TH Higgs predictions for HL/HE-LHC

News from LHCHXSWG 1

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HL/HE-LHC: Opportunities

High statistics / high energy allows for different kind of Higgs studies

- Rare processes (HH, H→μμ, exclusive decays, light Yukawas…)
- Explore new kinematics configurations (both from high lumi/high energy) (off-shell, boosted)
- Highest precision on ``standard'' analysis

$$\delta_{\text{new physics}} \sim \frac{Q^2}{\Lambda^2_{\text{new physics}}}$$

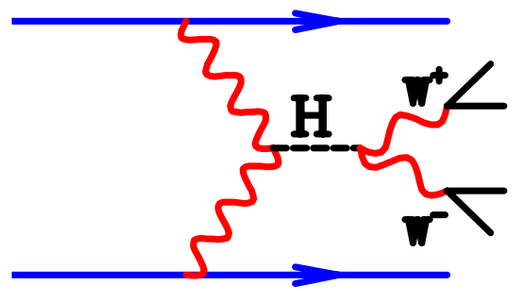
→ Q~ m_H: highest precision

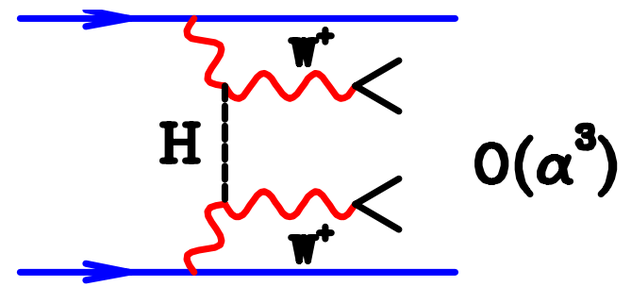
→ high Q: high energy

At least for HL-LHC, a lot of results already available (e.g. HH)

Example: Off-shell Higgs from same sign VBF

[Englert, Spannowski (2014); Campbell, Ellis (2015)]





VBF pp→VVjj

Nominal process	Cut	σ [fb] $O(\alpha^6)$	Factor	Events in 100 fb^{-1}
W^-W^+	$m_T^{WW} > 300$ GeV	0.2378	x4	95
W^+W^+	$m_T^{WW} > 300$ GeV	0.1358	x2	27
W^-W^-	$m_T^{WW} > 300$ GeV	0.0440	x2	9
W^+Z	$m_T^{WZ} > 300$ GeV	0.0492	x4	20
W^-Z	$m_T^{WZ} > 300$ GeV	0.0242	x4	10
ZZ	$m_T^{ZZ} > 300$ GeV	0.0225	x6	14
ZZ	$m_T^{WW} > 300$ GeV	0.0181	x6	11
ZZ	$m_{4l} > 300$ GeV	0.0218	x2	4

