EXPLORING THE HIGGS PORTAL

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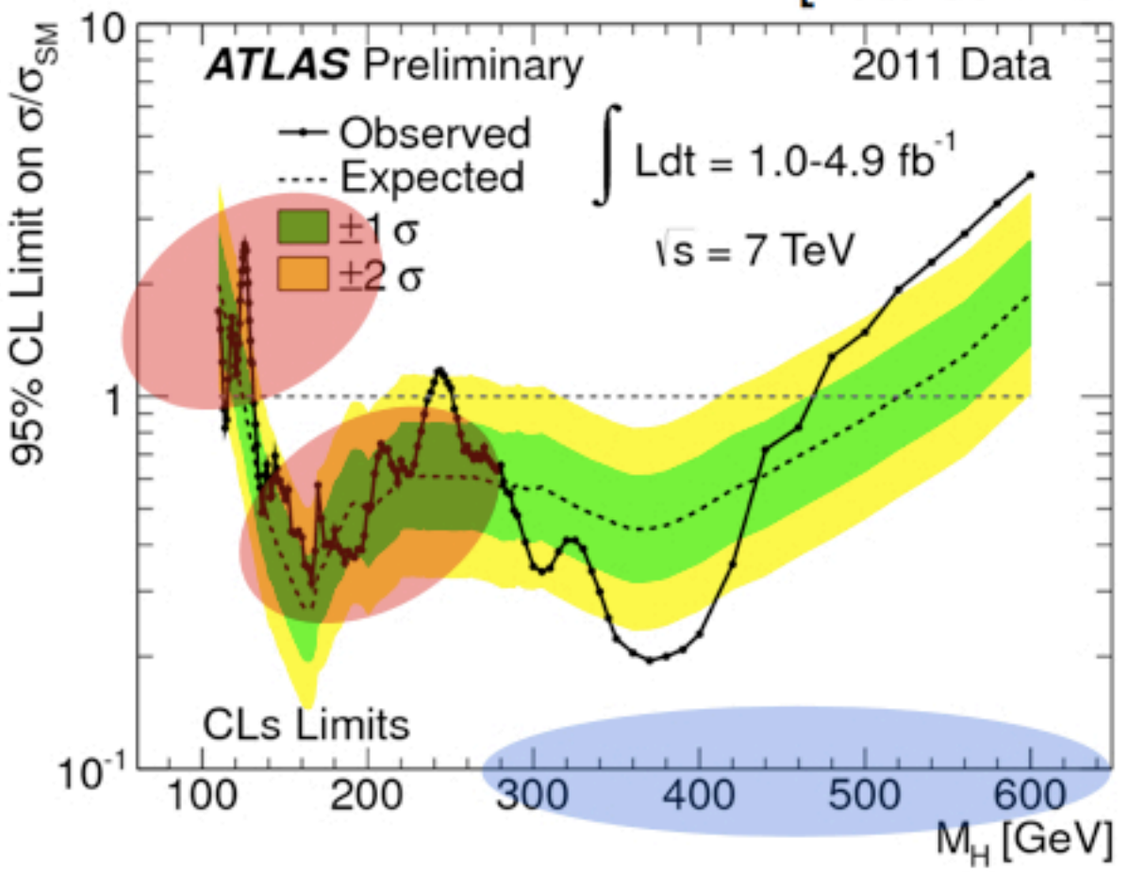
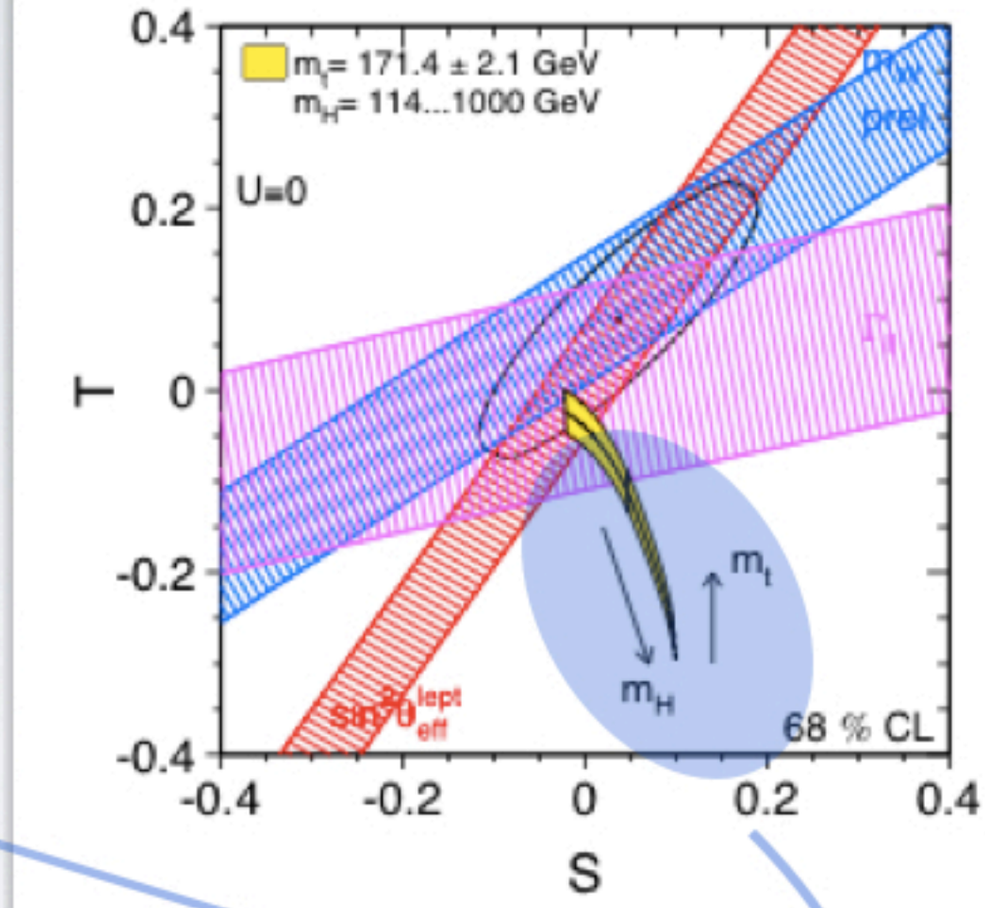
based on CE, Tilman Plehn, Michael Rauch, Dirk Zerwas, Peter M. Zerwas, Phys. Lett. B707, 512
CE, Tilman Plehn, Dirk Zerwas, Peter M. Zerwas, Phys. Lett. B703, 298

(avoiding) Higgs limits

[Atlas Conf-2011-163]





- bounds are determined by measurement of twin ratios

$$\kappa_{p,d} = \left(\frac{\Gamma^p \Gamma^d}{\Gamma^{\rm tot}}\right) \Big/ \left(\frac{\Gamma^p \Gamma^d}{\Gamma^{\rm tot}}\right)^{\rm SM} = (\sigma_p \times {\rm BR}_d)/(\sigma_p \times {\rm BR}_d)^{\rm SM}$$

[Bock, Lafaye, Plehn, Rauch, Zerwas, Zerwas `10]

- basically two ways to avoid current bounds (no way to reconcile in the SM)

$$1)\ \sigma_p < \sigma_p^{\rm SM} \qquad 2)\ {\rm BR}_d < {\rm BR}_d^{\rm SM}$$

Avoiding Higgs limits: the Higgs portal

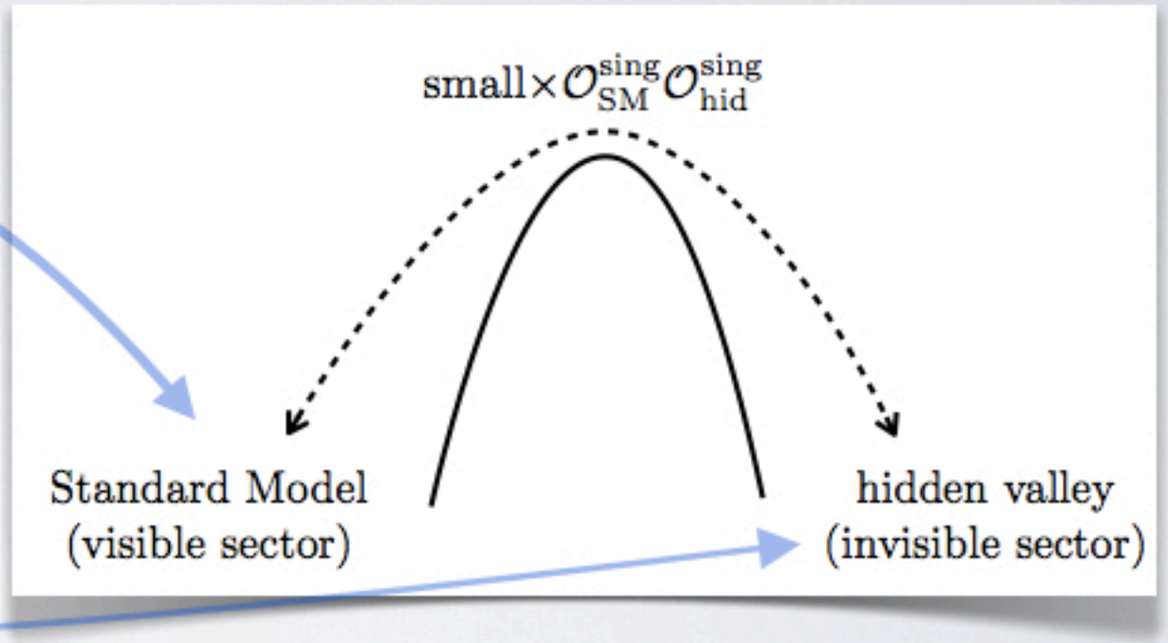
[Schabinger, Wells `05] [Patt, Wilczek `06] ...
[Bowen, Cui, Wells `07] [Barger et al. `08] ...

