Experimental SM and Higgs Physics at LHC

Lecture 2

Associated and multi- Vector boson production, and top quark

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Outline

Experimental SM and Higgs Physics at LHC

Lecture 1*: Basic Concepts, the LHC and precision measurements with Drell-Yan W and Z processes.*

Lecture 2*: Associated and multi- Vector boson production, and top quark*

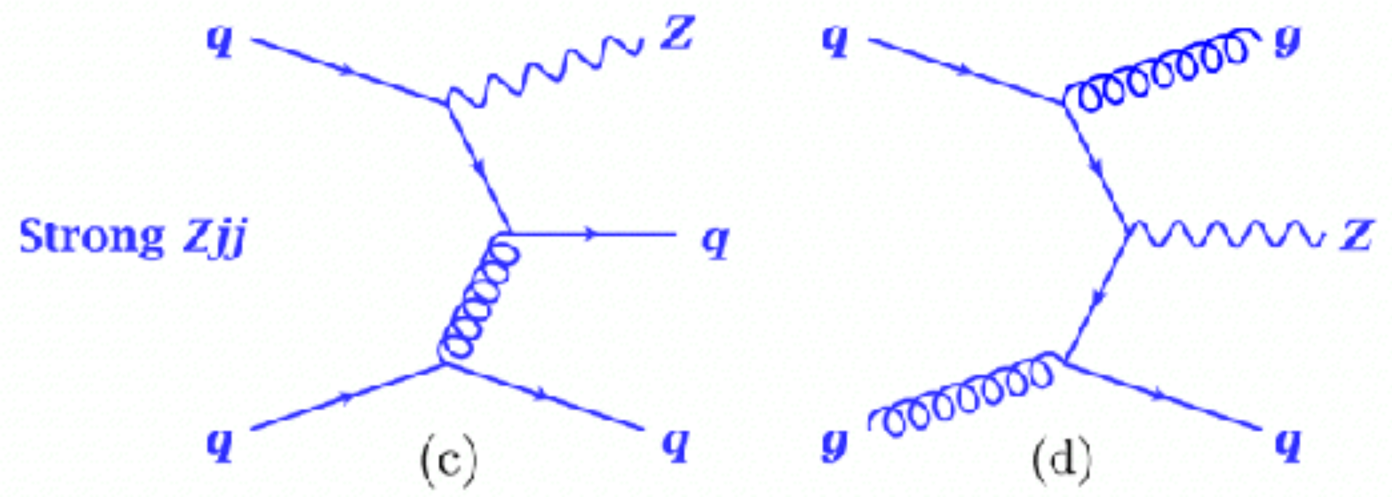
Lecture 3*: Higgs Physics*

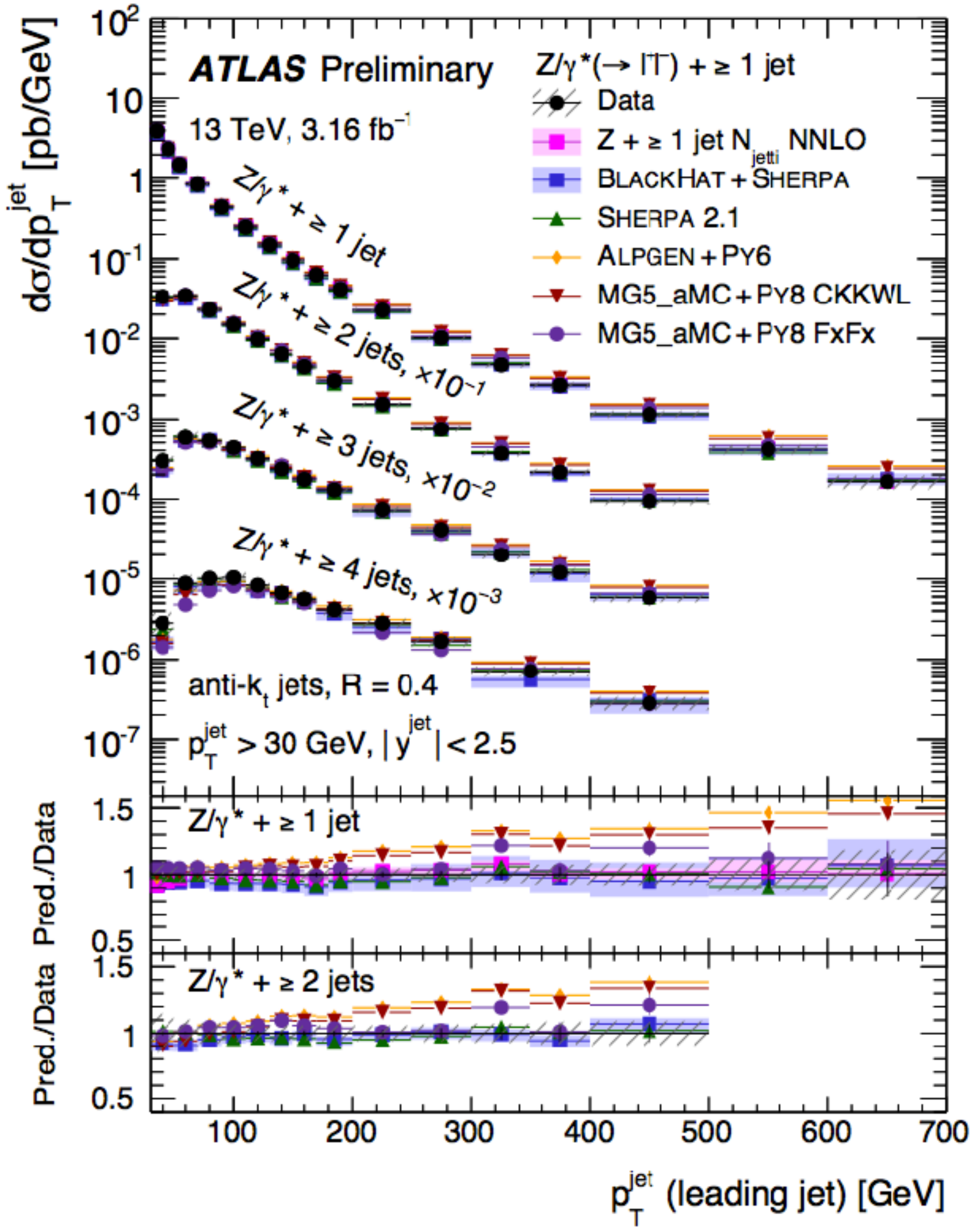
Lecture 4: *More Higgs Physics and Global interpretation*

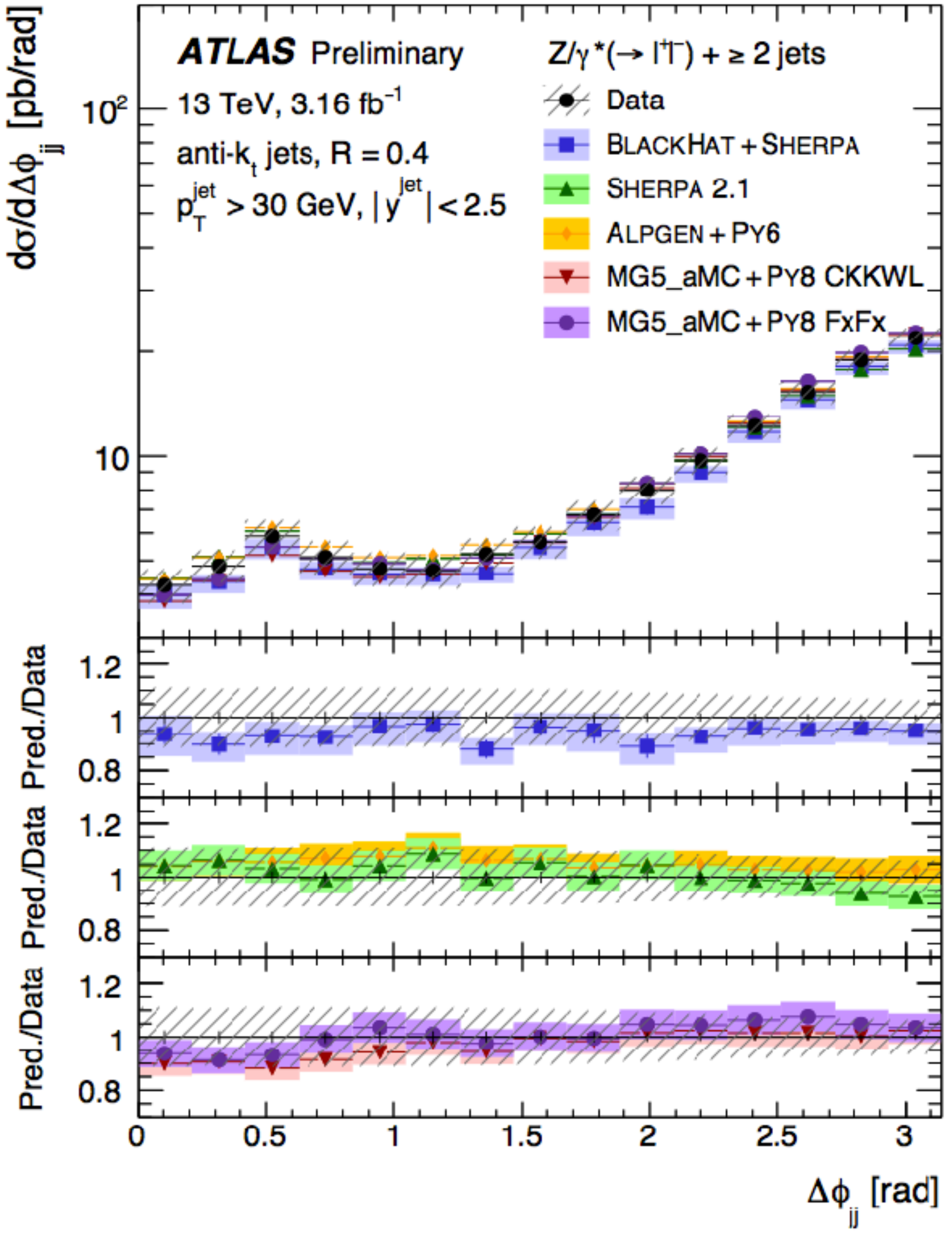
- **Disclaimer:** These lectures will be focused mostly on ATLAS and CMS (LHCb covered by Marco Gersabeck and QCD and jet physics covered by Peter Uwer)
- **Excellent resources for keeping up-to-date with the latest results**: Physics Briefings from ATLAS and CMS.

Vector Boson Production with Jets

QCD Vector boson and Jets







Vector boson production

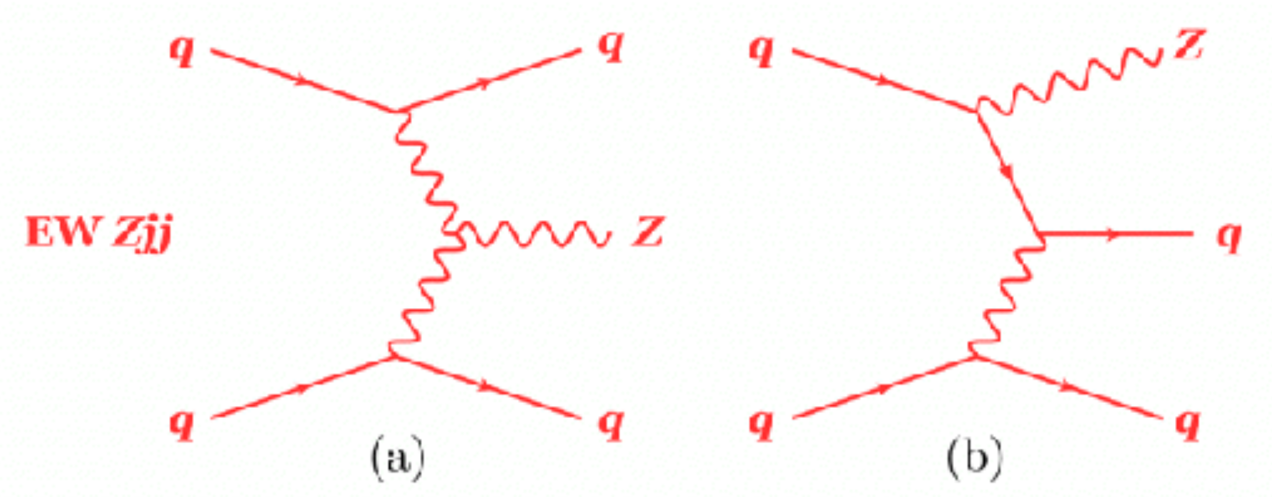
Probing state-of-the-art Monte Carlos

Essential ingredient (**ancillary**) of a number of searches and measurements (EW, top and Higgs physics in particular)!

Huge amount of work gone into further improving and tuning the MC modelling)!

Level of sophistication made generation times large (in some very specific cases even larger than simulation)

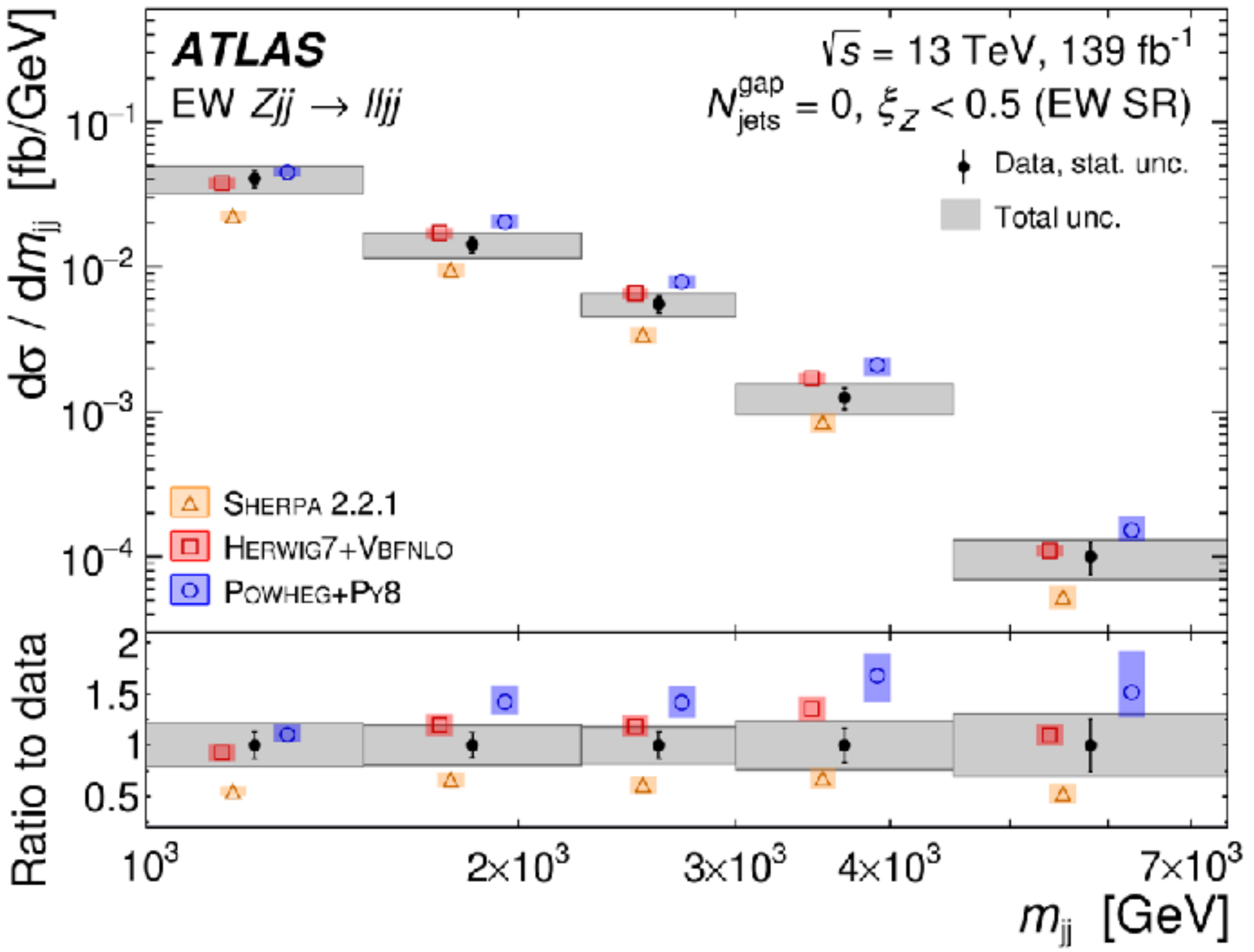
EW Vector boson and Jets

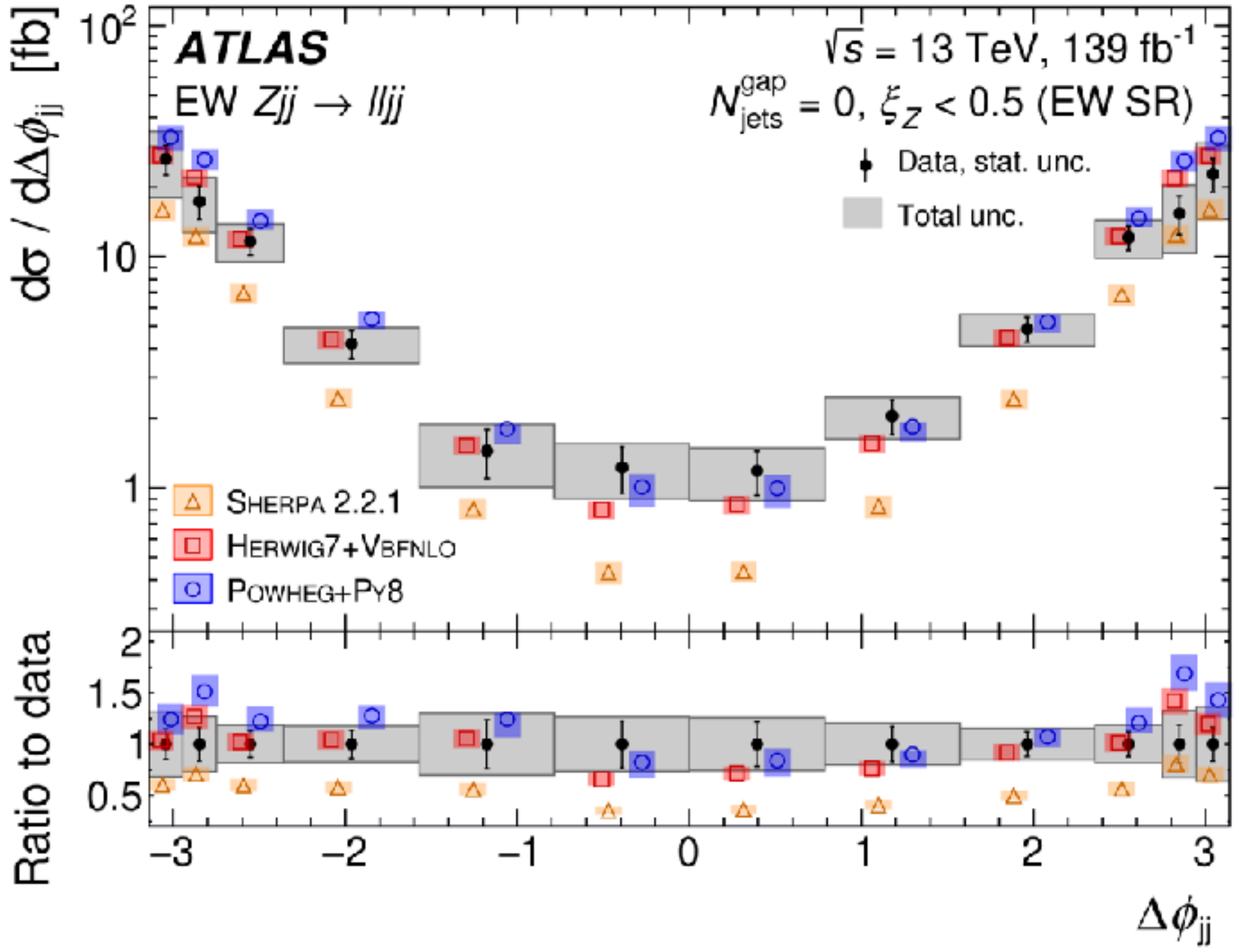


EW Vector boson production
Non trivial to isolate from QCD production

Essential ingredient for our understanding of color singlet EW production with forward tagging jets and **Central Jet Veto.**

Jet veto: no additional jet > 25 GeV





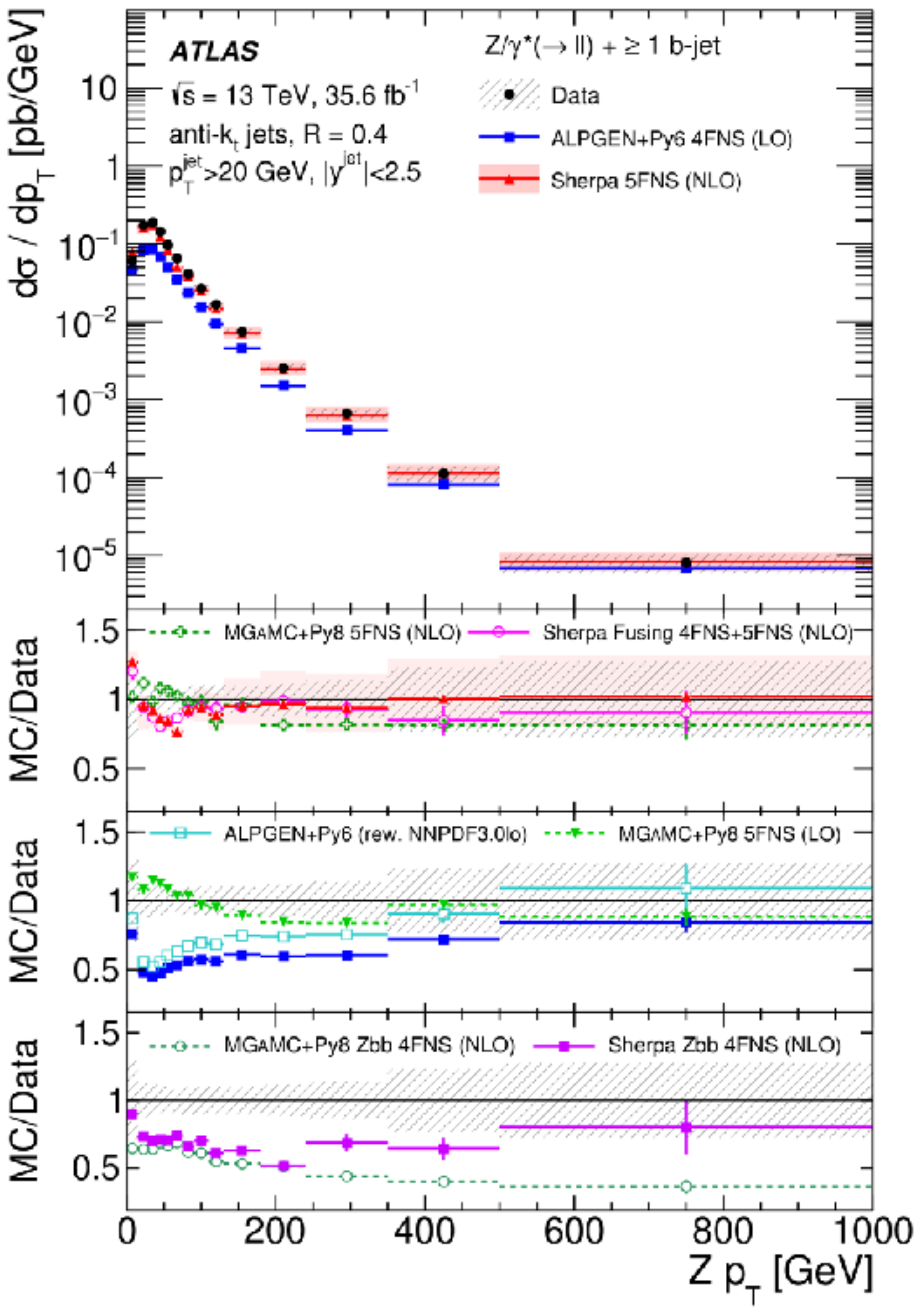
See paper

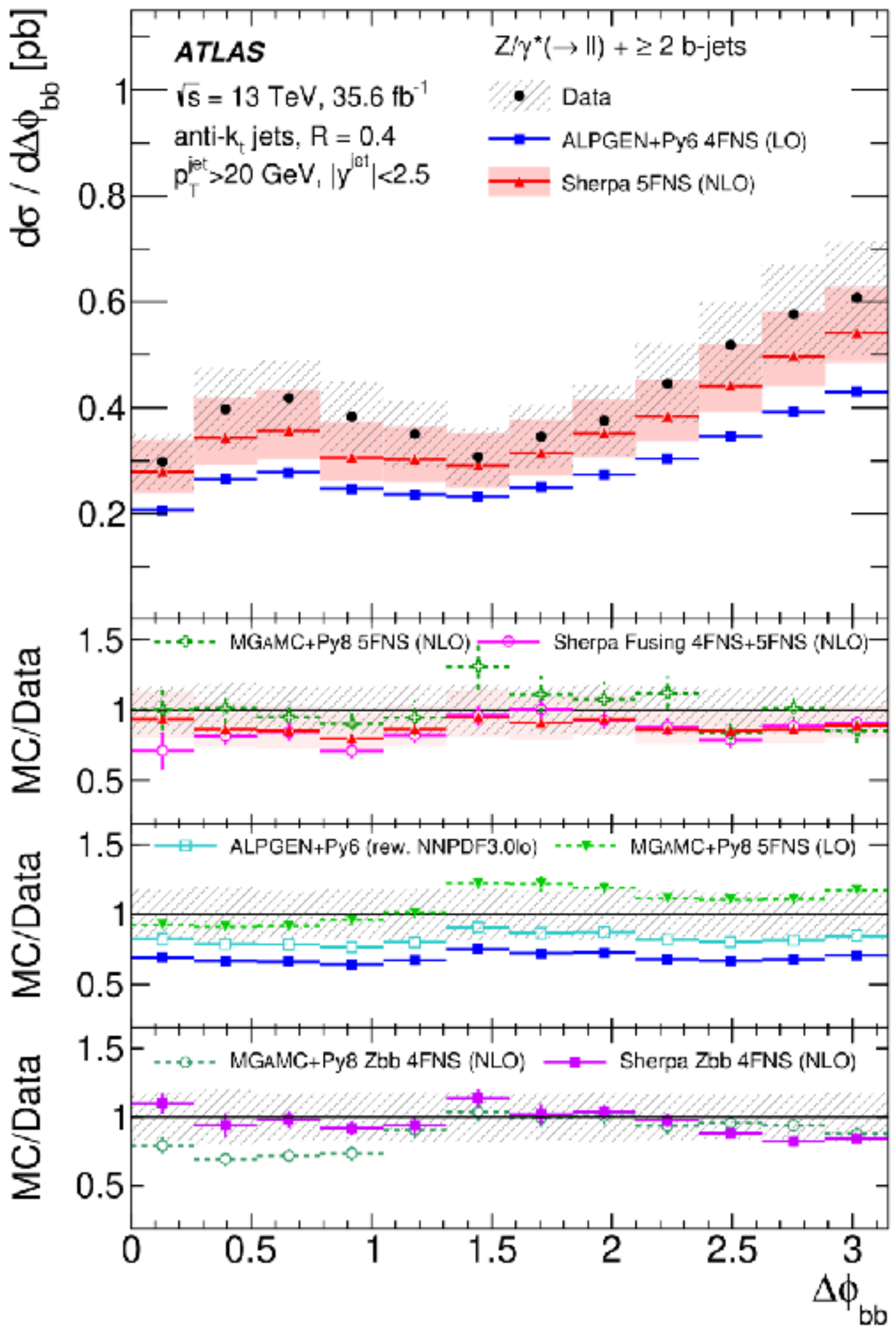
Z boson and 1 or 2 b-jets

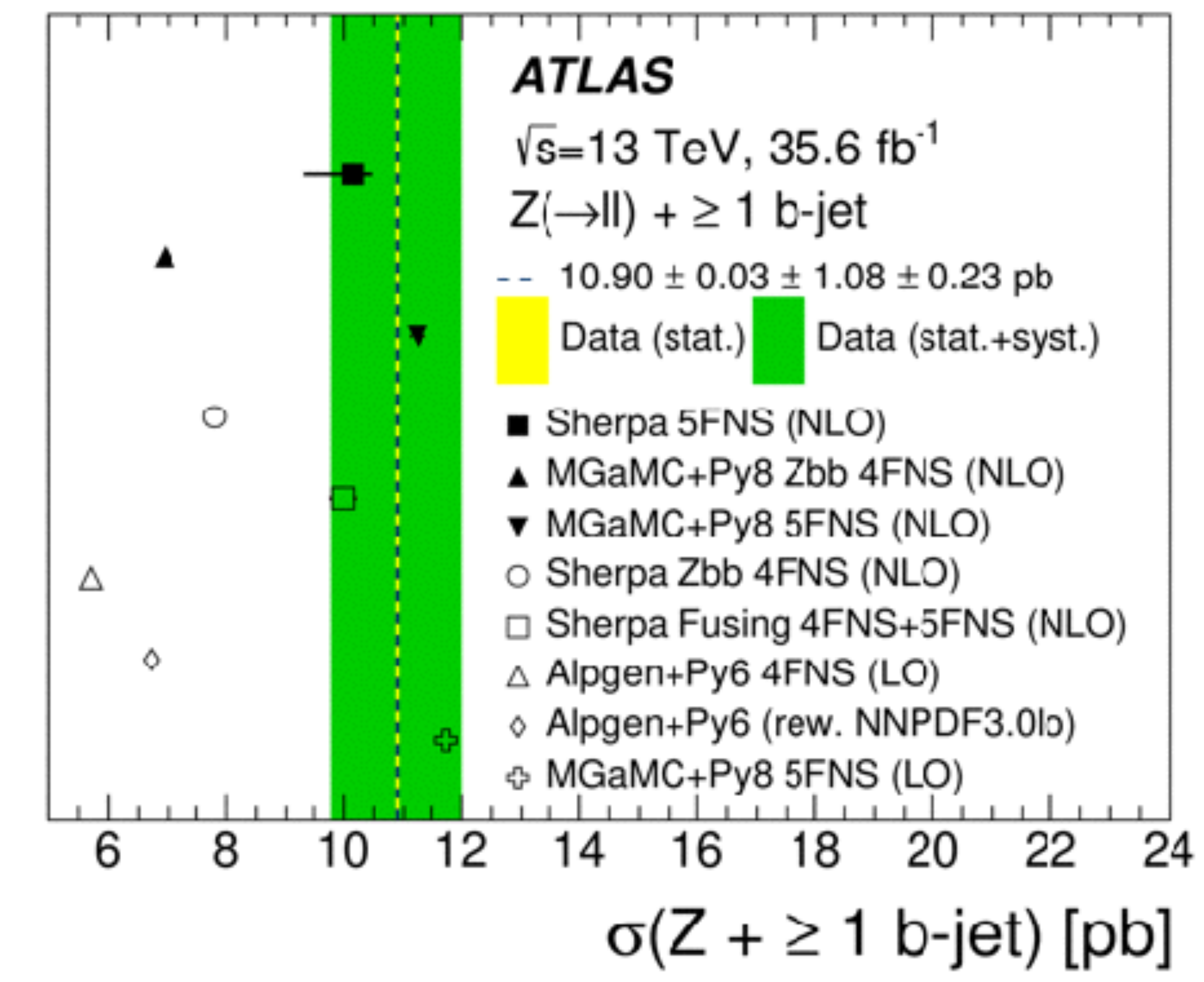
Z boson production with b-jets

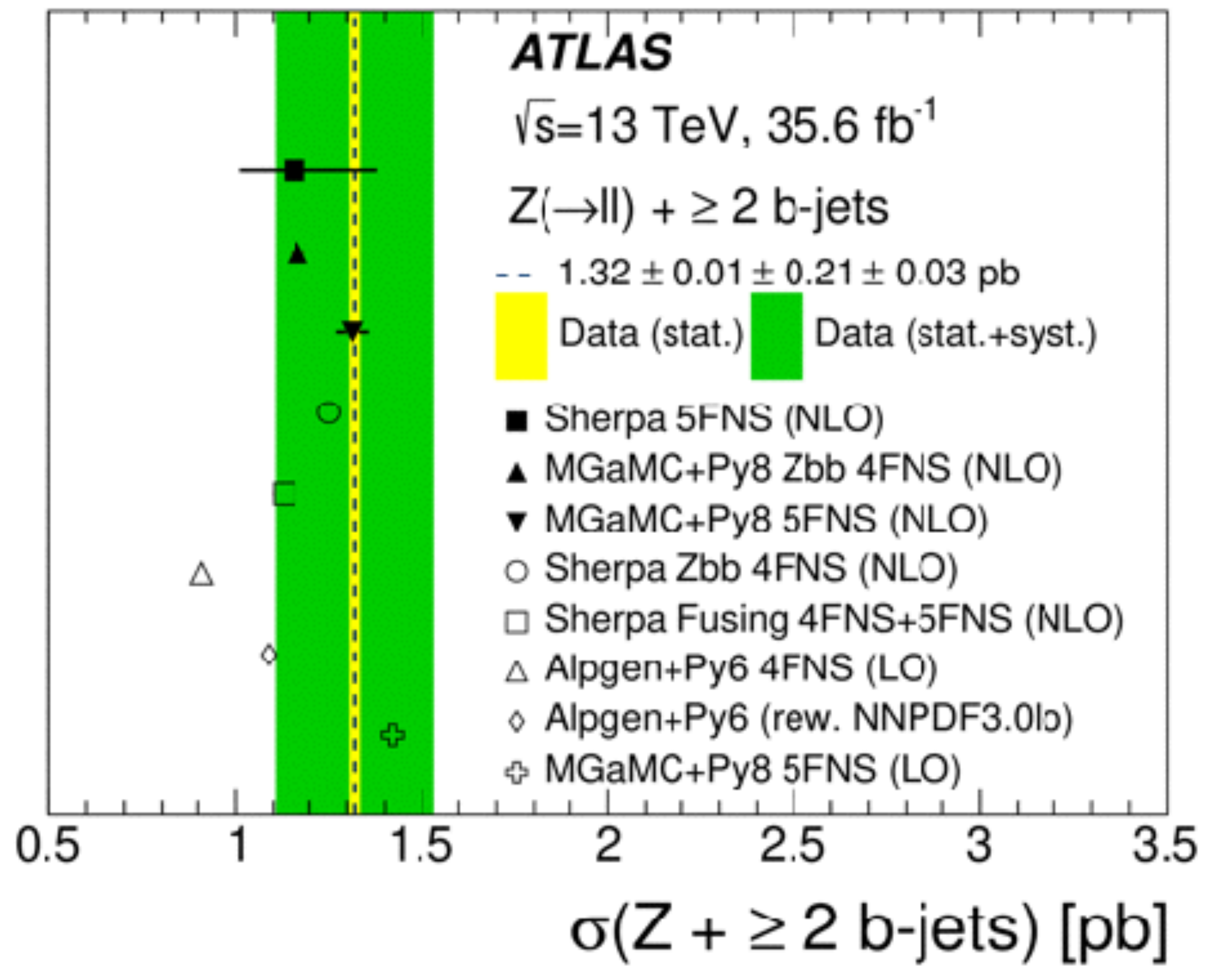
Essential background in the Higgs to b quarks measurements

2003.11960





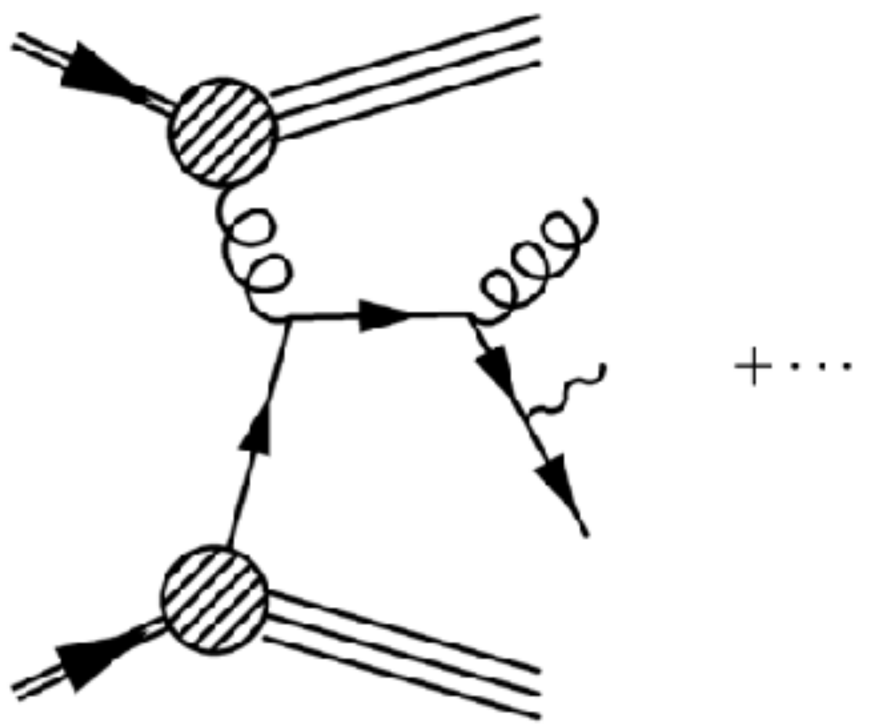




Multi boson production

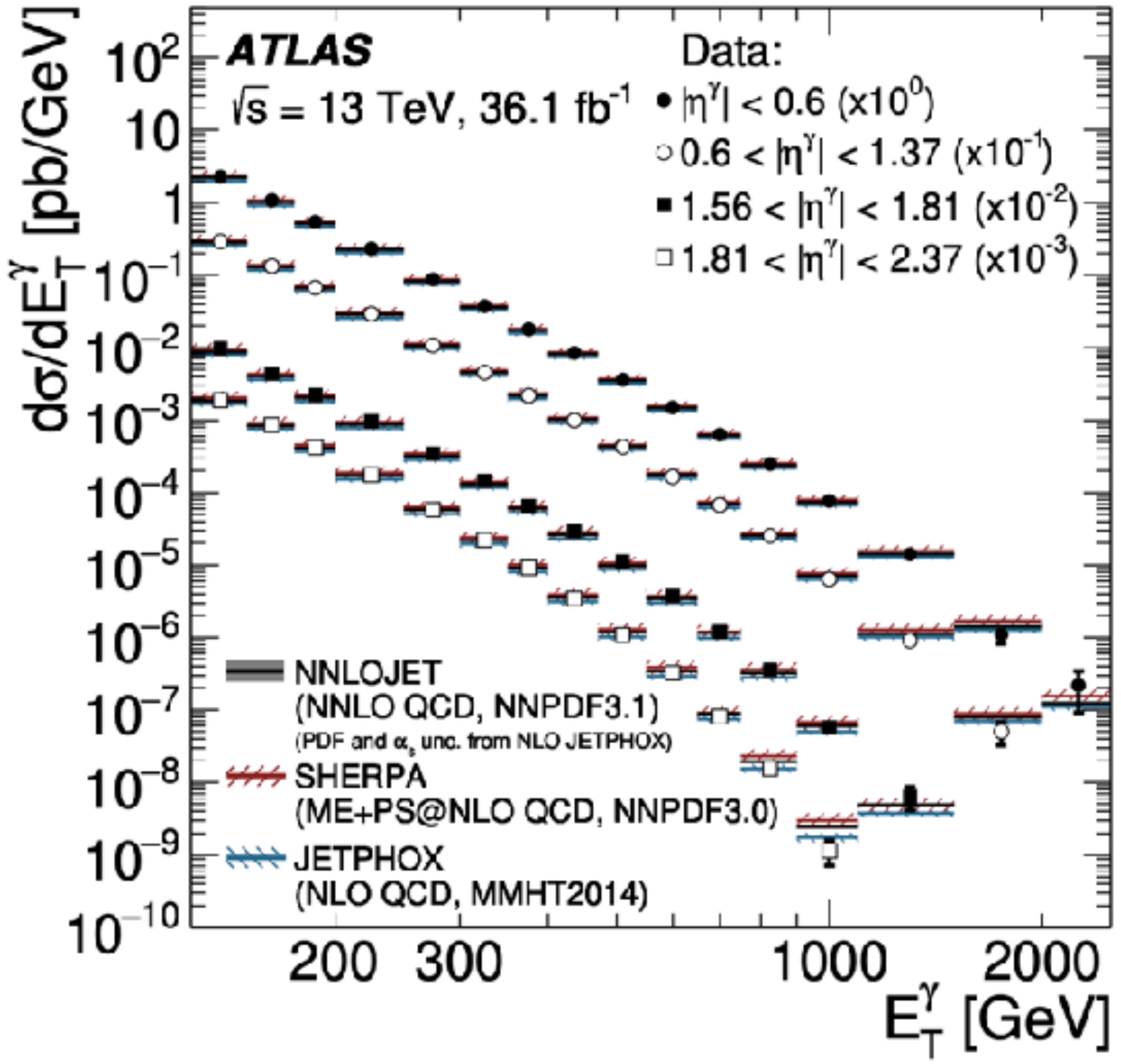
Photon-jet Production

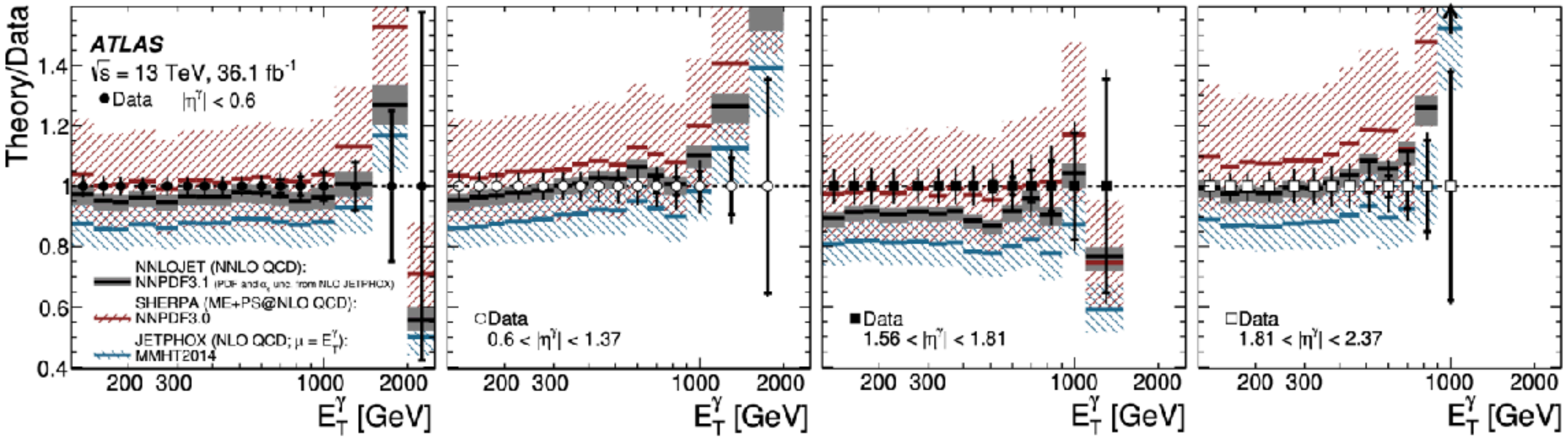
Photon-jet production is the largest reducible background in the measurements of the Higgs boson decays to two photons and is sensitive to gluon PDF!



Intricate process where the photon emission can be at parton level in the ME element or in the parton fragmentation.

The ME photon emission has a collinear divergence that can be eliminated by the Frixione isolation (used in Sherpa NLO QCD and in NNLOJET). The JetPhox Fixed Order TH calculation has a consistent calculation of cone isolation including the fragmentation component.

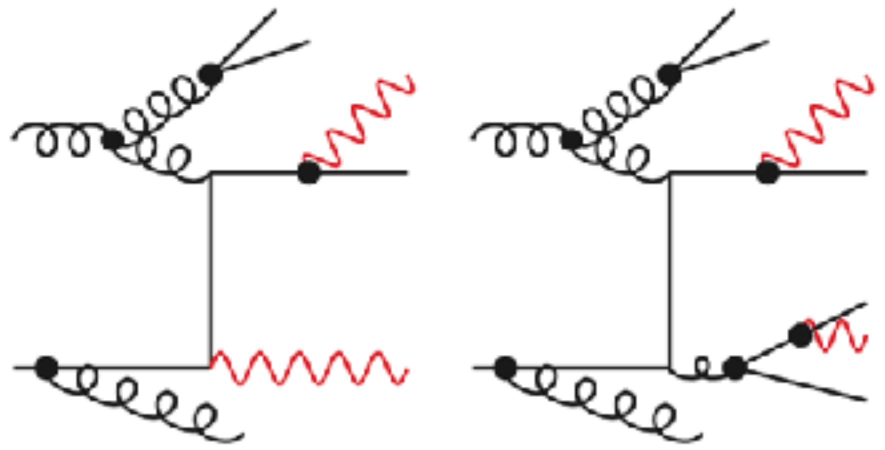




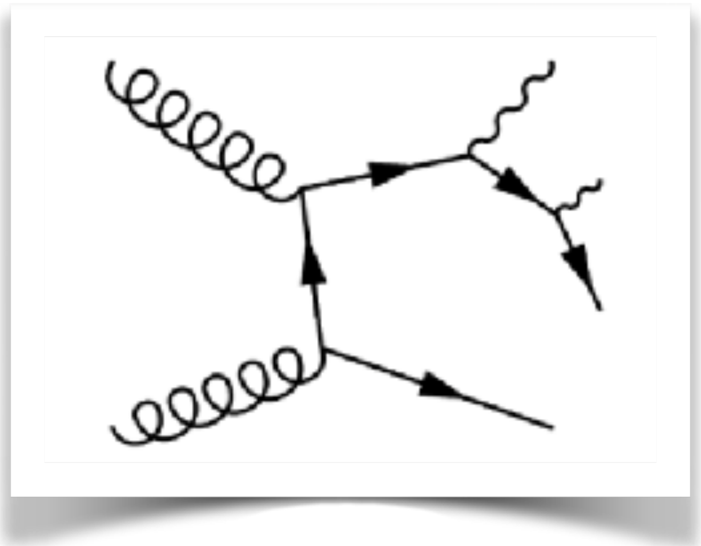
NLO descriptions already quite good, NNLO provides a significant improvement!

Diphoton Production Cross Section

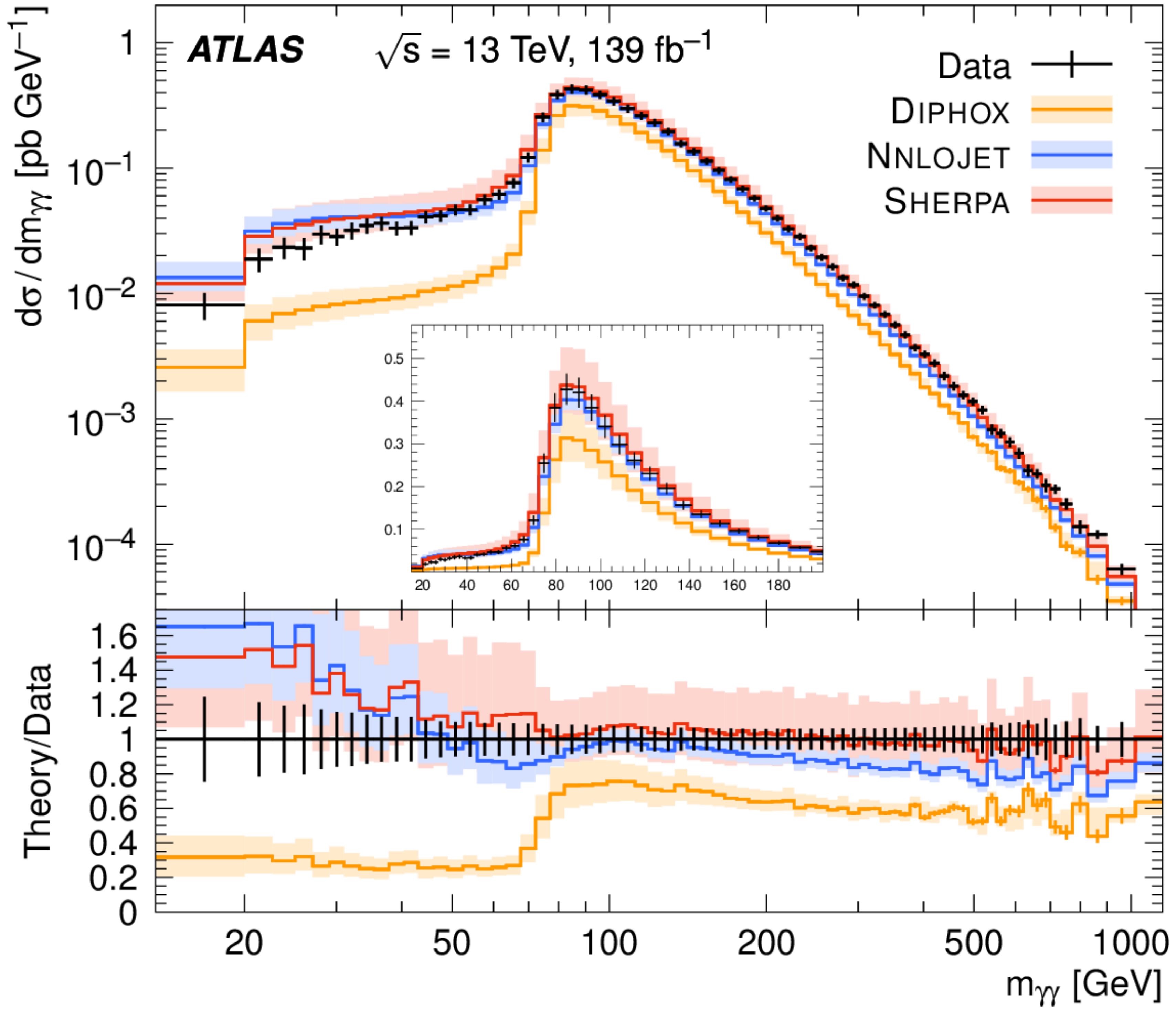
Measuring diphoton production is not only an electromagnetic process also non trivial strong dynamics!

