Highlights of Moriond QCD 2019

The ~~last winter~~ first spring conference of the year

Merijn van de Klundert
DESY, 2019 4 1

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Disclaimer

Strictly *personal* selection of *experimental* highlights

Over 90 contributions..

- **This is not an inclusive summary**
  - **Summary slides available on Moriond website**
- **Not expert in nearly all topics covered**
- **Gained new expertise though…**

Content

Strictly *personal* selection of *experimental* highlights

Over 90 contributions..

1 **Heavy flavor**

2 **Higgs and top**

3 **Electroweak**

4 **QCD**

Heavy flavour

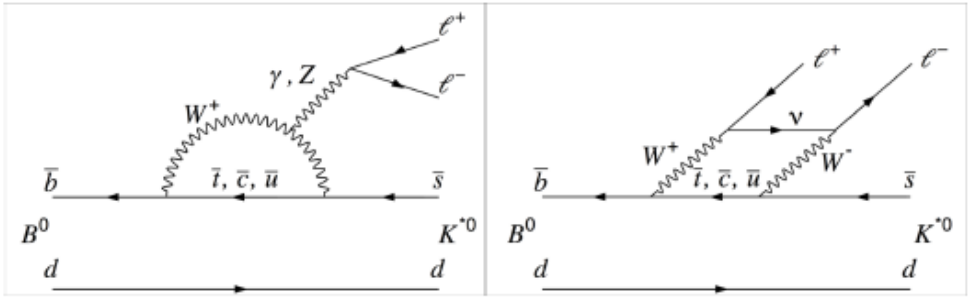
- **Whole SM flavour theory described by 10 parameters**
  - **6 Yukawa couplings/quark masses**
  - **3 CKM angles**
  - **1 CP phase**

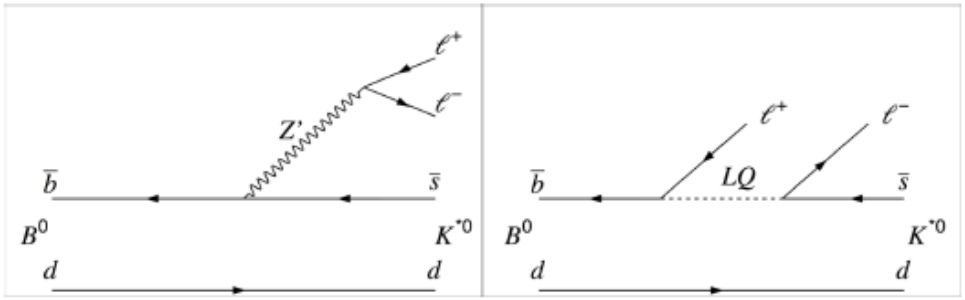
- **Updates (NOT inclusive):**
  - **CP-violation: interesting highlights, see pre. Loïc**
  - **Rare decays**
    - **Flavour Changing Neutral currents (FCNC)**
    - **Lepton Flavour Universality Violation**
    - **Lepton Flavour Violation**
      - **An observation constitutes directly new physics**
  - **Hadron spectroscopy**

Rare decays in a nutshell

Probe for BSM physics

- **SM flavour theory well-established**
  - **At tree level generally well understood**
  - **SM loop corrections calculable**
- **New physics can impose deviations beyond LHC (or Belle II) scale**
  - **Heavy BSM/SUSY particles may enter the loop**
  - **New physics may enter at Tree level:**
    - **Leptoquarks, Z'**
    - **Deviations of helicity/Cabibo suppressed decays**





FCNC and LFUV

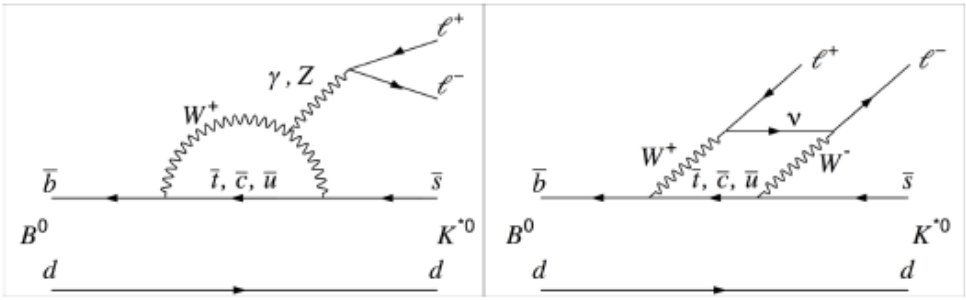
Status *before* Moriond 2019 (non-exhaustive!)

- **Flavour changing Neutral currents:**
  - In **b->s mumu** decays, deviations from SM observed
    - In various channels (B+->k+mumu, B_s- > phi mumu)
    - predictions *consistently* overestimate data!
- **Lepton Flavour Universality Violations**
  - Ratio R_{k^*} defined as: $B^+ \to k^+ mumu / B^+ \to k^+ ee$
    - **2.5 sigma** deviation w.r.t. SM (Run 1). Predictions *overestimate* data as well!
  - Ratio R_{D^*} defined as: $B \to D^* tautau / B \to D^* mumu$
    - **3.8 sigma** deviation w.r.t. SM. Predictions *underestimate* data

- **Exciting, consistent hint for BSM physics?**

  -> ICHEP 2018: leptoquarks “kind of trending topic”

  -> Review updates and new analyses!



FCNC

In b->s mumu

- LHCb Update: two new 2018 analyses:
  - TOP: JHEP 09 (2018) 145. Update, for 7 and 8 TeV p+p data

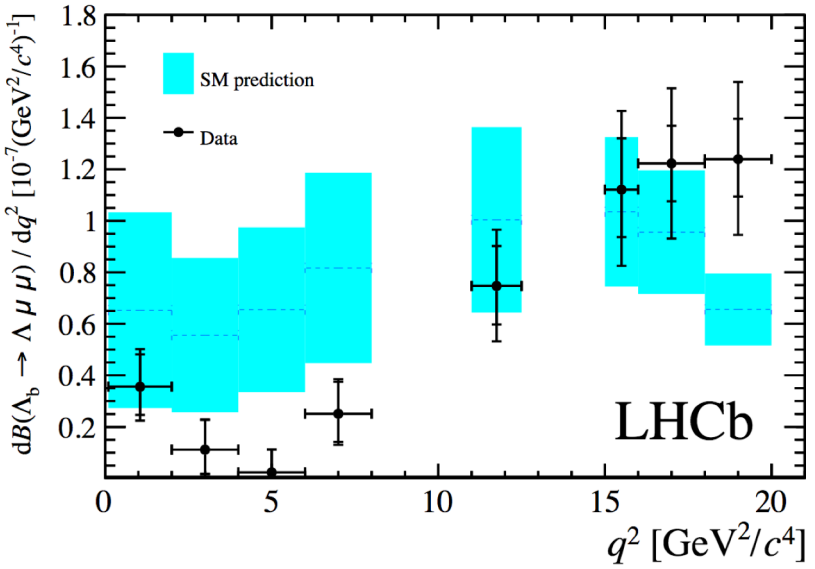
Differential branching fraction and angular analysis of Λ0*b*→Λμ+μ− decays

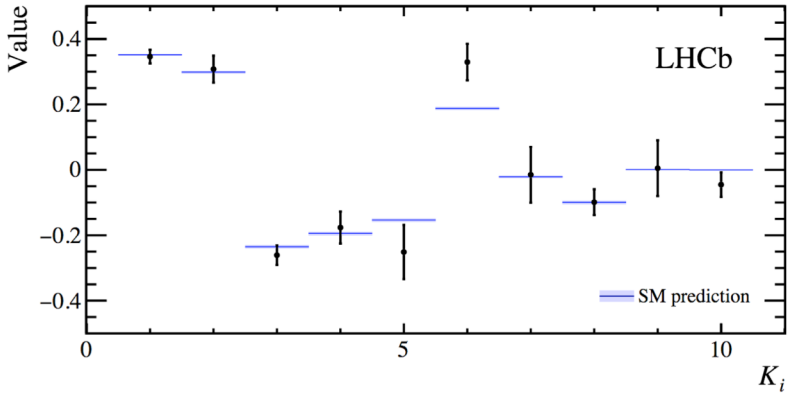
Low q^2 region: SM underestimates data

  - BTTOM: JHEP 09 (2018) 146. Update, 2011-2016 data

Angular moments of the decay Λ0*b*→Λμ+μ− at low hadronic recoil

Compatible with sm predictions





LFUV

Update on R_{k^*}

- LHCb update:

