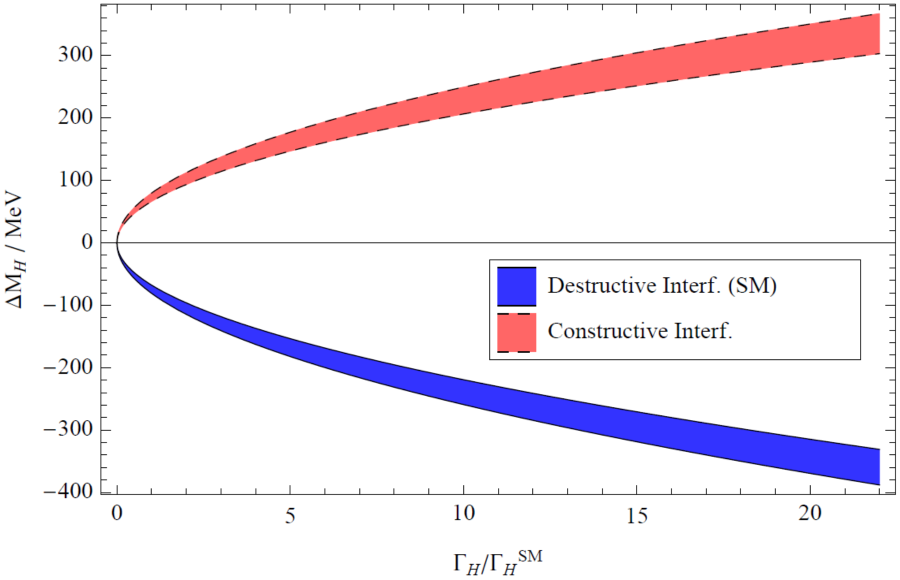
Bounding the Higgs Width using Interferometry



Lance Dixon (SLAC)

with Ye Li [1305.3854] and Stefan Höche

RADCOR2013, Lumley Castle, England

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Introduction

- Often said that LHC cannot measure the width of the Higgs boson.
- However, using interference with the continuum background for $gg \rightarrow \gamma\gamma$, it will be possible to put an upper limit on the Higgs width that is much better than ~ 1-5 GeV possible directly.
- It may eventually be possible to get close to the Standard Model width of 4 MeV.
- Similar idea can work for $gg \rightarrow ZZ$, far from Higgs resonance Kauer; Caola, Melnikov, 1307.4935

Schrödinger's Higgs

How to use quantum superposition

$$|\text{Higgs}\rangle \;+\; |q\bar{q}\rangle$$

to learn something new about the Higgs
(its lifetime)

Narrow resonance interference

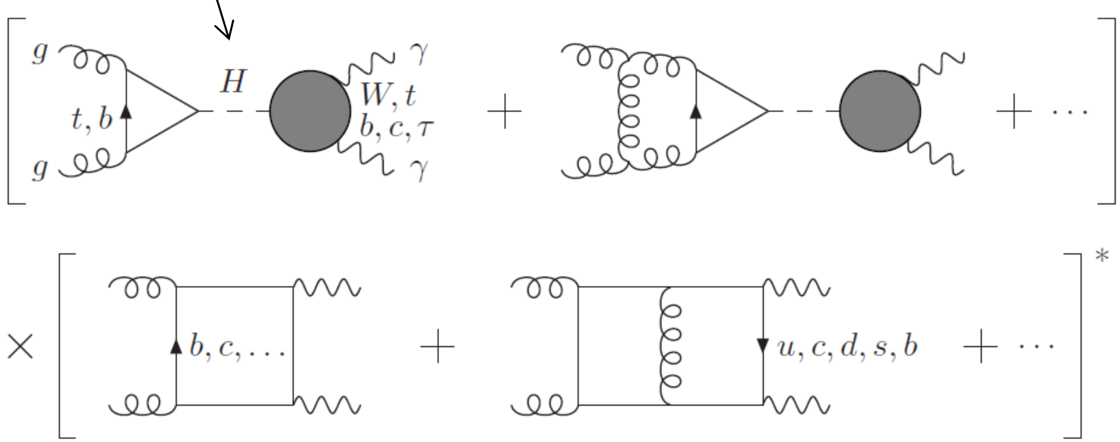
$$\mathcal{A}_{gg\to\gamma\gamma} = \frac{-\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}}{\hat{s} - m_H^2 + i m_H \Gamma_H} + \mathcal{A}_{\rm cont}$$

$$\rightarrow \quad \delta\hat{\sigma}_{gg\to H\to\gamma\gamma} = -2(\hat{s} - m_H^2)\frac{\mathrm{Re}\left(\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\rm cont}\right)}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2} - 2 m_H \Gamma_H \frac{\mathrm{Im}\left(\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\rm cont}\right)}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2}$$

shifts peak position (apparent mass)

shifts peak height (event yield)

or spin 2 “G”



(assume) dominantly real

Interference effects and Γ

LD, Y. Li 1305.3854

- All non-interference measurements at LHC give signal proportional to $c_i^2 \cdot c_f^2 / \Gamma$
- Invariant under scaling all $c_{i,f}$ uniformly,

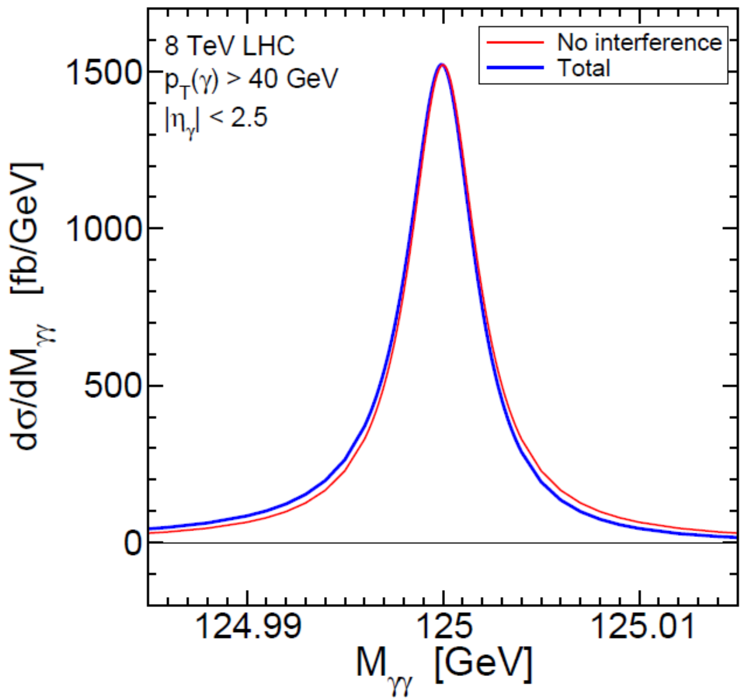
$$c_{i,f} \rightarrow \xi \, c_{i,f}$$
$$\Gamma \rightarrow \xi^4 \, \Gamma$$

