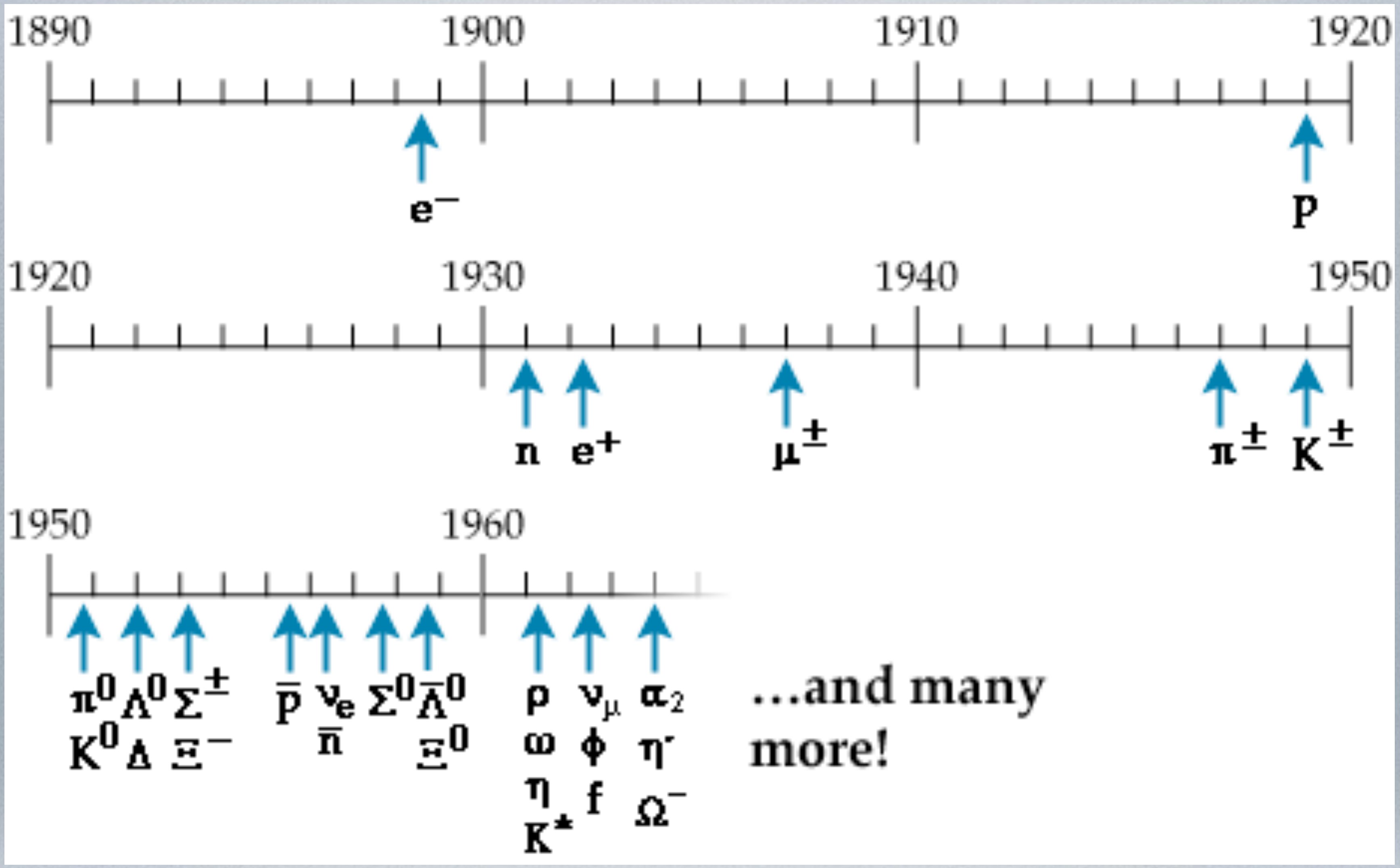
Precision for discovery

Gudrun Heinrich
Max Planck Institute for Physics, Munich

MPP 100 Year Anniversary,
October 12, 2017

Particle Discoveries



- around 1950: “particle zoo”

  new developments were **driven by experiment**

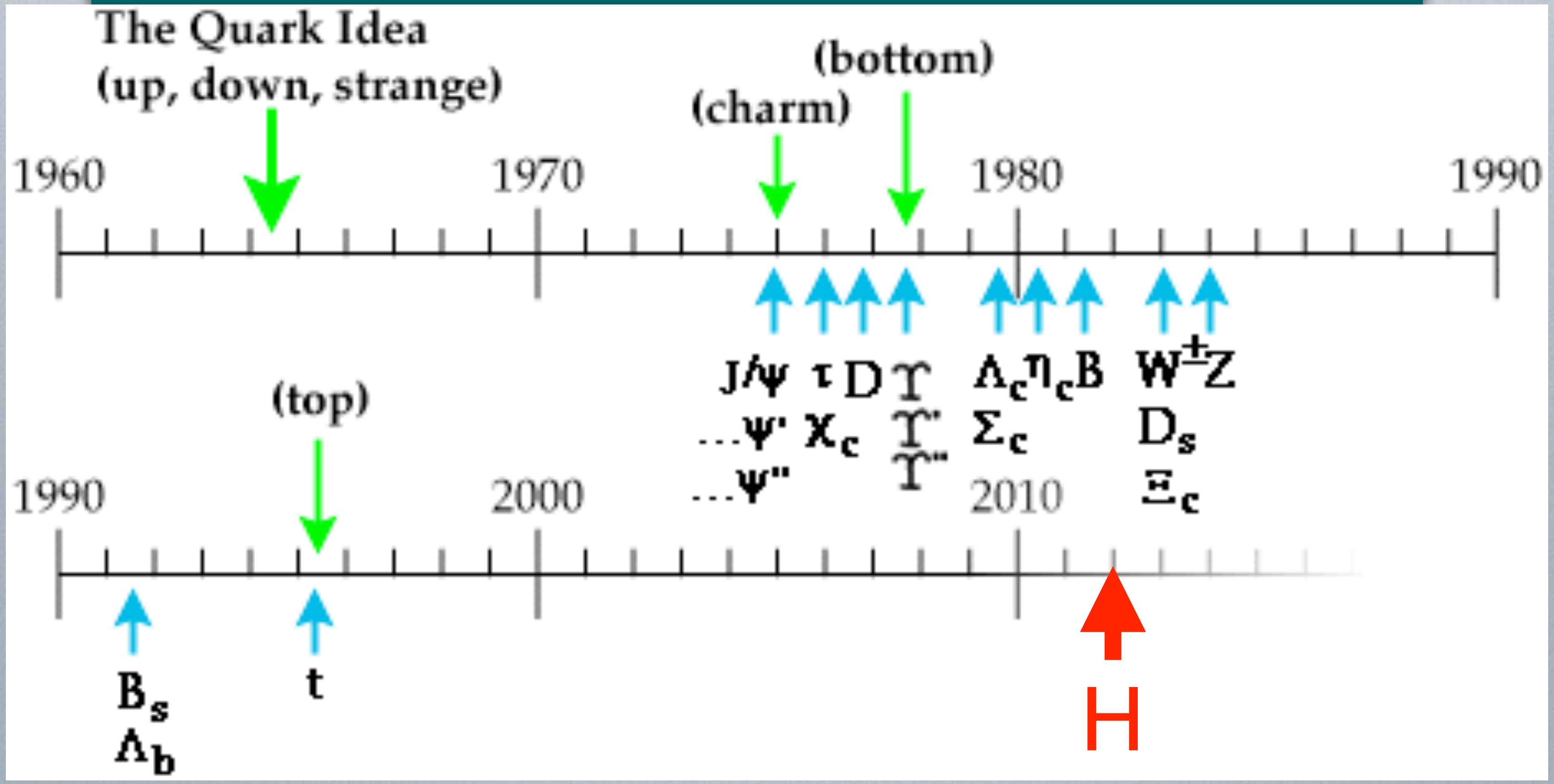
  led to the development of the quark model [Gell-Mann, Zweig 1964]

- 1960’s: beginning of a **theory-driven** era

  development of the Standard Model, concept of gauge theories

  [Glashow, Salam, Weinberg 1967; Higgs 1964; t’Hooft, Veltman 1972, …]

The theory-driven era



	predicted	discovered
charm quark	1964	1974
bottom quark	1973	1977
W/Z bosons	1968	1983
top quark	1973	1995
Higgs boson	1964	2012

Perspectives

"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement."

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J.P.G. von Jolly, 1809-1884, Professor of Physics, to Max Planck (considering to study physics)

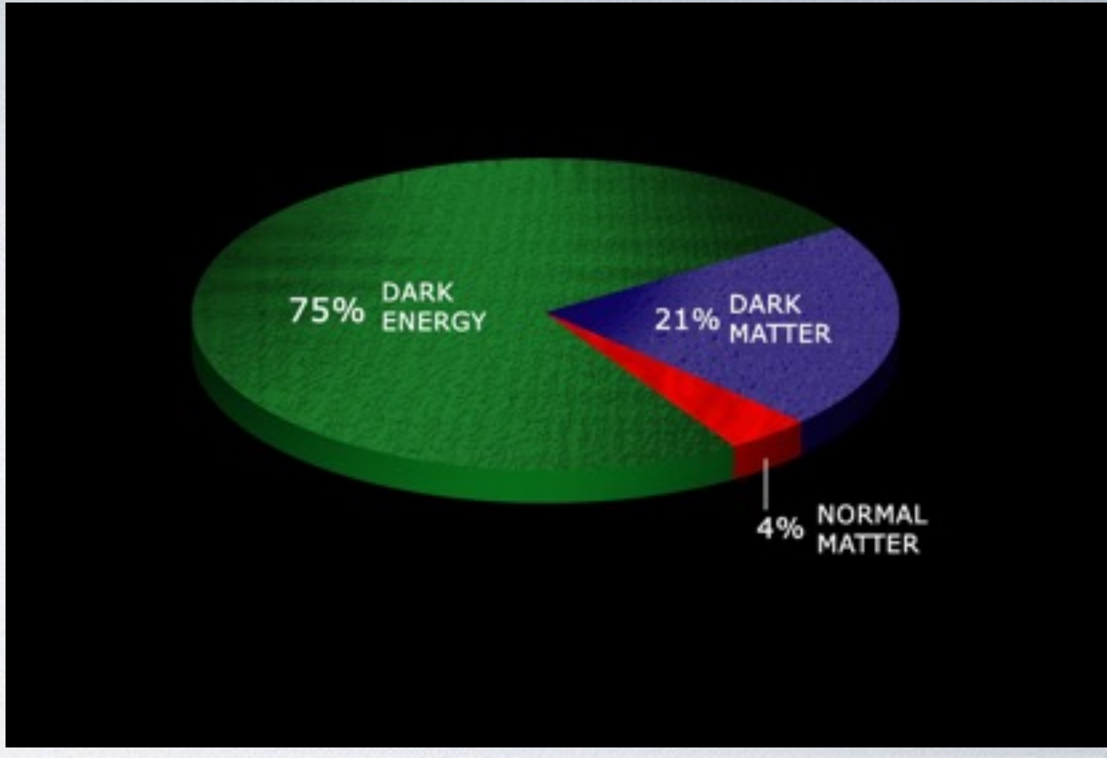
(Planck replied that he did not wish to discover new things, but only to understand the known fundamentals of the field)

Standard Model

the Standard Model is "complete", but leaves many puzzling questions!

- too many "ad hoc" parameters in the SM
- hierarchy problem
- dark matter
- baryon asymmetry in the Universe
- what drove inflation
- quantum theory of gravitation

⋮



We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the scale of new physics, unlike the case with the Higgs, and for not being sure of its couplings to other particles, except that they are probably all very small.

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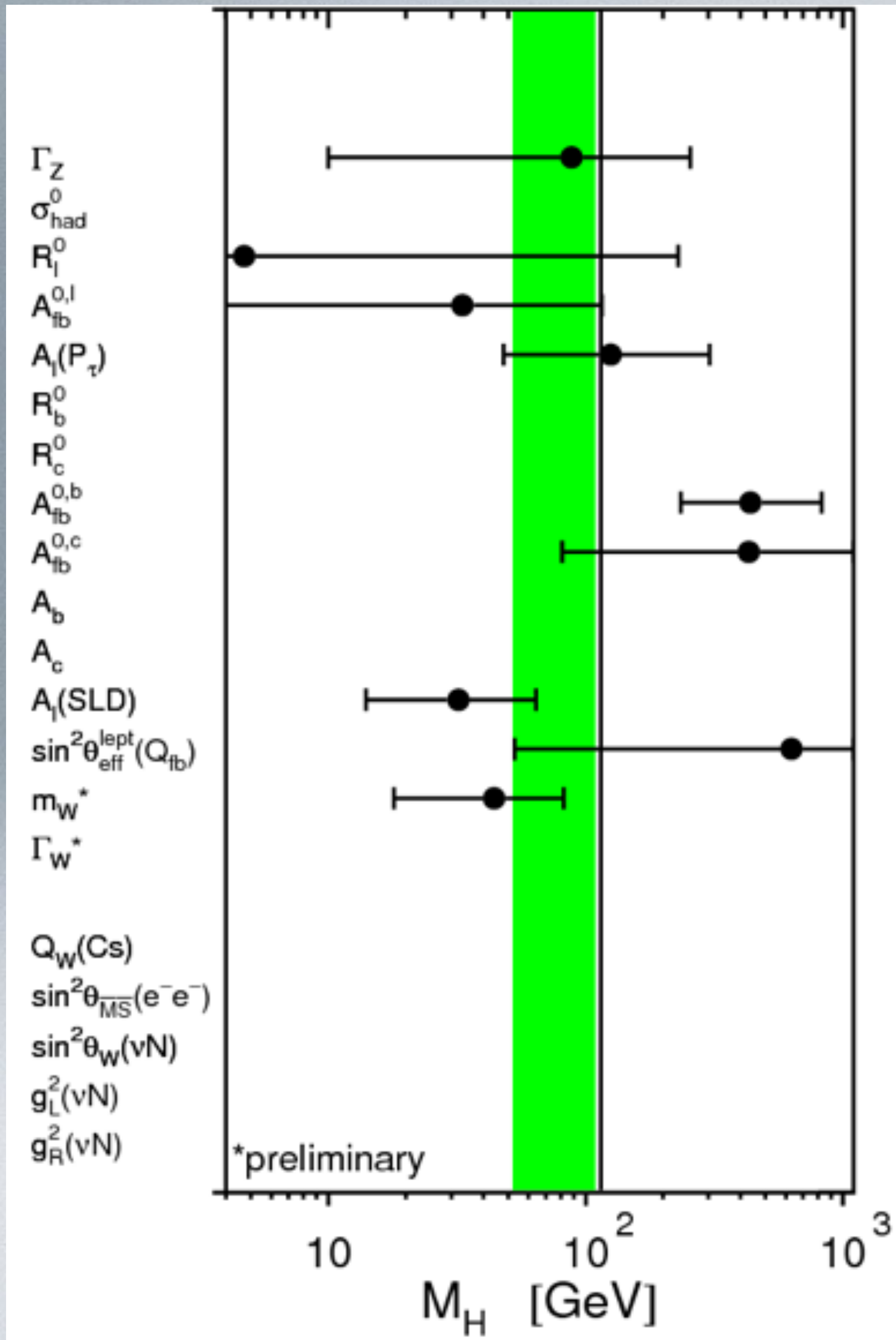
A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

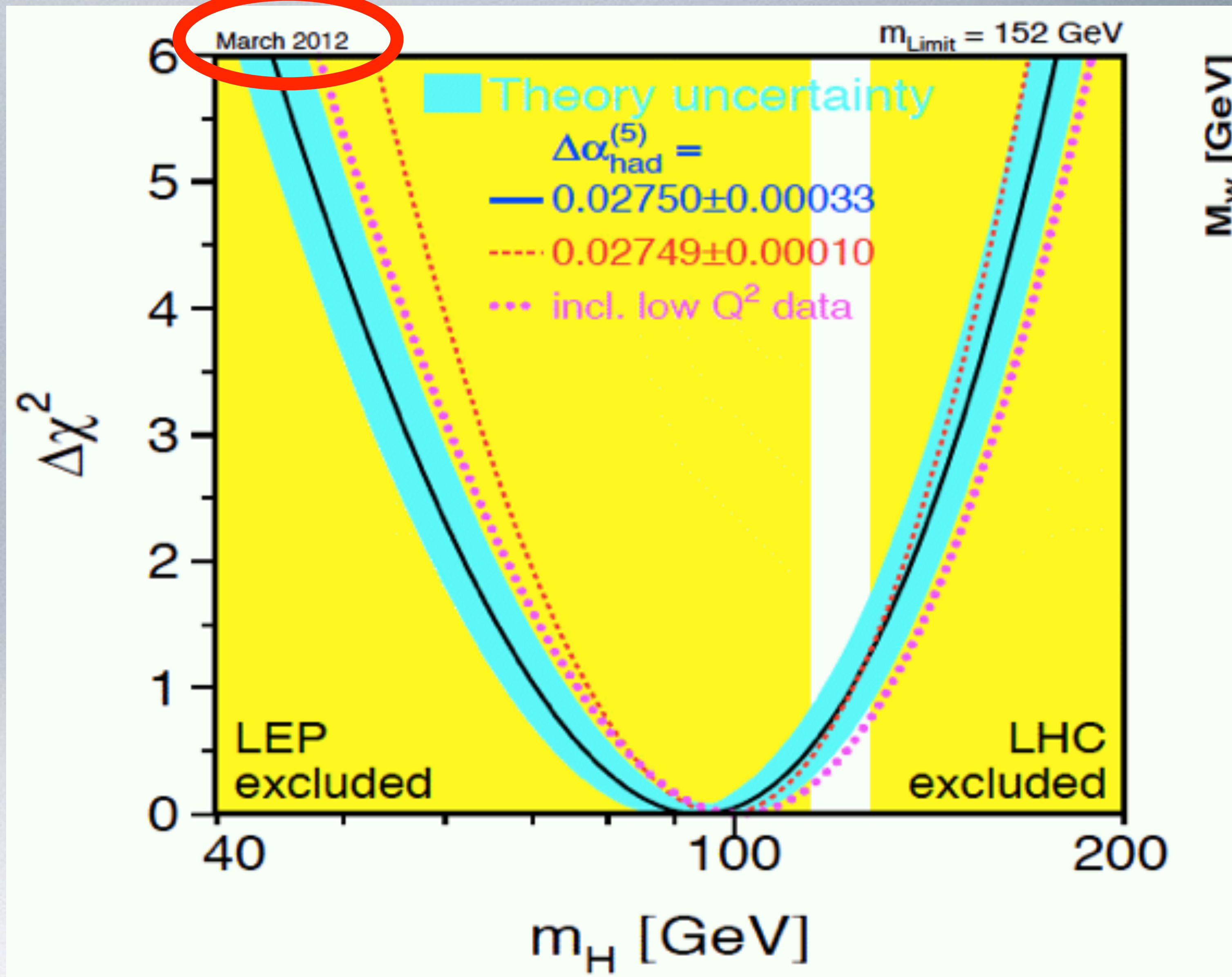
Received 7 November 1975

We should perhaps finish with an apology and a caution. We apologize to ex-perimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

precision measurements cornered the Higgs boson mass

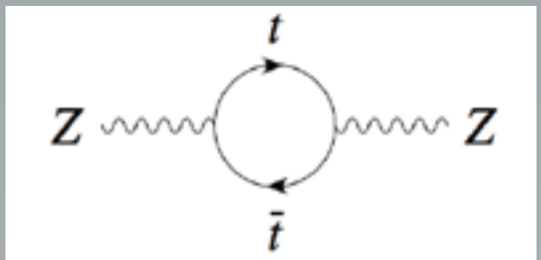


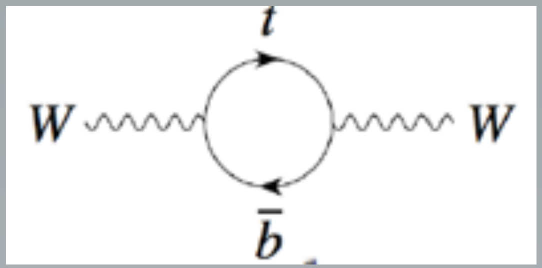
LEP EW working group 2009



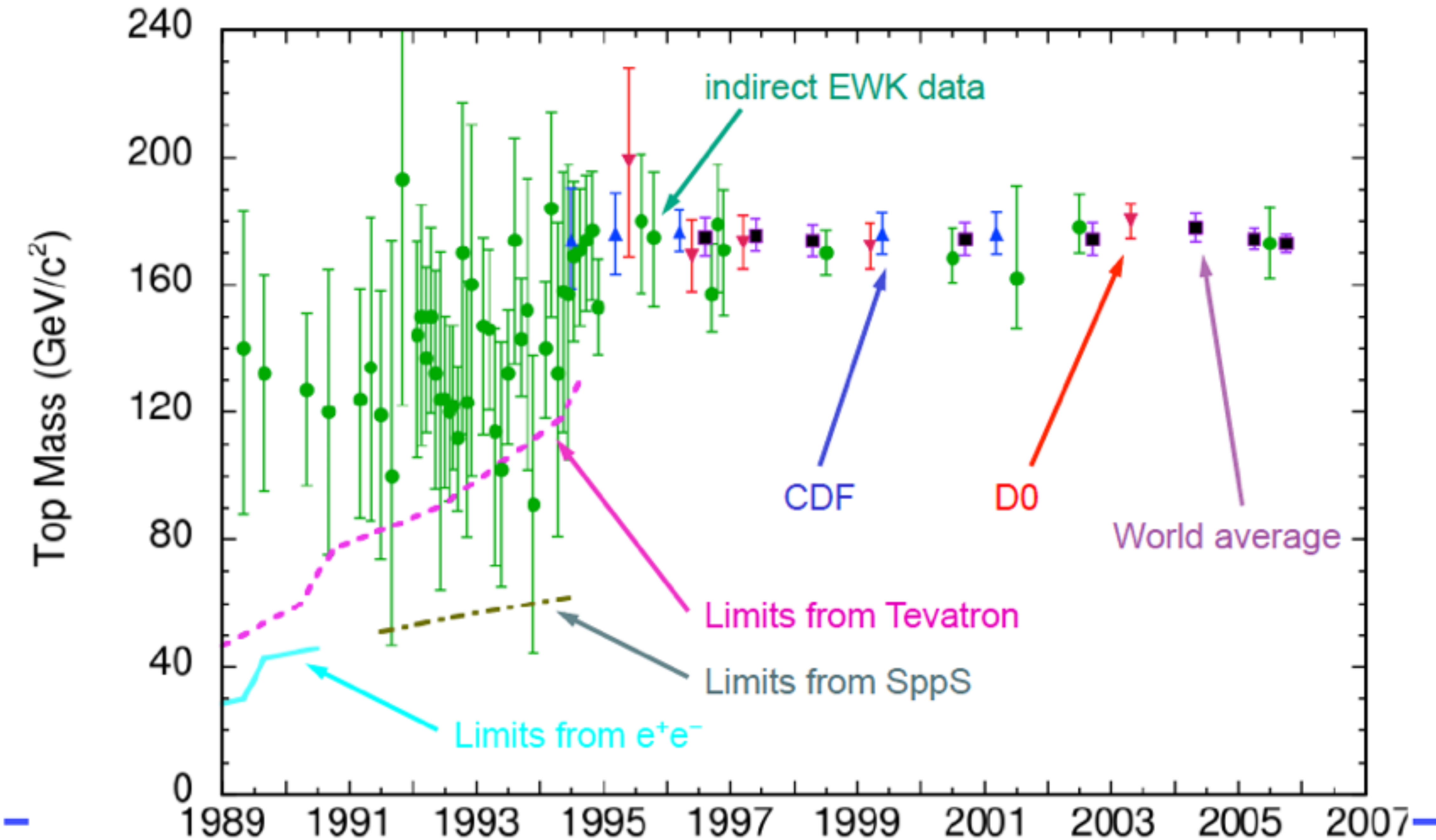
top quark: importance of precision measurements/calculations

top quark mass enters electroweak precision observables
indirectly via loop effects

