LHC Physics Overview and Opportunities

For ATLAS and CMS experiments - Selected Topics

Incontri di Fisica delle Alte Energie

IFAE Napoli - 8 Aprile, 2019

ATLAS Results

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

CMS Results

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

HL/HE-LHC Reports

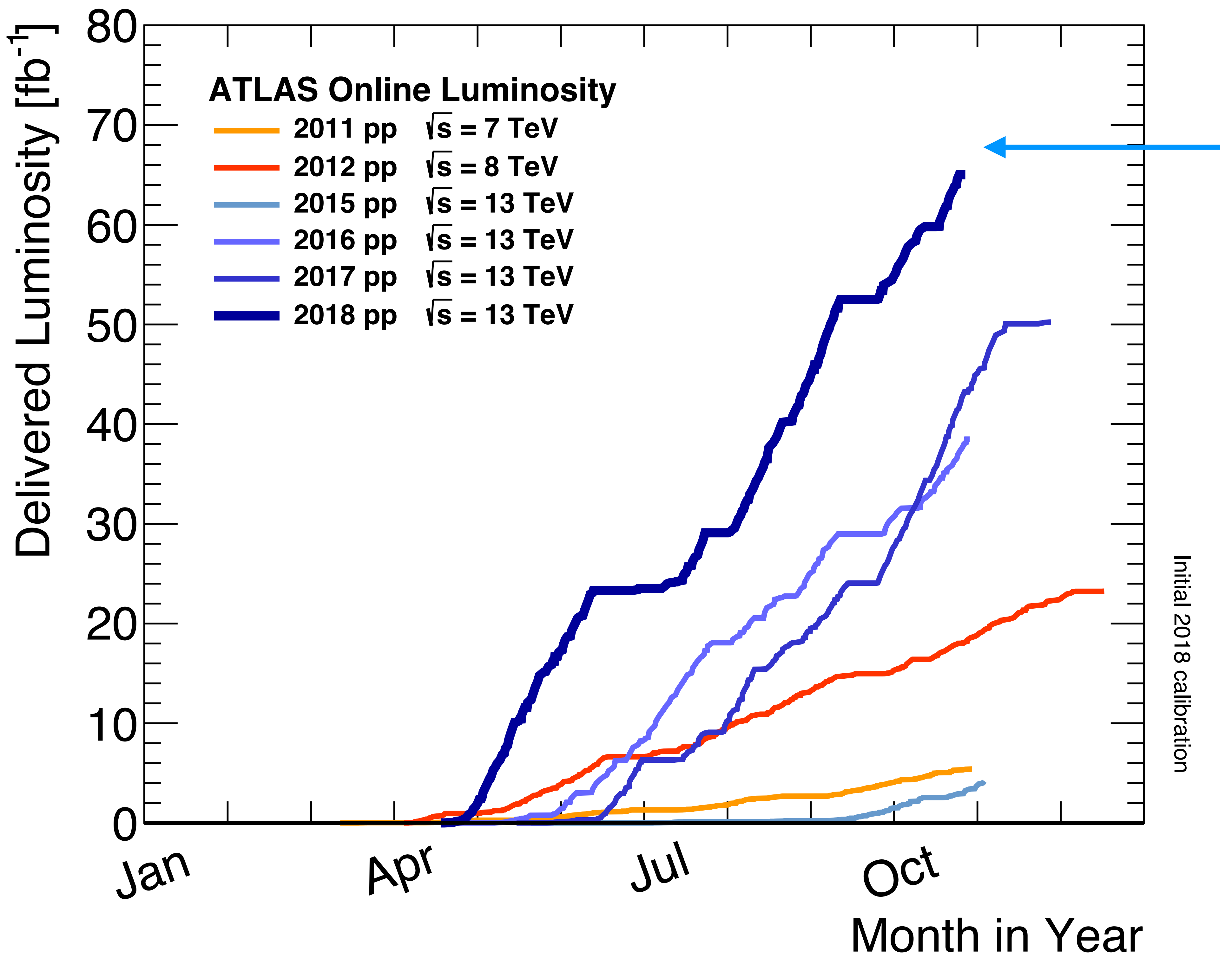
https://cms-results.web.cern.ch/cms-results/public-results/publications/

Marumi Kado

Università di Roma, Sapienza

The LHC Run 2 pp dataset

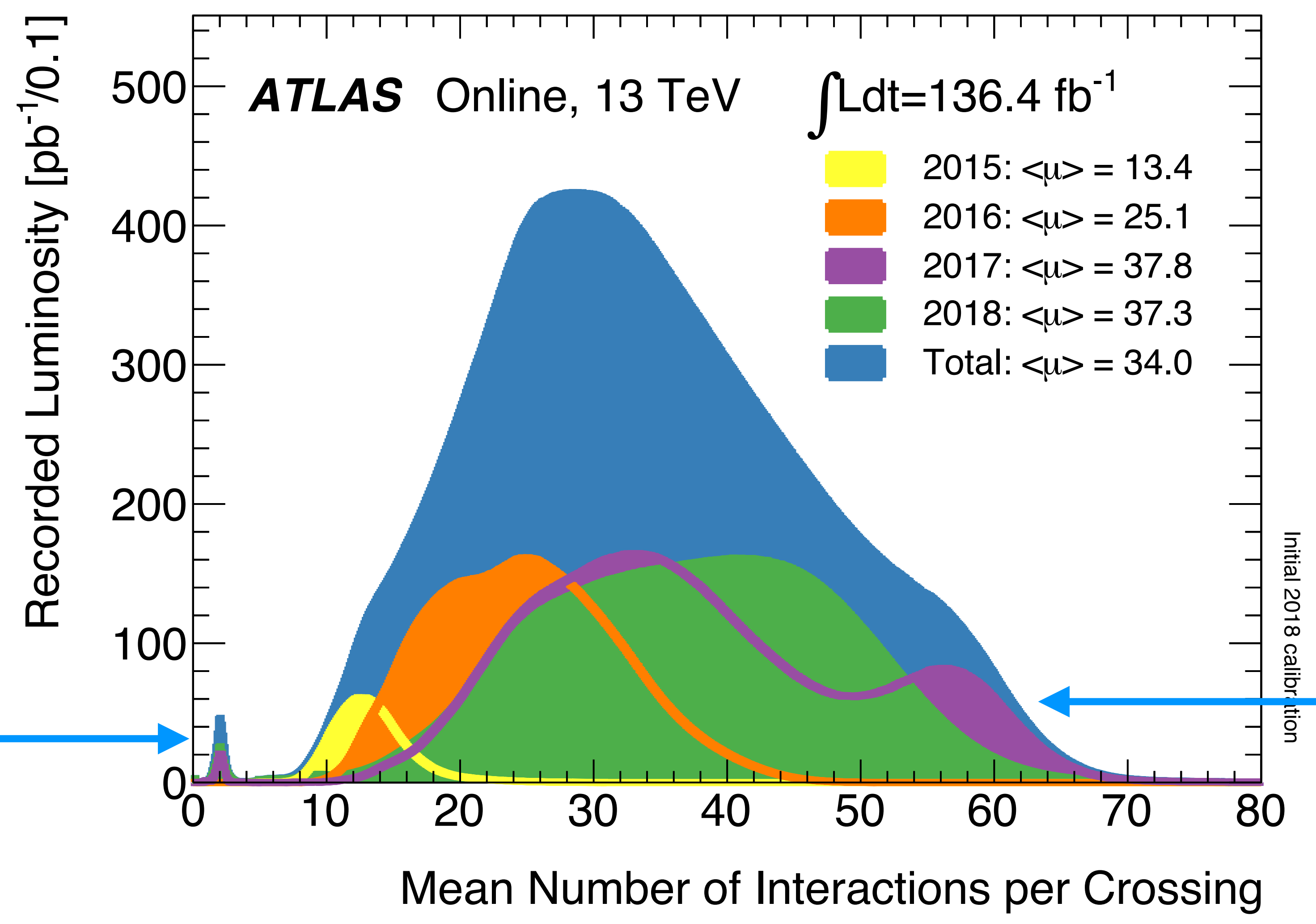
The LHC pp operations for Run 2 are completed, delivering a dataset of close to 160 fb^{-1} to ATLAS and CMS, splendid achievement!



Record year in 2018! More than 60 fb^{-1} collected by experiments

Splendid performance at the expense of large Pile Up (average approximately 40 in 2018)

Special low mu runs for EW measurements



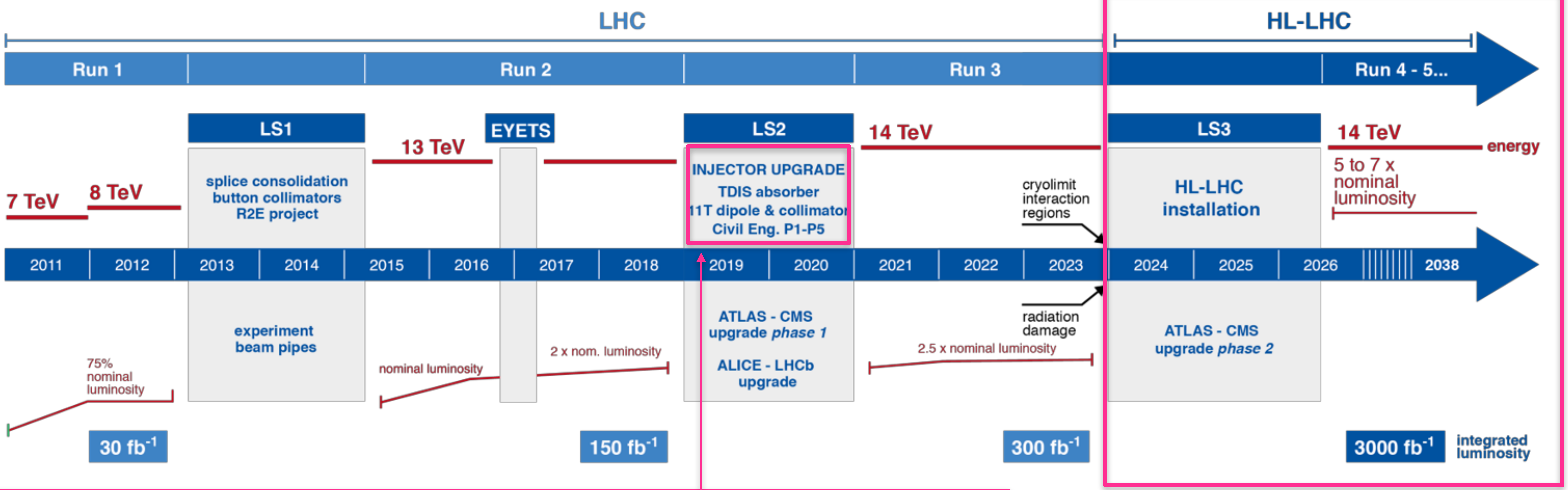
Larger PU following issue with 16L2 magnets

However splendid and impressive achievement this is, to get to 3000 fb^{-1} would require 50 full years of running the LHC!

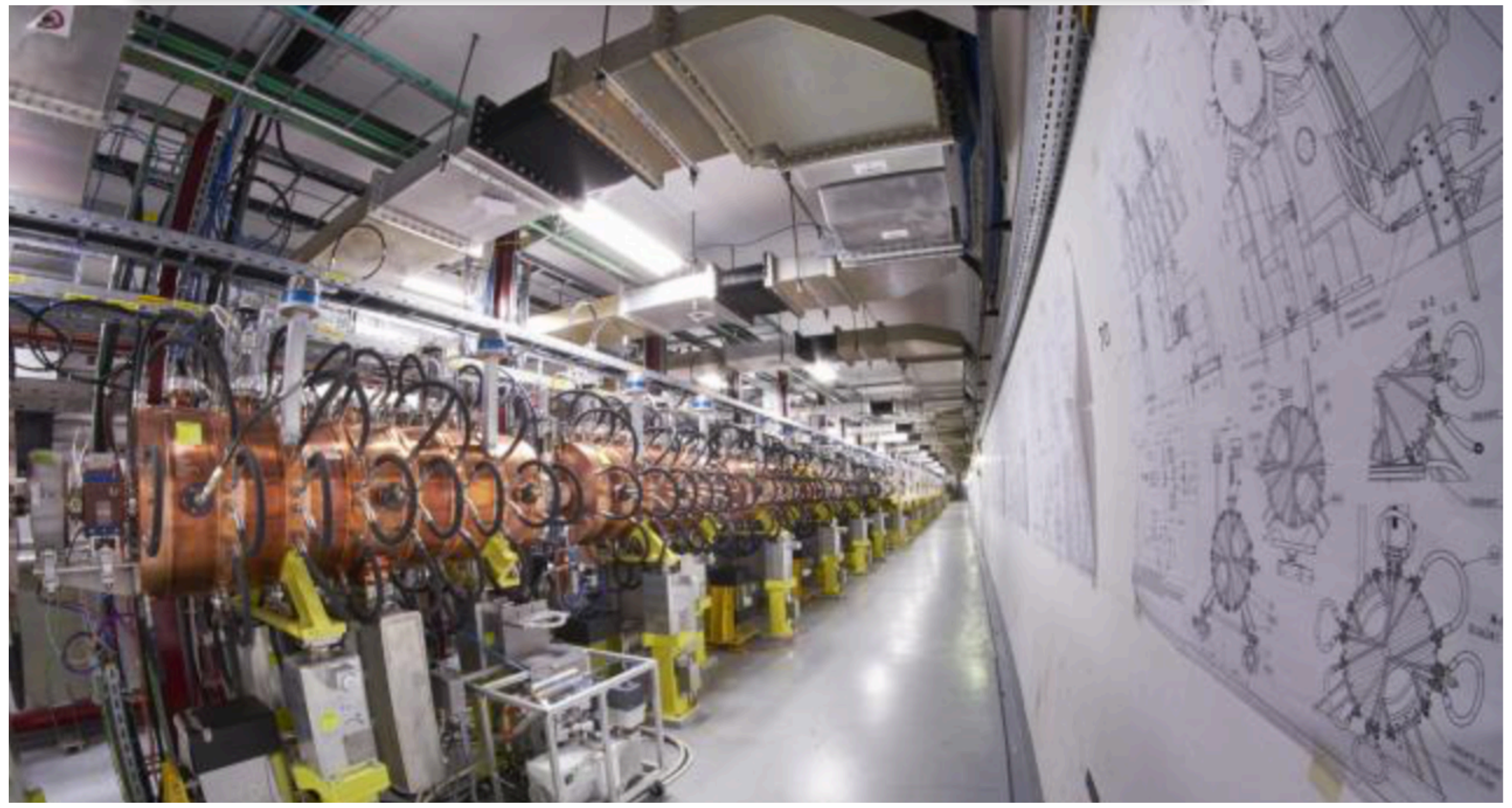
… also imply a **Pile Up of 140 - 200** !

Disclaimer: Very similar plot for CMS

The Road to HL-LHC



- LINAC 4: Extremely important milestone on the road towards higher luminosities (90 meters machine).
- « Crabbing protons » also one additional major step towards the High Luminosity, successfully tested at SPS.
- Ni3Sn ~100 magnet elements (dipoles and quadrupoles) with fields above 10T.
- TDIS (dump/absorber to protect downstream equipment)
- Collimation upgrades.
- Civil engineering at P1 - P5.



Will be accelerating negative Hydrogen ions. The electrons are stripped from the proton from the LINAC to the PS Booster (improves efficiency, intensity and quality).

The Complete LHC Schedule and ATLAS and CMS Upgrades

Phase 0 (Deployed successfully during LS1)

ATLAS

- **Additional insertable b-layer (Pixels)**
- New beam pipe
- Complete muon coverage
- Repairs (TRT, LAr, Tile)
- FTK (Fast Track Trigger)

CMS

- Complete muon coverage
- Replace HCAL photodetectors (forward and outer)
- **New pixel detector (EYETS)**
- New beam pipe

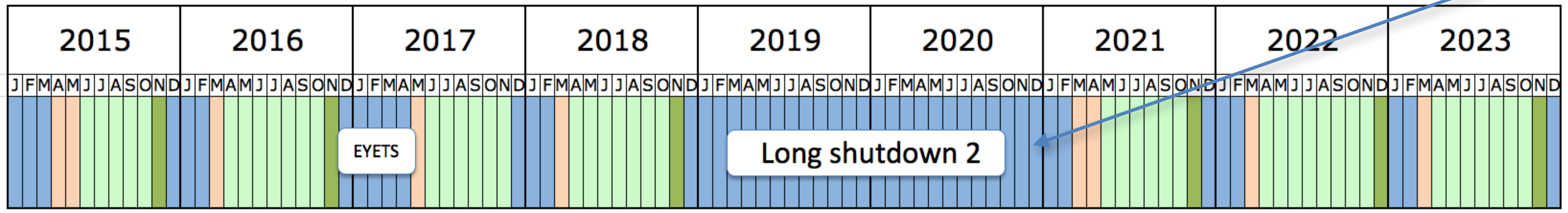
Phase 1 (Deployment now during LS2)

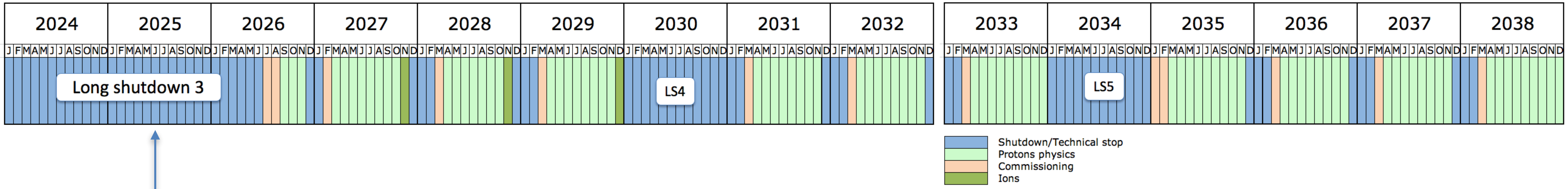
ATLAS

- New Small Wheel (Forward muons) for L1 muon trigger
- Topological L1 trigger processors
- High granularity L1 Calorimeter trigger.

CMS

- L1 trigger upgrade
- HCAL electronics





Phase 2 (Major upgrades with deployment during LS3)

ATLAS

- **Full Si tracker up to 4 (**with HW track trigger).
- Calorimeter electronics upgrade
- **Timing detector** with partial eta coverage (2.4 - 4) LGAD silicon: 30 ps resolution.
- Muon coverage (also possibly at LS4)

CMS

- **Strips and pixels replaced with higher granularity up to 3.8** (and HW trigger).
- New EndCap calorimeters HGCAL (High granularity) Silicon Pb/Steel 26 X0 and Scintillator/Steel 9 Int. Lengths.
- ECAL Barrel: New shaping with faster time rise to reach 30 ps timing resolution!
- **Full coverage timing** detector (up to eta 3) LGAD silicon: 30-40 ps resolution.

Performance Goals

- So far excellent trigger and object reconstruction performance in increasing levels of PU (see backup).

- The gain in acceptance and in performance with new detectors (to improve PU mitigation), new algorithms and new computing capabilities is expected to at least match current experimental performance.

    - Keeping Trigger thresholds at similar levels
    - Object reconstruction performance (efficiency vs rejection and resolution)

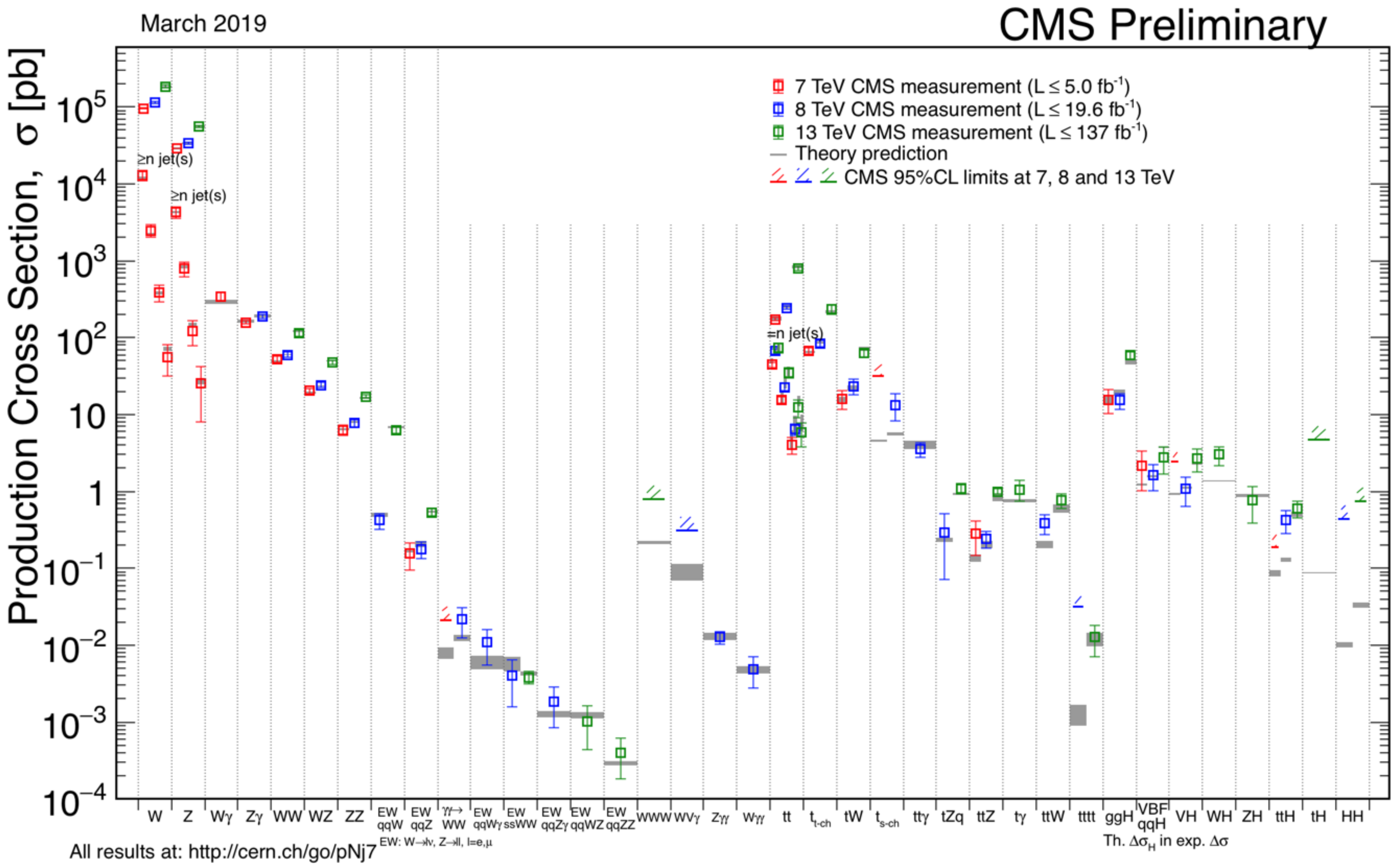
- Calibration is key (based on data) and its accuracy should improve with additional data.

Working assumption to extrapolate current analyses
(including estimate of the evolution of experimental systematic uncertainties have been estimated).

Modelling and Measurements

- TH / Modelling / MC - uncertainties play a central role in most analyses at the LHC (even when these are not explicit e.g. sideband data driven methods through MC closure).

- Outstanding collective success of **all** communities, making LHC a machine for **Precision Physics**!



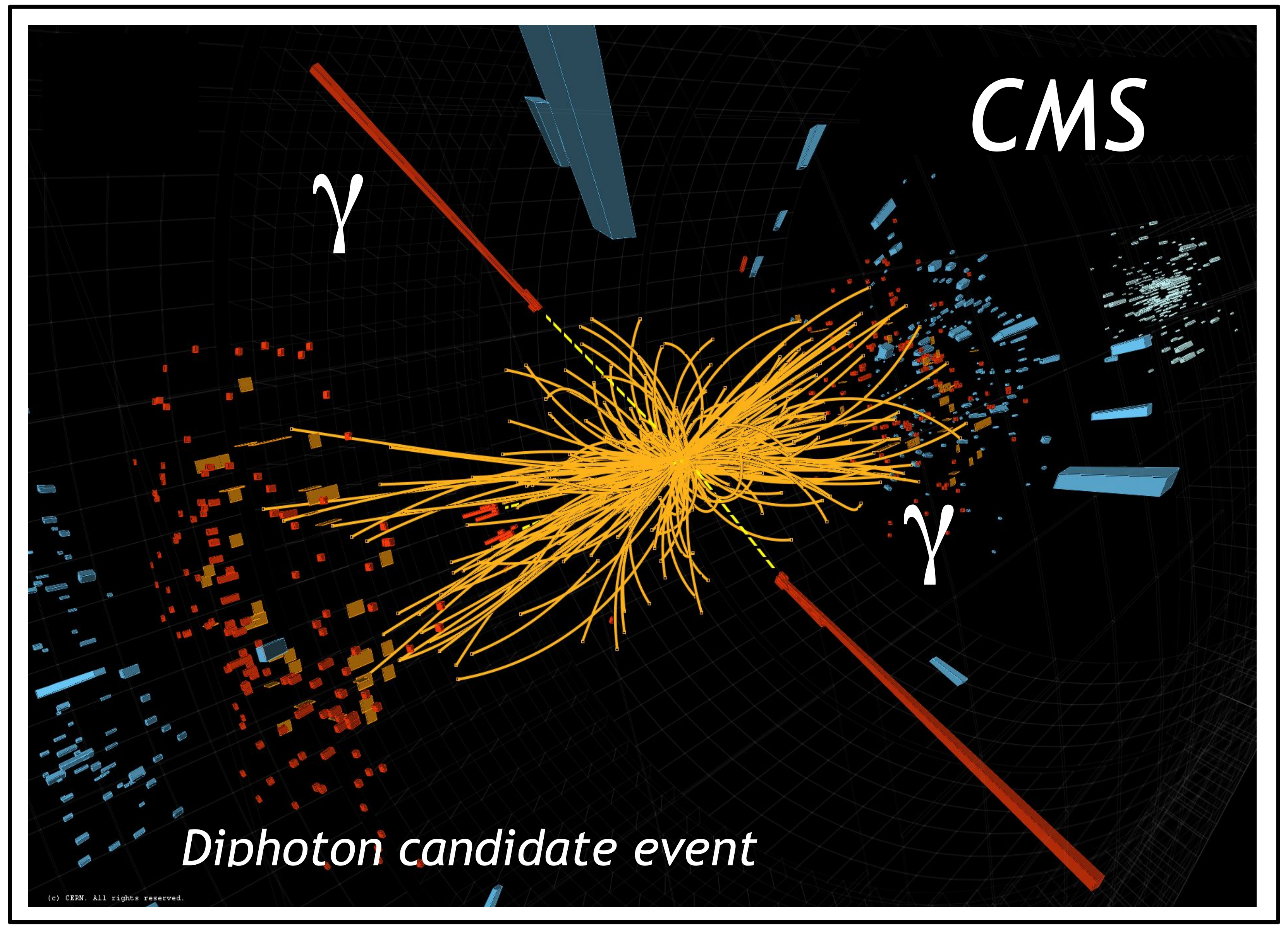
All Predictions at NLO QCD at least!

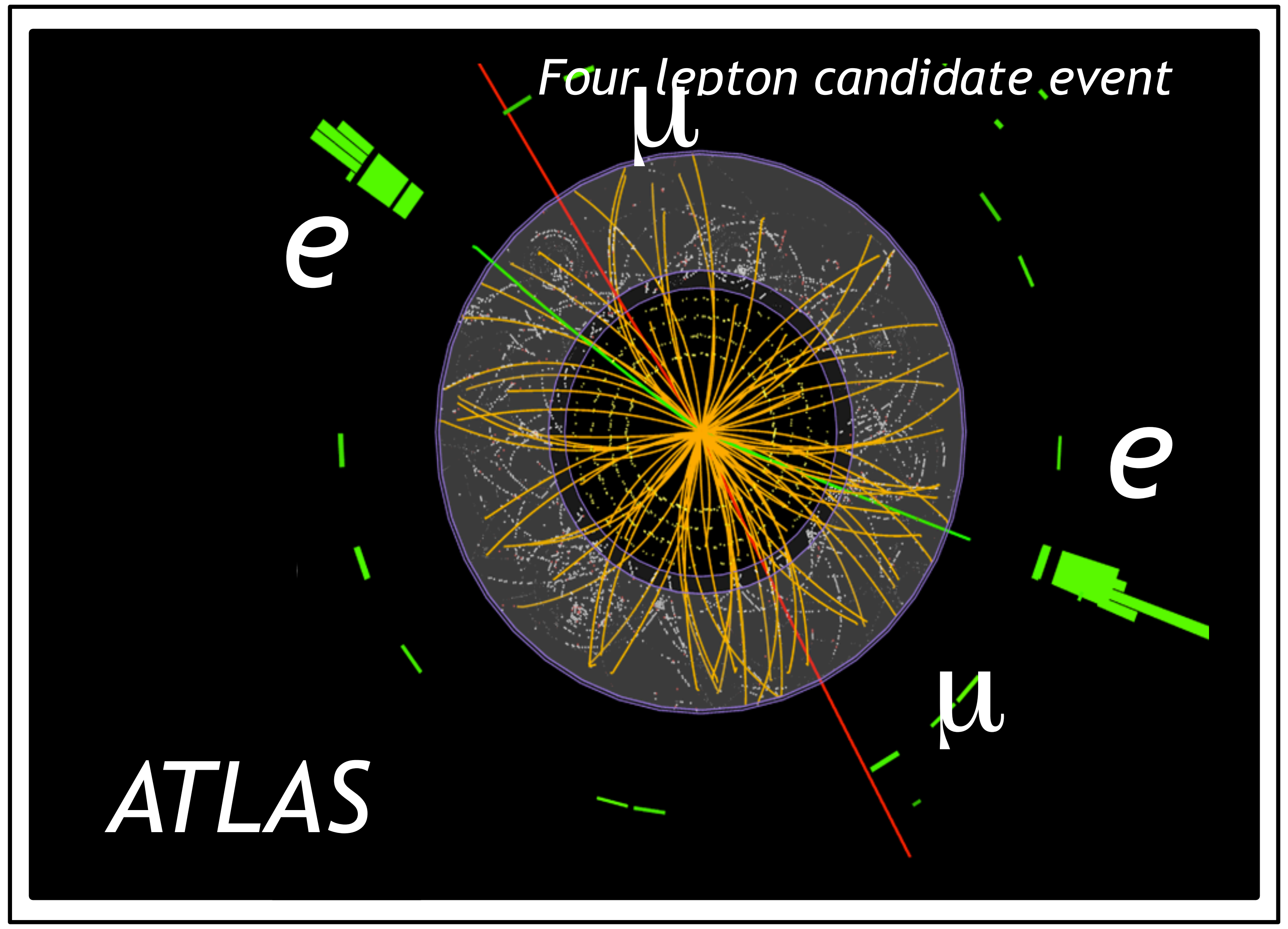
Higgs Physics

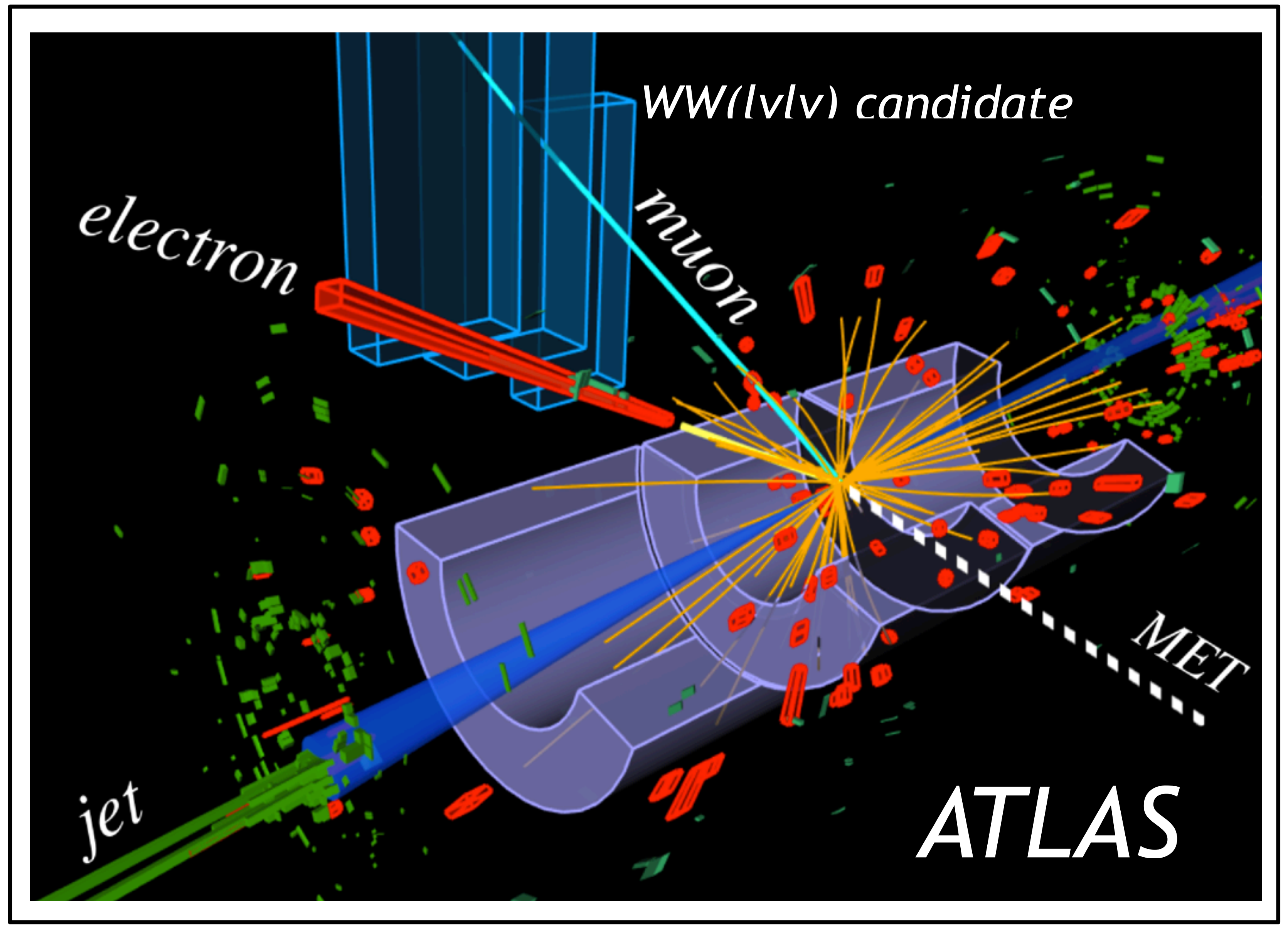
Discovery Channels

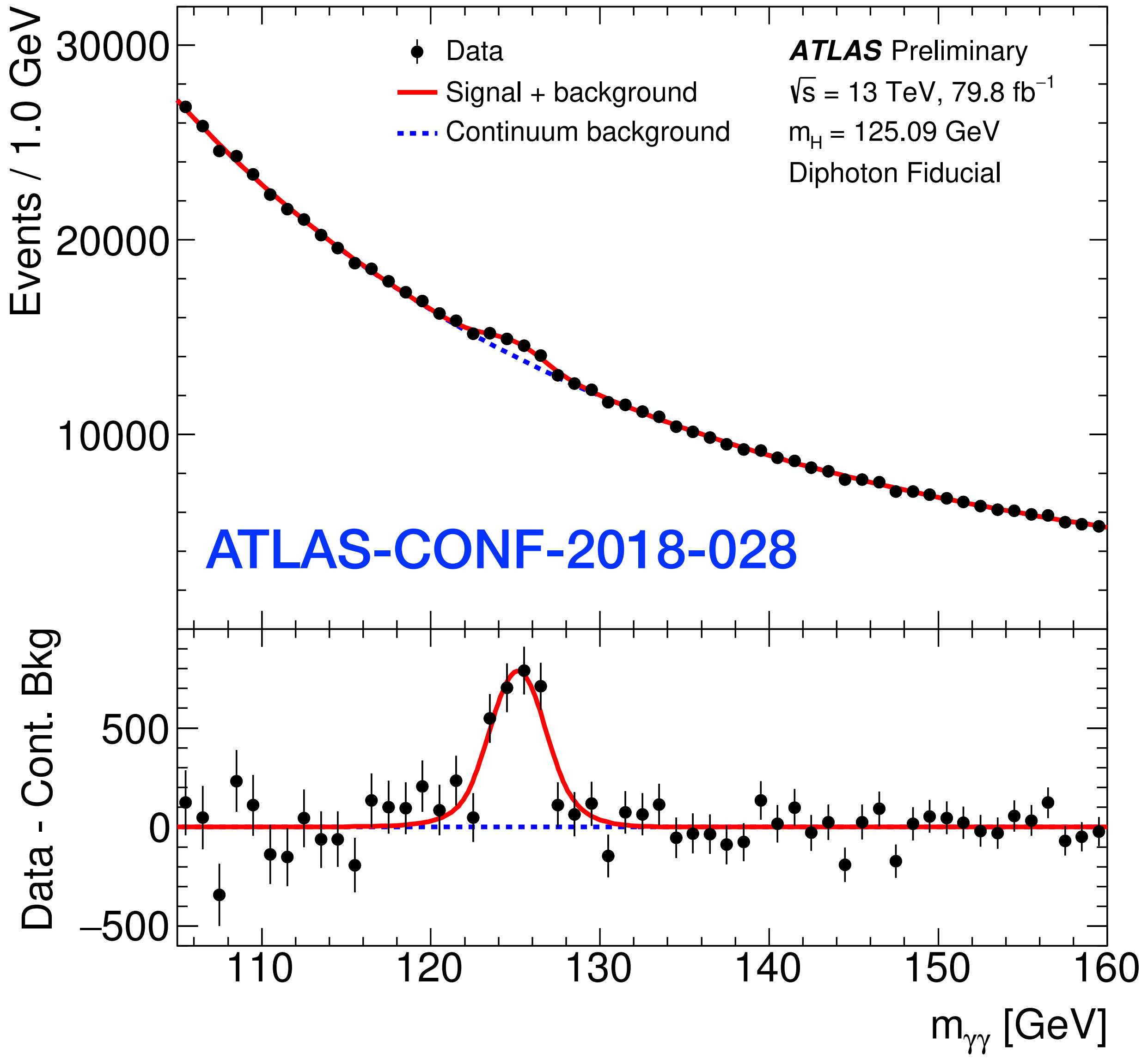
« **Bread and Butter** » O(1%) Mass resolution channels

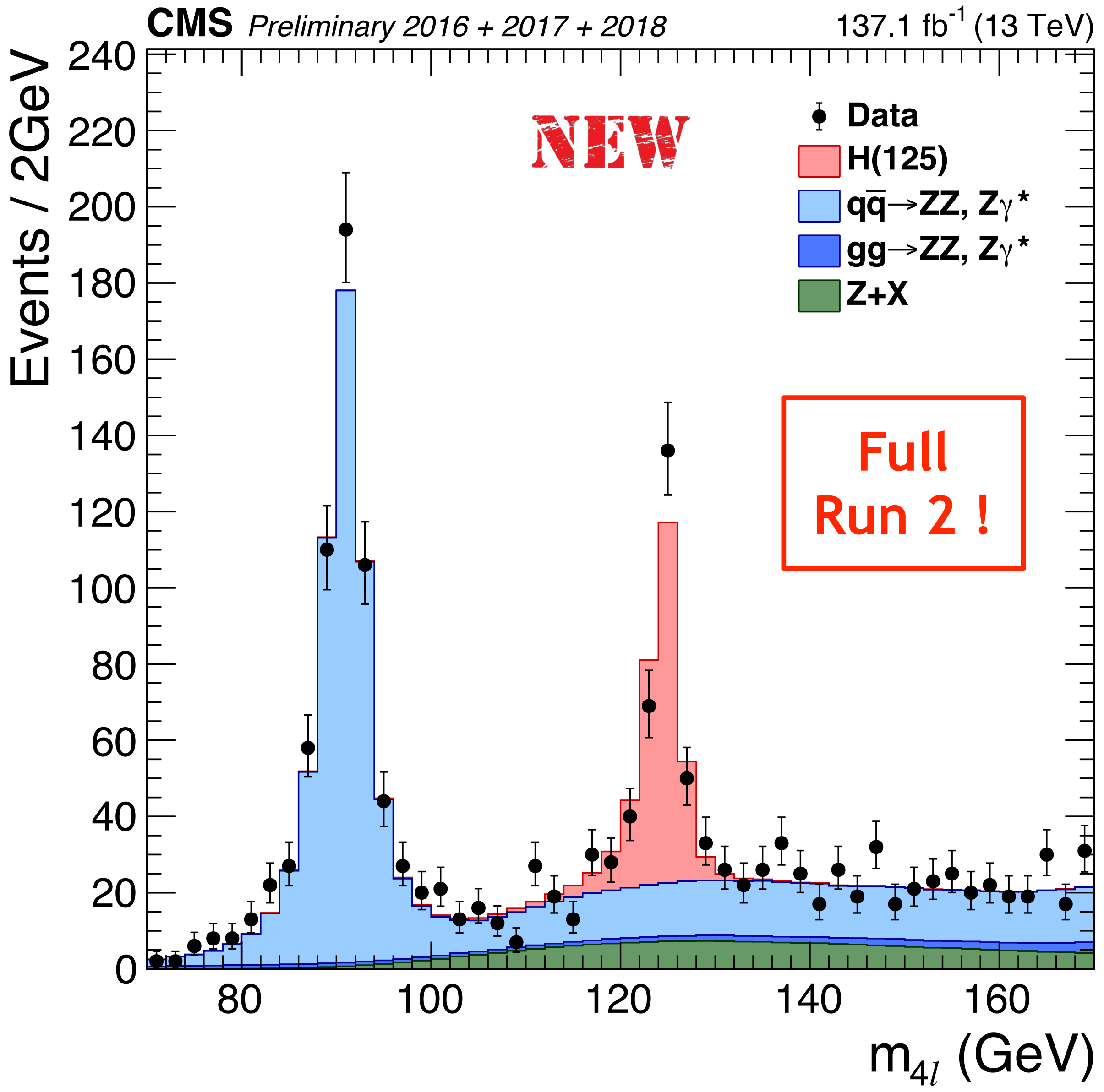
Strong but intricate WW channel





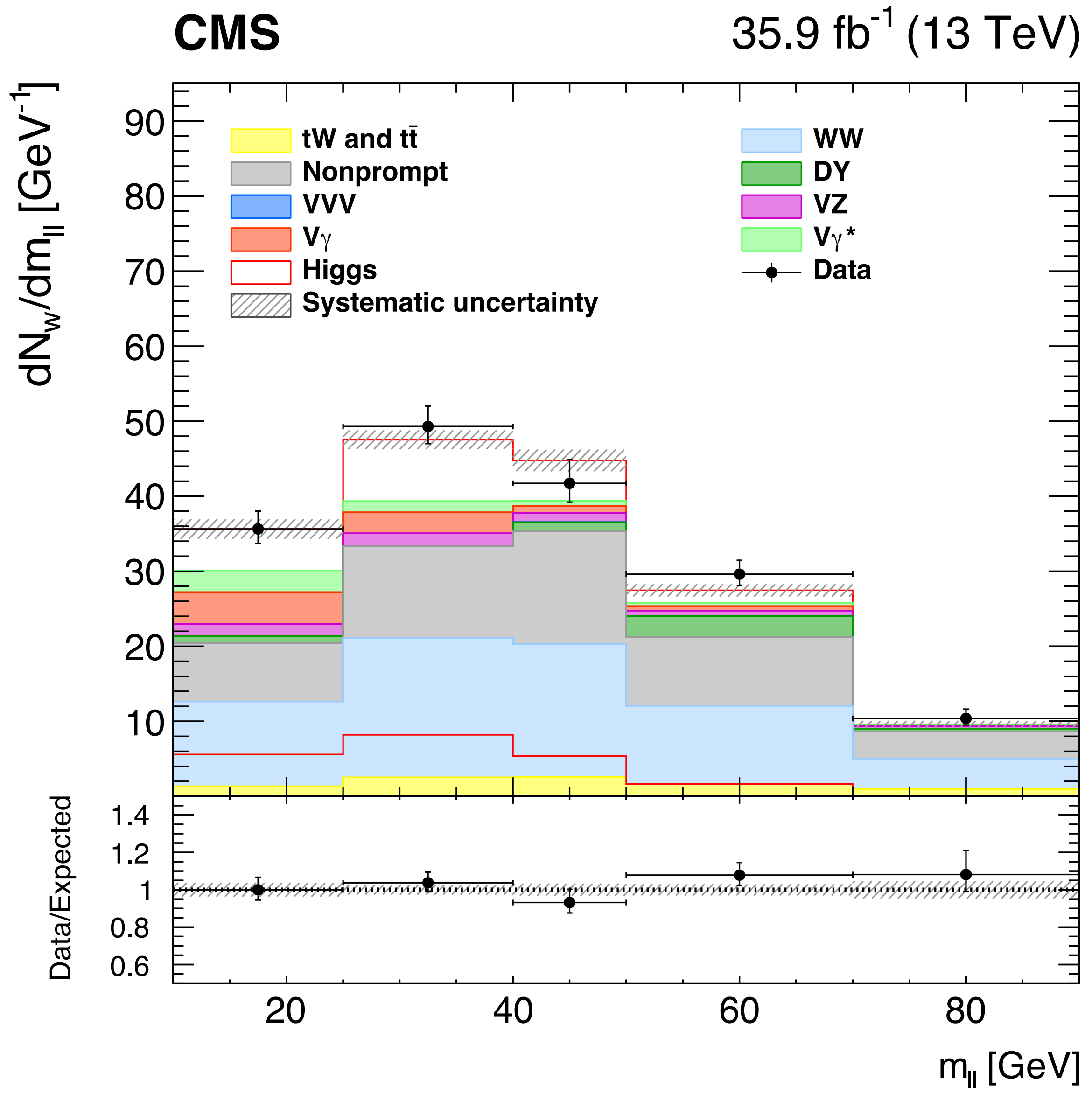






CMS-PAS-HIG-19-001

Excellent opportunities with increased statistics exclusive modes with s/b in excess of 10!



First Precision Measurement at the LHC?

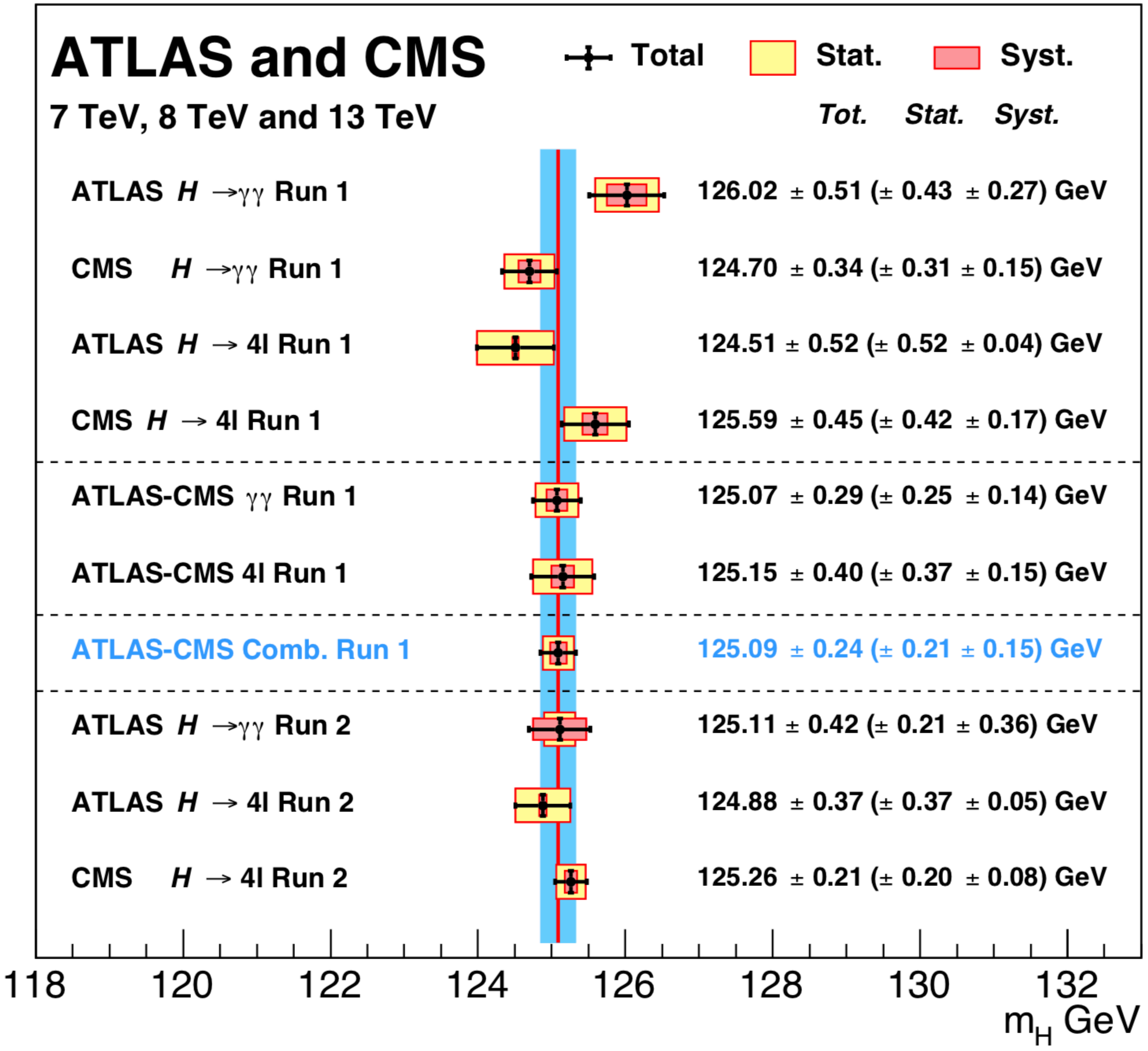
Higgs boson mass measurement

- Measurement in the diphoton and 4-leptons channel exclusively - dominated in sensitivity by the 4mu and 2e2mu channel (Z mass constraint on the 2e).

Current PDG average:

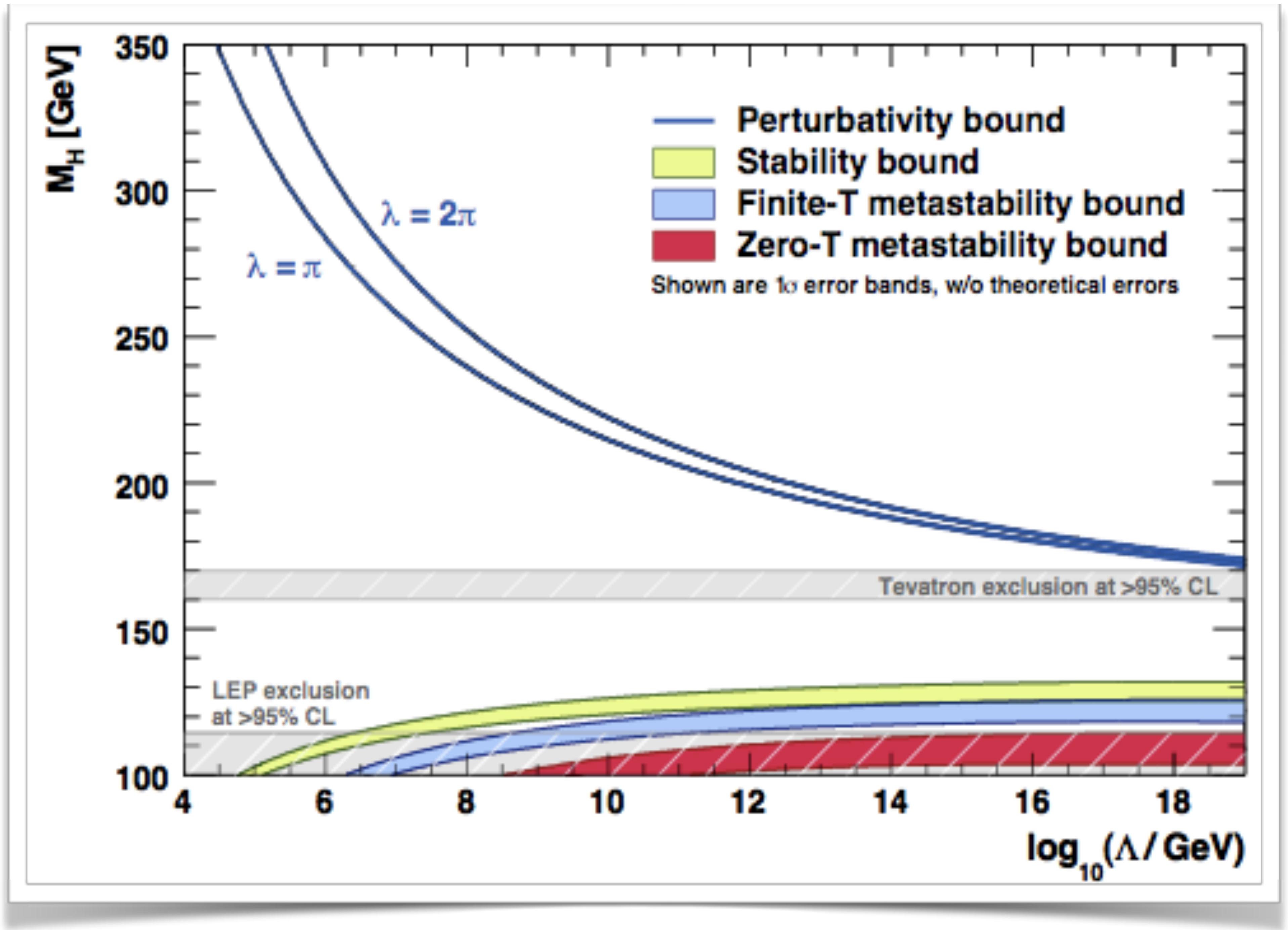
$$m_H = 125.18 \pm 0.16 \text{ GeV}$$

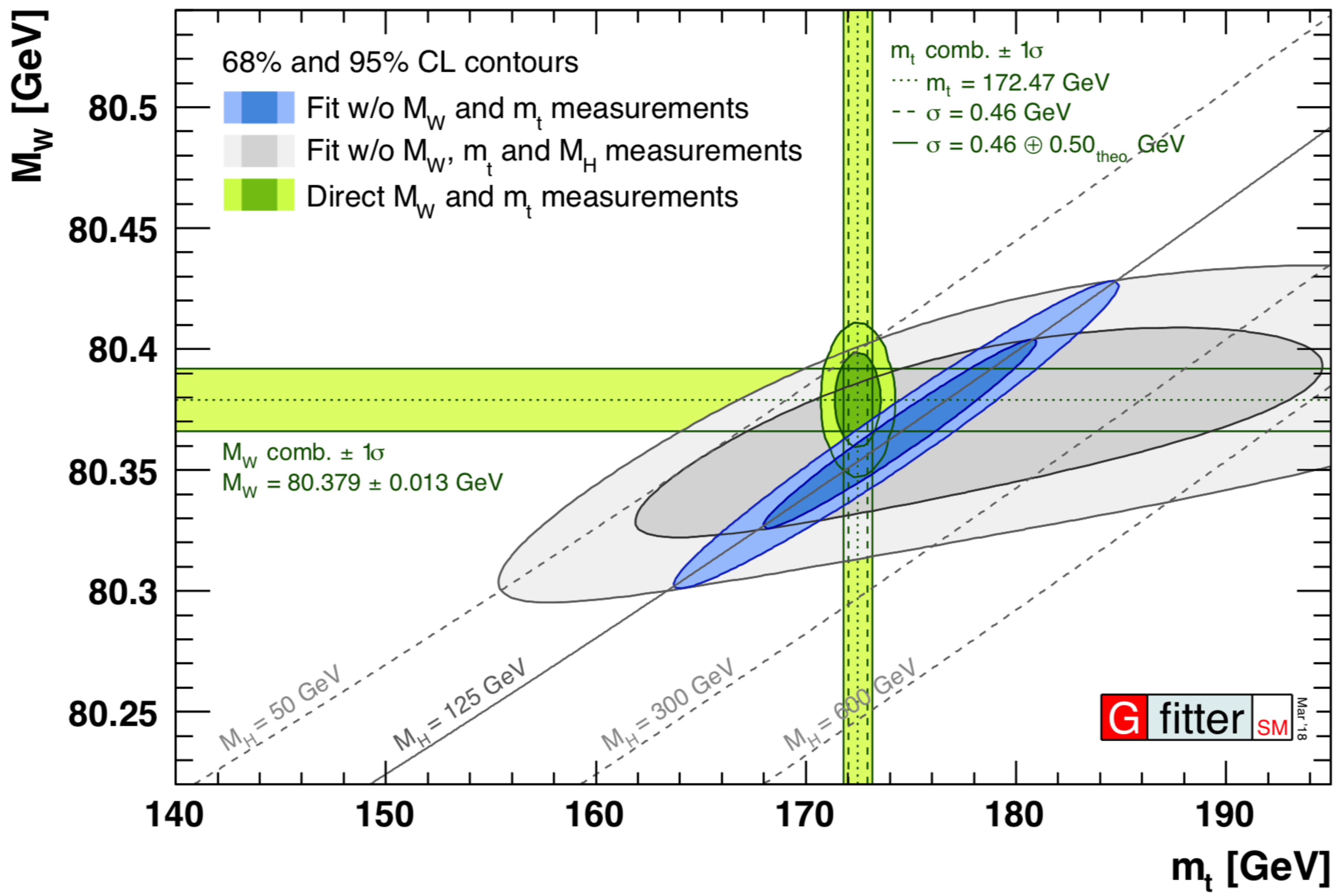
- Measurement not yet dominated by systematic uncertainties.
- With an analysis optimised for mass in high statistics, foresee an ATLAS-CMS combination **10 - 20 MeV** precision.



Triumph of the Standard Model?

Running of the Higgs self coupling:



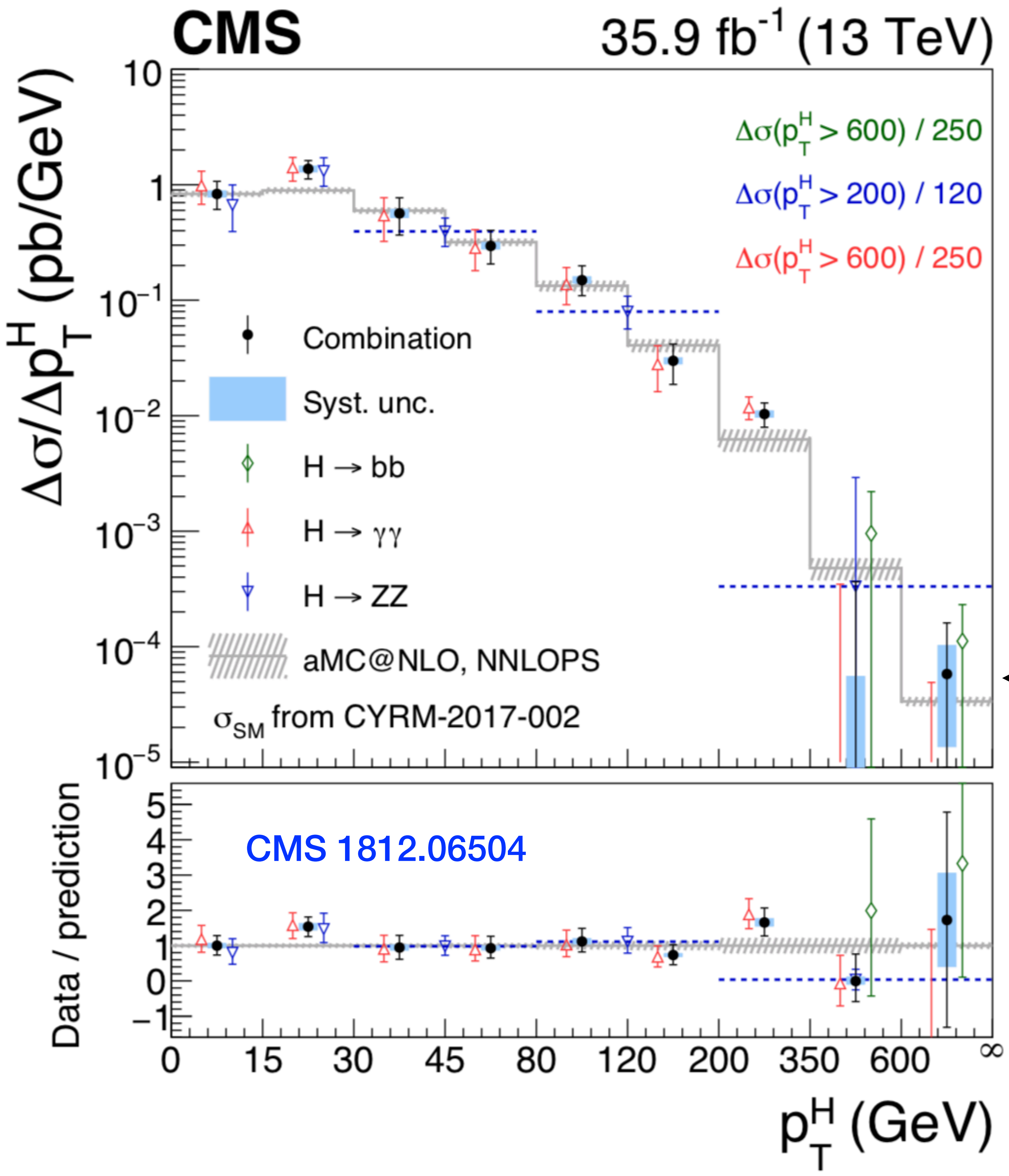


With the discovery of the Higgs,
for the first time in our history,
we have a self-consistent theory
that can be extrapolated to
exponentially higher energies.

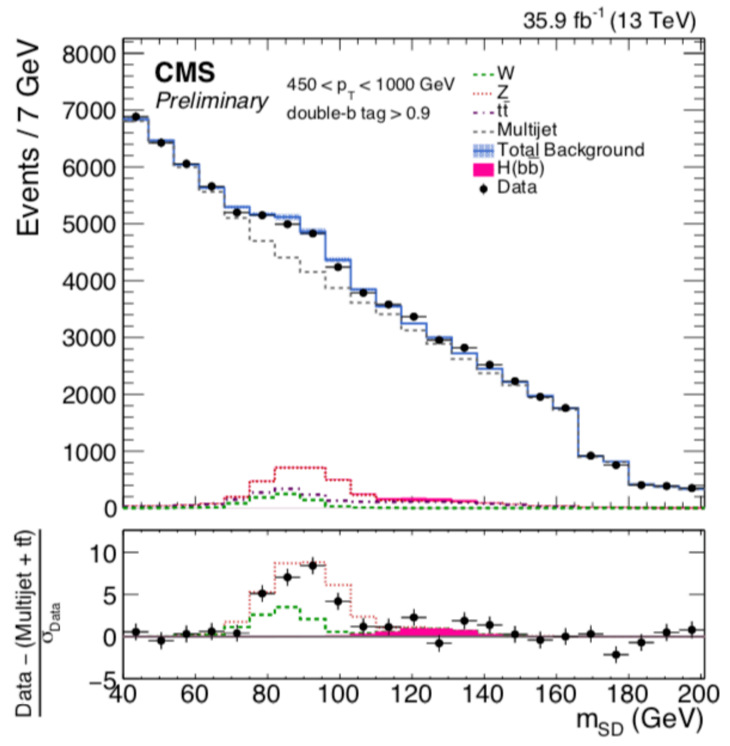
Nima Arkani Hamed

- Knowing the Higgs boson mass has a radical effect on global analysis of precision data and on the the fate of the Universe!
- Knowing the Higgs boson mass precisely has little impact on both aspects.

Fiducial and Unfolded Differential Cross Sections



Diphoton and 4-lepton differential cross section



CMS

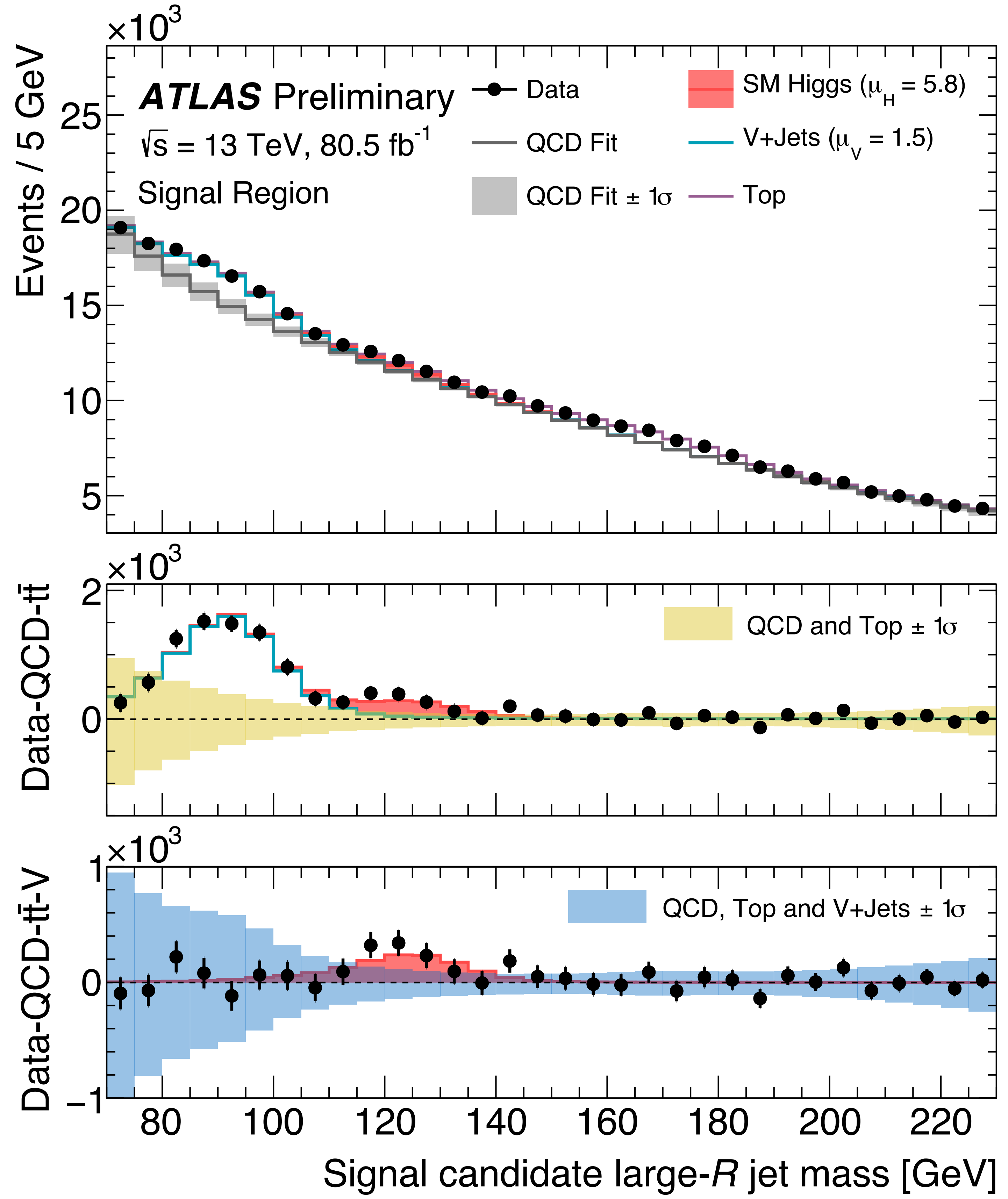
$H \to b\bar{b}$

$1.5\sigma\ (obs)$

$0.7\sigma\ (exp)$

Inclusive boosted analysis in bb at highest pT:

- At least one AK8 (CMS) jet and AK1-trimmed (ATLAS) of 450 GeV (CMS) and 480 GeV (ATLAS)
- One or two b-tags (double b-tagging efficiency pT dependent)

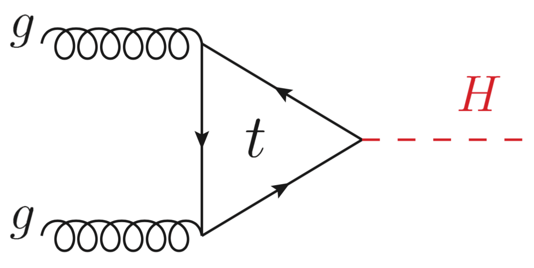
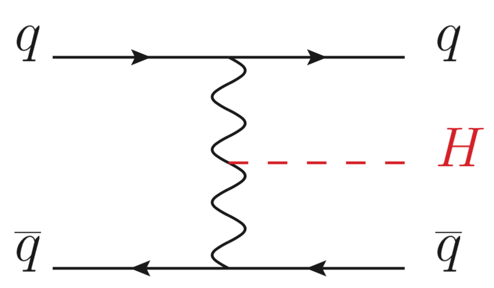
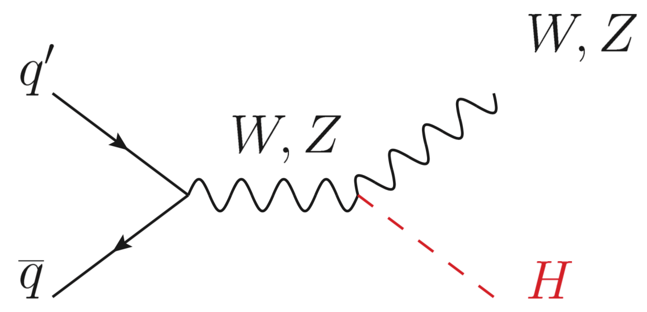
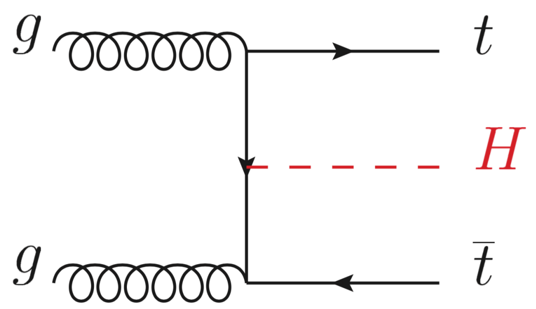


ATLAS ATLAS-CONF-2018-052 $1.6\sigma\ (obs)$

$$\mu_H = 5.8 \pm 3.1\ (\text{stat.}) \pm 1.9\ (\text{syst.}) \pm 1.7\ (\text{th.})$$

Nano Overview of Main Higgs Analyses at (HL) LHC

Most channels already covered at the Run 2 with only 3% (80 fb-1) of full HL-LHC dataset!

	Channel categories	Br	ggF  ~4 M vets produced	VBF  ~300 k vets produced	VH  ~200 k vets produced	ttH  ~40 k evts produced
	Cross Section 13 TeV (8 TeV)		48.6 (21.4) pb*	3.8 (1.6) pb	2.3 (1.1) pb	0.5 (0.1) pb
Observed modes	γγ	0.2 %	✓	✓	✓	✓
	ZZ	3 %	✓	✓	✓	✓
	WW	22 %	✓	✓	✓	✓
	ττ	6.3 %	✓	✓	✓	✓
	bb	55 %	✓	✓	✓	✓
Remaining to be observed	Zγ and γγ*	0.2 %	✓	✓	✓	✓
	μμ	0.02 %	✓	✓	✓	✓
Limits	Invisible	0.1 %	✓ (monojet)	✓	✓	✓

*N3LO

Run 2 Higgs Headlines

Run 2 Higgs Physics Milestones Already Reached: Third Generation (Charged) Completed!

Yukawas at LHC		tau	b	top
ATLAS	Exp. Sig.	5.4 σ	5.5 σ	5.1 σ
	Obs. Sig.	6.4 σ	5.4 σ	6.3 σ
	mu	1.09 ± 0.35	1.01 ± 0.20	1.34 ± 0.21 *
CMS	Exp. Sig.	5.9 σ	5.6 σ	4.2 σ
	Obs. Sig.	5.9 σ	5.5 σ	5.2 σ
	mu	1.09 ± 0.27 *	1.04 ± 0.20	1.26 ± 0.26 **

* 13 TeV only derived from cross section measurements

** Lower uncertainty (upper uncertainty 31)

Room for improvement:

- Larger statistics will allow to focus on more specific (and potentially less vulnerable to systematic) regions of phase space.