- Interference effects go like $c_i \cdot c_f$, break this degeneracy
- Allow one to measure or bound Higgs width

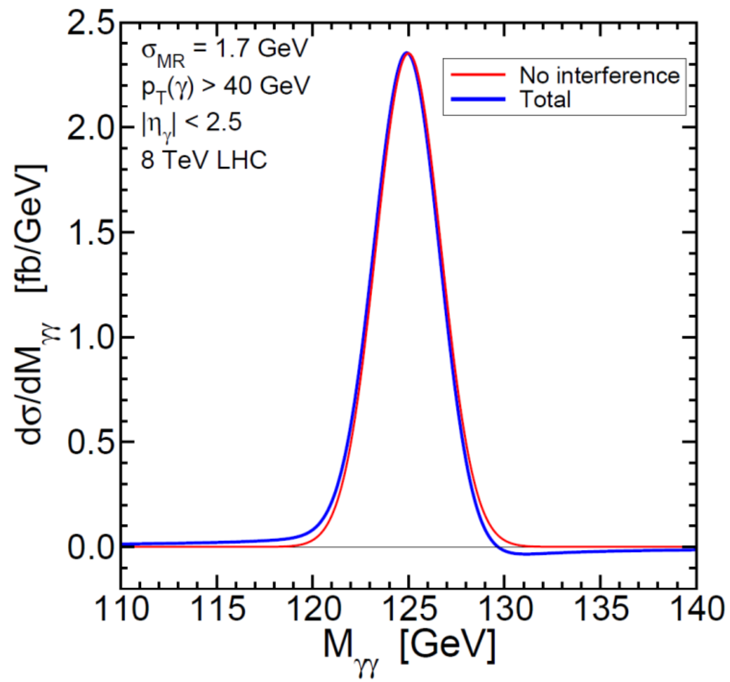
Mass shift from real part

S. Martin, 1208.1533, 1303.3342; D. de Florian et al, 1303.1397

Smear lineshape with Gaussian with width σ = 1.7 GeV



→



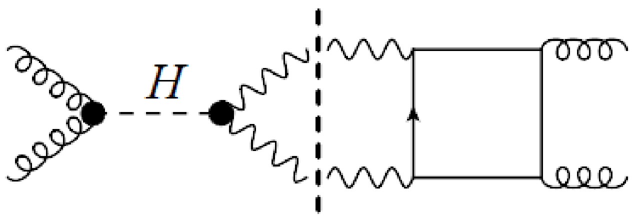
Perform least squares fit to Gaussian at mass $M + \delta M$

→ δM ~ 100 MeV in SM at LO

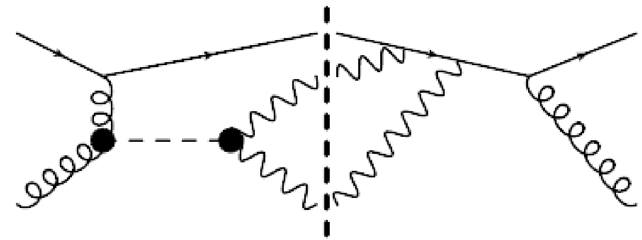
Diagrams for NLO mass shift

LD, Y. Li, 1305.3854

LO (gg):

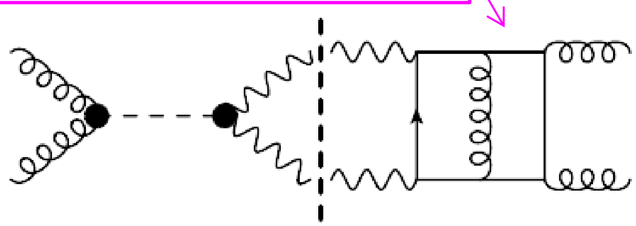


LO (qg):



Bern, de Freitas, LD, hep-ph/0109078

NLO (gg):



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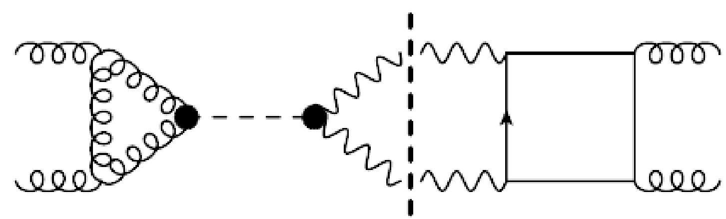

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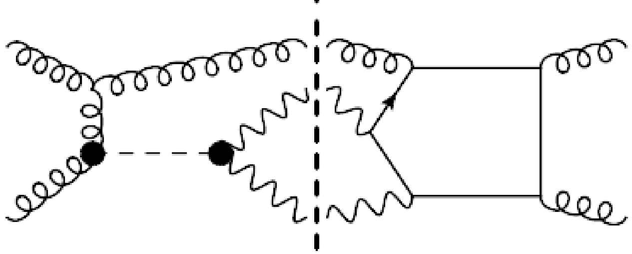

