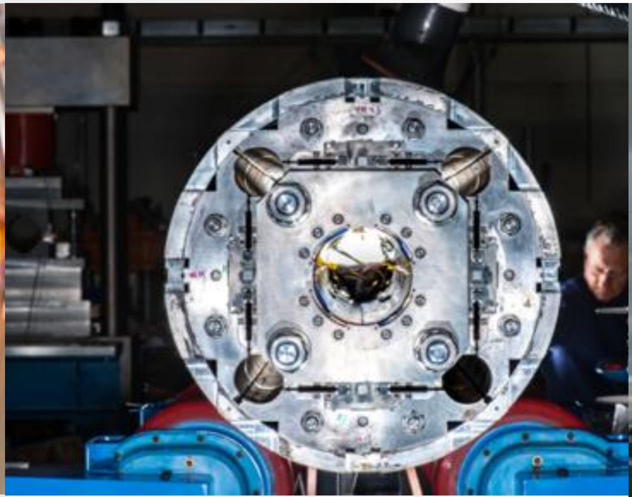
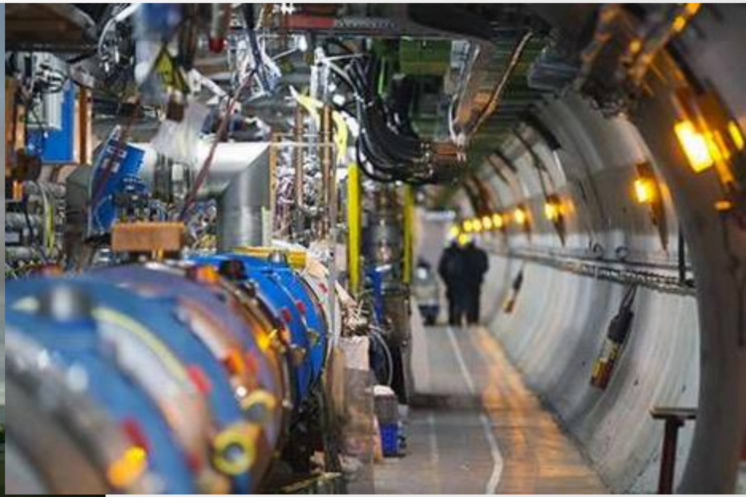
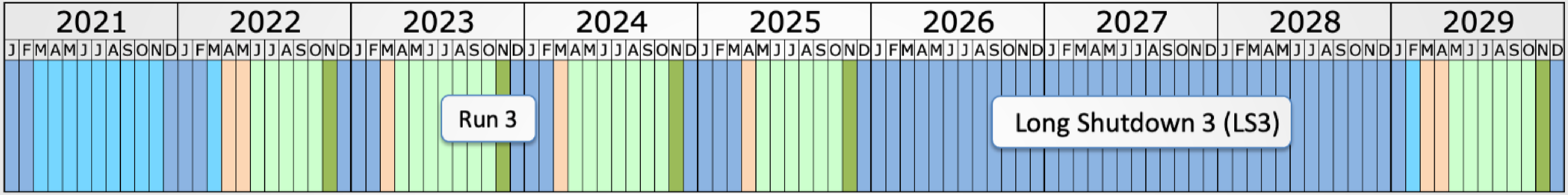
PROSPECTS FOR QCD, EWK AND TOP PHYSICS AT THE (HL-)LHC

R. Schöfbeck, HEPHY Vienna



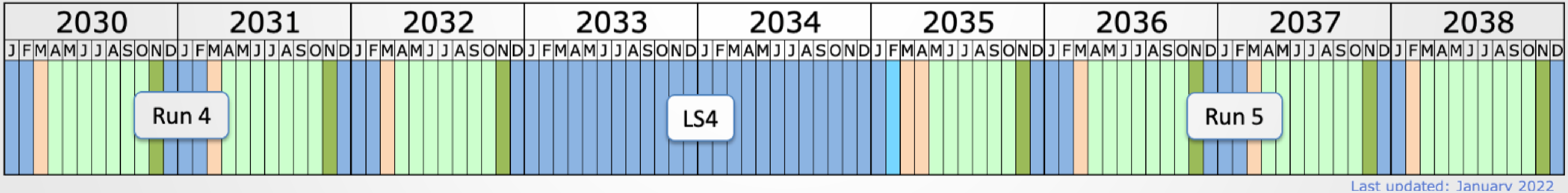
LHC LONG TERM SCHEDULE



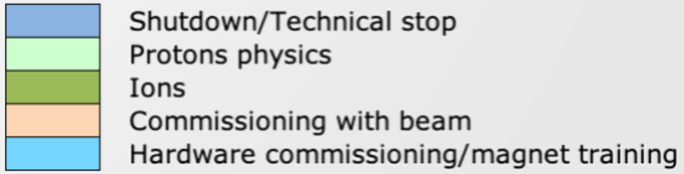
(~2x10^{34} $cm^{-2}s^{-1}$), "last significant low PU run" of PU 40-60

Run 3(+2): 300-350 fb^{-1}

⟶ HL-LHC



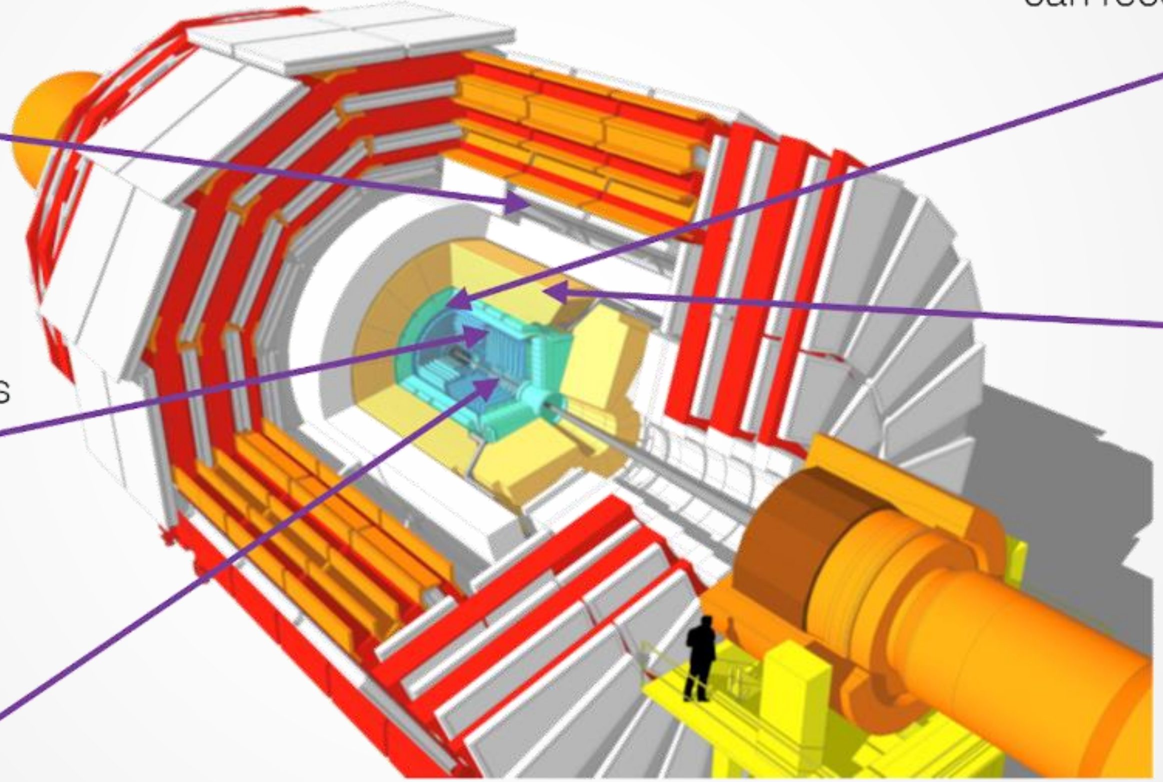
(~5-7 10^{34} $cm^{-2}s^{-1}$), 3-4 ab^{-1}, PU 140-200 ⟶ Major detector upgrades in LS3



CMS UPGRADES FOR HL-LHC

Improved muon coverage and trigger
increased RPC coverage (1.5 < |η| < 2.4)
new electronics
[CMS-TDR-016]

New endcap calorimeters
high granularity
can reconstruct showers in 3D
CMS-TDR-019



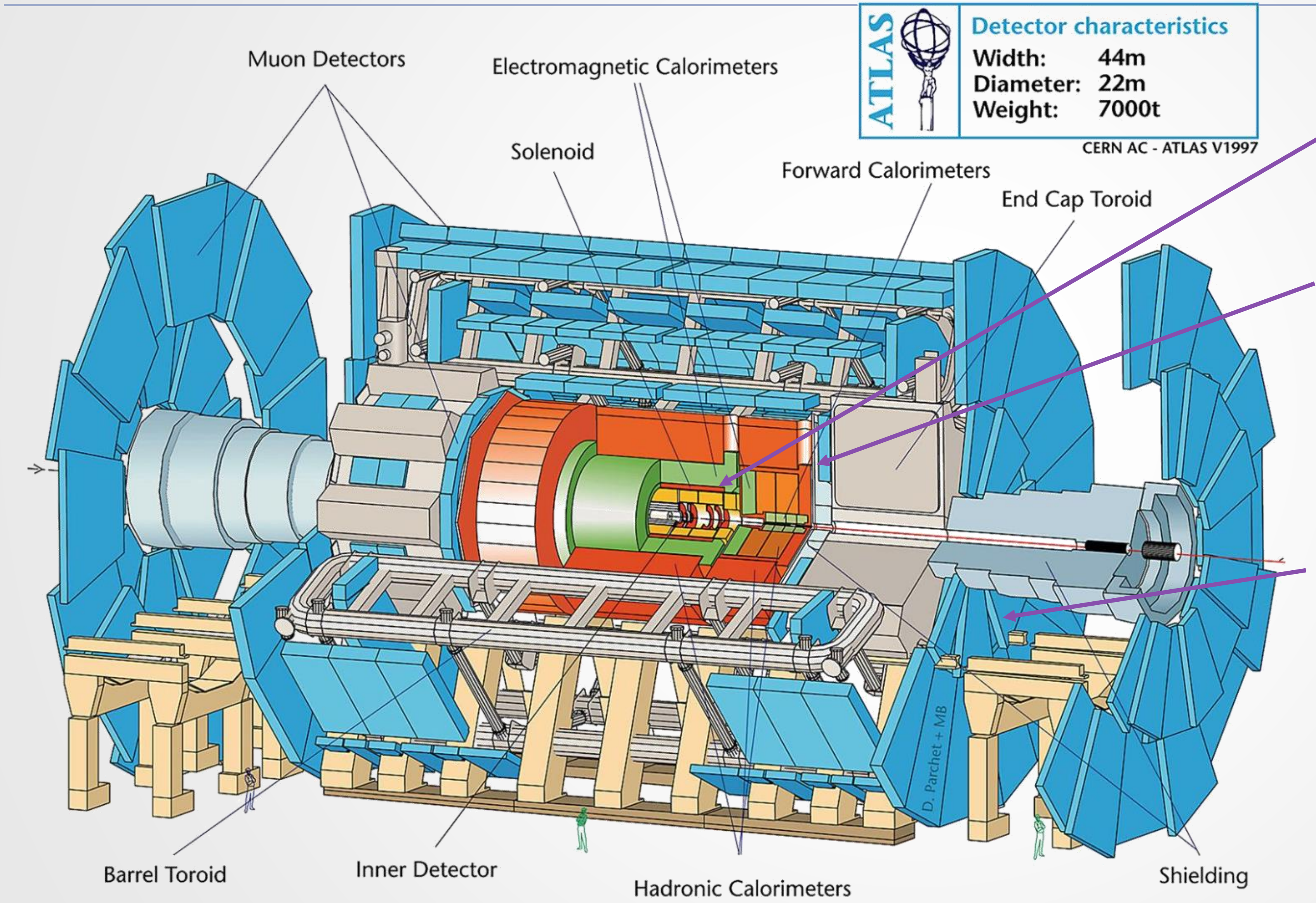
Updates to calorimeter and trigger
higher granularity
electronics for trigger

New precision timing detector
Timing resolution of 30-40 ps for MIPs
full coverage of |η| < 3.0
[CMS-TDR-020]

New inner tracker
all silicon tracker
4 layers of pixels
5 layers of strips
coverage to |η| < 4 [CMS-TDR-014]

Upgrade to trigger and DAQ
L1 rate increased to 750 kHz
High Level trigger rate to 7.5 kHz
Track information at L1
[L1: CMS-TDR-021]
[DAQ/HLT: CMS-TDR-022]

ATLAS UPGRADES FOR HL-LHC



Inner Tracking Detector (ITk)

All silicon, strips and Pixels up to $|\eta| \leq 4$
[ATLAS-TDR-025, ATLAS-TDR-030]

Muon system upgrade
New chambers in the Inner barrel region ($|\eta| \leq 2.7$)
[ATLAS-TDR-026]

High granularity timing detector (HGTD) $2.4 \leq |\eta| \leq 4.0$ with 30ps
[ATLAS-TDR-031]

Upgraded Trigger and
Data Aquisition System
[ATLAS-TDR-029]

FURTHER READING

- HL/HE-LHC WG Yellow report (2018-19)
  - [SM Physics] [Higgs Physics] [Beyond the SM] [Flavour Physics] [High-density QCD]
- European Particle Physics Strategy Update (EPPSU) [Physics Briefing Book]
- Snowmass Community Planning Exercise (until Oct. 2022) & [Snowmass White paper]

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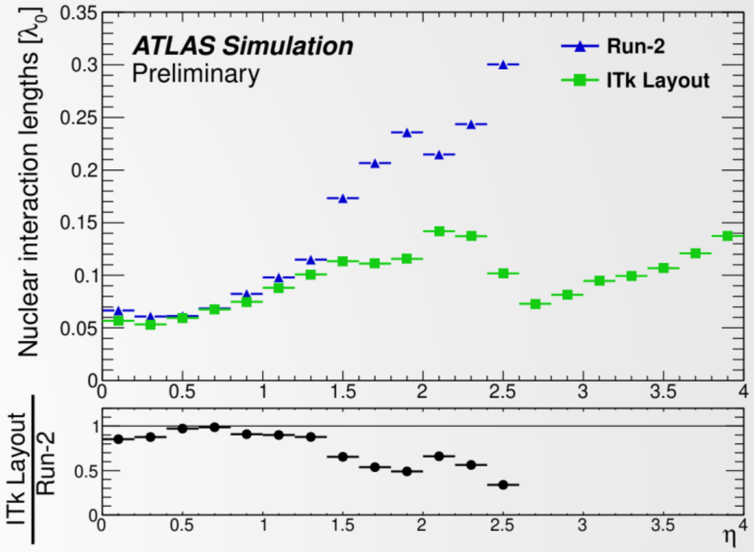
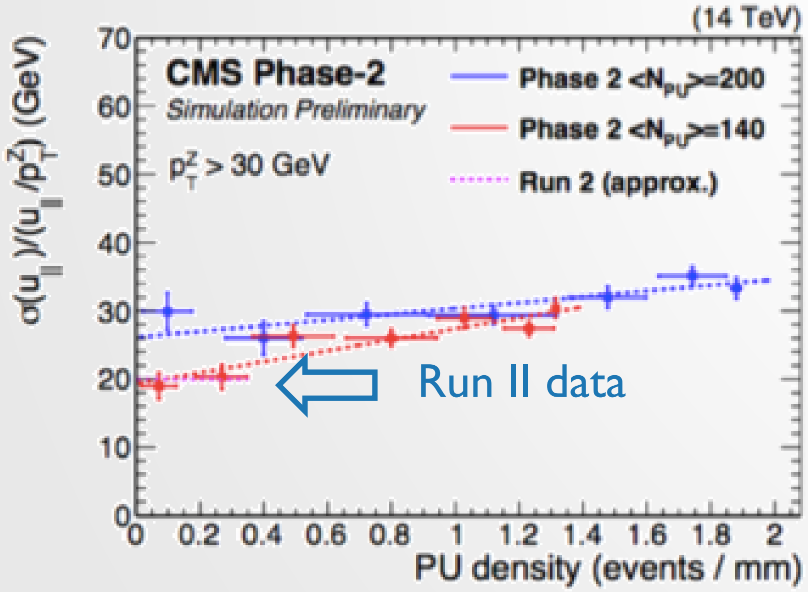
FREQUENTLY MADE ASSUMPTIONS

- "more data": scale statistical uncertainties with luminosity
- "can afford computing": no statistical uncertainty in simulation
- "anticipate accompanying theory developments": reduce theoretical uncertainties to 50%
  - cross sections, ISR/FSR scale, PDF, tuning, b-fragmentation, ren./fact. scales, color reconnection
- "detector upgrades balance harsh conditions": 1) nominal exp uncertainties from Run II analyses 2) statistical component reduced with lumi 3) lumi at 1%