- $\phi_s^\dagger \phi_s$ is a singlet under the electroweak group and can act as a portal

$$\mathcal{V} = \mu_s^2|\phi_s|^2 + \lambda_s|\phi_s|^4 \; + \; \mu_h^2|\phi_h|^2 + \lambda_h|\phi_h|^4 \; + \; \eta_\chi|\phi_s|^2|\phi_h|^2$$

- $\phi_s,\ \phi_h$ acquire vevs:

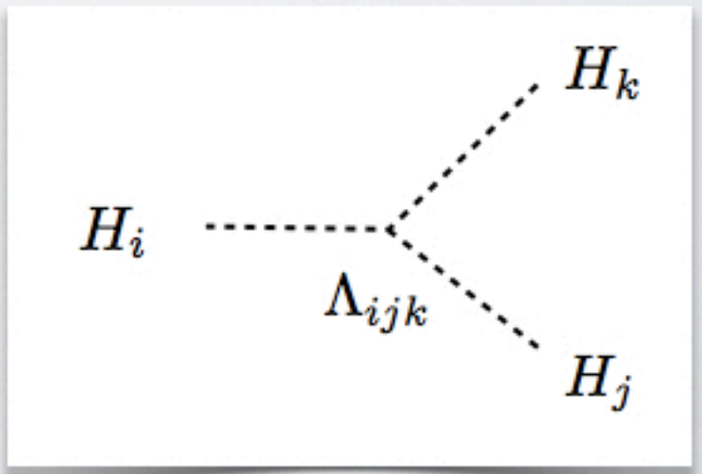
$$\begin{aligned} (H_{\rm SM} \sim)\ H_1 &= \quad \cos\chi\, H_s + \sin\chi\, H_h \\ H_2 &= -\sin\chi\, H_s + \cos\chi\, H_h \end{aligned}$$



- modified production cross sections and decay widths, cascades

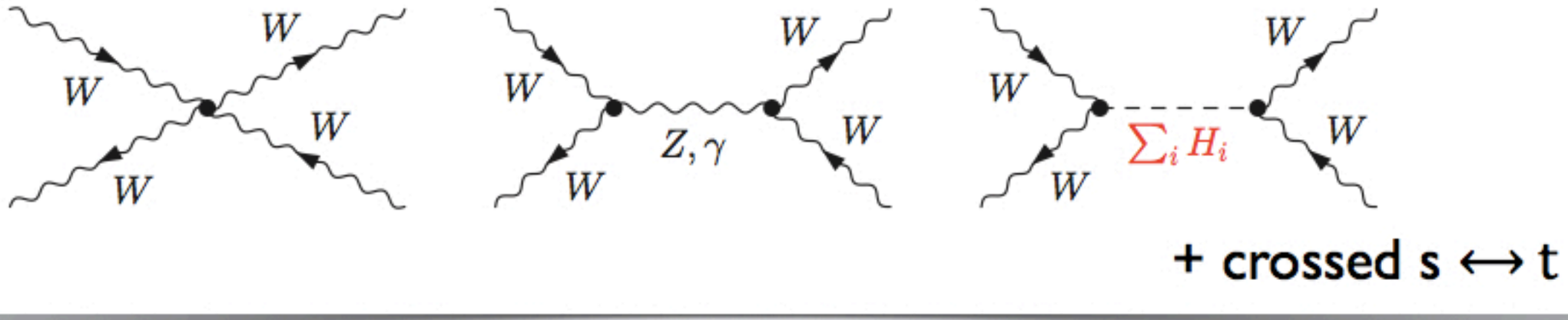
$$\begin{aligned} \sigma_1 &= \cos^2\chi\,\sigma_1^{\rm SM} & \sigma_2 &= \sin^2\chi\,\sigma_2^{\rm SM} \\ \Gamma_1^{\rm vis} &= \cos^2\chi\,\Gamma_1^{\rm SM} & \Gamma_2^{\rm vis} &= \sin^2\chi\,\Gamma_2^{\rm SM} \\ \Gamma_1^{\rm inv} &= \sin^2\chi\,\Gamma_1^{\rm hid} & \Gamma_2^{\rm inv} &= \cos^2\chi\,\Gamma_2^{\rm hid} \end{aligned}$$

$$\Gamma_2^{HH} = \frac{\Lambda_{211}^2}{32\pi}\,\frac{\beta_1}{M_2}$$

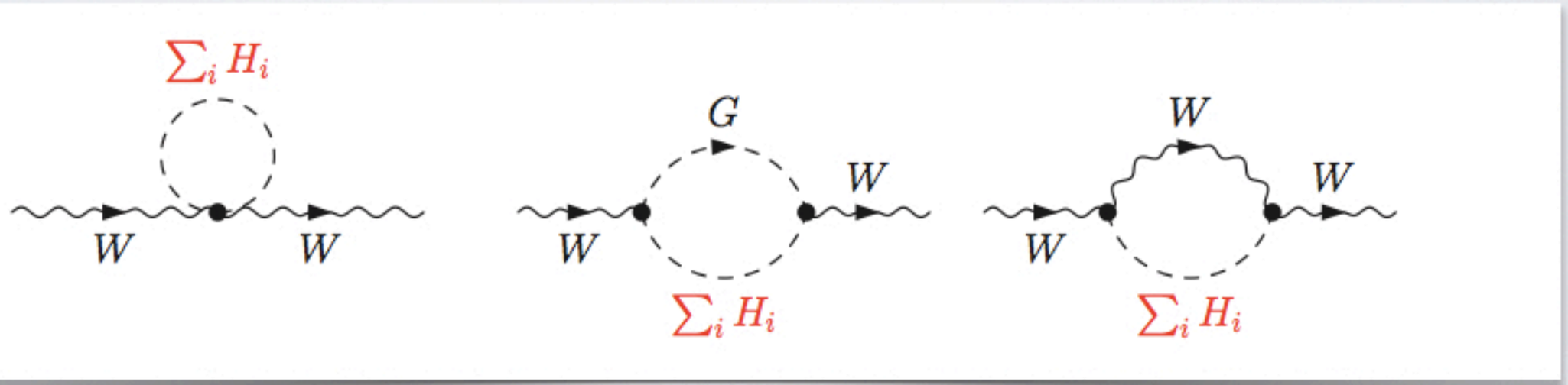


Higgs portal phenomenology

unitarity and electroweak precision data constrain the model parameter space:

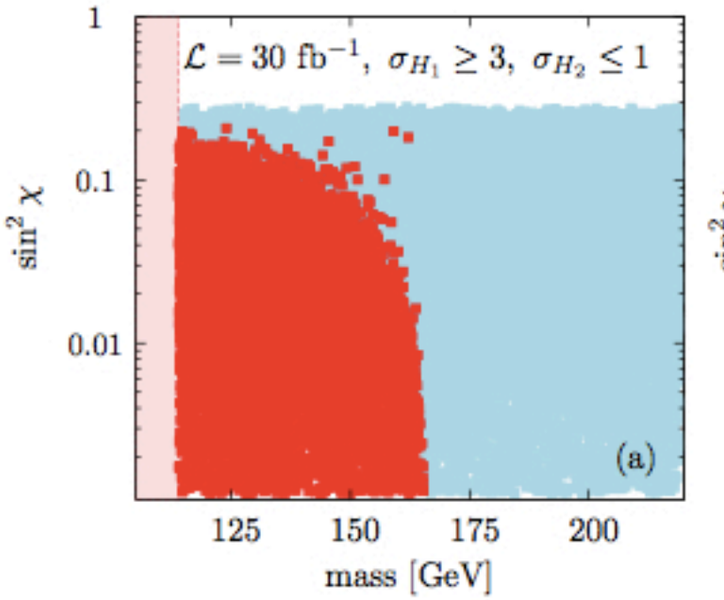


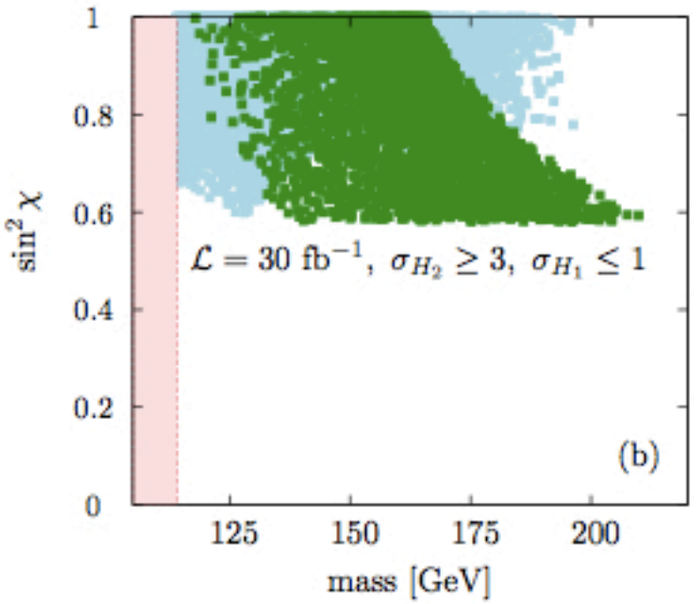
$$\rightsquigarrow M^2_{H_{\rm SM}} \to \langle M_i^2 \rangle \equiv \cos^2\chi\, M_1^2 + \sin^2\chi\, M_2^2 \leq 4\pi\sqrt{2}/3G_F \simeq (700\,{\rm GeV})^2$$



$$\rightsquigarrow \rho\ \text{param.}: \log M^2_{H_{\rm SM}} \to \langle \log M_i^2 \rangle \equiv \cos^2\chi \log M_1^2 + \sin^2\chi \log M_2^2 \leq \log(175\ \ {\rm GeV})^2$$

