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Higgs physics at 100 TeV

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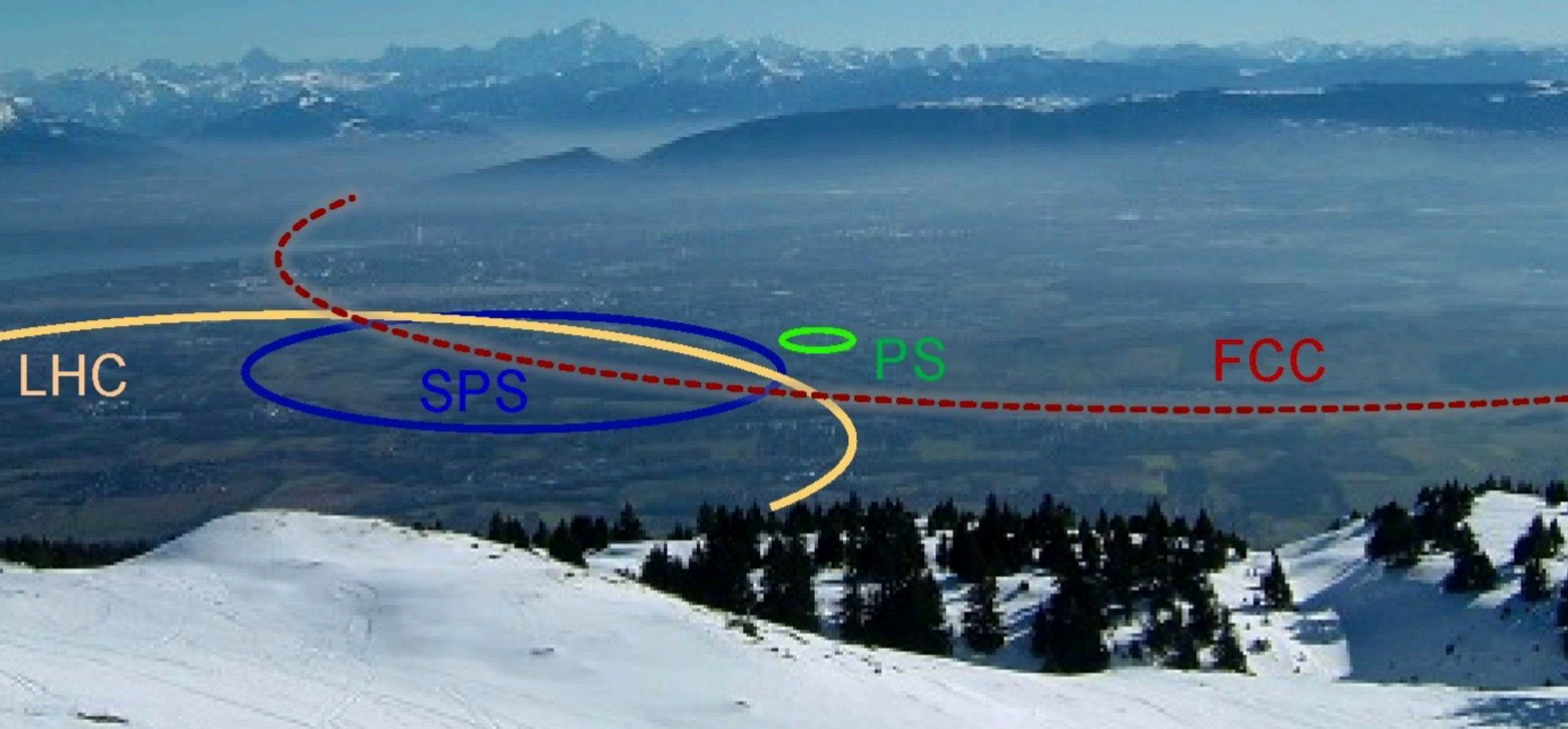
The context

Parameter	FCC-hh	LHC
Energy [TeV]	100 c.m.	14 c.m.
Dipole field [T]	16	8.33
# IP	2 main, +2	4
Luminosity/IP$_{main}$ [cm^{-2}s^{-1}]	5 - 25 x 10^{34}	1 x 10^{34}
Stored energy/beam [GJ]	8.4	0.39
Synchrotron rad. [W/m/aperture]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

- **Phase 1 (baseline): 5 x 10^{34} cm^{-2}s^{-1} (peak),**
  250 fb^{-1}/year (averaged)
  2500 fb^{-1} within 10 years (~HL LHC total luminosity)
- **Phase 2 (ultimate): ~2.5 x 10^{35} cm^{-2}s^{-1} (peak),**
  1000 fb^{-1}/year (averaged)
  ➔ 15,000 fb^{-1} within 15 years
- **Yielding total luminosity O(20,000) fb^{-1} over ~25 years of operation**



Report on Physics at a 100 TeV pp Collider

- **Volume 1: SM processes** (238 pages)
  - arXiv:1607.01831
- **Volume 2: Higgs and EW symmetry breaking studies** (175 pages)
  - arXiv:1606.09408
- **Volume 3: beyond the Standard Model phenomena** (189 pages)
  - arXiv:1606.00947
- **Volume 4: physics with heavy ions** (56 pages)
  - arXiv:1605.01389
- **Volume 5: physics opportunities with the FCC-hh injectors** (14 pages)

total ~700 pages

Higgs chapter of FCC physics report

CERN-TH-2016-113

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

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Contents

Why Higgs at 100 TeV?

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- At the LHC, the Higgs is already an analysis tool, if not a background, in searches of new particles (like W/Z and like the top quark). This will be even more true at 100 TeV!!

Higgs and BSM

Search for Extended Higgs sectors

Extended Higgs sectors are a prediction of many BSM scenarios.
They may play a role in the following open questions:

- (EW) Baryogenesis → Modified scalar potential can lead to a 1st order EW phase transition
- Identity of Dark Matter → Scalar DM with TeV mass; Scalar mediators in hidden-sector DM coupled to Higgs portal
- Smallness of the neutrino masses → Type-II see-saw through extra scalars
- Naturalness of the EW scale → Extended scalar sectors follows in natural theories:
  i) SUSY
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Unless otherwise stated, plots in the following are from the Report, where more details and ref's can be found

Higgs as a BSM probe: precision vs dynamic reach

$$L = L_{SM} + \frac{1}{\Lambda^2} \sum_k \mathcal{O}_k + \cdots$$

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For H decays, or inclusive production, $\mu \sim O(v, m_H)$

$$\delta O \sim \left(\frac{v}{\Lambda}\right)^2 \sim 6\% \left(\frac{\text{TeV}}{\Lambda}\right)^2$$

$\Rightarrow$ **precision** probes large Λ

e.g. $\delta O = 1\% \Rightarrow \Lambda \sim 2.5$ TeV

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For H production off-shell or with large momentum transfer Q, $\mu \sim O(Q)$

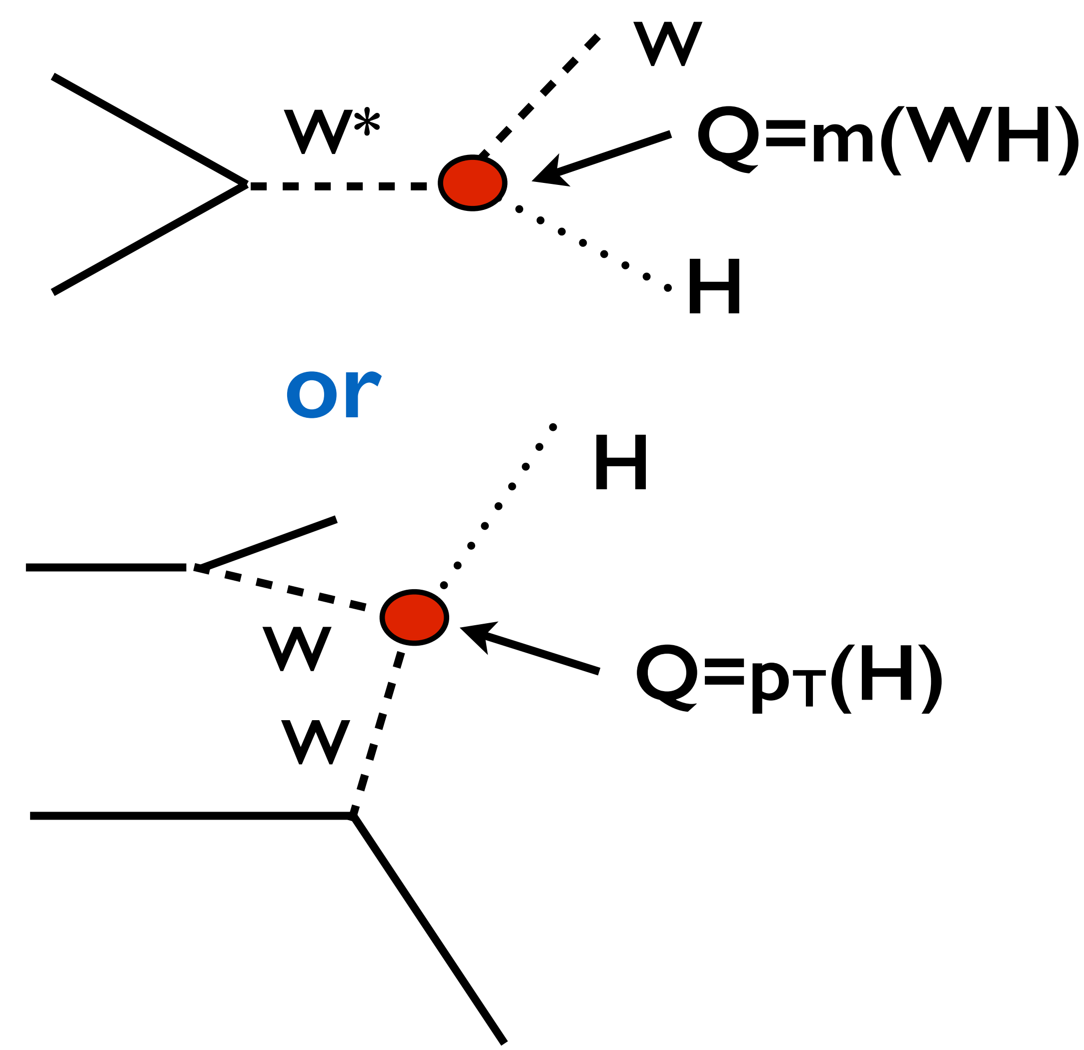
$$\delta O \sim \left(\frac{Q}{\Lambda}\right)^2$$

$\Rightarrow$ **kinematic reach** probes large Λ even if precision is low

e.g. $\delta O = 15\%$ at Q=1 TeV $\Rightarrow \Lambda \sim 2.5$ TeV

Examples

$\delta BR(H \to WW^*)$



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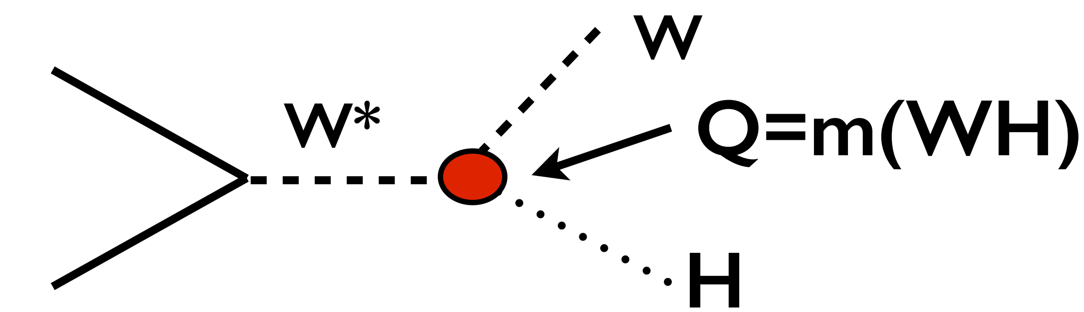
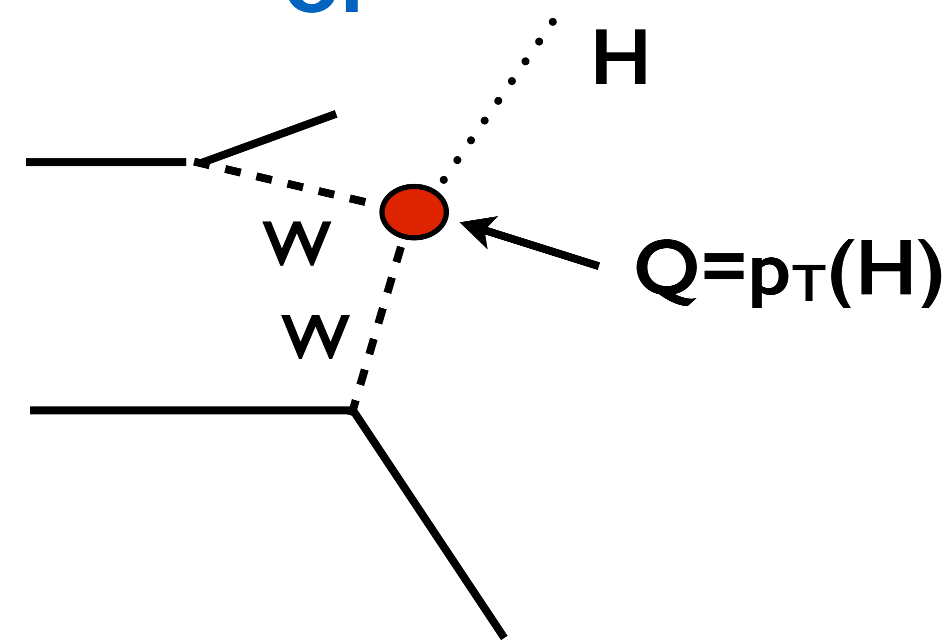
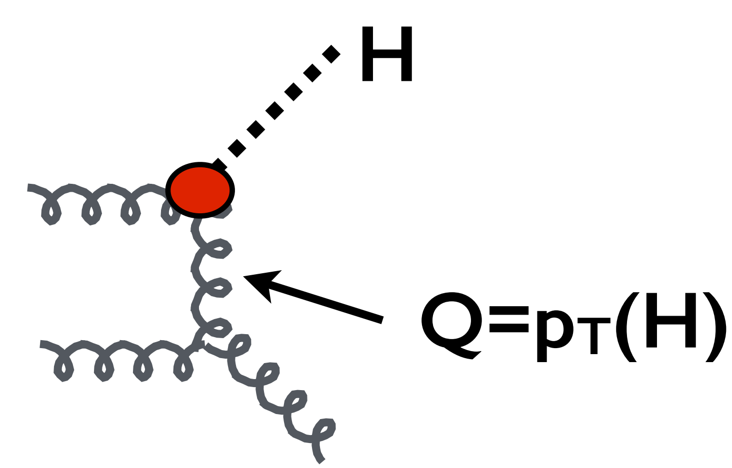


or



$\delta BR(H \to gg)$



$$\delta O_Q \sim \left(\frac{Q}{\Lambda}\right)^2 \quad \textbf{vs} \quad \delta O \sim \left(\frac{v}{\Lambda}\right)^2$$

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$$Q \sim v \left(\frac{\delta O_Q}{\delta O}\right)^{1/2}$$

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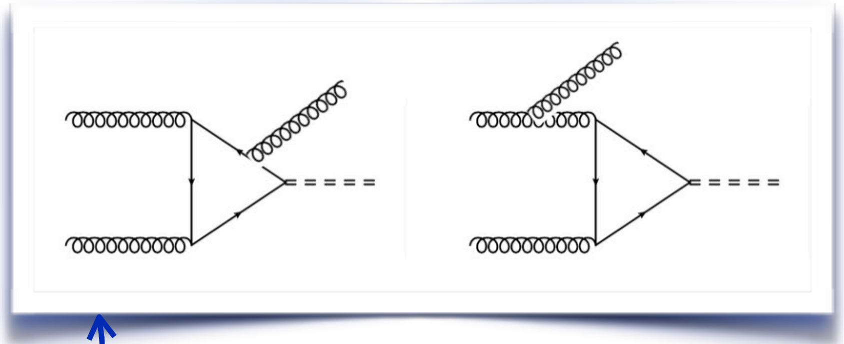
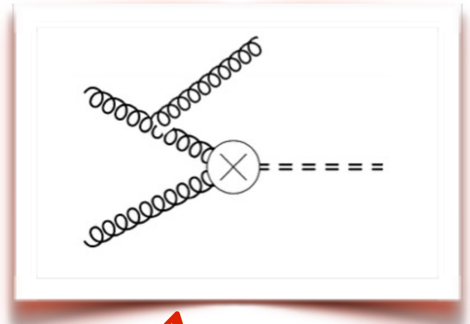
E.g. for $\delta O \sim 10^{-3}$ (goal of precision BR measurements at FCC-ee):