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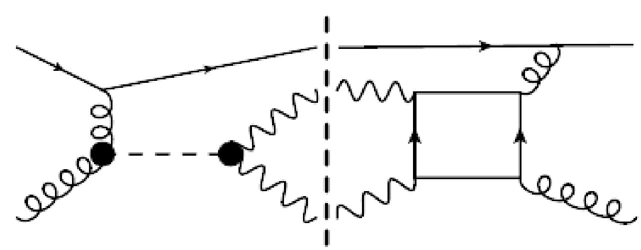
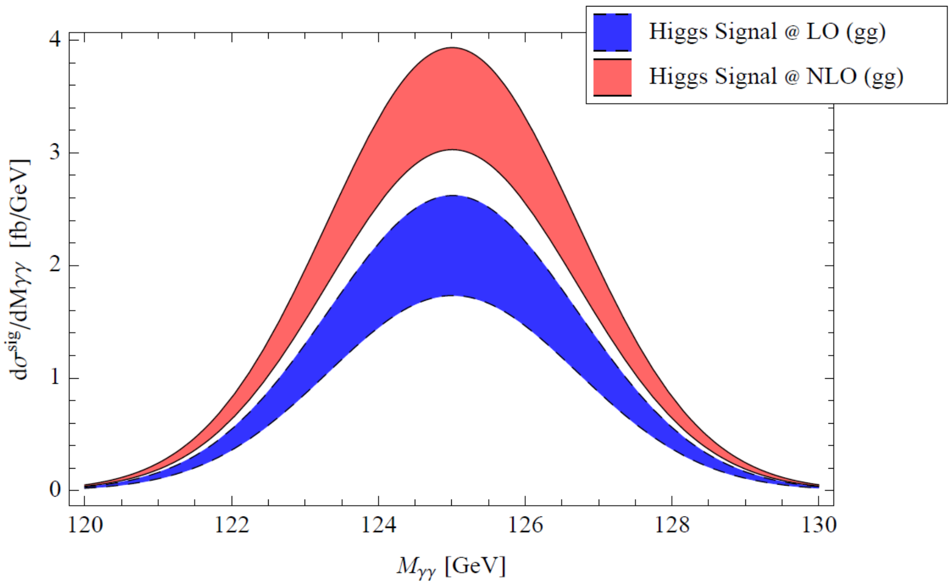
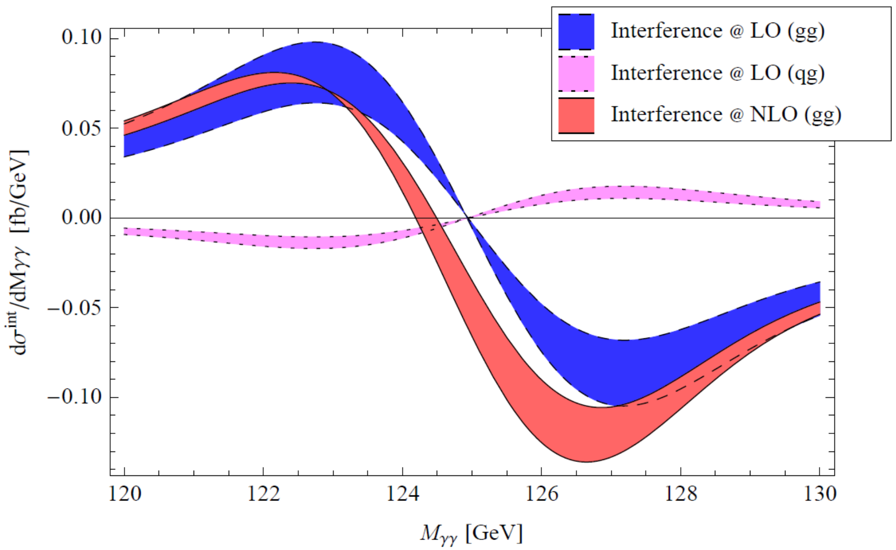