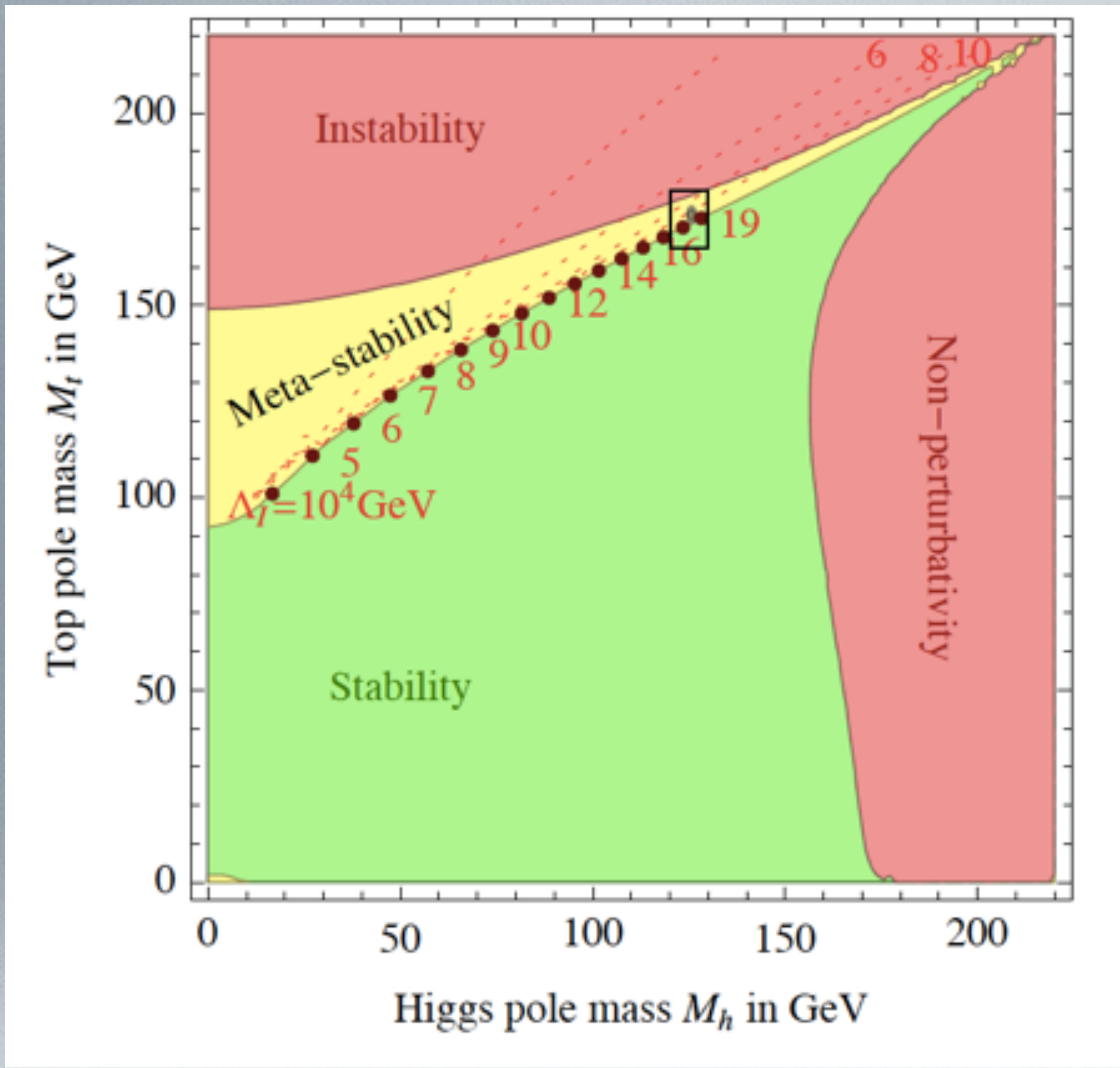




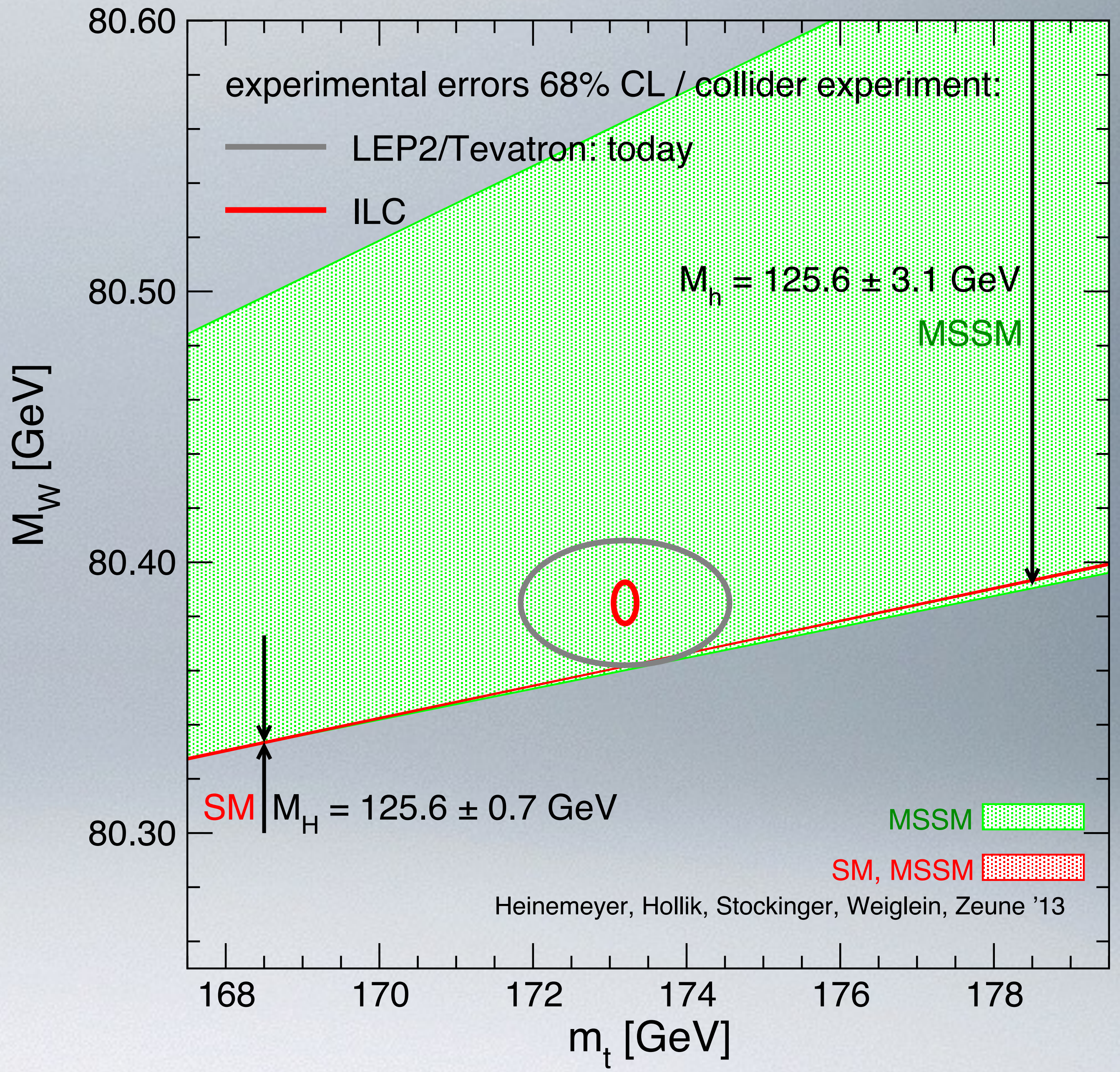
- Limits or estimate vs time



importance of precision



Buttazzo,Degrassi, Giardino, Giudice, Sala, Salvio, Strumia ’13

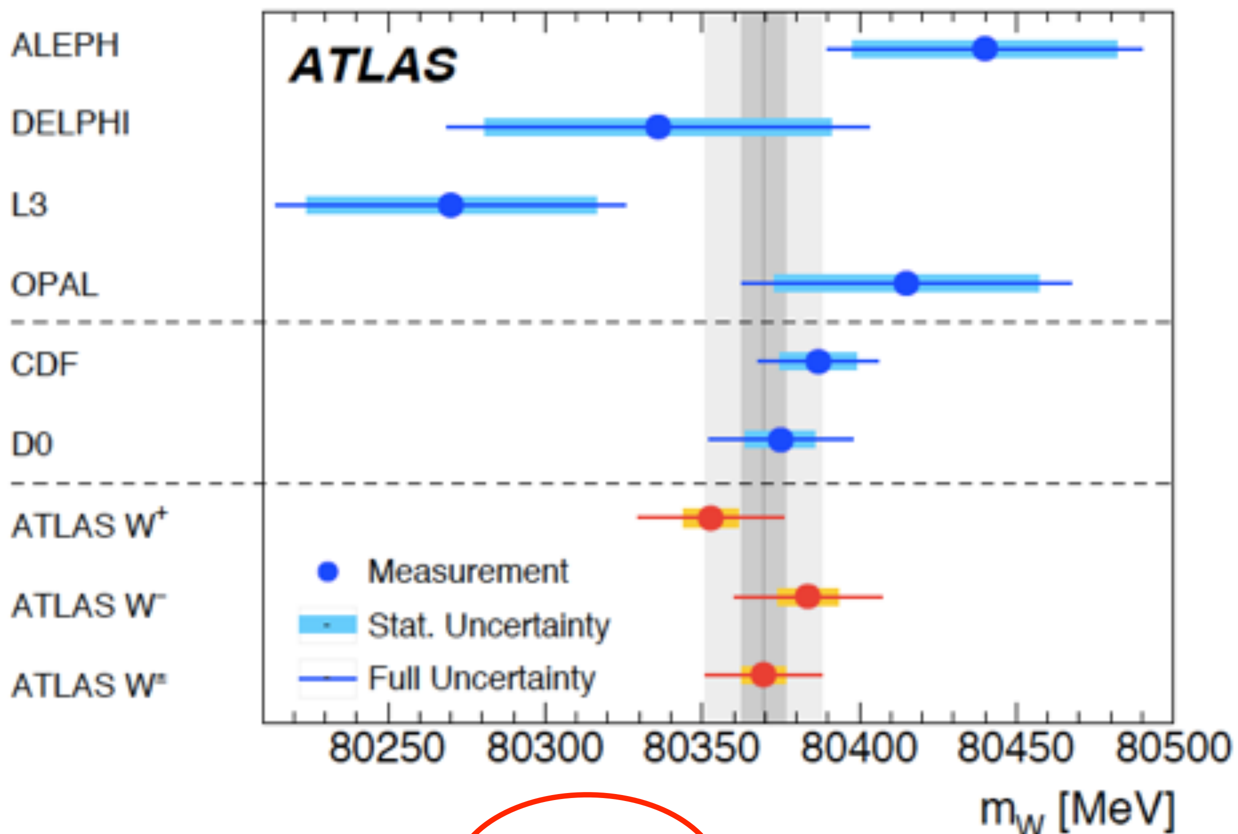


Heinemeyer, Hollik, Stöckinger, Weiglein, Zeune ’13

there is a lot we can learn without immediate discoveries of new particles

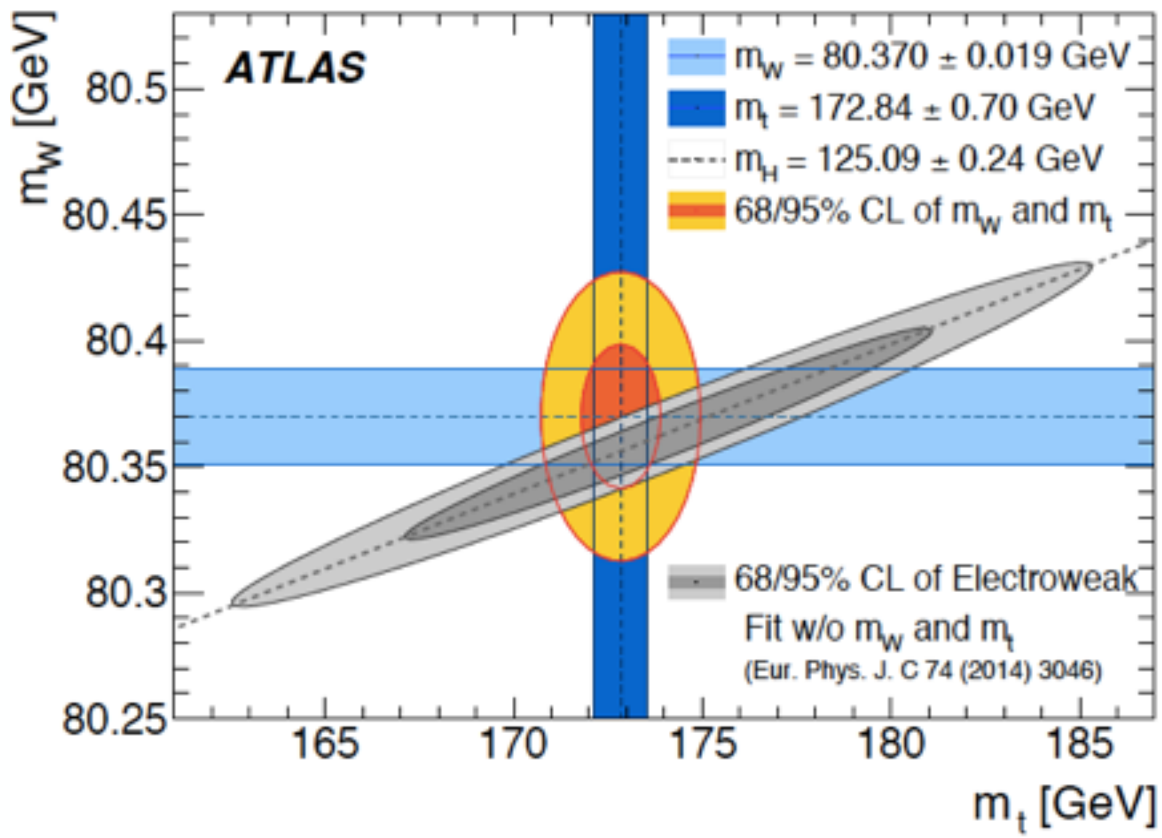
precision measurements: W boson mass

MW experimental values



$m_W = 80370 \pm 19$ MeV ATLAS arXiv:1701.07240

Global EW fit compared to ATLAS results



$m_W = 80356 \pm 8$ MeV

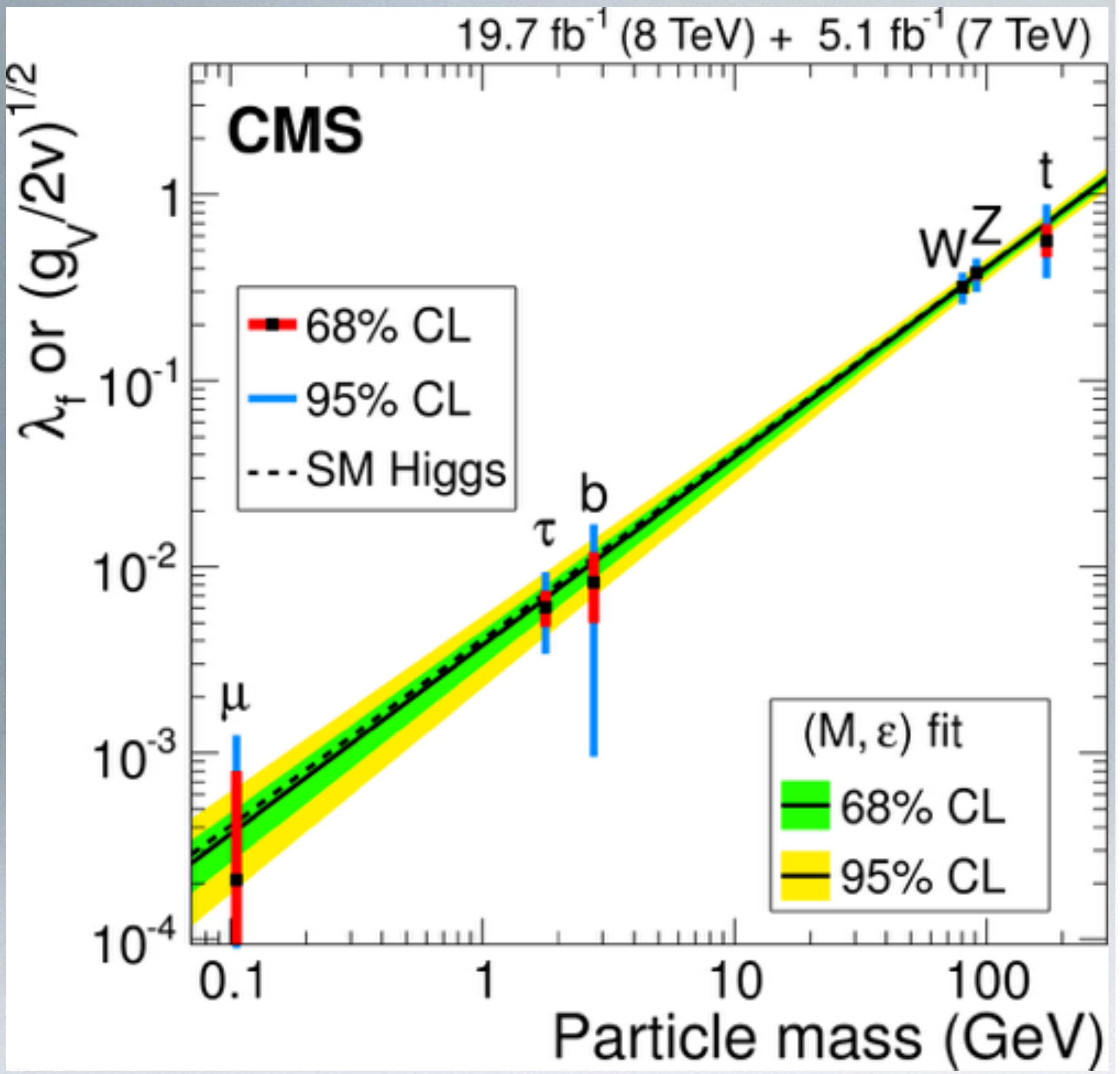
A. Vicini, LHCP 2017

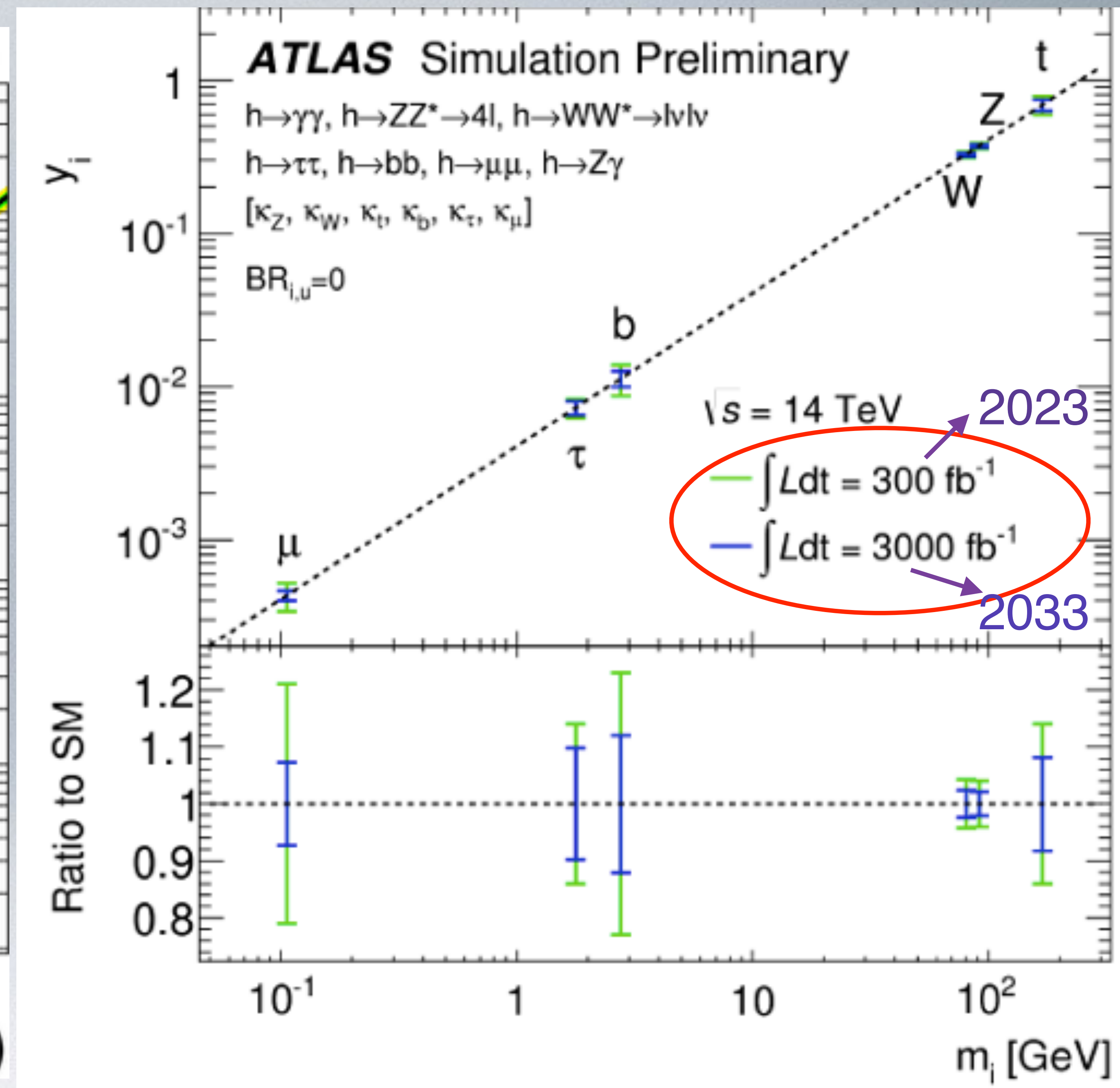
extraction of M_W from **shape** of p_T^l distribution

distortion of shape at permil level leads to $\mathcal{O}(10\,\mathrm{MeV})$ shift in mass

$\Rightarrow$ control of radiative corrections distorting the shape extremely important!

profile of the Higgs boson





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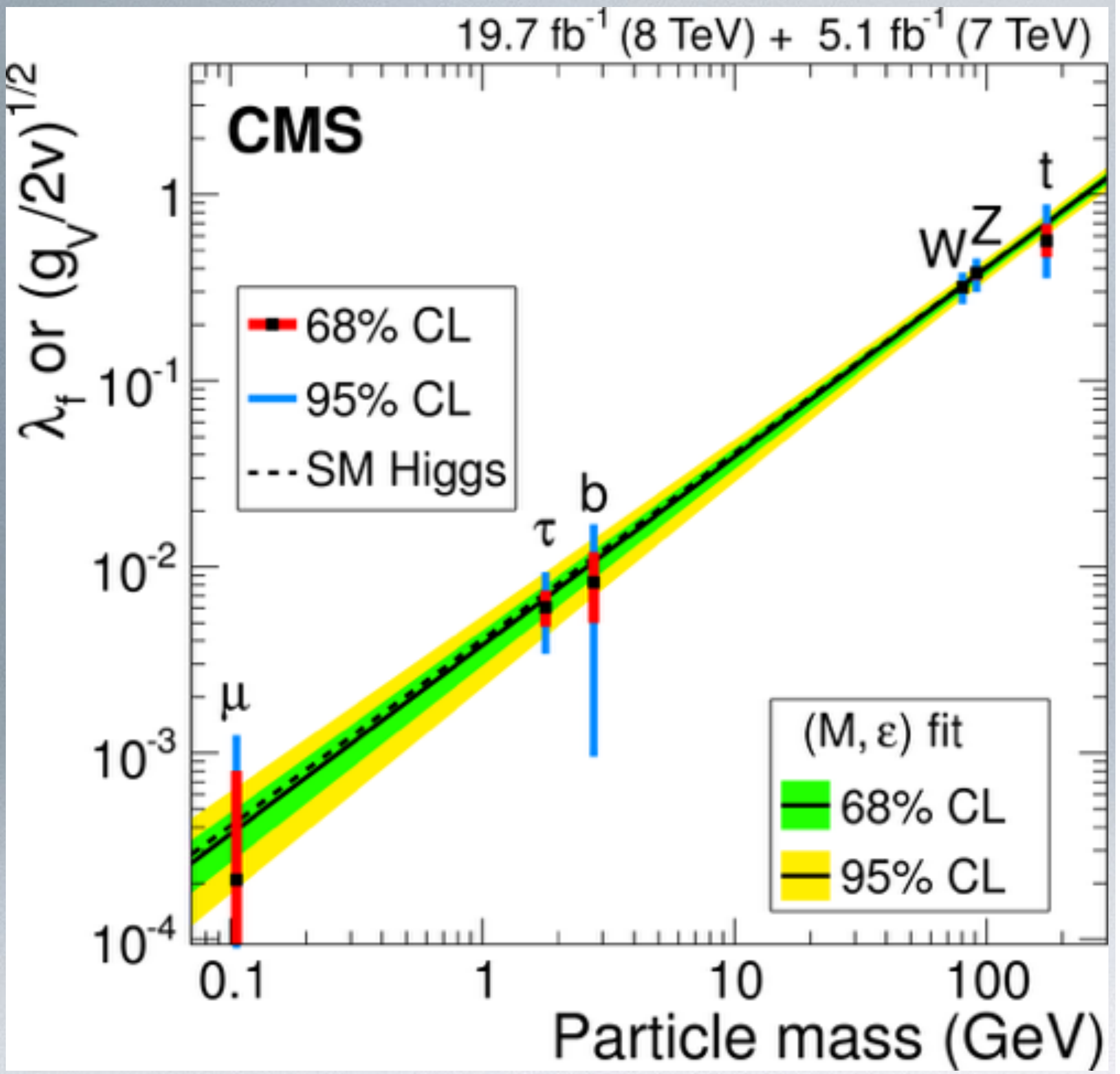
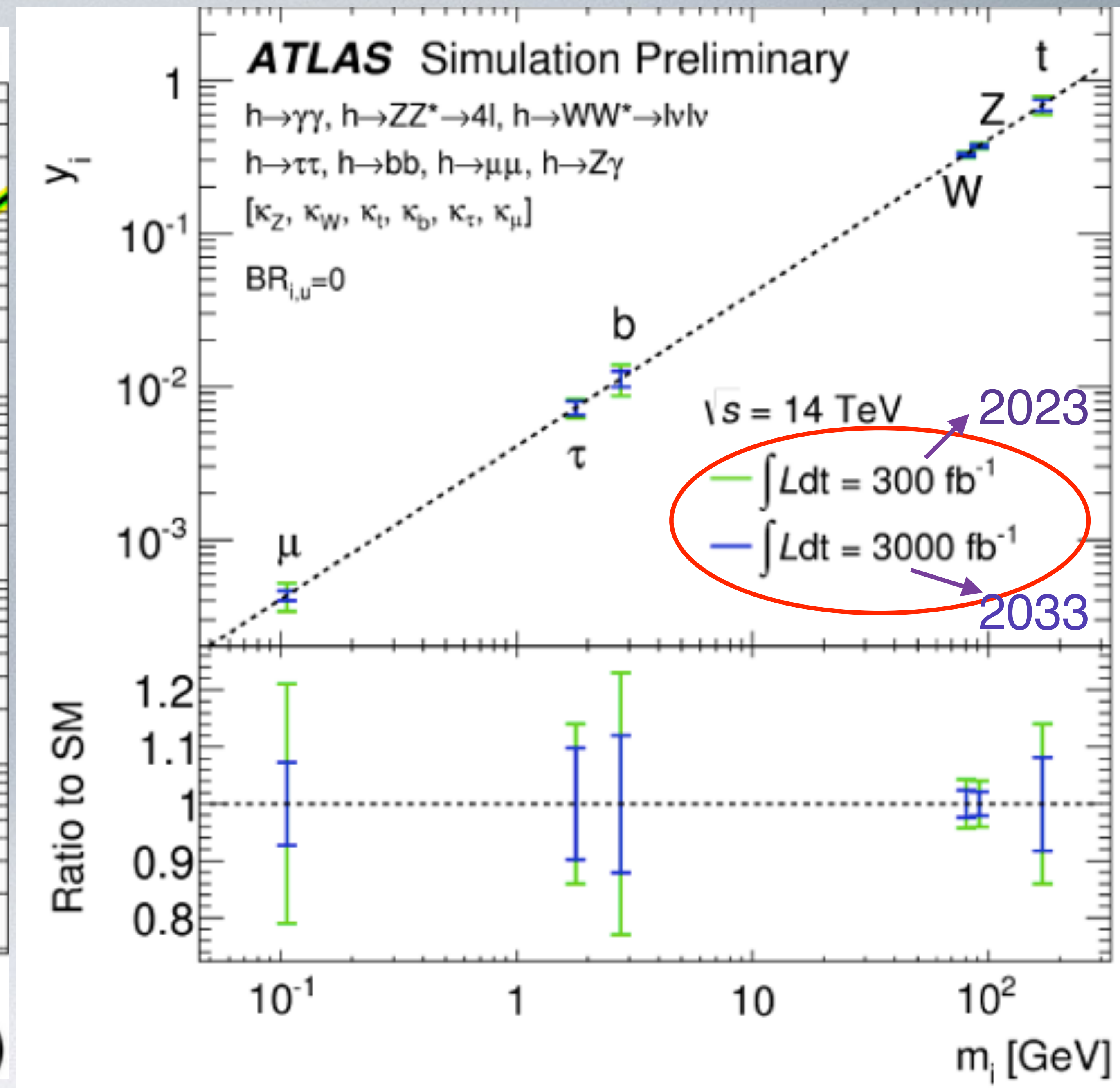