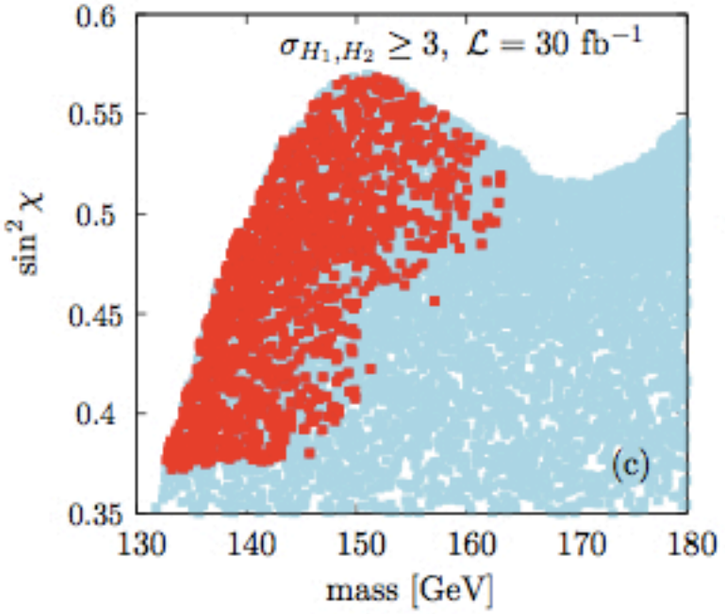
Higgs portal phenomenology @ LHC

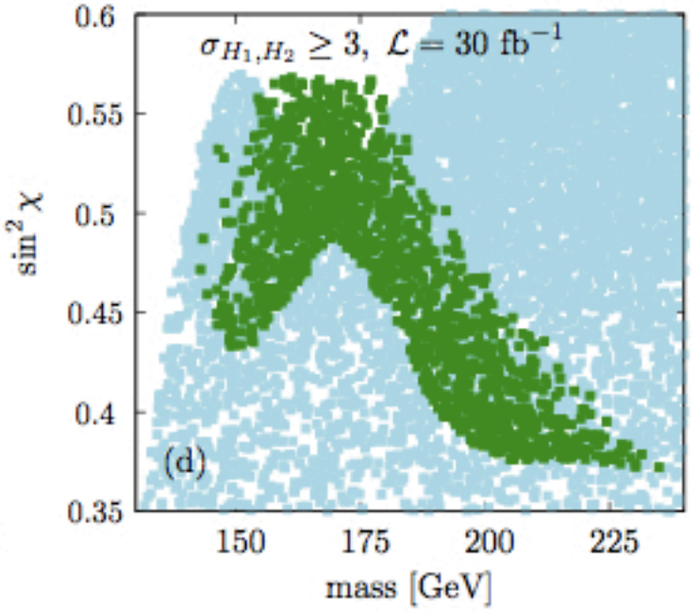




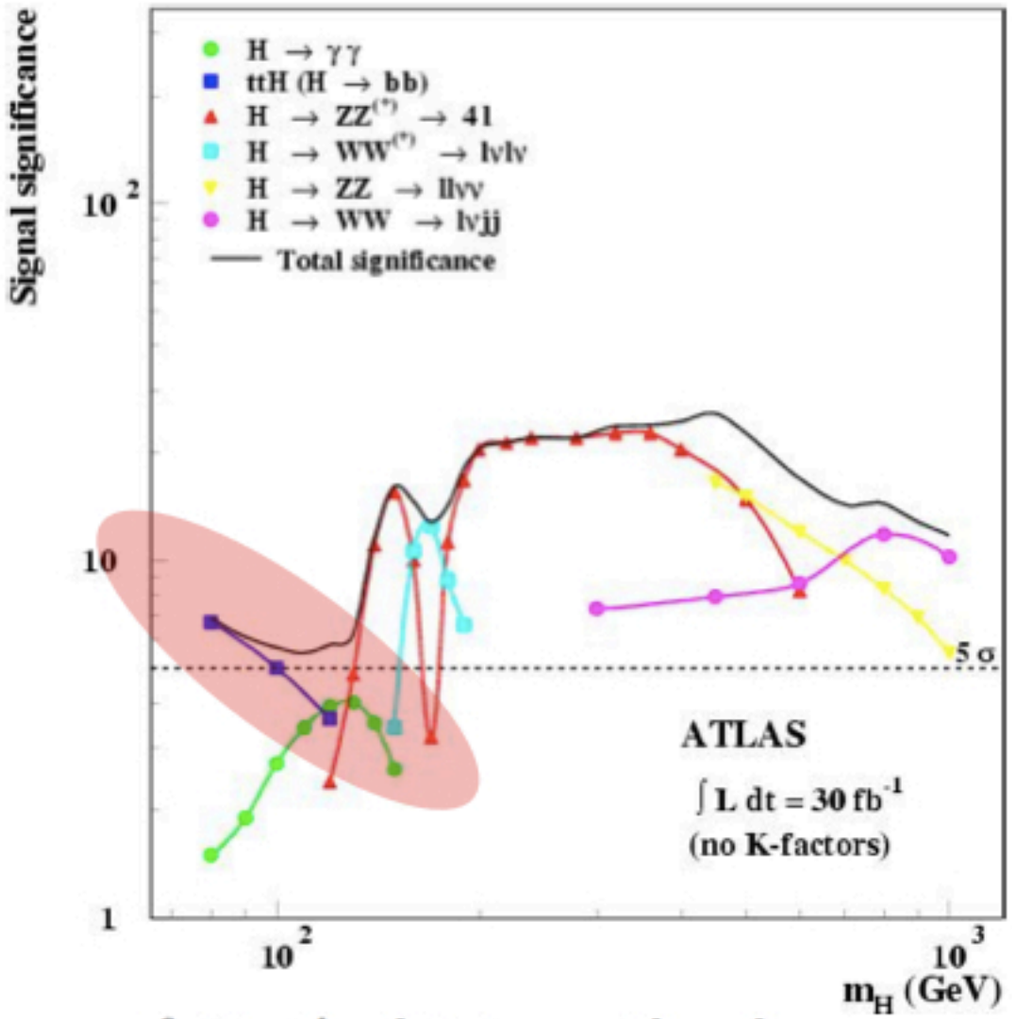
light SM-like Higgs H_1
excluded by EWP, unitarity
excluded by LEP

heavy dark Higgs H_2
excluded by EWP, unitarity
excluded by LEP





$\Gamma^{\text{hid}} \equiv \Gamma^{\text{SM}}$



fatjet/subjet methods

[Butterworth, Davison, Rubin, Salam `08]
[Plehn, Salam, Spannowsky `09]

Higgs portal profiling

- bounds are determined by measurement of twin ratios

$$\kappa_{p,d} = \left(\frac{\Gamma^p \Gamma^d}{\Gamma^{\rm tot}}\right) \Big/ \left(\frac{\Gamma^p \Gamma^d}{\Gamma^{\rm tot}}\right)^{\rm SM} = (\sigma_p \times {\rm BR}_d)/(\sigma_p \times {\rm BR}_d)^{\rm SM}$$

- strategy to acquire *complete* set of model parameters

$$\Gamma_1^{\rm tot} = \cos^2\chi\,\Gamma_1^{\rm SM} + \sin^2\chi\,\Gamma_1^{\rm hid} \qquad \Gamma_2^{\rm tot} = \sin^2\chi\,\Gamma_2^{\rm SM} + \cos^2\chi\,\Gamma_2^{\rm hid} + \Gamma_2^{HH}$$

$$\frac{\Gamma_1^{\rm inv}}{\Gamma_1^{\rm SM}} = \cos^2\chi\left[\frac{\cos^2\chi}{\kappa_1} - 1\right], \qquad \frac{\Gamma_1^{\rm tot}}{\Gamma_1^{\rm SM}} = \frac{\cos^4\chi}{\kappa_1} \Rightarrow {\rm BR}_1^{\rm inv}$$

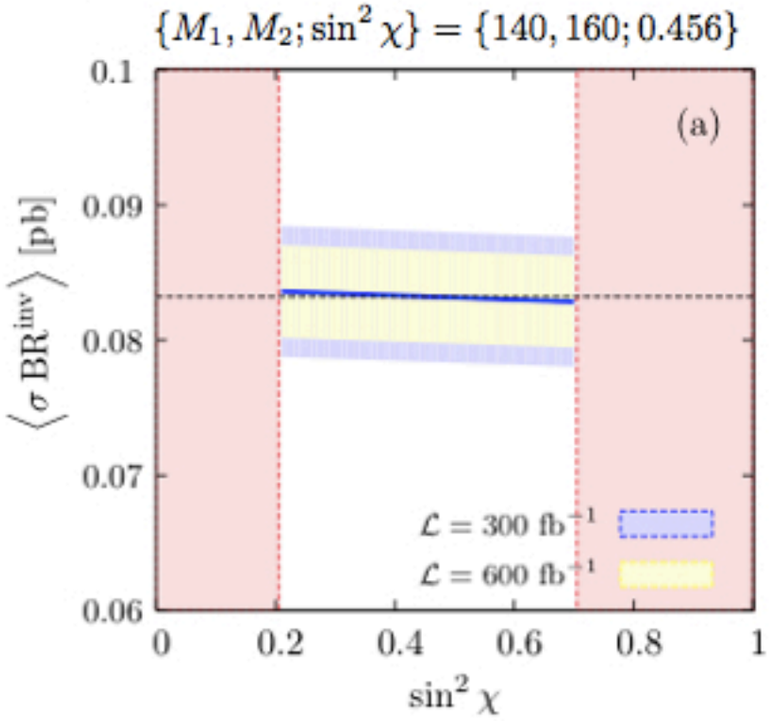
$$\frac{\Gamma_2^{\rm inv}}{\Gamma_2^{\rm SM}} = \sin^2\chi\left[\frac{\sin^2\chi}{\kappa_2} - 1 - \frac{1}{\cos^4\chi}\frac{{\rm BR}_2^{HH,{\rm vis}}}{{\rm BR}_2^{\rm vis}}\right], \qquad \frac{\Gamma_2^{\rm tot}}{\Gamma_2^{\rm SM}} = \frac{\sin^4\chi}{\kappa_2} \Rightarrow {\rm BR}_2^{\rm inv}$$