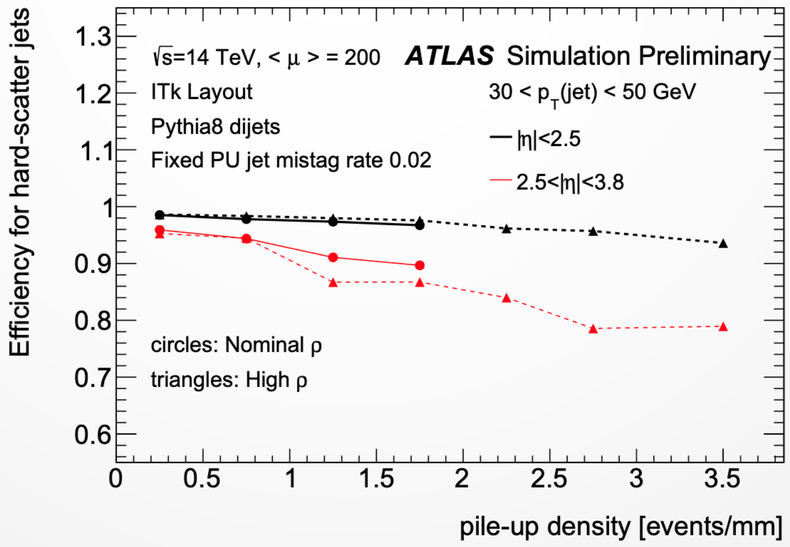
RECONSTRUCTION PERFORMANCE

- ATLAS ITk nuclear interaction length vs. η with extended tracking coverage
- impacts b-tagging performance similar to Run II (200PU & up to |η| < 4)
- Excellent & stable PU jet rejection across all PU densities
- E_T^{miss} resolution not much worse than in Run II

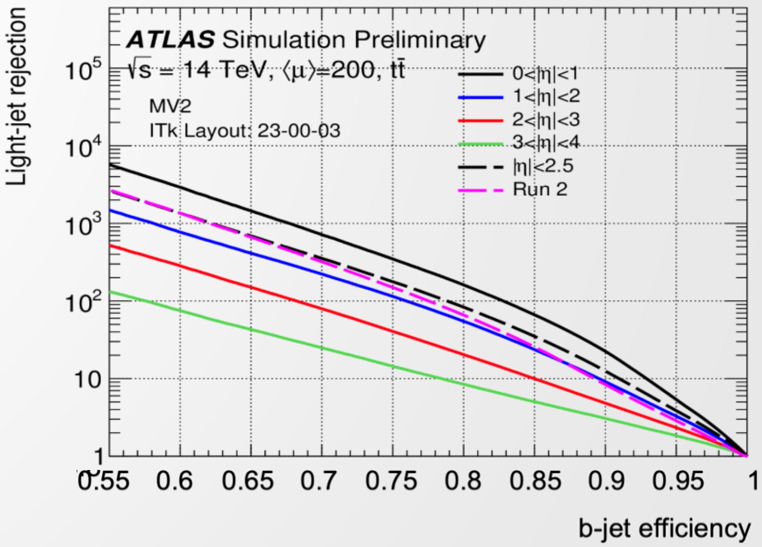




Puppi E_T^{miss} resolution for $p_T(Z)>30$



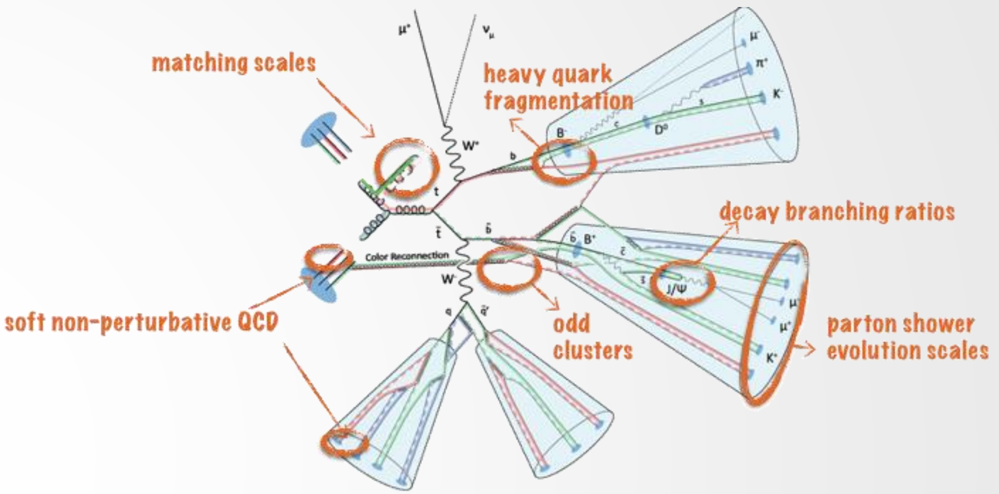
Hard-scatter jet efficiency vs. PU density



TOP QUARK MEASUREMENTS

[Phys. Rev. Lett. 116, 082003 (2016)]

- A great many things have to come together
  1. state of the art theoretical tools/calculations
  2. low-level understanding of sub-detector performance
  3. object performance – realistic projections
  4. novel analysis ideas that incorporate 1-3



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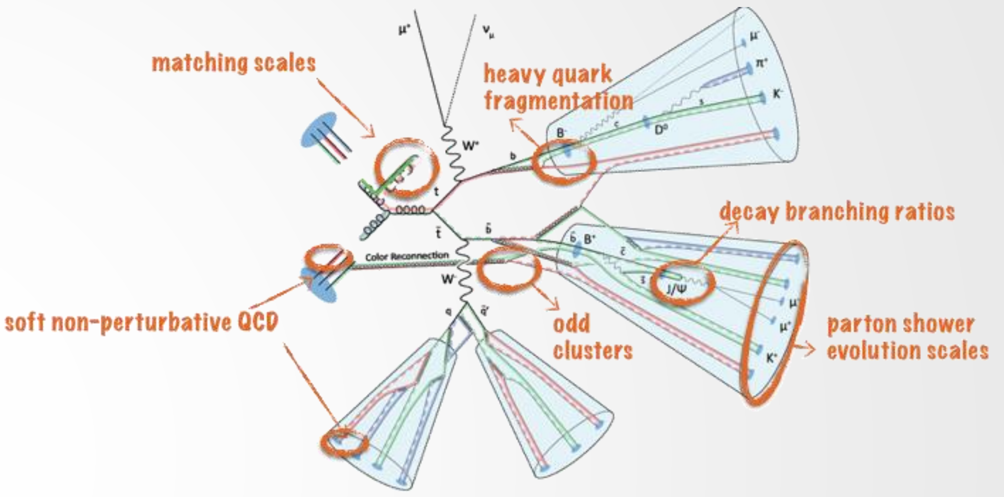
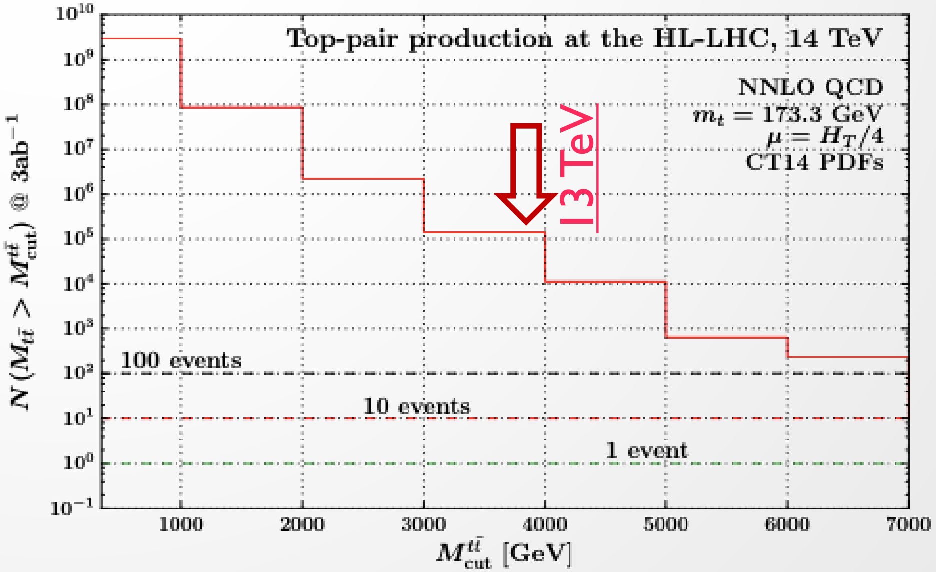


- kinematic reach
  - NNLO QCD for HL-LHC 14 TeV with 3/ab
  - EWK corrections essential for precision
  - increase reach by several TeV

Cumulative M^{tt} distribution for HL-LHC



≈10 events
M^{tt} > 7 TeV

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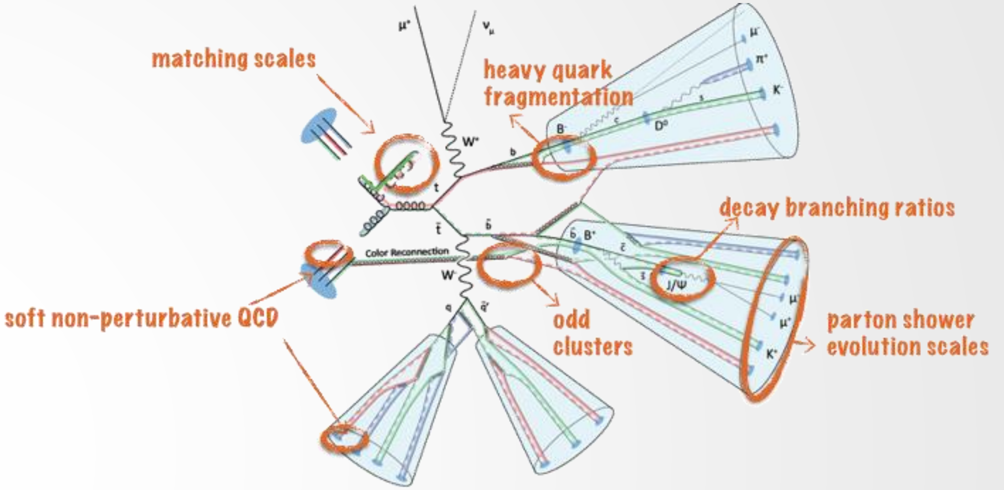

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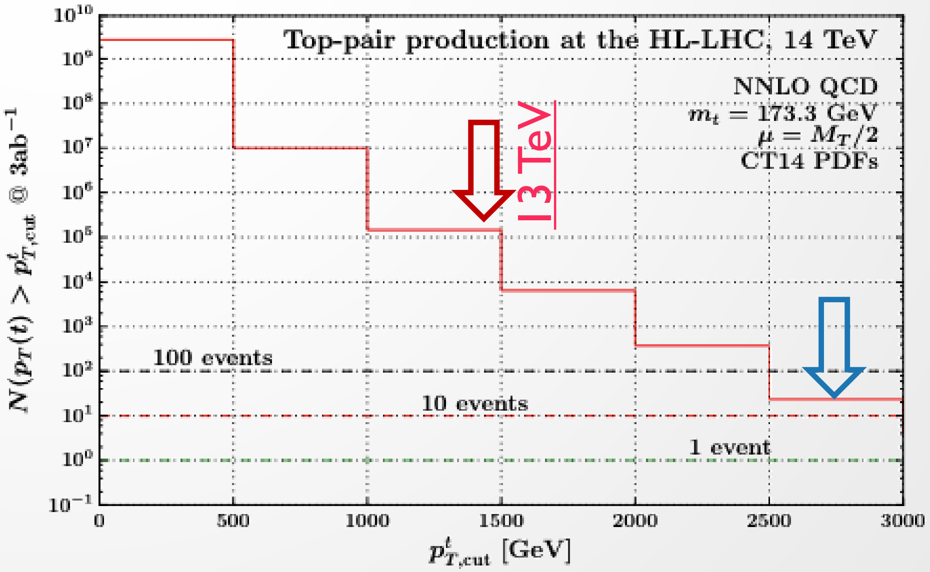
  - NNLO QCD for HL-LHC 14 TeV with 3/ab
  - EWK corrections essential for precision
  - increase reach by several TeV

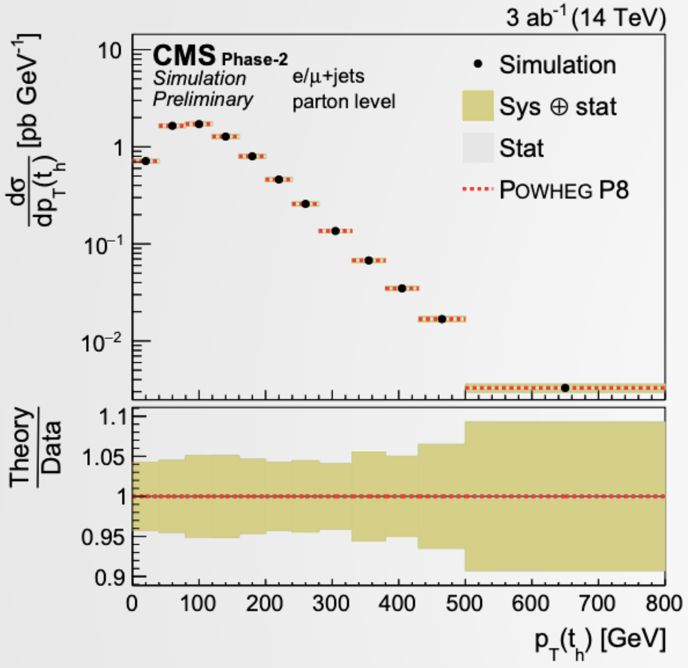
Cumulative $p_T(t)$ distribution for HL-LHC



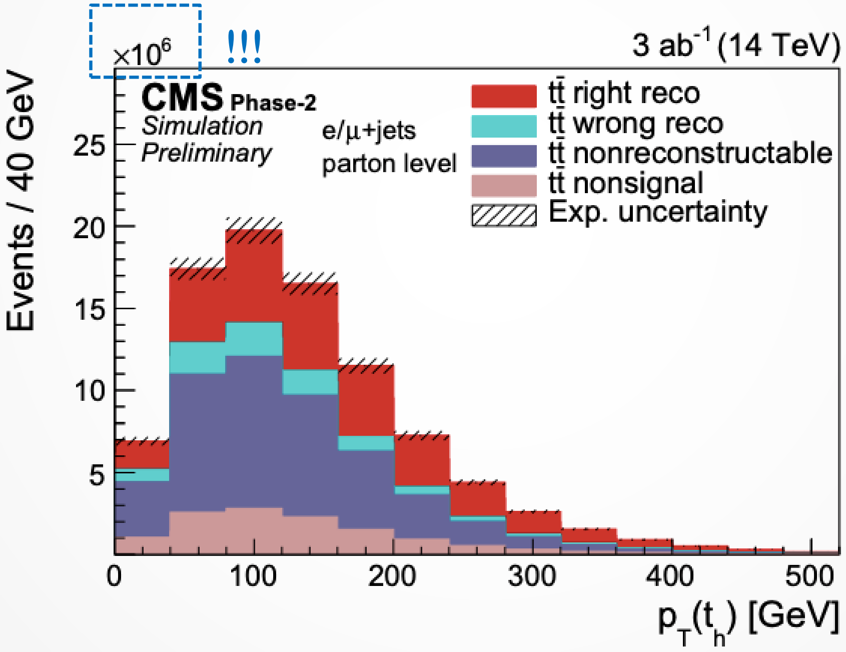
≈20 events
p_T > 2.5 TeV
TeV scale jets/leptons collimated to slim jets: ΔR ≈ 0.13
(16cm @ CMS ECAL)

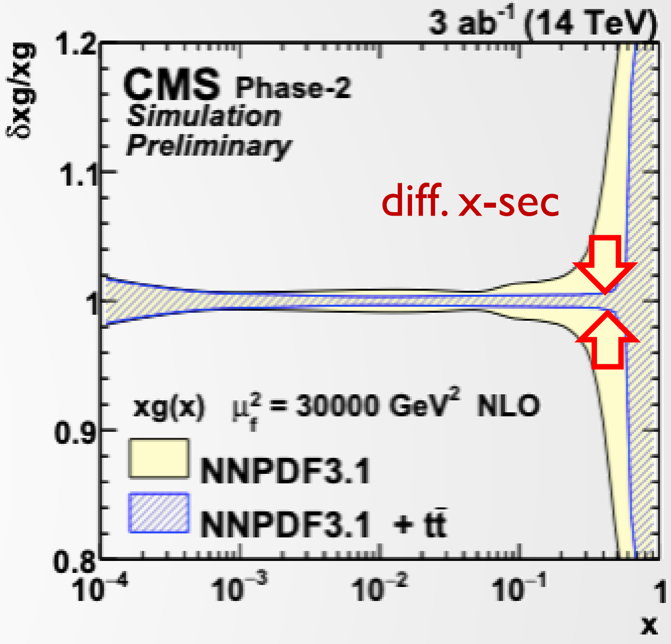
PRECISION FROM THE BULK AND FROM HIGH ETA

[CMS-FTR-18-015]
[arXiv:1311.1810]
[arXiv:1808.08865]



