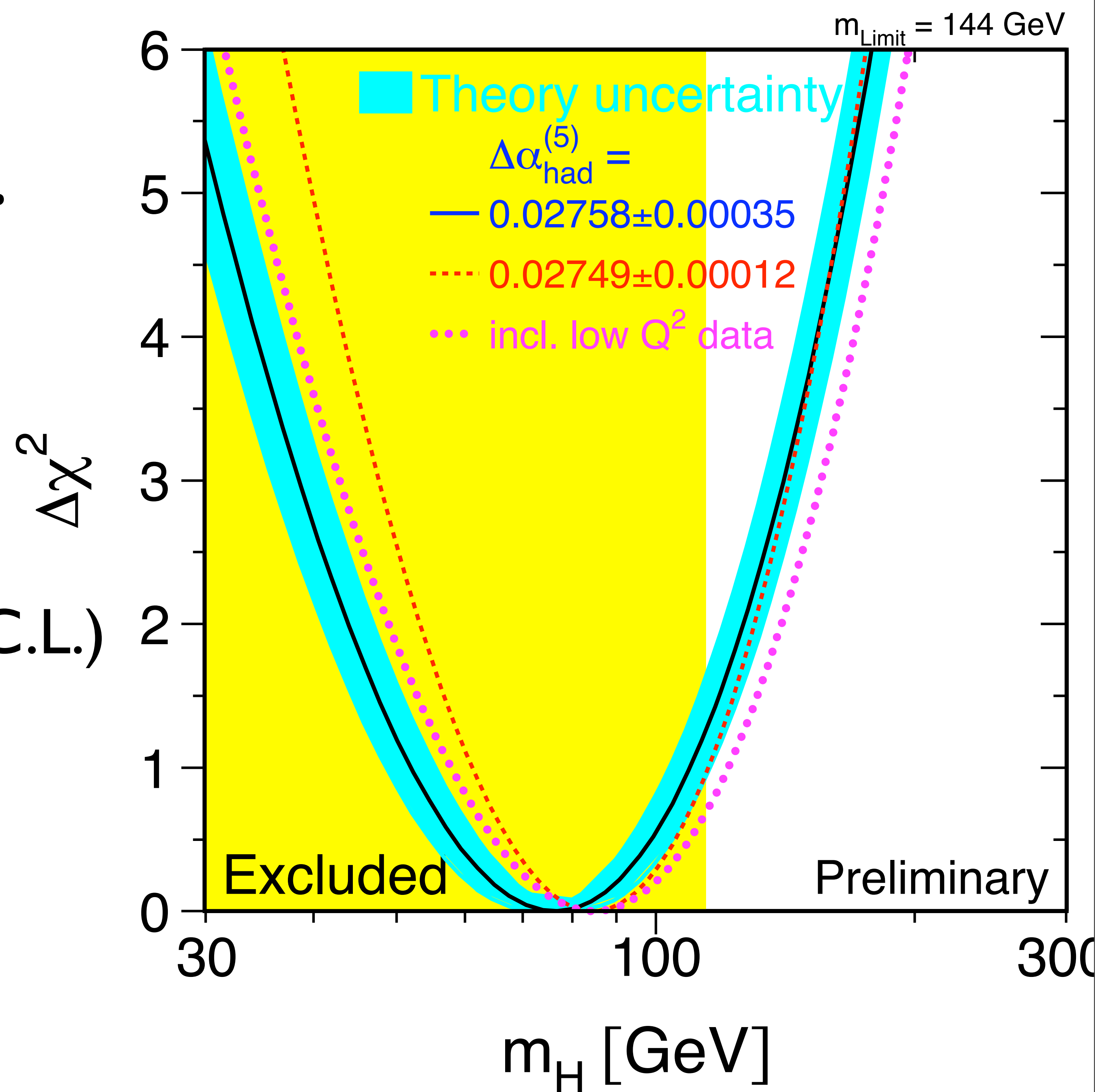


Higgs mass fit

55 $^{+18}_{-16}$ GeV

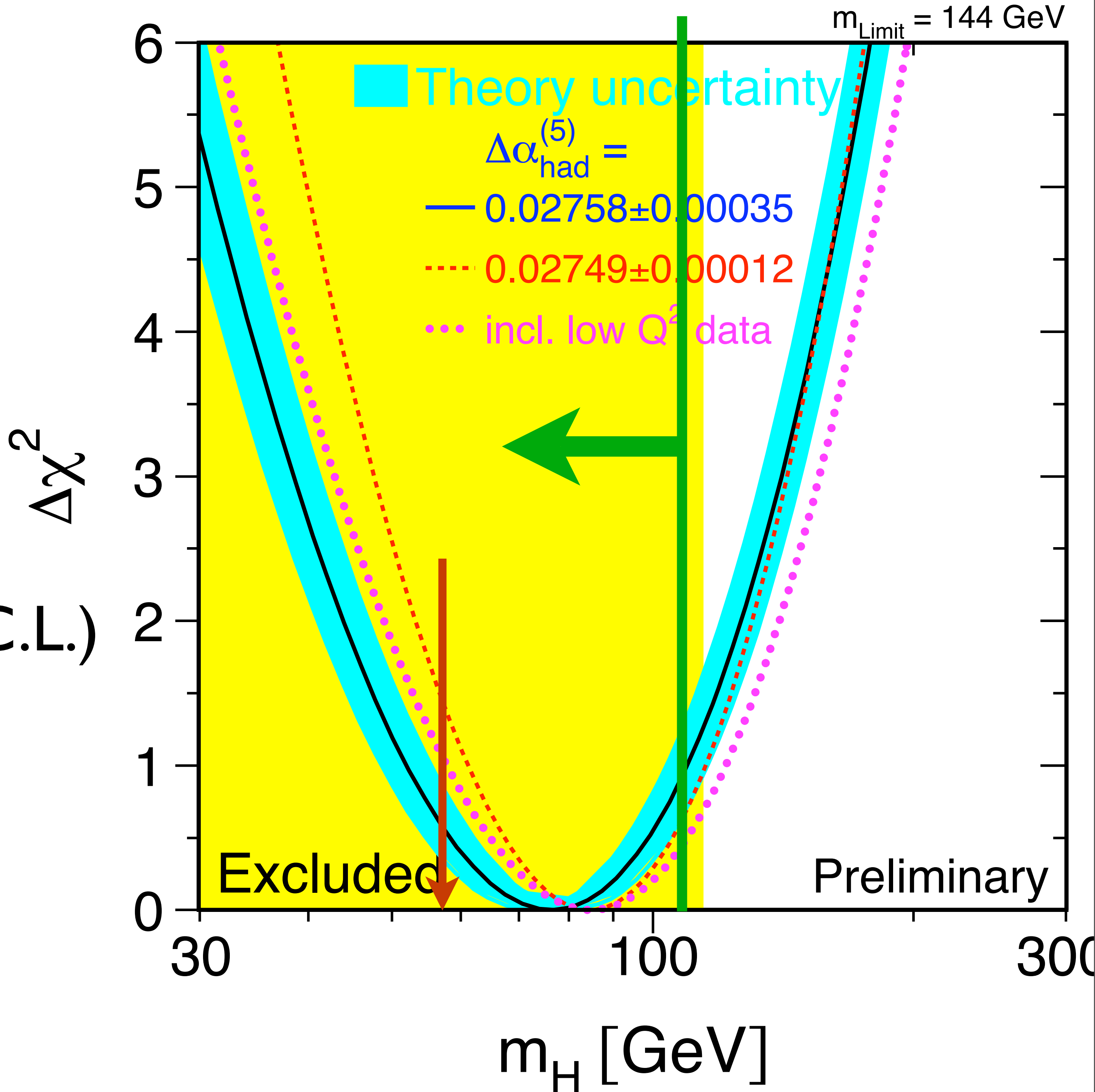
w/o A^b_{FB}

(Thanks Tim Tait)

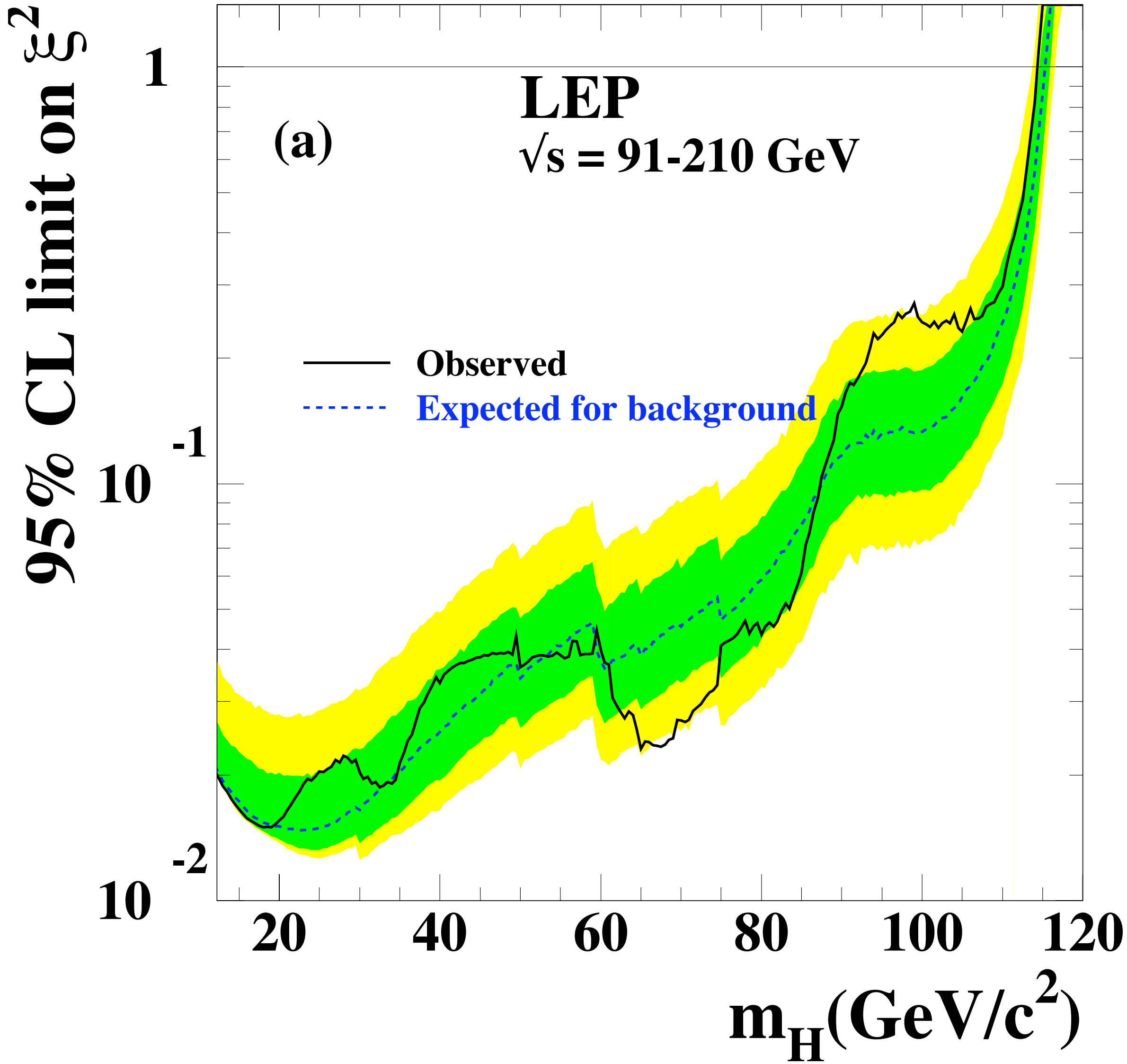
< 102 GeV (95% C.L.)

LEP II Bound:

