State of the Higgs address

(neither a systematic summary of HC16, nor an independent review ….)

Higgs Couplings 2016
SLAC, Nov 9-12

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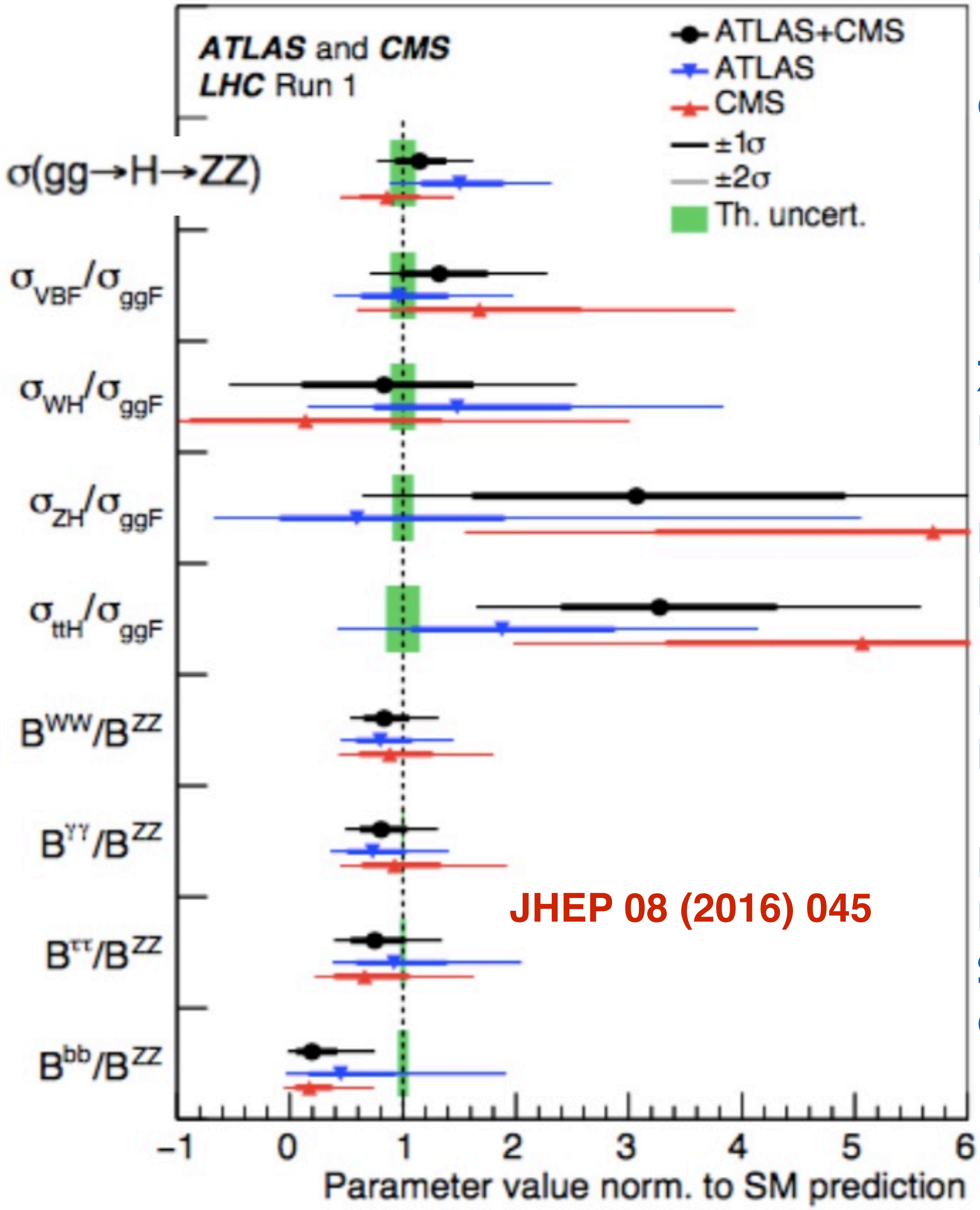


Guindon Comb

Mellado
Korpe YY

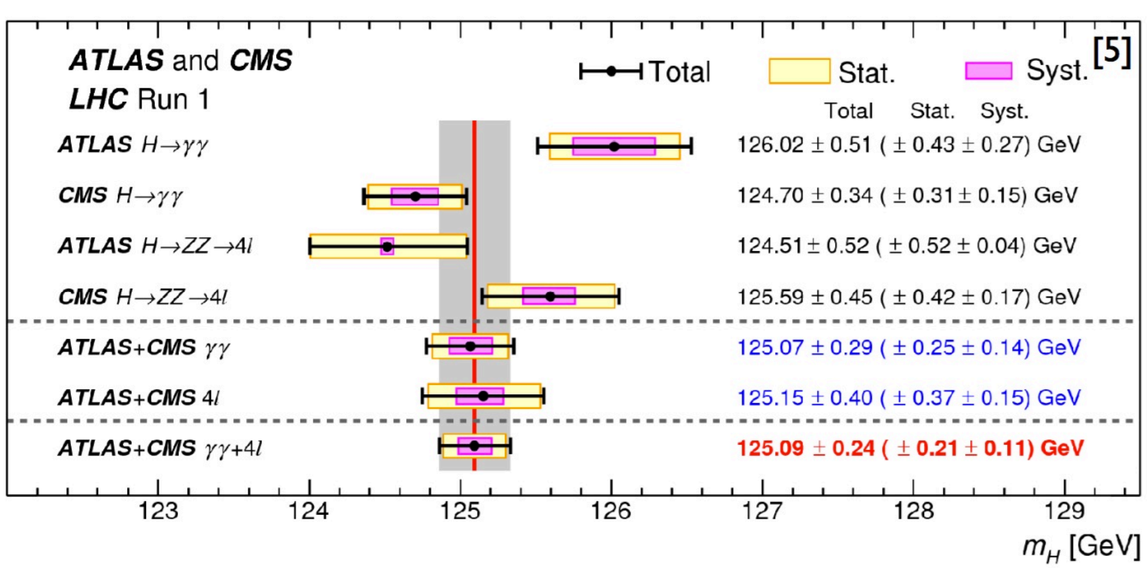
Zambito
Kumar VV

Davidek
Lane ττ

Mueller
Perrozzi bb

Enari
Kasieczka ttH
Sopczak
Gosh

Couderc



Compilation by **A.Falkowski**, using
ATLAS+CMS JHEP08(2016)045 + ICHEP + HC2016

Channel	Production	Run-1	ATLAS Run-2	CMS Run-2
$\gamma\gamma$	ggh	$1.10^{+0.23}_{-0.22}$	$0.62^{+0.30}_{-0.29}$ [4]	$0.77^{+0.25}_{-0.23}$ [5]
	VBF	$1.3^{+0.5}_{-0.5}$	$2.25^{+0.75}_{-0.75}$ [4]	$1.61^{+0.90}_{-0.80}$ [5]
	Wh	$0.5^{+1.3}_{-1.2}$	-	-
	Zh	$0.5^{+3.0}_{-2.5}$	-	-
	Vh	-	$0.30^{+1.21}_{-1.12}$ [4]	-
	$t\bar{t}h$	$2.2^{+1.6}_{-1.3}$	$-0.22^{+1.26}_{-0.99}$ [4]	$1.9^{+1.5}_{-1.2}$ [5]
$Z\gamma$	incl.	$1.4^{+3.3}_{-3.2}$	-	-
ZZ^*	ggh	$1.13^{+0.34}_{-0.31}$	$1.34^{+0.39}_{-0.33}$ [4]	$0.96^{+0.40}_{-0.33}$ [6]
	VBF	$0.1^{+1.1}_{-0.6}$	$3.8^{+2.8}_{-2.2}$ [4]	$0.67^{+1.61}_{-0.67}$ [6]
WW^*	ggh	$0.84^{+0.17}_{-0.17}$	-	-
	VBF	$1.2^{+0.4}_{-0.4}$	$1.7^{+1.2}_{-0.9}$	-
	Wh	$1.6^{+1.2}_{-1.0}$	$3.2^{+4.4}_{-4.2}$	-
	Zh	$5.9^{+2.6}_{-2.2}$	-	-
	$t\bar{t}h$	$5.0^{+1.8}_{-1.7}$	-	-
	incl.	-	-	0.3 ± 0.5 [7]
$\tau^+\tau^-$	ggh	$1.0^{+0.6}_{-0.6}$	-	-
	VBF	$1.3^{+0.4}_{-0.4}$	-	-
	Wh	$-1.4^{+1.4}_{-1.4}$	-	-
	Zh	$2.2^{+2.2}_{-1.8}$	-	-
	$t\bar{t}h$	$-1.9^{+3.7}_{-3.3}$	-	-
$b\bar{b}$	VBF	-	$-3.9^{+2.8}_{-2.9}$ [8]	$-3.7^{+2.4}_{-2.5}$ [9]
	Wh	$1.0^{+0.5}_{-0.5}$	-	-
	Zh	$0.4^{+0.4}_{-0.4}$	-	-
	Vh	-	$0.21^{+0.51}_{-0.50}$ [10]	-
	$t\bar{t}h$	$1.15^{+0.99}_{-0.94}$	$2.1^{+1.0}_{-0.9}$ [11]	$-0.19^{+0.80}_{-0.81}$
$\mu^+\mu^-$	incl.	$0.1^{+2.5}_{-2.5}$	$-0.8^{+2.2}_{-2.2}$ [13]	-
multi-ℓ	cats.	-	$2.5^{+1.3}_{-1.1}$ [14]	$2.3^{+0.9}_{-0.8}$ [15]

Zambito

Kasieczka

Run 2, CMS, m(4l), now compatible with ATLAS run 1

$$m_H = 124.50^{+0.47}_{-0.45}(\text{stat.})^{+0.13}_{-0.11}(\text{sys.})\ \text{GeV}$$

The progress in exptl analyses and sensitivities has been matched by the results of immense efforts in the modeling of TH production and decay properties

… as documented in HXSWG reports I-IV , arXiv:1101.0593, 1201.3084, 1307.1347, 1610.07922

Plenary reviews of SM predictions:
SM precision predictions for Higgs partial widths: Spira
Higgs production through gluon fusion: Gehrmann
Higgs production through Weak Boson Fusion: Zeppenfeld
SM tth production, signal & backgrounds: Reina
Off-shell and boosted Higgs production: Caola
Monte Carlo simulation & uncertainties: Schönherr

Parallel session contributions on SM predictions:
Parton distributions for high precision measurements at the LHC: Kassabov Zaharieva
Precision Higgs physics at N3LO, Dulat
Differential distributions for Higgs signals at 13 TeV: Specchia
Towards differential Higgs production at N3LO: Mistlberger
Higgs Boson Pair Production at NLO in QCD with Full Top-Quark Mass Dependence: Jones

Message:

- *by and large,* today's studies of Higgs production and properties are not limited by TH systematics *(see one of the possible exceptions next …)*
- there is no reason to doubt that future TH progress will match the reduction of statistical and exptl syst's, all the way through to the HL-LHC phase … *of course it will cost sweat and blood, but a **bright, motivated, committed and rewarded** community of **young** theorists is in continuous growth*
- a strong program of dedicated measurements, necessary for the validation and tuning of calculations and tools must remain integral part of the exptl priorities

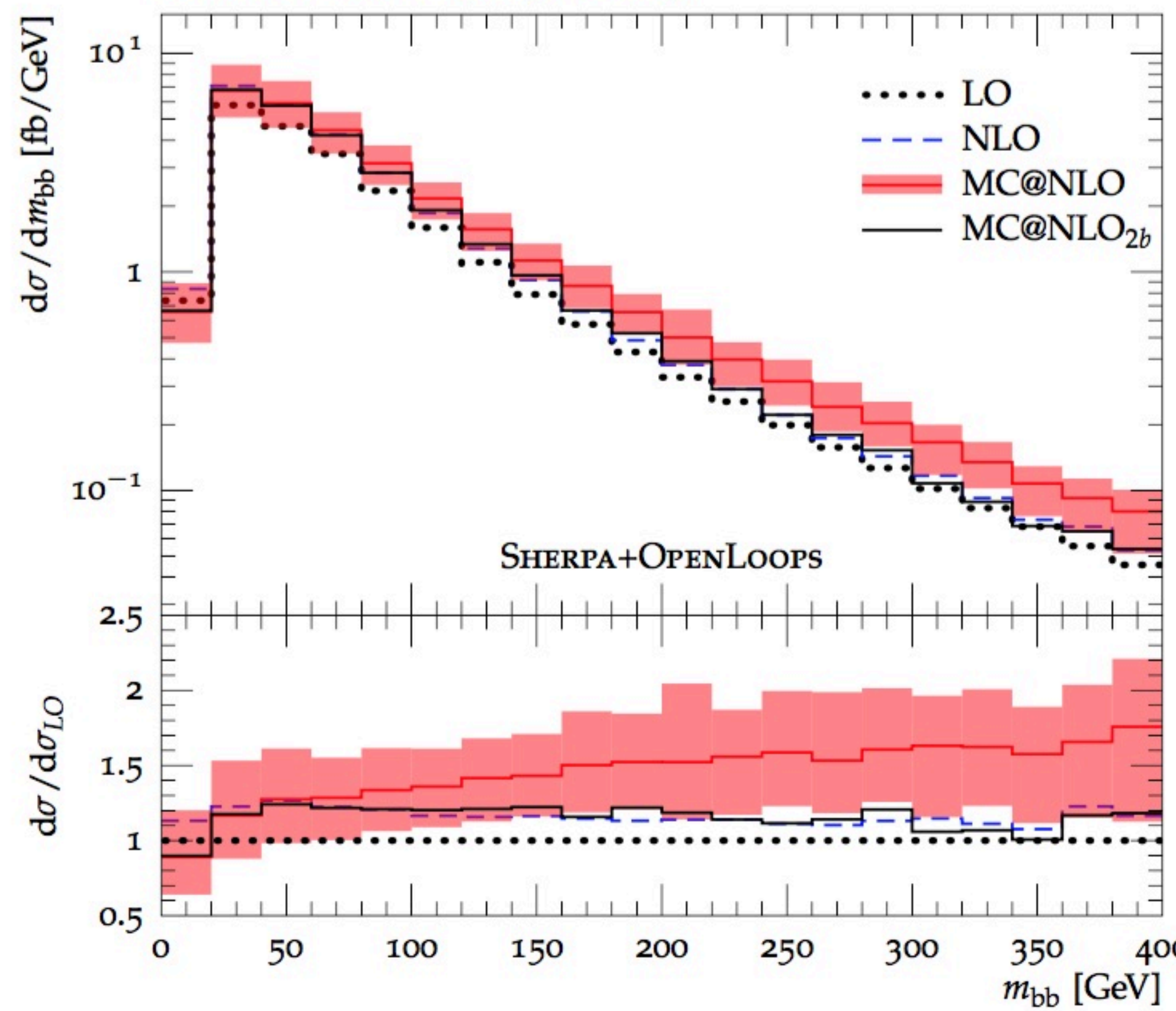
tt(H→bb)

Enari (ATLAS), Kasieczka (CMS), Reina (TH)

ATLAS

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modelling	+0.53	−0.53
Jet flavour tagging	+0.26	−0.26
$t\bar{t}H$ modelling	+0.32	−0.20
Background model statistics	+0.25	−0.25
$t\bar{t}+\geq 1c$ modelling	+0.24	−0.23
Jet energy scale and resolution	+0.19	−0.19
$t\bar{t}$+light modelling	+0.19	−0.18
Other background modelling	+0.18	−0.18
Jet-vertex association, pileup modelling	+0.12	−0.12
Luminosity	+0.12	−0.12
$t\bar{t}Z$ modelling	+0.06	−0.06
Light lepton (e,μ) ID, isolation, trigger	+0.05	−0.05
Total systematic uncertainty	+0.90	−0.75
$t\bar{t}+\geq 1b$ normalisation	+0.34	−0.34
$t\bar{t}+\geq 1c$ normalisation	+0.14	−0.14
Statistical uncertainty	+0.49	−0.49
Total uncertainty	+1.02	−0.89

ttbb QCD bg



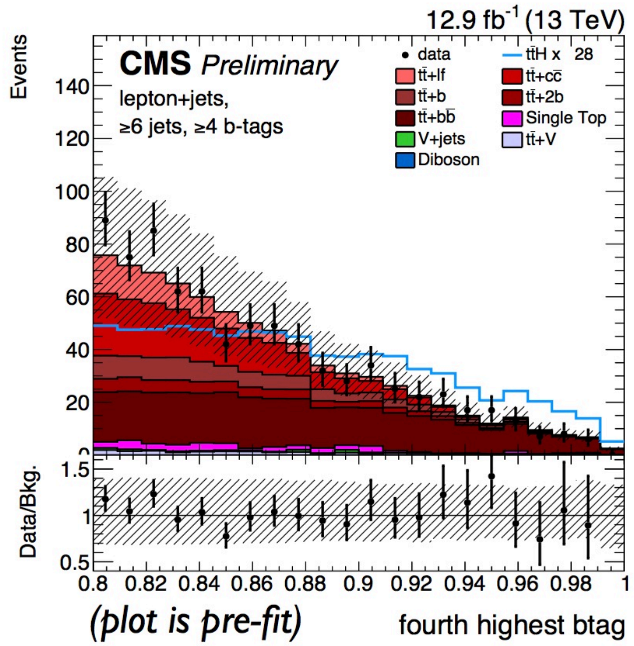
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ProposalTtbb

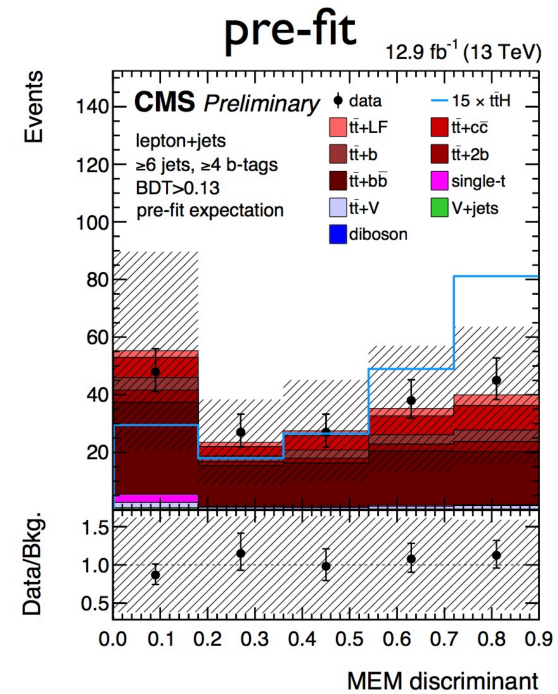
There are still important differences between ME and shower description of g→bb.

