# QCD@LHC: Introduction

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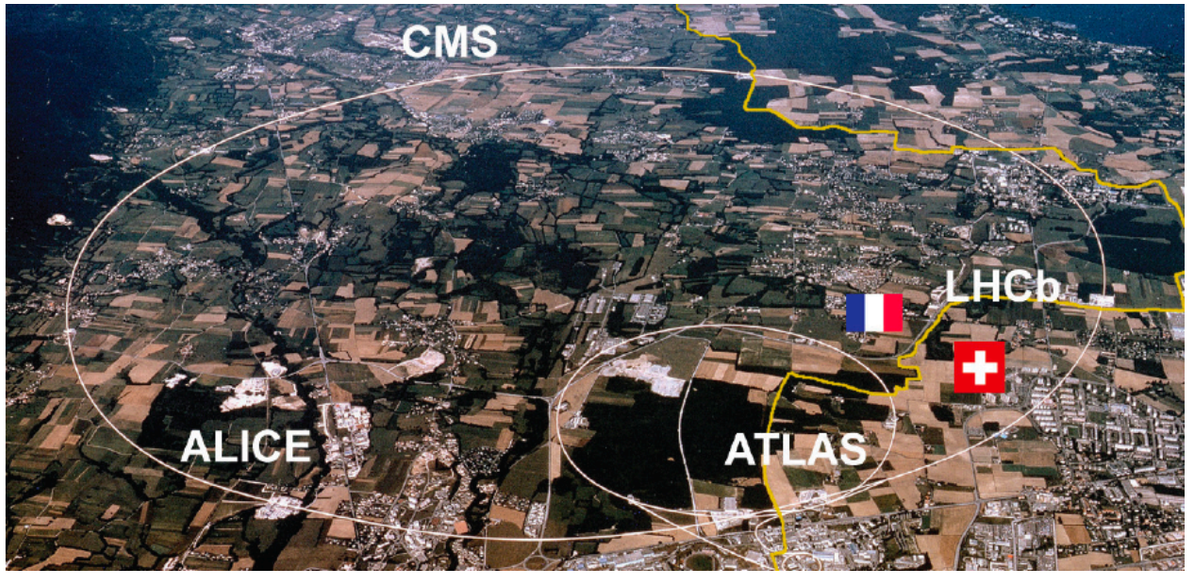
