Higgs precision at 100 TeV

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Higgs chapter of FCC physics report

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Physics at a 100 TeV pp collider: Higgs and EW symmetry breaking studies

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Contents

SM Higgs at 100 TeV

	N_{100}	N_{100}/N_8	N_{100}/N_{14}
$gg \to H$	16×10^9	4×10^4	110
VBF	1.6×10^9	5×10^4	120
WH	3.2×10^8	2×10^4	65
ZH	2.2×10^8	3×10^4	85
$t\bar{t}H$	7.6×10^8	3×10^5	420

$N_{100} = \sigma_{100\,\mathrm{TeV}} \times 20\ \mathrm{ab}^{-1}$

$N_8 = \sigma_{8\,\mathrm{TeV}} \times 20\ \mathrm{fb}^{-1}$

$N_{14} = \sigma_{14\,\mathrm{TeV}} \times 3\ \mathrm{ab}^{-1}$

- Huge production rates imply:
  - can afford reducing statistics, with tighter kinematical cuts that reduce backgrounds and systematics
  - can explore new dynamical regimes, where new tests of the SM and EWSB can be done

Example, $H \rightarrow \gamma\gamma$ (fiducial, all channels)

8 TeV reference results from ATLAS, arXiv:1407.4222

Fiducial cross section for $|\eta_\gamma| < 2.37$, *with* $p_{T\,\gamma}^{max} / m_{\gamma\gamma} > 0.35$ *and* $p_{T\,\gamma}^{min} / m_{\gamma\gamma} > 0.25$

Signal dominated by $gg \rightarrow H$

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Fiducial volume acceptance: $\varepsilon_{fid} \sim 3/4$

Detection efficiency within fiducial volume: $\varepsilon_{eff} \sim 2/3$

$\Rightarrow N_{signal} \sim 3/4 * 2/3 * \sigma(pp \rightarrow H) * BR(H \rightarrow \gamma\gamma) * Lum \sim 10^{-3}\, \sigma(pp \rightarrow H) * Lum$

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Observe 570 ± 130 signal events, over a bg of ~16000 events ($|m_{\gamma\gamma} - 125| < 4$ GeV *)*

Extract $\sigma_{FIDUCIAL}(pp \to H \to \gamma\gamma) = 43.2 \pm 9.4$ (stat.) ± 3.2 (syst.) ± 1.2 (lumi) fb

$\delta(\sigma \cdot B) / (\sigma \cdot B) \sim 22\%$ (stat.) $+ 7\%$ (syst.) $\pm 3\%$ (lumi)

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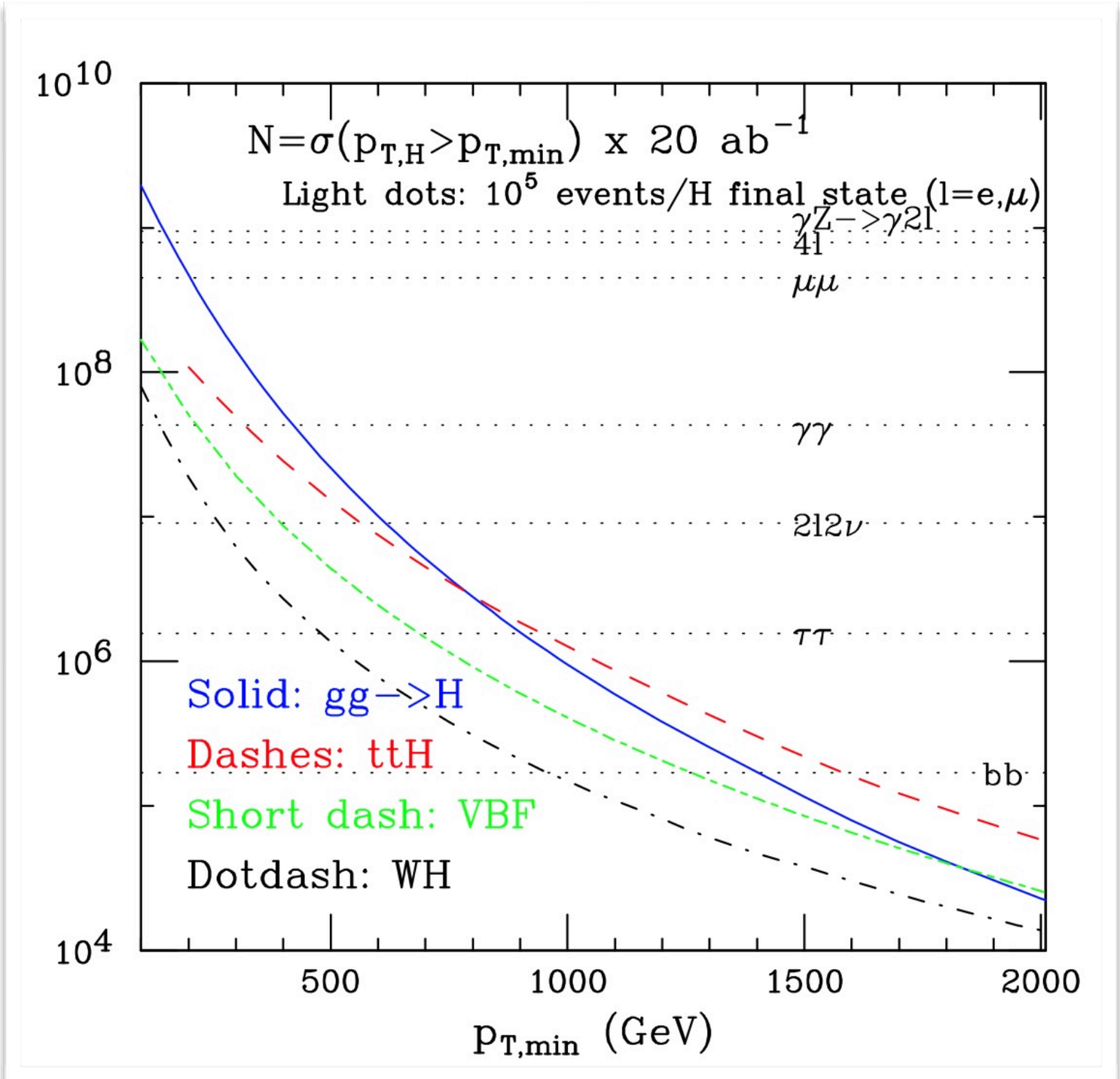
$N_{14}/N_8 \sim 400 \Rightarrow 22\%(stat) \to 1\%$ at HL-LHC

$N_{100}/N_8 \sim 4 \times 10^4 \Rightarrow 22\%(stat) \to 0.1\%$ at FCC

H at large p_T



- Hierarchy of production channels changes at large $p_T(H)$:
  - $\sigma(ttH) > \sigma(gg \to H)$ above 800 GeV
  - $\sigma(VBF) > \sigma(gg \to H)$ above 1800 GeV

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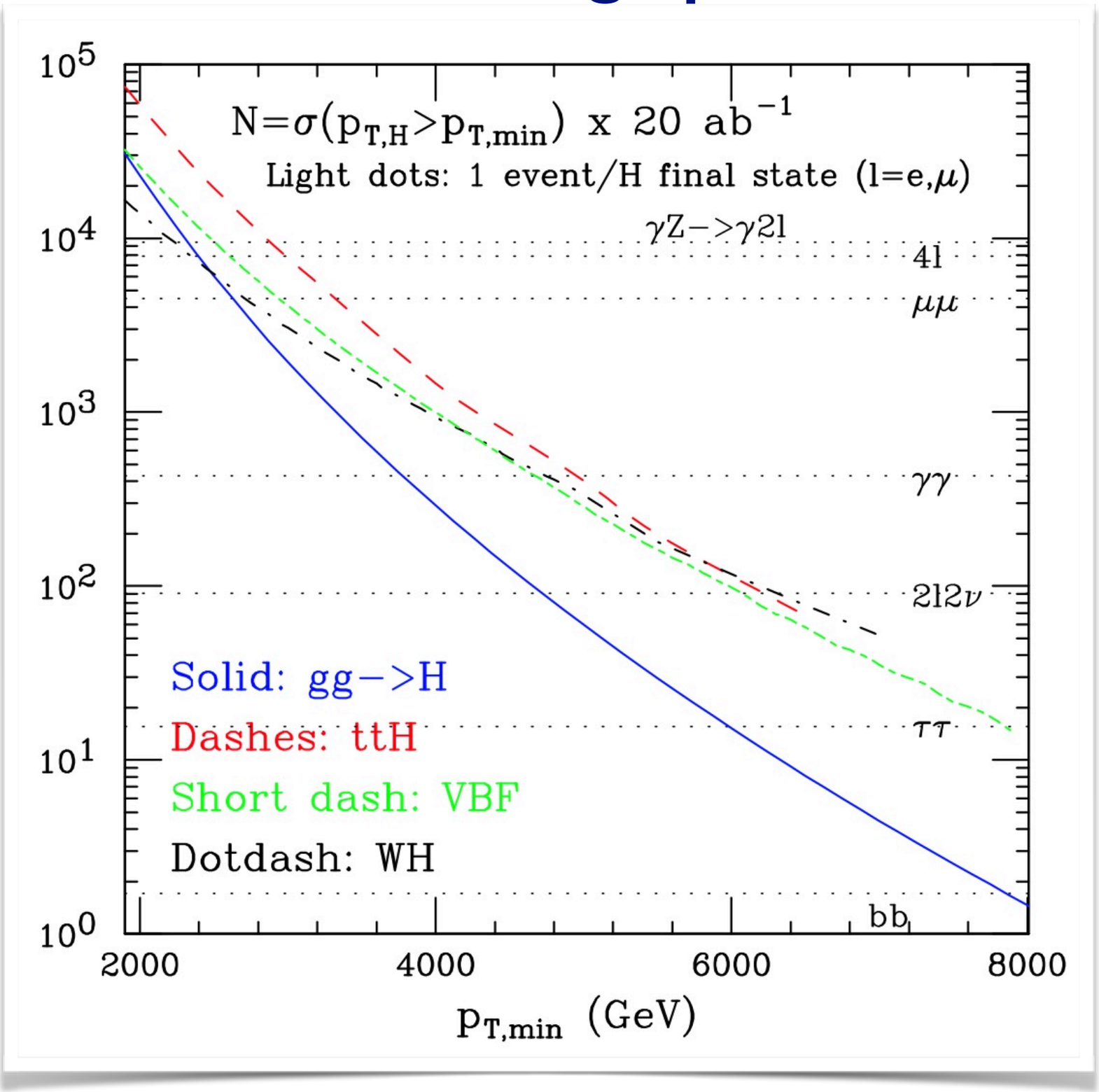
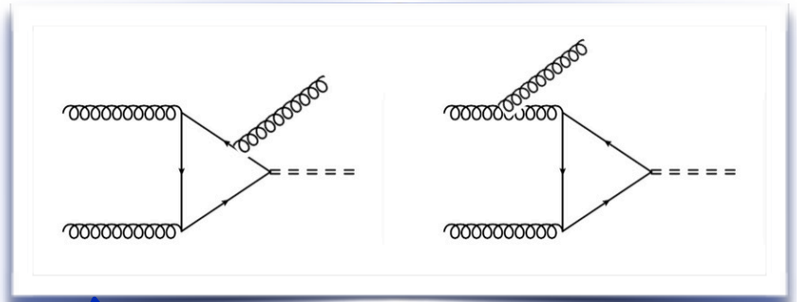
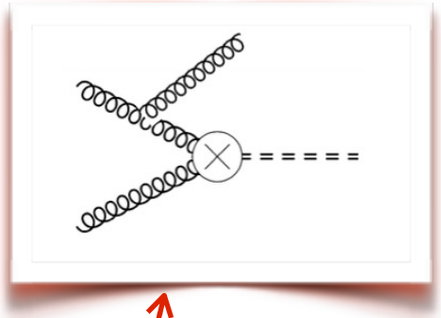
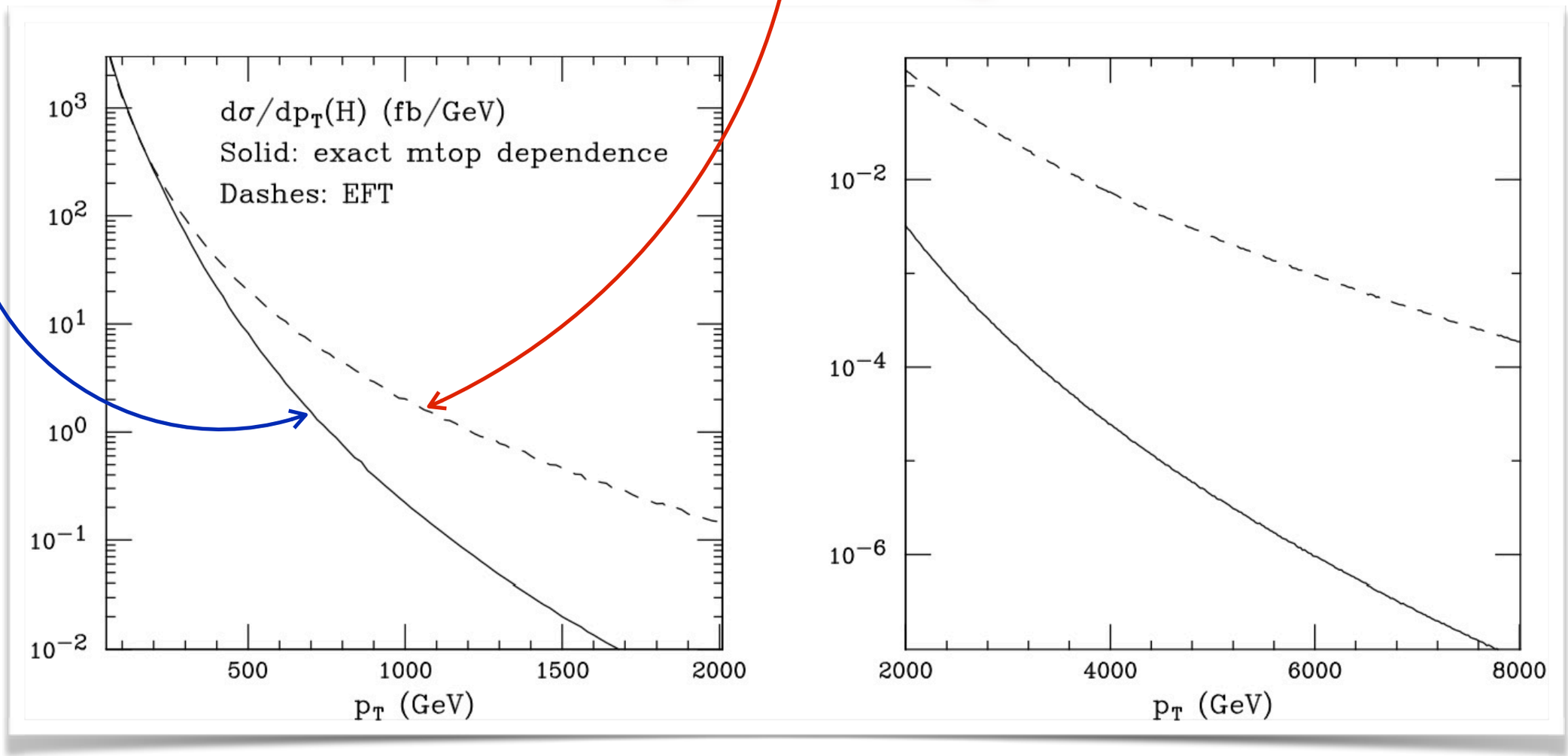