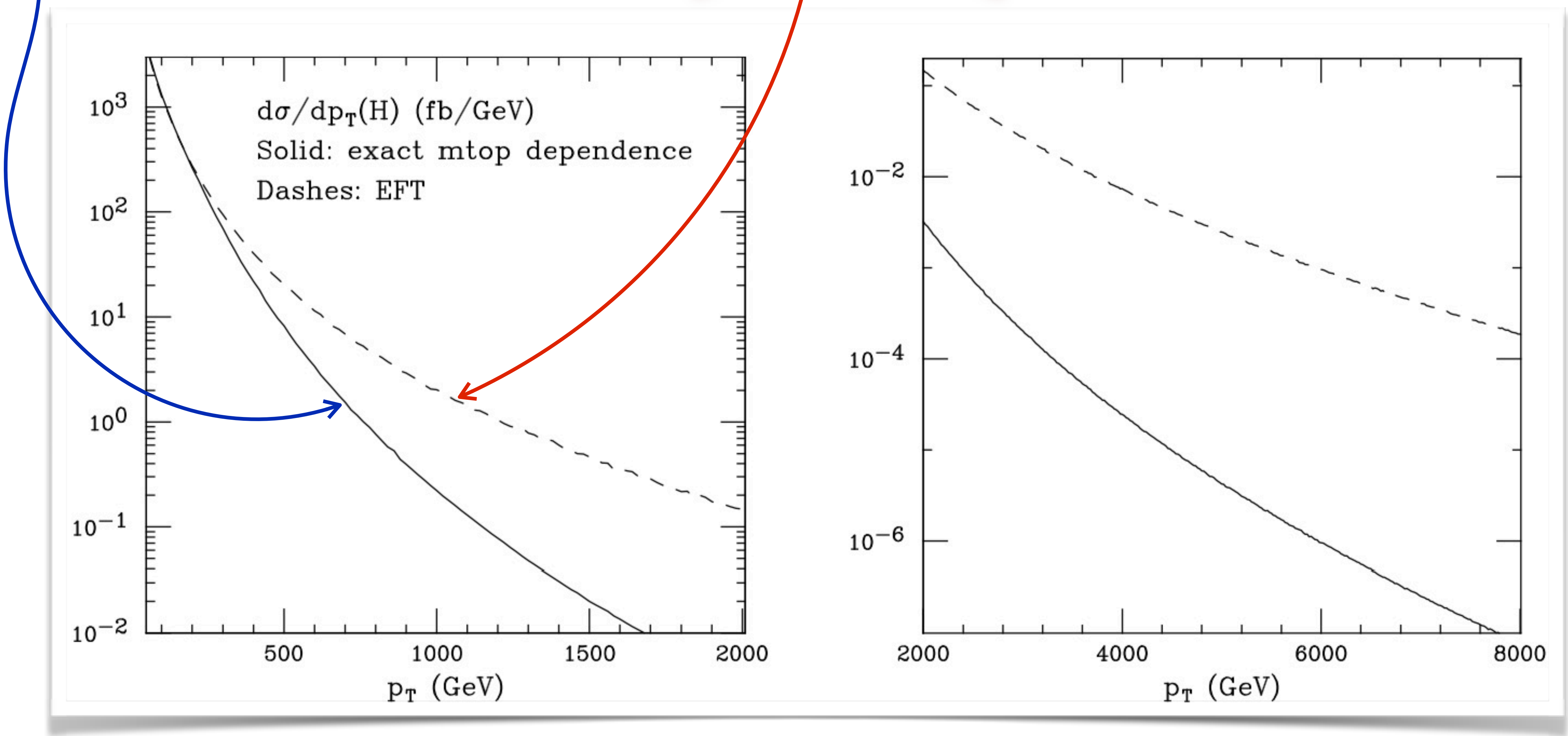
– $\delta O_Q \sim 10^{-1} \Rightarrow Q \sim 10\, v \sim 2.5$ TeV

– $\delta O_Q \sim 10^{-2} \Rightarrow Q \sim 3\, v \sim 750$ GeV

gg→H at large p_T







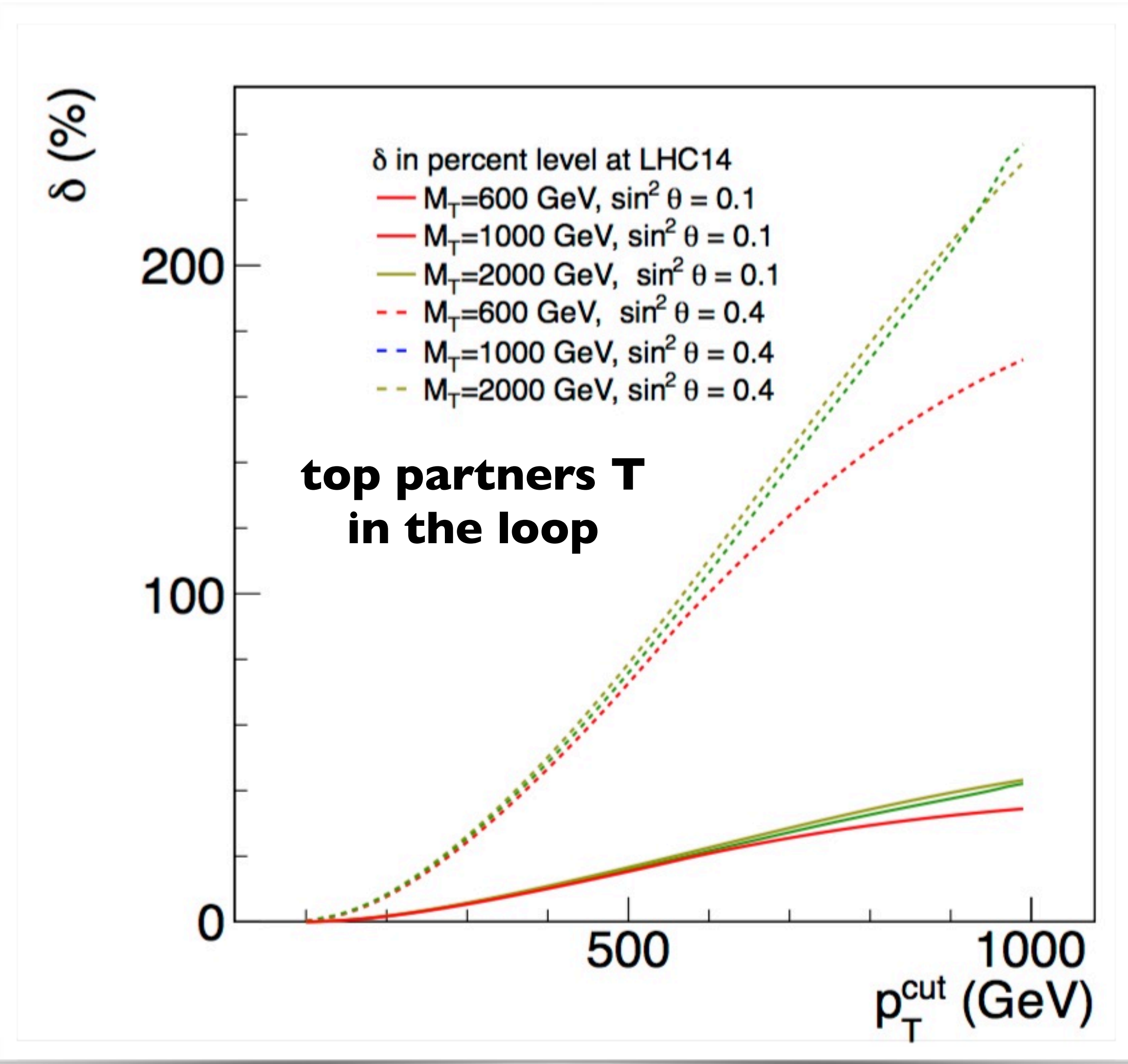
- At LHC, can measure only up to p_T~ few hundred GeV ⇒ reduced sensitivity to the inner guts of the ggH coupling
- At FCC, orders of magnitude difference between EFT and exact m_{top}

Examples

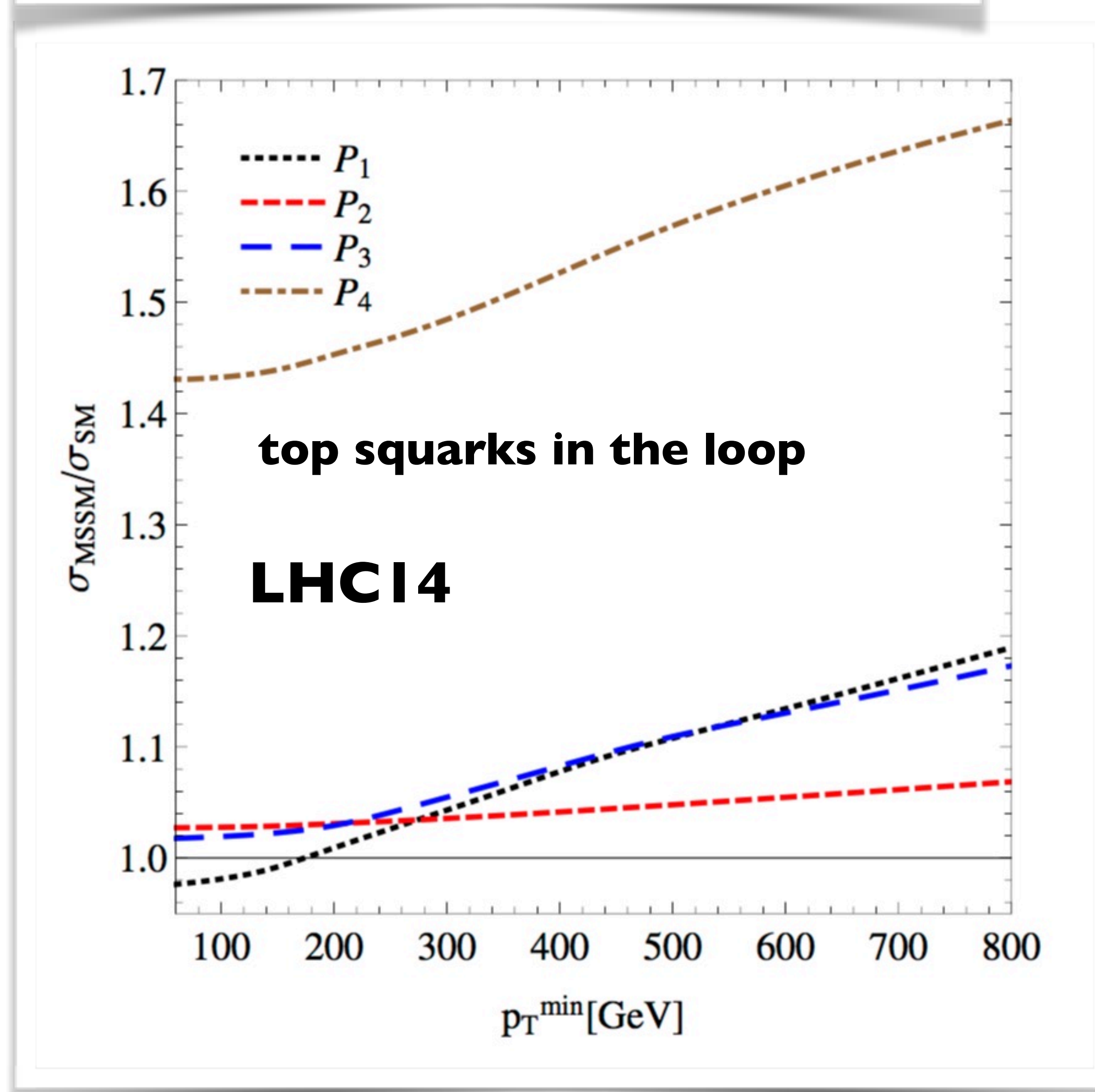
(See also
Azatov and Paul arXiv:1309.5273v3)

Table 3: The benchmark points shown in Fig. 7. We set $\tan\beta = 10$, $M_{A^0} = 500\,\mathrm{GeV}$, $M_2 = 1000\,\mathrm{GeV}$, $\mu = 200\,\mathrm{GeV}$ 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



Banfi Martin Sanz, arXiv:1308.4771



Grojean, Salvioni, Schlaffer, Weiler arXiv:1312.3317

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

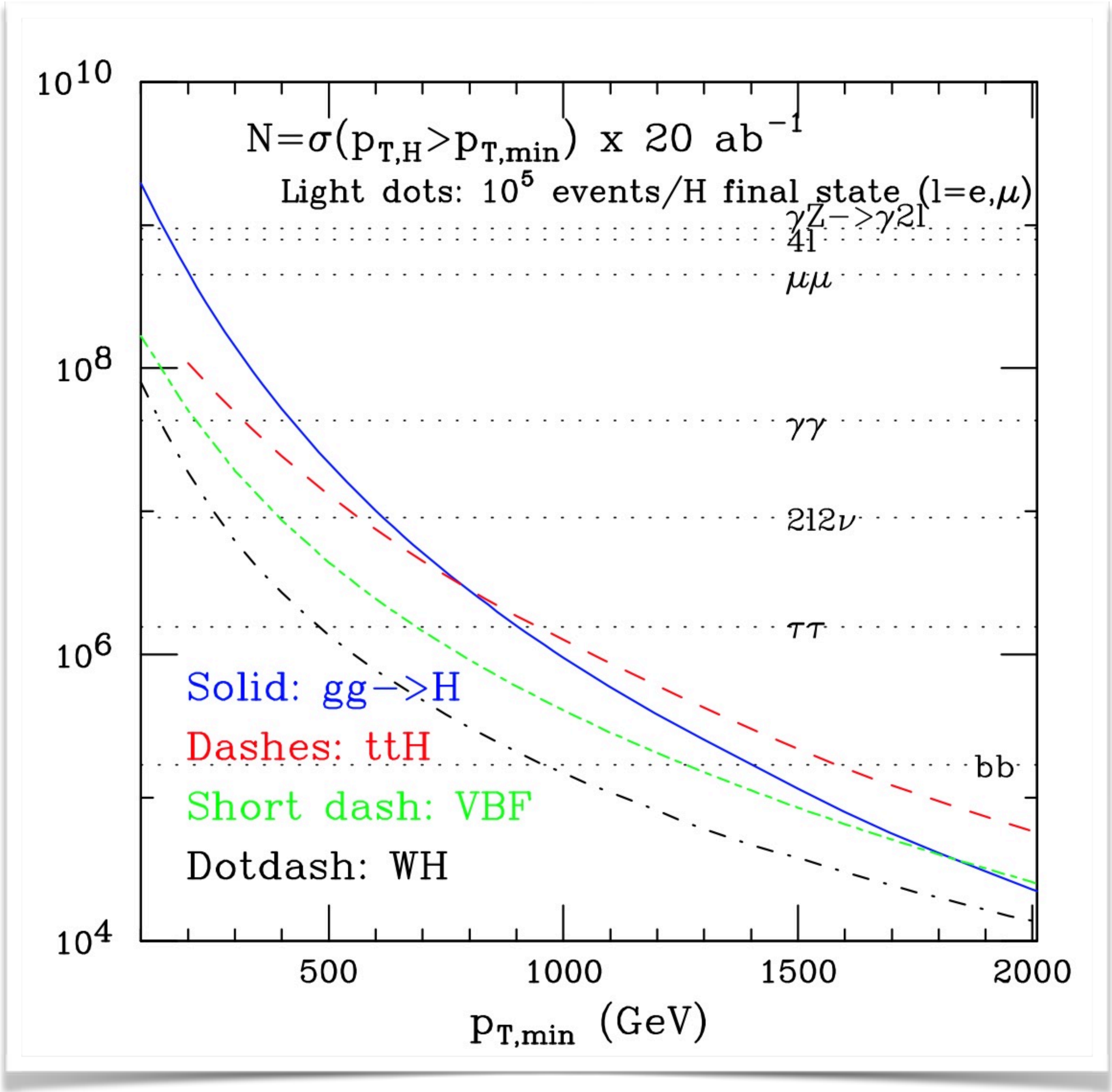
$N_{100} = \sigma_{100\,\mathrm{TeV}} \times 20\ \mathrm{ab}^{-1}$