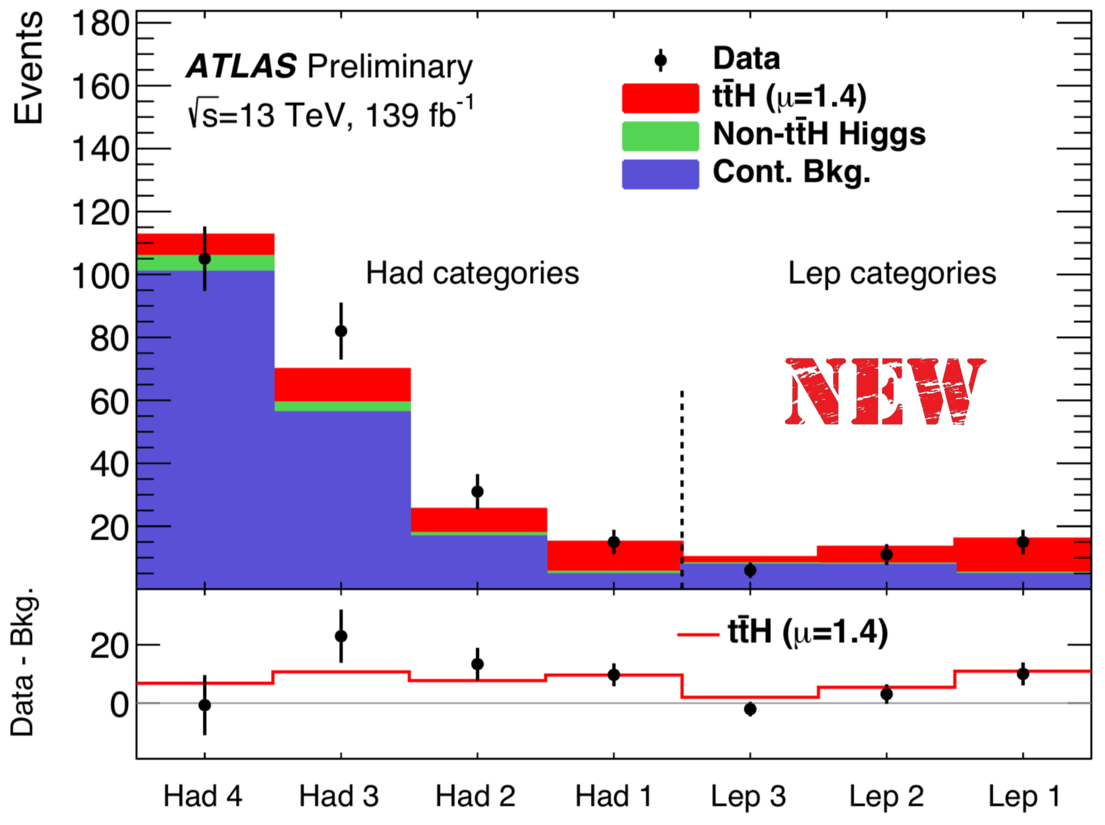
- Make ancillary measurements for a better control of the backgrounds.

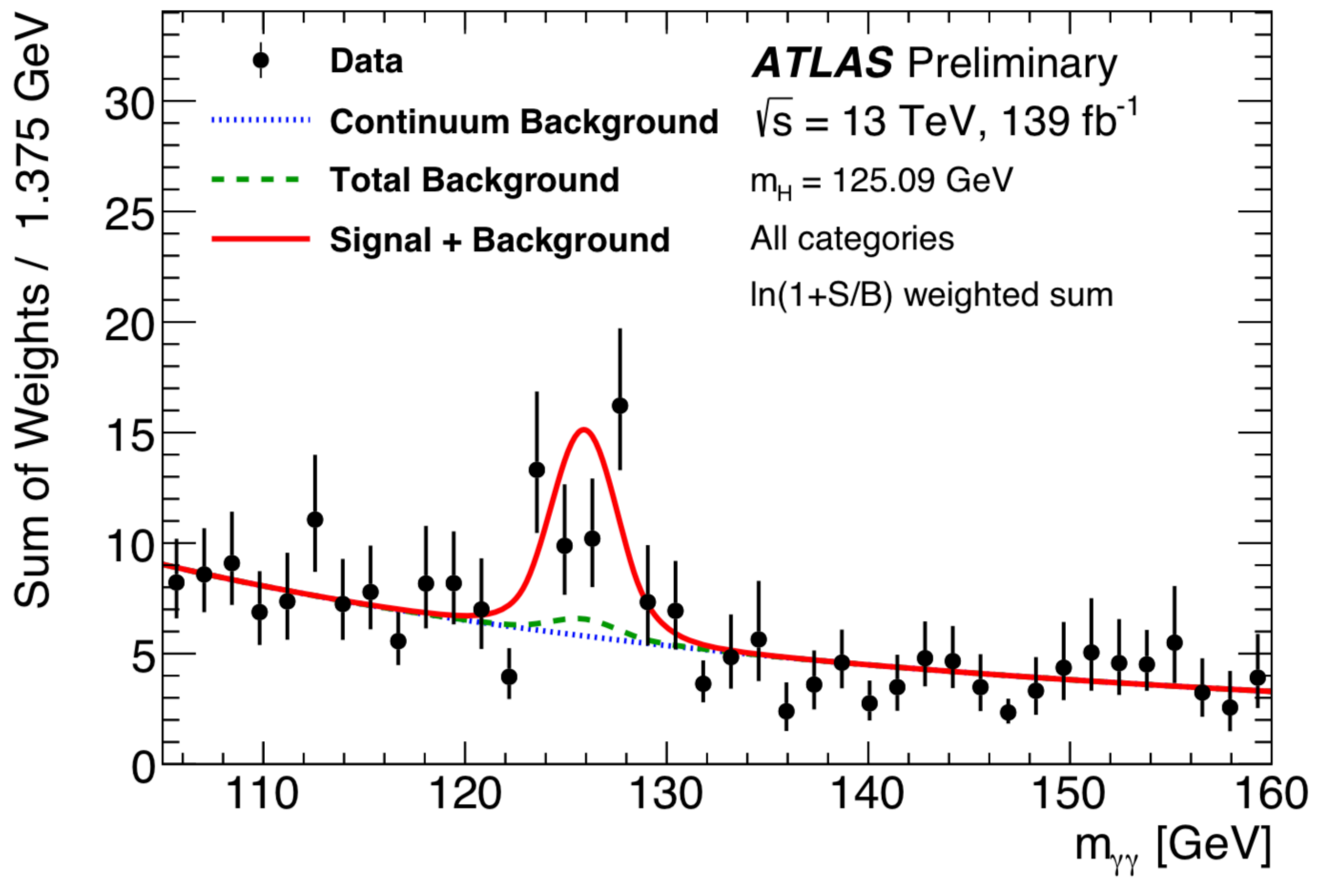
Highlight ttH single Channel Observation (in the diphoton channel)

ATLAS Full dataset!!

Observation and measurement of ttH production in the diphoton channel with 139 fb-1 of data at Run 2

ATLAS-CONF-2019-04





Observed

4.9σ

Expected

(4.2σ)

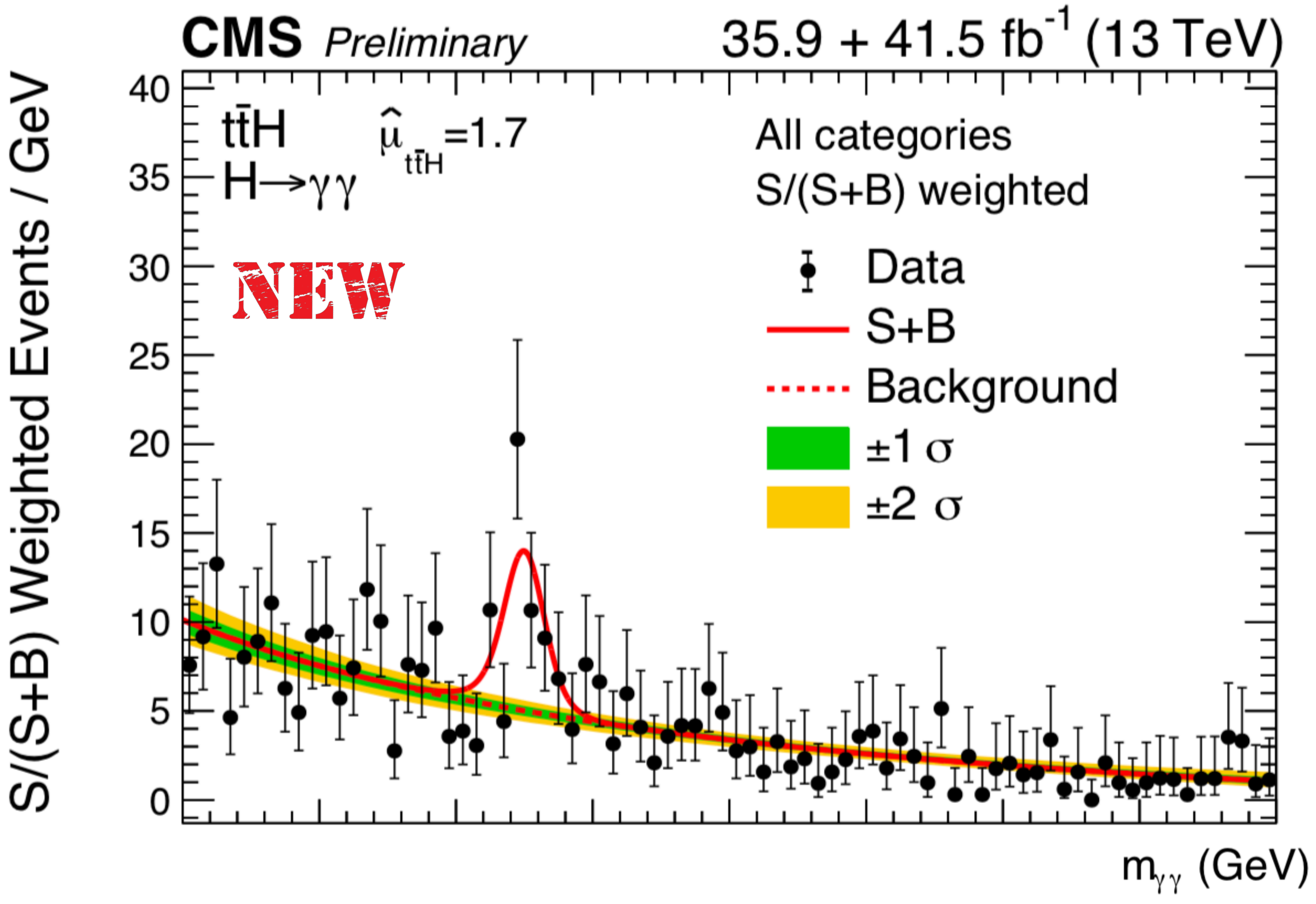
Measurement dominated by statistical uncertainties:

$$\sigma_{t\bar{t}H} \times B_{\gamma\gamma} = 1.59^{+0.38}_{-0.36}\,(\text{stat.})\,^{+0.15}_{-0.12}\,(\text{exp.})\,^{+0.15}_{-0.11}\,(\text{theo.})\ \text{fb}$$

CMS CMS-PAS-HIG-18-018

Similarly CMS analysis with 35.9 fb-1 (2016) + 41.5 fb-1 (2017)

Similar analysis with similar performance, difference in sensitivity largely due to difference in dataset.



Observed

4.1σ

Expected

(2.7σ)

Signal strength

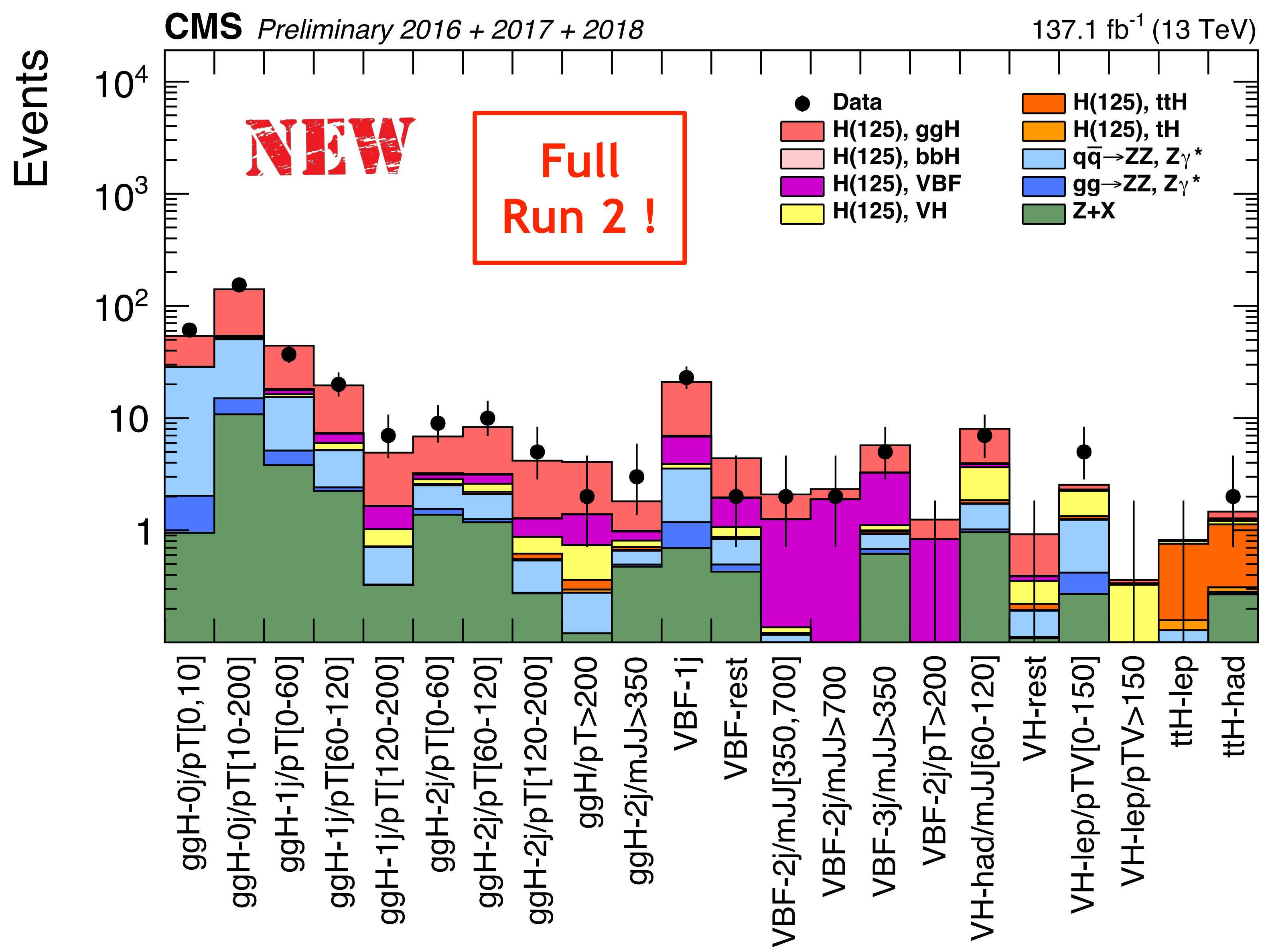
$$\mu_{ttH} = 1.7^{+0.6}_{-0.5}$$

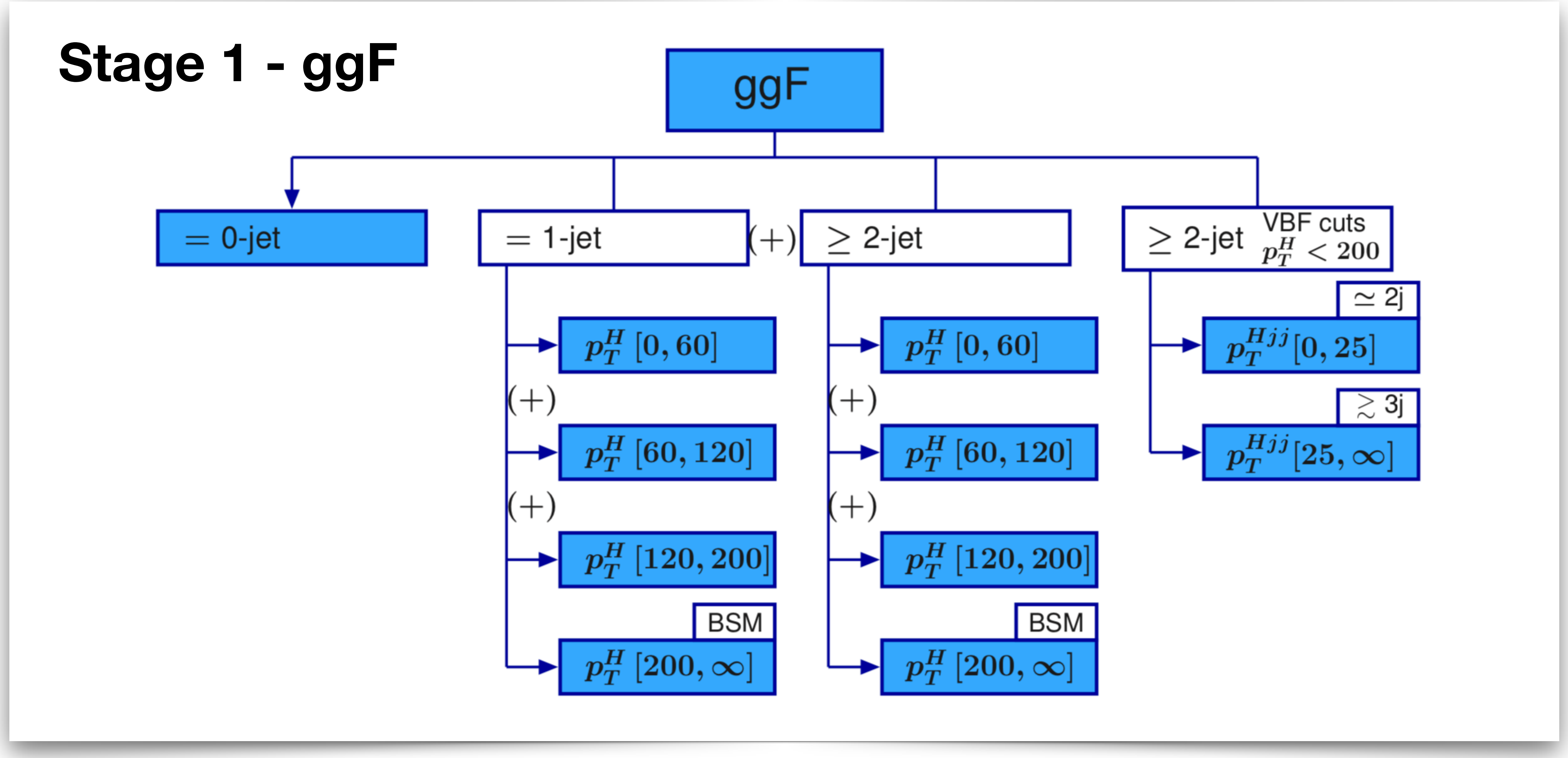
Hybrid Fiducial Approach: Simplified Template Cross Sections

- Integrate over the decay products of the Higgs.
- Define fiducial cuts at truth particle level on the Higgs production (eta, pT, number and kinematics of the additional jets or leptons in the events).
- Define (as much as possible) reconstruction level cuts corresponding to the fiducial volume of interest (as much as possible).
- Fit the defined partially fiducial defined cross sections in all regions simultaneously.

Advantage possibility to **combine decay channels** and use **multivariate techniques** in specific channels. **Compromise** as both aspects increase the extrapolation.

CMS-PAS-HIG-19-001





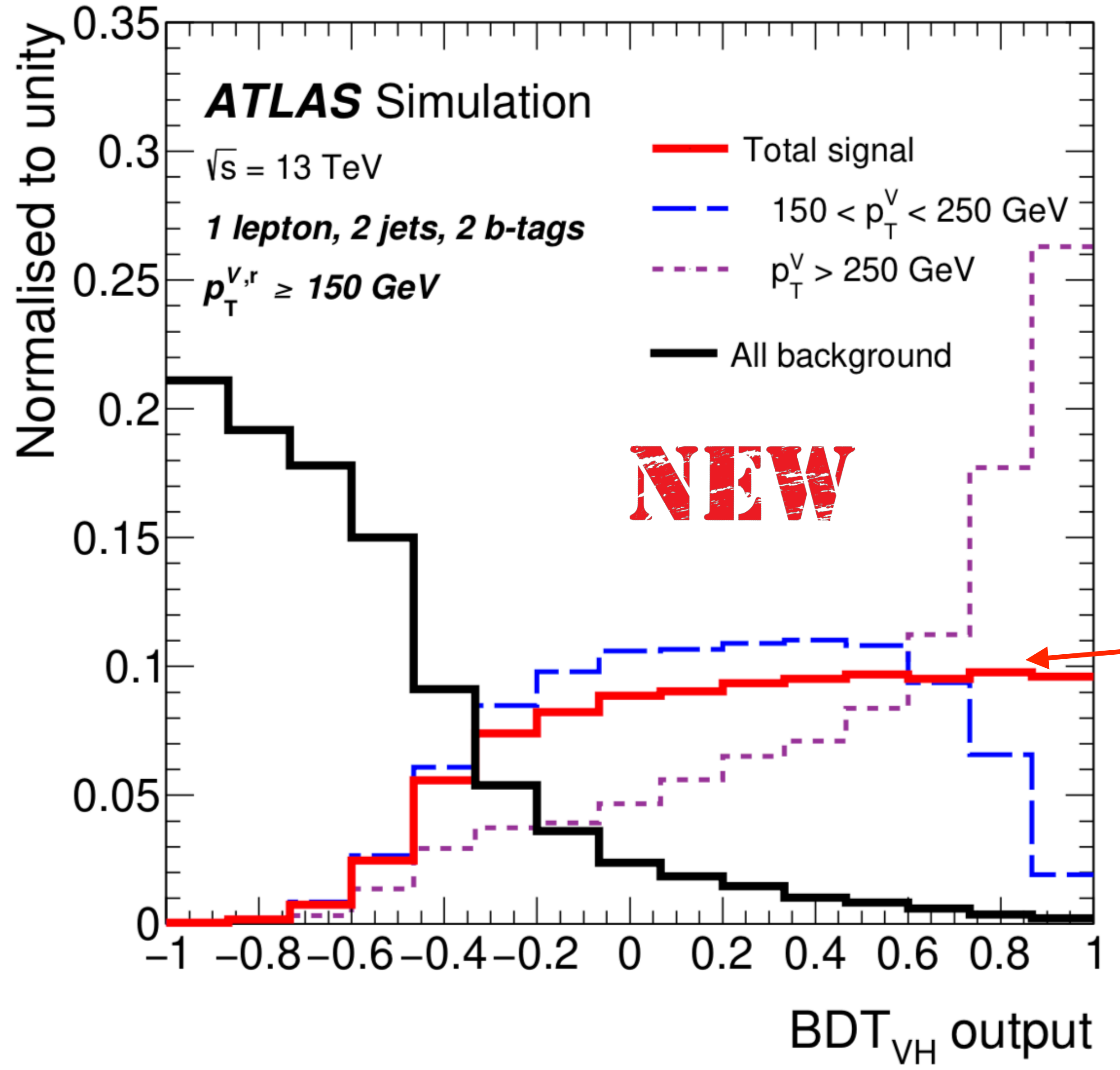
CMS-PAS-HIG-18-029 ATLAS-CONF-2018-028

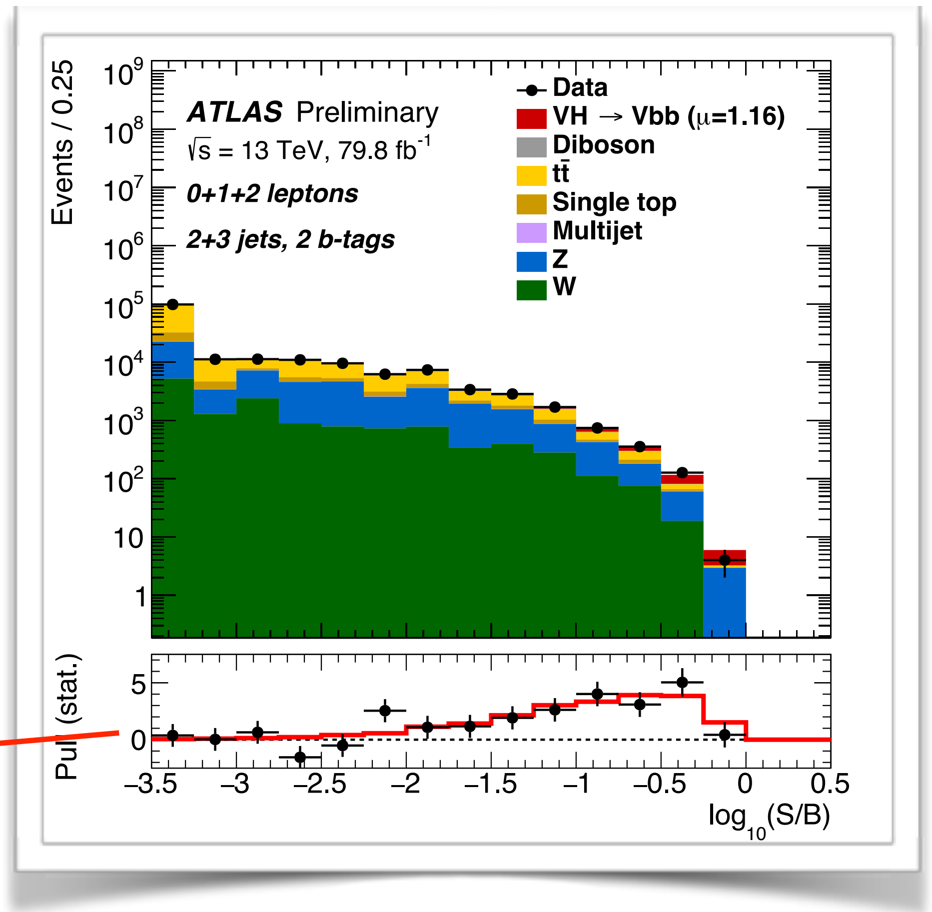
Also recent results based on the diphoton channel

Beyond the Headlines

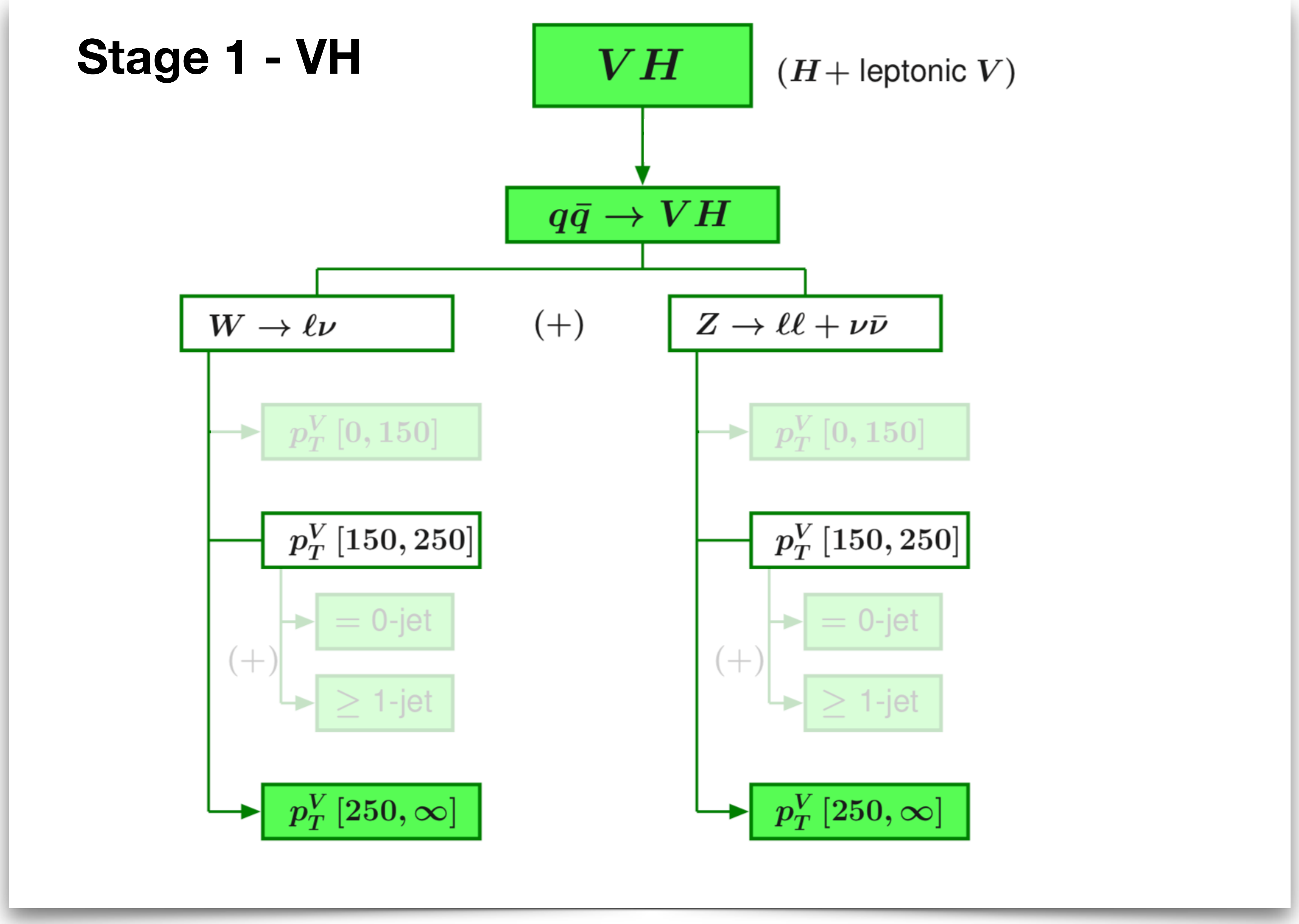
With the Higgs to b quarks decays !

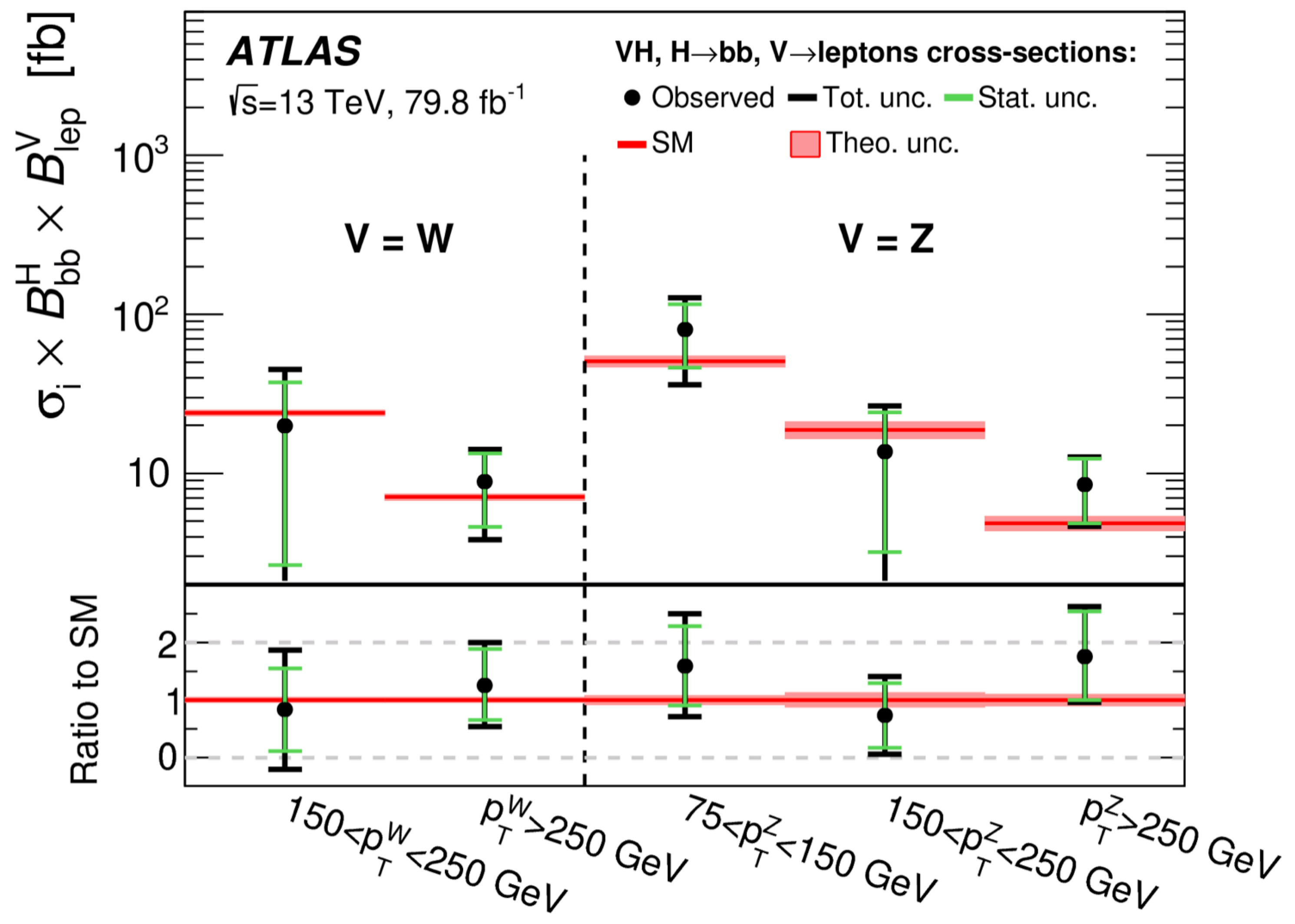
ATLAS 1903.04618





Observation analysis





Analysis based on three main channels targeting WH and ZH production, based on the W or Z decays:

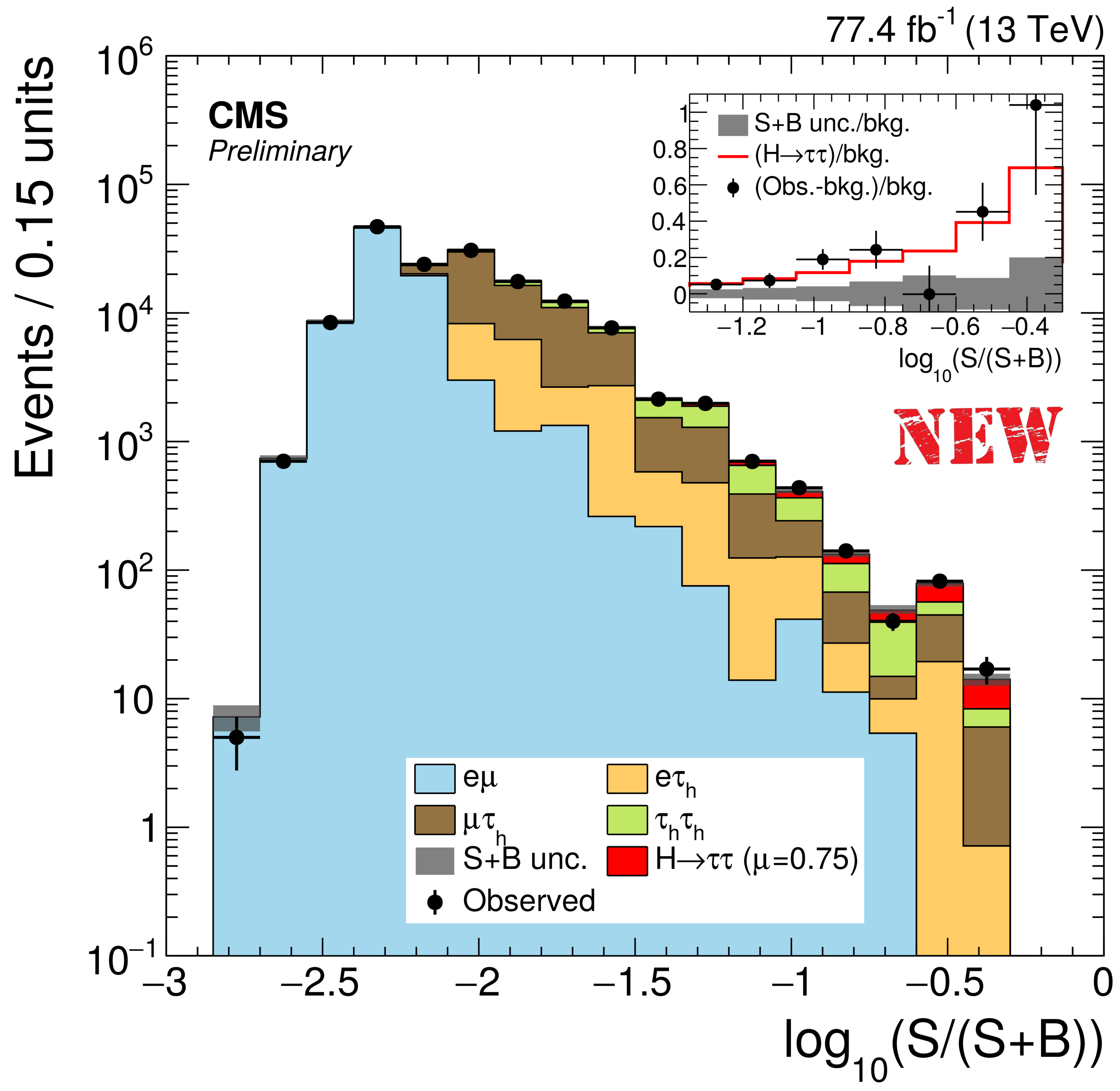
- 0 « leptons » (for neutrino decays of the Z)
- 1-lepton (W decaying to an electron or a muon)
- 2-leptons (Z decaying to electrons or muons)

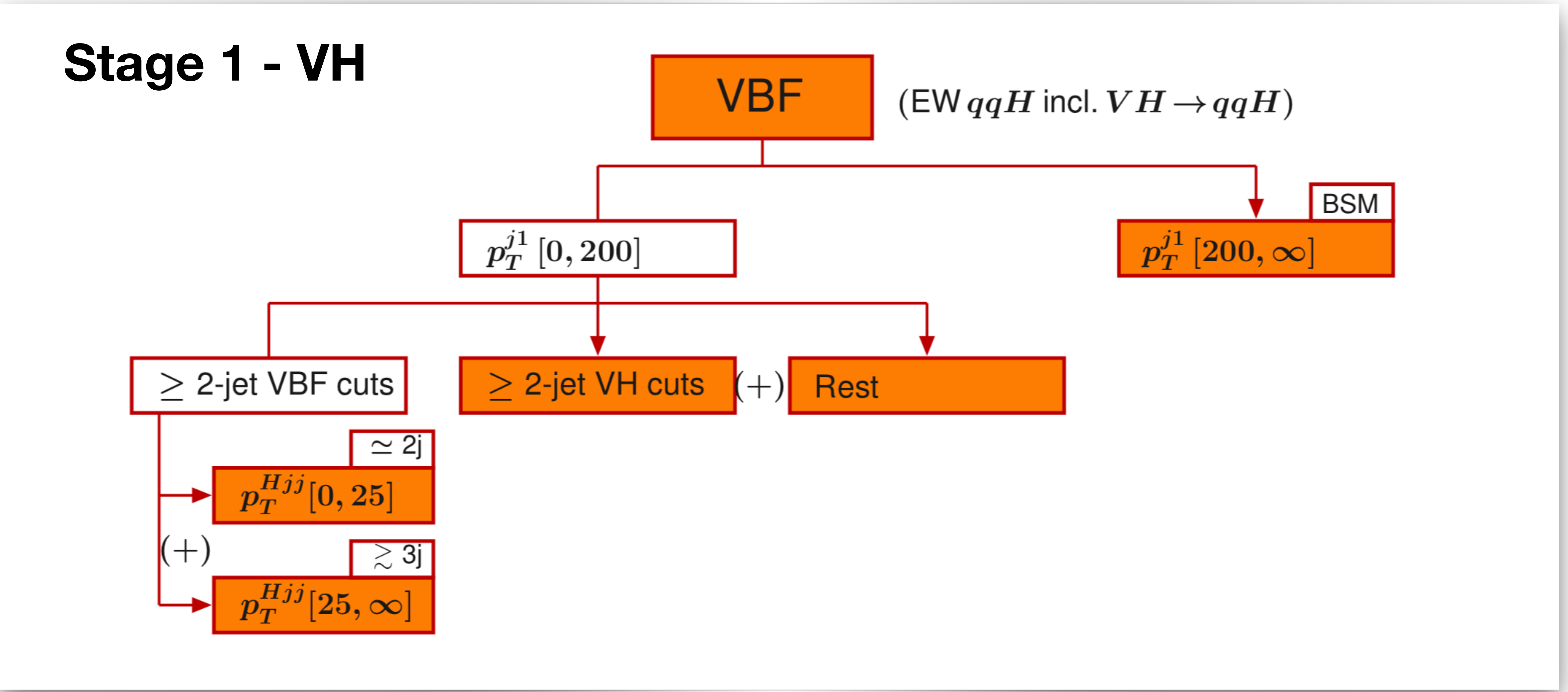
Main background is V+jets (in particular b-jets), relies on a good simulation, but is controlled in the mass side-bands!

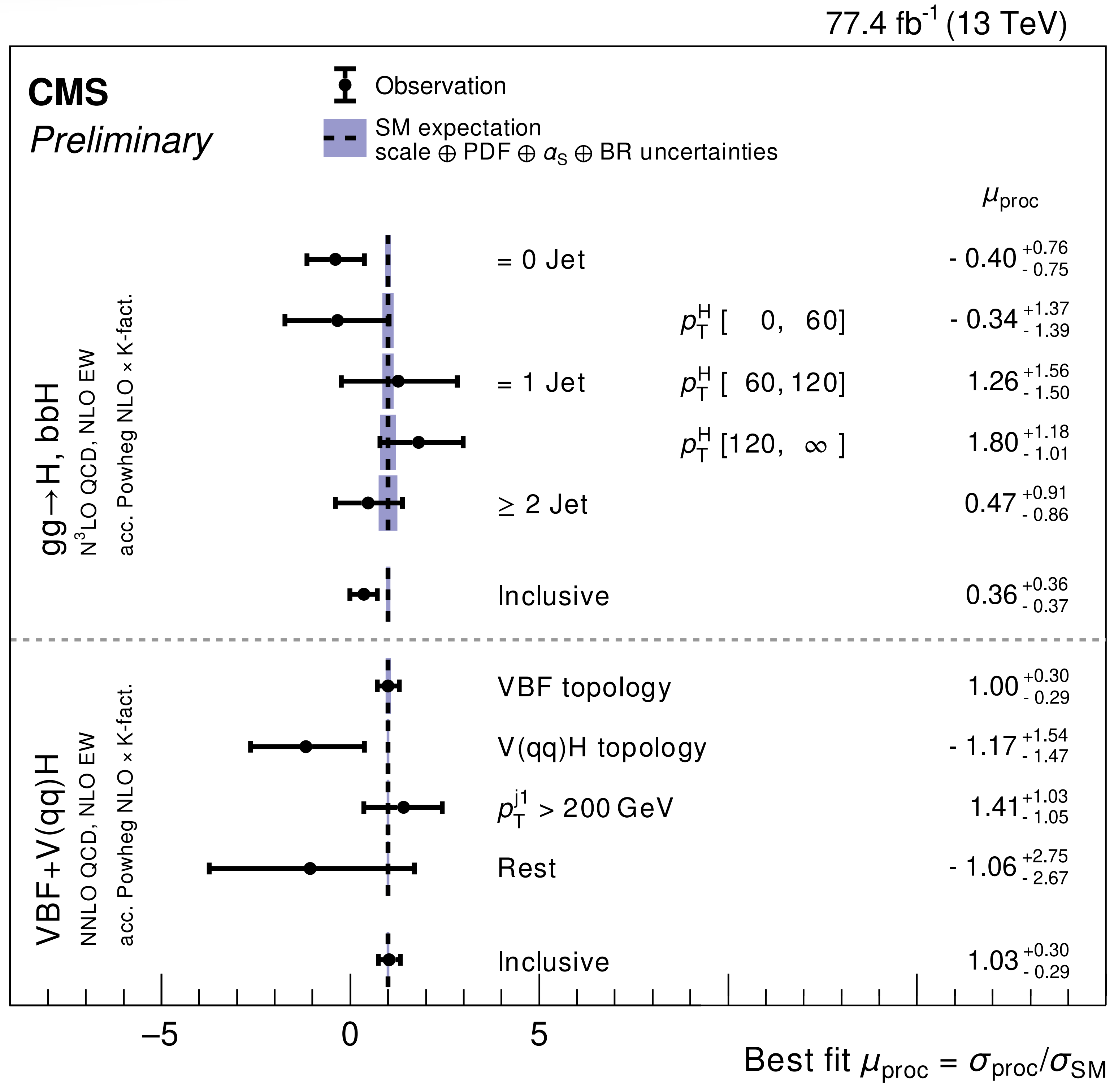
Beyond the Headlines

STXSs in Higgs to tau decays !

CMS-PAS-HIG-18-032







Simultaneous fit of the ggF STXSs (which have a non negligible impact in the specific fiducial regions.

Main background Z-jets estimated using embedding technique. Other backgrounds estimated using MC and fake factors.

Classification using a Multi-Class NN technique with 8 categories (ggH, qqH,Z-jets, diboson (dilepton), single top, tt, qcd, and misc other.

Memento on Invisible and Total Higgs Width

SM width (small i.e. potentially large relative variations from BSM couplings)

$$\Gamma^{H}_{SM} = 4.07 \pm 0.16 \text{ MeV}$$

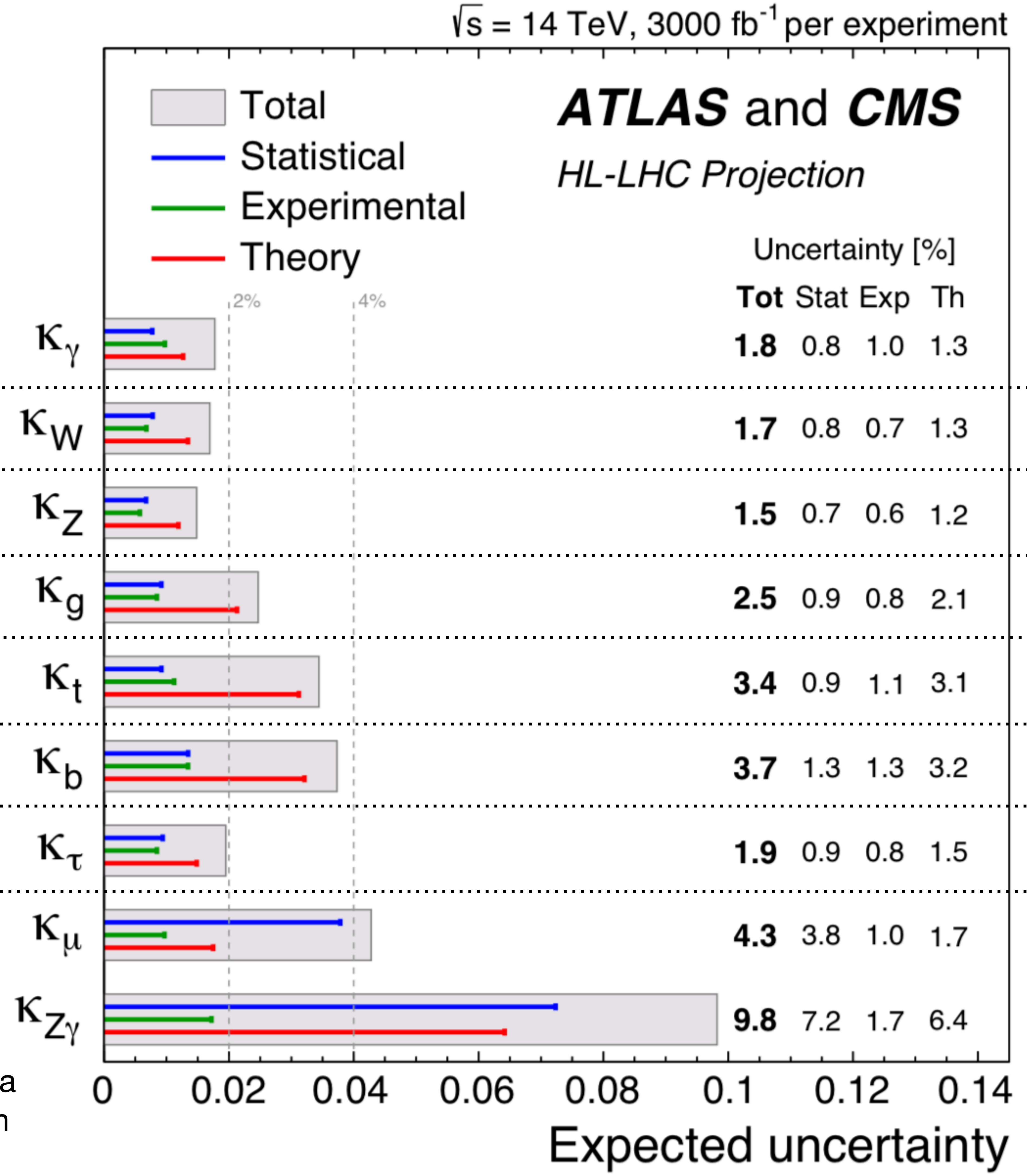
		Run 2 (ATLAS or CMS - not combined)	HL-LHC
Invisible width			
Invisible Higgs VBF		26%	3.8%
Invisible Higgs Combined		20%	2.5%
Total width			
Direct line shape		<1.1 GeV @ 95% CL	N.A.
Couplings combination (kV<1)	ATLAS-CONF-2019-04	22%	5%
Off Shell Higgs		100%	20%
Diphoton interferometry (normalisation)		N.A.	O(100%)
Diphoton interferometry (mass shift)		N.A.	<200 MeV @ 95% CL

HL-LHC YR
1902.00134

Combination of Main Decay and Production Channels Towards HL-LHC

NEW Measurement of the couplings properties of the Higgs boson - in this case assuming no BSM in the Higgs width

	ATLAS - CMS Run 1 combination	ATLAS Run 2	HL-LHC
κ_γ	13%	9%	1.8%
κ_W	11%	8.6%	1.7%
κ_Z	11%	7.2%	1.5%
κ_g	14%	11%	2.5%
κ_t	30%	14%	3.4%
κ_b	26%	18%	3.7%
κ_τ	15%	14%	1.9%
	JHEP 08 (2016) 045	ATLAS-CONF-2019-04	HL-LHC YR 1902.00134



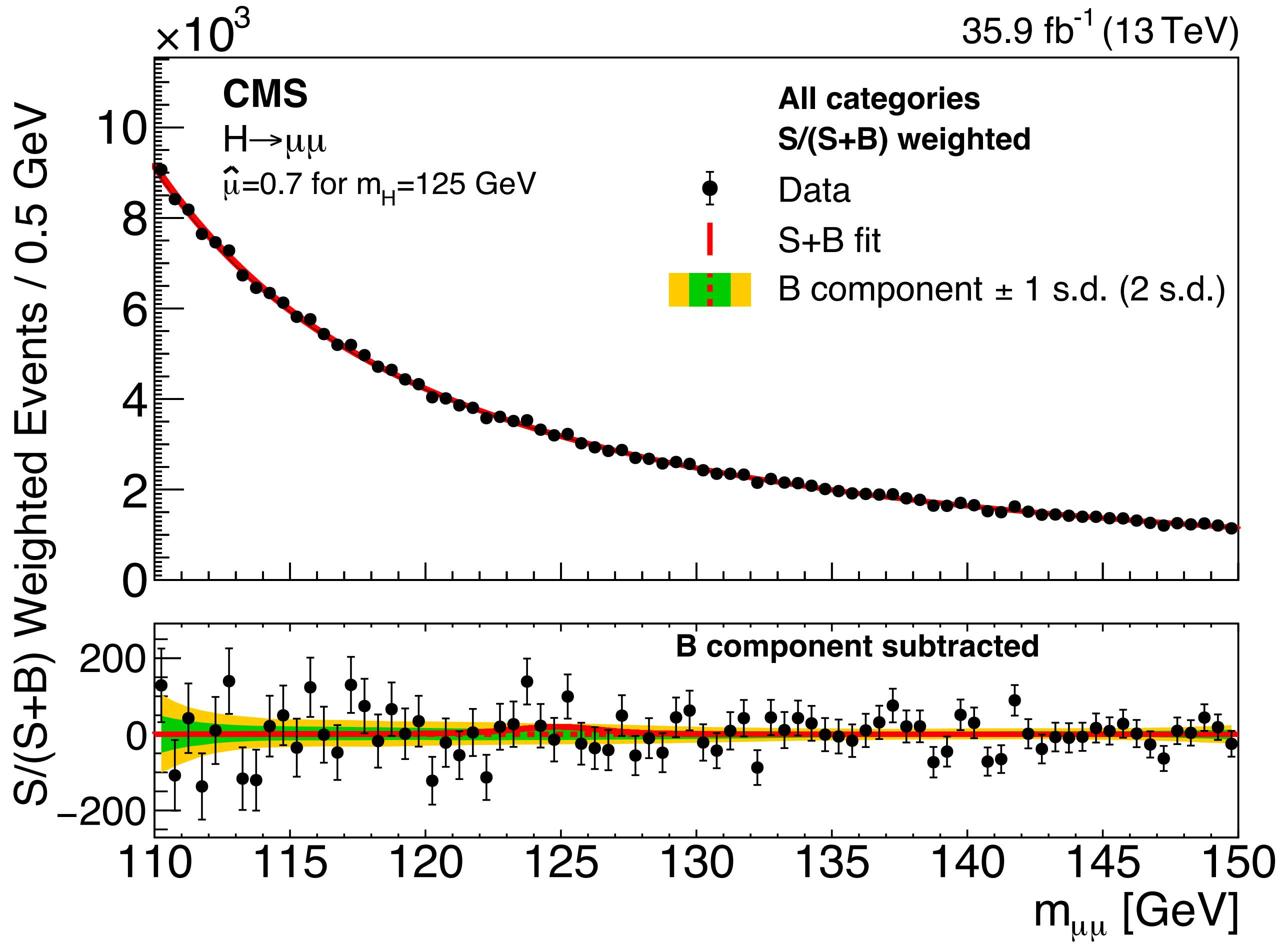
Experimental systematics non negligible

Improved TH and PDF uncertainties by a factor of 2 w.r.t. current (motivated from current PDF studies and current TH uncertainties assumptions)

Measuring 2d Generation Yukawa Couplings

The Next Challenge for Run 3

Analysis strategy: Very low s/b, search for peak in $m_{\mu\mu}$ spectrum over smooth background (categorise events according to a BDT which also separates ggF, VBF and VH signatures). Very low s/b require excellent background description.



Current limits at

$$\mu < 2.92\ (2.16\ \text{exp.})\ \text{at}\ 95\%\ \text{CL}$$

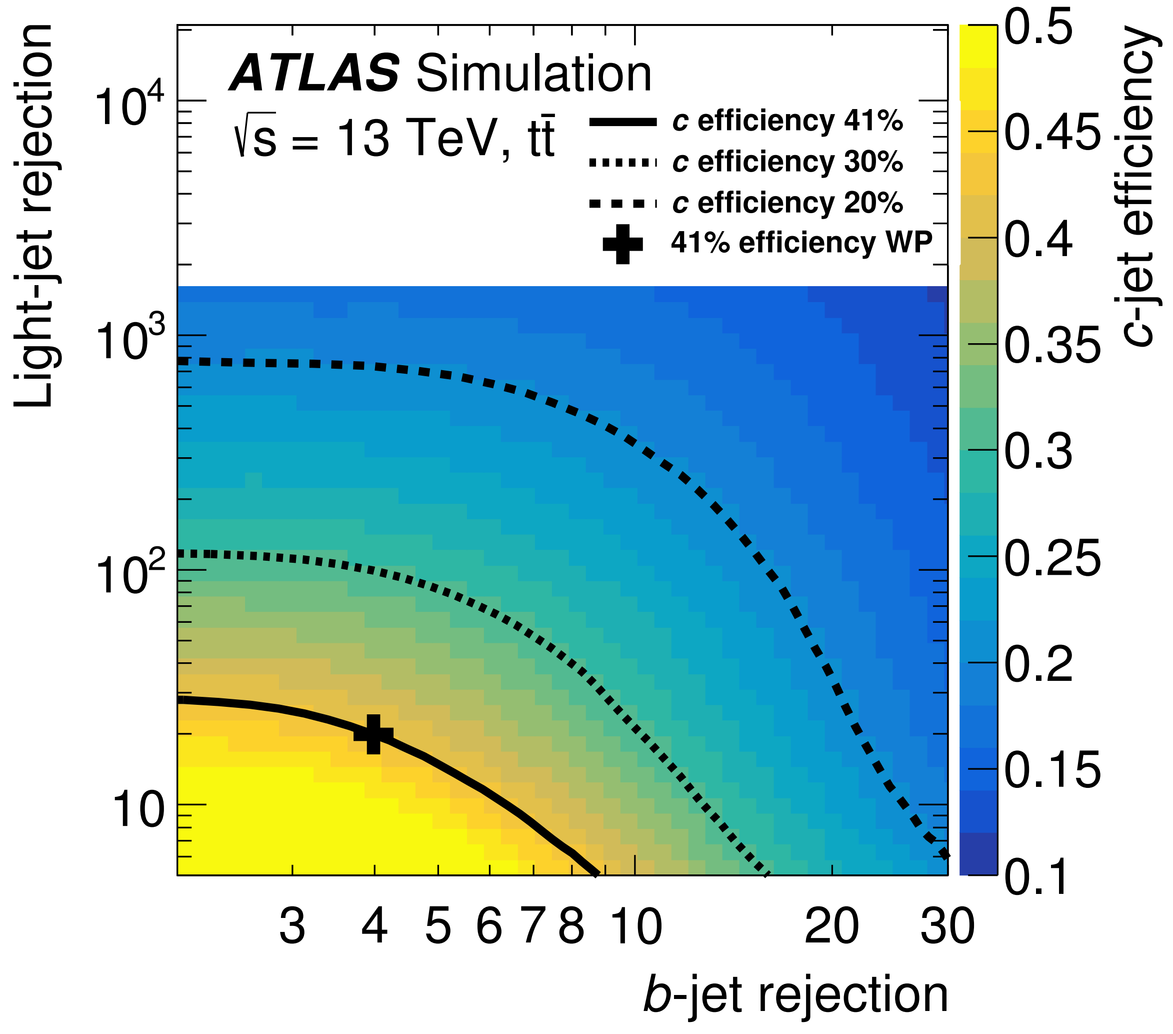
Coupling precision reach at HL-LHC*

~5%

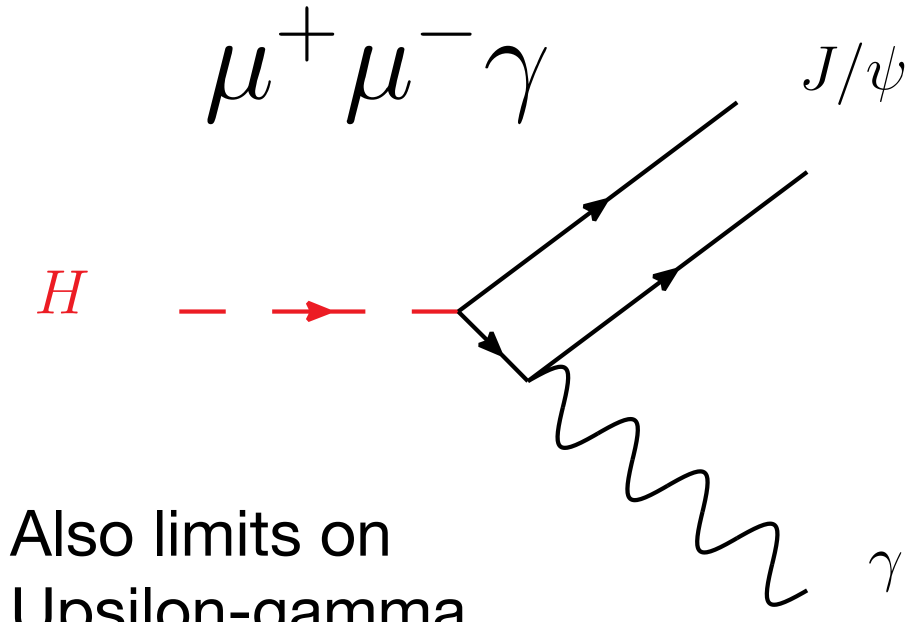
* With the kappa model assuming no BSM in the decay

Charm Yukawa

Inclusive



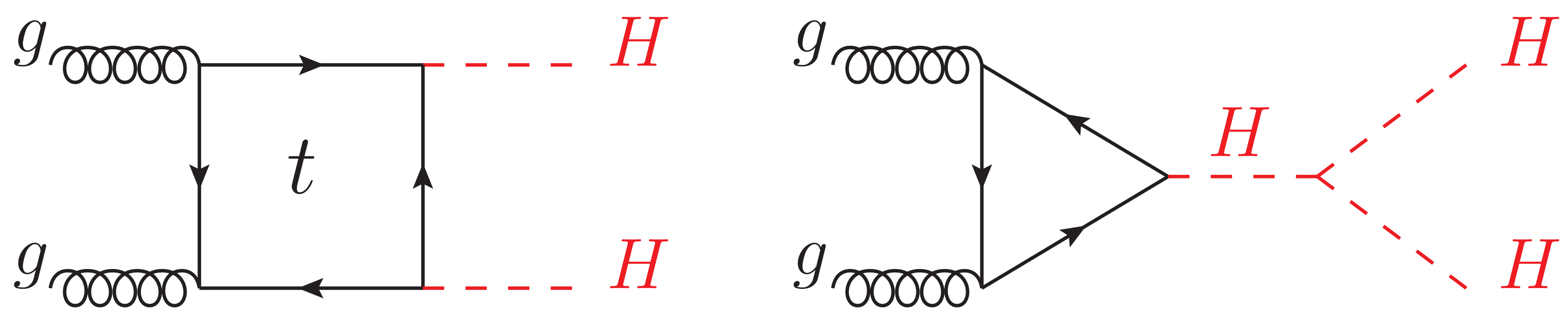
Exclusive



Also limits on Upsilon-gamma

Very challenging, various ways to constrain	Run 2	HL-LHC
– VH(cc) direct detection (relies on ability to distinguish b and c jets)	<100xSM	**<6xSM**
– Quarkonia decays	-	**<~80xSM**
– Differential cross sections- Charmonium-photon exclusive decays	<~30xSM	**<~8xSM**
– Total width from the couplings fit (kV<1)	-	**<1.7xSM**
– WH production charge asymmetry (PDFs)	-	**<6xSM**

Double Higgs Production and Higgs Self Coupling



- The total production cross section is very small, huge amount of recent work to improve the prediction at full NLO (differential)! First step is a limit on HH production.

- **Multiple channels investigated:** depending on the both Higgs decays considering (bb, yy, tautau, WW)

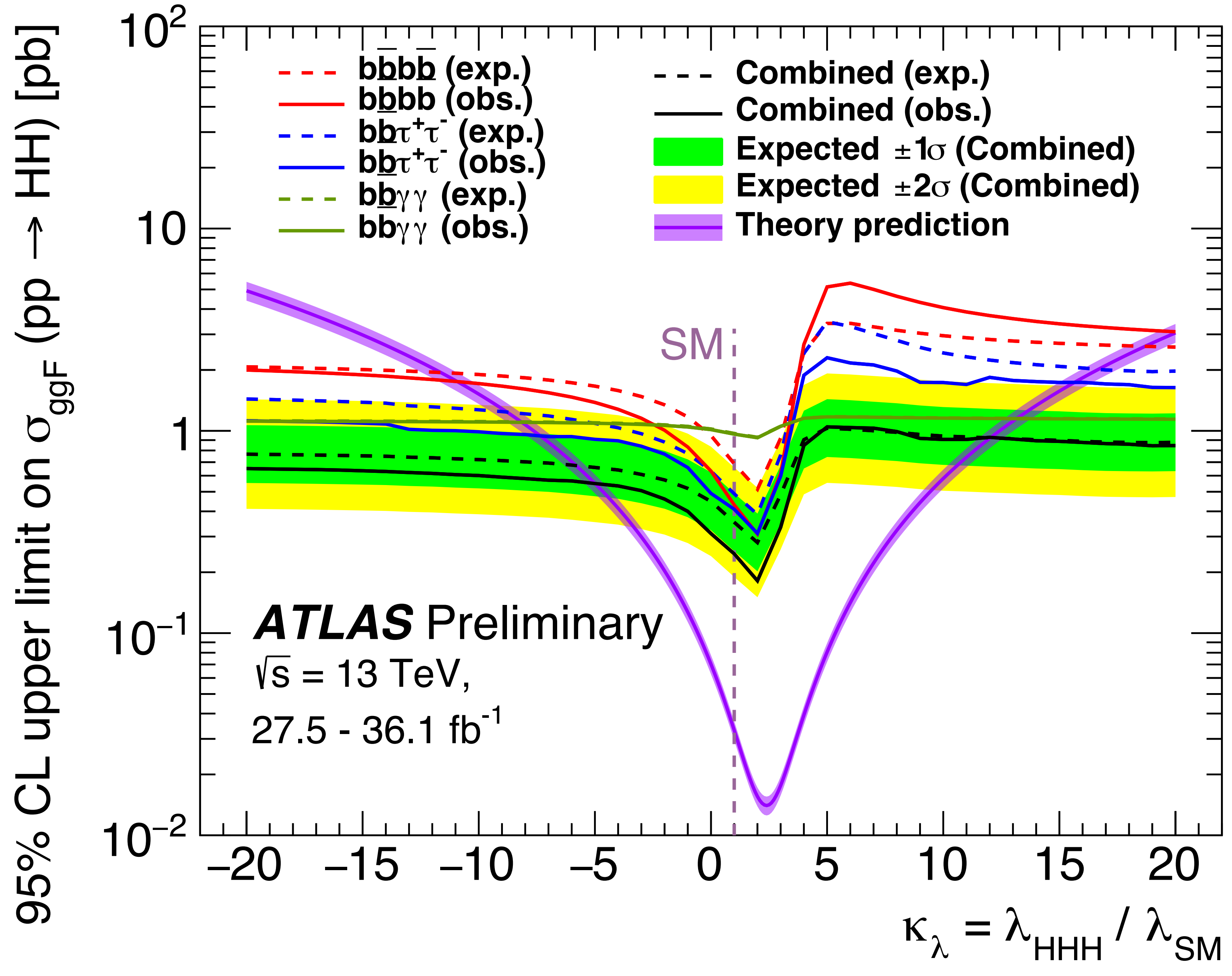
- Evolution of sensitivities has brought interesting surprises.

exp.	WW $\gamma\gamma$	bb $\gamma\gamma$	bb $\tau\tau$	bbWW	bbbb
$\sigma \times B$	0.1 %	0.26 %	7 %	25 %	34 %
ATLAS	<747 (386)	<22 (28)	**<13 (15)**	-	<13 (21)
CMS	-	<24 (19)	<30 (25)	<79 (89)	<75 (37)

(yellow) 12 fb-1
(orange) 36 fb-1

Combination (CMS) $\sigma_{HH} < 13 \times \sigma_{SM}$ (15 exp.)

Differential information taken into account with higher impact on trilinear constraints.

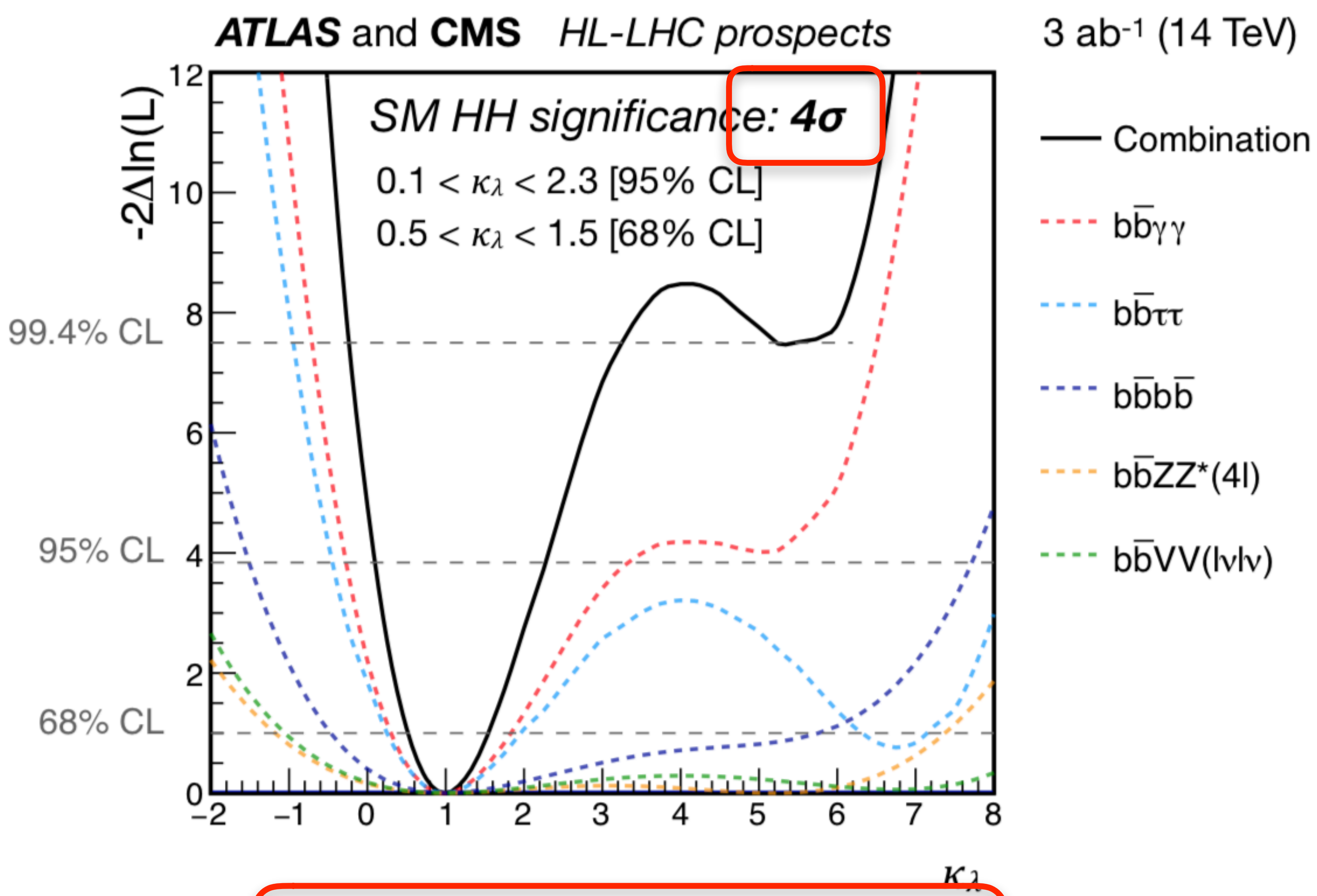


Combination (ATLAS) $-5.0 < \kappa_\lambda < 12.1$

Double Higgs Production and Higgs Self Coupling

At HL-LHC: Direct search

- Analyses completely reappraised.
- More channels investigated in detail.



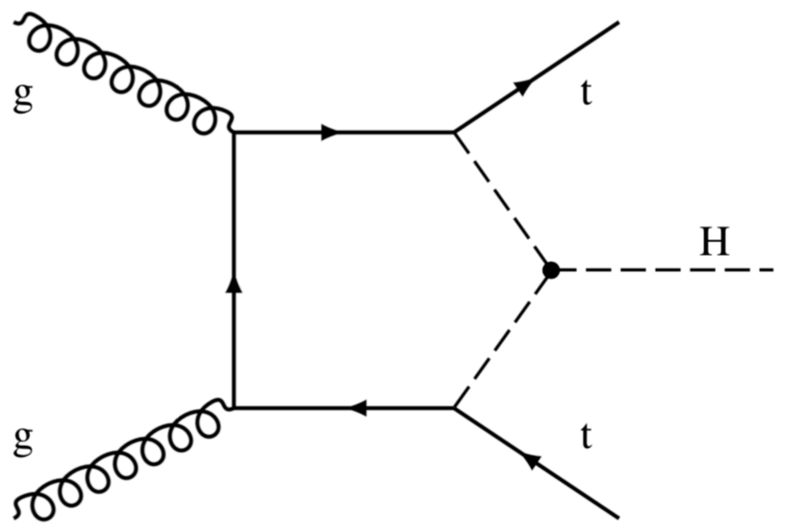
$$0.5 < \kappa_\lambda < 1.5$$

- Not quite 5 s.d. observation of HH signal.
- significant exclusion of the secondary minimum.
- Closing up on a measurement, but not decisive.

Huge progress made nevertheless! Probably still more (though not completely obvious).