- Statistics in potentially visible final states out to several TeV

H at large p_T



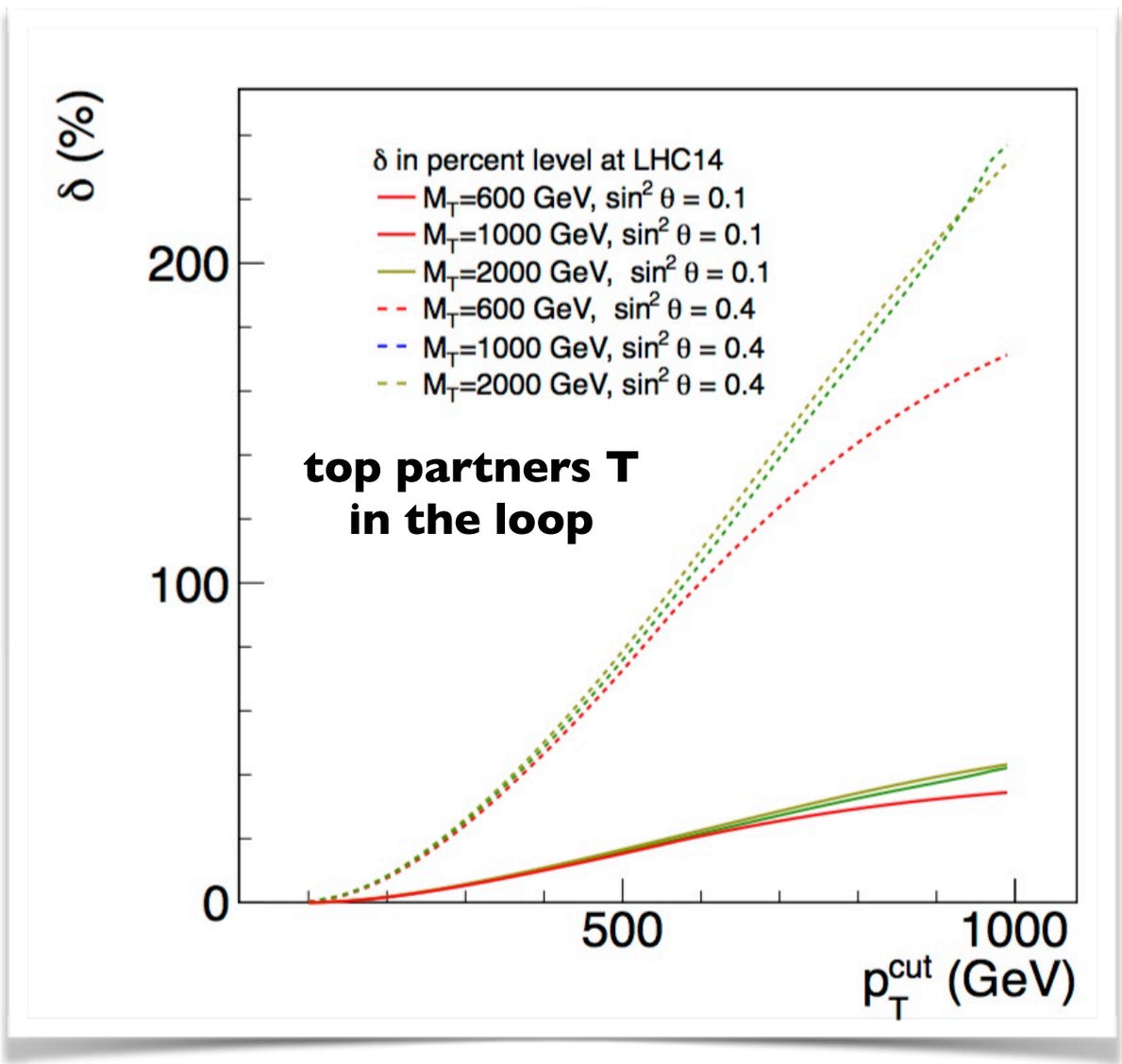




- At LHC, can measure only up to p_T~ few hundred GeV ⇒ reduced sensitivity to the inner guts of the ggH coupling
- At FCC, orders of magnitude difference between EFT and exact m_{top}

Examples

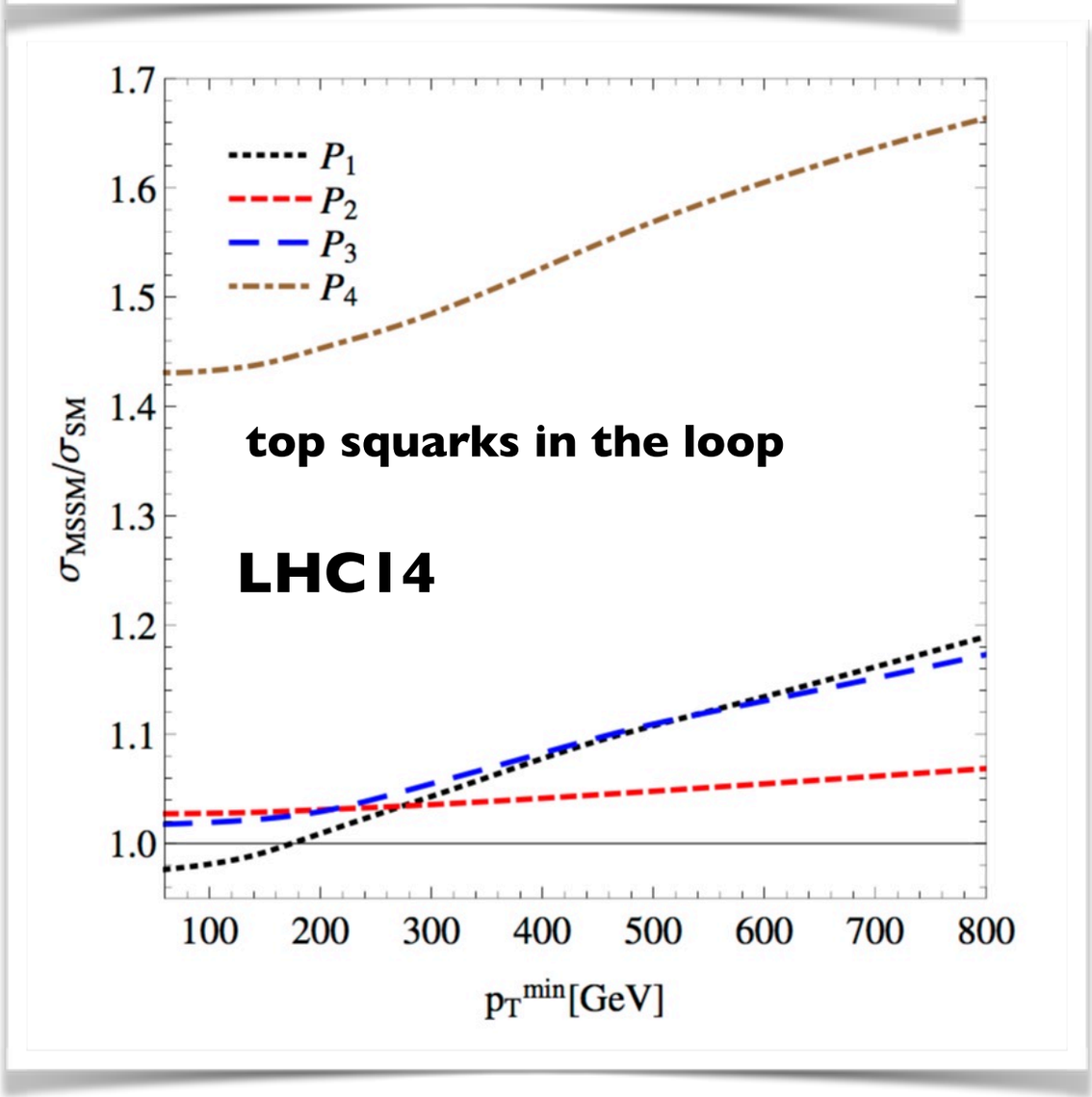
(See also
Azatov and Paul arXiv:1309.5273v3)



Banfi Martin Sanz, arXiv:1308.4771

Table 3: The benchmark points shown in Fig. 7. We set $\tan\beta = 10$, $M_{A^0} = 500\,\text{GeV}$, $M_2 = 1000\,\text{GeV}$, $\mu = 200\,\text{GeV}$ and all trilinear couplings to a common value A_t. The remaining sfermion masses were set to 1 TeV and the mass of the lightest CP-even Higgs was set to 125 GeV.

Point	$m_{\tilde{t}_1}$ [GeV]	$m_{\tilde{t}_2}$ [GeV]	A_t [GeV]	Δ_t
P_1	171	440	490	0.0026
P_2	192	1224	1220	0.013
P_3	226	484	532	0.015
P_4	226	484	0	0.18



Grojean, Salvioni, Schlaffer, Weiler arXiv:1312.3317

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  - precise determination of BR($H \to gg$) from e^+e^- (e.g. analysis of EFT couplings)?

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- Analyses likely based on shape (e.g. $\sigma(p_T > 2\ \text{TeV})/\sigma(p_T > 1\ \text{TeV})$), to reduce dependence on absolute production rate, ttH coupling, lumi, etc:
  - ultimate TH systematics?
  - ultimate EXP systematics?
  - what are the best decay channels?

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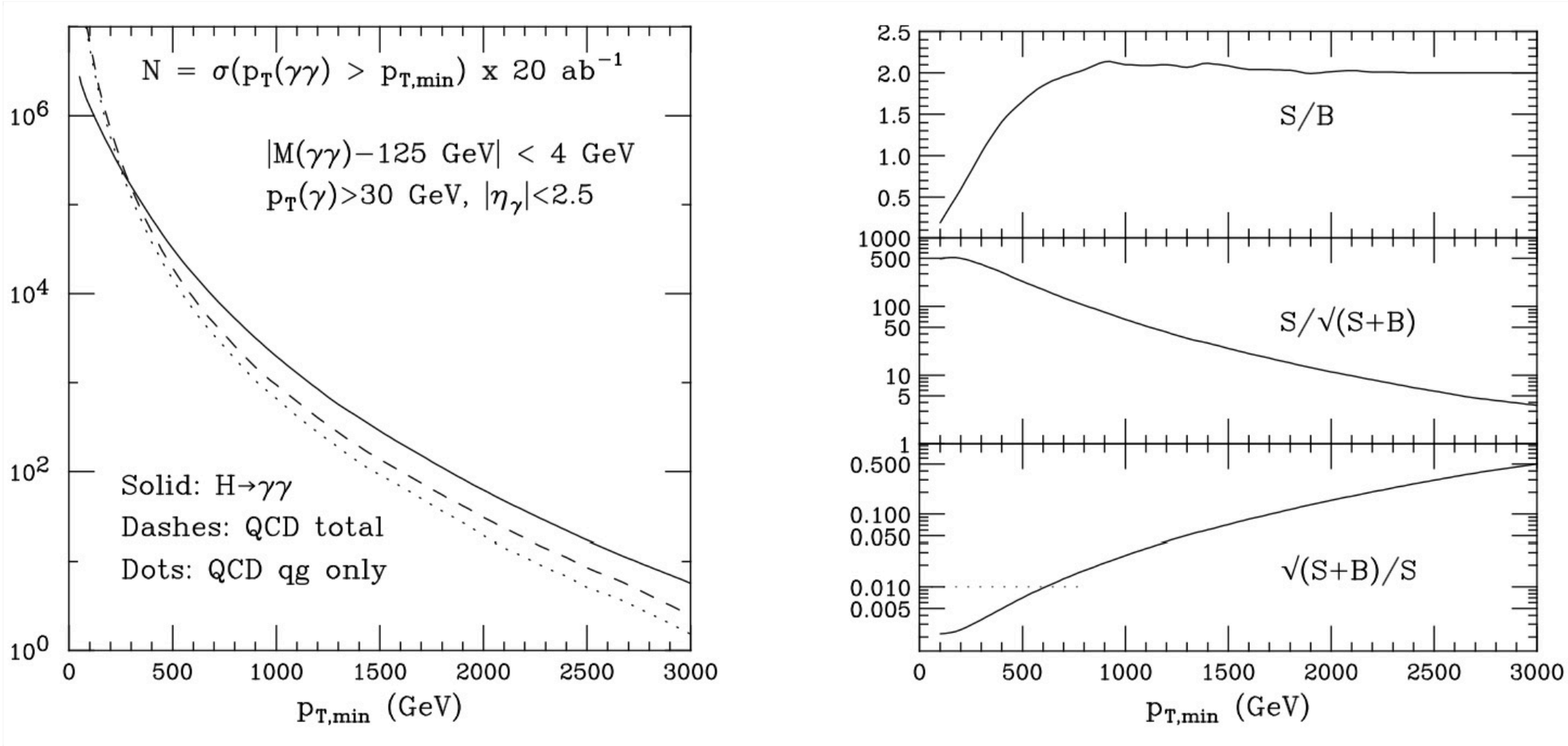
- More in general (for all production and decay channels):
  - ***Can high-pt measurements compete with precise BR's in probing EFT couplings?***
- *What's the status of integration of BSM in the loop-induced part of MG5_aMC@NLO?*