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

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

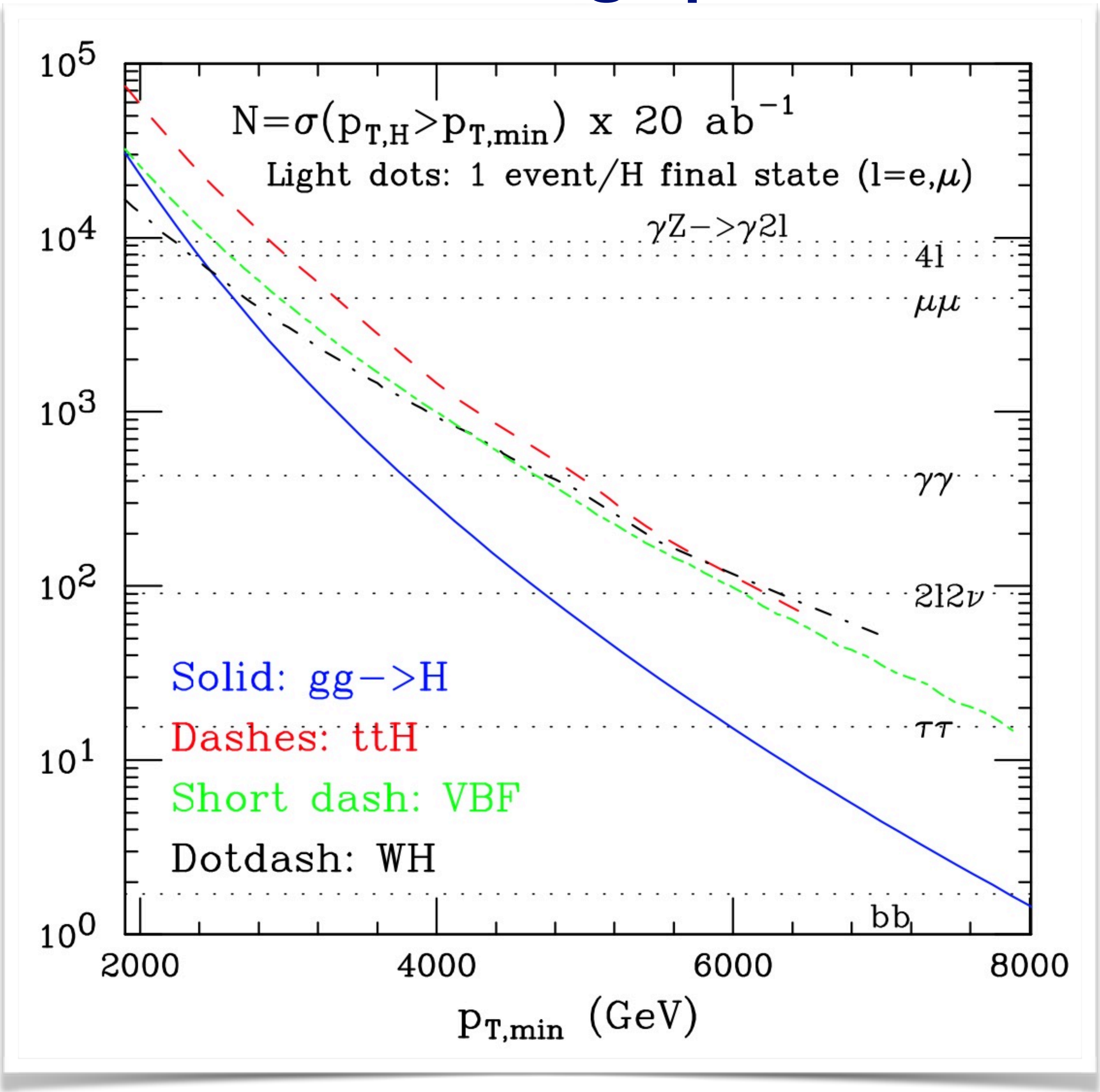
- Huge production rates imply:
  - can afford reducing statistics, with tighter kinematical cuts that reduce backgrounds and systematics
  - can explore new dynamical regimes, where new tests of the SM and EWSB can be done

H at large p_T



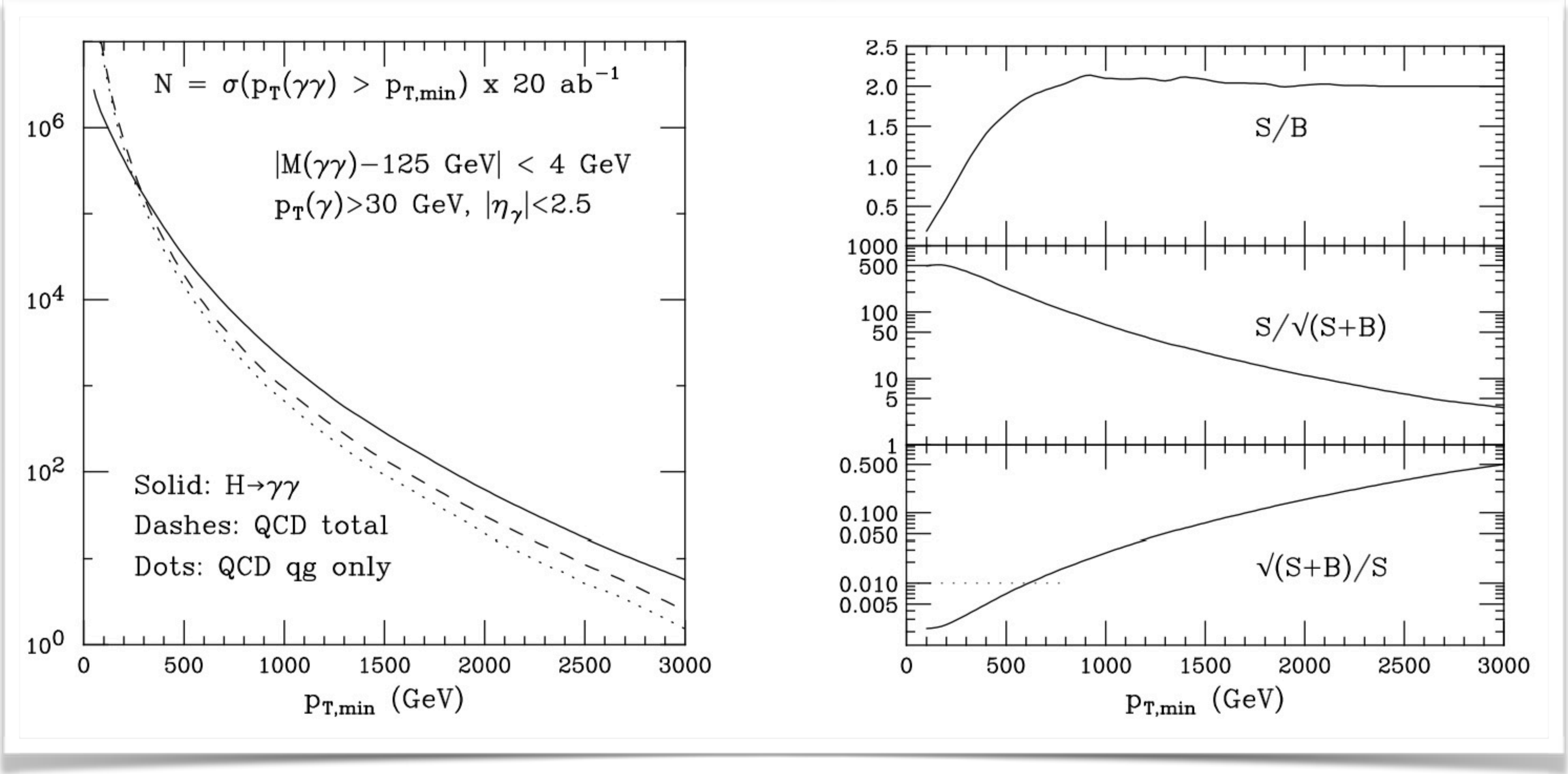
- Hierarchy of production channels changes at large $p_T(H)$:
  - $\sigma(ttH) > \sigma(gg \to H)$ above 800 GeV
  - $\sigma(VBF) > \sigma(gg \to H)$ above 1800 GeV

H at large p_T



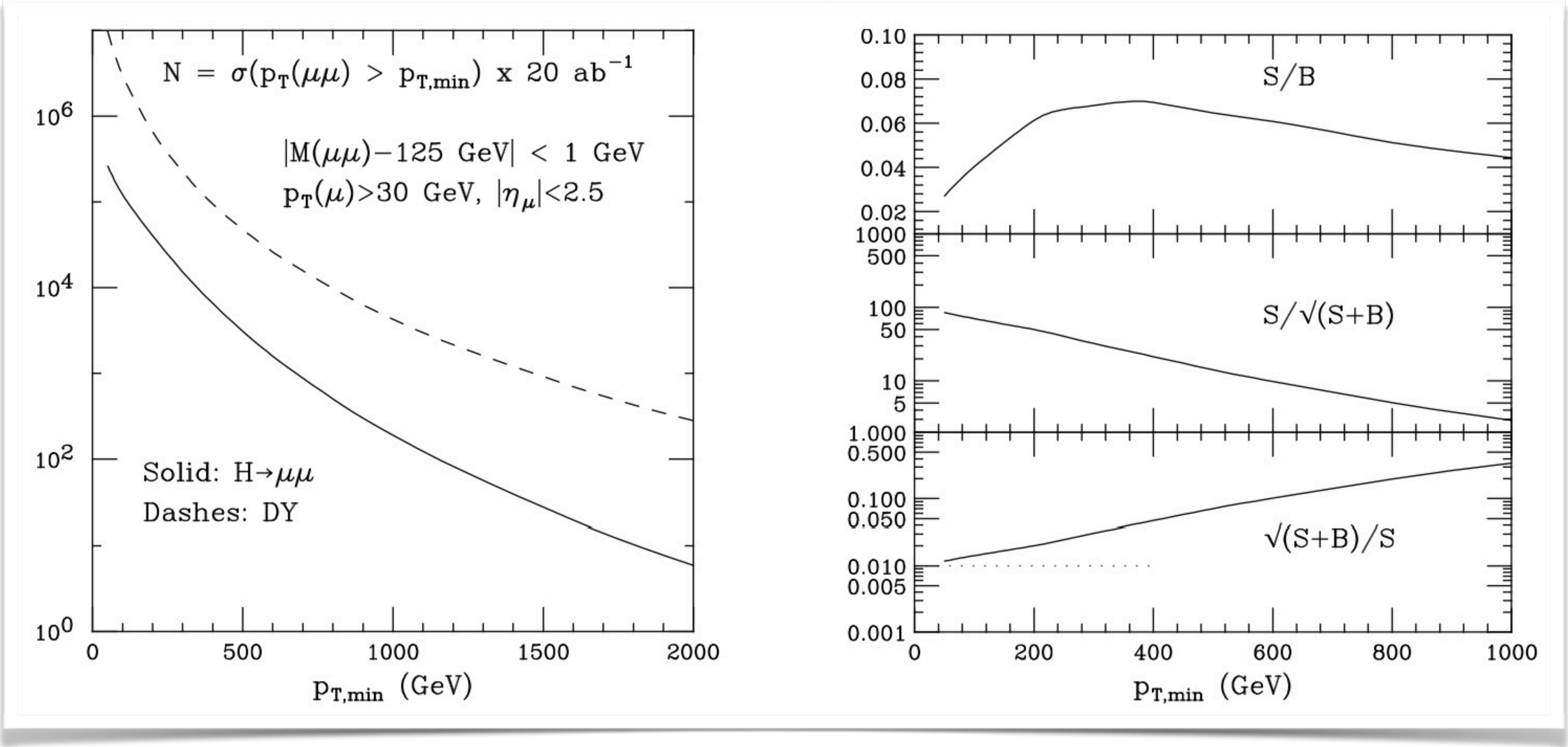
- Statistics in potentially visible final states out to several TeV

$gg \to H \to \gamma\gamma$ at large p_T



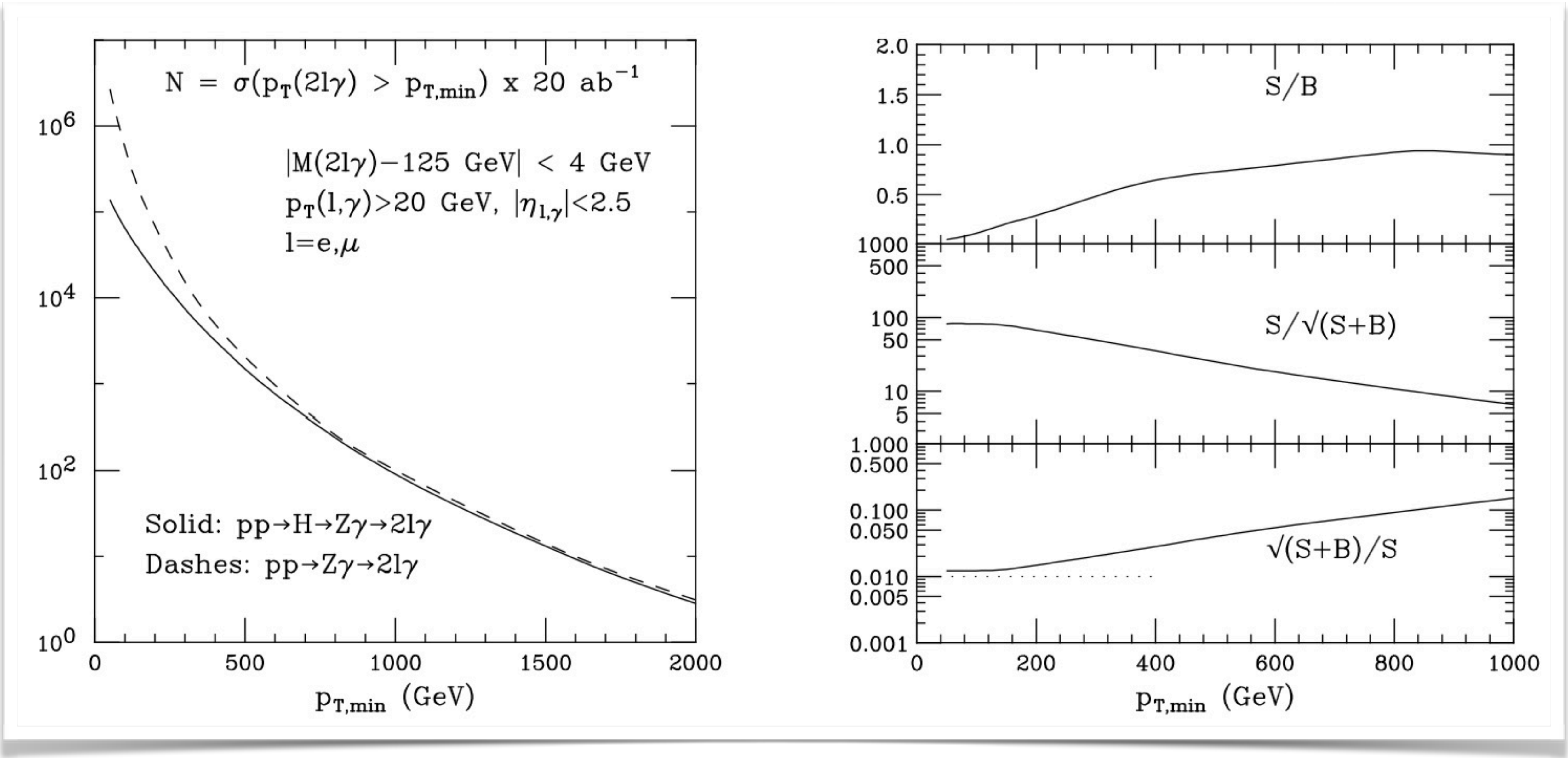
- At LHC, S/B in the $H \to \gamma\gamma$ channel is O(few %)
- At FCC, for $p_T(H)>300$ GeV, S/B~1
- Very clean probe of Higgs production up to large $p_T(H)$. What's the sensitivity required to probe relevant BSM deviations from SM spectrum?
- Exptl mass resolution at large pt(H)?

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→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($\gamma\gamma$) or B(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 ?