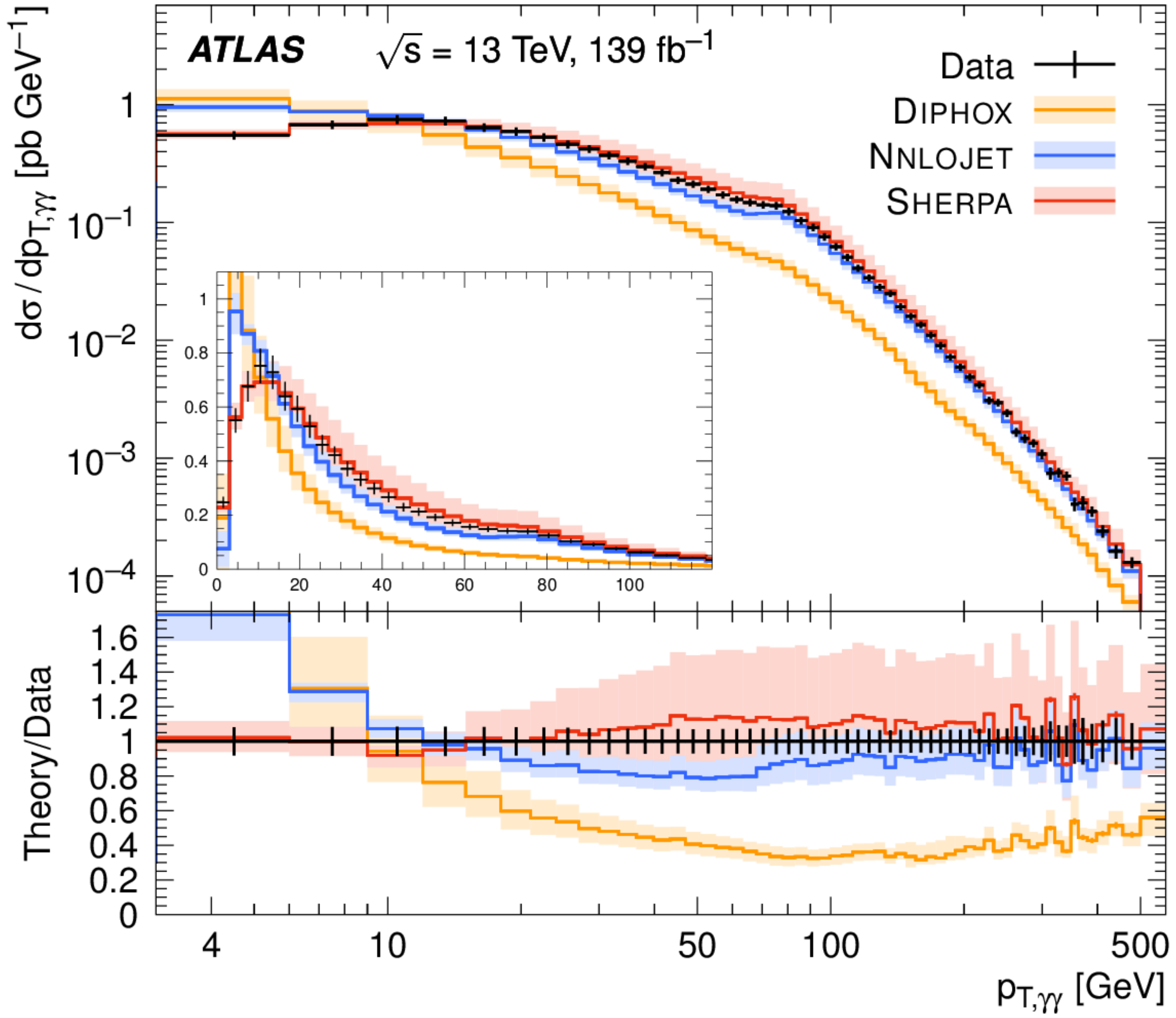


Estimate of PU events with two $\gamma - jet$ events in same bunch crossing (estimated using photon conversions)



Intricate effects as peak in $p_{T,\gamma\gamma}$ from double emission and kinematic cuts $p_{T,\gamma_1(\gamma_2)} > 40\,(30)$



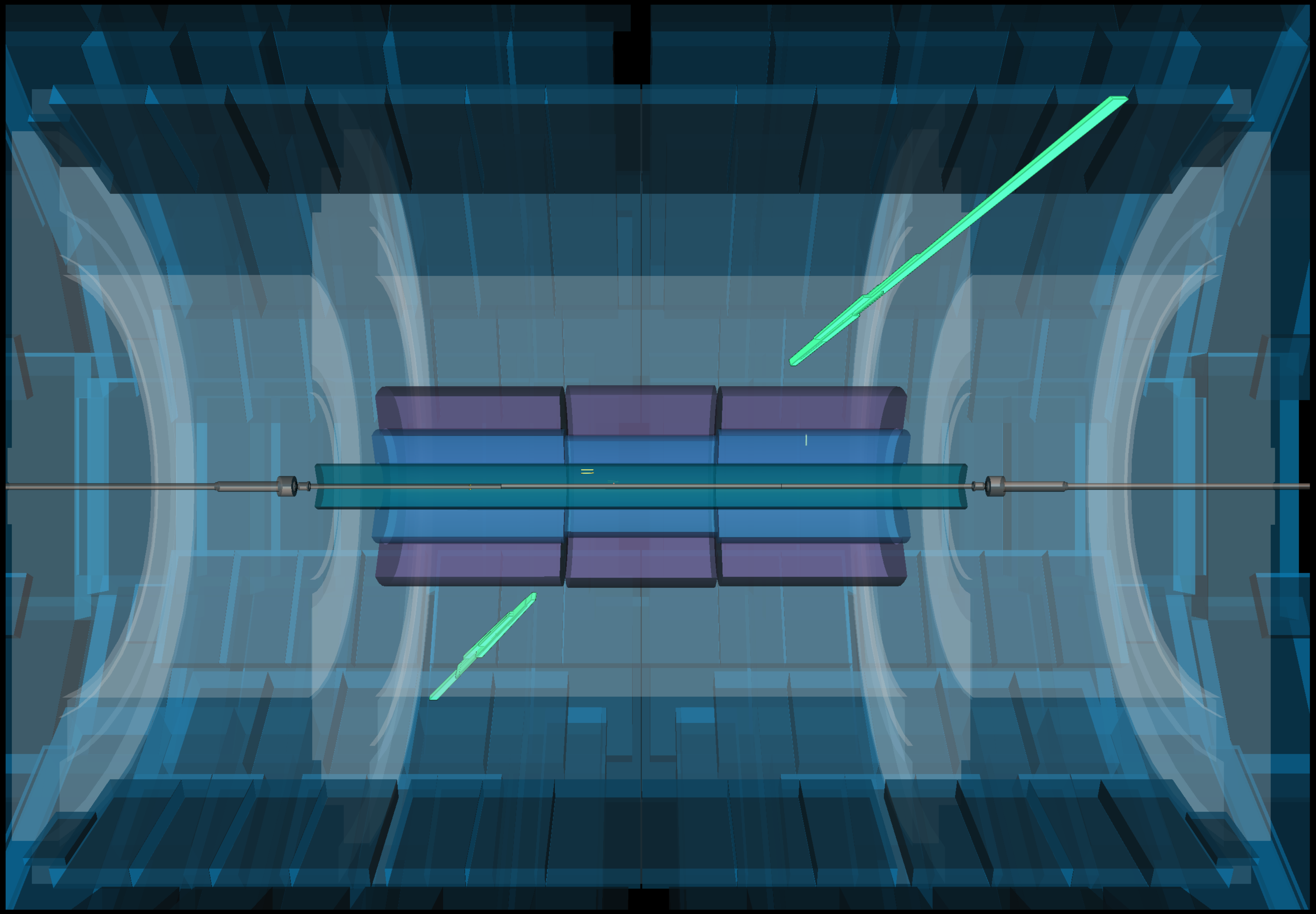


	Fixed-order accuracy						Fragmentation		QCD	NP
	$\gamma\gamma$	$+1j$	$+2j$	$+3j$	$+\geq 4j$	$gg \to \gamma\gamma$	single	double	res.	effects
DIPHOX	NLO	LO	-	-	-	LO	NLO		–	–
NNLOJET	NNLO	NLO	LO	-	-	LO	–	–	–	–
SHERPA	NLO		LO		PS	LO	ME+PS		PS	✓

Photon Interactions in HI Events

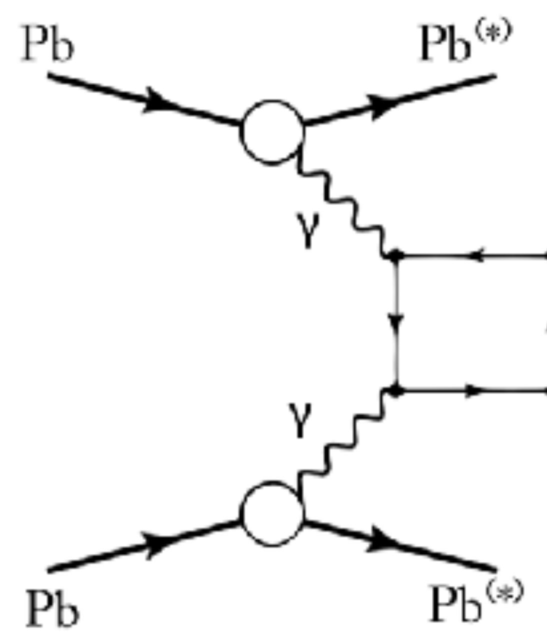
ATLAS EXPERIMENT

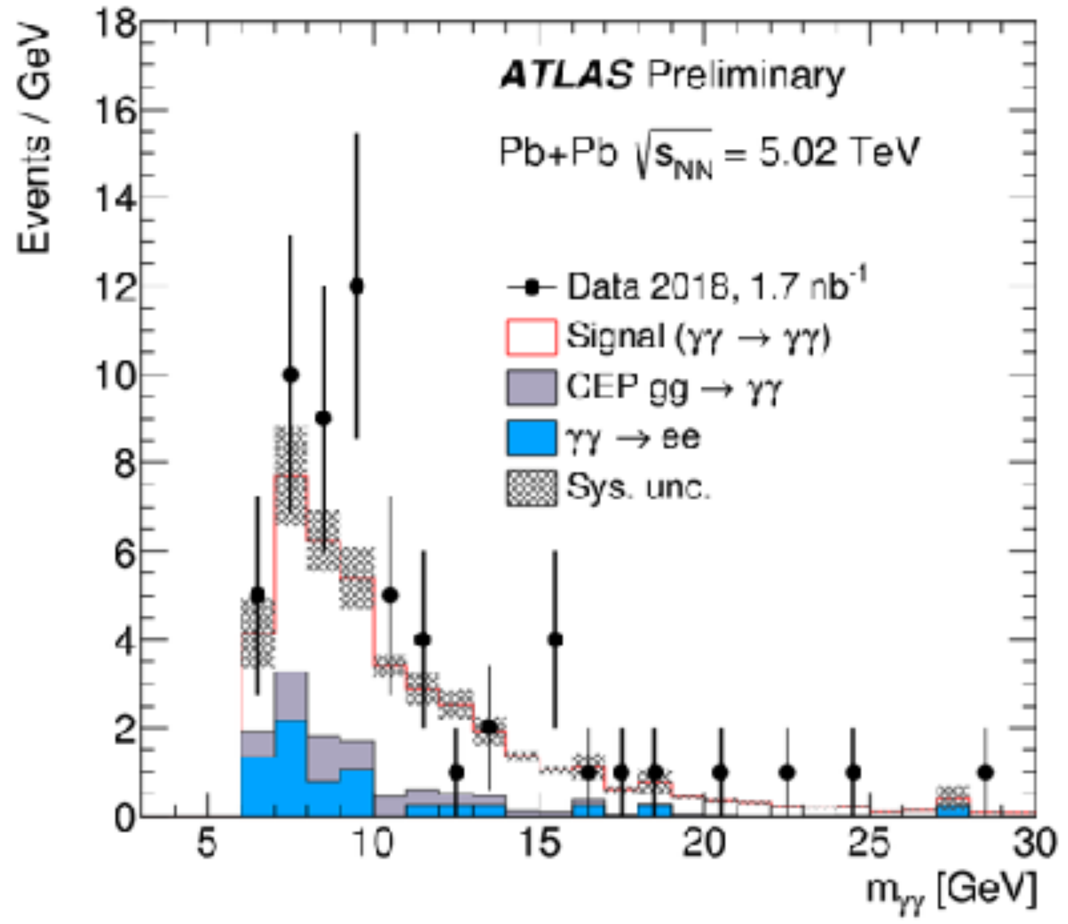
Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST



Observation of **Light-by-light scattering** (Central Exclusive Production)

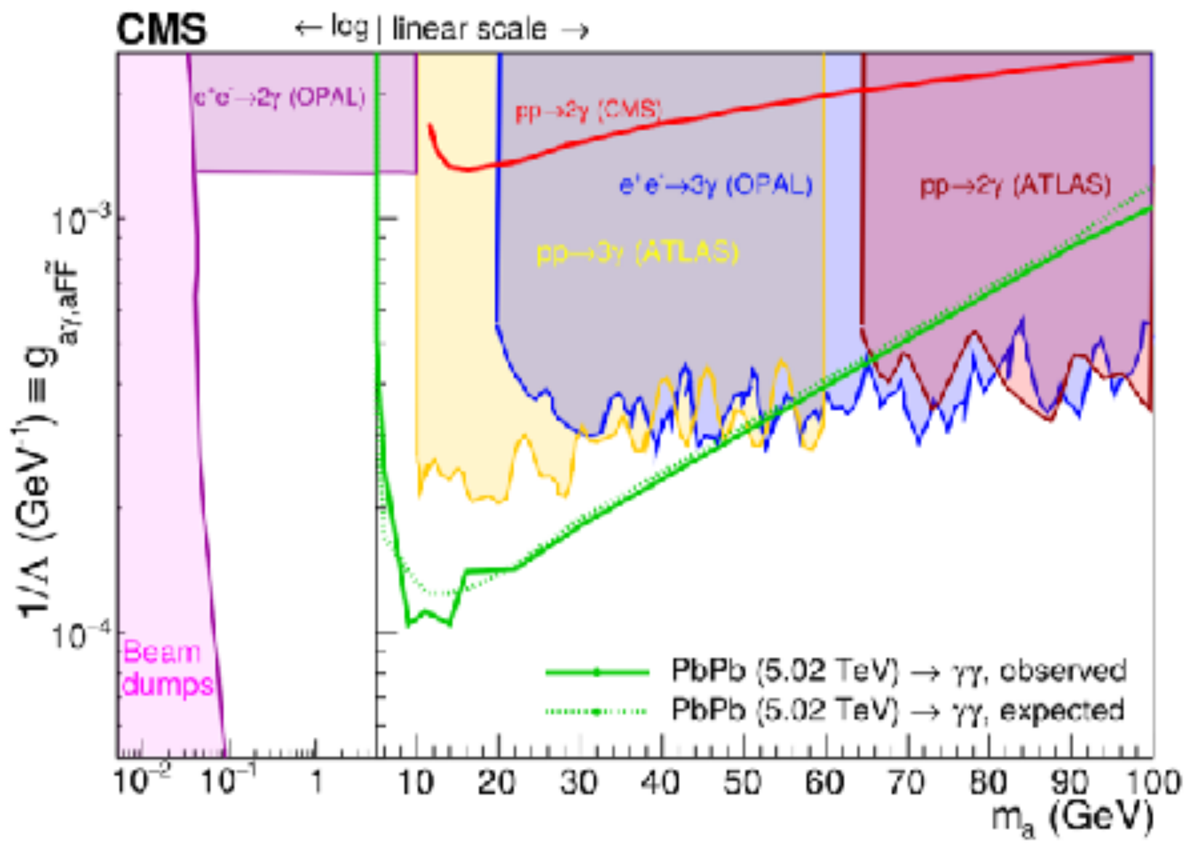
Phys. Rev. Lett. 123 (2019) 052001





Signal observed at more than 8 s.d.

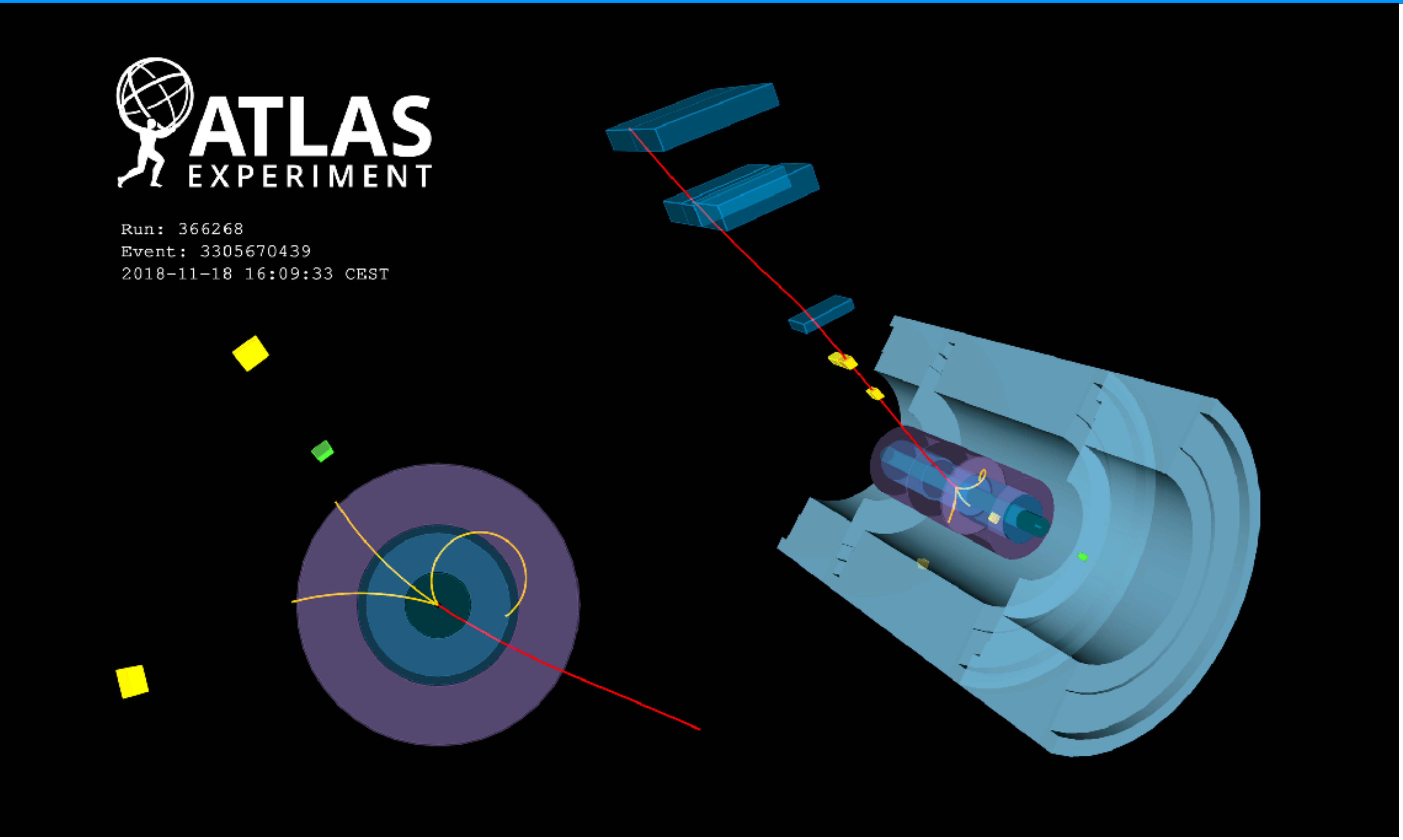
$$78 \pm 13\ (\text{stat.}) \pm 7\ (\text{syst.}) \pm 3\ (\text{lumi.})\ \text{nb}$$

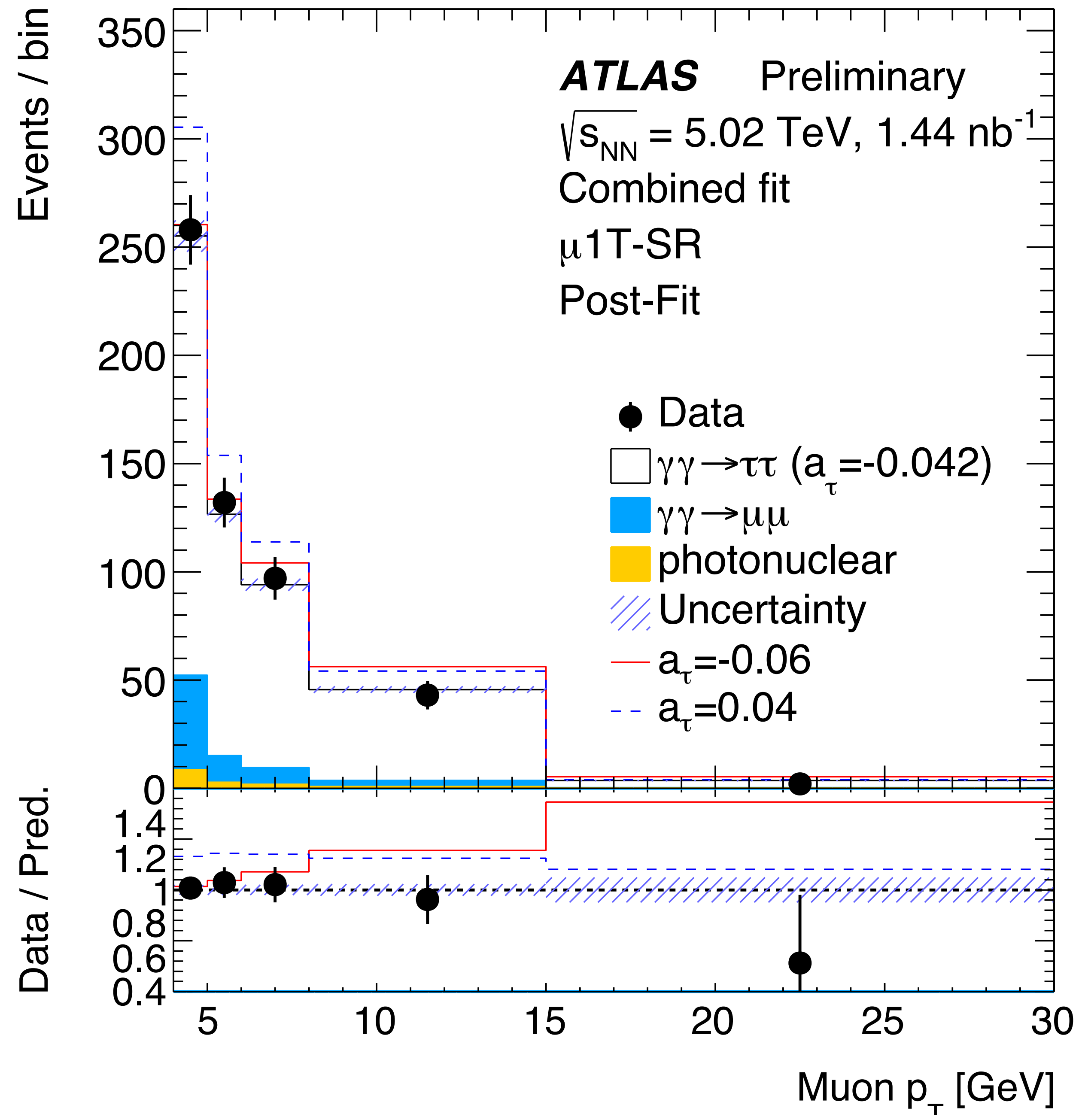


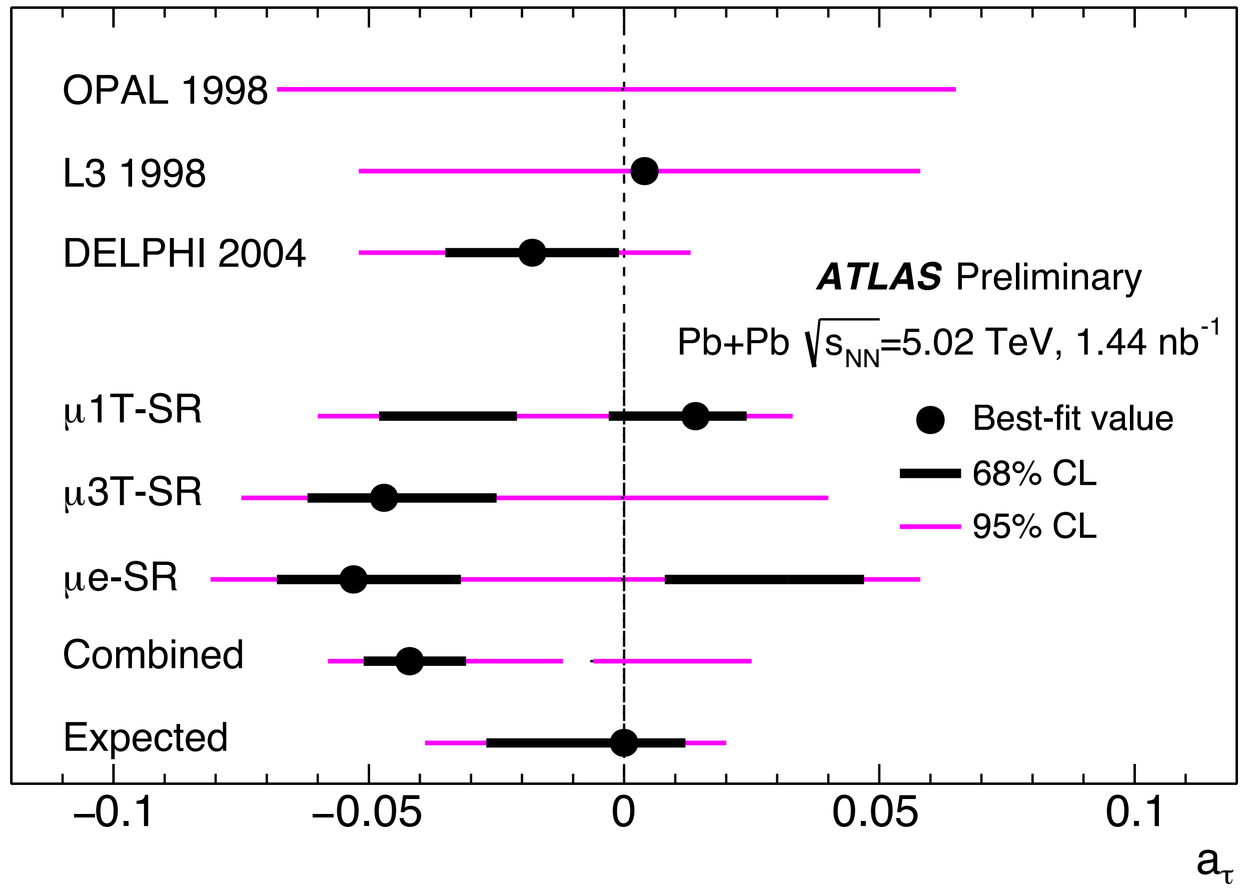
Constraints on ALP (Axion Like Particles) assuming sole coupling to photons.

CMS-FSQ-16-012

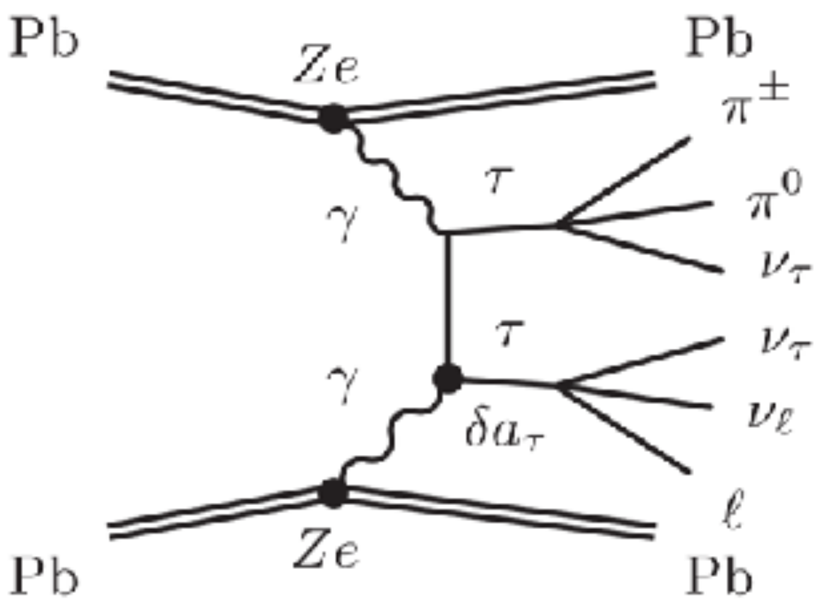
Tau magnetic moment and γγ → ττ Observation in PbPb





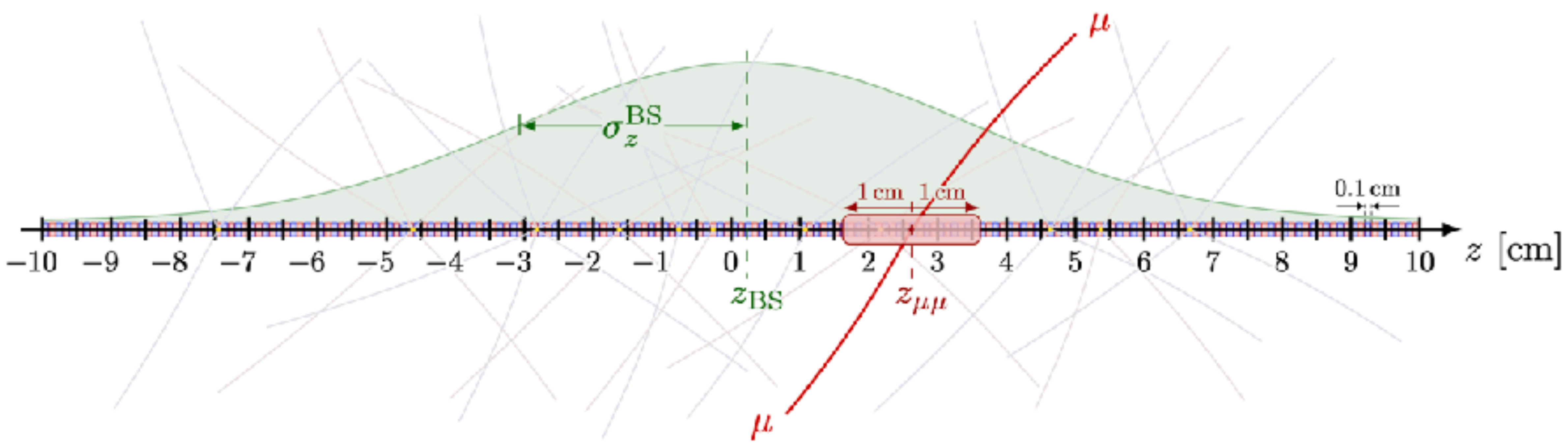


Observation of γγ → ττ in Pb-Pb collisions and constraint on tau anomalous magnetic moment



Physics Briefing, Interview

Tau Anomalous Magnetic Moments

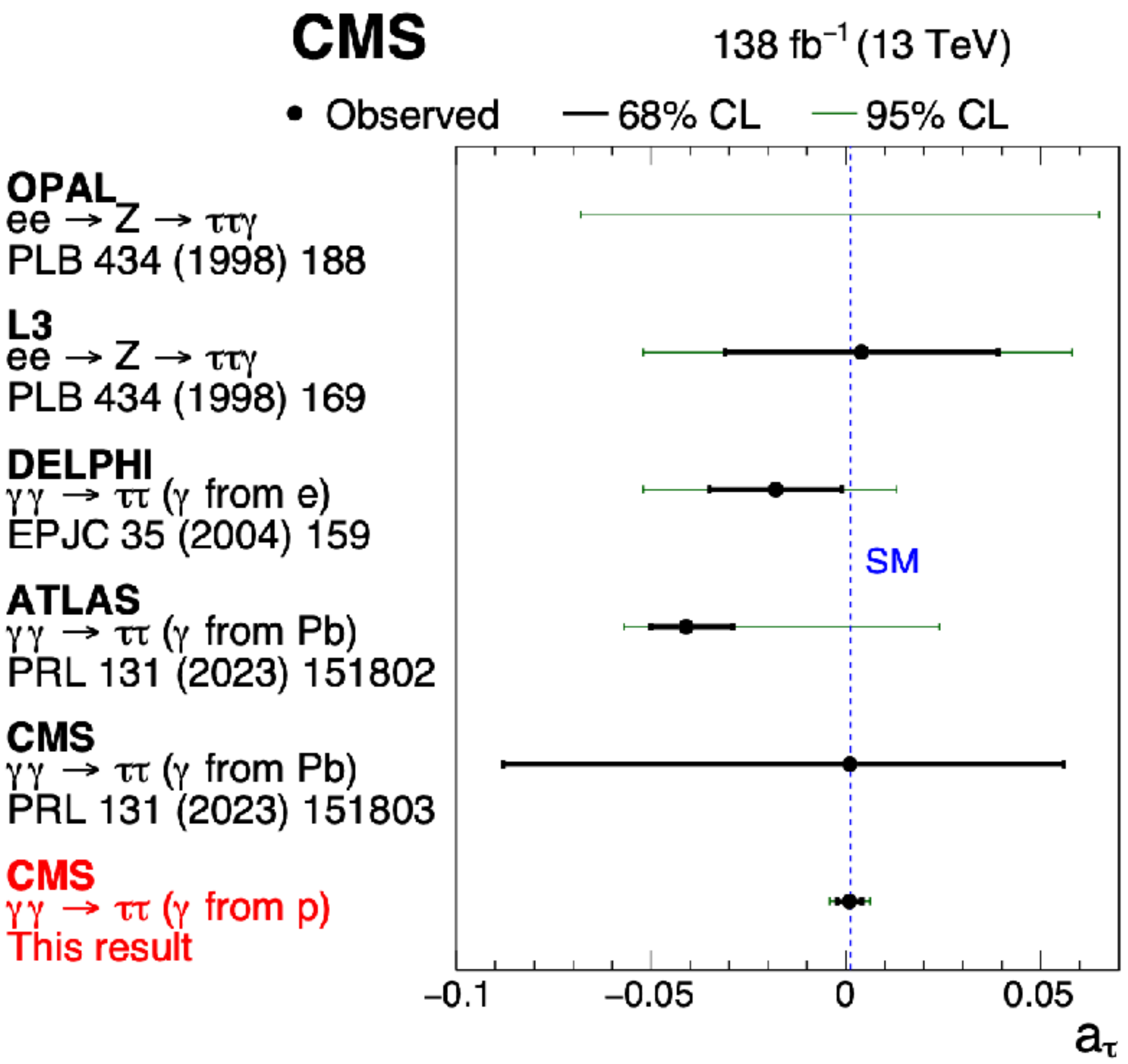


Beautiful analysis selecting isolated low multiplicity vertices, sensitive to photo-production of tau pairs!

Large gain in sensitivity! Only ~3 times larger than the **Schwinger term** (QED part)

However still almost **3-4 orders of magnitude above sensitive corrections e.g. EW !**

$$
\begin{aligned}
a_\tau^{\mathrm{QED}} &= 1.1732 \times 10^{-3}, \\
a_\tau^{\mathrm{had}} &= 3.2(4) \times 10^{-6}, \\
a_\tau^{\mathrm{EW}} &= 4.7 \times 10^{-7}.
\end{aligned}
$$



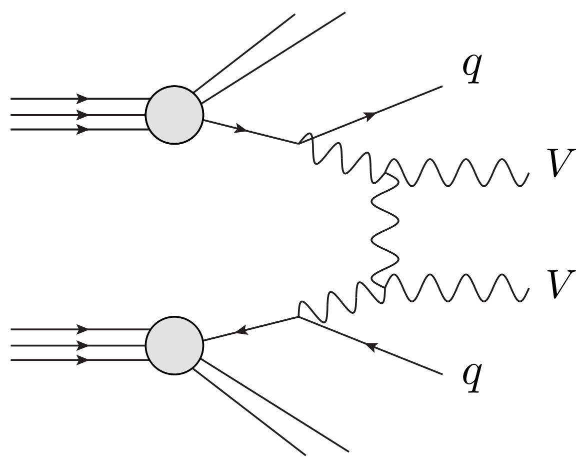
$$a_\tau = \frac{g_\tau}{2} - 1 = 0.0009^{+0.0032}_{-0.0031}$$

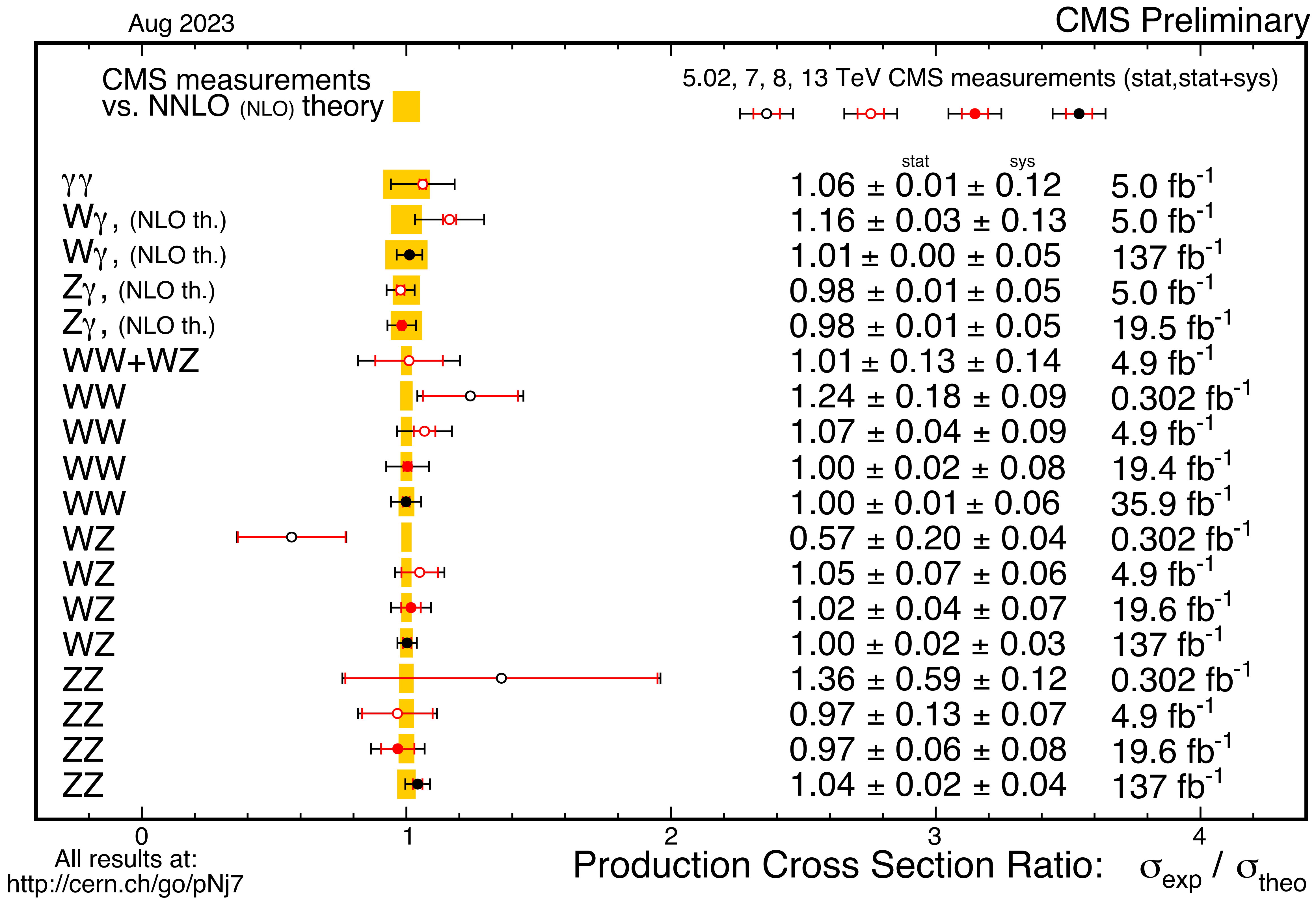
More di-boson measurements at the LHC

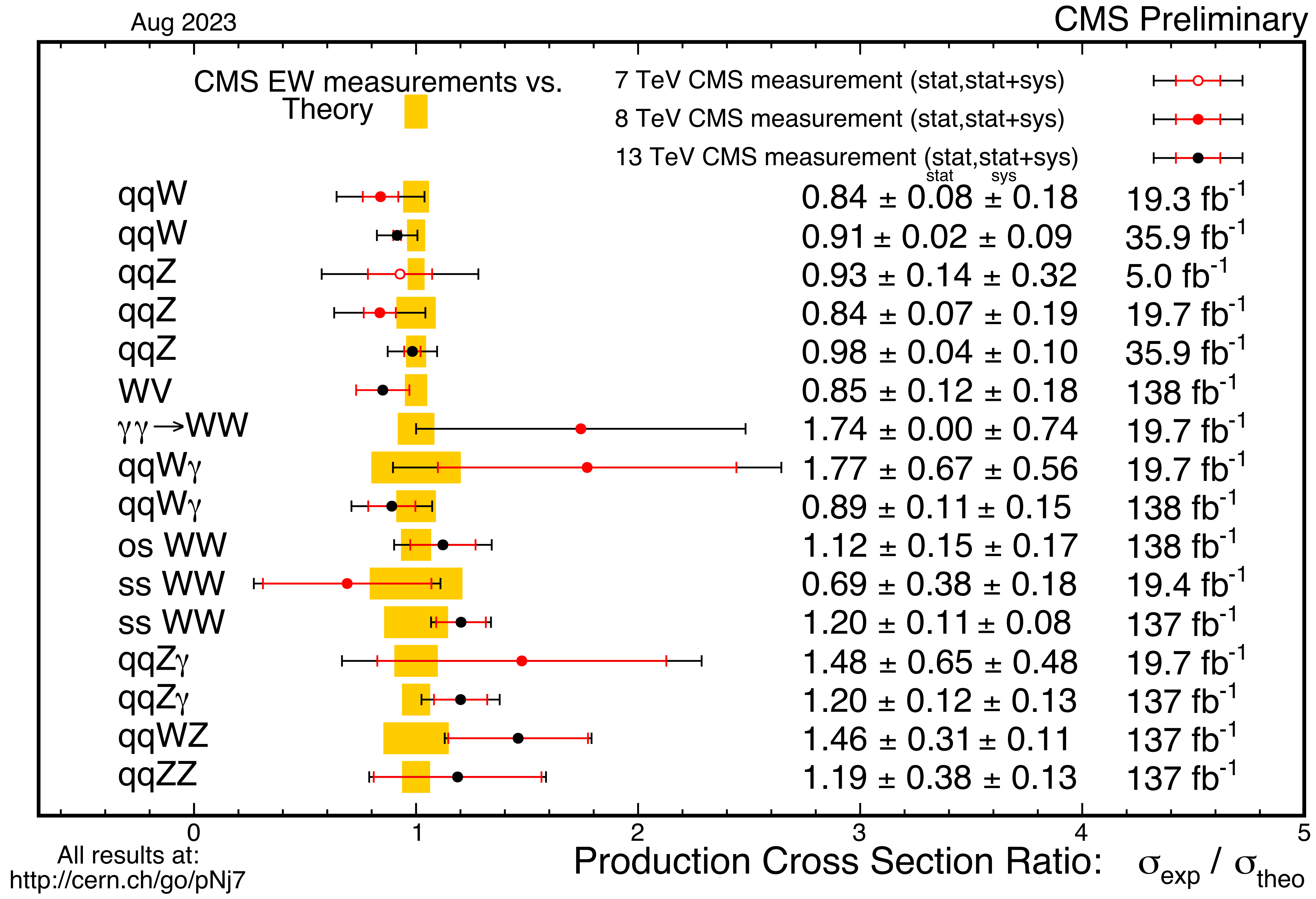
Large number of diboson processes measured in QCD and EW production which are key to probe the electroweak Sector of the Standard Model.

This will be further covered tomorrow when discussing Higgs physics.