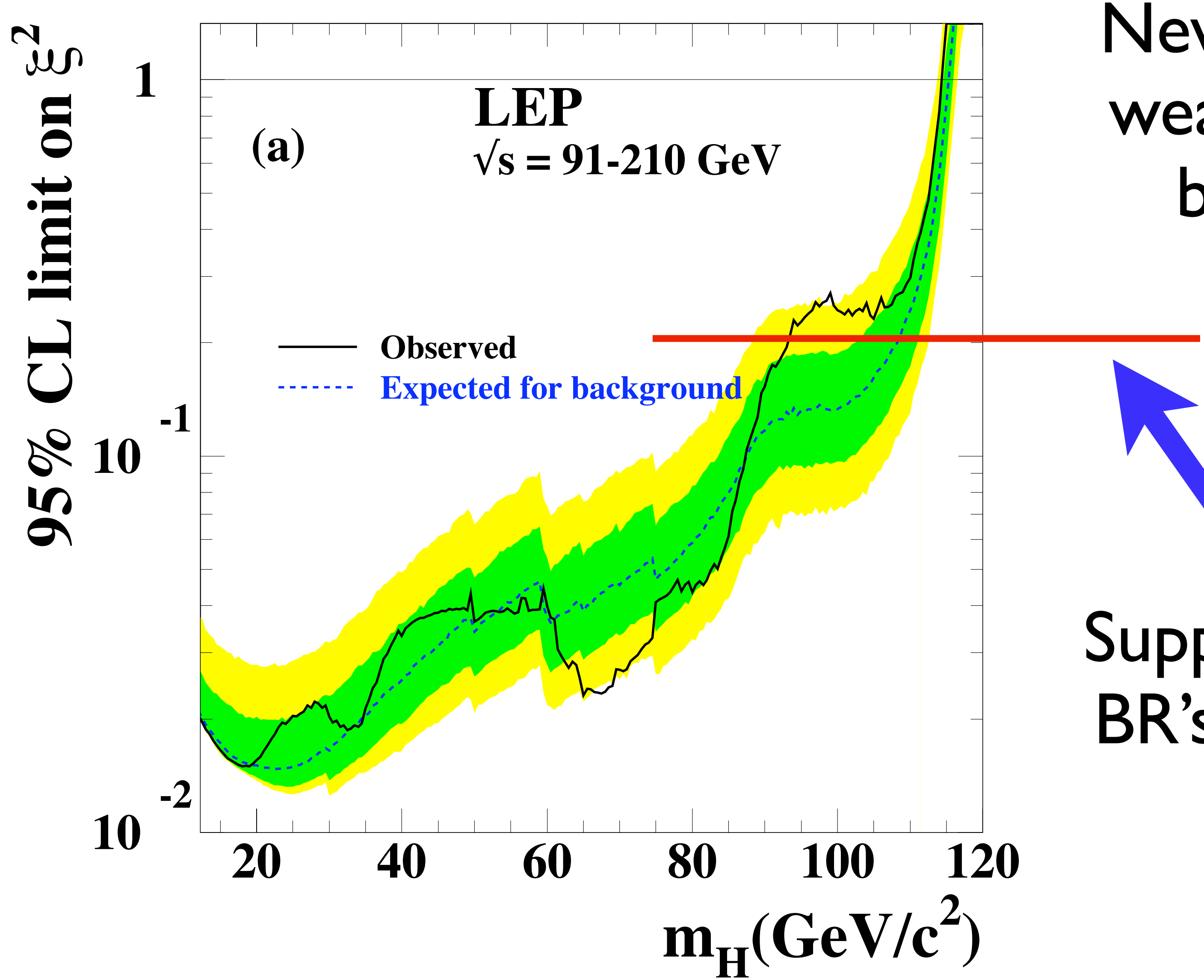
> 114.4 GeV



Higgs Mass Bound



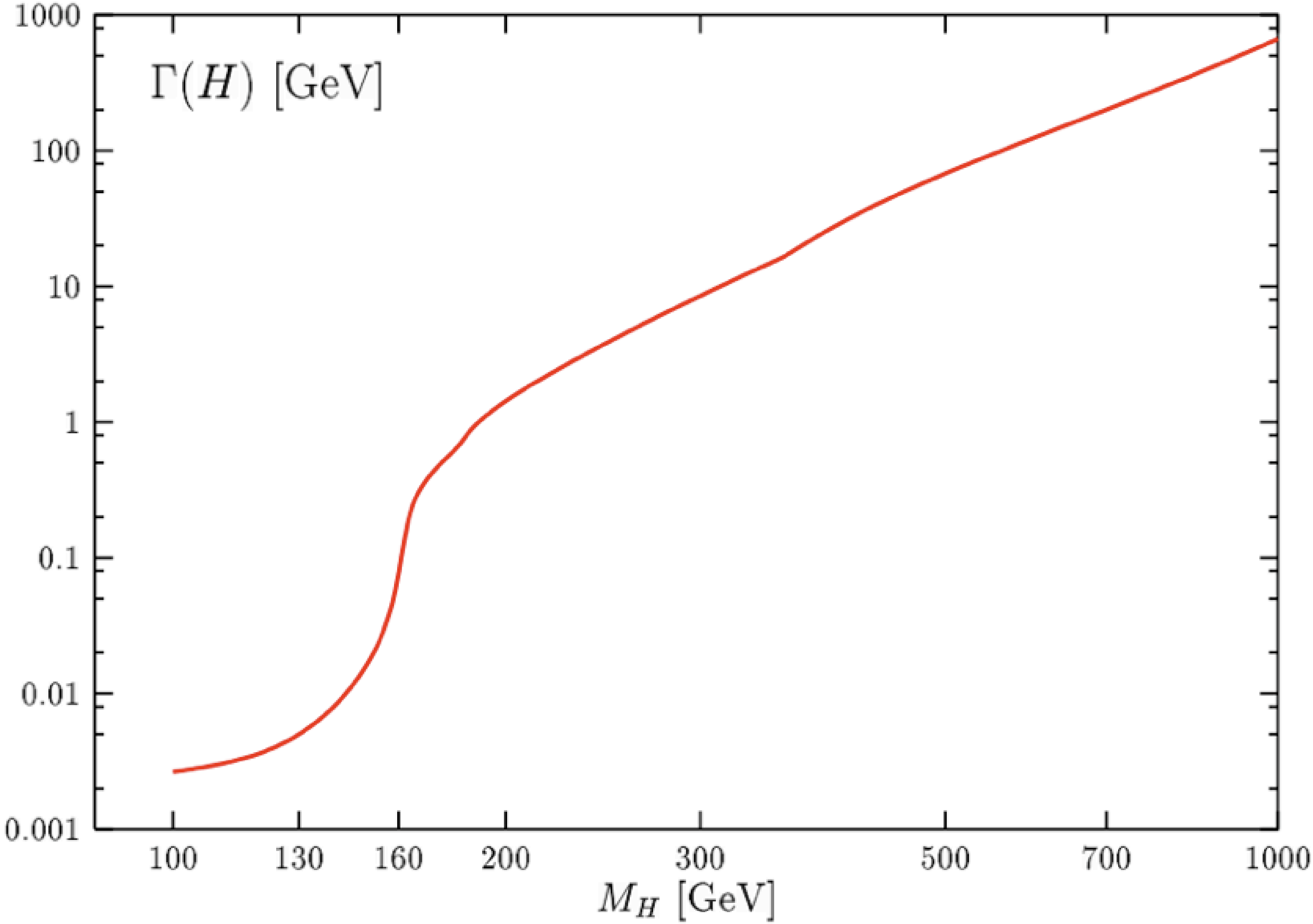
Higgs Mass Bound



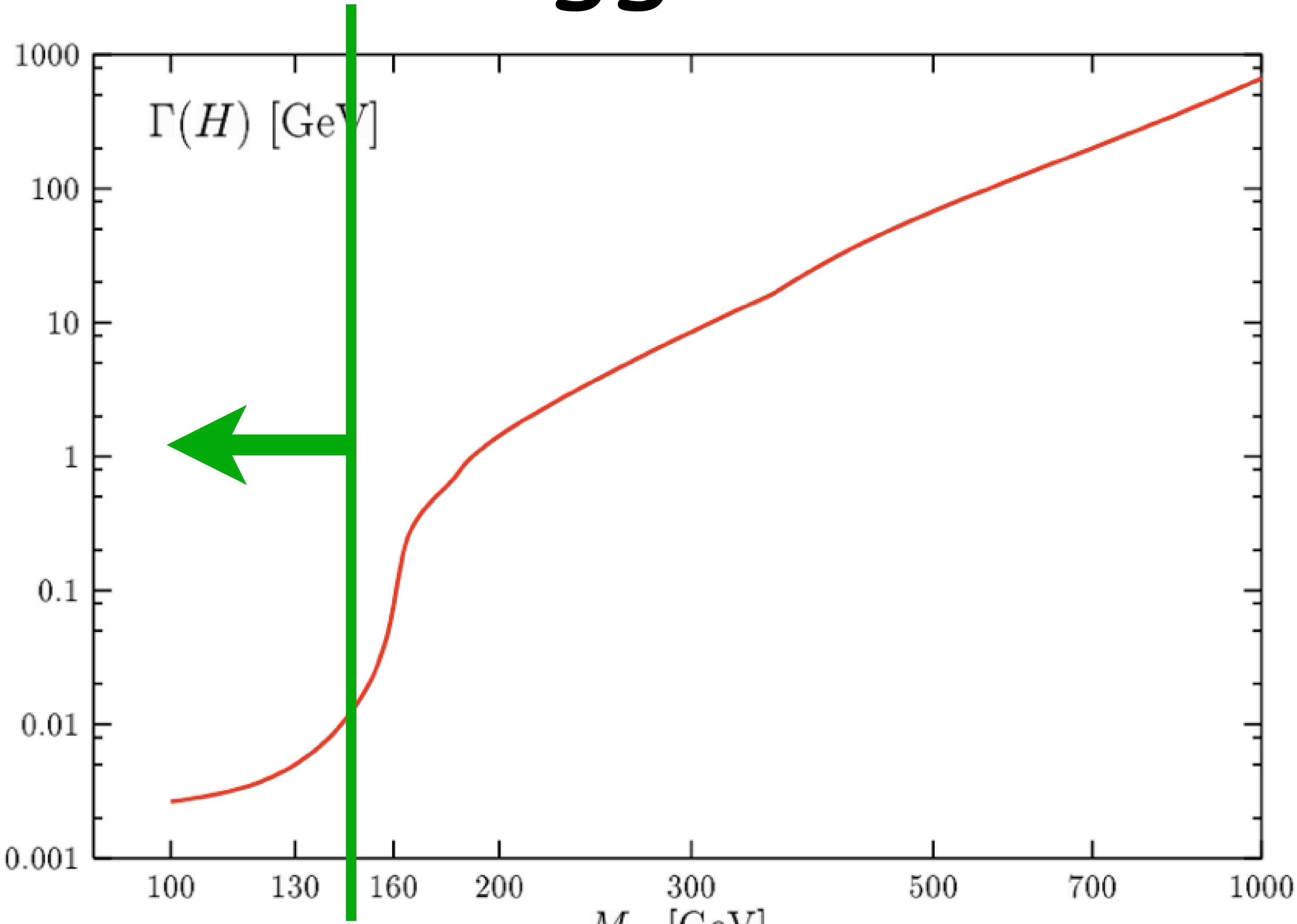
New decays weaken the bound.

Suppress SM BR's to 20%

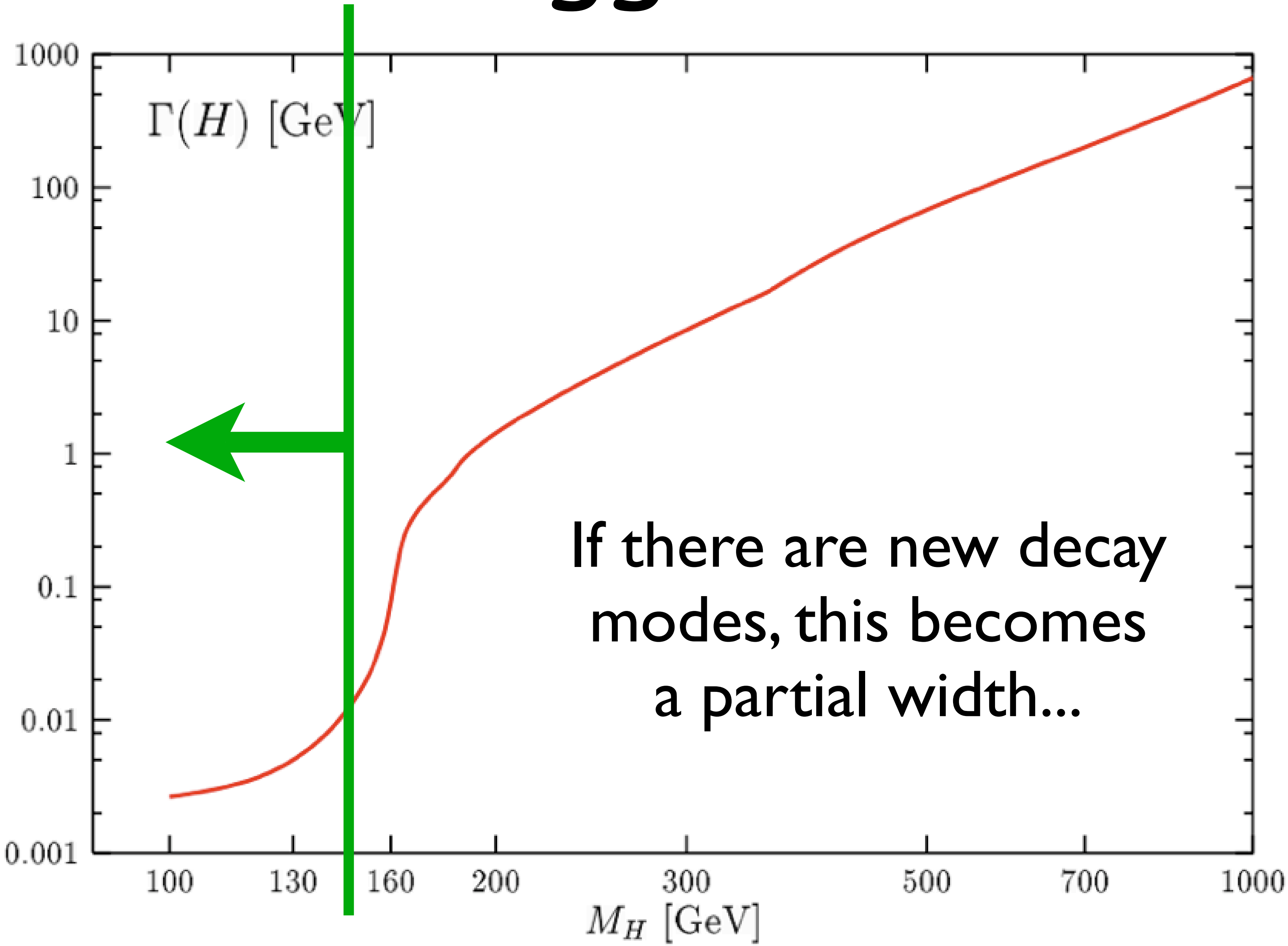
The Higgs Width



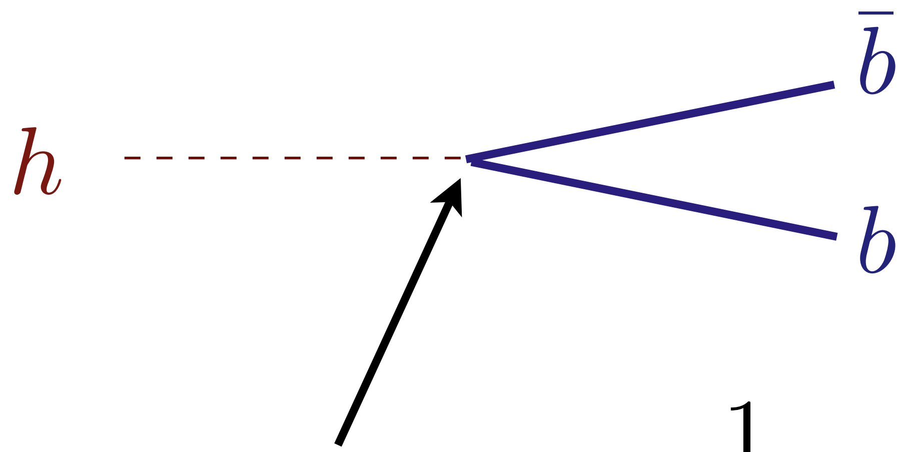
The Higgs Width



The Higgs Width



Higgs' Small Width

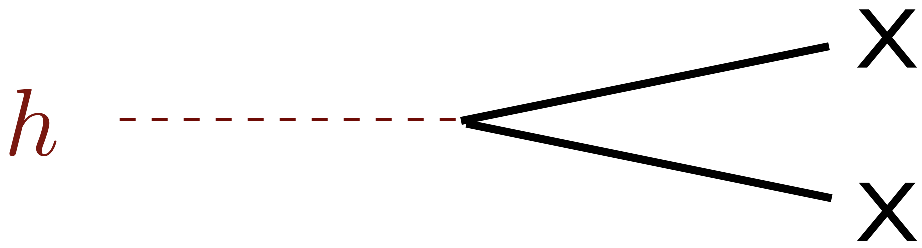


$$y_b(m_h) \sim \frac{1}{60}$$

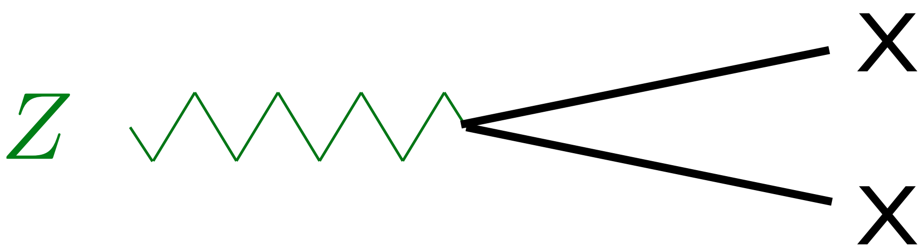
$$\Gamma_{h\to b\bar{b}} \sim y_b^2$$

New Particle In Decay

If



then, perhaps

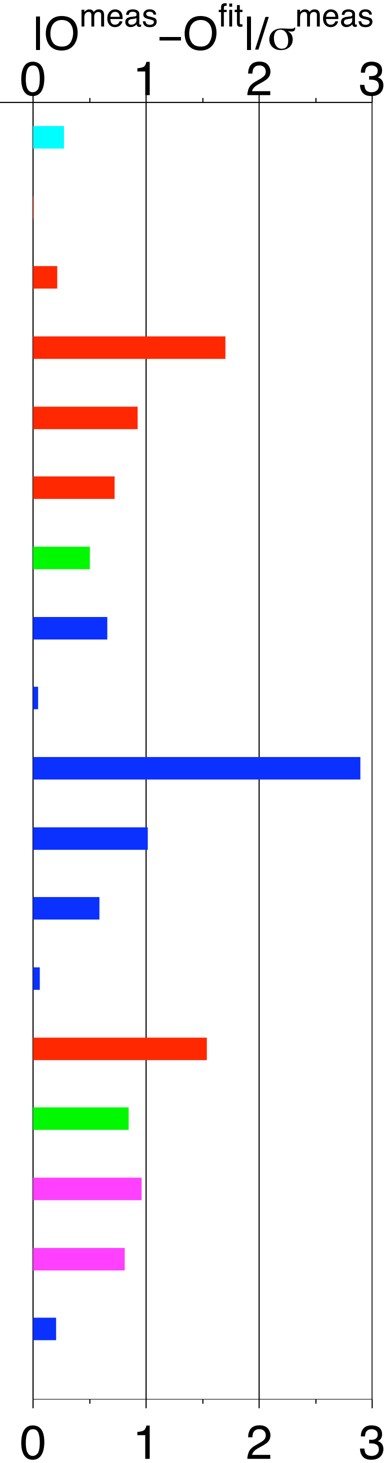


but $$\Gamma_Z \simeq 1000 \times \Gamma_h(m_h = 115\ \mathrm{GeV})$$

Precision Constraint

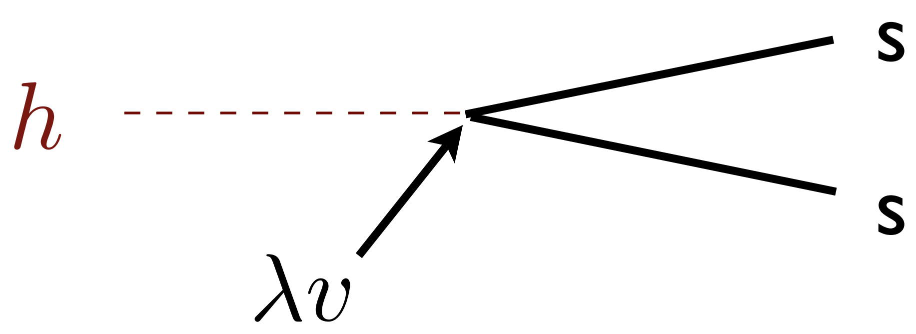
Error bar is about 1 per mil

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ_{had}^{0} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3



Simple Addition to the SM

Add $\lambda h^\dagger h s s$ to the Lagrangian



If the coupling is bigger than a few times 1/60, this decay dominates for a light Higgs.

Motivated Models

Minimal Supersymmetric Standard Model

$$h \to \chi^0 \chi^0$$

invisible

(mSUGRA disfavored)

MSSM w/ R-parity violation

$$h \to \chi^0 \chi^0 \to qqqqqq$$

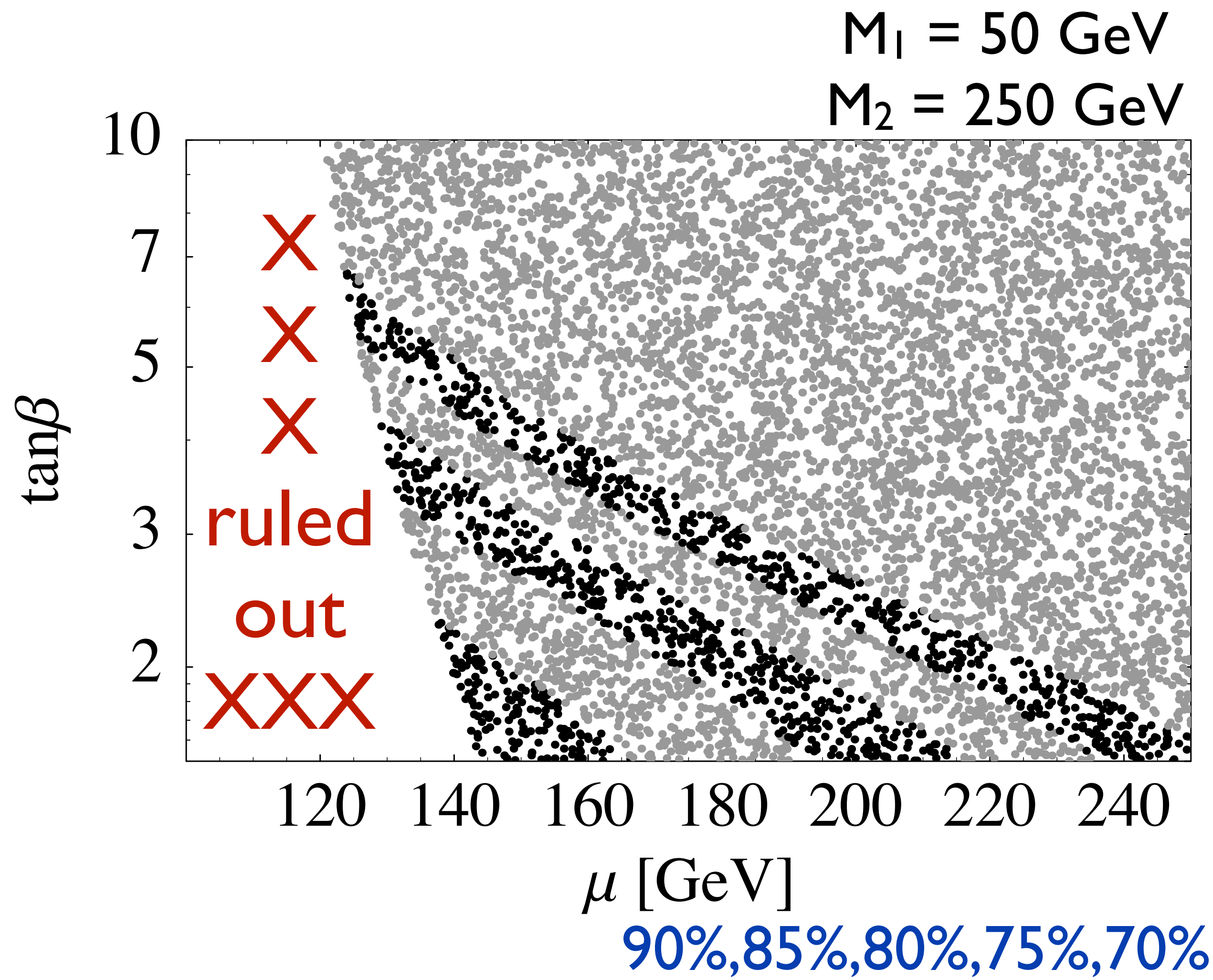
or $\to \ell\ell qqqq$

or $\to \ell\ell\ell\ell\nu\nu$

MSSM - Higgs

Broad regions where this decay is important.

If the neutralinos decay, the Higgs mass could be as low as 90 GeV



Carpenter, DEK, Rhee (2006)

RPV weakens bounds

For B violation

Sleptons (R)	94,85,70 GeV (A)
Sneutrinos	88,65,65 GeV (A)
Squarks ($u_{L/R}$,$d_{L/R}$)	87,80,86,56 GeV (L)
Stop	77 GeV (O,D,L)
Sbottom	7.5 (>55, <30) GeV (L)
Gluino	??? GeV ? (???)

Only Chargino bound roughly the same
(102.5 GeV)

Motivated Models

NMSSM (or MSSM with a singlet)

$$h \to aa \to \bar{b}b\bar{b}b$$

$$h \to aa \to \bar{\tau}\tau\bar{\tau}\tau$$

$$h \to aa \to gggg$$

$$h \to ss \to aaaa \to \bar{b}b\bar{b}b\bar{b}b\bar{b}b$$

New couplings and decays for the Higgs in SUSY can make it naturally heavier and make the LEP bounds weaker.