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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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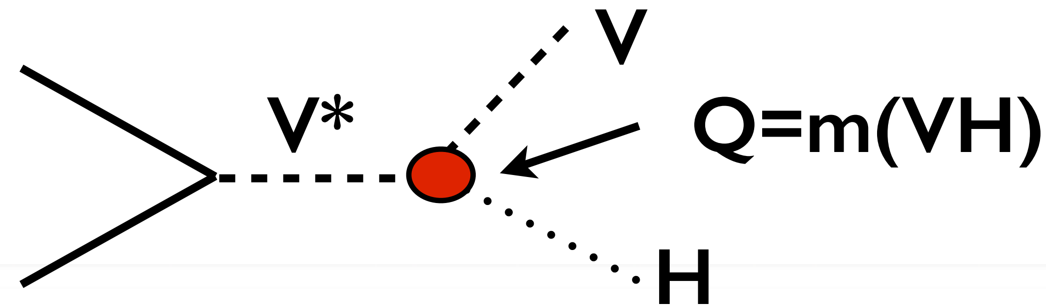
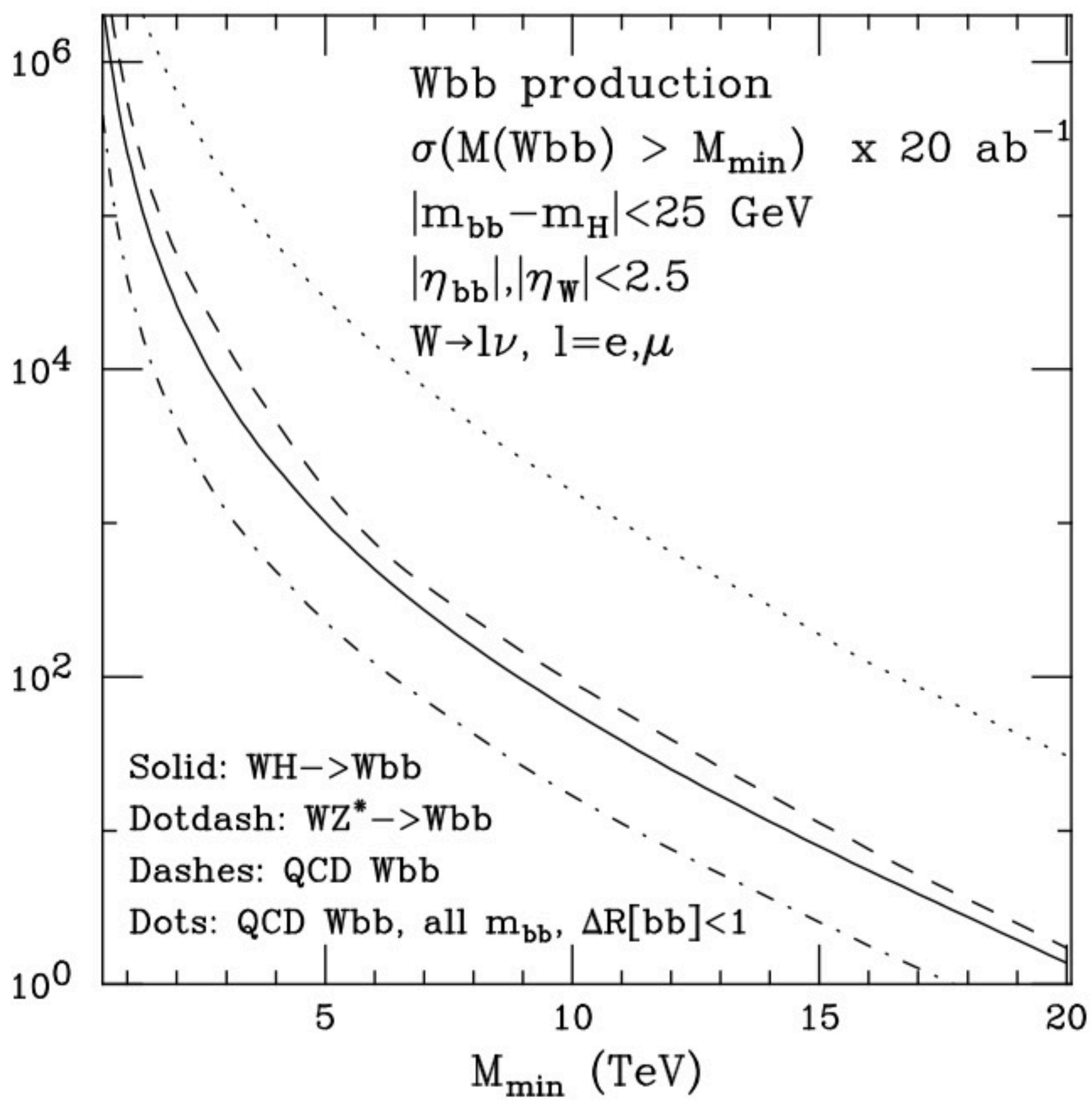
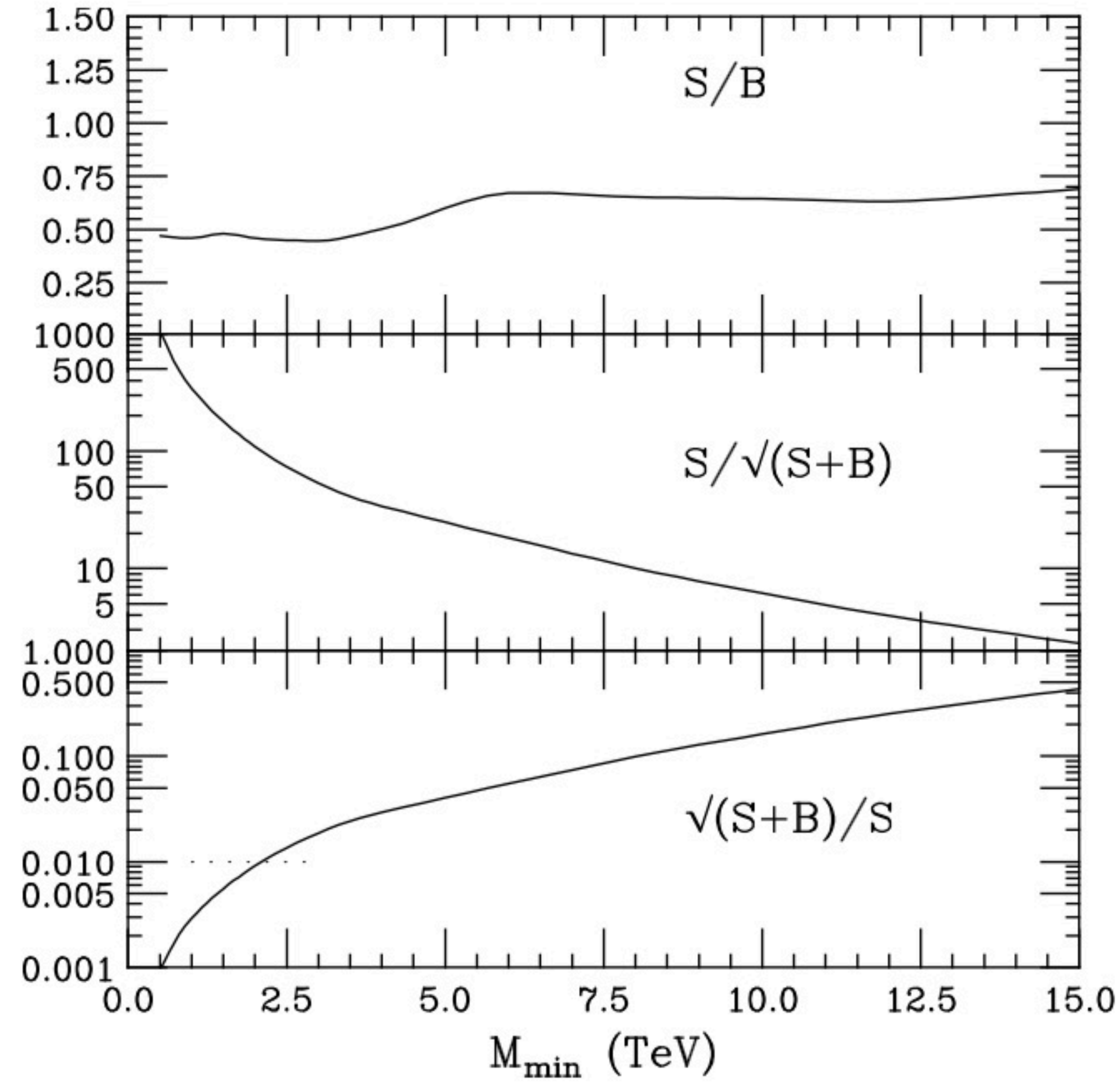
  - ultimate EXP systematics?
  - what are the best decay channels?
- More in general (for all production and decay channels):
  - *Can high-pt measurements compete with precise BR's in probing EFT couplings?*

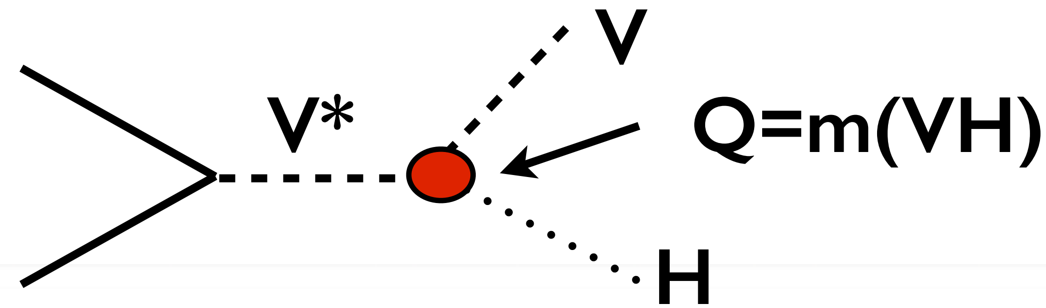
WH→Wbb at large M_{WH}

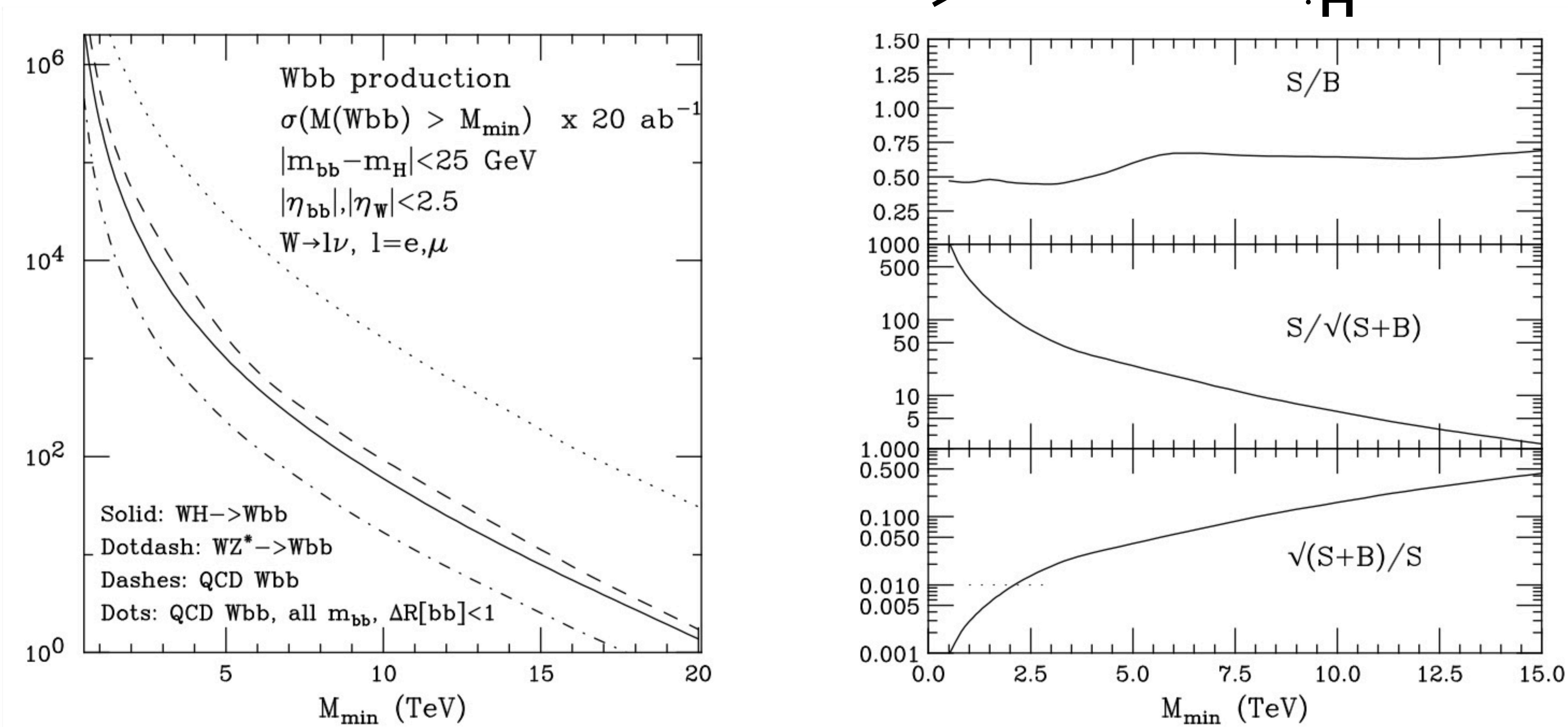






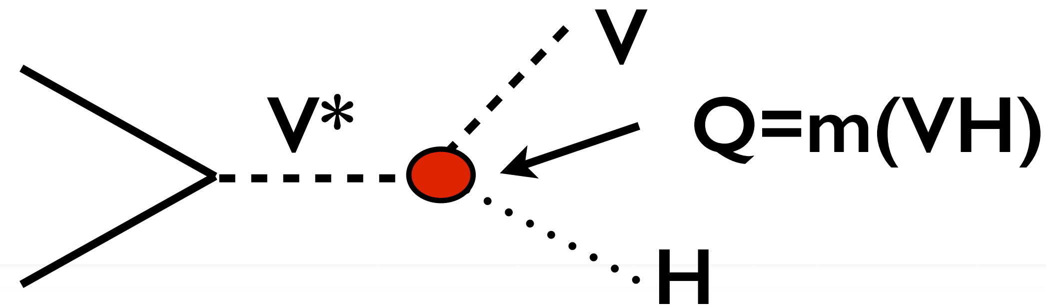
WH→Wbb at large M_{WH}

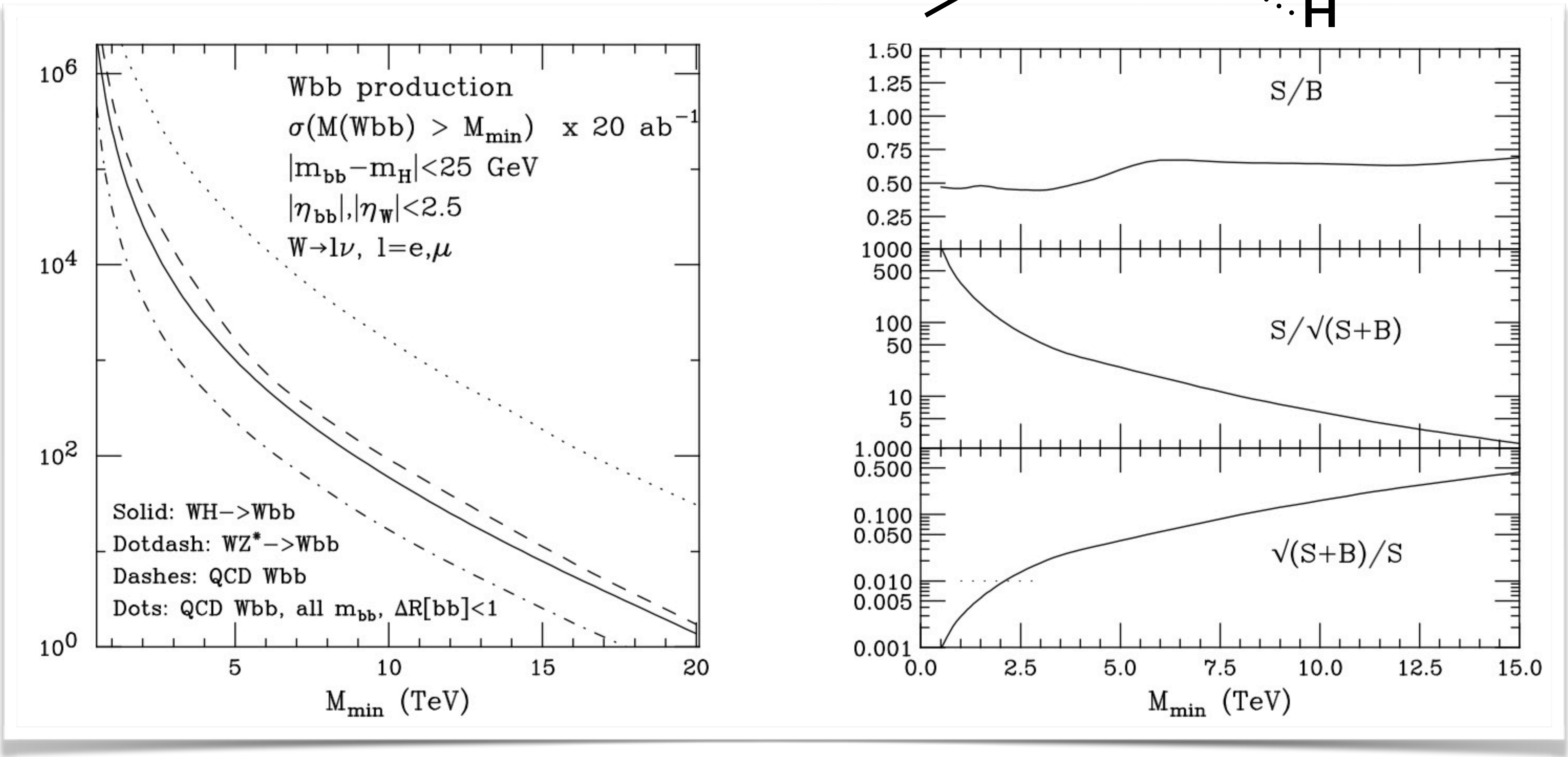




- Bg level greatly sensitive to bb mass resolution. Can be improved using jet substructure studies? => more work required

WH→Wbb at large M_{WH}





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- Sensitivity to higher-dim ops in the VVH coupling ⇔ B(H→VV*)?