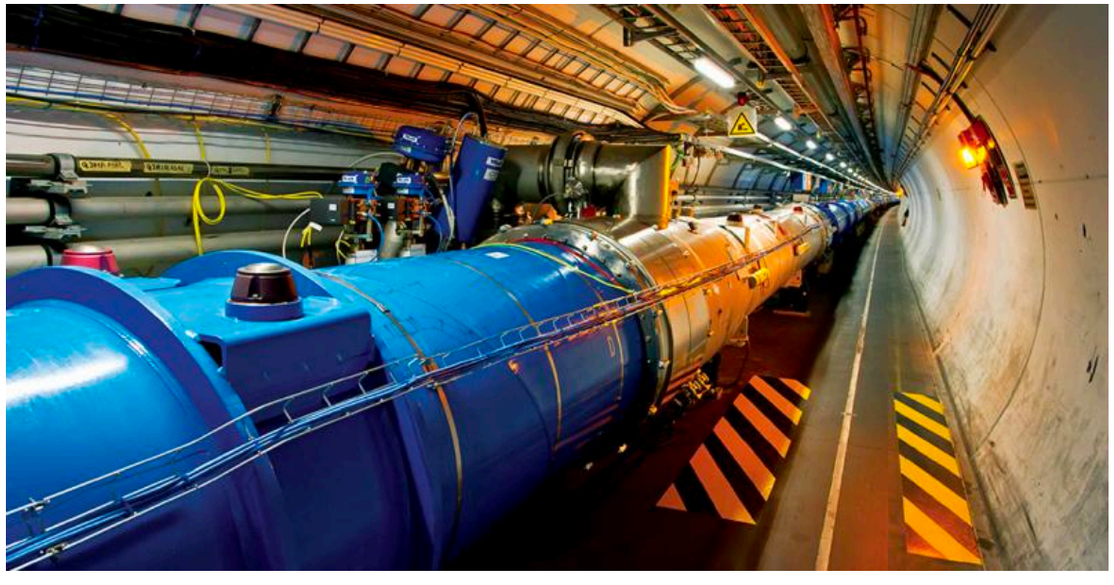
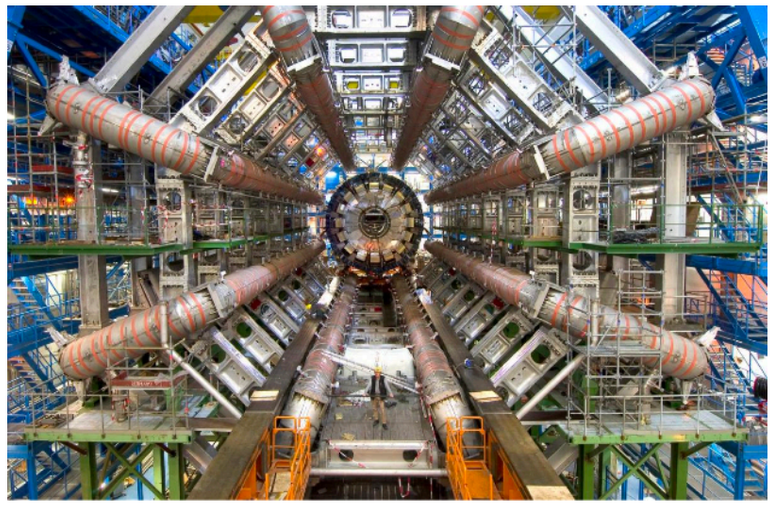
# The Large Hadron Collider