- uncertainty on differential top x-sec O(5%)
- significant impact on high x gluon PDF





[M. Guzzi: tt+jets on CT18]

PRECISION FROM THE BULK AND FROM HIGH ETA

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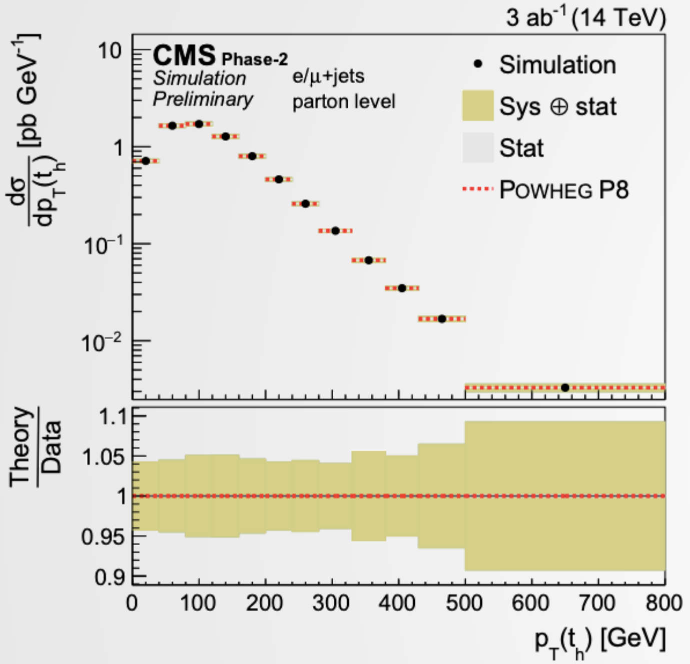
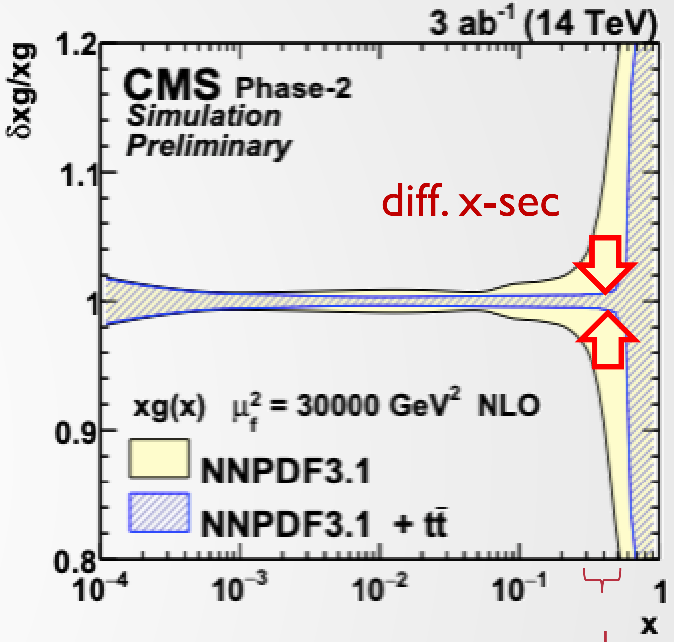


- uncertainty on differential top x-sec O(5%)
- significant impact on high x gluon PDF
- complemented with forward tops:
  1. 300/fb LHCb data probe high-x PDFs with partially reconstructed top quarks
  2. quark PDFs: use differential charge asymmetry vs. lepton **η**

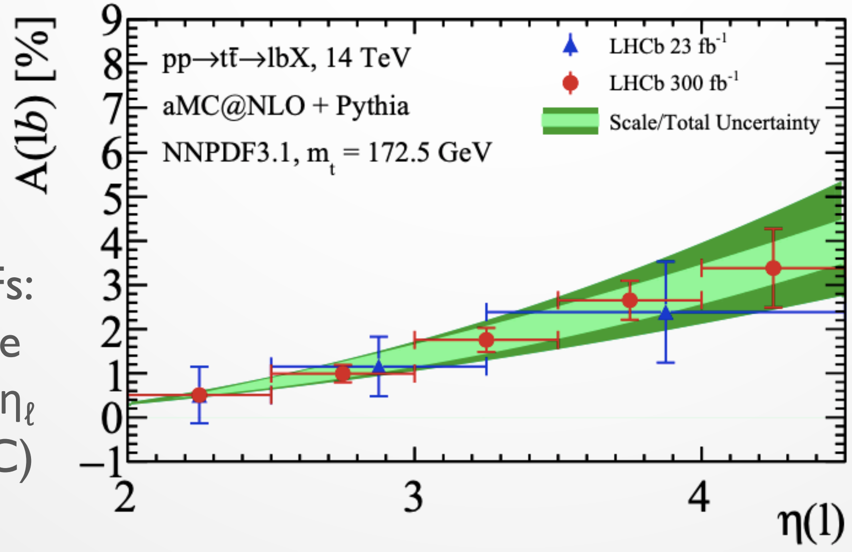


sensitivity from 300/fb of LHCb data in (partial) t and tt final states

stat precision

Final state	300 fb^{-1}	$< x >$
ℓb	830k	0.295
$\ell b\bar{b}$	130k	0.368
$\mu e b$	12k	0.348
$\mu e b\bar{b}$	1.5k	0.415

background level

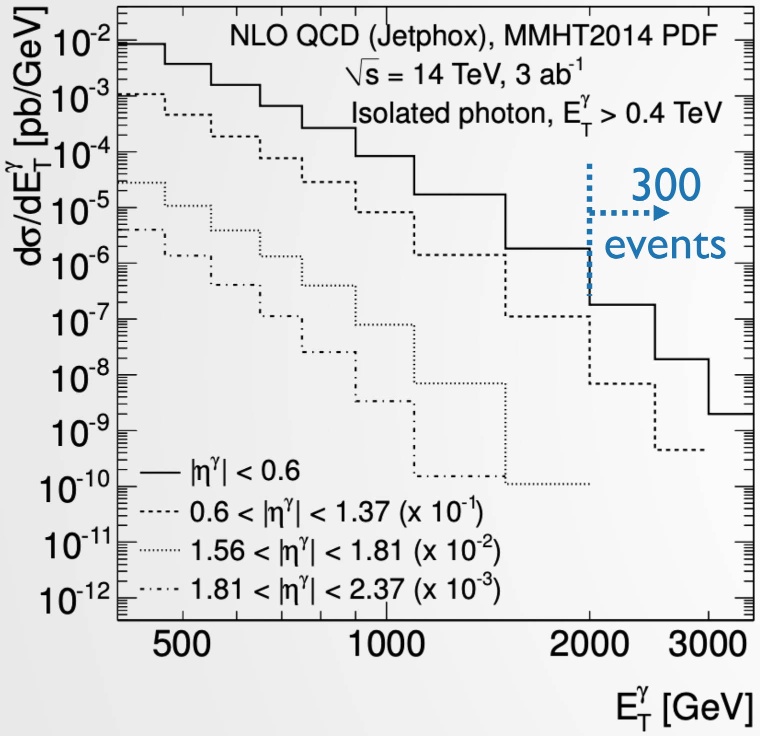


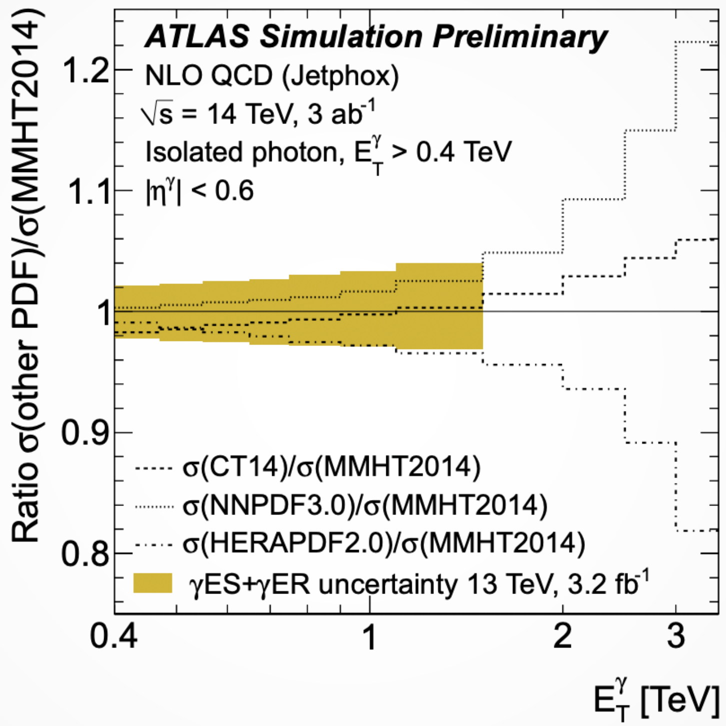
quark PDFs:
differential $l^{\pm}b$ charge asymmetry vs η_ℓ
(300/fb for HL/LHC)

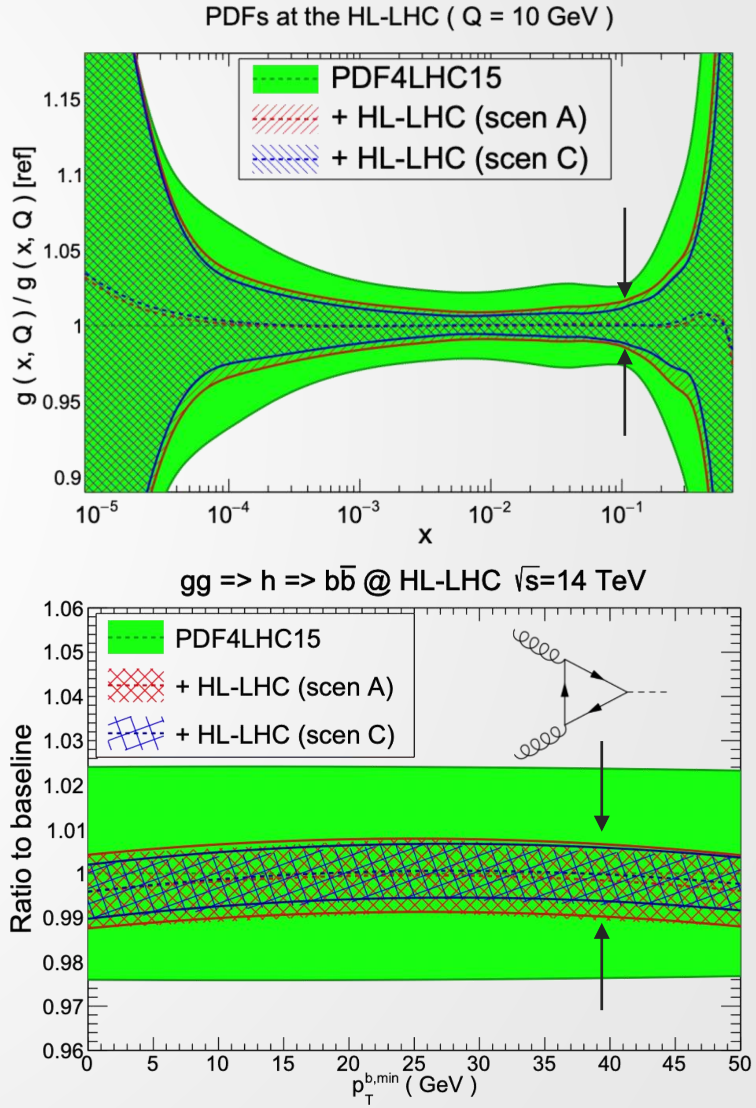
PDFs AT HL-LHC

[arXiv:1810.03639]
[ATLAS-PHYS-PUB-2018-051]

- ultimately: Drell-Yan at all m(ℓℓ), top quarks, W+charm, direct γ, forward W+Z, inclusive jets



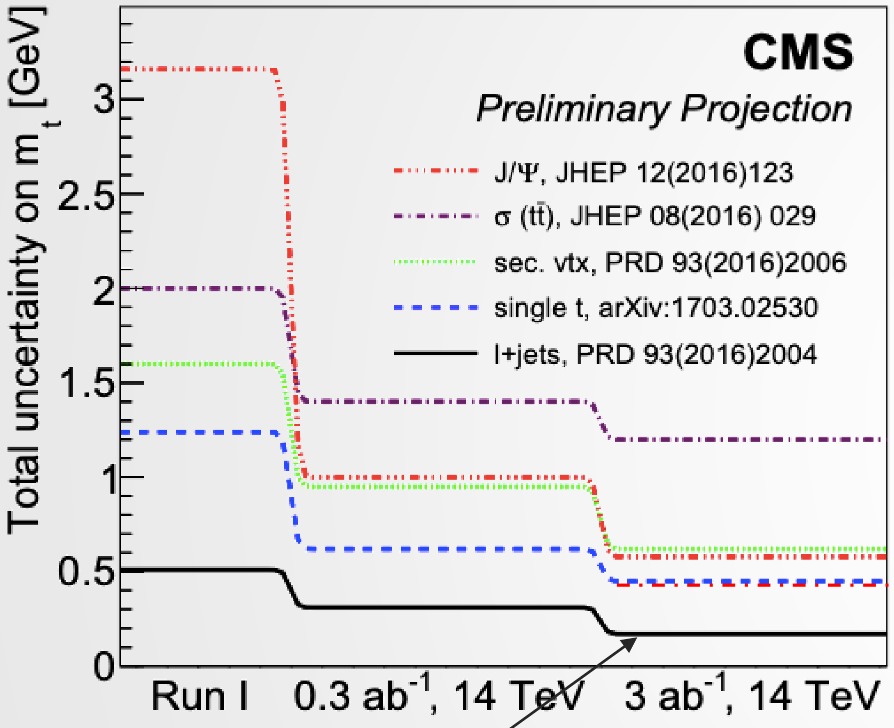




- ATLAS direct γ up to $E_T^\gamma \approx 2$ TeV with good statistics
- differential high- E_T^γ x-sec ratio for different PDF sets
- “ultimate” PDF precision for projected measurements: > factor 2

TOP MASS

[CMS-PAS-FTR-16-006]
[ATL-PHYS-PUB-2018-042]



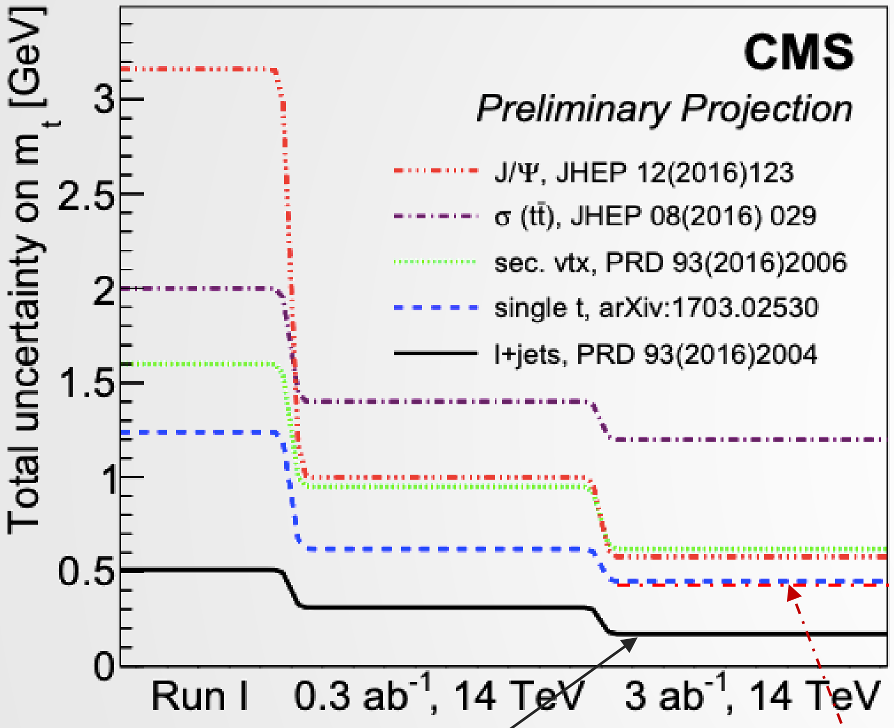
0.17 GeV ⟶ 0.1 %
dominated by JES

- top mass measurement requires precision on all fronts!

- simple concept:
  1. pick out jets from top
  2. pair up the right jets to each top
  3. calculate mass
- challenges (a selection)
  - efficient b tagging (combinatorics)
  - moderate p_T triggers
  - relate the 'MC mass' to a well defined parameter in a ren. scheme to 100 MeV [e.g. here]
  - precision JES & E_T^{miss}, lepton E scale

TOP MASS

[CMS-PAS-FTR-16-006]
[ATL-PHYS-PUB-2018-042]



combs.

0.17 GeV ⟶ 0.1 %
dominated by JES

ATLAS J/Ψ projection
± 0.14 (stat) ± 0.48 sys
(fragmentation modelling)

- top mass measurement requires precision on all fronts!