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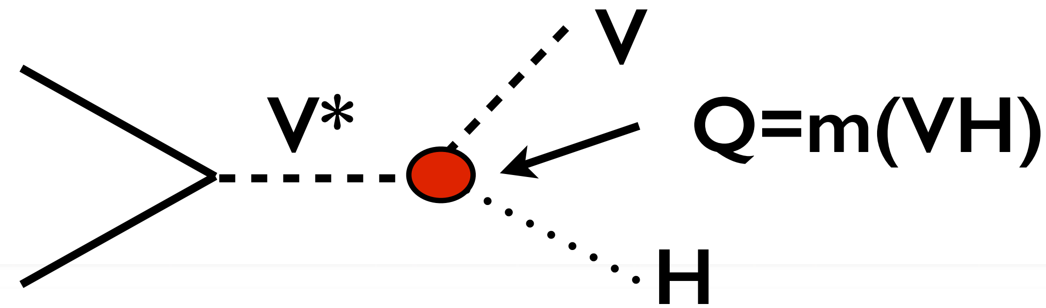
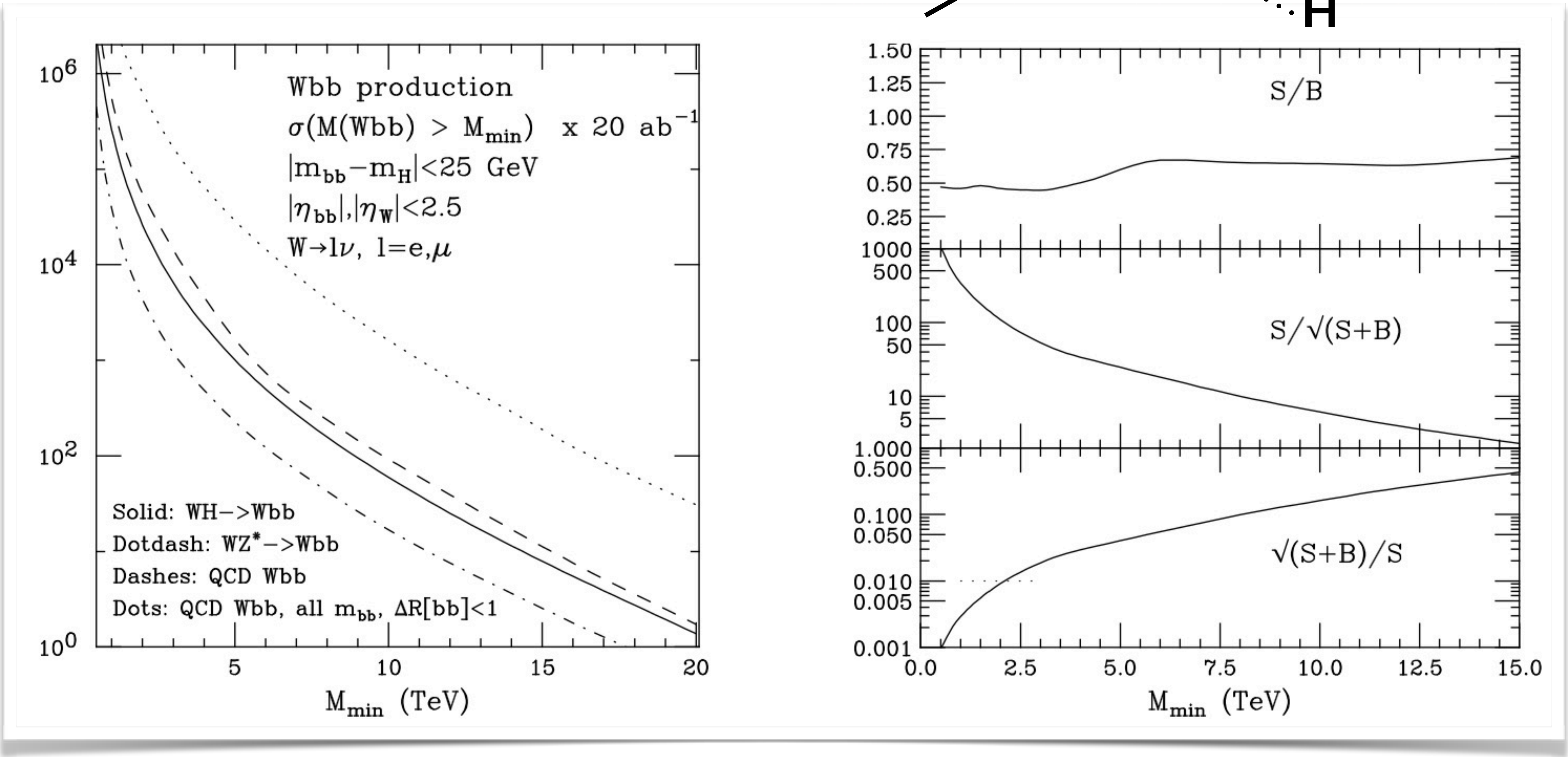
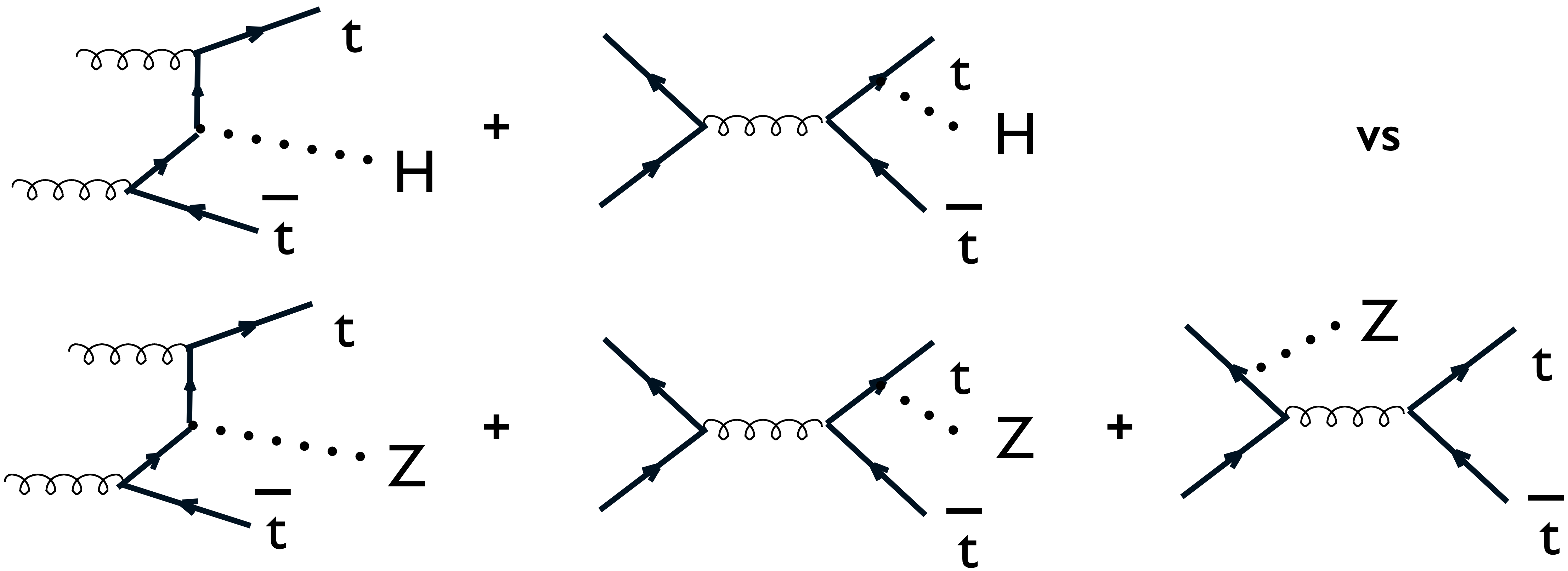




- Bg level greatly sensitive to bb mass resolution. Can be improved using jet substructure studies? => more work required
- Sensitivity to higher-dim ops in the VVH coupling ⇔ B(H→VV*)?
- Systematics on slope of M_{HV} ? (For EFT constraints don't need absolute rate)

Top Yukawa coupling from σ(ttH)/σ(ttZ)

arXiv:1507.08169



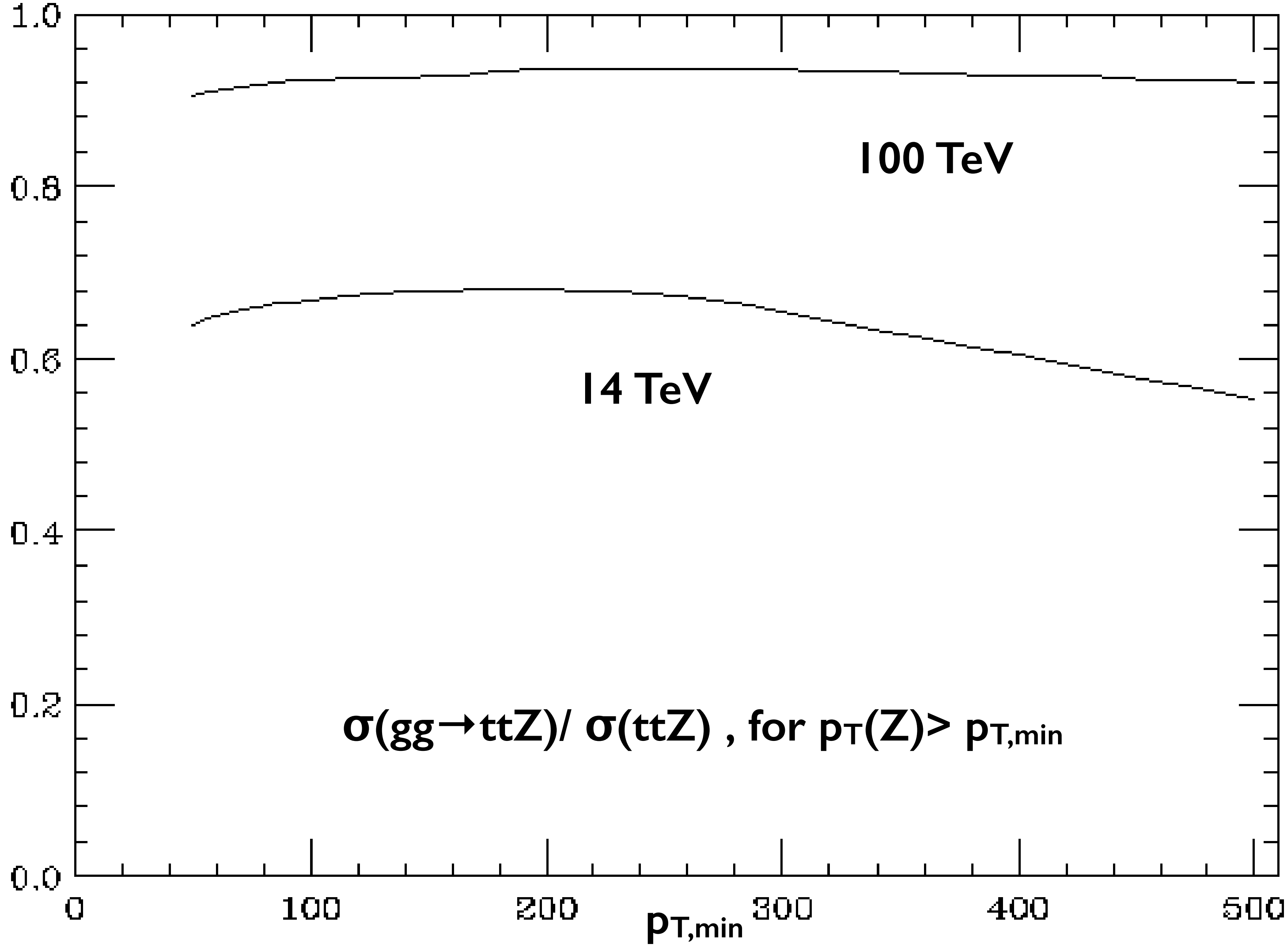
To the extent that the qqbar → tt Z/H contributions are subdominant:

- **Identical production dynamics:**
  - o correlated QCD corrections, correlated scale dependence
  - o correlated α_S systematics

- **$m_Z \sim m_H \Rightarrow$ almost identical kinematic boundaries:**
  - o correlated PDF systematics
  - o correlated m_{top} systematics

For a given y_{top}, we expect σ(ttH)/σ(ttZ) to be predicted with great precision

At 100 TeV, gg→tt X is indeed dominant ....



NB: At lower p_T values, gg fraction is slightly larger for ttZ than for ttH, since $m_Z < m_H$

Cross section ratio stability

	$\sigma(t\bar{t}H)$[pb]	$\sigma(t\bar{t}Z)$[pb]	$\frac{\sigma(t\bar{t}H)}{\sigma(t\bar{t}Z)}$
13 TeV	$0.475^{+5.79\%+3.33\%}_{-9.04\%-3.08\%}$	$0.785^{+9.81\%+3.27\%}_{-11.2\%-3.12\%}$	$0.606^{+2.45\%+0.525\%}_{-3.66\%-0.319\%}$
100 TeV	$33.9^{+7.06\%+2.17\%}_{-8.29\%-2.18\%}$	$57.9^{+8.93\%+2.24\%}_{-9.46\%-2.43\%}$	$0.585^{+1.29\%+0.314\%}_{-2.02\%-0.147\%}$

scale PDF

Cross section ratio stability

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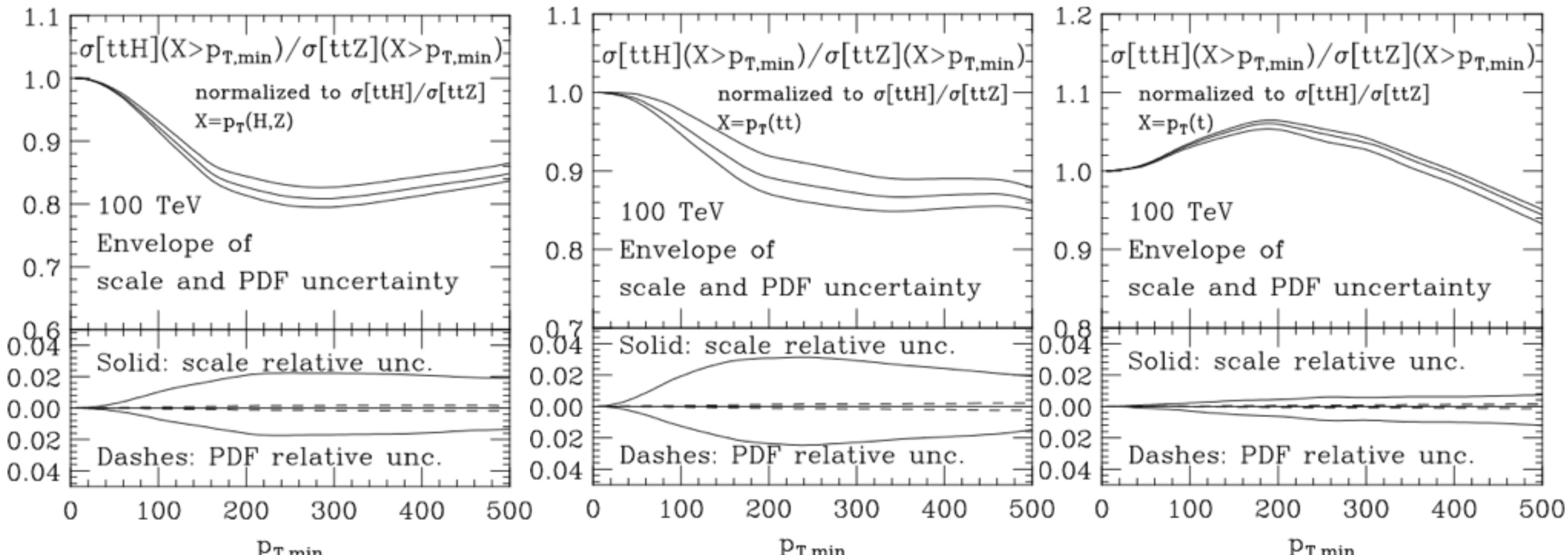
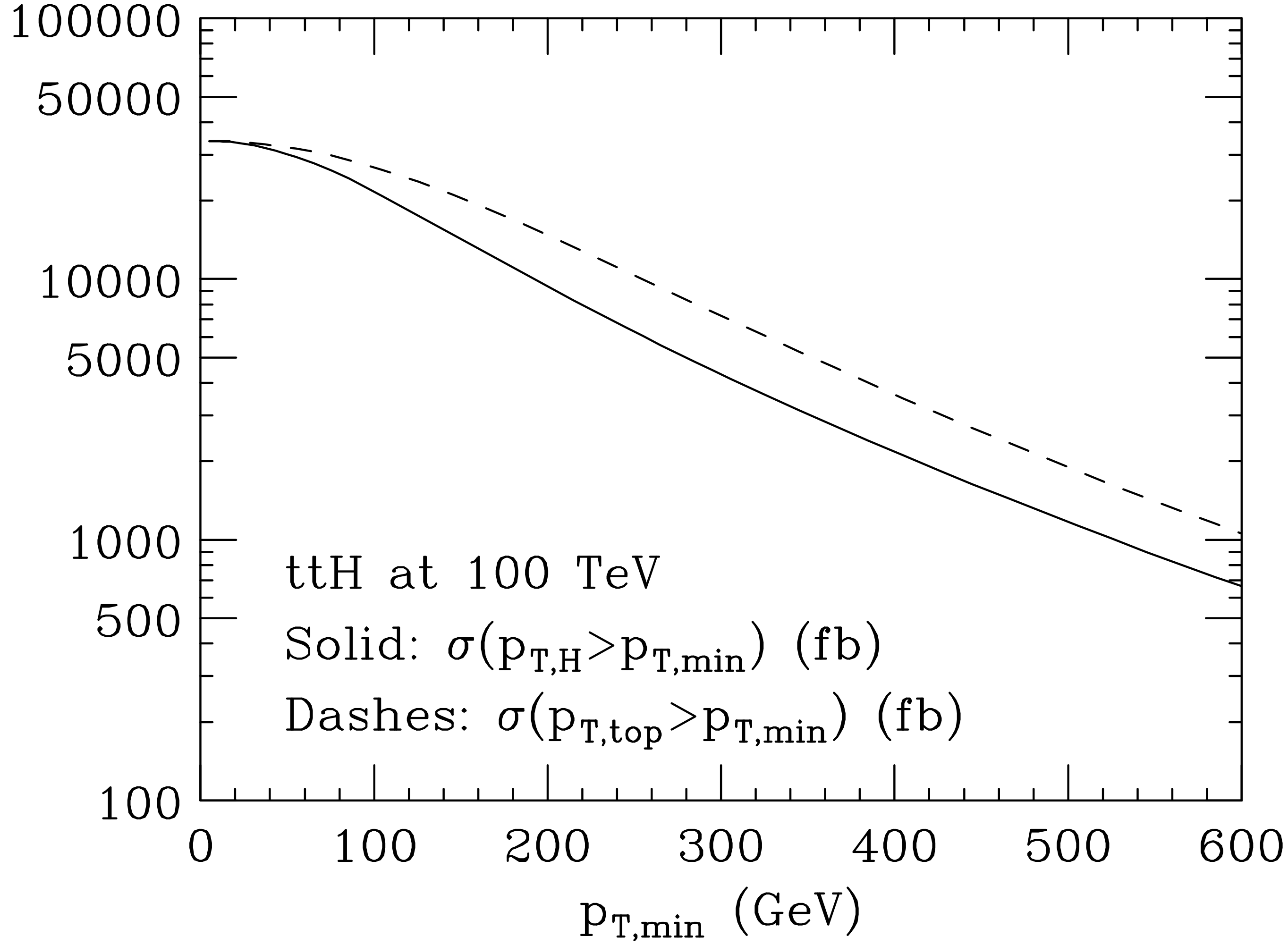
scale PDF