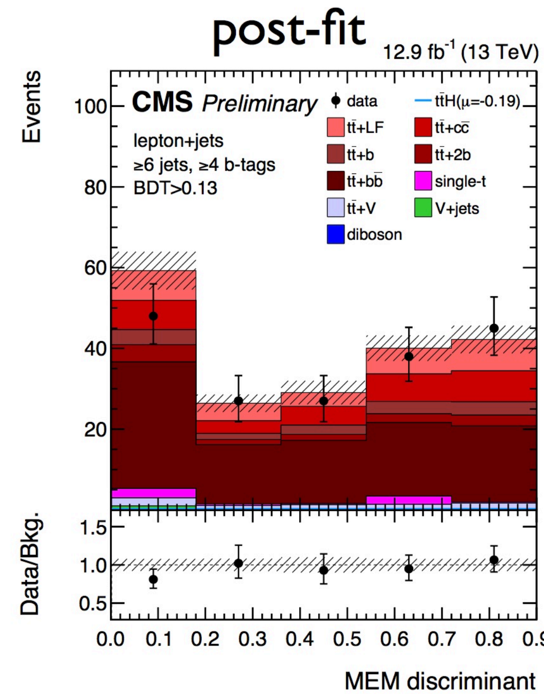
This leads to large systematics, which have devastating effects in this very low S/B context.

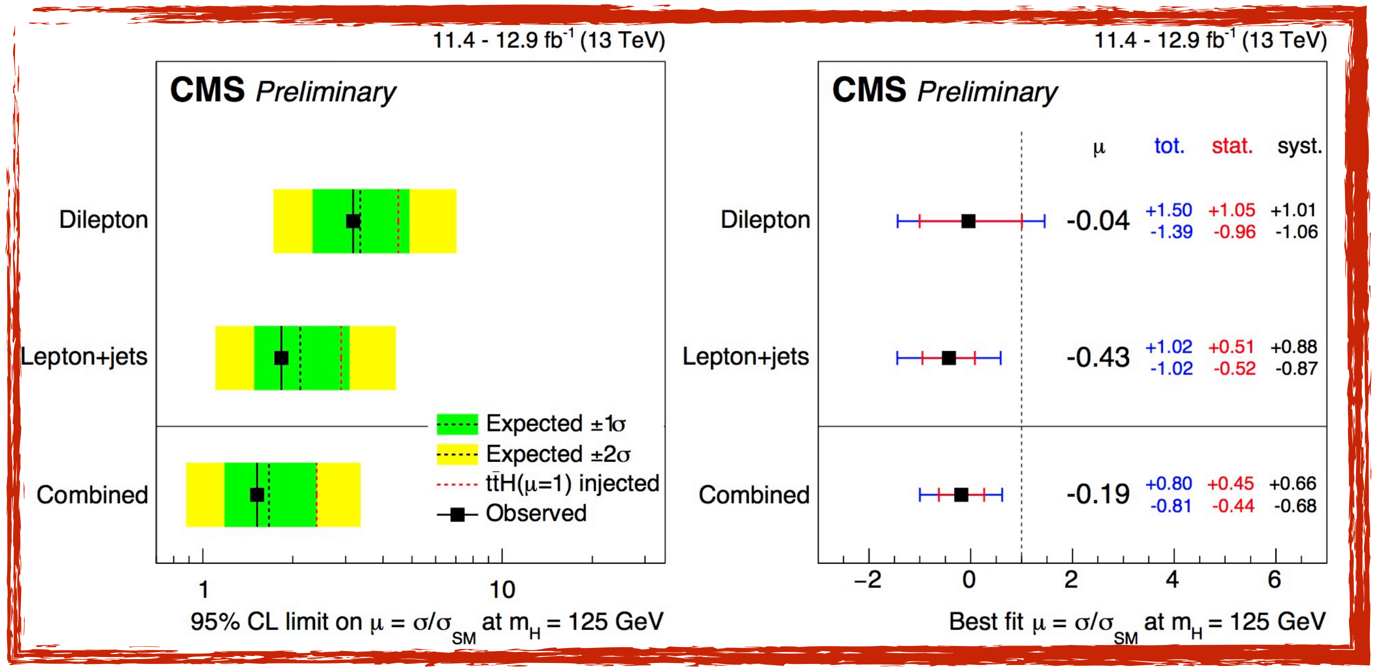
These issues are in principle common to other final states, such as generic jets+bb.

These could provide useful control samples to guide the progress on the TH side









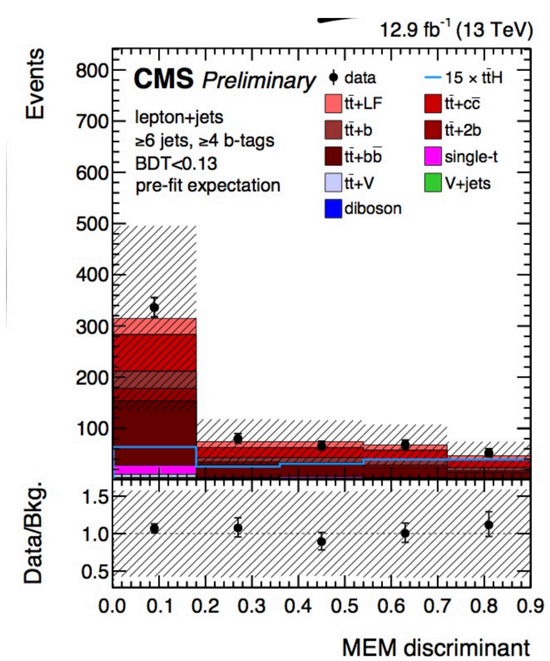
III: Matrix Element for ttH(bb) vs ttbb

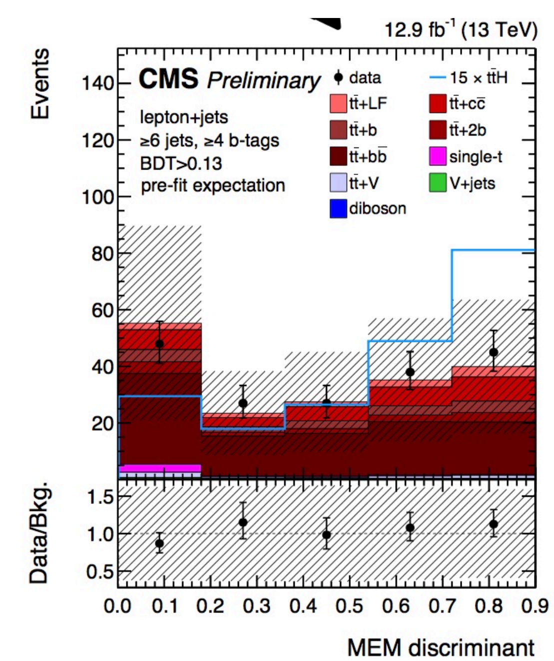
Numerical integration *Momentum conservation* *Resolution function (allow ISR)*

$$w(\vec{y}|\mathcal{H}) = \sum_{i=1}^{N_a} \int \frac{\mathrm{d}x_a \mathrm{d}x_b}{2 x_a x_b s} \int \prod_{k=1}^{8} \left(\frac{\mathrm{d}^3 \vec{p}_k}{(2\pi)^3 2E_k} \right) (2\pi)^4 \delta^{(E,z)} \left(p_a + p_b - \sum_{k=1}^{8} p_k \right) \mathcal{R}^{(x,y)} \left(\vec{\rho}_{\mathrm{T}}, \sum_{k=1}^{8} p_k \right) \times$$
$$g(x_a, \mu_{\mathrm{F}}) g(x_b, \mu_{\mathrm{F}}) |\mathcal{M}_{\mathcal{H}}(p_a, p_b, p_1, \ldots, p_8)|^2 W(\vec{y}, \vec{p}),$$

Parton density functions *LO Scattering amplitude (Open Loops)* *Detector transfer function*

$$P_{\mathrm{s/b}} = \frac{w(\vec{y}|\mathrm{t\bar{t}H})}{w(\vec{y}|\mathrm{t\bar{t}H}) + k_{\mathrm{s/b}} w(\vec{y}|\mathrm{t\bar{t}+b\bar{b}})}$$

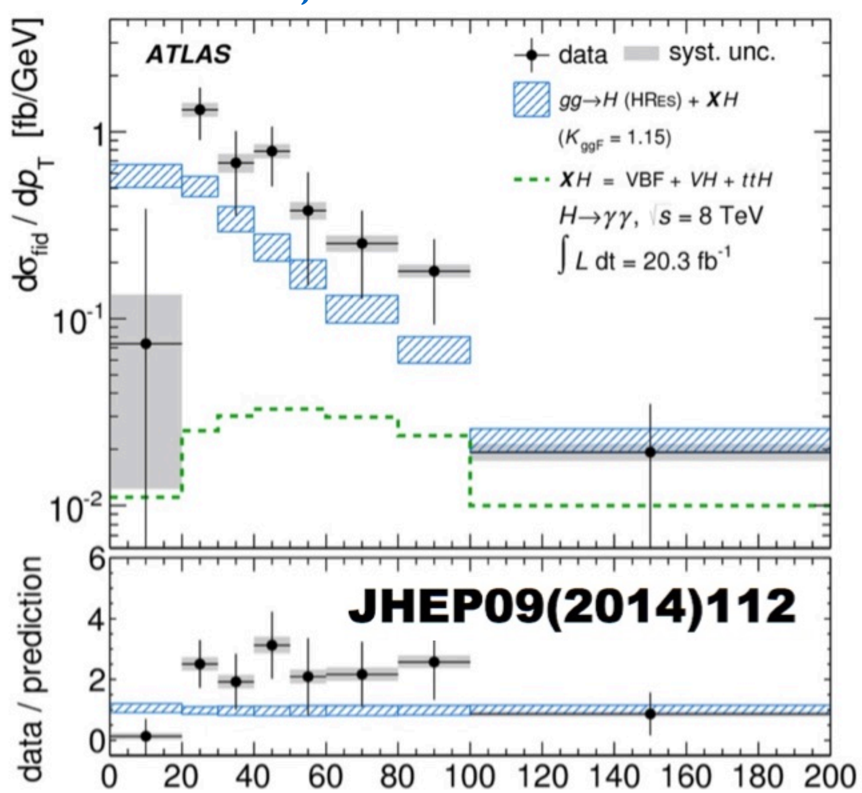




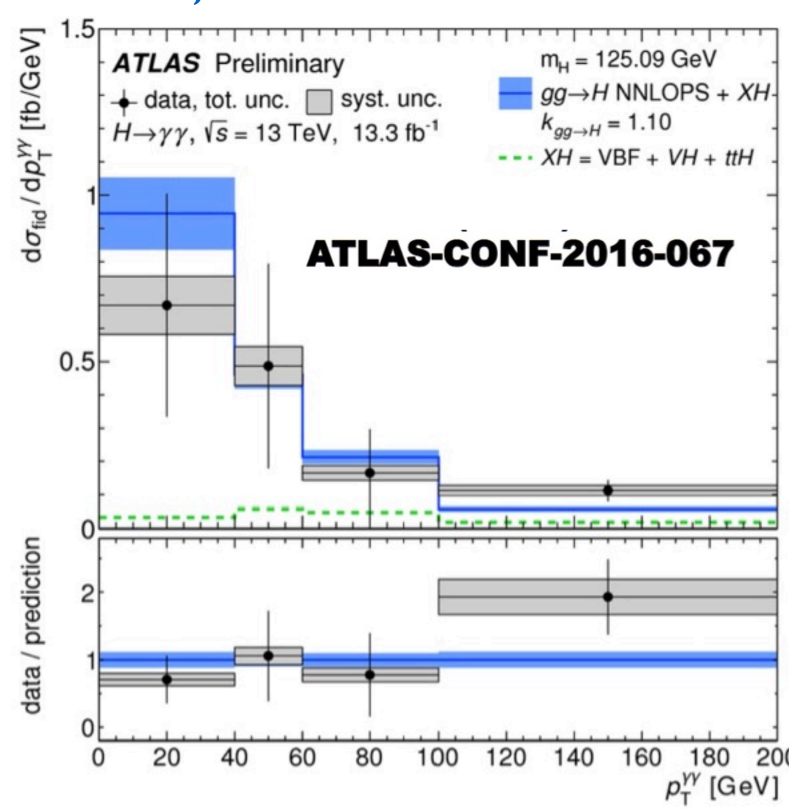
…. to do a proper job of validating and improving TH tools, we would benefit from a bit more transparency in the elucidation of the actual underlying dynamics, e.g. seeing data vs MC comparisons for more intuitive observables ….