Mass shift at NLO

- Reduced by 40% from LO

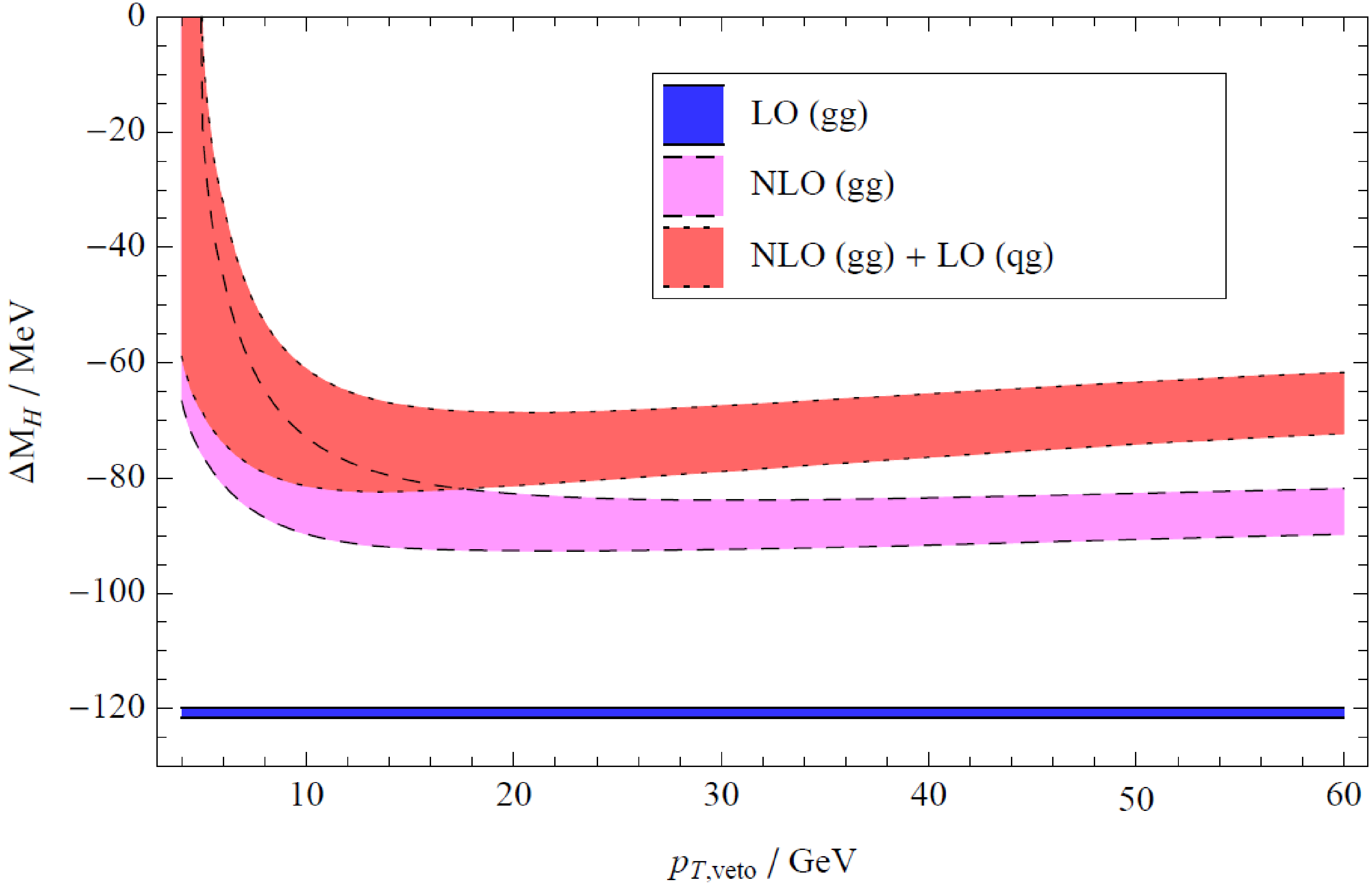
LD, Y. Li, 1305.3854





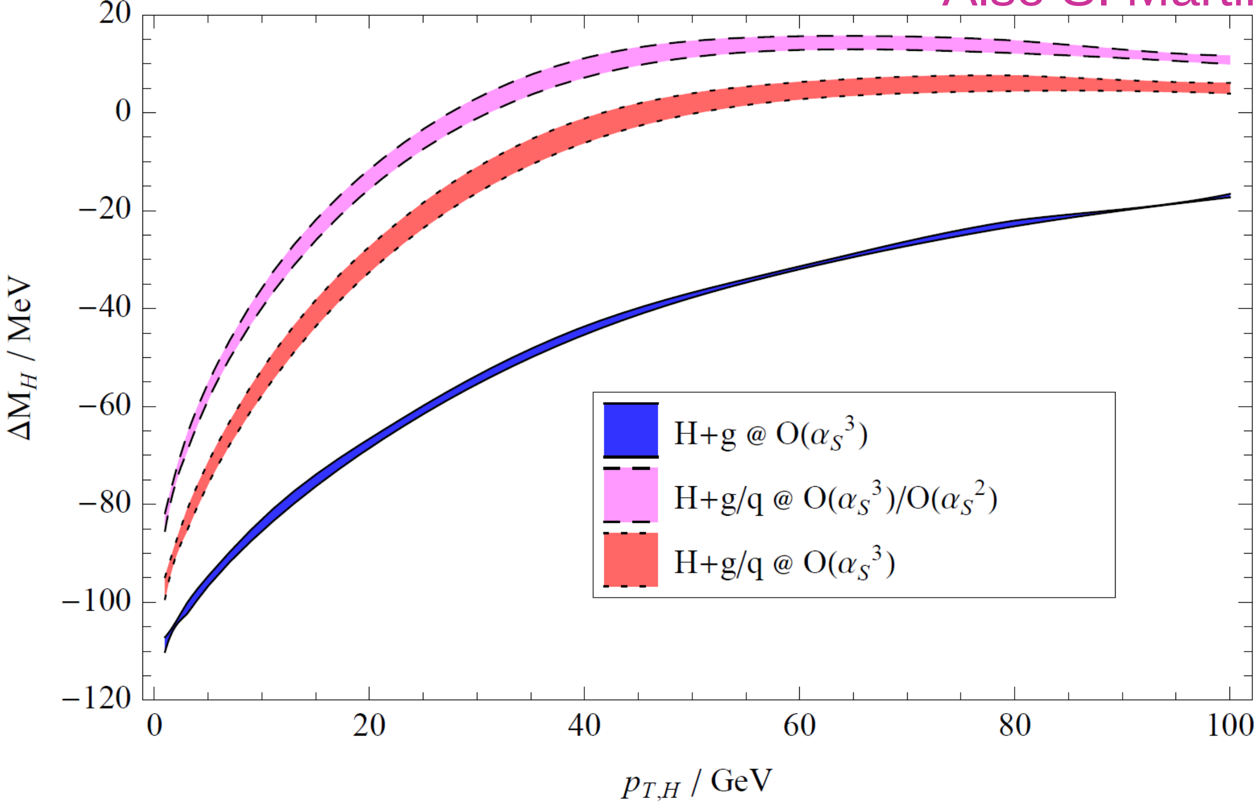
- Interference increases, but signal increases more

NLO mass shift vs. jet veto p_T



NLO mass shift vs. lower cut on Higgs p_T

Also S. Martin 1303.3342

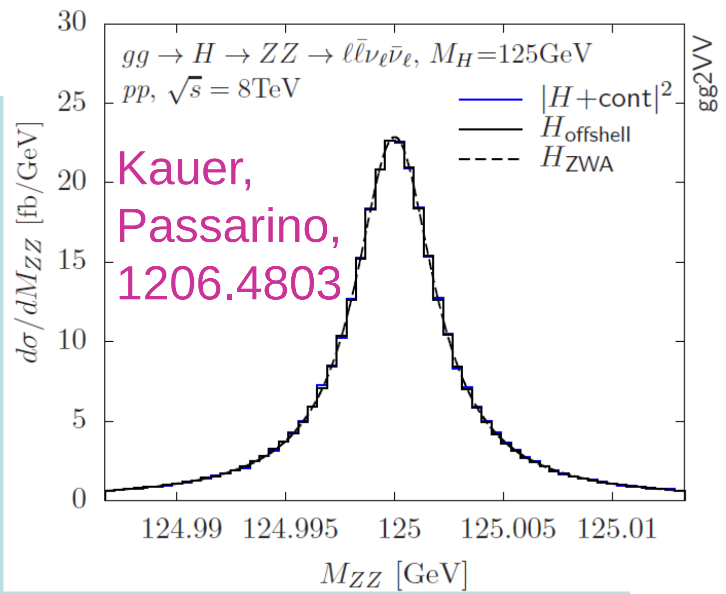


- Big cancellation between gg and qg channel at large p_T
- Allows use of p_T > 30 or 40 GeV sample as "control" mass

Two other possible control masses

1. ZZ* → 4 leptons

$$m_H^{\gamma\gamma} - m_H^{ZZ} = +2.3^{+0.6}_{-0.7} \pm 0.6 \text{ GeV (ATLAS)}$$
$$= -0.4 \pm 0.7 \pm 0.6 \text{ GeV (CMS)},$$



2. Mass in $\gamma\gamma$ in VBF enhanced sample
   LD, S. Hoeche, Y. Li, in progress

- In general, comparing two $\gamma\gamma$ masses could reduce systematics associated with e → γ energy calibration.