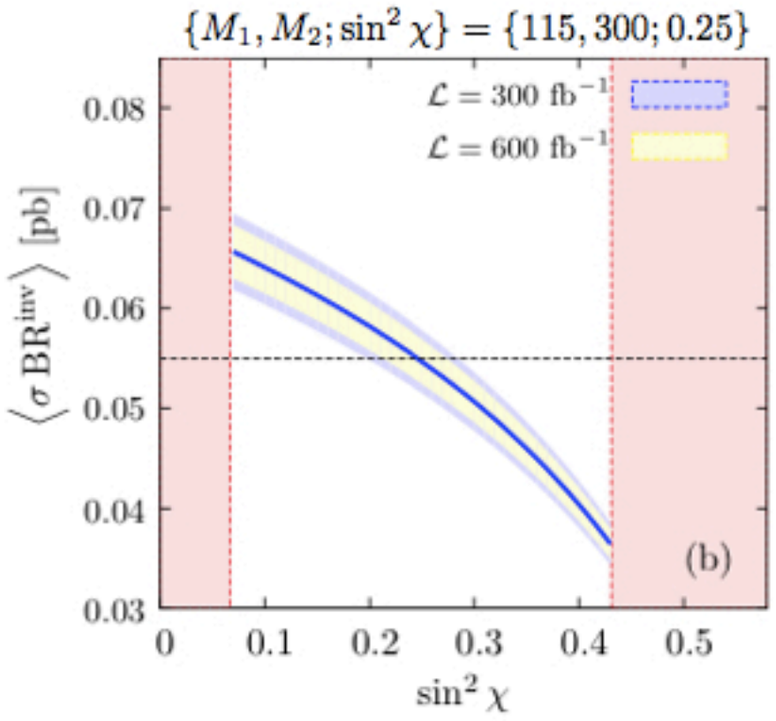
$\kappa_2 \leq \sin^2\chi \leq 1-\kappa_1$ due to positivity of Γ_i

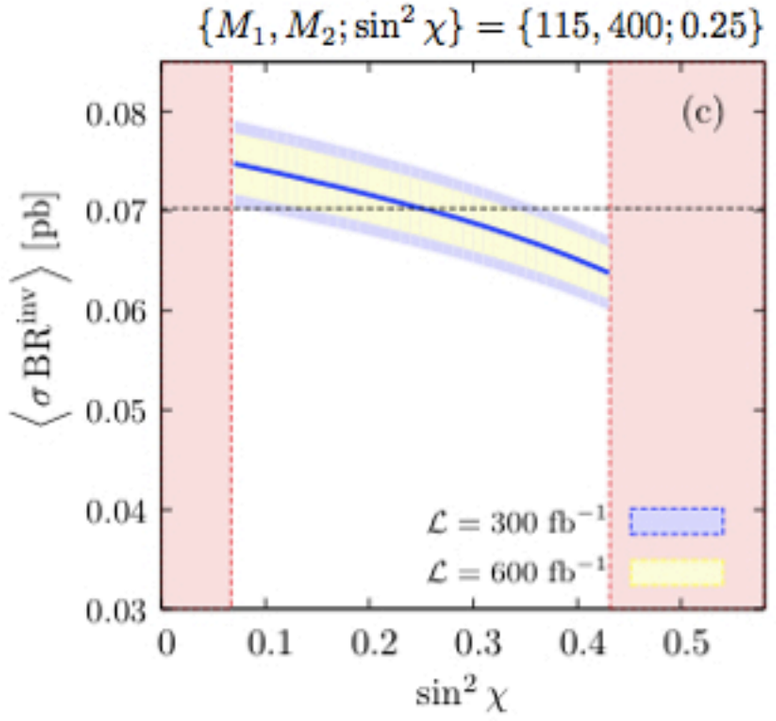
- invisible decays cannot be separated, instead we measure

$$\begin{aligned}\langle \sigma {\rm BR}^{\rm inv}\rangle &= \sigma_1 {\rm BR}_1^{\rm inv} + \sigma_2 {\rm BR}_2^{\rm inv} + {\rm Bkg}_{\rm inv} \\ &\sim f(\Lambda_{211}) - [\cos^2\chi + \{\sigma_2^{\rm SM}/\sigma_1^{\rm SM}\}\,\sin^2\chi] + {\rm Bkg}_{\rm inv}\end{aligned}$$

Higgs portal profiling







	reference point #1		reference point #2		
v_s [GeV]	246.22		246.22		
λ_s	0.18 ± 0.01	[0.19]	0.58 ± 0.03	(0.58 ± 0.02)	[0.58]
v_h [GeV]	85.72 ± 32.88	[85.75]	36.19 ± 5.06	(36.42 ± 3.63)	[36.42]
λ_h	1.53 ± 0.10	[1.52]	12.21 ± 1.25	(12.12 ± 0.89)	[12.11]
$\lvert\eta_\chi\rvert$	0.13 ± 0.40	[0.13]	3.67 ± 0.53	(3.66 ± 0.38)	[3.61]

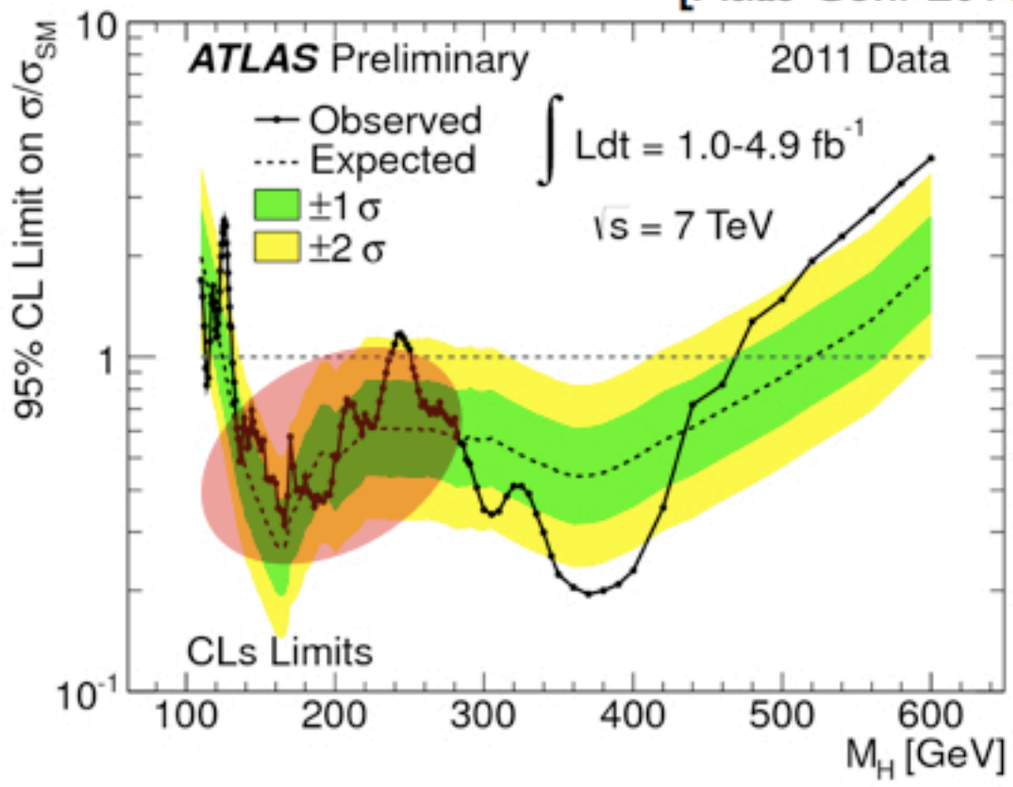
large luminosity searches with established resonances!

- invisible decays cannot be separated, instead we measure

$$\begin{aligned}\langle \sigma \mathrm{BR}^{\mathrm{inv}} \rangle &= \sigma_1 \mathrm{BR}_1^{\mathrm{inv}} + \sigma_2 \mathrm{BR}_2^{\mathrm{inv}} + \mathrm{Bkg}_{\mathrm{inv}} \\ &\sim f(\Lambda_{211}) - [\cos^2\chi + \{\sigma_2^{\mathrm{SM}}/\sigma_1^{\mathrm{SM}}\} \sin^2\chi] + \mathrm{Bkg}_{\mathrm{inv}}\end{aligned}$$

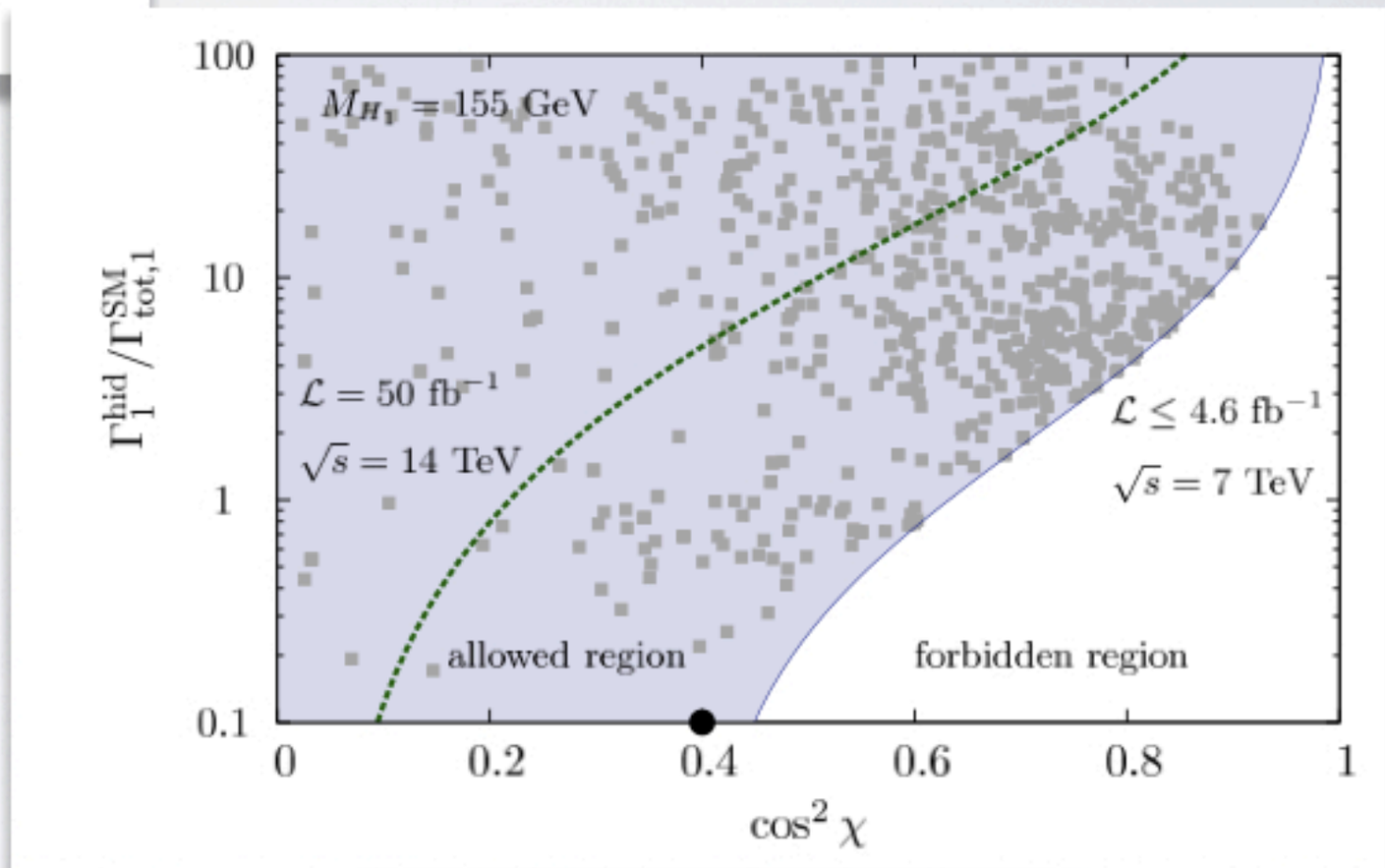
Higgs portal profiling with $\mathcal{L} \simeq 5\ \mathrm{fb}^{-1}$ @ 7 TeV