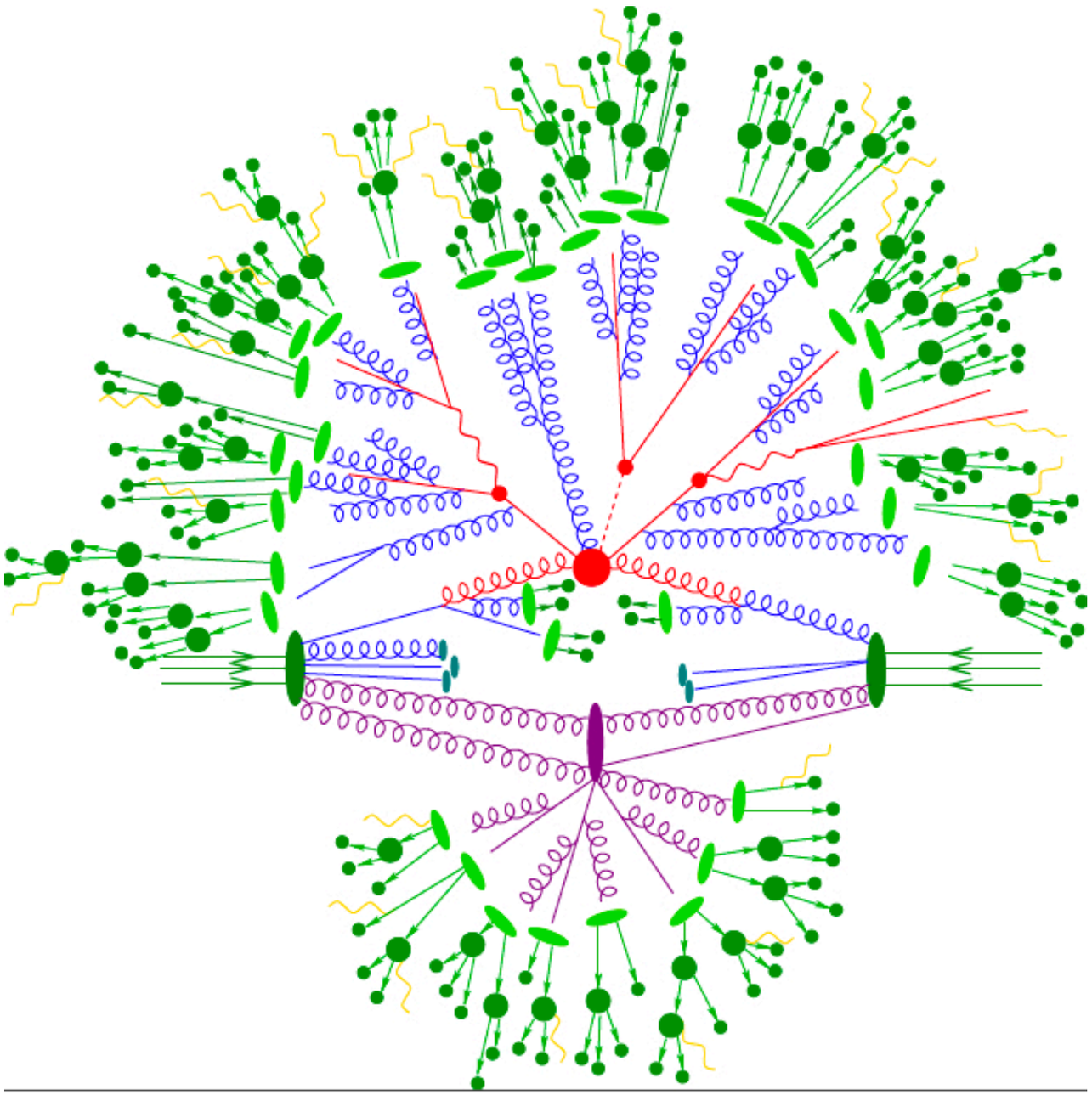


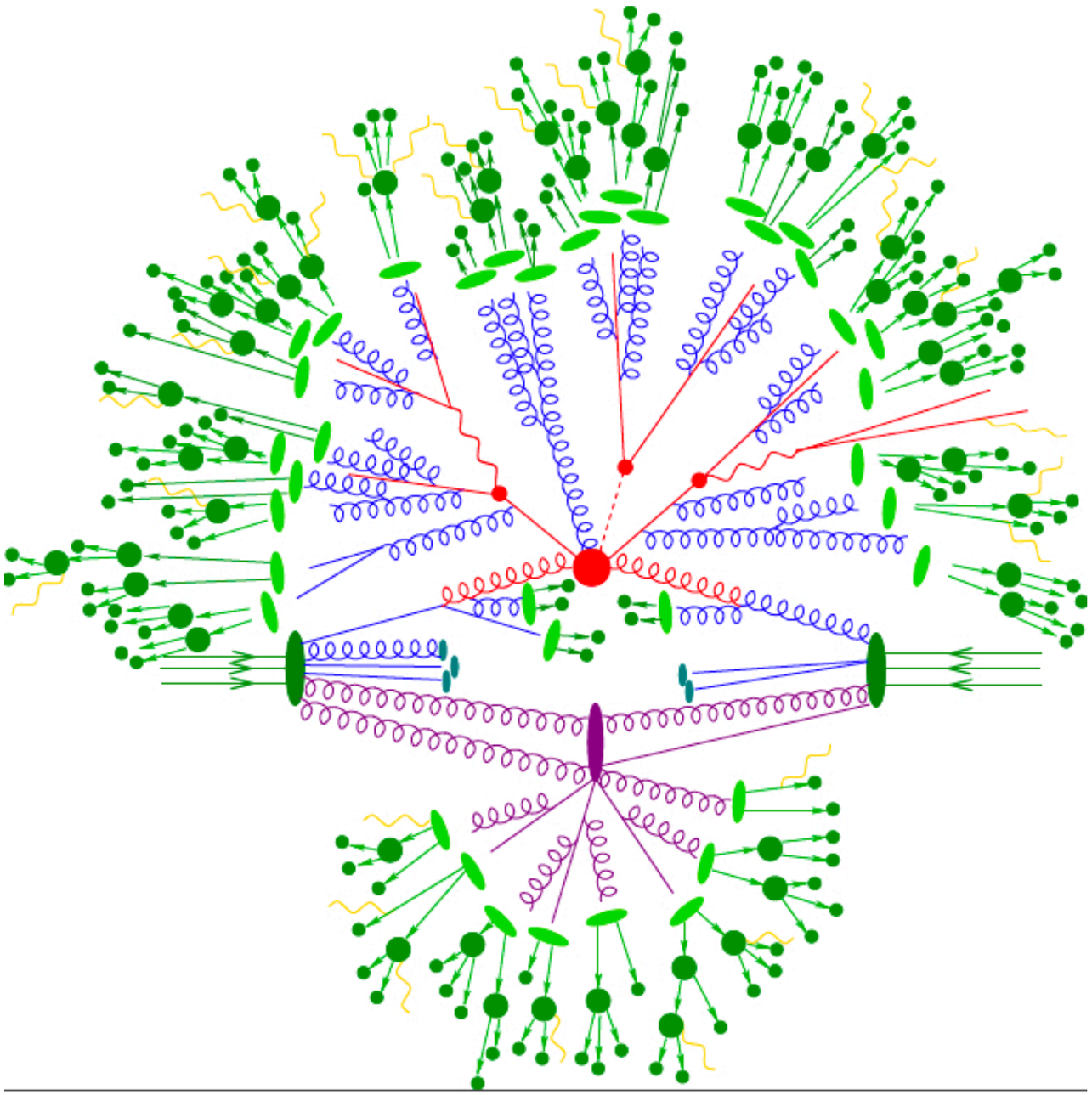