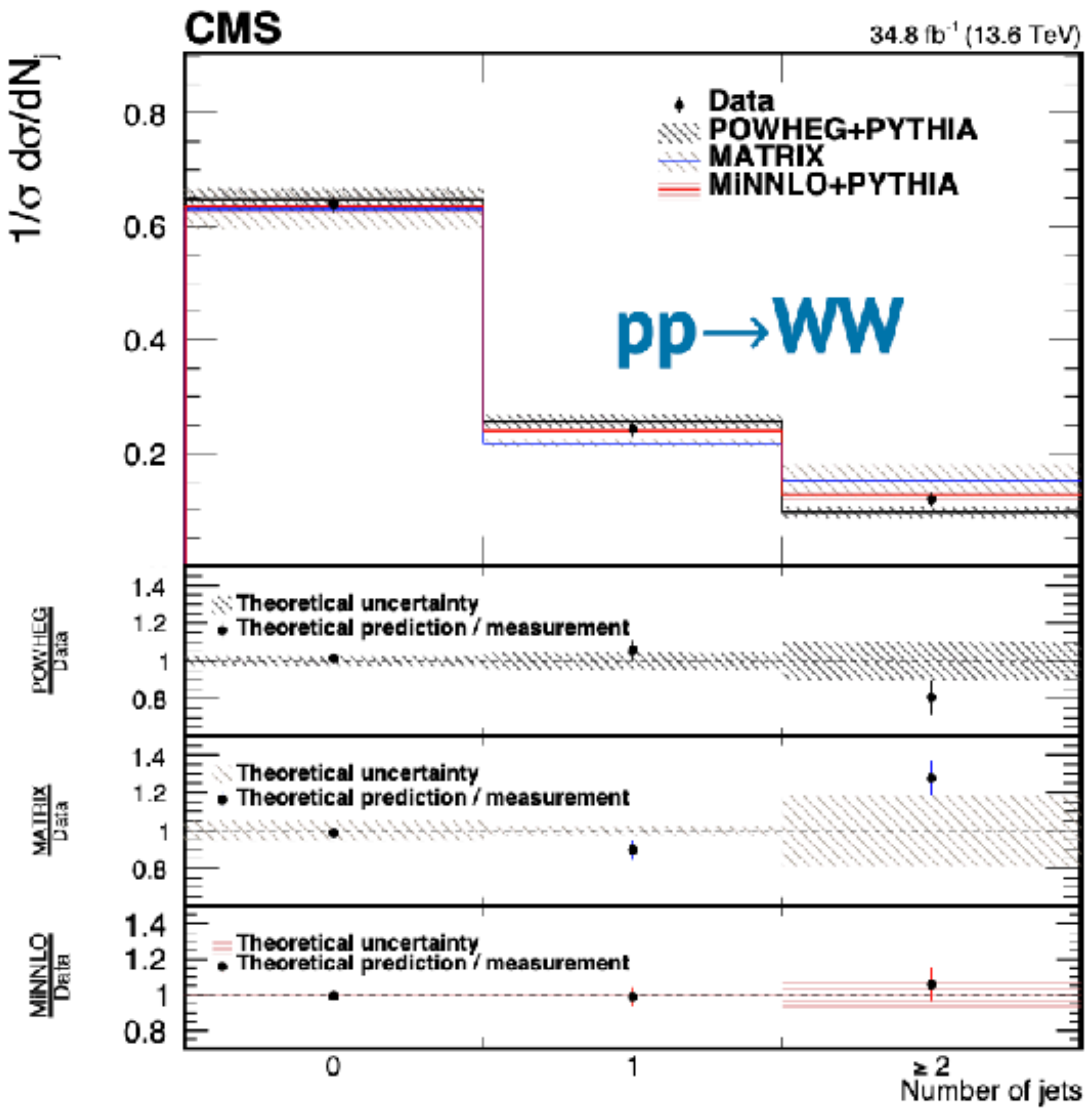
VBS diboson production (VVjj)

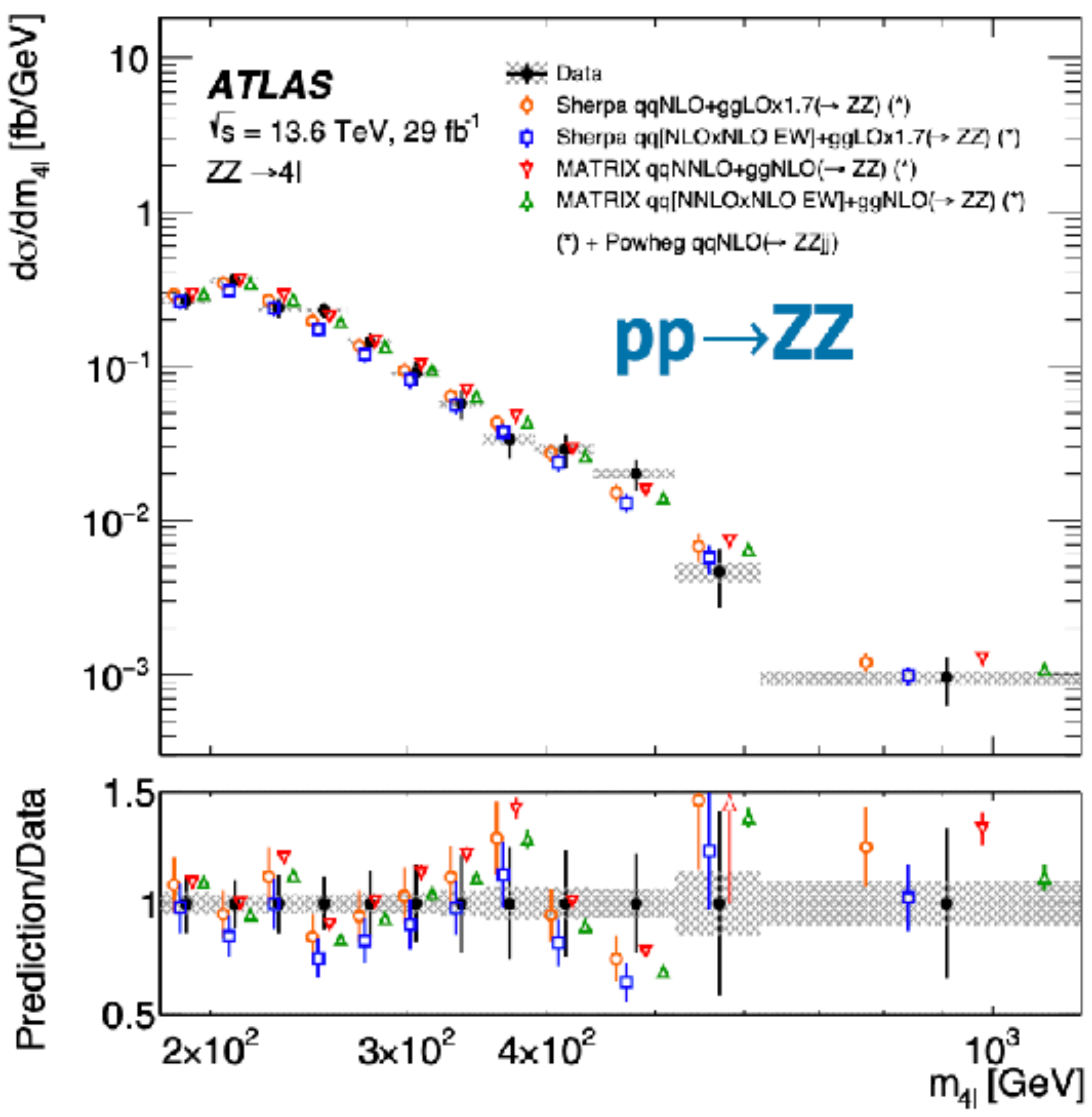


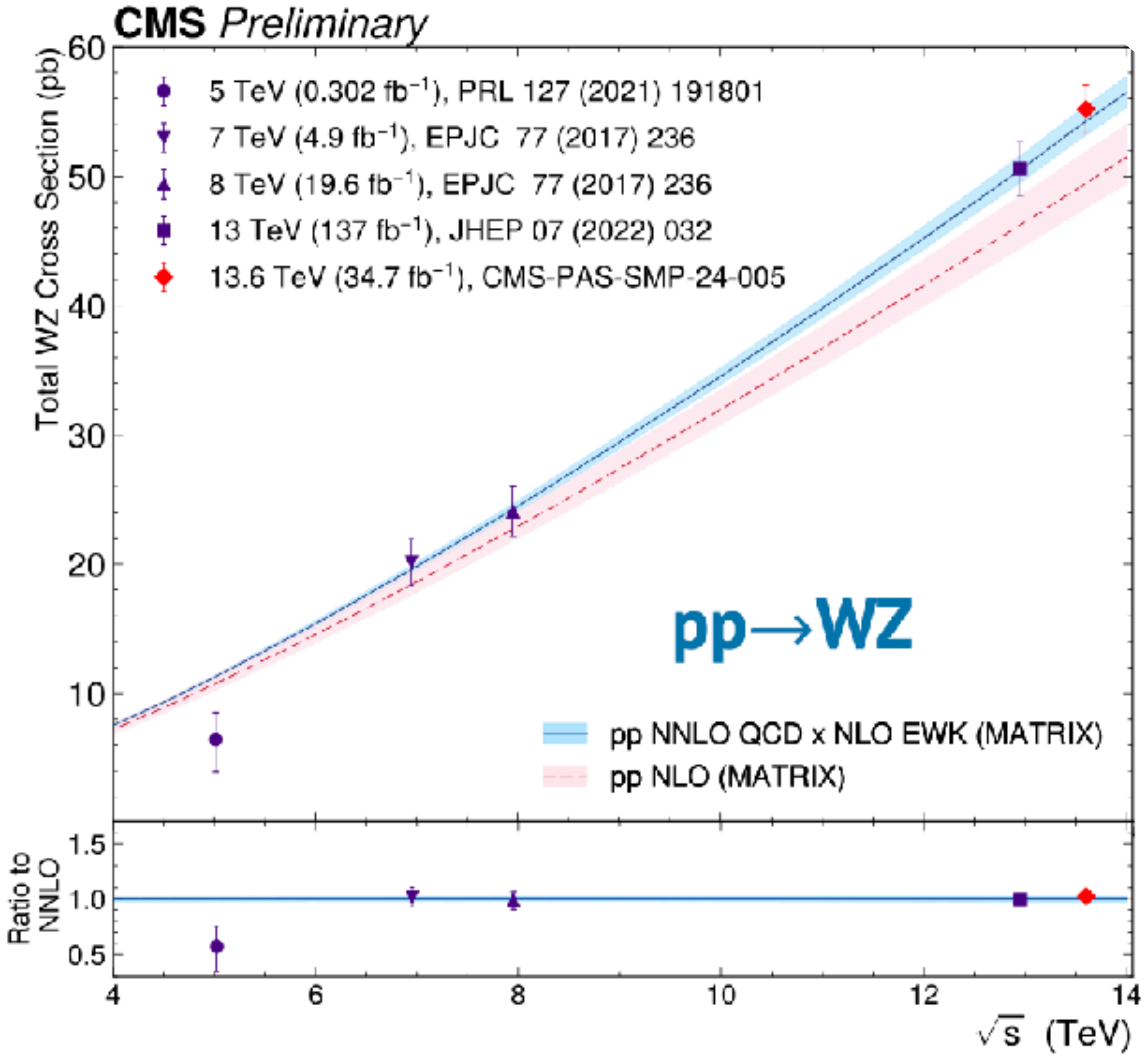




First Measurements of di-boson production at Run 3

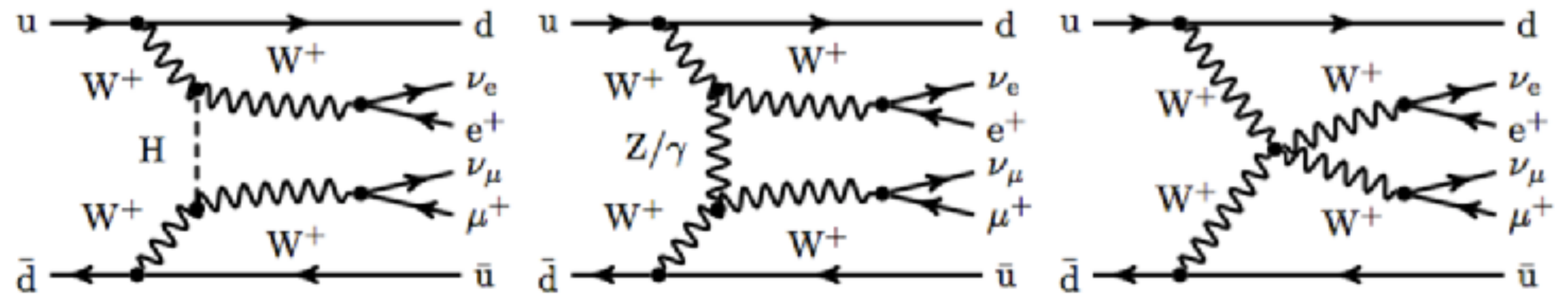






First measurements of the diboson processes at Run 3 (with 2022 data)

EW Vector Boson Scattering



EW Vector Boson Scattering process

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

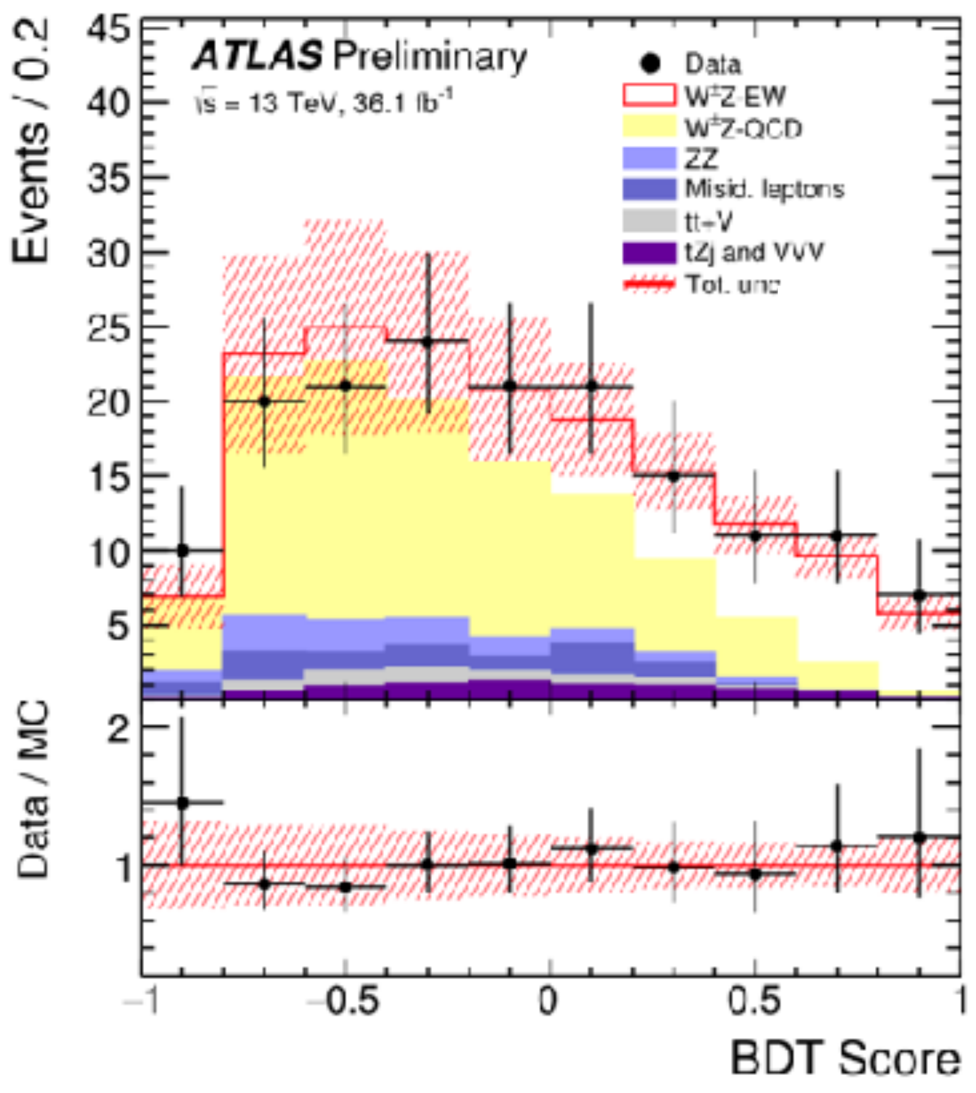
Longitudinal-Longitudinal Scattering

Important additional check of the EWSB sector.

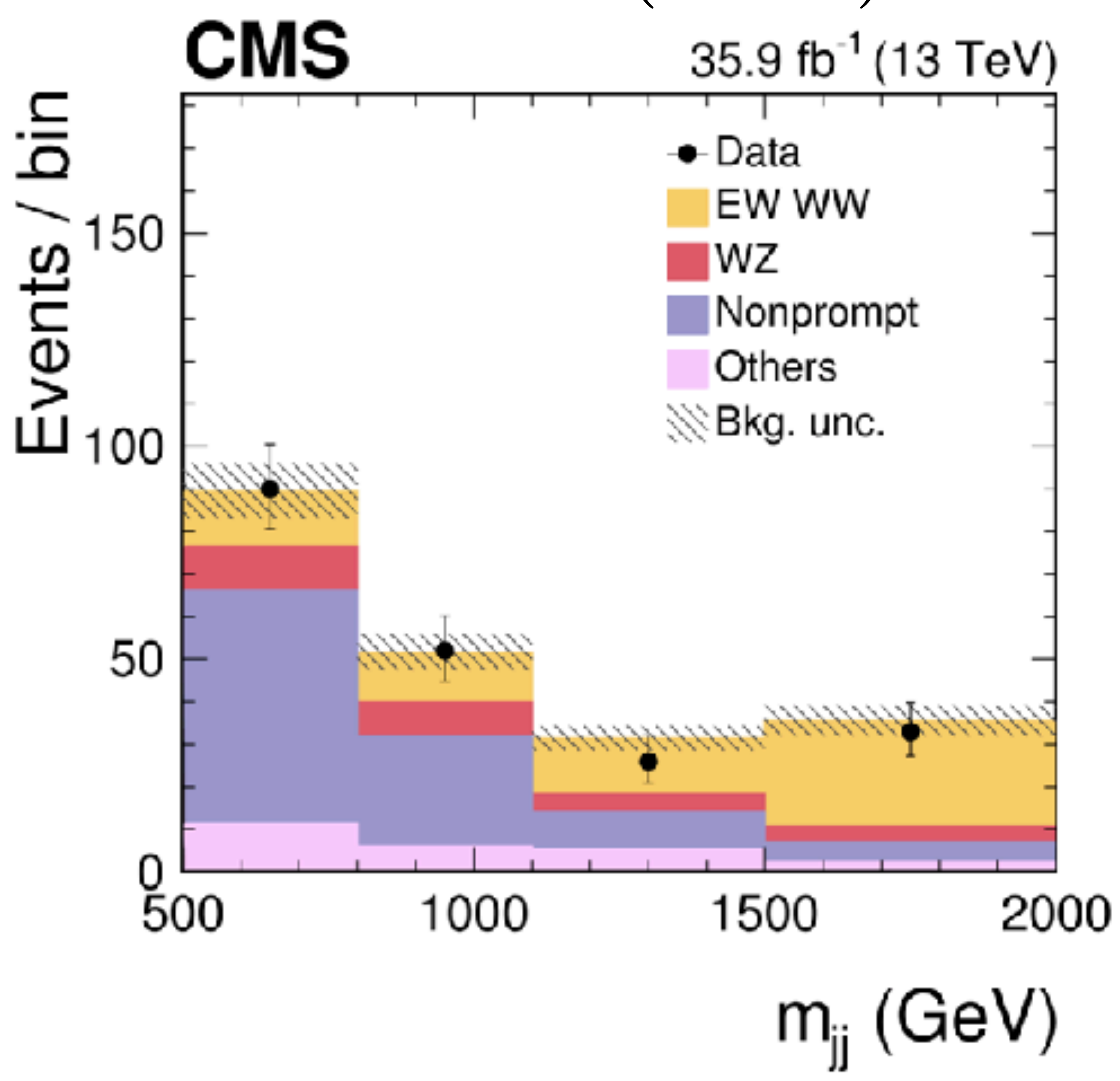
Suppressed from Higgs cancellation however with very large statistics and polarisation sensitive variables, there is sensitivity to SM LL signal almost **3**σ for CMS alone.

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

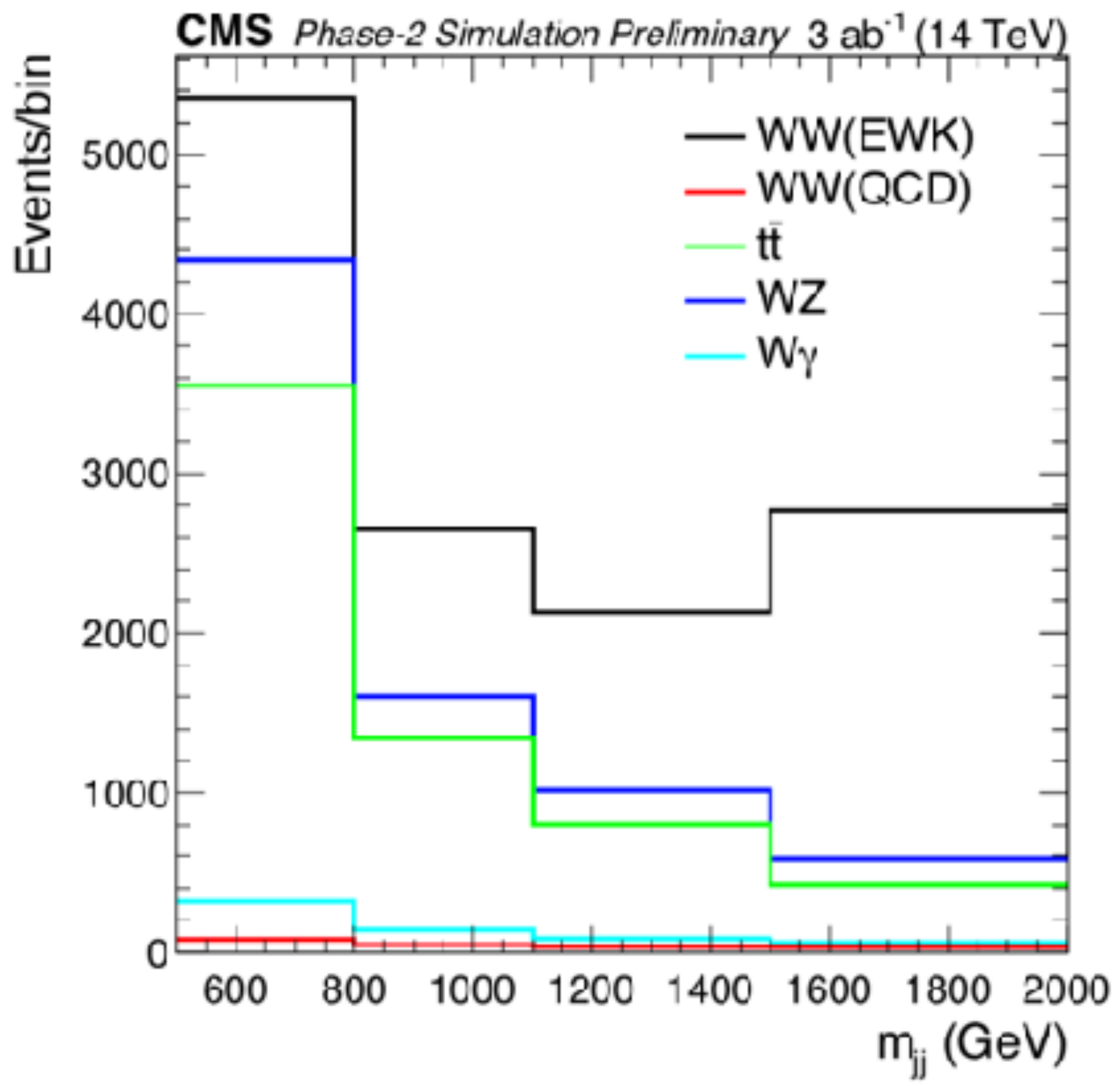
WZ $5.6\sigma\ (3.3\sigma)$

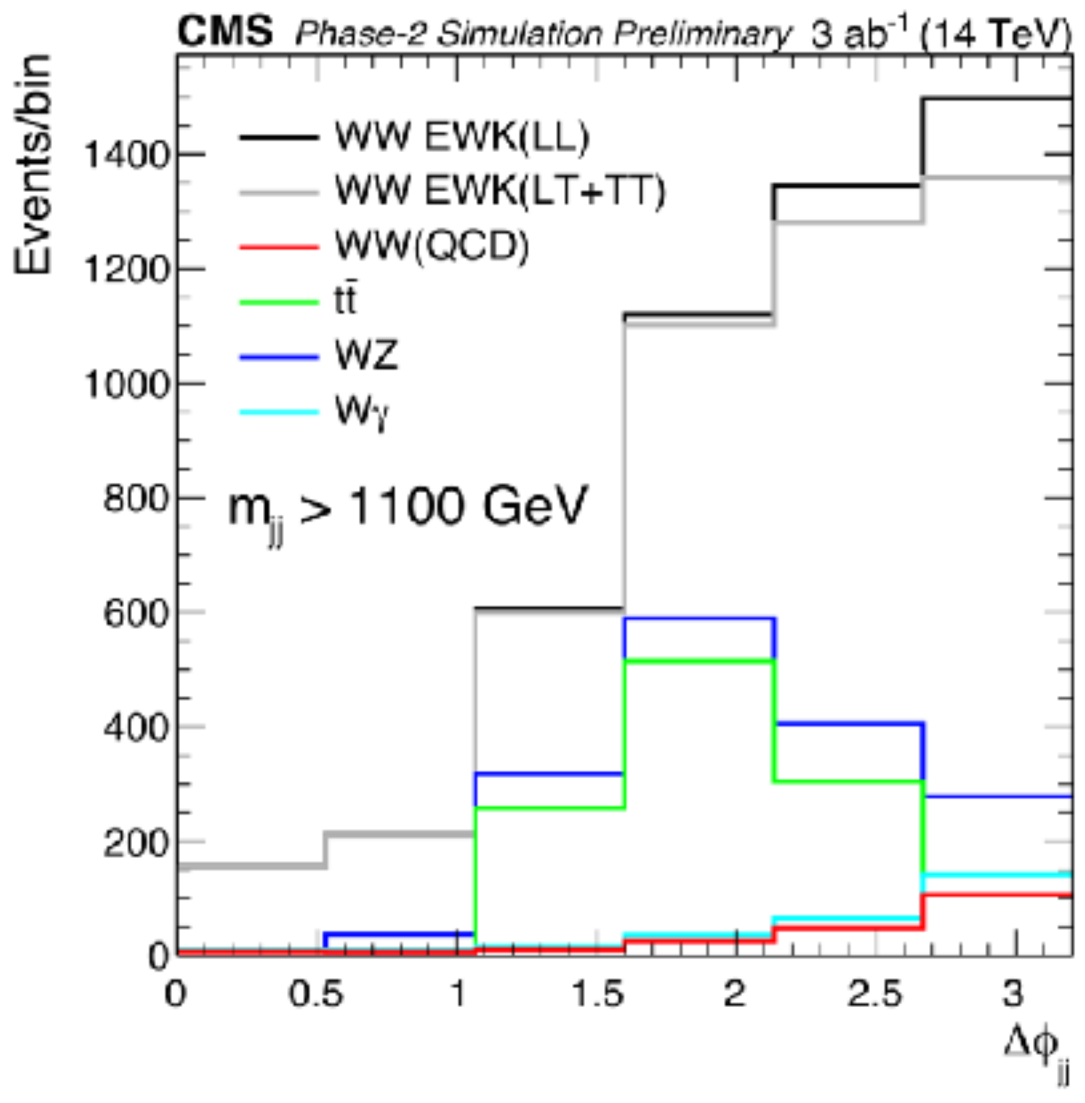


WW $5.5\sigma\ (5.7\sigma)$

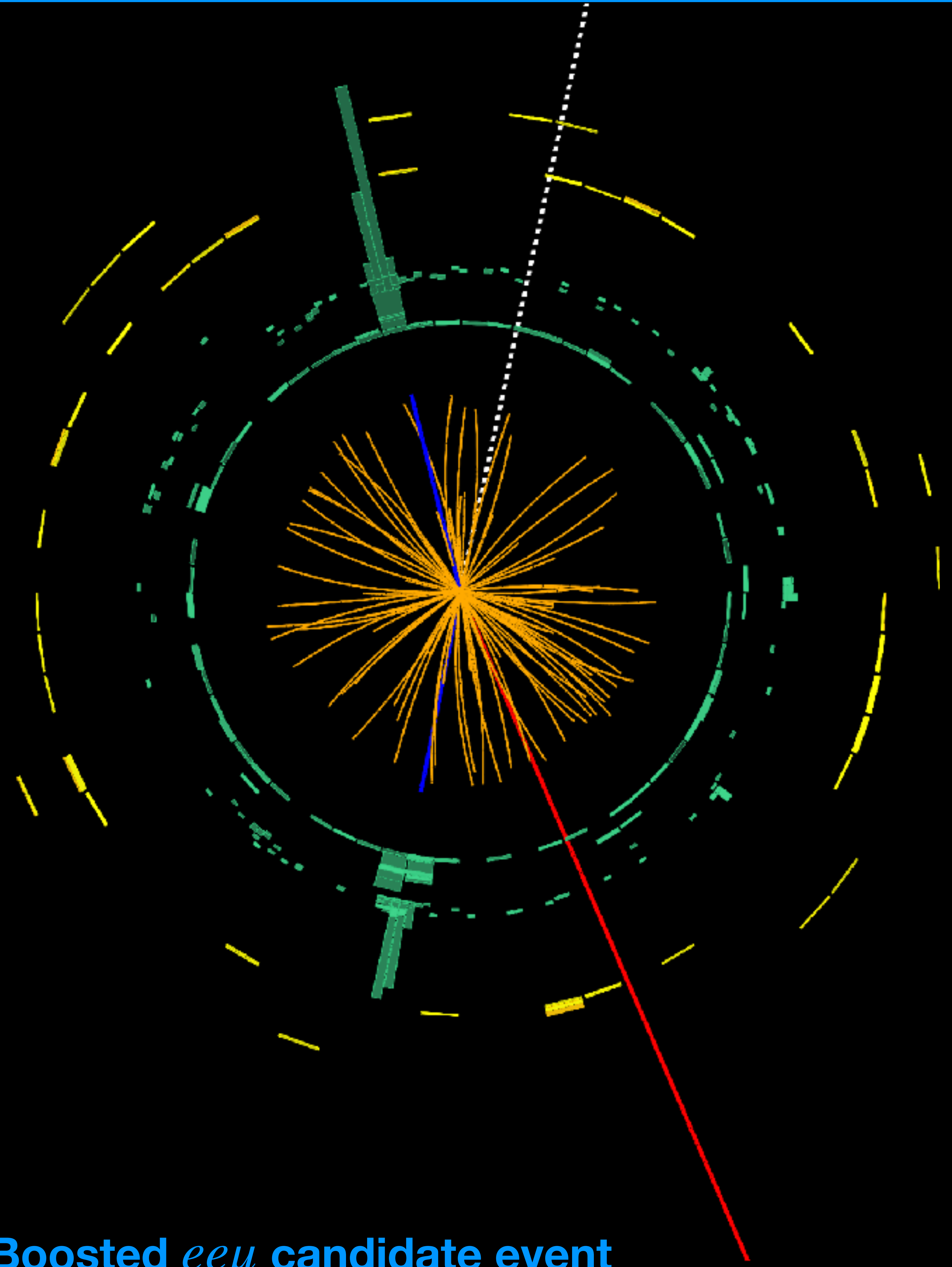


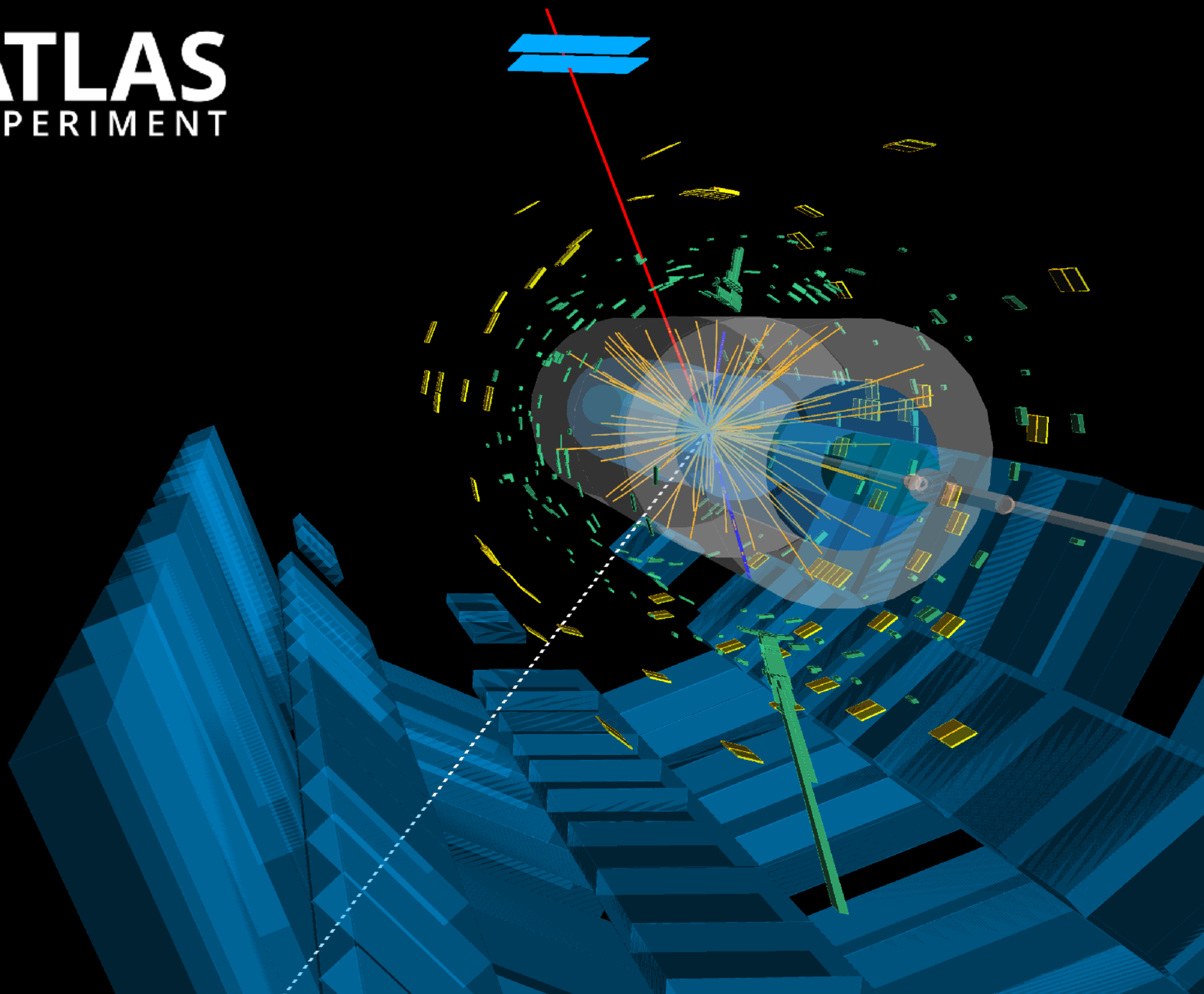
CMS FTR-2018-005





Tri-boson WWW Observation!



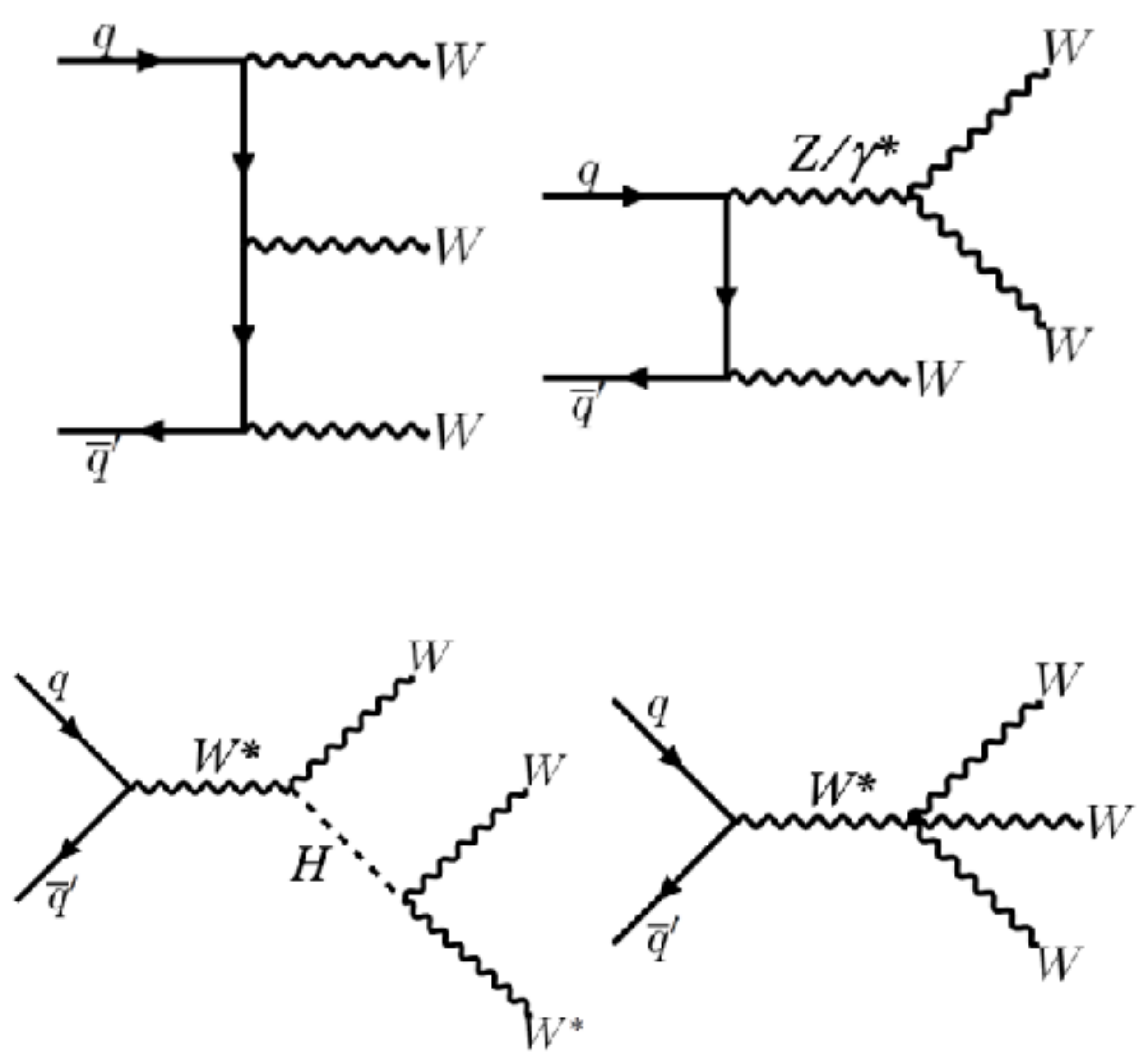


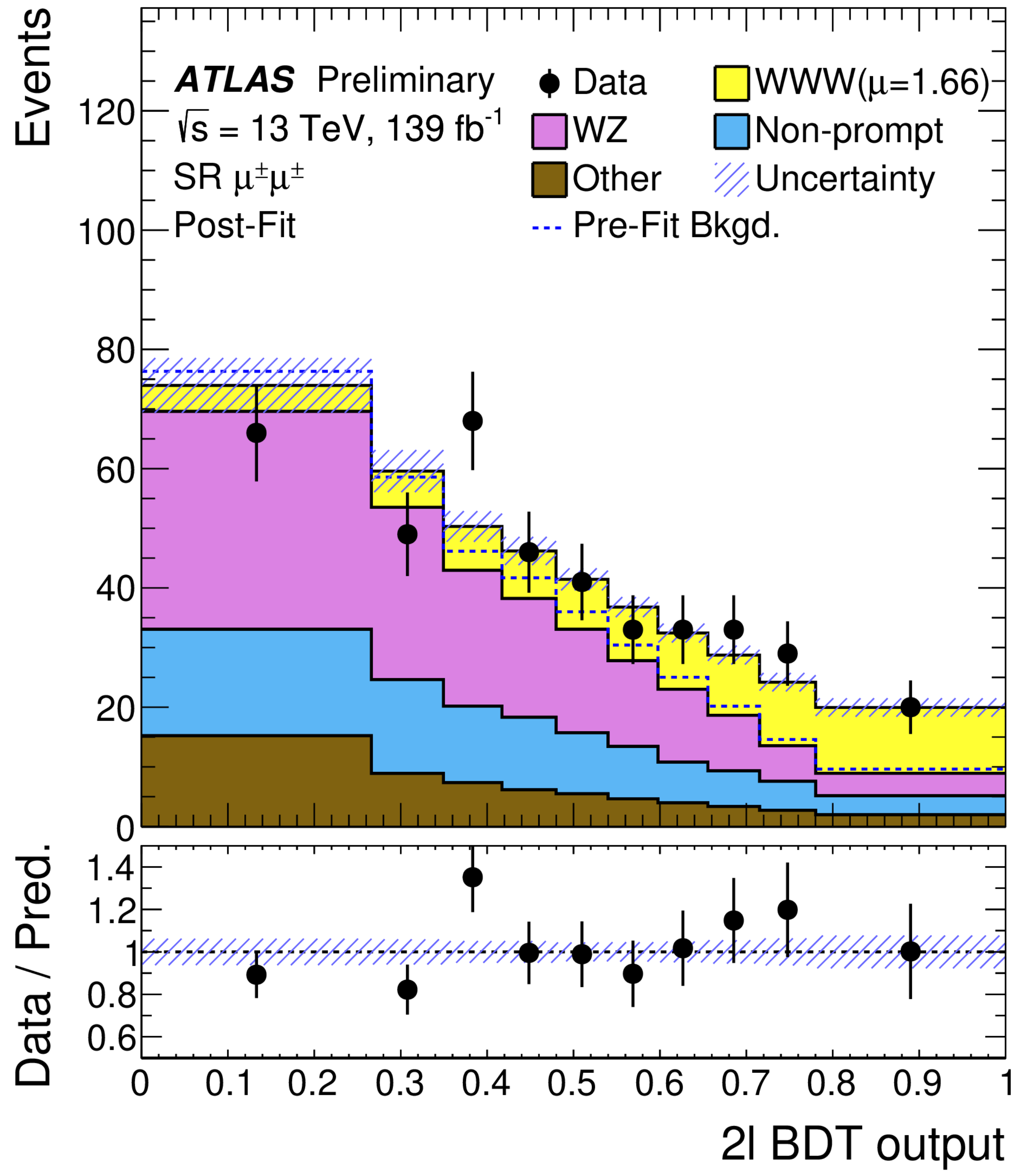
Boosted $ee\mu$ candidate event

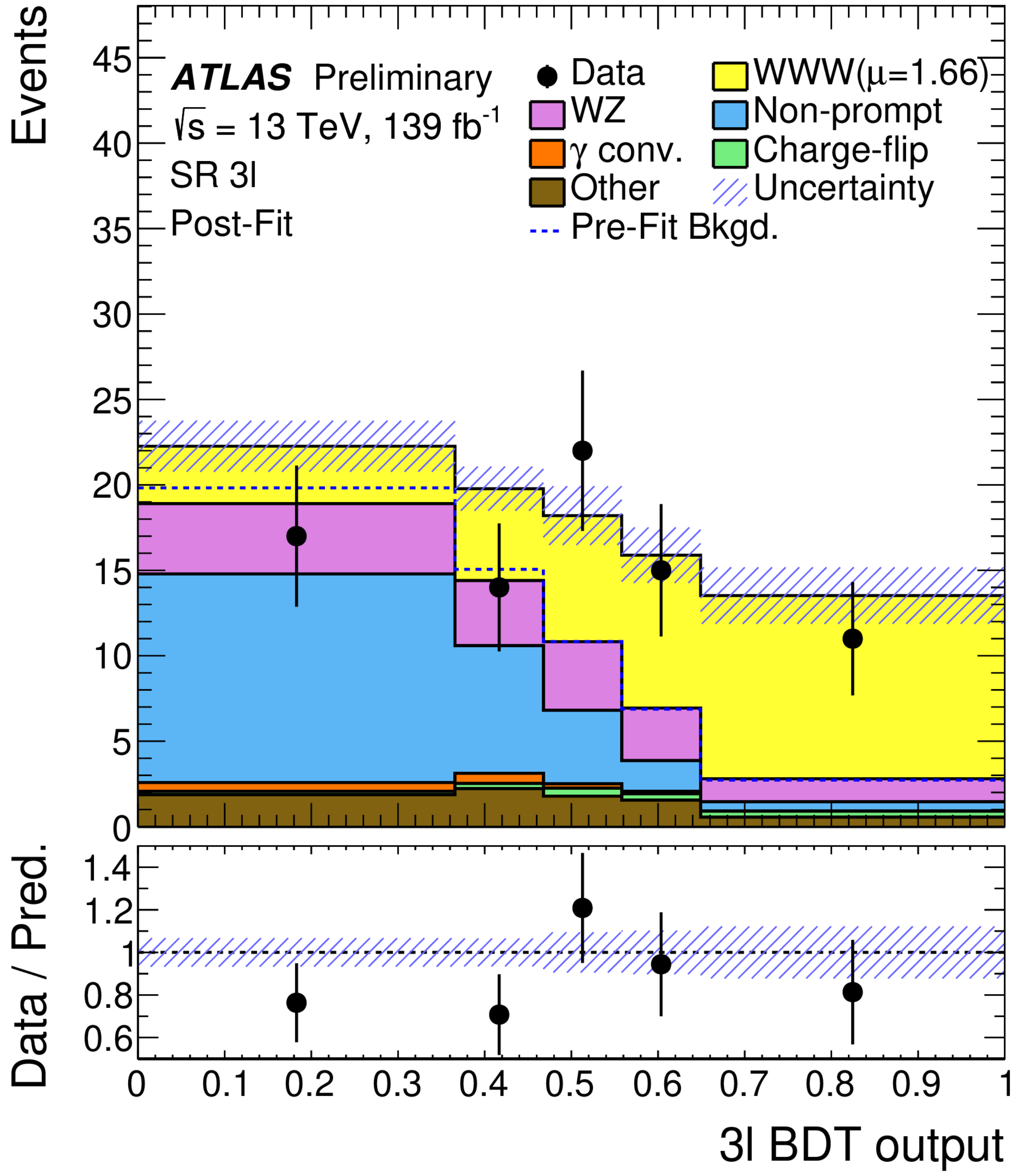
Triboson $W^{\pm}W^{\mp}W^{\mp}$ observation

Search for three W bosons production

Interesting process sensitive to Higgs boson exchange







Same sign 2-lepton channel

$\ell^{\pm}\nu\ell^{\pm}\nu jj$

3-lepton channel

$\ell^{\pm}\ell^{\pm}jj$

First observation of $W^{\pm}W^{\mp}W^{\mp}$ at **8.2σ** (5.4σ expected)!

Measured cross section:

$$\sigma(pp \to WWW) = 820 \pm 100\,(\text{stat.}) \pm 80\,(\text{syst.})\ \text{fb}$$

Predictions:

511 ± 18 fb

$pp \to W^+W^-W^-$ $\quad 76\,^{+4}_{-3}\,(\text{scale}) \pm 2\,(\text{PDF})\ \text{fb}$

$pp \to W^-W^+W^+$ $\quad 136\,^{+6}_{-5}\,(\text{scale}) \pm 4\,(\text{PDF})\ \text{fb}$

$pp \to WH \to WWW^*$ $\quad 293\,^{+1}_{-2}\,(\text{scale})\,^{+6}_{-5}\,(\text{PDF}) \pm 3\,(\alpha_s)\ \text{fb}$

Compatibility 2.6σ

Two recent Tri-Boson Observations!