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  1. pick out jets from top
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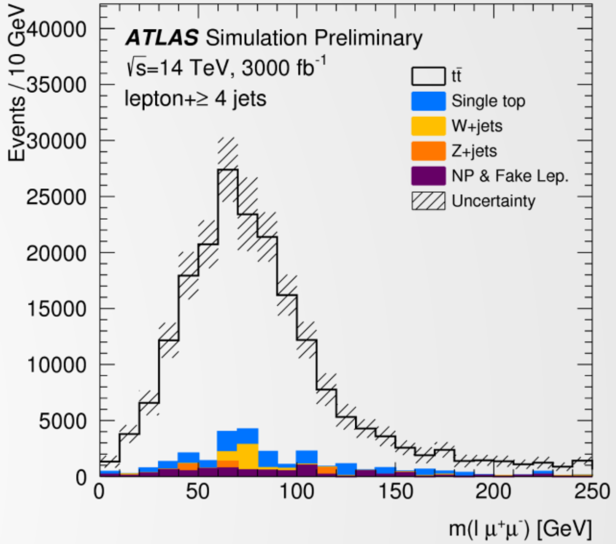
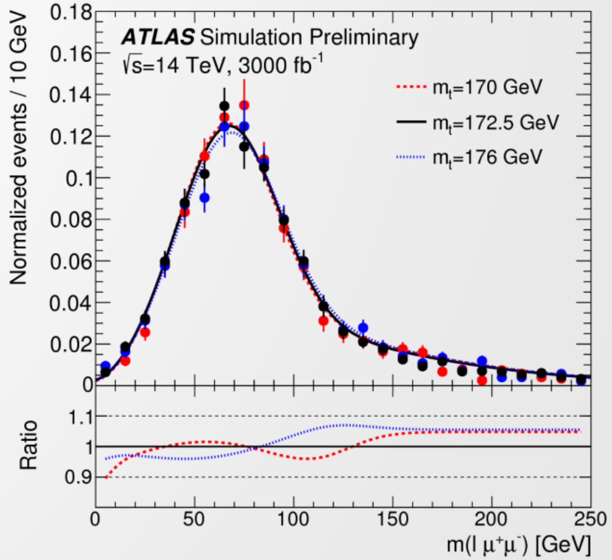
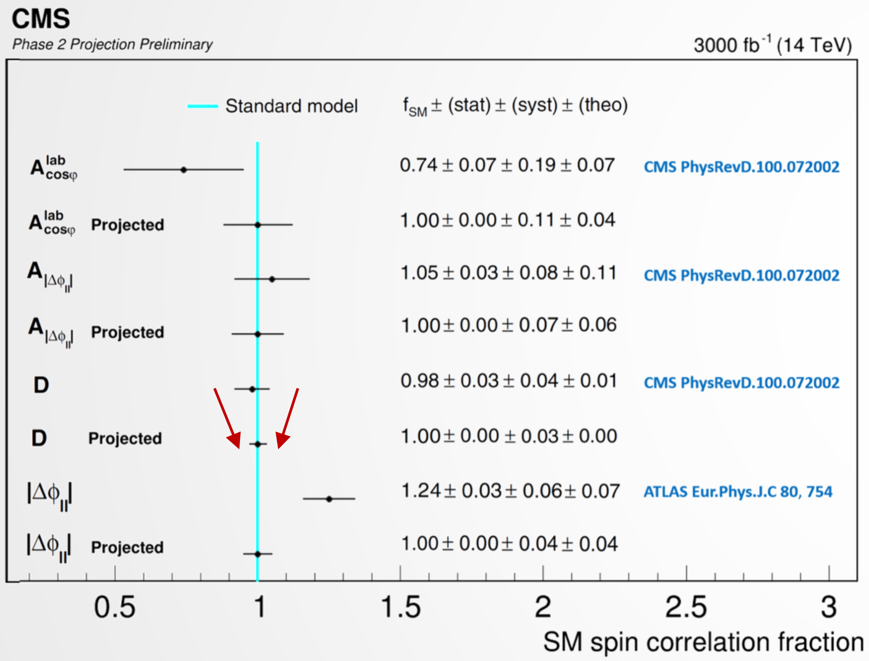
  3. calculate mass
- challenges (a selection)
  - efficient b tagging (combinatorics)
  - moderate p_T triggers
  - relate the 'MC mass' to a well defined parameter in a ren. scheme to 100 MeV [e.g. here]
  - precision JES & E_T^{miss}, lepton E scale
- Mitigate JES by considering 0.04% BR with a J/Psi: $t\bar{t} \rightarrow (W^+b)(W^-b)$ $\rightarrow (\ell\nu_\ell J/\psi(\rightarrow \mu^+\mu^-)X)(qq'b))$

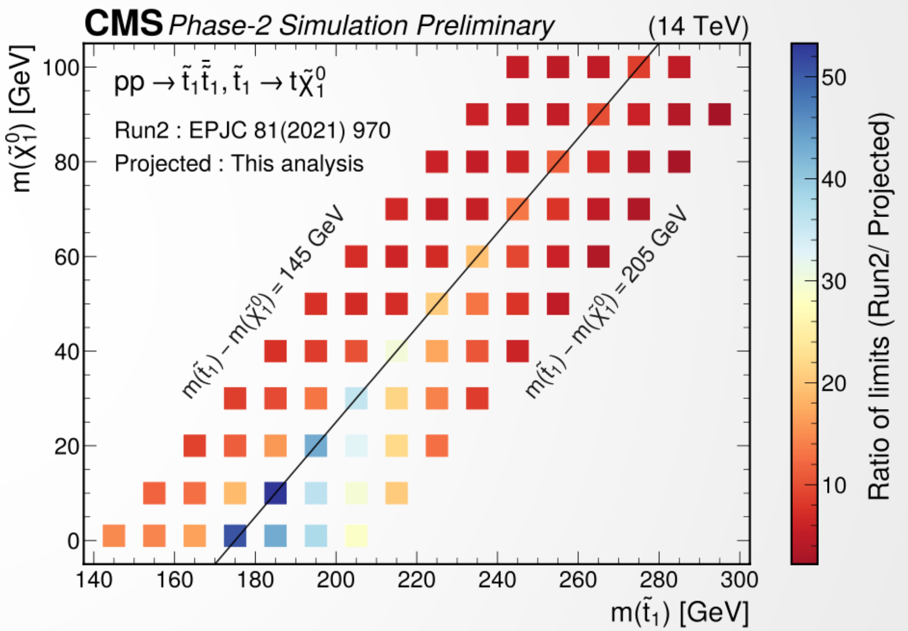




SPIN CORRELATION

- Fully reconstructed dileptonic top pairs provide access to polarization and spin correlation observables.
- Projection based on Run II analysis, 50% theory unc.





improve UL by factor ≈20

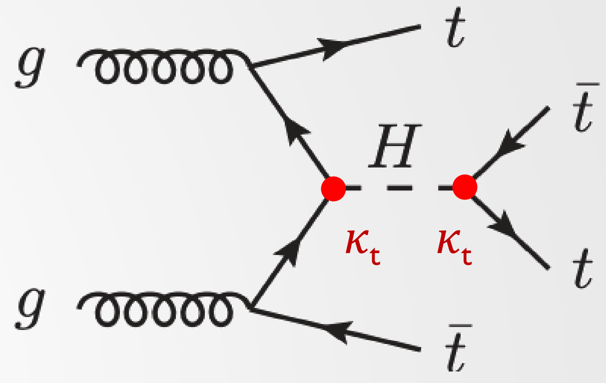
- 40% improvement for the most sensitive measurement of the spin correlation strength
- Set limits in SUSY top squark using a parametric DNN, trained on 19 kinematic features
- Improving SUSY mass limits by x10 where $M_{stop} \gtrsim M_{top}$ (corridor)and traditional SUSY searches are inefficient

FOUR TOP PRODUCTION

[EPJC 80 (2020) 1085, CMS-PAS-FTR-18-031]
[ATL-PHYS-PUB-§2022-004, JHEP 11 (2021) 118]

- complete NLO cross section 15.8 fb ± 20 % known (EWK: 11%)
  - Enhanced in BSM scenarios (SUSY gluinos, sgluons, 2HDM)
  - Relevant for y_t measurement, and 4-fermion operators in SM-EFT

$$\sigma(t\bar{t}t\bar{t}) = 13.14 - 2.01\kappa_t^2 + 1.52\kappa_t^4 \text{ [fb]} \quad (13\text{ TeV})$$

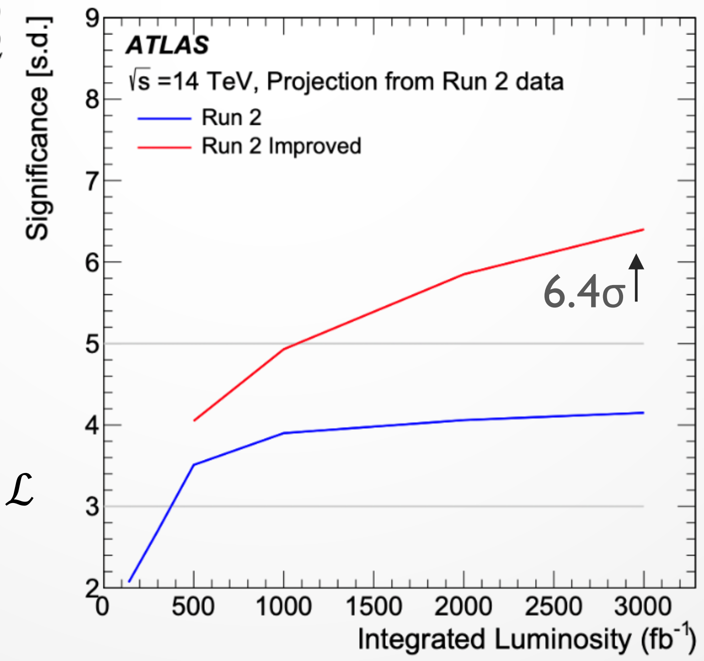


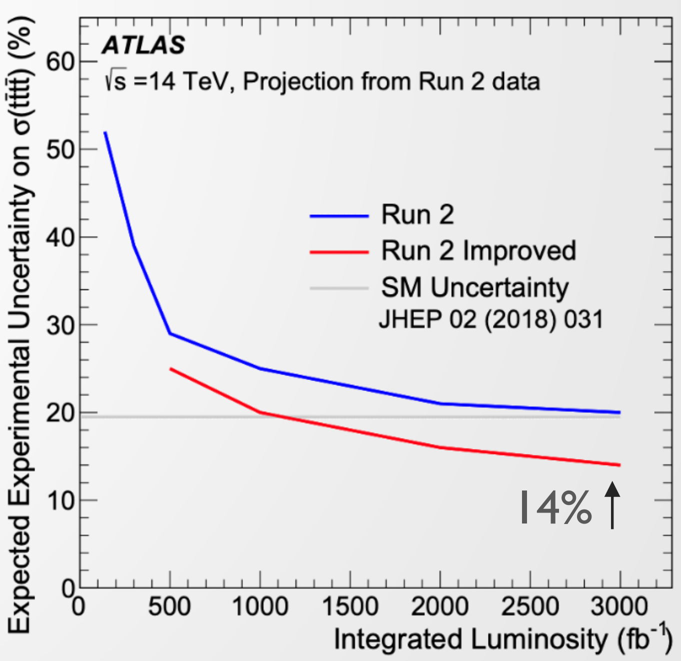
- ATLAS Run II observes 4.7σ (2.6σ), 1.9σ above SM

$$\mu = 2.2 \pm 0.7\,(\text{stat.})\,^{+1.5}_{-1.0}\,(\text{syst.}) = 2.2\,^{+1.6}_{-1.2}$$

  - important: ttW + 7/≥ 8 jets modelling

1. Run II (ttW nuisance post-fit)
2. Run II "improved"
   - 50% theory uncertainties
   - scale down ttX+HF uncertainties with $\mathcal{L}$
   - keep exp. uncertainties





- CMS limits on 4-top contact interactions

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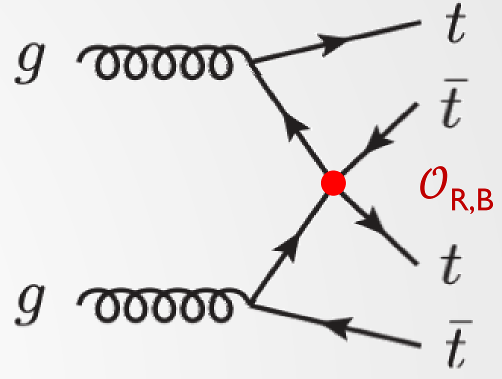

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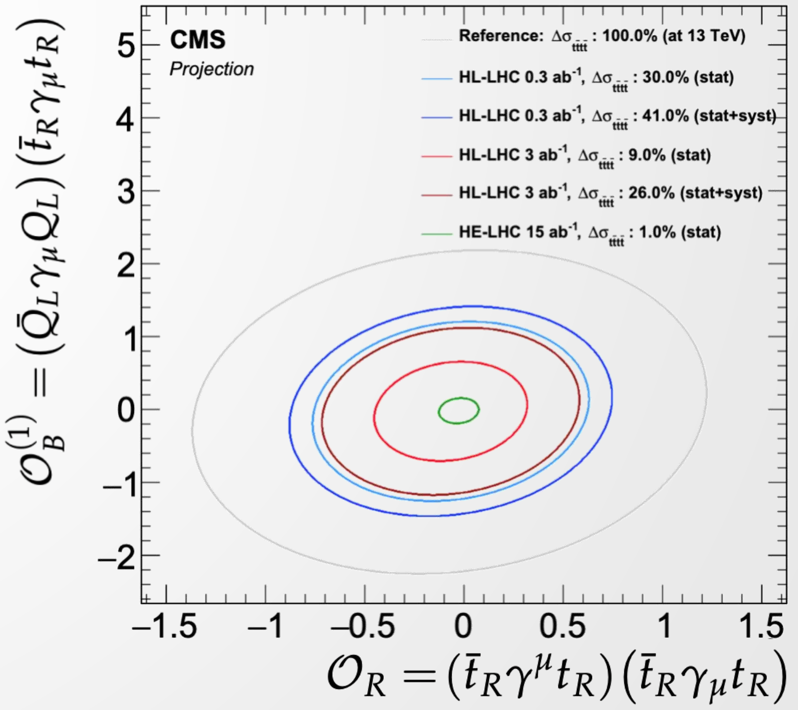
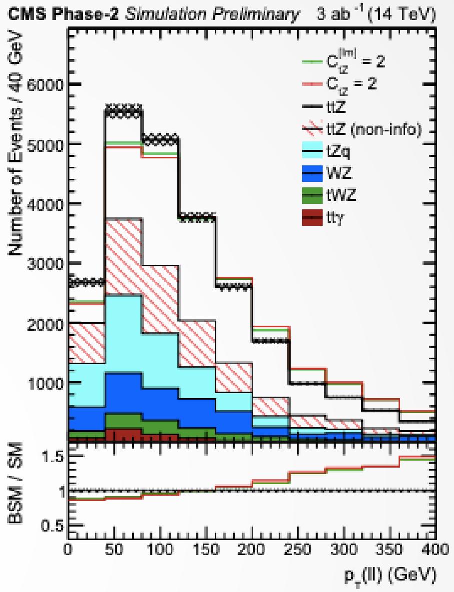
CMS expected limits on LL-RR& RR-RR 4-t interactions