[Atlas Conf-2011-163]



$$\frac{\sigma[pp \to H_1 \to F]}{\sigma[pp \to H_1 \to F]^{\mathrm{SM}}} = \frac{\cos^2\chi}{1+\tan^2\chi\,[\Gamma_1^{\mathrm{hid}}/\Gamma_{\mathrm{tot},1}^{\mathrm{SM}}]} \leq \mathcal{R}$$

$$\frac{\sigma[pp \to H_1 \to inv]}{\sigma[pp \to H_1]^{\mathrm{SM}}} = \frac{\sin^2\chi\,[\Gamma_1^{\mathrm{hid}}/\Gamma_{\mathrm{tot},1}^{\mathrm{SM}}]}{1+\tan^2\chi\,[\Gamma_1^{\mathrm{hid}}/\Gamma_{\mathrm{tot},1}^{\mathrm{SM}}]} \leq \mathcal{I}$$



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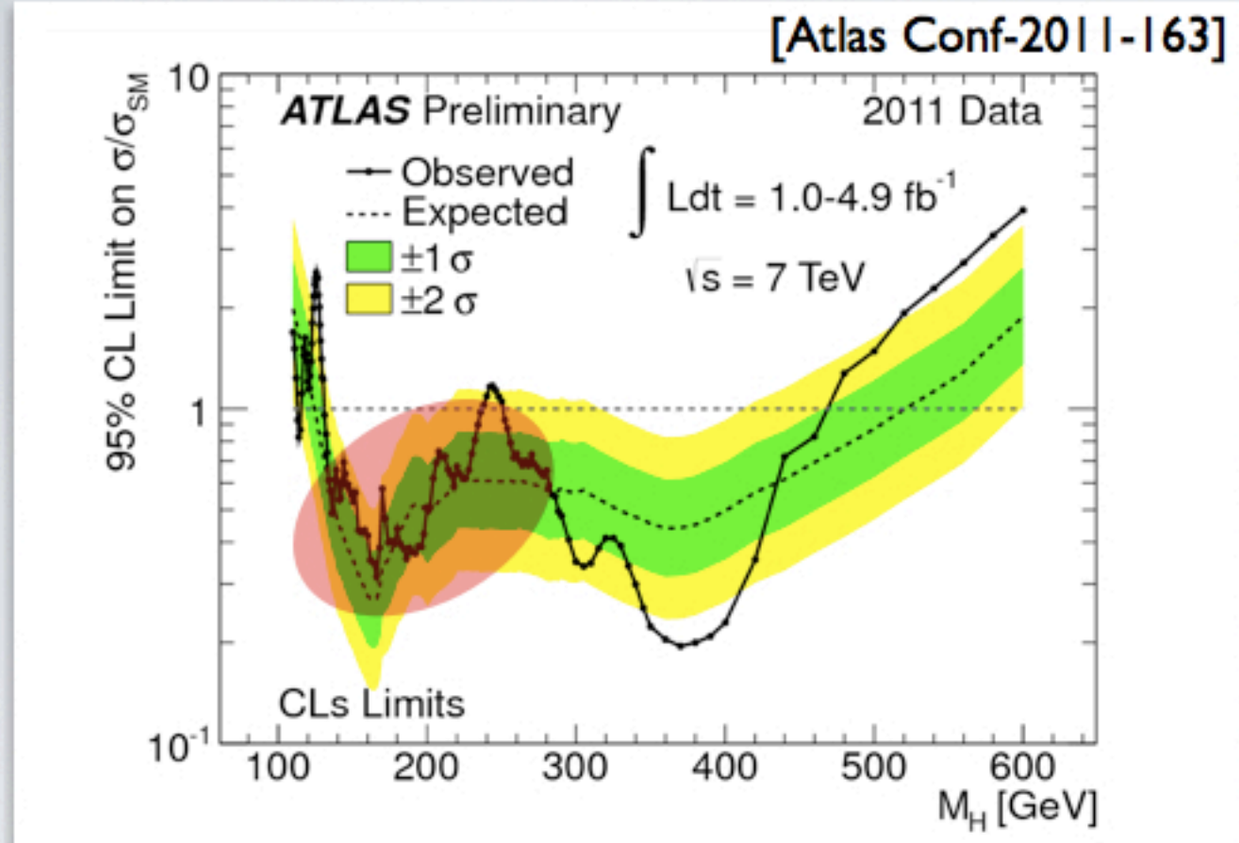

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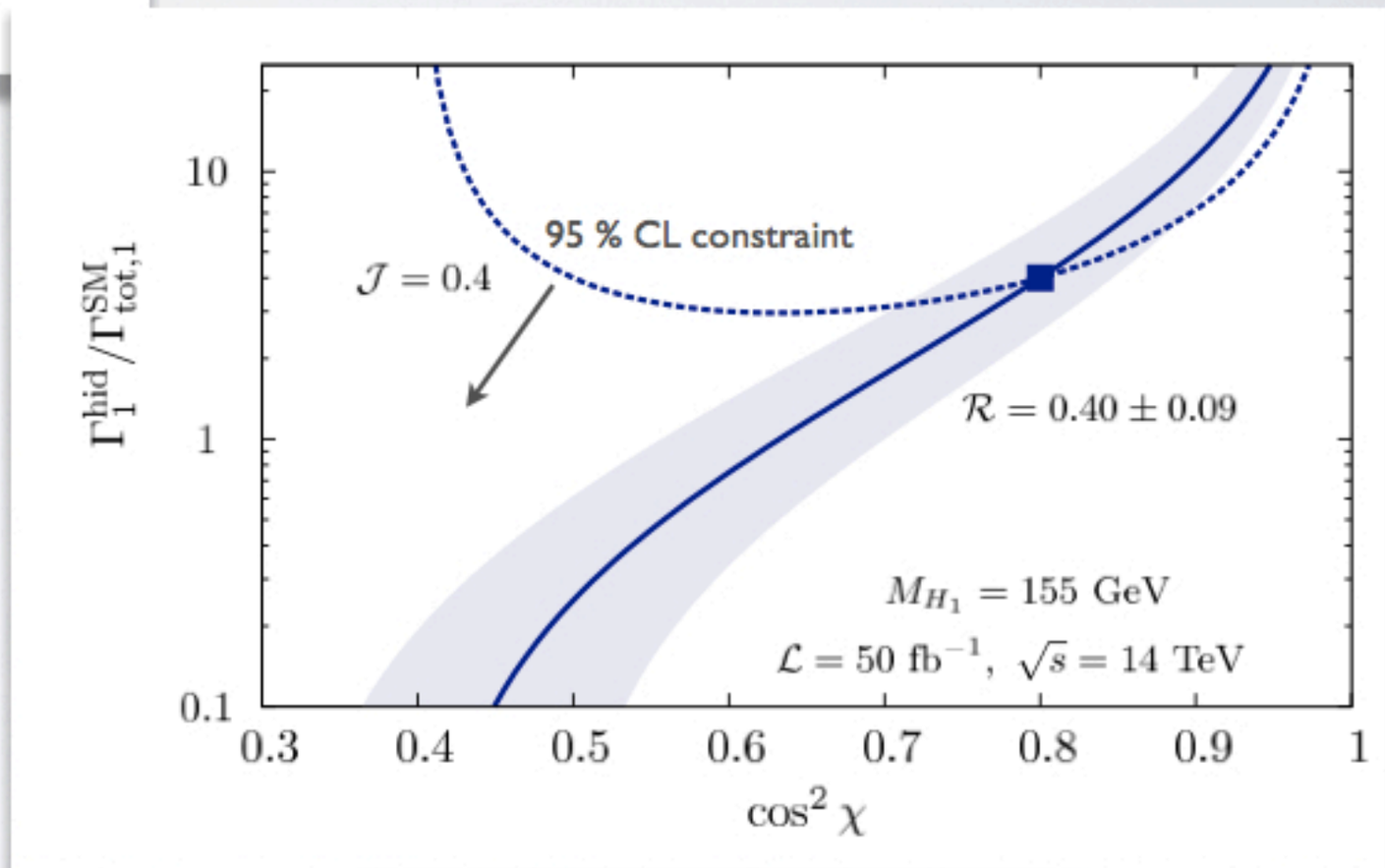