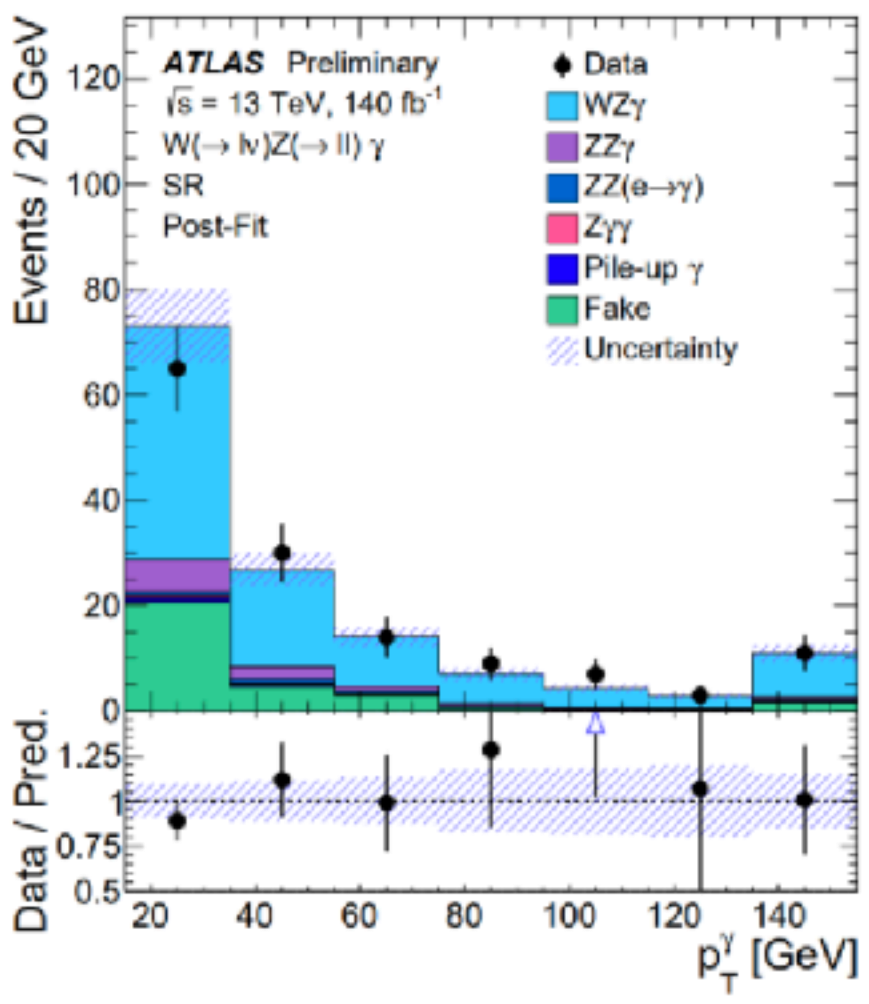
$WZ\gamma$ observation

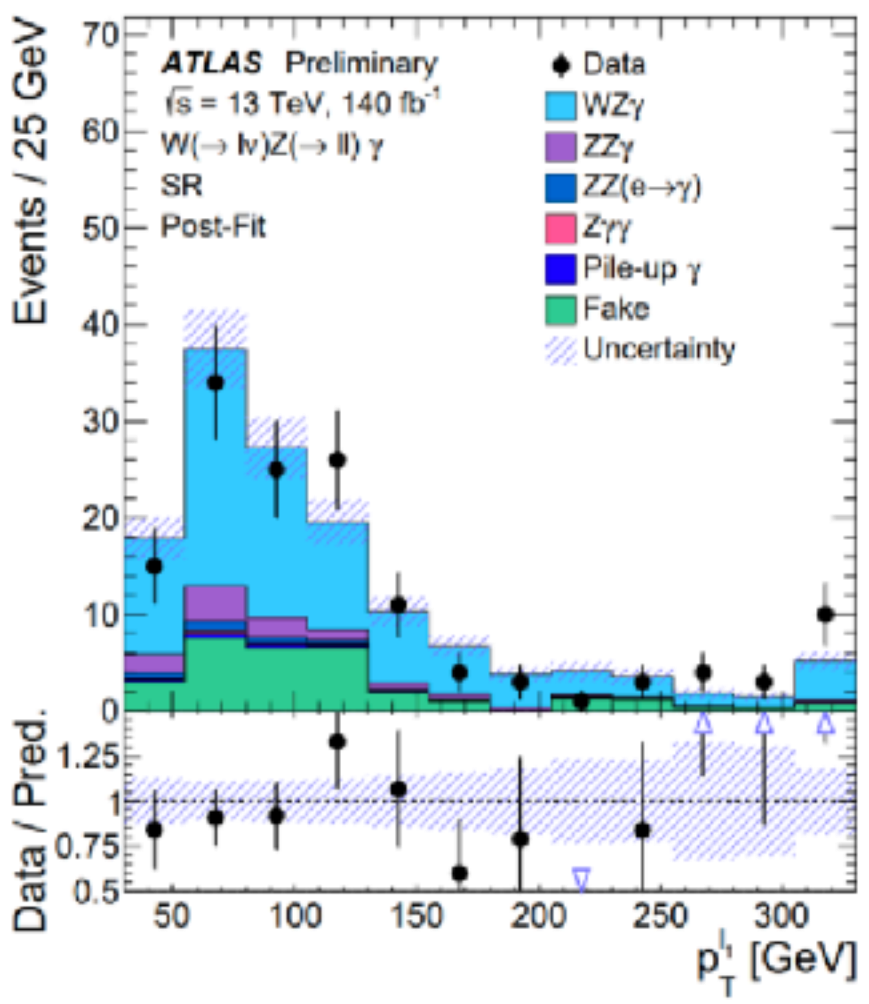
Simultaneous fit with $\mu_{ZZ\gamma}, \mu_{ZZ}$;

$WZ\gamma$ observed with 6.3 σ

$$\sigma_{WZ\gamma} = 2.01 \pm 0.30\ (\text{stat.}) \pm 0.16\ (\text{syst.})\ \text{fb}$$

Process	SR	$ZZ\gamma$ CR	$ZZ(e\to\gamma)$ CR
$WZ\gamma$	92 ± 15	0.21 ± 0.07	0.56 ± 0.14
$ZZ\gamma$	10.7 ± 2.3	23 ± 5	1.8 ± 0.4
$ZZ(e\to\gamma)$	3.0 ± 0.6	0.028 ± 0.020	30 ± 6
$Z\gamma\gamma$	1.05 ± 0.32	0.15 ± 0.06	0.29 ± 0.10
Fake background	30 ± 6	-	-
Pile-up γ	1.9 ± 0.7	-	-
Total predicted	139 ± 12	23 ± 5	33 ± 6
Data	139	23	33





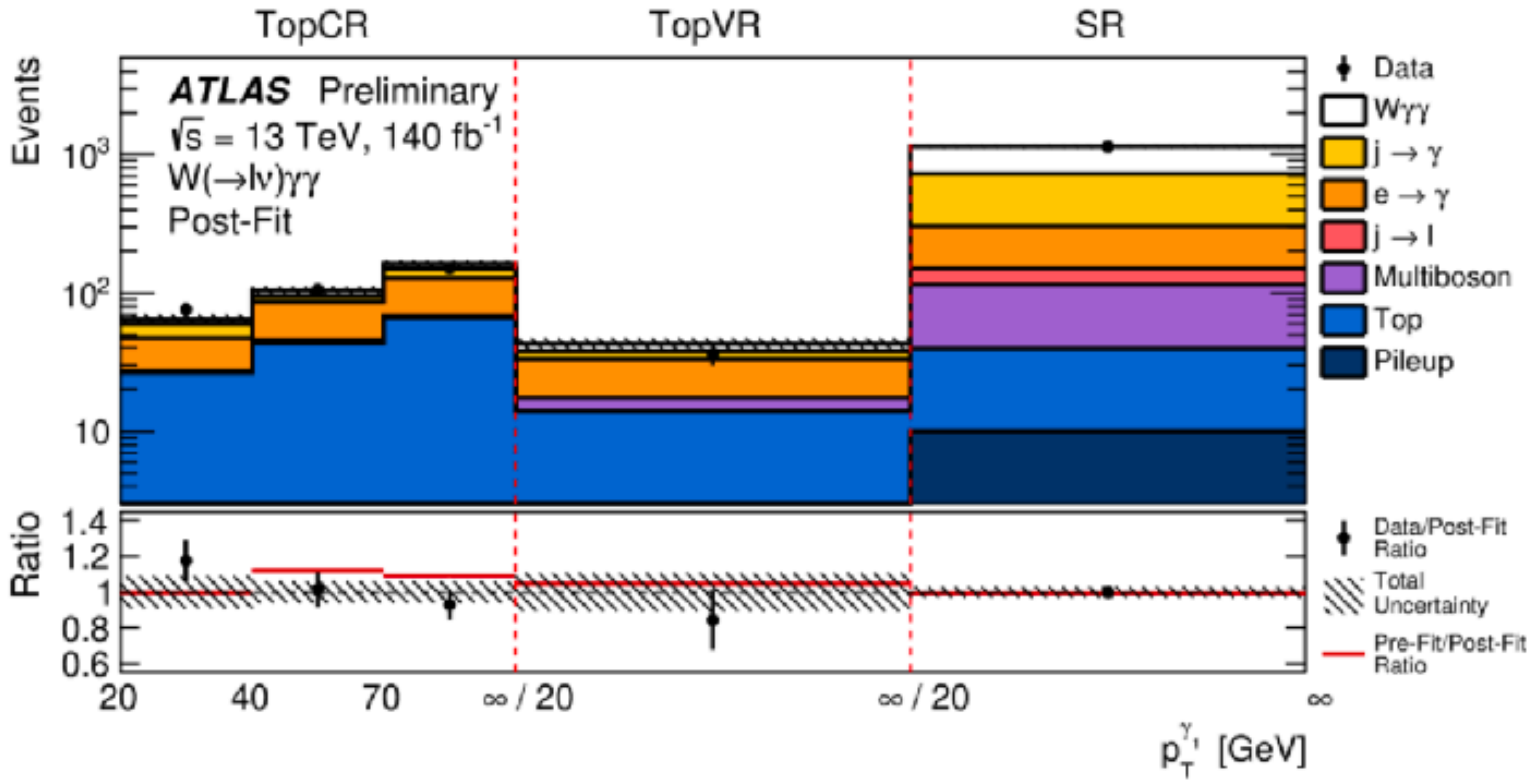
$W\gamma\gamma$ observation

data-driven Fake estimated in control regions

$WZ\gamma$ observed with 5.6 σ

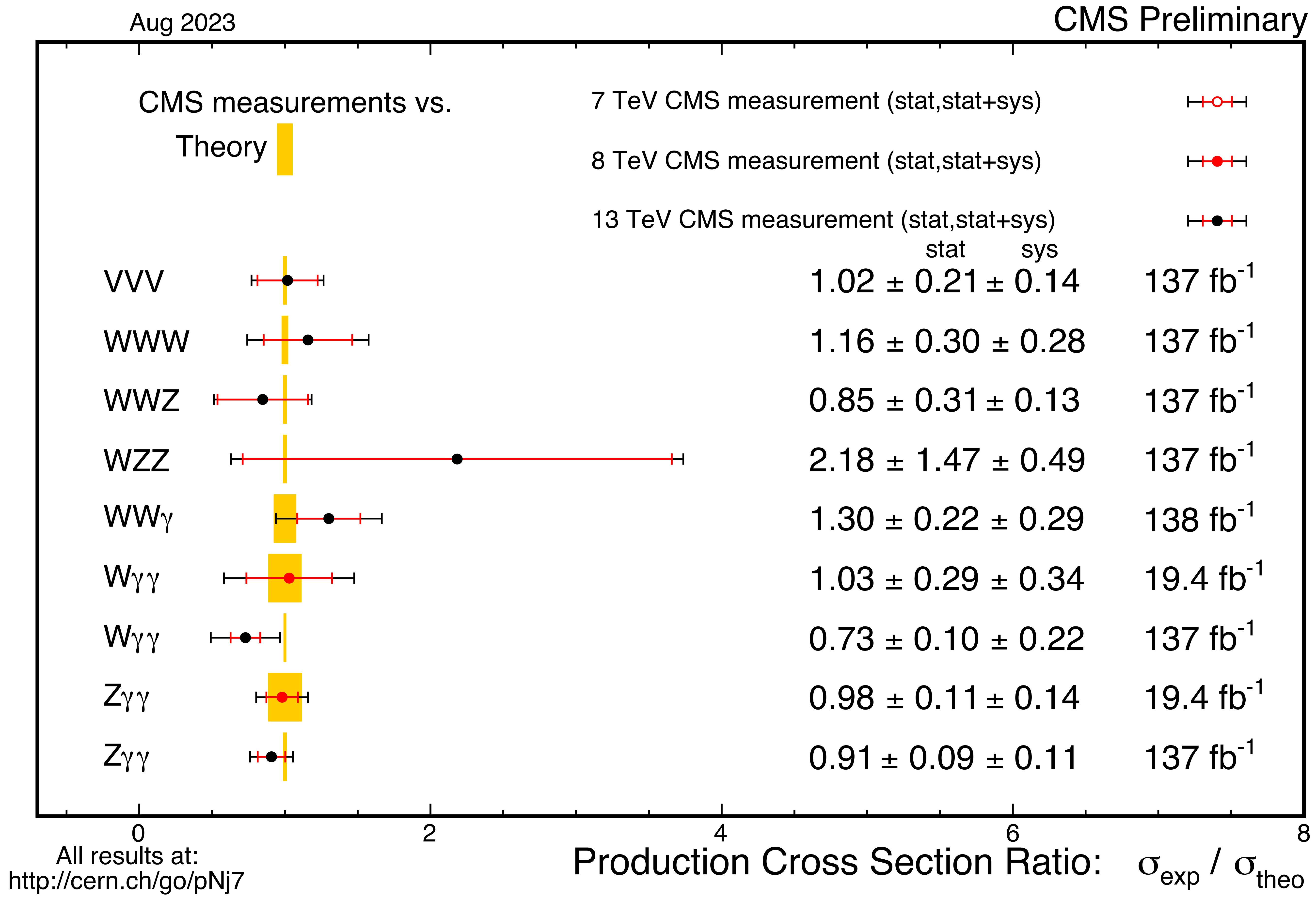
$$\sigma_{fid} = 12.1^{+2.5}_{-2.2}\ \text{fb}^{-1}$$

	SR	TopCR
$W\gamma\gamma$	410 ± 60	28 ± 5
Non-prompt $j\to\gamma$	420 ± 50	42 ± 20
Misidentified $e\to\gamma$	155 ± 11	120 ± 9
Multiboson ($WH(\gamma\gamma)$, $WW\gamma$, $Z\gamma\gamma$)	76 ± 13	5.2 ± 1.7
Non-prompt $j\to\ell$	35 ± 10	–
Top ($tt\gamma$, $tW\gamma$, $tq\gamma$)	30 ± 7	136 ± 32
Pileup	10 ± 5	–
Total	$1\,136 \pm 34$	332 ± 18
Data	$1\,136$	333



Tri-boson Summary

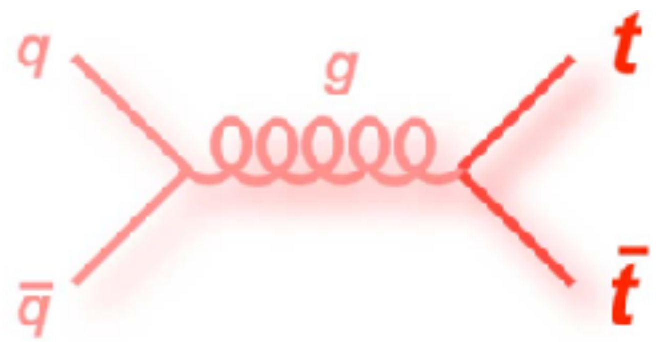
Summary (for CMS) of tri-boson processes, with already large number of final states studied!



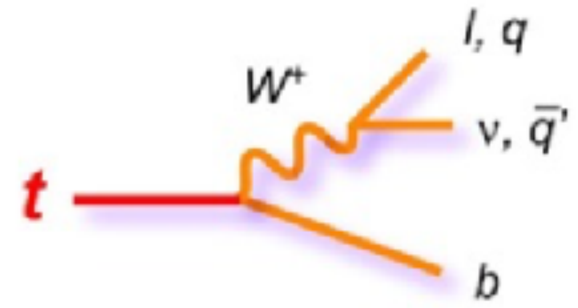
Top quark Production

Top pair production Cross Sections at the LHC

Top pair production is the main production mode of top quarks at the LHC



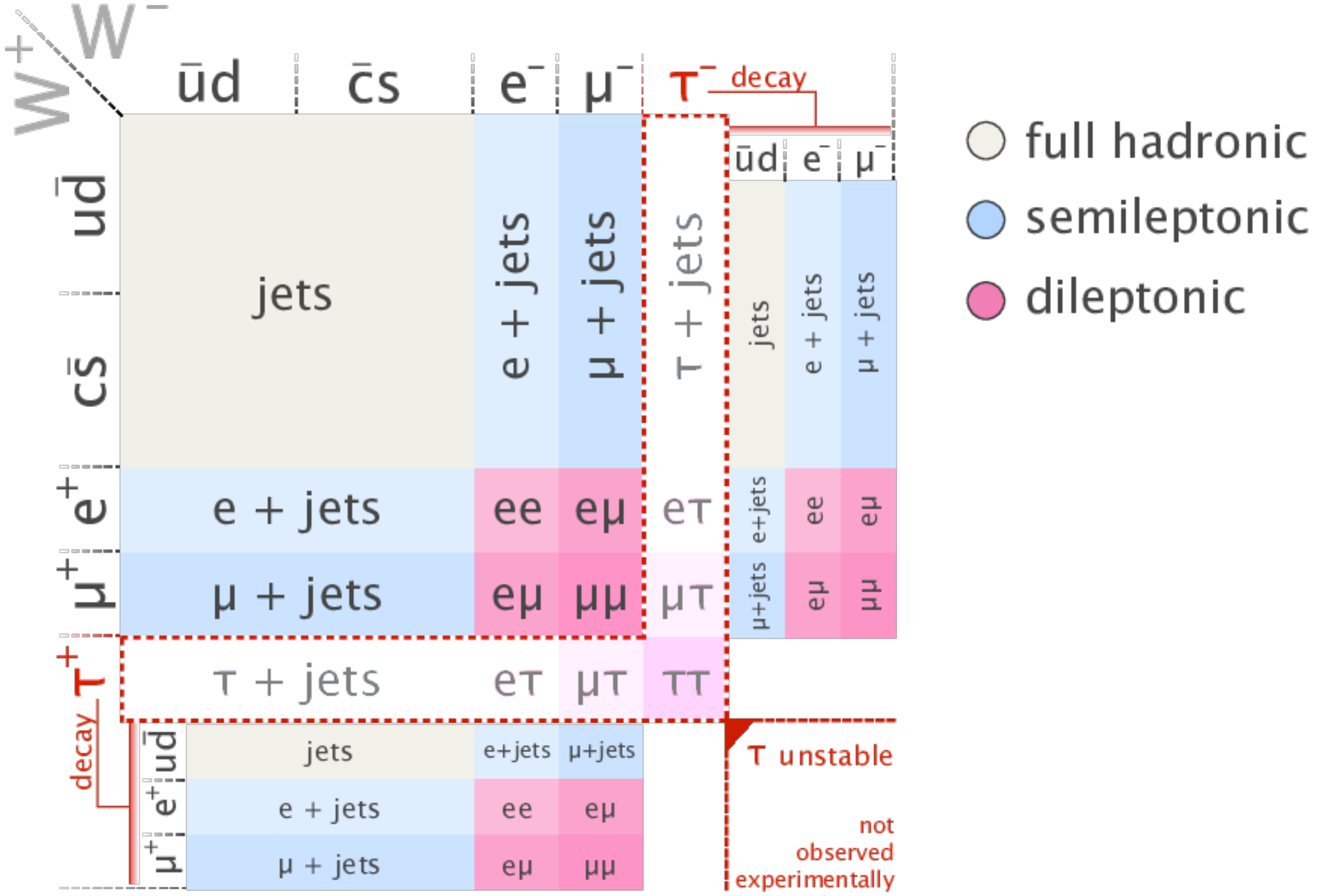
Each top quark decays mostly to a W and a b quark.



(Top pair production is de-facto a higher order special di-boson process)

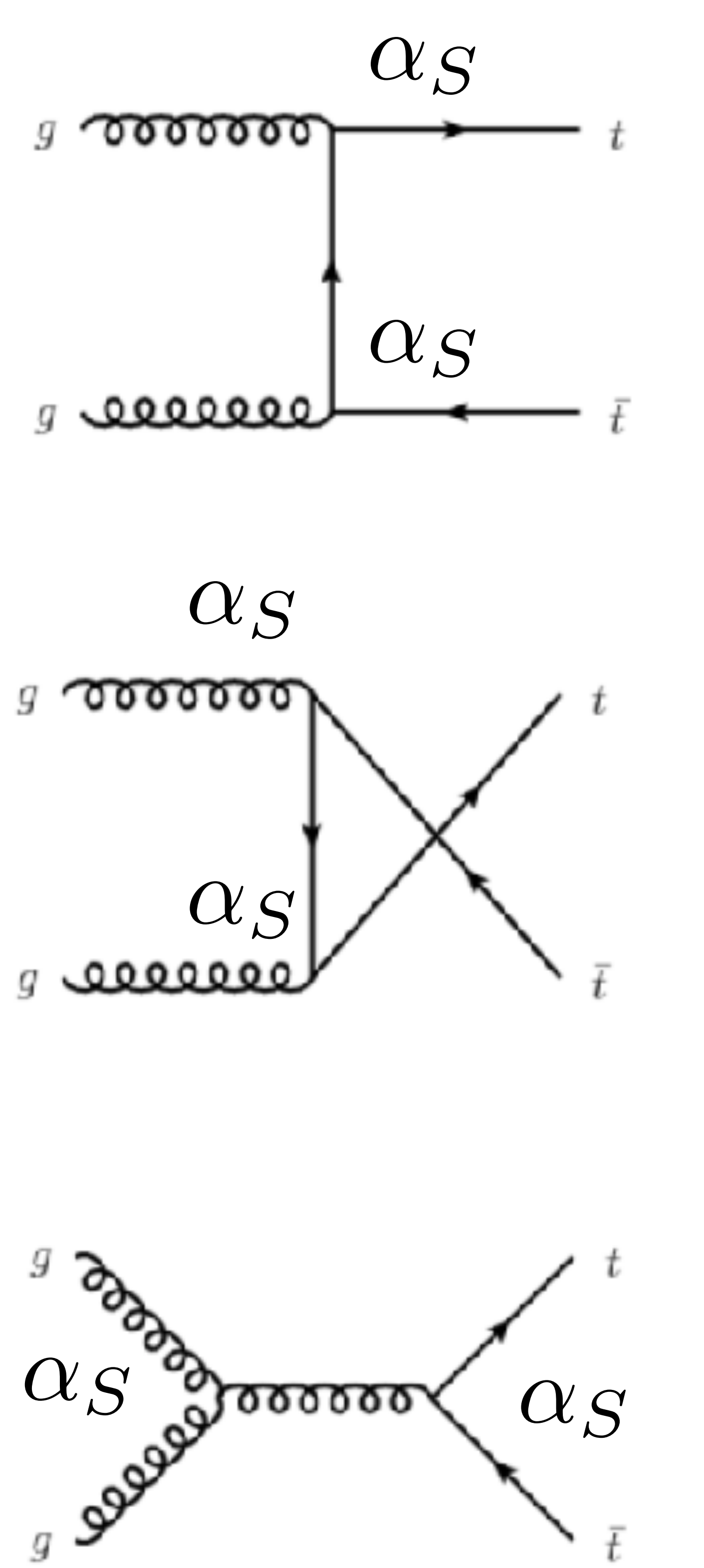
With possible decay modes of the W boson this gives rise to multitude of signatures (the most sensitive being the leptons-4jets)

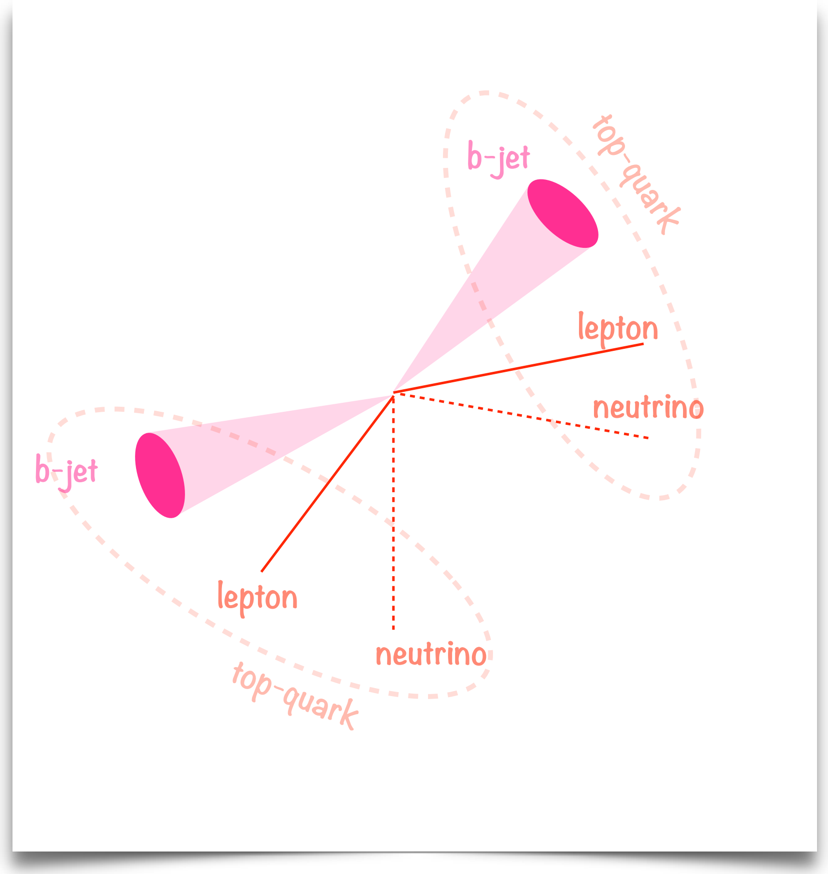
$$Br(W \to \ell\nu) = 10.9\,\%$$
$$Br(W \to \mathrm{u\bar{d}, c\bar{s}}) = 67.4\,\%$$



Top pair production Cross Sections at the LHC

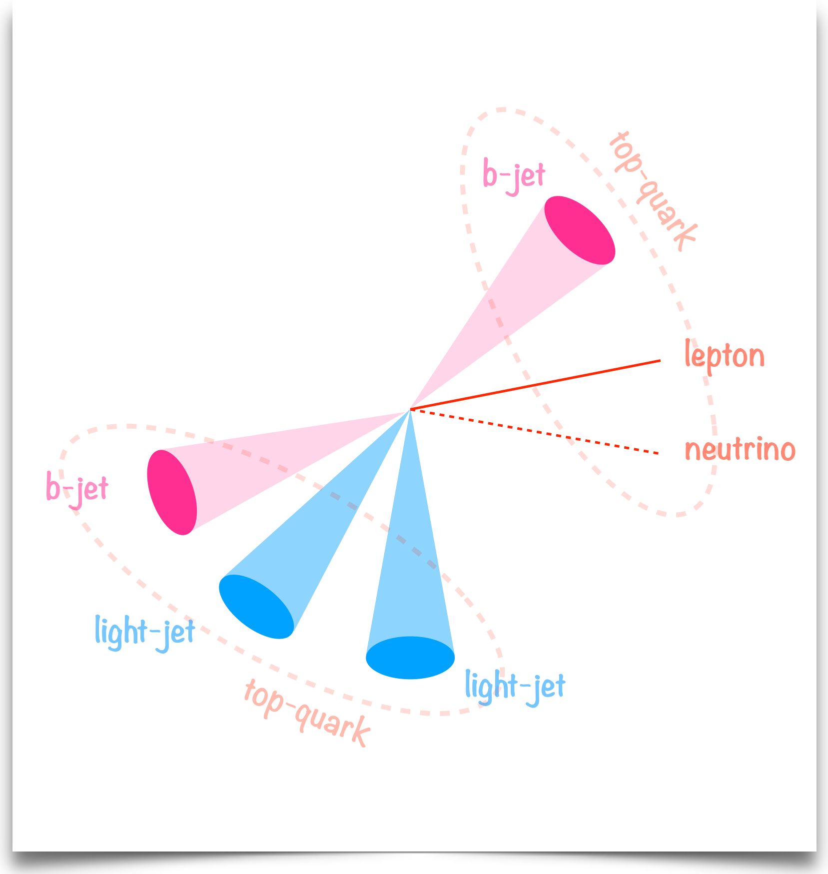
Main production diagrams
At tree level leading order
$O(\alpha_S^2)$





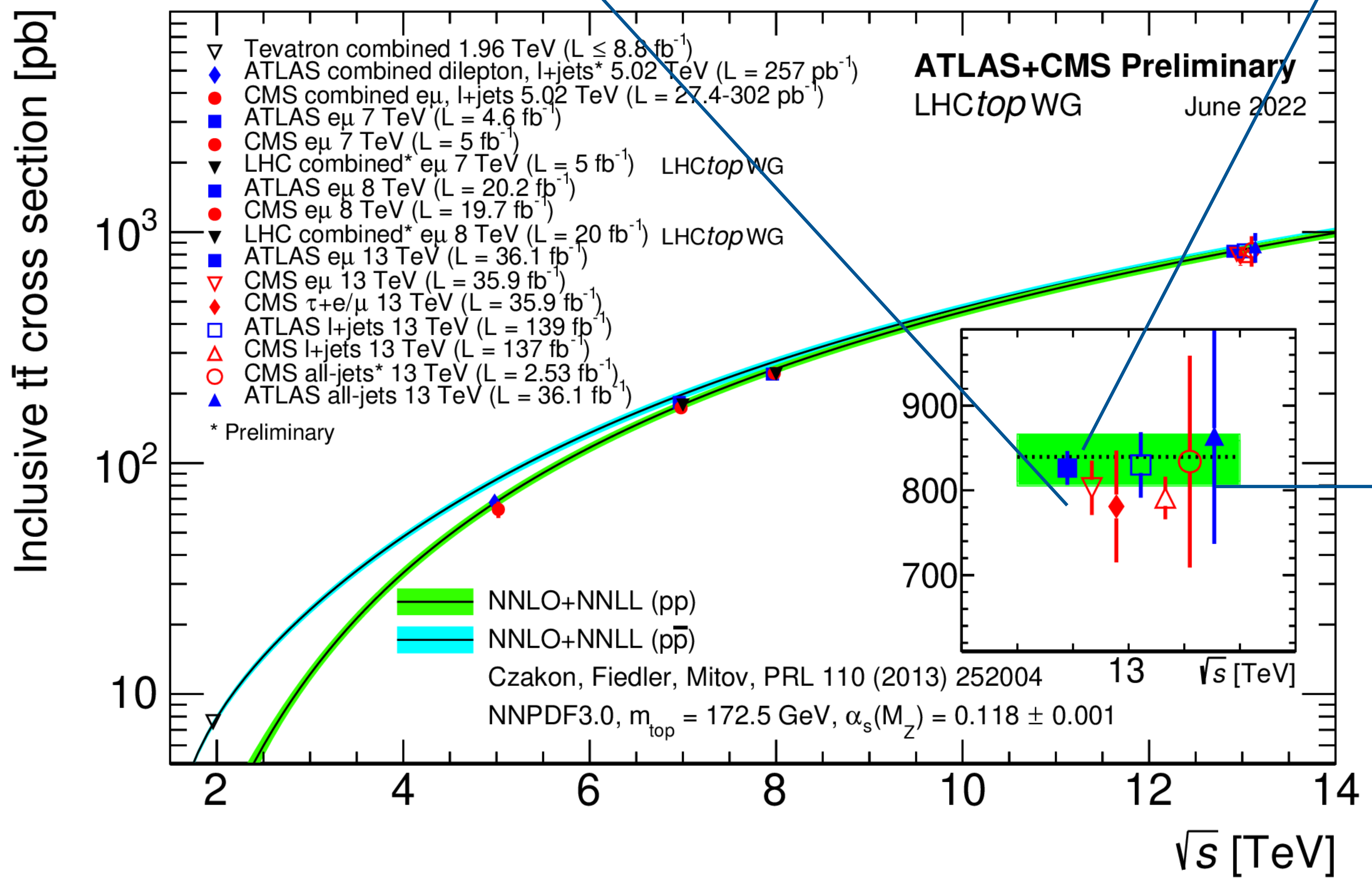
Di-lepton topology:

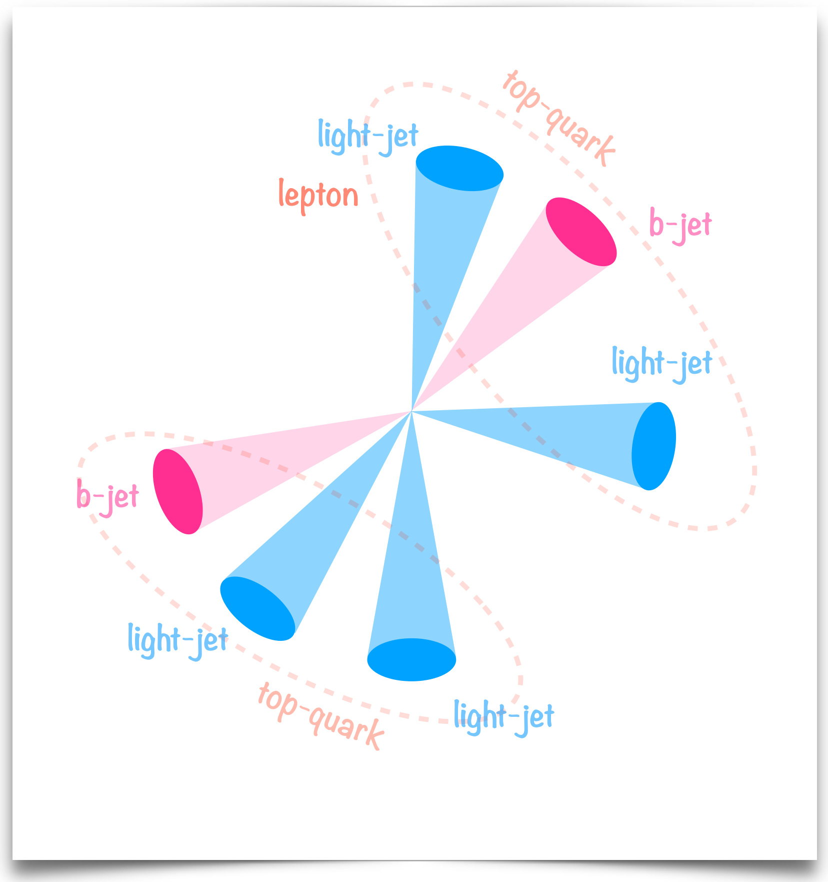
Excellent signal to background ratio in particular in the different flavour mode. Lower stats (4%).



Semi-leptonic topology:

Excellent compromise between statistics (30%) and signal to background ratio.





Full hadronic topology:

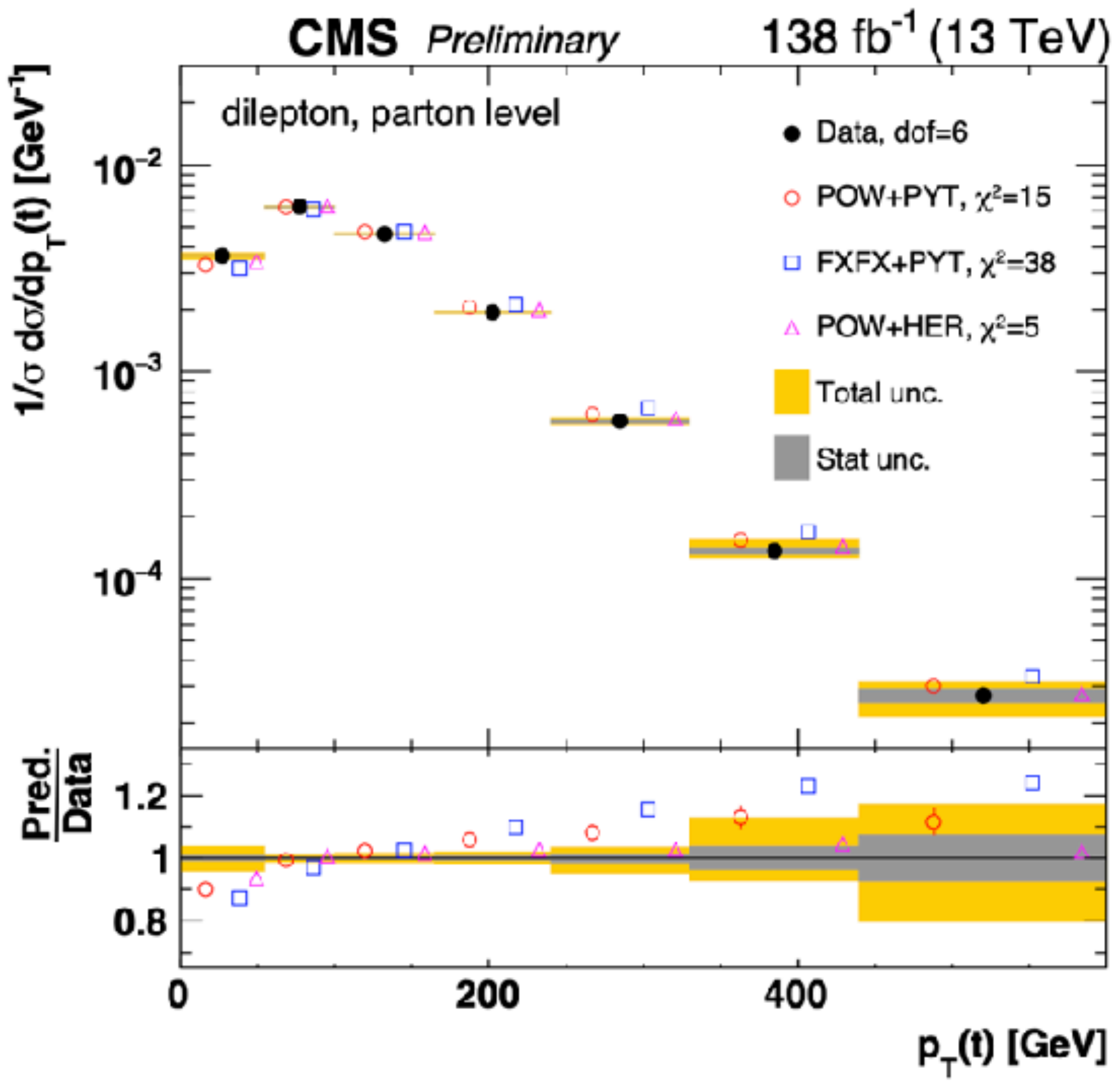
Largest stats (50%) but larger multi-jet background and large combinatorial.

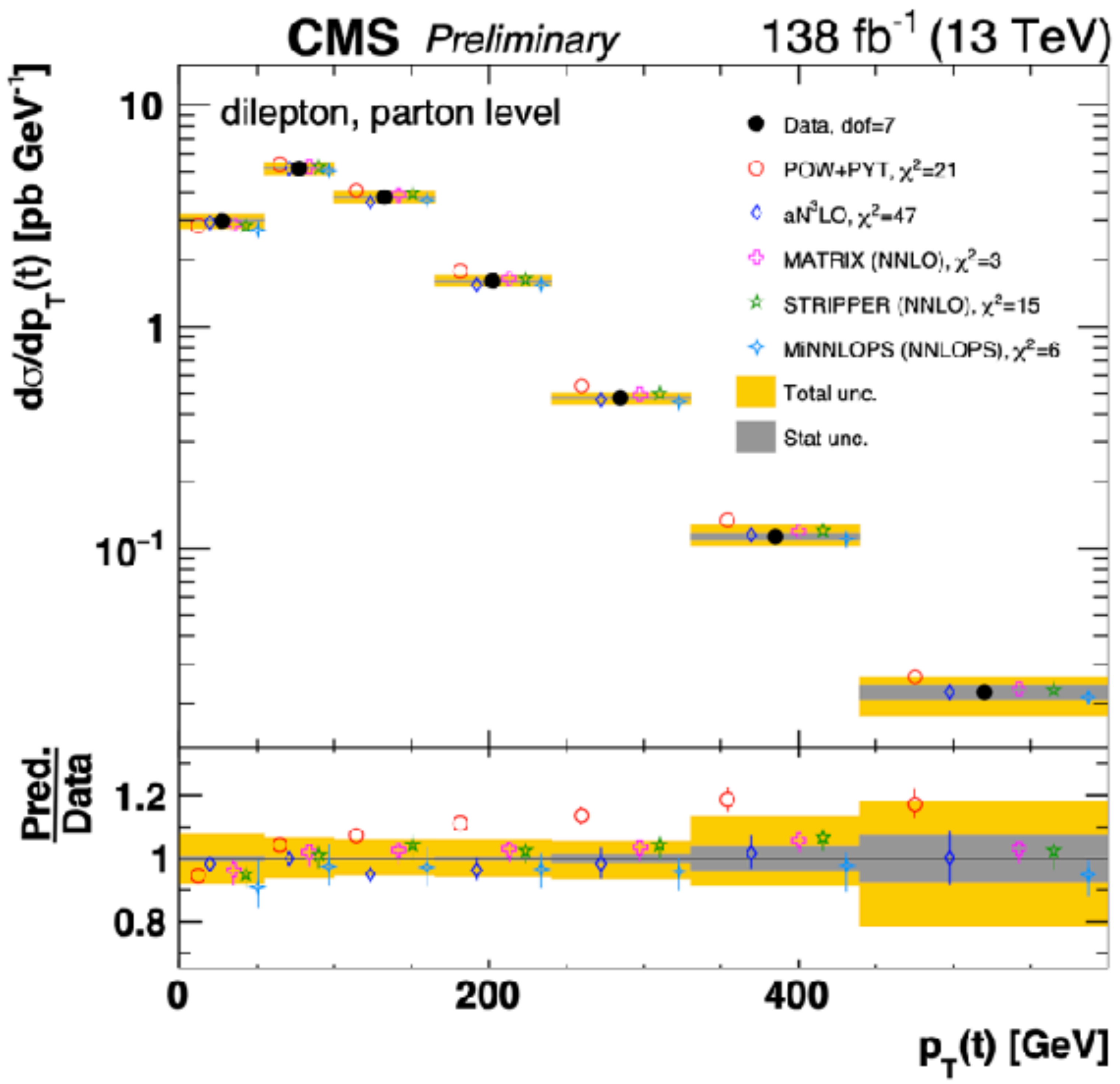
Top Production Modelling

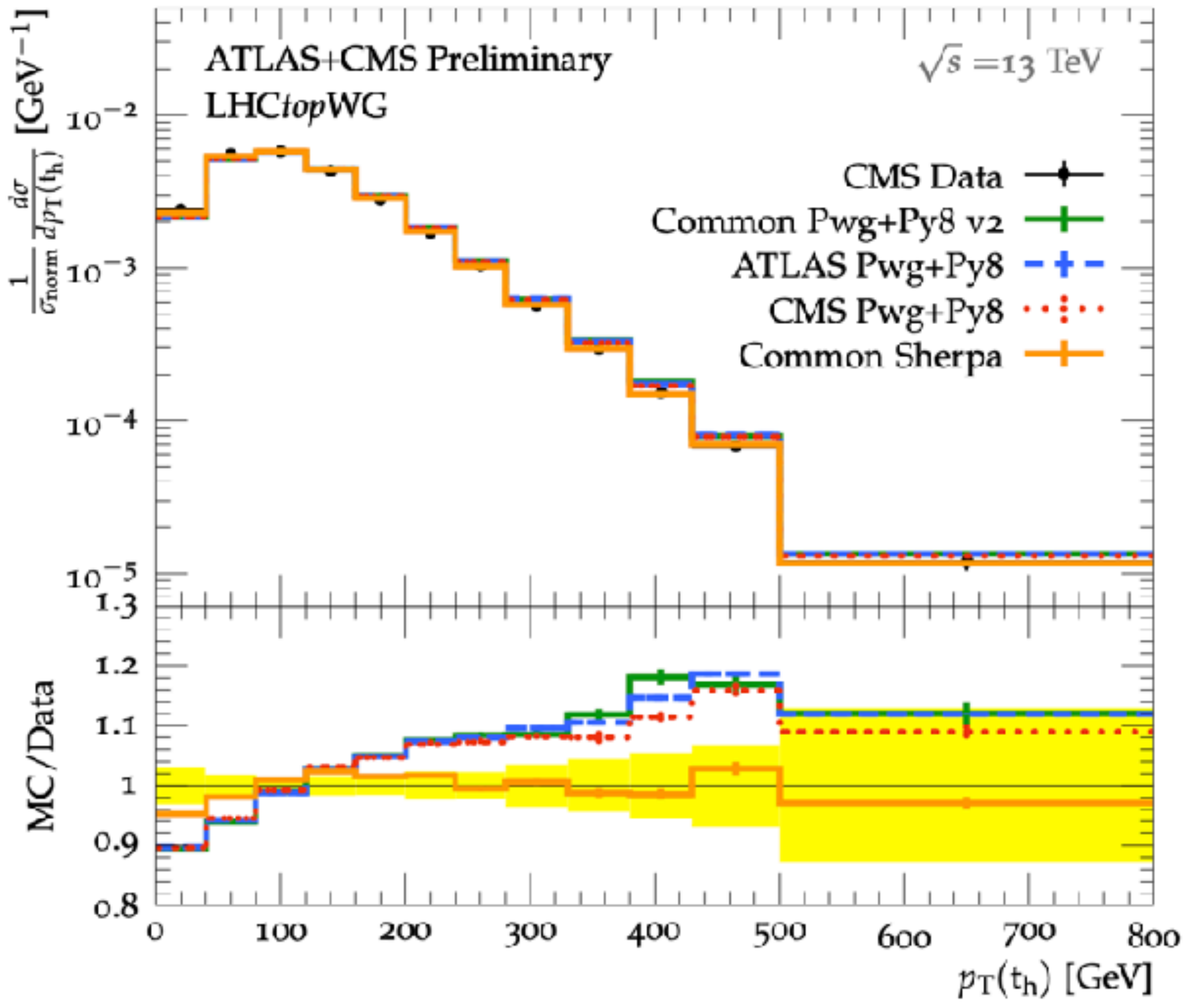
Excerpts from recent top pair production differential cross section measurements (paper link):

“NLO Monte Carlo generally fail to describe a large fraction of the measured cross sections. The calculations predict the top quark and antiquark to have harder transverse momentum and more central rapidity distributions than observed in the data.”

“NNLO model provides a data description quality that is on average comparable but not better than that of the NLO MC models”.



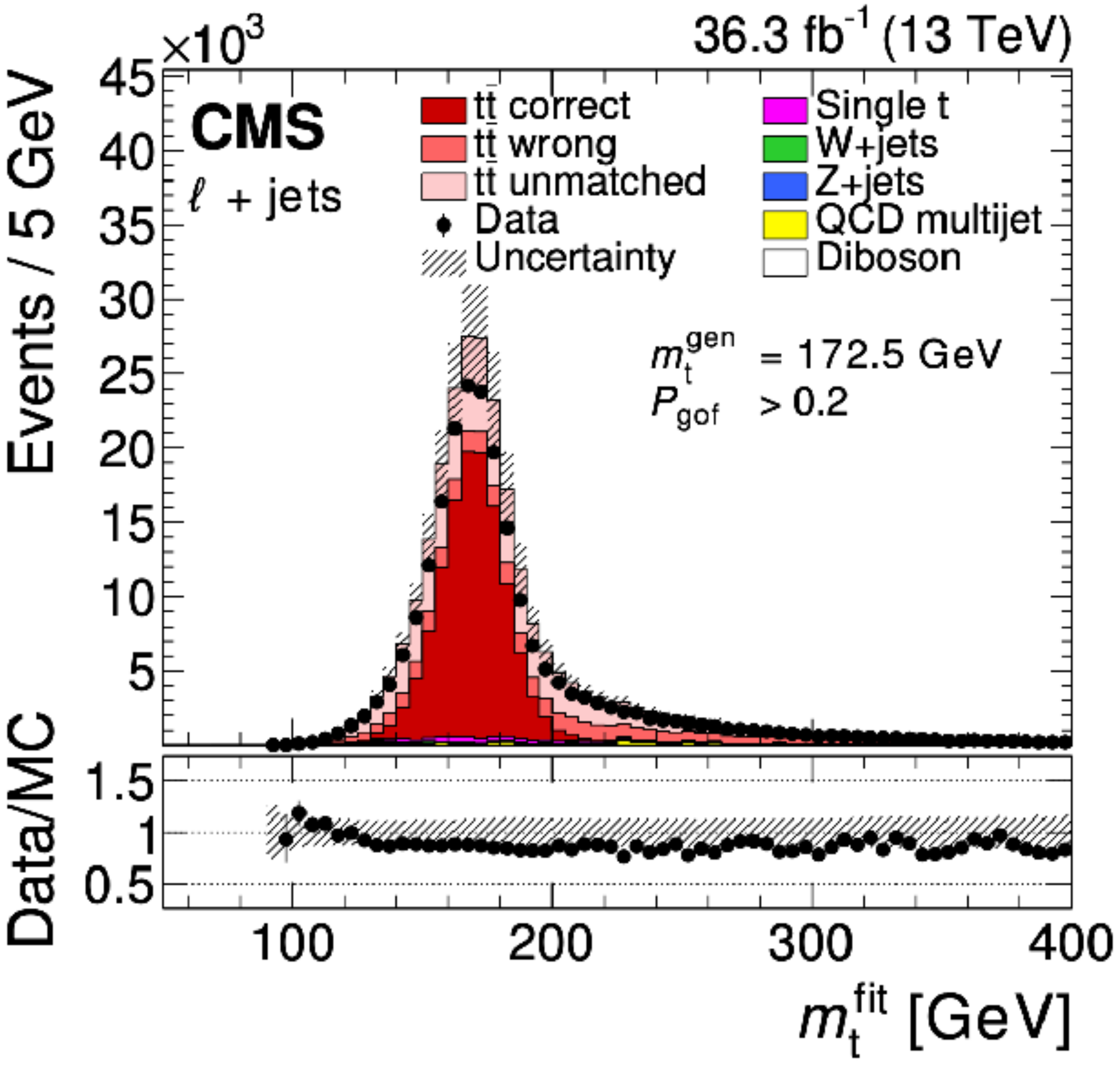




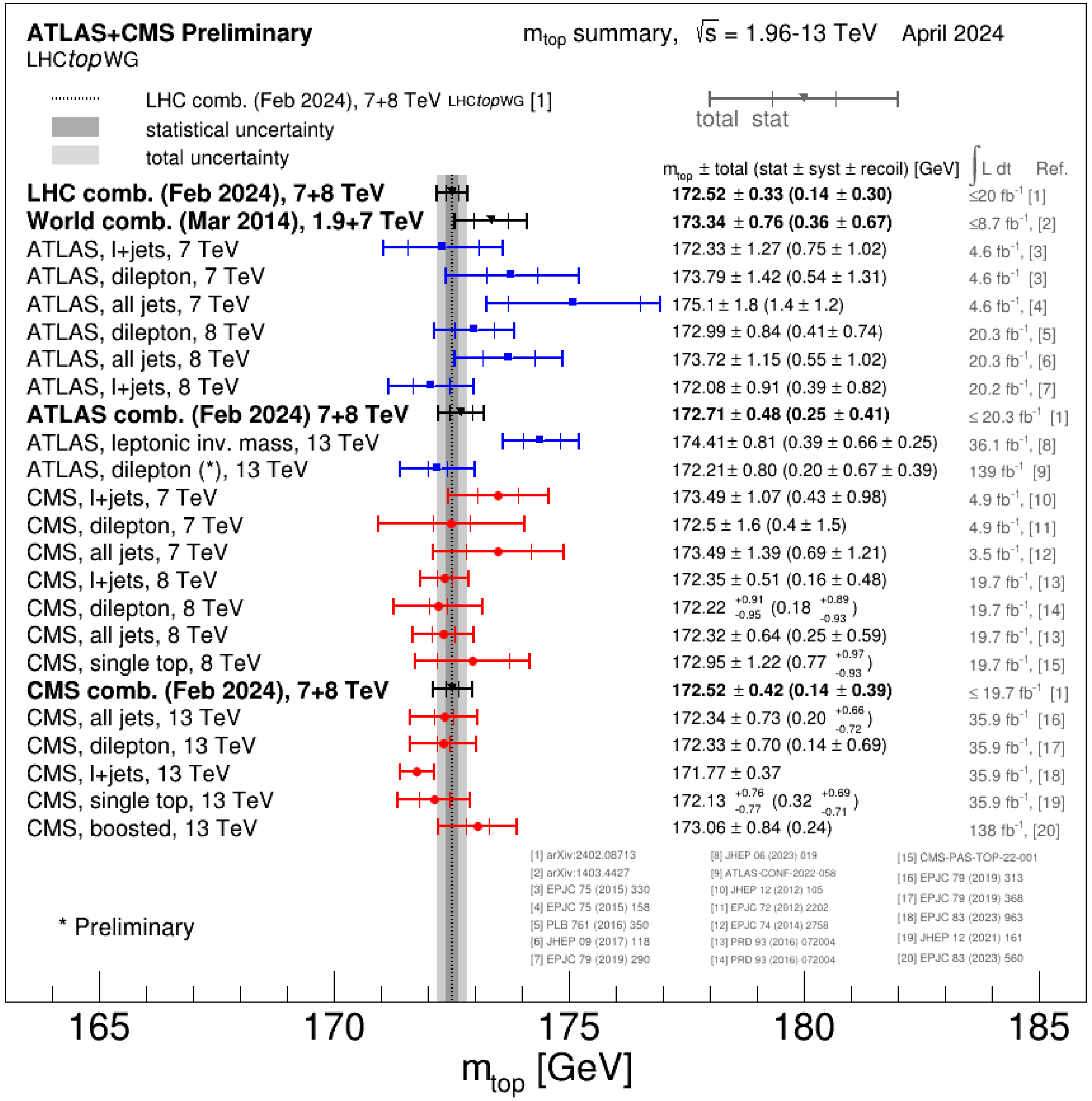
Common TH, ATLAS and CMS effort to address this modelling challenge.

Direct Top Mass Measurements

Most precise individual direct top mass measurement

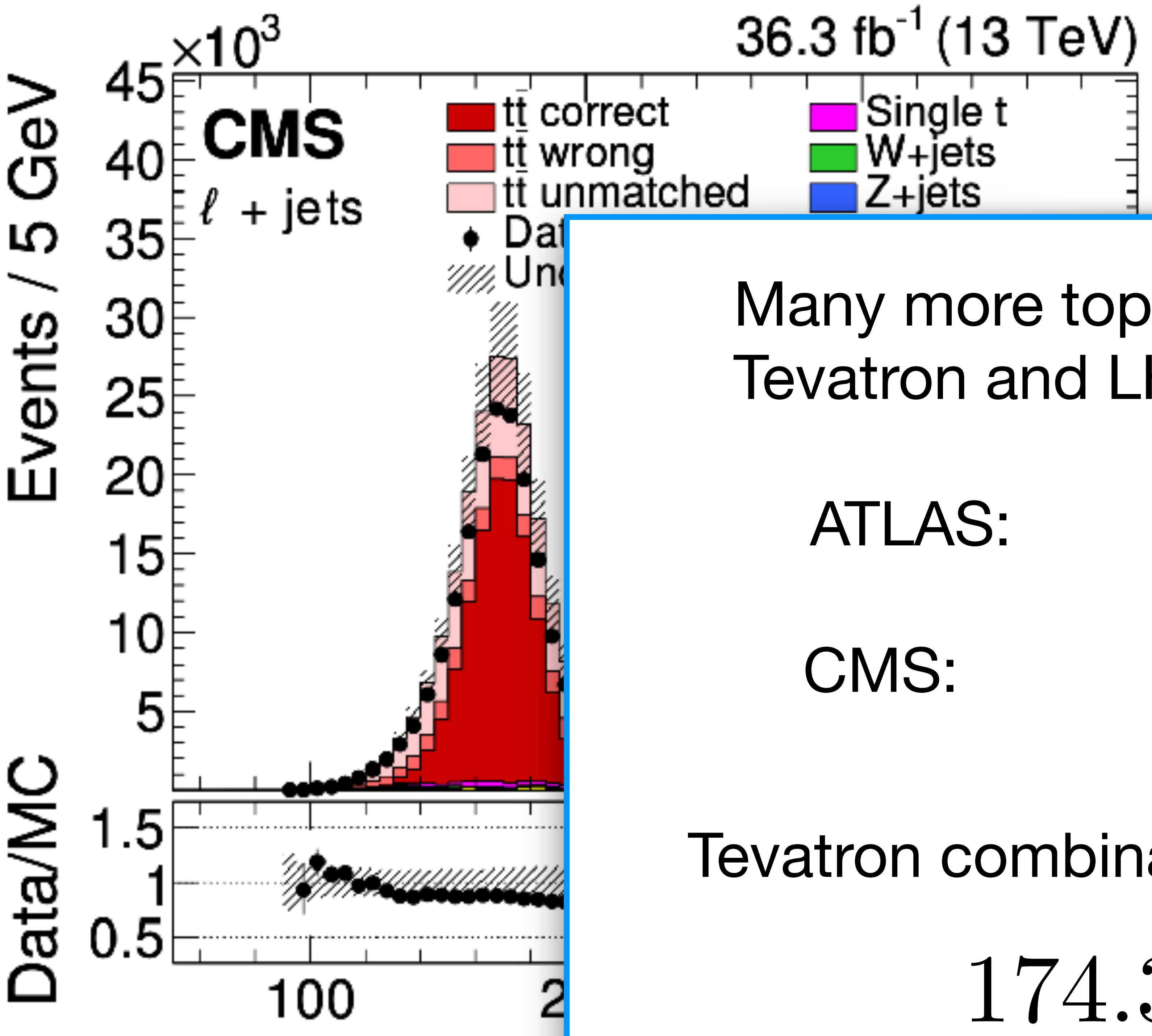


$$171.77 \pm 0.04\,(\text{stat}) \pm 0.37\,(\text{syst})\ \text{GeV}$$

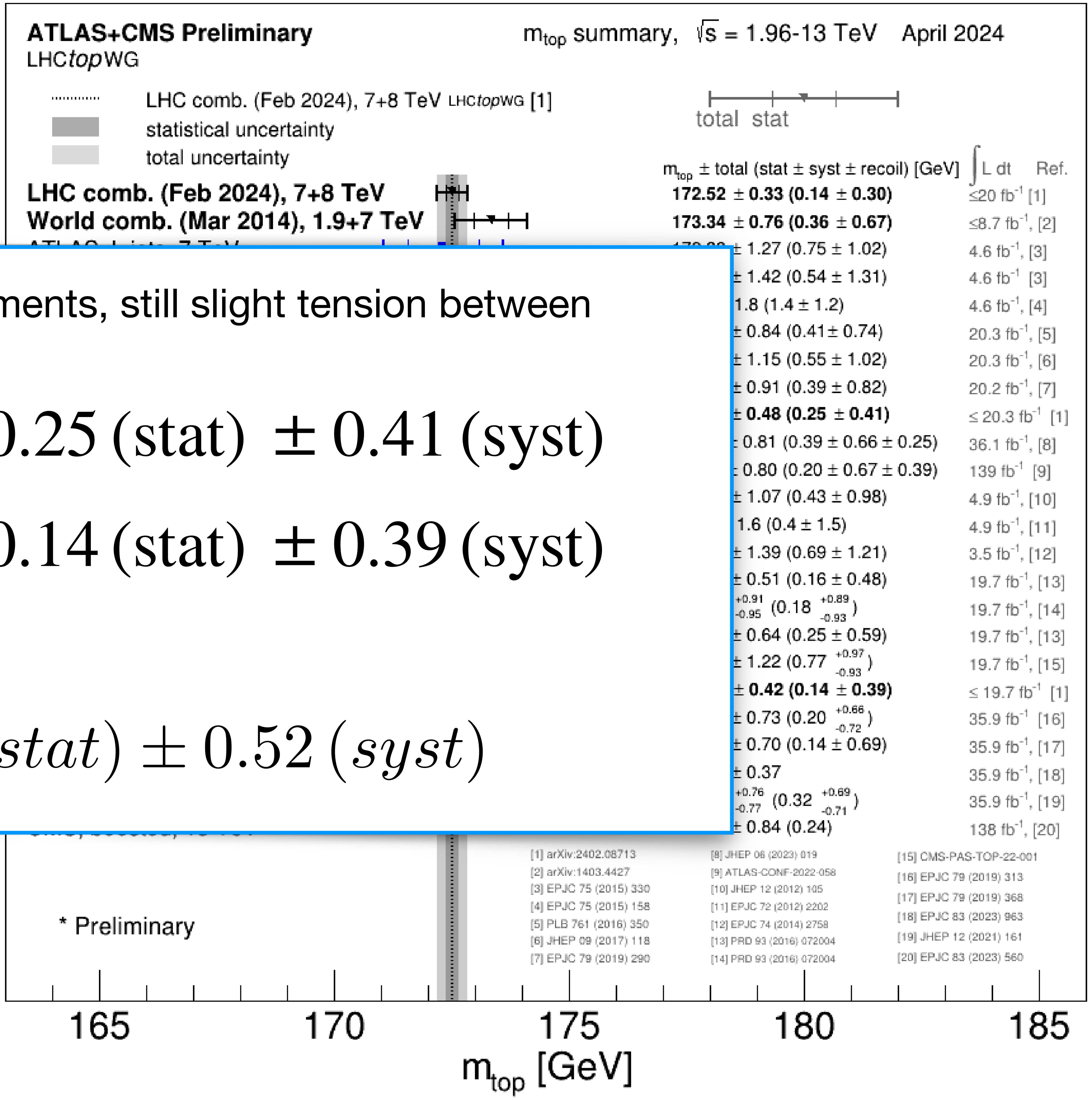


Direct Top Mass Measurements

Most precise individual direct top mass measurement



$$171.77 \pm 0.04\,(\text{stat}) \pm 0.37\,(\text{syst})\ \text{GeV}$$



Many more top mass measurements, still slight tension between Tevatron and LHC…

ATLAS: $$172.71 \pm 0.25\,(\text{stat}) \pm 0.41\,(\text{syst})$$

CMS: $$172.52 \pm 0.14\,(\text{stat}) \pm 0.39\,(\text{syst})$$

Tevatron combination:

$$174.34 \pm 0.37\,(stat) \pm 0.52\,(syst)$$

Direct Top Mass Measurements

Some basic and key concepts

1.- The correct assignment of b-jets to each top is essential to the measurement of the top mass.

2.- Observables are either the mass of the 3-jet qqb system or the ℓb system depending on the W decay.

3.- The W mass can be used to calibrate in-situ the jets from the hadronic W decays.

4.- The b-jet energy scale is a key element in the measurement of the top mass.

Taking a closer look at the top mass table!

1.- l-jets channels have reached excellent statistical precision.

2.- The di-lepton channel also the statistical uncertainty is now sub-dominant.

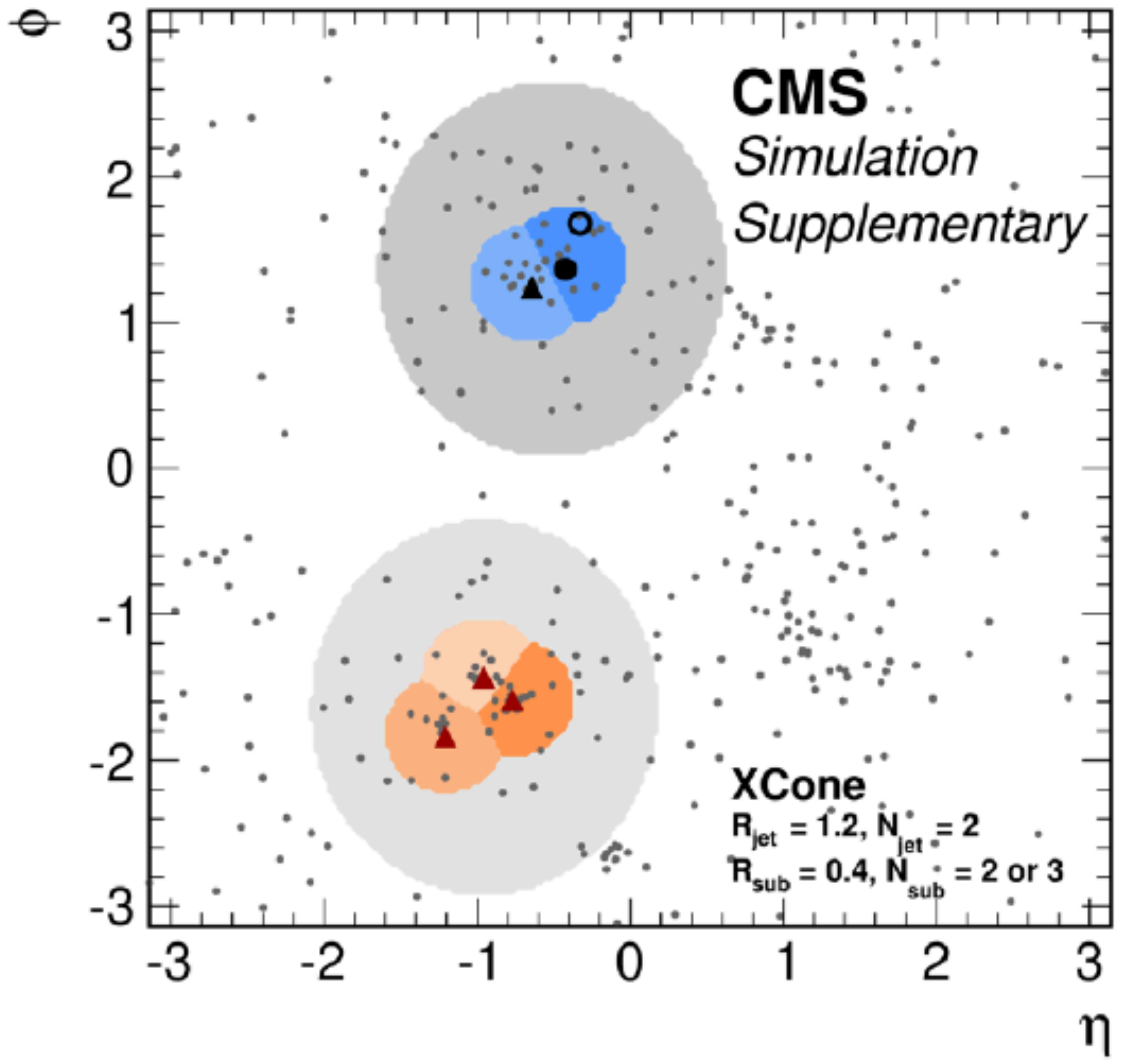
3.- There are significant differences in systematic uncertainties between ATLAS and CMS.

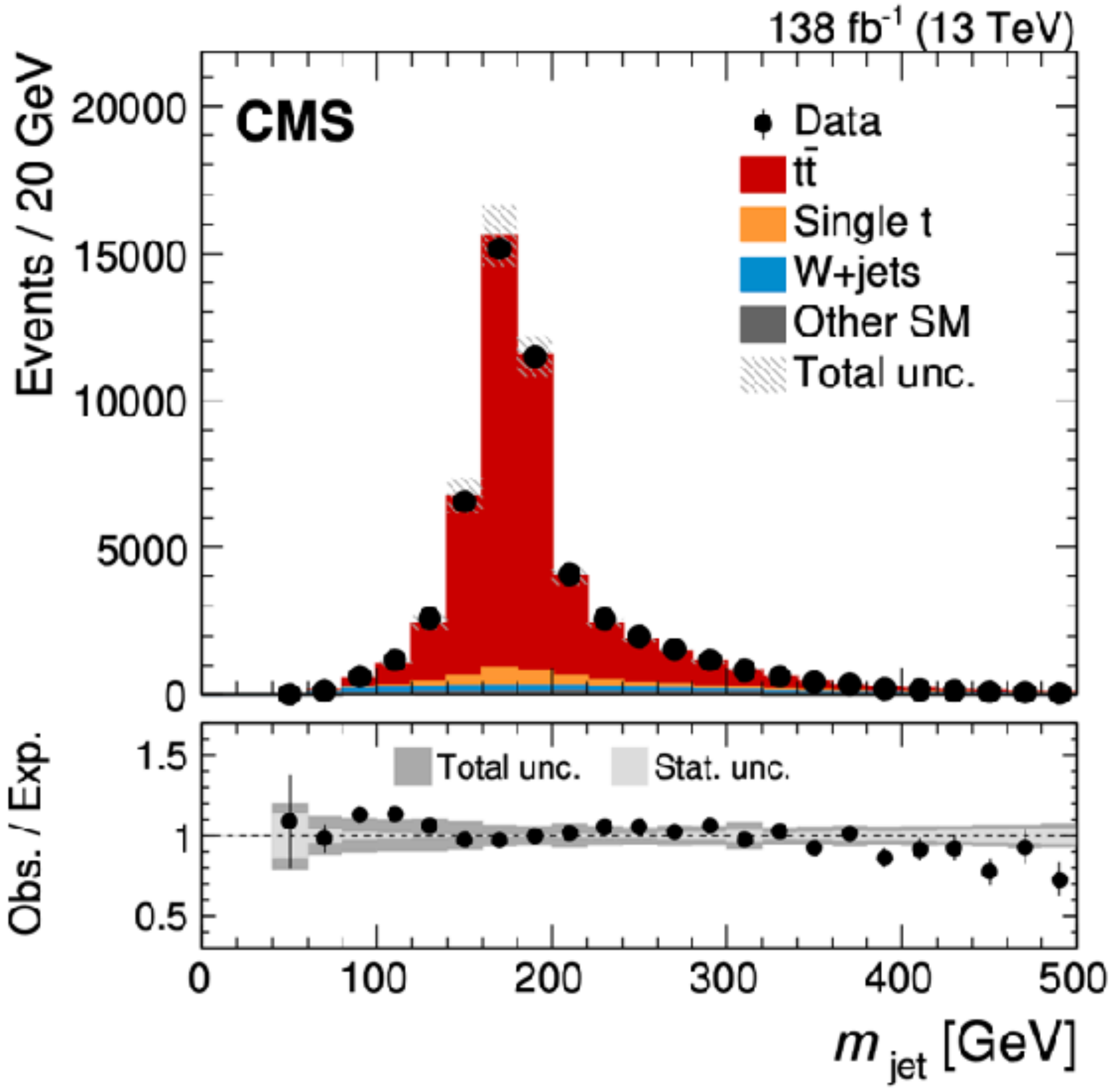
4.- New channels for the ‘direct’ mass measurement are investigated (single-top production, boosted top).

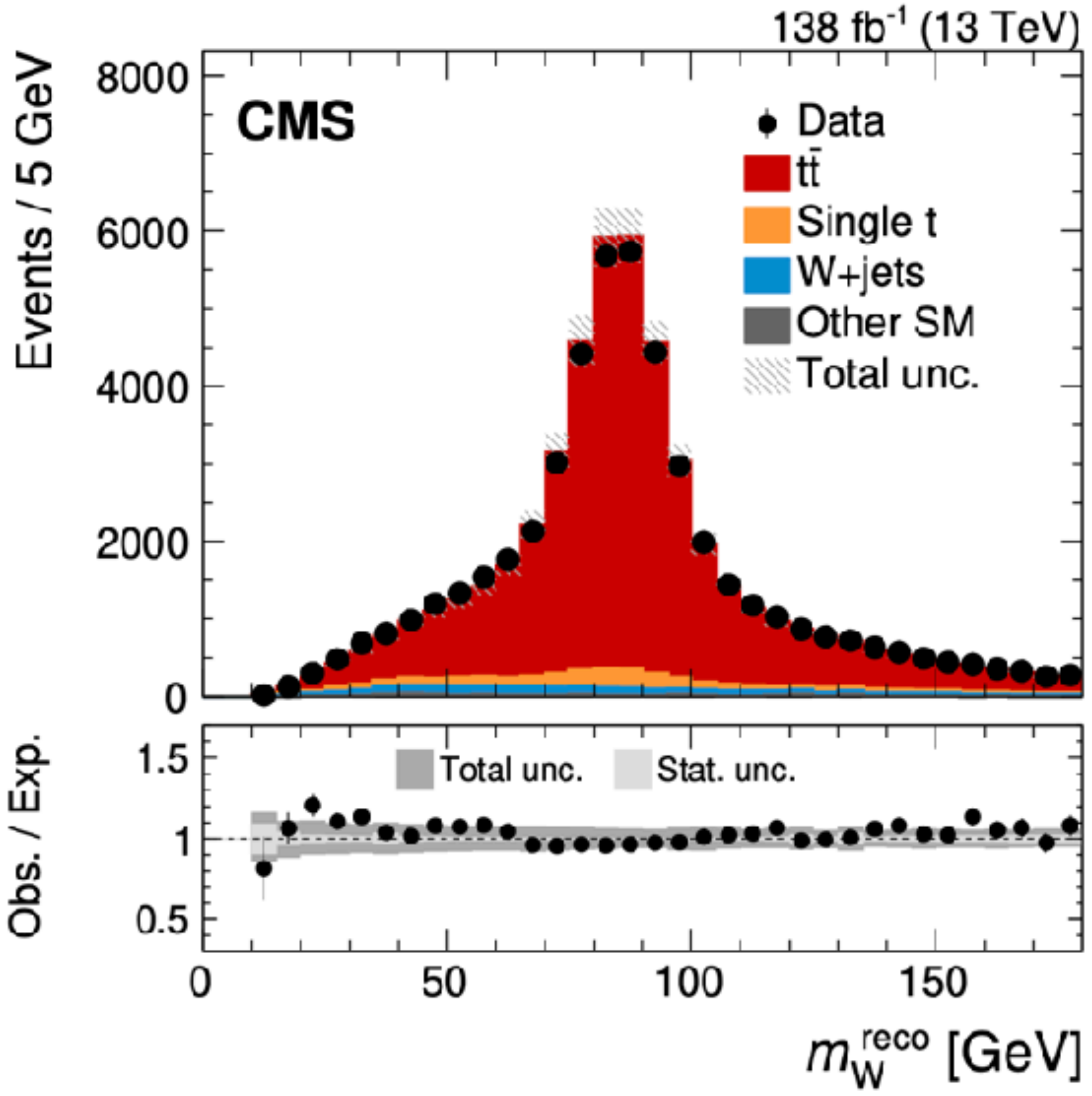
Boosted (top) Tagging

Boosted jet reconstruction with substructure has become a very active and exciting field! (See this summer's Boost conference in Genova!)

First introduced for Higgs boson reconstruction (Butterworth, Davison, Rubin and Salam - paper)

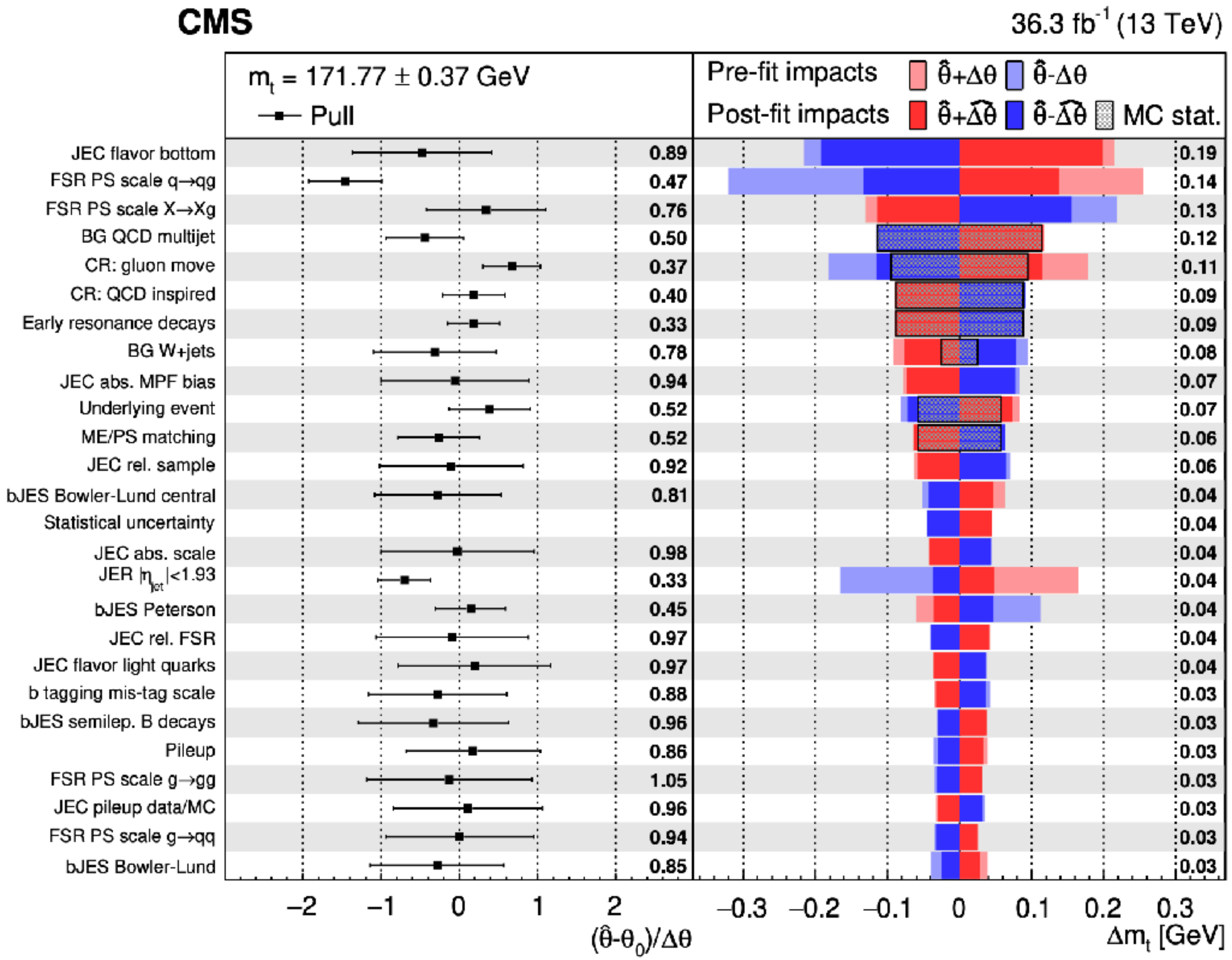






Tagging of hadronically decaying boosted heavy particles (W, Z, Higgs and top) has led to large improvements in the performance of the reconstruction of these objects and subsequently in a vast number of measurements and searches!

Digression on the Profiling Paradigm



1.- The dominant systematic uncertainties are b-JES and modelling.

2.- **Impact of MC uncertainties or limited MC stats** (this is a growingly important issue in a large number of analyses!)

3.- Profiling paradigm is a subject of debate (different approaches between ATLAS and CMS).

Personal view on profiling: as long as a single parameter is not overwhelmingly dominating the uncertainty, the specific distribution chosen should not matter so much (in the limit of large number of parameters, the central limit theorem should correctly lead to a gaussian distribution of the overall uncertainty). In the case of an outstanding systematic, there is no problem in not profiling it.

Digression on the Mass Measurement

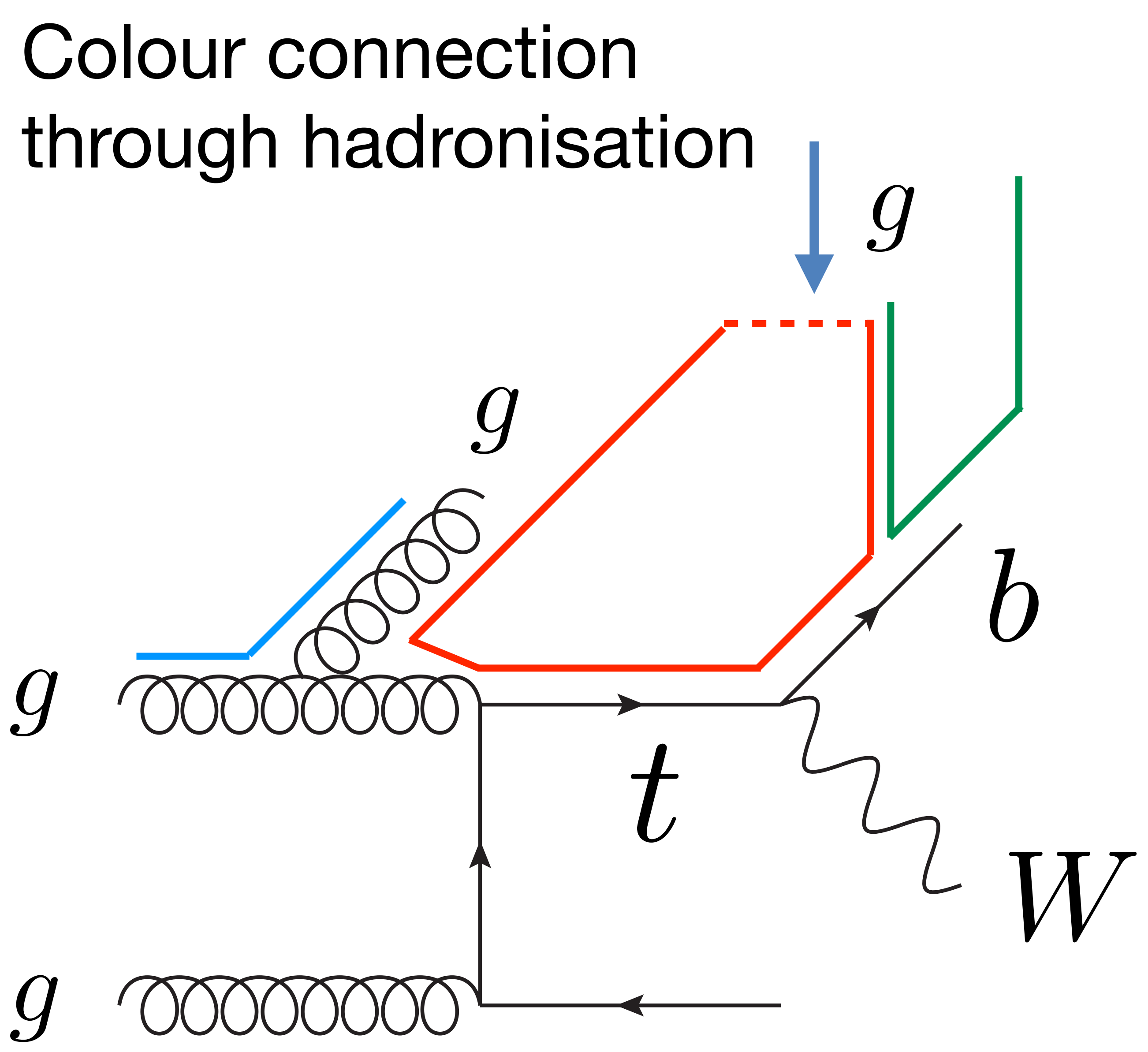
The relation between the Monte Carlo template used to fit the mass spectrum and the Field Theoretical parameter of the pole mass is not straightforward.

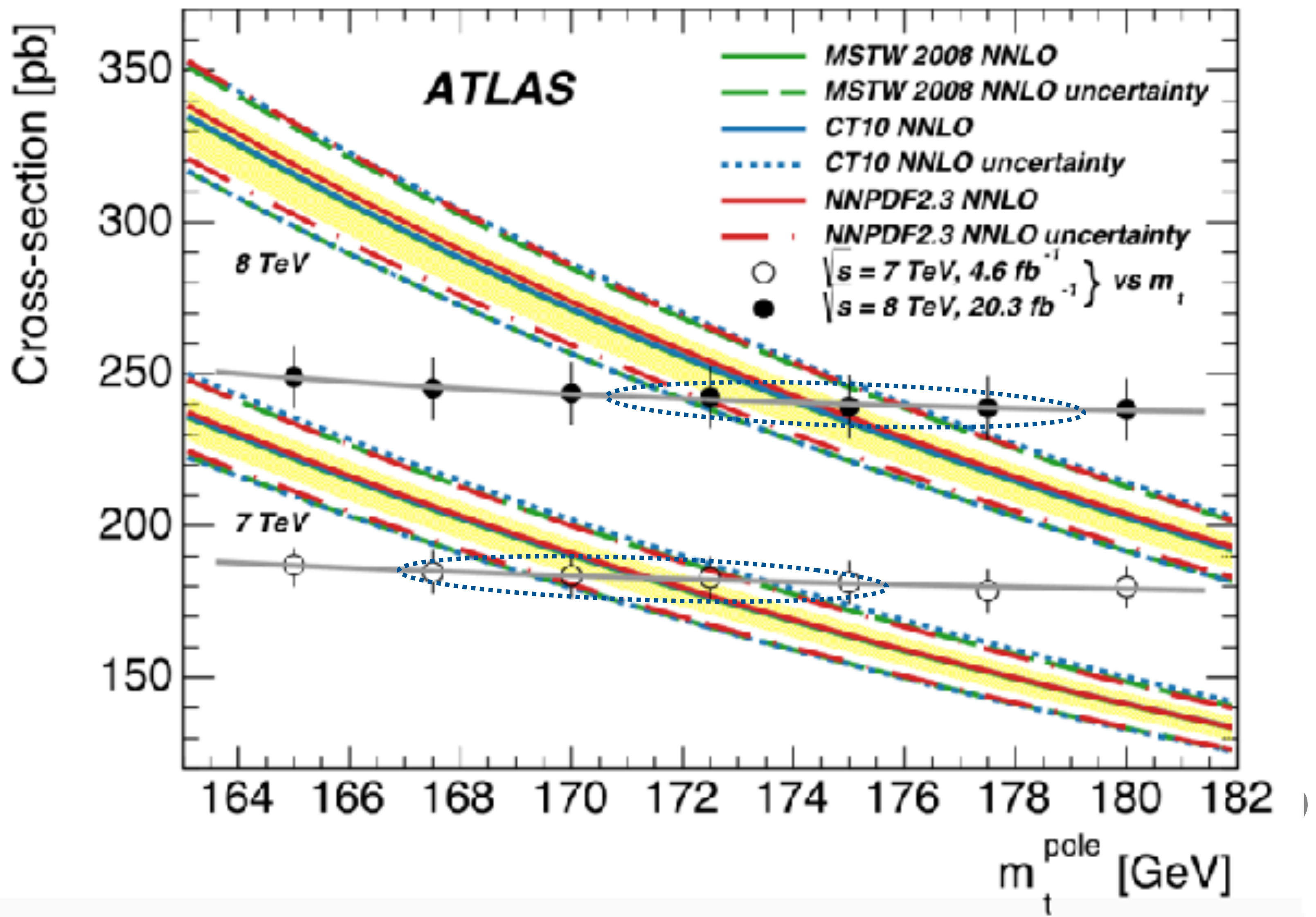
The top is coloured, so it is impossible to unambiguously associate every object in the final state to it!

These ambiguities lead to an uncertainty on the top mass measurement varying between 1 GeV and 200 MeV.

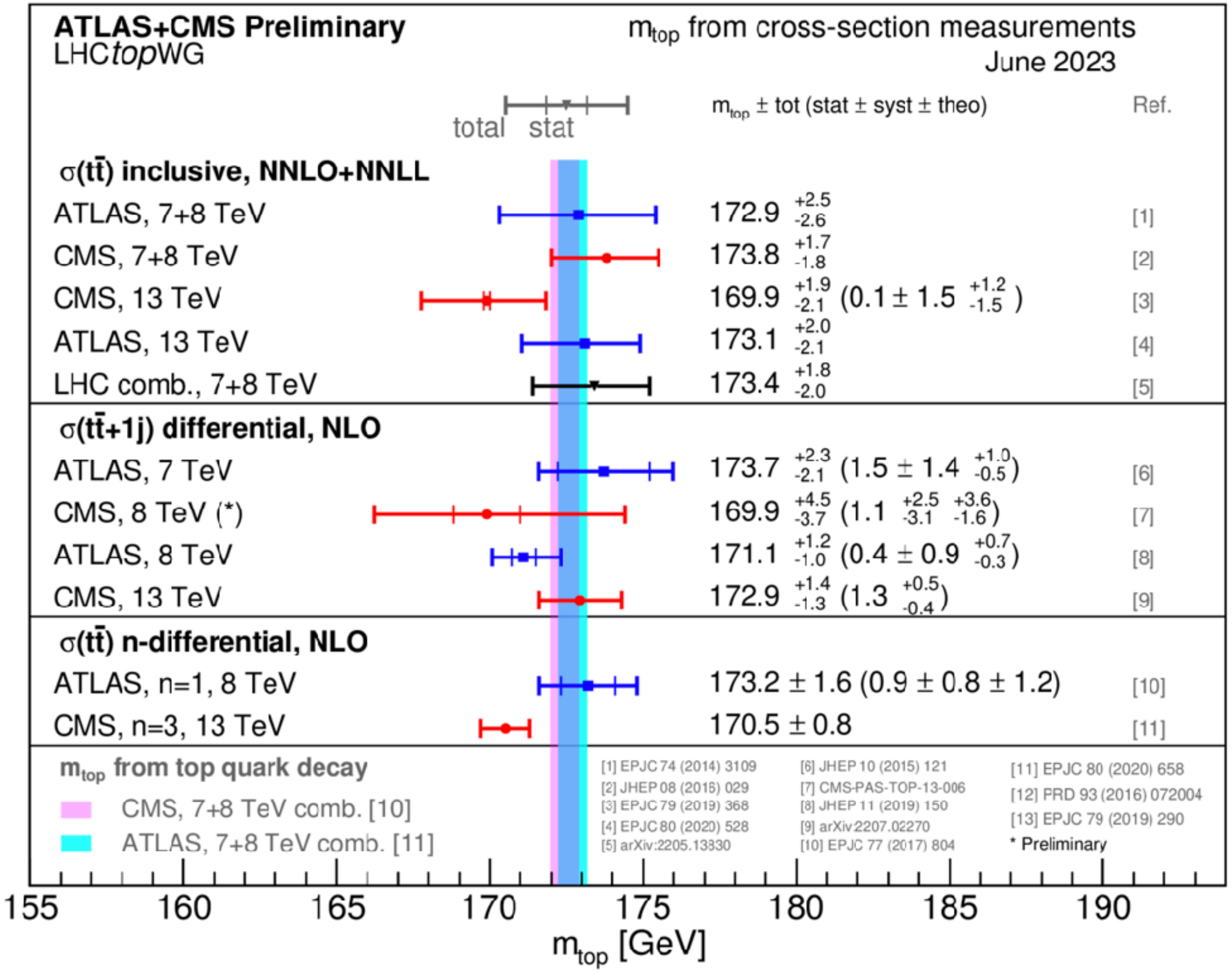
The pole mass can be measured using observables that are not dependent on the detailed reconstruction of the top system.

e.g. the pole mass can be measured using the top production cross section (at the cost of introducing a dependence on the production prediction).



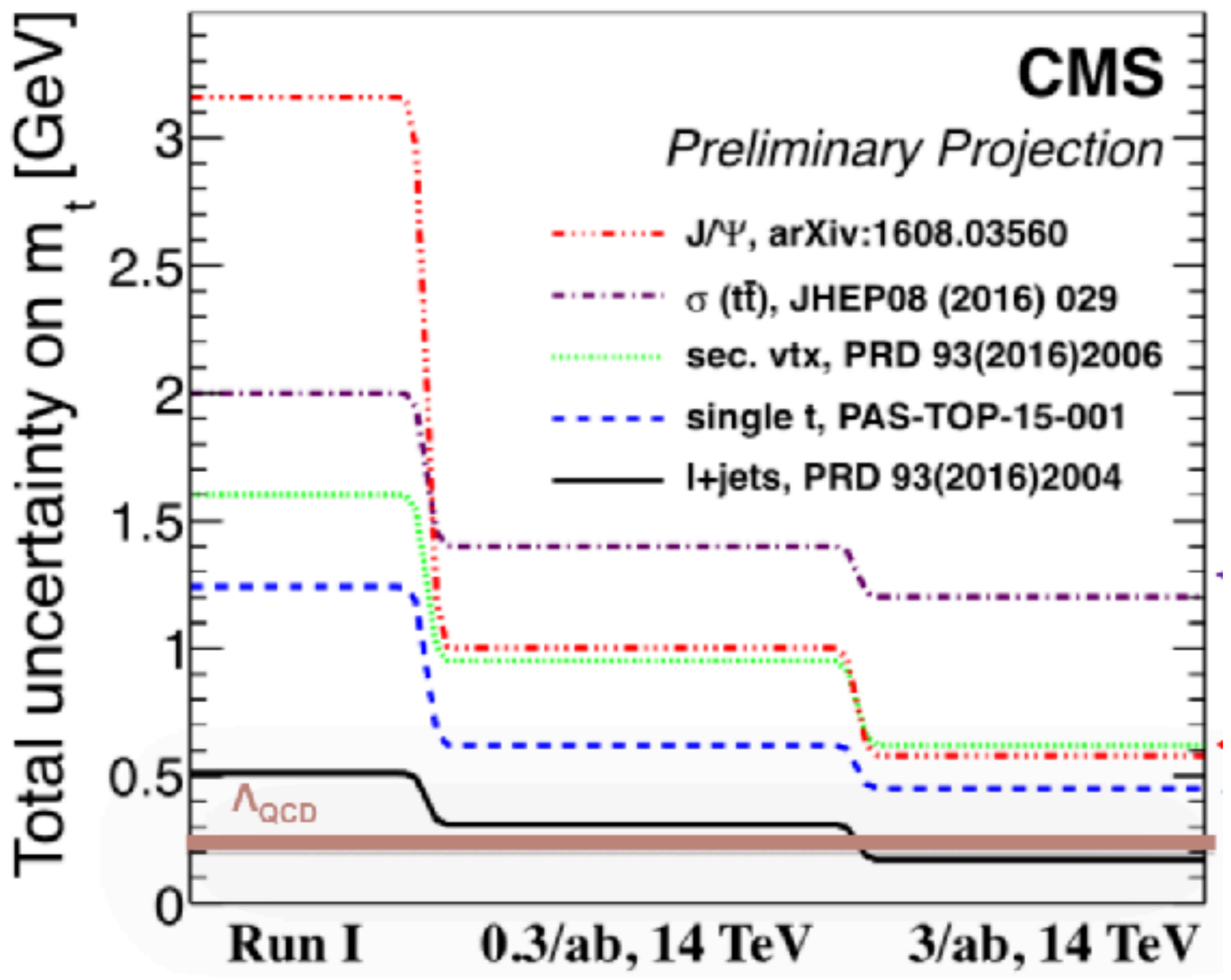


Top Mass from Cross-Section Measurements



Measurements from cross sections will be limited by prediction uncertainties and luminosity.

Study of the reach in precision at HL-LHC



Reaching a floor in the precision on the top mass at around HL-LHC Lambda QCD ~180 MeV

Top Pair Production at 5.02 TeV

Top pair production cross section measurement at 5.02 TeV

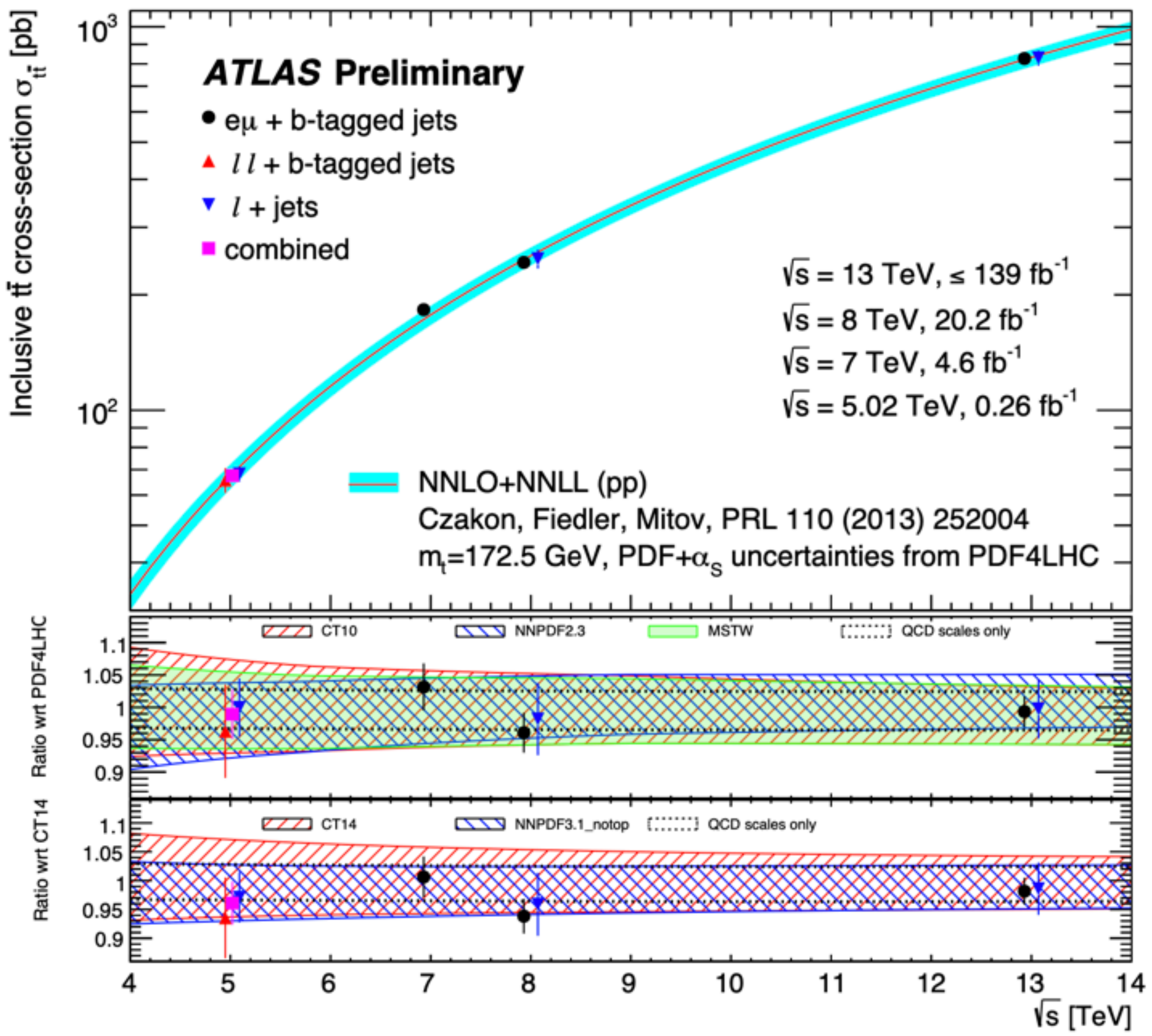
New lepton-jets measurement and combination with earlier di-lepton channel in low PU runs at 5.02 TeV

$$\sigma_{t\bar{t}} = 67.5 \pm 0.9\,(\text{stat.}) \pm 2.3\,(\text{syst.}) \pm 1.1\,(\text{lumi.}) \pm 0.2\,(\text{beam})\,\text{pb}$$

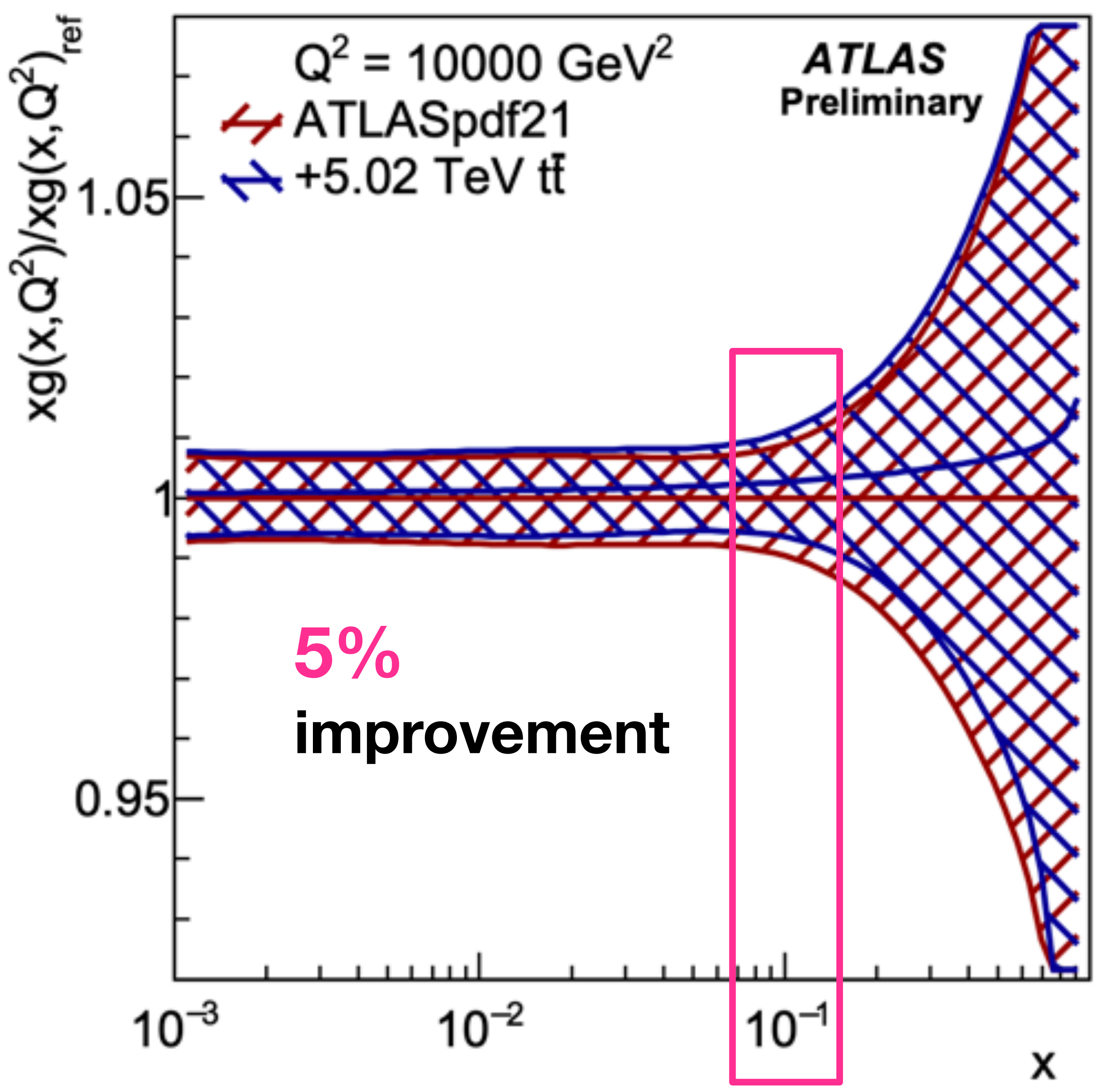
Excellent precision reached with small dataset of 0.26 fb^{-1}

In excellent agreement with the NNLO-NNLL TOP++ prediction

$$68.2 \pm 4.8^{+1.9}_{-2.3}\,\text{pb}$$

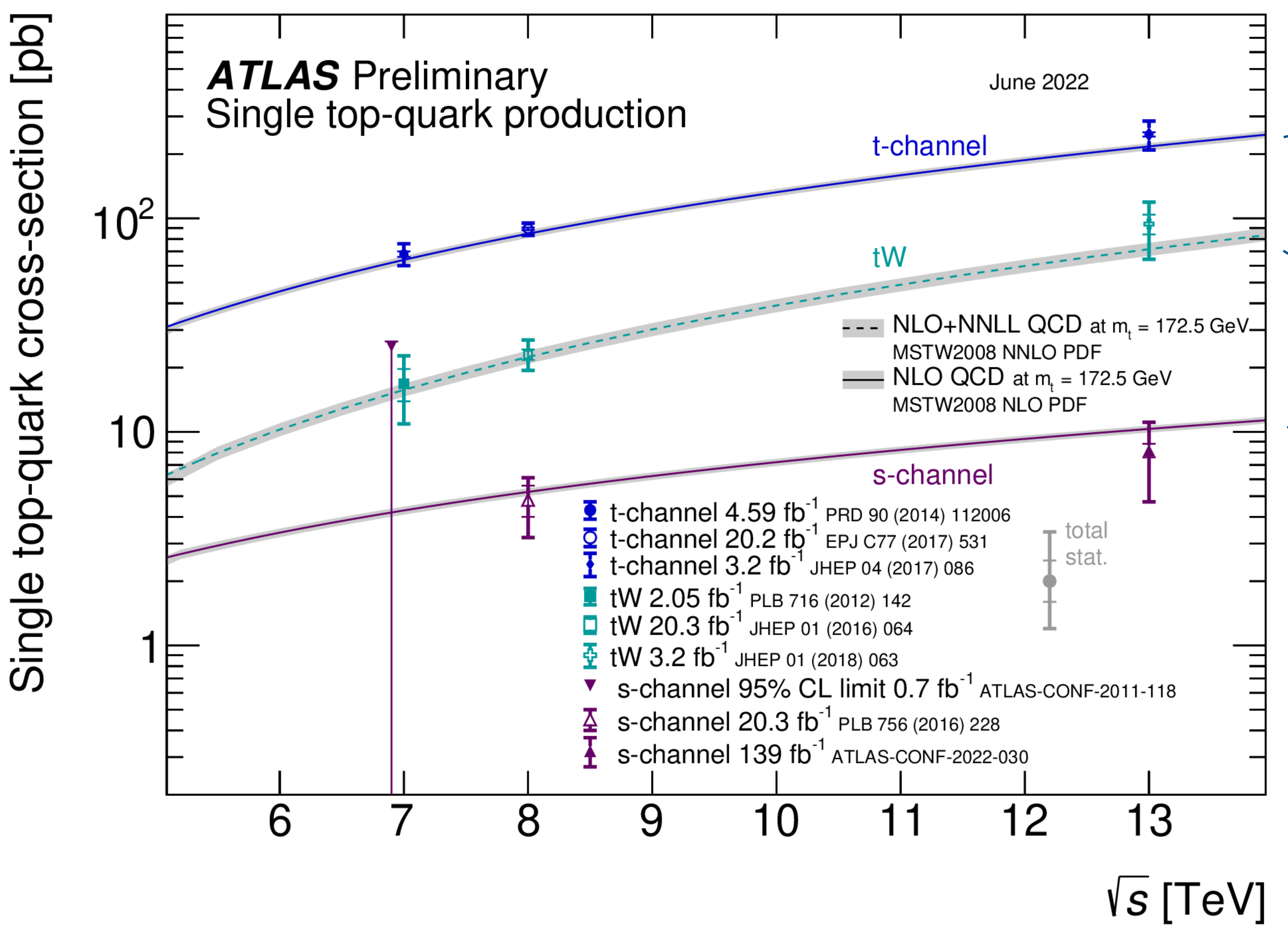


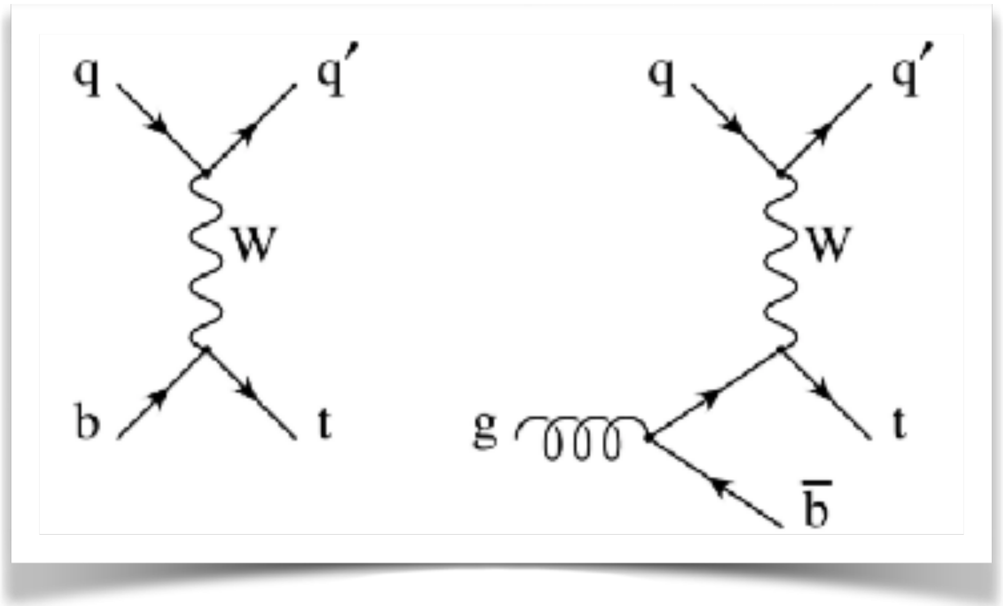
Gluon PDF

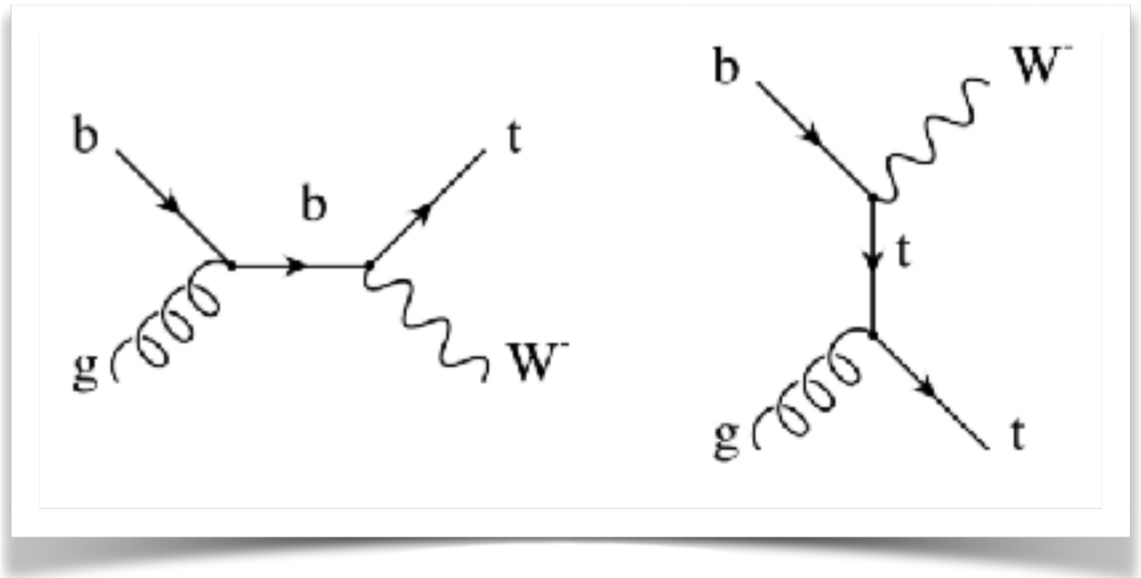


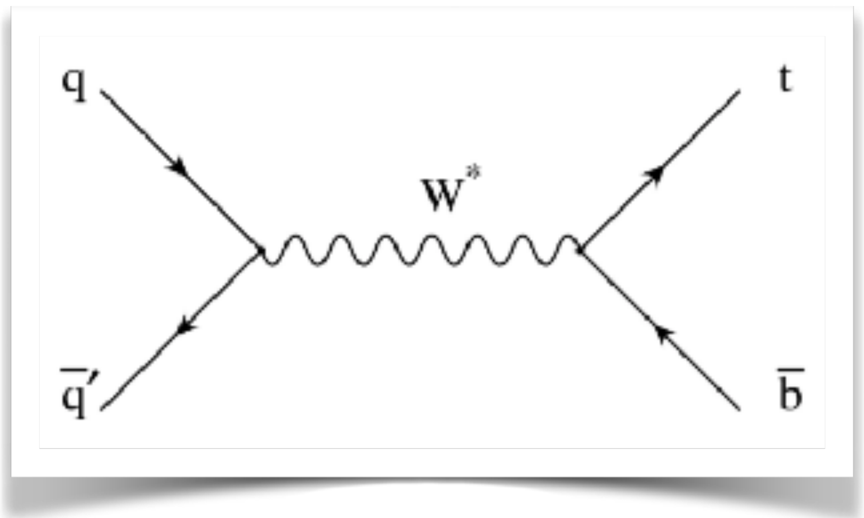
Important feedback to improve Higgs precision measurements

Single-top production Cross Sections





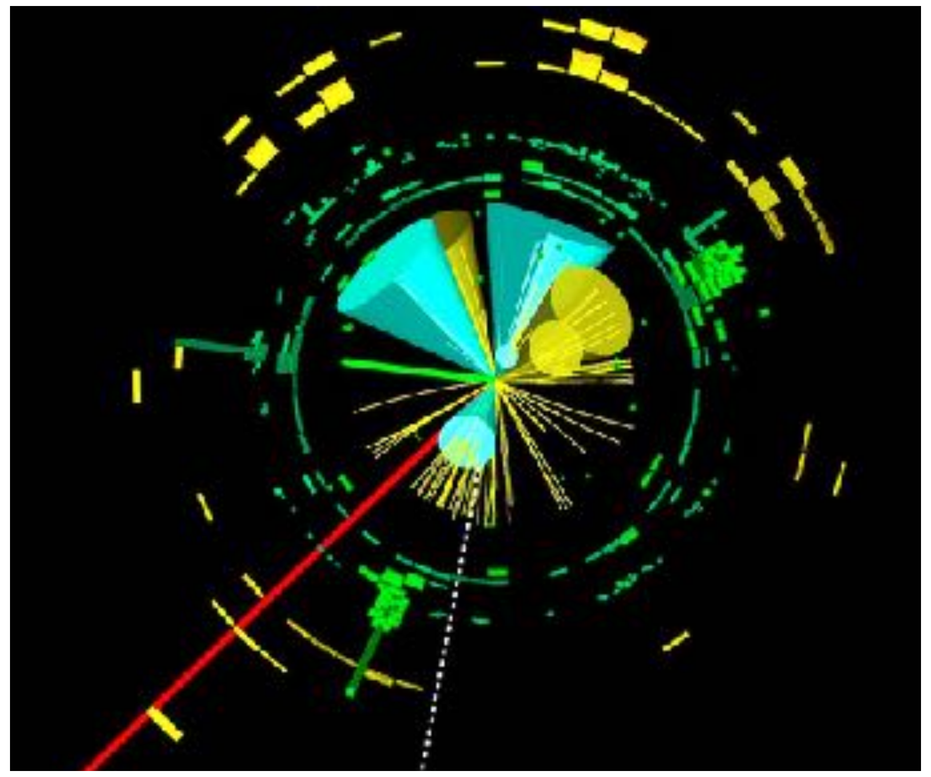




S-channel is particularly difficult even at Run 2 due to low cross section also larger top backgrounds!

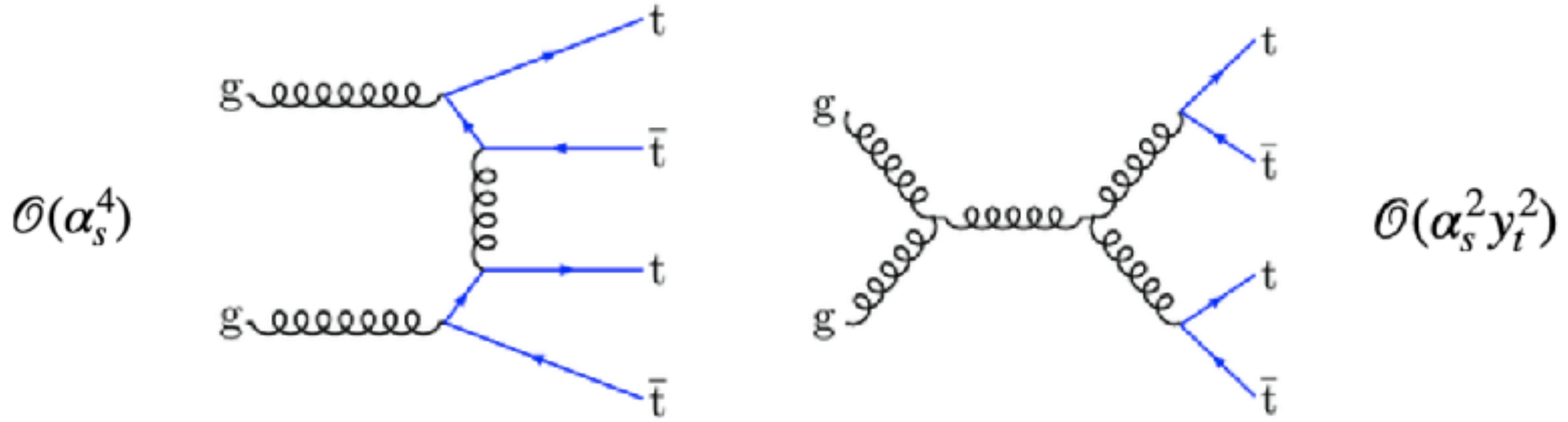
More intricate Processes and Top Properties

Four top Production at LHC



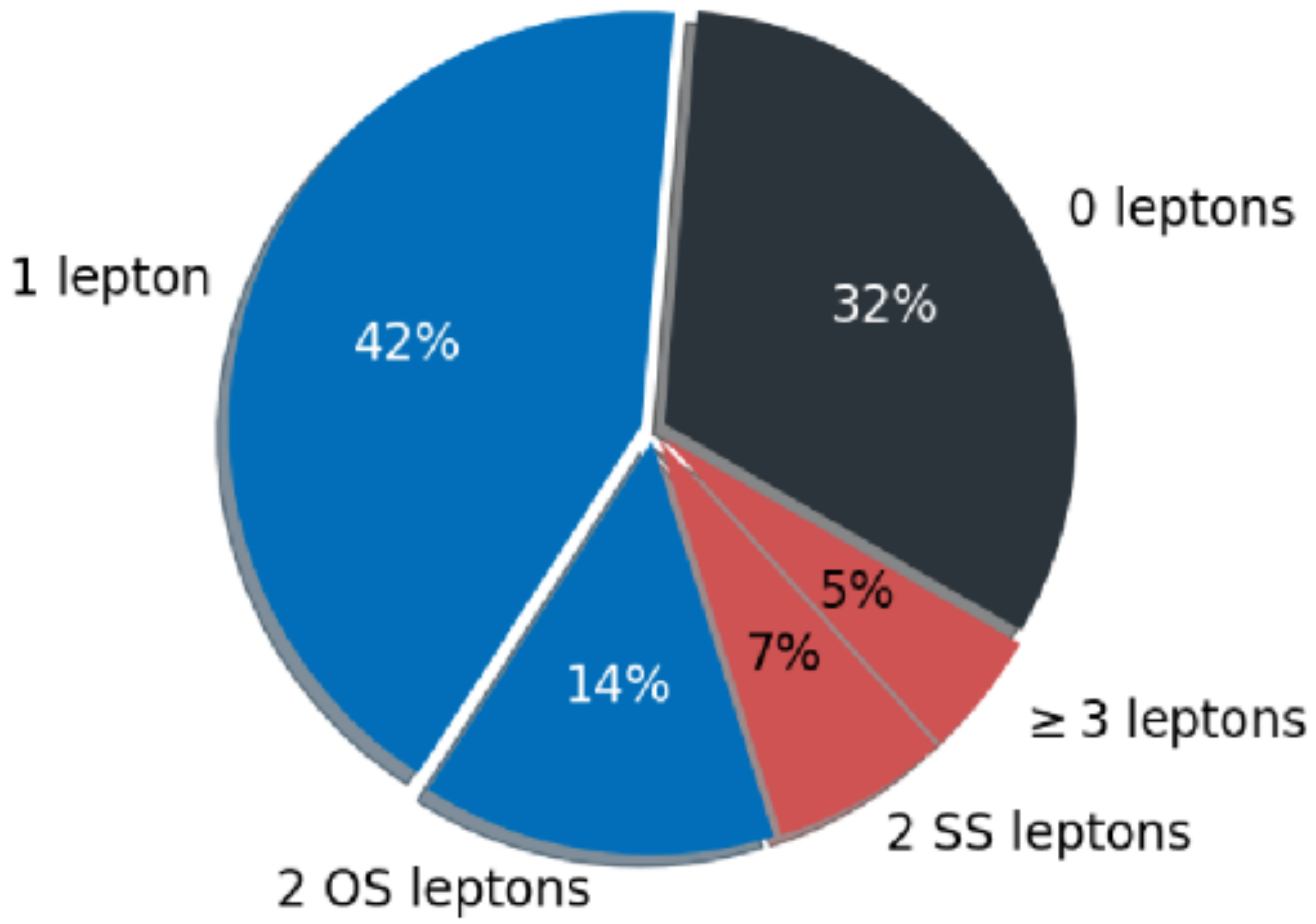
ATLAS and CMS observe simultaneous production of four top quarks

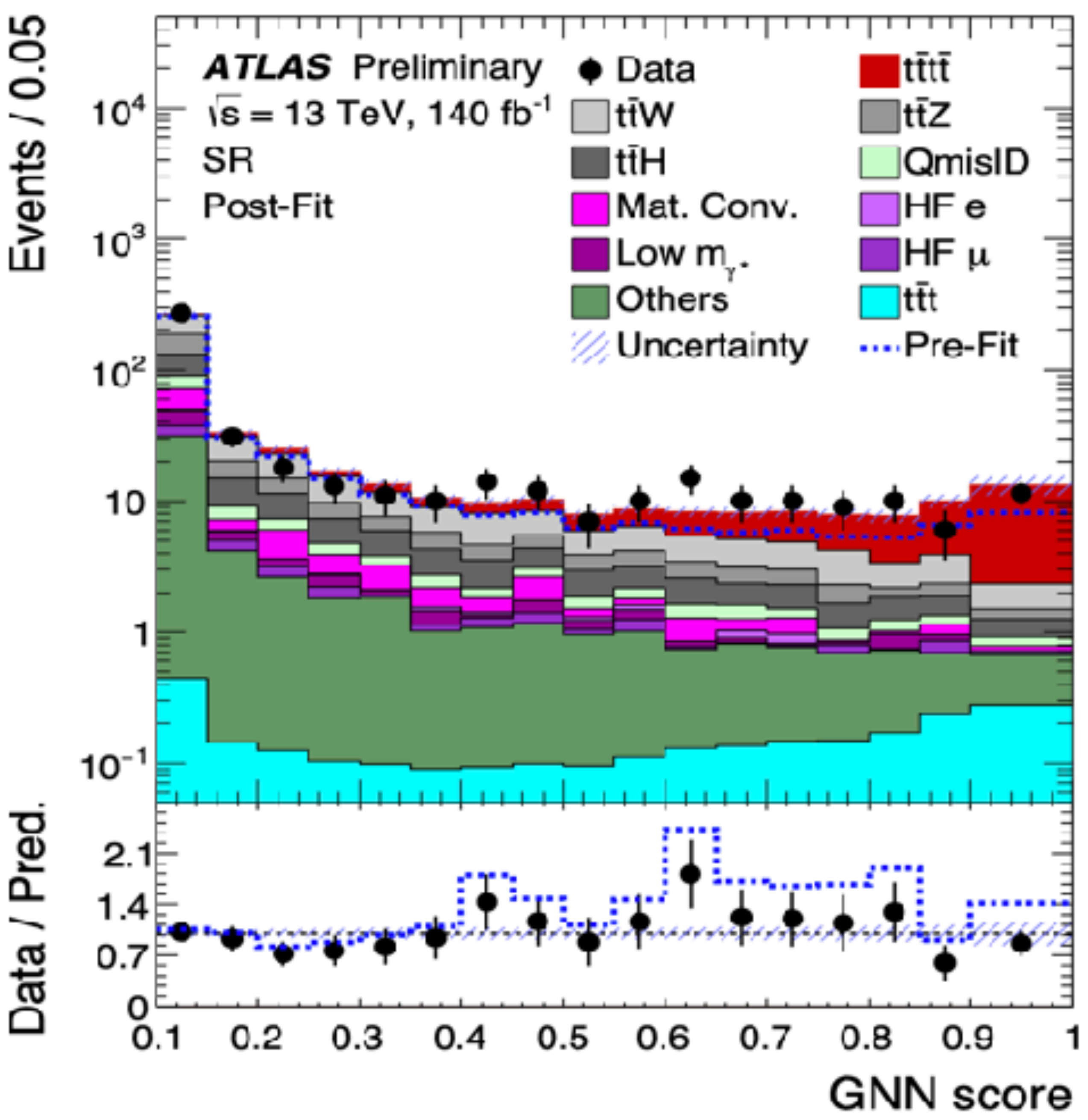
Link to CERN News

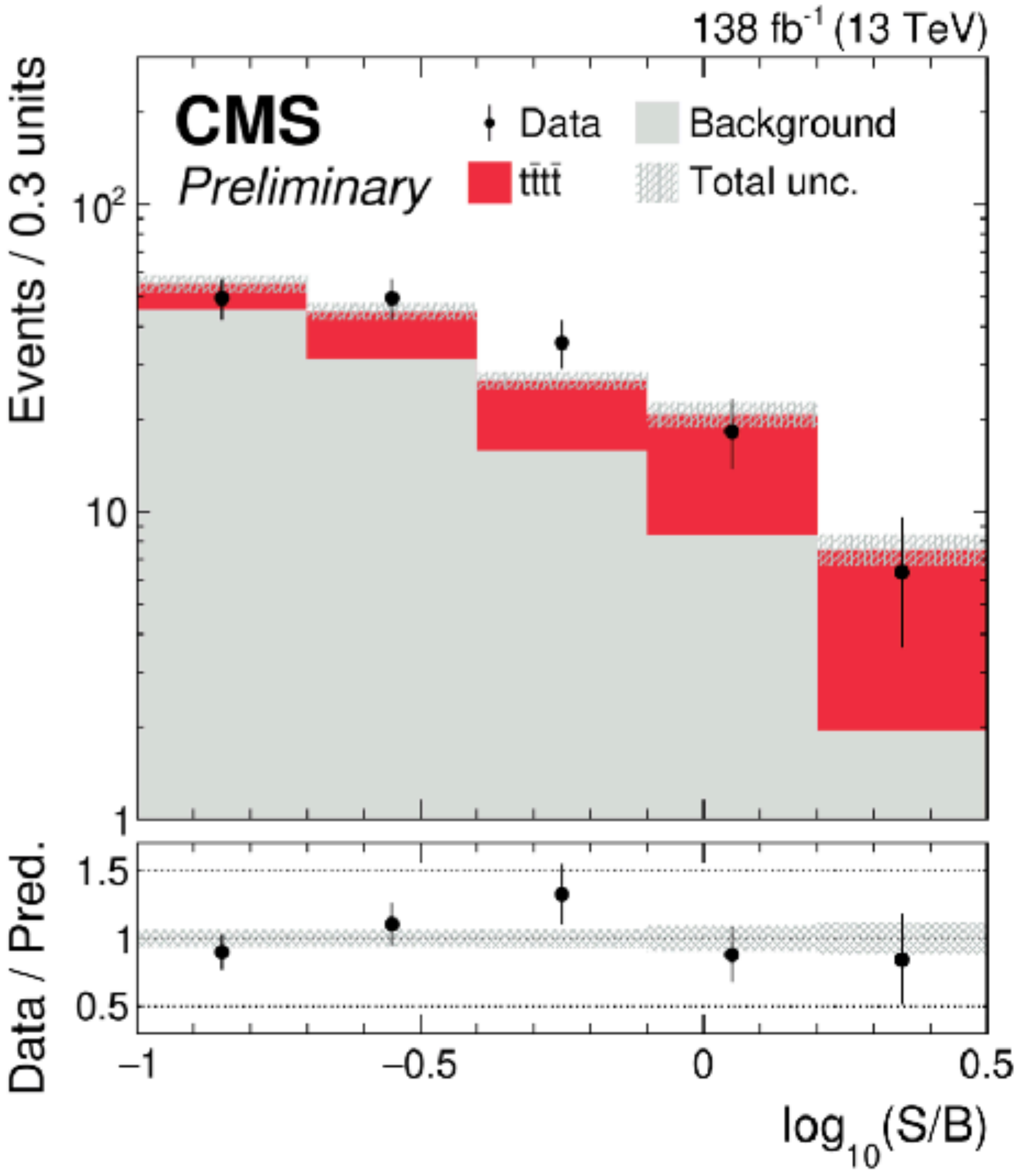


Final state with four W bosons and four b jets!

Numerous channels investigated!







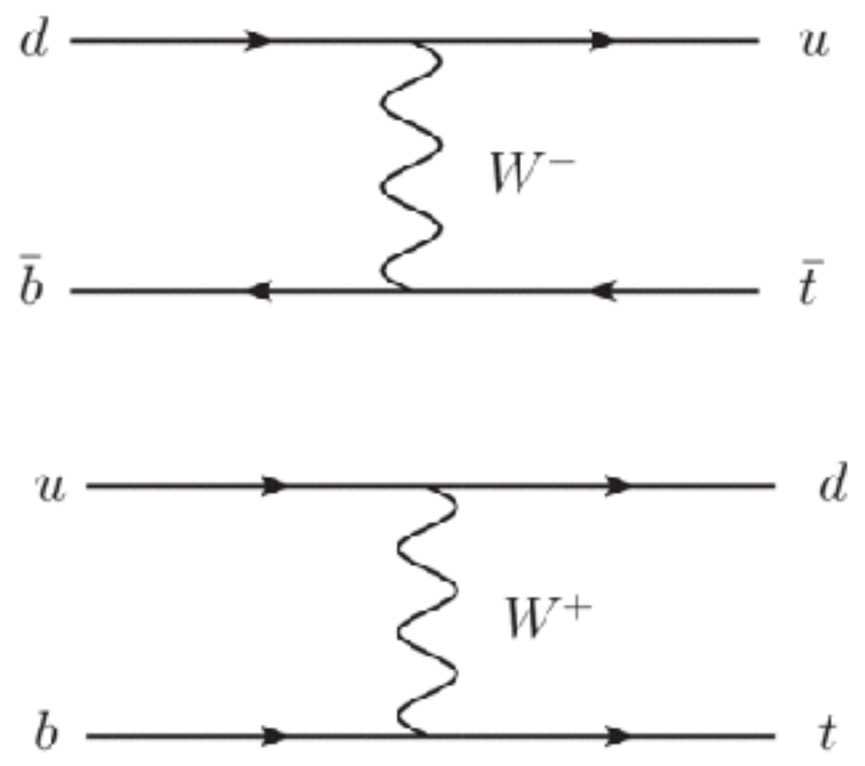
(Independent) Observation by ATLAS and CMS of 4 top production!

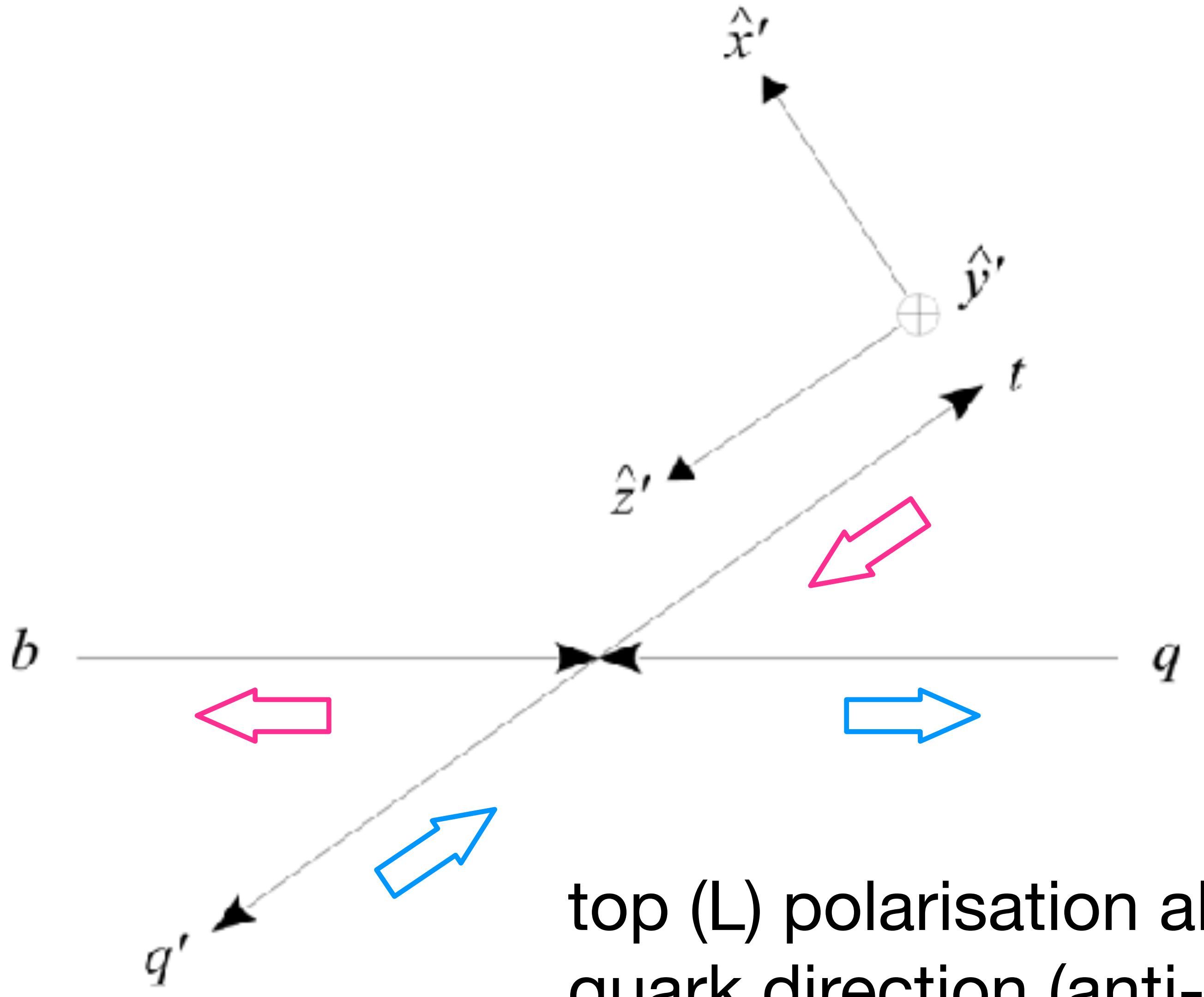
6.1 (4.3) σ observed (expected)

5.5 (4.9) σ observed (expected)

Top Polarisation in Single Top production

V-A coupling induces polarised production of single top quarks:

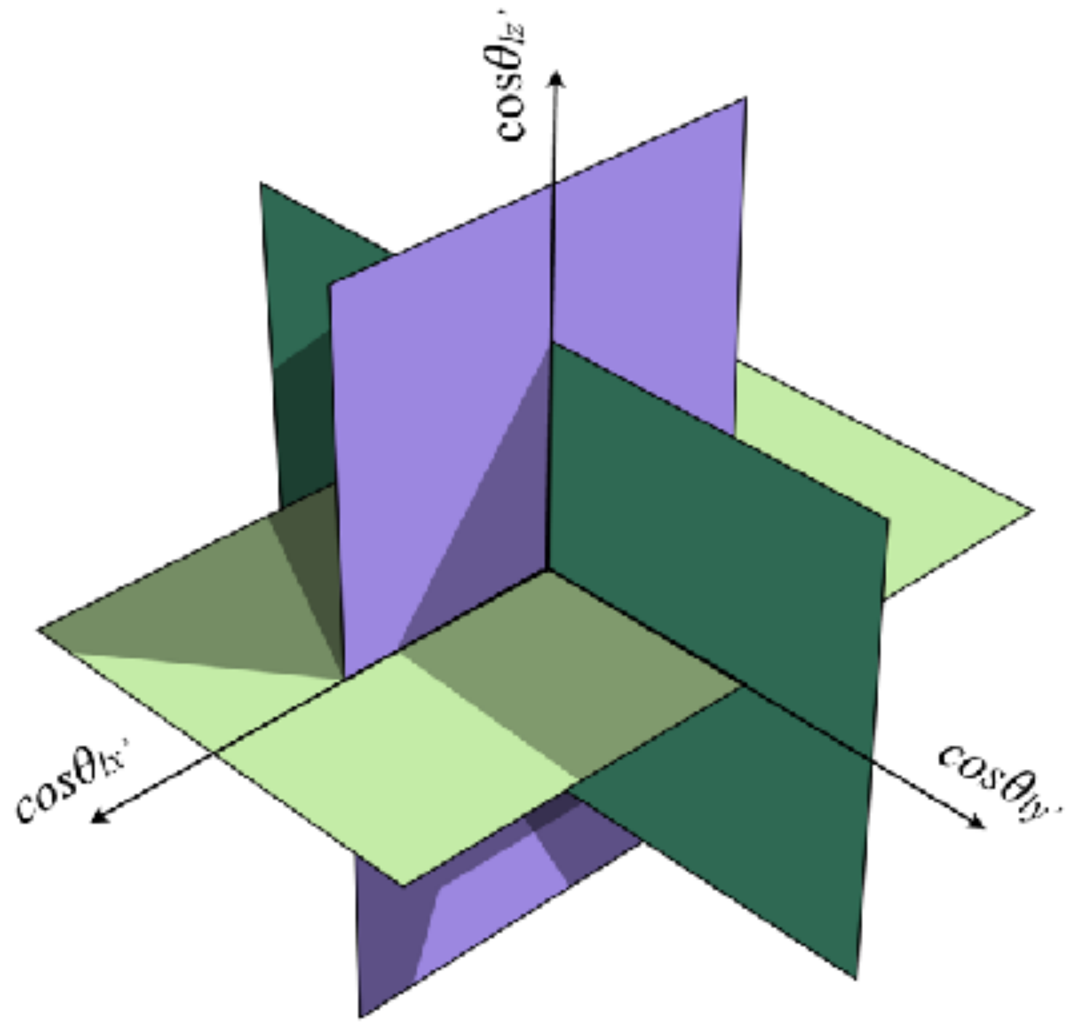


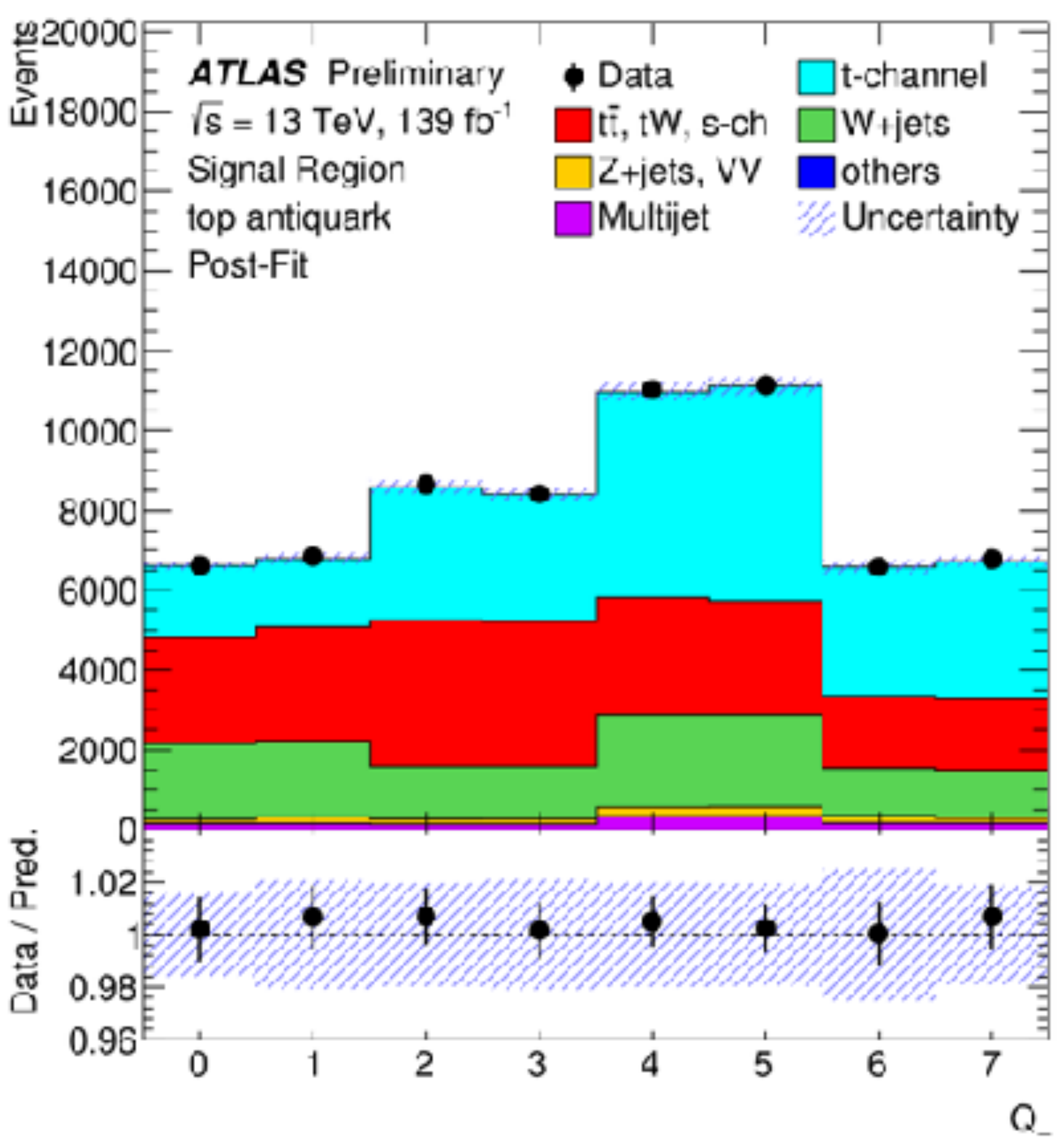


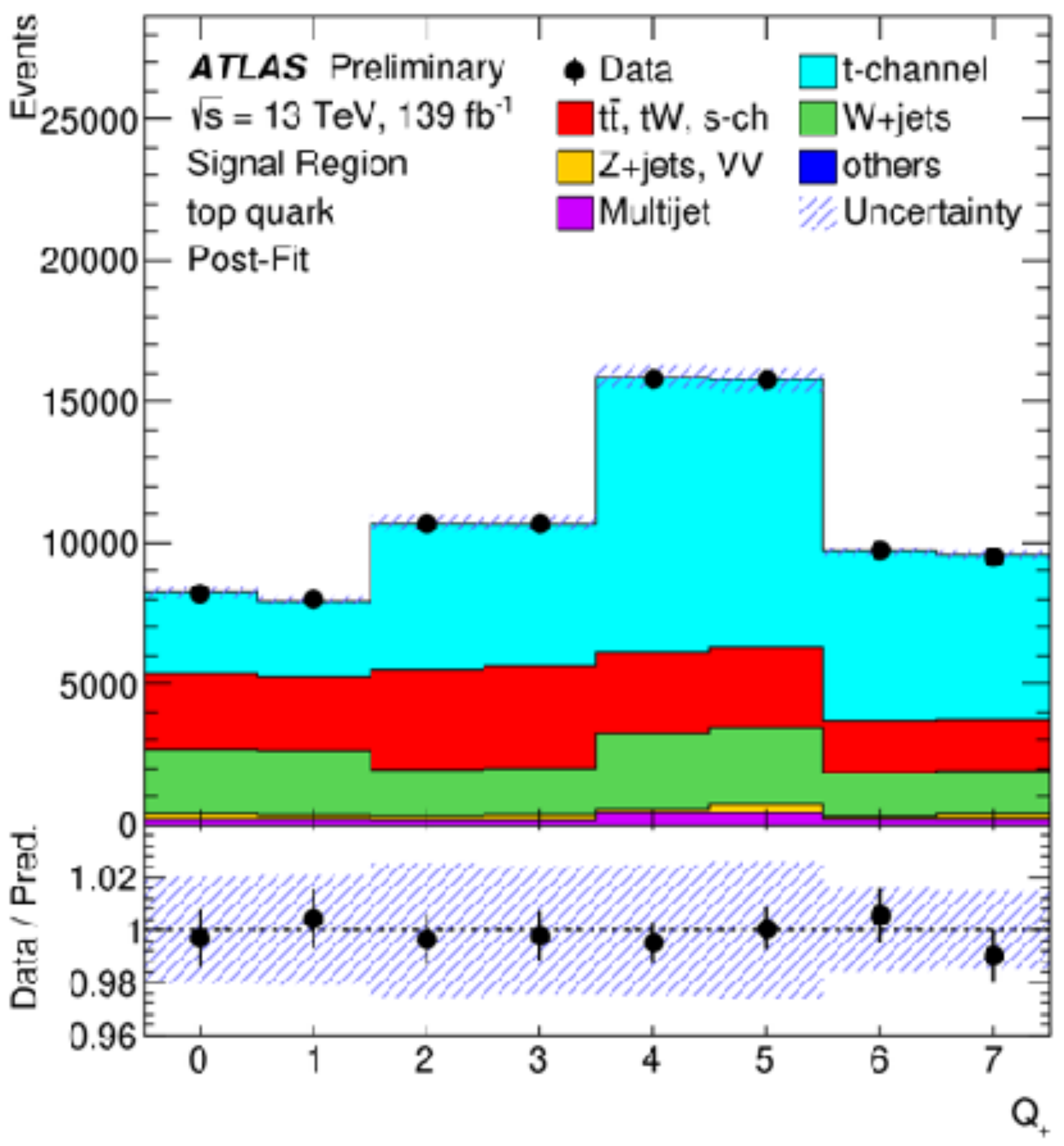
top (L) polarisation along spectator quark direction (anti-top (R) opposite)

Use semi-leptonic top decays!

Definition of a 3D discriminant based on the octant in which the lepton is produced!



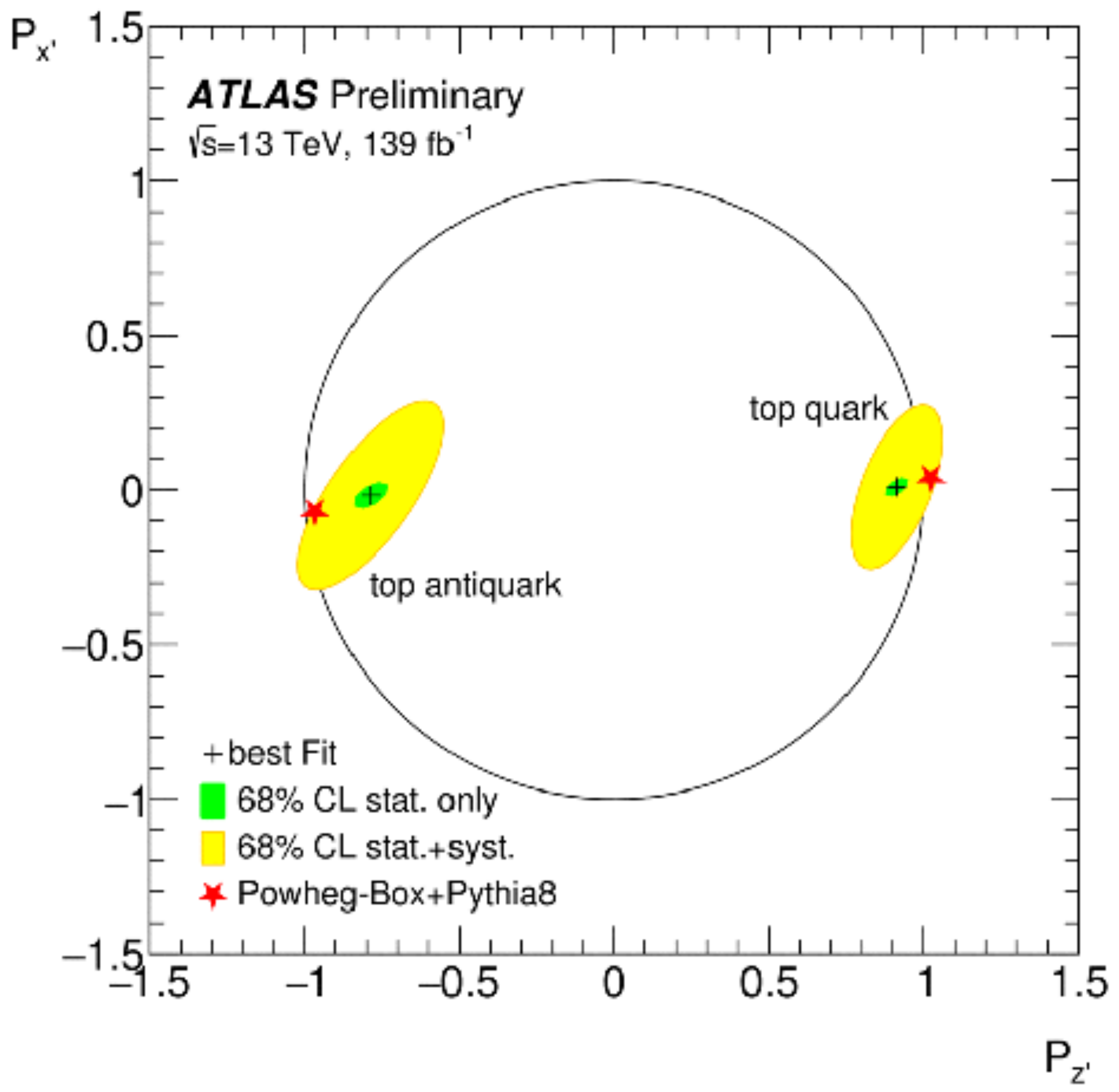




Fit to the polarisations Px, Py, Pz done using a parametrisation of this octant variable.

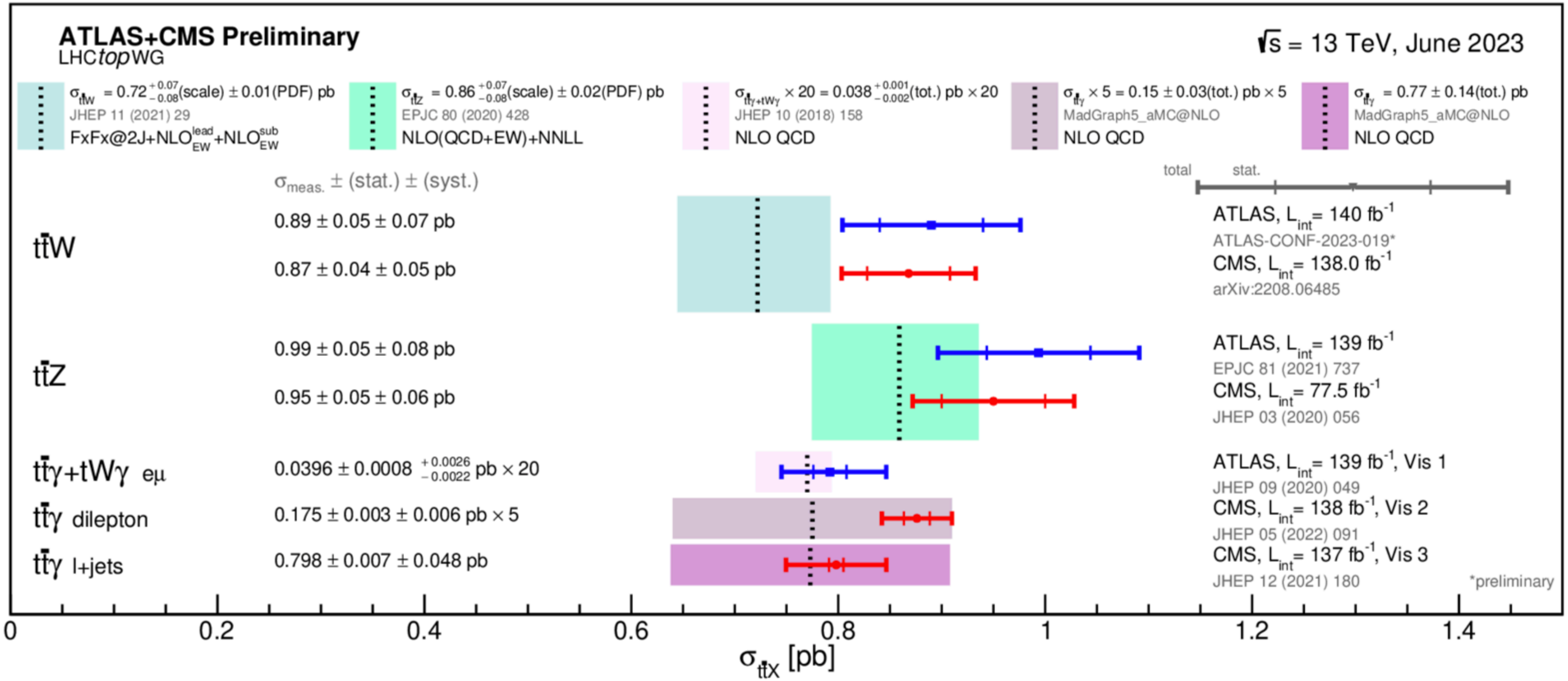
Py is sensitive to CP violating effects

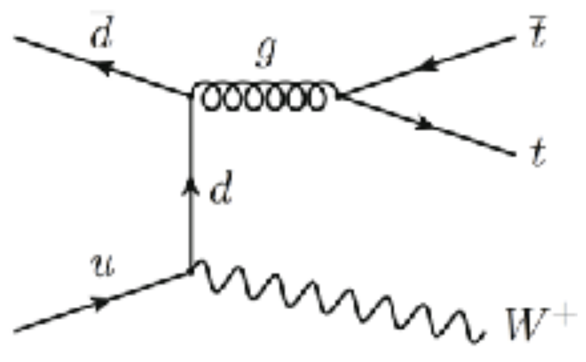
Px is sensitive to NLO QCD effects

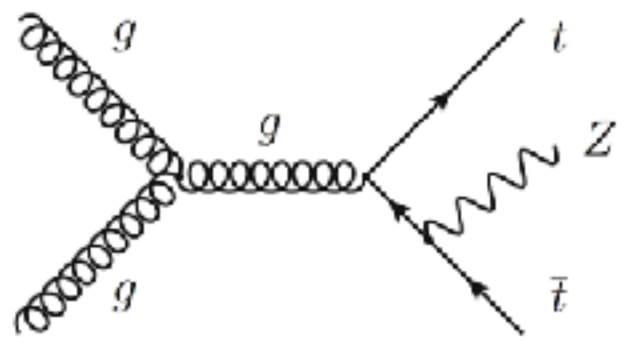


Top Pair Associated Production

Very important ancillary measurements for many Higgs measurements (e.g. ttH ML) and searches!







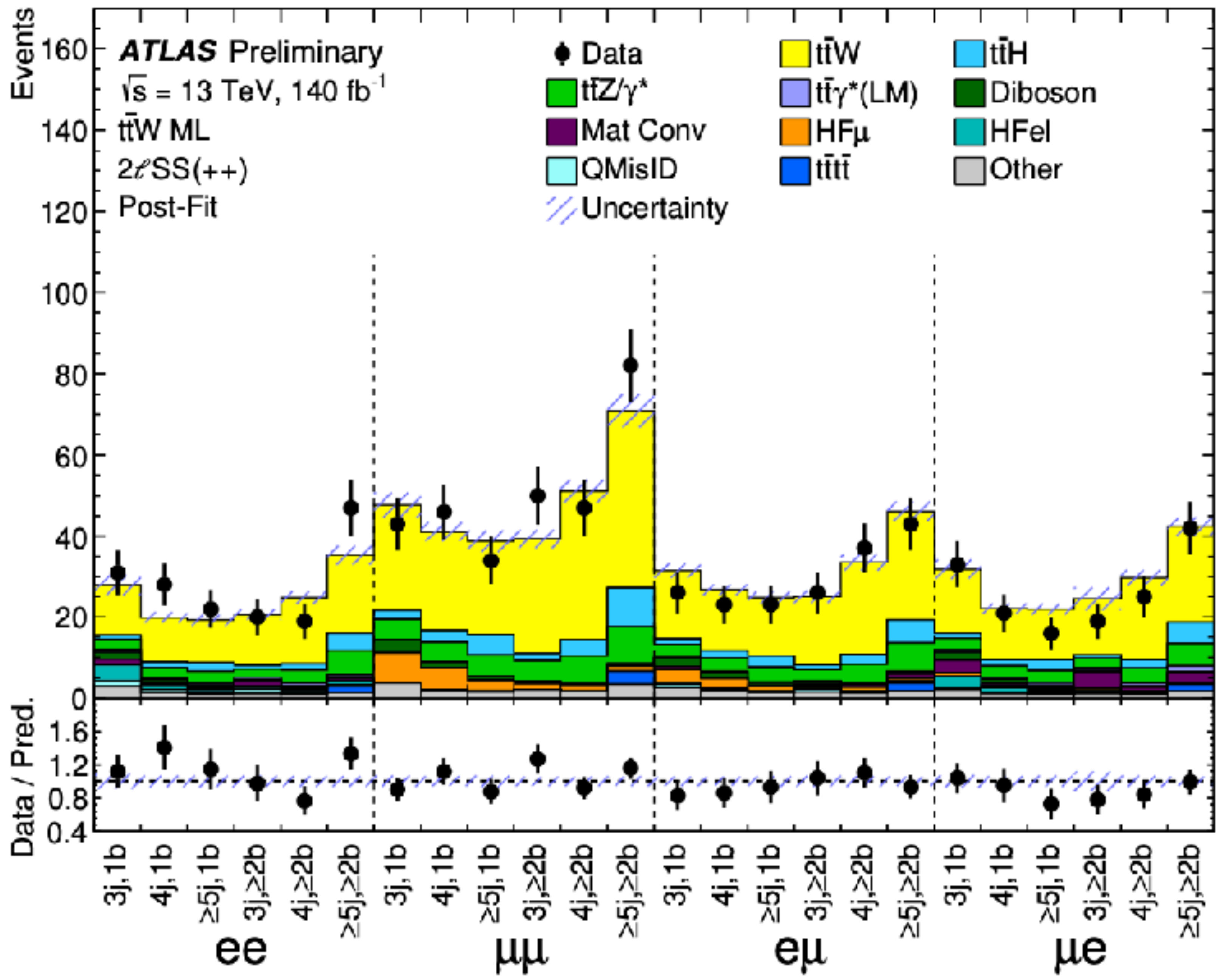
Different processes ttW ISR only and tty (ISR and FSR)

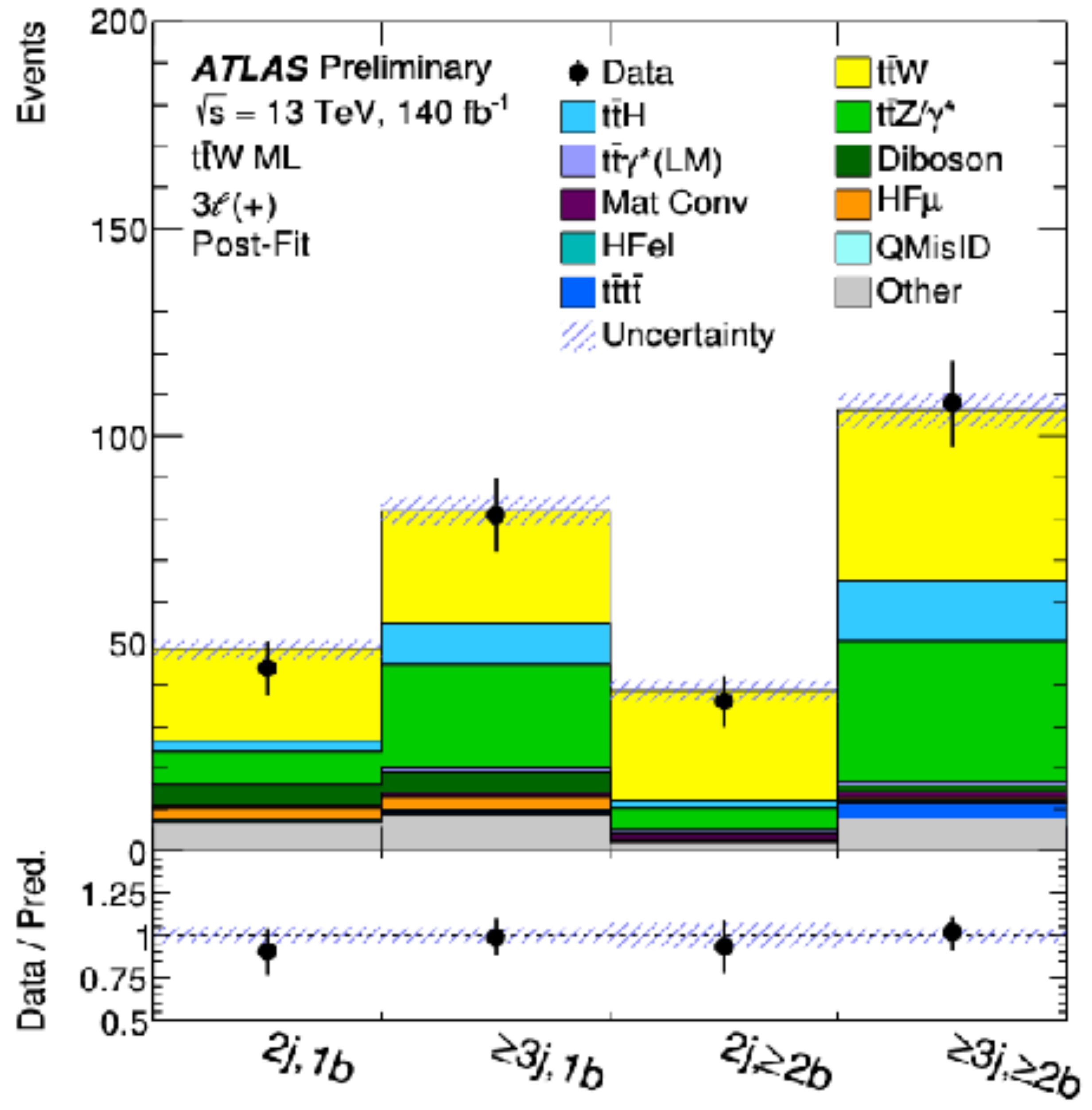
Associated production with a photon sensitive to the top quark charge.

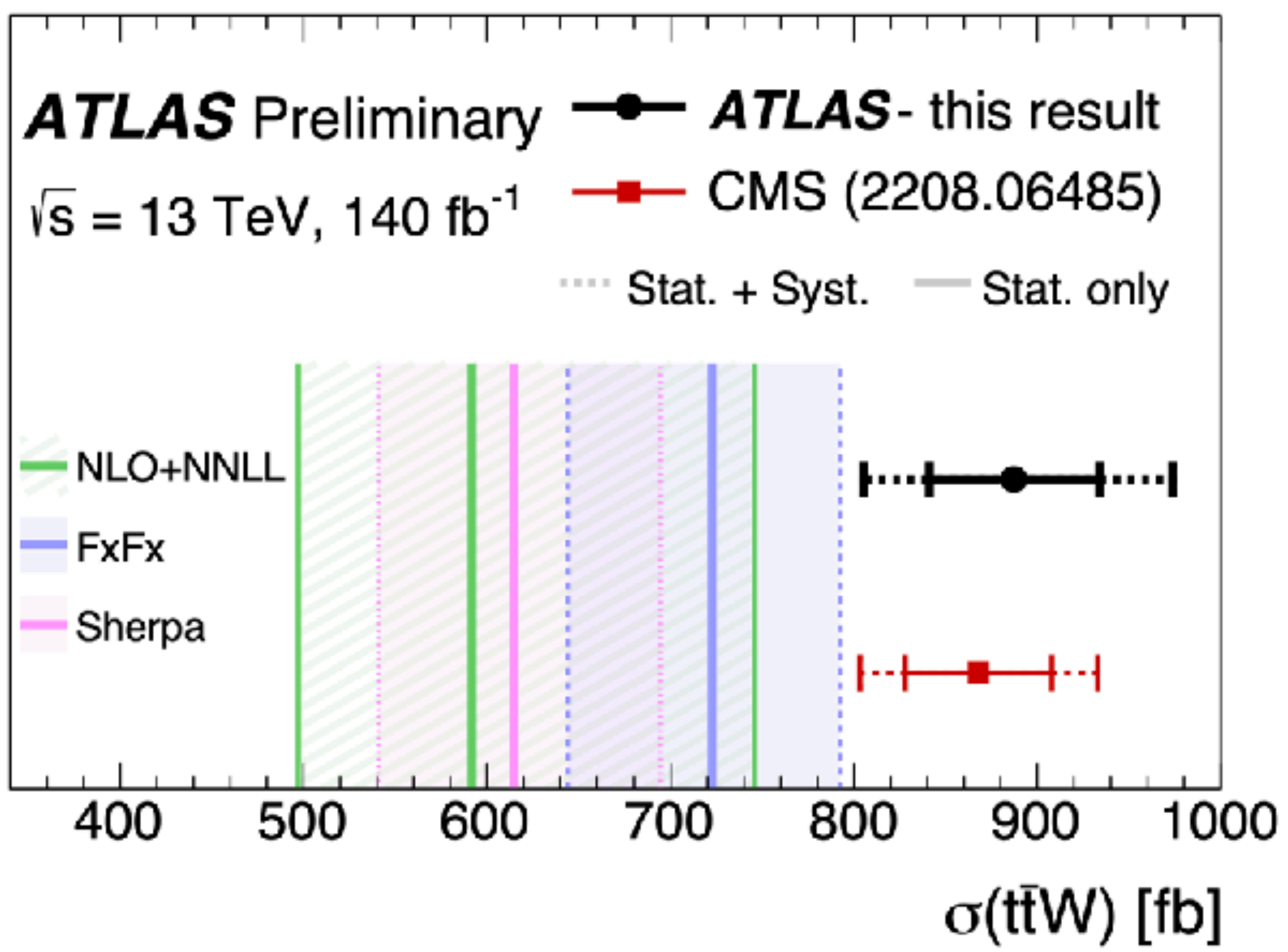
Top Associated Production

ATLAS Measurement of the ttW inclusive and differential cross sections (in 2 same sign leptons channel and 3 leptons)

- Long standing discrepancies
- Critical ancillary measurement for very large number of measurements (e.g. ttH)







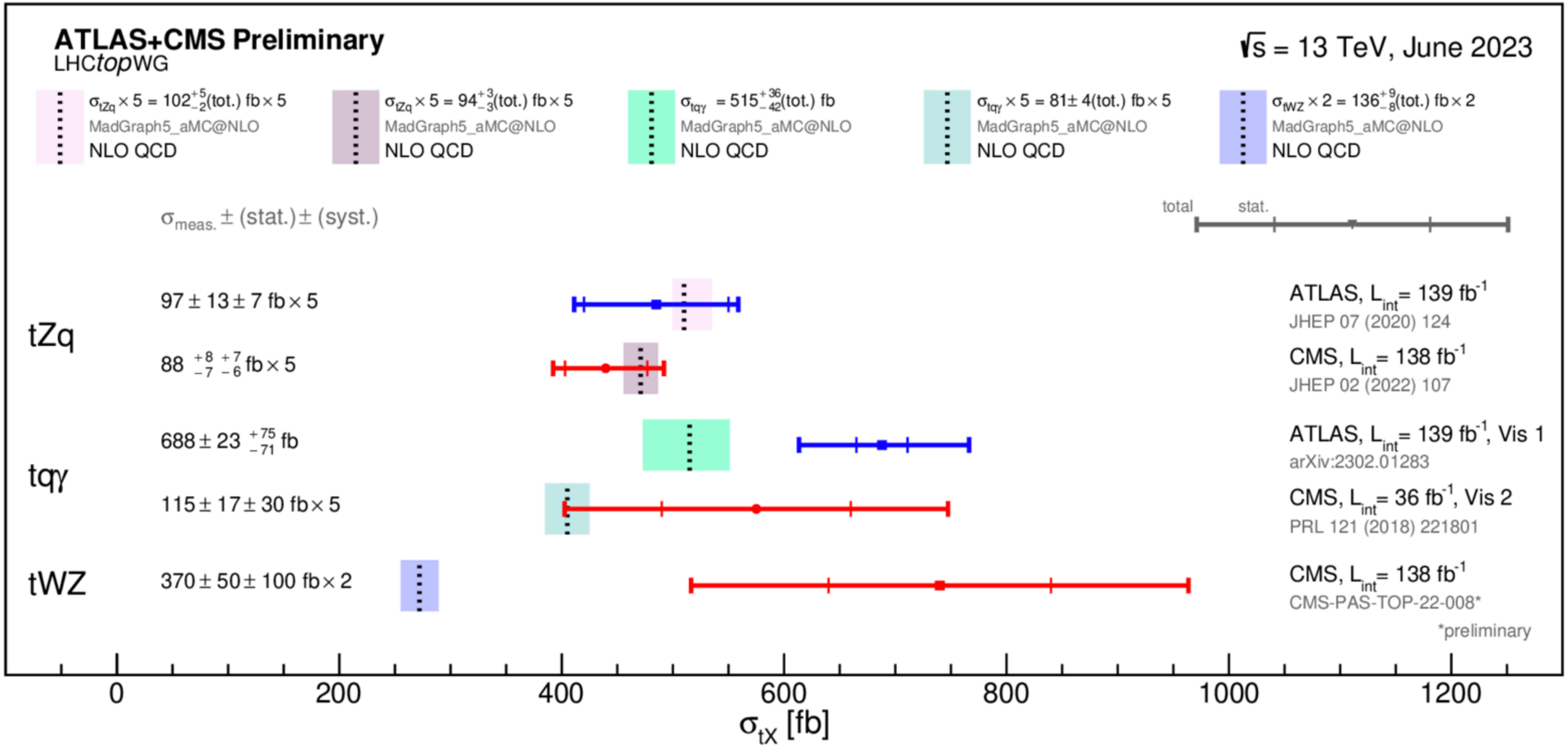
consistent at 1.5σ with theory calculation

$\sigma_{t\bar{t}W} = 722^{+70}_{-78}$ (scale) $\pm$ 7 (PDF) fb   JHEP 11 (2021) 029

$\sigma_{t\bar{t}W} = 890 \pm 50$ (stat) $\pm$ 70 (syst) fb

9% relative uncertainty

Single Top Associated Production

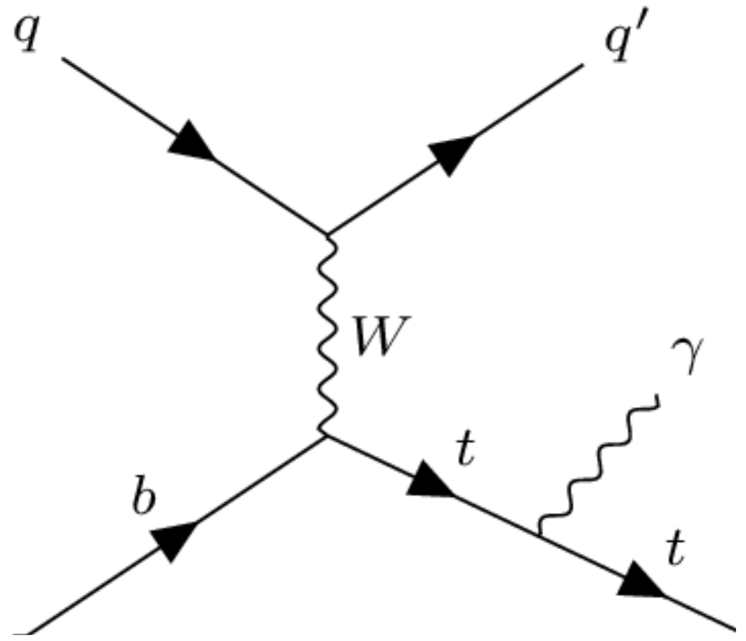


Rare single top production

Rare single top process observation

$tq\gamma$ Single-top quark and a photon

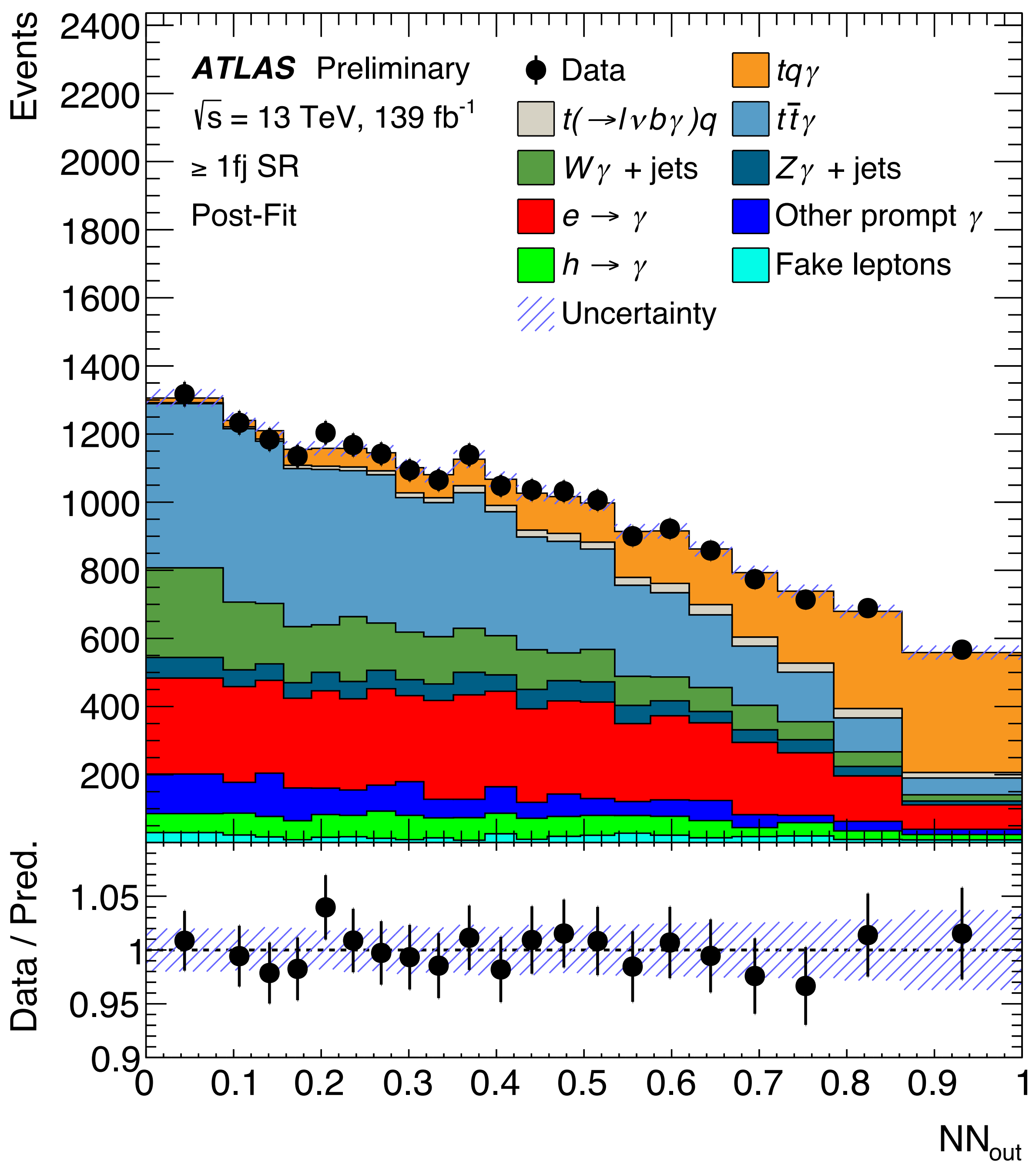
Powerful probe of top-EW coupling (and constraints on new physics)



Search in the semi-leptonic top decay mode

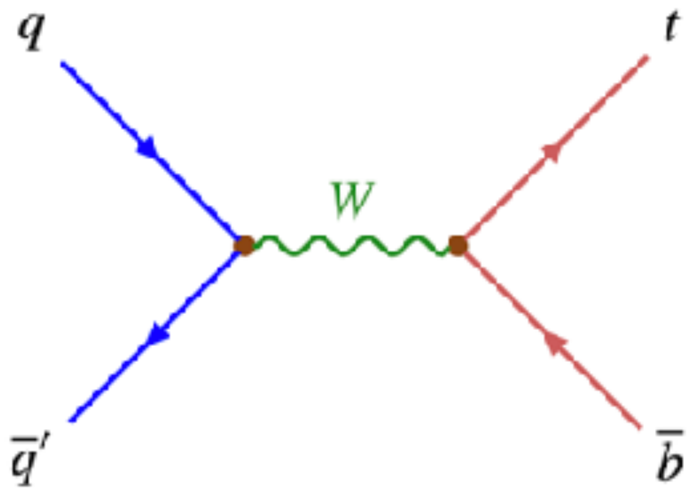
Requires 1-forward jet

$$2.5 < |\eta_{\text{jet}}| < 4.5$$



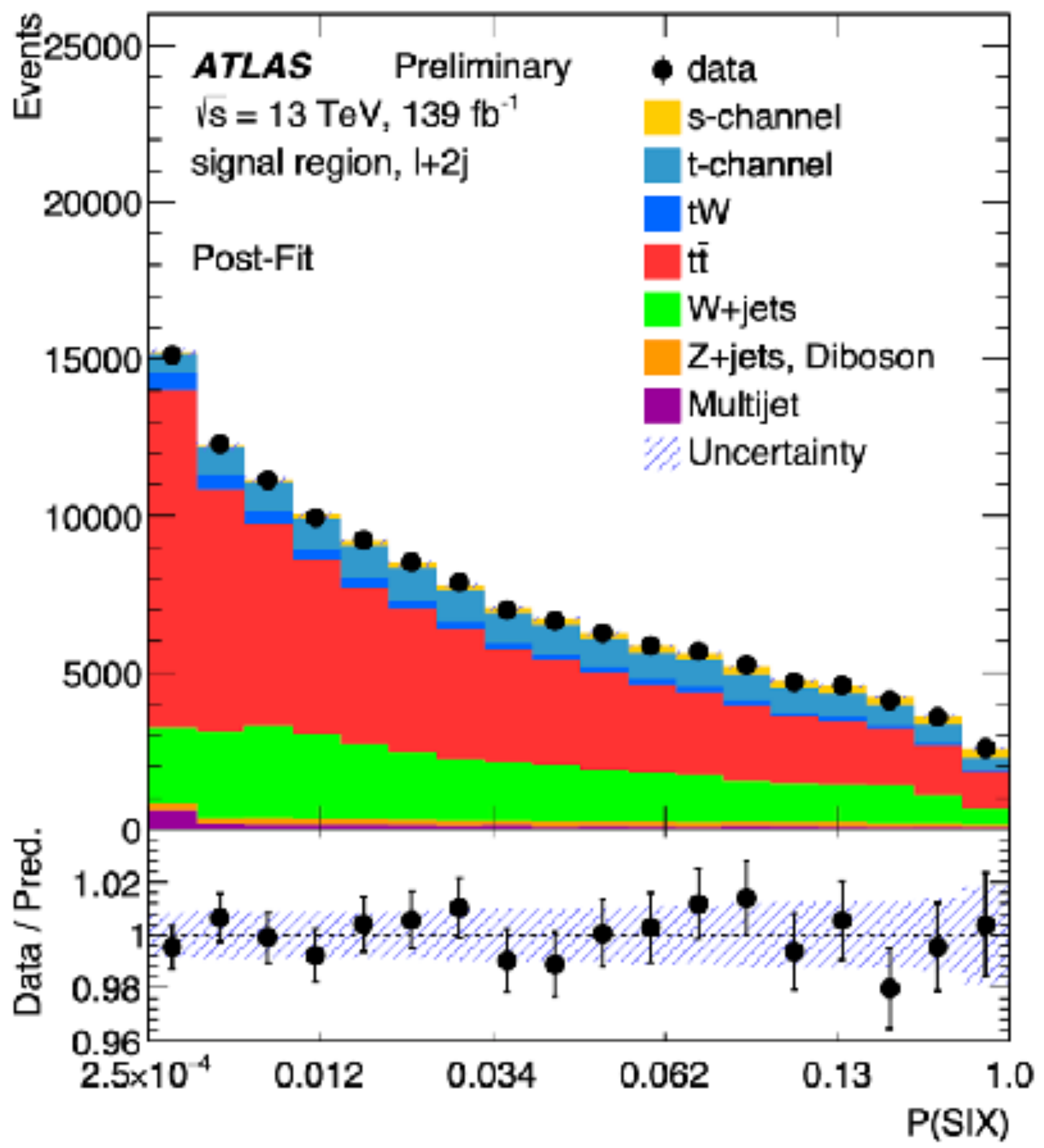
S-channel single top production

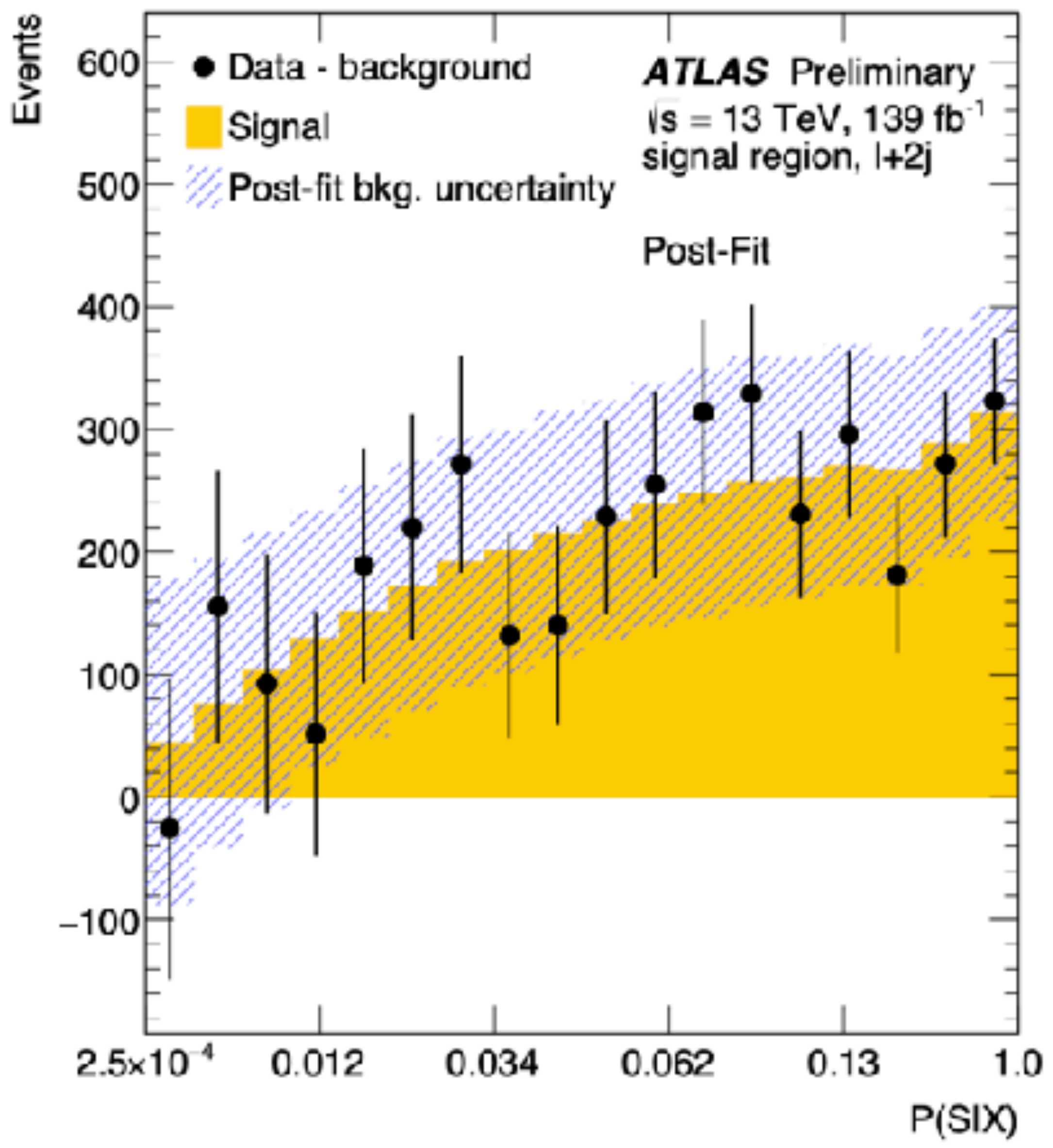
More challenging at higher energies to the smaller relative increase w.r.t. top pairs



Lowest cross-section measurement of all single-top processes!

Same sensitivity as Run 1 with **7 times more data!**





Main systematic:

W-jets and top modelling

Jet energy scale and resolution

Matrix Element Probability for a given event X to be a signal event S P(S|X)

3.3σ Observed (3.9 σ expected)

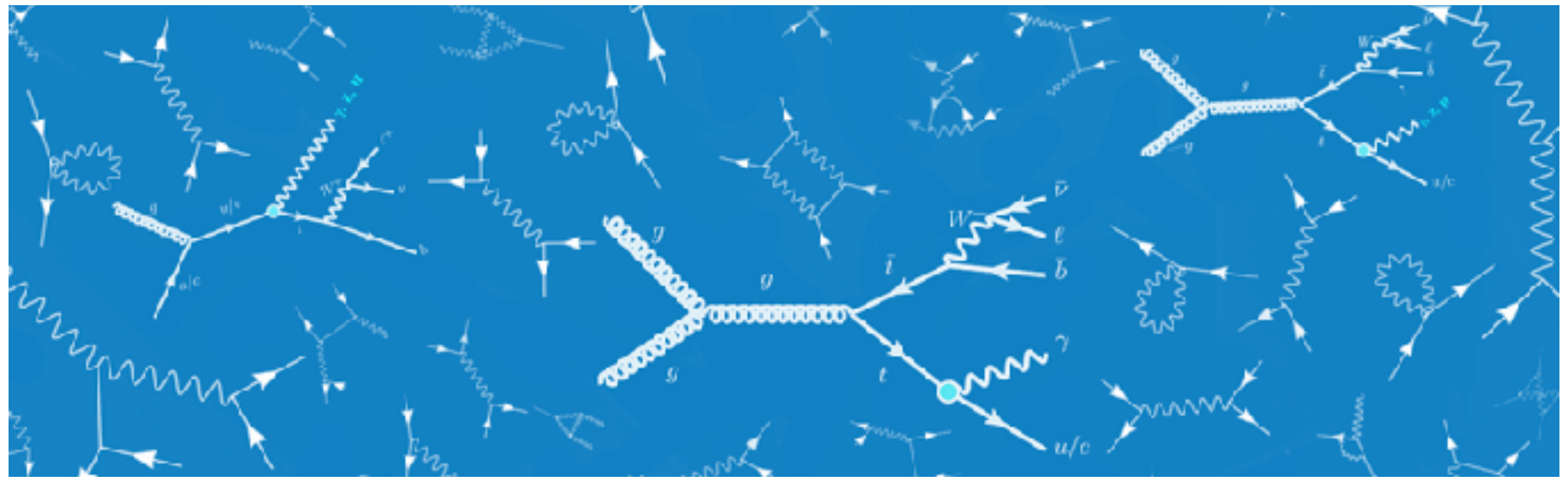
Prediction at NLO QCD

Measurement dominated by systematic uncertainties:

$$\sigma_s = 8.2^{+3.5}_{-2.9}\,\text{pb} \qquad \sigma_s^{SM} = 10.3 \pm 0.4\,\text{pb}$$

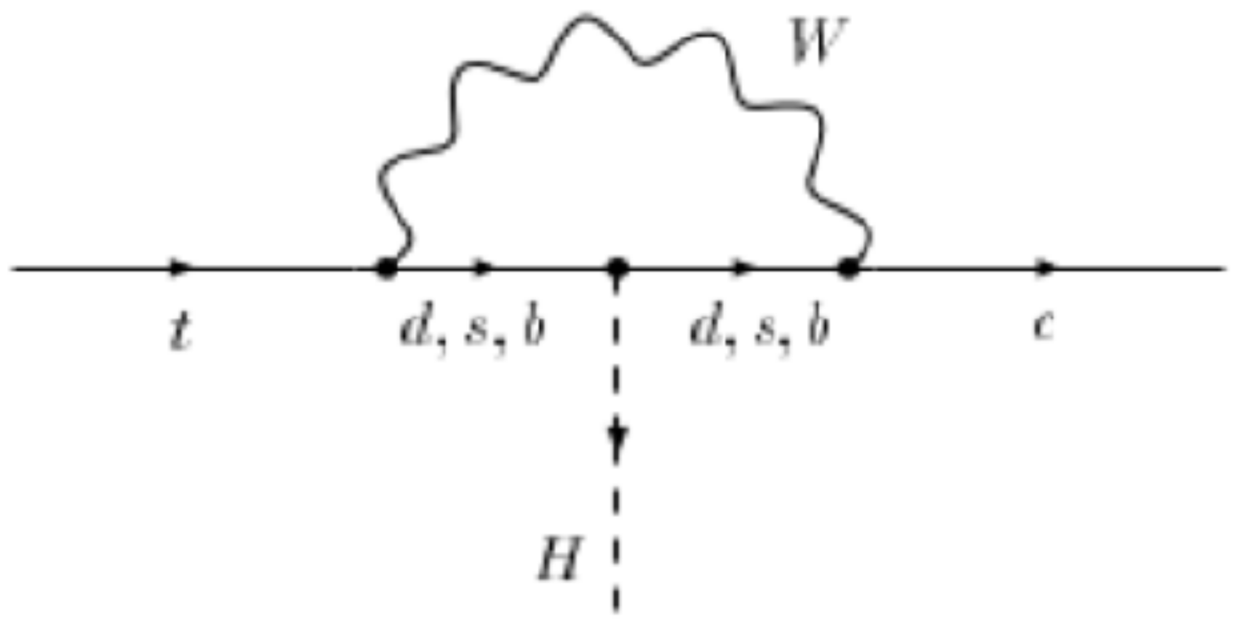
Top FCNC Decays

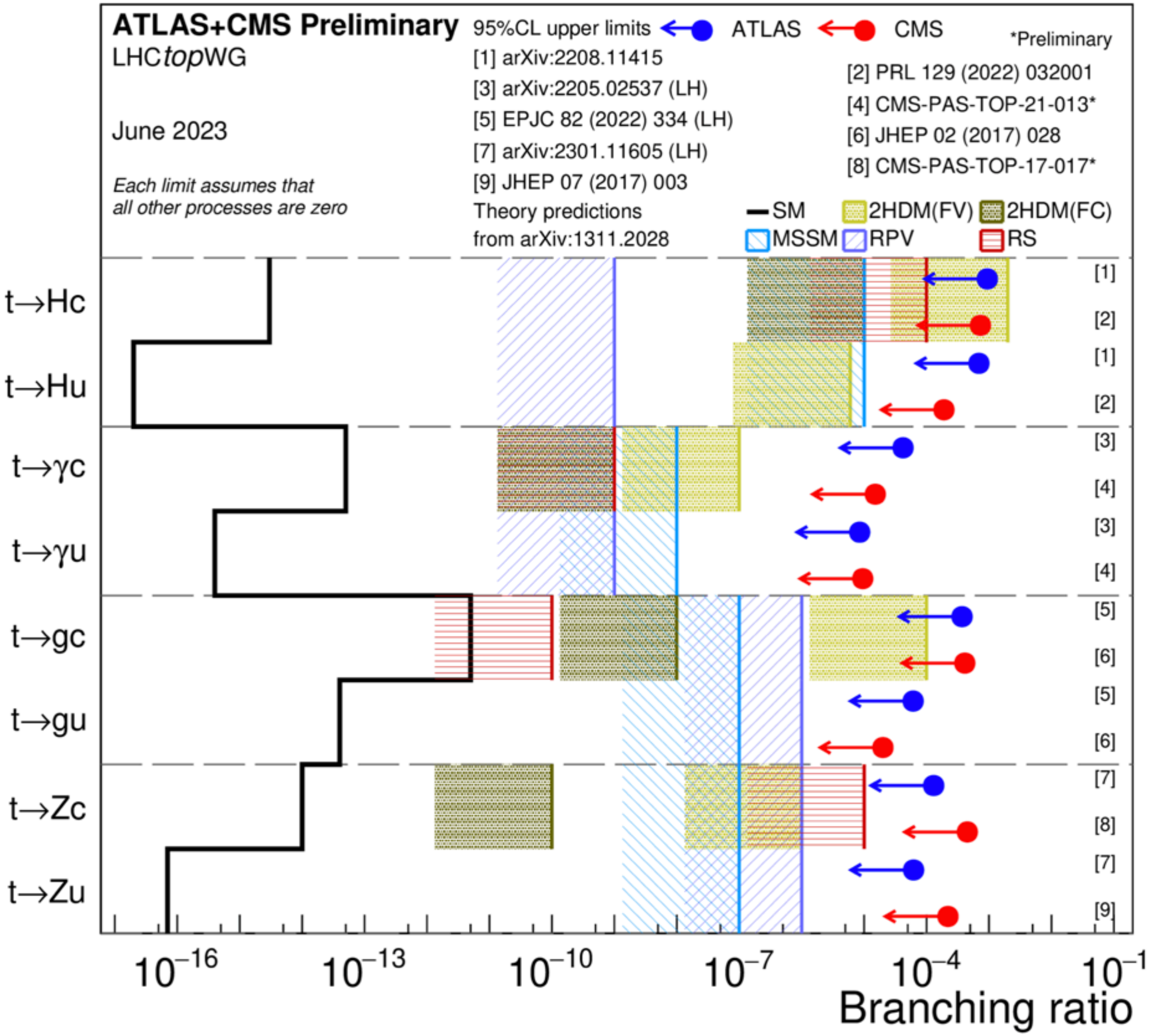
Looking for top quarks going against the current!



ATLAS Physics Briefing

Rare top quark decays include CKM suppressed 2-body Ws(d) or N-body decays, FCNC) FCNCs are greatly suppressed but could also be strongly enhanced due to BSM physics!



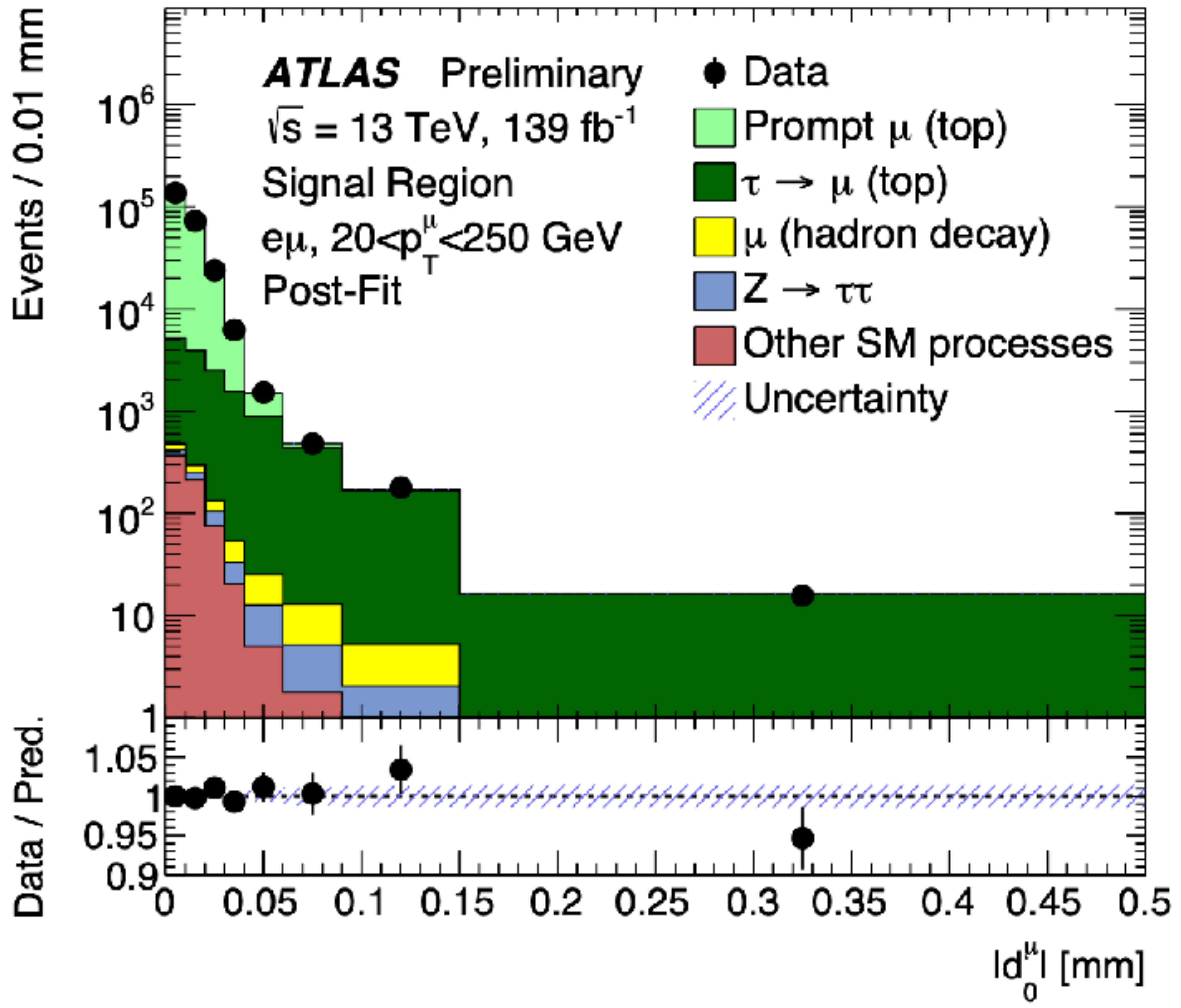


Measurement of Lepton Universality, W's from top

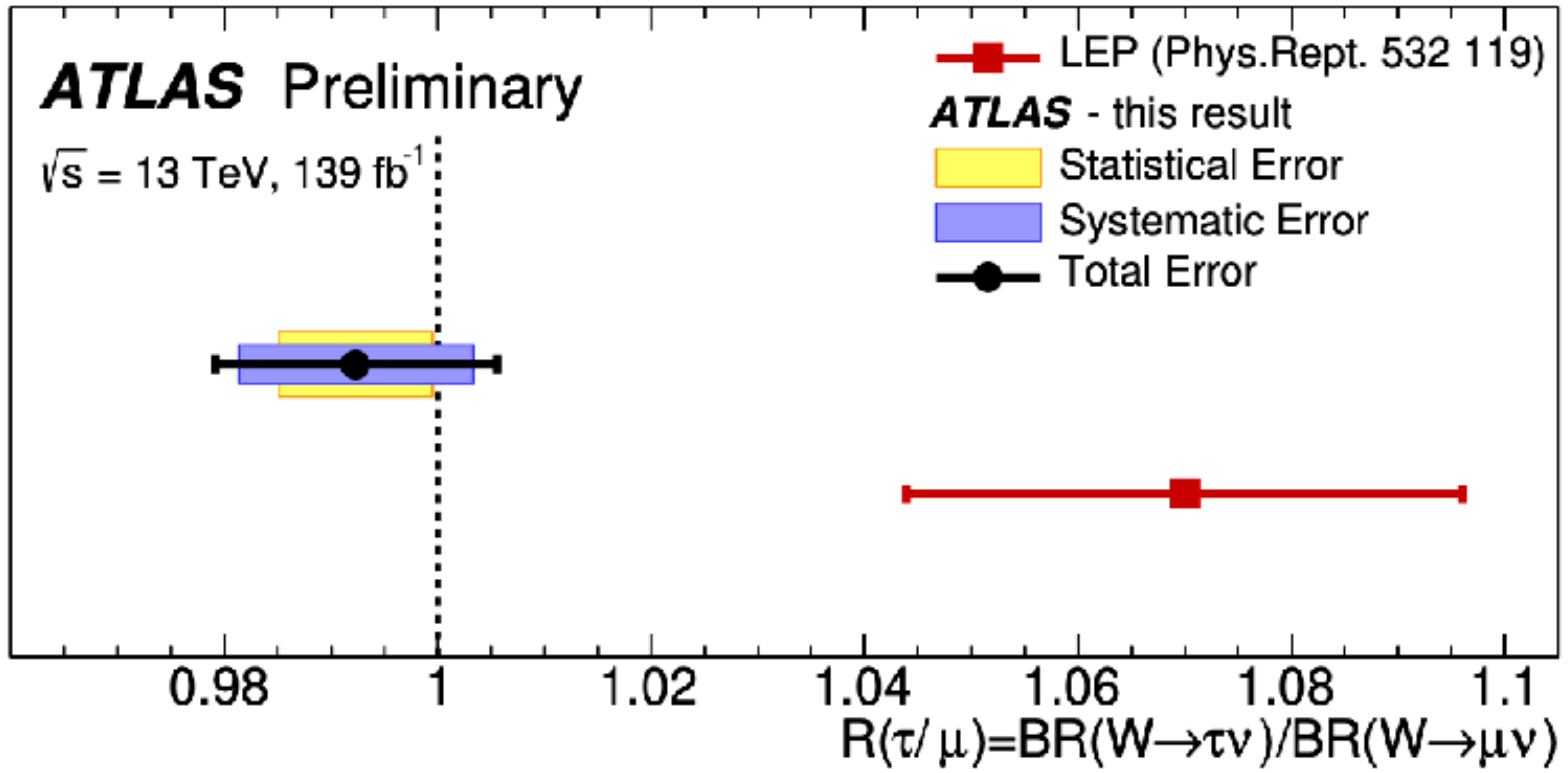
W boson decays to taus and muons

Probing a long standing 2.7 standard deviation discrepancy (since LEP)

See ATLAS press release



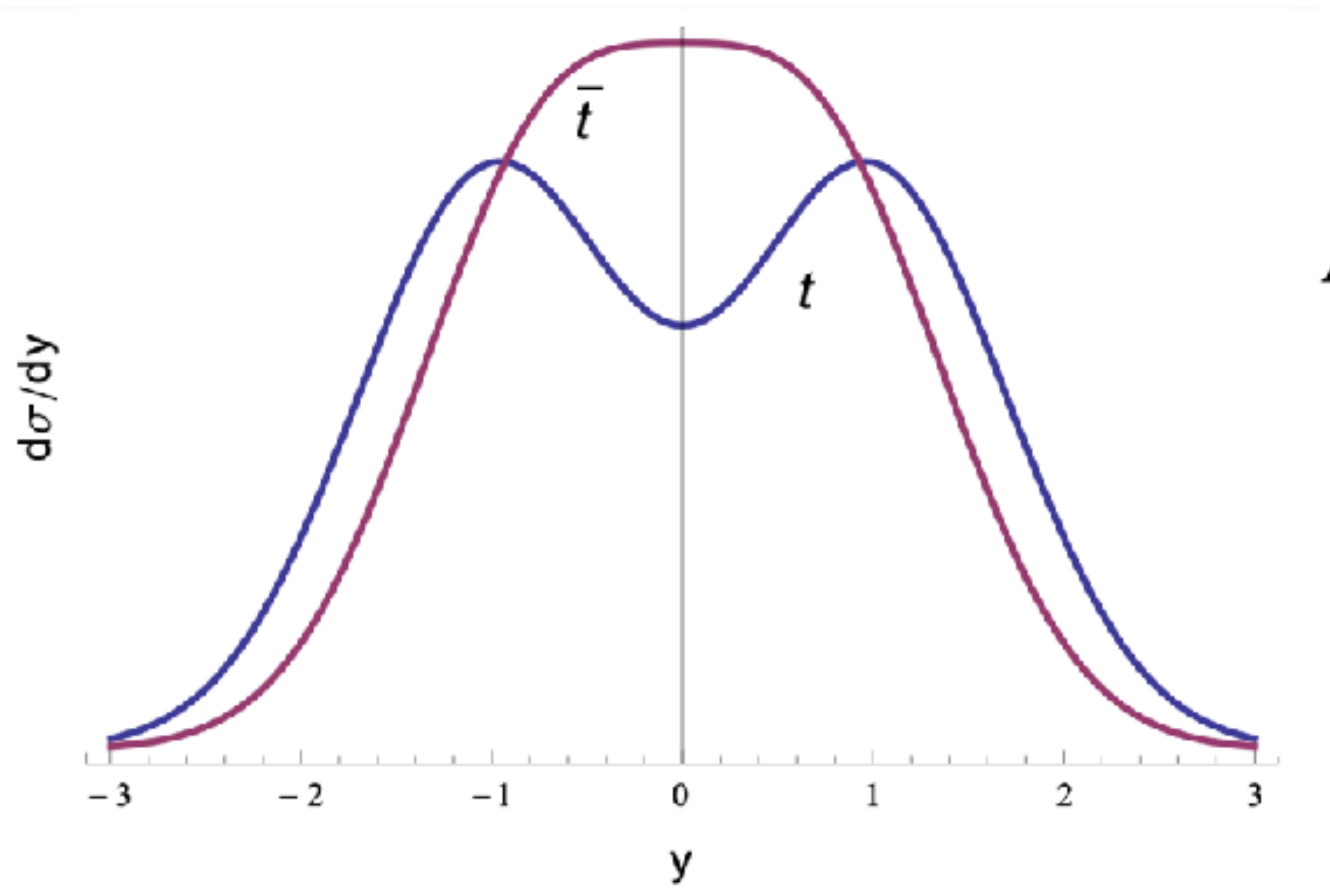
Using top pair production as a pure source of W bosons and investigating those tau decays to muons (from their impact parameter).