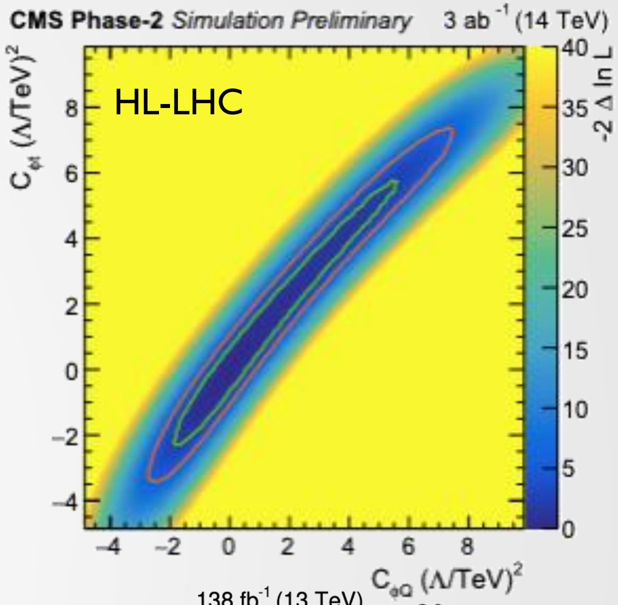


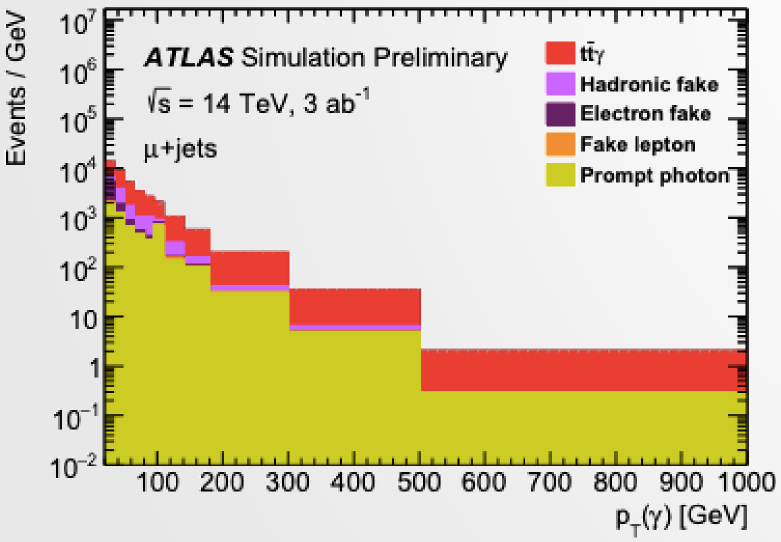
TOP-Z/γ COUPLING MEASUREMENTS

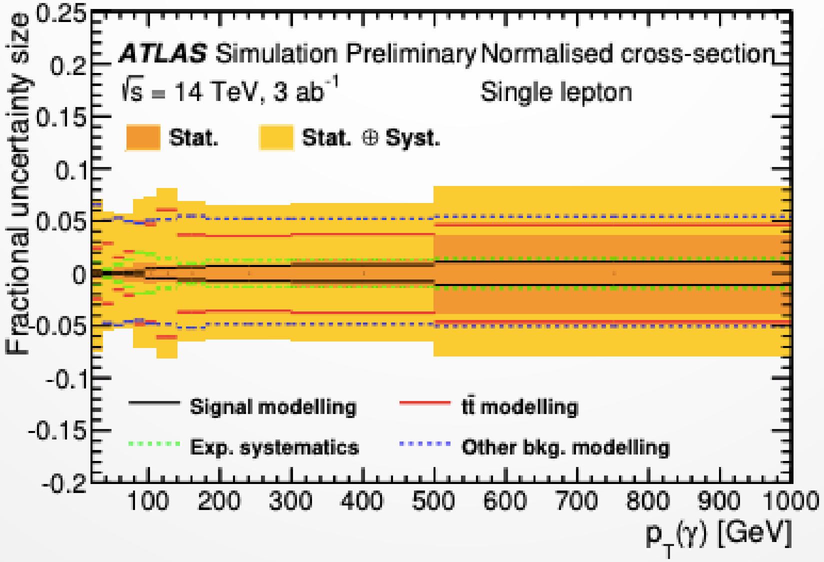
[ATL-PHYS-PUB-2018-049]
[CMS-TOP-21-001]
[CMS-FTR-18-036]

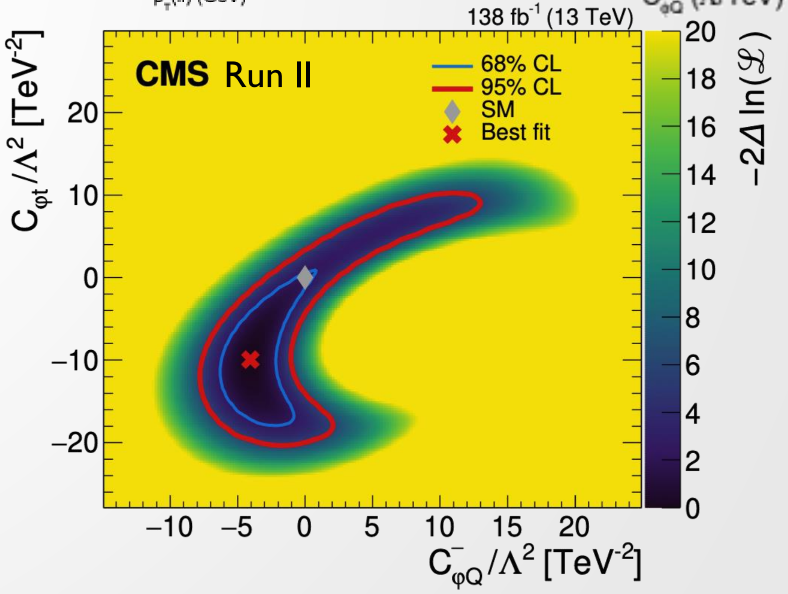
- ATLAS/CMS study using p_T(Z) and $p_T(\gamma)$ with Delphes
  - Constrain t-Z/γ coupling modifications
- ATLAS projects constraints for ttγ (1l/2l)
  - 5-7% uncertainty up to $p_T(\gamma) \approx 1$ TeV
- CMS ttZ (3ℓ): Up to factor 4 sensitivity improvements for EWK interactions of the top quark







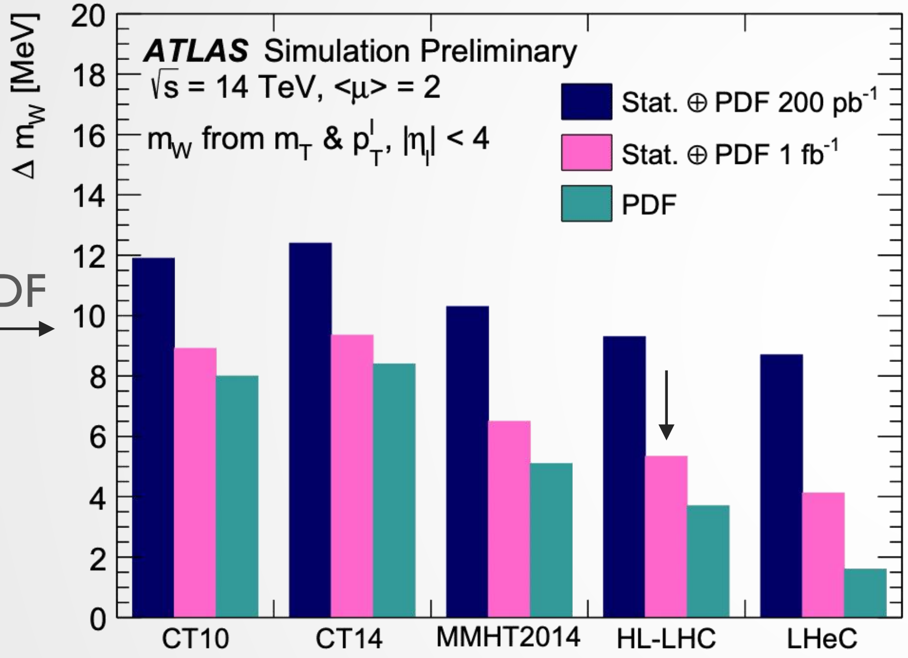




THE MASS OF THE W BOSON

[PHYS-PUB-2018-026]
[EPJC C78 (2018) 110]

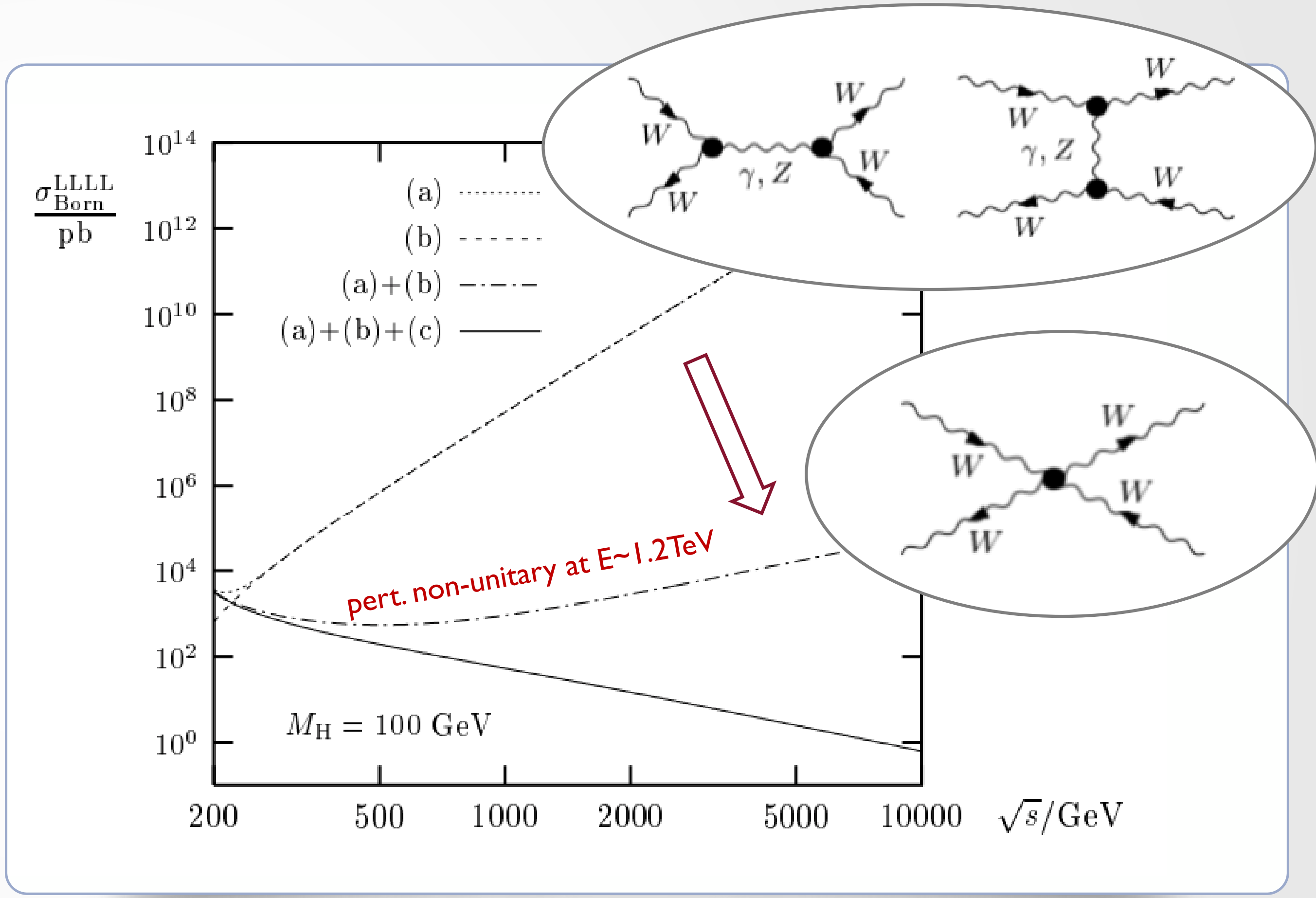
ATLAS 7 TeV
$\eta \leq 2.4$
CDF



- M_W: dedicated low-PU runs @ <μ> ≈2
  - 200 $pb^{-1} \approx \mathcal{O}$ (weeks), 1$fb^{-1} \approx \mathcal{O}$ (months)
- projection study by ATLAS
  - realistic combination of m_T & $p_T(\ell)$ fits
  - comparing different PDF sets
  - "HL-LHC" incorporates future constraints
  - high η bins important – 40% improvement
    - anti-correlation between different η bins
    - also expected for ATLAS/CMS/LHCb combination M.Pernas, LHCb talk!

DIBOSON VBS PRODUCTION

- Higgs observation established that W and Z acquire mass via BEH mechanism
- Vector boson scattering (VBS) is crucial in testing the fundamentals of the BEH
    - pert. non-unitarity for $W_L W_L$ at s~1.2 TeV



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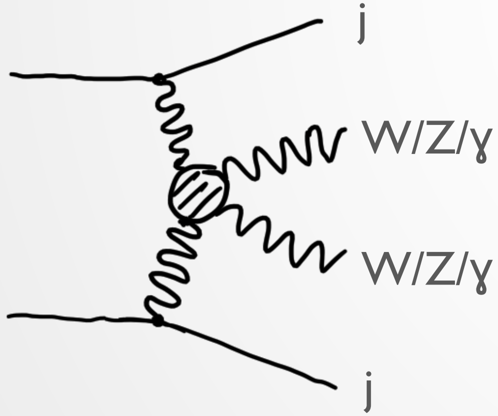
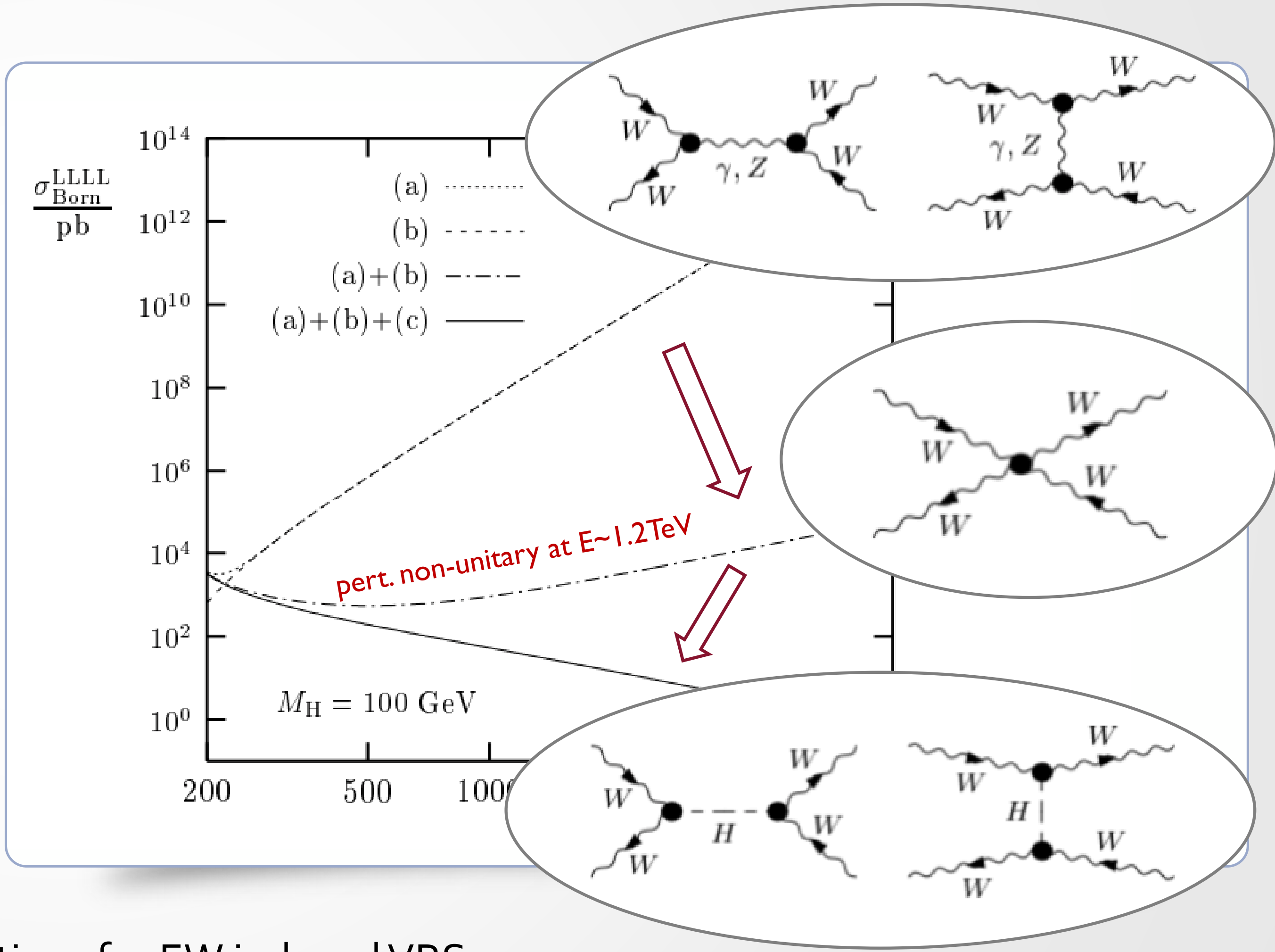
- Higgs observation established that W and Z acquire mass via BEH mechanism
- Vector boson scattering (VBS) is crucial in testing the fundamentals of the BEH
  - pert. non-unitarity for $W_L W_L$ at s~1.2 TeV
- LHC "laboratories": VBS systems

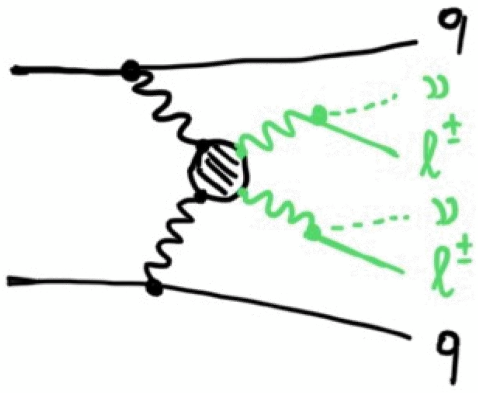




  - 2 jets, large M_{jj}, larger rapidity separation
  - Small deviations lead to large changes in predictions for EW induced VBS