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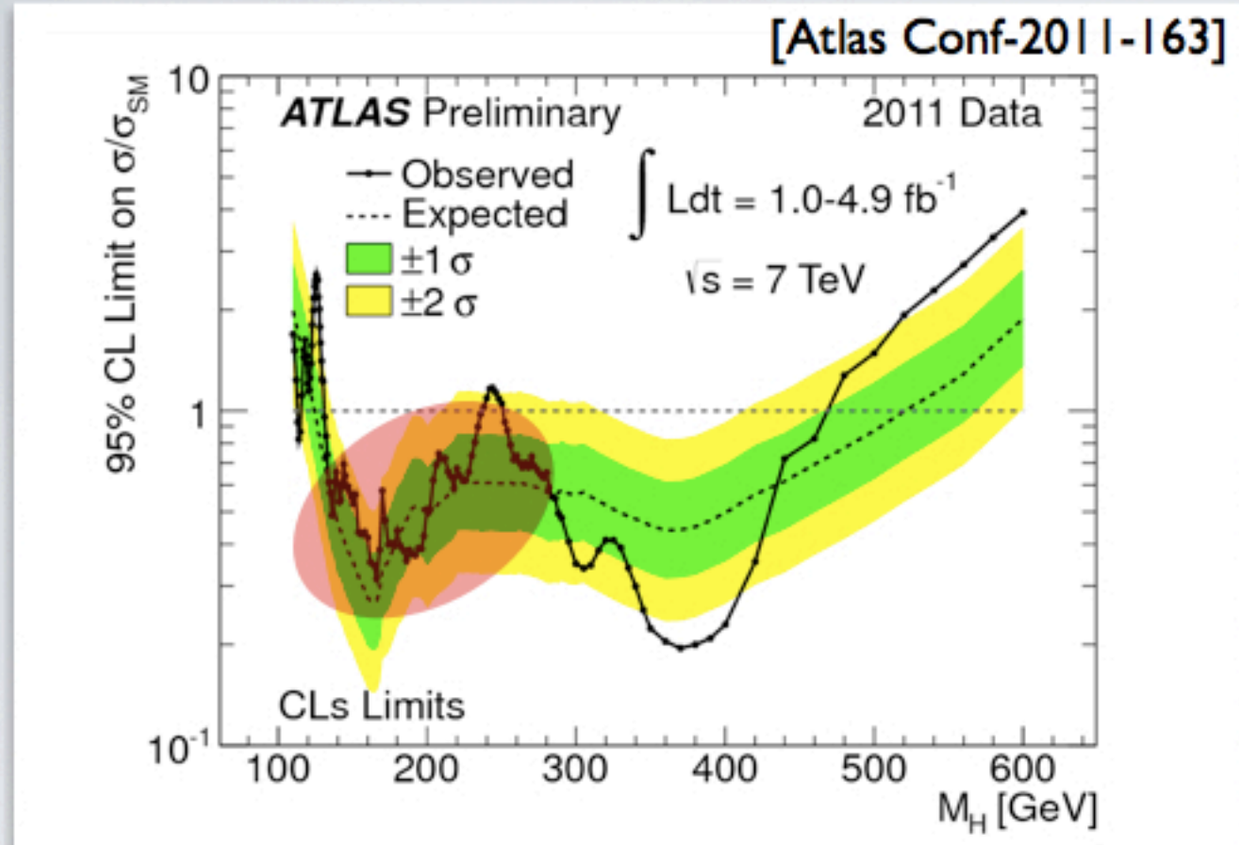

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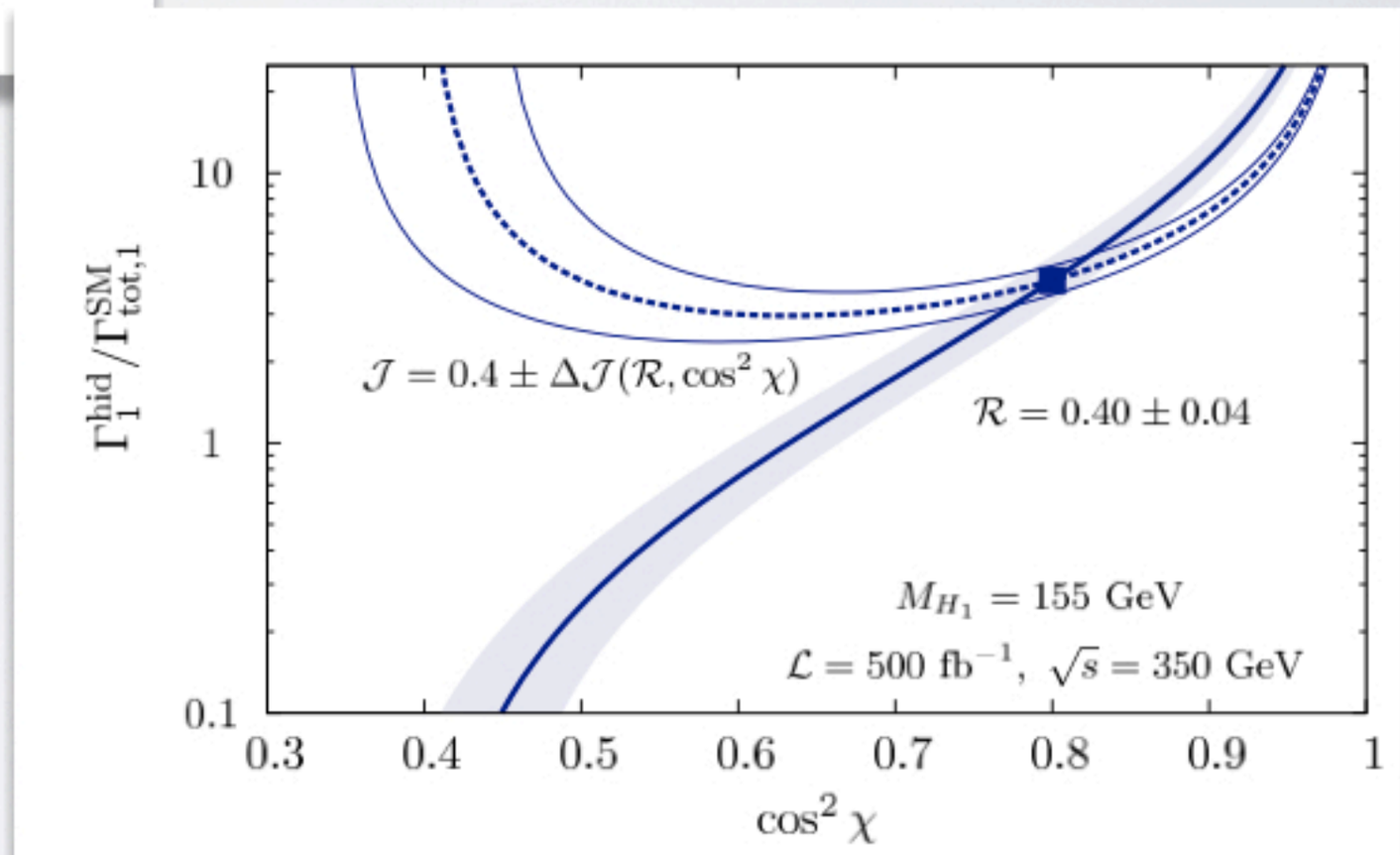
- switch on the ILC and measure invisible Higgs from associate production ee→HZ recoil spectrum

  [Schumacher `03] [talk by R. Poeschel]



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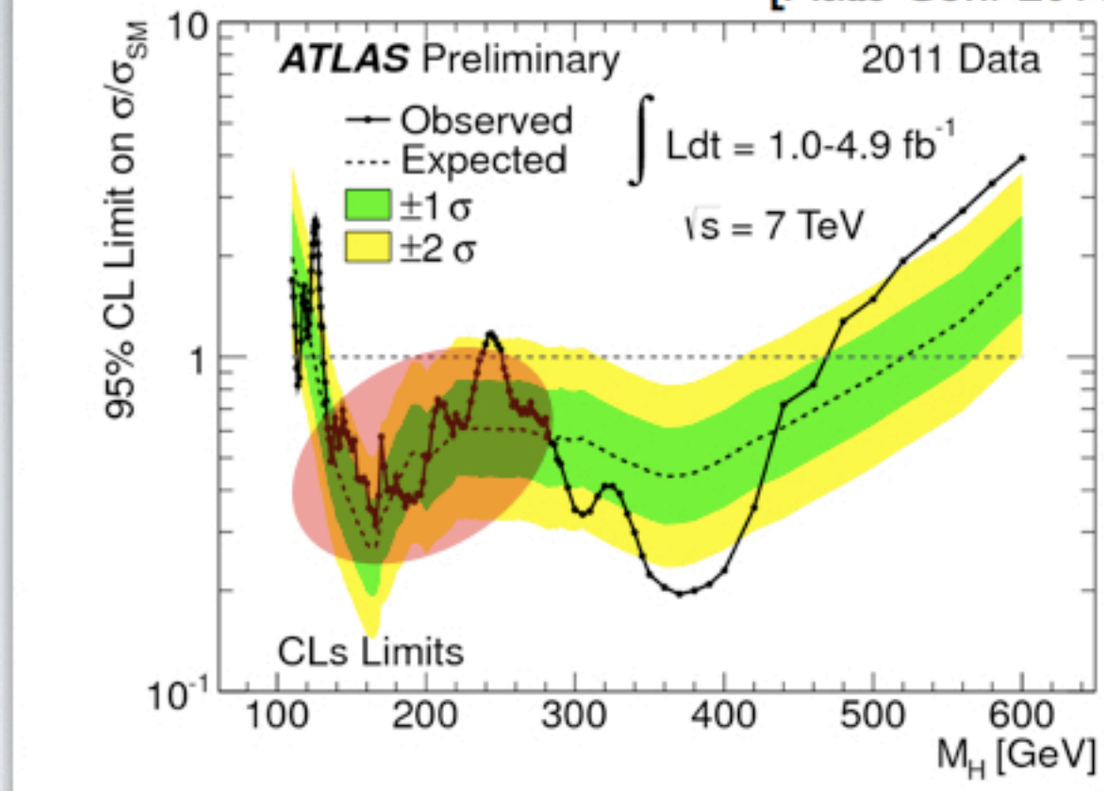