Mass shift increases with Γ

- Allows one to measure or bound Higgs width
- All non-interference measurements at LHC give signal proportional to $c_i^2 \cdot c_f^2 / \Gamma$
- Interference effects go like $c_i \cdot c_f$, break degeneracy of scaling all $c_{i,f}$ uniformly,

$$c_{i,f} \rightarrow \xi \, c_{i,f}$$
$$\Gamma \rightarrow \xi^4 \, \Gamma$$

Coupling vs. width

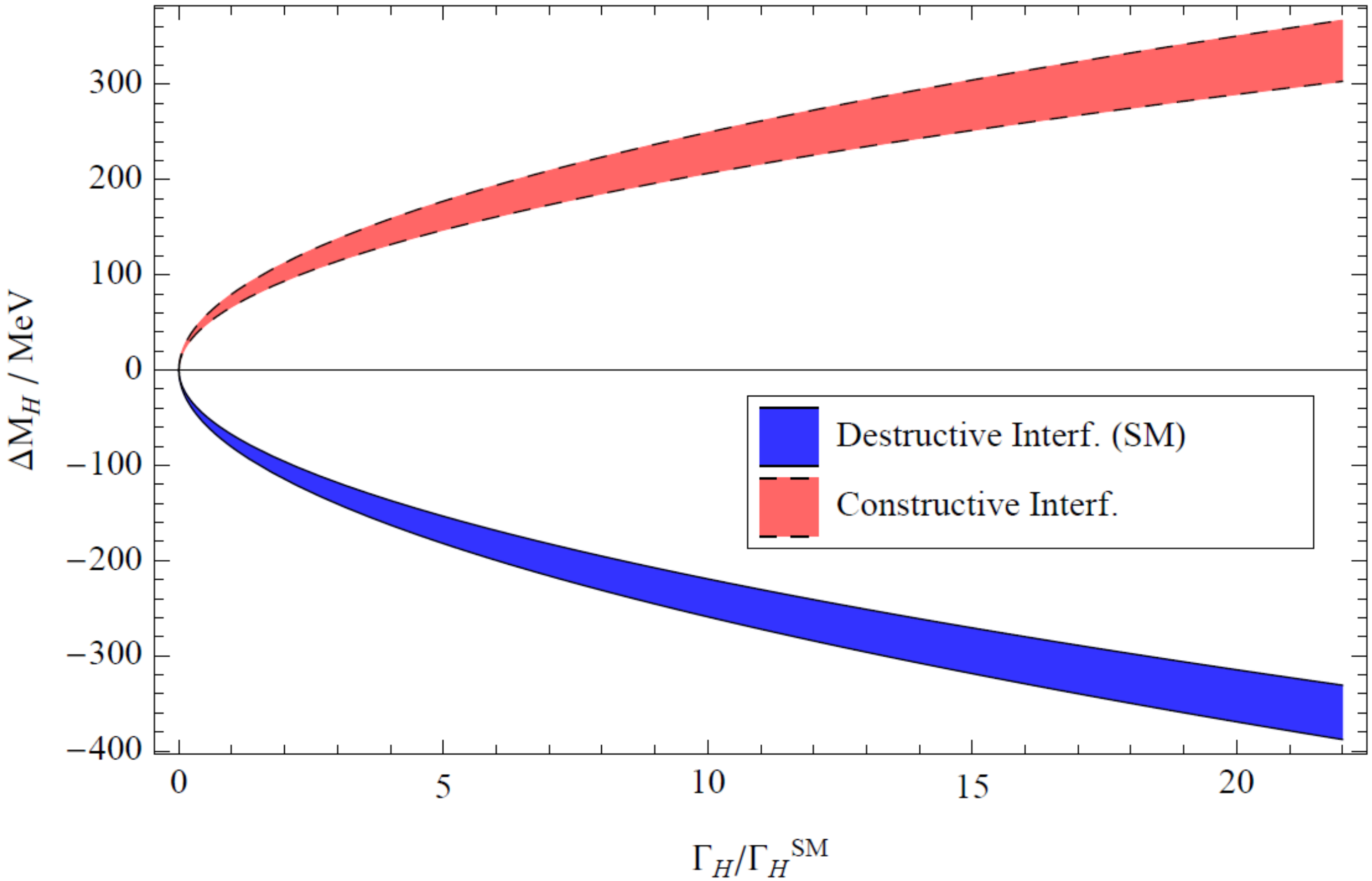
$$\mathcal{L} = -\left[\frac{\alpha_s}{8\pi} c_g b_g G_{a,\mu\nu} G_a^{\mu\nu} + \frac{\alpha}{8\pi} c_\gamma b_\gamma F_{\mu\nu} F^{\mu\nu}\right] \frac{h}{v}$$

- Coupling product $c_g \cdot c_\gamma = c_{g\gamma}$ determined by requiring that event yield is unaffected:

$$\frac{c_{g\gamma}^2 S}{m_H \Gamma_H} + c_{g\gamma} I = \left(\frac{S}{m_H \Gamma_H^{SM}} + I\right) \mu_{\gamma\gamma}$$

- Ignoring I, $c_{g\gamma} = \sqrt{\mu_{\gamma\gamma} \Gamma_H / \Gamma_H^{SM}}$

Mass shift vs. width



- Measurement statistically limited now, ~ 800 MeV
- Systematically limited in HL-LHC era, ~ 100-200 MeV

What about spin 2?