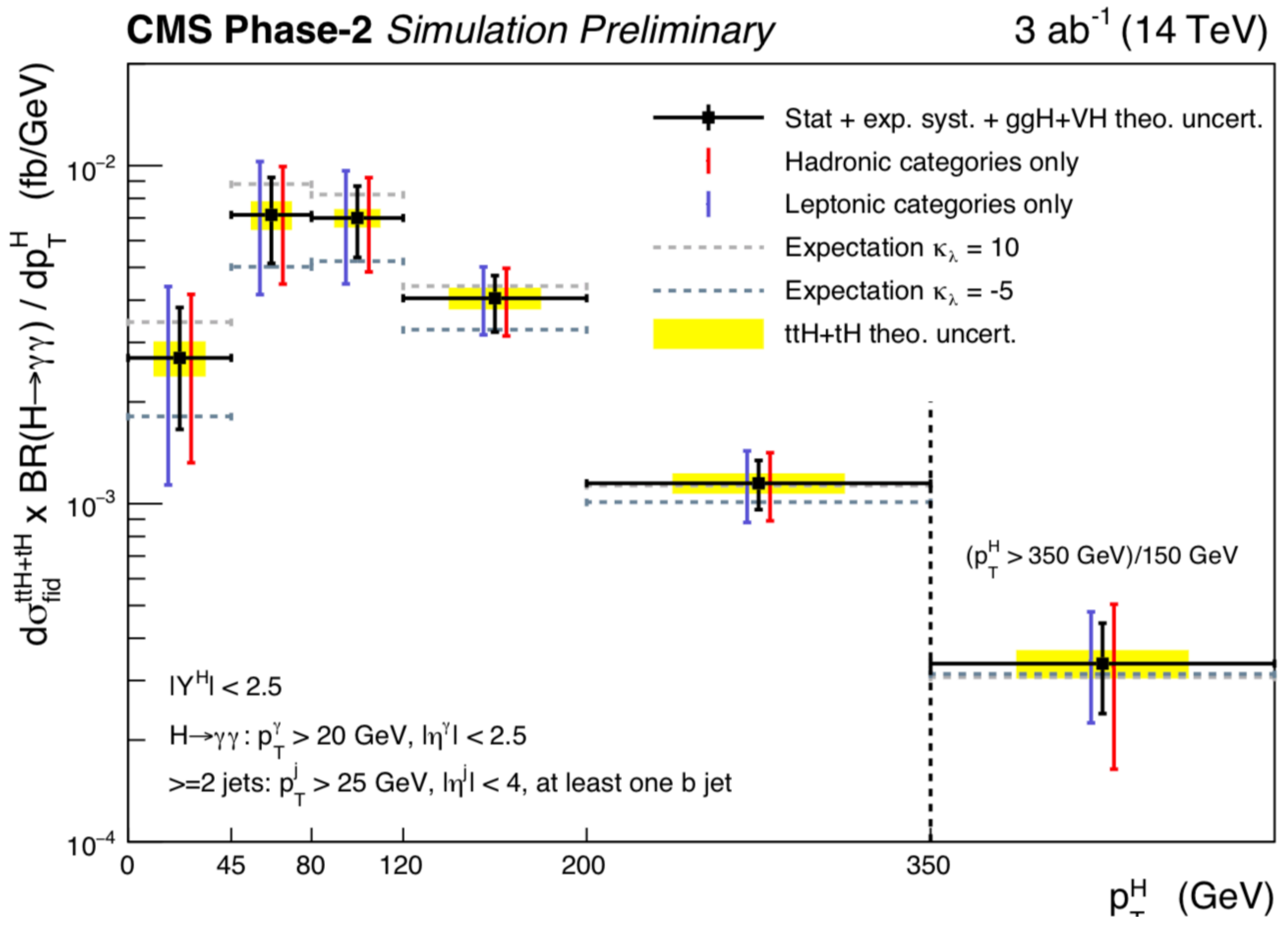
Indirect constraints through differential cross sections

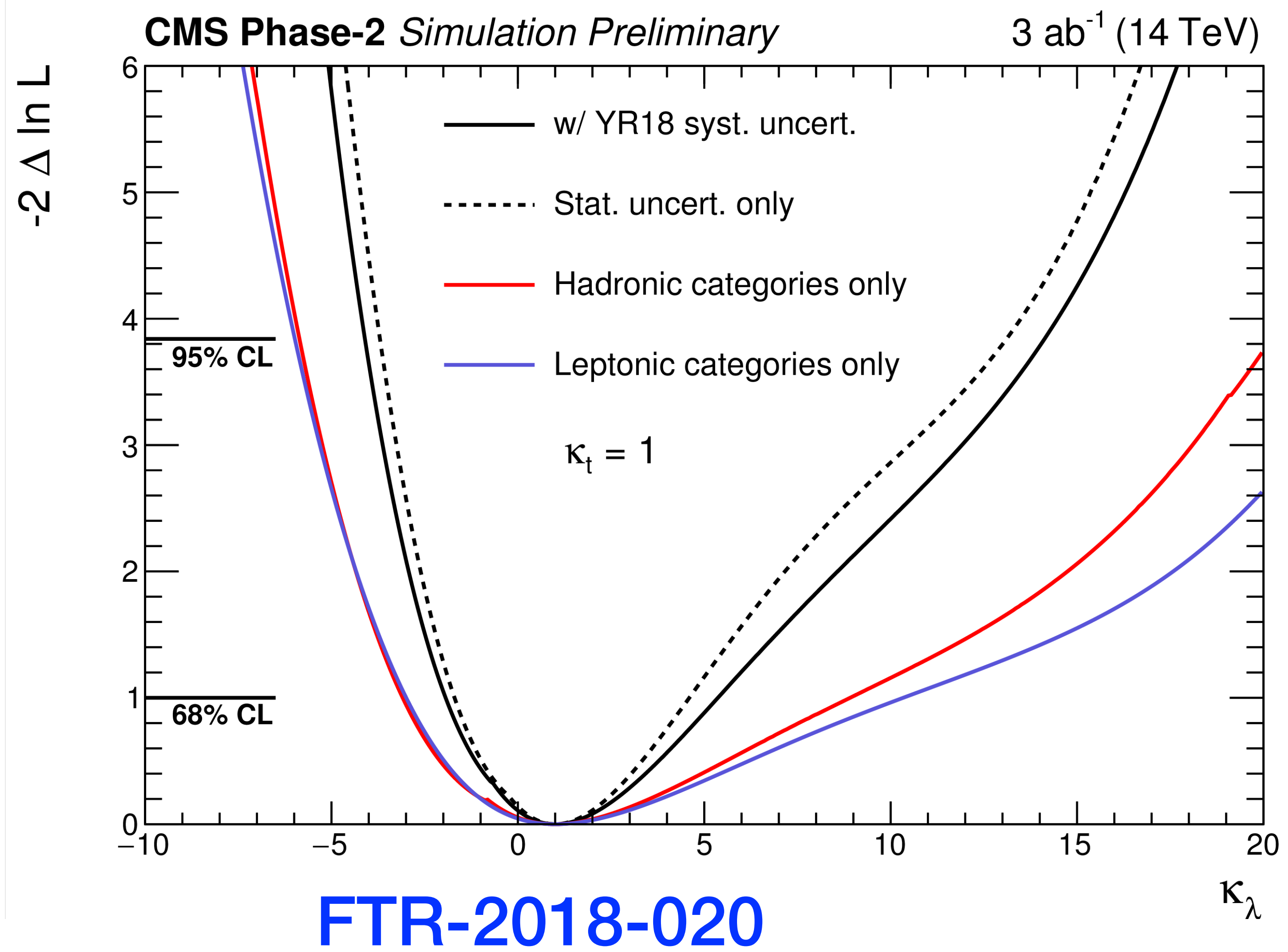
ttH Process (with subsequent decay to diphoton)



$$-4.1 < \kappa_\lambda < 14.1$$

Possible to disentangle effect of trilinear from other coupling modifications from the differential distribution

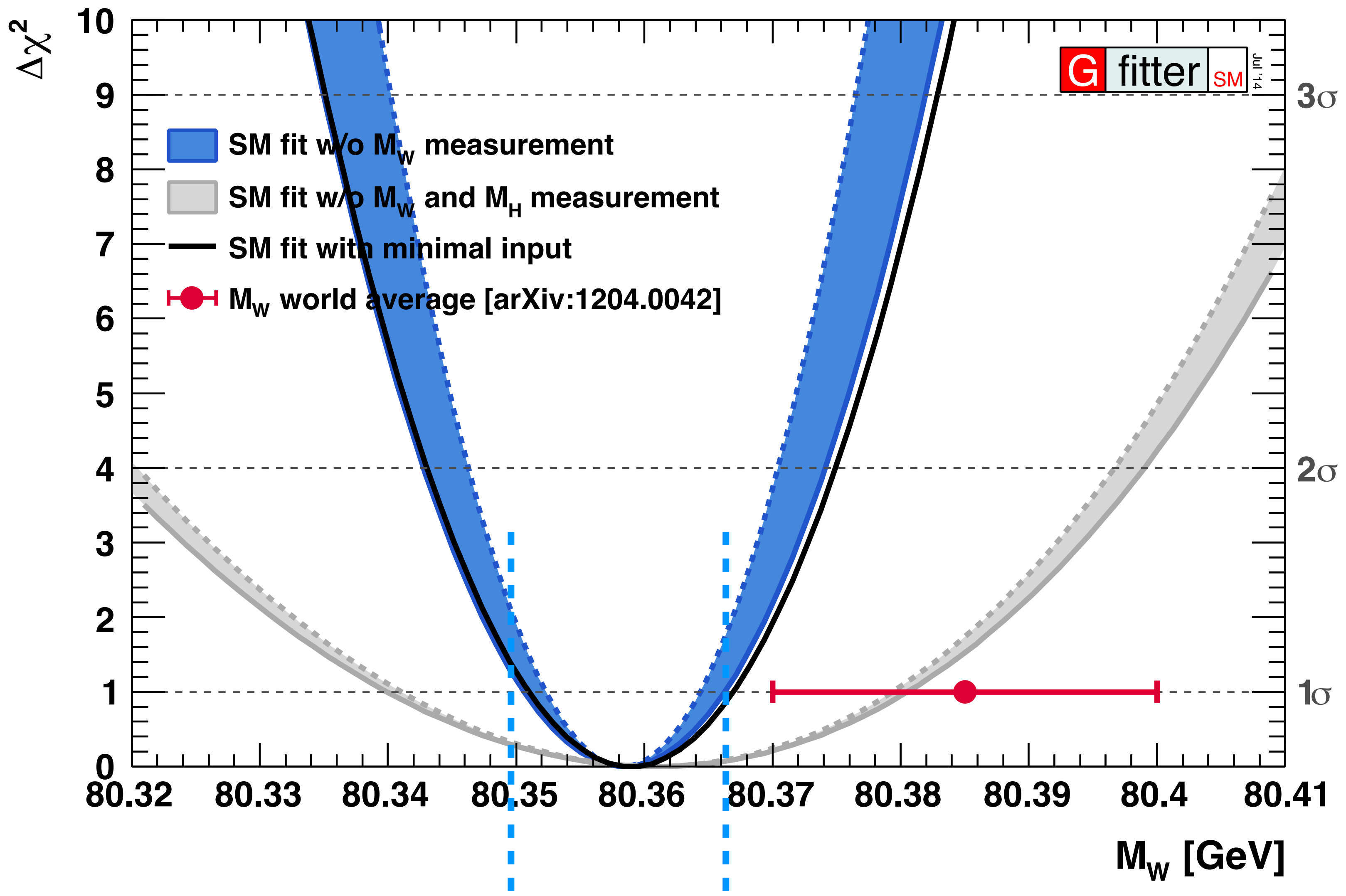


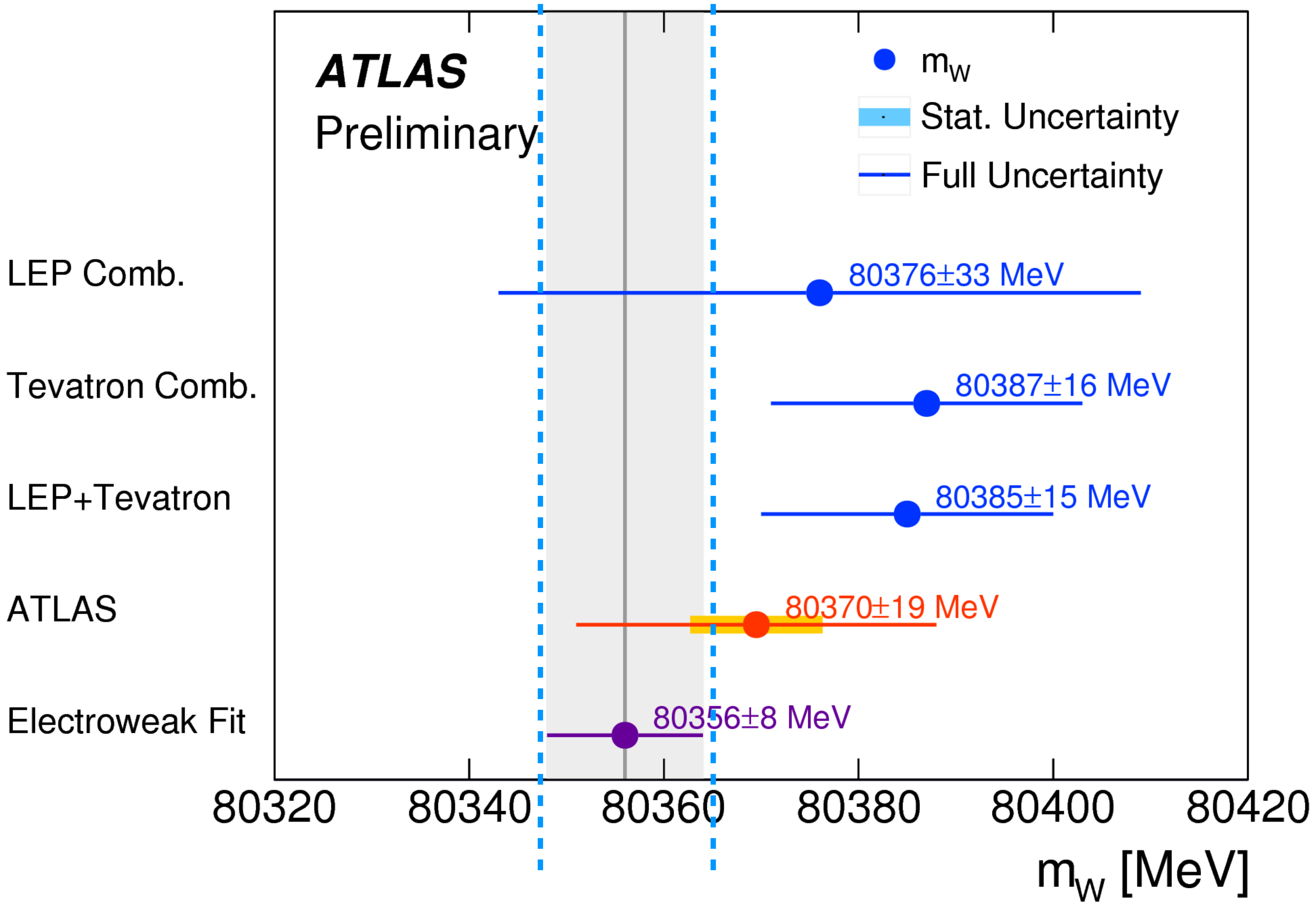


FTR-2018-020

Precision Standard Model Measurements

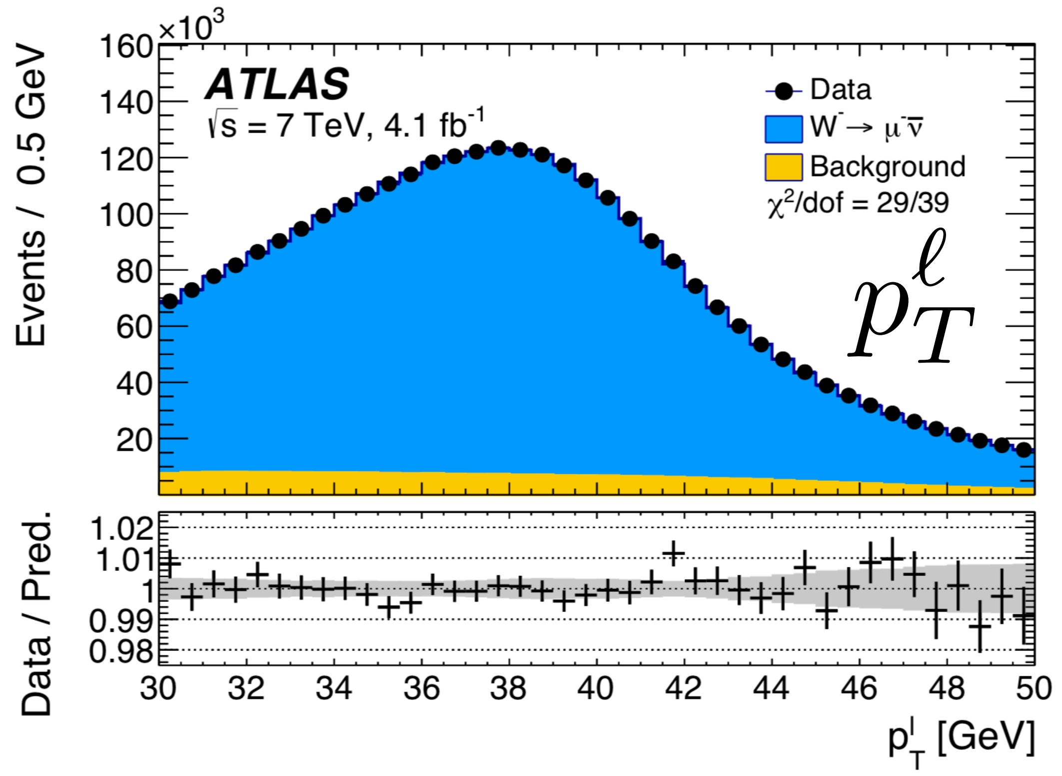
W Mass Measurement

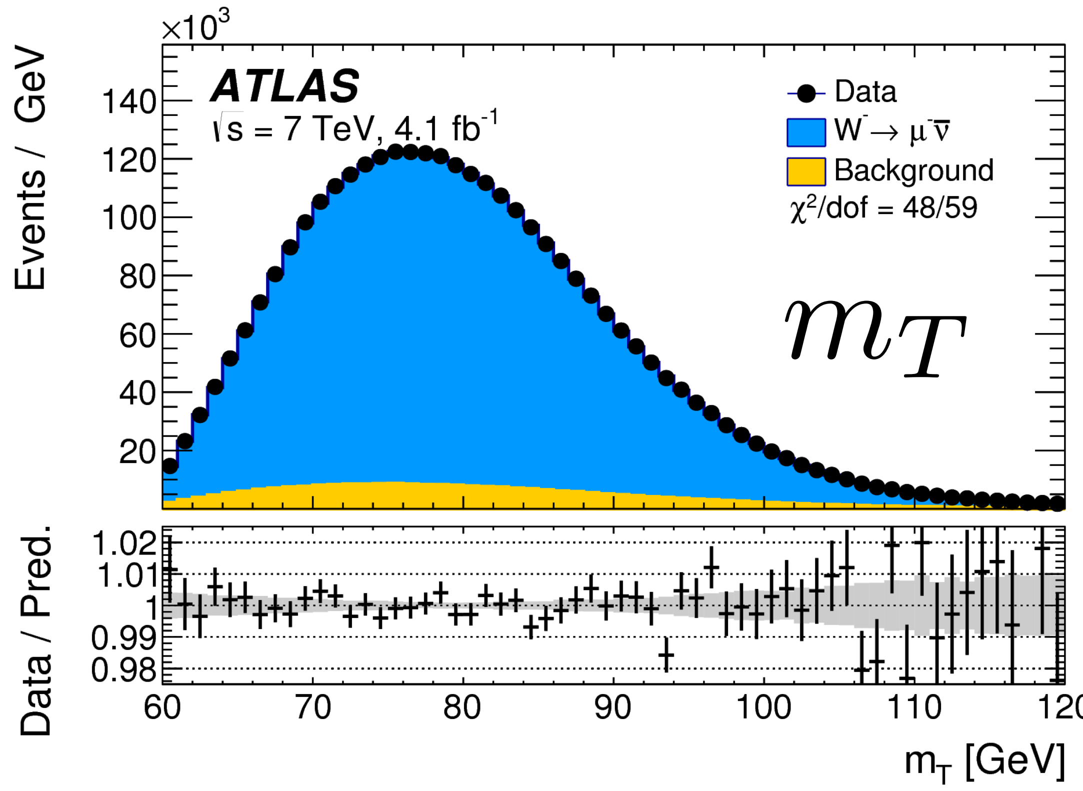




Analysis strategy based on p_T^ℓ and m_T fitted in several categories

Categories are defined by the charge of the reconstructed lepton, its flavor and its pseudo rapidity.





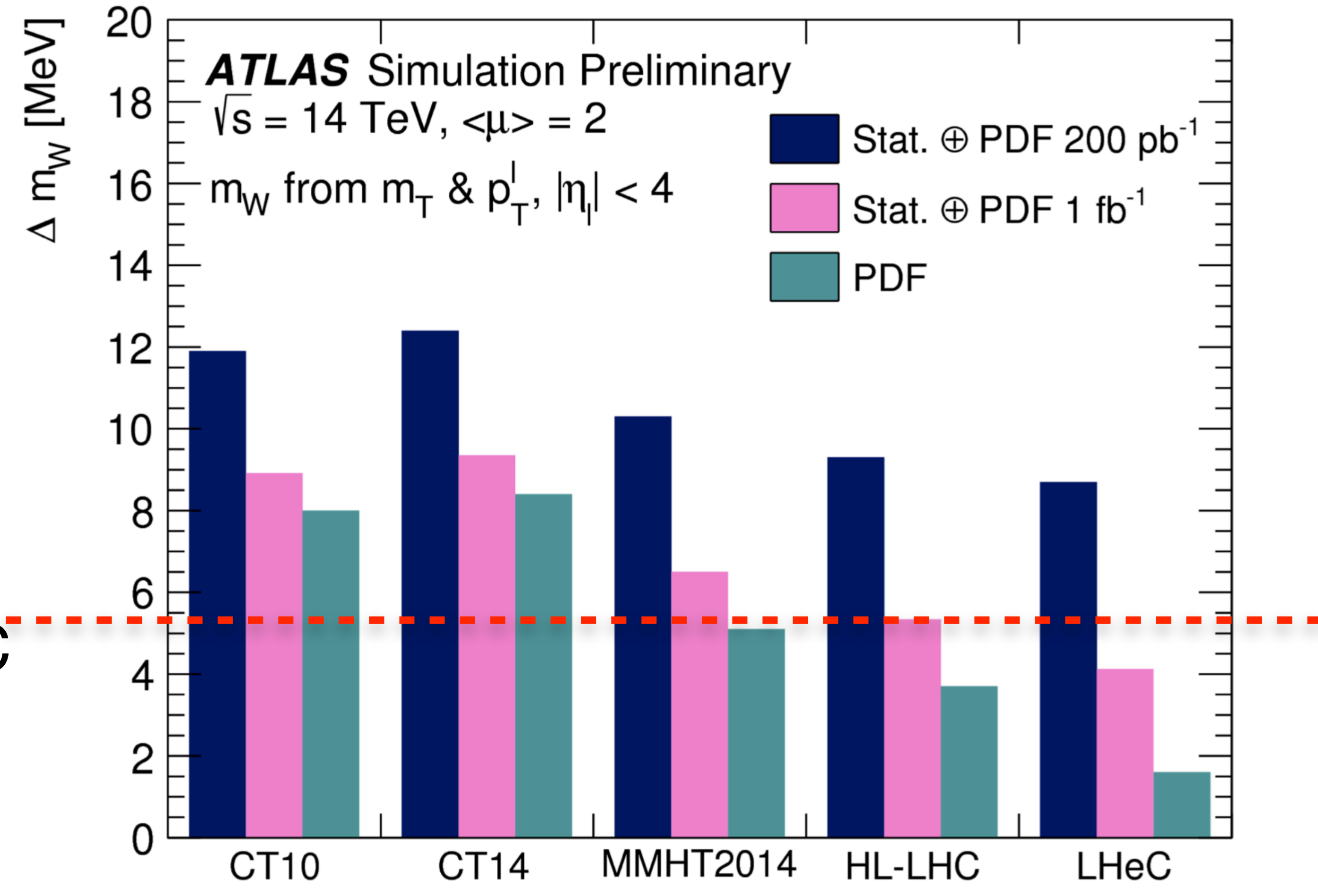
$$m_W = 80369.5 \pm 18.5 \text{ MeV}$$

$$\pm 6.8 \text{ (Stat)} \pm 10.6 \text{ (Exp)} \pm 13.6 \text{(Mod) MeV}$$

Prospects at HL-LHC:

ATL-PHYS-PUB-2018-026

- Need for low PU (~2)
- No need for huge amounts of data 200 pb^{-1} (already a good start only approximately one week at 14 TeV) to 1 fb^{-1}
- Larger TRK acceptance (and HE): reduce PDF



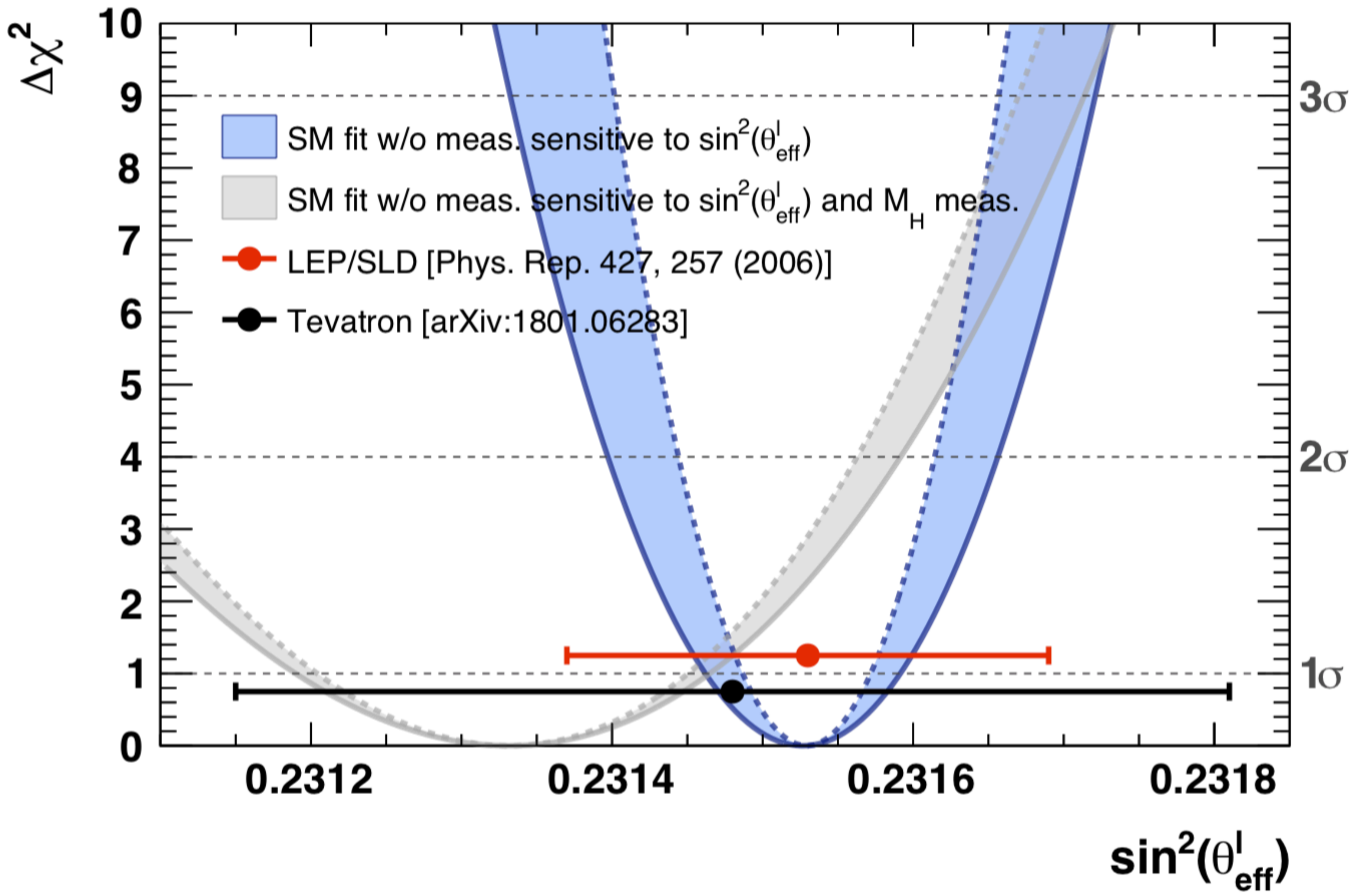
Current and projected PDFs HL-LHC and LHeC

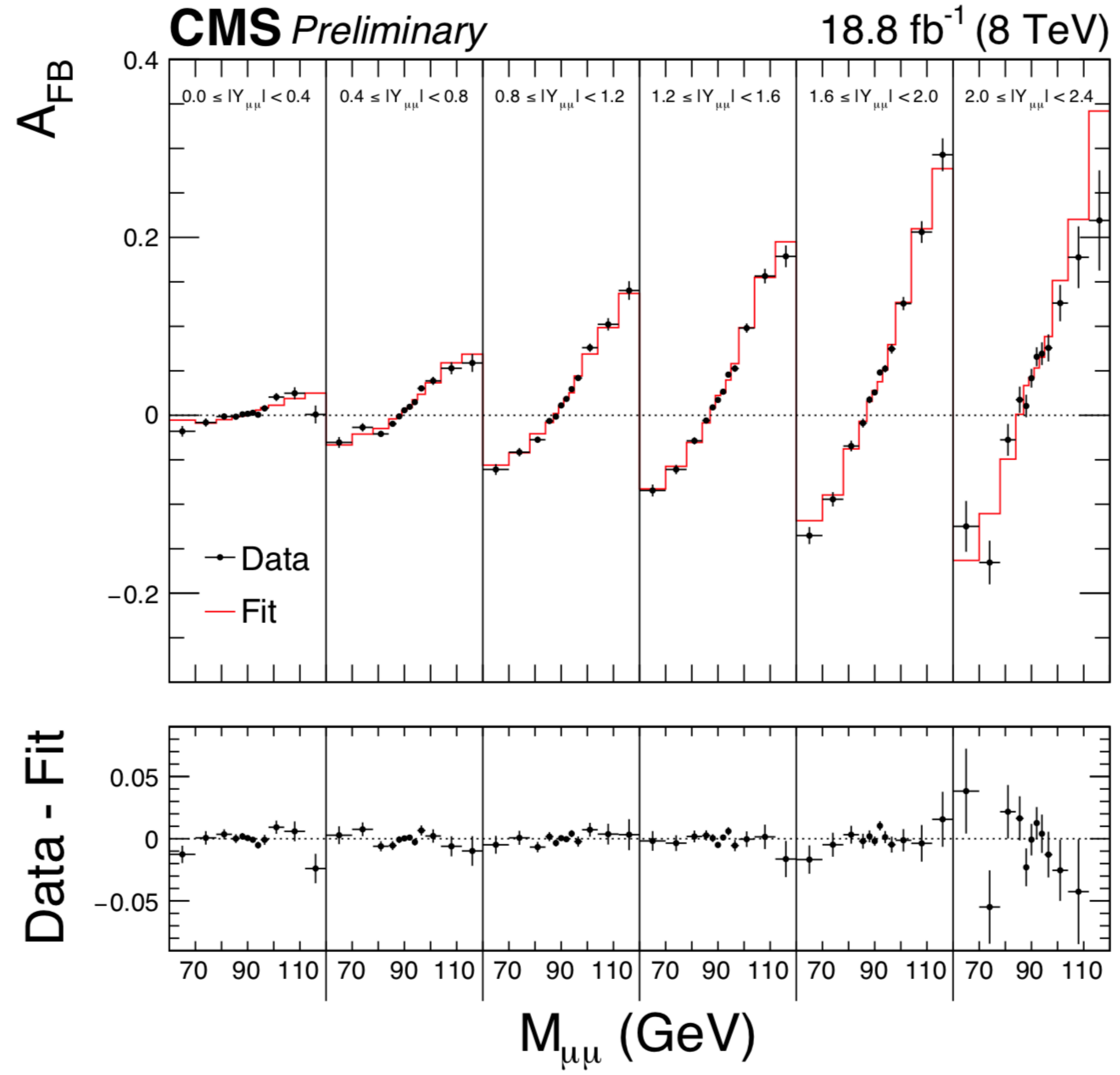
~10 MeV for 200 pb^{-1}

~6 MeV for 1 fb^{-1} (~4 MeV with LHeC)

Measurement of effective weak mixing angle at the LHC

With the improved other measurements (Higgs and W masses) measuring $\sin^2\theta^\ell_{\rm eff}$ become increasingly important.





At the LHC the direction for the FB asymmetry is the direction of the boost which is enhanced in valence quarks.

The size of the asymmetry as a function of the di-lepton mass will depend on the rapidity of the system (how boosted it is in the z direction). Where a high boost generates less ambiguity on the initial direction of the charge (from valence quarks).

Extraction of the weak mixing angle from the A4 Polarisation coefficient in the differential cross section as a function of mll and yll (for CMS in bins of these variables).

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{8}\left[1+\cos^2\theta^* + \frac{A_0}{2}(1-3\cos^2\theta^*) + A_4\cos\theta^*\right]$$

$$\sin^2\theta^\ell_{\rm eff} = 0.23101 \pm 0.00036\,({\rm stat}) \pm 0.00031\,({\rm PDFs}) \pm 0.00024\,({\rm syst})$$

EPJC 78 (2018) 701

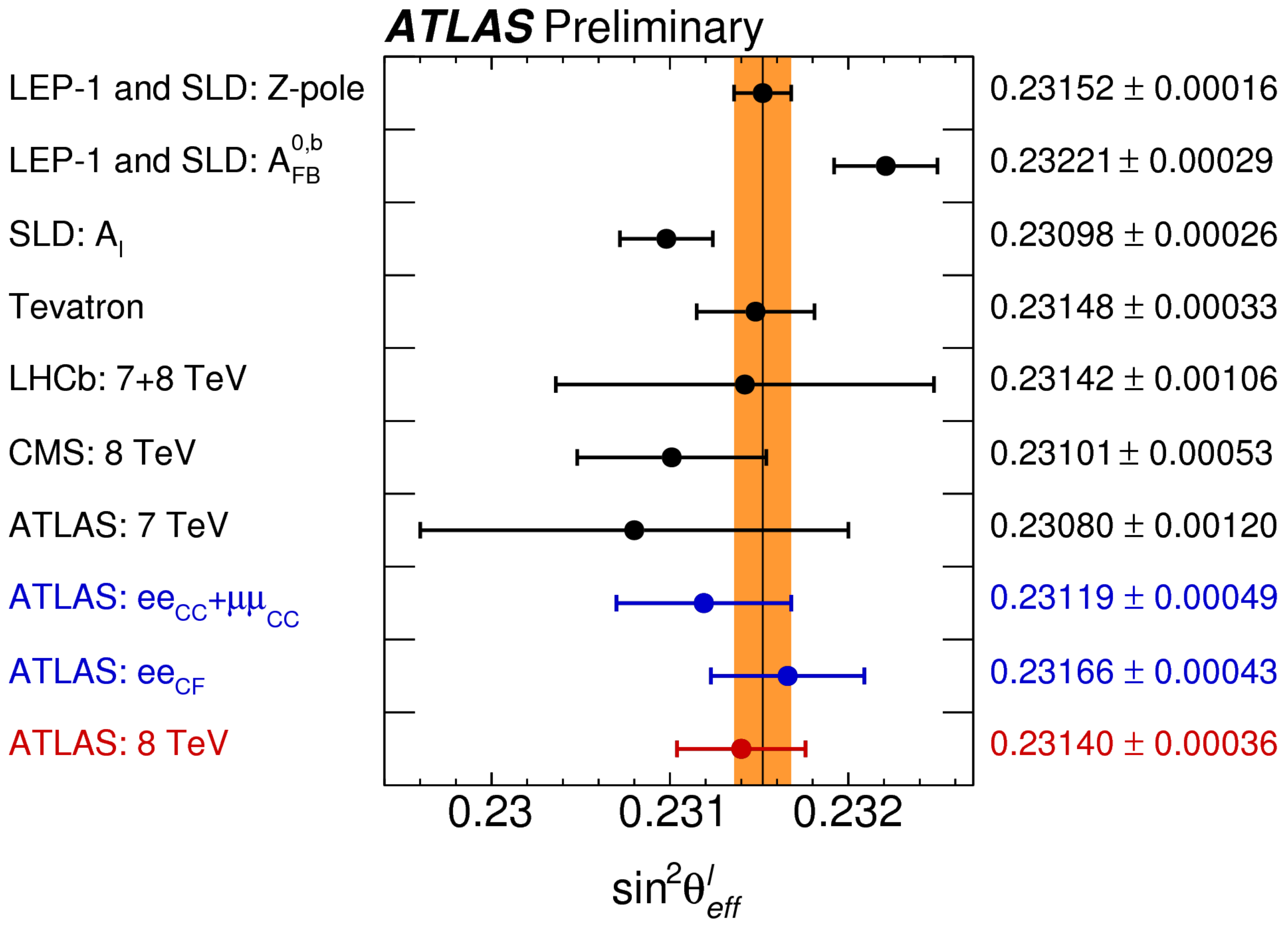
Measurement of effective weak mixing angle at the LHC

Latest ATLAS result using forward electrons up to eta of 4.9.

ATLAS-CONF-2018-037

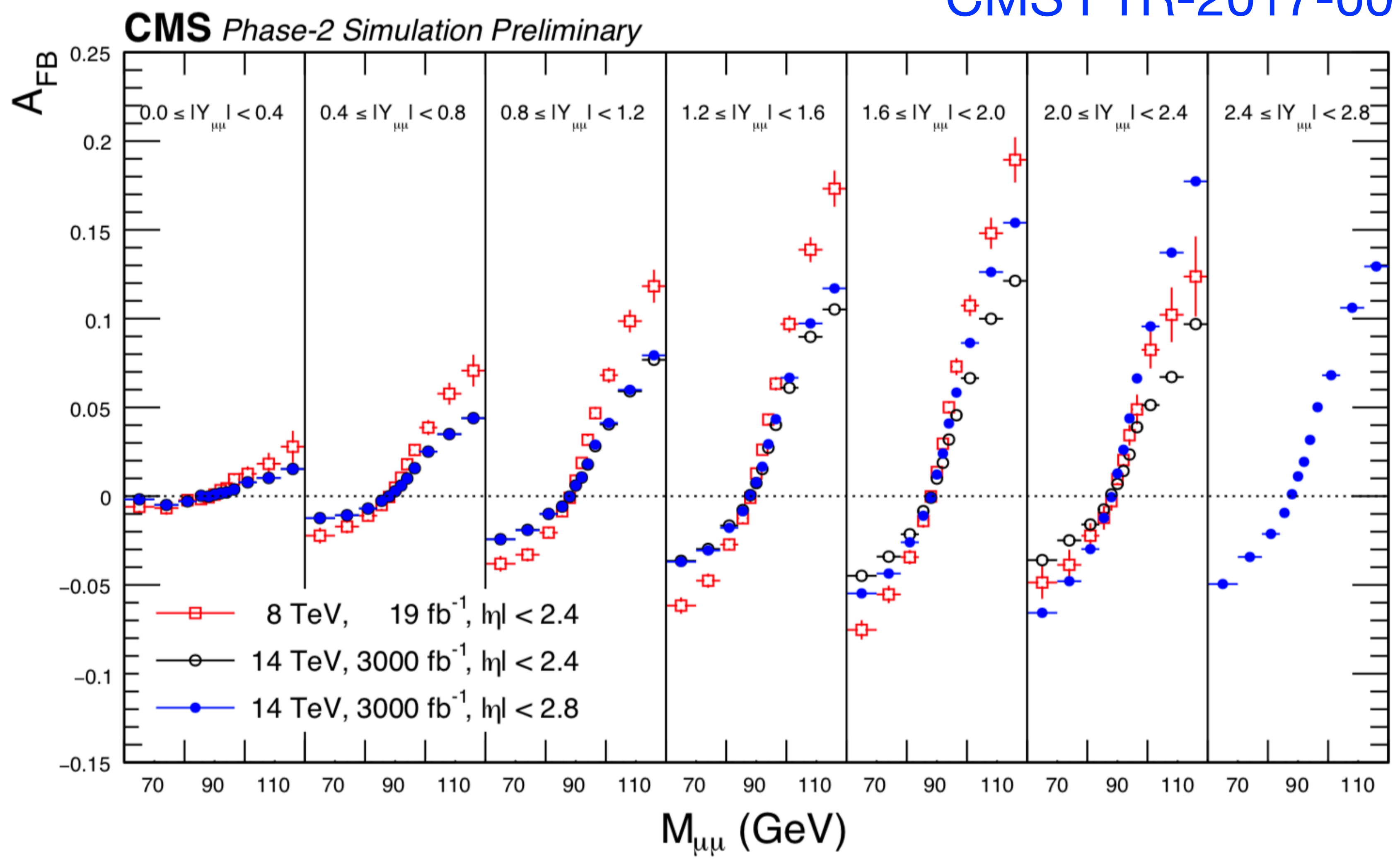
ATLAS result with a similar analysis (also with substantial constraint of the PDF uncertainties):

$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23140 \pm 0.00021\,(\text{stat}) \pm 0.00024(\text{PDFs}) \pm 0.00016\,(\text{syst})$$

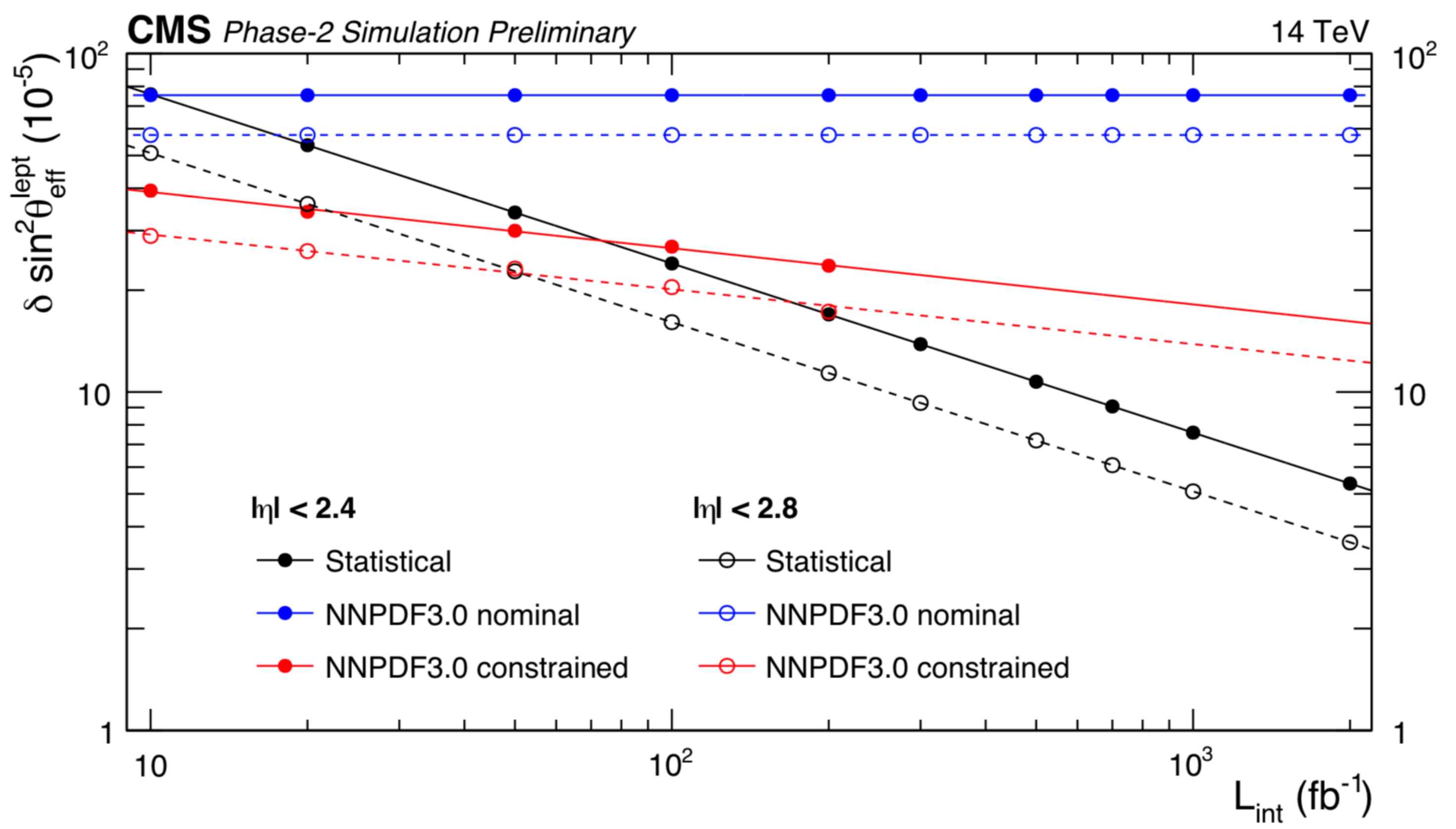


With the increased luminosity and muon acceptance in CMS (from eta 2.4 to 2.8)

CMS FTR-2017-001

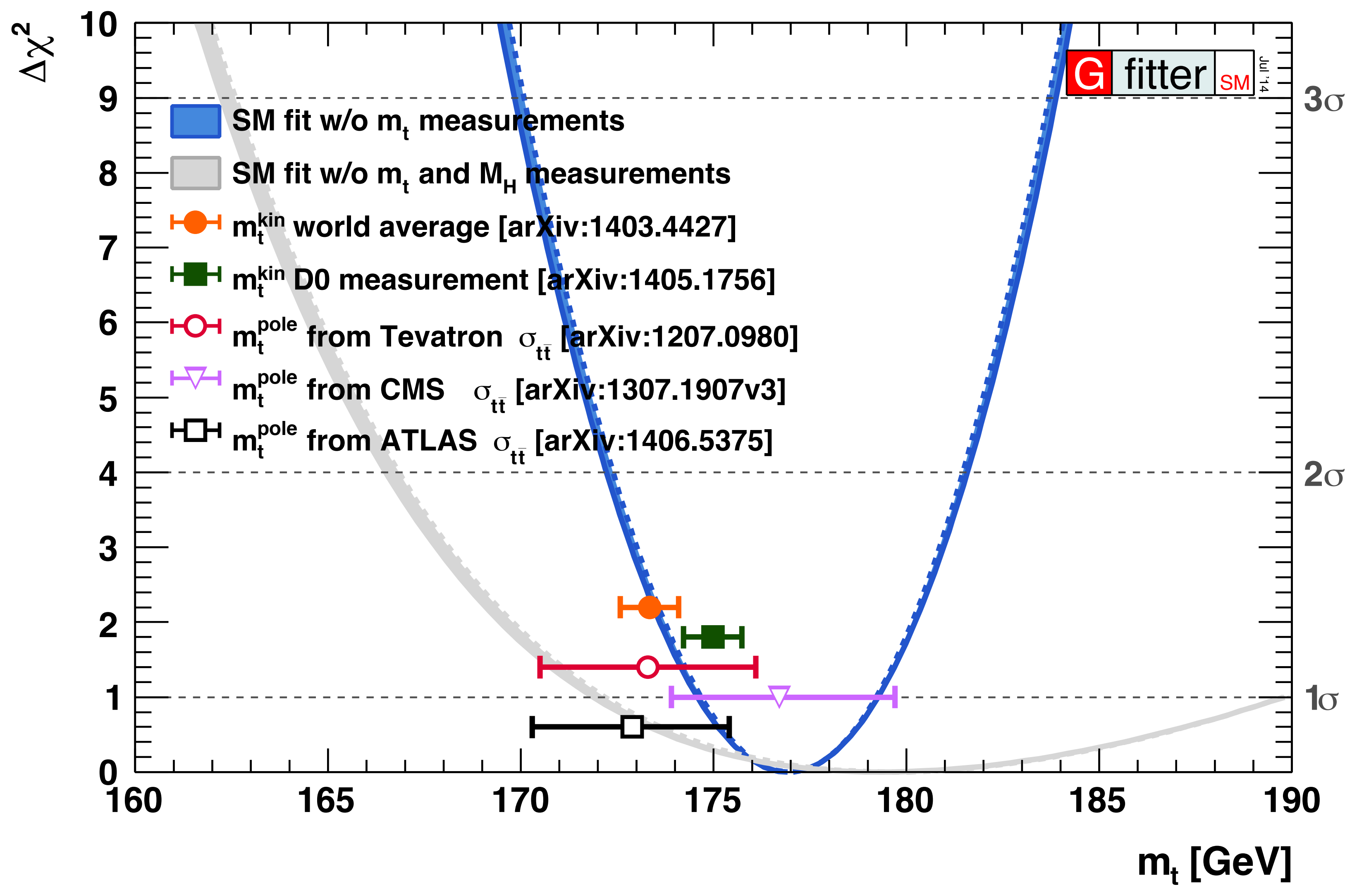


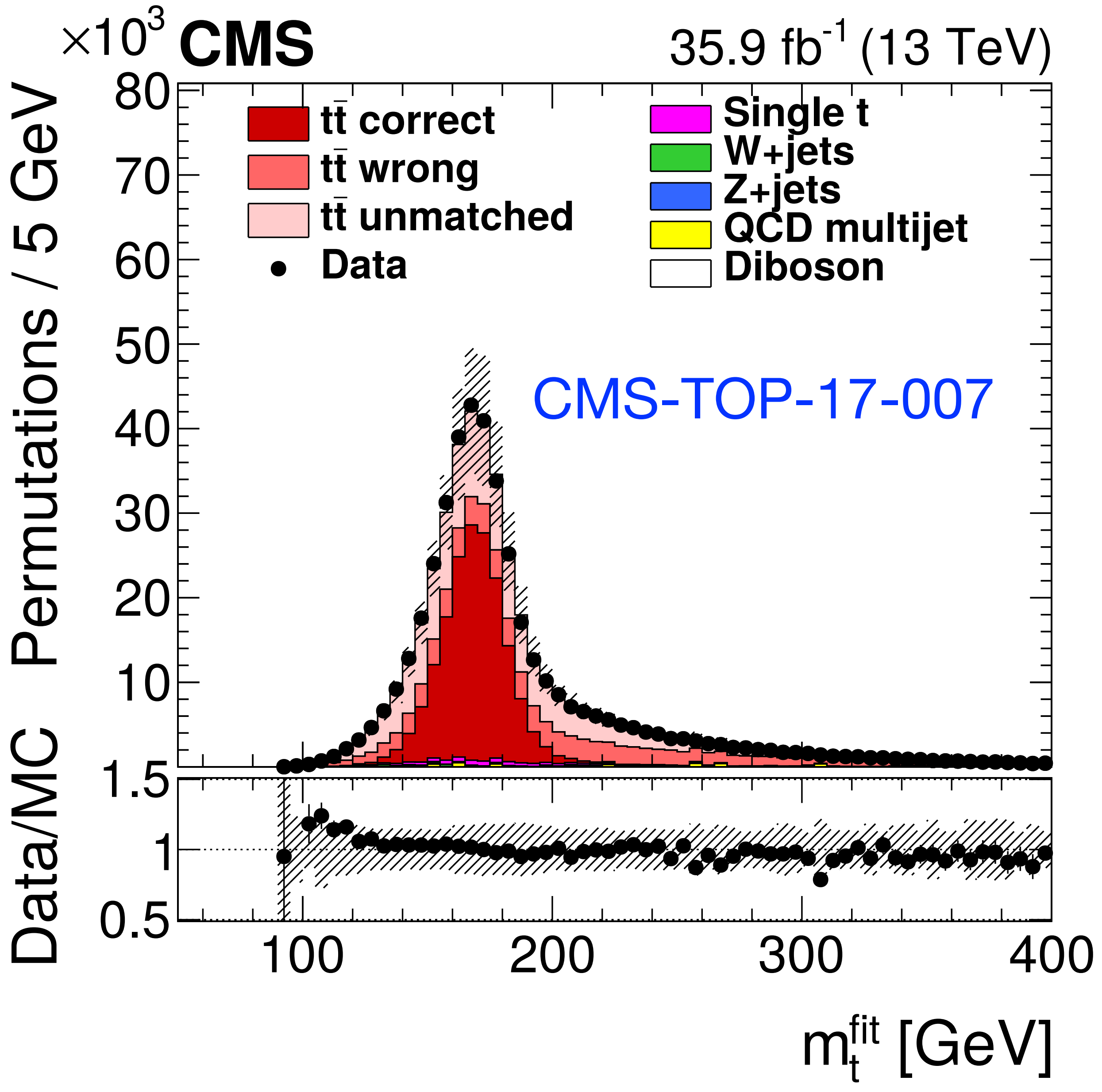
Individual measurements reach the level of the current World Average of 16 (10^{-5}) CMS estimate alone with muons.



The Top Mass

Direct measurements made using template fit to the reconstructed mass (event kinematics)



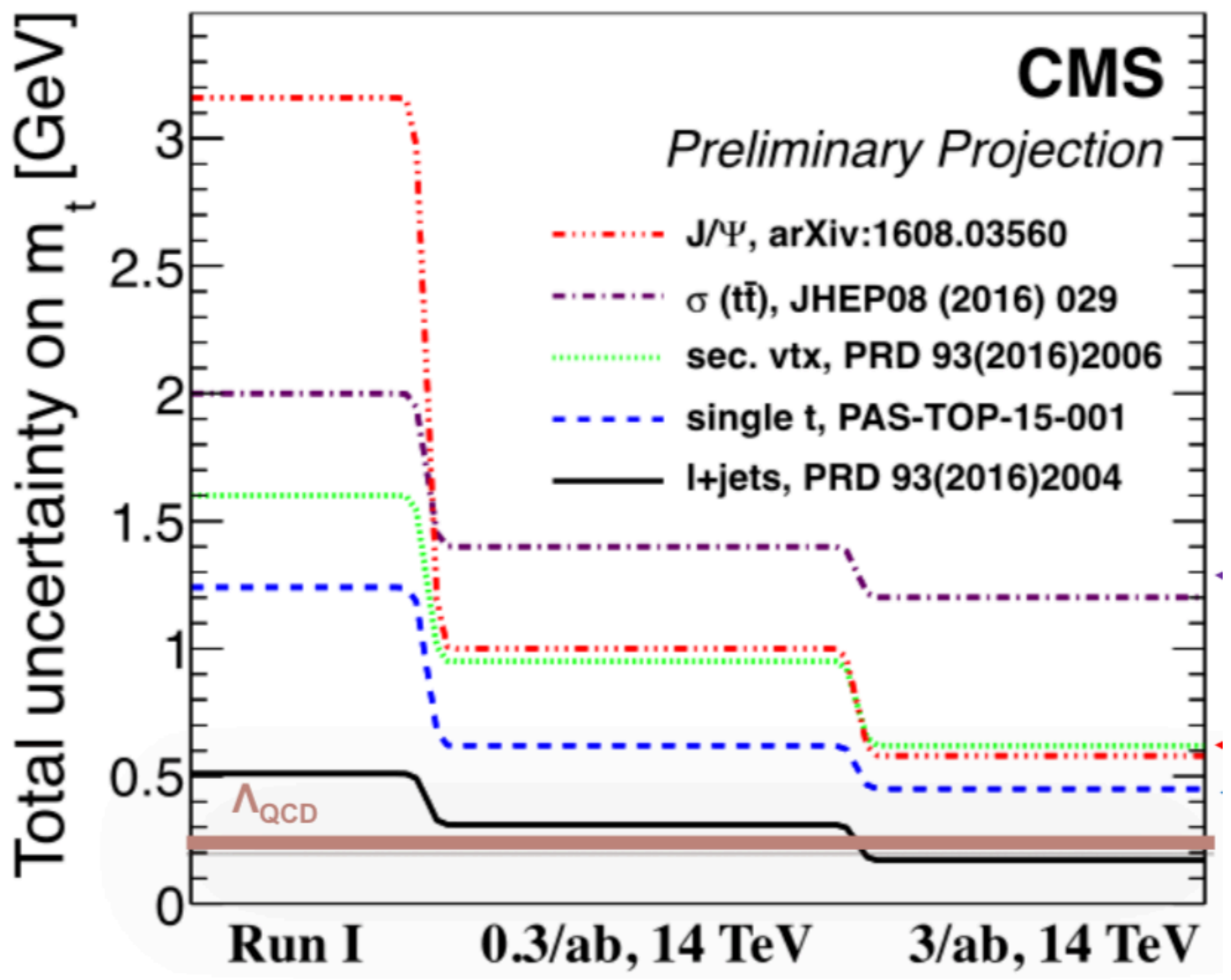


13 TeV CMS result

$$172.34 \pm 0.20\,(\mathrm{stat} + \mathrm{JSF}) \pm 0.76\,(\mathrm{syst})\ \mathrm{GeV}$$

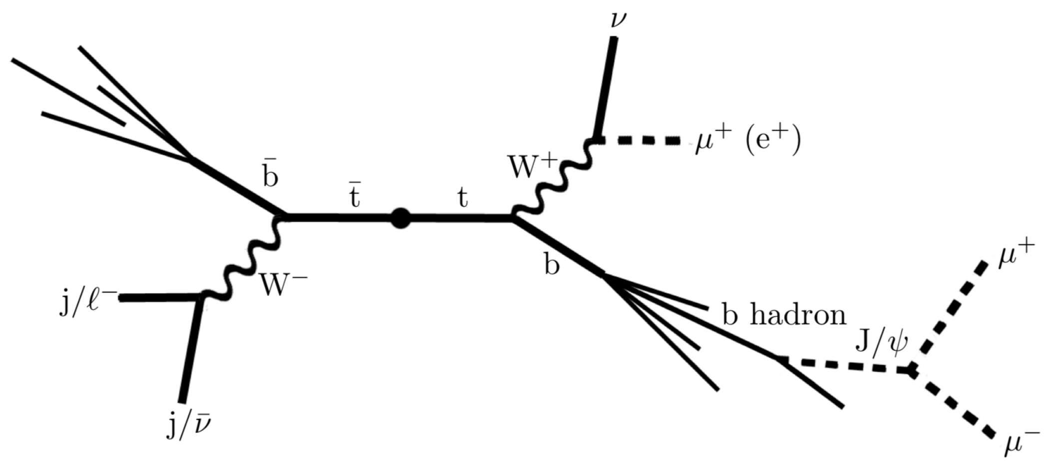
Syst: Jet Energy Corrections and Modelling

Measurements already dominated by systematics



Several possible approaches:

- From cross sections (limited by prediction uncertainties and luminosity)
- Using B decays to J/Psi (smaller jet related uncertainties)
- Traditional approaches



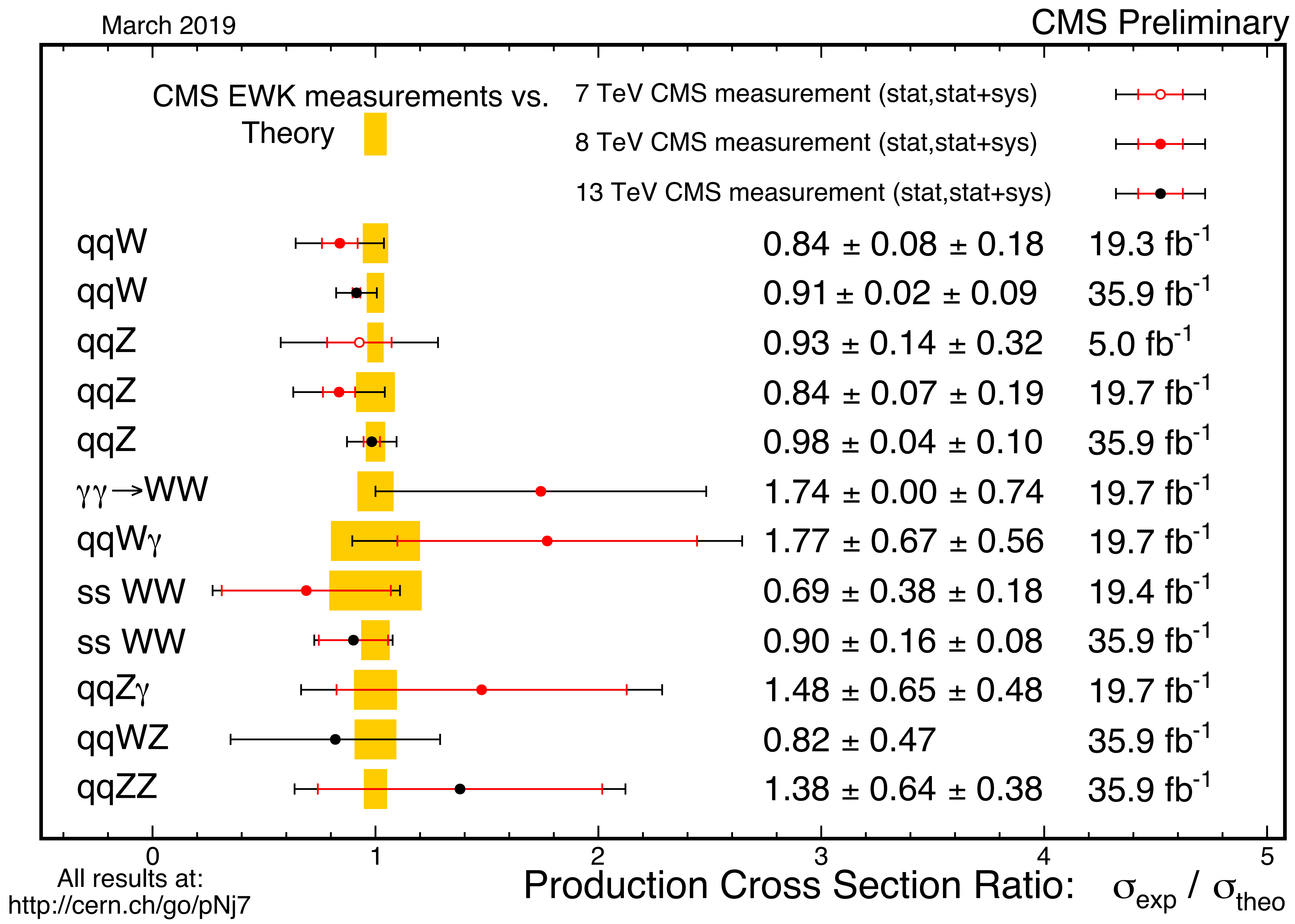
Typical reach Lambda QCD ~180 MeV

More possible approaches to explore e.g. using differential cross sections

Rare EW Processes

CMS rare EW measurements

Sensitivity to rare multi-boson processes

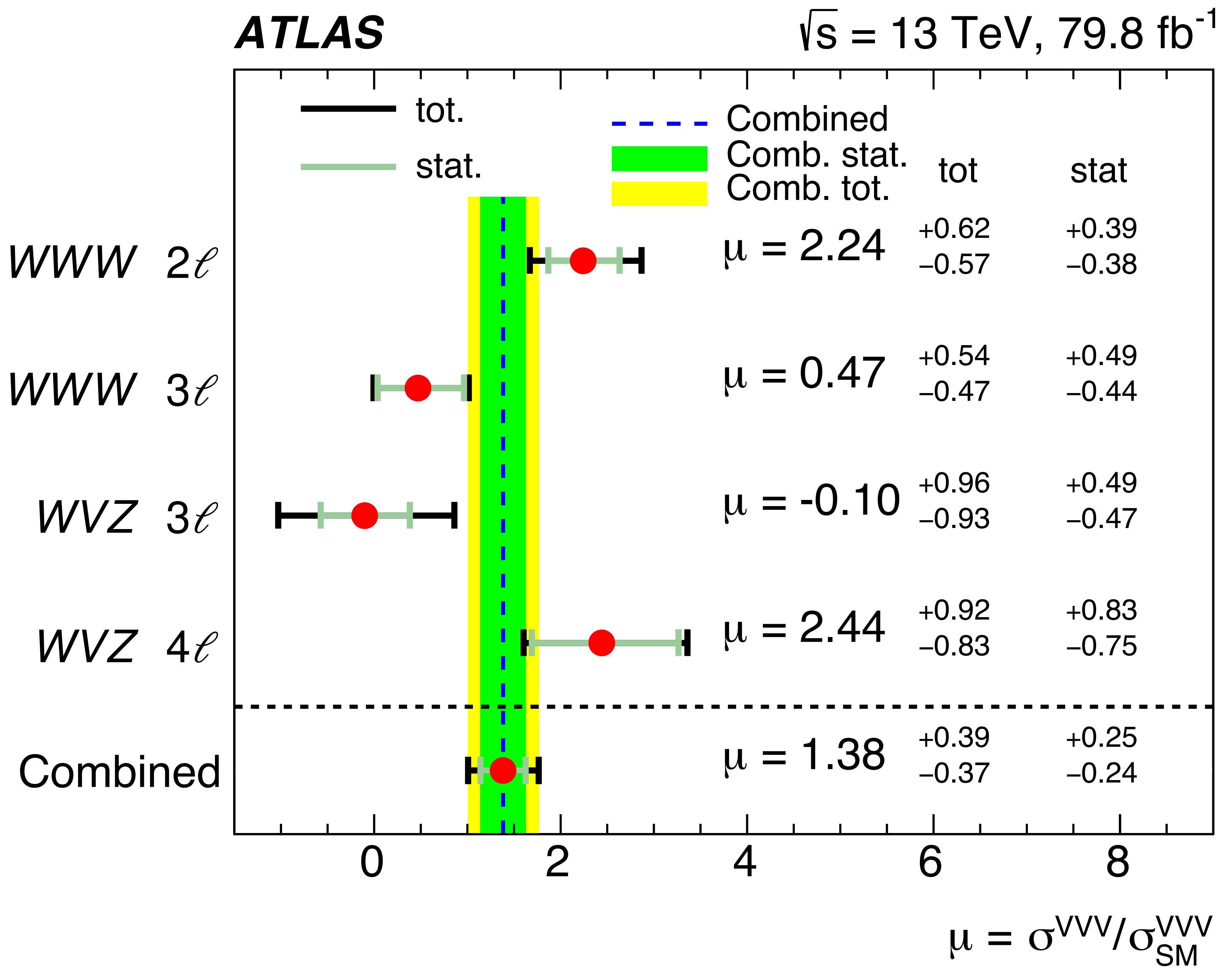


Tri-bosons in ATLAS

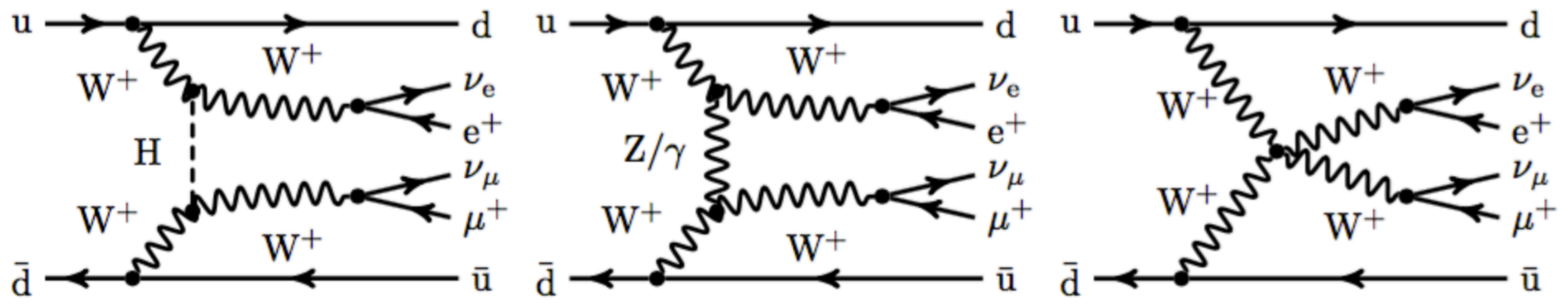
ATLAS 1903.10415

In the 3-lepton and 4-leptons channel.