Higgs boson self coupling(s)?

see later; triple Higgs coupling can be measured at HL-LHC

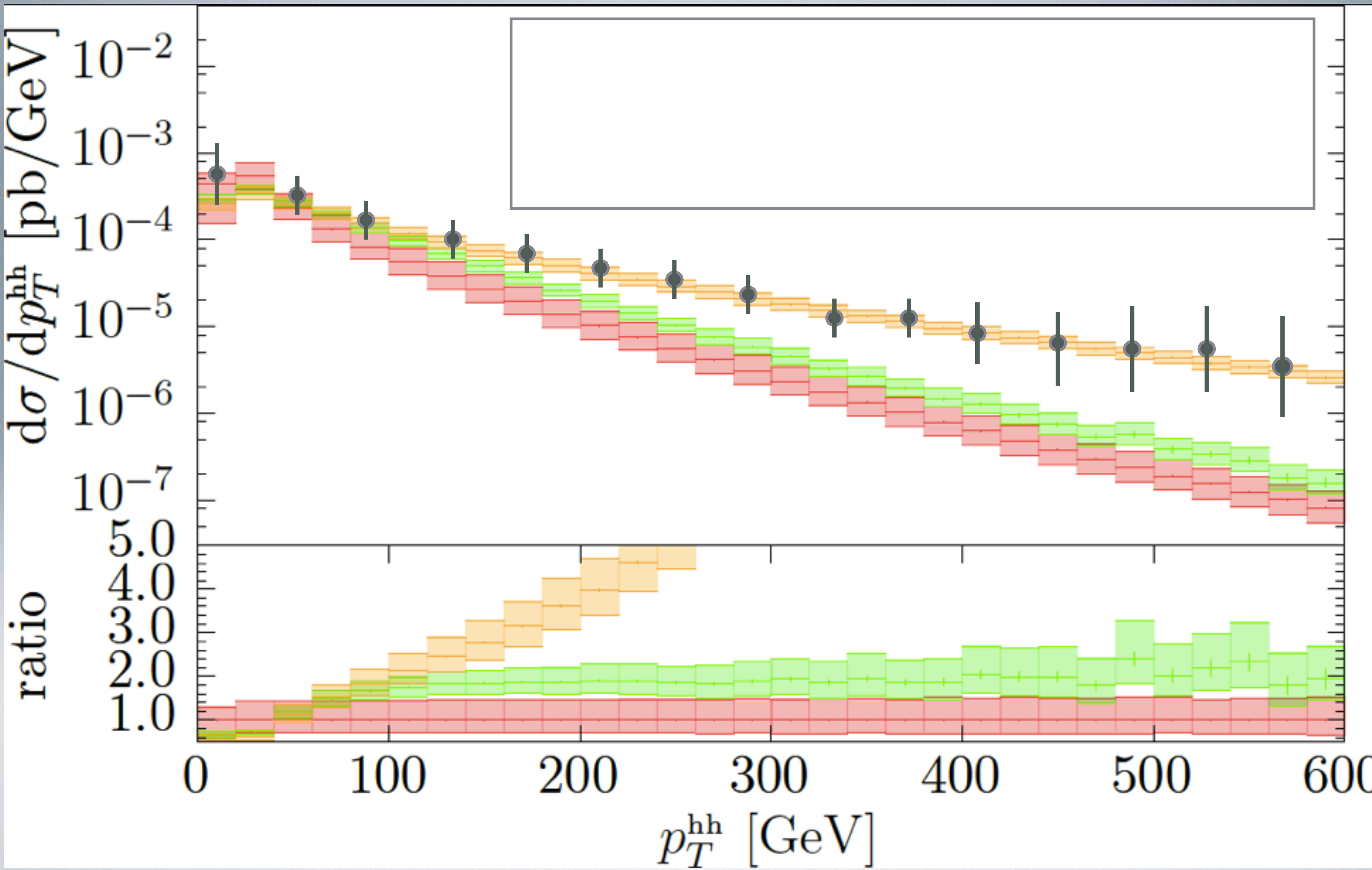
importance of precision

P. Meridiani, EPS2017

- SUSY (tanβ=5): $\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \text{TeV}}{m_A}\right)^2$
- Composite Higgs: $\frac{g_{hff}}{g_{h_{SM}ff}} \simeq \frac{g_{hVV}}{g_{h_{SM}VV}} \simeq 1 - 3\% \left(\frac{1\ \text{TeV}}{f}\right)^2$
- Top partners: $\frac{g_{hgg}}{g_{h_{SM}gg}} \simeq 1 + 2.9\% \left(\frac{1\ \text{TeV}}{m_T}\right)^2, \quad \frac{g_{h\gamma\gamma}}{g_{h_{SM}\gamma\gamma}} \simeq 1 - 0.8\% \left(\frac{1\ \text{TeV}}{m_T}\right)^2$

we need to be able to identify small deviations from the SM

Quiz: what could these (freely invented) data tell us?

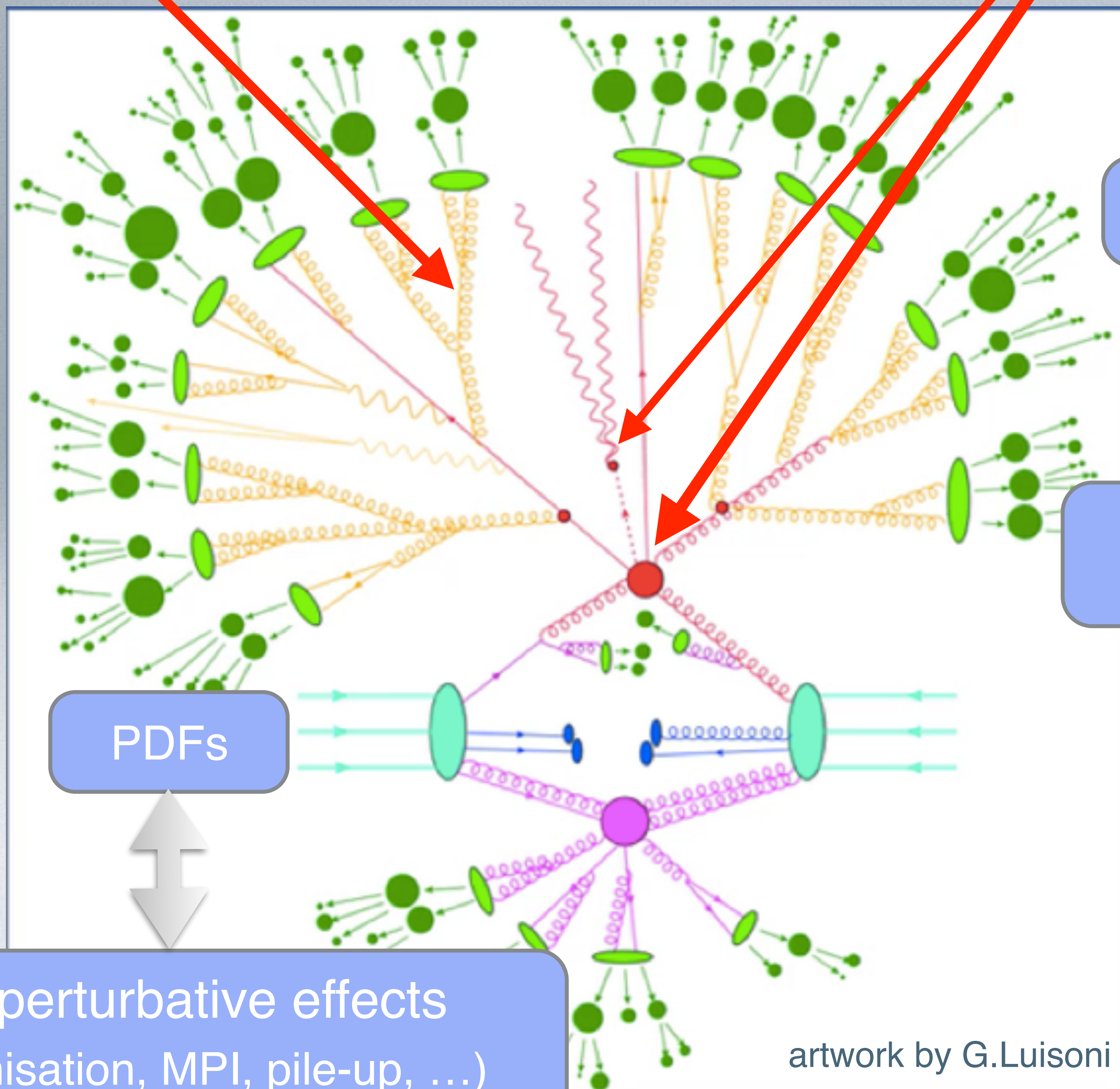


The precision frontier

parton shower ↔ resummation ↔ fixed order calculations NLO (QCD+EW), NNLO, …

quark mass effects

parametric uncertainties (e.g. couplings, masses)



artwork by G.Luisoni

PDFs

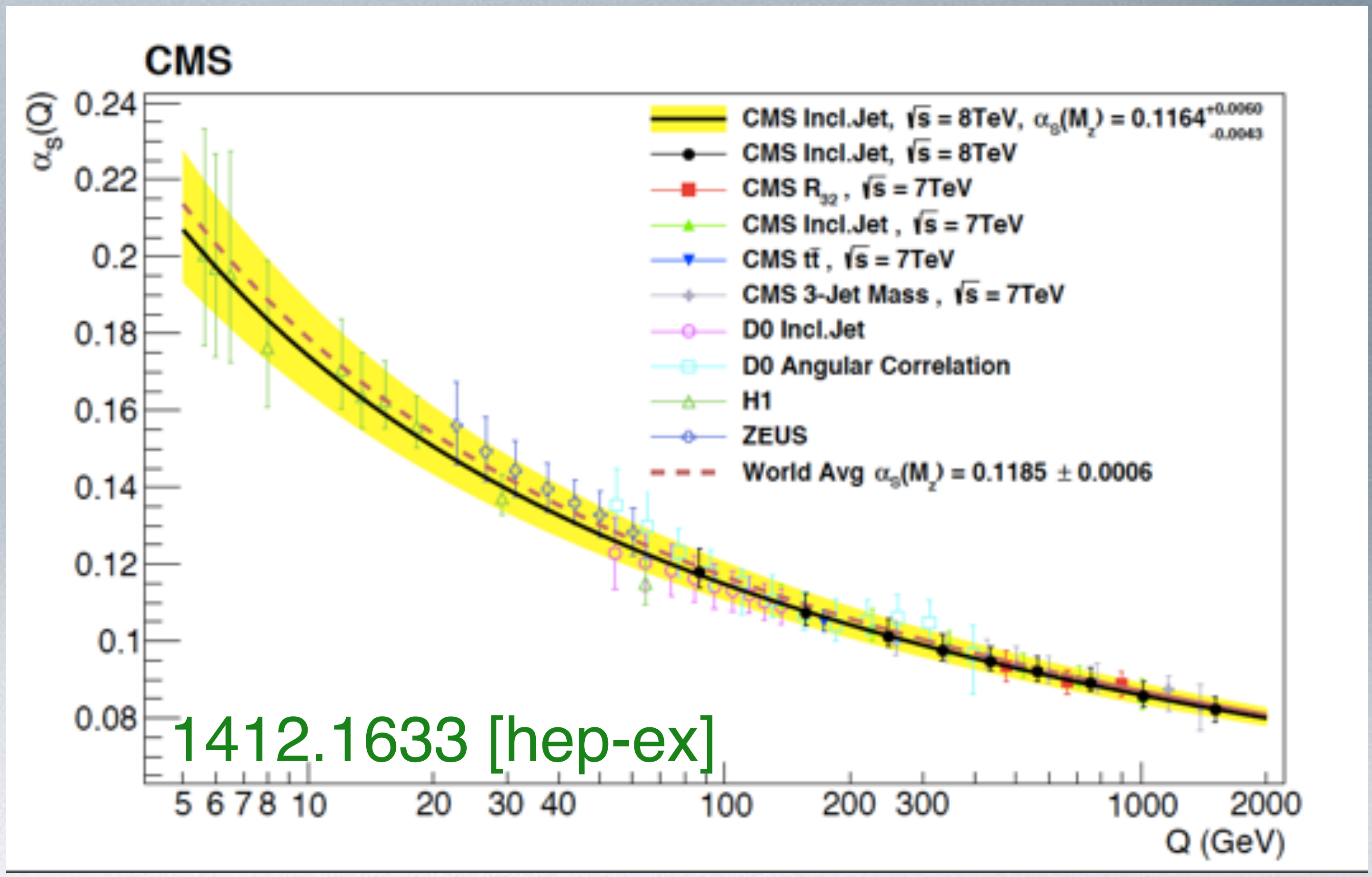
non-perturbative effects (hadronisation, MPI, pile-up, …)

theorist's basic toolbox

- local gauge invariance $SU(2) \times U(1) \times SU(3)_c$

- renormalisability

important principles of QCD:



- asymptotic freedom

- factorisation

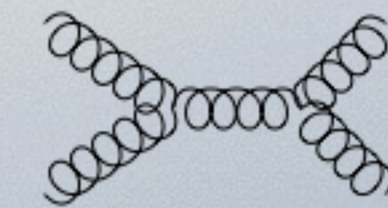
- perturbative expansions, e.g.

$$\hat{\sigma} = \alpha_s^k(\mu)\left[\hat{\sigma}^{\rm LO} + \alpha_s(\mu)\,\hat{\sigma}^{\rm NLO}(\mu) + \alpha_s^2(\mu)\,\hat{\sigma}^{\rm NNLO}(\mu) + \ldots\right]$$

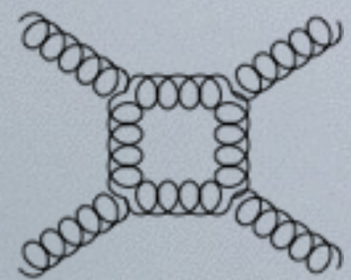
QCD corrections: building blocks

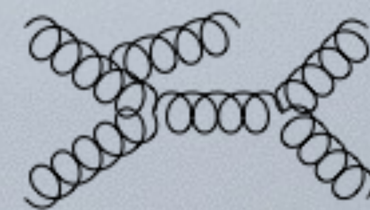
example 2 to 2 scattering

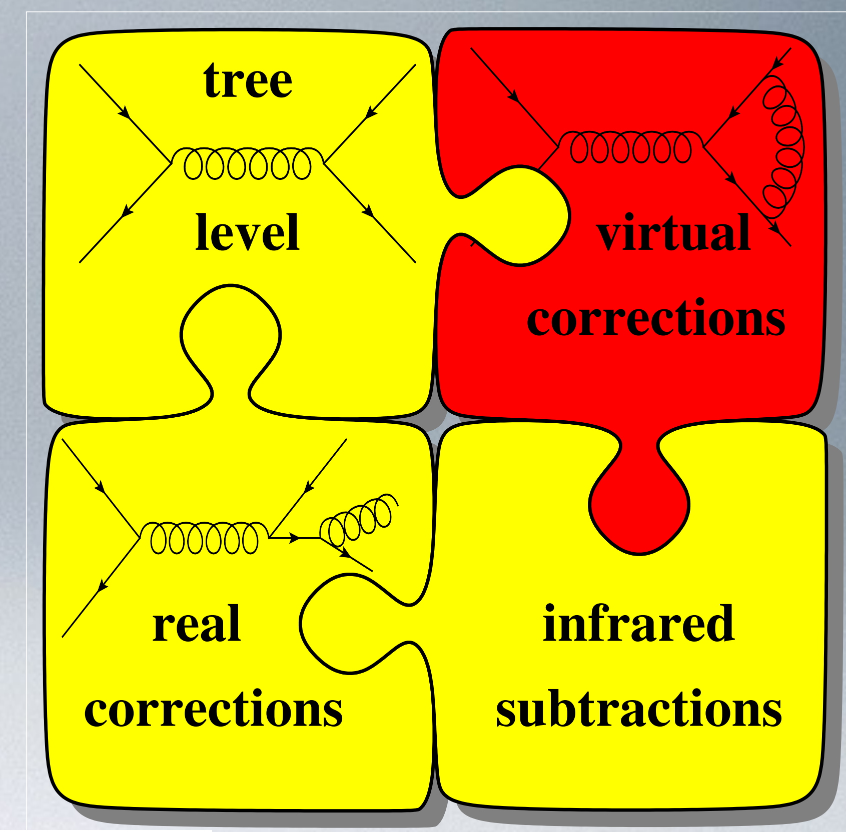
LO: usually tree level diagrams



NLO: one loop (virtual) + extra real radiation + subtraction terms







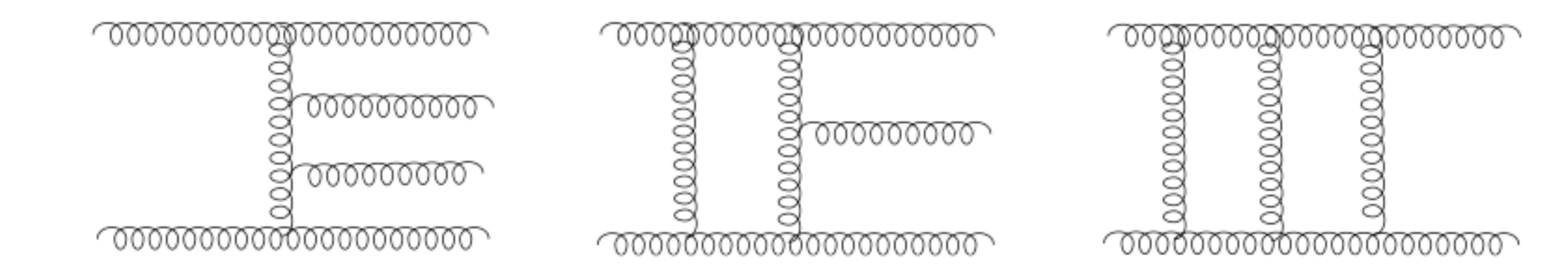
individual contributions are divergent

- requires the isolation of the singularities
  dimensional regularisation: $D = 4 - 2\epsilon$
- need a good subtraction method for singularities of individual contributions

$$\sigma^{NLO} = \underbrace{\int_{m+1} \left[d\sigma^R - d\sigma^S \right]_{\epsilon=0}}_{\text{numerically}} + \underbrace{\int_m \left[\underbrace{d\sigma^V}_{\text{cancel poles}} + \underbrace{\int_s d\sigma^S}_{\text{analytically}} \right]_{\epsilon=0}}_{\text{numerically}}$$

QCD corrections: building blocks

NNLO: example 2-jet final state



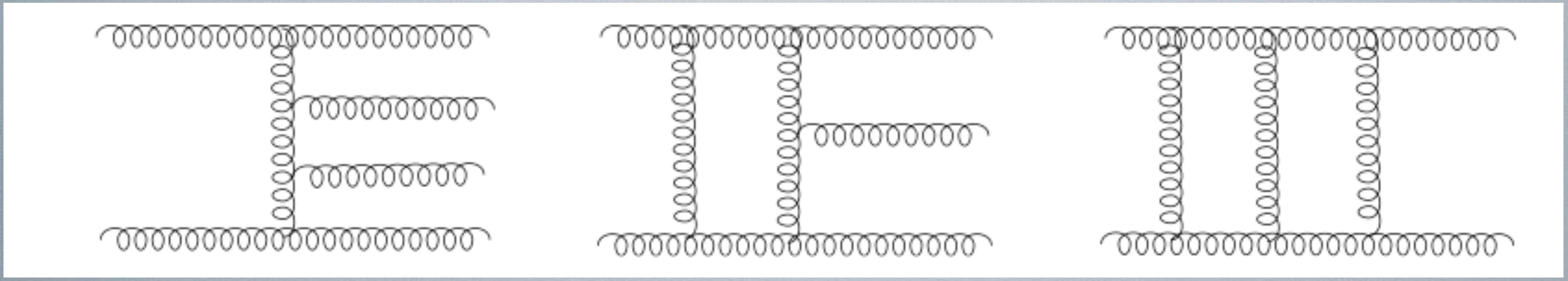
double real	1-loop virtual $\otimes$ single real	2-loop virtual
↓	↓	↓
implicit IR poles (PS integration)	explicit and implicit poles	explicit poles $1/\epsilon^{2L}$

bottlenecks: IR subtraction

two-loop integrals

QCD corrections: building blocks

NNLO: example 2-jet final state



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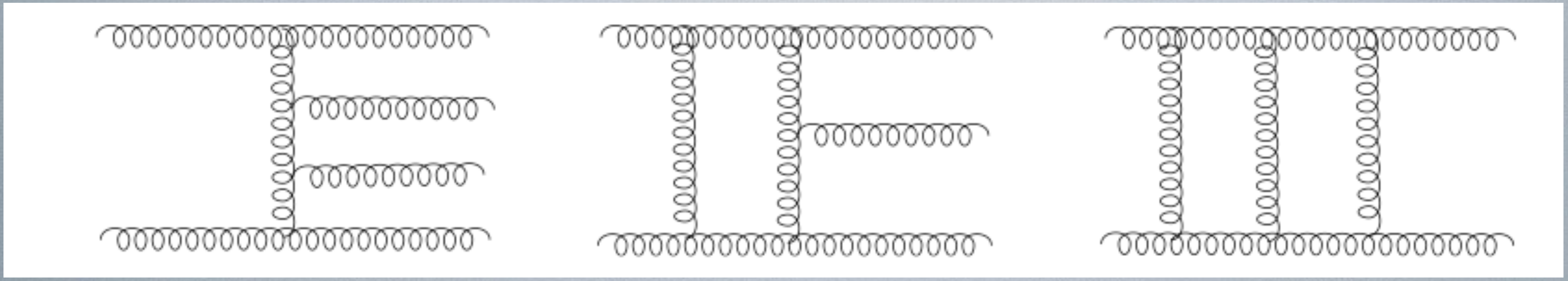
bottlenecks: IR subtraction   two-loop integrals

↑

harder with more massless particles
(intricate IR singularity structure)

QCD corrections: building blocks

NNLO: example 2-jet final state



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bottlenecks: IR subtraction

↑

harder with more massless particles
(intricate IR singularity structure)

two-loop integrals

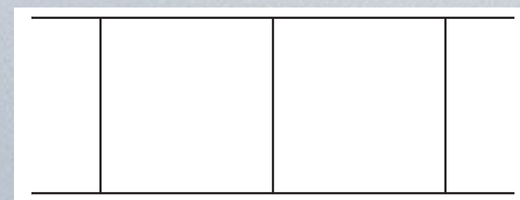
↑

harder with more massive/off-shell particles
(more scales → more complicated
analytic structure)

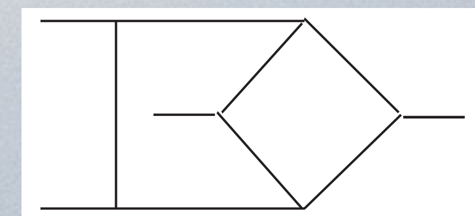
(analytic) results for two-loop integrals

2-loop 4-point: (black lines are massless, red lines massive)

- all massless:

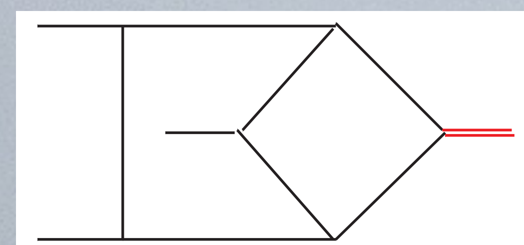


planar: Smirnov '99



non-planar: Tausk '99

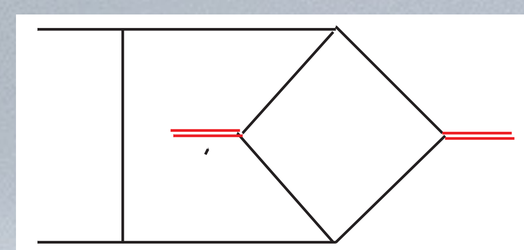
- one massive leg:
  e.g. pp to V+jet



Gehrmann and Remiddi '00-'02

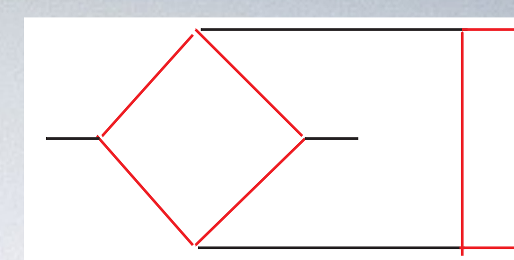
Moch, Uwer, Weinzierl '02

- two massive legs:
  e.g. pp to VV



Gehrmann, Tancredi, Weihs '13
Gehrmann, von Manteuffel, Tancredi, Weihs '14
Caola, Henn, Melnikov, Smirnov '14
Papadopoulos, Tommasini, Wever '14