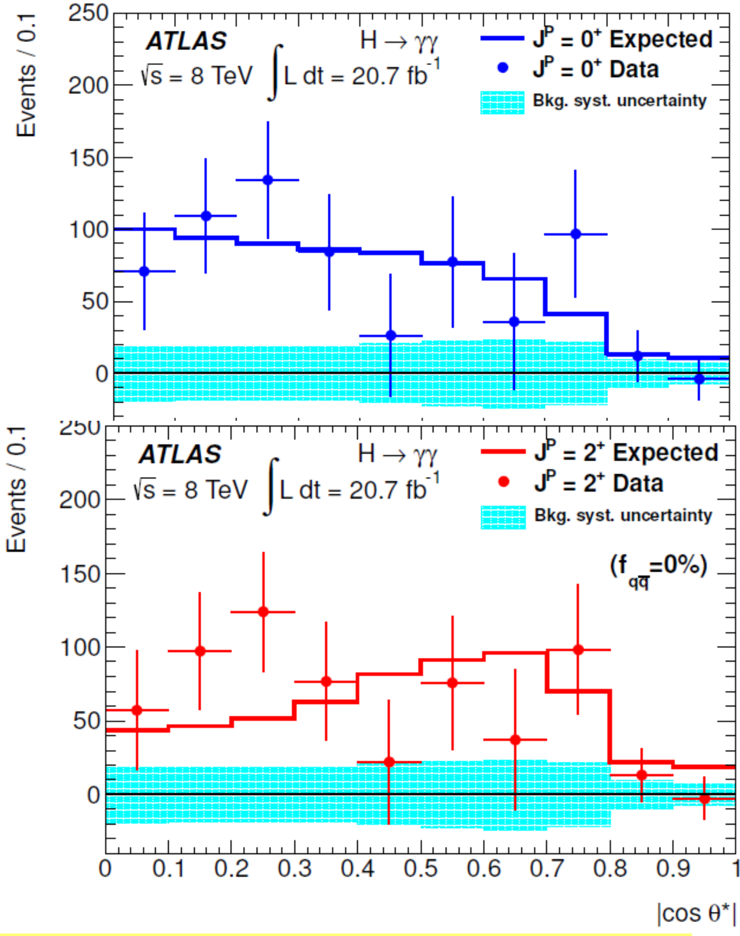
LD, Höche, Li, to appear

- Rejection of spin 2 vs. spin 0 relies on distribution in $\cos\theta^*$ for $gg \rightarrow \gamma\gamma$.
- Without interference, this is

~ 1 spin 0

$\sim 1 + 6\cos^2\theta^* + \cos^4\theta^*$ 2_m^+

- How much distortion from interference effects?
- SM Higgs: < few %

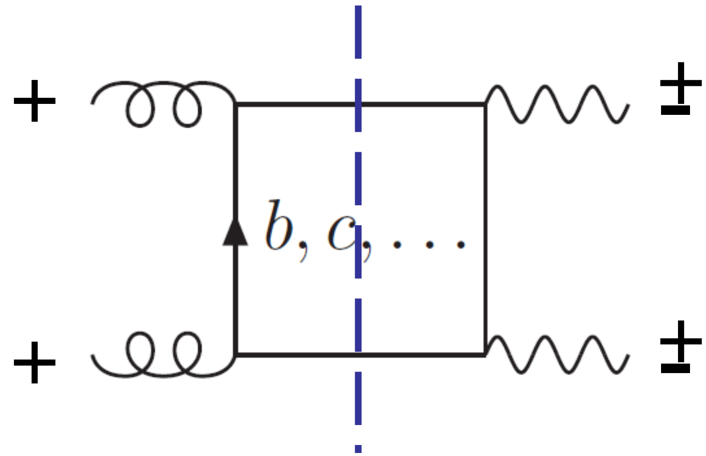


LD, Siu, hep-ph/0302233

Strong helicity dependence of Im part of background 1-loop amplitude

Spin 0

Im

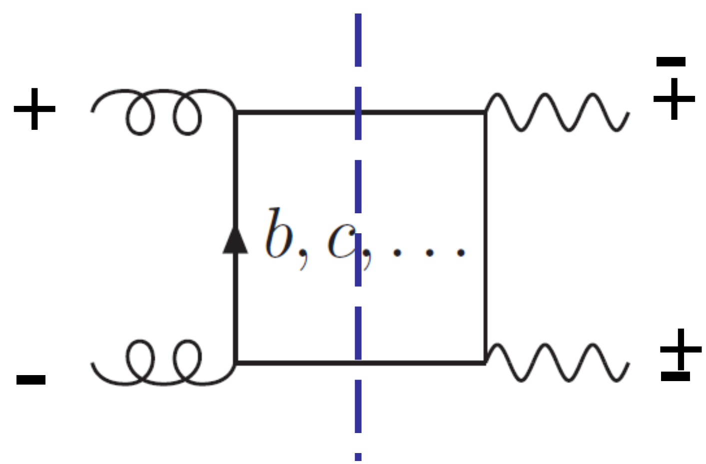


$= O(m_q^2/m_H^2) \sim 0$

Dicus, Willenbrock (1988)

Spin 2_m^+

Im

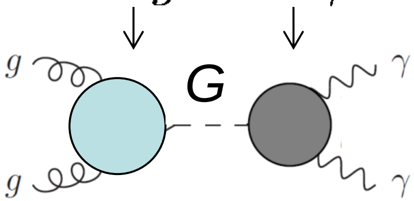


$= O(1)$

Non-minimal spin 2 can interfere with other helicity amplitudes, but only this helicity config. has Im part