Motivated Models

Models where the Higgs is a pseudo-Goldstone boson:

Composite Higgs (revived as part of RS models)
Little Higgs

From the "simplest little Higgs"

$$\Phi_1 = e^{i\Theta/f} \begin{pmatrix} 0 \\ 0 \\ f \end{pmatrix}$$

singlet field

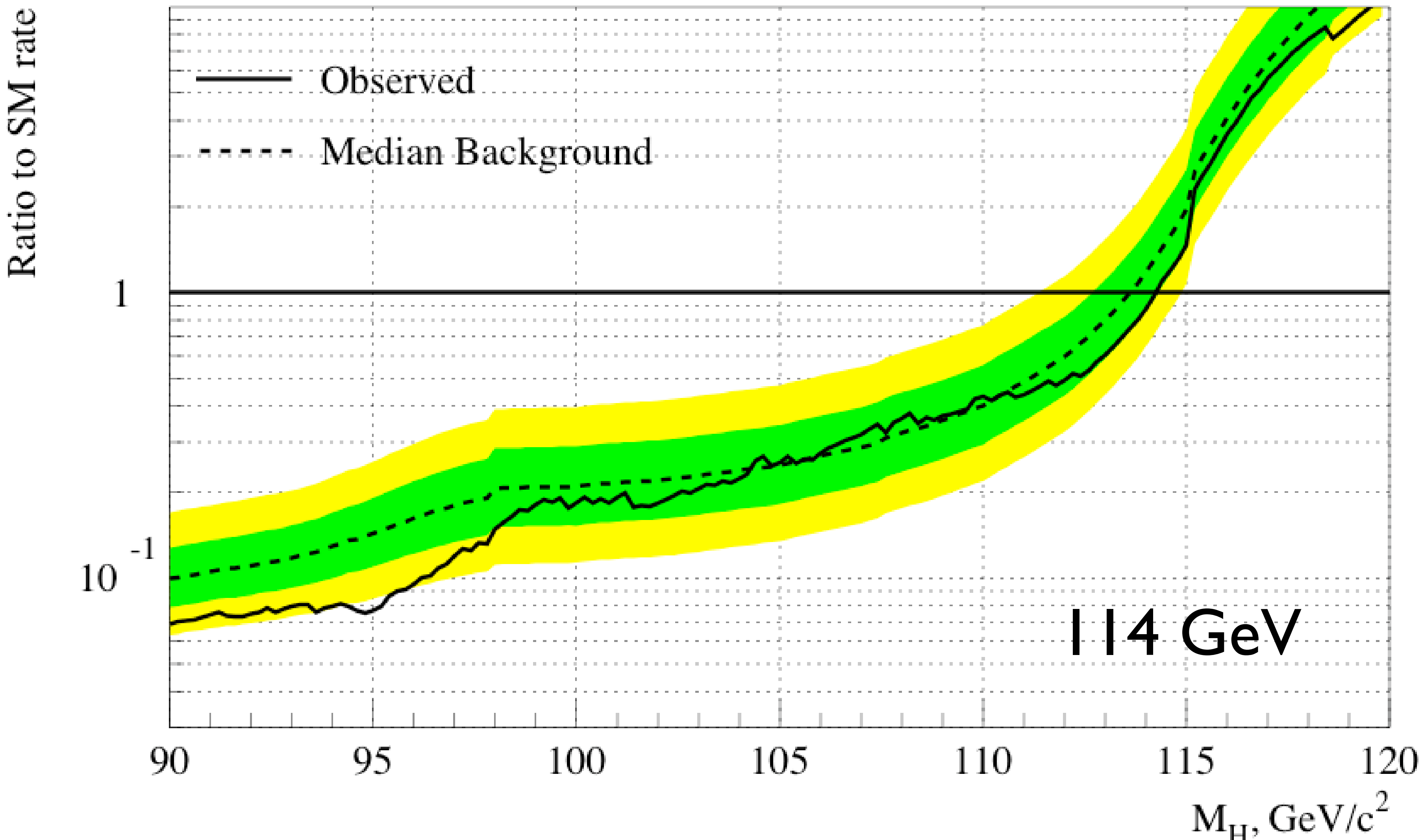
$$\Theta = \Theta^a T^a = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & \\ 0 & 0 & h \\ & h^\dagger & 0 \end{pmatrix} + \frac{\eta}{4} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

Generic Signals

- Invisible
- 4+ jets (perhaps heavy flavors)
- 4+ leptons
- 2+ leptons and missing E
- 4 Zs or Ws or a combination
- combined signals

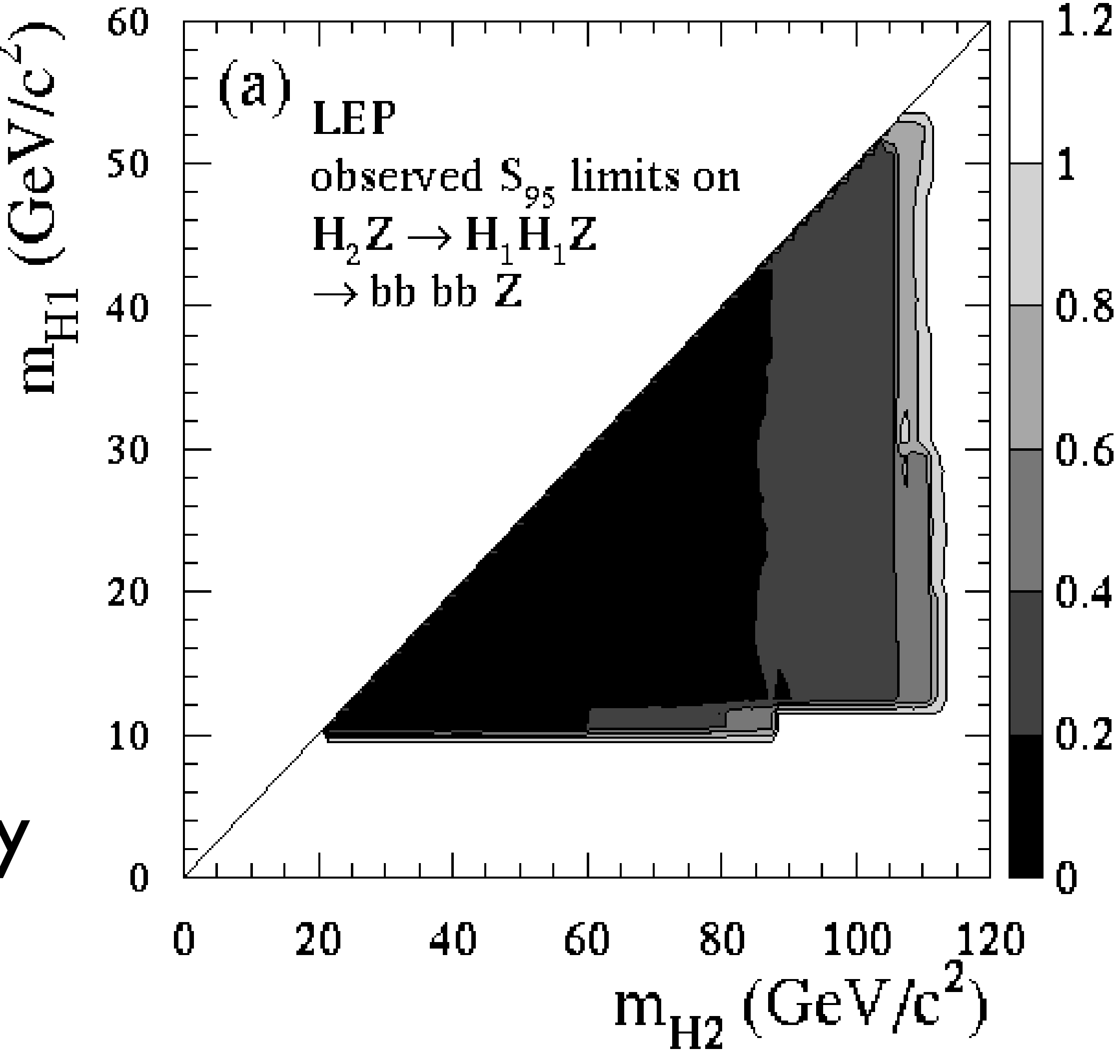
LEP Searches

Invisible Higgs



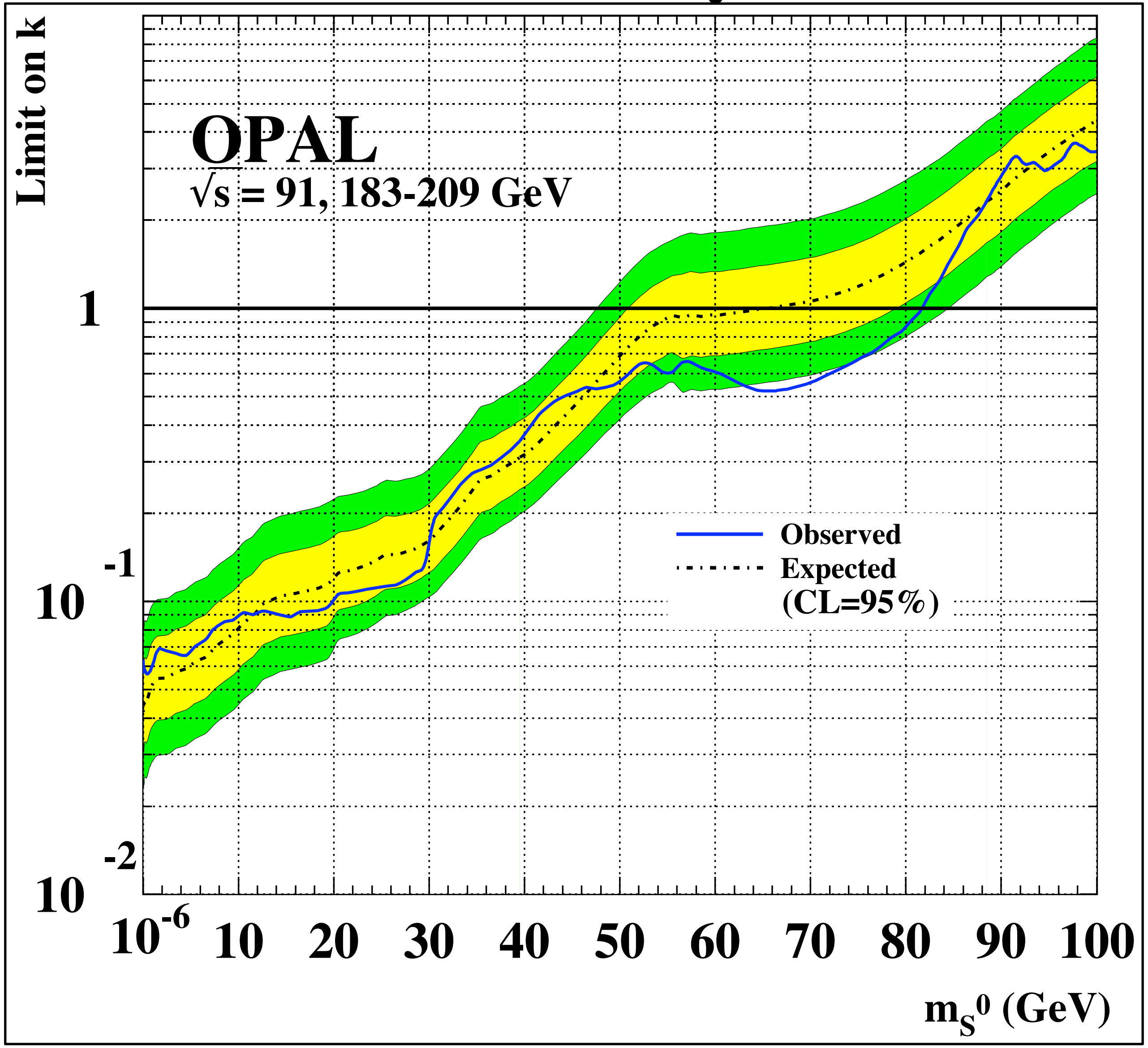
LEP Combined - '01

Higgs to 4b



110 GeV
(but taus only
> 86 GeV)

Model Independent



Thus the Higgs could be lighter (and EWP favors it)

Difficulty at hadron colliders

- h to jets hard - even standard decay to b's a challenge to recover at the LHC:

$$\sigma(gg \to h \to b\bar{b}) \sim 20 \text{ pb}$$
$$\sigma(\text{QCD} \ \to b\bar{b}) \sim 1/2 \text{ mb}$$

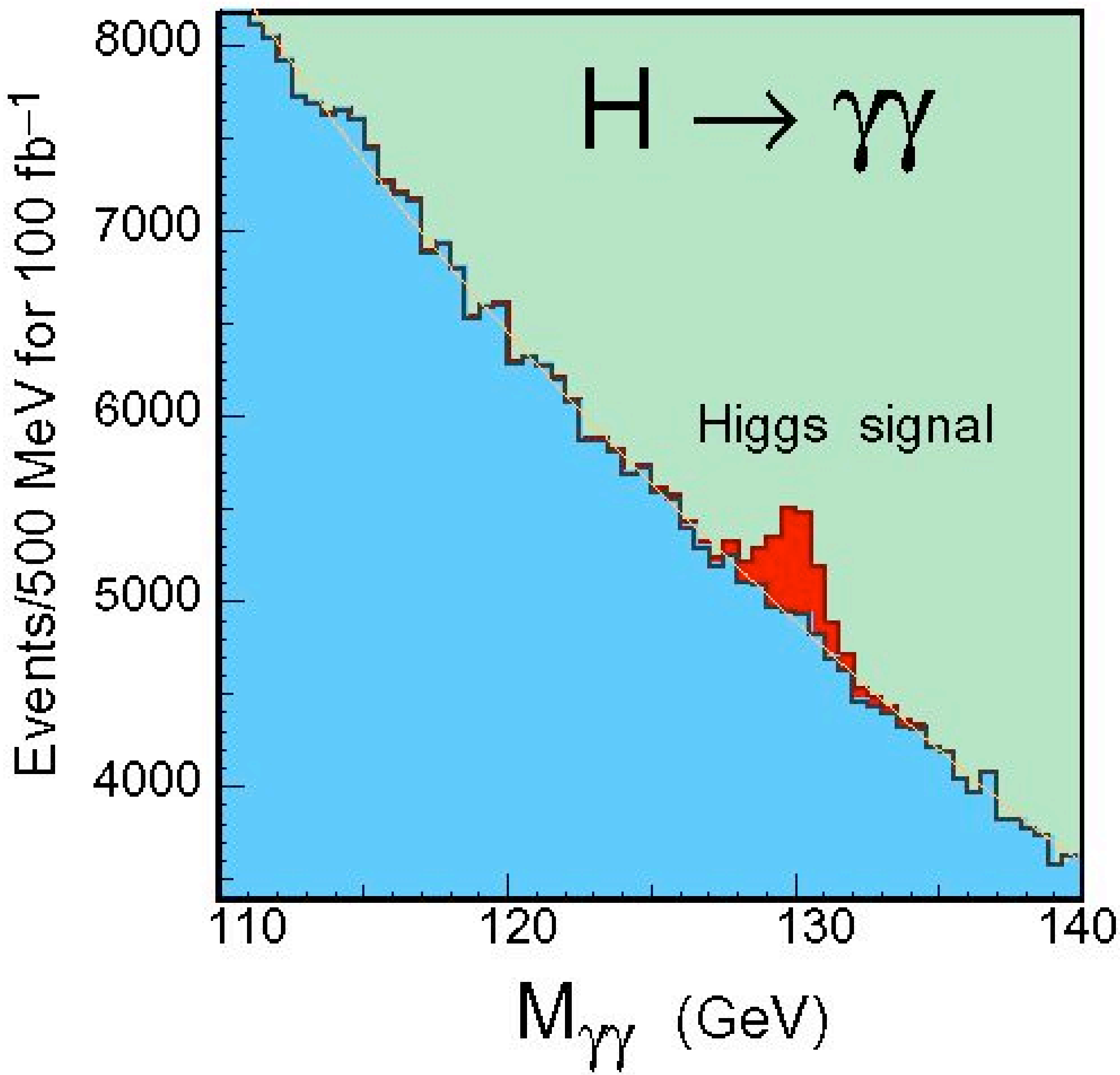
- h to multiple jets - soft jets difficult to reconstruct at the LHC

Strategies for searches

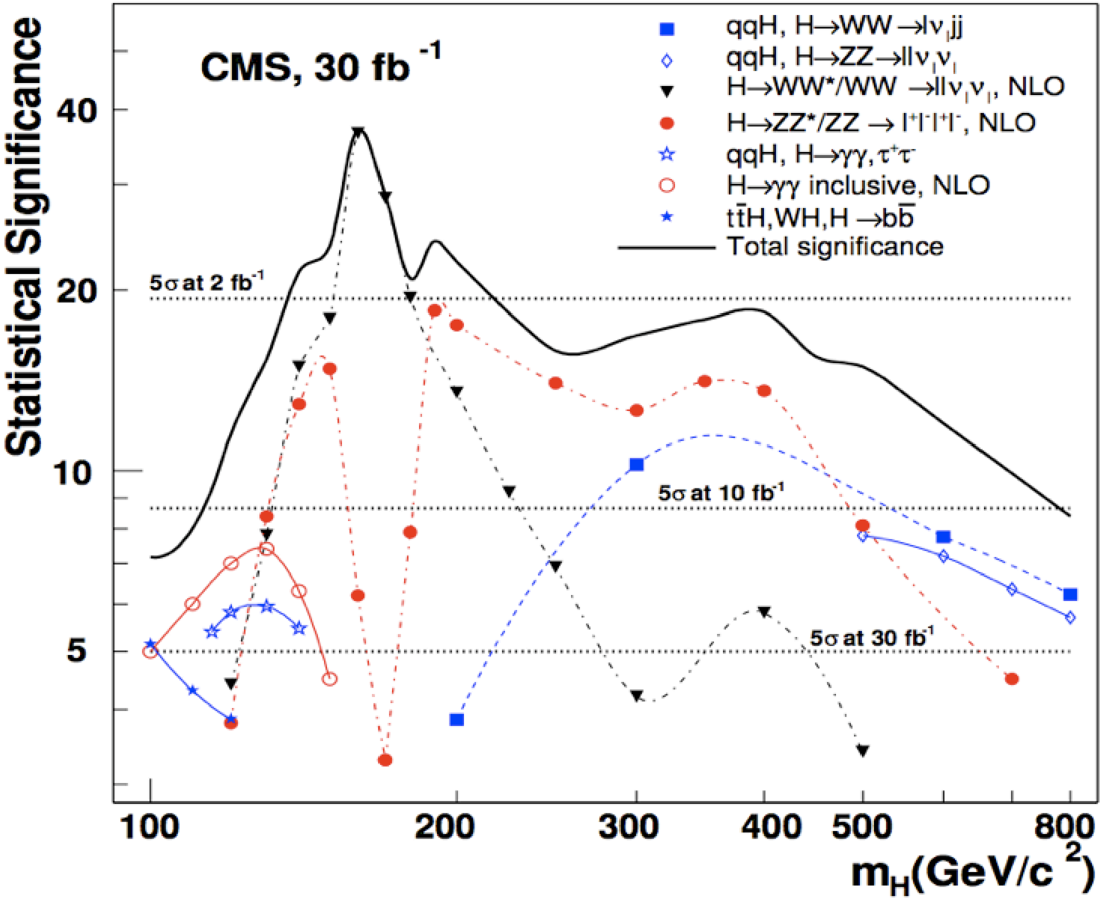
- Look at standard channels
- Look for new triggers
- Use non-standard experiments
- Use jet-shapes
- Come up with other ideas

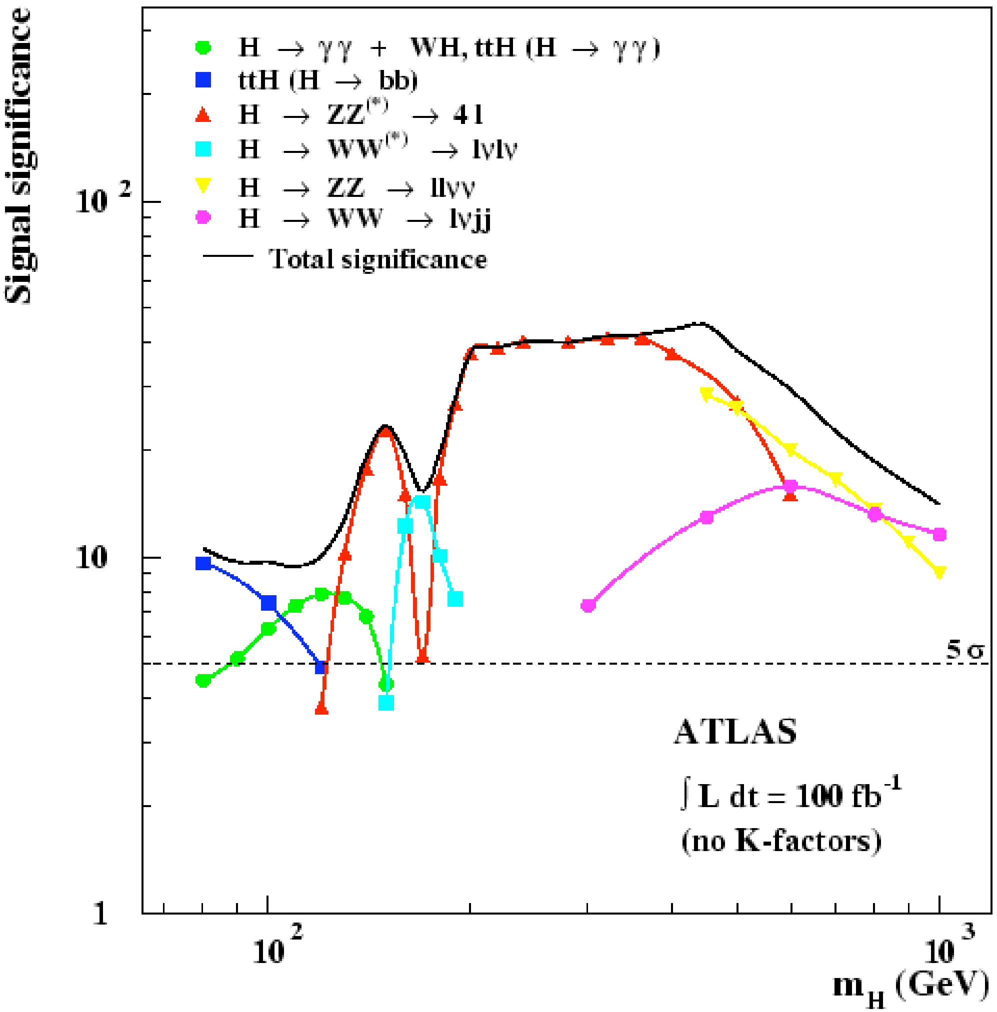
Standard searches

If the rate of Higgs boson decays to multiple jets is, for example, 4 times that into standard model modes, standard searches are dramatically weakened.