4.0 (3.1)σ observed (expected) significance for WWW+WVZ



EW Vector Boson Scattering

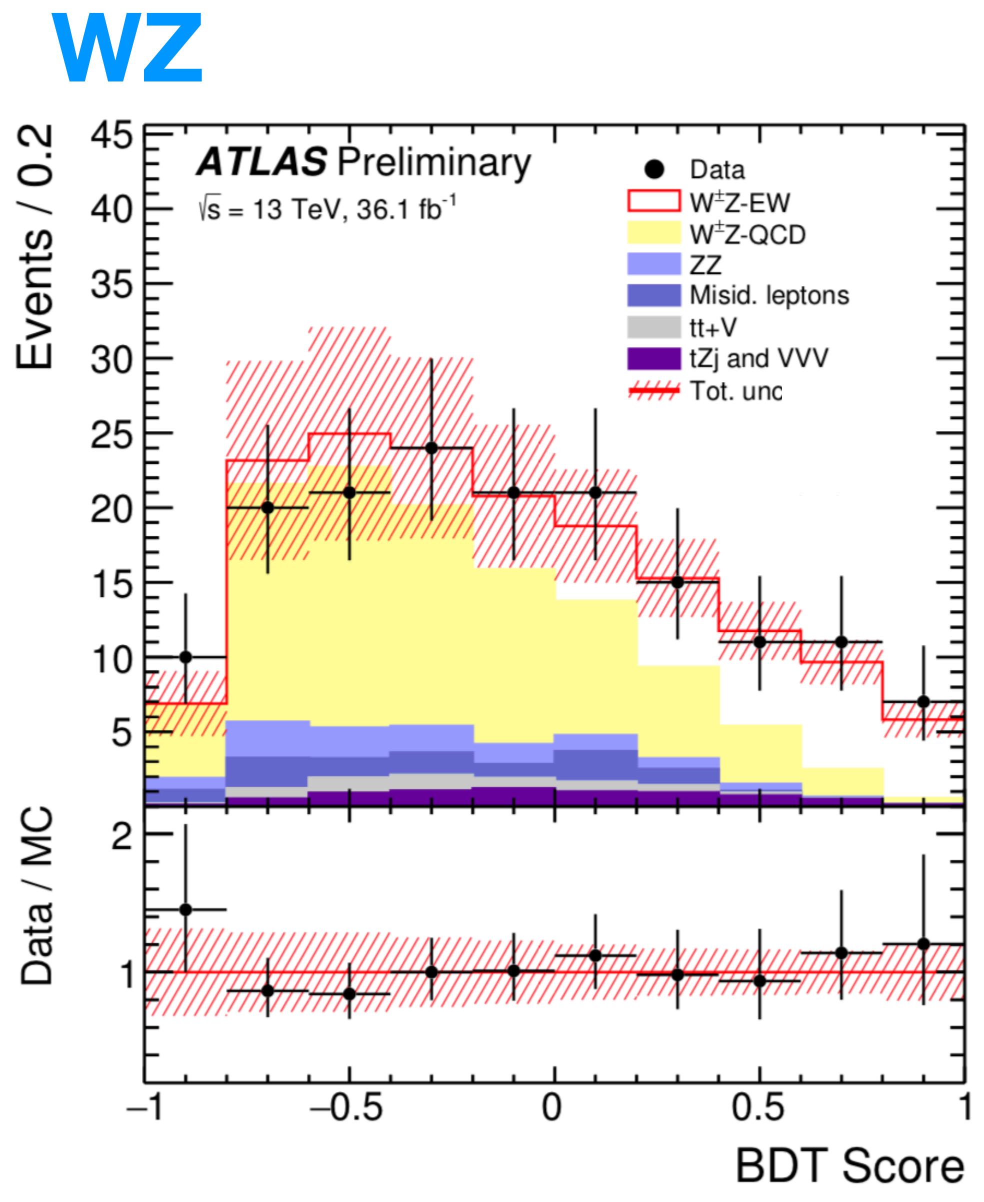


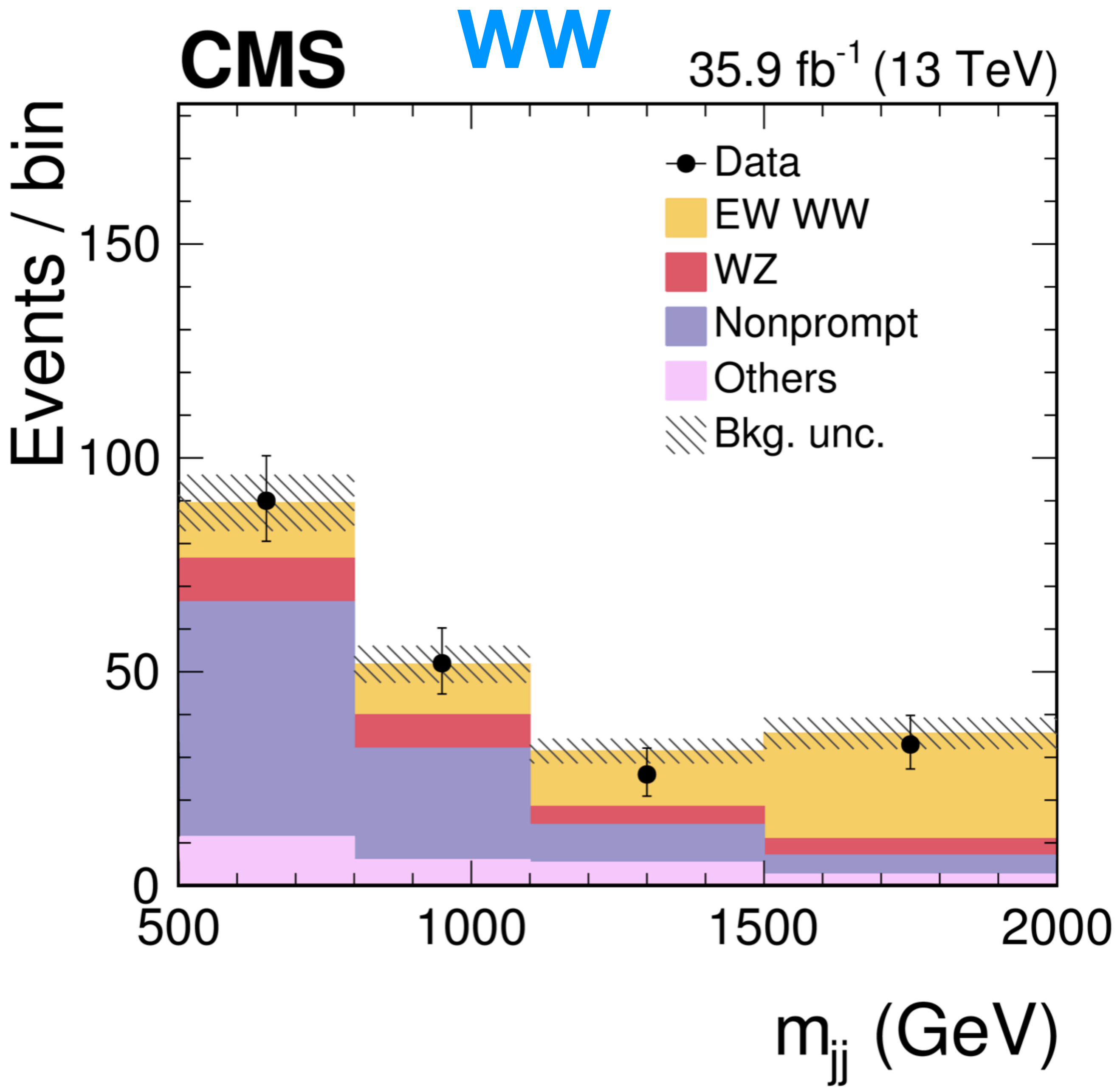
EW Vector Boson Scattering process

Unambiguously observed by both ATLAS and CMS (at more than 5σ) in the Same sign WW mode. Evidences in the WZ mode.

$$5.6\sigma\ (3.3\sigma)$$

$$5.5\sigma\ (5.7\sigma)$$





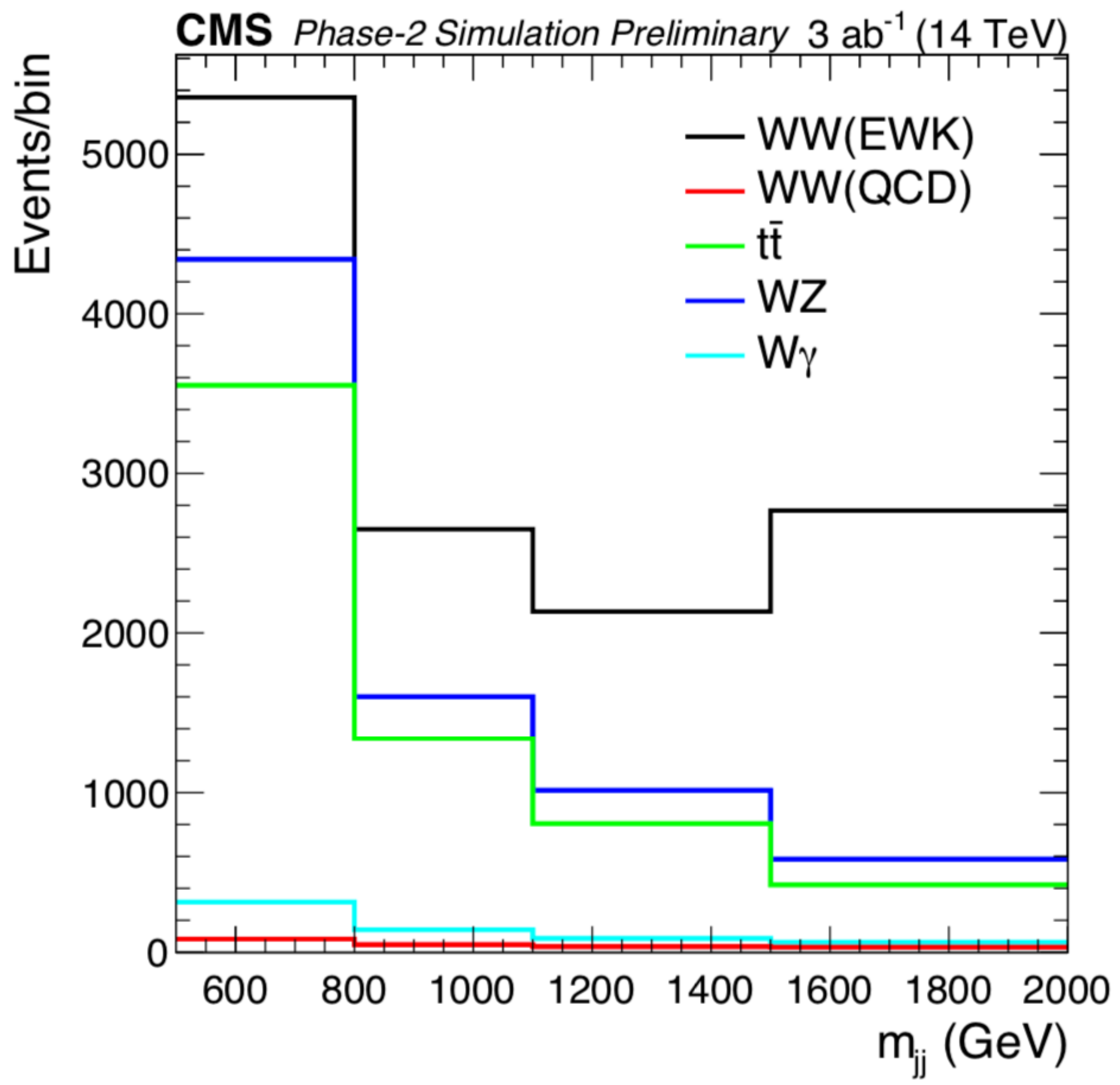
Longitudinal-Longitudinal Scattering

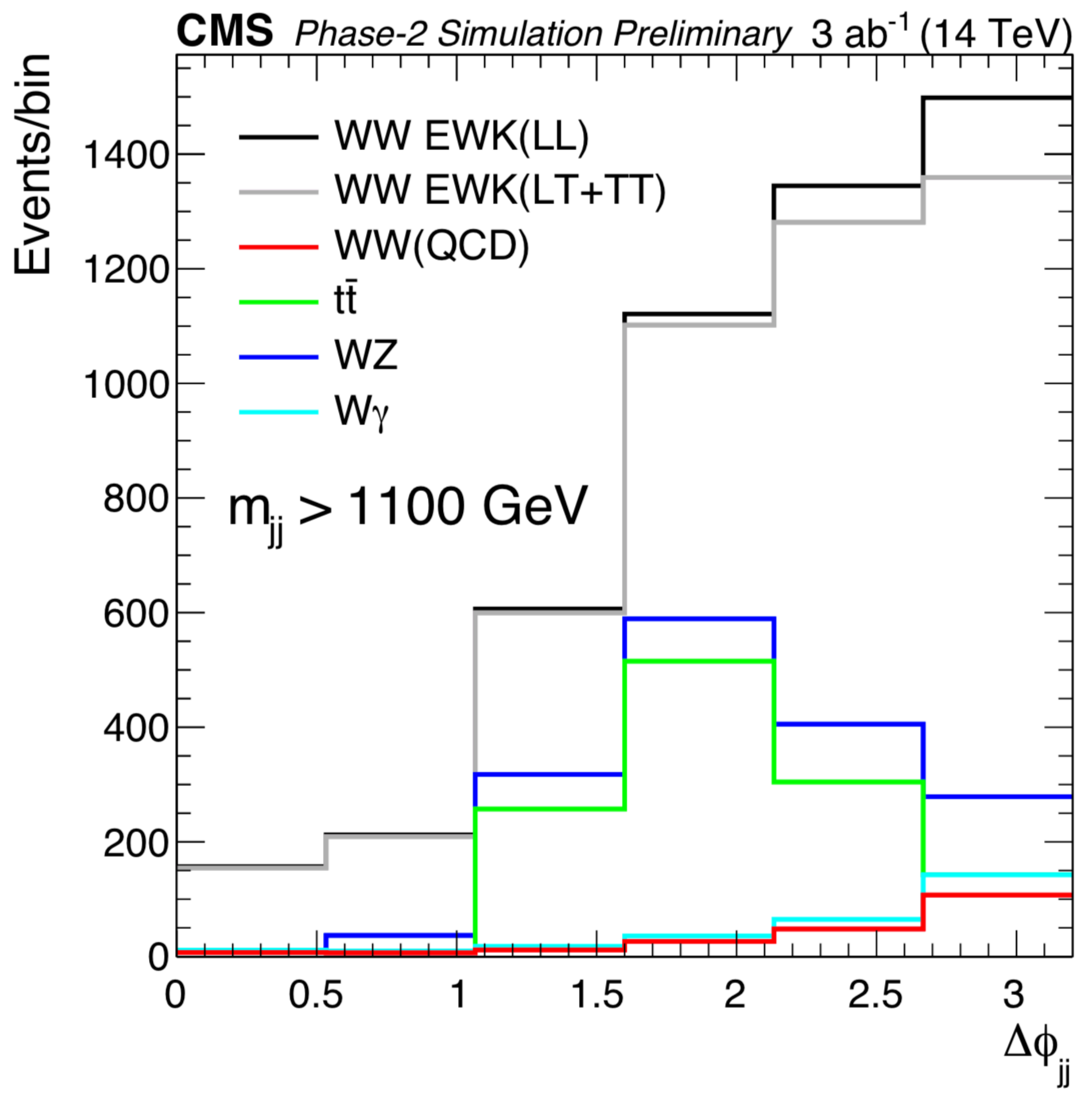
Important additional check of the EWSB sector.

Suppressed from Higgs cancellation however with very large statistics and polarisation sensitive variables, there is sensitivity to SM LL signal almost 3σ for CMS alone.

With ATLAS and more channels WZ and ZZ well above 3σ

CMS FTR-2018-005



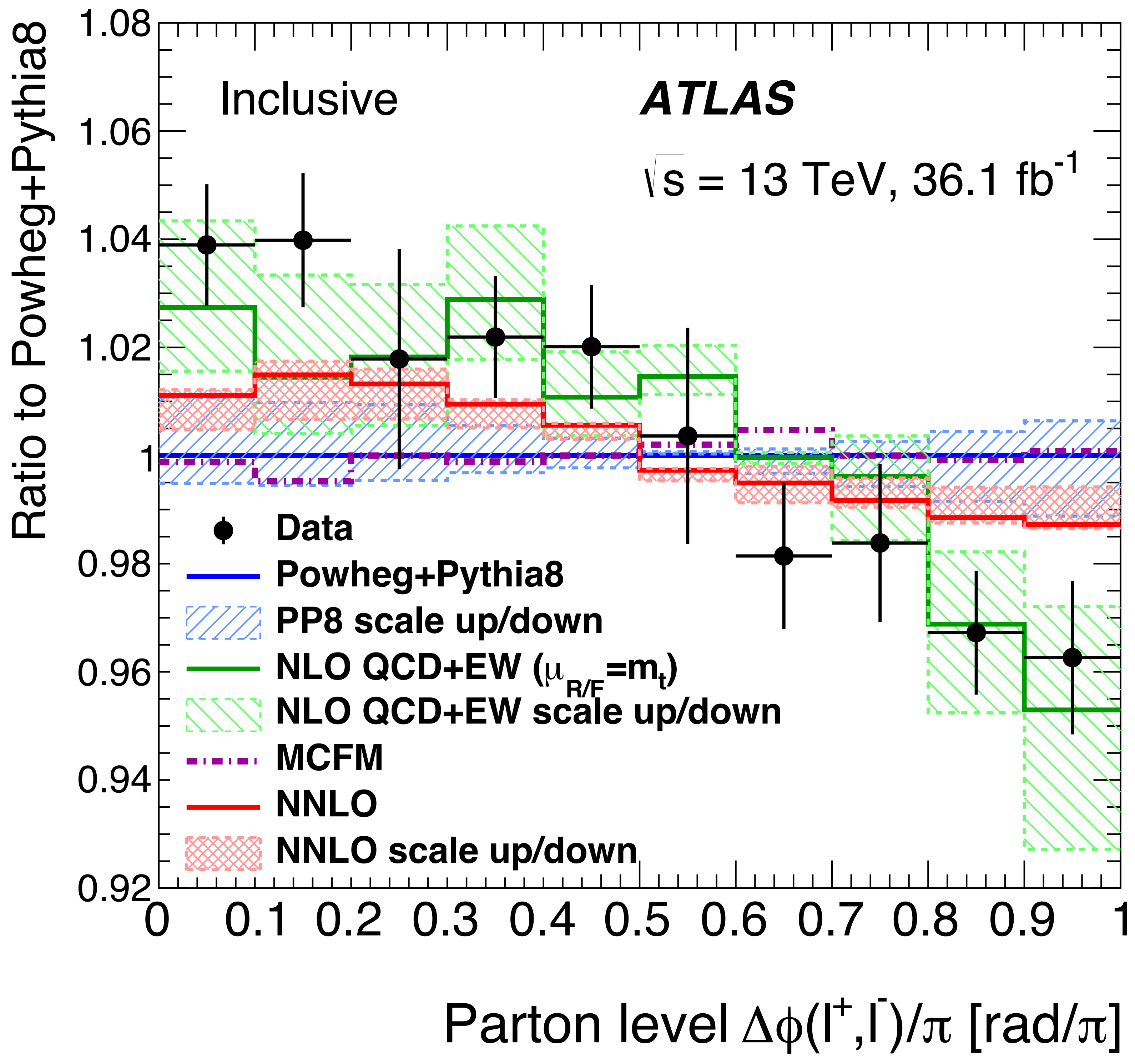


News from Top Measurements

Top pair spin correlation

In the di-lepton (e-mu) channel. Important ICHEP, now compared to fixed order recent NNLO and result NLO QCD and EW estimates in good agreement.

ATLAS 1903.07570

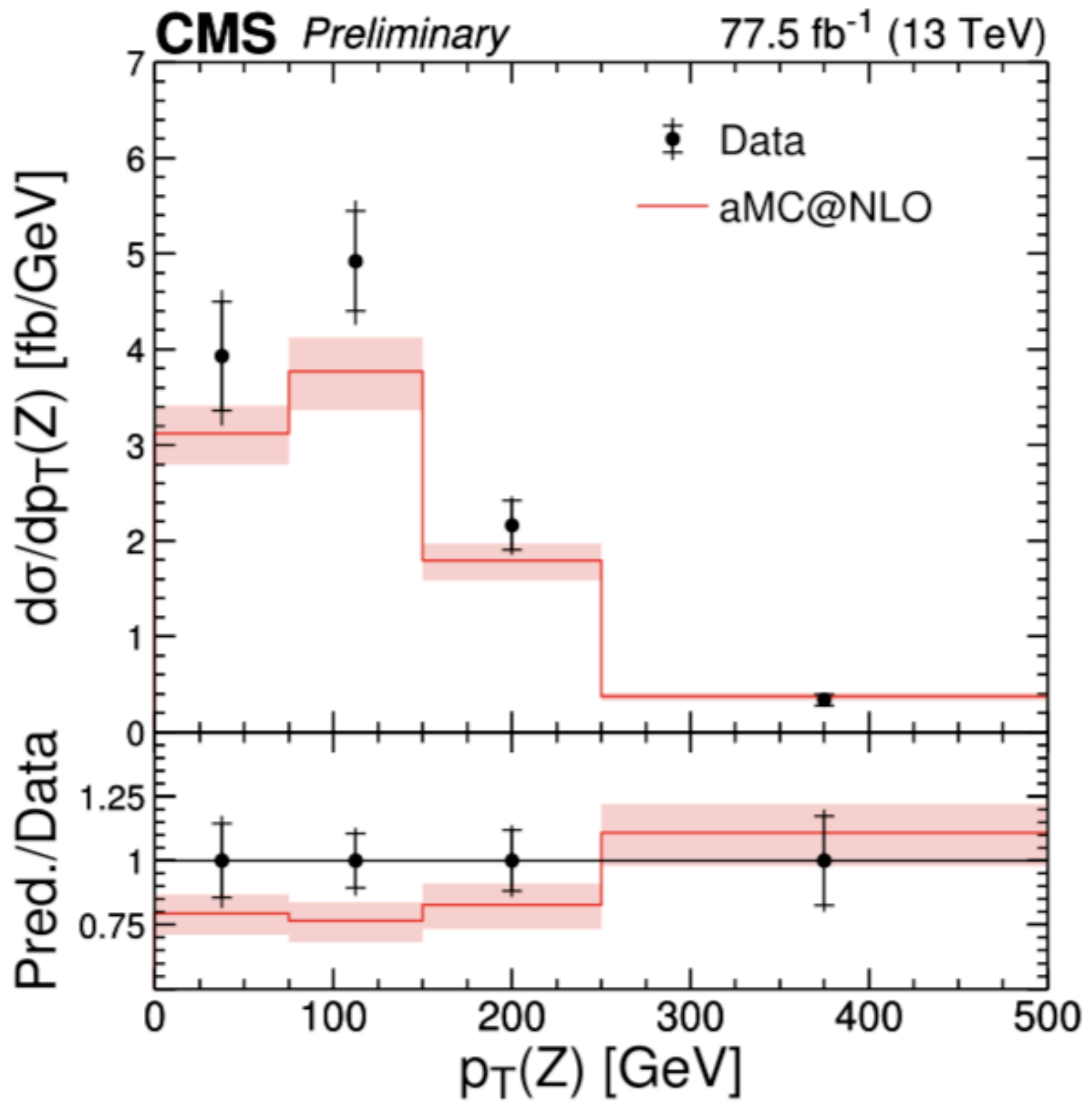


ttZ process

ttZ measured with 10% precision and differential measurements

$$\sigma(pp \to t\bar{t}Z) = 1.00\ ^{+0.06}_{-0.05}\,(\text{stat})\ ^{+0.07}_{-0.06}\,(\text{syst})\,\text{pb}$$

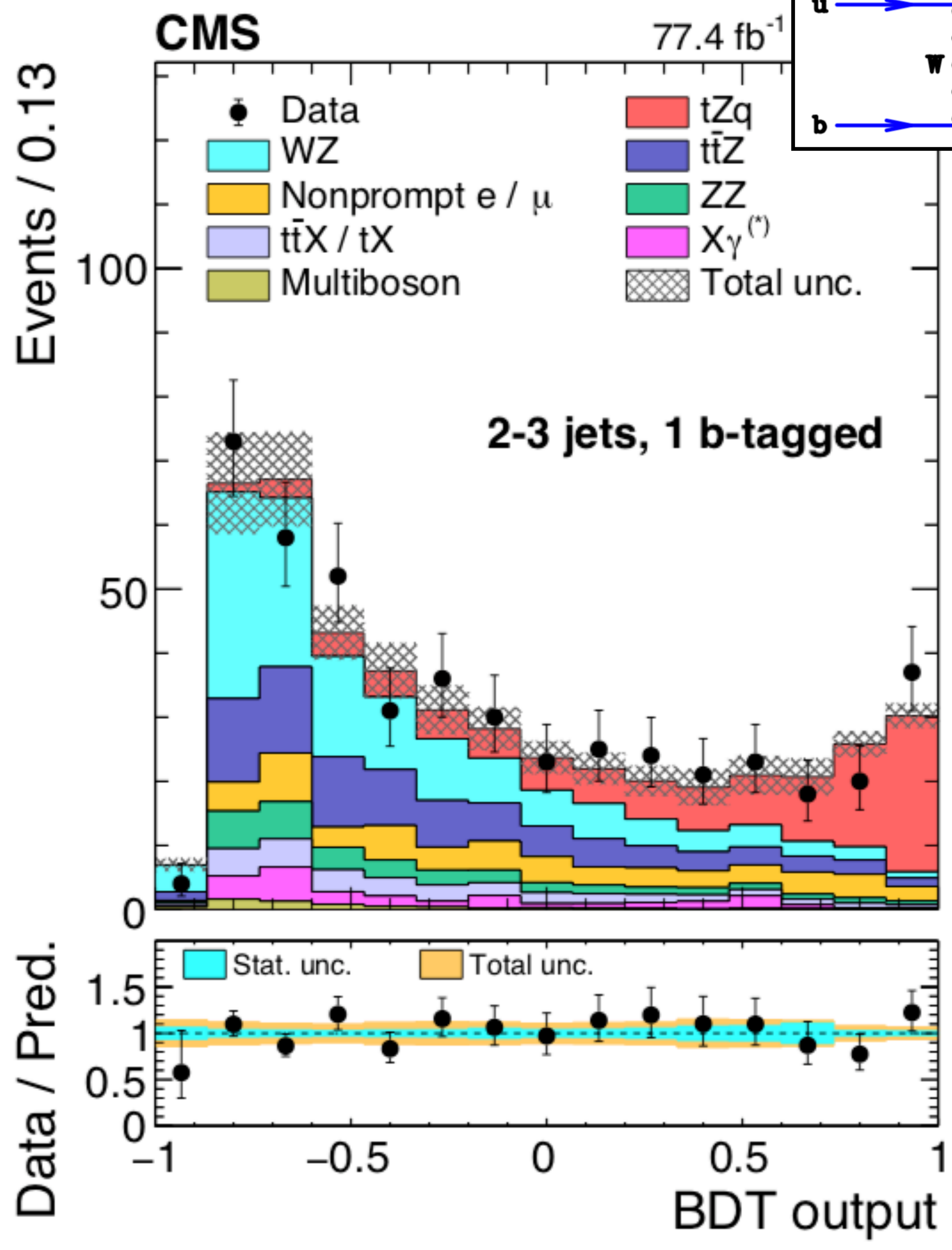
CMS-TOP-PAS-19-009

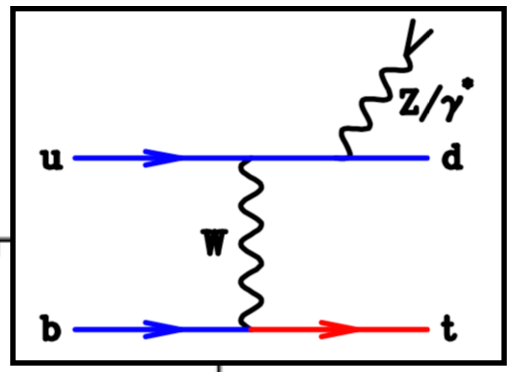


Single Top in association with Zq

In the 3-lepton channel (with Z to leptons).

CMS 1812.05900





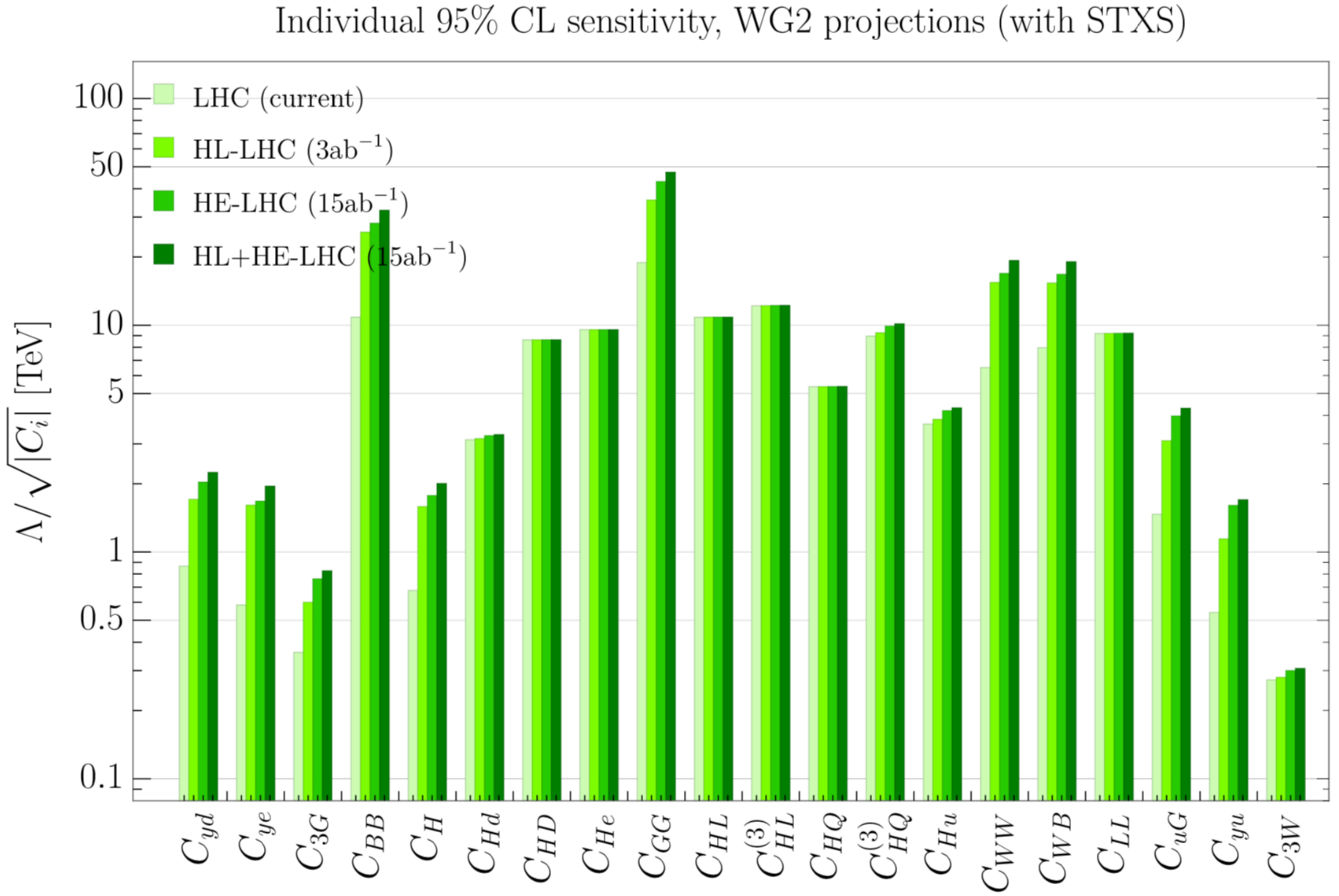
Campbell, Ellis and Rontsch 1302.3856

Global (SM) EFT Fit

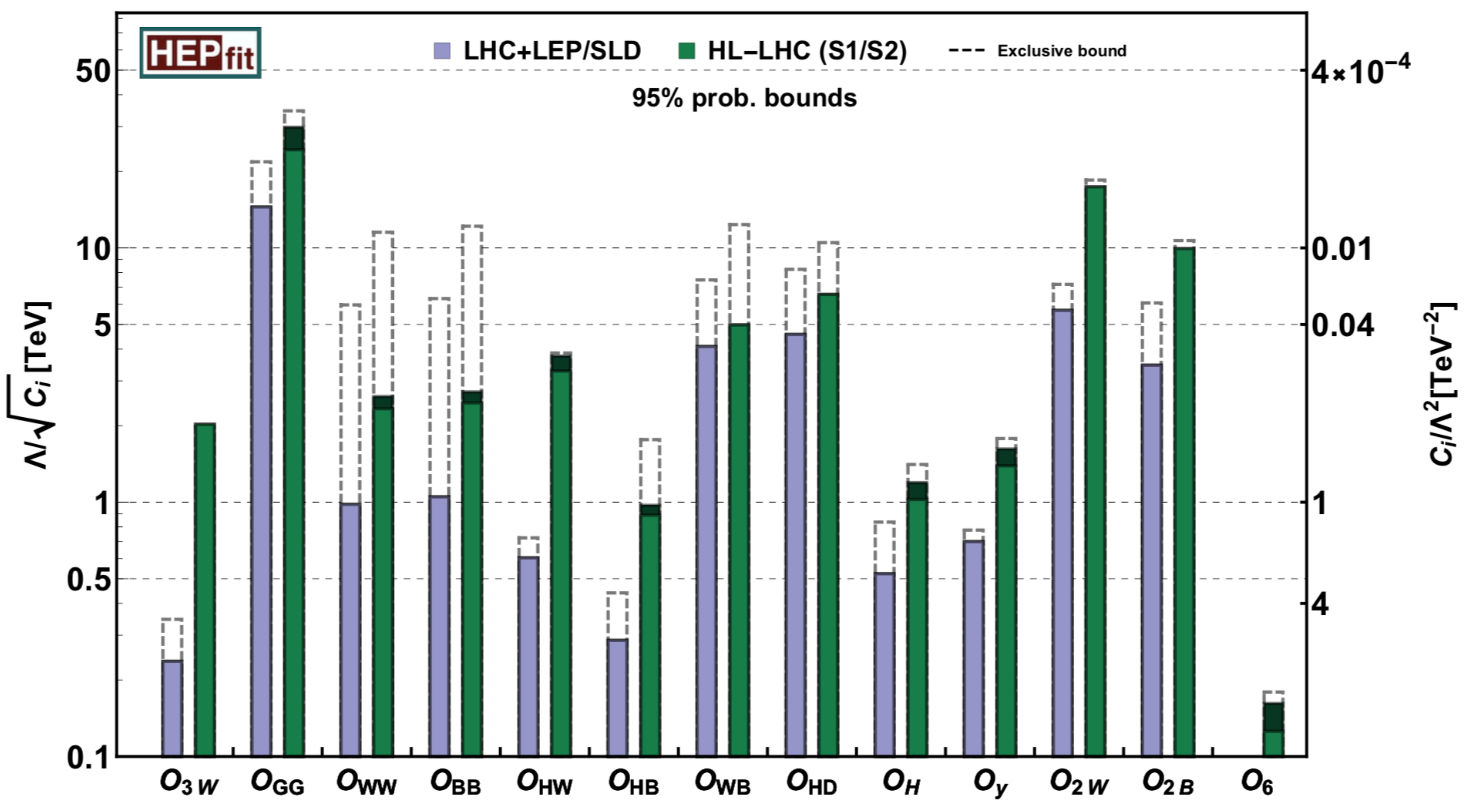
- **SMEFT with dimension 6 operators in the Warsaw basis:** with universality ~20 parameters

- **Approach 1 inputs**:
  - Z pole (LEP, SLC) and WW (LEP)
  - LHC Higgs signal strengths (in part VH).
  - LHC WW (with pT>120 GeV)
  - Higgs STXSs

- **Approach 2 inputs**:
  - LHC Higgs signal strengths (in part VH).
  - HH differential in baby
  - ZH in the high ZH mass regime
  - WZ (better than WW)
  - DY (high mass)



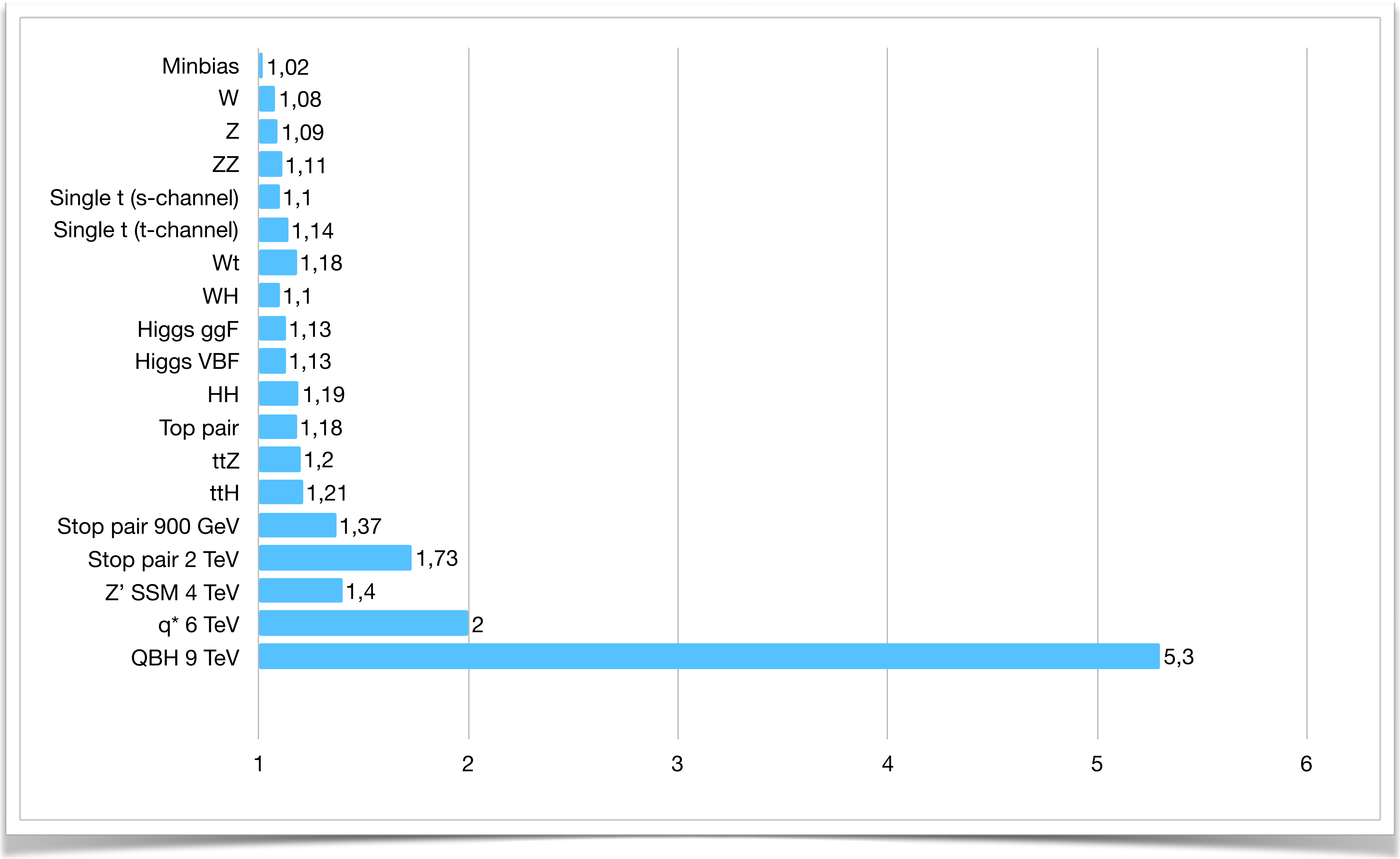
Only linear terms in parametrisation



Quadratic terms taken into account where needed.

Indirect sensitivity to new phenomena of O(10 TeV) and up to O(50 TeV)

Direct Searches for New Phenomena



Ratio of production cross sections (**from 13 TeV to 14 TeV**)
(from ratios of parton luminosities)

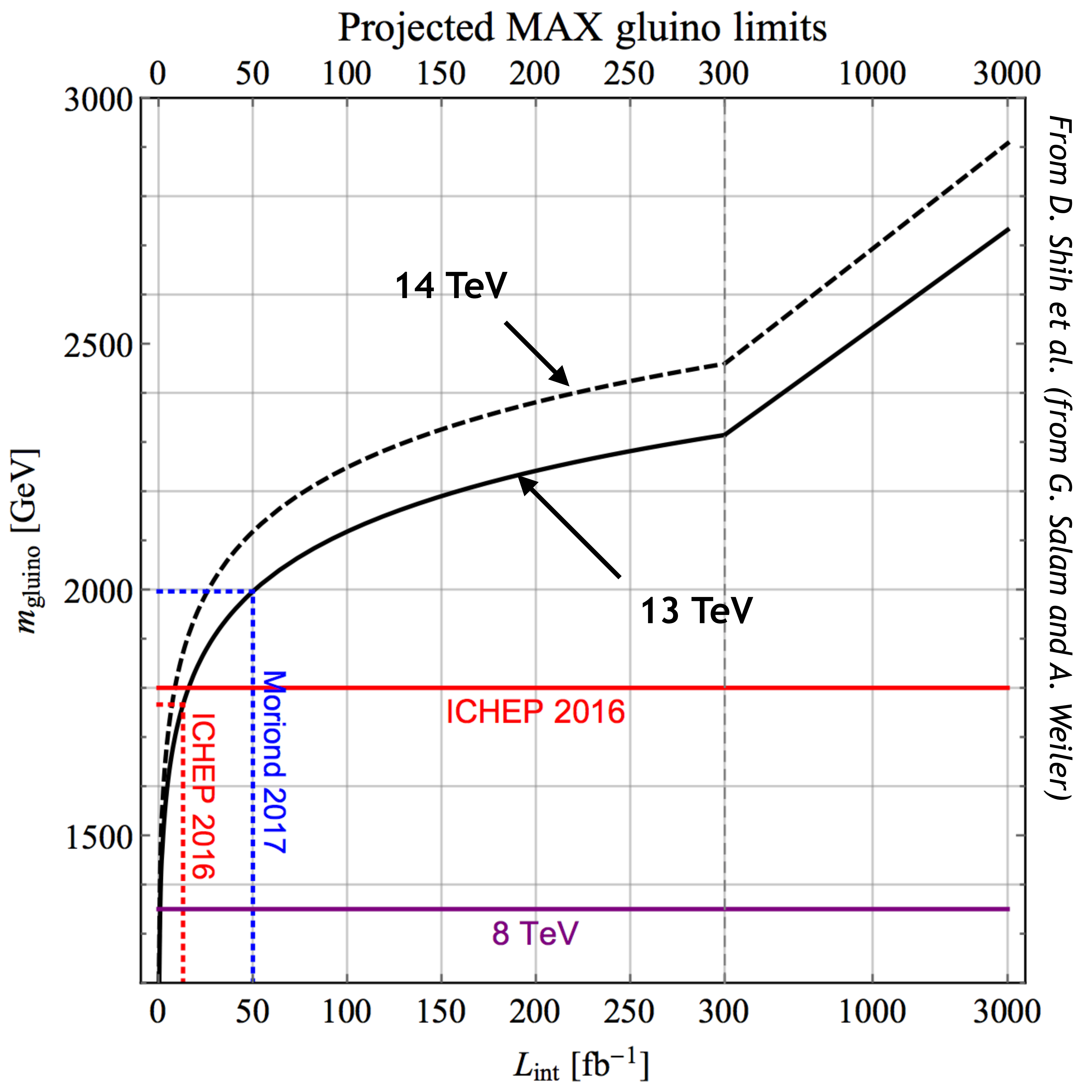
Towards HL-LHC and Precision Physics at LHC

- The Higgs boson discovered and all processes measuremed so far are all Standard Model-like.

- So far nothing else! However for most search analyses Run 2 data with only approximately 35 fb^{-1} have been published.

- Although the times of start of higher energy run when potentially spectacular discoveries were possible is essentially over, there is still **plenty of room for discoveries!**

- Luminosity will be essential in future Hadron colliders to fully exploit searches potential (the fixed mass sensitivity increase with S but the sensitivity relative to beam energy decreases!)

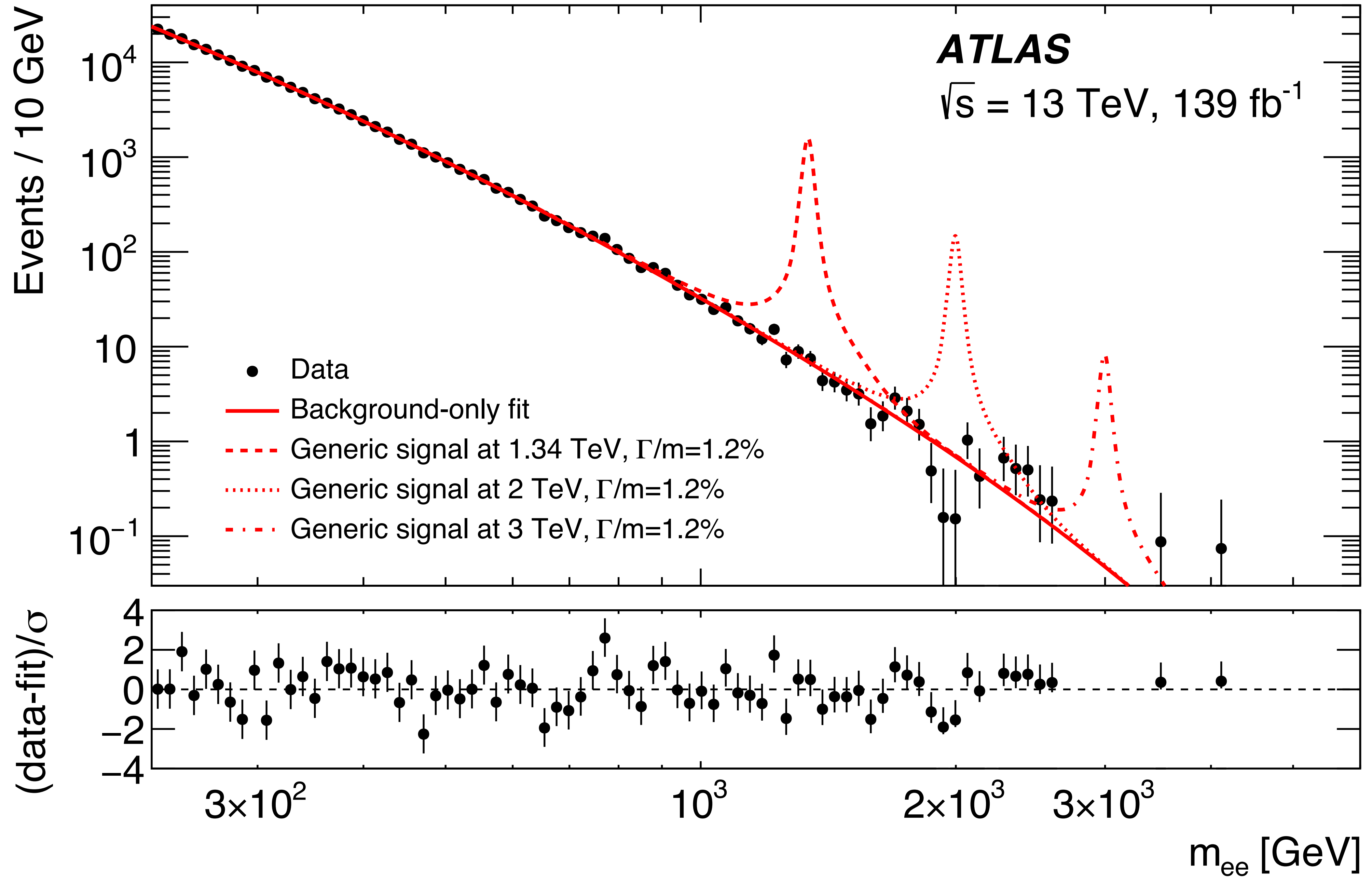


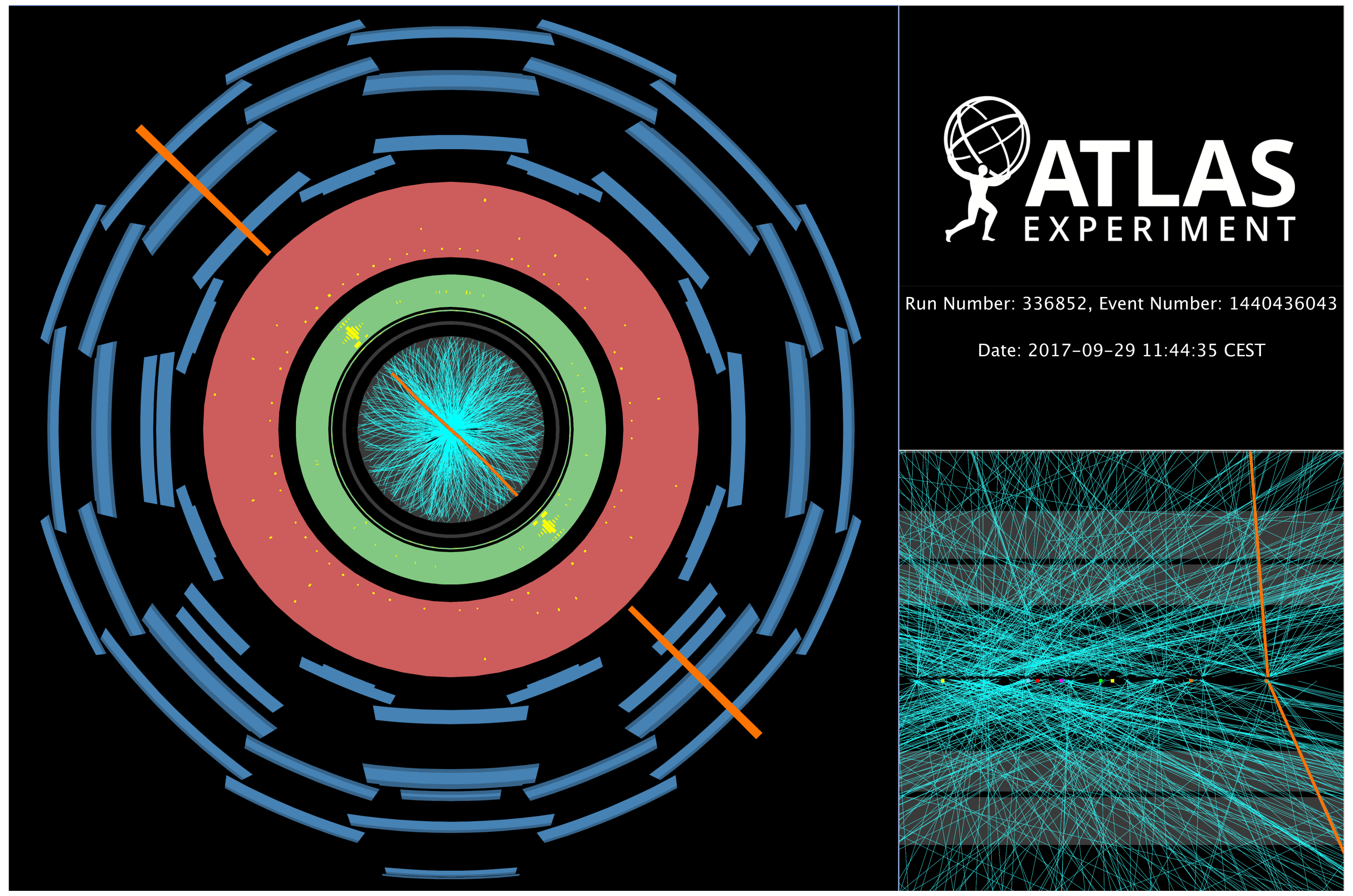
http://collider-reach.web.cern.ch/collider-reach/

Searches for High Mass Resonances

ATLAS Dilepton search

ATLAS 1903.06248



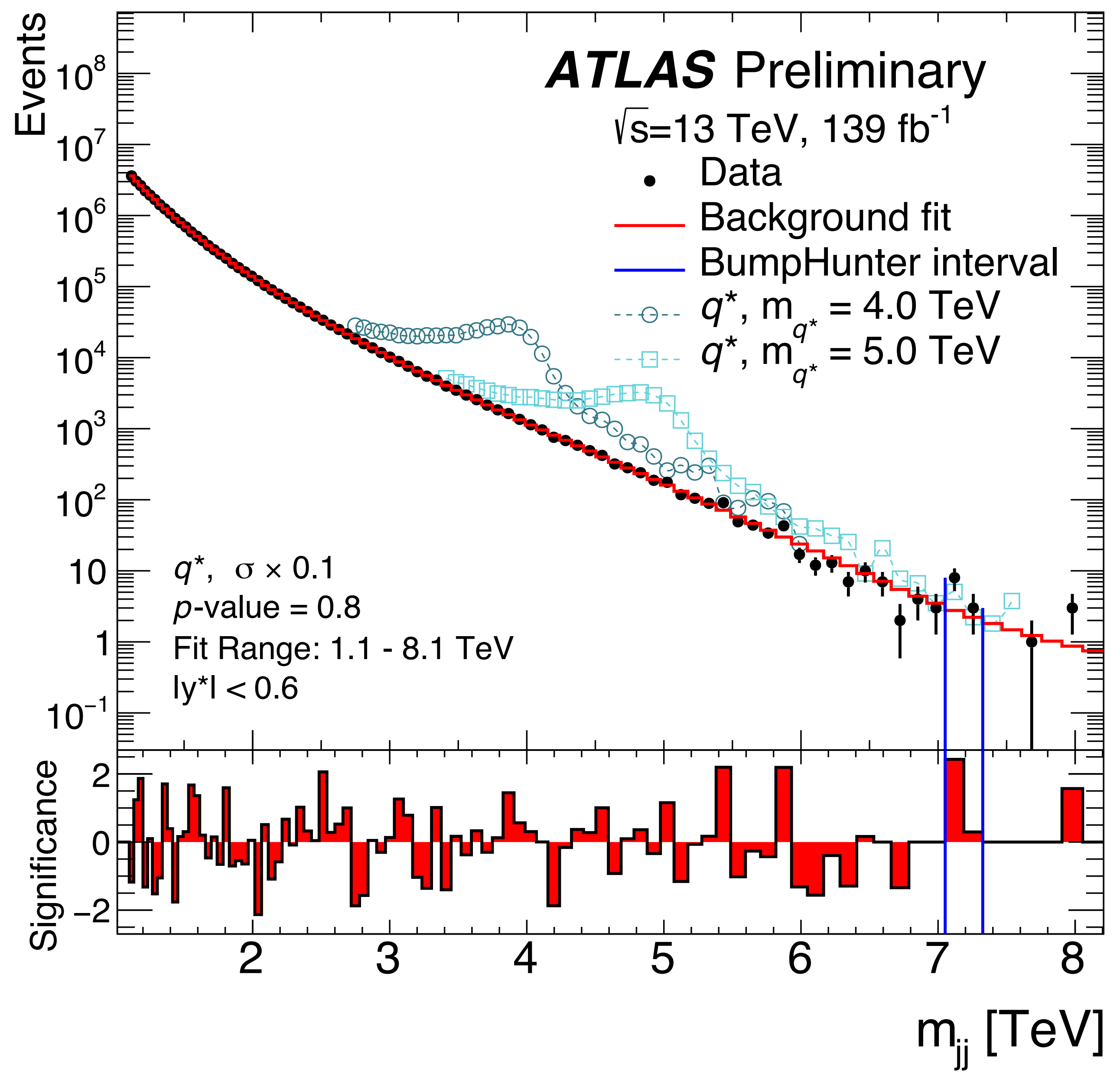


Exclusions up to ~5 TeV

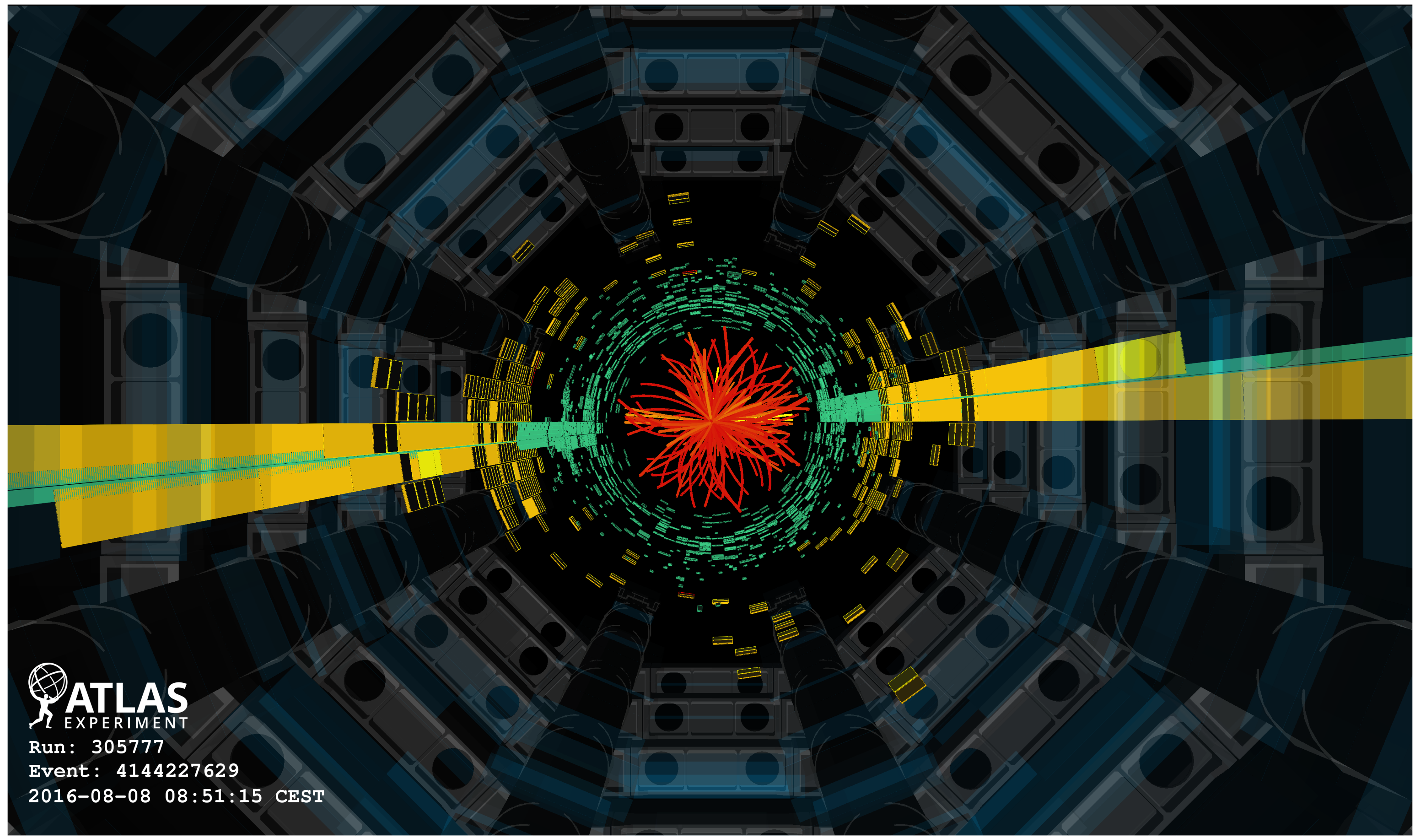
Highest mass di-electron event ~4 TeV

ATLAS Diet search

ATLAS-CONF-2019-007



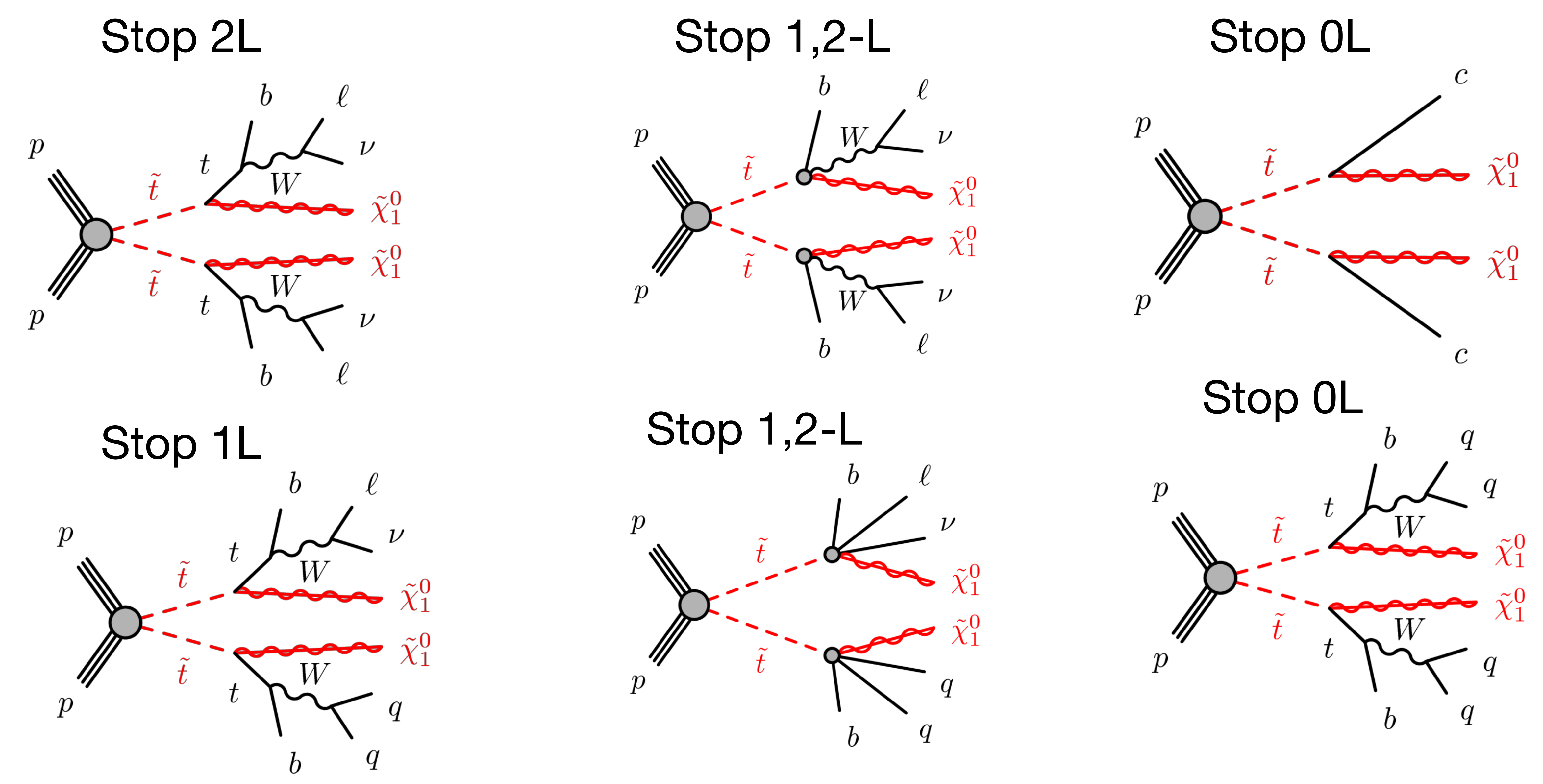
Limits on excited quarks at 6.7 TeV

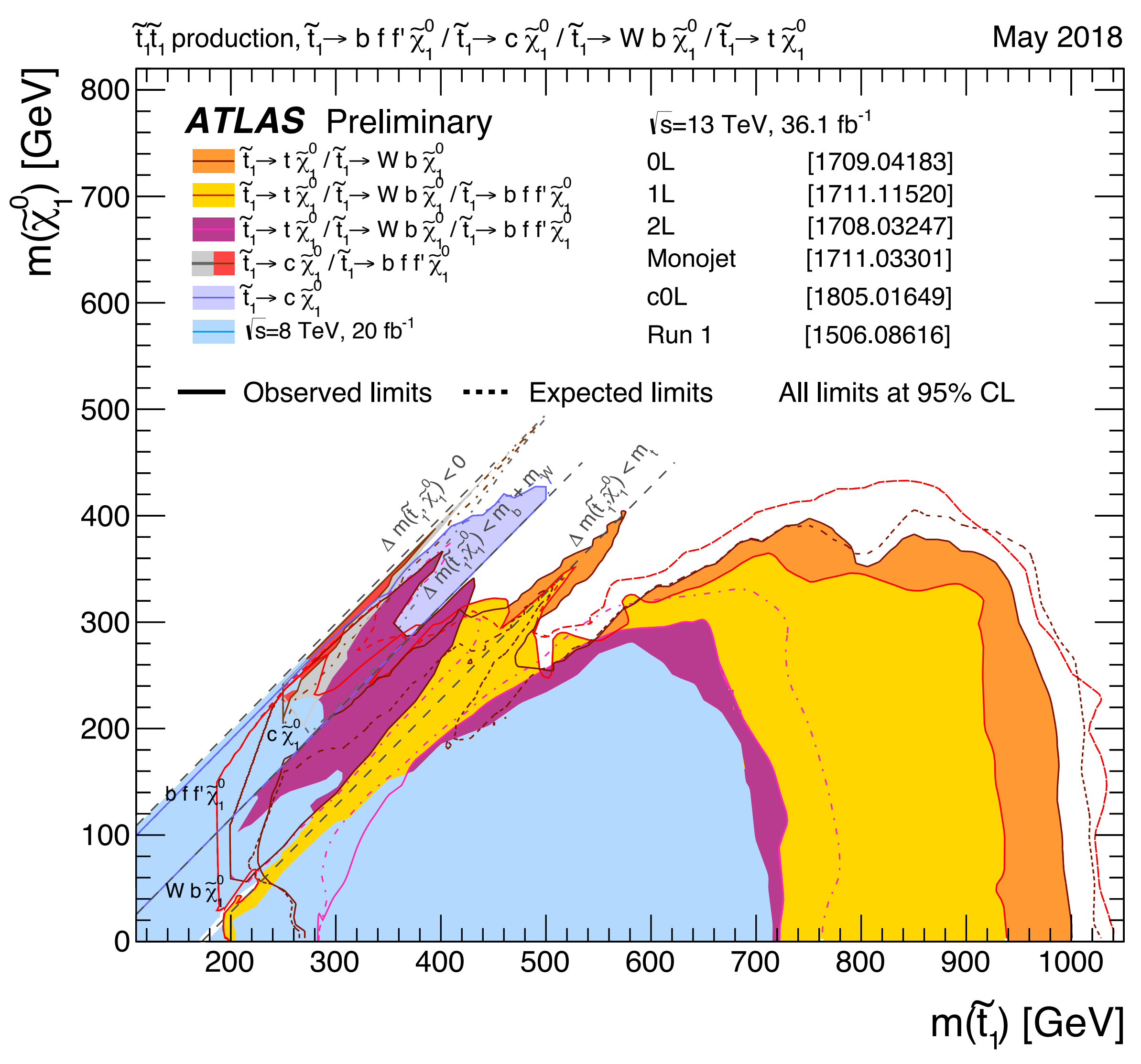


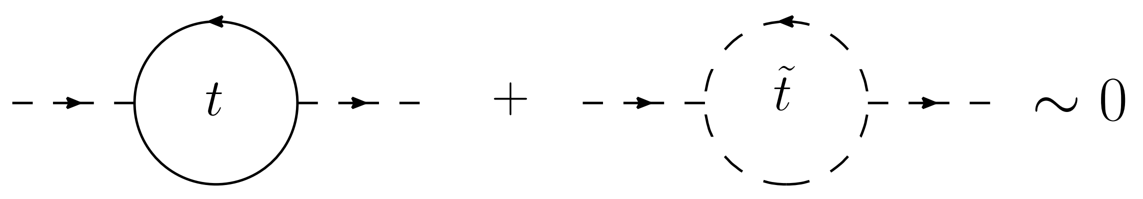
Highest mass (central) dijet event ~8 TeV

Searches for Natural and Strongly Produced SUSY

Stop

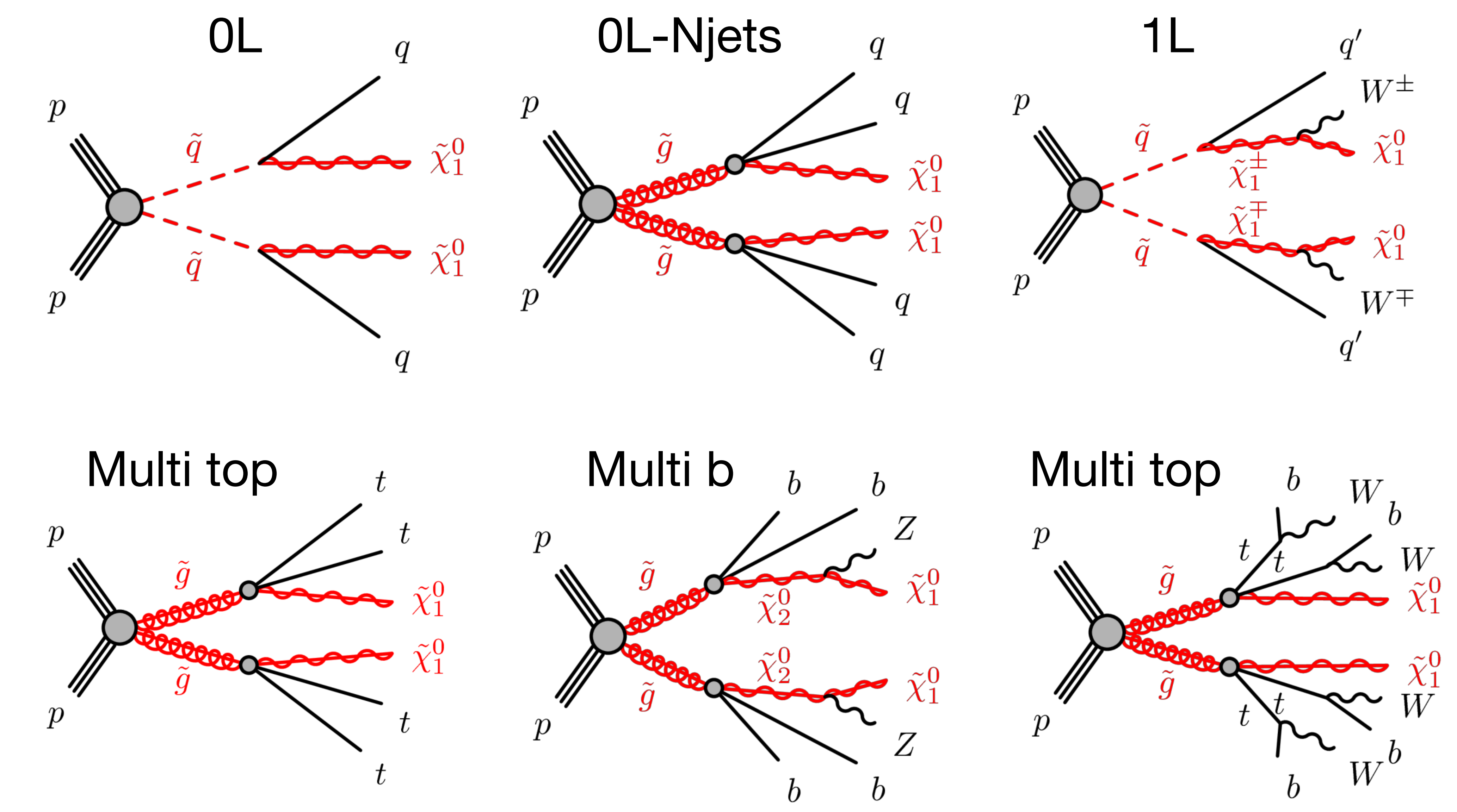


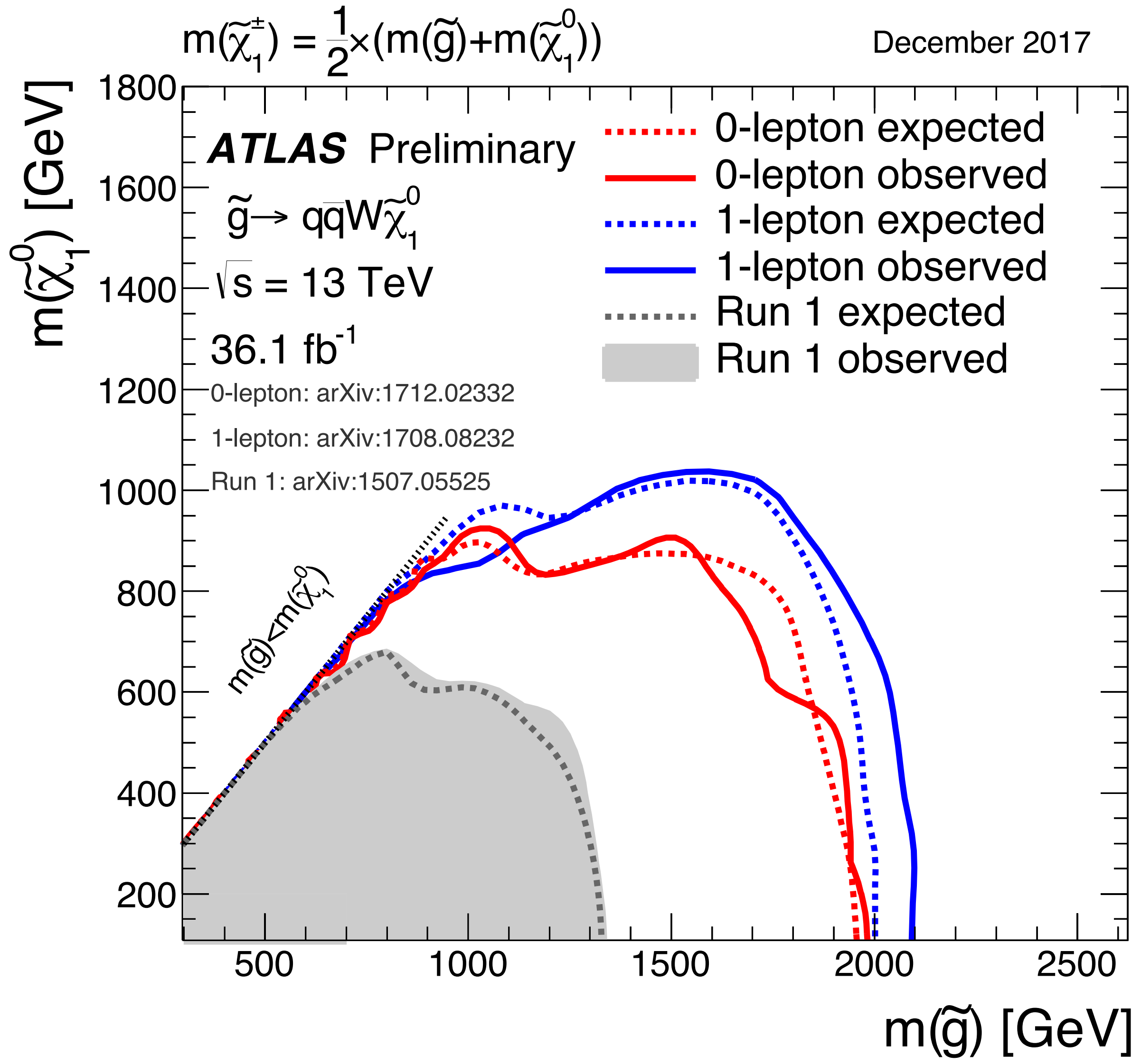


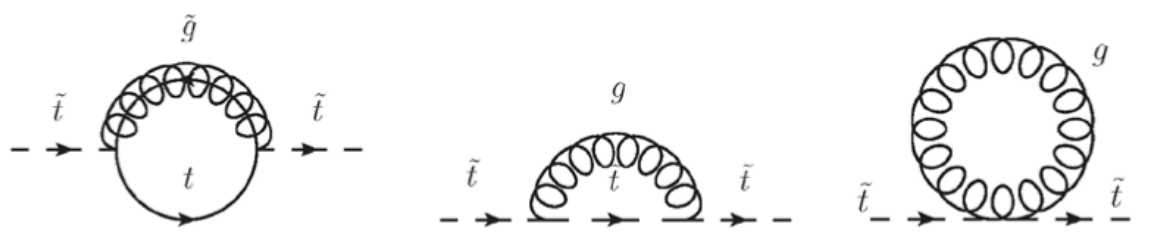


Not so natural SUSY: Stops > 1 TeV ~Tuning of factor 20, but these exclusions are under specific conditions, and there are unexcluded corridors.

Squarks and gluinos



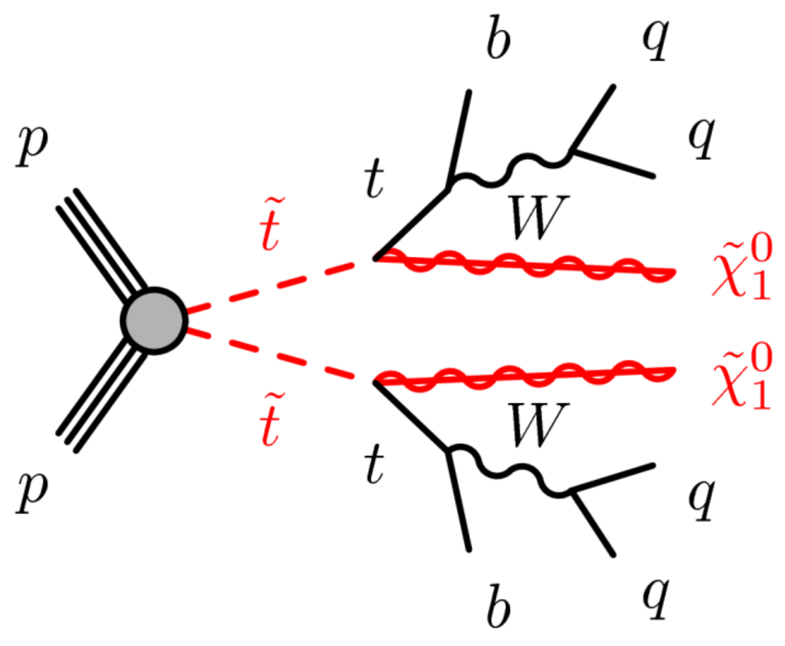




Stop also a scalar requires light gluinos to be light enough: for gluinos > 2 TeV ~tuning of Factor of 30

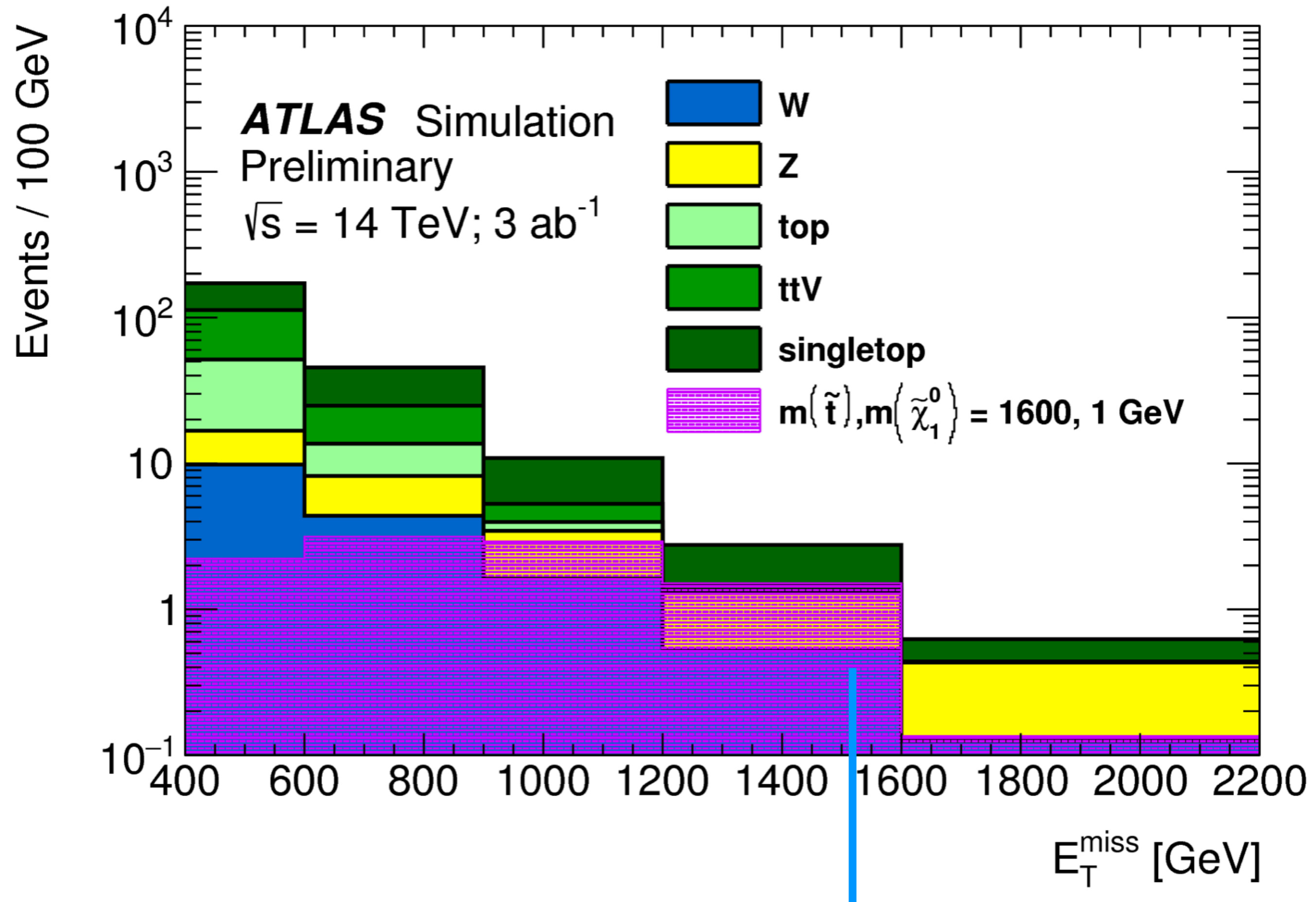
Strongly Produced SUSY Searches

Stop 0L at HL-LHC

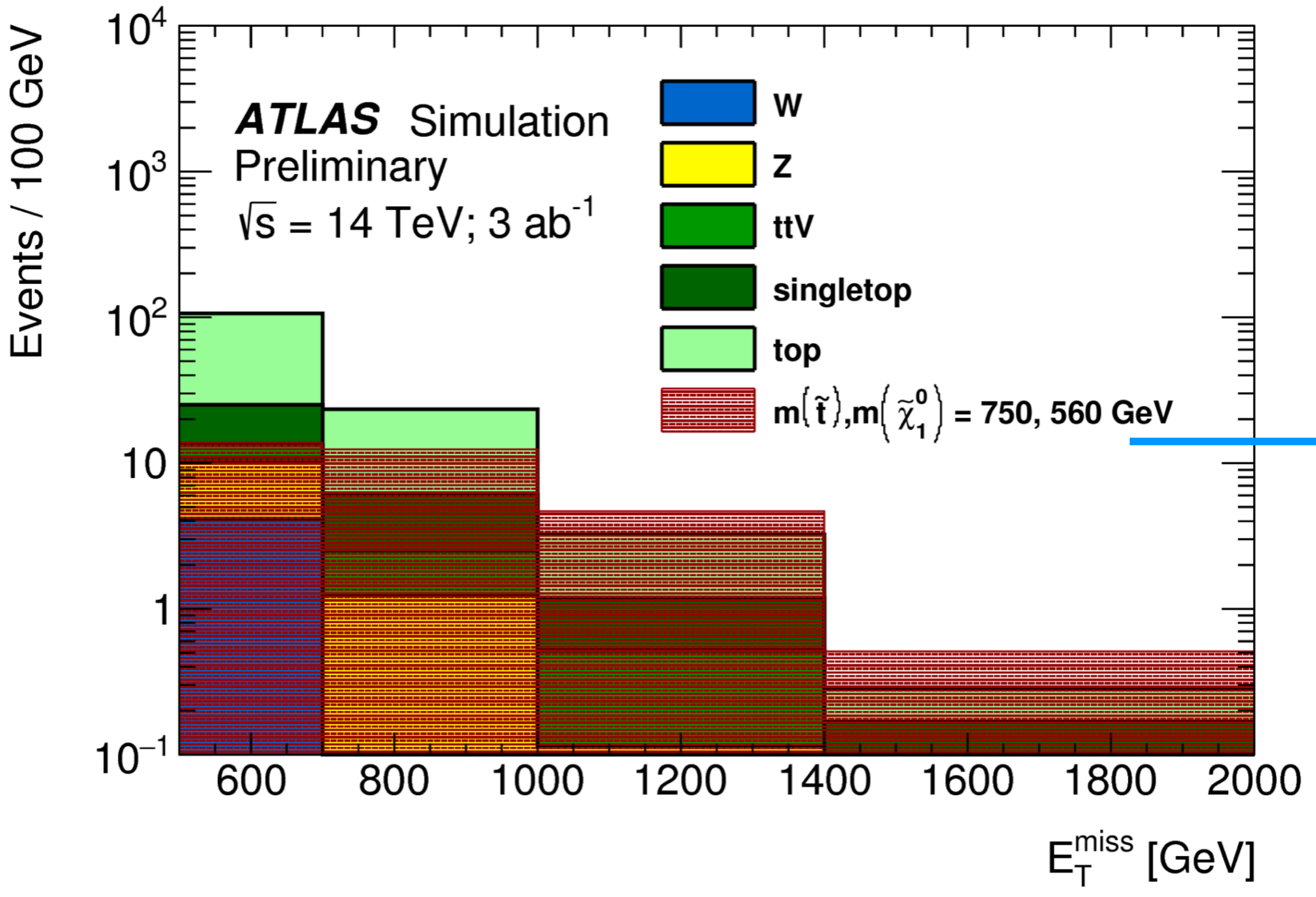


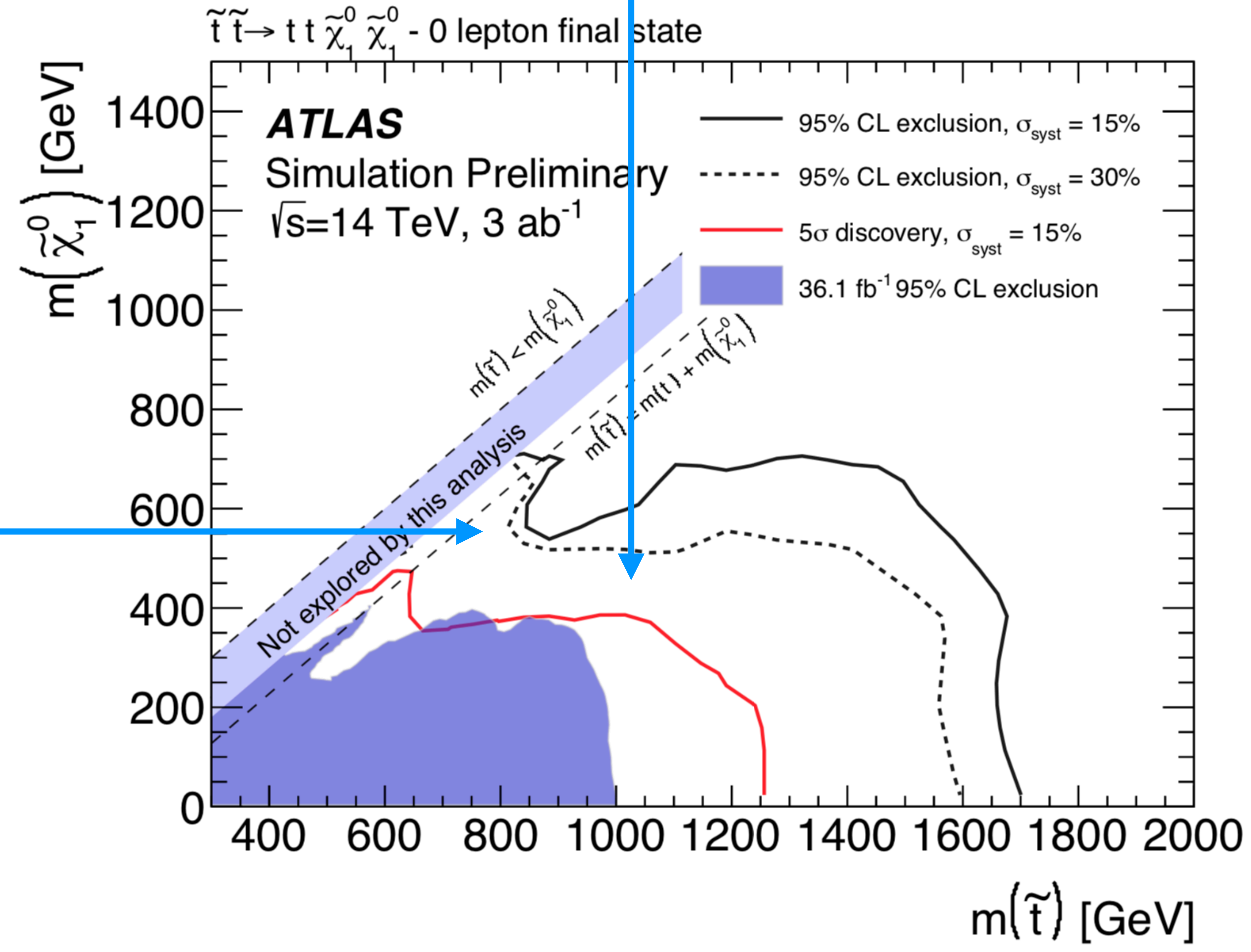
Complex final state

Large MET for large stop-neutralino mass differences

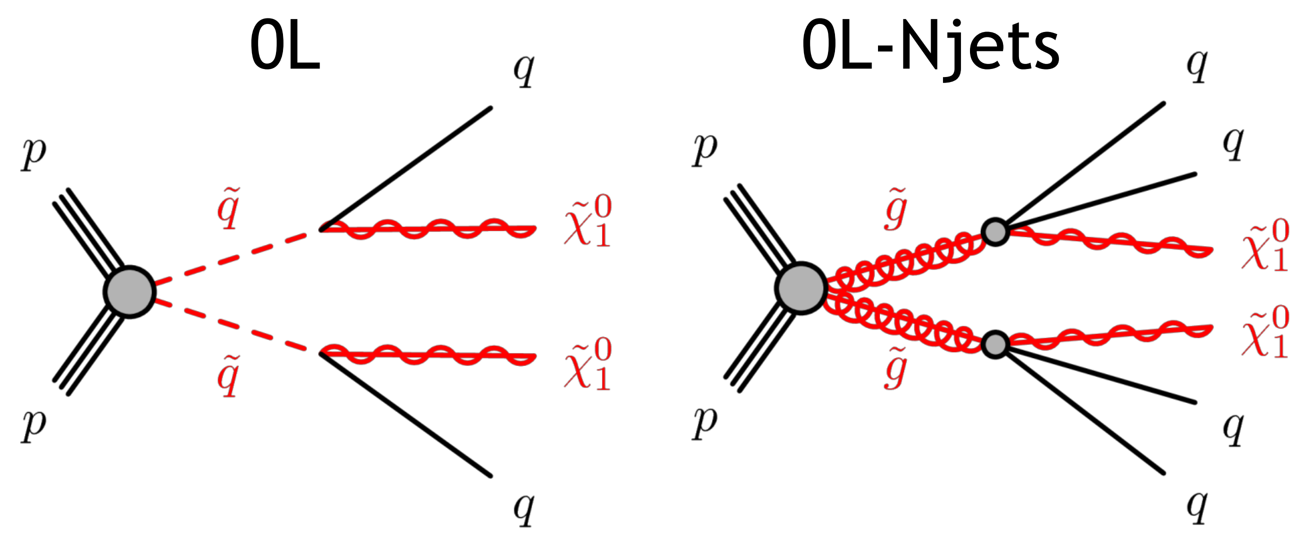


Smaller MET for small stop-neutralino mass differences: request boost generated from ISR (400 GeV)!

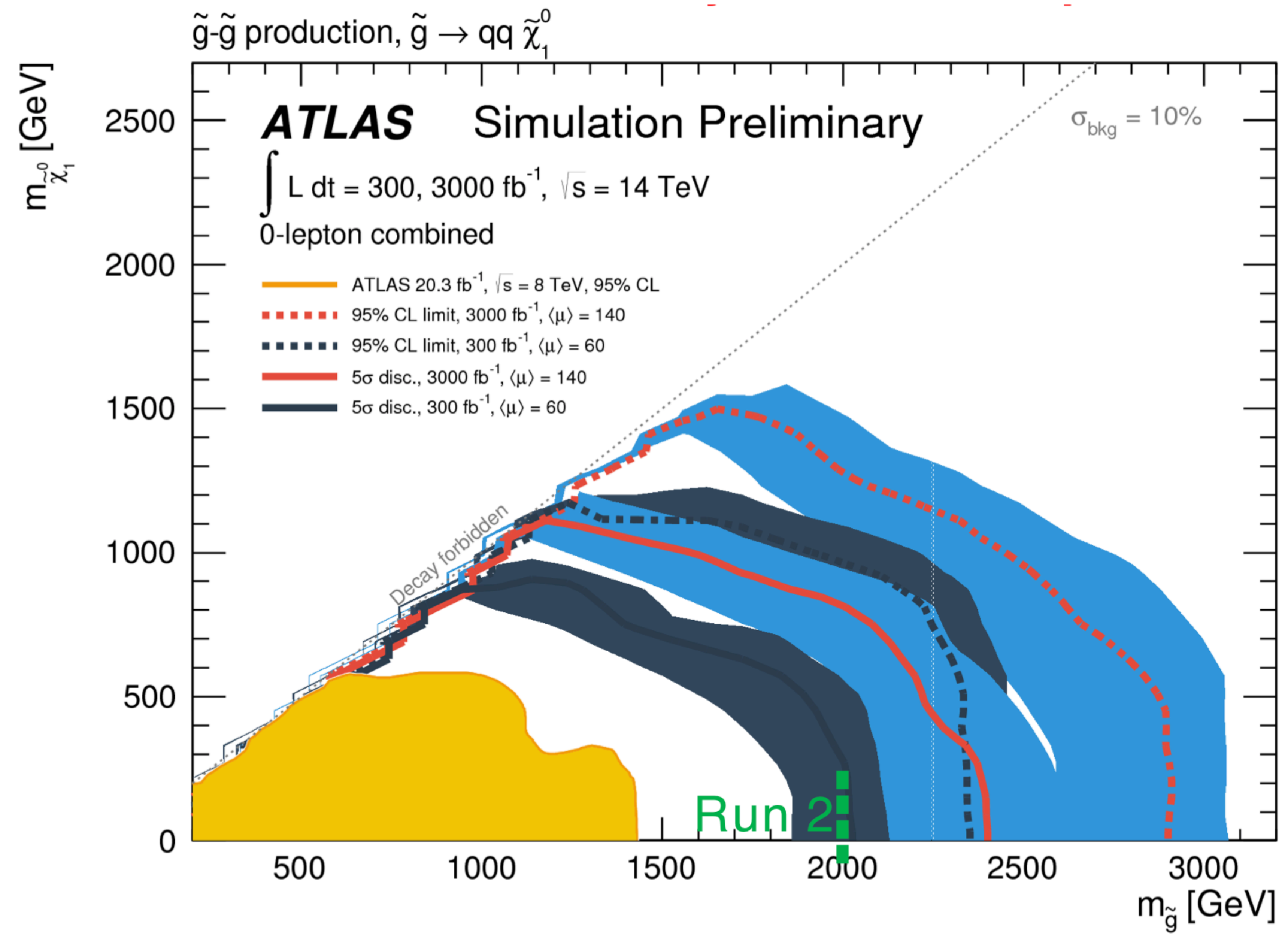




Squarks and gluinos

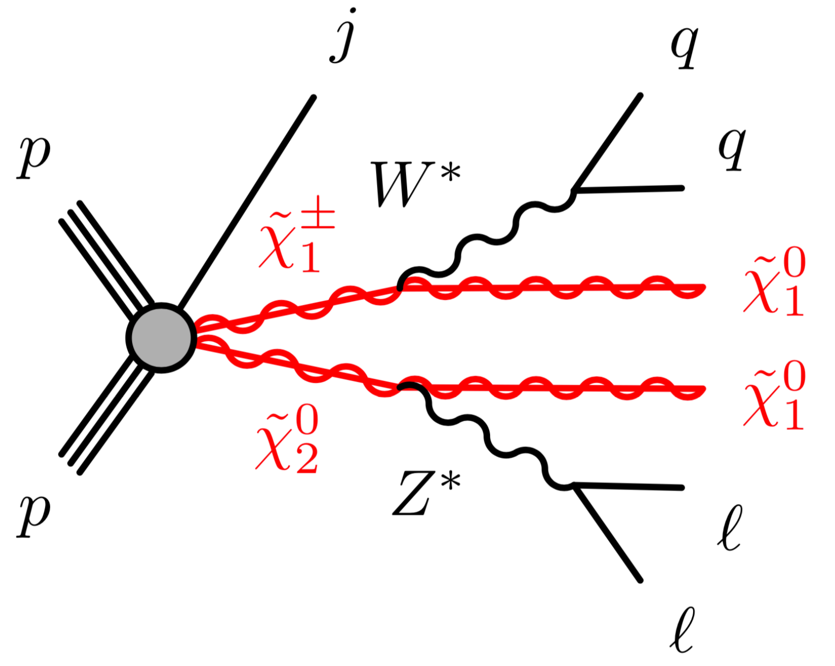


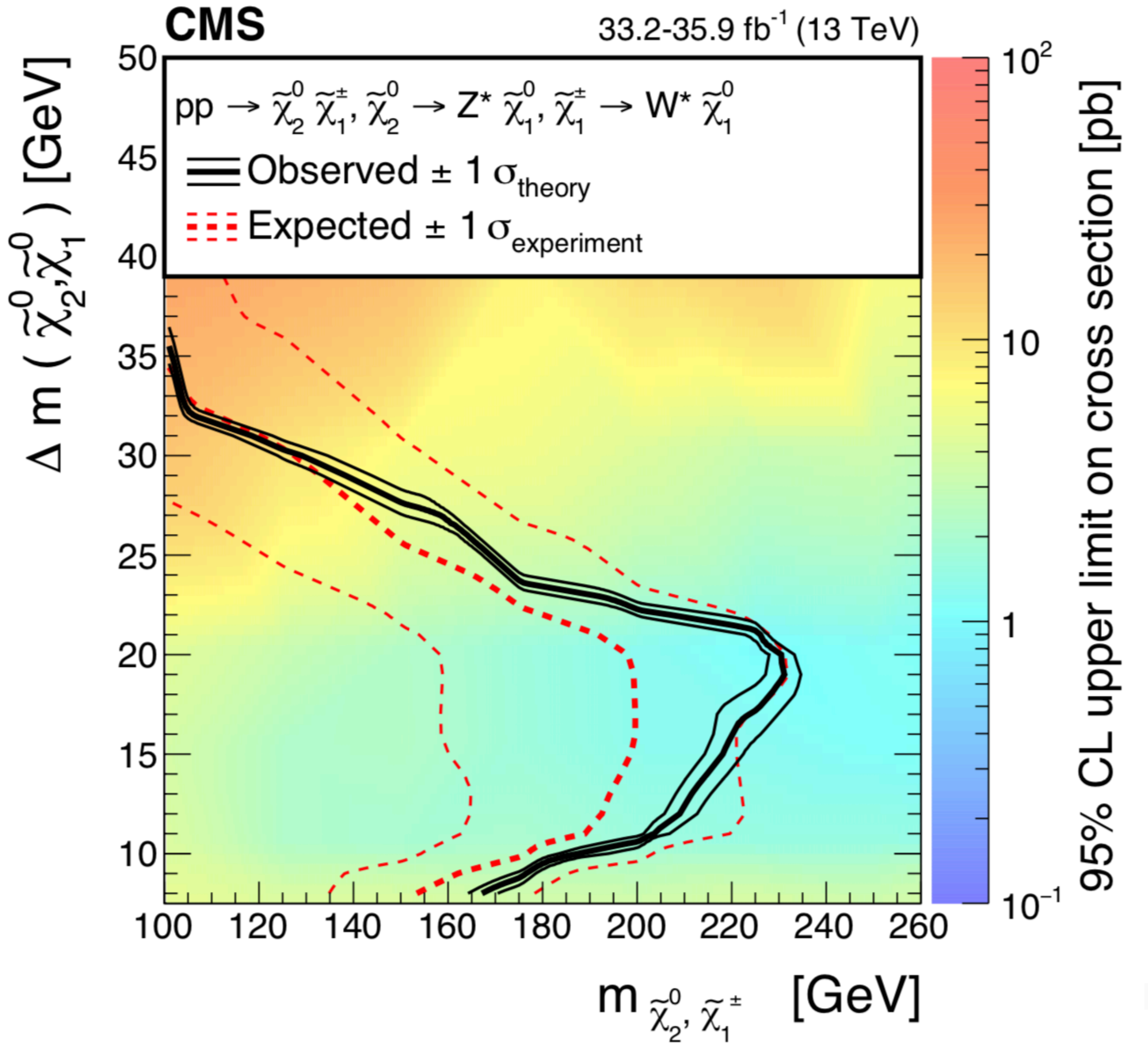
Reflection of progression plot as a function of luminosity (and COM energy).

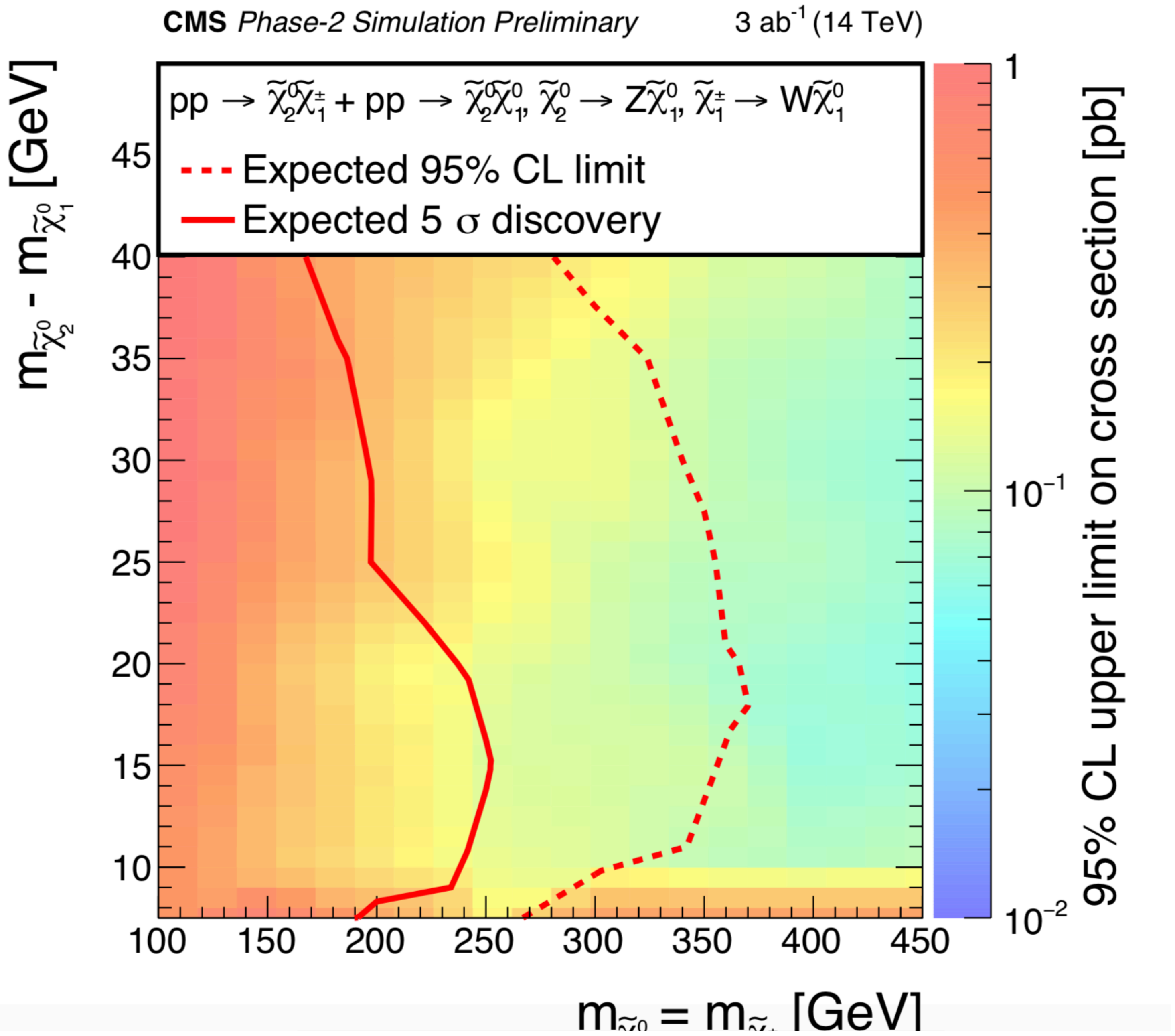


Electroweakinos or How can Natural SUSY have Escaped?

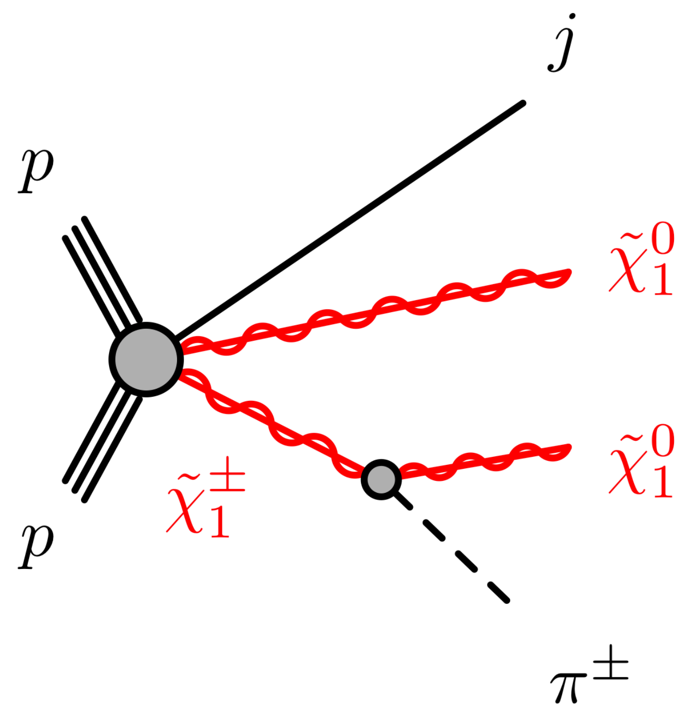
Weak production of chagrinos and neutralinos







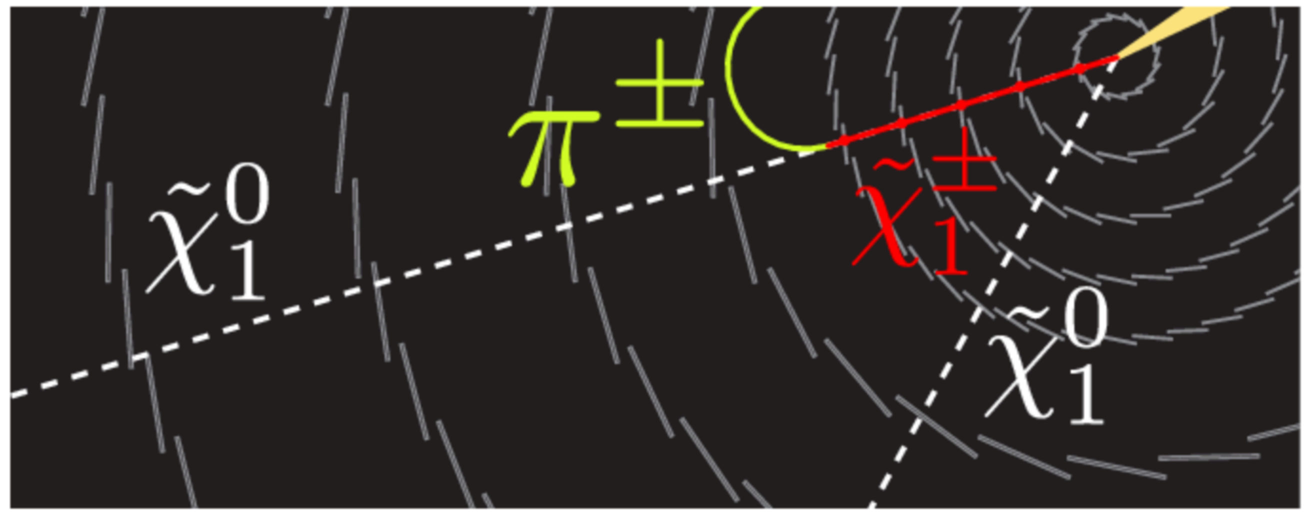
SUSY in highly compressed scenarios



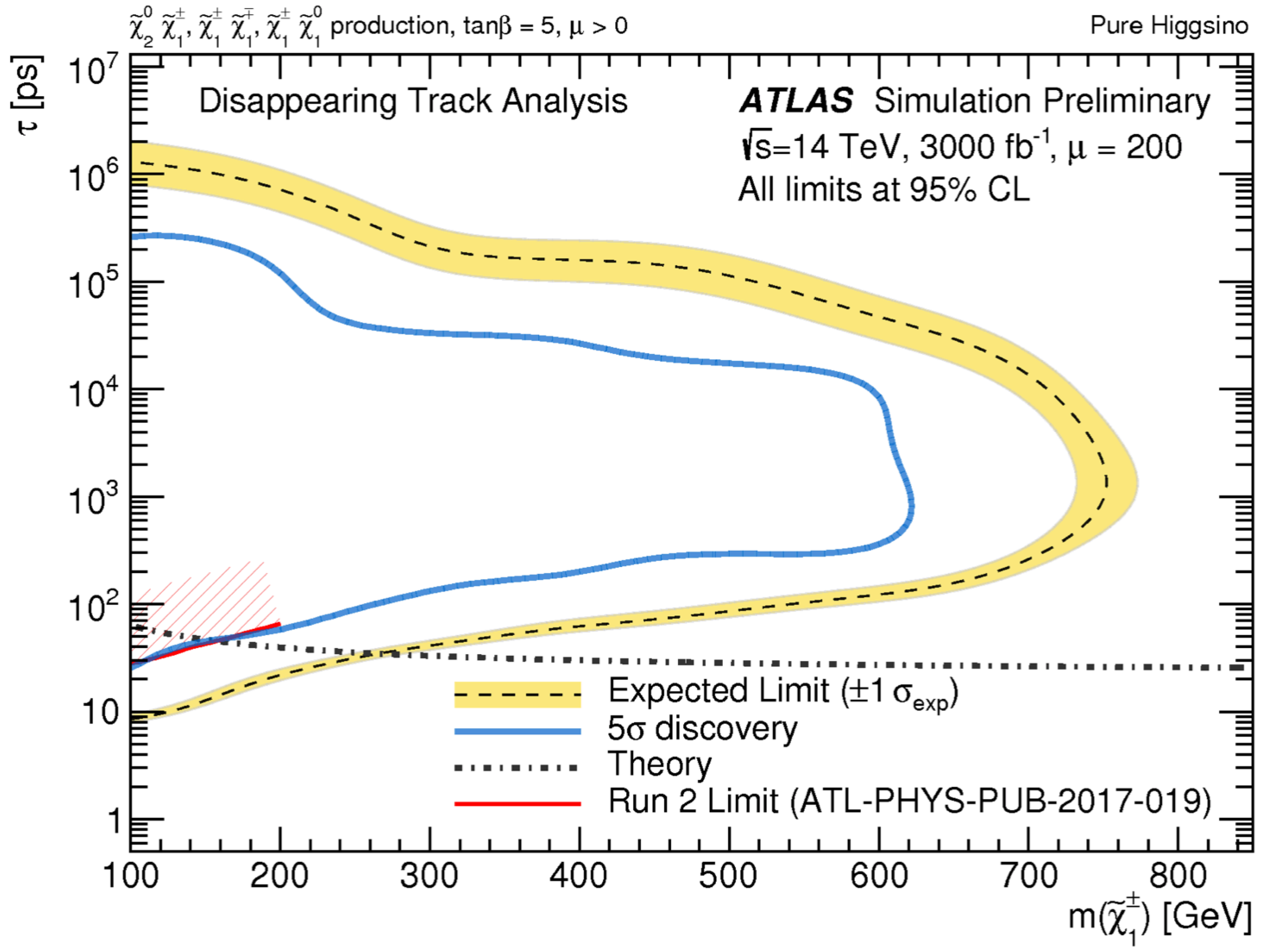
Disappearing tracks topologies

(Uses MET Trigger - requires ISR jet)

ATLAS-PHYS-PUB-2018-031



Scenario where the charginos and neutrino are almost degenerate (chargino has significant lifetime and is seen in the first layers of the ID).

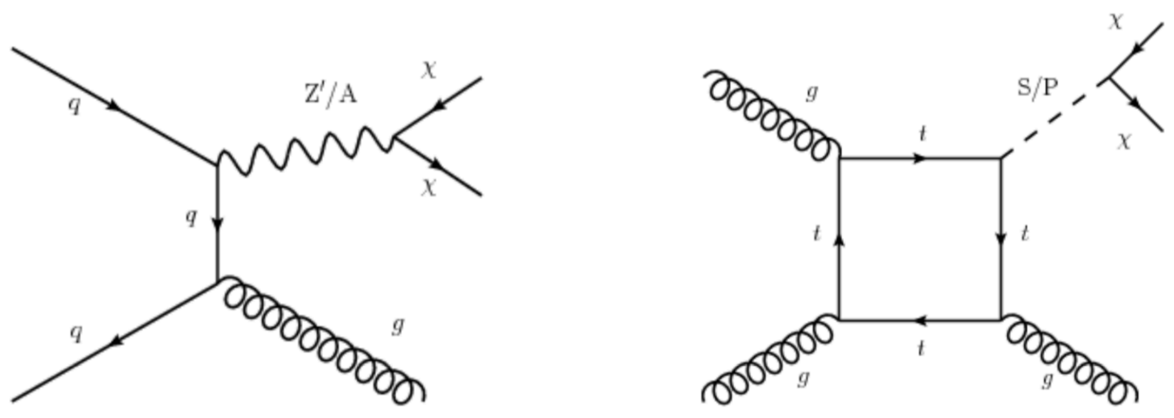


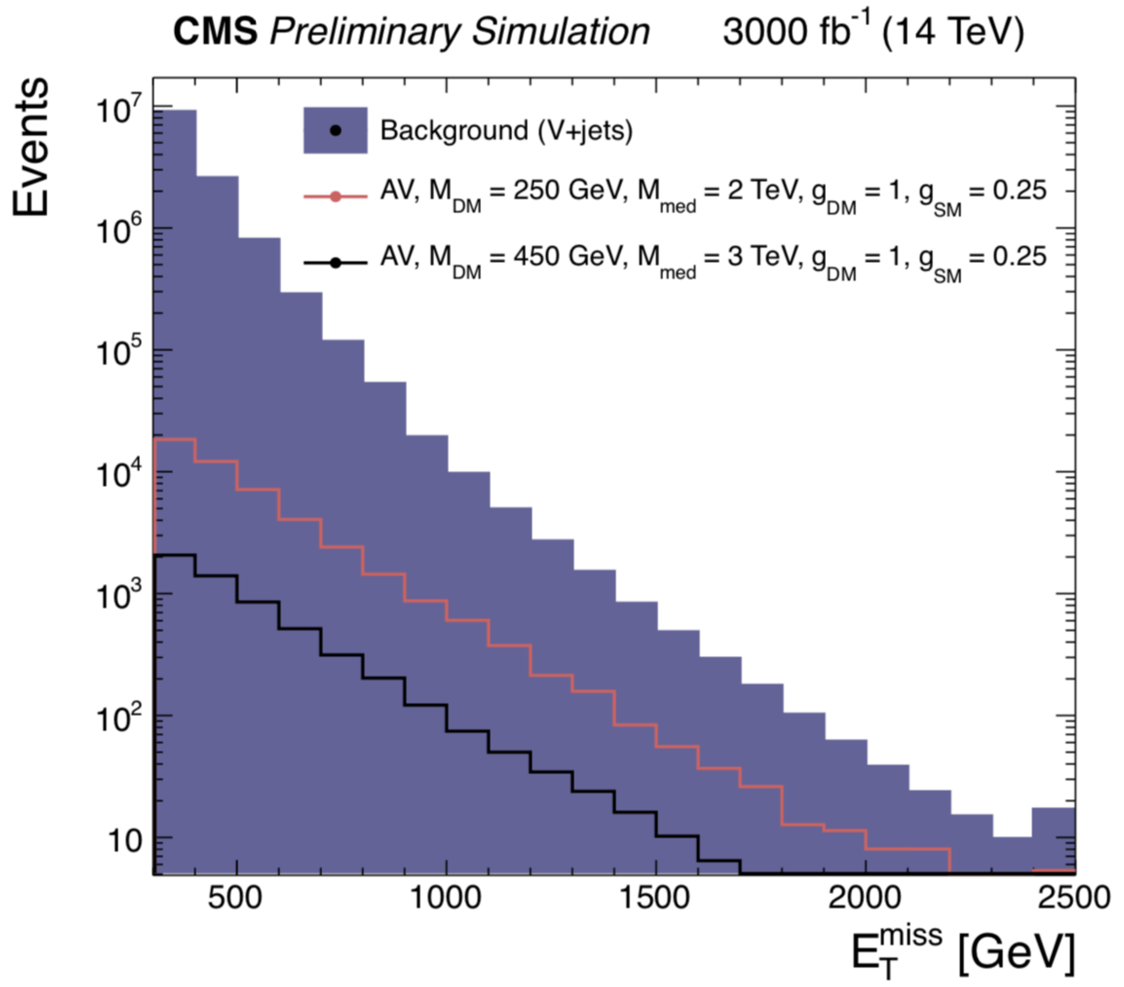
Generic Searches for Dark Matter

Searches also according to topologies and interpretations in simplified models: Mono-jet, mono-V, mono-photon mono-Higgs, mono-top, etc…

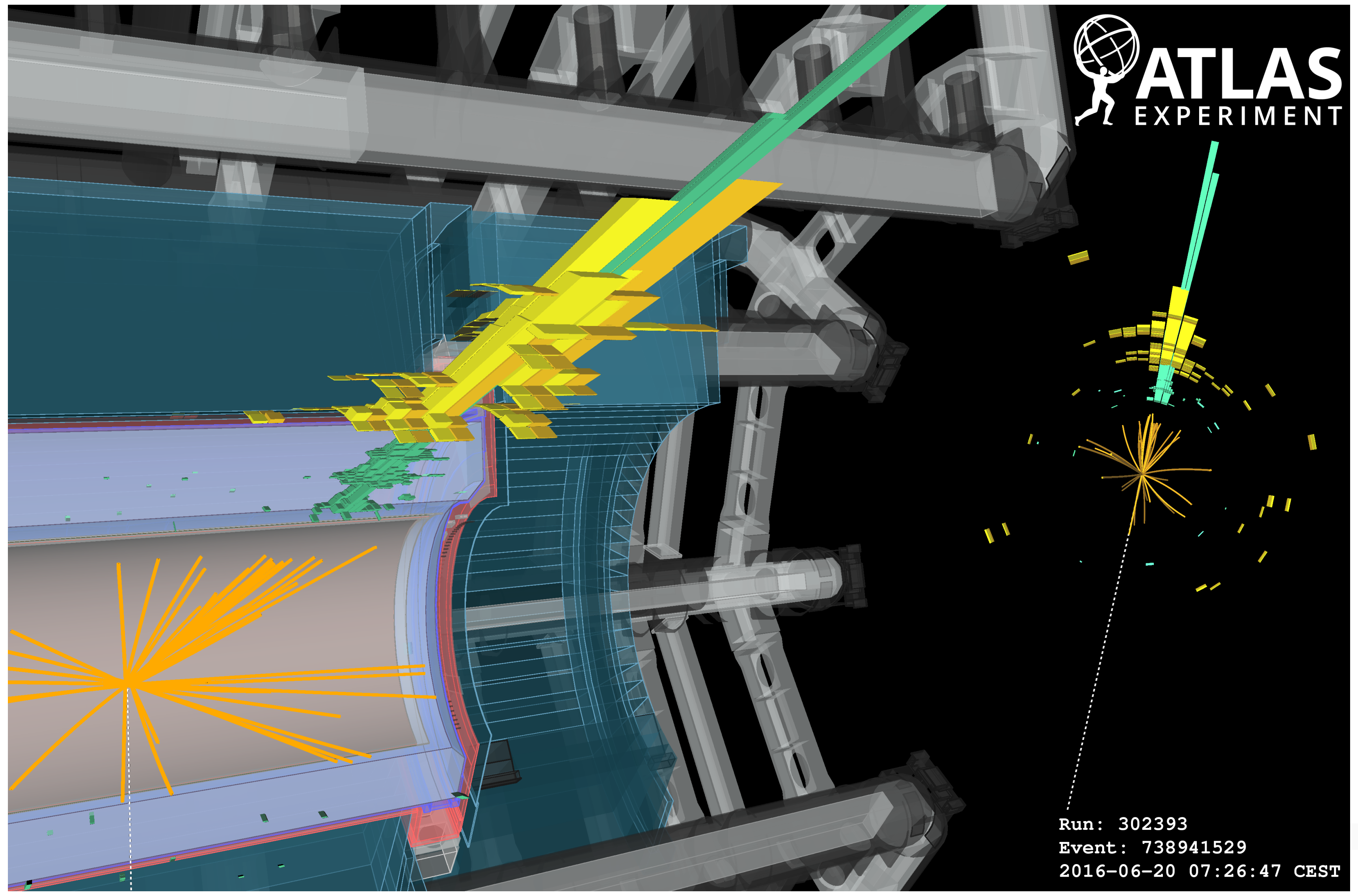
CMS Mono jet search prospects

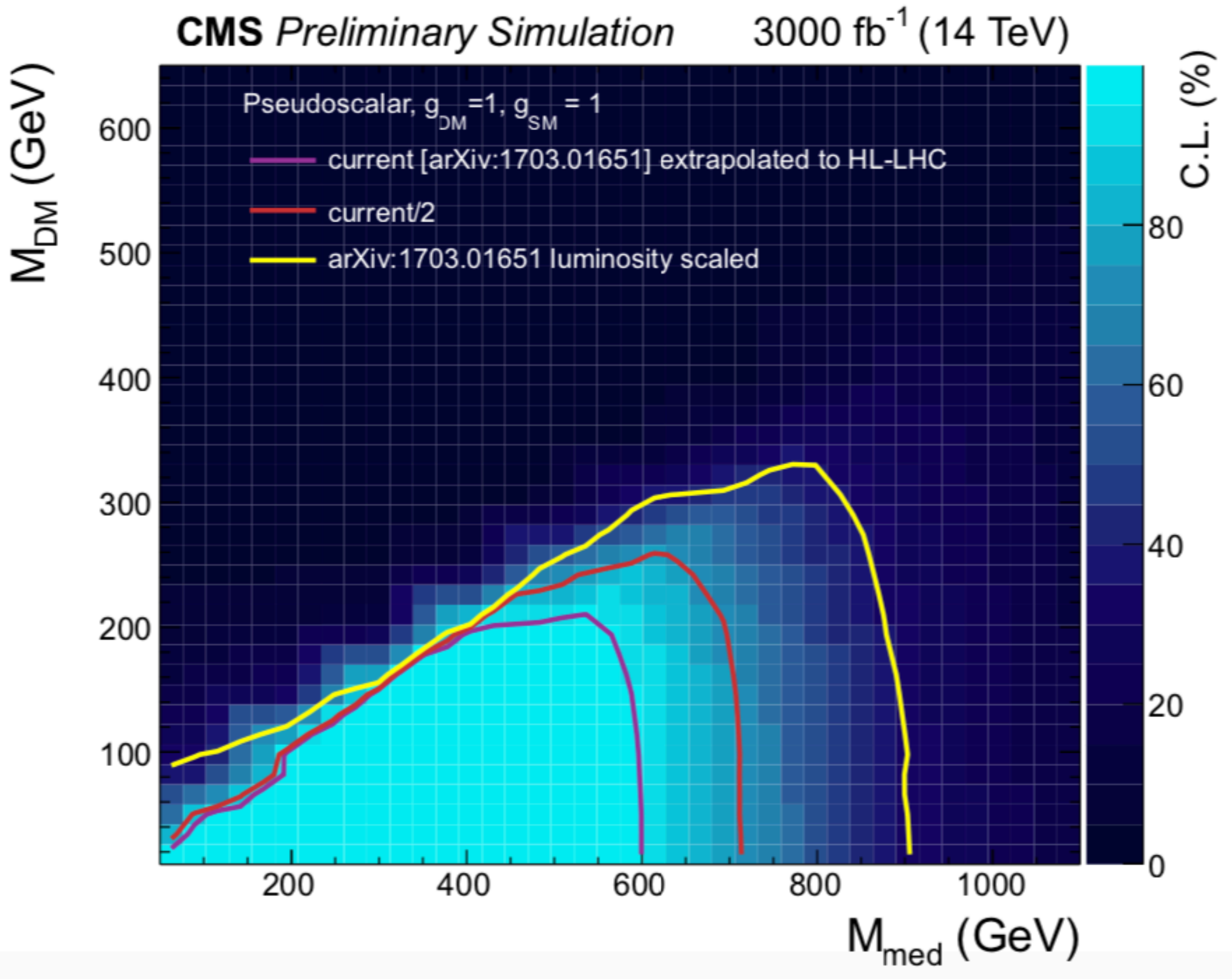
CMS FTR-16-05





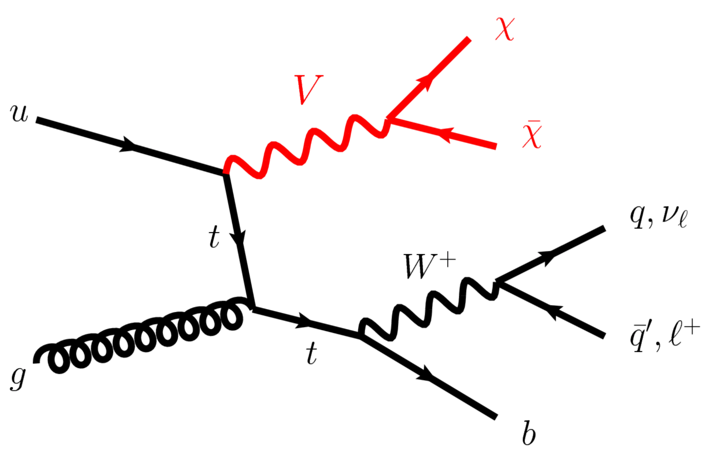
Simplified model interpretation with specific assumptions on the mediator couplings

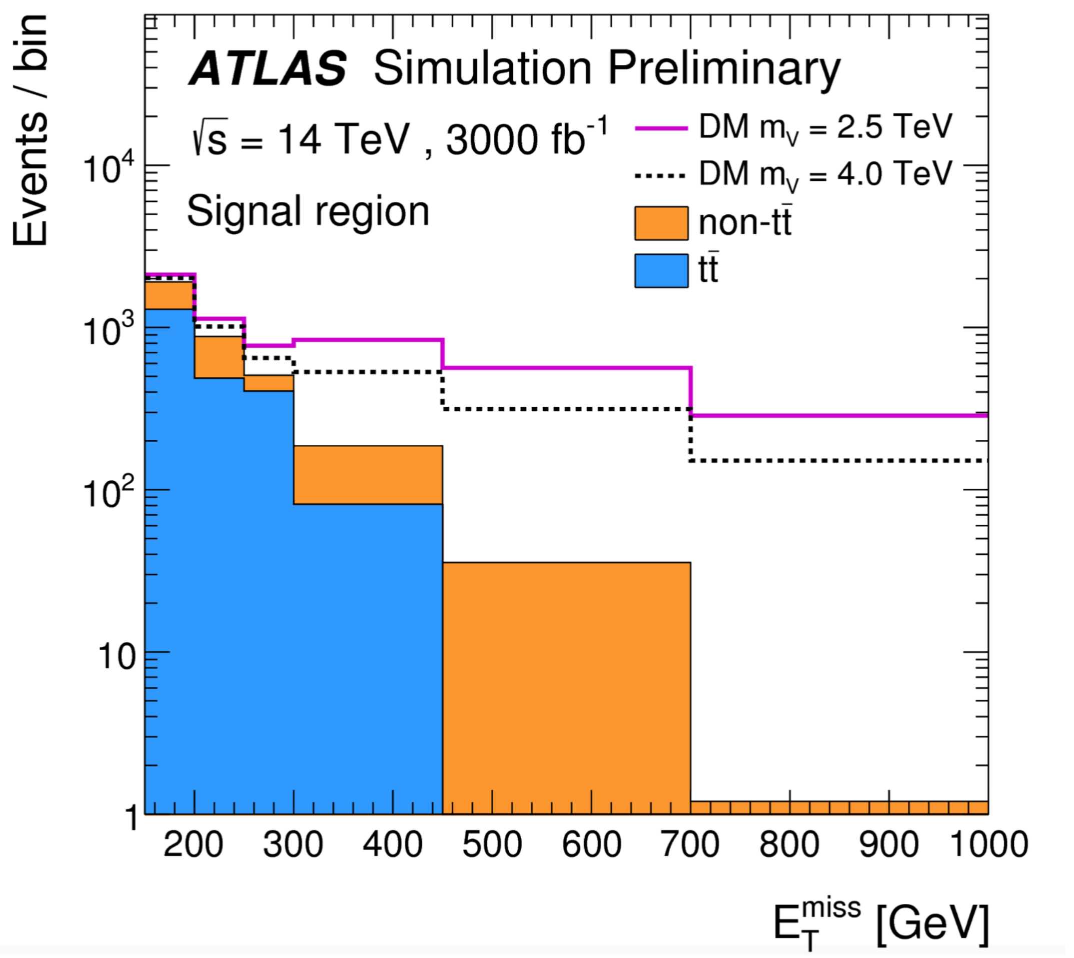


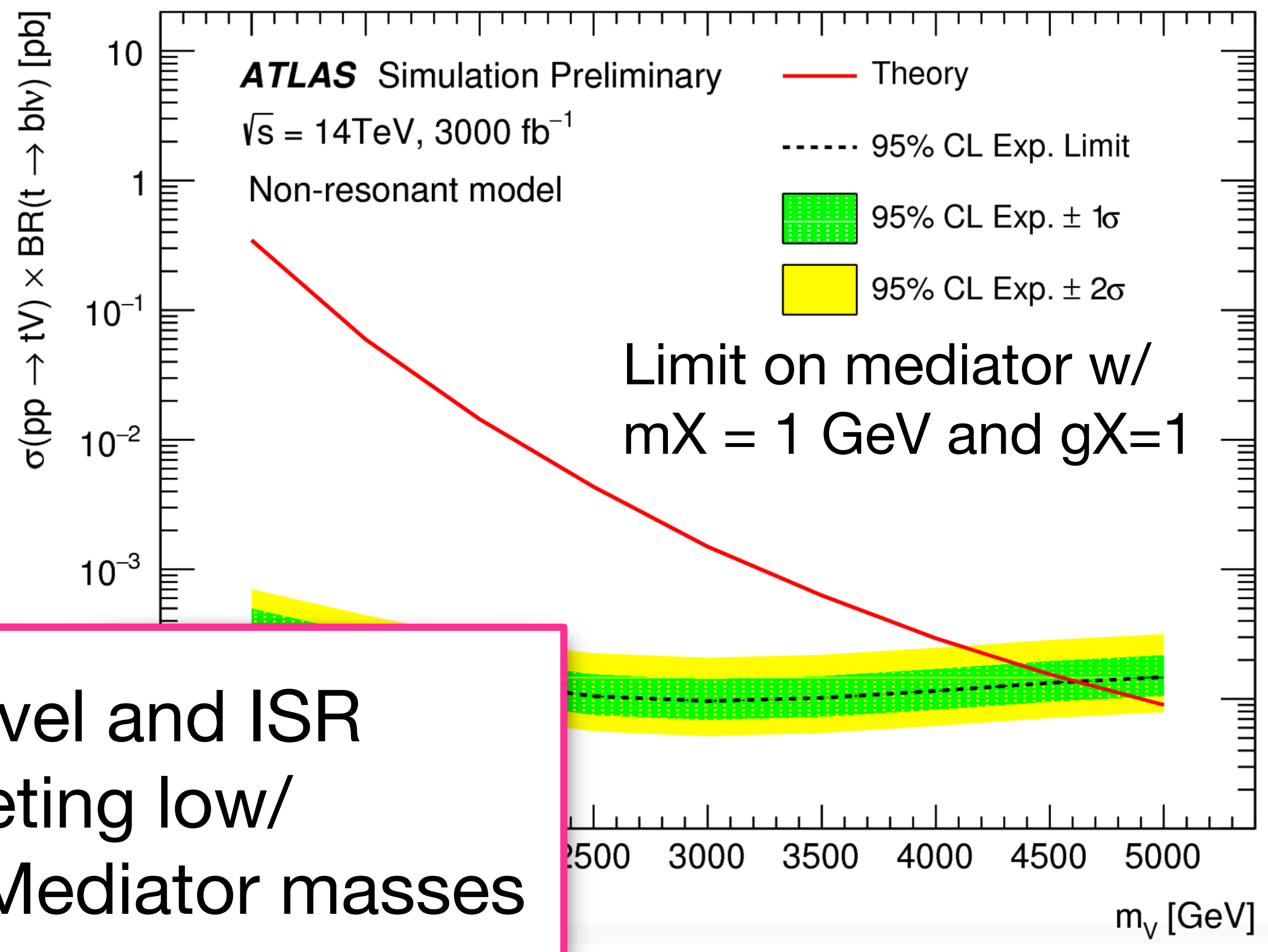


ATLAS mono-top search

In the semi-semi-leptonic top decays channels





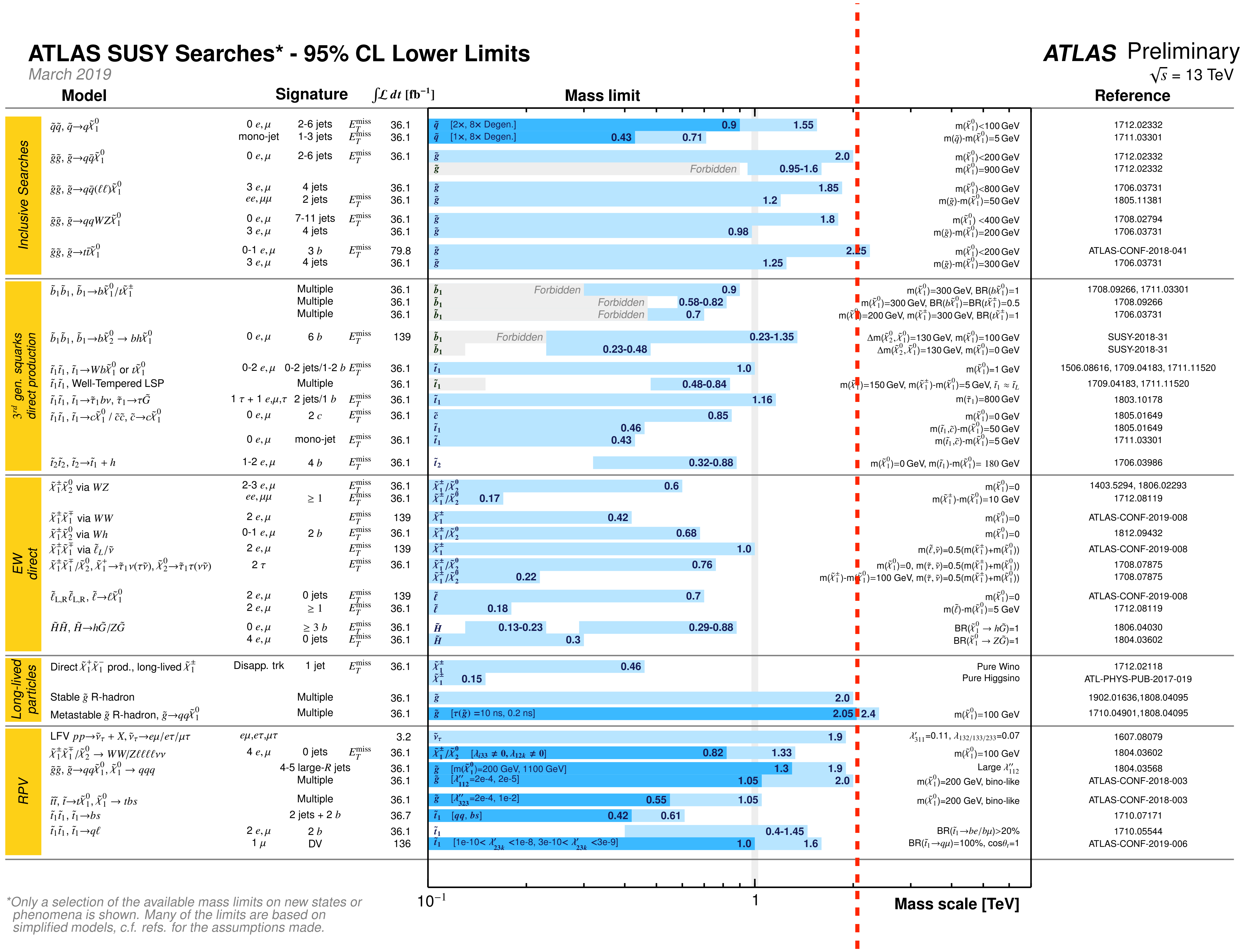


Limit on mediator w/ mX = 1 GeV and gX=1

Also trigger level and ISR analyses targeting low/ intermediate Mediator masses

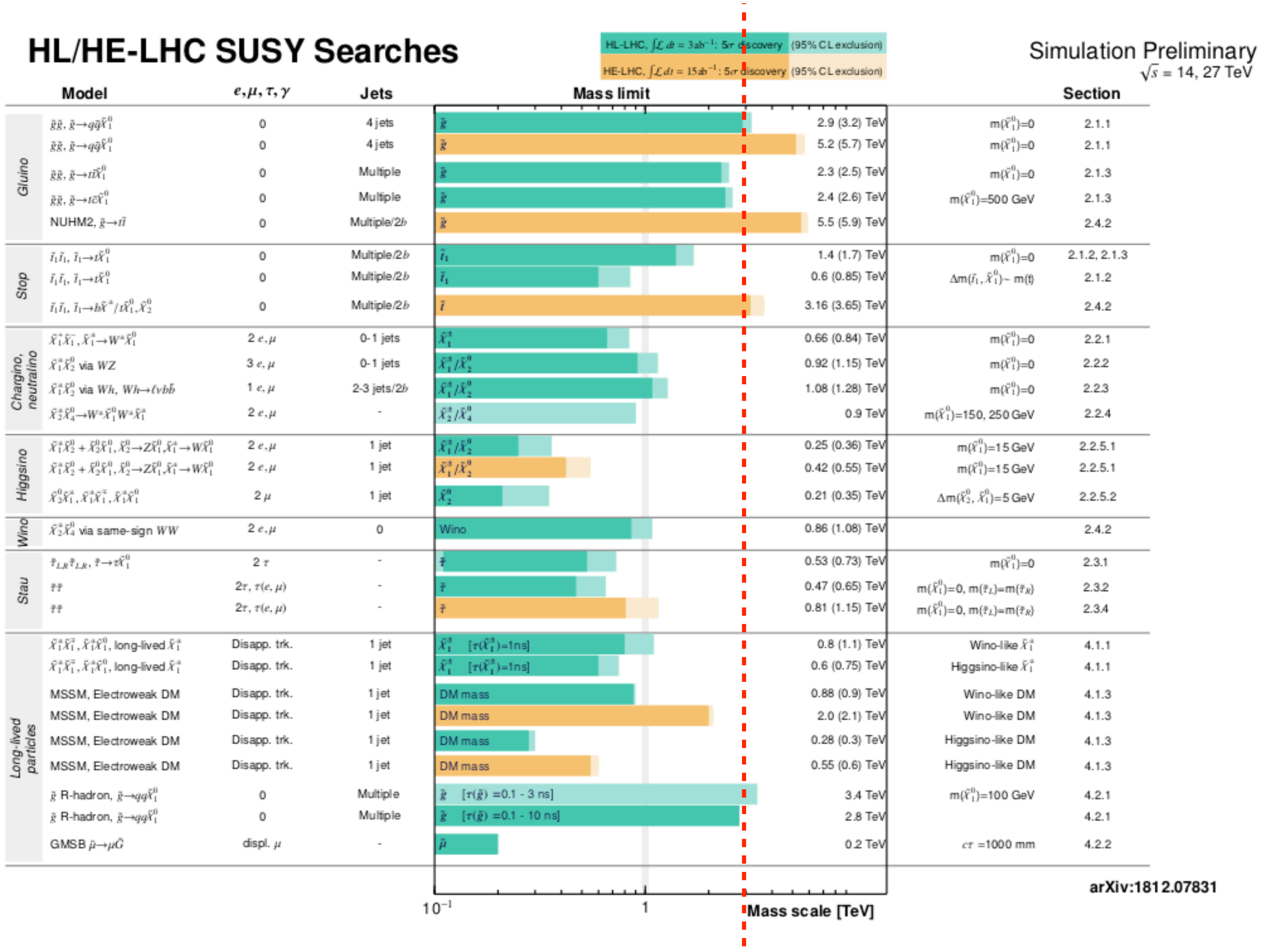
Very Large Number of Searches

(in large variety of topologies and models)



2 TeV

Example from ATLAS (same for CMS)

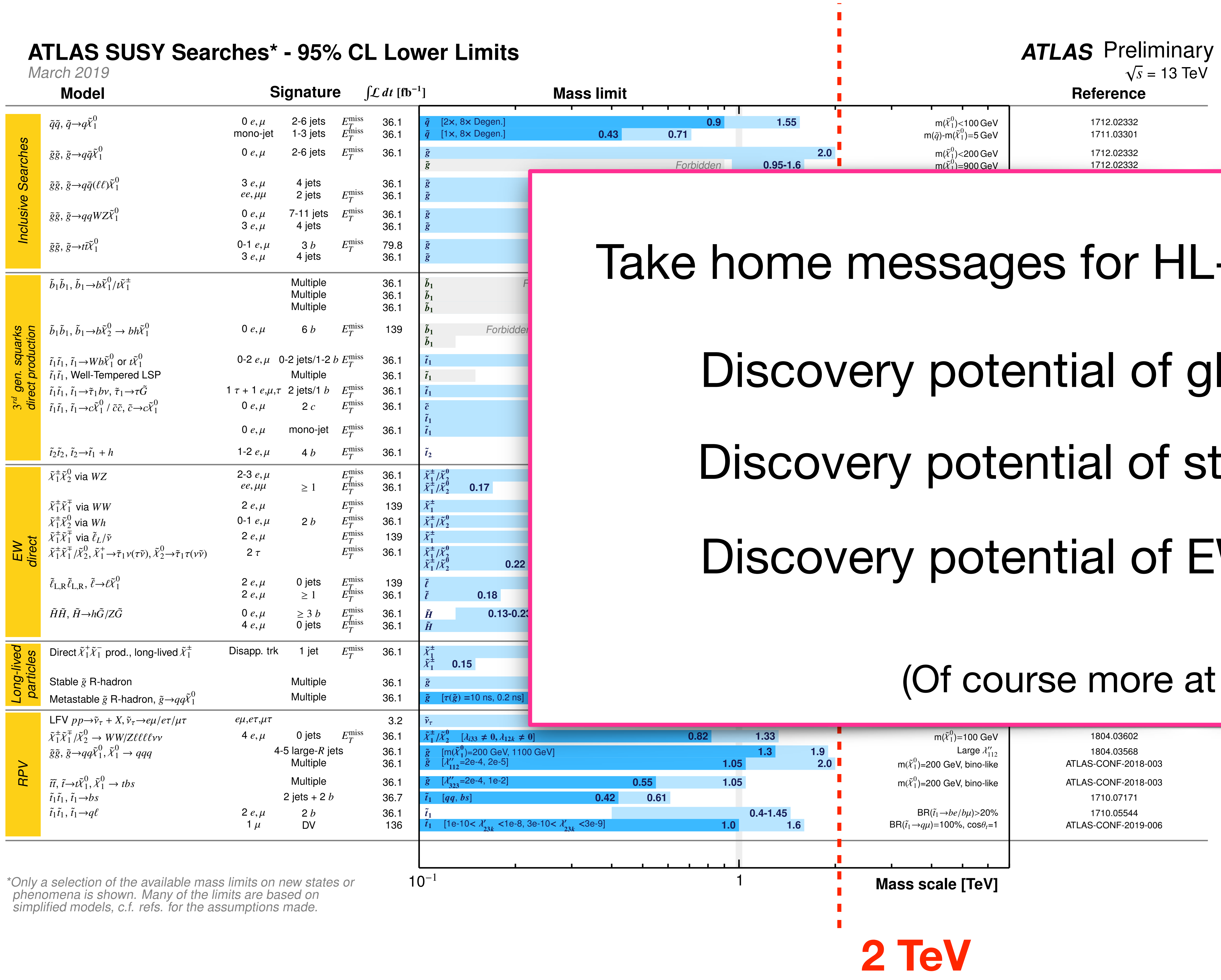


3 TeV

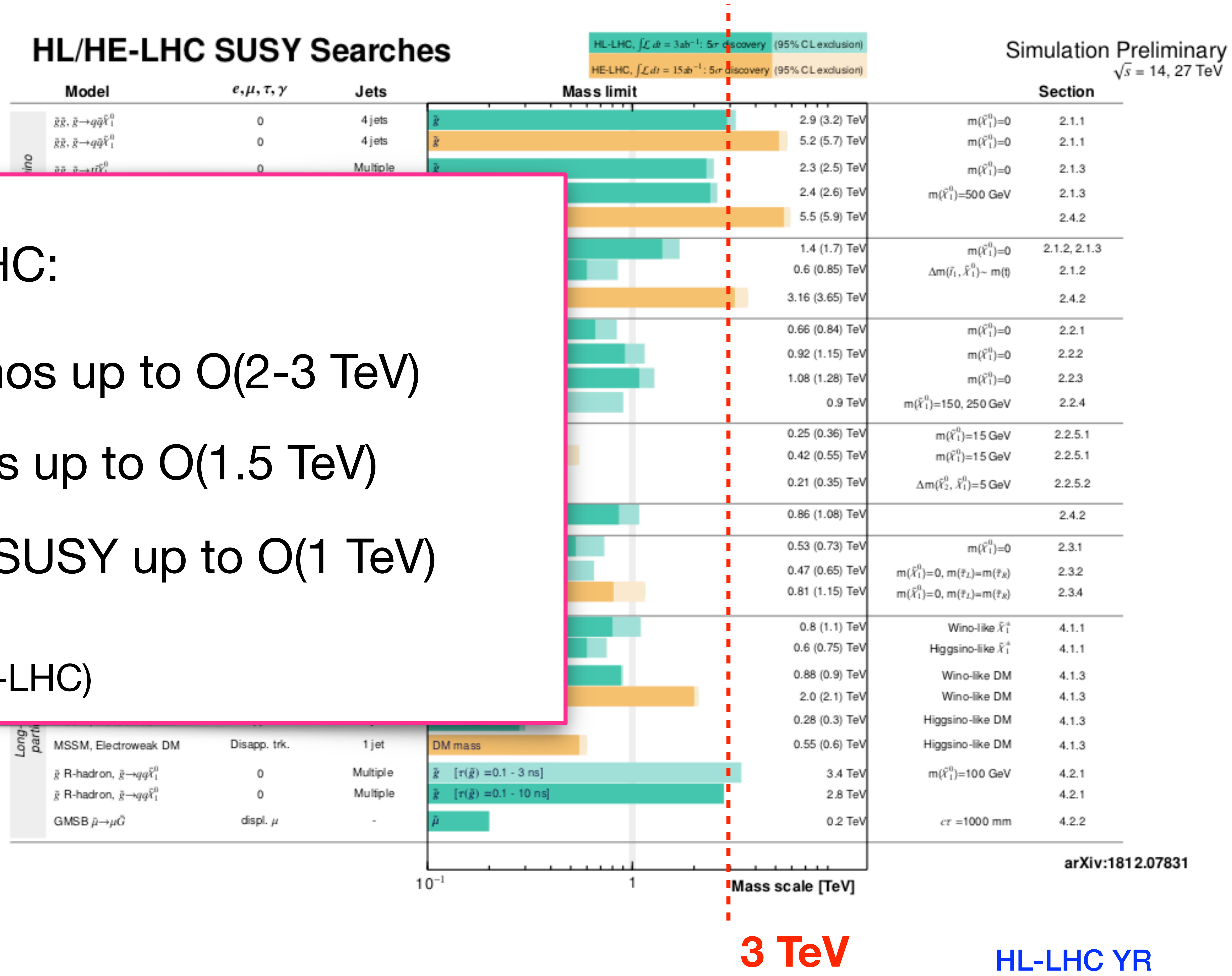
HL-LHC YR
1812.07831

Very Large Number of Searches

(in large variety of topologies and models)



Example from ATLAS (same for CMS)



HL-LHC YR
1812.07831

Take home messages for HL-LHC:

Discovery potential of gluinos up to O(2-3 TeV)

Discovery potential of stops up to O(1.5 TeV)

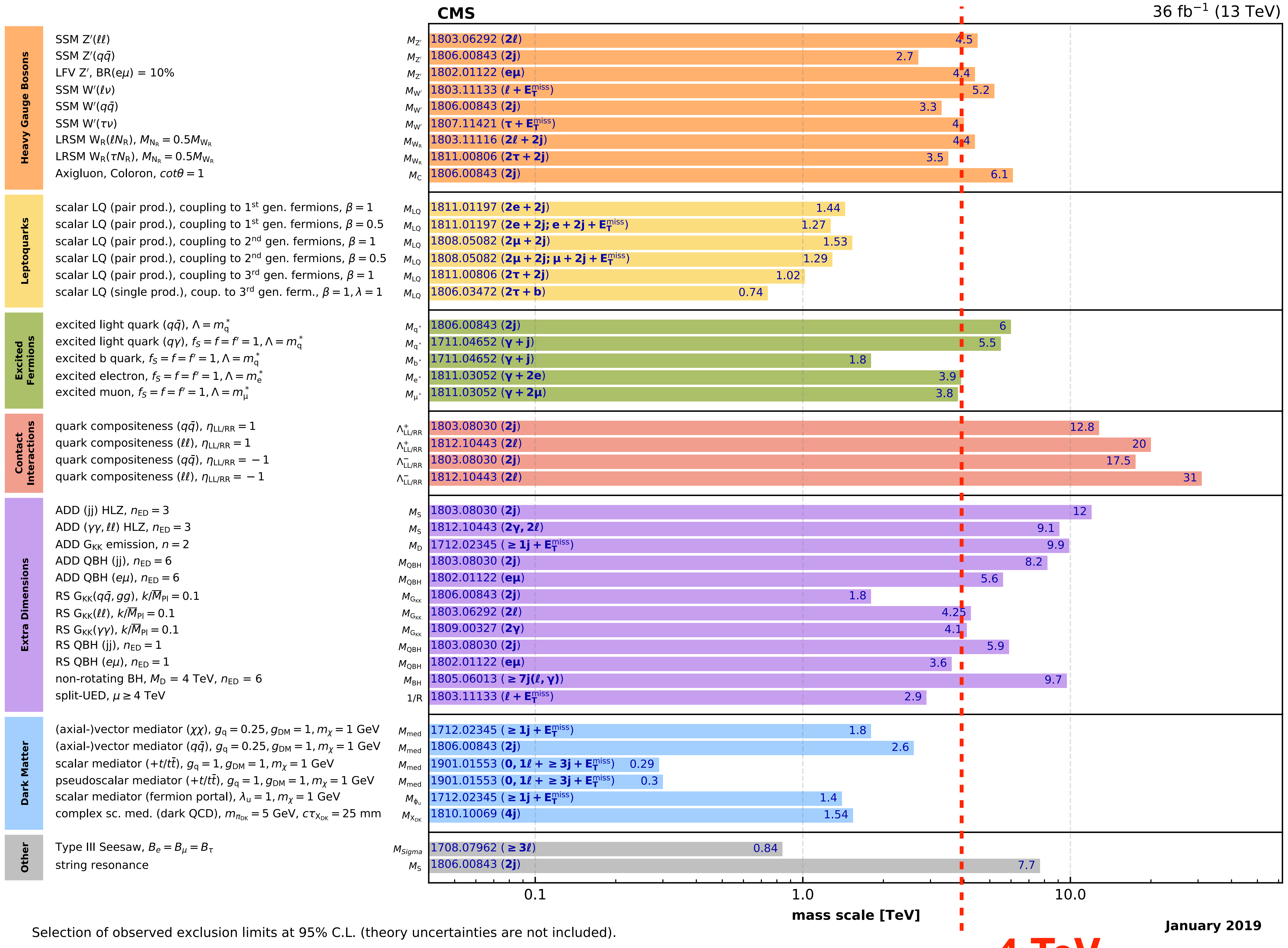
Discovery potential of EW SUSY up to O(1 TeV)

(Of course more at HE-LHC)

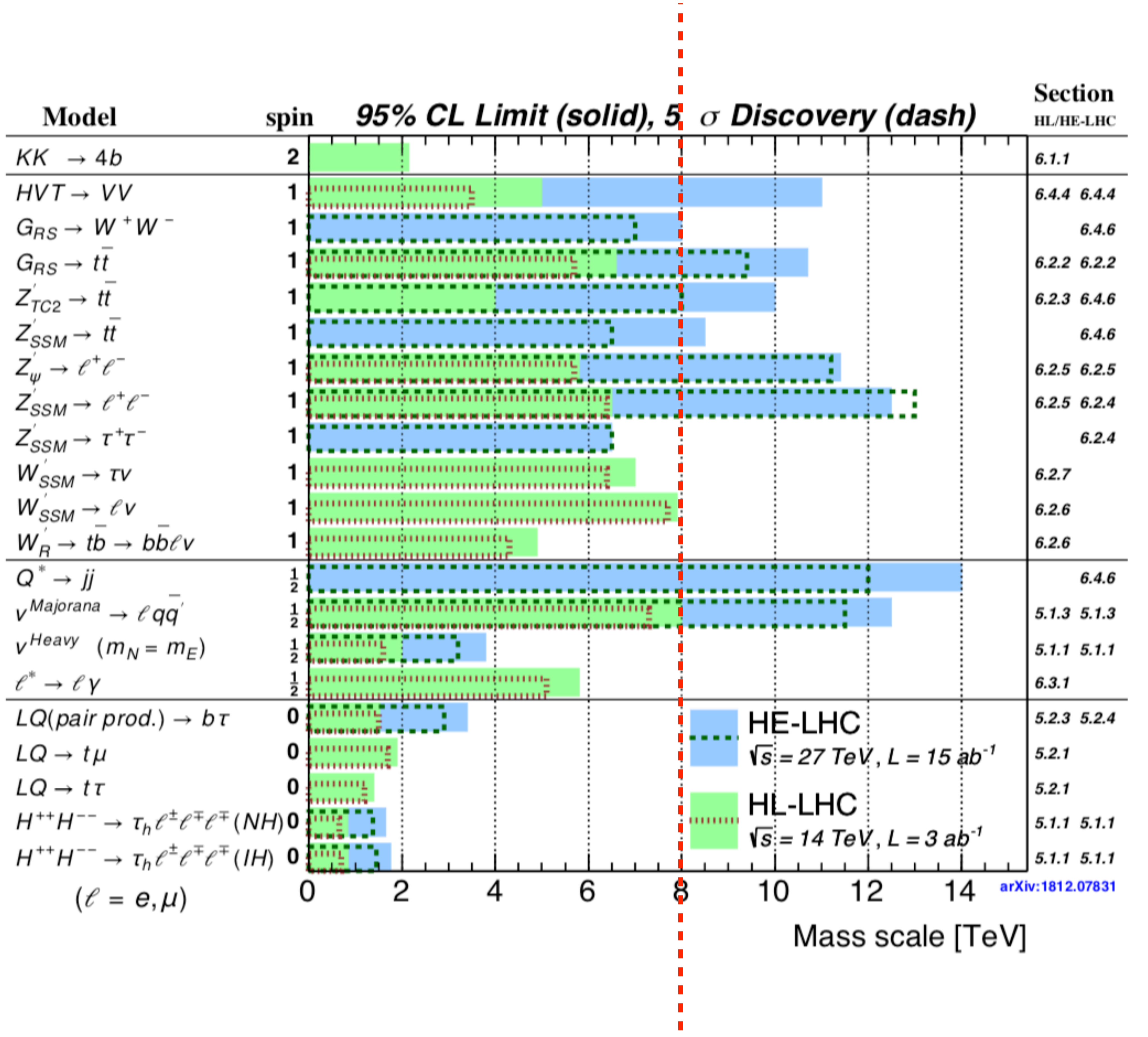
Very Large Number of Searches

(in large variety of topologies and models)

Overview of CMS EXO results



4 TeV



8 TeV

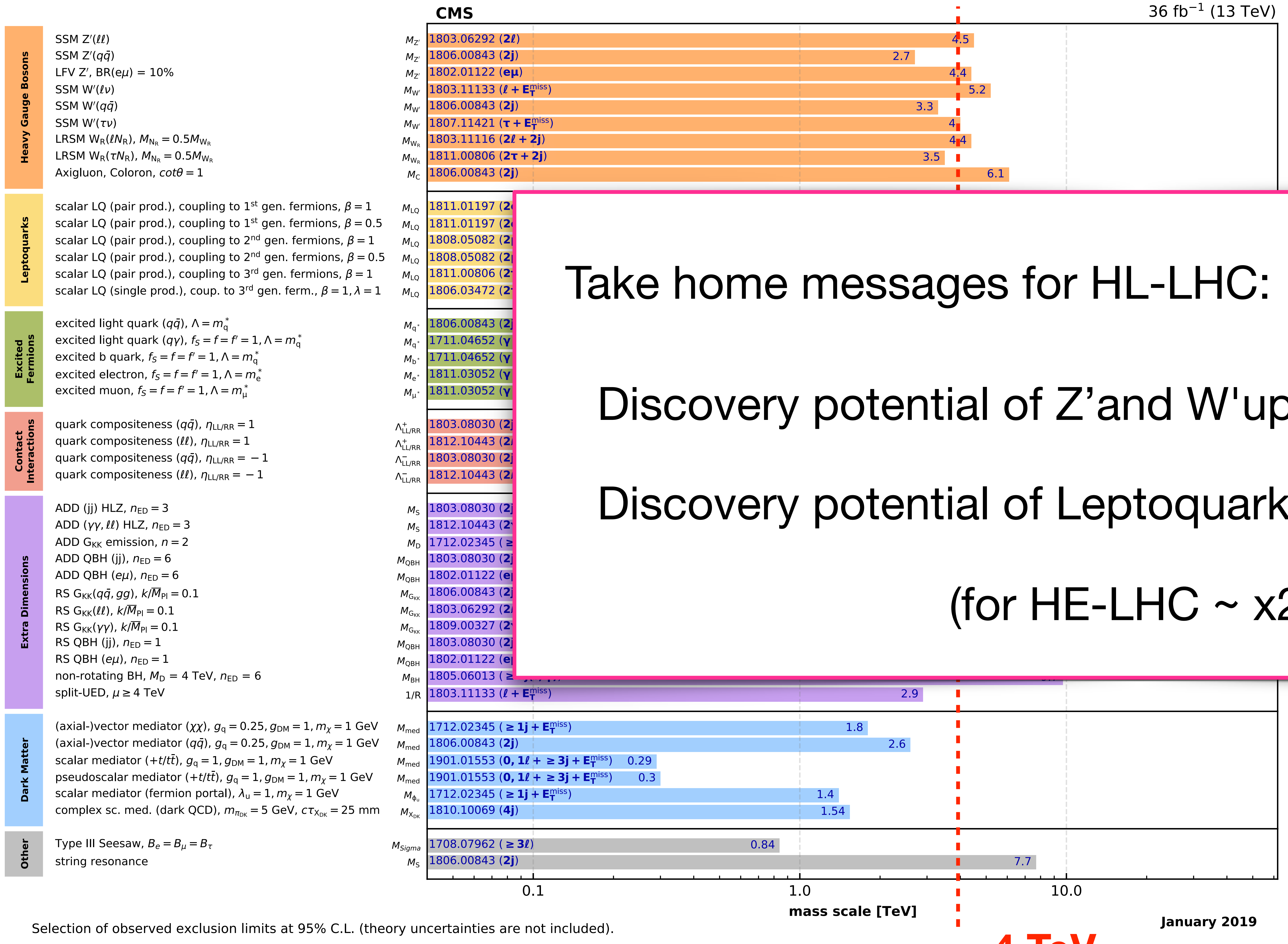
Example from CMS (similar for ATLAS)

HL-LHC YR
1812.07831

Very Large Number of Searches

(in large variety of topologies and models)

Overview of CMS EXO results

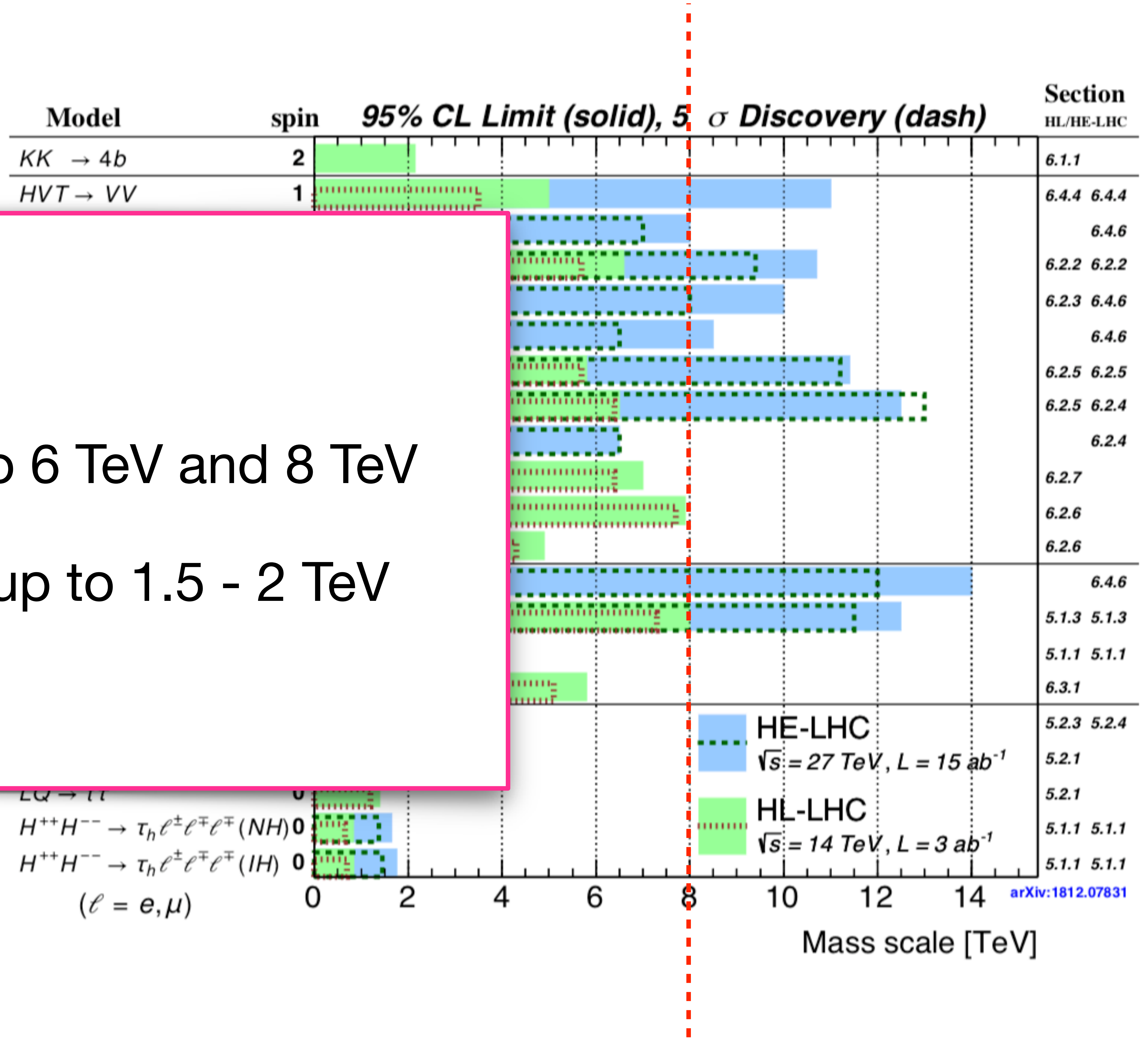


Take home messages for HL-LHC:

Discovery potential of Z’and W'up to 6 TeV and 8 TeV

Discovery potential of Leptoquarks up to 1.5 - 2 TeV

(for HE-LHC ~ x2)



Example from CMS (similar for ATLAS)

HL-LHC YR
1812.07831

Unconventional Signatures

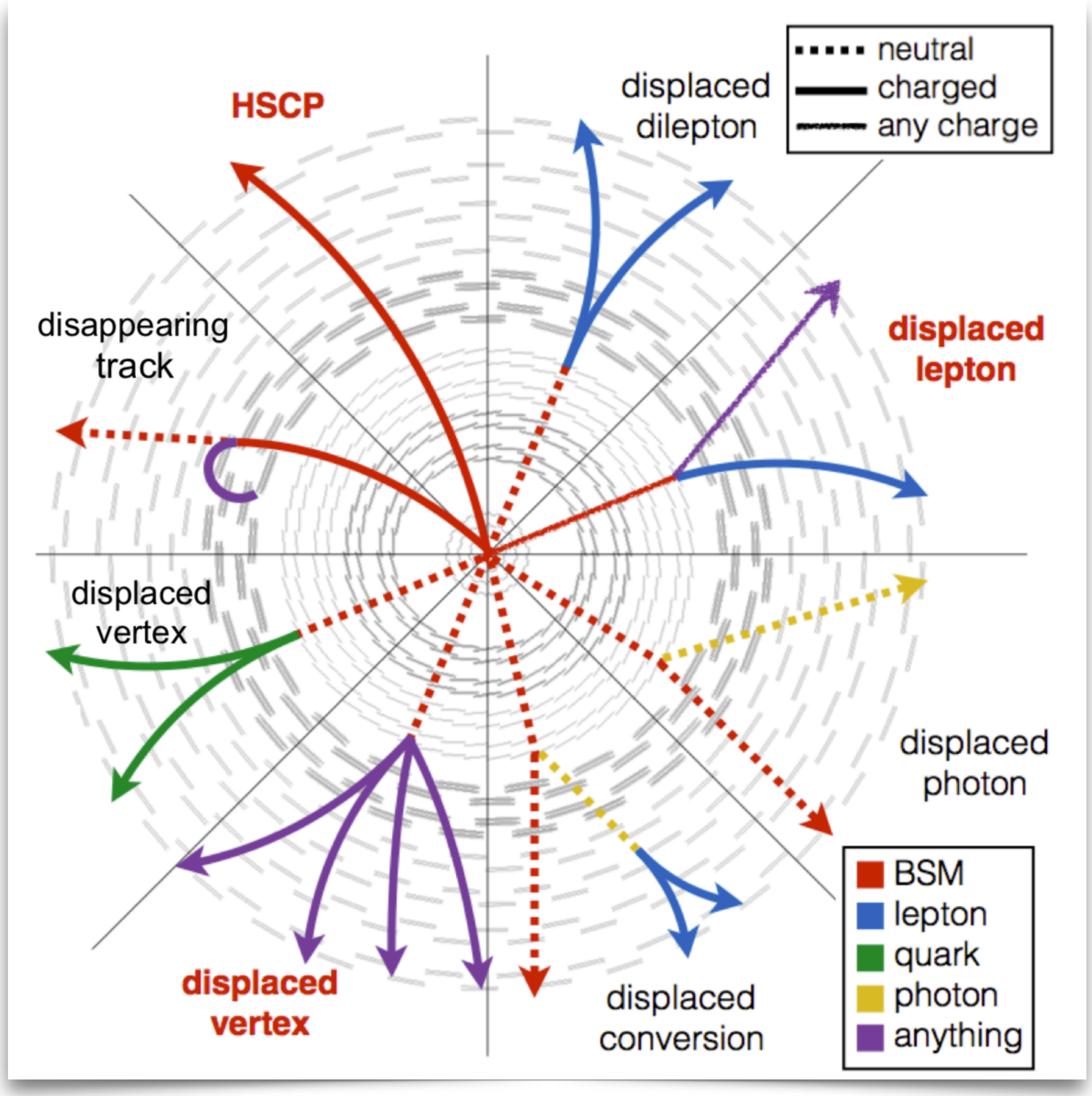
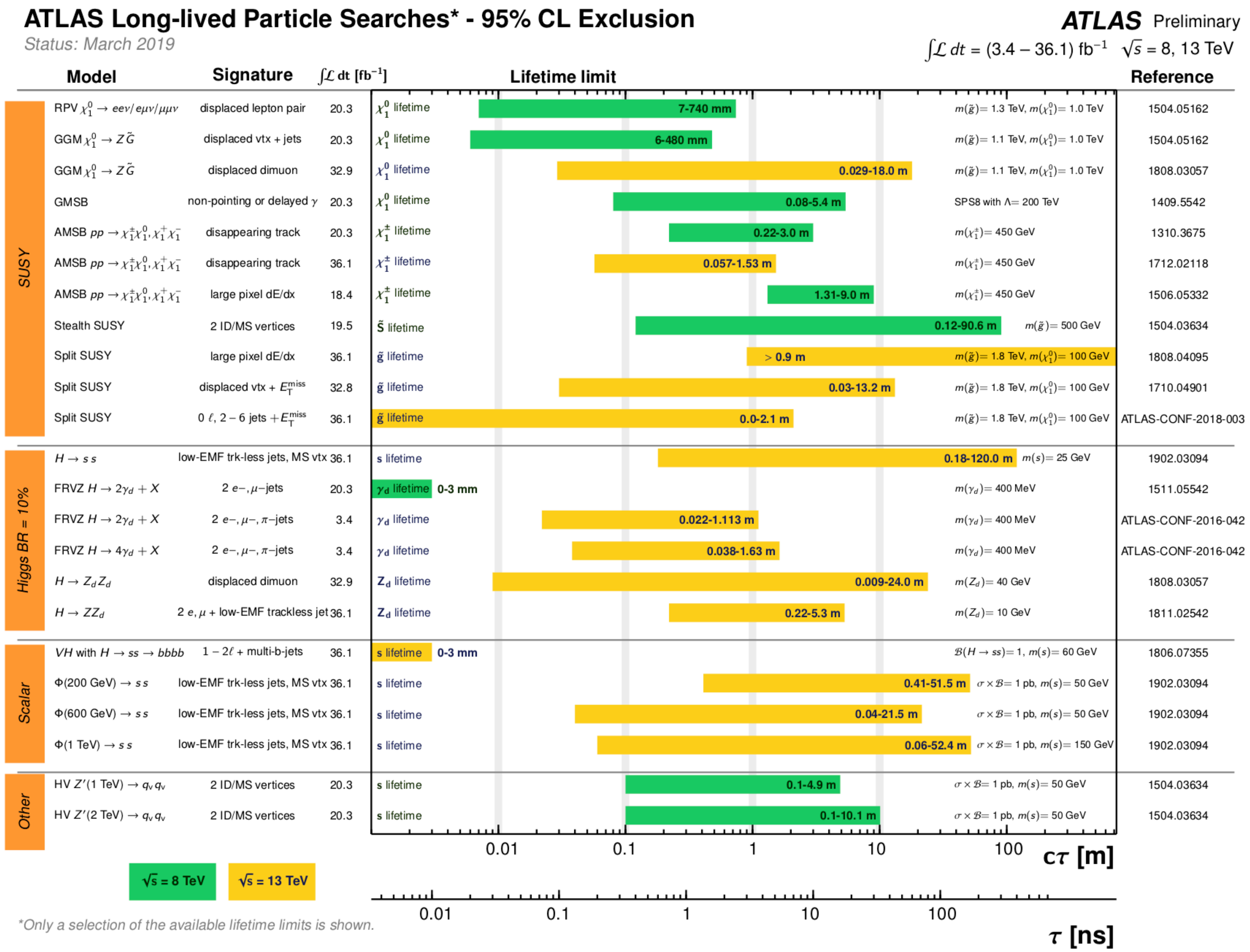


Image from J. Antonelli@ICHEP 2016

Many extensions of the Standard Model predict new particles that are long lived heavy (neutral and charged) and can decay after several cm or even meters.



Example of ATLAS (same for CMS)

Difficult signatures requiring specific reconstruction and trigger!

Summary and Conclusions

- The LHC has successfully reached the energy and luminosity frontiers.
- Landmark results: the **Higgs boson** (Standard Model like) and **So far** nothing else! However for most search analyses Run 2 data with only 35-80 fb^{-1} have been published although an already good number of full Run 2 Results have been presented at winter conferences.
- A vast program in precision Standard Model and Higgs measurements at LHC is being developed, with a host of new ideas and large number of more precise predictions (where precision is also key in direct searches).
- A milestone investigation of the HL-LHC (and HE-LHC) full potential has been done and published for the European Strategy for Particle Physics.
- Only a milestone, but showed the **remarkable number of opportunities for physics at the LHC**.

Backup

Recent Physics Studies

Searches for LLP	ATL-PHYS-PUB-2018-033
Searches for Charginos	ATL-PHYS-PUB-2018-031
Tau to 3 muons	ATL-PHYS-PUB-2018-032
Tri-boson production	ATL-PHYS-PUB-2018-030
Electroweak ZZ production	ATL-PHYS-PUB-2018-029
HH to 4b resonances	ATL-PHYS-PUB-2018-028
Four tops	ATL-PHYS-PUB-2018-027
W mass measurements	ATL-PHYS-PUB-2018-026
DM searches in mono-top	ATL-PHYS-PUB-2018-024
VBS WZ production	ATL-PHYS-PUB-2018-023
EW boson scattering	ATL-PHYS-PUB-2018-022
Stop searches	ATL-PHYS-PUB-2018-021
VH(cc) at HL-LHC	ATL-PHYS-PUB-2018-016
Higgs to dimuon	ATL-PHYS-PUB-2018-006
Bs to dimuon	ATL-PHYS-PUB-2018-005
CP Analysis Prospects	ATL-PHYS-PUB-2019-008

Displaced track jets	CMS-PAS-FTR-18-018
Indirect Self coupling via ttH	CMS-PAS-FTR-18-020
SUSY direct stau	CMS-PAS-FTR-18-010
Invisible Higgs decays	CMS-PAS-FTR-18-016
Higgs boson properties	CMS-PAS-FTR-18-011
Same sign WW VBS	CMS-PAS-FTR-18-005
Scalar Leptoquarks	CMS-PAS-FTR-18-008
Dark photons	CMS-PAS-FTR-18-002
Mono-Z search for DM	CMS-PAS-FTR-18-007
Top FCNC	CMS-PAS-FTR-18-004
Di-Higgs resonance in VBF	CMS-PAS-FTR-18-003

Many more studies and notes to come for the completion of the Yellow Reports.

Performance Achievements and Goals (I): Trigger

	Run 1	Run 2	HL-LHC (ATLAS/CMS)
Single e (isolated)	25	27	22 / 27
Single μ (isolated)	25	27	20 / 18
Single photon	120	140	120*
Two photons	25,25	25,25	25, 25 / 22,16
Two taus	40,30	40,30	40,30 / 56,56
Four jets	45	45	45 /65
HT	700	700	375 / 350
MET	150	200	200

Numbers from ATLAS (very similar in CMS) *ATLAS

- Thresholds approximately unchanged Run 1 to Run 2 (changes in total bandwidth and different selection criteria, e.g. isolation)

- Towards HL-LHC expect even improvements w.r.t. Run 2, key aspects:
  - Increase readout rate 750-1000 kHz (currently 100 kHz)
  - Increased latency
  - Enhanced data processing capabilities, storage rate up to 10 kHz (currently 1-2 kHz)

Performance Achievements (II): Object Reconstruction

Electrons, photons and muons

- Multivariate methods used for identification (at many levels) and calibration
- In-situ calibration using Z, W, J/Psi and Upsilons

Jets/MET

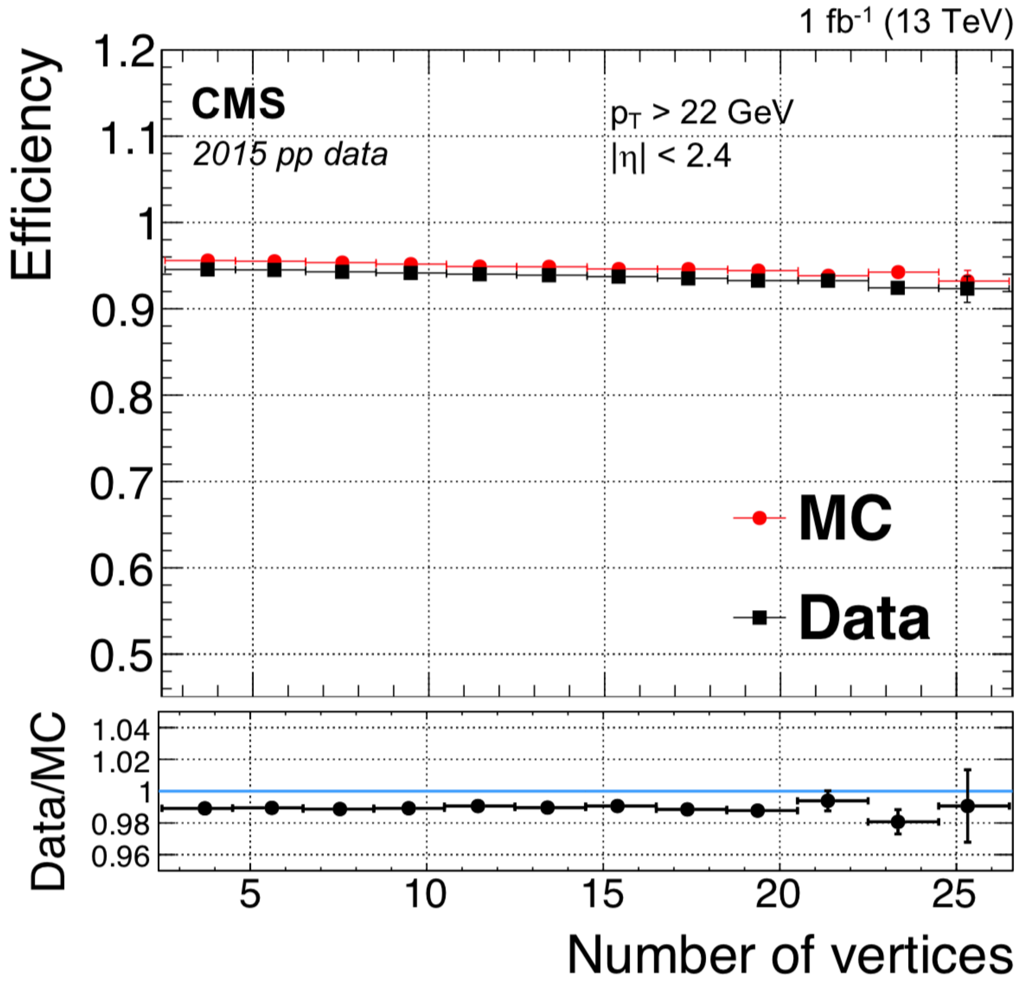
- JES in situ uncertainty reach ~1% level already (central and intermediate pT range) – using Z, γ and multi-jets.
- PU mitigation using associated tracks (jets and soft term in MET)

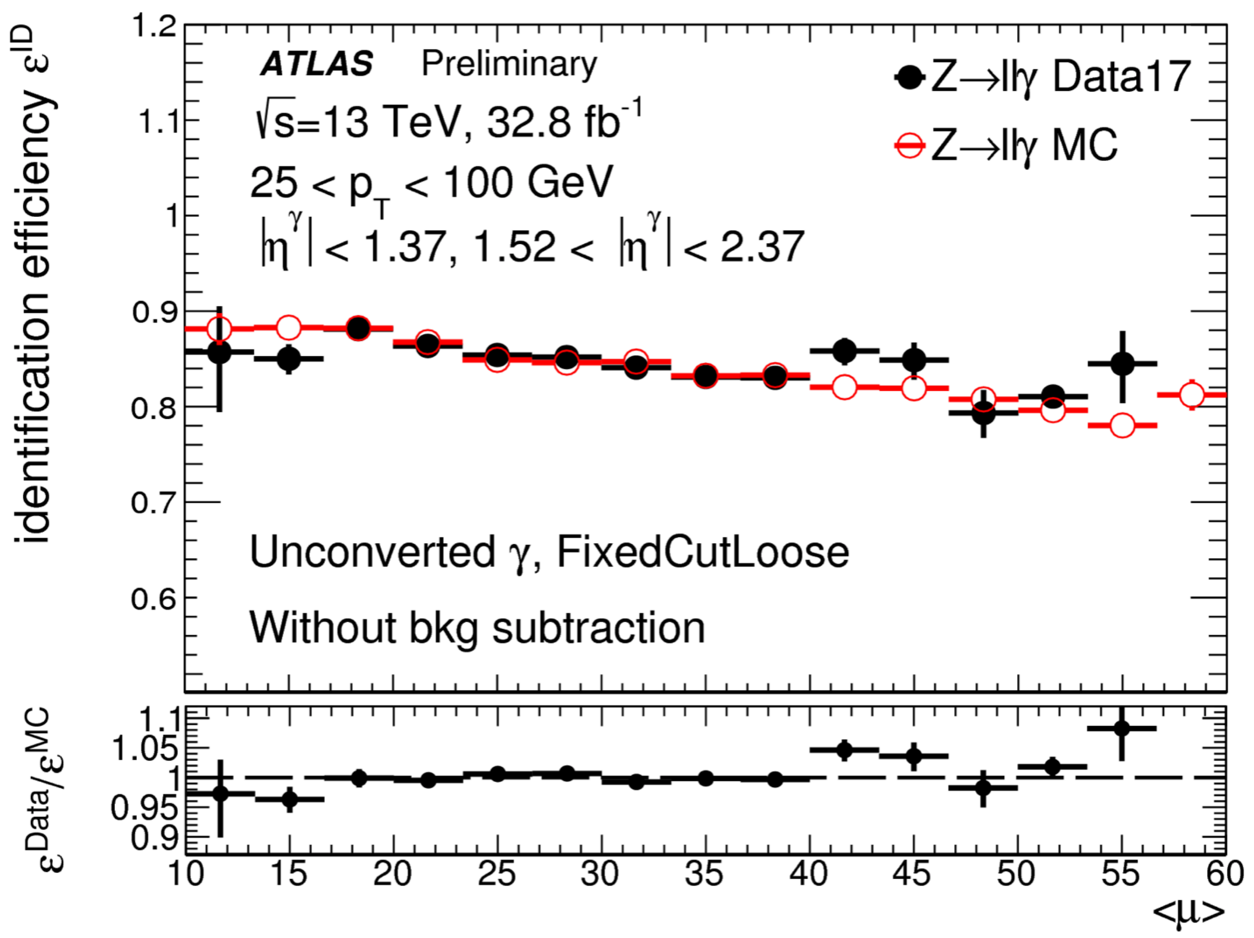
Taus

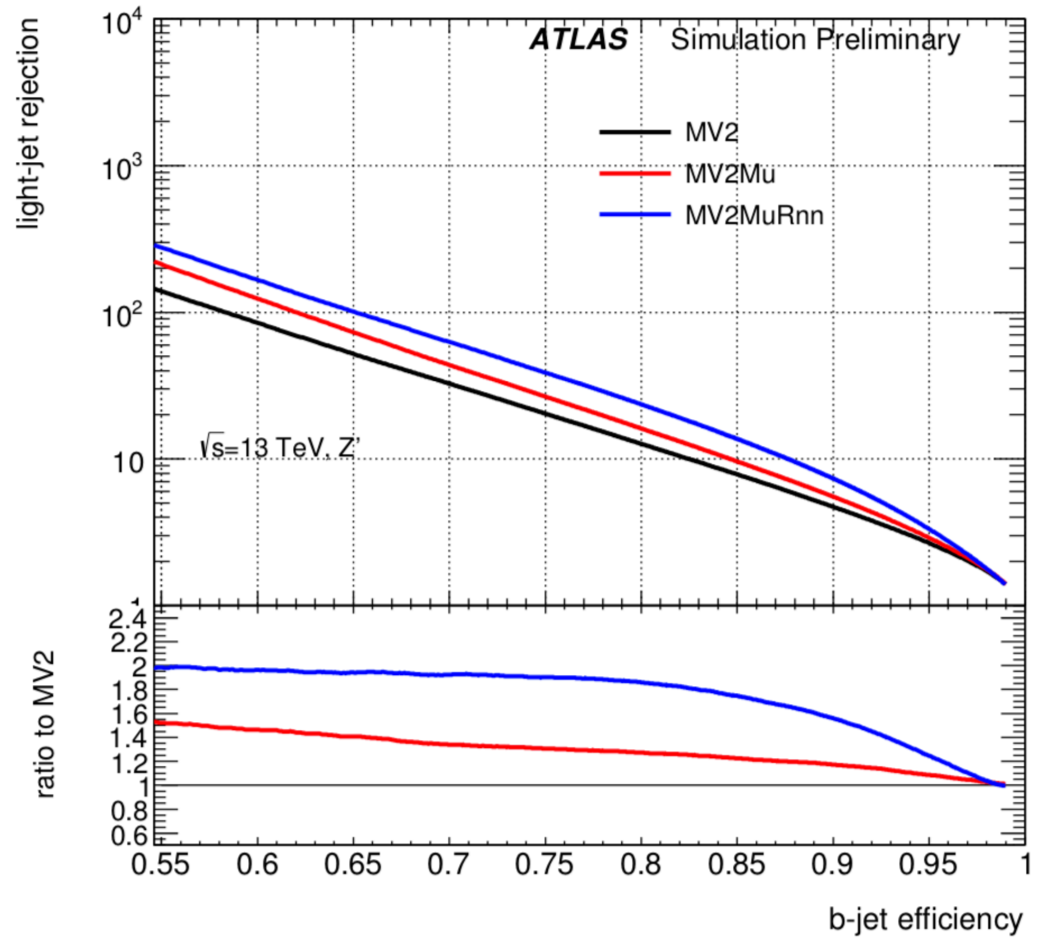
- BDT based identification (70% eff. and ~50 rej.)
- In-situ calibration based on Z events

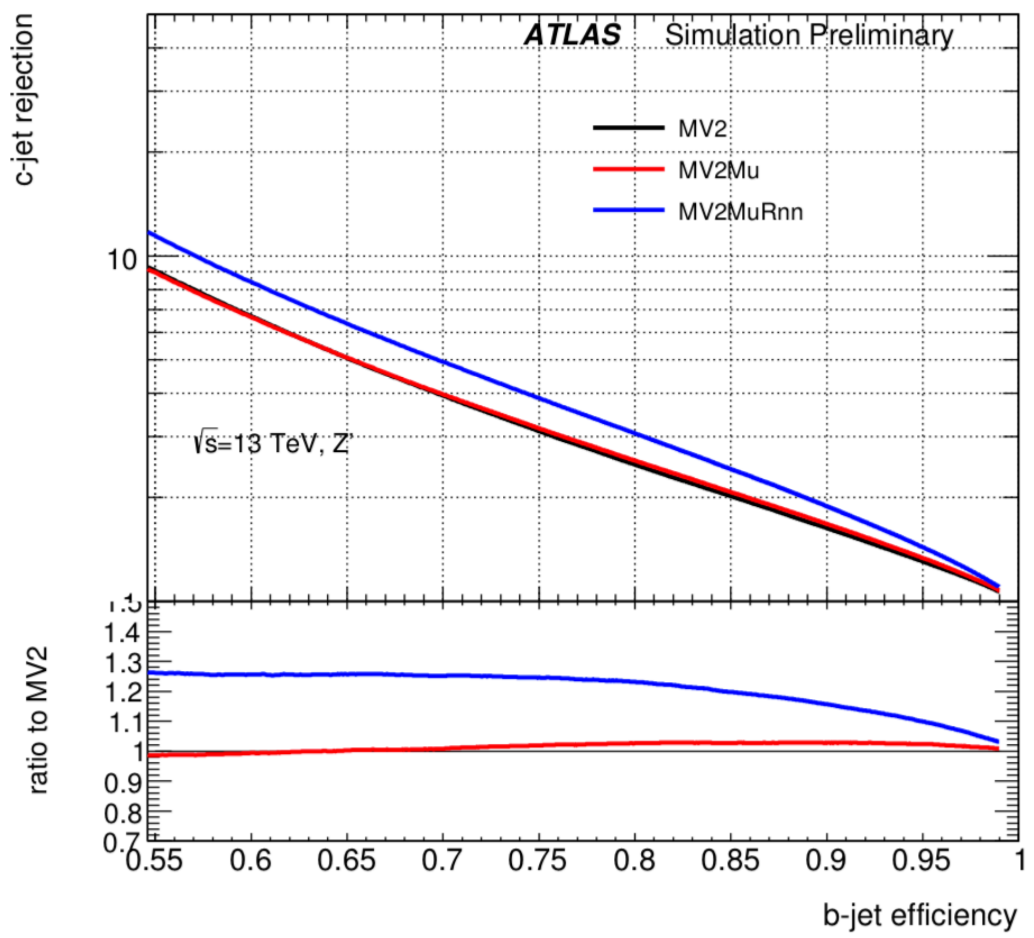
B-jets

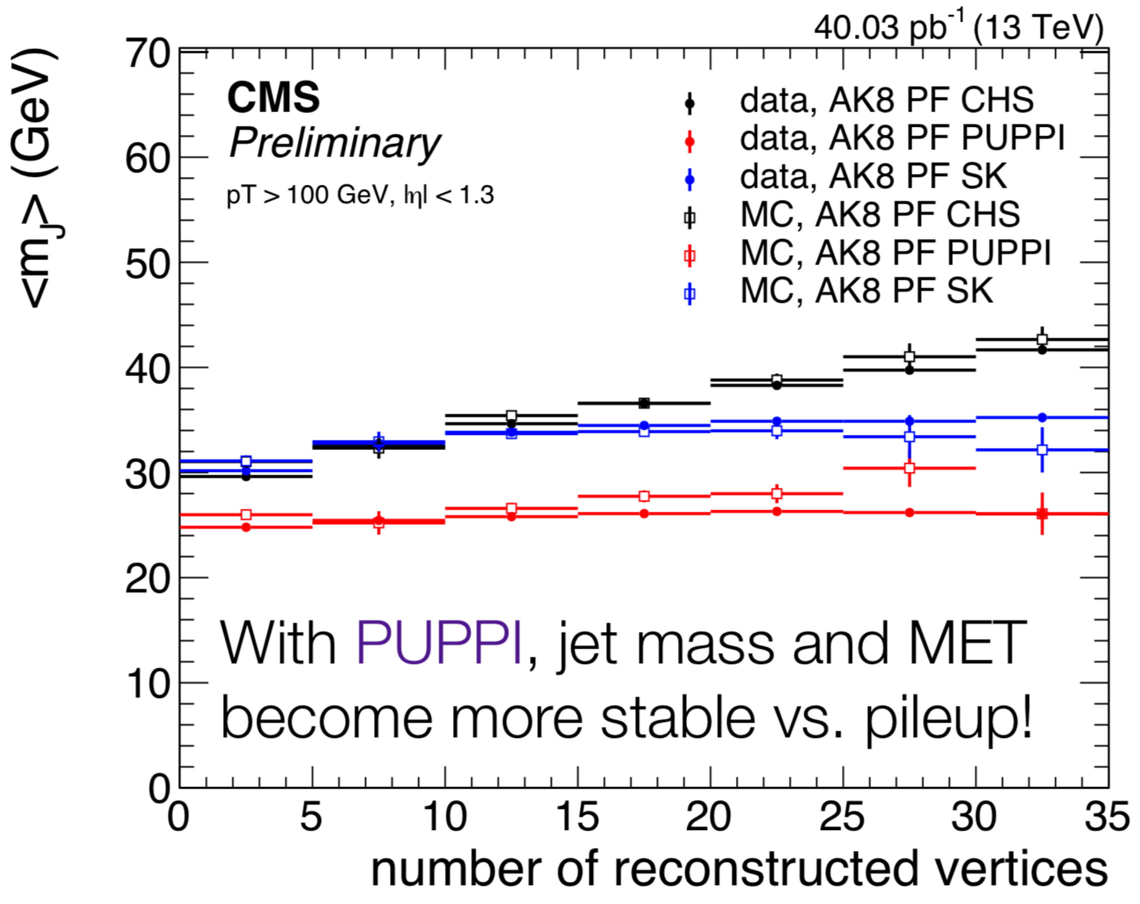
- In-situ calibration of b-tag efficiency (using top events and/or diet events)
- New Machine Learning Techniques bring non negligible improvements

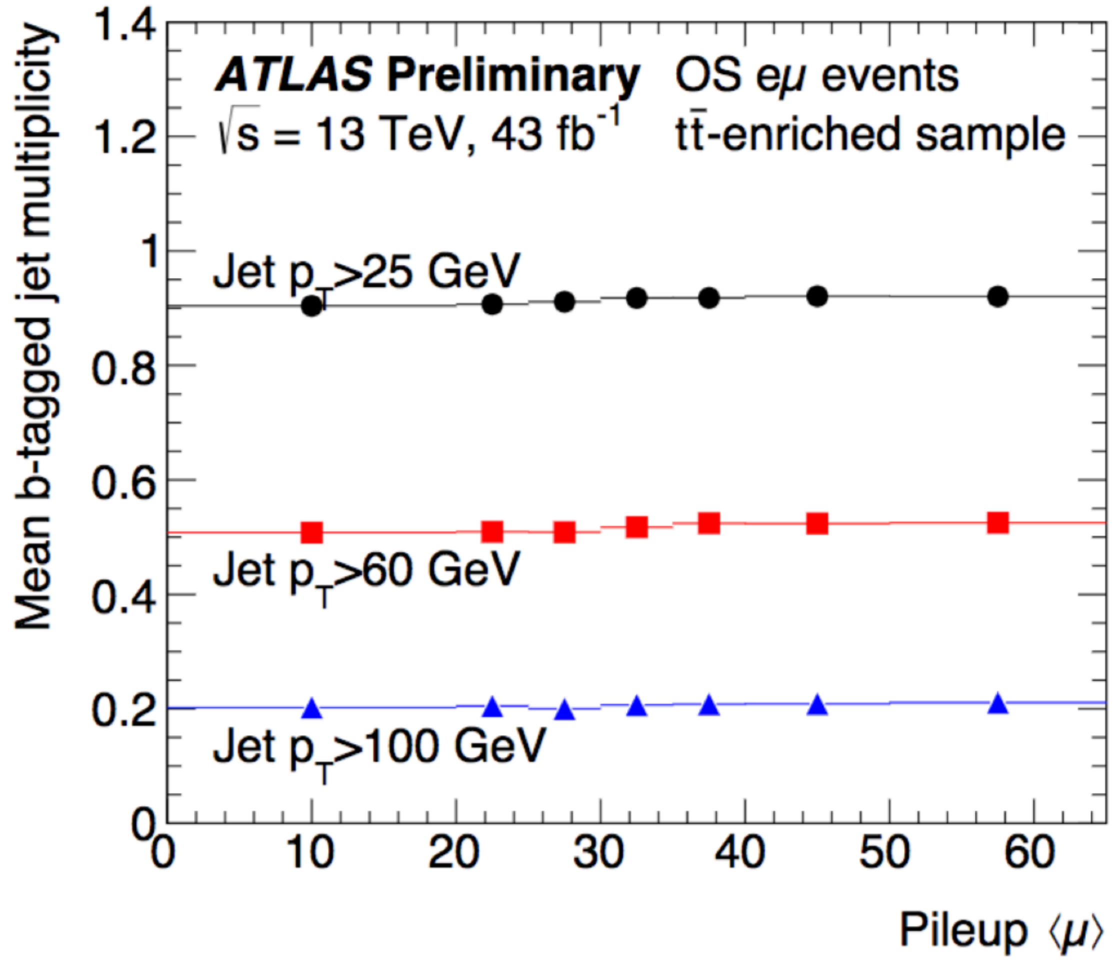












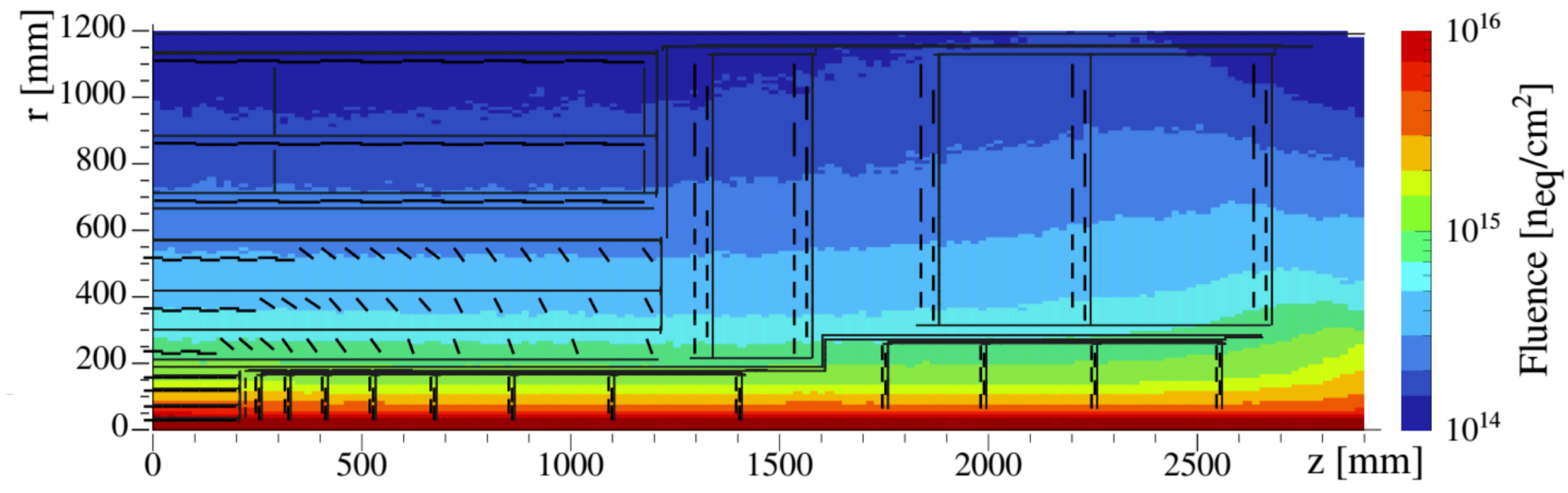
Reconstruction performance so far robust to PU

Performance Goals (III): Experimental Aspects

- The target performance for the upgrades is to perform as well or better than the current experiment's and its reconstruction performance in the actual PU environment.

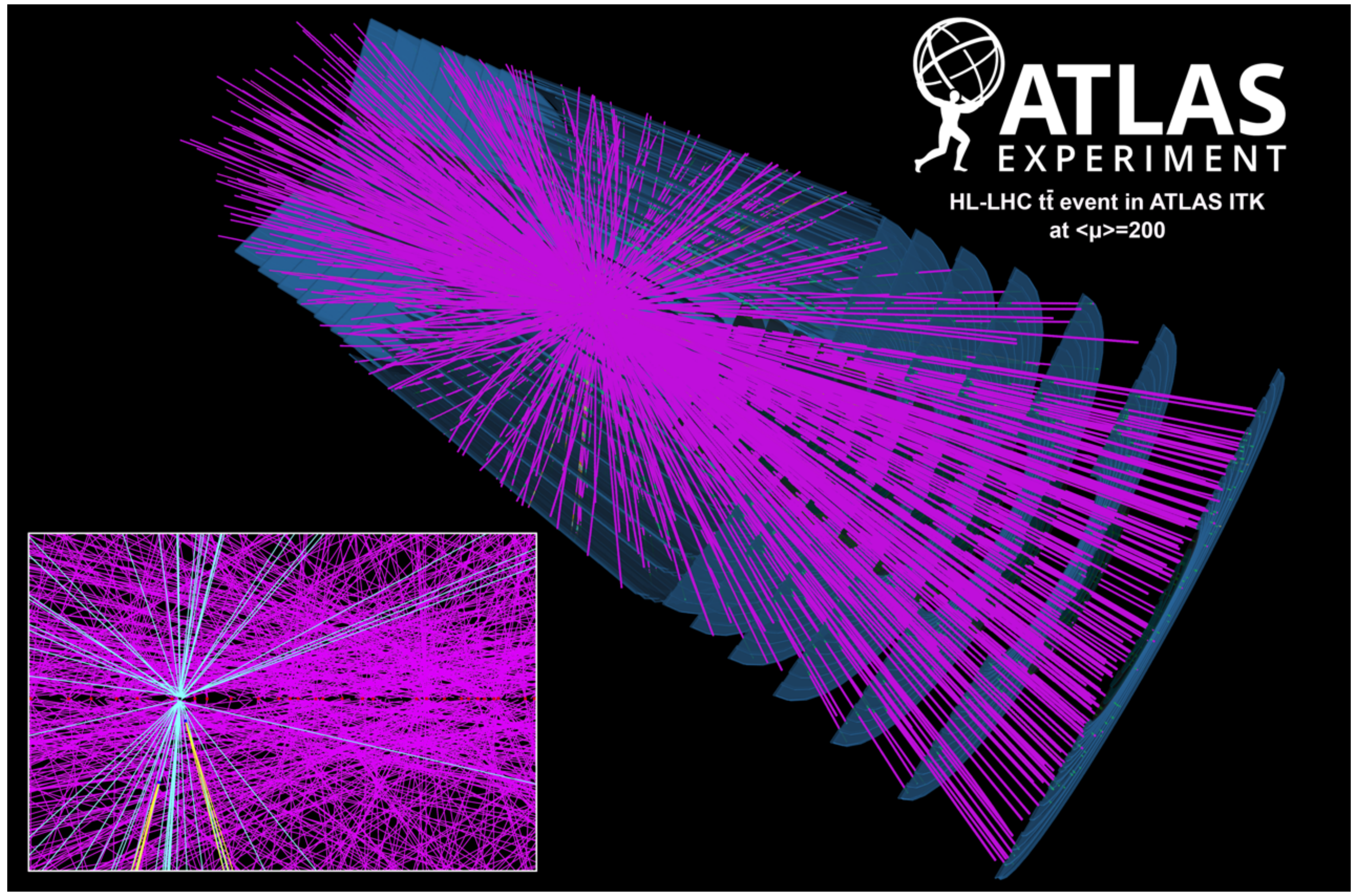
- The design of the upgrades which have had to account not only for high PU constraints but also very high radiation.

The design of the detectors needs to accommodate the expected radiation damage (assume that the two inner layers of the pixels will be replaceable)



- The gain in acceptance and in performance with new detectors (to improve PU mitigation), new algorithms and new computing capabilities is expected to match if not improve the current experimental performance.

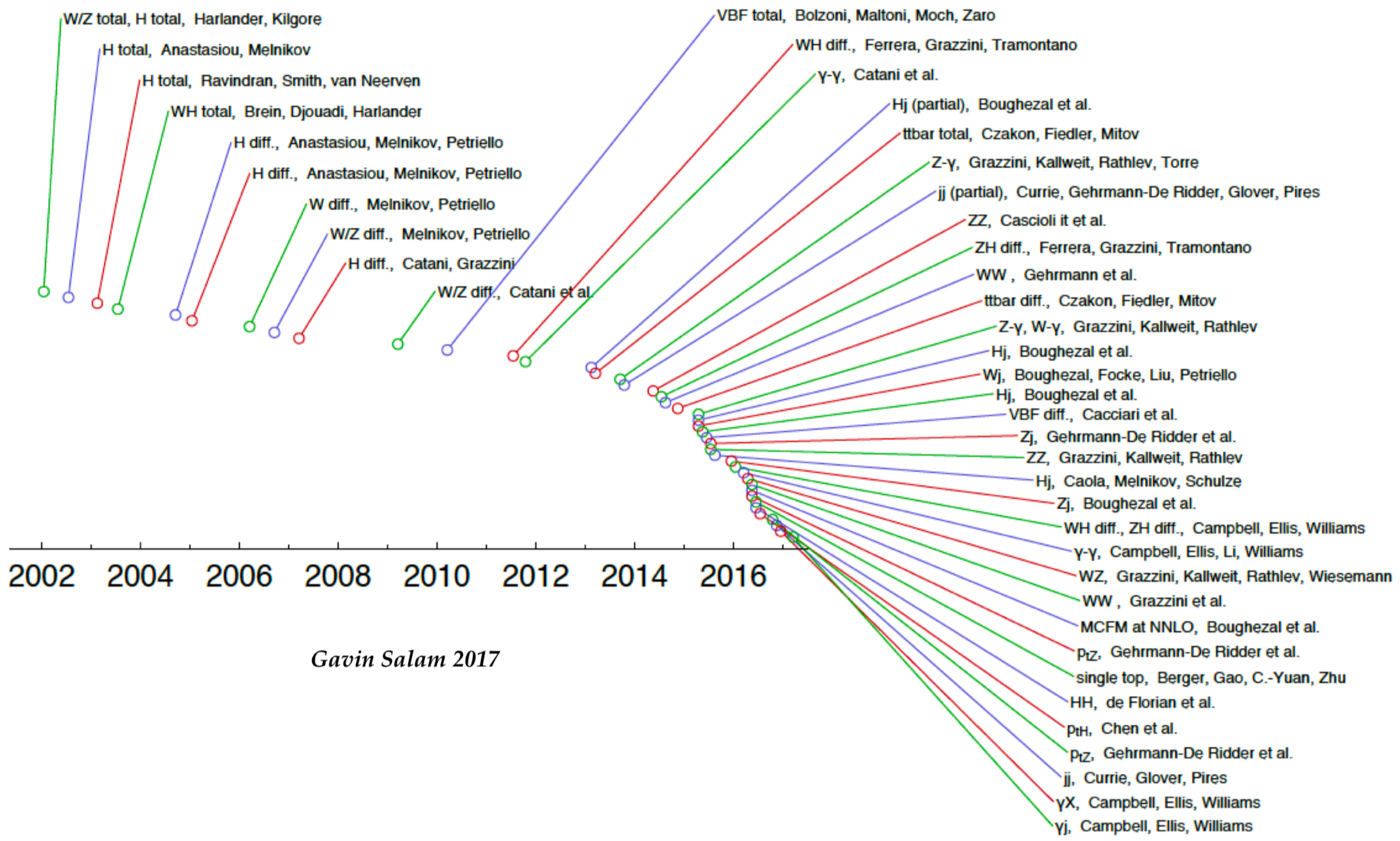
- Calibration accuracy will improve with additional data (see previous slide)



Working assumption to extrapolate current analyses (including estimate of the evolution of experimental systematic uncertainties have been estimated).

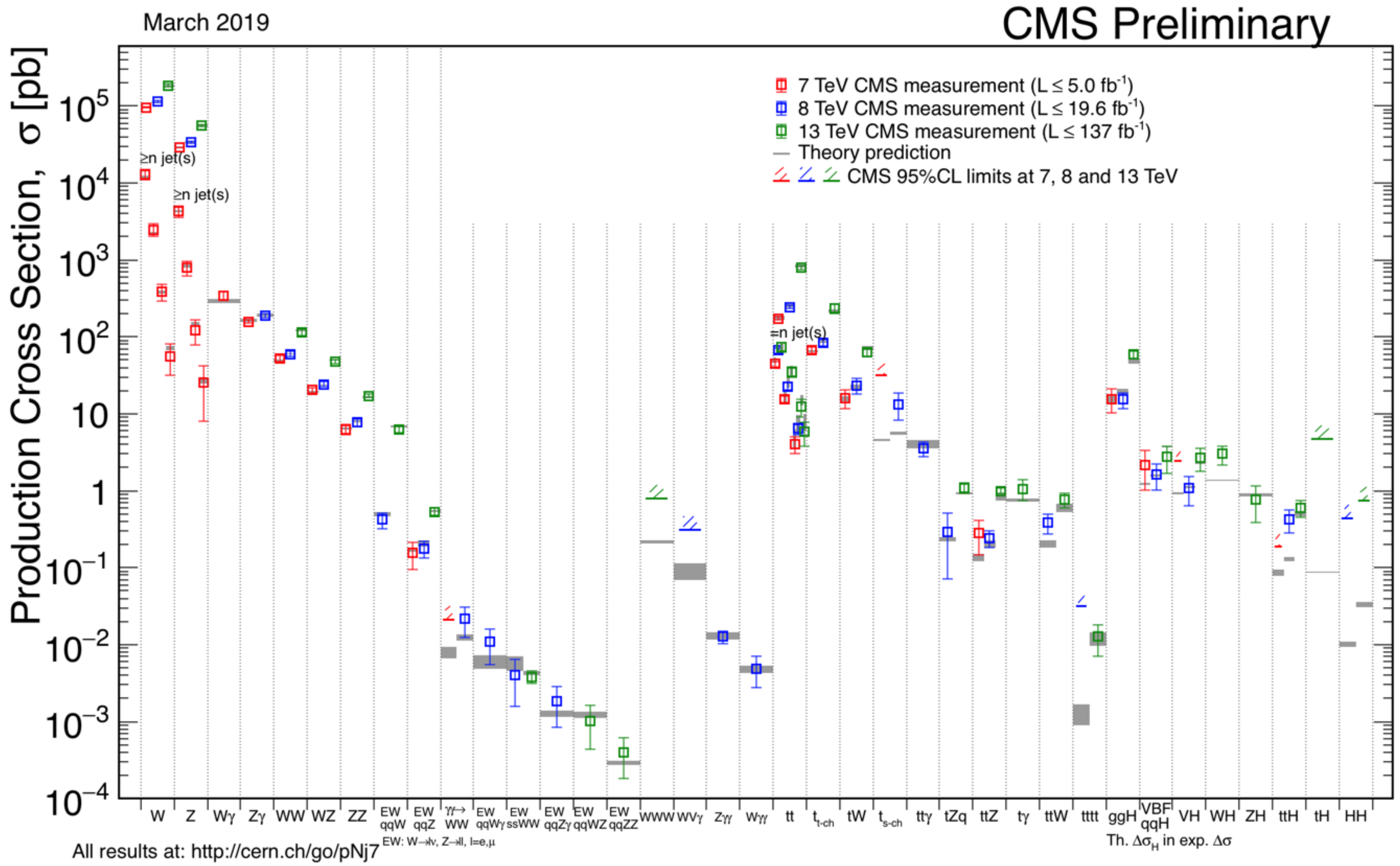
Modelling

- (TH - MC) Modelling uncertainties play a central role in most analyses at the LHC.
- Even when these are not explicit e.g. sideband data driven methods through MC closure.
- To fully profit from the TH progress **not always straightforward**:
  - Generation time (in some case can be longer than simulation).
  - Impact of large/negative weights.



Gavin Salam 2017

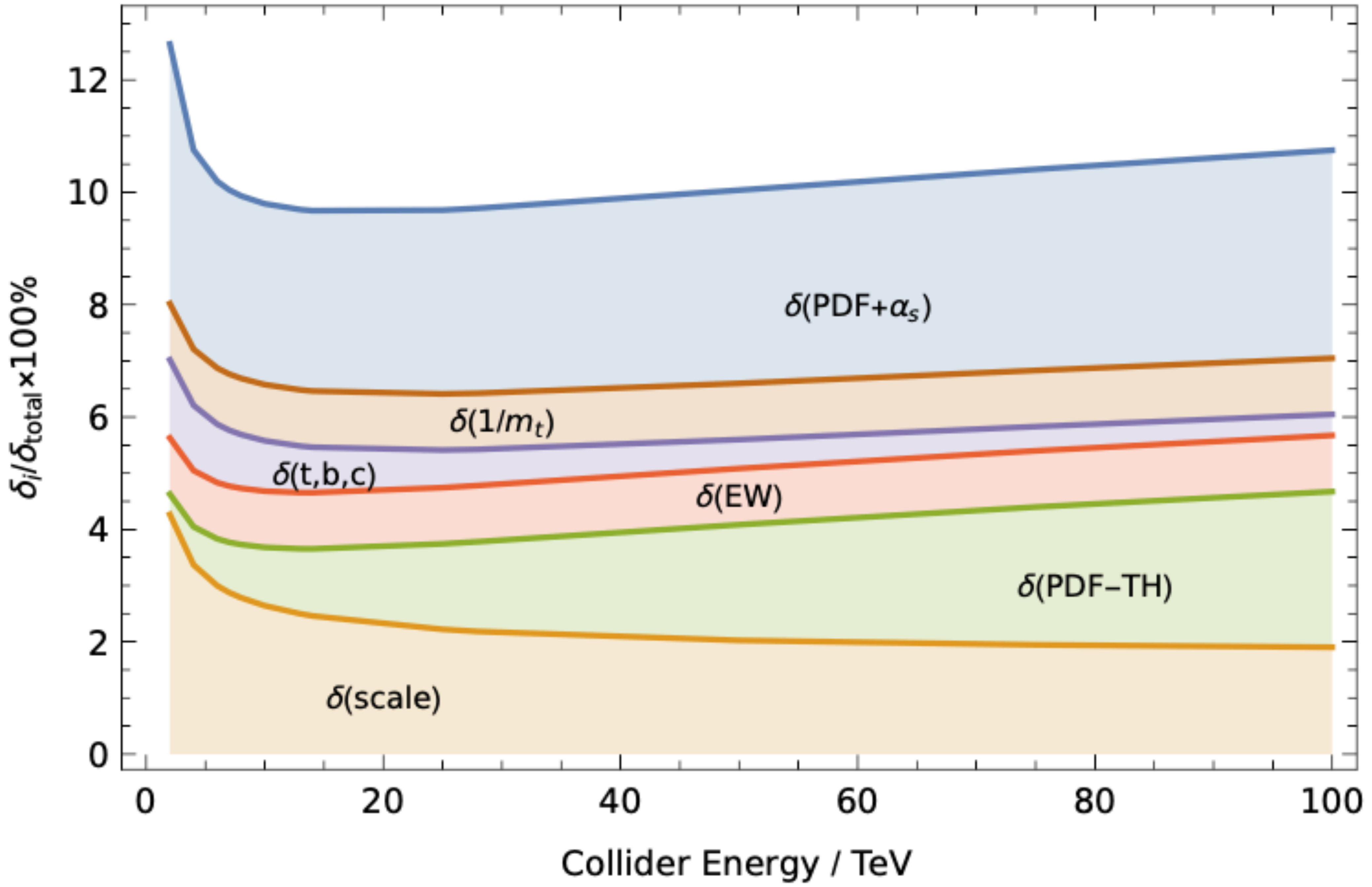
- Outstanding collective success of **all** communities, making LHC a machine for **Precision Physics**!



PDFs

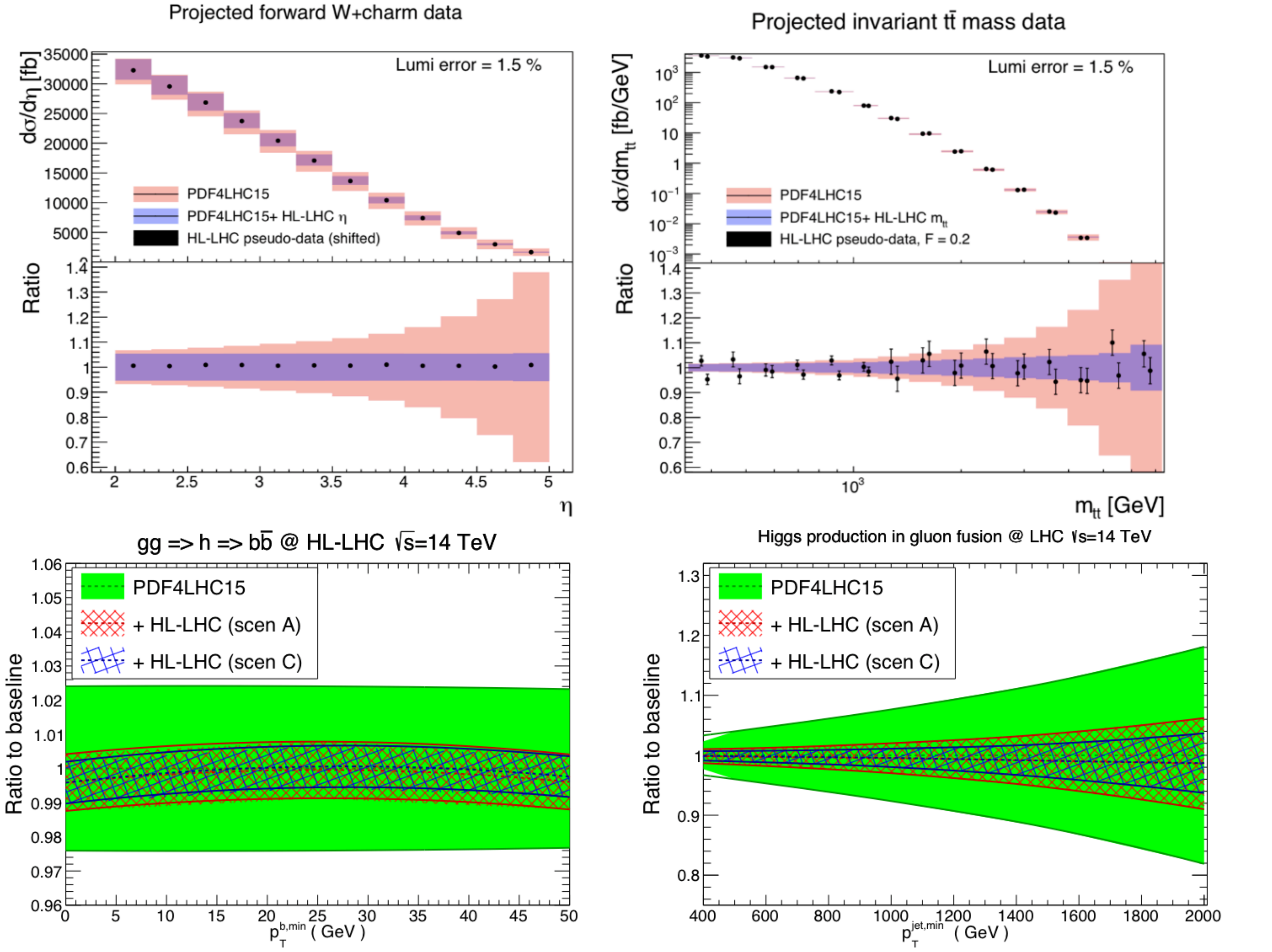
PDF uncertainties play a major role in the many flagship analyses.

One example is the measurement of the couplings of the Higgs!



TH and PDF uncertainties from LHC higgs XS WG

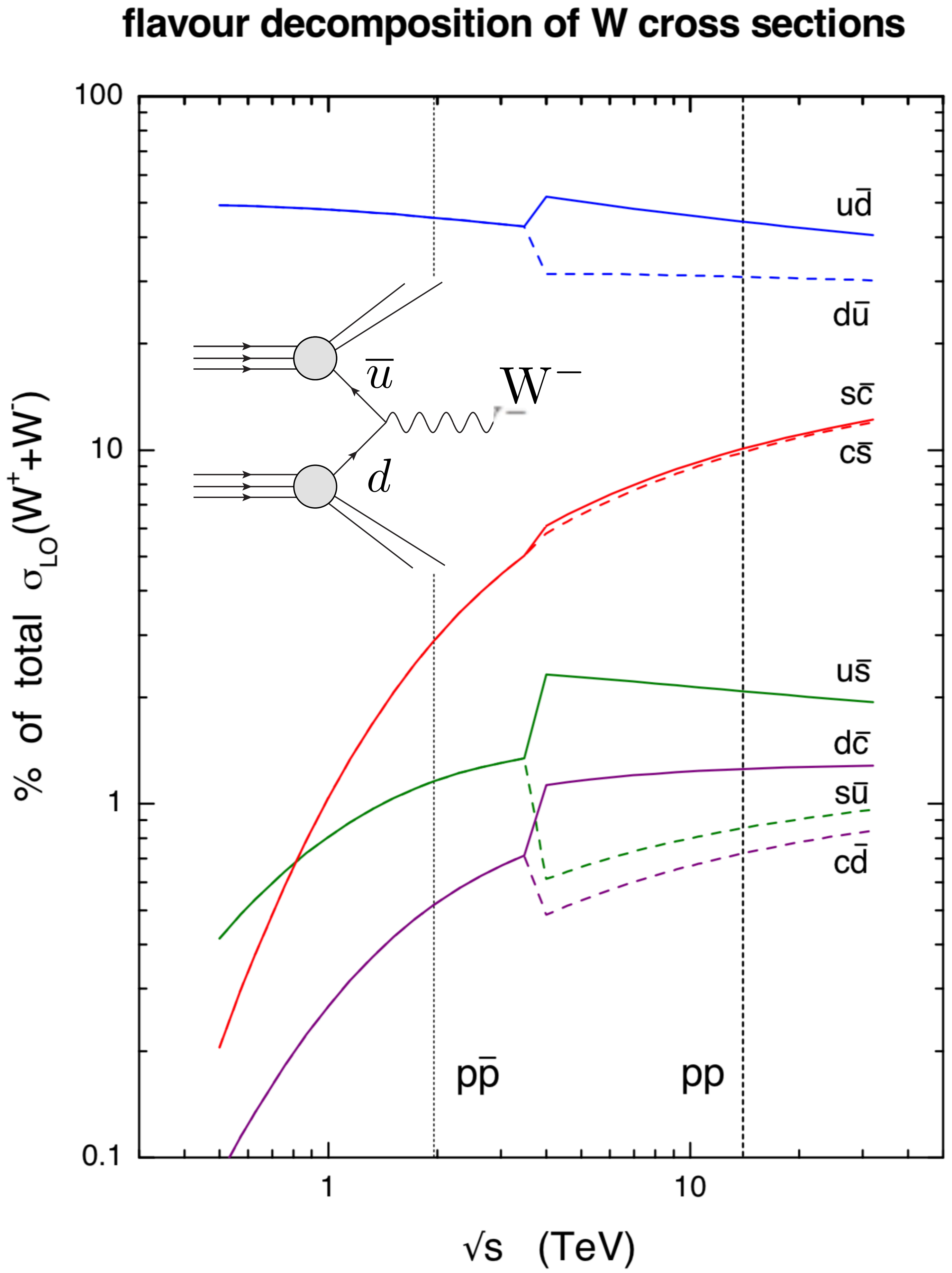
Rabah Abdul Khalek, Shaun Bailey, Jun Gao, Lucian Harland-Lang, and Juan Rojo

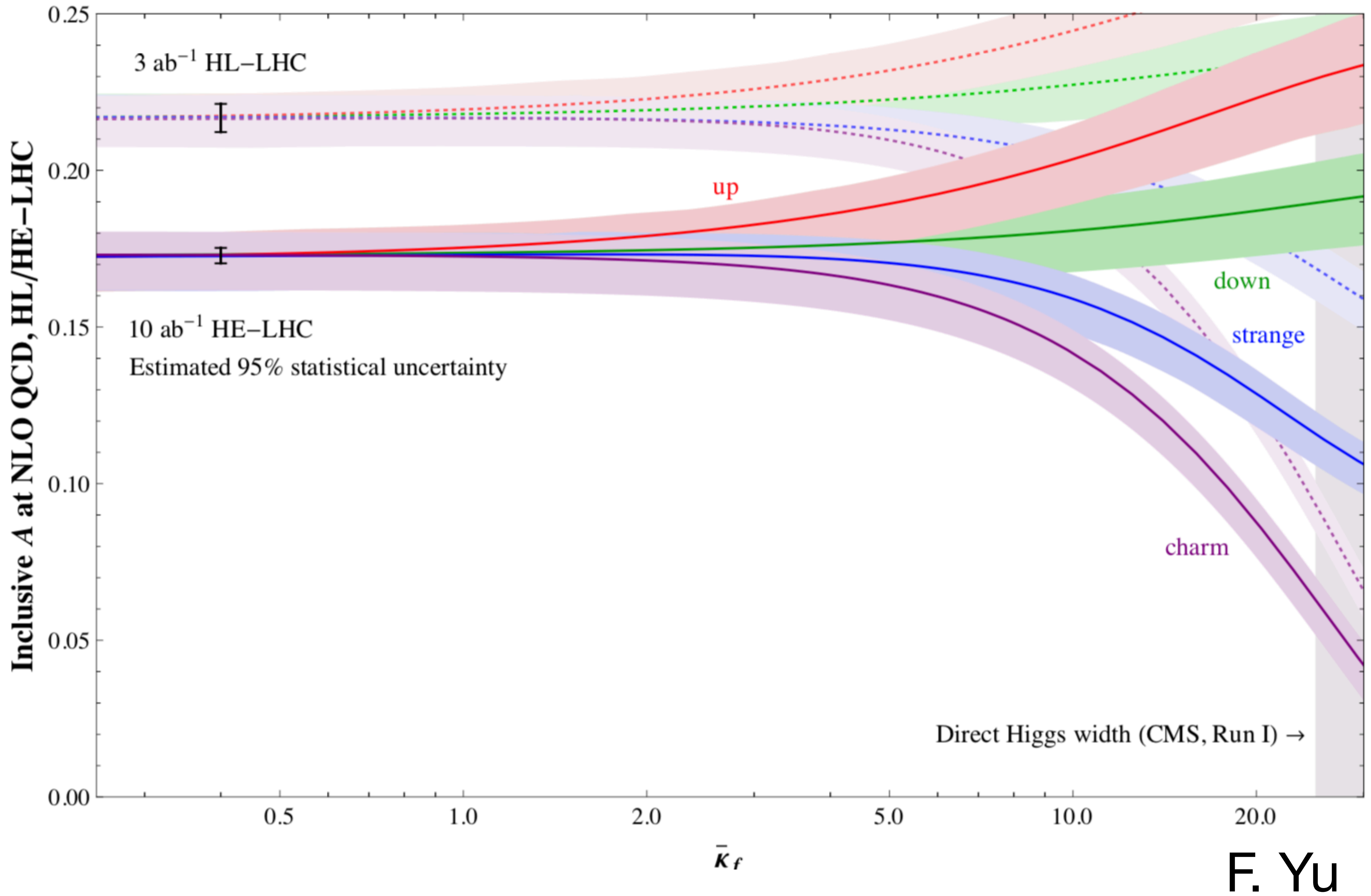


HL-LHC PDFs produced taking into account LHC cross sections for top, DY, W+charm, photon and jet production, etc…

Example new ideas: Second Generation Yukawa Couplings through Charm in the proton

- For Flavor diagonal Yukawa:
  - Many new ideas to constrain charm and light yukawas: charm tagging, exclusive modes and width.
  - Illustration: using PDFs in WH production with charge asymmetry.

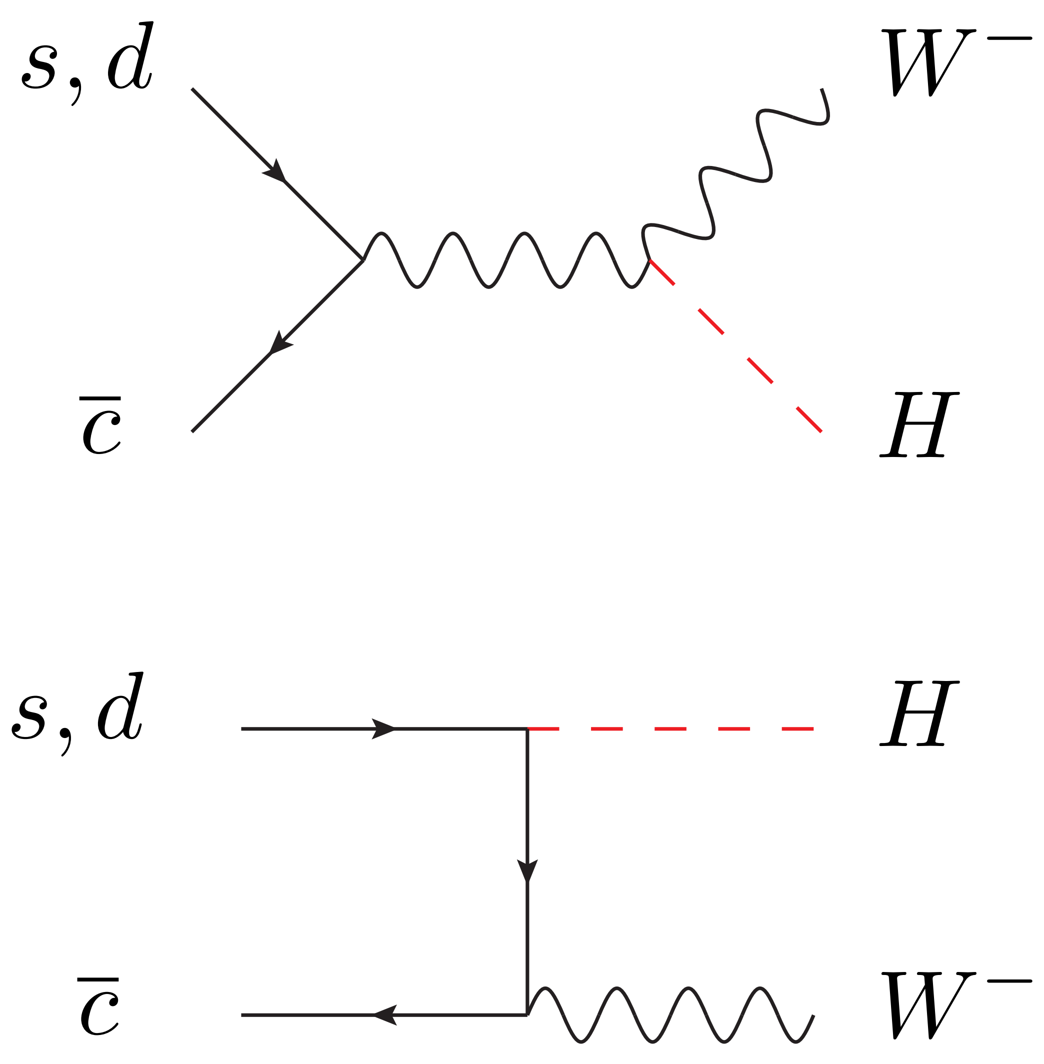




F. Yu

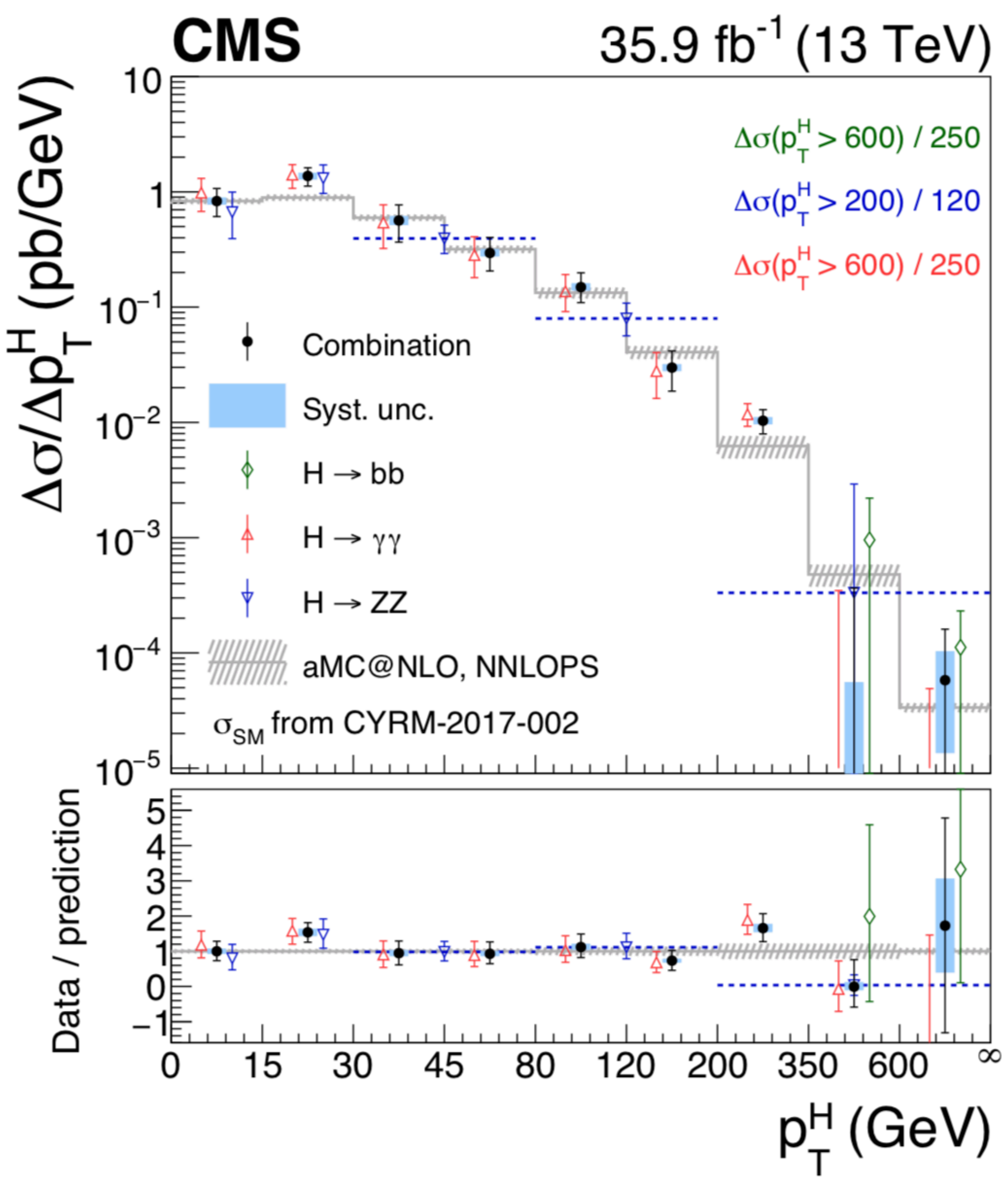
Excellent example of ratio where many TH uncertainties will cancel, of course in this case sensitive to PDFs.

$$A = \frac{\sigma(W^+h) - \sigma(W^-h)}{\sigma(W^+h) + \sigma(W^-h)}$$



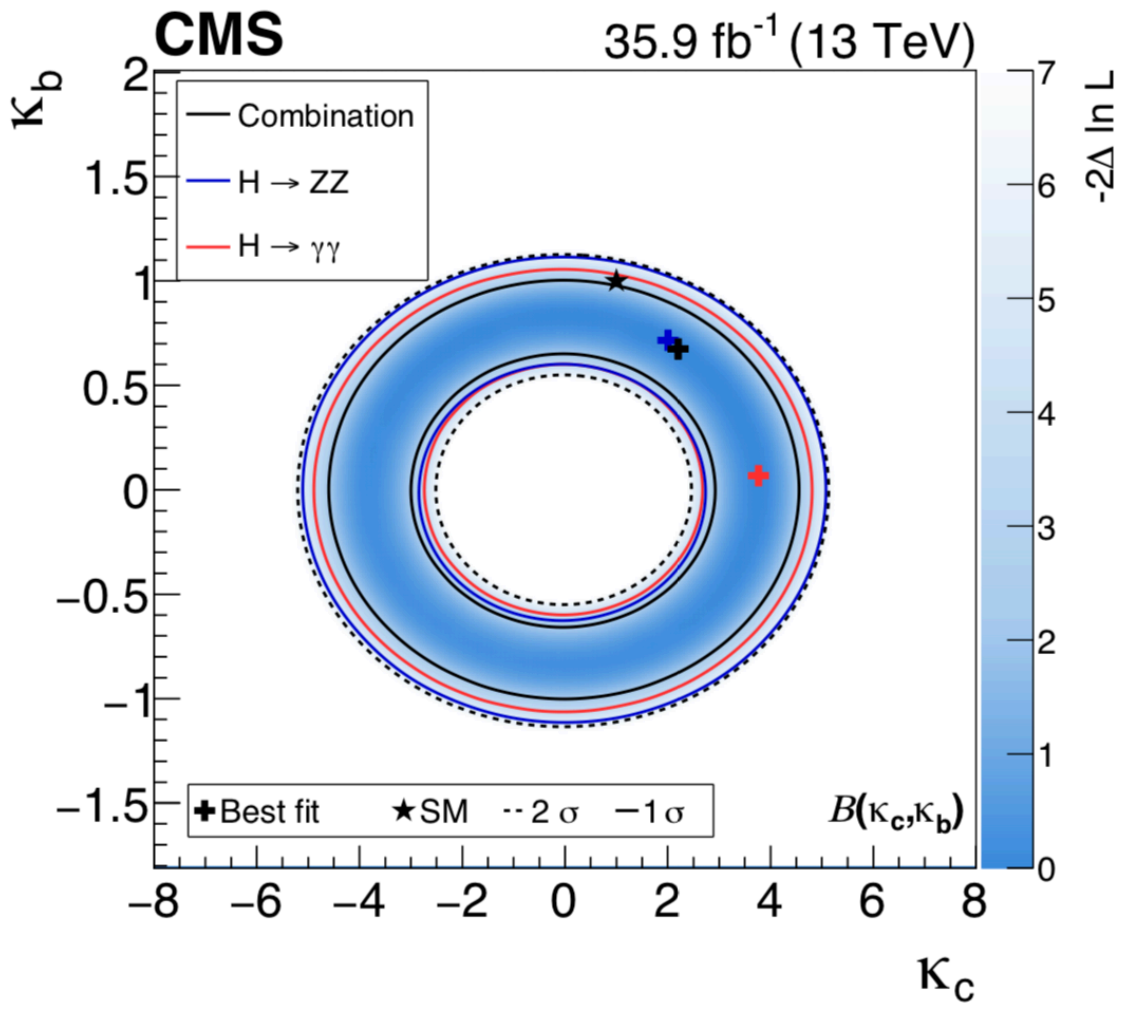
Fiducial and Unfolded Differential Cross Sections

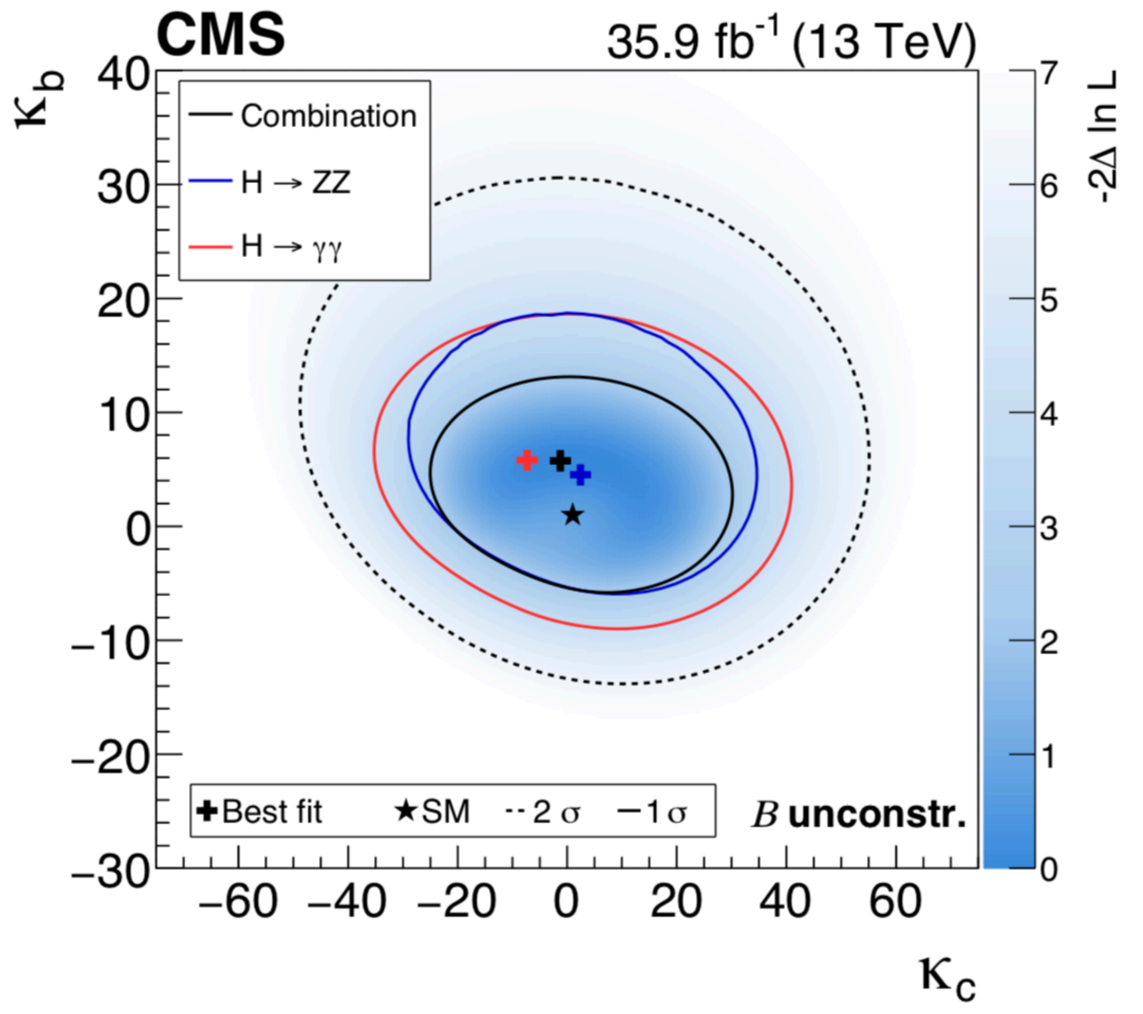
CMS 1812.06504

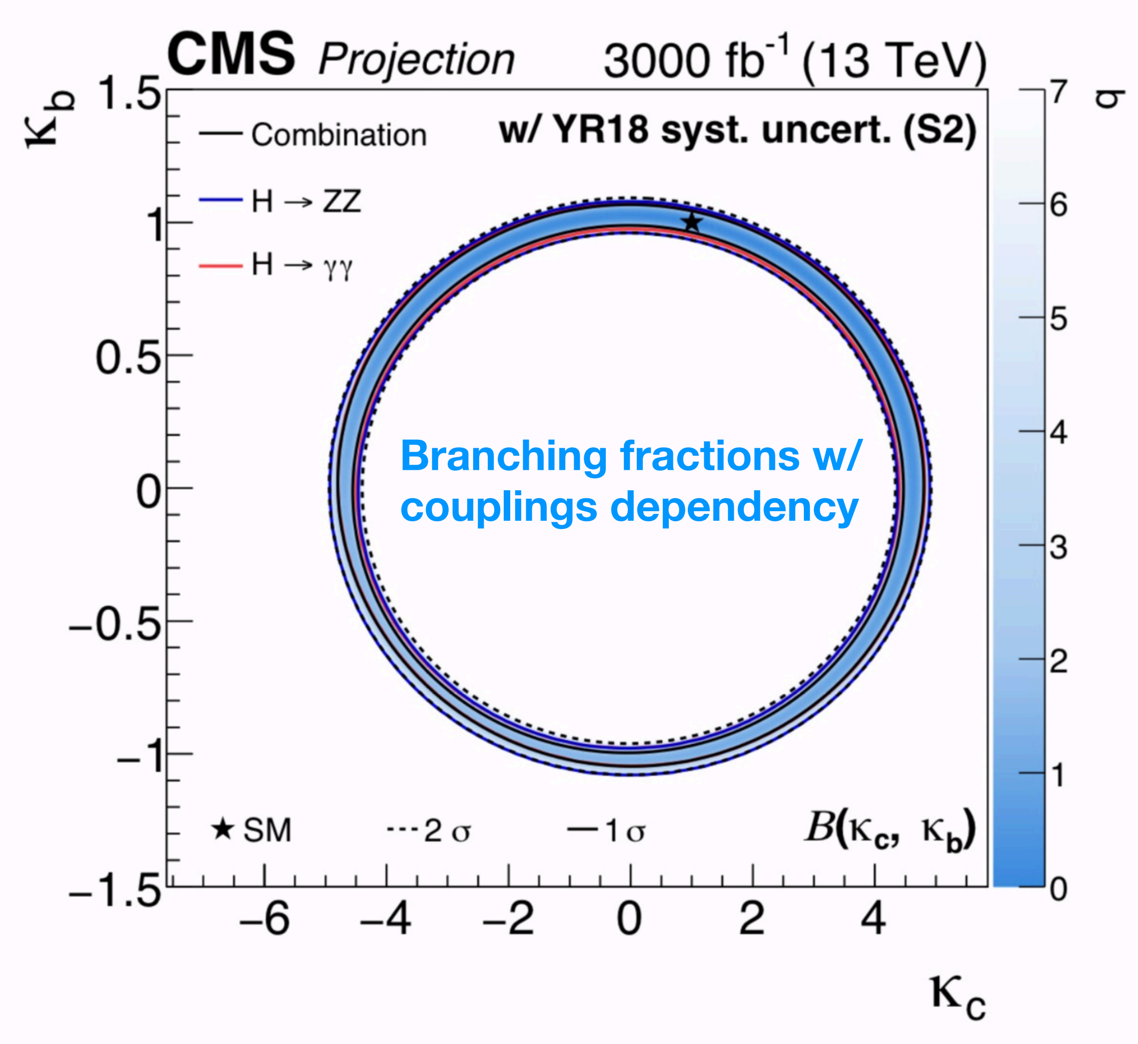


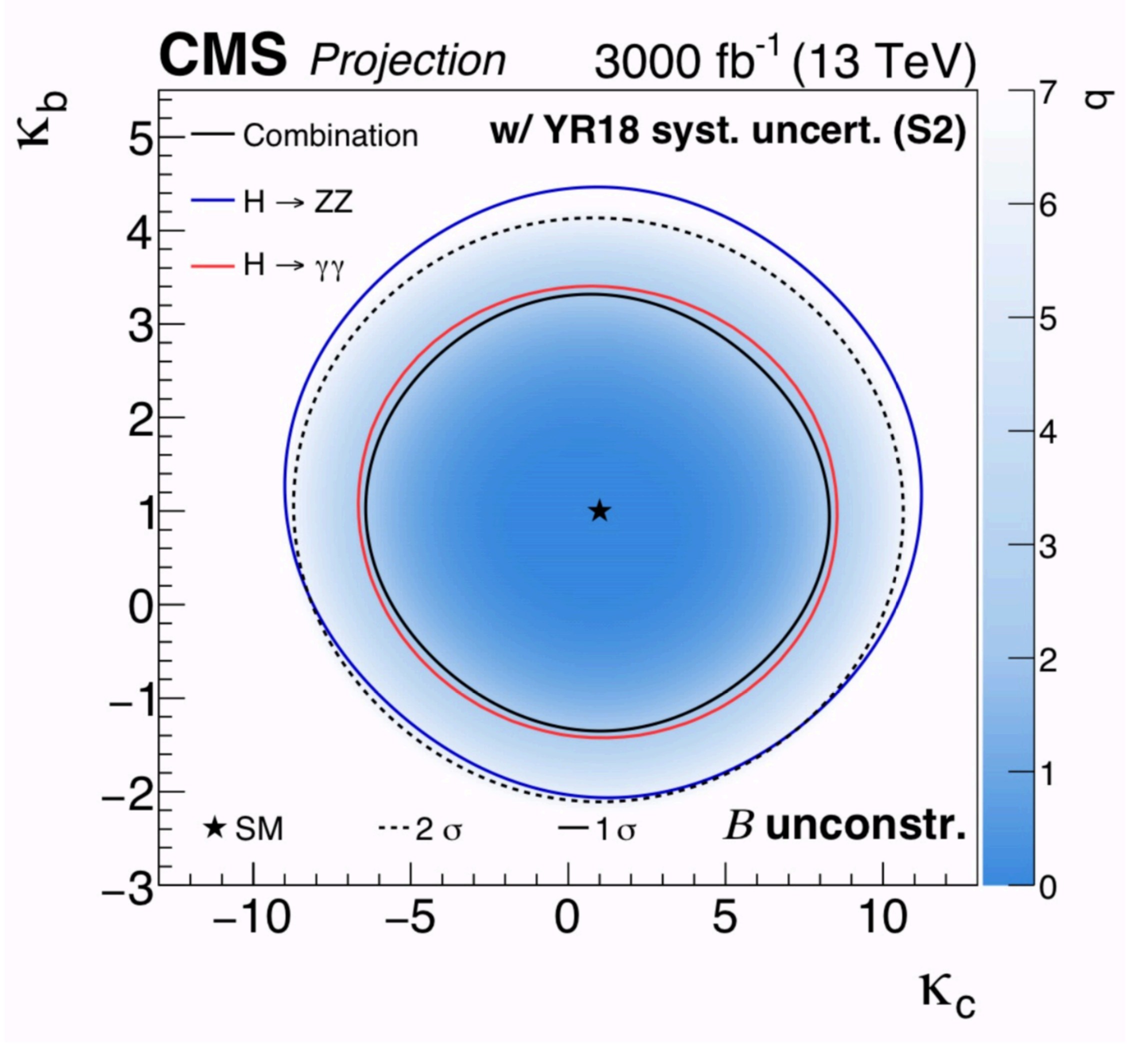
Diphoton, 4-lepton and bb differential cross section

Branching fractions w/ couplings dependency

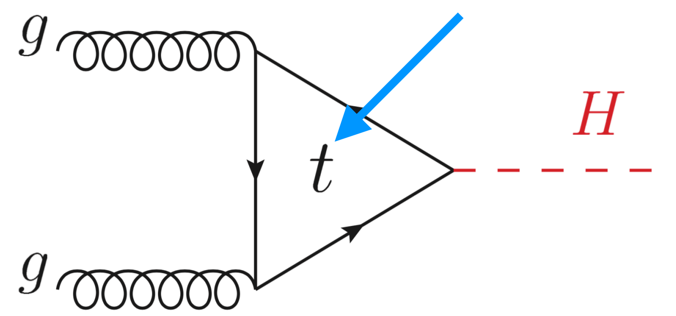








and b,c



Limits on Kc at Run 2

XS x Br	**~5 x SM**
Shape only	**~33 x SM**

HL-LHC YR 1902.00134

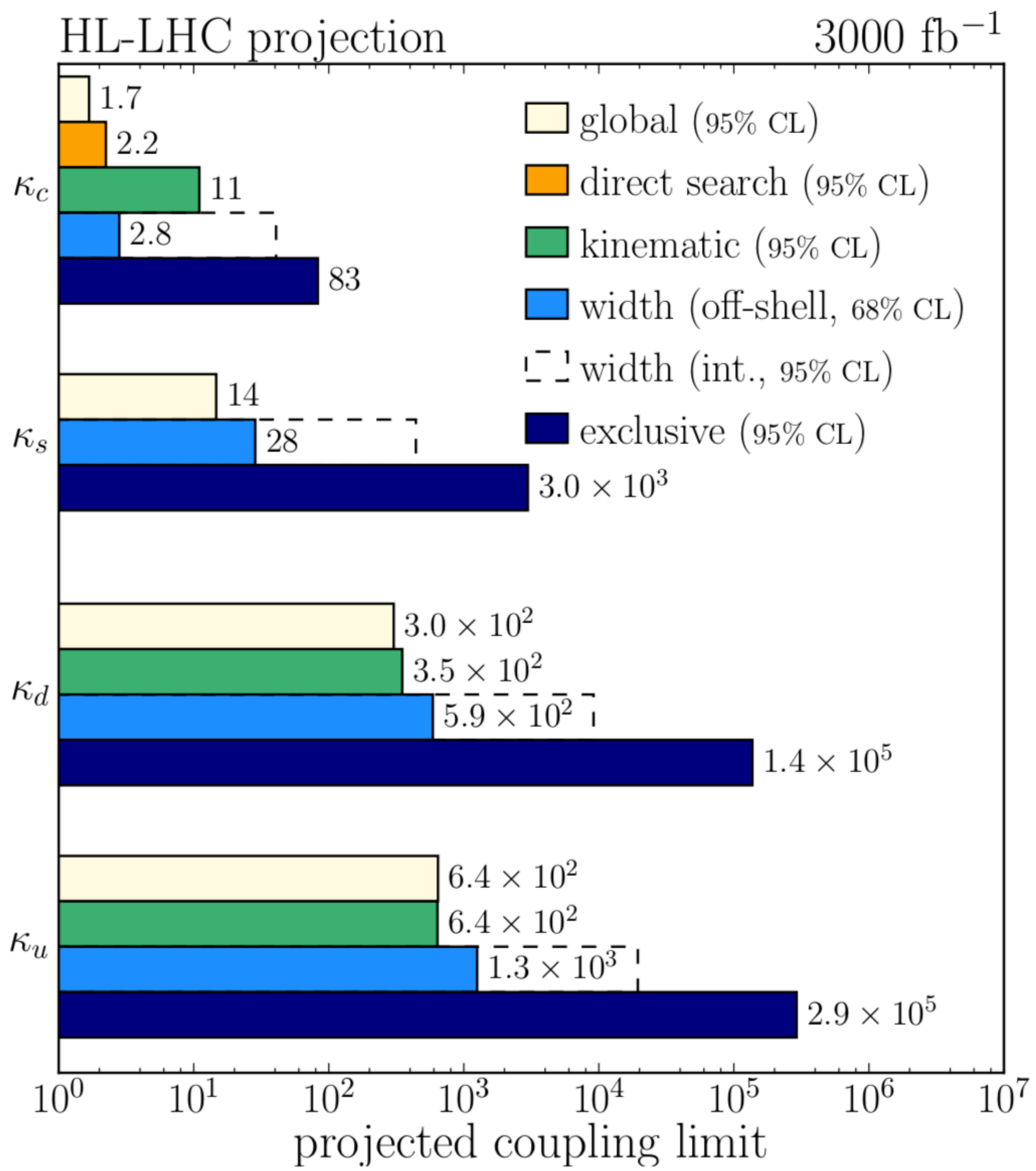
Limits on Kc at HL-LHC

XS x Br	**~4 x SM**
Shape only	**~8 x SM**

STXS Combination - Channels

$H\to\gamma\gamma$	$H\to ZZ^*\to 4\ell$	$H\to WW^*$	$H\to\tau\tau$	$H\to b\bar{b}$
$t\bar{t}H$ leptonic (3 categories) $t\bar{t}H$ hadronic (4 categories)	$t\bar{t}H$ leptonic $t\bar{t}H$ hadronic	$t\bar{t}H$ multilepton 1 ℓ + 2 $\tau_{\rm had}$ $t\bar{t}H$ multilepton 2 opposite-sign ℓ $t\bar{t}H$ multilepton 2 same-sign ℓ (categories for 0 or 1 $\tau_{\rm had}$) $t\bar{t}H$ multilepton 3 ℓ (categories for 0 or 1 $\tau_{\rm had}$) $t\bar{t}H$ multilepton 4 ℓ		$t\bar{t}H$ 1 ℓ, boosted $t\bar{t}H$ 1 ℓ, resolved (11 categories) $t\bar{t}H$ 2 ℓ (7 categories)
VH 2 ℓ VH 1 ℓ, $p_{\rm T}^{\ell+E_{\rm T}^{\rm miss}} \geq 150$ GeV VH 1 ℓ, $p_{\rm T}^{\ell+E_{\rm T}^{\rm miss}} <150$ GeV VH $E_{\rm T}^{\rm miss}$, $E_{\rm T}^{\rm miss} \geq 150$ GeV VH $E_{\rm T}^{\rm miss}$, $E_{\rm T}^{\rm miss} <150$ GeV VH+VBF $p_{\rm T}^{j1} \geq 200$ GeV VH hadronic (2 categories)	VH leptonic 0-jet, $p_{\rm T}^{4\ell} \geq 100$ GeV 2-jet, $m_{jj} < 120$ GeV			2 ℓ, $75 \leq p_{\rm T}^{V} < 150$ GeV, $N_{\rm jets} = 2$ 2 ℓ, $75 \leq p_{\rm T}^{V} < 150$ GeV, $N_{\rm jets} \geq 3$ 2 ℓ, $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} = 2$ 2 ℓ, $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} \geq 3$ 1 ℓ $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} = 2$ 1 ℓ $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} = 3$ 0 ℓ, $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} = 2$ 0 ℓ, $p_{\rm T}^{V} \geq 150$ GeV, $N_{\rm jets} = 3$
VBF, $p_{\rm T}^{\gamma\gamma jj} \geq 25$ GeV (2 categories) VBF, $p_{\rm T}^{\gamma\gamma jj} <25$ GeV (2 categories)	2-jet VBF, $p_{\rm T}^{j1} \geq 200$ GeV 2-jet VBF, $p_{\rm T}^{j1} <200$ GeV	2-jet VBF	VBF $p_{\rm T}^{\tau\tau} > 140$ GeV ($\tau_{\rm had}\tau_{\rm had}$ only) VBF high-m_{jj} VBF low-m_{jj}	
2-jet, $p_{\rm T}^{\gamma\gamma} \geq 200$ GeV 2-jet, 120 GeV$\leq p_{\rm T}^{\gamma\gamma} <200$ GeV 2-jet, 60 GeV$\leq p_{\rm T}^{\gamma\gamma} <120$ GeV 2-jet, $p_{\rm T}^{\gamma\gamma} < 60$ GeV 1-jet, $p_{\rm T}^{\gamma\gamma} \geq 200$ GeV 1-jet, 120 GeV$\leq p_{\rm T}^{\gamma\gamma} <200$ GeV 1-jet, 60 GeV$\leq p_{\rm T}^{\gamma\gamma} <120$ GeV 1-jet, $p_{\rm T}^{\gamma\gamma} < 60$ GeV 0-jet (2 categories)	1-jet, $p_{\rm T}^{4\ell} \geq 120$ GeV 1-jet, 60 GeV$\leq p_{\rm T}^{4\ell} <120$ GeV 1-jet, $p_{\rm T}^{4\ell} < 60$ GeV 0-jet, $p_{\rm T}^{4\ell} < 100$ GeV	1-jet, $m_{\ell\ell} < 30$ GeV, $p_{\rm T}^{\ell_2} < 20$ GeV 1-jet, $m_{\ell\ell} < 30$ GeV, $p_{\rm T}^{\ell_2} \geq 20$ GeV 1-jet, $m_{\ell\ell} \geq 30$ GeV, $p_{\rm T}^{\ell_2} < 20$ GeV 1-jet, $m_{\ell\ell} \geq 30$ GeV, $p_{\rm T}^{\ell_2} \geq 20$ GeV 0-jet, $m_{\ell\ell} < 30$ GeV, $p_{\rm T}^{\ell_2} < 20$ GeV 0-jet, $m_{\ell\ell} < 30$ GeV, $p_{\rm T}^{\ell_2} \geq 20$ GeV 0-jet, $m_{\ell\ell} \geq 30$ GeV, $p_{\rm T}^{\ell_2} < 20$ GeV 0-jet, $m_{\ell\ell} \geq 30$ GeV, $p_{\rm T}^{\ell_2} \geq 20$ GeV	Boosted, $p_{\rm T}^{\tau\tau} > 140$ GeV Boosted, $p_{\rm T}^{\tau\tau} \leq 140$ GeV	

Outlook On Flavors
First and Second Generation Yukawa at HL-LHC



First and Second generation Yukawas

- Extremely challenging at HL-LHC (most stringent constraint coming from the couplings fit assuming no BSM width).

- For the charm Yukawa then inclusive direct search still much better.

- Then sensitivity to coupling combination through width offshell.

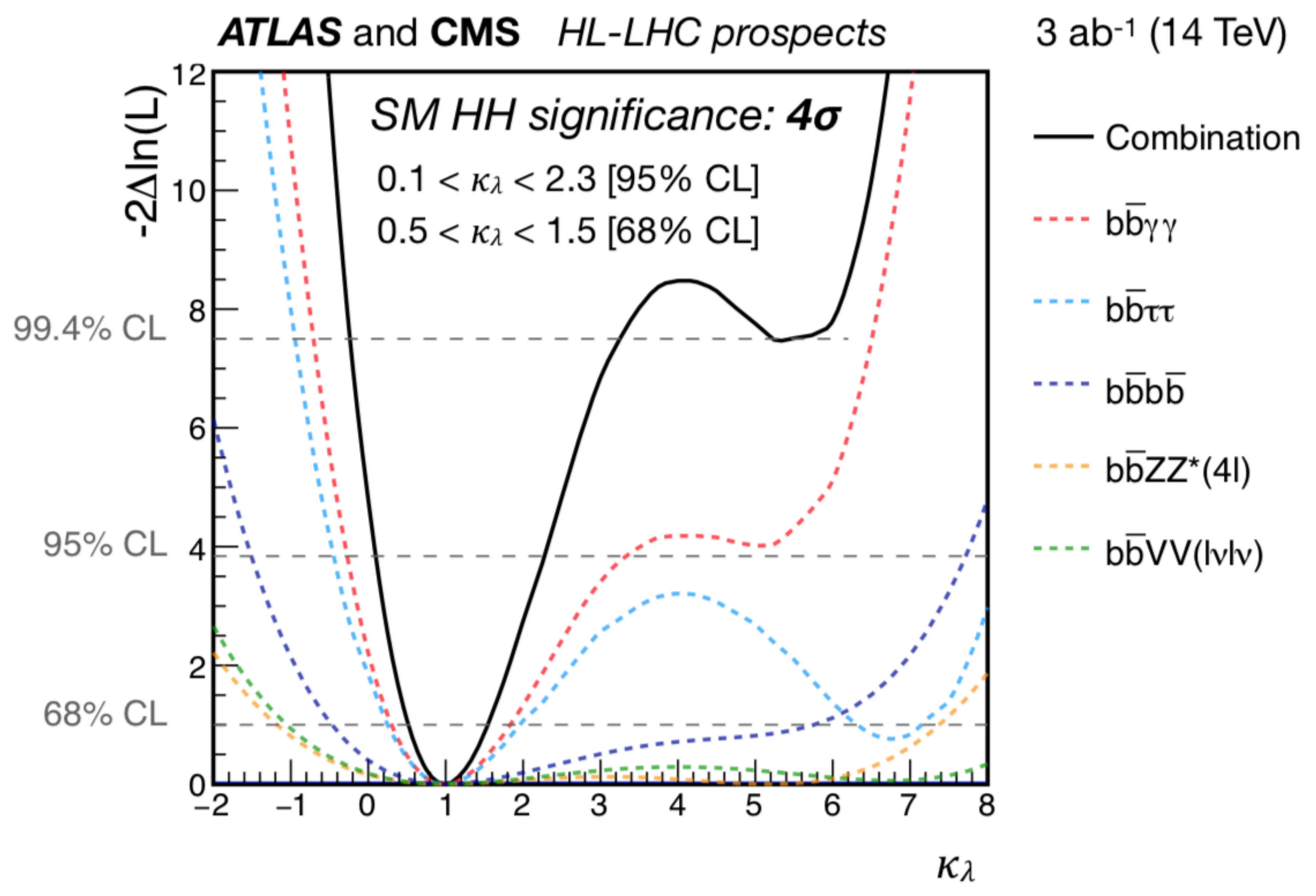
- Exclusive searches still only marginally sensitive.

- New emerging ideas to be explored with such large datasets.

Double Higgs Production and Higgs Self Coupling

At HL-LHC: Direct search

- Analyses completely reappraised.
- More channels investigated in detail.



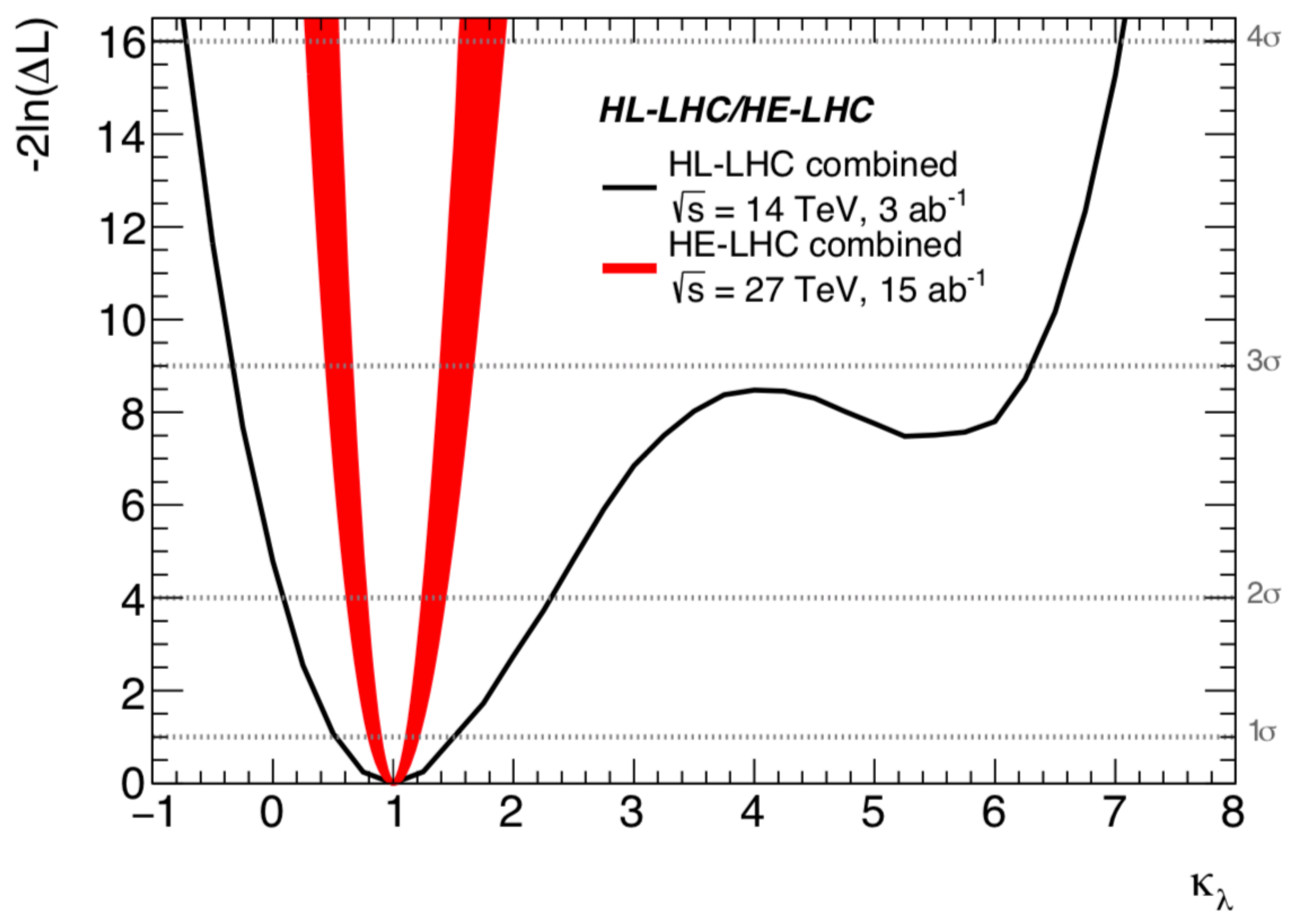
$$0.5 < \kappa_\lambda < 1.5$$

- Not quite 5 s.d. observation of HH signal.
- significant exclusion of the secondary minimum.
- Closing up on a measurement, but not decisive.

Huge progress made nevertheless! Probably still more (though not completely obvious).

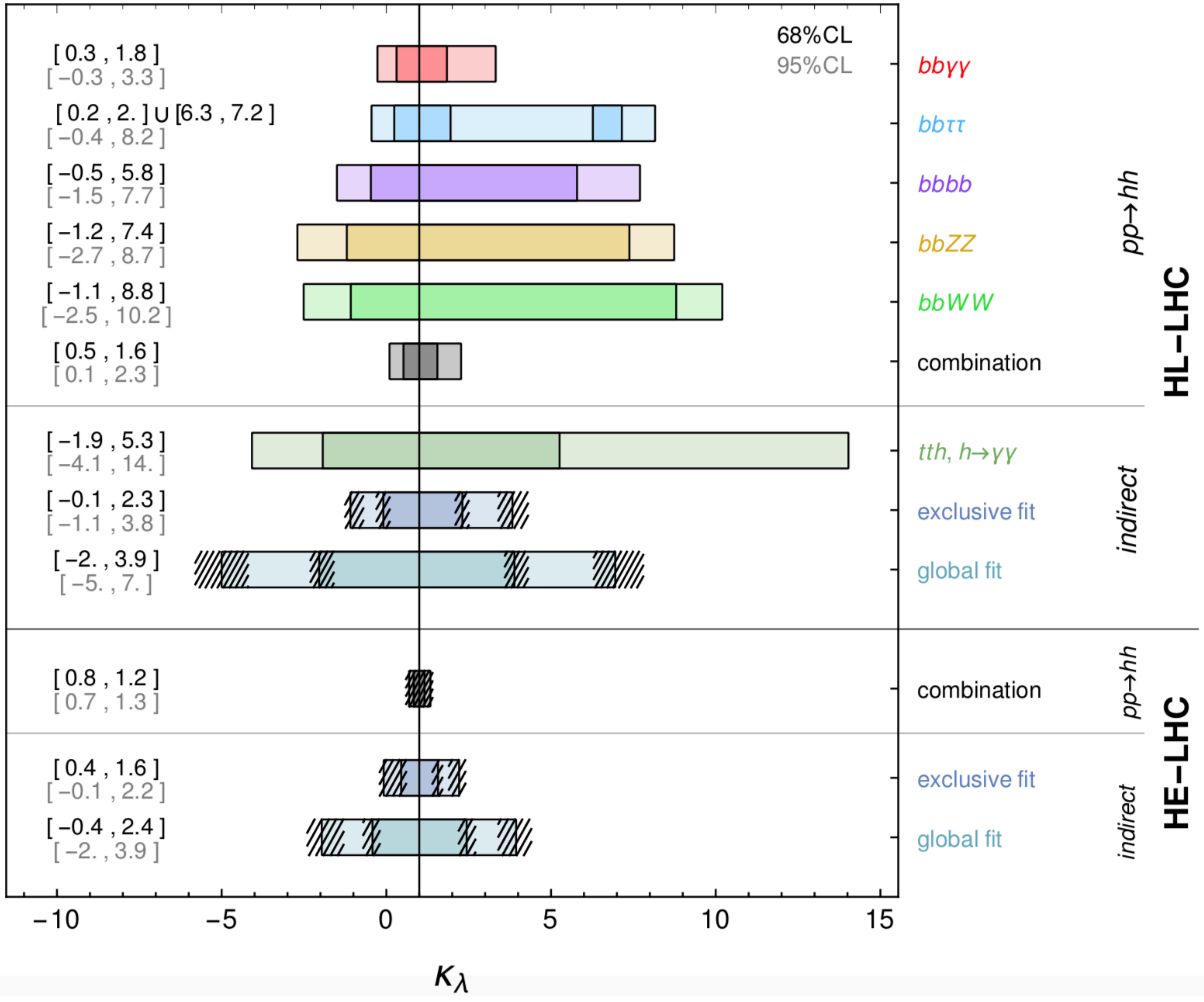
At HE-LHC

- Several single channel TH studies, compared with on EXP extrapolation of bbyy and bbtautau studies - One experiment reach at HE-LHC of 40% and 20% respectively on each channel.
- Some TH extrapolations provided a much improved sensitivity in the baby channel (15%) using HH with jet.
- Range of extrapolation then given between 10% and 20%.



Question: precision on HH signal strengths bbyy (~15% - 7 s.d.) and bbtautau (~10% - 10 s.d.)

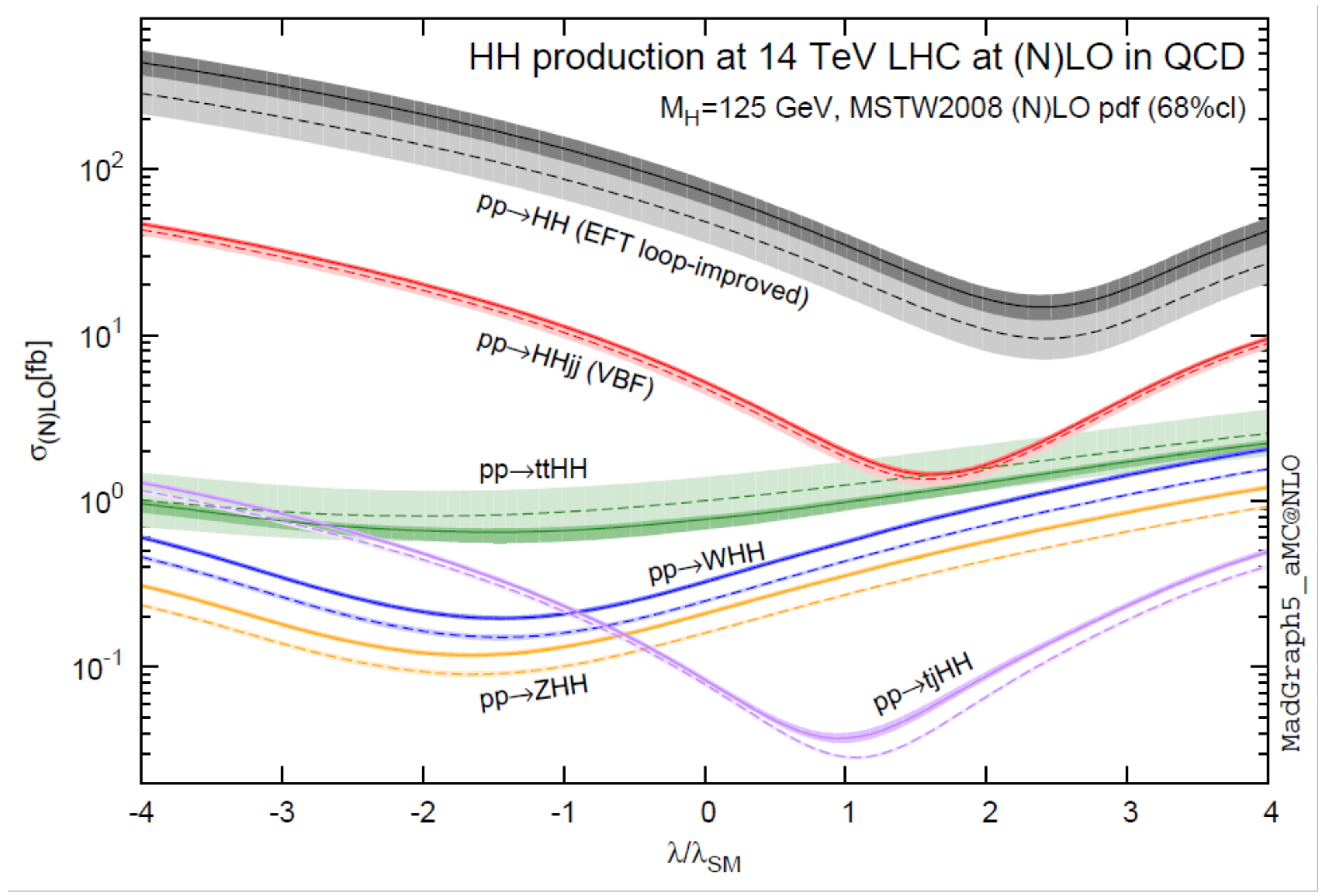
HH and Trilinear Coupling Summary



Preliminary conclusion

- Indirect constraints are interesting but in a realistic fit, the impact becomes very small relative to the direct HH measurements.

- More work can be done to explore using different production modes that can be very helpful in constraining the trilinear coupling.

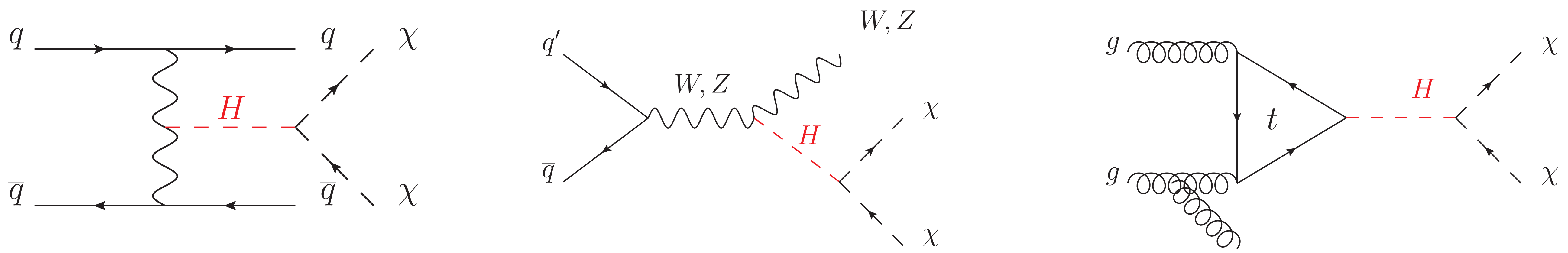


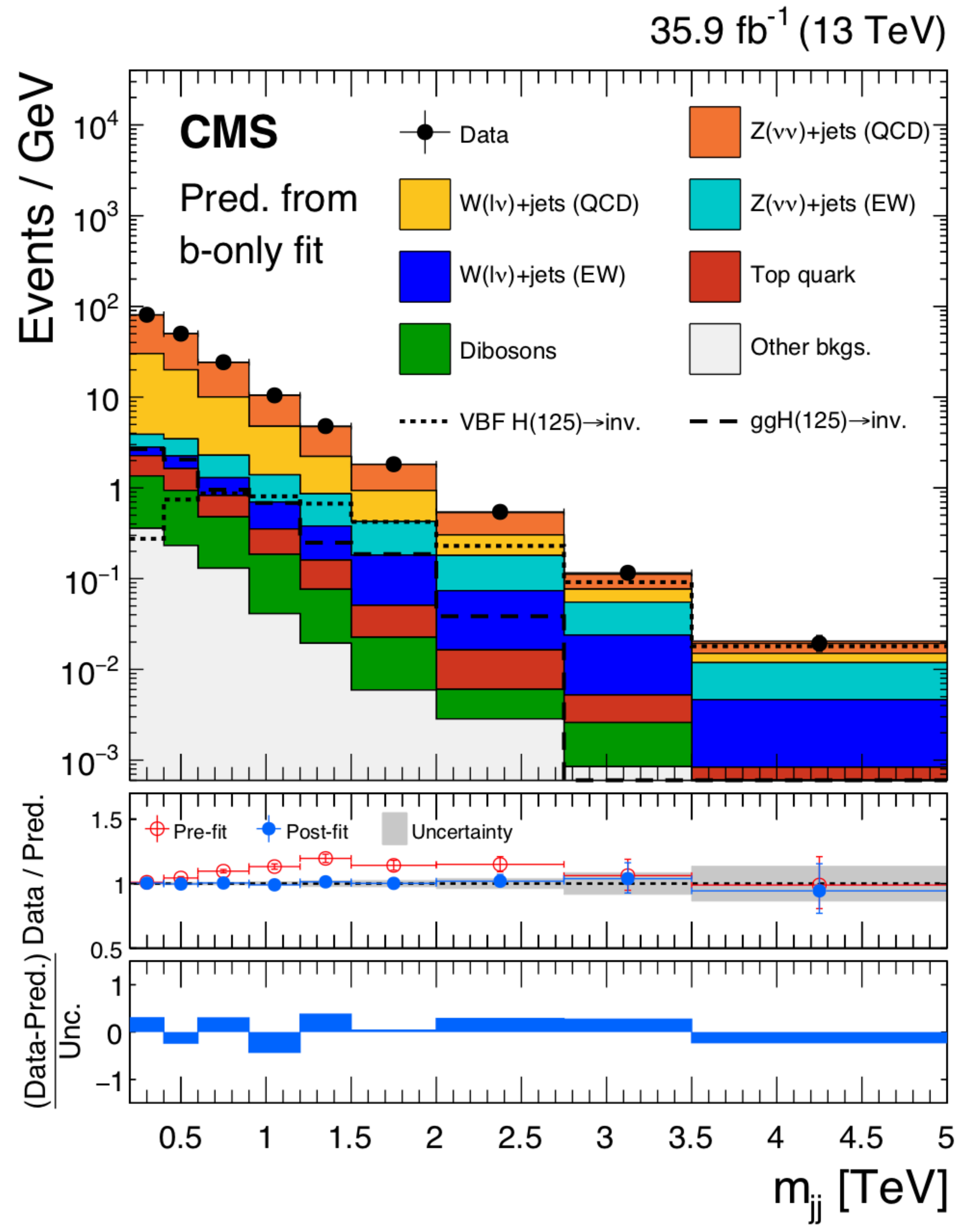
- Most importantly, HE-LHC provides a strong case for a first assessment of the Higgs trilinear coupling.

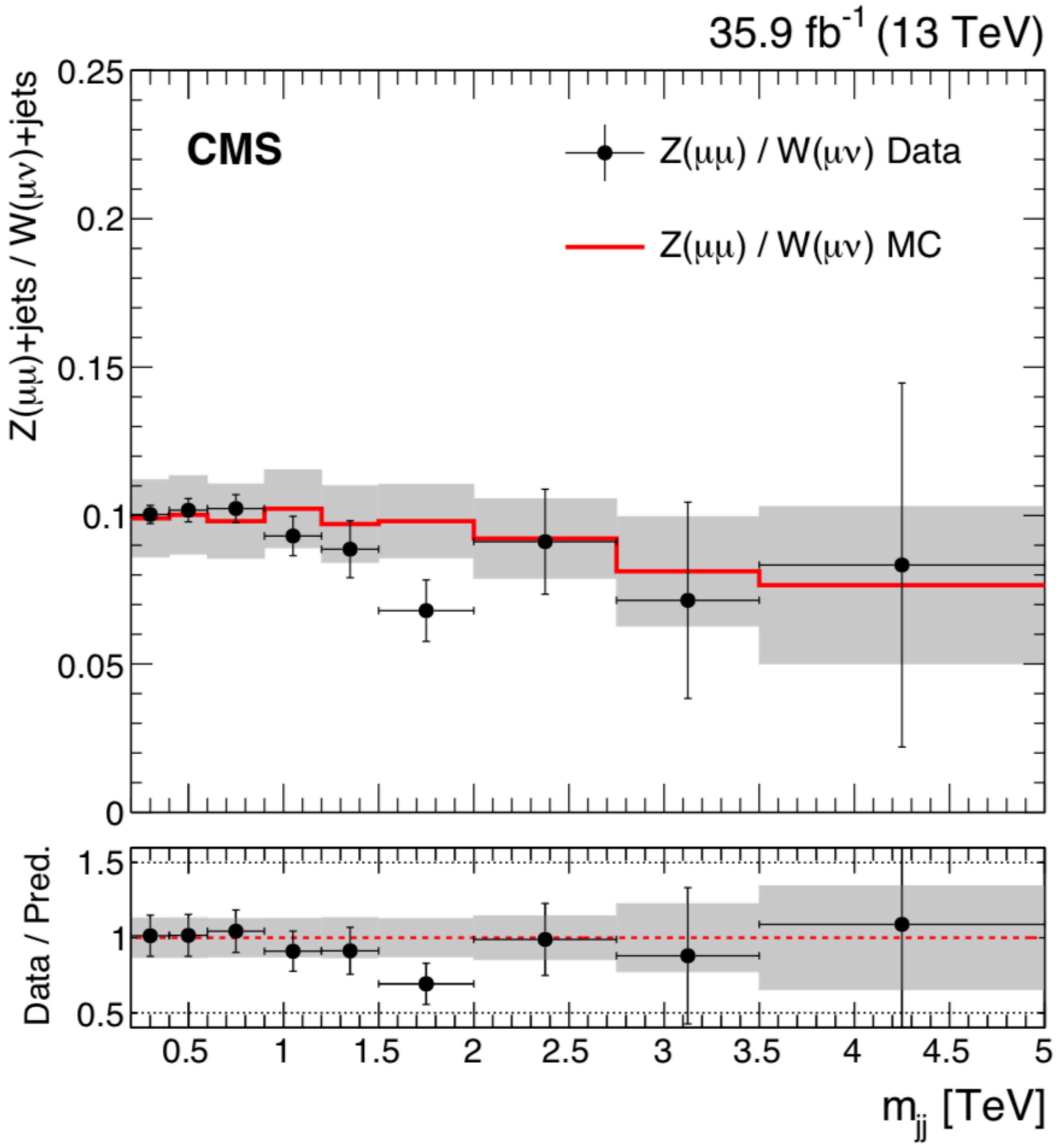
Invisible decays of the Higgs boson

CMS 1809.05937

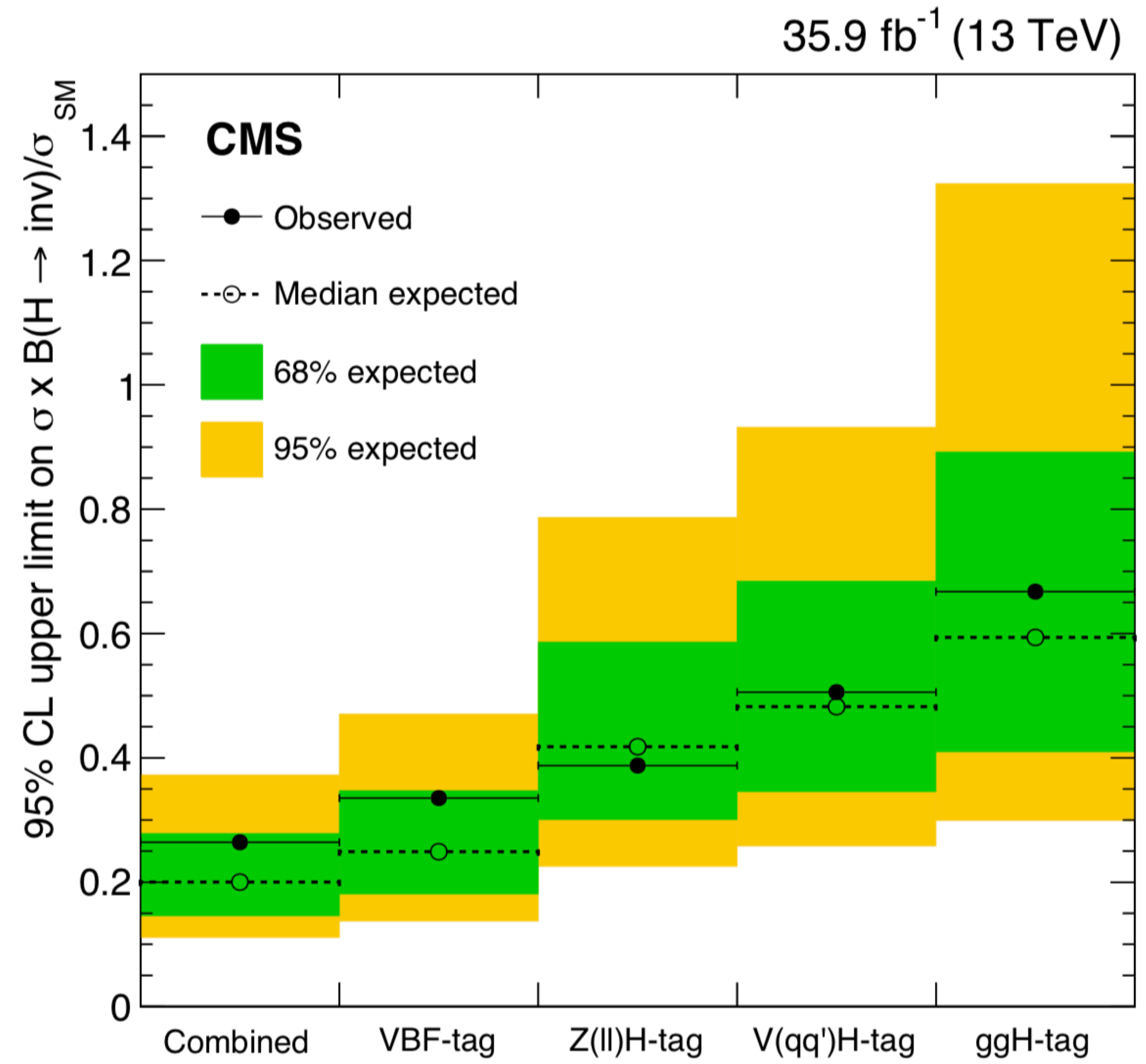
Comprehensive analysis of several channels and several datasets by CMS, to give current level of sensitivity on invisible branching fraction.







- Includes a mono-jet and mono-V hadronic boosted mode
- VBF is the most sensitive channel
- Challenge is the estimate of the V-jets backgrounds: estimated from control regions using W, Z and photon-jet events.



Interesting to note how all analyses are becoming sensitive.

$$\mathrm{Br}(\mathrm{H} \to \mathrm{inv.}) < 0.19\ (0.15)\ 95\%\ \mathrm{C.L.}$$

In combination with Run 1

Similar combined results obtained in an ATLAS:

$$\mathrm{Br}(\mathrm{H} \to \mathrm{inv.}) < 0.26\ (0.17)\ 95\%\ \mathrm{C.L.}$$

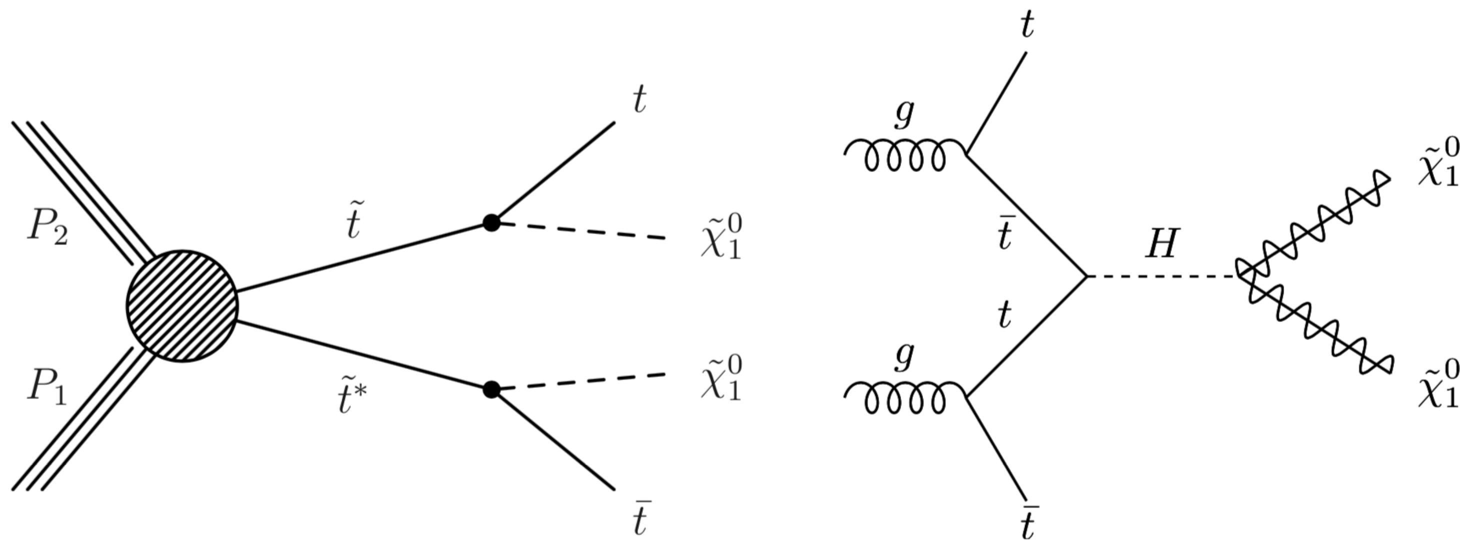
ATLAS-CONF-2019-04

ttH Invisible Search NEW

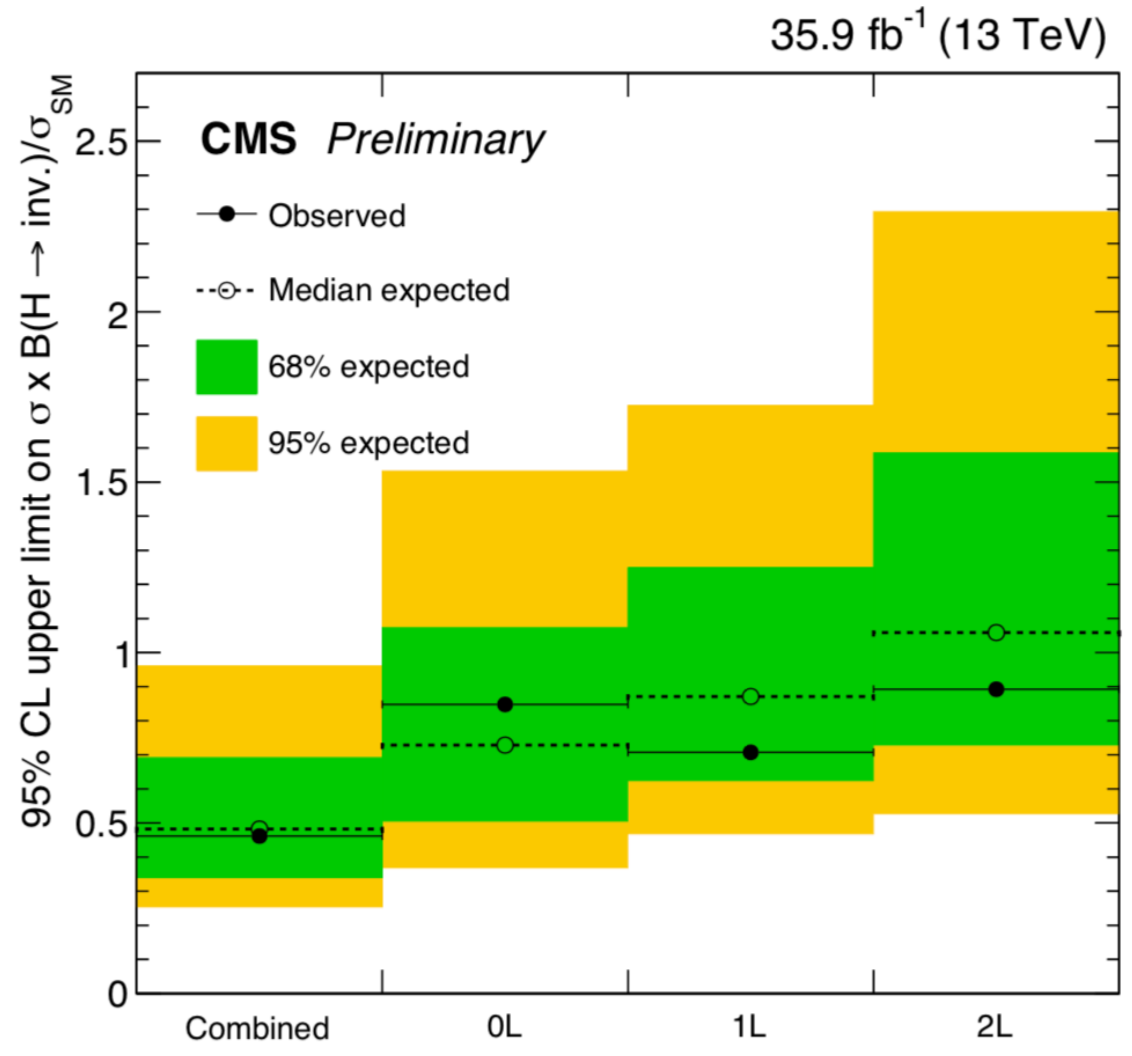
CMS-PAS-HIG-18-008

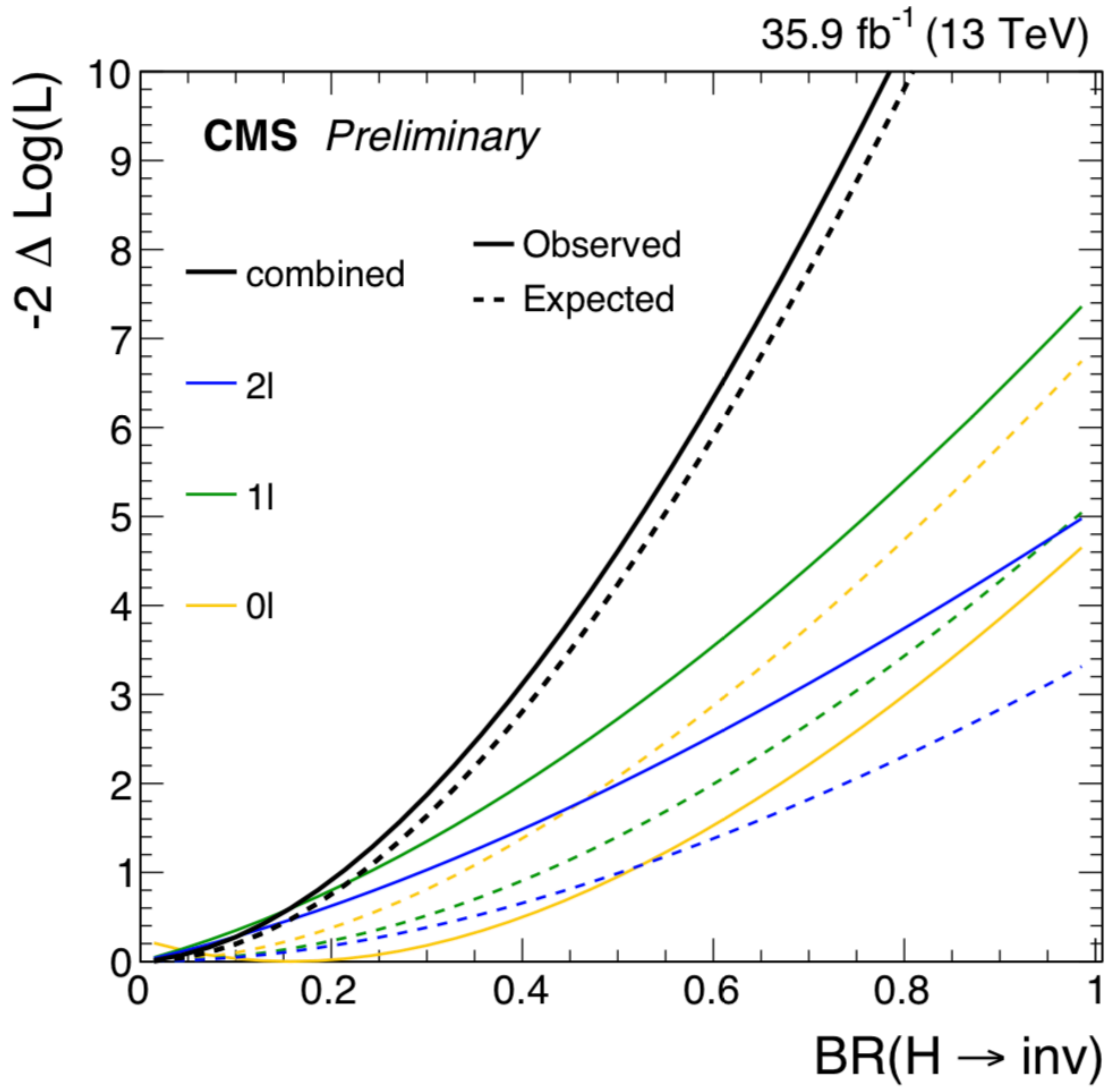
CMS ttH Invisible Search

Re-interpretation of stop search in strong production and in t-Neutralino decay into ttH Invisible:



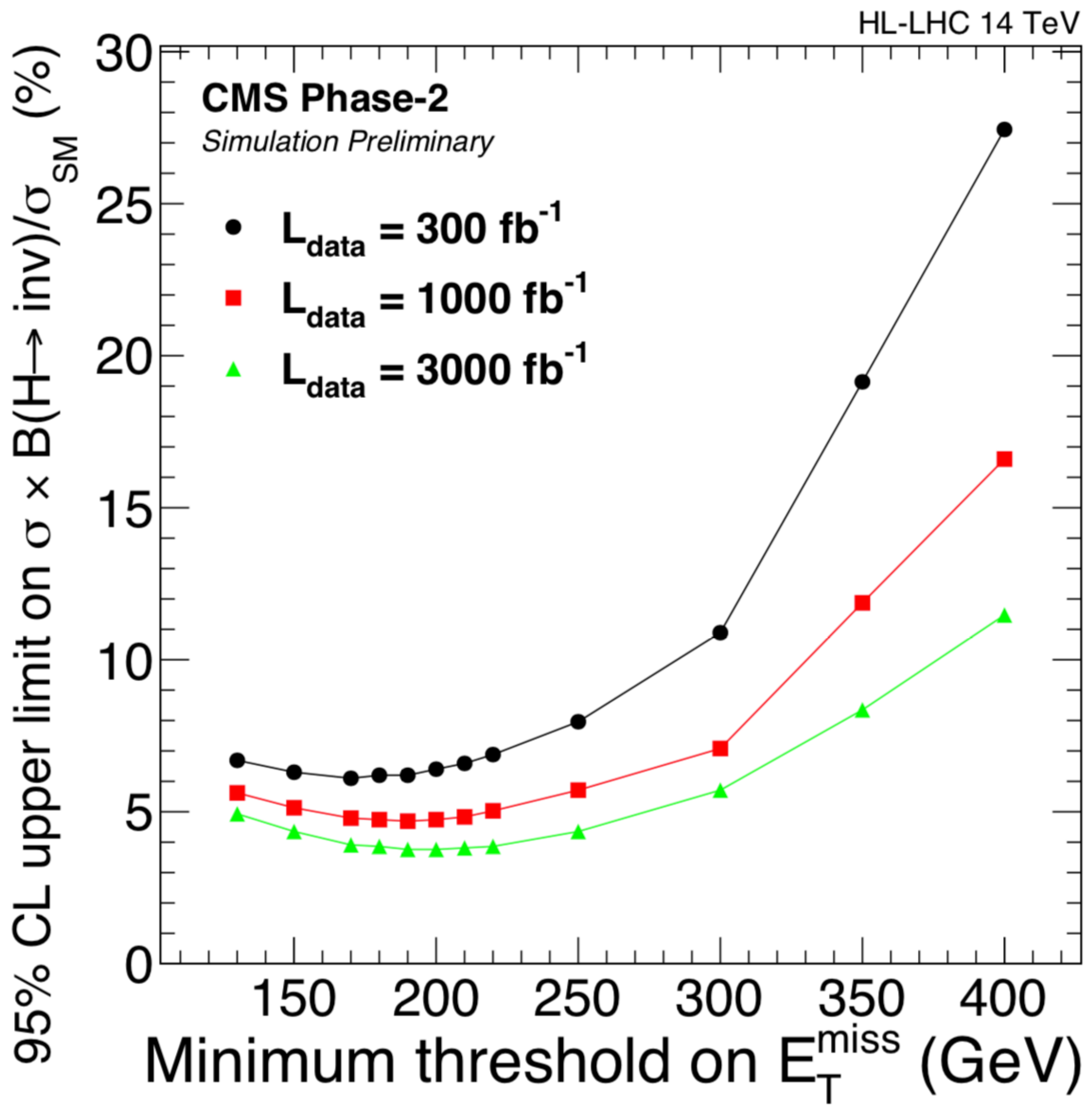
Complex analysis involving based on the three main channels 0L, 1L and 2L and a large number of sub channels (to cover a large region of stop phase space).





Invisible Higgs @ HL-LHC

Projection at HL-LHC in the VBF channel (single experiment):



CMS FTR 18-016

$$Br_{inv} < 3.8\%$$

Combination VH and VBF and consider ATLAS ~ CMS

$$Br_{inv} < 2.5\%$$

HL-LHC YR 1902.00134

Still room for improvement but sensitivity already slower than pure statistics

Measuring the Higgs boson Width at the LHC

SM width (small i.e. potentially large relative variations from BSM couplings)

$$\Gamma^H_{SM} = 4.07 \pm 0.16 \text{ MeV}$$

Width from Lineshape measurements

- Current constraints from the measurement of the higgs line shape from 4-leptons and diphoton channels:

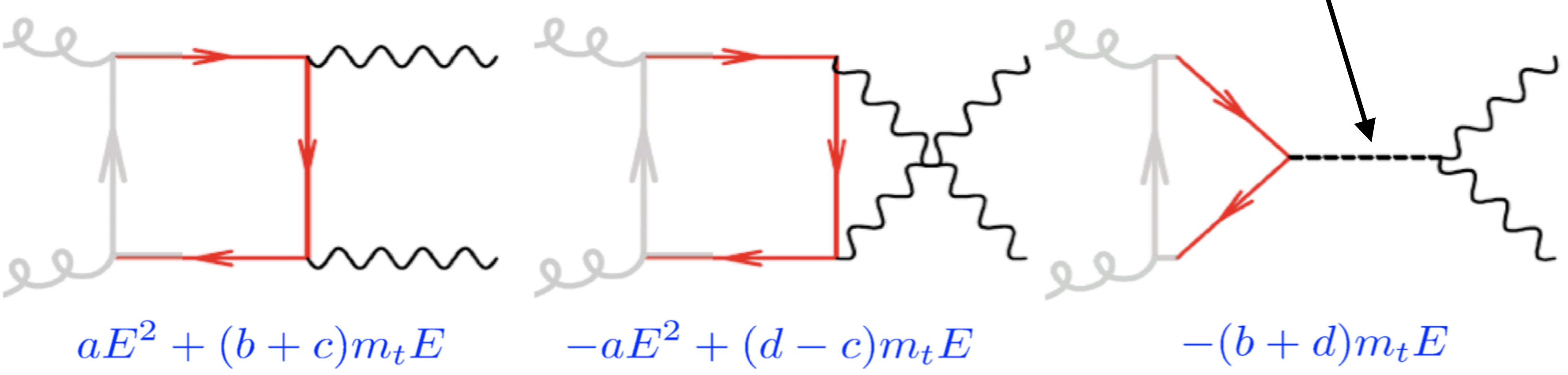
$$\Gamma^H_{SM} < 1.10 \text{ GeV at } 95\% \text{ CL}$$

(CMS-PAS-HIG-16-041 with 4l only and 36 fb-1)

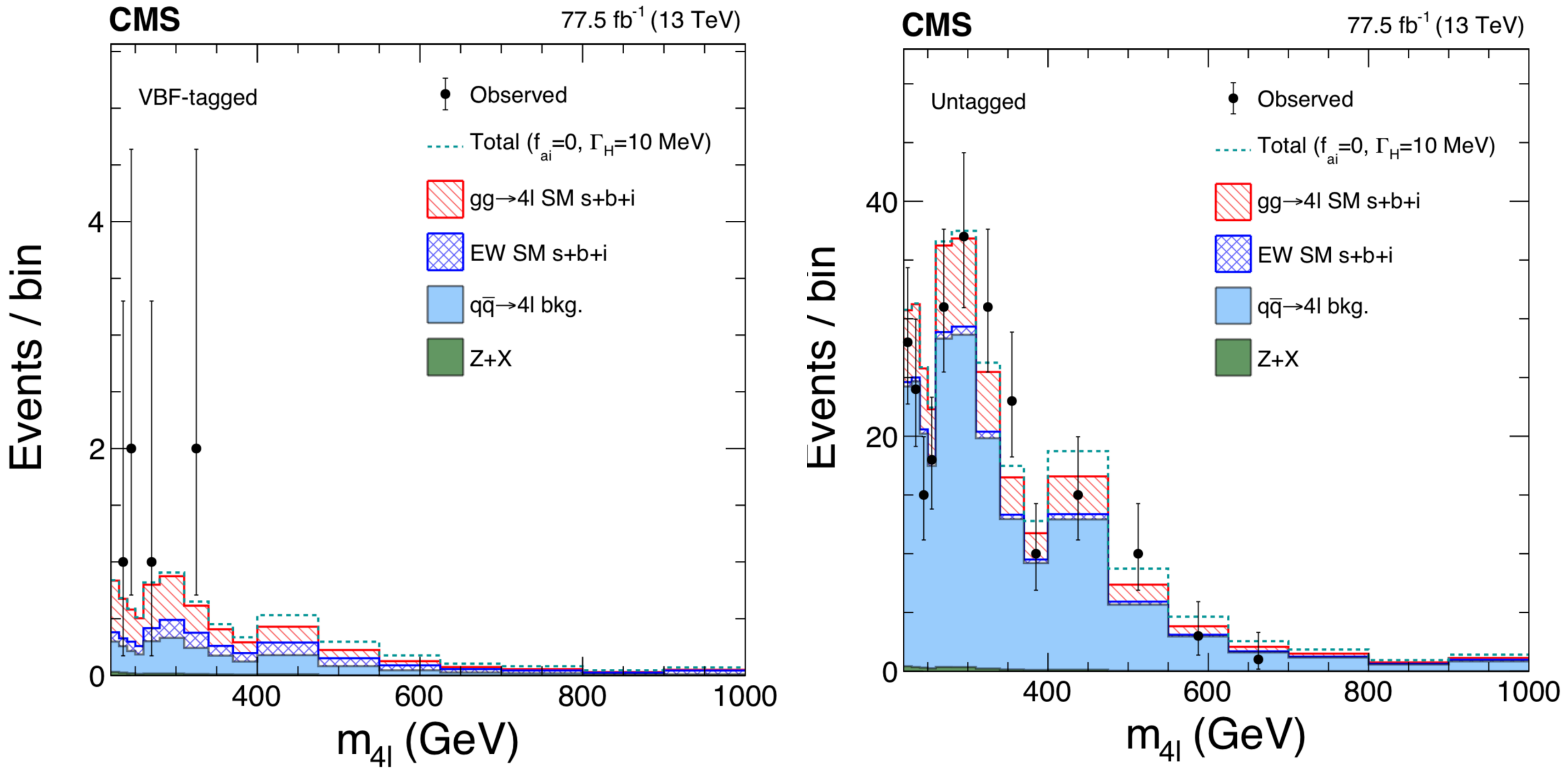
Offshell Higgs measurements

CMS 1901.00174

Study the 4-leptons spectrum in high mass regime where the Higgs boson acts as **propagator**



Courtesy J. Campbell



Using ggF, VBF and VH production (and WW decays at Run 1)

$$\Gamma_H = \frac{\mu_{off\ shell}}{\mu_{on\ shell}} \times \Gamma_H^{SM}$$

Assuming running of the SM running of the couplings and that

Parameter	Observed	Expected
Γ_H (MeV)	$3.2^{+2.8}_{-2.2}$ [0.08, 9.16]	$4.1^{+5.0}_{-4.0}$ [0.0, 13.7]

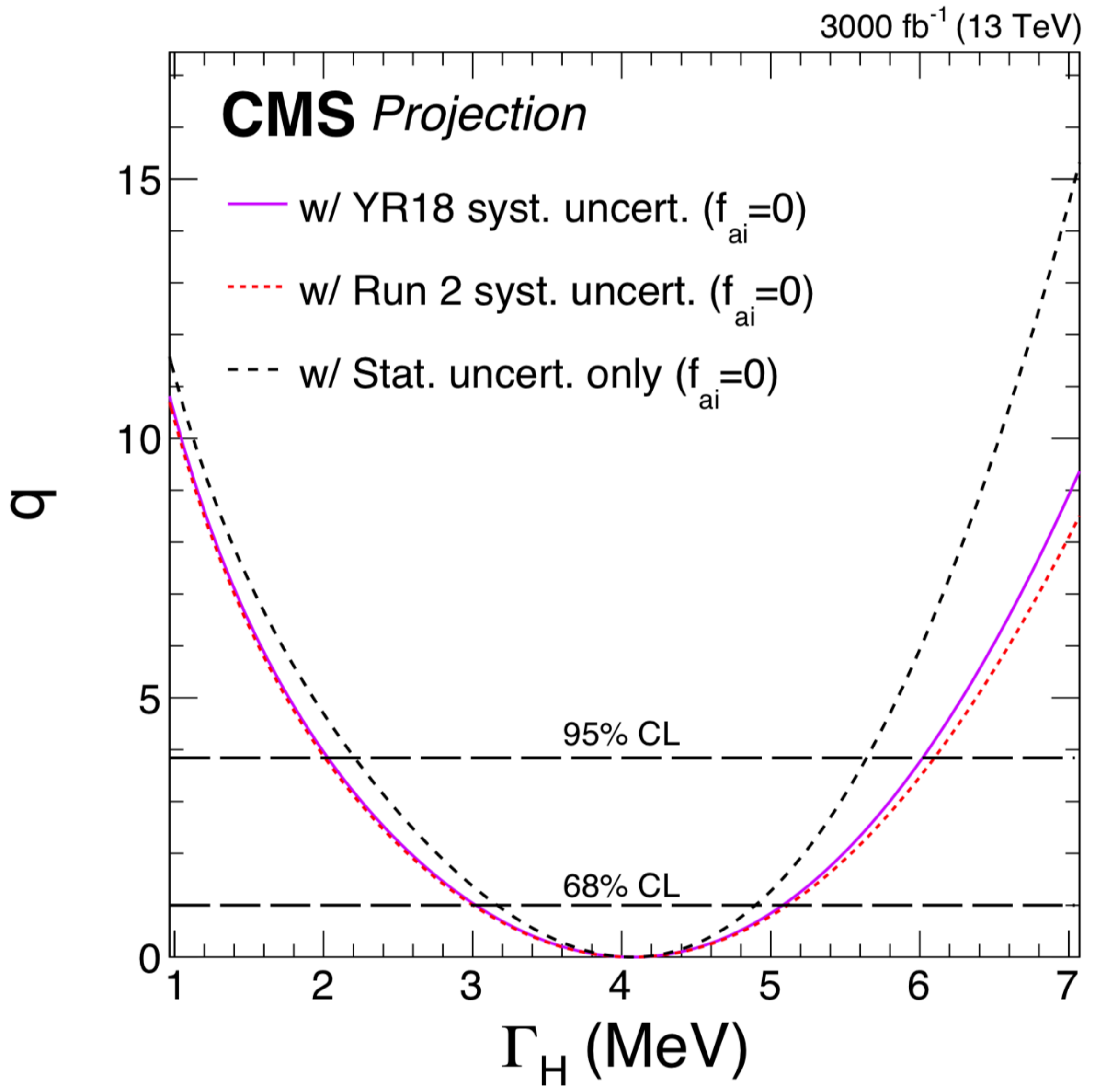
Impressively strong constraints with still room for improvements with higher statistics.

Careful to systematics from ggZZ (including interference term).

Off Shell Higgs @ HL-LHC

HL-LHC YR 1902.00134

Preliminary HL-LHC results with 3 ab-1:



HL-LHC: $\Gamma_H = 4.1^{+1.0}_{-1.1}$ MeV

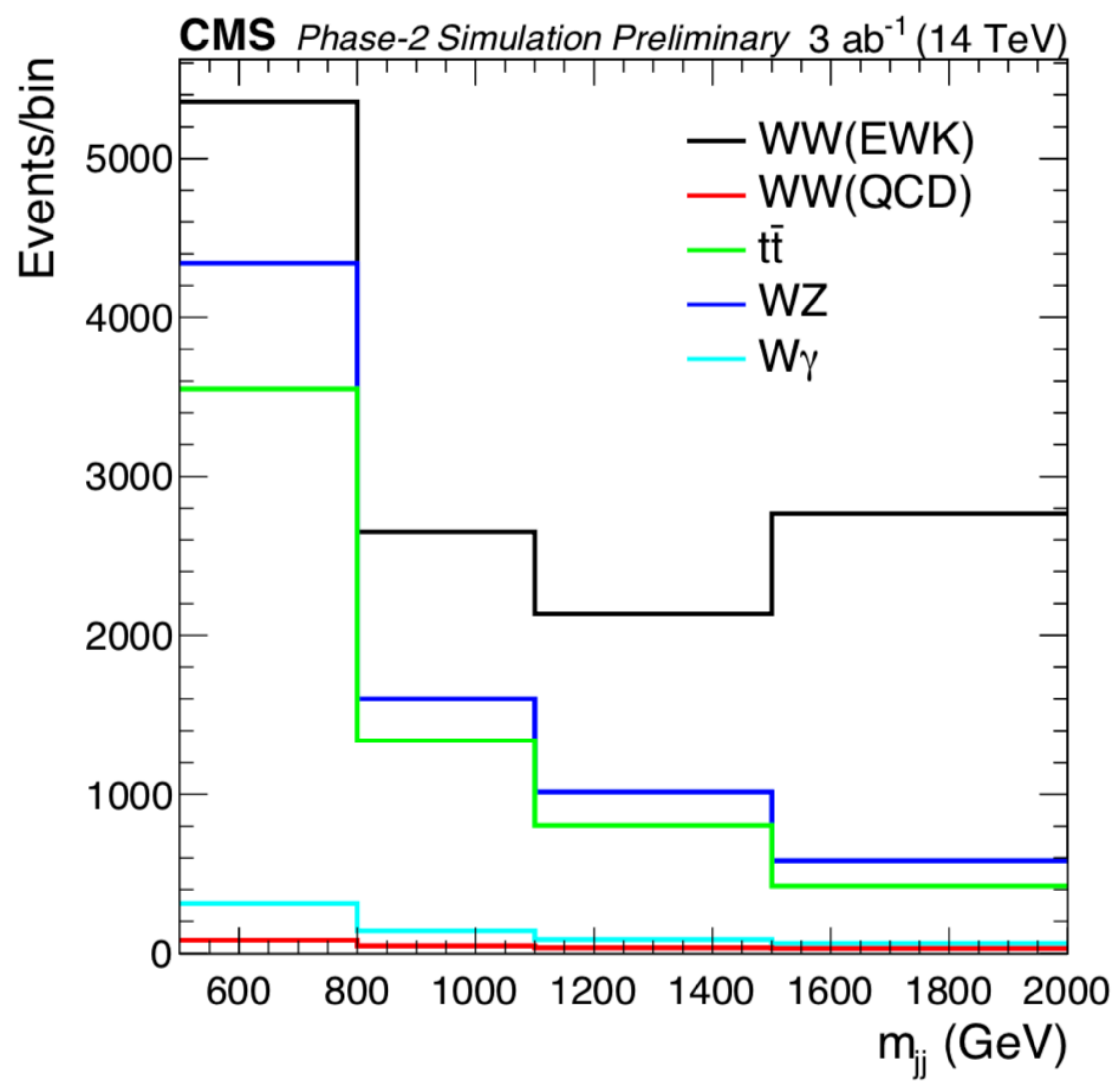
Also more ideas using diphoton interferometry

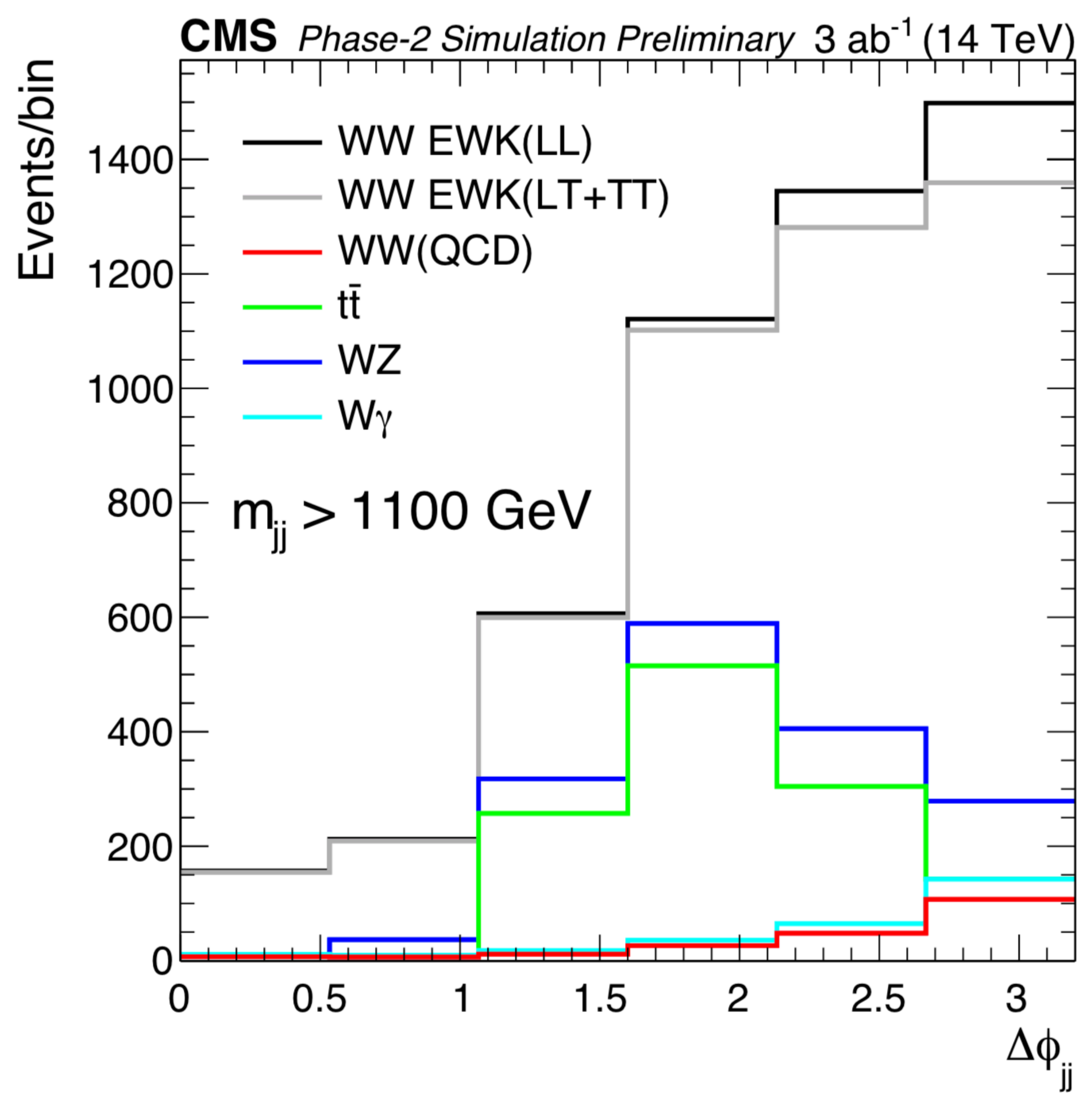
High Energy Probes
Vector Boson Scattering

CMS FTR-2018-005

EW Vector Boson Scattering process

Unambiguously observed by both ATLAS and CMS (at more than 5σ) in the Same sign WW mode. Evidences in the WZ mode.



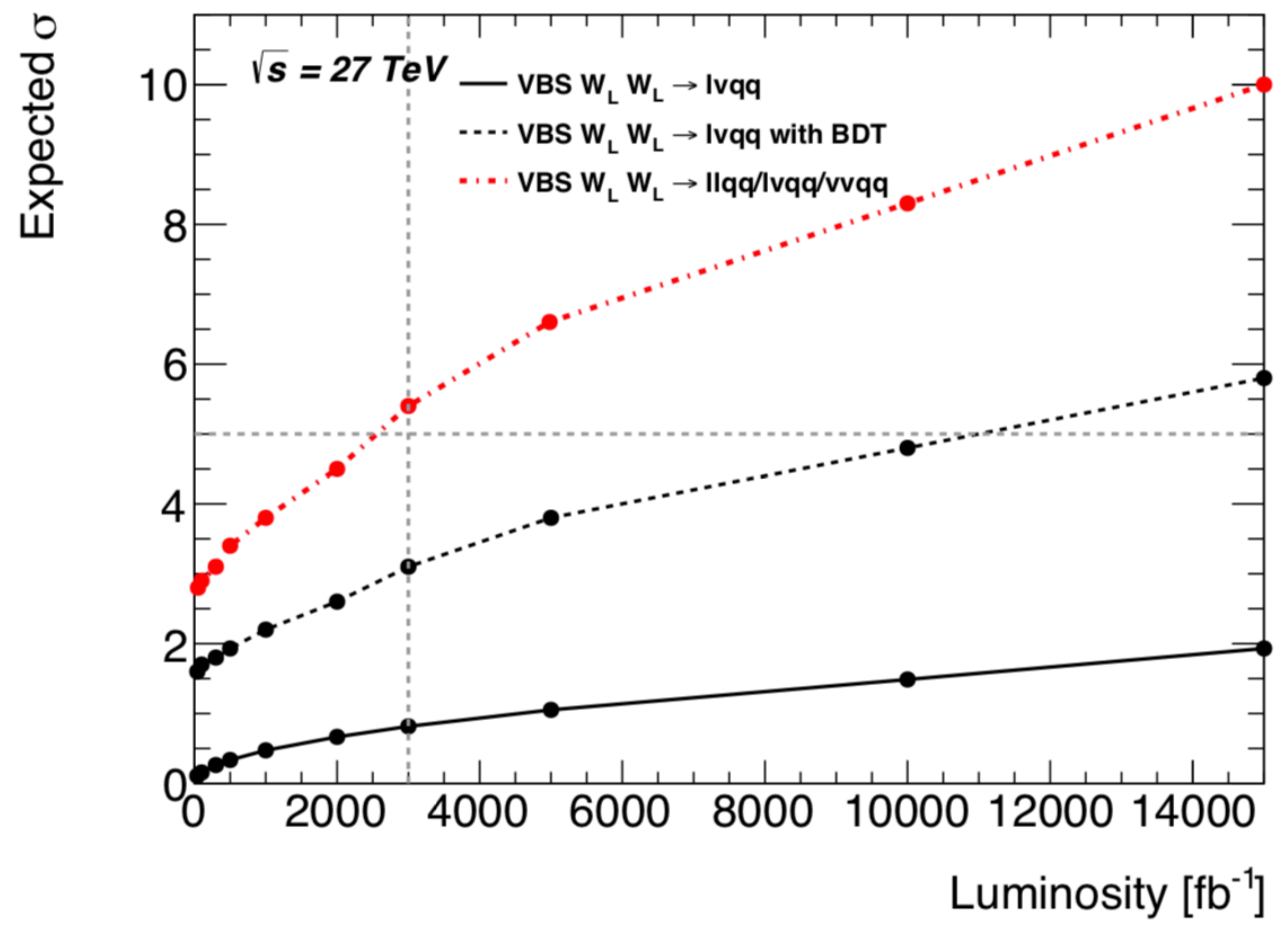


Longitudinal-Longitudinal Scattering at HL-LHC

Important additional check of the EWSB sector (could betray the composite nature of the Higgs boson).

Suppressed from Higgs cancellation however with very large statistics and polarisation sensitive variables, there is sensitivity to SM LL signal almost 3σ for CMS alone.

With ATLAS and more channels WZ and ZZ well above 3σ



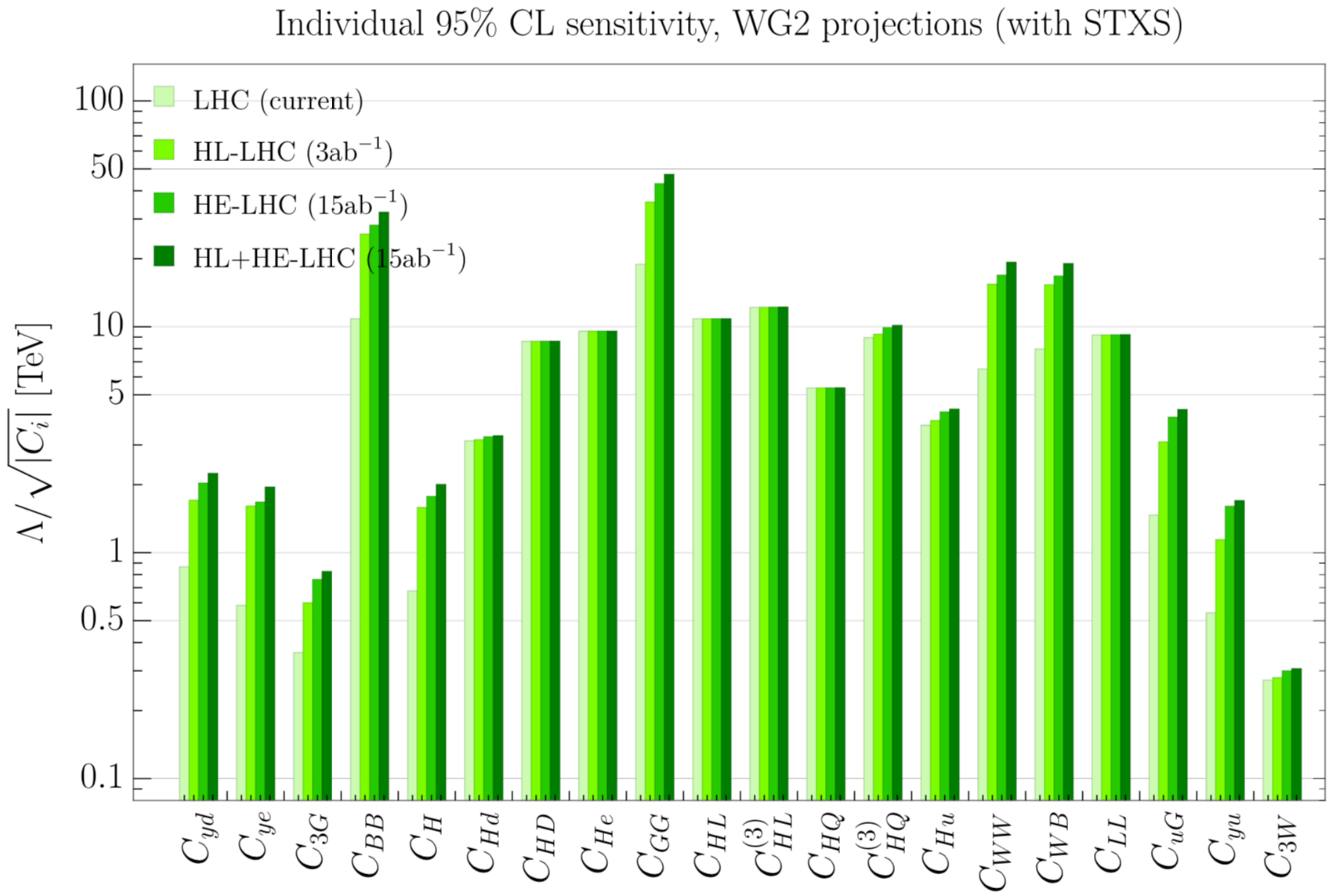
Longitudinal-Longitudinal Scattering at HE-LHC

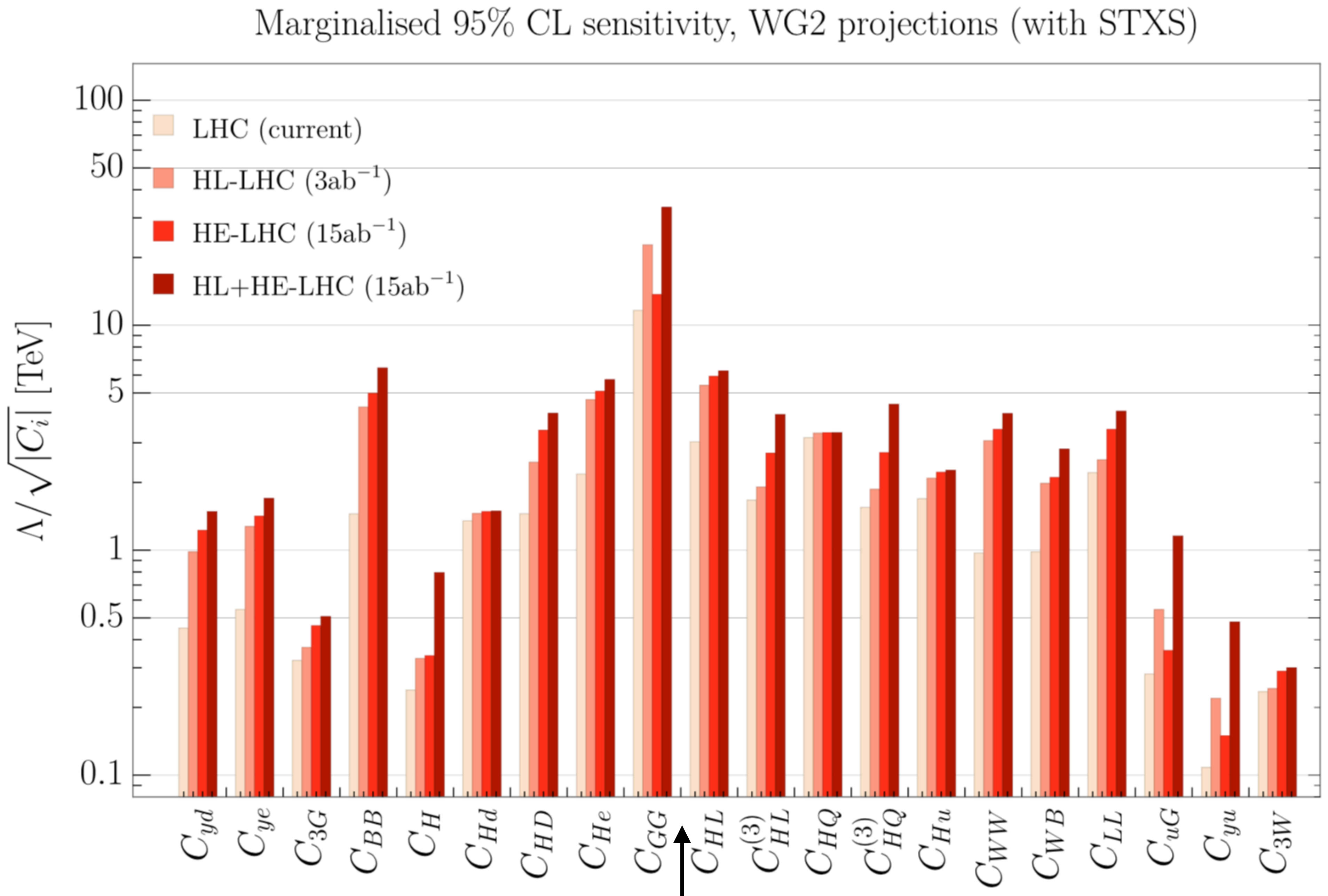
Should be able to surpass the 5σ threshold and reach a precision near 10%.

Global EFT Fit (I): Partially Universal EFT fit

- SMEFT with dimension 6 operators in the Warsaw basis
- Reduction of the (2499 baryon number preserving dim-6 Wilson coefficients) using U(3) flavour for the 5 light fermion fields (assuming $U(3)^5$ symmetry), reducing to 76 coefficient among which 20 relevant for di-boson, EWK precision and Higgs physics.

- **Inputs**:
  - Z pole (LEP, SLC) and WW (LEP)
  - LHC Higgs signal strengths (in part VH).
  - LHC WW (with pT>120 GeV)
  - Higgs STXSs





Due to opening of flat direction

Only linear terms in parametrisation taken into account, fair approximation (taking only SM-BSM interference) for precise measurements (BSM small) - observables not growing with energy, less otherwise.

Global EFT Fit (II) for Universal New Physics

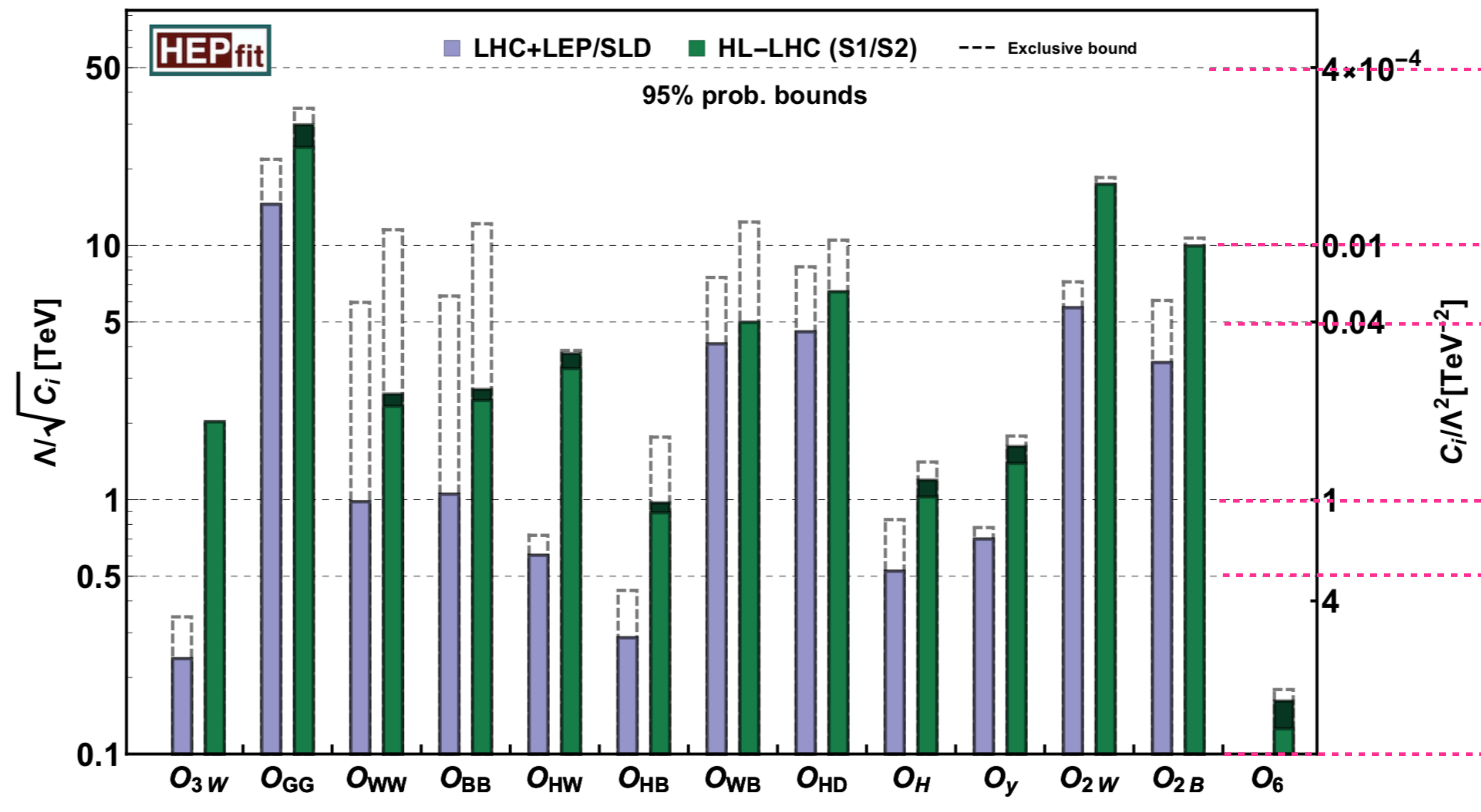
- SMEFT with dimension 6 operators in the Warsaw basis (as well).
- Assuming universality, which results in a slightly simpler model focussing on bosons and the following operators:

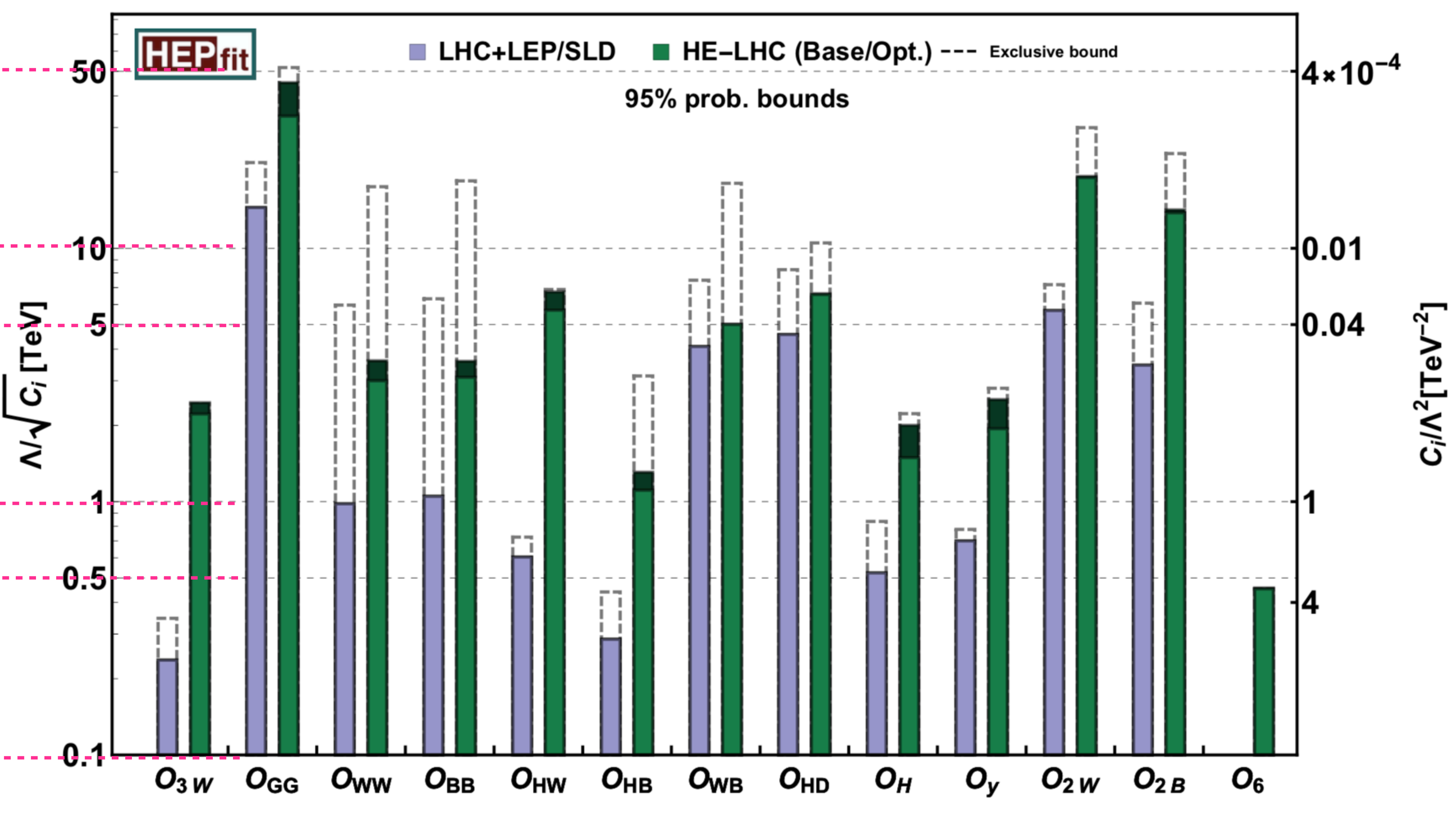
$$\{\mathcal{O}_H, \mathcal{O}_{HD}, \mathcal{O}_6, \mathcal{O}_{GG}, \mathcal{O}_{BB}, \mathcal{O}_{WW}, \mathcal{O}_{WB}, \mathcal{O}_{HB}, \mathcal{O}_{HW}, \mathcal{O}_{2B}, \mathcal{O}_{2W}, \mathcal{O}_{3W}, \mathcal{O}_y\}$$

- **Inputs**:
  - LHC Higgs signal strengths (in part VH).
  - HH differential in baby
  - ZH in the high ZH mass regime
  - WZ (better than WW)
  - DY (high mass)

See section 4 of YR

Quadratic terms taken into account where needed.

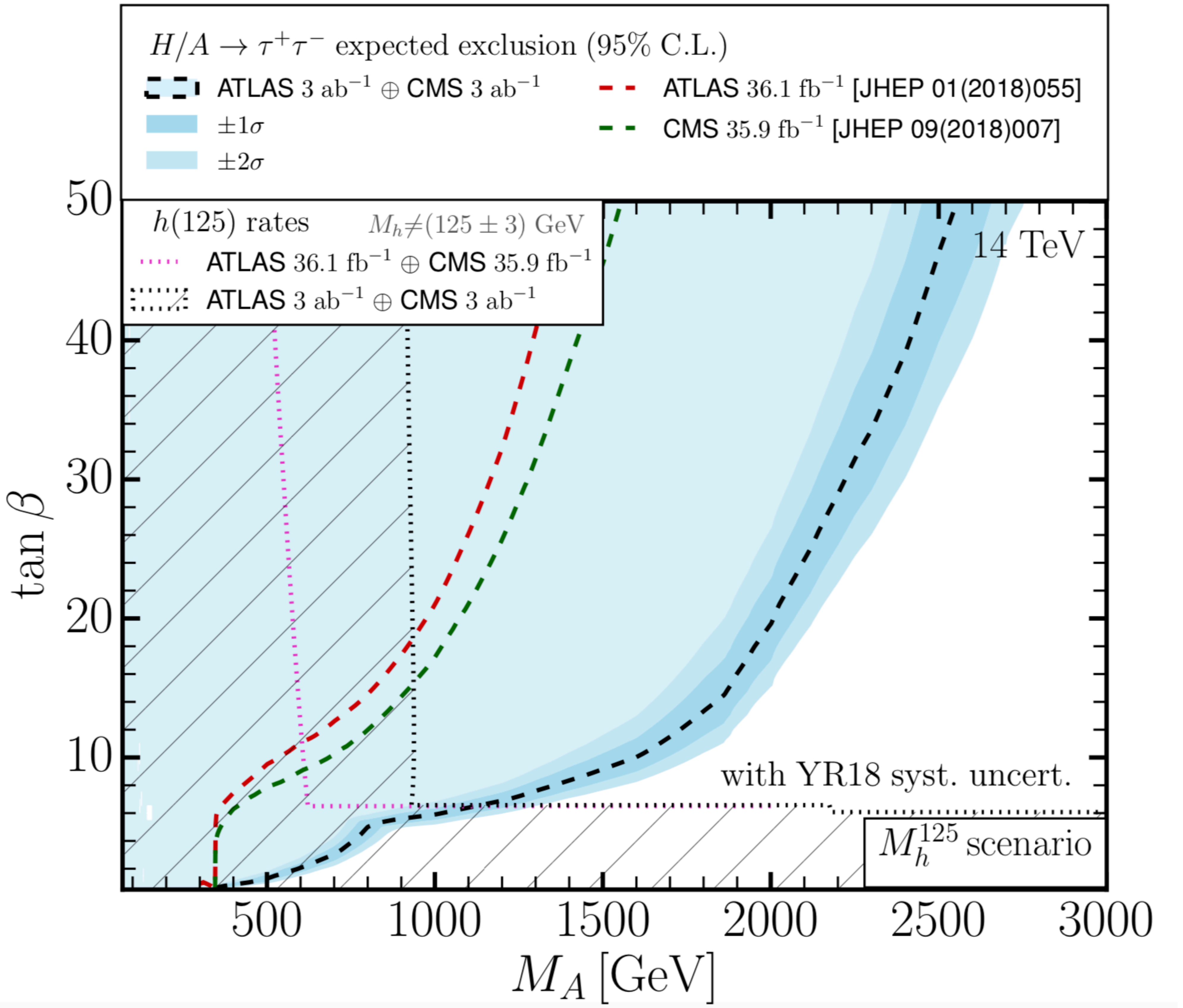




BSM Higgs Searches

- Define "BSM Higgs searches" as any search having as principal goal to search for the an extended Higgs sector (MSSM, 2HDM, NMSSM, Georgi-Machacek Triplets, additional singlets, etc…) not cases where the principal scope is a direct search for a BSM state with Higgs bosons in the final state.

- Because of their coupling properties and backgrounds in hadron collisions, searches for additional Higgs boson are typically in the intermediate mass range. Extension of mass reach is less spectacular than high mass strongly coupled states or additional vector bosons.



- Extending the direct search coverage in the intermediate tan beta region and high mass requires improving to-pair searches (taking into account the interference with the continuum background), progress can be made, but no conclusive prospect studies done so far.

- For typical processes such as e.g. $pp \to S \to hh$ HE-LHC could extend the mass reach by 1.5 to 2 times the HL-LHC reach.

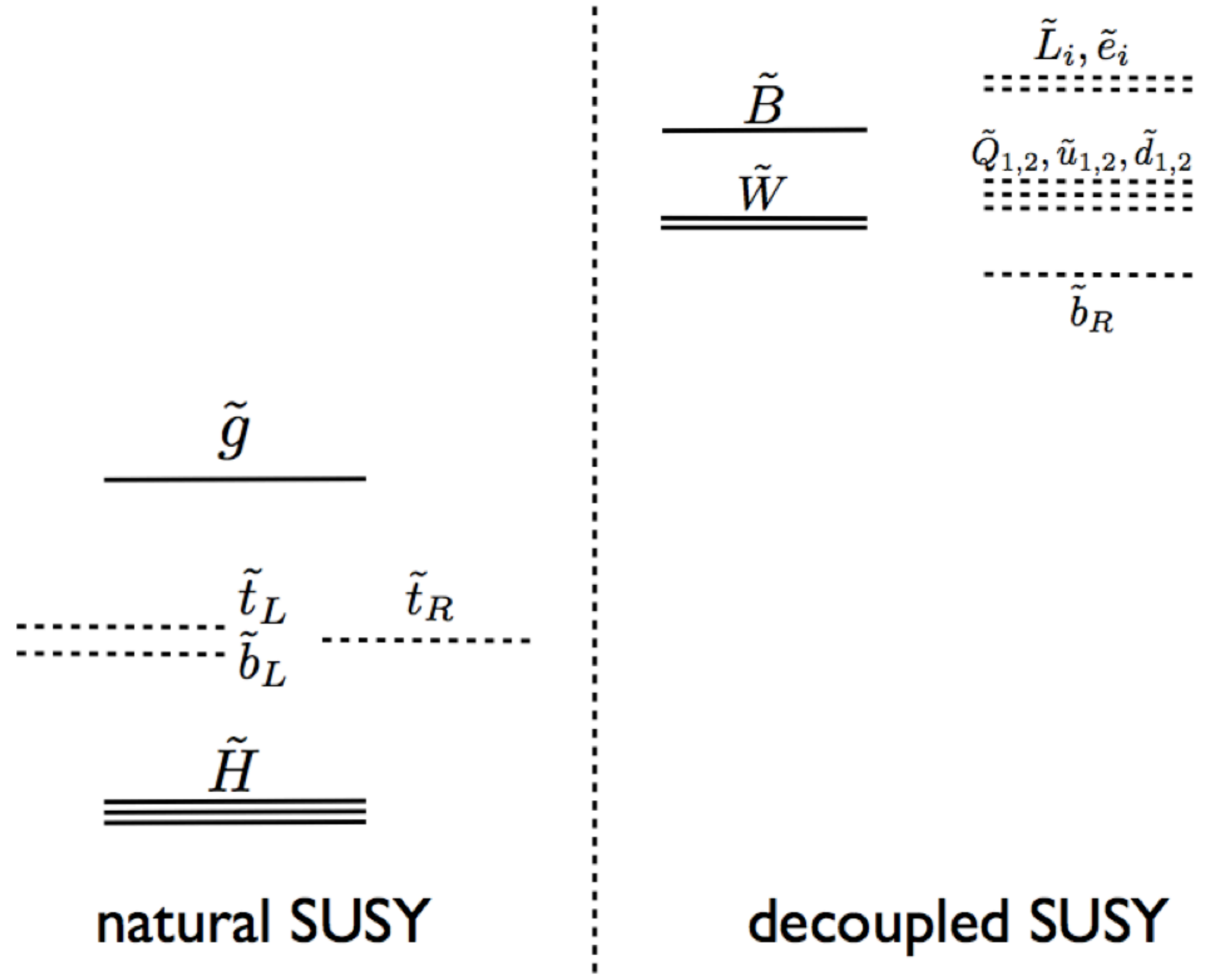
- HE-LHC with its much larger dataset will be important to cover rare modes (e.g. Higgs to axion-like particles or dark photons could probe branchings down to 10-8 - border-line BSM Higgs).

- Most importantly, if hints/evidence for a new state are observed at HL-LHC, HE-LHC could confirm/study it.

Searches for Natural SUSY

Searches

- 3d generation searches for stop and sbottom
- Gluino and squarks searches
- Searches for charginos and neutralinos “EW SUSY searches”
- Compressed scenarios: search for low pT stuff (soft leptons – trigger strategy is important, low pT b’s, etc…)
- Searches for RPV Supersymmetric scenarios



“Natural” SUSY scenario

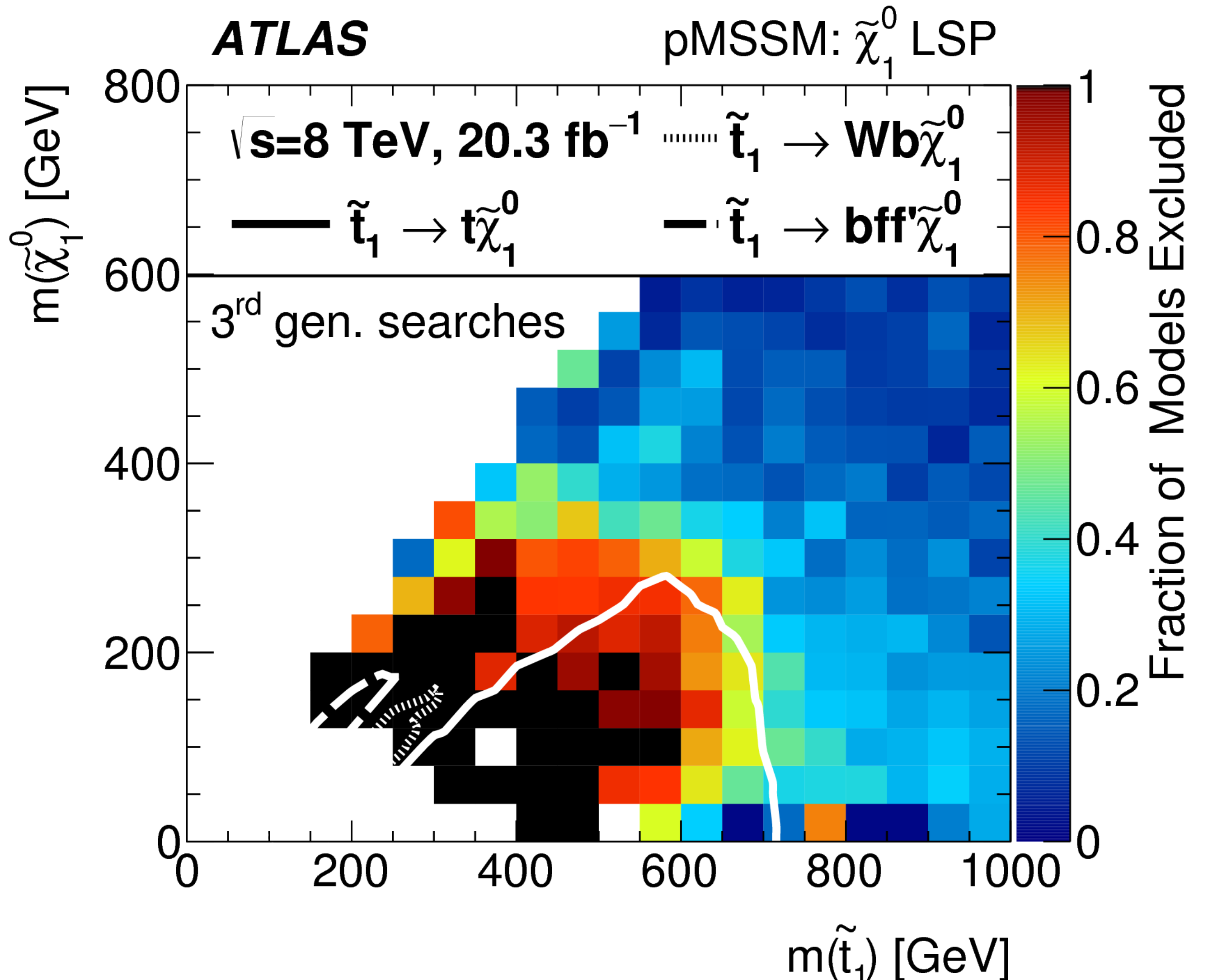
General Strategy

Use simplified models to cover the widest possible variety of **topologies**.
Typically complex signatures without mass peaks, generally with a fair amount of MET (but not always!).
Complex interpretation!

pMSSM Survey (Run 1 results)

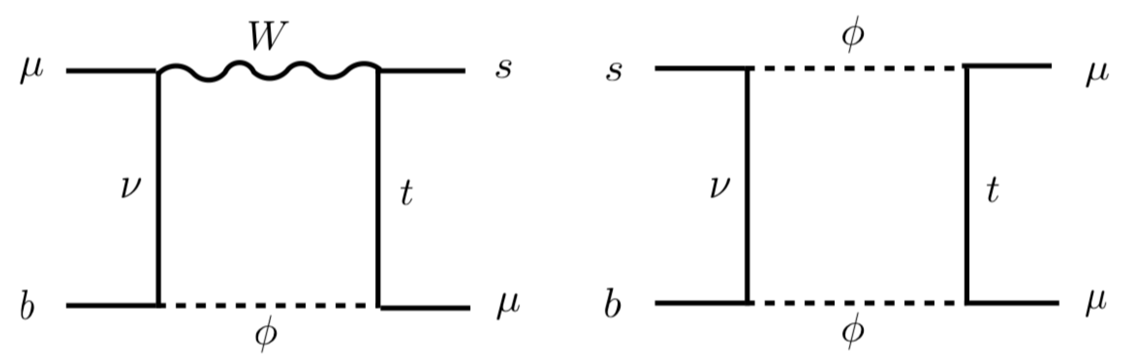
Survey of the 19 MSSM parameters using existing constraints

- 300 k models investigated
- 30 G evts generated
- Signal contamination in background normalisation taken into account

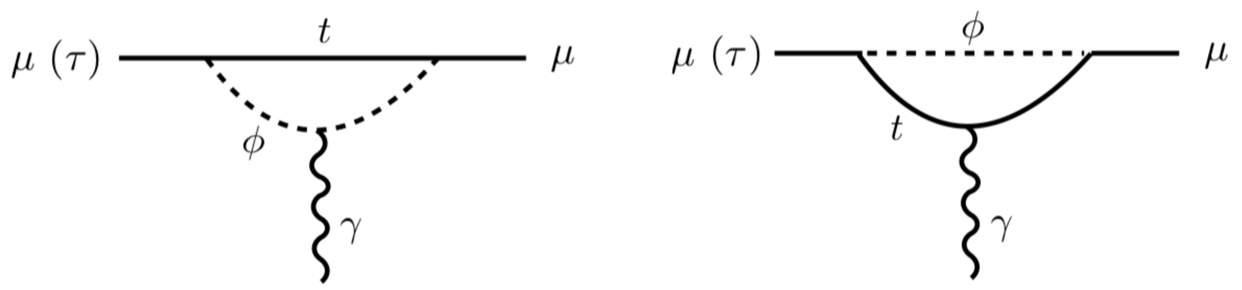


Searches for Leptoquarks

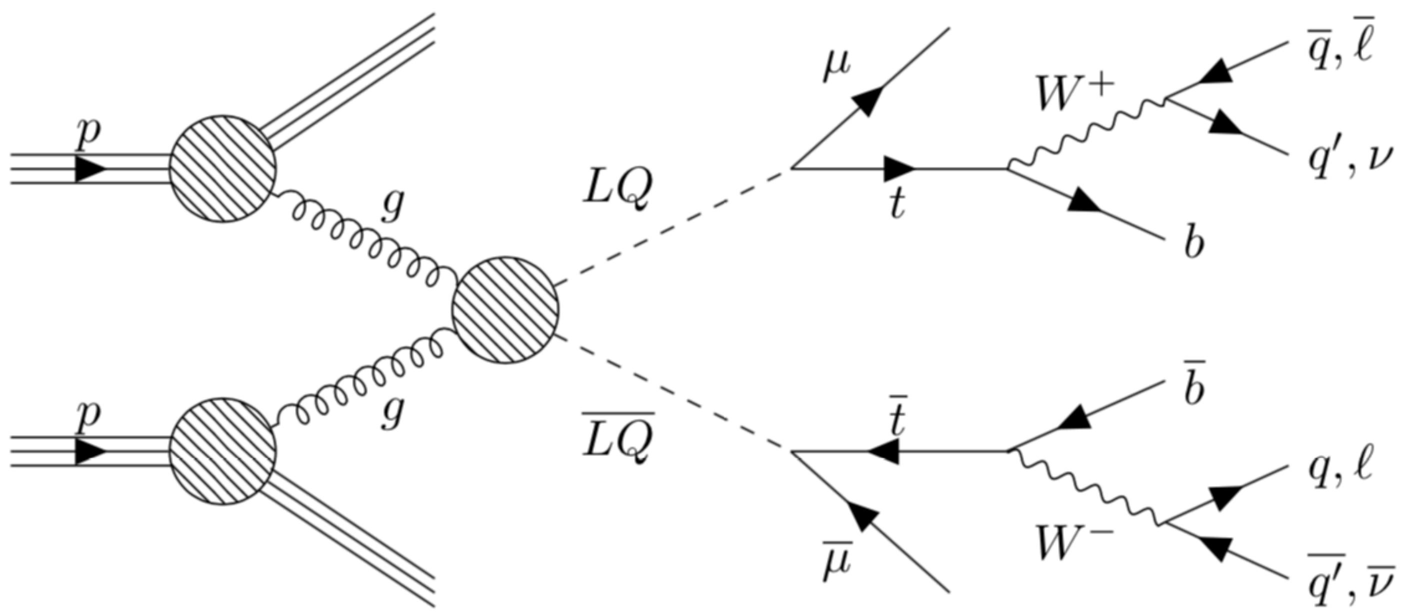
Leptoquarks models with large couplings to the third generation fermions could accommodate the Lepton Universality Anomalies in B decays R_{D^*} and R_{K^*}, and the muon (g-2) anomaly.

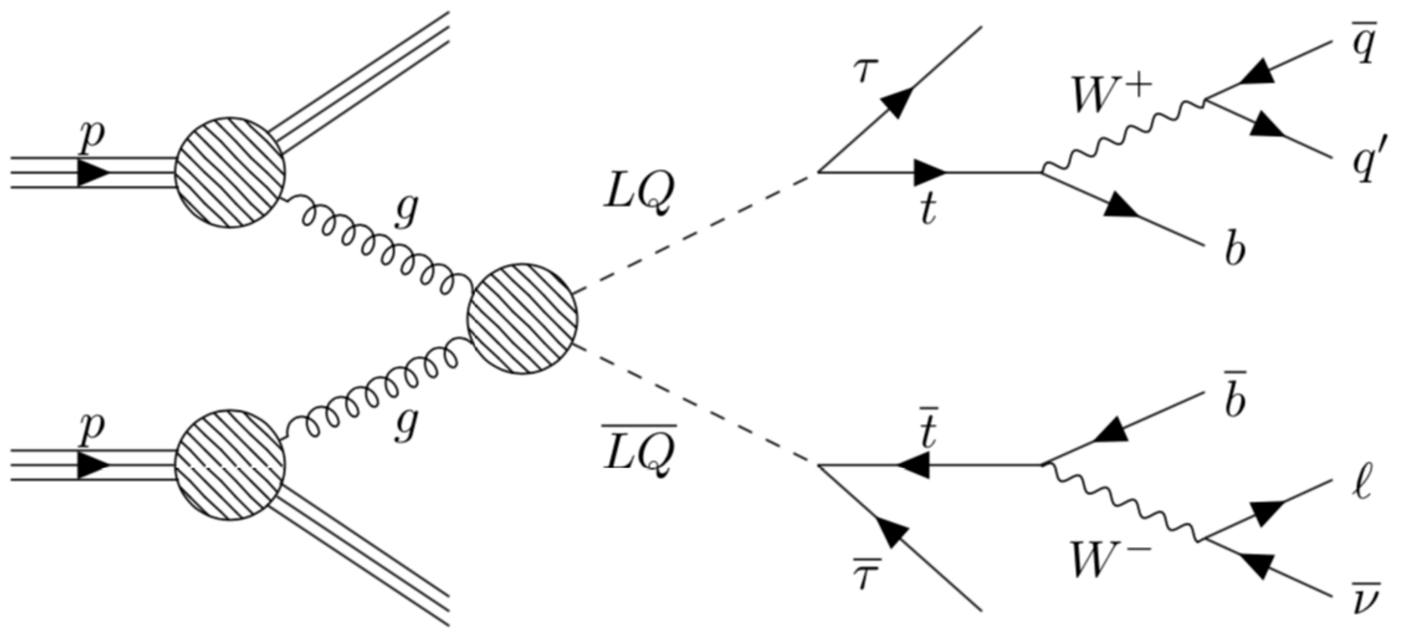


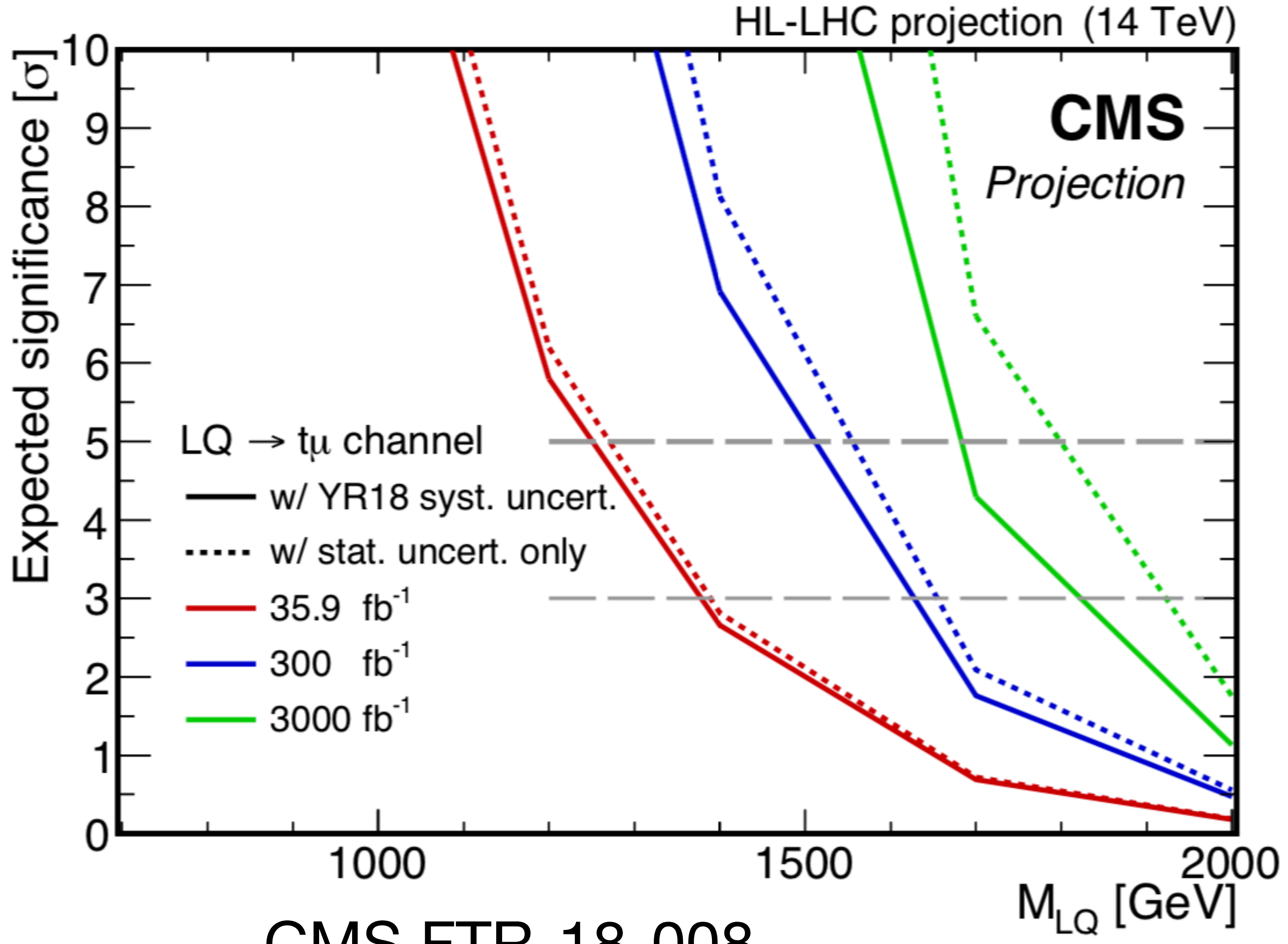
R_{K^*}

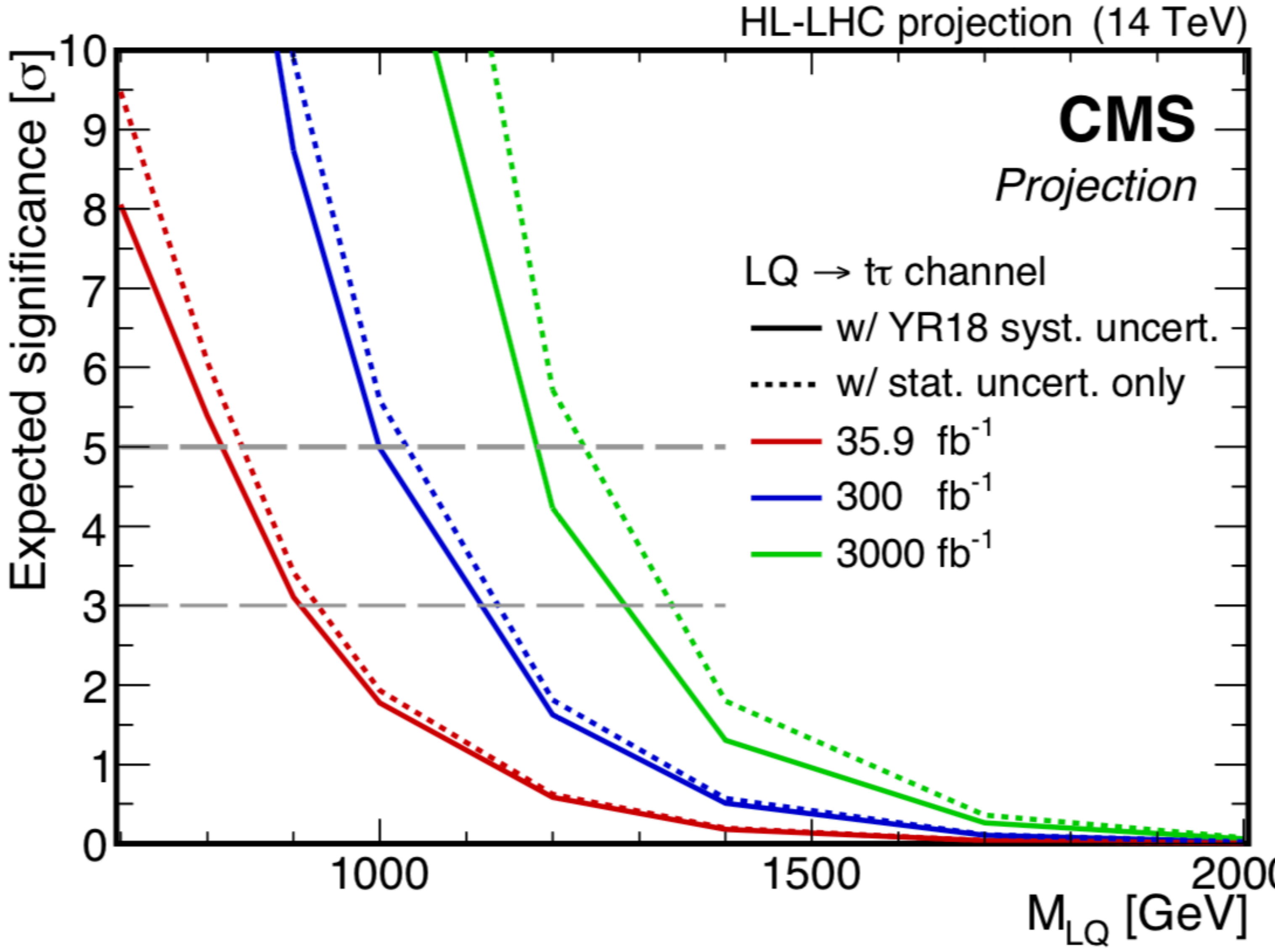


Muon (g-2)









CMS FTR-18-008

Perform a direct search for scalar leptoquarks in several modes decaying to a top and a muon top and a tau.