VBS DIBOSON SIGNATURES NOW AND IN THE FUTURE

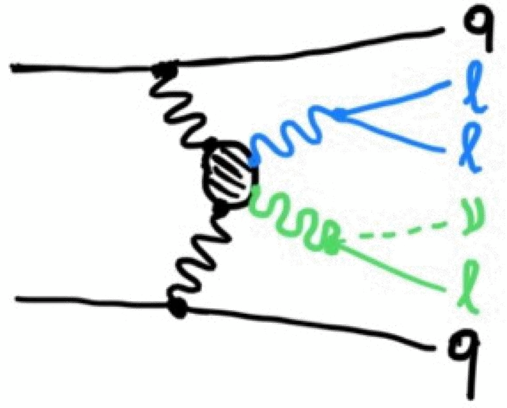
$W^{\pm}W^{\pm}$



[13 TeV] 6.5σ

[13 TeV] 5.7σ

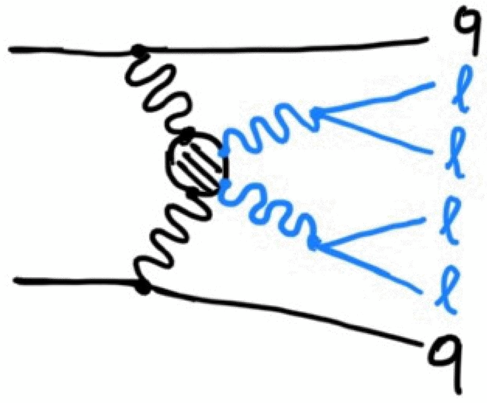
$W^{\pm}Z$



[13 TeV] 5.3σ

[13 TeV] 6.8σ

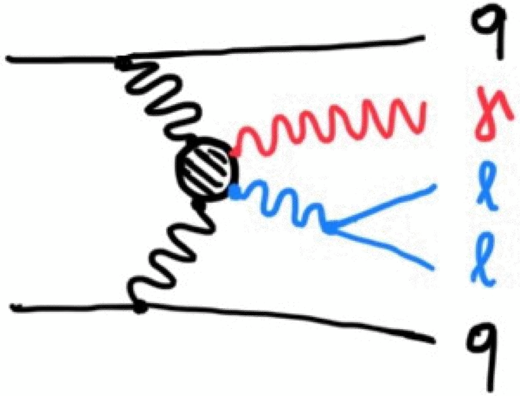
ZZ



[13 TeV] 5.5σ

[13 TeV] 4σ

Zγ

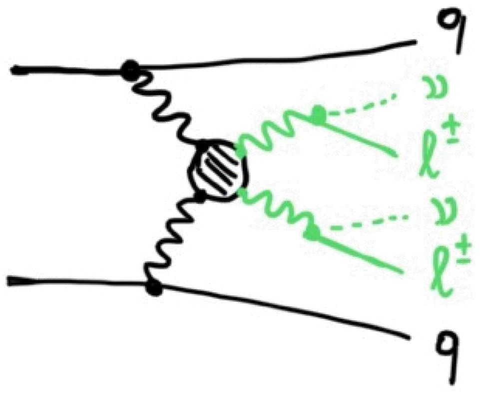


[13 TeV] 4.1σ

[13 TeV] >5σ

VBS DIBOSON SIGNATURES NOW AND IN THE FUTURE

$W^{\pm}W^{\pm}$



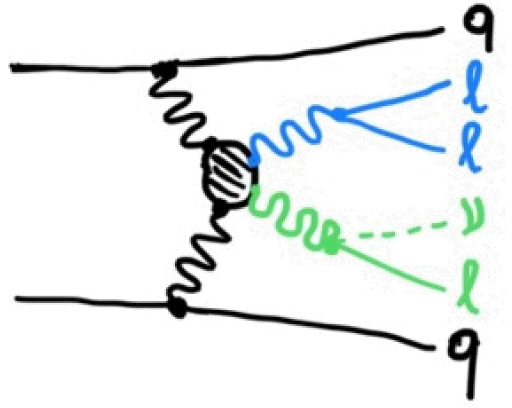
ATLAS [13 TeV] 6.5σ

CMS [13 TeV] 5.7σ

ATLAS [projection]
σ(x-sec) = 6%
$\sigma(W_L W_L)$ = 1.8σ

CMS [projection]
σ(x-sec) = 3%
$\sigma(W_L W_L)$ = 2.7σ

$W^{\pm}Z$



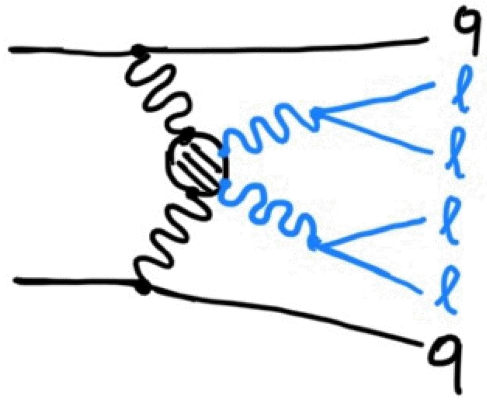
ATLAS [13 TeV] 5.3σ

CMS [13 TeV] 6.8σ

ATLAS [projection]
+27% purity from MVA
ind. pol., $F_0(W^+)$: 2.5σ

CMS [projection]
σ(x-sec)=3%-5%
$W_L Z_L \approx$ 1.5σ

ZZ



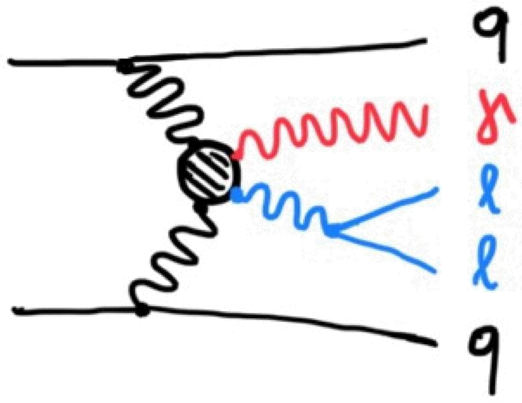
ATLAS [13 TeV] 5.5σ

CMS [13 TeV] 4σ

ATLAS [projection]
σ(x-sec)=20-100%
dep. on σ(ZZjj QCD)
$Z_L Z_L$: 4σ

CMS [projection]
σ(x-sec)≈10%

Zγ



ATLAS [13 TeV] 4.1σ

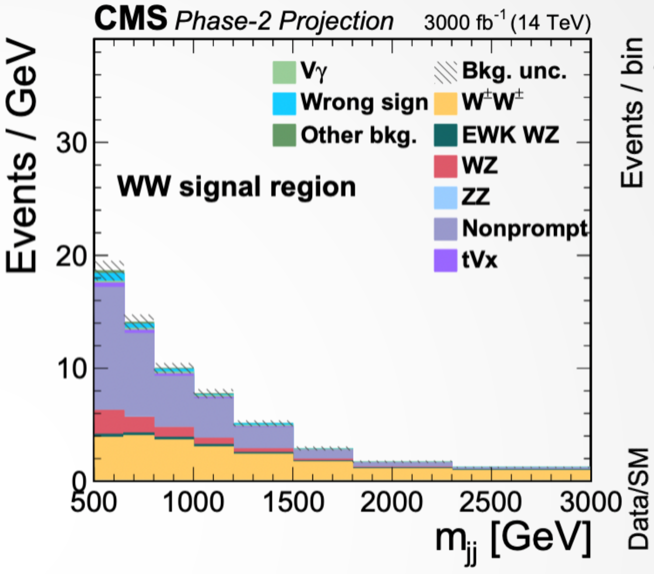
CMS [13 TeV] >5σ

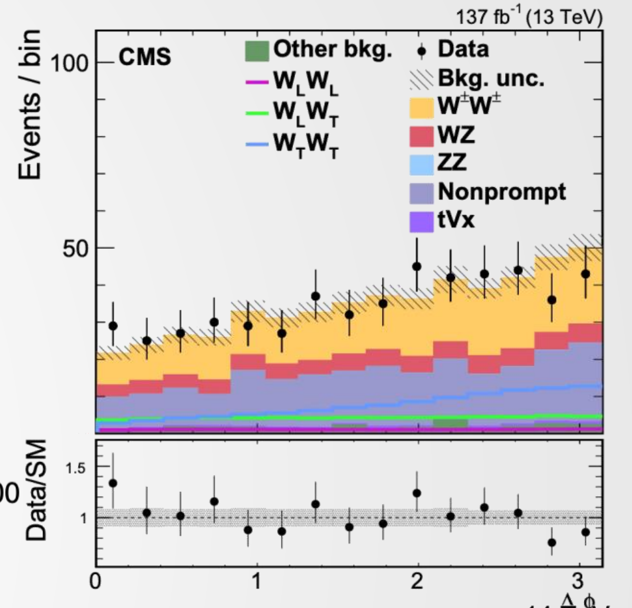
CMS EXTRAPOLATION FOR $W^{\pm}W^{\pm}$ AND WZ

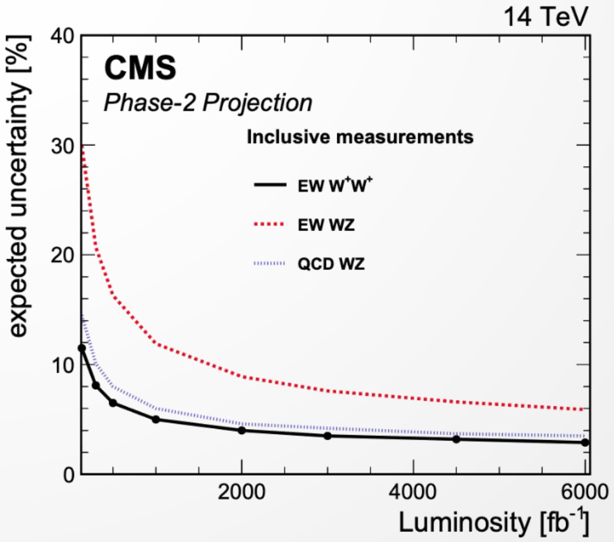
Snowmass CMS [FTR-21-001]

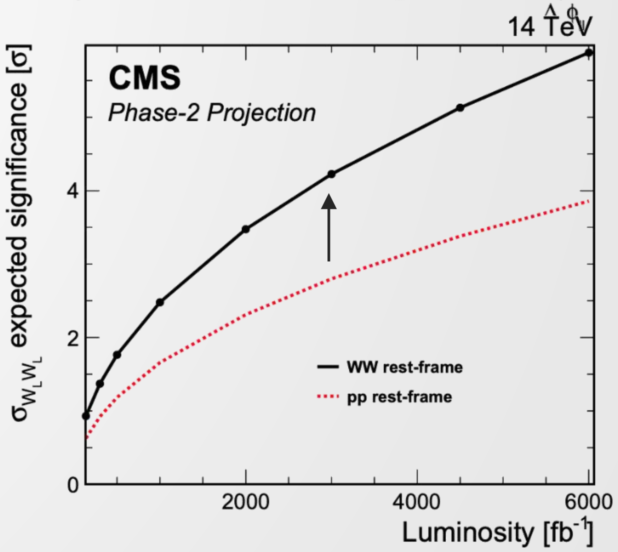
YR [ATLAS-PHYS-PUB-2018-052]

- targets EWK production of $W^{\pm}W^{\pm}$, Run II based
  - same-sign WW: comparably low backgrounds
  - YR study by ATLAS YR [ATLAS-PHYS-PUB-2018-052]
- W_L radiated closer to the quark direction
  - lower p_T and changes in decay angle distributions
  - $W_L^{\pm}W_L^{\pm}$ (10.9%), $W_L^{\pm}W_T^{\pm}$ (31.9%), $W_T^{\pm}W_T^{\pm}$ (57.2%)
- Extrapolation: Follows Run II strategy
  - Fit in BDT discriminants, sensitive to differences in polarized components
- significance of $\sigma_{WLWL} \approx 4\sigma$
  - >5σ in ATLAS combination
  - one of the last LHC discoveries could tackle one of the earliest SM LHC predictions