Production kinematics ratio stability



MLM, Plehn, Reimitz, Schell, Shao *arXiv:1507.08169*

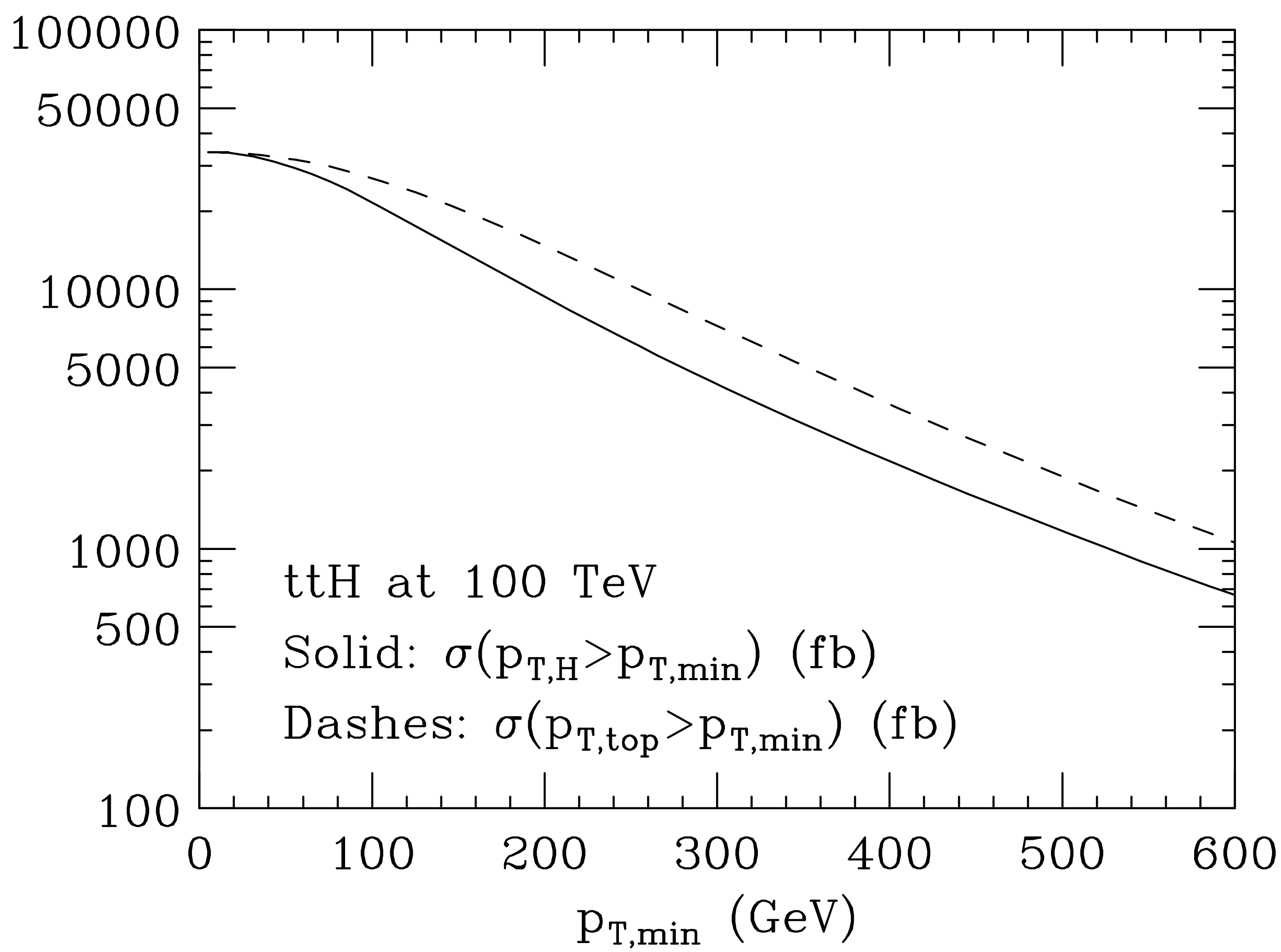


$H \to 4\ell$	$H \to \gamma\gamma$	$H \to 2\ell 2\nu$	$H \to b\bar{b}$
$2.6 \cdot 10^4$	$4.6 \cdot 10^5$	$2.0 \cdot 10^6$	$1.2 \cdot 10^8$

Events/20ab^{-1} , with tt→$\ell\nu$+jets

⇒ huge rates, exploit boosted topologies

MLM, Plehn, Reimitz, Schell, Shao arXiv:1507.08169



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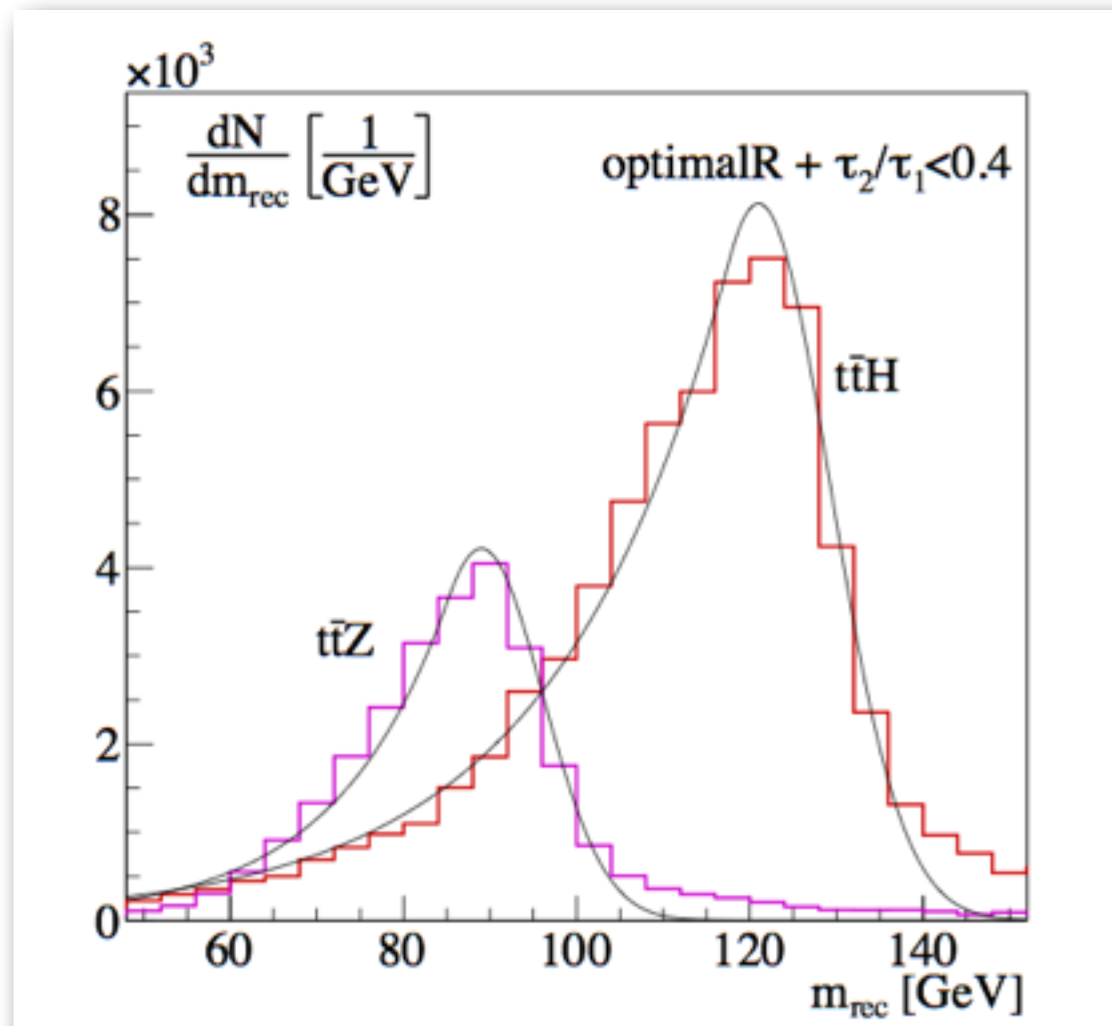
Events/20ab^{-1} , with tt→$\ell\nu$+jets

⇒ huge rates, exploit boosted topologies

Top fat C/A jet(s) with R = 1.2, |y| < 2.5, and $p_{T,j}$ > 200 GeV

- δy_t (stat + syst $_{TH}$) ~ 1%

- great potential to reduce to similar levels $\delta_{exp\ syst}$
- consider other decay modes, e.g. 2l2nu



Rare production modes: any good use for them?

$pp \to HW^+W^-$ (4FS)	$4.62 \cdot 10^0\ ^{+3\%}_{-2\%}\ ^{+2\%}_{-2\%}$	$1.68 \cdot 10^2\ ^{+5\%}_{-6\%}\ ^{+2\%}_{-1\%}$	36
$pp \to HZW^\pm$	$2.17 \cdot 10^0\ ^{+4\%}_{-4\%}\ ^{+2\%}_{-2\%}$	$9.94 \cdot 10^1\ ^{+6\%}_{-7\%}\ ^{+2\%}_{-1\%}$	46
$pp \to HW^\pm\gamma$	$2.36 \cdot 10^0\ ^{+3\%}_{-3\%}\ ^{+2\%}_{-2\%}$	$7.75 \cdot 10^1\ ^{+7\%}_{-8\%}\ ^{+2\%}_{-1\%}$	33
$pp \to HZ\gamma$	$1.54 \cdot 10^0\ ^{+3\%}_{-2\%}\ ^{+2\%}_{-2\%}$	$4.29 \cdot 10^1\ ^{+5\%}_{-7\%}\ ^{+2\%}_{-2\%}$	28
$pp \to HZZ$	$1.10 \cdot 10^0\ ^{+2\%}_{-2\%}\ ^{+2\%}_{-2\%}$	$4.20 \cdot 10^1\ ^{+4\%}_{-6\%}\ ^{+2\%}_{-1\%}$	38
$pp \to HW^\pm j$	$3.18 \cdot 10^2\ ^{+4\%}_{-4\%}\ ^{+2\%}_{-1\%}$	$1.07 \cdot 10^4\ ^{+2\%}_{-7\%}\ ^{+2\%}_{-1\%}$	34
$pp \to HW^\pm jj$	$6.06 \cdot 10^1\ ^{+6\%}_{-8\%}\ ^{+1\%}_{-1\%}$	$4.90 \cdot 10^3\ ^{+2\%}_{-6\%}\ ^{+1\%}_{-1\%}$	81
$pp \to HZj$	$1.71 \cdot 10^2\ ^{+4\%}_{-4\%}\ ^{+1\%}_{-1\%}$	$6.31 \cdot 10^3\ ^{+2\%}_{-7\%}\ ^{+2\%}_{-1\%}$	37
$pp \to HZjj$	$3.50 \cdot 10^1\ ^{+7\%}_{-10\%}\ ^{+1\%}_{-1\%}$	$2.81 \cdot 10^3\ ^{+2\%}_{-5\%}\ ^{+1\%}_{-1\%}$	80

Table 1: Production of a single Higgs boson at the LHC and at a 100 TeV FCC-hh. The rightmost column reports the ratio ρ of the FCC-hh to the LHC cross sections. Theoretical uncertainties are due to scale and PDF variations, respectively. Monte-Carlo-integration error is always smaller than theoretical uncertainties, and is not shown. For $pp \to HVjj$, on top of the transverse-momentum cut of section 2, I require $m(j_1, j_2) > 100$ GeV, j_1 and j_2 being the hardest and next-to-hardest jets, respectively. Processes $pp \to Htj$ and $pp \to Hjj$ (VBF) do not feature jet cuts.

P.Torrielli, arXiv:1407.1623

New analysis of HH production for the FCC report

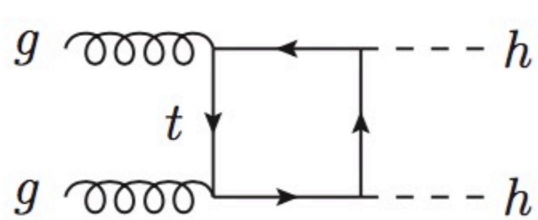
R.C., C. Englert, G. Panico, A. Papaefstathiou, J. Ren, M. Selvaggi, M. Son, M. Spannowsky, W. Yao

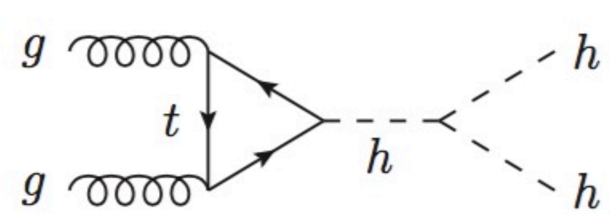
- **Goals:**
  1. improve on previous studies and get a commonly-agreed estimate
  2. study dependence on efficiencies and systematics

Previous analyses:

W. Yao arXiv:1308.6302 (Snowmass Summer Study 2013)
Barr, Dolan, Englert, de Lima, Spannowsky JHEP 1502 (2015) 016
Azatov, R.C., Panico, Son PRD 92 (2015) 035001
H-J. He, J. Ren, W. Yao PRD 93 (2016) 015003

Signal: double Higgs production via gluon fusion ($gg \to hh$)





$\sim const.$

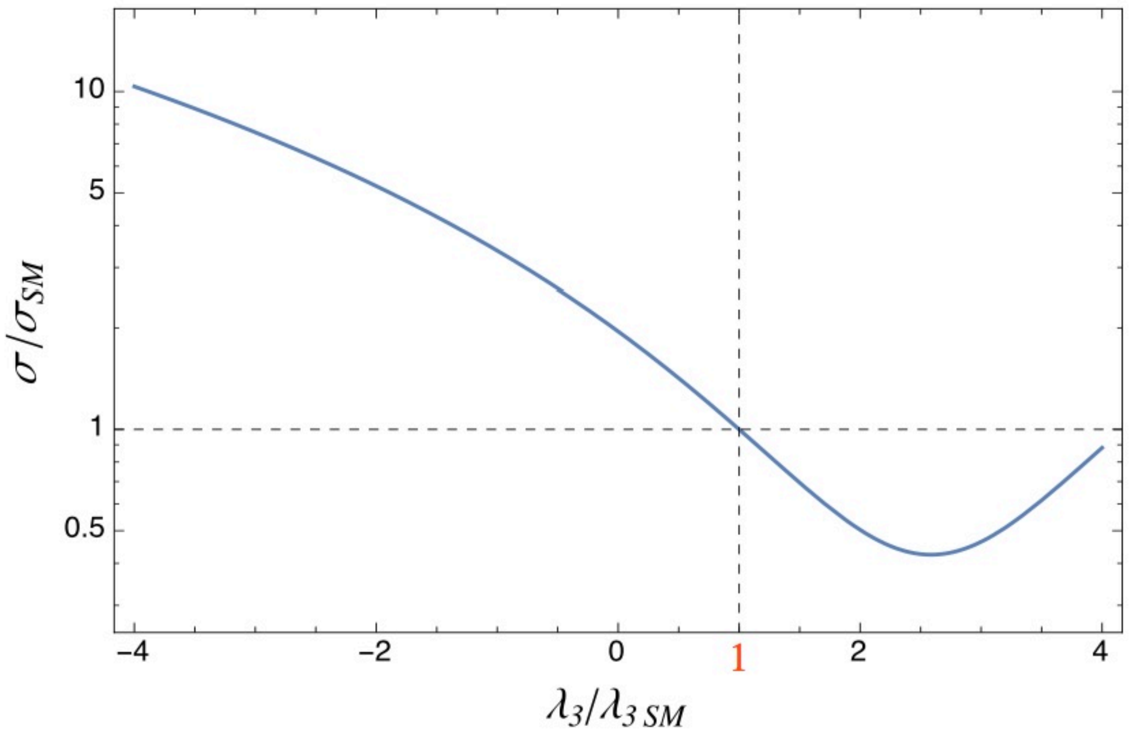
$\sim \lambda_3 \times \frac{m_h^2}{\hat{s}} \log^2\left(\frac{m_t^2}{\hat{s}}\right)$ → Most sensitivity on trilinear coupling comes from threshold events

Slides from R.Contino Higgs chapter overview at Rome's FCC-week, April 2016

	Signal cross section [fb] at NNLO+NNLL *
14 TeV	$45.05^{+4.4\%}_{-6.0\%} \pm 3.0\% \pm 10\%$
100 TeV	$1749^{+5.1\%}_{-6.6\%} \pm 2.7\% \pm 10\%$

~ 40 × increase

Theoretical uncertainties: scale; PDFs $+\alpha_s$; infinite m_t approx.



	# Higgs pairs to bbγγ
LHC: 14TeV 300fb^{-1}	36
HL-LHC: 14TeV 3ab^{-1}	360
FCC: 100TeV 20ab^{-1}	92 x 10^{3}

← percent precision physics

Backgrounds:

- $b\bar{b}\gamma\gamma$
- $t\bar{t}h(\gamma\gamma)$
- $b\bar{b}h(\gamma\gamma)$
- $jj\gamma\gamma$ (two fake b-jets)
- $b\bar{b}j\gamma$ (one fake photon)

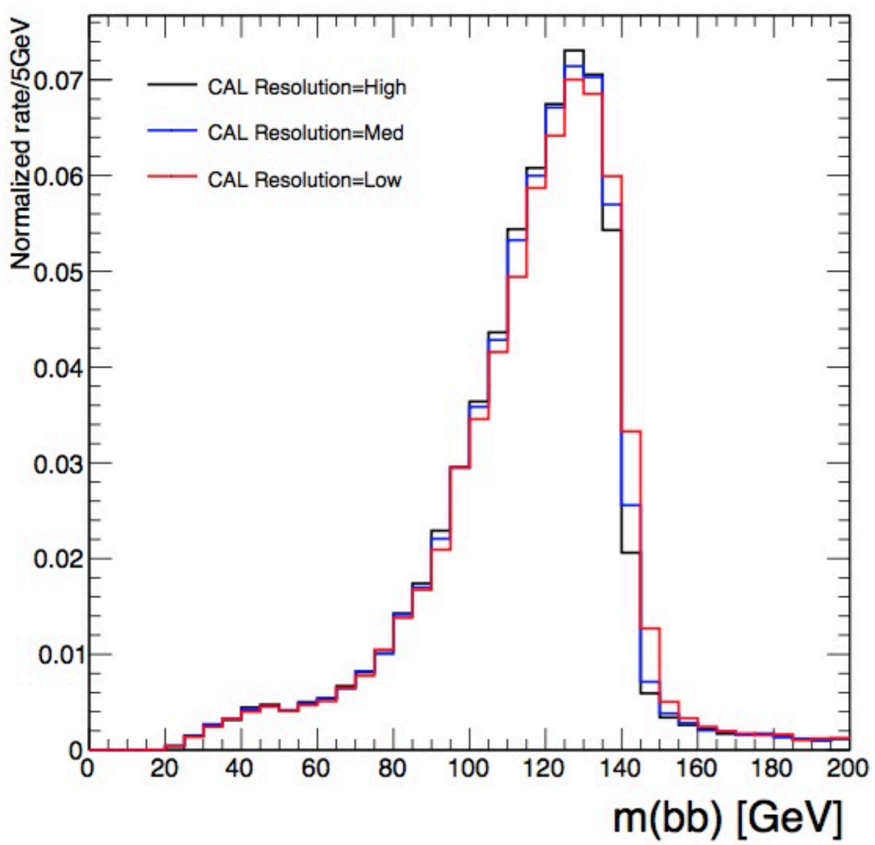
* Results of the recent full-m_{top} NLO calculation (Borowka et al, arXiv: 1604.06447) not included here (as yet….)

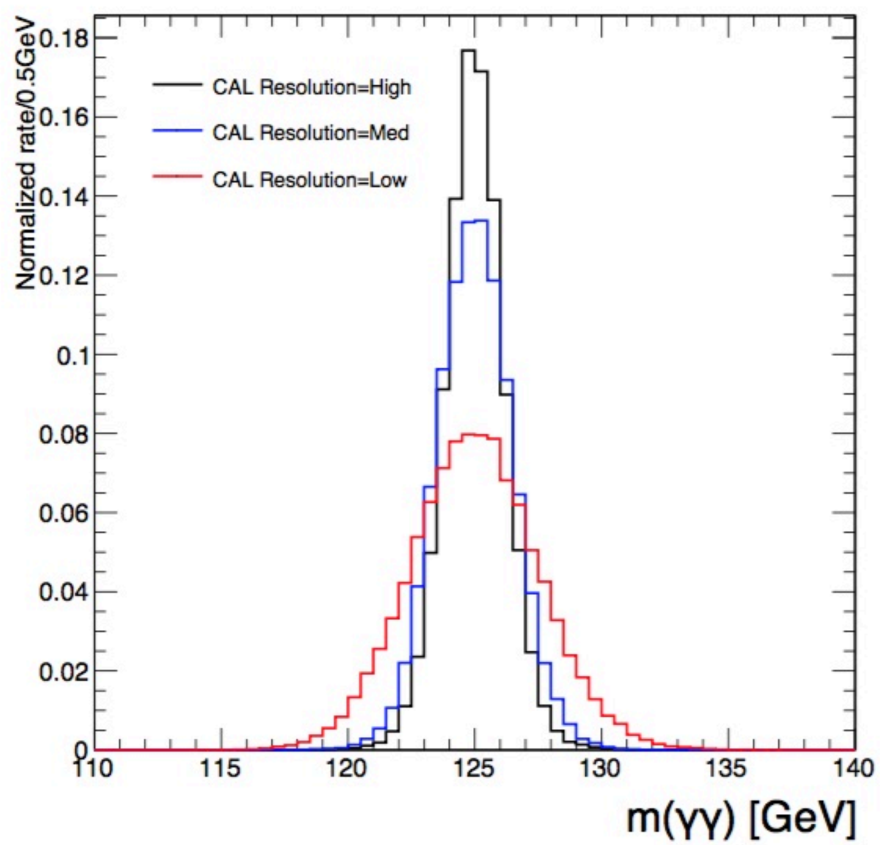
Montecarlo Simulation: MadGraph5_aMC@NLO ⟶ Pythia 6 ⟶ Delphes (FCC card)

Three benchmark scenarios for ECAL and HCAL resolution:

$$\Delta E = \sqrt{a^2 E^2 + b^2 E}$$

	ECAL				HCAL			
	$\lvert\eta\rvert \leq 4$		$4 < \lvert\eta\rvert \leq 6$		$\lvert\eta\rvert \leq 4$		$4 < \lvert\eta\rvert \leq 6$	
	a	b	a	b	a	b	a	b
low	0.02	0.2	0.01	0.1	0.05	1.0	0.05	1.0
medium	0.01	0.1	0.01	0.1	0.03	0.5	0.05	1.0
high	0.007	0.06	0.01	0.1	0.01	0.3	0.03	0.5





High
$\Delta m(\gamma\gamma) = 1.5\,\mathrm{GeV}$

Med
$\Delta m(\gamma\gamma) = 2.0\,\mathrm{GeV}$

Low
$\Delta m(\gamma\gamma) = 3.0\,\mathrm{GeV}$

- overall rescaling of background rate $n_B \to r_B \times n_B$

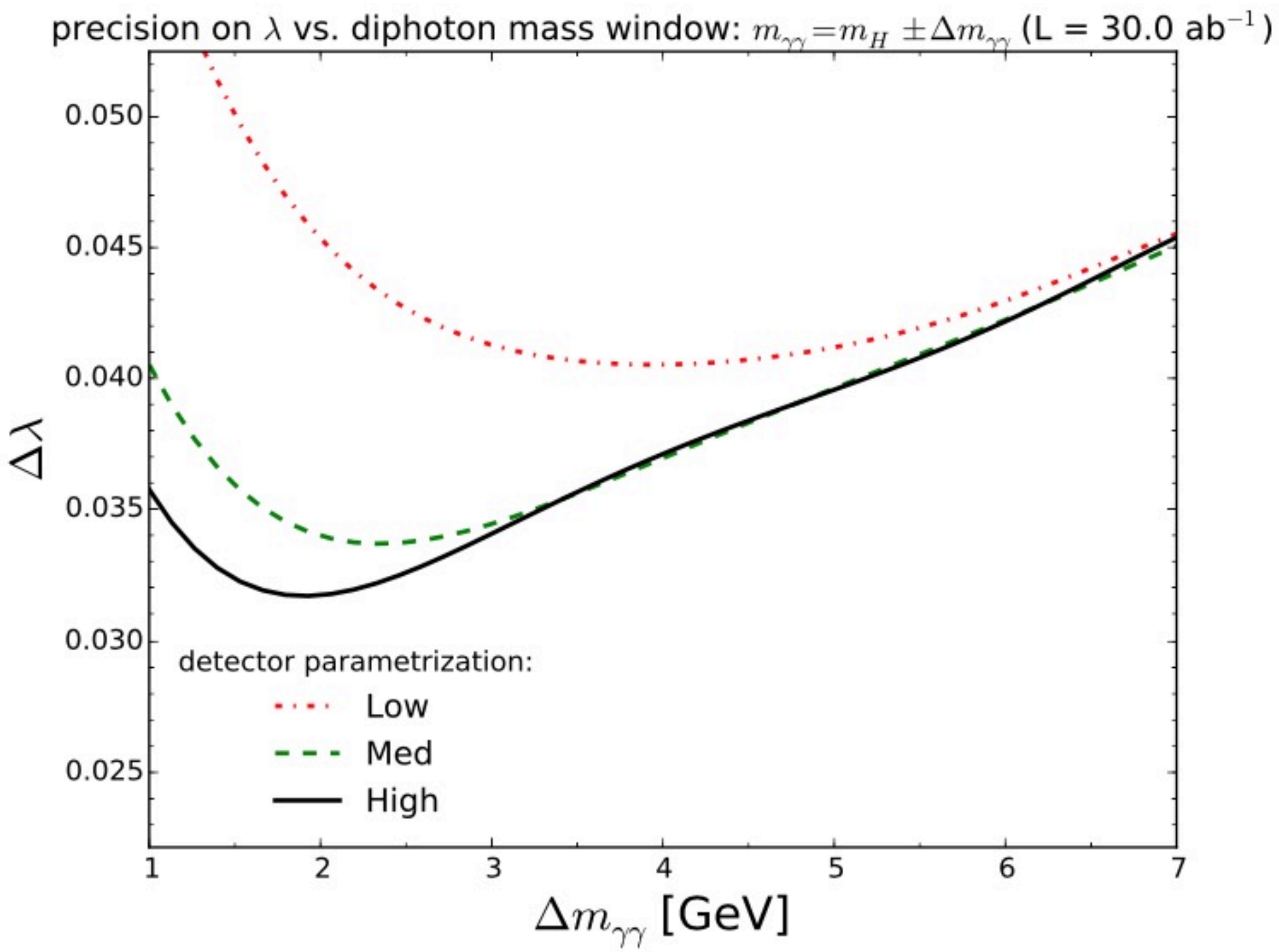
- uncertainty on signal rate $\Delta_S = \dfrac{\Delta\sigma(pp \to hh)}{\sigma(pp \to hh)}$

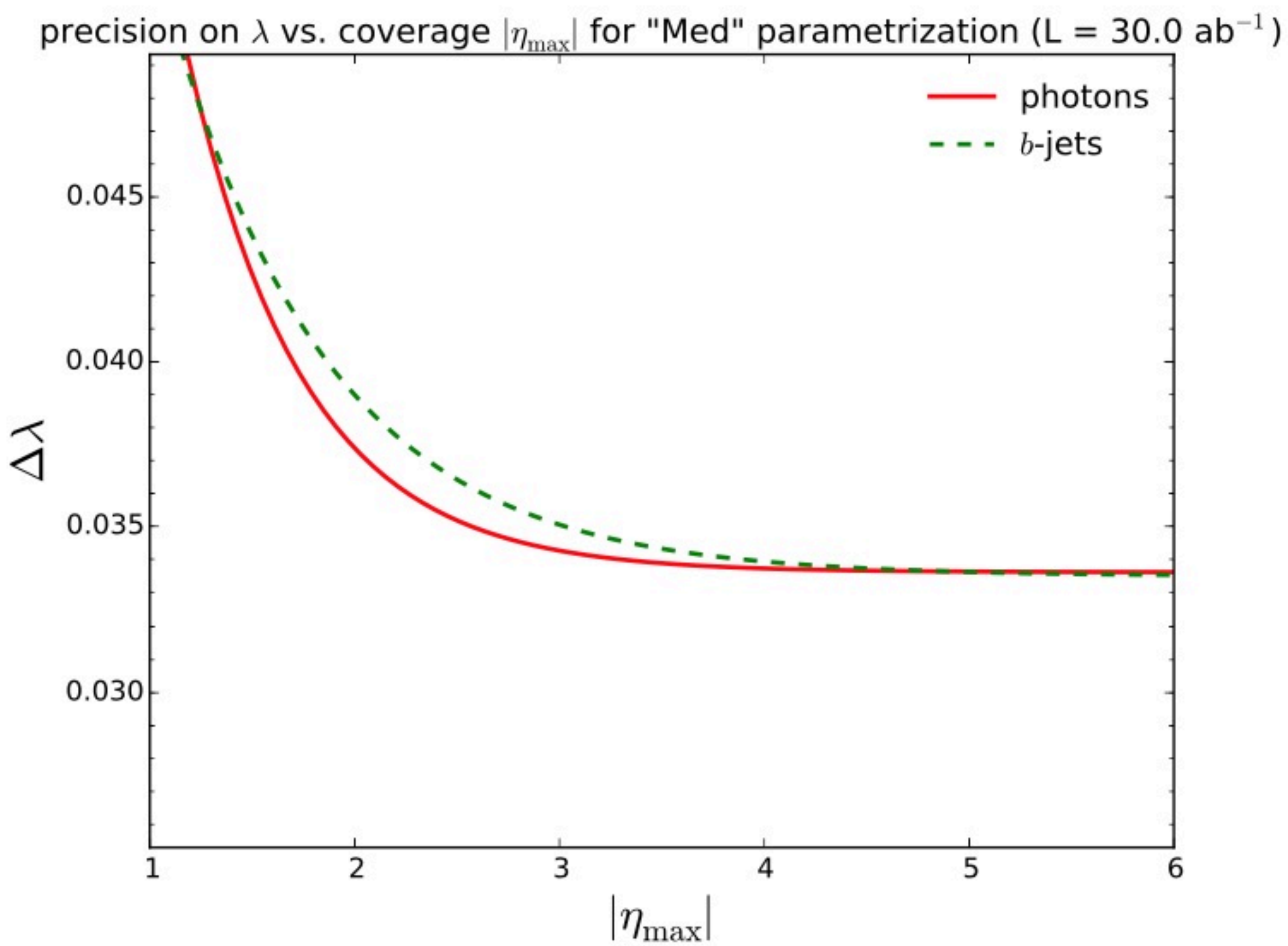
using "medium" calorimeter resolution

$\Delta\lambda_3$	$\Delta_S = 0.00$	$\Delta_S = 0.01$	$\Delta_S = 0.015$	$\Delta_S = 0.02$	$\Delta_S = 0.025$
$r_B = 0.5$	2.7%	3.4%	4.1%	4.9%	5.8%
$r_B = 1.0$	3.4%	3.9%	4.6%	5.3%	6.1%
$r_B = 1.5$	3.9%	4.4%	5.0%	5.7%	6.4%
$r_B = 2.0$	4.4%	4.8%	5.4%	6.0%	6.8%
$r_B = 3.0$	5.2%	5.6%	6.0%	6.6%	7.3%