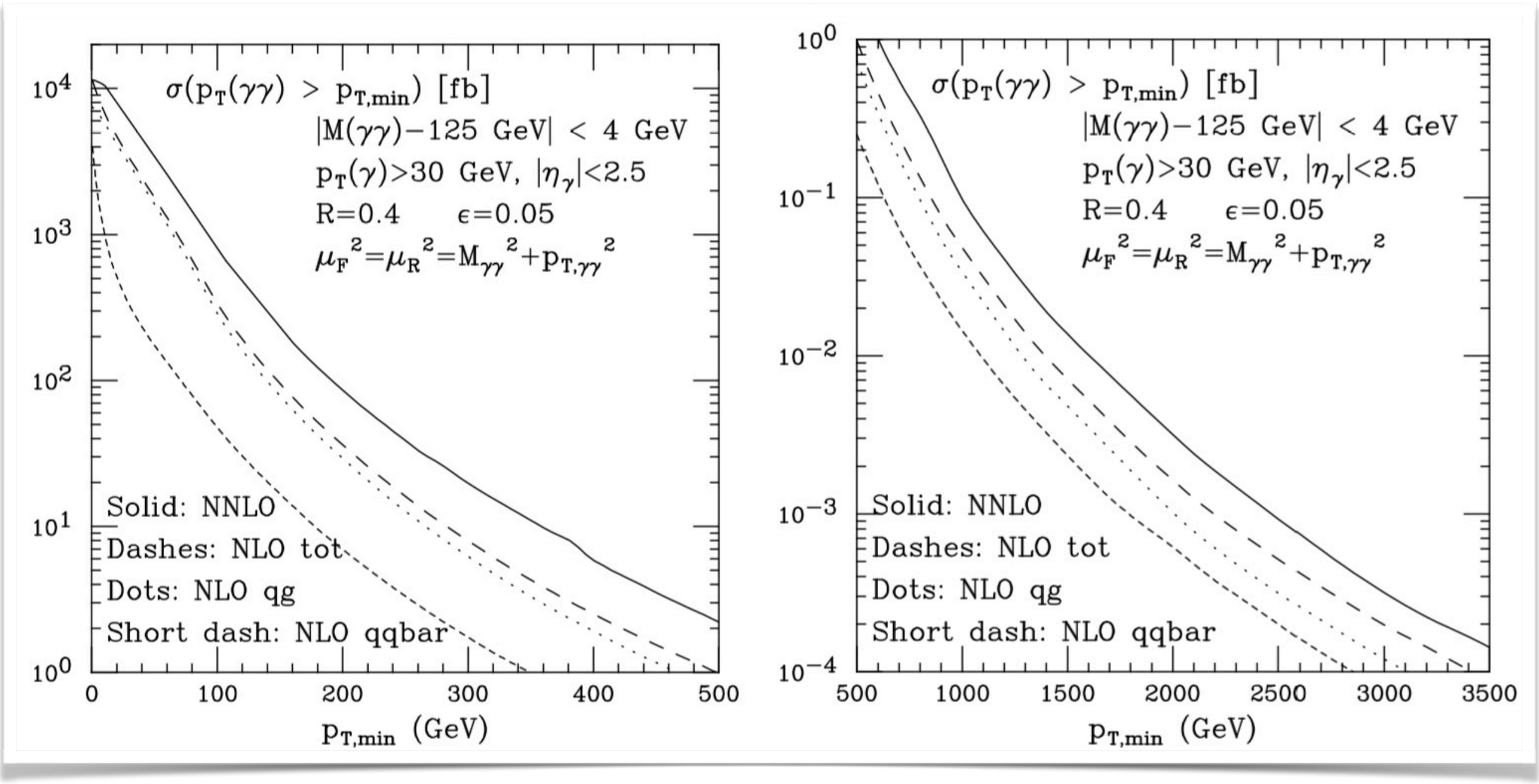
Some examples of results from the 100 TeV report

gg→H→γγ at large p_T



- At LHC, S/B in the H→γγ channel is O(few %)
- At FCC, for p_T(H)>300 GeV, S/B~1
- Very clean probe of Higgs production up to large p_T(H). What's the sensitivity required to probe relevant BSM deviations from SM spectrum?
- Exptl mass resolution at large pt(H)?