- massive propagators (also massive on-shell legs) e.g. $t\bar{t}$



Czakon et al '07-'13 (**numerically**)

Bonciani, Ferroglia, Gehrmann, von Manteuffel, Studerus '10, '13 (analytic, **partial**, tT)

Henn, Smirnov '13 (analytic, **partial**, Bhabha)

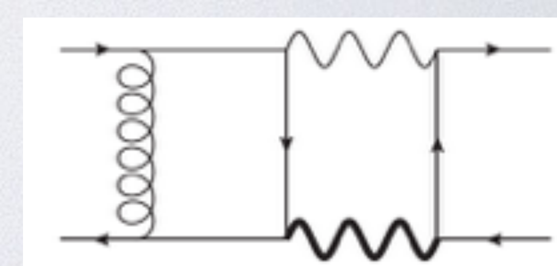
Mastrolia, Passera, Primo, Schubert '17 (analytic, **partial**, $\mu\, e$)

- massive propagators (one mass)

Bonciani, Di Vita, Mastrolia, Schubert '16;

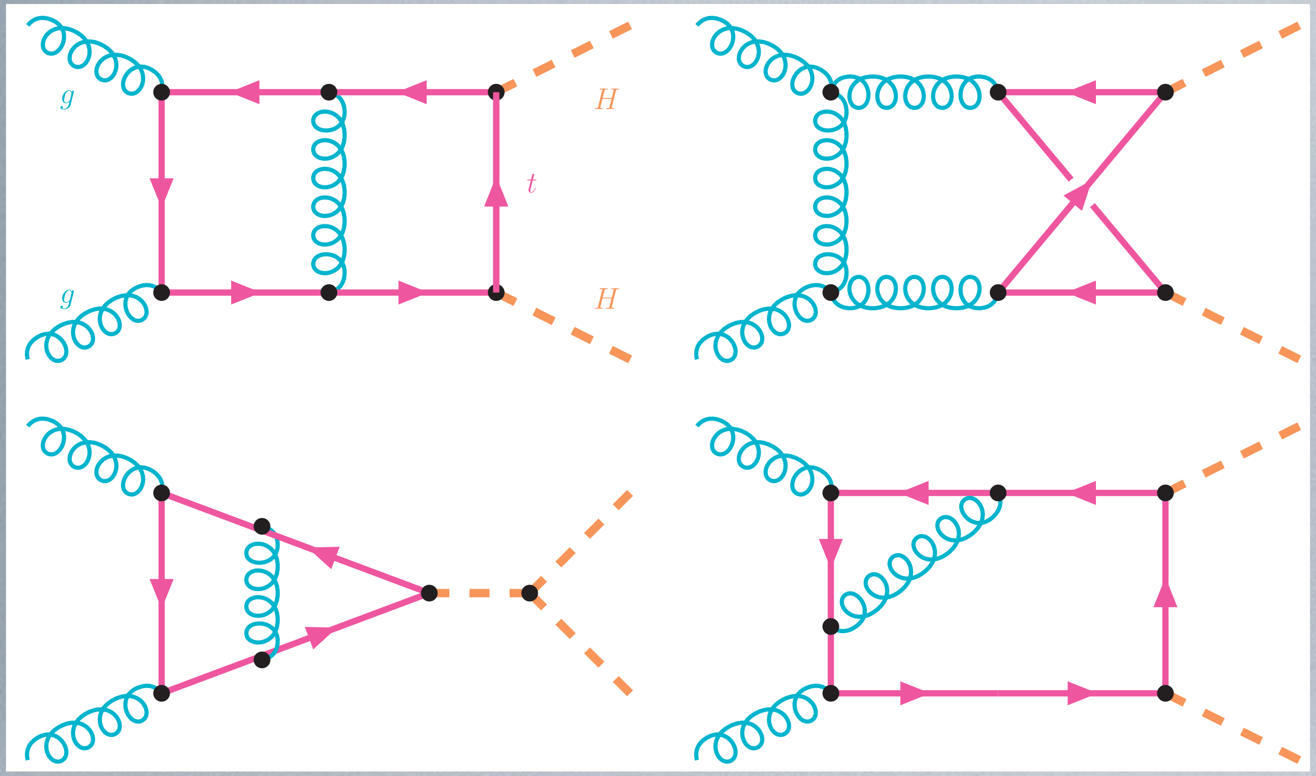
von Manteuffel, Schabinger '17

e.g. mixed QCD-EW corrections to Drell-Yan, analytic, **partial**



results for two-loop integrals

- massive propagators + massive legs with different mass (two additional mass scales) e.g. $gg \to HH$



graphics by S.Jones

4 independent scales
s12, s23, mH, mt

analytic results for master integrals mostly unknown

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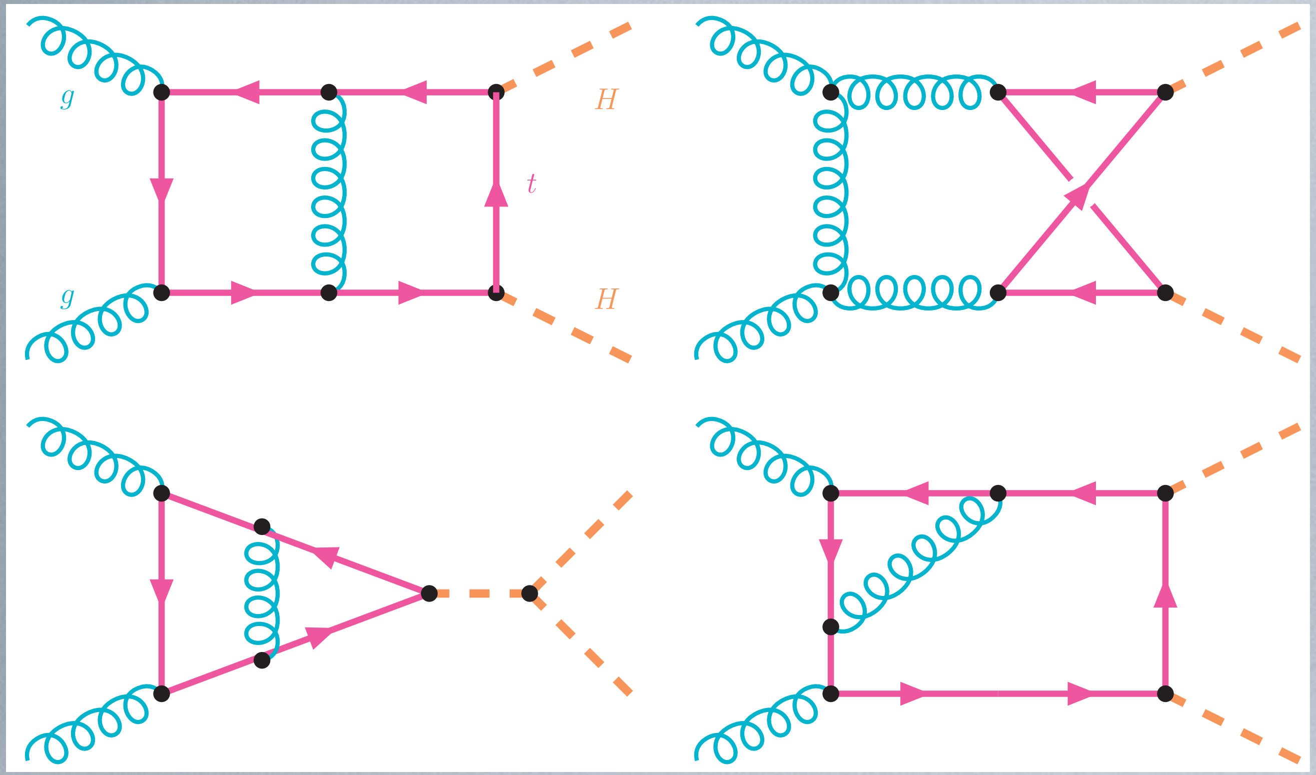


graphics by S.Jones

4 independent scales
s12, s23, mH, mt

analytic results for master integrals mostly unknown

- **NLO calculation with full top mass dependence**

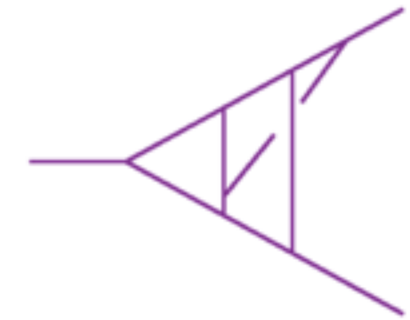
Borowka, Greiner, GH, Jones, Kerner, Schlenk, Schubert, Zirke '16

- all integrals calculated **numerically** with **SecDec**
- total number of integrals: before reduction: ~10000, after reduction ~330, after sector decomposition 11244 (3086 non-planar)

numerical evaluation of multi-loop integrals

http://secdec.hepforge.org   https://github.com/mppmu/secdec/releases

SecDec is hosted by Hepforge, IPPP Durham



SecDec

Sophia Borowka, Gudrun Heinrich, Stephan Jahn, Stephen Jones, Matthias Kerner, Johannes Schlenk, Tom Zirke

A program to evaluate dimensionally regulated parameter integrals numerically

home   download program   user manual   faq   changelog

NEW! The latest version of pySecDec is available on github. The manual is available on readthedocs.
Download the version 1.1.2 of pySecDec as pySecDec-1.1.2.tar.gz. The manual is available here.
Download version 1.1.1 of pySecDec as pySecDec-1.1.1.tar.gz. The manual is available here.
Download version 1.1 of pySecDec as pySecDec-1.1.tar.gz. The manual is available here.
The first release version of pySecDec can be downloaded as pySecDec-1.0.tar.gz. The manual is available here.
See also the corresponding paper arXiv:1703.09692.

algorithm: T. Binoth, GH ‘00

version 1.0: J. Carter, GH ‘10

version 2.0: S.Borowka, J. Carter, GH ‘12

version 3.0: S.Borowka, GH, S.Jones, M.Kerner, J.Schlenk, T.Zirke ‘15

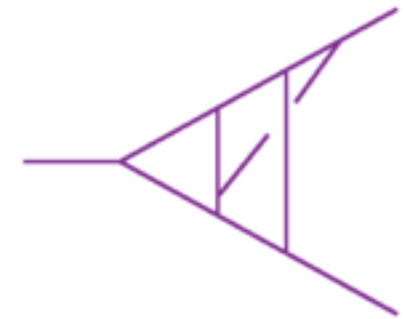
pySecDec: S.Borowka, GH, S.Jahn, S.Jones, M.Kerner, J.Schlenk, T.Zirke ‘17

numerical evaluation of multi-loop integrals

http://secdec.hepforge.org https://github.com/mppmu/secdec/releases

SecDec is hosted by Hepforge, IPPP Durham

MAX-PLANCK-GESELLSCHAFT



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home download program user manual faq changelog

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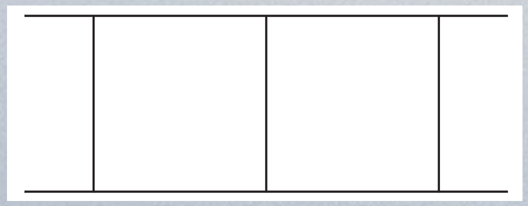
pySecDec: S.Borowka, GH, S.Jahn, S.Jones, M.Kerner, J.Schlenk, T.Zirke **'17**

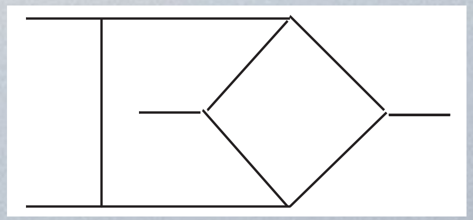
New!
can be used as an integral library

(analytic) results for two-loop integrals

2-loop 4-point: (black lines: massless, red: massive/off-shell)

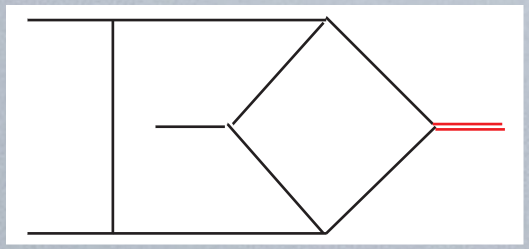
- all massless:





planar: Smirnov '99 non-planar: Tausk '99

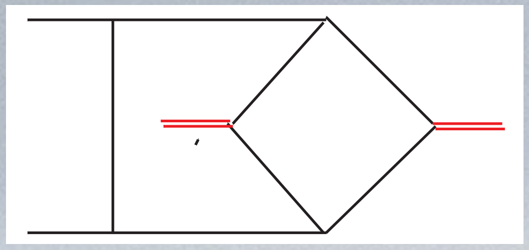
- one massive leg:
  e.g. pp to V+jet



Gehrmann and Remiddi '00-'02

Moch, Uwer, Weinzierl '02

- two massive legs:
  e.g. pp to VV



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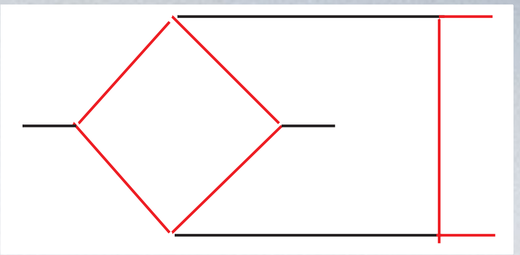

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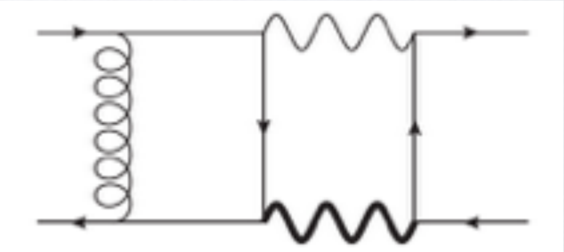

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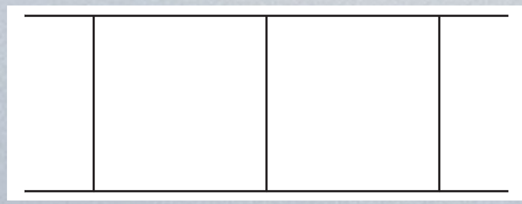

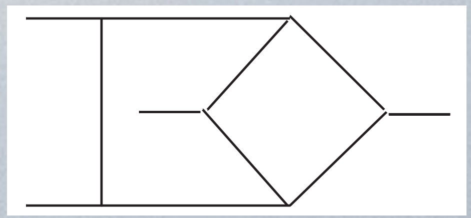

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- one massive leg:
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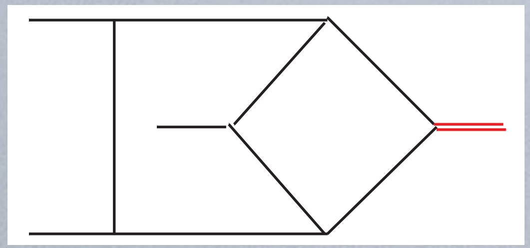

Gehrmann and Remiddi '00-'02

Moch, Uwer, Weinzierl '02

- two massive legs:
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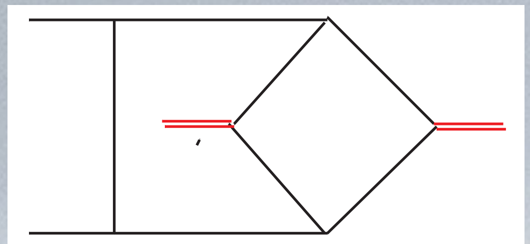

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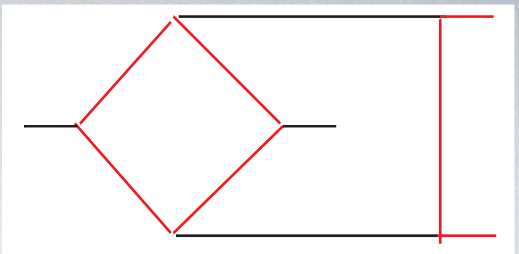

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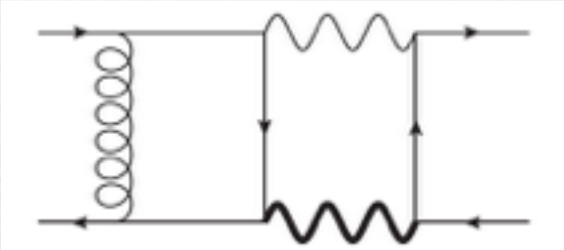

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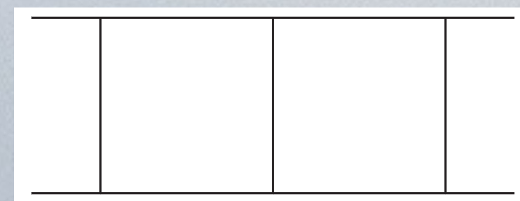

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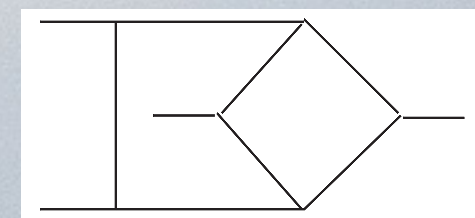

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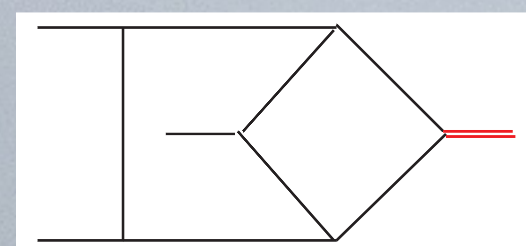

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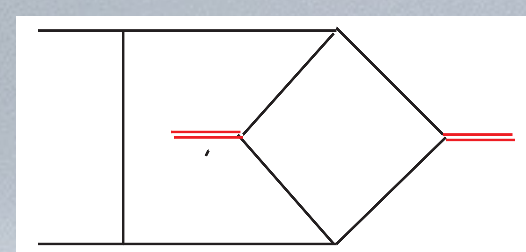

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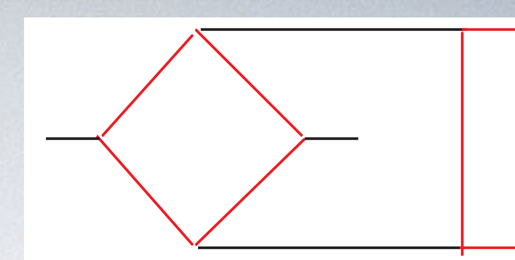

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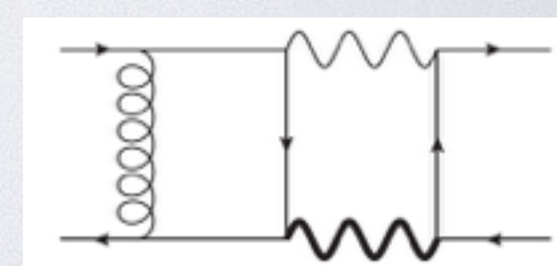

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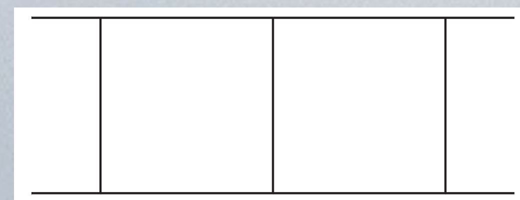

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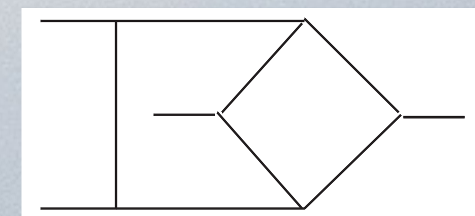

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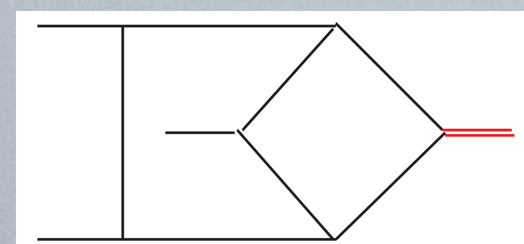

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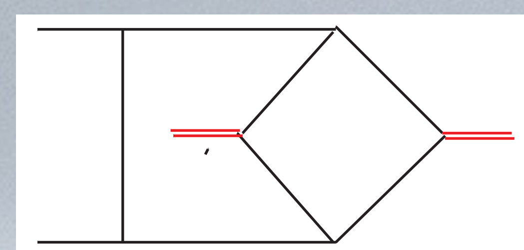

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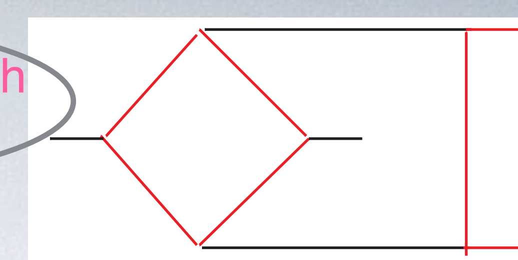

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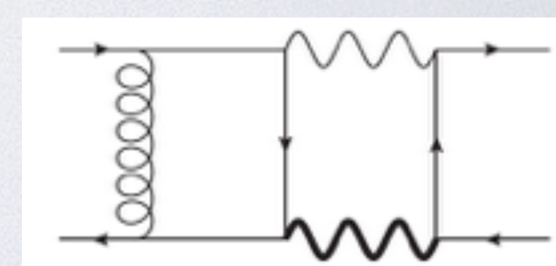

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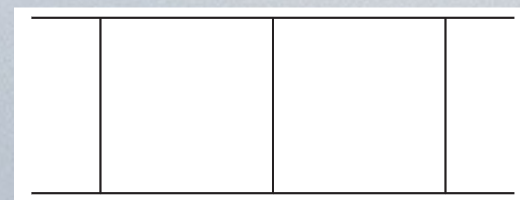

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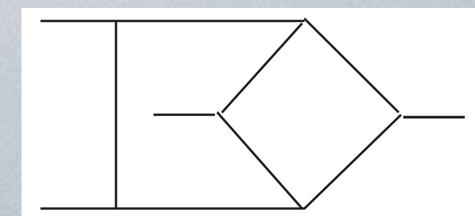

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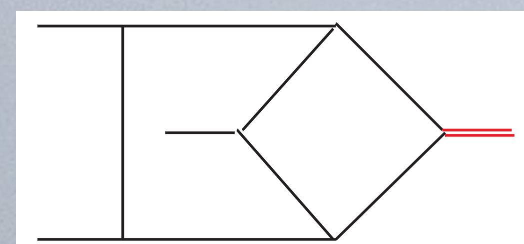

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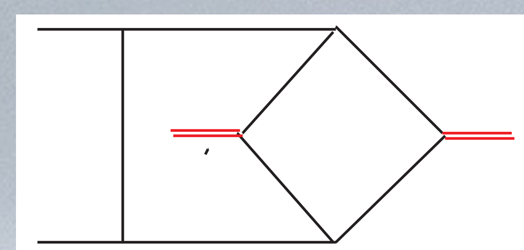

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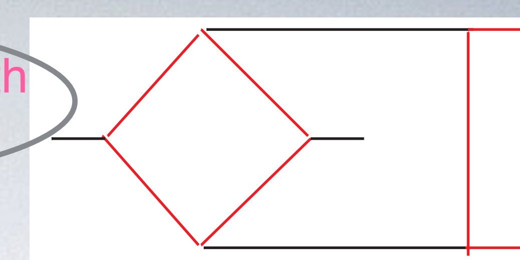

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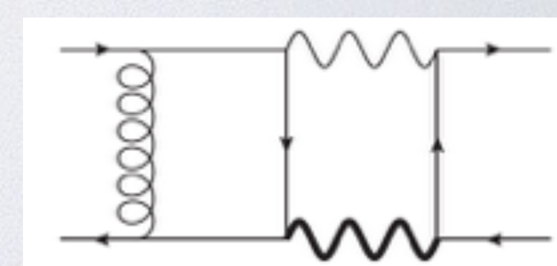


Exploring the Higgs sector

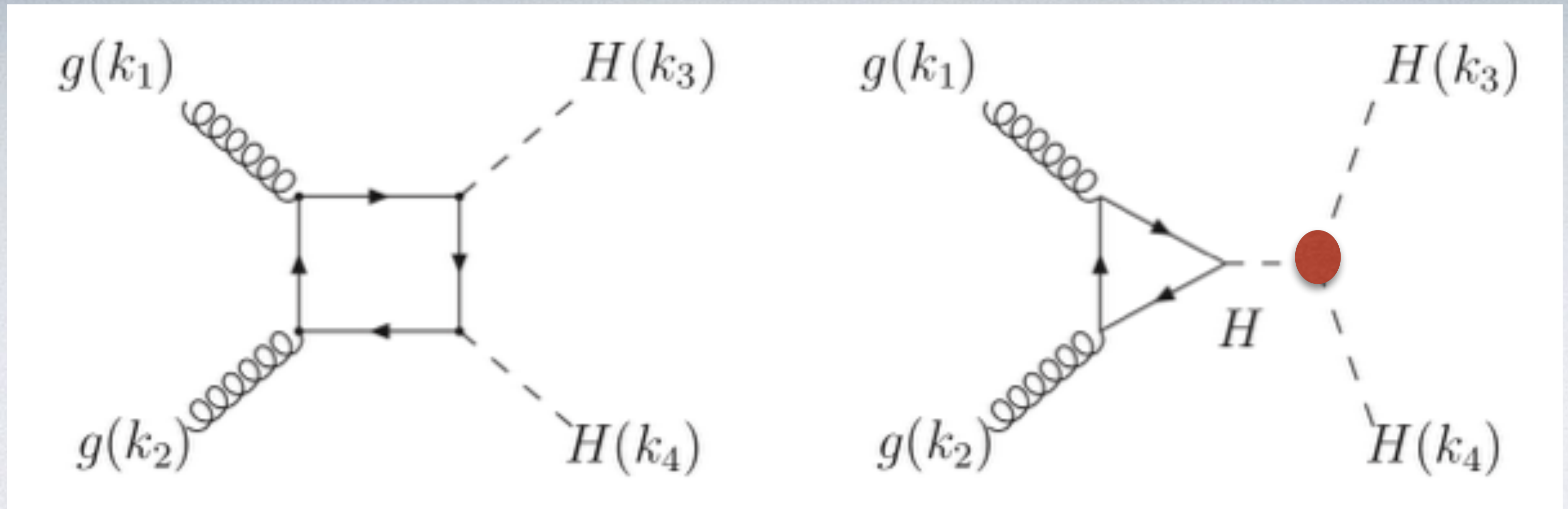
SM: $V(\Phi) = -\frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$