Higgs searches





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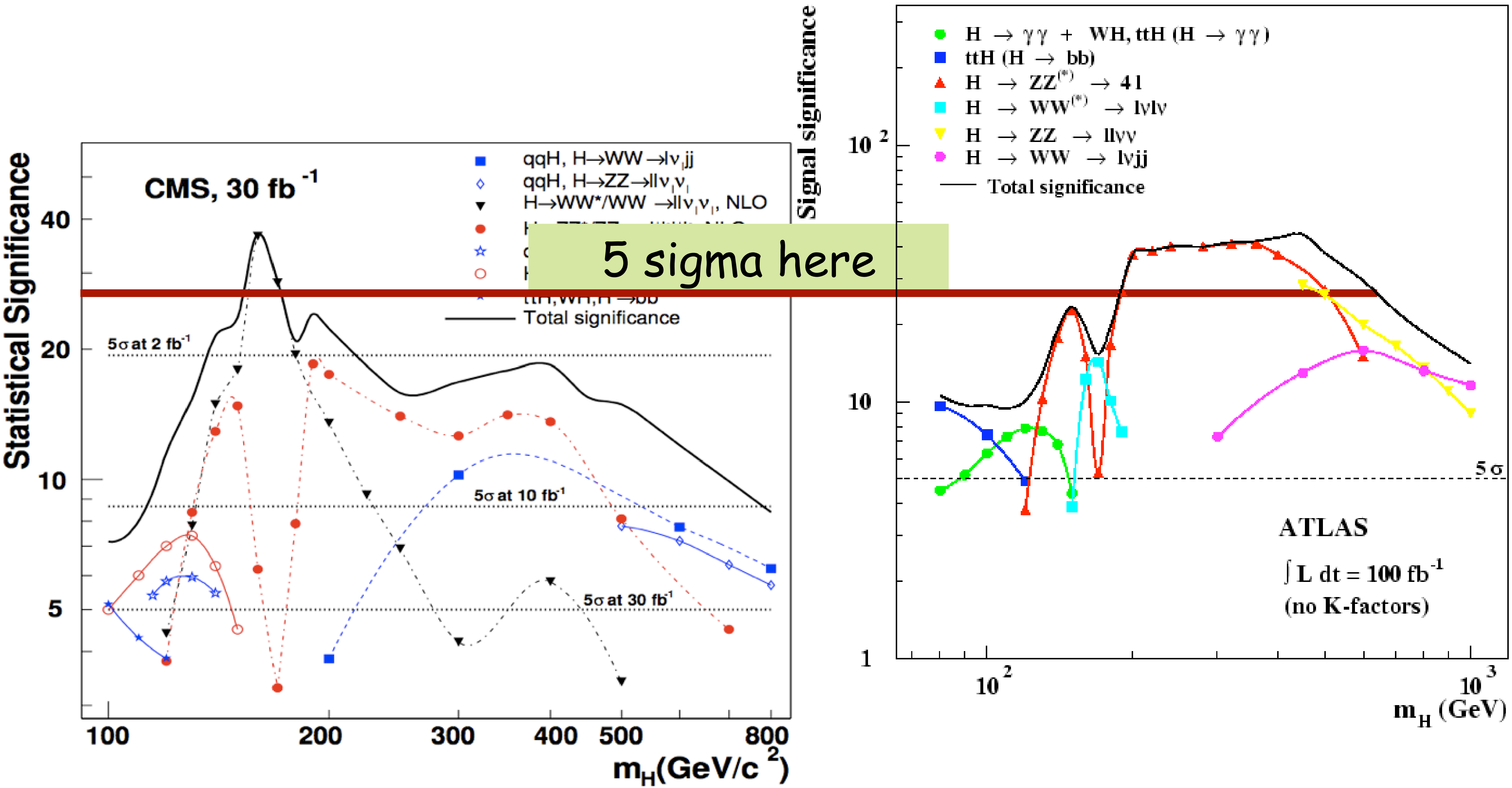

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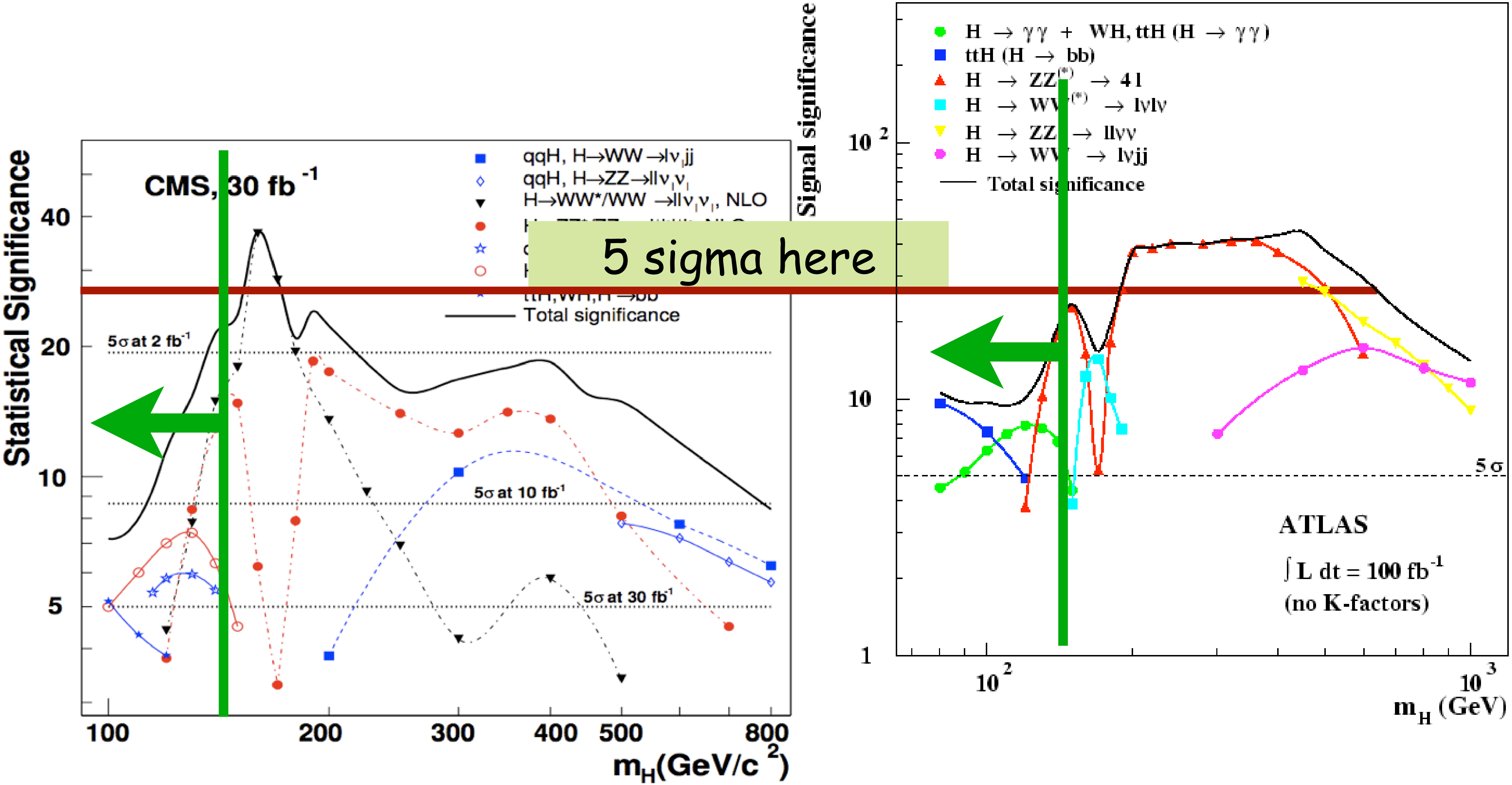
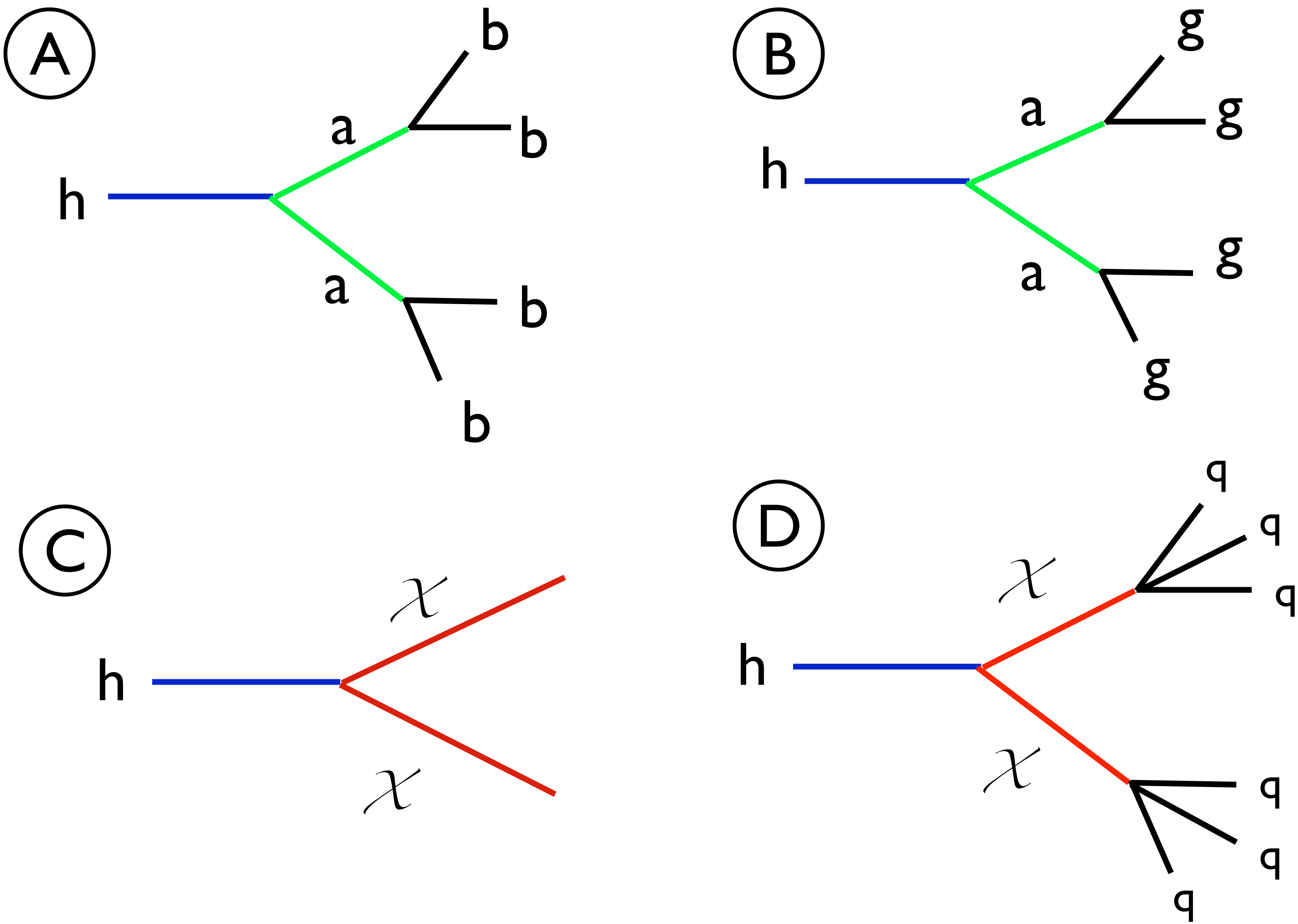
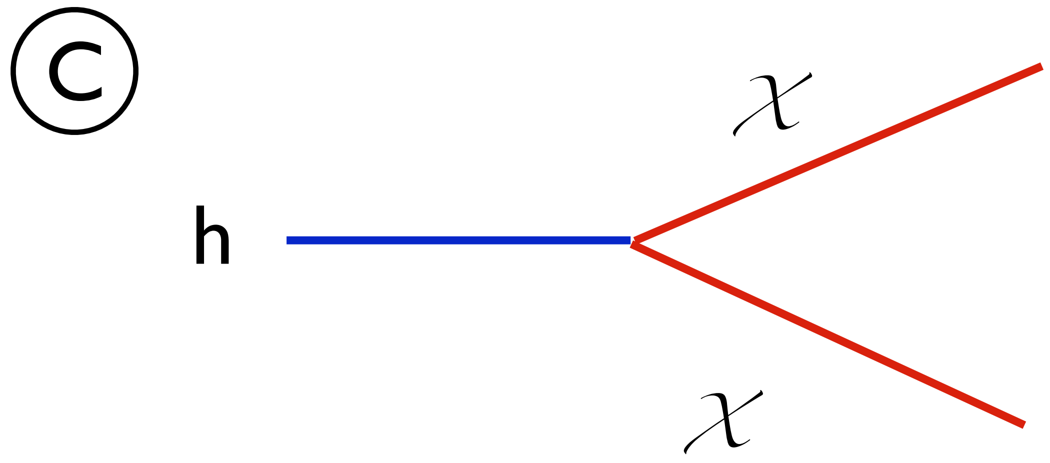


We **must** study
the new decay
modes.

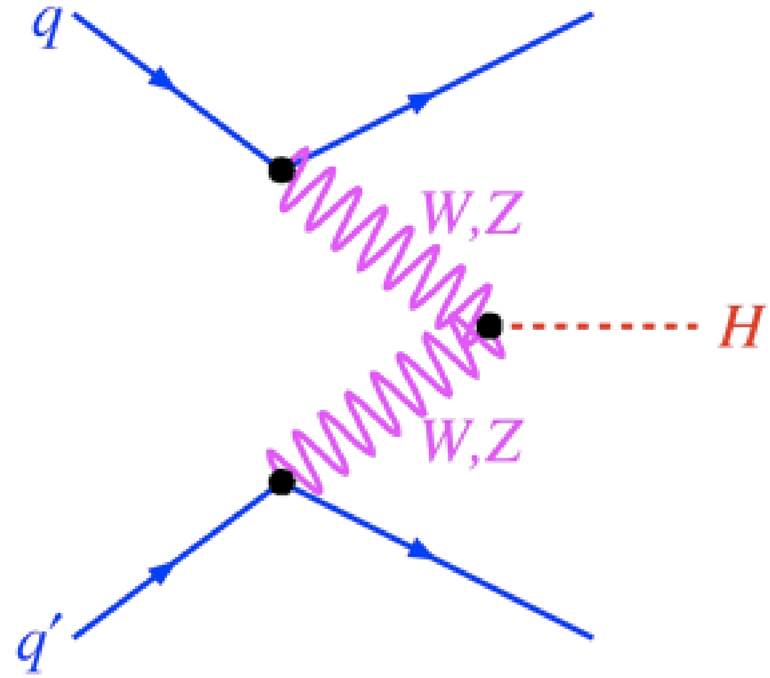
Typical decays



The Invisible Higgs



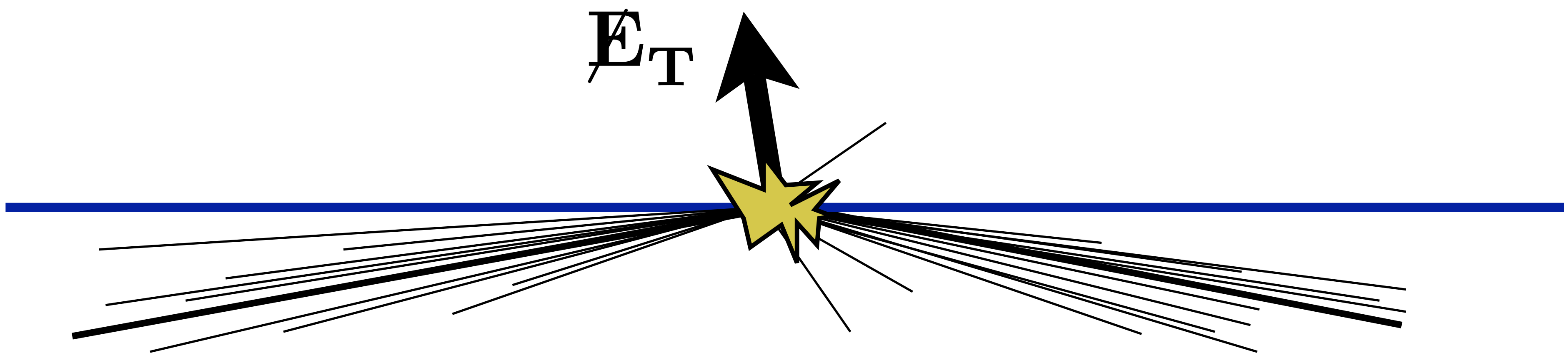
Two forward jets



M_H (GeV)	110	120	130	150	200	300	400
10 fb^{-1}	12.6%	13.0%	13.3%	14.1%	16.3%	22.3%	30.8%
100 fb^{-1}	4.8%	4.9%	5.1%	5.3%	6.2%	8.5%	11.7%

Eboli, Zeppenfeld (2000)

Two forward jets



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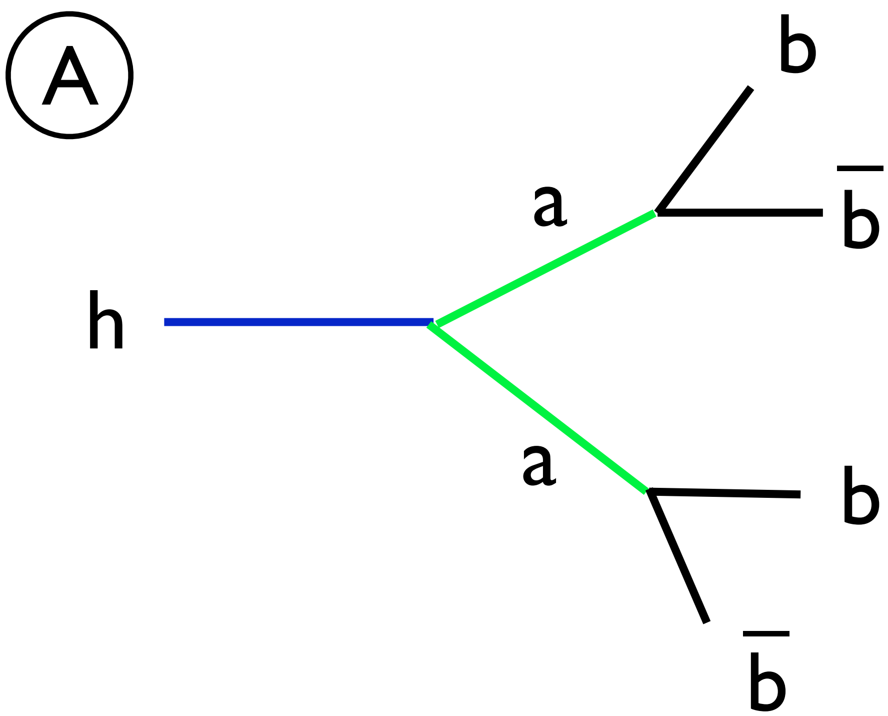
Eboli, Zeppenfeld (2000)

Hadronic decays

Much harder.