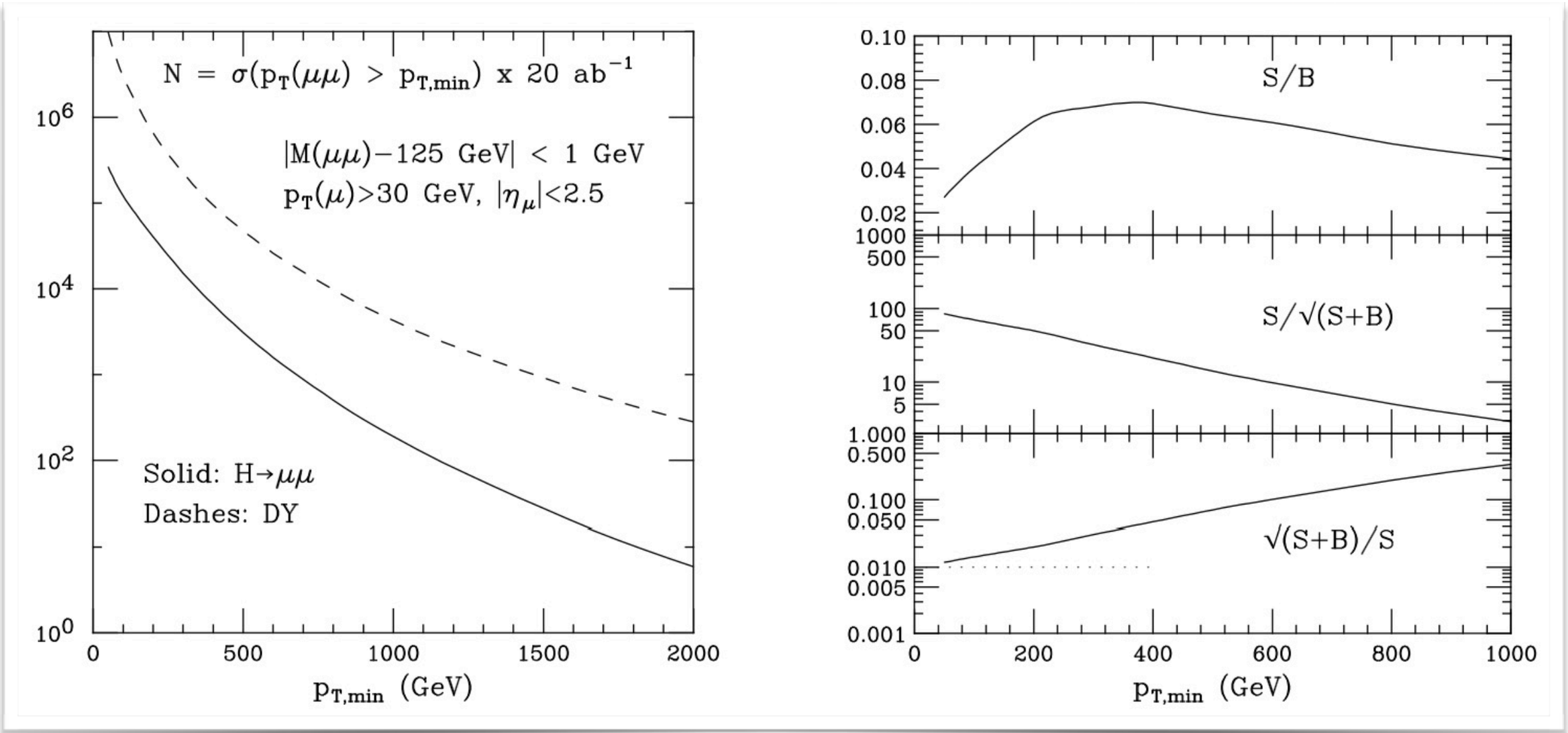
γγ background



NLO: $O(\alpha_S)$

NNLO: $O(\alpha_S^2)$. No gg contribution for $p_T>0$ at this order

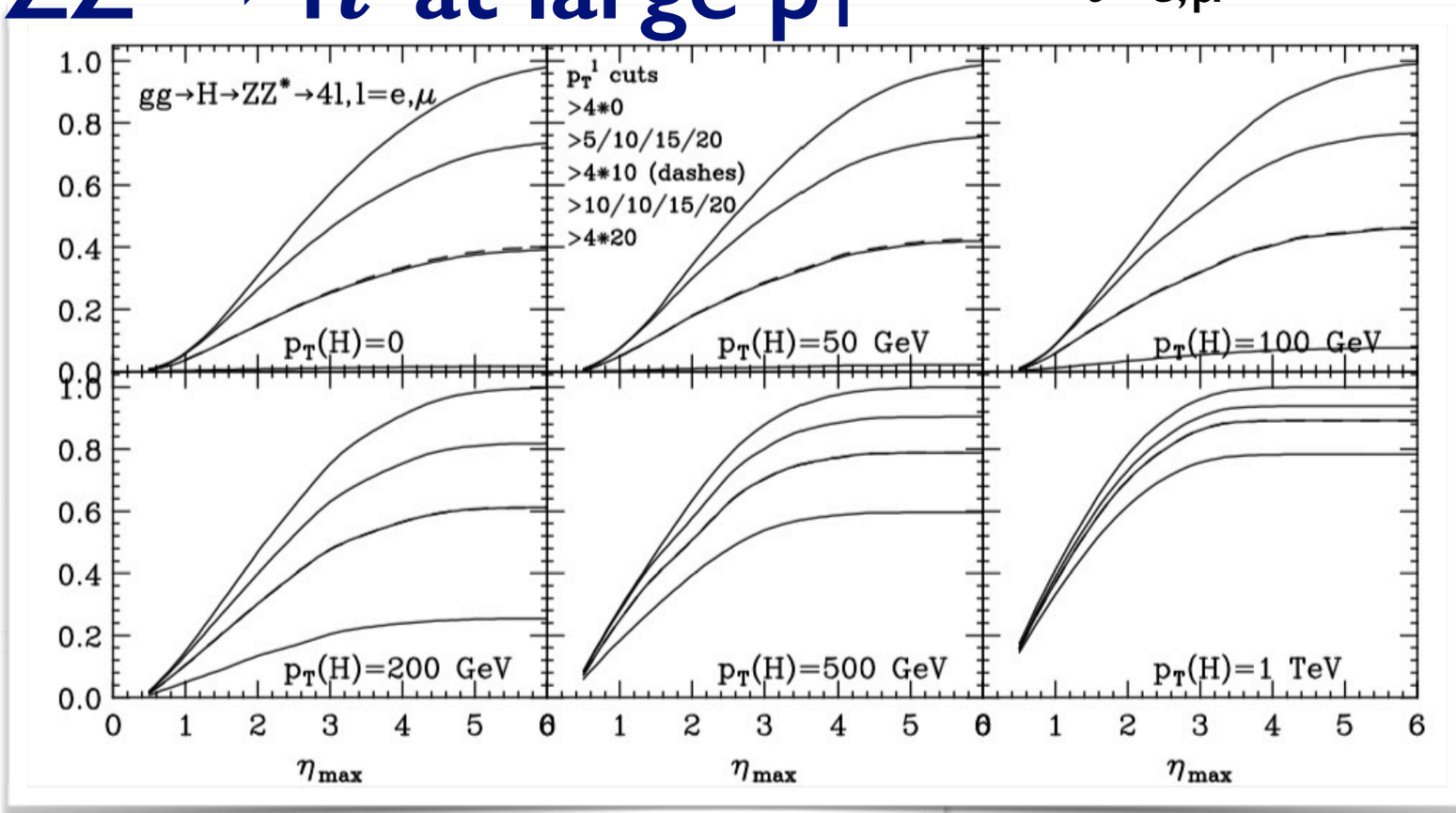
gg→H→μμ at large p_T

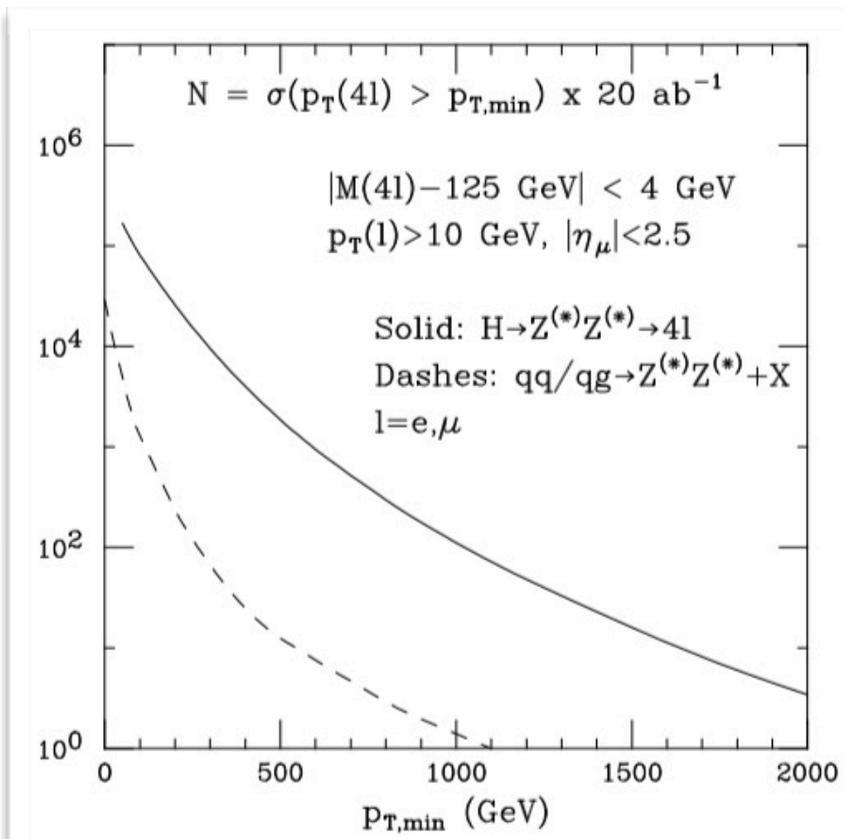


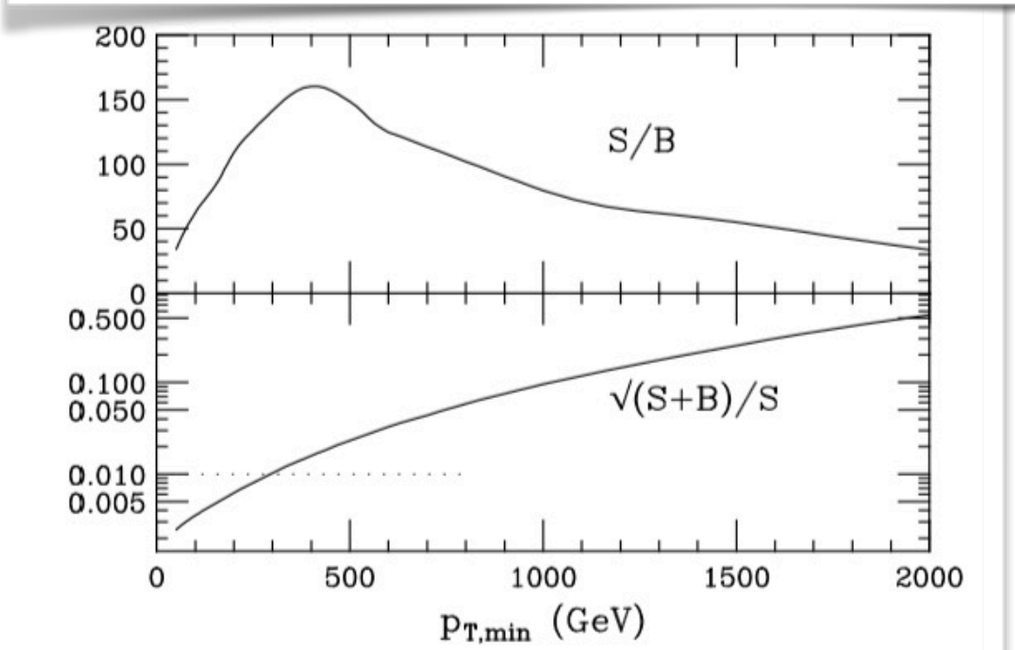
- Stat reach ~1% at p_T~100 GeV
- Exptl systematics on BR(μμ)/BR(γγ)? (use same fiducial selection to remove H modeling syst's)

gg→H→ZZ*→4ℓ at large p_T

ℓ=e,μ

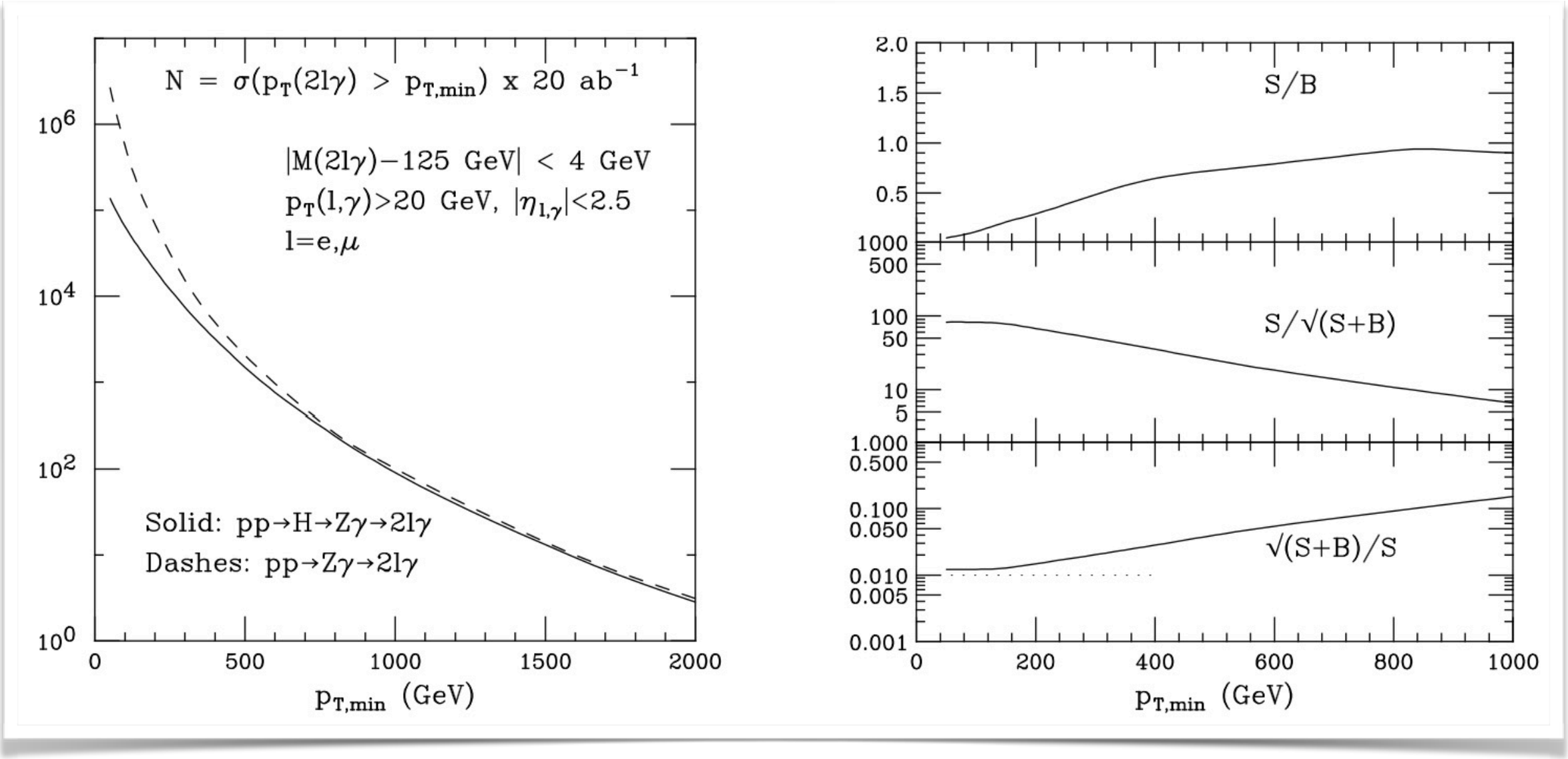






- S/B ≫ 1
- Stat reach ~1% at pT~300 GeV
- Exptl systematics on BR(ZZ*)/BR(Zγ,γγ)?

gg→H→Zγ→ℓℓγ at large p_T

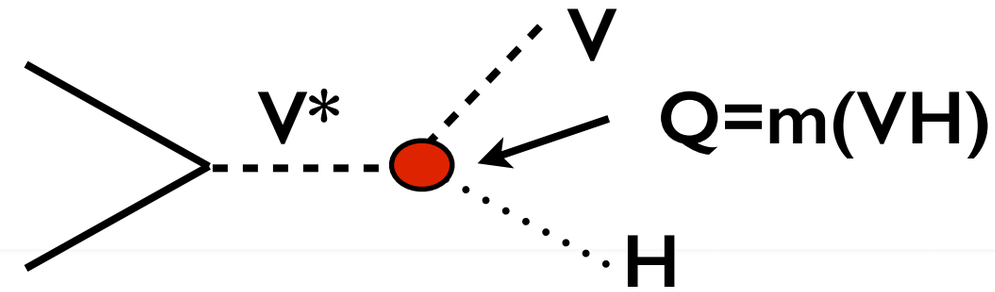


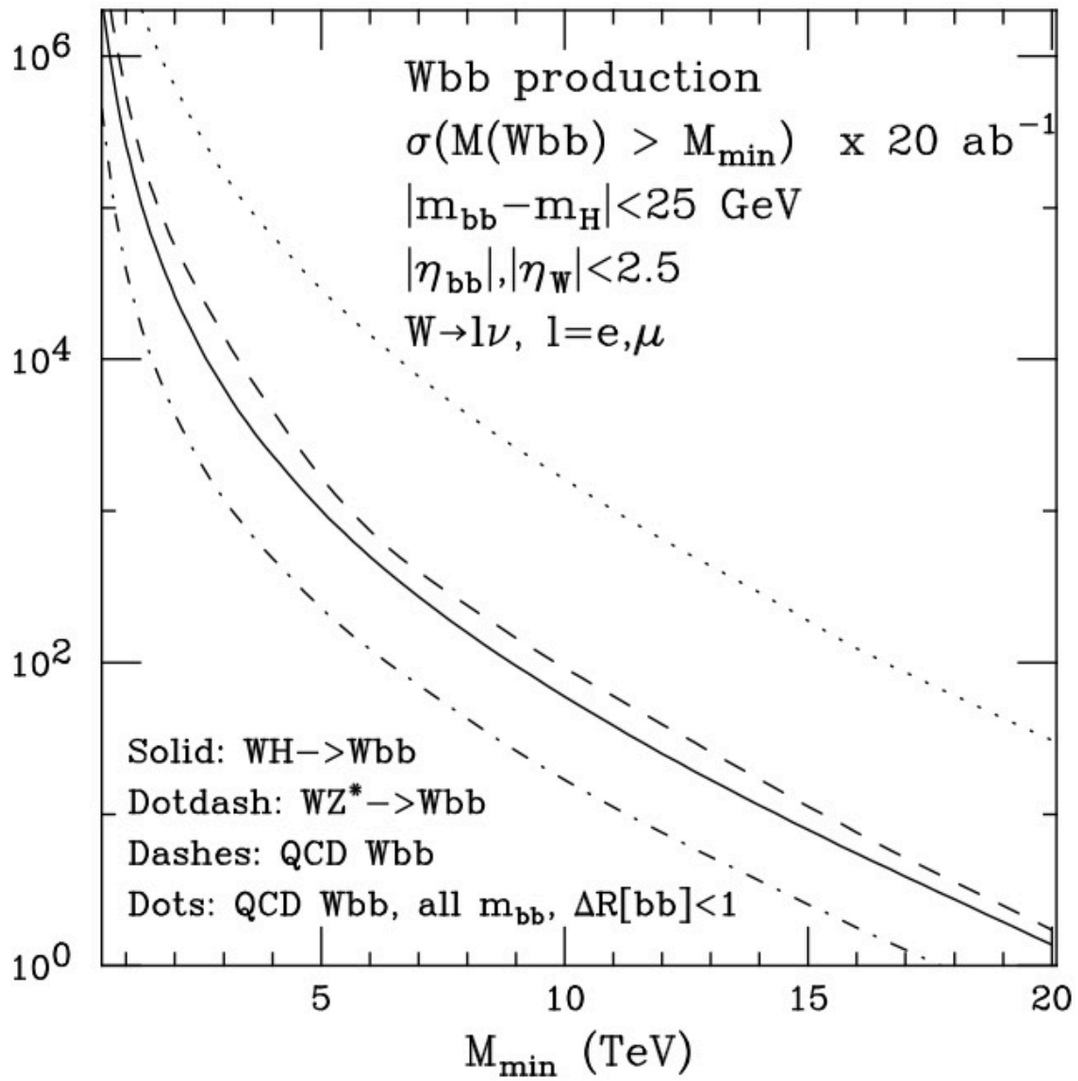
- S/B improves greatly at larger p_T
- Stat reach ~1% at pT~100 GeV
- Exptl systematics on BR(Zγ)/BR(γγ)?