(spin 2) - 1-loop interference simple

$$G_g \times G_\gamma \equiv G_{g\gamma}$$



$$\overline{|\mathcal{A}|^2} = \left[\frac{G_{g\gamma}^2}{256} f_0(c) + \pi\xi M\Gamma f_i(c)\right]\frac{1}{(\hat{s}-M^2)^2+M^2\Gamma^2} + \xi f_r(c)\frac{\hat{s}-M^2}{(\hat{s}-M^2)^2+M^2\Gamma^2},$$

where $c = \cos\theta$

$$f_0(c) = 1 + 6c^2 + c^4,$$

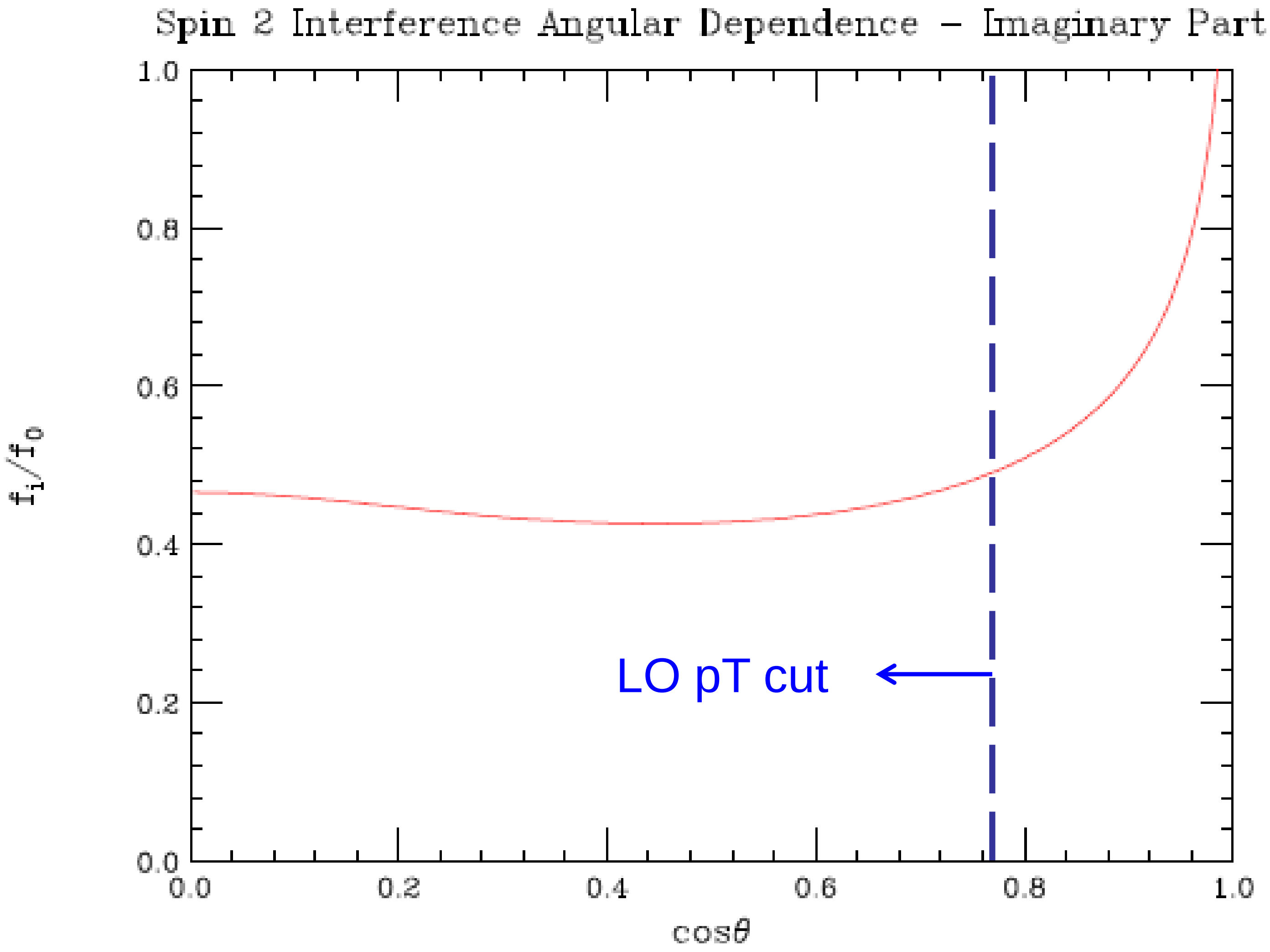
$$f_i(c) = 2\left[\left(1+\frac{(1-c)^2}{4}\right)\ln\left(\frac{2}{1-c}\right) + \left(1+\frac{(1+c)^2}{4}\right)\ln\left(\frac{2}{1+c}\right)\right] - 3 + c^2,$$

$$f_r(c) = \left(1+\frac{(1-c)^2}{4}\right)\ln^2\left(\frac{2}{1-c}\right) - \frac{(1+c)(3-c)}{2}\ln\left(\frac{2}{1-c}\right) + \left(1+\frac{(1+c)^2}{4}\right)\ln^2\left(\frac{2}{1+c}\right) - \frac{(1-c)(3+c)}{2}\ln\left(\frac{2}{1+c}\right) + 1 + c^2,$$

and

$$\xi = \frac{11}{72} G_{g\gamma}\alpha\alpha_s.$$

Im part remarkably flat in cosθ



Size of interference as function of width Γ

- Event yield ~ $c_1 G_{g\gamma}^2 + c_2 G_{g\gamma} \Gamma$
- Normalize to SM Higgs