Signal:

$\sigma \sim 25\text{pb}$

5×10^4 events

Background:

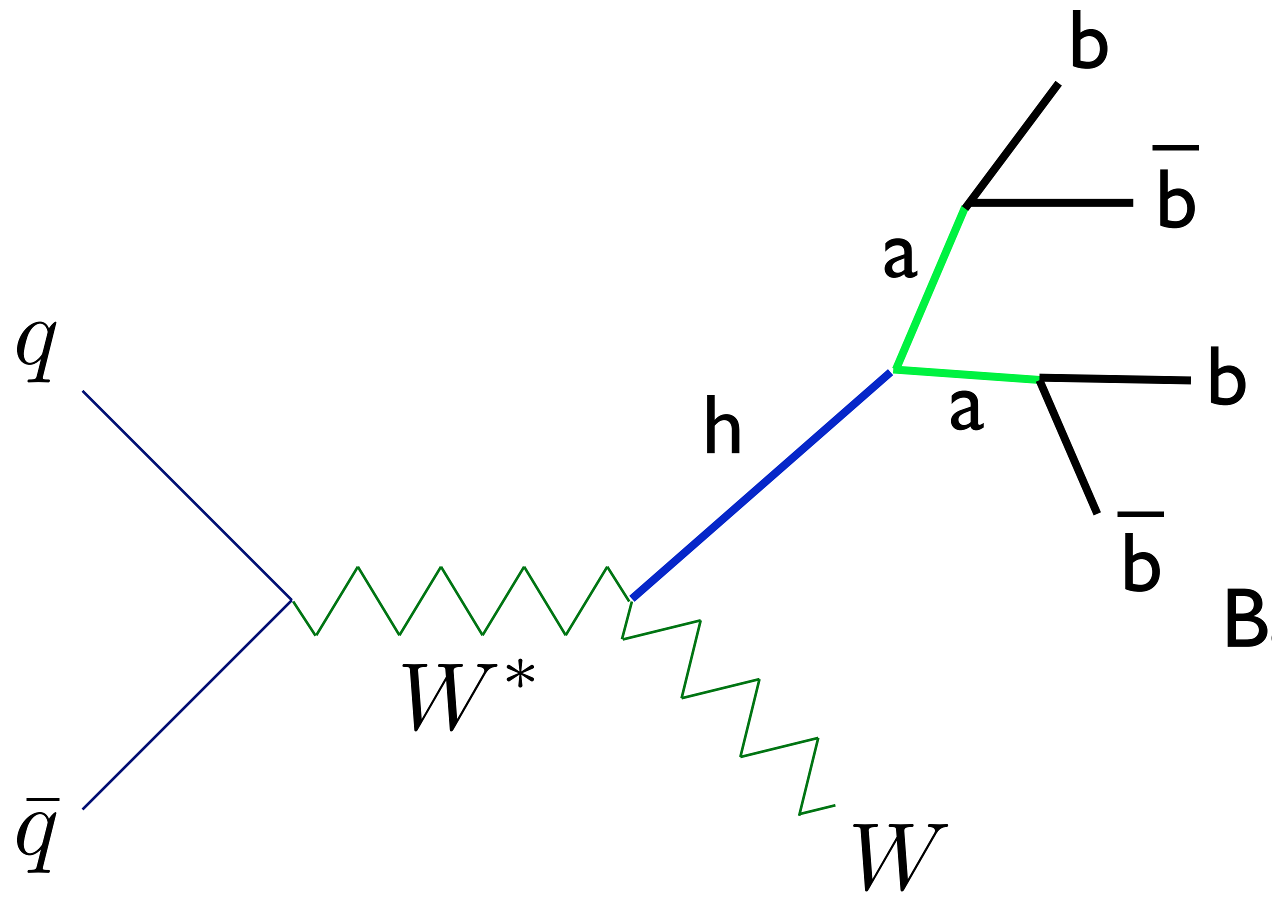
$\sigma \sim 0.5\mu\text{b}$

$\sim 500,000\text{pb}$

10^9 events

P_T cuts help!

Associated production



(with cuts)

Signal:

$\sigma \sim 1\text{pb}$

2,000 events

Background:

$\sigma \sim 10\text{pb}$

20,000 events

Tagging 4b's

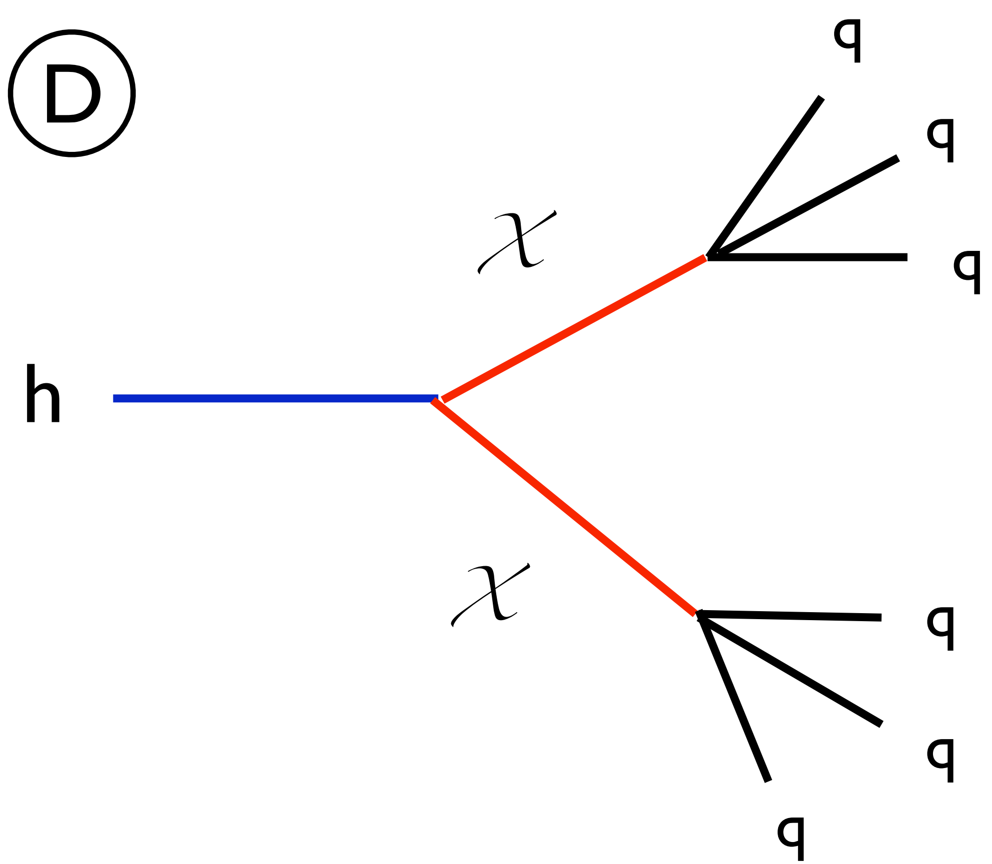
Softer b-jets make tagging and jet reconstruction difficult

A **vertex** trigger should go in at Level 2

We have run higgs to 4b through CDF's b-physics triggers and found 30% efficiency!

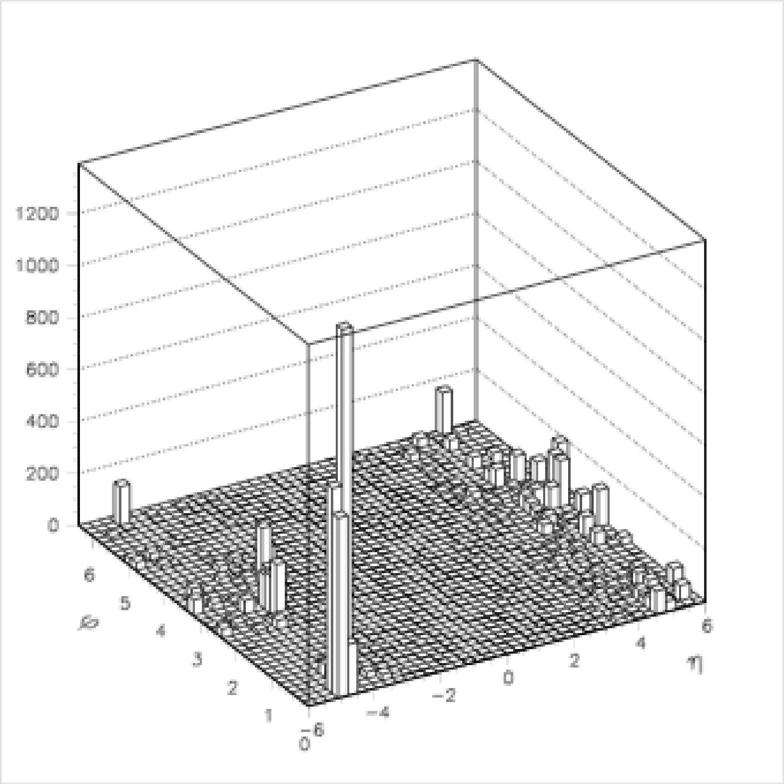
(Petar Maksimovic and Mark Mathis)

Decaying fermion

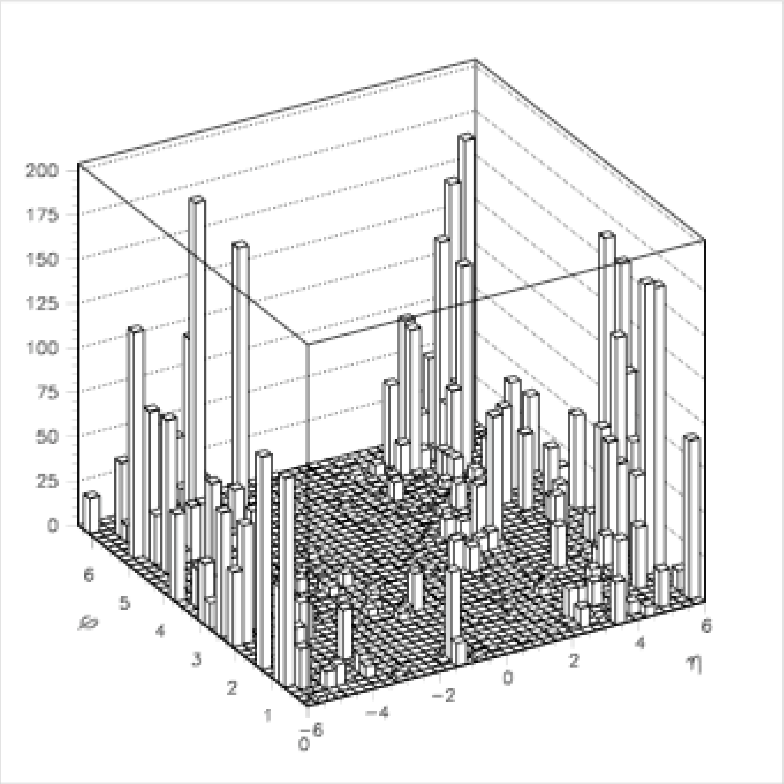


6 jets in principle has a smaller background, but these jets are of very low energy. would have to go to associated production in order to trigger at Level 1

Soft jets

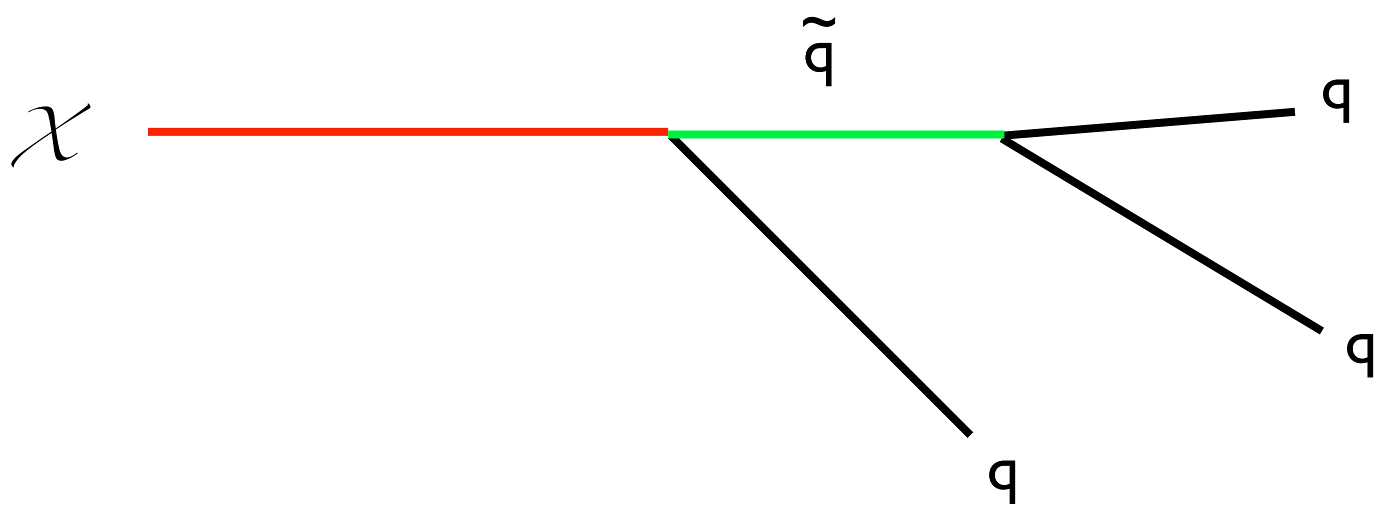


$$h^0 \to b\bar{b}$$



$$h^0 \to \tilde{\chi}^0 \tilde{\chi}^0 \to 6 \text{ jets}$$

Neutralino decay



Like b hadrons, neutralinos may have a long decay length.

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

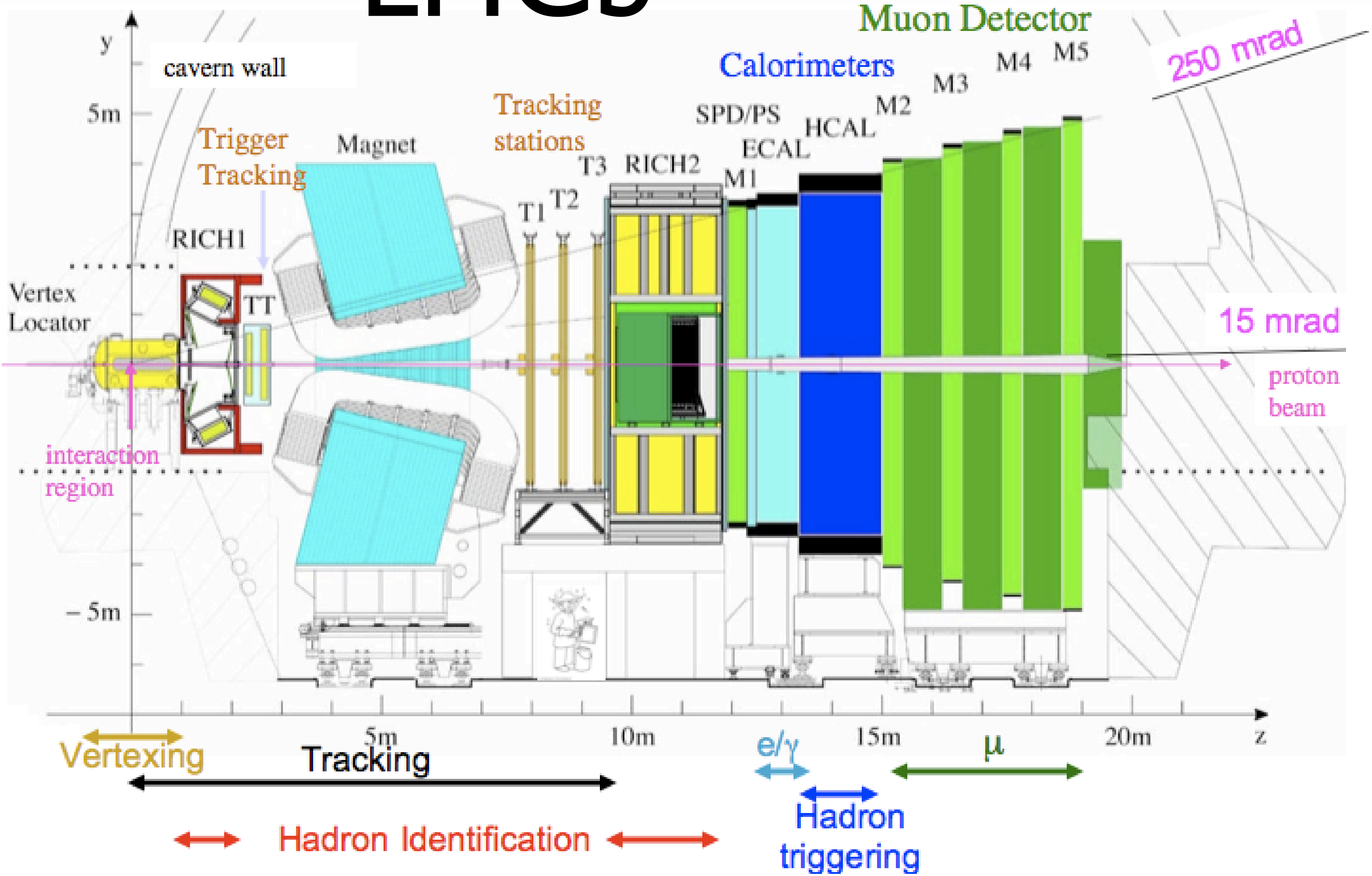
Tevatron B-physics triggers

CDF has roughly 1 fb^{-1} of B-physics data (not pre-scaled)