EW symmetry breaking

$$\frac{m_h^2}{2} h^2 + \frac{m_h^2}{2v} h^3 + \frac{m_h^2}{8v^2} h^4$$

λ_{3h} completely determined in the SM

can be measured e.g. in Higgs boson pair production



current best limit $\sigma_{HH} \leq 19\,\sigma_{HH}^{SM}$ ($b\bar{b}\gamma\gamma$ channel)

measurement of λ_{3h} only at HL-LHC

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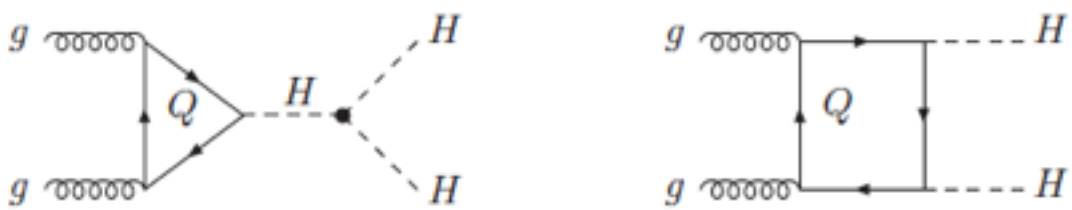
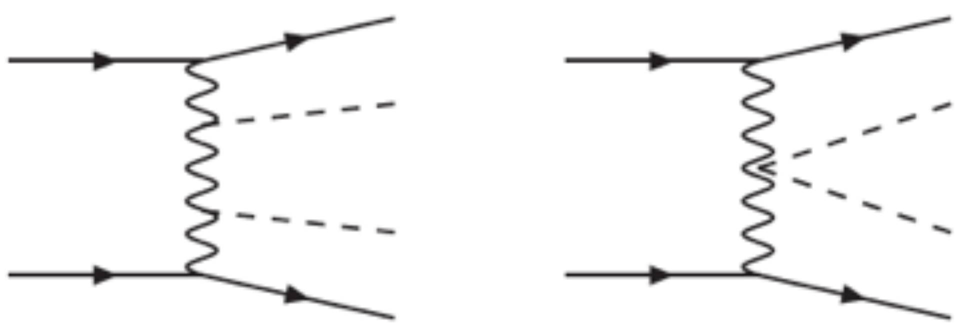
Higgs boson pair production mechanisms

- gluon fusion

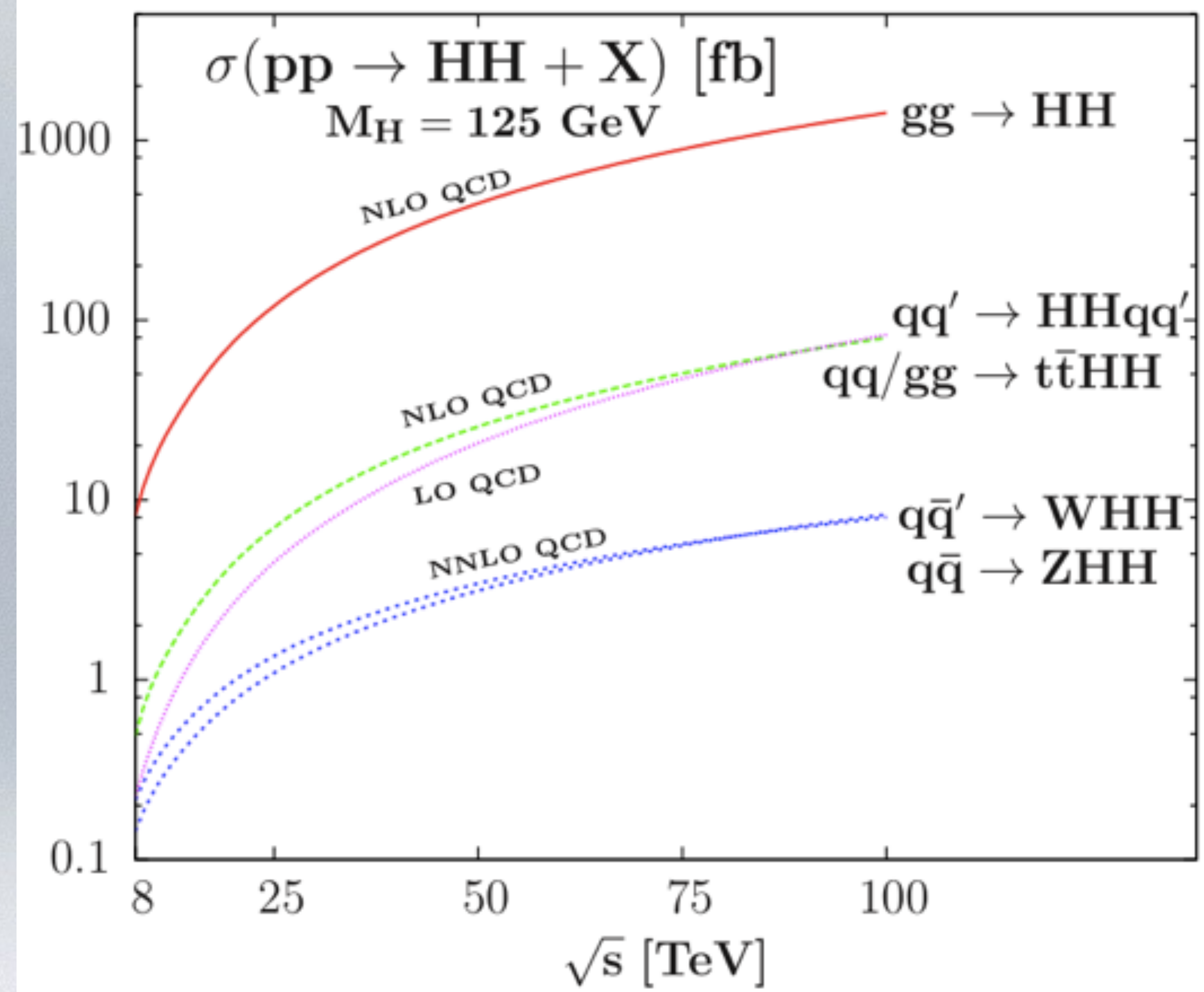


- vector boson fusion



- top-quark associated

- Higgs-strahlung



Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, Spira '12

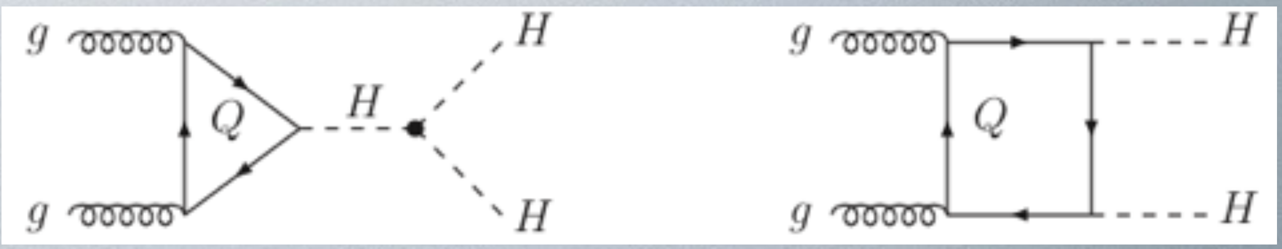
largest cross section from gluon fusion, but still

$$\sigma_{ggHH} \sim 10^{-3}\,\sigma_{ggH}$$

Higgs boson pair production in gluon fusion

LO with full heavy quark mass dependence

Glover, van der Bij '88, Plehn, Spira, Zerwas '96



$m_t \to \infty$ limit: "Higgs Effective Field Theory" (HEFT)

Note:

HEFT strictly valid only for $\sqrt{\hat{s}} \ll 2m_t$
HH production threshold: $2m_H < \sqrt{\hat{s}}$

$\Rightarrow$ validity of HEFT limited to $250\,\mathrm{GeV} < \sqrt{\hat{s}} < 340\,\mathrm{GeV}$

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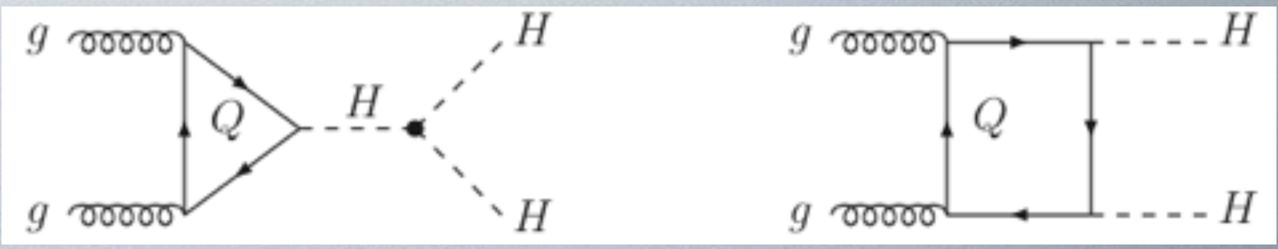

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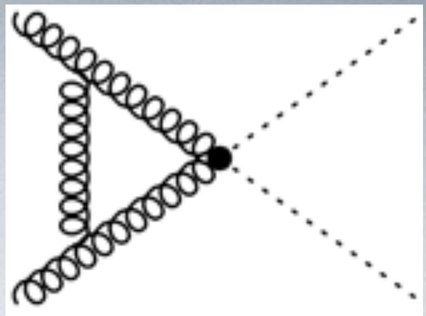
"Born-improved NLO HEFT": rescale by $\mathcal{M}^{LO}(m_t)/\mathcal{M}^{LO}_{\mathrm{HEFT}}$

NLO in Born-improved HEFT Dawson, Dittmaier, Spira '98 (**HPAIR**) $K \simeq 2$



- **supplemented with $1/m_t$ expansion:** $(\pm 10\%)$

  Grigo, Hoff, Melnikov, Steinhauser '13, '15 ; Degrassi, Giardino, Gröber '16

- **full mass dependence in NLO real radiation ("FTapprox")** **-10%**

  Frederix, Hirschi, Mattelaer, Maltoni, Torrielli, Vryonidou, Zaro '14;
  Maltoni, Vryonidou, Zaro '14

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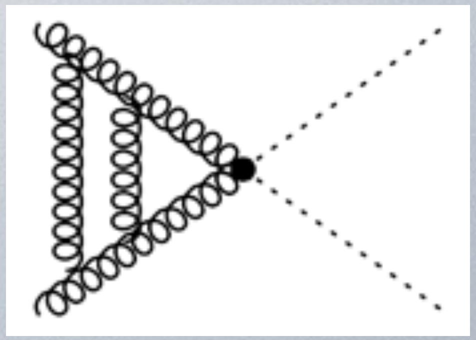


NNLO in $m_t \to \infty$ limit: **+20%**

- **total xs NNLO** De Florian, Mazzitelli '13
- **including all matching coefficients** Grigo, Melnikov, Steinhauser '14
- **supplemented with $1/m_t$ expansion:** Grigo, Hoff, Steinhauser '15
- **soft gluon resummation NNLL matched to NNLO** **+9%**

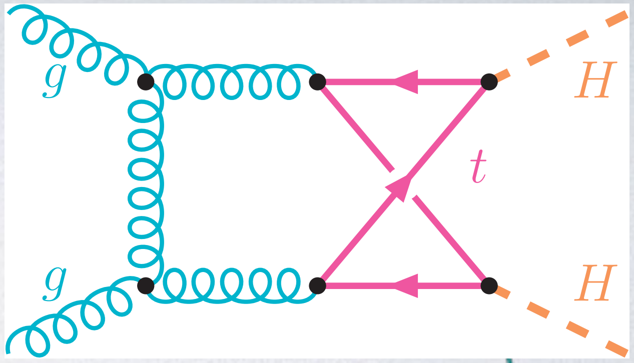
  Shao, Li, Li, Wang '13, De Florian, Mazzitelli '15

- **differential NNLO** De Florian, Grazzini, Hanga, Kallweit, Lindert, Maierhöfer, Mazzitelli, Rathlev '16

- **NLO calculation with full top mass dependence**

  Borowka, Greiner, GH, Jones, Kerner, Schlenk, Schubert, Zirke '16

- **q_T resummation NLL+NLO** Ferrera, Pires '16



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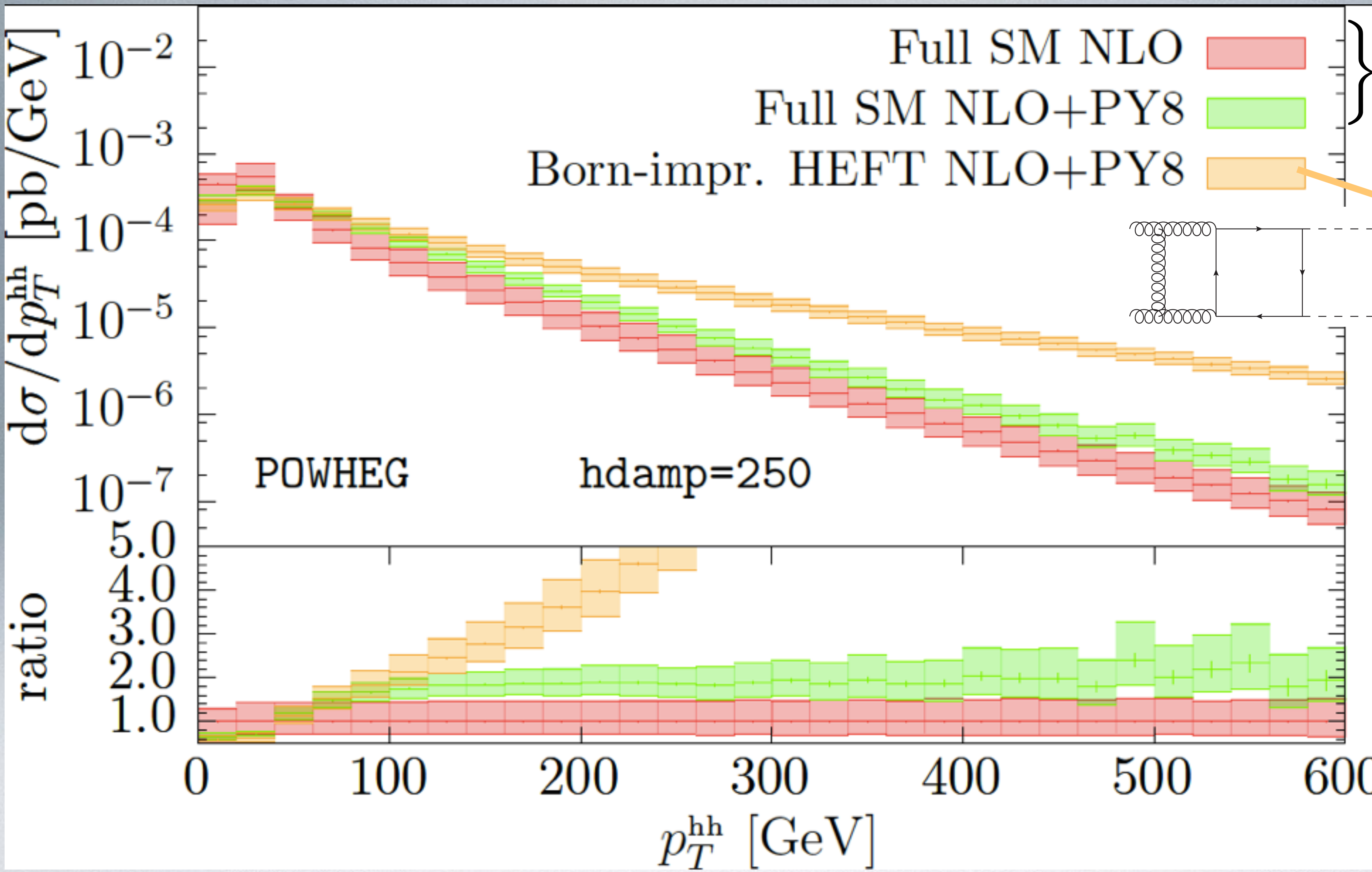
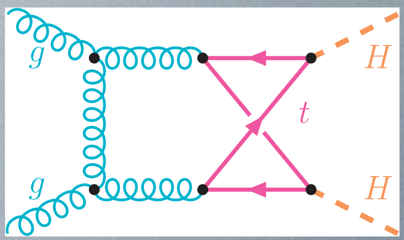
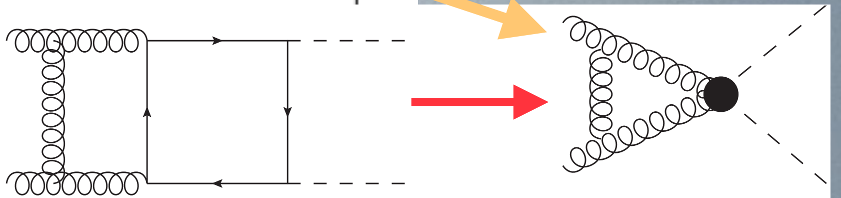
GH, S.Jones, M.Kerner, G.Luisoni, E.Vryonidou 1703.09252







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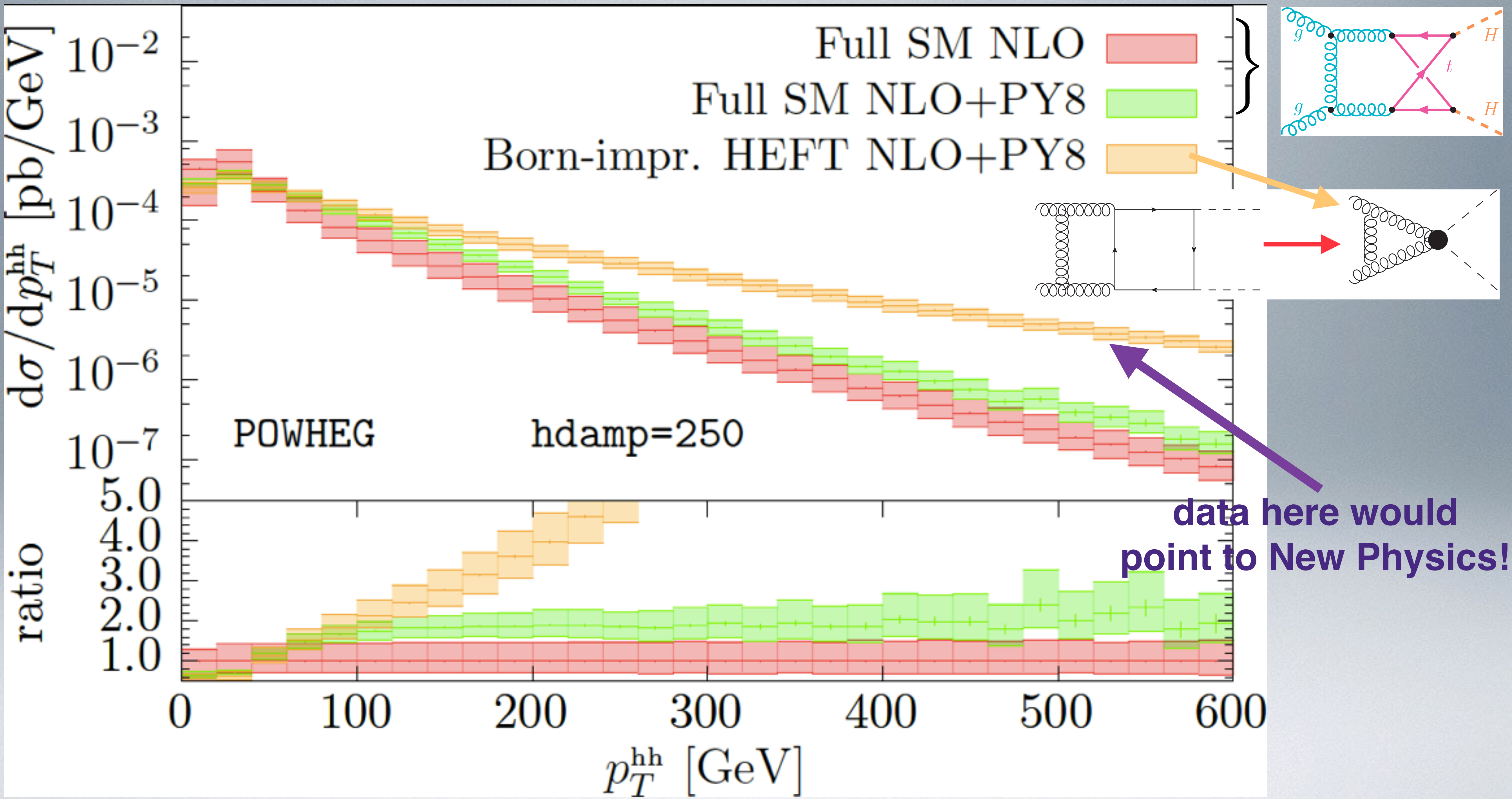

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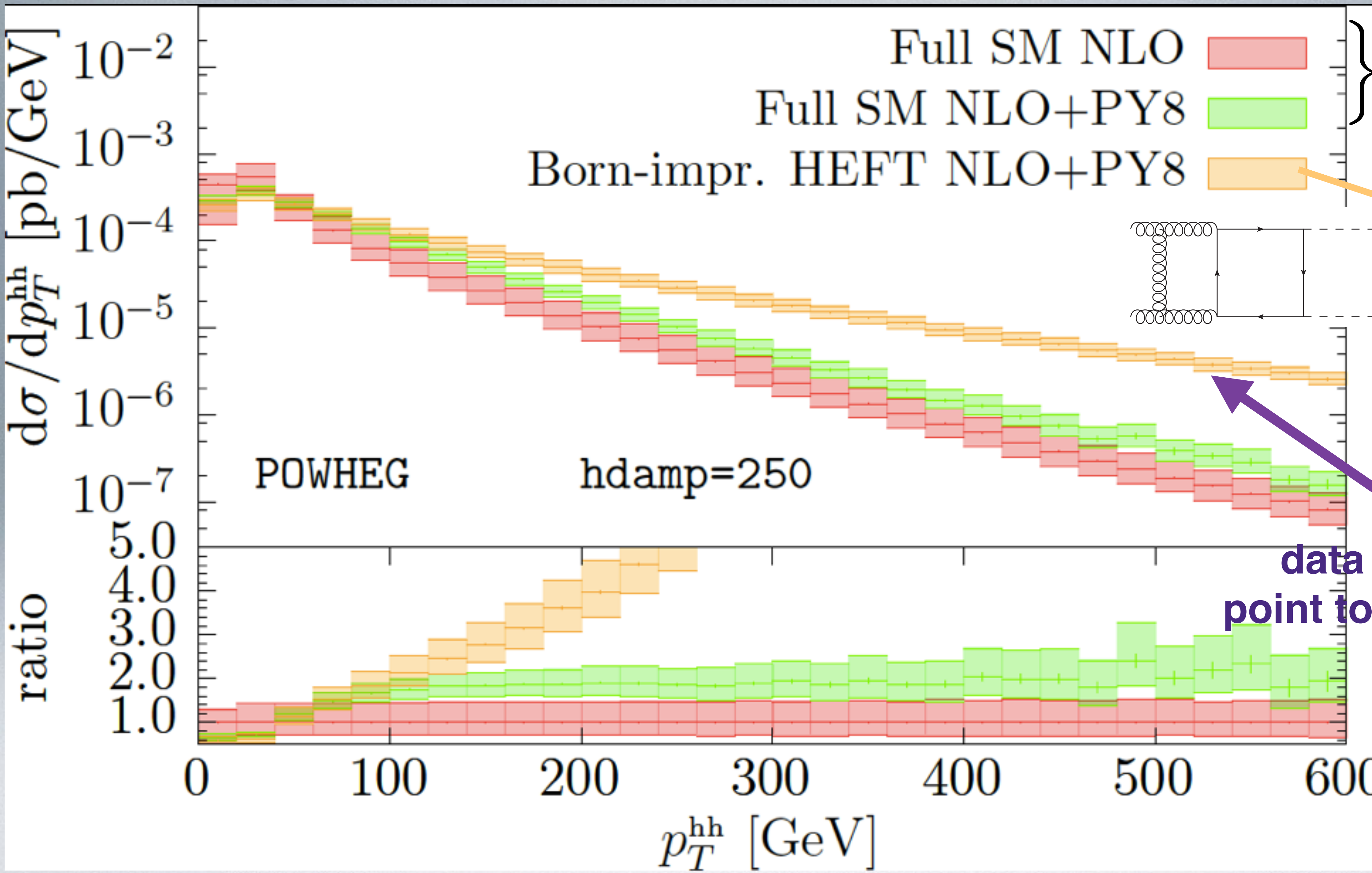

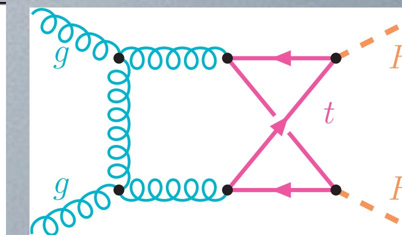

data here would point to New Physics!