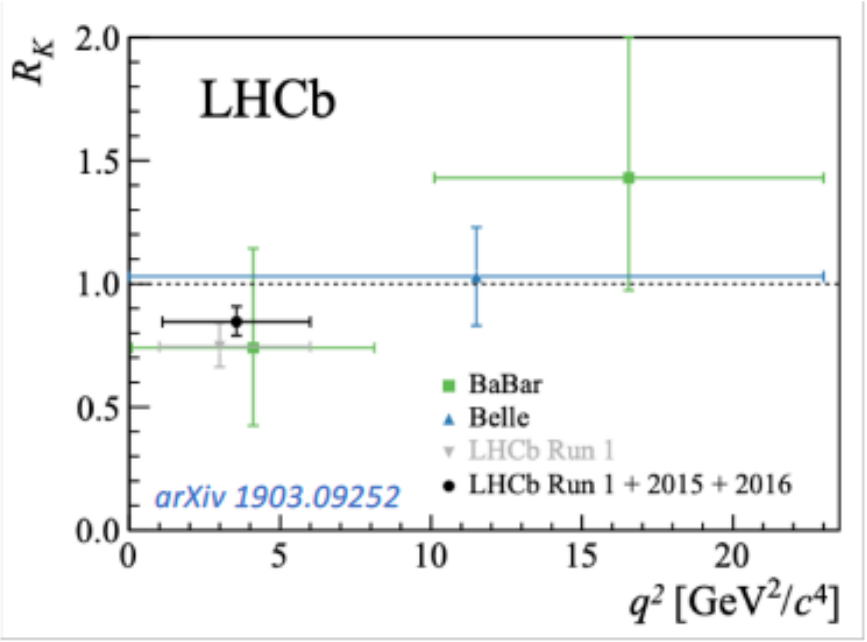
Adds 2 fb^{-1} of Run2 data (13 TeV 2015-2016) to
3 fb^{-1} of Run1 data (7/8TeV 2011/2012)

- *Improved reconstruction and reoptimized analysis strategy*
- *Double the statistics of previous measurement*

Measure double ratio:

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to J/\psi(\to \mu^+ \mu^-) K^+)} \Big/ \frac{\mathcal{B}(B^+ \to K^+ e^+ e^-)}{\mathcal{B}(B^+ \to J/\psi(\to e^+ e^-) K^+)}$$

- Uncertainty in result decreased by ~30%
- Deviation remains unchanged at 2.5 sigma ☹
- Full Run II analysis will double statistics
- CMS: stay tuned for summer LHCC update

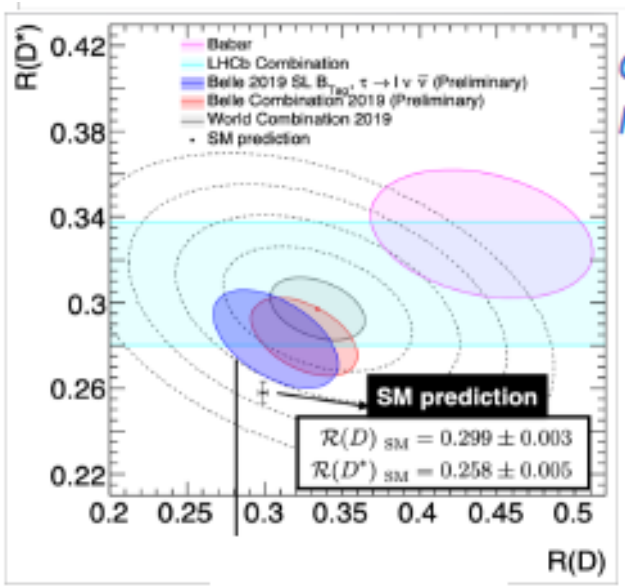


LFUV

Update on R_{D^*}

- Pre-Moriond: deviation 3.8 sigma
- Belle experiment updated before Moriond EW:

  R_{D^*} deviation decreased to 3.1 sigma

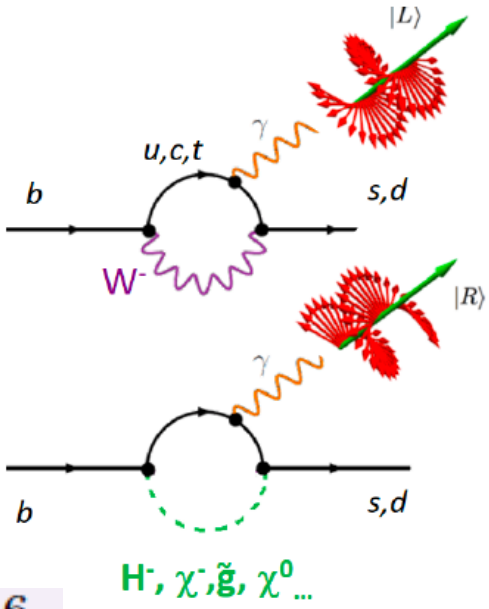


Giacomo Caria Moriond EW

combined significance ~~3.8σ~~ 3.1σ

Other new LHCb results on FCNC

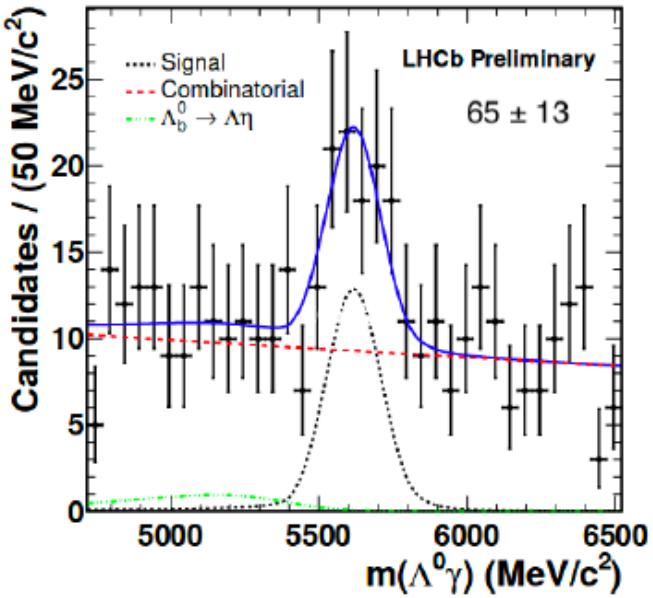
Two Radiative b -> gamma s decays



- First observation Lambda$_b$->lambda+ gamma
- Expect small right-handed component
- SM: expect 10^-5 > Branching > 10^-7.
- Result LHCb 2016 data: **arXiv:1808.00264**

$$\mathcal{B}(\Lambda_b \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.7 \pm 0.6) \times 10^{-6}$$

- Consistent with SM prediction
- Further result LHCb 2016 data: **arXiv:1808.00264**
- CP violation in B^0_s->phi+gamma
- Consistent with SM prediction

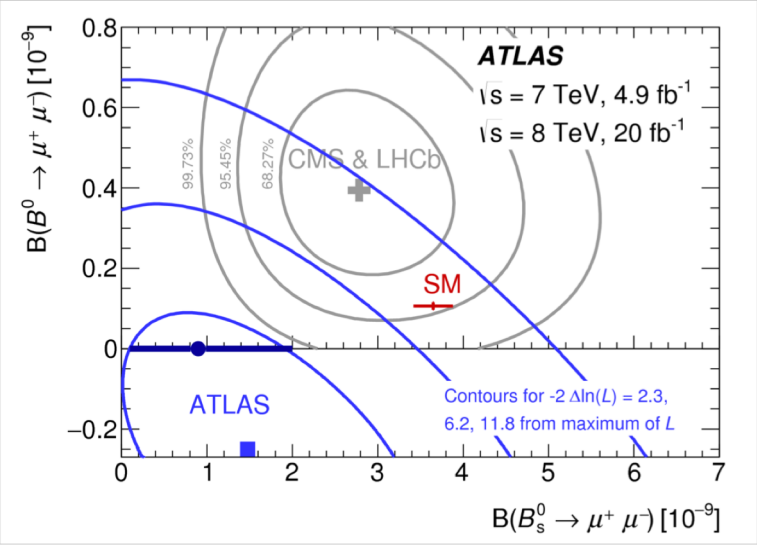


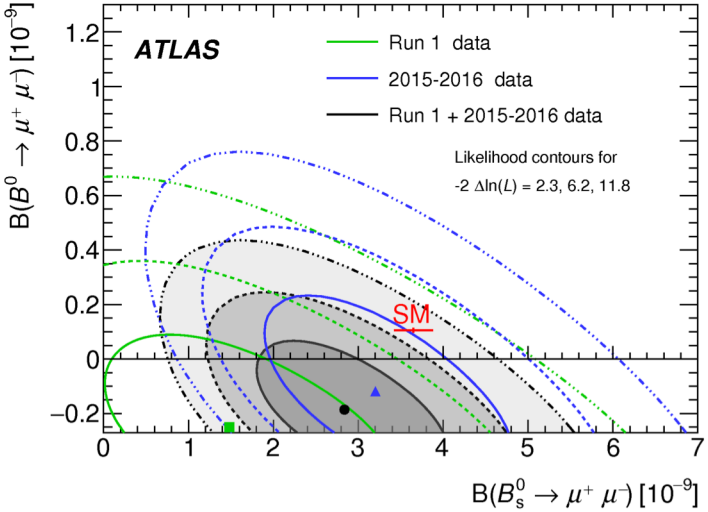
ATLAS Run II result on rare decays

"Study of the rare decays of B0s and B0 into muon pairs from data collected during 2015 and 2016 with the ATLAS detector"

- Decay heavily helicity surpressed
  - SUSY predicts large deviations
  - Leptoquarks and Z' predict deviations
- Already observed by LHCb and combi LHCb-CMS
- New ATLAS result arXiv: 1812.03017. Based on 2015+2016 data:
- Deviation smaller, compatible with SM at 2.4 sigma