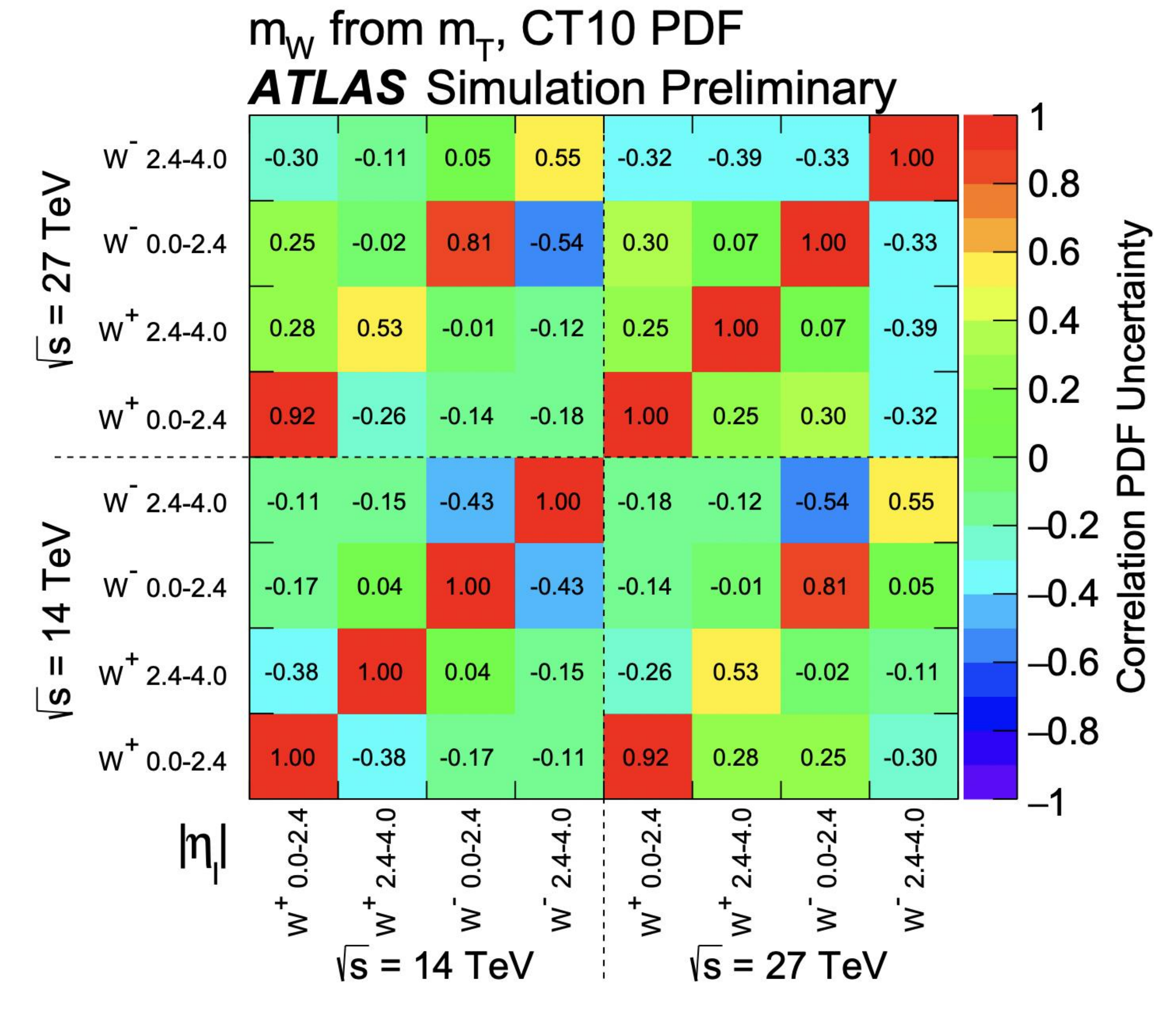




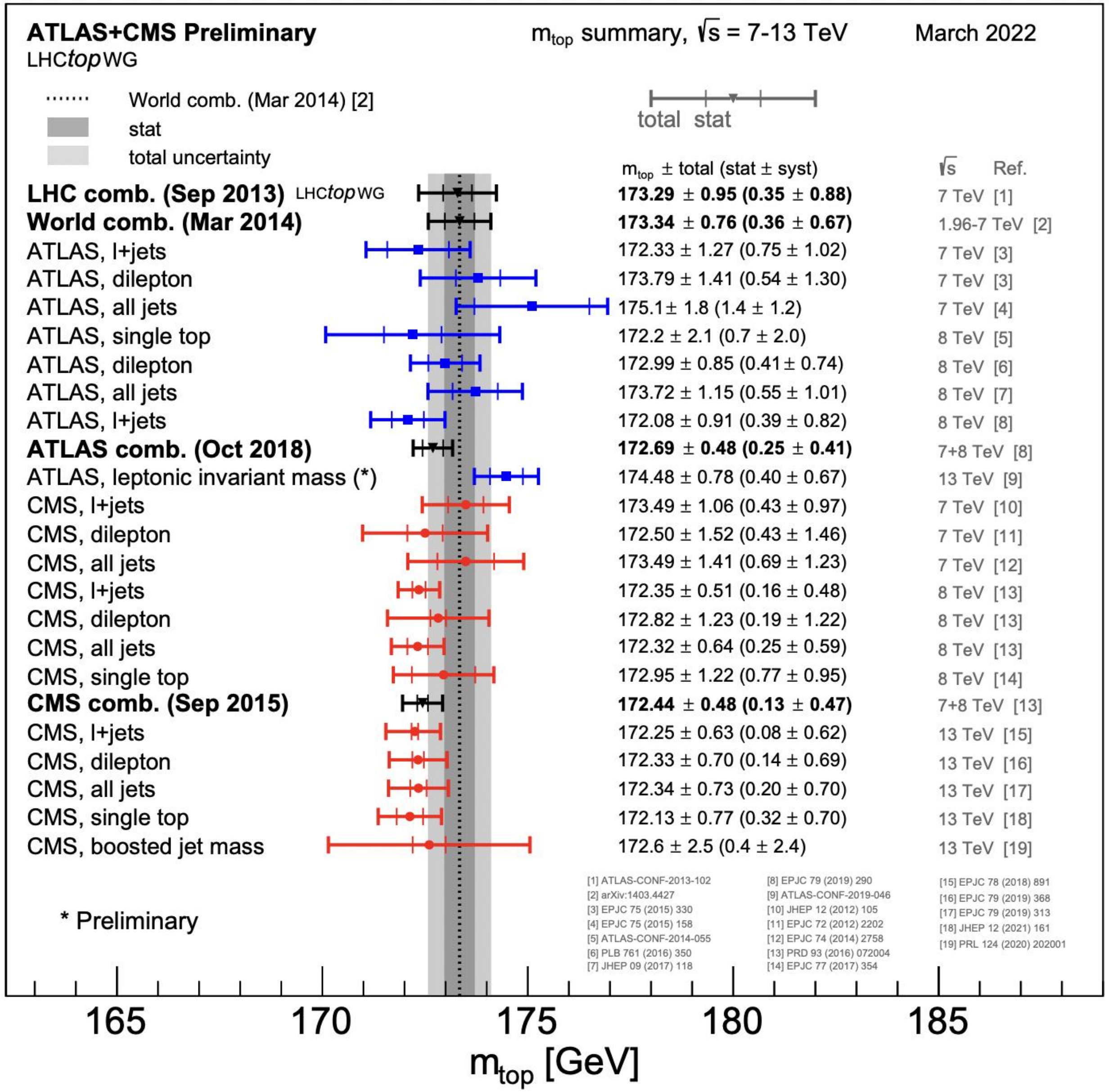
SUMMARY

- With $3ab^{-1}$ HL-LHC will be the workhorse for many years to come
  - We're now convinced that PU140-200 is a challenge we can meet
  - Detector upgrades enlarge the physics scope
  - Highly energetic tails and low-xsec processes pose many sensitive tests of the SM – many of them new
- Improvements on theoretical and modelling uncertainties crucial!
- The value of upgrade studies is to facilitate new ideas!
  - The best is yet to come!

MW UNCERTAINTY CORRELATIONS

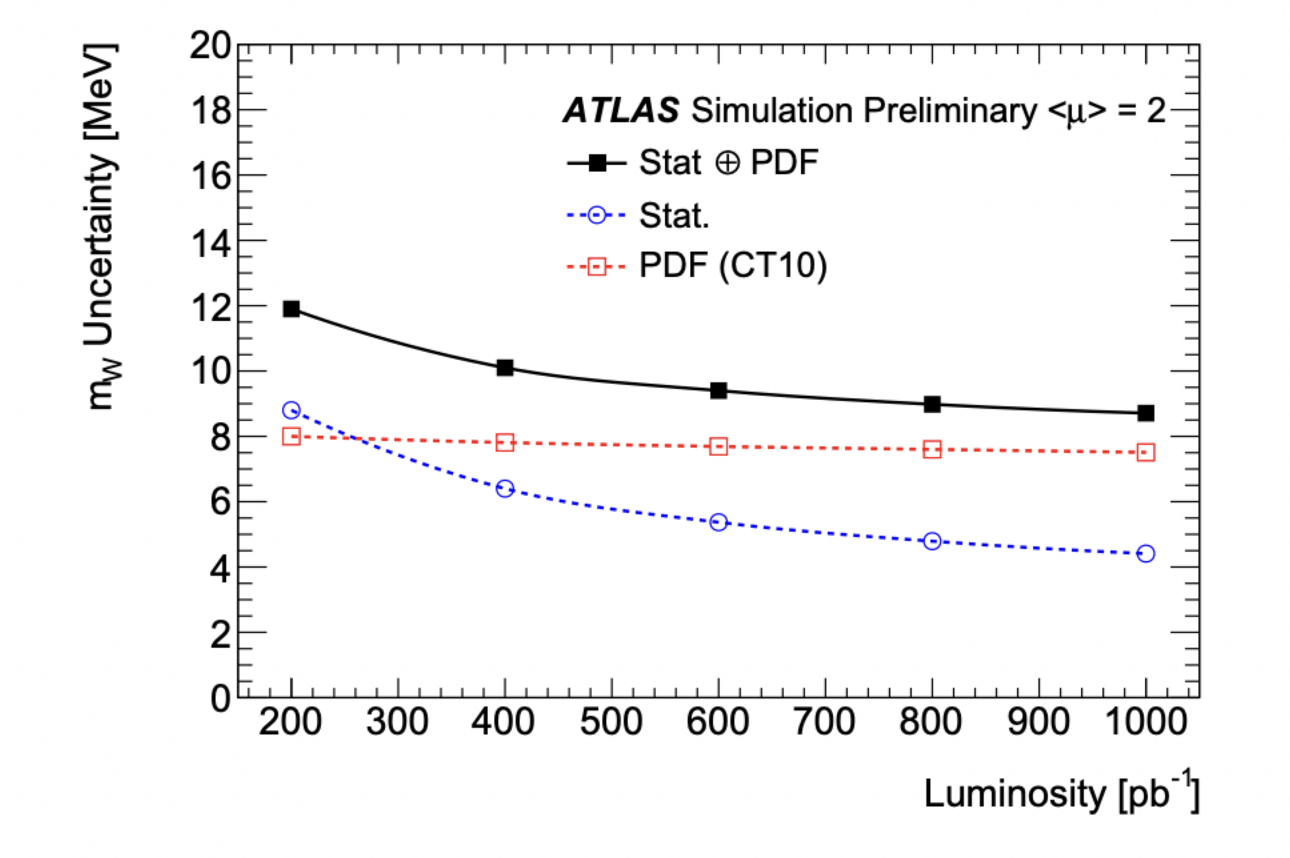


TOP MASS COMBINATIONS (MARCH2022)



M_W UNCERTAINTY EVOLUTION (FULL FIT)

[M_W extrapolation]



UNCERTAINTY DETAILS (TOP MASS)

Source	Value (GeV) 8 TeV, 19.7 fb^{-1}	14 TeV, 0.3 ab^{-1}	14 TeV 3 ab^{-1}	Comment
Method calibration	± 0.04	± 0.02	± 0.02	MC stat. $\times 4$
Lepton energy scale	$+0.01$	± 0.01	± 0.01	unchanged
Global JES	± 0.13	± 0.12	± 0.04	3D fit, differential
★ Flavor-dependent JES	± 0.19	± 0.17	± 0.06	3D fit, differential
Jet energy resolution	-0.03	± 0.02	< 0.01	differential
E_T^{miss} scale	$+0.04$	± 0.04	± 0.04	unchanged
b tagging efficiency	$+0.06$	± 0.03	± 0.03	improved with data
Pileup	-0.04	± 0.04	± 0.04	unchanged
Backgrounds	$+0.03$	± 0.01	± 0.01	cross sections
ME generator	-0.12 ± 0.08	–	–	NLO ME generator
Ren. and fact. scales	-0.09 ± 0.07	± 0.06	± 0.06	NLO ME generator, MC stat.
ME-PS matching	$+0.03 \pm 0.07$	± 0.06	± 0.06	MC stat.
Top quark p_T	$+0.02$	< 0.01	< 0.01	improved with data
b fragmentation	< 0.01	< 0.01	< 0.01	unchanged
Semileptonic b hadron decays	-0.16	± 0.11	± 0.06	improved with data
Underlying event	$+0.08 \pm 0.11$	± 0.14	± 0.09	improved with data, MC stat.
Color reconnection	$+0.01 \pm 0.09$	± 0.05	< 0.01	improved with data
PDF	± 0.04	± 0.03	± 0.02	improved with data
Systematic uncertainty	± 0.48	± 0.30	± 0.17	
Statistical uncertainty	± 0.16	± 0.04	± 0.02	
Total	± 0.51	± 0.31	± 0.17	

COMMON SYSTEMATICS

- Renormalization and factorization scales (includes ME and PS): factor 1/2 (improve with more data and more studies)
- Top pt: factor 1/3 or even less (more differential cross sections, NLO generators, 2D-differential NNLO predictions used for differential k-factors.)
- MC statistics: no uncertainty
- https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCCommonSystematics

Object Efficiency	uncertainty	Recommendation
Muons	muon reco+ID (all WP)	0.1%
	muon reco+ID+isolation (all WP)	0.5%
Electrons/photons	electron reco=ID (incl. isolation), all WP (pt > 20 GeV)	0.5%
	photon reco+ID+incl. isolation)	~2% (?)
tau	tau reco+ID+isolation (all WP)	5% as in Run2
		recommend 2.5% for analyses where tau efficiency is one of the diominant uncertainties
flavor tagging	b-jets (all working points)	~ 1% for 30<pt<300 GeV, 2--6% for pt>300 GeV
	c-jets (all working points)	~2%
	light jets (loose WP)	5%
	light jets (medium WP)	10%
	light jets (tight WP)	15%
	subjet b-tagging	
	double-b tag	
Jets	JES	
	abs. scale	0.1-0.2%
	rel. scale	0.1-0.5%
	Pile up	0-2%
	Jet Flavour	0.75%
	JER	
Jet substructure	Jet mass scale uncertainty	1%
	Jet mass resolution	10%
	W tagging efficiency	10% (governed by Herwig vs Pythia)
Integrated luminosity		1%

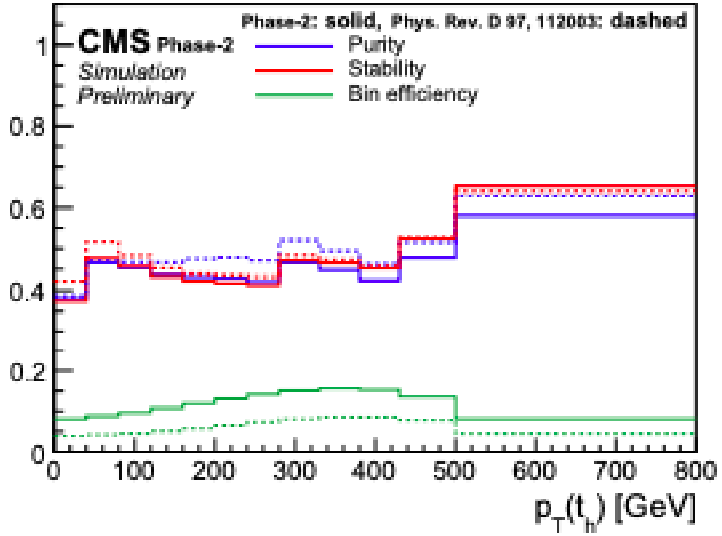


Fig. 70: Expected signal yields (top-left), migration matrices (top-right), and its properties (bottom) for measurements of $p_{\mathrm{T}}(\mathrm{t_h})$ for the HL-LHC (Phase-2) simulation. The purity is defined as the fraction of parton-level top quarks in the same bin at the detector level, the stability as the fraction of detector-level top quarks in the same bin at the parton level, and the bin efficiency as the ratio of the number of events found in a certain bin at detector level and the number of events found at parton-level in the same bin.

CMS $W^{\pm}W^{\pm}$ VBS SELECTION

Table 2: Selection to define the $W^{\pm}W^{\pm}$ and WZ SRs. The looser lepton p_T requirement on the WZ selection refers to the trailing lepton from the Z boson decays. The $|m_{\ell\ell} - m_Z|$ requirement is applied to the dielectron final state only in the $W^{\pm}W^{\pm}$ SR.

Variable	$W^{\pm}W^{\pm}$	WZ
Number of leptons	2	3
p_T^{ℓ}	$> 25/20$ GeV	$> 25/10/20$ GeV
p_T^{j}	> 50 GeV	> 50 GeV
$\lvert m_{\ell\ell} - m_Z \rvert$	> 15 GeV (ee)	< 15 GeV
$m_{\ell\ell}$	> 20 GeV	-
$m_{\ell\ell\ell}$	-	> 100 GeV
p_T^{miss}	> 30 GeV	> 30 GeV
Anti b-tagging	Applied	Applied
τ veto	Applied	Applied
$max(z_{\ell}^{*})$	< 0.75	< 1.0
m_{jj}	> 500 GeV	> 500 GeV
$\lvert \Delta\eta_{jj} \rvert$	> 2.5	> 2.5

CMS $W^{\pm}Z$ VBS SELECTION

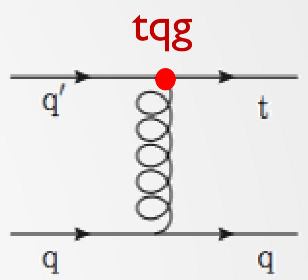
Table 3: Selection to define the nonprompt, WZb, and ZZ CRs. The looser lepton p_T requirement on the WZb CR selection refers to the trailing lepton from the Z boson decays. The $|m_{\ell\ell} - m_Z|$ requirement is applied to the dielectron final state only in the nonprompt CR. The lepton p_T requirements in the ZZ CR are ordered by the p_T values themselves.

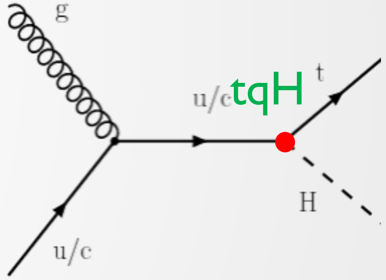
Variable	Nonprompt	WZb	ZZ
Number of leptons	2	3	4
p_T^{ℓ}	$> 25/20\,GeV$	$> 25/10/20\,GeV$	$p_T > 25/20/10/10\,GeV$
p_T^{j}	$> 50\,GeV$	$> 50\,GeV$	$> 50\,GeV$
$\|m_{\ell\ell} - m_Z\|$	$> 15\,GeV$ (ee)	$< 15\,GeV$	$< 15\,GeV$ (both pairs)
$m_{\ell\ell}$	$> 20\,GeV$	-	-
$m_{\ell\ell\ell}$	-	$> 100\,GeV$	-
p_T^{miss}	$> 30\,GeV$	$> 30\,GeV$	-
Anti b-tagging	Inverted	Inverted	-
τ veto	Applied	Applied	-
$max(z_{\ell}^{*})$	< 0.75	< 1.0	< 0.75
m_{jj}	$> 500\,GeV$	$> 500\,GeV$	$> 500\,GeV$
$\|\Delta\eta_{jj}\|$	> 2.5	> 2.5	> 2.5

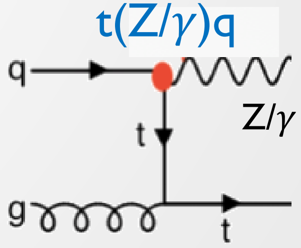
FLAVOR CHANGING NEUTRAL CURRENTS

- FCNC BR suppressed to $10^{-12} - 10^{-15}$ in SM by GIM mechanism
- sensitive probe BSM models (2HDM, SUSY, RPV, …)
- traditionally use anomalous coupling Lagrangian:

$$
\begin{aligned}
\mathcal{L}_{FCNC} = \sum_{q=u,c}\Bigg[& \sqrt{2}g_s \frac{\kappa_{tgq}}{\Lambda}\left(\bar{q}\sigma^{\mu\nu}T^a(f^L_{gq}P_L + f^R_{gq}P_R)t\right) G^a_{\mu\nu} \\
& + \frac{g}{\sqrt{2}}\kappa_{tqH}\left(\bar{q}(f^L_{Hq}P_L + f^R_{Hq}P_R)t\right) H \\
& + e\frac{\kappa_{tq\gamma}}{\Lambda}\left(\bar{q}\sigma^{\mu\nu}(f^L_{\gamma q}P_L + f^R_{\gamma q}P_R)t\right) F_{\mu\nu} \\
& + \frac{g}{\sqrt{2}c_W}\frac{\kappa_{tqZ}}{\Lambda}\left(\bar{q}\sigma^{\mu\nu}(\hat{f}^L_{Zq}P_L + \hat{f}^R_{Zq}P_R)t\right) Z_{\mu\nu} \\
& + \frac{g}{4c_W}\zeta_{tqZ}\left(\bar{q}\gamma^{\mu}(\bar{f}^L_{Zq}P_L + \bar{f}^R_{Zq}P_R)t\right) Z_{\mu}\Bigg] + \text{h.c.}
\end{aligned}
$$