- circumference = 26.7 km
- Ecm = 13 TeV

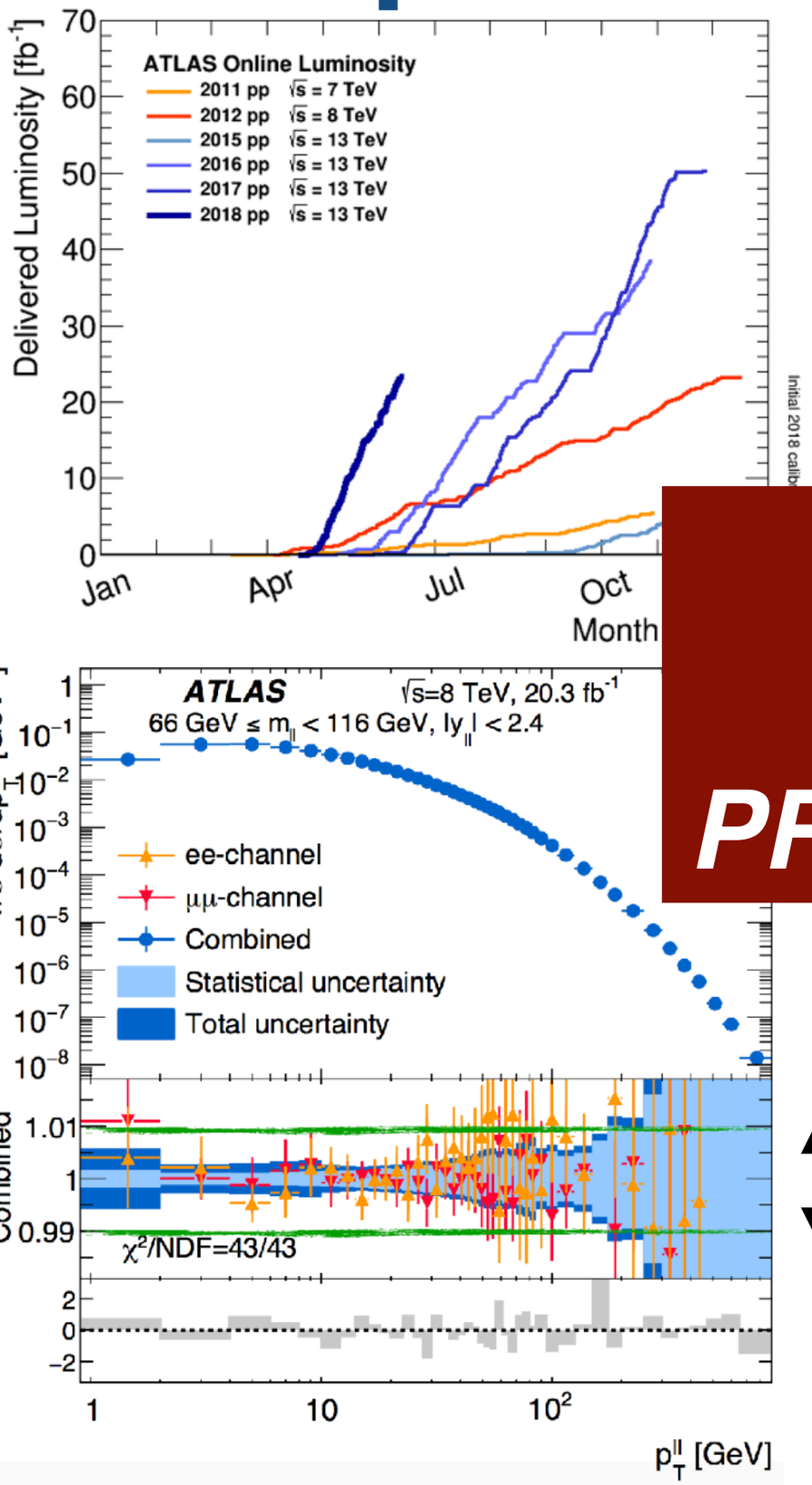
**Largest Science Experiment of Human Being**