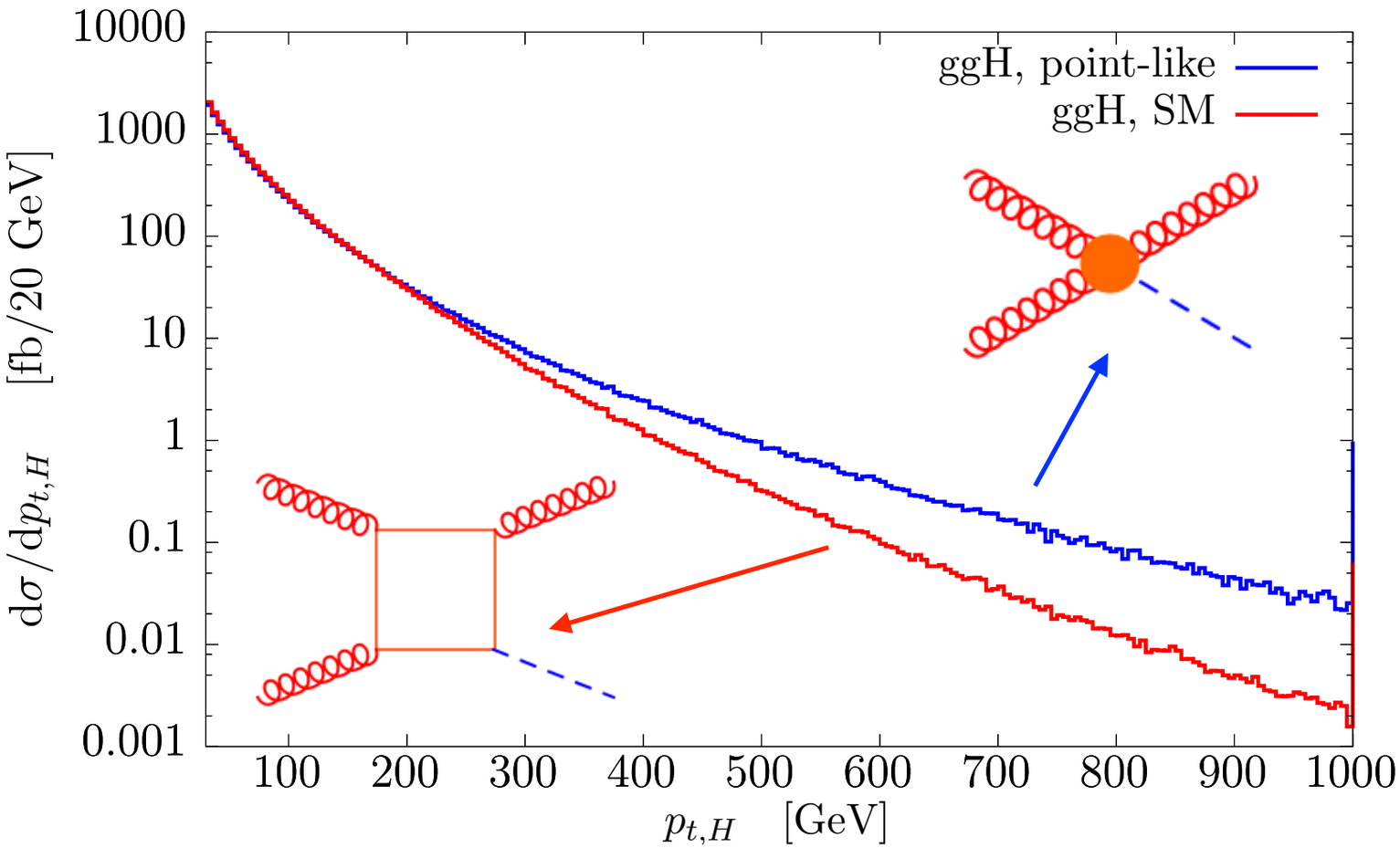
QCD pp→VVjj

Nominal process	Cut	σ [fb] $O(\alpha^4\alpha_s^2)$	Factor	Events in 100 fb^{-1}
W^-W^+	$m_T^{WW} > 300$ GeV	0.2227	x4	89
W^+W^+	$m_T^{WW} > 300$ GeV	0.0079	x2	2
W^-W^-	$m_T^{WW} > 300$ GeV	0.0025	x2	0
W^+Z	$m_T^{WZ} > 300$ GeV	0.0916	x4	37
W^-Z	$m_T^{WZ} > 300$ GeV	0.0454	x4	18
ZZ	$m_T^{ZZ} > 300$ GeV	0.0143	x6	9
ZZ	$m_T^{WW} > 300$ GeV	0.0118	x6	7
ZZ	$m_{4l} > 300$ GeV	0.0147	x2	3

Standard VBF selection cuts, extra off-shell m_T/m_{4l} cut

- Good S/B ratio
- Future runs: off-shell constraints ~ or better than current from ggF (≠ *TH systematics, no ttH - ggH interplay…)*

Example: Boosted Higgs



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

- Proof-of-concept CMS analysis already exists [PRL 120, 071802 (2018)]
- Substructure techniques seem to work
- Run II: statistics
- Will benefit from both HL-HE upgrades
- *NLO in the full theory computed this year* [Lindert et al; Jones et al.]. Allows to circumvent all the problems of the CMS ``theory'' prediction

Higgs predictions: status

Process	~ 15 y ago	Now	What we want
ggH	towards $NNLO_{inc}$	N^3LO_{inc}, NNLOPS, NNLL, $QCDxEW_{approx}$	$N^3LO(PS)$ *+small details*
VBF	NLO	N^3LO_{inc}, NNLO	$N^3LO(PS)$
VH	NLO	NNLO	gg→VH@NLO
ttH	LO	NLO	NNLO?
Hj	NLO	NNLO, NLO_{mass}	$NNLO_{mass}$?
Hjj	LO	NLO	NNLO
pp→γγ	NLO	NNLO+gg@NLO	/ /
pp→VV	NLO	NNLO+gg@NLO	gg@NLO massive
pp→HH	LO, NLO_{HEFT}	NLO_{mass}, $NNLO_{HEFT}$	$NNLO_{mass}$?