A good example: first probes of production dynamics, $p_T(H)$ spectrum

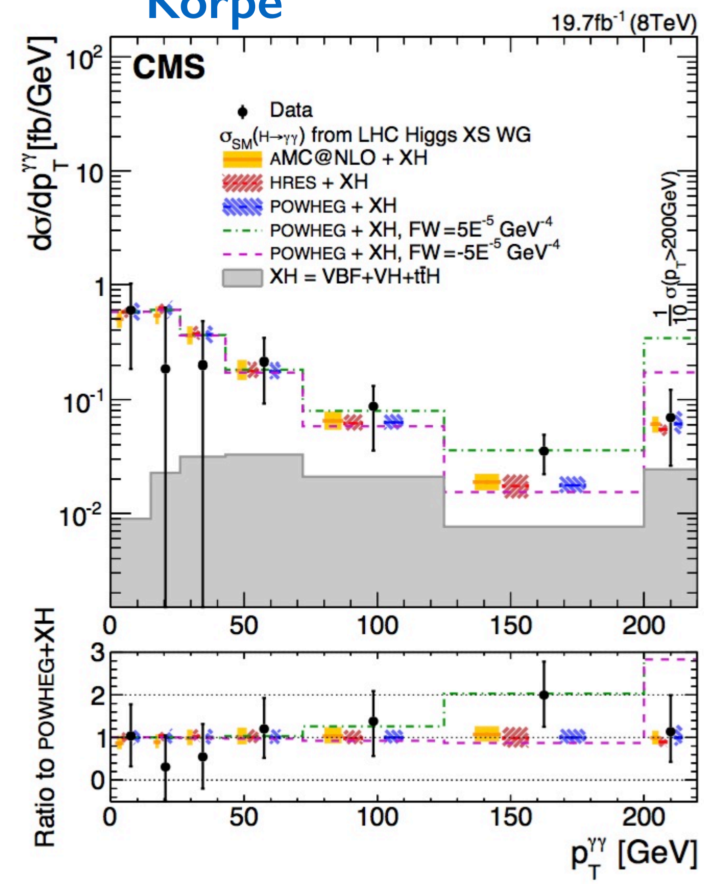
ATLAS γγ run 1
Mellado, Bellerive



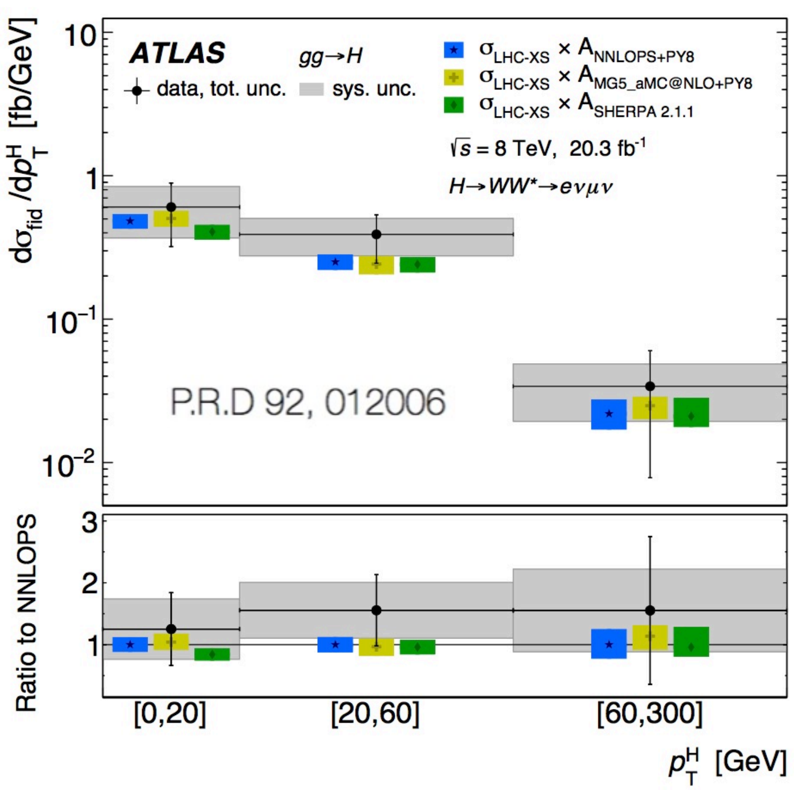
ATLAS γγ run 2
Mellado, Bellerive



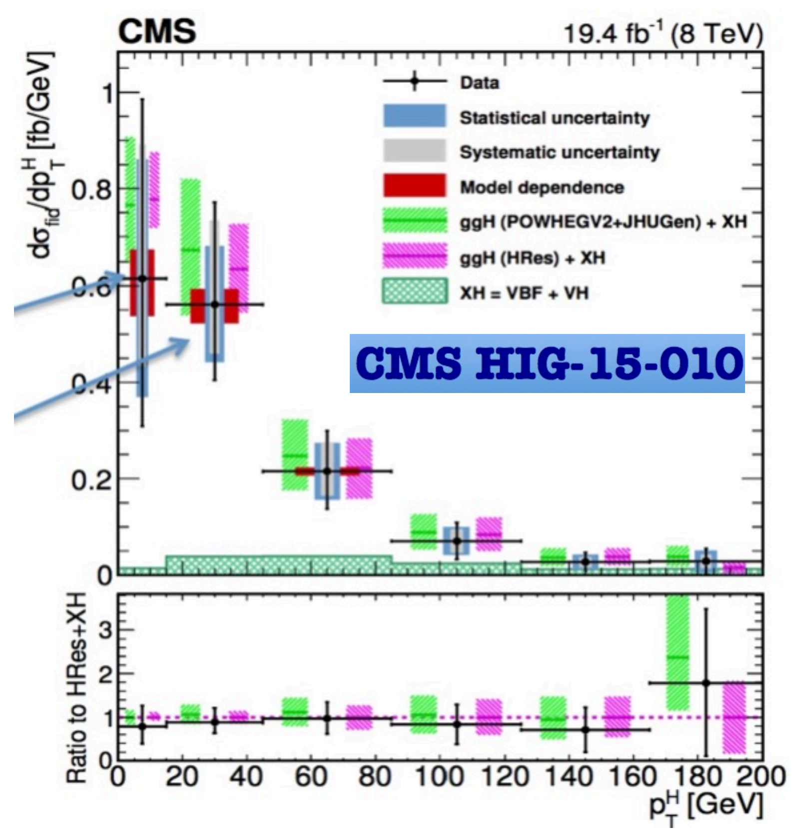
CMS γγ run 1
Korpe



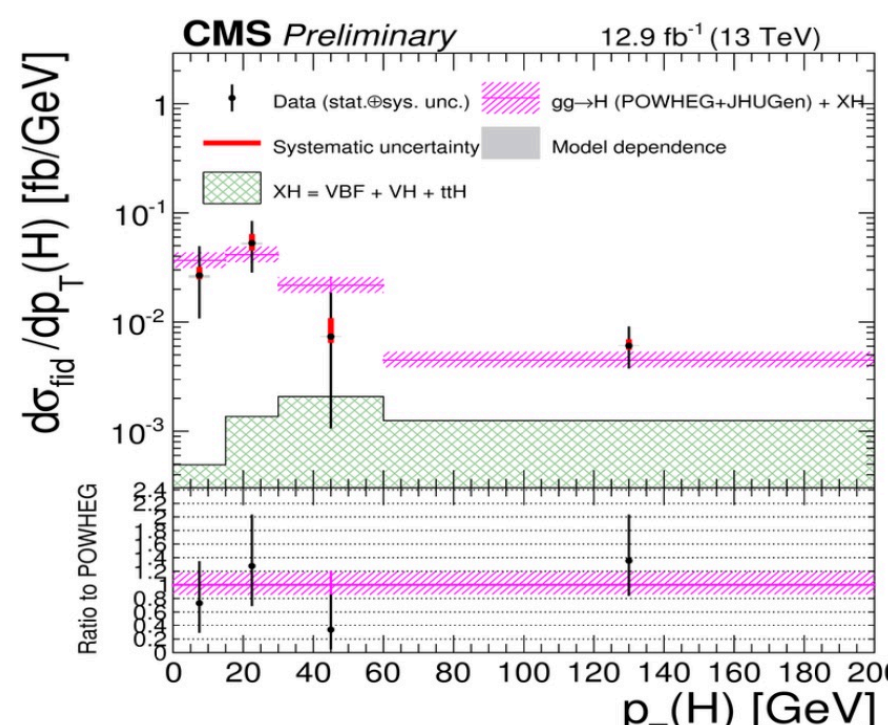
ATLAS 2l2ν run 1
Zambito

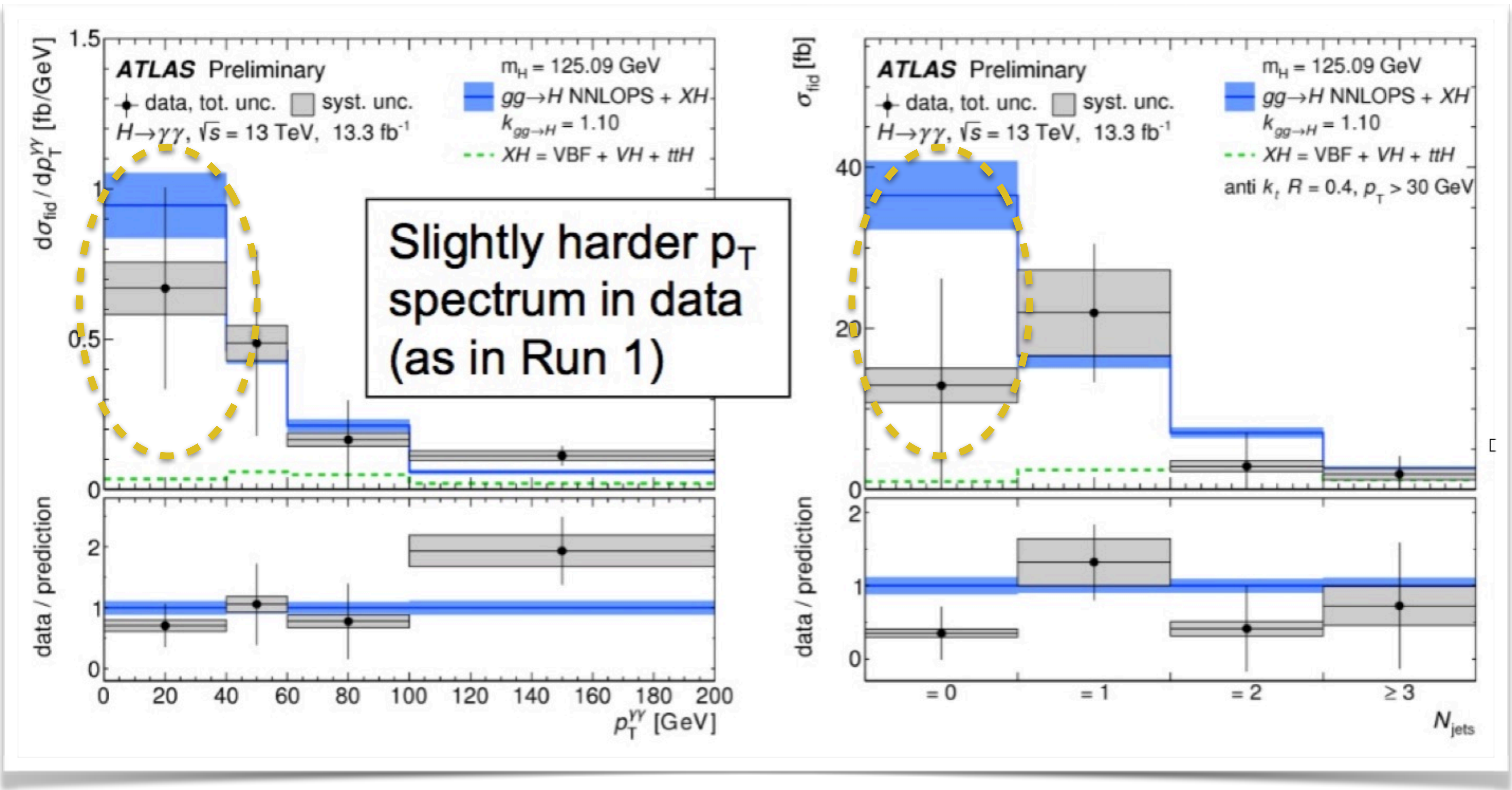


CMS 2l2ν run 1
Kumar, Roskes



CMS 4l run 2
Kumar, Roskes





- δstat ~ 5 δexp => ~25xL ~300fb^{-1} to equalize exp&stat uncert'y
- O(ab^{-1}) will provide an accurate, purely exptl determination of $p_T(H)$ in the theoretically delicate region 0-50 GeV, and **strongly reduce/suppress th'l modeling systematics affecting other measurements (e.g. WW*)**
- More in general, a global programme of higher-order calculations, data validation, MC improvements, PDF determinations, etc, will push further the TH precision….

Remark on EW corrections

For most Higgs physics (e.g. decays, inclusive production) these are under control, known, and small (5% or less, see Spira and Zeppenfeld)

But for more general explorations of EWSB in the high-Q2 regime, they are large, may require NNLO, and the development of dedicated progress

Example: EW corrections to VBS, *Biedermann, Denner, Pellen, arXiv:1611.0295*

$$p_{\mathrm{T,j}} > 30\,\mathrm{GeV}, \quad |y_{\mathrm{j}}| < 4.5, \tag{6}$$

$$p_{\mathrm{T},\ell} > 20\,\mathrm{GeV}, \quad |y_{\ell}| < 2.5. \tag{7}$$

The missing energy is required to fulfill

$$E_{\mathrm{T}}^{\mathrm{miss}} > 40\,\mathrm{GeV}. \tag{8}$$

For the pair of jets, an invariant mass cut and a cut on the difference of the rapidities is applied,

$$M_{\mathrm{jj}} > 500\,\mathrm{GeV}, \quad |\Delta y_{\mathrm{jj}}| > 2.5. \tag{9}$$

Finally, the leptons are required to be isolated,

$$\Delta R_{\ell\ell} > 0.3, \quad \Delta R_{\mathrm{j}\ell} > 0.3, \tag{10}$$

σ^{LO} [fb]	$\sigma^{\mathrm{NLO}}_{\mathrm{EW}}$ [fb]	δ_{EW} [%]
1.5348(2)	1.2895(6)	−16.0

TABLE I: LO and NLO cross section for pp $\to \mu^+\nu_\mu e^+\nu_e jj$ at 13 TeV at the LHC. The corresponding EW corrections are given in per cent. The digit in parenthesis indicates the integration error.

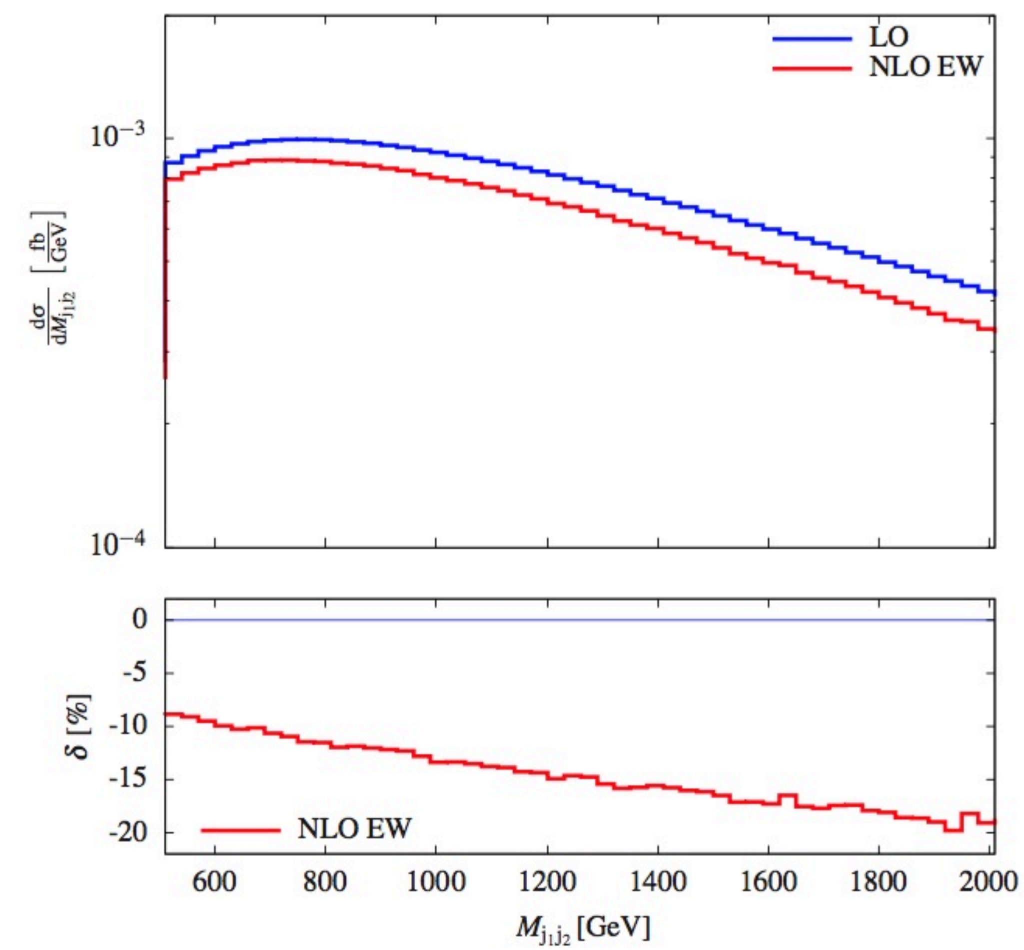


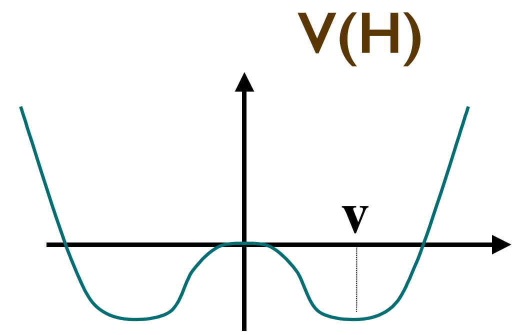
FIG. 1: Dijet invariant-mass distribution in pp $\to \mu^+\nu_\mu e^+\nu_e jj$ including NLO EW corrections (upper panel) and relative NLO EW corrections (lower panel).

=> Possible need for resummation. Need to establish reliability of on-shell results w.r.t. full off-shell ones, since the former are more likely to allow for inclusion of NNLO effects

Higgs couplings

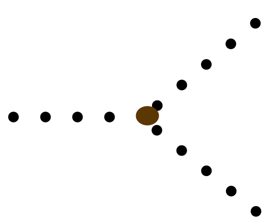
The Higgs sector is defined in the SM by two parameters, **μ** and **λ**:

$$V_{SM}(H) = -\mu^2 \, |H|^2 + \lambda \, |H|^4$$

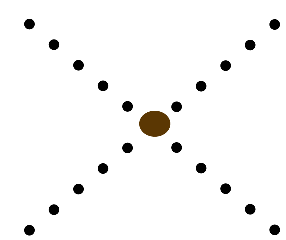


$$\frac{\partial V_{SM}(H)}{\partial H}|_{H=v} = 0 \quad \text{and} \quad m_H^2 = \frac{\partial^2 V_{SM}(H)}{\partial H \partial H^*}|_{H=v} \quad \Rightarrow \quad \boxed{\begin{aligned} \mu &= m_H \\ \lambda &= \frac{m_H^2}{2v^2} \end{aligned}}$$

These relations uniquely determine the strength of Higgs selfcouplings in terms of the two now accurately known parameters m_H and v



$g_{3H} \Rightarrow 4\lambda v = \boxed{\frac{2m_H^2}{v}}$



$g_{4H} \Rightarrow \lambda = \boxed{\frac{m_H^2}{2v^2}}$

See the talks 2hrs ago for the motivations (Perelstein), and the near (Petersen) and far (Klute, Tanabe)-term prospects for the direct measurement of g_{3H}

The couplings to fermions and gauge bosons are fixed by the known v, g, g' and m_f

➡ in the context of the SM, there is nothing more to be learned from the Higgs.

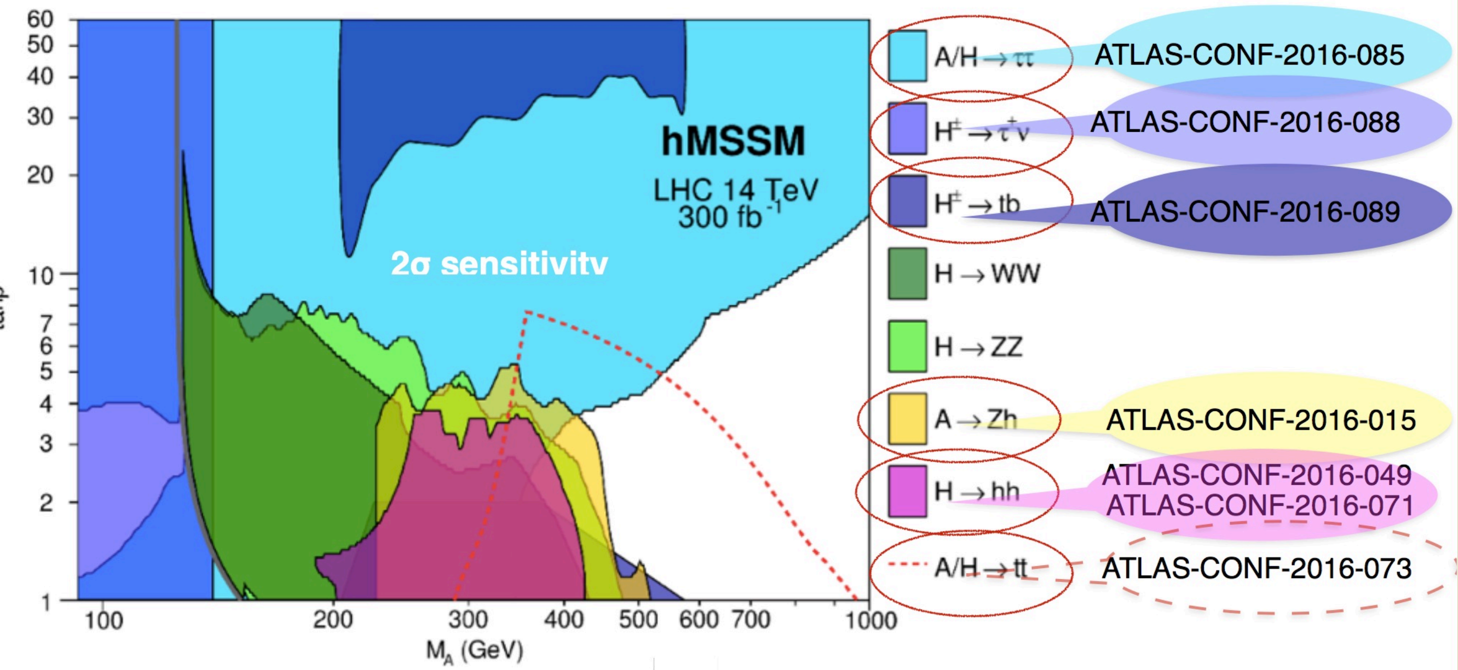
- This is a blessing and a curse:
  - A curse, since we might spend the rest of our lives confirming what we already know
  - A blessing, since we now have all ingredients required to assess the (in)consistency of exptl data with the SM itself
- In the same way all other SM objects (W/Z, top, b, …) are today essential probes of physics BSM, the Higgs is becoming a “routine” tool for the exploration of new phenomena
- In particular, the Higgs remains interesting even if the SM Higgs mechanism turned out to be the true underlying source of EWSB