=> Altogether, observed deviations inconclusive



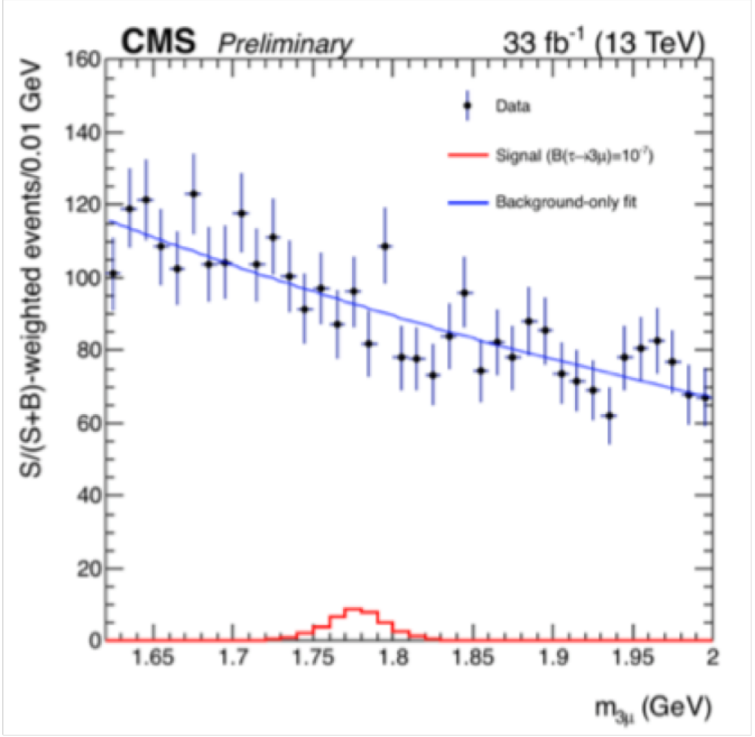


CMS Run II result on LFV

Observation would directly imply new physics!

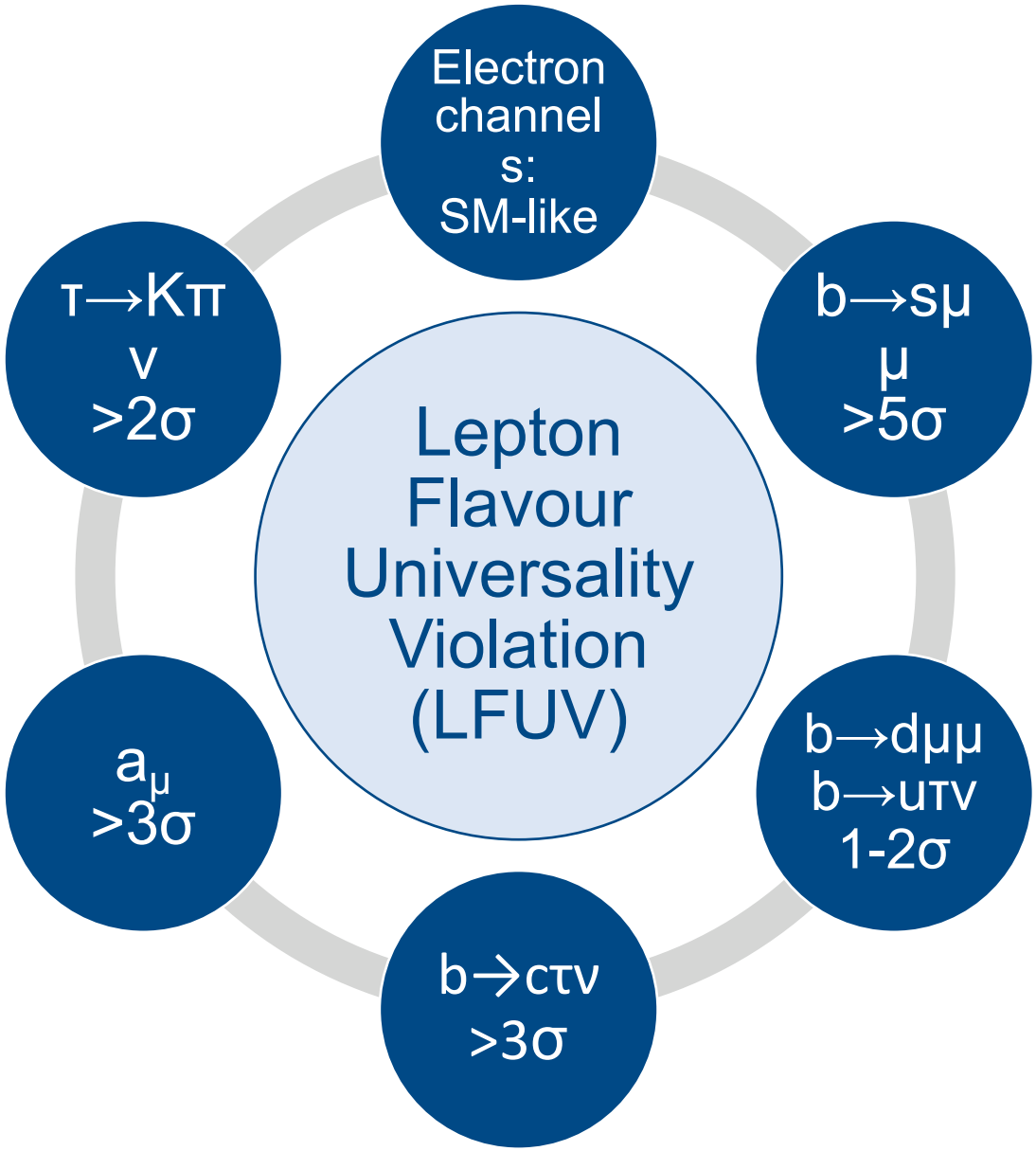
- CMS-PAS-BPH-17-004)
- Tau->mu+mu+mu
- B(Tau->mu+mu+mu)<8.8·10^{-8} with 33fb-1
- Comparable performance to BaBar-Belle
- Good Prospects, particularly

Belle II!



BR($\tau \to 3\mu$) (90% CL limit)	Ref.	Comments
3.8×10^{-7}	ATLAS [429]	Actual limit (Run 1)
4.6×10^{-8}	LHCb [428]	Actual limit (Run 1)
3.3×10^{-8}	BaBar [417]	Actual limit
2.1×10^{-8}	Belle [423]	Actual limit
3.7×10^{-9}	CMS HF-channel at HL-LHC	Expected limit (3000 fb^{-1})
6×10^{-9}	ATLAS W-channel at HL-LHC	Expected limit (3000 fb^{-1})
2.3×10^{-9}	ATLAS HF-channel at HL-LHC	Expected limit (3000 fb^{-1})
$\mathcal{O}(10^{-9})$	LHCb at HL-LHC	Expected limit (300 fb^{-1})
3.3×10^{-10}	Belle-II [196]	Expected limit (50 ab^{-1})

Explaining the flavour anomalies



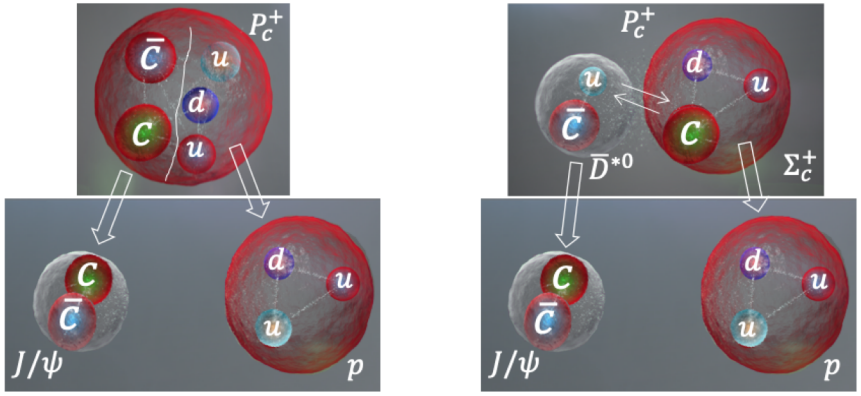
Explaining the flavour anomalies

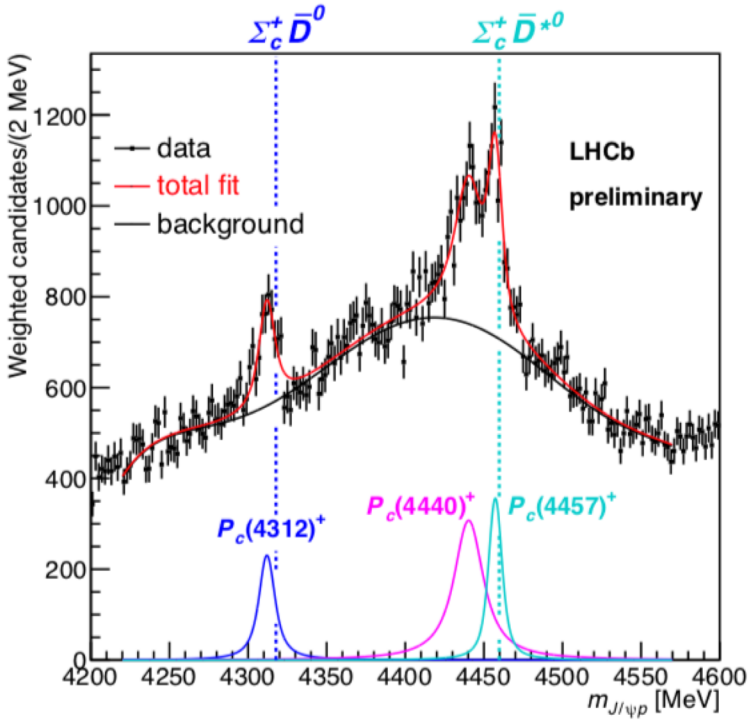
- The Pati-Salam Leptoquark is tailor made to explain the flavour anomalies
- Explanation of R(D) and R(D*) requires a generic flavour structure:
  - Explaining R(D) and R(D*) with the Pati-Salam leptoquark give the right loop effects in $b \to s\ell\ell$
- Good solution, but difficult UV completion