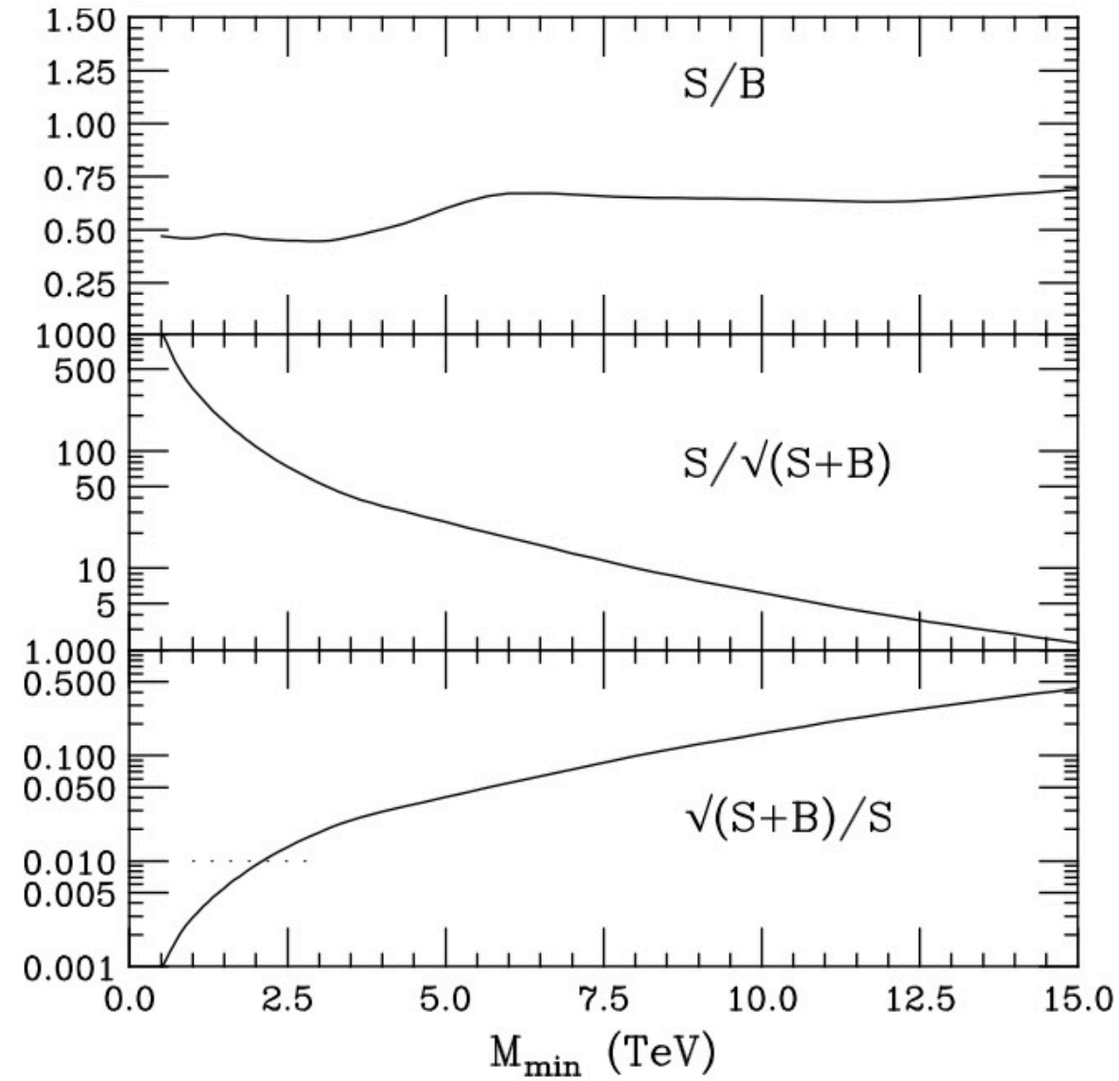
Remarks on gg→H

- Reach for %-level measurement of very rare decay modes ($Z\gamma$, $\mu\mu$) (absolute, if $B(\gamma\gamma/ZZ)$ known from e^+e^-, or relative w.r.t. $B(\gamma\gamma)$ using pp-only data)
- Much larger statistics and p_T reach for modes like WW and $\tau\tau$. Needs dedicated studies to check potential precision (e.g. systematics from corrections to common fiducial regions, impact of neutrinos, …)
- Reach for H→bb ?