Higgs and BSM

- Two extreme scenarios ….
  - EWSB is intrinsically BSM (e.g. composite Higgs)
    - Higgs properties are directly modified
  - EWSB is basically SM, it is not affected by BSM
    - Higgs properties are not visibly modified, but BSM particles manifest themselves through the Higgs (e.g. $\chi_2 \to h\chi_1$)
- … plus every scenario in between

This makes Higgs physics immensely rich, diverse and challenging

H & BSM, direct searches



Additional Higgses

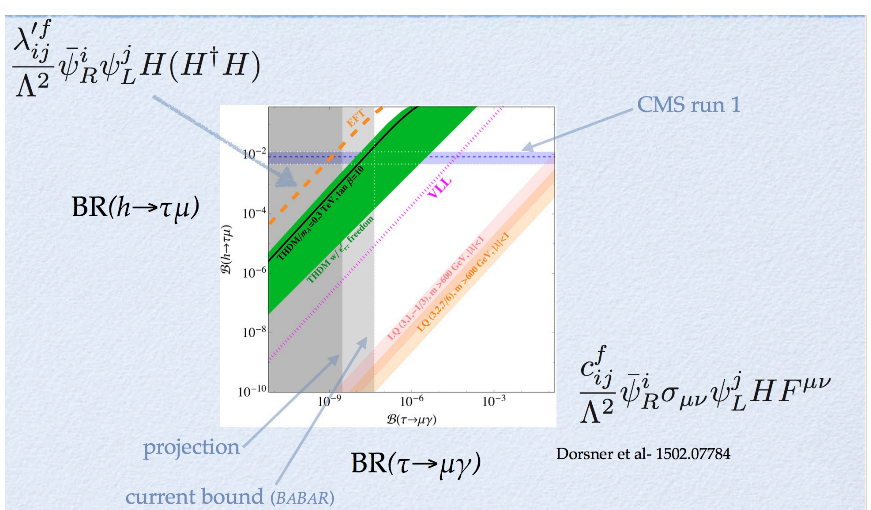
Ferrari (ATLAS)
Mohammadi (CMS)
Shaffer (ATLAS)
Chertok (CMS)
Haber (TH)

Higgs as BSM final state

Etzion

BSM decays, flavour

Ospanov (ATLAS/CMS)
Dasu (ATLAS/CMS)
Gori (TH)
Yu (TH)
Soreq (TH)



BSM + Higgs tags new results (ICHEP++)

➡ Higgs in EXOT/SUSY cascades

- CMS EW prod. of charginos and neutralinos in the WH
- CMS SUSY with a Higgs to γγ (razor)
- ATLAS Res. to W/Z + H in qqbb, in llbb, lvbb,vvbb

➡ Vector like quarks

- ATLAS VLQ T'->Zt , T'->Wb
- CMS VLQ single T'->tH (l+H) , T'->tH (hadronic)
- CMS VLQ pair T->boosted tH (leptonic)

➡ DM searches

- CMS DM + jet / hadronically decaying W/Z
- ATLAS DM association with a hadronically decaying W/Z
- ATLAS DM with b quarks, with top quarks …

➡ Mono Higgs

- ATLAS DM + H(γγ)
- ATLAS DM + H(bb)
- CMS DM + H(γγ), DM + H(bb)

➡ DiHiggs

- ATLAS hh the bbbb final
- ATLAS hh in the γγWW*
- CMS hh in 4b resonance and non resonance
- CMS hh in bbττ resonance and non resonance
- CMS hh in bbγγ, hh in bbℓνℓν

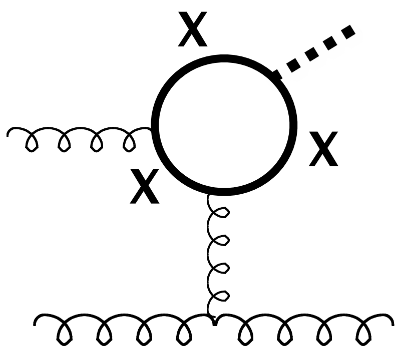
BSM H model building, DM and pheno

Tait
Falkowski
Rattazzi

- The scenarios we are interested in will reflect into the tools to be used
  - BSM at large E scales ⇒ EFT ⇒ precision physics of BRs, TGCs, …
  - BSM at accessible E scales ⇒ go after direct production
- Once again, there is however plenty of variety in between:
  - low-mass BSM particles may be invisible ($H \to inv$), or
  - they may be elusive in direct searches (EWinos in the few-100 GeV region, stops near m_{top} or beyond direct reach, etc.)

Example: gg-> H at large p_T

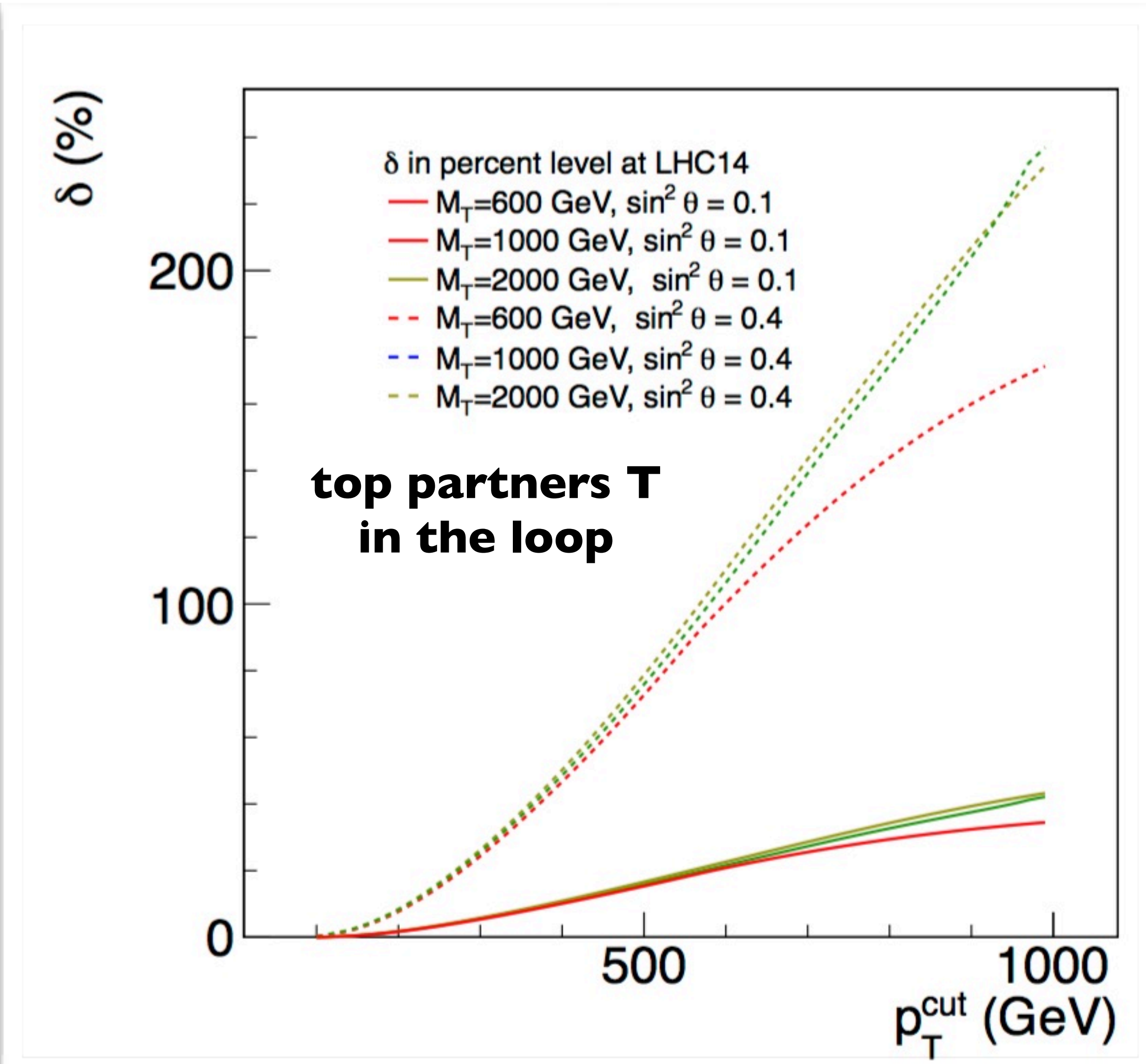
Monitor deviations in $d\sigma/dp_T(H)$ at large p_T induced by extra particles in the ggH loop

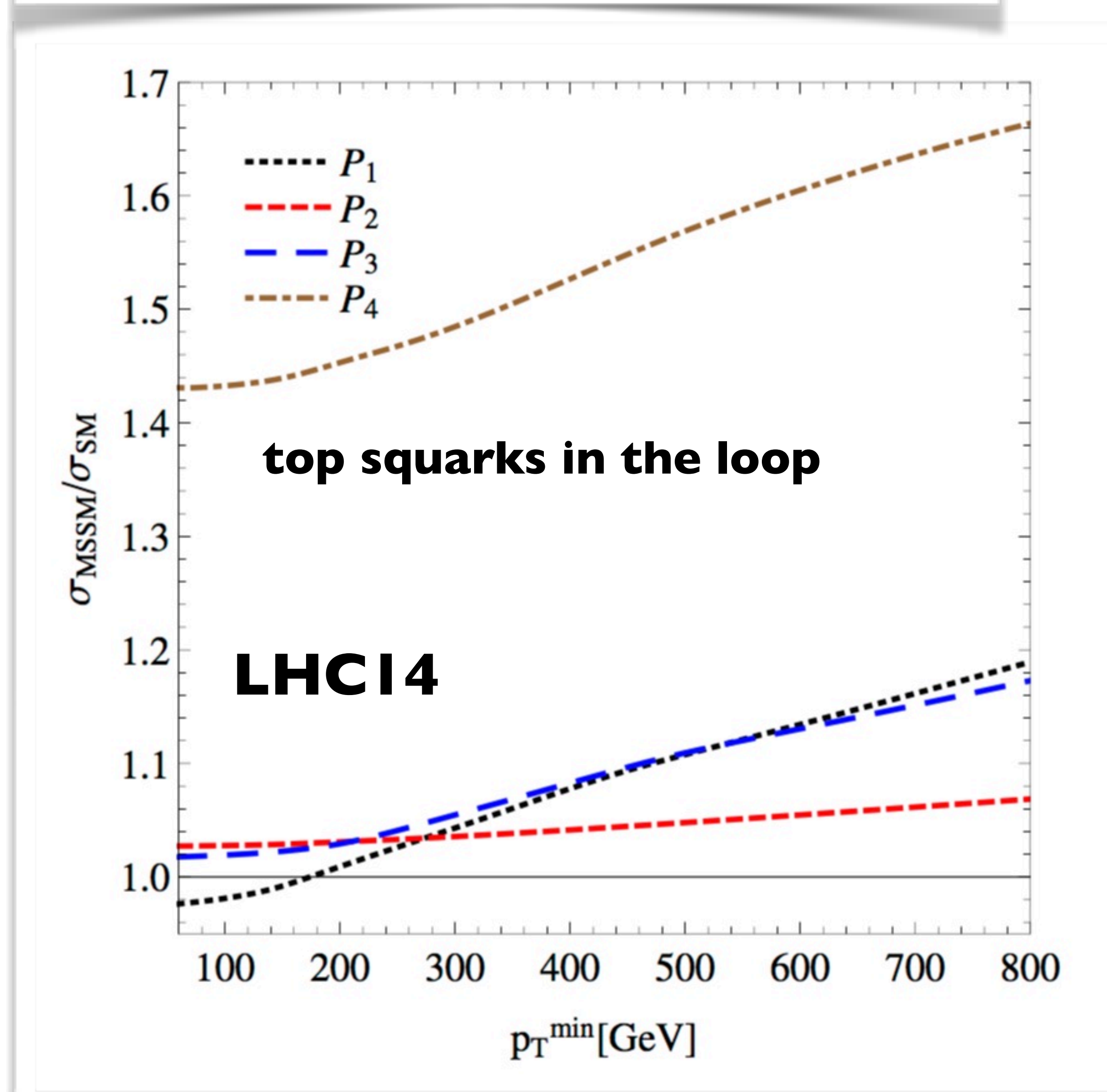


X=t, stop, T, …

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

(See also Azatov and Paul arXiv:1309.5273v3)

Indirect Higgs probes of new physics at large statistics

- Higher statistics shifts the balance between systematic and statistical uncertainties. It can be exploited to define different signal regions, with better S/B, better systematics, pushing the potential for better measurements beyond the "systematics wall" of low-stat measurements.

- We often talk about "**precise**" Higgs measurements. What we actually aim at, is "**sensitive**" tests of the Higgs properties, where *sensitive* refers to the ability to reveal BSM behaviours.

- *Sensitivity* may not require extreme precision
    - Going after "sensitivity", rather than *just* precision, opens itself new opportunities …

Higgs as a BSM probe: precision vs dynamic reach

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

$$O = | \langle f|L|i\rangle |^2 = O_{SM} \left[1 + O(\mu^2/\Lambda^2) + \cdots\right]$$

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. δO=1% $\Rightarrow$ $\Lambda \sim$ 2.5 TeV

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

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

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

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

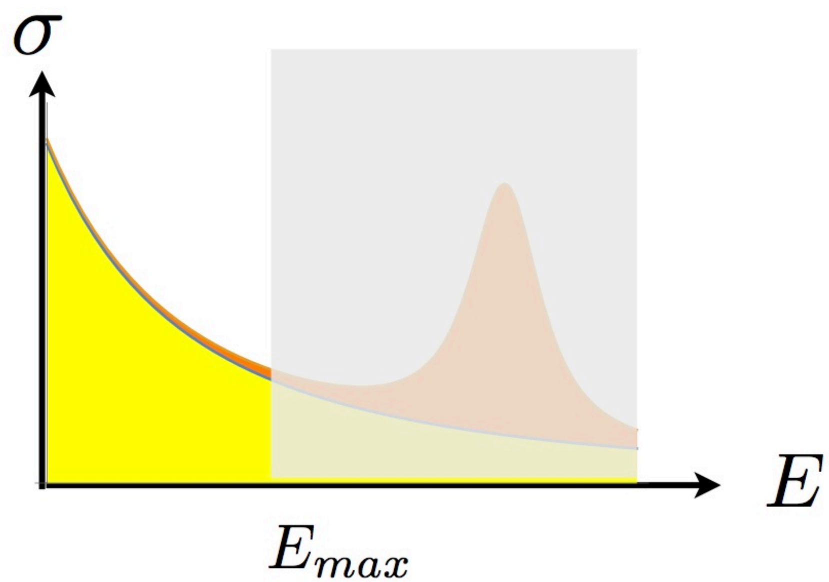
Nota Bene

- This argument is independent of a rigorous approach to EFT. It's intended to establish a crude connection between the sensitivity of low-Q and high-Q observables. It highlights the potential complementarity and synergy of the two approaches, and underscores the emergence at high luminosity of new independent observables
- Assessing in detail the connection between these two EFT probes will well require, and reinforce the need of, the rigorous EFT/PO frameworks that have recently emerged.

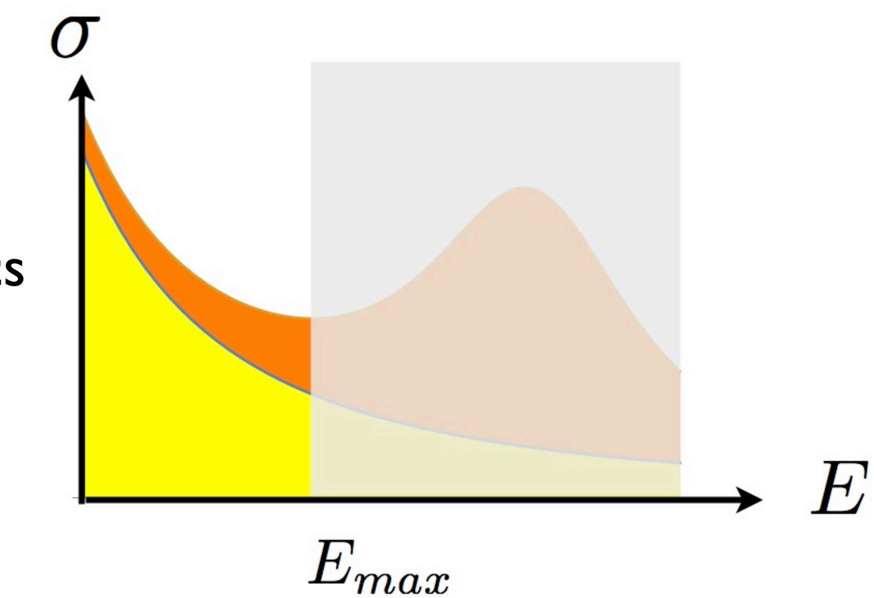
Plenary:	Parallel:
Manohar	Gomez Ambrosio
Isidori	Krause
Dawson	
Sanz	

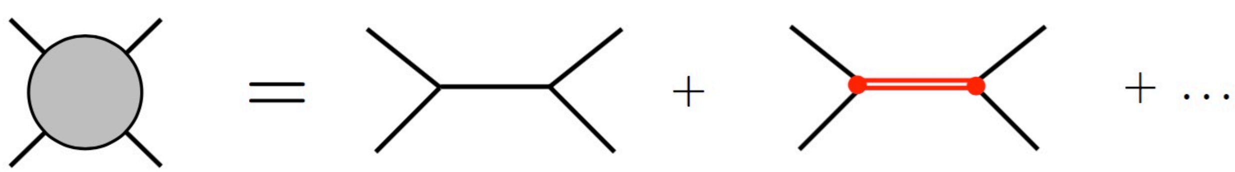
Rattazzi

Weak dynamics
Better have e^+e^-



Strong dynamics
Better have pp





$$\mathcal{A}(2 \to 2) \quad \sim \quad g_{SM}^2 \; + \; g_*^2 \frac{E^2}{m_*^2} \; + \ldots$$

Experiment: $\quad \dfrac{\Delta\mathcal{A}}{\mathcal{A}_{SM}} < \epsilon \qquad m_* > \dfrac{E}{\sqrt{\epsilon}} \times \dfrac{g_*}{g_{SM}}$

Effectively, at LHC often $\epsilon \sim O(1)$

The study is meaningful only if $g_* > g_{SM}$

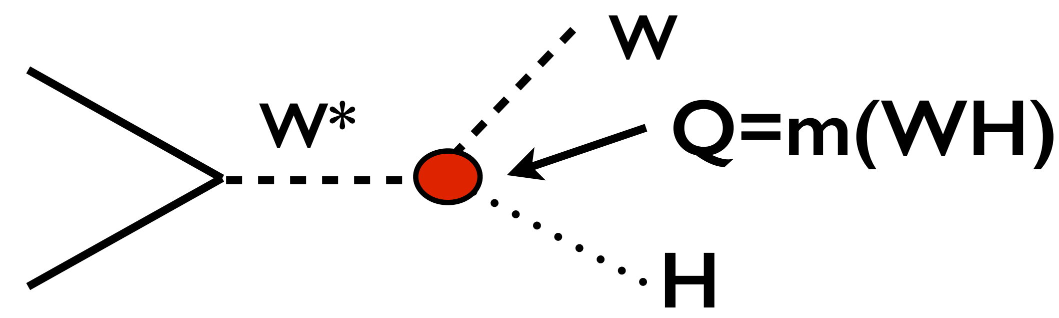
If $g_* \sim g_{SM}$ must directly search for resonances

But higher statistics and better precision may allow to extend the range over which pp high-E observables allow to probe either weaker couplings, or scales above the direct reach:

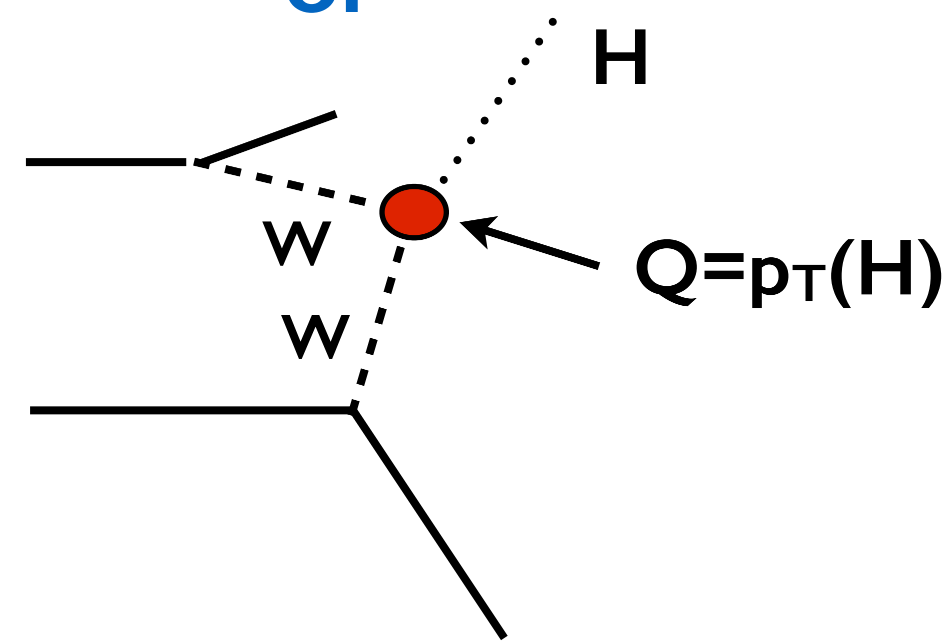
ε~10% => m_* > 3 E also for $g_* \sim g_{SM}$

Examples

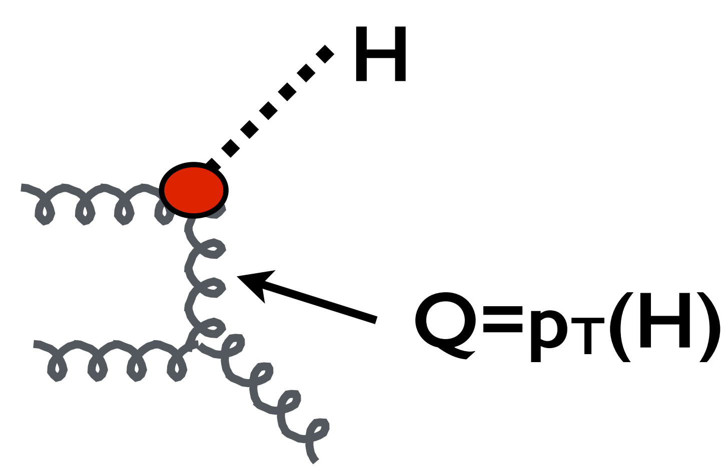
$\delta BR(H \to WW^*)$



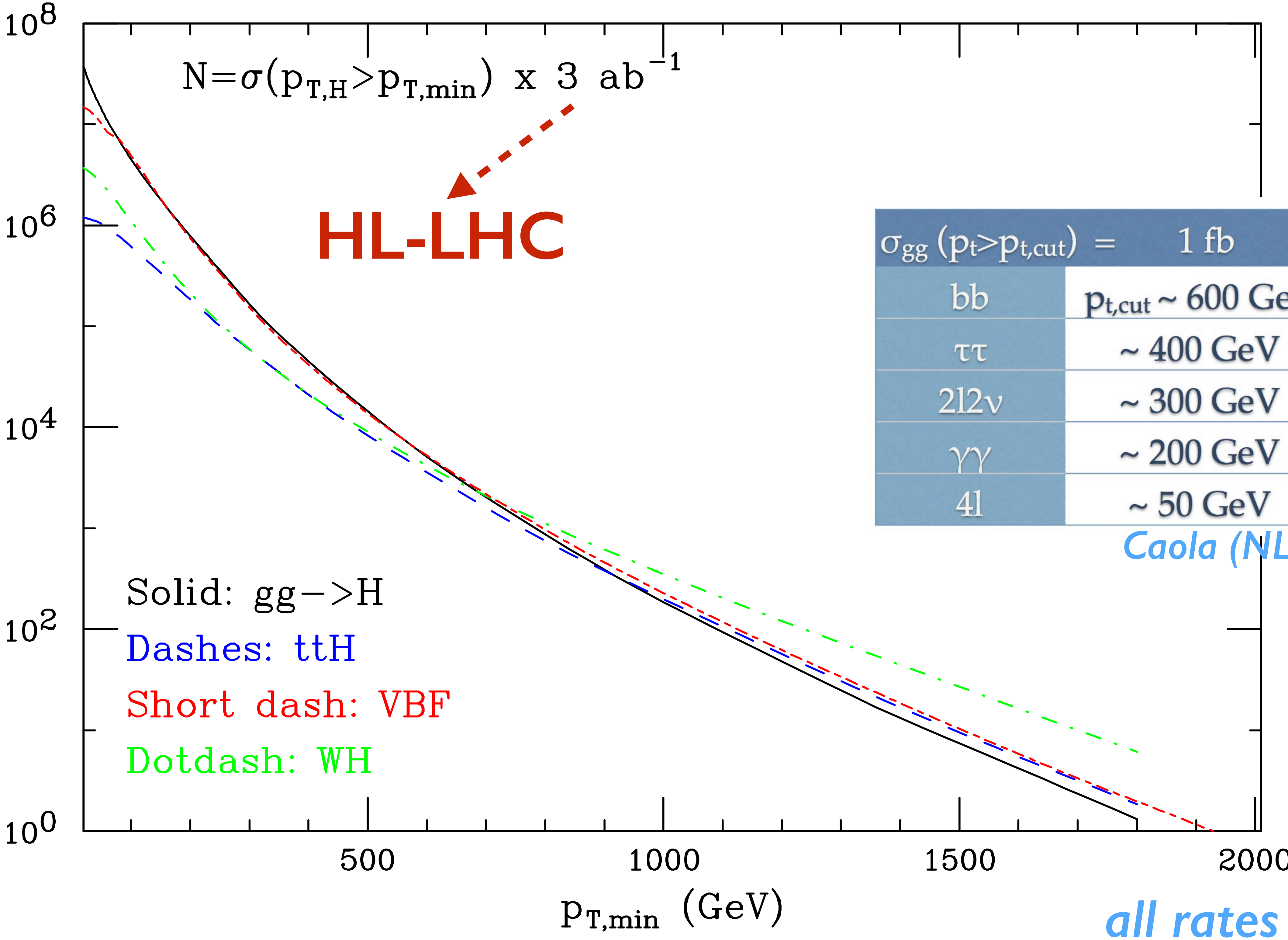
or



$\delta BR(H \to gg)$



Probing large Q:
Higgs production at large p_T



σ_{gg} (p_t>$p_{t,cut}$) =	1 fb	1 ab
bb	$p_{t,cut}$ ~ 600 GeV	$p_{t,cut}$ ~ 1.5 TeV
ττ	~ 400 GeV	~ 1.2 TeV
2l2ν	~ 300 GeV	~ 1 TeV
γγ	~ 200 GeV	~ 750 GeV
4l	~ 50 GeV	~ 450 GeV

Caola (NLO rates for gg->H)

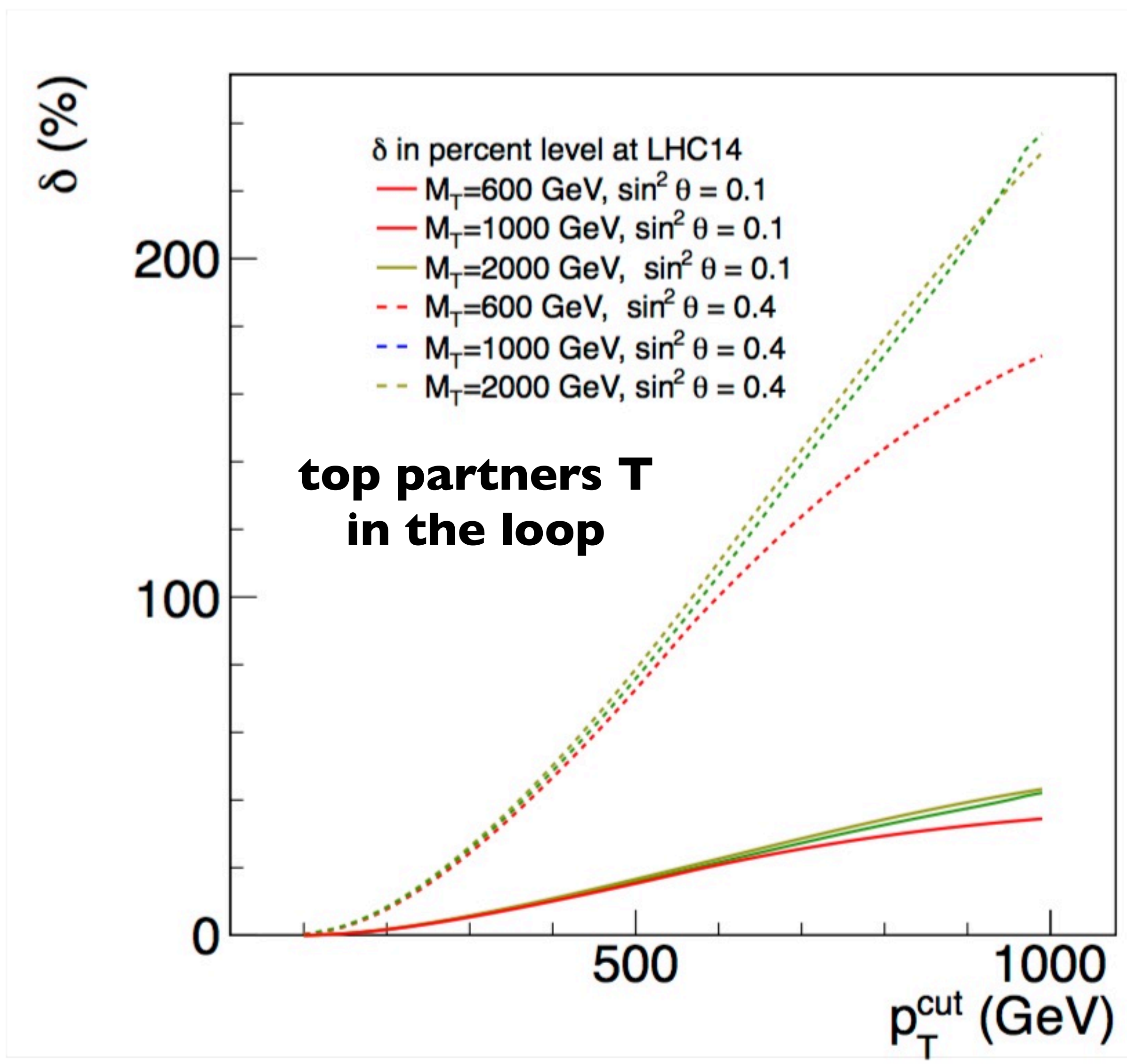
all rates LO

Examples: gg-> H at large p_T

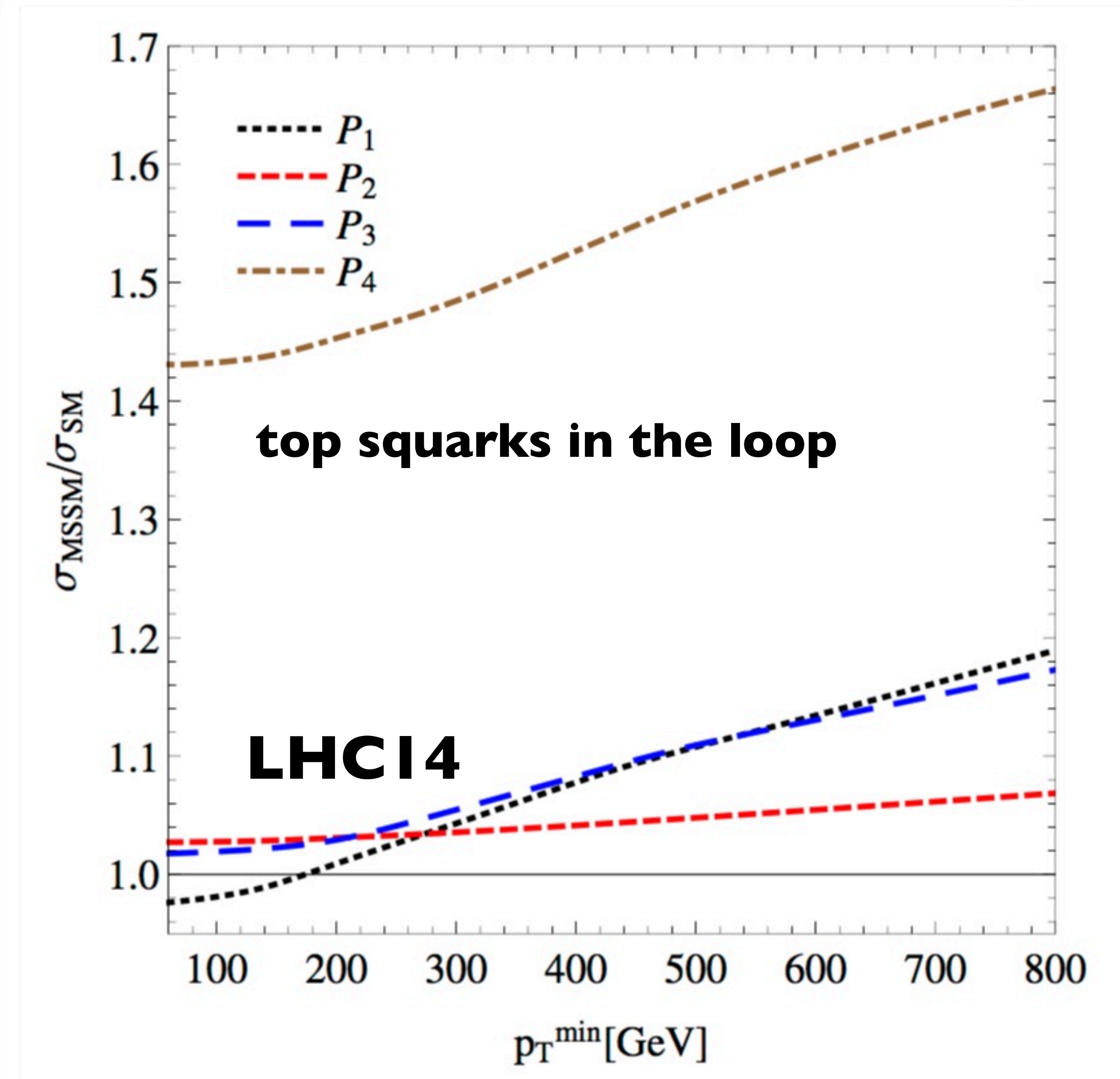
Table 3: The benchmark points shown in Fig. 7. We set $\tan\beta = 10$, $M_{A^0} = 500$ GeV, $M_2 = 1000$ GeV, $\mu = 200$ GeV and all trilinear couplings to a common value A_t. The remaining sfermion masses were set to 1 TeV and the mass of the lightest CP-even Higgs was set to 125 GeV.

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

(See also
Azatov and Paul arXiv:1309.5273v3)



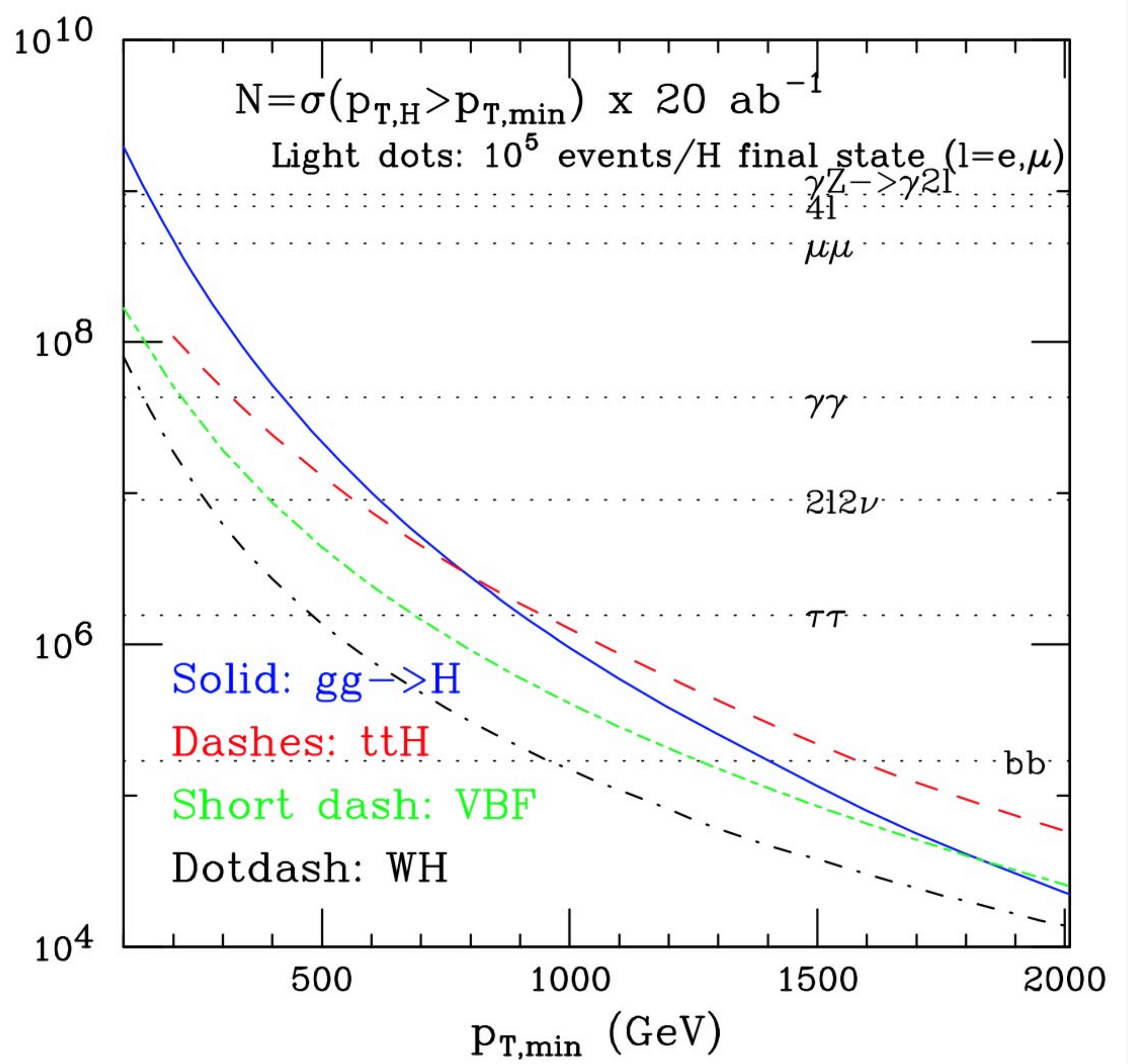
Banfi Martin Sanz, arXiv:1308.4771



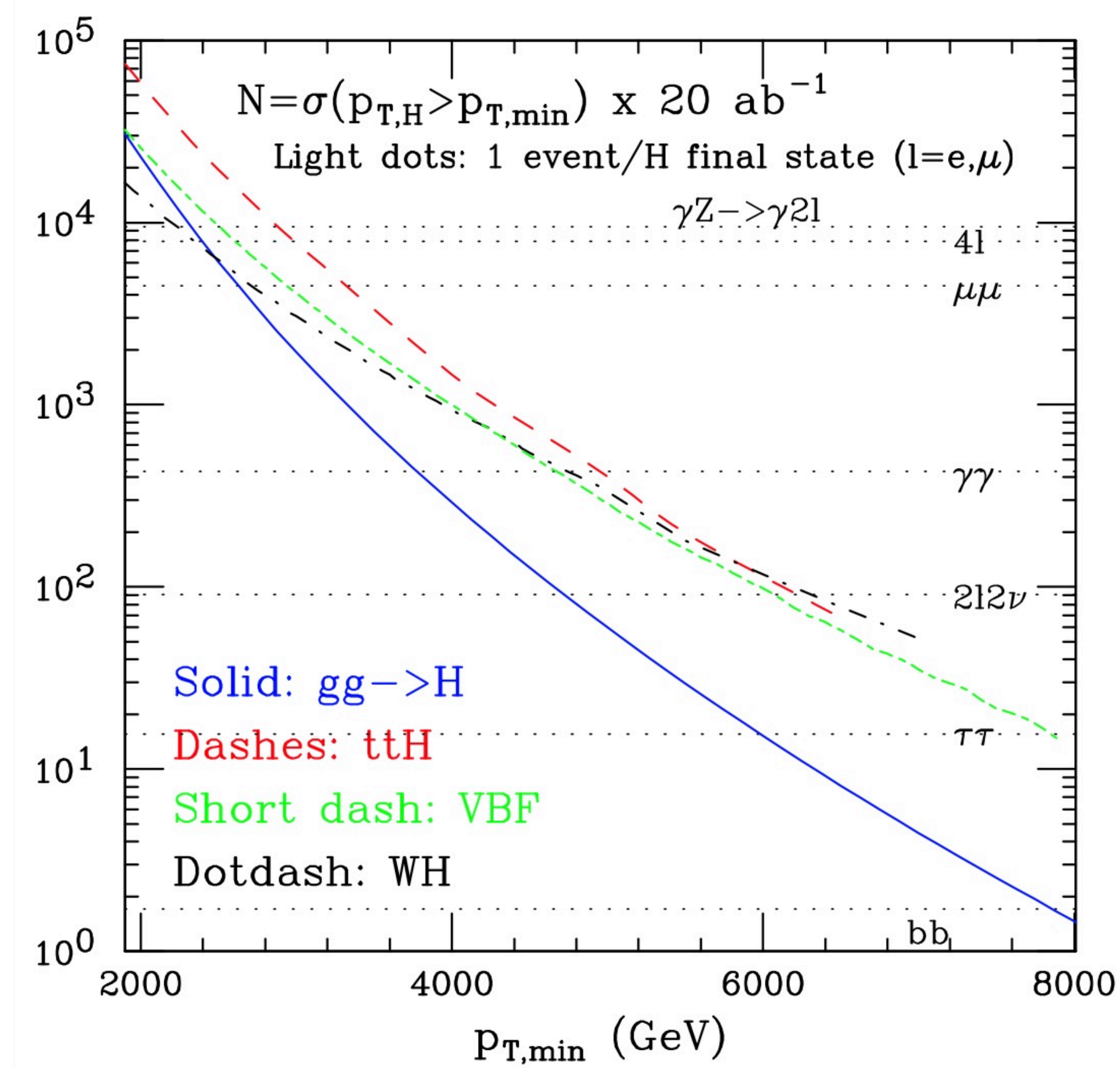
Grojean, Salvioni, Schlaffer, Weiler arXiv:1312.3317

10% sensitivity at p_T(H)~1TeV is compatible with 3ab^{-1} rates in previous page

... at 100 TeV ...

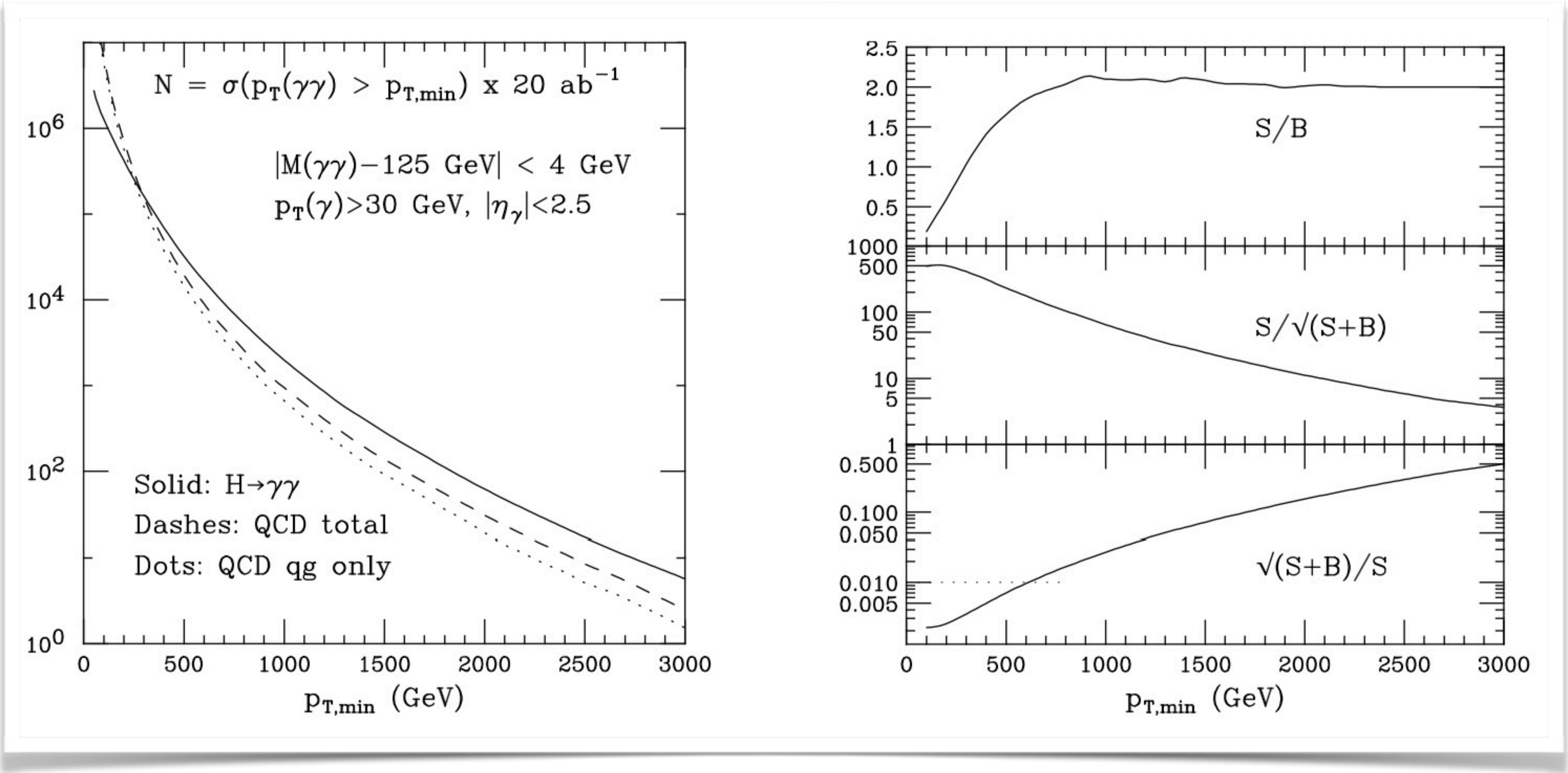


$N=\sigma(p_{T,H}>p_{T,min})$ x 20 ab^{-1}
Light dots: 10^5 events/H final state (l=e,μ)
$\gamma Z\to\gamma 2l$
4l
$\mu\mu$
$\gamma\gamma$
2l2ν
$\tau\tau$
bb
Solid: gg->H
Dashes: ttH
Short dash: VBF
Dotdash: WH
$p_{T,min}$ (GeV)



$N=\sigma(p_{T,H}>p_{T,min})$ x 20 ab^{-1}
Light dots: 1 event/H final state (l=e,μ)
$\gamma Z\to\gamma 2l$
4l
$\mu\mu$
$\gamma\gamma$
2l2ν
$\tau\tau$
bb
Solid: gg->H
Dashes: ttH
Short dash: VBF
Dotdash: WH
$p_{T,min}$ (GeV)

$H \to \gamma\gamma$ S/B at large p_T — (100 TeV)

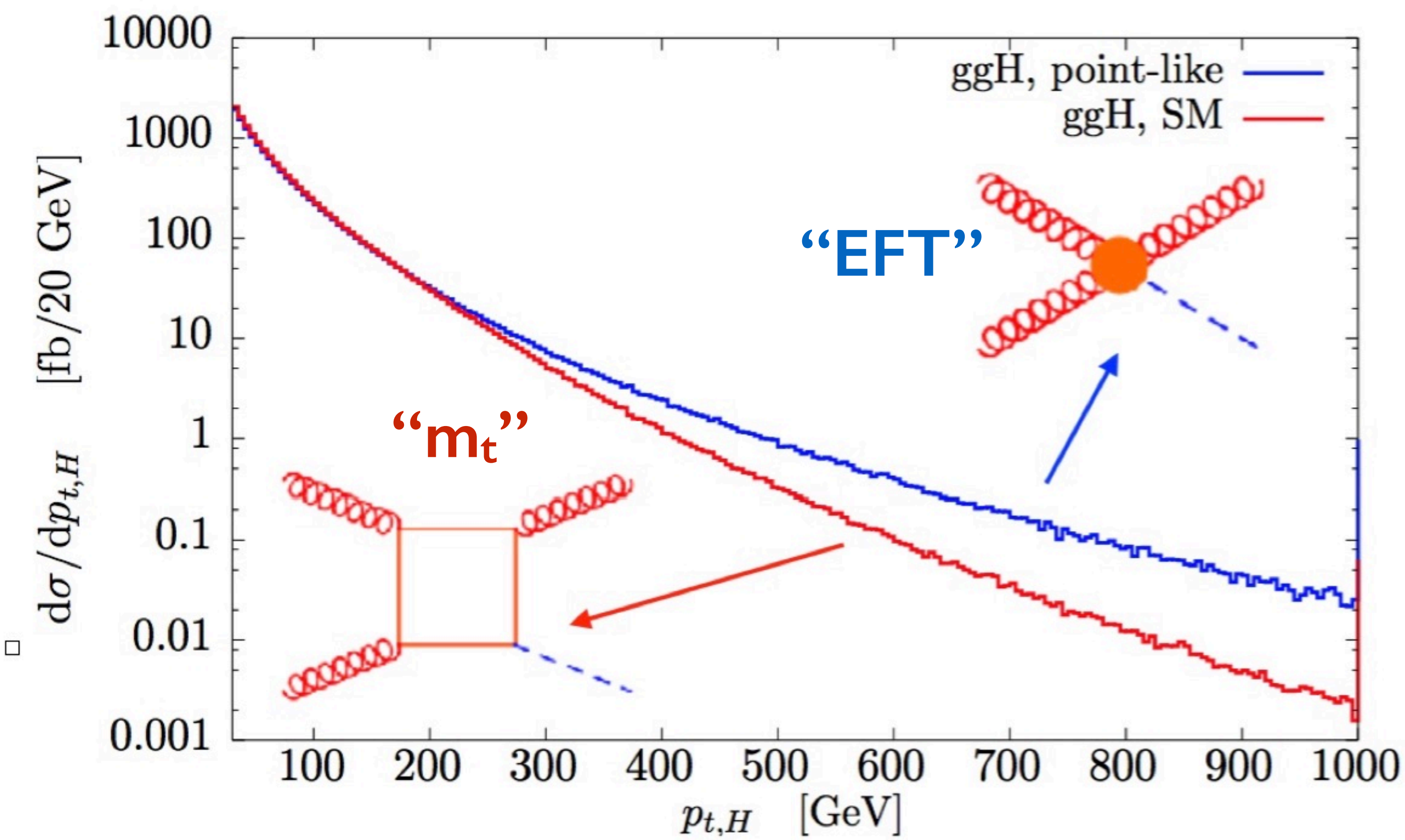


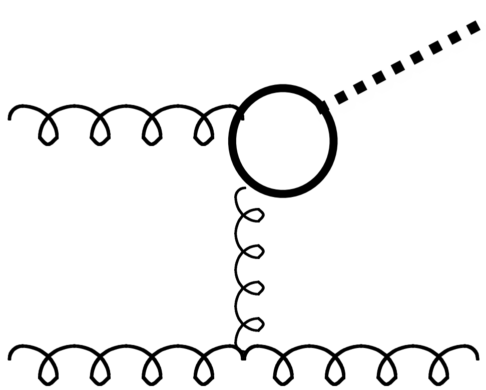
- At LHC, S/B in the $H \to \gamma\gamma$ channel is O(few %)
- At FCC, for $p_T(H)>300$ GeV, S/B~1

- For high-Q observables, e.g. differential distributions vs Q, anomalies amount to changes, w.r.t. SM, in the shape of the distributions.
- Shapes are free from ultimate and possibly unbeatable experimental systematics, such as the luminosity determination
- Shapes are also independent of the impact of BSM on BR's, which could compensate the impact on rates for inclusive production
- Shapes are typically less susceptible to theoretical systematics: one can often rely on a direct experimental determination of the SM reference behaviour, and can benefit from validation of the theoretical SM modeling through data/MC comparisons in control samples.
- Systematic studies of SM dynamics provide therefore a critical component of the LHC programme of "sensitive" Higgs measurements

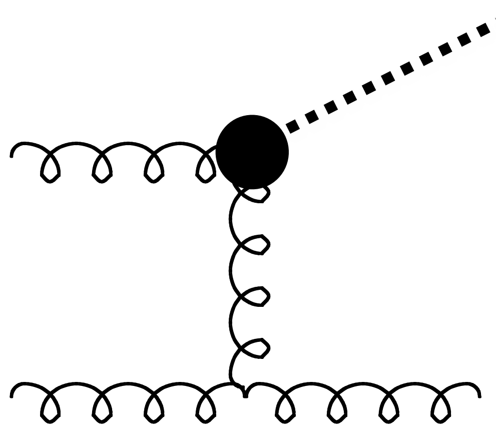
TH syst's at large p_T^H

F.Caola





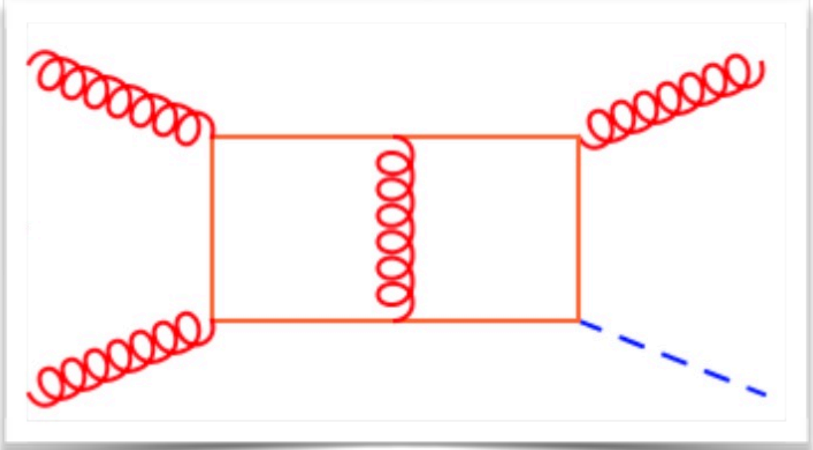
$\sim f(\, p_T/m \,)$



$$f \sim \frac{4m^2}{4m^2 + p_T^2} \quad \begin{array}{l} \to 1 \text{ for } p_T \ll m \\ \to 1/p_T^2 \text{ for } m \ll p_T \end{array}$$

No NLO available for finite m_{top} ....

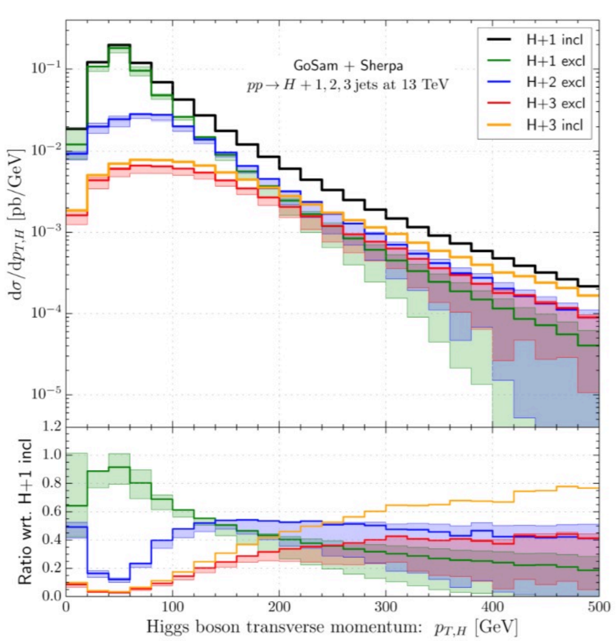
F.Caola



- NLO at high momentum transfer: 2-loop amplitudes with several external (s, p_t, m_h) and internal (m_t) mass scales → *significantly more complicated than any amplitude computed so far*

Boosted Higgs: interim solution

In the boosted kinematic regime, sizable contribution of the full QCD correction comes from Real Radiation → 1 Loop



[Luisoni, based on Greiner et al (2016)]

- Recent studies of mass-effects in multi-leg one-loop amplitudes [Frederix et al (2016), Greiner et al (2016)]
- NLO K-factor for HEFT has the qualitative behavior predicted by high-energy resummation [Muselli et al (2016)]
- *Reasonable* to expect similar behavior in the full theory
- Consistency check: different incarnation of the same idea (real emission dominance) should give the same qualitative picture

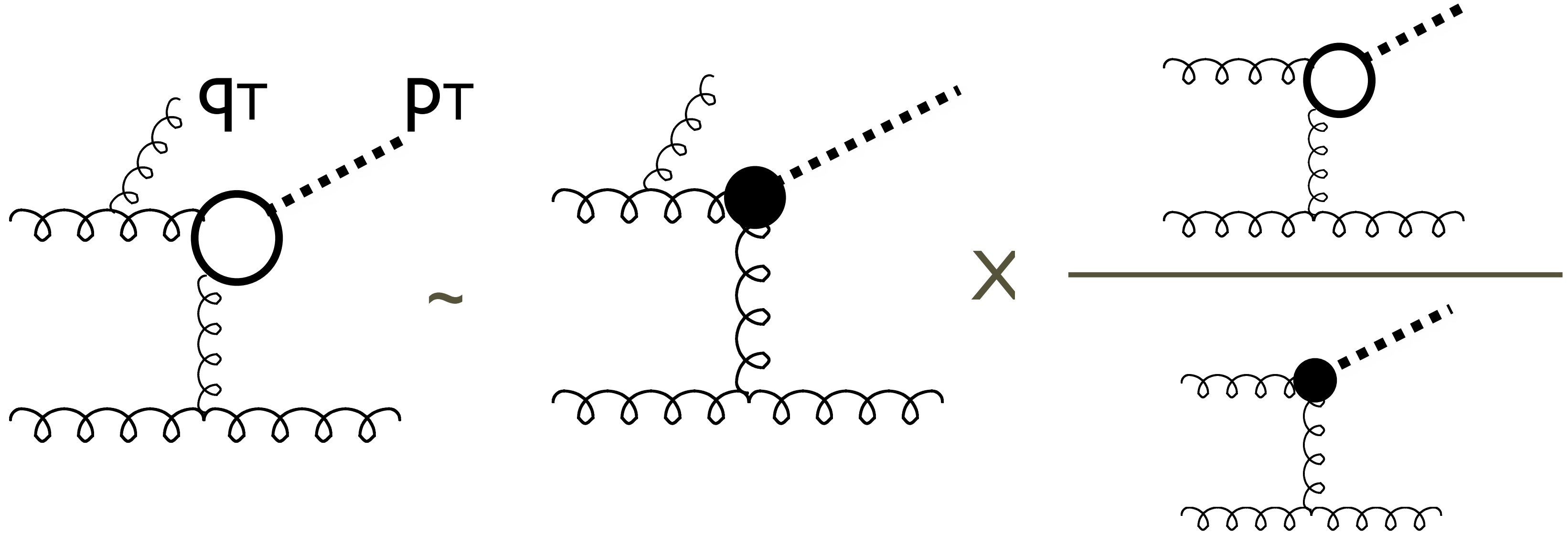
$$\left[\frac{d\sigma_{NLO}}{dp_T}\right]_{m_t} = f(p_T/m)\left[\frac{d\sigma_{NLO}}{dp_T}\right]_{EFT}$$

Merging approach

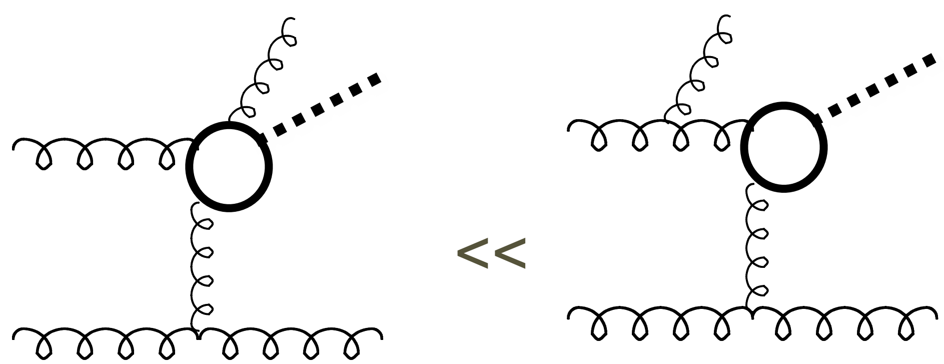
Justification for this approximation:

For $q_T < p_T$

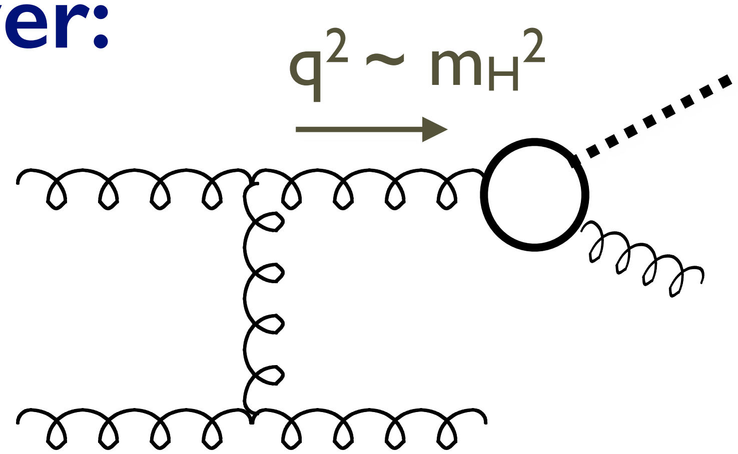
(a)



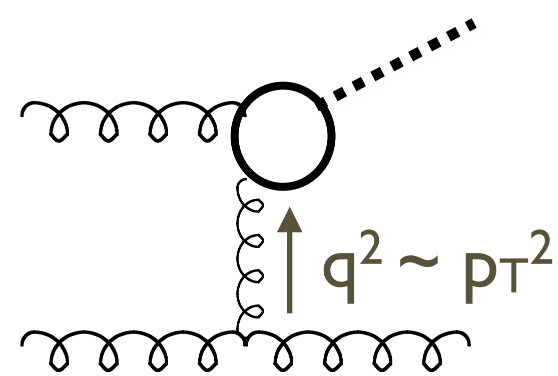
(b)



However:



$$\sim \# \, \alpha_S \, \frac{m^2 + p_T^2}{m^2}$$

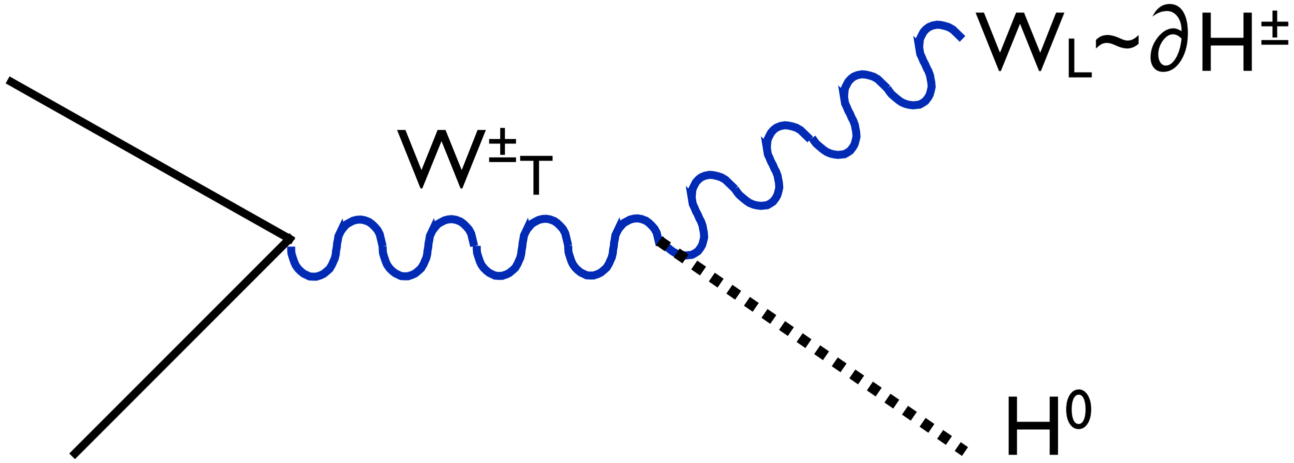


These diagrams will eventually take over at very large p_T.

They are not covered by the “merging” approach …. this should be looked at in some more detail ….

VH prodution at large m(VH)

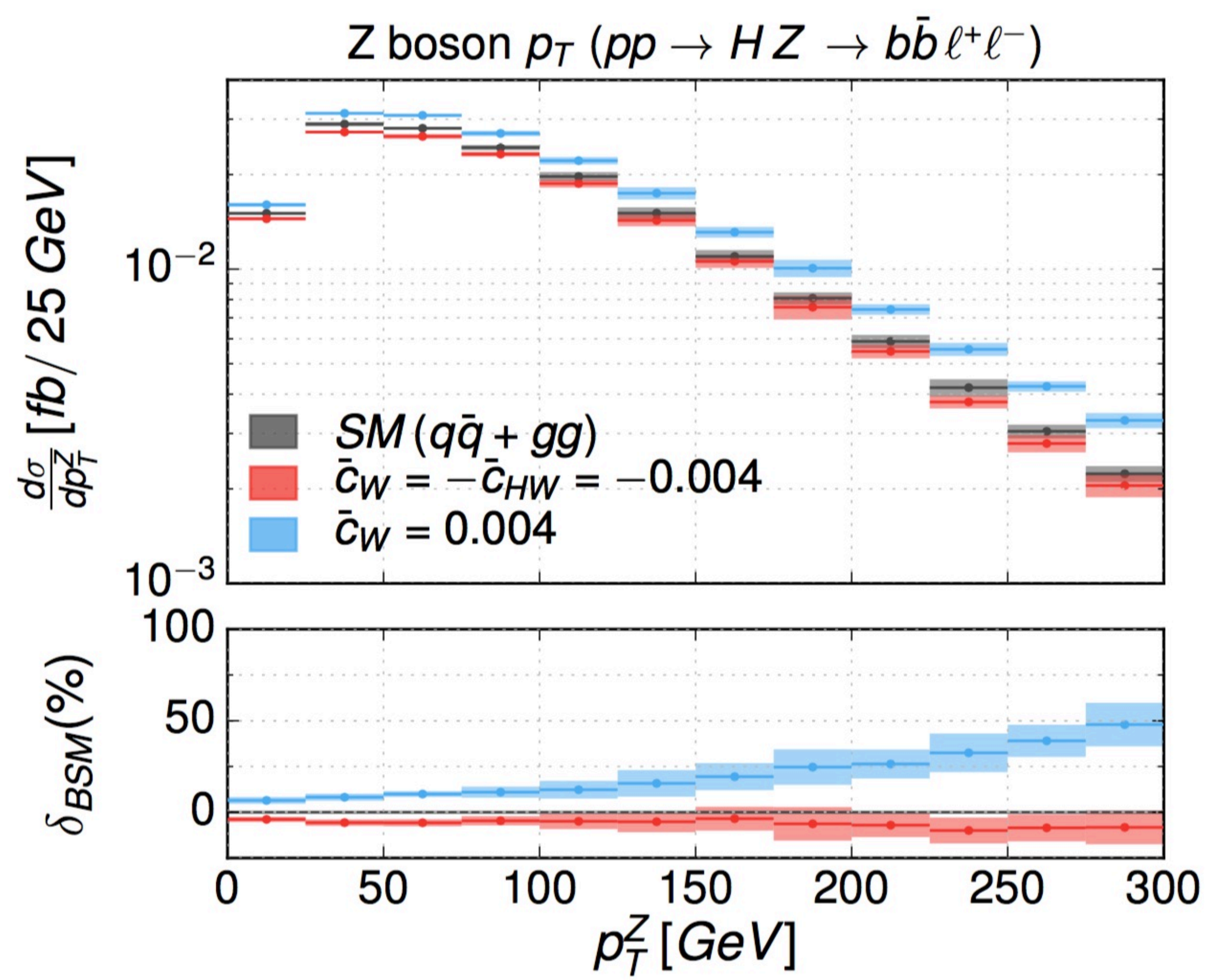
See e.g.
Biekötter, Knochel, Krämer, Liu, Riva, arXiv:1406.7320



In presence of a higher-dim op such as:

$$L_{D=6} = \frac{ig}{2}\frac{c_W}{\Lambda^2}\left(H^\dagger \sigma^a D^\mu H\right) D^\nu V^a_{\mu\nu}$$

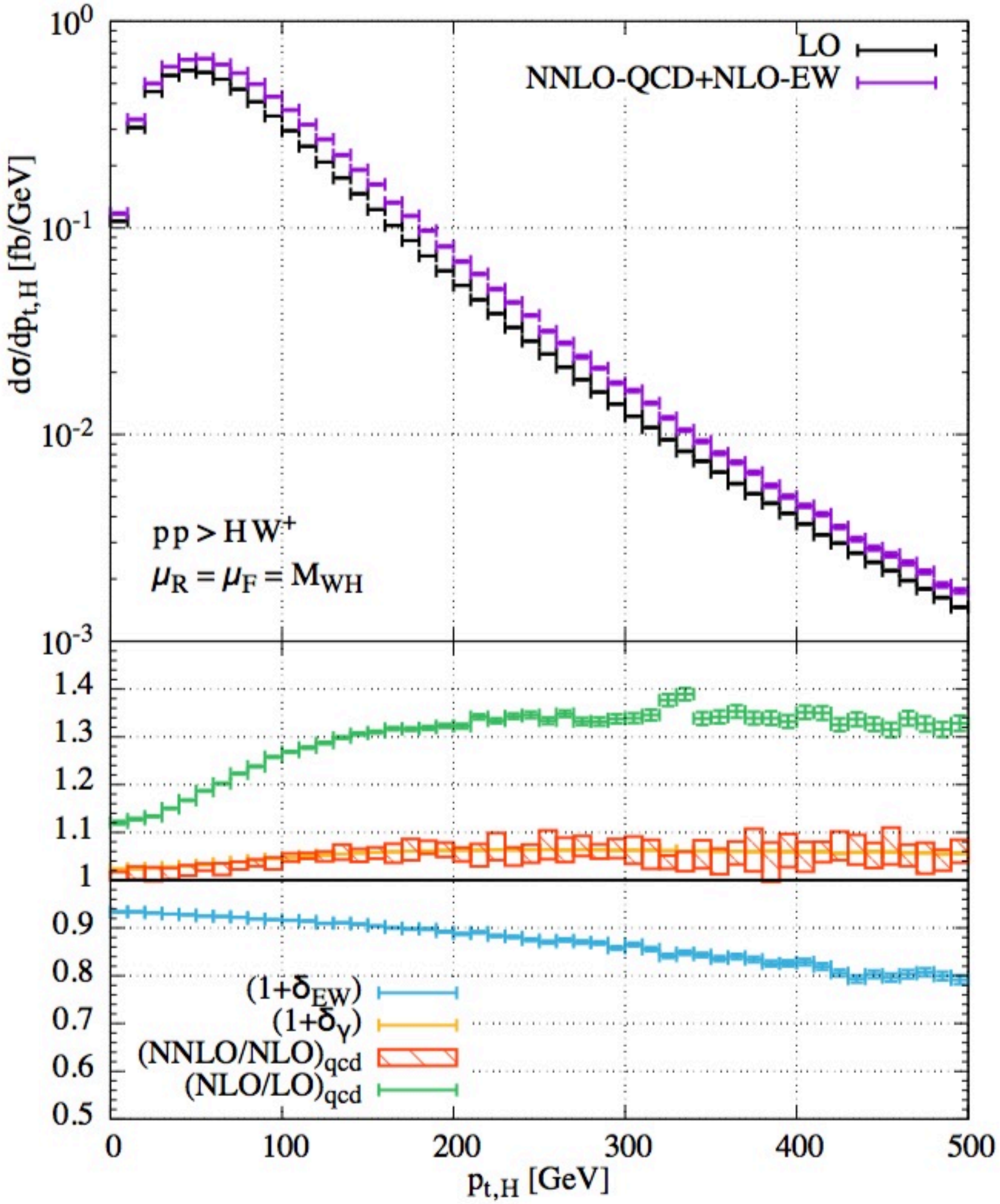
$$\frac{\sigma}{\sigma_{SM}} \sim \left(1 + c_W \frac{\hat{s}}{\Lambda^2}\right)^2$$