had we only the Born-improved HEFT results, we wouldn't be able to tell

Summary and outlook

- the Higgs sector is just starting to get explored
- it is likely that New Physics is hiding in small deviations
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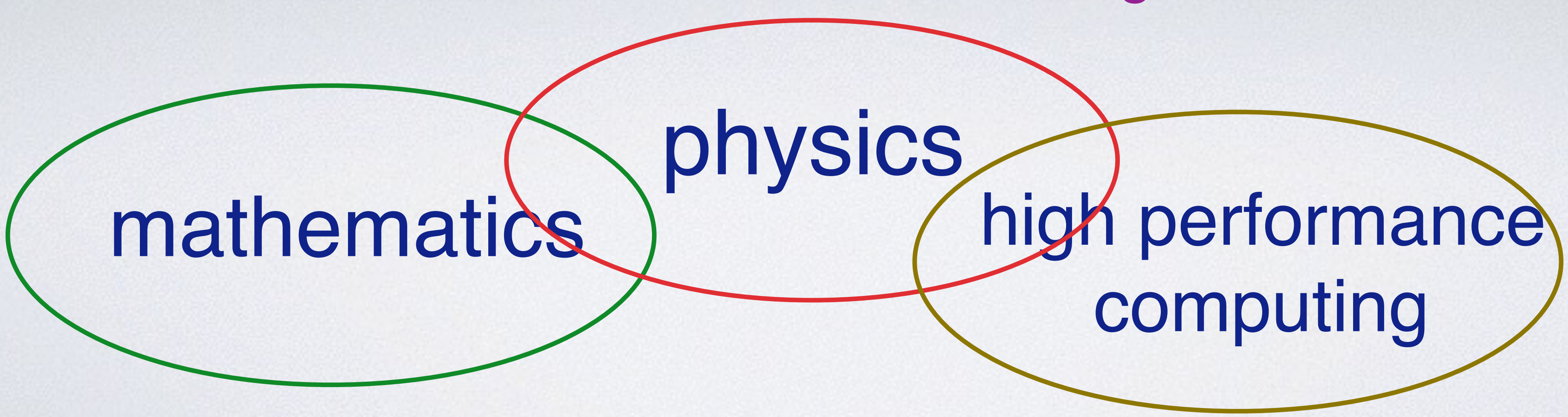
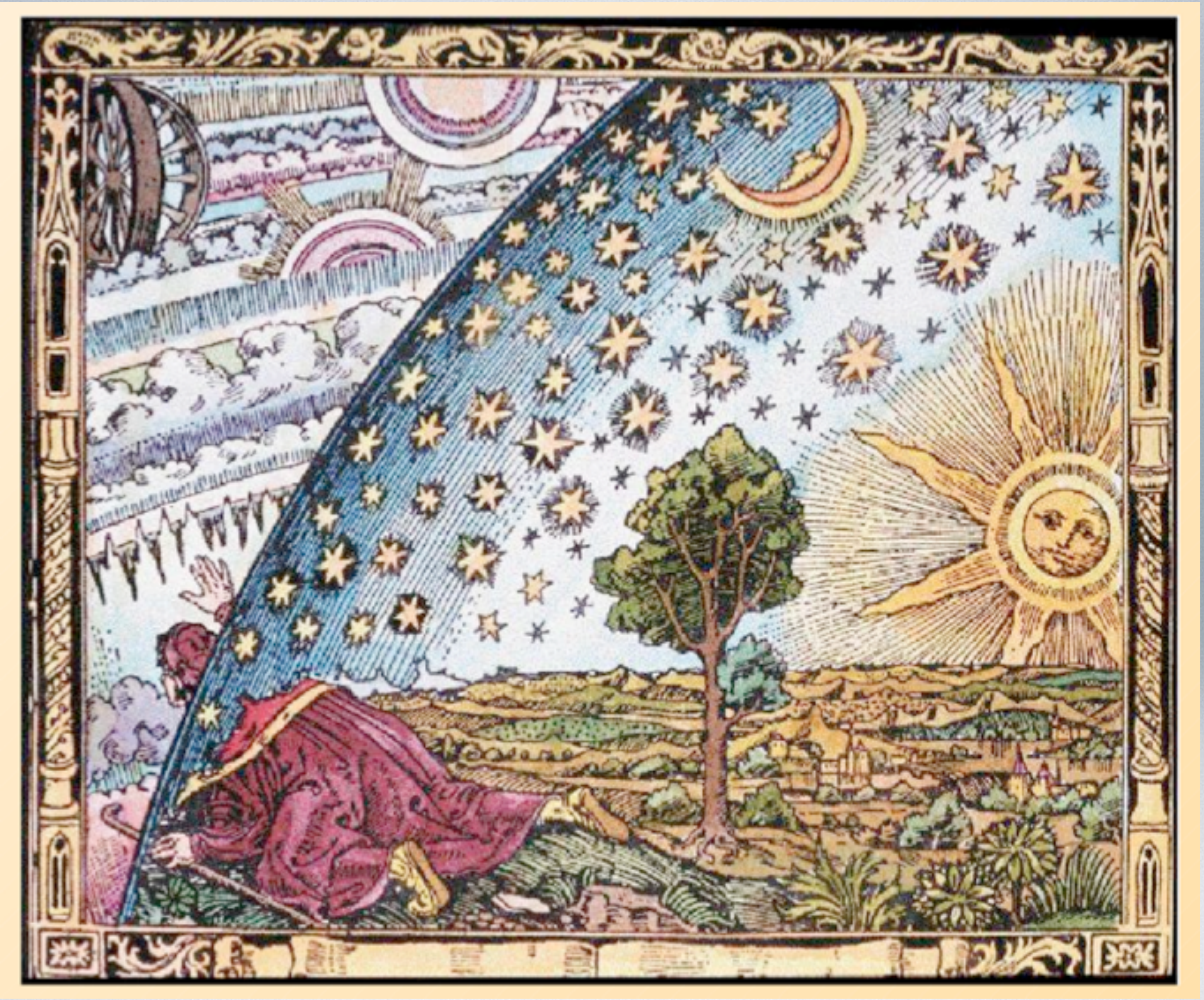


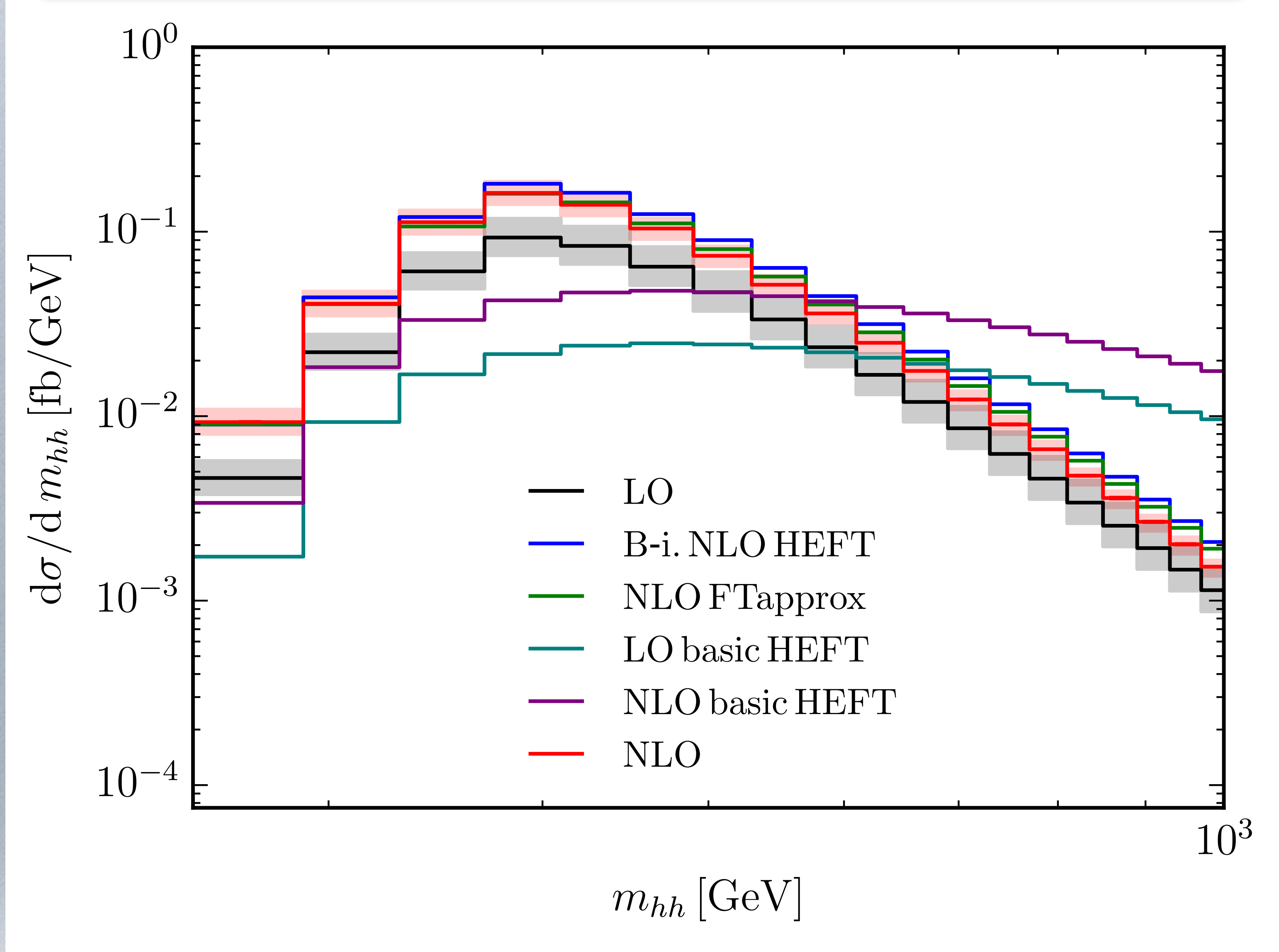
The Standard Model is unlikely to be the full picture

precision calculations/measurements
may uncover the unexpected !



BACKUP SLIDES

scaling behaviour



$\frac{d\hat{\sigma}}{dm_{hh}} \sim m_{hh}^{-3}$ i.e. partonic cross section scales as $\hat{s}^{-1}$

HEFT approximation: $\frac{d\hat{\sigma}}{dm_{hh}} \sim m_{hh}$ i.e. $\hat{\sigma} \sim \hat{s}$

similar for H+jet: [Greiner, Höche, Luisoni, Schönherr, Winter '16]

$$\frac{d\hat{\sigma}}{dp_{T,h}} \sim 1/p_{T,h}^{a} \text{ with } a = 2(\text{full}), a = 1(\text{HEFT})$$

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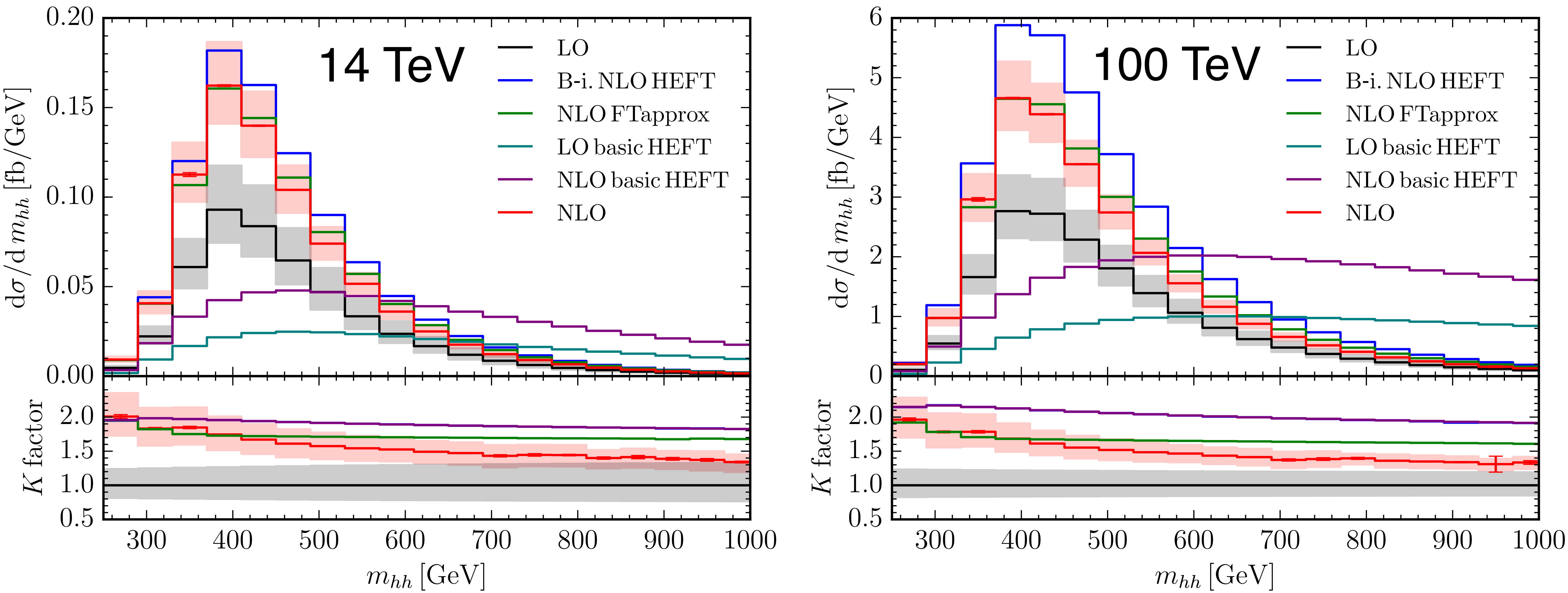
Higgs boson pair invariant mass



for large invariant masses:

Born-improved NLO HEFT overestimates by about 50%, FTapprox by about 40%
(at 14 TeV, worse at 100 TeV)

top quark loops resolved → HEFT has wrong scaling behaviour at high energies

full mass dependence at NLO more important for shape than NNLO in an approximate theory (HEFT)

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Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

top mass effects

total cross sections at 14 TeV $\mu_0 = m_{HH}/2$

	σ_{LO}[fb]	σ_{NLO}[fb]	σ_{NNLO}[fb]
HEFT	$17.07^{+30.9\%}_{-22.2\%}$	$31.93^{+17.6\%}_{-15.2\%}$	$37.52^{+5.2\%}_{-7.6\%}$
B-i. HEFT	$19.85^{+27.6\%}_{-20.5\%}$	$38.32^{+18.1\%}_{-14.9\%}$	
$\mathrm{FT}_{\mathrm{approx}}$	$19.85^{+27.6\%}_{-20.5\%}$	$34.26^{+14.7\%}_{-13.2\%}$	
full m_t dep.	$19.85^{+27.6\%}_{-20.5\%}$	$32.91^{+13.6\%}_{-12.6\%}$	

PDF4LHC15_nlo_30_pdfas

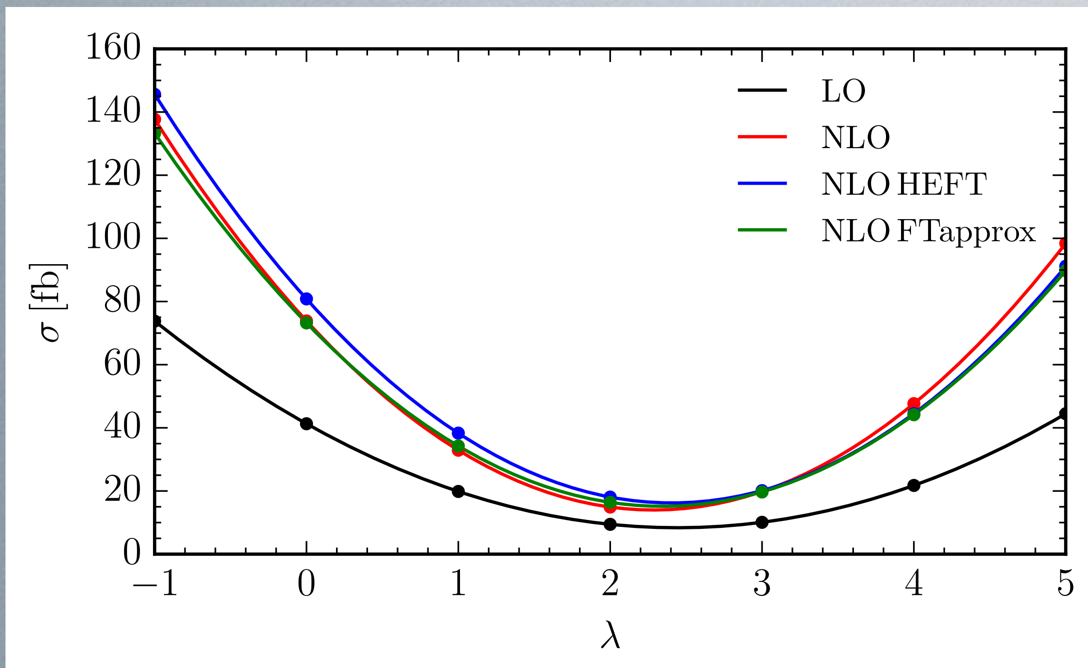
m_H=125 GeV, m_t=173 GeV

uncertainties: $\mu_{R,F} \in [\mu_0/2, 2\,\mu_0]$ (7-point variation)

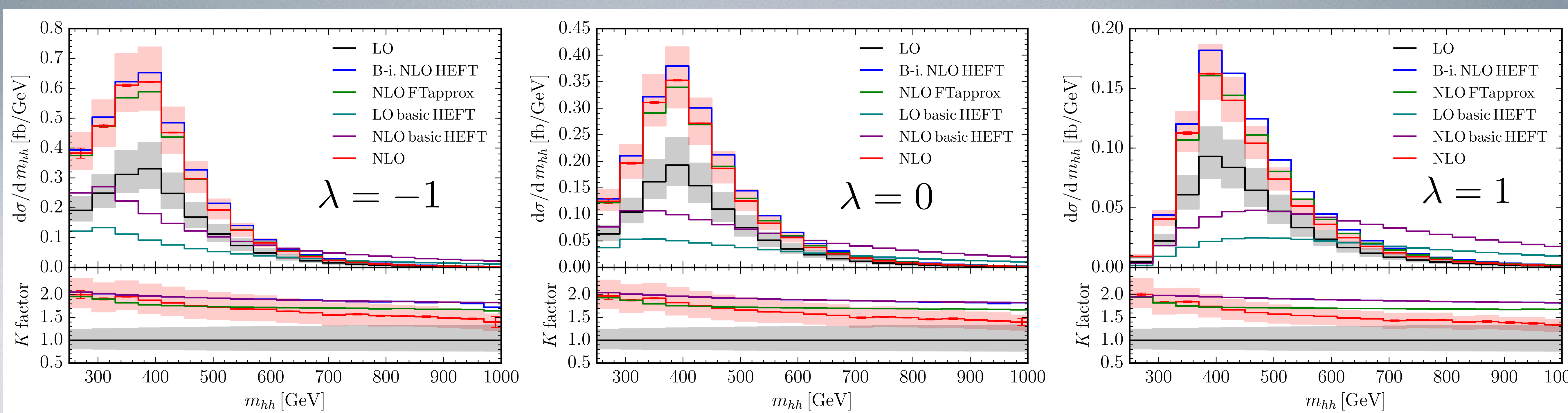
HXSWG: $\sigma'_{NNLL} = \sigma_{NNLL} + \delta_t\,\sigma^{\mathrm{HEFT}}_{NLO} = 39.64^{+4.4\%}_{-6.0\%}$

variation of triple Higgs coupling

$$\lambda = \lambda_{BSM}/\lambda_{SM}$$



cross section has a minimum around $\lambda = 2$ due to destructive interference between diagrams containing λ and box-type diagrams



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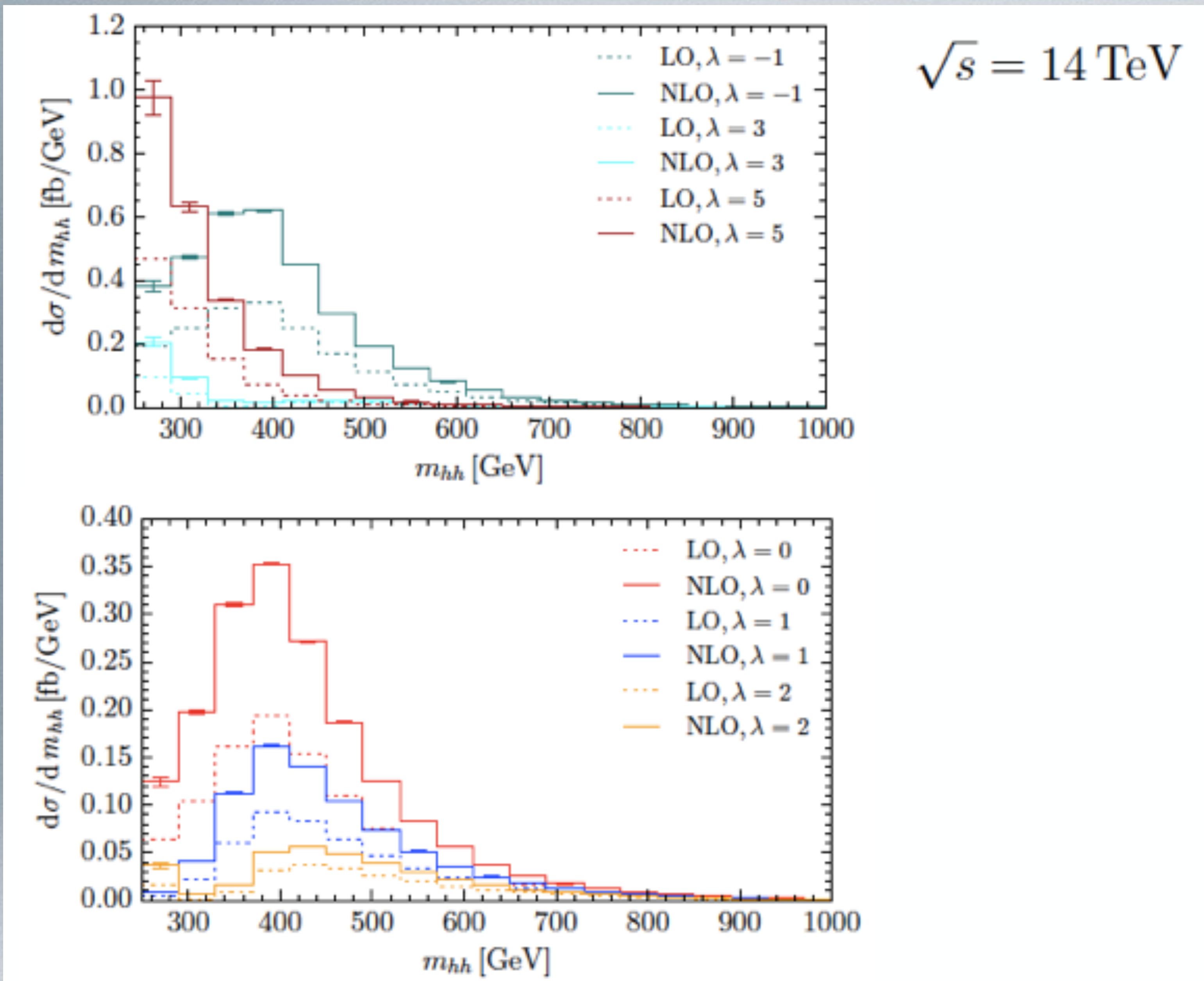
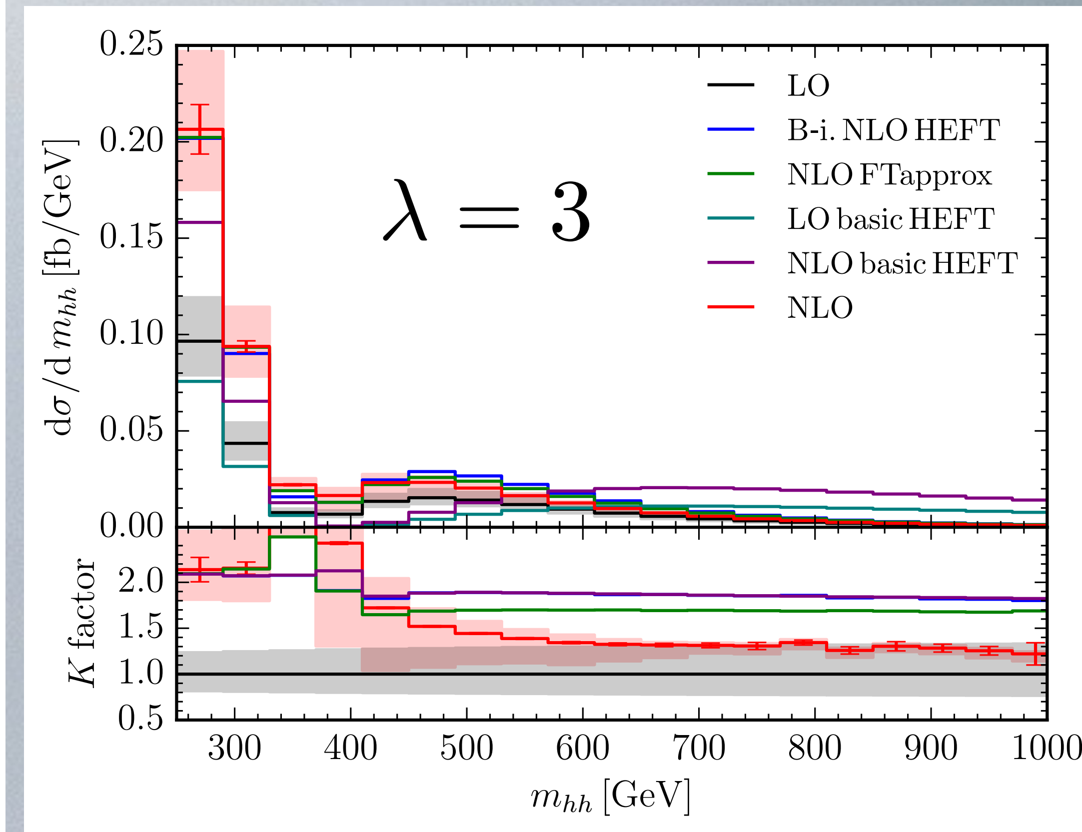
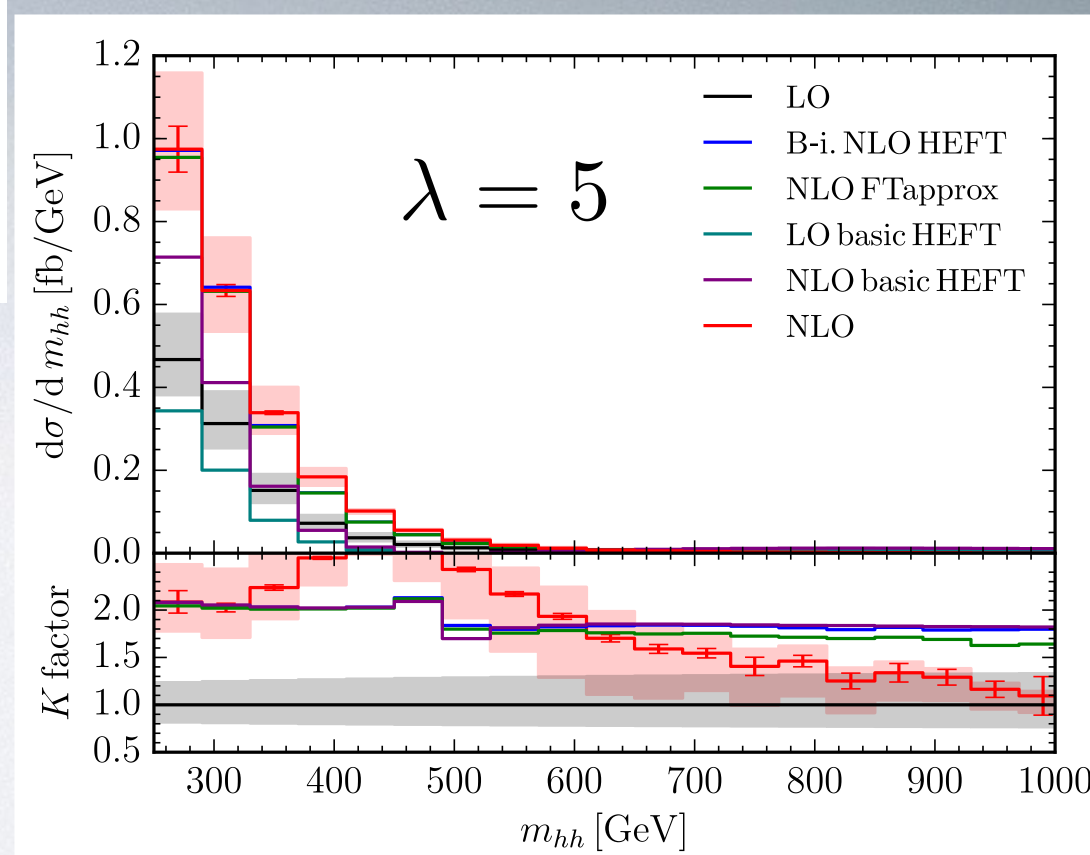
variation of triple Higgs coupling