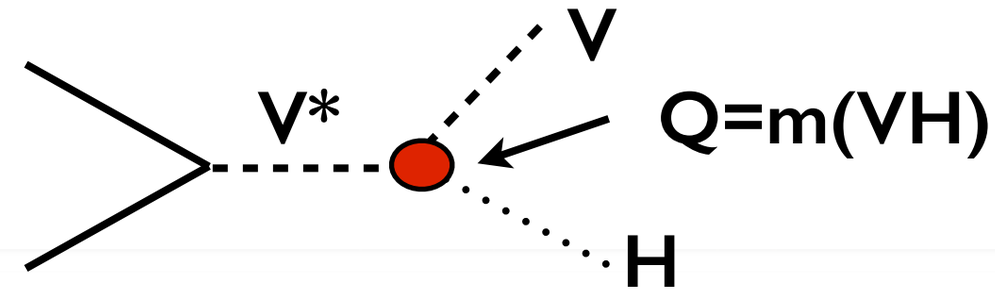
WH→Wbb at large M_{WH}

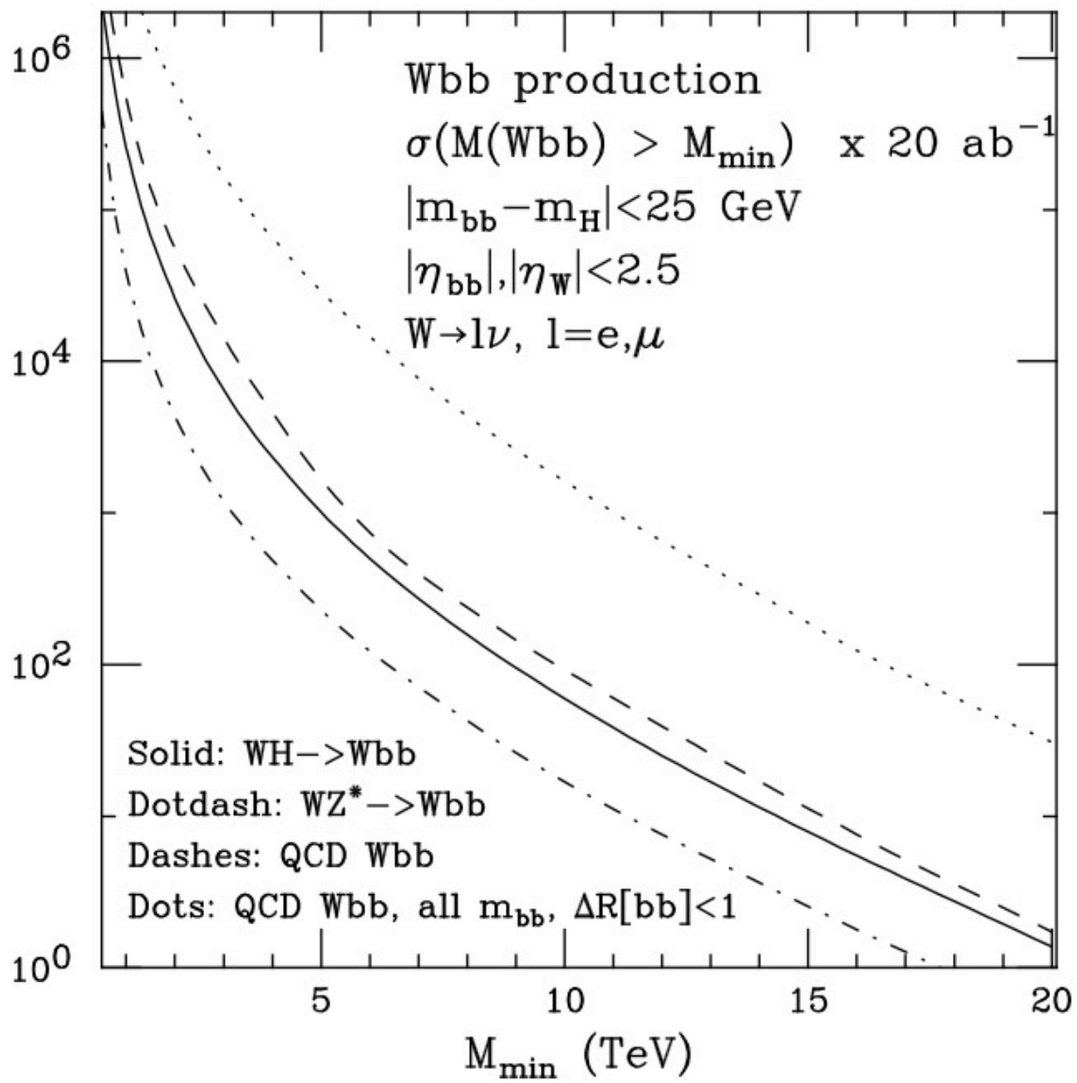


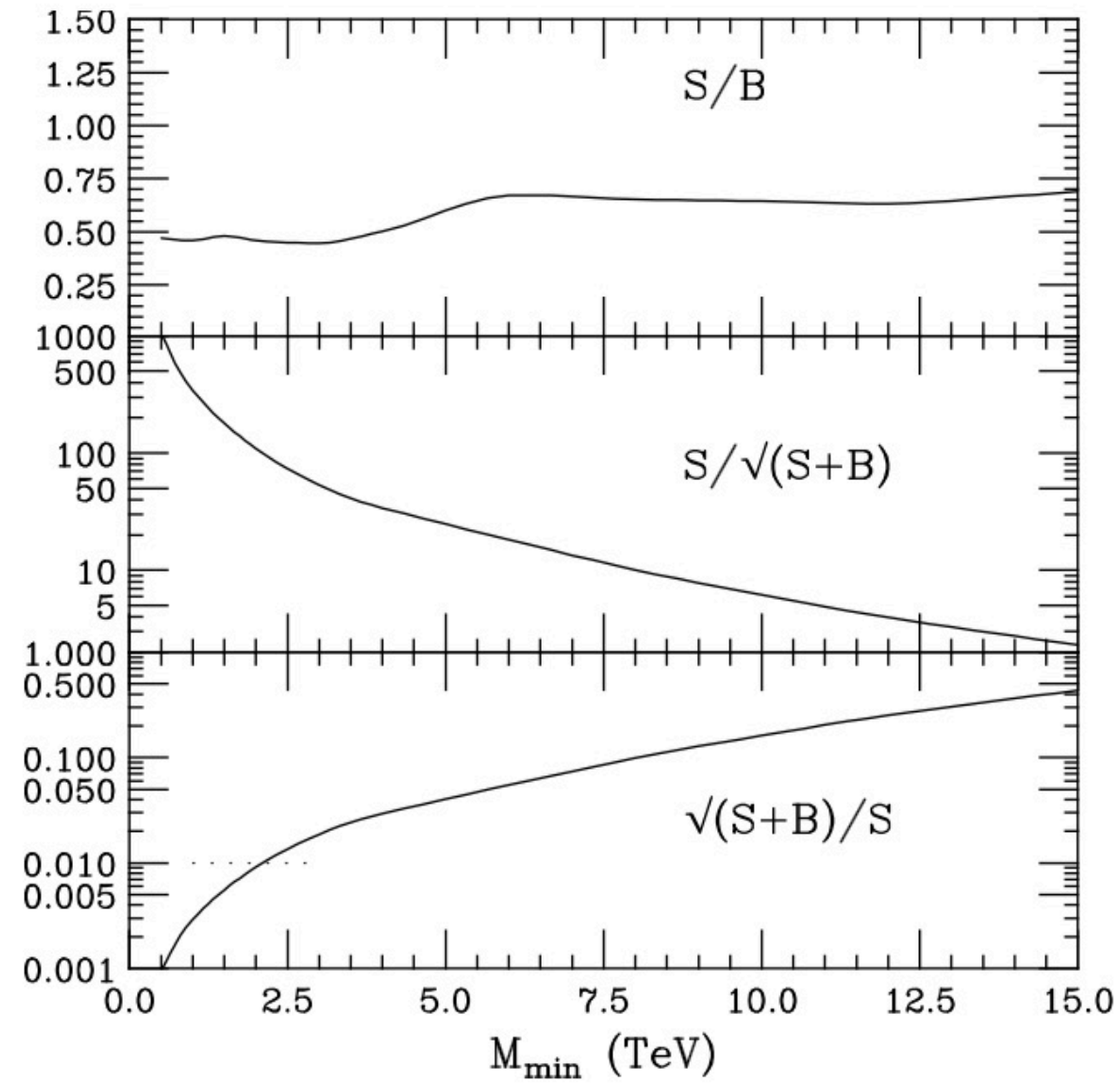




WH→Wbb at large M_{WH}

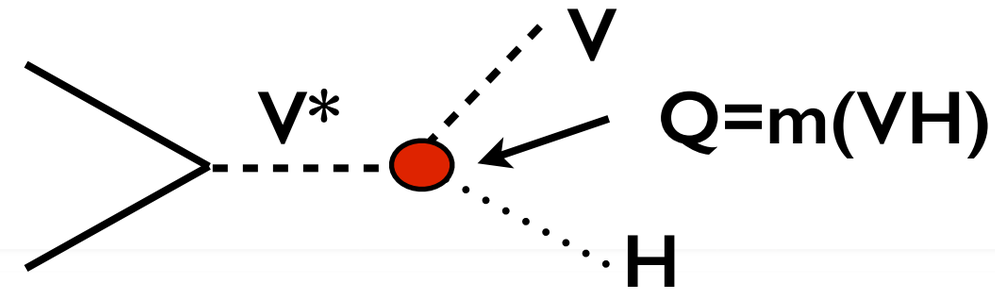


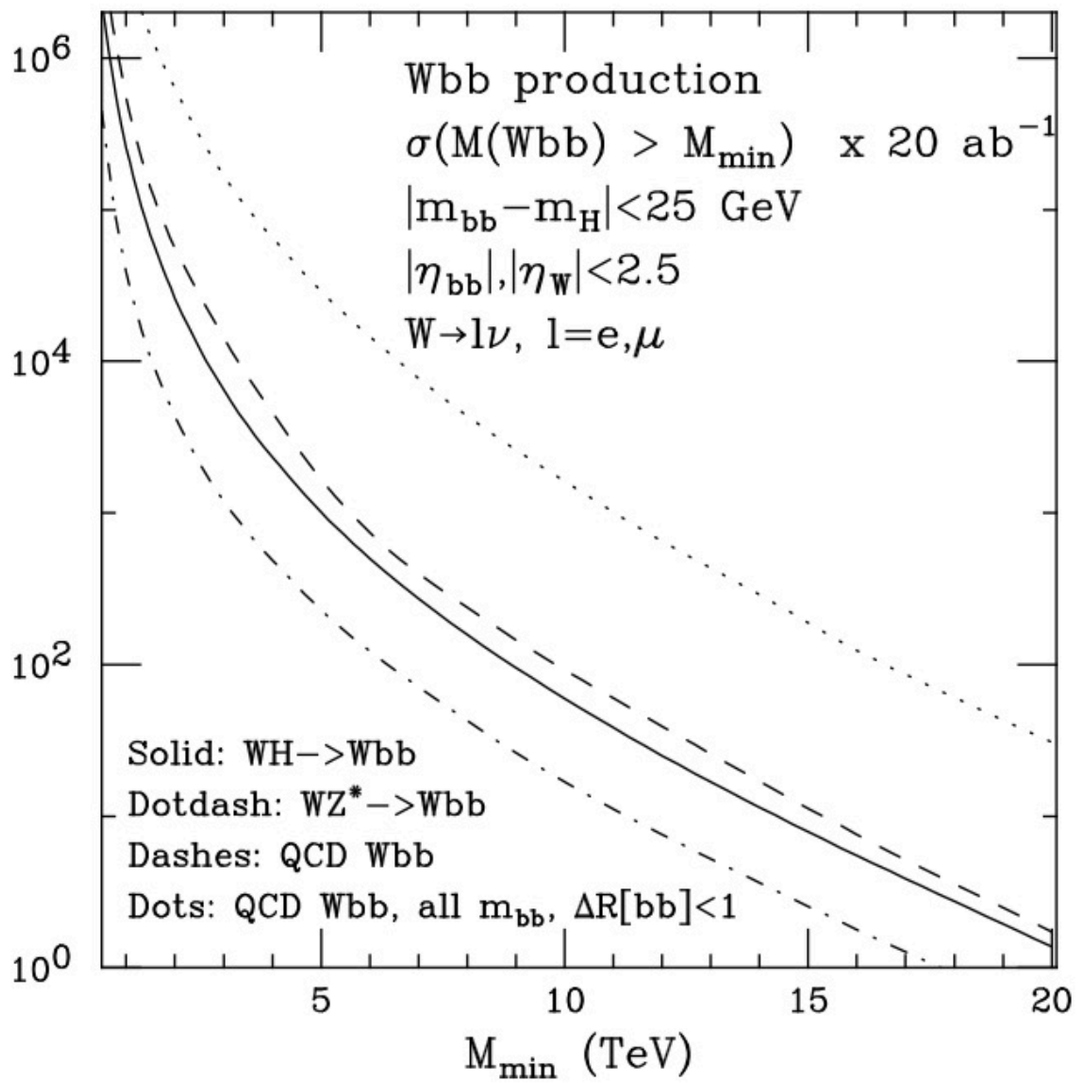


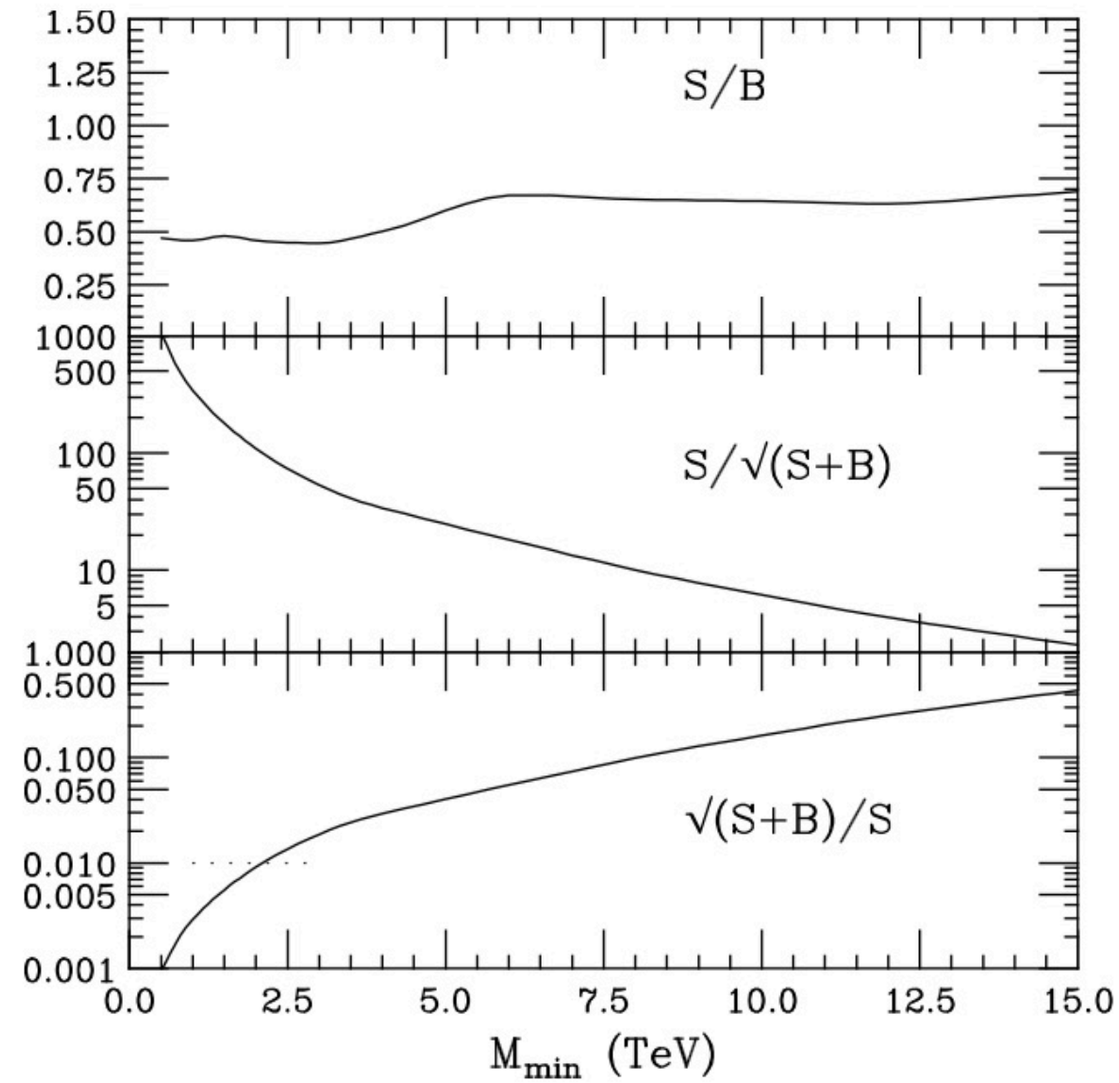


- Bg level greatly sensitive to bb mass resolution. Can be improved using jet substructure studies? => more work required

WH→Wbb at large M_{WH}







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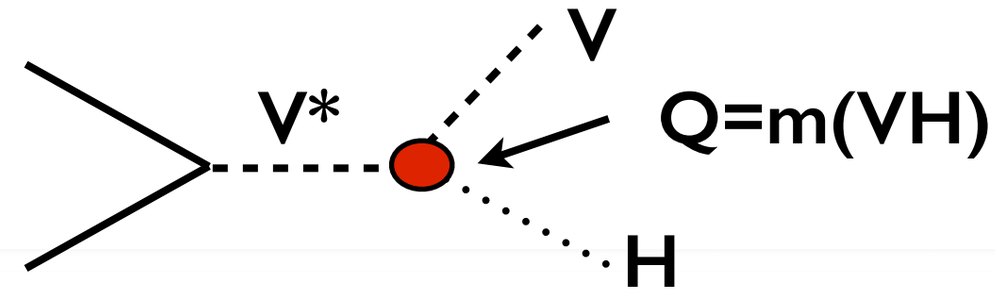
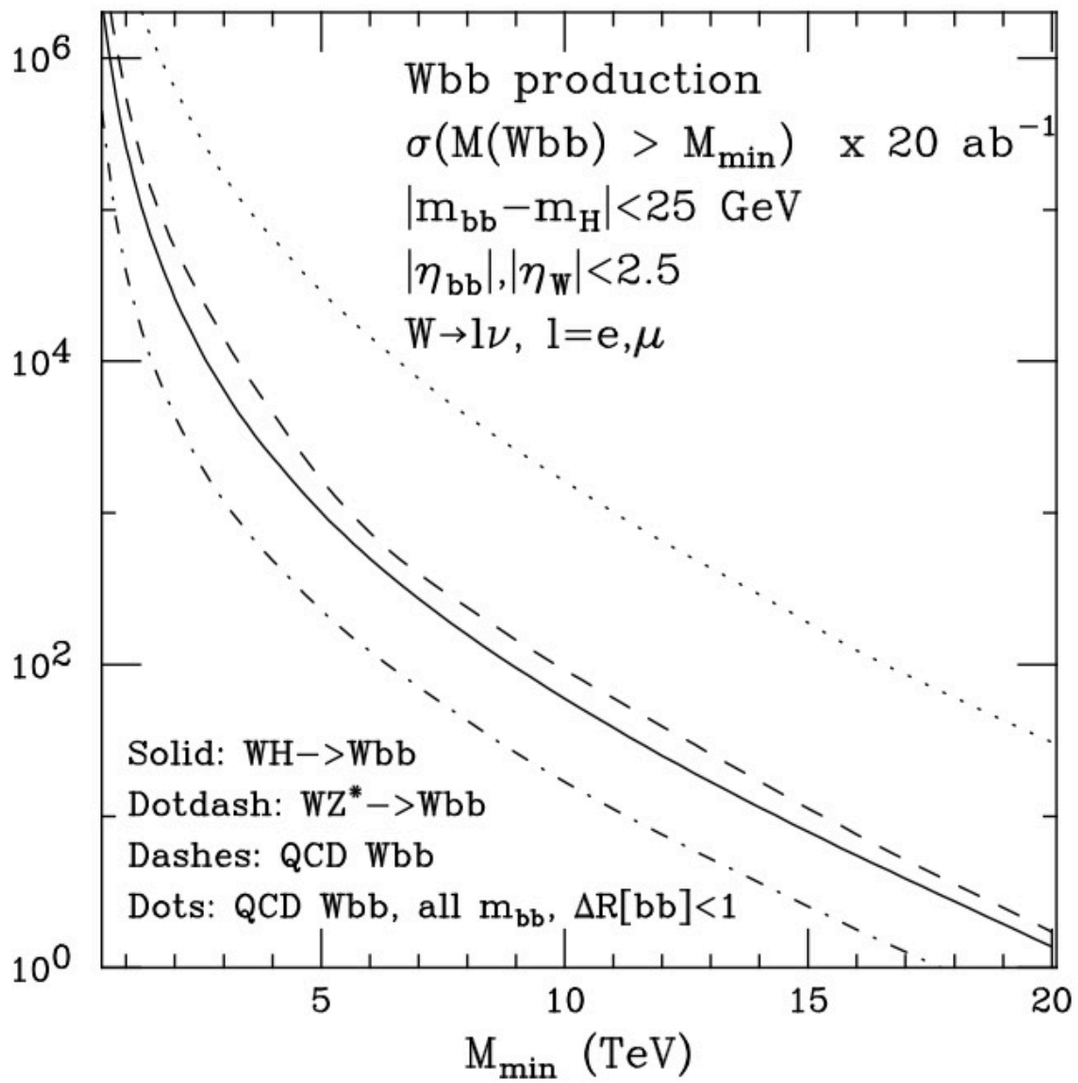
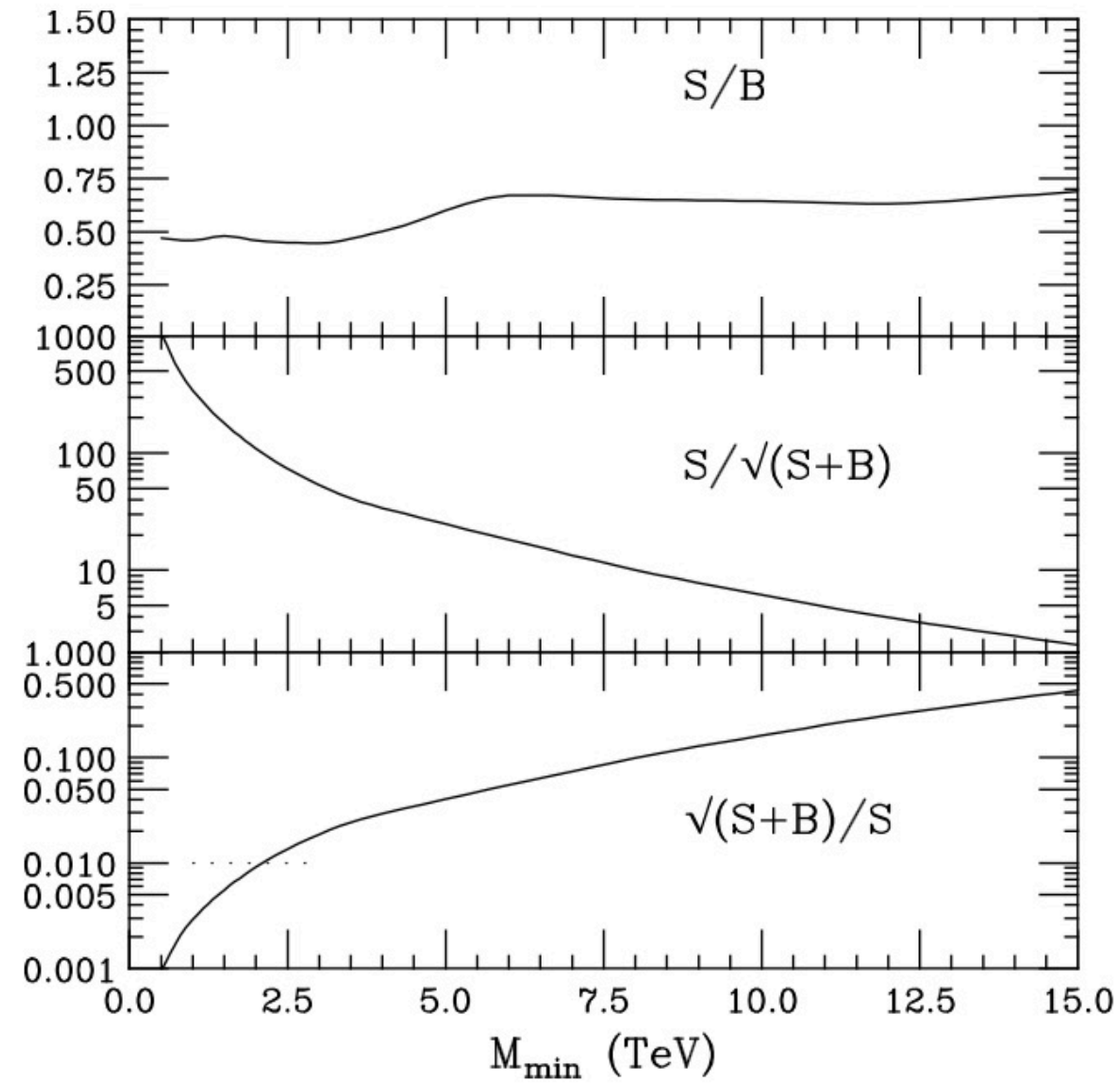