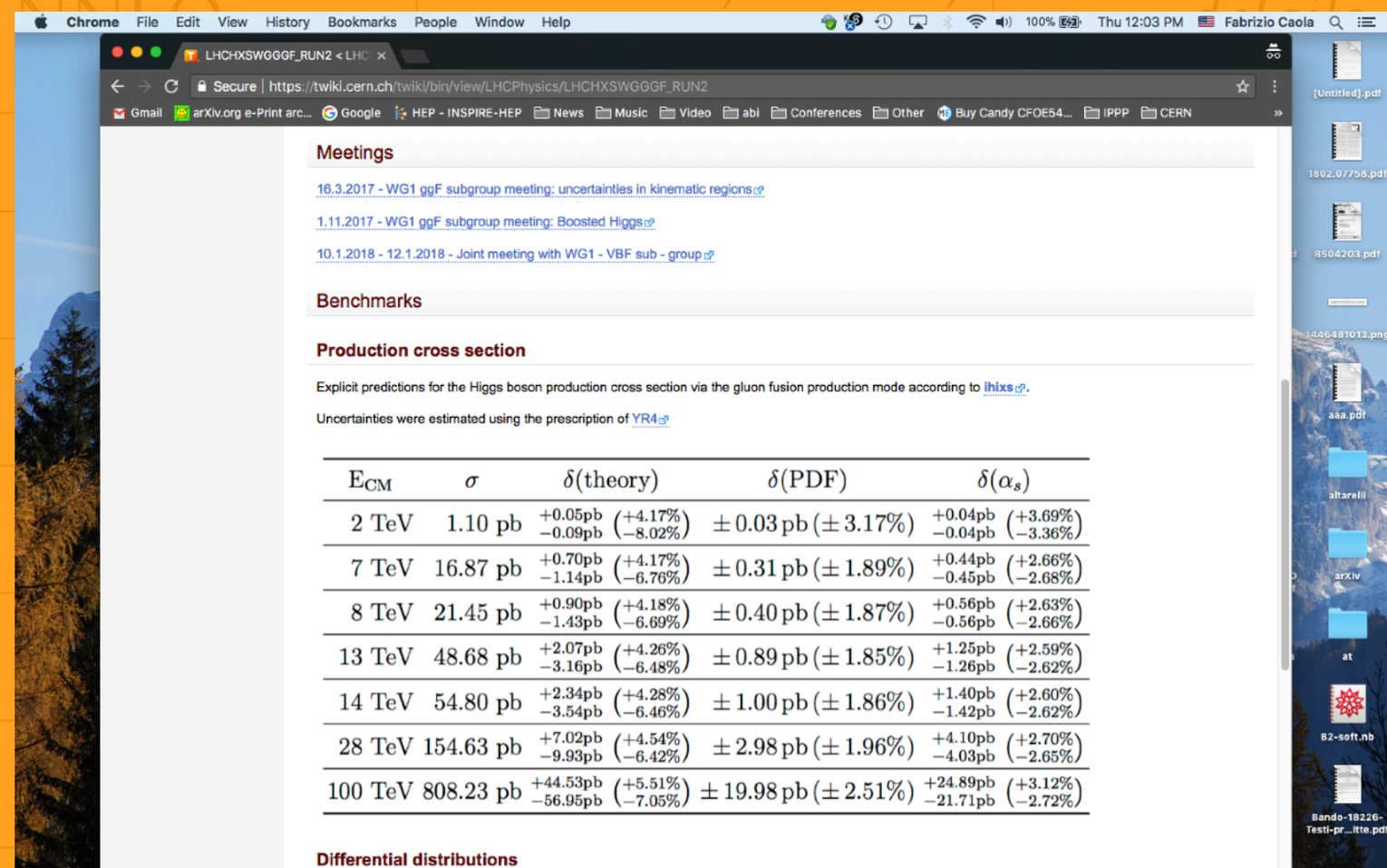
Higgs predictions: status

- Theory predictions already very advanced. In some cases, already at their asymptotic limit (as of today, no reason to trust pQCD below 1%)
- A lot of recent progress
- Personally: Would be (very) surprised if the third column not completed in time for HL-LHC physics. Would be (extremely) surprised if all completed [and validated!] in time for the report
- *Realistically*: use the results already available. WG1 sub-conveners are already very busy with Run II issues…
- In many cases, the real problems are background: ttH, VBF [gg contamination…]. *Can we use high lumi to investigate some of these issues*? [ttbb, central veto…]
- At least in comes cases: HL ``simpler'' from TH point of view (can move away from ``dangerously soft/collinear'' regions). *To which extent this is possible in practice?*

Higgs predictions: status

- Situation slightly different for HE
- Step 0: produce ``YR4'' numbers for HE-LHC setup
- In some cases, already known…

ggF WG1 twiki page



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Meetings

16.3.2017 - WG1 ggF subgroup meeting: uncertainties in kinematic regions

1.11.2017 - WG1 ggF subgroup meeting: Boosted Higgs

10.1.2018 - 12.1.2018 - Joint meeting with WG1 - VBF sub - group

Benchmarks

Production cross section