Top Charge Asymmetry

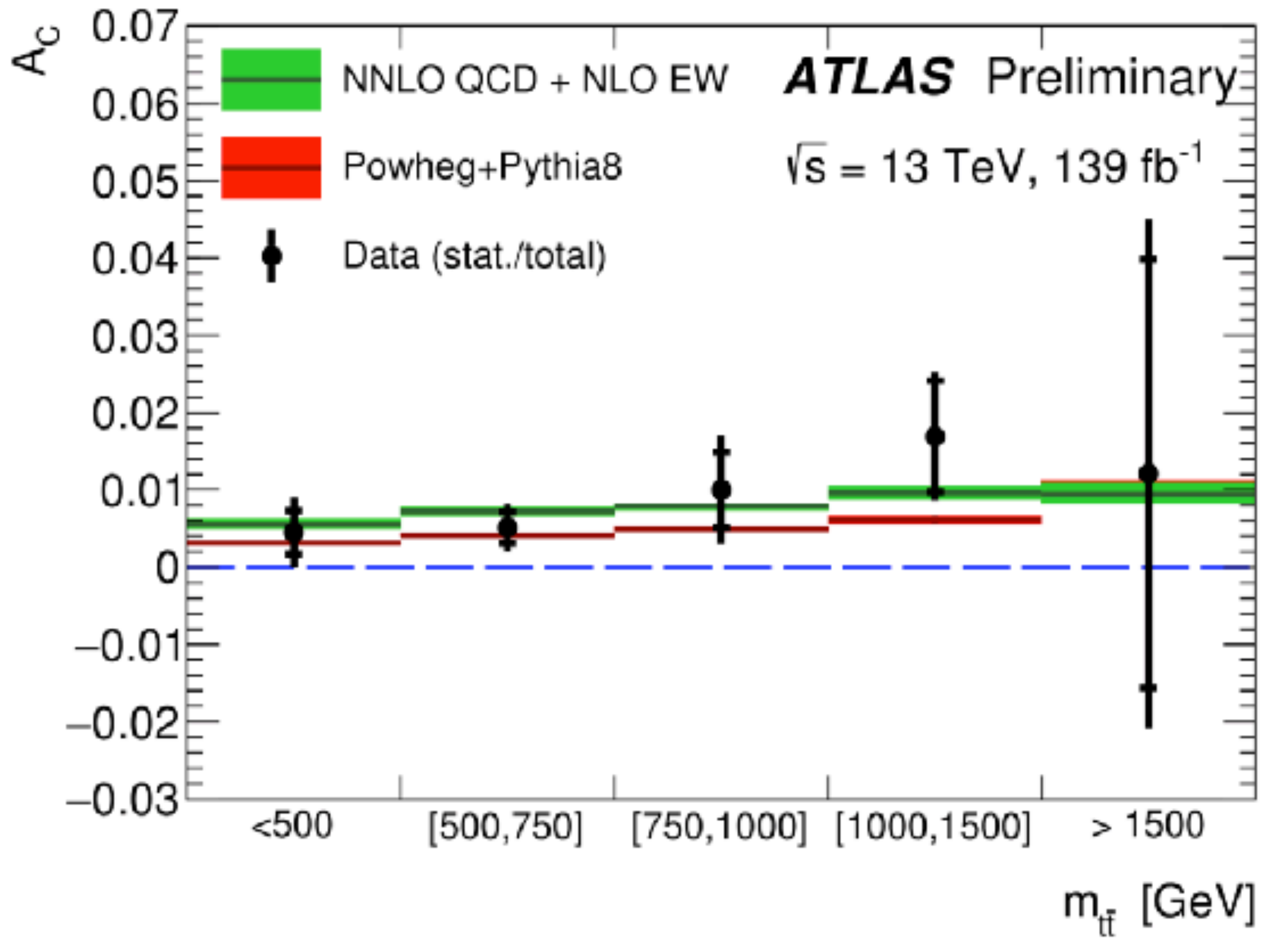
While at the Tevatron there is a forward-backward asymmetry between t and $\bar{t}$ at the LHC the asymmetry in charge makes t to be produced more centrally and $\bar{t}$ more forward. See ATLAS Briefing.

The charge asymmetry arises from the interference at tree level $q\bar{q} \to t\bar{t}g$ (between ISR and FSR) and in $q\bar{q} \to t\bar{t}$ in the interference between the s-channel lowest level diagram and the box. The effect grows with the invariant mass of the $t\bar{t}$ system.



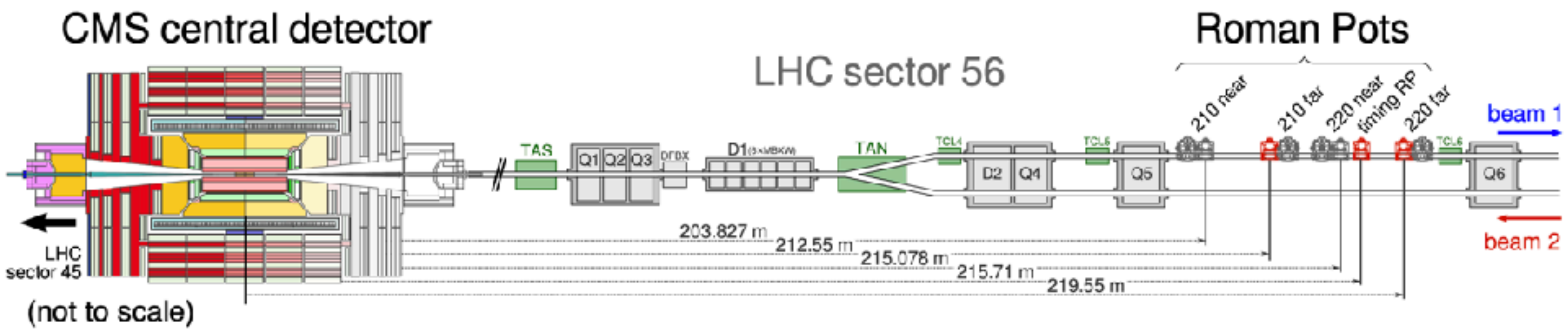
$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) \; - \; N(\Delta|y| < 0)}{N(\Delta|y| > 0) \; + \; N(\Delta|y| < 0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

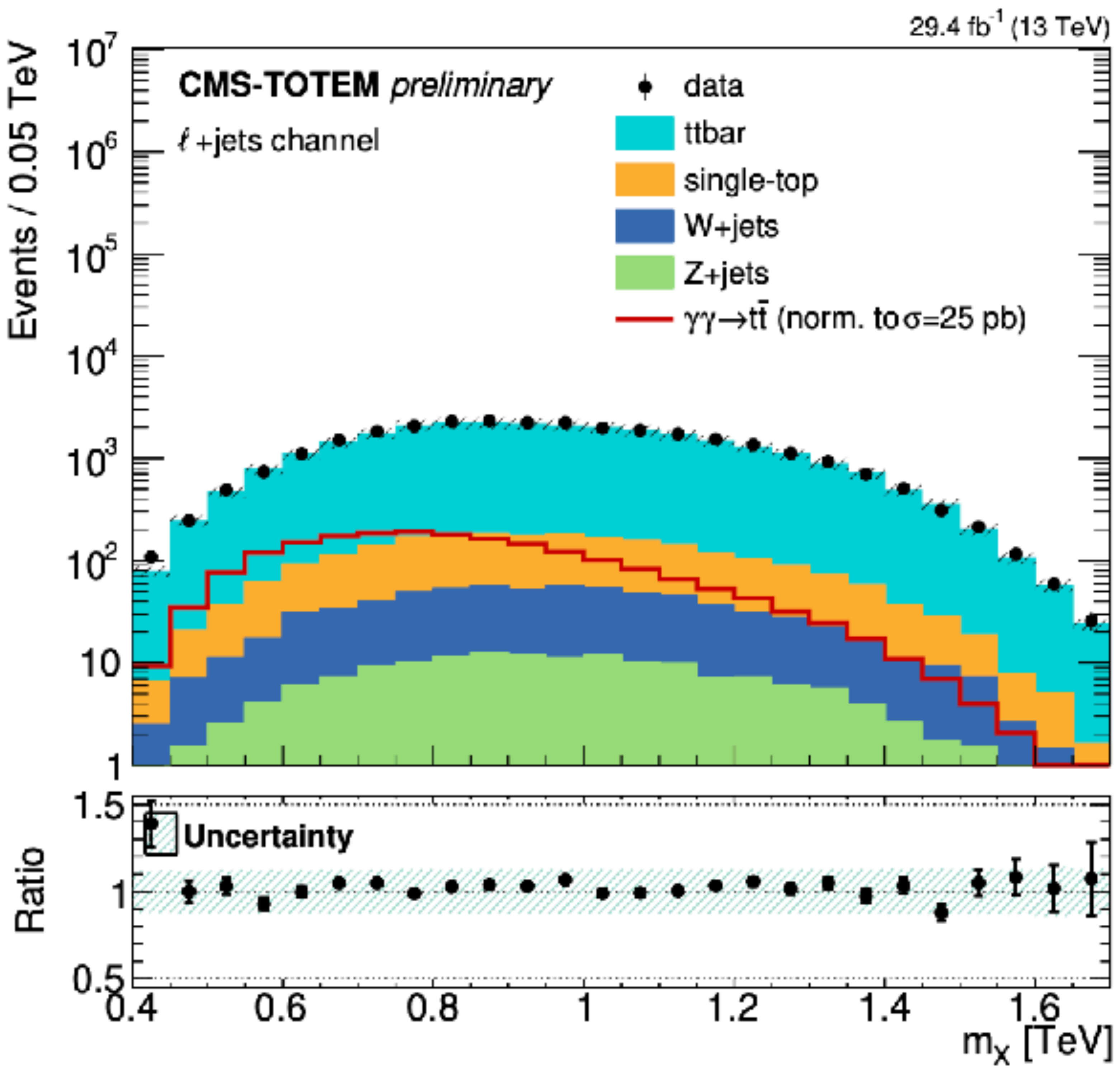


Very subtle effect observed at the 4σ level $A_C = 0.0060 \pm 0.0015$

Top Exclusive Production



Example of exclusive measurement in pp collisions with tagged protons in high luminosity running using CT-PPS (CMS-TOTEM Precision Proton Spectrometer)

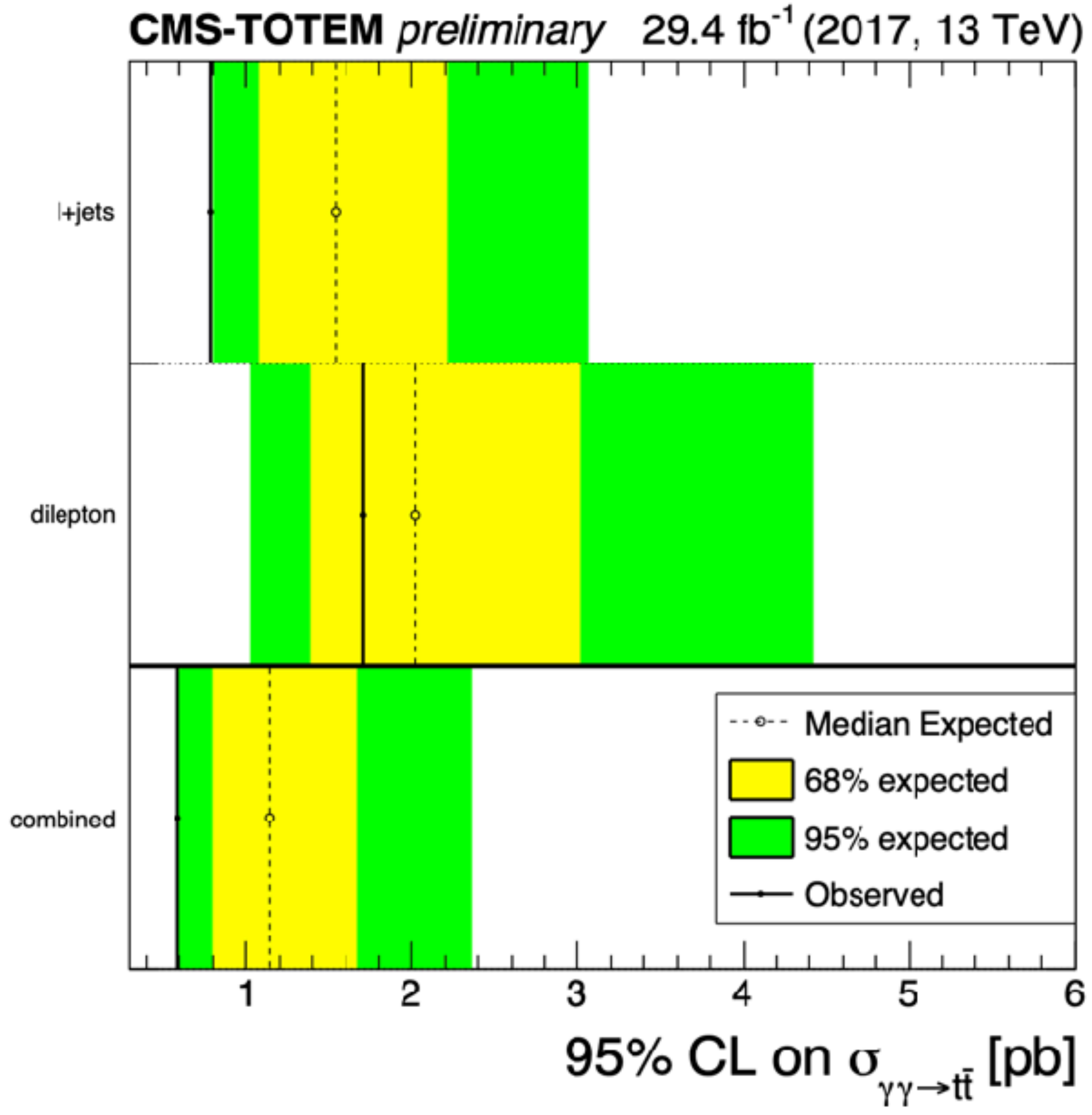


With discrimination form the forward proton tagging.

$$M_X = \sqrt{s\xi_1\xi_2}$$

Where ξ_1, ξ_2 are the fractional momentum loss of the intact protons in $pp \rightarrow pt\bar{t}p$

This process is sensitive to anomalous EM couplings of the top quark.



Quantum Information at High Energies

In top pair production at the LHC, top quarks are **not produced polarised,** however in the gluon dominated production (90%) a **spin correlation** exists.

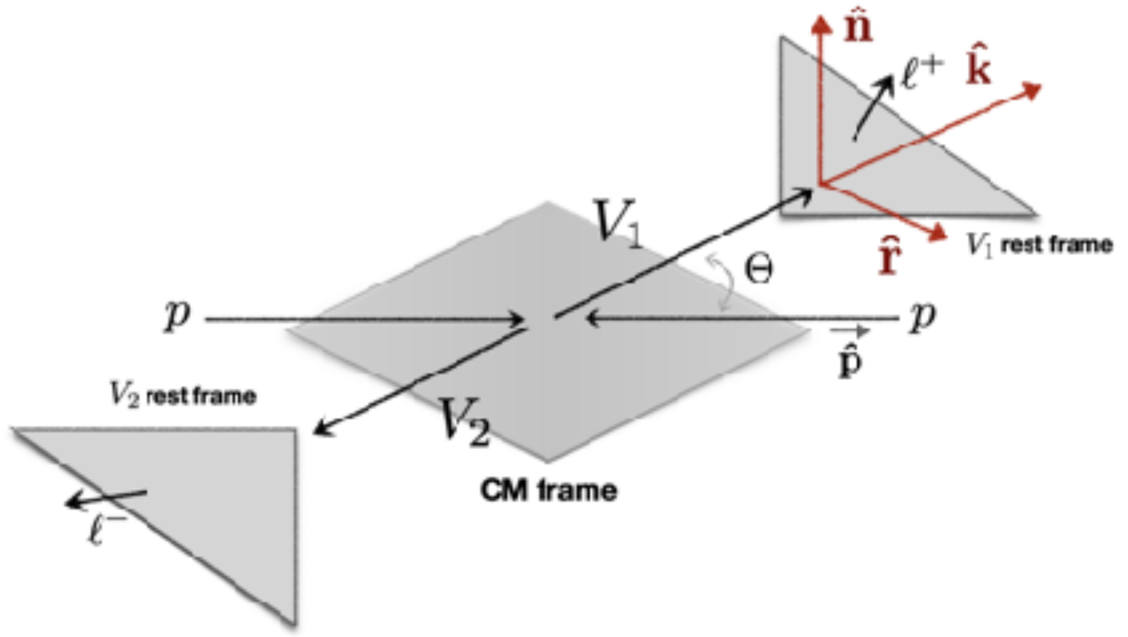
Spin correlations $pp \rightarrow t\bar{t}$ already measured, however could be used to demonstrate that the two tops are in a non separable state (i.e. entangled).

The lifetime of the top quark is shorter than the timescale for hadronisation (~10^{-23} s) and much shorter than the spin decorrelation time (~10^{-21} s) the spin information of the top quark is therefore

The spin configurations at threshold production i.e. $\beta_t \sim 0$ the $gg \rightarrow t\bar{t}$ is dominated by the "singlet" spin configuration, **which is a pure, superposed and maximally entangled Bell state**:

$$\frac{1}{\sqrt{2}}(|\uparrow\downarrow> - |\downarrow\uparrow>)$$

Measure of entanglement level:
The trace of the three dimensional spin correlation matrix C (in the base illustrate here)



$$D = \mathrm{tr}[\mathbf{C}]/3 < -1/3$$

Analysis by ATLAS using fully leptonic electron/muon top pair events measuring D at the particle level in the near-threshold region [340, 380] GeV

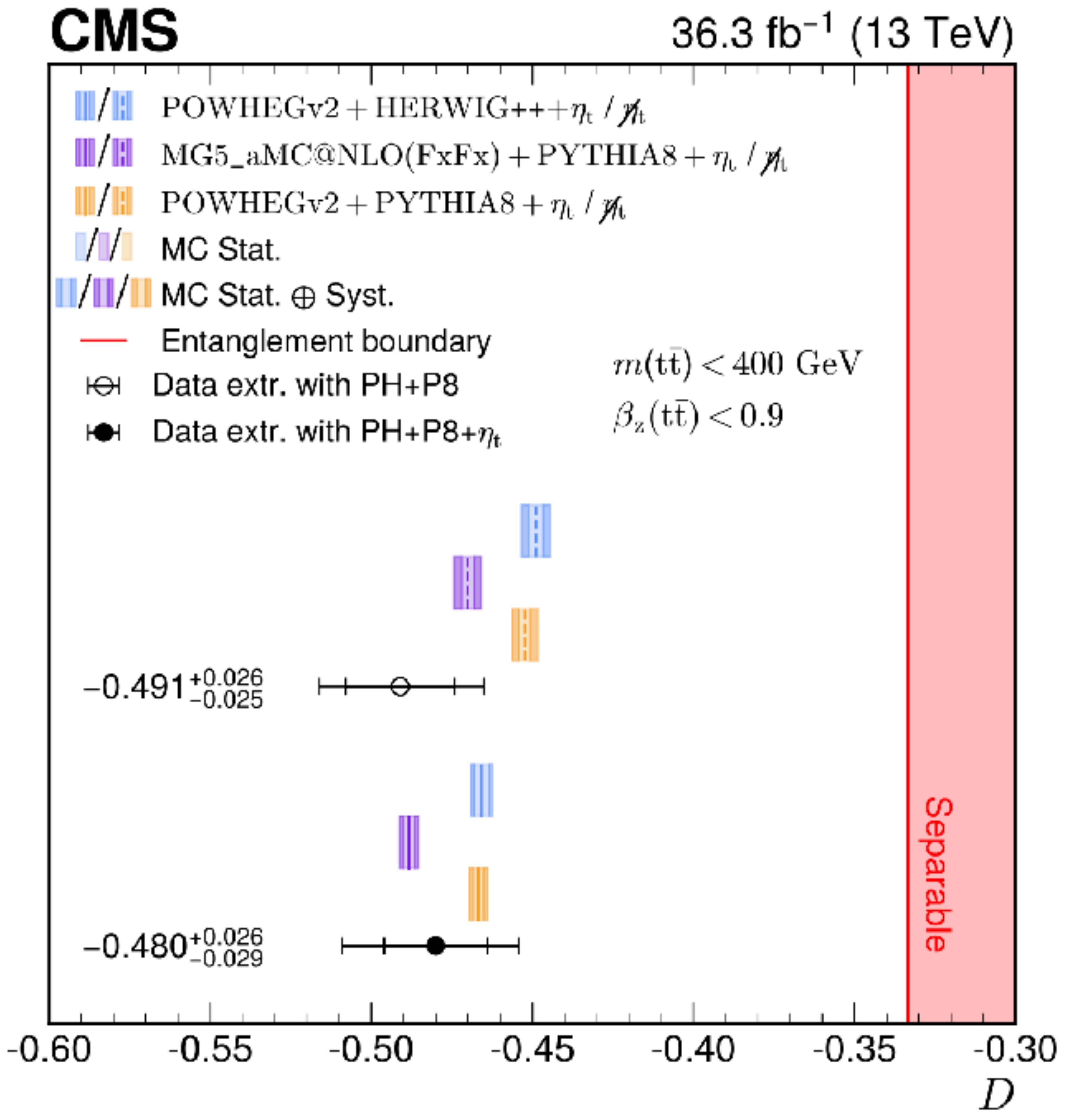
$$D = -0.547 \pm 0.002\ (\mathrm{stat}) \pm 0.021\ (\mathrm{syst})$$

Unambiguous observation of entanglement!

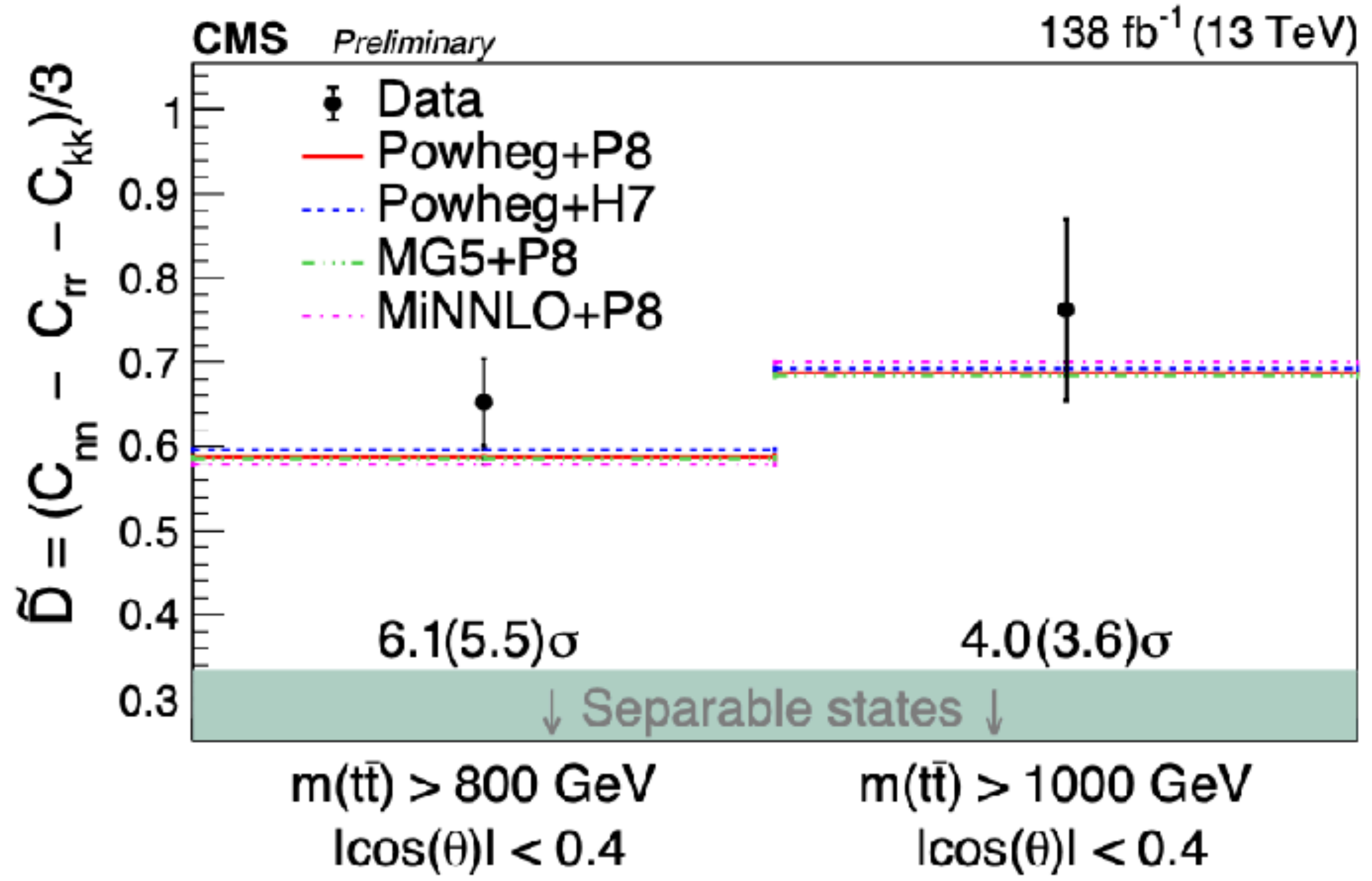
Quantum Information at High Energies

Initially measured near threshold where it is easier!
CMS went beyond with:

- At production threshold in $t\bar{t} \rightarrow b\ell\nu b\ell\nu$ events



- At high m_{tt} with $t\bar{t} \rightarrow b\ell\nu bq\bar{q}$ events, (phase space dominated 90% by space-like events)

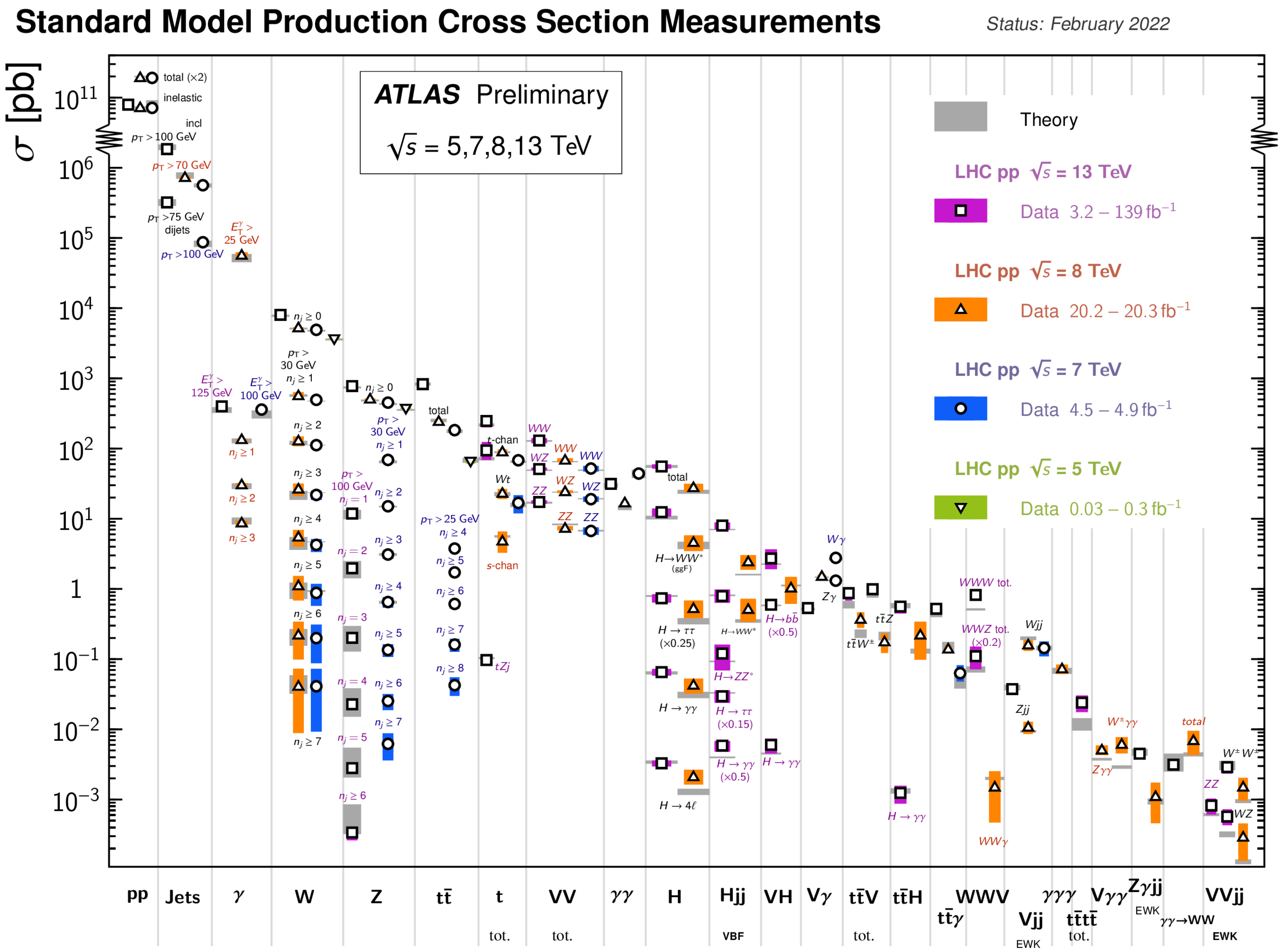


Very important elements (space-like) to go beyond entanglement towards the **violation of Bell Inequalities!** (With higher sensitivity)

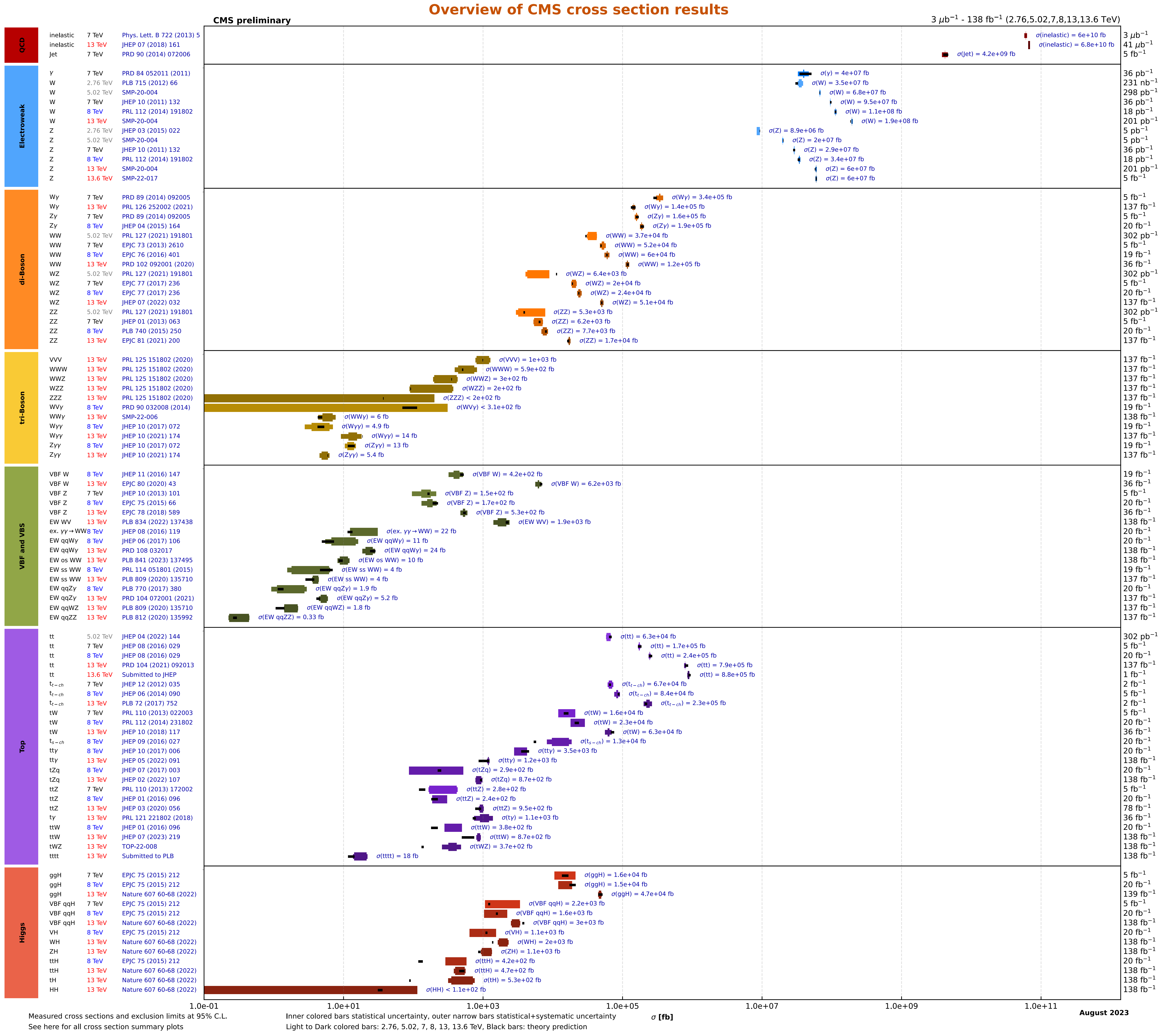
Overview and Global PDF Fit

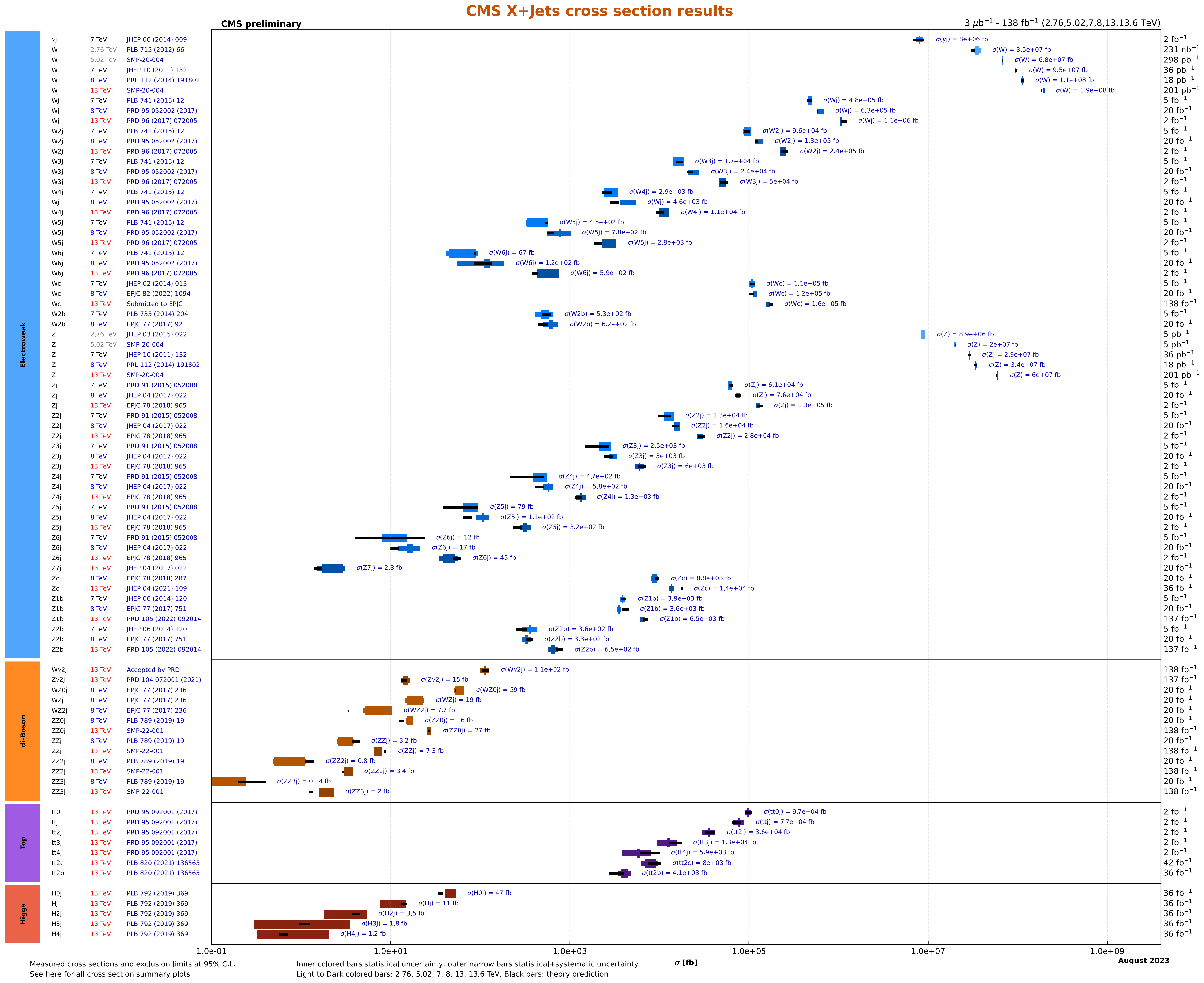
Cross Section Measurements

Vast number of cross section **measurements** made at the LHC



Cross Section Measurements





Even impossible to include in a legible way in one slide! See link.

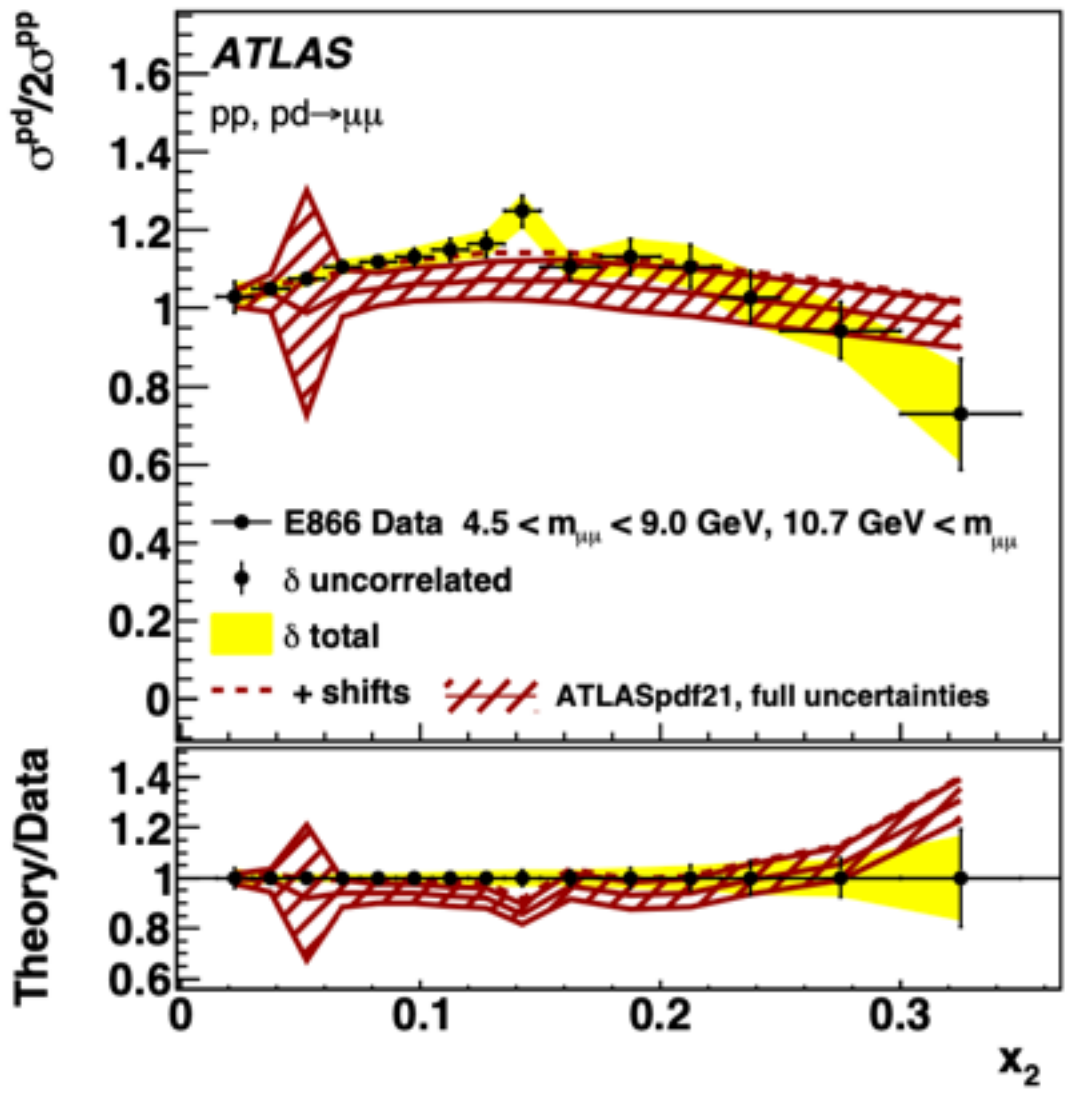
Global PDF Fits

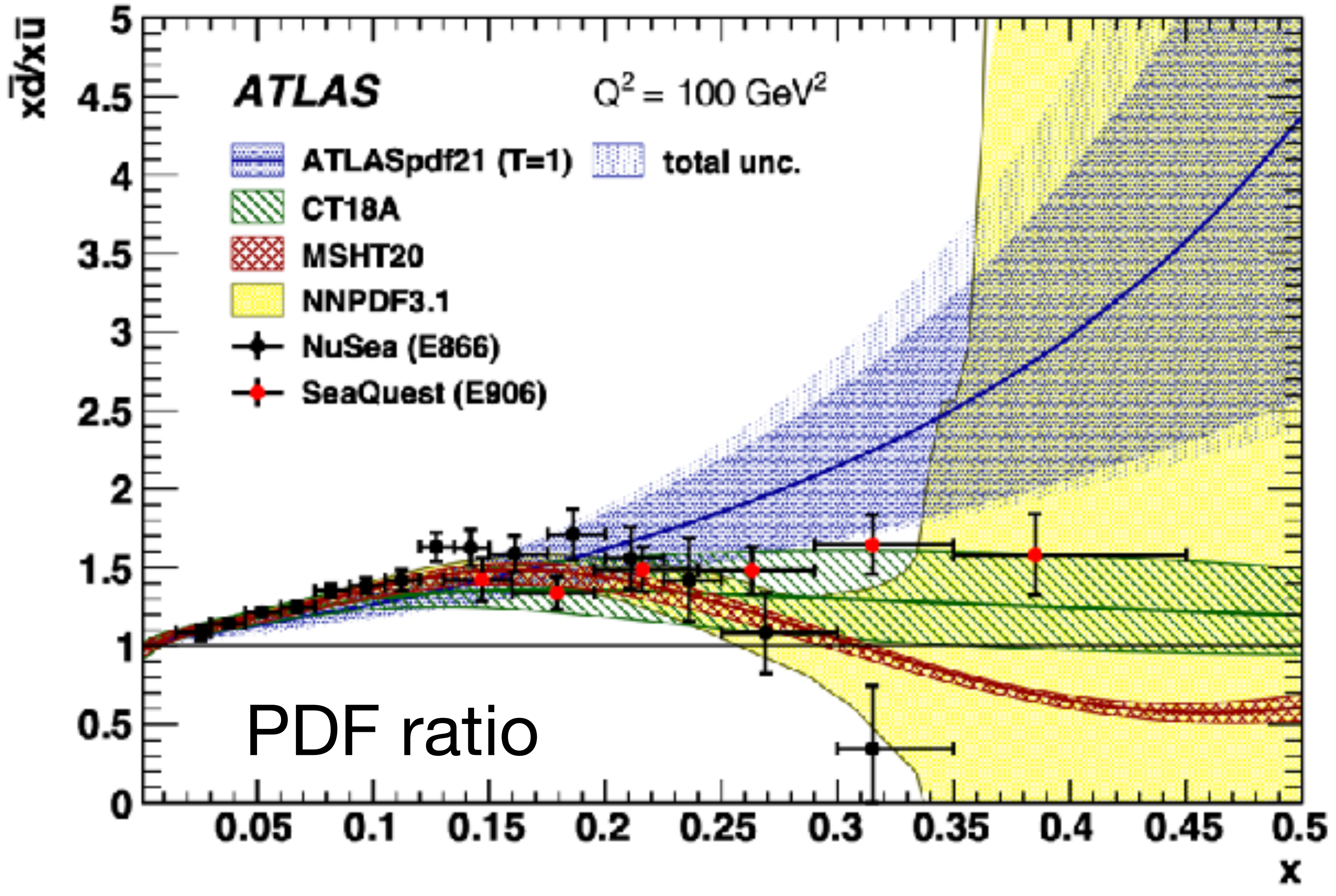
ATLAS PDF fit

Using exclusively **HERA ep** data and selected ATLAS measurements with the addition of **W, Z (+jets), tt, jets, photon** differential cross section measurements (fit done at NNLO in QCD, NLO in EW)

Light sea-quark contributions

See [paper]

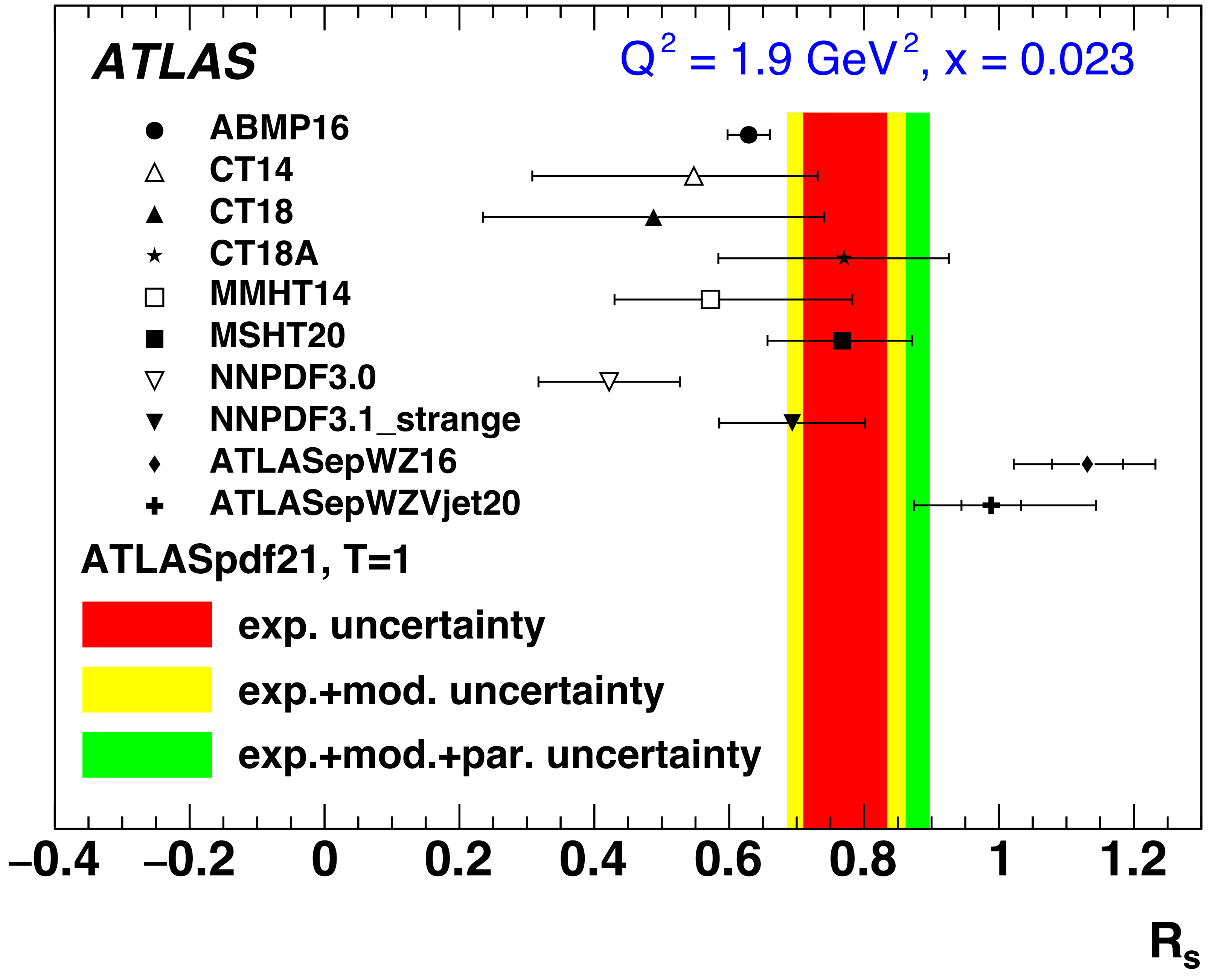




ATLAS data can be used to predict pD fixed target DY cross sections

Check relative densities of $\bar{u}$ and $\bar{d}$ sea contributions compatible with recent SeaQuest data E906 (at high x) than with NuSea (E866)

Strange quark composition



Improvement w.r.t. previous ATLAS PDFs

V+jets data suppresses R_s at high x (with effect on low x), as well as improved low-x parametrisation