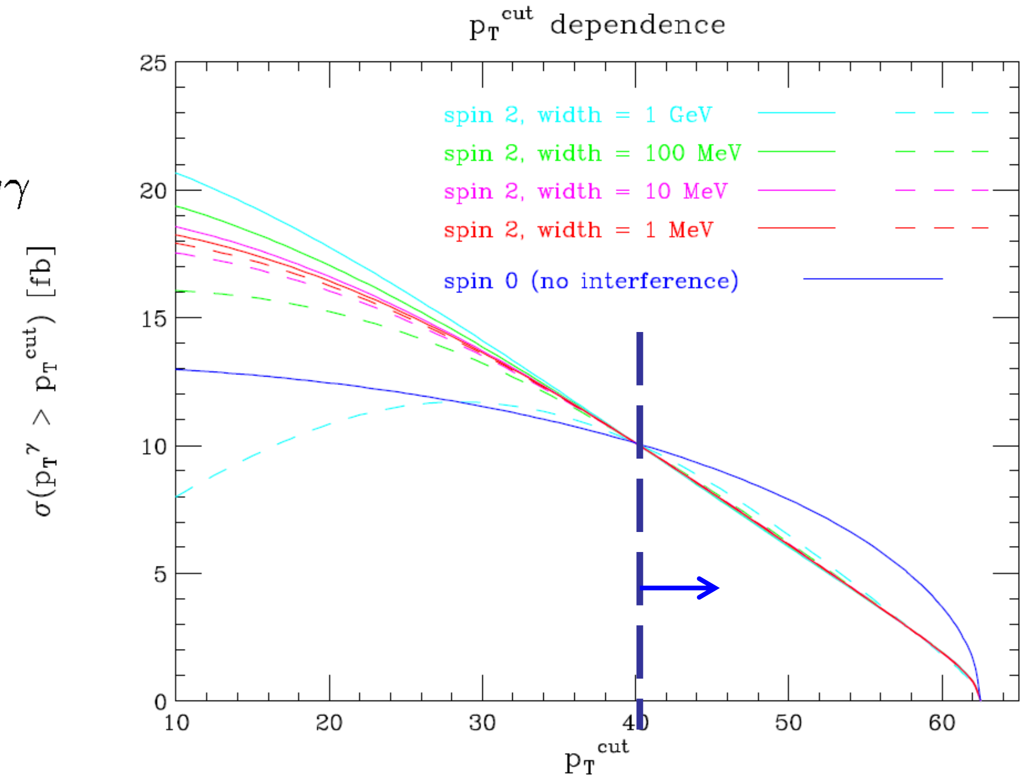
at photon p_T^{cut} = 40 GeV.

- Quadratic equation for $G_{g\gamma}$
- Constructive,

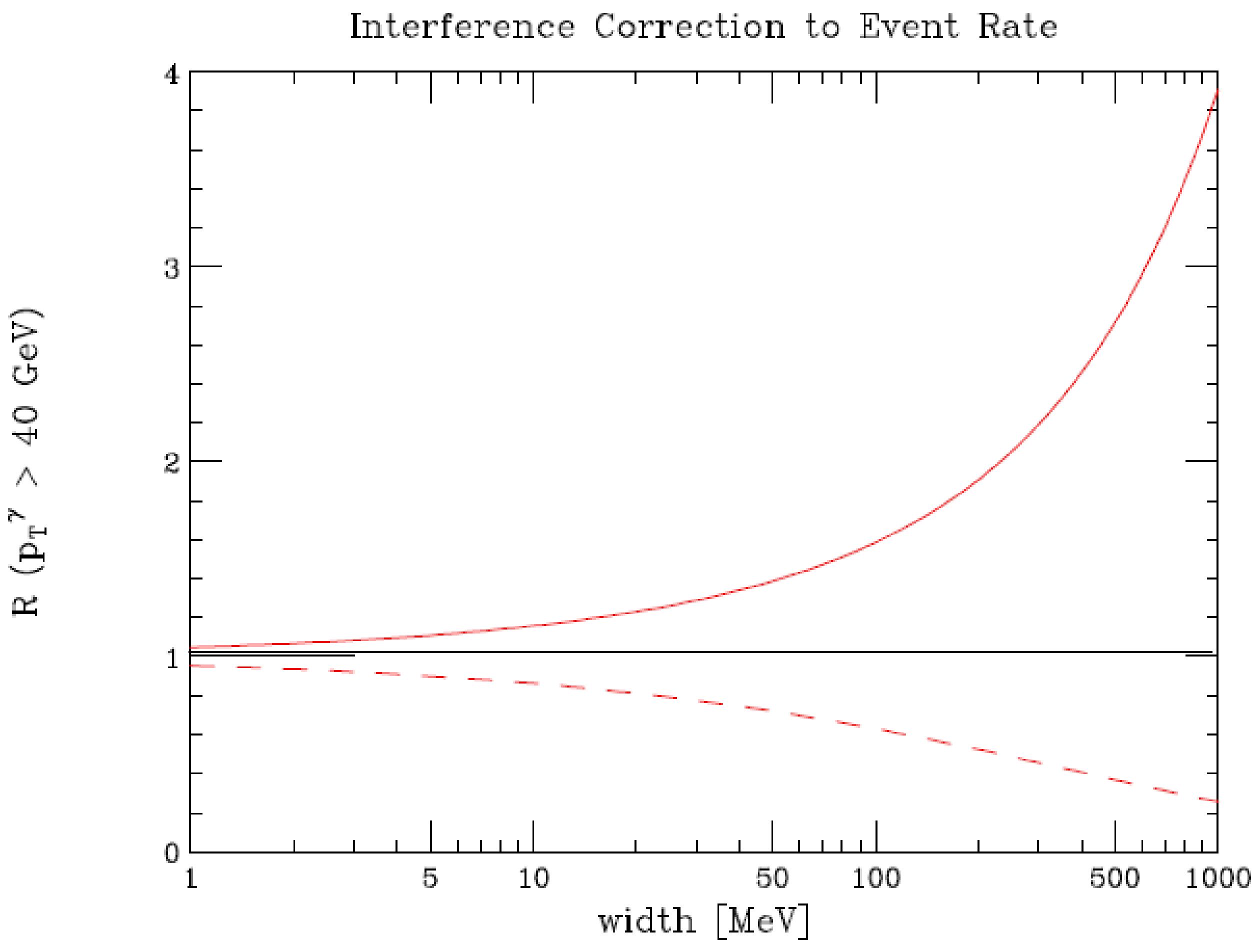
destructive solutions

- Completely model

independent with respect to coupling strengths, other channels.



Spin 2 yield might be strongly affected – even if cosθ* distribution is not



Conclusions

- Interference effects, in particular the mass shift in $\gamma\gamma$, allow the possibility of bounding the Higgs width to well under the direct experimental resolution, maybe eventually approaching the SM width. Now under study experimentally.
- A few possible control masses.
- In principle, interference effects also important for testing non-SM hypotheses – e.g. spin 2 in $\gamma\gamma$. In practice, distortion of the $\cos\theta^*$ distribution is very small where it is measurable.

Spin-2 mass shift from real part

Smear lineshape with Gaussian with width σ = 1.7 GeV.
Do least squares fit to Gaussian at mass $M + \delta M$.