# QCD is everywhere at the LHC!

# pQCD in the LHC era




**Today**

- 20 fb$^{-1}$ @ 8 TeV
- ~110 fb$^{-1}$ @ 13 TeV

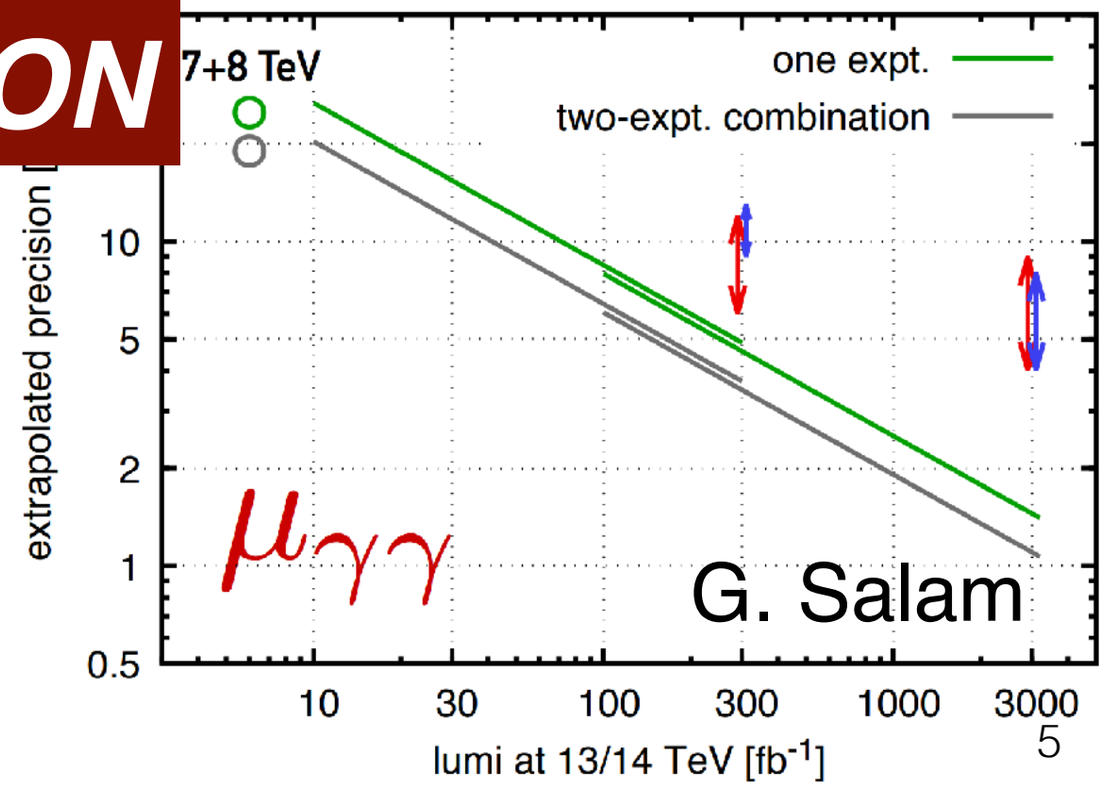
**Future**

2023: 300 fb$^{-1}$

2035: 3000 fb$^{-1}$@14 TeV

***AGE OF PRECISION***

±1%



# The 2007 Les Houches wishlist

| Process ($V \in \{Z, W, \gamma\}$) | Comments |
|---|---|
| Calculations completed since Les Houches 2005 | |
| 1. $pp \to VV$jet | $WW$jet completed by Dittmaier/Kallweit/Uwer [3]; Campbell/Ellis/Zanderighi [4] and Binoth/Karg/Kauer/Sanguinetti (in progress) |
| 2. $pp \to$ Higgs+2jets | NLO QCD to the $gg$ channel completed by Campbell/Ellis/Zanderighi [5]; NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier [6,7] |
| 3. $pp \to VVV$ | $ZZZ$ completed by Lazopoulos/Melnikov/Petriello [8] and $WWZ$ by Hanke[illegible]epp[illegible]d [9] |
| Calculations remaining from Les Houches 2005 | |
| 4. $pp \to t\bar{t}\,b\bar{b}$ | re[illegible] for [illegible] |
| 5. $pp \to t\bar{t}$+2jets | relevan[illegible] for $t$[illegible] |
| 6. $pp \to VV\,b\bar{b}$, | el[illegible]or VBF $\to H \to VV, t\bar{t}H$ |
| 7. $pp \to VV$+2jets | relevant for VBF $\to H \to VV$ |
| 8. $pp \to V$+3jets | VBF contributions calculated by (Bozzi/)Jäger/Oleari/Zeppenfeld [10–12] various new physics signatures |
| NLO calculations added to list in 2007 | |
| 9. $pp \to b\bar{b}b\bar{b}$ | Higgs and new physics signatures |
| Calculations beyond NLO added in 2007 | |
| 10. $gg \to W^*W^*$ $\mathcal{O}(\alpha^2\alpha_s^3)$ | backgrounds to Higgs |
| 11. NNLO $pp \to t\bar{t}$ | normalization of a benchmark process |
| 12. NNLO to VBF and $Z/\gamma$+jet | Higgs couplings and SM benchmark |
| Calculations including electroweak effects | |
| 13. NNLO QCD+NLO EW for $W/Z$ | precision calculation of a SM benchmark |