Hadron spectroscopy

New pentaquark news from LHCb

- First observation: two charged states: one narrow dubbed $P_c(4450)$ and one broader dubbed $P_c(4380)$, decaying into $J/\psi p$
- Tightly bound or molecular?
- Update by LHCb using full Run-2 statistics
- x9 increase w.r.t. the Run-1 analysis
- The previously found $P_c(4450)$ reveals a finer structure with two close peaks, and a new peak is found at 4312 MeV

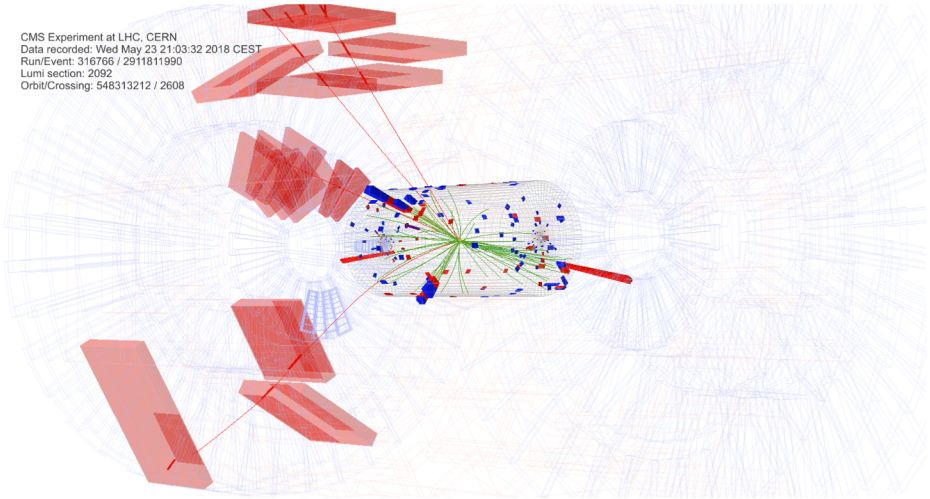




New results on Higgs and Top Physics

From observations to precision measurements

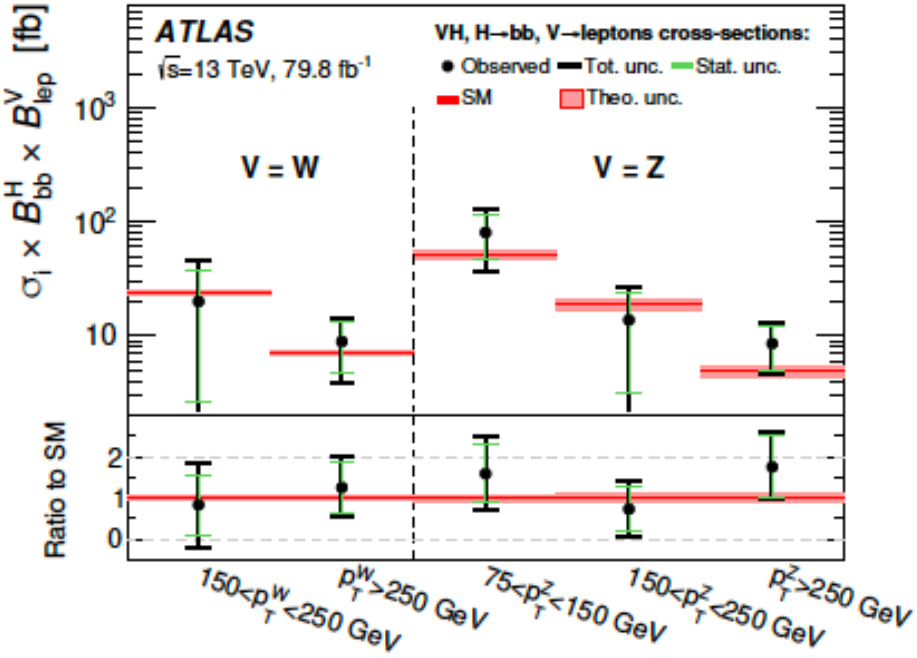
- Interesting year behind us, with major results ATLAS-CMS:
  - Higgs-tt observation established
    - Left: first CMS H+tt candidate event in 4l final state
  - Higgs decay to b-quarks discovered
  - VH channel observed
- Hunt for rare decays ongoing
- Other channels: transistion to precision measurements



ATLAS Updates:

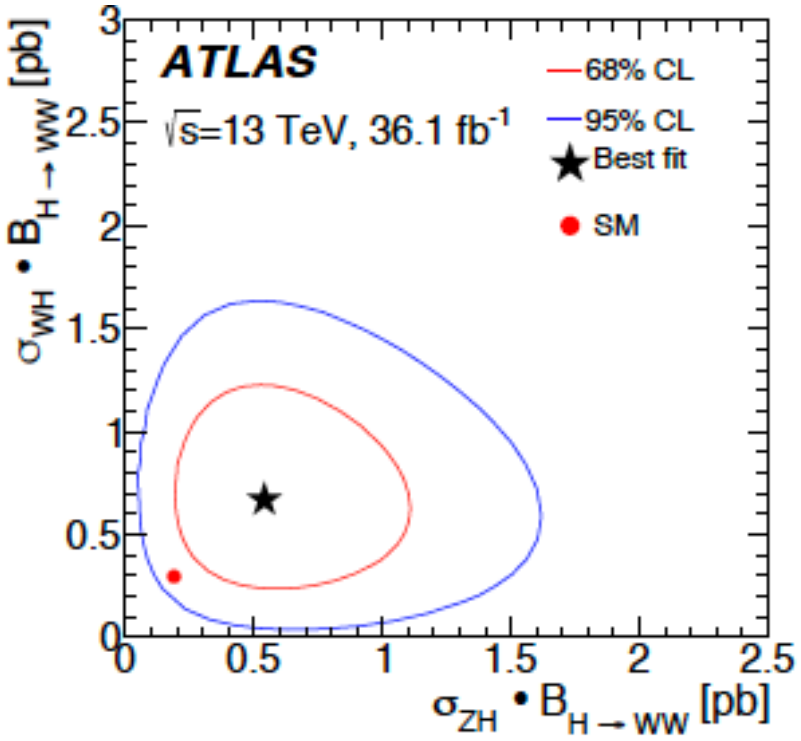
H->bb in VH channel

- For 80 fb–1, arXiv:1903.04618
- From observation to Simplifield Template Cross sections (STXS):
  - Split in production mode and kinematics regions phase space
  - Benefits (non-exclusive): reduce model dependecne, enhance sensitivity
  - facilitates combinations decay channels
- Analysis:
  - Split in WH and ZH
  - 8 BDT‘s in 8 separate signal regions
  - Extract pT spectrum, heavily optimised to sensitivity
  - Constrain effective Lagrangian models



ATLAS Updates:

H-> WW in VH channel



- Strategy:
  - WH-> l nu l nu l nu
  - ZH-> l l l nu l nu

- Results, reported with respect to SM predictions:

$$\mu_{WH} = 2.3^{+1.1}_{-0.9}(\text{stat.})^{+0.41}_{-0.33}(\text{theo syst.})^{+0.49}_{-0.36}(\text{exp syst.}) = 2.3^{+1.2}_{-1.0}$$

$$\mu_{ZH} = 2.9^{+1.7}_{-1.3}(\text{stat.})^{+0.66}_{-0.27}(\text{theo syst.})^{+0.54}_{-0.28}(\text{exp syst.}) = 2.9^{+1.9}_{-1.3}$$

$$\mu_{VH} = 2.5^{+0.8}_{-0.7}(\text{stat.})^{+0.37}_{-0.26}(\text{theo syst.})^{+0.30}_{-0.23}(\text{exp syst.}) = 2.5^{+0.9}_{-0.8}$$

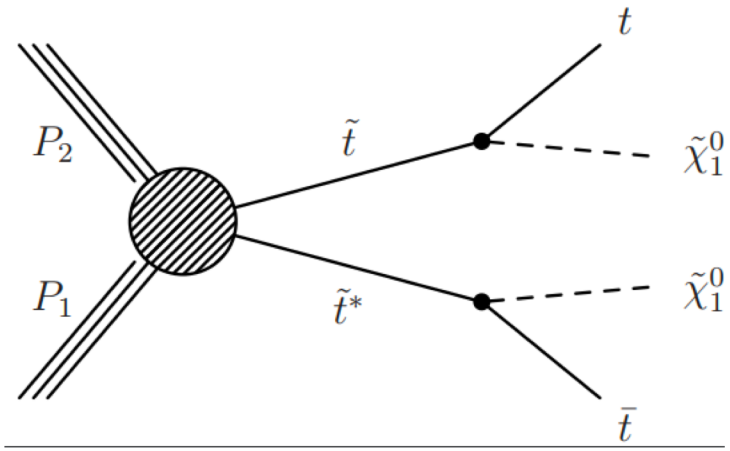
- Compatible with the SM
  - within 1.3σ of SM for *WH* and 1.5σ for *ZH*
- Observed (expected) *VH* significance: **4.1σ (1.9σ)**