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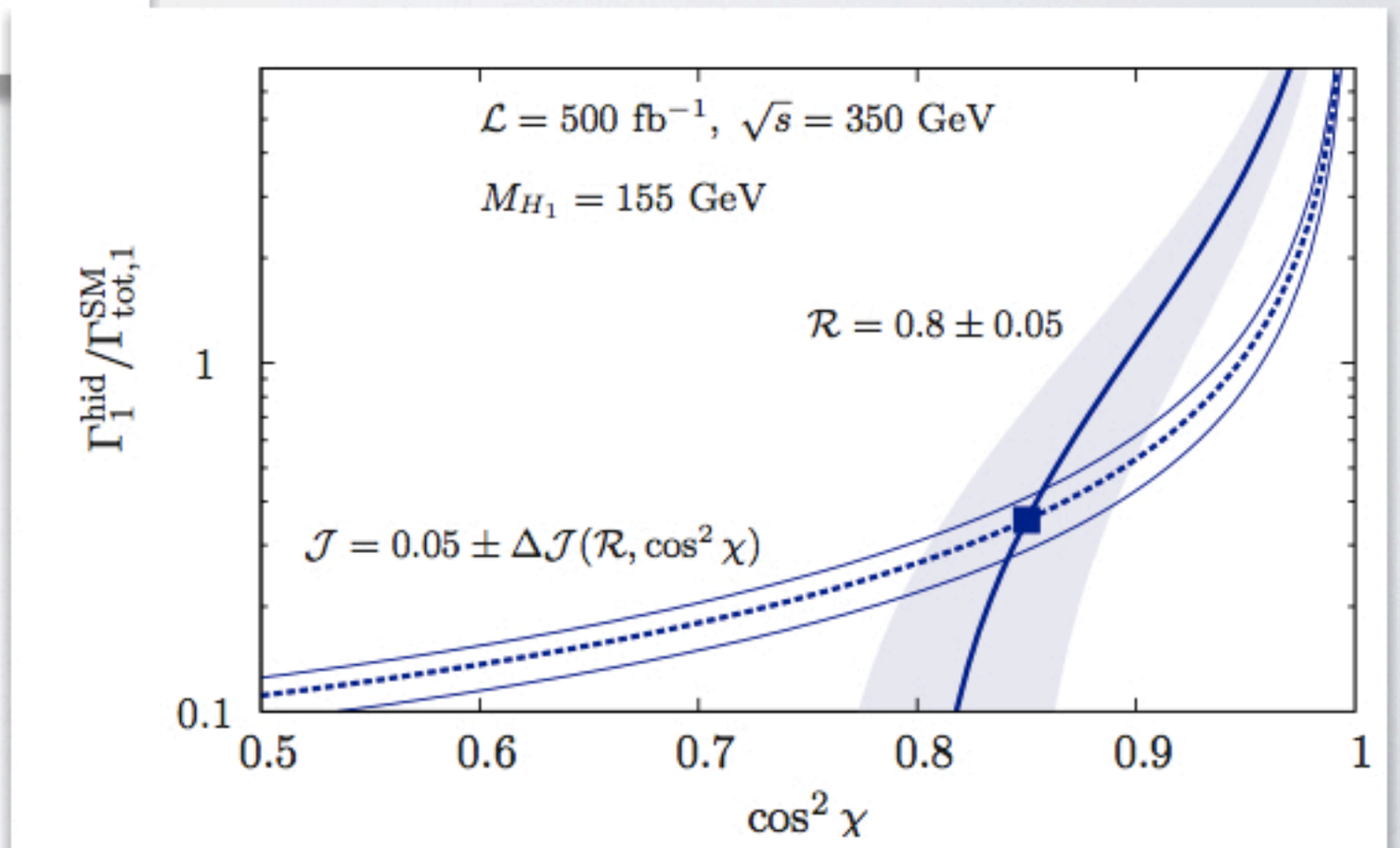

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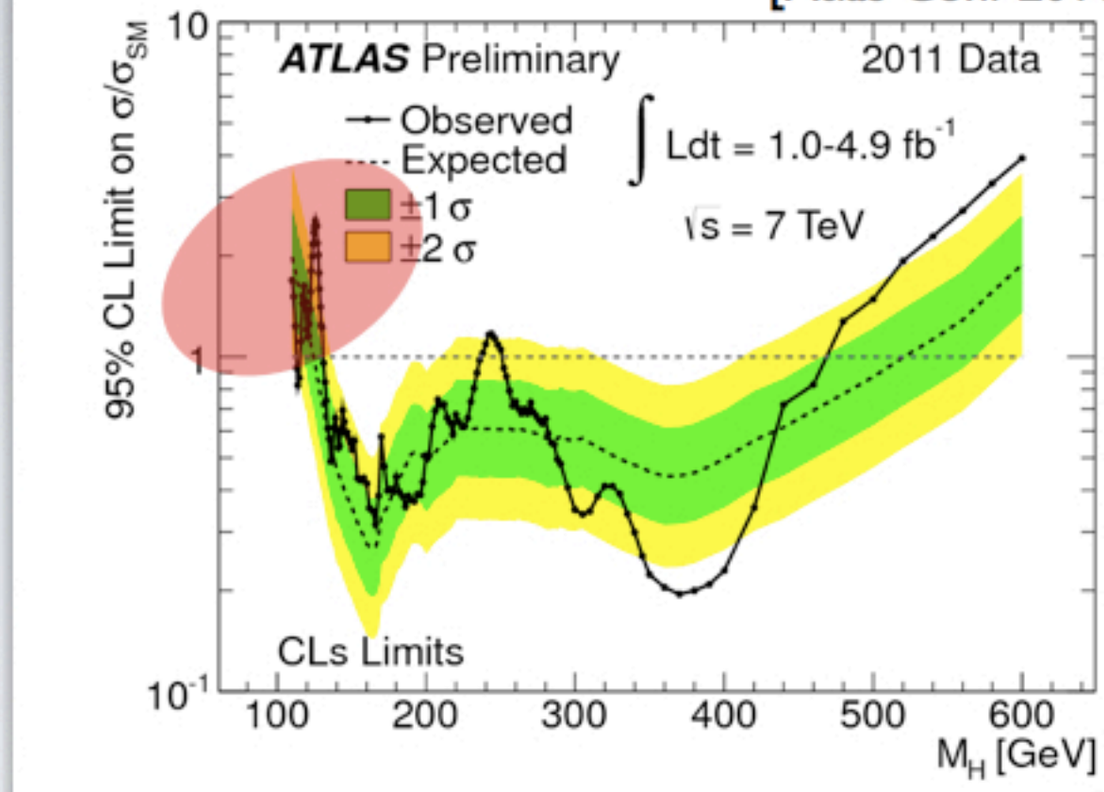

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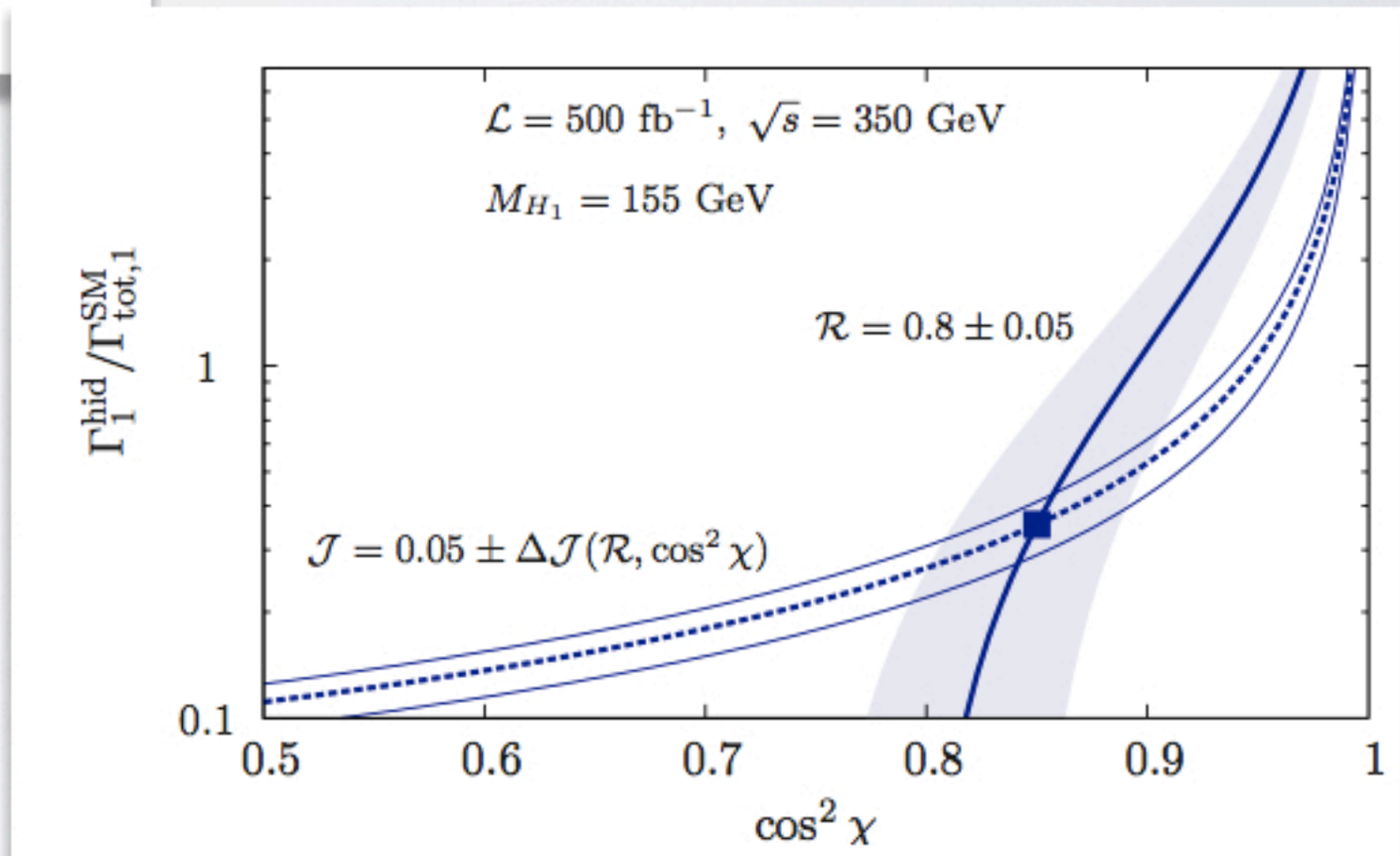