CLOSED

Table 1: The updated experimenter's wishlist for LHC processes

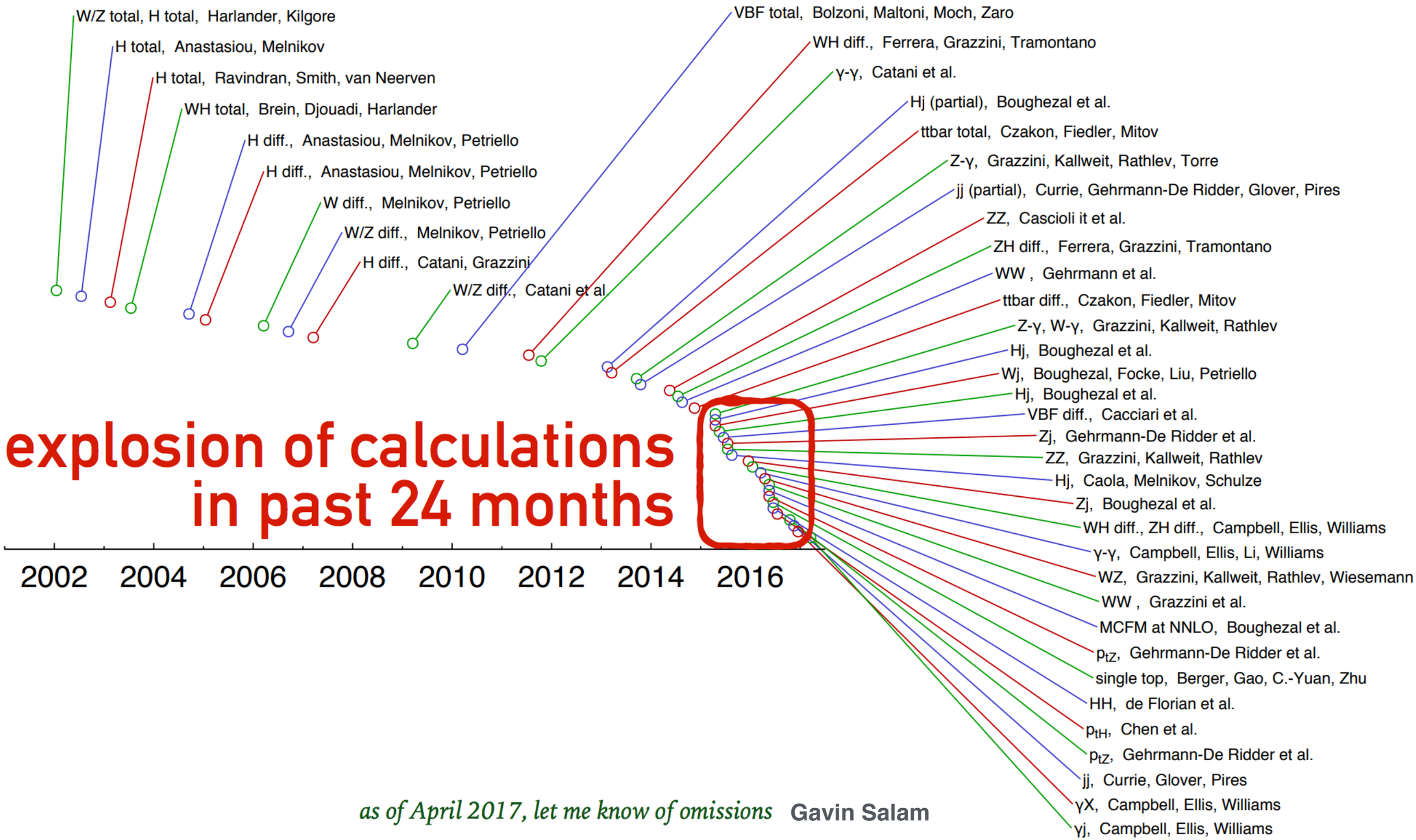
with Feynman diagrams

with Feynman diagrams or unitarity/onshell methods

*The NLO multi-leg Working group report 0803.0494*

from Zanderighi

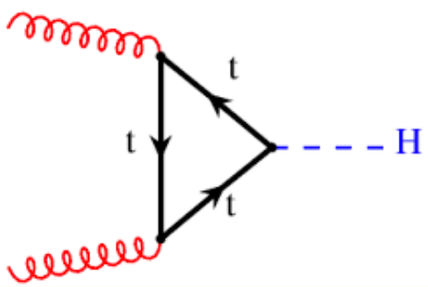
# Explosion of NNLO calculations




*as of April 2017, let me know of omissions* **Gavin Salam**

# Inclusive cross section prediction

- **90%** of Higgs produced through **gg** fusion at the LHC
- Notorious **slowly convergent** perturbative series




$$\sigma_H = 16\ \text{pb} + 20.6\ \text{pb} + 9.79\ \text{pb} + 2\ \text{pb}$$

LO | δNLO | δNNLO | δN³LO

- Success application of **near threshold soft expansion**
- First N3LO hadronic cross section
- Crucial for precision Higgs program

Anastasiou, Duhr, Dulat, Furlan, et al., 1403.4616
Y. Li, von Manteuffel, Scharbinger, HXZ, 1412.2771

Anastasiou, Duhr, Dulat, Furlan, et al., 1411.3584

Alternative approach:
**principle of maximum conformality applied to Higgs production/decay**

S.Q. Wang, X.G. Wu, Brodsky, Mojaza, 1605.02572
J. Zeng, X.G. Wu, S. Bu, J.M. Shen, S.Q.Wang, 1801.01414