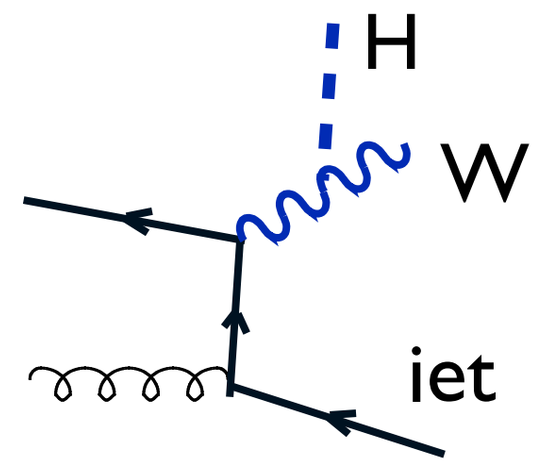




- Bg level greatly sensitive to bb mass resolution. Can be improved using jet substructure studies? => more work required
- Sensitivity to higher-dim ops in the VVH coupling ⇔ B(H→VV*)?
- Systematics on slope of M_{HV} ? (For EFT constraints don't need absolute rate)

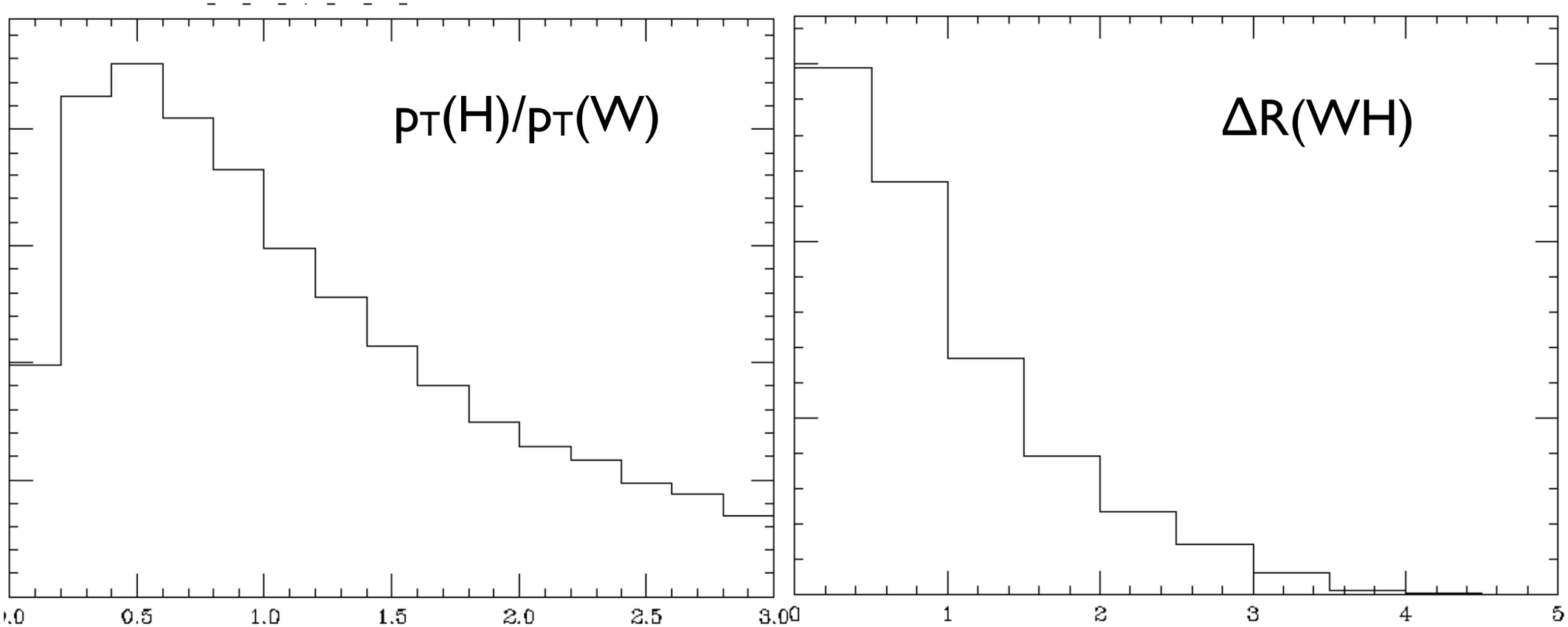
WH→Wbb at large $p_{T,WH}$

- At large p_T, important contribution from the following diagram:



- Production in this kinematics tends to have small m(HW), and the WH system recoiling against the jet

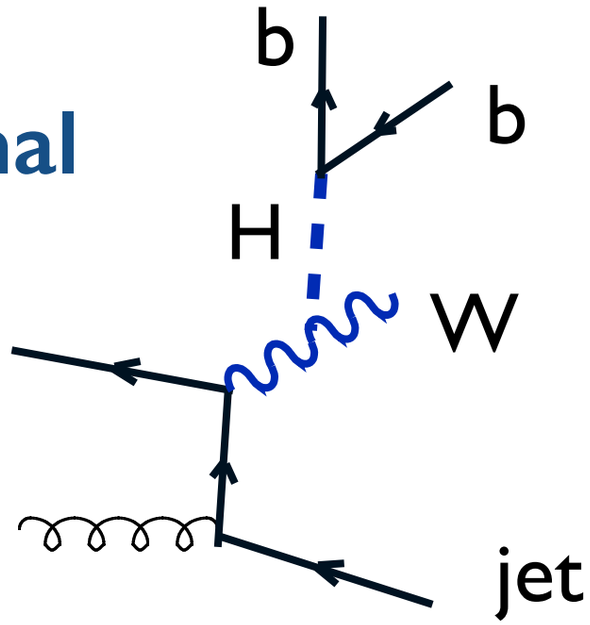
E.g for events with p_T(jet) > 1 TeV



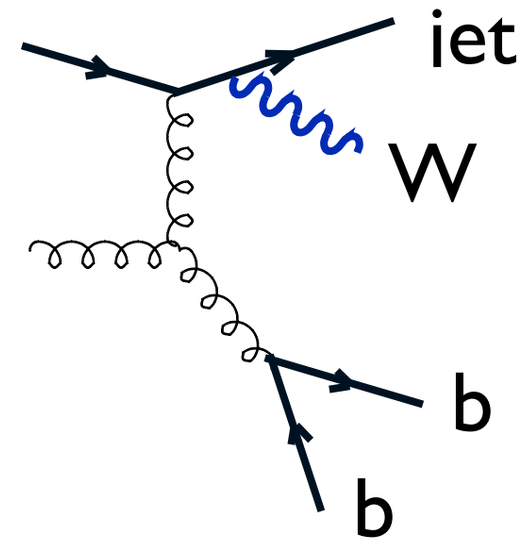
WH→e ν bb at large p_T(WH), S vs B

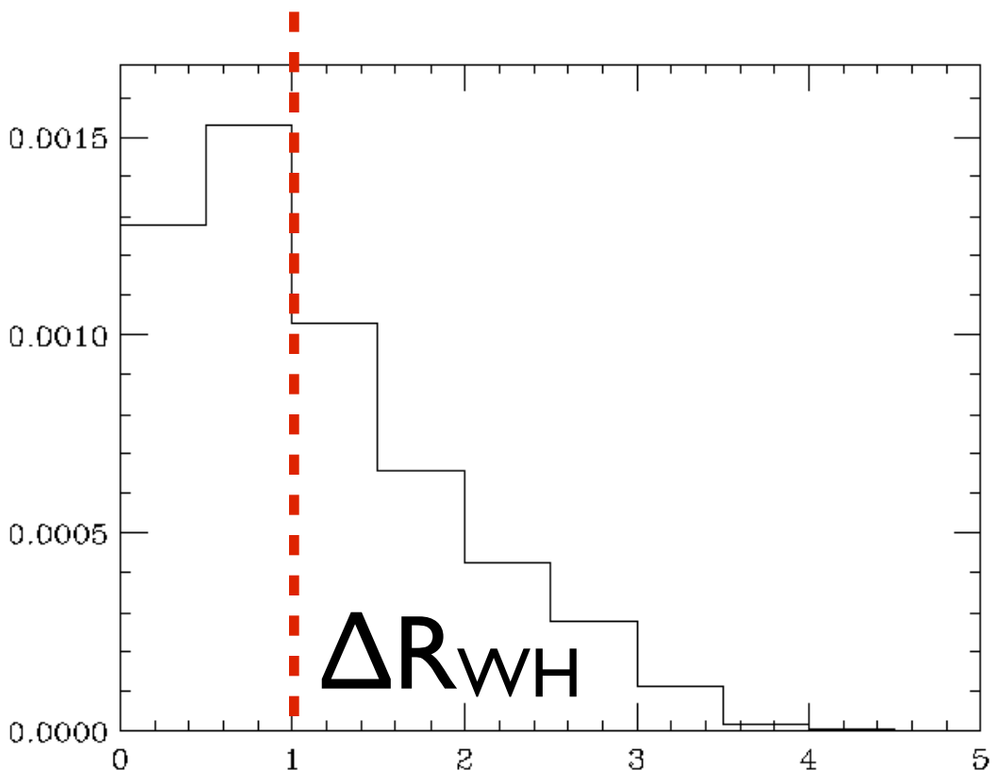
(p_T(jet) > 500 GeV here)