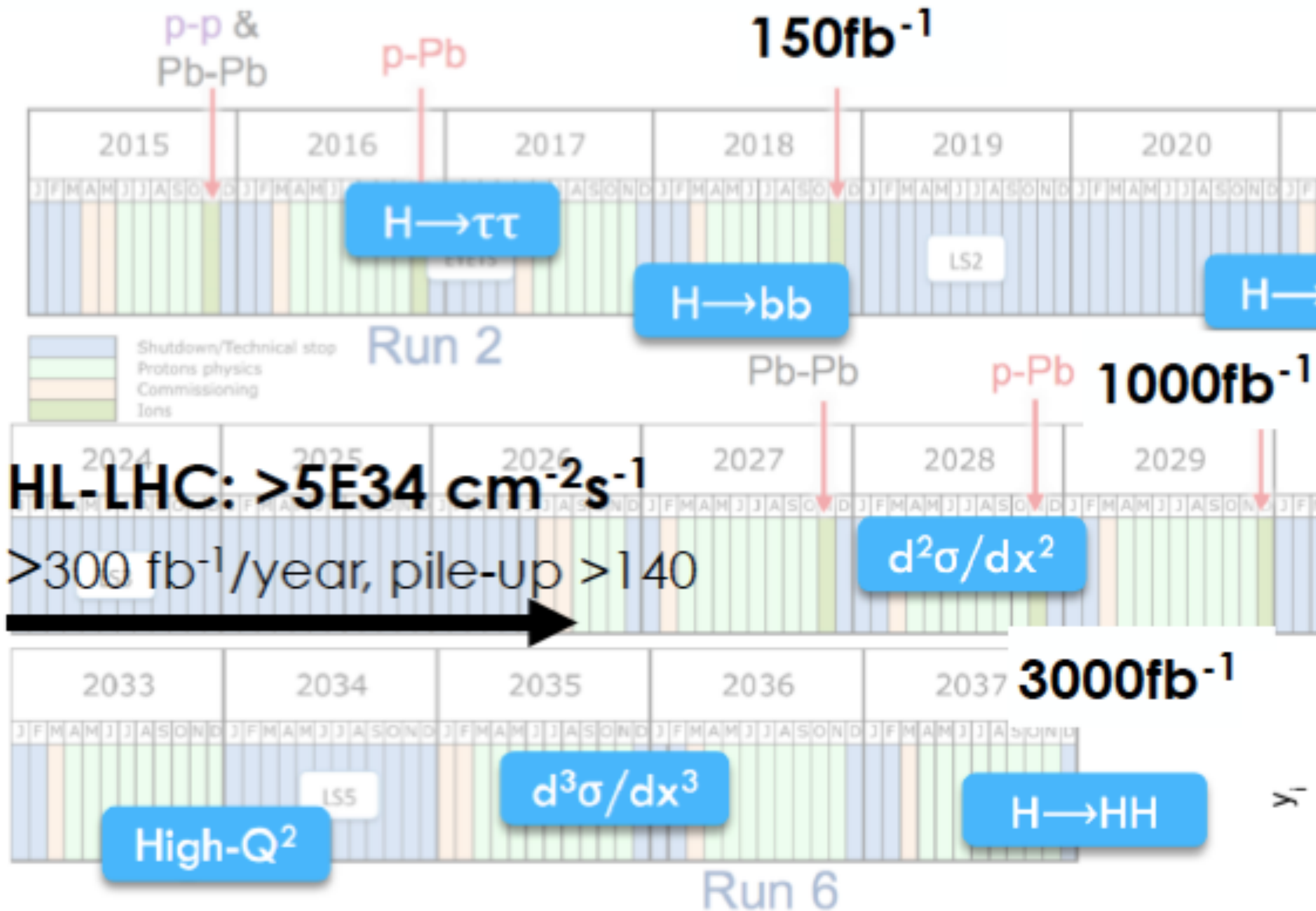
distributions have discriminating power

full analysis requires inclusion of other operators, e.g. $t\bar{t}hh$ coupling

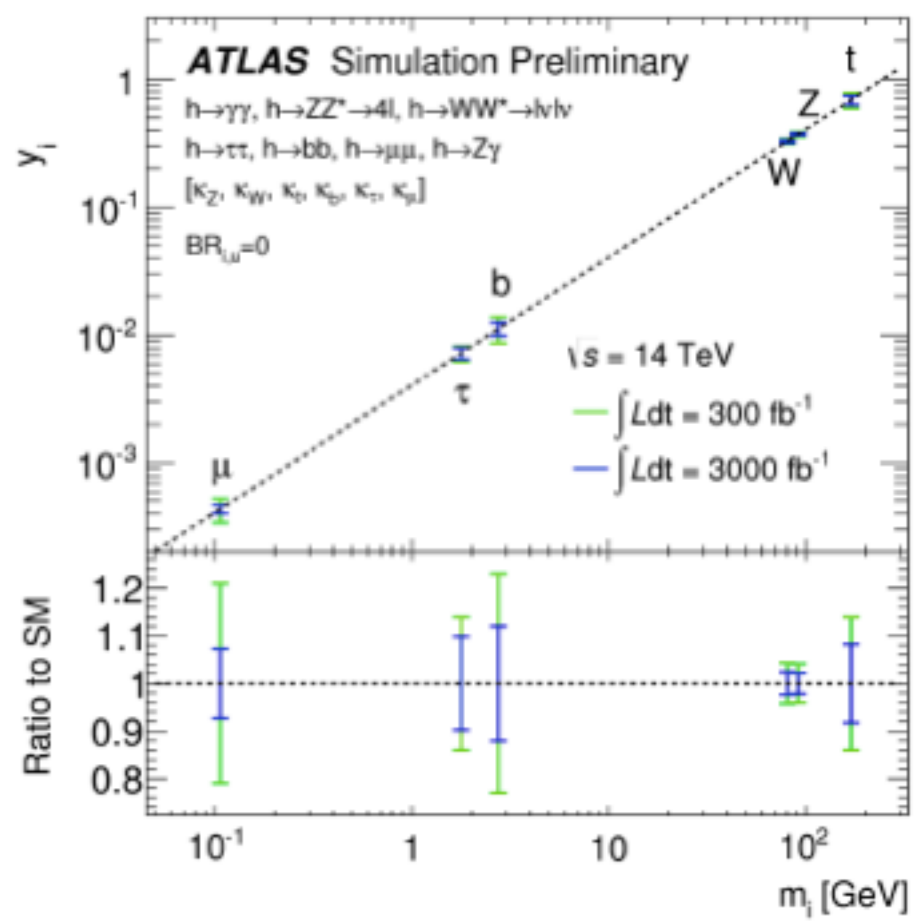
MAX-PLANCK-GESELLSCHAFT

TIMELINE BEYOND RUN2

Credits: A. David @ GRC 2017



P.Meridiani, EPS 2017



limits on di-Higgs production

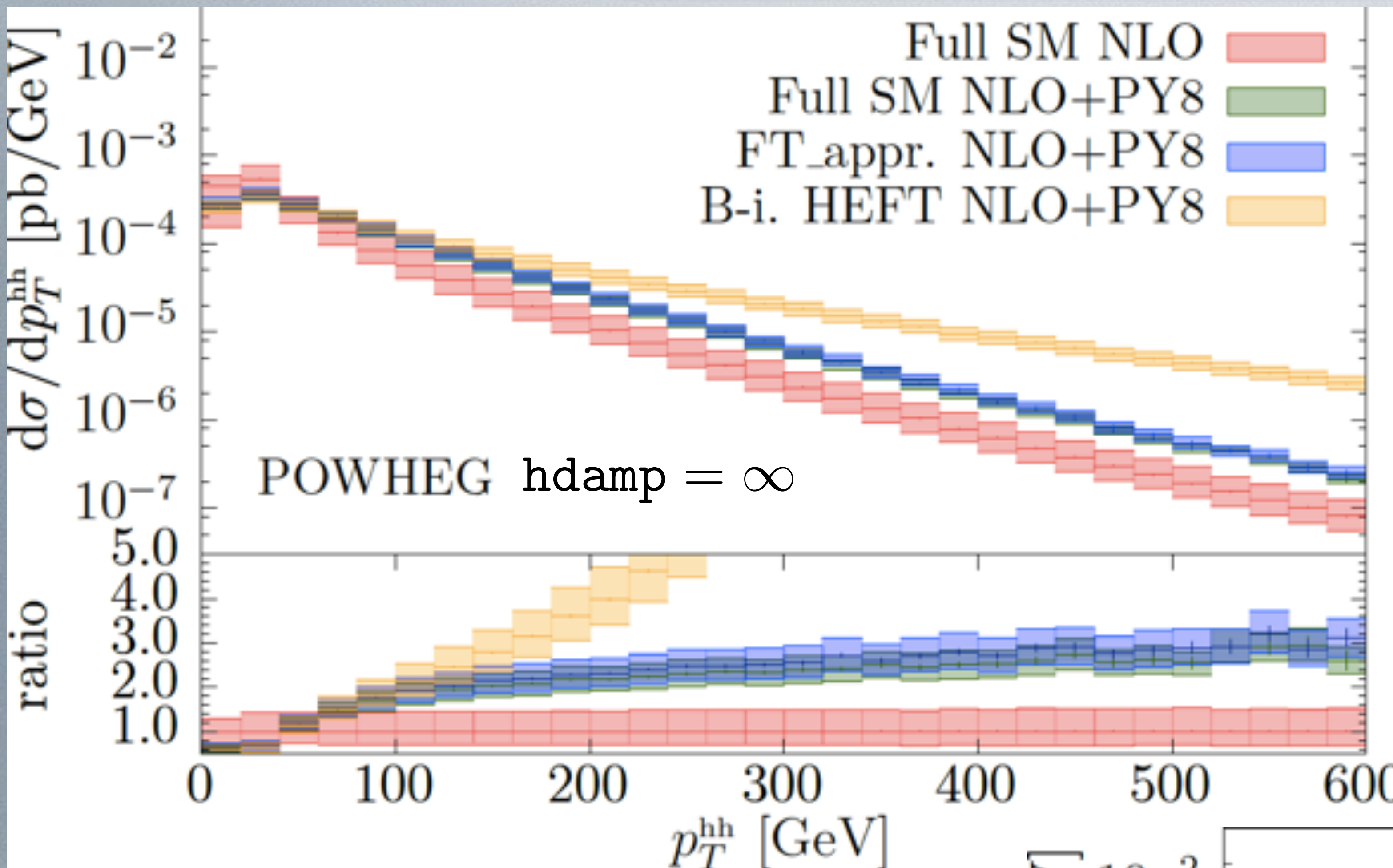
(July 2017)

σ/σ_{SM} 95% CL (exp)

	ATLAS	CMS
bbbb	<29 (38)	<342 (308)
bbWW		<79 (89)
$bb\tau\tau$		<28 (25)
$bb\gamma\gamma$	<117 (161)	<19 (17) NEW
$WW\gamma\gamma$	<747 (386)	

Run2			
	3 fb^{-1}	13 fb^{-1}	36 fb^{-1}

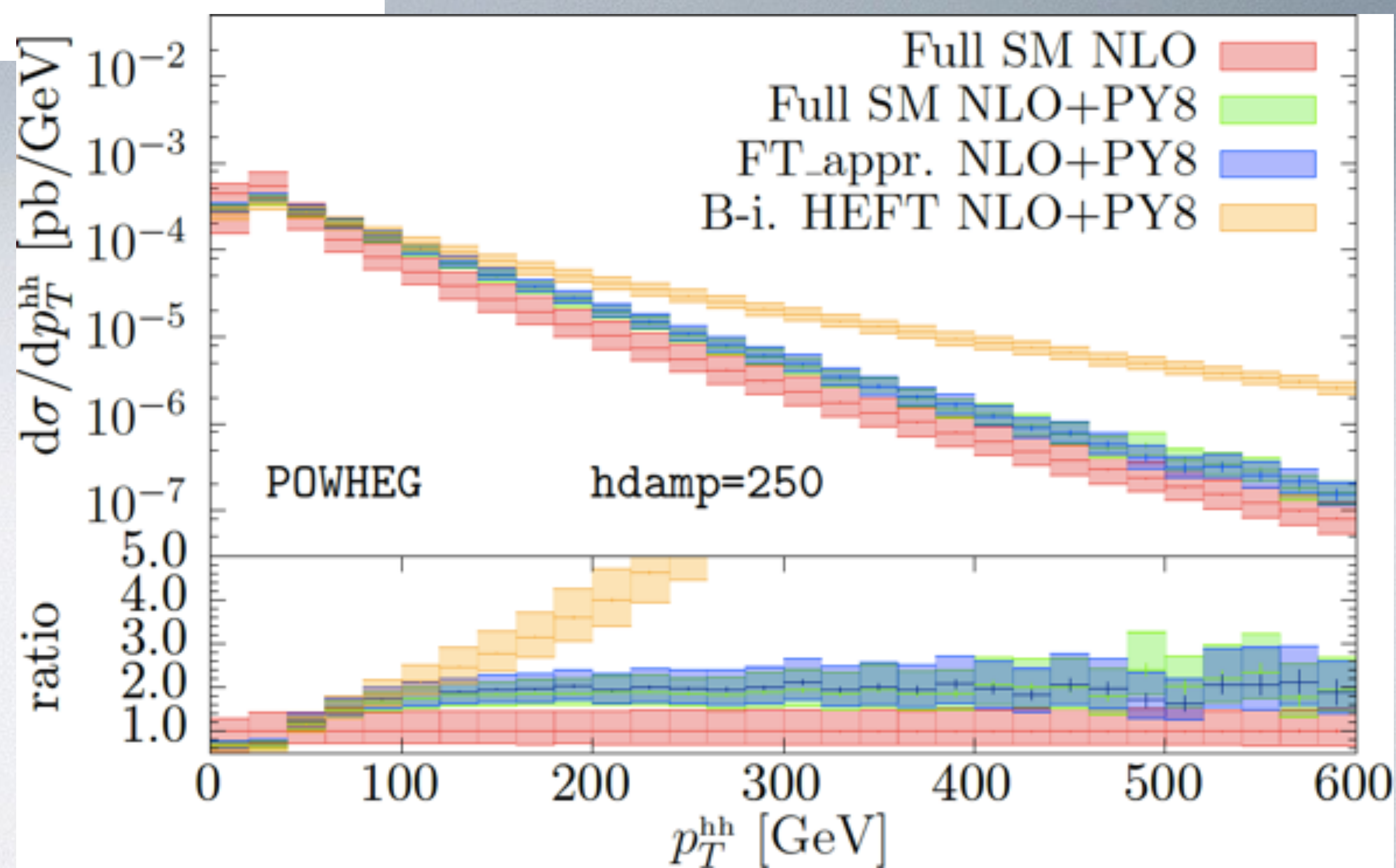
dependence on shower parameters



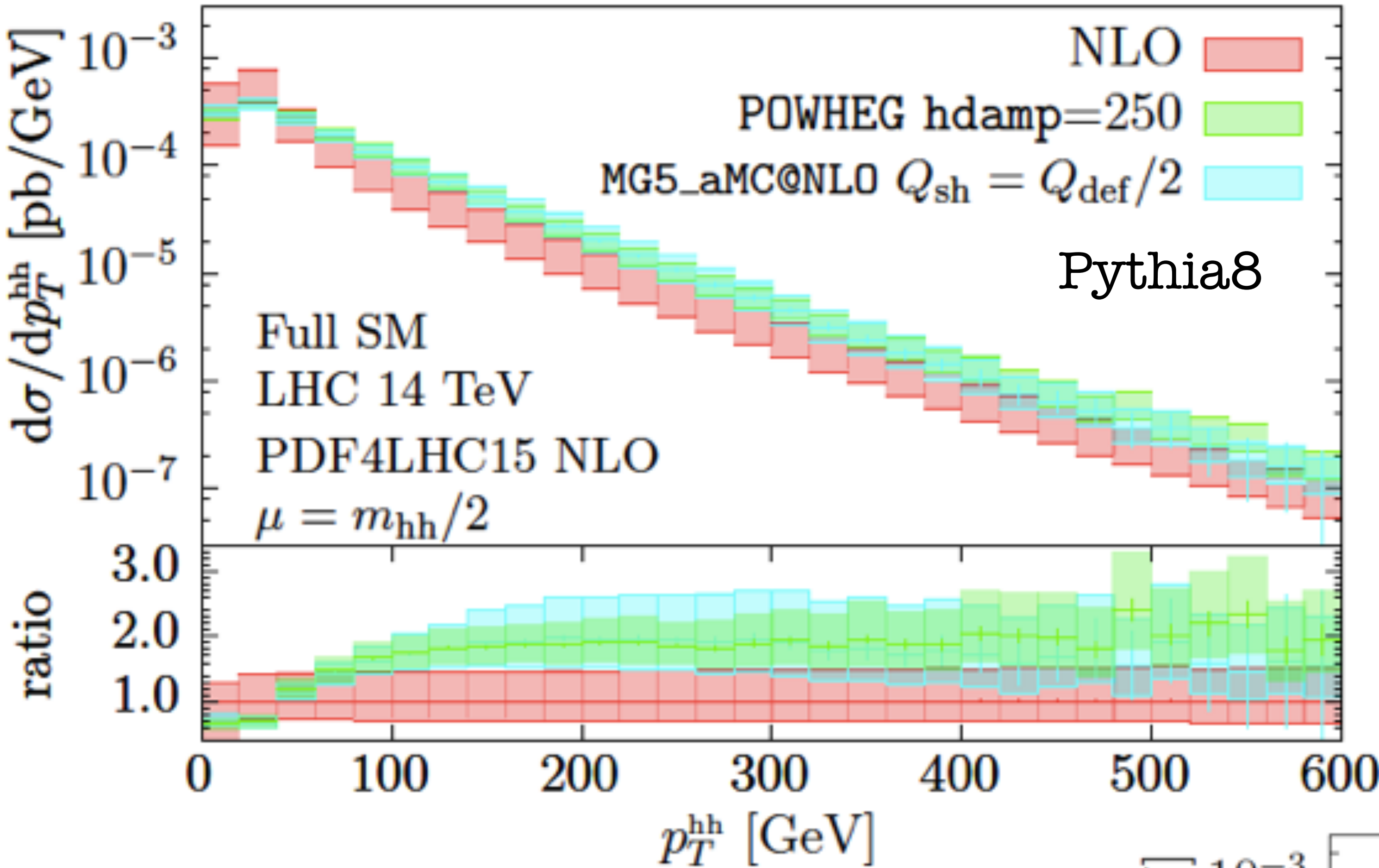
hdamp=h limits amount of exponentiated hard radiation

$$R_{\text{sing}} = R \times F\,,$$
$$R_{\text{reg}} = R \times (1 - F)$$

$$F = \frac{h^2}{(p_T^{\text{hh}})^2 + h^2}$$



dependence on shower parameters



MG5_aMC@NLO:

Q_{def} : default shower starting scale

shower starting scale picked with some probability distribution in

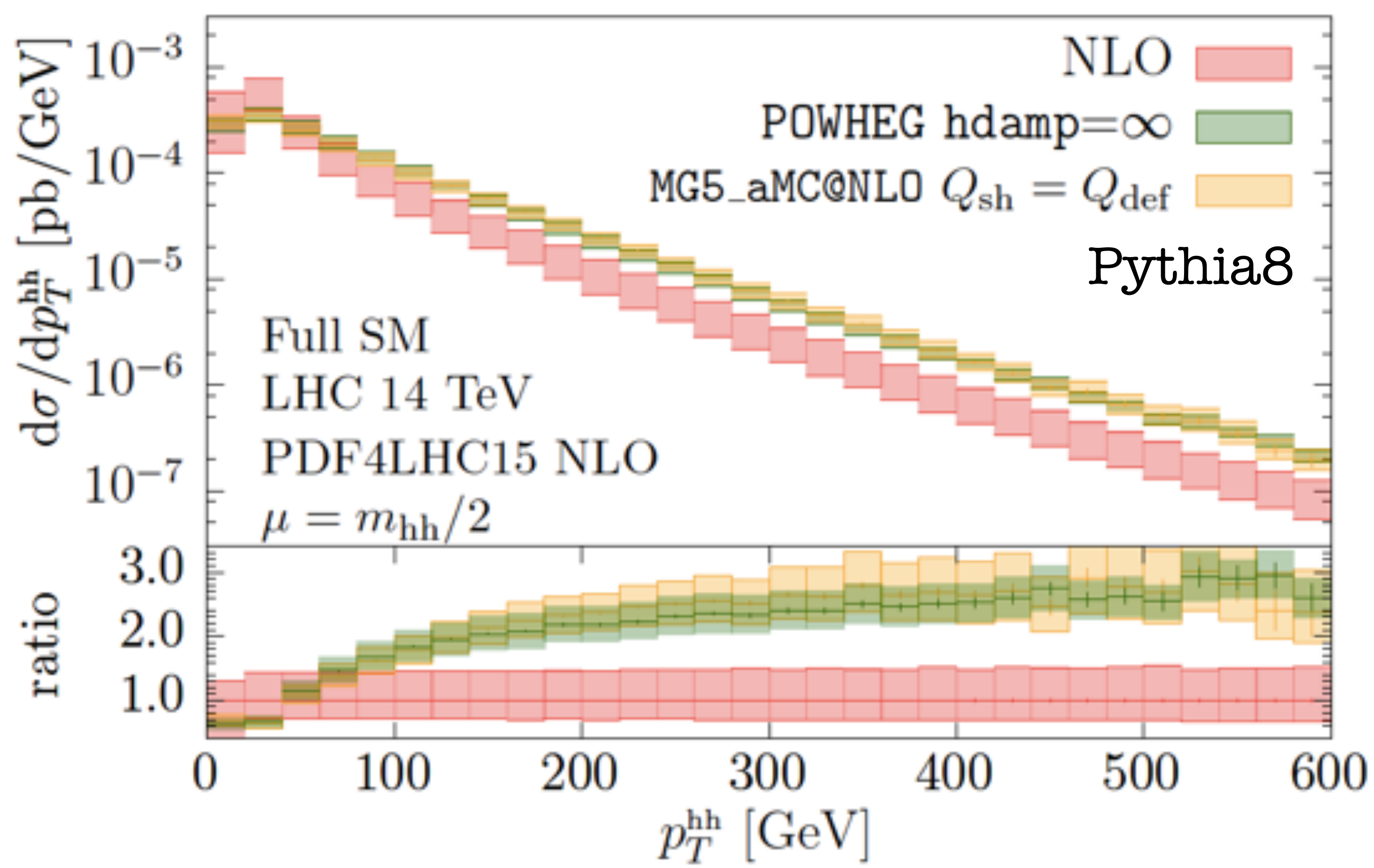
$\texttt{shower\_scale\_factor} \times [0.1\sqrt{\hat{s}}, \sqrt{\hat{s}}]$