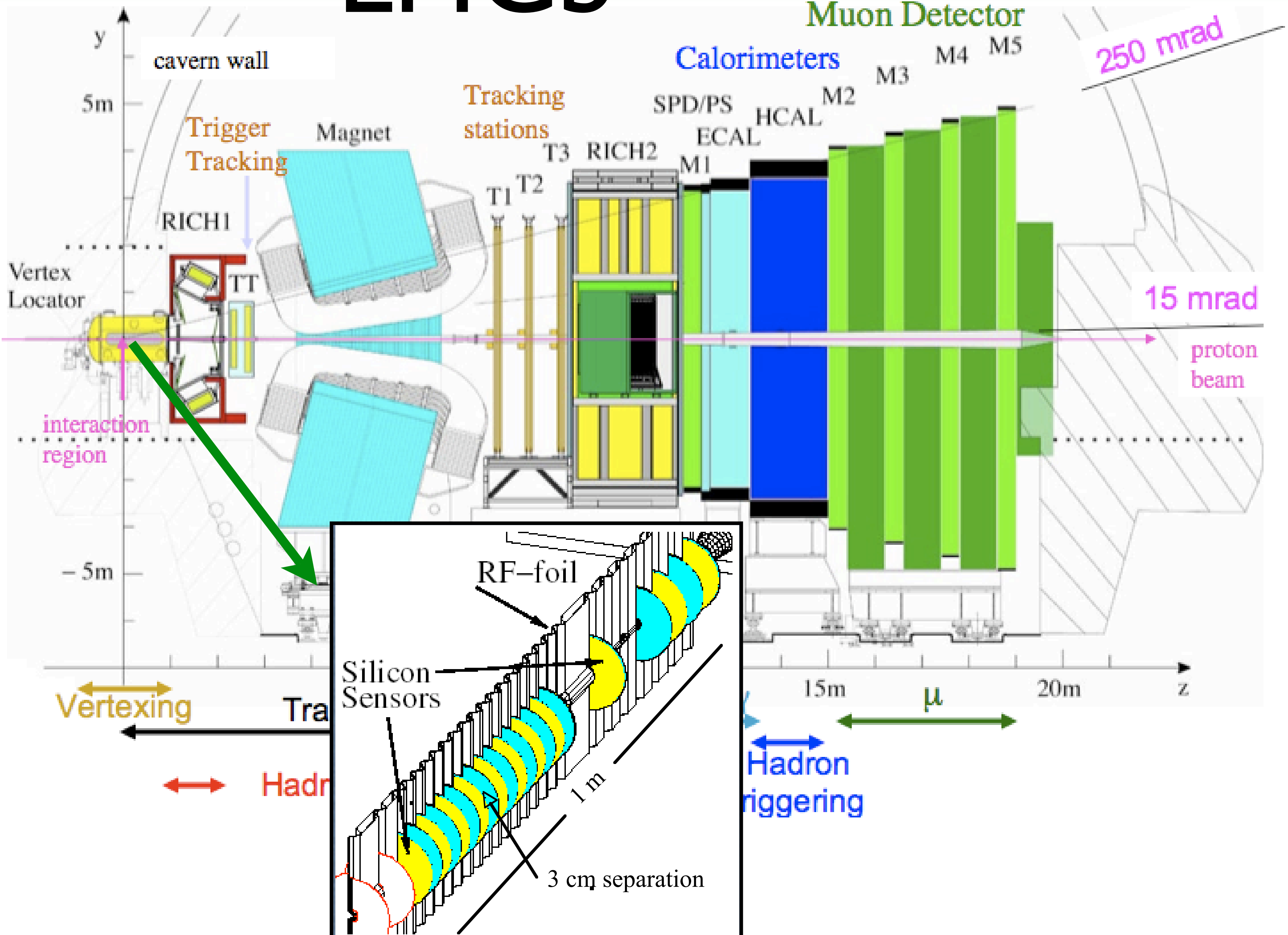
M_χ	M_H	Efficiency	No. events expected in $1fb^{-1}$	No. events to tape
$M_\chi = 7.753GeV$		0.1%	1200	1.2
$M_\chi = 30.21GeV$	$M_H = 95GeV$	24.5 %	1200	294
$M_\chi = 42.74GeV$		16.2 %	1200	194
$M_\chi = 20.78GeV$		6.50 %	700	46
$M_\chi = 45.36GeV$	$M_H = 120GeV$	12.7 %	700	89
$M_\chi = 52.83GeV$		5.9 %	700	41

Table 1: The efficiencies of the 2 Track Trigger with Scenario A cuts for each of the scenarios simulated

LHCb


y
cavern wall
5m
– 5m
Trigger
Tracking
Magnet
Tracking
stations
Muon Detector
Calorimeters
250 mrad
M4
M5
M3
M2
SPD/PS
HCAL
ECAL
T3
RICH2
M1
T1
T2
RICH1
Vertex
Locator
TT
15 mrad
proton
beam
interaction
region
5m
10m
15m
20m
z
Vertexing
Tracking
e/γ
μ
Hadron Identification
Hadron
triggering

LHCb


cavern wall
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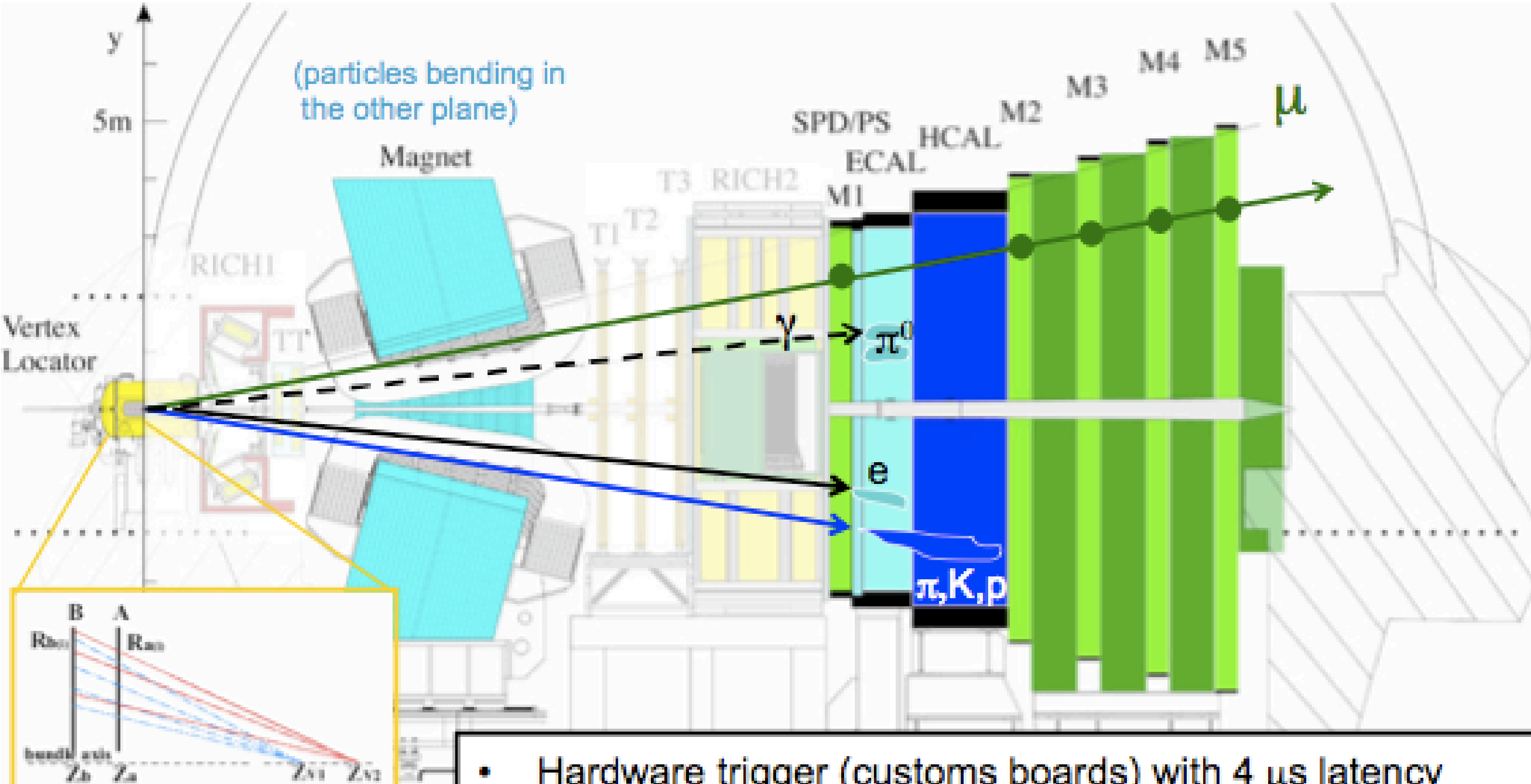
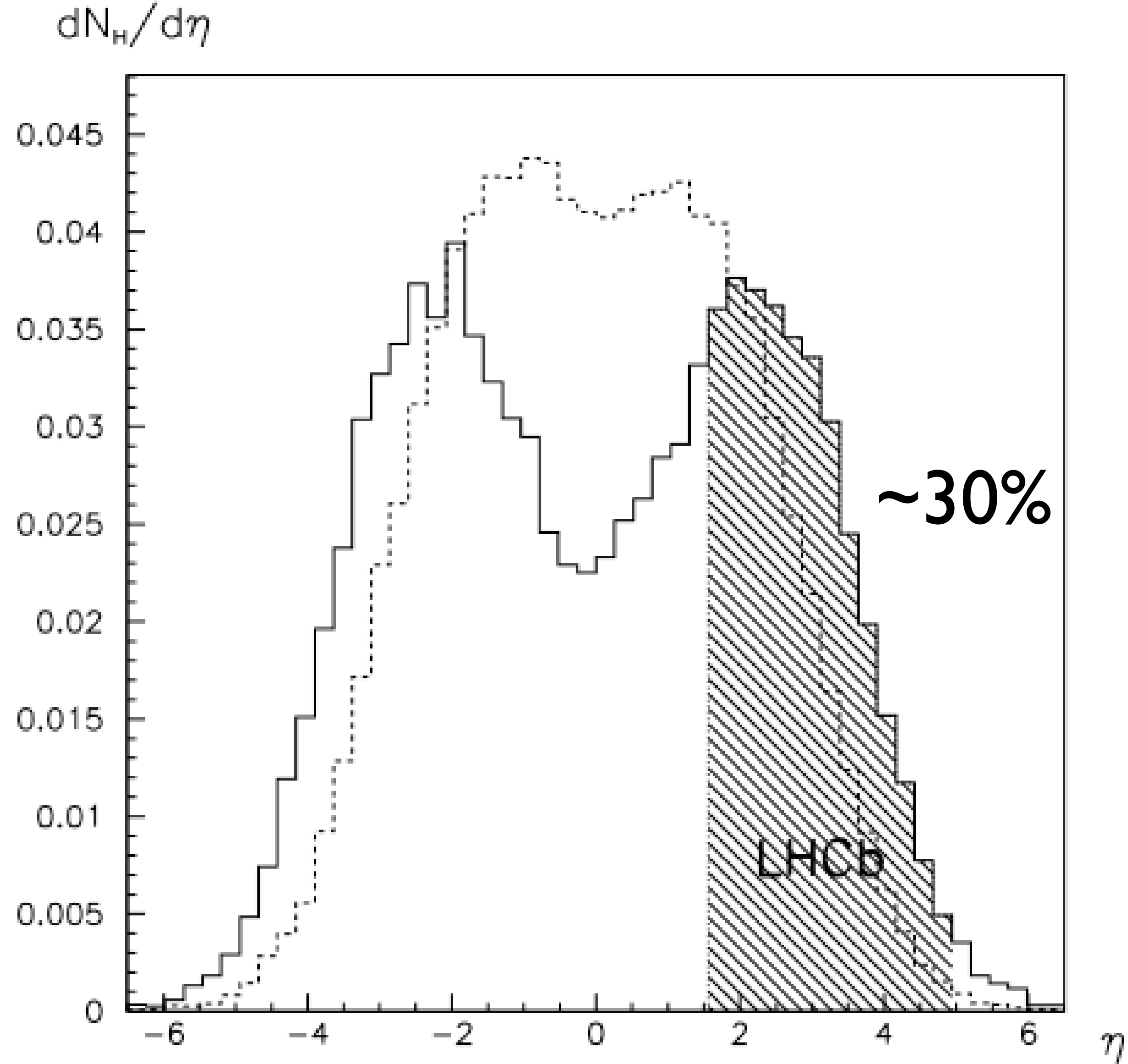
region
15m
20m
z
μ
Vertexing
Hadron
riggering
RF−foil
Silicon
Sensors
1 m
3 cm separation

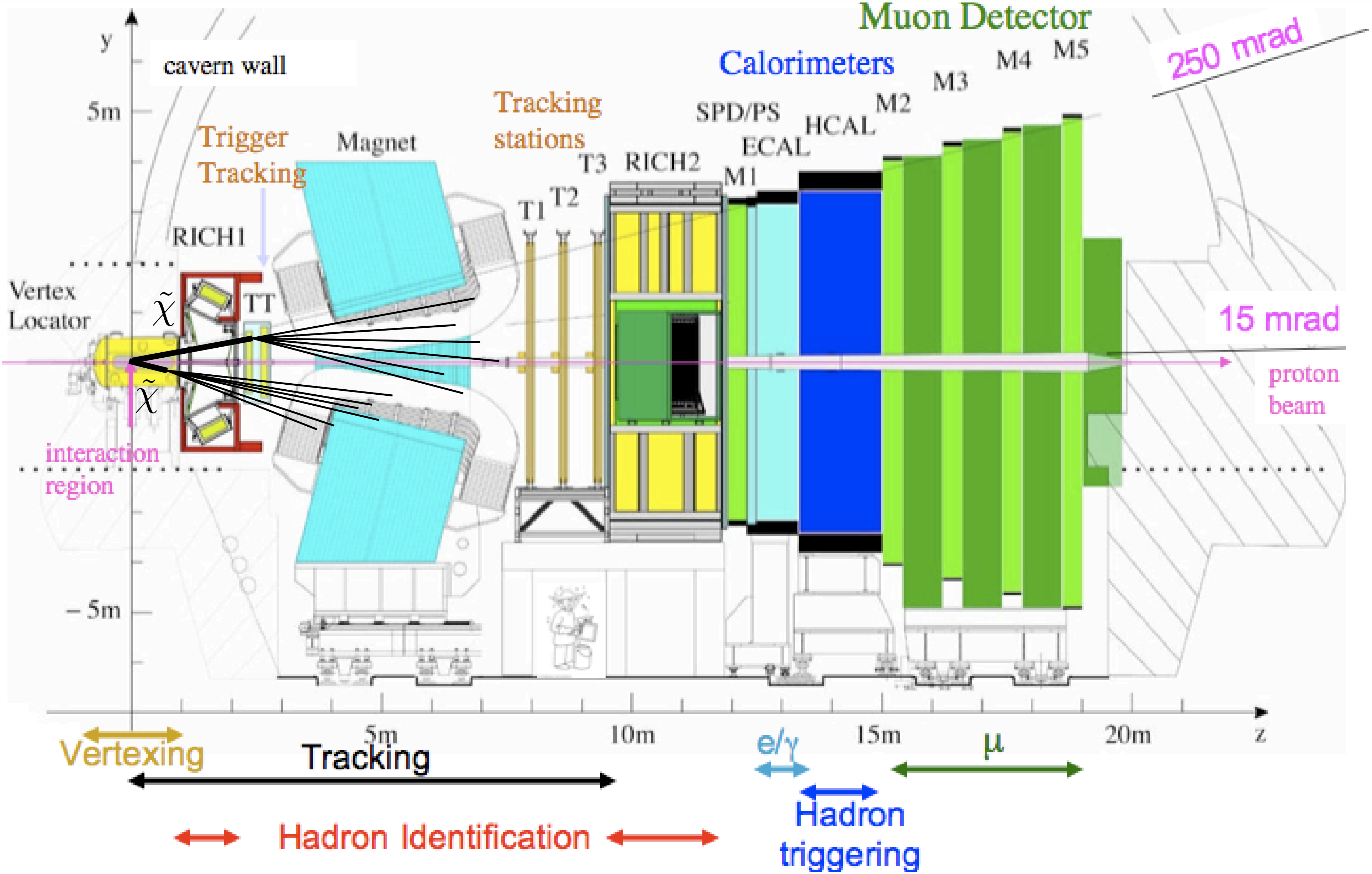


Pile-up veto:
Remove bunch crossings with too many beam-beam interactions
(not applied to μ-trigger)

- Hardware trigger (customs boards) with 4 μs latency
- Reduces 10 MHz inelastic collision rate to 1 MHz:
  - $Pt_{\mu 1}$ (+ $Pt_{\mu 2}$) > 1.3 GeV
  - Et_e > 2.8 GeV Et_γ > 2.6 GeV Et_{π^0} > 4.0 GeV
  - $Et_{\pi,K,p}$ > 3.6 GeV

Light Higgses are boosted





Muon Detector
250 mrad
cavern wall
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interaction
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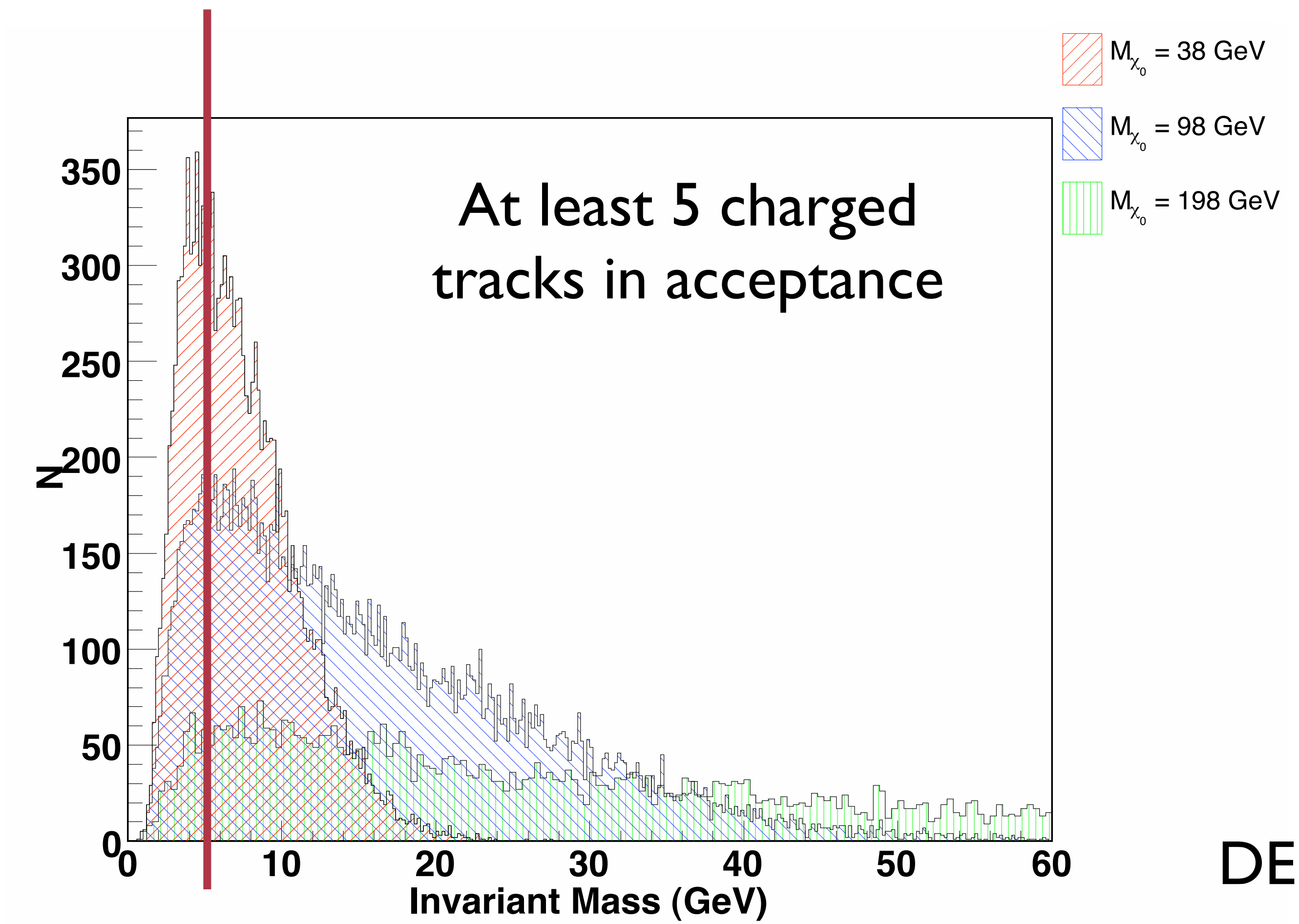
− 5m
5m
10m
15m
20m
z
y
Vertexing
Tracking
e/γ
μ
Hadron
triggering
Hadron Identification