Explicit predictions for the Higgs boson production cross section via the gluon fusion production mode according to ihixs.

Uncertainties were estimated using the prescription of YR4

E_{CM}	σ	δ(theory)	δ(PDF)	$\delta(\alpha_s)$
2 TeV	1.10 pb	$^{+0.05\text{pb}}_{-0.09\text{pb}}$ $(^{+4.17\%}_{-8.02\%})$	± 0.03 pb $(\pm 3.17\%)$	$^{+0.04\text{pb}}_{-0.04\text{pb}}$ $(^{+3.69\%}_{-3.36\%})$
7 TeV	16.87 pb	$^{+0.70\text{pb}}_{-1.14\text{pb}}$ $(^{+4.17\%}_{-6.76\%})$	± 0.31 pb $(\pm 1.89\%)$	$^{+0.44\text{pb}}_{-0.45\text{pb}}$ $(^{+2.66\%}_{-2.68\%})$
8 TeV	21.45 pb	$^{+0.90\text{pb}}_{-1.43\text{pb}}$ $(^{+4.18\%}_{-6.69\%})$	± 0.40 pb $(\pm 1.87\%)$	$^{+0.56\text{pb}}_{-0.56\text{pb}}$ $(^{+2.63\%}_{-2.66\%})$
13 TeV	48.68 pb	$^{+2.07\text{pb}}_{-3.16\text{pb}}$ $(^{+4.26\%}_{-6.48\%})$	± 0.89 pb $(\pm 1.85\%)$	$^{+1.25\text{pb}}_{-1.26\text{pb}}$ $(^{+2.59\%}_{-2.62\%})$
14 TeV	54.80 pb	$^{+2.34\text{pb}}_{-3.54\text{pb}}$ $(^{+4.28\%}_{-6.46\%})$	± 1.00 pb $(\pm 1.86\%)$	$^{+1.40\text{pb}}_{-1.42\text{pb}}$ $(^{+2.60\%}_{-2.62\%})$
28 TeV	154.63 pb	$^{+7.02\text{pb}}_{-9.93\text{pb}}$ $(^{+4.54\%}_{-6.42\%})$	± 2.98 pb $(\pm 1.96\%)$	$^{+4.10\text{pb}}_{-4.03\text{pb}}$ $(^{+2.70\%}_{-2.65\%})$
100 TeV	808.23 pb	$^{+44.53\text{pb}}_{-56.95\text{pb}}$ $(^{+5.51\%}_{-7.05\%})$	± 19.98 pb $(\pm 2.51\%)$	$^{+24.89\text{pb}}_{-21.71\text{pb}}$ $(^{+3.12\%}_{-2.72\%})$