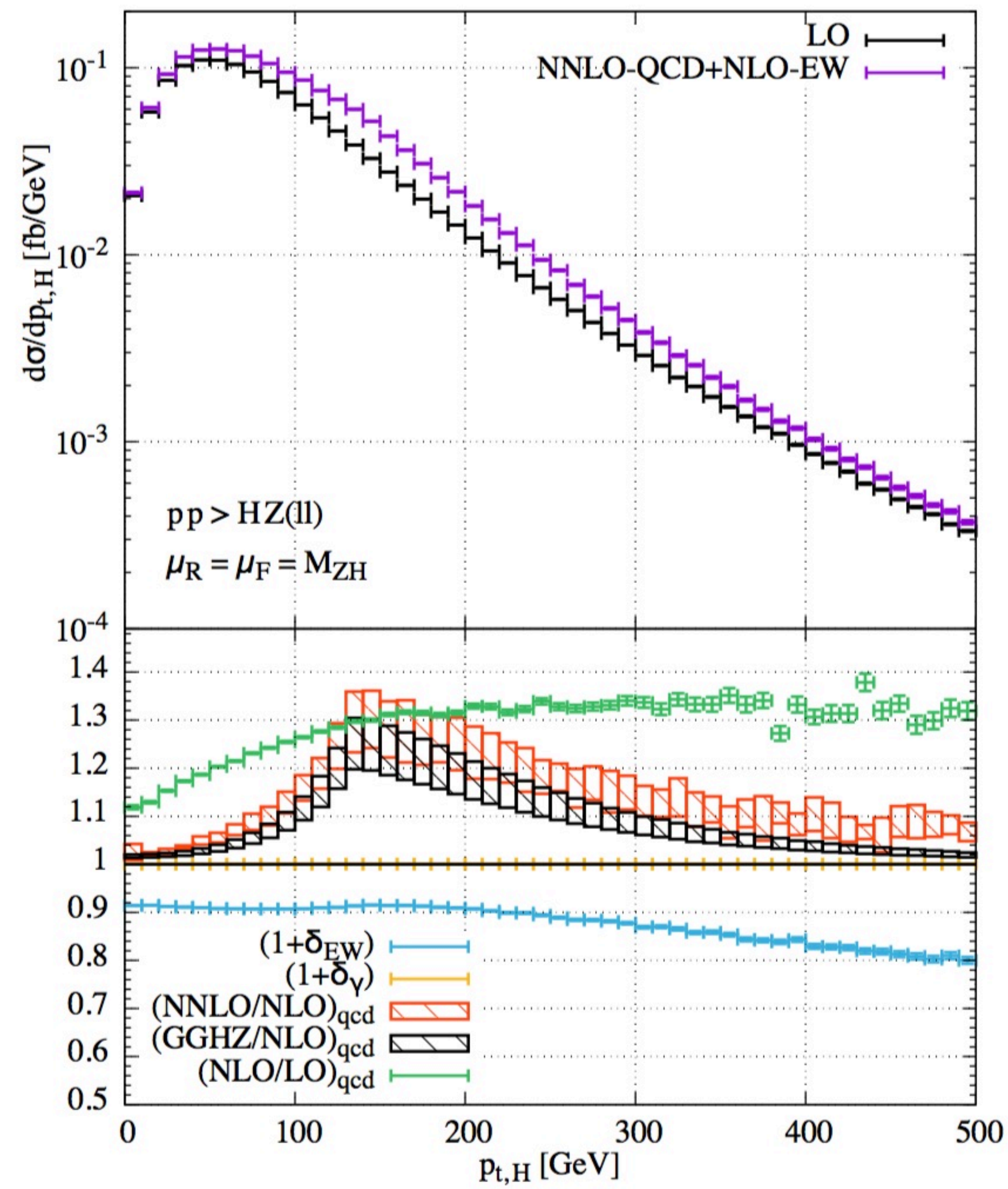


Mimasu, Sanz, Williams, arXiv:1512.02572v

important higher-order effects (QCD & EW) must be included to control theoretically the signal slope to the few-% level

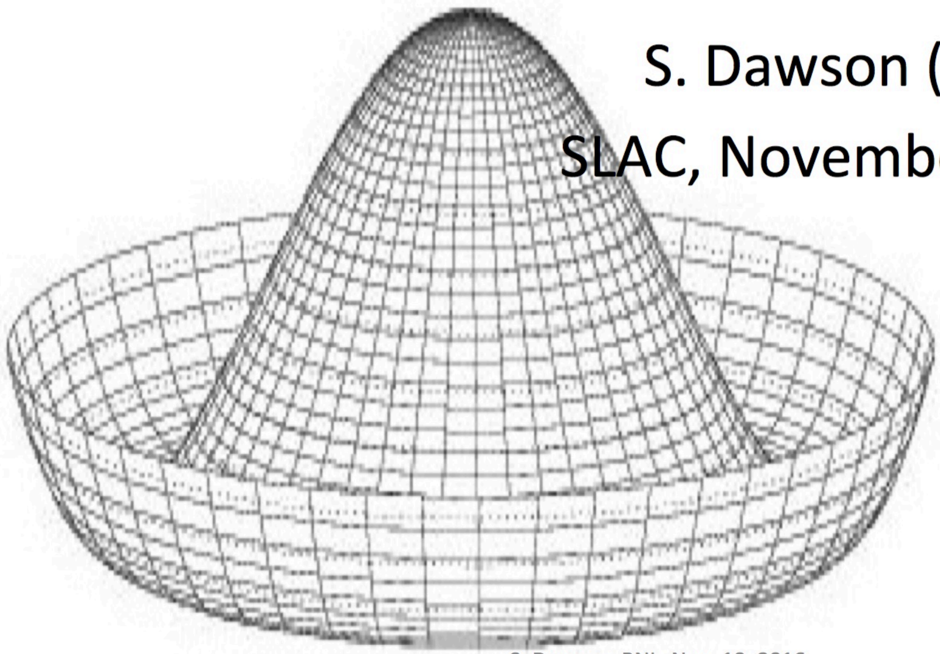
=> SM-dynamics measurements will help validating these calculations !!





Higgs XSWG report vol 4

It's not just the Higgs



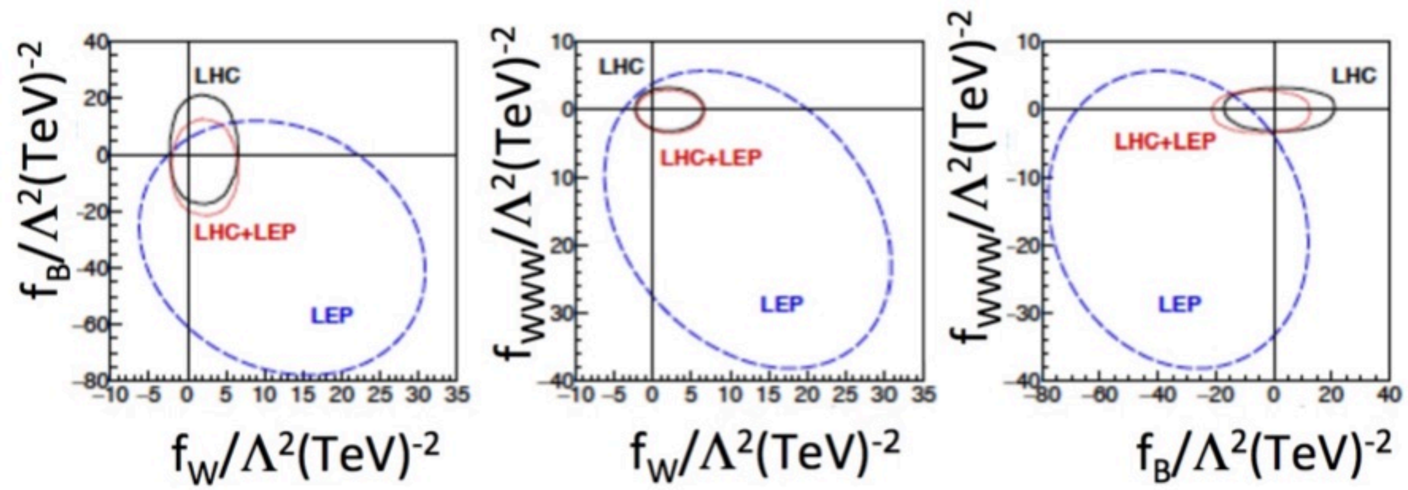
S. Dawson (BNL)

SLAC, November, 2016

S. Dawson, BNL, Nov. 10, 2016

- Precision measurements, direct searches for new Higgs bosons, and measurements of Higgs couplings give complementary information
  - Higgs is the new precision observable
  - Can not look at only one piece of the puzzle

- Include Run 1 WW and WZ



LHC Limits are greatly improved from LEP limits

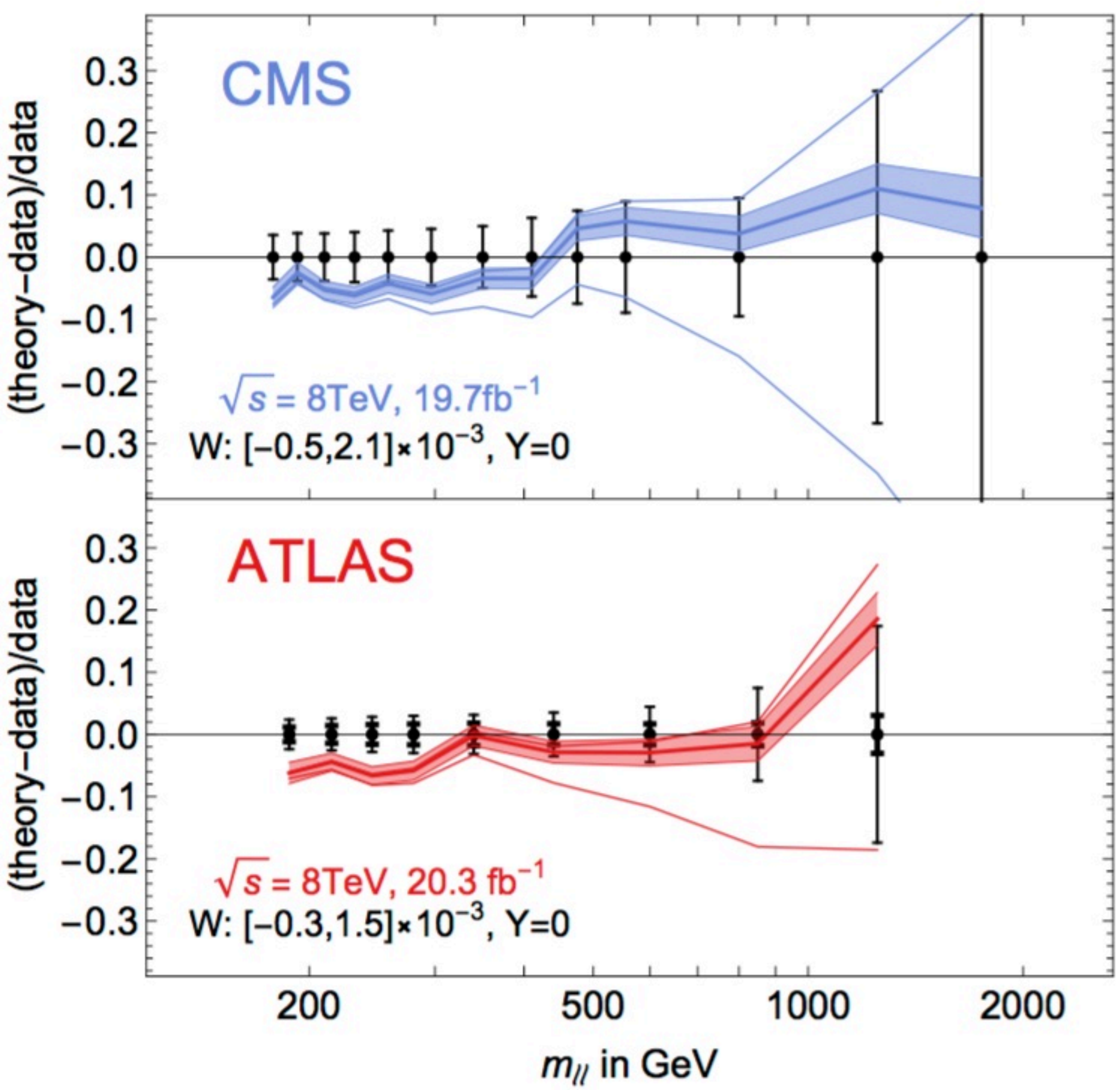
* Study includes (dim-6)^2 terms

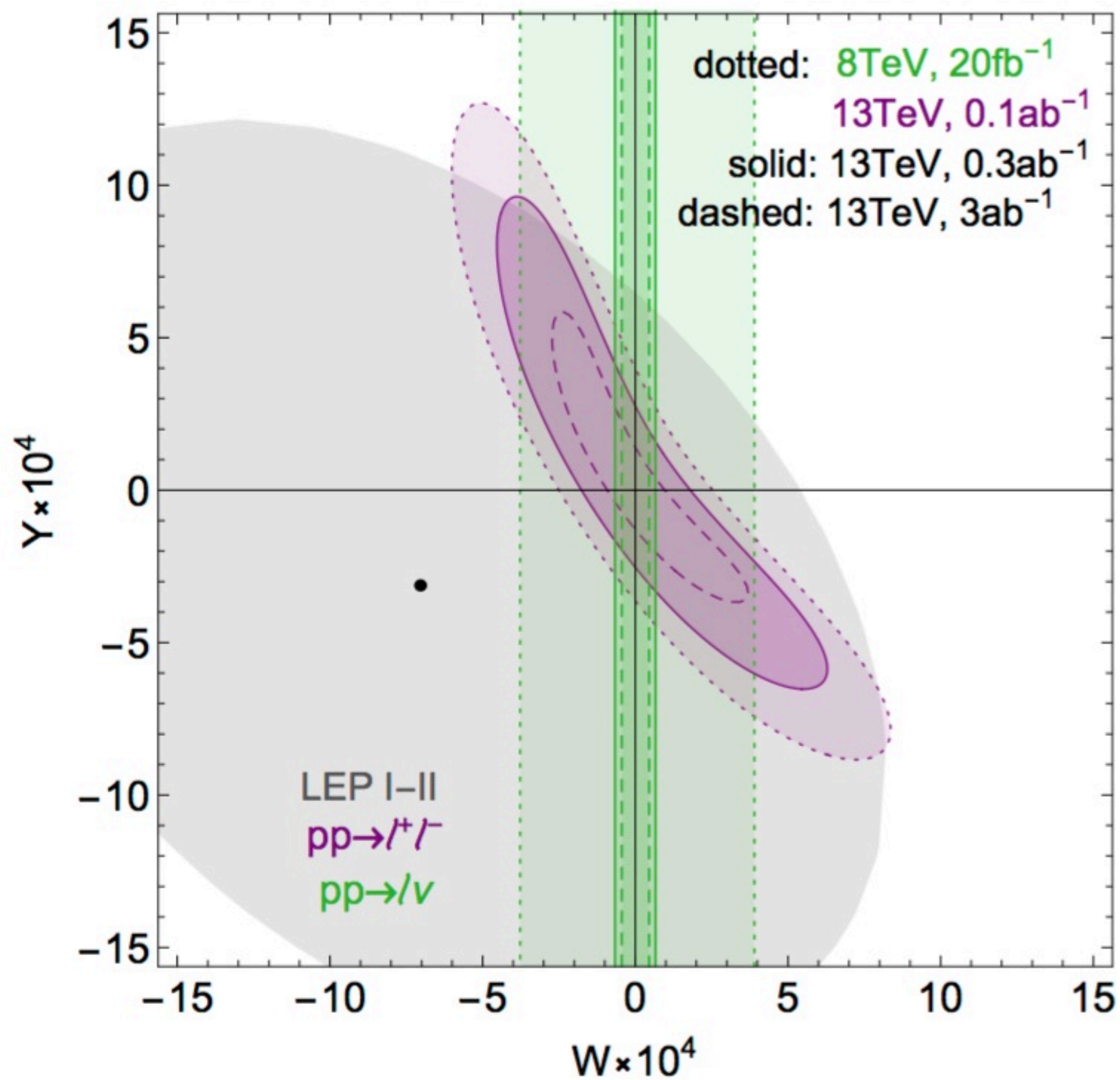
[Butter, Eboli, Gonzalez-Fraile, Gonzalez-Garcia, Plehn, Rauch, arXiv:1604.03105]

Ex: Probes of dim-6 op's with high-mass DY

M.Farina et al, arXiv:1609.08157

	universal form factor ($\mathcal{L}$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$





Final remarks

- Back to JoAnne's moving opening:

  "We need to learn to educate the public on the value of studying Higgs physics …."
  We should start this process by educating the HEP community at large about the value and richness of the Higgs programme …
- The Higgs physics programme is broad and challenging at many levels, calling on all our skills and handles:
  - theoretical progress in both SM and BSM
  - exptl analysis of a hugely diverse range of Higgs signals and final states
  - exptl analysis of "bread and butter" SM processes to be used for validation and tuning of TH modeling and systematics
- There is plenty of room for new ideas and approaches
- Skepticism towards the ability to continue improving the theoretical precision and experimental systematics should not curtail the ambition to produce ever better Higgs measurements, and probe its properties to (sub)-percent precision at HL-LHC: there are plenty of opportunities for new tackles that will emerge as we move along ….
- Contrary to the direct BSM search programme, which will approach its asymptotic limits well before the $3ab^{-1}$ are collected, the study of Higgs properties will dominate the endgame (cfr $m_{W,top}$ at Tevatron)

Thanks to our hosts for a perfect and friendly organization

and

thanks to all participants for the rich contributions and lively atmosphere!!