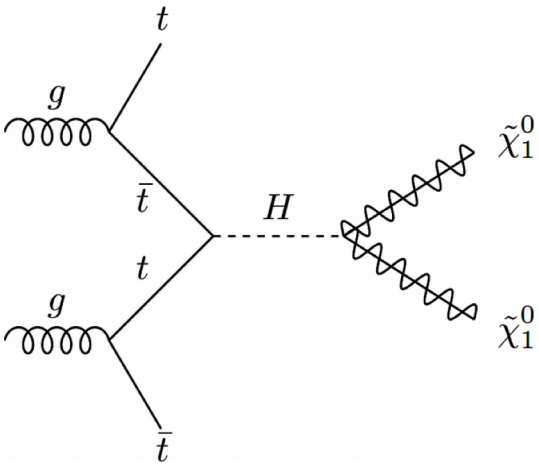
CMS Updates:

Higgs-> Invisible. arXiv:1809.05937

- First measurement in ttH topology
- 36 fb^{-1}
- **RESULT:** B (h-> Inv)< 0.46 (exp. 0.48)

Analysis	Backgrounds
0L	tt(1L), Z->vv and ttZ(->vv)
1L	tt(2L), W+jets and ttZ(->vv)
2L	tt(2L), ttZ(->vv) and DY/VV

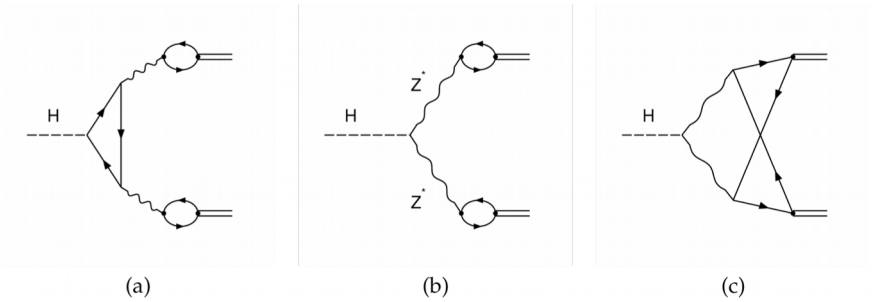




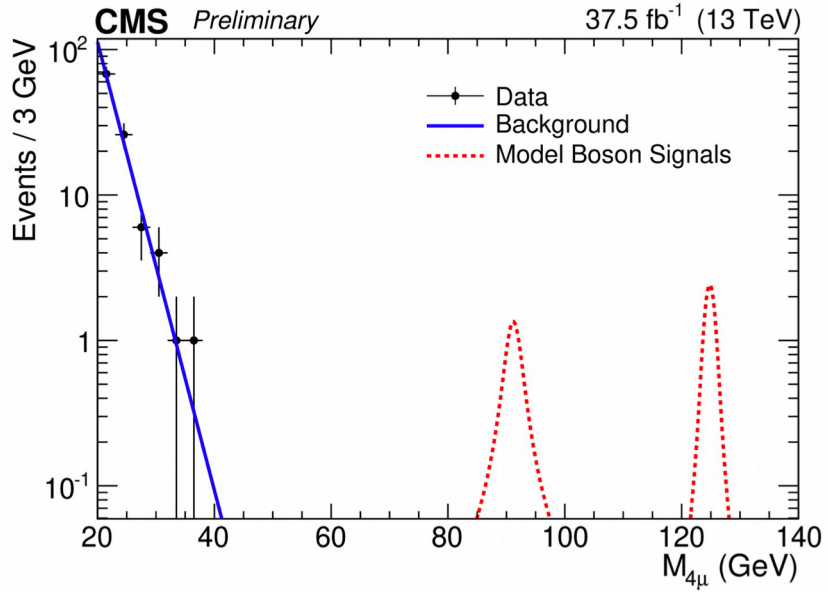
CMS Updates:

h125→J/ψ J/ψ and YY. HIG-18-025

- Experimentally opportune: almost background free!
- SM prediction small & uncertain
  - BSM enhancement (new amplitudes)?
- Obtained limits. Well in agreement with SM:



	observed	expected
$\mathcal{B}(\mathrm{H} \to \mathrm{J}/\psi\mathrm{J}/\psi) \times 10^3$	1.8	$1.8^{+0.2}_{-0.1}$
$\mathcal{B}(\mathrm{H} \to \mathrm{YY}) \times 10^3$	1.4	1.4 ± 0.1
$\mathcal{B}(\mathrm{Z} \to \mathrm{J}/\psi\mathrm{J}/\psi) \times 10^6$	2.2	$2.8^{+1.2}_{-0.7}$
$\mathcal{B}(\mathrm{Z} \to \mathrm{YY}) \times 10^6$	1.5	1.5 ± 0.1



Higgs combined measurements

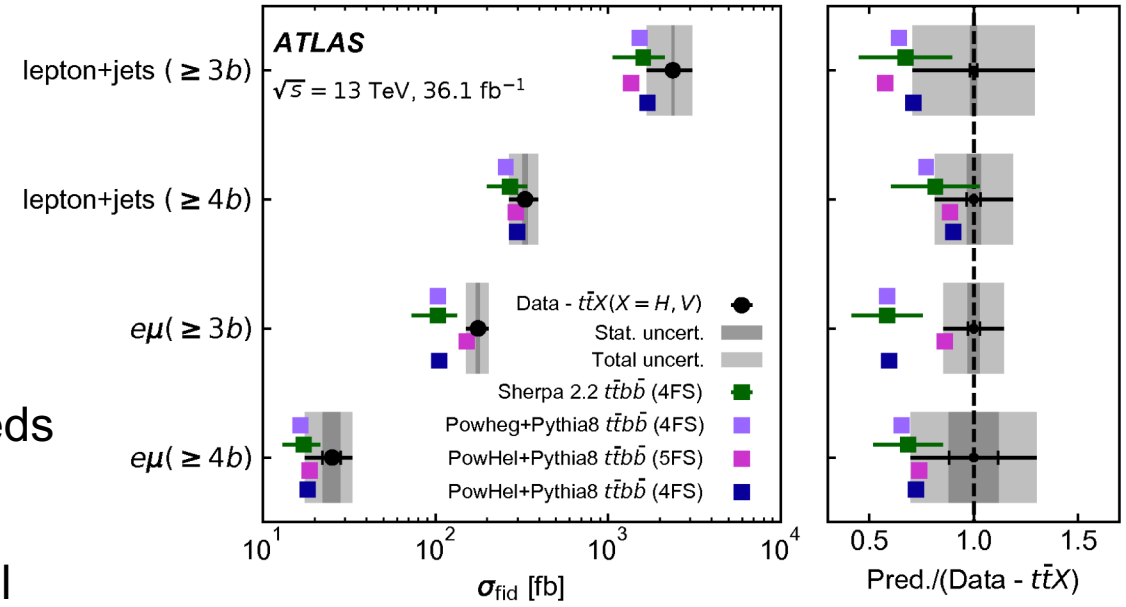
Overview

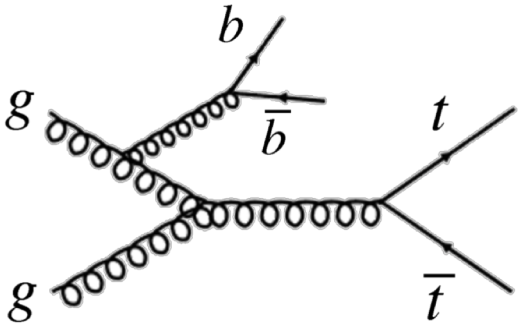
- Coupling modifiers, STXS stage 1, On 80 fb^{-1}
- CMS:
  - H->gamma+gamma
  - H->tautau
- ATLAS
  - H-> (gamma+gamma, ZZ, WW, tau+tau, b+b)
- Fiducial Xsec, STXS stage 1.1
  - 137 fb^{-1} CMS
  - H->ZZ
- Generally, precision inclusive quantities improved by ~10%
- More complete RunII results in preparation!

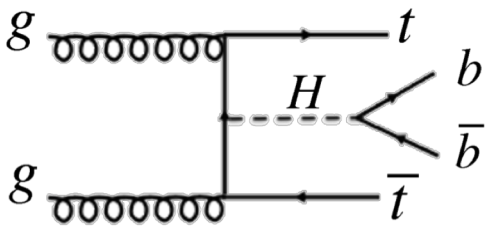
ATLAS results on tt+bb

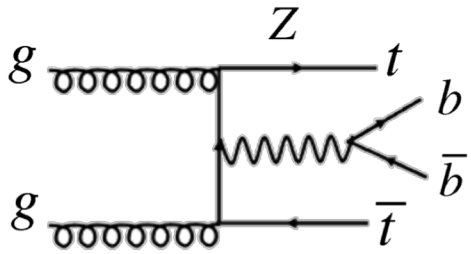
Important background to ttH measurements!

- ATLAS, arXiv:1811.12113
- 36.1 fb-1
- Both fiducial cross sections and differential extracted
- Experimental precision exceeds theoretical knowledge.
- Predictions lower than fiducial measurements but compatible.







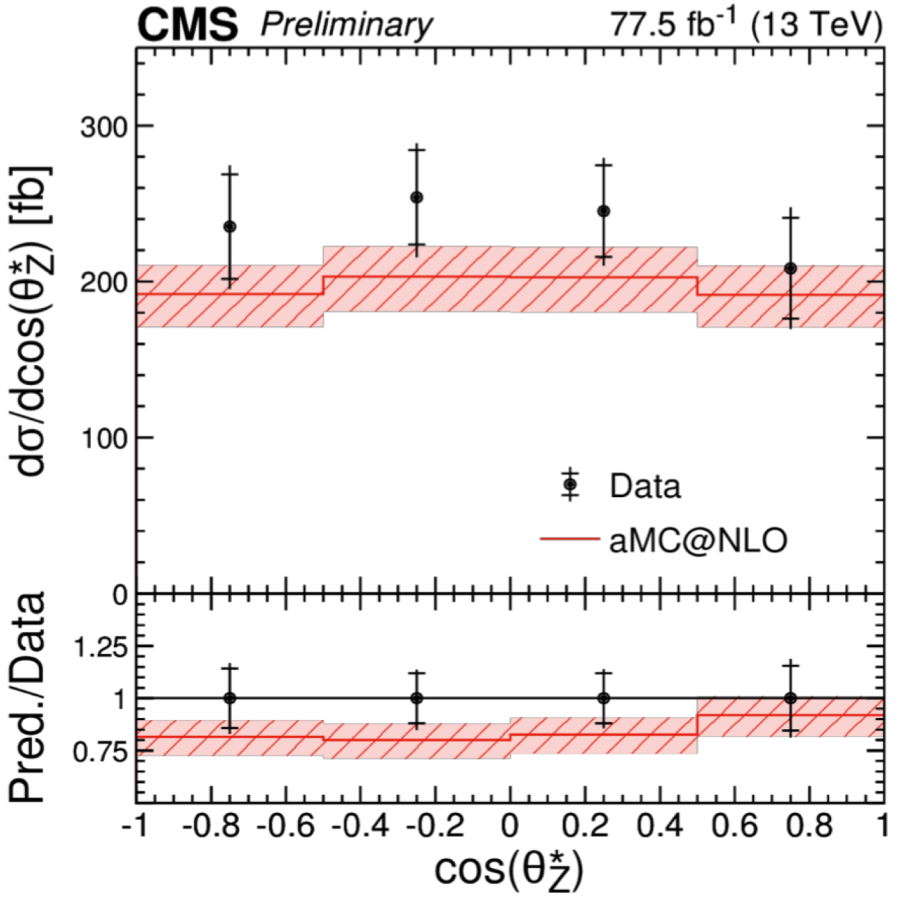


CMS preliminary $t\bar{t}Z$ results @ 13 TeV

Updated with more stastistics

- Results:
- Differential $t\bar{t}Z$ cross-section w.r.t pT(Z) and cos(θ*Z) (angle between Z and negatively charged lepton from the Z decay in the Z-rest frame)
- – Interpreted within EFT and anomalous $t\bar{t}Z$ couplings:
- Analysis reached better precision than NLO calculations

Absolute differential cos(θ*Z) distribution



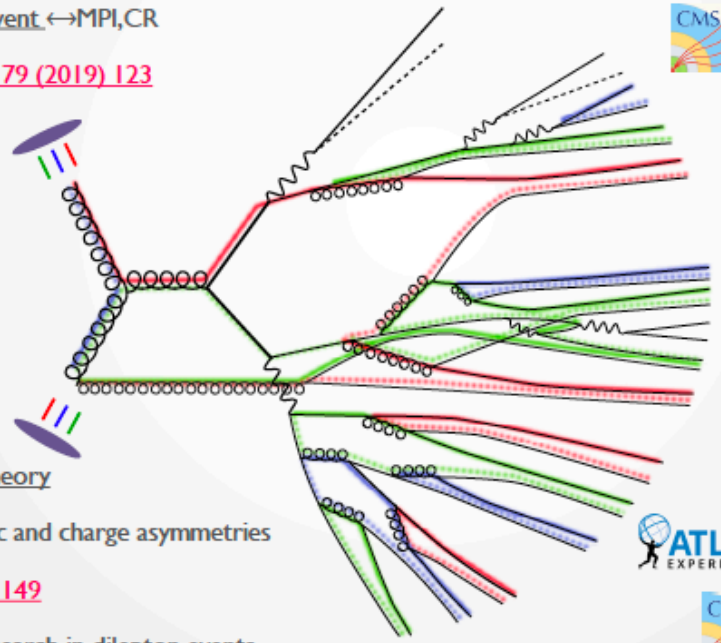
$$\sigma_{t\bar{t}Z} = 1.00\ ^{+0.06}_{-0.05}\ (\text{stat})\ ^{+0.07}_{-0.06}\ (\text{syst})\ \text{pb}$$

Note: ATLAS and CMS released also first analyses on 4 top production!

Wealth of new top physics results published

Further tt+X, top mass, cross sections, properties, and theory updates: see Moriond slides!

SUMMARY



Color flow in W decays

ATLAS EXPERIMENT Eur. Phys. J. C 78 (2018) 847

Underlying Event ↔MPI,CR

CMS Eur. Phys. J. C 79 (2019) 123

Spin correlations

ATLAS EXPERIMENT arXiv:1903.07570

CMS CMS-TOP-PAS-18-006

Top Yukawa coupling

CMS CMS-PAS-TOP-17-004

Jet substructure

ATLAS EXPERIMENT arXiv:1903.02942

CMS Phys. Rev. D 98, 092014 (2018)

CMS Effective field theory

differential x-sec and charge asymmetries

JHEP 02 (2019) 149

dedicated EFT search in dilepton events

CMS-TOP-PAS-17-020

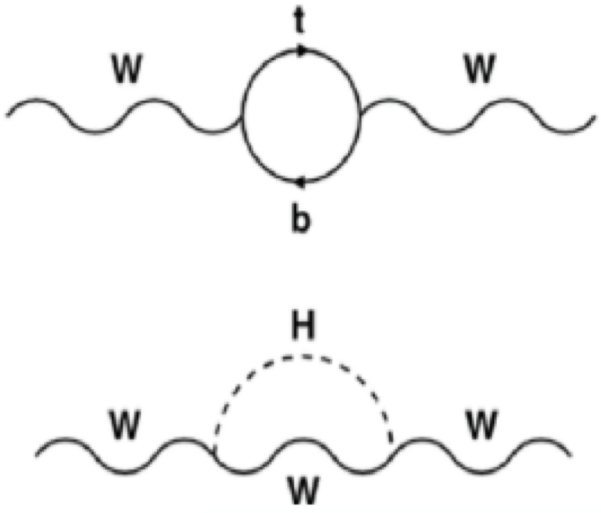
tt+Z/W cross section

ATLAS EXPERIMENT arXiv:1901.03584

CMS CMS-PAS-TOP-18-009

Electroweak measurements

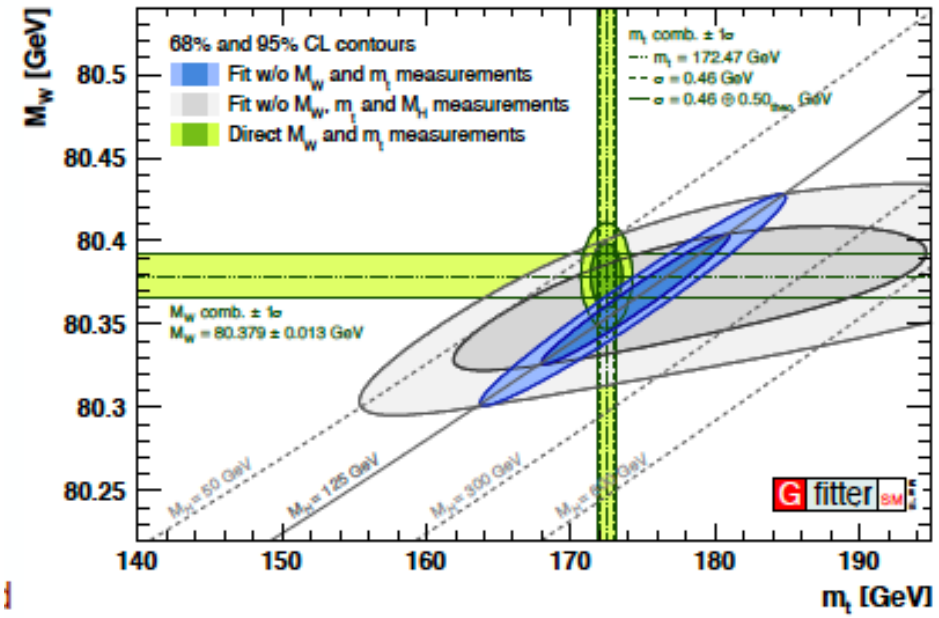
First LHC W-mass measurement (ATLAS)



- M_W sensitive to M_H and M_t via radiative corrections
- The global EW fit yields M_W with an uncertainty

$$\Delta m_W^{theory} = 8 \text{ MeV} < \Delta m_W^{exp} = 15 \text{ MeV}$$

- Only M_W measurement at LHC so far! from ATLAS
- M_W = 80370 ± 7 (stat.) ± 11 (exp. syst.) ± 14 (mod. syst.) MeV
- Precision 0.02%, dominating uncertainty from theory: QCD, PDF
- **ATLAS measurement alone competes with Tevatron combination**



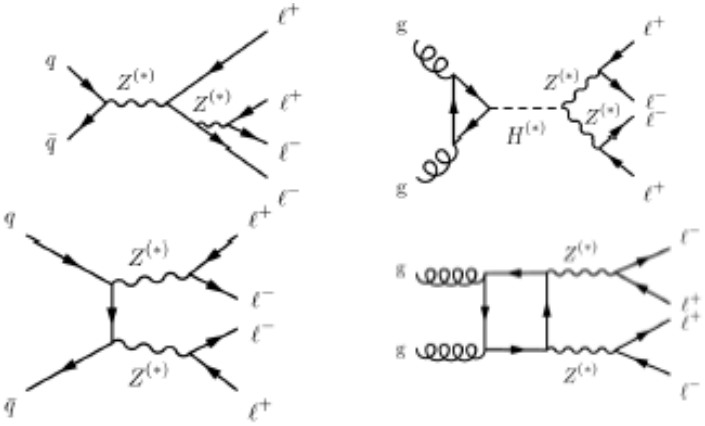
EW measurements

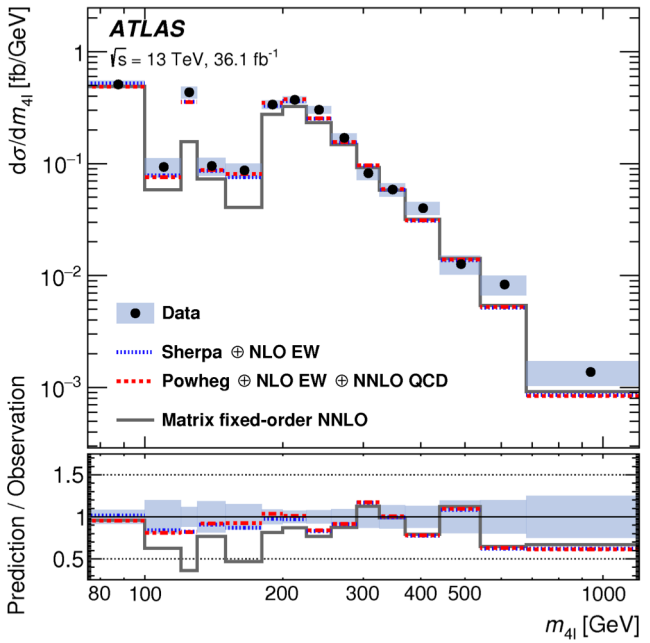
ATLAS: fist ZZ->4l measurement

- ZZ->4ℓ differential measurement
  - Provide unfolded m4ℓ, pT

  4ℓ, y4ℓ and a matrix element
- discriminant.
- Use these measurements to make reinterpretations.
  - μgg4ℓ=1.3±0.5
  - Constraint off-shell Higgs

  boson signal strength.
  - Modified Higgs coupling



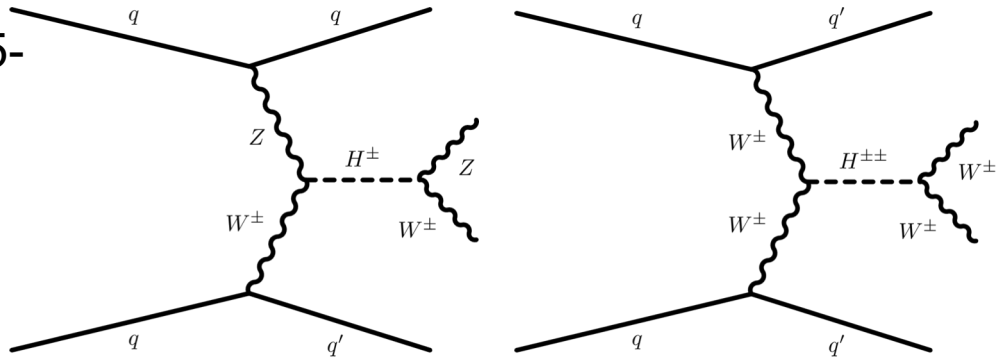


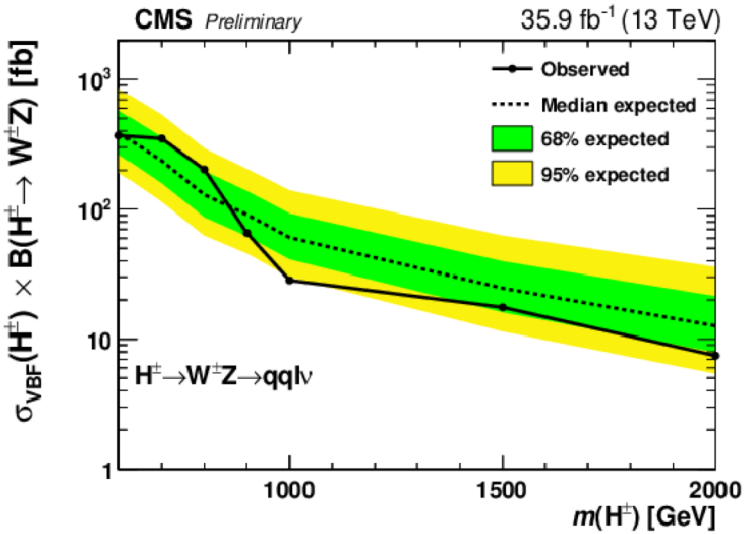
Measurement	$\mathcal{B}_{Z\to 4\ell}/10^{-6}$
ATLAS, $\sqrt{s} = 7$ TeV and 8 TeV [8]	$4.31 \pm 0.34(\text{stat}) \pm 0.17(\text{syst})$
CMS, $\sqrt{s} = 13$ TeV [6]	$4.83\ ^{+0.23}_{-0.22}(\text{stat})\ ^{+0.32}_{-0.29}(\text{syst}) \pm 0.08(\text{theo}) \pm 0.12(\text{lumi})$
ATLAS, $\sqrt{s} = 13$ TeV	$\mathbf{4.70 \pm 0.32(stat) \pm 0.21(syst) \pm 0.14(lumi)}$

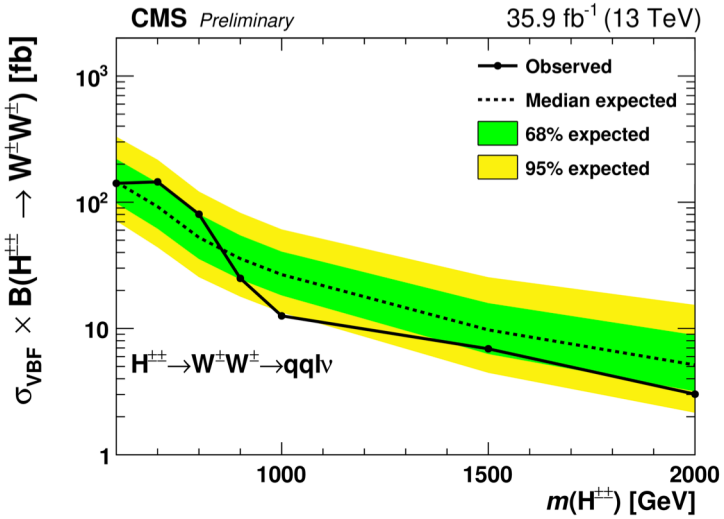
Electroweak measurements

CMS new result on VBS VVjj->ℓνJjj or ℓℓJjj. CMS-PAS SMP-18-006

- CMS using 36 fb-1 of data (2015-2016)
- Analysis not sensitive to SM coupling.
- Set limit on aQGC.
- Sensitive to exotic charged Higgs scenario.







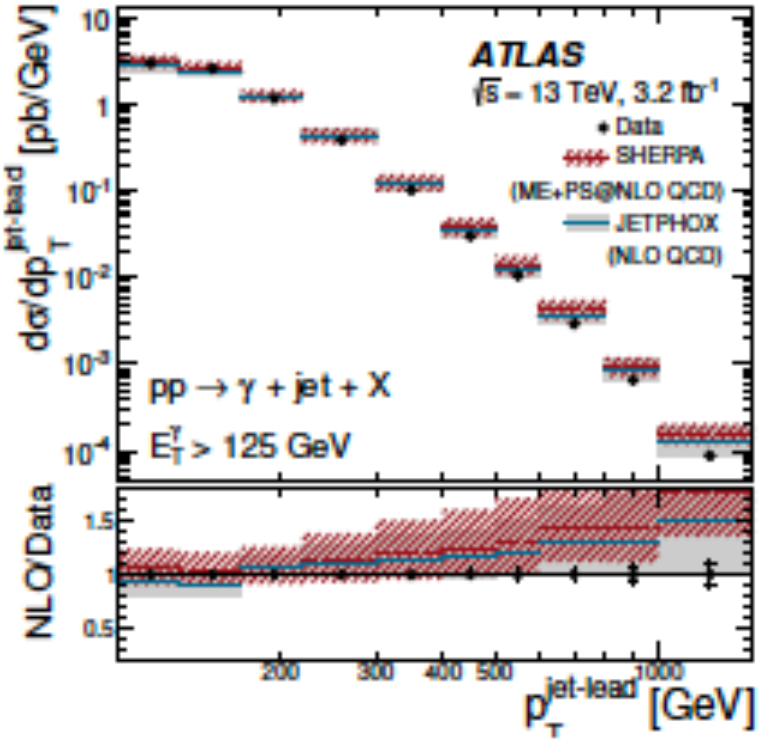
General observations

- Limits on new physics, anomalous gauge couplings etc. have improved
  - Anomalous gauge couplings higher sensitivity than LEP or Tevatron
- Obtained sensitivity to NNLO QCD
- No strong hints of BSM physics

QCD

Photons+Jets at ATLAS

- Prompt photon: colour-neutral probe for scale event
- Isolated-photon plus jet production cross section at ps = 13 TeV
- Measurement for several observables
- All measurements are in agreement with the LO and NLO pQCD predictions



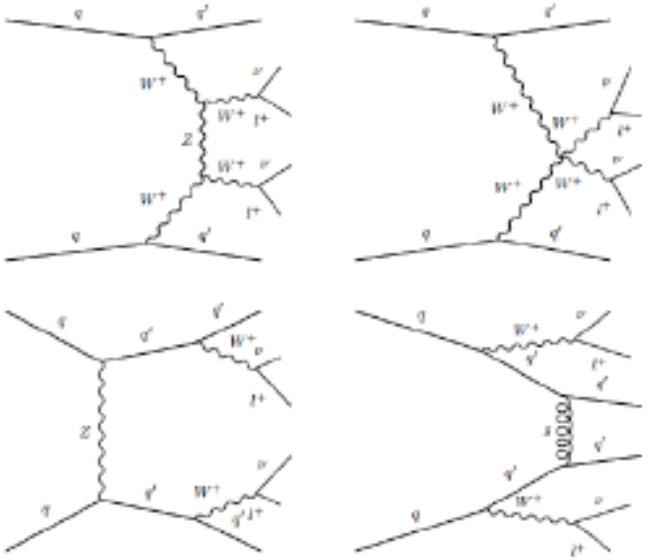
CMS: DPS in same sign WW production at 13 TeV SMP-18-015

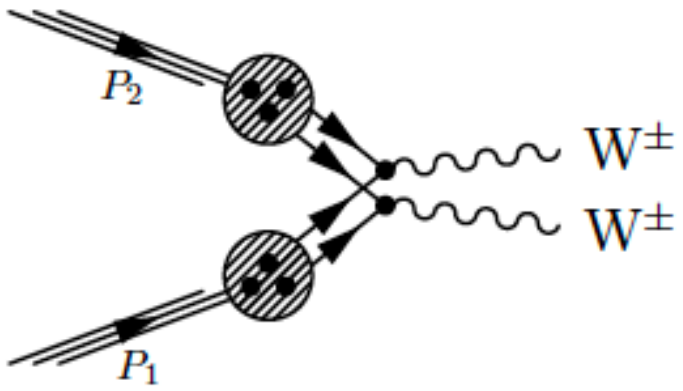
First evidence for DPS in this channel!

- For 13 TeV data (2016+2017)
- Hypothesis:

$$\sigma_{AB}^{DPS} = \frac{n}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

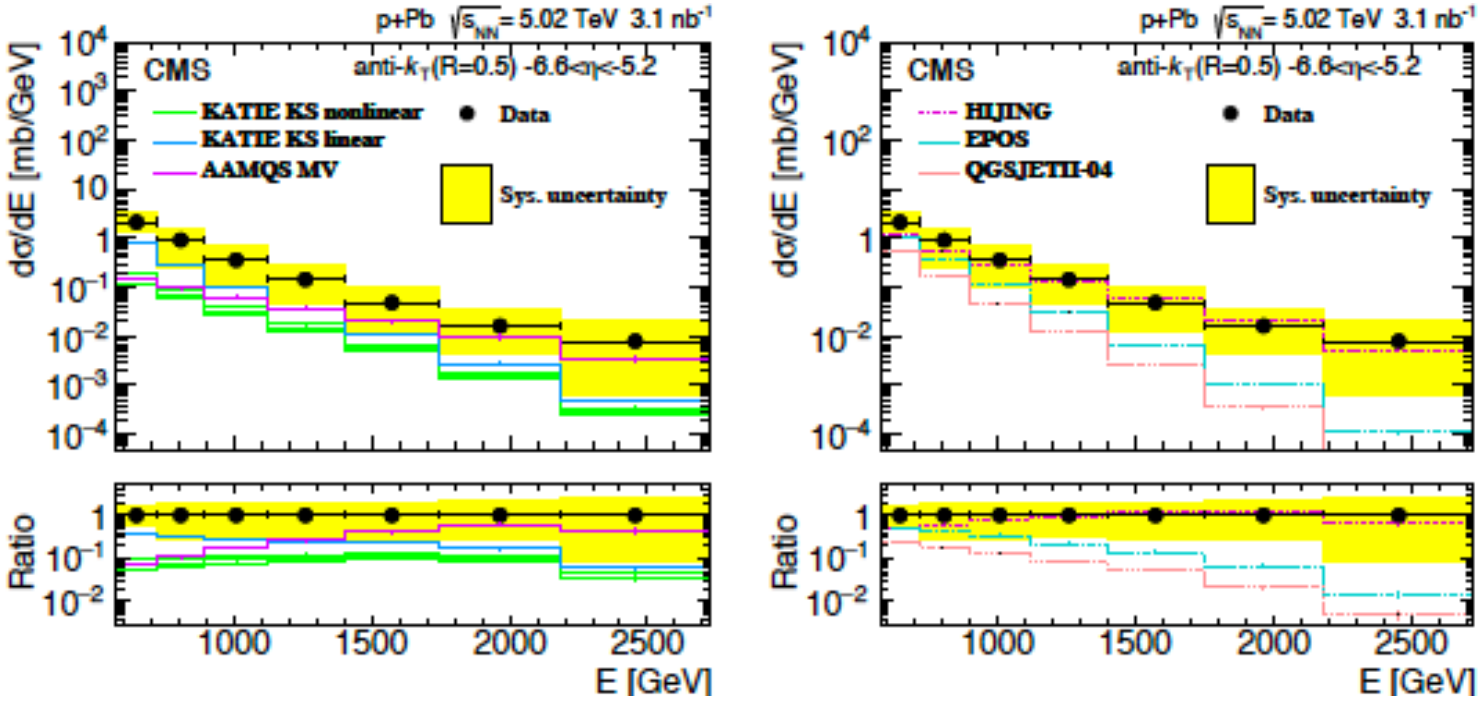
  - Longitudinal and transversal parton correlations?
- Same sign WW experimentally advantageous channel
- Measurement:
  - 1.41 0.28 (stat) 0.28 (sys) pb
  - First evidence!
- Well situated between Pythia8 and factorised predictions
- Observation expected





CMS: very forward jets with CASTOR in p+Pb

First jet measurement with CASTOR calorimeter!



- Measurement highly sensitive to saturation
- No saturation model decsribes data well

Summary CASTOR jet study in CERN courier, in March/April issue

- Hijing describes data well
- EPOS and QGSJet too soft
- Ratio p+Pb/Pb+p: no model describes all data!

Summary

Moriond is a great conference to attend!

- Great overview of experimental and theoretical progress
  - Excellent presentations from world experts
- Regrettably, no clear signs of new physics
  - In particular, LHCb hints have not become stronger with added data
- Perturbative QCD and higher order calculations generally describe new LHC measurements well
- Again, many results not covered here (mu-2-g, cosmic rays, NA(62), LHC and Belle II status, theory, …)
  - Excellent Moriond summaries online!
- … Stay tuned for full LHC Run II

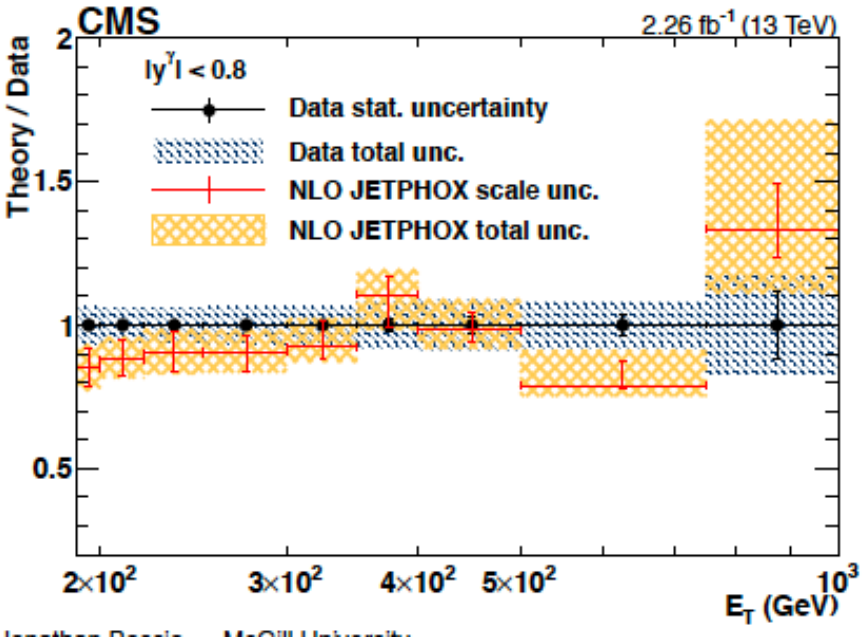
- Friendly, informal setting. Great place for great discussions!
- Great place to ski (and you should ;-)

…Thanks for your attention!

QCD

Photons+Jets at CMS

- Prompt photon: colour-neutral probe for scale event
- CMS: inclusive isolated-photon+jet cross sections at 13 TeV
- photon+jet cross sections measured as a function of E_t in different y^{photon} and y^{jet} bins
- Allows to test gluon PDF in different x and Q^2 values
- All measurements are in agreement with the NLO pQCD predictions



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