Powheg with hdamp = 250

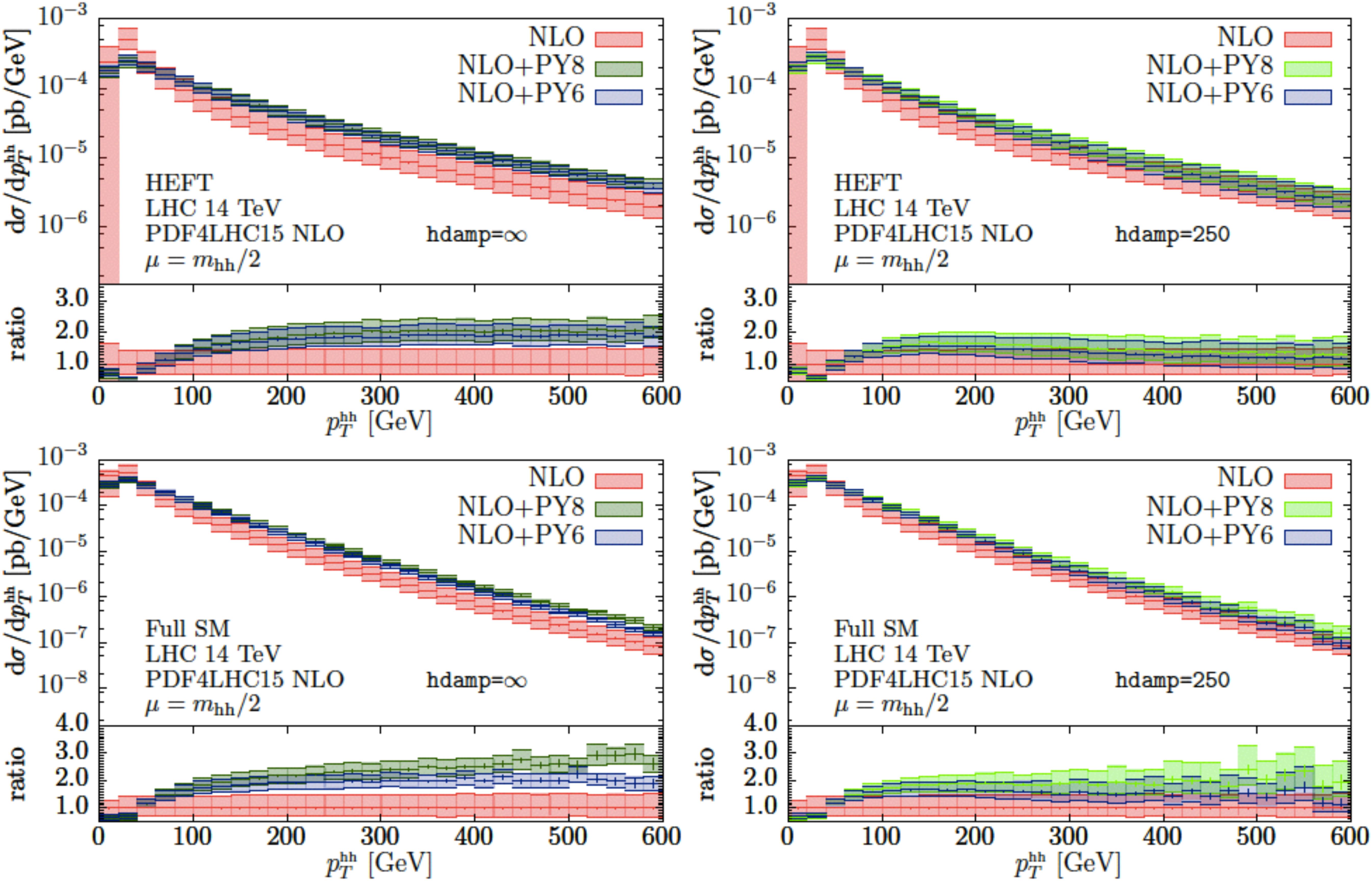
and MG5_aMC@NLO

with $Q = Q_{def}/2$

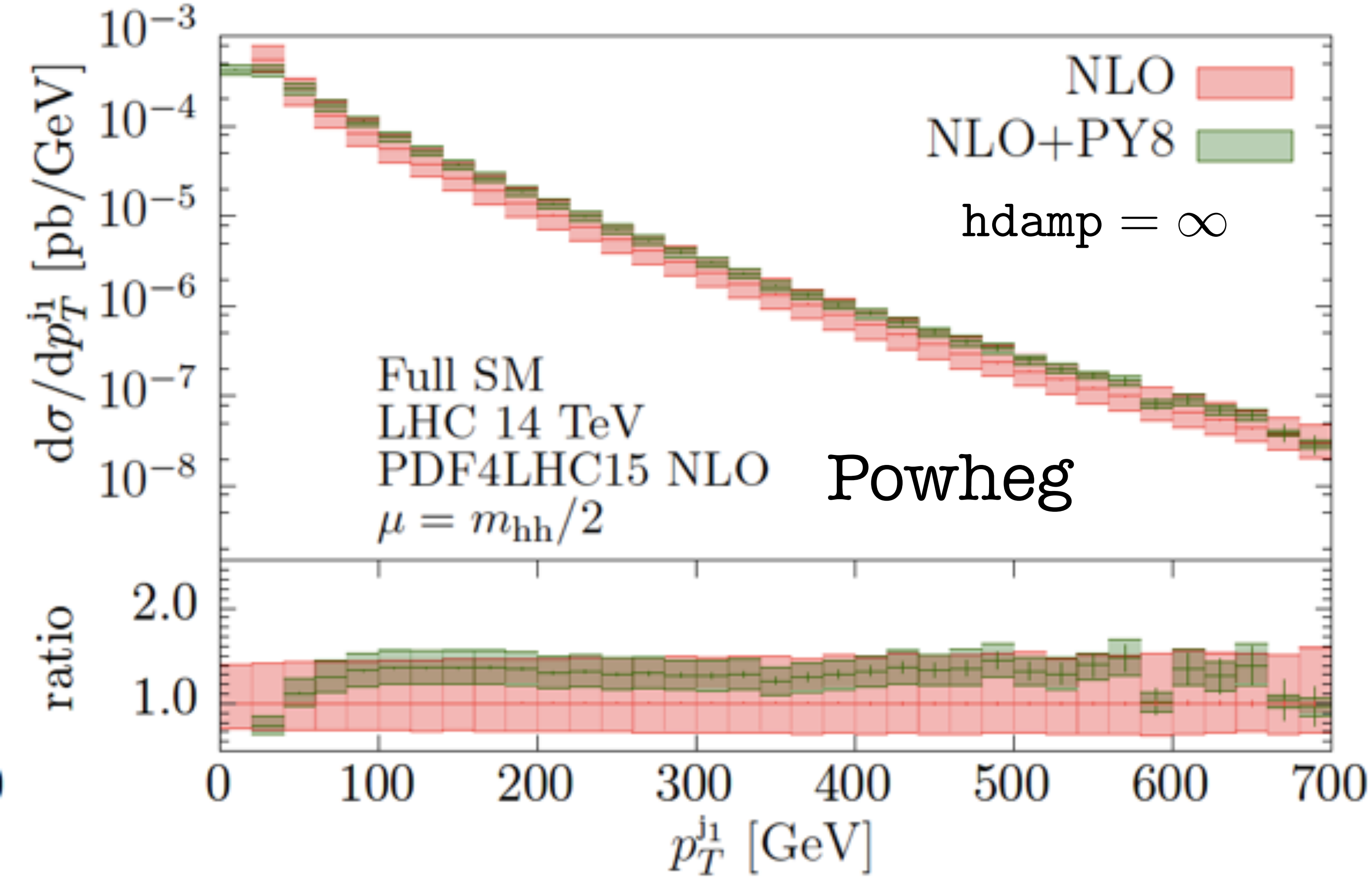
show similar behaviour

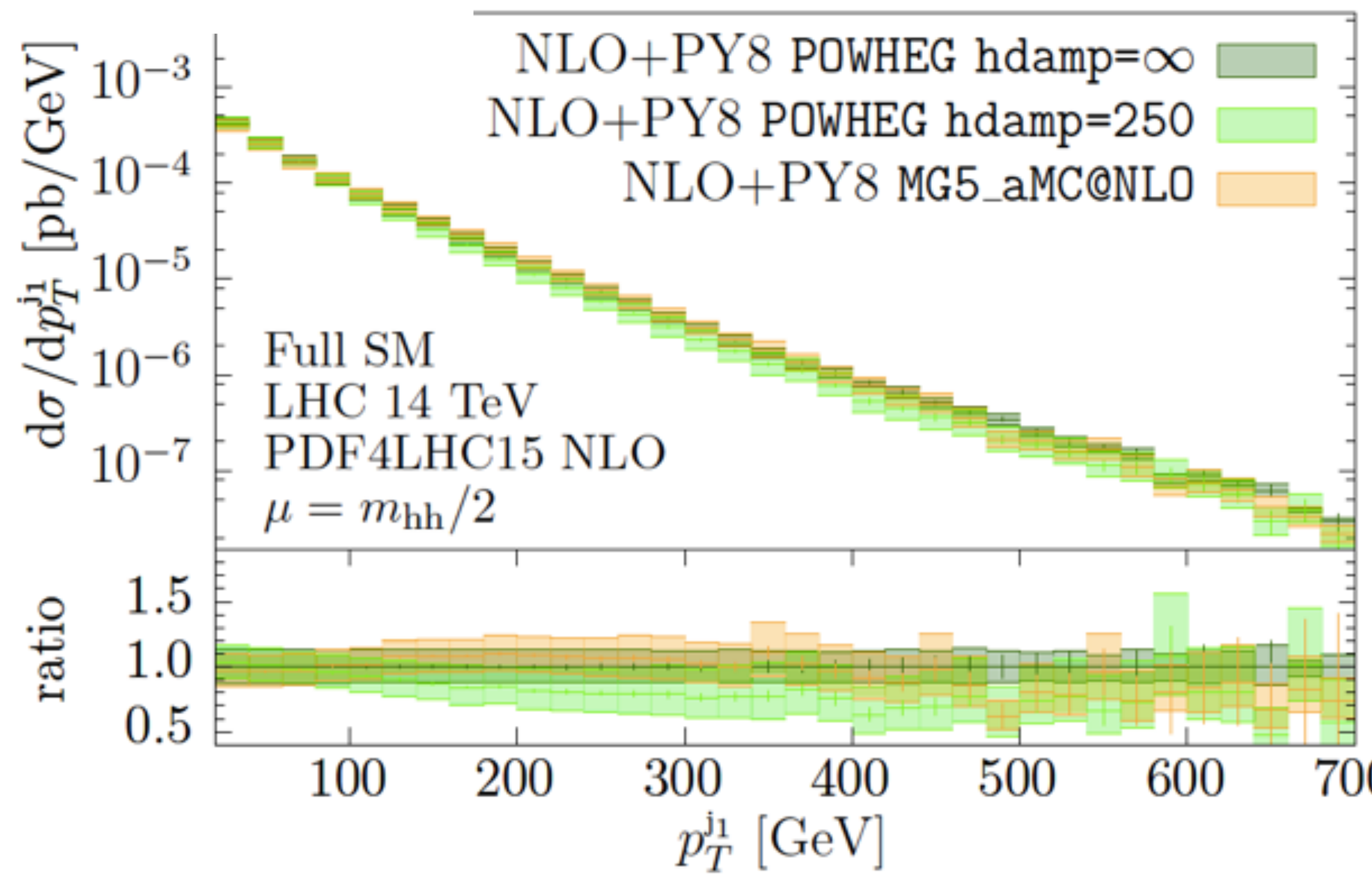


comparison Pythia6 vs. Pythia8



thanks: G.Luisoni





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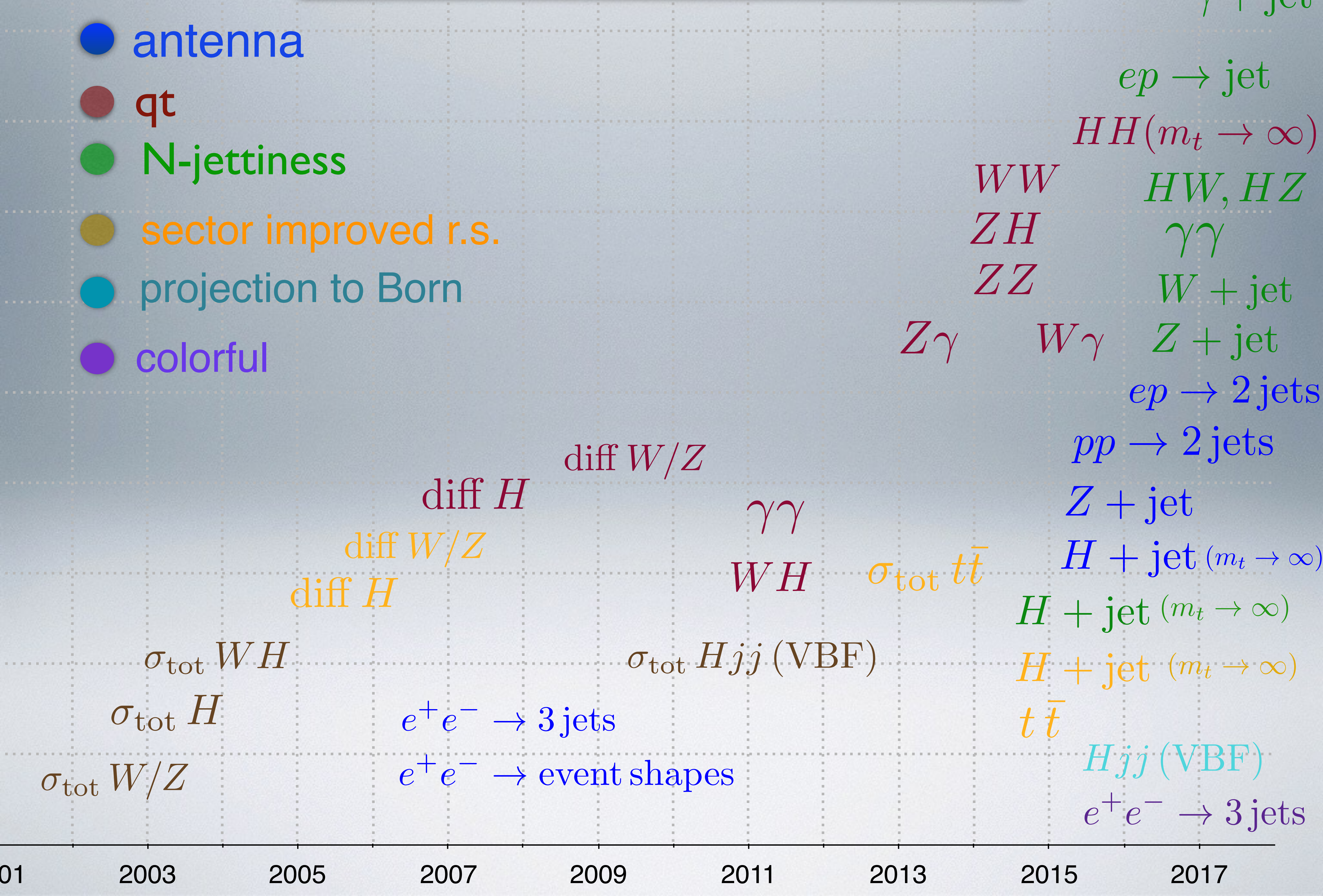
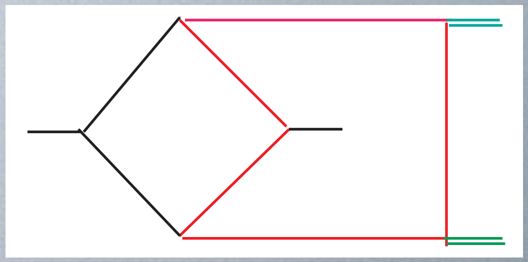
NNLO


antenna
qt
N-jettiness
sector improved r.s.
projection to Born
colorful
$\gamma + \text{jet}$
$ep \to \text{jet}$
$HH(m_t \to \infty)$
WW
HW, HZ
ZH
$\gamma\gamma$
ZZ
$W + \text{jet}$
$Z\gamma$
$W\gamma$
$Z + \text{jet}$
$ep \to 2\,\text{jets}$
$pp \to 2\,\text{jets}$
diff W/Z
diff H
$\gamma\gamma$
$Z + \text{jet}$
diff W/Z
$H + \text{jet}\ (m_t \to \infty)$
WH
$\sigma_{\text{tot}}\ t\bar{t}$
diff H
$H + \text{jet}\ (m_t \to \infty)$
$\sigma_{\text{tot}}\ WH$
$\sigma_{\text{tot}}\ Hjj\ (\text{VBF})$
$H + \text{jet}\ (m_t \to \infty)$
$\sigma_{\text{tot}}\ H$
$e^+e^- \to 3\,\text{jets}$
$t\,\bar{t}$
$Hjj\ (\text{VBF})$
$\sigma_{\text{tot}}\ W/Z$
$e^+e^- \to \text{event shapes}$
$e^+e^- \to 3\,\text{jets}$
01
2003
2005
2007
2009
2011
2013
2015
2017

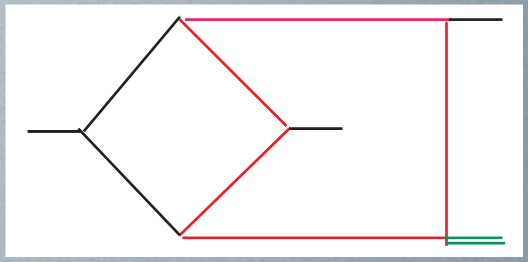
results for two-loop integrals

- massive propagators + massive legs with different mass (two additional mass scales) e.g. $gg \to HH$



Borowka, Greiner, GH, Jones, Kerner, Schlenk, Schubert, Zirke '16 **numerically**

- same number of scales e.g. H+jet:



lots of work on elliptic functions, some integrals still unknown

Tancredi, Remiddi '16; Adams, Bogner, Weinzierl '15,'16

Bonciani, Del Duca, Henn, Frellesvig, Moriello, Smirnov '16

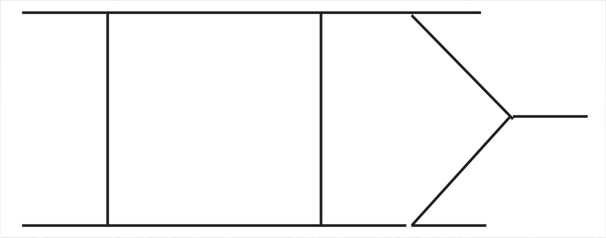
Tancredi, Primo '16,'17; Abreu, Britto, Duhr, Gardi '17

b-mass dependence: Melnikov, Tancredi, Wever '16,'17

2-loop 5-point:

- all massless, planar:

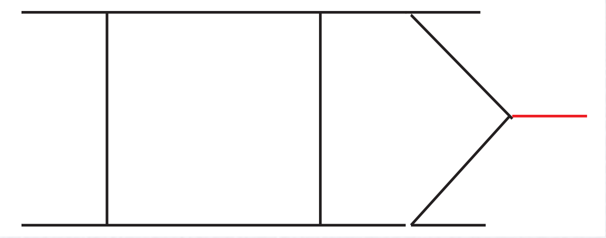
e.g. pp to 3jets



Gehrmann, Henn, Lo Presti '15

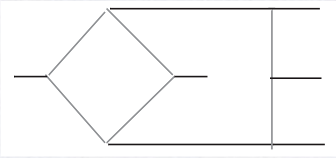
- one off-shell leg, planar:

e.g. pp to H+2jets



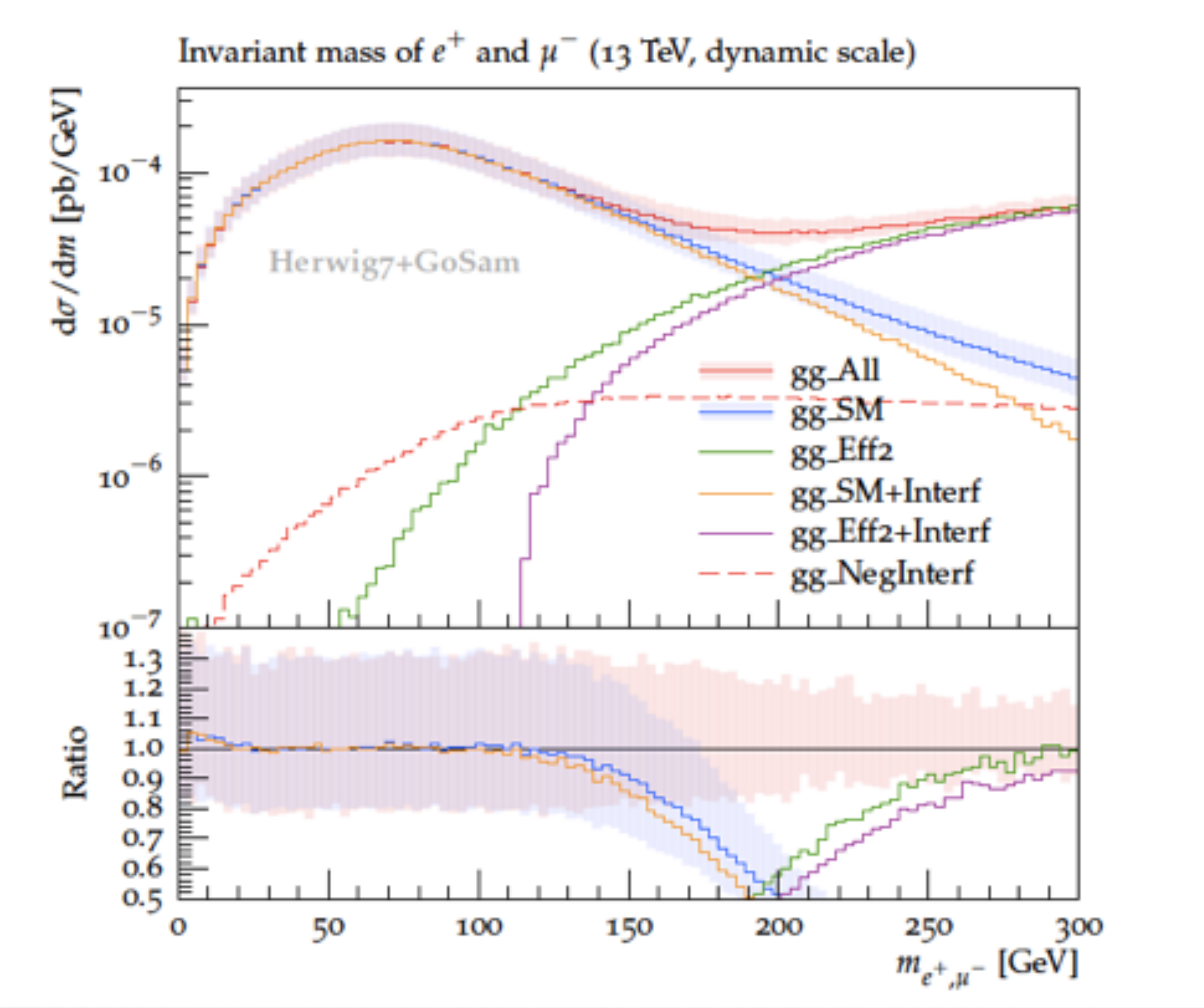
Papadopoulos, Tomassini, Wever '15

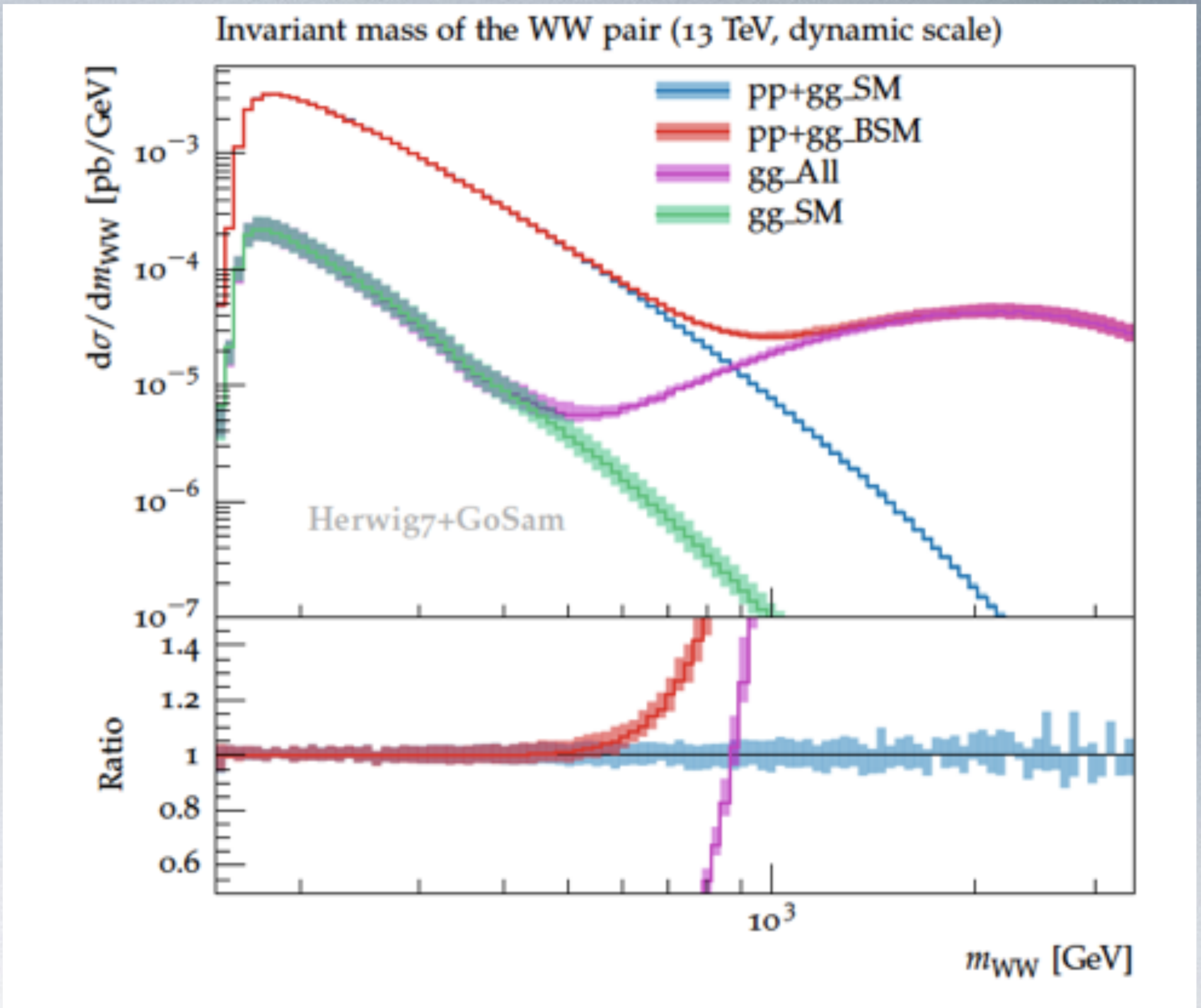
- non-planar still unknown



pp to WW including dimension 8 operators

J. Bellm, S. Gieseke, N. Greiner, GH, S. Plätzer, C. Reuschle, J.F. von Soden-Fraunhofen 1602.05141






1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61 62 63 64 65 66 67 68 69 70
71 72 73 74 75 76 77 78 79 80
81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100
101 102 103 104
$HPL(e^{i\pi/3})$
elliptic
$HPL(e^{i\pi/3})$+ elliptic
$HPL(e^{i\pi/2}) + HPL(e^{i\pi/3})$
$HPL(e^{i\pi/2}) + HPL(e^{i\pi/3})$+elliptic