Higgs/Neutralino search at LHCb

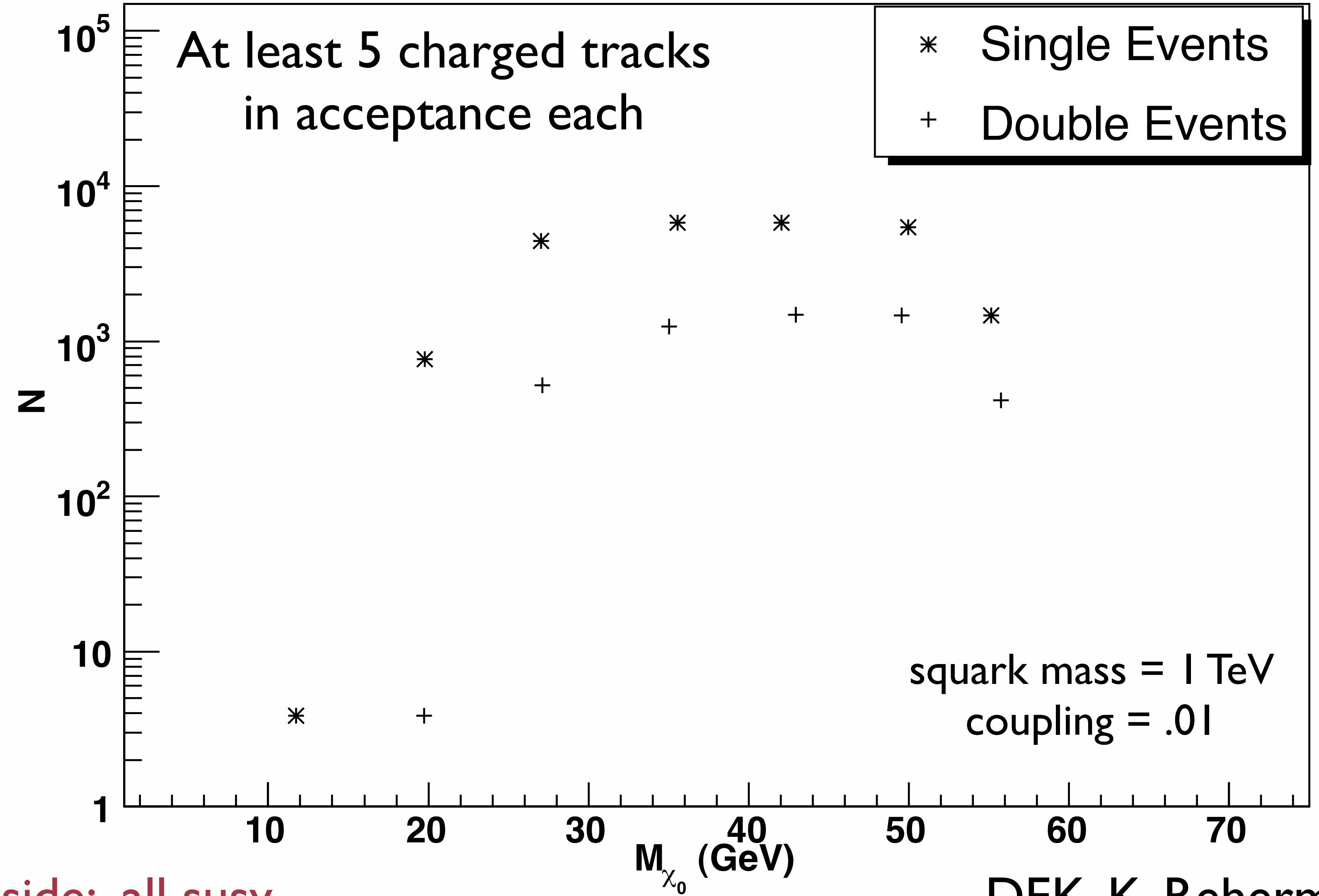
Main worry: distinguish from b-quarks.



Number and invariant mass of charged particles larger than for b's

DEK, K. Rehermann (2007)

Higgs/Neutralino search at LHCb

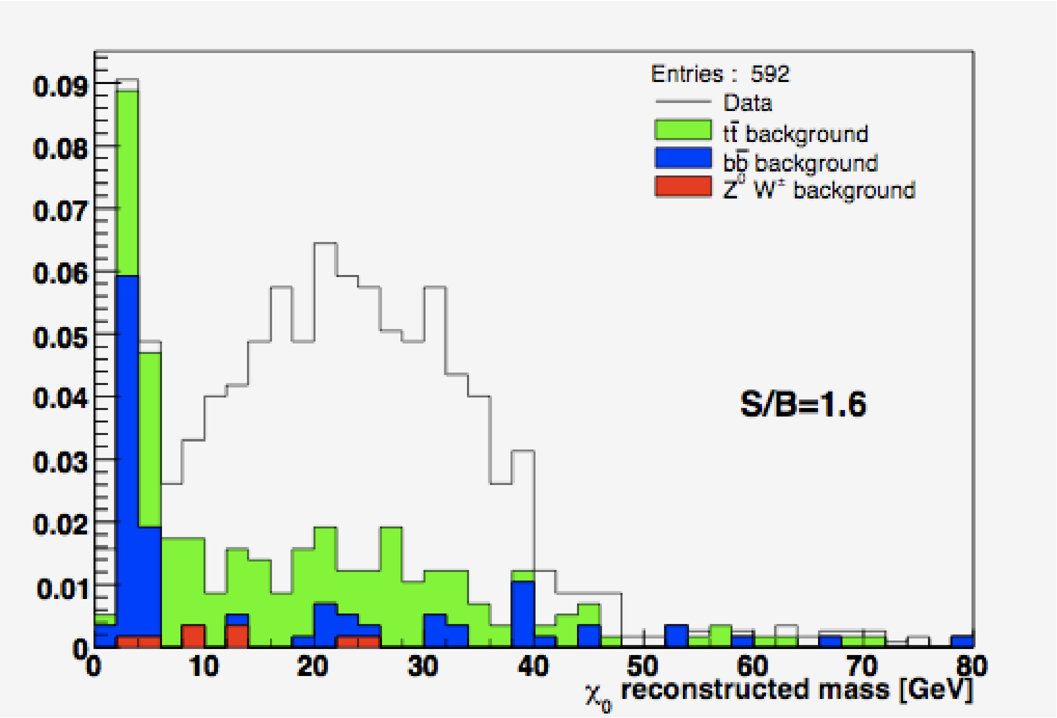


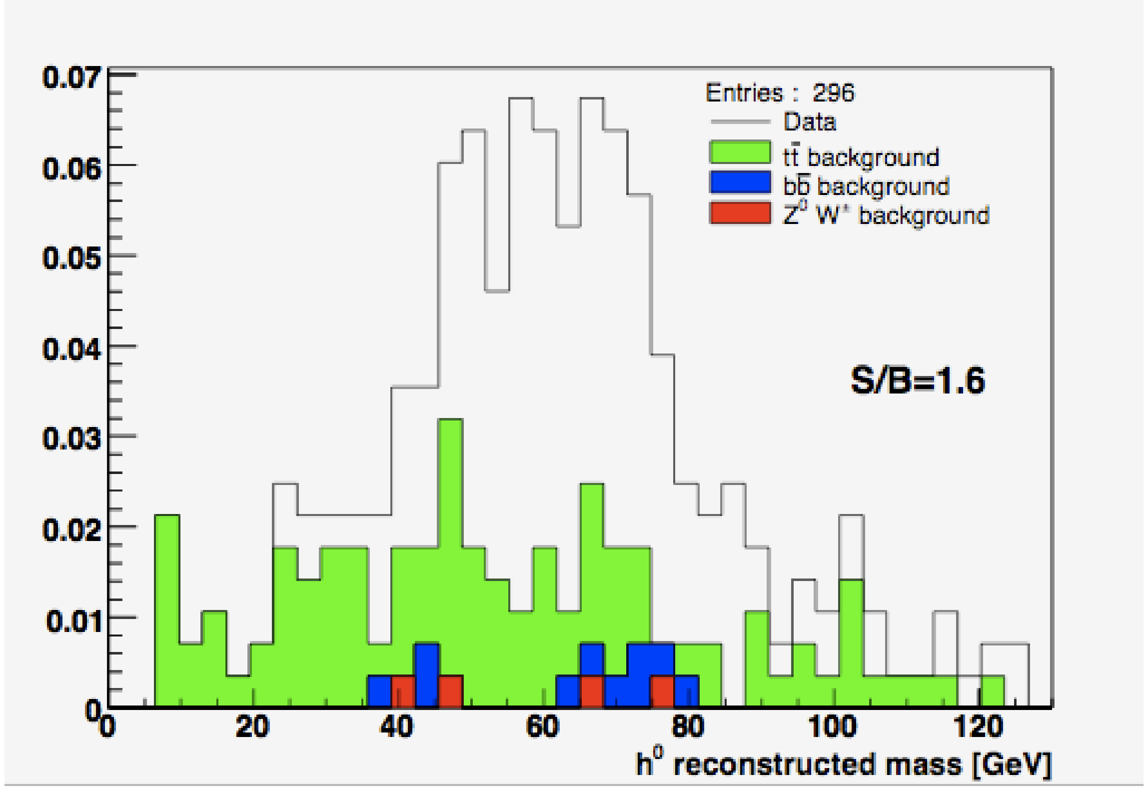
1 year of running

Aside: all susy

DEK, K. Rehermann (2007)

LHCb simulated data after acceptance requirements and cuts:

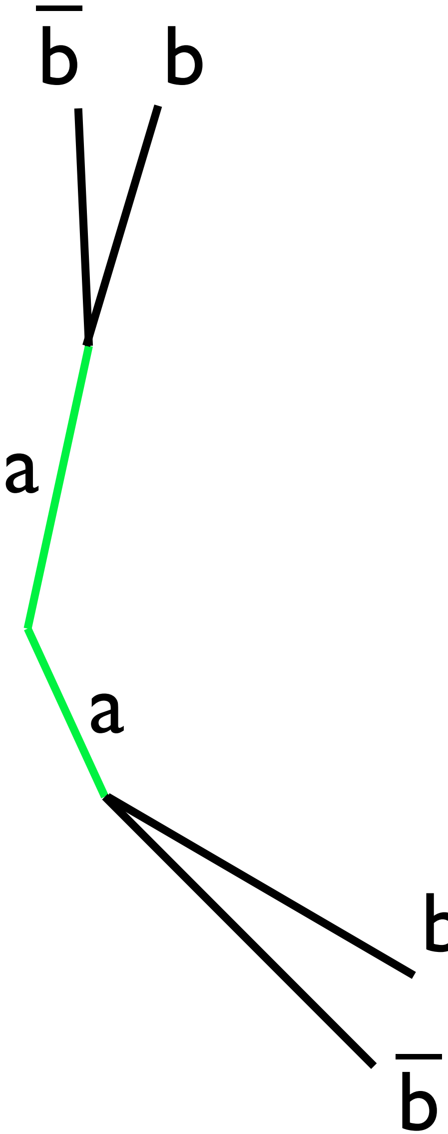


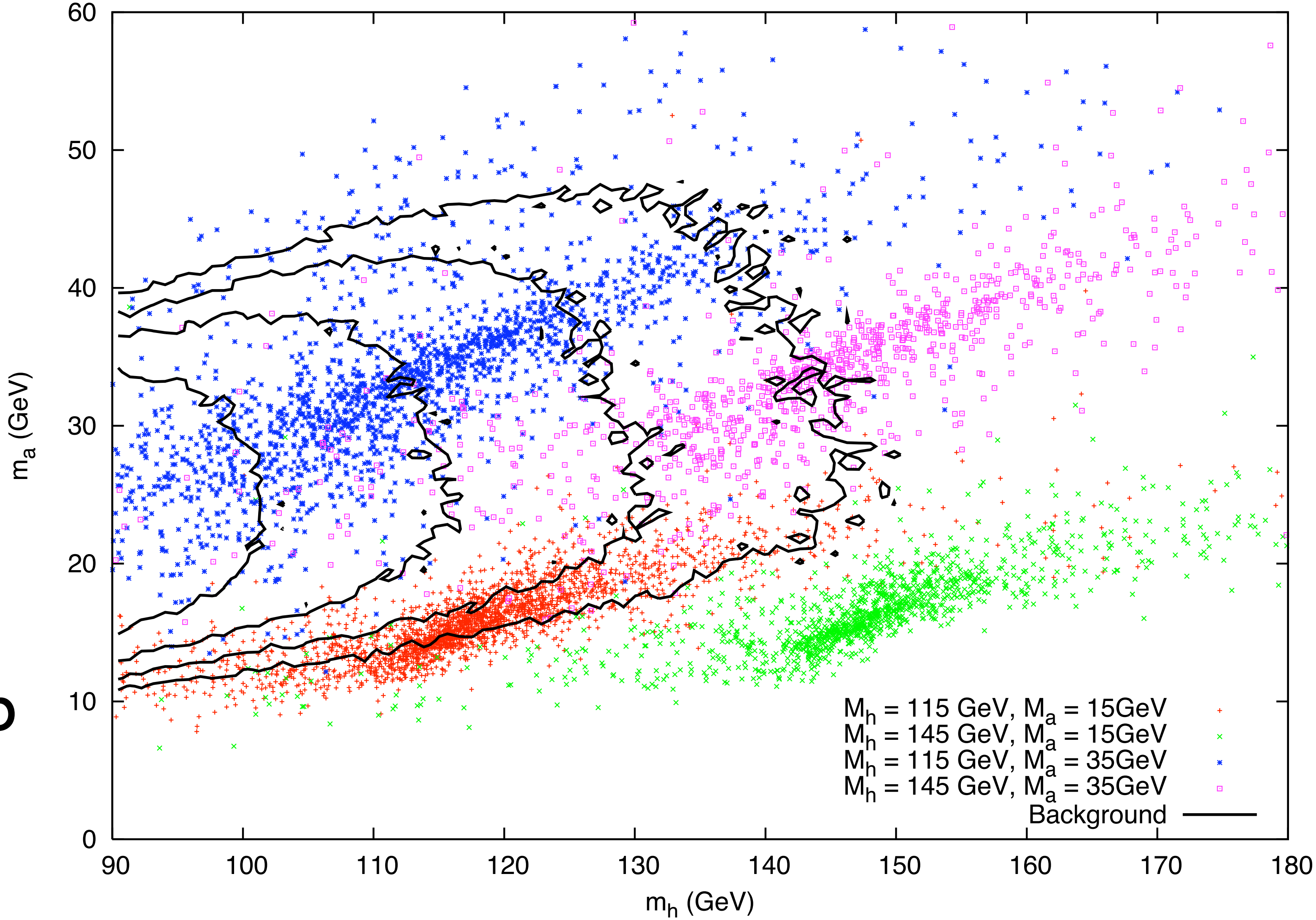


Could reconstruct the Higgs and measure its mass with ~10% accuracy.

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

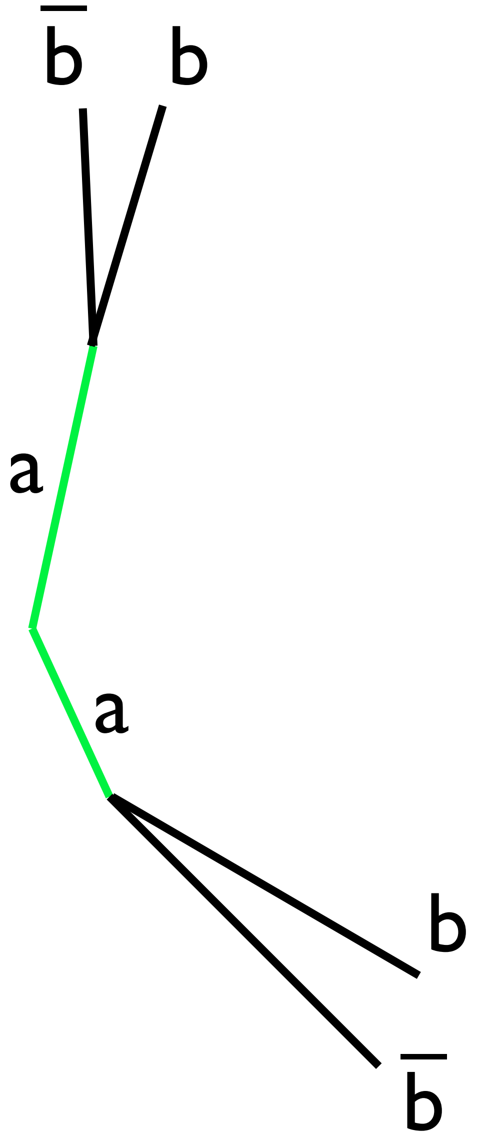
Even 4b at small m_a





DEK, M. McEvoy (2007)

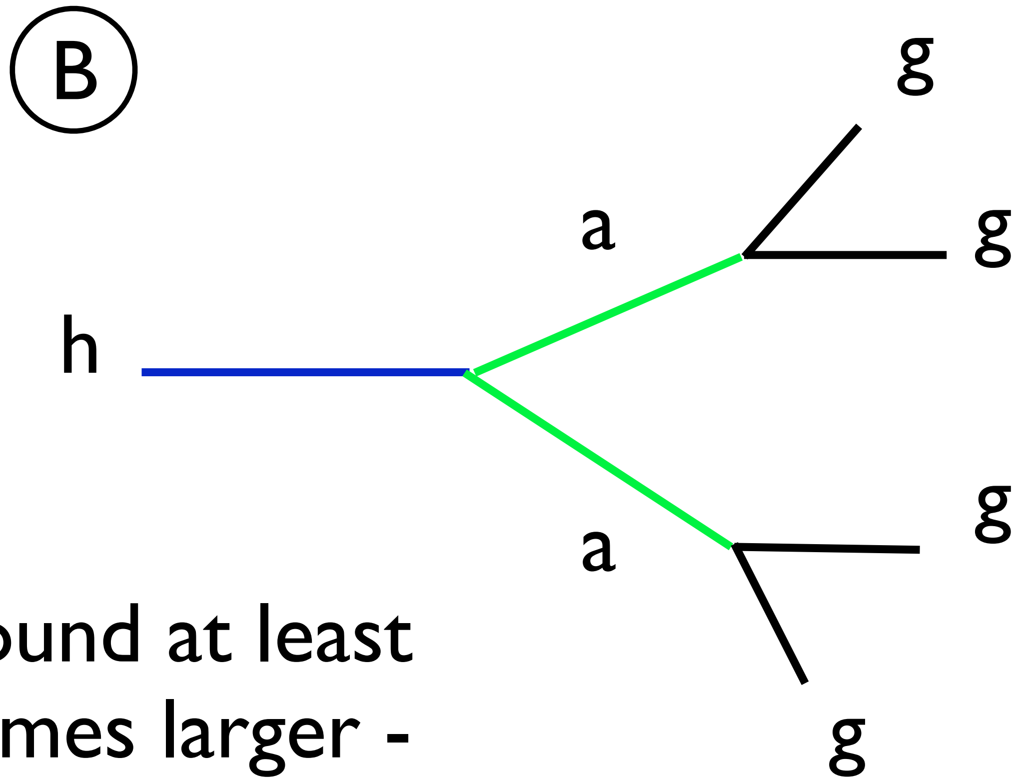
Even 4b at small m_a



DEK, M. McEvoy (2007)

m_h	m_a	q^+	q^-	ϵ_{req}	S/B
115	15	105	72.5	0.06	0.11
115	20	135	57.5	0.24	0.023
115	25	135	42.5	0.39	0.016
115	30	135	27.5	0.69	0.012
115	35	135	12.5	1.15	0.009
130	15	125	87.5	0.05	0.175
130	20	145	72.5	0.24	0.034
130	25	155	57.5	0.39	0.025
130	30	155	42.5	0.59	0.020
130	35	155	27.5	0.88	0.017
145	15	135	102.5	0.05	0.38
145	20	155	87.5	0.22	0.052
145	25	165	72.5	0.46	0.029
145	30	165	57.5	0.78	0.022
145	35	165	42.5	1.00	0.020

For all gluons



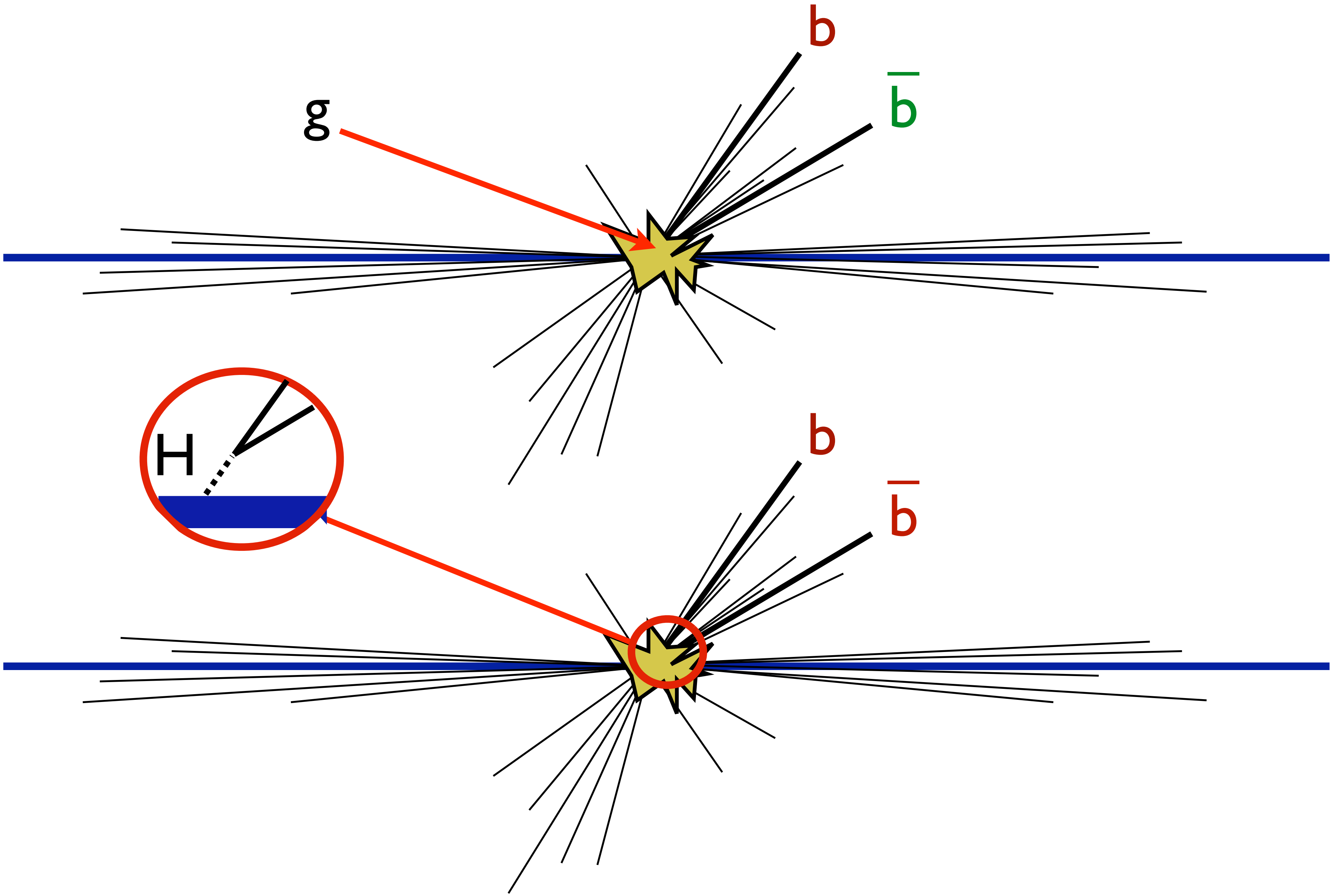
Background at least 1,000 times larger - no tricks yet...

Other discriminants

So heavy flavors and other macroscopic decays (‘displaced vertices’) and perhaps special kinematics allow for distinguishing above background.

We need more generic observables if possible...

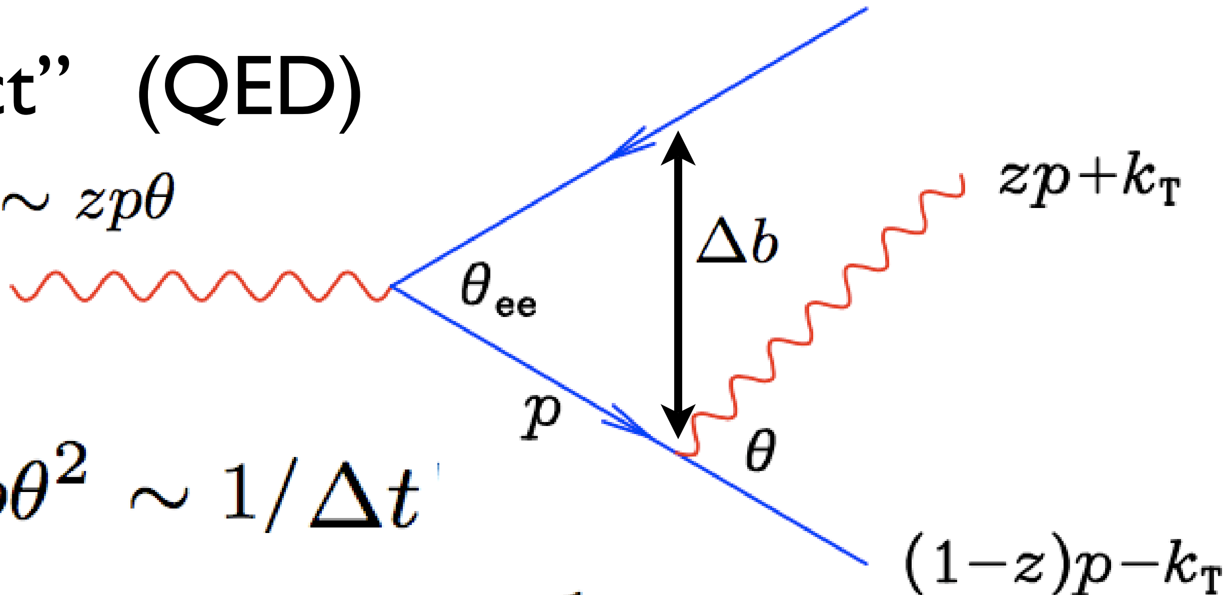
Color flow



Showering differences

The "Chudakov Effect" (QED)

$\theta_{ee}, \theta \ll 1 \longrightarrow k_T \sim zp\theta$



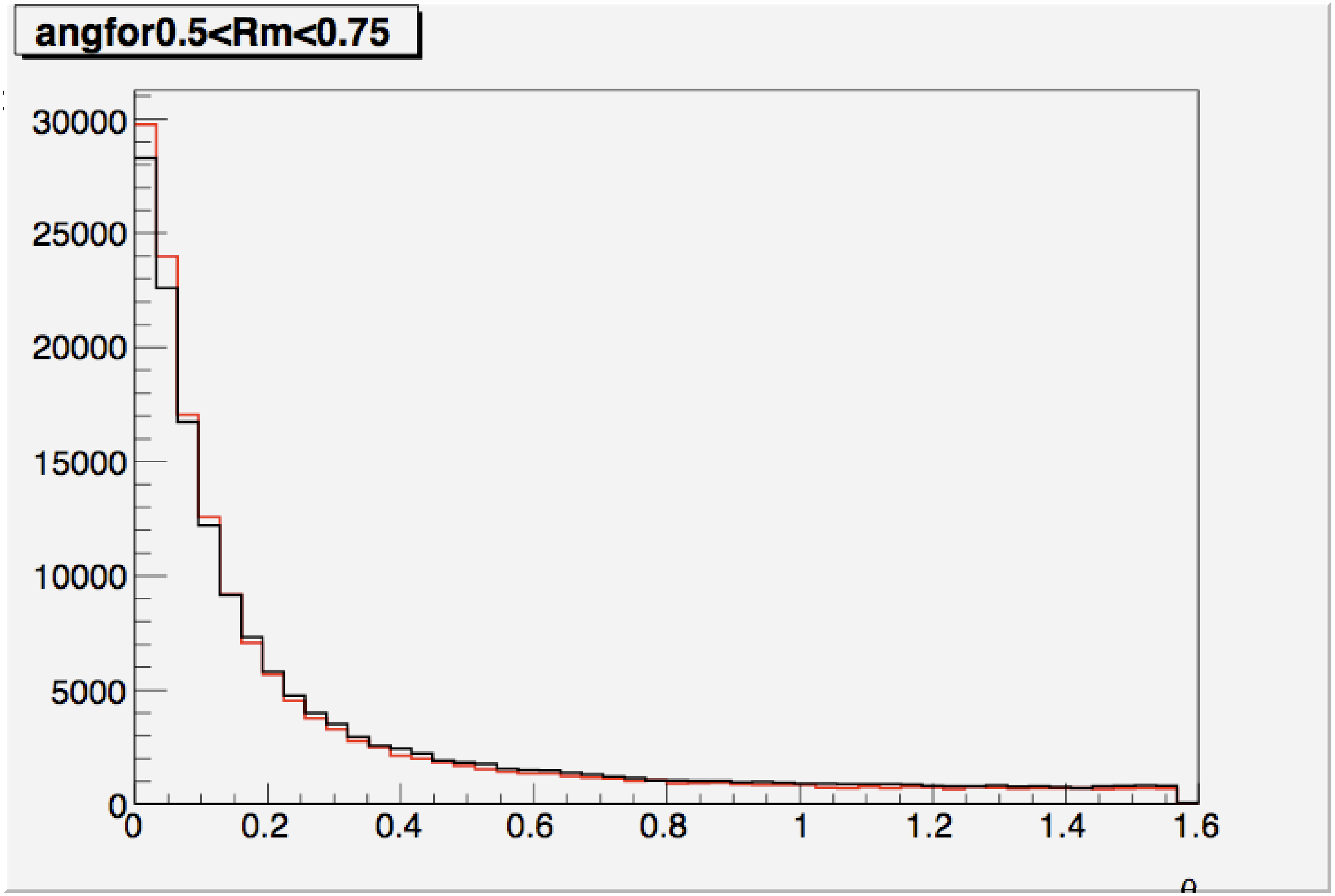
$$\Delta E \sim k_T^2/zp \sim zp\theta^2 \sim 1/\Delta t$$

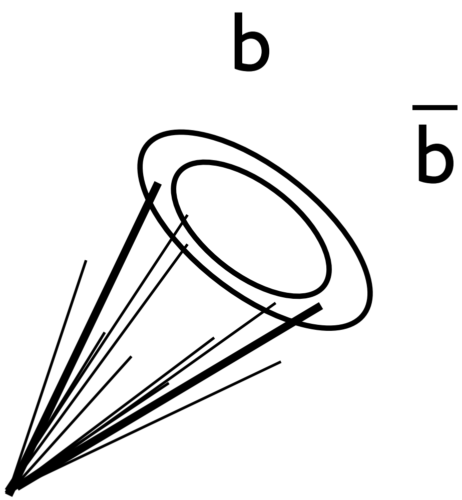
$$\Delta b \sim \theta_{ee}\Delta t > \lambda/\theta \sim (zp\theta)^{-1}$$

$$\theta_{ee}(zp\theta^2)^{-1} > (zp\theta)^{-1} \longrightarrow \theta_{ee} > \theta$$

Preliminary tests

Here is a simulation of Higgs production and QCD production of two b-jets boosted w.r.t. the lab frame.





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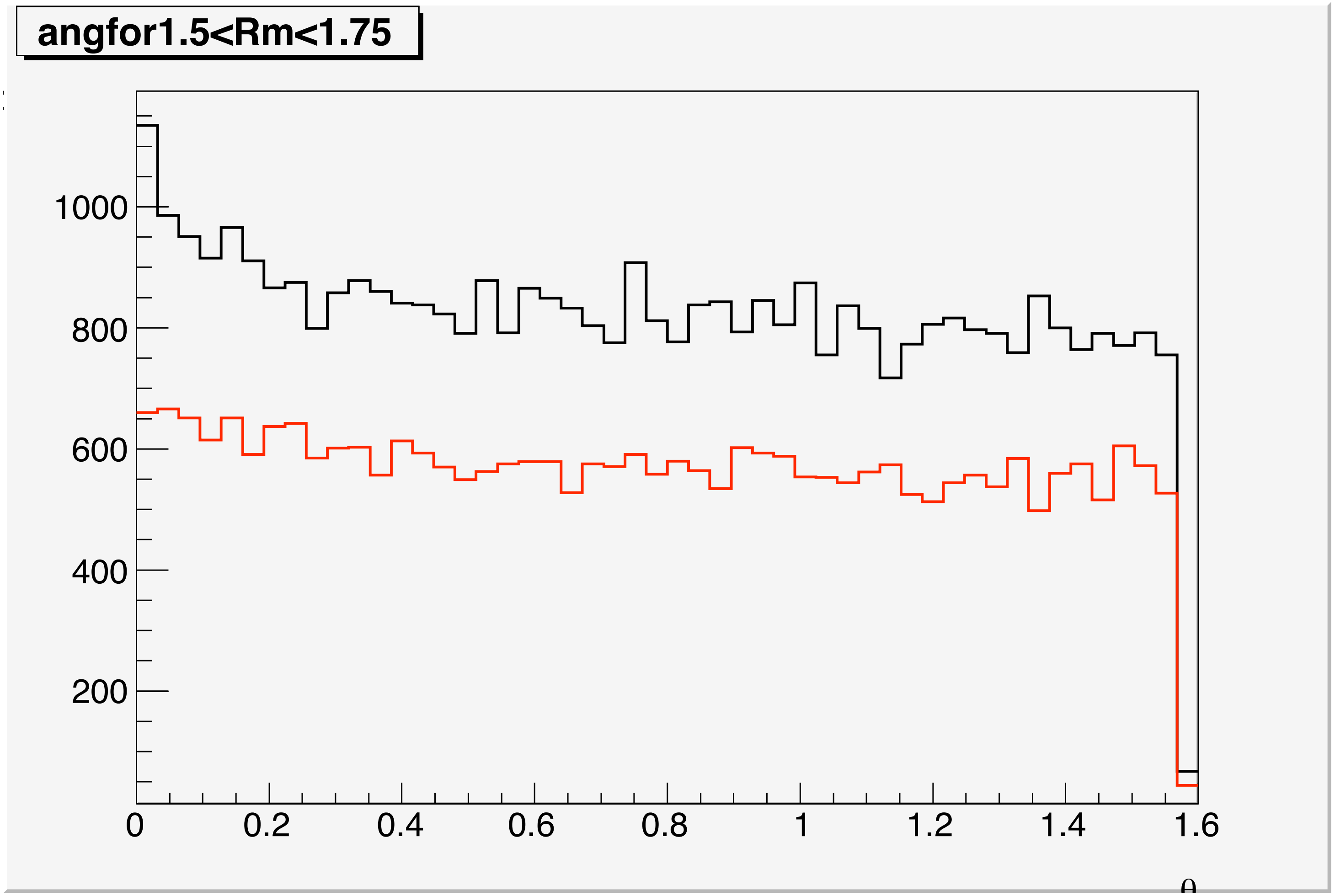
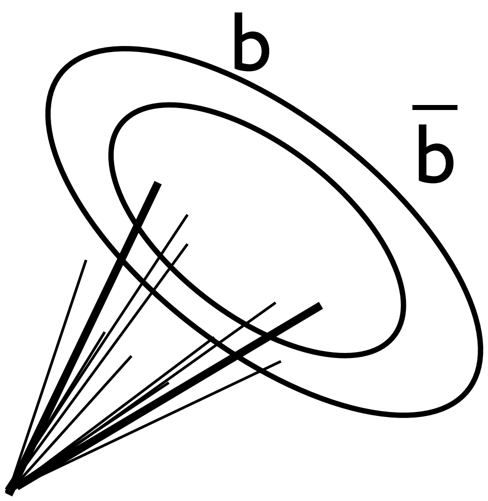
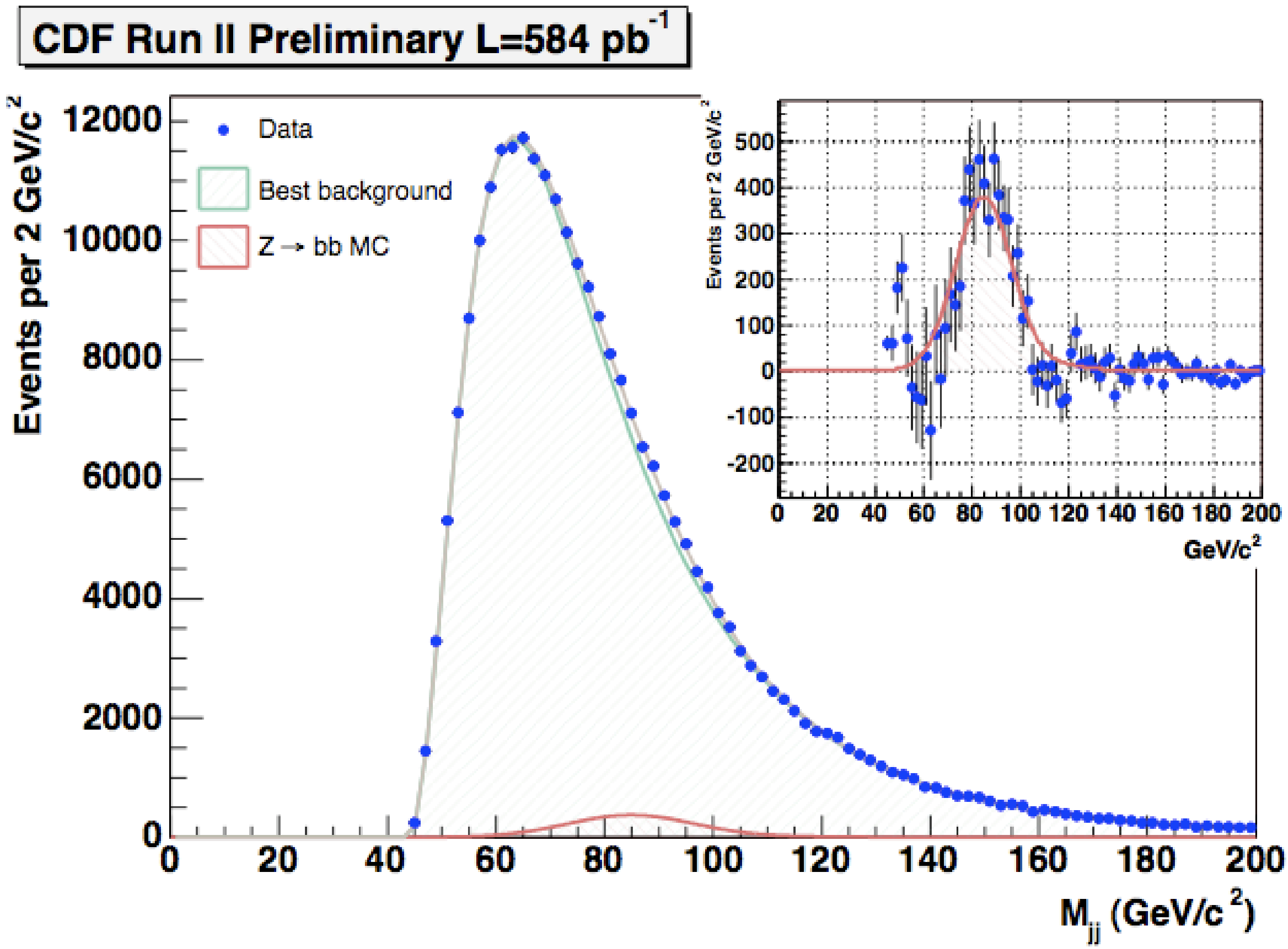




Testing ground



Conclusion

The Higgs search is 'at risk' because the Higgs width is very sensitive to new light unseen physics.

If so, new approaches may be needed to see the Higgs in a reasonable amount of time.

And we could get lucky

“Is that a Higgs in your data, or are you just happy to see me?”