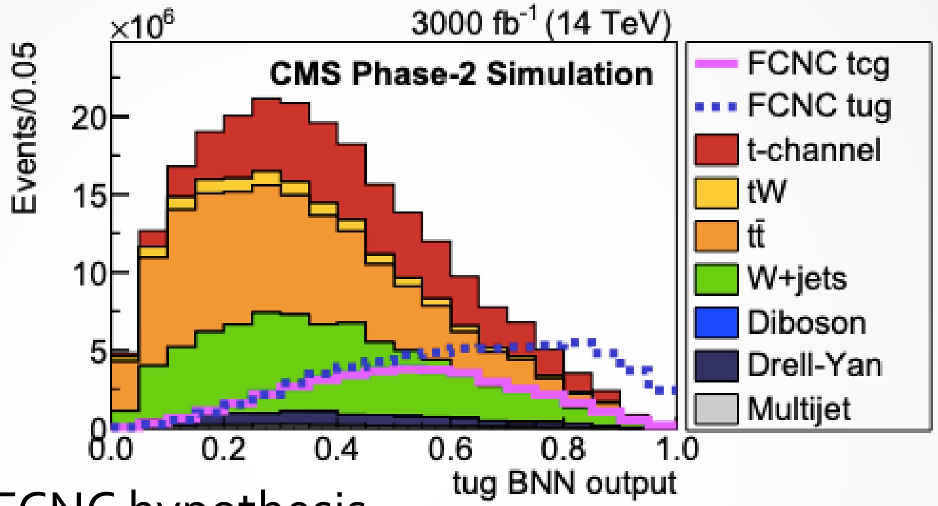


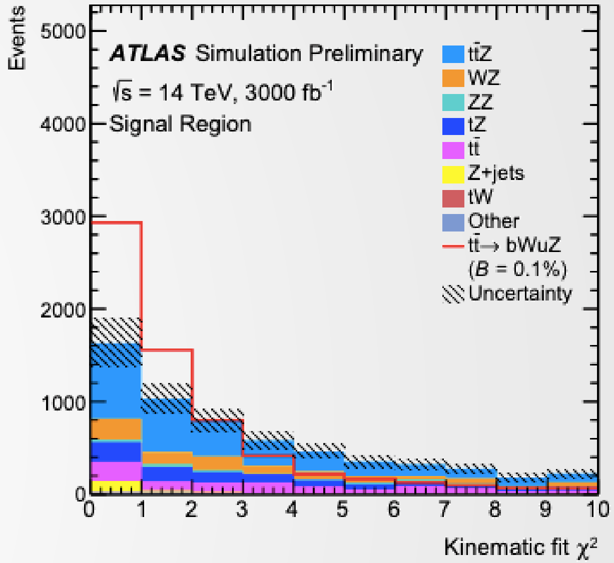
- In practice, often simplify chiral structure, e.g. $f^R = 1$
- q = u,c with more sensitivity to u (higher x-sec)

ATLAS AND CMS ON FCNC

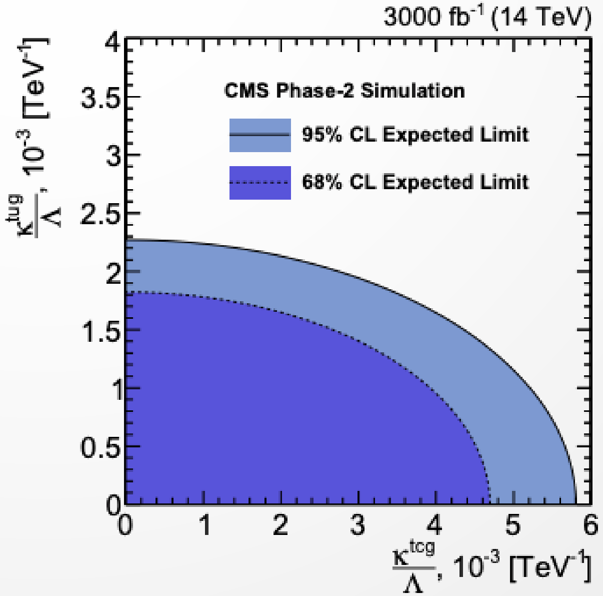
ATL-PHYS-PUB-2019-001, CMS-PAS-FTR-18-004

- Comprehensive studies by ATLAS (tZq) and CMS (tqg)
- Both simulate dedicated signal and background samples and follow the Run-II startegies
- CMS uses BNN on kinematic input
- ATLAS uses χ^2 constructed under FCNC hypothesis
- Improvement typically one order of magnitude





$\mathcal{B}$ limit at 95%C.L.	HL-LHC 3 ab^{-1}, 14 TeV	HE-LHC 15ab^{-1}, 27 TeV	Run-II (36/fb)
$t \to gu$	3.8×10^{-6}	5.6×10^{-7}	2 x 10^{-5}
$t \to gc$	32.1×10^{-6}	19.1×10^{-7}	4 x 10^{-4}
$t \to Zq$	$2.4 - 5.8 \times 10^{-5}$		1.7-2.4 x 10^{-4}
$t \to \gamma u$	8.6×10^{-6}		1.3 10^{-4}
$t \to \gamma c$	7.4×10^{-5}		2.0 10^{-3}
$t \to Hq$	10^{-4}		1.1 10^{-3}



- SM-EFT limits:

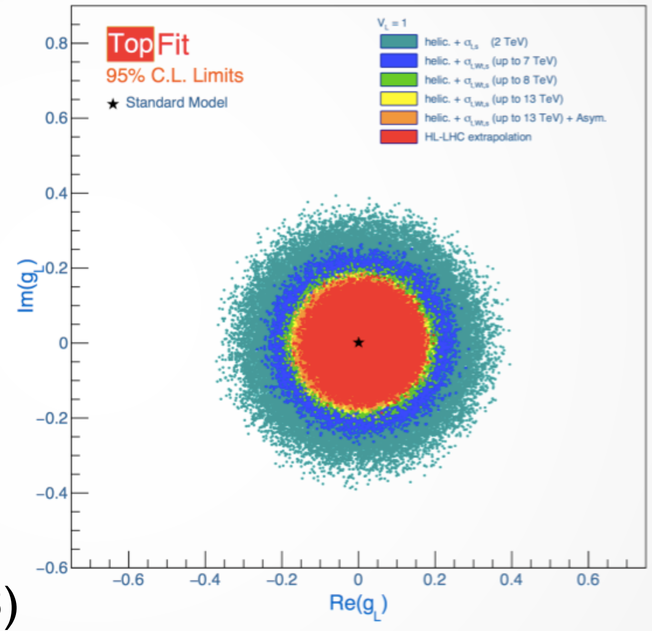
Operator	Expected limit
$\|C_{uB}^{(31)}\|$	0.13
$\|C_{uW}^{(31)}\|$	0.13
$\|C_{uB}^{(32)}\|$	0.14
$\|C_{uW}^{(32)}\|$	0.14

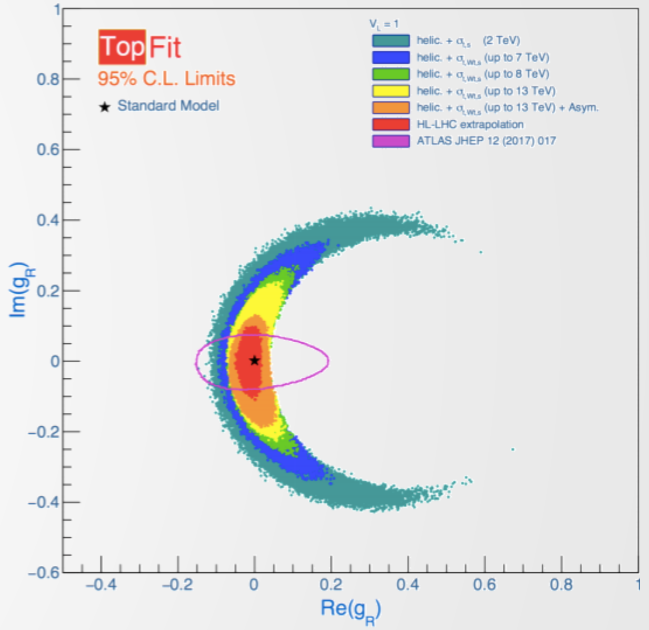
TOP-W COUPLING

arXiv:1811.02492

- W boson helicity measurements, asymmetries and single top production are able to constrain potential anomalous Wtb couplings:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-} + \text{h.c.}$$



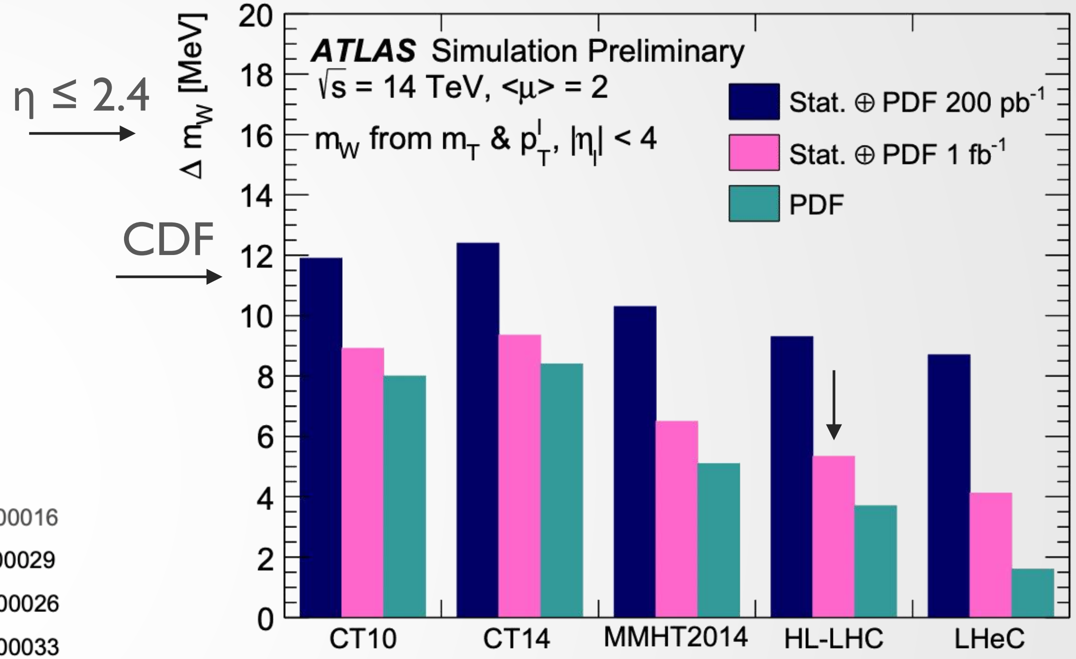


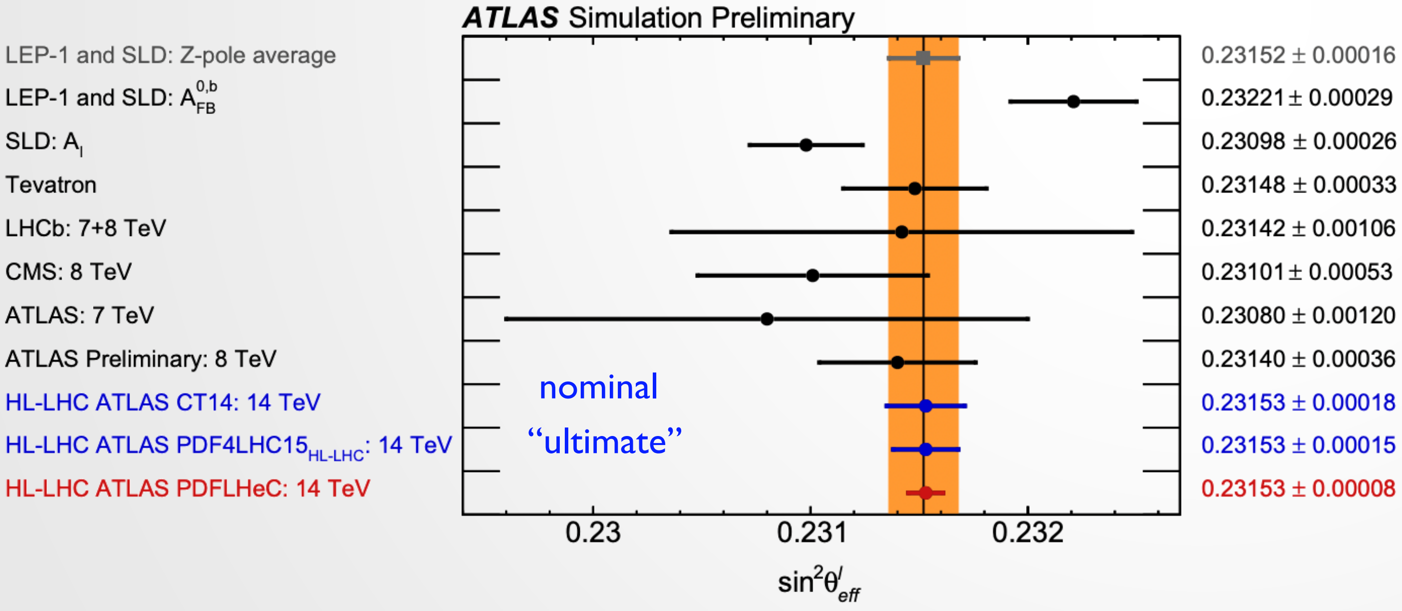
- comprehensive list of measurements
  - W boson helicity from Tevatron & LHC (8 TeV)
  - A_{FB} from LHC (8 TeV)
  - single top x-sec from Tevatron and LHC (7/8/13)
- Extrapolate to 3/ab & include scaled results
  - Reconstruction level uncertainties were kept (b-tagging was divided by two)

HL-LHC	g_R	g_L	V_R
Allowed Region (Re)	[-0.05 , 0.02]	[-0.17 , 0.19]	[-0.28 , 0.32]
Allowed Region (Im)	[-0.11 , 0.10]	[-0.19 , 0.18]	[-0.30 , 0.30]

$SIN^2\theta_{EFF}$ AND THE MASS OF THE W BOSON [PHYS-PUB-2018-026] [PHYS-PUB-2018-037]

- tackle important discrepancies, profit from ITk at $|\eta| \leq 4$
  - $Sin^2\theta_{eff}$ di-electron Drell-Yan events
  - fitting rapidity dependence of A_{FB} and $m(\ell\ell)$
  - Benefit from $\eta \sim 4$ extension of the ATLAS Itk upgrade
  - Can resolve LEP/SLD disagreement with similar precision





- M_W: dedicated low-PU runs @ $<\mu> \approx 2$
- Combine m_T, $p_T(\ell)$ fits
- "HL-LHC" incorporates future constraints

CMS AND ATLAS SPIN CORRELATION

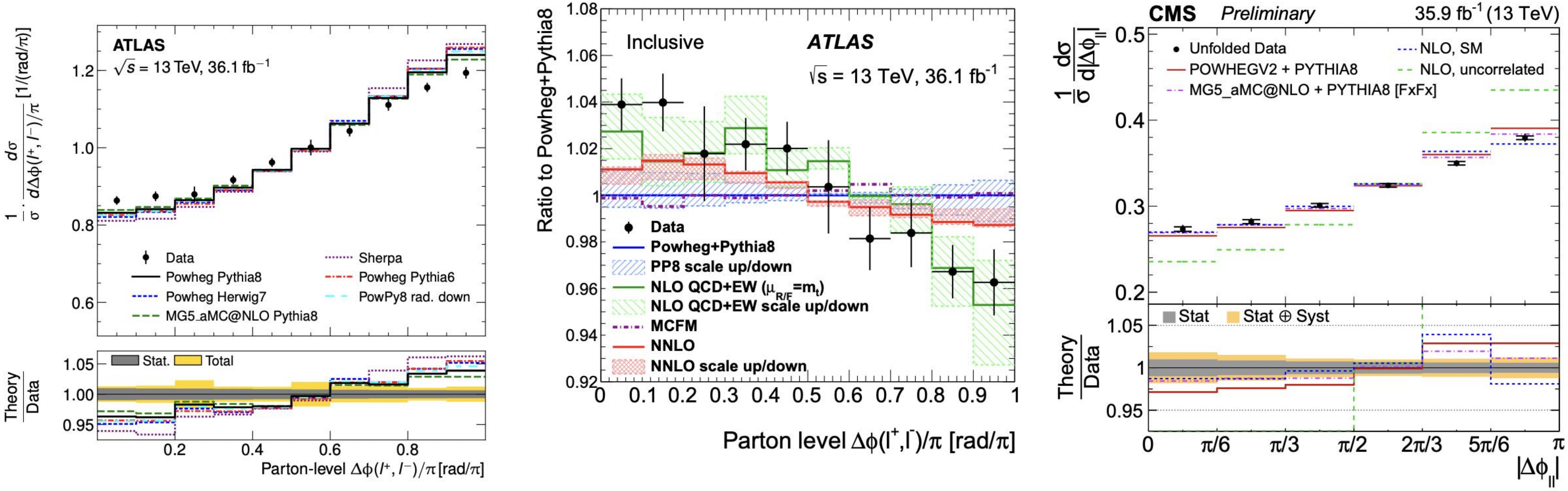


Figure 1 – Parton-level $|\Delta\phi_{\ell\ell}|$ distributions measured by ATLAS [7] (left) and CMS [8] (right), compared with various predictions. In the centre, the ATLAS measurement is compared with fixed-order calculations [3,11].