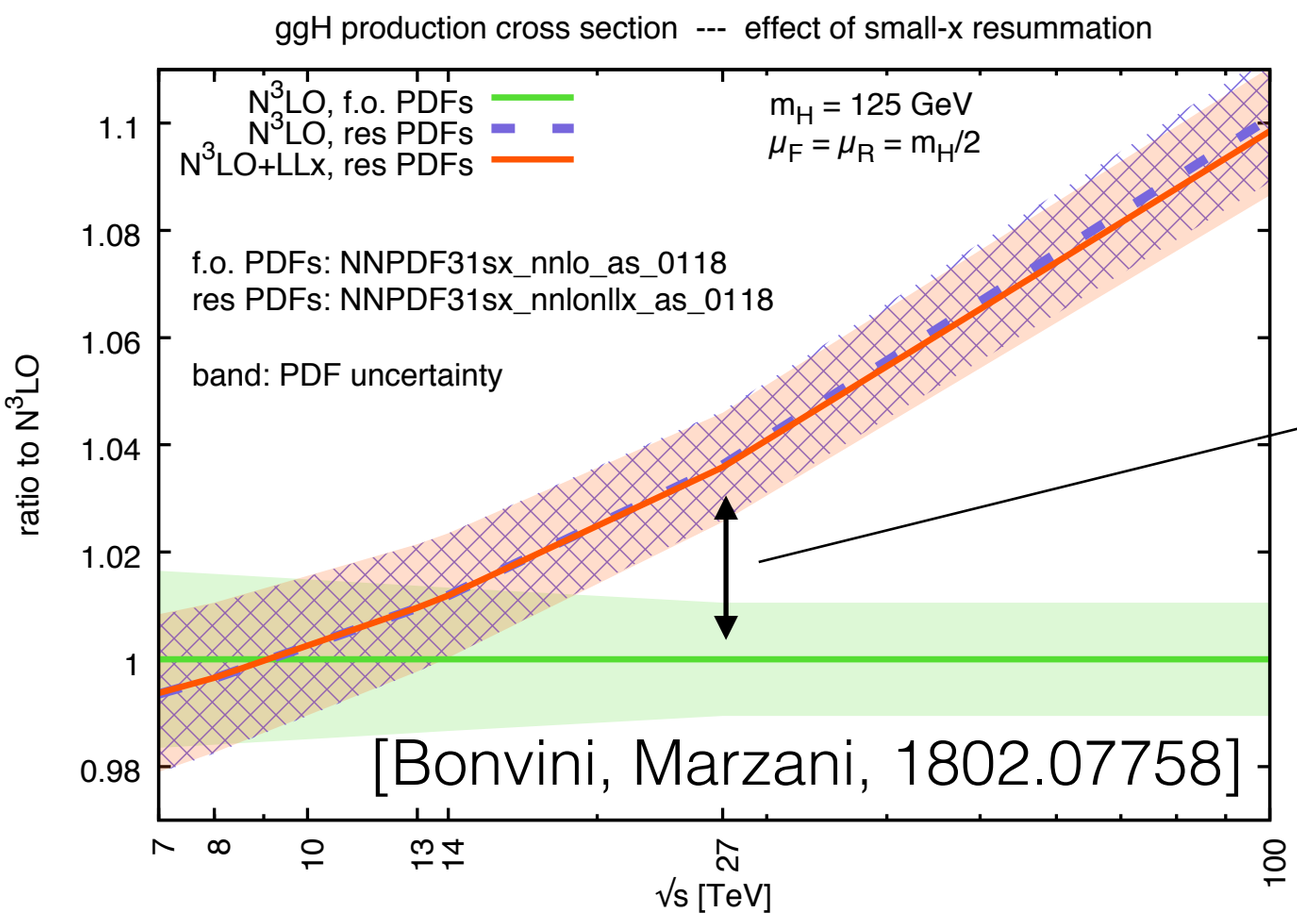
Differential distributions

- More interesting: study physics potential *[boosted/off-shell, different analysis strategies, different channels…]*. More difficult to predict timescale…

Potential issues: example

$\sigma_{\mathrm{TOT,ggH}}$

DO WE KNOW PDFS WELL ENOUGH?



PDF error: PDF with ~small-x resummation

Effect of switching on/off (small-x) resummation in the PDFs

PDF error: f.o.

- To which extent these effects are relevant (e.g.: central region, boosted Higgs…)
- *Can we use HL results and fit gluon at high scale*, to avoid/ minimize evolution issues? [~ for N^{3}PDF…]

Thank you for your attention!

LHCHXSWG1 contacts:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG1