Physics projections from ATLAS and CMS with upgraded detectors

BERKELEY LAB

BERKELEY EXPERIMENTAL PARTICLE PHYSICS

Benjamin Nachman

on behalf of the ATLAS and CMS collaborations

ATLAS EXPERIMENT

LHCP 2019, Puebla, Mexico

Saturday, May 25, 2019

CMS Compact Muon Solenoid

EW/QCD

CERN-LPCC-2018-03

Jets + photons

W^+W^+

$\sin^2\theta_W$

Disclaimer:

Only a selection of recent key results: the HL-LHC era will have a rich physics program.

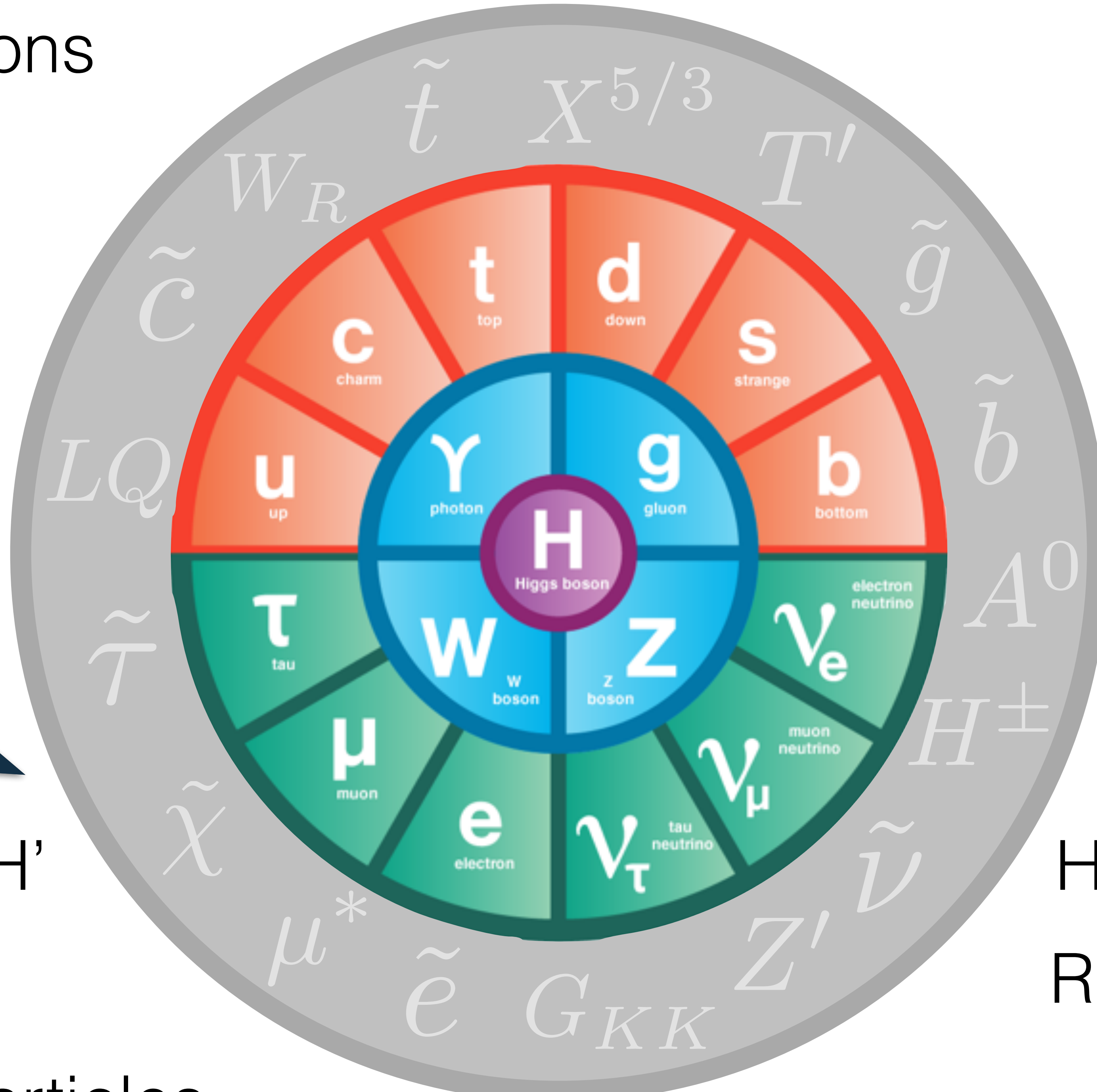
Heavy W’/Z’/H’

Sleptons

Long lived particles

BSM

CERN-LPCC-2018-05



Top quarks

CERN-LPCC-2018-03

4 tops

tt+V

FCNCs

Couplings

H → invisible

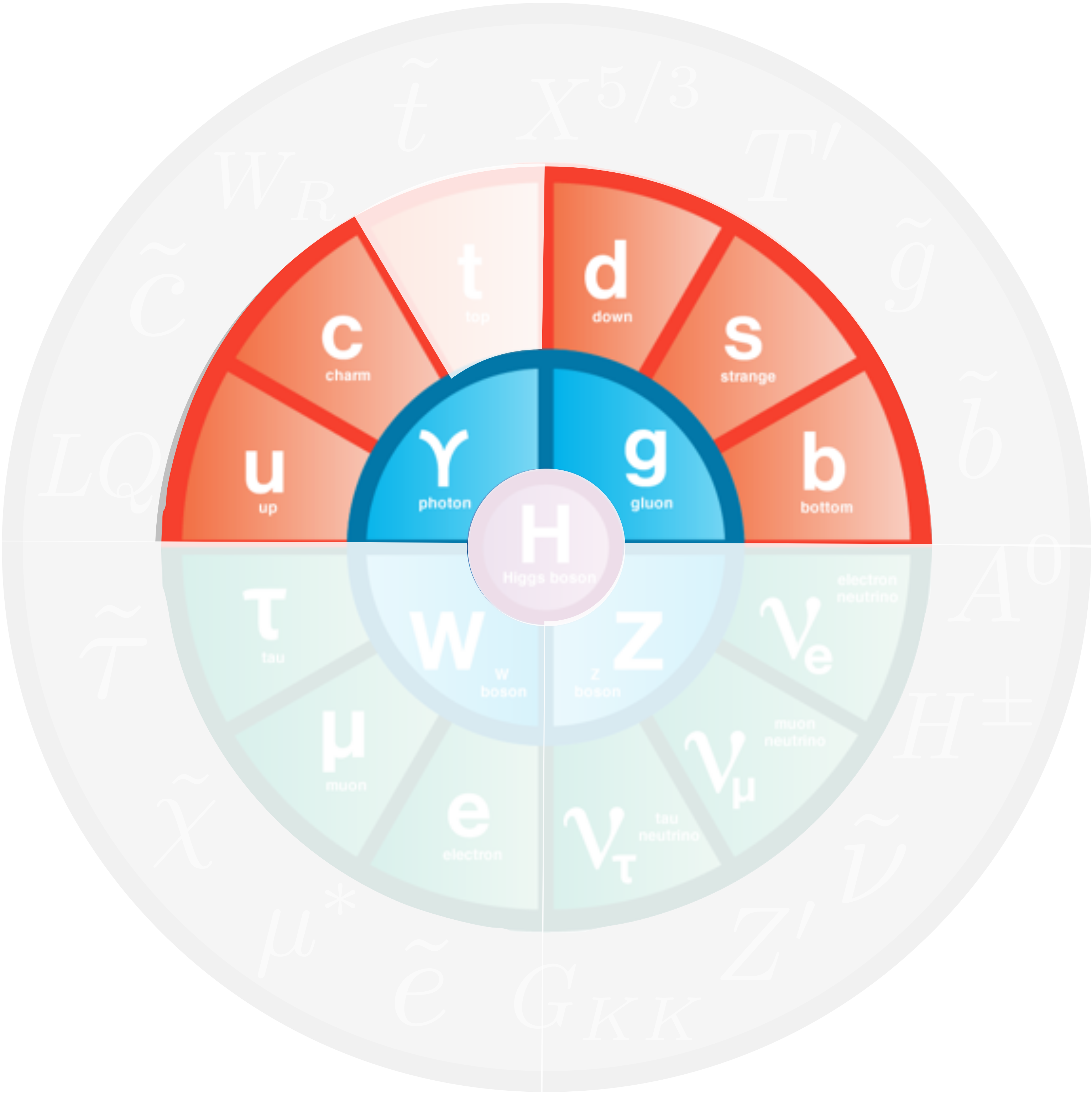
Rare decays

di-Higgs

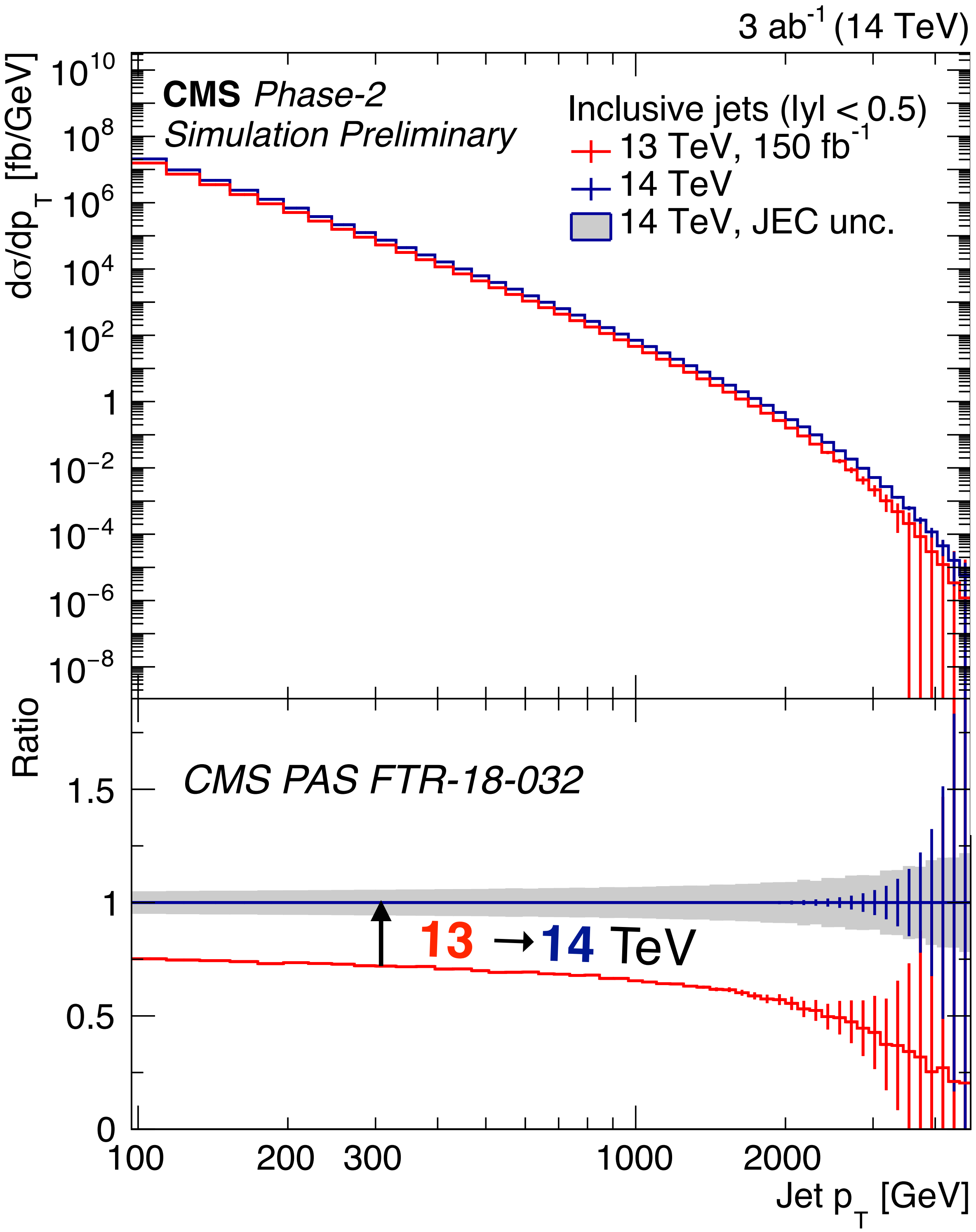
Higgs

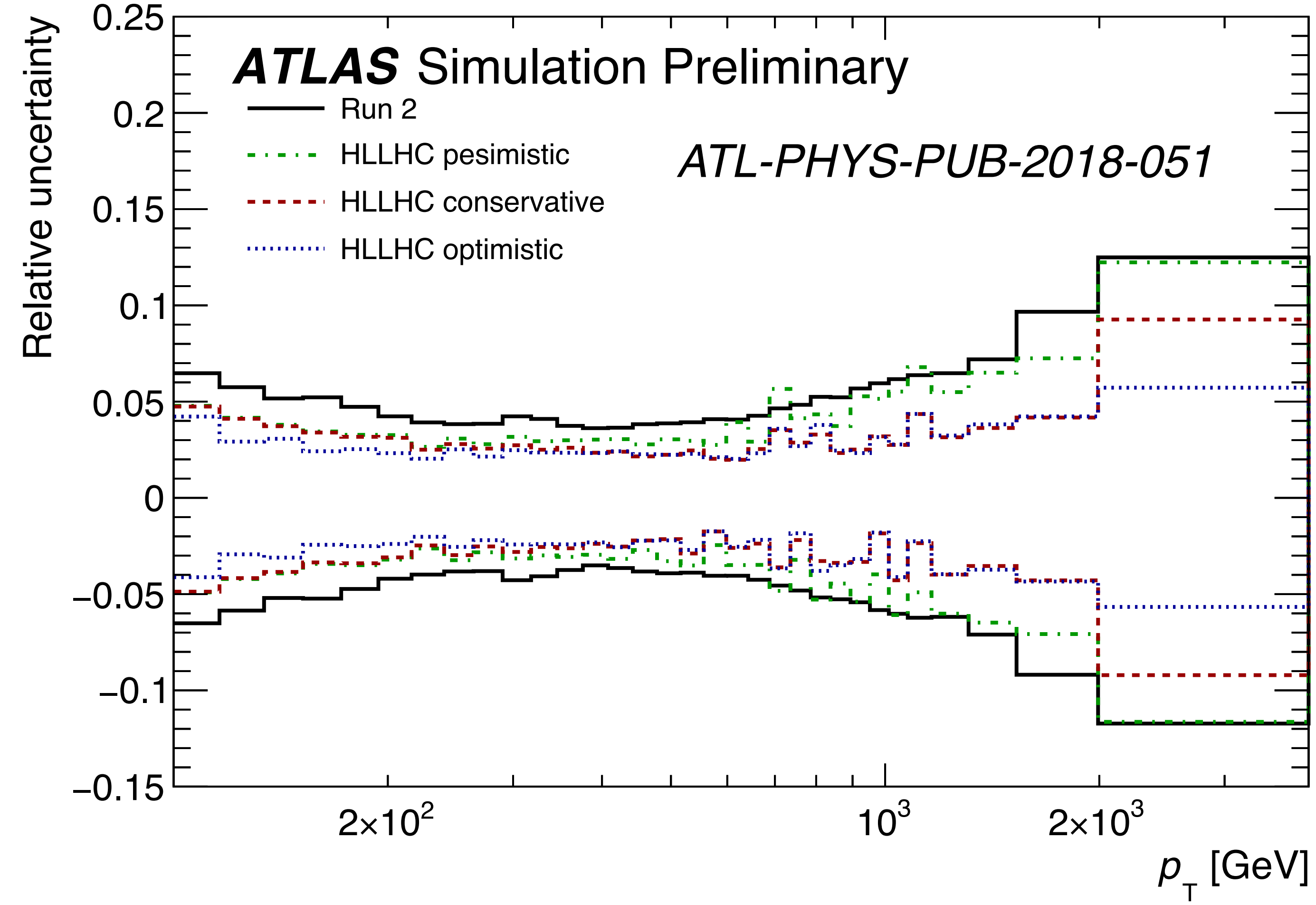
CERN-LPCC-2018-04

Jets and photons



Jets



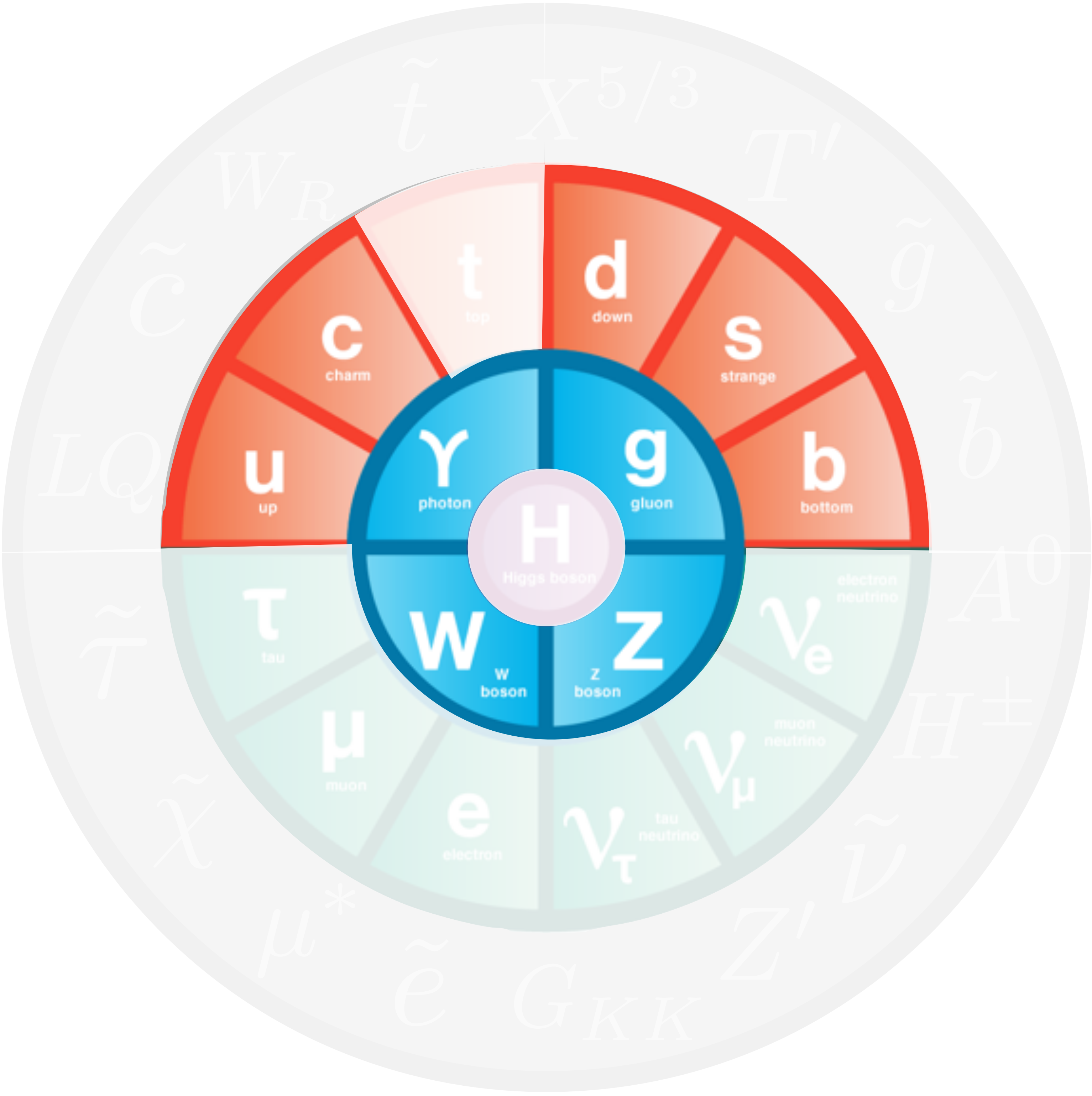


~10% out to 4 TeV

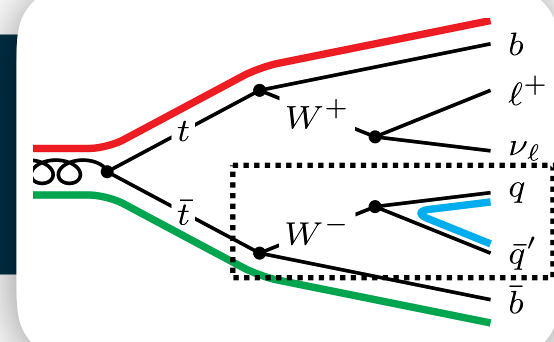
(10% out to 2 TeV with full Run 1 (7+8 TeV))

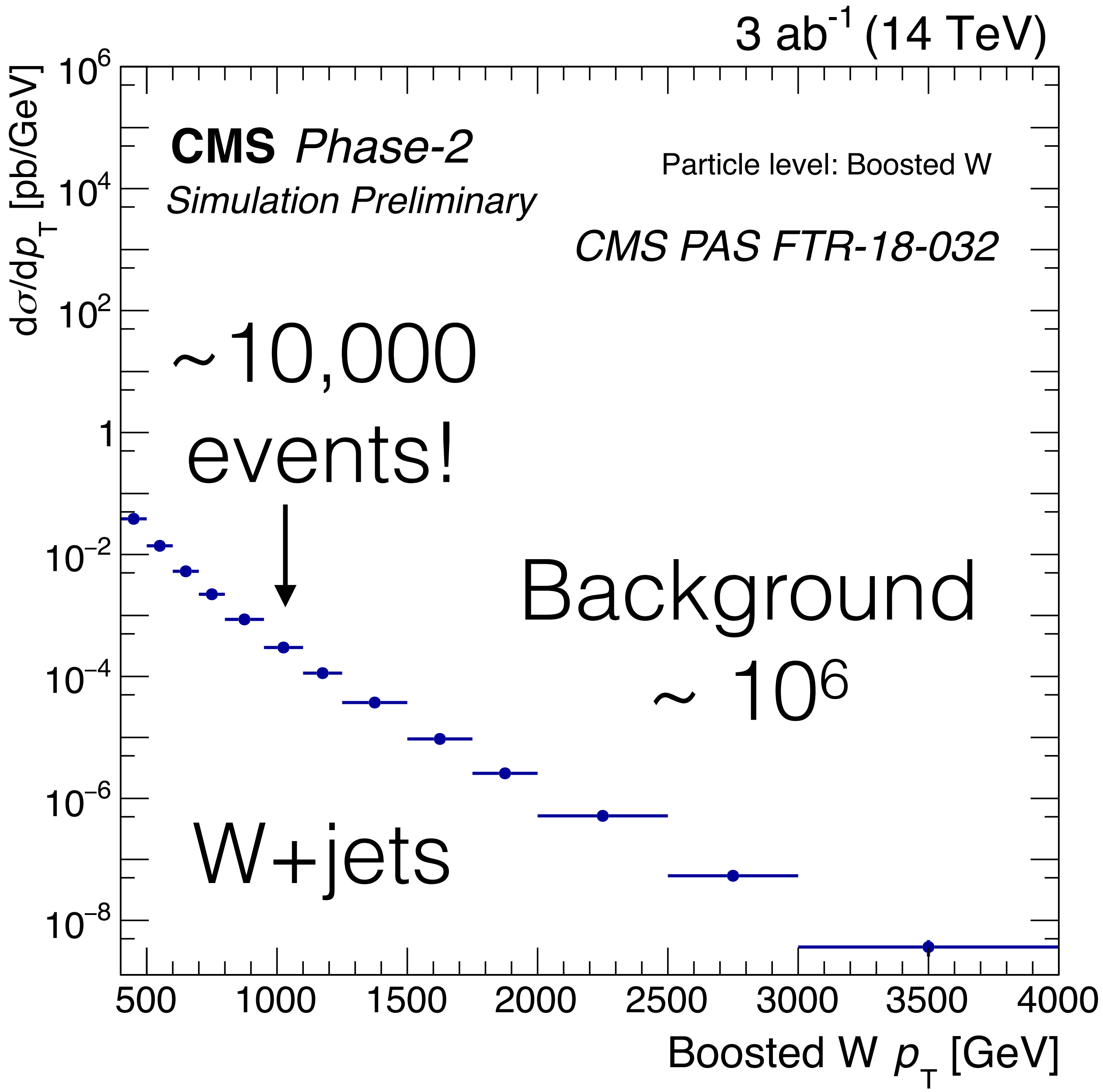
PDFs, α_S (NNLO), indirect searches for colored particles

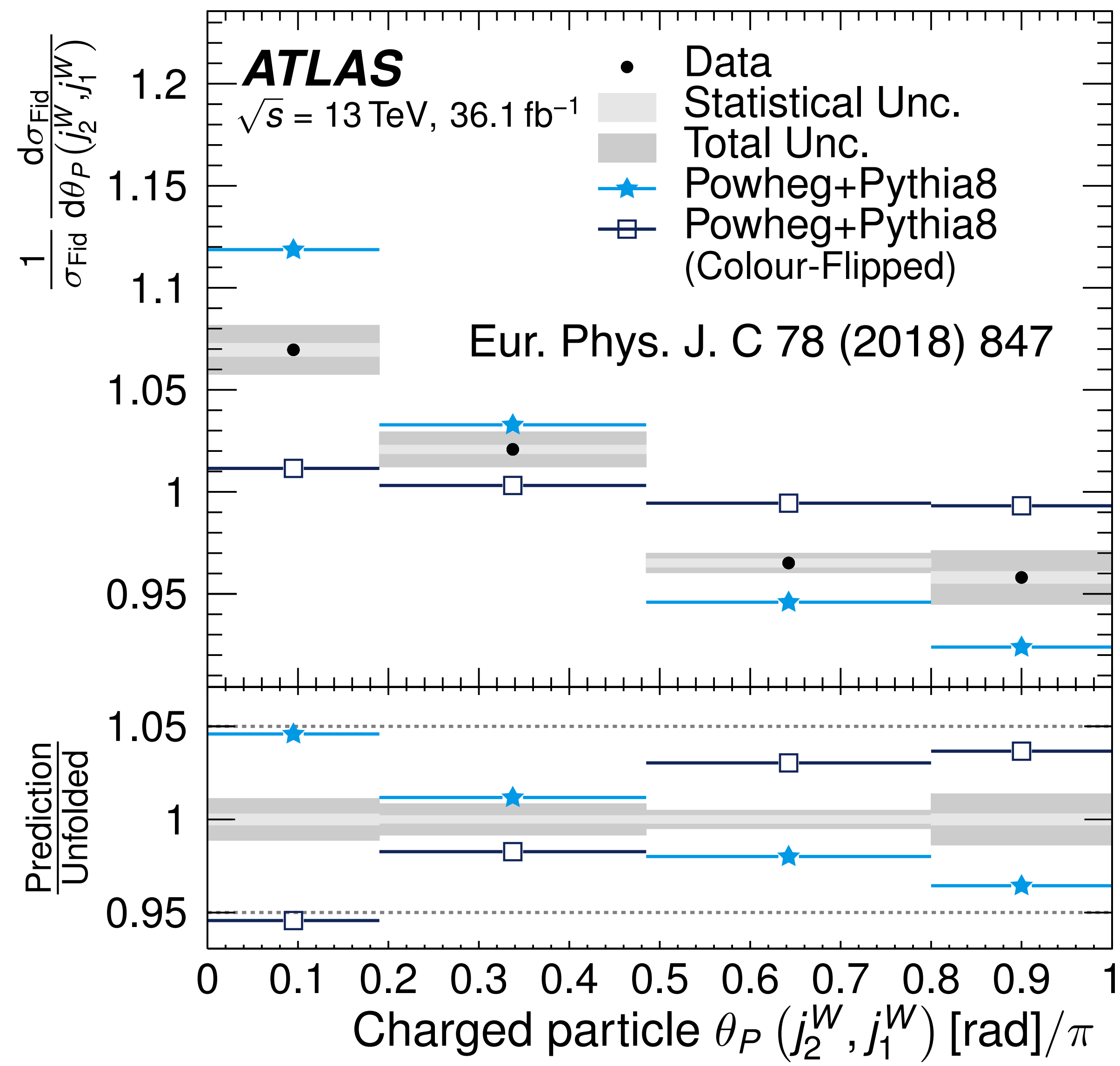
+Electroweak



Boosted Bosons



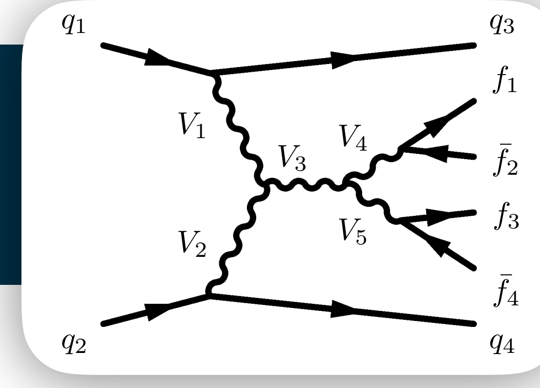


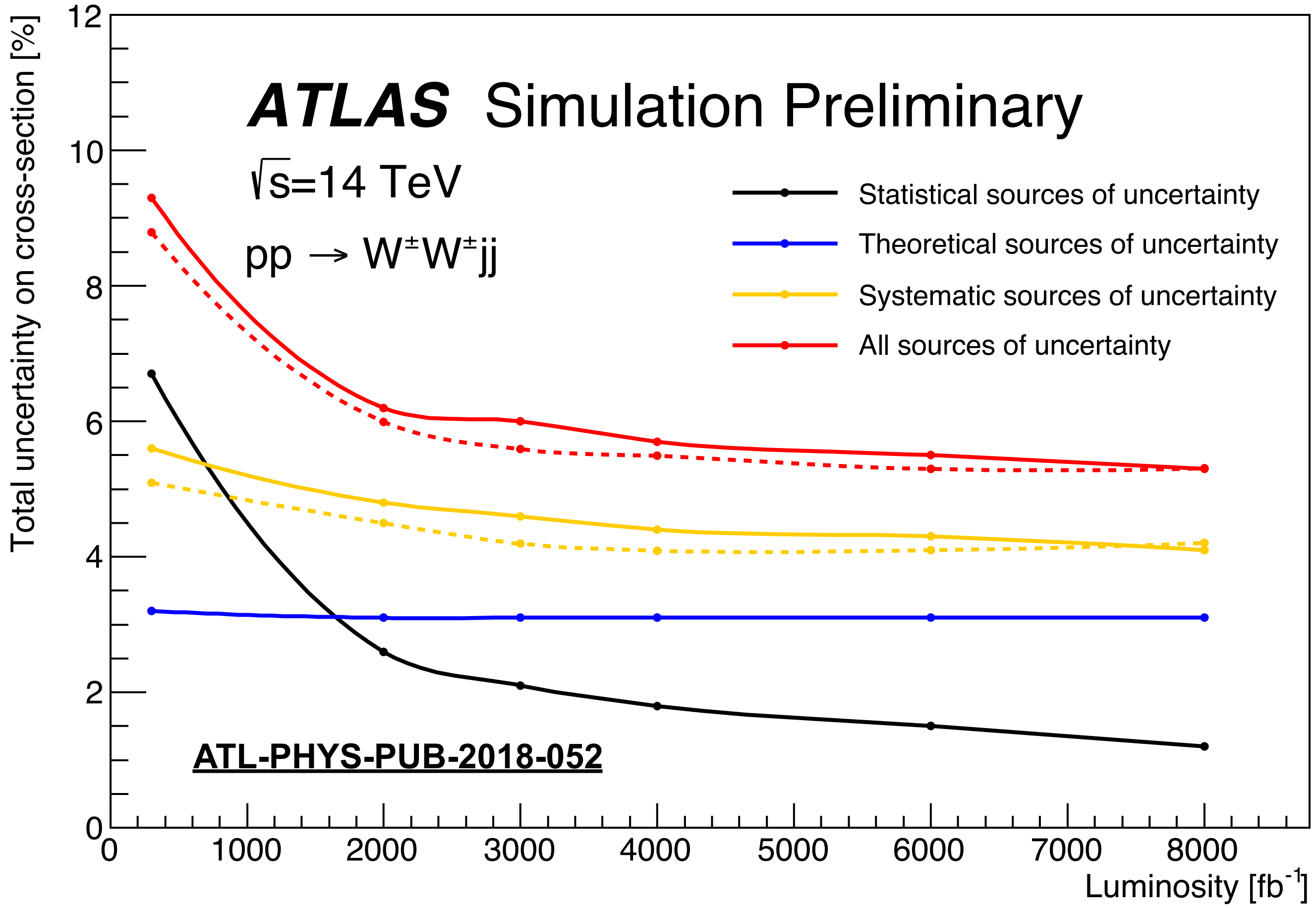


Hadronic W/Z decays are a great **laboratory for QCD studies.**

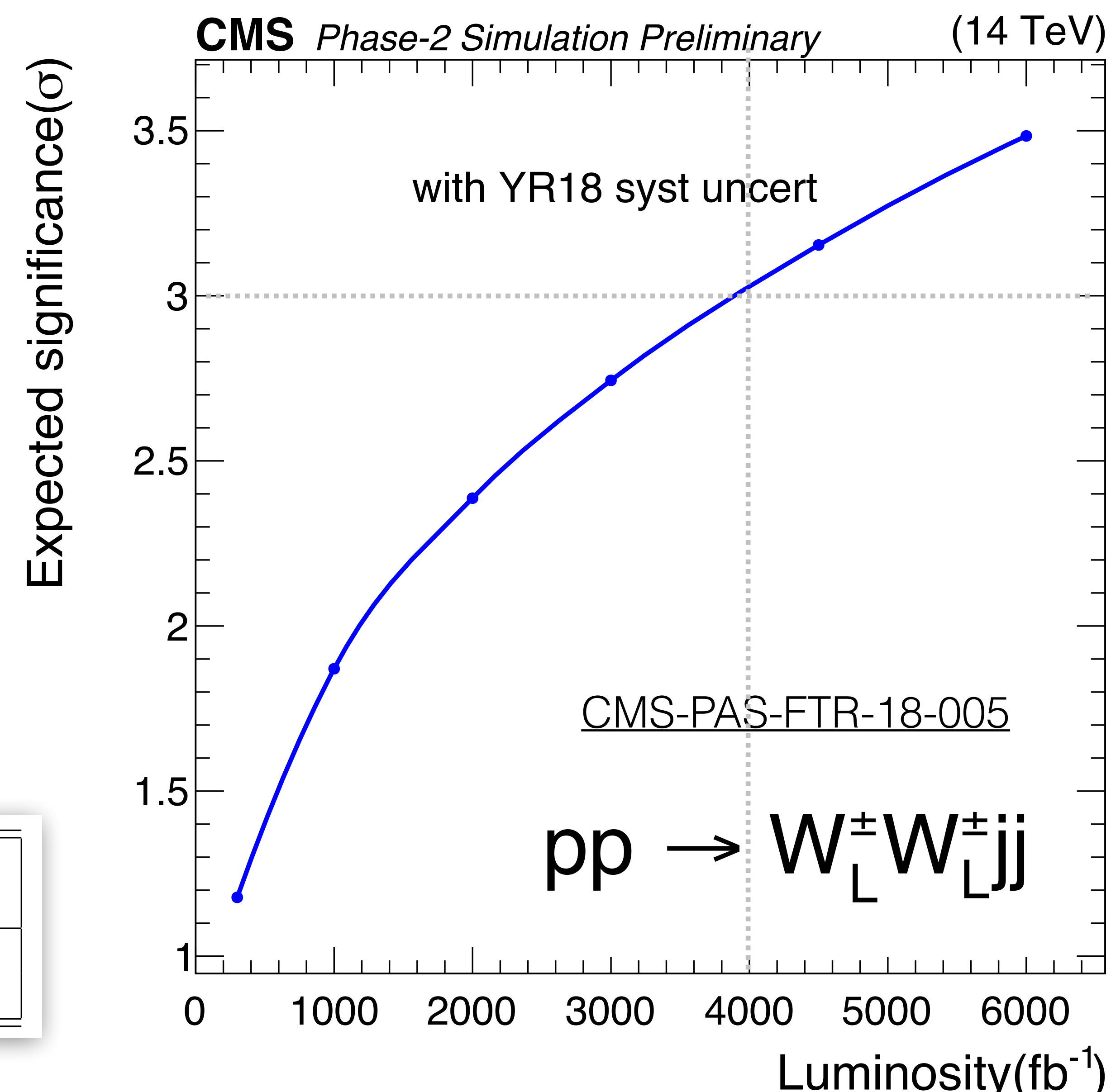
Close-by b-jet limits W's from tops. W+jets allows higher p_T!

Vector boson scattering





Process	$W^\pm W^\pm$	WZ	WV	ZZ	WWW	WWZ	WZZ
Final state	$\ell^\pm\ell^\pm$jj	3ℓjj	ℓjjjj	4ℓjj	$3\ell 3\nu$	$4\ell 2\nu$	$5\ell\nu$
Precision	6%	6%	6.5%	10–40%	11%	27%	36%
Significance	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	3.0σ	3.0σ



Observation of longitudinal production

(remember, $V_L V_L \rightarrow V_L V_L$ diverges without the Higgs)

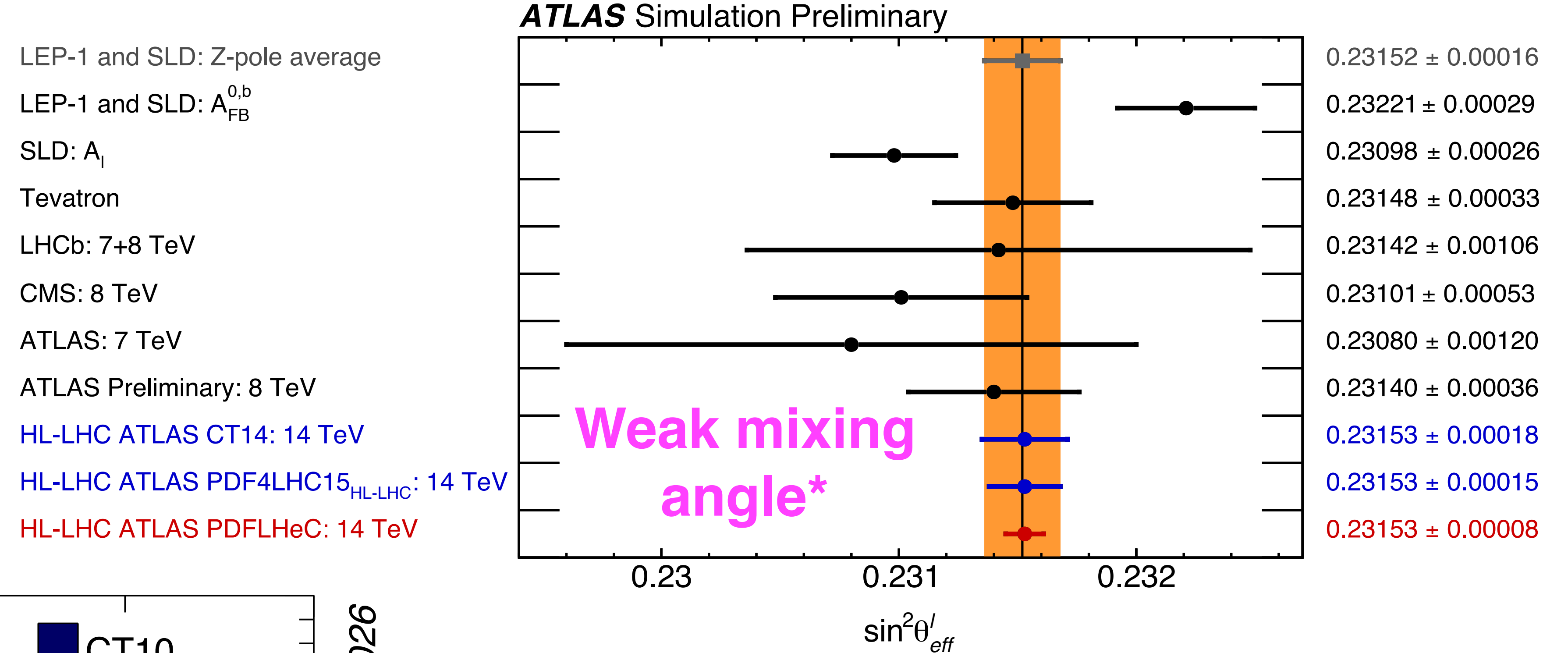
For ZZ, see FTR-18-014/PUB-18-029 and for WZ, see FTR-18-038/PUB-18-023

Ultra precision

It is not all about energy and lumi!

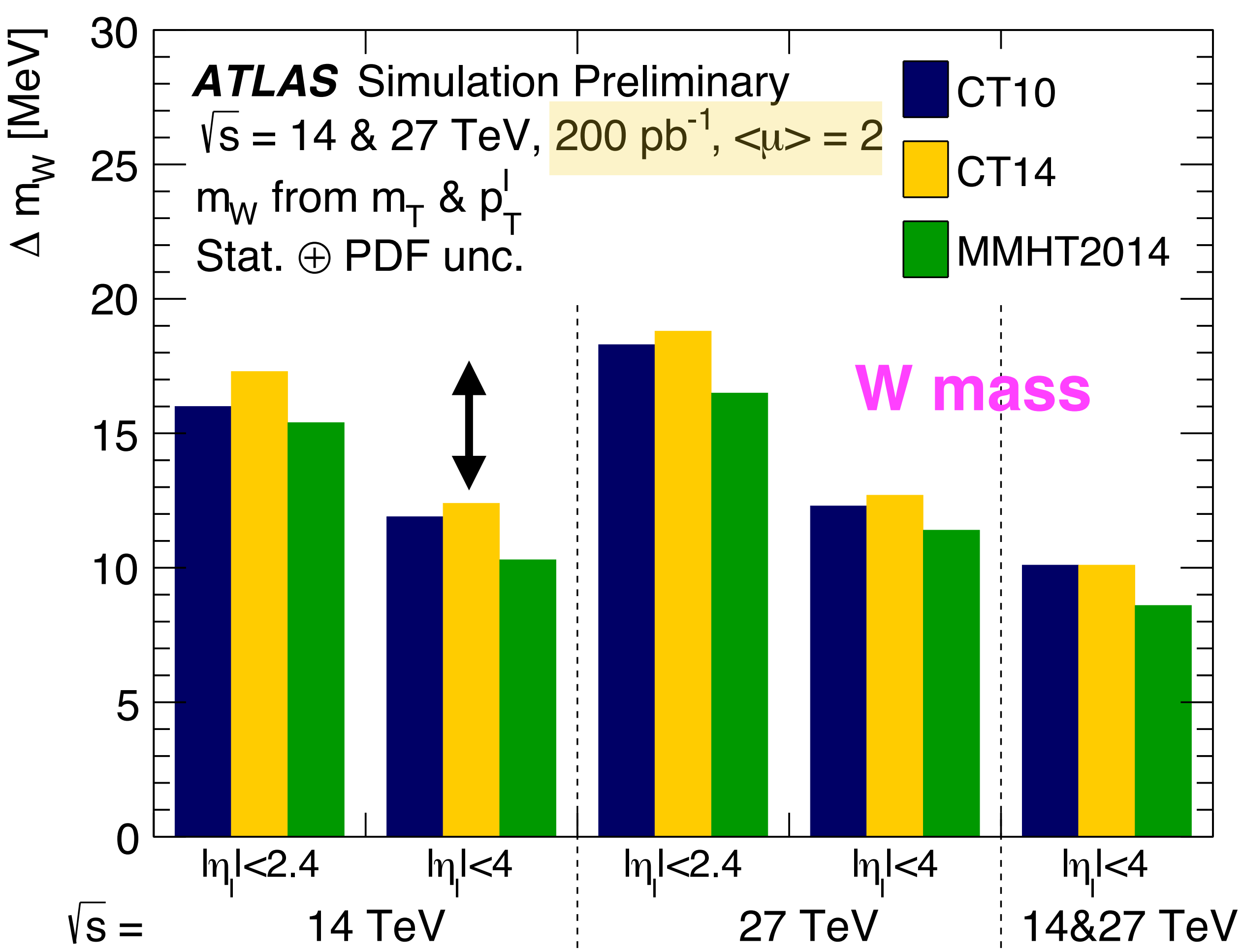
Gains also from acceptance and PDF improvements

ATL-PHYS-PUB-2018-037



from angular distributions in $p\, p \rightarrow$ *leptons*

N.B. 3s tension between most precise LEP & SLD measurements

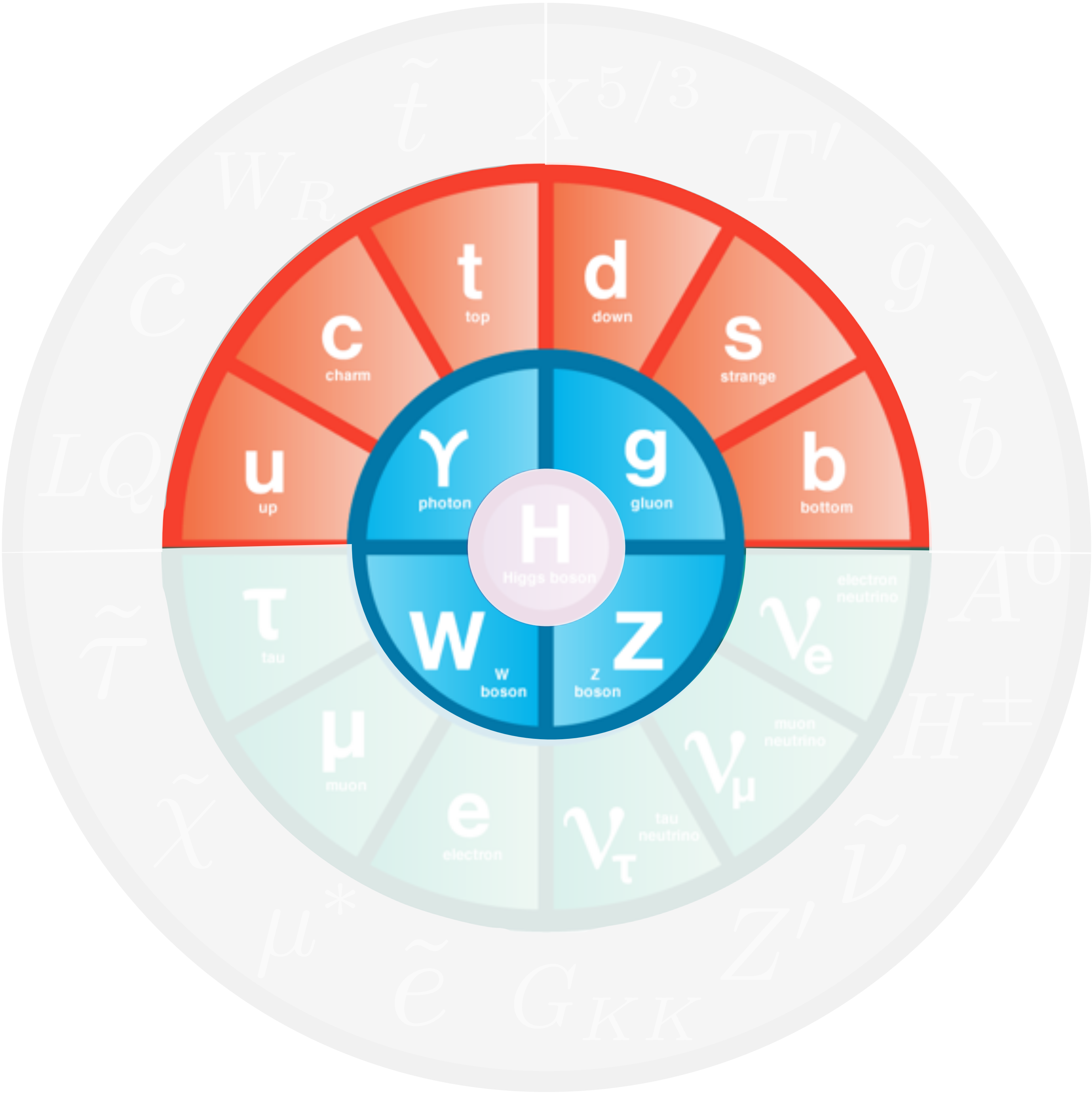


ATL-PHYS-PUB-2018-026

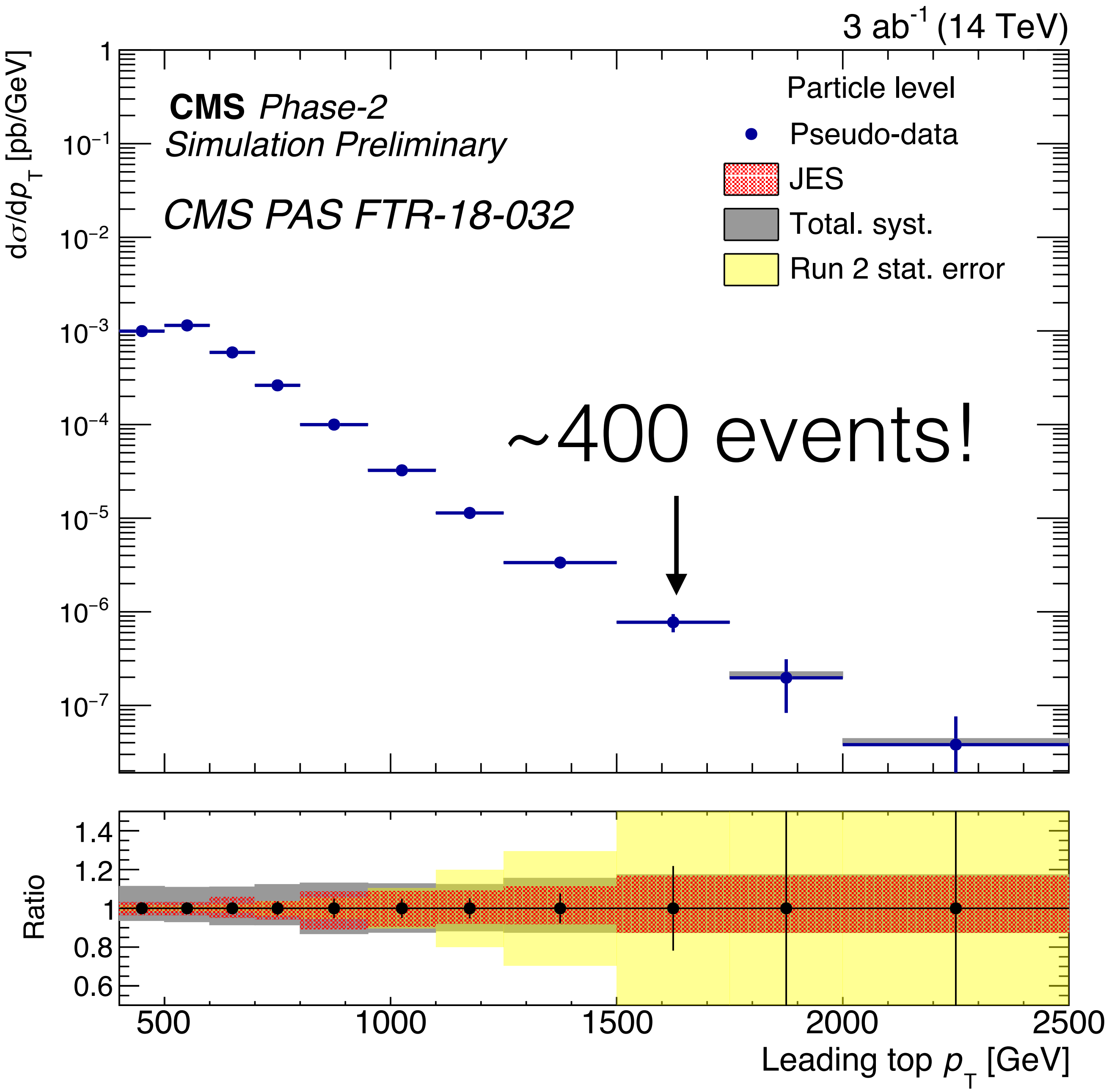
Potential to match LEP for weak mixing angle and significantly exceed Tevatron for W mass.

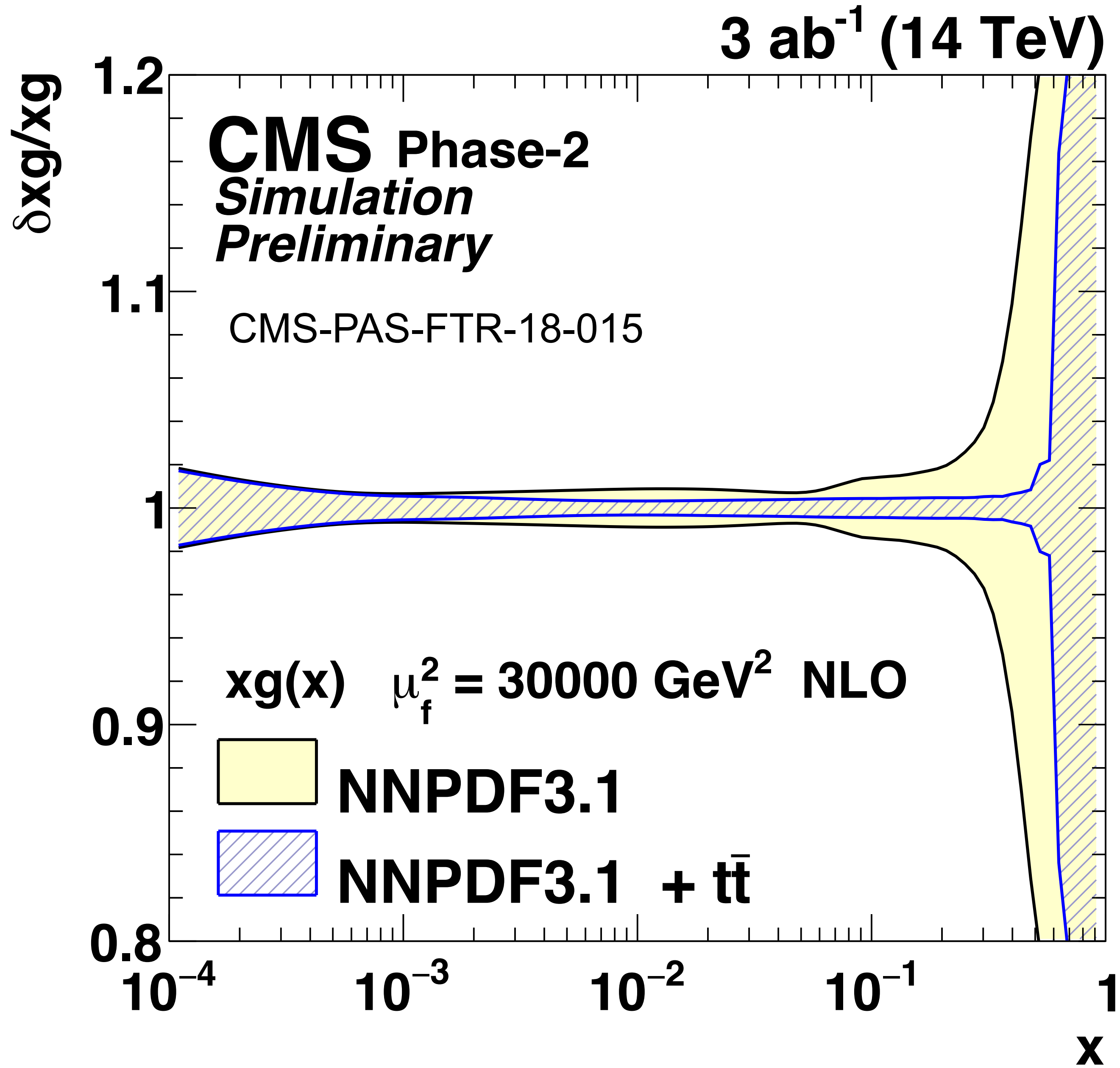
*for similar result from CMS, see FTR-17-001

+Top quark physics



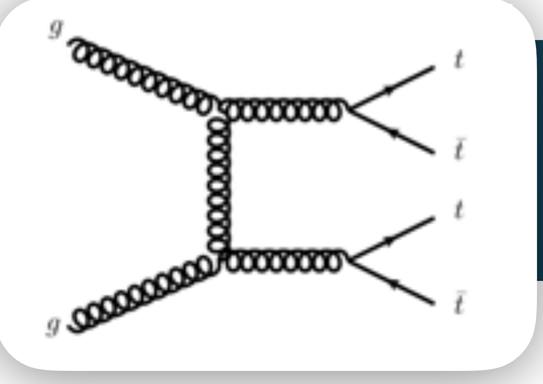
Boosted top quarks





We will have an enormous top quark dataset at high p_T, which can be used for α_S (NNLO) and PDFs (high x-gluon)

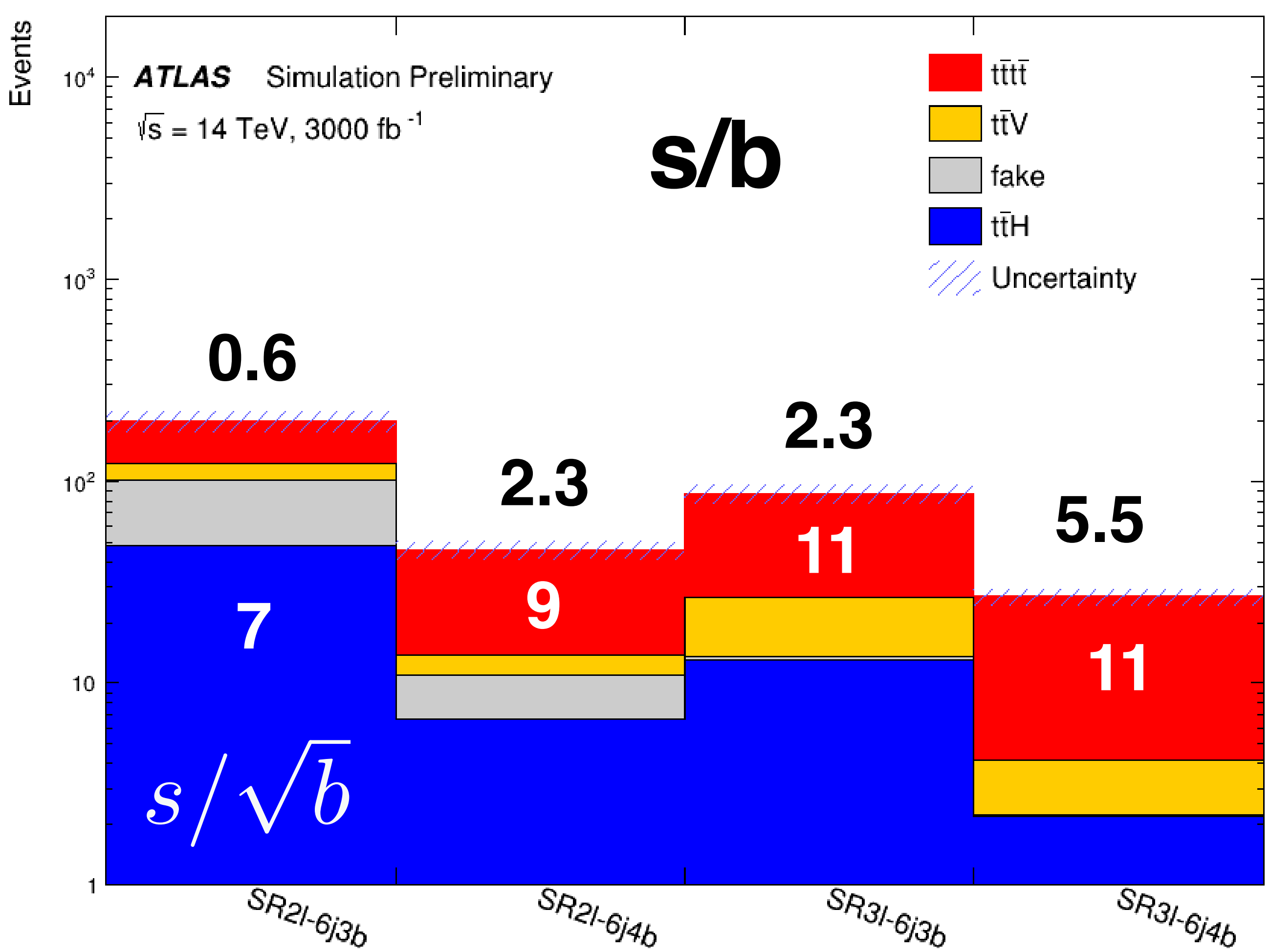
Top quark pairs + X



ex. X = top quark pairs

CMS-PAS-FTR-18-031

ATL-PHYS-PUB-2018-047



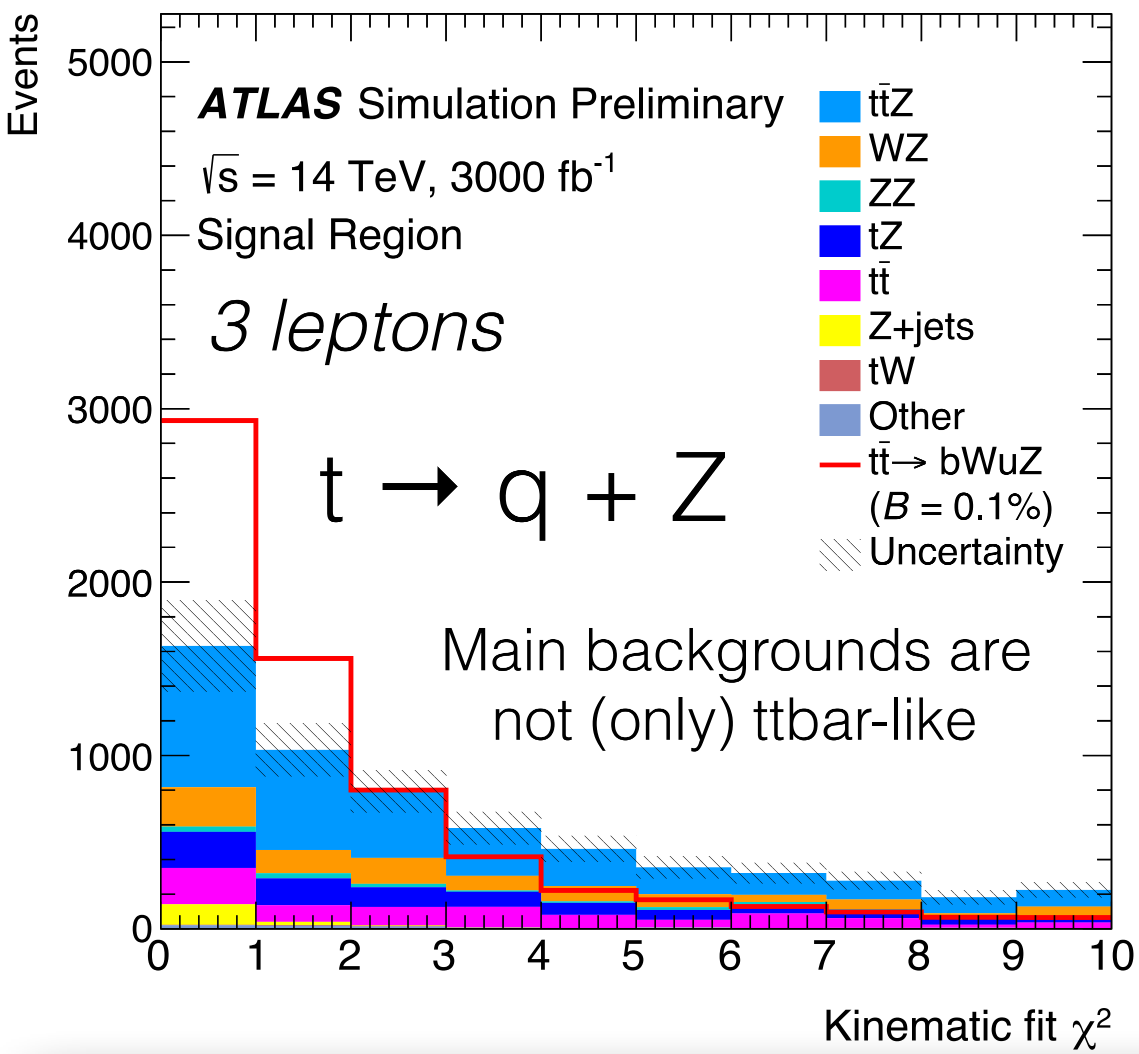
Source	Uncertainty (%)
Integrated luminosity	2.5
Pileup	0–6
Trigger efficiency	2
Lepton selection	4–10
Jet energy scale	1–15
Jet energy resolution	1–5
b tagging	1–15
Size of simulated sample	1–10
Scale and PDF variations	10–15
ISR/FSR (signal)	5–15
$t\bar{t}$H (normalization)	50
Rare, Xγ, $t\bar{t}$VV (norm.)	50
$t\bar{t}Z/\gamma*$, $t\bar{t}$W (normalization)	40
Charge misidentification	20
Nonprompt leptons	30–60

Evidence in Run 3, < 20% measurement possible with HL-LHC.

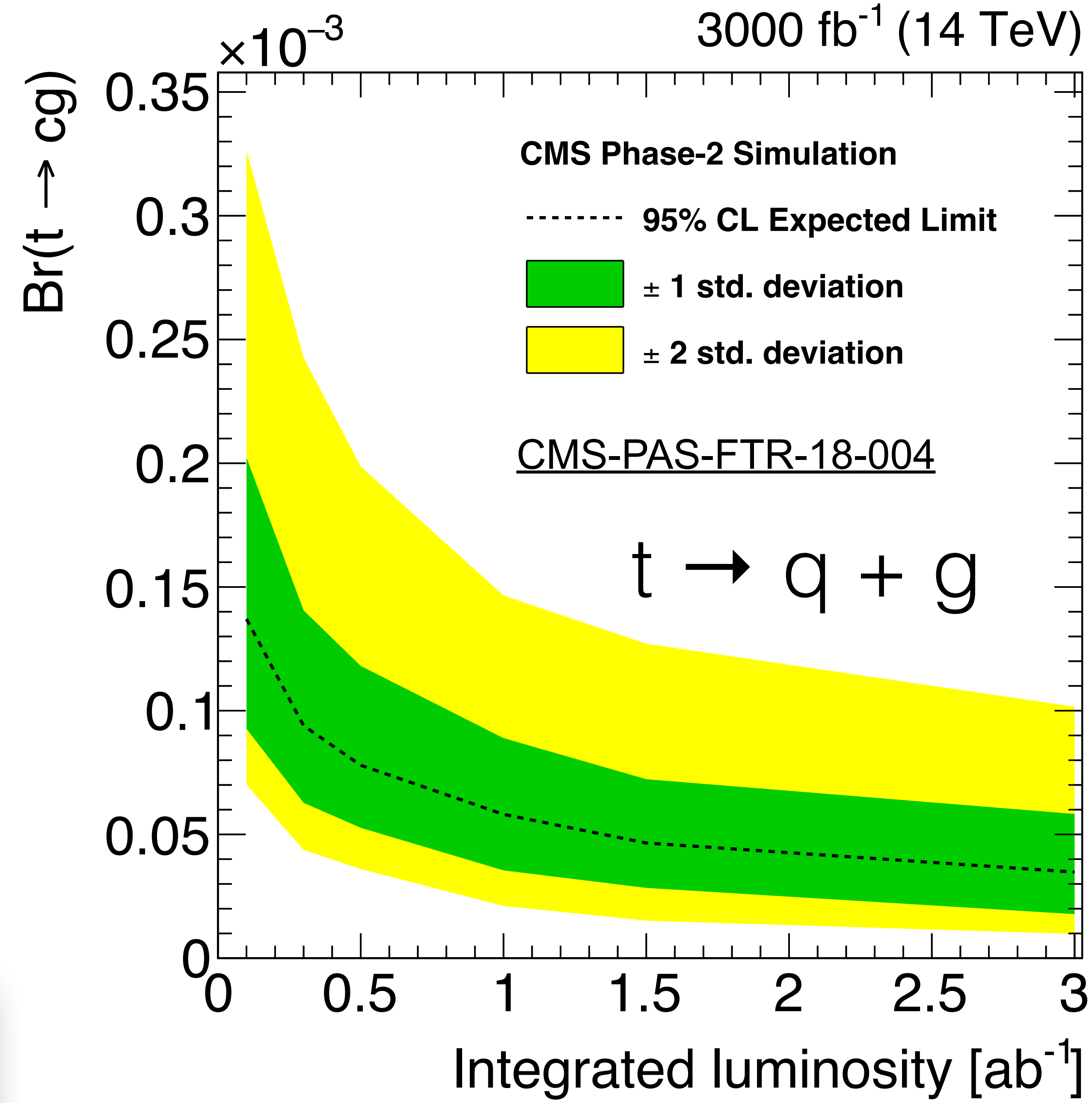
For X = Z, see FTR-18-036 and for X = γ, see PUB-18-049.

Flavor Changing Neutral Currents

ATL-PHYS-PUB-2019-001



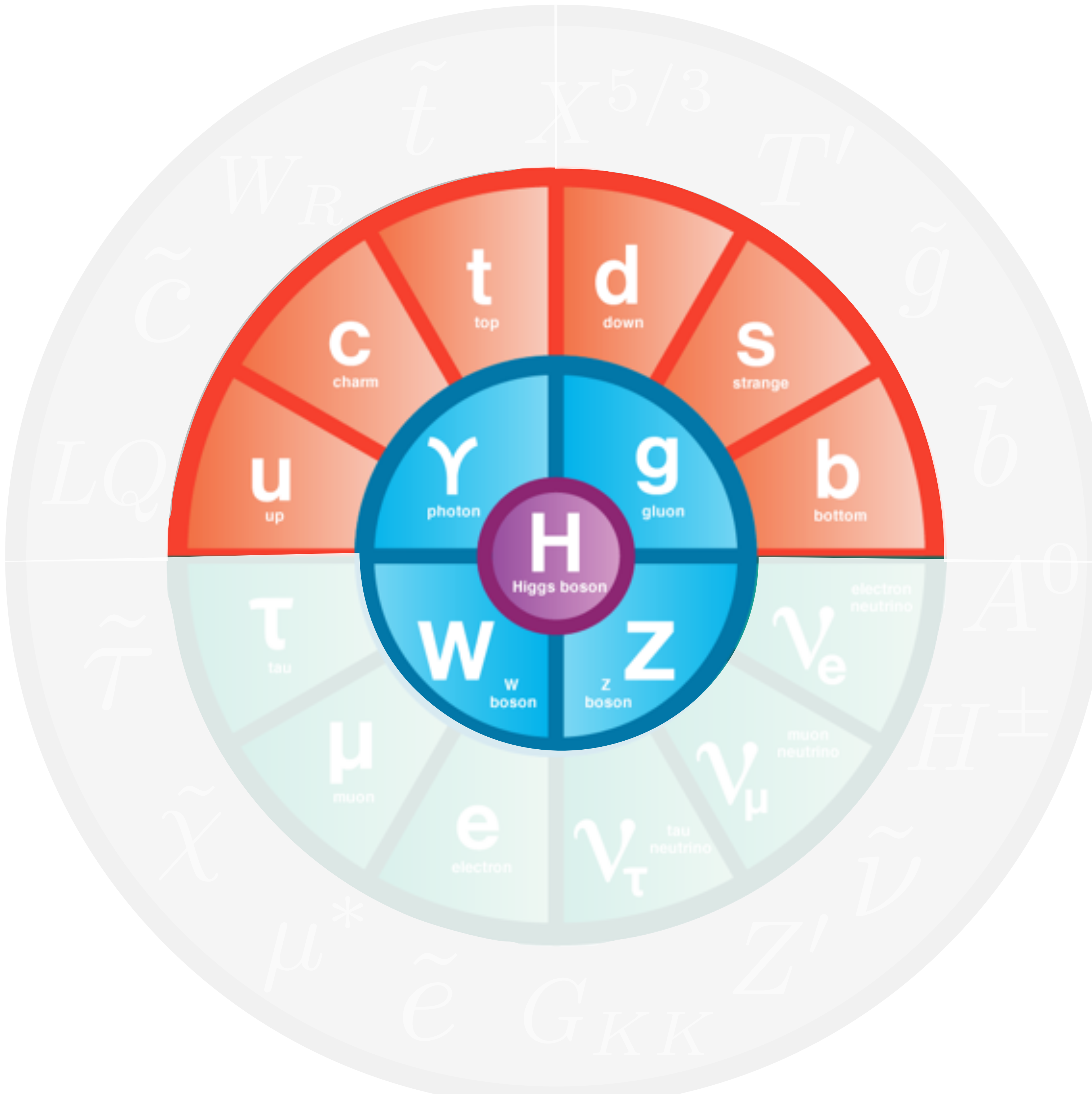
	-1σ	Expected	$+1\sigma$
$\mathcal{B}(t \to uZ)$	4.9×10^{-5}	6.9×10^{-5}	9.7×10^{-5}
$\mathcal{B}(t \to cZ)$	5.8×10^{-5}	8.1×10^{-5}	12×10^{-5}



Run 2 (36 fb-1): ~2 x 10^{-4}

Run 1 (25 fb-1): ~4 x 10^{-4}

+Higgs


t
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up
b
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photon
g
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H
Higgs boson
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w
boson
Z
z
boson
τ
tau
μ
muon
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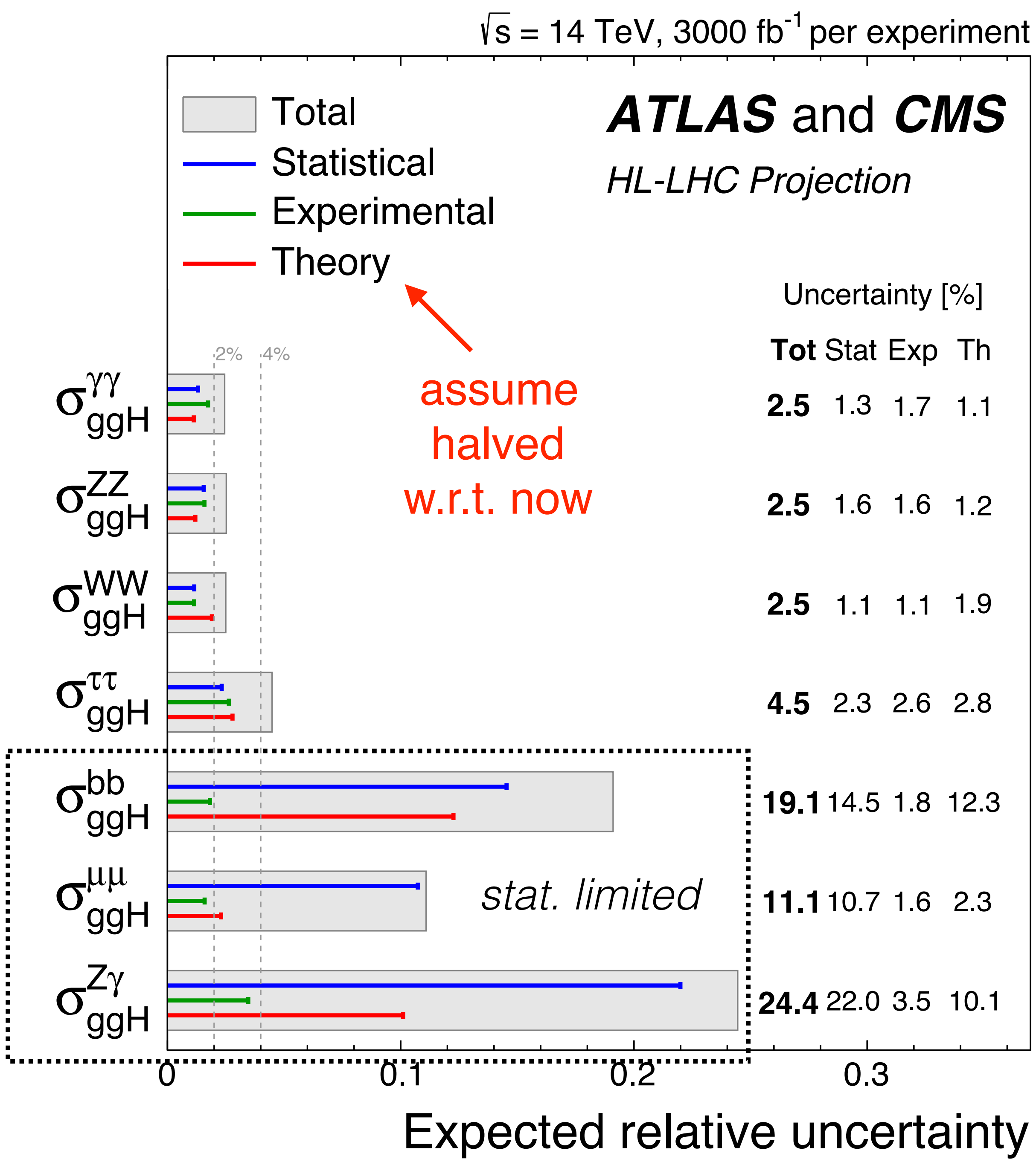
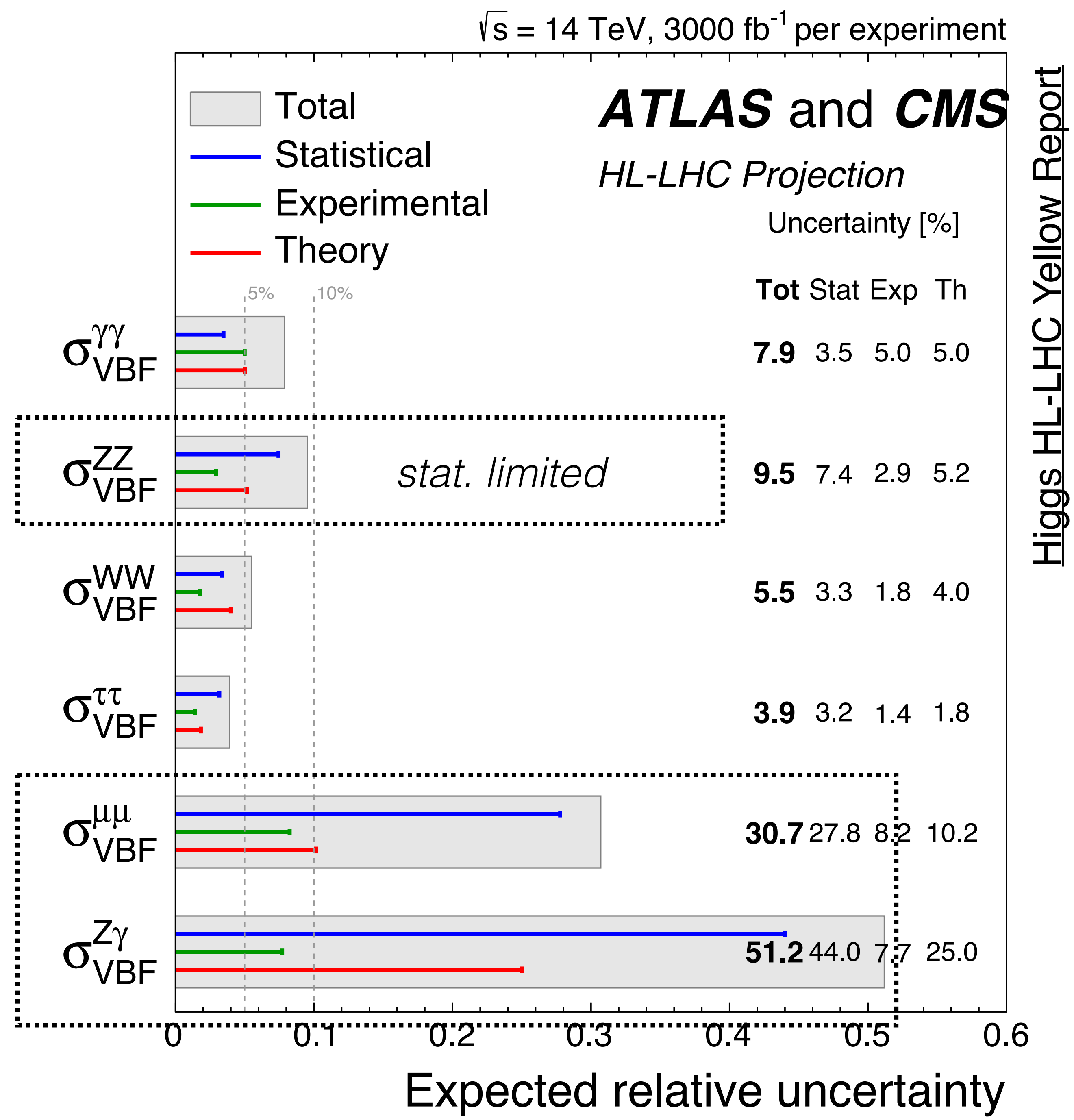
electron
ν_e
electron
neutrino
ν_μ
muon
neutrino
ν_τ
tau
neutrino

Cross sections and Branching Ratios





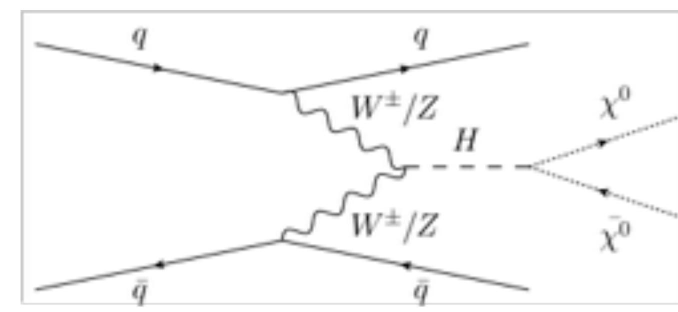
theory ~ experiment uncertainty in many cases!

(many more details of this important program in the references)

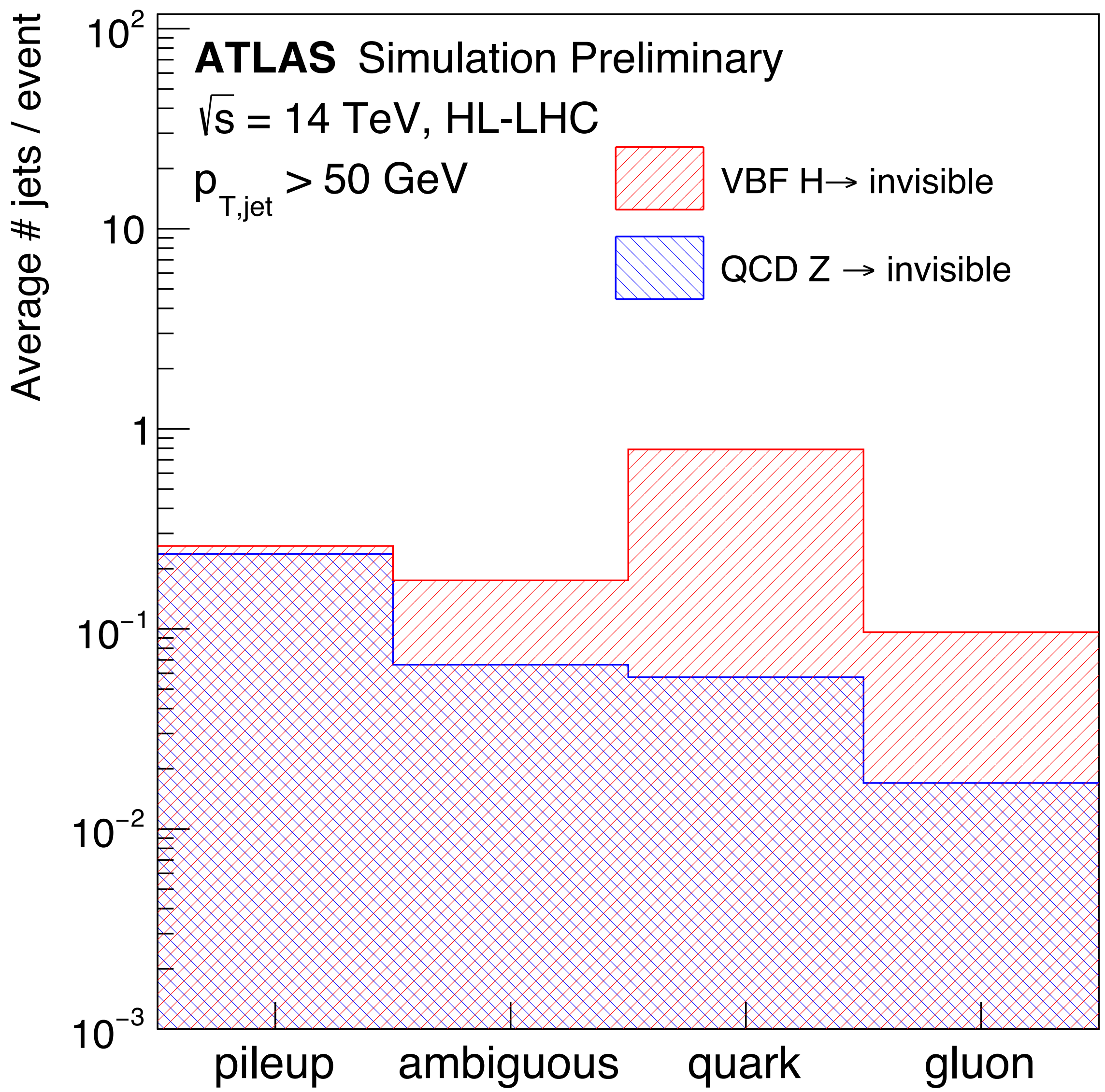
CMS-PAS-FTR-18-011

ATL-PHYS-PUB-2018-054

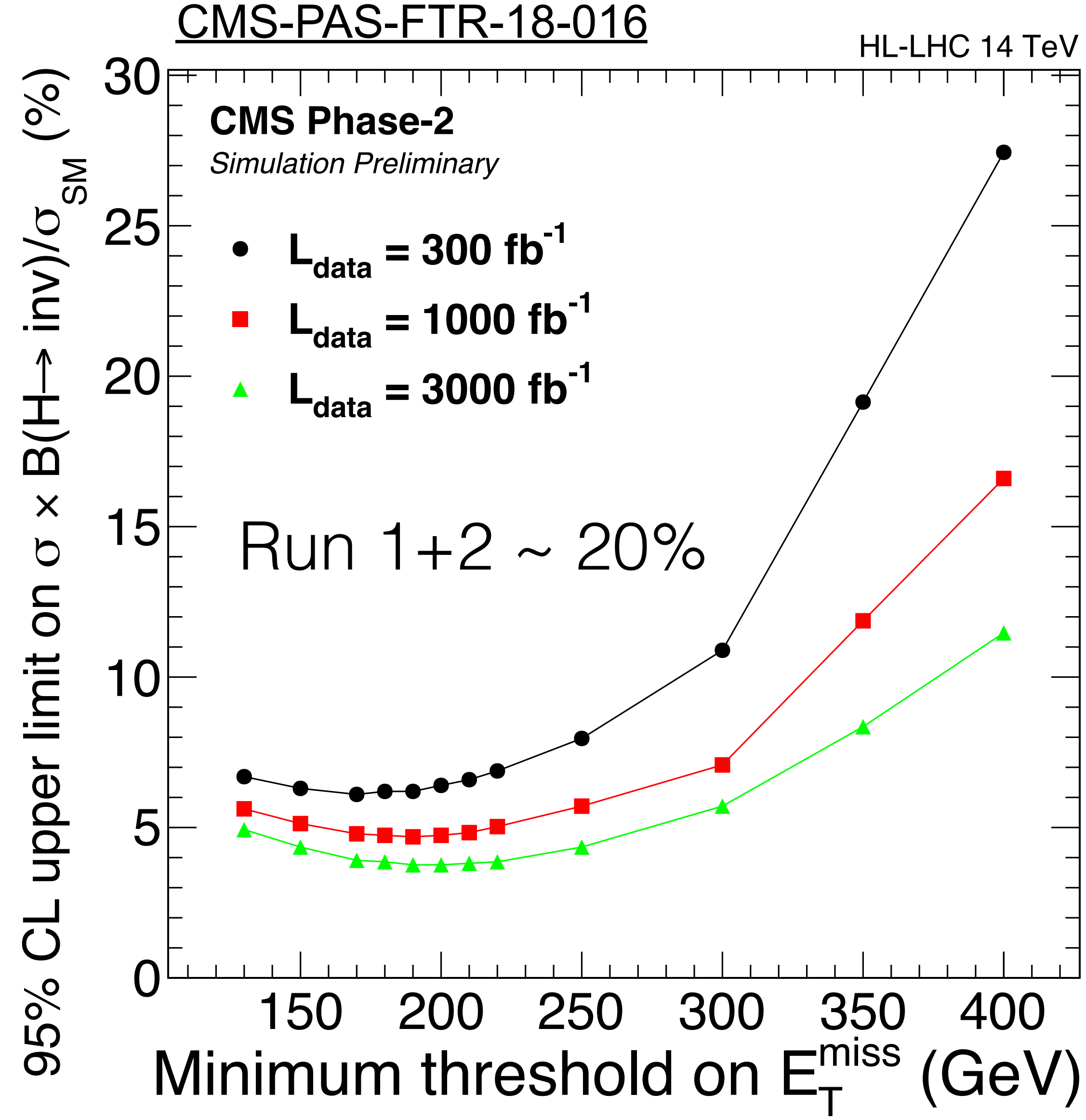
Invisible decays



ATL-PHYS-PUB-2018-038



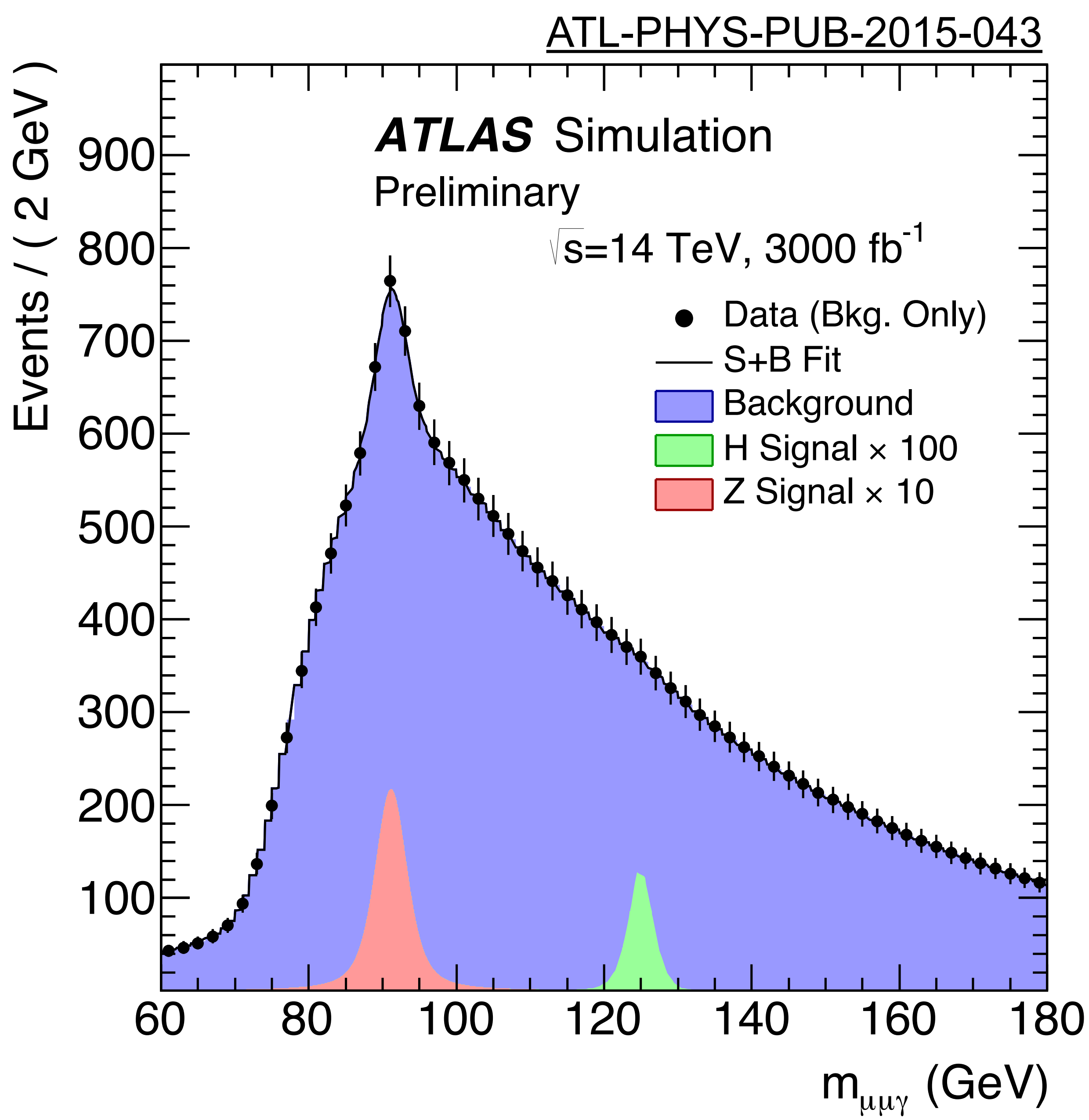
CMS-PAS-FTR-18-016

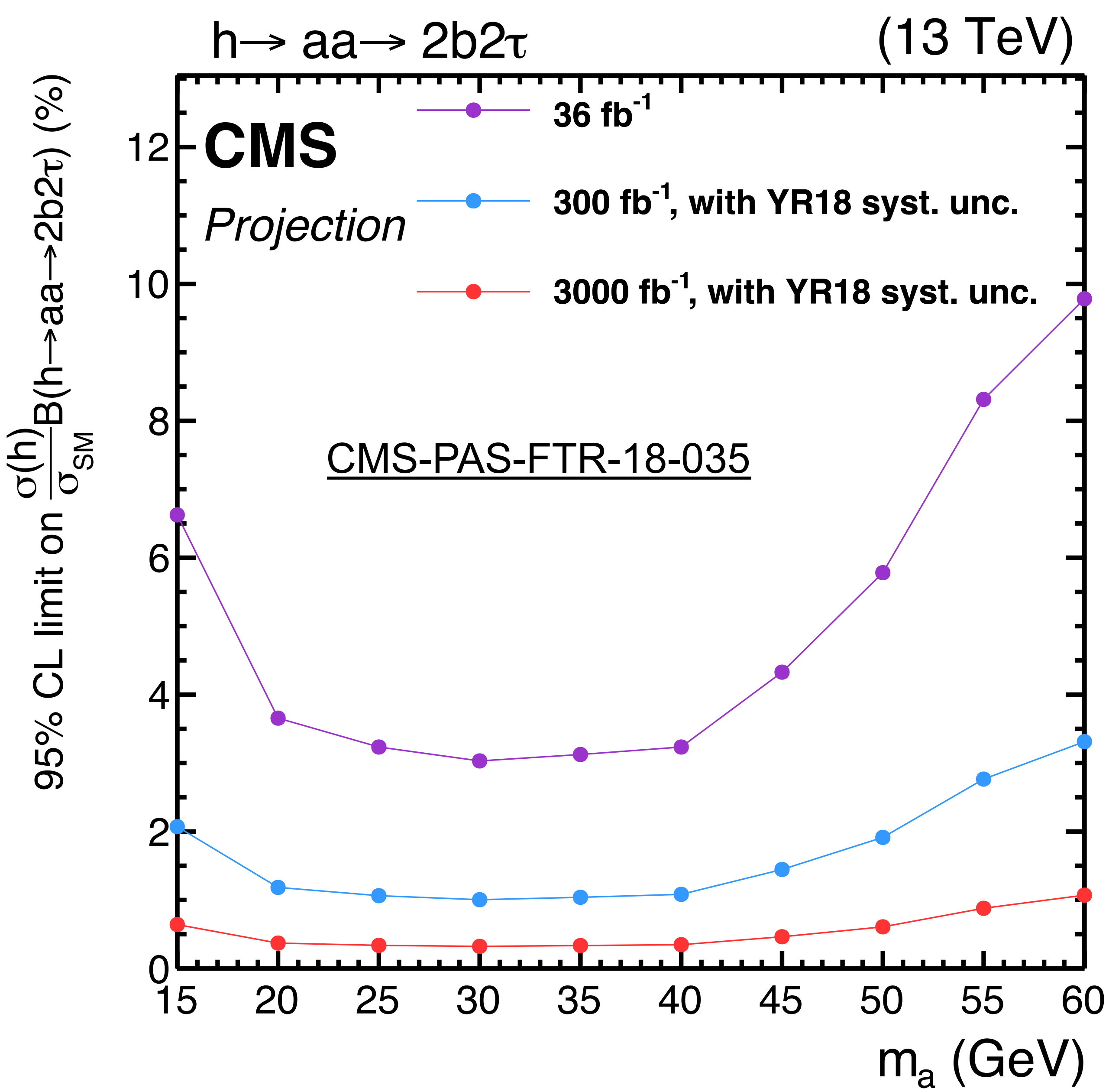


Forward quark jets are a significant experimental challenge, but this is an important channel for broad sensitivity to (semi)invisible decays.

Rare and BSM decays

High BR decays still possible - we must explore all possibilities!





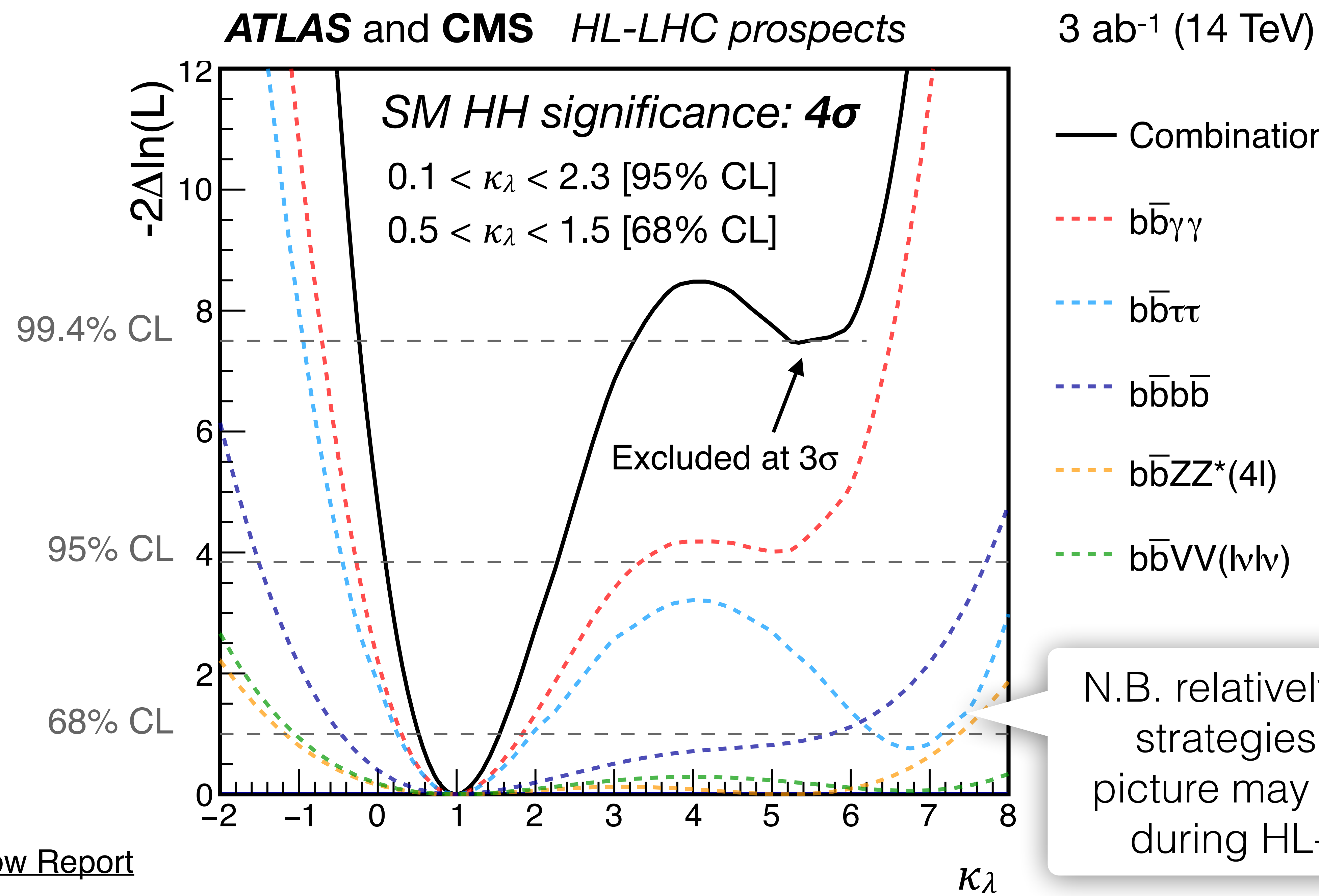
Precision of ~15x SM (4x for the Z)

Large program for exotic decays, including τ > mm.

See PUB-18-016 for alternative probes of $H \to cc$.

Di-Higgs and Higgs self-coupling

HH at ~3σ / experiment; self coupling with ~50%.



N.B. relatively simple strategies - this picture may change during HL-LHC!

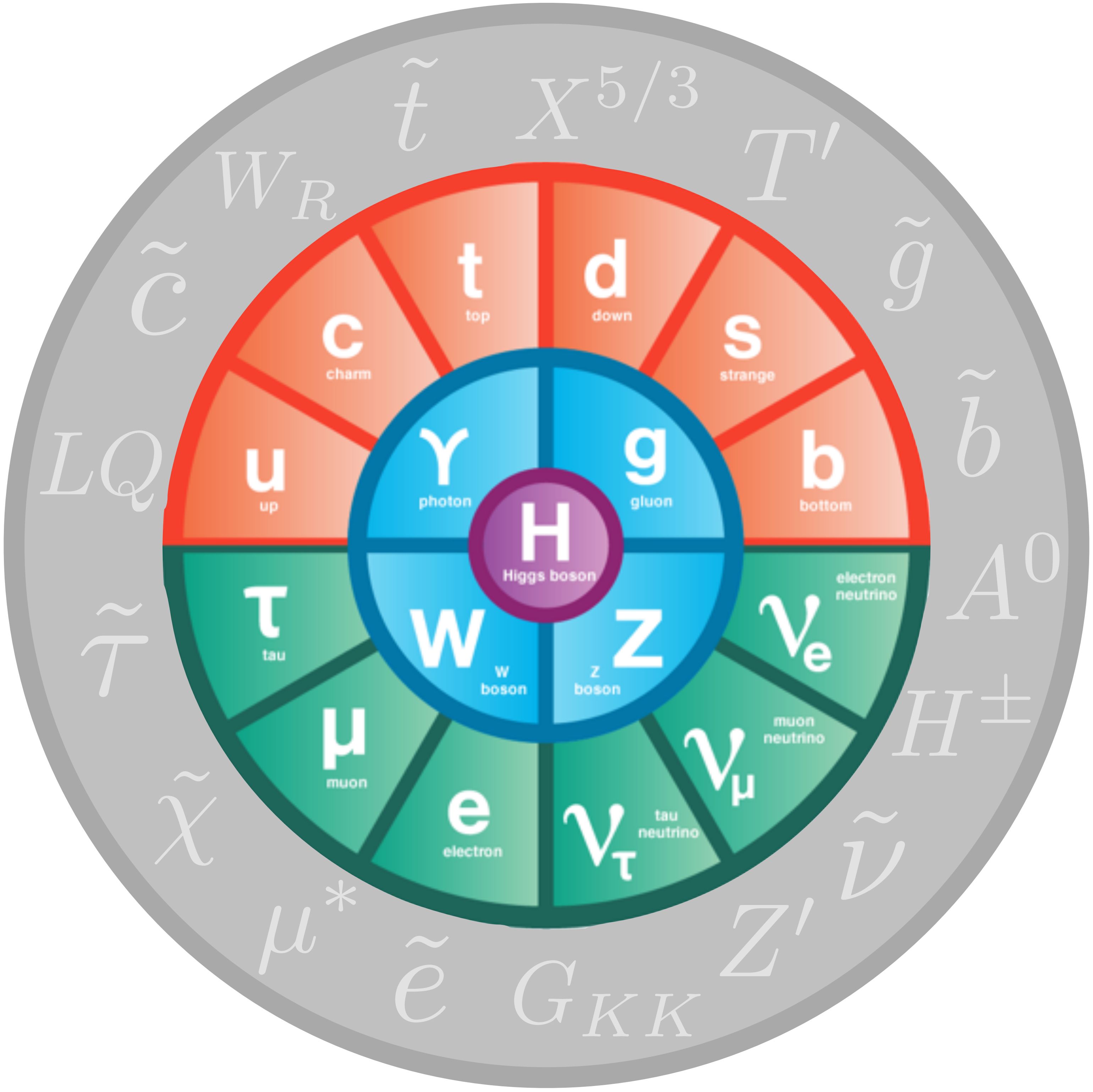
Higgs HL-LHC Yellow Report

CMS-PAS-FTR-18-019

ATL-PHYS-PUB-2018-053

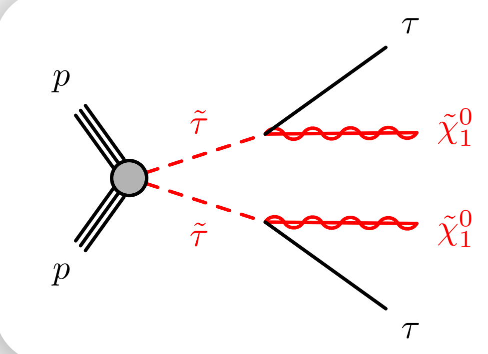
See FTR-18-020 for alternative probes of the self-coupling.

+BSM

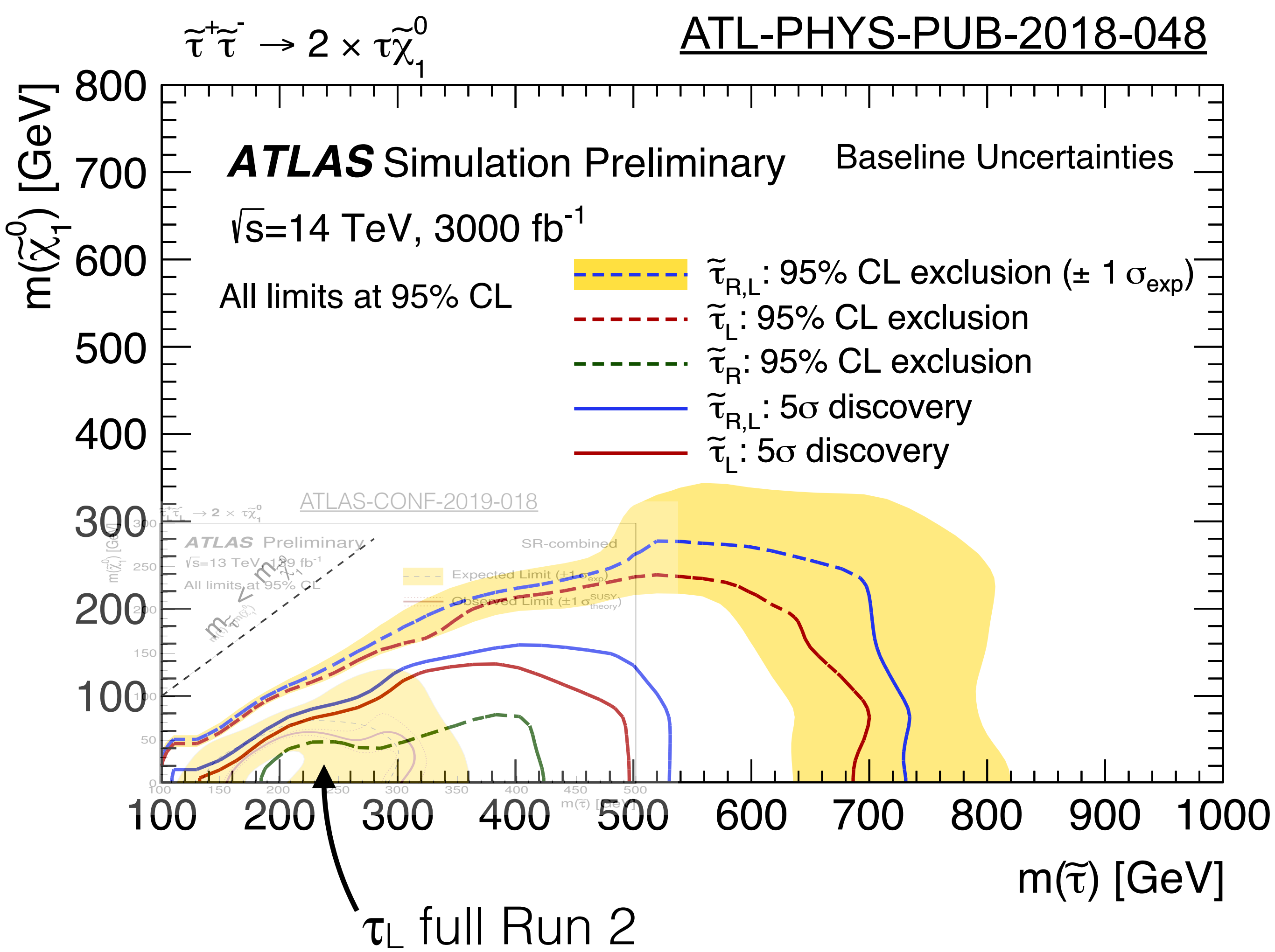

t
top
d
down
c
charm
s
strange
u
up
b
bottom
γ
photon
g
gluon
H
Higgs boson
W
w boson
Z
z boson
τ
tau
μ
muon
e
electron
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
$\tilde{t}$
$X^{5/3}$
T'
W_R
$\tilde{g}$
$\tilde{c}$
$\tilde{b}$
LQ
A^0
$\tilde{\tau}$
$H^\pm$
$\tilde{\chi}$
$\tilde{\nu}$
μ^*
Z'
$\tilde{e}$
G_{KK}

Sleptons

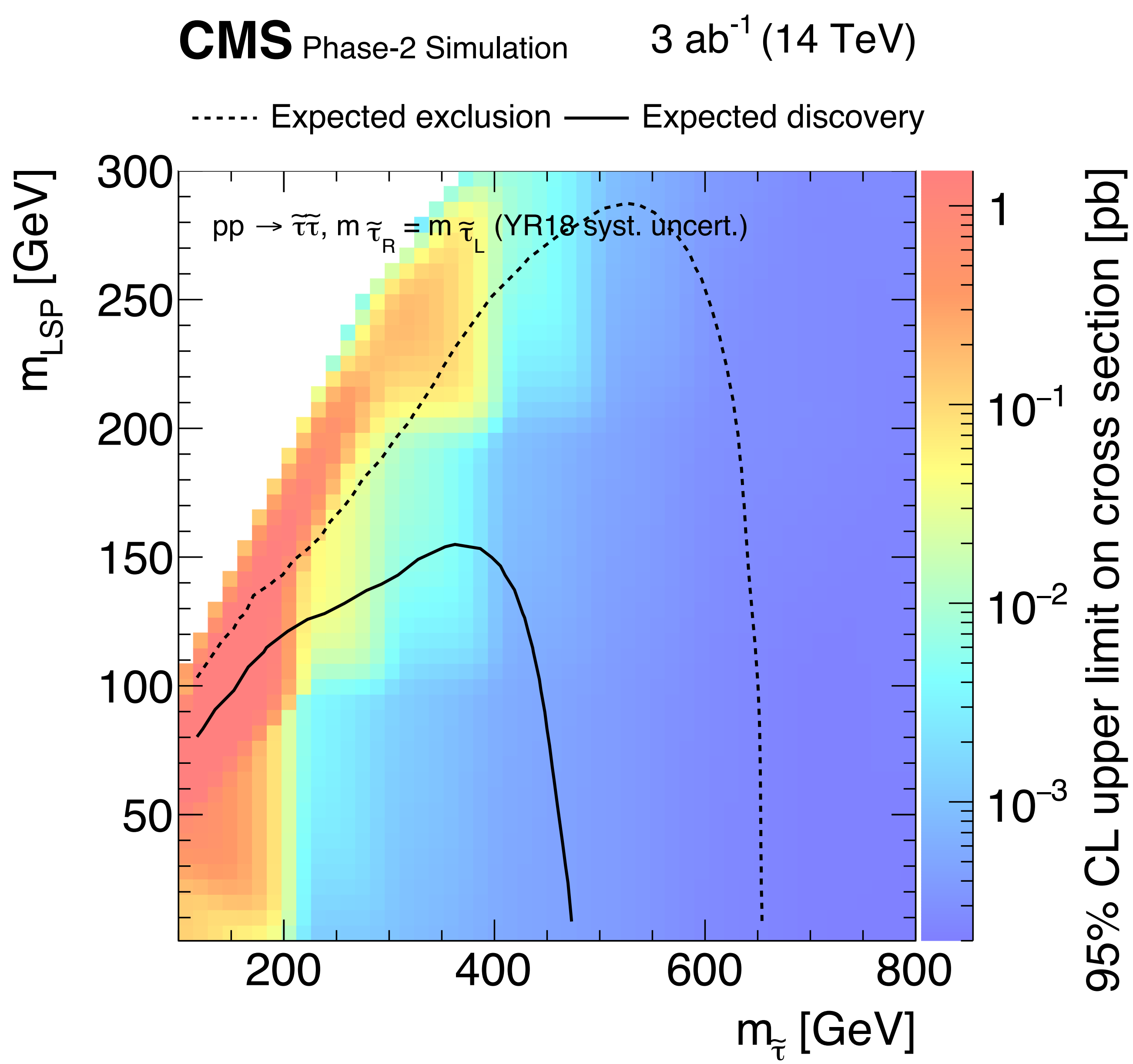
Electroweakinos in backup



Current limits only marginally better than LEP (~100 GeV)



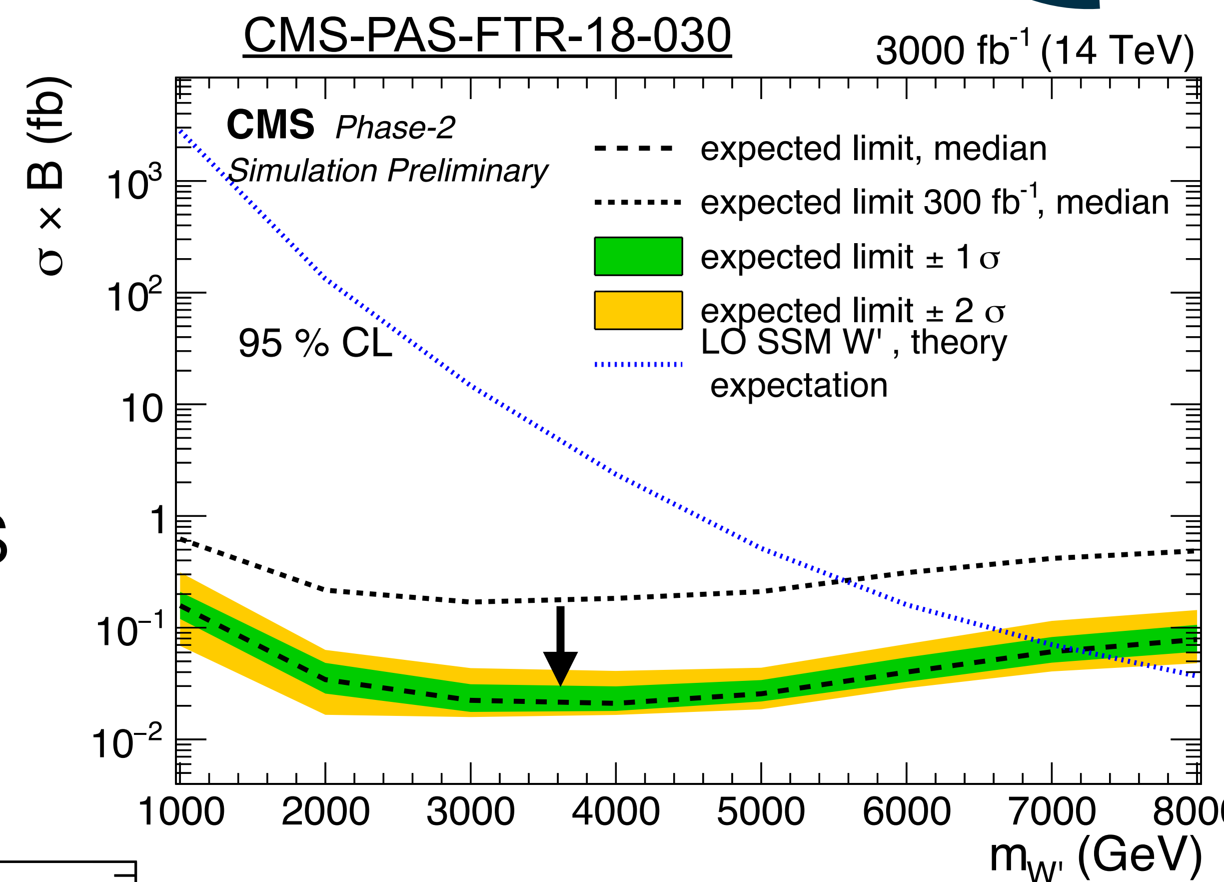
CMS-PAS-FTR-18-010

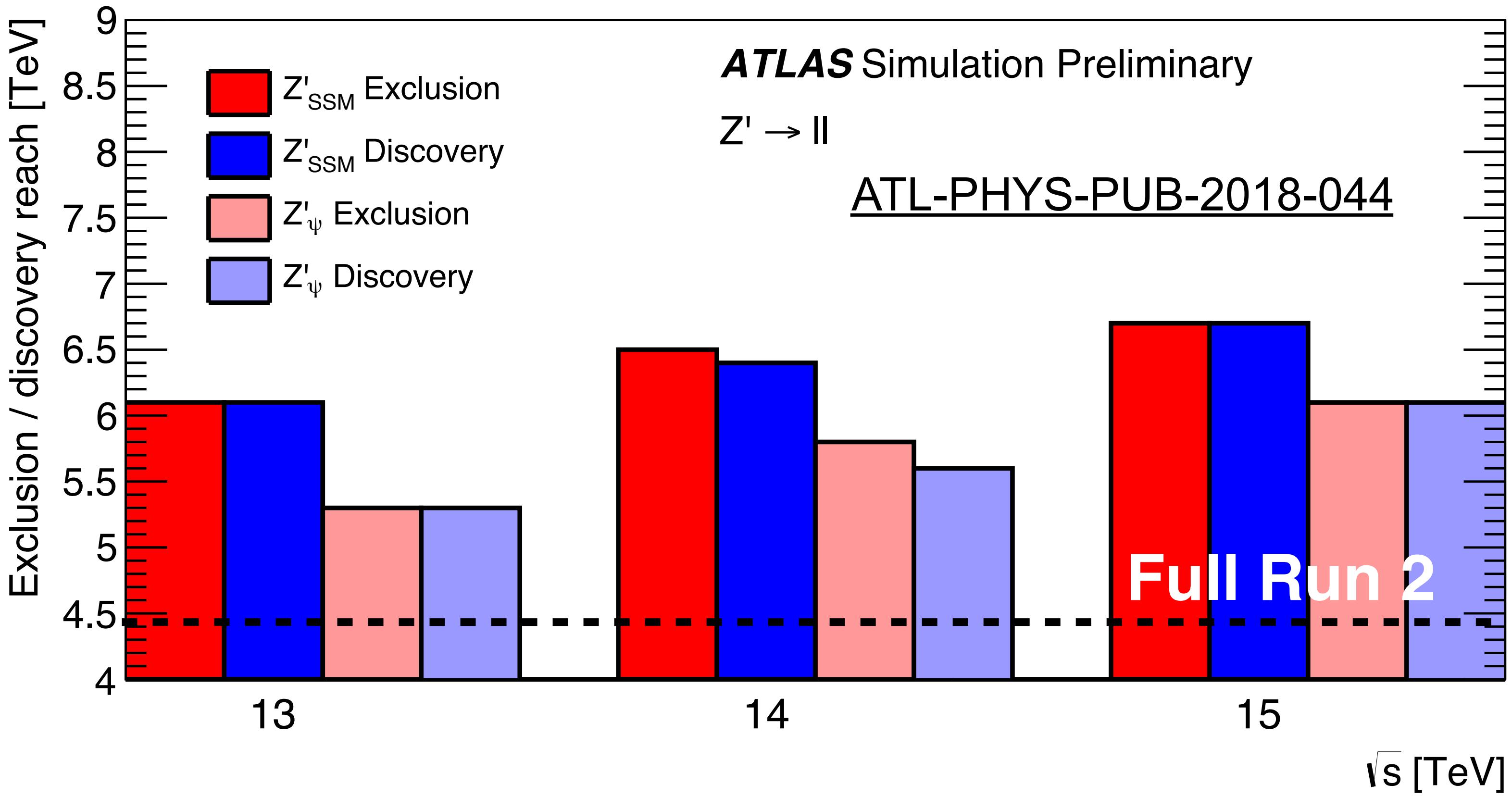


Much smaller cross-sections compared with squarks and gluinos - huge gains from HL-LHC dataset.

Z'/W'

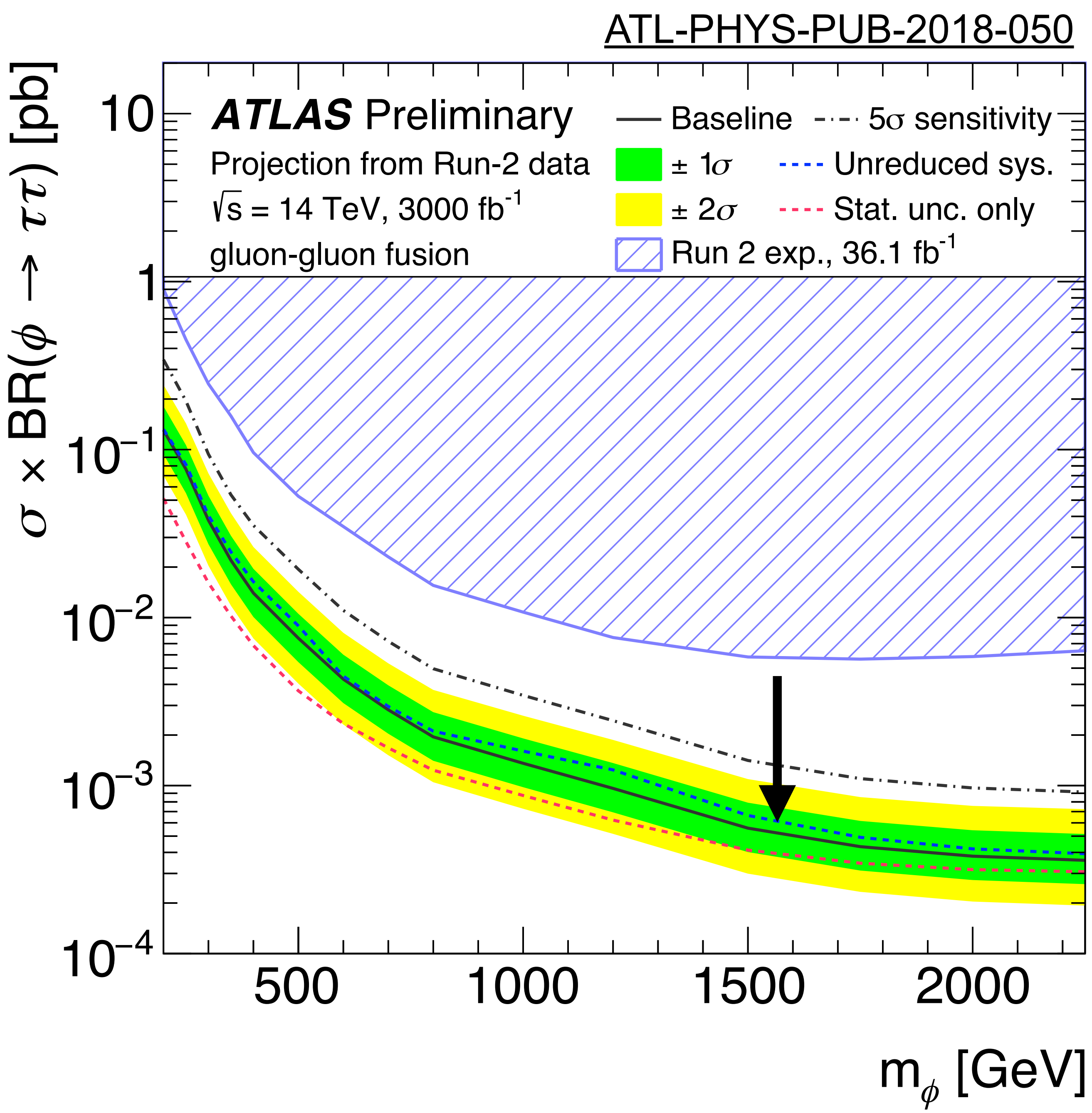
Significant extension in reach for charged and neutral new bosons

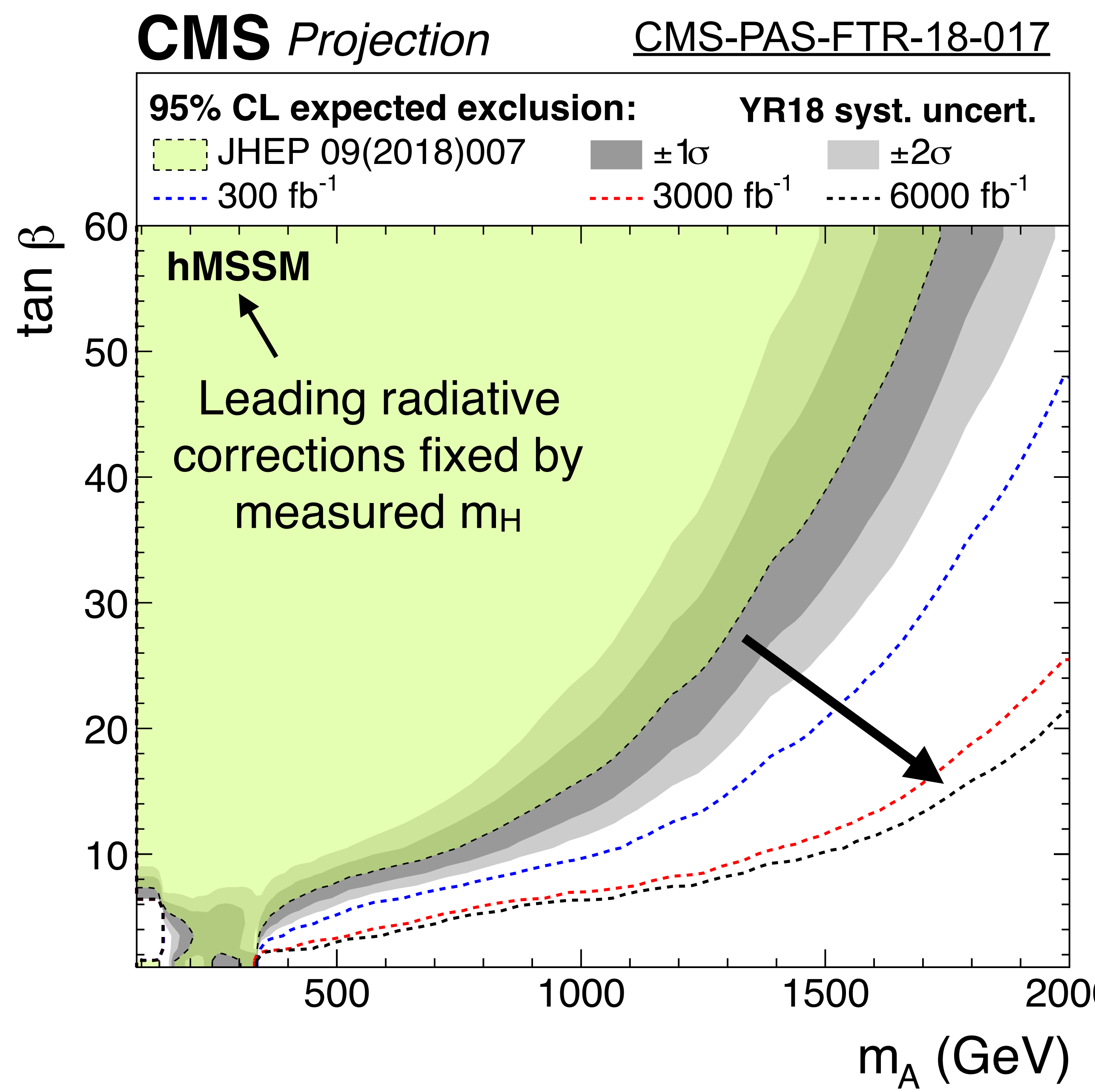




Discovery potential beyond Run 2 exclusion!

Heavy Higgs

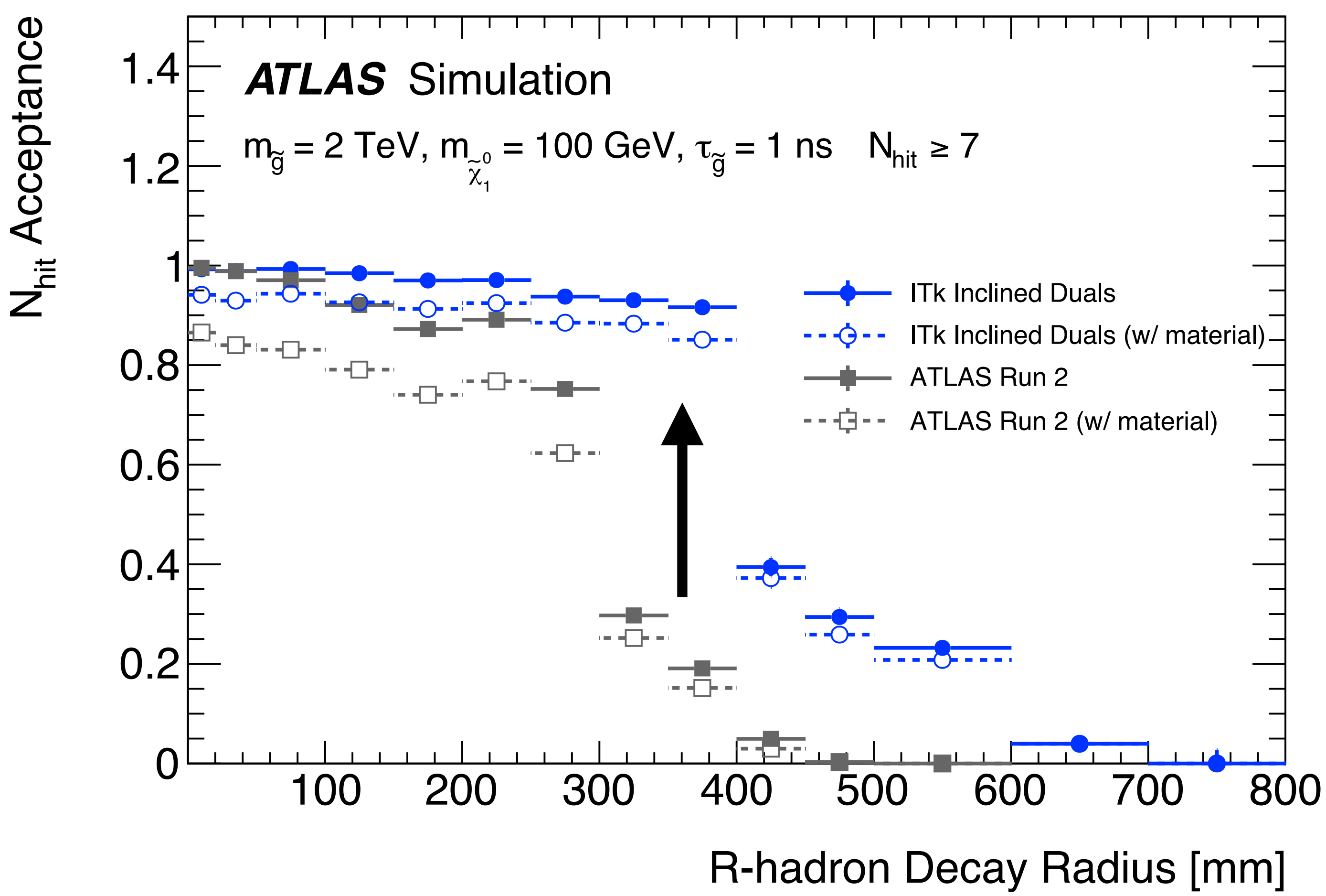


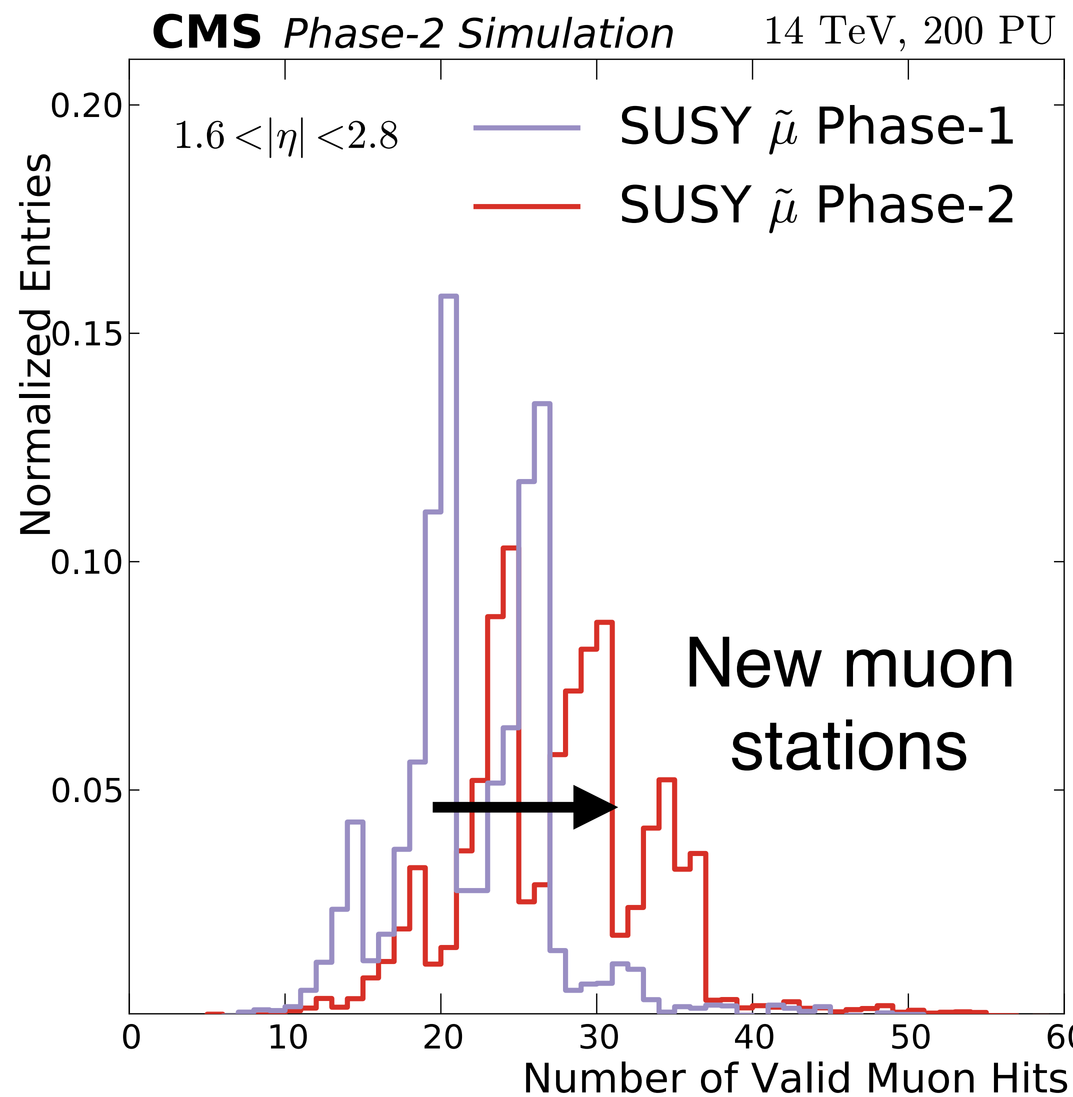


There are many channels, H → ττ is key channel and important motivation for improving τ reconstruction performance.

Long lived particles

There is also many possibilities for long lived particle searches using the increased detector capabilities + larger luminosity.





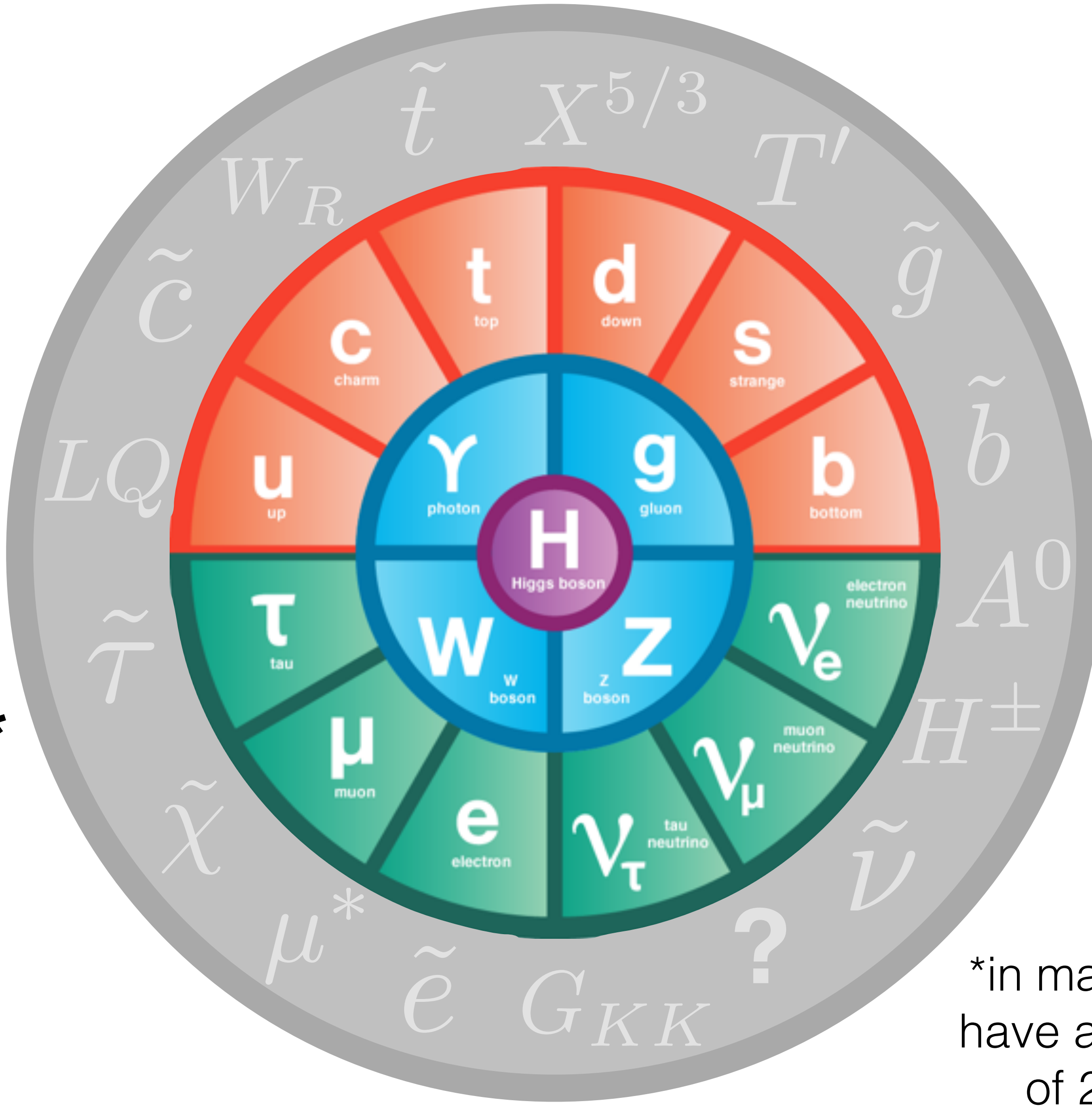
…also possibilities with precision timing, etc.

Conclusions and Outlook

HL-LHC dataset will be a rich source of physics analysis **for many years**!

Many places where gains could be bigger with **improvements in modeling***

(from both theory and auxiliary measurements)



*in many places, we have assumed factor of 2 reduction!

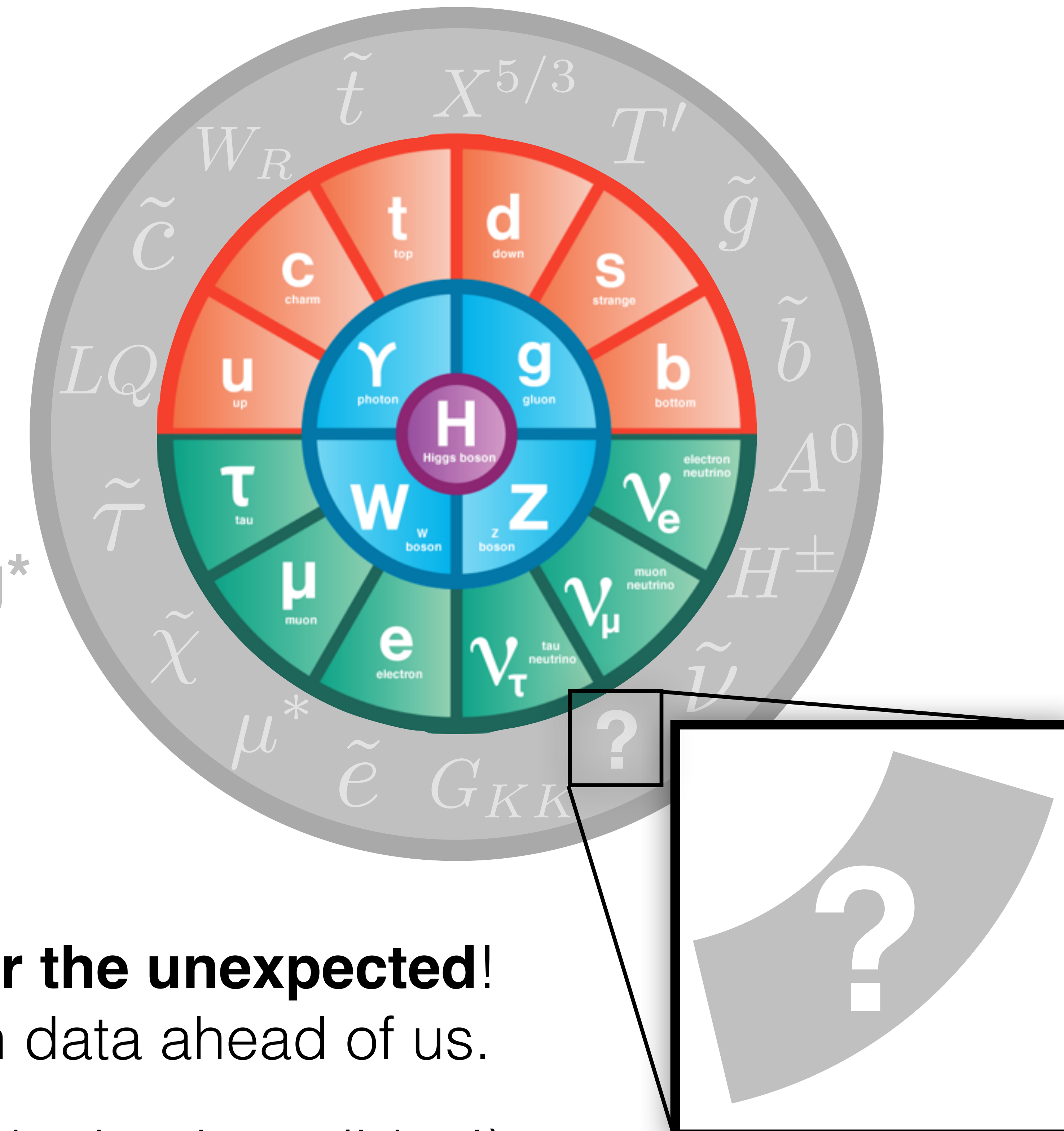
There are also many places where analysis innovation (e.g. **deep learning**) will be essential … in fact, some of the results shown today used modern machine learning tools!

Conclusions and Outlook

HL-LHC dataset will be a rich source of physics analysis **for many years**!

Many places where gains could be bigger with **improvements in modeling***

(from both theory and auxiliary measurements)



We must also be **prepared for the unexpected**!
…we have many years of rich data ahead of us.

(see **LHC Olympics 2020** in the backup slides!)

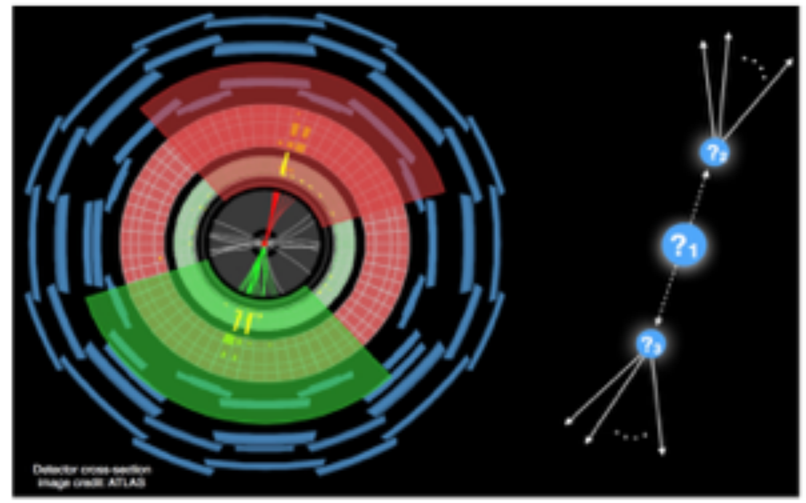
Questions?

LHC Olympics 2020

indico.cern.ch/e/ML4Jets2020

- Overview
- Timetable
- Participant List
- LHCOlympics2020
- Slack channel

LHCOlympics2020



Despite an impressive and extensive effort by the LHC collaborations, there is currently no convincing evidence for new particles produced in high-energy collisions. At the same time, there has been a growing interest in machine learning techniques to enhance potential signals using all of the available information.

In the spirit of the first LHC Olympics (circa 2005-2006) [1st, 2nd, 3rd, 4th], we are organizing the 2020 LHC Olympics. Our goal is to ensure that the LHC search program is sufficiently well-rounded to capture "all" rare and complex signals. The final state for this olympics will be focused (generic dijet events) but the observable phase space and potential BSM parameter space(s) are large: all hadrons in the event can be used for learning (be it "cuts", supervised machine learning, or unsupervised machine learning).

For setting up, developing, and validating your methods, we provide background events and a few benchmark signal models. You can download these from [ZENODO LINK]. To help get you started, we have also prepared simple python scripts to read in the data and do some basic processing.

The final test will happen 2 weeks before the ML4Jets2020 workshop. We will release new datasets where the "background" will be similar to but not identical to the one in the development set (as is true in real data!). Each of these datasets will have signal injected somewhere and it is up to you to see if you can find (a) find a signal (b) what is the mass, and (c) what is the cross section. To keep the scope limited, all signals will be of the form X -> hadrons, where X is a new massive particle with an O(TeV) mass. The events require at least one R = 1.0 jet with p_T > 1 TeV. For each event, we provide a list of all hadrons (p_T, eta, phi, p_T, eta, phi, ...) zero-padded up to 600 hadrons.

We strongly encourage you to publish your original research methods using these datasets (before or after) the unveiling of the results. Anyone who participates will be part of a summary paper to be prepared following the workshop.

Please do not hesitate to ask questions: we will use the ML4Jets slack channel to discuss technical questions related to this challenge.

Good luck!

Gregor Kasieczka, Ben Nachman, and David Shih

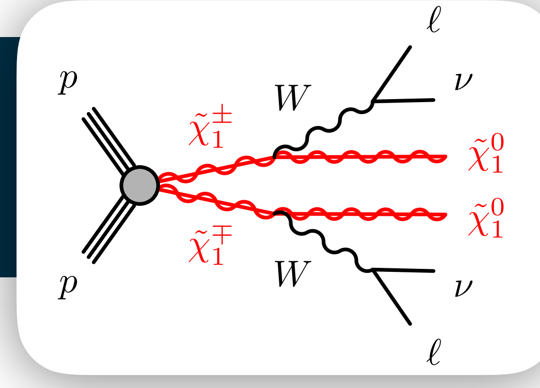
Upgrade Parallel Talks

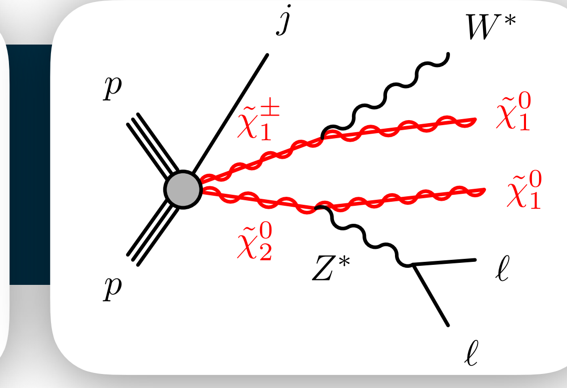
BSM: Giuliano Gustavino

SM: Alexander Savin

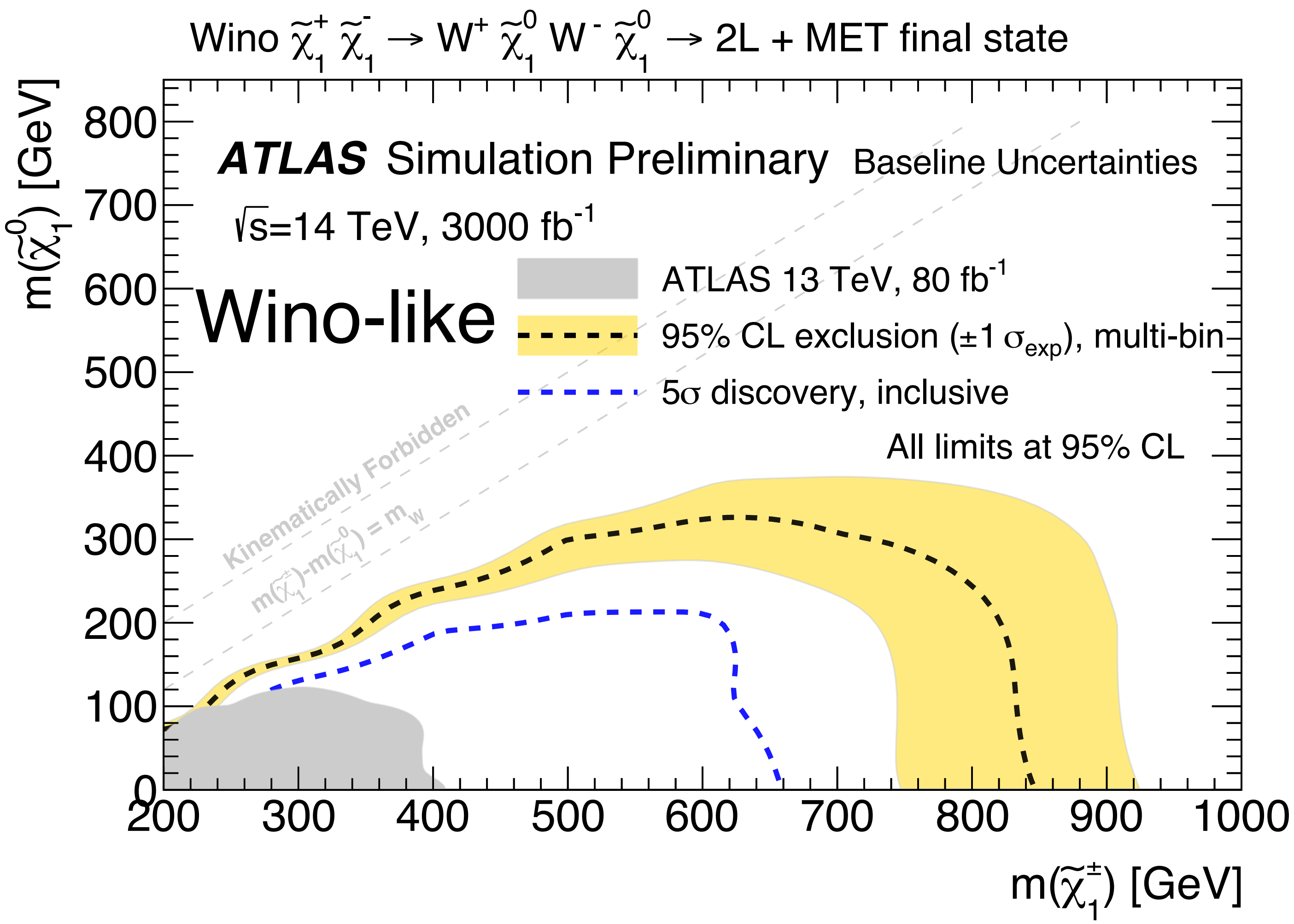
Higgs: Jose Feliciano Benitez

Electroweakinos

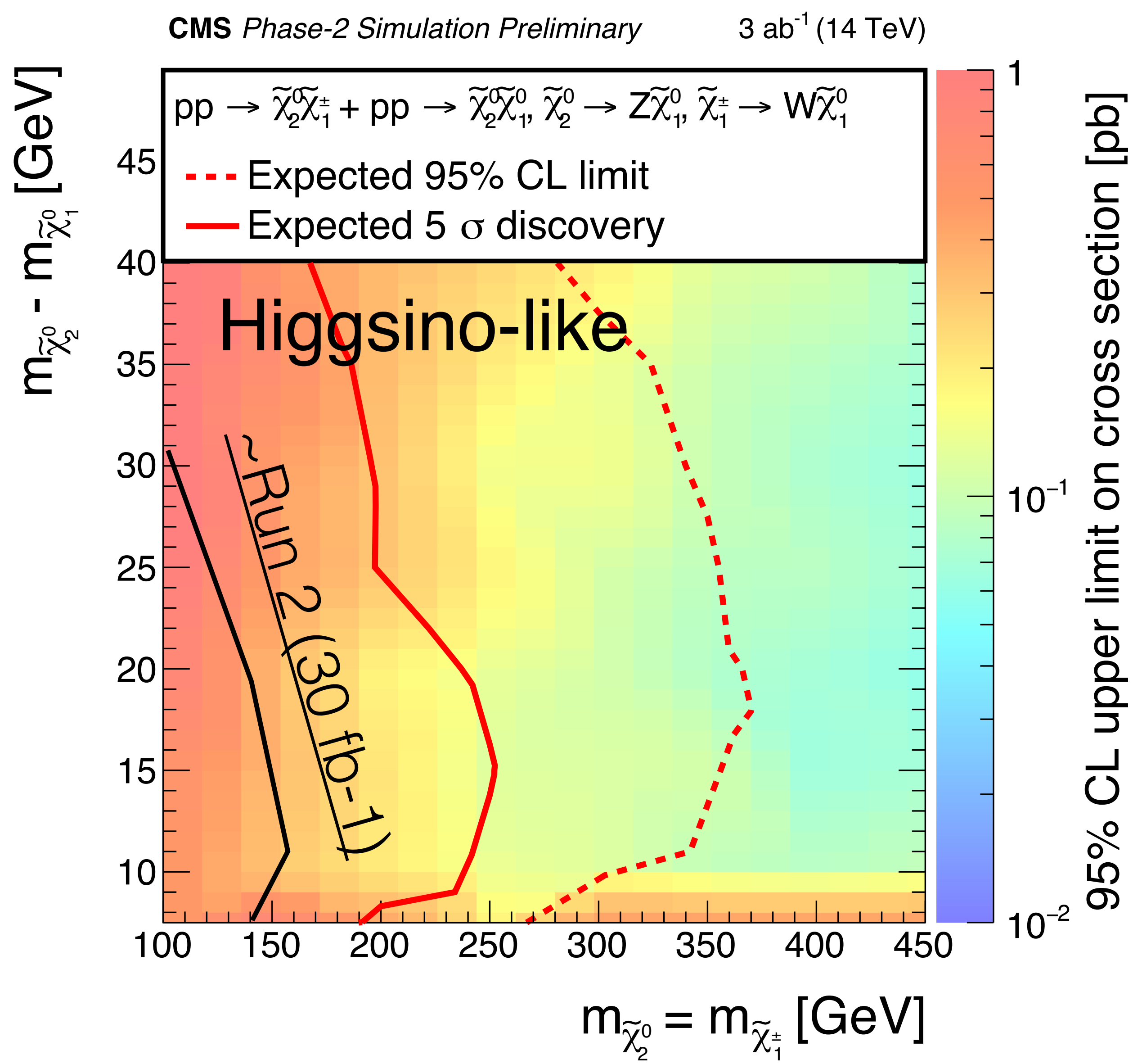




ATL-PHYS-PUB-2018-048



CMS-PAS-FTR-18-001



Much smaller cross-sections compared with squarks and gluinos - huge gains from HL-LHC dataset.

Object performance + uncertainties

CMS NOTE -2018/006

ATL-PHYS-PUB-2016-026

Executive summary of Yellow Report:

https://twiki.cern.ch/twiki/pub/LHCPhysics/HLHELHCWorkshop/report.pdf

ATLAS an CMS upgrade physics twiki pages:

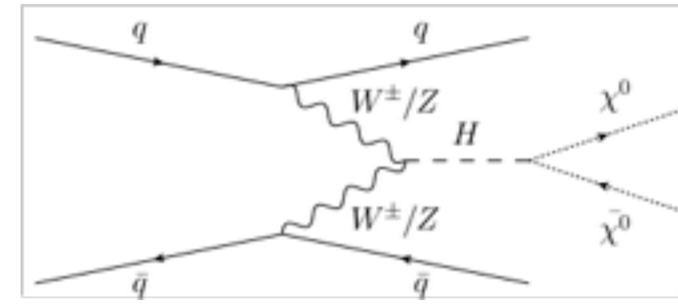
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FTR/index.html

European Strategy
Update

Open Symposium: Update of the European Strategy for Particle Physics: https://indico.cern.ch/event/808335/

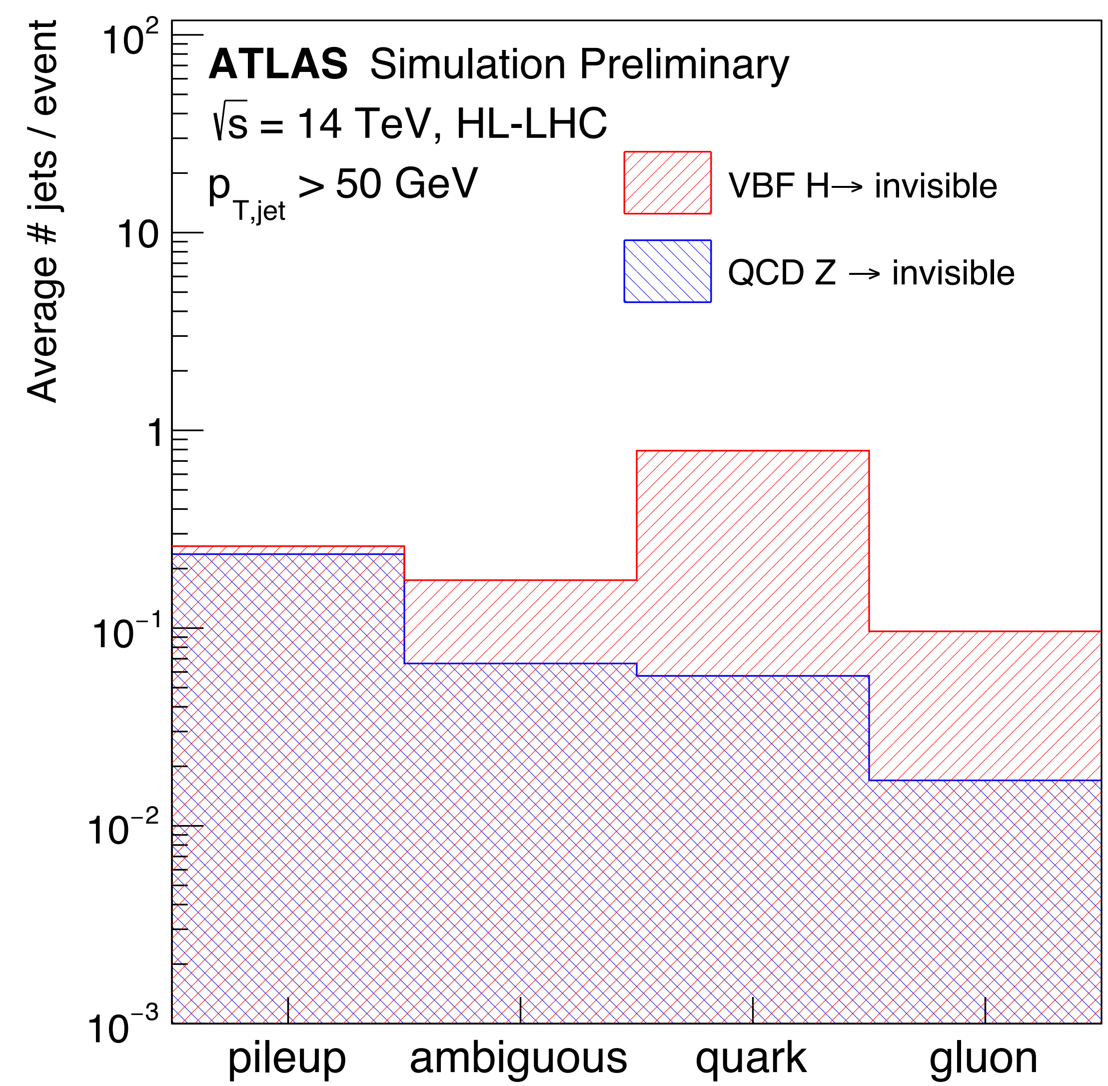
Invisible decays



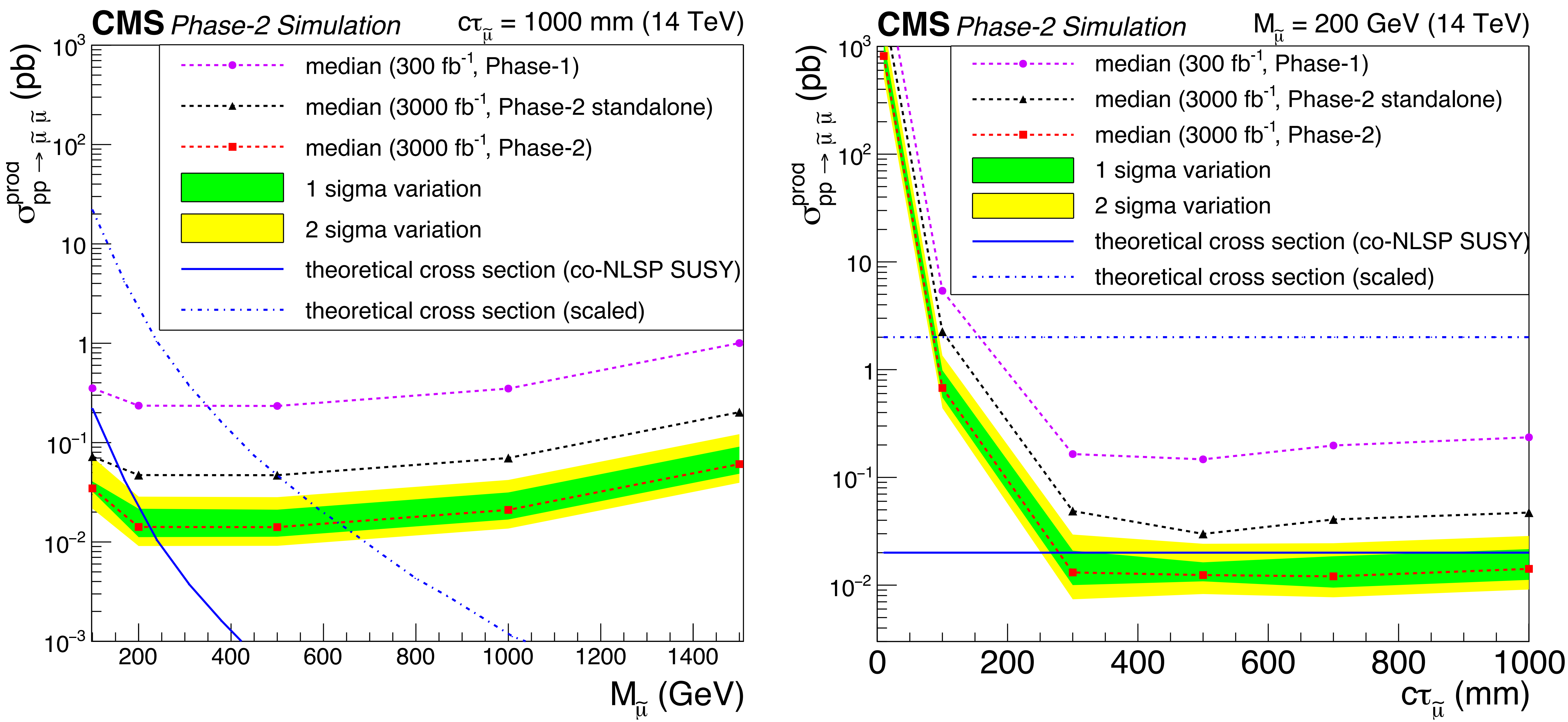
ATL-PHYS-PUB-2018-038

	$\frac{\mathcal{B}(H\to\text{invs.})}{\mathcal{B}_{\text{Truth, Nominal}}(H\to\text{invs.})}$	Systematic Uncertainties [% of nominal] 100%	50%	50% + fixed efficiency	10%
PU jet rejection	None	–	–	0.31	0.59
	$R_{p_{\mathrm{T}}}$	–	–	0.28	0.48
	Truth	1.0	0.48	0.07	0.10

↓ Relative BR limit



CERN-LHCC-2017-012



ATL-PHYS-PUB-2018-037

	ATLAS $\sqrt{s}$ = 8 TeV	ATLAS $\sqrt{s}$ = 14 TeV	ATLAS $\sqrt{s}$ = 14 TeV
$\mathcal{L}$ [fb^{-1}]	20	3000	3000
PDF set	MMHT14 [18]	CT14 [13]	PDF4LHC15$_{\text{HL-LHC}}$ [19]
$\sin^2\theta_{eff}$ [$\times 10^{-5}$]	23140	23153	23153
Stat.	± 21	± 4	± 4
PDFs	± 24	± 16	± 13
Experimental Syst.	± 9	± 8	± 6
Other Syst.	± 13	-	-
Total	± 36	± 18	± 15