Signal

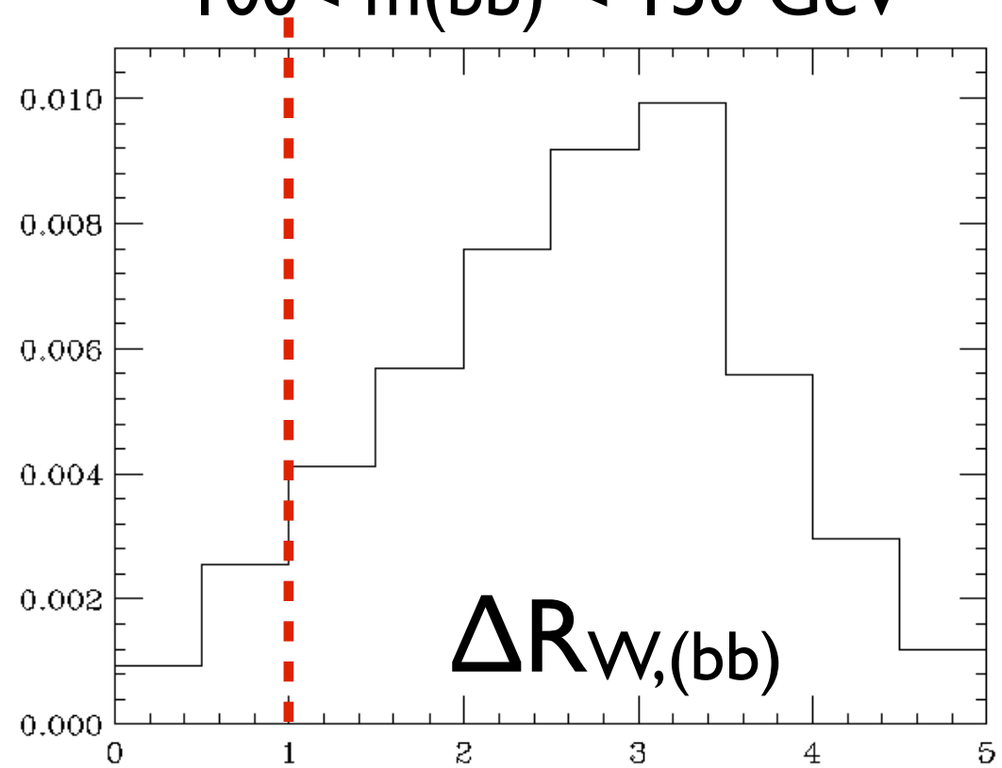


Bg





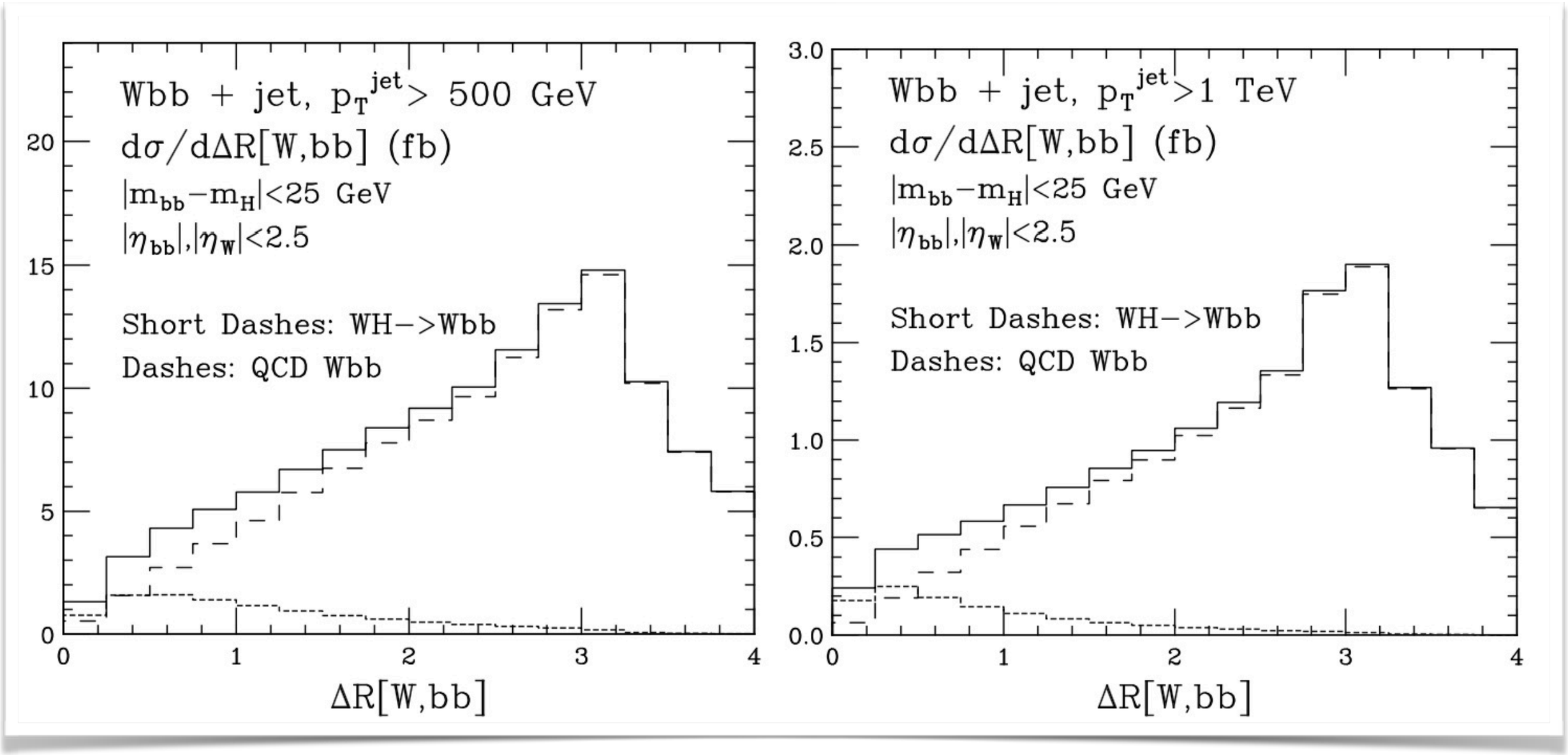
100< m(bb) < 150 GeV



σ=5fb → σ(ΔR<1)=2.8fb

σ=50fb → σ(ΔR<1)=3.5fb

S/B: 1/10 → ~1/1 with 60% efficiency !



issue: Gionata and Francesco tried to do this at NLO for the Report, finding huge K factors for the bg. I've never been convinced this was correct, so the thing is still pending.

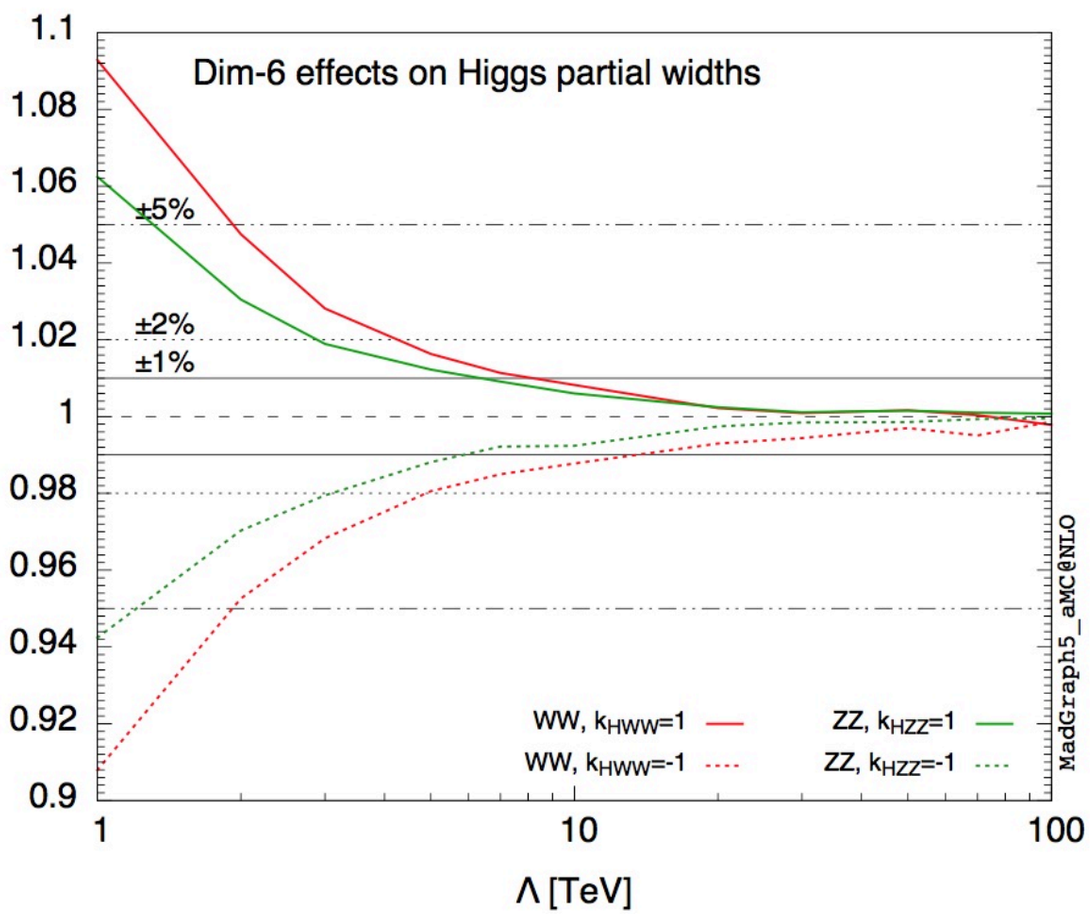
High-p_T Higgs in VBF

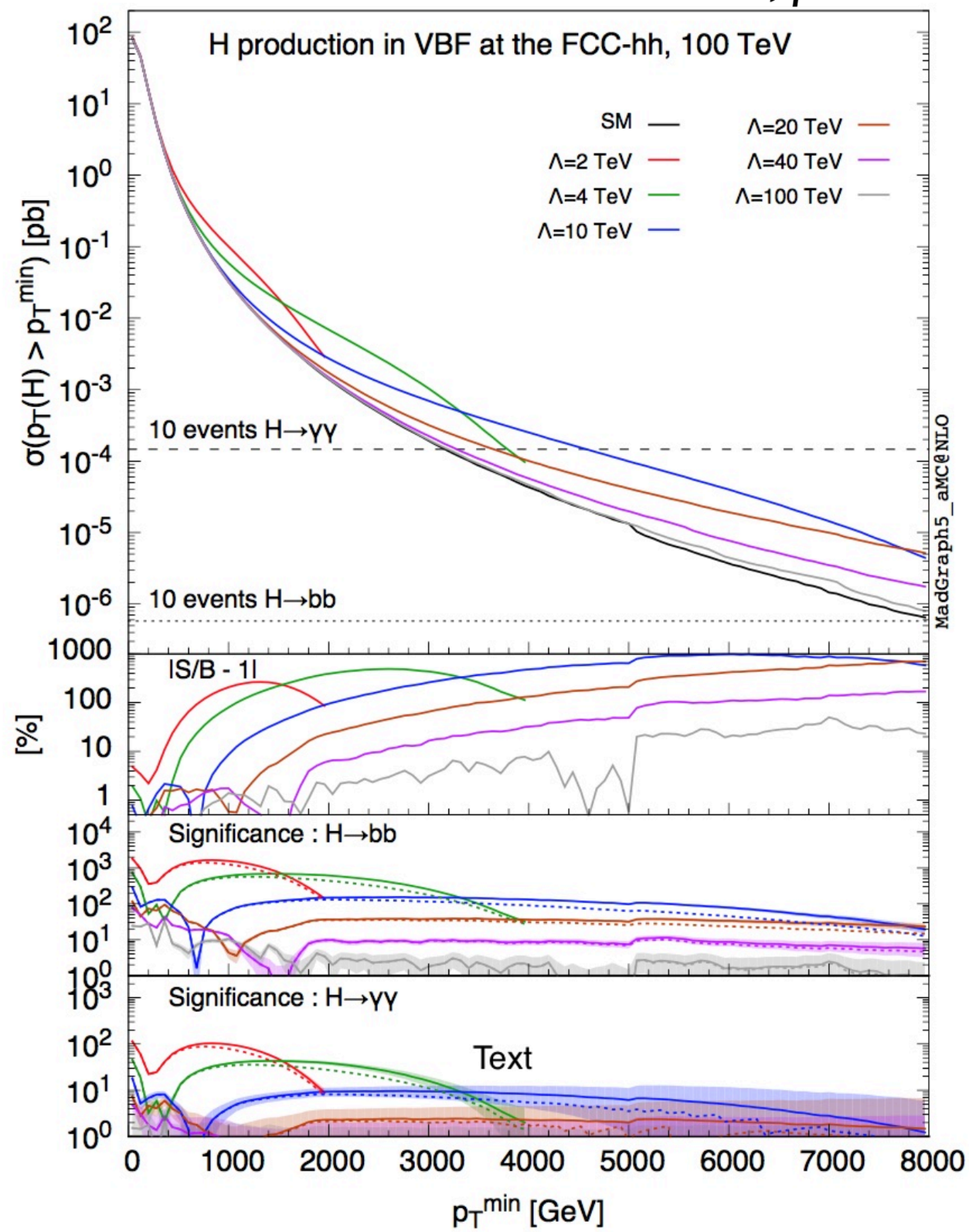
sensitivity to higher-dim ops, w.r.t. BR(H→VV)*

with M.Zaro, prelim

$$O_V^1 = a\frac{1}{\Lambda}k_{HVV}V^{\mu\nu}V_{\mu\nu}H$$

a=1/2 (1/4) for W (Z)





$\delta_{BR} < 1\% \Rightarrow \Lambda \gtrsim 8\,TeV$