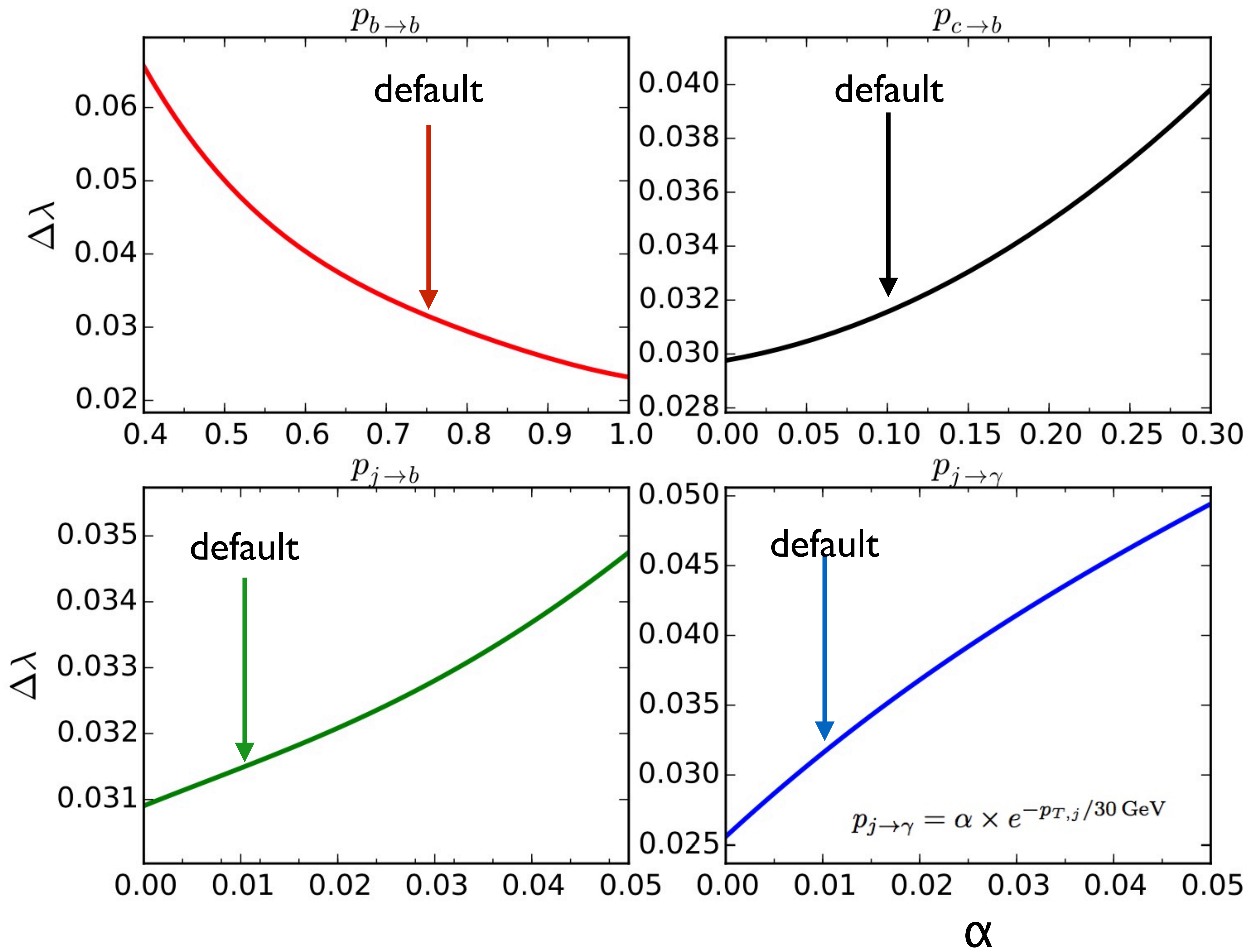
For $\Delta_S \gtrsim 2.5\%$ the precision on λ_3 is dominated by the theory error on the signal: $\Delta\lambda_3 \simeq 2\Delta_S$

impact of detector performance, I





impact of detector performance, 2

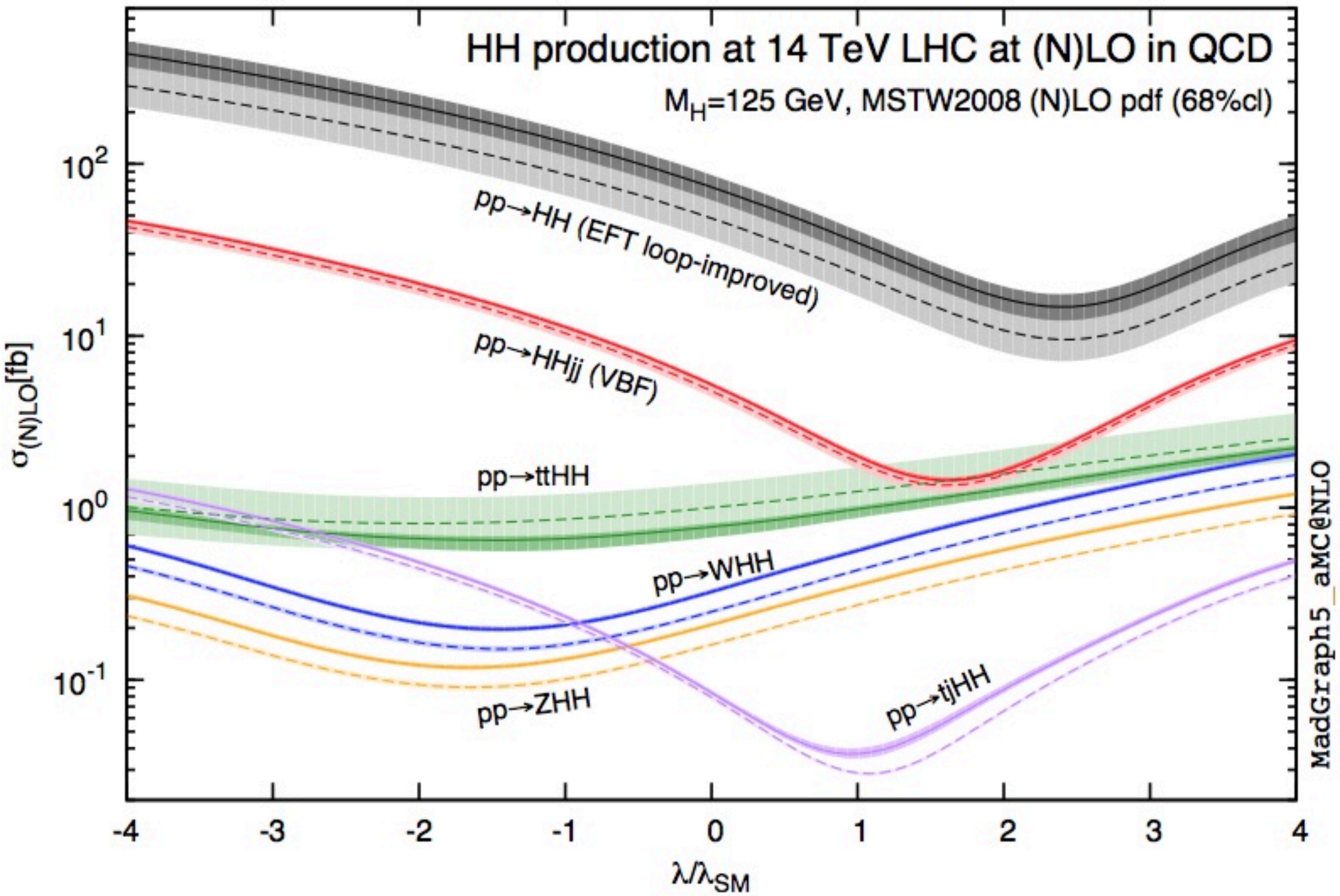


other HH+X production modes

process	σ(14 TeV) (fb)	σ(100 TeV) (fb)	accuracy
HH (ggf)	$45.05^{+4.4\%}_{-6.0\%} \pm 3.0\% \pm 10\%$	$1749^{+5.1\%}_{-6.6\%} \pm 2.7\% \pm 10\%$	NNLL matched to NNLO
$HHjj$ (VBF)	$1.94^{+2.3\%}_{-2.6\%} \pm 2.3\%$	$80.3^{+0.5\%}_{-0.4\%} \pm 1.7\%$	NLO
HHZ	$0.415^{+3.5\%}_{-2.7\%} \pm 1.8\%$	$8.23^{+5.9\%}_{-4.6\%} \pm 1.7\%$	NNLO
HHW^+	$0.269^{+0.33\%}_{-0.39\%} \pm 2.1\%$	$4.70^{+0.90\%}_{-0.96\%} \pm 1.8\%$	NNLO
HHW^-	$0.198^{+1.2\%}_{-1.3\%} \pm 2.7\%$	$3.30^{+3.5\%}_{-4.3\%} \pm 1.9\%$	NNLO
$HHt\bar{t}$	$0.949^{+1.7\%}_{-4.5\%} \pm 3.1\%$	$82.1^{+7.9\%}_{-7.4\%} \pm 1.6\%$	NLO
$HHtj$	$0.0364^{+4.2\%}_{-1.8\%} \pm 4.7\%$	$4.44^{+2.2\%}_{-2.6\%} \pm 2.4\%$	NLO
HHH	$0.0892^{+14.8\%}_{-13.6\%} \pm 3.2\%$	$4.82^{+12.3\%}_{-11.9\%} \pm 1.8\%$	NLO

Table 25: Cross sections for production of two or three SM Higgs bosons, including associated production channels, at a 14 TeV and 100 TeV hadron collider [1]. The cross sections are computed by choosing $\mu = M_{hh}/2$ ($\mu = M_{hhh}/2$ in the case of triple production). The error intervals correspond to scale variation and PDF + α_s uncertainty. In HH production in the gluon-fusion channel a conservative 10% uncertainty is included to take into account the effects of the infinite top-mass approximation (see Section 3.1.1).

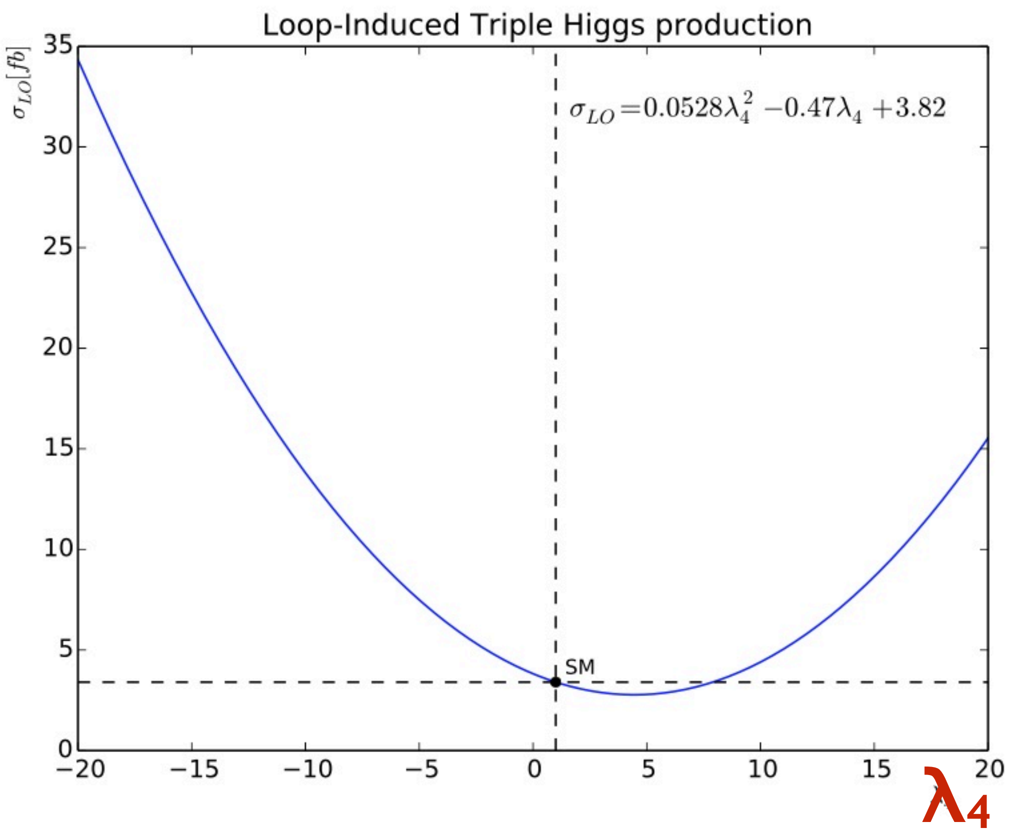
other channels, first assessments ….



λ dependence at 14 and 100 TeV are similar

process	precision on σ_{SM}	68% CL interval on Higgs self-couplings
$HH \to b\bar{b}\gamma\gamma$	3%	$\lambda_3 \in [0.97, 1.03]$
$HH \to b\bar{b}b\bar{b}$	5%	$\lambda_3 \in [0.9, 1.5]$
$HH \to b\bar{b}4\ell$	$O(25\%)$	$\lambda_3 \in [0.6, 1.4]$
$HH \to b\bar{b}\ell^+\ell^-$	$O(15\%)$	$\lambda_3 \in [0.8, 1.2]$
$HH \to b\bar{b}\ell^+\ell^-\gamma$	–	–

Quartic Higgs selfcoupling



observable	selection cut
$p_{T,b_{\{1,2,3,4\}}}$	$> \{80, 50, 40, 40\}$ GeV
$\lvert\eta_b\rvert$	< 3.0
$m_{bb}^{\text{close},1}$	$\in [100, 160]$ GeV
$m_{bb}^{\text{close},2}$	$\in [90, 170]$ GeV
$\Delta R_{bb}^{\text{close},1}$	$\in [0.2, 1.6]$
$\Delta R_{bb}^{\text{close},2}$	no cut
$p_{T,\gamma_{\{1,2\}}}$	$> \{70, 40\}$ GeV
$\lvert\eta_\gamma\rvert$	< 3.5
$\Delta R_{\gamma\gamma}$	$\in [0.2, 4.0]$
$m_{\gamma\gamma}$	$\in [124, 126]$ GeV

process	σ_{LO} (fb)	$\sigma_{\text{NLO}} \times \text{BR} \times \mathcal{P}_{\text{tag}}$ (ab)	$\epsilon_{\text{analysis}}$	$N^{\text{cuts}}_{30\ \text{ab}^{-1}}$
$hhh \to (b\bar{b})(b\bar{b})(\gamma\gamma)$, SM	2.89	5.4	0.06	9.7
$b\bar{b}b\bar{b}\gamma\gamma$	1.28	1050	2.6×10^{-4}	8.2
hZZ, (NLO) $(ZZ \to (b\bar{b})(b\bar{b}))$	0.817	0.8	0.002	$\ll 1$
hhZ, (NLO)$(Z \to (b\bar{b}))$	0.754	0.8	0.007	$\ll 1$
hZ, (NLO) $(Z \to (b\bar{b}))$	8.02×10^3	1130	$\mathcal{O}(10^{-5})$	$\ll 1$
$b\bar{b}b\bar{b}\gamma$ + jets	2.95×10^3	2420	$\mathcal{O}(10^{-5})$	$\mathcal{O}(1)$
$b\bar{b}b\bar{b}$ + jets	5.45×10^3	4460	$\mathcal{O}(10^{-6})$	$\ll 1$
$b\bar{b}\gamma\gamma$ + jets	98.7	4.0	$\mathcal{O}(10^{-5})$	$\ll 1$
hh + jets, SM	275	593	7×10^{-4}	12.4

=> λ_4 in [– 4 , 16] at 95%CL

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  - what is the complementarity of the high-sensitivity measurements of Higgs properties possible at 100 TeV, and the reach of direct BSM searches?
  - how far can we push the detector technology to maximize the Higgs measurement capabilities?

Conclusions

- With the exception of ttH and HH, where some attempt at complete analyses has been made, there is still no reliable quantitative study of the actual precision potential of a 100 TeV pp collider at 20 ab^{-1}.
- It is clear from the previous slides that this is however a ballgame different from the LHC.
- There are many opportunities, exploiting the large statistics and the novel kinematical regimes
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  - what's the synergy/complementarity with the e^+e^- collider results?
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  - ....