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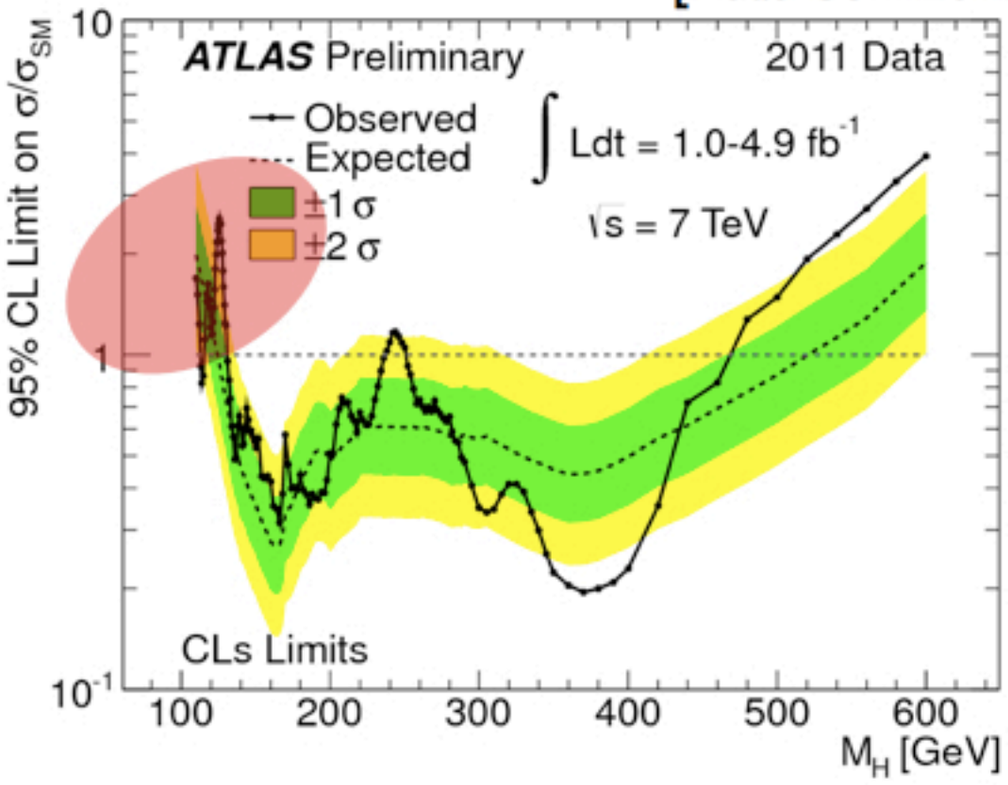

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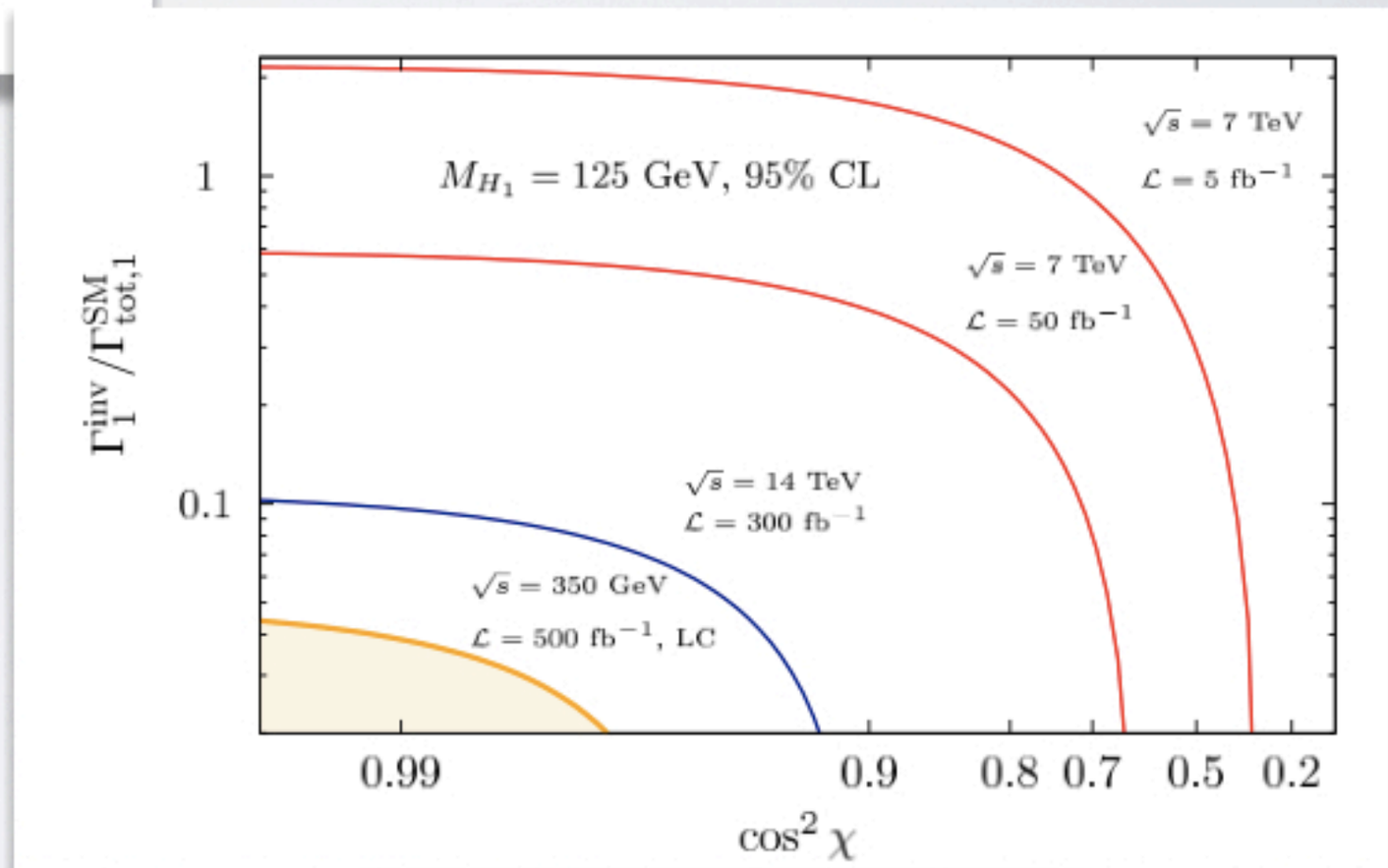
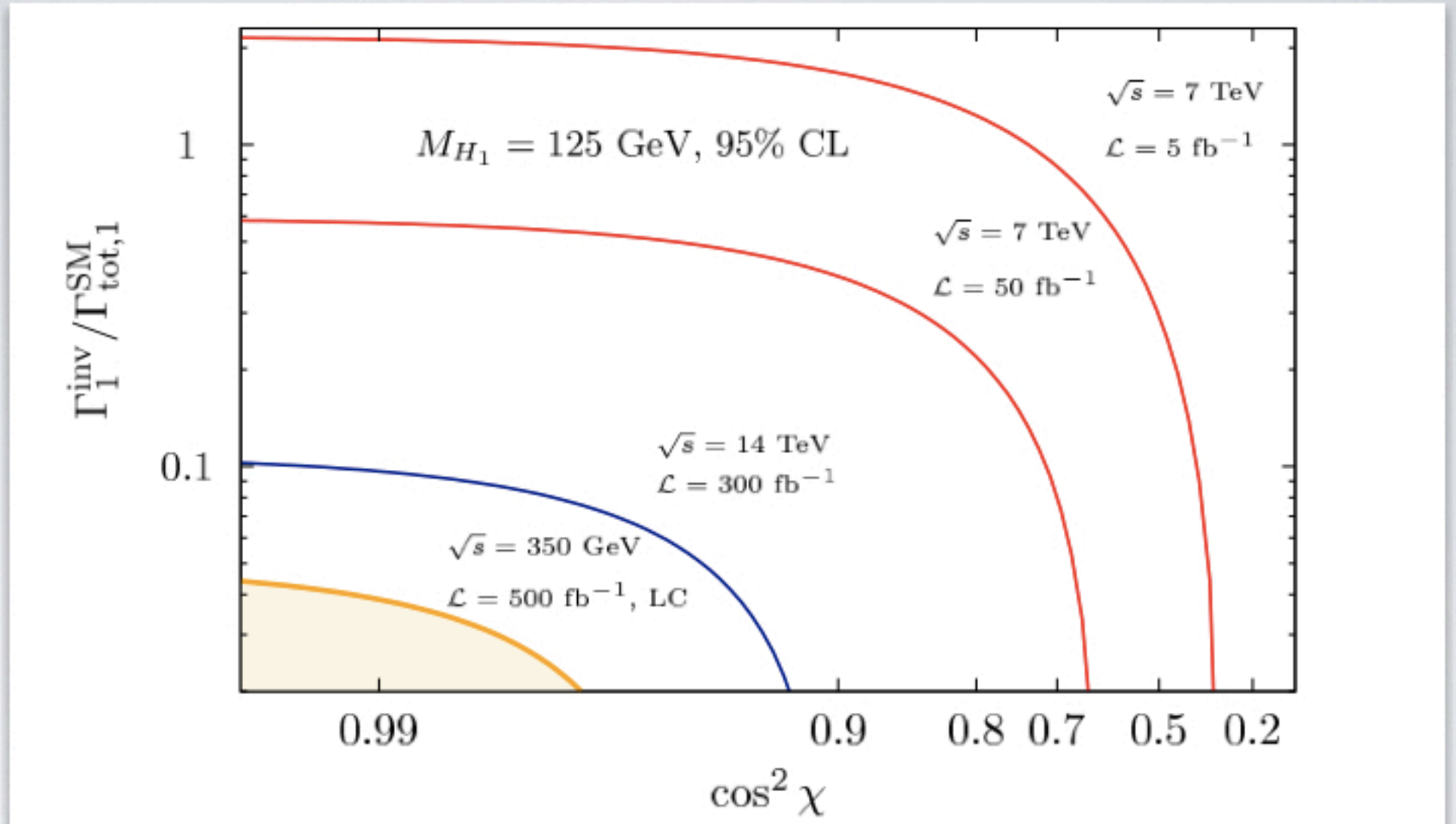
  [Schumacher `03] [talk by R. Poeschel]

- Higgs spectroscopy benefits form clean LC environment





summary

- exciting times: data and new analyses almost on daily basis
- Higgs portal is phenomenological model that parametrizes universal deviations from the SM (minimally non-minimal)
- **LHC**: search potential eventually limited by systematics ~10%, blind spots
- **LC**: push exclusion limits, spectroscopy by measuring invisible decays